W mass measurement in the ATLAS experiment

for the Atlas collaboration

Motivations

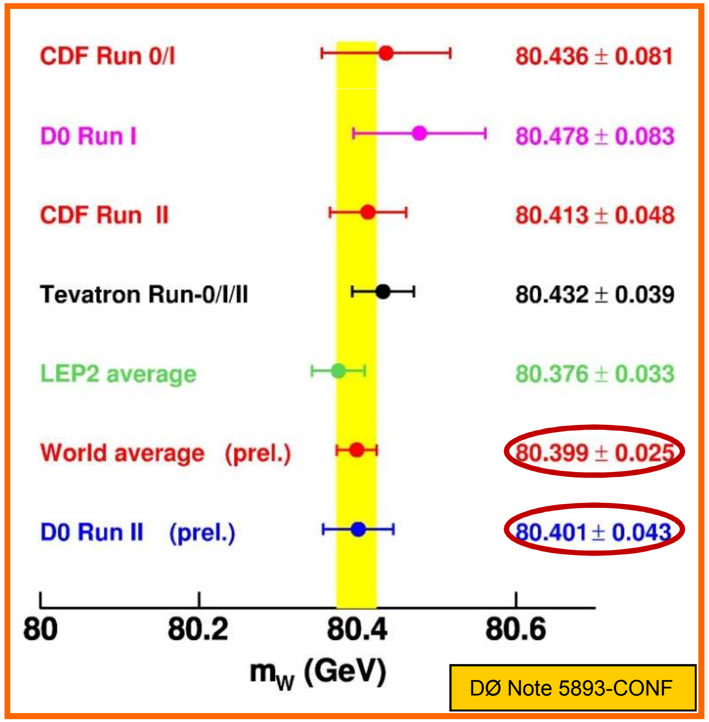
- In SM, masses of top quark, W boson and Higgs boson related through radiative corrections:

$$M_W = 4\sqrt{\frac{\pi^2\alpha^2}{2G_F^2}}\,\frac{1}{\sin\theta_W(1-\Delta R)}$$

$$\Delta R \rightarrow M_{top}^2, \log M_H$$

- Precision measurements allow
  - Consistency check of SM (comparison between direct and indirect measurements)
  - Give hints of new physics
  - Constraint the mass of SM Higgs boson

- Up to date values →



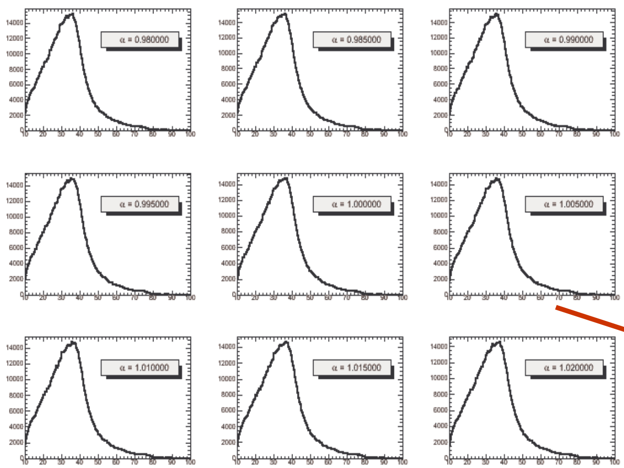
- Outline:
  - Method
  - Analysis with first data
  - Long term perspectives
  - Conclusions

W mass at LHC

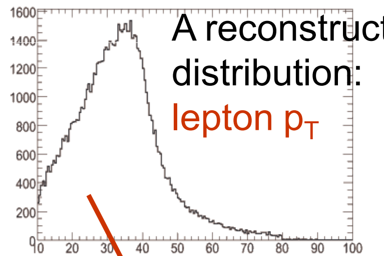
- NNLO cross section 20.5 nb per leptonic channel @ 14 TeV
  W $\rightarrow \ell\nu$ 65 000 evts selected per channel in 15 pb^{-1}
  10 times less Z. Only lepton channels are usefull

- 3 observables sensitive to the W mass (with ≠ systematics):
  m_T (defined as $\sqrt{2p_T^{\ell}p_T^{\nu}(1-\cos(\phi^{\ell}-\phi^{\nu}))}$)
  p_T (lepton)
  p_T (neutrino)

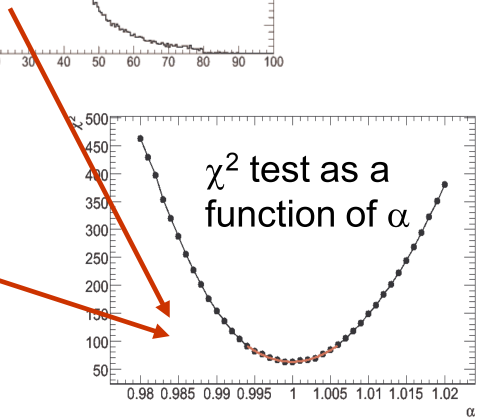
- **Template method**



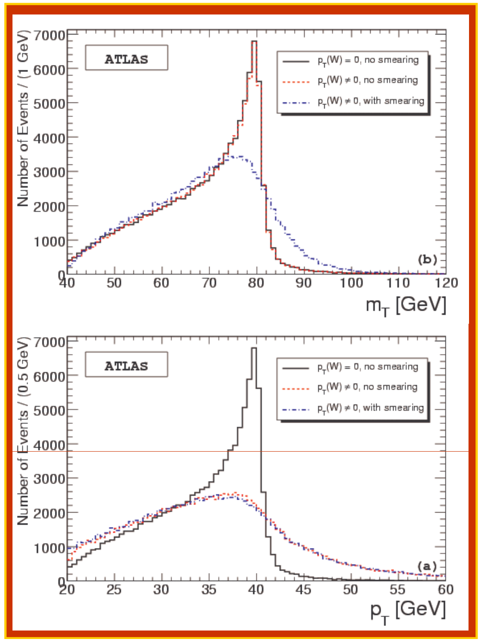
A set of distributions characterized by a scale factor α



A reconstructed distribution:
lepton p_T



χ^2 test as a function of α



ATL-PHYS-PUB-2009-036

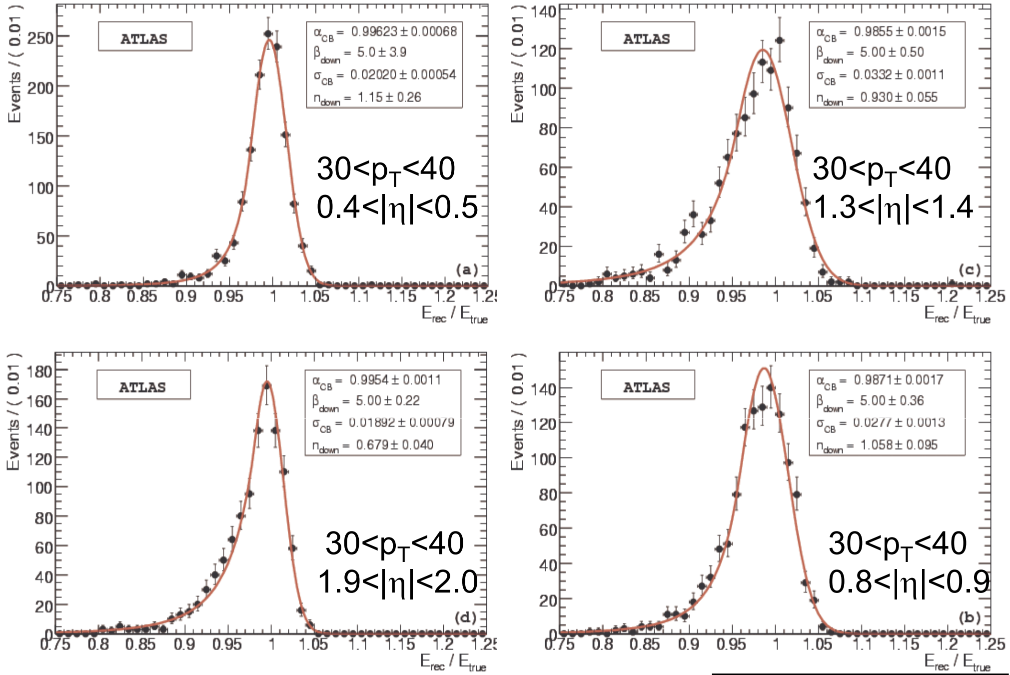
Simple and efficient but crucially relies on control of any effect distorting the test distribution

- **Effects distorting the test distributions:**
  - Experimental sources of uncertainty:
    - Lepton energy scale and linearity
    - Lepton energy resolution
    - Non gaussian tails of the energy distributions
    - Recoil scale and resolution
    - Reconstruction Efficiency
  - Theoretical sources:
    - Direct effect on lepton: FSR
    - W distributions: y(W) and p_T(W) (PDF, ISR); Γ_W
  - Environmental sources:
    - Backgrounds, underlying event, pileup, beam crossing angle
- To control these effects in the templates, rely on our great knowledge of the Z physics by calibrating the effects on the Z events.

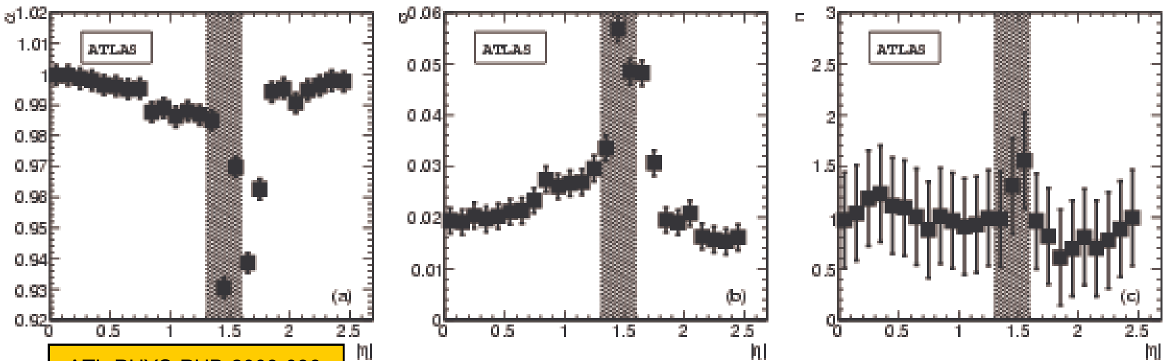
I. Validation of the modelisation of the detector templates effects (1)

Parameters we need to control:
energy scale α, resolution σ, tails

$$CB(x) = \begin{cases} e^{-\left(\frac{x-\alpha_E}{\sigma_E}\right)^2}, & x > \alpha_E - n\sigma_E \\ \left(\beta / n - |n| - x\right)^{-\beta}, & x < \alpha_E - n\sigma_E \end{cases}$$



ATL-PHYS-PUB-2009-036



ATL-PHYS-PUB-2009-036

Smear the leptons according to shapes fitted on E_{rec}/E_{true} distributions in bins in $|\eta|$ and p_T

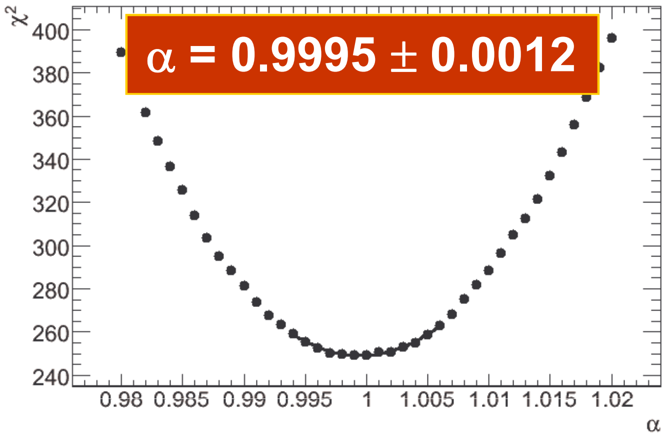
I. Validation of the modelisation of the detector templates effects (2)

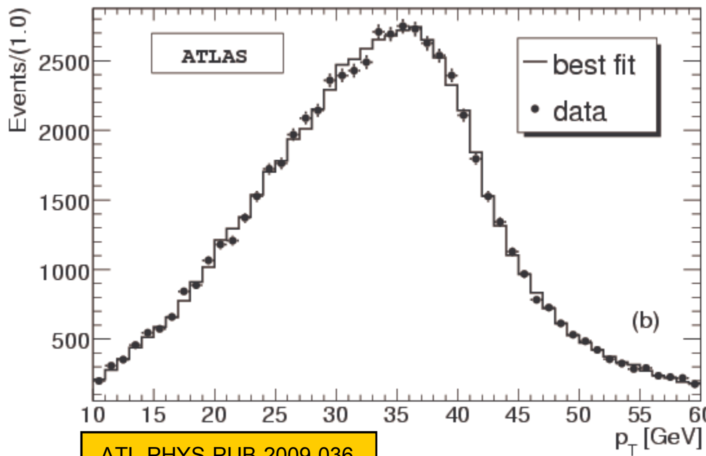
- **Result**:

  15 pb^{-1}, $W \to e\nu$, p_T lepton

  Selection and backgrounds
  - High p_T isolated lepton, $\not{E}_t$, had. Recoil, EM crack
    ε ~ 22%
  - Backgrounds W to τ, Z to leptons, jet events
    - After selection 2.2% of evts are background mainly $W \to \tau\nu$

- **In terms of mass:**
  - Fit result: m_W = 80.468 ± 0.117 GeV
  - To be compared to m_W^{true} = 80.405 GeV



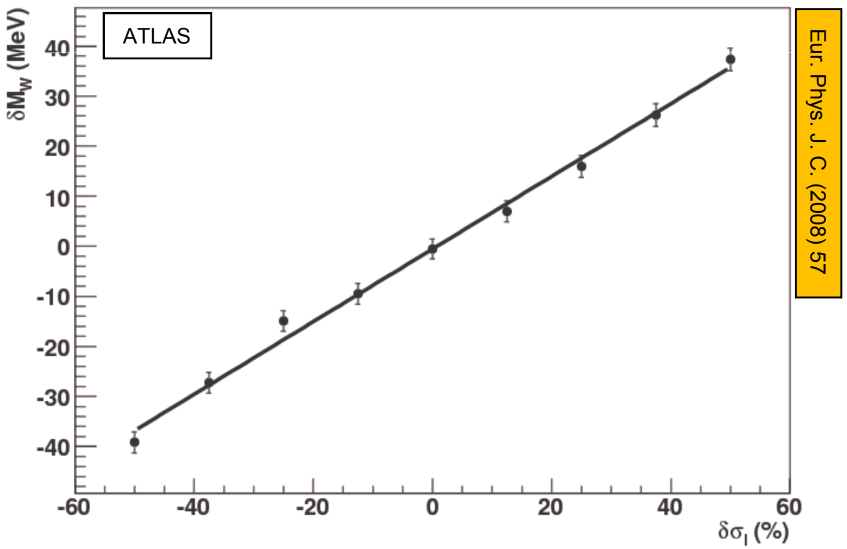


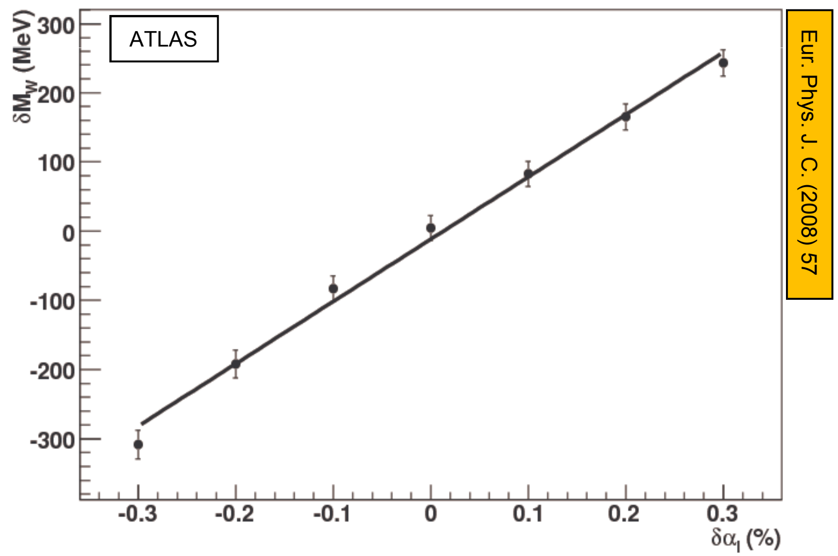
ATL-PHYS-PUB-2009-036

I. Sensitivity of m_W^{fit} to the template components(1)

- **Estimation of the impact of an effect:**
  Templates are produced with varying effect sizes

- **Energy scale and resolution**



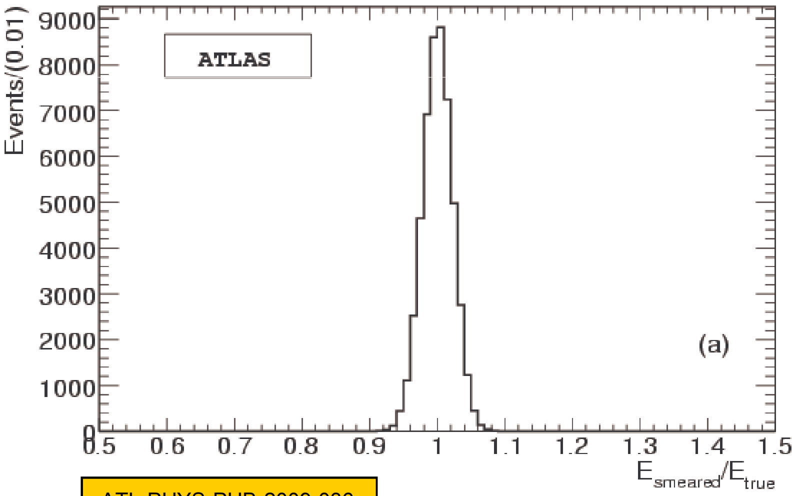


$\partial m_W/\partial\alpha_E$ = 800 MeV/% $\partial m_W/\partial\sigma_E$ = 0.8 MeV/%

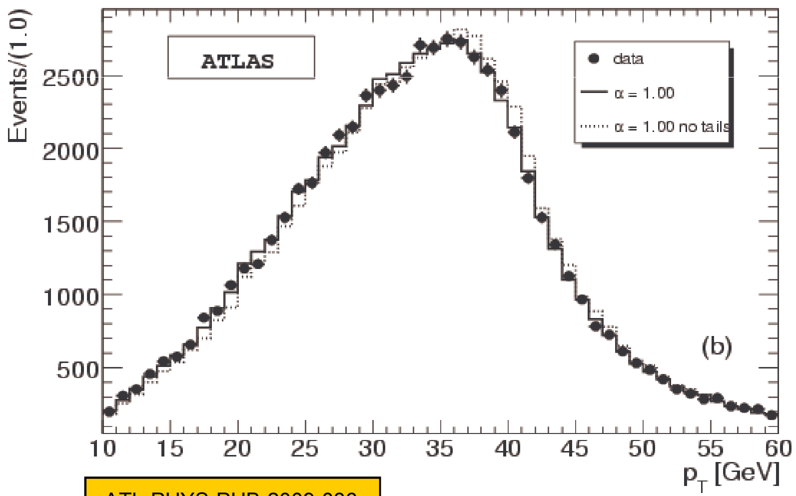
I. Sensitivity of m_W^{fit} to the template components (2)

- **Non gaussian tails**

Assuming a pure gaussian response test the biais induced by not taking into account the non gaussian tails



ATL-PHYS-PUB-2009-036



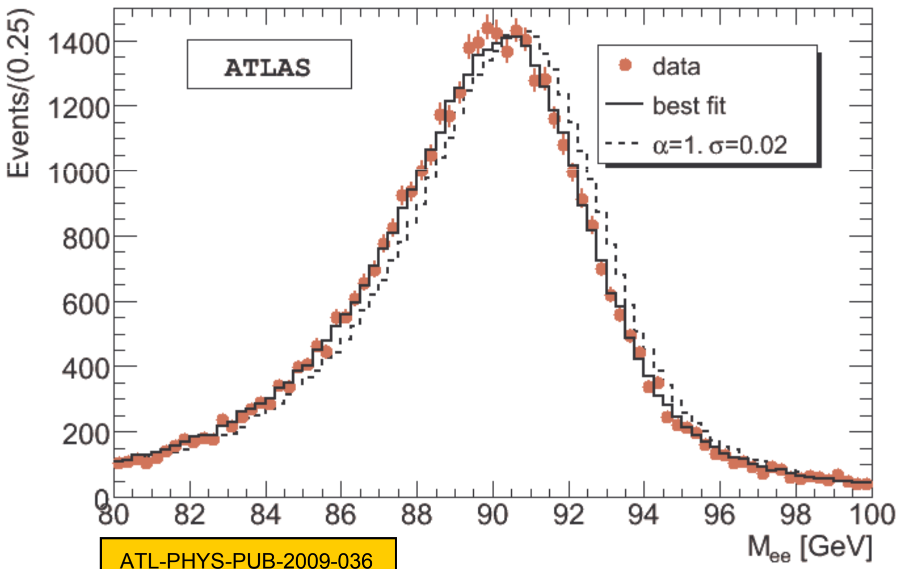
ATL-PHYS-PUB-2009-036

$\partial m_W / \partial \tau$ = -5.5 MeV/%

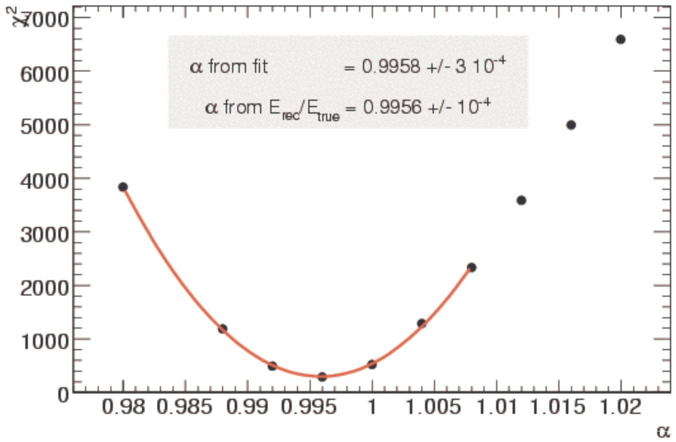
II. Calibration on Z events

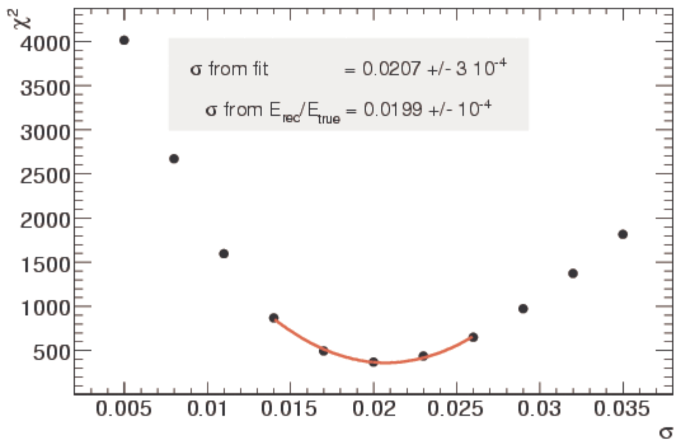
- **Scale and resolution**

With the low statistic, only average scale and resolution can be derived simultaneously with a template method



ATL-PHYS-PUB-2009-036

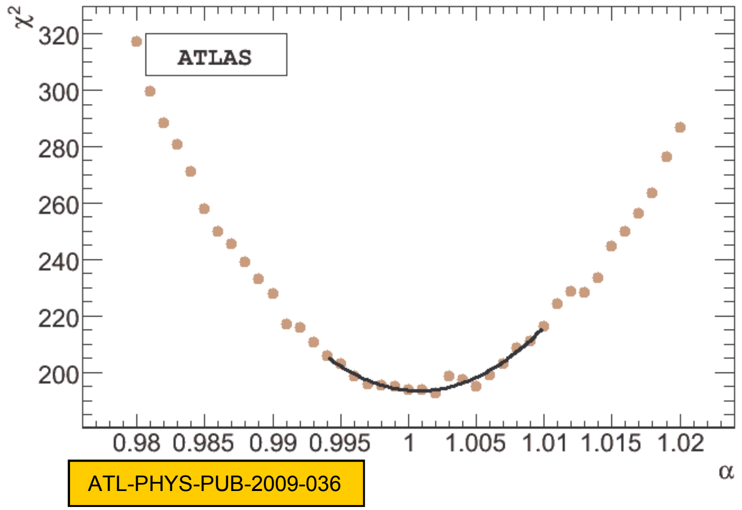


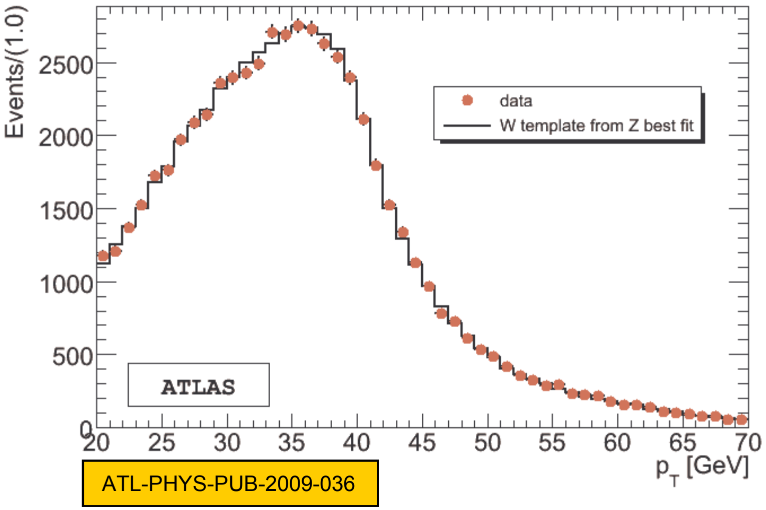


Non Gaussian tails taken from fits on rec/gen. Have to be determined very precisely with independent methods (E/p,…)

III. From Z to W events

- **Example with pT (e) spectrum:**
  - Response parameters determined insitu using Z events are then used to produce templates of the electron p_T, tested against the data
  - Fit result: $m_W = 80.466 \pm 0.110$ GeV
  - To be compared to $m_W^{true} = 80.405$ GeV No bias!





Results

- Results at 15 pb^{-1}

Method	p_T (e) [MeV]	p_T (μ) [MeV]	m_T (e) [MeV]	m_T (μ) [MeV]
δM_W (stat.)	120	106	61	57
δM_W (scale)	110	110	110	110
δM_W (resol)	5	5	5	5
δM_W (tails)	28	<28	28	<28
δM_W (eff.)	14	-	14	-
δM_W (recoil)	-	-	200	200
δM_W (bkg)	3	3	3	3
δM_W (PDF)	25	25	25	25

- With p_T lepton

  δM_W = 110 (stat) $\oplus$ 114 (exp.) $\oplus$ 25 (PDF) MeV

  main systematic uncertainty: energy scale

- With m_T

  δM_W = 60 (stat) $\oplus$ 230 (exp.) $\oplus$ 25 (PDF) MeV

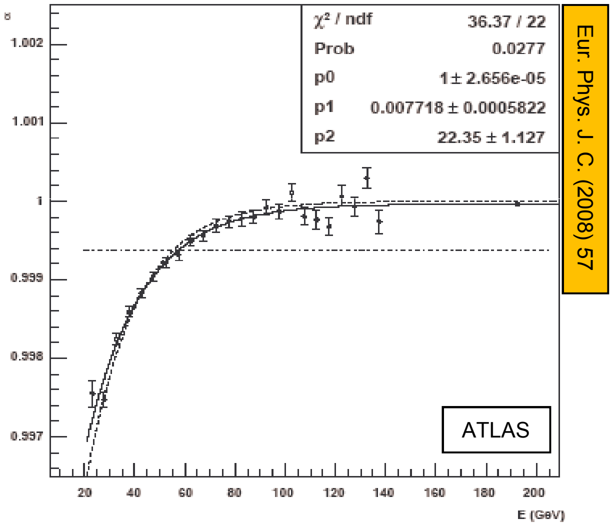
  main systematic uncertainty: recoil scale

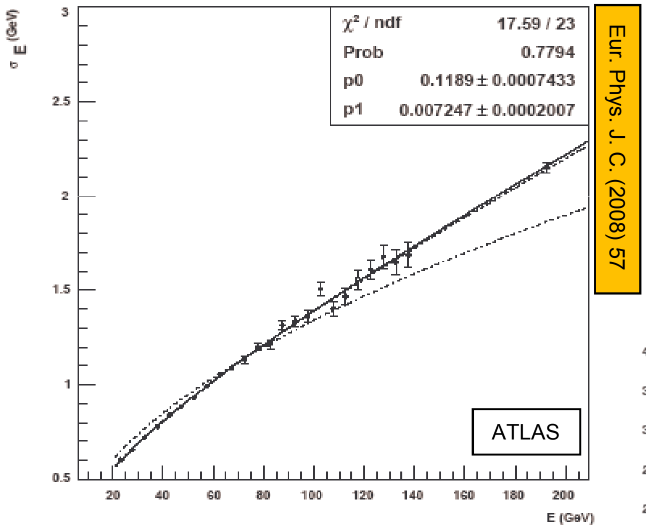
Long term perspectives (10 fb^{-1})

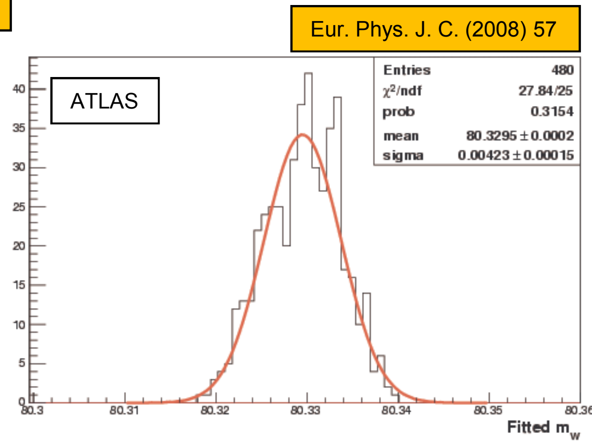
- **Statistics allows further studies:**
  - ~45 000 000 of W bosons per leptonic channel
  - ~ 4 500 000 of Z bosons per leptonic channel
- **Extensive systematic studies. Examples:**
  - Experimental sources of uncertainty:
    - Lepton energy scale and resolution, linearity
  - Theoretical sources:
    - W distributions: y(W)
    - FSR

- **First example:** energy dependent scale and resolution

- Same template method allowing to determine average scale and resolution simultaneously but in bins of electron energy
- Whereas there's an hypothesis on the shape of of the resolution with respect to the lepton energy, the method allows to recover the true shape







- Draw ~500 random scale parameters within their uncertainties ➡ distribution RMS ~4 MeV

For 10 fb^{-1} control up to 2 10^{-4} ➡ **$\delta M_W (\alpha) \approx$ 4 MeV** and **$\delta M_W (\sigma) \approx$ 1 MeV**

- **Second example: W distributions**
  - **Rapidity distribution**

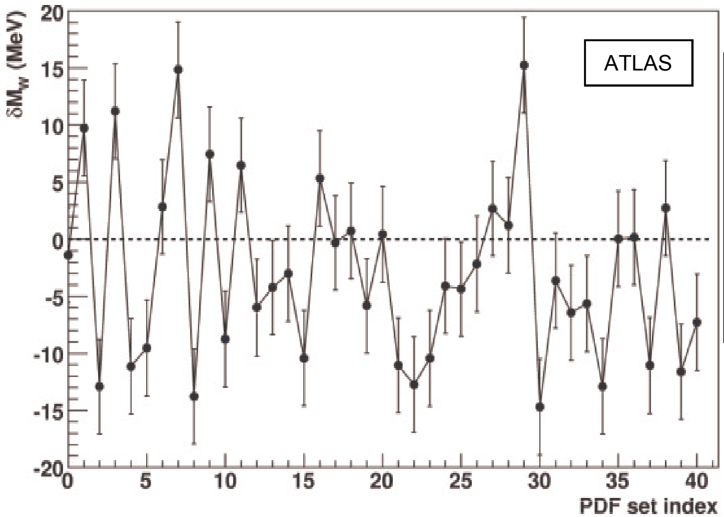
Essentially driven by the PDFs
With CTEQ6.1, 20 diagonal parameters, ± 1σ: $\delta M_W \approx 25$ MeV

Sea quarks interactions, ~symmetric
➡ strong correlation between y_W and y_Z with respect to PDF variations

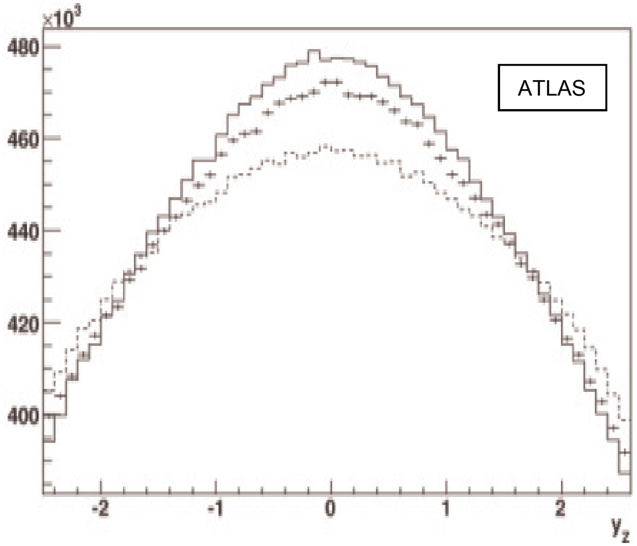
With 10 fb^{-1} improvement on Z rapidity distribution factor ~30 → improvement on W rapidity distribution by a factor 20

➡ **$\delta M_W \approx 3$ MeV**

Releasing the $s = \bar{s}$ constraint (CTEQ6.6), slight loss of correlation, change of slope



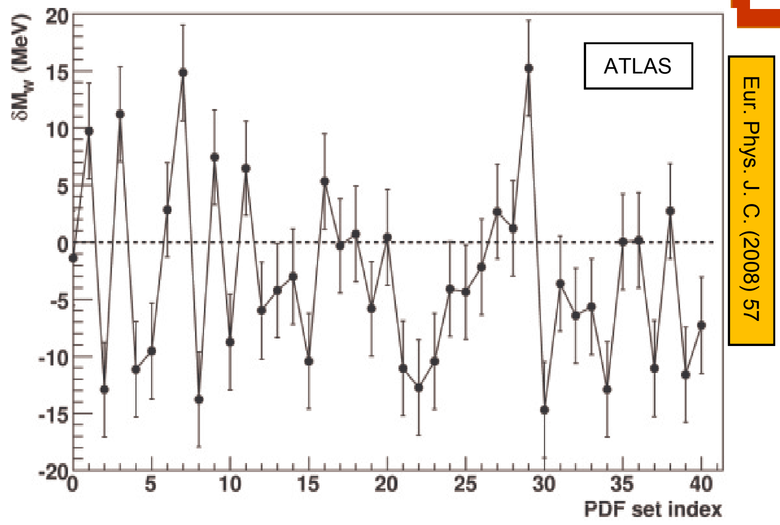
Eur. Phys. J. C. (2008) 57



Eur. Phys. J. C. (2008) 57

- **Second example: W distributions**
  - **Rapidity distribution**

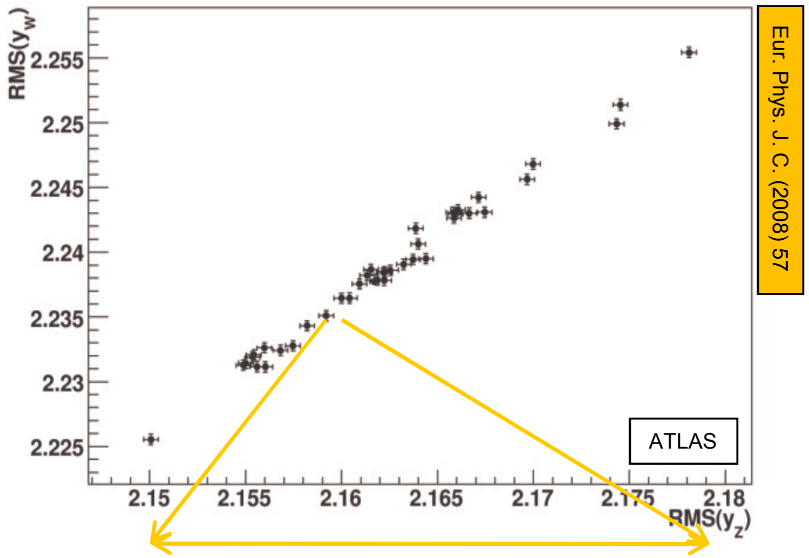
Essentially driven by the PDFs
With CTEQ6.1, 20 diagonal parameters, ± 1σ: $\delta M_W \approx 25$ MeV



Sea quarks interactions, ~symmetric
➡ strong correlation between y_W and y_Z with respect to PDF variations

With 10 fb^{-1} improvement on Z rapidity distribution factor ~30 → improvement on W rapidity distribution by a factor 20

➡ **$\delta M_W \approx 3$ MeV**



Releasing the $s = \bar{s}$ constraint (CTEQ6.6), slight loss of correlation, change of slope

- **Second example: W distributions**
  - **Rapidity distribution**

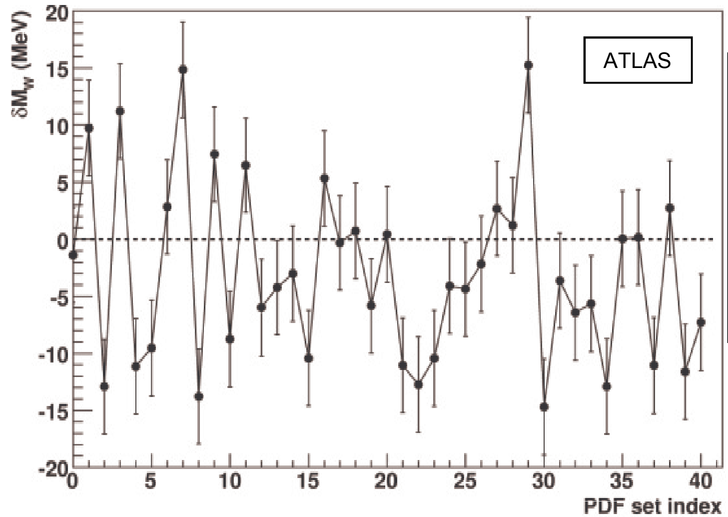
Essentially driven by the PDFs
With CTEQ6.1, 20 diagonal parameters, $\pm 1\sigma$: $\delta M_W \approx 25$ MeV

Sea quarks interactions, ~symmetric
➡ strong correlation between y_W and y_Z with respect to PDF variations

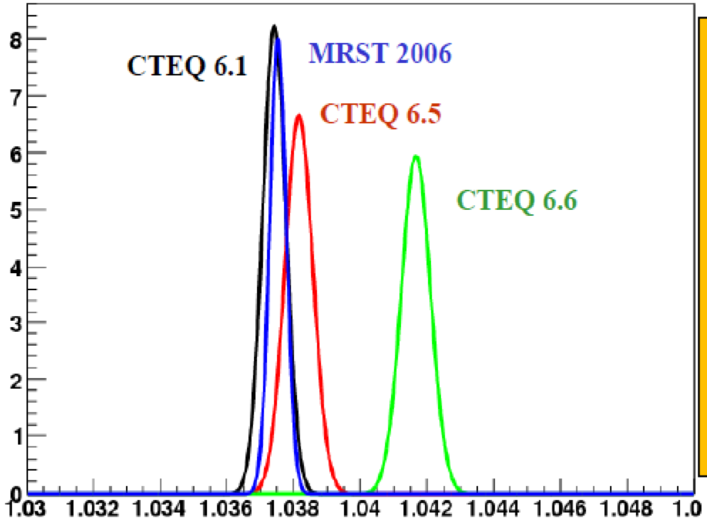
With 10 fb^{-1} improvement on Z rapidity distribution factor ~30 → improvement on W rapidity distribution by a factor 20

➡ **$\delta M_W \approx 3$ MeV**

Releasing the $s = \bar{s}$ constraint (CTEQ6.6), slight loss of correlation, change of slope

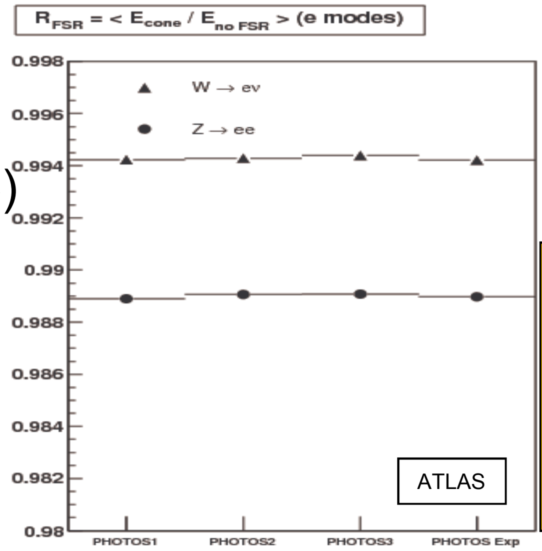


Eur. Phys. J. C. (2008) 57



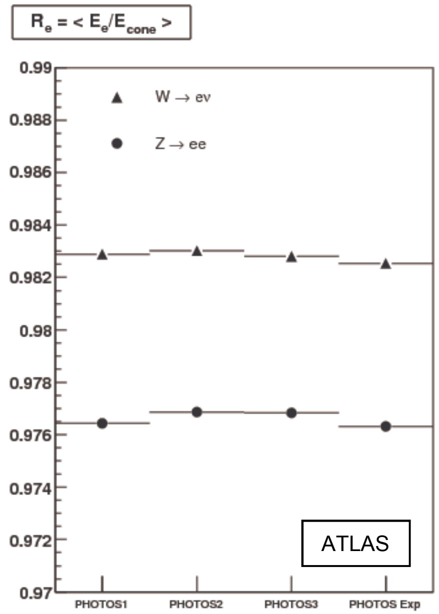
Hera LHC workshop – Maarten Boonekamp

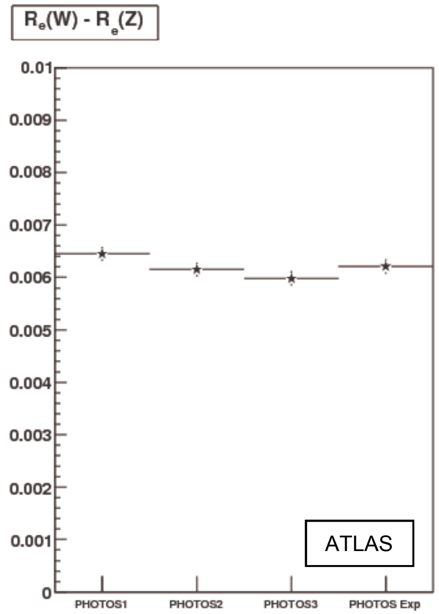
- **Third example: QED FSR**
  - Average of 1% energy lost, (800 MeV on M_W)
  - ➡ theory stable to around 2.10^{-4} (compatible with stat)
  - Theoretical uncertainty very small



Eur. Phys. J. C. (2008) 57

- Scale from Z on mixture of e and γ which have diff. scale (1%)
- Z electrons diff. from W electrons
- ➡ biais in scale transportation
- 0.6 % thus corr. factor of 6.10^{-5} (5 MeV on M_W)
- Good stability
- ➡ Ultimately a significant effect, but carries no uncertainty





source	effect	δm_W (MeV)
Theoretical model	Γ_W	0.5
	y_W	1
	p_{tW}	3
	QED radiation	<1
Lepton measurement	linearity and scale	4
	resolution	1
	efficiency	3 (e); <1 (μ)
Backgrounds	$W \rightarrow \tau\nu$	0.4
	$Z \rightarrow l$ (l)	0.2
	$Z \rightarrow \tau\tau$	0.1
	Jet events	0.5
Pile-up and UE		<1 (e); ~0 (μ)
Beam crossing angle		<0.1
total		~7

One channel (e) and one study (p_T)

Conclusion

- Analysis with early data (15 pb^{-1}), examples:
  - Electron channel, electron p_T, δM_W = 110 (stat) ⊕ 114 (exp.) ⊕ 25 (PDF) MeV
  - Muon channel, transverse mass, δM_W = 60 (stat) ⊕ 230 (exp.) ⊕ 25 (PDF) MeV
  - The statistics correponds to
    - 4h of data taking @ 14 TeV and $\mathcal{L} = 10^{33}\ cm^{-2}s^{-1}$

      (« low luminosity » nominal setting)
    - ~25 days of data taking @ 10 TeV and $\mathcal{L} = 10^{31}\ cm^{-2}s^{-1}$

- Analysis with higher statistics (10 fb^{-1}), the challenge will be to reduce systematic uncertainties
  - Each decay channel δM_W ~ 7 MeV
  - The statistics corresponds to 1 year of data taking @ 14 TeV and $\mathcal{L} = 10^{33}\ cm^{-2}s^{-1}$
  - Or 1 day at high luminosity

- Data forseen this winter @ 8 or 10 TeV

Many thanks to
the Atlas collaboration, especially to
Maarten Boonekamp, Anna Di Ciaccio,
Lucia Di Ciaccio, Stefan Tapprogge,
Bruno Mansoulié

References

ATL-PHYS-PUB-2006-007

Determination of the absolute lepton scale using Z boson decays. Application to the measurement of M_W

Eur. Phys. J. C. (2008) 57:627-651

Re-evaluation of the LHC potential for the measurement of M_W

ATL-PHYS-PUB-2009-036

Measurement of the W Boson Mass with Early Data

http://indico.cern.ch/conferenceOtherViews.py?view=cdsagenda_olist&confId=27458

Cross-section measurements at ATLAS : Luminosity and impact of PDF uncertainties
(by M. Boonekamp presented at the 4th HERA and the LHC workshop)

DØ Note 5893-CONF

Measurement of the W boson mass with 1 fb^{-1} of DØ Run II data