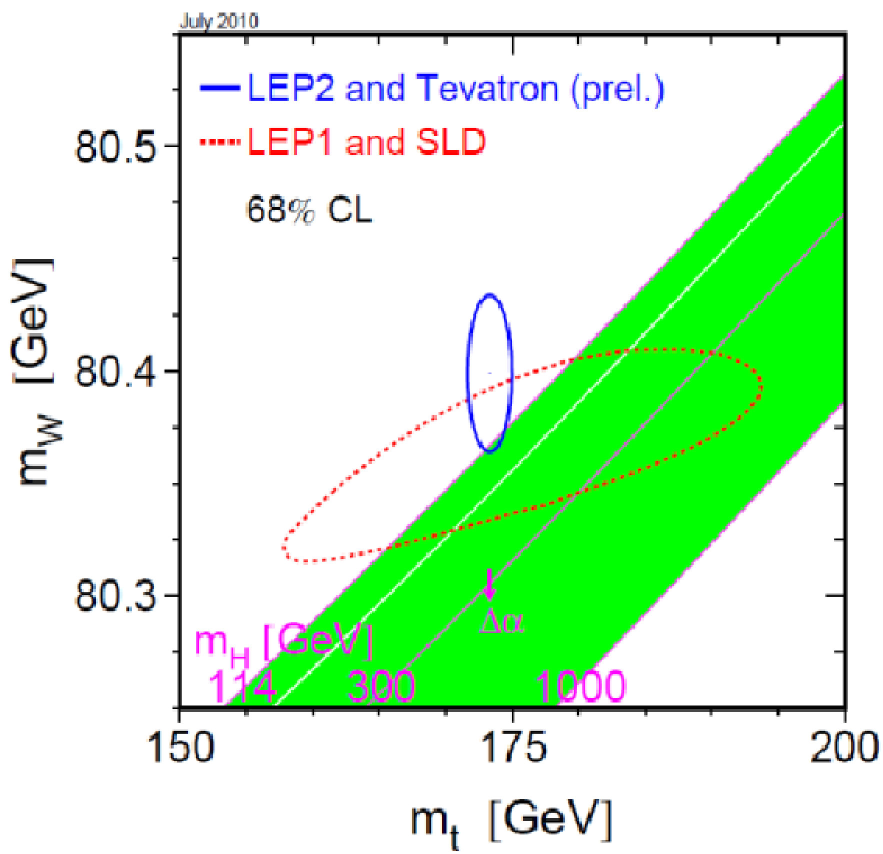
Towards High Precision with ATLAS

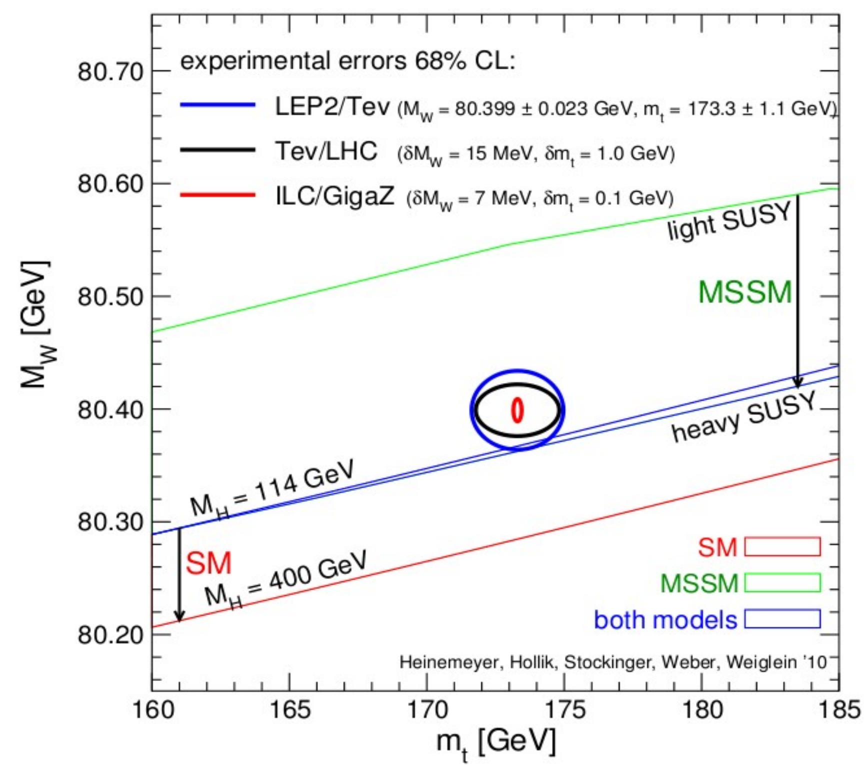
Maarten Boonekamp, IRFU

- Focus on Electroweak parameters from Leptonic final states
  - M_W
  - Probing higher scale interactions with Drell-Yan events
- Experimental and theoretical challenges in the LHC context
- Requirements for a sound measurement

Why measure the W?

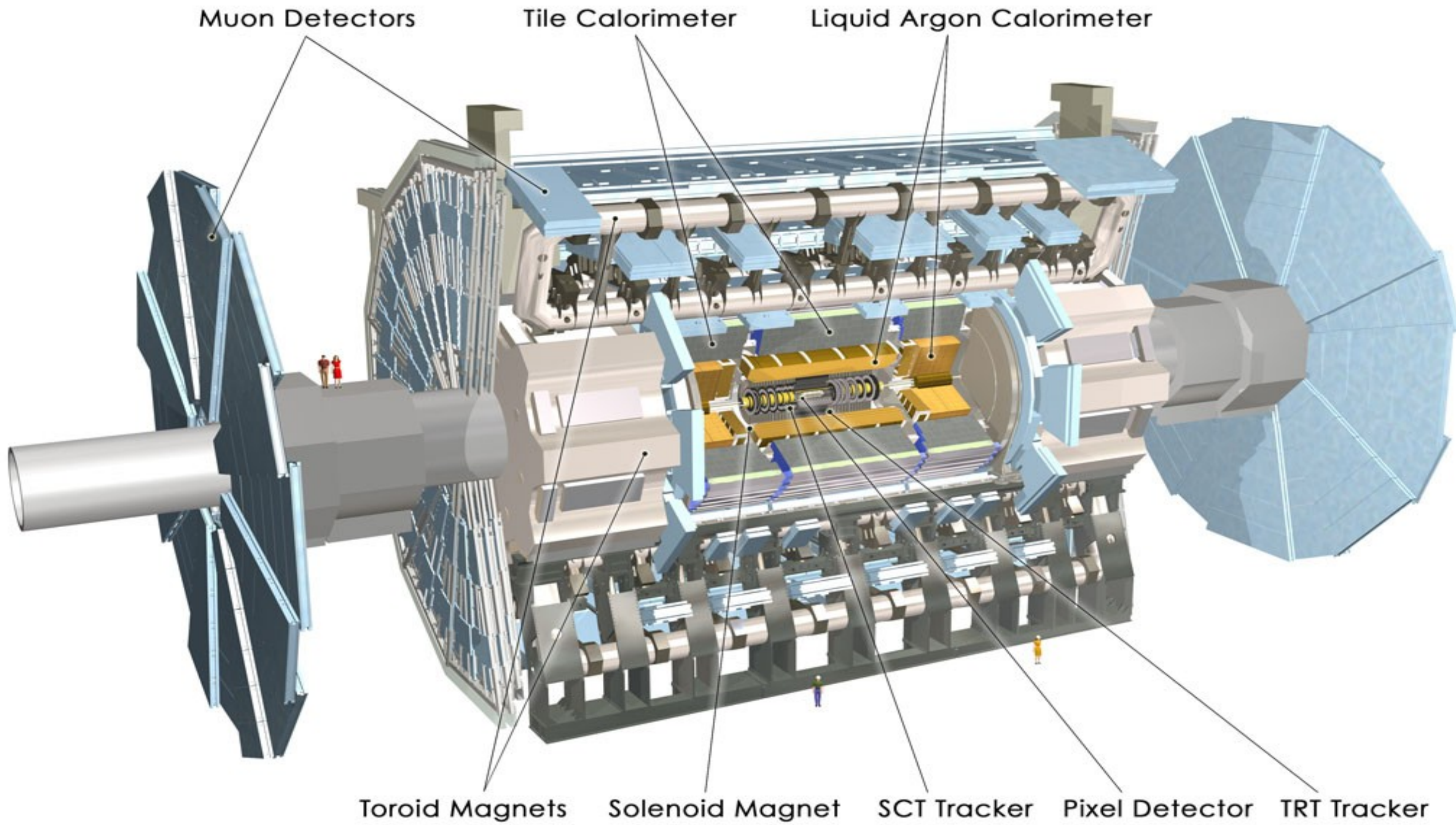
- Within the Standard Model framework, and with current knowledge, the W boson and top quark masses are the main handles to further constrain the Electroweak Symmetry breaking sector.





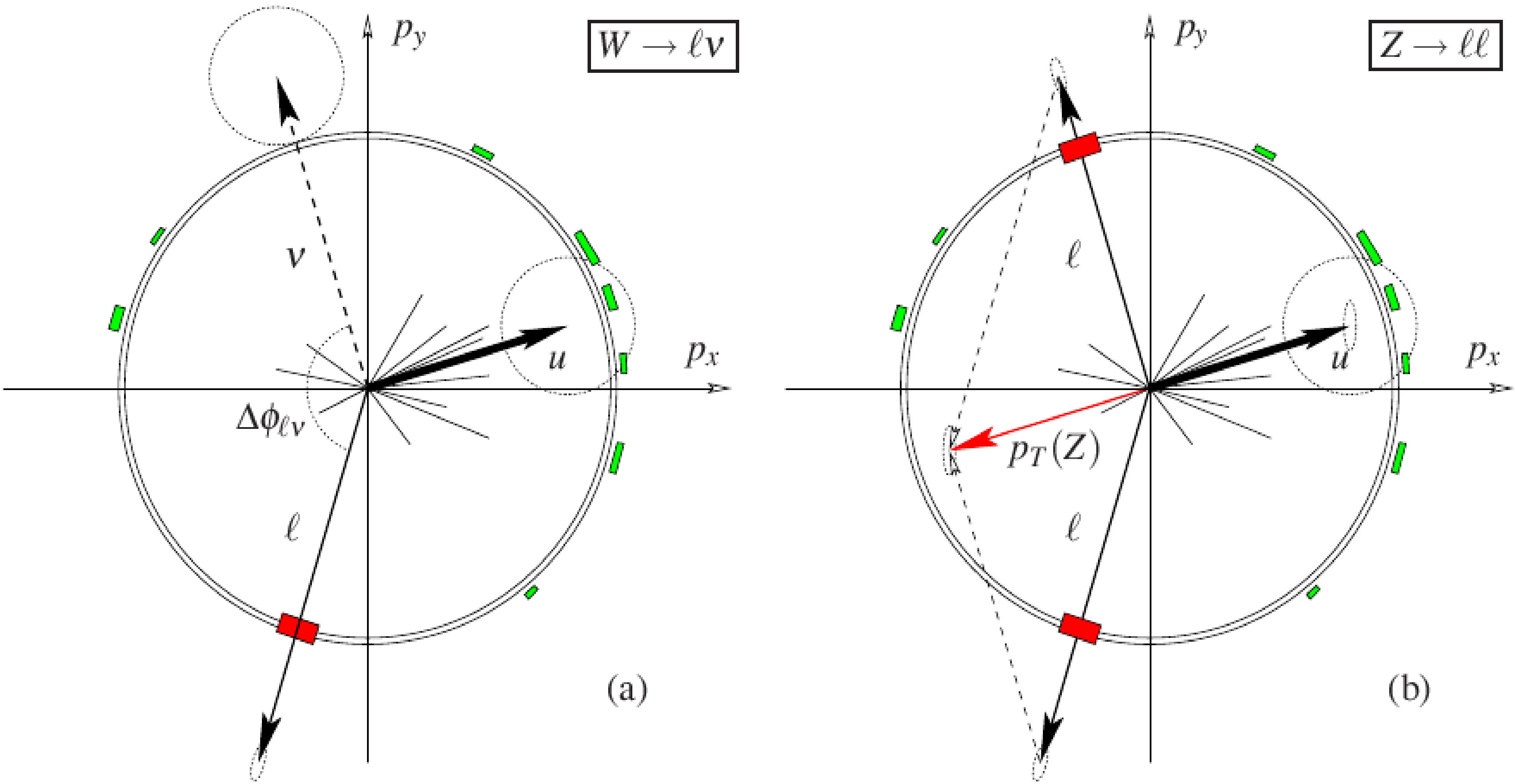
- Given expected LHC statistics and hard lower bounds, our objectives should be δM_W~5 MeV and δm_t~0.5 GeV.

Measuring W and Z with ATLAS



- Electron and muon reconstruction within $|\eta|<\sim 2.5$, and $p_T>\sim 5$ GeV. Resolution ~2% in the W,Z range, combining relevant subdetectors
- Calorimeter coverage up to $|\eta|\sim 4.9$ allows to measure the soft calorimetric activity, hence MET, with a resolution of 5-10 GeV.

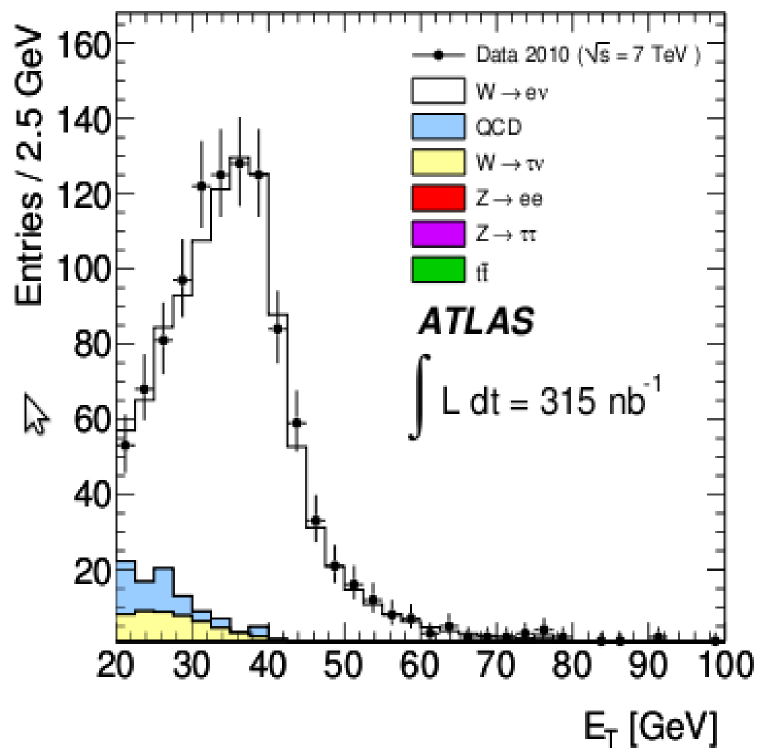
Measuring W and Z with ATLAS

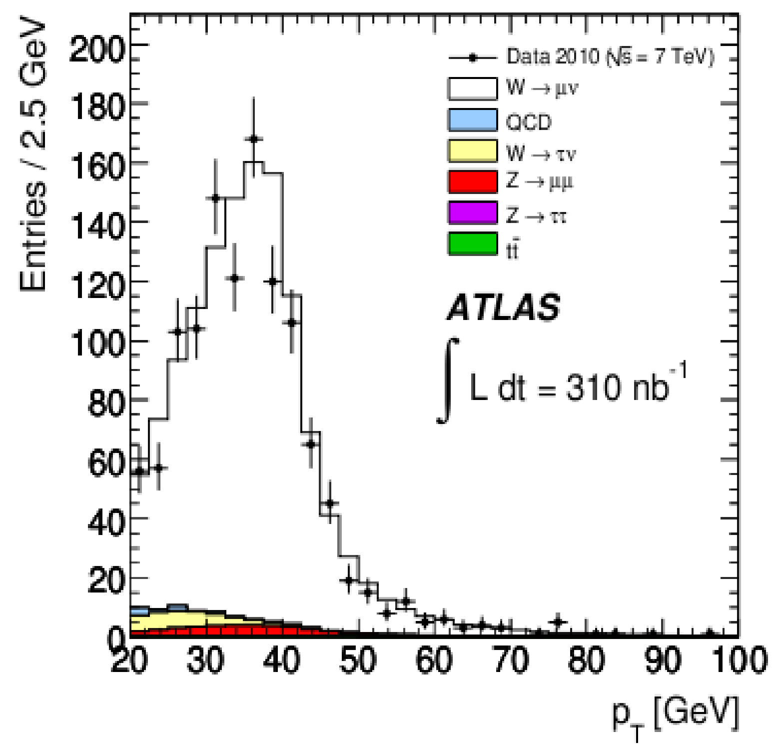


W & Z production at the LHC : first shot

(ATLAS Coll., arXiv:1010.2130, acc.by JHEP)

- Integrated luminosity ~ 0.3 pb^{-1}
- First aim : observation of the signals





W & Z production at the LHC : first shot

(ATLAS Coll., arXiv:1010.2130, acc.by JHEP)

- Second aim : early cross section measurements
  - Fiducial cross sections : W & Z rates within our detector volume, corrected for efficiencies and resolutions

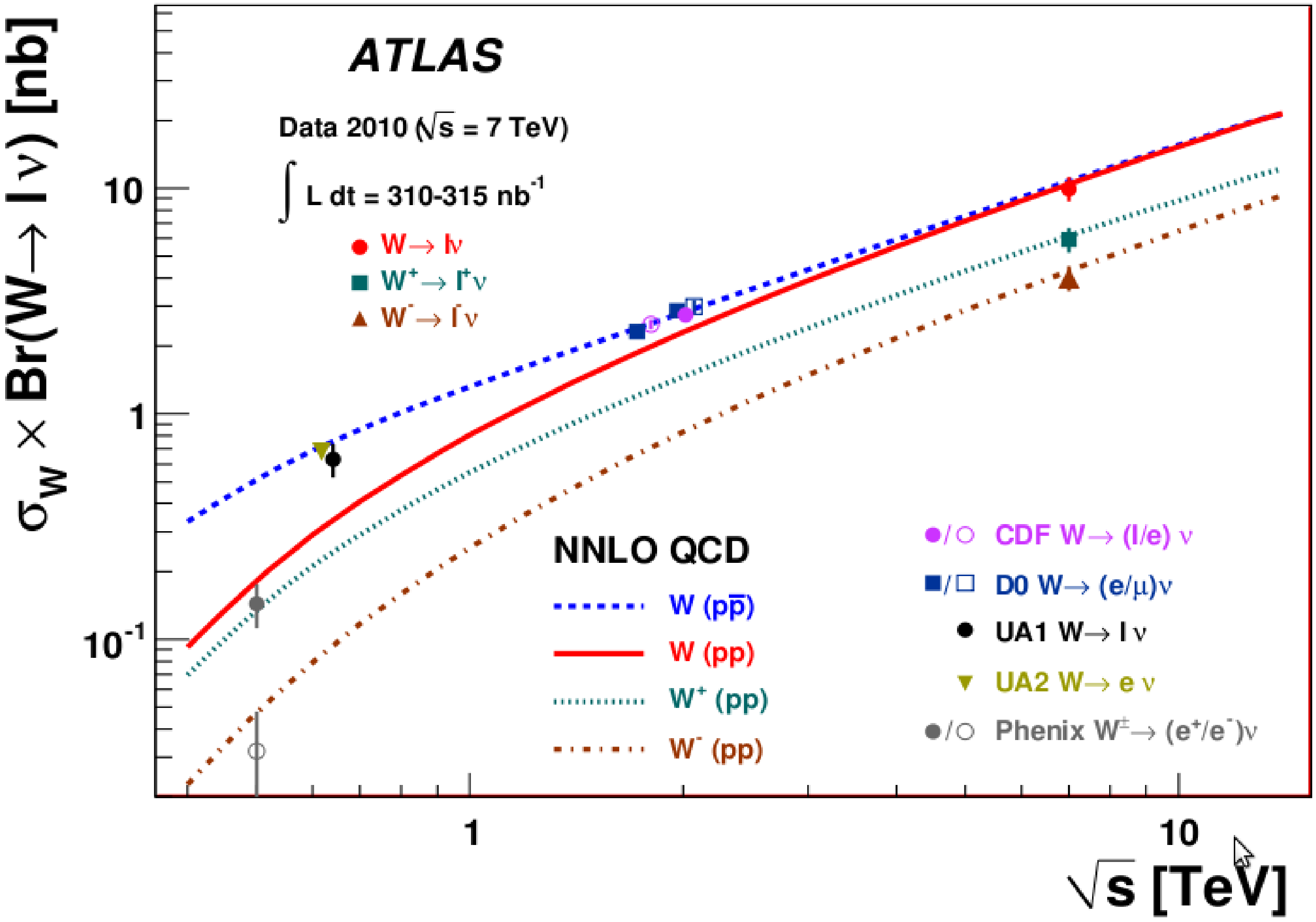
	$\sigma^{\text{fid}}_{W(\pm)} \cdot \text{BR}(W \to e\nu)$ [nb]	$\sigma^{\text{fid}}_{W(\pm)} \cdot \text{BR}(W \to \mu\nu)$ [nb]
W^+	$2.92 \pm 0.12(\text{stat}) \pm 0.21(\text{syst}) \pm 0.32(\text{lumi})$	$2.77 \pm 0.11(\text{stat}) \pm 0.12(\text{syst}) \pm 0.30(\text{lumi})$
W^-	$1.93 \pm 0.10(\text{stat}) \pm 0.14(\text{syst}) \pm 0.21(\text{lumi})$	$1.83 \pm 0.09(\text{stat}) \pm 0.08(\text{syst}) \pm 0.20(\text{lumi})$
W	$4.85 \pm 0.16(\text{stat}) \pm 0.34(\text{syst}) \pm 0.53(\text{lumi})$	$4.60 \pm 0.15(\text{stat}) \pm 0.20(\text{syst}) \pm 0.51(\text{lumi})$

	$\sigma^{\text{fid}}_{Z/\gamma^*} \cdot \text{BR}(Z/\gamma^* \to ee)$ [nb], $66 < m_{ee} < 116$ GeV	$\sigma^{\text{fid}}_{Z/\gamma^*} \cdot \text{BR}(Z/\gamma^* \to \mu\mu)$ [nb], $66 < m_{\mu\mu} < 116$ GeV
Z/γ^*	$0.33 \pm 0.04(\text{stat}) \pm 0.03(\text{syst}) \pm 0.04(\text{lumi})$	$0.43 \pm 0.04(\text{stat}) \pm 0.02(\text{syst}) \pm 0.05(\text{lumi})$

W & Z production at the LHC : first shot

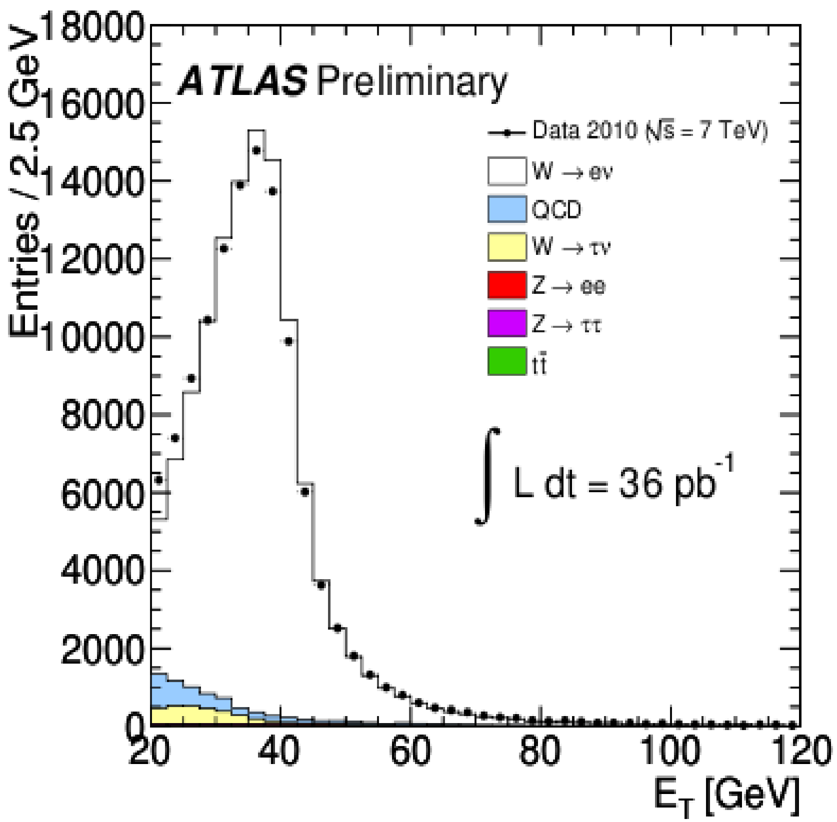
(ATLAS Coll., arXiv:1010.2130, acc.by JHEP)

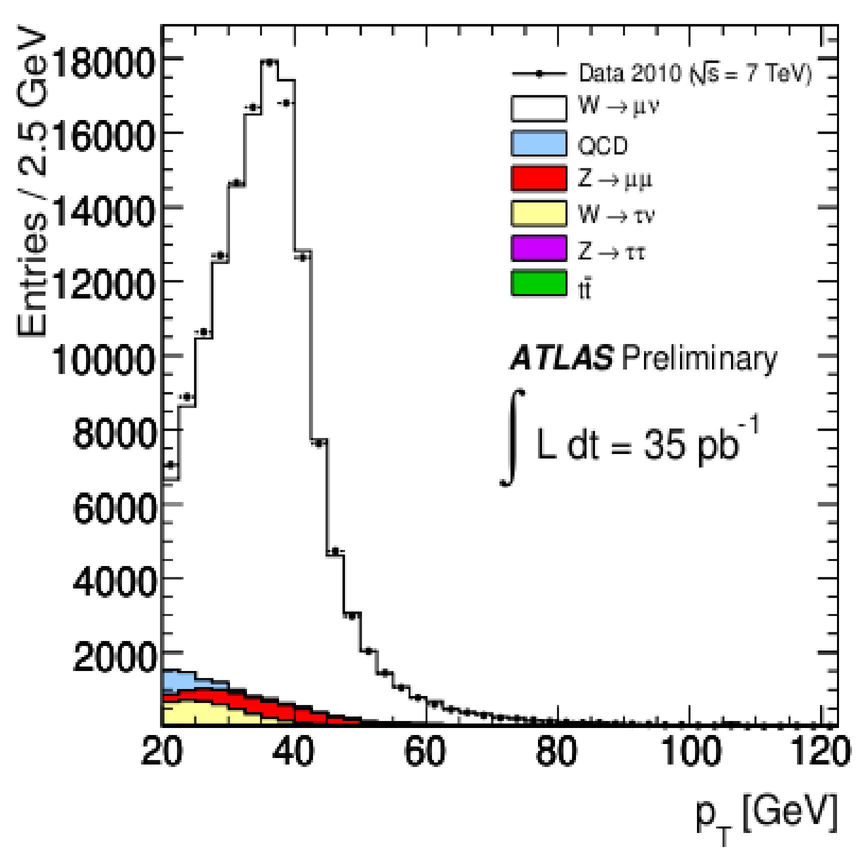
- Comparison to theory



W & Z production : updated distributions

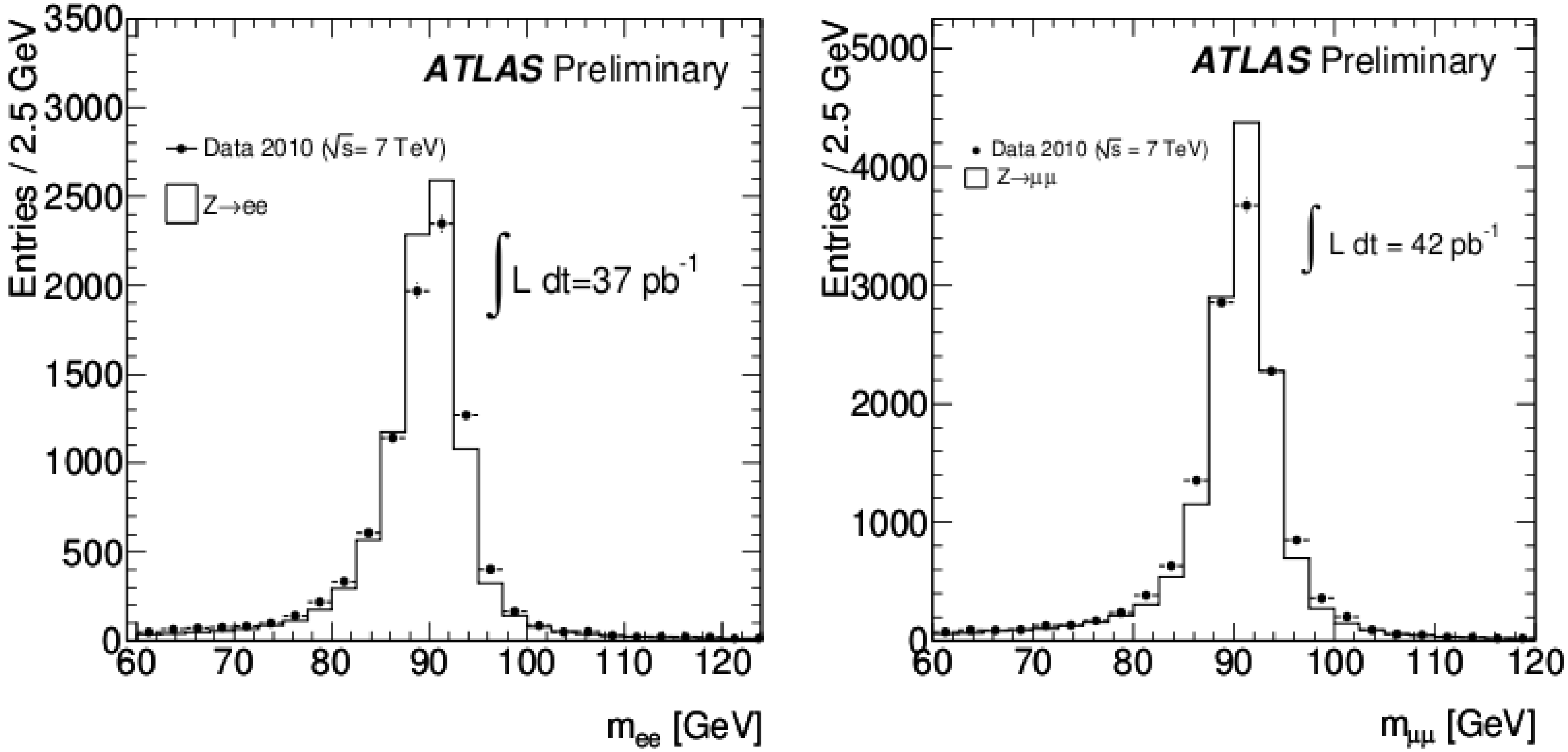
- ~35 pb^{-1}
- $p_T(e,\mu)$ in W events





W & Z production : updated distributions

- ~40 pb^{-1}
- M(ee,μμ) in Z events

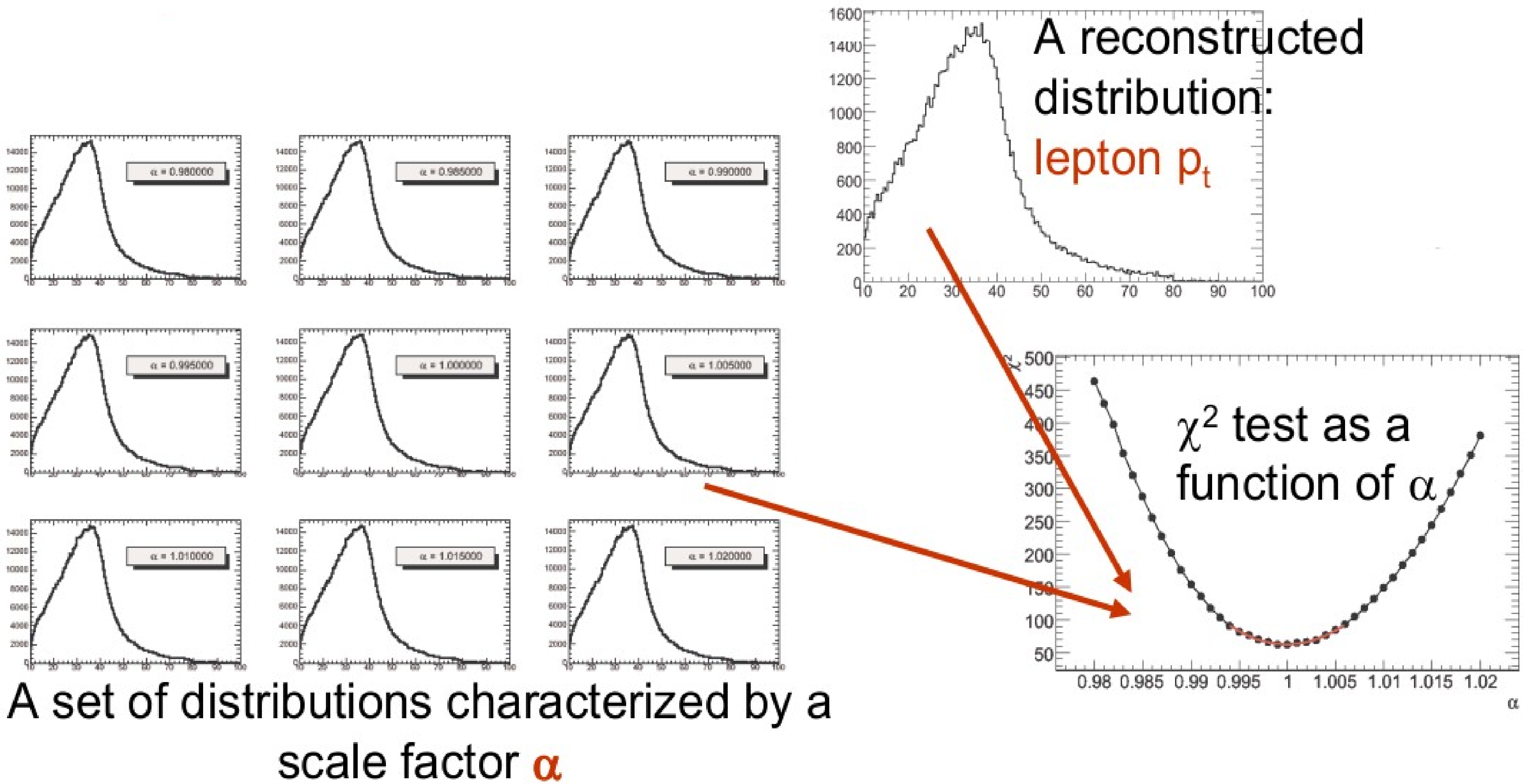


M_W

- About the prospective study
    - Up to 2008, ATLAS was still claiming ~25 MeV reach based on simple estimations
    - By then it was already clear that the Tevatron would do better with much less statistics
    - So we revisited all usual systematics to see whether we could improve – and we could, at least in principle
    - Finally the paper states that “~7 MeV is a reasonable goal”, motivating work in this direction.

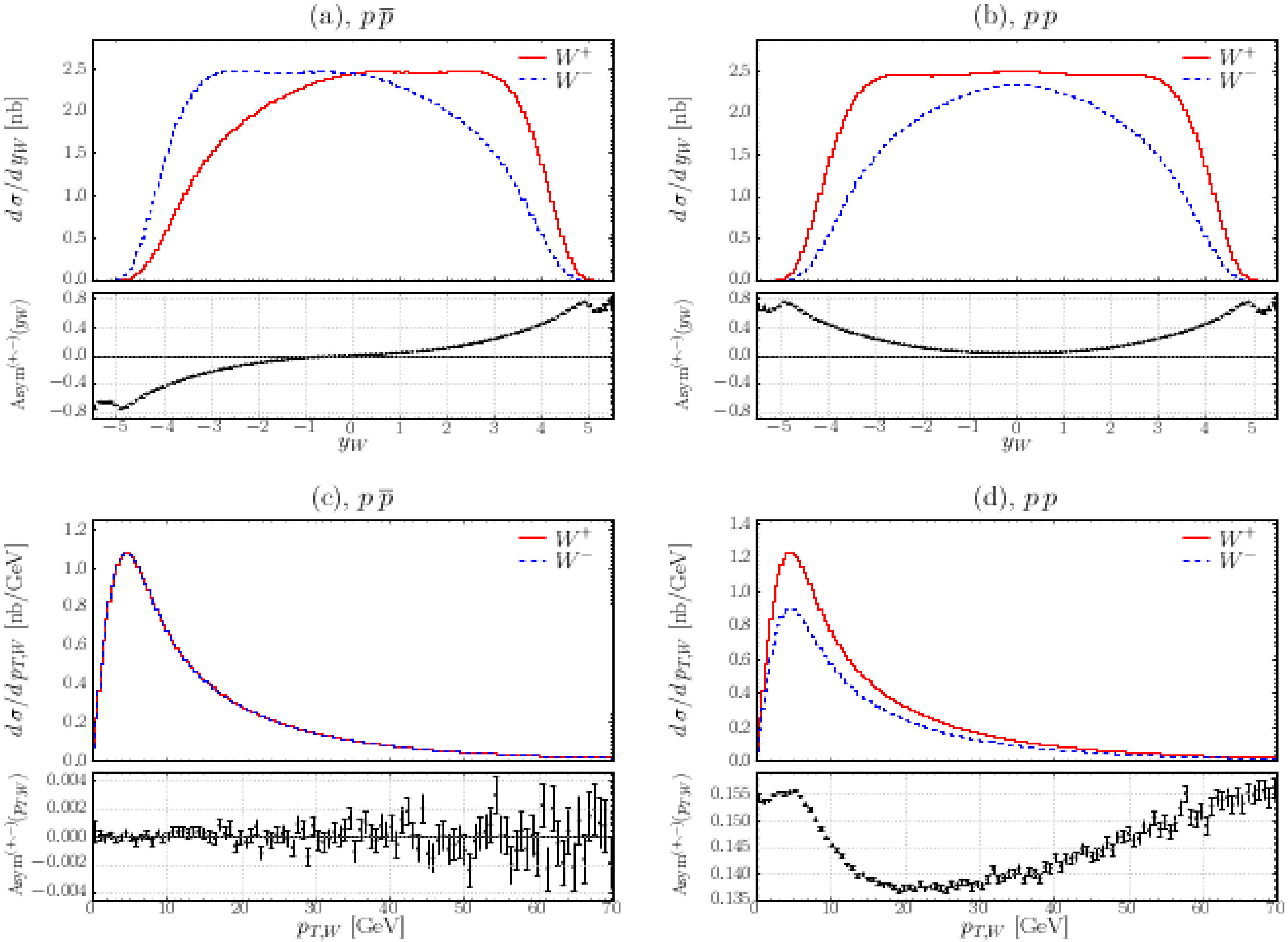
M_W : measurement method

Compare data to models (templates) of the kinematical distributions



W physics : LHC specifics

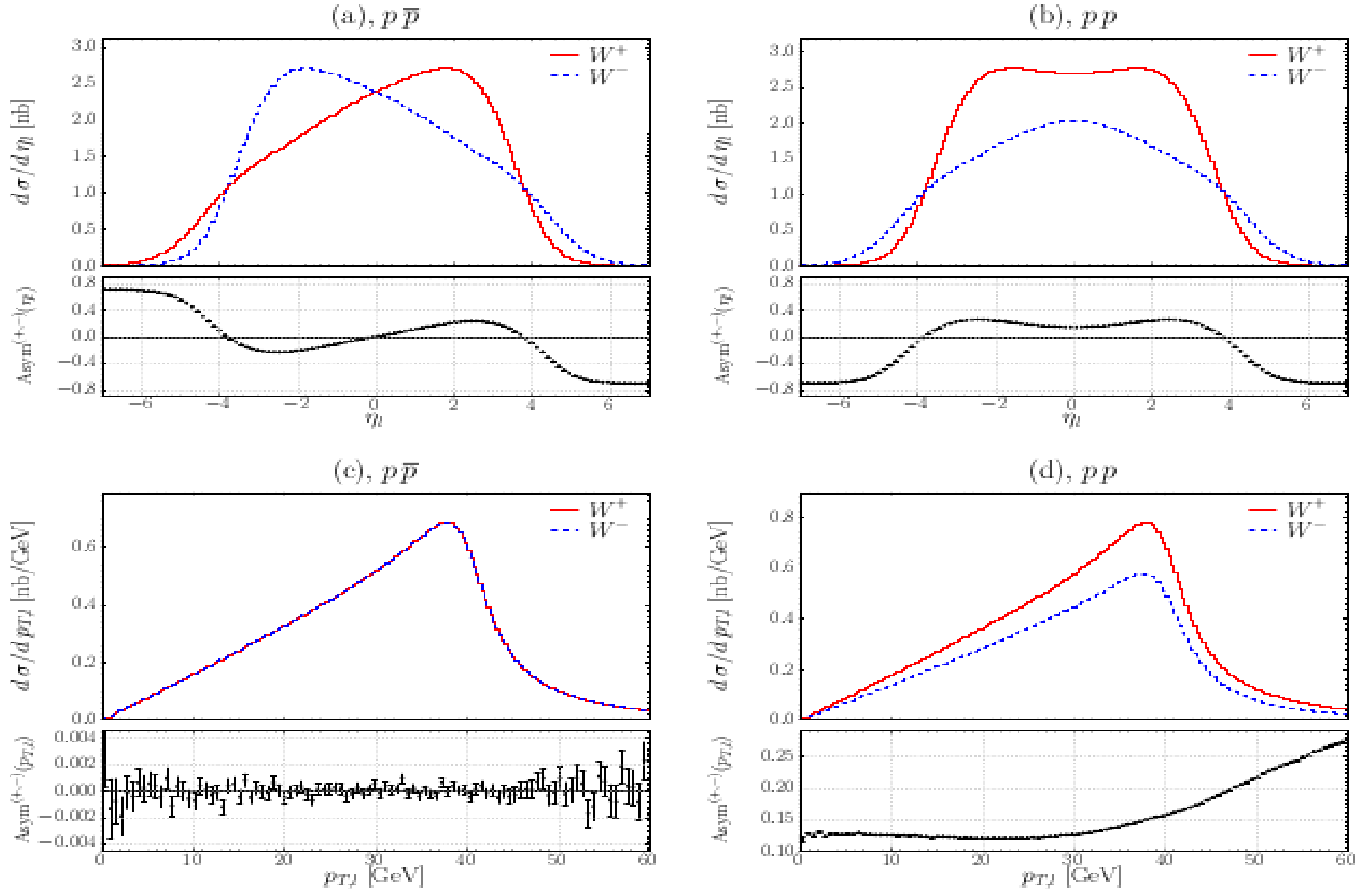
- asymmetries



Krasny et al, Eur.Phys.J.C69:379-397,2010

W physics : LHC specifics

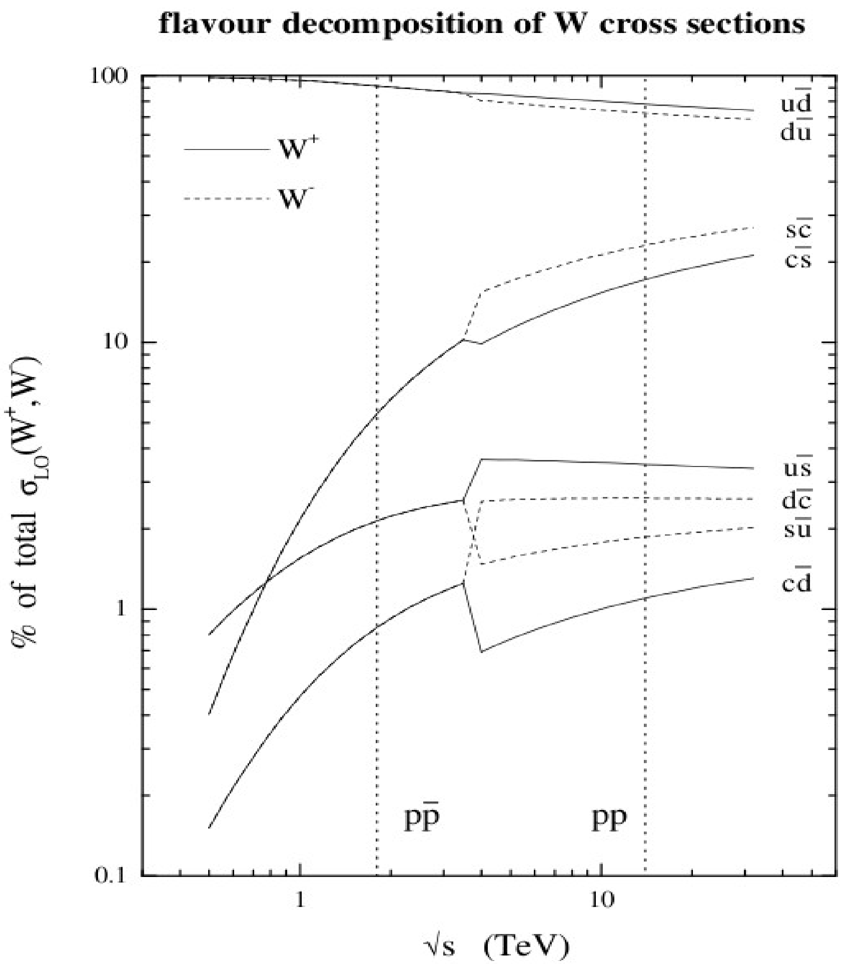
- asymmetries



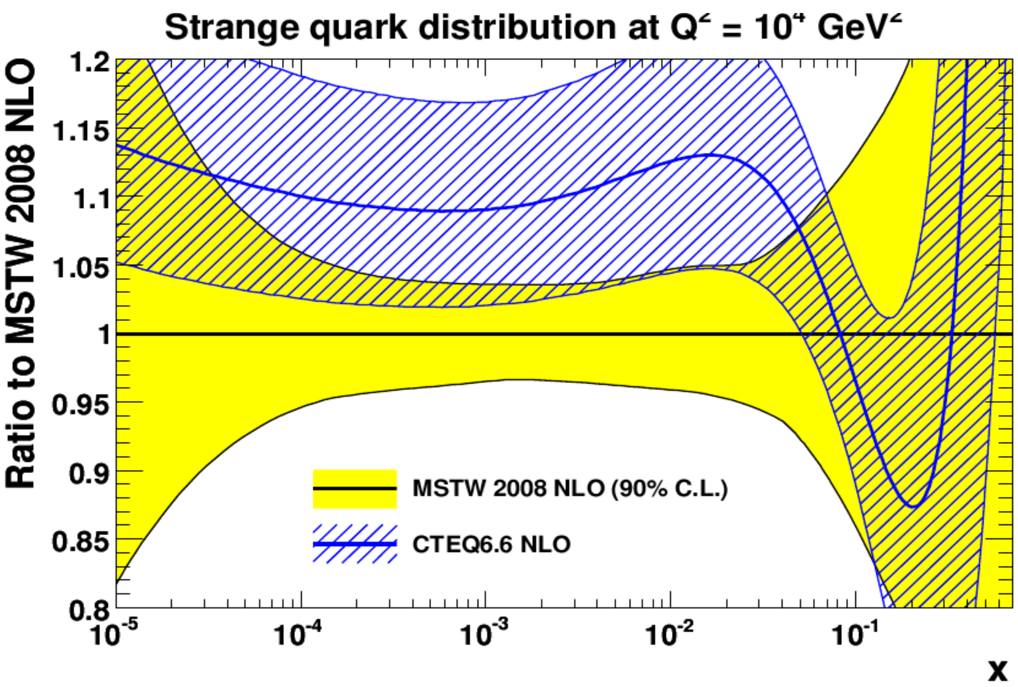
Krasny et al, Eur.Phys.J.C69:379-397,2010

W physics : LHC specifics

- Strange contribution to W production



MRST, arXiv:hep-ph/9907231v1

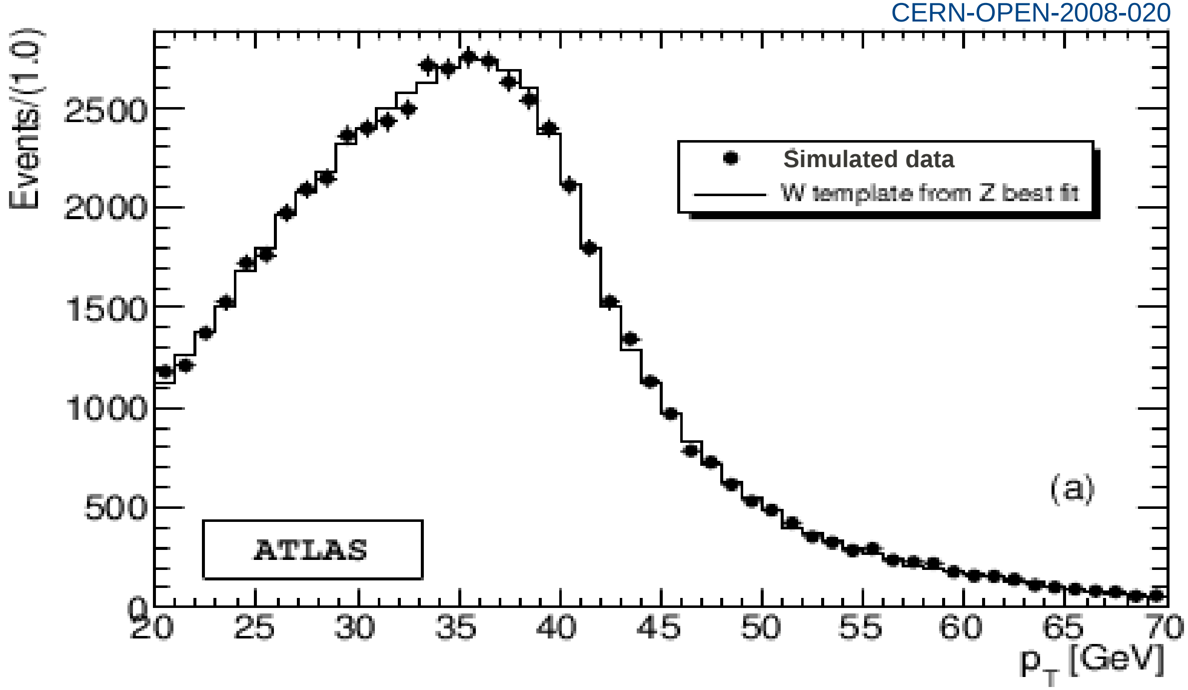


MSTW, arXiv:0901.0002v3

M_W prospects with early data

- Last prospective exercise with simulated data (~15 pb^{-1})
  - Mock-data from full simulation; models from truth + smearing

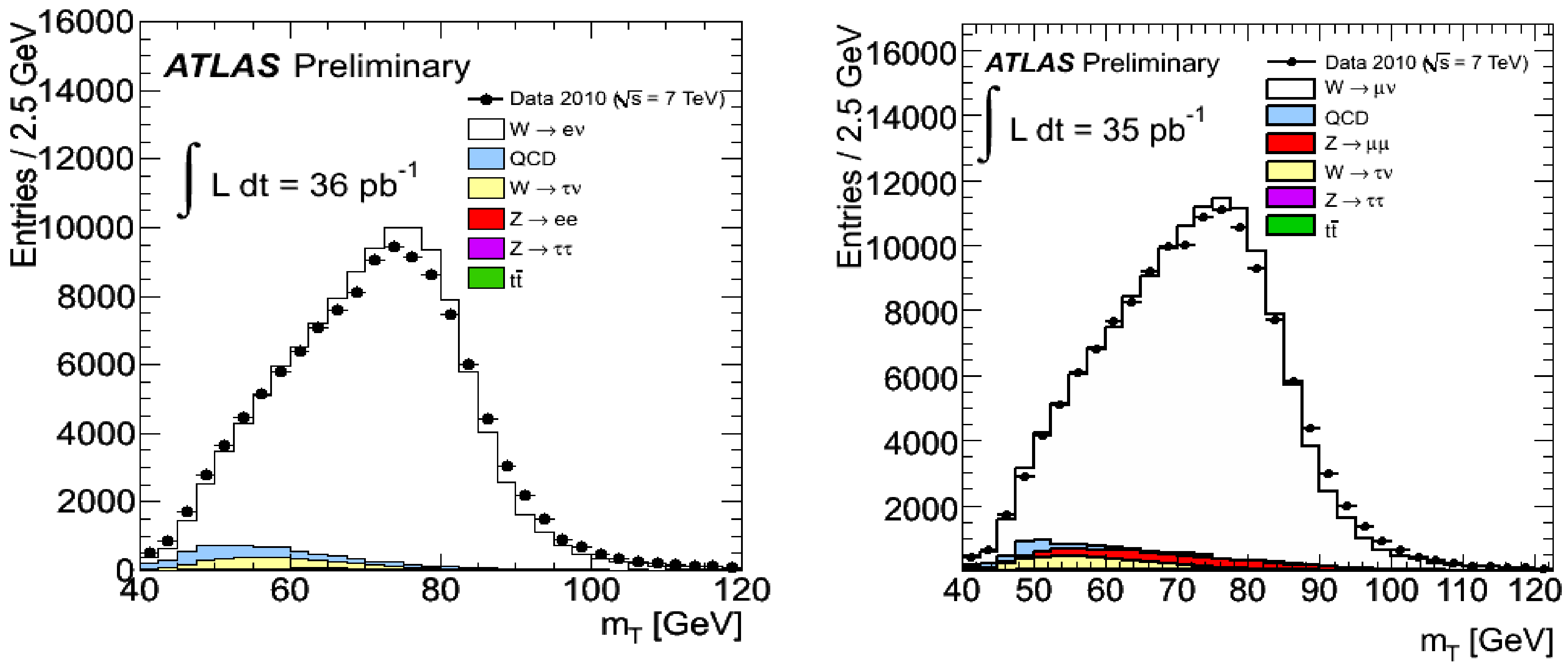
CERN-OPEN-2008-020



- Statistical sensitivity
  - p_T(l) : ~110 MeV / channel
  - M_T(W) : ~60 MeV / channel → **40 MeV overall**

M_W prospects with early data

- Today : ~36 pb^{-1}



- Statistical sensitivity with ~120k events / channel, scaling from the previous study
  - $M_T(W)$: ~40 MeV / channel → **30 MeV overall**
- And, as obvious from these distributions, a lot to understand first

Some projections...
… and starting to address the real questions

- **Statistical sensitivity.**
  - Currently : ~35 pb^{-1} at 7 TeV : ~10^5 events x (e,μ) → **δM_W(stat) ~ 30 MeV**
  - Guess for 2011/12 : ~5 fb^{-1} at 7 TeV : ~1.5 10^7 events x (e,μ) → **δM_W(stat) ~ 3 MeV**
  - Ultimately : ~10 fb^{-1} at 14 TeV : ~6 10^7 events x (e,μ) → **δM_W(stat) ~ 1 MeV**

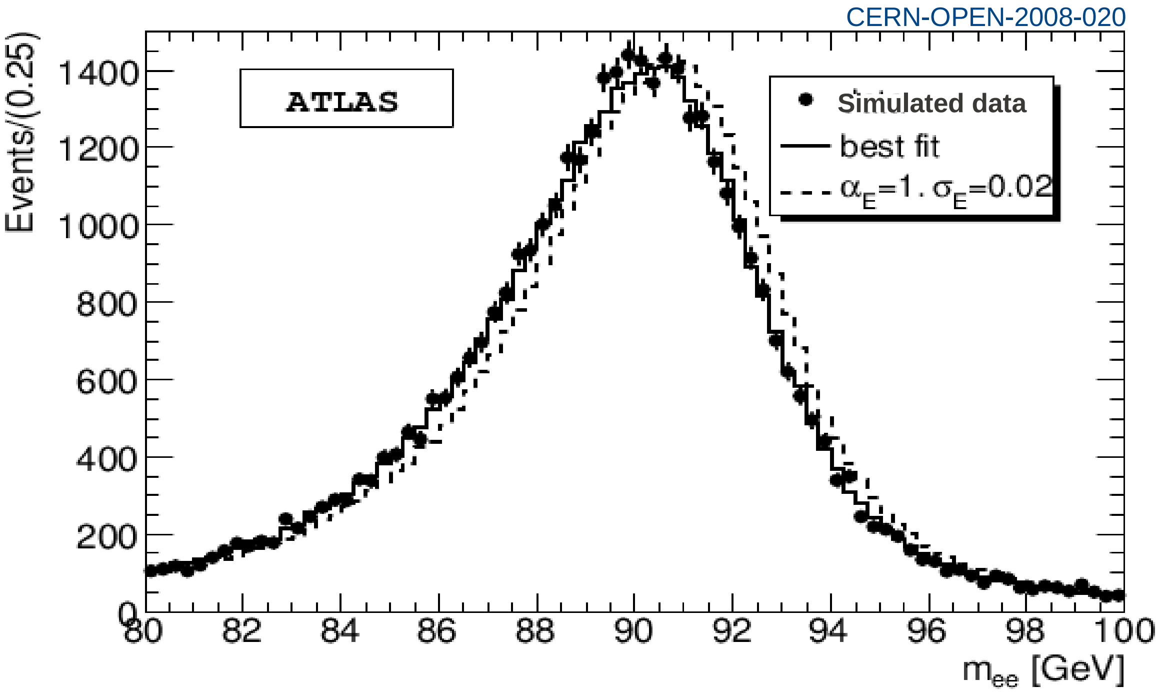
- **Analysis strategy.** For template production, need to manipulate samples of ***O*(10⁹)** simulated events routinely. NB : using full grid power, can produce ~10^6 fully simulated events/day
  - Rely on state-of-the-art QCD+EW exclusive final state generators, for description of signal and calibration samples
  - Adaptive simulation : switch between parton level / fast simulation / full simulation dynamically, system by system
  - Carefully select stored information / event
  - Produce sets of templates from all samples, and varying physics and detector uncertainties one by one
  - Repeat fits with all template sets and derive final uncertainty

Some projections...
… and starting to address the real questions

- **Analysis strategy (continued).**
  - produce MC models of the W signal, of the “candles” - J/Psi, ..., Z, and of any relevant basic detector-level distribution
  - Exploit “candles” to determine the size of effective corrections (energy scales, resolutions, efficiencies, …)
  - If significant data/MC differences, correct templates for these
  - Fit W boson mass, store result
  - Feed-back the data/MC differences to the upstream simulation and go back to point 1
  - Monitor the stability of M_W along these iterations. Converge when
    - All effective corrections are 1 (most ambitious)
    - M_W is stable after effective corrections (fall-back, in case of too slow simulation)

Selected systematics : energy/momentum scale and resolution

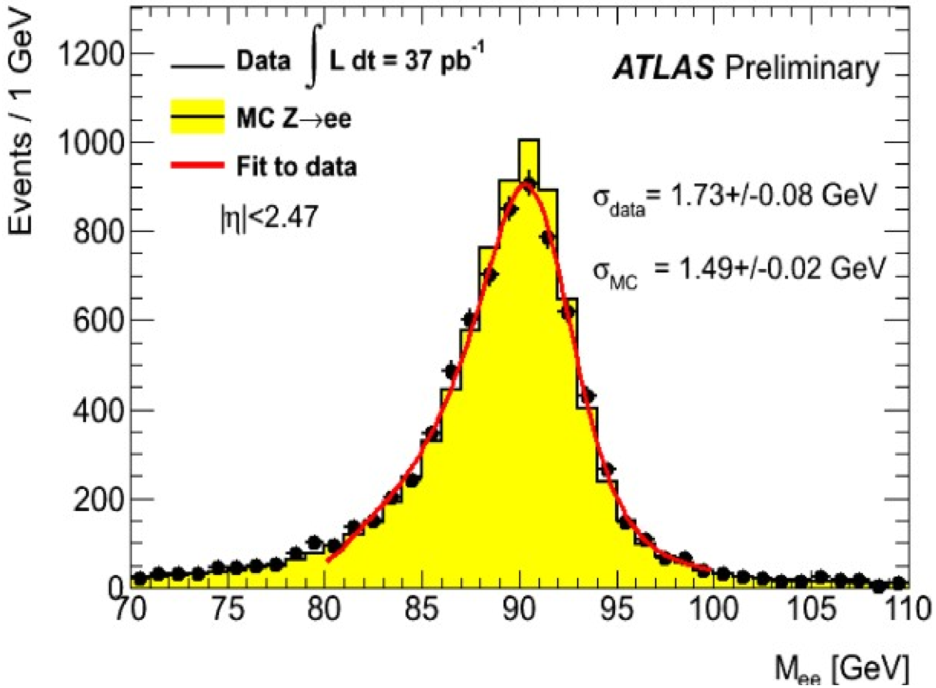
- Prospective study : ~200 pb-1 : lepton response from Z resonance tuning
  - Mock-data from full simulation; models from truth + smearing

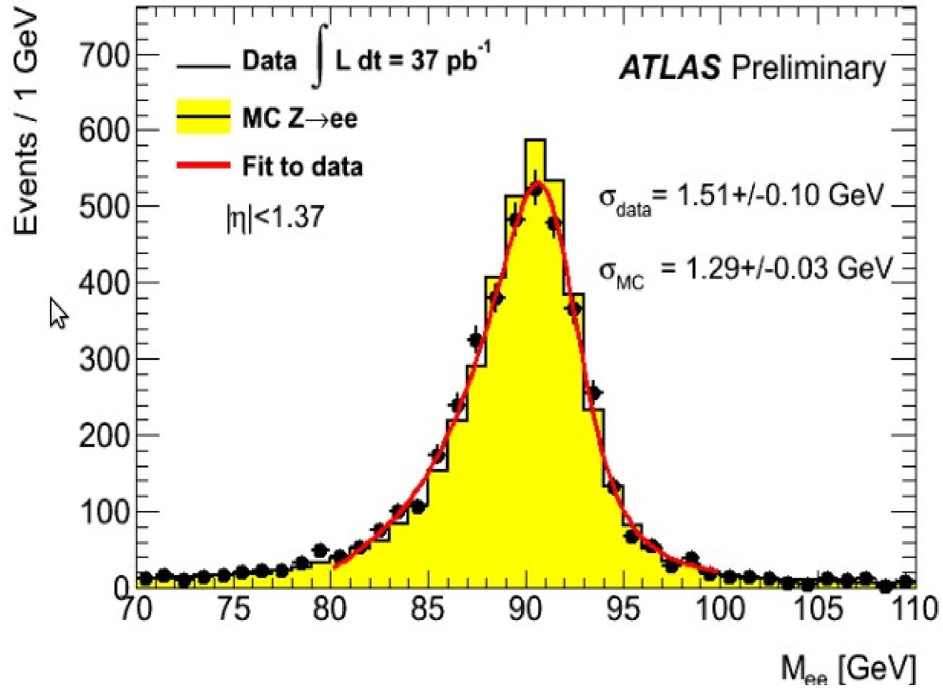


- Sensitivity to parameters averaged over the Z sample:
  - Energy scale : **~3 10^{-4}**
  - Resolution : **~1% relative**
- Need to differentiate in order to apply such calibrations to different samples

Selected systematics : energy/momentum scale and resolution

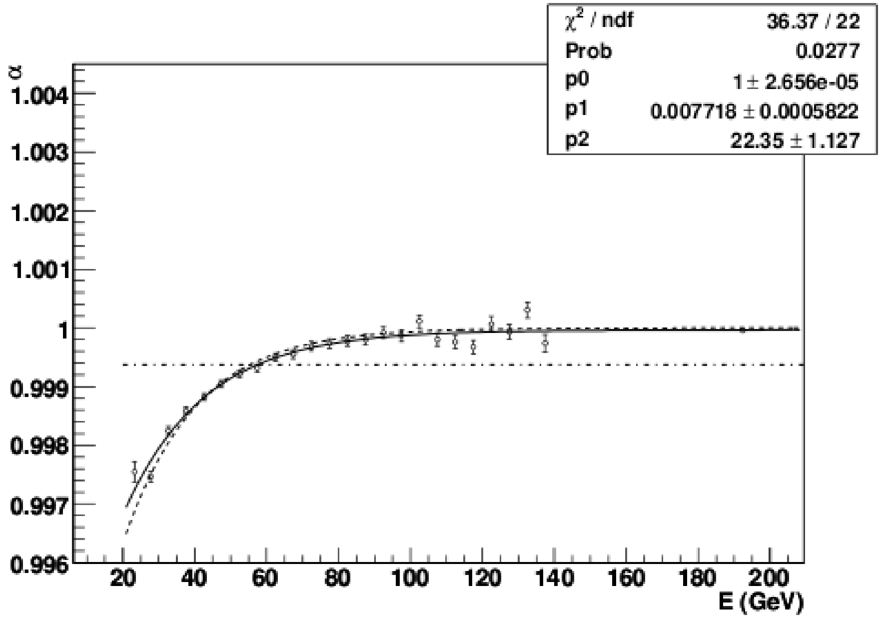
- Today
  - Effective calibration determined for barrel and endcap to ~ 3 10^{-3}
  - Resolution : ~15% mismatch between data and MC, probed to ~25% relative

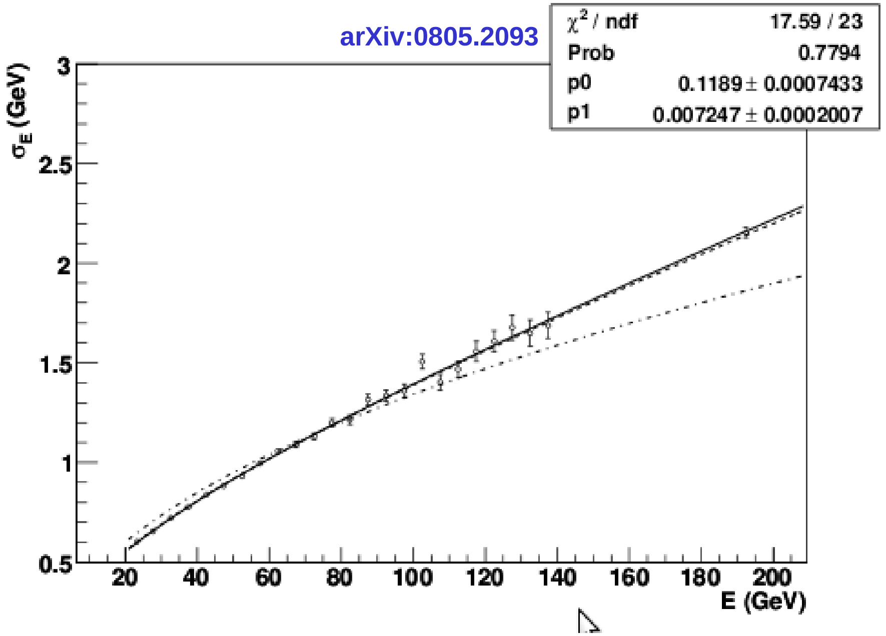




Selected systematics : energy/momentum scale and resolution

- Tomorrow
  - Z prospects with 10 fb^{-1} : determine effective calibration vs. lepton kinematics

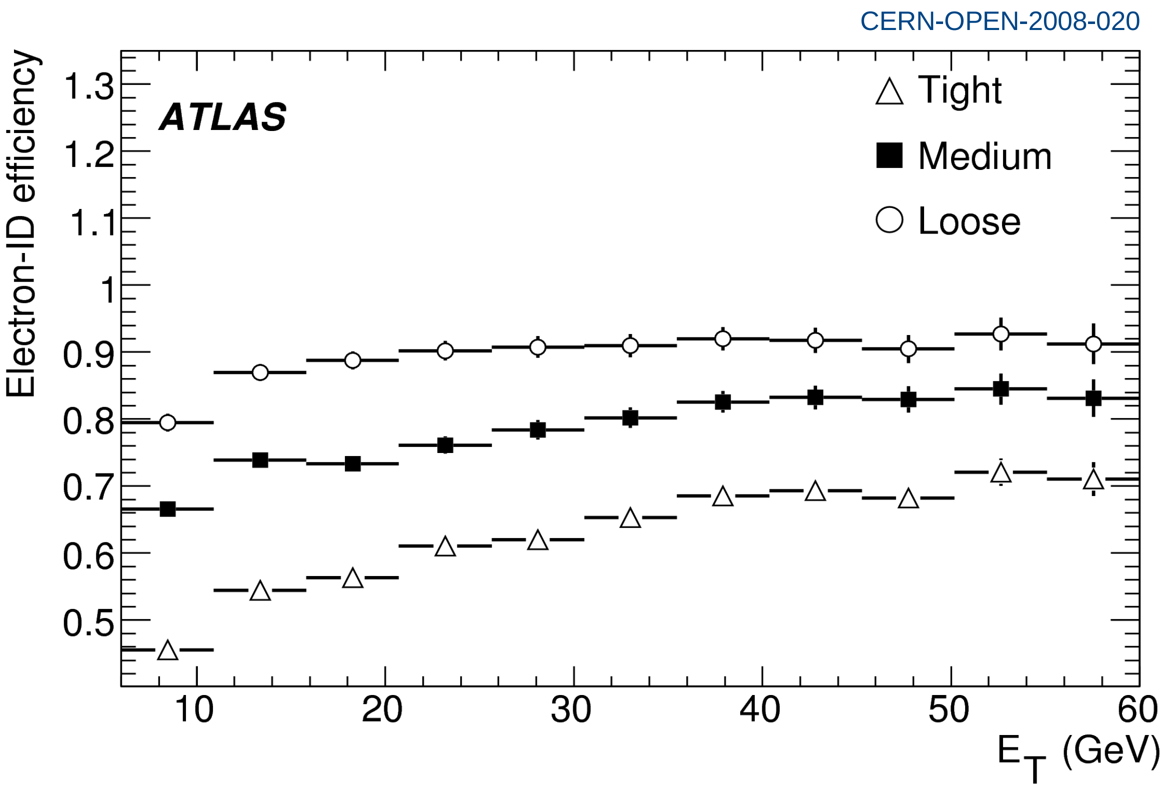




- Issues : charge-dependent scale
  - The different kinematic distributions for W^+ and W^- require separate determinations for positive and negative leptons
  - Handles : signals with charge-symmetric distributions, e.g J/Psi decays and e^+e^- from conversions.

Selected systematics : electron reconstruction efficiency

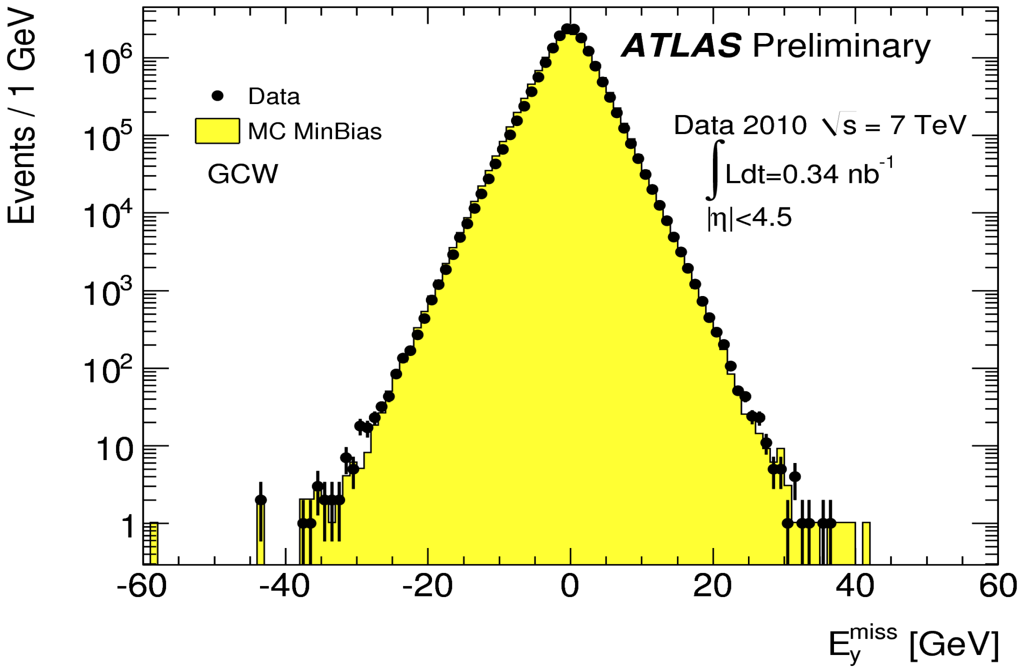
- The electron reconstruction efficiency is a strong function of pT (and right in the jacobian region):

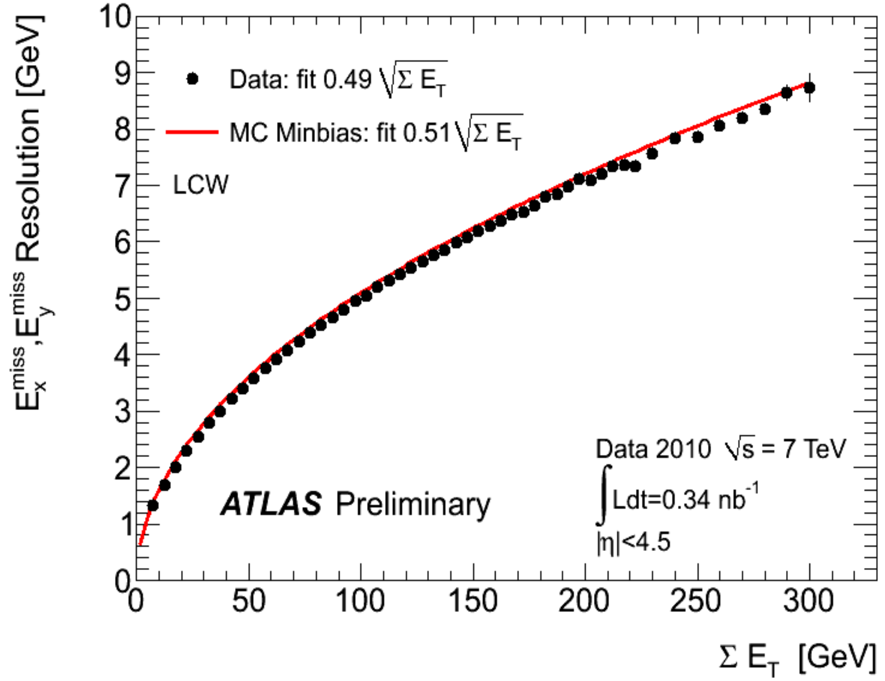


- From prospective studies, entirely neglecting this dependence in the templates leads to a bias of δM_W = +360 MeV – in other words, a bias of +4 MeV / %

Selected systematics :
recoil calibration

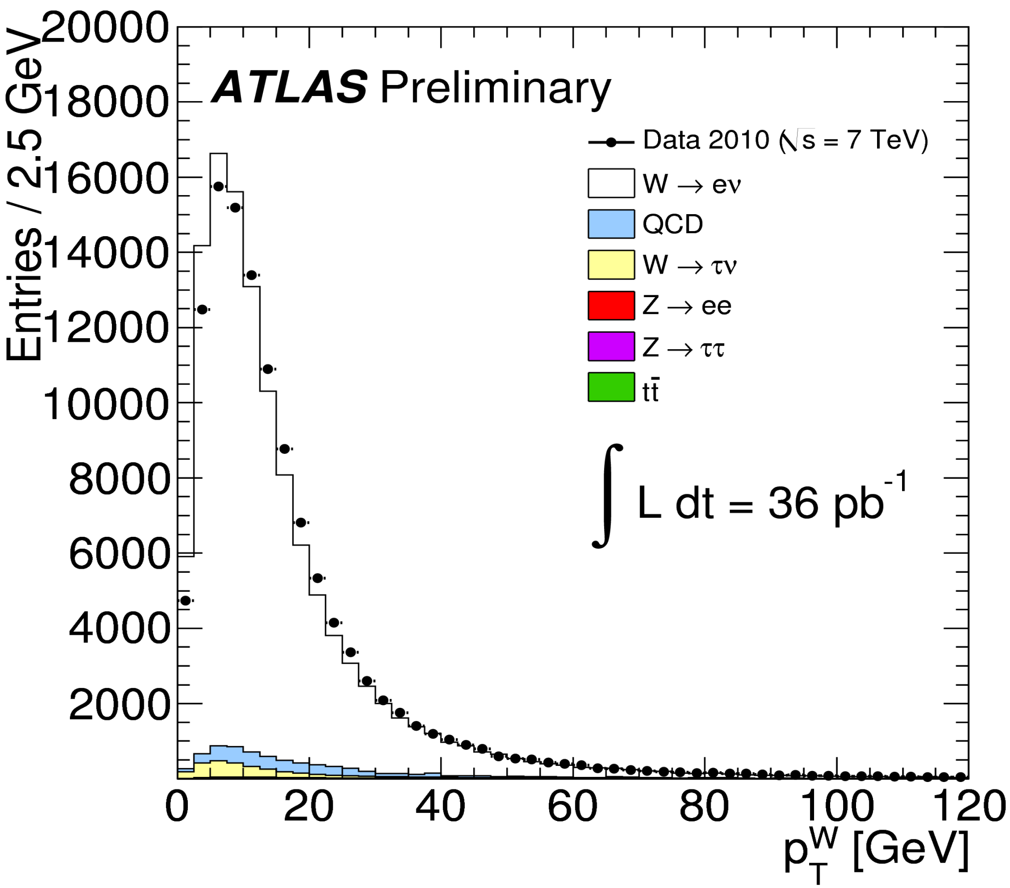
- The hadronic recoil enters the analysis through
  - $\vec{p}_T(\nu) = -[\vec{p}_T(l) + \vec{R}]$
  - $M_T(W) = [2\, p_T(e)\, p_T(\nu)(1 - \cos\Delta\phi)]^{1/2}$
- Current performance encouraging; J/Psi- and Z-based calibrations underway

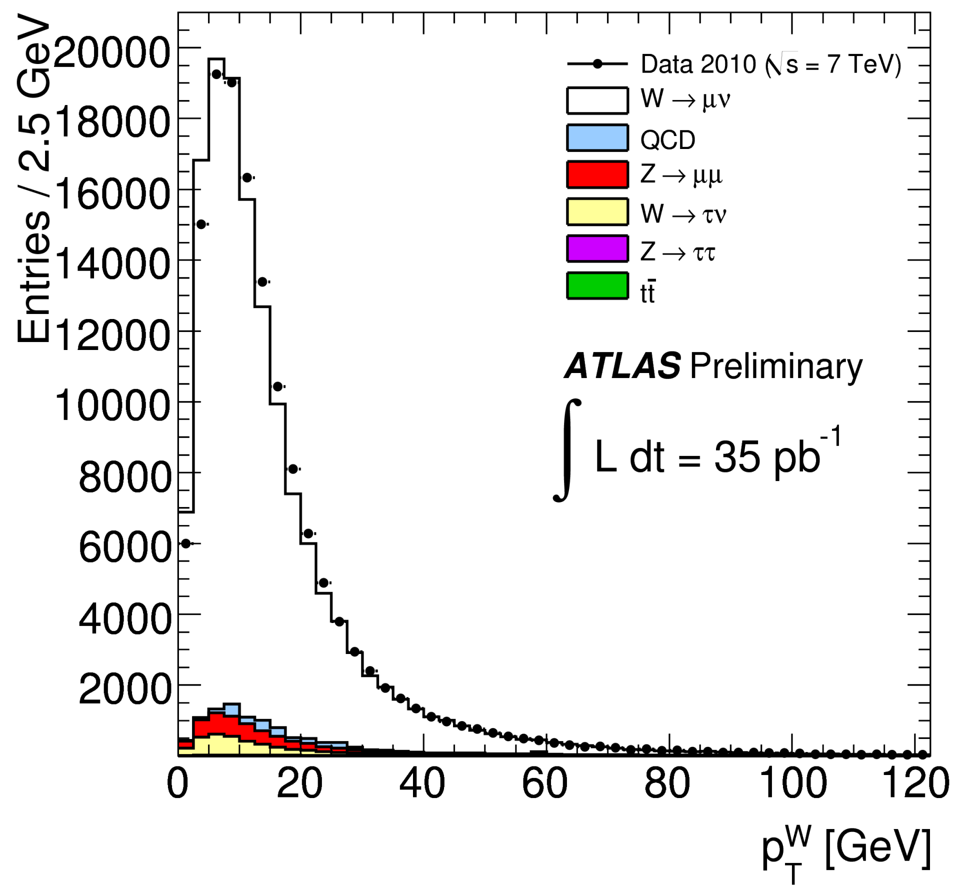




Selected systematics : recoil calibration

- in W events : $p_T(W)$, which is just the hadronic recoil. Uncorrected distributions below:





W dynamics : the p_T distribution

- No public plots yet... below a summary of our strategy

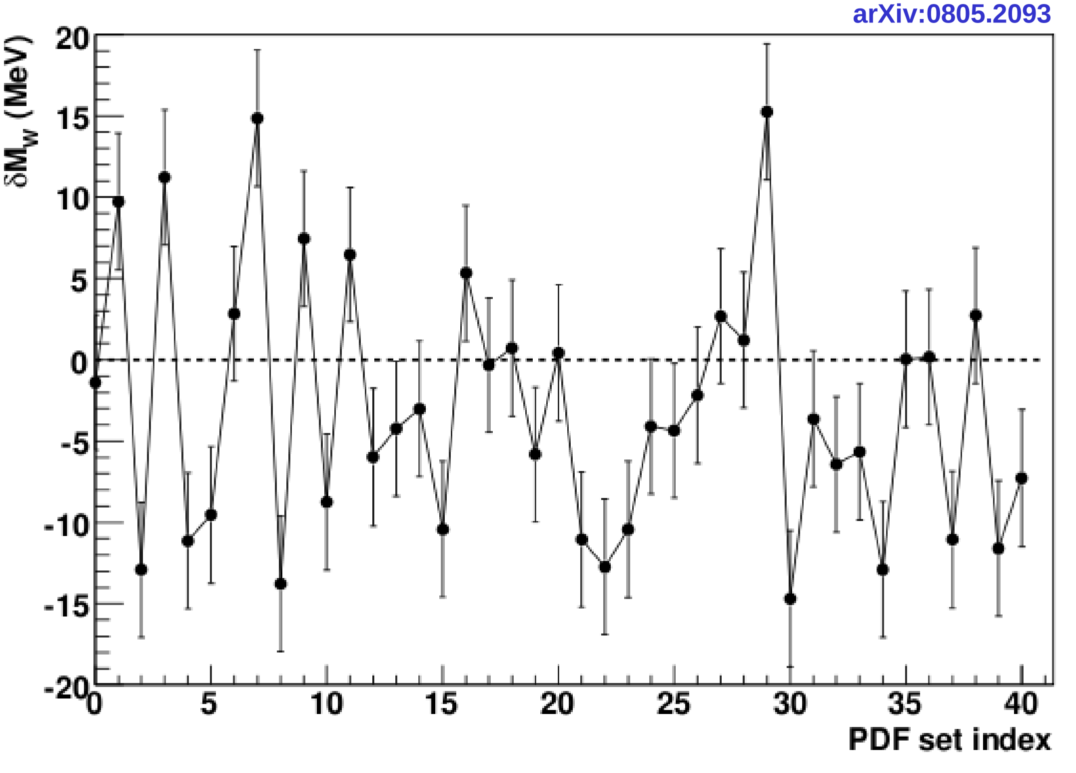
- The hadronic recoil is diagnosed using
  - MinBias events : resolution dependence vs. event activity (SumET)
  - J/Psi and Z events probe, in addition, its bias and resolution vs. lepton pair p_T
  - This information is fed back as
    - Improvement to the UE tuning
    - Effective calibration for the residual effects

- With this calibration in hand, we measure the pT(W) distributions, in W^+ and W^- events separately. Cross check performed on Z events, comparing there the lepton-pair based p_T(Z) measurement to the recoil-based one.

- This information is then used to constrain the models, and integrated in the template production.

W dynamics : the rapidity distribution

- Let us assume, to simplify, that rapidity ↔ PDFs
- PDF uncertainties, estimated using CTEQ61
  - Templates from current “best fit”
  - Pseudo-data from 1-σ excursions in all PDF parameters; collect and sum biases

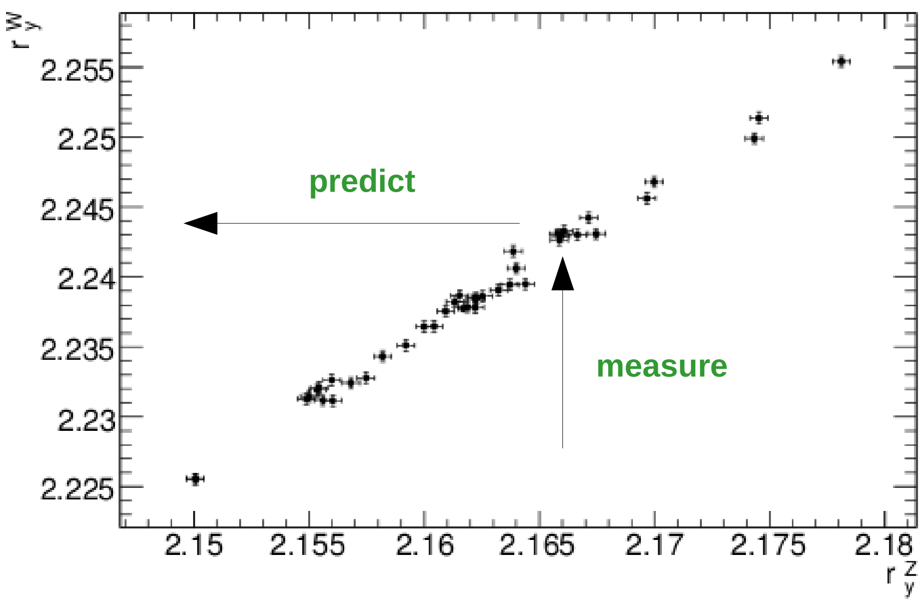


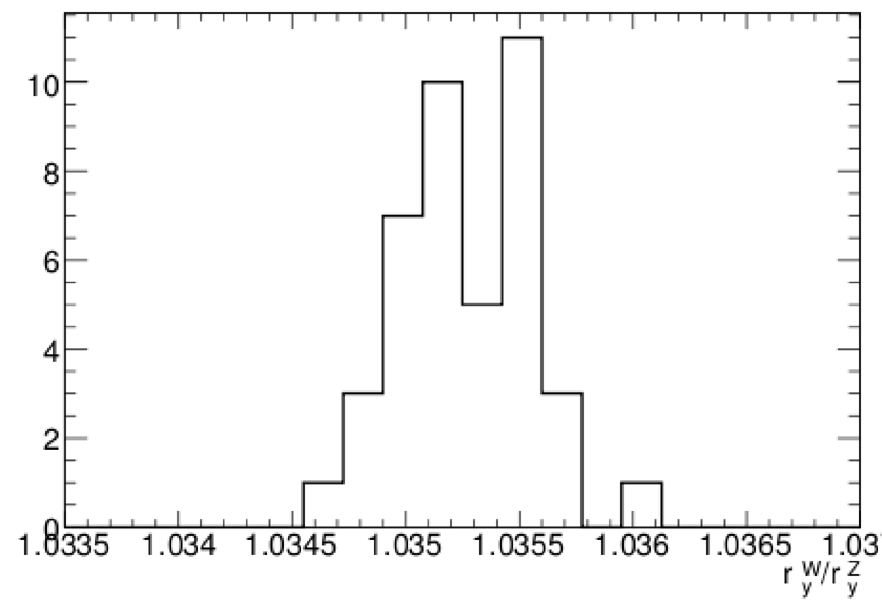
- Induced uncertainty on M_W ~30 MeV

W dynamics : the rapidity distribution

- The W rapidity can not be measured directly (undetected neutrino) but:
  - Correlation between W & Z rapidity distributions under PDF variations:

arXiv:0805.2093





  - In other words we predict the W rapidity distribution as

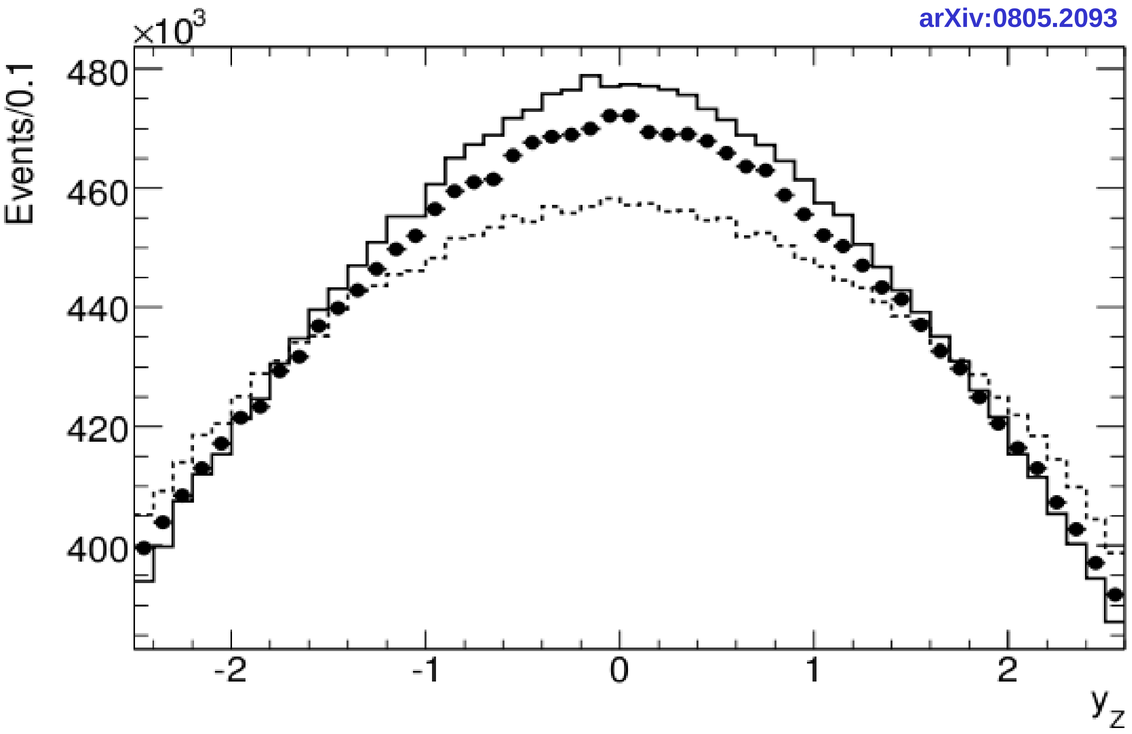
$$d\sigma_W / dy \;\rightarrow\; \frac{d\sigma_W / dy}{d\sigma_Z / dy} \;\times\; d\sigma_Z / dy$$

Raw prediction **Precise prediction** **Measured**

  - Hence measuring the Z to ultimate precision is crucial!

W dynamics : the rapidity distribution

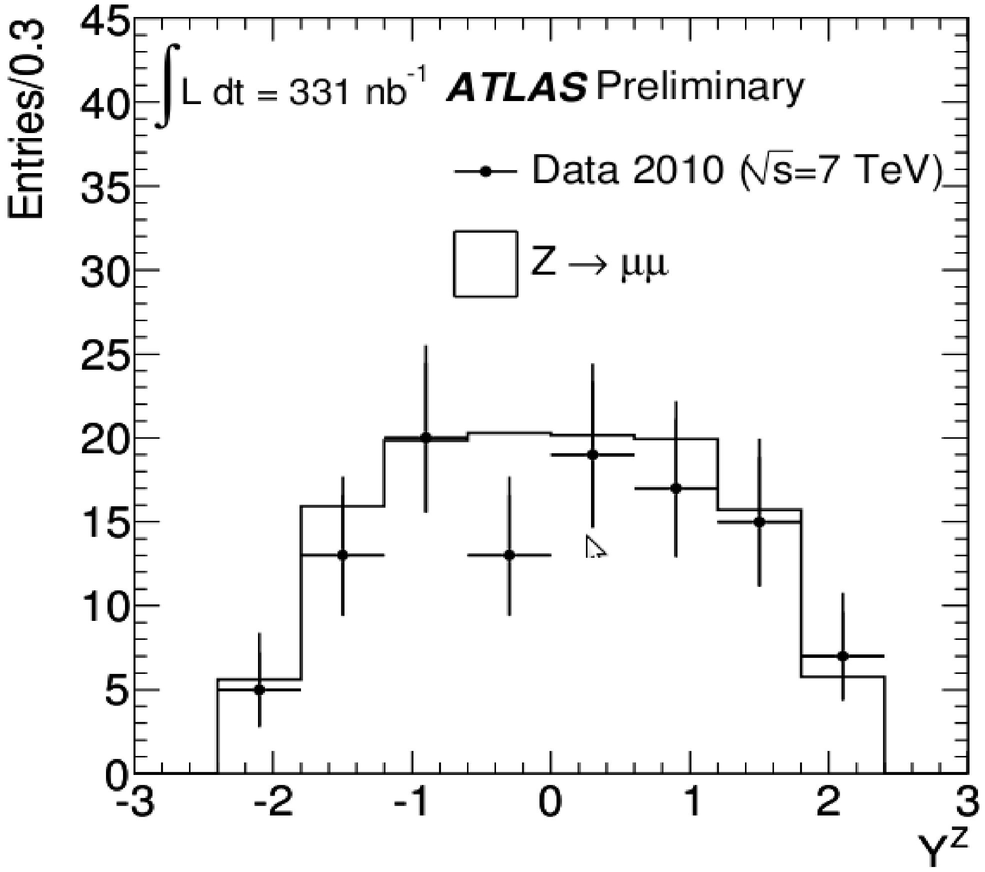
- Z rapidity data with 10 fb^{-1}, compared to the PDF uncertainty on this distribution



- Ultimately δM_W ~ 2 MeV from this source (+ cross-check with other PDF-sensitive measurements) – but see next pages....

W dynamics : the rapidity distribution

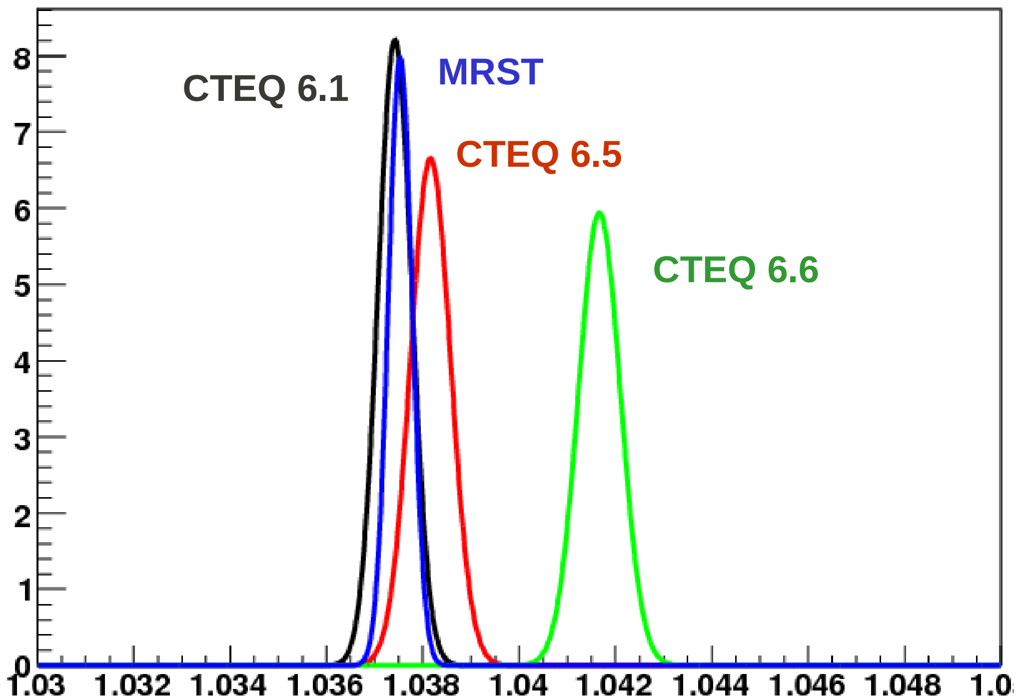
- Not quite there yet!
  - the 0.3 pb^{-1} plot (uncorrected data) - Measurement planned with 40 pb^{-1}



W dynamics : the rapidity distribution

- Let us repeat this exercise with different PDF sets. We find:

arXiv:0902.1678



$R = r_y^W / r_y^Z$

- CTEQ 61 – standard NLO fit

  CTEQ 65 – improved HF treatment

  MRST – NNLO fit

vs. CTEQ 66 – ~free strange PDF

M_W : summary

- Experimental challenges – keeping systematics below ~5 MeV requires
  - energy/momentum scale control to < 10^{-4} (average), ~10^{-3} (locally)
  - resolution to ~1%
  - p_T dependence of lepton efficiency to 1%
- Strategy to control the $p_T(W)$ distribution :
  - Rely on state of the art generators to predict the lepton distributions at given $p_T(W)$
  - Measure the pT(W) distribution from the recoil distribution, calibrating from MinBias, J/Psi, and Z boson events, separately in W^+ and W^- events
  - Ultimately, measure M_W in bins of $p_T(W)$, with two benefits
    - Exploit a sharper Jacobian peak at low $p_T(W)$: improve the statistical sensitivity
    - M_W^{fit} vs $p_T(W)$, separating by charge, provides an excellent control plot
- The y(W) distribution
  - Much information will be extracted from y(Z); also A(W); low-mass DY
  - Still, the strange contribution to W production remains critical to control
  - And whatever the situation, we need to dispose of a real uncertainty estimate!

M_W : needs from theoretical community

- The $p_T(W)$ distribution
  - As said, we will always compare predictions to our data, and correct them when needed. But this measurement will greatly benefit from theoretical assistance!
  - The Good Generator will
    - Incorporate all well-known theory
    - Summarize uncertainties into a few phenomenological parameters, that the experiments can fit
    - Allow to do this externally – we need to be able to do this ourselves, and iterate quickly

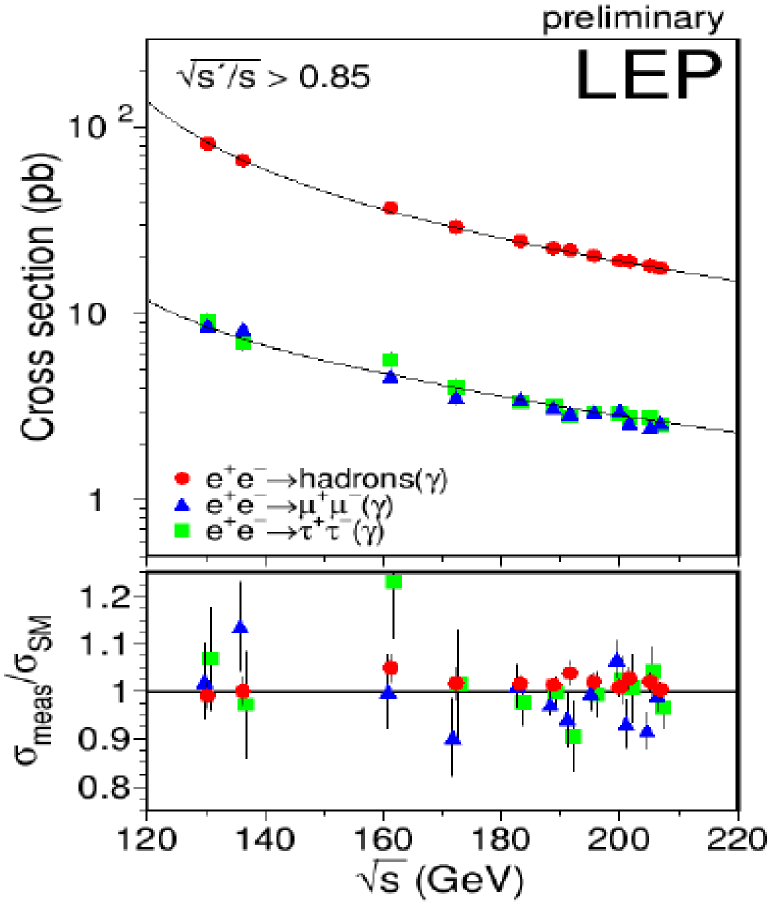
- PDFs
  - We have many potential handles :
    - W charge asymmetry; Z rapidity distribution
    - Low-mass Drell-Yan ($\bar{u}$ / $\bar{d}$ separation)
    - W + charm (strangeness!)
  - But some are really challenging. To define a realistic strategy, we ABSOLUTELY need to dispose of realistic PDF uncertainty estimates, and a flexible PDF fitting framework allowing us to vary parameters everywhere needed at a fast pace.

Another brief example...

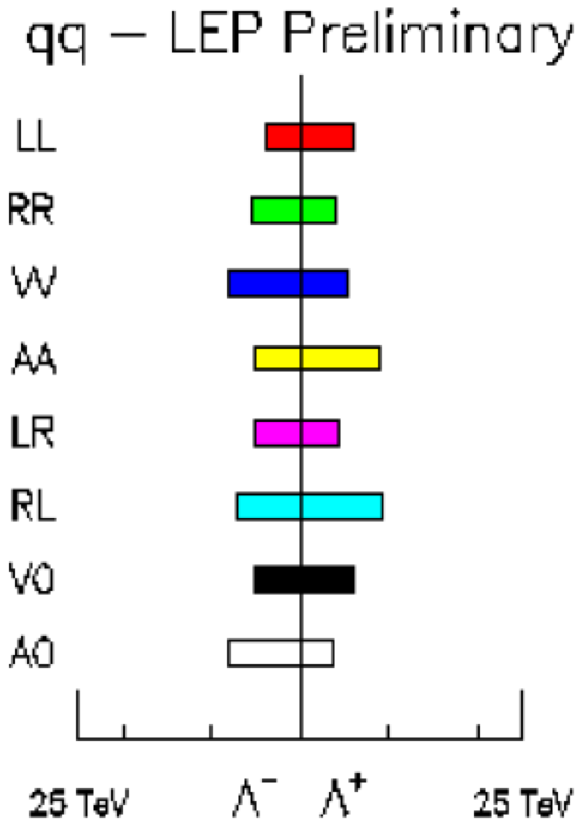
High-mass Drell-Yan

Precision measurement above the Z. Cf. LEP2 :

- ~30 measurements, precision ~1-5%



⇒



High-mass Drell-Yan

- Current uncertainty at LHC: ~6-7% for 100 GeV < M < 1 TeV and y~0
- → Gain a factor ~5. To do this, relate – simple model – :
  - $\sigma(m,y=0) \sim f^2(x,m)$ (at m [low-mass], **measure**)
  - $\sigma(m_Z,y\neq 0) \sim f(X,m_Z) \times f(x,m_Z)$ (at M_Z, **measure**)
  - $\sigma(M,y=0) \sim f^2(X,M)$ (at M [high-mass], **predict**)
- Specifically, write:

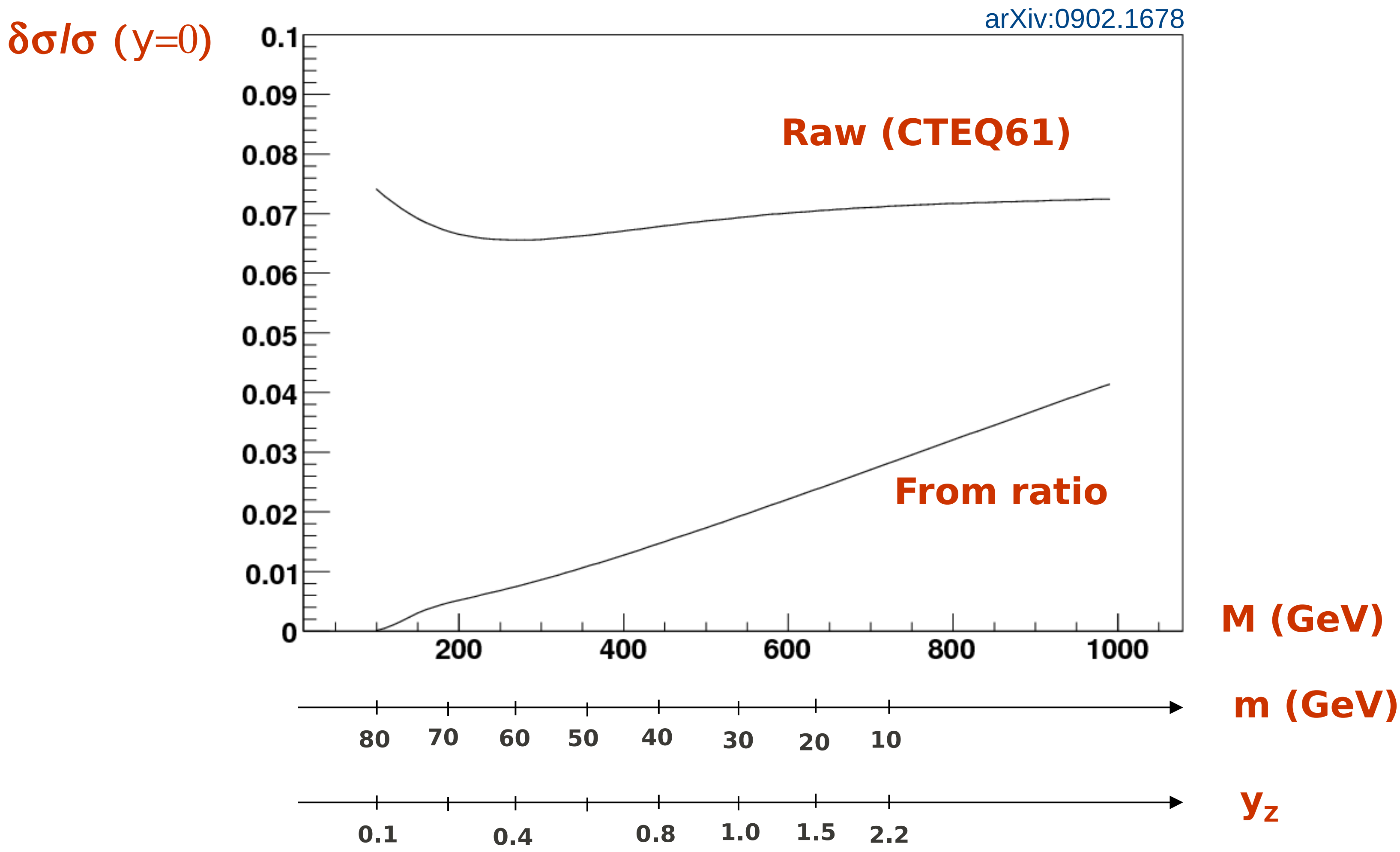
$$\sigma(M,y=0) \rightarrow \frac{\sigma(M,y=0)\times\sigma(m,y=0)}{\sigma^2(M_Z,y\neq 0)} \times \frac{\sigma^2(M_Z,y\neq 0)}{\sigma(m,y=0)}$$

Raw prediction **Smaller PDF dependence?** **Measured**

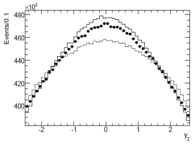
chosing m, M and y such that $m = M_Z e^{-y}$; $M = M_Z e^{+y}$

High-mass Drell-Yan

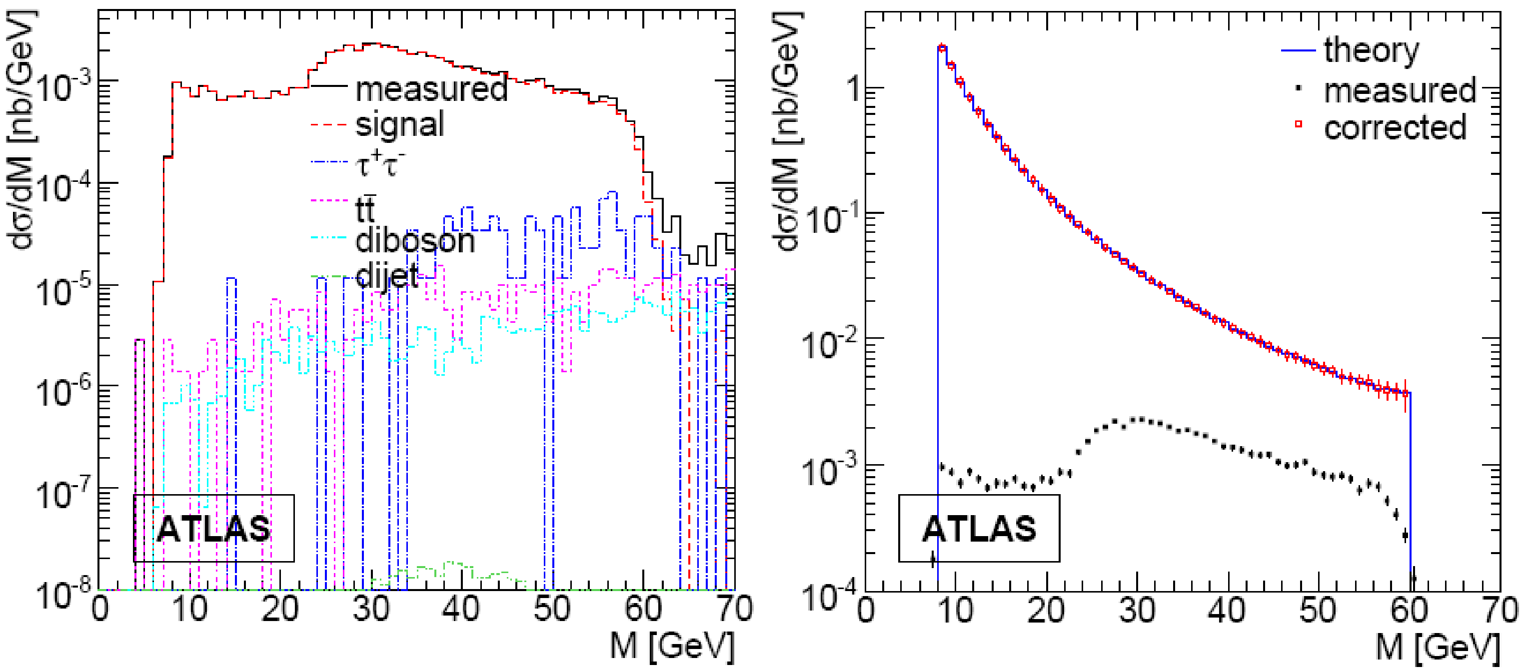
- Precision of the ratio prediction :



High-mass Drell-Yan

- Measured quantities:
  - dσ/dy (Z) already shown too much ()
  - dσ/dm at low mass : a(nother) challenging measurement in preparation

CERN-OPEN-2008-020



- Disclaimer : we don't know whether will this measurement will be achieved to the needed precision !

Summary

- Electroweak precision measurements : program starting now; a long way to go

- Detector performance has been beyond hopes in 2010. A very encouraging situation for the future

- Measurements should be organized to be minimally dependent on strong interaction theory. Where unavoidable, replace imprecise direct predictions by well chosen ratios, and complete by ancillary measurements

- Any remaining theoretical or model uncertainty will become potentially dominant. Hence uncertainties need to be well defined. Among these :
  - The $p_T(W)$ distribution can be measured; we should not rely exclusively on theory here. High precision is a challenge, but uncertainties are well defined.
  - PDFs : any “superfluous” assumption concerning parametrical form and/or relations between parton densities can break the measurement – need the highest possible flexibility.