Electroweak physics measurements at the LHC

for the Atlas and CMS collaborations

Mass of the top quark

Mass of the W boson

Introduction

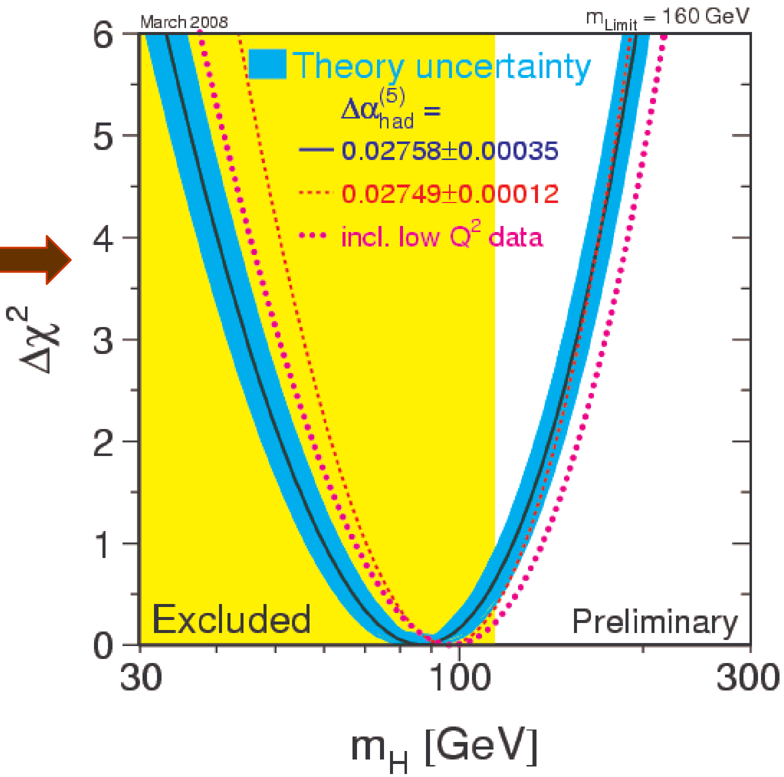
- In SM, masses of top quark, W boson and Higgs boson are related through radiative corrections:

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

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

- Precise measurements of M_{top} and M_W allow
  - Consistency check of SM
  - Give hints of new physics
  - Constraint the mass of SM Higgs boson

- Up to date values:
  - **M_{top} = 172.6 ± 0.8 (stat.) ± 1.1 (syst.) GeV**
  - **M_W = 80.398 ± 0.025 GeV**
  - ⇨ **M_H = 87^{+36}_{-27} GeV & M_H< 160 (190)GeV**

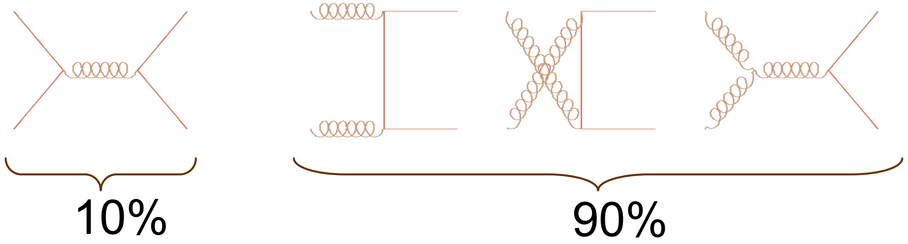


- LHC = 10 days ⇔1 fb^{-1}, 1 year ⇔ 10 fb^{-1}

Challenge = **systematics uncertainties**

- Outline
  - Top quark mass measurements at LHC
  - W boson mass measurement at LHC
  - Conclusion

Top pairs at LHC



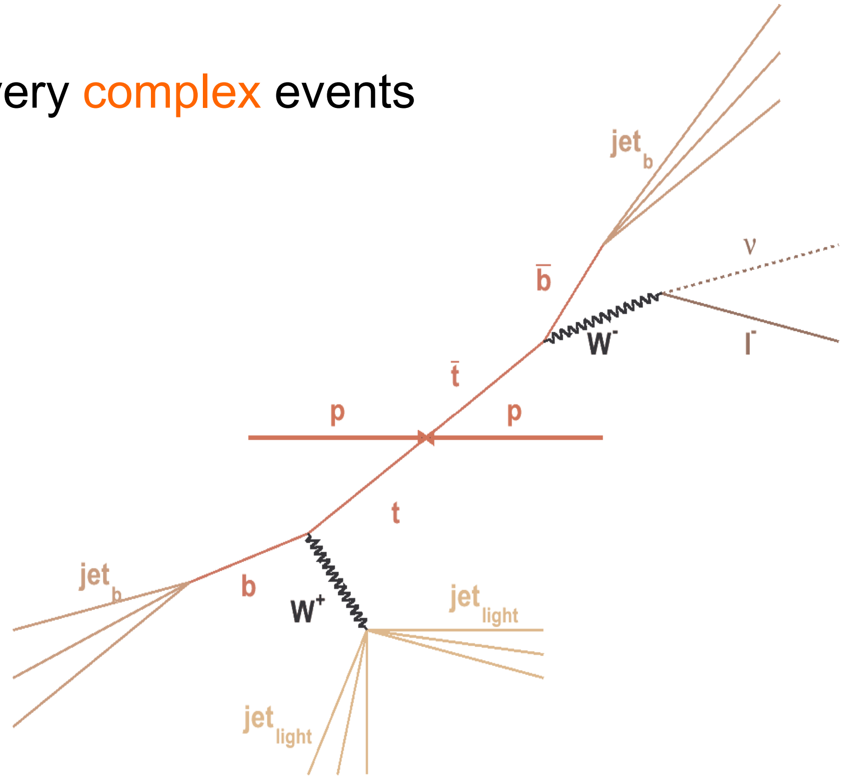
High center of mass energy
- 14 TeV

High cross section
- 833 pb (NLO)

High luminosity
- 10^{33} to 10^{34} cm^2s^{-1}

A lot of events
- 800 000 top pairs (1 fb^{-1})

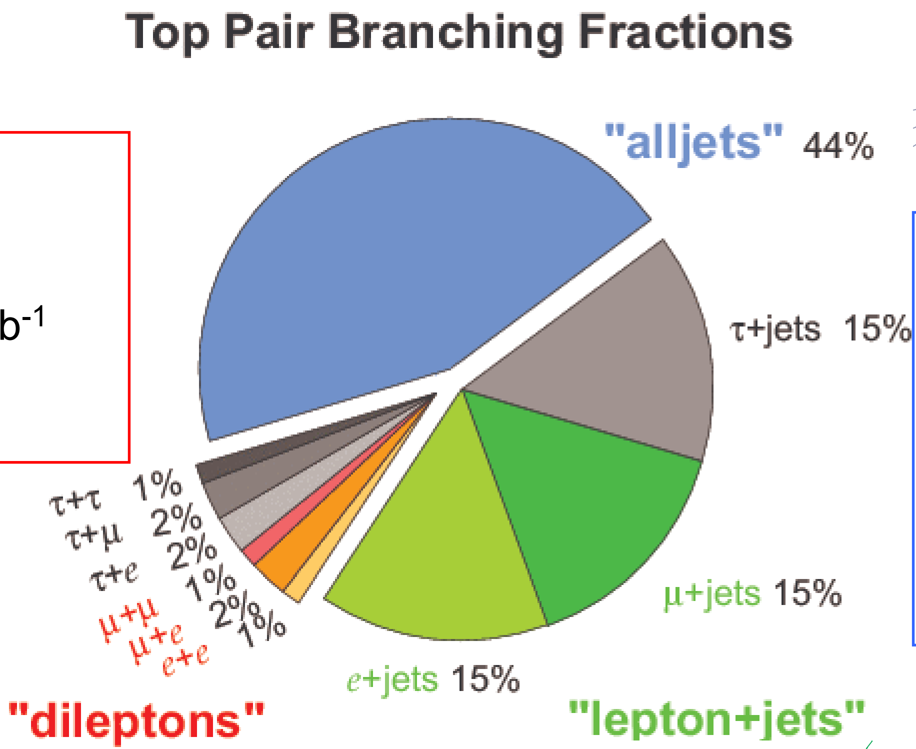
But very complex events

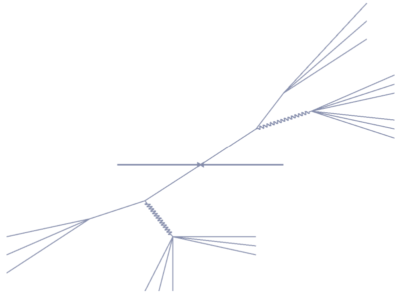


Many different objects:
- Light jets
- b jets
- Missing E_t
- Leptons

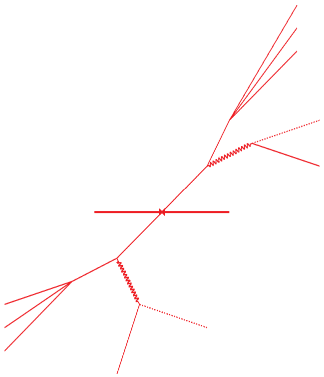
Many sources of uncertainty:
- Jet Energy Scale (JES)
- ISR/FSR
- Backgrounds
- Combinatorial background
- b fragmentation…

Top pairs: decays

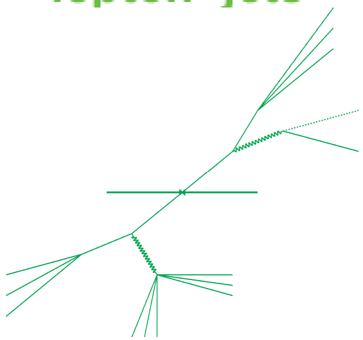




Low background
Low combinatorics
Small BR
  ≈ 50 000 evts for 1fb^{-1}
Final state difficult to reconstruct



Enormous background
Huge combinatorics
  10 ways to combine 6 jets
High BR
  ≈ 350 000 for 1 fb^{-1}
Possible to reconstruct the whole event



Good compromise
≈ 250 000 evts for 1 fb^{-1}

Top mass: semileptonic channel (1/5)

250 000 events for 1 fb^{-1} with S/B $\approx 10^{-5}$ prior to any cut and selection

- Event selection
  - One and only one isolated lepton inside acceptance
    ($|\eta| < 2.5$, $p_t > 20$ GeV (μ) or $p_t > 25$ GeV (e))
  - Missing $E_t > 20$ GeV
  - At least 4 jets with $p_t > 40$ GeV
  - Among them exactly 2 which are b-tagged

S/B $\approx$10

- Backgrounds
  - Single top and ttbar fully hadronic (isolation) & dileptonic (1 lepton only)
  - W+jets (b-tagging) and Z+jets
  - Di bosons (low cross section)
  - QCD (missing E_t, lepton p_t)

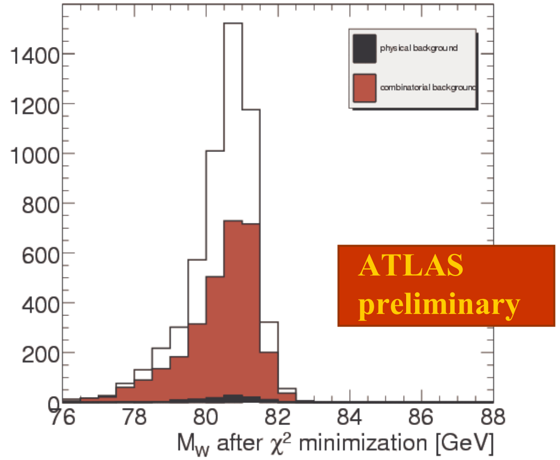
- After lepton cuts QCD negligible and top all jets reduced by 2/3

Top mass: semileptonic channel (2/5)

- W hadronic side, choice and *in situ* rescaling

  After selection of pairs in a mass range determined on 2 light jets events

$$\chi^2 = \frac{\left(M_{jj} - M_W^{PDG}\right)^2}{\Gamma_W^2} + \frac{\left(E_{j1}(1-\alpha_1)\right)^2}{\sigma_1^2} + \frac{\left(E_{j2}(1-\alpha_2)\right)^2}{\sigma_2^2}$$



- Efficiency: ε = 1.93%

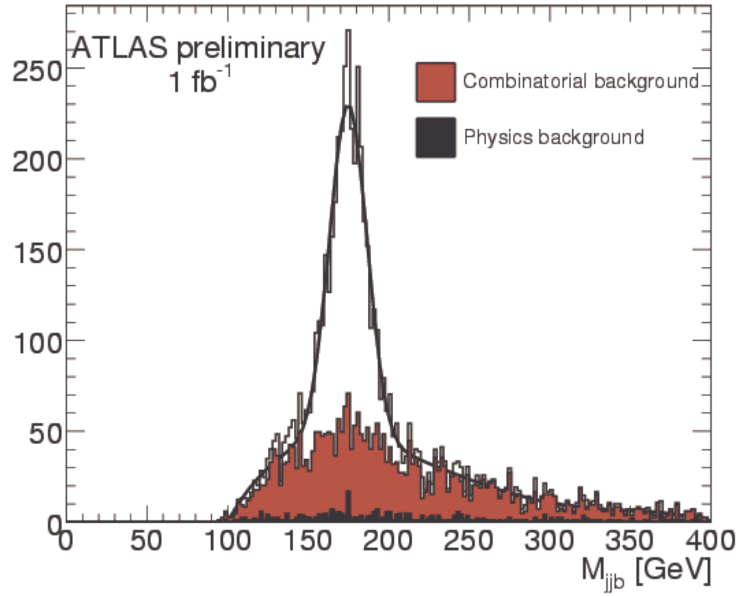
- Pairing:

  Several methods: here b closest to W

- Gaussian fit + polynomial

M_{top} = 175.0 ± 0.2 GeV

σ_{top} = 11.6 ± 0.2 GeV



Top mass: semileptonic channel (3/5)

- Systematics

Systematic uncertainty sources	Effect on m_{top}
Light jet energy scale	0.2 GeV/%
b-jet energy scale	0.7 GeV/%
ISR/FSR	$\approx$ 0.3 GeV
b fragmentation	$\leq$ 0.1 GeV
Background	negligible

Most important source of uncertainty

- Light JES
  (reduced thanks to *in situ* rescaling, if it's not done the slope $\Rightarrow$ 1 GeV/%)
- b-jets energy scale

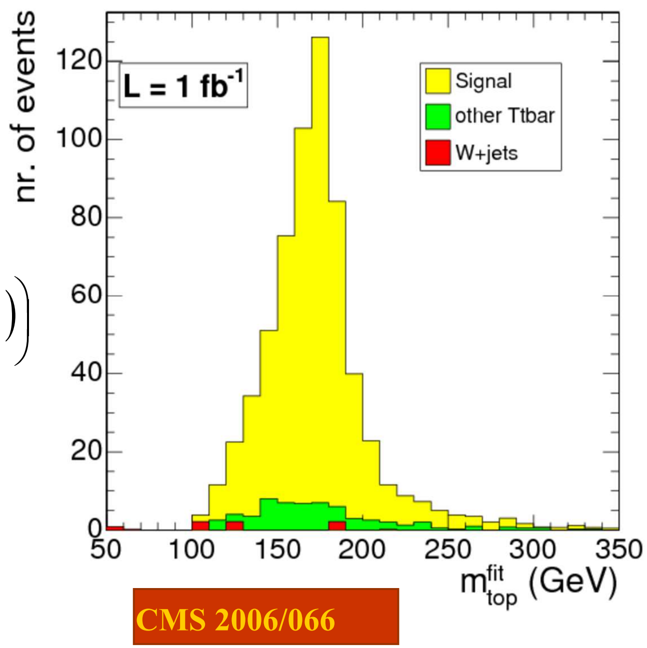
- JES studies:
  - This analysis: JES taken from rec./sim. differences
  - Template method comparing reconstructed jj invariant masses with smeared Ws
    - Systematic uncertainties (combinatorial, template ingredients, top mass..) all below 0.5% ➡ **1% for 1 fb^{-1}**
  - This analysis: b-jet energy scale obtained from MC correction factors

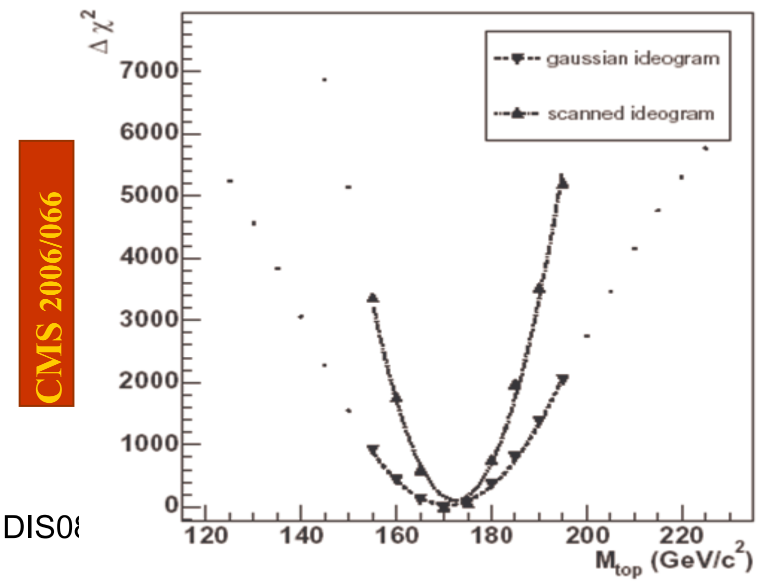
M_{top} = 175.0 $\pm$ 0.2 (stat.) $\pm$ 1 (syst.) GeV

Top mass: semileptonic channel (4/5)

- Alternative analysis based on likelihoods:
  - Probability from selection P_{sign}
  - Probability from jet combination P_{comb}
  - Probability from kinematic fit forcing M_W
    - Fitting M_{top}, probability from χ^2 → $$\chi^2(\{\bar{p}_j\}|m_t) = \left(\frac{m_t - m_t^{fit}}{\sigma_{m_t}^{fit}}\right)^2$$
    - Forcing M_{top}, probability from mass scan → $$P(\{\bar{p}_j\}|m_t) \approx \exp\left(-\frac{1}{2}\chi^2(\{\bar{p}_j\}|m_t)\right)$$

After kinematic fit





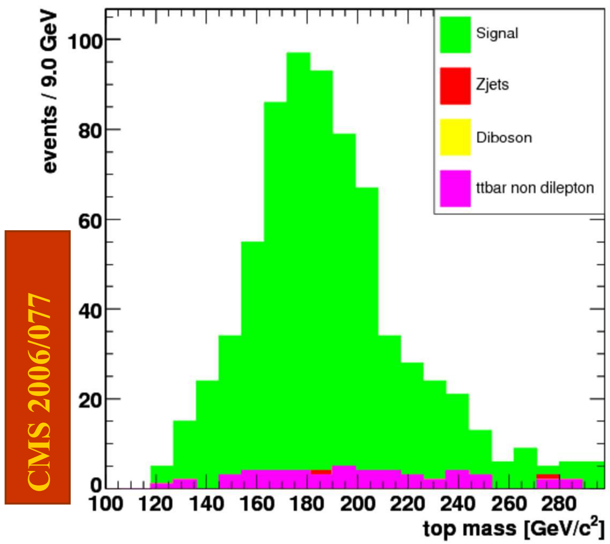
Mass scan gives (1 fb^{-1}, only μ channel)

M_{top} = 172.42 ± 0.66 GeV (stat) ± 1.13 (syst)

Largest : JES for b jets

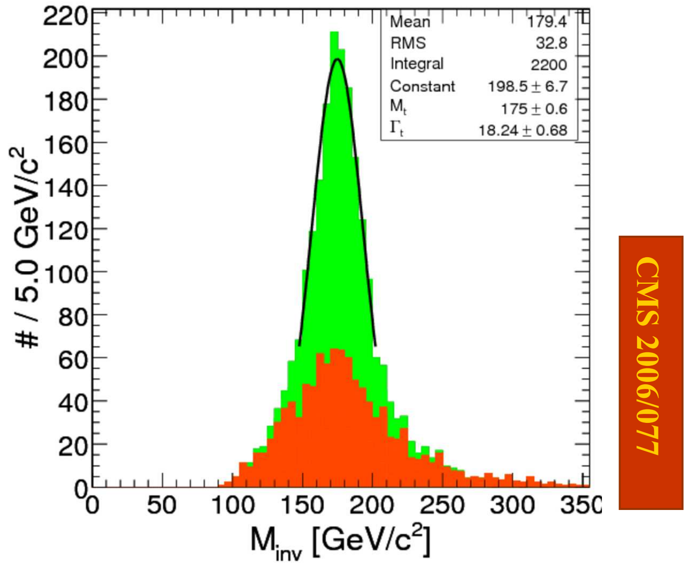
Top mass: dileptonic & fully hadronic channels (1 fb^{-1})

Starting from S/B ≈ 5 10^{-3}
Selection S/B ≈ 7
Kinematical reconstruction of the event and pairing with likelihood (660 evts)
S/B ≈ 12 ε = 1.2%



M_{top} = 178.5 ± 1.5 (stat) ± 4.2 (syst)
Syst.: JES, kinematical hypothesis

Starting from S/B < 10^{-6}
Selection S/B ≈ 1/9 ε = 2.7%
Likelihood on masses and angles to perform the pairing + top choice



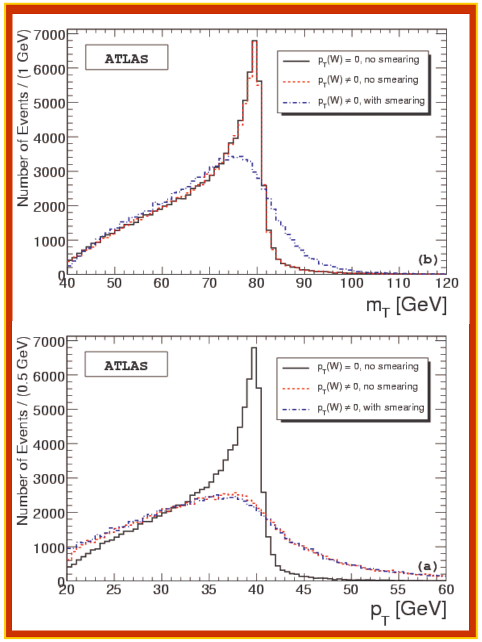
M_{top} = 175 ± 0.6 (stat.) ± 4.2 (syst.)
Syst.: QCD background, JES, ISR/FSR

W mass at LHC

- NNLO cross section 20.5 nb per lepton channel

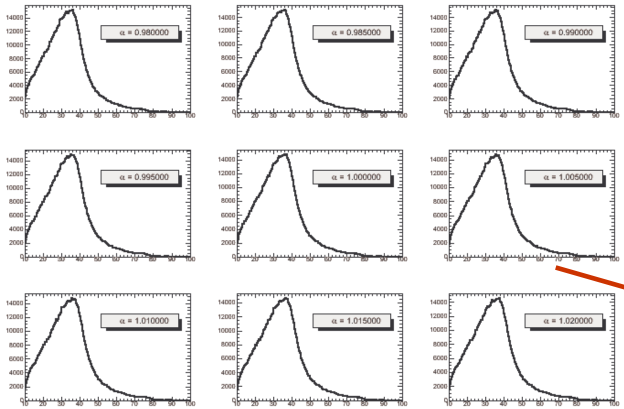
W $\rightarrow \ell\nu$ 3 000 000 evts selected per channel in 1 fb^{-1}

10 times less Z i.e. 300 000 evts selected per channel

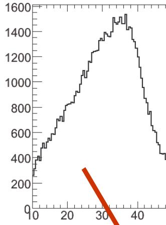


- 2 observables sensitive to the W mass:
  m_T and **p_t(lepton)**

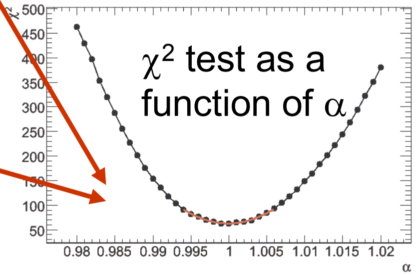
- **Template method**



A set of distributions characterized by a scale factor α



A reconstructed distribution: lepton p_t



χ^2 test as a function of α

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 p_t: FSR
    - Effect on lepton p_t via the W distribution y(W) et p_t(W) : Γ_W, PDF, ISR
  - 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, either by creating the templates from the Z events or by calibrating the effects on the Z events.

Creation of templates from Z events

Scaled observable method

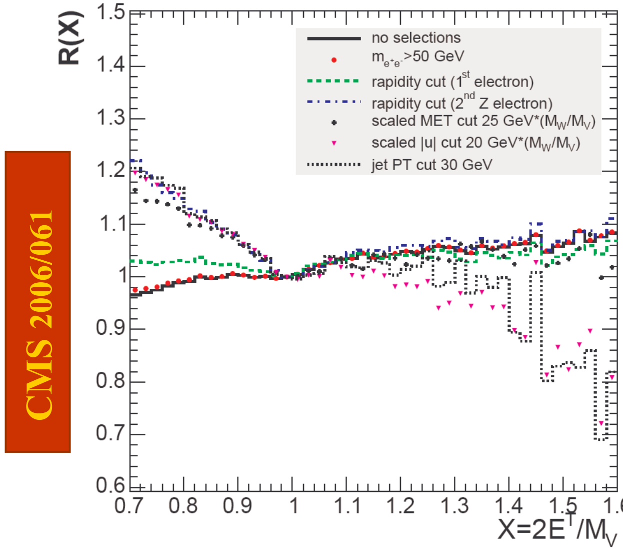
with lepton p_t distribution in $W \to e\nu$ for 1 fb^{-1}

- Randomly remove 1 e in $Z \to ee$
- Rescaling of the observable $X_V = p_t/M_V$
- Weight by **R(X)**

$$R(X) = \frac{d\sigma^W / dX_W}{d\sigma^Z / dX_Z}, X_V = \frac{p_t^e}{M_V}, V = W, Z$$

R(X) depend on theory and sel. & det. effects

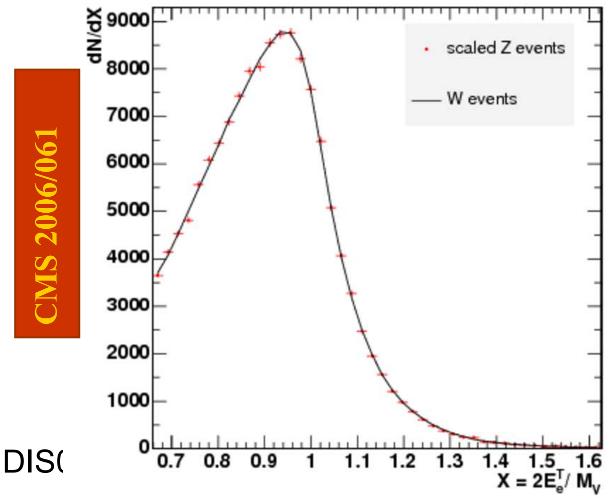
- Apply W selection on Z events with scale e.g. Missing $\not{E}_T$ > 29 GeV **x M_W/M_Z**



40 (stat.) ⊕ 40 (exp.) ⊕ 40 (theo.) MeV

Dominated by lepton energy scale linearity

Most common uncertainties cancel



Morphing

scaling the Z event instead of scaling the observable

With m_T $W \to \mu\nu$ for 1 fb^{-1}

40 (stat.) ⊕ 64 (exp.) ⊕ 20 (theo.) MeV

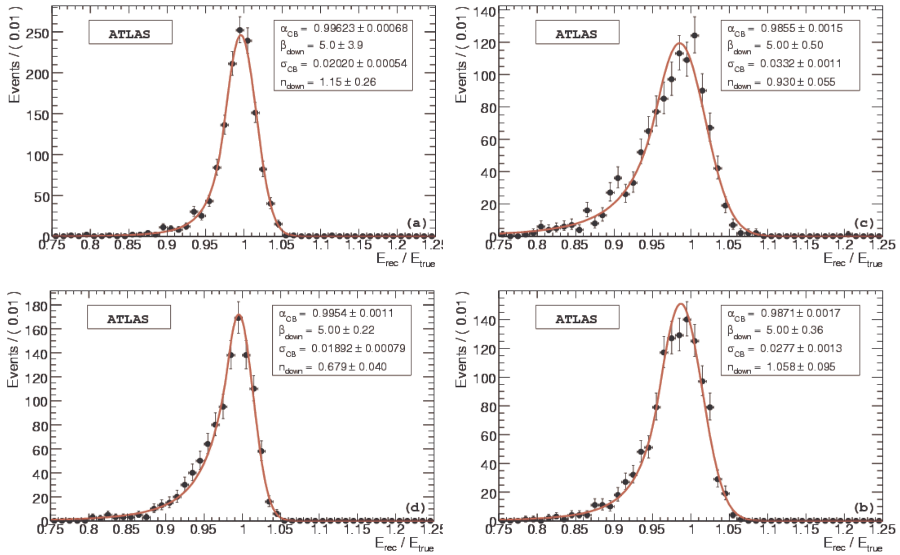
Dominated by $\not{E}_T$ scale

Calibrate templates with Z constraints

- First step: validate the modelisation of detector effects

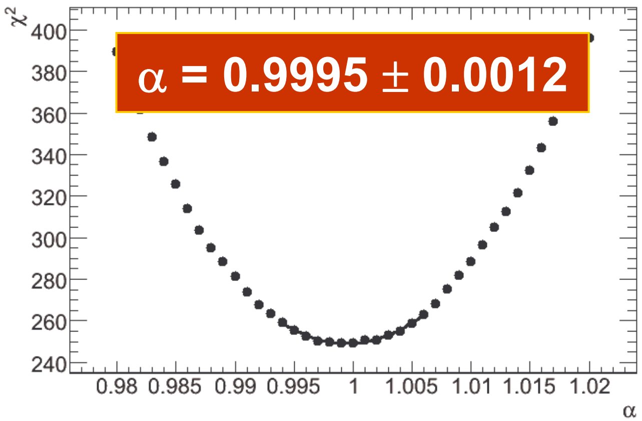
Parameters we need to control:
energy scale α, resolution σ, tails τ

$30<p_t<40$
$0.4<|\eta|<0.5$ (a), $0.8<|\eta|<0.9$ (b),
$1.3<|\eta|<1.4$ (c), $1.9<|\eta|<2.0$ (d)



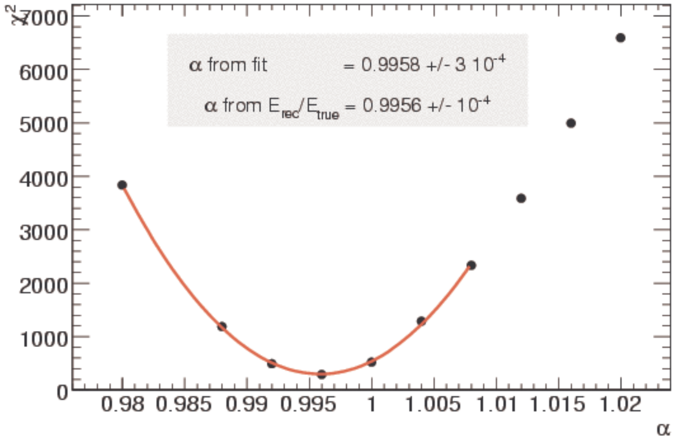
Smear the leptons according to shapes fitted on E_{rec}/E_{true} distributions in bins in $|\eta|$ and p_t.

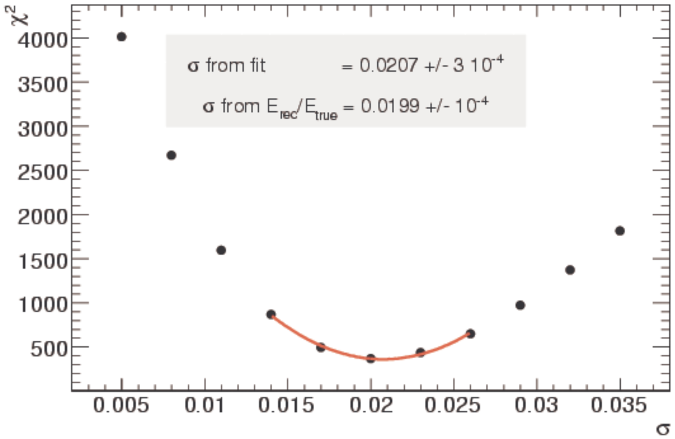
- Example: very early data **15 pb^{-1}**, $W\to e\nu$, p_t lepton
  Selection and backgrounds
  - High p_t isolated lepton, $\not{E}_T$, had. recoil **ε = 22%**
  - Backgrounds W to τ, Z to leptons, jet events
    - After selection 2.2% of evts are background mainly $W\to\tau\nu$

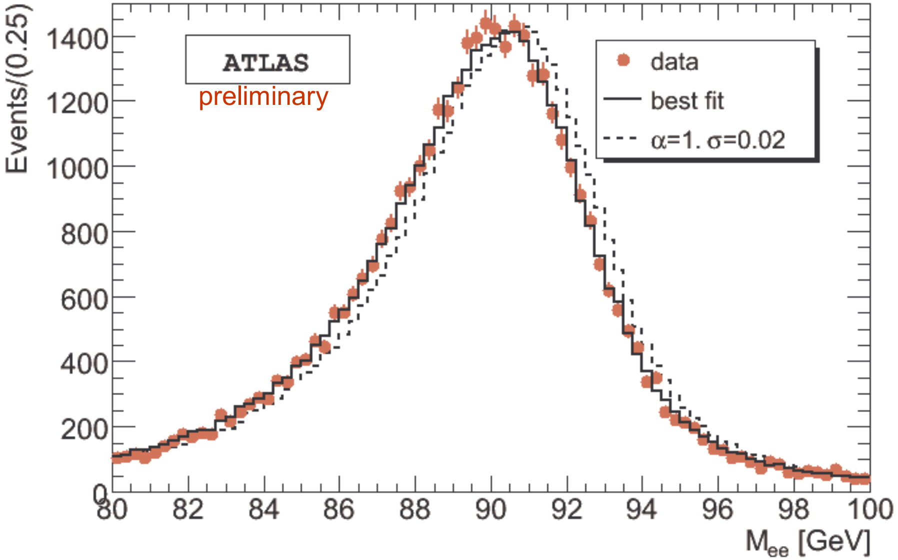


- Second step: calibrate the parameters on $Z \rightarrow ee$ events
  - Non gaussian tails
  - **Scale and resolution**

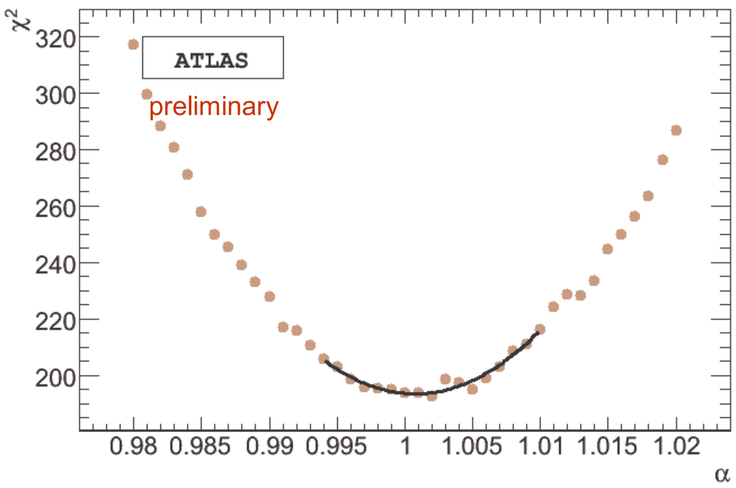
With the low statistics, only average scale and resolution can be derived with a template method

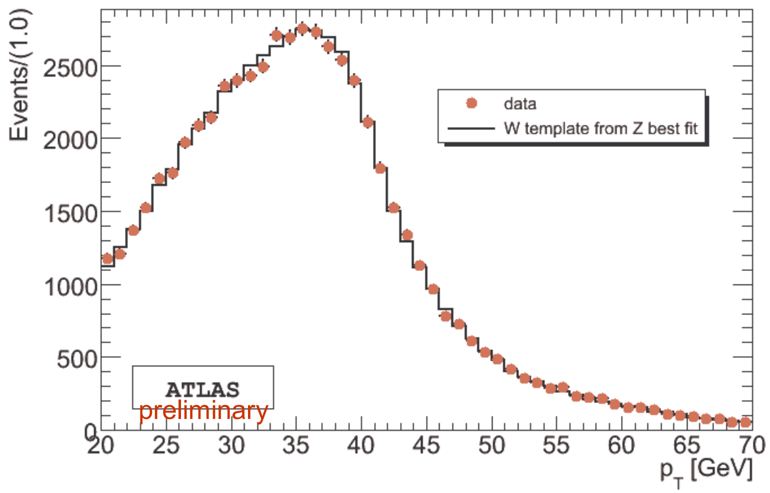






- Third step: validate we can « transport » calibration from Z events to W events





- Results 15pb^{-1}
  - With p_t lepton (electron channel)

δM_W = 110 (stat) ⊕ 114 (exp.) ⊕ 25 (PDF) MeV

main systematic uncertainty: energy scale

  - With m_T (muon channel)

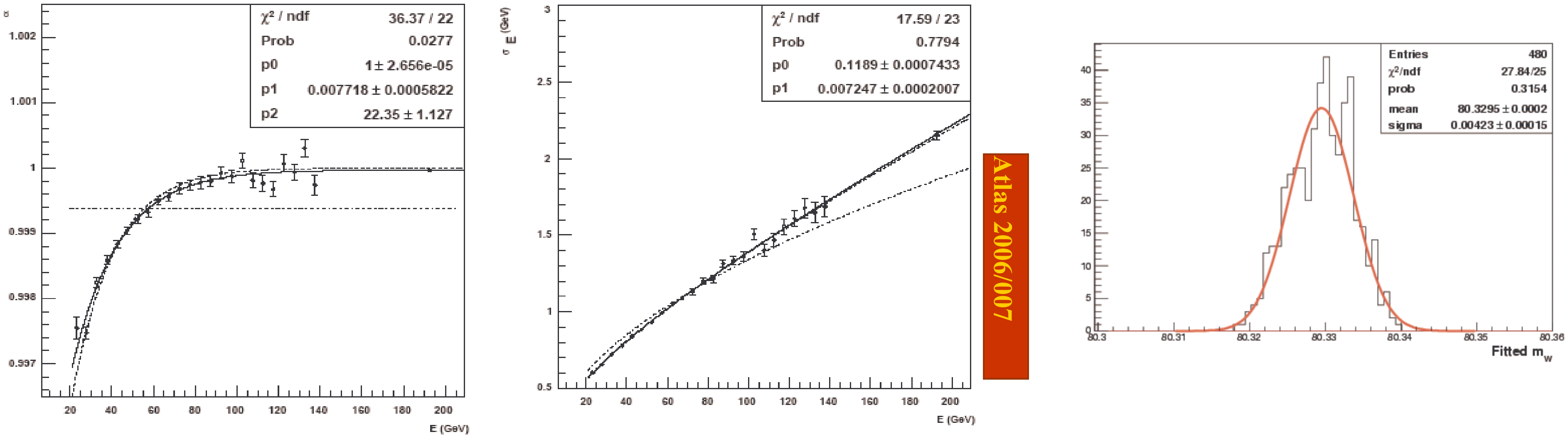
δM_W = 60 (stat) ⊕ 230 (exp.) ⊕ 25 (PDF) MeV

main systematic uncertainty: recoil scale

Long term perspectives

- **Extensive systematic studies. Examples:**
  - Experimental sources of uncertainty:
    - Lepton energy scale and resolution, linearity
  - Theoretical sources:
    - W distributions y(W) et $p_t(W)$

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

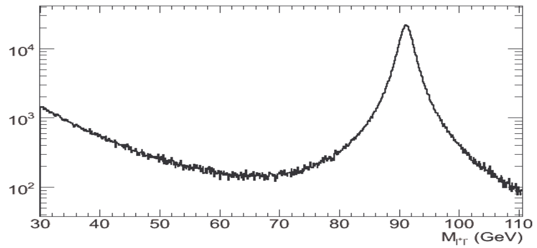


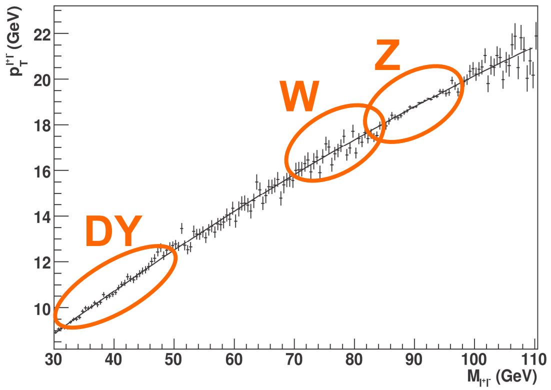
For 10 fb^{-1} control up to 2 10^{-4} ➡ $\delta M_W(\alpha) \approx$ **4 MeV** and $\delta M_W(\sigma) \approx$ **1 MeV**

- **Second example: W distributions**
  - **Transverse momentum**

Contribution from intrinsic p_t of partons and ISR

Final states l^+l^- $p_t(l^+l^-)$ versus $m(l^+l^-)$ with a huge lever arm





With $10fb^{-1}$ expected precision on p_t in W region of the order of 8MeV

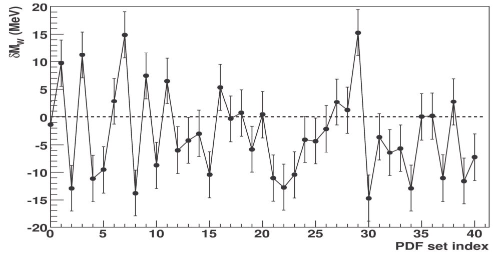
⇨ **$\delta M_W \approx 3$ MeV**

- **Rapidity**

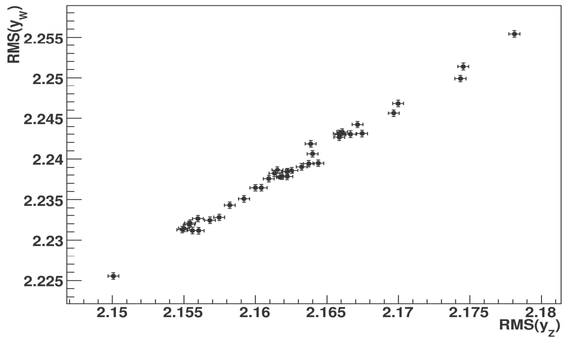
Contribution from PDF

For the moment

$\delta M_W \approx 25$ MeV

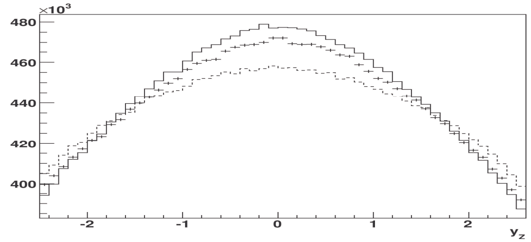


Strong correlation between y_W and y_Z with respect to PDF variations



With 10 fb^{-1} improvement by a factor 20

⇨ **$\delta M_W \approx 3$ MeV**

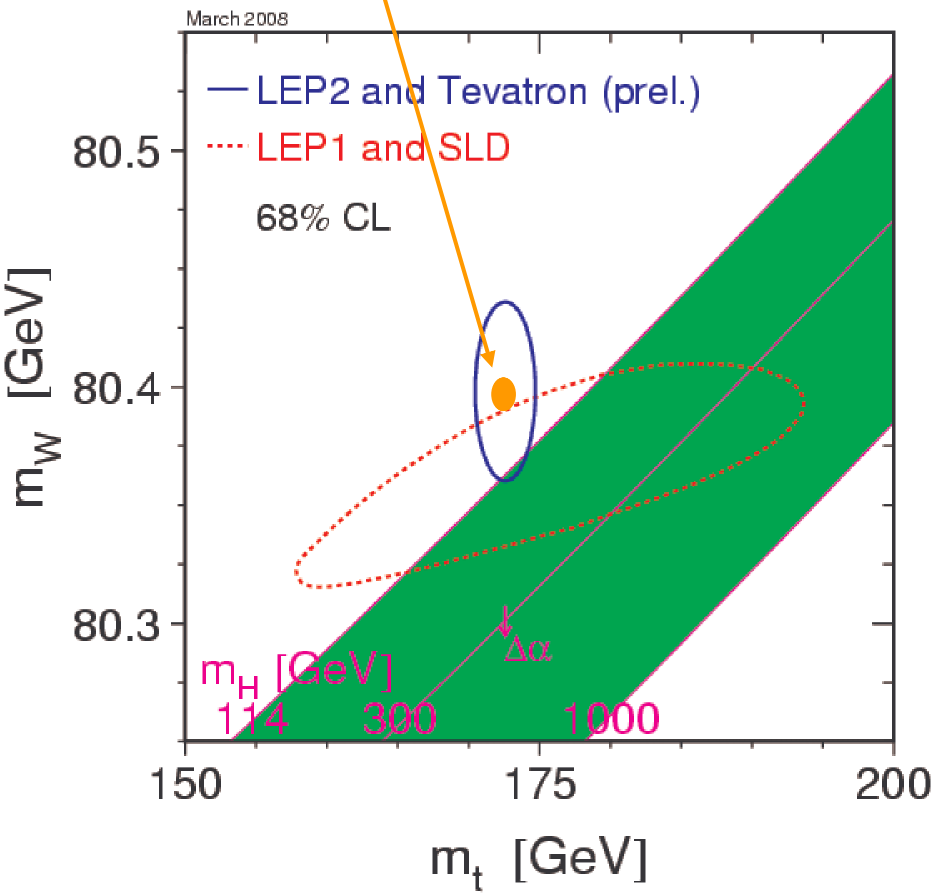


Source	effect	δm_W (MeV)
Theoretical model	Γ_W	0.5
	y_W	1
	p_{tW}	3
	QED radiation	<1
Lepton measurement	linearity and scale	4
	resolution	1
	efficiciency	4.5 (e); <1 (μ)
Backgrounds	$W \to \tau\nu$	2.0
	$Z \to$ l (l)	0.3
	$Z \to \tau\tau$	0.1
	jet events	0.5
Pile-up and UE		<1 (e); ~0 (μ)
Beam crossing angle		<0.1
total		**~7(e); 6(μ)**

One channel and one study (can be done for m_T)

Conclusion

- The challenge will be clearly to reduce systematic uncertainties
- $\delta M_{top} \approx$ 1GeV and $\delta M_W \approx$ 7 MeV seem within reach
- With 10 $fb^{-1}$and a lot of hard work we might go to



- Really eager to have data to work on!

Many thanks to
the Atlas and CMS collaborations, especially to Juan Alcaraz, Maarten Boonekamp, Martine Bosman, Jorgen D'Hondt, Anna Di Ciaccio, Lucia Di Ciaccio, Anne-Isabelle Etienvre, Tom LeCompte, Bruno Mansoulié

References

ATLAS

- ATL-PHYS-PUB-2006-007
  - Determination of the absolute lepton scale using Z boson decays. Application to the measurement of M_W
- Forthcoming "CSC" notes
  - Top quark mass measurement with ATLAS
  - Measurement of W mass at ATLAS with early data
- To be published
  - Re-evaluation of the LHC potential for the measurement of M_W

CMS

- CMS note 2006/066
  - Top quark mass measurement in single leptonic ttbar events
- CMS note 2006/077
  - Measurement of top-pair cross section and top-quark mass in the di-lepton and full-hadronic channels with CMS
- CMS note 2006/061
  - Prospects for the precision measurement of the W mass with the CMS detector at the LHC

LEPEWWG

- http://lepewwg.web.cern.ch/LEPEWWG/