Observation of Exclusive $\gamma\gamma$ Production in CDF

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Ph.D. thesis of Erik Brucken (U. Helsinki)

$$p + \bar{p} \rightarrow p + \gamma\gamma + \bar{p}$$

3 Classes of Hadron-Hadron Collisions:

>> Elastic Scattering : no particles produced
>> Inelastic : multi- hadron production
>> Inelastic, with no hadrons produced

ALMOST ELASTIC

Observation of Exclusive $\gamma\gamma$ Production in CDF

Introduction

$$p + \bar{p} \to p + X + \bar{p}$$ X = e^+e^-, $\mu^+\mu^-$, J/ψ, ψ(2S), χ_c, $\gamma\gamma$

CDF Detectors, Triggers & Data

Selection of Exclusive Events:

$$p + \bar{p} \to p + \{2EM\ showers\} + \bar{p}$$

e+e-, $\gamma\gamma$, or $\pi^0\pi^0$ background ?, Cross sections

Summary & Conclusions

Implications for Exclusive Higgs at LHC

Executive Summary

In CDF we have observed (>> 5 σ) the new clean process:

$$p + \bar{p} \rightarrow p + \gamma\gamma + \bar{p}$$

Photons central, E_T > 2.5 GeV

The cross section is about 2.5 pb, i.e. 1 per 25 billion inelastic collisions

Needed:

A good level 1 trigger (EM showers + Forward gap-seeds)

Extended rapidity coverage of CDF to $\eta = \pm 7.4$

Understand noise levels in all calorimeters and counters.

Demonstrate we understand "empty events" (non-interaction in 0-bias)

Use $p + \bar{p} \rightarrow p + e^{+}e^{-} + \bar{p}$ via γγ (QED) as a control (σ known)

Show that EM showers are from γ and not π^0

High Energy Hadron-Hadron Collisions

TWO DISTINCT CLASSES:

Elastic

σ(elastic) ~ 20 mb

Inelastic, multi-hadron production

σ(inelastic) ~ 60 mb (at Tevatron)

NOT DISTINCT CLASSES:

Diffractive

Non-diffractive

A "NEW" 3rd DISTINCT CLASS:

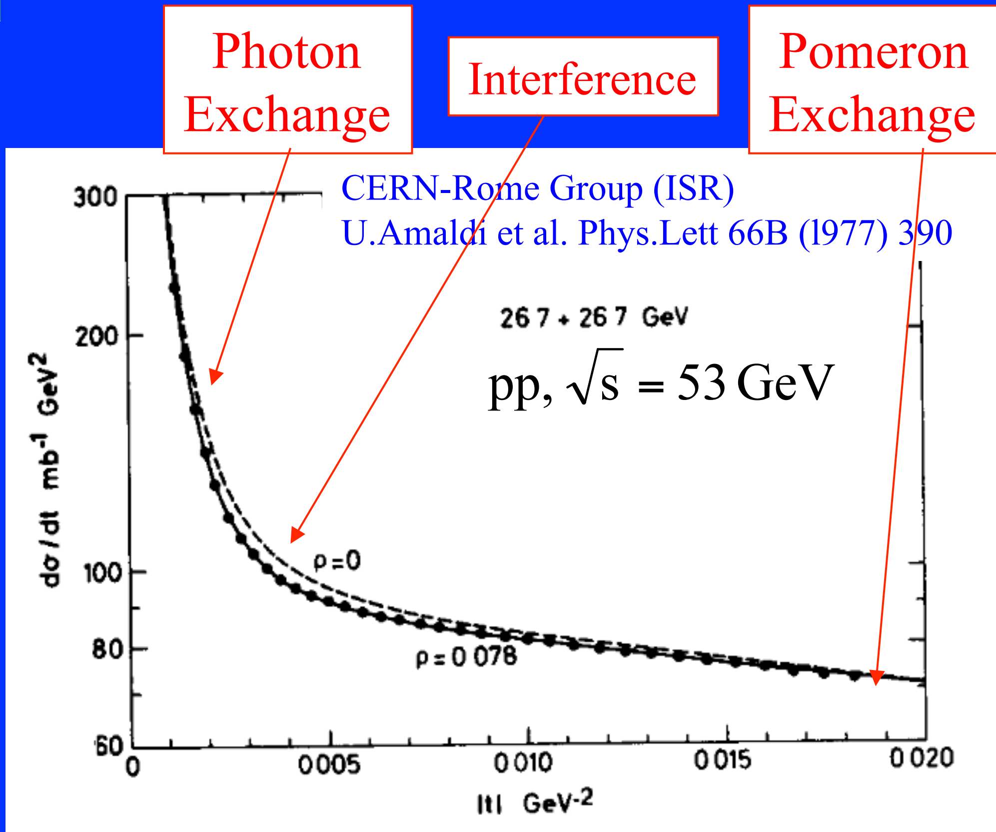
Almost elastic (99%), no hadrons produced:

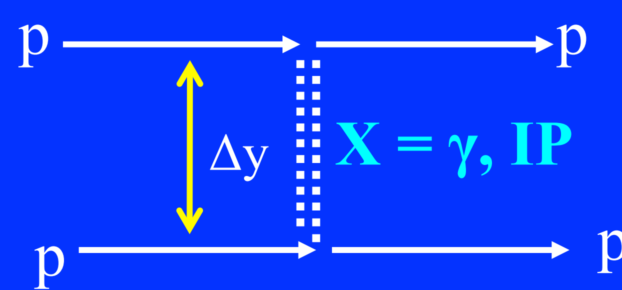
e+e- μ+μ- γ+γ & at LHC: W+W- H

Observed in CDF, σ ~ pb

Observable at LHC, σ ~ 10's fb

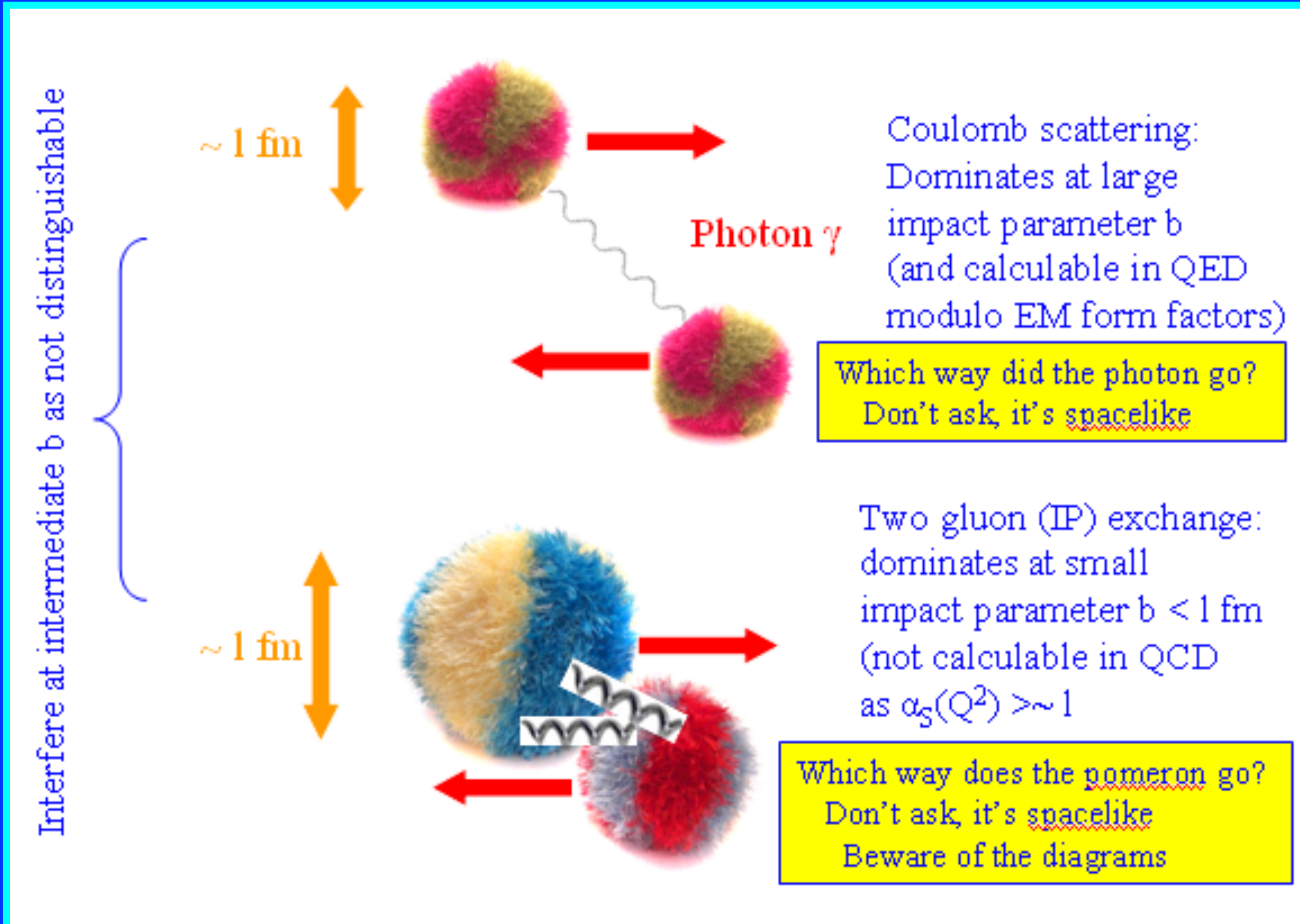
Elastic pp scattering at very small angles == large distances





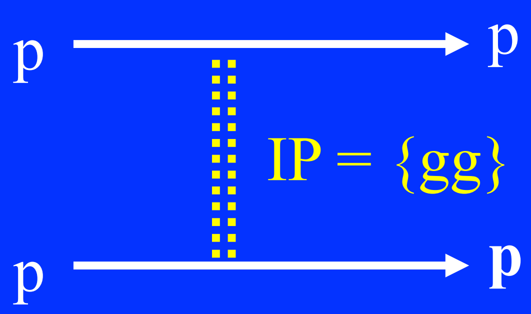
The only allowed t-channel exchanges have Q = 0, Color = 0
and at high energy (Large Δy) spin J >= 1.
Photon dominates at small |t| ~ p_T^2
Strong Interaction: 2-gluons is simplest. Called the **pomeron** IP
Effective spin α(t=0) > 1 … that's why total cross section σ_{TOT} rises.

Elastic Scattering by Electromagnetic and Strong Interactions



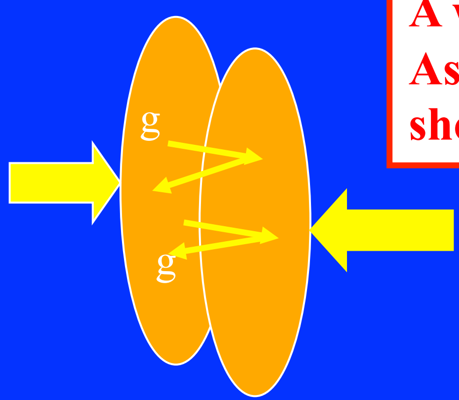
Elastic Scattering by strong interaction

MISLEADING PICTURE



Unlike the QED case, do not imagine this as the emission from one proton of a color singlet {gg} state (glueball) propagating freely like a hadron.

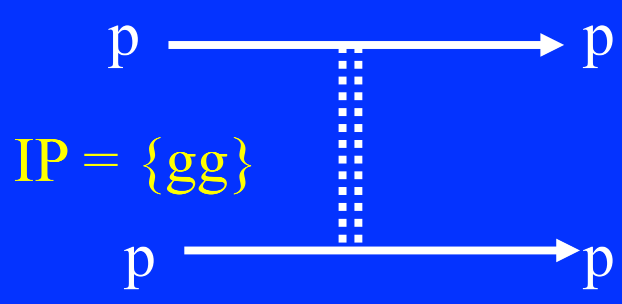
ANOTHER (BETTER) VISUALIZATION:

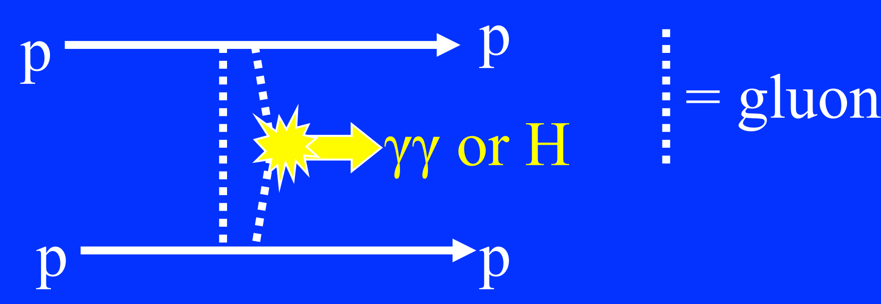


A wee x_{Bj} gluon is turned around.
As the p separate … color field …
shorted out by a 2nd exchange

Or: a pair of gluons annihilate (→ H e.g.).
As the p separate … color field …
shorted out by a 2nd exchange (rarely)

From elastic scattering to exclusive $\gamma\gamma$ or H production





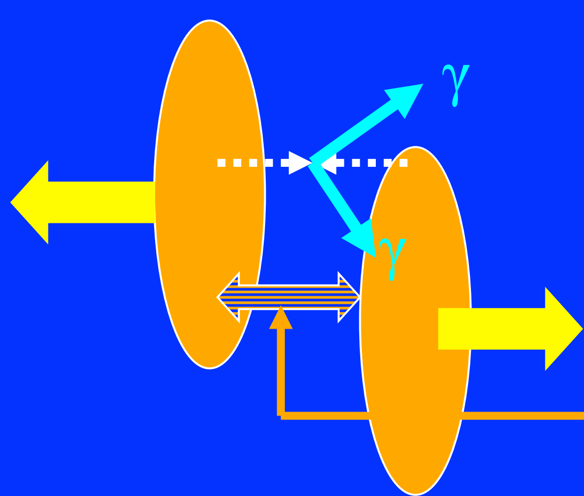
About 25% of σ_{TOT}

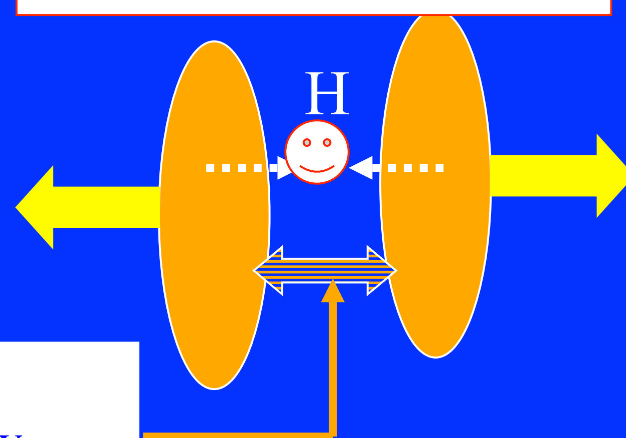
About $10^{-11} - 10^{-13}$ of σ_{TOT}

These are related processes!

$$p + \bar{p} \rightarrow p + \gamma\gamma + \bar{p}$$

$$p + \bar{p} \rightarrow p + H + \bar{p}$$



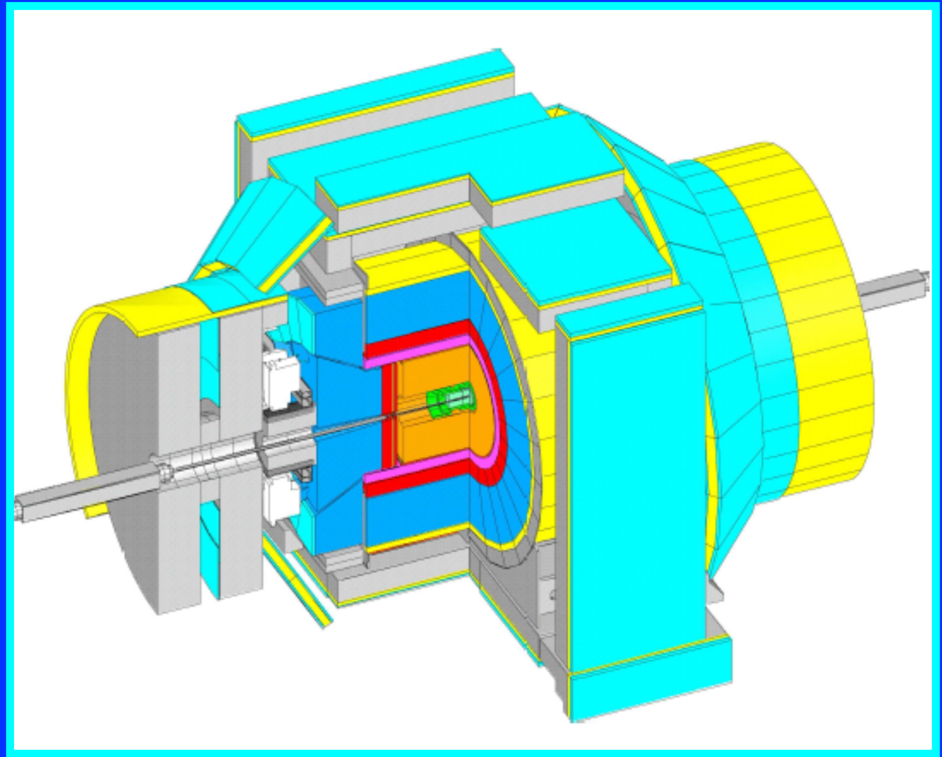


Color field;
shorted out by
another g exchange

CDF: The Collider Detector at Fermilab

CENTRAL:

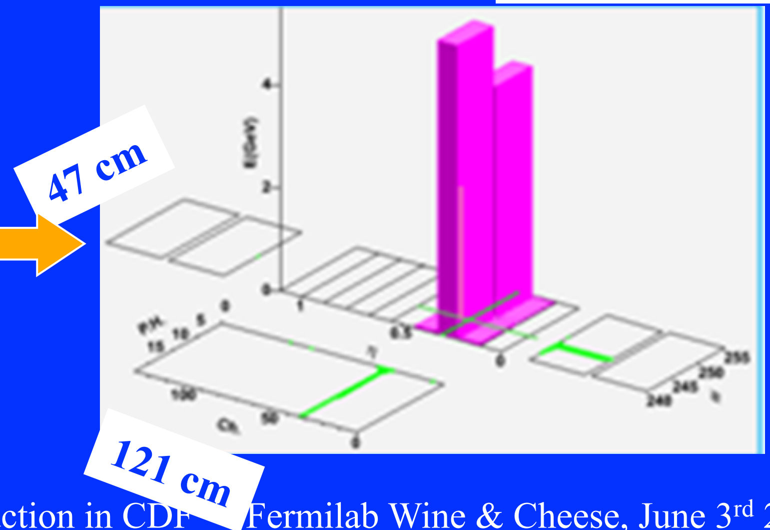
Silicon tracker ↙ **COT**
Drift chamber tracker
Time-of-Flight barrel
EM calorimeters w/
CES shower max PC
Hadron Calorimeters
Muon chambers



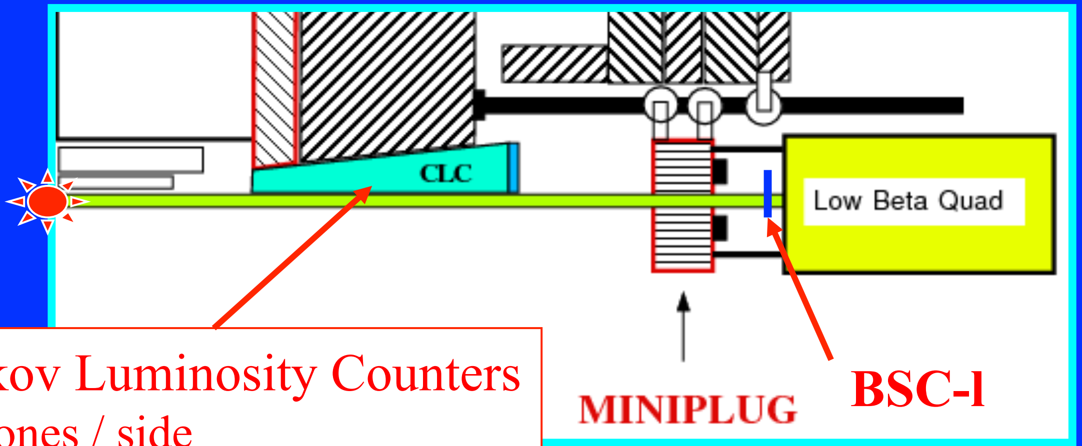
FORWARD
NEXT slides
(Important)

CES shower maximum
proportional chambers
at 6 X_0
1.5 cm anode wires in φ
1.7 – 2.0 cm strips in η
92% active over $|\eta| < 1.1$

10 GeV electron



Forward Detectors in CDF I: Cherenkov Luminosity Counters



55 m

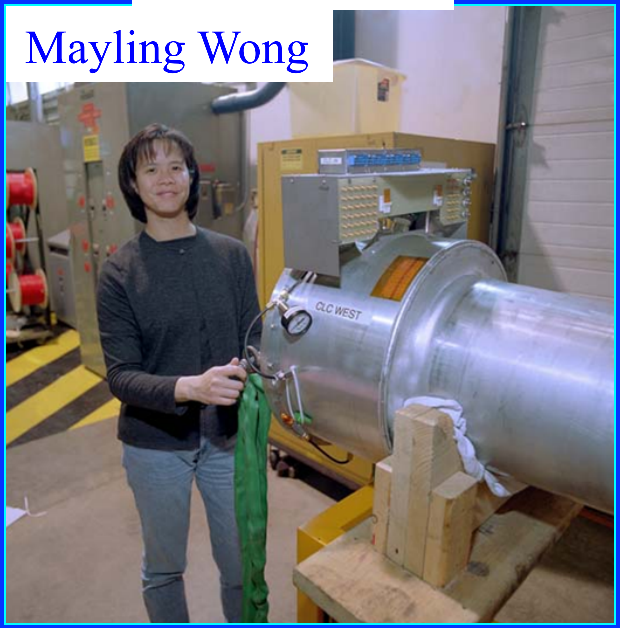
BSC-2, -3

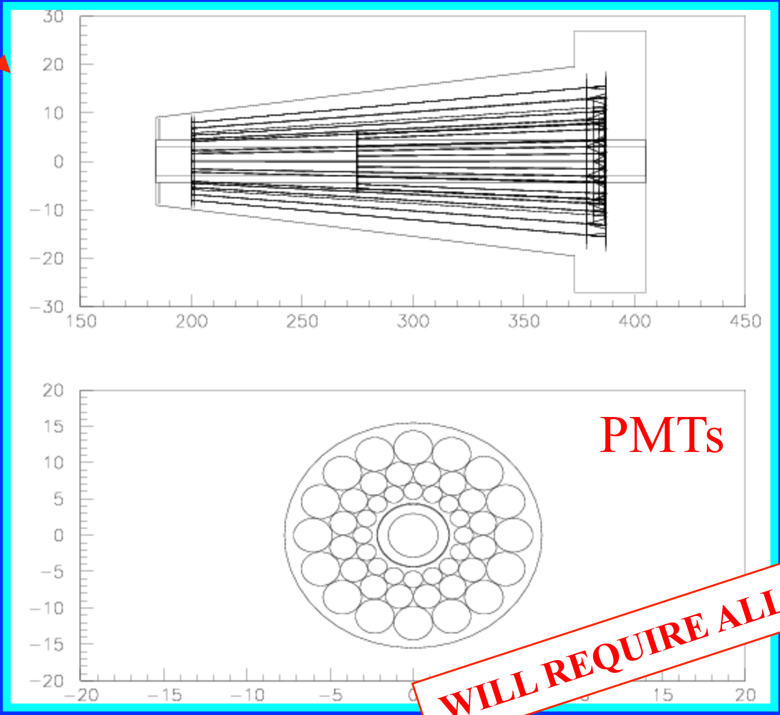
CLC = Cherenkov Luminosity Counters
48 PMT + Gas cones / side

$3.7 < |\eta| < 4.7$

Univ. Florida

Mayling Wong





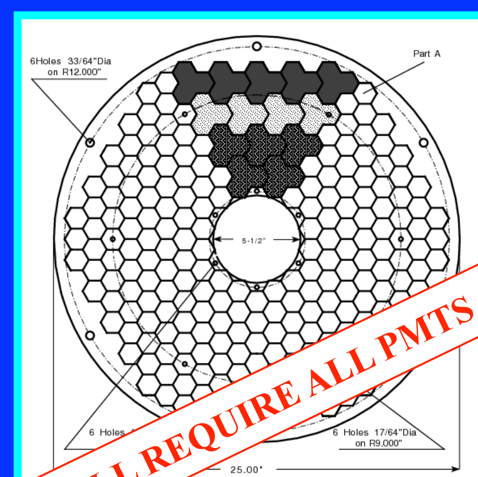
WILL REQUIRE ALL PMTS < NOISE CUT

Very Forward Detectors in CDF   II : MiniPlugs

Rockefeller Univ.

MiniPlug Calorimeters: $3.6 < |\eta| < 5.1$

Lead + Liquid Scintillator + WLS Fibers



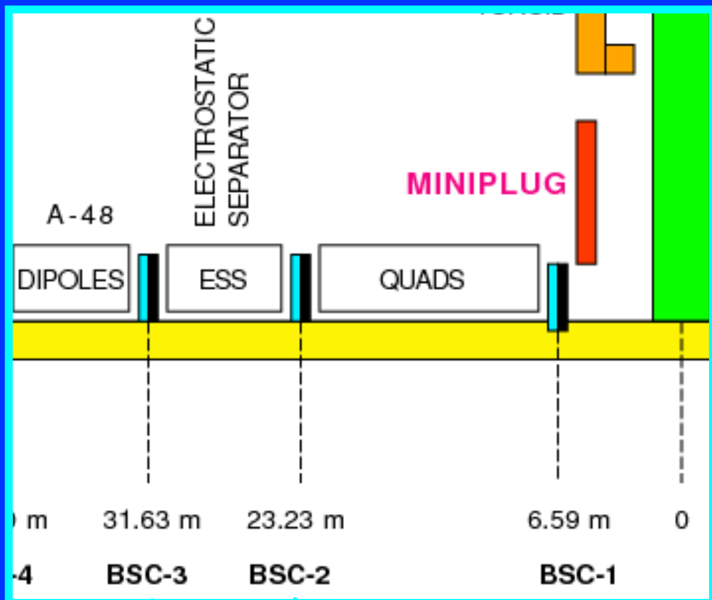
WILL REQUIRE ALL PMTS < NOISE CUT

Very Forward Detectors in CDF   III: BSC

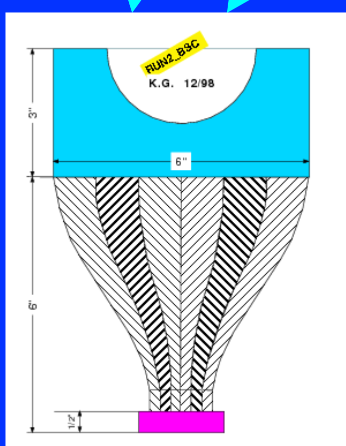
Beam Shower Counters (BSC)

$5.5 < |\eta| < 7.4$ (Scintillators + PMT)

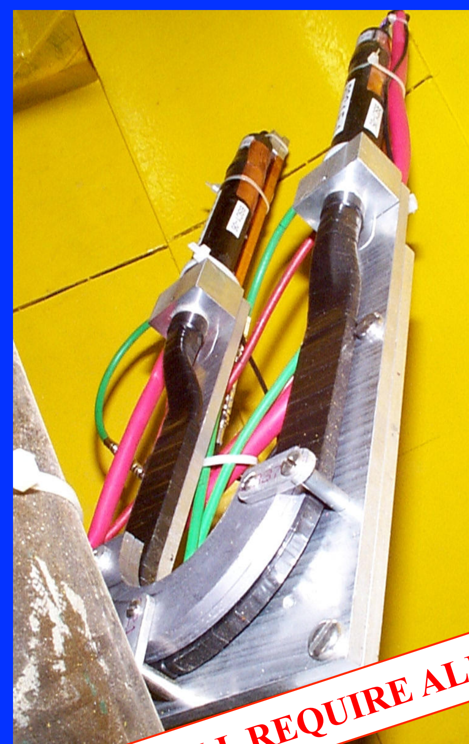
Rockefeller Univ.



BSC-1 (4 PMTs)



2 PMTs / station



WILL REQUIRE ALL PMTS < NOISE CUT

Central Exclusive Production, examples:

p + p → p + X + p

where + = true rapidity gap, **no hadrons**
and X = "simple" system fully measured.

→ *γ or IP exchange*

States observed in CDF for first time in hadron-hadron collisions:

Quantum Number restrictions	$\gamma + \gamma$	$e^{+}e^{-}, \mu^{+}\mu^{-}$
	$\gamma + IP$	$J/\psi, \psi(2S)$
	$IP + IP$	$f_0(600)/\sigma, f_0(980), \ldots \chi_c, JJ, +\gamma\gamma$

Observed at CERN ISR

NEW

Central Exclusive Production Diagrams

Also in e+e- and e+p | **Also in e+p** | **Only in hadron-hadron**

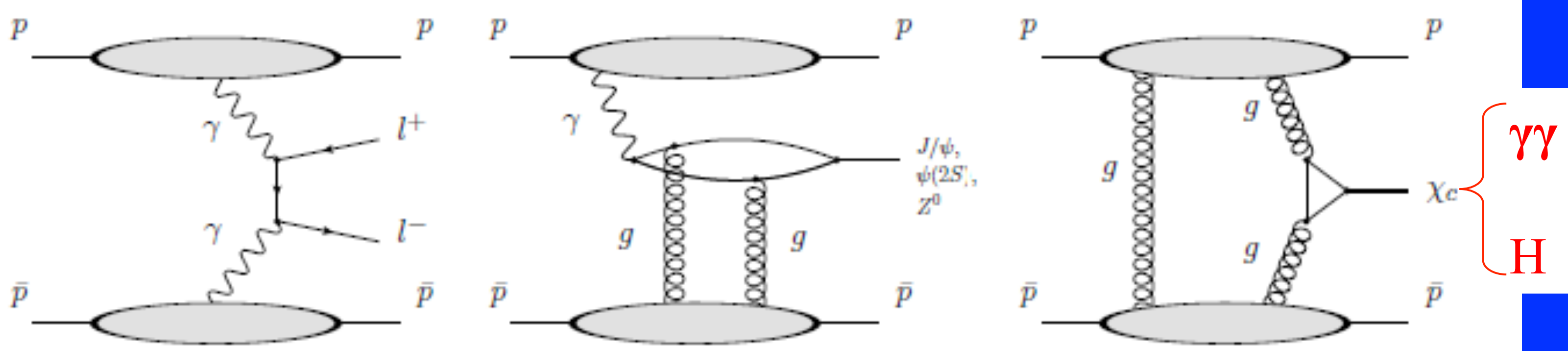


Figure 10: Feynman diagrams for processes contributing to the exclusive di-lepton signal. (a) $\gamma\gamma \to l^+l^-$, (b) $\gamma I\!P \to J/\psi, \psi(2S), Z^0$, and (c) $I\!P I\!P \to \chi_{c0}$.

LPAIR MC:
J.A.M.Vermaseren, Nucl.Phys.B229 (1983) 347

Photoproduction

SuperCHIC MC:
L.Harland-Lang et al, arXiv:1005.0695 [hep-ph]

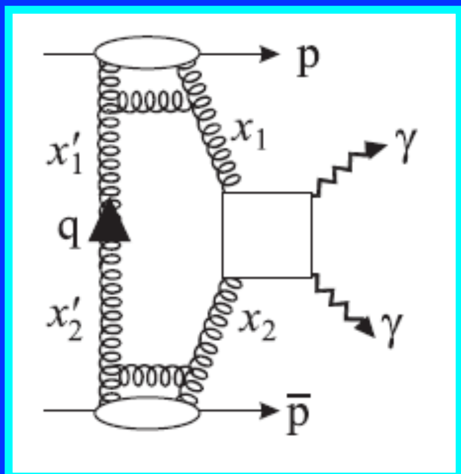
>>> Not essential to detect protons; can require all forward detectors to be at noise levels, for $|\eta| < \sim 7.4$

>>> Quasi-elastic protons inferred.

>>> No pile-up interactions allowed.

Theoretical prediction for exclusive γγ

Khoze, Martin, Ryskin & Stirling
Eur.Phys. J.C38 (2005) p.475

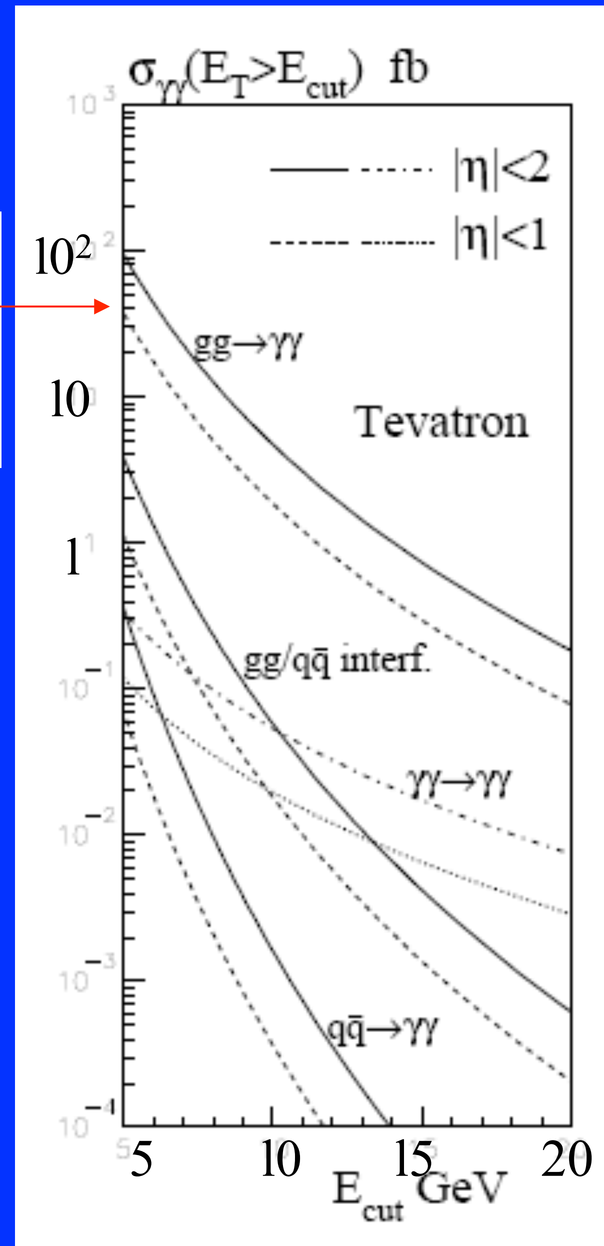


$E_T(\gamma)_{min} = 5$ GeV

$|\eta(\gamma)| < 1$

$\sim 38\,^{\times 3}_{\div 3}$ fb @ 1.96 TeV

Factor 3 claimed



Ingredients:

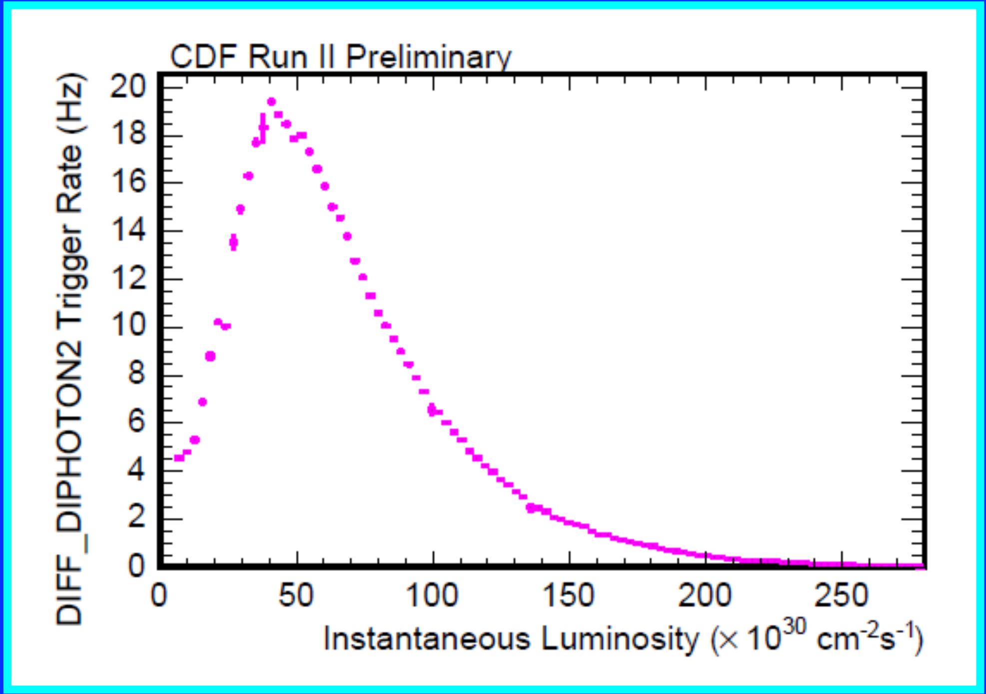
σ(g + g → γ + γ)
Unintegrated g(x,x') $\sigma \sim g^4$
Loop integral
No gluon/hadron radiation
No other parton-parton interaction
(Gap survival factor)

Later extend down to 2 GeV: L.Harland-Lang et al.

Trigger and Data Taking

Level 1 trigger : [1 EM Tower C&P > 2 GeV] * [BSC-1 (E & W) veto]
No prescale needed: Veto kills pile-up and most single interactions
Level 2+3 : 2 EM Towers > 2, Clean up, e.g. Ratio (HAD/EM) < 0.125

One year 2006-2007, Integrated luminosity 1.11 +/- 0.7 /fb
Trigger rate peaks when $\bar{n}e^{-\bar{n}}$ is maximum, L = 40 x $10^{30}cm^{-2}s^{-1}$

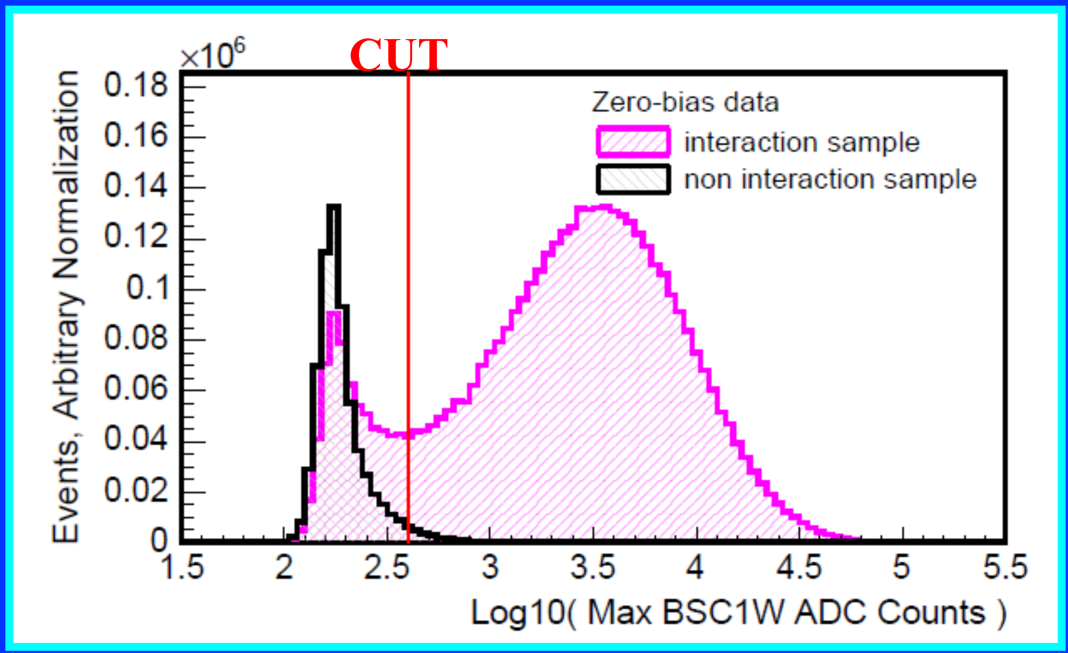


"Exclusive efficiency" = Prob. event not killed by P-U, calculated bunch x bunch.

Selection of Exclusive Events

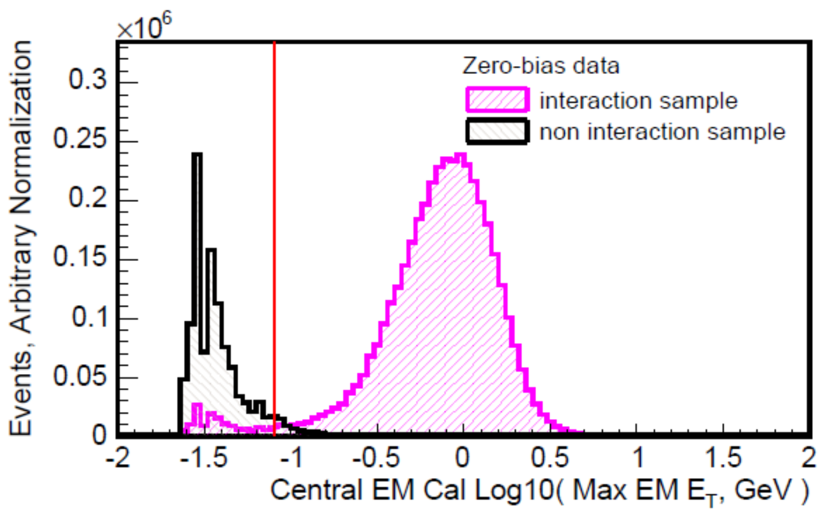
Require no other particles detected in entire CDF, including forward to $|\eta| = 7.4$
p & pbar are not detectable: stay in beam pipe.
Study noise levels: ZERO-BIAS (bunch crossing) trigger (crucial).
Make 2 classes: No COT tracks, no CLC hits, no muon stubs : **NON-INTERACTION**
All other events : **INTERACTION** (or several interactions)
For each sub-detector, plot "hottest" PMT signal or E_T signal (Log_{10} scale handy)
Choose cut separating noise from signals.

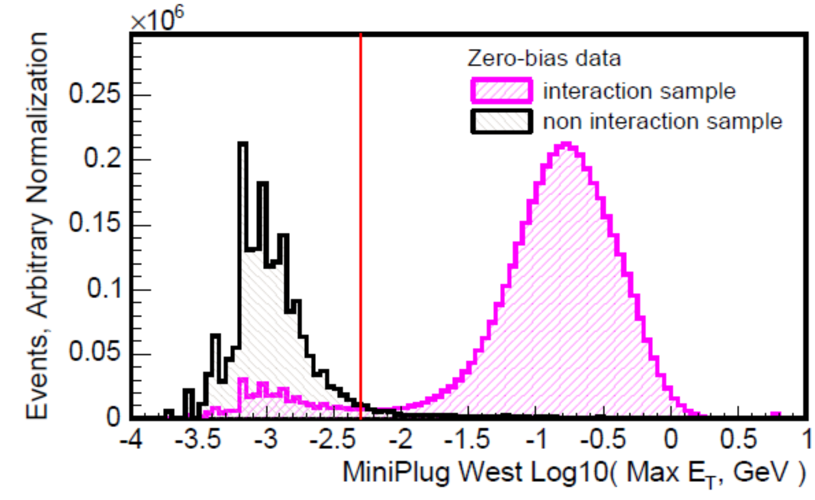
EXAMPLE:



INTERACTION events below cut : interactions having no particles in BSC-1

Two more examples of noise studies and exclusive cuts:





Exclusive Filter Cuts

Detector Part	max. Signal	$\|\eta\|$ coverage
Central EM Calorimeter (E_T):	80 MeV	0 - 0.66
Central HAD Calorimeter (E_T):	200 MeV	0 - 0.66
End Wall EM Calorimeter (E_T):	80 MeV	0.66 - 1.32
End Wall HAD Calorimeter (E_T):	200 MeV	0.66 - 1.32
Mid Plug Calorimeter (E_T):	80 MeV	1.32 - 2.11
Forward Plug Calorimeter (E_T):	30 MeV	2.11 - 3.64
Mini Plug Calorimeter (E_T):	5 MeV	3.6 - 5.2
BSC-1 (ADC):	400 counts	5.4 - 5.9
BSC-2 (ADC):	300 counts	6.4 - 7.1
BSC-3 (ADC):	400 counts	6.7 - 7.4
CLC (Sum of West and East) (ADC):	6300	3.7 - 4.7

Apart from 2 EM towers, events pass all exclusive cuts

Exclusive Efficiency, and Empty Detector

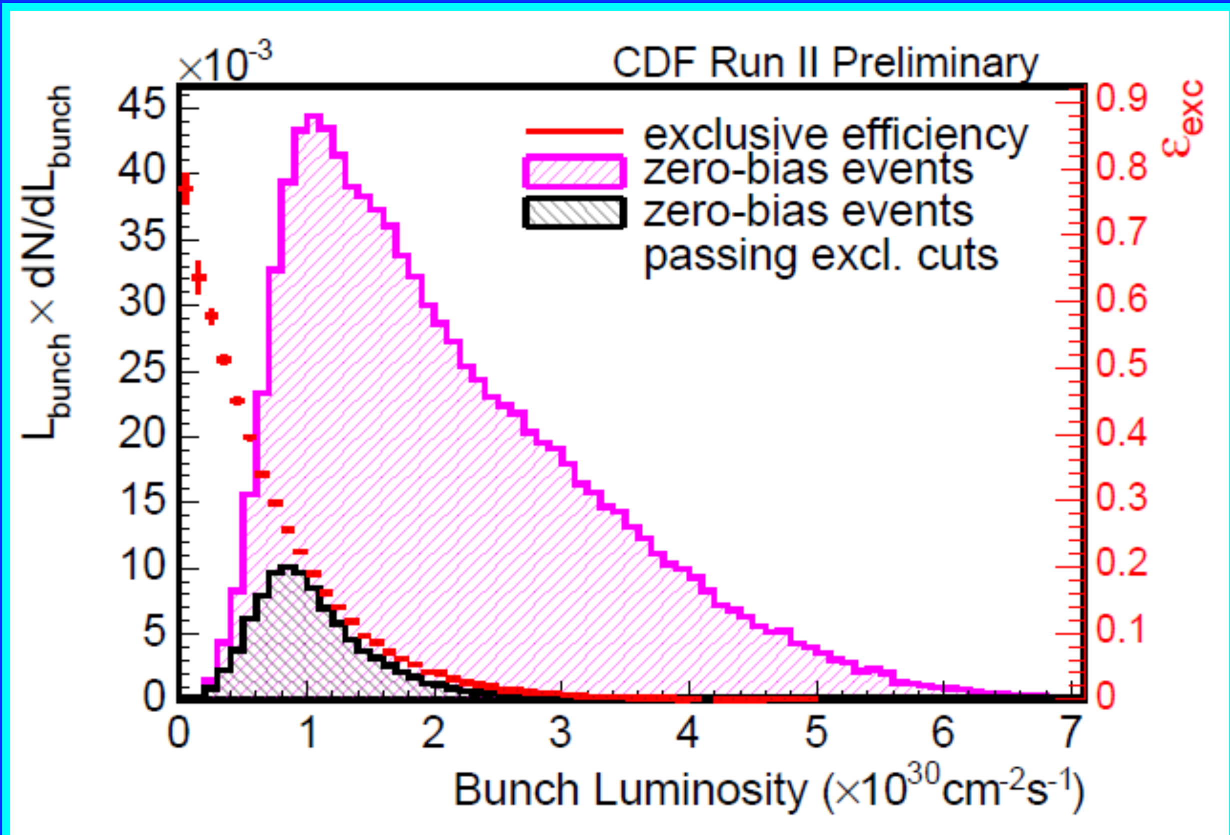
Exclusive efficiency ε_{excl} :

Prob. good event not spoiled by another inelastic interaction (Pile-Up)

Apply all noise cuts to **ZERO-BIAS** events (no EM towers).

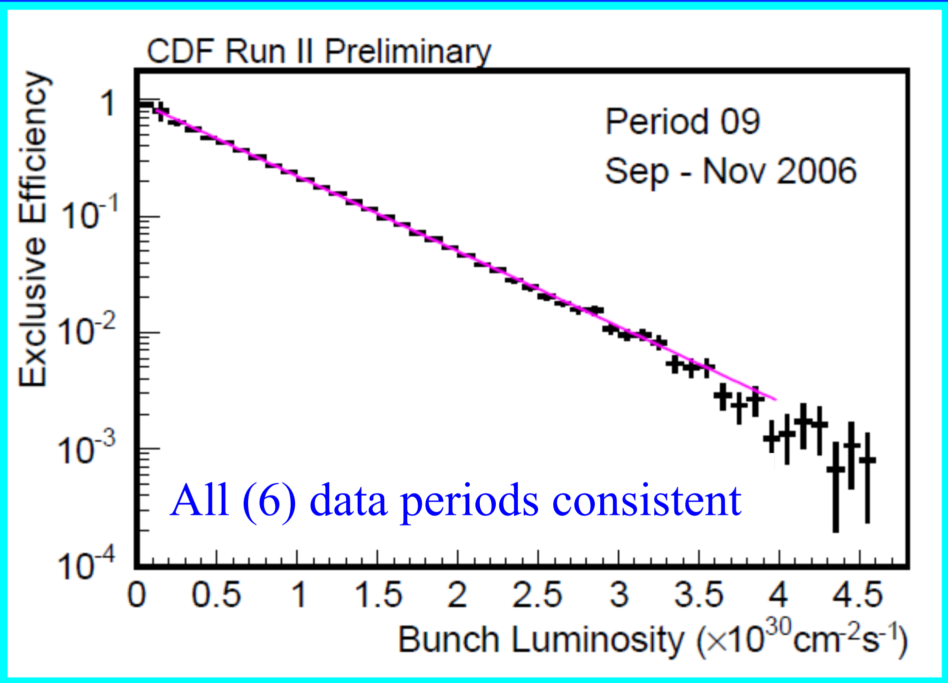
Measure P(0) = Prob(empty) vs Bunch luminosity (B x B)

[Not all the 36 bunch crossings have same Luminosity]



Red points:
Right scale
Ratio black:**pink**
(exponential)

Probability all CDF empty vs bunch luminosity = exclusive efficiency



$$P(0) = \bar{n}.e^{-\bar{n}}$$

$$\bar{n} = \left(\frac{L_{bunch}}{46{,}500}\right) \times \sigma_{inel}$$

$$46{,}500 = \text{orbits / sec}$$

$$\Rightarrow \sigma_{\text{inel}}$$

Intercept should be 1.0
→at L = 0 all should pass
unless noise kills event

Total L = 1114 pb^{-1} Intercept = 0.98±0.02,
Slope = 67±4 mb
ε_{excl} = 0.068±0.004 ; Leff = 75.8 pb^{-1}

$$CDF : \sigma_{TOT} = 80.0 \pm 2.2 \text{ mb at } \sqrt{s} = 1800 \text{ GeV}$$

$$\sigma_{\text{ELASTIC}} = 19.7 \pm 0.9 \text{ mb}$$

$$\Rightarrow \sigma_{INEL} = 60.3 \pm 2.4 \text{ mb at} \sqrt{s} = 1800 \text{ GeV}$$

$$\text{We are at } \sqrt{s} = 1960 \text{ GeV}$$

"Cross section" agreement:
Not missing inelastic interactions

Confidence that exclusive efficiency method and normalization are good

Numbers of events, after sequential cuts:

Number of events after exclusive cuts

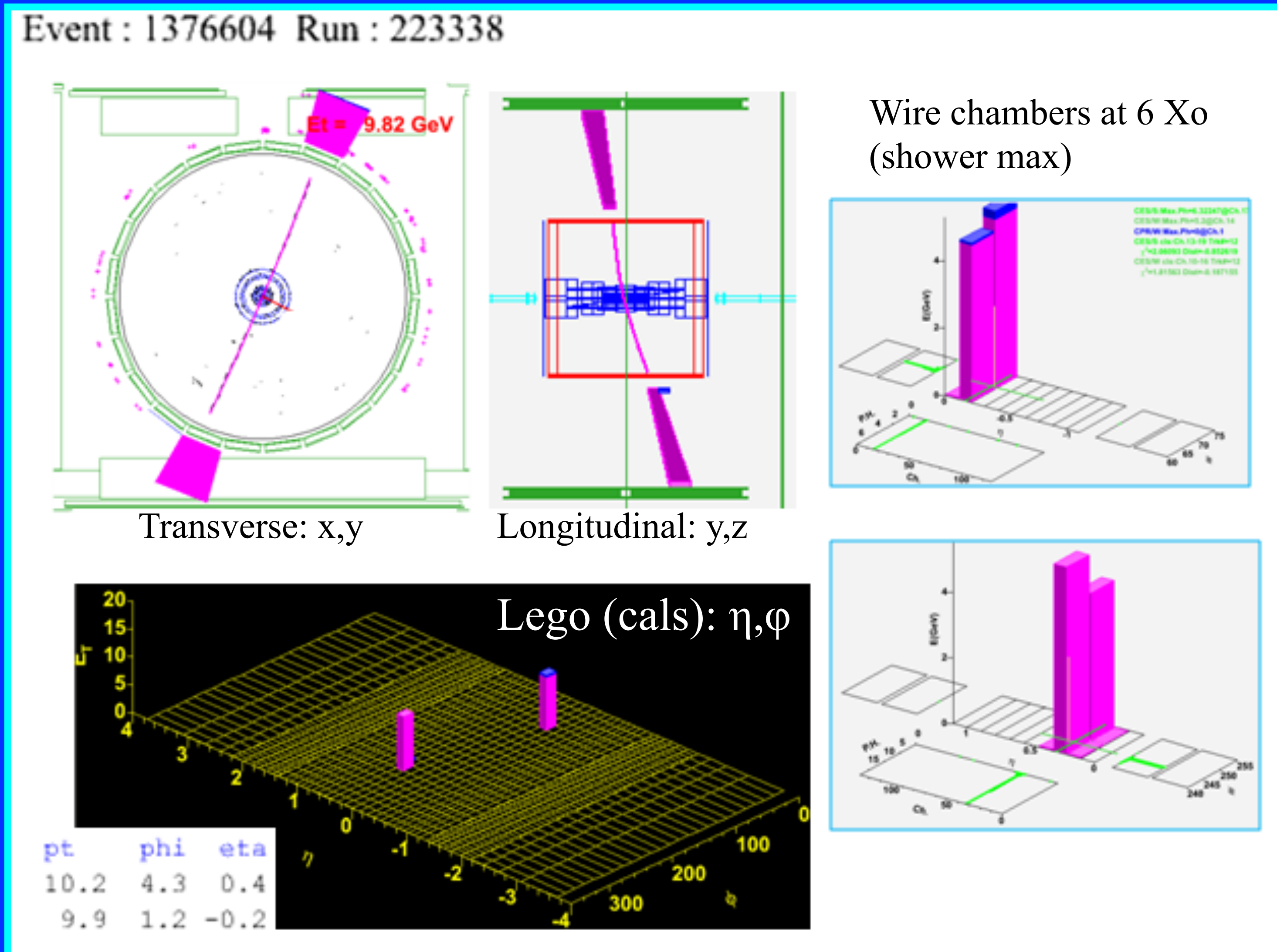
Trigger:	200,143,239
Presel: (2EMO > 2 GeV, $\|\eta\| < 1.8$):	93,976,483
Empty BSC counters (all):	39,099,062
Empty Miniplug and CLC:	136,914
Empty Forward Plug Calorimeter:	13,974
Empty Mid Plug:	5,254
Empty Low Plug:	1,359
Empty Central Calorimeter:	421
2 EMO Central $\|\eta\| < 1.0$:	180
2 EMO Central $\|\eta\| < 1.0$ and $E_T > 2.5$ GeV	82

Up to now NO TRACK REQUIREMENTS:
Blind to COT Drift Chamber (& Silicon, Muons). Now look at COT tracker:

$$2 \text{ Opposite charge tracks } (e^+e^-) : 34$$

$$\text{No tracks at all } (\gamma\gamma, \text{ or } \pi^0\pi^0?) : \quad 43$$

Event display: the highest mass e^+e^- event: $M(e^+e^-) = 20\ GeV/c^2$

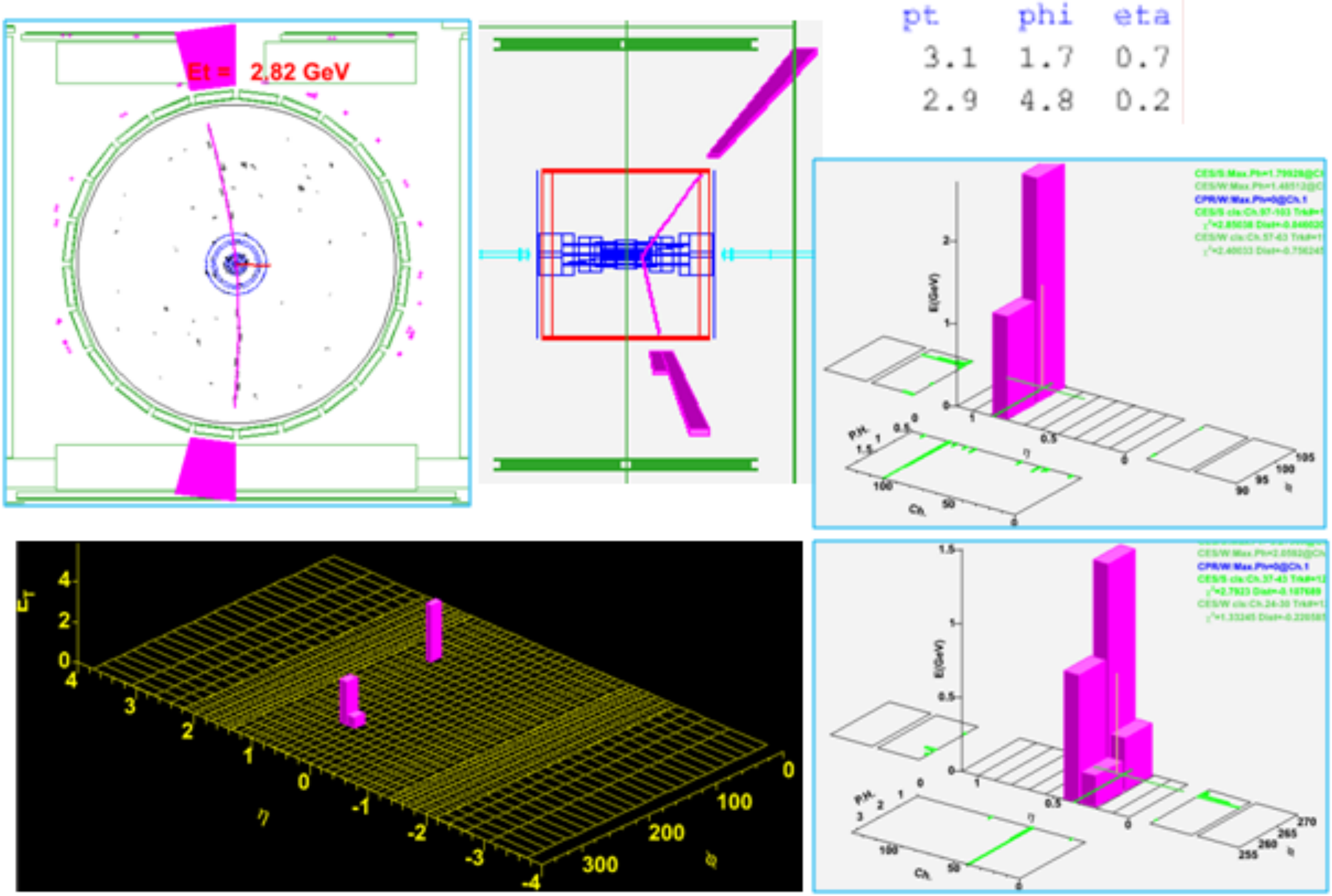


Tracking efficiency very high: hard to miss an isolated high p_T central track

Event display: a typical e^+e^- event: $M(e^+e^-) \sim 6$ GeV

Event : 6633770 Run : 243730

pt	phi	eta
3.1	1.7	0.7
2.9	4.8	0.2



Checks and Efficiencies: Summary

Rate of final events (per effective luminosity) independent of run period.
Trigger efficiency (~ 92%)
Efficiency of **HAD/EM** cut vs E(e) (~ 93%)
Efficiency of **track finding/fitting** independent of η, p_T (~ 96%) : Using J/ψ data +MC
Efficiency of event not being lost by **radiation** (CDFSIM, ~ 40%)

Reconstruction efficiency: Full Monte Carlo simulation including reconstruction of electrons or photons.
Values are low and more dependent on E_T and η (1 – 2)
because of bremstrahlung, conversions, δ-rays.
Decided to select **|η| < 1.0** to minimize such dependence.
Scanning events confirmed more ambiguities there: "e → γ" and "γ → e"

Reconstruction efficiency:

Electron pairs (LPAIR)

E_T cut (GeV)	2.5	5.0
$\varepsilon_{rec}^{e^+e^-}$	0.508	0.802
Stat Err	±0.007	±0.017
Syst Err	±0.016	±0.037

Photon pairs (SuperCHIC)

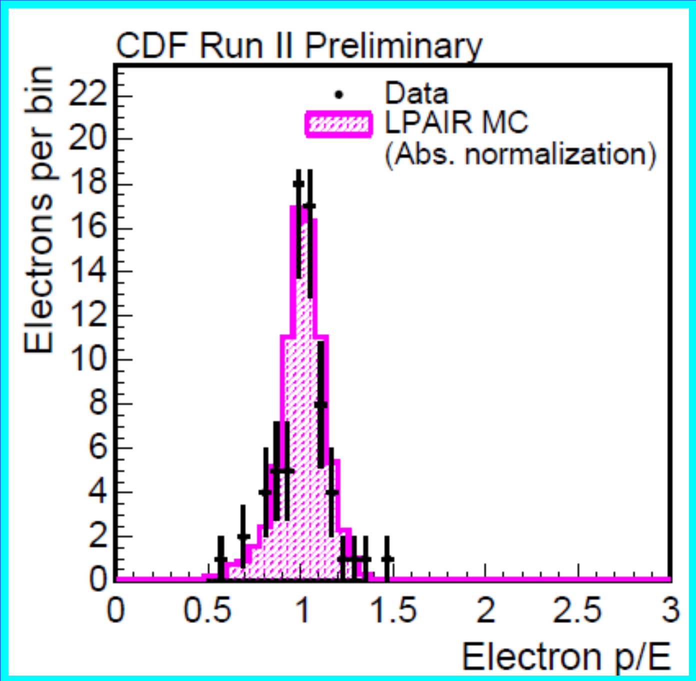
E_T cut (GeV)	2.5
$\varepsilon_{rec}^{\gamma\gamma}$	0.553
Stat Err	±0.005
Syst Err	±0.029

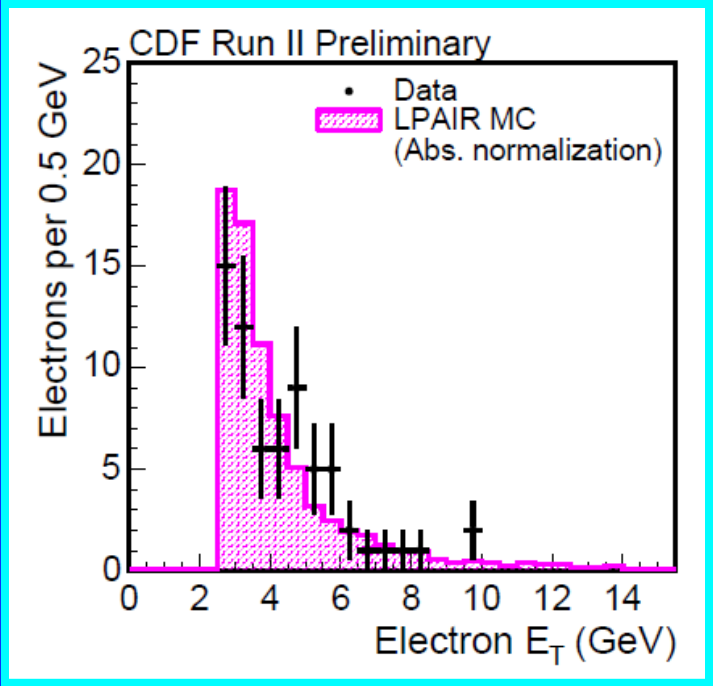
Properties of single tracks cf LPAIR e+e- simulation + CDFSIM

$E_T(e) > 2.5$ GeV
$\eta(e) < 1.0$
34 events,
>> 68 e's

$$\gamma + \gamma \rightarrow e^+ + e^-$$

Absolute normalization (to LPAIR/QED σ)

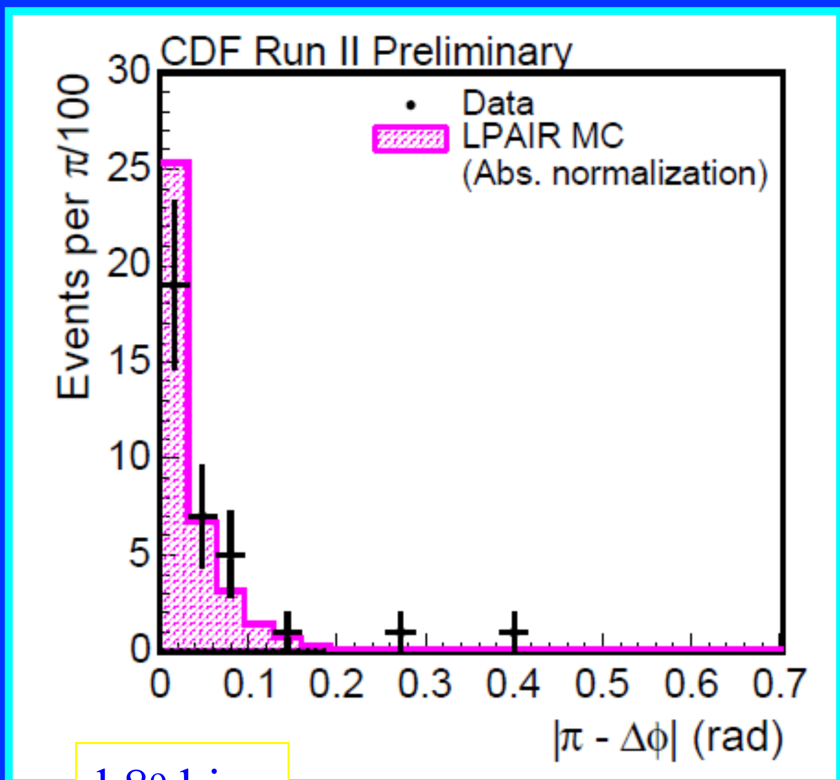




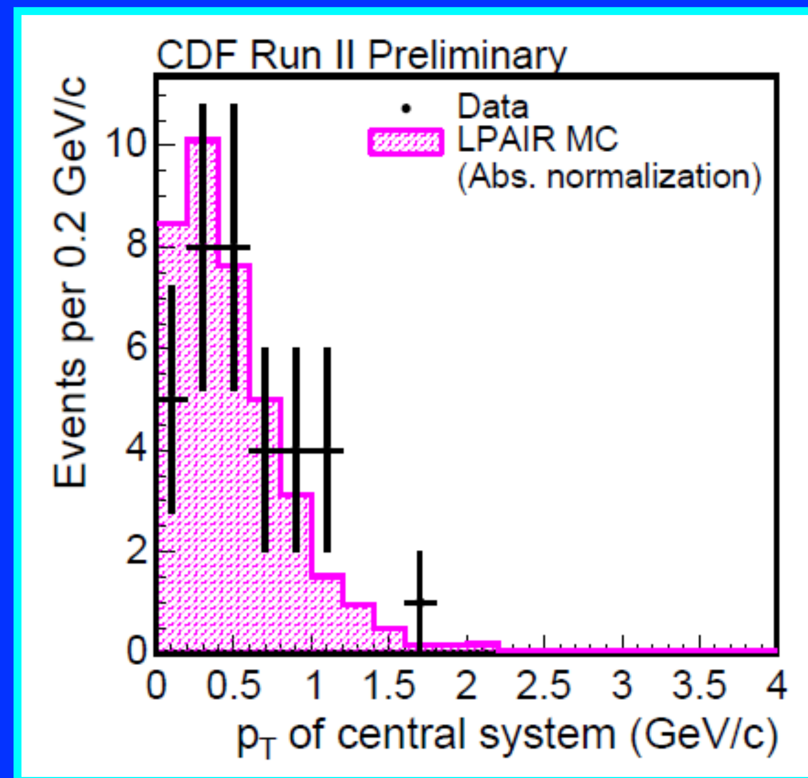
Distributions in η(e) and φ(e) … flat … also agree well with LPAIR + CDFSIM

Electron pair properties (34 events)

$$\gamma + \gamma \rightarrow e^{+} + e^{-}$$



1.8° bins

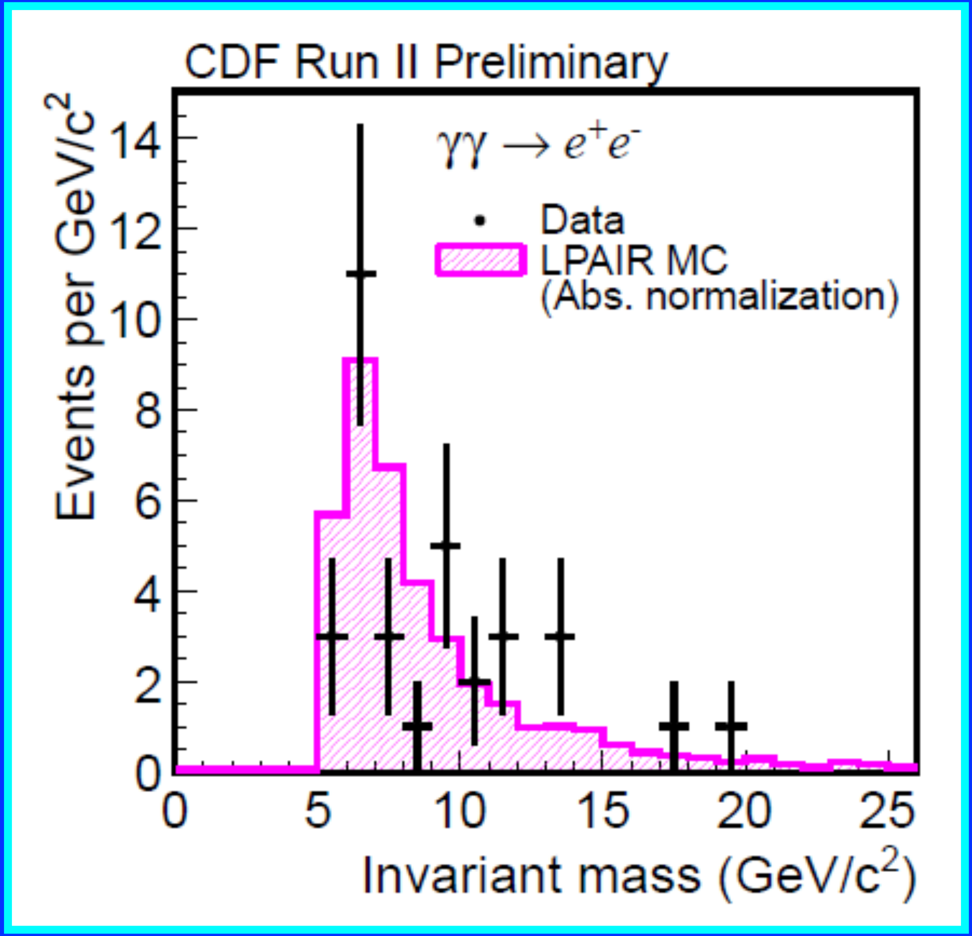


Photons … Coulomb.. <p_T> very small.

Detector resolution (and Final State Radiation) dominates spread.

Mass spectrum (e+e-)

$$\gamma + \gamma \rightarrow e^{+} + e^{-}$$



Final Results on $p + \bar{p} \rightarrow p + e^+e^- + \bar{p}$ via $\gamma + \gamma$ (QED)

Table: Statistics summary of all relevant parameters for the measurement of the exclusive e^+e^- for an E_T cut of 2.5 GeV and $|\eta| < 1.0$.

	Value	Stat. error	Syst. error
$\mathcal{L}_{int}$	1.11 fb^{-1}	$\pm 0.7 pb^{-1}$	
e^+e^- (events)	34		
Trigger efficiency	0.920	± 0.009	± 0.018
Reconstruction efficiency	0.508	± 0.007	± 0.016
Identification efficiency	0.912	± 0.017	± 0.013
Tracking efficiency	0.963	0.003	
Radiative acceptance	0.419	± 0.001	± 0.077
Exclusive efficiency	0.0680	negligible	0.004
Dissoc. B/G (events)	3.8	0.4	0.9

$$\sigma^{|\eta|<1, E_T>2.5GeV}_{e^+e^- excl.} = 2.88 \pm 0.59(stat) \pm 0.62(sys)\,pb$$

$$\sigma^{|\eta|<1, E_T>2.5GeV}_{LPair} = 3.25 \pm 0.07\,pb$$

AGREE

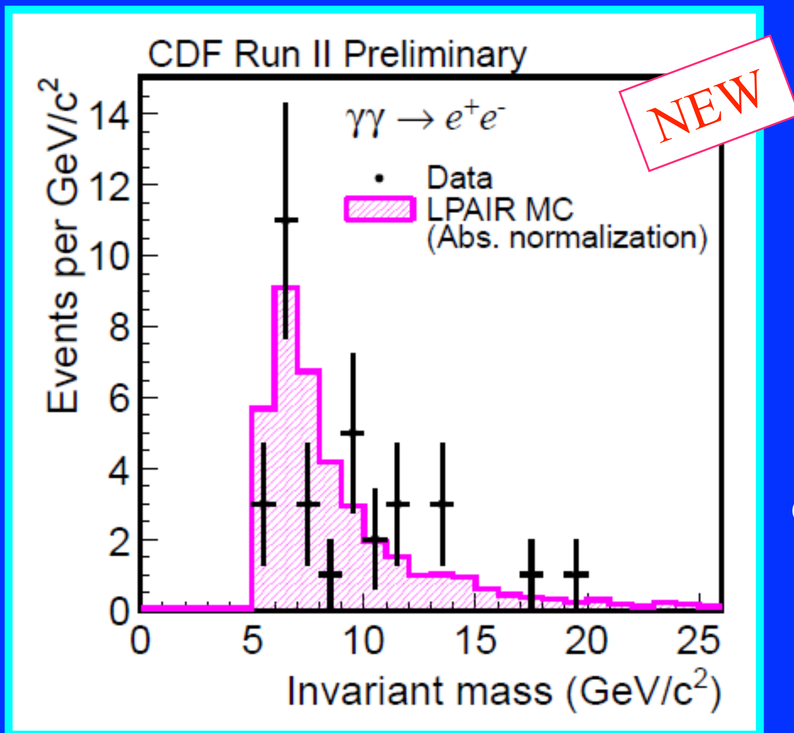
$$\sigma^{|\eta|<1, E_T>5.0GeV}_{e^+e^- excl.} = 0.60 \pm 0.28(stat) \pm 0.14(sys)\,pb$$

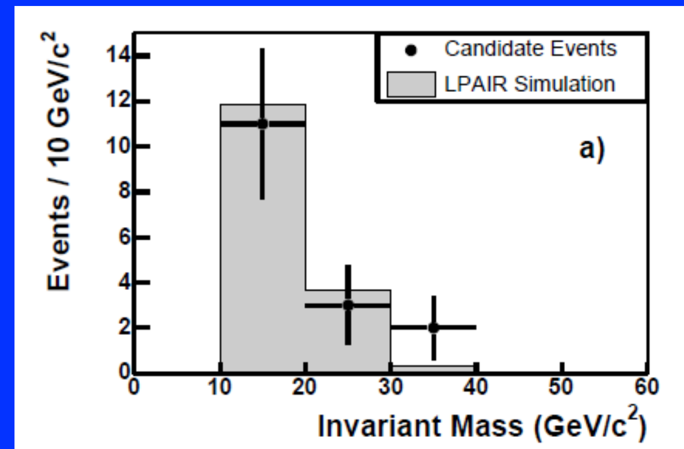
$$\sigma^{|\eta|<1, E_T>5.0GeV}_{LPair} = 0.58 \pm 0.003\,pb$$

AGREE

Confidence that exclusive efficiency method and normalization are good

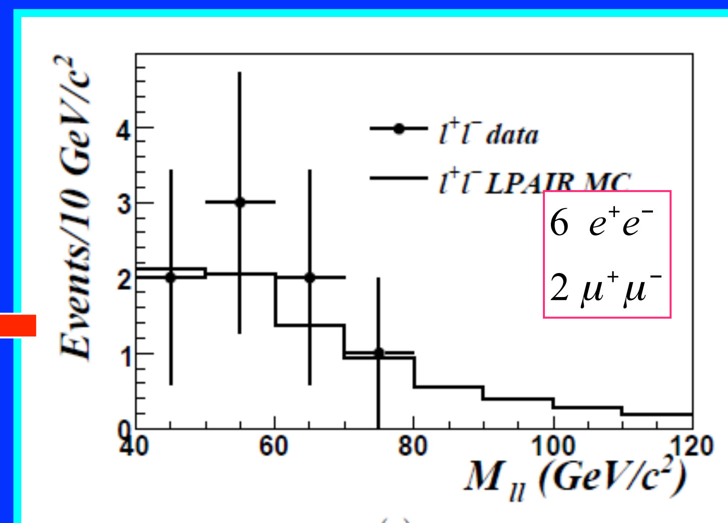
Mass spectra (e+e-): Other CDF results cf QED (LPAIR)





CDF Phys.Rev.Lett. 98 (2007) 112001 (lst observation.)

All pairs have 180º – Δφ < 1º



AGREEMENT With LPAIR

CDF: Phys.Rev.Lett. 102 (2009) 222002
(Search for exclusive Z photoproduction)

43 Events with no tracks in COT ($\gamma\gamma$ candidates: $\pi^0\pi^0$?)

How do we know if they are $\gamma\gamma$ or $\pi^0\pi^0$?

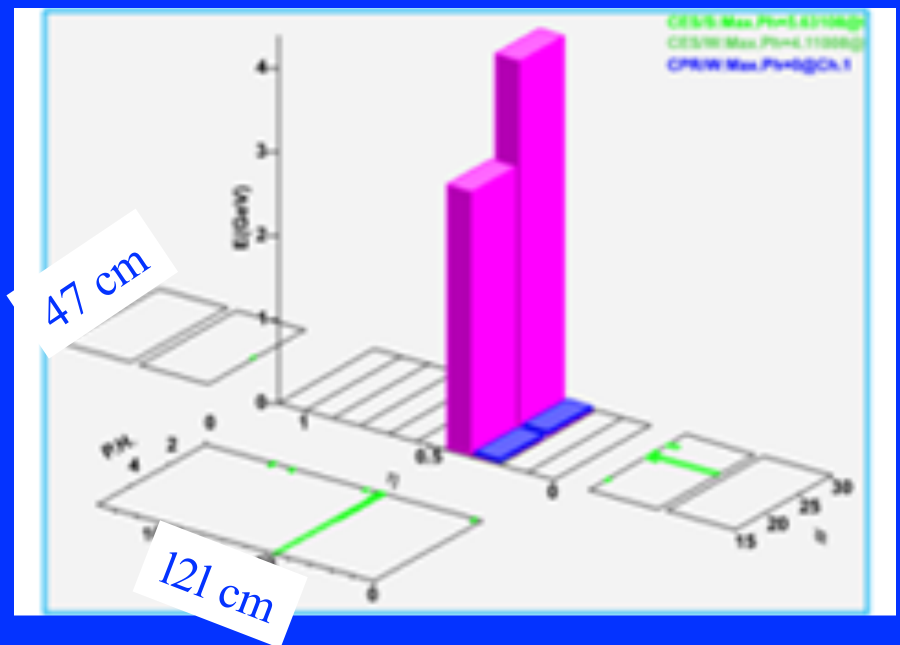
Note that exclusive **p + $\gamma\,\pi^0$ + p** is forbidden (e.g. parity P)

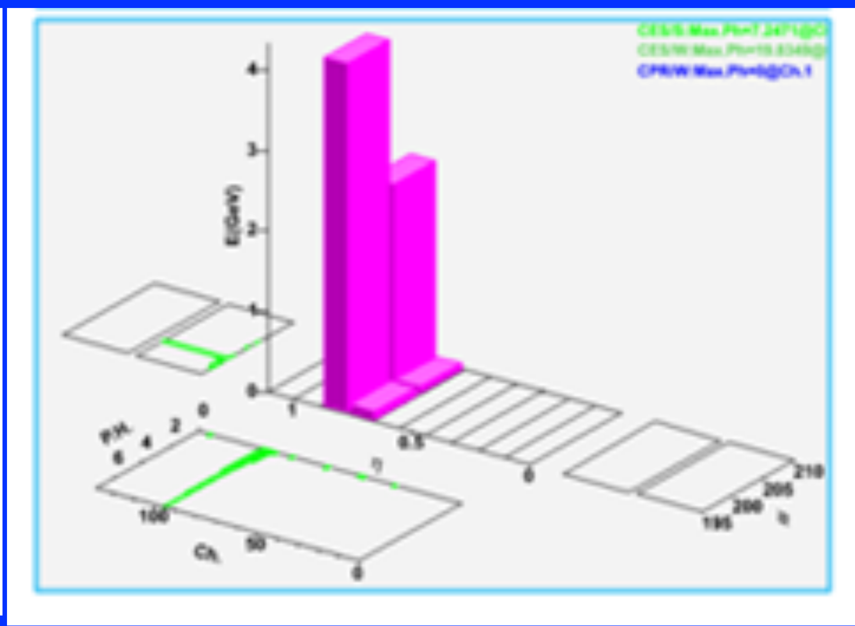
Count showers in CES strip chambers. **Wires 1.45 cm, strips ~ 1.8 cm**

Two photons cannot merge:

$$\theta(\gamma\gamma)_{min} = 2 \times \left(\frac{m_\pi}{p_\pi}\right) = 3.2^0 \text{ for } p_\pi = 5\ \text{GeV/c}$$

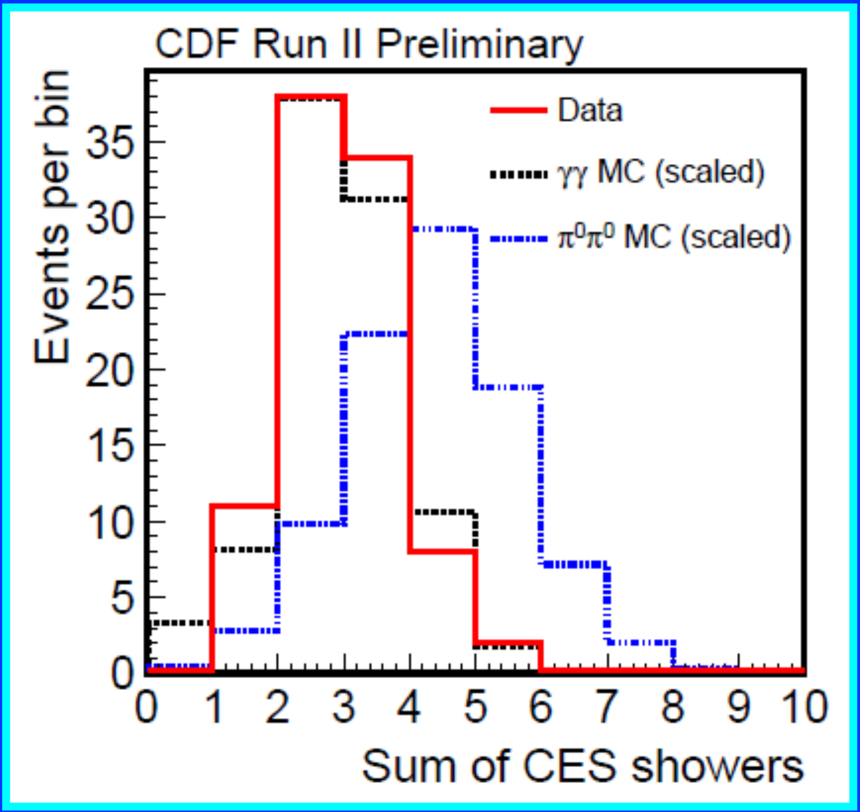
$$= 11.2 \text{ cm at } 2 \text{ m.}$$

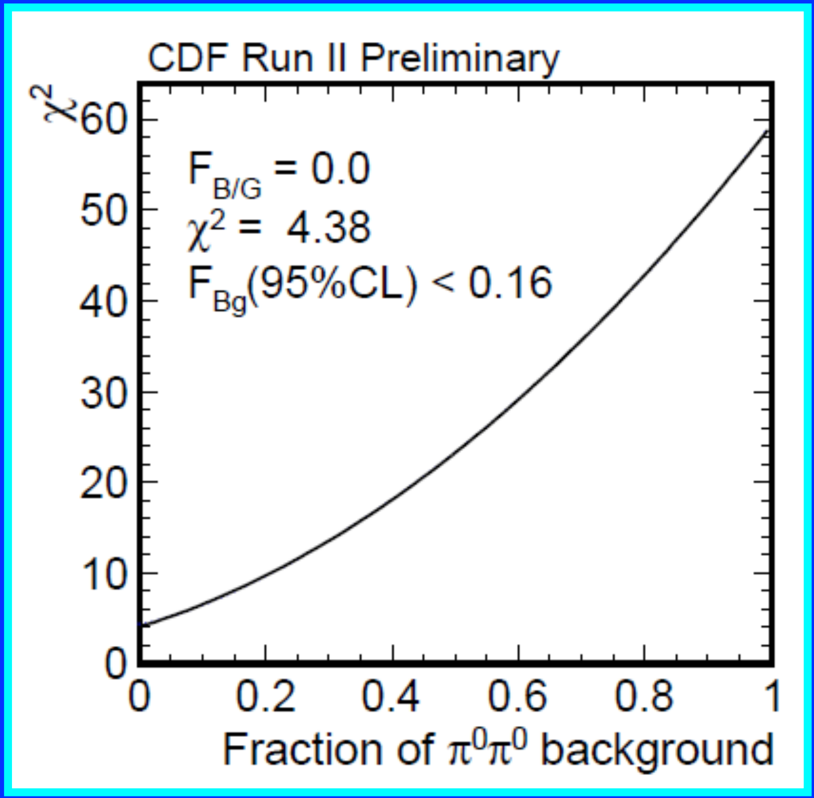




Are any events not $\gamma\gamma$ but $\pi^0\pi^0$?

Add # showers on both sides (there is no correlation)





Result: Best fit is with ZERO background from $\pi^0\pi^0 \rightarrow 4\gamma$

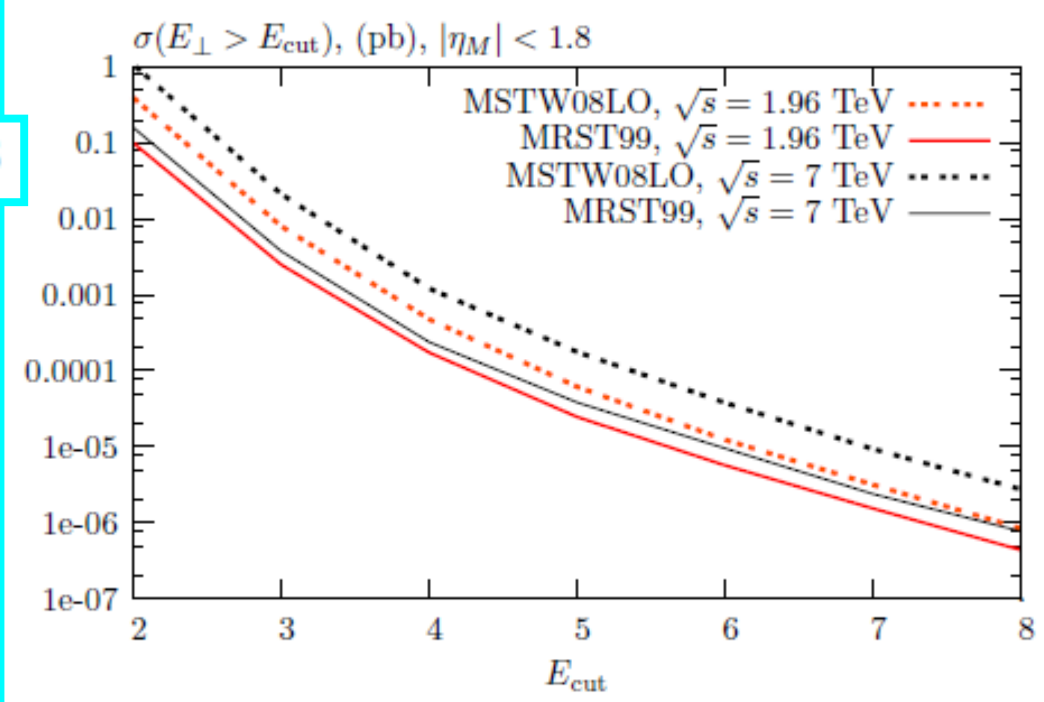
Pearson's χ^2 test: fraction of $\gamma\gamma$ events in sample < 16% (95% C.L.)

Theoretical Prediction of p + $\pi^0\pi^0$ + p (After our conclusion)

L.Harland-Lang, V.Khoze, M.Ryskin and W.J.Stirling, arXiv:1105.1626

$\sigma(p + \pi^0\pi^0 + p)$

$\sigma(E_\perp > E_{\rm cut})$, (pb), $|\eta_M| < 1.8$



$$\sqrt{s} = 1960\ GeV$$

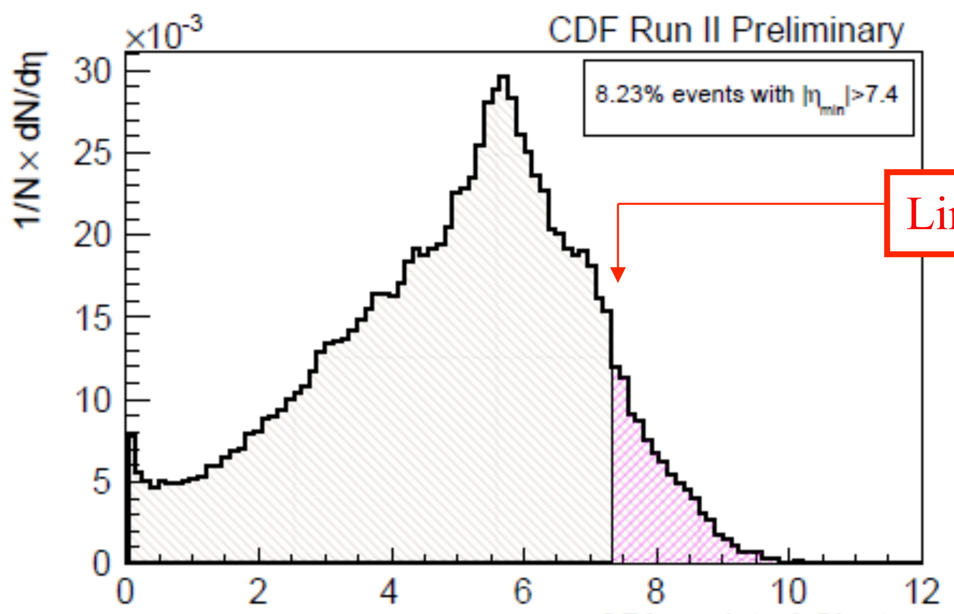
$|\eta| < 1.0$, $E_T > 2.5$ GeV

6 – 24 fb … negligible.

$\eta^0\eta^0$ also negligible.

Undetected p-dissociation e.g. $p \rightarrow p\,\pi^+\,\pi^-$

Still $\gamma+\gamma$ or IP + IP but not truly exclusive. Consider as B/G



η(min) of dissociating cluster particles

MinBias Rockefeller (MBR) Monte Carlo

Limit of BSC counters

~ 10 % for e+e-

< 1 % for γγ

e+e- Dissociation Background (events)

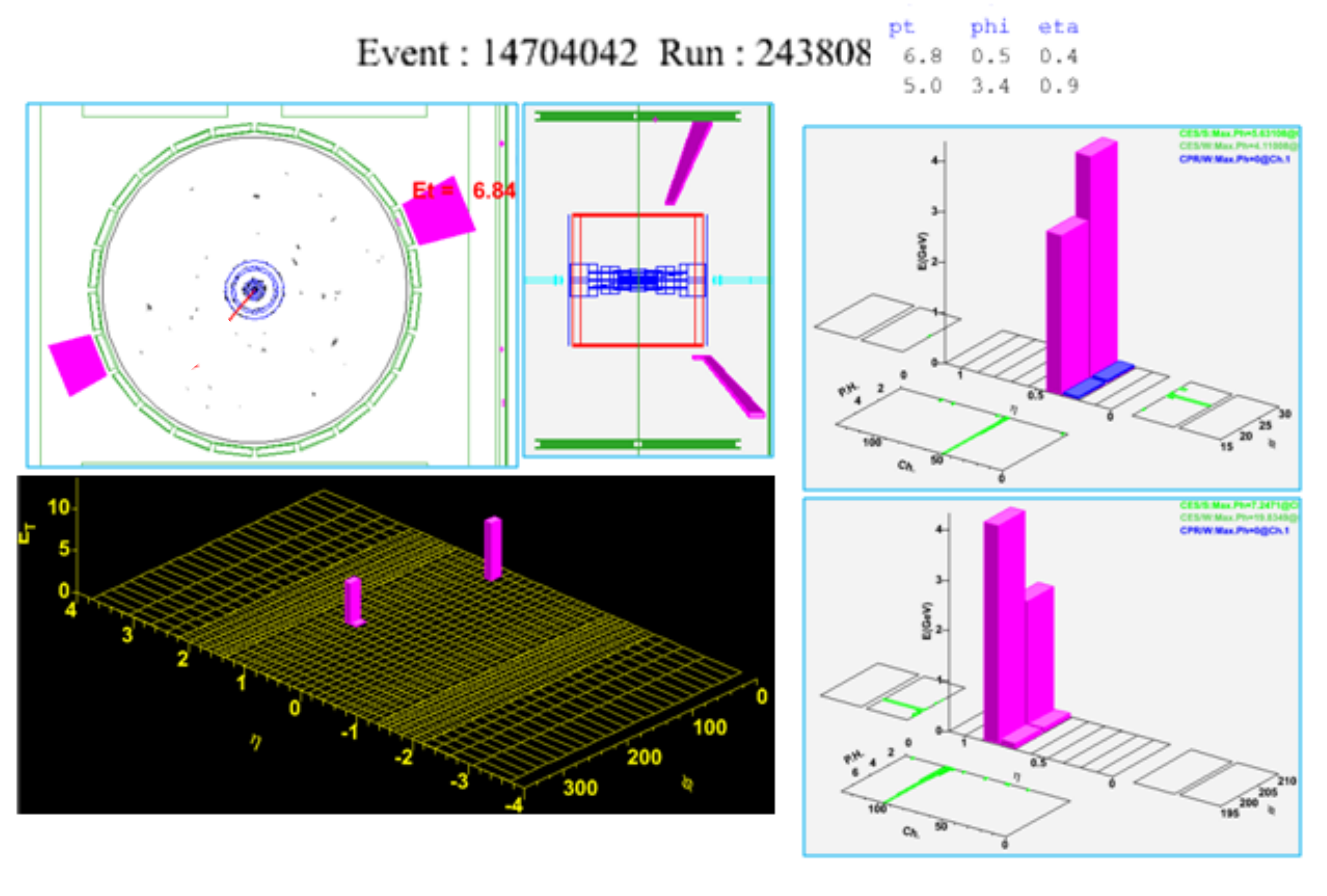
E_T cut [GeV]	Fraction	Background
2.5	0.12±0.01(stat)±0.03(sys)	3.8±0.4(stat)±0.9(sys)
5.0	0.13±0.02(stat)±0.03(sys)	1.3±0.2(stat)±0.3(sys)

γγ

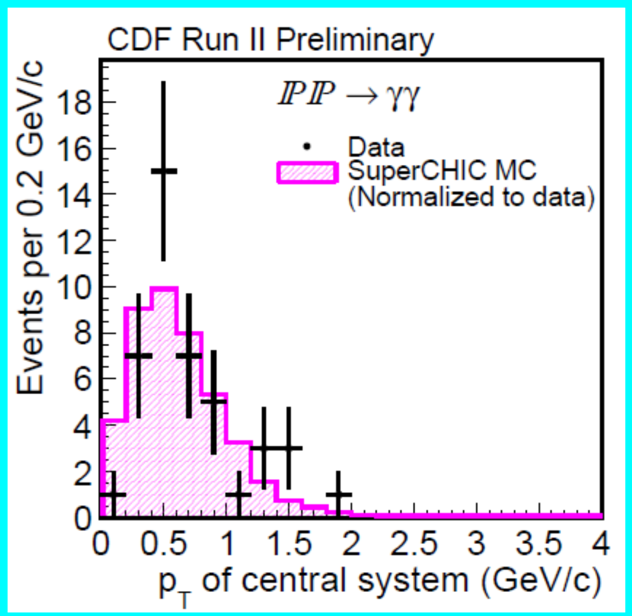
- Same approach as in published excl. $\gamma\gamma$ paper.
- Durham estimation using our selection rules with large rapidity gaps.
- Dissociation background estimate for $E_{T,min} = 2.5$ GeV:

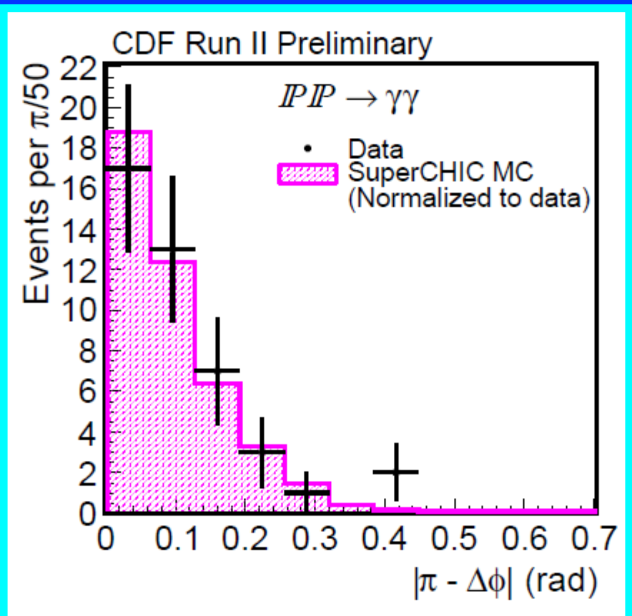
  0.14 ± 0.14(syst) events

Example of γγ event

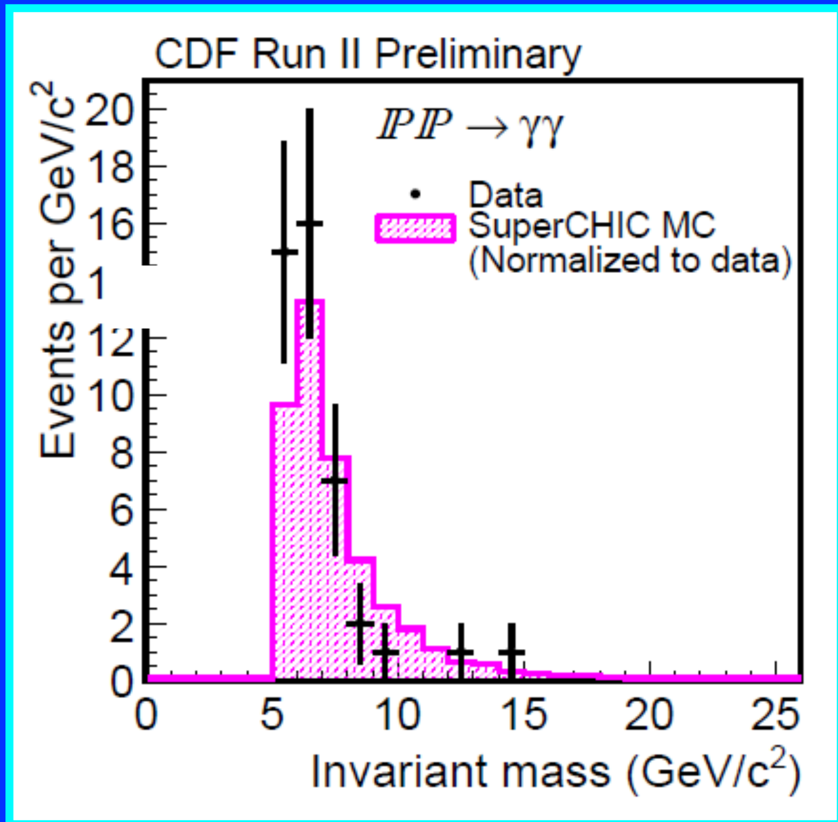


Kinematic distributions of photon pairs





Normalization to equal area
(shape comparison)
Note differences: $\gamma+\gamma$ vs IP+IP



Final results on $p + \bar{p} \rightarrow p + \gamma\gamma + \bar{p}$ via $IP + IP$ (QCD)

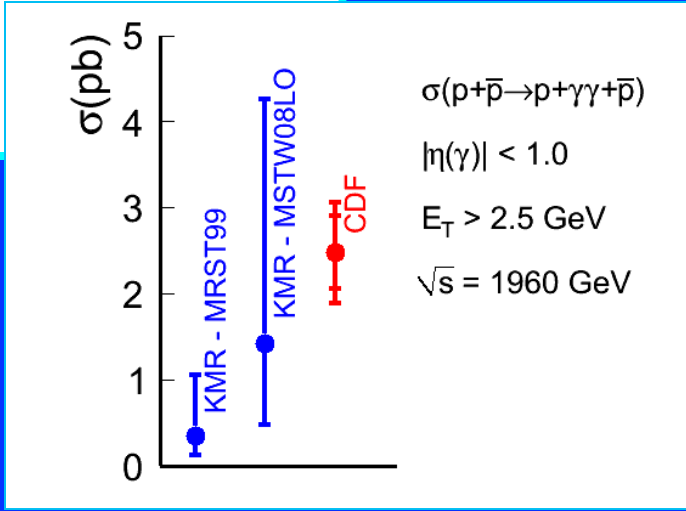
Table: Statistics summary of all relevant parameters for the measurement of the exclusive photon pair cross section for an E_T cut of 2.5 GeV and $|\eta| < 1.0$.

	Value	Stat. error	Syst. error
$\mathcal{L}_{int}$	1.11 fb^{-1}		± 0.7pb^{-1}
$\gamma\gamma$ (events)	43		
Trigger efficiency	0.918	± 0.005	± 0.018
Reconstruction efficiency	0.553	± 0.005	± 0.029
Identification efficiency	0.927	± 0.017	± 0.013
Exclusive efficiency	0.0680	negligible	0.004
Conversion acceptance	0.568	± 0.001	± 0.063
π^0 background	0.0		$<$16% (95% C.L.)
Dissoc. B/G (events)	0.14		0.14

$$\sigma^{|\eta|<1, E_T>2.5\text{GeV}}_{\gamma\gamma\text{excl.}} = 2.48 \pm 0.42(\text{stat}) \pm 0.41(\text{sys})\ \text{pb}$$

$$\sigma^{|\eta|<1, E_T>2.5\text{GeV}}_{\text{SuperCHIC (MSTW08LO)}} = 1.42^{\times 3}_{\div 3}\ \text{pb}$$

$$\sigma^{|\eta|<1, E_T>2.5\text{GeV}}_{\text{SuperCHIC (MRST99)}} = 0.35^{\times 3}_{\div 3}\ \text{pb}$$



Executive Summary (Repeat)

We have observed (43 events, >> 5 σ) the new clean process:

$$p + \overline{p} \rightarrow p + \gamma\gamma + \overline{p}$$

We needed:

A good level 1 trigger (EM showers + Forward gap-seeds with BSC-1)

Extended rapidity coverage of CDF to $\eta = \pm 7.4$

Understood noise levels in all calorimeters and counters.

Demonstrated understanding of "empty events" (non-interaction in 0-bias)

Used $p + \overline{p} \rightarrow p + e^{+}e^{-} + \overline{p}$ via $\gamma\gamma$ (QED) as a control (σ known)

Showed that EM showers are from γ and not π^0 as theoretically expected

Conclusions

In CDF we have observed exclusive 2-photon production, i.e. $p + \bar{p} \rightarrow p + \gamma\gamma + \bar{p}$ with $E_T(\gamma) > 2.5$ GeV and with no hadrons.

43 events with background consistent with zero, and < 8 events (95% CL)

The cross section is ~ 2.5 pb, consistent with a theoretical prediction.

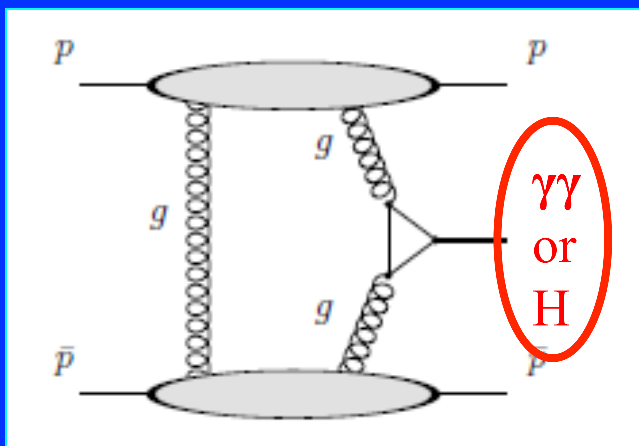
This confirms the picture of a hard pomeron as {gg}.

This is the first OBSERVATION of exclusive 2-photon production in hadron-hadron collisions.

Exclusive Photon-Pair Production	
Theoretical	$\sigma_{\rm SuperCHIC}^{|\eta|<1,E_T>2.5\rm GeV} = 0.35^{\times 3}_{\div 3}$pb (MRST99)
	$\sigma_{\rm SuperCHIC}^{|\eta|<1,E_T>2.5\rm GeV} = 1.42^{\times 3}_{\div 3}$pb (MSTW08LO)
Measured	$\sigma_{\gamma\gamma\rm excl.}^{|\eta|<1,E_T>2.5\rm GeV} = 2.48 \pm 0.42(\rm stat) \pm 0.41(\rm sys)$ pb

Note: This corresponds to 1 in 25 billion inelastic collisions!

Exclusive Higgs at LHC : Implications



Same process from QCD perspective.
u,d,s,c,b loops → (b and) t loops
Q^2 different. x(g) similar

σ(SMH ~ 120 GeV) ~ 10 fb (MSSM bigger)

Measuring both protons at 240m & 420m : σ(M) ~ 2 GeV/event
S:B only a few. → J=0, CP = ++, Γ(H), Γgg.

TDR being prepared to add very forward proton spectrometers to CMS (& ATLAS)

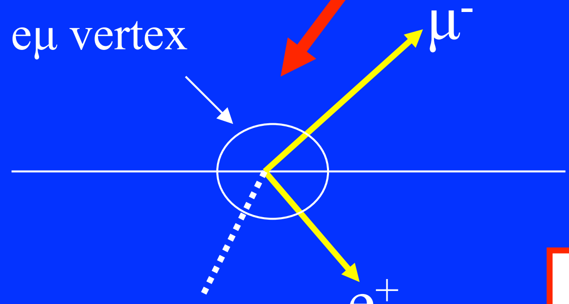
The cleanest, simplest inelastic pp collisions.

Class 3 Interactions at the LHC:
"Inelastic, with no hadrons produced"

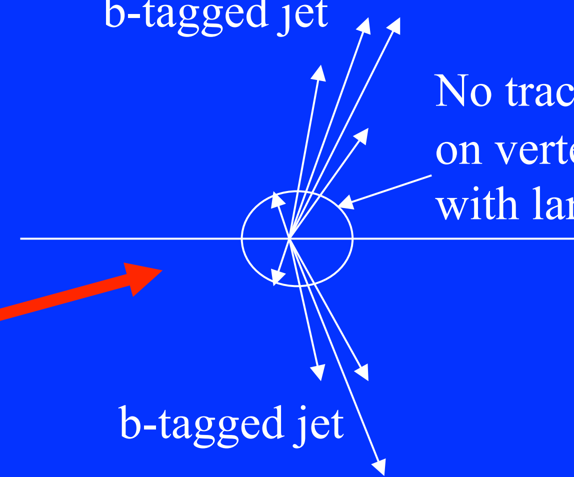
Consider WW + nothing (p's go down pipe, small p_T)
σ ($\gamma\gamma \rightarrow W^+W^-$) ~ 50 fb … or H + nothing

Could be H→WW.
Know M(WW) if
measure p's

No other tracks
on eμ vertex



or



Could be H→$b\bar{b}$.
Know M($b\bar{b}$) if
measure p's

Missing E_T
E_z too if measure p's

Thanks to the Accelerator Division for providing (too much) luminosity, Computing Division, and Particle Physics Division

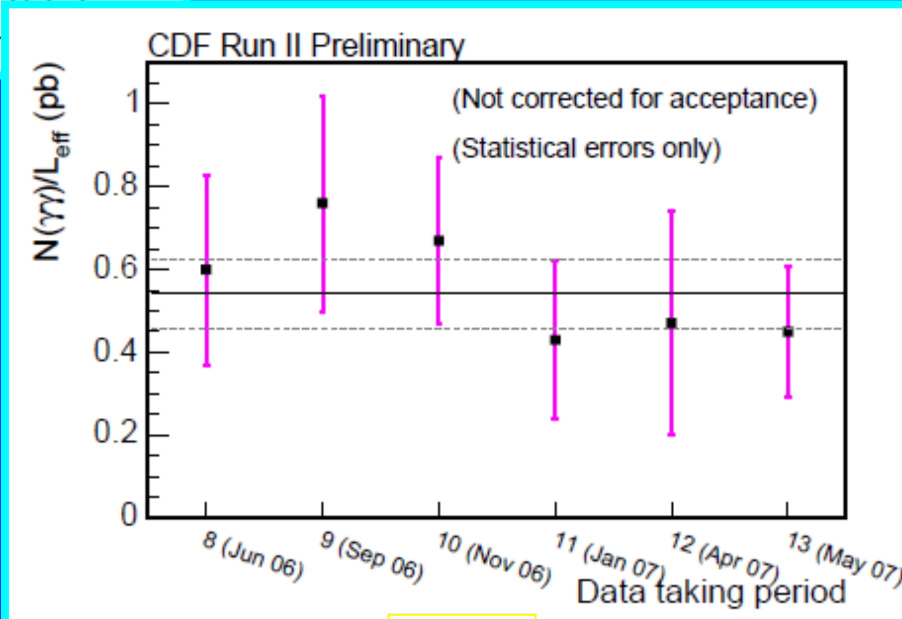
Thank you for your attention

Rate of γγ Events is constant over the data year

Table: γγ candidates

		E_T > 2.5 GeV	
Period	$\mathcal{L}_{eff}$[pb^{-1}]	γγ	÷$\mathcal{L}_{eff}$[pb]
8	11.7	7	0.60
9	11.8	9	0.76
10	16.5	11	0.67
11	11.7	5	0.43
12	6.4	3	0.47
13	17.7	8	0.45
Tot:	75.8	43	0.57

Rate consistent over time



1 year

Table: Conversion Acceptance

E_T cut (GeV)	2.5
Acceptance$_{conv}$	0.568
Stat Err	±0.001
Syst Err	±0.063