CDF W mass result experimental mini-review

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Josh Isaacson will follow with a mini-review of the theory important for the measurement (not the possible theory explanations of the result, which would take a full day)

Many of the figures are borrowed from Ashutosh Kotwal's seminar at Fermilab.

The ~~face~~ W mass that launched a thousand ~~ships~~ archive papers

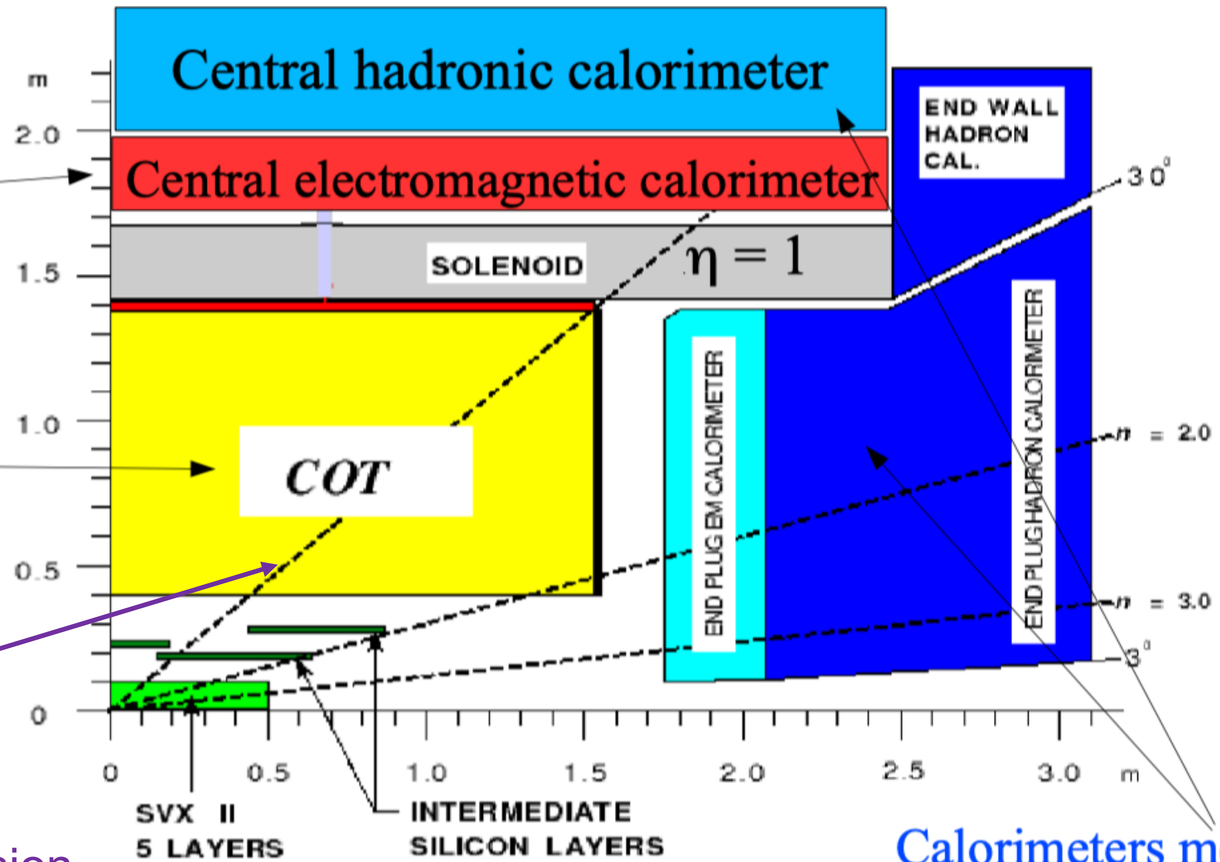
No motivation needed for the importance of W mass measurements

The experiment (my home for almost 2 decades)

EM calorimeter provides precise electron energy measurement

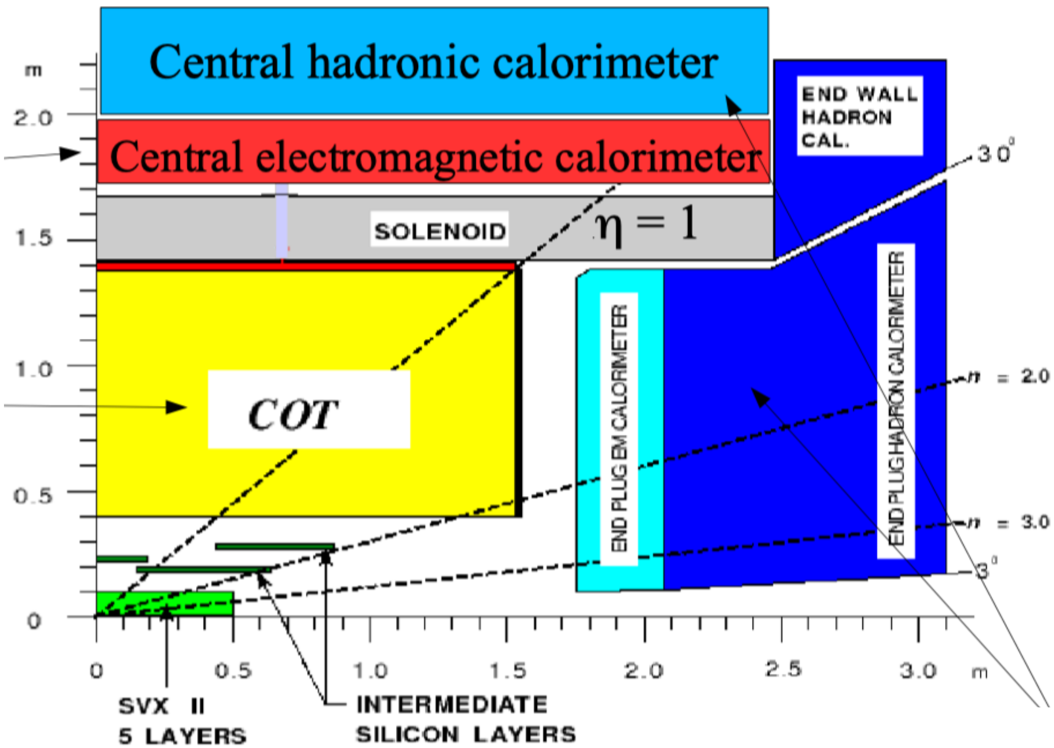
COT provides precise lepton track momentum measurement

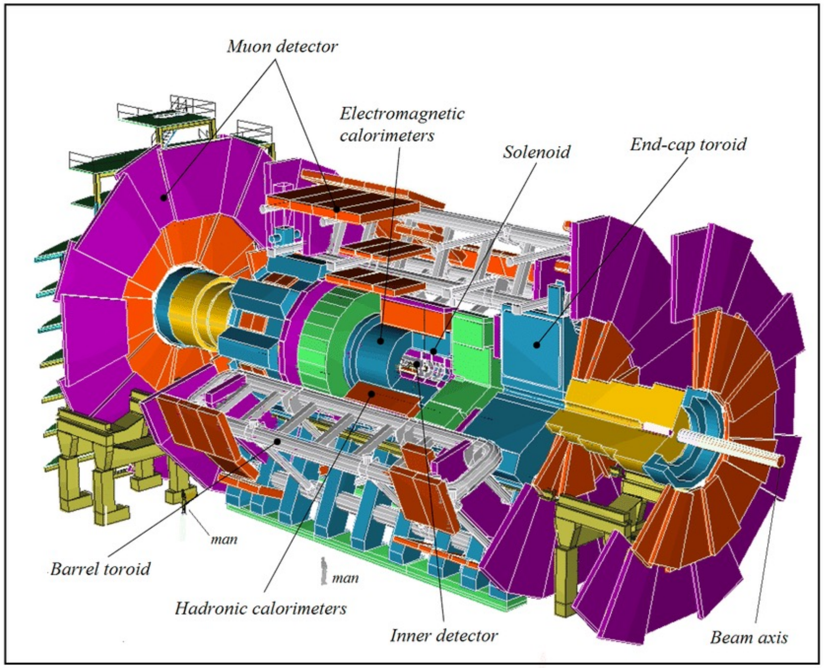
restrict lepton measurements to $|\eta|<1$, where measurement precision is greatest



Calorimeters measure hadronic recoil particles

Tevatron vs LHC experiments





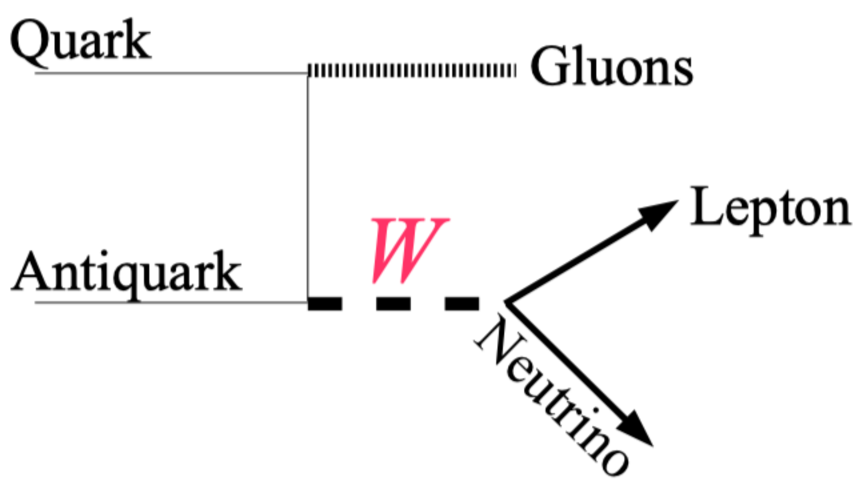
CDF has a smaller detector, smaller magnetic field, smaller precision tracking region, smaller collaboration than ATLAS.

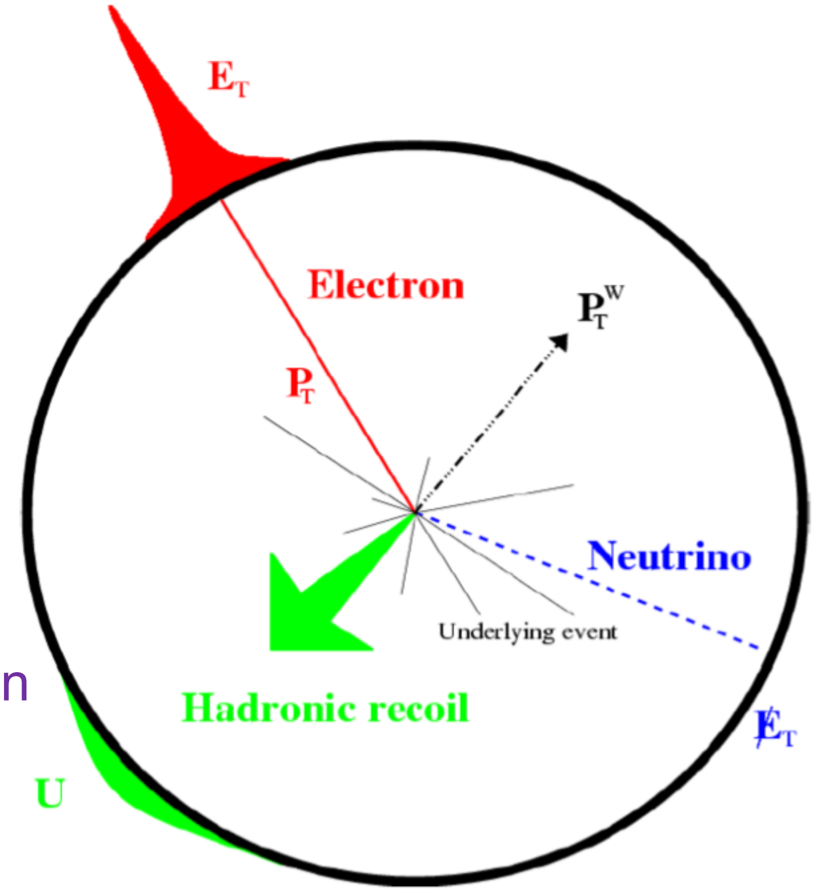
only 5% of overall W production involves 2nd generation quarks

But it also has smaller PDF uncertainties, smaller pileup and smaller "QCD" effects, as well as decades of experience. In addition, in comparison to the LHC experiments, it is a *noiseless* detector.

So expect very competitive measurements of m_W.

The measurement





Quark-antiquark annihilation dominates (80%) mostly in valence region

Lepton p_T carries most of *W* mass information, can be measured precisely (achieved 0.004%)

W mass can be determined through p_T of lepton, p_T of neutrino, and transverse mass, in both electron and muon channels, for both charge signs -> powerful cross-checks; more symmetry then at LHC because of pbar-p collider

Event selection for high purity W sample

- Electron
  - track: $30<p_T<55$ GeV
- Muon
  - track: $30<p_T<55$ GeV
- Missing transverse momentum
  - $30<p_T<55$ GeV
- Recoil u
  - $|\vec{u}|<15$ GeV
  - *similar to a cut on W p_T*
- W selection (for mass)
  - one (and only one) lepton, $|\eta_l|<1$, missing transverse momentum, $|u|<15$ GeV
  - $60<m_T<100$ GeV
- Z selection
  - two leptons, opposite sign
  - $66<m_{ll}<116$ GeV

- Data set of 8.8 fb^{-1}, collected from Feb 2002-Sept 2011

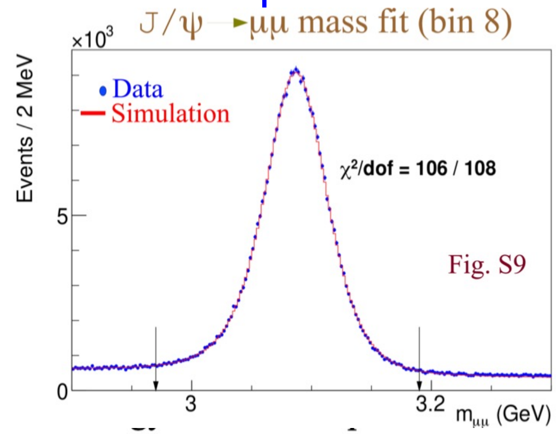
Sample	Candidates
W → electron	1 811 700
Z → electrons	66 180
W → muon	2 424 486
Z → muons	238 534

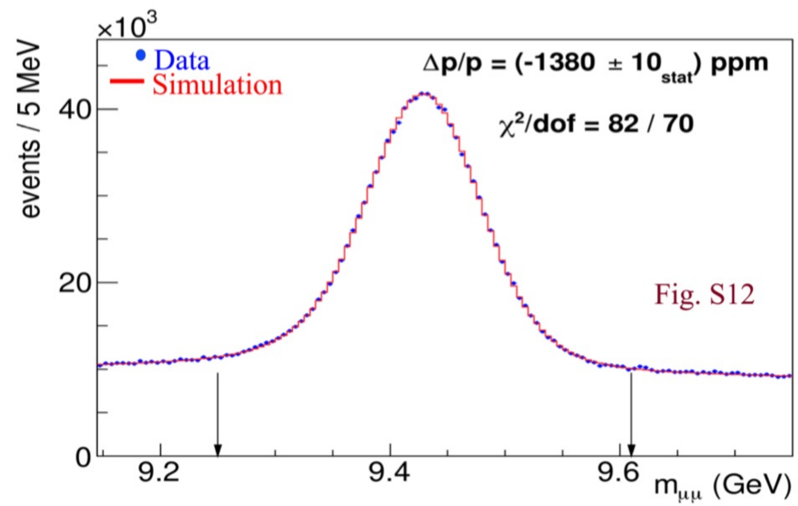
Very good background rejection;
mis-identification backgrounds ~ 0.5%

Calibration

- Tracker
  - alignment of COT using cosmic rays
  - COT momentum scale constrained using J/ψ->μμ and Υ->μμ
    - confirmed using Z->μμ
- EM calorimeter
  - momentum scale transferred to EM calorimeter using E/p spectrum
    - confirmed using Z->ee
- Hadronic recoil modeling
  - p_T-balance in Z->ll events

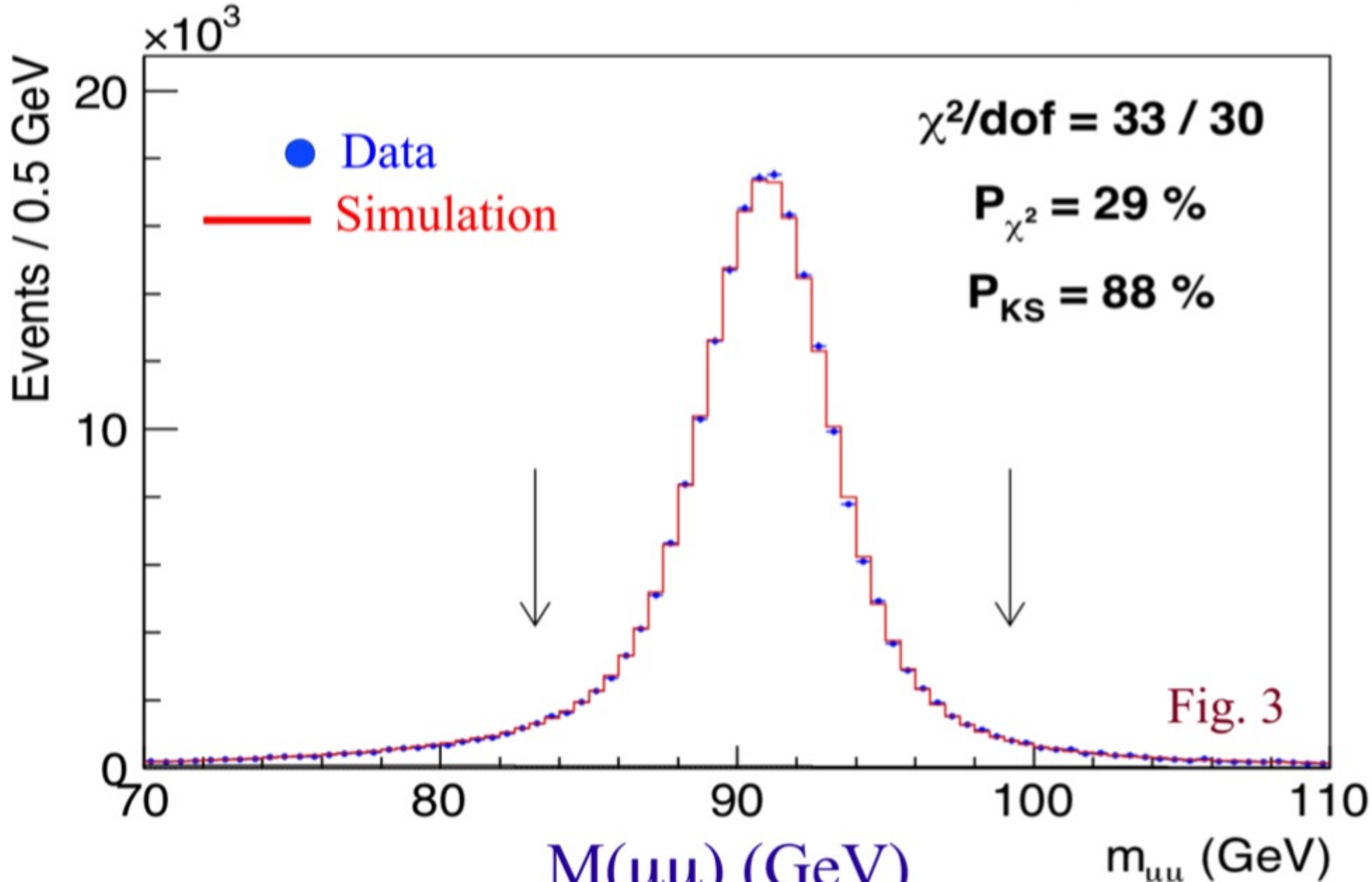
- Custom Monte Carlo detector simulation, with tracks and photons propagated through a high-resolution 3-D lookup table of material properties





(Blinded) Z->μμ mass check (momentum scale)

- Z mass consistent with PDG value (91188 MeV) (0.7σ statistical)
- $M_Z = 91192.0 \pm 6.4_{stat} \pm 2.3_{momentum} \pm 3.1_{QED} \pm 1_{alignment}$ MeV

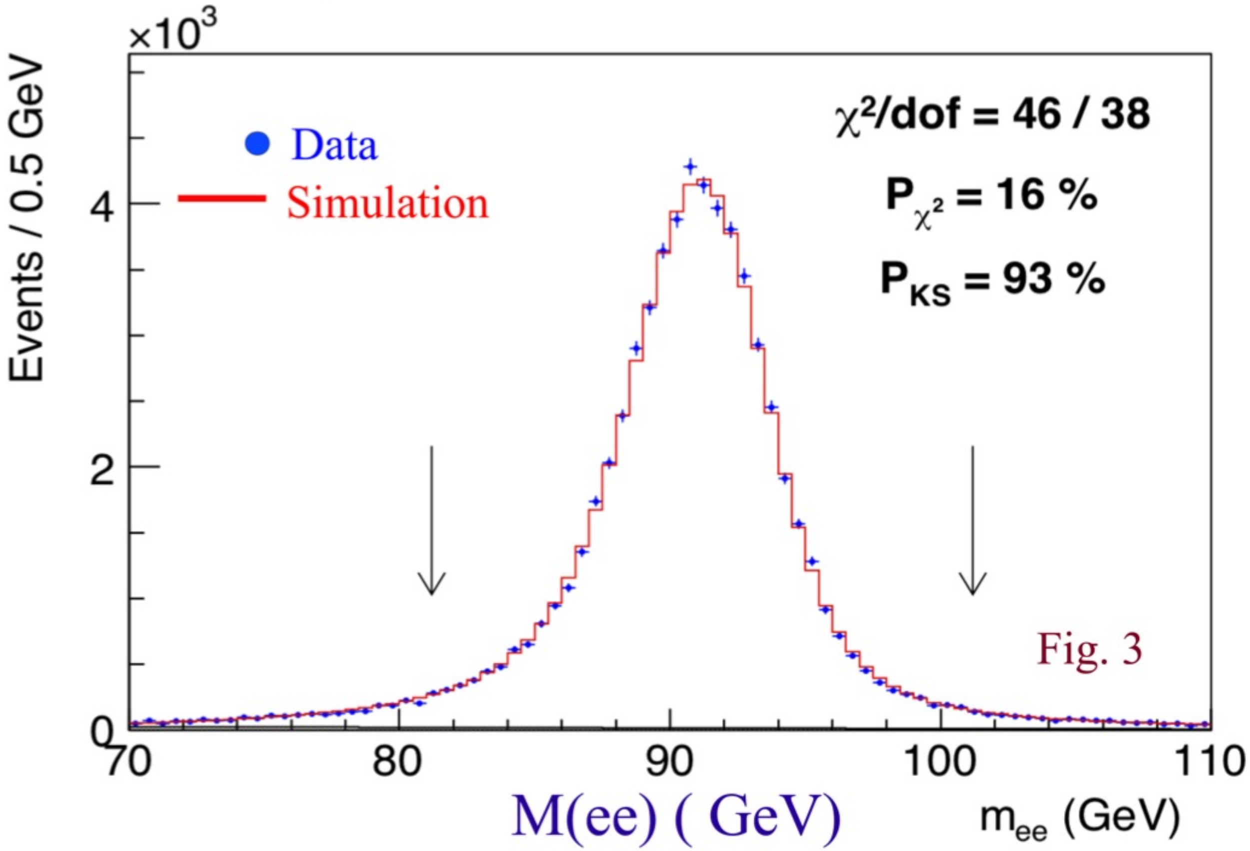


M(μμ) (GeV)

(Blinded) Z->ee mass check (energy scale)

- Consistent with PDG value (91188 MeV) within 0.5σ (statistical)
- $M_Z = 91194.3 \pm 13.8_{stat} \pm 6.5_{calorimeter} \pm 2.3_{momentum} \pm 3.1_{QED} \pm 0.8_{alignment}$ MeV

• Combine E/p-based calibration with $Z \to ee$ mass for maximum precision

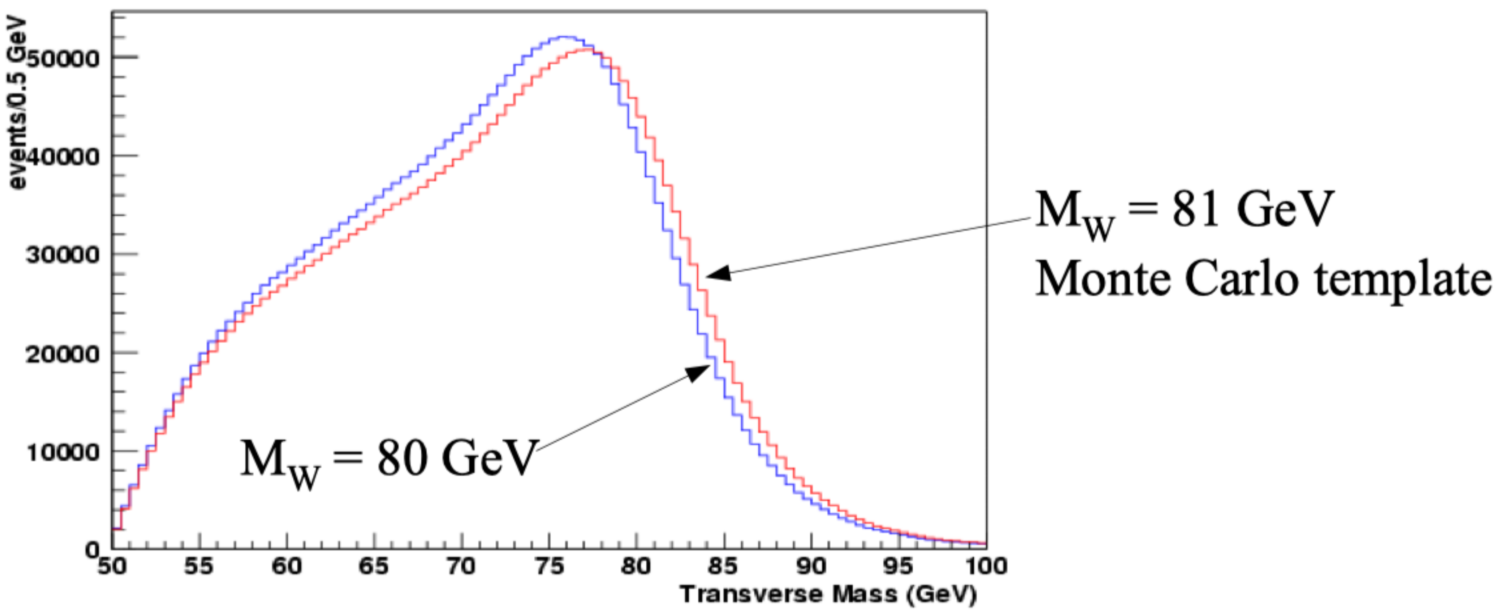


M(ee) (GeV)

ΔS_E = -14 ± 72 ppm

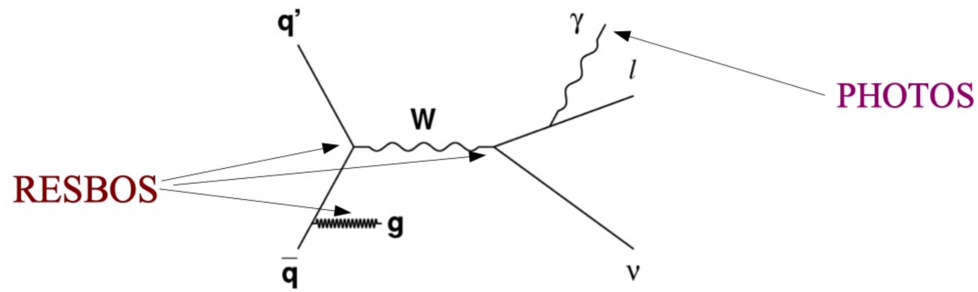
Signal simulation and template fitting

- Signals simulated using custom fast Monte Carlo
- W mass extracted from 6 kinematic distributions
  - transverse mass $$m_T = \sqrt{2\left(p_T^\ell p_T^\nu - \vec{p}_T^{\,\ell} \cdot \vec{p}_T^{\,\nu}\right)}$$
  - charged lepton p_T
  - neutrino p_T (missing E_T)
  - both electron and muon channels



Theory-level predictions

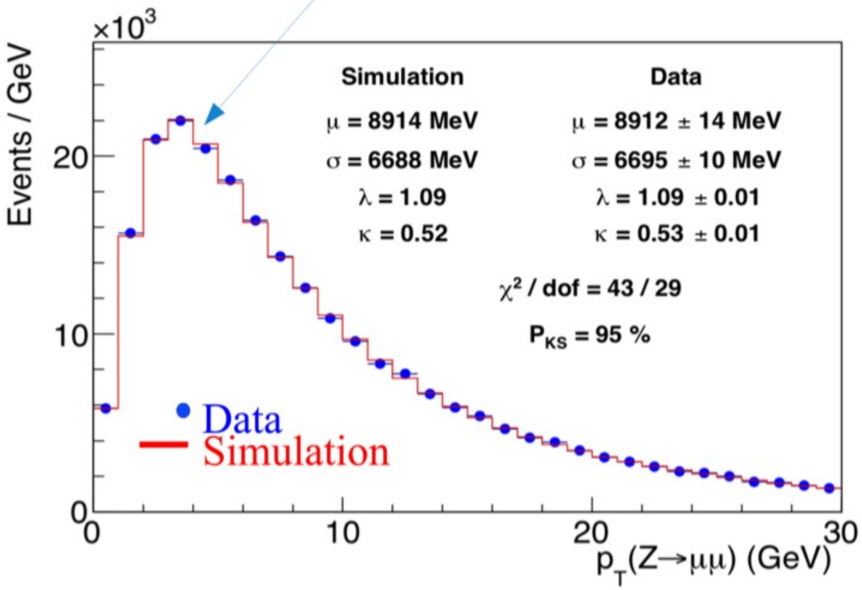
- Predictions for W/Z production and decay provided by ResBos
  - with multiple radiative photons generated by PHOTOS
- Characterize transverse momentum distributions; <u>at low p_T, have tunable non-perturbative parameters</u>

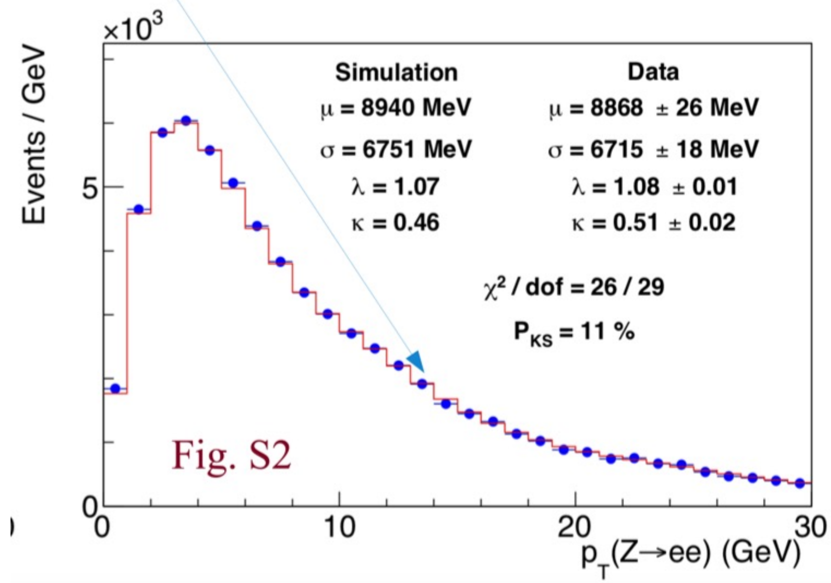


The version used is NNLL+NLO. See Josh's talk for impact of higher orders and of PDFs.

Position of peak in boson p_T spectrum depends on g_2 (non-perturbative Sudakov factor)

Tail to peak ratio depends on α_s





W Transverse Mass Fits

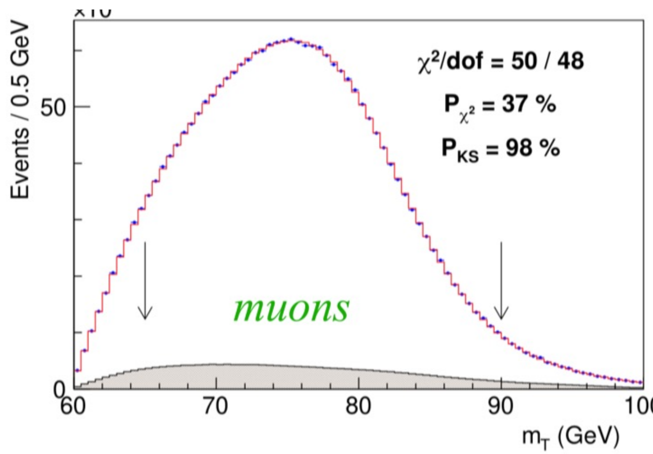
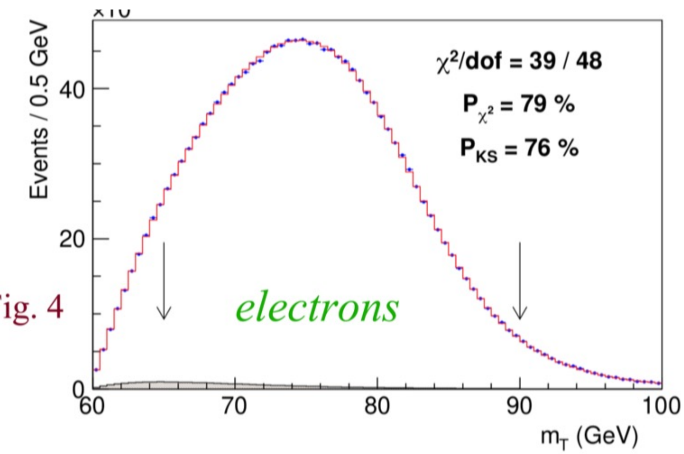
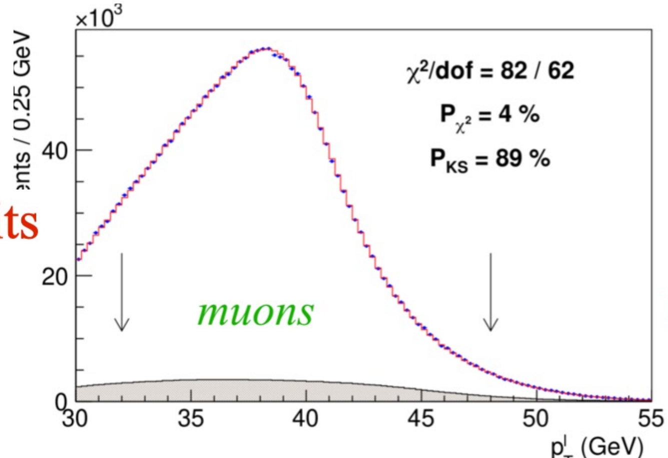


Fig. 4



restrict W mass fit range to that shown by arrows; a bit more restrictive then purity cuts

W Charged Lepton p_T Fits



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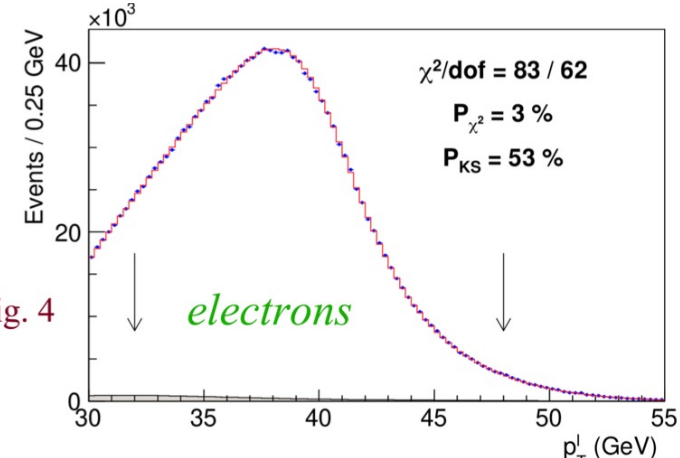
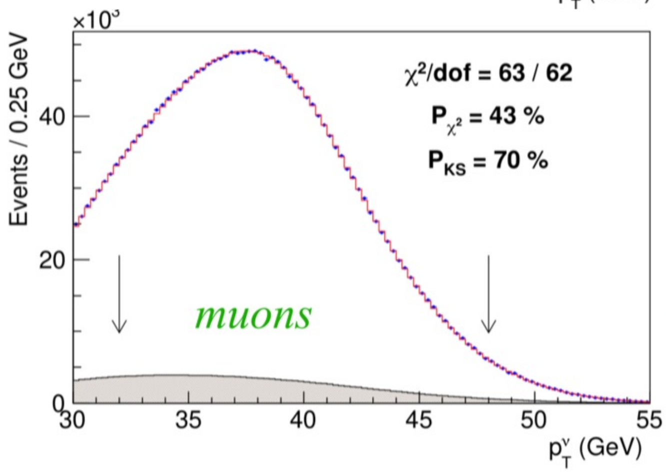


W Neutrino p_T Fits



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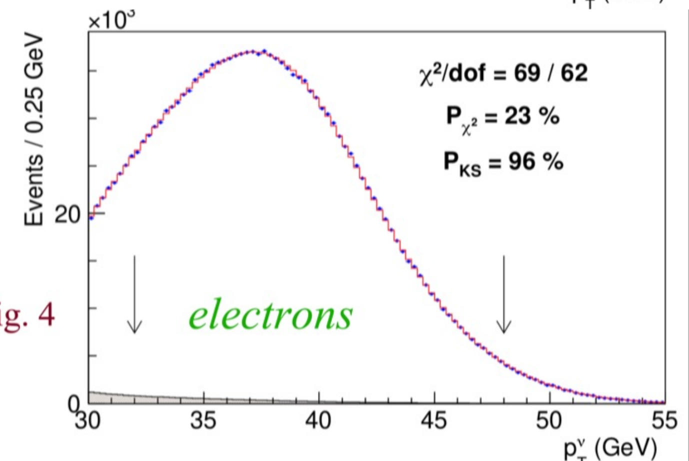

Distribution	W-boson mass (MeV)	χ^2/dof
$m_T(e,\nu)$	$80\ 429.1 \pm 10.3_{\text{stat}} \pm 8.5_{\text{syst}}$	39/48
$p_T^\ell(e)$	$80\ 411.4 \pm 10.7_{\text{stat}} \pm 11.8_{\text{syst}}$	83/62
$p_T^\nu(e)$	$80\ 426.3 \pm 14.5_{\text{stat}} \pm 11.7_{\text{syst}}$	69/62
$m_T(\mu,\nu)$	$80\ 446.1 \pm 9.2_{\text{stat}} \pm 7.3_{\text{syst}}$	50/48
$p_T^\ell(\mu)$	$80\ 428.2 \pm 9.6_{\text{stat}} \pm 10.3_{\text{syst}}$	82/62
$p_T^\nu(\mu)$	$80\ 428.9 \pm 13.1_{\text{stat}} \pm 10.9_{\text{syst}}$	63/62
combination	$80\ 433.5 \pm 6.4_{\text{stat}} \pm 6.9_{\text{syst}}$	7.4/5

Combination	m_T fit		p_T^ℓ fit		p_T^ν fit		Value (MeV)	χ^2/dof	Probability (%)
	Electrons	Muons	Electrons	Muons	Electrons	Muons			
m_T	✓	✓					$80\ 439.0 \pm 9.8$	1.2 / 1	28
p_T^ℓ			✓	✓			$80\ 421.2 \pm 11.9$	0.9 / 1	36
p_T^ν					✓	✓	$80\ 427.7 \pm 13.8$	0.0 / 1	91
m_T & p_T^ℓ	✓	✓	✓	✓			$80\ 435.4 \pm 9.5$	4.8 / 3	19
m_T & p_T^ν	✓	✓			✓	✓	$80\ 437.9 \pm 9.7$	2.2 / 3	53
p_T^ℓ & p_T^ν			✓	✓	✓	✓	$80\ 424.1 \pm 10.1$	1.1 / 3	78
Electrons	✓		✓		✓		$80\ 424.6 \pm 13.2$	3.3 / 2	19
Muons		✓		✓		✓	$80\ 437.9 \pm 11.0$	3.6 / 2	17
All	✓	✓	✓	✓	✓	✓	$80\ 433.5 \pm 9.4$	7.4 / 5	20

Table S9

- Combined electrons (3 fits): $M_W = 80424.6 \pm 13.2$ MeV, $P(\chi^2) = 19\%$
- Combined muons (3 fits): $M_W = 80437.9 \pm 11.0$ MeV, $P(\chi^2) = 17\%$

Weights in combination (%)

	m_T	p_T^l	p_T^ν
e	30	6.7	0.9
μ	34.2	18.7	9.5

m_T is the most important

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Combination	m_T fit		p_T^ℓ fit		p_T^ν fit		Value (MeV)	χ^2/dof	Probability (%)
	Electrons	Muons	Electrons	Muons	Electrons	Muons			
m_T	✓	✓					$80\ 439.0 \pm 9.8$	1.2 / 1	28
p_T^ℓ			✓	✓			$80\ 421.2 \pm 11.9$	0.9 / 1	36
p_T^ν					✓	✓	$80\ 427.7 \pm 13.8$	0.0 / 1	91
m_T & p_T^ℓ	✓	✓	✓	✓			$80\ 435.4 \pm 9.5$	4.8 / 3	19
m_T & p_T^ν	✓	✓			✓	✓	$80\ 437.9 \pm 9.7$	2.2 / 3	53
p_T^ℓ & p_T^ν			✓	✓	✓	✓	$80\ 424.1 \pm 10.1$	1.1 / 3	78
Electrons	✓		✓		✓		$80\ 424.6 \pm 13.2$	3.3 / 2	19
Muons		✓		✓		✓	$80\ 437.9 \pm 11.0$	3.6 / 2	17
All	✓	✓	✓	✓	✓	✓	$80\ 433.5 \pm 9.4$	7.4 / 5	20

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New CDF Result (8.8 fb^{-1})
All Fit Uncertainties (MeV)

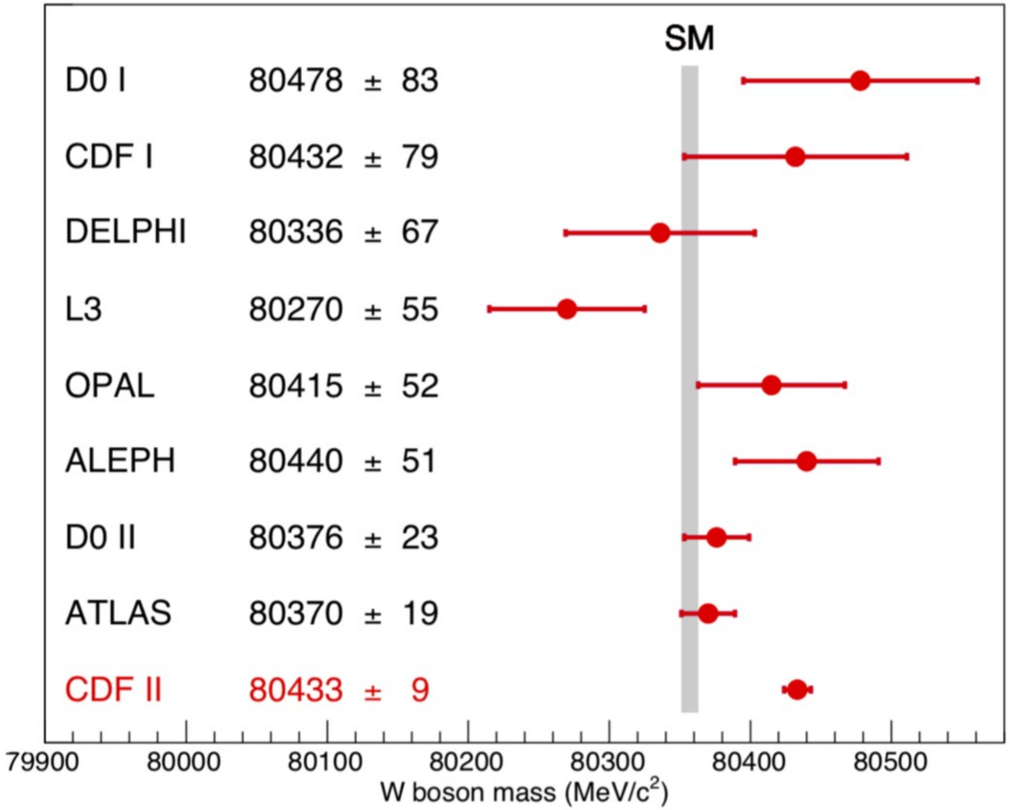
Source of systematic uncertainty	m_T fit			p_T^ℓ fit			p_T^ν fit		
	Electrons	Muons	Common	Electrons	Muons	Common	Electrons	Muons	Common
Lepton energy scale	5.8	2.1	1.8	5.8	2.1	1.8	5.8	2.1	1.8
Lepton energy resolution	0.9	0.3	-0.3	0.9	0.3	-0.3	0.9	0.3	-0.3
Recoil energy scale	1.8	1.8	1.8	3.5	3.5	3.5	0.7	0.7	0.7
Recoil energy resolution	1.8	1.8	1.8	3.6	3.6	3.6	5.2	5.2	5.2
Lepton $u_{\|\|}$ efficiency	0.5	0.5	0	1.3	1.0	0	2.6	2.1	0
Lepton removal	1.0	1.7	0	0	0	0	2.0	3.4	0
Backgrounds	2.6	3.9	0	6.6	6.4	0	6.4	6.8	0
p_T^Z model	0.7	0.7	0.7	2.3	2.3	2.3	0.9	0.9	0.9
p_T^W/p_T^Z model	0.8	0.8	0.8	2.3	2.3	2.3	0.9	0.9	0.9
Parton distributions	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9
QED radiation	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7
Statistical	10.3	9.2	0	10.7	9.6	0	14.5	13.1	0
Total	13.5	11.8	5.8	16.0	14.1	7.9	18.8	17.1	7.4

Table S8

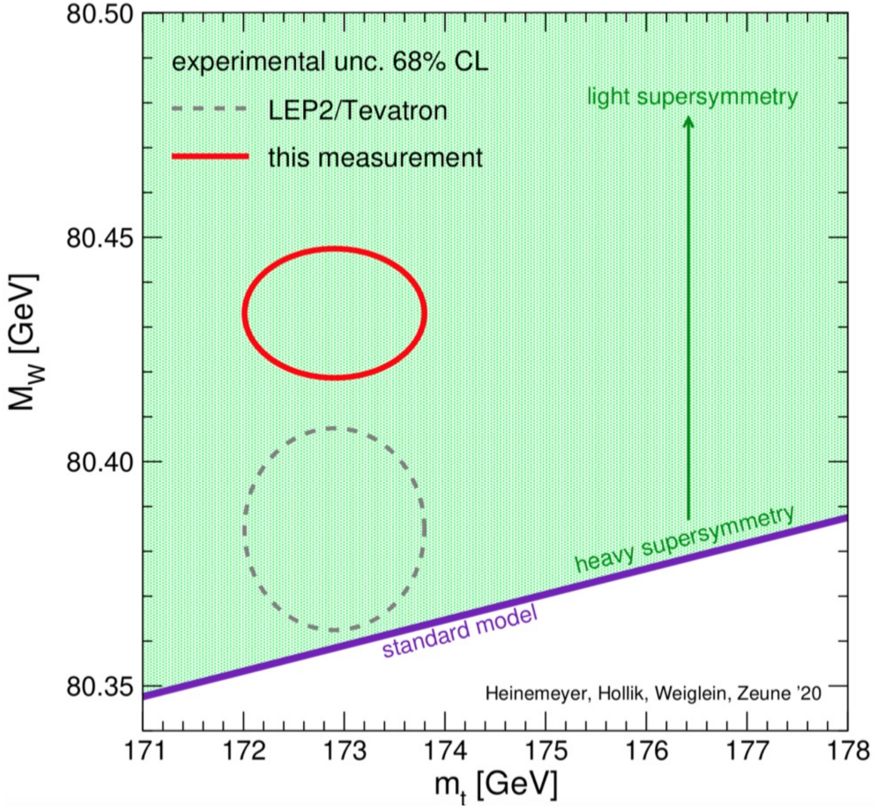
Comparison to result with 2 fb^{-1}

- Statistical precision of the measurement improves by almost a factor of 2
- Analysis improvements have reduced systematic errors
  - COT alignment and drift model and uniformity of the EM calorimeter response
  - accuracy and robustness of detector response and resolution model in the simulation
  - updates of theoretical inputs->see Josh's talk
- Improved understanding of PDFs and track reconstruction would have increased previous measurement by 13.5 MeV to 80,400.5 MeV (consistency with new measurement at the level of 1%)

Comparison



CDF M_W *vs* m_{top}



Some concluding throughts

- Fits with three different observables, with two lepton flavors, are all consistent, but inconsistent with SM prediction, and with many other measurements of W mass
- Could there be some common systematic(s) among all six of the CDF analyses?
- Would it be worthwhile to do a W-mass analysis of Z-> ee/$\mu\mu$?
  - it will be statistics limited, but confirmation of the central value would add an extra degree of robustness.

The ~~face~~ W mass that launched a thousand ~~ships~~ archive papers

We know the direction that all of these ships are sailing. The question is whether it will be worth the trip. (And whether it will take 20 years to get back.)