CDF's New Results for ICHEP

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Fermilab Wine & Cheese
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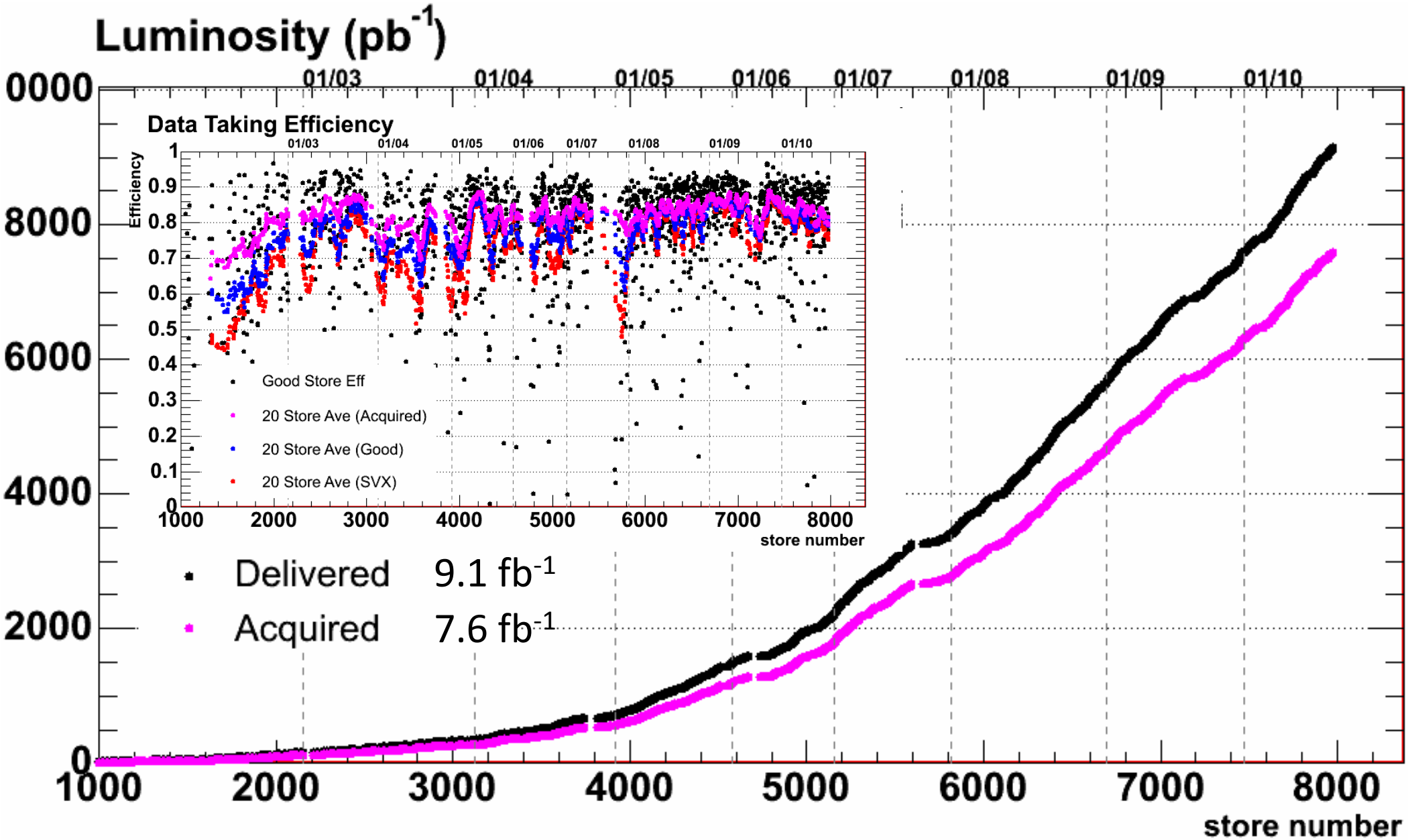
Contents

- Introduction
- B physics
- QCD
- Electroweak
- Top
- Exotic
- Higgs
- Conclusion

- 31 new preliminary results and 16 papers published since Winter 2010 conferences

- CDF detector/DAQ is performing very well
- Offline data processing running well (2-3 month turnaround)

CDF Performance



Results today using up to 6.0 fb^{-1}

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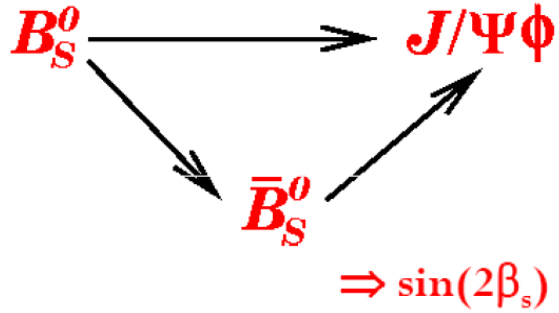
- CPV in the B_s system
- Rare B_s decays
- Y(4140) observation
- Charm baryon spectroscopy

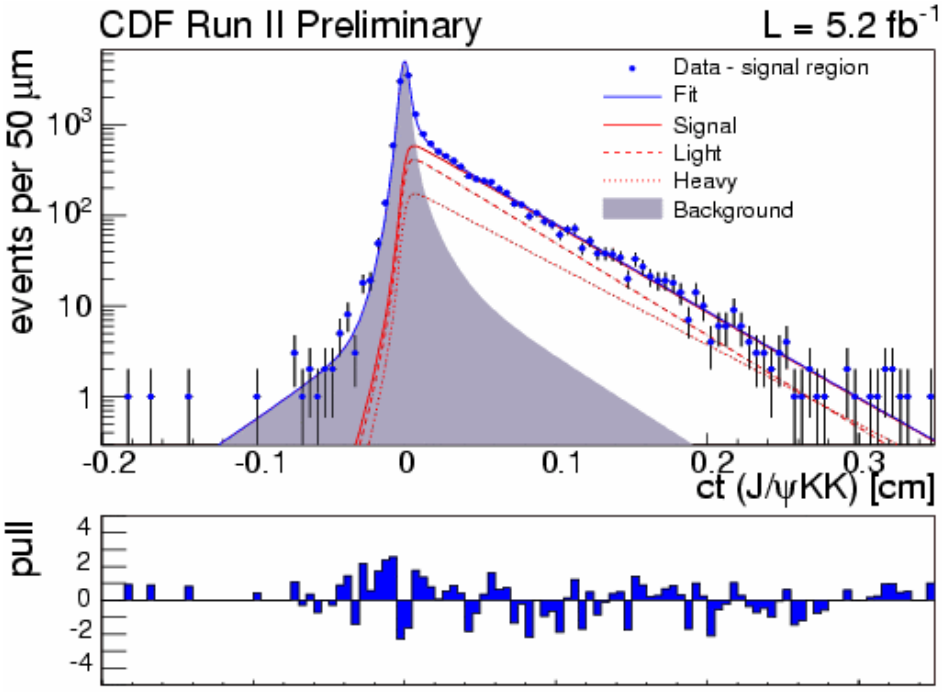
CP-Violating Phase β_s

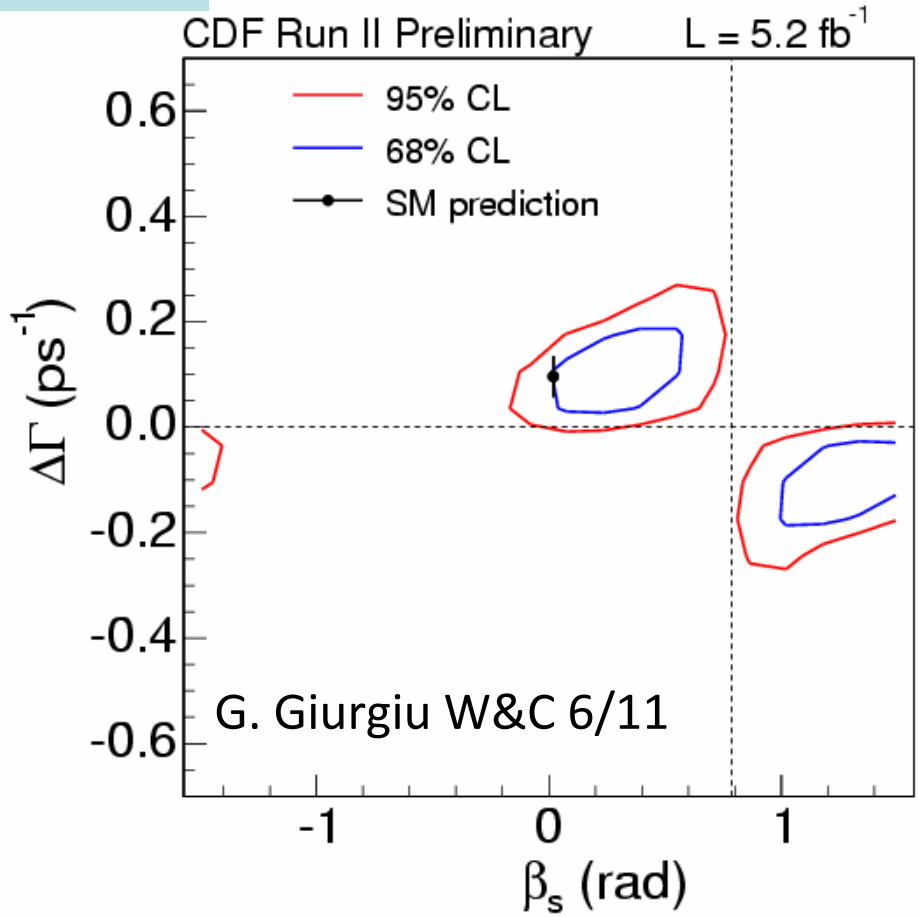
Interference of decays with/without mixing

Angular correlations of decay products to separate CP-even/CP-odd components as a function of proper time

Last summer, Tevatron combined result (2.8 fb^{-1}) consistent with SM at 3.4% level (2.1σ)







$c\tau_s$ = 458.7 ± 7.5 (stat) ± 3.6 (syst) μm
$\Delta\Gamma_s$ = 0.075 ± 0.035 (stat) ± 0.01 (syst) ps^{-1}
$|A_{||}(0)|^2$ = 0.231 ± 0.014 (stat) ± 0.015 (syst)
$|A_0(0)|^2$ = 0.524 ± 0.013 (stat) ± 0.015 (syst)

[0.02, 0.52] U [1.08, 1.55] at 68% CL
SM consistency 0.8σ (was 1.5σ)

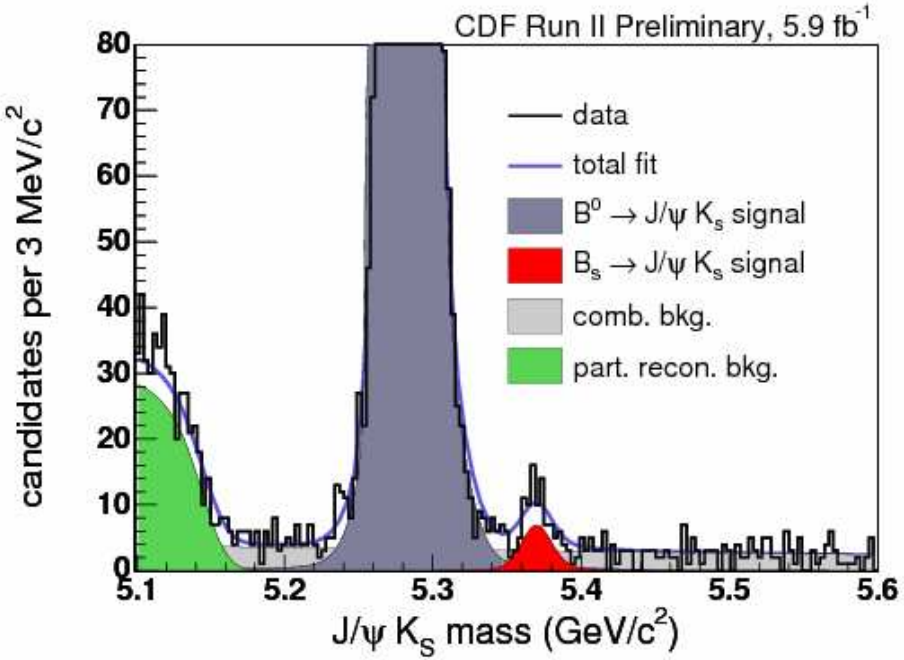
Rare B_s Decays

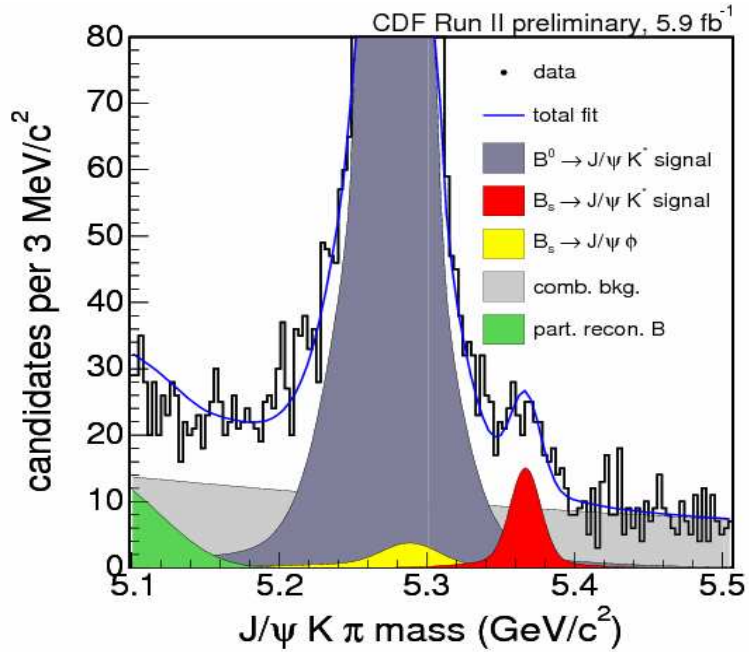
$B_s \to J/\psi\, K_s$ and $B_s \to J/\psi\, \overline{K}^*$ not yet observed (until now)

- Suppressed by V_{cd}
- Could be used to measure CKM angle γ (Eur.Phys.J. C10 (1999) 299-306)

First step is observation and branching ratio determinations

- Start from $J/\psi \to \mu\mu$ triggered dataset
- Multivariate (K_s) or multiple-cut ($\overline{K}^*$) rejection of combinatoric bkgd





$$\frac{Br(B_s \to J/\psi\, K^*)}{Br(B^0 \to J/\psi\, K^*)} = 0.062 \pm 0.009\ (\text{stat.}) \pm 0.025\ (\text{sys.}) \pm 0.008\ (\text{frag.})$$

$$\frac{Br(B_s \to J/\psi\, K_S)}{Br(B^0 \to J/\psi\, K_S)} = 0.041 \pm 0.007\ (\text{stat.}) \pm 0.004\ (\text{sys.}) \pm 0.005\ (\text{frag.})$$

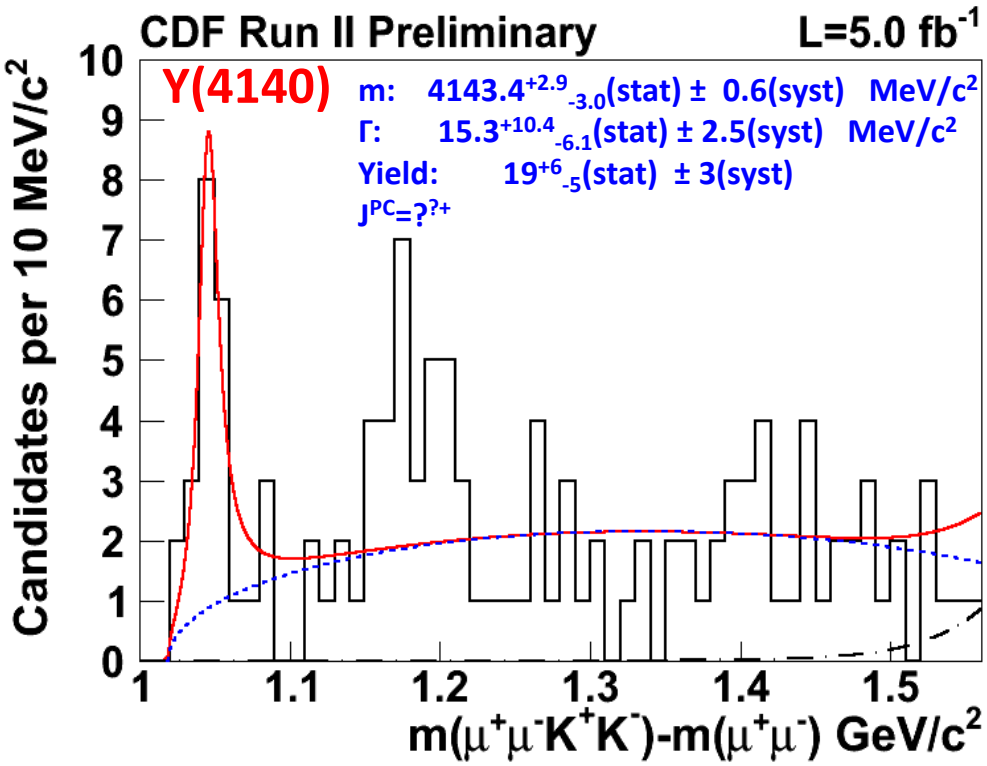
Observation of Y(4140)

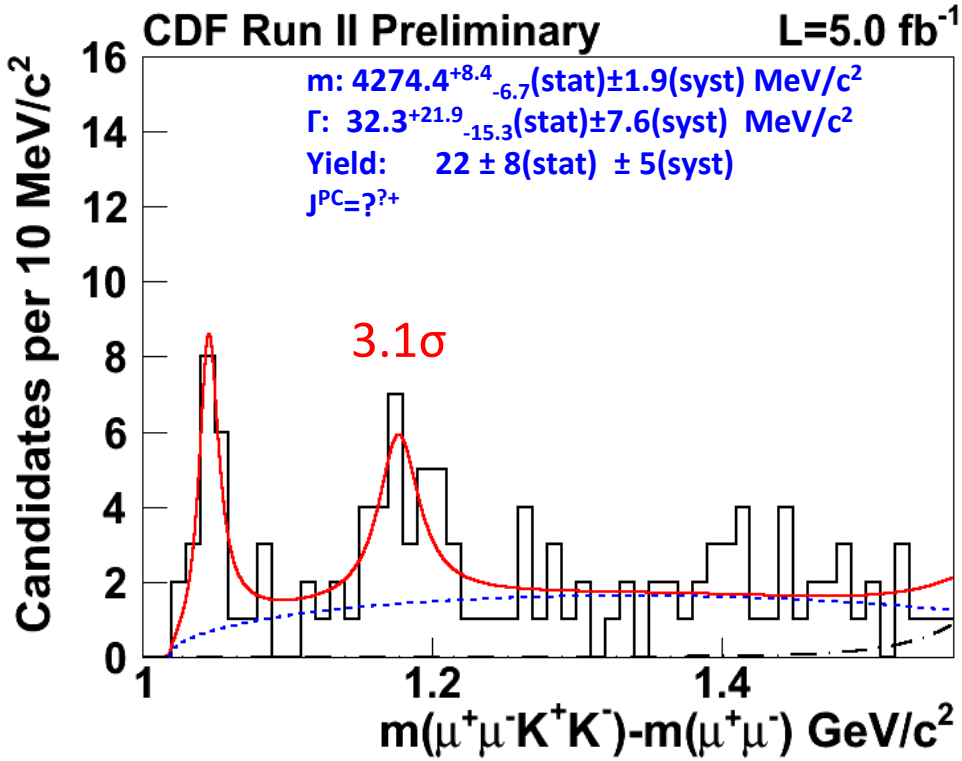
Evidence (>3.8σ) of a new structure Y(4140) was found @CDF using 2.7 fb^{-1}

$Y(4140) \rightarrow J/\psi\phi$ through exclusive $B^+ \rightarrow Y(4140)K^+$ decay (PRL 102, 242002)

Y(4140) significance >5σ with the same cuts as before using 5.0fb^{-1} data

Suggestive evidence emerging for another structure at 4270 MeV/c^2



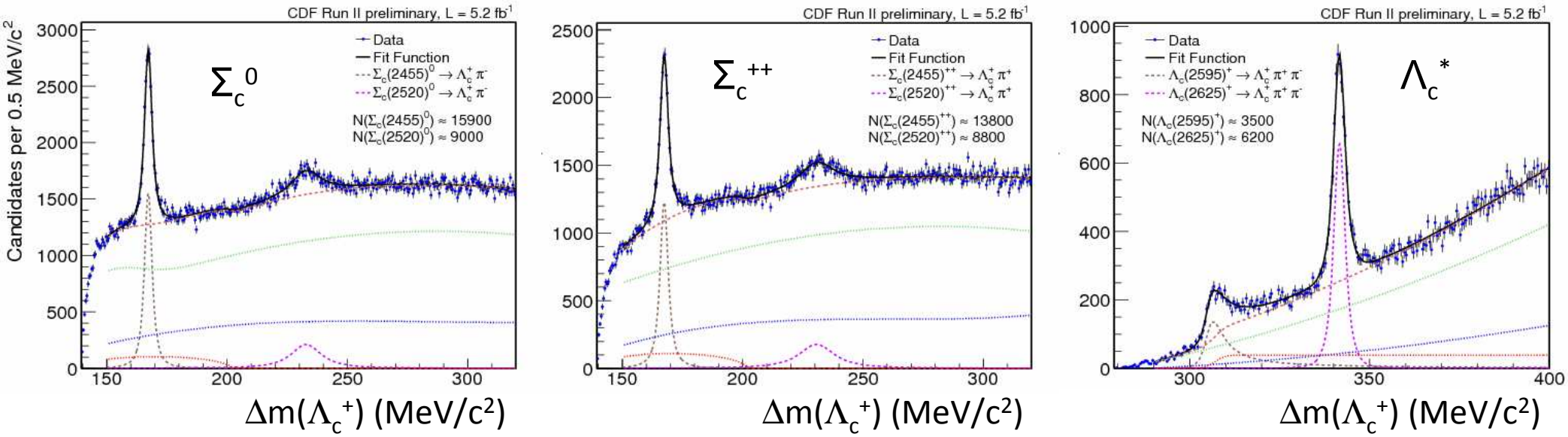


Relative BF: $\frac{\mathcal{B}(B^+ \rightarrow Y(4140)K^+, Y(4140) \rightarrow J/\psi\phi)}{\mathcal{B}(B^+ \rightarrow J/\psi\phi K^+)} = 0.149 \pm 0.039(\text{stat}) \pm 0.034(\text{syst})$

Charm Baryon Spectroscopy

Exploit our large sample of triggered $\Lambda_c \rightarrow pK\pi$ events to study Σ_c^0, Σ_c^{++}, Λ_c^* states

Simultaneous analysis incorporating all cross-talk between channels and threshold effects



	$m - m(\Lambda_c^+)[\mathrm{MeV}/c^2]$		$\Gamma[\mathrm{MeV}/c^2]$	
$\Sigma_c(2455)^0$	167.28 ± 0.12	0.11	1.65 ± 0.50	0.3
$\Sigma_c(2455)^{++}$	167.44 ± 0.13	0.11	2.34 ± 0.47	0.4
$\Sigma_c(2520)^0$	232.88 ± 0.46	0.6	12.51 ± 2.28	1.9
$\Sigma_c(2520)^{++}$	230.73 ± 0.58	0.5	15.03 ± 2.52	2.1
$\Lambda_c(2595)^+$	305.79 ± 0.24	0.6	2.59 ± 0.56	+2.0-1.3
$\Lambda_c(2625)^+$	341.65 ± 0.13	0.6	$< 0.97(90\%CL)$	<1.9

Comparable or improved precision compared to PDG uncertainties (in red)

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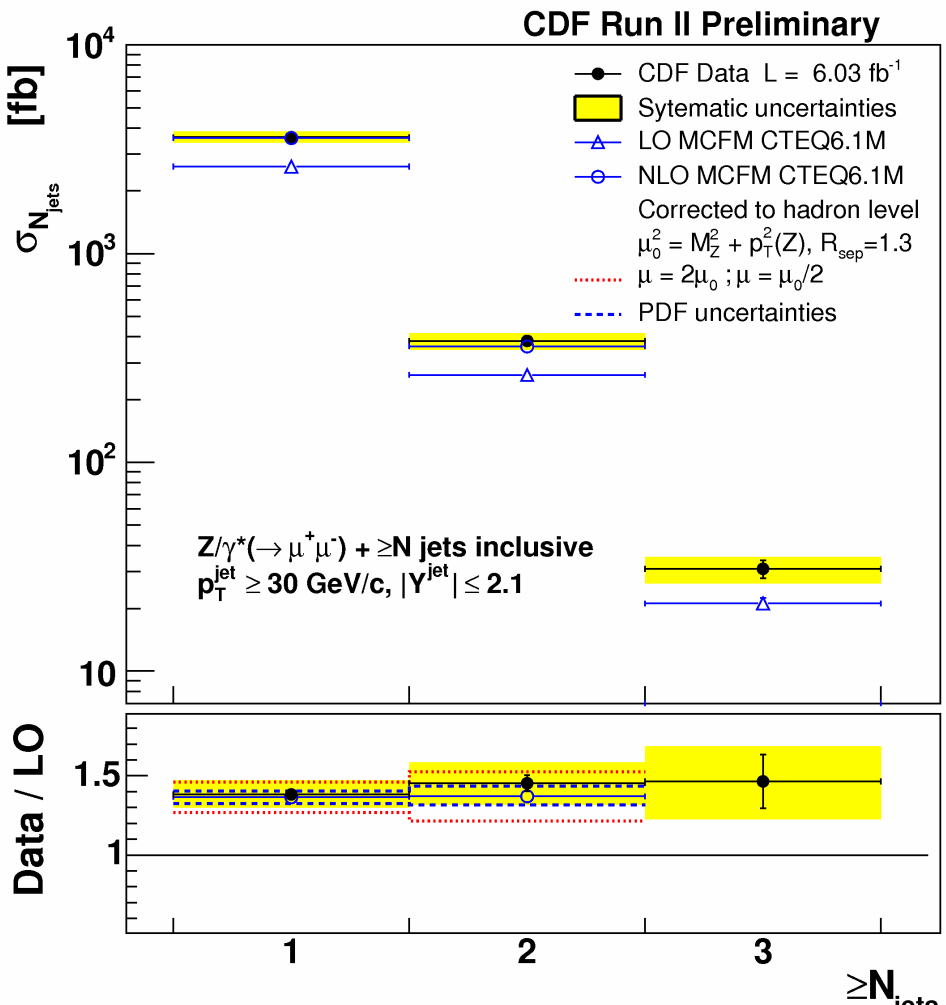
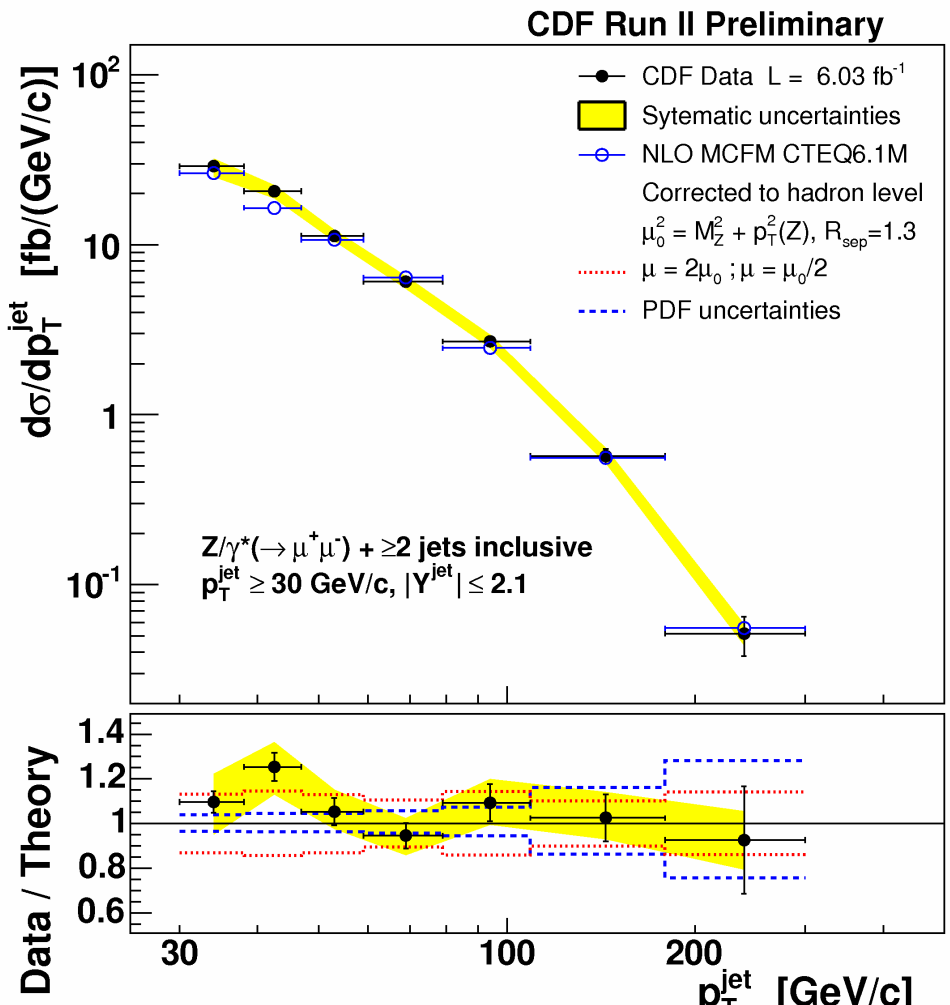
- $Z \rightarrow \mu\mu$ + jets
- Prompt diphoton production
- Jet substructure

$Z \rightarrow \mu\mu$ + Jets

- Updated with 6.0 fb^{-1}
- Select Z's in mass window 66-116 GeV/c^2
- Midpoint cone-0.7 jets with p_T > 25 GeV, $|\eta|$<2.1, correct to hadron level
- Test QCD by comparing with NLO calculations (MCFM)



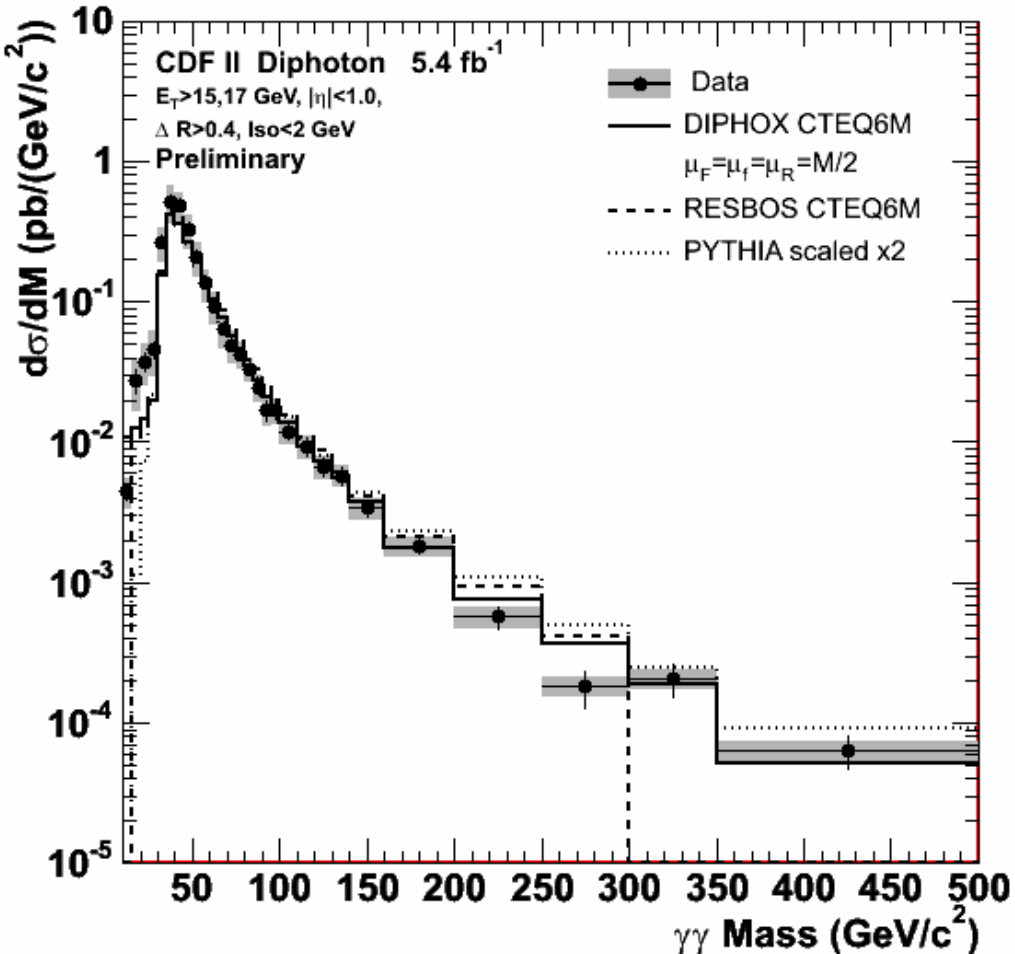


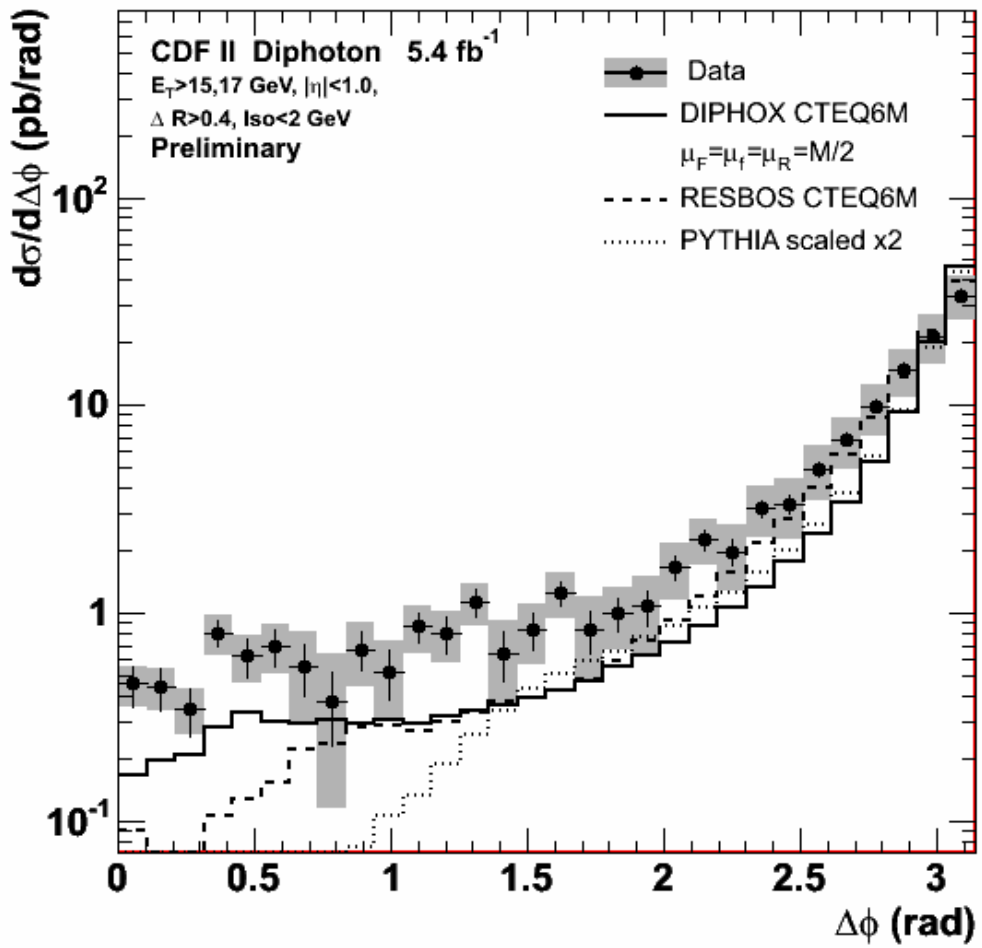
Prompt Diphoton Production

Another sensitive test of our understanding of QCD

Two isolated photons with lead (second) $E_T > 17(15)$ GeV

Jet $\rightarrow$ photon fakes subtracted using new 'track isolation' algorithm





Split data into large number of kinematic regions, compare to Pythia and two NLO calculations (DIPHOX and RESBOS)

Jet Substructure

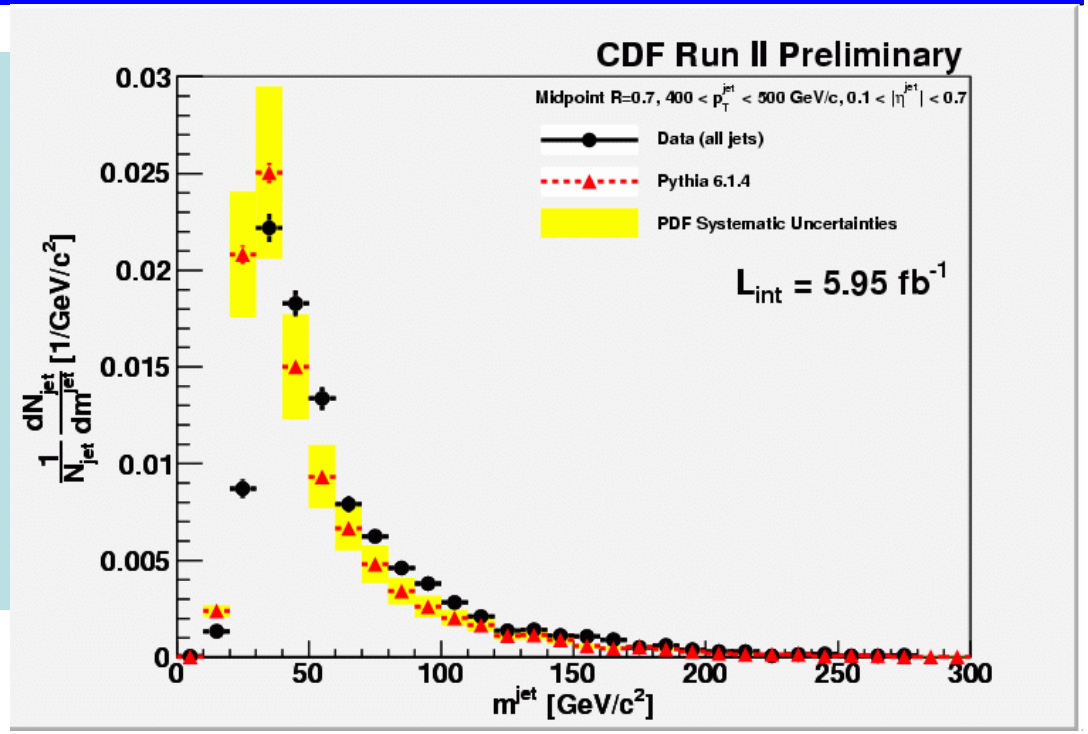
Boosted heavy particles manifesting as single jets recent hot topic

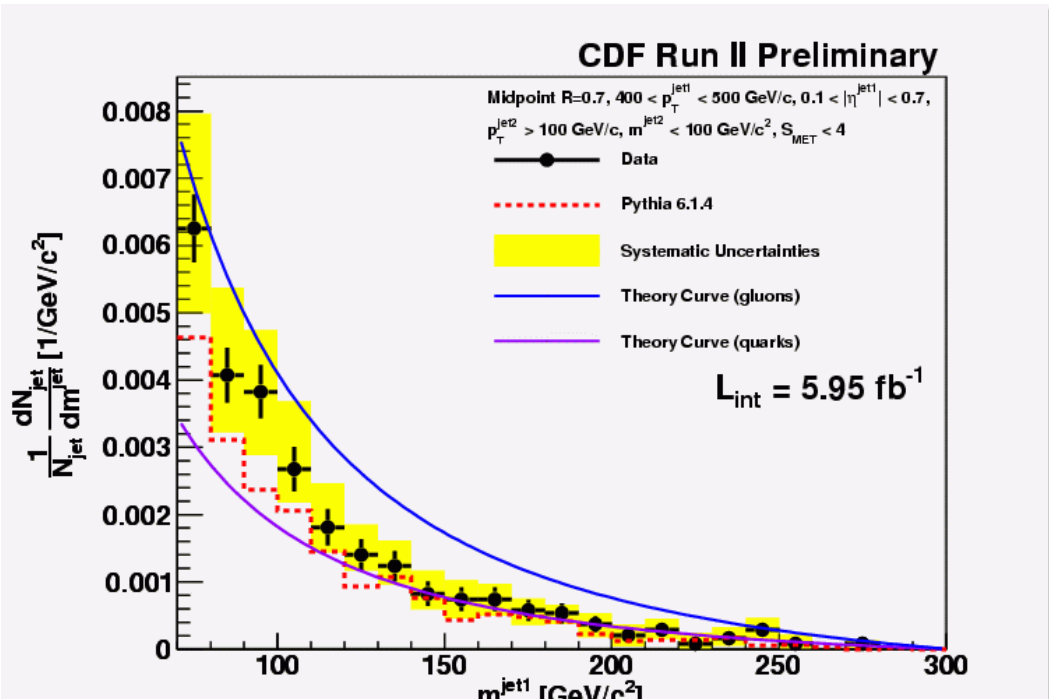
Lead jet E_T>400 GeV, second jet E_T>100 GeV

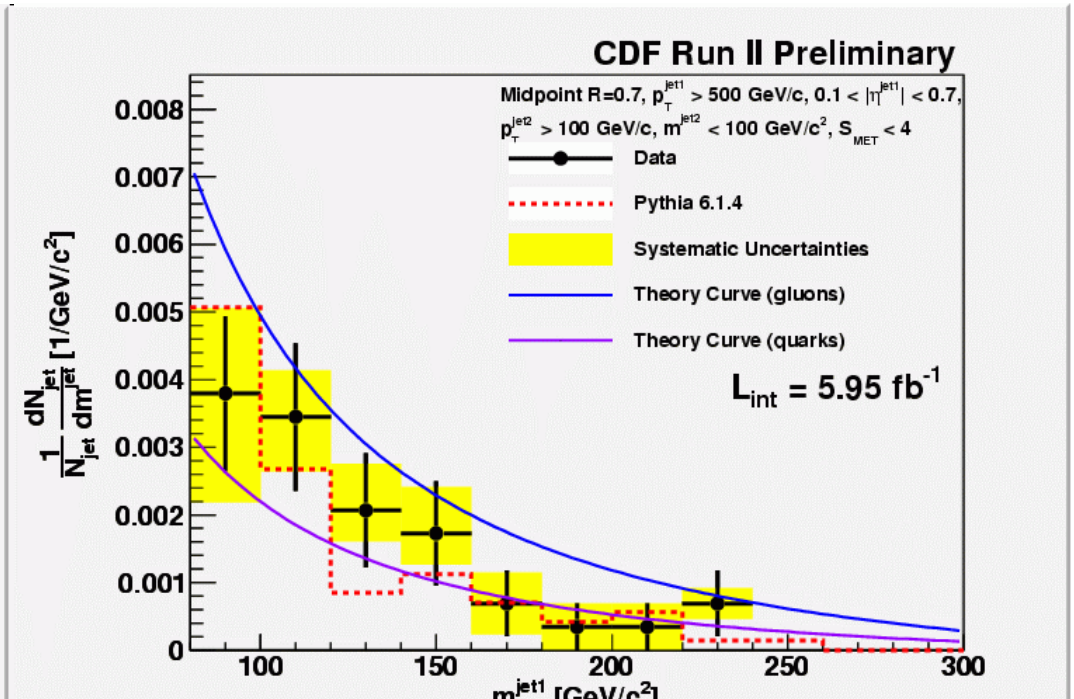
Remove potential t-tbar contribution

- second jet mass < 100 GeV (all-hadronic)
- MET significance < 4 (lepton+jets)

Compare to PYTHIA and theory







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- WZ production
- WZ and ZZ production
- Anomalous triple gauge couplings in Zγ events

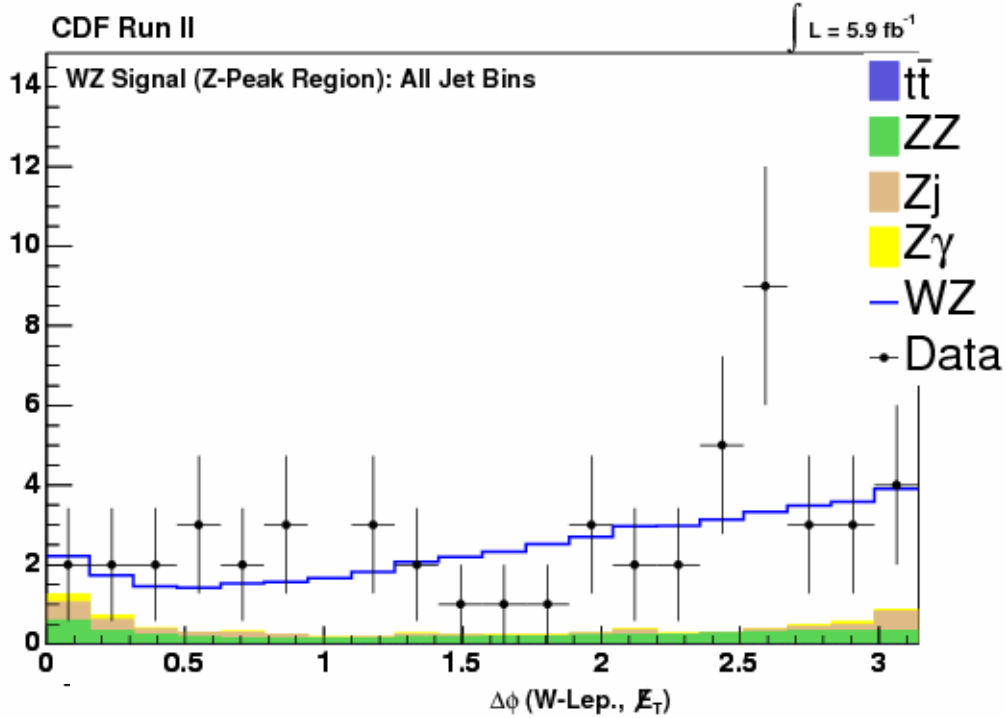
WZ Production

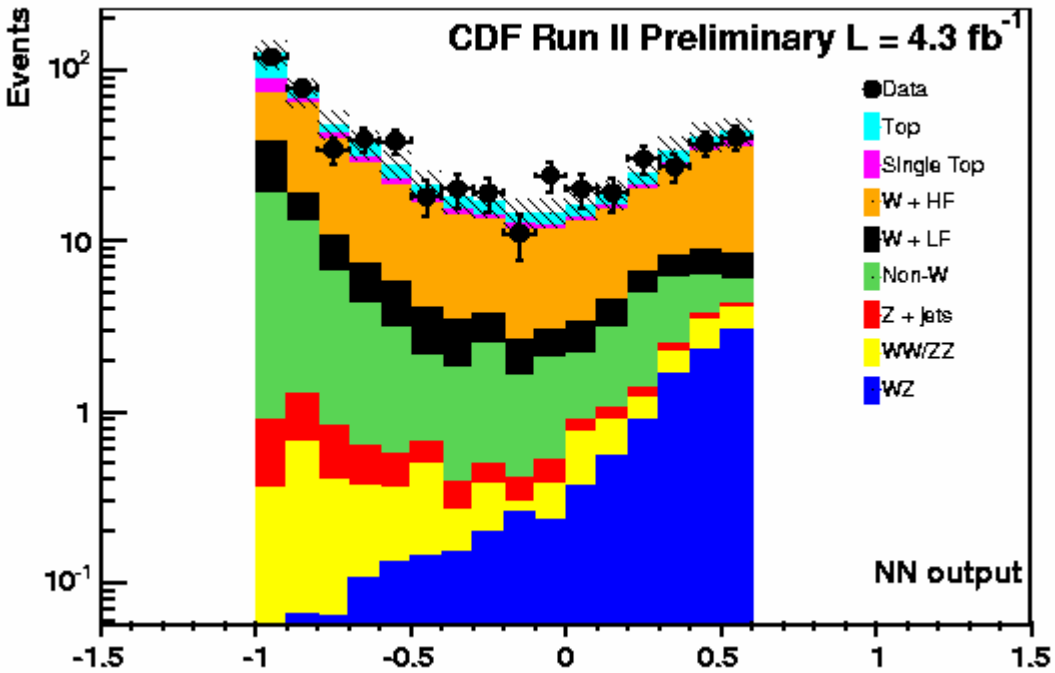
WZ → lllν with 5.9 fb^{-1}

- Three leptons p_T > 20,10,10 GeV
- MET > 25, any # jets

Suppress background by fitting multivariate discriminant

$\sigma(WZ) = 3.7 \pm 0.6_{stat} +0.6-0.4_{syst}$ pb





Starting to search for WZ in Z → bb decay modes

Like WH but larger background at 90 vs >115 GeV

High-p_T lepton, high MET, two jets b-tagged with very loose multivariate b-tagger (RomaNN)

Limit: σ(WZ)/SM < 3.9 @ 95% CL

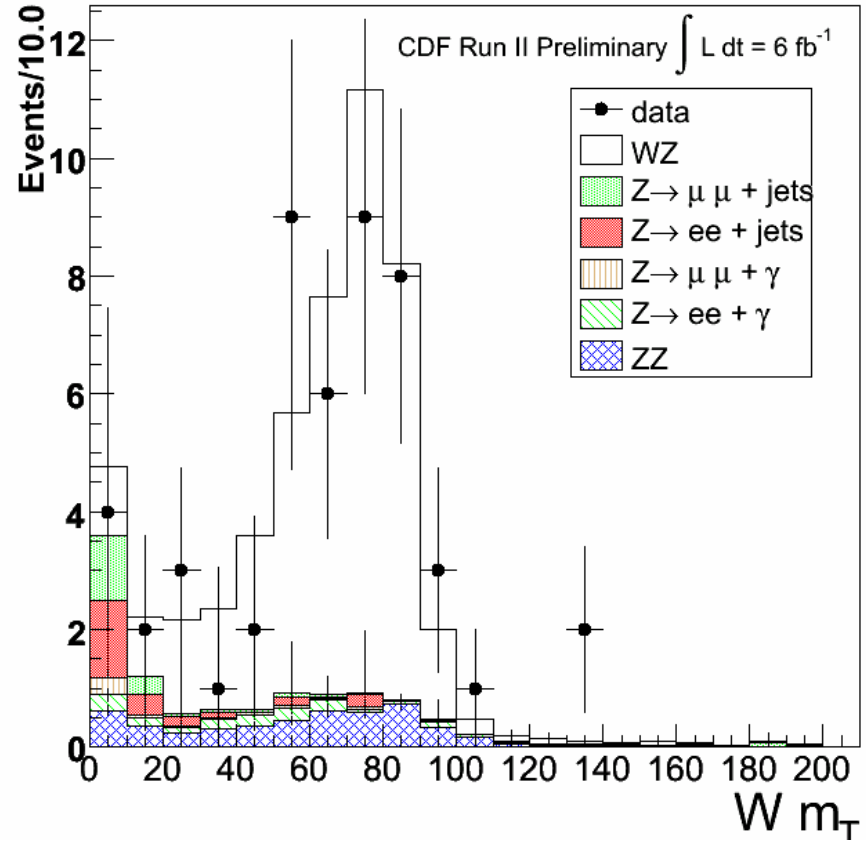
WZ and ZZ Production

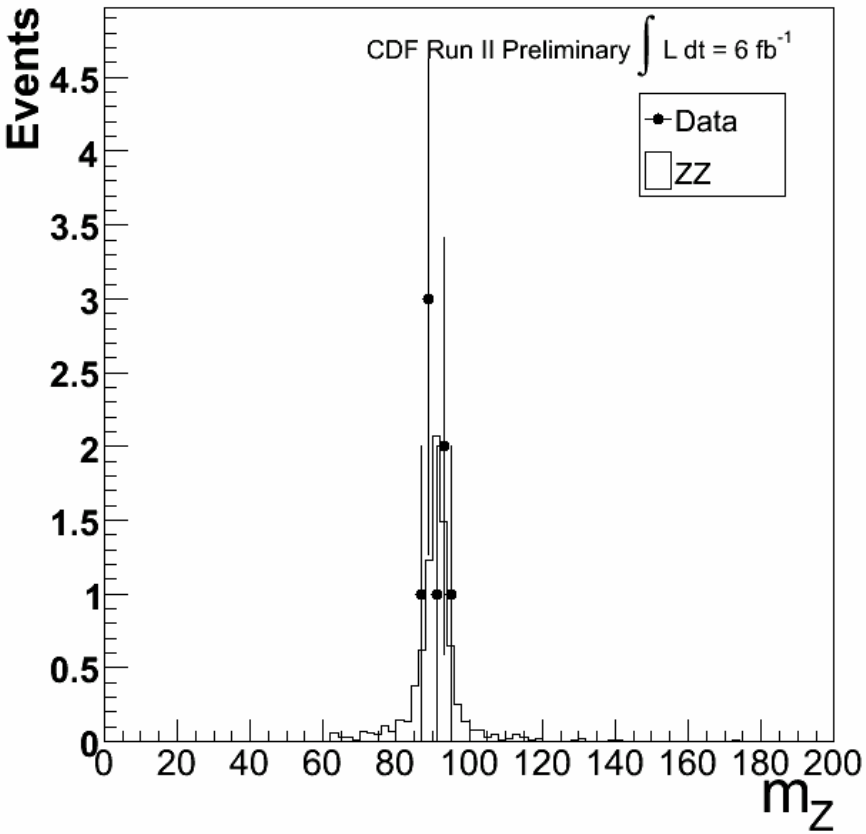
Lepton ID optimization

- Improved electron/muon isolation
- Recover central/plug transition
- Tight track quality

Selection: 3 leptons + MET>25 GeV

Normalize to Z → ll cross section





Also select ZZ → llll (bkgd < 0.01 event!)

Only M(ZZ) < 300 GeV region for now
(high mass is a search region)

$$\sigma(p\bar{p} \to WZ) = (4.1 \pm 0.6(stat) \pm 0.4(syst))\text{pb}$$

$$\sigma(p\bar{p} \to ZZ) = (1.7\ ^{+1.2}_{-0.7}(stat) \pm 0.2(syst))pb$$

ATGC in Zγ Events

No ZZγ, Zγγ vertex in the SM

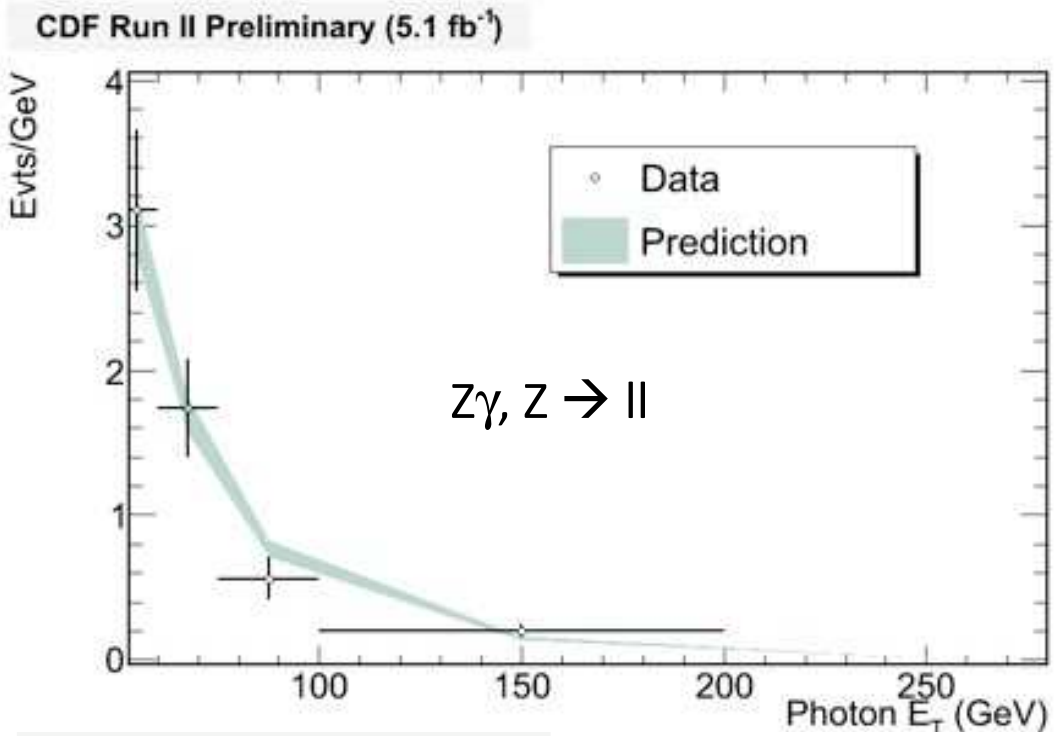
General trilinear model for ZγV has 8 parameters h_i^V (i=1-4, V=Z or g)

Only consider CP-conserving h_3^V and h_4^V

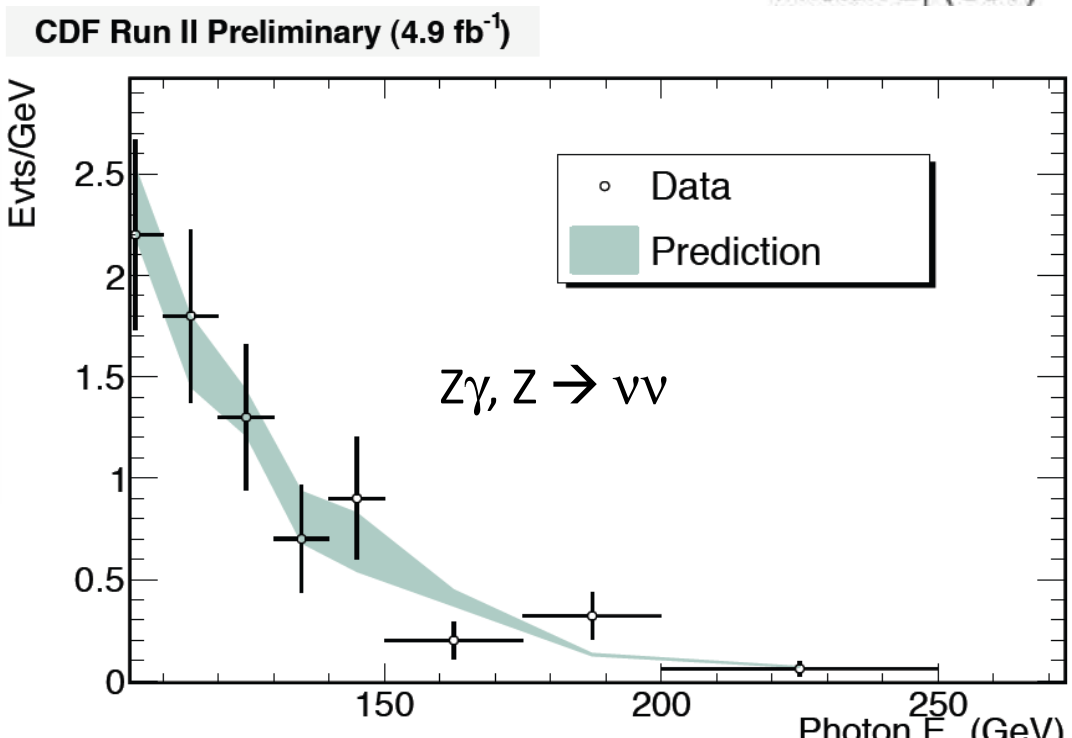
Select Zγ in Z → ll and Z → νν decays

Optimize photon p_T cut, compare high-p_T tails to templates of various h_i^V

Data are consistent with SM, set limits (for cutoff of Λ = 1.5 TeV)



Parameter	Measured Limit in Data
h_3^γ	(-0.017, 0.016)
h_4^γ	(-0.0006, 0.0006)
h_3^Z	(-0.017, 0.016)
h_4^Z	(-0.0006, 0.0005)



Better than x2 improvement compared to Z → ll alone!

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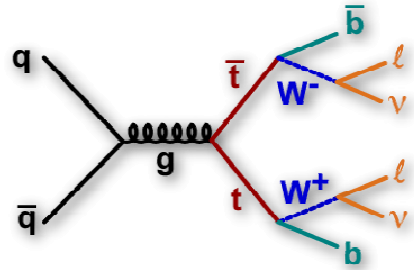
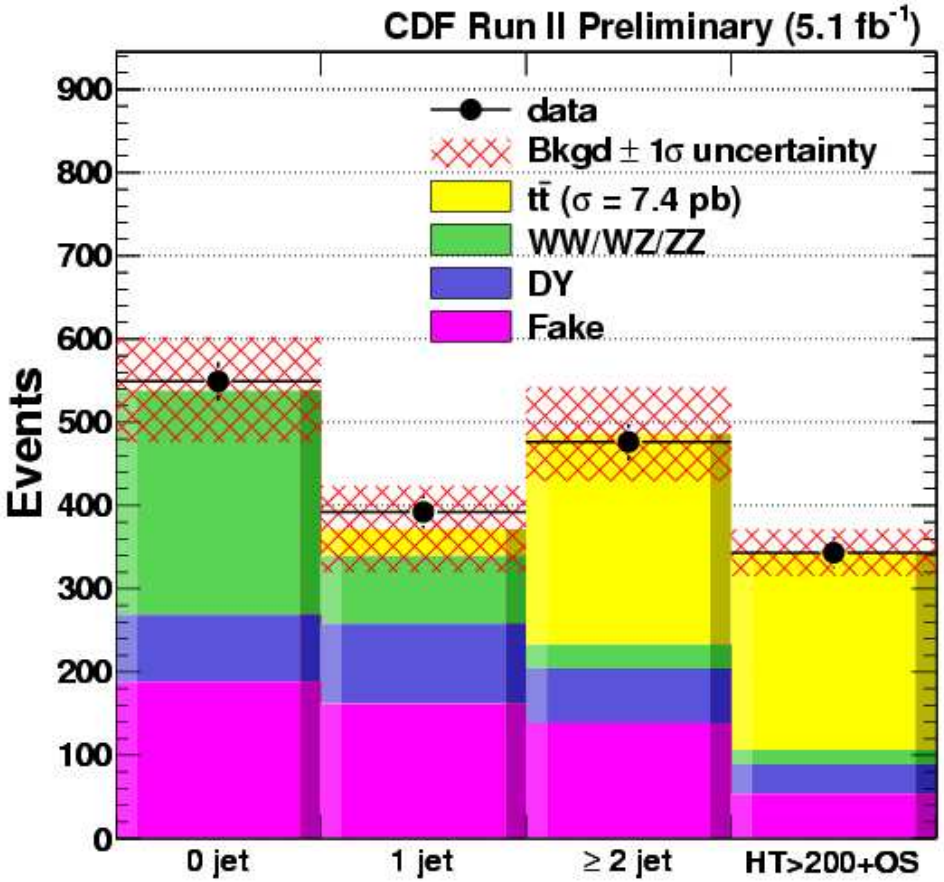
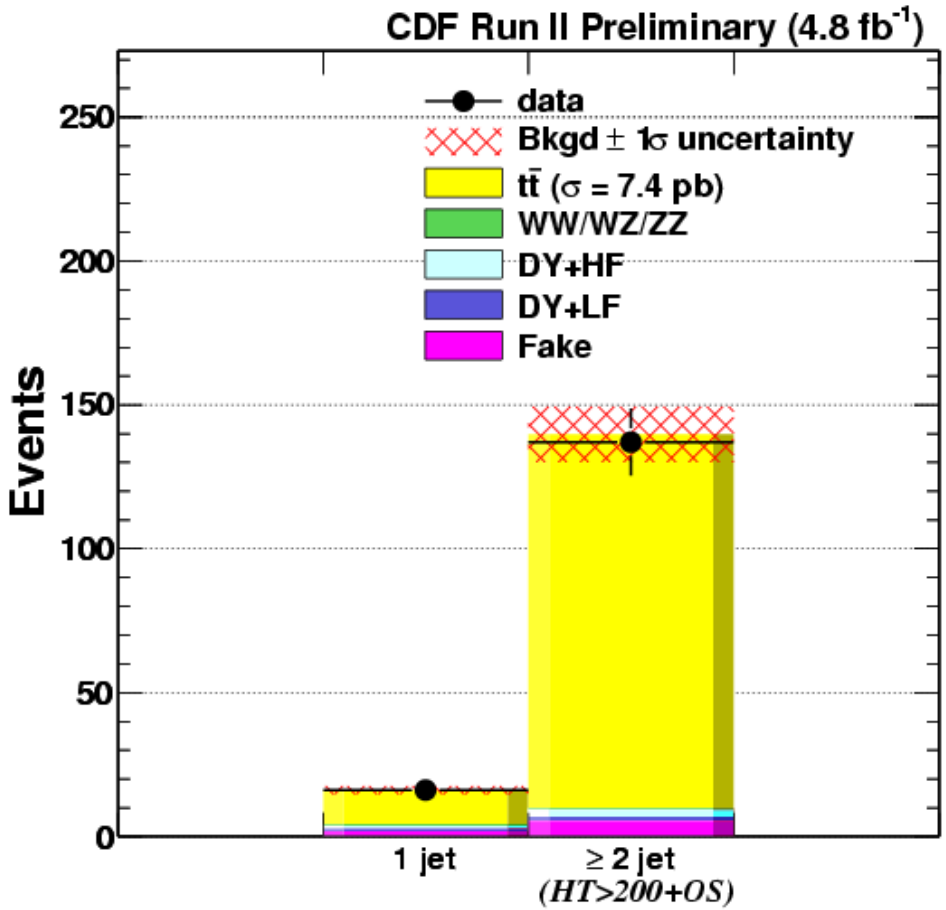
- Top pair cross section
- Top quark mass
- Top-antitop mass difference
- A_{FB} in top production
- High mass resonances decaying to top pairs
- Boosted top
- Singly-produced heavy quark search

Top Pair Cross Section in Dileptons

- Low BR relative to l+jets but high purity
- Require two high-p_T leptons, high MET
- Opposite-charge, ≥2 jets and H_T > 200 GeV, b-tagging







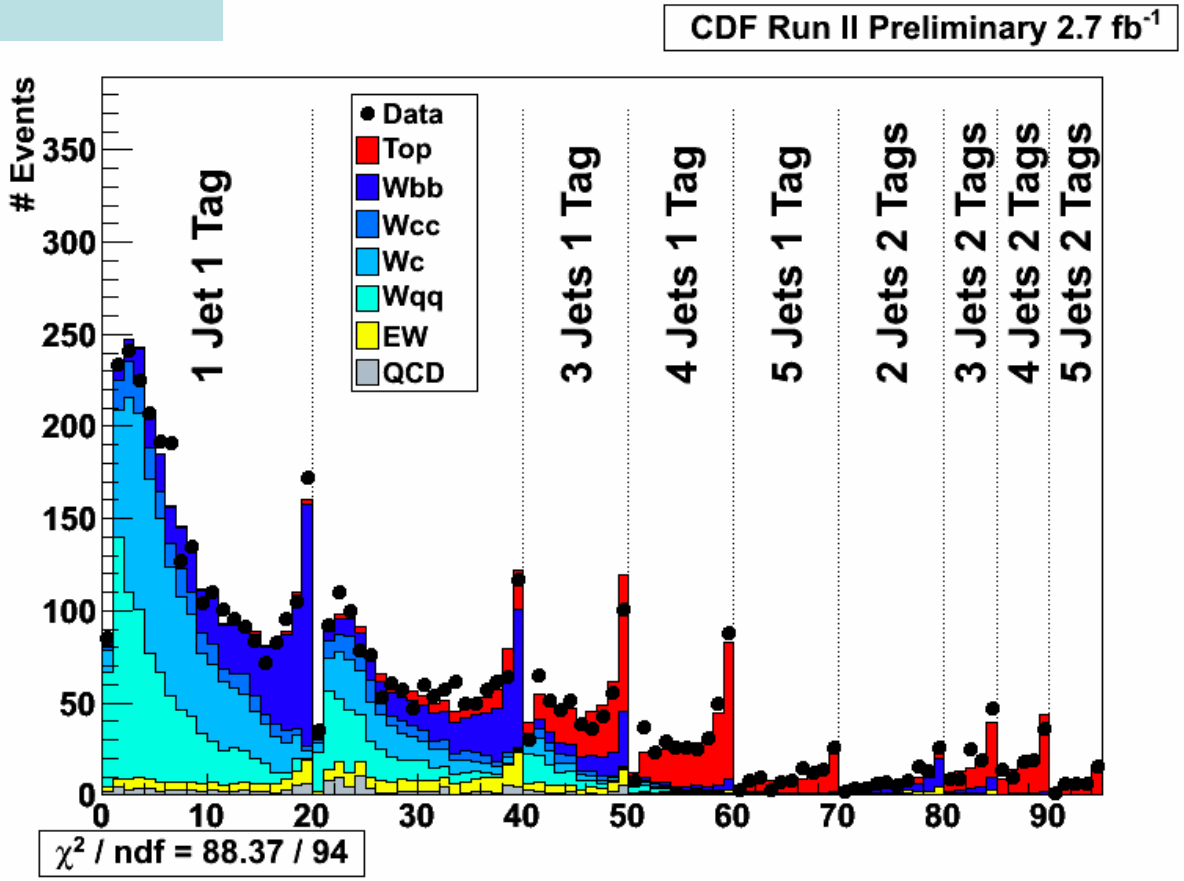
$$\sigma_{pretag} = 7.4 \pm 0.6_{stat} \pm 0.6_{syst} \pm 0.5_{lumi}\ pb$$
$$\sigma_{btag} = 7.3 \pm 0.7_{stat} \pm 0.5_{syst} \pm 0.4_{lumi}\ pb$$

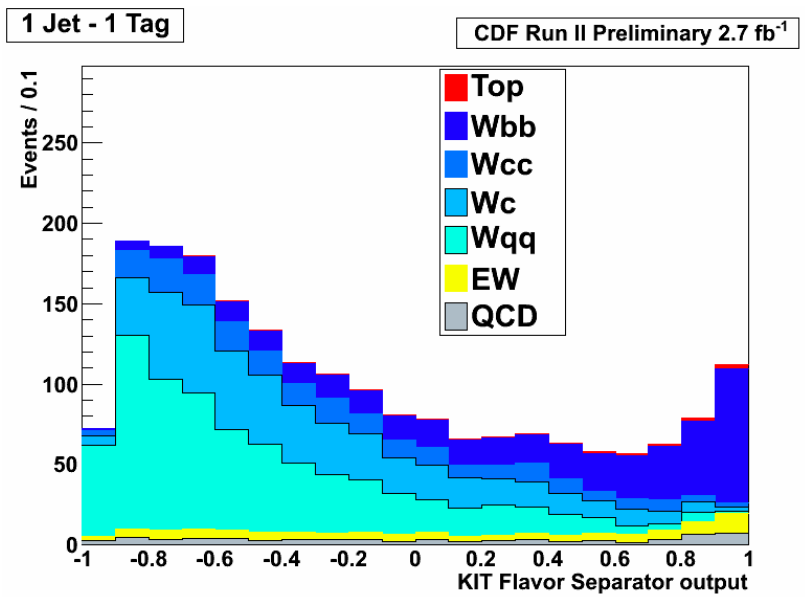
Top Pair Cross Section in Lepton+Jets

- High-statistics l+jets decay mode
- One high-p_T lepton, high MET, b-tagging
- Main background is W+jets

Use jet multiplicity and flavor/multiplicity of the b-tagged jets to fit for W+jets cross sections and b-tag efficiency

Jet flavor determination using properties of the b-tag displaced vertices





$$\sigma_{tt} = 7.64 \pm 0.57_{stat+syst} \pm 0.45_{lumi}\ pb$$

Top Pair Cross Section in MET+Jets

Select t-tbar in MET + 2/3 jets

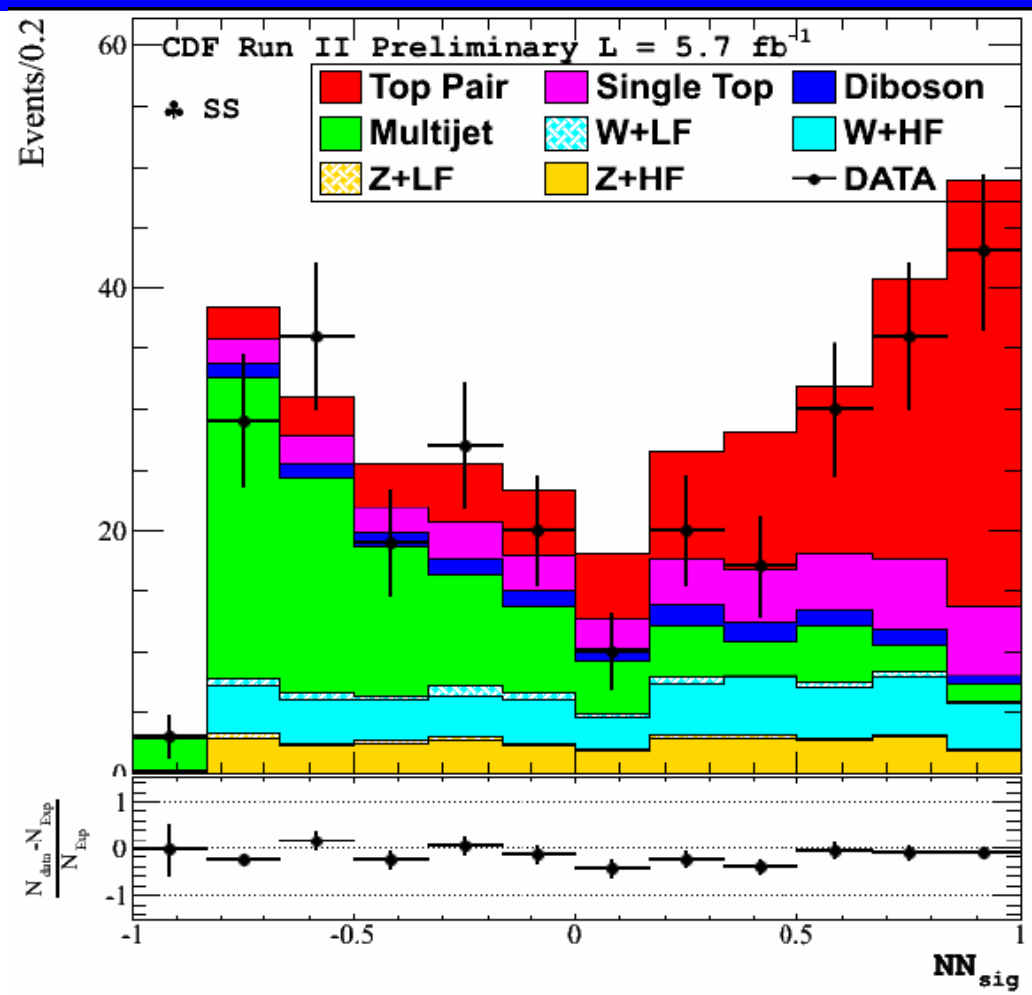
Veto charged leptons – no overlap

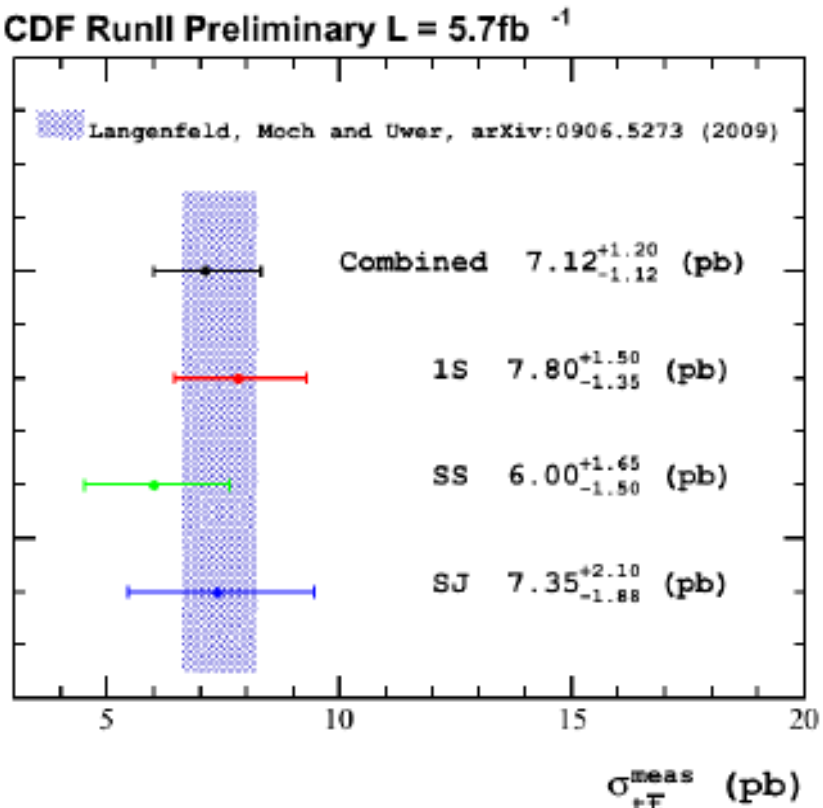
Recover dilepton and l+jets events where the lepton is lost

MET > 50 GeV, jet E_T > 35,25,(15)

At least one of two lead jets b-tagged

Multivariate discriminant to separate signal/backgrounds





Split sample by b-tag multiplicity as in Higgs, single-top searches

Good consistency between channels

$$\sigma_{tt} = 7.12\ ^{+1.20}_{-1.12}\ \text{(stat+syst) pb}$$

Top Quark Mass in Lepton+Jets

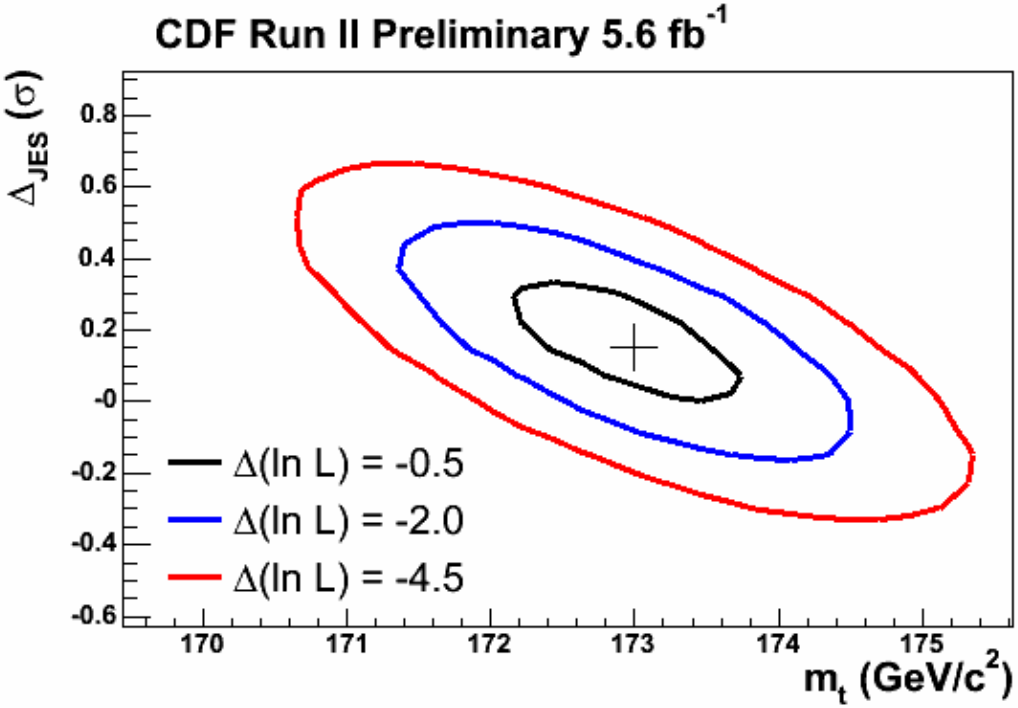
Lepton+jets channel is the most powerful for top mass

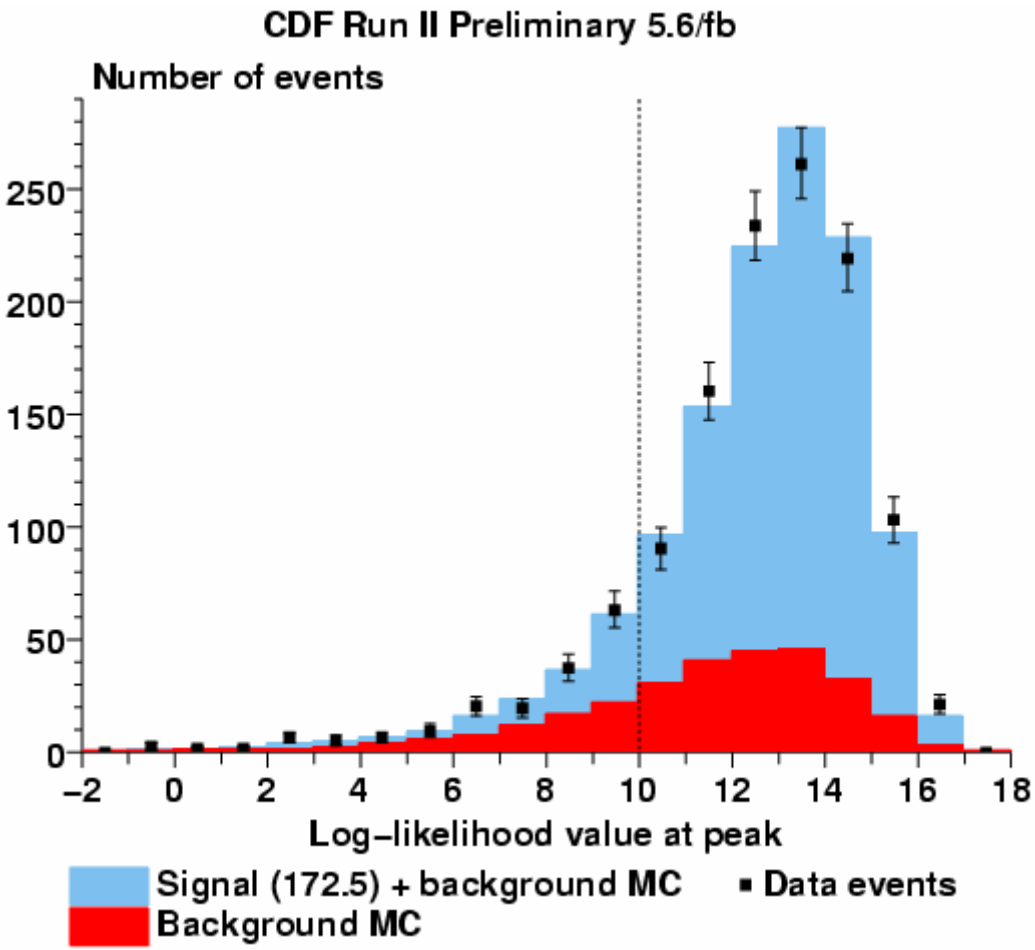
Good yield vs purity, only one neutrino

High-p_T lepton, high MET, =4 jets, b-tag

Event-by-event background probability from kinematic NN

Matrix element probability reflects event constraints/correlations

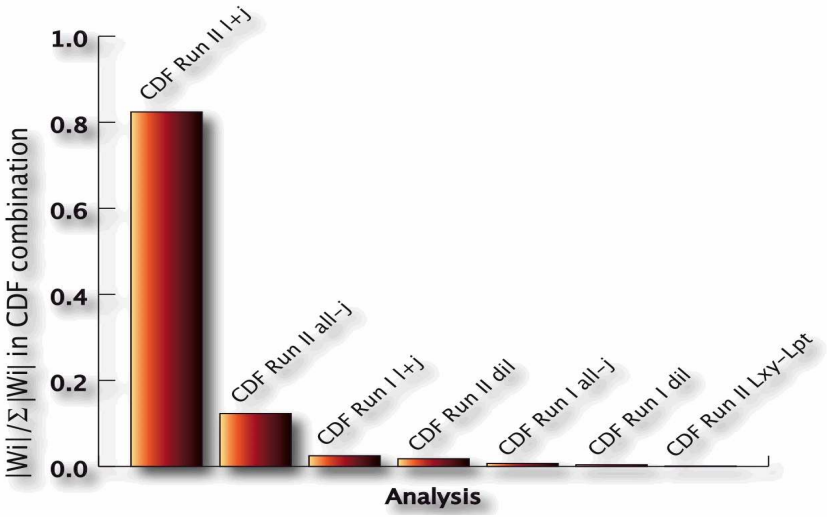


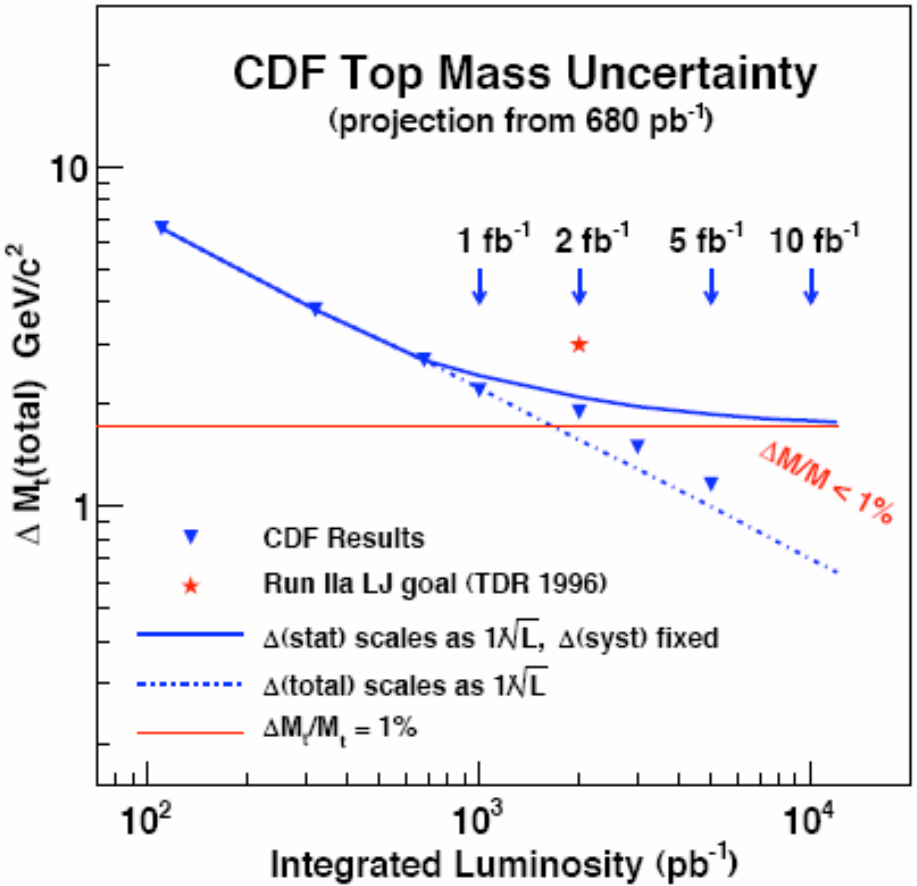


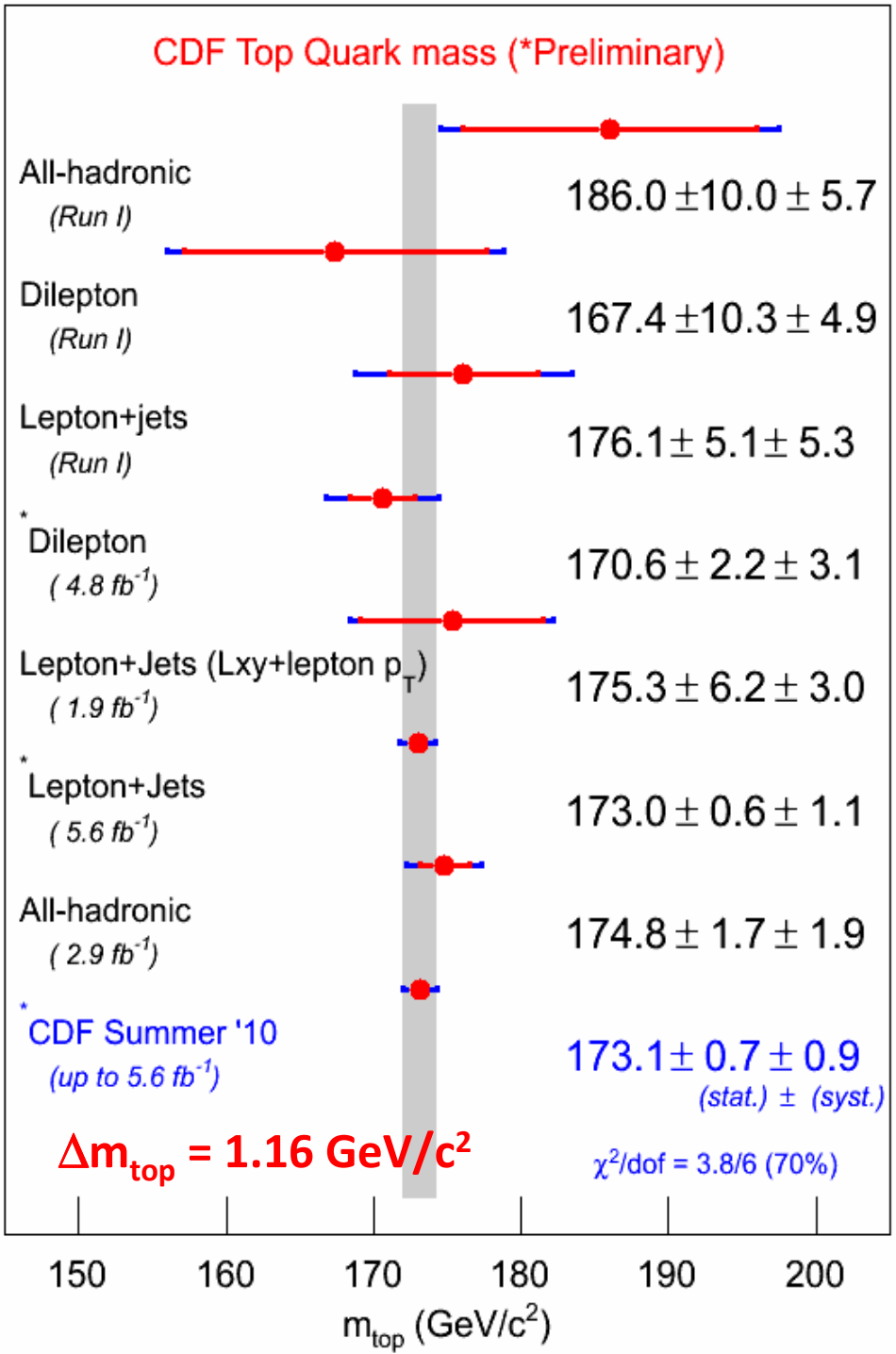
Calibrate the jet energy scale from the hadronic W decay jets

$$m_t = 173.0 \pm 0.7_{stat} \pm 0.6_{JES} \pm 0.9_{syst}\ \mathrm{GeV}/c^2 = 173.0 \pm 1.2\ \mathrm{GeV}/c^2$$

CDF Top Mass Combination



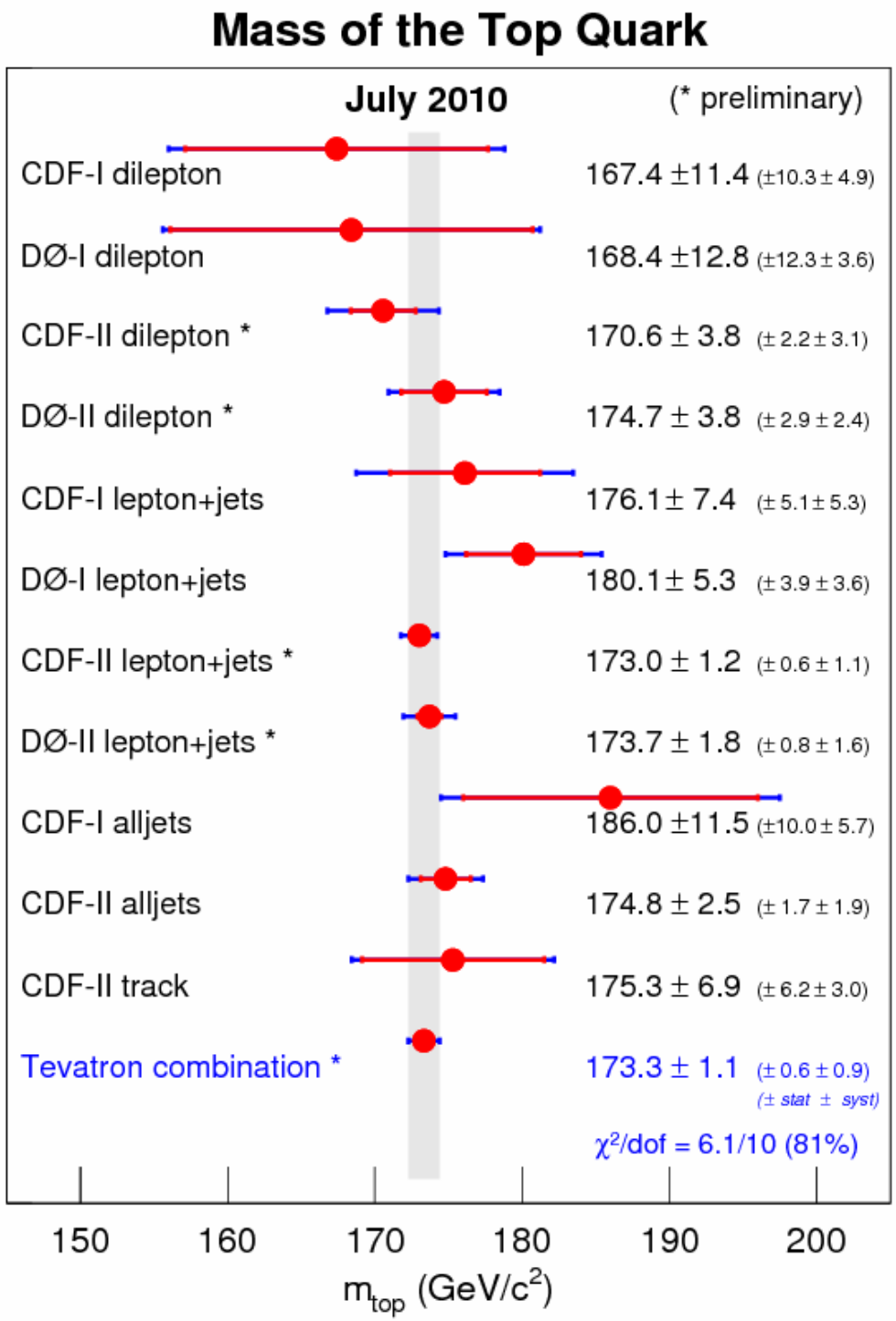




Tevatron Top Mass Combination

$m_t = 173.3 \pm 1.1$ GeV/c^2

0.6% precision!

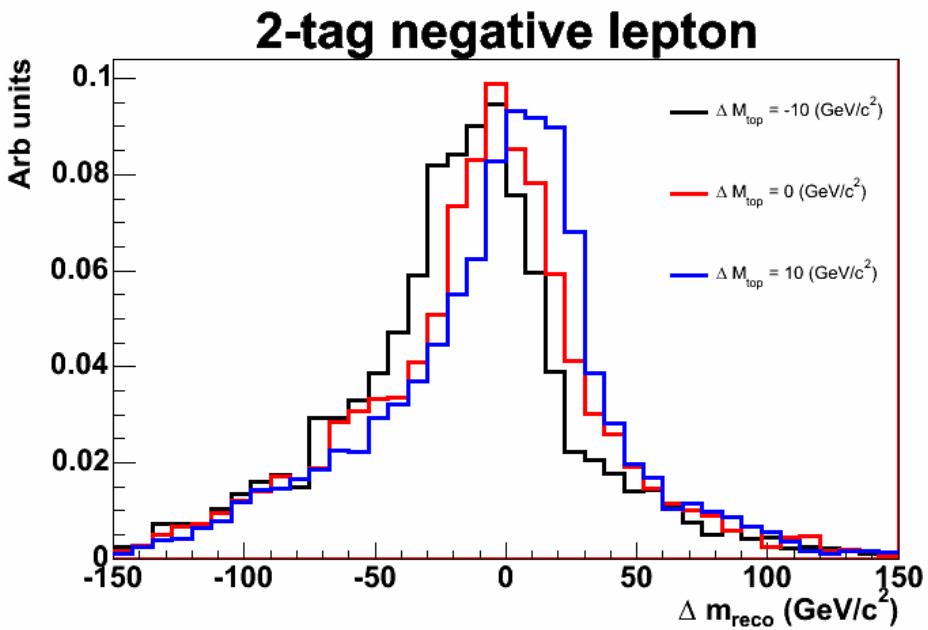


Top-Antitop Mass Difference

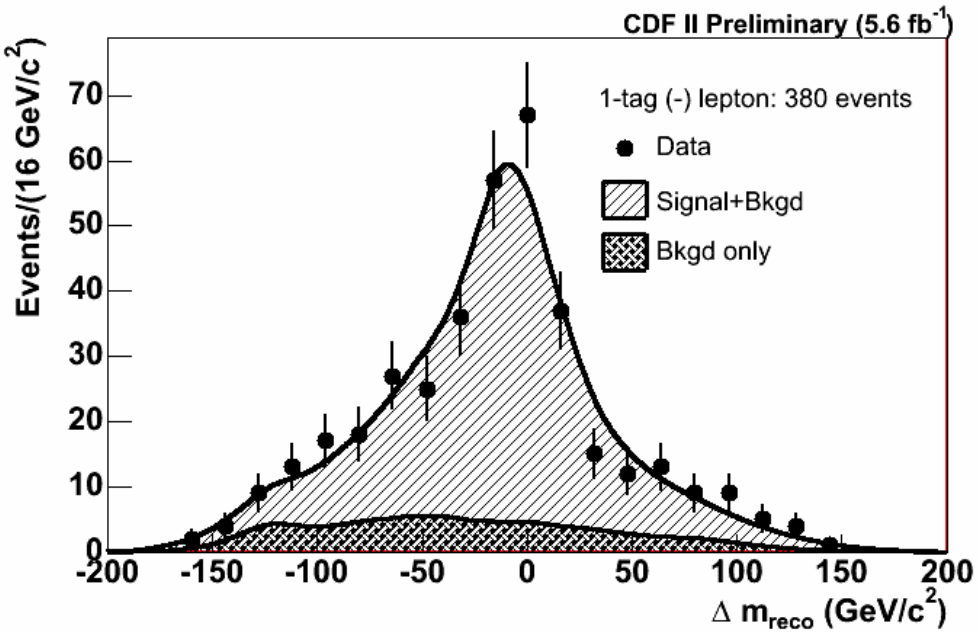
Test of CPT invariance using the high-precision top mass machinery (5.6 fb^{-1})

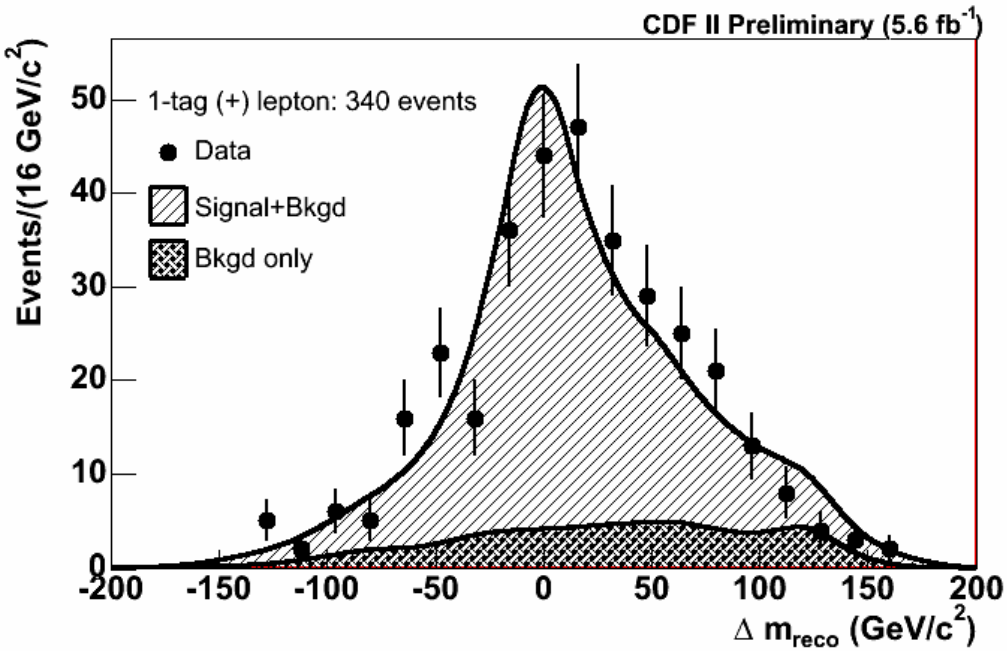
- Lepton+MET+4 jets, split by 0,1,2 b-tags
- Split by lepton charge
- Introduce $\Delta m_{reco} = m_{top} - m_{antitop}$ in fit

Correct to "true" Δm_{top} using MC samples



$$\Delta m_{top} = -3.3 \pm 1.4_{stat} \pm 1.0_{syst}\ GeV/c^2$$





A_{FB} in Top Pair Production

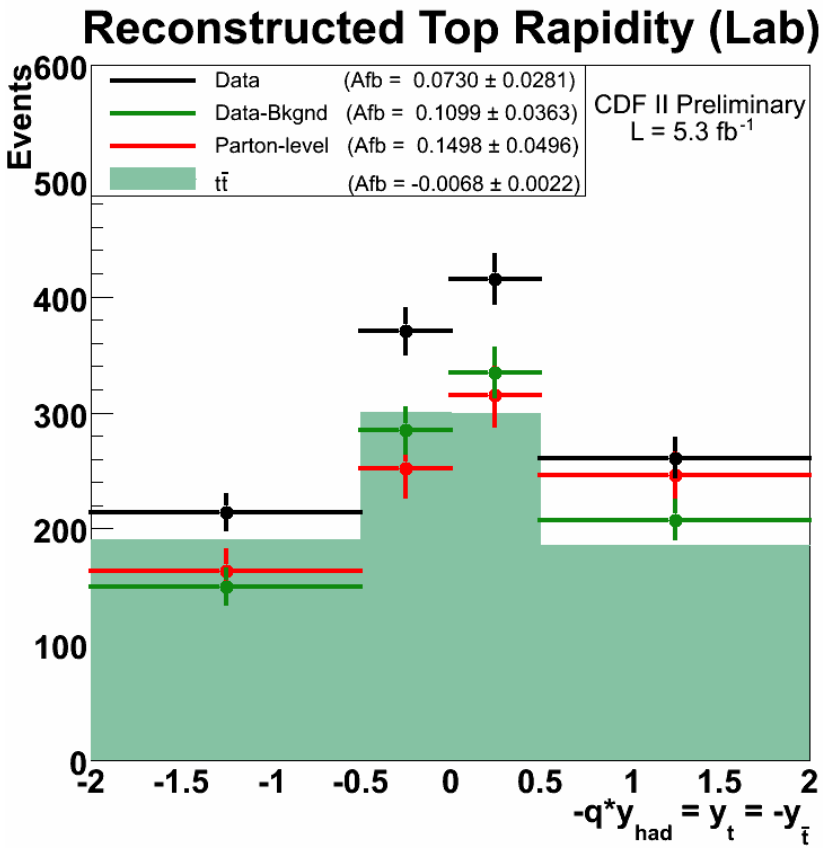
QCD predicts a small effect (4-6% from MCFM)

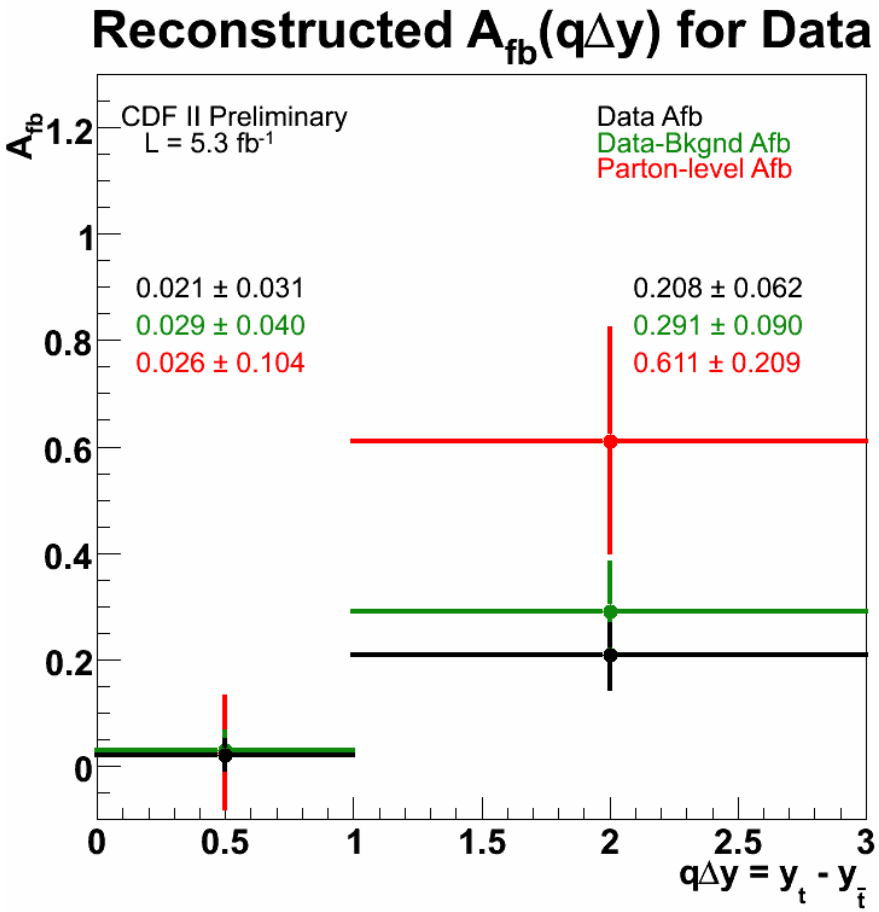
Hadronic top decay has best rapidity pointing

Measure A_{FB} in lab frame

Rapidity difference allows access to t-tbar frame

Unfold to parton-level using migration matrix





A_{lab}: $A_{FB} = 0.150 \pm 0.050_{stat} \pm 0.024_{syst}$

A_{ttbar}: $A_{FB} = 0.158 \pm 0.072_{stat} \pm 0.017_{syst}$

Study rapidity dependence using A_{ttbar}

$\Delta y<1.0$: $A_{FB} = 0.026 \pm 0.104_{stat} \pm 0.055_{syst}$

$\Delta y>1.0$: $A_{FB} = 0.611 \pm 0.210_{stat} \pm 0.141_{syst}$

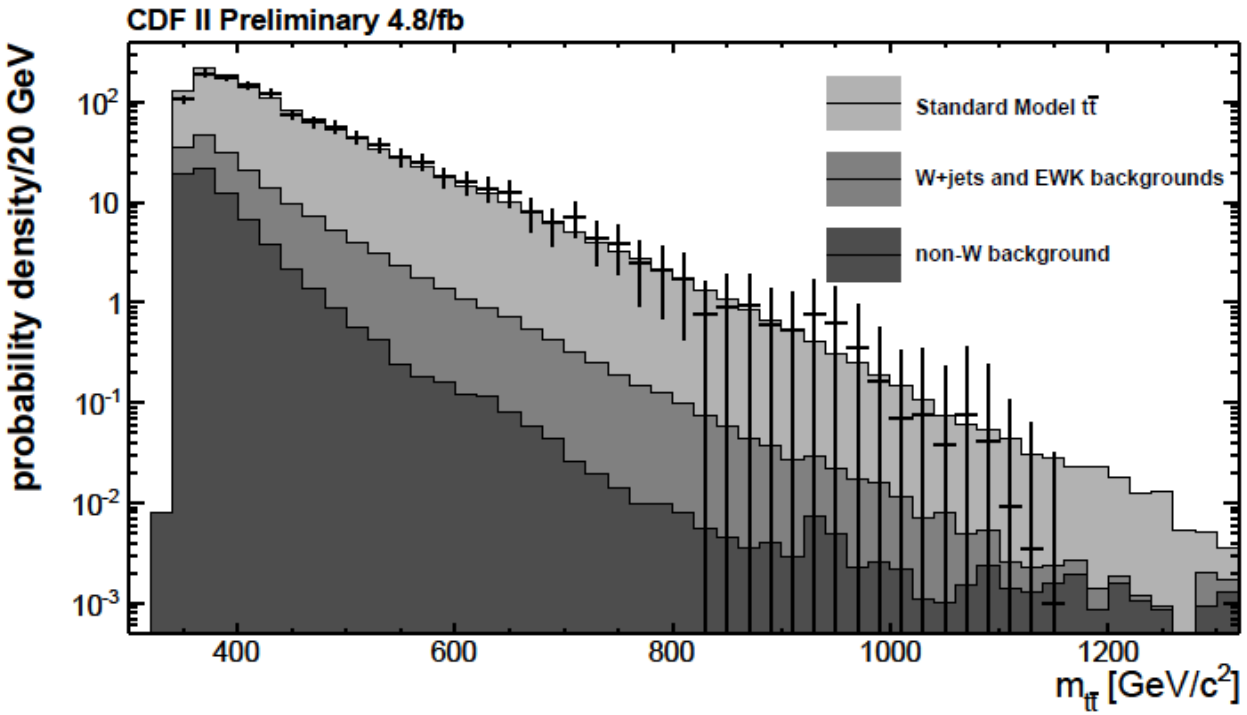
MCFM : 0.039 ± 0.006 (<1), 0.123 ± 0.018 (>1)

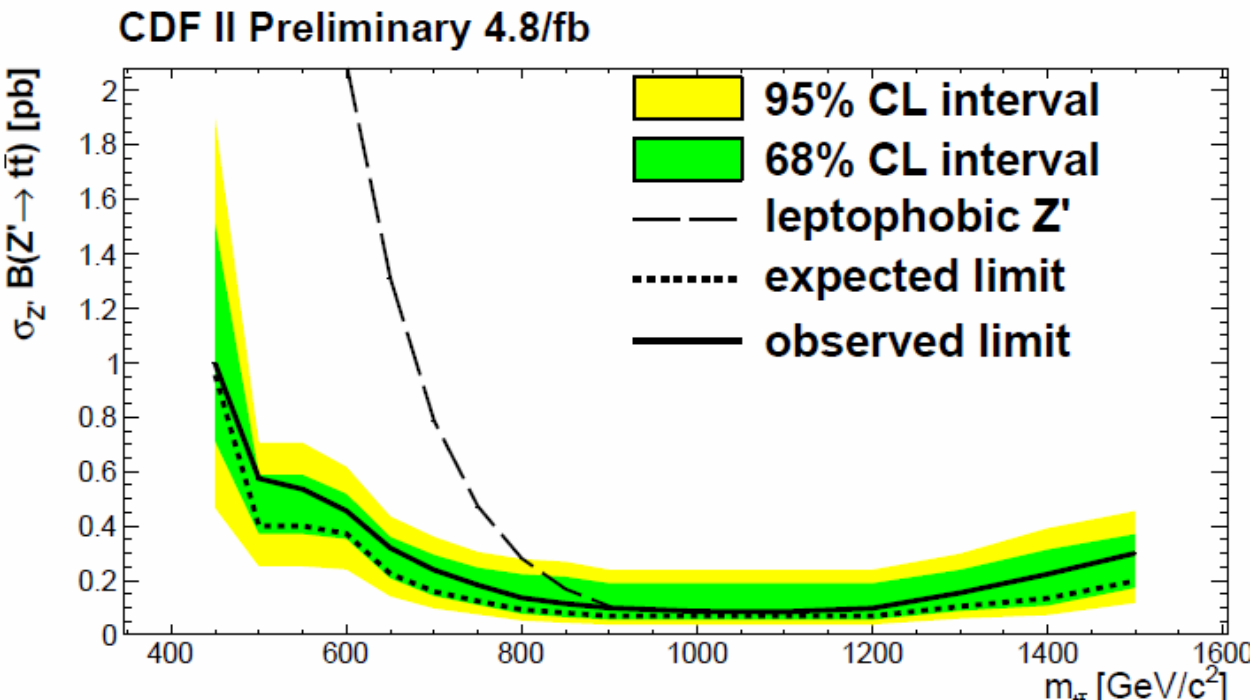
Top-Antitop Resonances

Matrix element event analysis in lepton+jets sample

Use full probability density for each event (previously used mean m_{tt} from each event)

Preserves information about high-mass tails





Data are consistent with SM expectations

Exclude σ x BR more than 70-260 fb for resonances above 650 GeV/c^2

Boosted Top

Like jet substructure, but reverse the t-tbar veto cuts

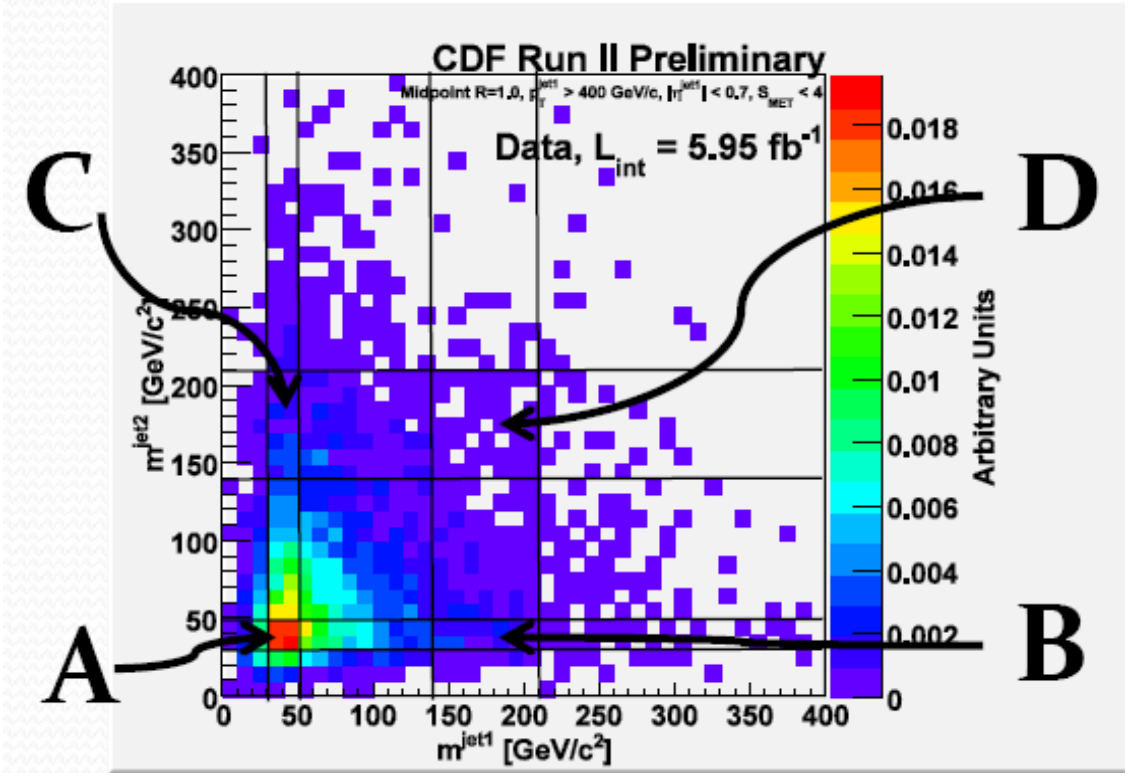
Cone-1.0, jet p_T > 400 GeV

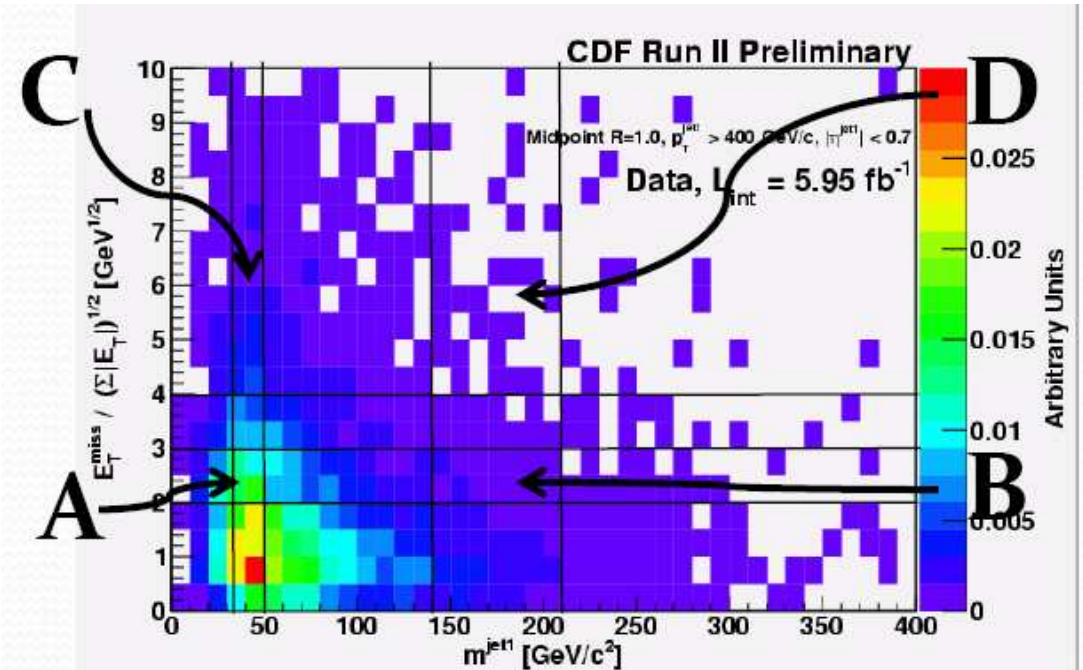
All-hadronic:
both in 140<m<210 GeV, S_{MET}<4

Lepton+jets:
$140<m_1<210$ GeV and $4<S_{MET}<10$

Double-sideband method to estimate backgrounds

Expect 5.8 top events (σ=4.6 fb)





Bkgd: 76 ± 10_{stat} +26-20_{syst}

Observe: 103 events

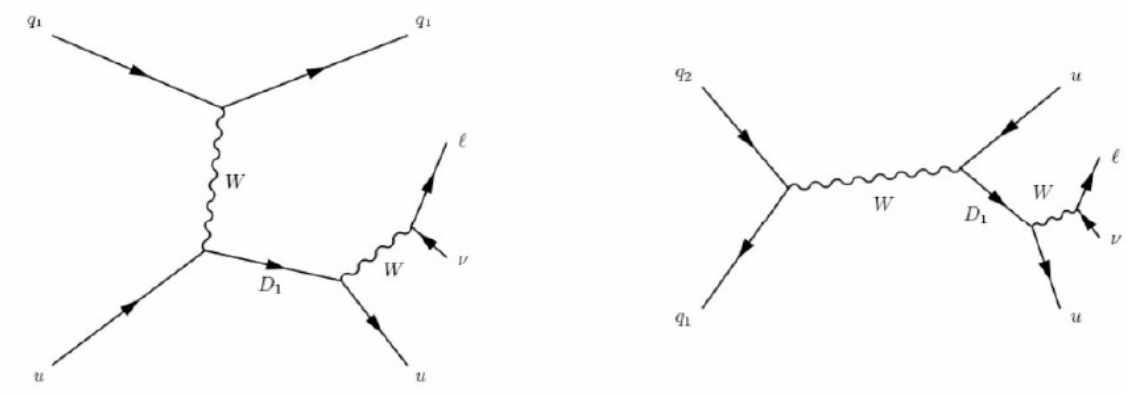
$\sigma_{tt}(p_T>400)$ < 54 fb @ 95% CL

Singly-Produced Heavy Quarks

Produced with a spectator light quark

Decay to light quark 100%

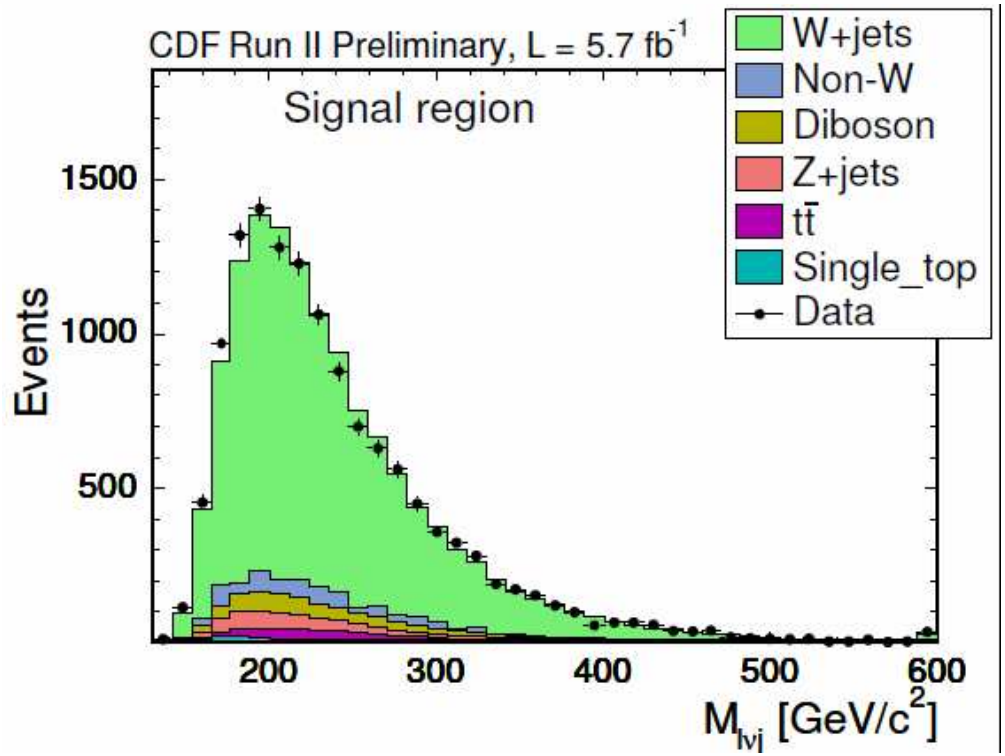
Similar to single-top but no b-jets

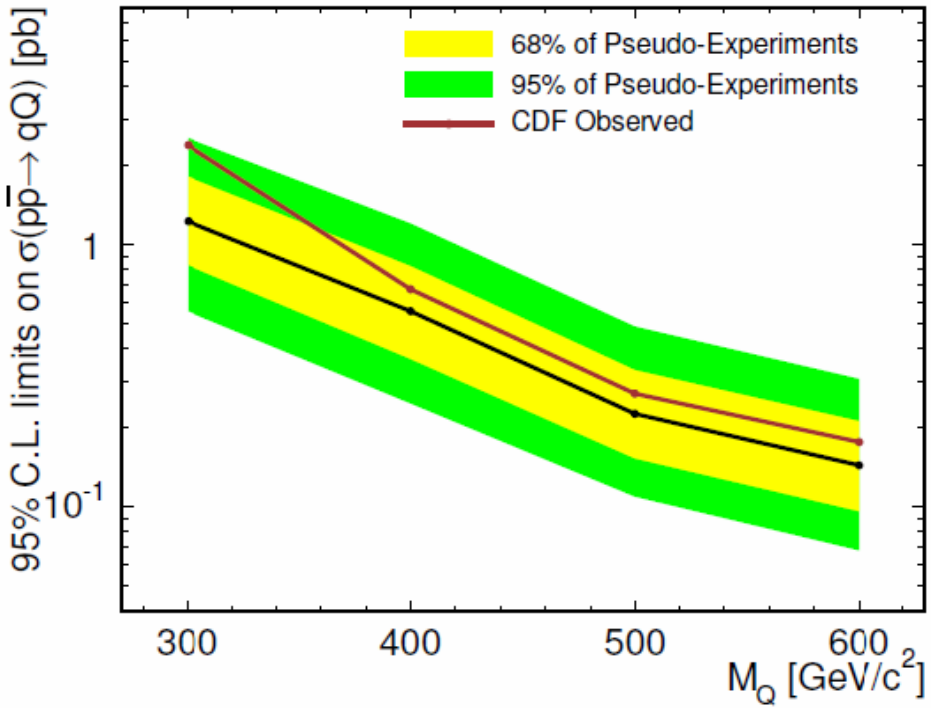


High-p_T lepton, high MET, 2 jets

jet E_T > 60 GeV optimal

Main background W+jets





Search in M(lνj), mass of the lepton, neutrino, and leading jet

No excess observed, limits on $\sigma(pp \rightarrow qQ)$

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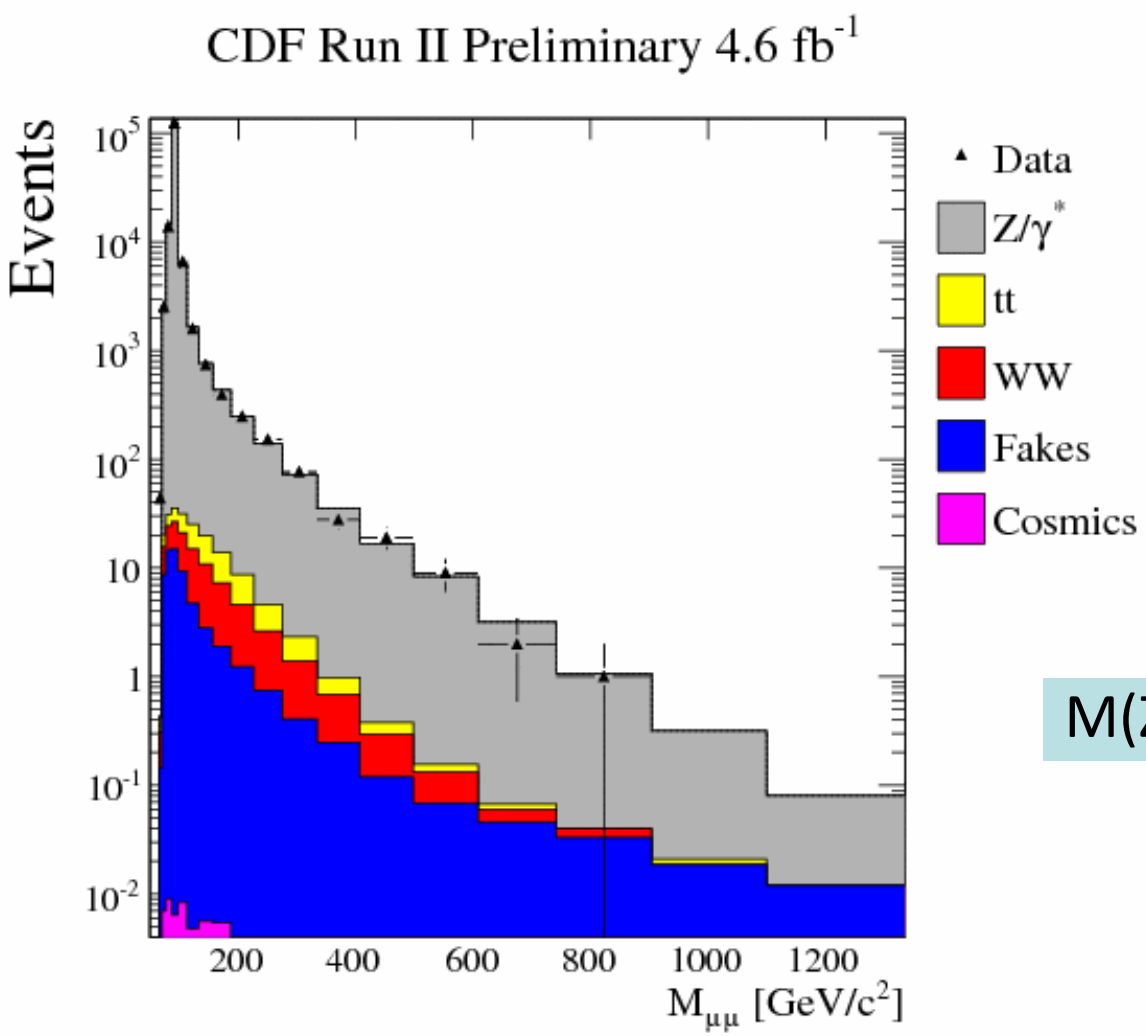
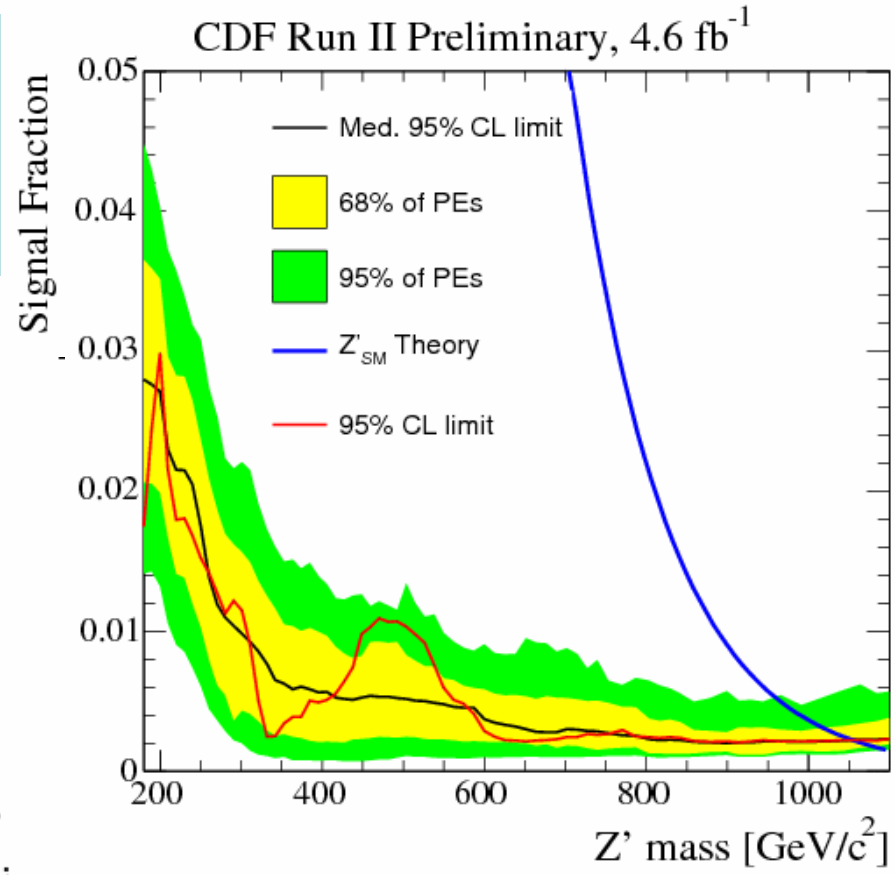
- High mass diphoton resonances
- Multijet resonances

High-Mass Dimuon Resonances

First CDF direct exclusion above 1 TeV
PRL 102, 091805 (2009), 2.3 fb^{-1}

New: twice the luminosity, matrix element to incorporate muon p_T resolution weighting



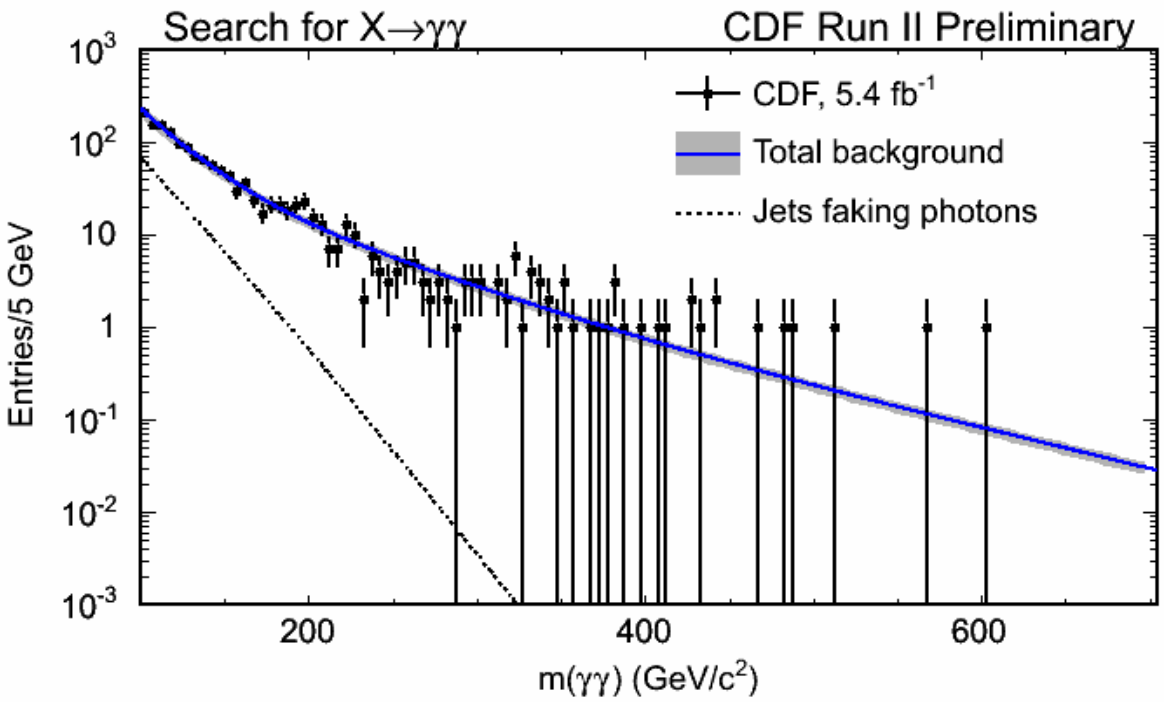


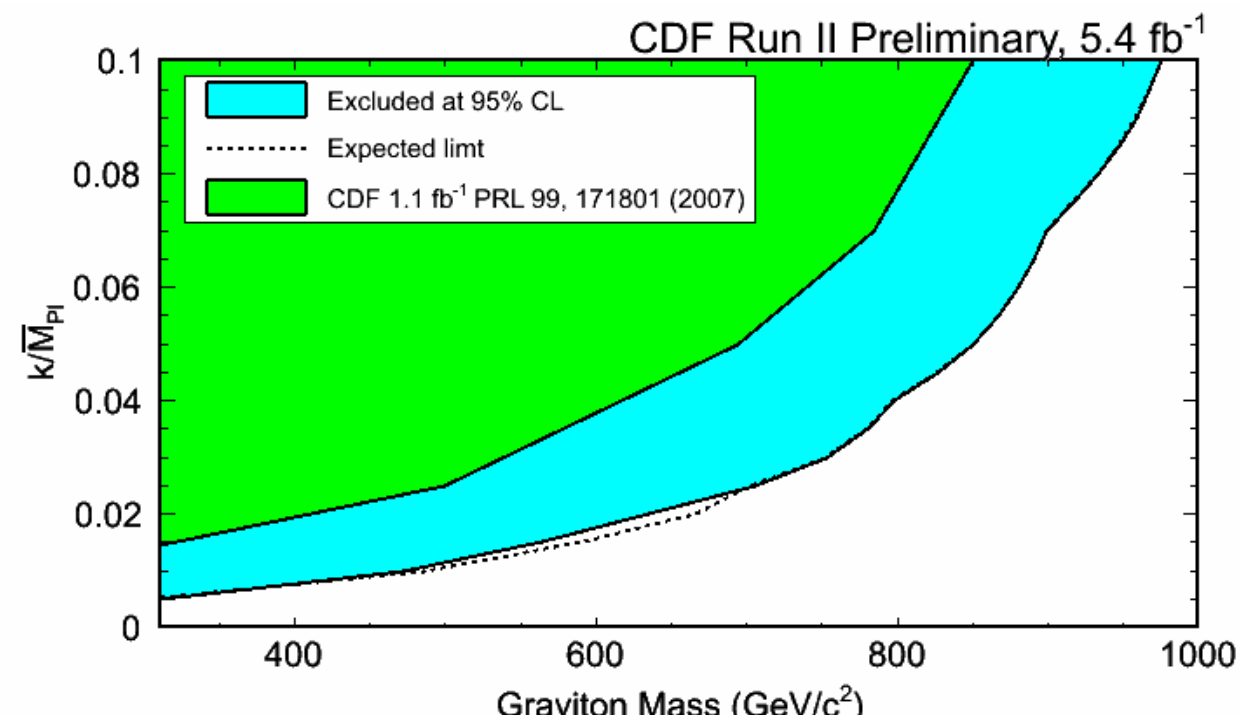
$M(Z'_{SM}) > 1071$ GeV/c^2 (95% C.L.)

High-Mass Diphoton Resonances

General search, interpret in Randall-Sundrum graviton scenario

SM diphoton background: DIPHOX NLO calculation matched to Pythia





Limits on RS graviton mass and coupling parameter k/M_{pl}

Exclude up to 976 GeV/c^2 for $k/M_{pl} = 0.1$

Multijet Resonances

Model independent search for pp → QQ → 3j+3j = 6j

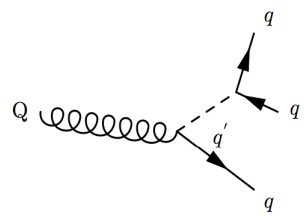
Start with 6 jet selection

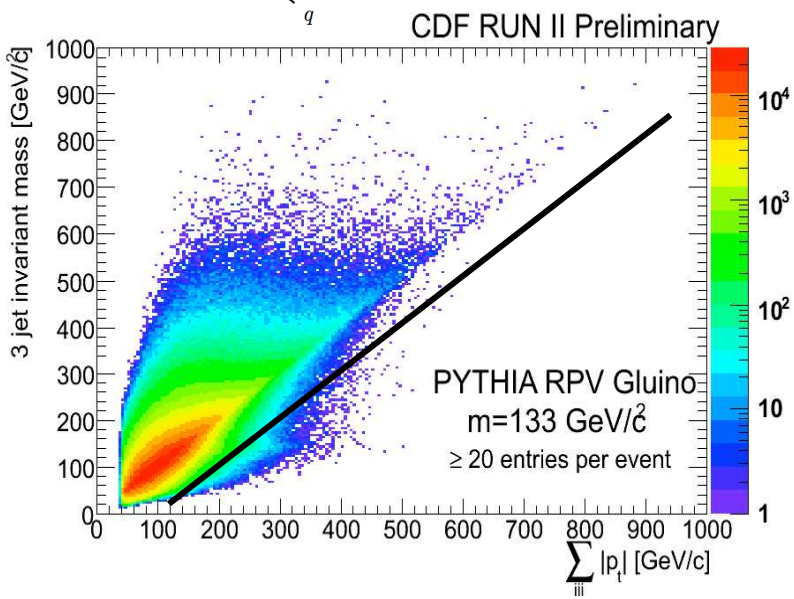
- Separate three-jet combinations that are potentially correlated using diagonal cut (invariant mass pole)
- Optimize cut for each mass point

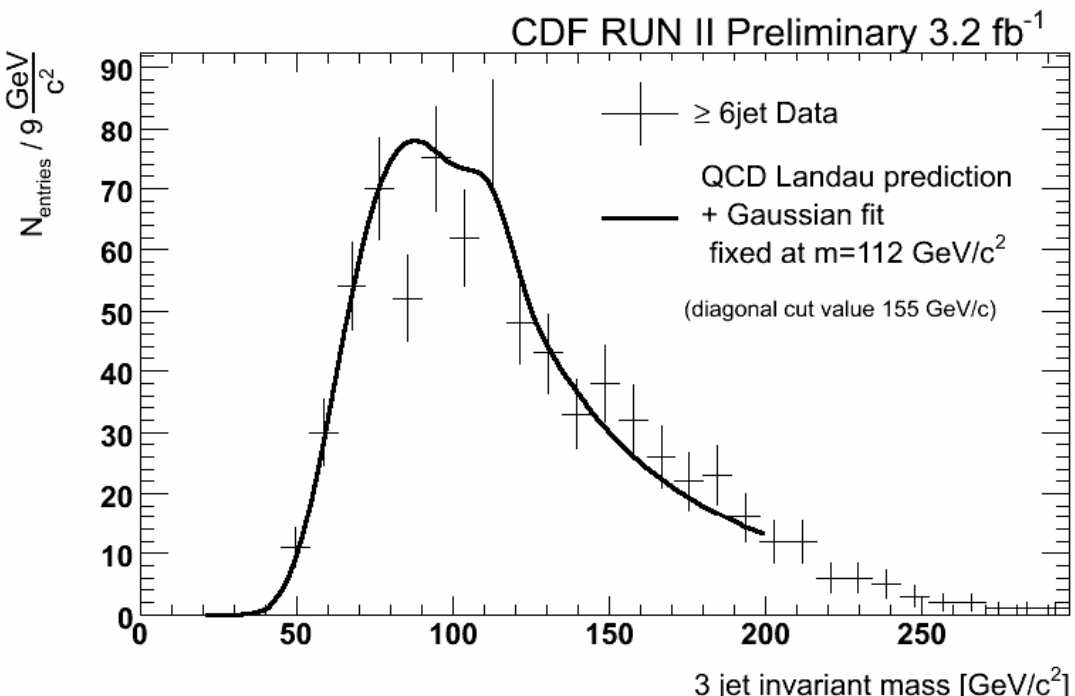
QCD background parametrized from 5-jet events

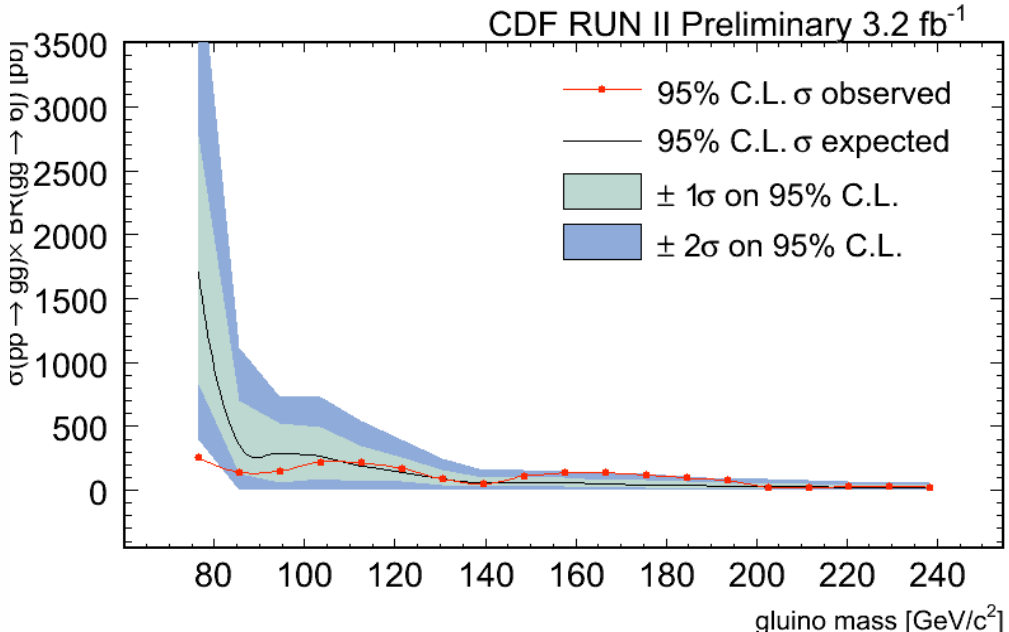
Set limits on RPV gluino scenario

- Most significant excess 2σ near top mass (only expect ~1 entry for t-tbar)









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- SM Higgs channel updates
  - $WH \rightarrow l\nu bb$
  - $ZH \rightarrow llbb$
  - $VH \rightarrow MET + bb$
  - $H \rightarrow \tau\tau$
  - $H \rightarrow WW$

- More luminosity
- Analysis improvements

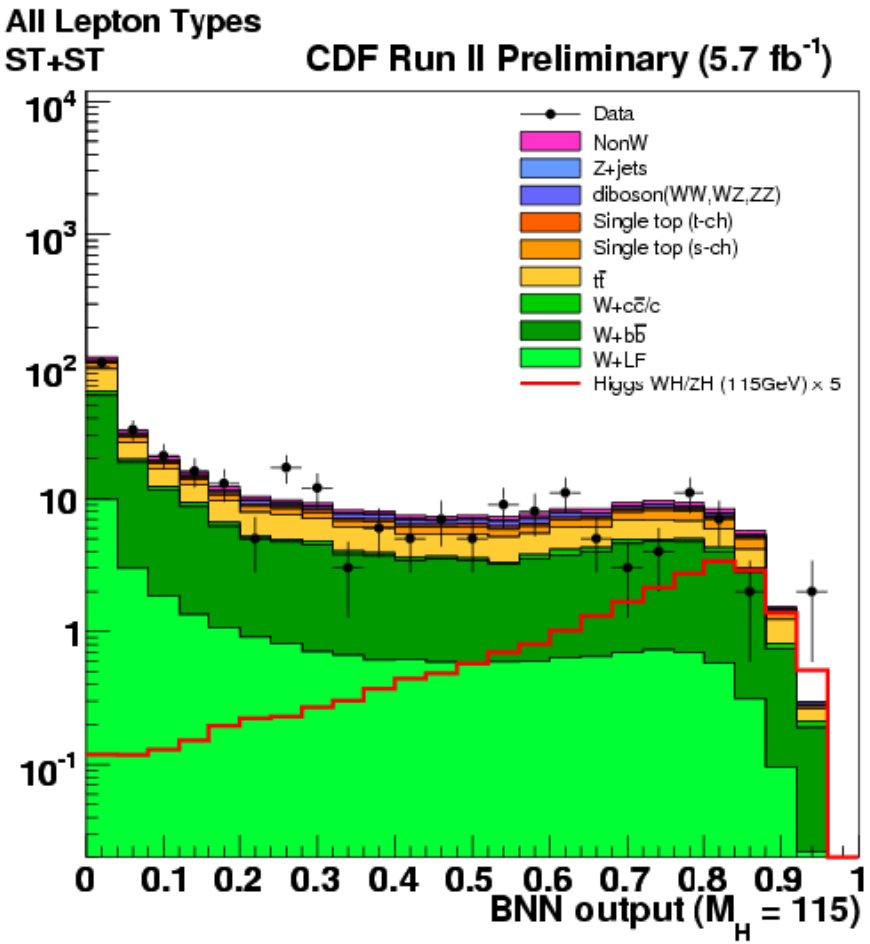
WH → lνbb (Neural Net, 4.3 → 5.7 fb^{-1})

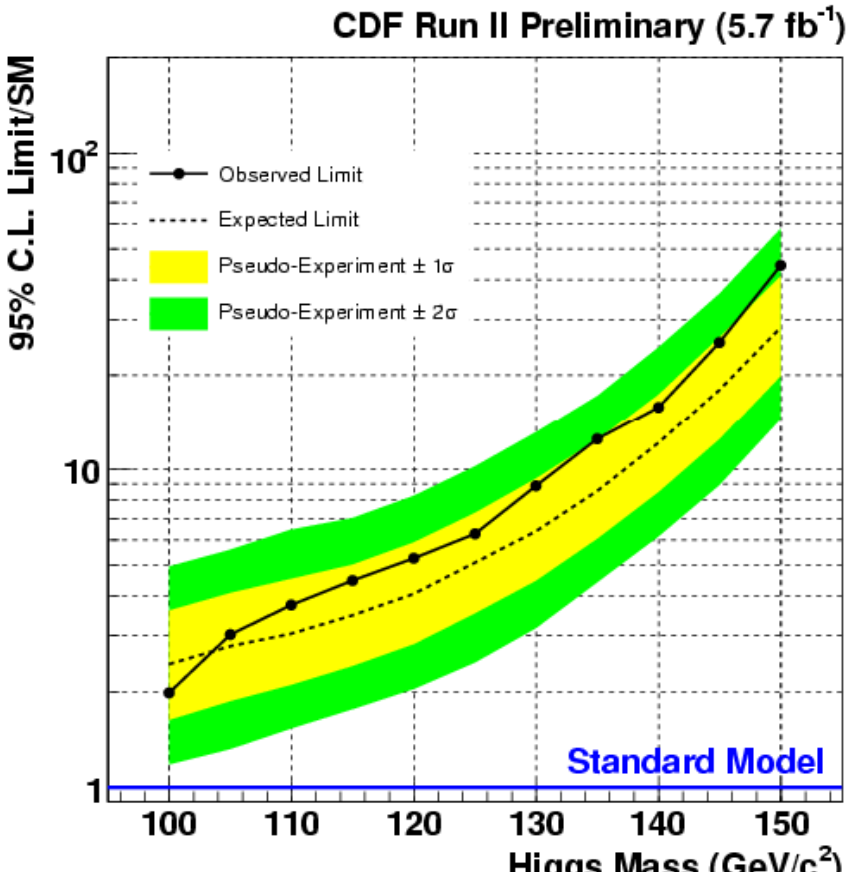
Multiple subchannels to optimize S/B

- Four b-tagging combos of three algorithms
- Flavor separation for single-tags
- New isotrack selection (loose electron/tau)

Multivariate jet energy estimator (improved m_{jj})

Final Bayesian neural net discriminant





Exclude 4.5xSM @ 115 (expect 3.5)

10% sensitivity gain beyond luminosity for this iteration

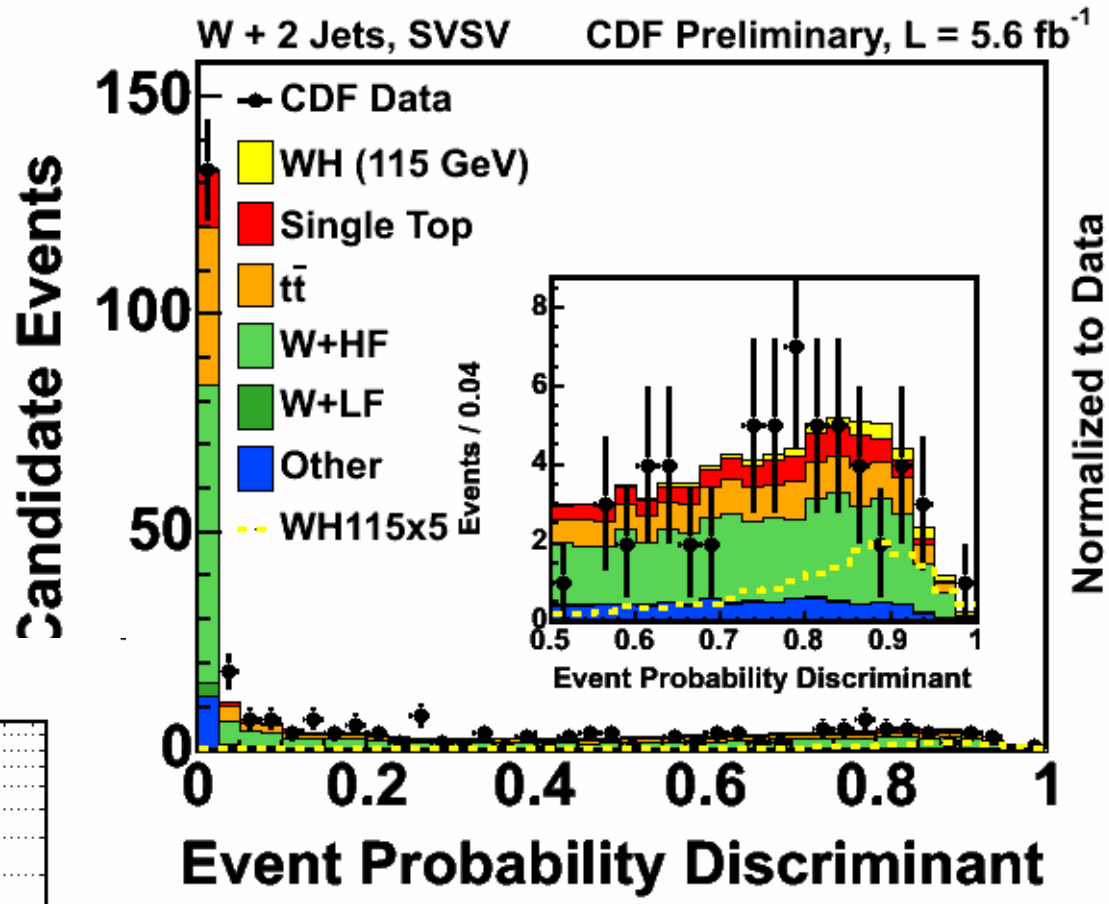
WH → lνbb (Matrix Element, 4.8 → 5.6 fb^{-1})

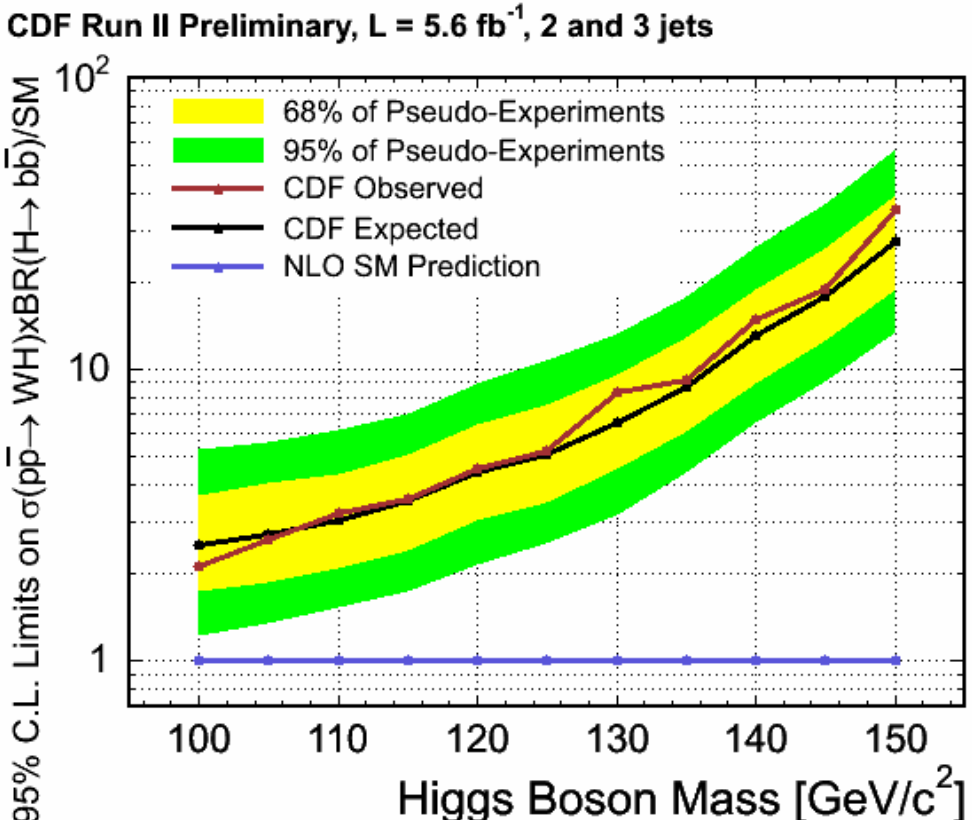
Similar selection and subchannel division as NN method

Doesn't include loose lepton and third b-tag algorithm used by NN method

Does include 3-jet events as second channel

NN → matrix element probability





Exclude 3.6xSM @ 115 (expect 3.5)

- 2jet : 4.5 (3.7)
- 3jet : 8.5 (15.8)

ZH → llbb (4.1 → 5.7 fb^{-1})

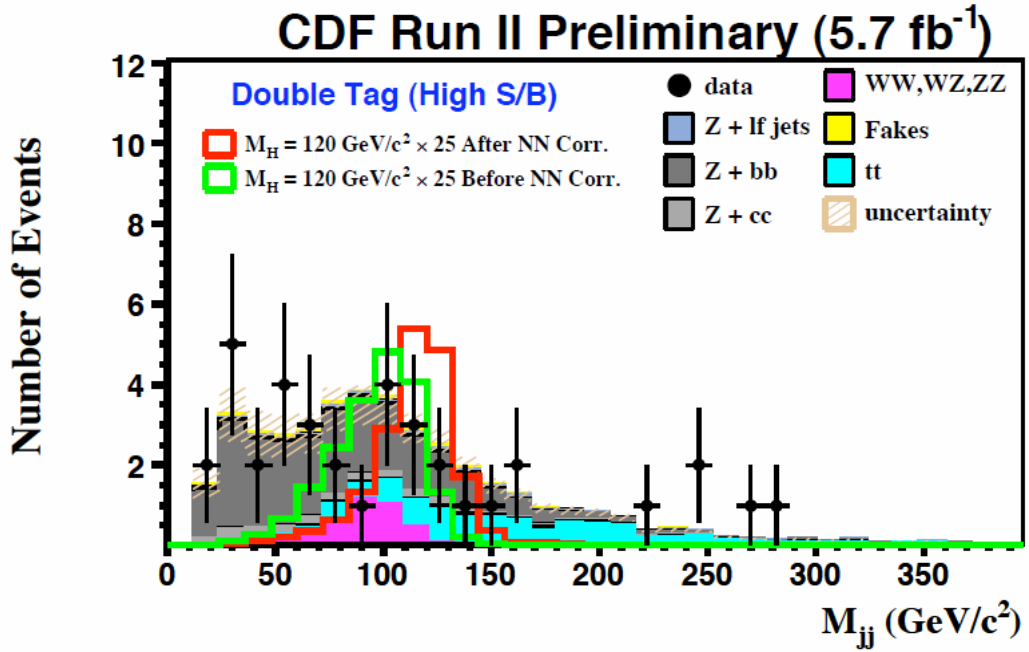
Lower BR but high purity

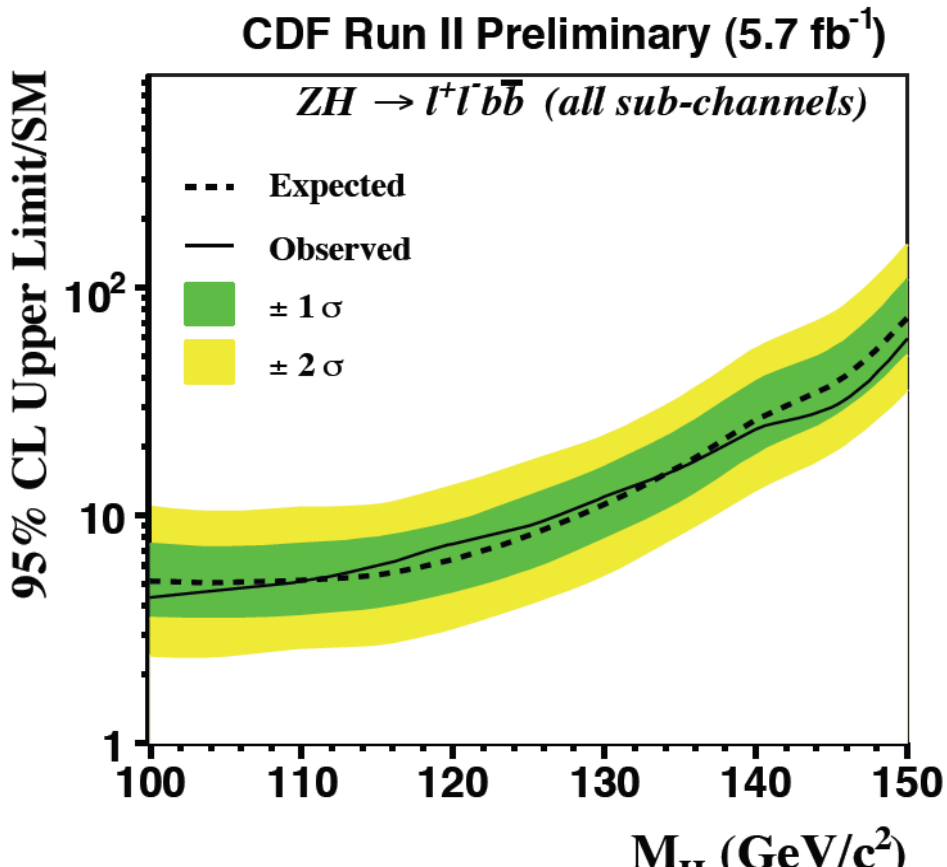
No neutrinos – can use p_T balance to correct jet energies

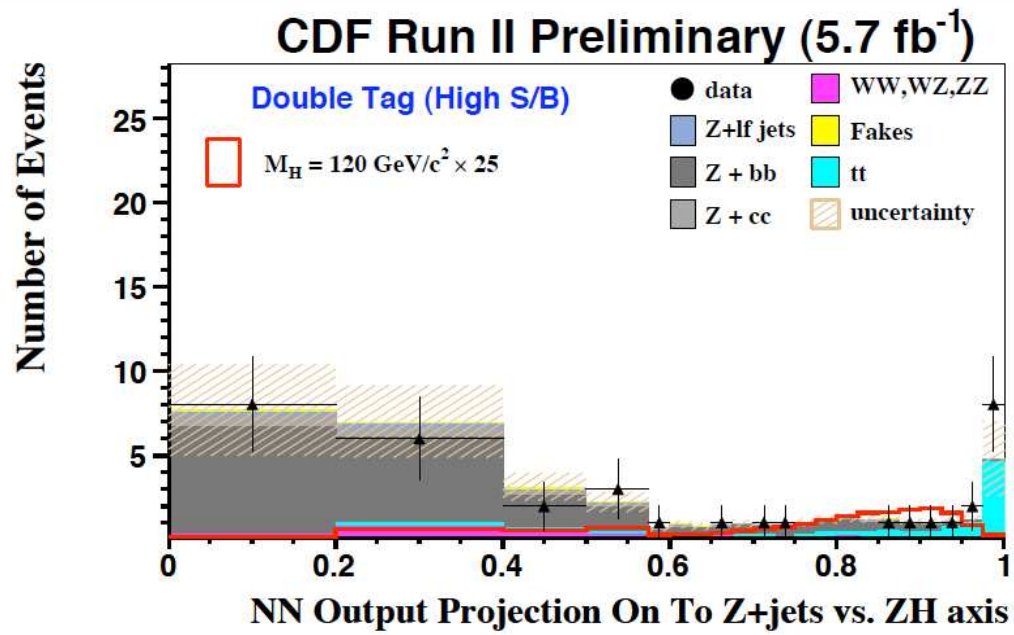
Separate by b-tag and by lepton purity

New – include events with two loose muons – 10% gain in sensitivity!

2D NN to separate ZH/top and ZH/Z+jets







Exclude 6.0xSM @ 115 (expect 5.5)

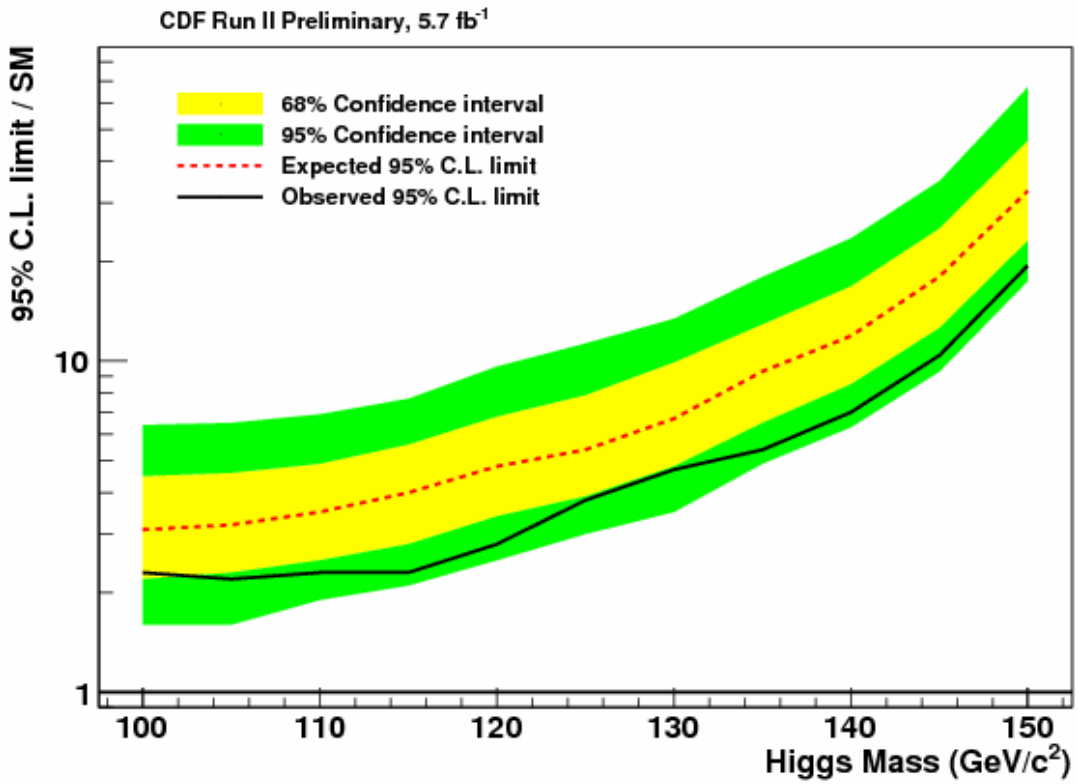
VH → MET + bb (3.6 → 5.7 fb^{-1})

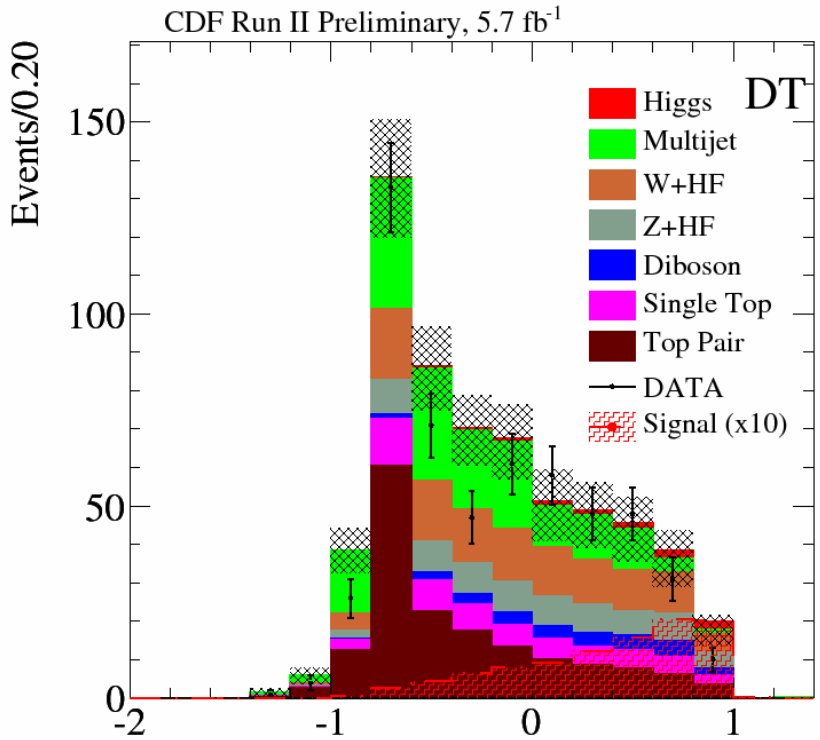
Select on missing energy to pick up both Z → νν and W → lν with lost lepton

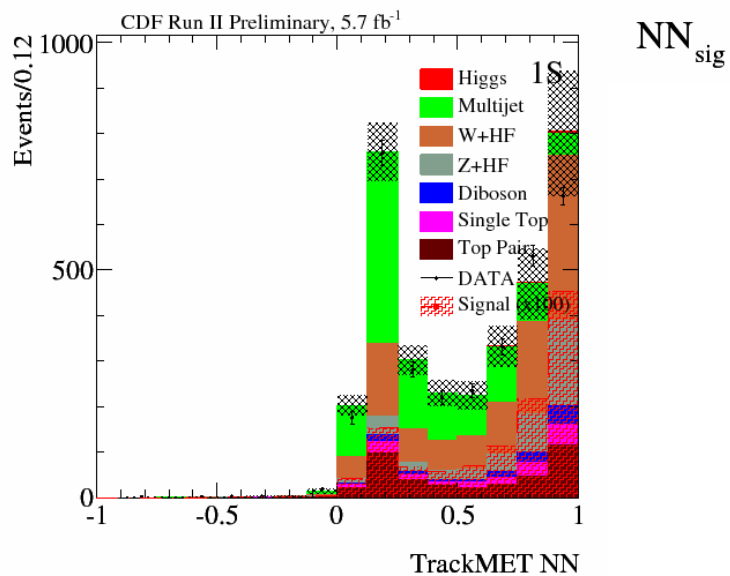
Data-driven estimate of fake tags/MET

Reject much of fake MET using a second track-based MET estimate

W/Z + HF from ALPGEN+PYTHIA







Exclude 2.3xSM @ 115 (expect 4.0)

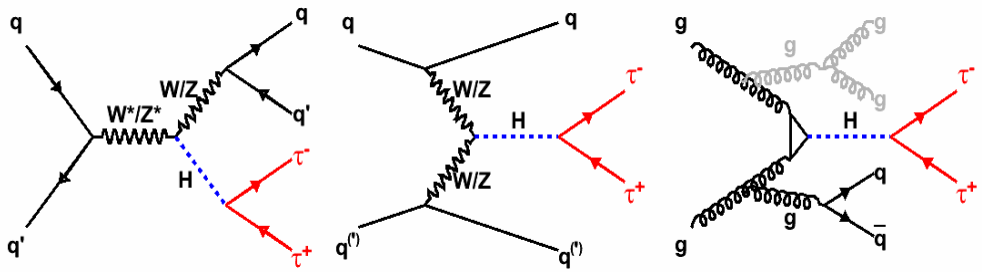
$H \to \tau\tau$ $(2.0 \to 2.3\ fb^{-1})$

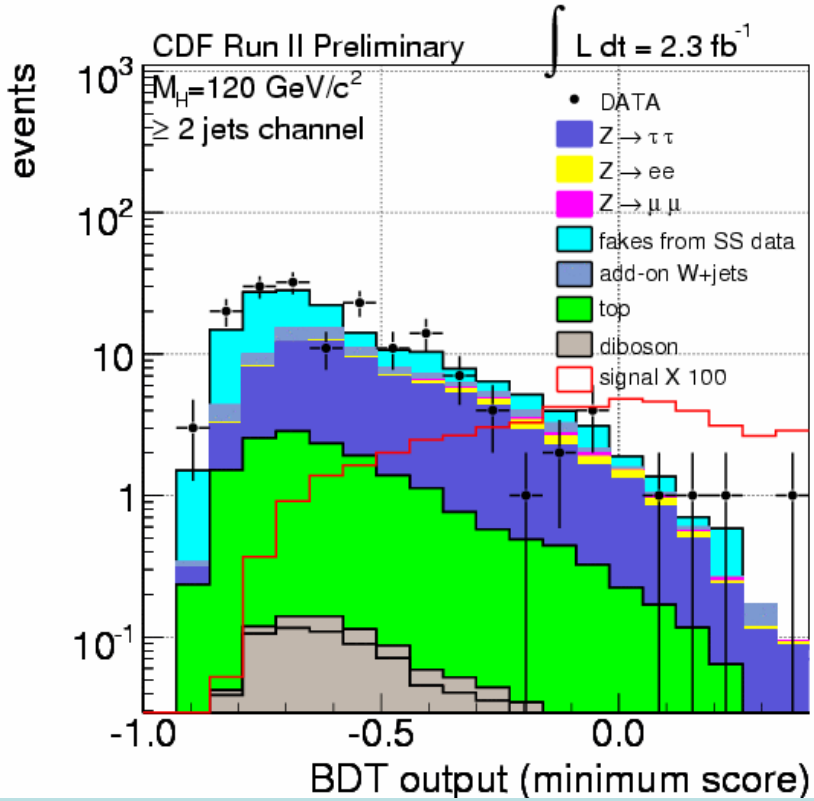
Can probe VH, VV → H, gg → H together

Only access to gg → H at low mass

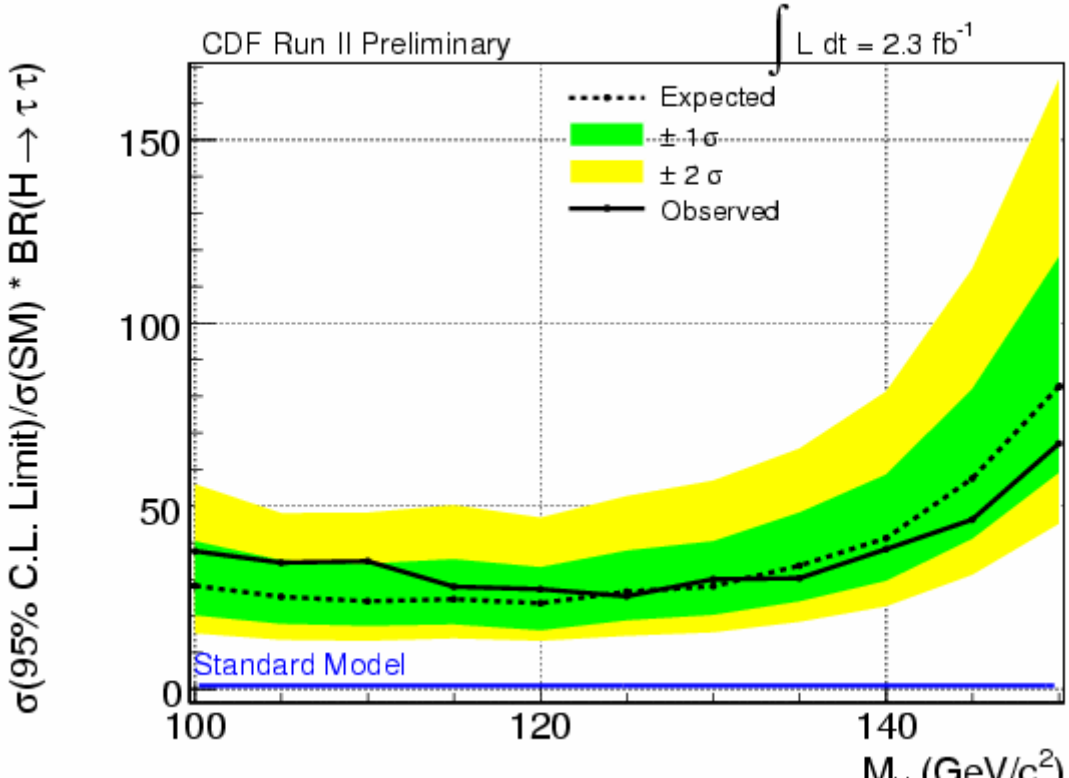
One e/μ p_T > 10 GeV, hadronic τ p_T > 15 GeV

Two channels: 1 jet and ≥2 jets





ID hadronic τ and separate signal/bkgd using multiple boosted decision tree discriminants

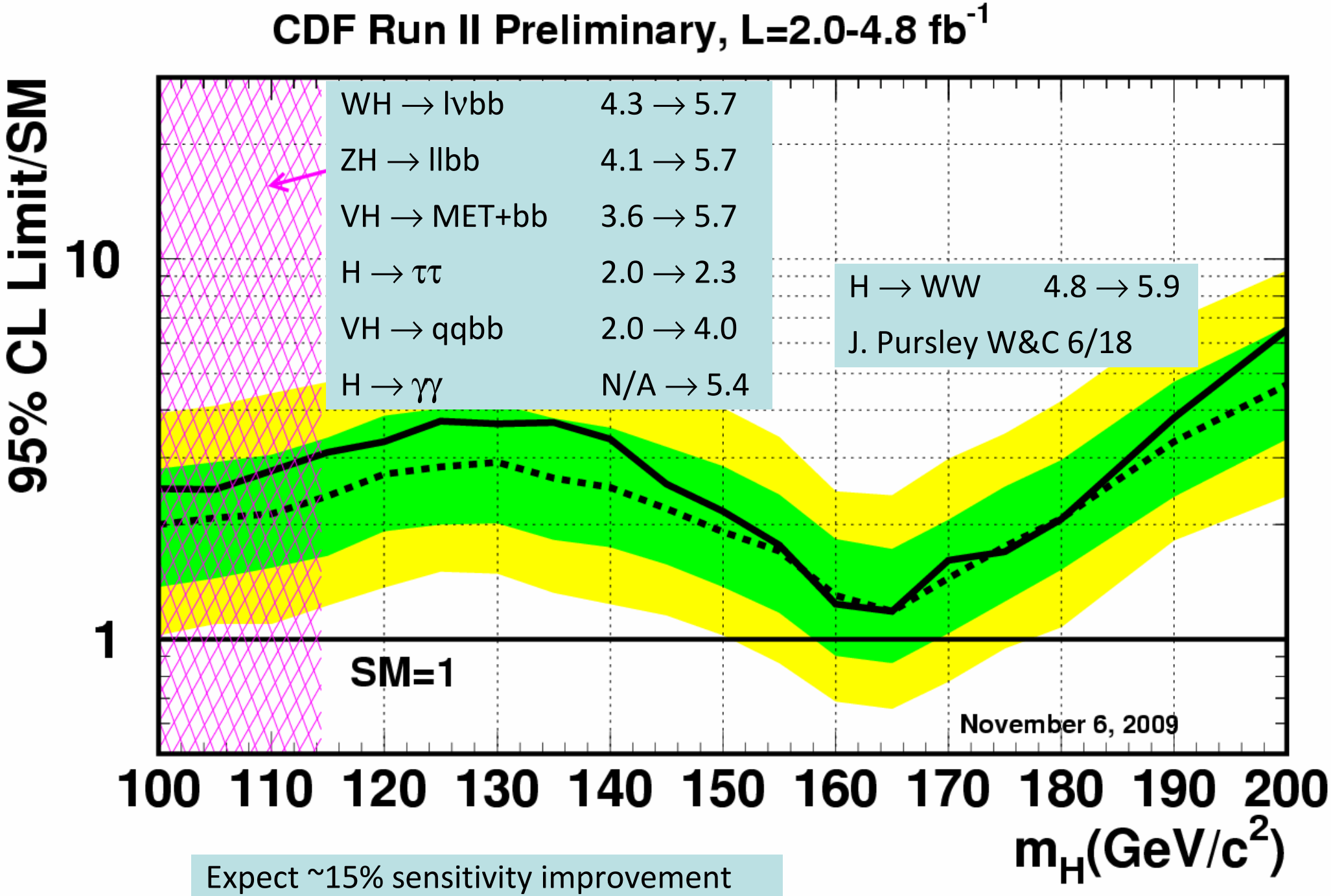


Flat sensitivity vs mass compared to bb

Exclude 28xSM @ 115 (expect 25)

10-40% better sensitivity vs last year

Since Last Combination (Nov 09)



Expect ~15% sensitivity improvement

Conclusion

- CDF physics program is strong and vibrant
- Large number of new results in the past few months
  - High precision and high sensitivity
  - Analysis techniques evolving to maximize the information from each event
- Future looks just as bright
  - Large additional dataset still to collect & analyze
  - Searching in signatures never before examined

- Thanks to everyone in CDF, D0, FNAL accelerator and computing divisions, and our funding agencies for making all of this possible!