W Boson Mass and Backgrounds in the Muon Channel

Oliver Stelzer-Chilton

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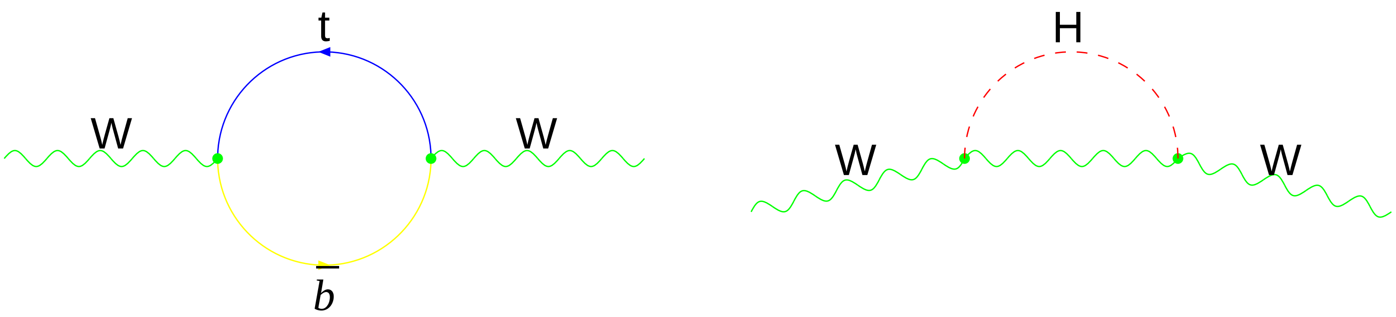
1. Measurement Motivation
2. Backgrounds to the $W \to \mu\nu$ Signal
3. Momentum Scale Cross-Check
4. Outlook

Motivation for Measuring M_W

- Precision measurement of M_W allow a consistency test of the Standard Model
- M_W and M_{top} are connected to M_H through radiative corrections:

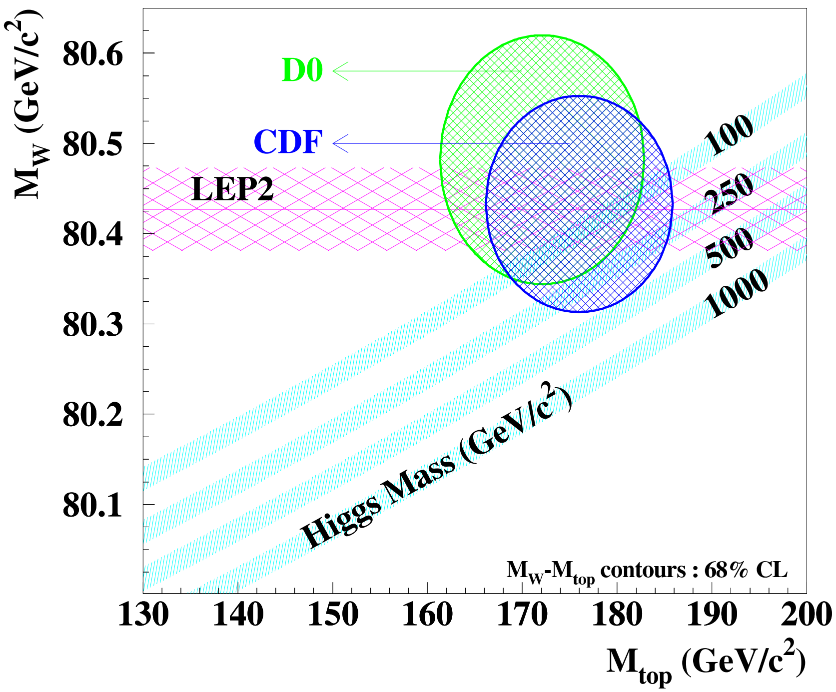
$$M_W = 80.38 - 0.06 \ln\frac{M_H}{100GeV} - 0.52 \left[\frac{\Delta\alpha^5_{had}}{0.03} - 1\right] + 0.54 \left[\left(\frac{M_{top}}{175GeV}\right)^2 - 1\right] - 0.09 \left[\frac{\alpha_s(M_Z)}{0.12} - 1\right]$$



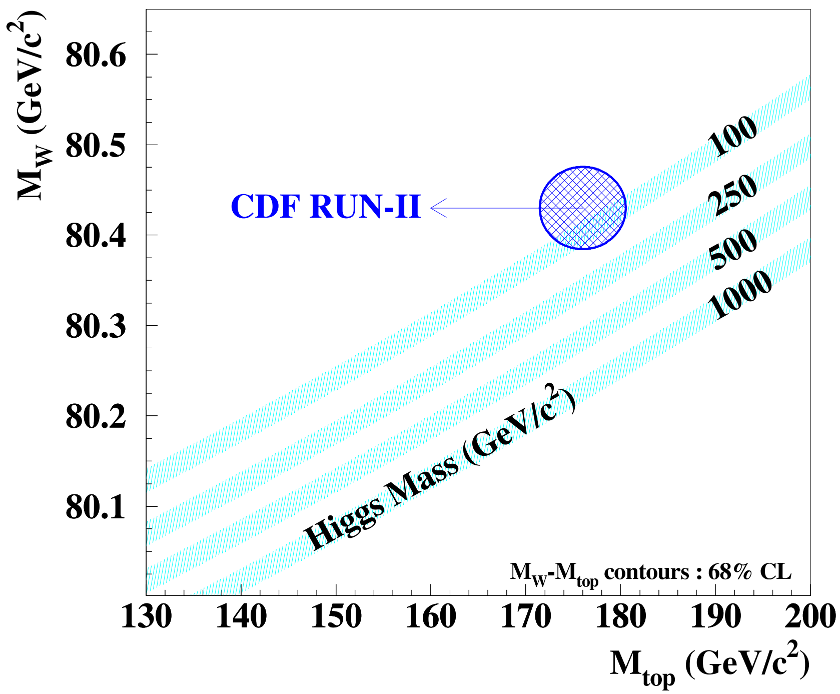
- M_W is sensitive to properties of new particles (populate loops in the W propagator)
- M_W and M_Z define weak mixing angle:

$$cos\theta_W = M_W/M_Z$$

Constraining the Higgs Mass



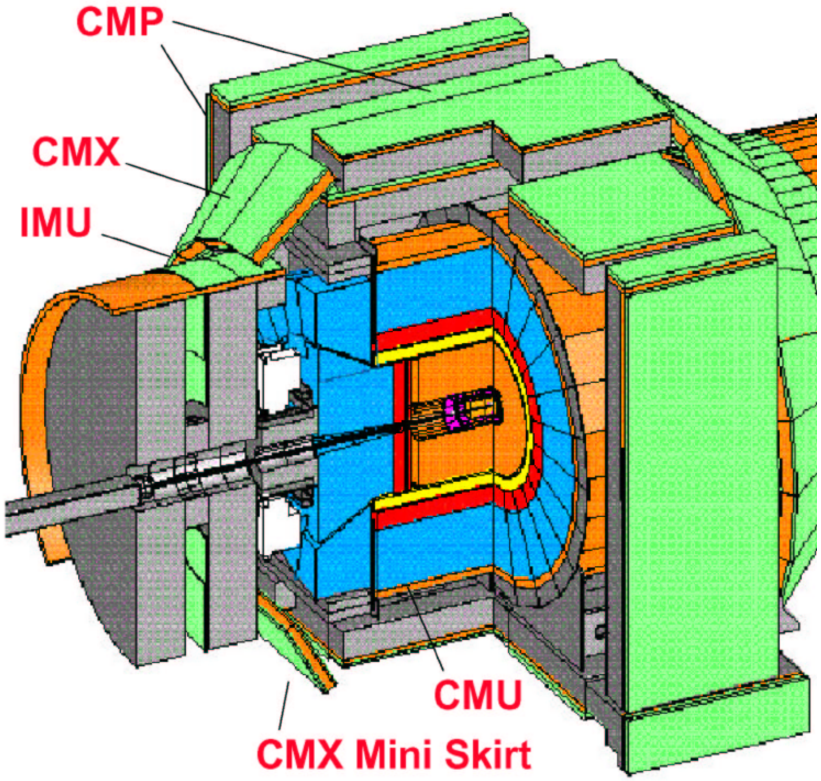
- Run I



- Run IIa (2/fb):
  ΔM_W = 40 MeV/c^2
  ΔM_{top} = 3.5 GeV/c^2

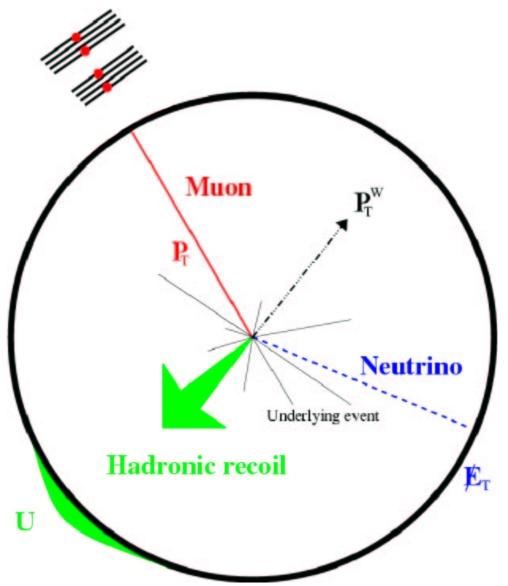
CDF Run II

- Run IIa well underway
- Tevatron supplying $\mathcal{L} = 3{\times}10^{31}\mathrm{cm}^{-2}\mathrm{s}^{-1}$
- Approaching Run I dataset sizes
- With $\sqrt{s}$ = 1.96 TeV, cross-section for W and Z production increases by $\sim$10 %
  - Run I: σB($W \rightarrow e\nu$) = 2.49 $\pm$ 0.12 nb
  - Run II: σB($W \rightarrow \mu\nu$) = 2.64 $\pm$ 0.3 nb
- With 500 pb^{-1} can expect of the order of 200 000 central W events, compared to the 30 000 in Run Ib



Nature of W Events

- p_T of W boson is balanced by the p_T of hadrons produced (recoil)



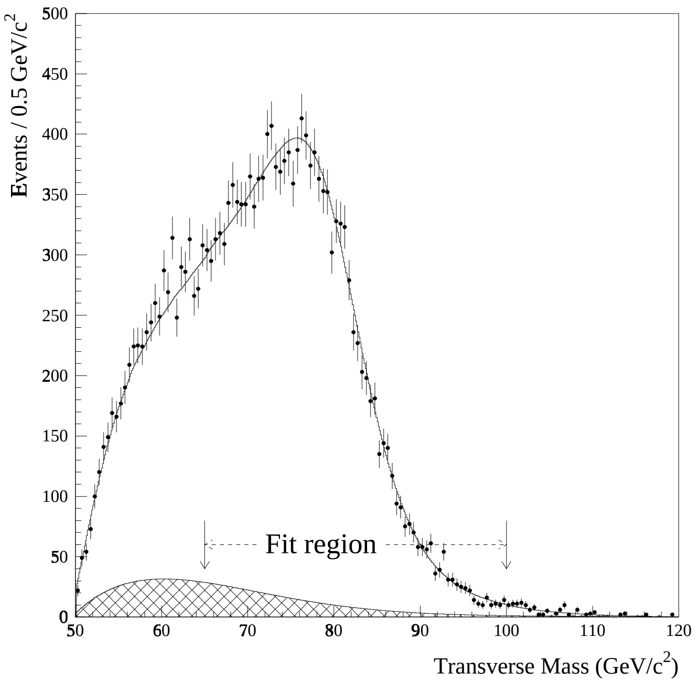
Leaves a clear signature in the detector:
$\rightarrow$ high p_T lepton
$\rightarrow$ missing E_T from neutrino

- Since the apparatus neither detects the neutrino nor the longitudinal momentum of the recoil $\Rightarrow$ measure only transverse components

W Mass Measurement

- Mass can be obtained by a fit to the transverse mass spectrum

$$M_T = \sqrt{[E_T(l) + E_T(\nu)]^2 - [\vec{p}_T(l) + \vec{p}_T(\nu)]^2}$$



- In the $W \to \mu\nu$ channel, most important quantity is muon p_T
  $\Rightarrow$ needs to be measured with lowest systematic uncertainty

- Spectrum cannot be predicted analytically (finite detector acceptance, resolution, W p_T)
- Must be simulated with realistic Monte Carlo
- For a given value of the true mass, MC predicts the observed spectrum

Backgrounds in $W \to \mu\nu$ events

- $Z \to \mu\mu$

  - If second muon in tracking chamber
  $\to$ Can be removed
  - If second muon track outside
  $\to$ Lost

- $W \to \tau\nu$

  - Where $\tau \to \mu\nu\nu$

- Cosmic Background

  - Cosmic Rays, not removed by the Cosmic Tagger can fake signal

- QCD Background

  - QCD dijet events, where one jet fakes a muon
  - Decay of b quark in high p_T muon

Backgrounds will be added to the simulated MC templates

$\Rightarrow$ Omitting backgrounds would shift W mass

Data and Monte Carlo Samples

- Data
  - Inclusive high p_T muon data set (btop1g)
  - Good muon runs from 141544 (March 02) to 156487 (January 03)
  - Total integrated luminosity $\sim$72 pb^{-1}

- Monte Carlo (Pythia) reconstructed with 4.9.1
  - $W \to \mu\nu$ $\sim$1.1M events
  - $Z \to \mu\mu$ $\sim$0.3M events
  - $W \to \tau\nu$ $\sim$0.4M events

W Selection Cuts

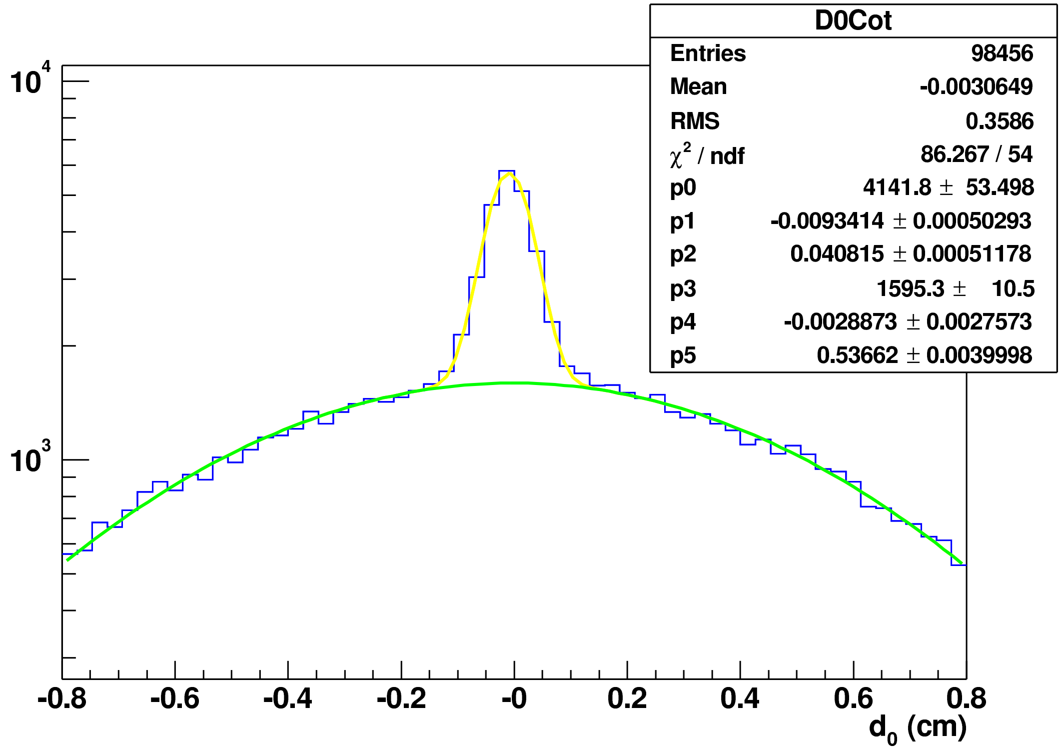
- Muon Cuts:
  - CMUP muon
  - $p_T > 20$ GeV/c
  - $|d0| < 0.2$ cm for COT tracks
  - $|d0| < 0.03$ cm for Si tracks
  - isolation $<$ 0.1 in 0.4 cone divided by p_T
  - stub match in CMU $<$ 3 cm, CMP $<$ 5 cm
  - hadronic energy $<$ 6 GeV/c^2
  - em energy $<$ 2 GeV/c^2
  - $|z0| < 60$ cm
  - 3 or more axial layers with 7 or more hits
  - 3 or more stereo layers with 7 or more hits

- Event cuts:
  - Must have L3MUON_CMUP18 trigger
  - Event not identified by cosmic tagger

- Z rejection: No second track:
  - $p_T > 10$ GeV/c
  - minimum ionizing
  - isolated

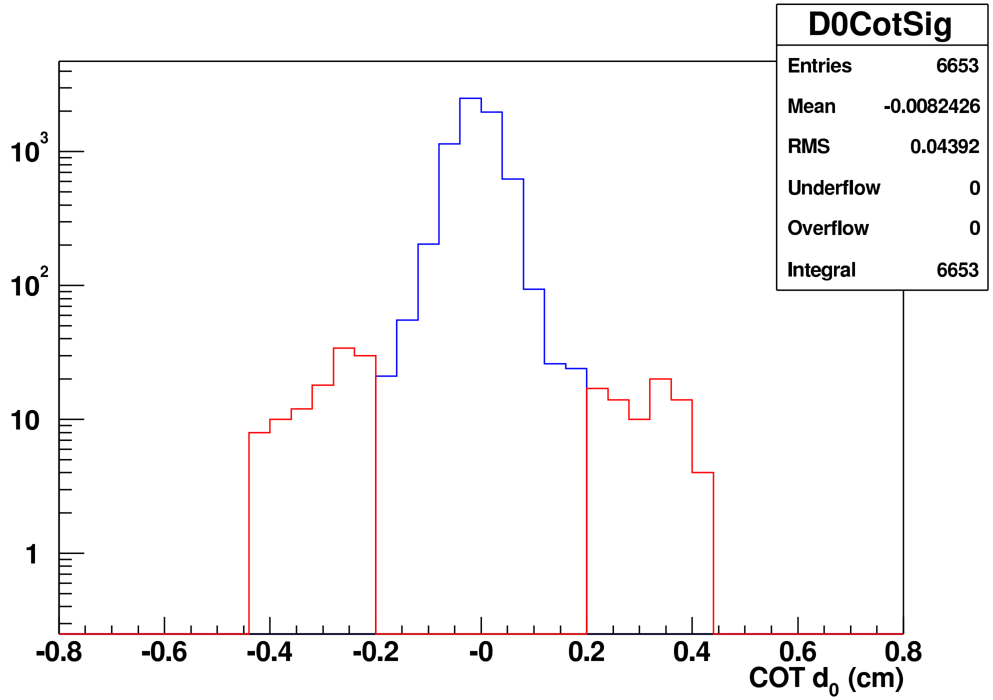
- W selection:
  - Missing E$_T$ $>$ 20 GeV
  - 30 ¡ M$_T$ ¡ 120 GeV/c^2

Cosmic Background



- Use sidebands of d0 distribution to emulate background
- Assume that distribution does not change after applying cuts
- Normalize background to area under the signal region

Cosmic Background



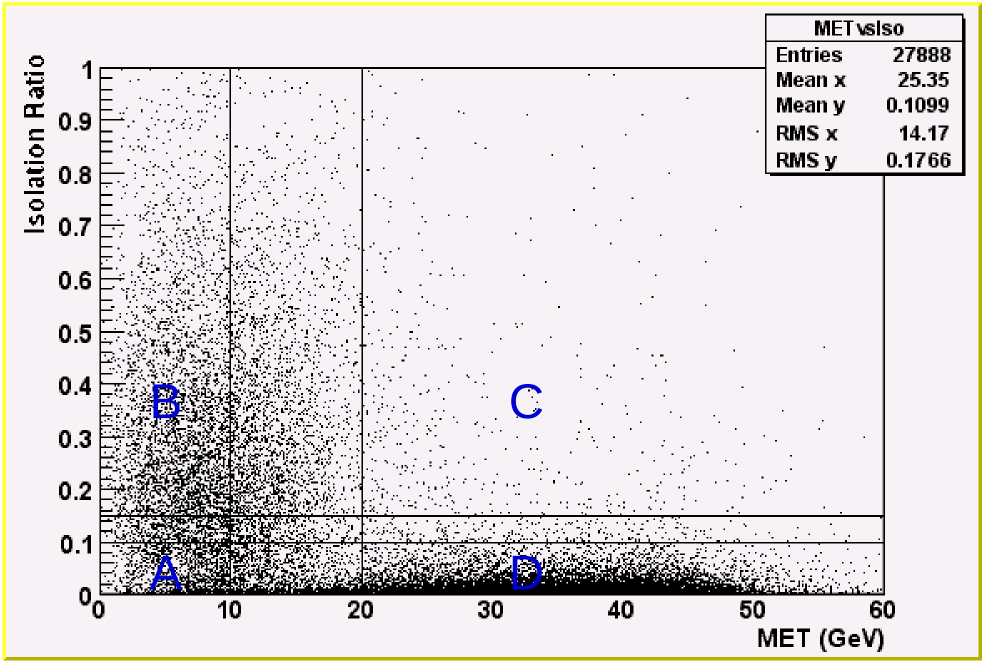
- Same method applies to silicon tracks
- Gives a total of 337 events

$\rightarrow$ Corresponds to 1.53 % of the W signal

QCD Background

- Missing E_T versus isolation distribution
- Signal Region
  - MET $>$ 20 GeV
  - isolation fraction $<$ 0.1
- $N_{QCD} = N_C \times N_A/N_B$
- = 279 events

$\rightarrow$ Corresponds to 1.17 % of the W signal



Z Rejection

- Form invariant mass for dimuon events in all detector regions
- Tight CMUP (W selection) and minimum ionizing track
- Especially CMUP-Stubless case disagrees

Number and fraction of dimuon events of CMUP-X in two mass regions

Detector type	CMUP	CMU	CMP	CMX	Stubless	BMU	ALL
MC/Data [69-111 GeV]	396 $\pm5/\pm20$	211 $\pm4/\pm15$	202 $\pm3/\pm14$	432 $\pm5/\pm21$	593 $\pm6/\pm24$	228 $\pm3/\pm15$	2079 $\pm11/\pm46$
MC events [18-69 GeV]	36 ±2	16 ±1	17 ±1	27 ±1	37 ±2	12 ±1	144 ±3
fraction in %	9.0 ±0.4	7.4 ±0.5	8.4 ±0.5	6.3 ±0.3	6.2 ±0.3	5.4 ±0.3	6.9 ±0.2
Data events [18-69 GeV]	36 ±6	21 ±5	16 ±4	30 ±6	90 ±10	16 ±4	209 ±15
fraction in %	9.1 ±1.6	10.0 ±2.3	7.9 ±2.1	6.9 ±1.3	15.2 ±1.7	7.0 ±1.8	10.1 ±0.7
absolute num subtracted	0 ±6	5 ±5	-1 ±4	3 ±6	53 ±10	4 ±4	65 ±15
fraction subtracted	0.1 ±1.7	2.6 ±2.4	-0.5 ±2.2	0.6 ±1.3	9.0 ±1.7	1.6 ±1.8	3.2 ±0.7
MC Lum MC/DATA	16.0 ±0.8	13.1 ±0.9	18.0 ±1.3	15.1 ±0.8	14.5 ±0.6	22.9 ±1.6	16.2 ±0.4

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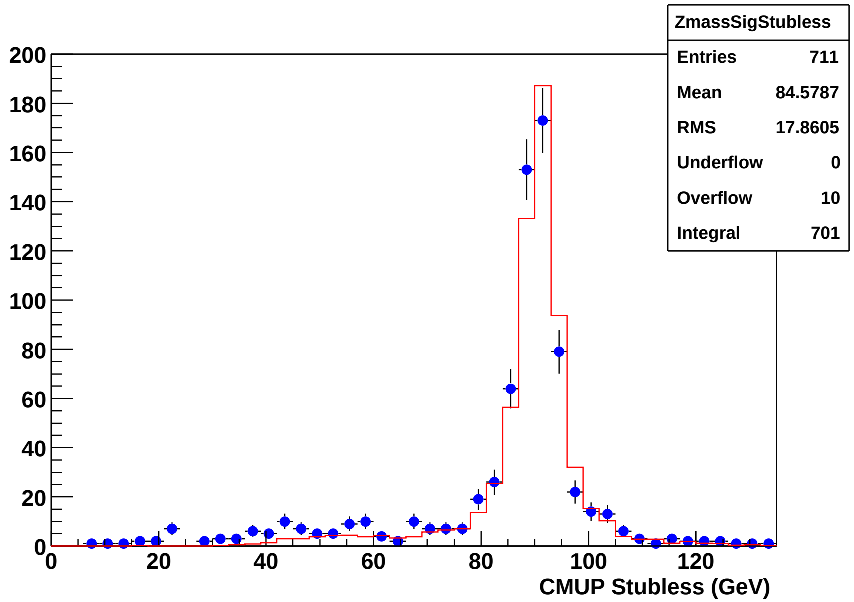
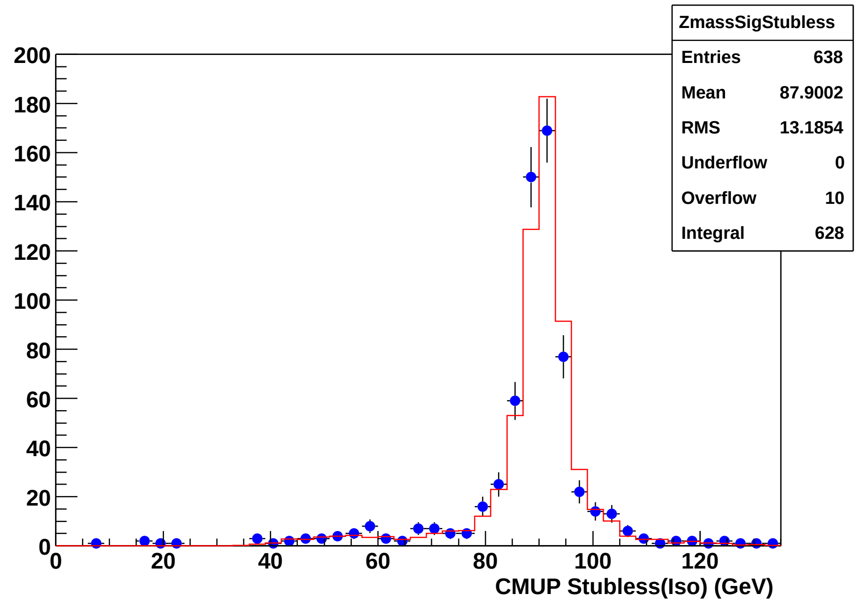
Z Rejection

- Requiring the second leg to be isolated, brings data and MC into better agreement
- Example CMUP-Stubless





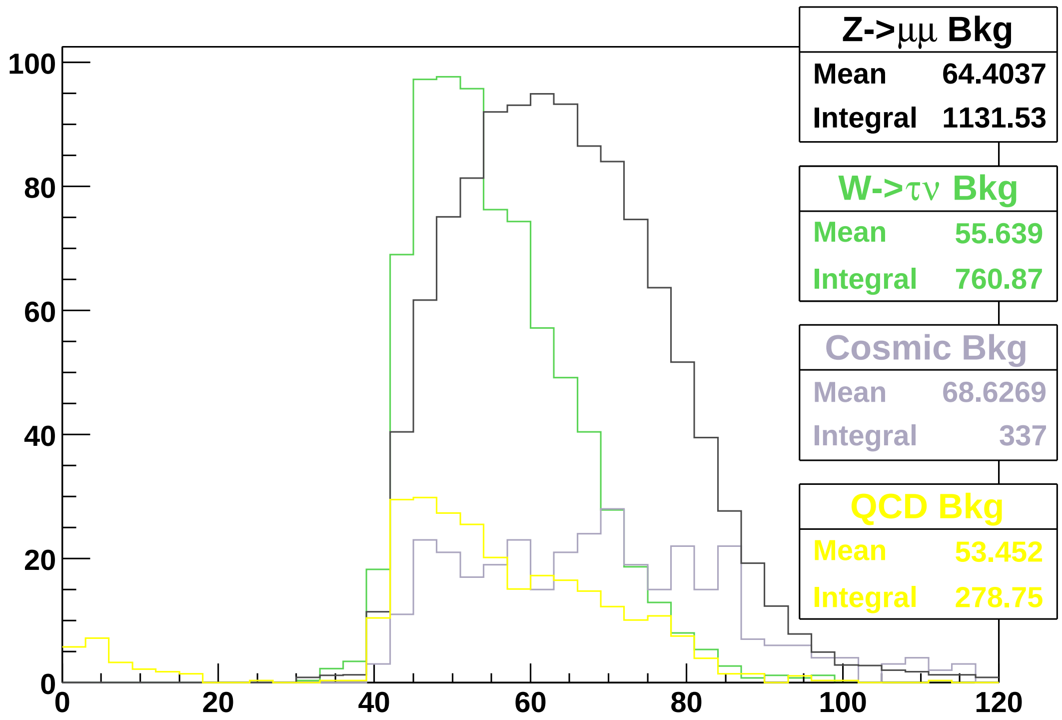
→ Reject any additional isolated, minimum ionizing track above 10 GeV/c

$Z \to \mu\mu$ and $W \to \tau\nu$ Backgrounds

- Use MC samples to estimate backgrounds
- Calculate acceptances passing W selection cuts
- Assumption:
  - $\sigma(W \to \tau\nu) = \sigma(W \to \mu\nu)$
  - $\sigma(Z \to \mu\mu) = 1/R\ \sigma(W \to \mu\nu)$
- Acceptances found are:
  - $A_{Sig} = 0.1313$
  - $A_Z = 0.0823$
  - $A_\tau = 0.0051$
- Correcting the data signal events for QCD and cosmic background

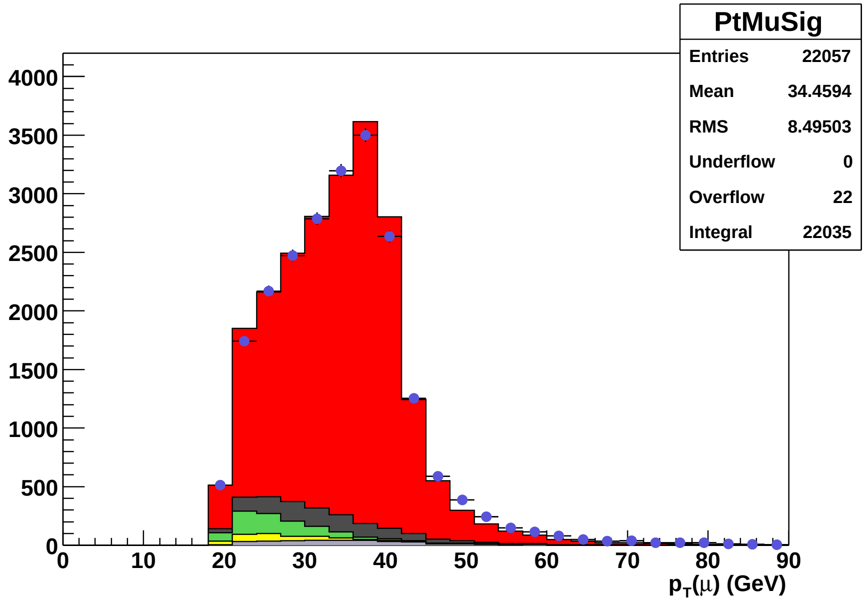
$\Rightarrow W \to \tau\nu$ background corresponds to 3.45 % and $Z \to \mu\mu$ to 5.13 % of the W signal

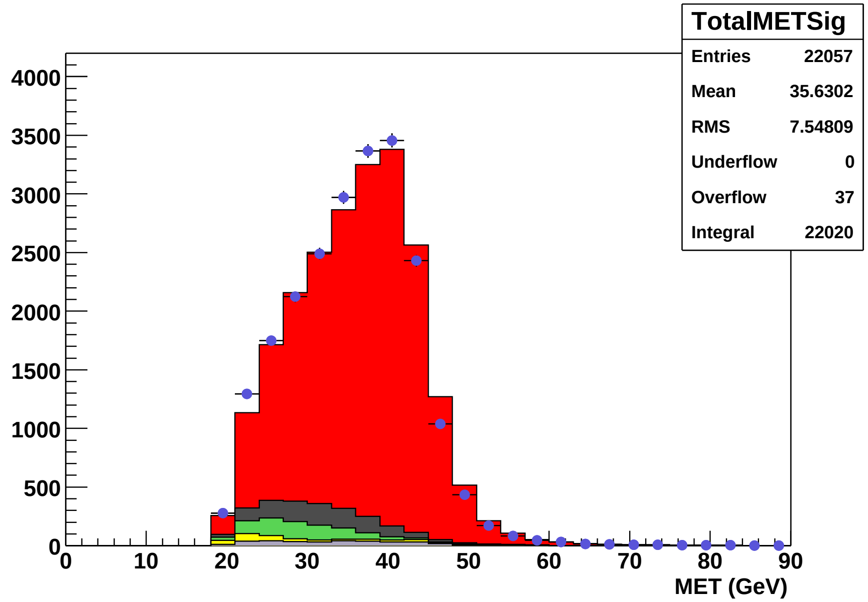
M_T Distributions of Backgrounds



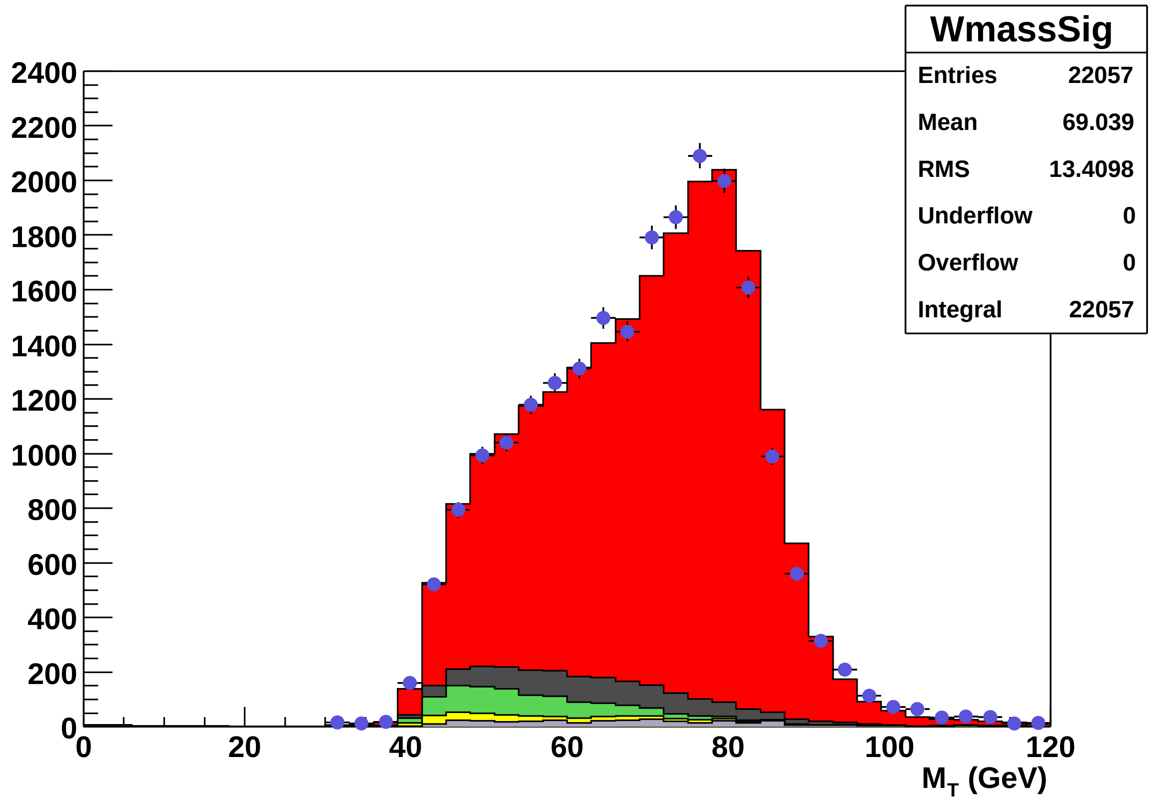
→ Total background accounts for 11.3 % of the W signal

Data-MC Comparison





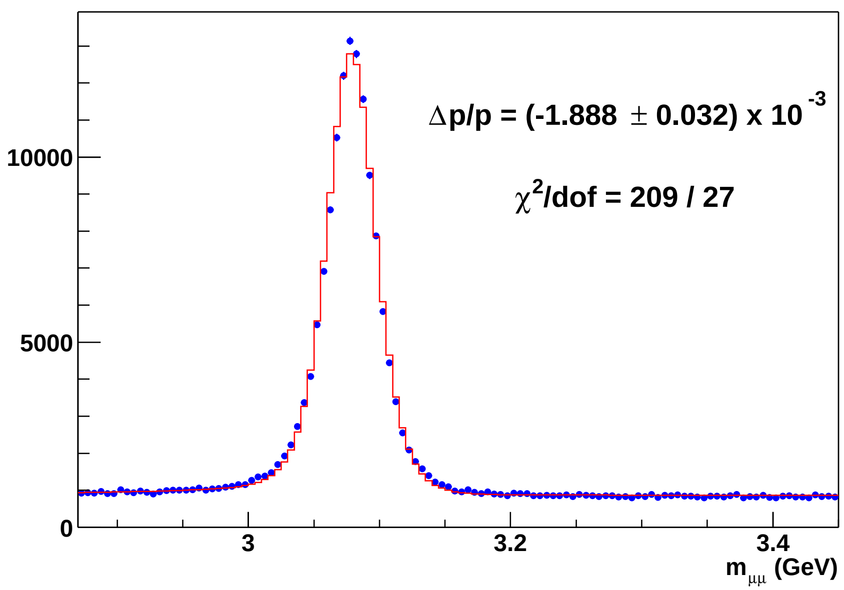
Data-MC Comparison

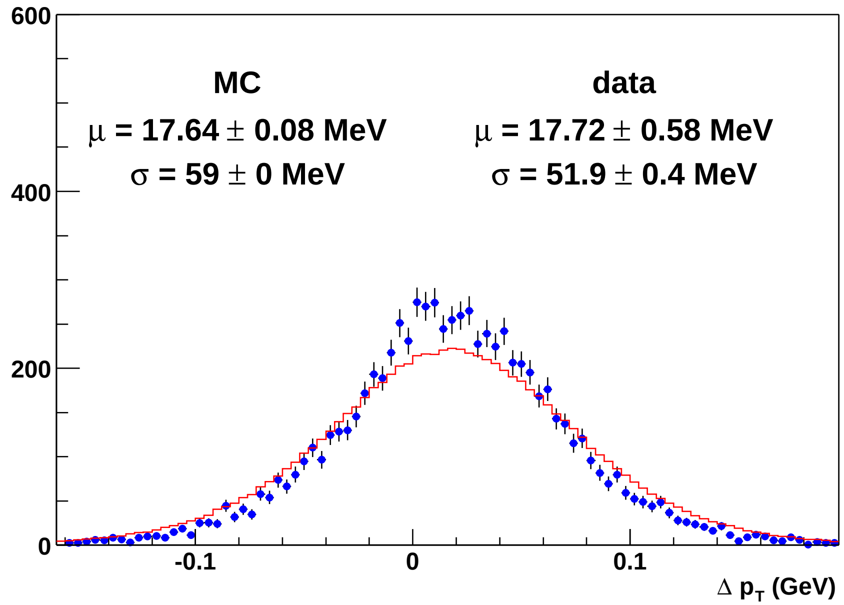


Momentum Scale

- Consistent momentum scale essential for W mass measurement in muon channel
- Largest systematic uncertainty in RunI (85 MeV/c^2)
- Momentum scale for Winter Conferences set with large statistic J/Ψ sample
- Upsilon resonances are ideal cross-checks for scale
- Energy loss due to ionization changes momentum
  $\rightarrow$ Need to correct for energy loss

Momentum Scale and Energy Loss in Run II





Momentum Scale Cross-Check using $\Upsilon \to \mu\mu$ Events

- Used Datasets: `jbot1h` and `jbmm08` from B group

- Select tight CMUP/CMU(P) dimuon events ($\sim$ 4200 signal events in $\Upsilon(1S)$ state)

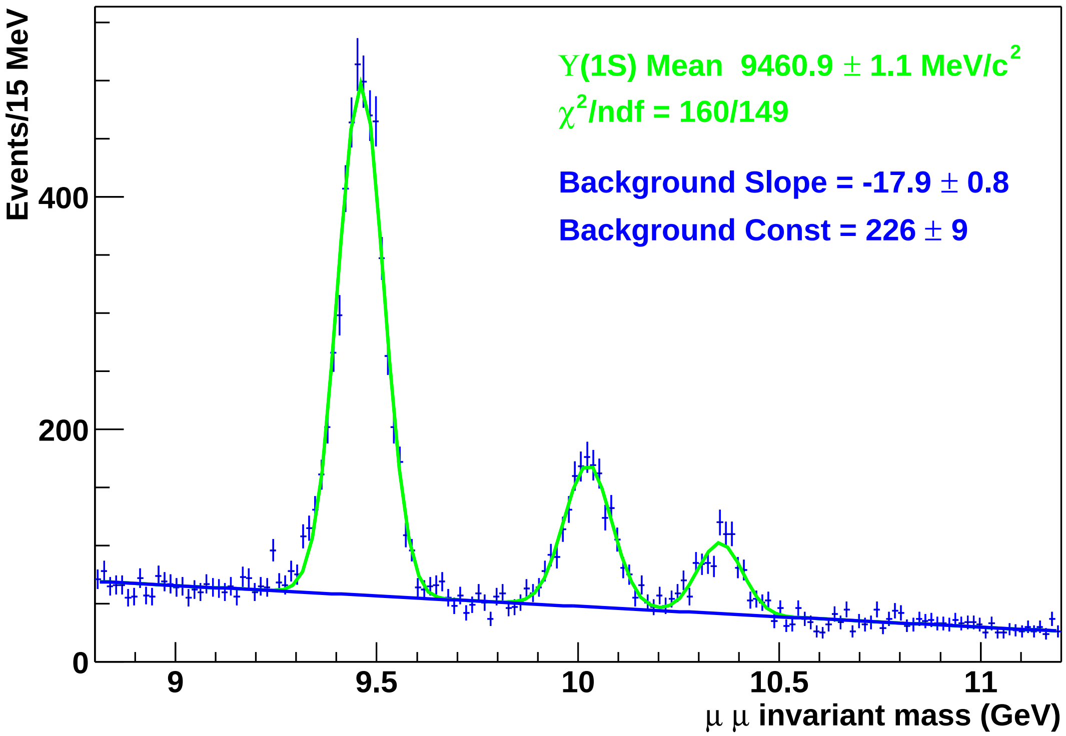
- Apply following corrections:

  $\to$ Larry's curvature correction
  $C' = Q * C - 0.00042 - 0.00116 * sin(\phi + 0.3)$

  $\to$ Add average muon energy loss
  From cosmic ray study: Δp_T = 8.86 $\pm$ 0.29 MeV

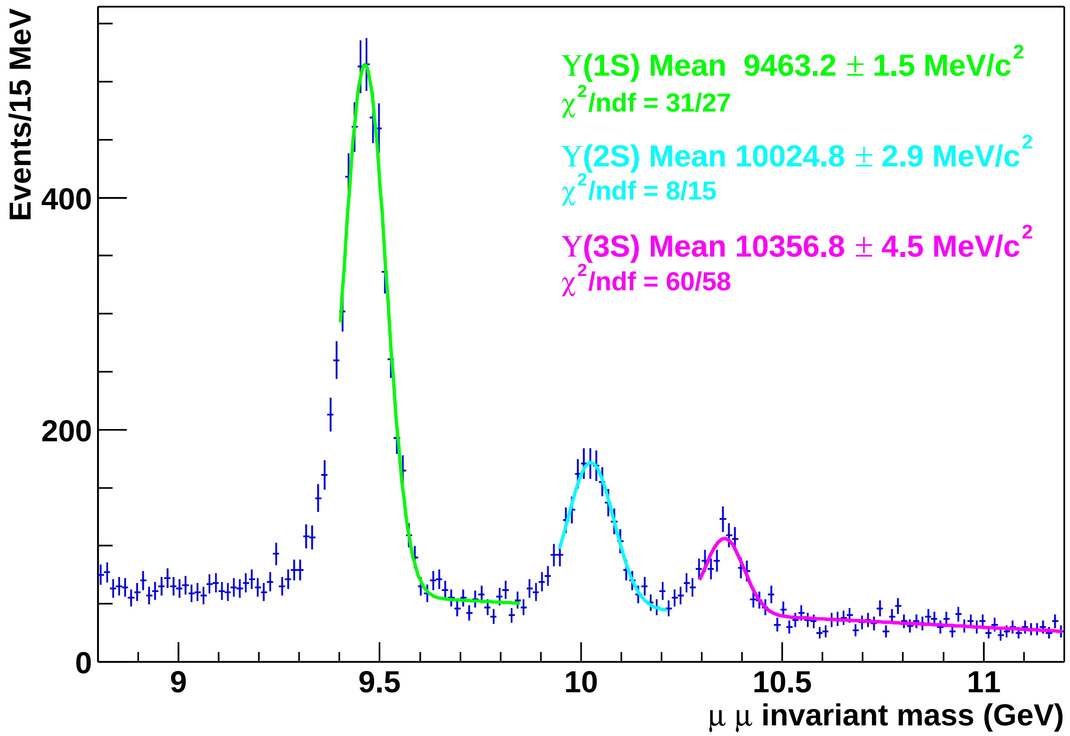
  $\to$ Apply averaged momentum scale factor
  S = 1.00175 $\pm$ 0.00015

Momentum Scale Cross-Check using $\Upsilon \to \mu\mu$ Events



- QED radiative tails distort gaussian fits
  $\to$ fit truncated gaussian distributions

Momentum Scale Cross-Check using $\Upsilon \rightarrow \mu\mu$ Events



- Mean of Υ(1S) shifts by 3.3 MeV/c^2
- PDG values:
  - Υ(1S): 9 460.30±0.26 MeV/c^2
  - Υ(2S): 10 023.26±0.31 MeV/c^2
  - Υ(3S): 10 355.2 ±0.5 MeV/c^2

Momentum Scale Cross-Check using $\Upsilon \to \mu\mu$ Events

- Estimate of uncertainties for $\Upsilon(1S)$ state

Source of Uncertainty	Value in MeV/c^2	Comment
Statistical	1.5	from fit
Momentum Scale	1.4	shift in mass due to $\pm\sigma_{Scale}$
QED Radiative Effects	0.8	varying fit range
Muon Energy Loss	0.5	shift in mass due to $\pm\sigma_{ELoss}$
Background Shape	0.1	shift in mass for other shapes
Combined Systematics	1.7	
Total	2.3	

- Obtain a mass value of 9463.2 $\pm$ 2.3 MeV/c^2

- PDG value: 9460.30 $\pm$ 0.26 MeV/c^2

$\Rightarrow$ Momentum scale set with the J/Ψ sample is consistent for the over three times heavier $\Upsilon(1S)$

Outlook

- Continuing work on backgrounds

  - Possibilities to further reduce cosmic background:
  $\rightarrow$ Refitting all muon tracks with floating t0
  $\rightarrow$ Attaching silicon hits to refitted cosmic tracks

  - Assign systematic uncertainties

- Second iteration of upsilon cross-check after new COT alignment

- Other areas important for W mass:

  - Realistic MC generator
  - Fast detector simulation
  - Recoil Model