Electroweak and Hints of New Phenomena at the Tevatron

Andrew Askew
June 8, 2012

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- Several recent EWK/NP searches (diboson, multilepton final states, analyses which are sensitive to the description from the SM, and physics beyond).

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- Specifically:
  - Dileptons (Z p_T and A_{FB})
  - Zγ and Search for GMSB in Zγ
  - Trileptons and multileptons (WZ,ZZ)

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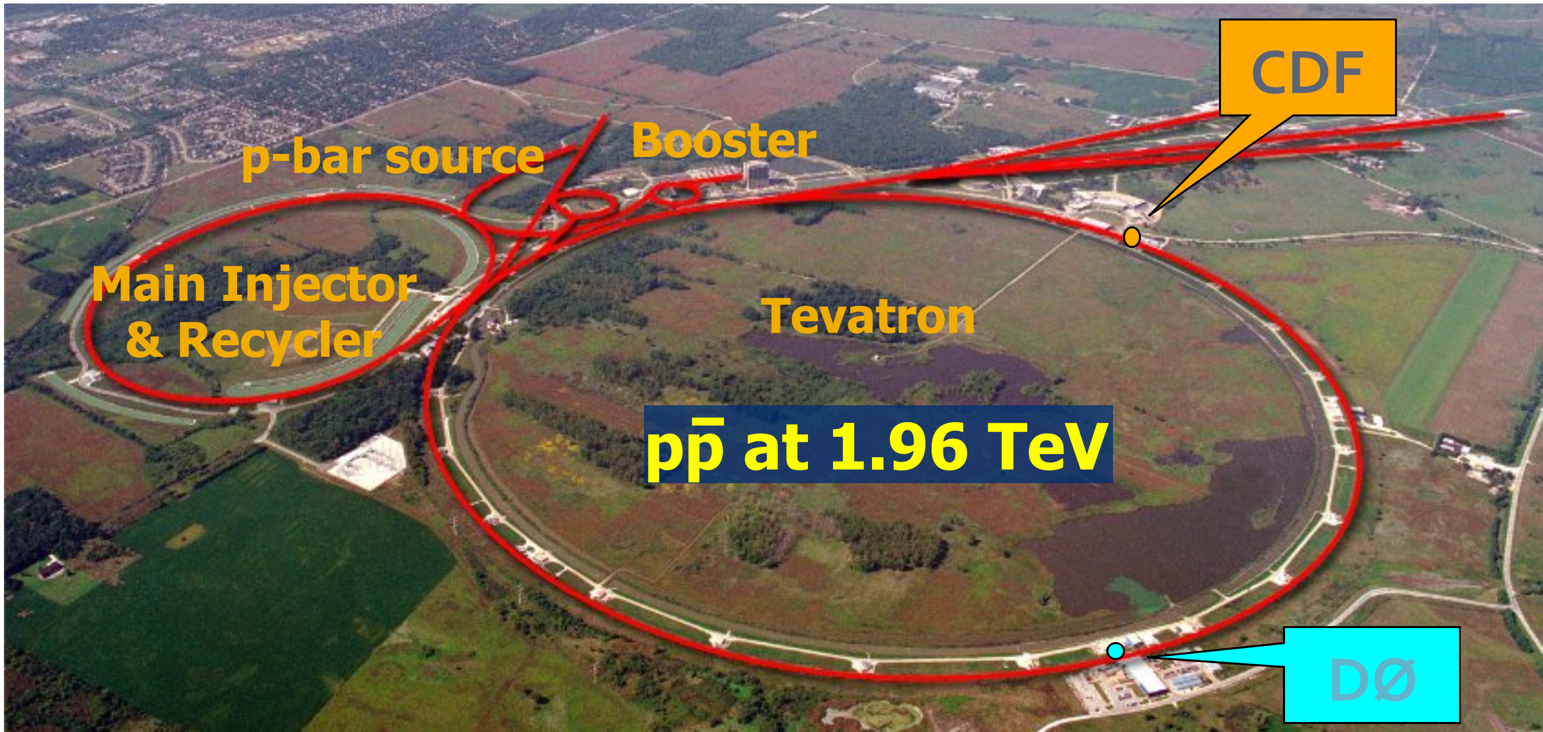
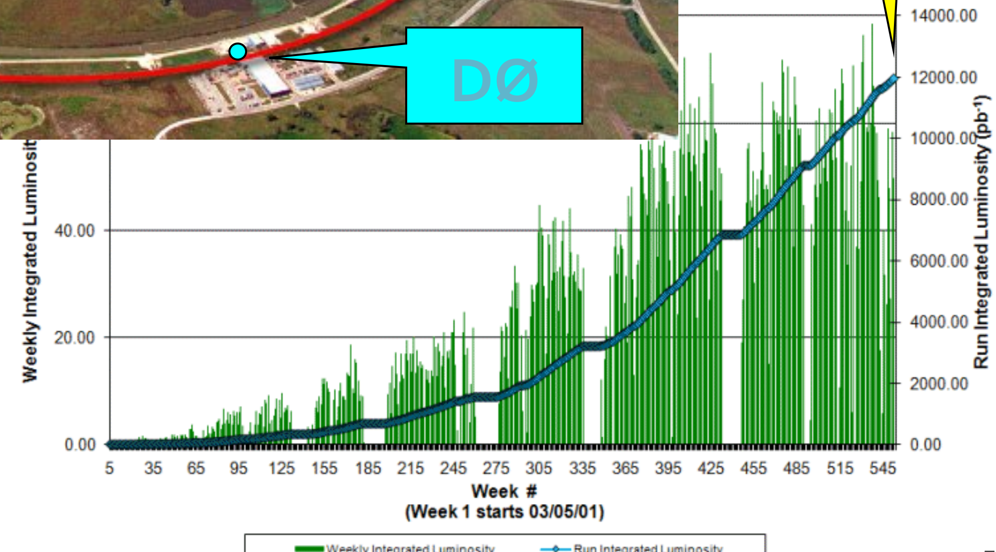
- Several recent EWK/NP searches (diboson, multilepton final states, analyses which are sensitive to the description from the SM, and physics beyond).
- High precision measurement of the W mass (which gives indirect sensitivity to the search for the Higgs).

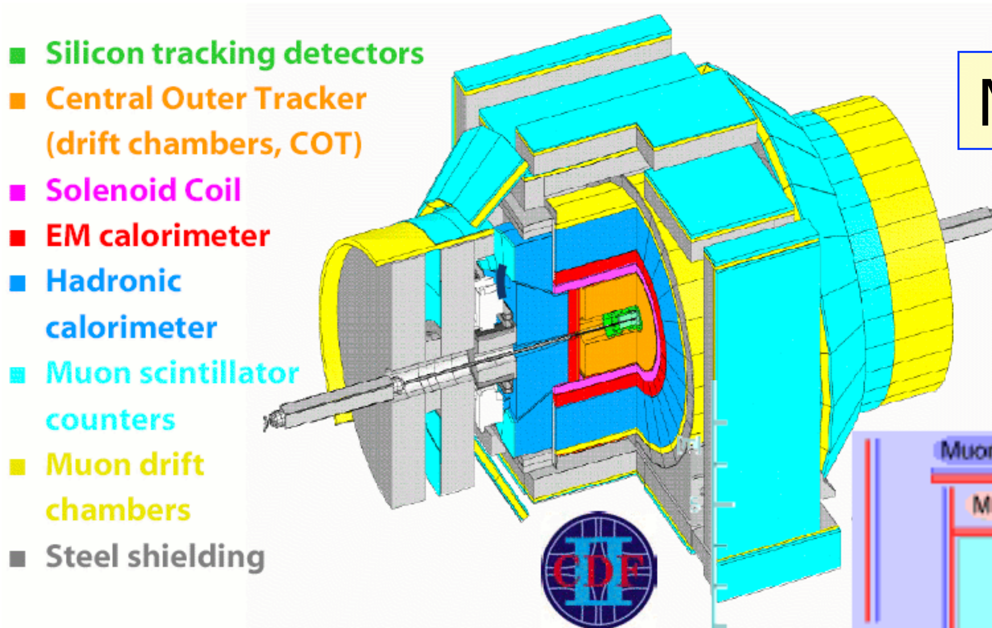
Run II: The Fermilab Tevatron



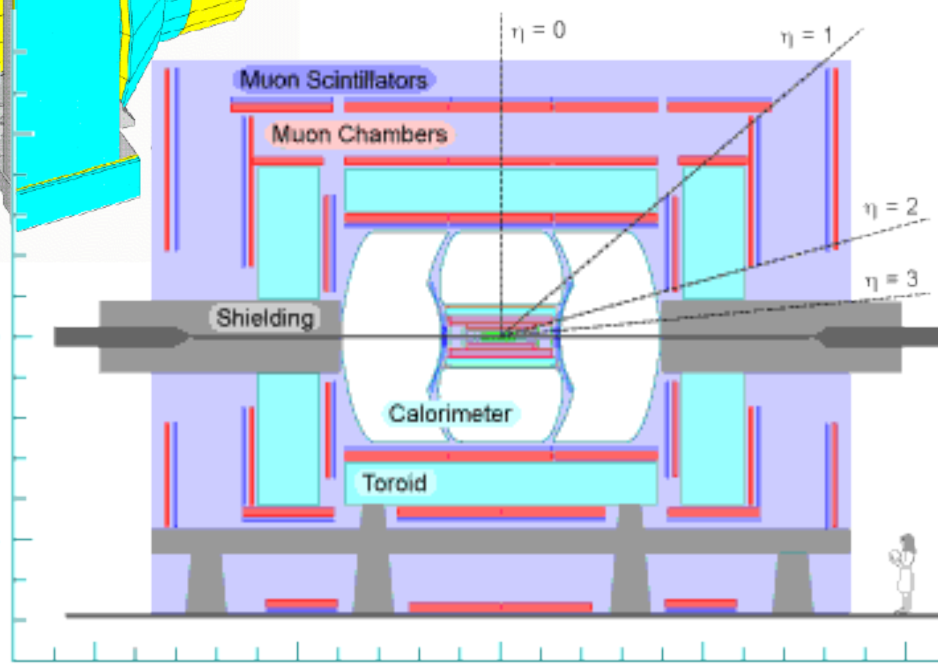


- Run II: March 2001 – Sept 2011
- 36x36 bunches
- Bunch crossing 396 ns
- Peak Luminosity: 4.2×10^{32} cm^{-2} sec^{-1}
- Run II total delivered: 12 fb^{-1}
- In this talk, 2.1-8.6 fb^{-1}

The Experiments:



Multi-purpose Detectors

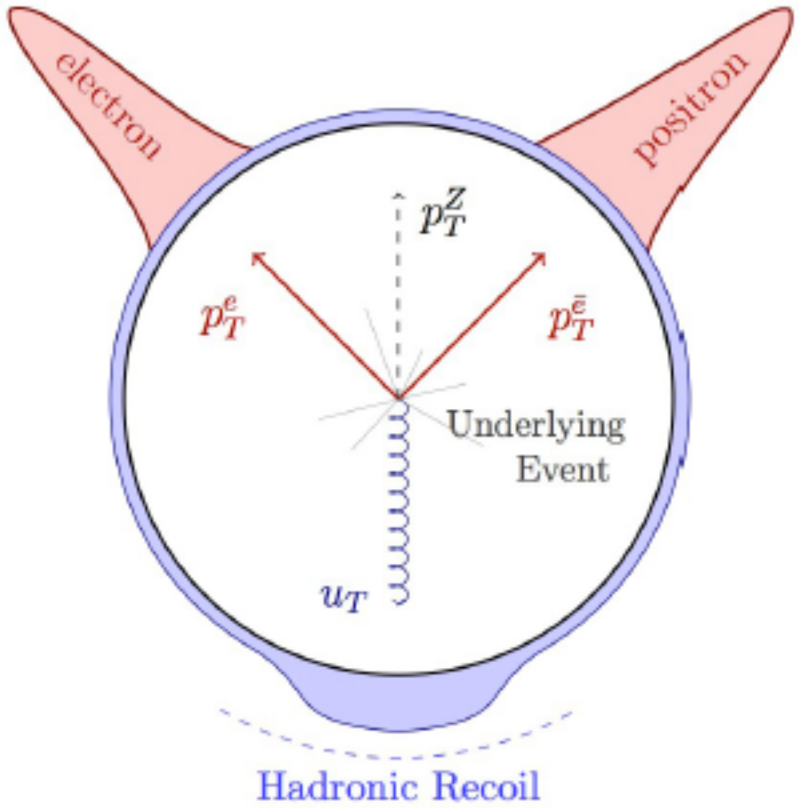


- vertexing
- precision tracking
- calorimetry
- muon system
- (hermetic → missing E_T)

- No experimental talk is complete unless one shows our beloved detectors. I will come back to this too, when I talk about the W mass.

Z→ee

- In principle, a simple topology, but can yield insights into higher order effects from QCD and fundamental constants of the SM:
  - Z p_T distribution
  - A_{FB}, $\sin^2\theta_W$



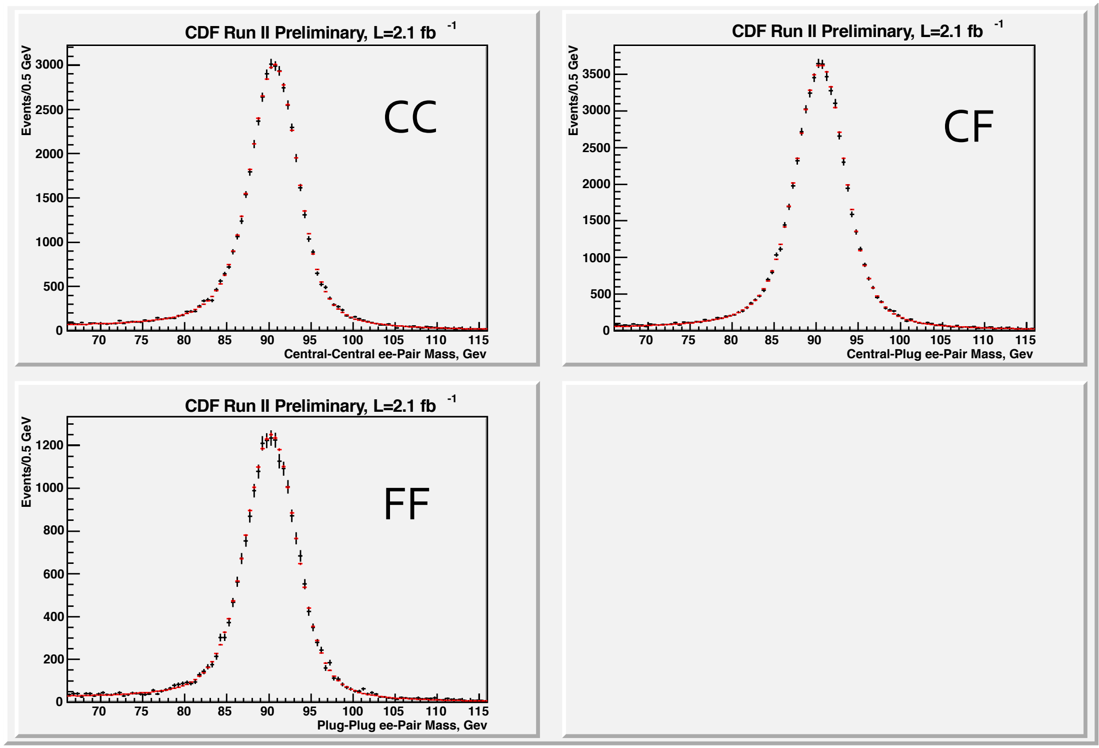
Z p_T: CDF

- Same 2.1 fb^{-1} dataset as used for previously published rapidity distribution, and angular coefficients.
  - $66 < M_{ee} < 116$ GeV
  - Three categories:

Both electrons $|\eta|<1.1$,

One electron $|\eta|<1.1$ and one electron $1.2 <|\eta|<2.8$,

Both electrons $1.2 <|\eta|<2.8$.



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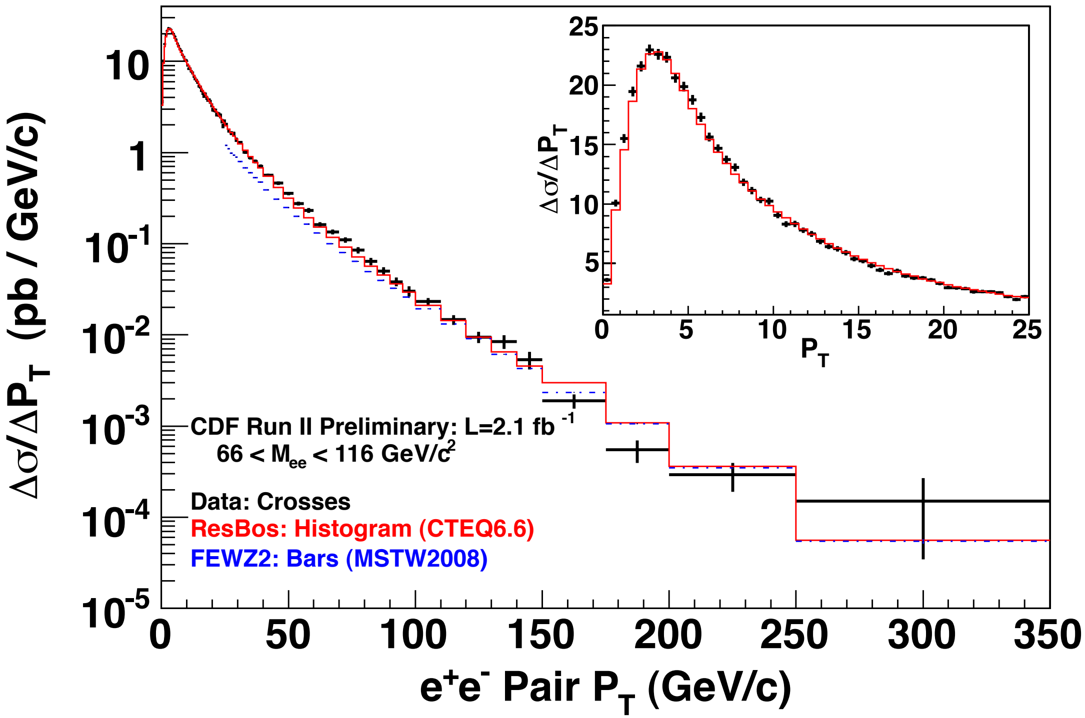

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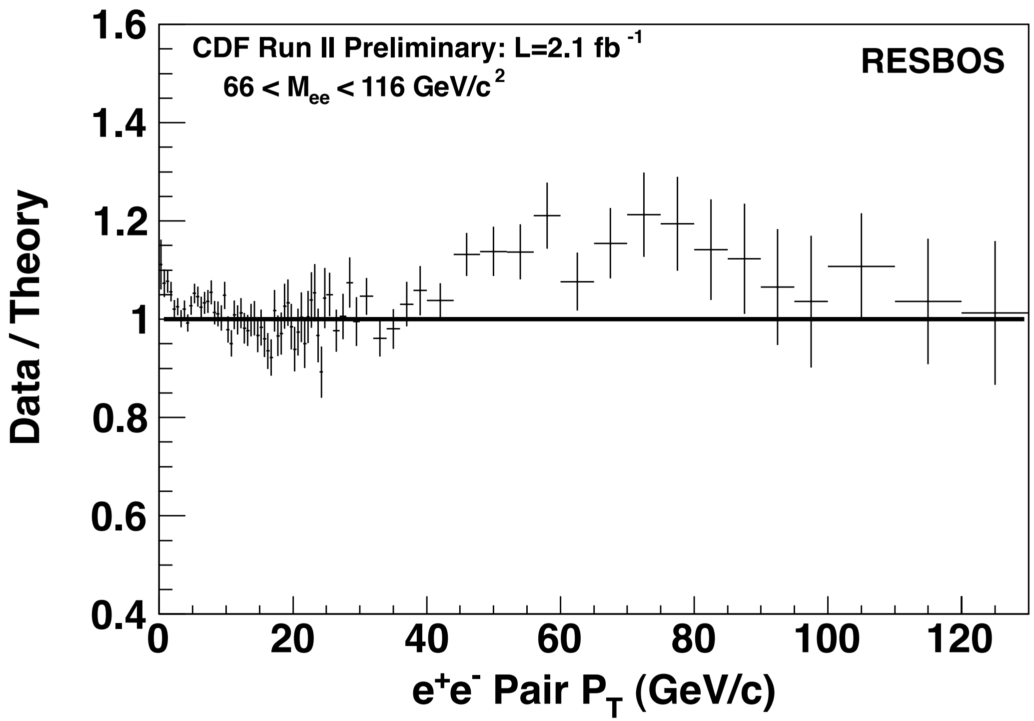
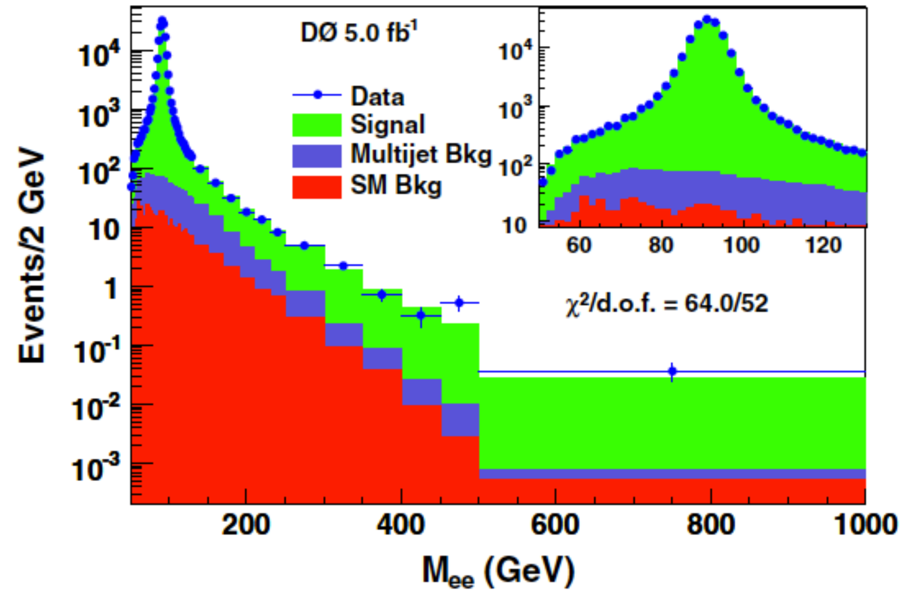
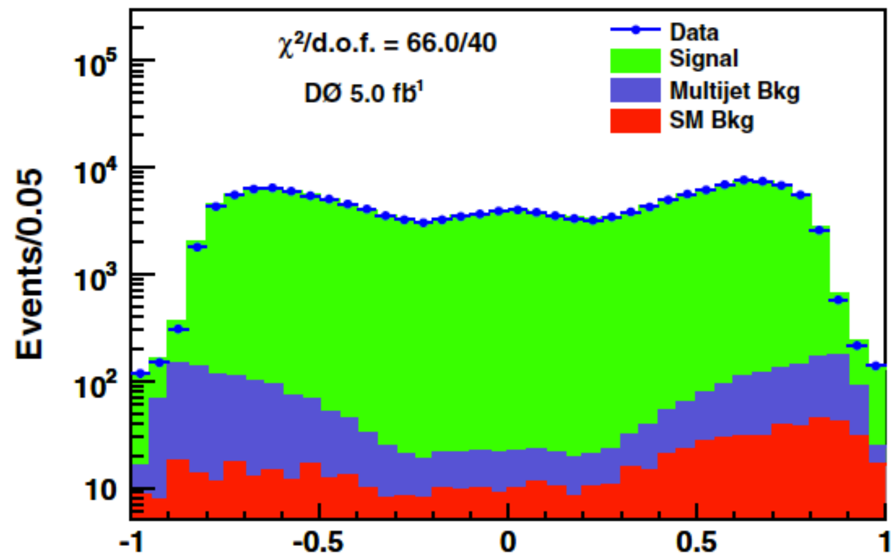


$\sin^2\theta_W$: DØ

- The forward-backward asymmetry in the vicinity of the Z mass is sensitive to $\sin^2\theta_W$ and the vector and axial-vector couplings of the u- and d-quarks.
  - $\sin^2\theta_W$ is measured in the mass range from 70-130 GeV





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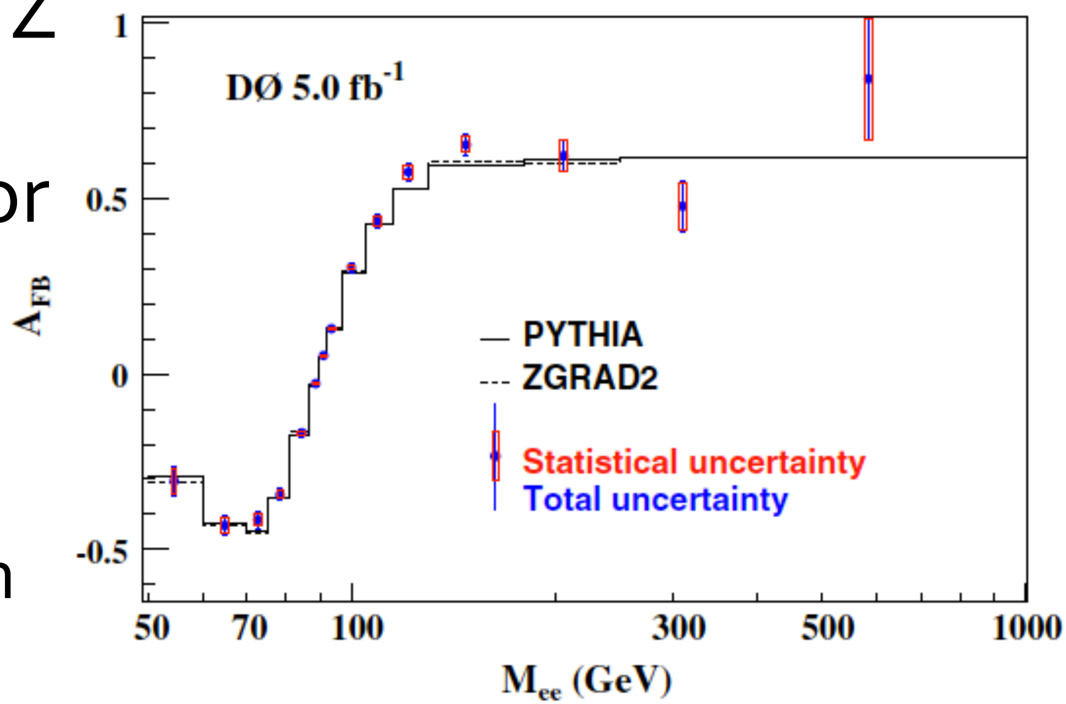
PRD 84, 012007 (2011)



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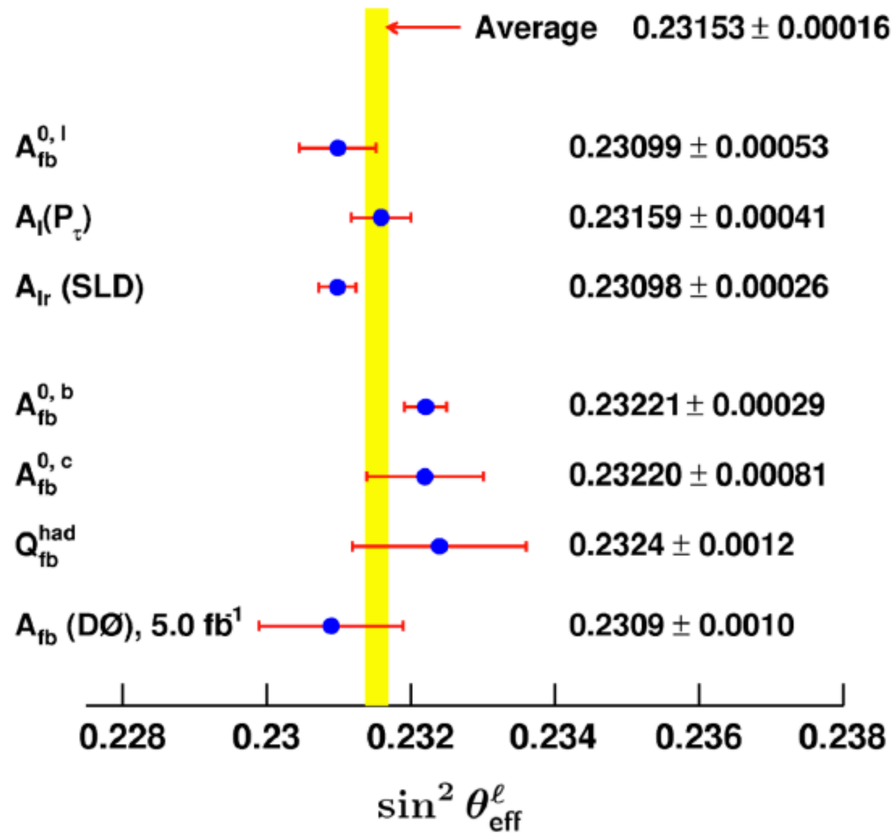
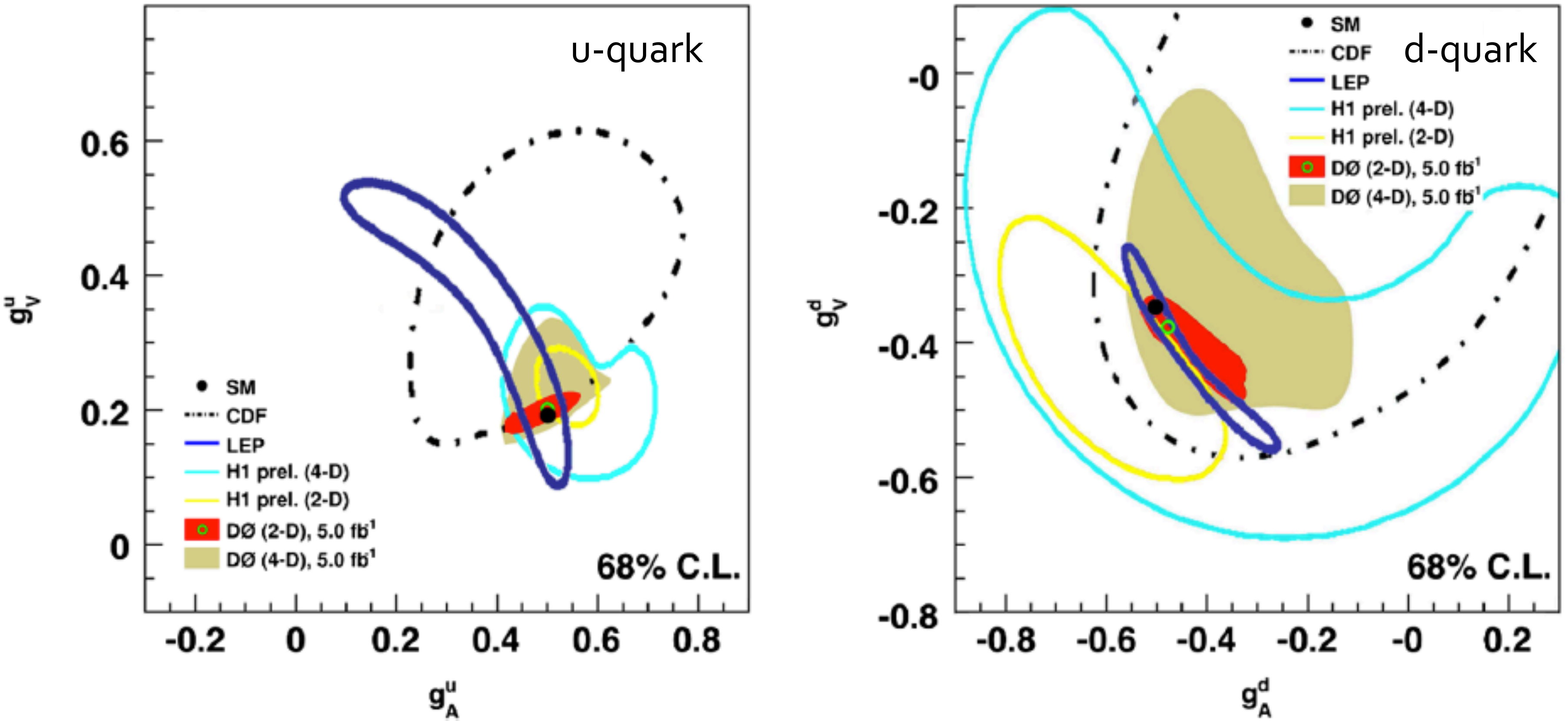


CDF also made a preliminary measurement of $\sin^2\theta_W$=0.2320 +/- $0.008^{+0.001}_{-0.0009}$ using 2.1 fb^{-1}

Couplings:

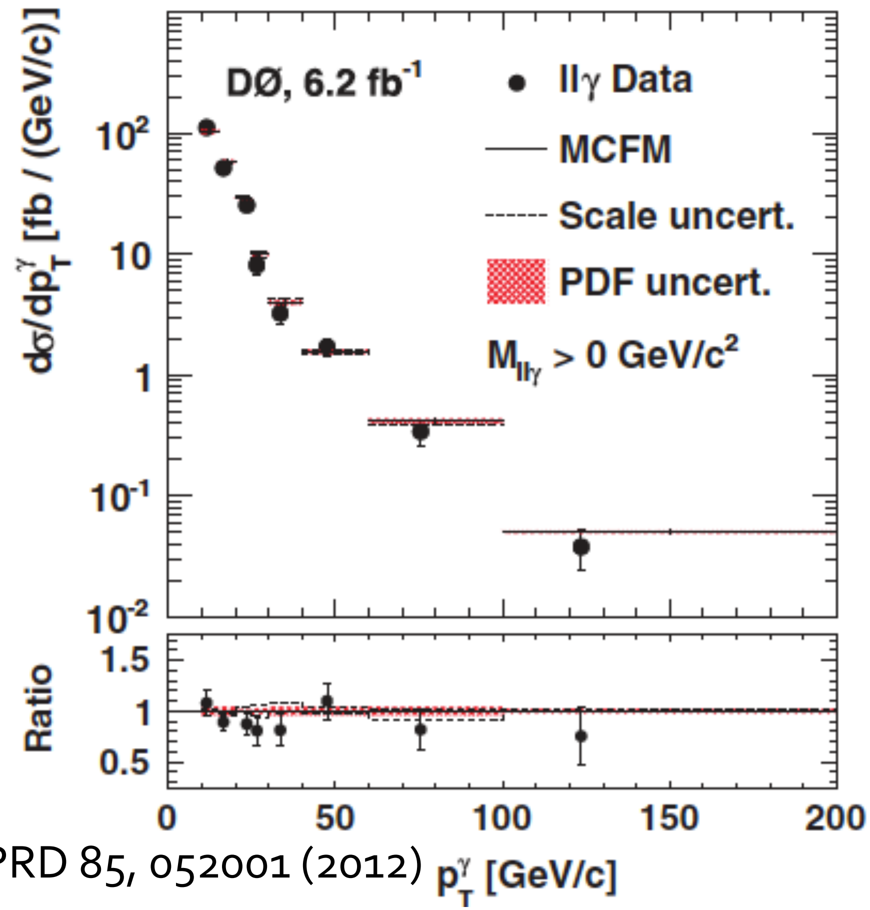
PRD 84, 012007 (2011)



- A quick comparison between the new DØ measurement and other measurements.

Zγ: DØ

- In diboson final states, the SM makes unambiguous statements about the couplings, so any deviation is a sign of new physics.
- Thus measuring these cross sections are both measurements and searches.

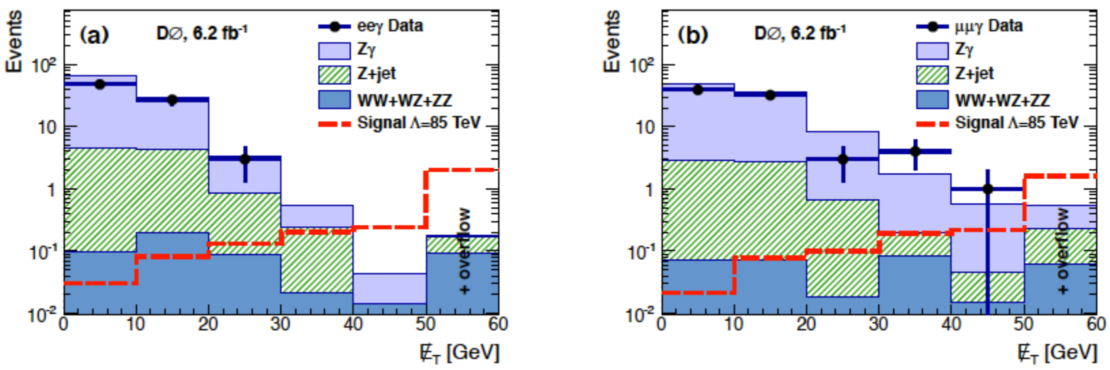


PRD 85, 052001 (2012)

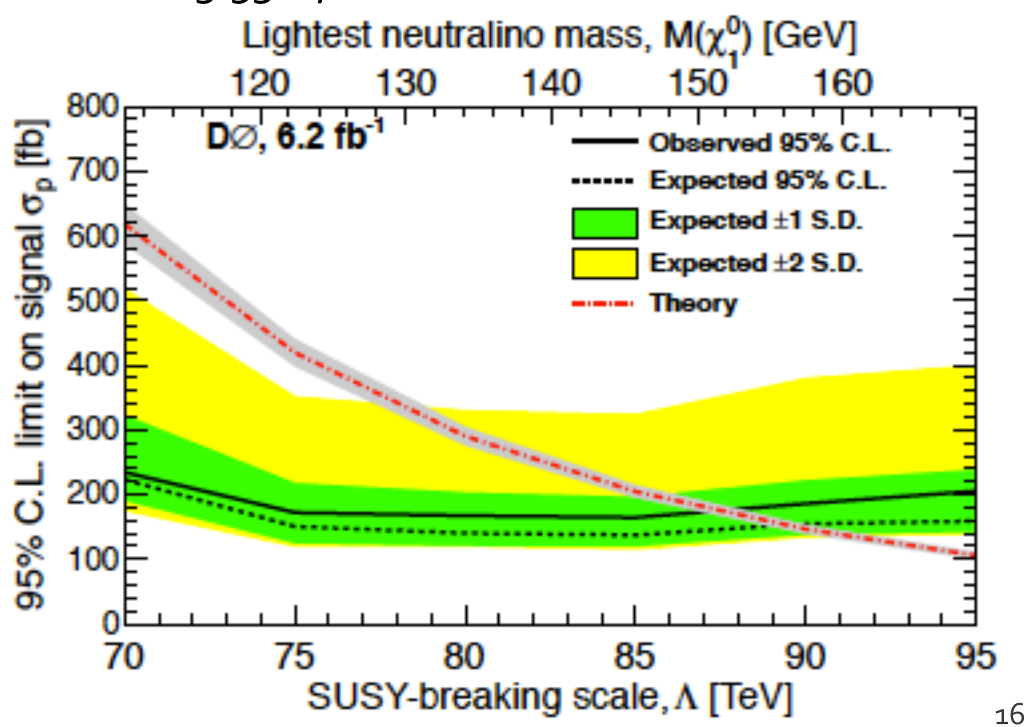
	$\sigma_{Z\gamma} \times \mathcal{B}$ [fb]
$ee\gamma$ data	281 ± 17(stat.) ± 11(syst.)
$\mu\mu\gamma$ data	306 ± 28(stat.) ± 11(syst.)
$\ell\ell\gamma$ combined data	288 ± 15(stat.) ± 11(syst.)
NLO MCFM	294 ± 10(PDF)$^{+1}_{-2}$(scale)

Zγ: DØ

- Zγ is also a final state that is sensitive to GMSB SUSY (as well as a heretofore unexploited state)
- A complement to the more typical channels (γγ +missing E_T)

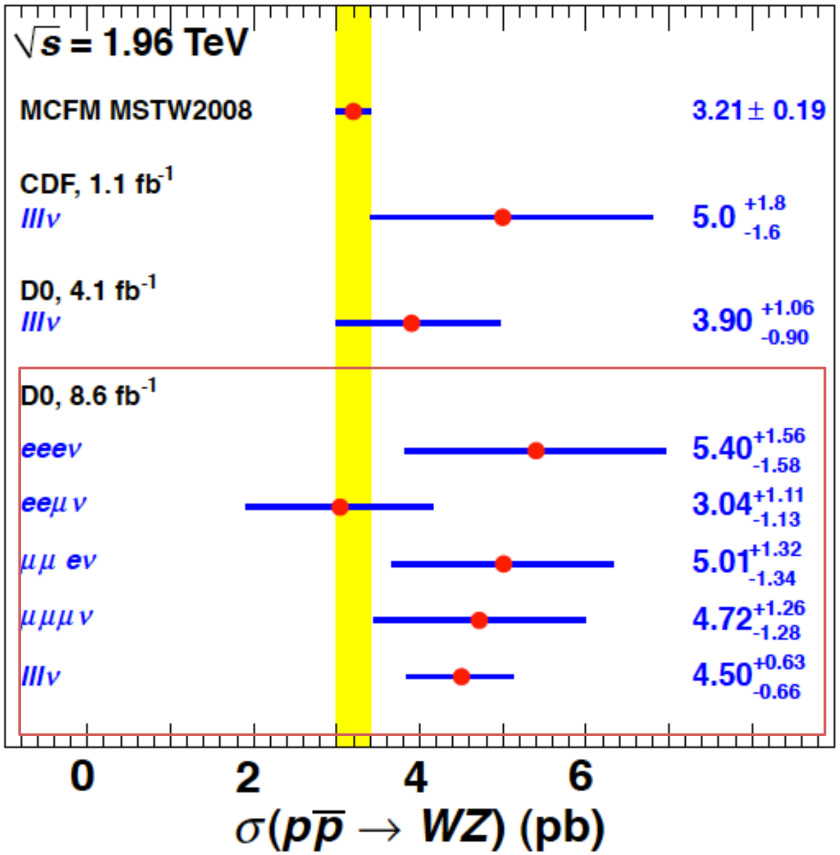


arXiv:1203.5311, submitted to PRL



WZ/ZZ: DØ

- In a similar vein, one can measure the other diboson cross sections, implicitly searching for new physics.
- These serve as both a test of the gauge structure of the SM, and an important legacy of the Tevatron.



arXiv:1201.5652, accepted by PRD

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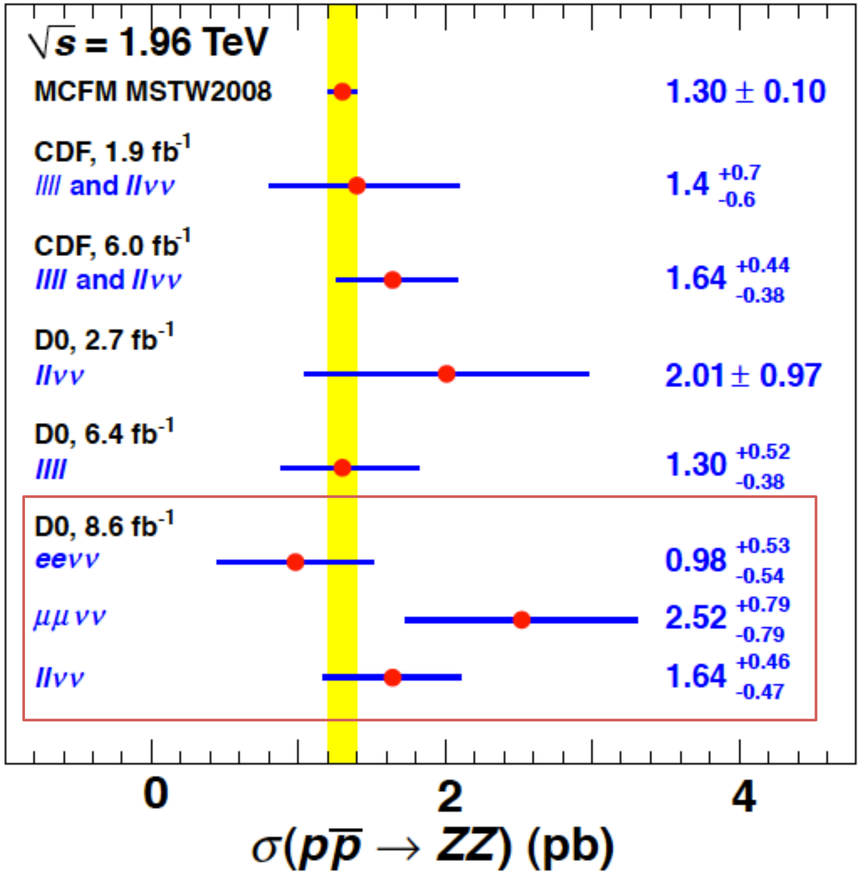

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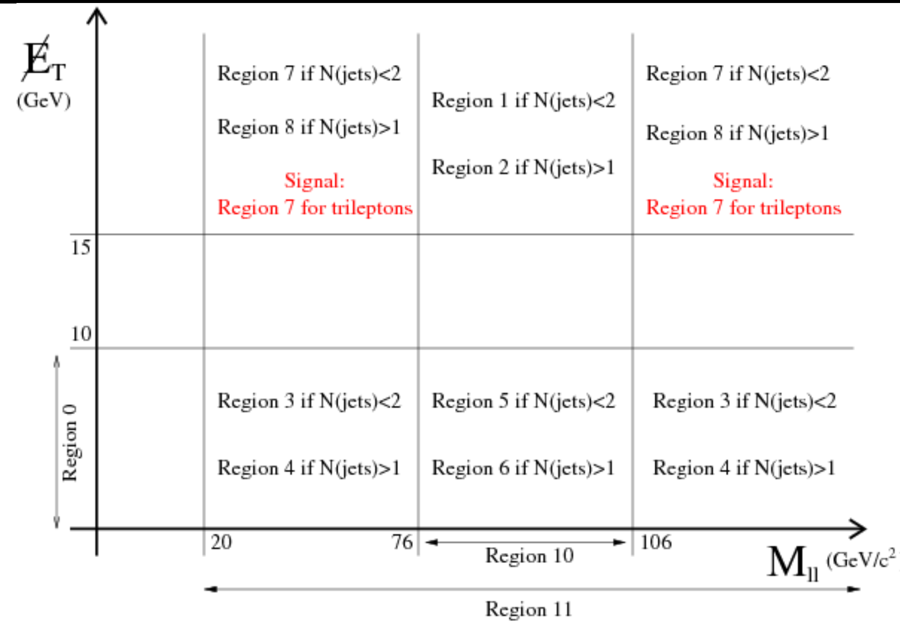
Trileptons: CDF

- In a different sense, one can choose the trilepton state (ee+l or track, μμ +l or track), and define control regions to ensure proper descriptions of the data.
- Then armed with that confidence, invade the areas where signals from SUSY are expected.



Definition of Control and Signal Regions			
Region	$M_{\ell\ell}$ cut (Gev/c^2)	($\not{E}_T$) cut (GeV)	N_{jet} cut
Region0	$M_{\ell\ell} > 20$	$\not{E}_T < 10$	–
Region1	$76 < M_{\ell\ell} < 106$	$\not{E}_T > 15$	$N_{jet} \leq 1$
Region2	$76 < M_{\ell\ell} < 106$	$\not{E}_T > 15$	$N_{jet} \geq 2$
Region3	$20 < M_{\ell\ell} < 76$ or $M_{\ell\ell} > 106$	$\not{E}_T < 10$	$N_{jet} \leq 1$
Region4	$20 < M_{\ell\ell} < 76$ or $M_{\ell\ell} > 106$	$\not{E}_T < 10$	$N_{jet} \geq 2$
Region5	$76 < M_{\ell\ell} < 106$	$\not{E}_T < 10$	$N_{jet} \leq 1$
Region6	$76 < M_{\ell\ell} < 106$	$\not{E}_T < 10$	$N_{jet} \geq 2$
Region7	$20 < M_{\ell\ell} < 76$ or $M_{\ell\ell} > 106$	$\not{E}_T > 15$	$N_{jet} \leq 1$
Region8	$20 < M_{\ell\ell} < 76$ or $M_{\ell\ell} > 106$	$\not{E}_T > 15$	$N_{jet} \geq 2$
Region9	$20 < M_{\ell\ell} < 76$ or $M_{\ell\ell} > 106$	$\not{E}_T > 20$	$N_{jet} \leq 1$
Region10	$76 < M_{\ell\ell} < 106$	–	–
Region11	$M_{\ell\ell} > 20$	–	–

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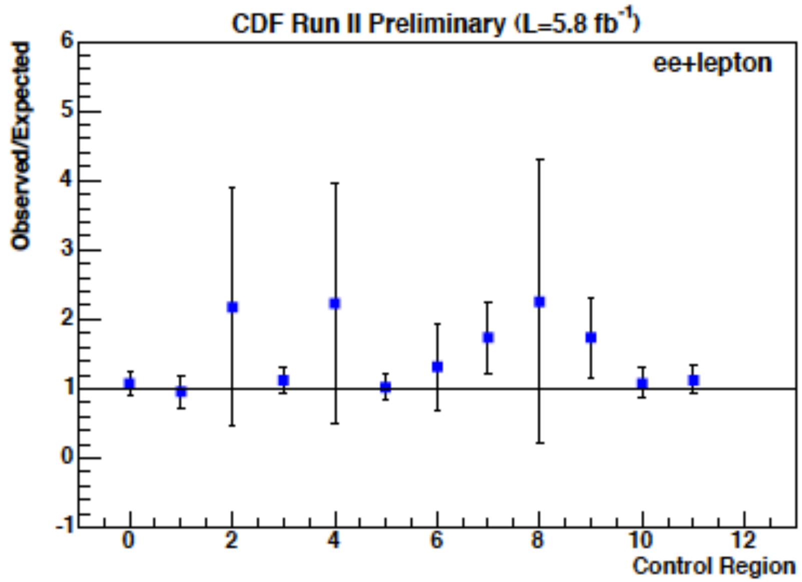

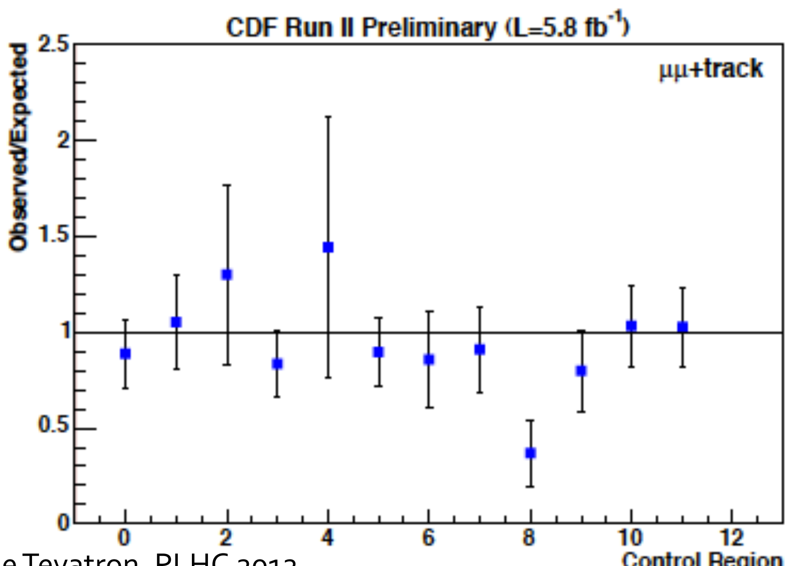

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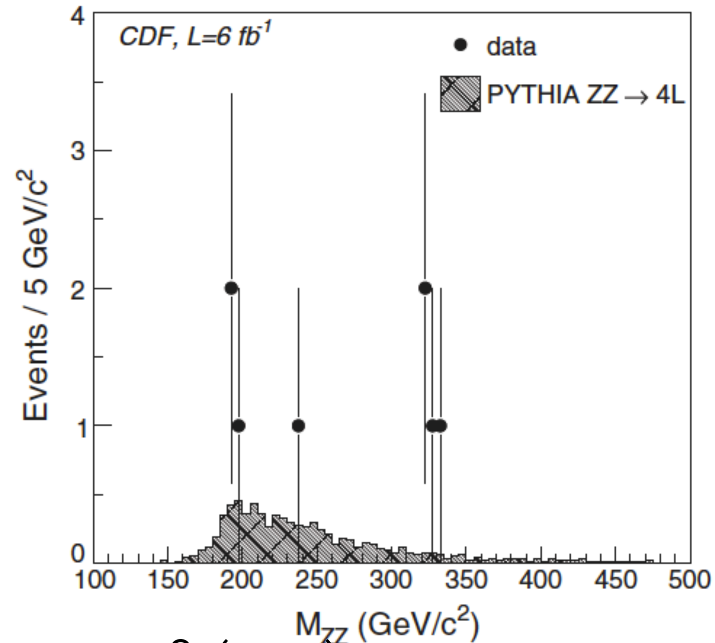
- Then armed with that confidence, invade the areas where signals from SUSY are expected.
- Optimize final cuts for the desired brand of SUSY.

Optimization cuts	
$M_{\ell_1\ell_2}$	$> M_{\tilde{\chi}_1^\pm} - M_{\tilde{\chi}_1^0}$
$M_{\ell_1\ell_3}$	< 75 GeV/c^2
$M_{\ell_2\ell_3}$	< 75 GeV/c^2
$\not\!\!E_T$	> 25 GeV
$p_{T,2}$	$(> 8$ and $< 36 - 65)$ GeV/c
$p_{T,3}$	> 8 GeV/c

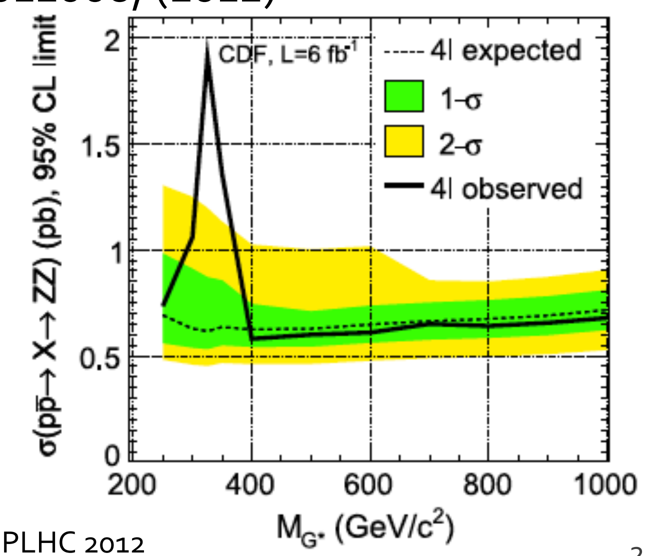
Optimized Trilepton Yields for Benchmark			
Channel	SM background	SUSY signal	Observation
ee+lepton	1.5 ± 0.4	8.0 ± 0.8	**3**
ee+track	11.6 ± 1.7	7.6 ± 0.8	**13**
$\mu\mu$+lepton	0.5 ± 0.1	6.7 ± 0.7	**0**
$\mu\mu$+track	3.6 ± 1.0	6.2 ± 0.6	**3**

ZZ: CDF

- At first explicitly a search for high mass resonances decaying to ZZ.
  - In addition, the four charged lepton channel actually appeared to hint at a bona fide excess.
  - Naturally, the thing to do would be to look in alternative ZZ channels: llνν, and lljj.

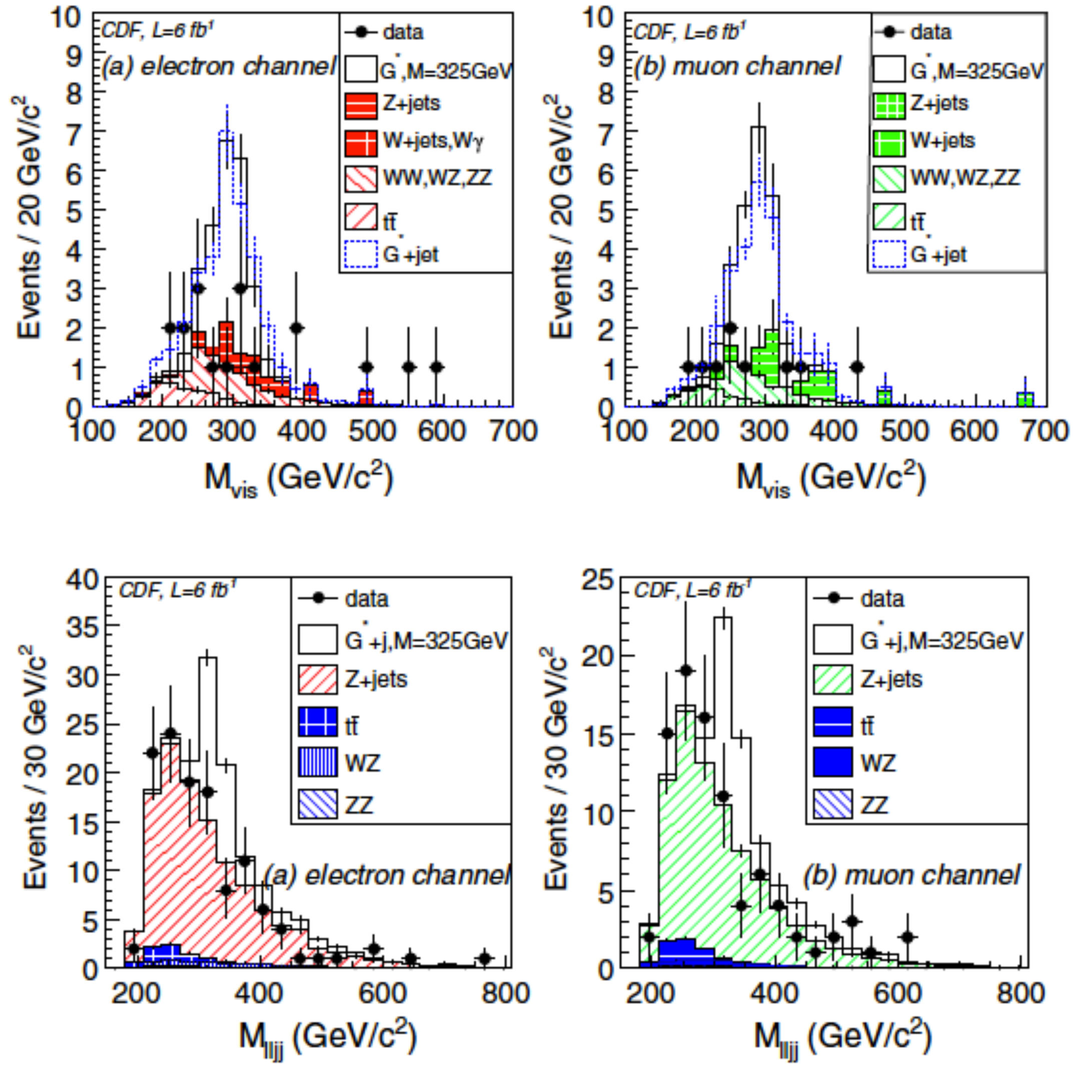


PRD 85, 012008, (2012)



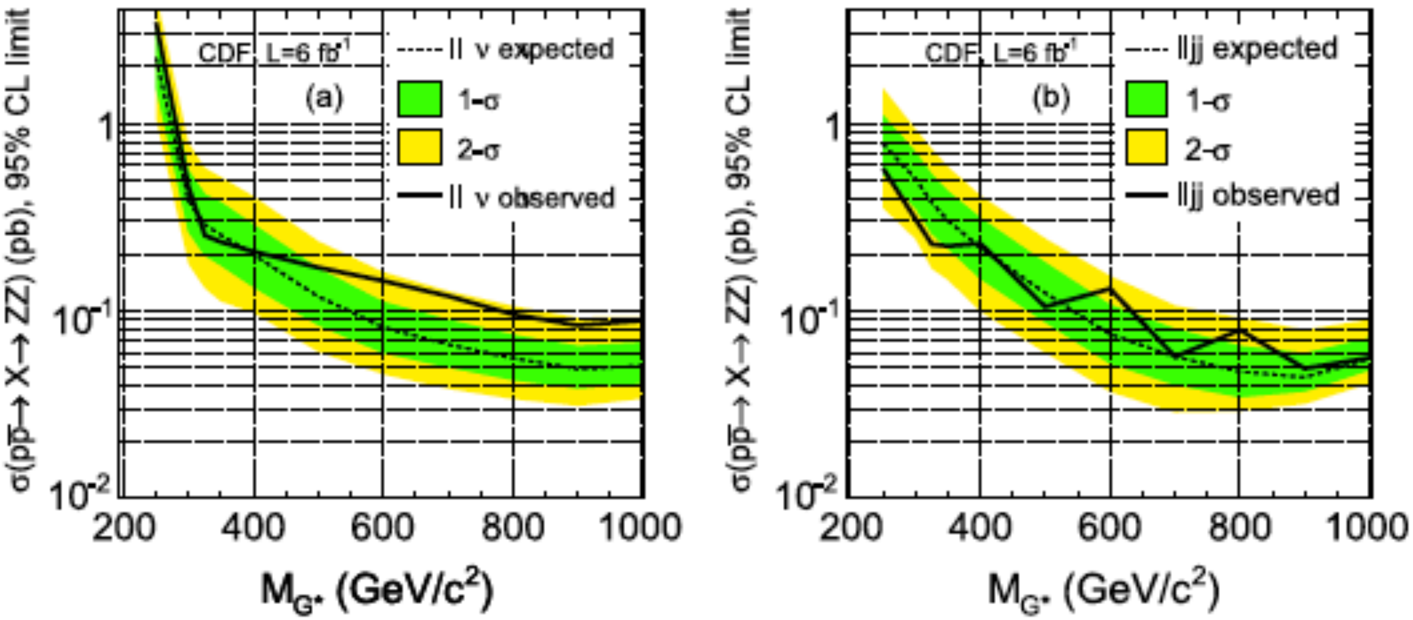
ZZ: CDF

- Subsequent checks in the alternatives revealed no excesses.
  - Note on the plots displayed that the empty histogram would be representative of a similar signal to the implied excess.



PRD 85, 012008, (2012)

ZZ: CDF

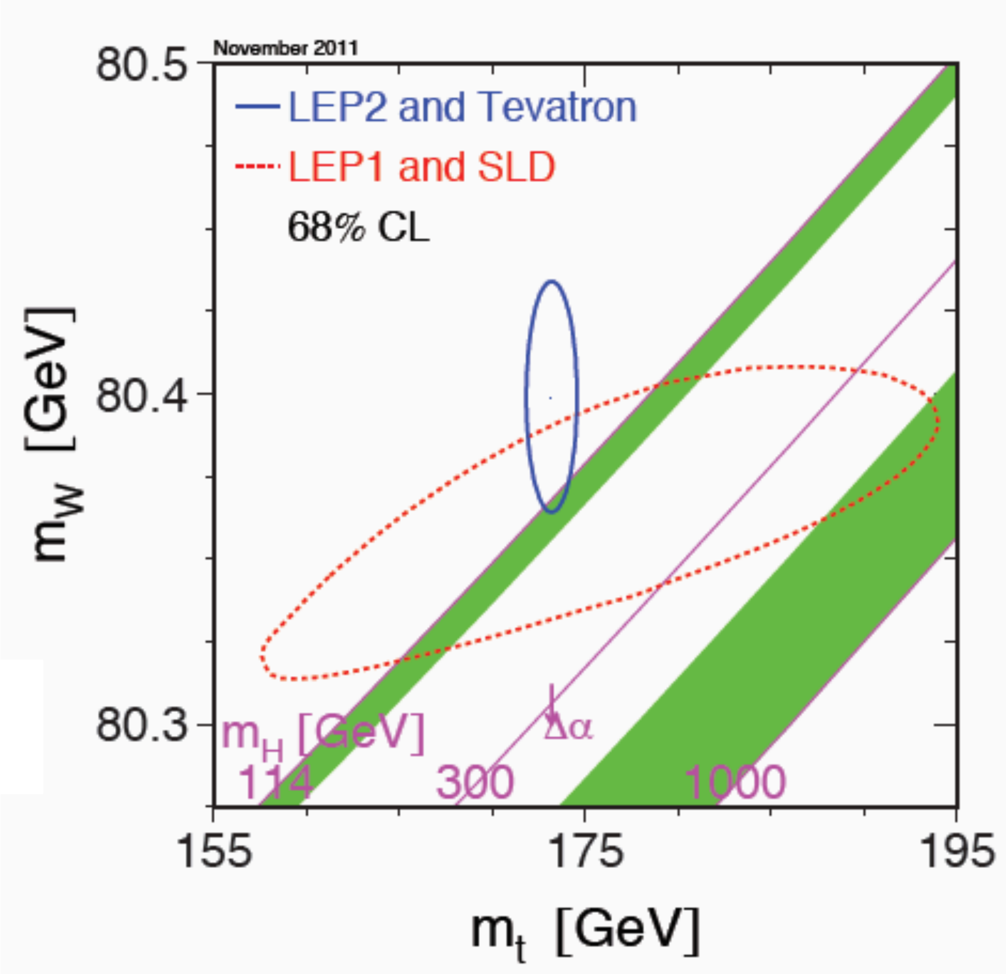


PRD 85, 012008, (2012)

- Subsequent checks in the alternatives revealed no excesses.
  - Shown are the corresponding limit plots, nothing to see here.

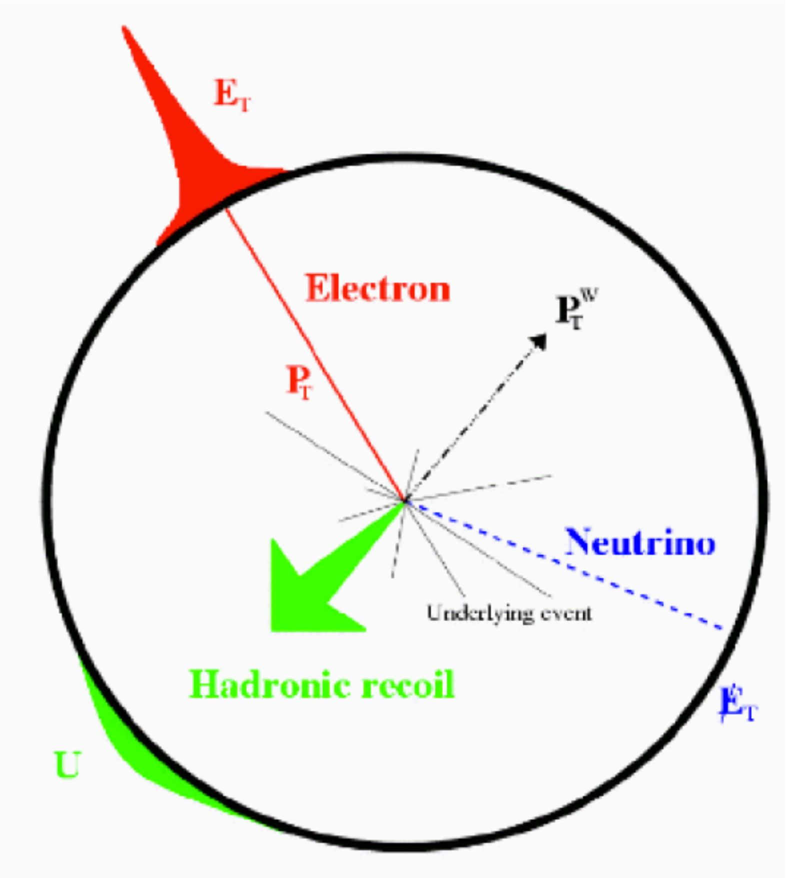
W Mass Measurement

- Precise measurements of M_W and M_t constrain the SM Higgs mass.
- Prior to this year, the status looked something like the plot on the right (from the W mass point of view).



Methodology

- This entire business sounds easy in general, but the level of detail required to reach the desired precision on the mass is extreme, and requires an attention to detail unlike most other hadron collider measurements.



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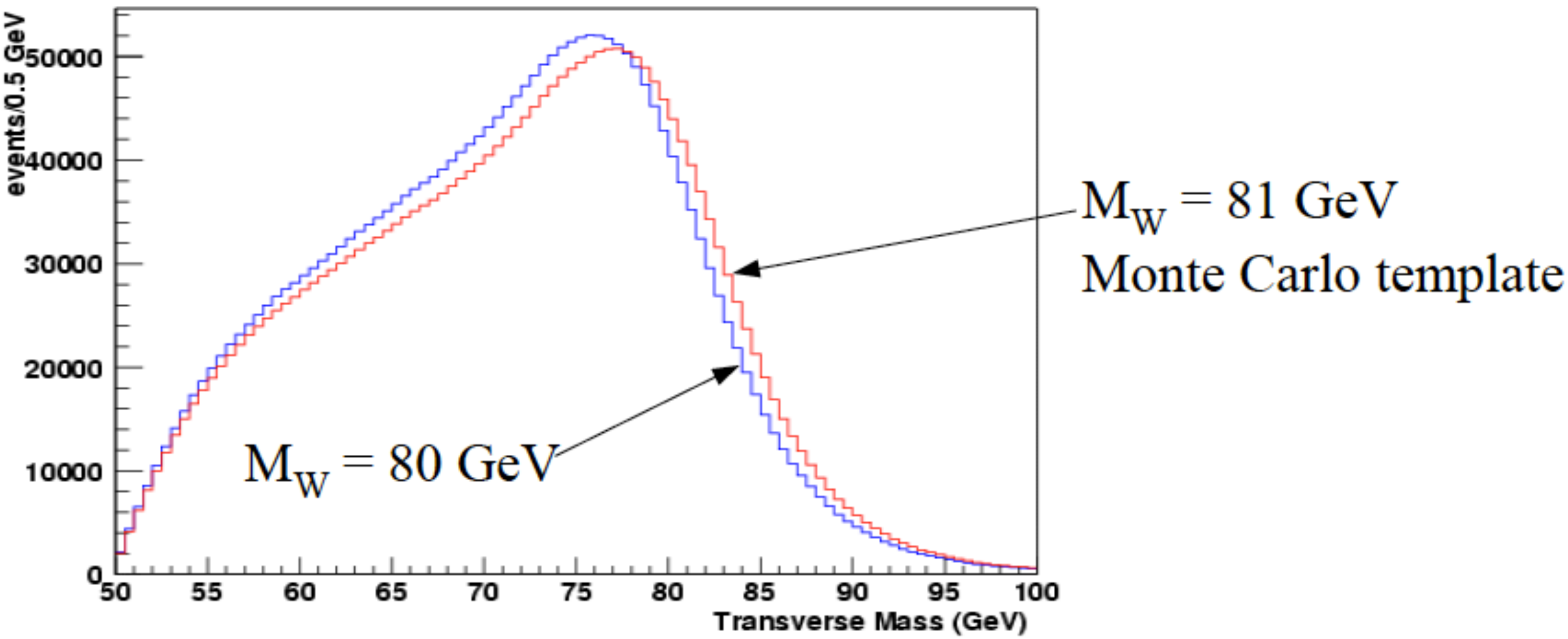
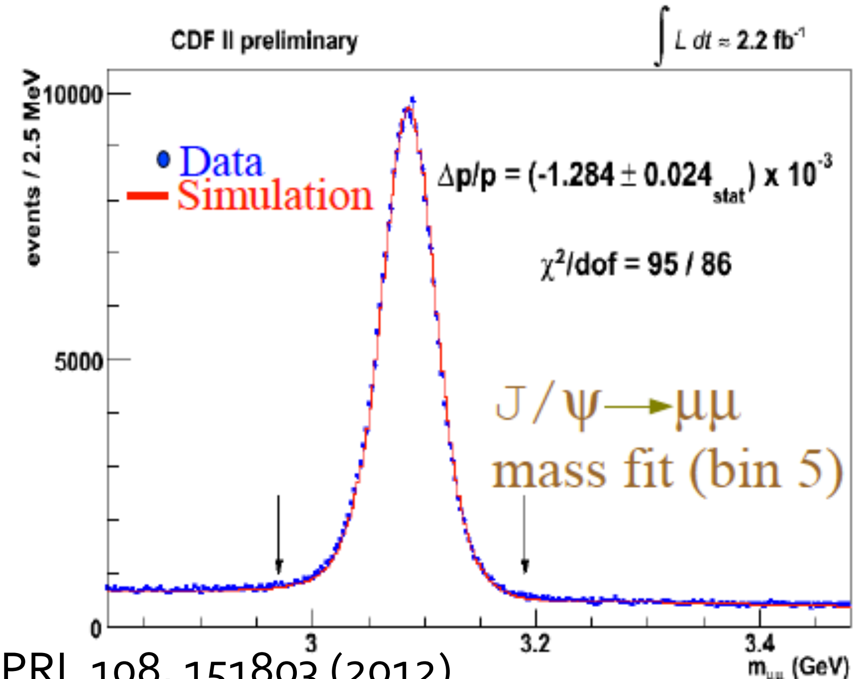


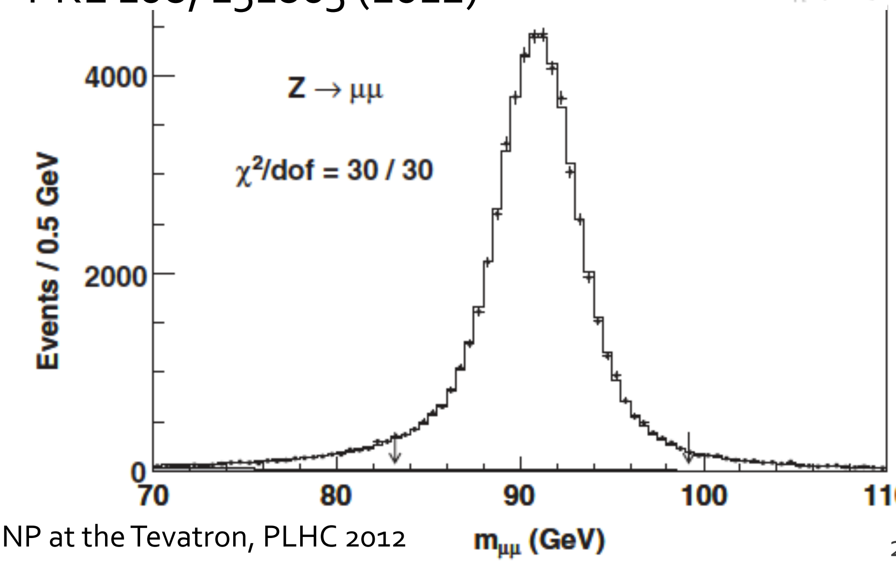
- Both experiments will follow the same general strategy:
  - Build up a model of the detector and the inactive material, verify lepton energy scales and recoil energy resolution.
  - Then using this model, generate templates of the W mass lineshape and compare with data. Both experiments also do this procedure blinded. But methods for doing the above are specific to the strengths of the different detectors.

W Mass: CDF

- CDF starts with its very precise tracking.
  - Verify tracking alignment with cosmics.
  - Momentum scale and linearity from J/ψ and Ψ
  - Perform independent measurement of Z→μμ mass as an important scale check.

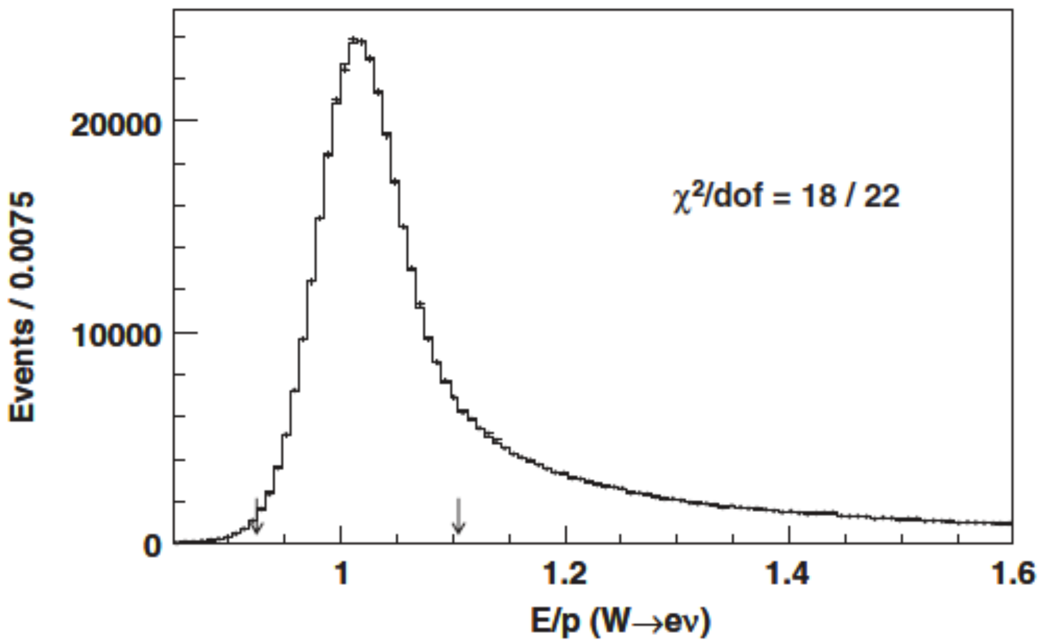


PRL 108, 151803 (2012)



W Mass: CDF

- Once the tracking scale is nailed, can then transfer this to the calorimeter through E/p measurement (energy loss, radiative component and width), and in bins of E_T.
- Can then likewise check against description of the Z peak.



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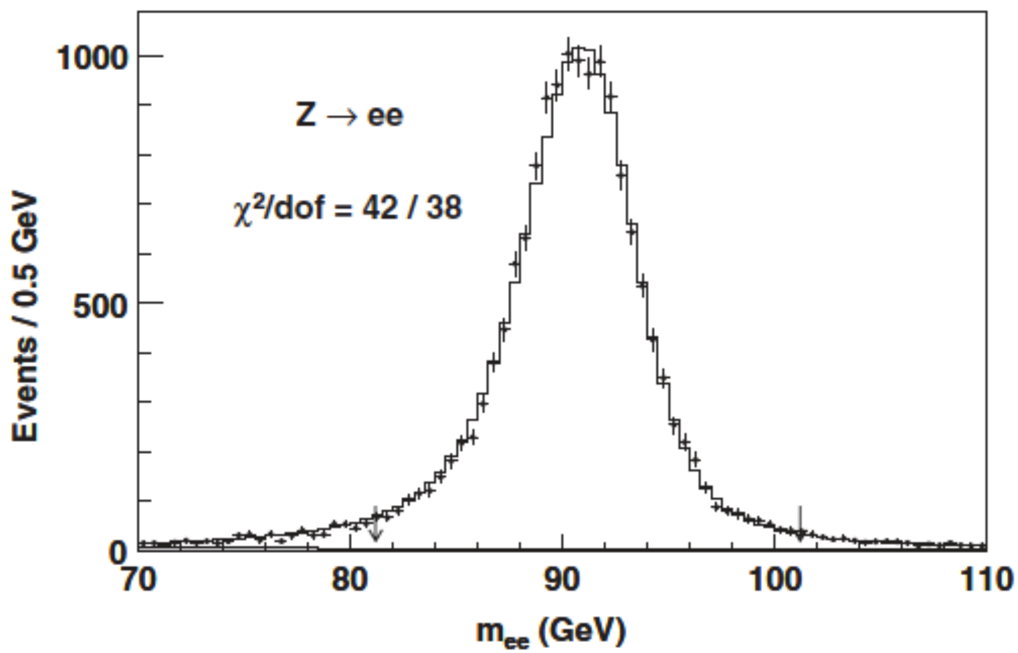
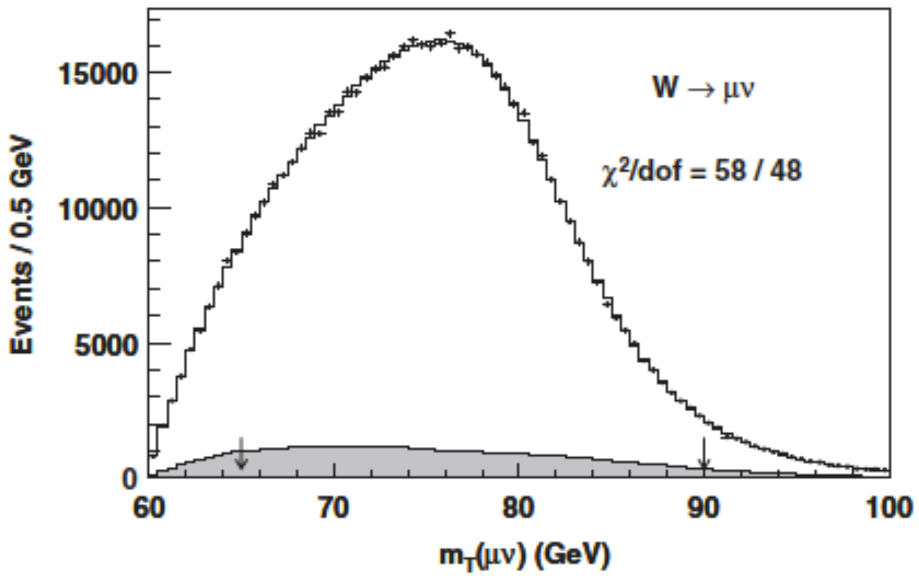


PRL 108, 151803 (2012)

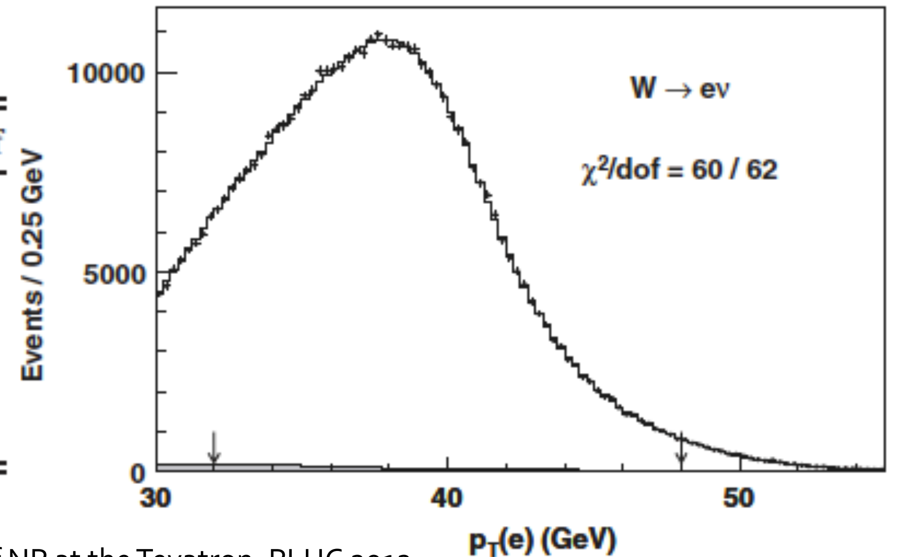
W Mass: CDF

- Use M_T, E_T and missing E_T for both electron and muon channels, and then combine taking into account correlations.



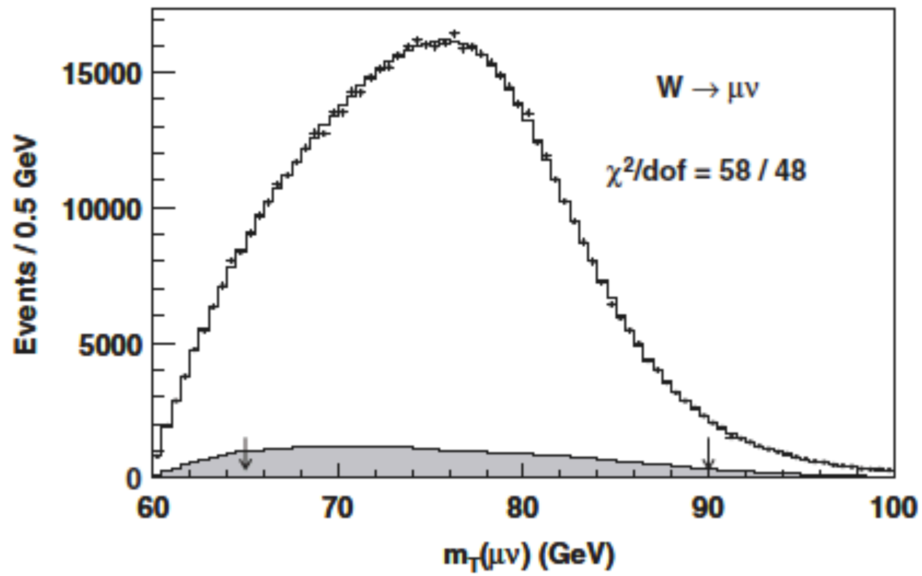
PRL 108, 151803 (2012)

Distribution	W-boson mass (MeV)	χ^2/dof
$m_T(e, \nu)$	$80\,408 \pm 19_{\rm stat} \pm 18_{\rm syst}$	52/48
$p_T^\ell(e)$	$80\,393 \pm 21_{\rm stat} \pm 19_{\rm syst}$	60/62
$p_T^\nu(e)$	$80\,431 \pm 25_{\rm stat} \pm 22_{\rm syst}$	71/62
$m_T(\mu, \nu)$	$80\,379 \pm 16_{\rm stat} \pm 16_{\rm syst}$	58/48
$p_T^\ell(\mu)$	$80\,348 \pm 18_{\rm stat} \pm 18_{\rm syst}$	54/62
$p_T^\nu(\mu)$	$80\,406 \pm 22_{\rm stat} \pm 20_{\rm syst}$	79/62



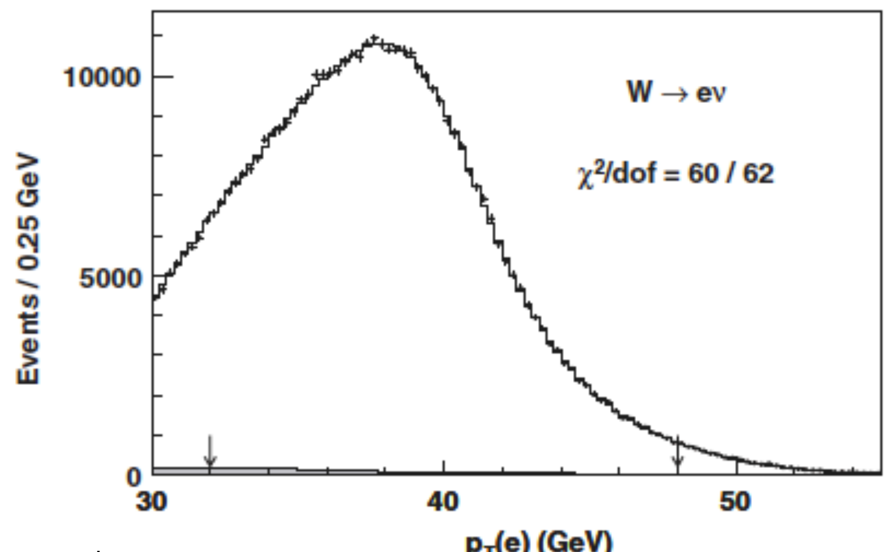
W Mass: CDF

- Reach a final measurement of M_W=80387 +/- 19 MeV, using 2.2 fb^{-1}.

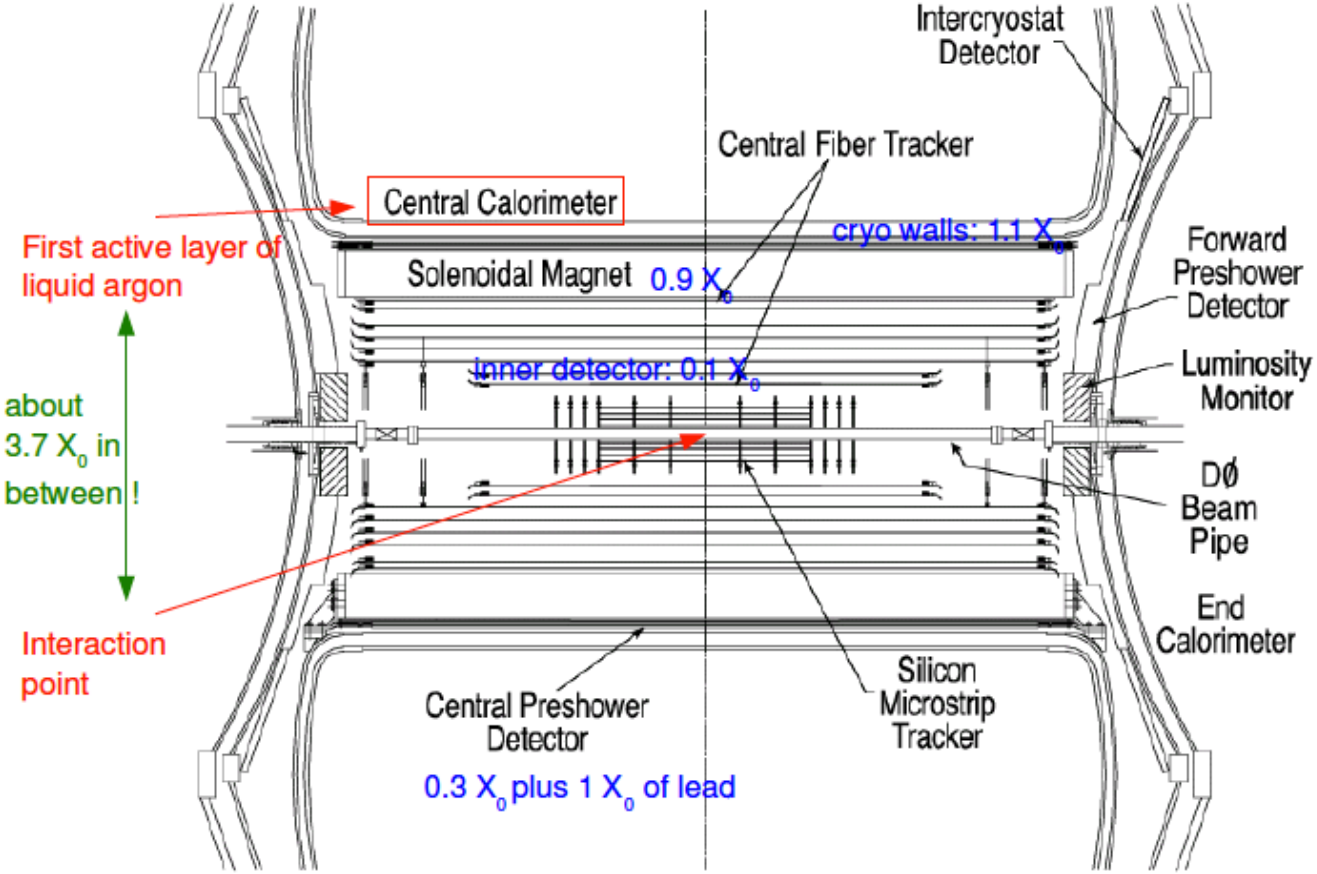


PRL 108, 151803 (2012)

Source	Uncertainty (MeV)
Lepton energy scale and resolution	7
Recoil energy scale and resolution	6
Lepton removal	2
Backgrounds	3
$p_T(W)$ model	5
Parton distributions	10
QED radiation	4
W-boson statistics	12
Total	19



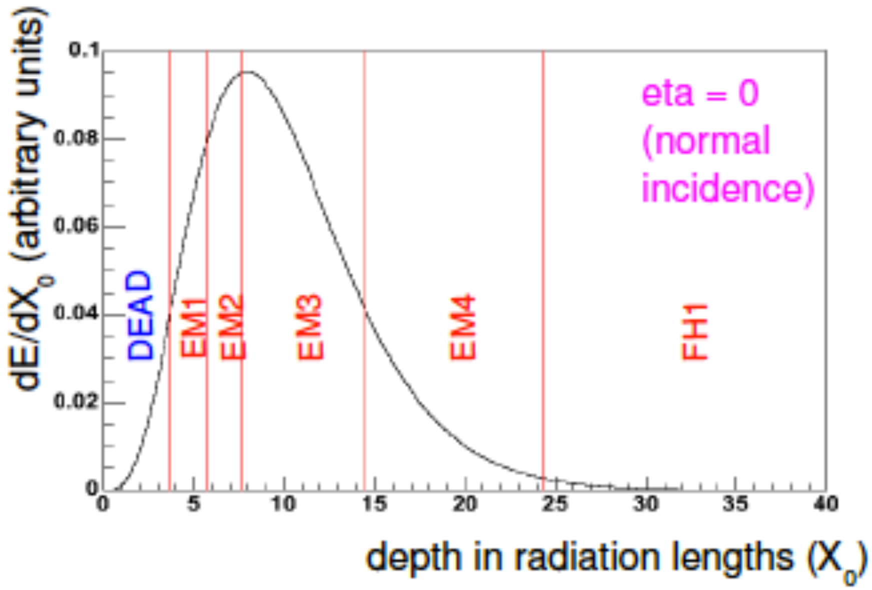
W Mass: DØ

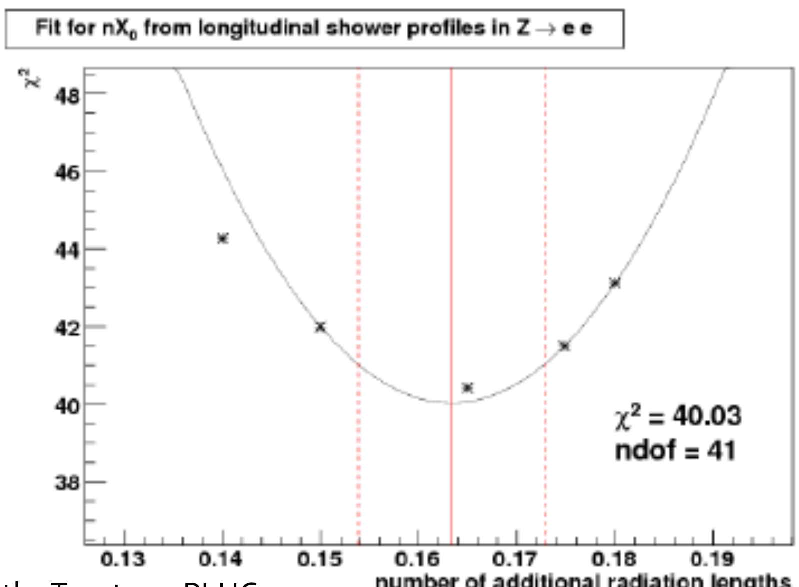


- As previously stated, the game is the same, but the method is different (solely studying W→eν here). Tracking is not as precise, and there is a lot of material to account for prior to the EM calorimetry.

W Mass: DØ

- Sampling calorimeter, very sensitive to the amount of material prior to calorimeter.
- Allow dead material and the energy scale of each layer to float, and minimize the global data/MC χ^2, using Z→ee events split into categories based on rapidity.





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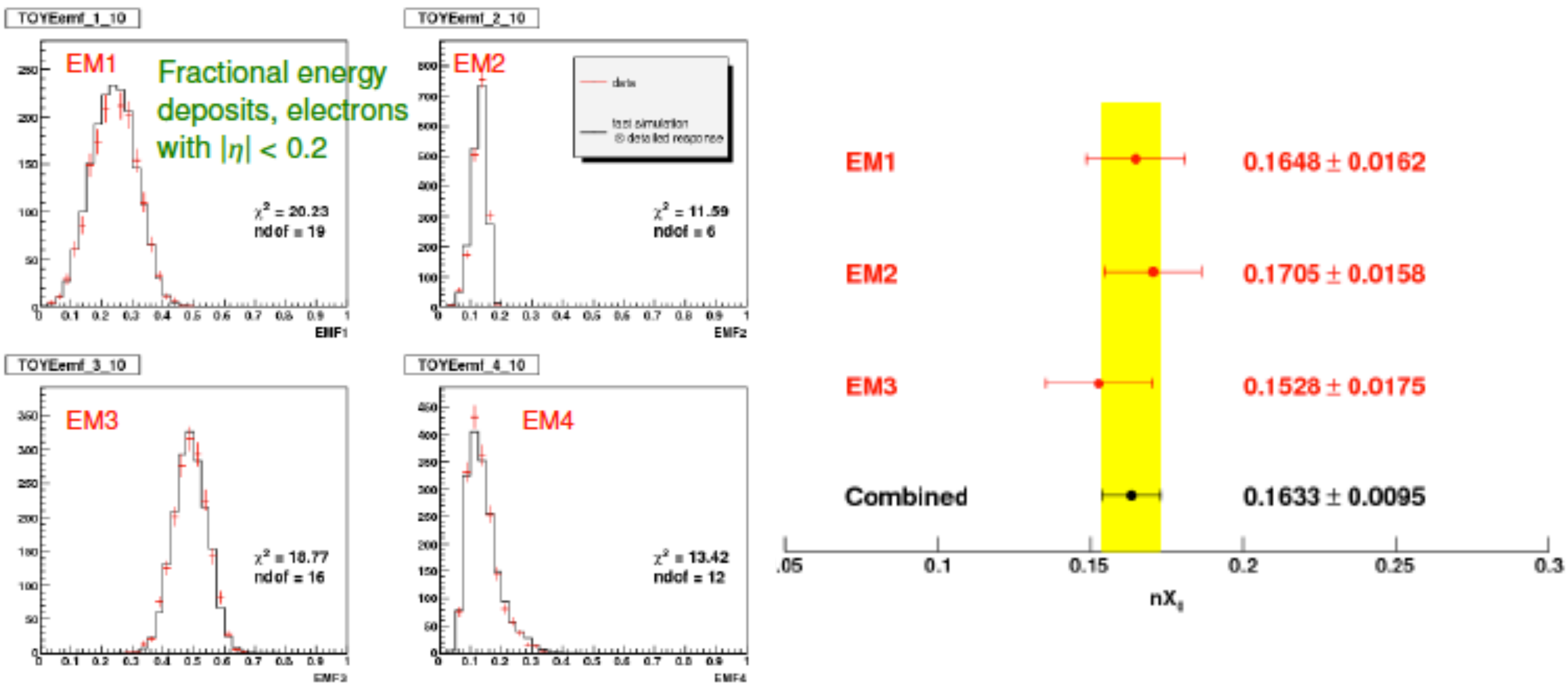
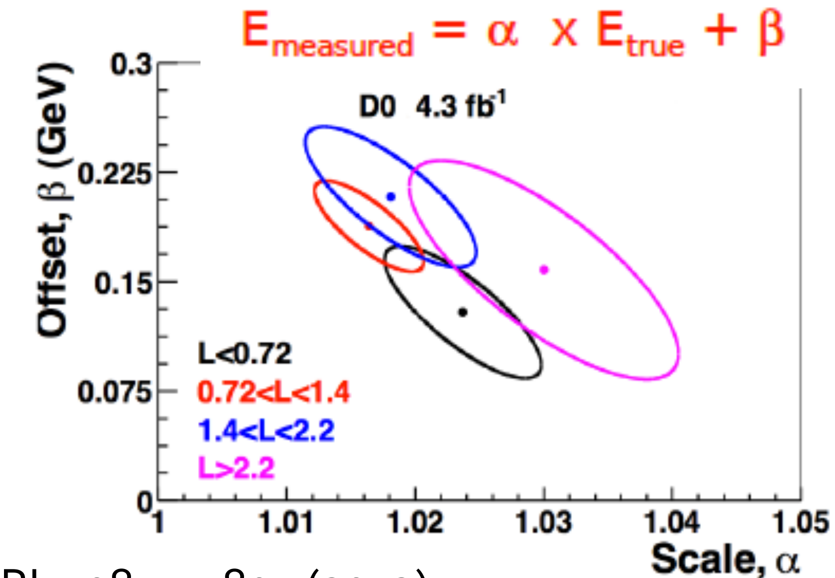


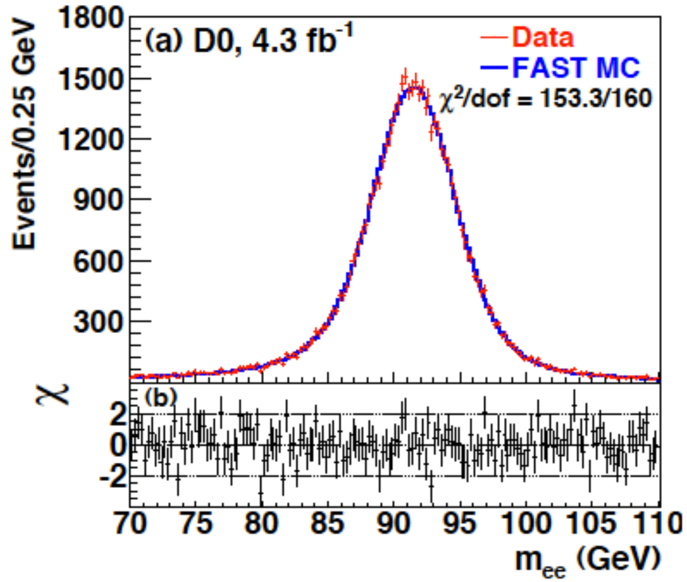
- Cross check this, to make sure that the description is robust (done for 1 fb^{-1} anaysis and repeated for subsequent 4.3 fb^{-1})

W Mass: DØ

- Energy scale and offset (with the corrected material description), verified for different ranges of instantaneous luminosity (potential systematic effects from pileup).

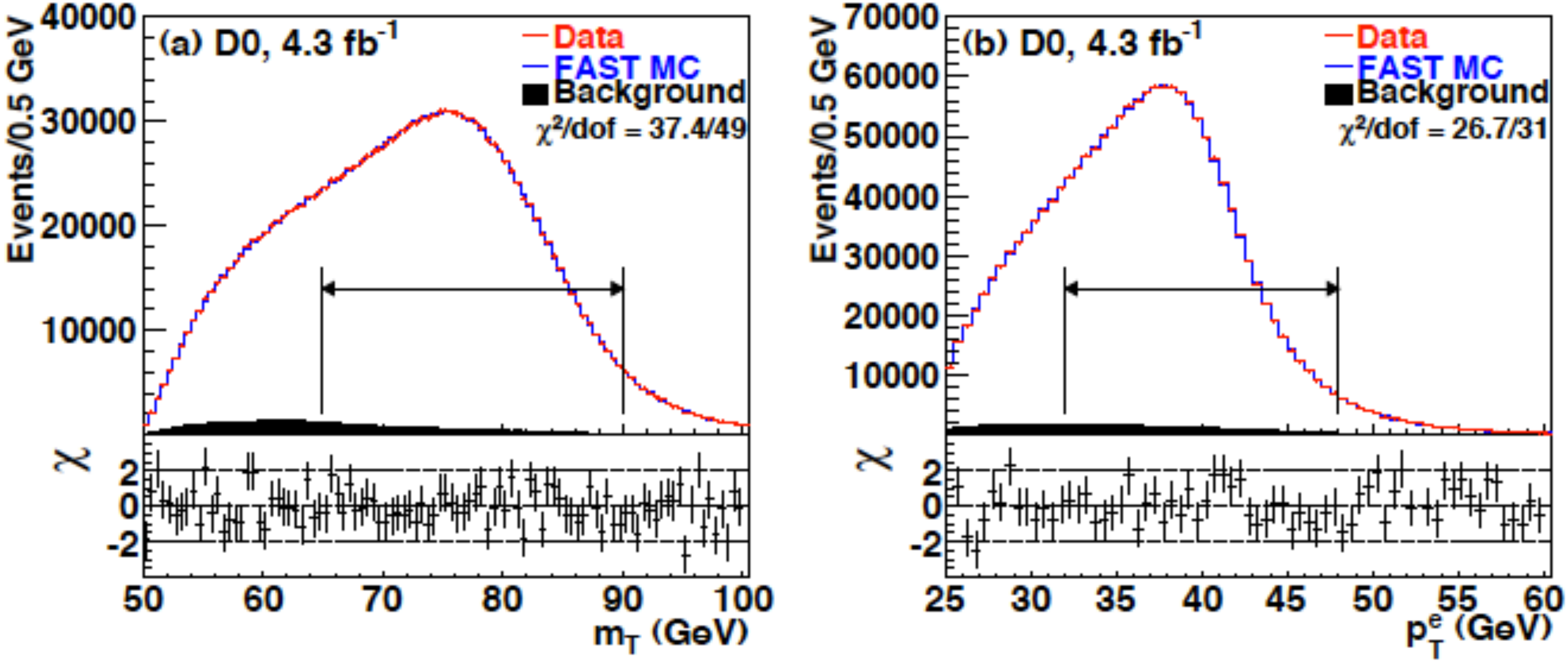


PRL 108, 151804 (2012)



W Mass: DØ

PRL 108, 151804 (2012)



- After taking into account correlations, even though all three variables are used, only p_T and M_T contribute to the final measured value value (when combined with earlier 1 fb^{-1} result): M_W=80375+/-23 MeV

W Mass: DØ

Source	ΔM_W (MeV) m_T	p_T^e	$\not{E}_T$
Electron energy calibration	16	17	16
Electron resolution model	2	2	3
Electron shower modeling	4	6	7
Electron energy loss model	4	4	4
Hadronic recoil model	5	6	14
Electron efficiencies	1	3	5
Backgrounds	2	2	2
Experimental subtotal	18	20	24
PDF	11	11	14
QED	7	7	9
Boson p_T	2	5	2
Production subtotal	13	14	17
Total	22	24	29

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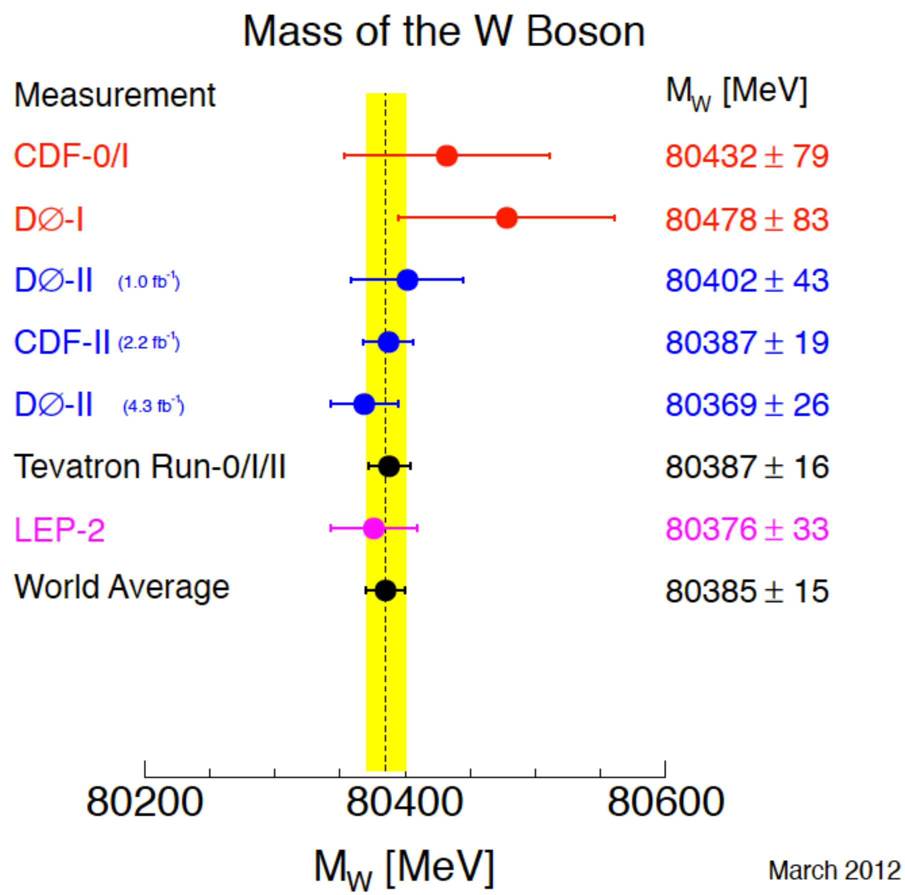
W Mass: Tevatron

- Not yet the final word for W mass at the Tevatron, but here is the new combined value.
- Tevatron Run II results now dominate the precision on the world average.



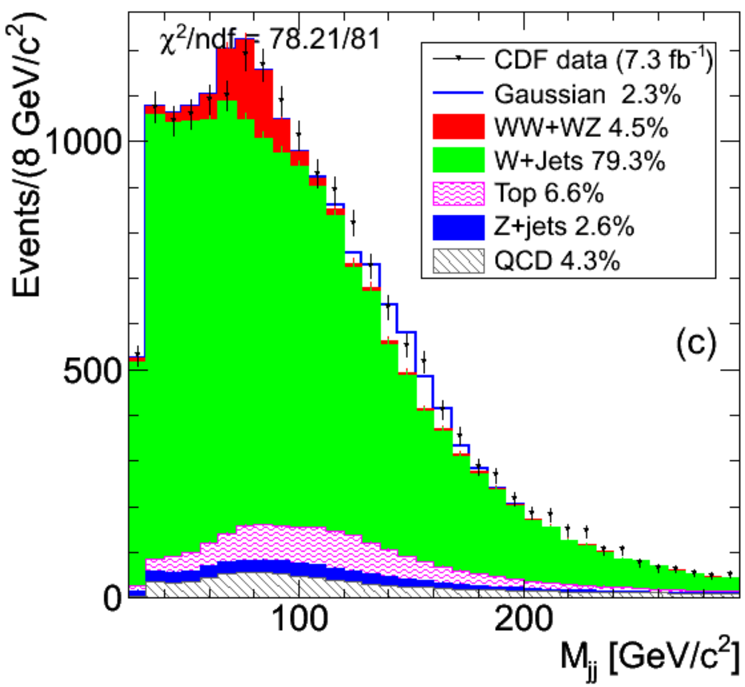
arXiv: 1204.0042

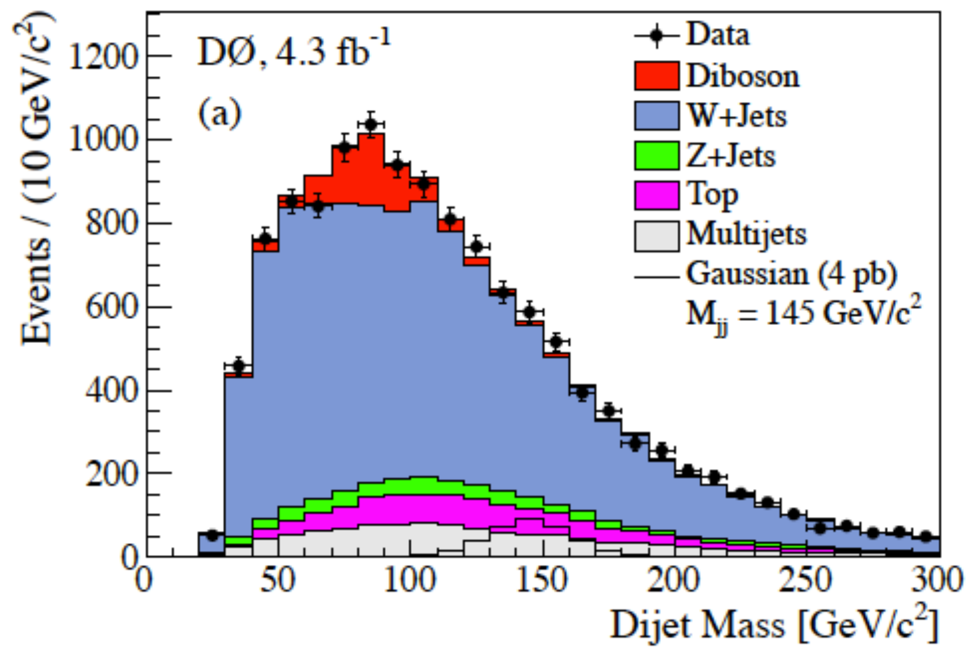
Summary:

- The search for new physics at the Tevatron continues in many directions!
- I've barely scratched the surface of all of these topics, and there were still more I couldn't cover because of time.
- Check out the references that I've strewn through this talk, as well as:
  - http://www-cdf.fnal.gov/physics/physics.html
  - http://www-do.fnal.gov/Run2Physics/WWW/results.htm

BACKUP

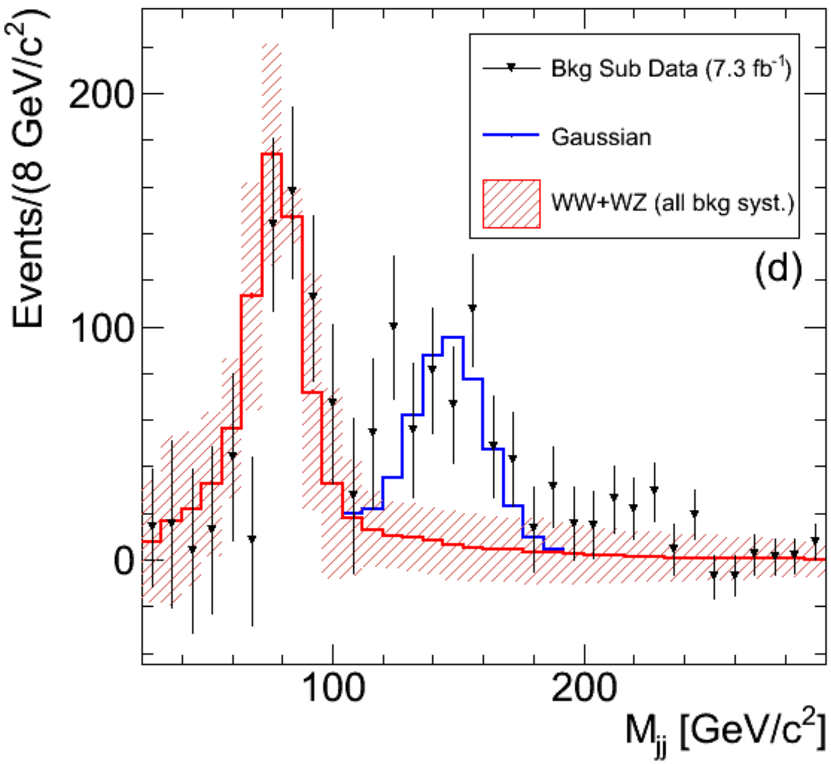
W+jets bump

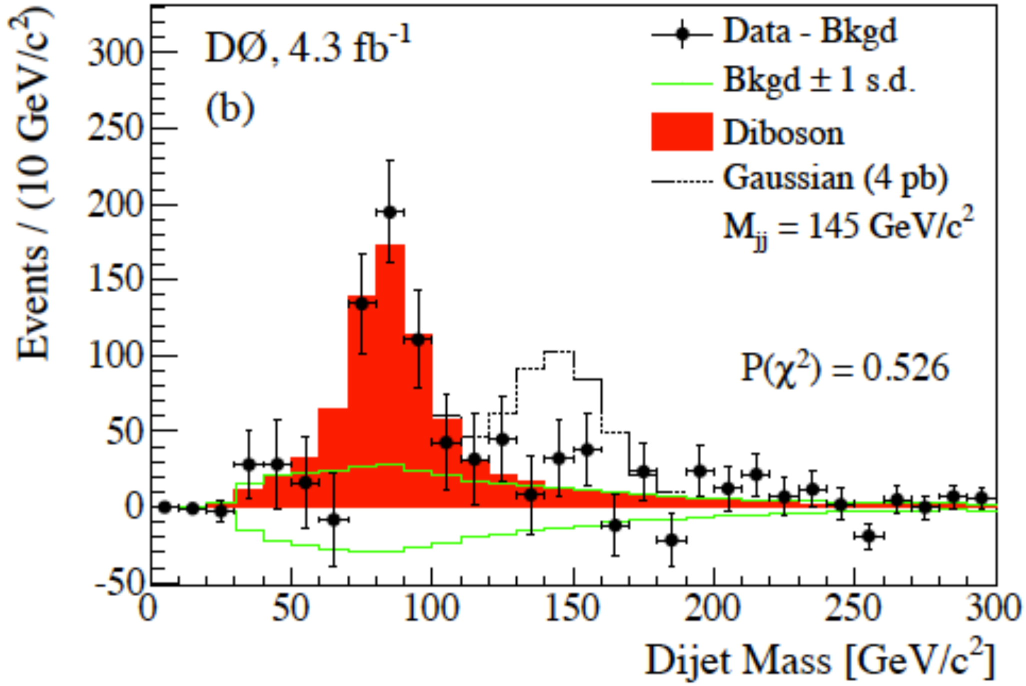




- Here are the dijet invariant mass distributions for W+jets.

W+jets bump





- Here we are with background subtracted. Word is that CDF will have an additional update soon.