Tevatron Energy Scan

Energy Dependence of the "Underlying Event"

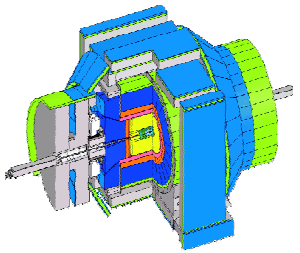
Rick Field

Craig Group & David Wilson

University of Florida

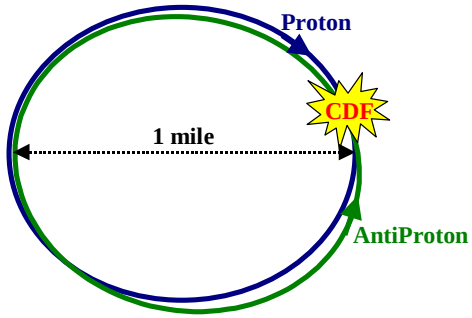
Outline of Talk

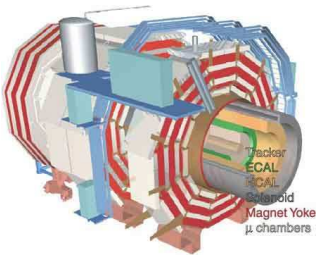
- **Wine & Cheese talk, October 4, 2002.**
  Studying the underlying event (UE) at CDF.
- **The PYTHIA UE tunes.**
- **LPCC MB&UE working group "common plots".**
- **CDF MB "common plots" from the Tevatron Energy Scan.**
- **CDF UE "common plots" from the Tevatron Energy Scan.**
- **Mapping out the energy dependence of MB & UE: Tevatron to the LHC!**
- **CDF new UE observables from the Tevatron Energy Scan.**
- **Summary & Conclusions.**



CDF Run 2

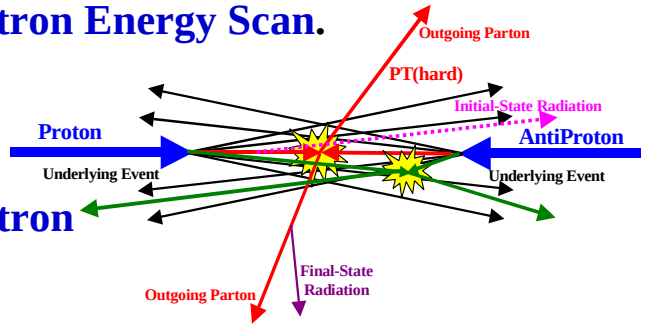
300 GeV, 900 GeV, 1.96 TeV



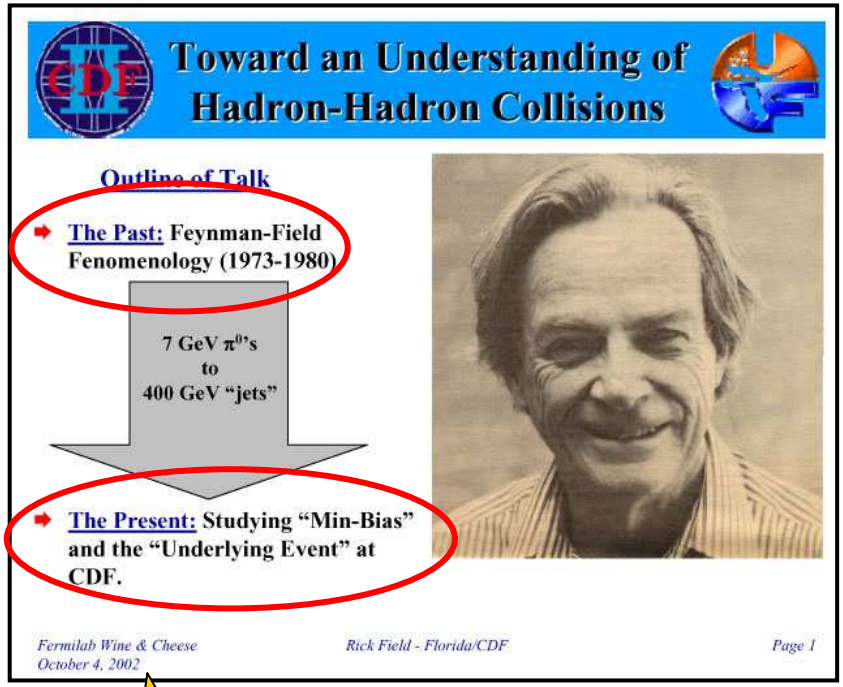


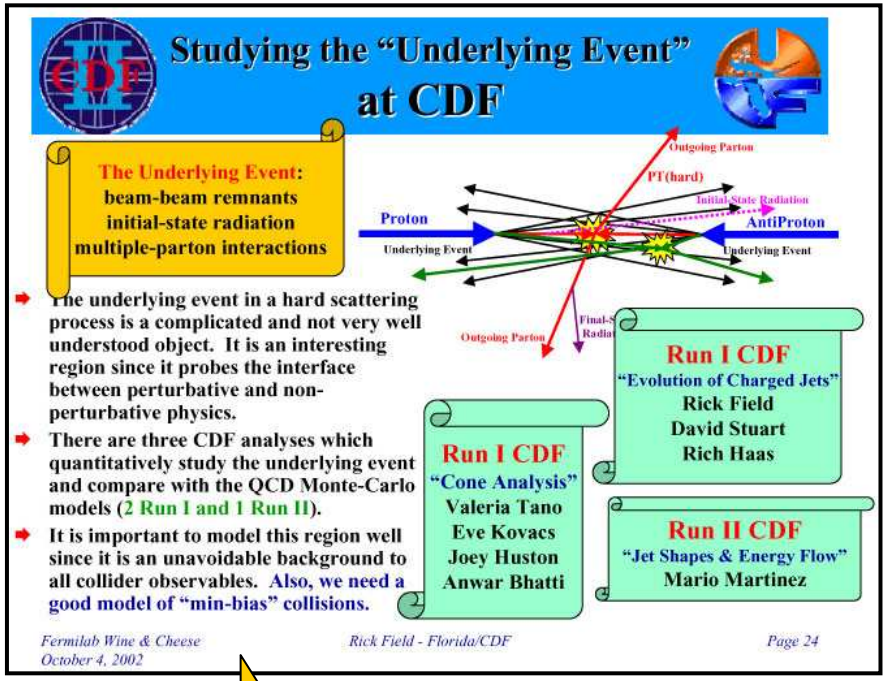
CMS at the LHC

900 GeV, 7 & 8 TeV



2002 Wine & Cheese Talk

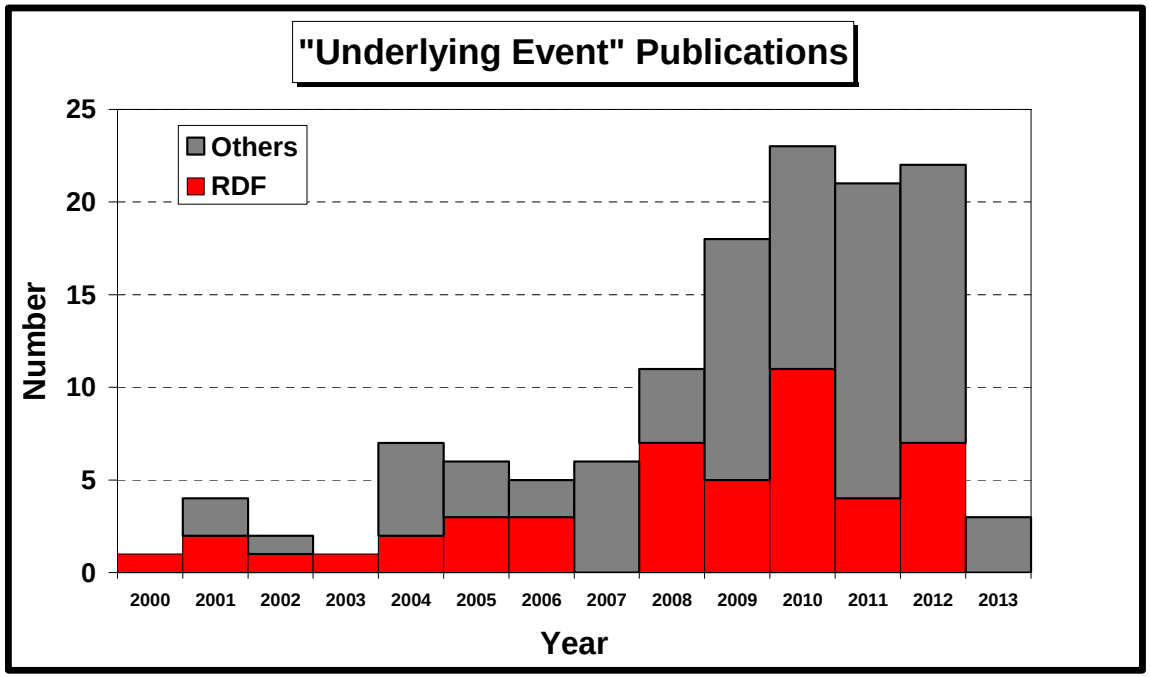




Rick Field Wine & Cheese Talk October 4, 2002

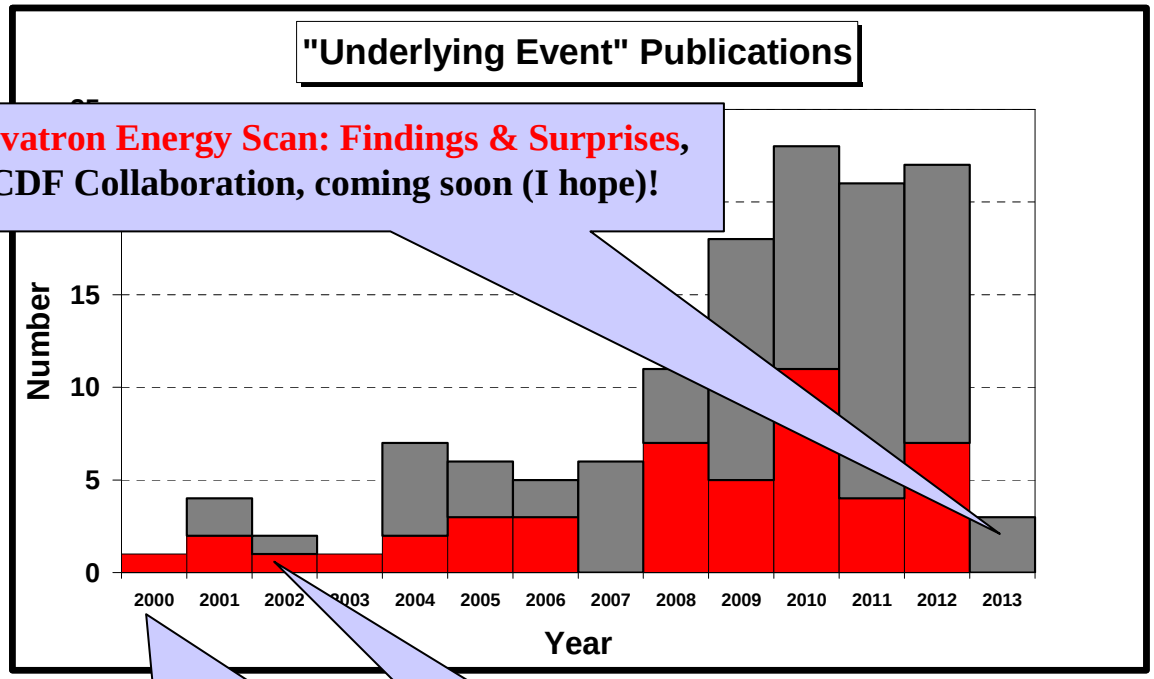
Studying the "underlying event" at CDF!

UE Publications



➡ **Publications with "underlying event" in the title.**

UE Publications



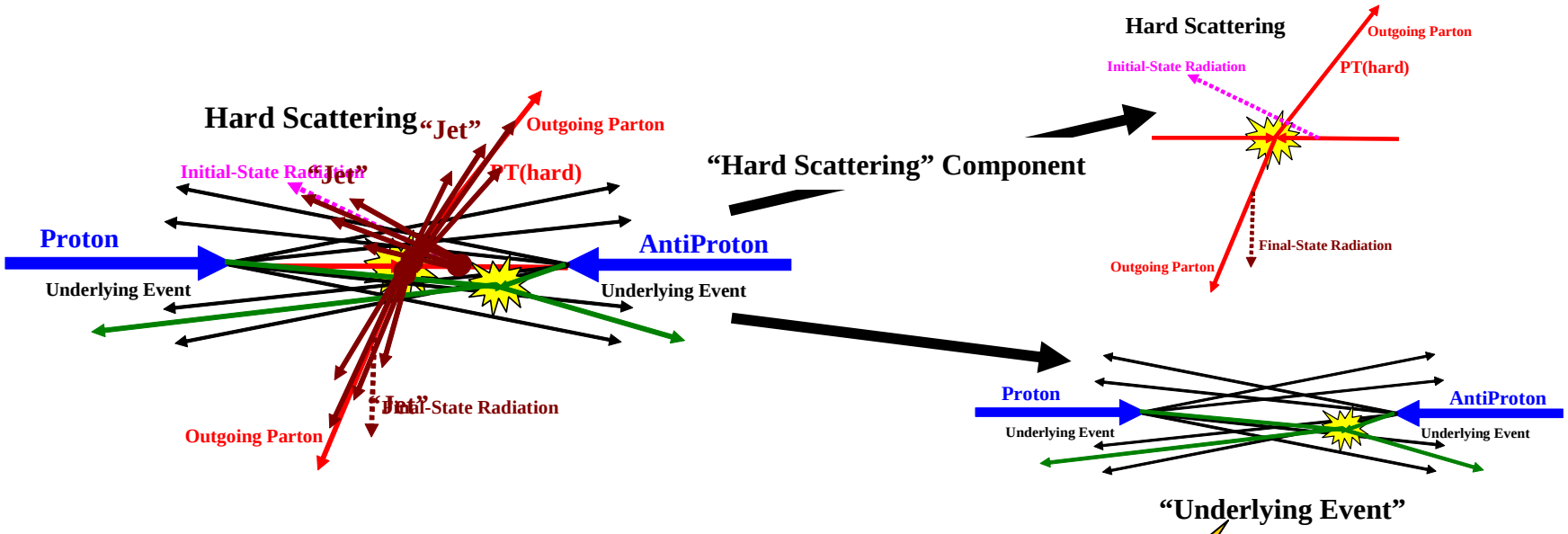
Tevatron Energy Scan: Findings & Surprises, CDF Collaboration, coming soon (I hope)!

➡ **Publications with "ur… g even… the title.**

The Underlying Event in Large Transverse Momentum Charged Jet and Z−boson Production at CDF, R. Field, published in the proceedings of DPF 2000.

Charged Jet Evolution and the Underlying Event in Proton-Antiproton Collisions at 1.8 TeV, CDF Collaboration, Phys. Rev. D65 (2002) 092002.

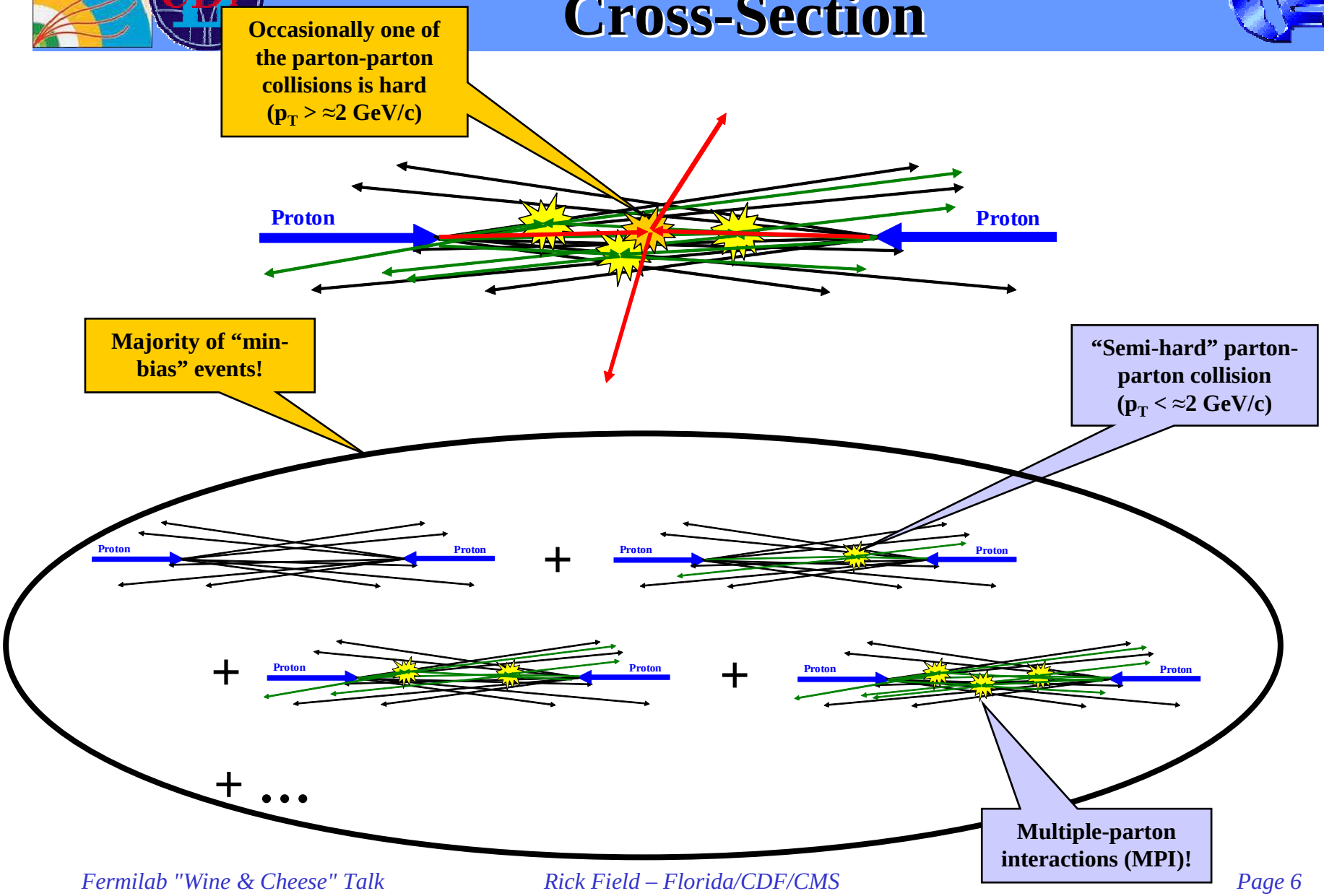
QCD Monte-Carlo Models: High Transverse Momentum Jets



- Start with the perturbative 2-to-2 (or sometimes 2-to-3) parton-parton scatter[illegible]g and add initial and final-state gluon radiation (in the leading log approximation or modified leadin[illegible] approximation).
- The "underlying event" consists of the "beam-beam remnants" and [illegible]articles arising from soft or semi-soft multiple parton interactions (MPI).
- Of course the outgoing colored parton[illegible]ly "underlying event" observables receive contributions fron[illegible]

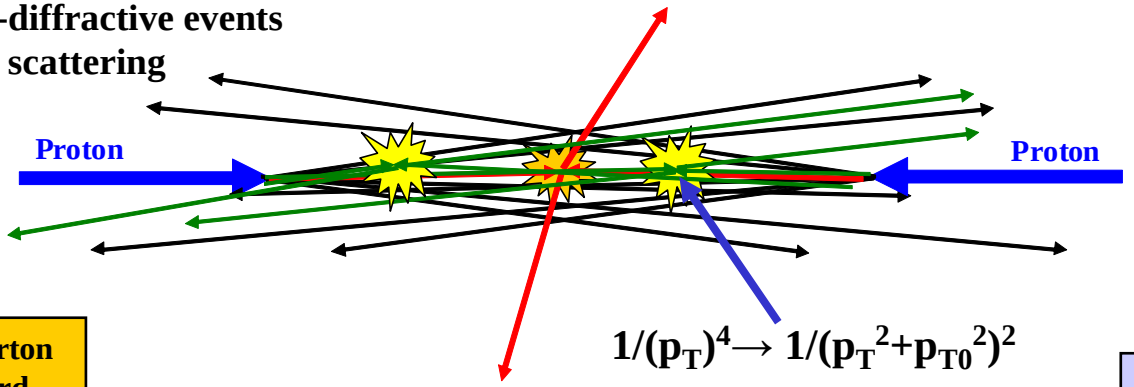
The "underlying event" is an unavoidable background to most collider observables and having good understand of it leads to more precise collider measurements!

The Inelastic Non-Diffractive Cross-Section



The "Underlying Event"

Select inelastic non-diffractive events that contain a hard scattering

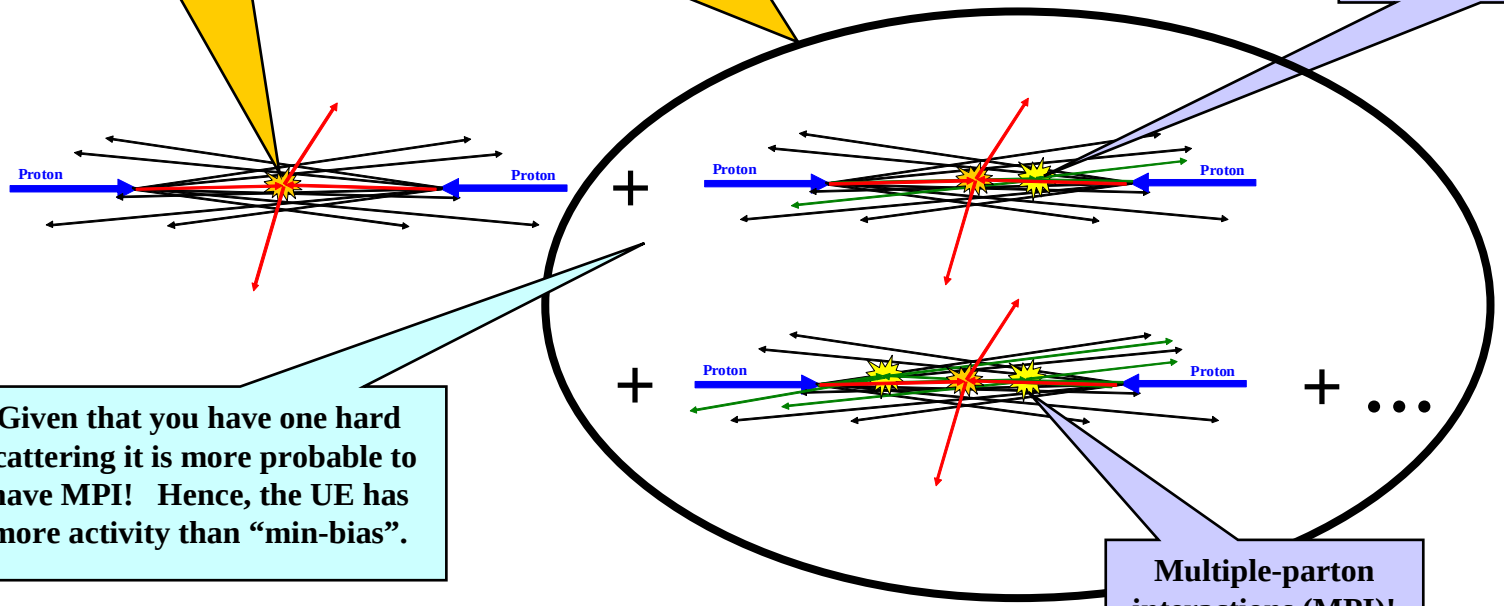


$1/(p_T)^4 \rightarrow 1/(p_T^2+p_{T0}^2)^2$

Hard parton-parton collisions is hard (p_T > ≈2 GeV/c)

The "underlying-event" (UE)!

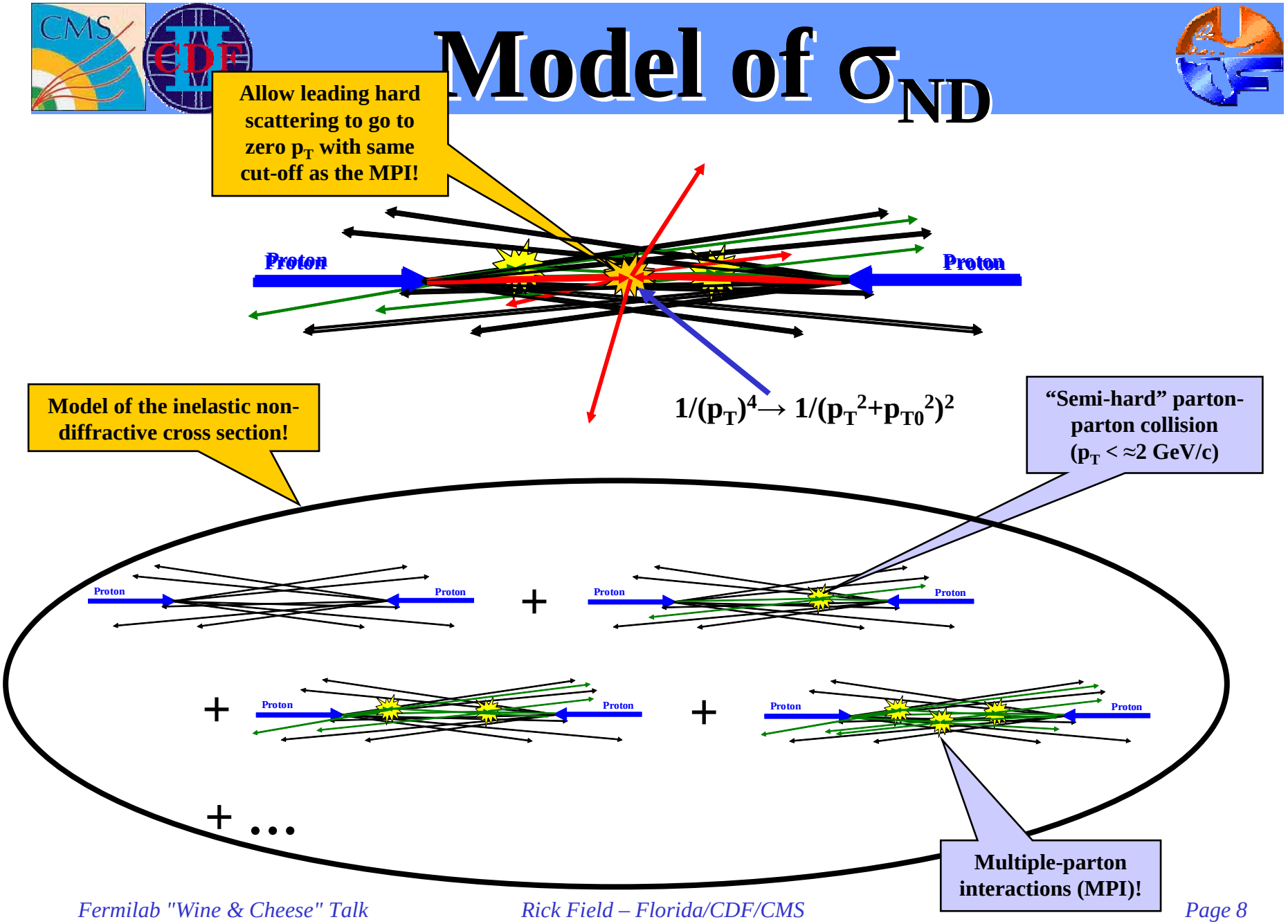
"Semi-hard" parton-parton collision (p_T < ≈2 GeV/c)



Given that you have one hard scattering it is more probable to have MPI! Hence, the UE has more activity than "min-bias".

Multiple-parton interactions (MPI)!

Model of σ_{ND}

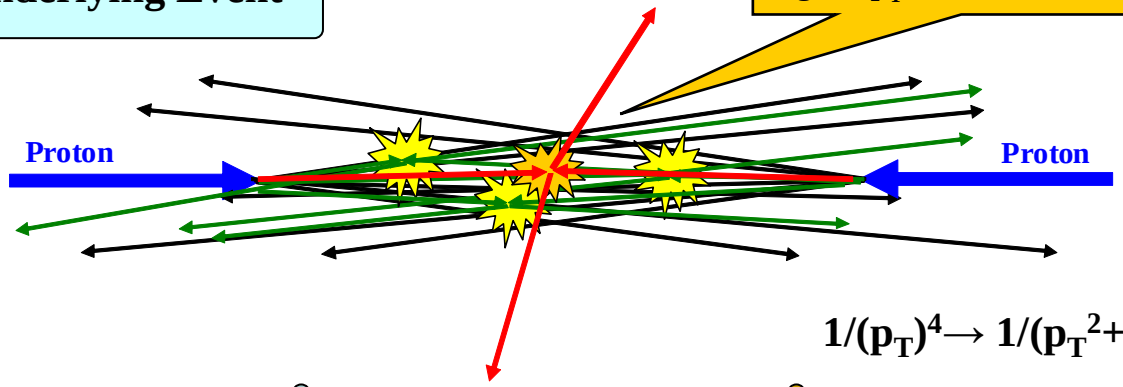


UE Tunes

"Underlying Event"

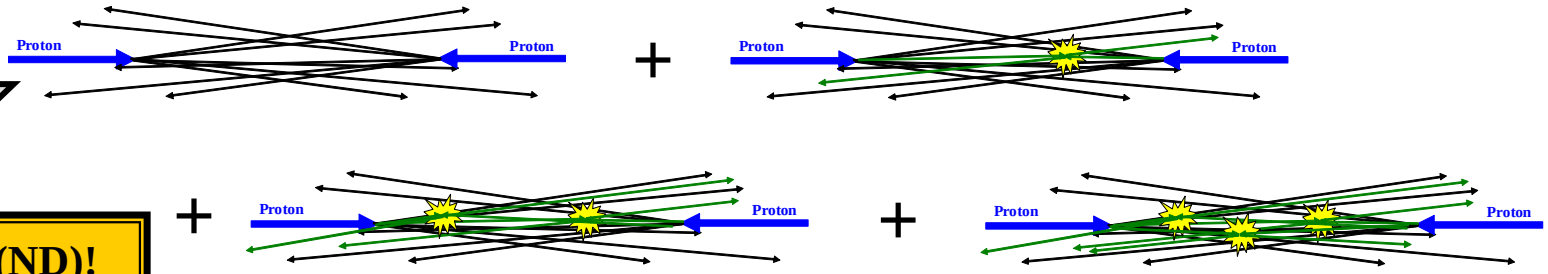
Allow primary hard-scattering to go to $p_T = 0$ with same cut-off!

Fit the "underlying event" in a hard scattering process.



$1/(p_T)^4 \rightarrow 1/(p_T^2+p_{T0}^2)^2$

"Min-Bias" (add single & double diffraction)



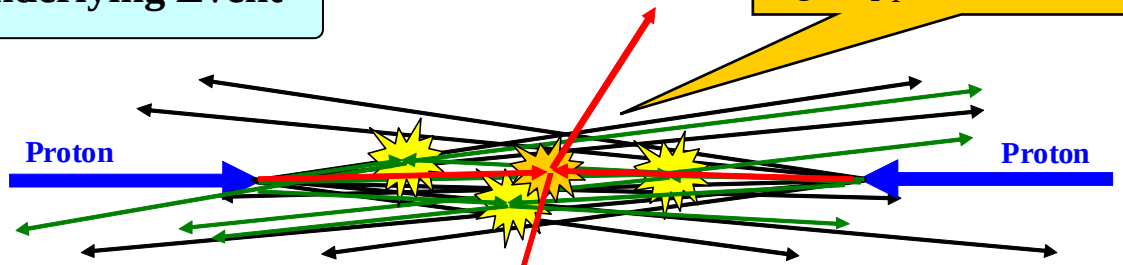
Predict MB (ND)!

UE Tunes

"Underlying Event"

Allow primary hard-scattering to go to $p_T = 0$ with same cut-off!

Fit the "underlying event" in a hard scattering process.

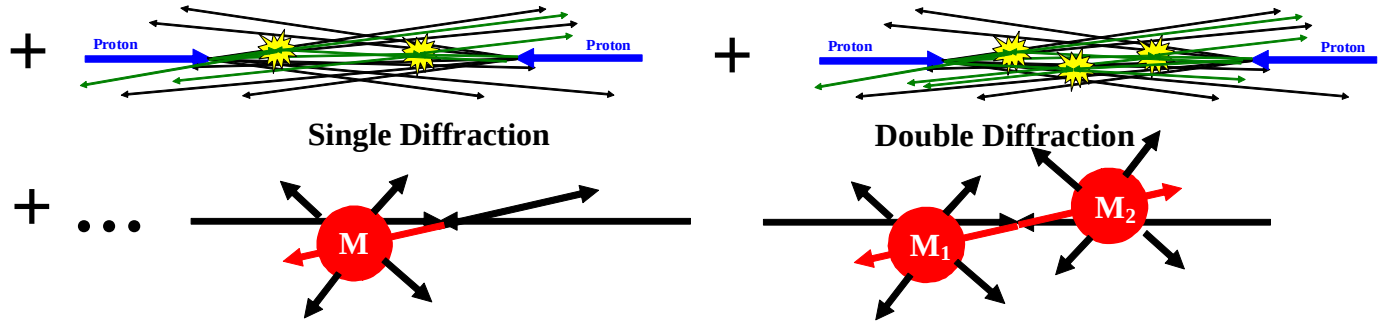


$1/(p_T)^4 \rightarrow 1/(p_T^2+p_{T0}^2)^2$

"Min-Bias" (add single & double diffraction)

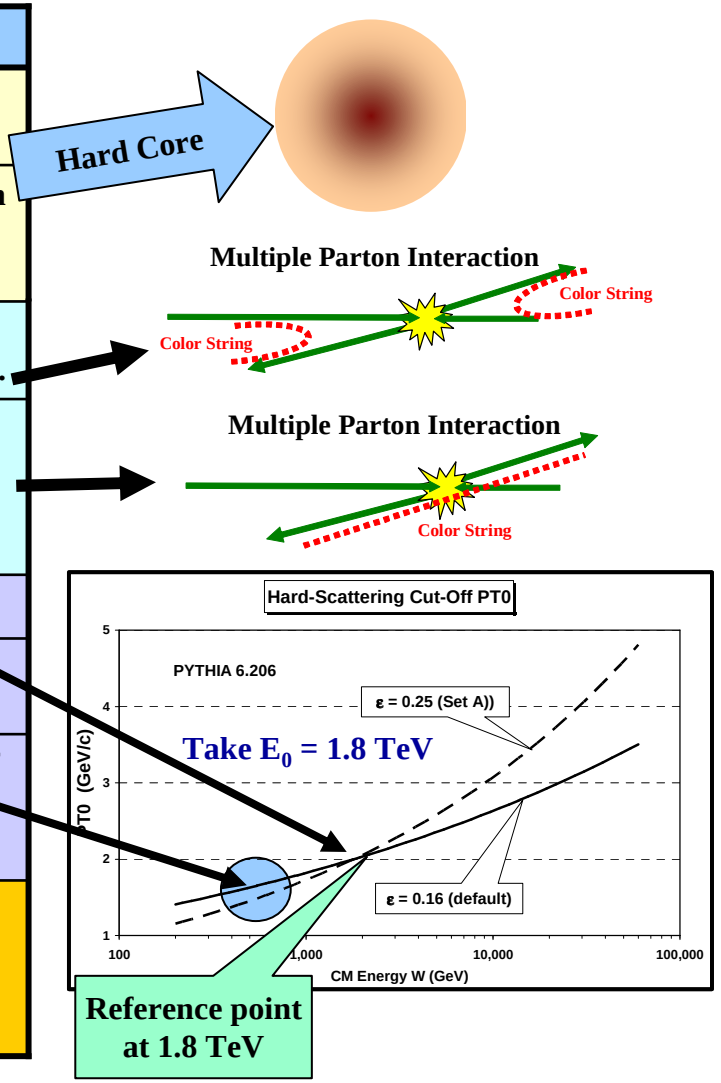
Predict MB (ND)!

Predict MB (IN)!



Tuning PYTHIA 6.2:
Multiple Parton Interaction Parameters

Parameter	Default	Description
PARP(83)	0.5	Double-Gaussian: Fraction of total hadronic matter within PARP(84)
PARP(84)	0.2	Double-Gaussian: Fraction of the overall hadron radius containing the fraction PARP(83) of the total hadronic matter.
PARP(85)	0.33	Probability that the MPI produces two gluons with color connections to the "nearest neighbors.
PARP(86)	0.66	Probability that the MPI produces two gluons either as described by PARP(85) or as a closed gluon loop. The remaining fraction consists of quark-antiquark pairs.
PARP(89)	1 TeV	Determines the reference energy E_0.
PARP(82)	1.9 GeV/c	The cut-off P_{T0} that regulates the 2-to-2 scattering divergence $1/PT^4 \rightarrow 1/(PT^2+P_{T0}^2)^2$
PARP(90)	0.16	Determines the energy dependence of the cut-off P_{T0} as follows $P_{T0}(E_{cm}) = P_{T0}(E_{cm}/E_0)^{\varepsilon}$ with ε = PARP(90)
PARP(67)	1.0	A scale factor that determines the maximum parton virtuality for space-like showers. The larger the value of PARP(67) the more initial-state radiation.



Tuning PYTHIA 6.2:
Multiple Parton Interaction Parameters

Parameter	Default	Description
PARP(83)	0.5	Double-Gaussian: Fraction of total hadronic matter within PARP(84)
PARP(84)	0.2	Double-Gaussian: Fraction of the overall hadron radius containing the fraction PARP(83) of the total hadronic matter
PARP(85)	0.33	Pr…uces two gluons w…nearest neighbors.
PARP(86)	0.66	Prob…luons ei…closed …h loop. …ists of …uark-antiqua…rs.
PARP(89)	1 Te…	Determin… reference energy E_0.
PARP(82)	…9 GeV/c	The c…off P_{T0} that regulates the 2-to-2 sc…ring divergence $1/PT^4 \rightarrow 1/(PT^2+P_{T0}^2)^2$
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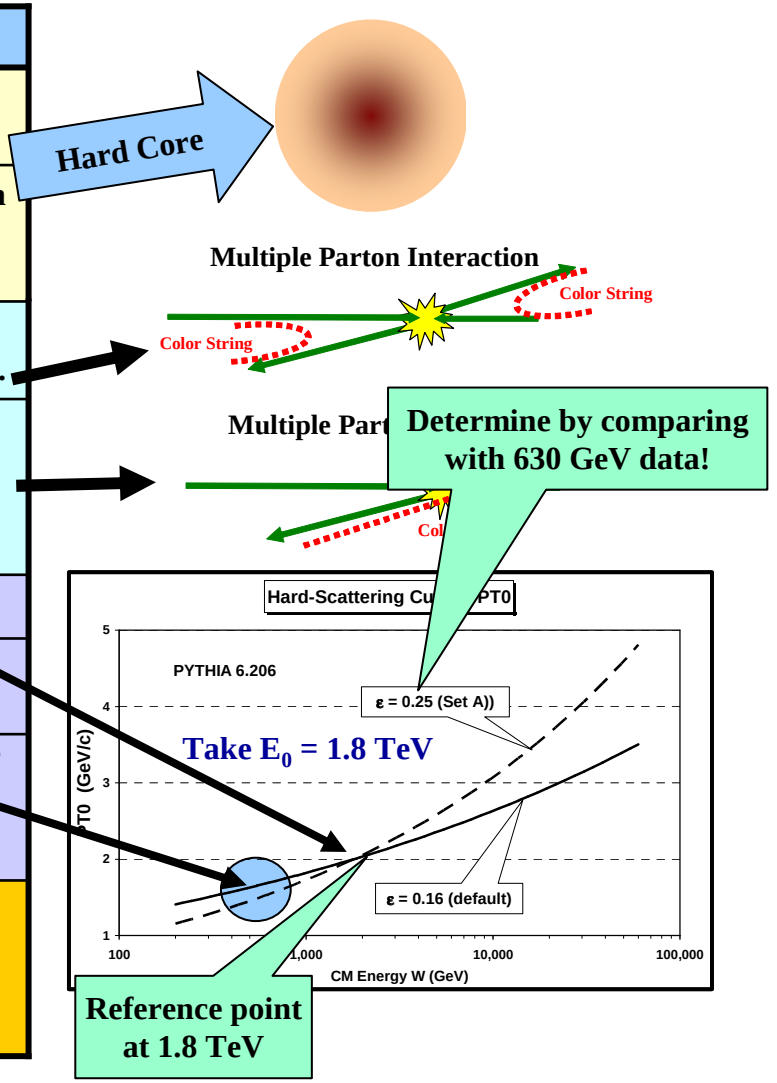
PARP(67)	1.0	A scale factor that determines the maximum parton virtuality for space-like showers. The larger the value of PARP(67) the more initial-state radiation.

Determines the energy dependence of the MPI!

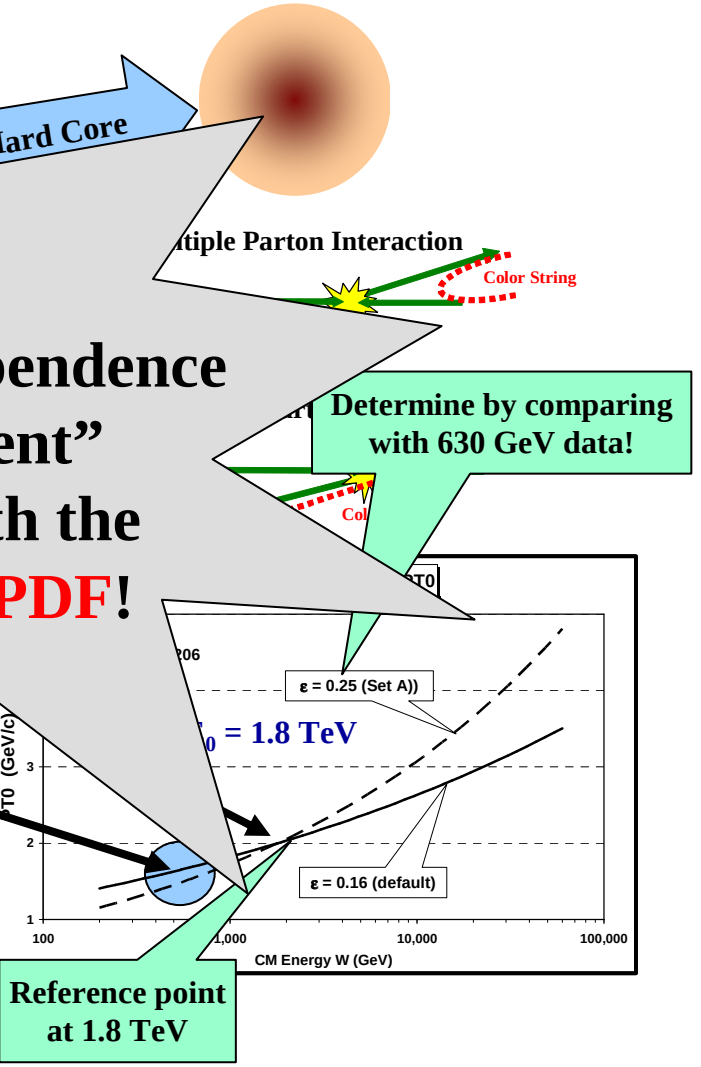
Affects the amount of initial-state radiation!



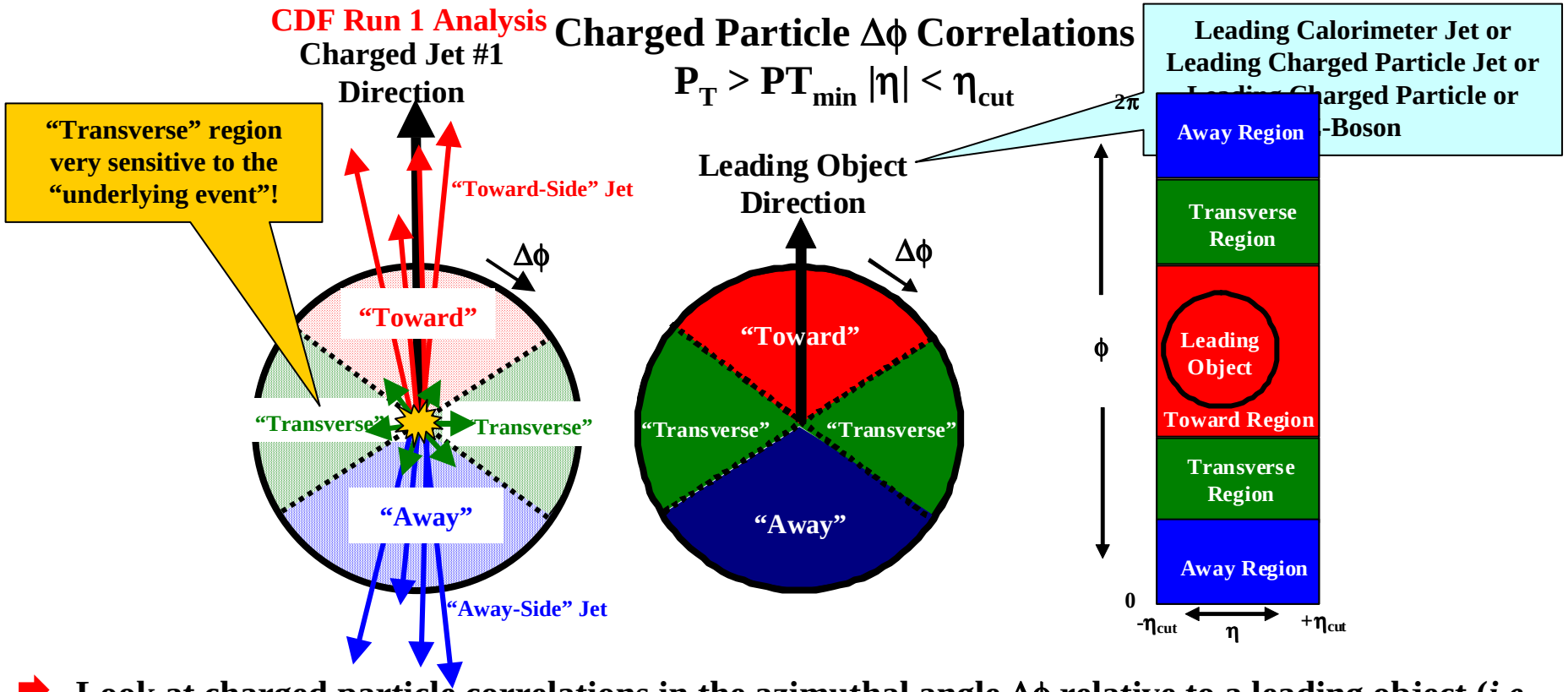
Tuning PYTHIA 6.2:
Multiple Parton Interaction Parameters

Parameter	Default	Description
PARP(83)		Double-Gaussian: Frac… total hadron… …er within PARP(8…
PARP(84)	0.2	…sian: Fr… …e ra… tota…
PARP(85)	0.33	D…
PARP(86)		
PARP(89)	1 Te…	
PARP(82)	GeV/c	sc… …ring d…
PARP(90)	0.16	Determine… …or P_{T0} as fol… $P_{T0}(E_{cm})$ …$E_0)^{\varepsilon}$ w… ε = PAR… …0)
PARP(67)	1.0	A scale factor that dete… …the maximum… parton virtuality for spa… …e showers. The larger the value of PARP(67) the more initial-state radiation.

Remember the energy dependence of the "underlying event" activity depends on both the ε = PARP(90) and the PDF!

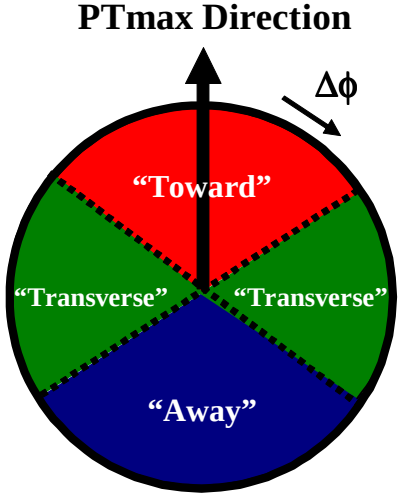


Traditional Approach



- Look at charged particle correlations in the azimuthal angle Δϕ relative to a leading object (*i.e.* CaloJet#1, ChgJet#1, PTmax, Z-boson). For CDF PTmin = 0.5 GeV/c $\eta_{cut} = 1$.
- Define $|\Delta\phi| < 60^o$ as "Toward", $60^o < |\Delta\phi| < 120^o$ as "Transverse", and $|\Delta\phi| > 120^o$ as "Away".
- All three regions have the same area in η-ϕ space, $\Delta\eta \times \Delta\phi = 2\eta_{cut} \times 120^o = 2\eta_{cut} \times 2\pi/3$. Construct densities by dividing by the area in η-ϕ space.

UE Observables



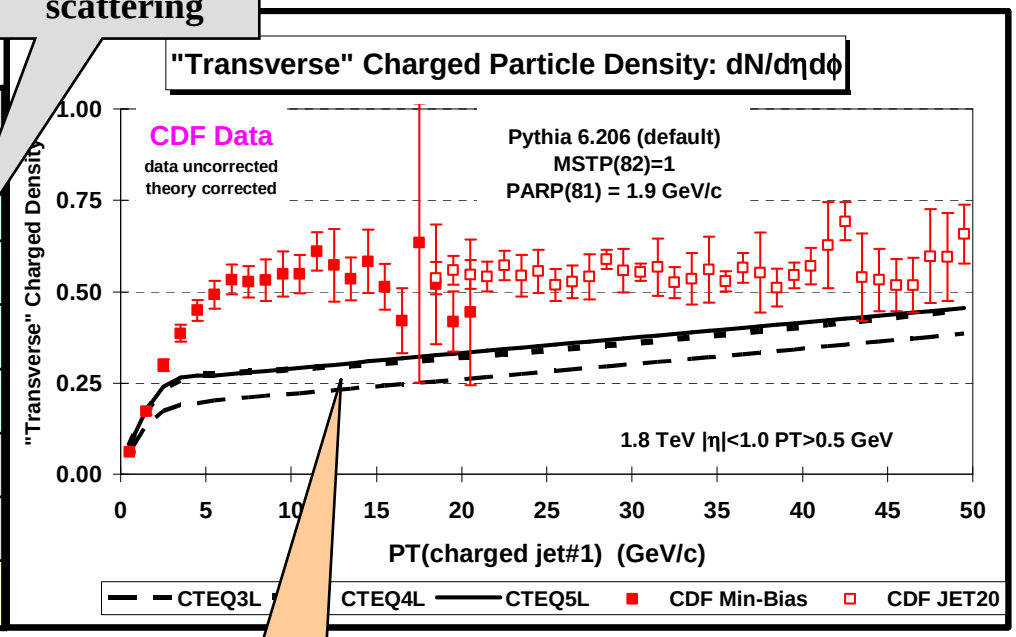
- **"Transverse" Charged Particle Density:** Number of charged particles ($p_T > 0.5$ GeV/c, $|\eta| < \eta_{cut}$) in the "transverse" region as defined by the leading charged particle, PTmax, divided by the area in η-ϕ space, $2\eta_{cut} \times 2\pi/3$, averaged over all events with at least one particle with $p_T > 0.5$ GeV/c, $|\eta| < \eta_{cut}$.
- **"Transverse" Charged PTsum Density:** Scalar p_T sum of the charged particles ($p_T > 0.5$ GeV/c, $|\eta| < \eta_{cut}$) in the "transverse" region as defined by the leading charged particle, PTmax, divided by the area in η-ϕ space, $2\eta_{cut} \times 2\pi/3$, averaged over all events with at least one particle with $p_T > 0.5$ GeV/c, $|\eta| < \eta_{cut}$.
- **"Transverse" Charged Particle Average P_T:** Event-by-event $\langle p_T \rangle$ = PTsum/Nchg for charged particles ($p_T > 0.5$ GeV/c, $|\eta| < \eta_{cut}$) in the "transverse" region as defined by the leading charged particle, PTmax, averaged over all events with at least one particle in the "transverse" region with $p_T > 0.5$ GeV/c, $|\eta| < \eta_{cut}$.
- **Zero "Transverse" Charged Particles:** If there are no charged particles in the "transverse" region then Nchg and PTsum are zero and one includes these zeros in the average over all events with at least one particle with $p_T > 0.5$ GeV/c, $|\eta| < \eta_{cut}$. However, if there are no charged particles in the "transverse" region then the event is not used in constructing the "transverse" average p_T.

PYTHIA 6.206 Defaults

PYTHIA default parameters

Parameter	6.115	6.125	6.158	6.206
MSTP(81)	1	1	1	1
MSTP(82)	1	1	1	1
PARP(81)	1.4	1.9	1.9	1.9
PARP(82)	1.55	2.1	2.1	1.9
PARP(89)		1,000	1,000	1,000
PARP(90)		0.16	0.16	0.16
PARP(67)	4.0	4.0	1.0	1.0

MPI constant probability scattering



➡ **Plot shows the "Transverse" charged particle density versus P_T(chgjet#1) compared to the QCD hard scattering predictions of PYTHIA 6.206 (P_T(hard) > 0) using the default parameters for multiple parton interactions and CTEQ3L, CTEQ4L, and CTEQ5L.**

Note Change
PARP(67) = 4.0 (< 6.138)
PARP(67) = 1.0 (> 6.138)

Default parameters give very poor description of the "underlying event"!

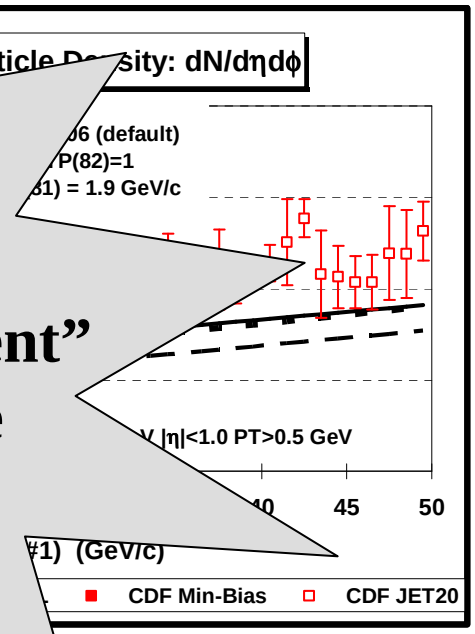
PYTHIA 6.206 Defaults

PYTHIA d… parameters

Parameter	6.115	6.	6.2
MSTP(81)	1	1	
MSTP(82)	1		
PARP(81)			
PARP(82)	1.55		
PARP(89)		1,0	
PARP(90)			
PARP(67)			1.

MPI constant probability scattering

Remember the "underlying event" activity depends on both the cut-off p_{T0} and the PDF!



➡ **Plot shows the "Trans… rt… vers… gjet#1) compared to the QCD hard scatter… predi… PYT… 06 (P_T(ha… > 0) using the default parameters for mult…ple parton …ctions a… EQ3L, CTEQ…L, and CTEQ5L.**

Note Change
PARP(67) = 4.0 (< 6.138)
PARP(67) = 1.0 (> 6.138)

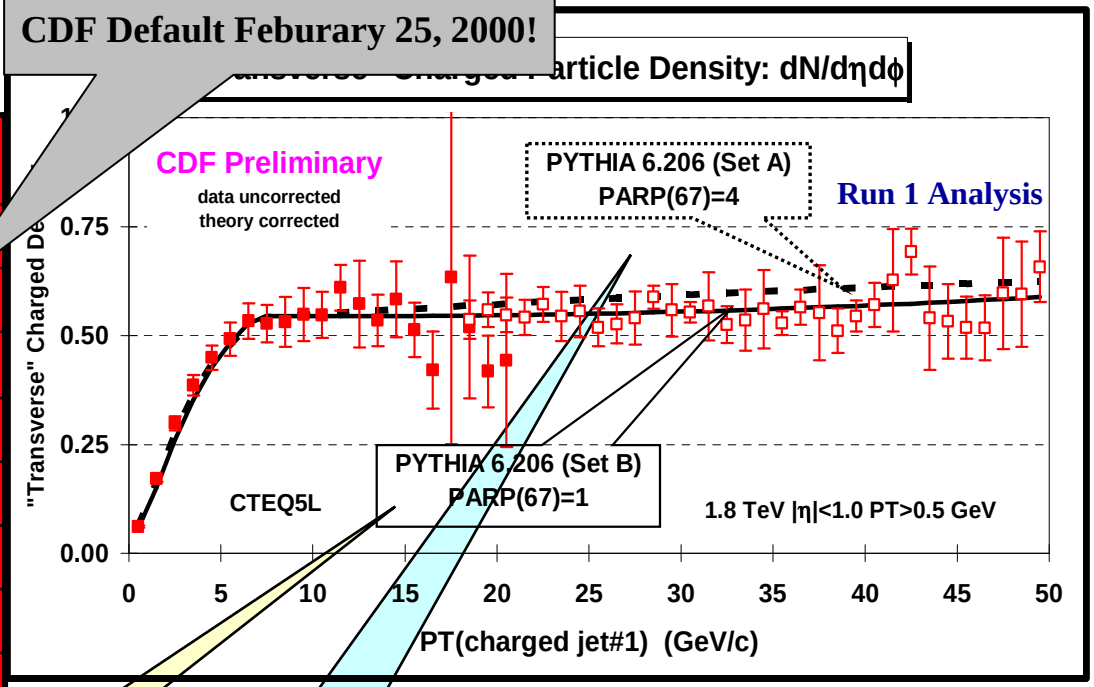
D… t parameters g… ve… oor description of th… underlying event"!

Run 1 PYTHIA Tune A

PYTHIA 6.206 CTEQ5L

Parameter	Tune B	Tune A
MSTP(81)	1	1
MSTP(82)	4	4
PARP(82)	1.9 GeV	2.0 GeV
PARP(83)	0.5	0.5
PARP(84)	0.4	0.4
PARP(85)	1.0	0.9
PARP(86)	1.0	0.95
PARP(89)	1.8 TeV	1.8 TeV
PARP(90)	0.25	0.25
PARP(67)	1.0	4.0

CDF Default Feburary 25, 2000!



Plot shows the "transverse" charged particle density versus P_T(chgjet#1) compared to the QCD hard scattering predictions of two tuned versions of PYTHIA 6.206 (CTEQ5L, Set B (PARP(67)=1) and Set A (PARP(67)=4)).

New PYTHIA default (less initial-state radiation)

Old PYTHIA default (more initial-state radiation)

PYTHIA 6.2 Tunes

All use LO α_s with Λ = 192 MeV!

UE Parameters

ISR Parameter

Intrinsic KT

Parameter	Tune AW	Tune DW	Tune D6
PDF	CTEQ5L	CTEQ5L	CTEQ6L
MSTP(81)	1	1	1
MSTP(82)	4	4	4
PARP(82)	2.0 GeV	1.9 GeV	1.8 GeV
PARP(83)	0.5	0.5	0.5
PARP(84)	0.4	0.4	0.4
PARP(85)	0.9	1.0	1.0
PARP(86)	0.95	1.0	1.0
PARP(89)	1.8 TeV	1.8 TeV	1.8 TeV
PARP(90)	0.25	0.25	0.25
PARP(62)	1.25	1.25	1.25
PARP(64)	0.2	0.2	0.2
PARP(67)	4.0	2.5	2.5
MSTP(91)	1	1	1
PARP(91)	2.1	2.1	2.1
PARP(93)	15.0	15.0	15.0

Uses CTEQ6L

Tune A energy dependence!

PYTHIA 6.2 Tunes

All use LO α_s with Λ = 192 MeV!

UE Parameters

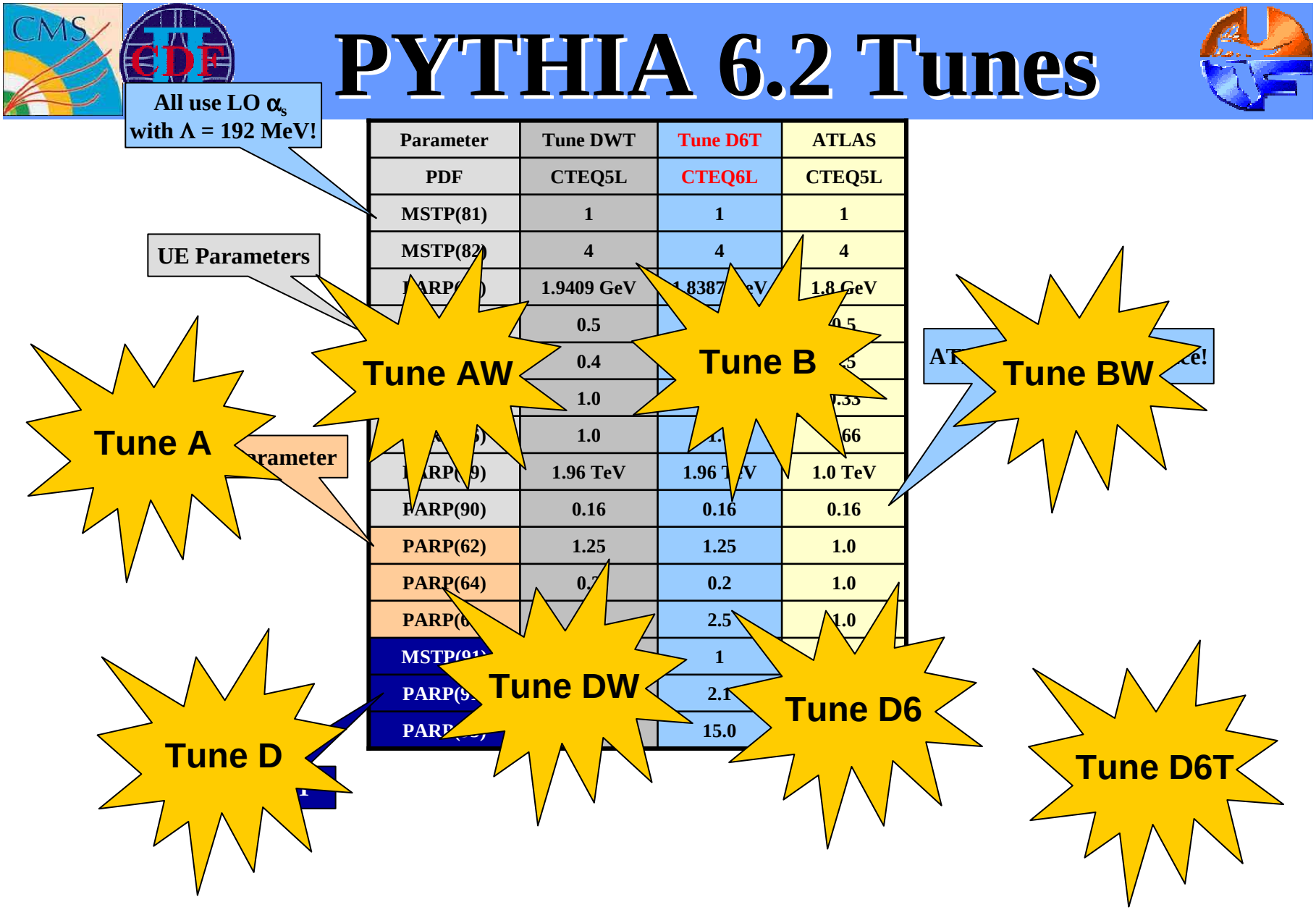
ISR Parameter

Intrinsic KT

Parameter	Tune DWT	Tune D6T	ATLAS
PDF	CTEQ5L	CTEQ6L	CTEQ5L
MSTP(81)	1	1	1
MSTP(82)	4	4	4
PARP(82)	1.9409 GeV	1.8387 GeV	1.8 GeV
PARP(83)	0.5	0.5	0.5
PARP(84)	0.4	0.4	0.5
PARP(85)	1.0	1.0	0.33
PARP(86)	1.0	1.0	0.66
PARP(89)	1.96 TeV	1.96 TeV	1.0 TeV
PARP(90)	0.16	0.16	0.16
PARP(62)	1.25	1.25	1.0
PARP(64)	0.2	0.2	1.0
PARP(67)	2.5	2.5	1.0
MSTP(91)	1	1	1
PARP(91)	2.1	2.1	1.0
PARP(93)	15.0	15.0	5.0

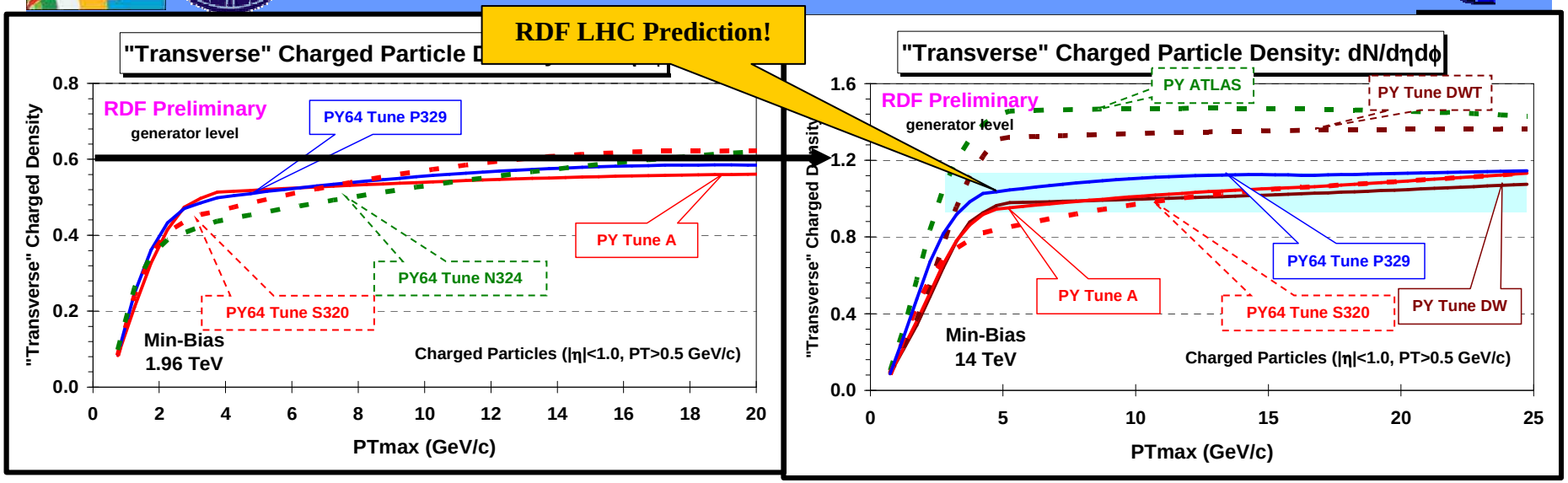
ATLAS energy dependence!

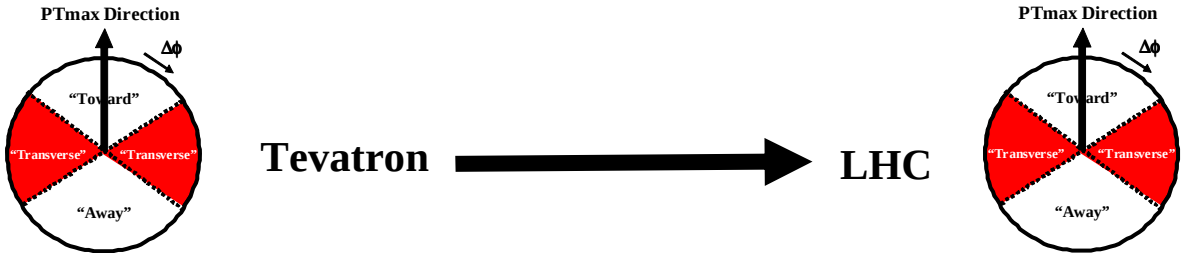
PYTHIA 6.2 Tunes



Parameter	Tune DWT	Tune D6T	ATLAS
PDF	CTEQ5L	CTEQ6L	CTEQ5L
MSTP(81)	1	1	1
MSTP(82)	4	4	4
PARP( )	1.9409 GeV	1.8387 eV	1.8 GeV
	0.5		0.5
	0.4		5
	1.0		.33
	1.0	1.	66
ARP(9)	1.96 TeV	1.96 TeV	1.0 TeV
PARP(90)	0.16	0.16	0.16
PARP(62)	1.25	1.25	1.0
PARP(64)	0.7	0.2	1.0
PARP(6		2.5	1.0
MSTP(91)		1	
PARP(9		2.1	
PARP( )		15.0	

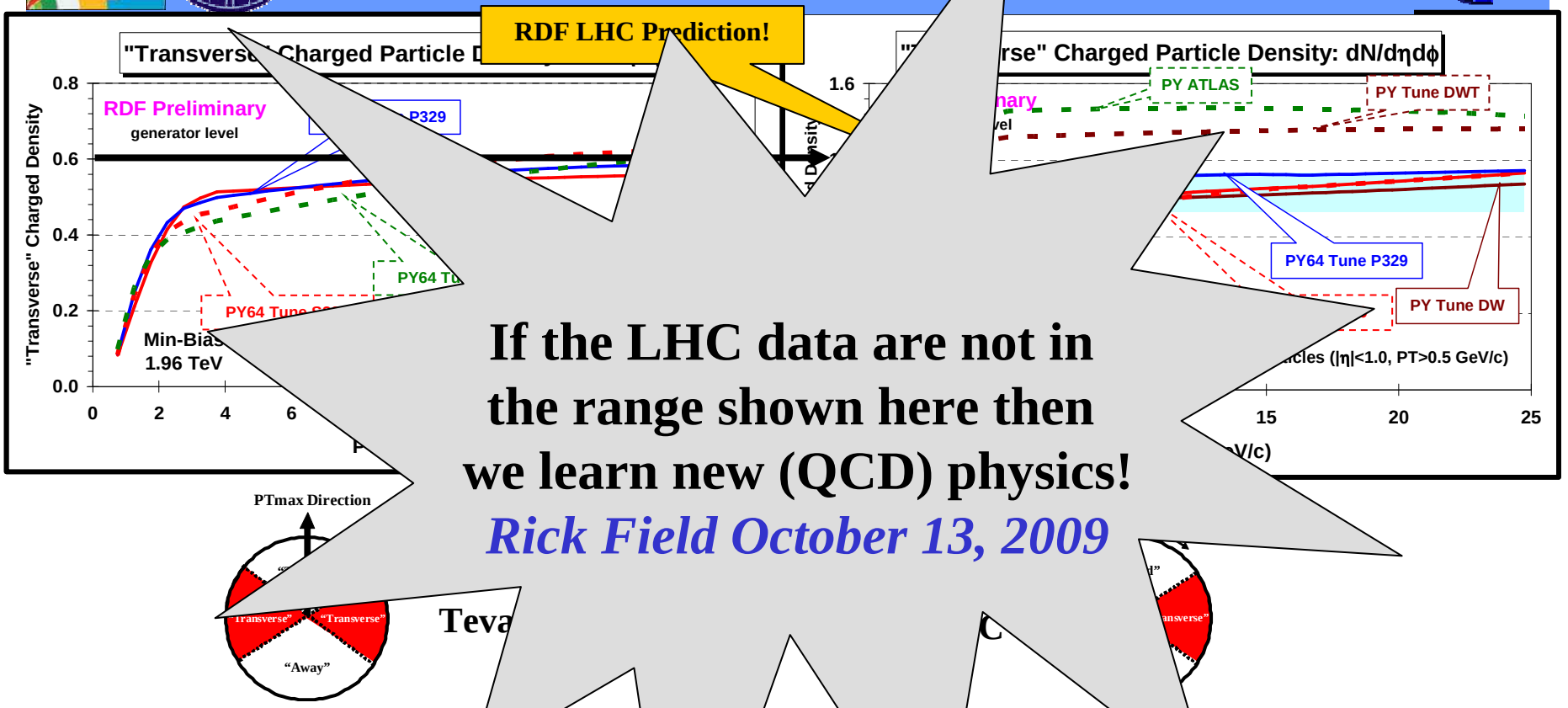
Transverse Charged Particle Density





- Shows the "associated" charged particle density in the "transverse" region as a function of PTmax for charged particles (p_T > 0.5 GeV/c, |η| < 1, *not including PTmax*) for "min-bias" events at 1.96 TeV from PYTHIA Tune A, Tune S320, Tune N324, and Tune P329 at the particle level (*i.e.* generator level).
- Extrapolations of PYTHIA Tune A, Tune DW, Tune DWT, Tune S320, Tune P329, and pyATLAS to the LHC.

Transverse Charged Particle Density

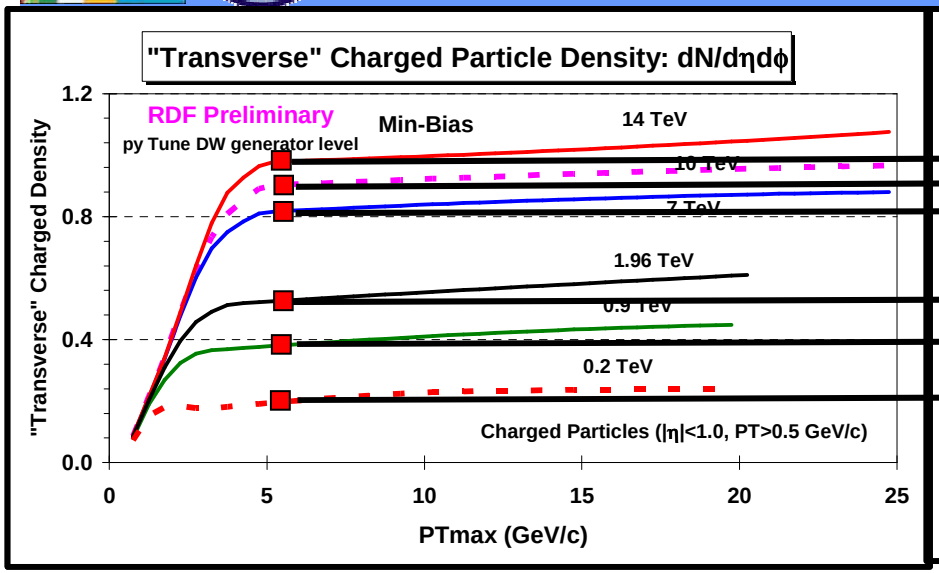


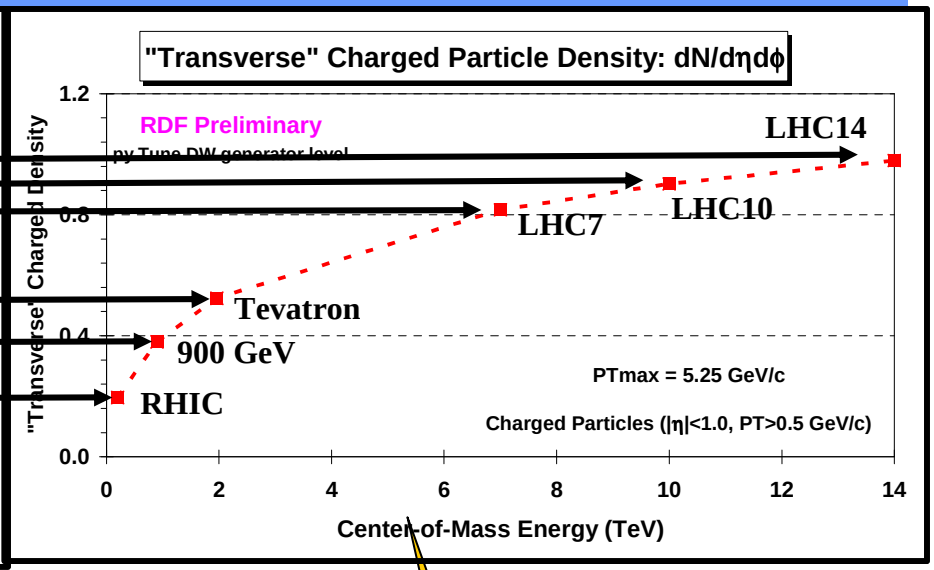
If the LHC data are not in the range shown here then we learn new (QCD) physics!

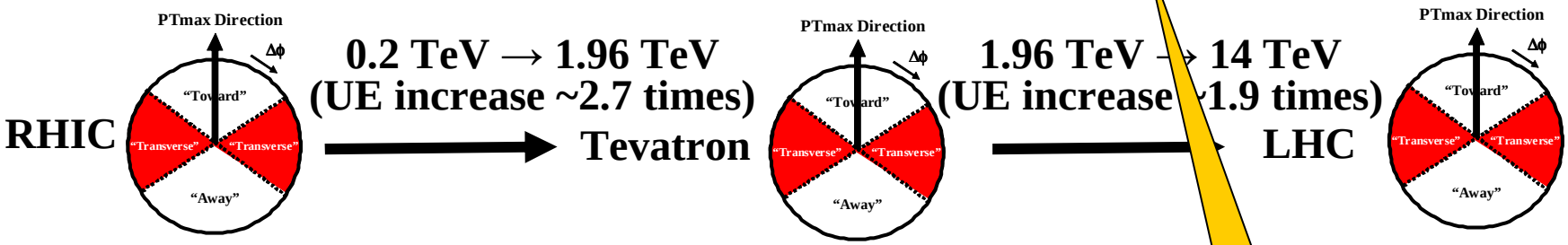
Rick Field October 13, 2009

- **Shows the "associated" charged particle density in the "transverse" region as a function of PTmax for charged particles (p_T > 0.5 GeV/c, |η| < 1 *including PTmax*) for "min-bias" events at 1.96 TeV from PYTHIA Tune A, Tune S320, Tune 324, and Tune P329 at the particle level (*i.e.* generator level).**
- **Extrapolations of PYTHIA Tune A, Tune DW, Tune DWT, Tune S320, Tune P329, and pyATLAS to the LHC.**

"Transverse" Charged Particle Density



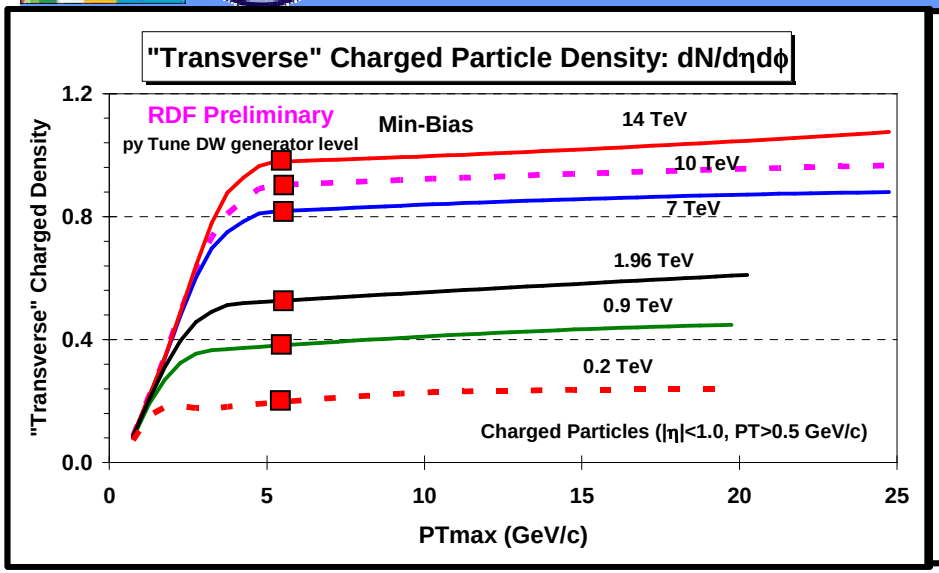


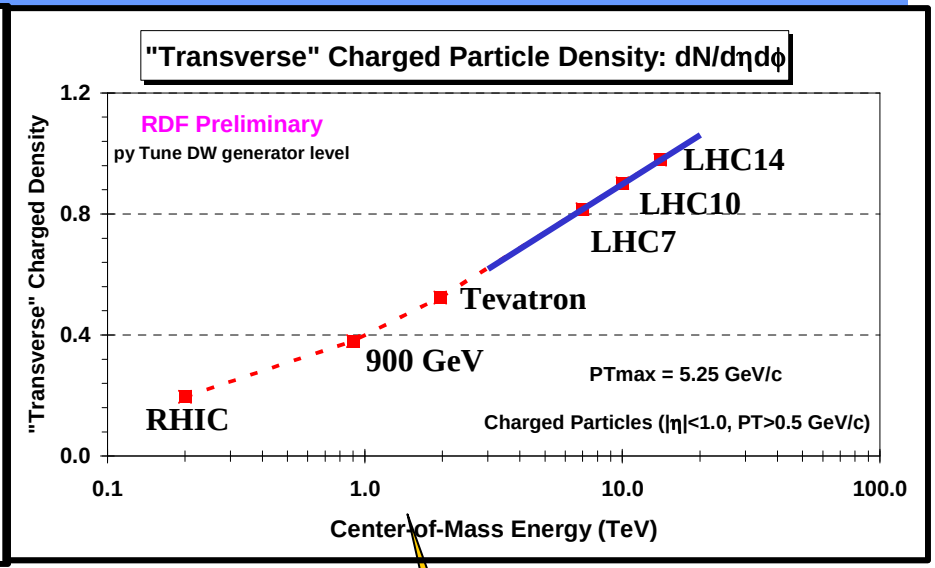


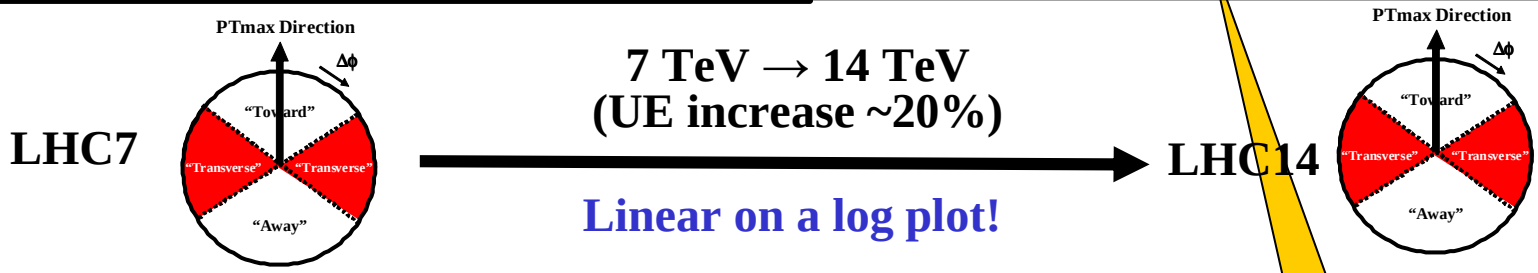
Linear scale!

➡ **Shows the "associated" charged particle density in the "transverse" region as a function of PTmax for charged particles (p_T > 0.5 GeV/c, |η| < 1, *not including PTmax*) in "min-bias" events at 0.2 TeV, 0.9 TeV, 1.96 TeV, 7 TeV, 10 TeV, 14 TeV predicted by PYTHIA DW at the particle level (*i.e.* generator level).**

"Transverse" Charged Particle Density



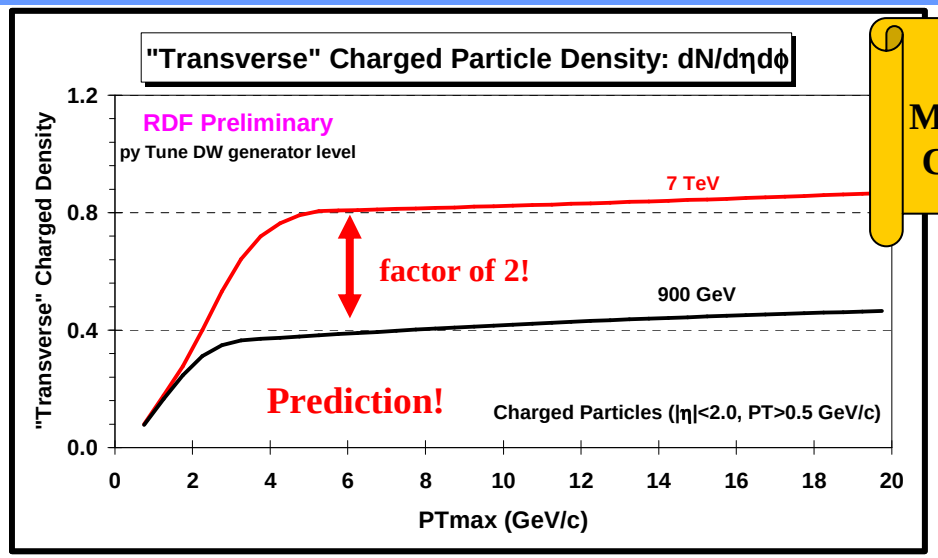




- **Shows the "associated" charged particle density in the "transverse" region as a function of PTmax for charged particles (p_T > 0.5 GeV/c, |η| < 1, *not including PTmax*) in "min-bias" events at 0.2 TeV, 0.9 TeV, 1.96 TeV, 7 TeV, 10 TeV, 14 TeV predicted by PYTHIA DW at the particle level (*i.e.* generator level).**

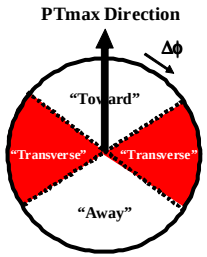
Log scale!

"Transverse" Charge Density



Rick Field
MB&UE@CMS Workshop
CERN, November 6, 2009

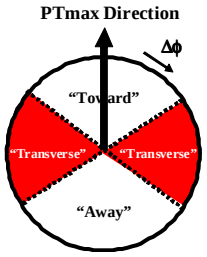
LHC 900 GeV



900 GeV → 7 TeV
(UE increase ~ factor of 2)

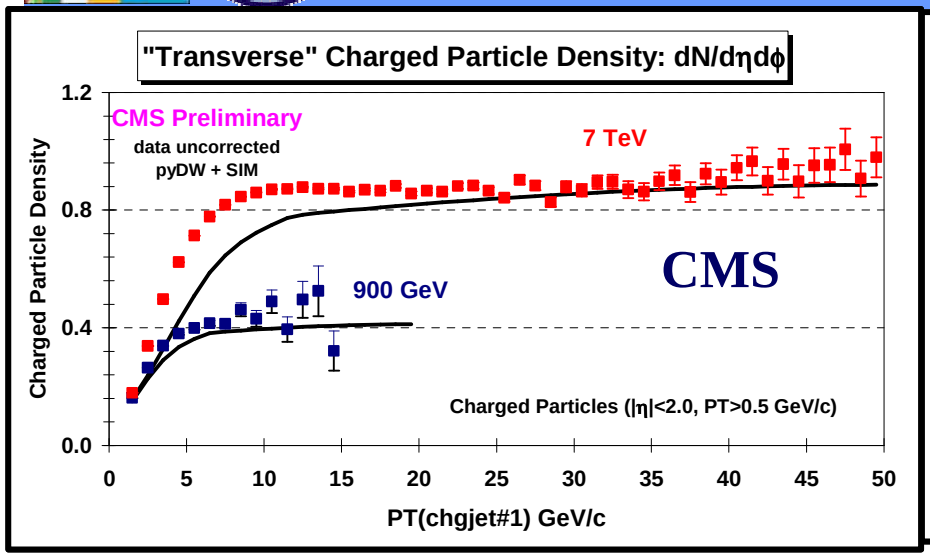
~0.4 → ~0.8

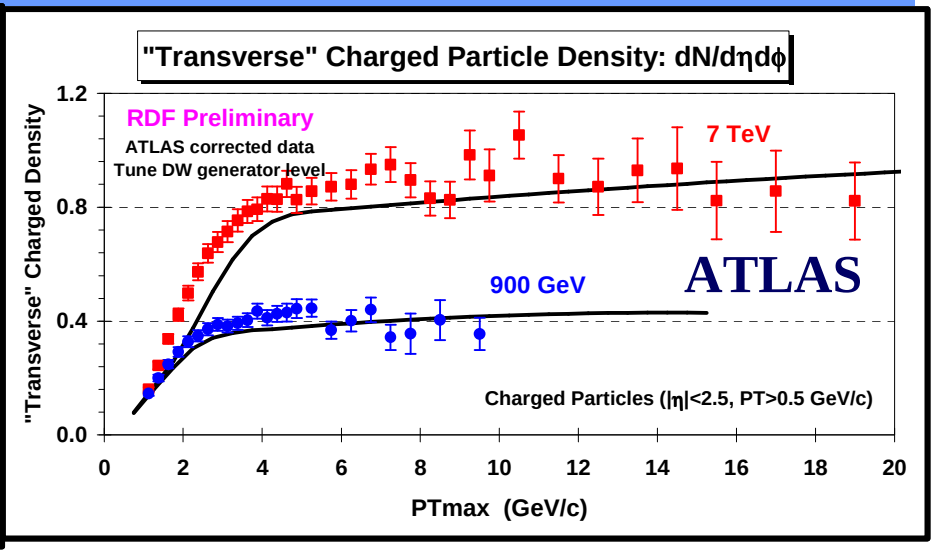
LHC 7 TeV



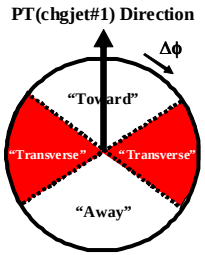
- **Shows the charged particle density in the "transverse" region for charged particles (p_T > 0.5 GeV/c, |η| < 2) at 900 GeV and 7 TeV as defined by PTmax from PYTHIA Tune DW and at the particle level (*i.e.* generator level).**

PYTHIA Tune DW

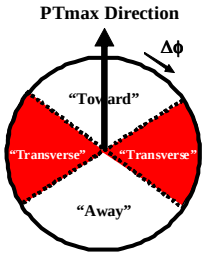




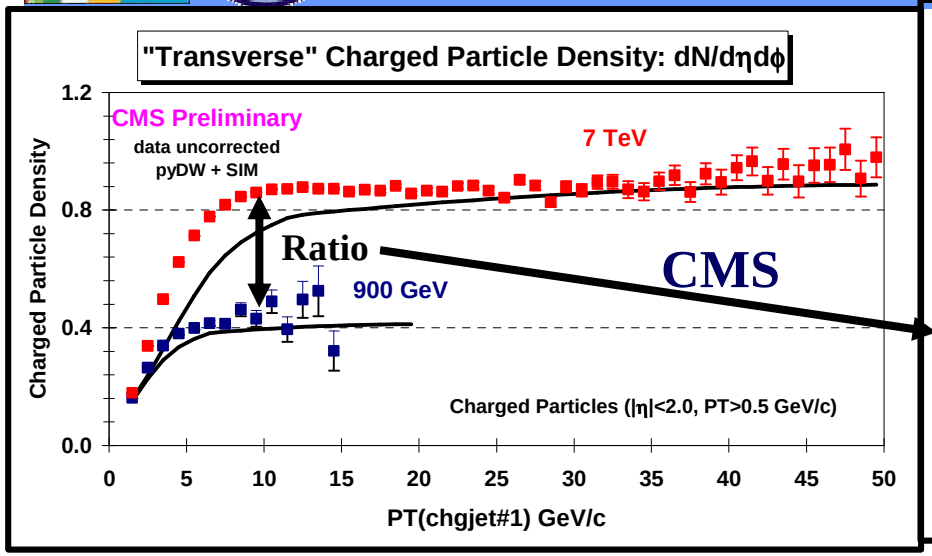
➡ **CMS preliminary data at 900 GeV and 7 TeV on the "transverse" charged particle density, dN/dηdϕ, as defined by the leading charged particle jet (chgjet#1) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 2$. The data are uncorrected and compared with PYTHIA Tune DW after detector simulation.**

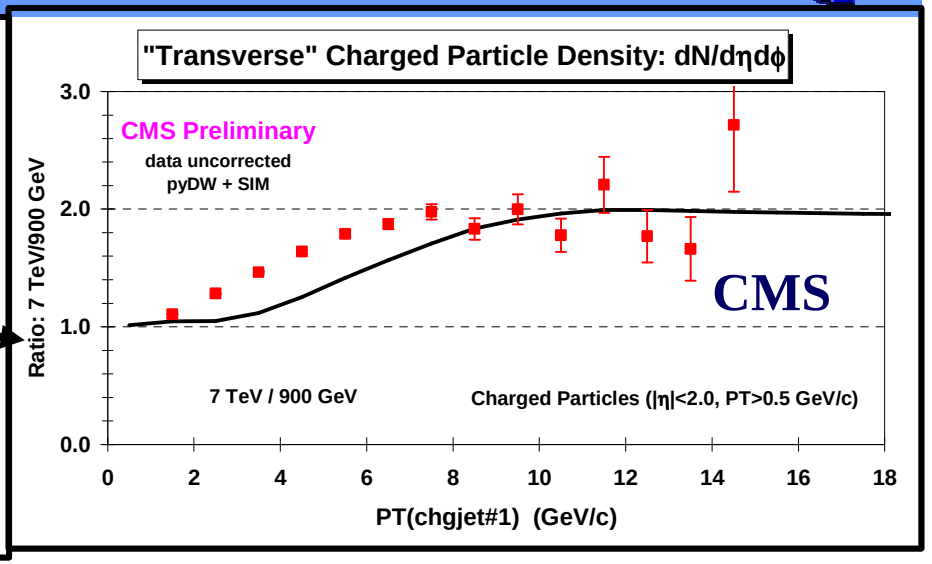


➡ **ATLAS preliminary data at 900 GeV and 7 TeV on the "transverse" charged particle density, dN/dηdϕ, as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 2.5$. The data are corrected and compared with PYTHIA Tune DW at the generator level.**

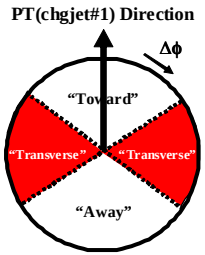


PYTHIA Tune DW

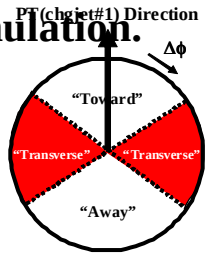




➡ **CMS preliminary data at 900 GeV and 7 TeV on the "transverse" charged particle density, dN/dηdϕ, as defined by the leading charged particle jet (chgjet#1) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 2$. The data are uncorrected and compared with PYTHIA Tune DW after detector simulation.**

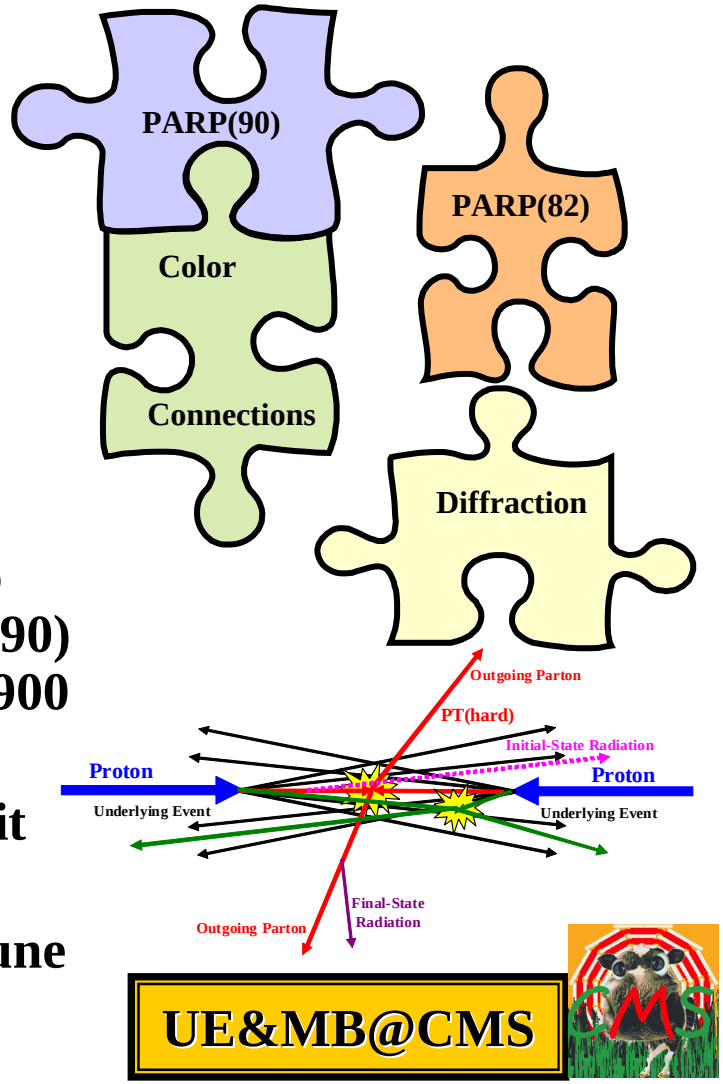


➡ **Ratio of CMS preliminary data at 900 GeV and 7 TeV on the "transverse" charged particle density, dN/dηdϕ, as defined by the leading charged particle jet (chgjet#1) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 2$. The data are uncorrected and compared with PYTHIA Tune DW after detector simulation.**



PYTHIA Tune Z1

- All my previous tunes (A, DW, DWT, D6, D6T, CW, X1, and X2) were PYTHIA 6.4 tunes using the old Q^2-ordered parton showers and the old MPI model (really 6.2 tunes)!
- I believe that it is time to move to PYTHIA 6.4 (p_T-ordered parton showers and new MPI model)!
- **Tune Z1:** I started with the parameters of ATLAS Tune AMBT1, but I changed LO* to CTEQ5L and I varied PARP(82) and PARP(90) to get a very good fit of the CMS UE data at 900 GeV and 7 TeV.
- The ATLAS Tune AMBT1 was designed to fit the inelastic data for Nchg ≥ 6 and to fit the PTmax UE data with PTmax > 10 GeV/c. Tune AMBT1 is primarily a min-bias tune, while Tune Z1 is a UE tune!

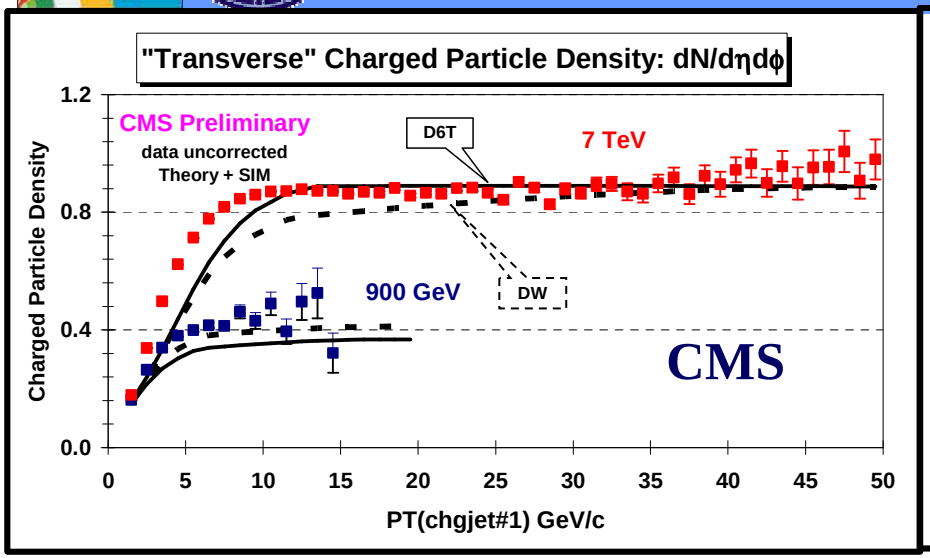


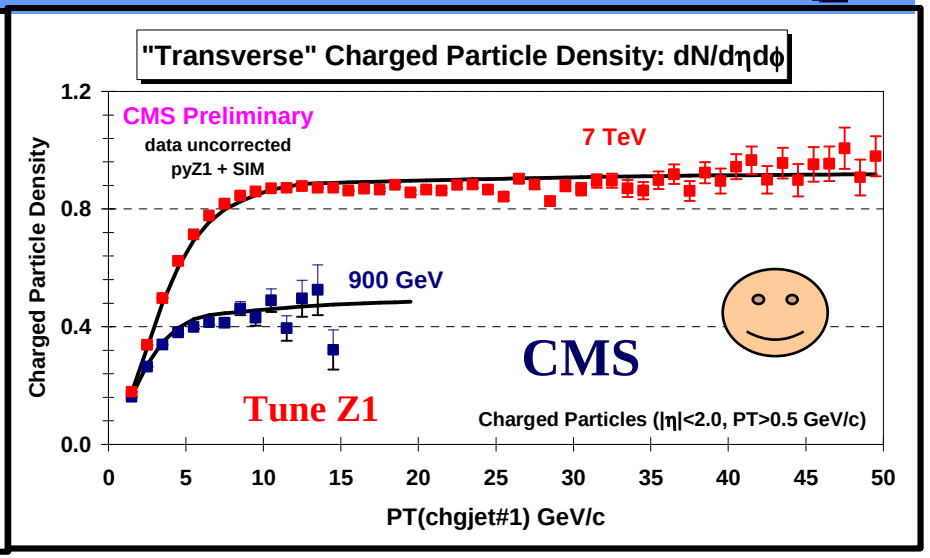
PYTHIA Tune Z1

Parameters not shown are the PYTHIA 6.4 defaults!

Parameter	Tune Z1 (R. Field CMS)	Tune AMBT1 (ATLAS)
Parton Distribution Function	CTEQ5L	LO*
PARP(82) – MPI Cut-off	1.932	2.292
PARP(89) – Reference energy, E0	1800.0	1800.0
PARP(90) – MPI Energy Extrapolation	0.275	0.25
PARP(77) – CR Suppression	1.016	1.016
PARP(78) – CR Strength	0.538	0.538
PARP(80) – Probability colored parton from BBR	0.1	0.1
PARP(83) – Matter fraction in core	0.356	0.356
PARP(84) – Core of matter overlap	0.651	0.651
PARP(62) – ISR Cut-off	1.025	1.025
PARP(93) – primordial kT-max	10.0	10.0
MSTP(81) – MPI, ISR, FSR, BBR model	21	21
MSTP(82) – Double gaussion matter distribution	4	4
MSTP(91) – Gaussian primordial kT	1	1
MSTP(95) – strategy for color reconnection	6	6

CMS UE Data





➡ **CMS preliminary data at 900 GeV and 7 TeV on the "transverse" charged particle density, dN/dηdϕ, as defined by the leading charged particle jet (chgjet#1) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 2.0$. The data are uncorrected and compared with PYTHIA Tune DW and D6T after detector simulation (SIM).**

➡ **CMS preliminary data at 900 GeV and 7 TeV on the "transverse" charged particle density, dN/dηdϕ, as defined by the leading charged particle jet (chgjet#1) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 2.0$. The data are uncorrected and compared with PYTHIA Tune Z1 after detector simulation (SIM).**

Color reconnection suppression.
Color reconnection strength.

Tune Z1 (CTEQ5L)
PARP(82) = 1.932
PARP(90) = 0.275
PARP(77) = 1.016
PARP(78) = 0.538

Tune Z1 is a PYTHIA 6.4 using p_T-ordered parton showers and the new MPI model!

PYTHIA 6.2 Tunes

Parameter	Tune AW	Tune DW	Tune D6
PDF	CTEQ5L	CTEQ5L	CTEQ6L
MSTP(81)	1	1	1
MSTP(82)	4	4	4
PARP(82)	2.0 GeV	1.9 GeV	1.8 GeV
PARP(83)	0.5	0.5	0.5
PARP(84)	0.4	0.4	0.4
PARP(85)	0.9	1.0	1.0
PARP(86)	0.95	1.0	1.0
PARP(89)	1.8 TeV	1.8 TeV	1.8 TeV
PARP(90)	0.25	0.25	0.25
PARP(62)	1.25	1.25	1.25
PARP(64)	0.2	0.2	0.2
PARP(67)	4.0	2.5	2.5
MSTP(91)	1	1	1
PARP(91)	2.1	2.1	2.1
PARP(93)	15.0	15.0	15.0

UE Parameters

ISR Parameter

Intrinsic KT

Uses CTEQ6L

Reduce PARP(82) by factor of 1.8/1.9 = 0.95 Everything else the same!

Tune A energy dependence! (not the default)

CMS: We wanted a CTEQ6L version of Tune Z1 in a hurry!

PYTHIA Tune Z2

Parameter	Tune Z1 (R. Field CMS)	Tune Z2 (R. Field CMS)
Parton Distribution Function	CTEQ5L	CTEQ6L
PARP(82) – MPI Cut-off	1.932	1.832
PARP(89) – Reference energy, E0	1800.0	1800.0
PARP(90) – MPI Energy Extrapolation	0.275	0.275
PARP(77) – CR Suppression	1.016	1.016
PARP(78) – CR Strength	0.538	0.538
PARP(80) – Probability colored parton from BBR	0.1	0.1
PARP(83) – Matter fraction in core	0.356	0.356
PARP(84) – Core of matter overlap	0.651	0.651
PARP(62) – ISR Cut-off	1.025	1.025
PARP(93) – primordial kT-max	10.0	10.0
MSTP(81) – MPI, ISR, FSR, BBR model	21	21
MSTP(82) – Double gaussion matter distribution	4	4
MSTP(91) – Gaussian primordial kT	1	1
MSTP(95) – strategy for color reconnection	6	6

My guess!

Reduce PARP(82) by factor of 1.83/1.93 = 0.95
Everything else the same!

PYTHIA Tune Z2

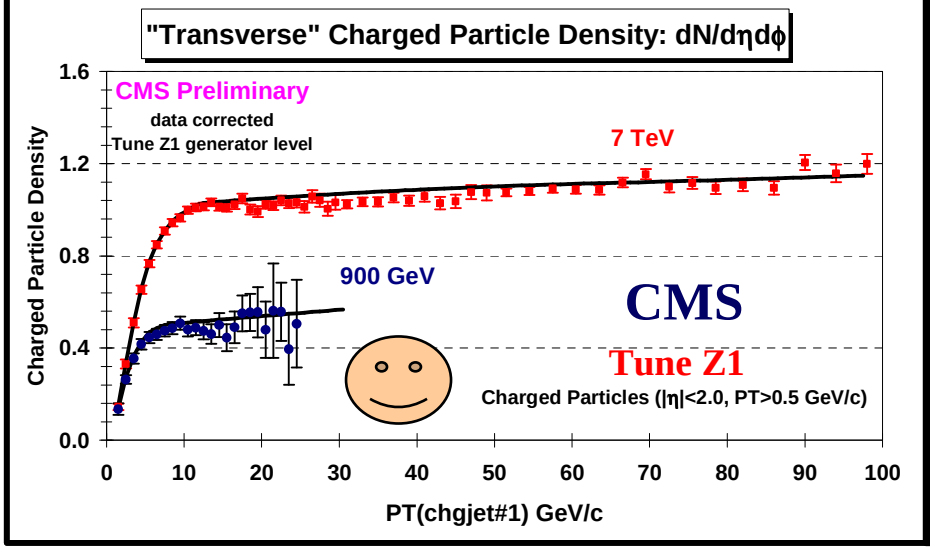
Parameter	Tune Z1 (R. Field CMS)	Tune Z2 (R. Field CMS)
Parton Distribution Function	CTEQ5L	CTEQ6L
PARP(82) – MPI Cut-off	1.932	1.832
PARP(89) – Reference energy, E0	1800.0	1800.0
PARP(90) – MPI Energy Extrapolation	0.275	0.275
PARP(77) – CR Suppression	1.016	1.016
PARP(78) – CR Strength	0.538	0.538
PARP(80) – Probability colored parton from BBR	0.1	0.1
PARP(83) – Matter fraction in core	0.356	0.356
PARP(84) – Core of matter overlap	0.651	0.651
PARP(62) – ISR Cut-off	1.025	1.025
PARP(93) – primordial kT-max	10.0	10.0
MSTP(81) – MPI, ISR, FSR, BBR model	21	21
MSTP(82) – Double gaussion matter distribution	4	4
MSTP(91) – Gaussian primordial kT	1	1
MSTP(95) – strategy for color reconnection	6	6

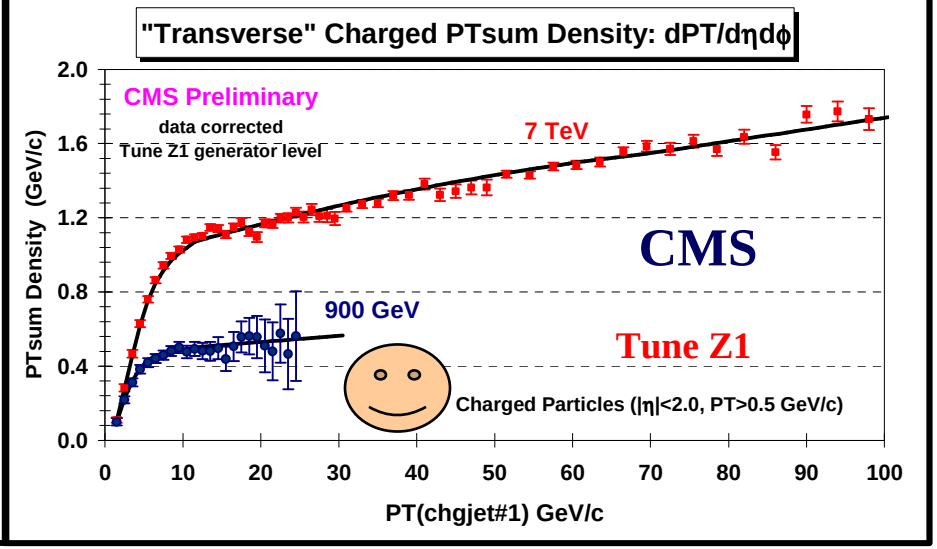
My guess!

Reduce PARP(82) by factor of 1.83/1.93 = 0.95 Everything else the same!

PARP(90) same For Z1 and Z2!

PYTHIA 6.4 Tune Z2





➡ **CMS preliminary data at 900 GeV and 7 TeV on the "transverse" charged particle density, dN/dηdϕ, as defined by the leading charged particle jet (chgjet#1) for charged particles with p_T > 0.5 GeV/c and |η| < 2.0. The data are corrected and compared with PYTHIA Tune Z1 at the generator level.**

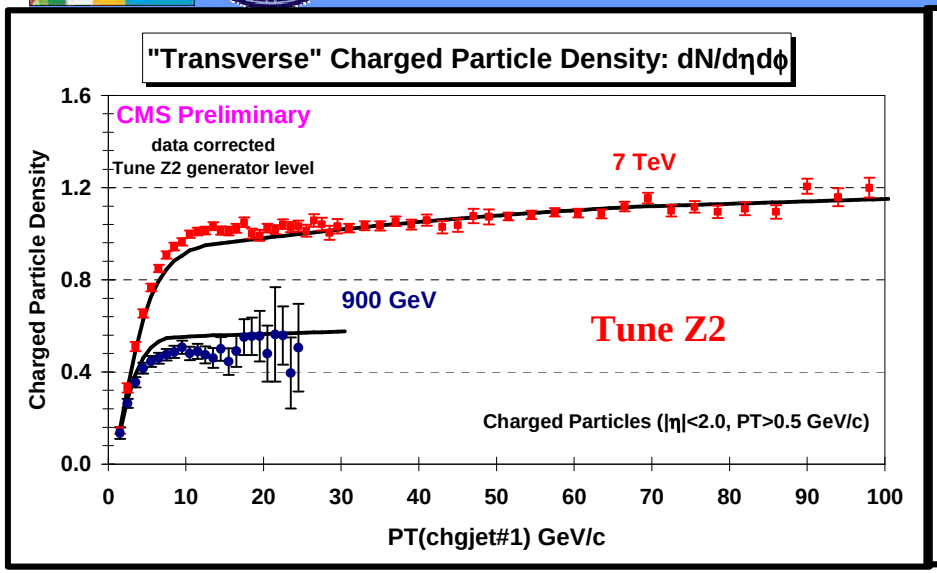
➡ **CMS preliminary data at 900 GeV and 7 TeV on the "transverse" charged PTsum density, dPT/dηdϕ, as defined by the leading charged particle jet (chgjet#1) for charged particles with p_T > 0.5 GeV/c and |η| < 2.0. The data are corrected and compared with PYTHIA Tune Z1 at the generator level.**

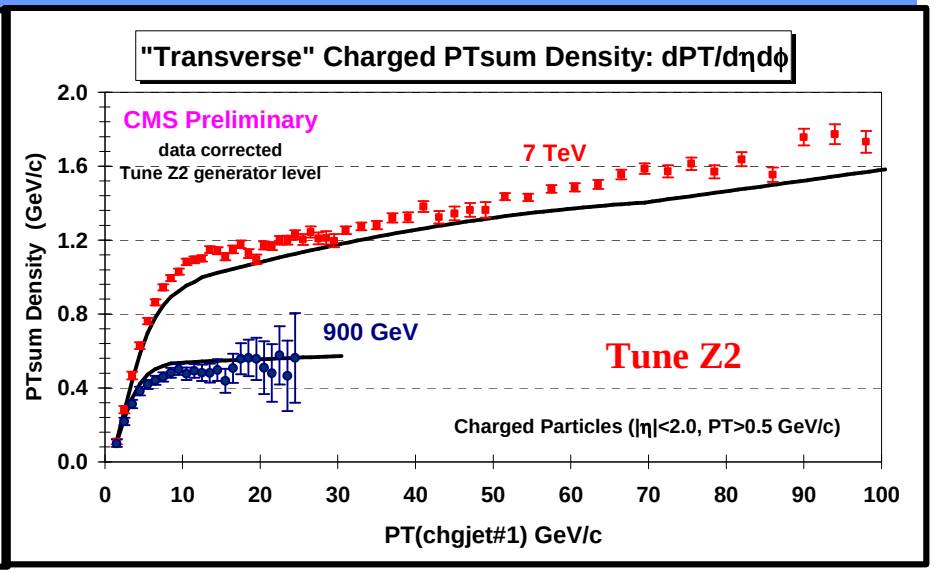
CMS corrected data!

Very nice agreement!

CMS corrected data!

PYTHIA 6.4 Tune Z2





- **CMS preliminary data at 900 GeV and 7 TeV on the "transverse" charged particle density, dN/dηdϕ, as defined by the leading charged particle jet (chgjet#1) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 2.0$. The data are corrected and compared with PYTHIA Tune Z2 at the generator level.**

- **CMS preliminary data at 900 GeV and 7 TeV on the "transverse" charged PTsum density, dPT/dηdϕ, as defined by the leading charged particle jet (chgjet#1) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 2.0$. The data are corrected and compared with PYTHIA Tune Z2 at the generator level.**

CMS corrected data!

Not good! Bad energy dependence!

CMS corrected data!

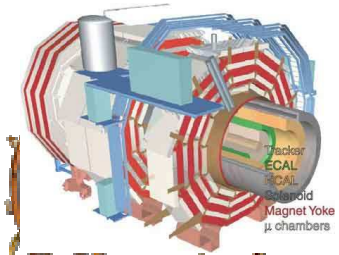
PYTHIA Tune Z2*

Parameter	Tune Z1 (R. Field CMS)	Tune Z2 (R. Field CMS)	Tune Z2* (CMS)
Parton Distribution Function	CTEQ5L	CTEQ6L	CTEQ6L
PARP(82) – MPI Cut-off	1.932	1.832	1.93
PARP(89) – Reference energy, E0	1800.0	1800.0	1800.0
PARP(90) – MPI Energy Extrapolation	0.275	0.275	0.23
PARP(77) – CR Suppression	1.01	1.016	1.016
PARP(78) – CR Strength		0.538	0.538
PARP(80) – Probability colored parton		0.1	0.1
PARP(83) – Matter fraction in core	0.356	0.356	0.356
PARP(84) – Core of matter overlap	0.651	0.651	0.651
PARP(62) – ISR Cut-off	1.025	1.025	1.025
PARP(93) – primordial kT-max	10.0	10.0	10.0
MSTP(81) – MPI, ISR, FSR, BBR model	21	21	21
MSTP(82) – Double gaussion matter distribution	4	4	4
MSTP(91) – Gaussian primordial kT	1	1	1
MSTP(95) – strategy for color reconnection	6	6	6

A. Knutsson & M. Zakaria using Rivet & the Professor

MB & UE Common Plots

Quantum Chromo-Dynamics



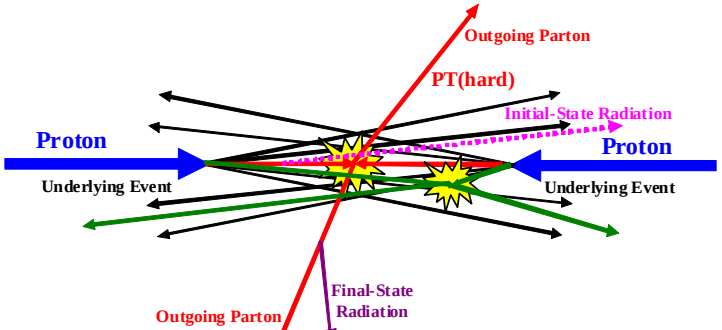
CMS

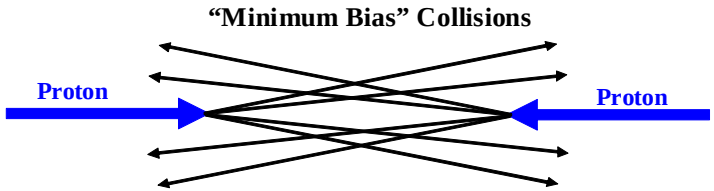
ATLAS

➡ **The LPCC MB&UE Working Group has suggested several MB&UE "Common Plots" the all the LHC groups can produce and compare with each other.**

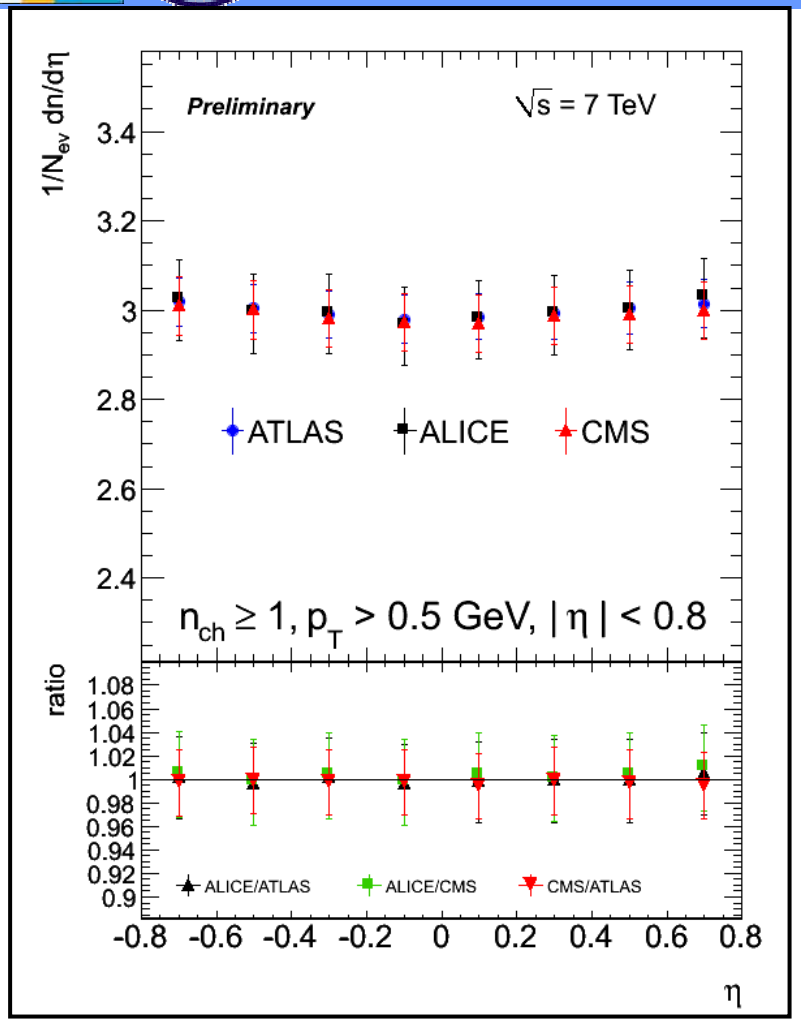
ALICE

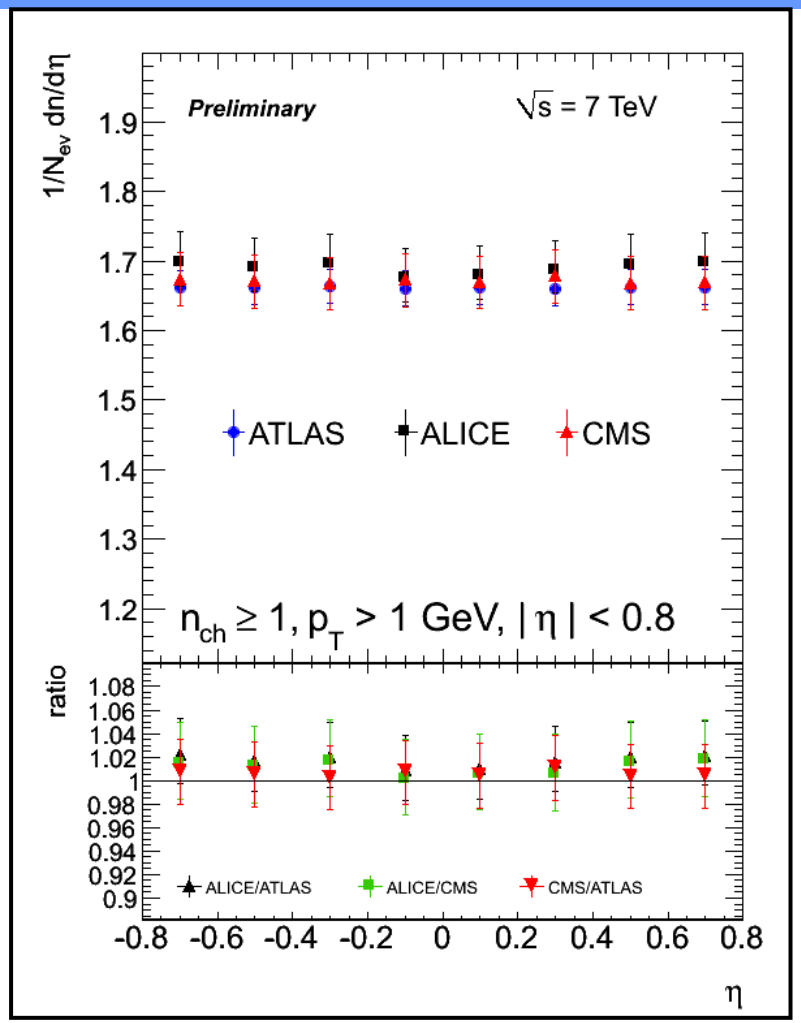
LHCb





MB Common Plots 7 TeV





Direct charged particles (including leptons) corrected to the particle level with no corrections for SD or DD.

CMS Common Plots

Observable	900 GeV	7 TeV
MB1: $dN_{chg}/d\eta$ $N_{chg} \geq 1$ $\|\eta\| < 0.8$ $p_T > 0.5$ Gev/c & 1.0 GeV/c	Done QCD-10-024	Done QCD-10-024
MB2: dN_{chg}/dp_T $N_{chg} \geq 1$ $\|\eta\| < 0.8$	Stalled	Stalled
MB3: Multiplicity Distribution $\|\eta\| < 0.8$ $p_T > 0.5$ GeV/c & 1.0 GeV/c	Stalled	Stalled
MB4: $\langle p_T \rangle$ versus Nchg $\|\eta\| < 0.8$ $p_T > 0.5$ GeV/c & 1.0 GeV/c	In progress (Antwerp)	In progress (Antwerp)
UE1: Transverse Nchg & PTsum as defined by the leading charged particle, PTmax $\|\eta\| < 0.8$ $p_T > 0.5$ GeV/c & 1.0 GeV/c	Done FSQ-12-020	Done FSQ-12-020

Direct charged particles (including leptons) corrected to the particle level with no corrections for SD or DD.

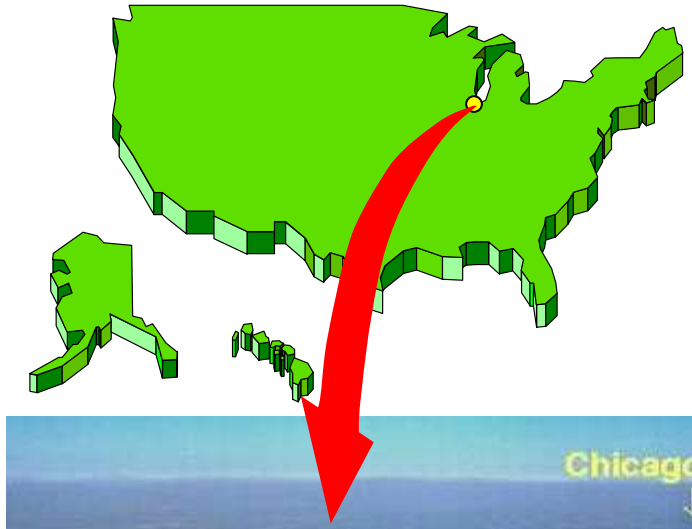
CMS Common Plots

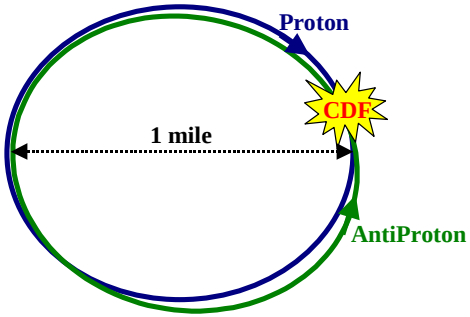
Observable	900 GeV	7 TeV
MB1: $dN_{chg}/d\eta$ $N_{chg} \geq 1$ $\|\eta\| < 0.8$ $p_T >$ /c & 1.0 G	Do QC	Done 0-024
MB2: dN_{chg}/dp_T		talled
MB $\|\eta\| < 0.8$ p		
MB4: $\langle p_T \rangle$ ver $\|\eta\| < 0.8$ $p_T >$		cs
UE1: Transverse Nchg defined by the leading particle, PTmax $\|\eta\| < 0.8$ $p_T > 0.5$ GeV/c & 1.0 G	FSQ	one F 2-020

Note that all the "common plots" require at least one charged particle with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$!
This done so that the plots are less sensitive to SD and DD.

Direct charged partic (including leptons) corrected to the particle level with o corrections for SD or DD.

Tevatron Energy Scan



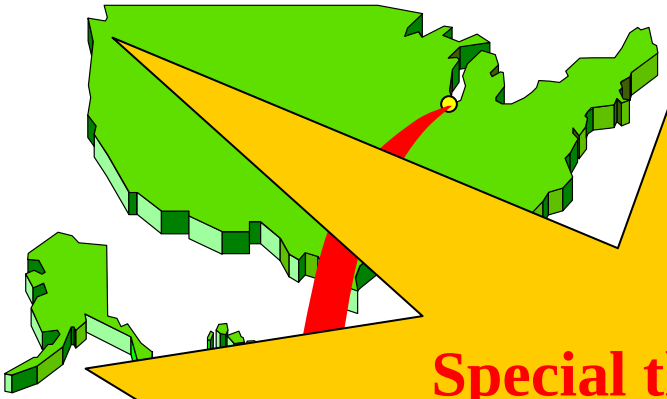


- **Just before the shutdown of the Tevatron CDF has collected more than 10M "min-bias" events at several center-of-mass energies!**

300 GeV 12.1M MB Events

900 GeV 54.3M MB Events

Tevatron Energy Scan



Special thanks to Mike Albrow, Michelangelo Mangano, Rob Roser, and everyone that helped make this happen!

AntiProton

f the Tevatron CDF
more t I "min-bias" events
at se ter-of-mass rgies!

300 eV 12.1M MB Events

900 GeV 54.3M MB Events

CDF Common Plots

Observable	300 GeV	900 GeV	1.96 TeV
MB1: $dN_{chg}/d\eta$ $N_{chg} \geq 1$ $\|\eta\| < 0.8$ $p_T > 0.5$ Gev/c & 1.0 GeV/c	Done	Done	Done
MB2: dN_{chg}/dp_T $N_{chg} \geq 1$ $\|\eta\| < 0.8$	In progress	In progress	In progress
MB3: Multiplicity Distribution $\|\eta\| < 0.8$ $p_T > 0.5$ GeV/c & 1.0 GeV/c	In progress	In progress	In progress
MB4: $\langle p_T \rangle$ versus Nchg $\|\eta\| < 0.8$ $p_T > 0.5$ GeV/c & 1.0 GeV/c	In progress	In progress	In progress
UE1: Transverse Nchg & PTsum as defined by the leading charged particle, PTmax $\|\eta\| < 0.8$ $p_T > 0.5$ GeV/c & 1.0 GeV/c	$p_T > 0.5$ GeV/c Done	$p_T > 0.5$ GeV/c Done	$p_T > 0.5$ GeV/c Done

Direct charged particles (including leptons) corrected to the particle level with no corrections for SD or DD.

R. Field, C. Group, and D. Wilson.

CDF Common Plots

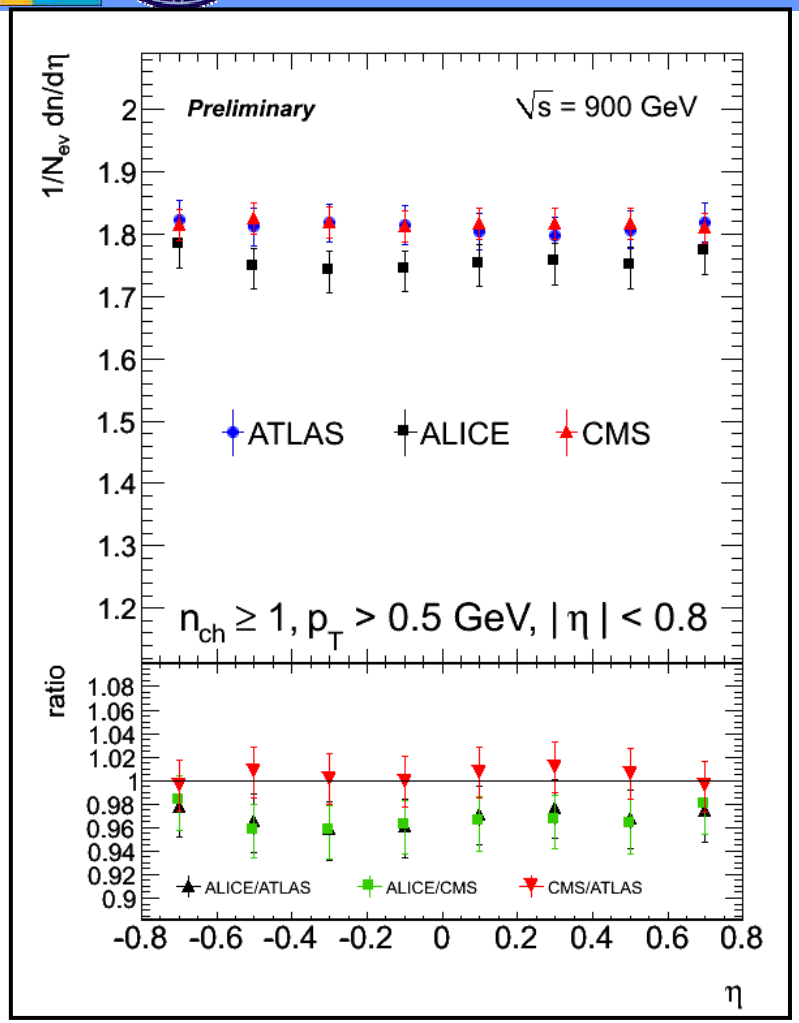
Observable	300 GeV	900 GeV	1.96 TeV
MB1: dN_{chg}/d ... ≥ 1 $\|\eta\| < 0.8$ $p_T > 0.5$ ... 1.0 GeV/c	Done	Done	Done
MB2: dN_{chg}/dp_T $N_{chg} \geq$		...ss	In progress
MB3: M... $\|\eta\| < 0.8$ $p_T >$ ...			...n progress
MB4: $\langle p_T \rangle$ versus N $\|\eta\| < 0.8$ $p_T > 0.5$ ...			...progress
UE1: Tra... Nchg & P... defined by the leading char... particle, PTmax $\|\eta\| < 0.8$ $p_T > 0.5$ GeV/c & 1.0 GeV/c	0.5 ... Done	p_T > ... V/c Done	$p_T > 0.5$ GeV/c Done

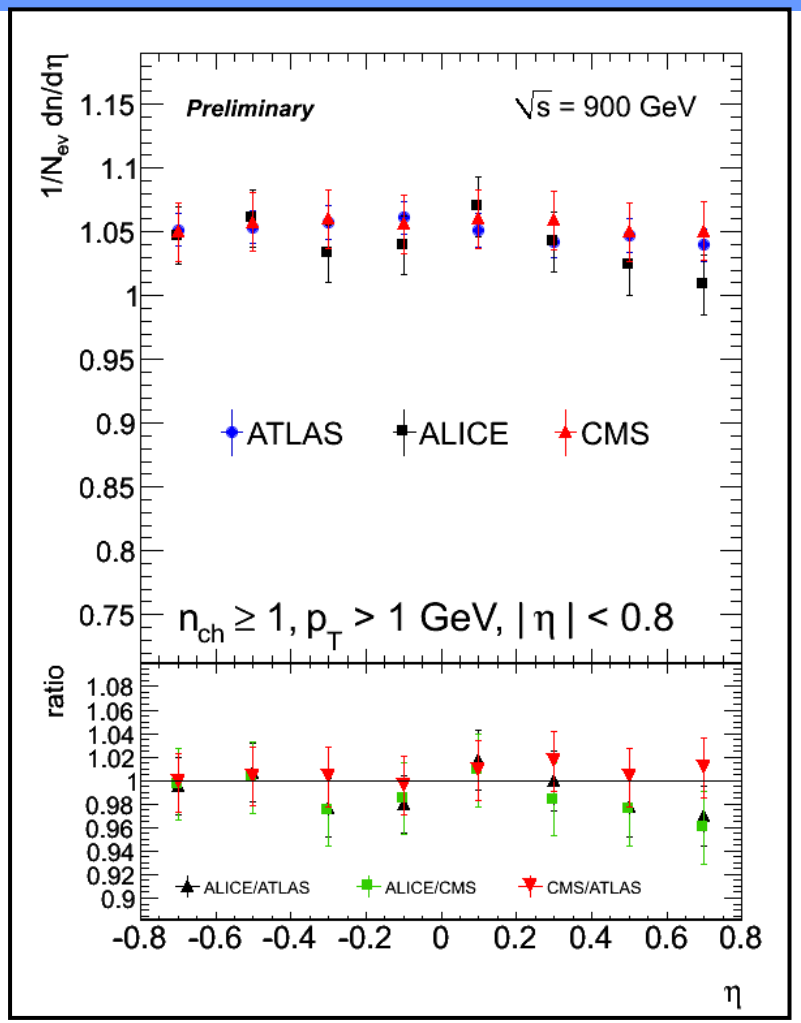
Direct charged pa...les (including le...tons) corrected to the particle level w...h no corrections for SD or DD.

R. Field, C. Group, and D. Wilson.

Special thanks to Mary Convery, Ray Culbertson, and Jonathan Lewis for their help with the datasets!

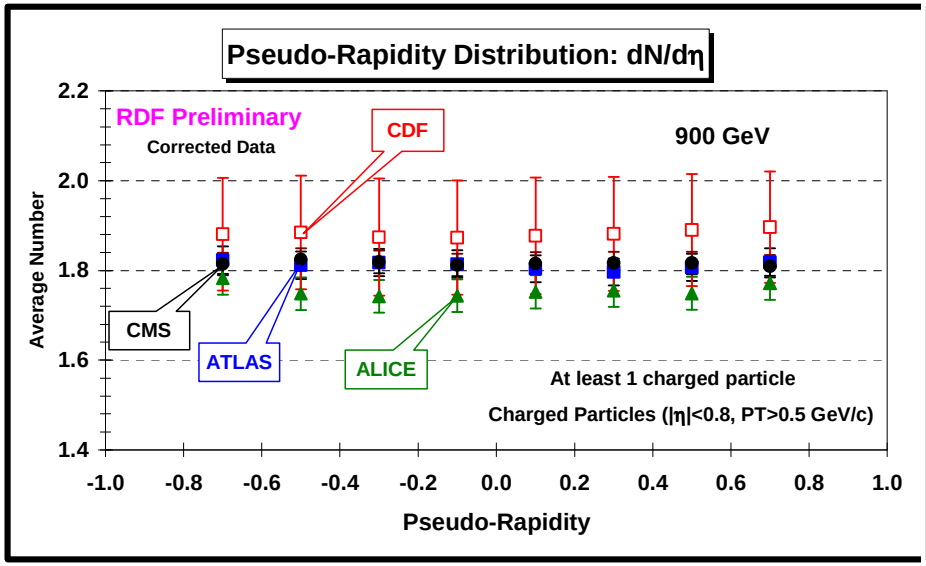
MB Common Plots 900 GeV

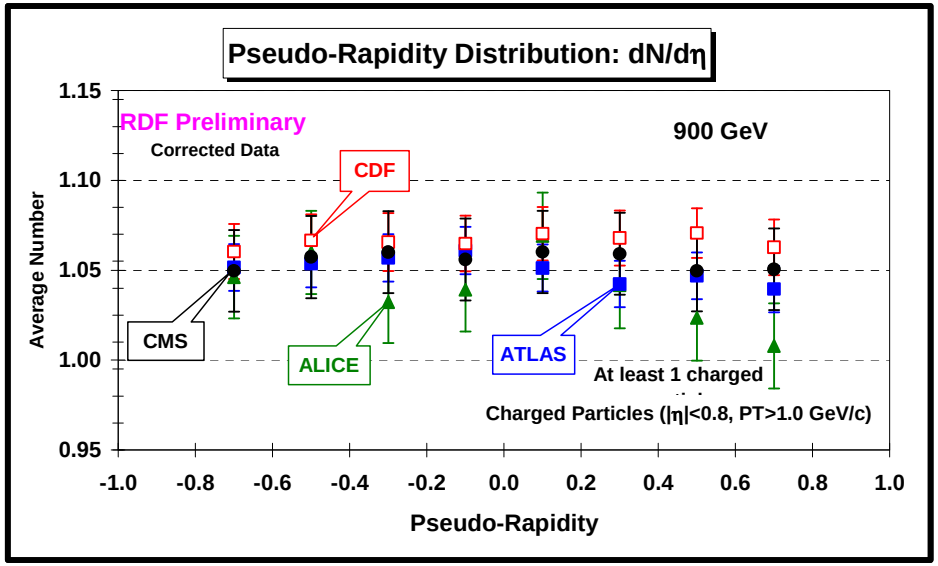


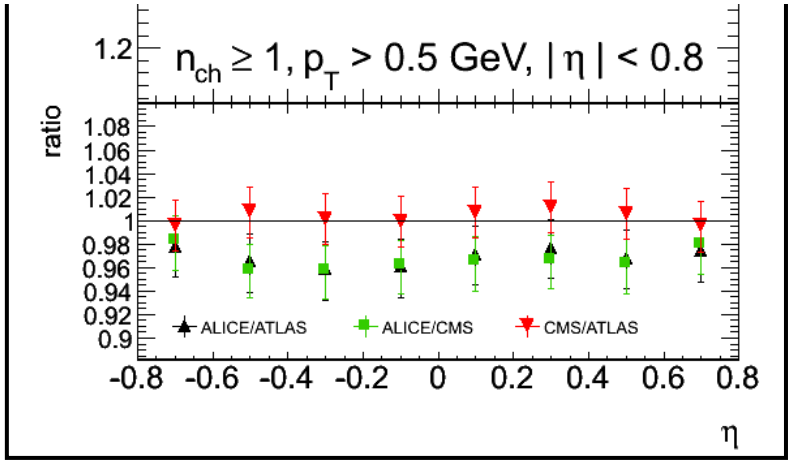


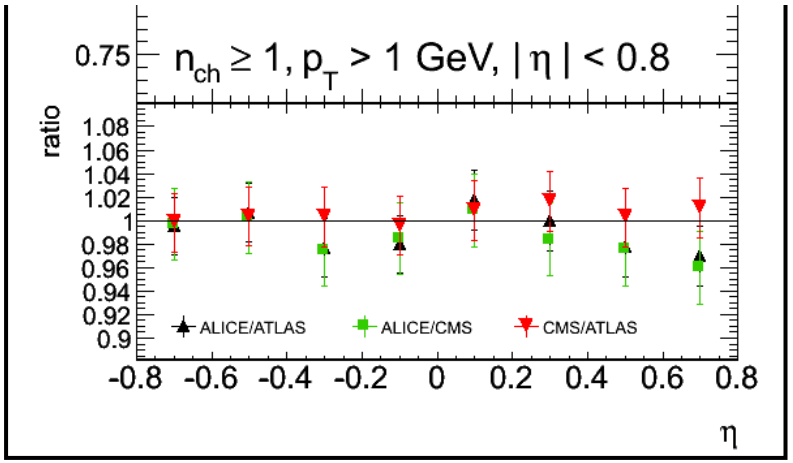
Direct charged particles (including leptons) corrected to the particle level with no corrections for SD or DD.

MB Common Plots 900 GeV



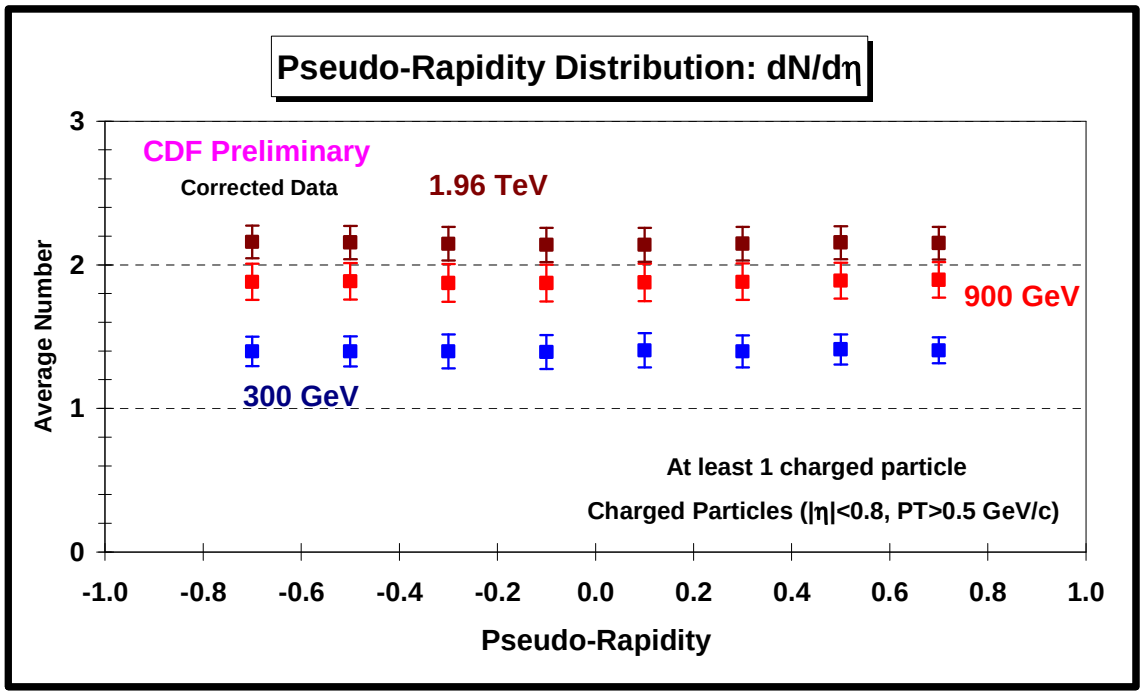






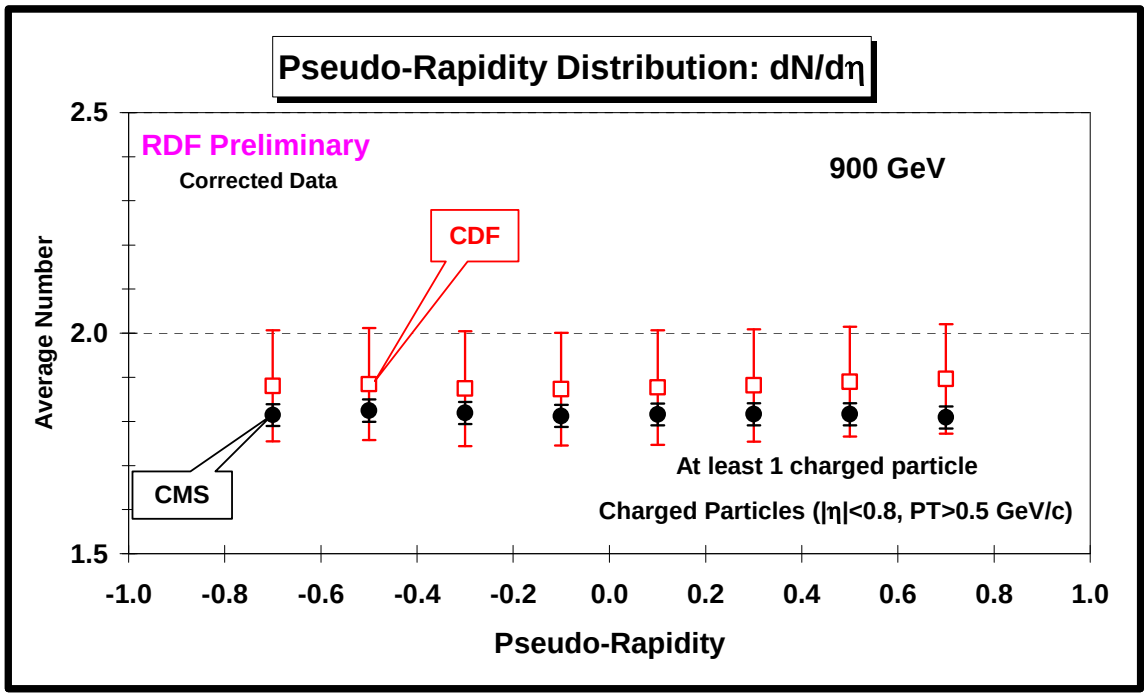
Direct charged particles (including leptons) corrected to the particle level with no corrections for SD or DD.

New CDF MB Data



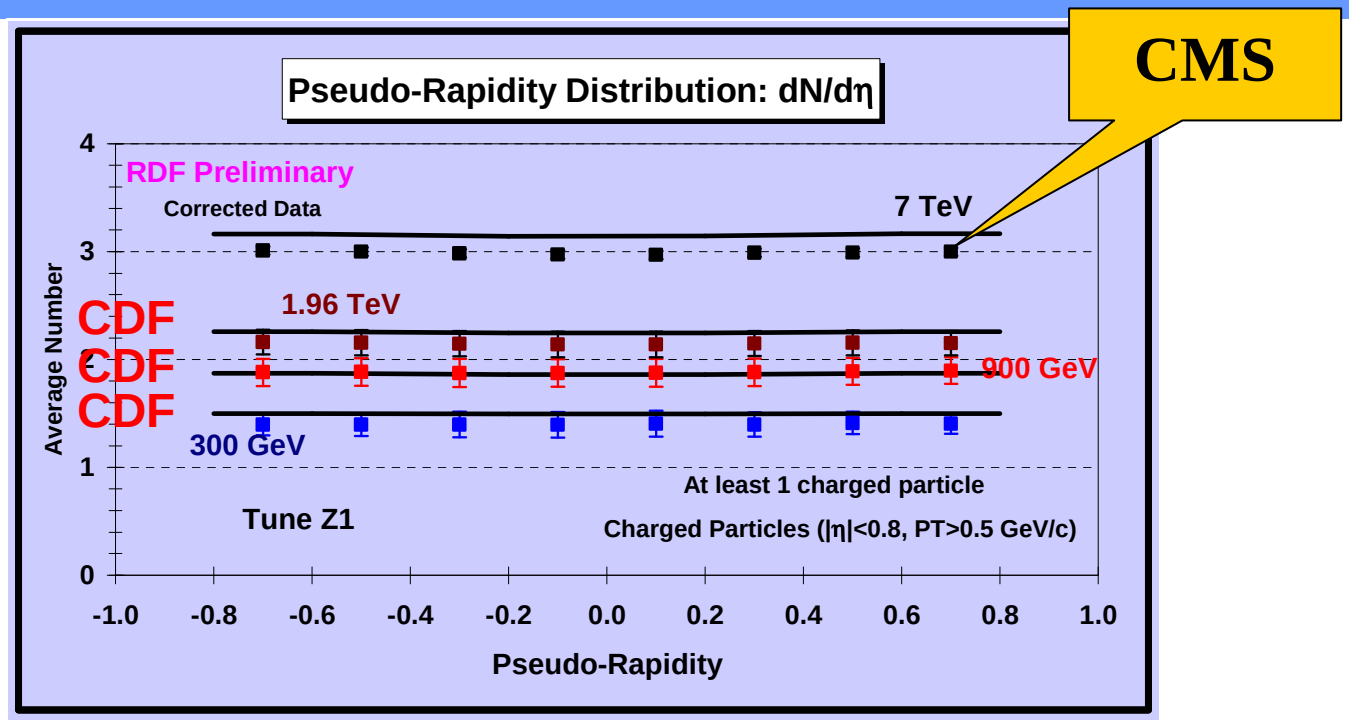
➡ **New Corrected CDF data at 300 GeV, 900 GeV, and 1.96 TeV on on pseudo-rapidity distribution of charged particles, dN/dη, with $p_T > 0.5$ GeV/c. Events are required to have at least one charged particle with $|\eta| < 0.8$ and $p_T > 0.5$ GeV/c. The data are corrected to the particle level with errors that include both the statistical error and the systematic uncertainty.**

New CDF MB Data



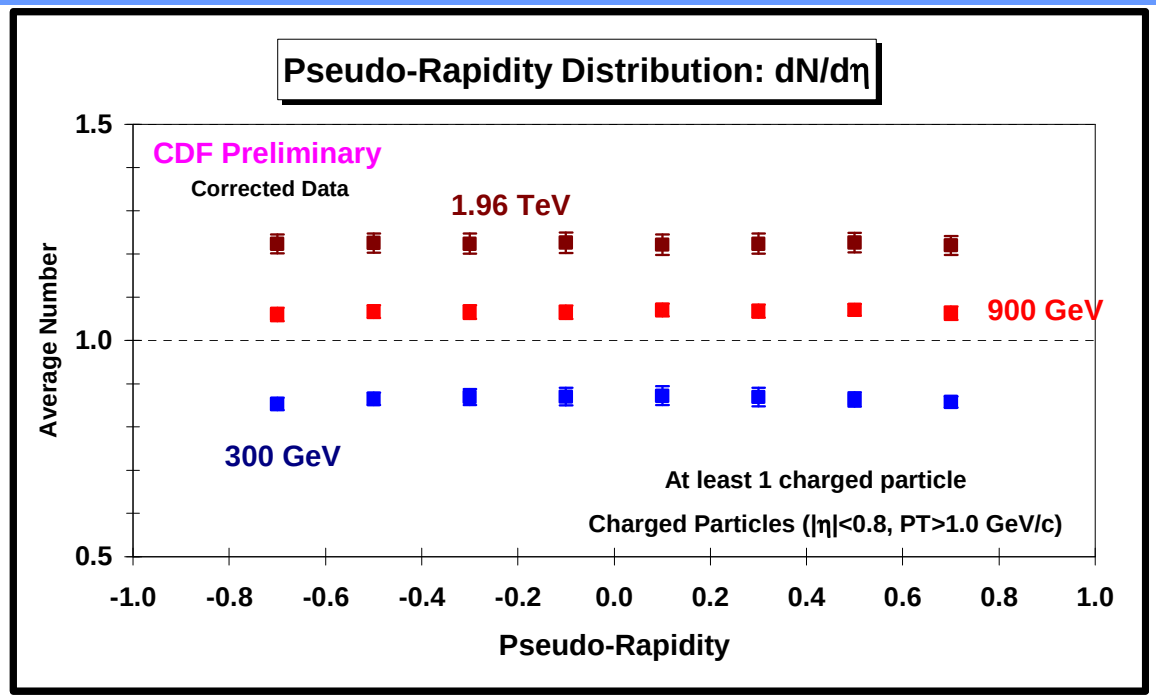
➡ **New Corrected CDF data at 300 GeV, 900 GeV, and 1.96 TeV on on pseudo-rapidity distribution of charged particles, dN/dη, with $p_T > 0.5$ GeV/c. Events are required to have at least one charged particle with $|\eta| < 0.8$ and $p_T > 0.5$ GeV/c. The data are corrected to the particle level with errors that include both the statistical error and the systematic uncertainty.**

New CDF MB Data



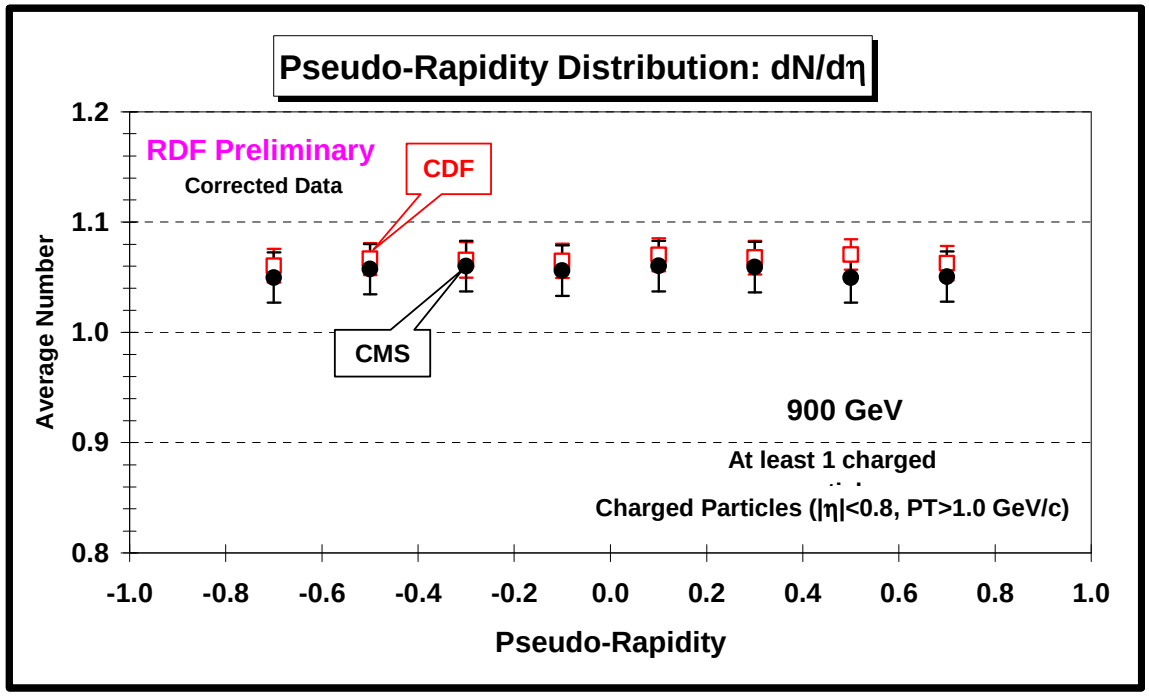
➡ **New Corrected CDF data at 300 GeV, 900 GeV, and 1.96 TeV on on pseudo-rapidity distribution of charged particles, dN/dη, with $p_T > 0.5$ GeV/c. Events are required to have at least one charged particle with $|\eta| < 0.8$ and $p_T > 0.5$ GeV/c. The data are corrected to the particle level with errors that include both the statistical error and the systematic uncertainty.**

New CDF MB Data



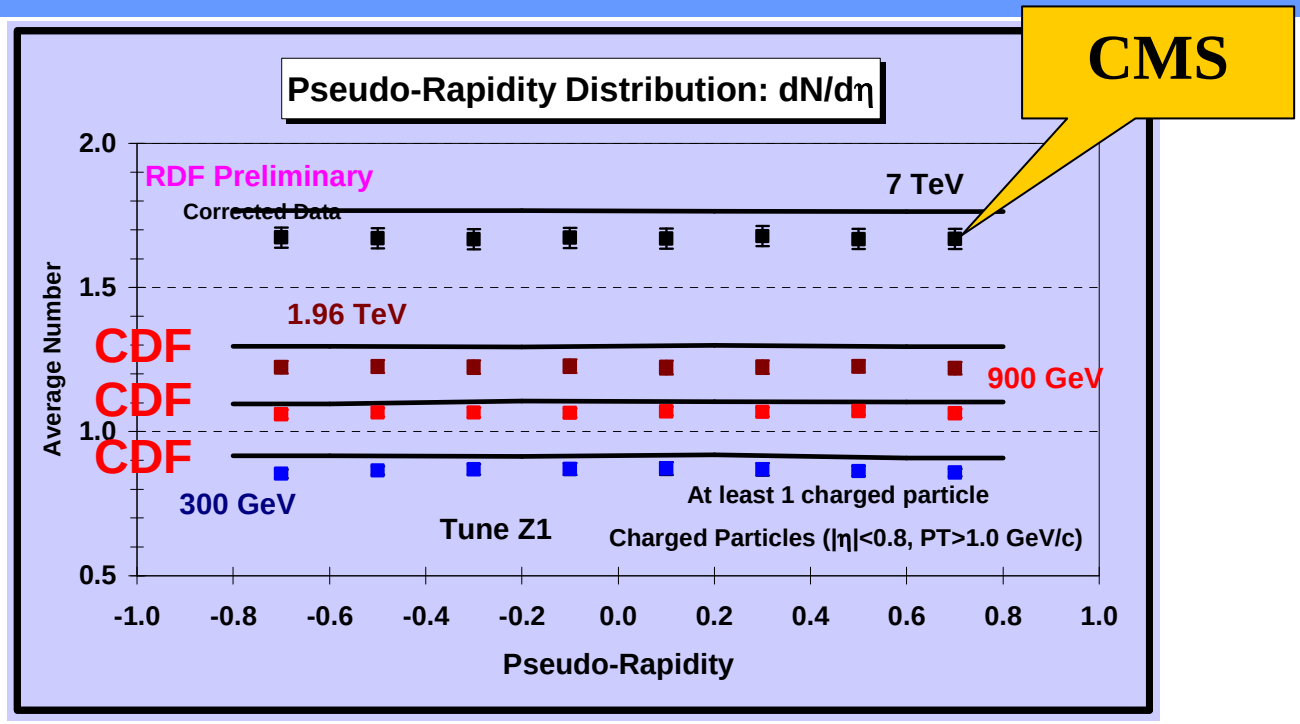
➡ **New Corrected CDF data at 300 GeV, 900 GeV, and 1.96 TeV on on pseudo-rapidity distribution of charged particles, dN/dη, with p_T > 1.0 GeV/c. Events are required to have at least one charged particle with |η| < 0.8 and p_T > 1.0 GeV/c. The data are corrected to the particle level with errors that include both the statistical error and the systematic uncertainty.**

New CDF MB Data



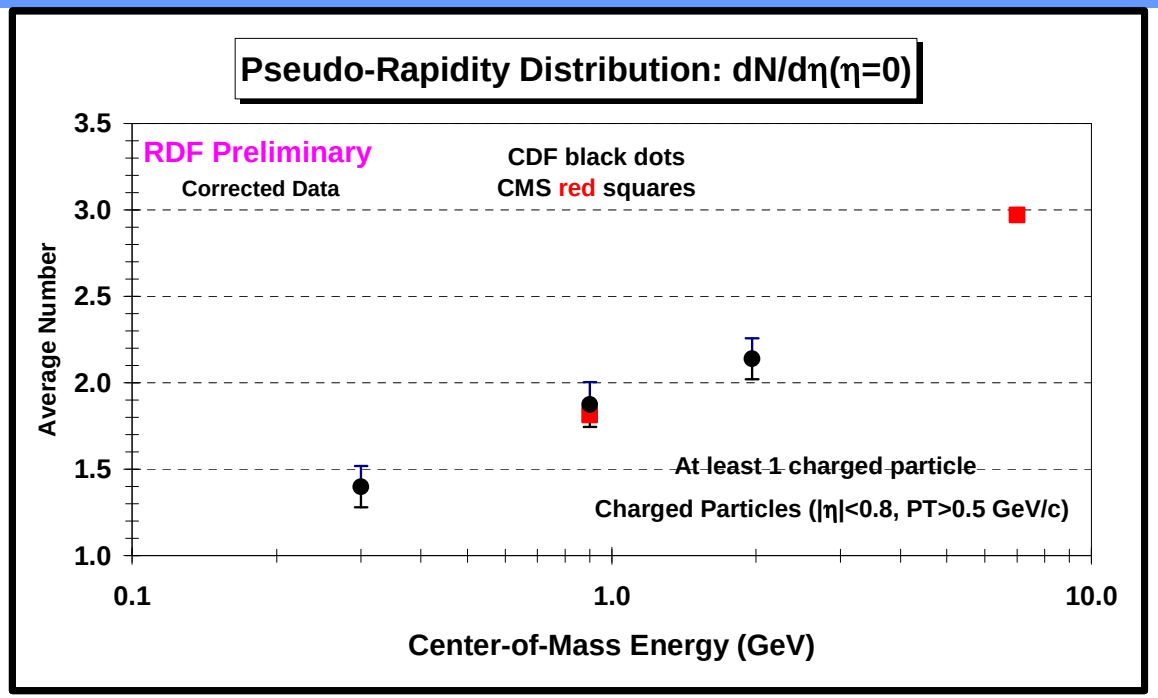
➡ **New Corrected CDF data at 300 GeV, 900 GeV, and 1.96 TeV on on pseudo-rapidity distribution of charged particles, dN/dη, with p_T > 1.0 GeV/c. Events are required to have at least one charged particle with |η| < 0.8 and p_T > 1.0 GeV/c. The data are corrected to the particle level with errors that include both the statistical error and the systematic uncertainty.**

New CDF MB Data



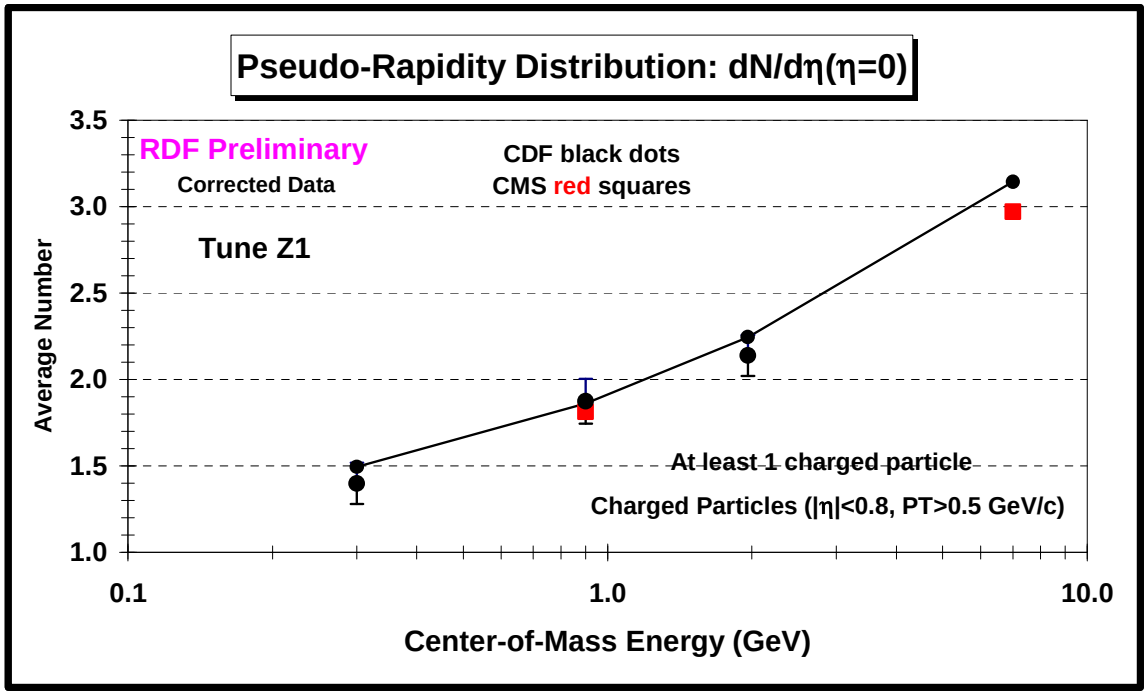
➡ **New Corrected CDF data at 300 GeV, 900 GeV, and 1.96 TeV on on pseudo-rapidity distribution of charged particles, dN/dη, with p_T > 1.0 GeV/c. Events are required to have at least one charged particle with |η| < 0.8 and p_T > 1.0 GeV/c. The data are corrected to the particle level with errors that include both the statistical error and the systematic uncertainty.**

Energy Dependence dN/dη



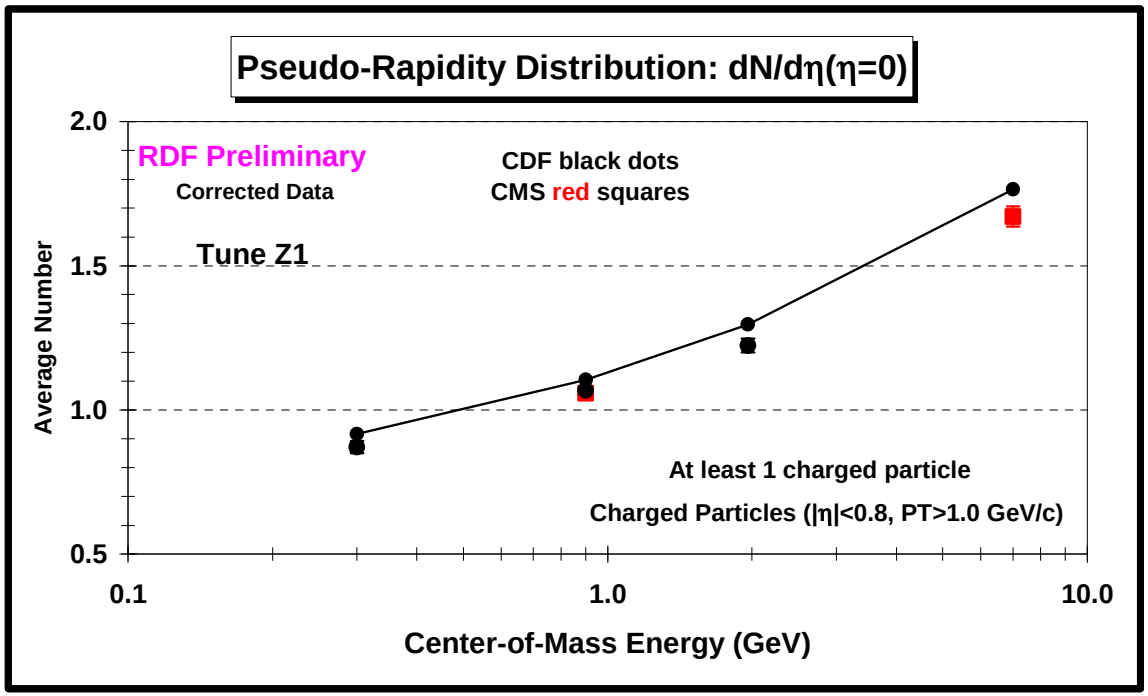
➡ **CMS data at 7 TeV and 900 GeV and CDF data at 1.96 TeV, 900 GeV, and 300 GeV on dN/dη at η = 0 with p_T > 0.5 GeV/c as a function of the center-of-mass energy. Events are required to have at least one charged particle with |η| < 0.8 and p_T > 0.5 GeV/c. The data are corrected to the particle level with errors that include both the statistical error and the systematic uncertainty.**

Energy Dependence dN/dη



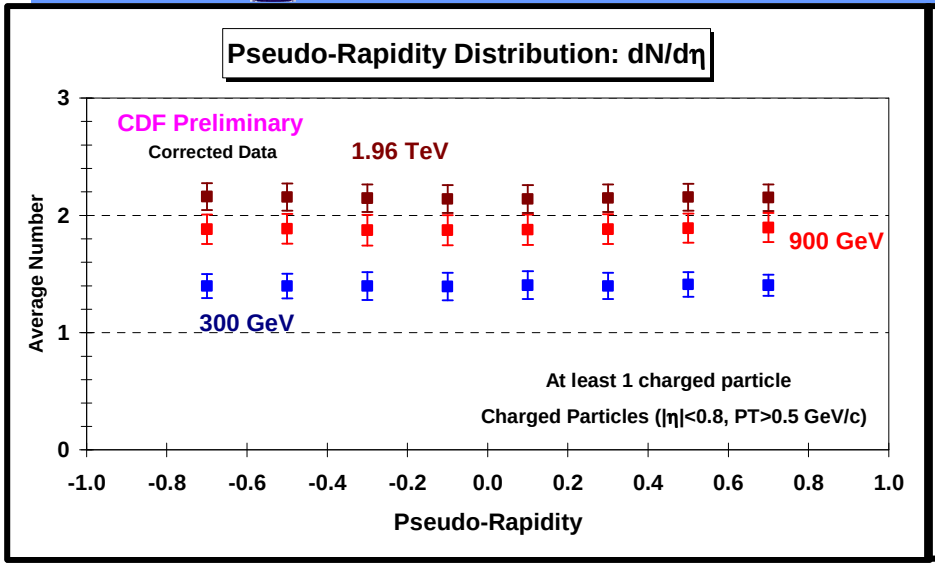
➡ **CMS data at 7 TeV and 900 GeV and CDF data at 1.96 TeV, 900 GeV, and 300 GeV on dN/dη at η = 0 with p_T > 0.5 GeV/c as a function of the center-of-mass energy. Events are required to have at least one charged particle with |η| < 0.8 and p_T > 0.5 GeV/c. The data are corrected to the particle level with errors that include both the statistical error and the systematic uncertainty.**

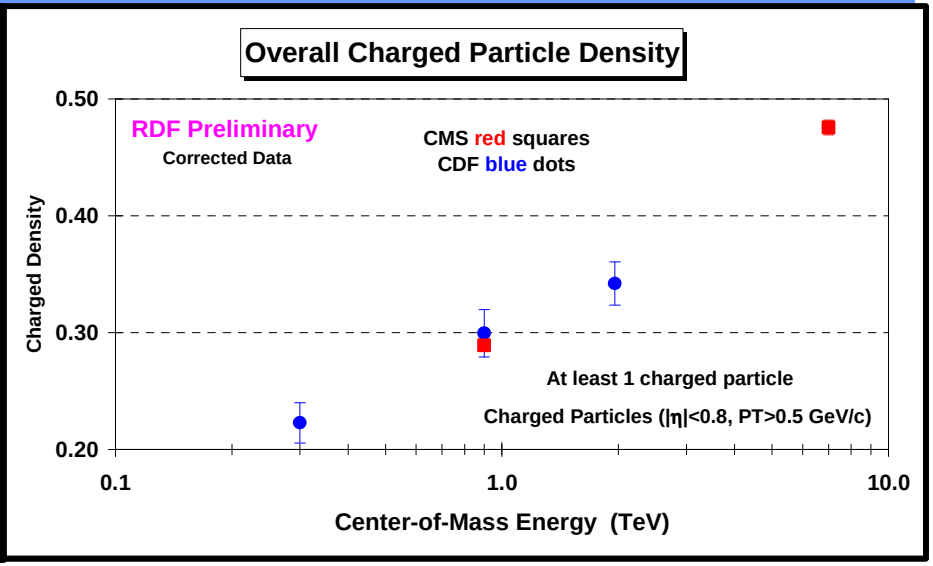
Energy Dependence dN/dη



➡ **CMS data at 7 TeV and 900 GeV and CDF data at 1.96 TeV, 900 GeV, and 300 GeV on dN/dη at η = 0 with p_T > 1.0 GeV/c as a function of the center-of-mass energy. Events are required to have at least one charged particle with |η| < 0.8 and p_T > 1.0 GeV/c. The data are corrected to the particle level with errors that include both the statistical error and the systematic uncertainty.**

Overall Charged Particle Density





➡ **Corrected CDF data on the pseudo-rapidity distribution, dN/dη, for charged with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$ for events with at least one charged particle with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$.**

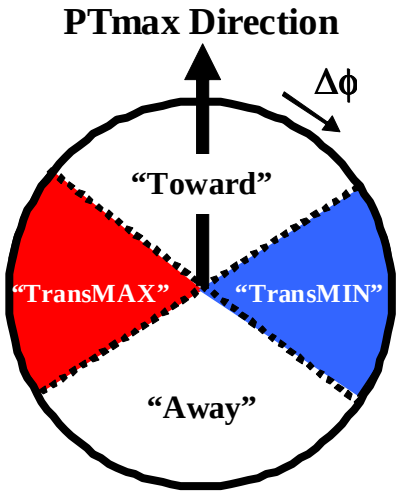
Ecm	Nchg	error	NchgDen	error
300 GeV	2.241	0.175	0.223	0.017
900 GeV	3.012	0.203	0.300	0.020
1.96 TeV	3.439	0.186	0.342	0.019

➡ **Corrected CDF and CMS data overall density of charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$ for events with at least one charged particle with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$ plotted versus the center-of-mass energy (*log scale*). The data are corrected to the particle level with errors that include both the statistical error and the systematic uncertainty.**

$$N_{chg} = \int_{-0.8}^{0.8} \frac{dN}{d\eta} d\eta$$

New UE Observables

- **"transMAX" and "transMIN" Charged Particle Density:** Number of charged particles ($p_T > 0.5$ GeV/c, $|\eta| < 0.8$) in the the maximum (minimum) of the two "transverse" regions as defined by the leading charged particle, PTmax, divided by the area in η-ϕ space, $2\eta_{cut} \times 2\pi/6$, averaged over all events with at least one particle with $p_T > 0.5$ GeV/c, $|\eta| < \eta_{cut}$.
- **"transMAX" and "transMIN" Charged PTsum Density:** Scalar p_T sum of charged particles ($p_T > 0.5$ GeV/c, $|\eta| < 0.8$) in the the maximum (minimum) of the two "transverse" regions as defined by the leading charged particle, PTmax, divided by the area in η-ϕ space, $2\eta_{cut} \times 2\pi/6$, averaged over all events with at least one particle with $p_T > 0.5$ GeV/c, $|\eta| < \eta_{cut}$.



Note: The overall "transverse" density is equal to the average of the "transMAX" and "TransMIN" densities. The "TransDIF" Density is the "transMAX" Density minus the "transMIN" Density

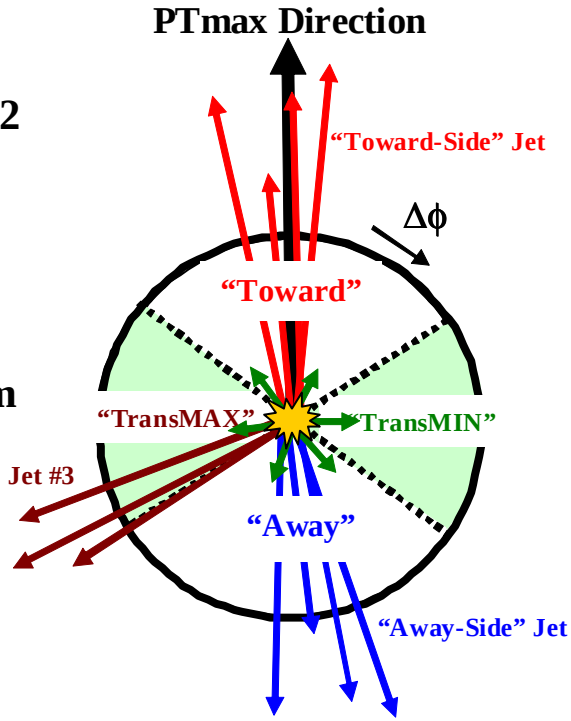
"Transverse" Density = "transAVE" Density = ("transMAX" Density + "transMIN" Density)/2

"TransDIF" Density = "transMAX" Density - "transMIN" Density

$\eta_{cut} = 0.8$

"transMIN" & "transDIF"

- **The "toward" region contains the leading "jet", while the "away" region, on the average, contains the "away-side" "jet". The "transverse" region is perpendicular to the plane of the hard 2-to-2 scattering and is very sensitive to the "underlying event". For events with large initial or final-state radiation the "transMAX" region defined contains the third jet while both the "transMAX" and "transMIN" regions receive contributions from the MPI and beam-beam remnants. Thus, the "transMIN" region is very sensitive to the multiple parton interactions (MPI) and beam-beam remnants (BBR), while the "transMAX" minus the "transMIN" (*i.e.* "transDIF") is very sensitive to initial-state radiation (ISR) and final-state radiation (FSR).**



"TransMIN" density more sensitive to MPI & BBR.

"TransDIF" density more sensitive to ISR & FSR.

0 ≤ "TransDIF" ≤ 2×"TransAVE"

"TransDIF" = "TransAVE" if "TransMIX" = 3×"TransMIN"

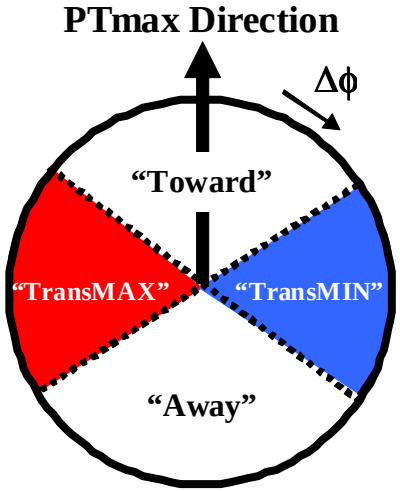
PTmax UE Data

- **CDF PTmax UE Analysis: "transMAX", "transMIN", "transAVE", and "transDIF" charged particle and PTsum densities (p_T > 0.5 GeV/c, |η| < 0.8) in proton-antiproton collisions at 300 GeV, 900 GeV, and 1.96 TeV (R. Field analysis).**

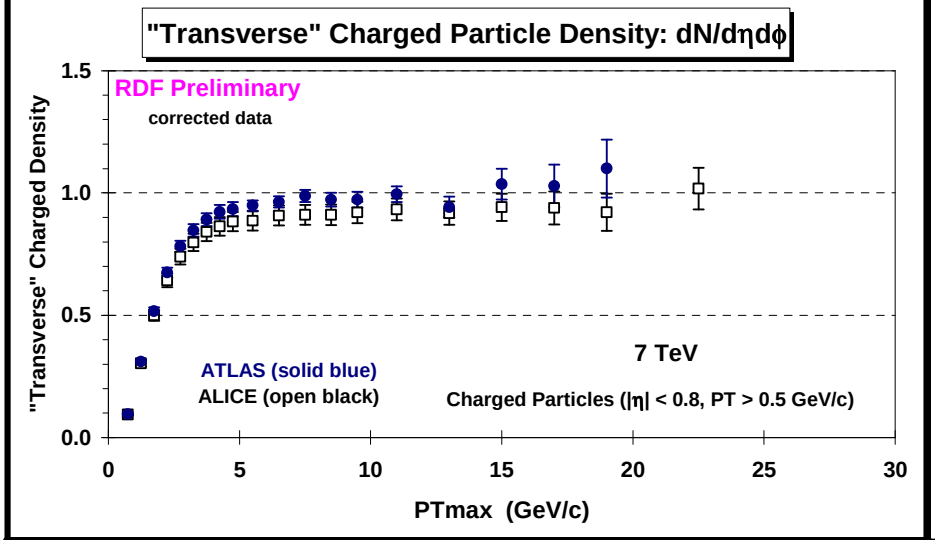
- **CMS PTmax UE Analysis: "transMAX", "transMIN", "transAVE", and "transDIF" charged particle and PTsum densities (p_T > 0.5 GeV/c, |η| < 0.8) in proton-proton collisions at 900 GeV and 7 TeV (M. Zakaria analysis). The "transMAX", "transMIN", and "transDIF" are not yet approved so I can only show "transAVE" which is approved.**

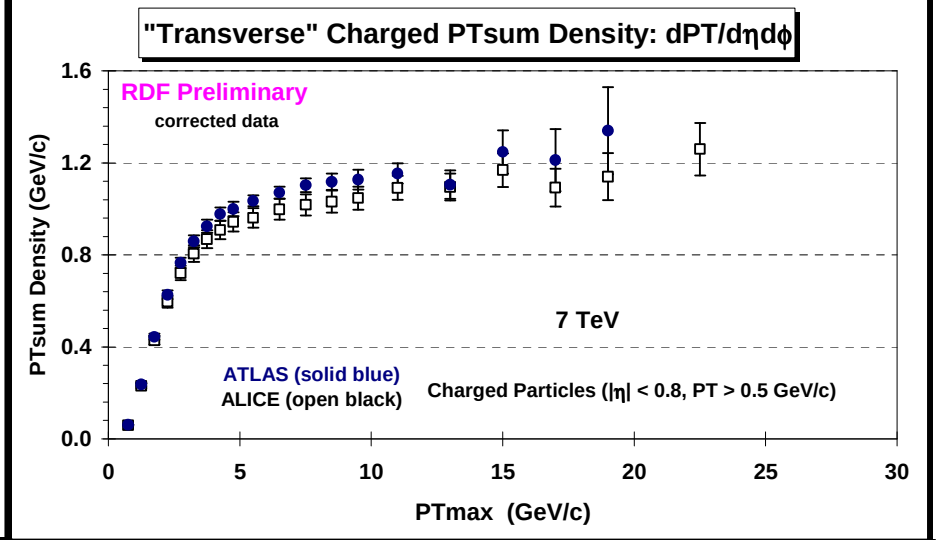
- **CMS UE Tunes: PYTHIA 6.4 Tune Z1 (CTEQ5L) and PYTHIA 6.4 Tune Z2* (CTEQ6L). Both were tuned to the CMS leading chgjet "transAVE" UE data at 900 GeV and 7 TeV.**

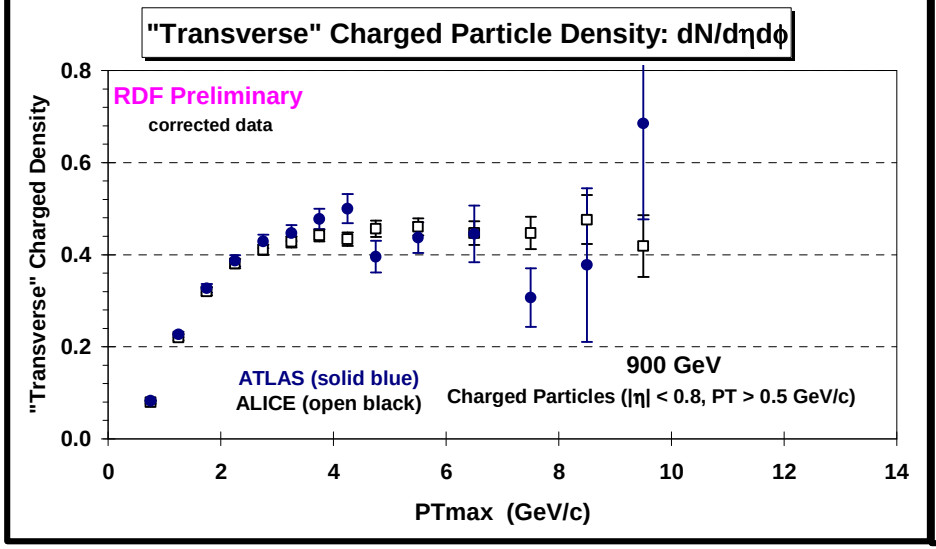
- **PYTHIA 8: Some comparisons with PYTHIA 8 Tune 4C (CTEQ6L), Richard Corke and Torbjörn Sjöstrand, JHEP 1103:032 (2011), arXiv:1011.1759.**

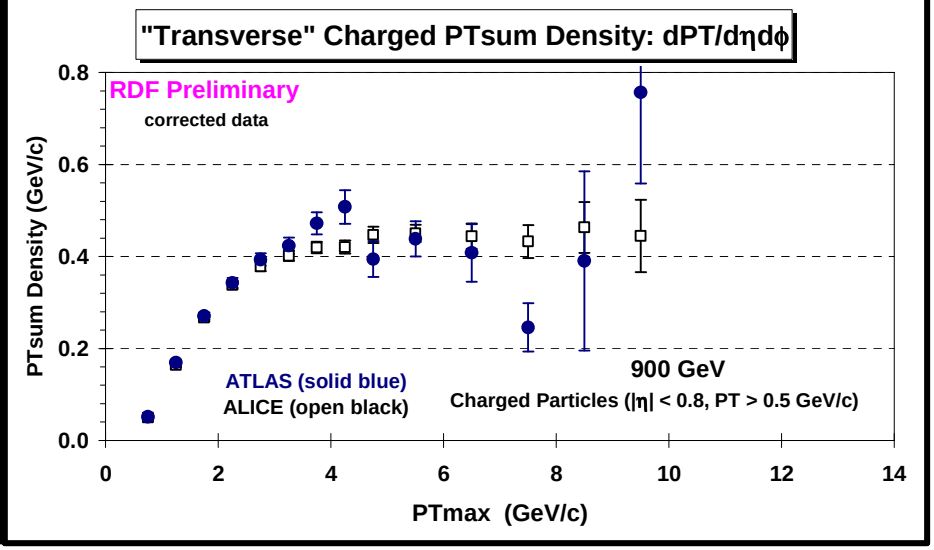


UE Common Plots

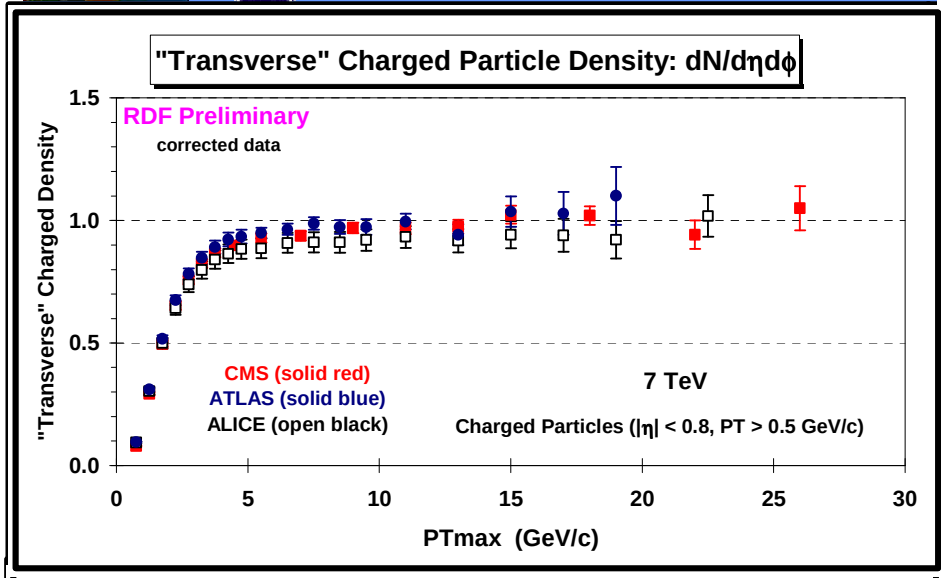


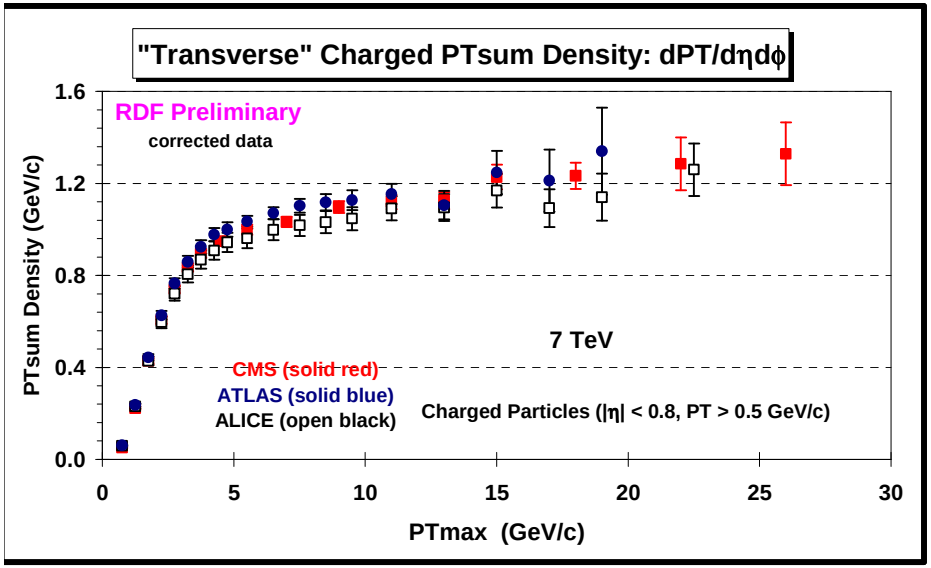


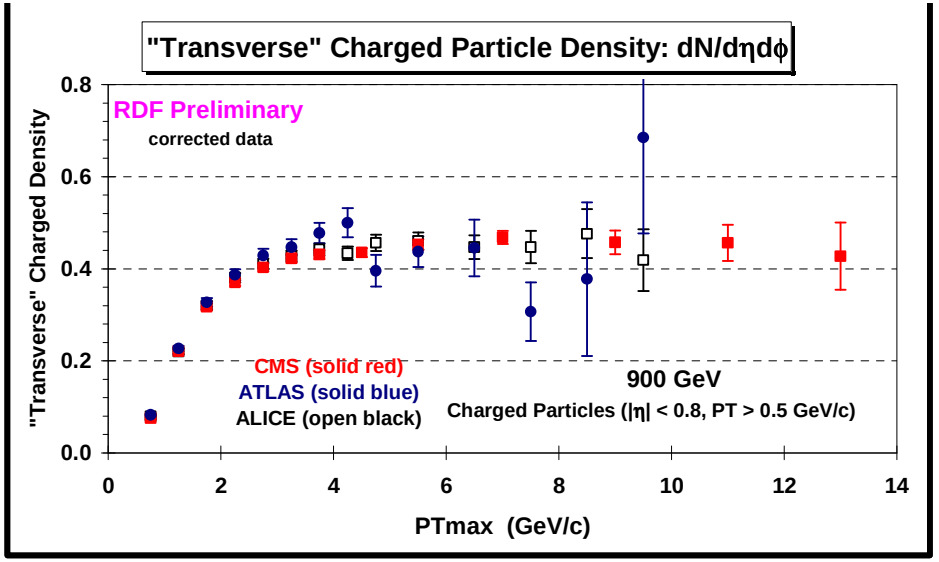


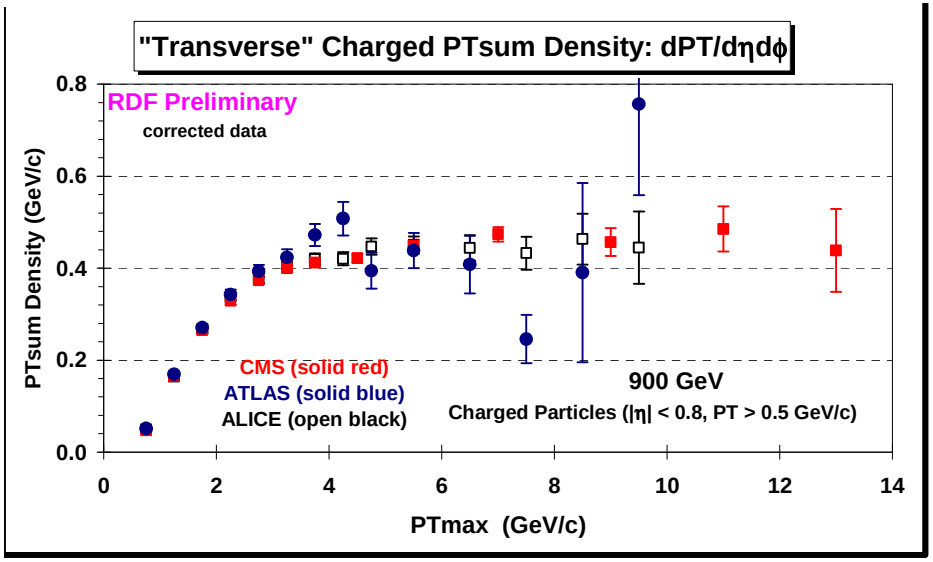


UE Common Plots

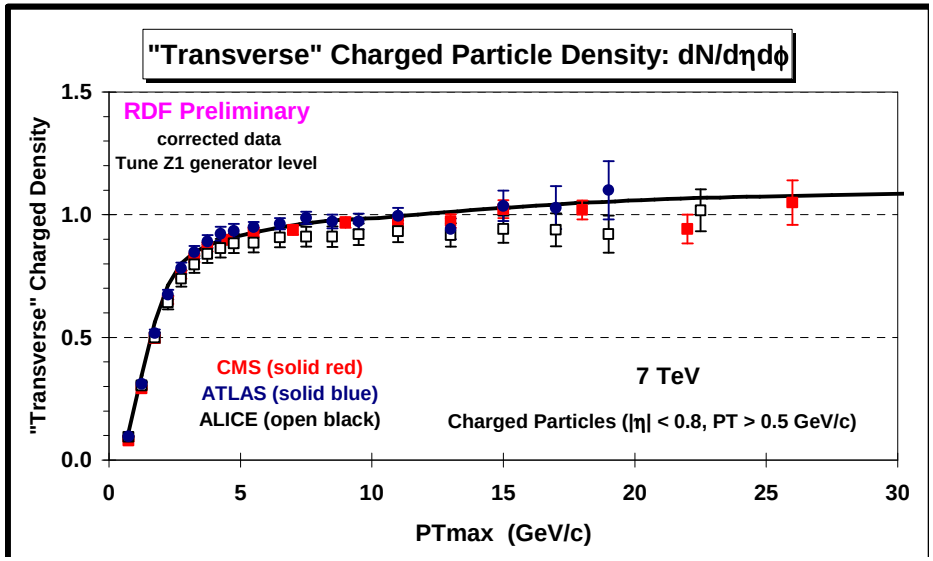


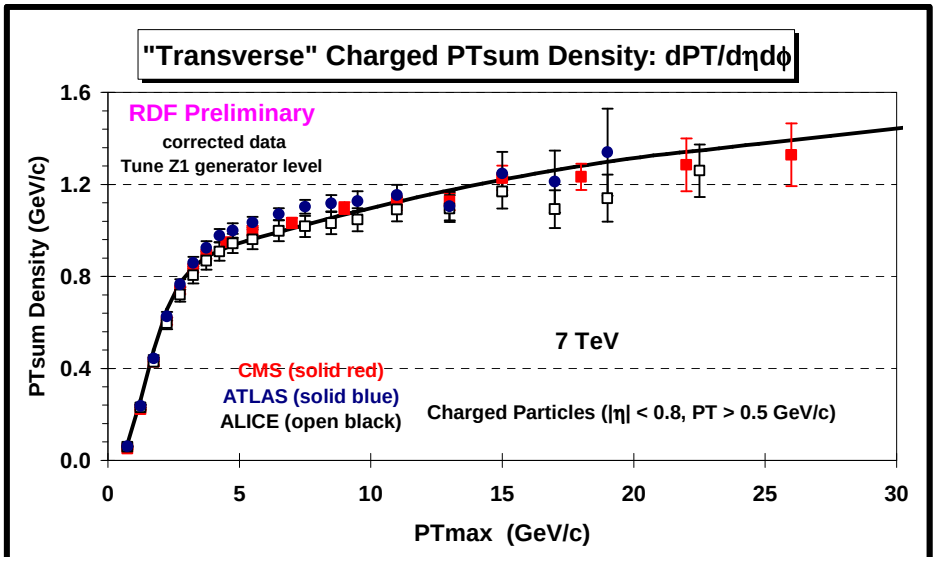


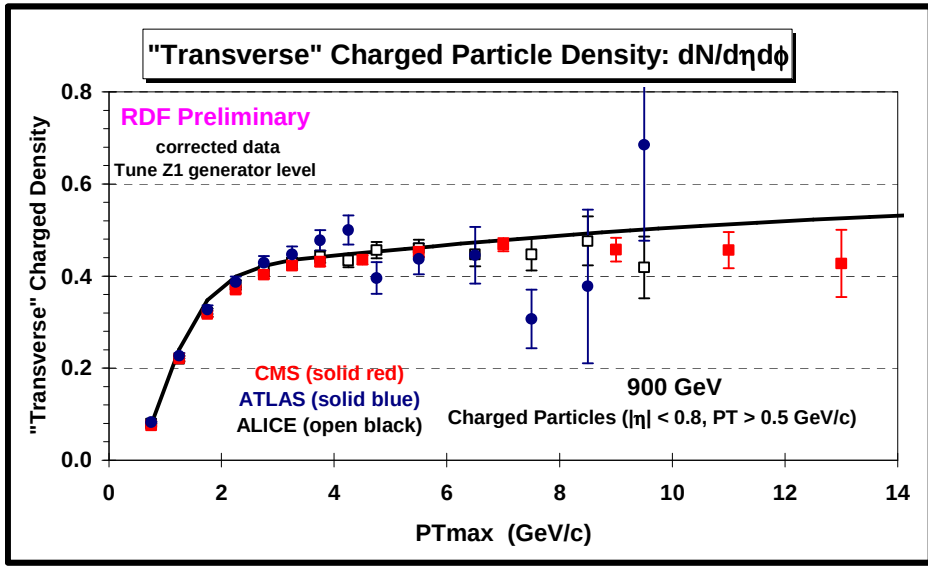


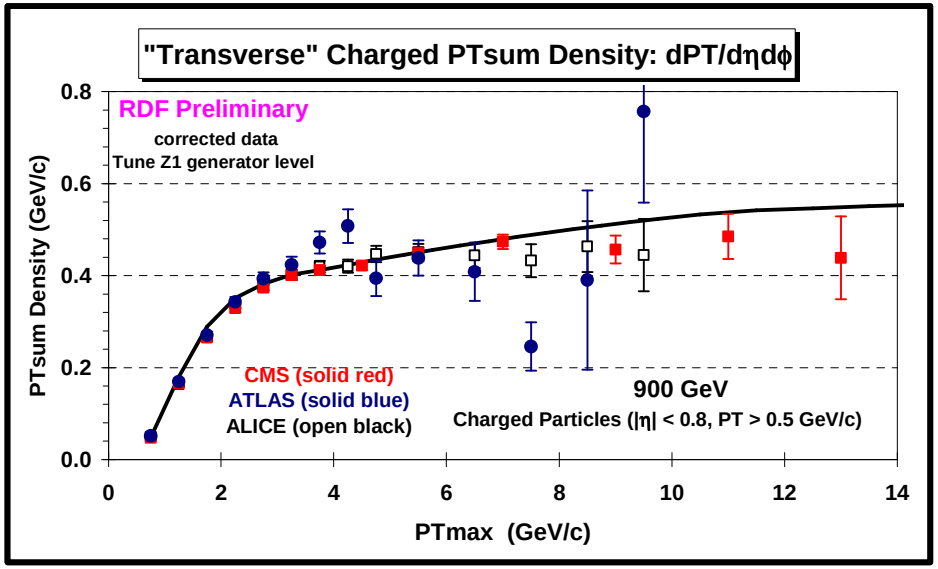


UE Common Plots

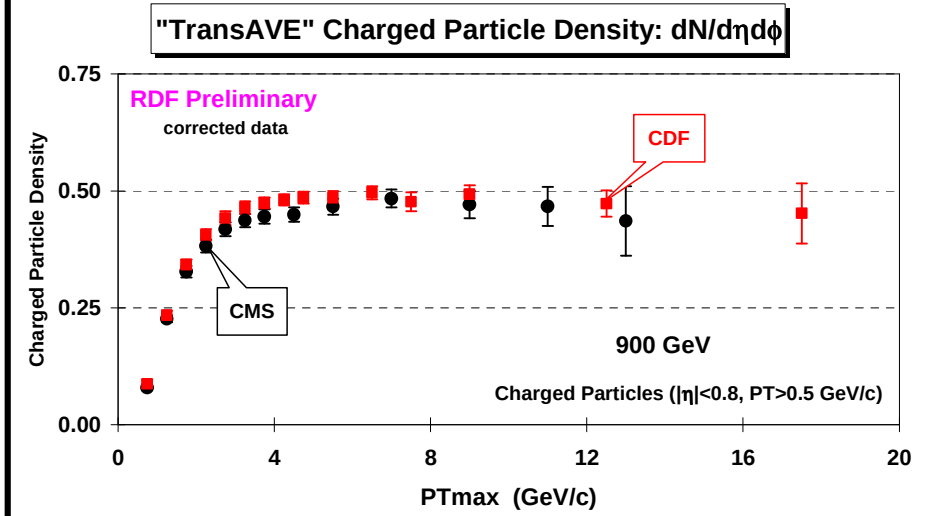


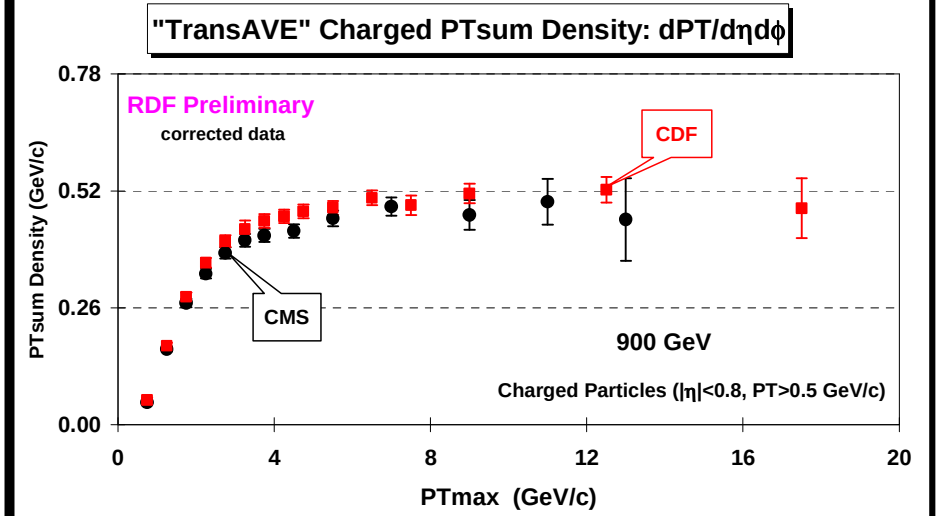






CDF versus LHC

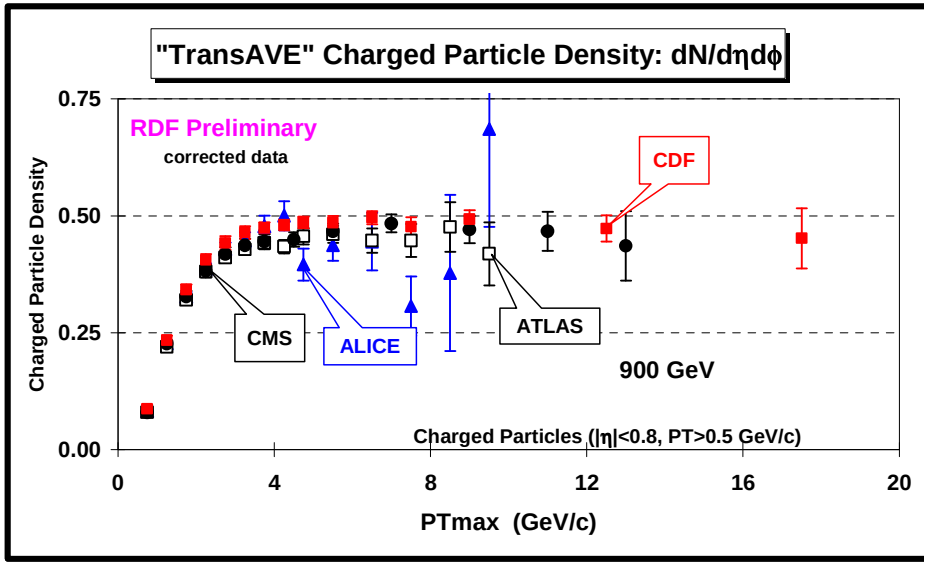


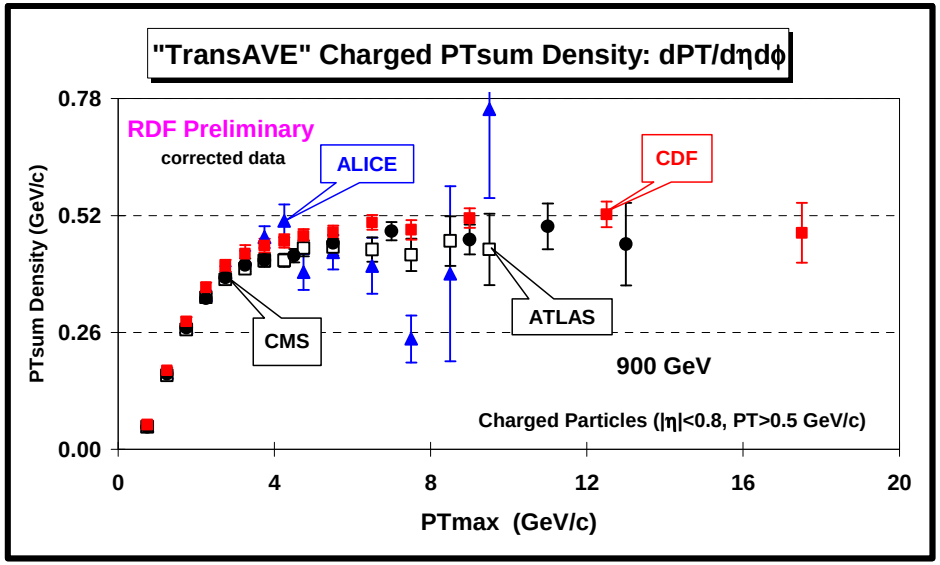


➡ **CDF and CMS data at 900 GeV/c on the charged particle density in the "transverse" region as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$. The data are corrected to the particle level with errors that include both the statistical error and the systematic uncertainty.**

➡ **CDF and CMS data at 900 GeV/c on the charged PTsum density in the "transverse" region as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$. The data are corrected to the particle level with errors that include both the statistical error and the systematic uncertainty.**

CDF versus LHC

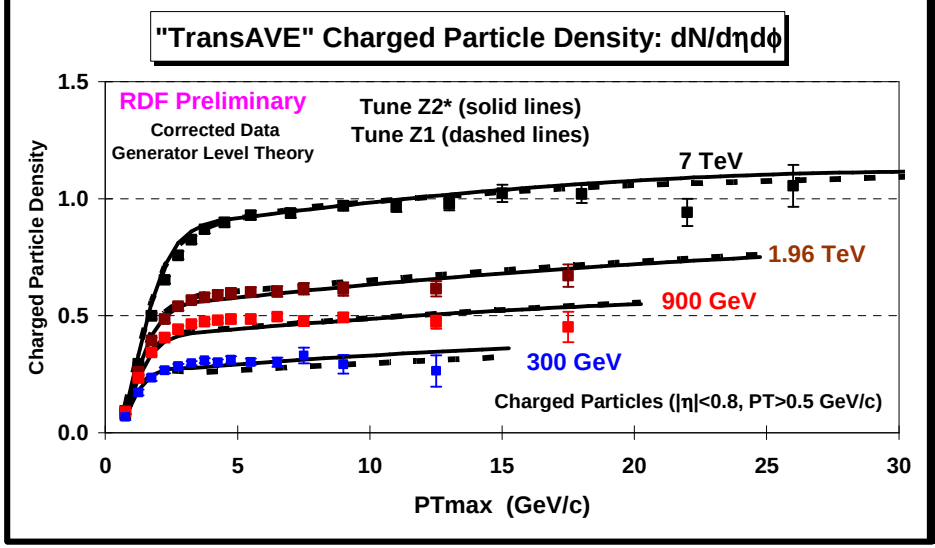


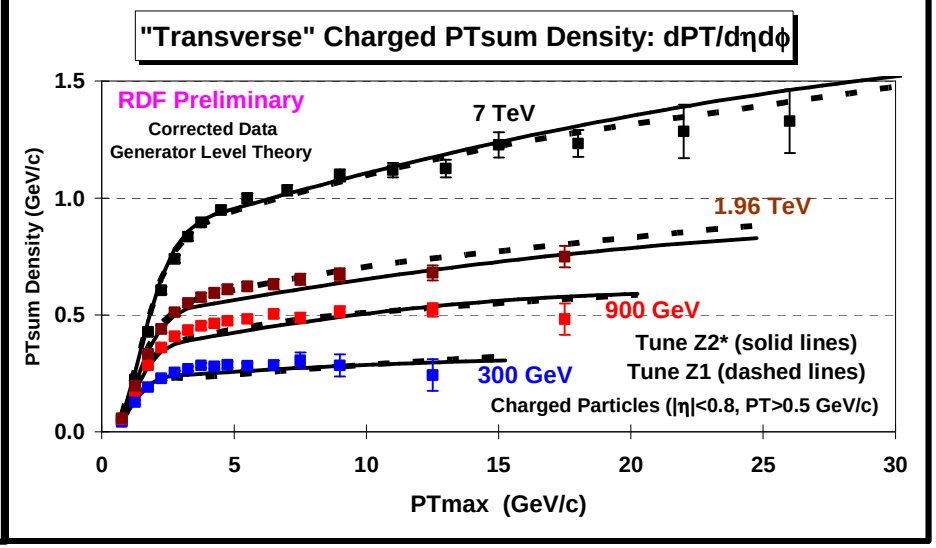


➡ **CDF and CMS data at 900 GeV/c on the charged particle density in the "transverse" region as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$. The data are corrected to the particle level with errors that include both the statistical error and the systematic uncertainty.**

➡ **CDF and CMS data at 900 GeV/c on the charged PTsum density in the "transverse" region as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$. The data are corrected to the particle level with errors that include both the statistical error and the systematic uncertainty.**

"TransAVE" Density

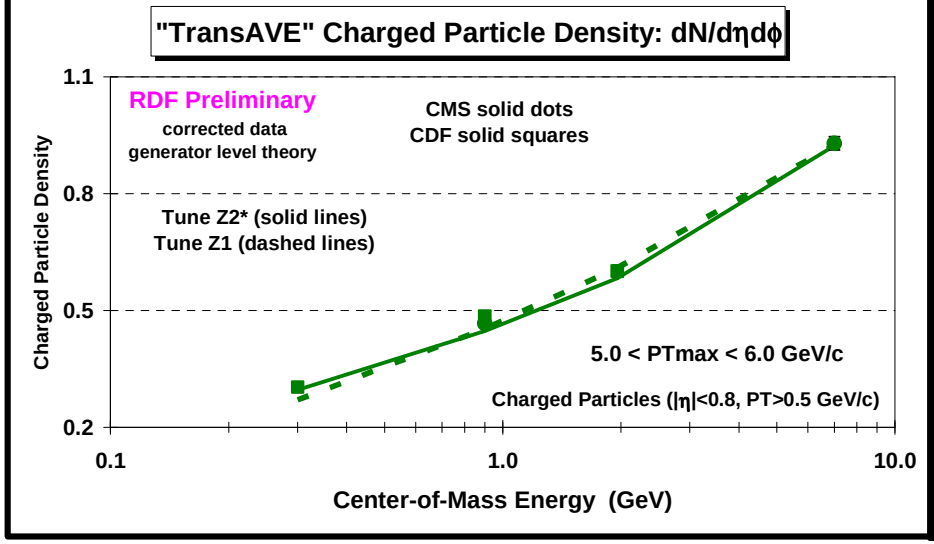


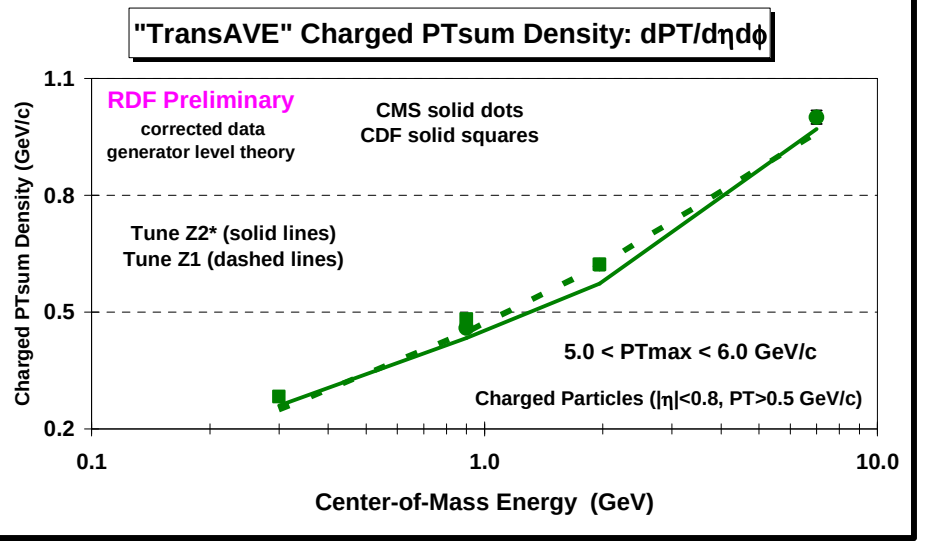


➡ **Corrected CMS data at 7 TeV and CDF data at 1.96 TeV, 900 GeV, and 300 GeV on the charged particle density in the "transAVE" region as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$. The data are corrected to the particle level with errors that include both the statistical error and the systematic uncertainty. The data are compared with PYTHIA Tune Z1 and Tune Z2*.**

➡ **Corrected CMS data at 7 TeV and CDF data at 1.96 TeV, 900 GeV, and 300 GeV on the charged PTsum density in the "transAVE" region as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$. The data are corrected to the particle level with errors that include both the statistical error and the systematic uncertainty. The data are compared with PYTHIA Tune Z1 and Tune Z2*.**

"TransAVE" vs E_{cm}

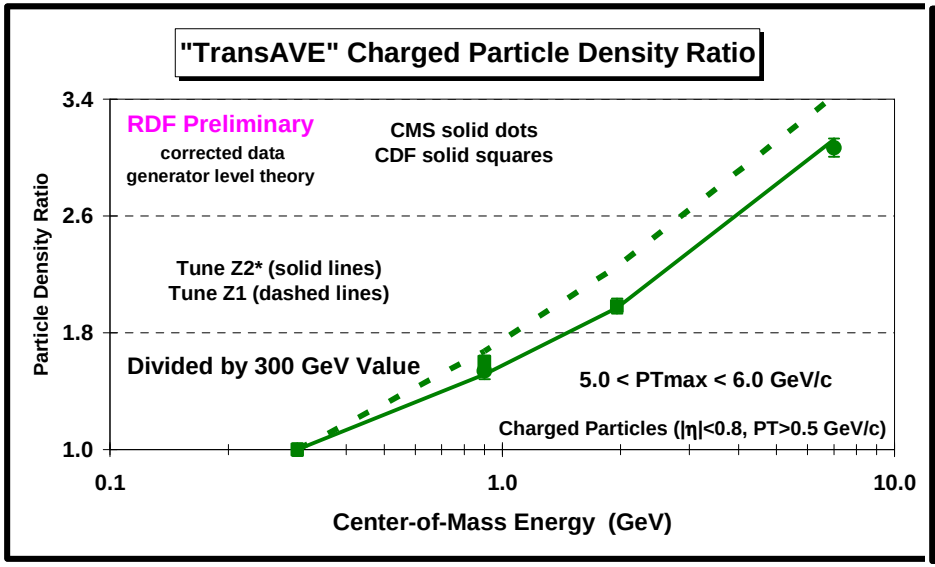


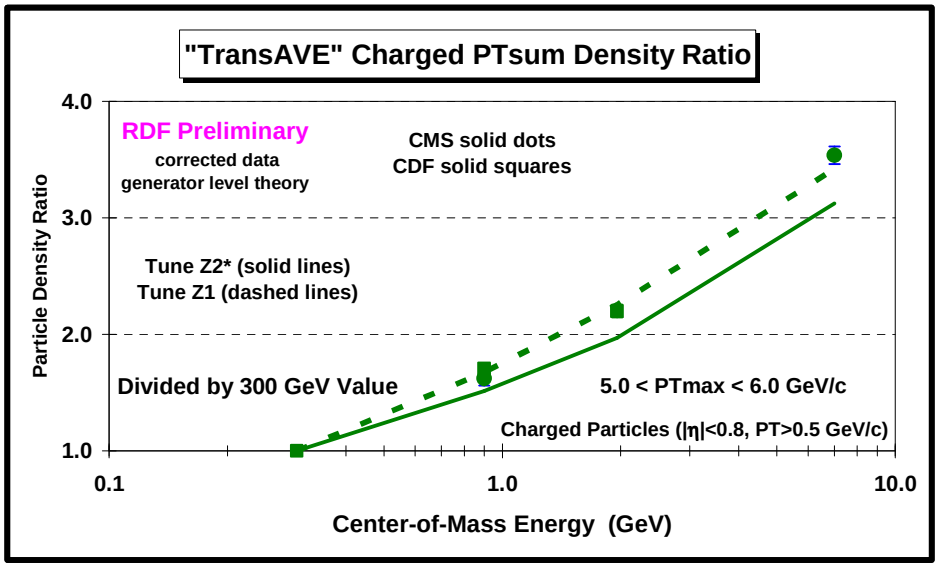


➡ **Corrected CMS data at 900 GeV and 7 TeV and CDF data at 1.96 TeV, 900 GeV, and 300 GeV on the charged particle density in the "transAVE" region as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$ with $5 < PTmax < 6$ GeV/c. The data are plotted versus the center-of-mass energy (*log scale*). The data are compared with PYTHIA 6.4 Tune Z1 and Tune Z2*.**

➡ **Corrected CMS data at 900 GeV and 7 TeV and CDF data at 1.96 TeV, 900 GeV, and 300 GeV on the charged PTsum density in the "transAVE" region as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$ with $5 < PTmax < 6$ GeV/c. The data are plotted versus the center-of-mass energy (*log scale*). The data are compared with PYTHIA 6.4 Tune Z1 and Tune Z2*.**

"TransAVE" vs E_{cm}



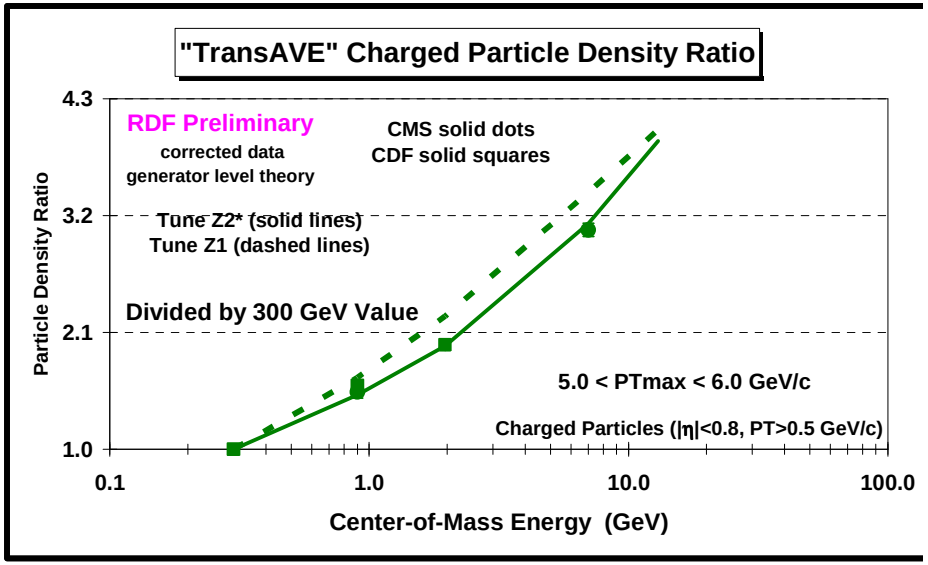


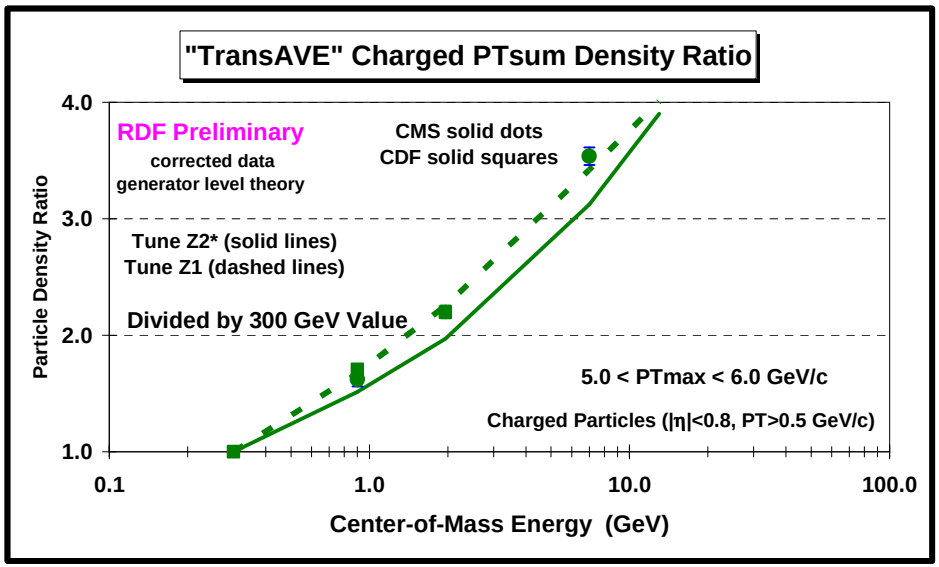
➡ **Corrected CMS data at 900 GeV and 7 TeV and CDF data at 1.96 TeV, 900 GeV, and 300 GeV on the charged particle density in the "transAVE" region as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$ with $5 < PTmax < 6$ GeV/c. The data are plotted versus the center-of-mass energy (*log scale*). The data are compared with PYTHIA 6.4 Tune Z1 and Tune Z2*.**

➡ **Corrected CMS data at 900 GeV and 7 TeV and CDF data at 1.96 TeV, 900 GeV, and 300 GeV on the charged PTsum density in the "transAVE" region as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$ with $5 < PTmax < 6$ GeV/c. The data are plotted versus the center-of-mass energy (*log scale*). The data are compared with PYTHIA 6.4 Tune Z1 and Tune Z2*.**

The data are "normalized" by dividing by the corresponding value at 300 GeV.

"TransAVE" vs E_{cm}



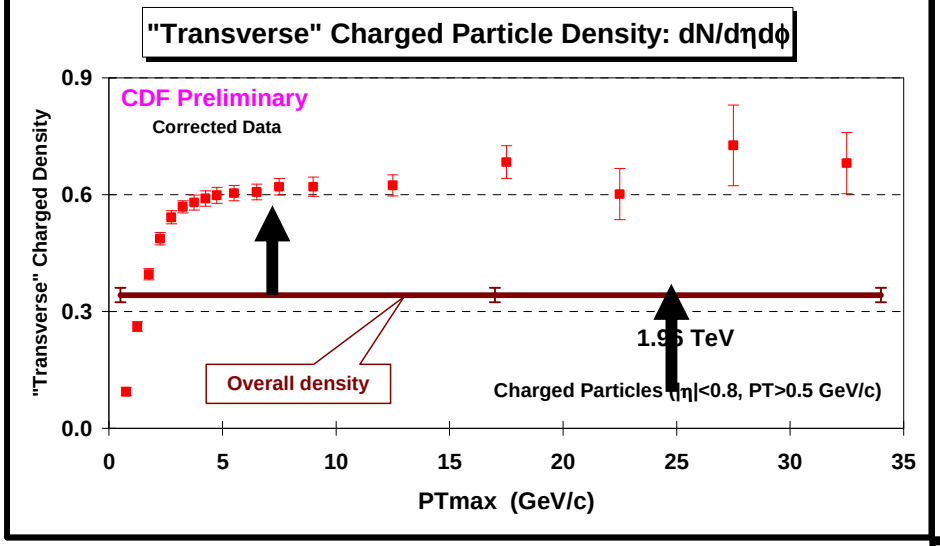


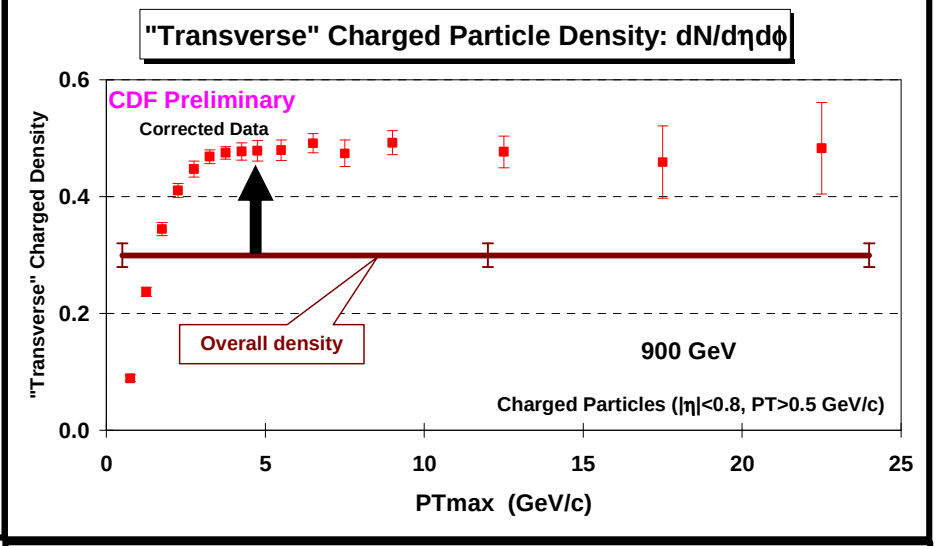
➡ **Corrected CMS data at 900 GeV and 7 TeV and CDF data at 1.96 TeV, 900 GeV, and 300 GeV on the charged particle density in the "transAVE" region as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$ with $5 < PTmax < 6$ GeV/c. The data are plotted versus the center-of-mass energy (*log scale*). The data are compared with PYTHIA 6.4 Tune Z1 and Tune Z2*.**

➡ **Corrected CMS data at 900 GeV and 7 TeV and CDF data at 1.96 TeV, 900 GeV, and 300 GeV on the charged PTsum density in the "transAVE" region as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$ with $5 < PTmax < 6$ GeV/c. The data are plotted versus the center-of-mass energy (*log scale*). The data are compared with PYTHIA 6.4 Tune Z1 and Tune Z2*.**

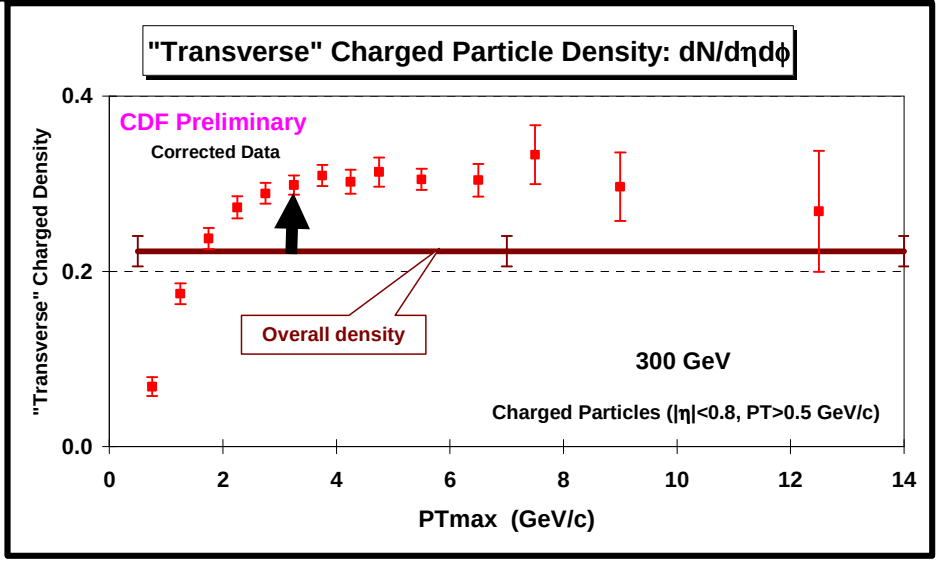
The data are "normalized" by dividing by the corresponding value at 300 GeV.

MB versus the UE

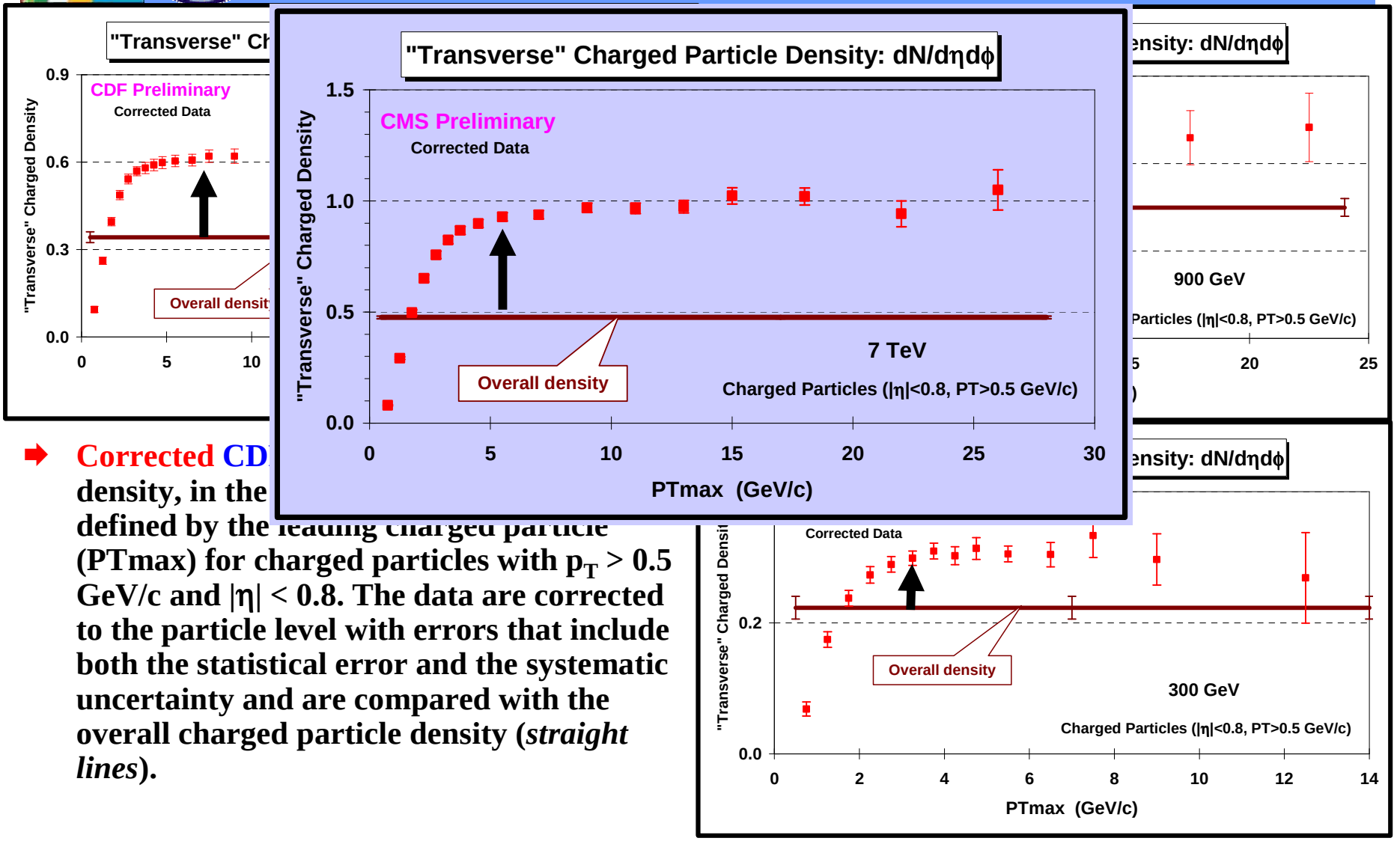




- **Corrected CDF data on the charged particle density, in the "transverse" region as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$. The data are corrected to the particle level with errors that include both the statistical error and the systematic uncertainty and are compared with the overall charged particle density (*straight lines*).**

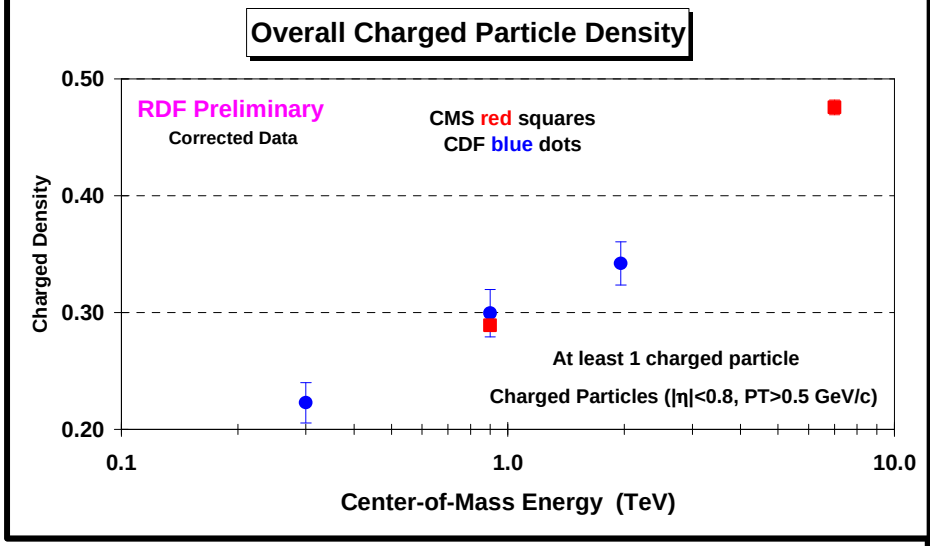


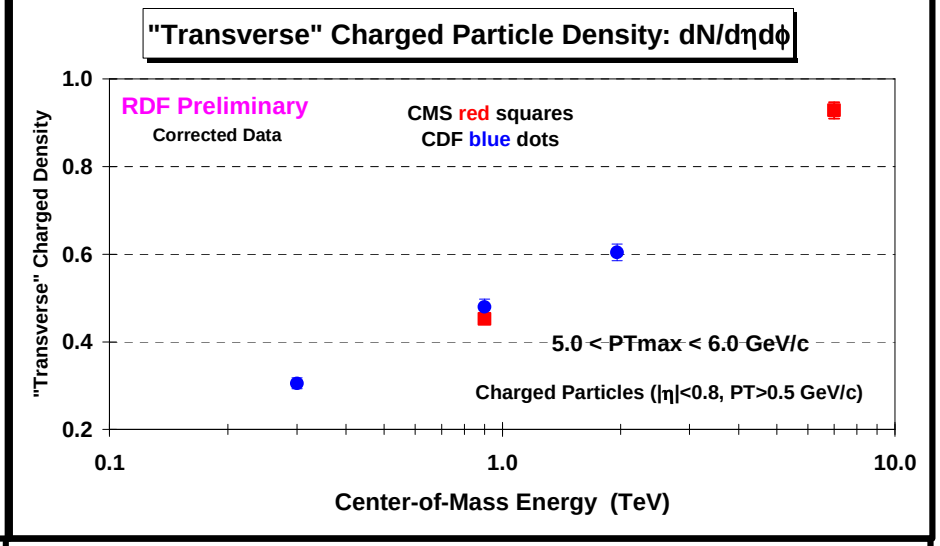
MB versus the UE



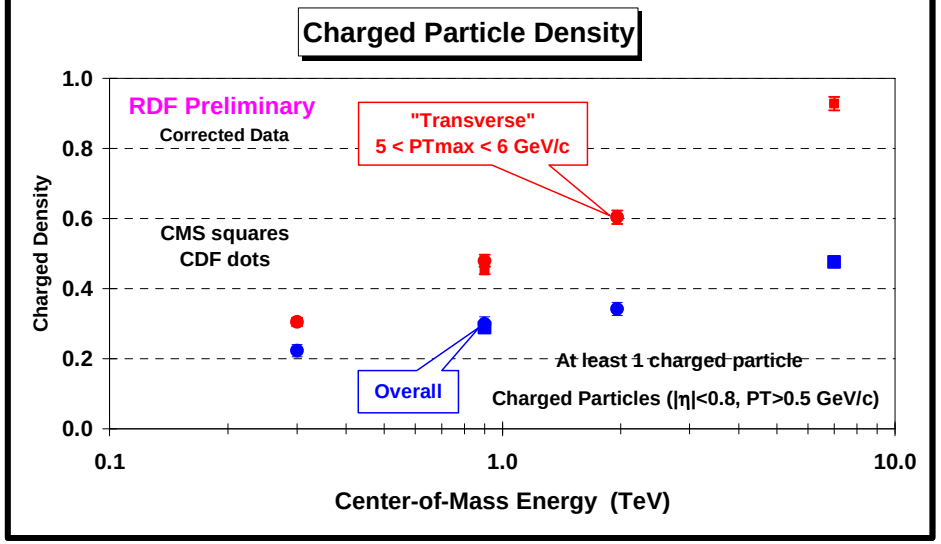
➡ **Corrected CD density, in the defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$. The data are corrected to the particle level with errors that include both the statistical error and the systematic uncertainty and are compared with the overall charged particle density (*straight lines*).**

MB versus the UE

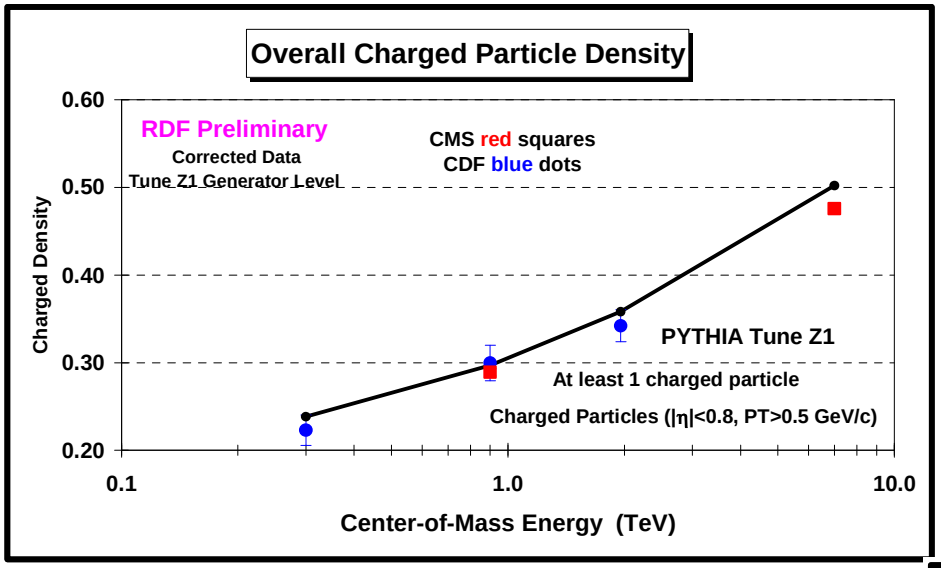


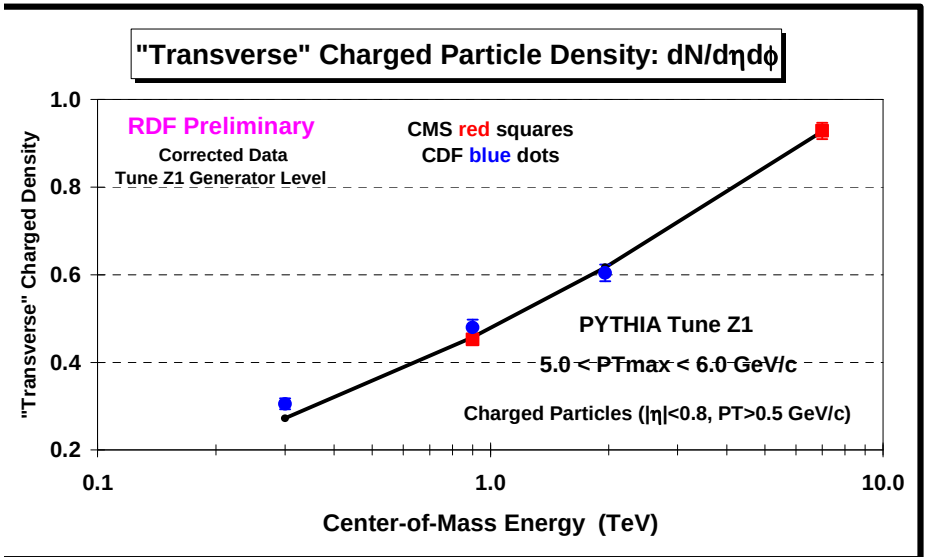


➡ **Corrected CDF and CMS data on the overall density of charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$ for events with at least one charged particle with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$ and on the charged particle density, in the "transverse" region as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$ with $5 < PTmax < 6$ GeV/c. The data are plotted versus the center-of-mass energy (*log scale*).**

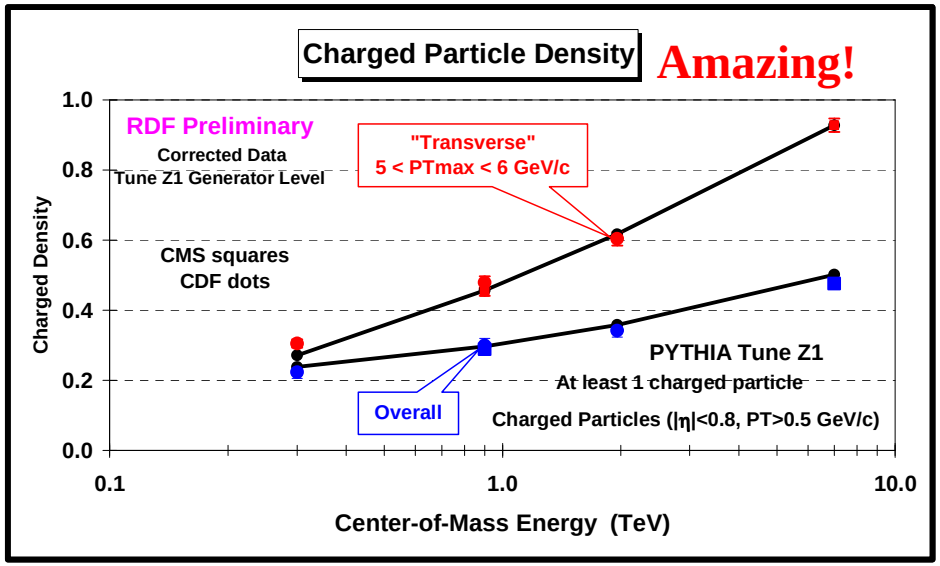


MB versus the UE

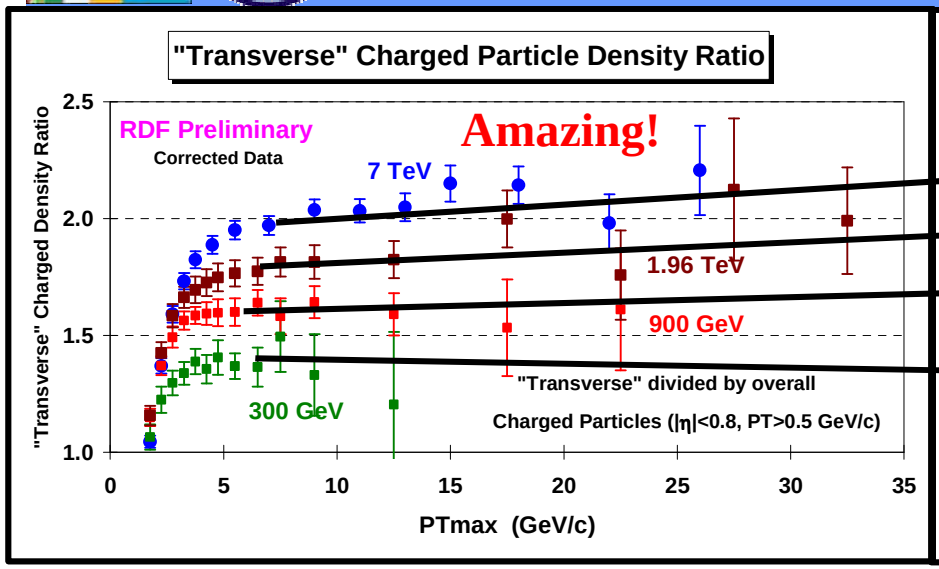


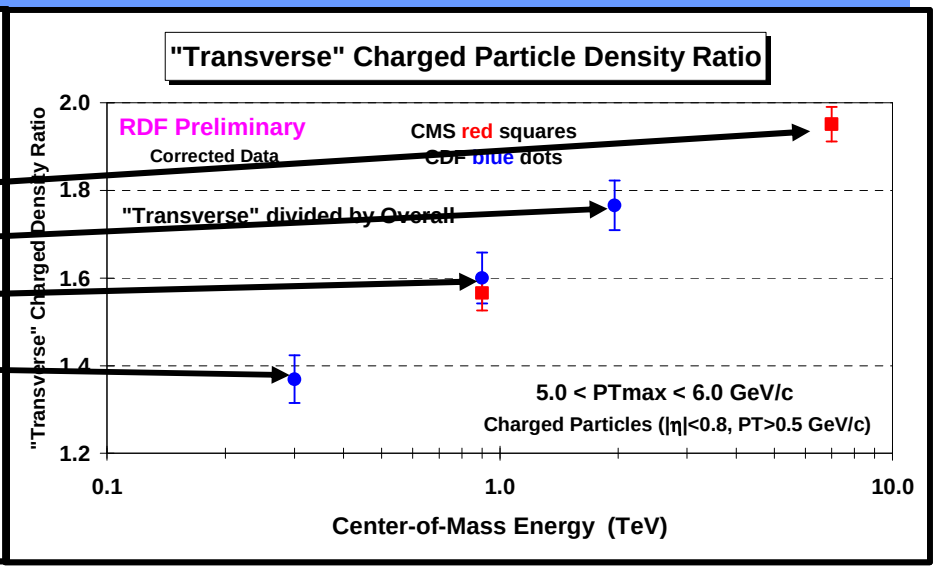


➡ **Corrected CDF and CMS data on the overall density of charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$ for events with at least one charged particle with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$ and on the charged particle density, in the "transverse" region as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$ with $5 < PTmax < 6$ GeV/c. The data are plotted versus the center-of-mass energy (*log scale*).**



"Transverse"/Overall

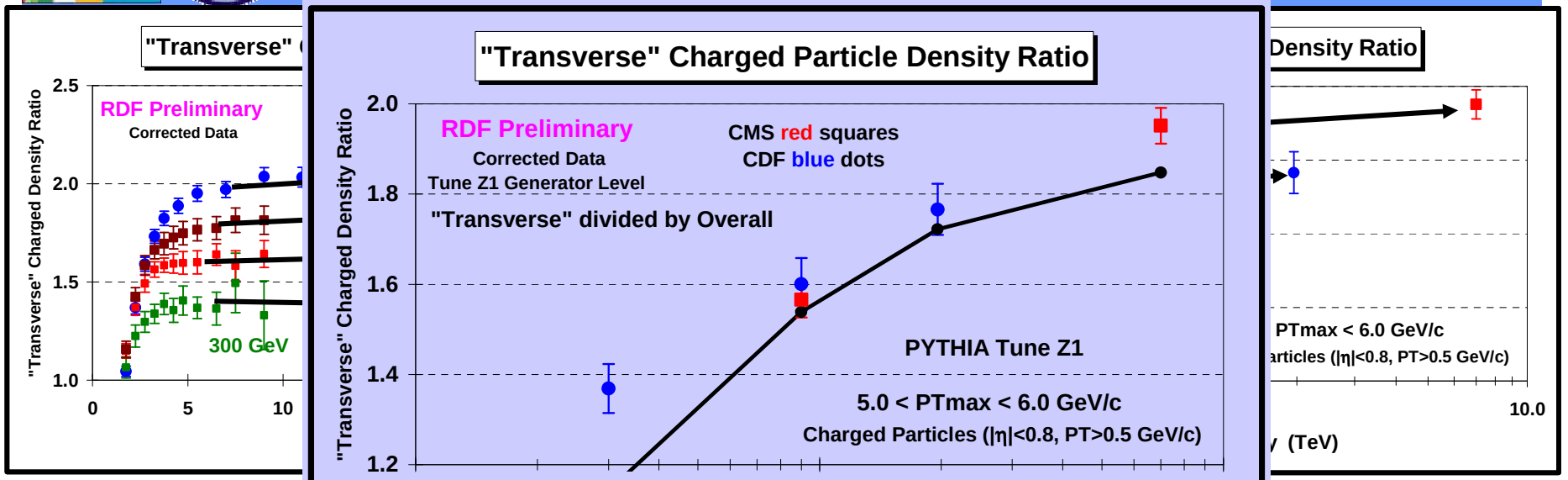




- **Corrected CDF and CMS data on the charged particle density ratio, in the "transverse" region as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$. The ratio corresponds to the "transverse" charged particle density divided by the overall charged particle density ($N_{chg} \geq 1$).**

- **Corrected CDF and CMS data on the charged particle density ratio, in the "transverse" region as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$ for $5 < PTmax < 6$ GeV/c. The ratio corresponds to the "transverse" charged particle density divided by the overall charged particle density ($N_{chg} \geq 1$). The data are plotted versus the center-of-mass energy (*log scale*).**

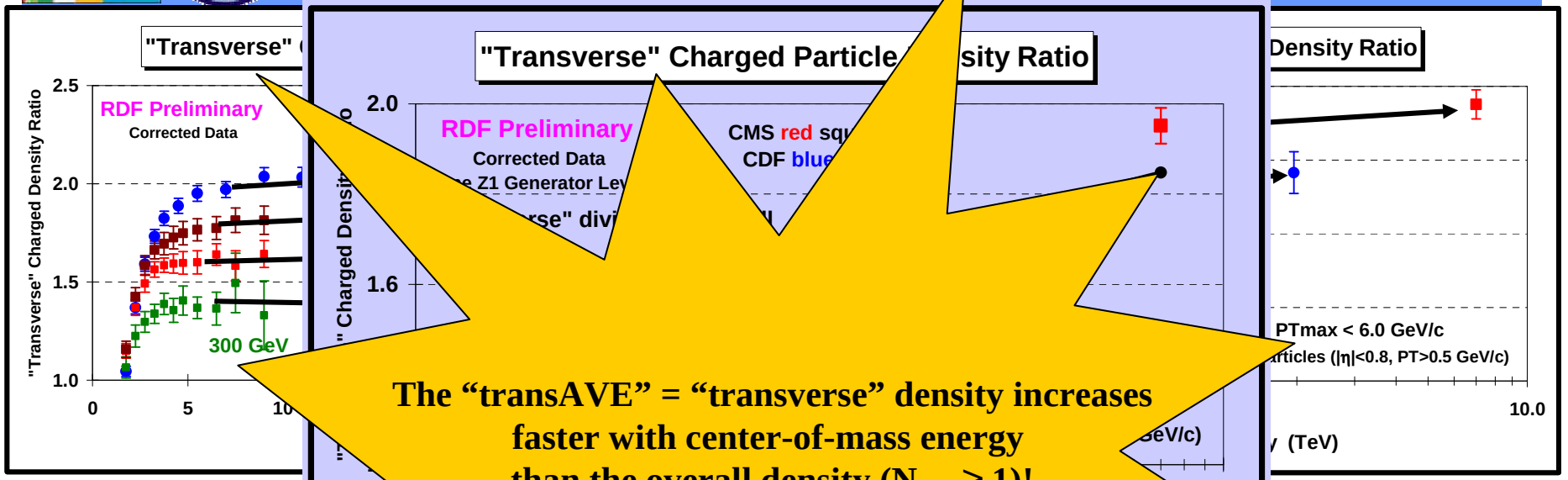
"Transverse"/Overall



➡ **Corrected CDF data on the charged particle density in the "transverse" region as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$. The ratio corresponds to the "transverse" charged particle density divided by the overall charged particle density ($N_{chg} \geq 1$).**

"transverse" region as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$ for $5 < PTmax < 6$ GeV/c. The ratio corresponds to the "transverse" charged particle density divided by the overall charged particle density ($N_{chg} \geq 1$). The data are plotted versus the center-of-mass energy (*log scale*).

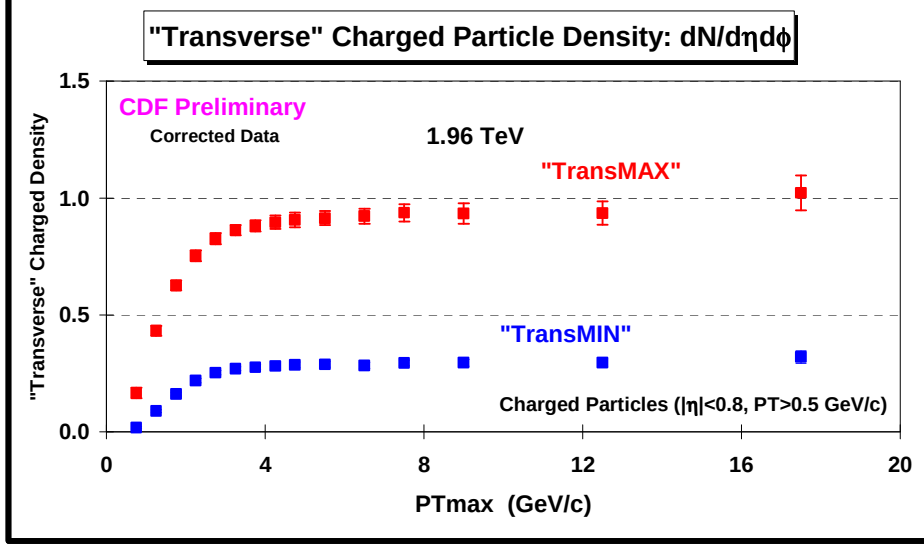
"Transverse"/Overall

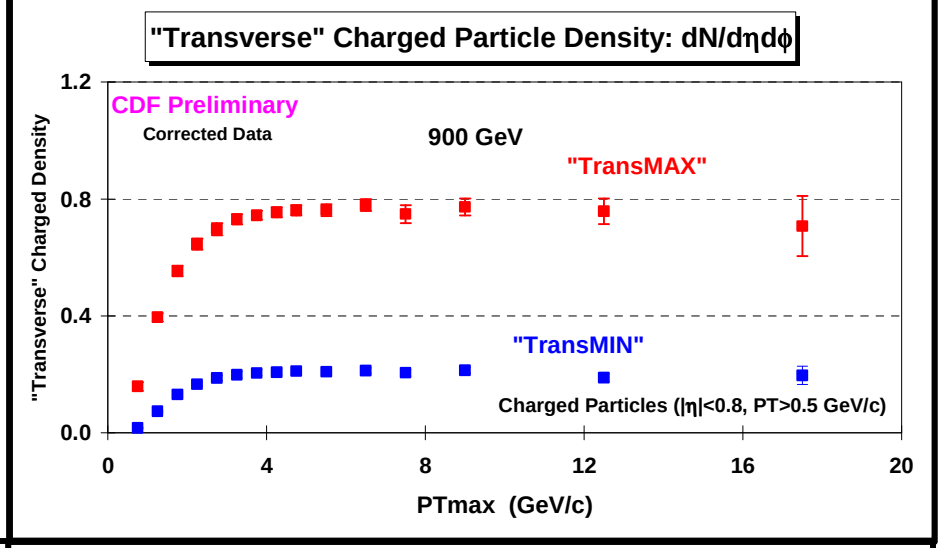


The "transAVE" = "transverse" density increases faster with center-of-mass energy than the overall density ($N_{chg} \geq 1$)!

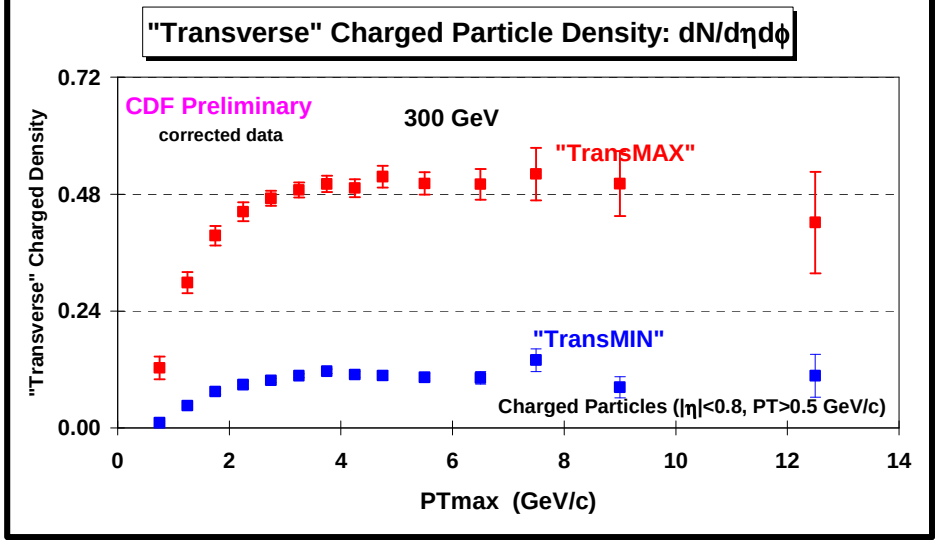
- Corrected CD ata on the charged partic io, in the "transverse" r gion as defined by the leading cha ged particle (PT particle (PTmax) for charged particles with p_T > with p_T > 0.5 GeV/c and $|\eta| < 0.8$. The ratio corresp to t ed p 0.8 for Tmax < 6 GeV/c. The ratio "transverse" charged part e densi esponds to "transverse" charged divided by the overall charged parti icle density d ided by the overall density ($N_{chg} \geq 1$). c ged particle density ($N_{chg} \geq 1$). The data are plotted versus the center-of-mass energy (*log scale*).

"transMAX/MIN" NchgDen

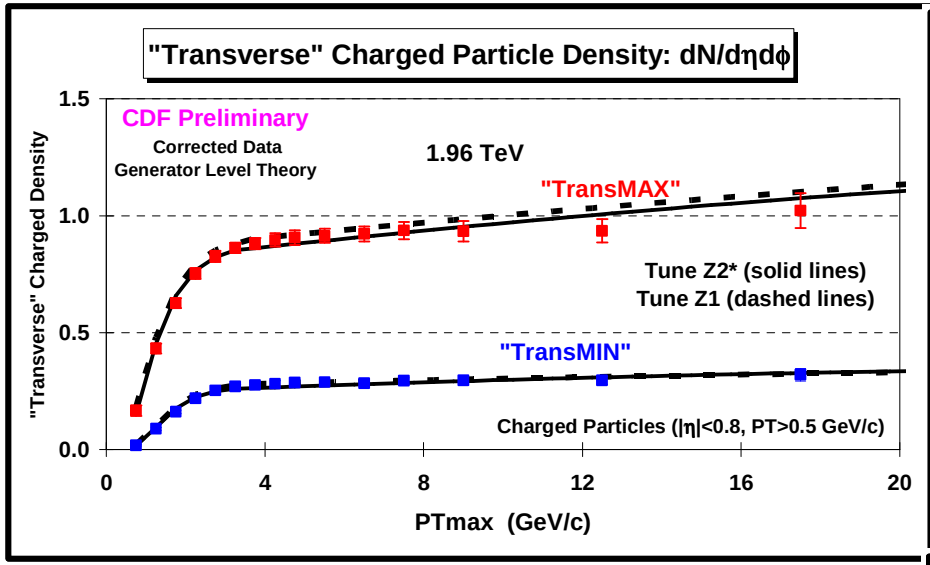


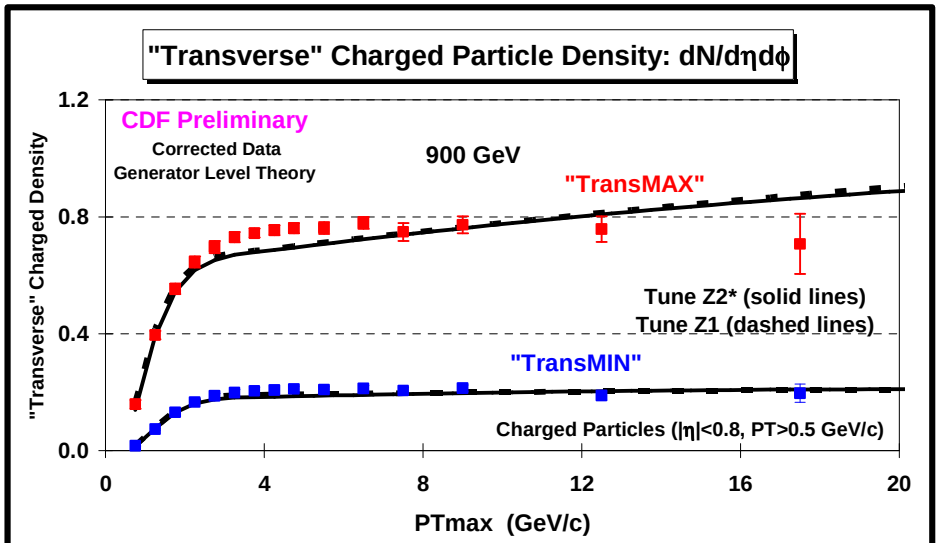


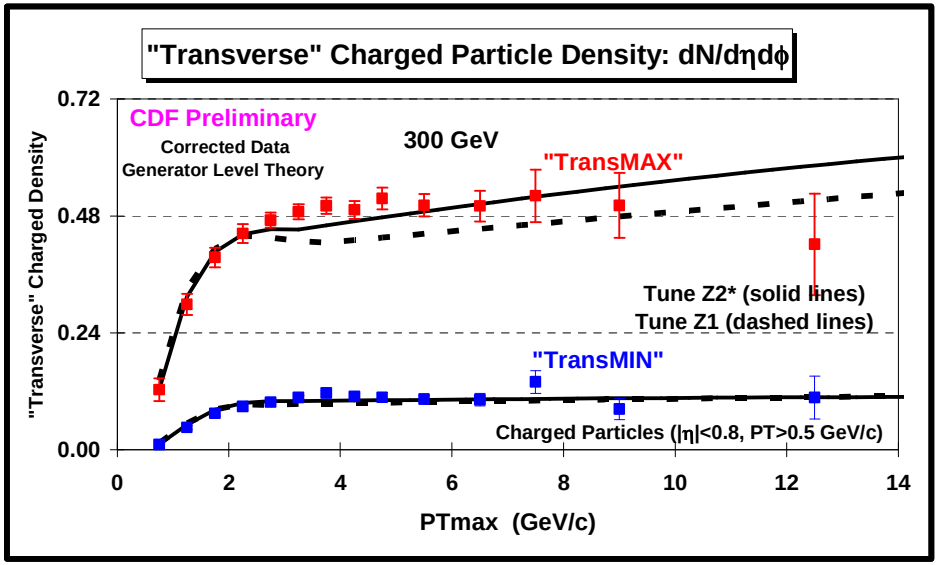
- **Corrected CDF data at 1.96 TeV, 900 GeV, and 300 GeV on the charged particle density in the "transMAX" and "transMIN" regions as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$. The data are corrected to the particle level with errors that include both the statistical error and the systematic uncertainty.**



"transMAX/MIN" NchgDen



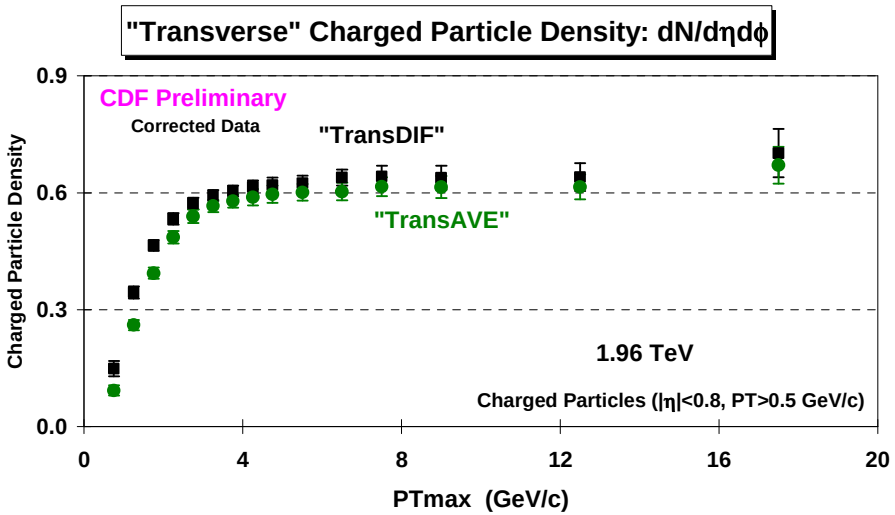


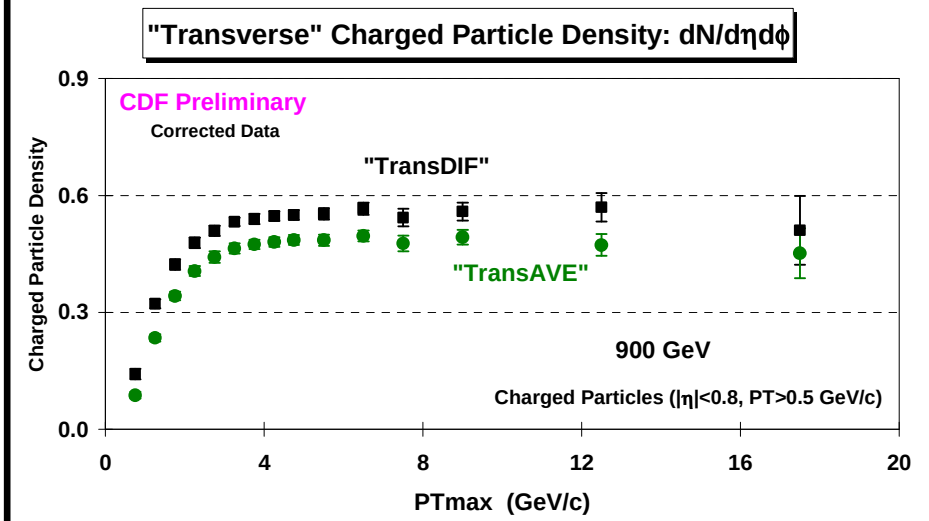


➡ **Corrected CDF data at 1.96 TeV, 900 GeV, and 300 GeV on the charged particle density in the "transMAX" and "transMIN" regions as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$. The data are corrected to the particle level with errors that include both the statistical error and the systematic uncertainty.**

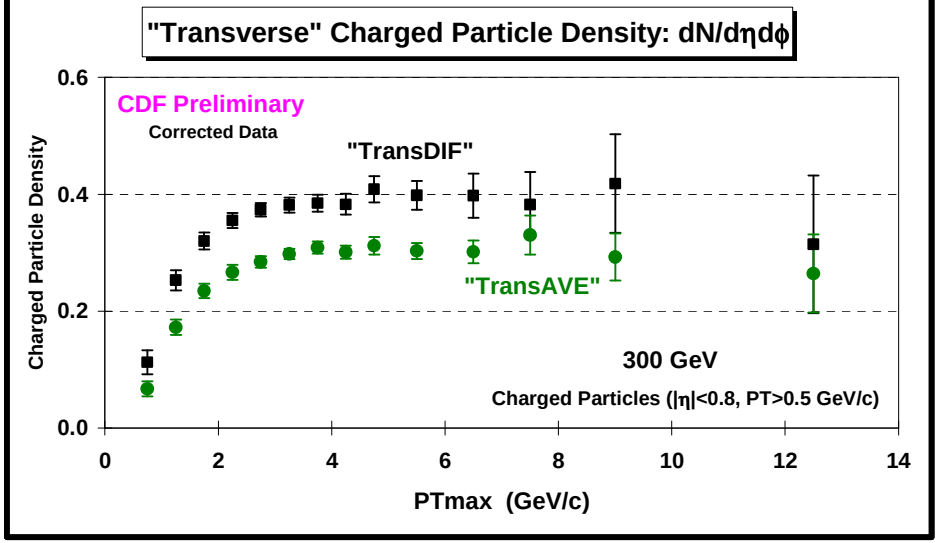
The data are compared with PYTHIA 6.4 Tune Z1 and Tune Z2*.

"transDIF/AVE" NchgDen

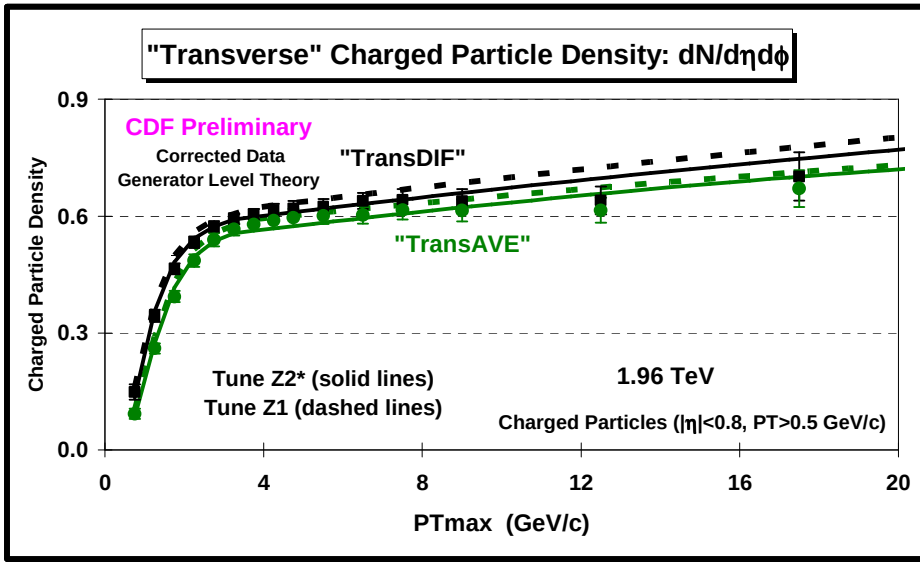


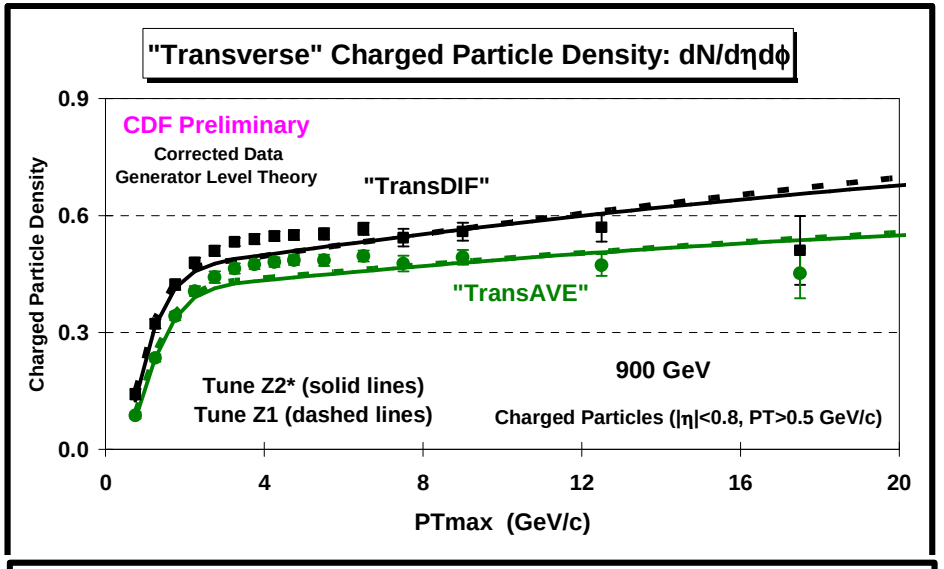


➡ **Corrected CDF data at 1.96 TeV, 900 GeV, and 300 GeV on the charged particle density in the "transAVE" and "transDIF" regions as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$. The data are corrected to the particle level with errors that include both the statistical error and the systematic uncertainty.**

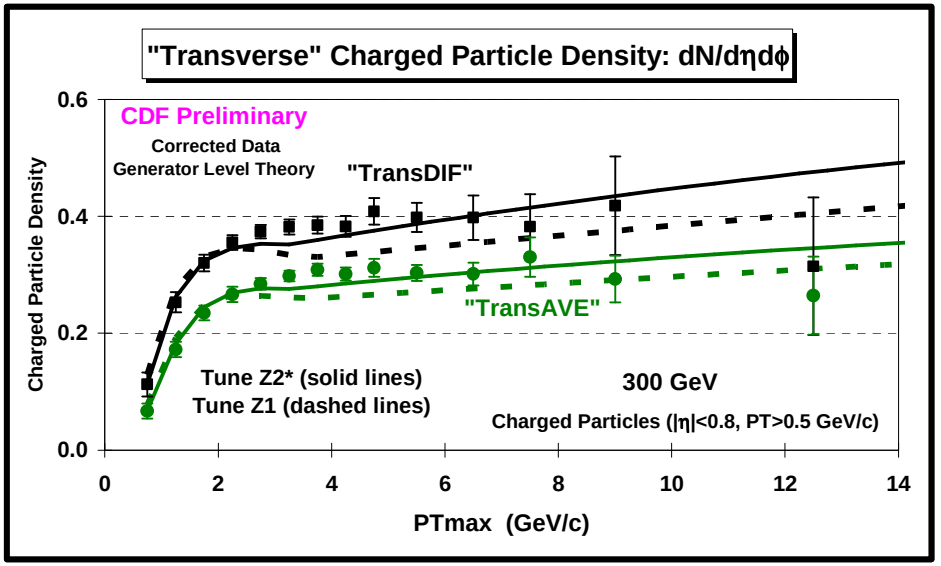


"transDIF/AVE" NchgDen

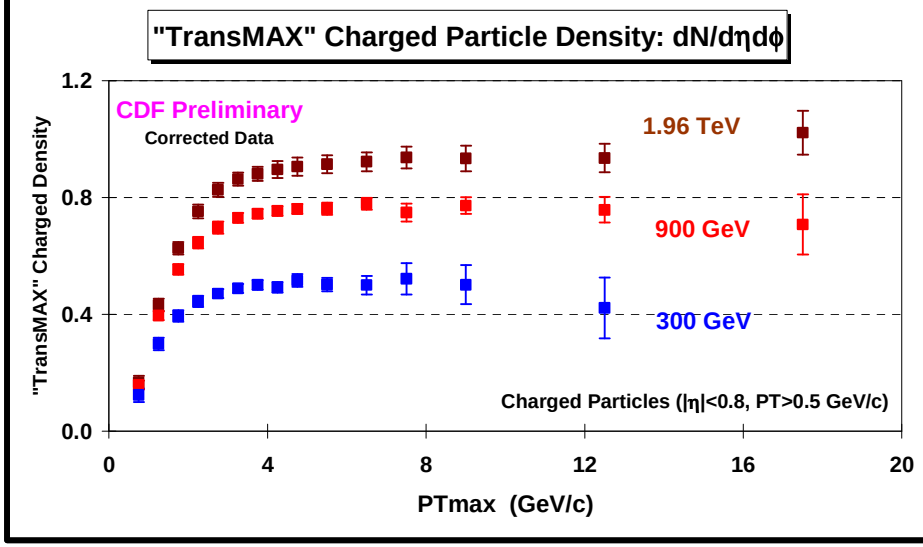


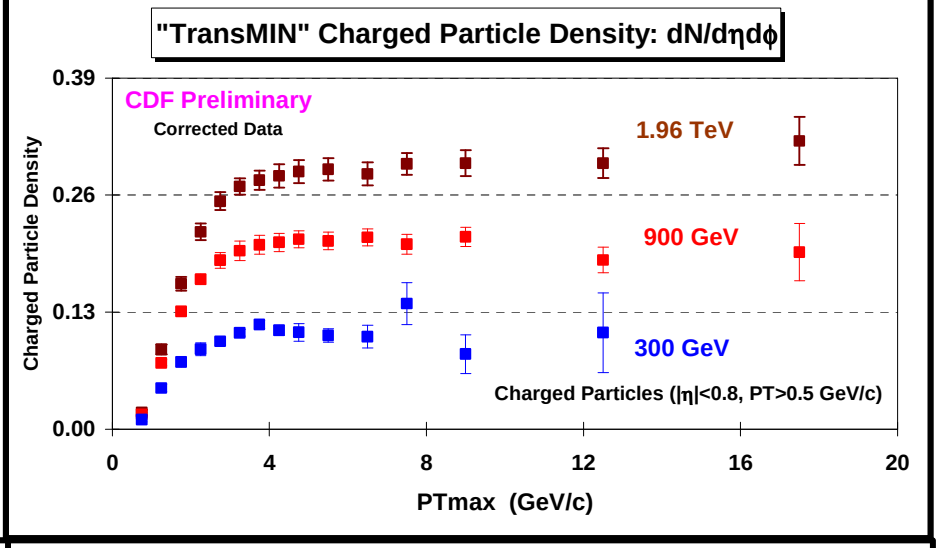


- **Corrected CDF data at 1.96 TeV, 900 GeV, and 300 GeV on the charged particle density in the "transAVE" and "transDIF" regions as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$. The data are corrected to the particle level with errors that include both the statistical error and the systematic uncertainty. The data are compared with PYTHIA 6.4 Tune Z1 and Tune Z2*.**

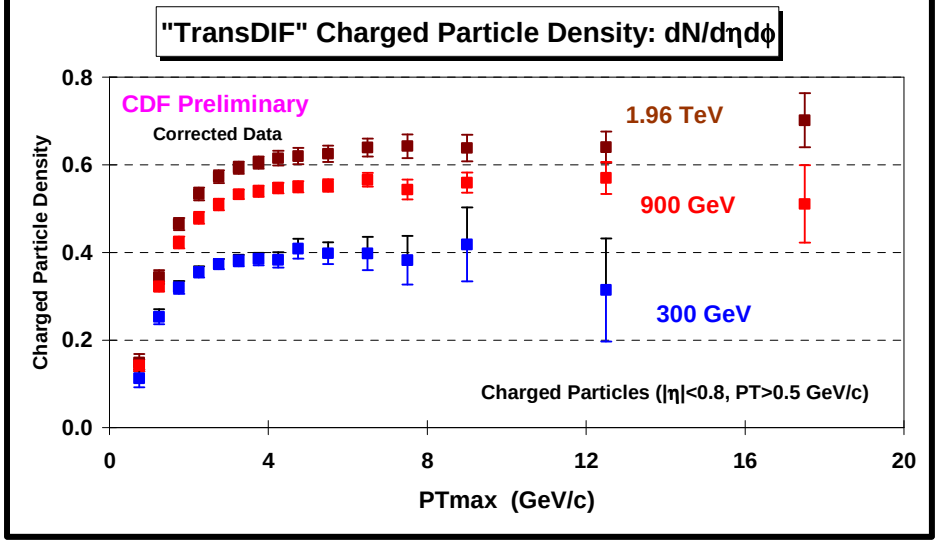


"transMAX/MIN" NchgDen

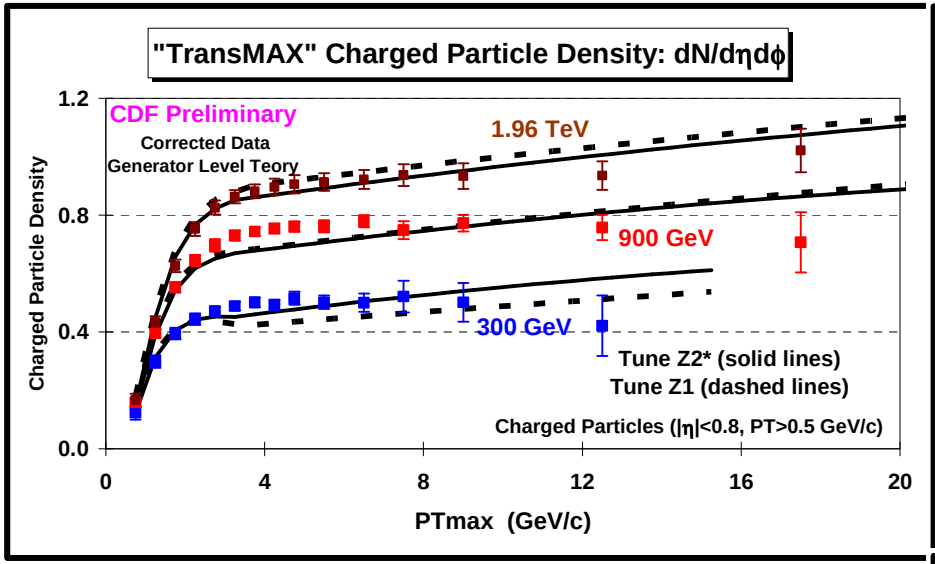


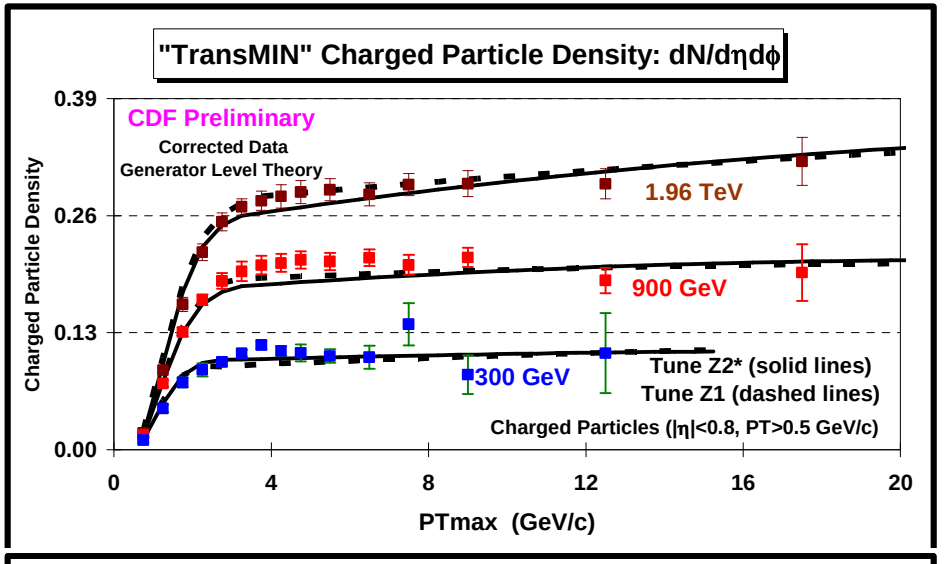


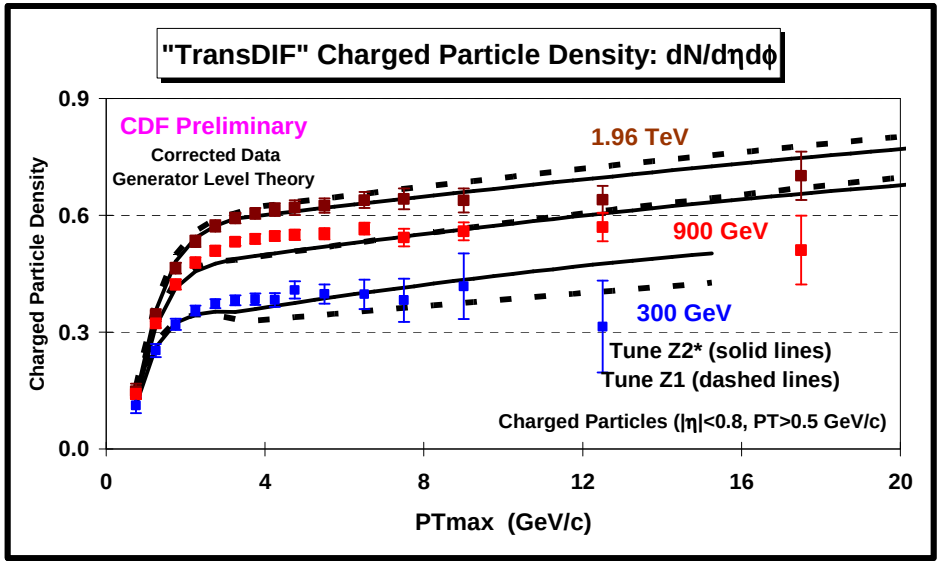
- **Corrected CDF data at 1.96 TeV, 900 GeV, and 300 GeV on the charged particle density in the "transMAX", "transMIN", and "transDIF" regions as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$. The data are corrected to the particle level with errors that include both the statistical error and the systematic uncertainty.**



"transMAX/MIN" NchgDen



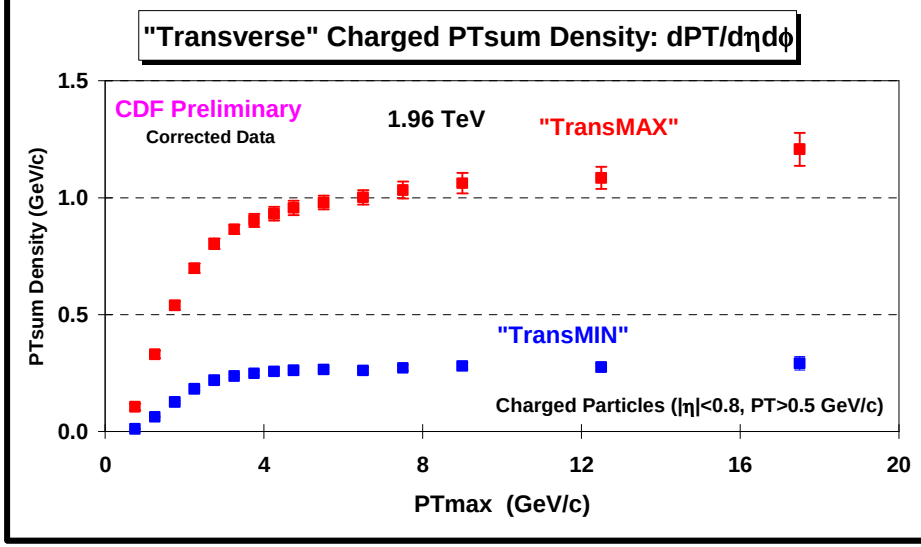


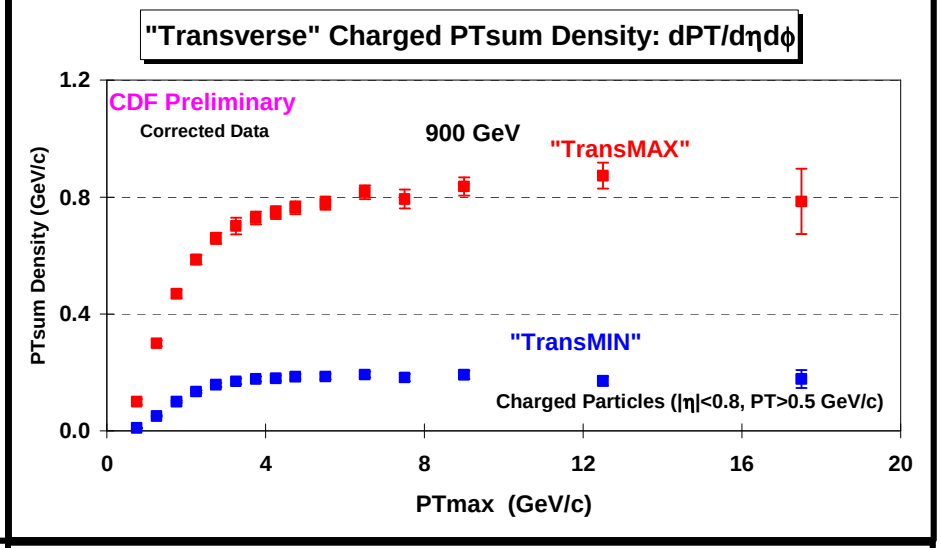


➡ **Corrected CDF data at 1.96 TeV, 900 GeV, and 300 GeV on the charged particle density in the "transMAX", "transMIN", and "transDIF" regions as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$. The data are corrected to the particle level with errors that include both the statistical error and the systematic uncertainty.**

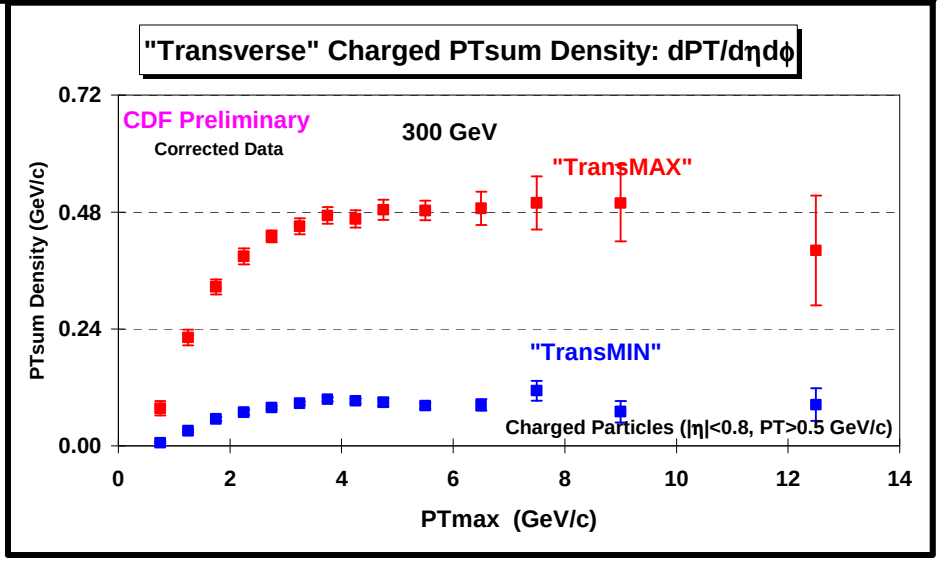
The data are compared with PYTHIA 6.4 Tune Z1 and Tune Z2*.

"transMAX/MIN" PTsumDen

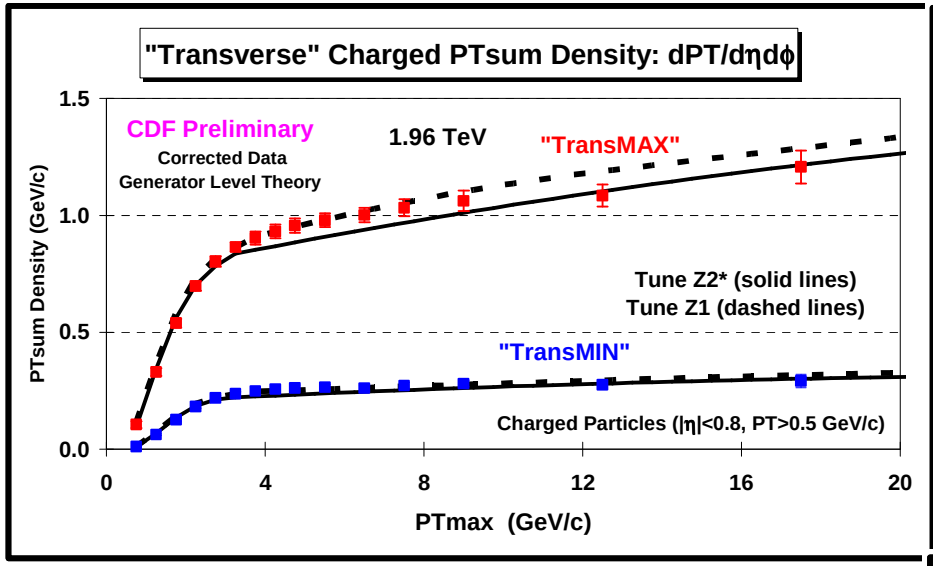


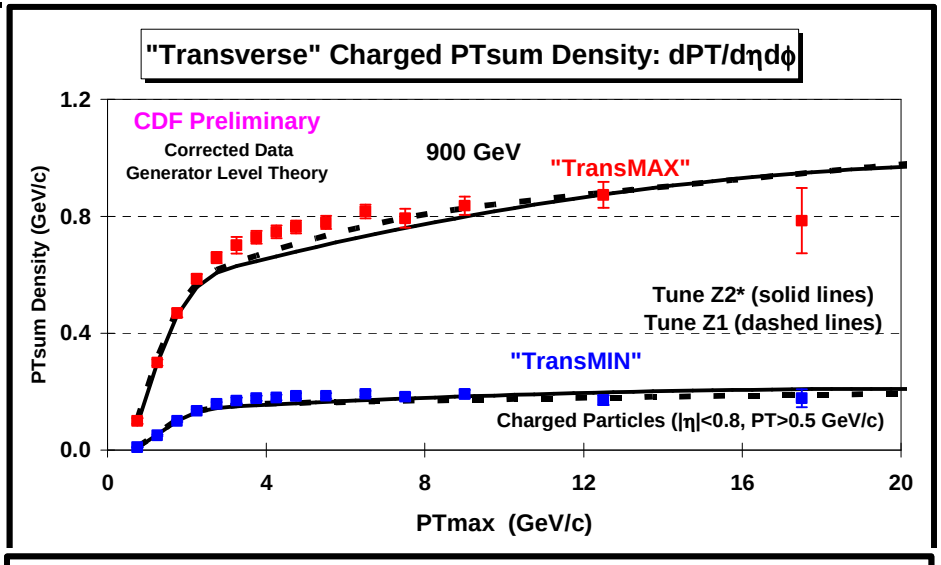


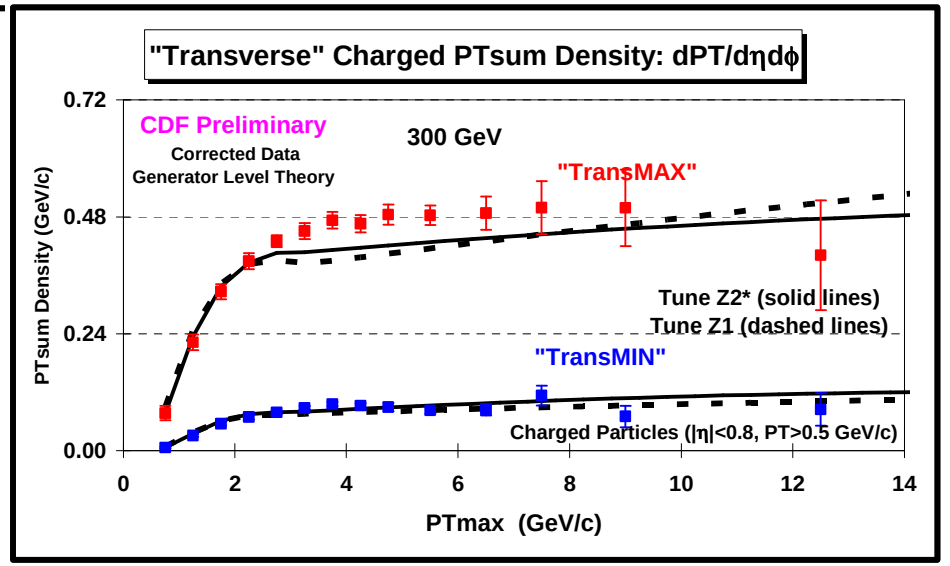
➡ **Corrected CDF data at 1.96 TeV, 900 GeV, and 300 GeV on the charged PTsum density in the "transMAX" and "transMIN" regions as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$. The data are corrected to the particle level with errors that include both the statistical error and the systematic uncertainty.**



"transMAX/MIN" PTsumDen



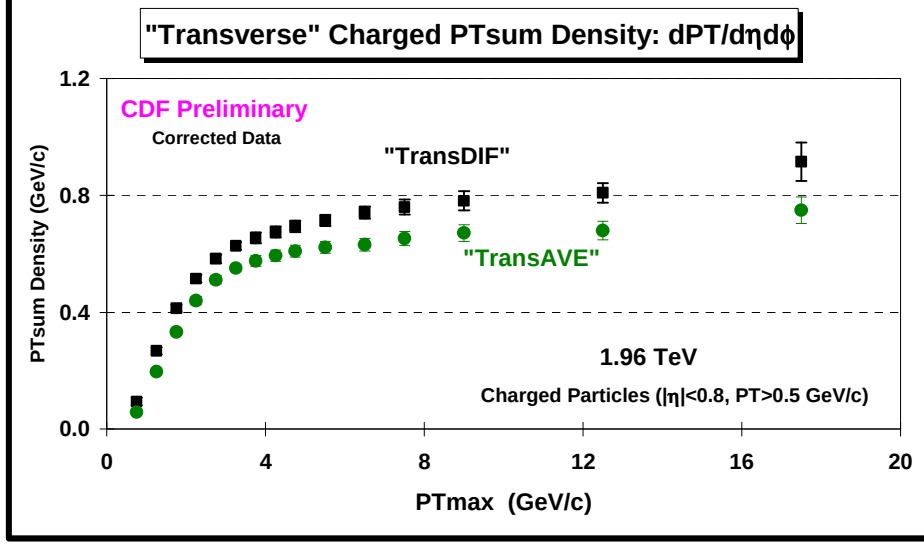


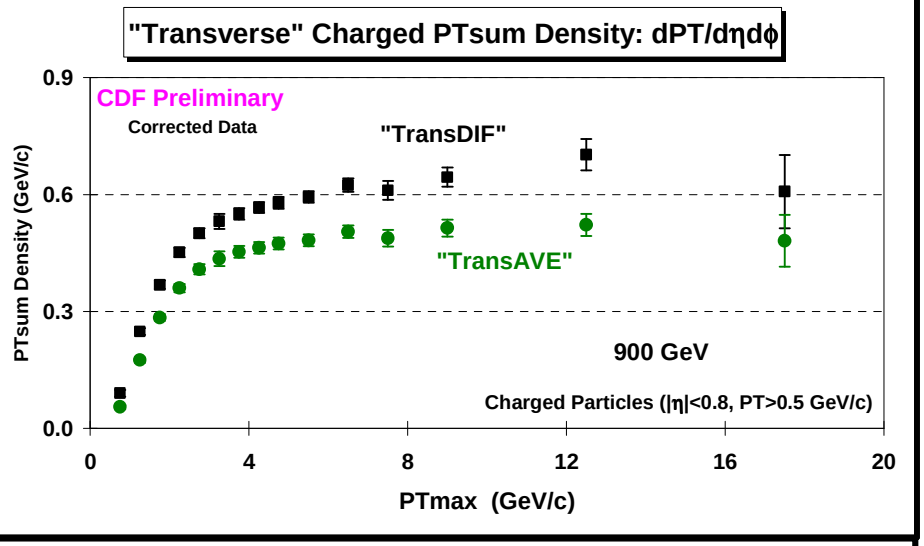


➡ **Corrected CDF data at 1.96 TeV, 900 GeV, and 300 GeV on the charged PTsum density in the "transMAX" and "transMIN" regions as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$. The data are corrected to the particle level with errors that include both the statistical error and the systematic uncertainty.**

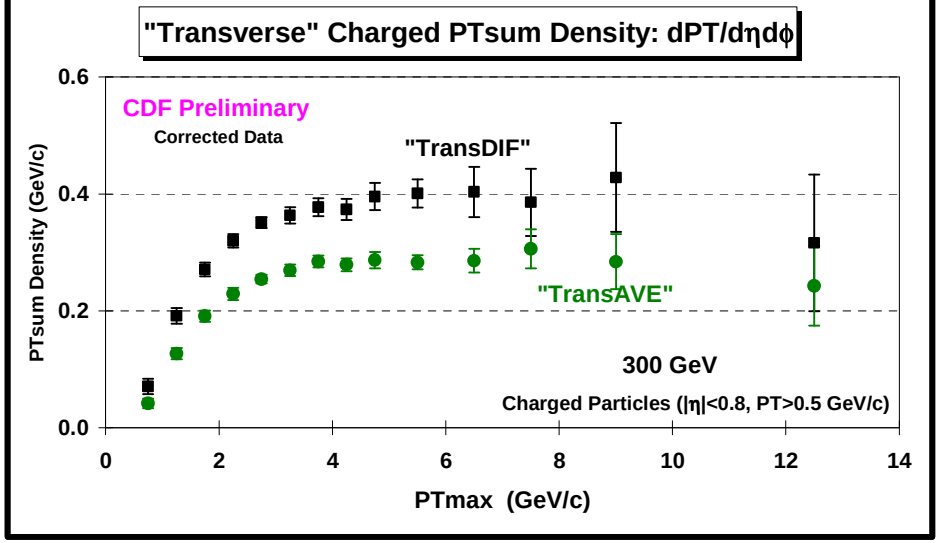
The data are compared with PYTHIA 6.4 Tune Z1 and Tune Z2*.

"transDIF/AVE" PTsumDen

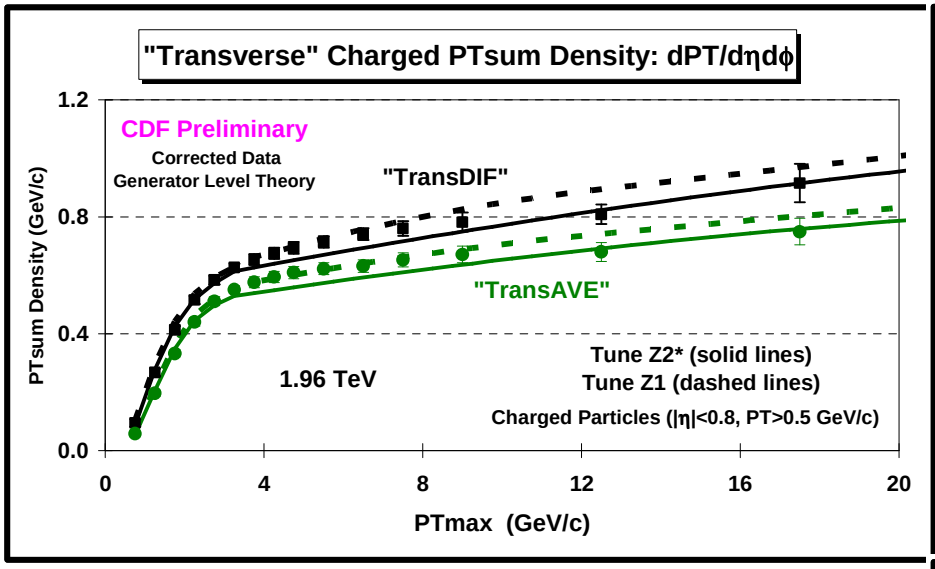


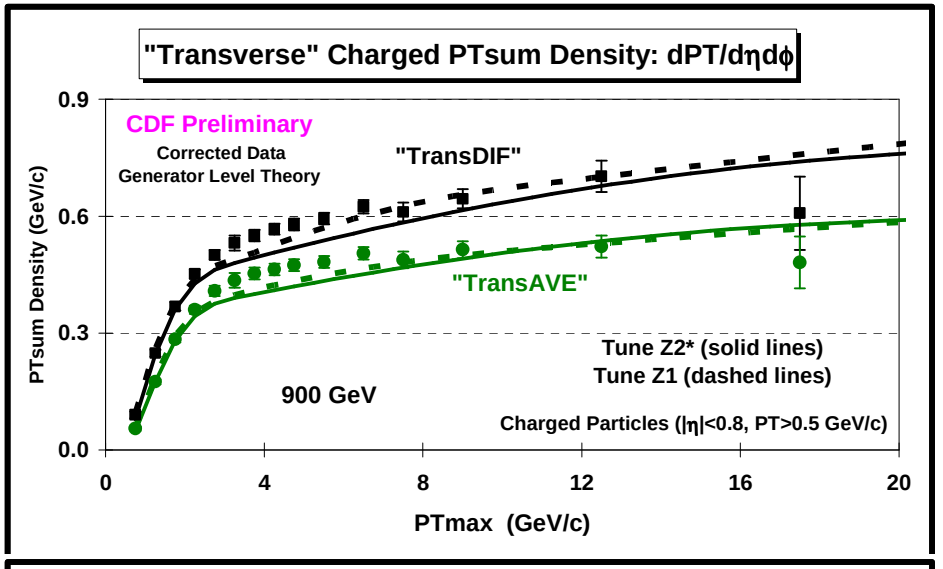


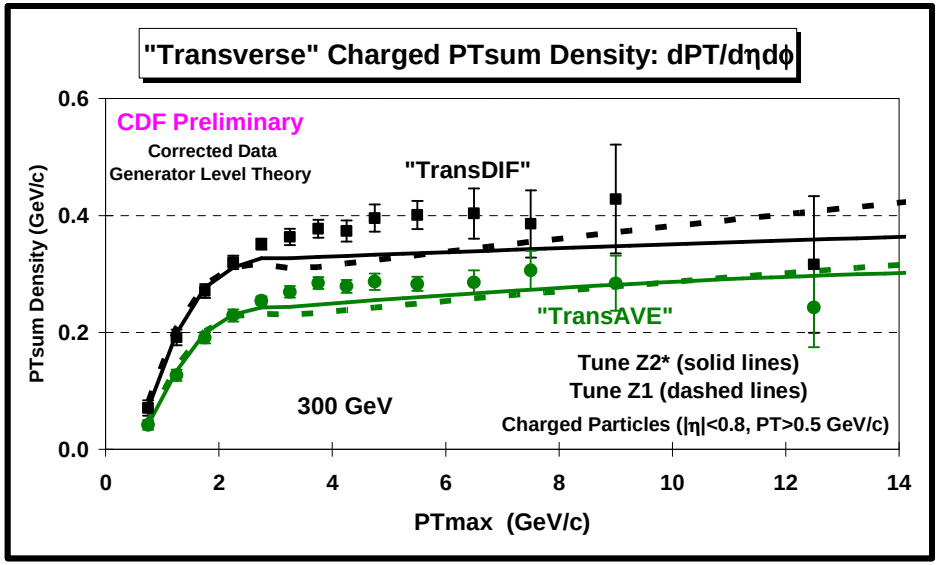
➡ **Corrected CDF data at 1.96 TeV, 900 GeV, and 300 GeV on the charged PTsum density in the "transAVE" and "transDIF" regions as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$. The data are corrected to the particle level with errors that include both the statistical error and the systematic uncertainty.**



"transDIF/AVE" PTsumDen



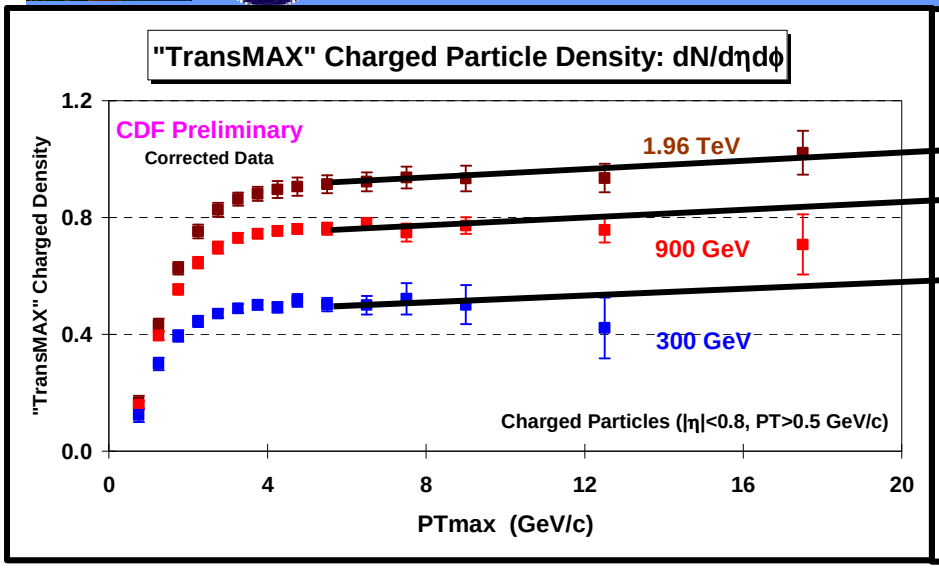


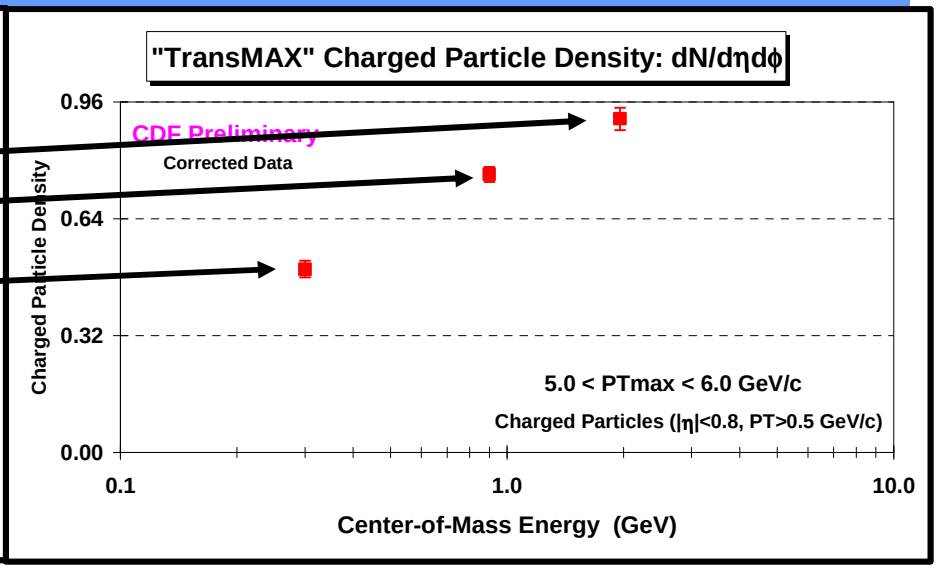


➡ **Corrected CDF data at 1.96 TeV, 900 GeV, and 300 GeV on the charged PTsum density in the "transAVE" and "transDIF" regions as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$. The data are corrected to the particle level with errors that include both the statistical error and the systematic uncertainty.**

The data are compared with PYTHIA 6.4 Tune Z1 and Tune Z2*.

"transMAX" NchgDen vs E_{cm}

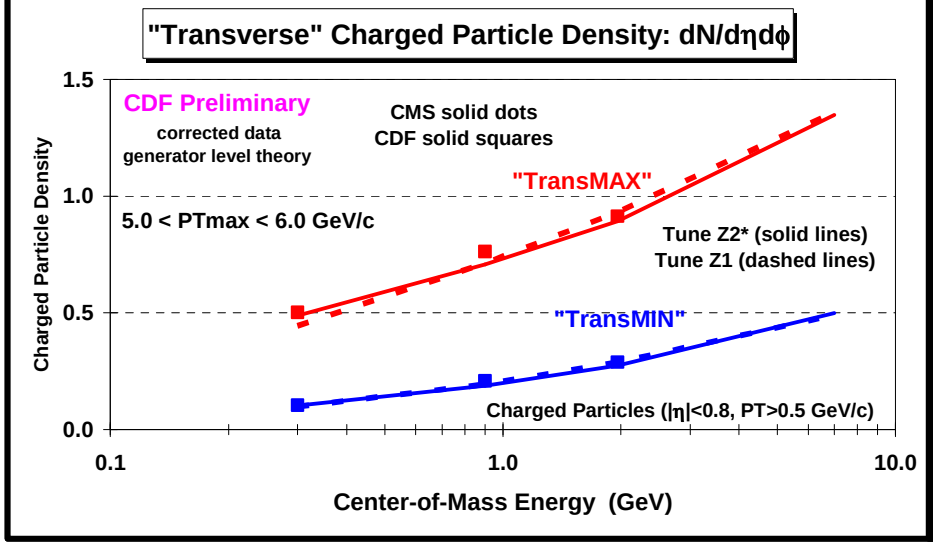


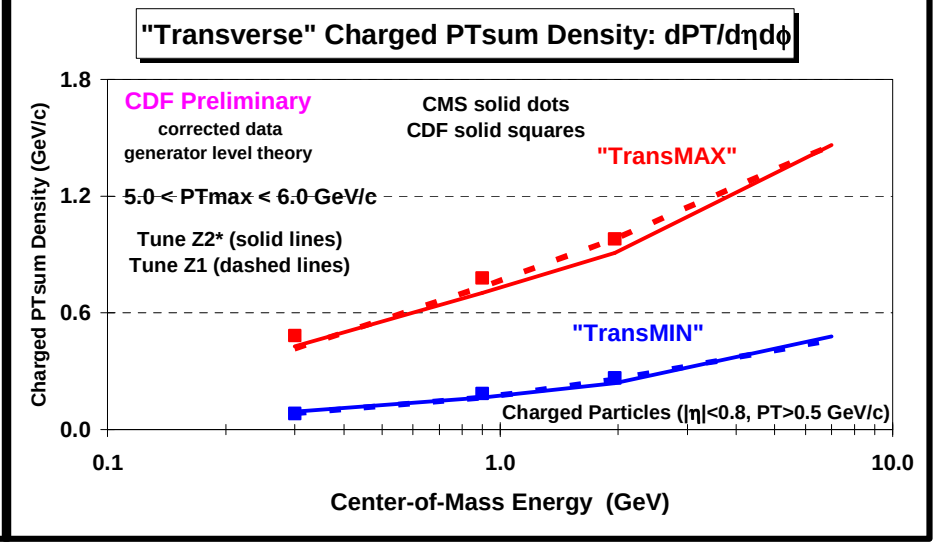


➡ **Corrected CDF data at 1.96 TeV, 900 GeV, and 300 GeV on the charged particle density in the "transMAX" region as defined by the leading charged particle (PTmax) for charged particles with p_T > 0.5 GeV/c and |η| < 0.8. The data are corrected to the particle level with errors that include both the statistical error and the systematic uncertainty.**

➡ **Corrected CDF data on the charged particle density in the "transMAX" region as defined by the leading charged particle (PTmax) for charged particles with p_T > 0.5 GeV/c and |η| < 0.8 with 5 < PTmax < 6 GeV/c. The data are plotted versus the center-of-mass energy (*log scale*).**

"TransMAX/MIN" vs E_{cm}

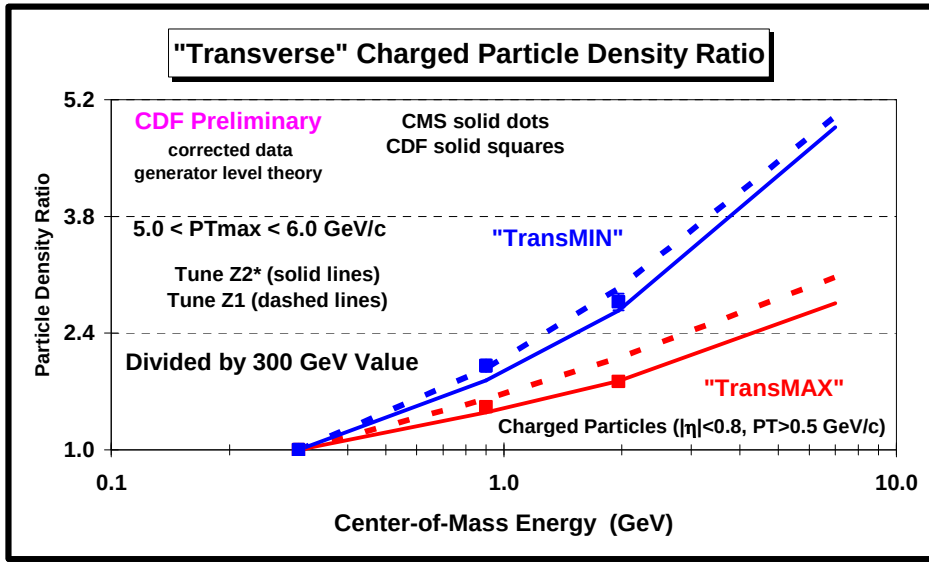


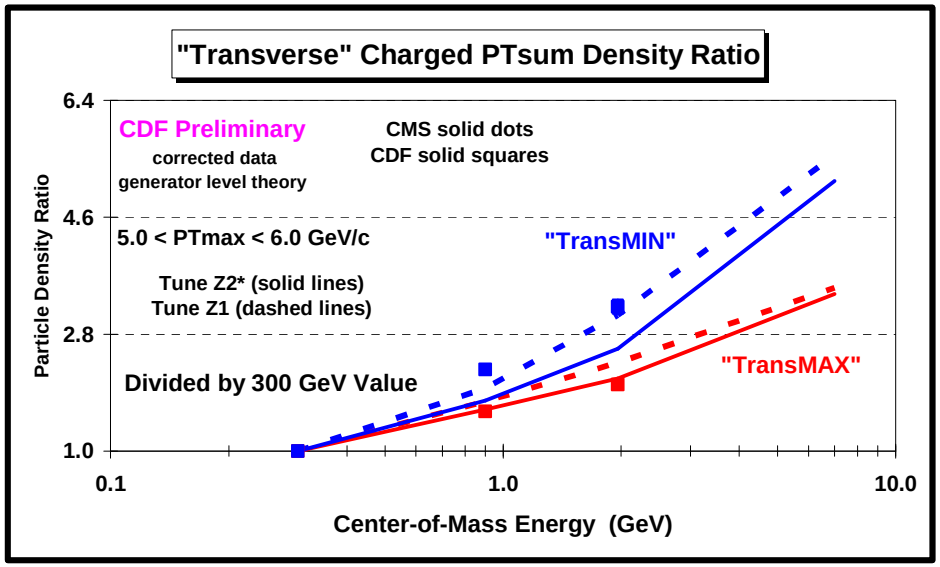


➡ **Corrected CDF data at 1.96 TeV, 900 GeV, and 300 GeV on the charged particle density in the "transMAX", and the "transMIN", regions as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$ with $5 < PTmax < 6$ GeV/c. The data are plotted versus the center-of-mass energy (*log scale*). The data are compared with PYTHIA 6.4 Tune Z1 and Tune Z2*.**

➡ **Corrected CDF data at 1.96 TeV, 900 GeV, and 300 GeV on the charged PTsum density in the "transMAX", and the "transMIN", regions as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$ with $5 < PTmax < 6$ GeV/c. The data are plotted versus the center-of-mass energy (*log scale*). The data are compared with PYTHIA 6.4 Tune Z1 and Tune Z2*.**

"TransMAX/MIN" vs E_{cm}



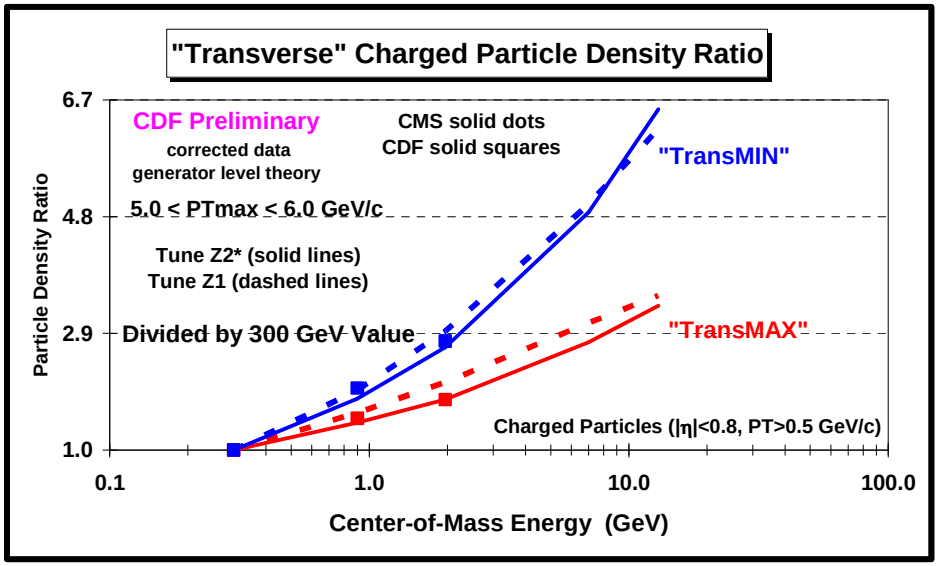


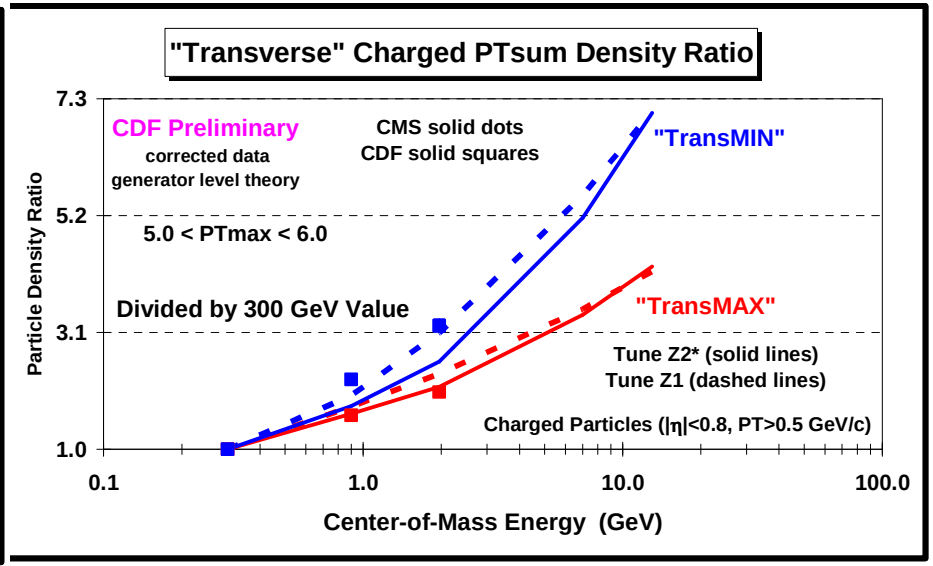
➡ **Corrected CDF data at 1.96 TeV, 900 GeV, and 300 GeV on the charged particle density in the "transMAX", and the "transMIN", regions as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$ with $5 <$ PTmax < 6 GeV/c. The data are plotted versus the center-of-mass energy (*log scale*). The data are compared with PYTHIA 6.4 Tune Z1 and Tune Z2*.**

➡ **Corrected CDF data at 1.96 TeV, 900 GeV, and 300 GeV on the charged PTsum density in the "transMAX", and the "transMIN", regions as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$ with $5 <$ PTmax < 6 GeV/c. The data are plotted versus the center-of-mass energy (*log scale*). The data are compared with PYTHIA 6.4 Tune Z1 and Tune Z2*.**

The data are "normalized" by dividing by the corresponding value at 300 GeV.

"TransMAX/MIN" vs E_{cm}



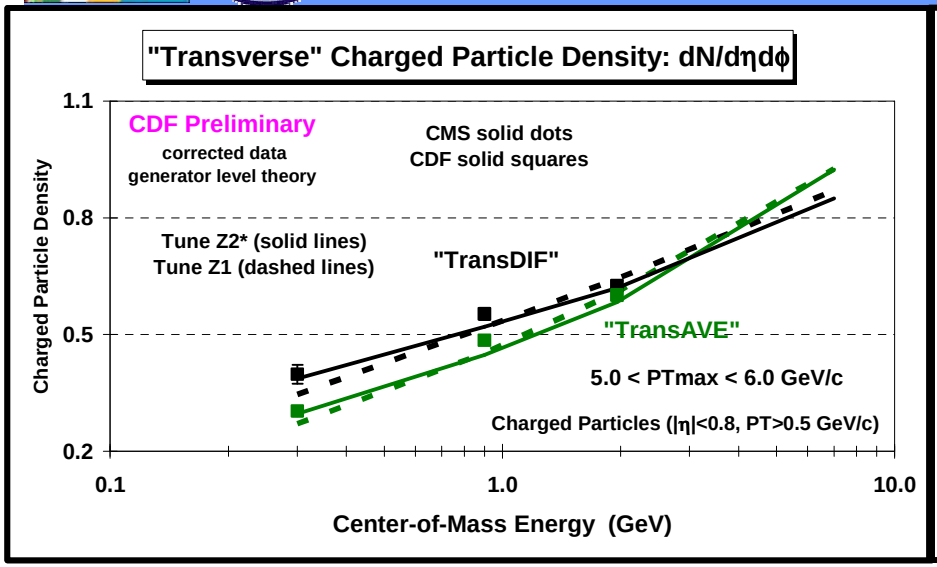


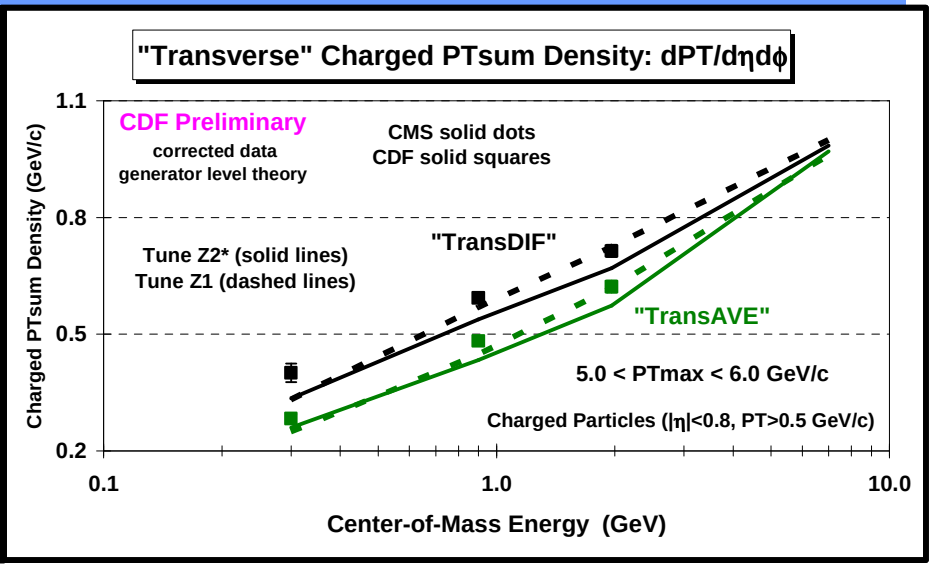
➡ **Corrected CDF data at 1.96 TeV, 900 GeV, and 300 GeV on the charged particle density in the "transMAX", and the "transMIN", regions as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$ with $5 < PTmax < 6$ GeV/c. The data are plotted versus the center-of-mass energy (*log scale*). The data are compared with PYTHIA 6.4 Tune Z1 and Tune Z2*.**

➡ **Corrected CDF data at 1.96 TeV, 900 GeV, and 300 GeV on the charged PTsum density in the "transMAX", and the "transMIN", regions as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$ with $5 < PTmax < 6$ GeV/c. The data are plotted versus the center-of-mass energy (*log scale*). The data are compared with PYTHIA 6.4 Tune Z1 and Tune Z2*.**

The data are "normalized" by dividing by the corresponding value at 300 GeV.

"TransDIF/AVE" vs E_{cm}





- **Corrected CDF data at 1.96 TeV, 900 GeV, and 300 GeV on the charged particle density in the "transAVE", and the "transDIF", regions as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$ with $5 < PTmax < 6$ GeV/c. The data are plotted versus the center-of-mass energy (*log scale*). The data are compared with PYTHIA 6.4 Tune Z1 and Tune Z2*.**

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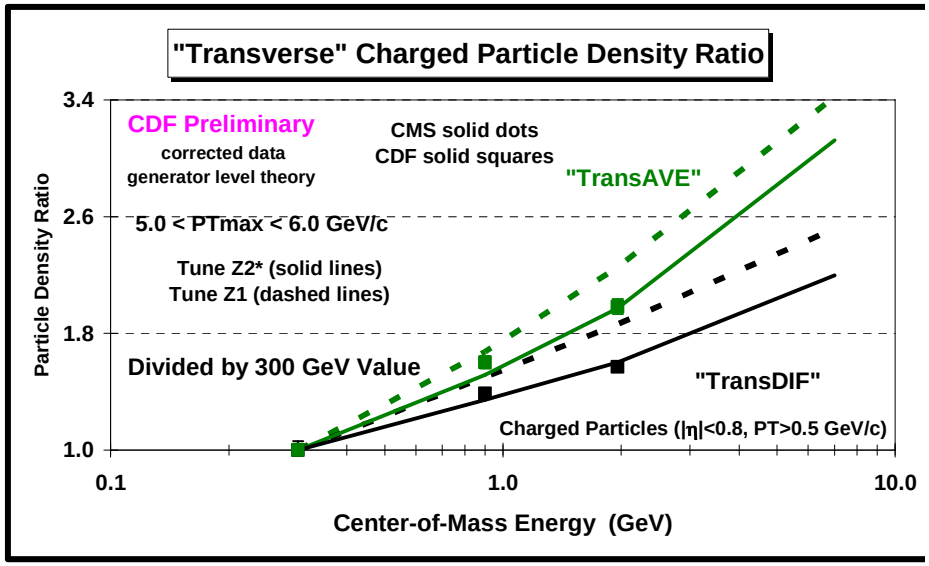
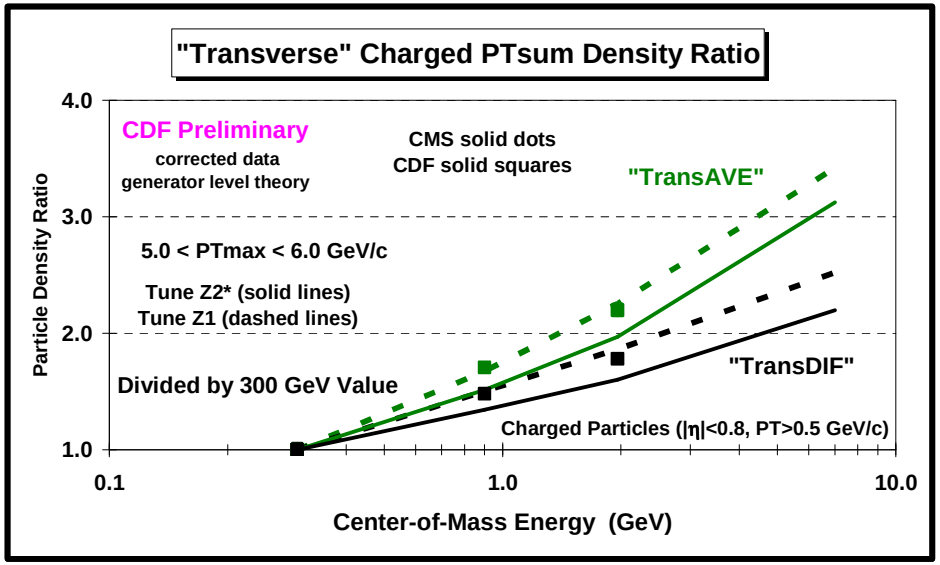
"TransDIF/AVE" vs E_{cm}



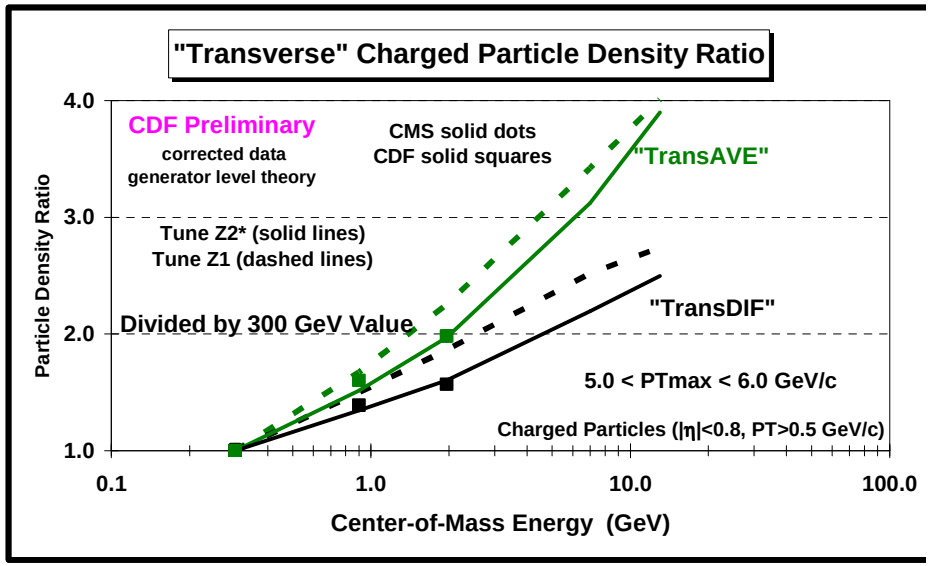


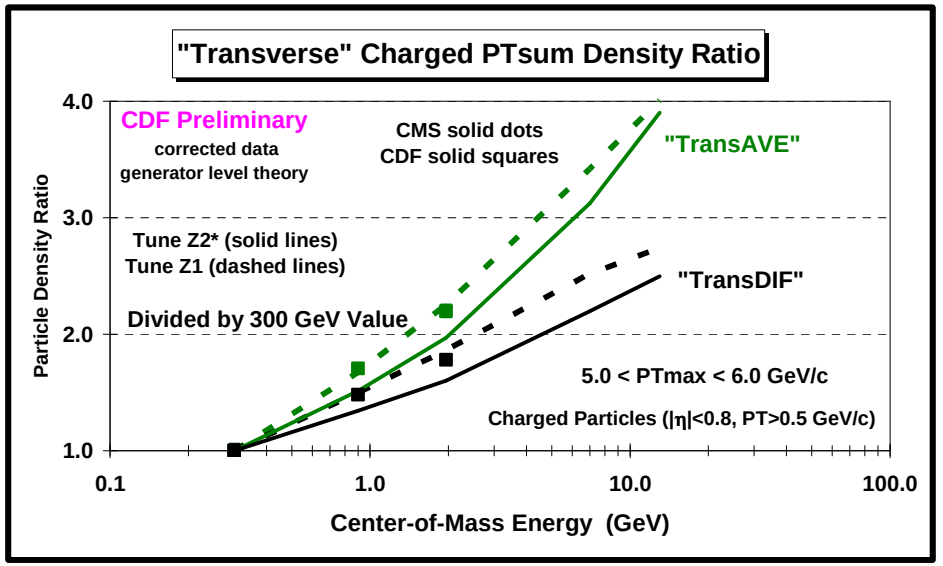
➡ **Corrected CDF data at 1.96 TeV, 900 GeV, and 300 GeV on the charged particle density in the "transAVE", and the "transDIF", regions as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$ with $5 < PTmax < 6$ GeV/c. The data are plotted versus the center-of-mass energy (*log scale*). The data are compared with PYTHIA 6.4 Tune Z1 and Tune Z2*.**

➡ **Corrected CDF data at 1.96 TeV, 900 GeV, and 300 GeV on the charged PTsum density in the "transAVE", and the "transDIF", regions as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$ with $5 < PTmax < 6$ GeV/c. The data are compared with PYTHIA 6.4 Tune Z1 and Tune Z2*.**

The data are "normalized" by dividing by the corresponding value at 300 GeV.

"TransDIF/AVE" vs E_{cm}



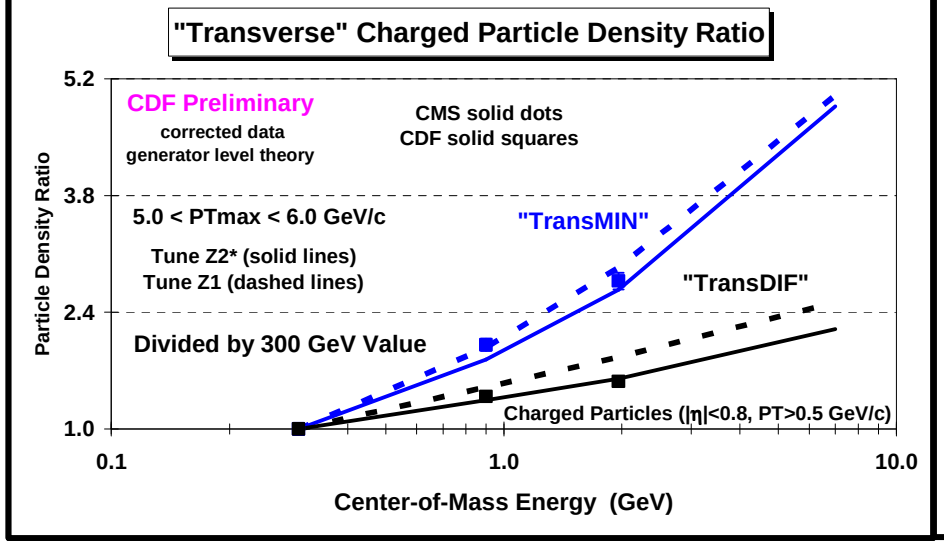


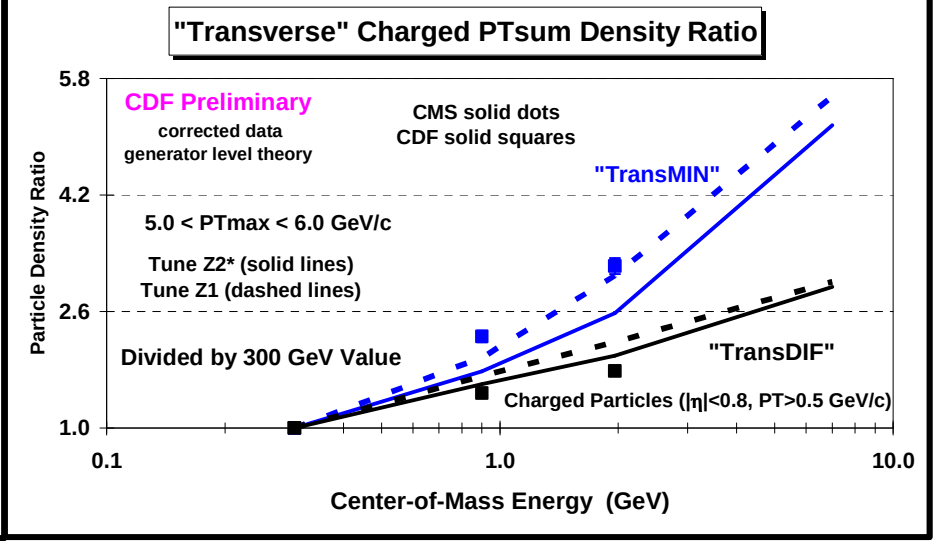
➡ **Corrected CDF data at 1.96 TeV, 900 GeV, and 300 GeV on the charged particle density in the "transAVE", and the "transDIF", regions as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$ with $5 < PTmax < 6$ GeV/c. The data are plotted versus the center-of-mass energy (*log scale*). The data are compared with PYTHIA 6.4 Tune Z1 and Tune Z2*.**

➡ **Corrected CDF data at 1.96 TeV, 900 GeV, and 300 GeV on the charged PTsum density in the "transAVE", and the "transDIF", regions as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$ with $5 < PTmax < 6$ GeV/c. The data are plotted versus the center-of-mass energy (*log scale*). The data are compared with PYTHIA 6.4 Tune Z1 and Tune Z2*.**

The data are "normalized" by dividing by the corresponding value at 300 GeV.

"TransMIN/DIF" vs E_{cm}



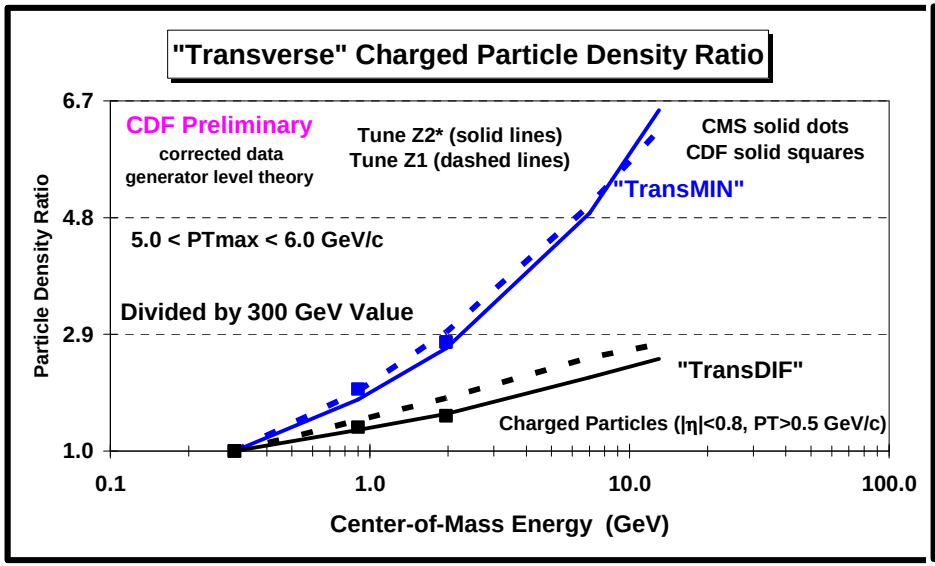


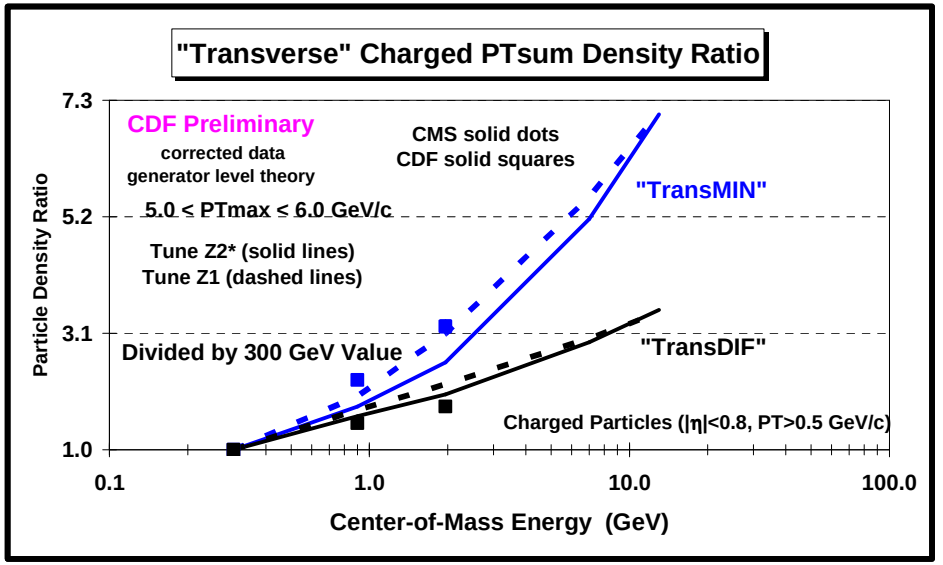
➡ **Ratio of CDF data at 1.96 TeV, 900 GeV, and 300 GeV to the value at 300 GeV for the charged particle density in the "transMIN", and "transDIF" regions as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$ with $5 < PTmax < 6$ GeV/c. The data are plotted versus the center-of-mass energy (*log scale*). The data are compared with PYTHIA 6.4 Tune Z1 and Tune Z2*.**

➡ **Ratio of CDF data at 1.96 TeV, 900 GeV, and 300 GeV to the value at 300 GeV for the charged PTsum density in the "transMIN", and "transDIF" regions as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$ with $5 < PTmax < 6$ GeV/c. The data are plotted versus the center-of-mass energy (*log scale*). The data are compared with PYTHIA 6.4 Tune Z1 and Tune Z2*.**

The data are "normalized" by dividing by the corresponding value at 300 GeV.

"TransMIN/DIF" vs E_{cm}





➡ **Ratio of CDF data at 1.96 TeV, 900 GeV, and 300 GeV to the value at 300 GeV for the charged particle density in the "transMIN", and "transDIF" regions as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$ with $5 < PTmax < 6$ GeV/c. The data are plotted versus the center-of-mass energy (*log scale*). The data are compared with PYTHIA 6.4 Tune Z1 and Tune Z2*.**

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The data are "normalized" by dividing by the corresponding value at 300 GeV.

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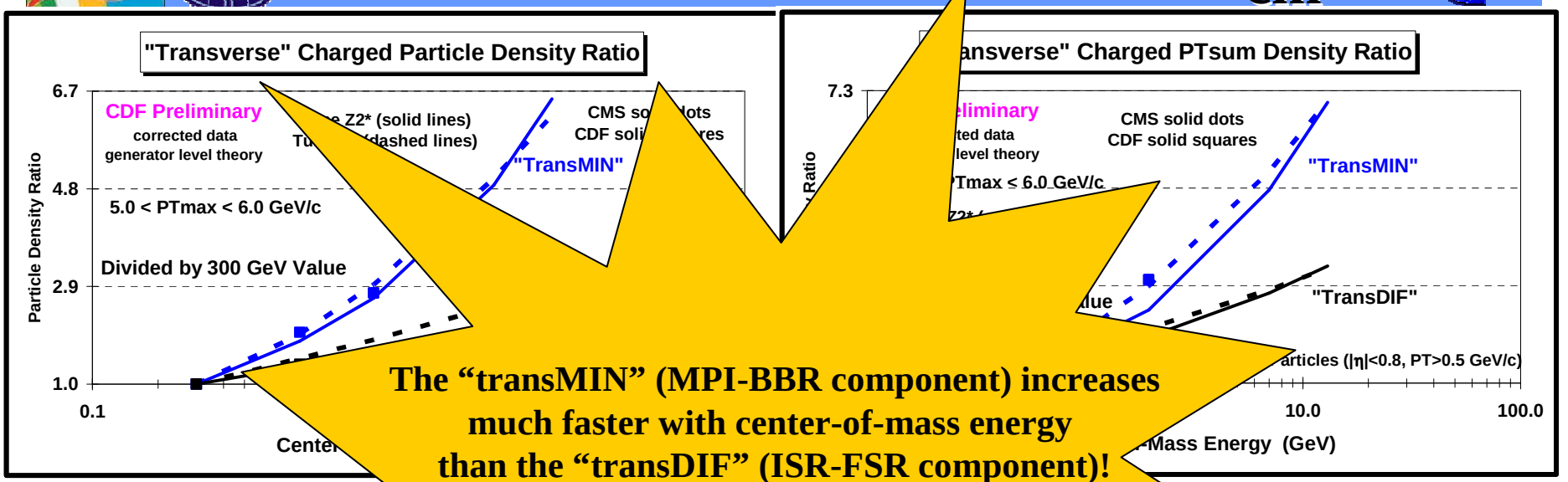

The "transMIN" (MPI-BBR component) increases much faster with center-of-mass energy than the "transDIF" (ISR-FSR component)! Duh!!

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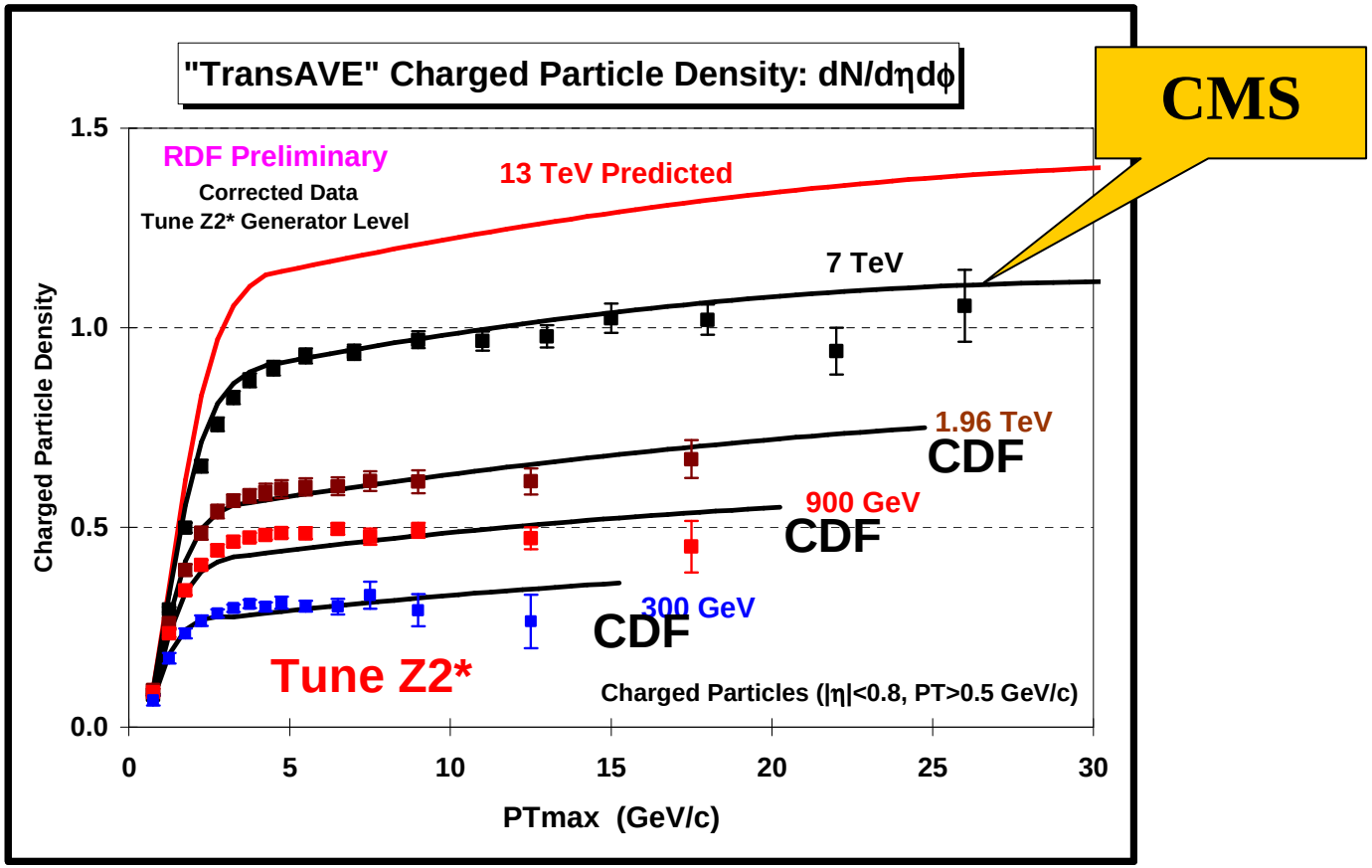
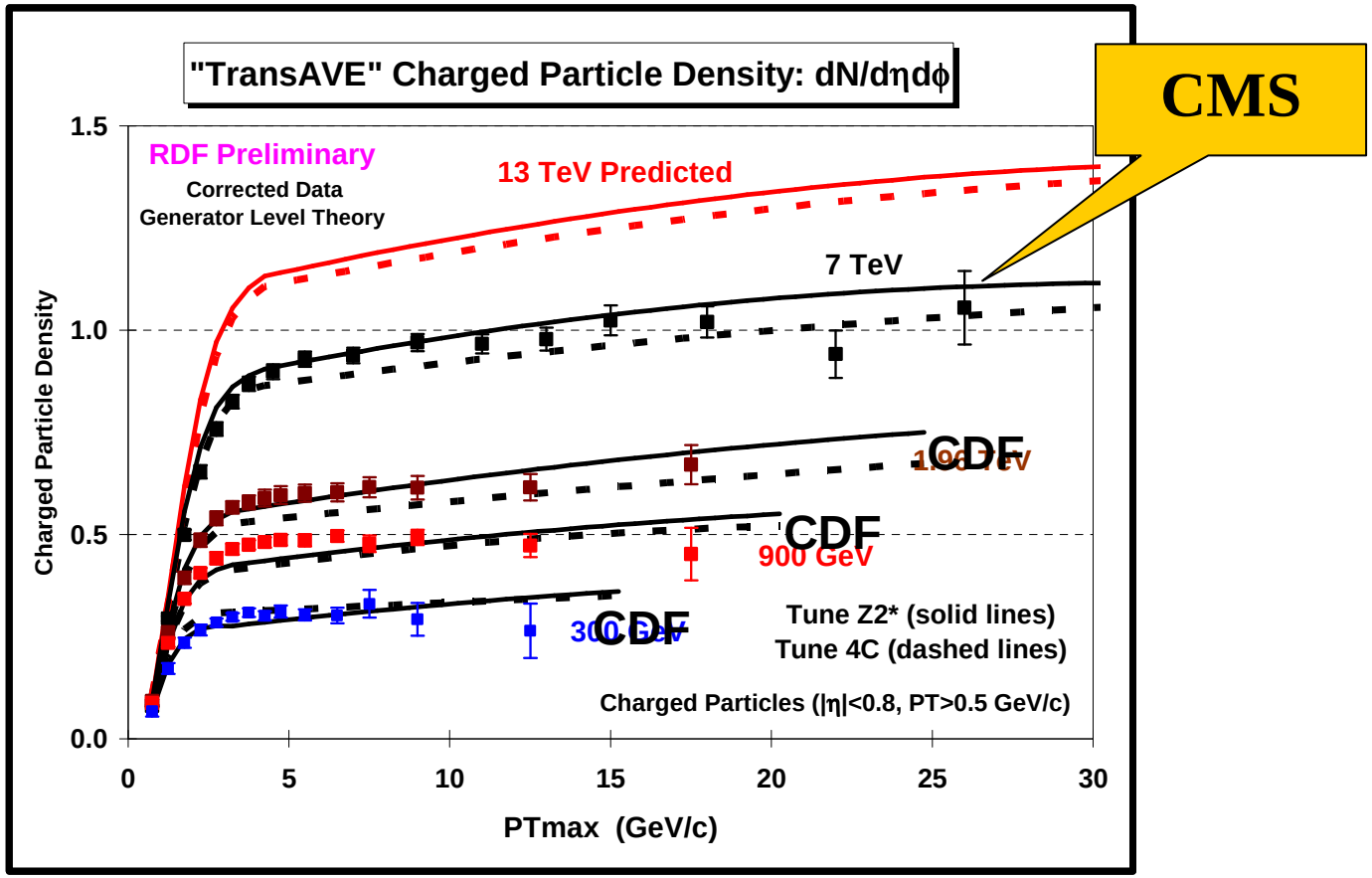
"Tevatron" to the LHC

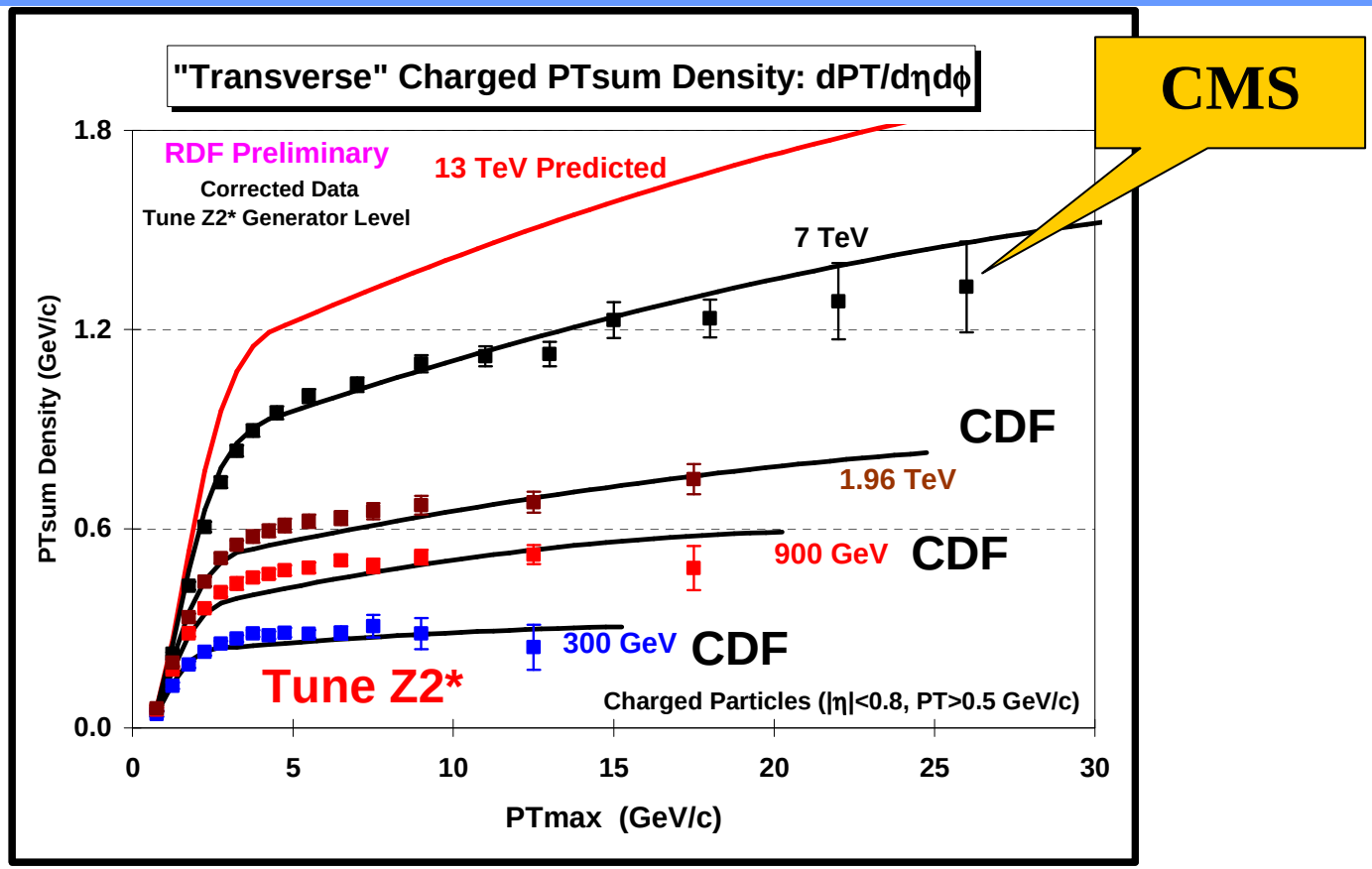


"Tevatron" to the LHC

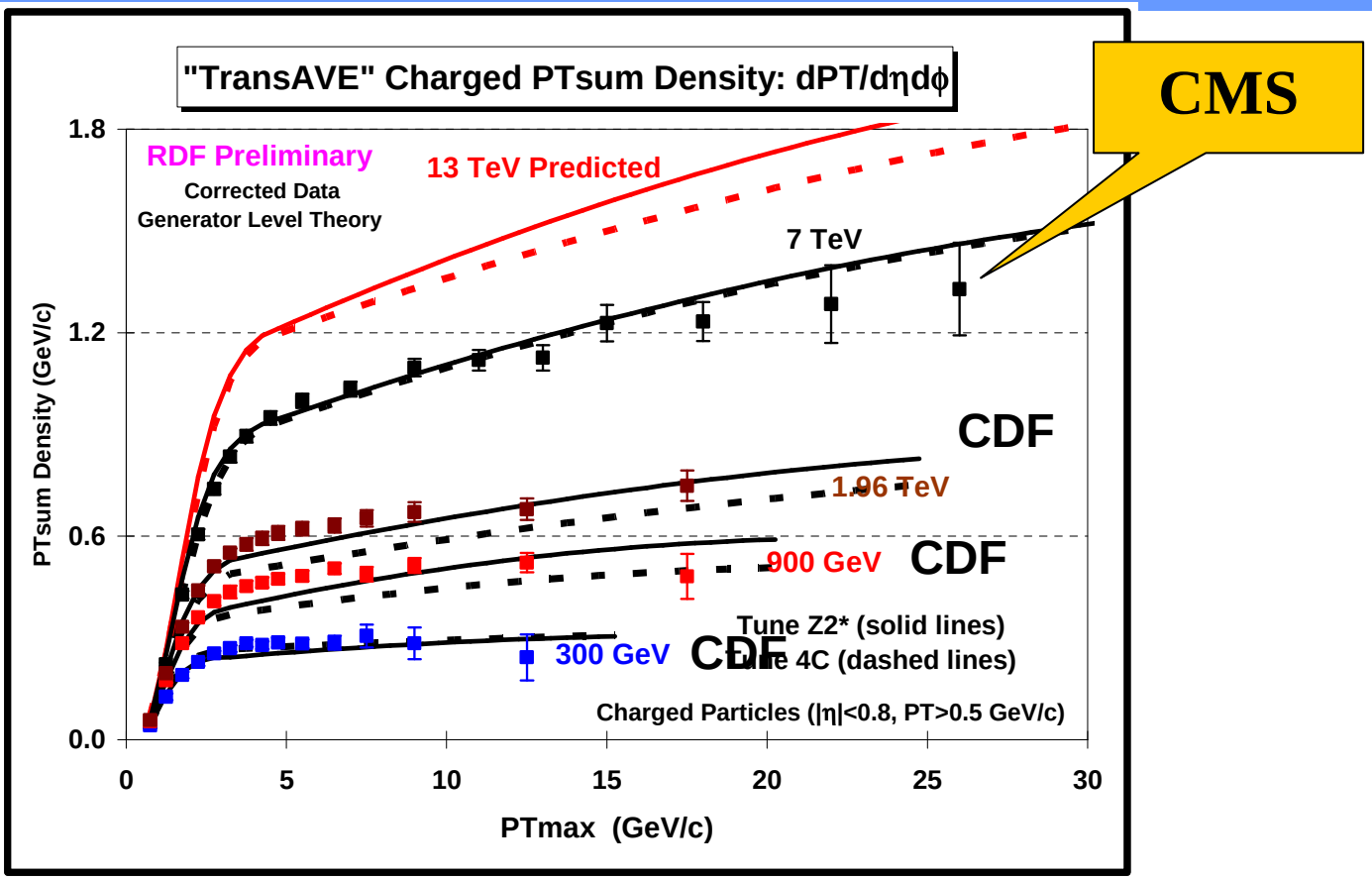


PYTHIA 8 Tune 4C (dashed lines) - Corke & Sjöstrand

"Tevatron" to the LHC



"Tevatron" to the LHC



PYTHIA 8 Tune 4C (dashed lines) - Corke & Sjöstrand

Summary & Conclusions

- The "transverse" density increases faster with center-of-mass energy than the overall density (Nchg ≥ 1)! However, the "transverse" = "transAVE" region is not a true measure of the energy dependence of MPI since it receives large contributions from ISR and FSR.
- The "transMIN" (MPI-BBR component) increases much faster with center-of-mass energy than the "transDIF" (ISR-FSR component)! Previously we only knew the energy dependence of "transAVE".

We now have at lot of MB & UE data at
300 GeV, 900 GeV, 1.96 TeV, and 7 TeV!
We can study the energy dependence
more precisely than ever before!

- Both PYTHIA 6.4 Tune Z1 (CTEQ5L) and PYTHIA 6.4 Tune Z2* (CTEQ6L) go a fairly good job (although not perfect) in describing the energy deperdence of the UE!

Summary & Conclusions

- The “t…nsverse” density inc…ases faster w… enter-of-mass energy than the … all density (Nc… 1)! How… he “transverse” = “transAVE… is not a… as… en… endence of MPI since it re… SR.

- The “transMIN”… with cent… t)! Previous… VE”.

W… eV!

We ca…

mo… ha… befo…

What we are learning should allow for a deeper understanding of MPI which will result in more precise predictions at the future LHC energy of 13 TeV!

- Both PYTHIA 6.4 Tune Z1 … EQ5L) a… PYTHIA 6.4 Tune Z2* (CTEQ6L) go a fairly good … (although n…t perfect) in describing the energy deperdence of the UE

Summary & Co nclusions

- The "tr ansverse" density inc reases faster w ... enter-of-mass energy than the ... all density (Nc ... 1)! How ... e "transverse" = "transAV E" ... is not a ... as ... en ... ndence of MPI since it ... R.
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W ... eV!

We ca ... mo ... na ... befo

I would like to thank the CDF-SM conveners, Christina Mesropian, Bo Jayatilaka, and Larry Nodulman for their help and encouragement!

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