Measurement of the W-mass with the ATLAS detector

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Motivation

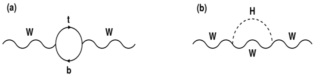
Relation between M_W and α_{EM}, G_F, $sin^2\theta$

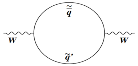
$$M_W^2 = \frac{\pi\alpha_{EM}}{\sqrt{2}G_F(1-M_W^2/M_Z^2)(1-\Delta r)}$$

Today the Δr is known up to $\delta M_W^{SM,theory} = 4MeV$

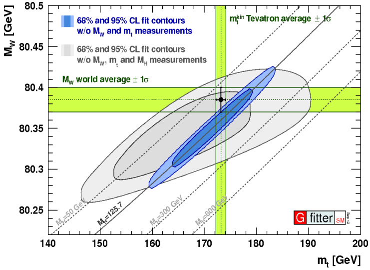
- Precise knowledge of M_W, m_t and M_H provides a test of the SM
- Comparison of measured and predicted M_W provides sensitivity to the new physics

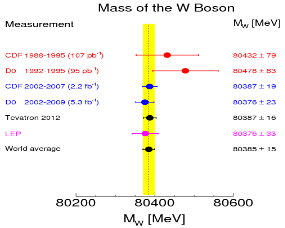
Radiative corrections Δr depend on m_t as $\sim m_t^2$ and on M_H as $\sim \log M_H$





Corrections from squark loops can increase the predicted M_W by $100 - 200MeV$

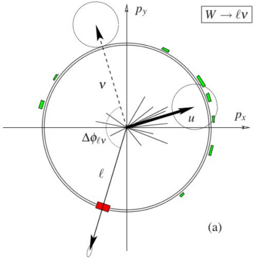




World average: $M_W = 80.385 \pm 0.015MeV$
Most precise measurement at the Tevatron

Strategy of W-mass measurement

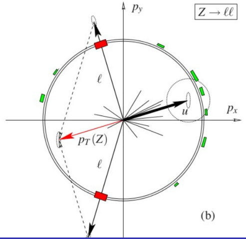
- W leptonic decay is used $W \to l\nu,\ l = e, \mu$
- Basic objects: lepton(l) and hadronic recoil(u)
- Goal: Select events with 1 lepton of high p_T^l and small hadronic recoil → minimize Bkgs
- In presence of a neutrino we cannot compute invariant mass M_W of $W \to l\nu$(cannot estimate longitudinal p_z^ν)



Measure the **Jacobian peak** of transverse distribution
Use observables sensitive to M_W: **template fit method**

Lepton transverse momentum	p_T^l
Transvese mass	$m_T^W = \sqrt{2 p_t^l p_T^\nu (1 - \cos \Delta\phi_{l\nu})}$
Neutrino transverse momentum	$E_T^\nu = \lvert \vec{p_T^\nu} \rvert, \vec{p_T^\nu} = -(\vec{p_T^l} + \vec{u})$

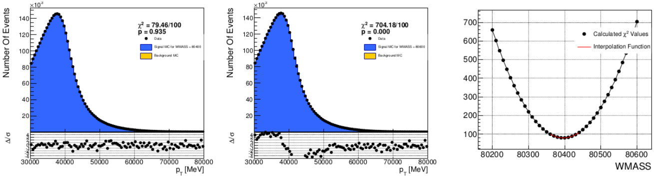
p_T^μ: Inner Detector
p_T^e: EM calorimeter+ID
$u = \sum_{cluster} E$: calo



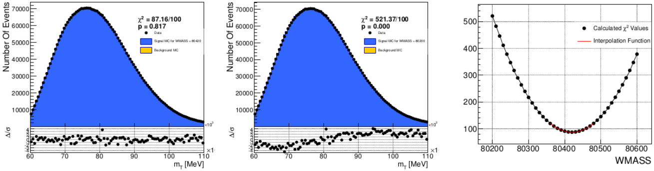
- $Z \to ll$ used for the calibration: $M_{ll} = M_Z, \vec{u} = -\vec{p_T^{ll}}$
- Apply the same strategy for M_Z extraction → → verify calibration

Template fit method

- The p_T^l, m_T^W and E_T^{miss} distributions are computed with MC for different M_W
- Each template is compared to data
- The value which maximizes binned likelihood agreement is prefered M_W



(a) p_T: Best fitting template (b) p_T: Worst fitting template (c) p_T: χ^2 distribution



- Sharper the Jacobian peak → better precision of M_W:

Expected stat. sensitivity: $\delta M_W \sim 7 MeV(p_T^l)$, $\delta M_W \sim 12 MeV(m_T^W)$

W-mass at the LHC

Main differences between Tevatron and LHC:

- Higher pile-up → recoil calibration
- pp instead of $p\bar{p}$ → larger theor. unc.
- Assymetric production of W^+ and W^- → → charge dependent analysis

W^+ from $u\bar{d} + u\bar{s} + u\bar{b} + \dots$

W^- from $d\bar{u} + d\bar{c} + s\bar{u} + \dots$

Different polarization→ p_T^l spectra

- Higher statistics at the LHC:
  $W \to e\nu$ 6M events
  $W \to \mu\nu$ 8.7M events
  $Z \to \mu\mu$ 1.5M events
  $Z \to ee$ 0.6M events

Source	at CDF (MeV)	Expected at LHC(MeV)	Measurement which provides constraints
Lepton calibration	7	8	$Z \to ll$ invariant mass peak
Recoil calibration	6	7	p_T^Z,$\sum E_T$ in $Z \to \mu\mu$
Statistics	12	7	Template fit method
Backgrounds	3	~ 5	Multijet background
Total experimental	10	~ 10	
Physics	12	TBD	Z-rapidity, W-asymmetry,W-polarization
Total	19	TBD	

Lepton Calibration

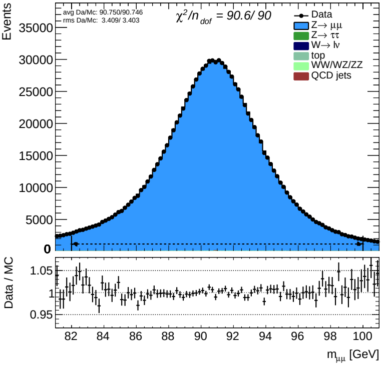
- Precise lepton calibration is needed for precise M_W measurement
- Muon momentum calibration performed on $J/\psi \to \mu\mu$ and $Z \to \mu\mu$

resonance peaks from data

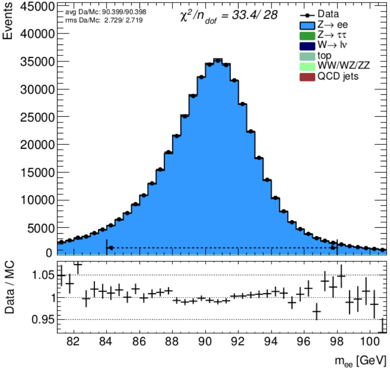
- Electron momentum calibration performed on $Z \to ee$ decays

  Systematics to M_W:

7.5MeV for p_T^{μ}, 7.8MeV for m_T^W



9MeV for p_T^{e}, 9.2MeV for m_T^W



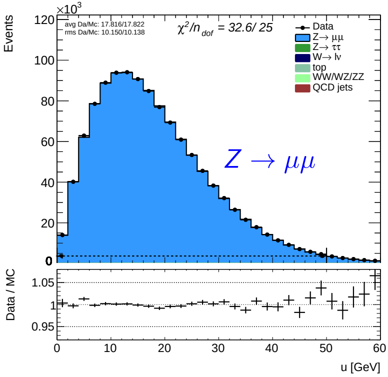
Recoil Calibration

- Recoil $u =$ vector sum of all calo clusters excluding cones around the signal lepton and replaced by another cone (same $|\eta|$, different ϕ)
- Recoil is affected by emission of quarks or gluons(ISR) or photons(ISR/FSR)
  $Z \rightarrow \mu\mu$ is used to model the recoil
- E_T^{miss} and m_T^W are derived quantities
- Correction performed for W^+, W^- for different pile-up bins

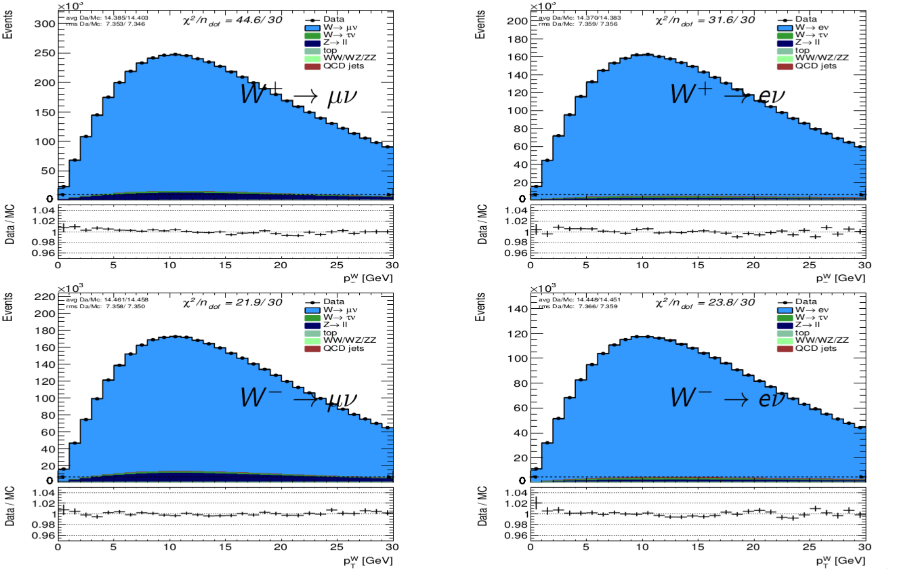
Recoil calibration:

1) Equalize Pile-up in Data and MC
2) MC to Data correction of $\sum E_T$
3) Residual correction to the hadronic recoil in $(\sum E_T^{cor}, p_T^V)$ plane

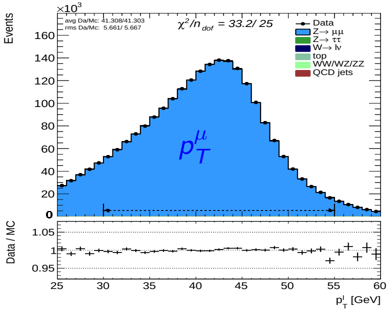
Systematics $\sim 7 MeV$

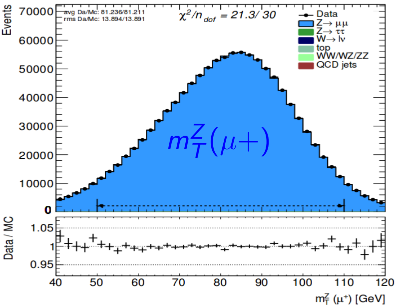


Recoil Calibration: control plots



Z-mass fits





- W-like transverse mass m_T^{l+}:
  - Reconstructed from recoil and $l+$
  - Similarly defined m_T^{l-}
- Calibration is verified with M_Z template fit method of p_T^l and m_T^l

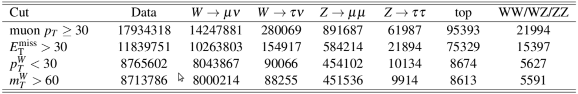
  $\rightarrow$ M_Z value compatible within 1σ with the PDG value

Channel	$\delta m_Z : p_T^{l+}$ [MeV]	$\delta m_Z : p_T^{l-}$ [MeV]	$\delta m_Z : p_T^{l\pm}$ [MeV]
Electron	7 ± 29	-34 ± 29	-13 ± 20
Muon	33 ± 21	-18 ± 21	8 ± 14
Combined	24 ± 17	-23 ± 17	1 ± 12

Channel	$\delta m_Z : m_T^{l+}$ [MeV]	$\delta m_Z : m_T^{l-}$ [MeV]	$\delta m_Z : m_T^{l\pm}$ [MeV]
Electron	-86 ± 35	1 ± 35	-33 ± 23
Muon	22 ± 23	36 ± 23	29 ± 15
Combined	-11 ± 19	25 ± 19	7 ± 13

Backgrounds in muon channel

- The following backgrounds are fully simulated with MC: $W \to \tau\nu$, $Z \to \mu\mu$, $Z \to \tau\tau$, top and dibosons decays



Cut	Data	$W \to \mu\nu$	$W \to \tau\nu$	$Z \to \mu\mu$	$Z \to \tau\tau$	top	WW/WZ/ZZ
muon $p_T \geq 30$	17934318	14247881	280069	891687	61987	95393	21994
$E_{\mathrm{T}}^{\mathrm{miss}} > 30$	11839751	10263803	154917	584214	21894	75329	15397
$p_T^W < 30$	8765602	8043867	90066	454102	10134	8674	5627
$m_T^W > 60$	8713786	8000214	88255	451536	9914	8613	5591

Another background comes from jets. Sources:
1) b/c-quarks decay semileptonically
2) punch-trough hadrons
3) pions and kaons decaying in flight within tracking system

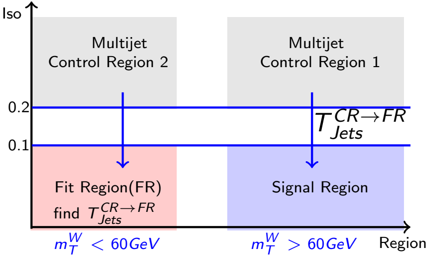
- Difficult to get good prediction of multijet background from MC
- Data-driven techniques are used
- The main goal: estimate the multijet fraction and shape of the distribution

  →Needed for W-mass template fit method

Method

Method uses 4 regions in phase space:
- Signal Region(described above) and corresponding Jet Control Region 1
- Fit Region and corresponding Jet Control Region 2

- Find Fit Region with isolated electrons where jet fraction is big
- Respective jet control regions: same cuts but anti-isolated electrons
- Determine Jet bkg shape (subtract EW)
- Fit Jets+EW to Data and find $T^{CR\rightarrow FR}_{Jets}$. $T^{CR\rightarrow FR}_{Jets}$ is normalization of Jet bkg
- Scale Jet bkg distribution from CR1 with $T^{CR\rightarrow FR}_{Jets}$. Recalculate jet fraction in SR as N_{Jets}/N_{Data}

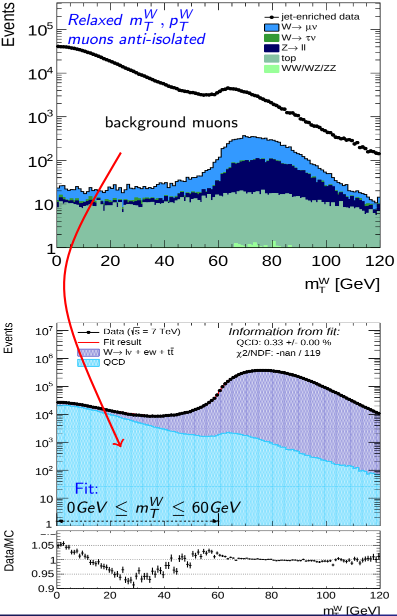


Muon isolation $\sum p_T^{tracks}/p_T^{muon}$ in cone $\leq 0.$

- $Iso < 0.1 \rightarrow$ signal dominated events

- $0.2 < Iso < 0.4 \rightarrow$ Jets enriched events

Method example for m_T^W

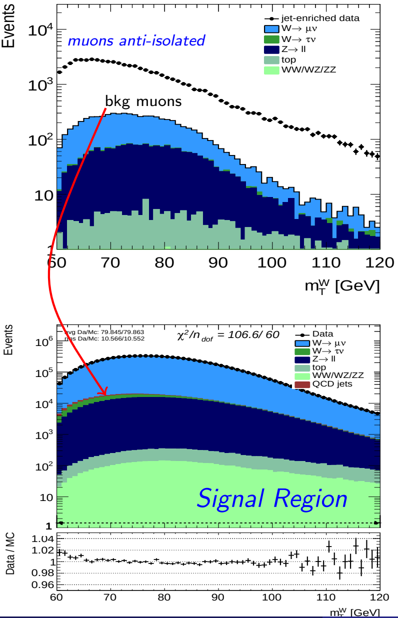


- Fit Region: p_T^W relaxed, $0\,GeV \leq m_T^W \leq 60\,GeV$
- Determine jet background distribution in respective Multijet Control Region 2.
- Subtract predicted EW contamination (according to cross-sections)
- Amount of EW contamination: $\approx 1\%$

- Apply pure jet distribution H_{Jets} to Fit Region assuming their shape is the same
- Fit $H_{Data} = T_{Jets}^{CR\rightarrow FR} H_{Jets} + K_{EW} H_{EW}$ using **RooFit** and find $T_{Jets}^{CR\rightarrow FR} = 0.51$

- Plot corresponds to m_T^W, p_T^W *relaxed*. Here EW distribution additionally scaled by $\frac{N_{Data} - N_{Jets}}{N_{EW}}$

Method example for m_T^W



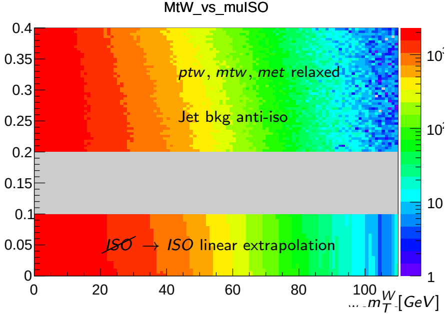
- Signal Region: $p_T^W < 30\,GeV$, $m_T^W > 60\,GeV$
- Determine jet background distribution in respective Multijet Control Region 1.
- Subtract predicted EW contamination (according to cross-sections)
- Amount of EW contamination: $\approx 11\%$

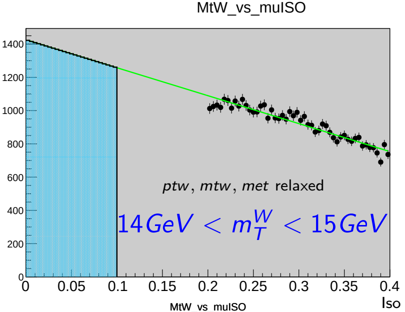
- Scale pure jet distribution by $T^{CR\to FR}_{Jets} = 0.51$
- Jet fraction in Signal Region is

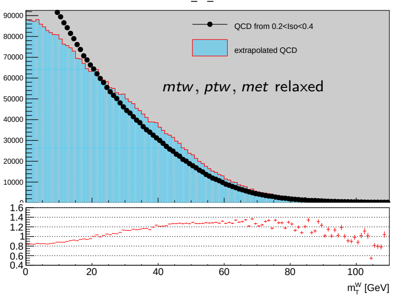
$$frac = \frac{N_{Jets}}{N_{Data}} = \frac{T^{CR\to FR}_{Jets} N^{Data}_{\cancel{Iso}}}{N^{Data}_{SR}} = 0.33\%$$

- Control Plot m_T^W in Signal Region with 0.33% of data driven Jet bkg

Jets $\cancel{ISO} \rightarrow ISO$ 2D correction of m_T^W



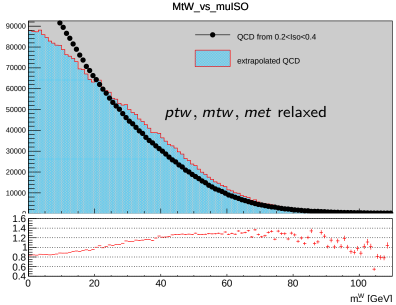


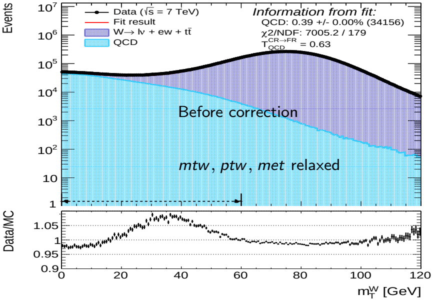


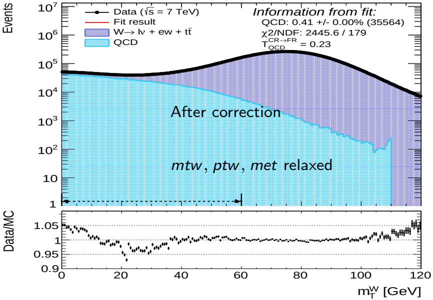
- Jet bkg distribution in $\cancel{ISO}$ can differ from real Jet distribution in ISO region
- Correct Jet bkg shape:
  - → Plot (Iso, m_T^W) in $0.2 < Iso < 0.4$ region
  - → Fit each slice of m_T^W by line
  - → Extrapolate the line from $\cancel{ISO}$ to ISO
  - → Produce (Iso, m_T^W) in $Iso < 0.1$ according to extrapolated lines

Jets $\cancel{ISO} \rightarrow ISO$ 2D correction of m_T^W

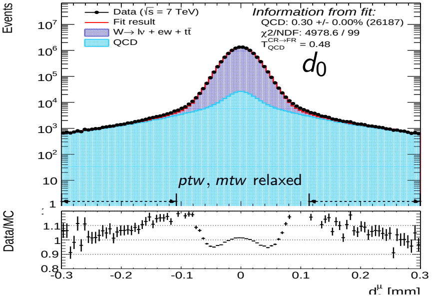
- Corrected Jet bkg shape provides better agreement in Jet+EW to Data fit
- Method works for different kinematical distributions

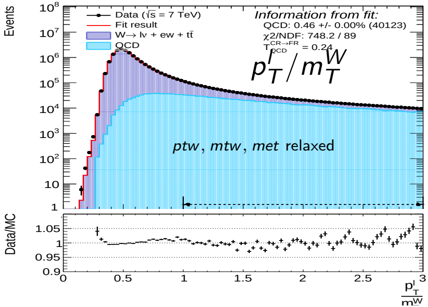


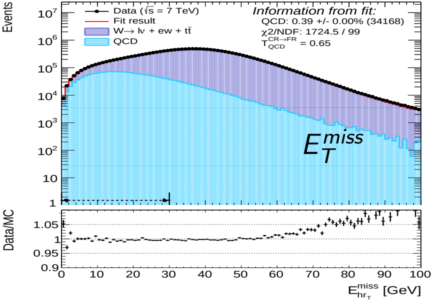




Other discriminative distributions

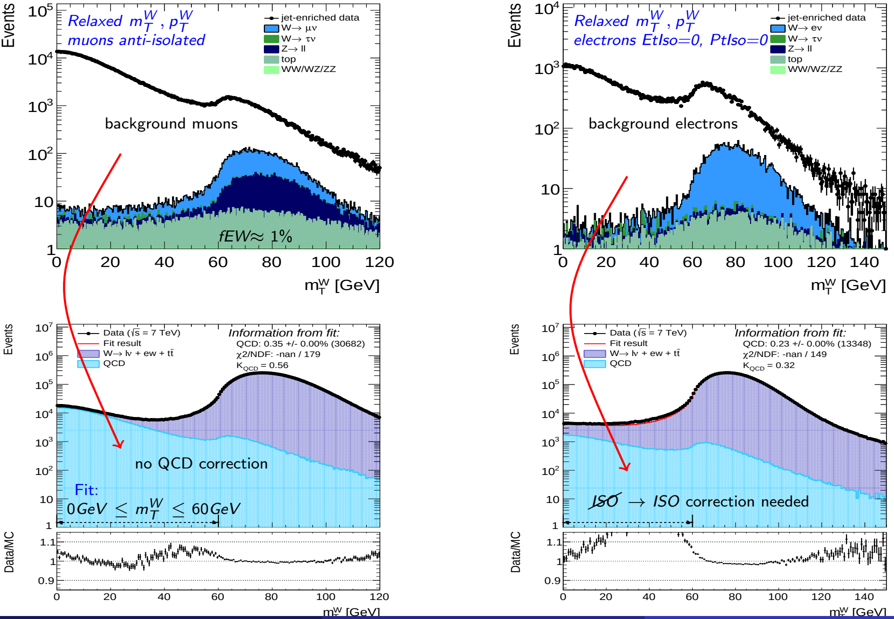






- Muons coming from b/c quark decays are non-prompt → d_0 tails Jets dominated
- Peak at 0.5 of *ptl*/*mtw* corresponds to $\phi(l,\nu) = \pi$. Angle between l and ν can be any for Jet events
- Jet misidentified as lepton+mismeasurement of jet p_T → E_T^{miss} peaked at lower value

Jet bkg fit of m_T^W: e/μ comparison(m_T^W and p_T^W relaxed)



Variable and Fit Regions

The following variables and corresponding Fit Regions are used:

Variables	Fit Regions
m_T^W	p_T^W relaxed, fit $0 < m_T^W < 60\mathrm{GeV}$
p_T^W	m_T^W relaxed, fit $30 < p_T^W < 100\mathrm{GeV}$
p_T^μ / m_T^W	m_T^W and p_T^W relaxed, fit $1 < p_T^\mu / m_T^W < 3$
d_0	m_T^W and p_T^W relaxed, fit $\lvert d_0 \rvert > 0.12$ mm
$\lvert d_0/\sigma(d_0) \rvert$	m_T^W and p_T^W relaxed, fit $\lvert d_0/\sigma(d_0) \rvert > 4$
d_0	fit $\lvert d_0 \rvert > 0.12$ mm in Signal Region
$\lvert d_0/\sigma(d_0) \rvert$	fit $\lvert d_0/\sigma(d_0) \rvert > 4$ in Signal Region

Results

variable	W^+	W^-	W	W(combined p_T^l bins
d_0 (signal region)	0.25	0.33	0.27	0.30
$d_0/\sigma(d_0)$ (signal region)	0.33	0.42	0.37	0.36
m_T^W (relaxed selection)	0.29	0.39	0.33	0.36
p_T^W (relaxed selection)	0.31	0.41	0.35	0.36
d_0 (relaxed selection)	0.26	0.35	0.30	0.30
$d_0/\sigma(d_0)$ (relaxed selection)	0.28	0.37	0.32	0.330
	0.29 ± 0.04	0.38 ± 0.05	0.32 ± 0.05	0.33 ± 0.03

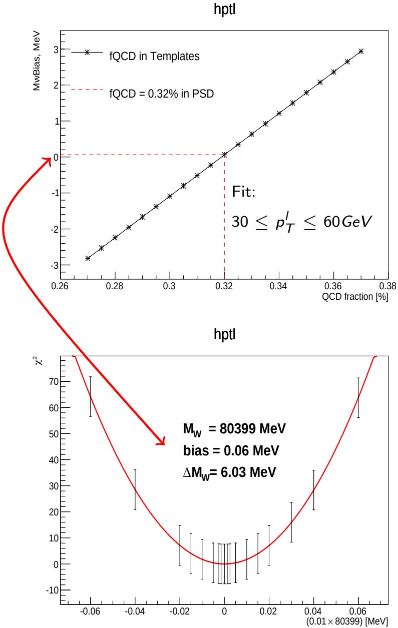
Amount of jet background in Signal Region is found to be between 0.27% and 0.37%

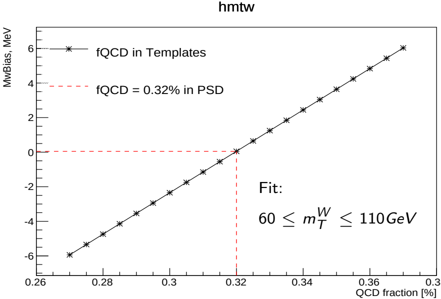
$\lvert\eta\rvert$ range	0 – 0.8	0.8 – 2.0	2.0 – 2.4	Inclusive
$W^\pm$	0.37 ± 0.12	0.3 ± 0.03	0.31 ± 0.05	0.32 ± 0.05
W^+	0.37 ± 0.07	0.27 ± 0.04	0.27 ± 0.05	0.29 ± 0.04
W^-	0.42 ± 0.13	0.34 ± 0.04	0.39 ± 0.08	0.38 ± 0.05

Table: Measured multijet background fraction as a function of muon pseudorapidity (coarse binning).

MW uncertainty from multijet fraction

- PseudoData: EW+top+QCD(0.32%)
- Templates: EW+top+QCD(0.27 → 0.37%)
- Jet bkg taken from Data
- MC normalized to cross-sections
- Uncertainty$=\frac{Max(MwBias)-Min(MwBias)}{2}$
- **Results:** $p_T^l \to 2.8$ MeV
  $m_T^W \to 6.2$ MeV





Conclusions

Simplified table. Numbers below apply to p_T^l fit and are preliminary

Channel	Statistics	Calibration	Efficiencies	Recoil	Background	Total exp.
Electron	$\sim 7MeV$	$\sim 8MeV$	$\sim 9MeV$	$\sim 7MeV$	$\sim 5MeV$	$\sim 16MeV$
Muon	$\sim 7MeV$	$\sim 8MeV$	$\sim 2MeV$	$\sim 7MeV$	$\sim 5MeV$	$\sim 14MeV$
Combined						$\sim 10.5MeV$

- We are finalizing the background uncertainty and PDF uncertainty estimates which are the last steps before a complete result