experimental systematics from lepton/ missing et calibrations on Wmass

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On behalf of ATLAS and CMS collaborations

Outline

This talk touch mainly two aspects:

1. I will give an overview of the experimental challenges and … on how the experiments are approaching it.

2. At the same time I will make a few examples where we need clear directions from the theory community

Previous measurements

CDF:
http://arxiv.org/pdf/1311.0894v2.pdf
(2.2/fb RUN2)

TABLE XIV: Uncertainties in units of MeV on the final combined result on M_W.

Source	Uncertainty
Lepton energy scale and resolution	7
Recoil energy scale and resolution	6
Lepton tower removal	2
Backgrounds	3
PDFs	10
$p_T(W)$ model	5
Photon radiation	4
Statistical	12
Total	19

DO:
http://arxiv.org/pdf/1310.8628v2.pdf
(4.3/fb RUN2)

TABLE VI: Systematic uncertainties on M_W (in MeV). The section of this paper where each uncertainty is discussed i in the Table.

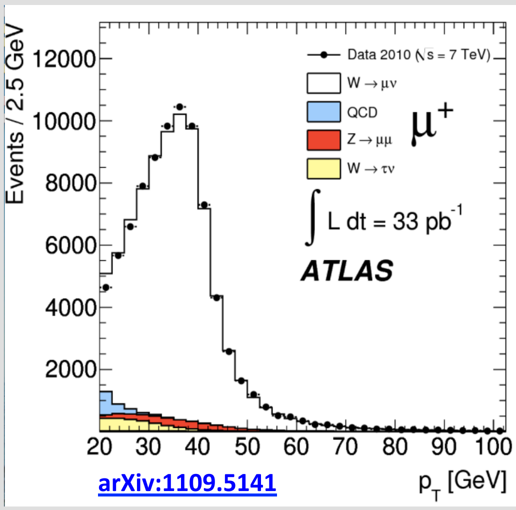
Source	Section	m_T	p_T^e	$\not{E}_T$
Experimental				
Electron Energy Scale	VII C 4	16	17	16
Electron Energy Resolution	VII C 5	2	2	3
Electron Shower Model	V C	4	6	7
Electron Energy Loss	V D	4	4	4
Recoil Model	VII D 3	5	6	14
Electron Efficiencies	VII B 10	1	3	5
Backgrounds	VIII	2	2	2
$\sum$(Experimental)		18	20	24
W Production and Decay Model				
PDF	VI C	11	11	14
QED	VI B	7	7	9
Boson p_T	VI A	2	5	2
$\sum$(Model)		13	14	17
Systematic Uncertainty (Experimental and Model)		22	24	29
W Boson Statistics	IX	13	14	15
Total Uncertainty		26	28	33

The MW measurement at the LHC follows a strategy similar to the Tevatron. Important differences:

- Higher pile-up environment → affect hadronic recoil calibration
- Different theoretical uncertainties due to pp instead of ppbar collisions
- Different energy regime 2 TeV vs 7/8/13 TeV → potentially larger theoretical uncertainties
- W^+ and W^- production is not symmetric → Requires a charge dependent analysis

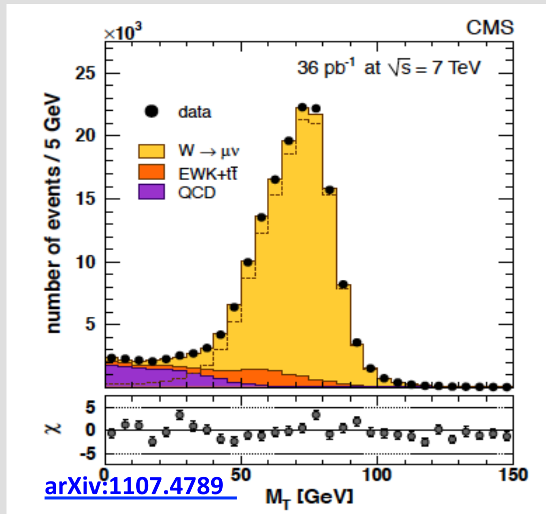
Wmass: analysis strategy

Lepton PT



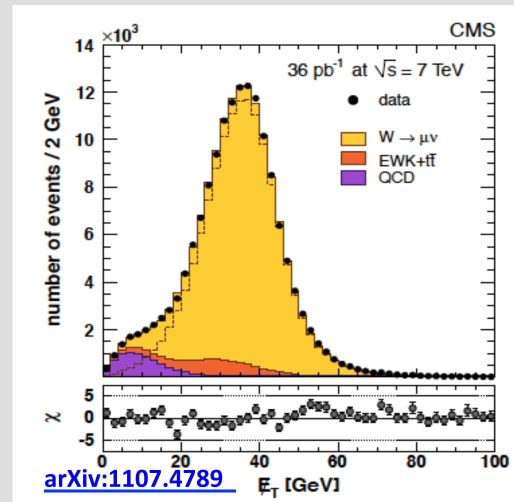
- Muon momentum scale
- Boson PT

MT



- MET response/resolution

Missing Energy

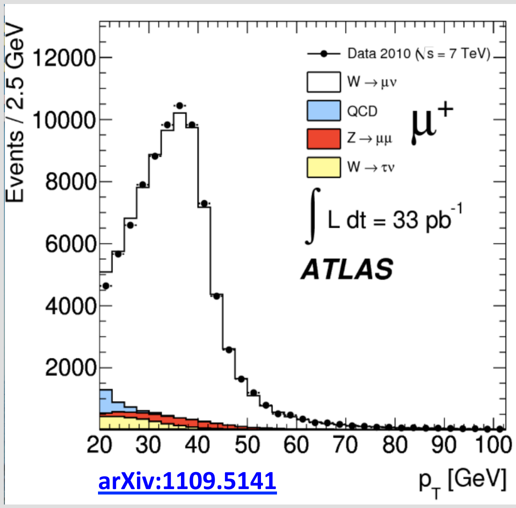


- MET response/resolution
- Boson PT

1. Template MC distribution is computed several times, with different values of M_W
2. Each MC template (generator + detector simulation) is corrected for data/MC scale factors derived in control samples
3. Each template is compared to the data with likelihood fit ratio
4. The measured M_W correspond to the template that maximizes the agreement with the data

Wmass: analysis strategy

Lepton PT



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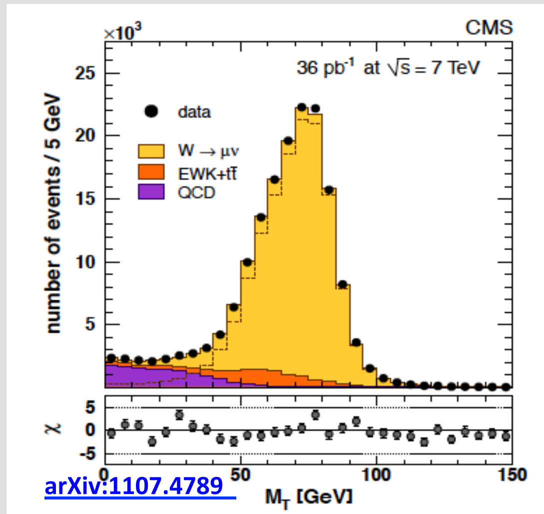
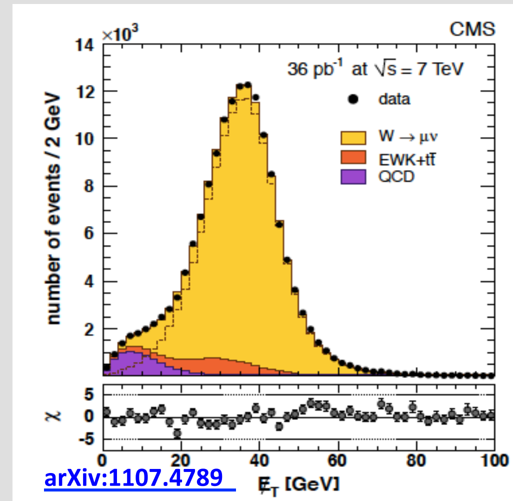


- missing et resolution

Missing Energy

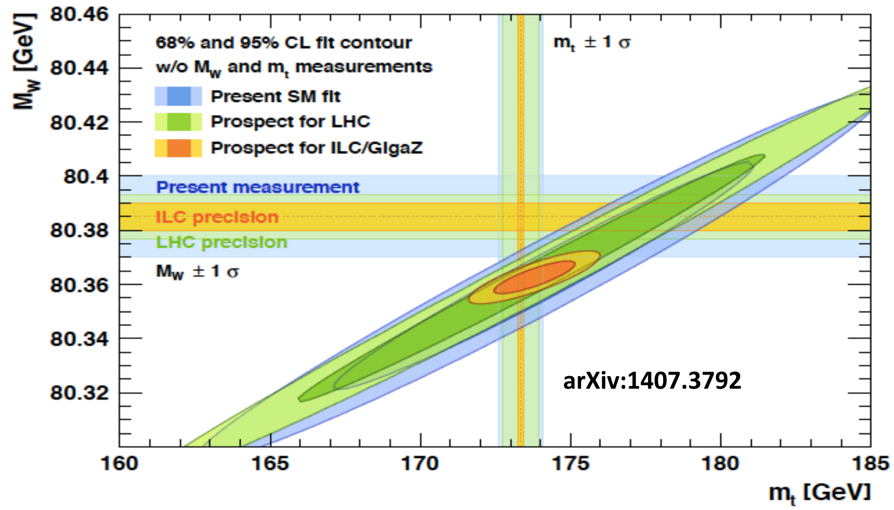


- missing et resolution
- Boson PT

Both ATLAS and CMS construct their MC template with detector **full simulation**:
This is build on the knowledge of detector gained during the construction phase and the Run1. It also benefit from the computing model (i.e. GRID) refined over the years.

The challenge

Extrapolated future uncertainties in the global electroweak fit.
15 MeV is the present measurement
8 MeV may be in reach for a combination of the LHC, Tevatron and LEP.
5 MeV is pospected at future collider



*Precision physics at the LHC can be considered as **portals** of BSM **discovery.***

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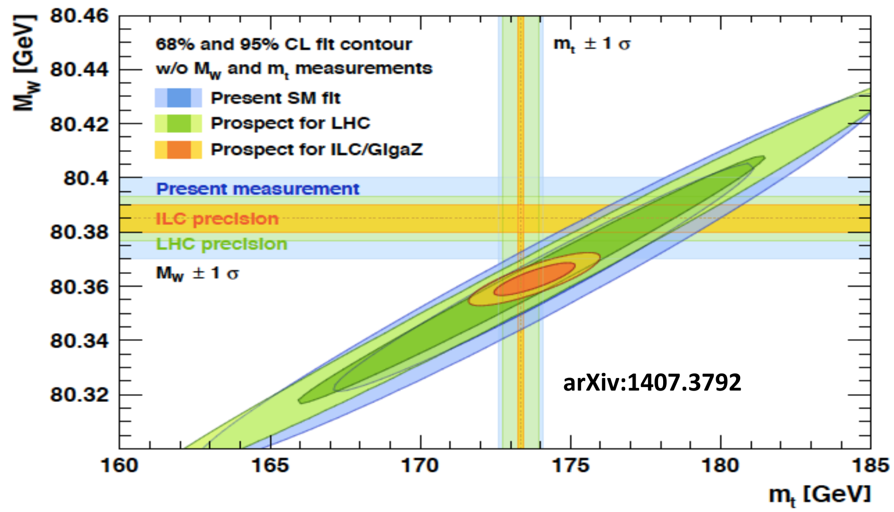

LHC, a few considerations:

The **statistical error** scales with the amount of W data collected with the ATLAS/CMS detector at the LHC.
For example: considering the W+ and Muon decay channel
@ 7eV Lint = 4. 5 fb^{-1} → Stat error O(10 MeV)
@ 8TeV Lint = 19.5 fb^{1} → Stat error O(5 MeV) ***:: important to analyze the 8TeV data***
@ 13TeV a lot more

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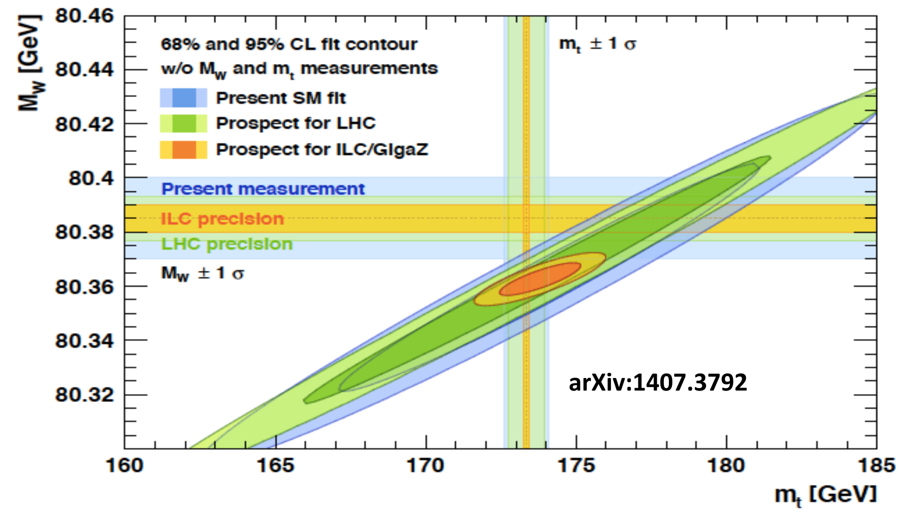
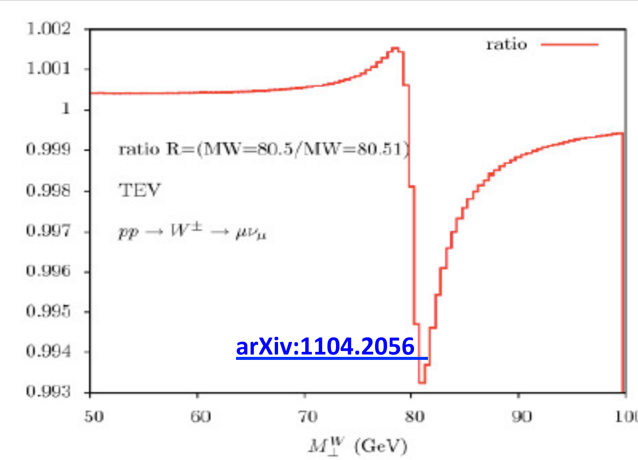


If we aim at measuring M_W with 10 MeV of error, we need to be able to control the shape of the distributions below the per mill level.

In this talk I will show what ATLAS and CMS do to derive and apply the correction to the muon momentum scale and MET on top of the full simulation .



Control sample

Many of the experimental systematics uncertainties are being constrained *in situ* using the high-statistics sample of leptonic Z decays.

These will be used for instance to set the:

- lepton scale,
- The recoil resolution and response
- the pT spectrum of the W .

Advantages:

- closest topology to the signal sample W->$\ell\nu$
  - (i.e. lepton of similar scale)
- low BKG
- precise candle ptZ and mZ *(Z lineshape measured at LEP)*
  - The Z boson decay channels can be fully reconstructed and the momenta of muons originating from Z decays are reconstructed with very good resolutions.
- any MET reconstructed is purely due to resolution effects with which the hadronic activity in the event gets reconstructed.

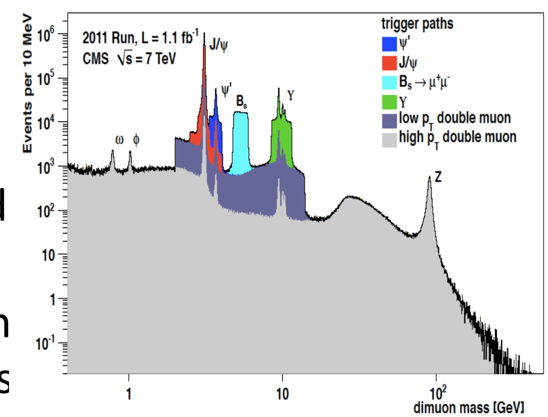
Leptons momentum scale calibration

The lepton momentum scale enters linearly in the Lepton PT and MT fits.

$$m_T^2 = 2p_T E_T^{miss}(1 - cos(\Delta\phi))$$
$$m_W \sim 2p_T + u_{||}$$

where $u_{||}$ is the projection of the recoil on lepton axis

In ***CMS***, the first Wmass measurement will come in the ***muon*** final state. ***ATLAS*** is performing in parallel the ***muon and electron***. (This will lead to a statistical improvement of order sqrt(2) on the Wmass)



For the 13 TeV incoming runs, we need to have an unprescaled and efficient single lepton **trigger** with low thresholds (~ 30 GeV). ATLAS/CMS can explore trigger options such as dedicated runs with lower luminosity, data parking (keep the events with looser triggers to be processed later in 2016) …

Raising the **p**T threshold from 0 GeV hurts low dimuon mass calibration triggers too.

→ Is worth to measure the Wmass at 7, 8 ,13 TeV → Will some of the theoretical systematics be significantly lowered if we combine the 2,7,8,13 TeV ?

Muon calibration overview

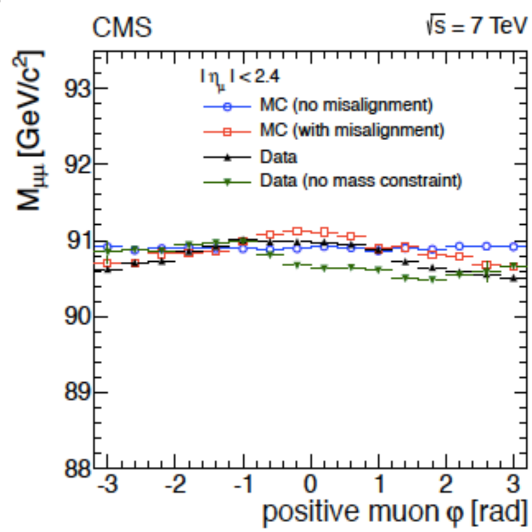
Aim to a calibrate the scale with a few MeV. Various sources affect a mis-reconstruction of the muon curvature:

- detector mis-alignment,
- material effects,
- magnetic field modeling

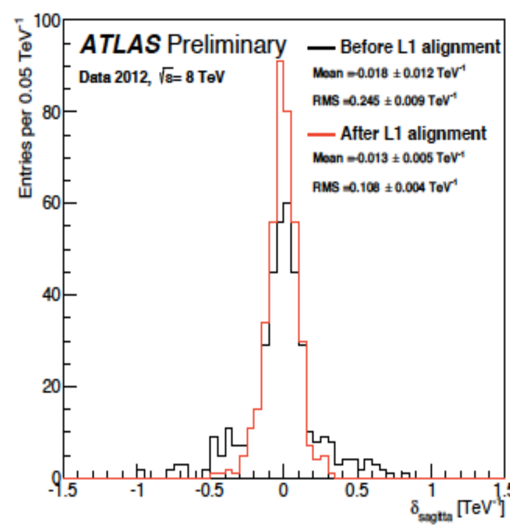
Detectors initially aligned using cosmic ray charged particles, with additional information from optical surveys.

Residual bias in the reconstructed track curvature due to distortions of the tracker geometry, are investigated using the reconstructed Z->mumu mass, as a function of the muon direction and separating μ+ and μ-

arXiv:1403.2286



ATLAS-CONF-2014-047



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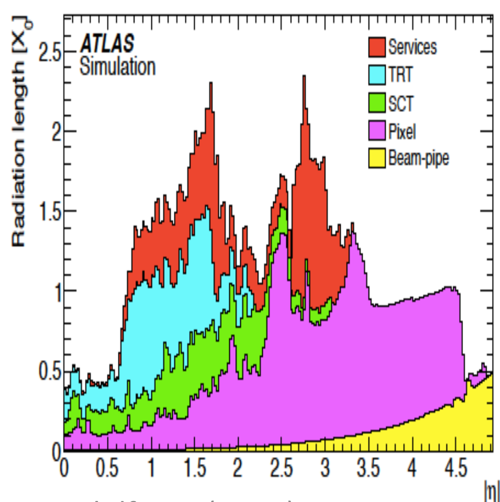
- material effects,
- magnetic field modeling

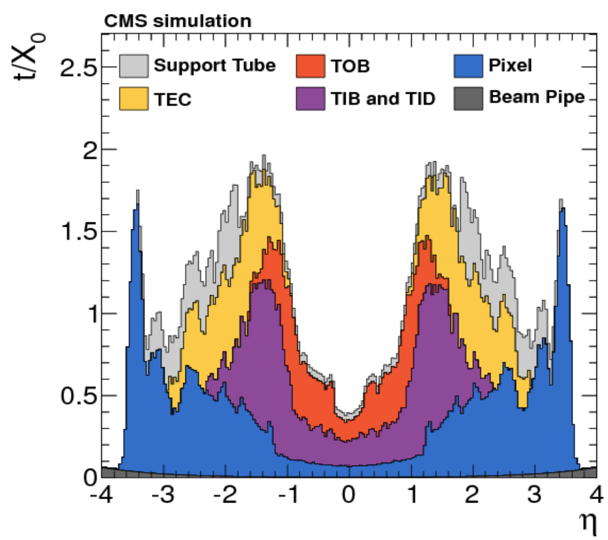
The simulation describe the tracker material budget with an accuracy of better than 10% . This is established by measuring the distribution of reconstructed nuclear interactions and photon conversions in the tracker.

Additional calibration in situ with the j/psi.

arXiv:1404.2240



arXiv:1405.6569



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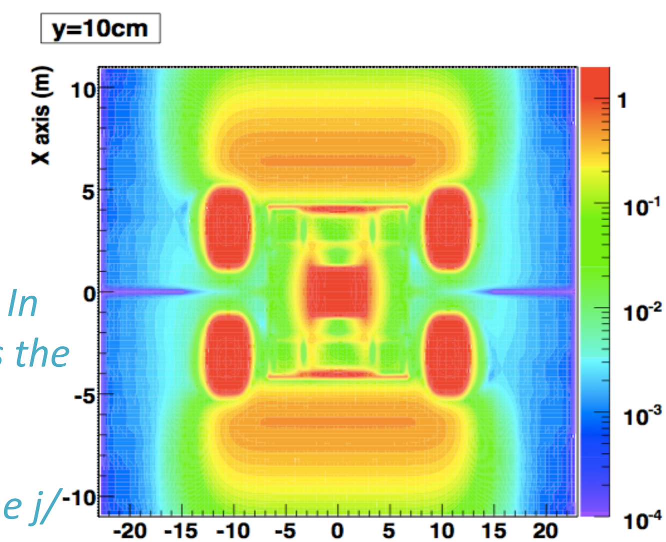
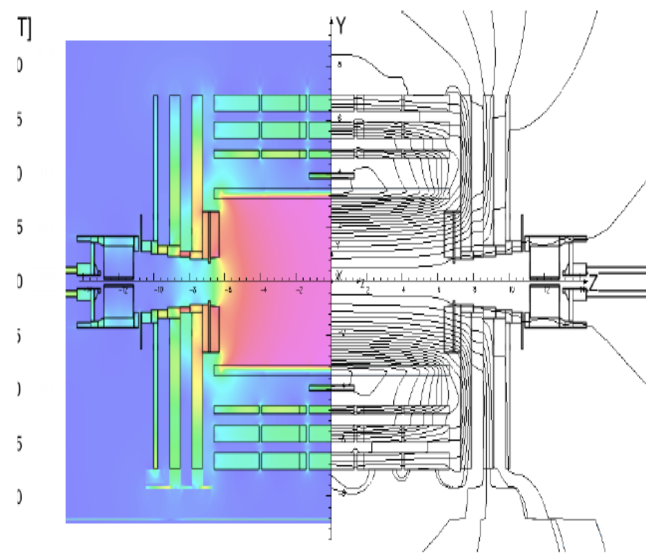
- detector mis-alignment,
- material effects,
- magnetic field modeling

Different concept for the Magnetic field in ATLAS (2 T solenoid + Toroid) and CMS (3.8 T solenoid).

For the typical muon pt from W, In both Exp the inner tracker drives the measurement of the muon momentum scale.
Mainly calibrated in situ with the j/psi.



http://arxiv.org/abs/0910.5530



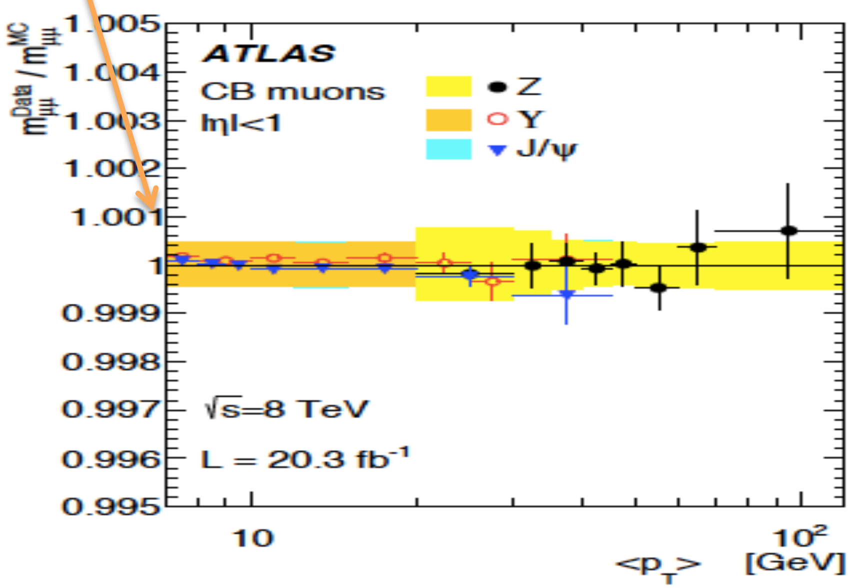
The starting point

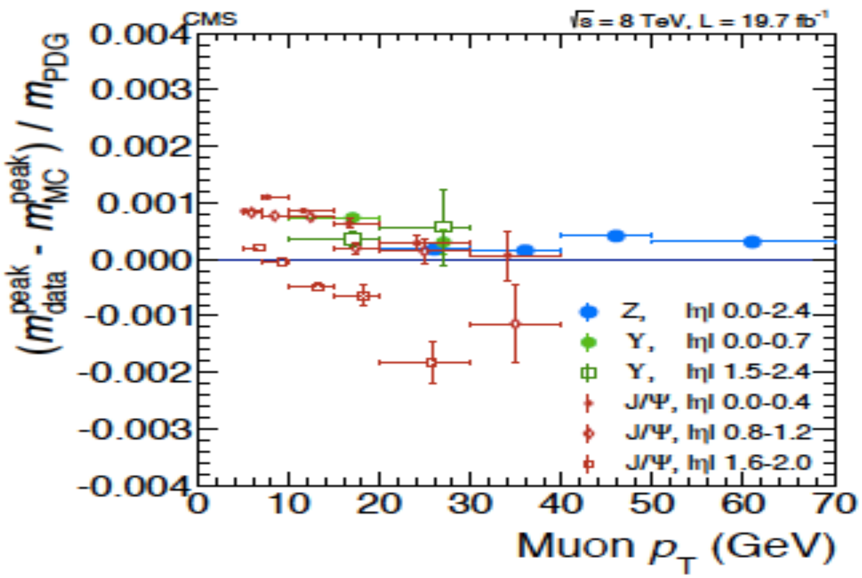
~ 100 MeV

Looking at the Higgs results:
ATLAS has 2 times better scale

http://arxiv.org/pdf/1407.3935.pdf

http://arxiv.org/pdf/1312.5353.pdf





New techniques are being developed to calibrate the muon momentum scale with the required precision O(10 MeV).

Electron calibration

Electrons in ATLAS are measured using the inner detector (ID) and electromagnetic calorimeter (EMC). Need to calibrate the:

- Identification Efficiency :

Typically involve shower shape an track matching cuts very dependent on electron et

arXiv:1404.2240

- Energy scale

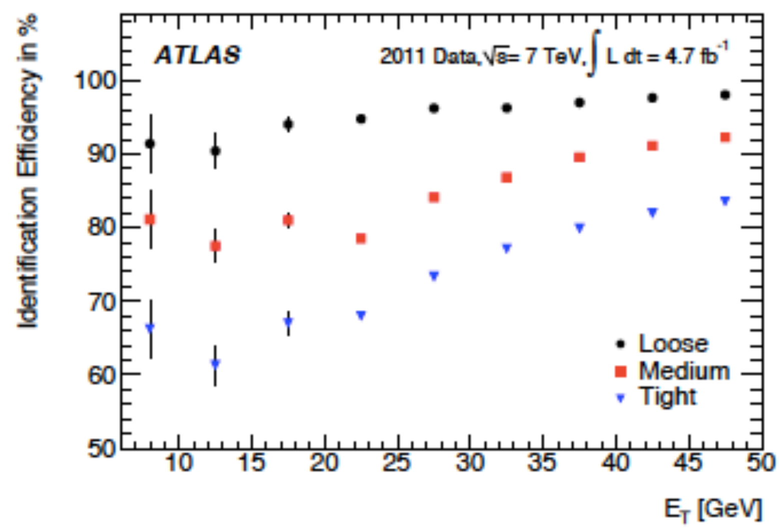
Calibration with Z→ee, J/psi→ee

Correlation vs eta being studies

Energy dependence of the calibration

calorimeter layer intercalibration

material budget



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arXiv:1407.5063

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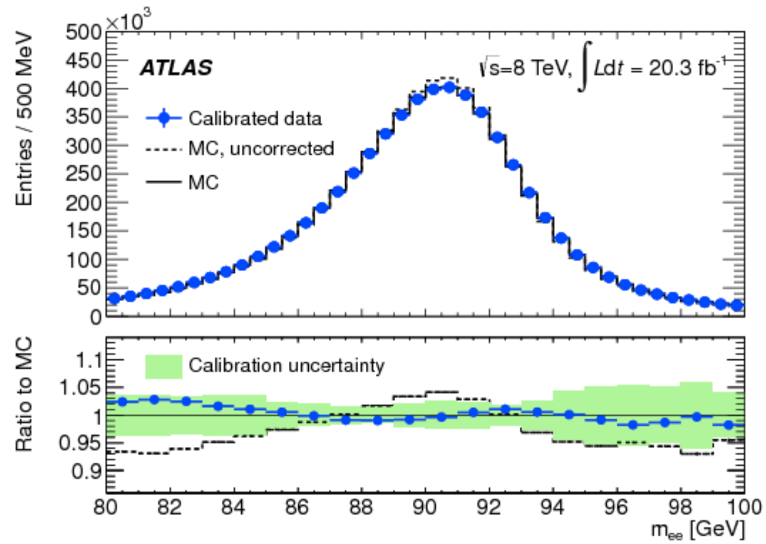


MET in CMS and ATLAS

Reconstruction:

- The **CMS** experiment uses **particle-flow (PF)** event reconstruction, which consists of reconstructing and identifying each particle with an optimized combination of all subdetector information.
- **ATLAS** uses **calorimeter clusters**

The signal we want to isolate *(low pt W boson)* is characterized by low objects multiplicity

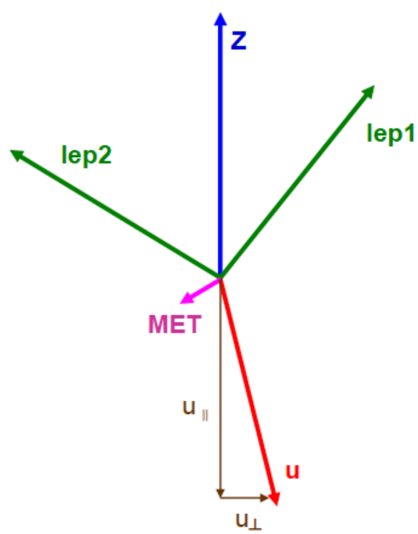
→ And the soft event represent one major challenge for the pile up suppression.

ATLAS and CMS are designed to cope with LHC bunch crossing frequency and high interaction rate:

- experiments suppress in-time pile-up not considering PF hadrons/ clusters associated to vertices other than the Primary Vertex.
- Calorimeter Signal shaping help to suppress the out of time PU

For W-mass measurement, the Experiments aim to control the PU with the needed precision → Is worth to provide the results at 7, 8 ,13 TeV → Will some of the theoretical systematics be significantly lowered if we combine the 2,7,8,13 TeV ?

MET calibration



Essentially we sum over all Pf particle/calorimeter clusters to define the hadronic recoil of the vector boson.

The recoil defined as the sum of all measured objects except lepton(s)

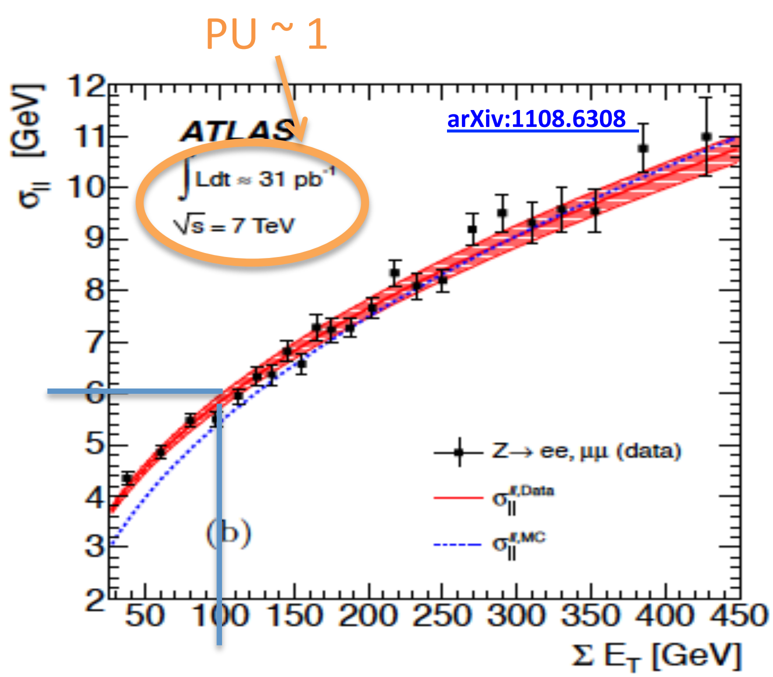
$$\vec{U} \;=\; -\vec{\not{E}}_{\rm T} - \Sigma_{\rm i}\vec{p_{\rm T}}\,(\ell_{\rm i}) \;\; .$$

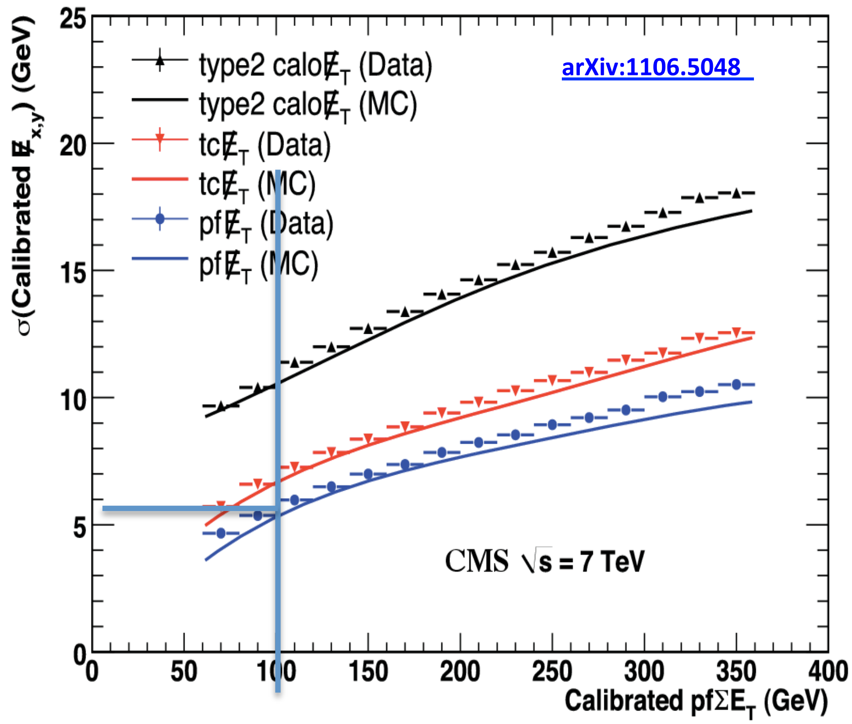
The recoil is projected with respect the boson pt.
Two components are looked at:

1. Component perpendicular to the boson pt (U2)
   - mainly affected by the underlying event

2. Component parallel to the boson pt (U1)
   - mainly affected by the hadronic recoil

Missing Energy





- Similar MET resolution is ATLAS and CMS
- Similar data/MC correction factor needed at the box at low boson PT

Important Milestone: W-like system

As validation of the Wmass extraction, we use the Z→μμ events as test sample to measure the Z mass as if it was a W-like system.

i.e. we can build a W-like system removing one lepton and recalculate met and Mt.

We will unblind the Wlike data before the W data ! *This is a necessary first step.*

Statistical erros		
Systematic source	W-like	W
PDF	✓ YES	✓ YES
Boson PT	✓ YES	✓ YES
Boson PT W/Z extrapolation	**NO**	✓ YES
EWK correction	✓ YES	✓ YES
μ momentum scale	✓ YES	✓ YES
μ tr-iso-id efficiency	✓ YES	✓ YES
Missing et scale/resolution DATA/MC agreement	✓ YES	✓ YES
MET W/Z extrapolation	**NO**	✓ YES
Background to 1-l	**NO**	✓ YES

Tipically a x3 higher in the Wlike than in the W

A few systematics are W specific, but most of them are common.

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Tipically a x3 higher in the Wlike than in the W

A few systematics are W specific, but most of them are common.

*State the obvious: **Experiments** can validate the MET, lepton momentum scale, boson PT with the **Wlike** closure test*

*But **THE W-mass** requires a common **exp.-theor.** efforts*

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Tipically a x3 higher in the Wlike than in the W

A few systematics are W specific, but most of them are common.

On the Z/W extrapolation how we proceed ?

So we know all the details that are needed if want achieve the needed precision ?

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Background to 1-l	**NO**	✓ YES

Tipically a x3 higher in the Wlike than in the W

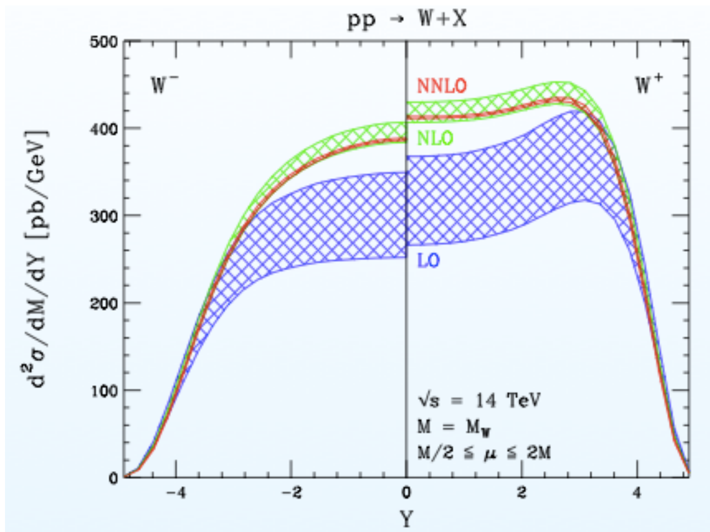
A few systematics are W specific, but most of them are common.

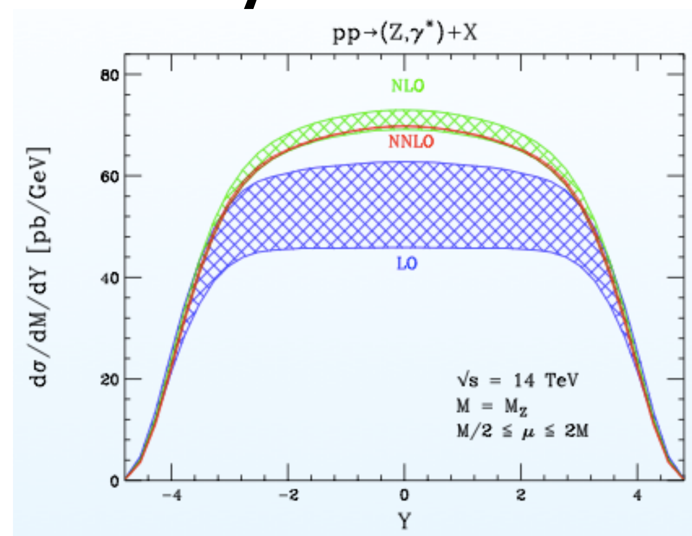
Exp. would like to avoid as much as possible produce new samples every time something new comes from theor. side.

What are the exp input theorists need to have to convince the exp that we have a relevant decrease of the theo uncertainties so that it's worth to update the measurements? *(more in maarten talks)*

W+/W-/Z differences
Production and Decay

Production
PDF effect





http://www.slac.stanford.edu/cgi-wrap/getdoc/slac-pub-14409.pdf

Decay
Polarization

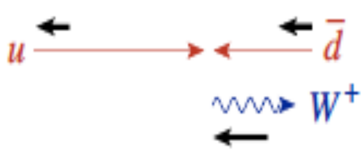


FIG. 2: When a W^+ is produced at lowest order by $u(x_1)\bar{d}(x_2) \to W^+$ with $x_1 > x_2$, it is 100% left-handed polarized along its direction of motion, which is along the beam axis in the quark direction. Thick (black) arrows represent spin vectors; the other arrows represent momentum vectors in the pp center-of-mass frame.

The W polarization is analyzed with 100% analyzing power through its leptonic decay. A left-handed W^+ tends to decay with the left-handed neutrino forward (along its direction of motion) and the right-handed positron backward. A left-handed W^- tends to put the left-handed electron forward and the right-handed anti-neutrino backward.

W+ neutrino forward; muon backward
W- muon forward; anti-neutrino backward

MET calibration

The missing ET is an event variable.
Precision of extrapolation from the Z to W behavior is not straight forward.

With the recoil correction described earlier, we do not have simple knobs to adjust to make the MC agree with DATA.

We are applying an overall scale factor as function of boson pt.

Some questions
The different boson rapidity poses for example some question.

- How different is the UE is in W and Z, at given rapidity and boson pT.

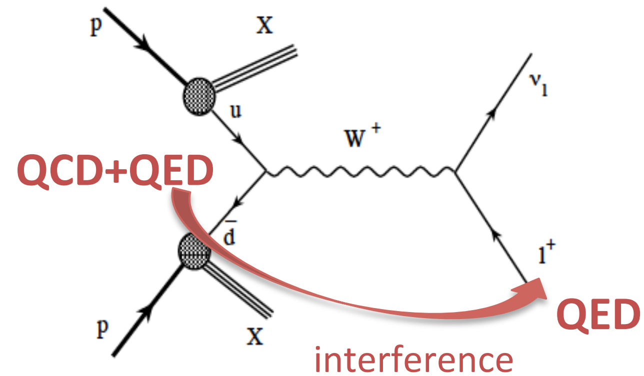
Population of different response can have different fraction in data than in MC

- How the heavy quark PDF uncertainties will affect the final state recoil (W production via cs, sc is larger at the LHC, Z production has cc, bb).
- Gluon initiated process will have a different response than valence and sea quark.

Lepton calibration: FSR

Final-state radiated photons (FSR) production is important since it takes away some of the momentum of the lepton, and the invariant mass of the lepton and neutrino will be smaller than the W boson invariant mass, biasing the measurement.

It enter already at the lepton calibration step.



From the exp. side: QED Final State Radiation (FSR) can be understood in context of detector response.

- *FSR photons are mostly produced with a direction nearly collinear with the parent lepton and have a harder spectrum than background photons from initial-state radiation or pileup interactions.*

From the theor. side

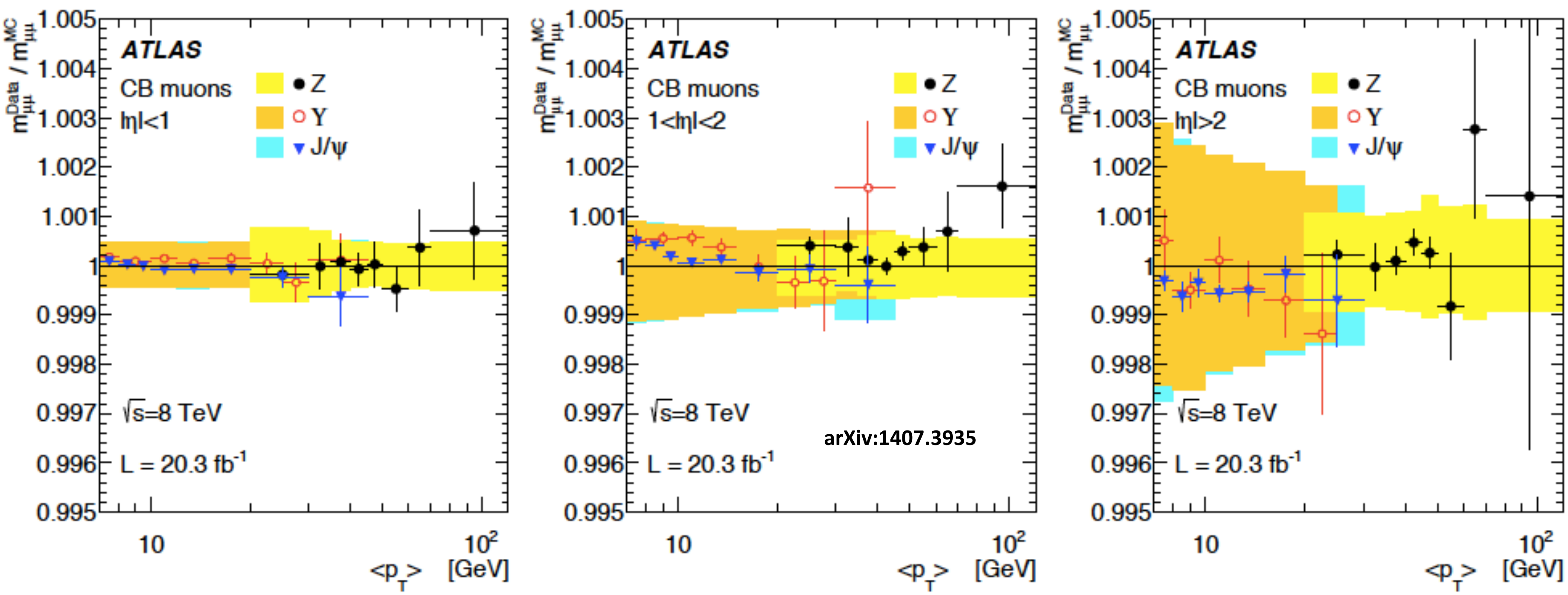
→ What we use to generate the leading effects of real photon emission.

→ We need to agree on theoretical models (EW NLO calculation available ?) to estimate the uncertainties from the modeling.

Lepton calibration: endcap

State of art:
Knowledge of the lepton scale is worst in the endcap.

→ How much this is important to lower i.e. the pDF syst ?



PDF in practice

Assuming we do an excellent job in the experimental calibration, the PDF error will be [probably] the largest of the theory uncertainties and will dominate the final uncertianties.

- How do we assign the PDF error ?
  - We would like to have a community agreed procedure

- How do we make the measurement updatable when there will be better PDF knowledge in the future ?

- Which ancillary plots/measurements can be of interest to reduce the PDF error ?

→ In this context the 7,8 and 13 TeV comparison may be useful.

Summary and outlook

Experiments working on the lepton and MET calibration to the precision we need
W-like will be the first milestone for the experiments

From the **theory community** we need a clear answer on:

- Where/how much we gain performing the Wmass measurement at 7, 8, 13 TeV
  - PDF, Boson PT ?
- How to transport the calibration from the Z to W to complete the Wmass measurements.
- What is the “right” way to present the results such that we have a clear feedback on if/how much the uncertainties (PDF, boson pT) will be lowered.
  - ancillary plots/measurements ?
  - Parameterization of Wmass results ?