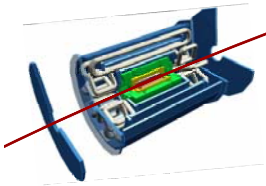
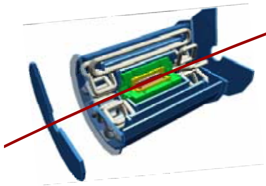


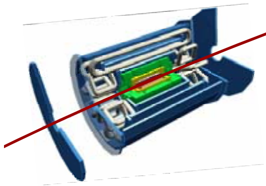
Luminosity measurements at ATLAS
and
impact of PDF uncertainties
on LHC physics

Maarten Boonekamp on behalf of ATLAS
Hera-LHC workshop, 26/5/8



Outline

- Cross-section measurements : single process
  - Luminosity
  - Efficiency (scale, resolution…)
  - Acceptance
- Multiple processes : ratios
  - Cross-normalizing experiment
  - Cross-normalizing theory
- Examples:
  - Z as case study
  - Applications to W, high-mass Drell-Yan, top pairs, Higgs
- Discussion



Cross-section measurements

- Counting rate :

$$N = \sigma \, L \, \varepsilon \, A + B$$

(function of)
fundamental parameter(s)

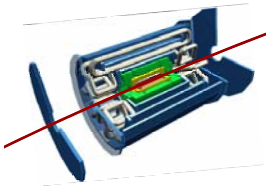
nuisance

- Uncertainty :

$$\frac{d\sigma}{\sigma} = \frac{dN \oplus dB}{N - B} \oplus \frac{dL}{L} \oplus \frac{d\varepsilon}{\varepsilon} \oplus \frac{dA}{A}$$

Assume B/N small and/or well known:
Term decreases statistically

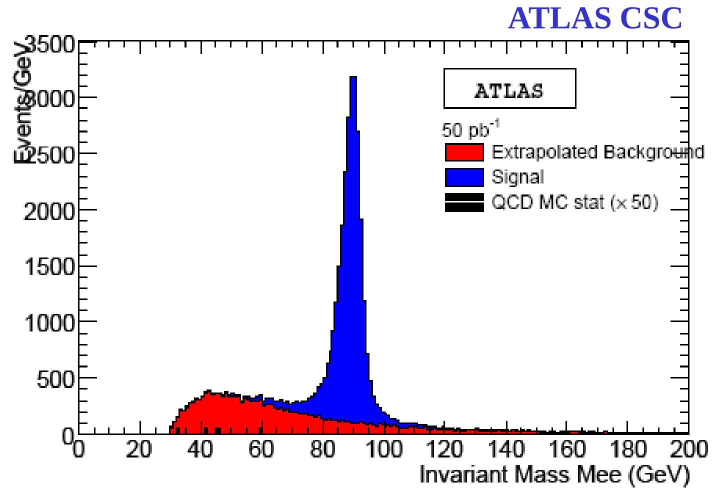
To be addressed -
Auxiliary measurements



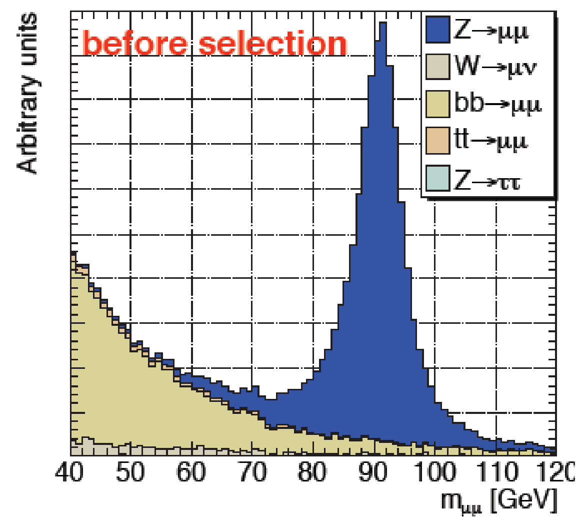
Example selections : Z → ee, μμ

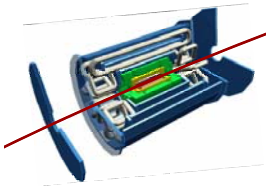
- Events (/10^4) in 50 pb^{-1}

Selection	$Z \to ee$	jets
Trigger	6.70 ± 0.01	3110 ± 40
$p_T > 15$ GeV, $\|\eta\| < 2.4$, 80 GeV $< M_{ee} <$ 100GeV	2.76 ± 0.01	11.1 ± 0.8
Electron ID	2.64 ± 0.01	0.8 ± 0.2
Isolation	2.48 ± 0.01	0.2 ± 0.1



Selection	$Z \to \mu\mu$	$b\bar{b} \to \mu\mu X$	$W \to \tau\nu$	$Z \to \tau\tau$
Trigger	3.76 ± 0.01	10.08 ± 0.04	36.7 ± 0.1	0.09 ± 0.01
2 muons +				
opp. charge	3.33 ± 0.01	3.00 ± 0.04	1.14 ± 0.02	0.04 ± 0.01
$M_{\mu\mu}$ cut	3.04 ± 0.01	0.26 ± 0.01	0.04 ± 0.01	$(14 \pm 4) \times 10^{-4}$
p_T cut	2.76 ± 0.01	0.125 ± 0.001	0.004 ± 0.001	$(11 \pm 4) \times 10^{-4}$
Isolation	2.56 ± 0.01	$(18 \pm 5) \times 10^{-4}$	$(9 \pm 5) \times 10^{-4}$	$(11 \pm 4) \times 10^{-4}$



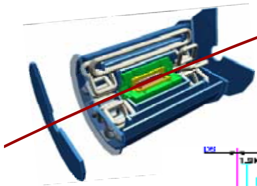


1 : Luminosity measurement

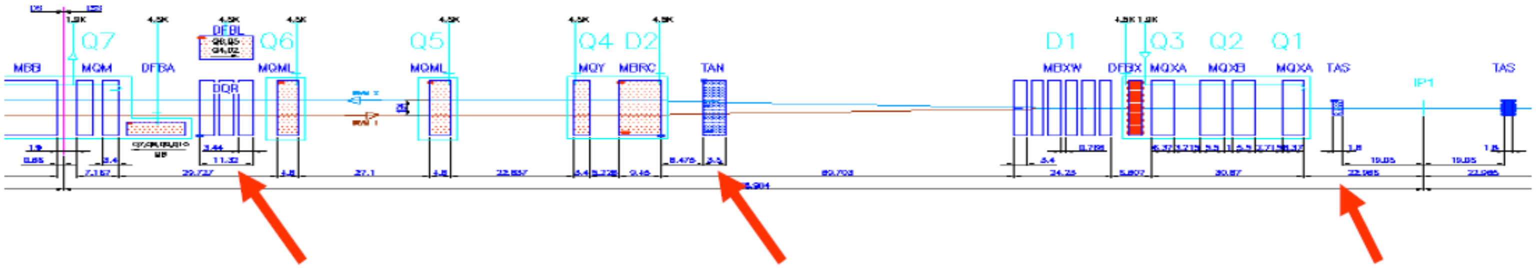
(material : TDR and Per Grafstrom, LHCC, May 08)

- Machine estimates
  - Early running : 20-25%
  - Using special calibration runs with simplified machine parameters : get to 10% or better

- Dedicated experiment
  - Relative luminosity monitors :
    - LUCID, ZDC
    - LAr/Tile currents; MBTS activity…
  - Absolute luminosity measurement : ALFA
    - Elastic scattering at small angles : well calculable Coulomb process
    - Dedicated machine optics; low luminosity. Result scaled to normal running conditions using the monitors
  - Used before : UA4, but also e+e- machines (Bhabha scattering)
  - Aim : $<3\%$



ATLAS forward detectors

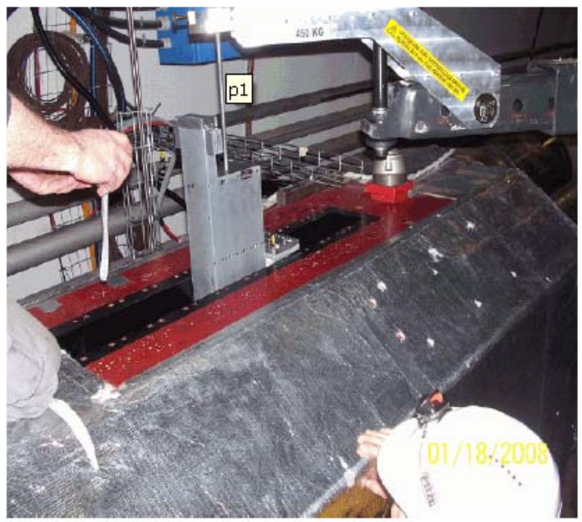


ALFA at 240 m

Absolute Luminosity for ATLAS

TDR submitted CERN/LHCC/2008-004

ZDC at 140 m



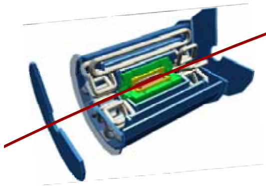
Zero Degree Calorimeter

Phase I (partially) installed

LUCID at 17 m

Luminosity Cerenkov Integrating Detector

Phase I ready for installation



Absolute luminosity from low-t elastic scattering

- General expression of the elastic cross-section at 0 angle:

$$\left.\frac{dN}{dt}\right|_{t\approx 0} = L\pi\left|f_C + f_N\right|^2 \approx L\pi\left|-\frac{2a_{EM}}{|t|} + \frac{\sigma_{tot}}{4\pi}(i+\rho)e^{-b|t|/2}\right|^2$$

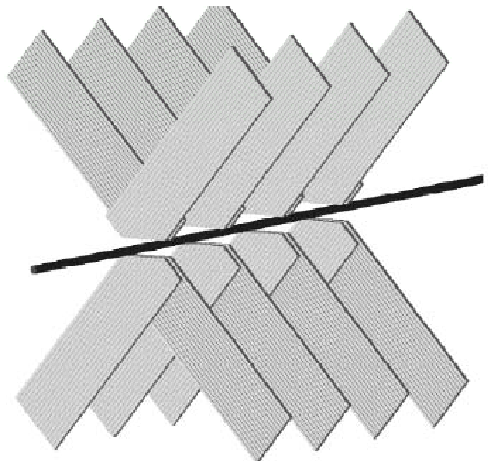
- Allows a 4-parameter fit to L and hadronic parameters σ_{tot}, ρ, b

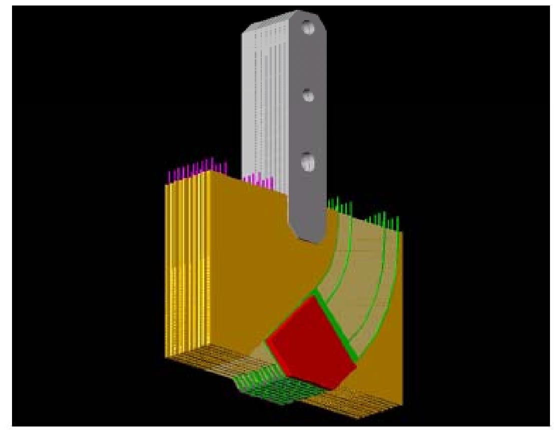
- Requires :
  - Detecting protons at $\theta \sim 3.5\ \mu$rad (UA4 : 120 μrad).
  - Special machine parameters : parallel-to-point focusing; L ~ 10^{27}
  - Edgeless detector for optimal acceptance
  - Precision mechanics controlling movement towards/away from beam
  - Backgrounds low and under control

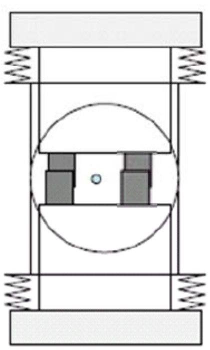
The detector and the Roman Pot

Concept

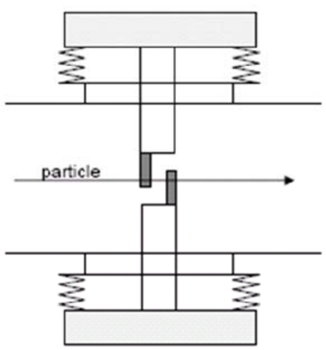
- 2x10 U planes
  2x10 V planes
- Scintillating fibers
  0.5 mm^2 squared
- Staggered planes
- MAPMT readout



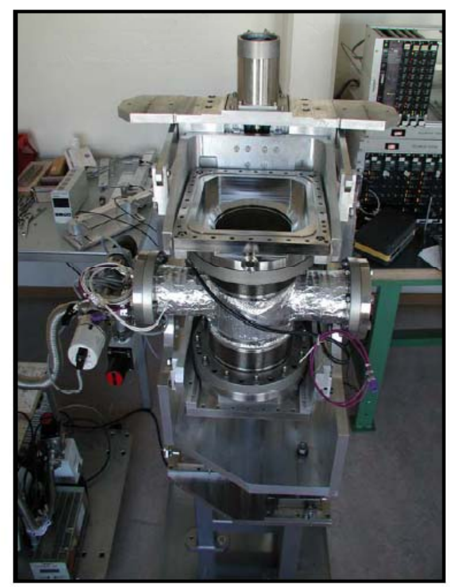


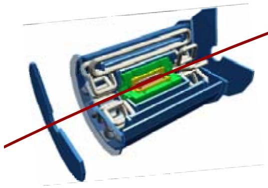


Front view

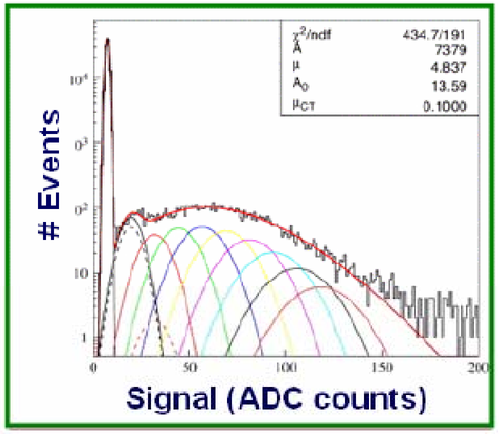


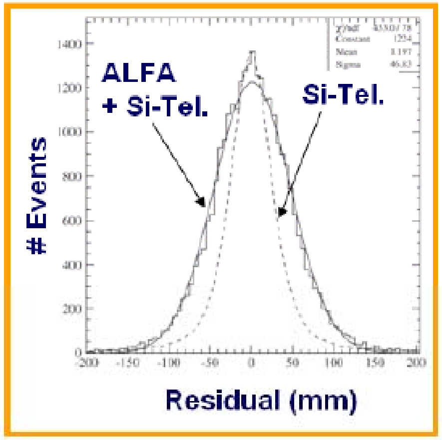
Side view

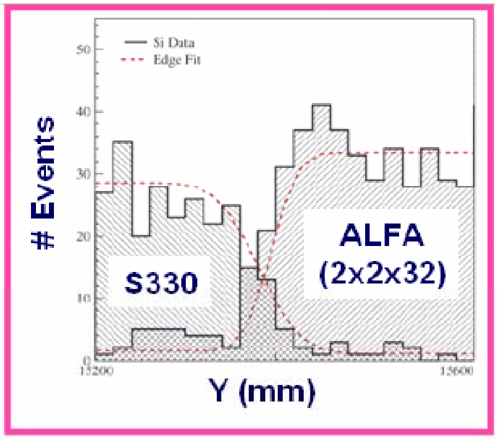




Performance – Test beam

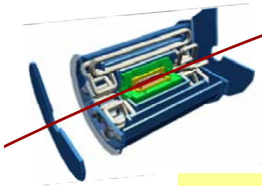






Main results:

- Light yield ~ 4 p.e.
- resolution σ ~ 25 μm
- non-active edge << 100 μm

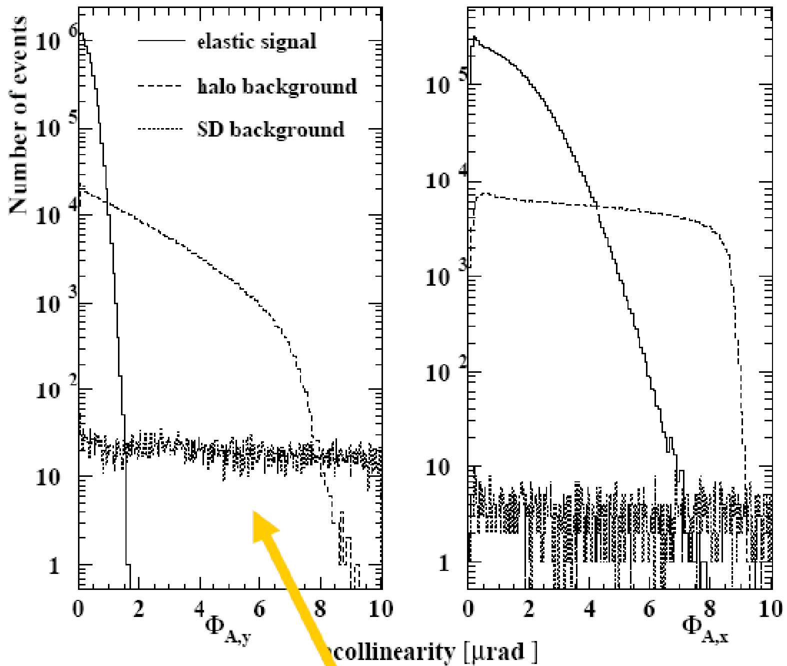


Backgrounds

Main handles:

Elastic signature:
- left -right coincidence
- acollinearity cut

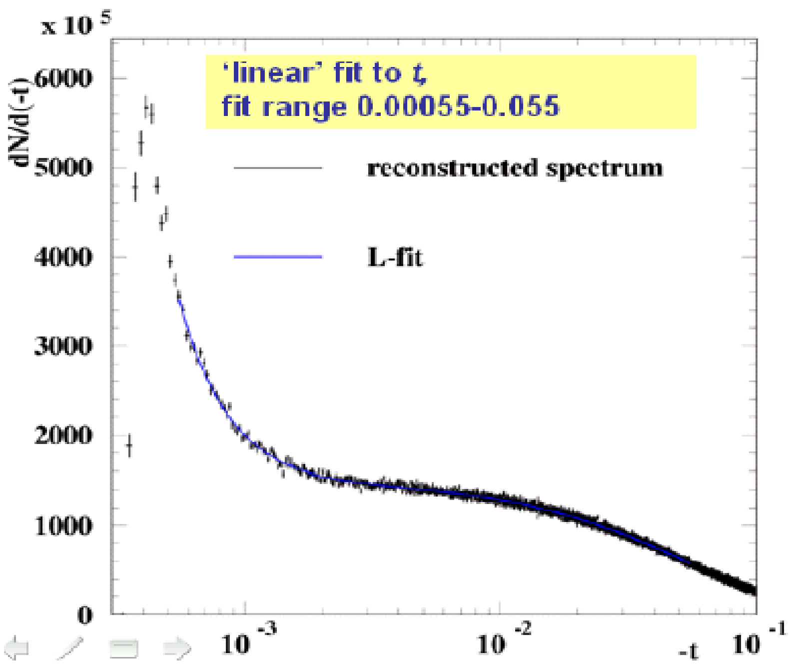
Vertex cut



Background reduced to 2 % of the elastic signal

Single diffractive background (generated with PYTHIA) negligible : << 1 permille

Expected performance
~100 hours at 10^{27}

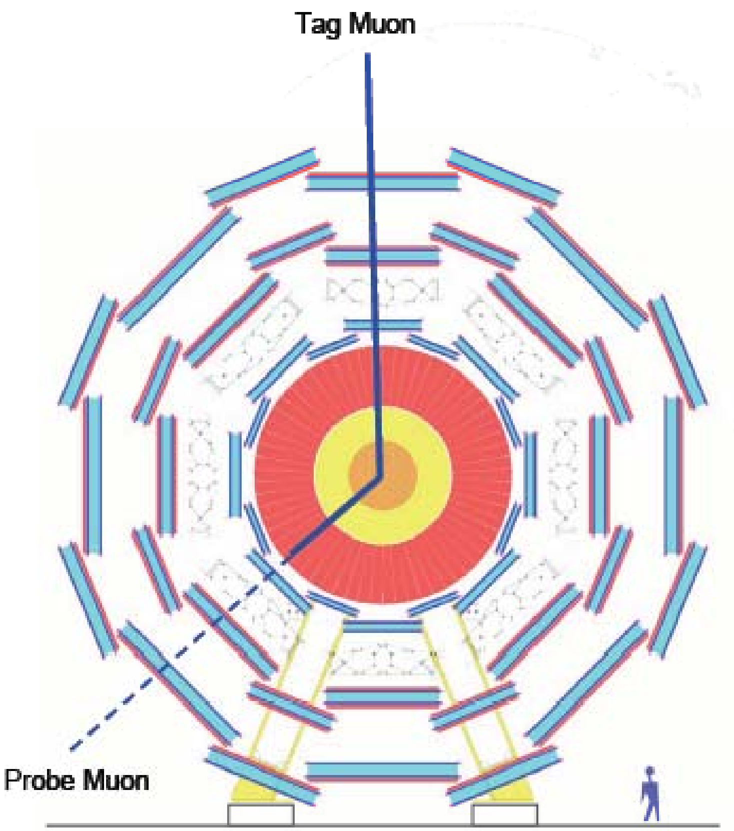


	Input	Lin.fit	Error (%)
L (10^{26} cm^{-2} s^{-1})	8.10	8.15	1.8
σ_{tot} (mb)	101	101.1	0.9
B (Gev^{-2})	18	17.9	0.25
ρ	0.15	0.14	4.3

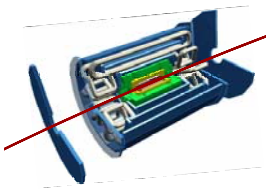
Systematic uncertainties [%]	Linear fit
Nominal result for L	8.15
Statistical error	1.77
Beam divergence	0.31
Crossing angle	0.18
Optical functions	0.59
Phase advance	1.0
Detector alignment	1.3
Geometrical detector acceptance	0.52
Detector resolution	0.35
Background subtraction	1.10
Total experimental systematic uncertainty	2.20
Total uncertainty	2.82

2 : Efficiency

- Simplest example : Z production. Two isolated leptons – Tag & probe

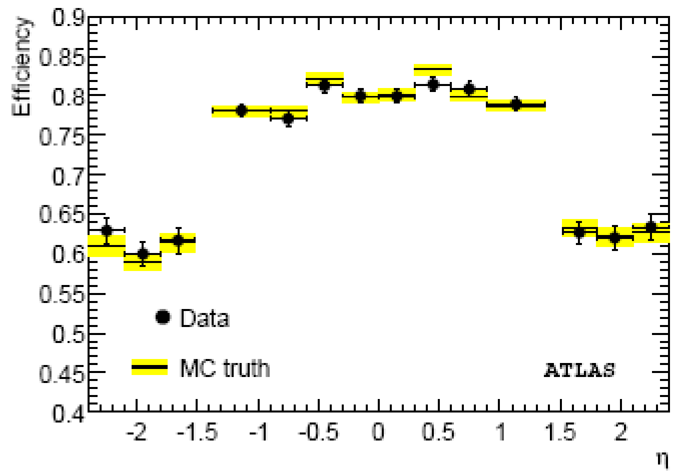


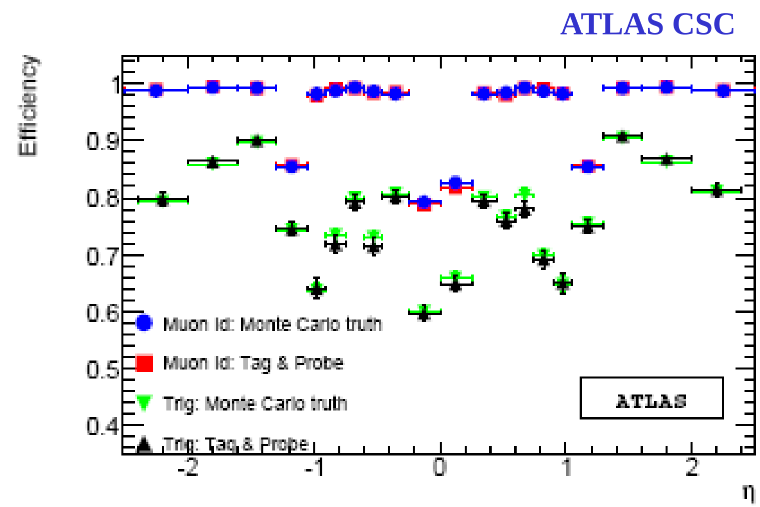
- Tag Muon: Track in Inner Detector AND Muon Spectrometer (+Isolation and pT-Cuts)
- Probe Muon: Track in Inner Detector (+Isolation and pT-Cuts)
- If this di-muon mass is near 91 GeV and $\Delta\varphi>2$, then the probe muon is assumed to be a real muon
- muon efficiency is given by the fraction of probe muons with tracks in the Muon Spectrometer



Efficiency results

- Electron and muon channels





- Lepton efficiency : $d\varepsilon_l/\varepsilon_l \sim 2\%$ (50 pb^{-1}); 0.5% (1 fb^{-1})
- The low backgrounds have ~no effect on the efficiency determination

- Cross-section : $d\varepsilon_Z/\varepsilon_Z \sim 3\%$ (50 pb^{-1}); 0.8% (1 fb^{-1})

3 : Acceptance

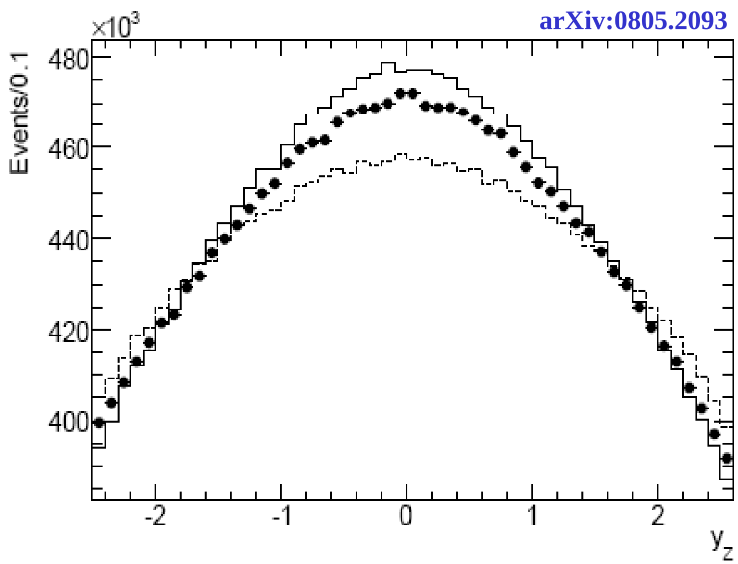
- Total Z cross-section : which fraction of events lies within the detector acceptance?

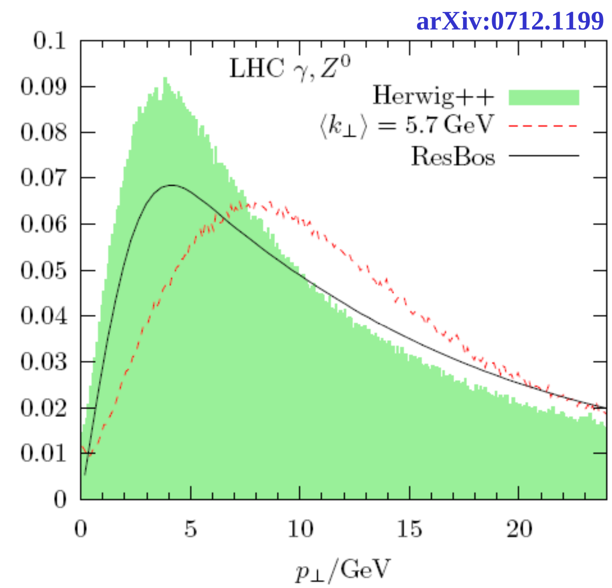
- Two factors : PDF(Z) and PDF(e,μ | Z)

- First factor : $d\sigma/dy$, $d\sigma/dp_T$, related to proton PDFs and parton showers
  Not well known

- Second factor : angular distributions and QED/EW radiation in Z rest frame.
  Well predicted using state of the art tools (MC@NLO+Photos, ResBos, Horace, Winhac/Zinhac…)

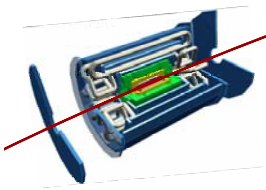
Acceptance





- Proton PDF induced uncertainty dA/A ~ 1%
- QCD higher orders and resummation contributes dA/A ~ 3%

- Our ATLAS study; also CMS note 2006/082; Mangano, Frixione, 2004 (W production); Adam, Halyo, Yost, 2008 (Z production)

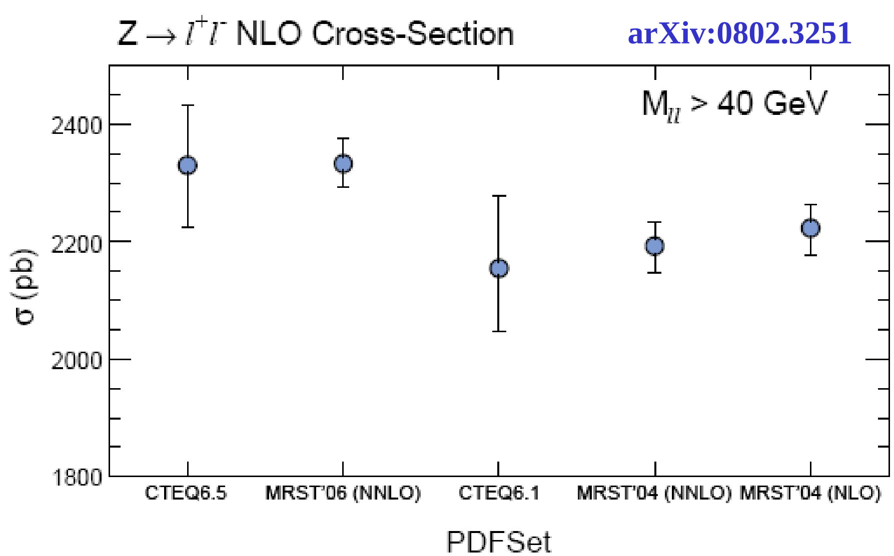


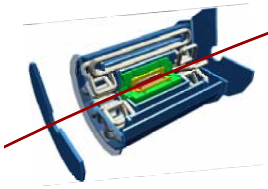
Summary, so far

- Z total cross-section:
  - dL/L ~ 10% → <3%
  - dε/ε ~ 3% → <1%
  - dA/A ~ 3% irreducible at this stage

- Acceptance uncertainties will play a dominant role, especially when measuring cross-section ratios where L cancels

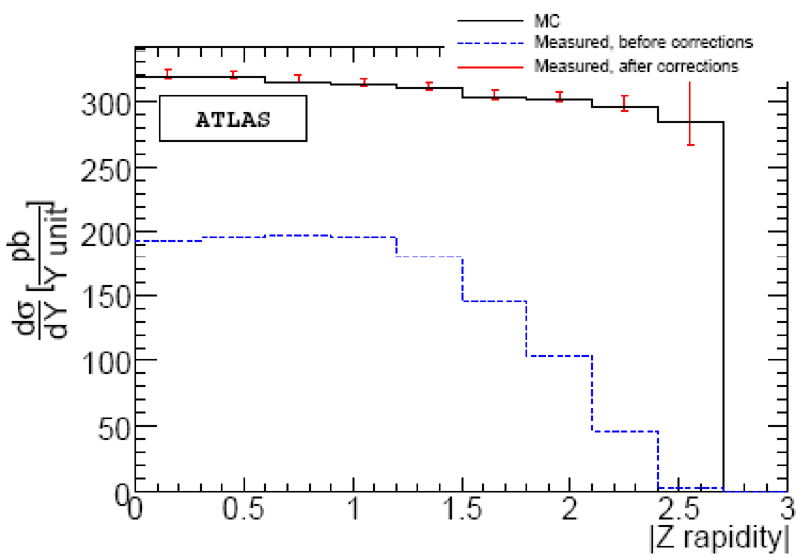
- Z as luminosity monitor : account for overall normalization uncertainty ~5% : this is, at best, a temporary hack

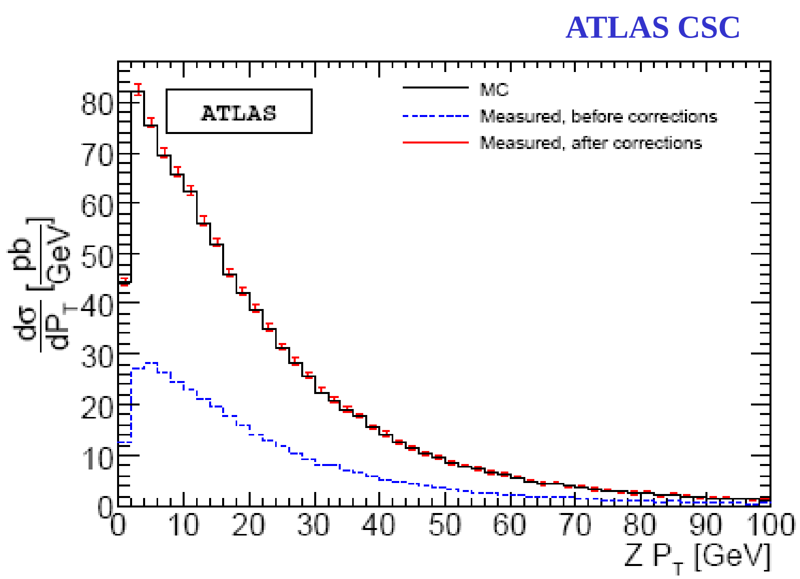




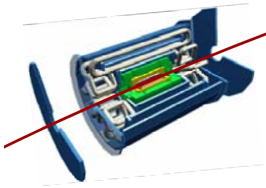
→ Differential cross-sections

- Total cross-section measurements are thus limited by the very effects we want to constrain! Differential cross-sections provide more insight - acceptance uncertainties small (cf slide 14)



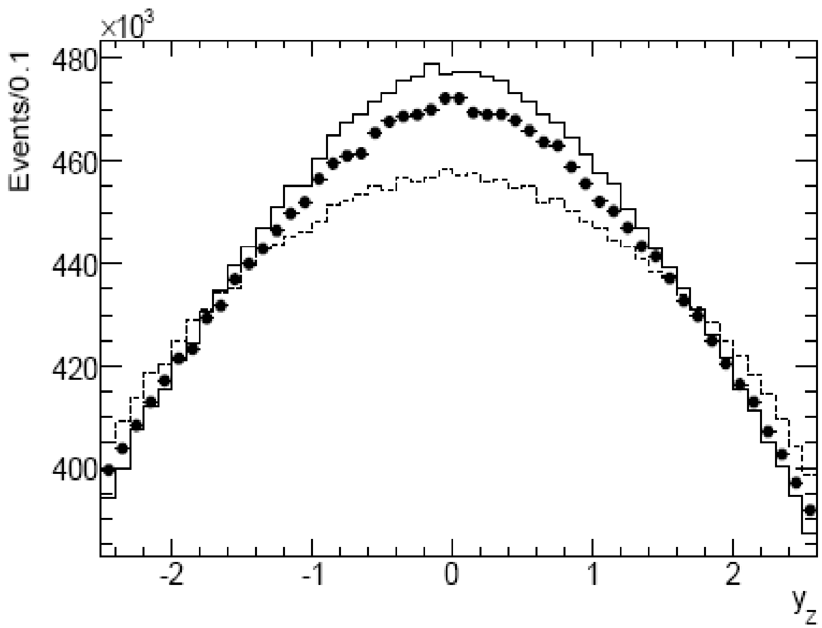


~200 pb^{-1}

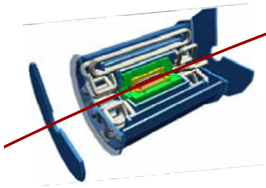


→ Differential cross-sections

- Total cross-section measurements are limited by the very effects we want to constrain. Differential cross-sections provide better constraints - acceptance uncertainties small (cf slide 14)



~10 fb⁻¹



Ratios : cross-normalizing experiment

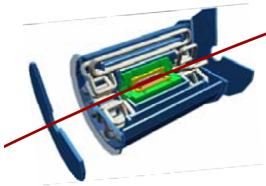
- Measure R = σ / σ_{ref} :

$$\frac{dR}{R} = \underbrace{\frac{dN}{N} \oplus \frac{dN_{REF}}{N_{REF}}}_{\text{Statistical terms}} \oplus \underbrace{0}_{\text{No lumi term!}} \oplus \underbrace{\frac{d(\varepsilon/\varepsilon_{REF})}{(\varepsilon/\varepsilon_{REF})} \oplus \frac{d(A/A_{REF})}{(A/A_{REF})}}_{\text{Additional terms from REF}}$$

- So careful : the interest of this is not always obvious!
  - Gain : no luminosity dependence
  - But additional terms from ε_{REF} and A_{REF}

- Might be good (if one expects correlated $\varepsilon \sim \varepsilon_{REF}$ and $A \sim A_{REF}$) : even more cancelation;
  or bad (if uncorrelated) : larger uncertainty

- Conversely : when possible, define R keeping this in mind, i.e maximize correlation with REF



Ratios (2)

- Random example : σ_{tt}

ATLAS CSC

Source	Likelihood fit Electron	Likelihood fit Muon	Counting method (elec) Default	Counting method (elec) W const.
Statistical	10.5	8.0	2.7	3.5
Lepton ID efficiency	1.0	1.0	1.0	1.0
Lepton trigger efficiency	1.0	1.0	1.0	1.0
50% more W+jets	1.0	0.6	14.7	9.5
20% more W+jets	0.3	0.3	5.9	3.8
Jet Energy Scale (5%)	2.3	0.9	13.3	9.7
PDFs	2.5	2.2	2.3	2.5
ISR/FSR	8.9	8.9	10.6	8.9
Shape of fit function	14.0	10.4	-	-

$$\text{Likelihood method:} \quad \Delta\sigma/\sigma = (7(\text{stat}) \pm 15(\text{syst}) \pm 3(\text{pdf}) \pm 5(\text{lumi}))\%$$

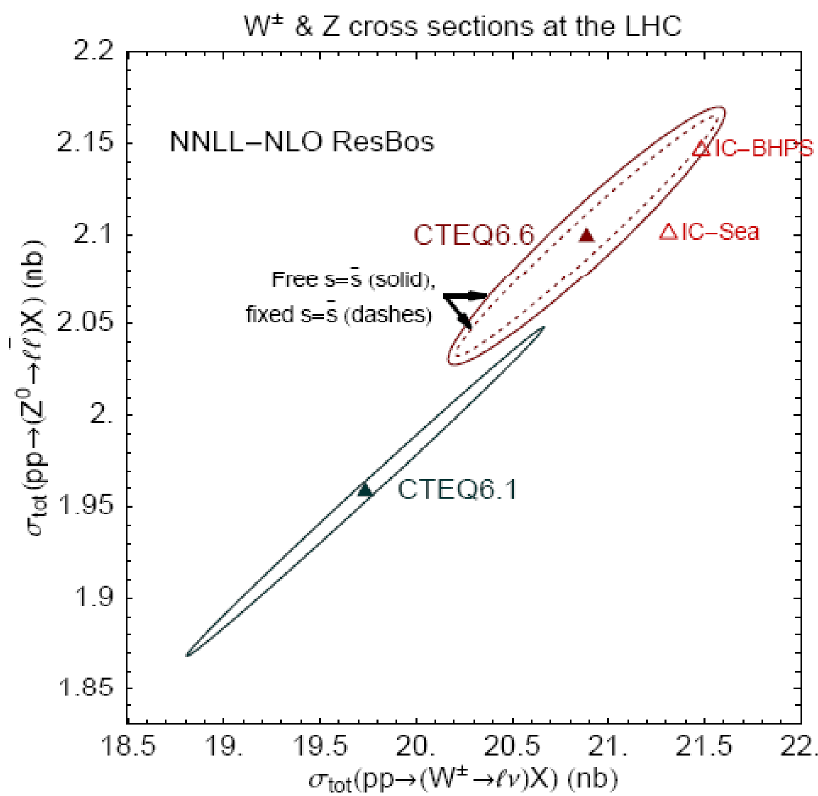
$$\text{Counting method:} \quad \Delta\sigma/\sigma = (3(\text{stat}) \pm 16(\text{syst}) \pm 3(\text{pdf}) \pm 5(\text{lumi}))\%$$

- The ratio to Z production, σ_{tt}/σ_Z, makes little sense
  - Cancels out L indeed
  - All other systematics are essentially independent; also add Z rate uncertainty
  - hence a worse result

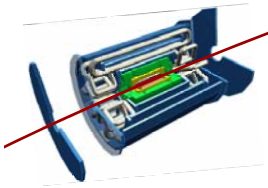
Ratios (3)

arXiv:0802.0007

- Golden example : σ_W / σ_Z
  - Very similar experimentally
    - isolated leptons, same p_T range
    - Can be selected using same trigger
    - (difference : EtMiss)
  - Quark initial state; singlet final state
    → similar QCD corrections
  - Behave similarly under PDF variations



- In σ_W / σ_Z, almost everything cancels
  Hence a beautiful test of QCD



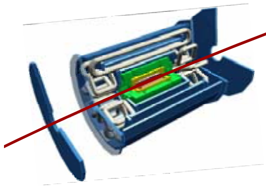
Ratios : cross-normalizing theory

- Data-driven predictions :

$$\sigma_{pred} = \left(\frac{\sigma}{\sigma^{REF}}\right)_{pred} \left(\sigma^{REF}\right)_{meas}$$

Poor prediction — Precise prediction — Measurement

- σ_{pred} can then be :
  - compared against σ_{meas} : e.g search for, or interpretation of new physics
  - Used as input for precision measurements



Data-driven predictions (1)

- Example : W mass. Need to predict W **distributions** (not rates), e.g $d\sigma_W/dy$

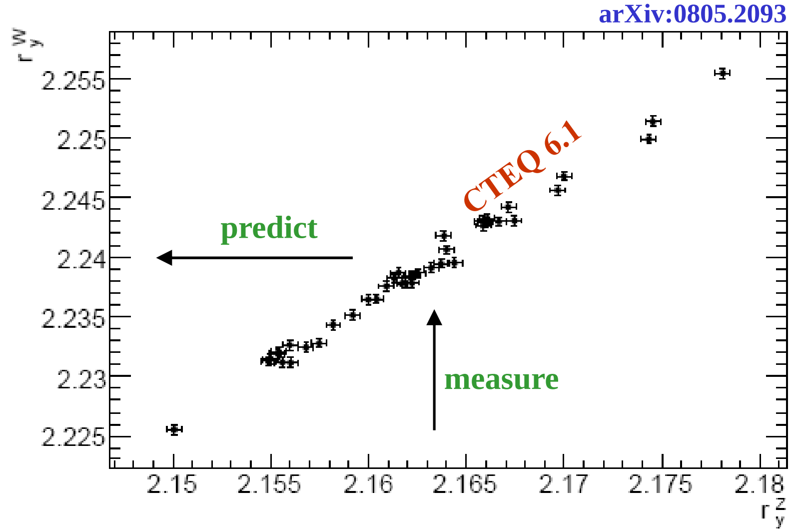
- Define :

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

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

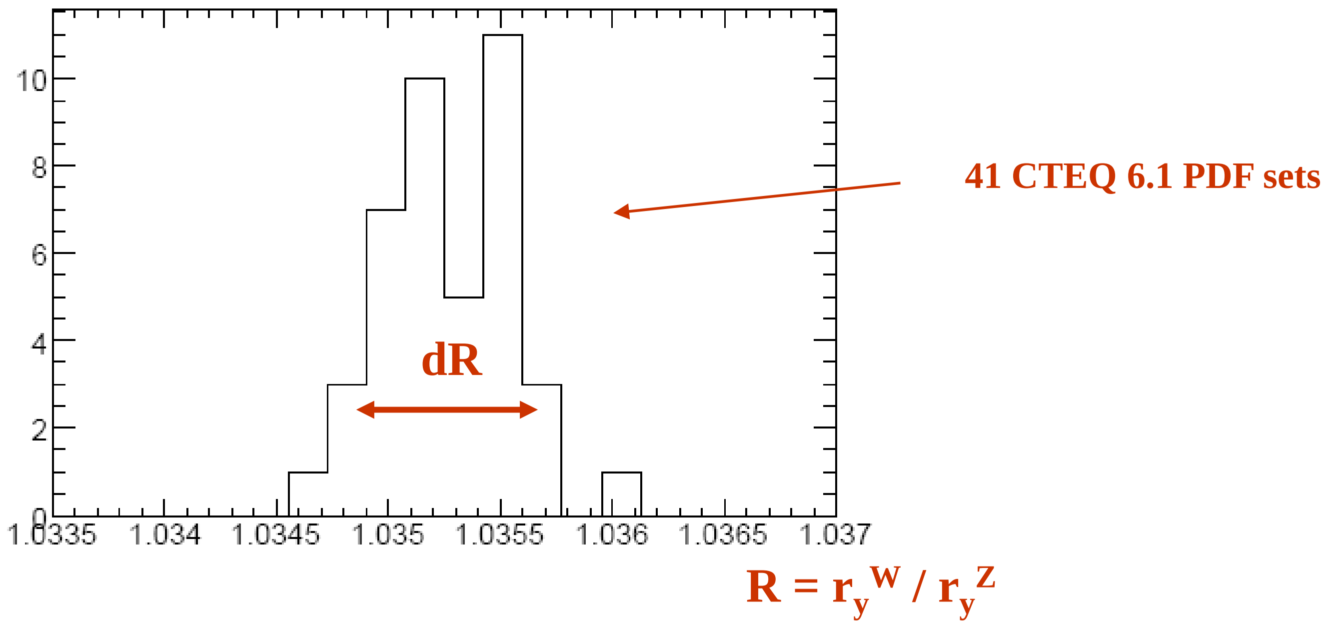
- Use RMS of rapidity distribution, $r_y^{W,Z}$, to quantify $d\sigma/dy$ and their variations (choice not unique)

arXiv:0805.2093

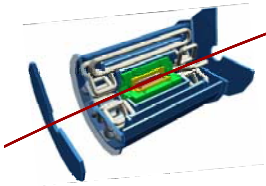


$d\sigma_W/dy$

- Spread of R :

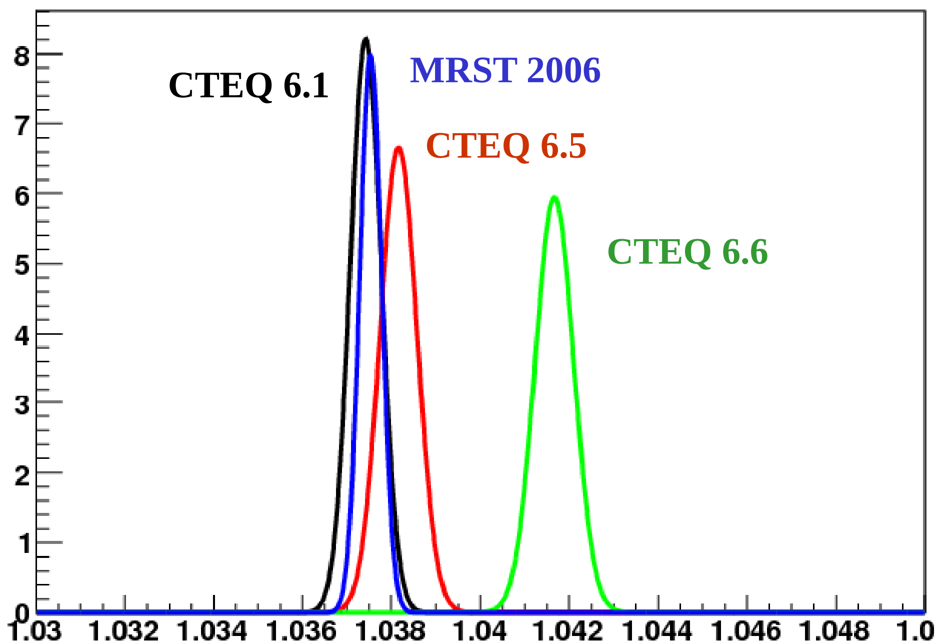


Ratio prediction ~20x more precise than raw



$d\sigma_W/dy$

- Careful : precise but incompatible predictions!



$R = r_y^W / r_y^Z$

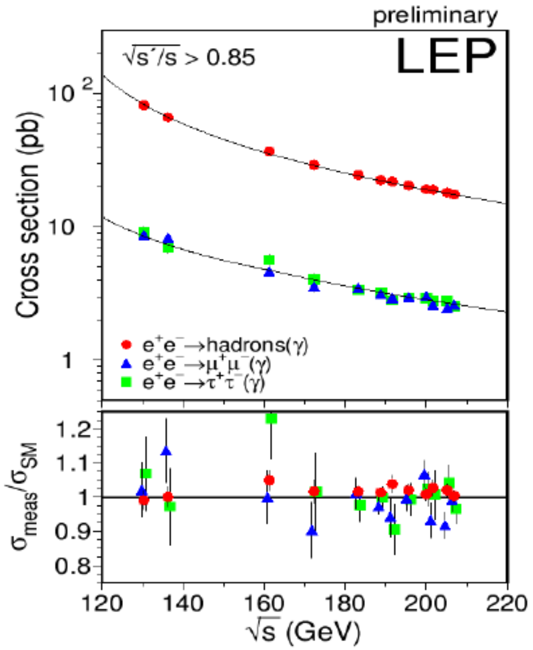
- Studied sets agree on correlations, not on central values
  - different starting assumptions and theoretical frameworks

Data-driven predictions (2)

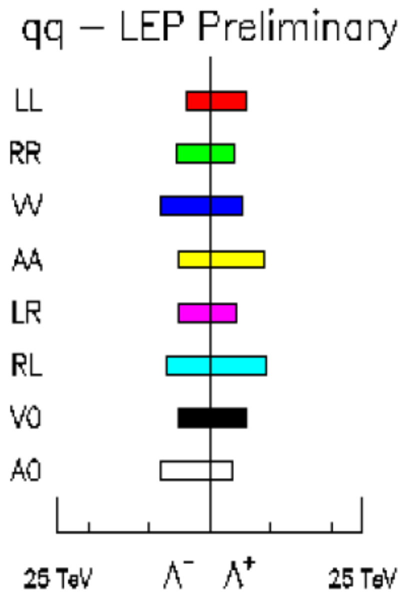
- Example : High-mass DY. Motivation:

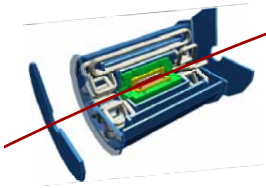
Precision measurement above the Z. Cf. LEP2 :

- ~30 measurements, precision ~1-5%



⇒





High-mass Drell-Yan

- Current LHC uncertainty : ~6-7% for 100 GeV < M < 1 TeV and y~0

- → Gain a factor ~5. To do this, relate:
  - $\sigma(m,y=0) \sim f^2(x,m)$ (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:

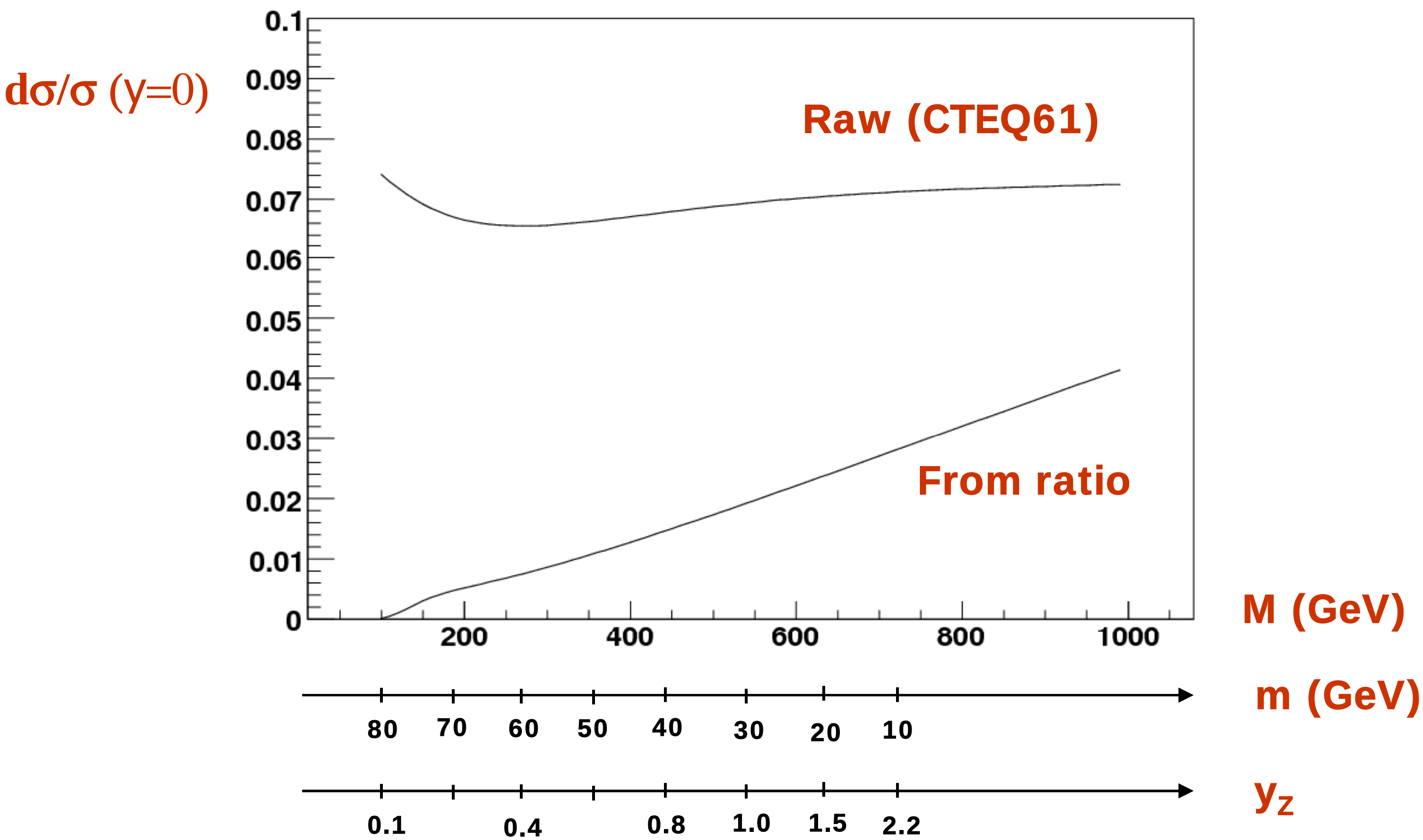
$$\sigma(M,y=0) \rightarrow \frac{\sigma(M,y=0)\times\sigma(m,y=0)}{\sigma^2(M_Z,y\neq 0)} \times \frac{\sigma^2(M_Z,y\neq 0)}{\sigma(m,y=0)}$$

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

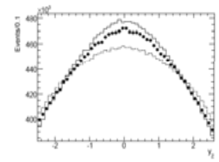
chosing m, M and y such that $m = M_Z\, e^{-y}$; $M = M_Z\, e^{+y}$

- Work with Florent chevallier, in preparation

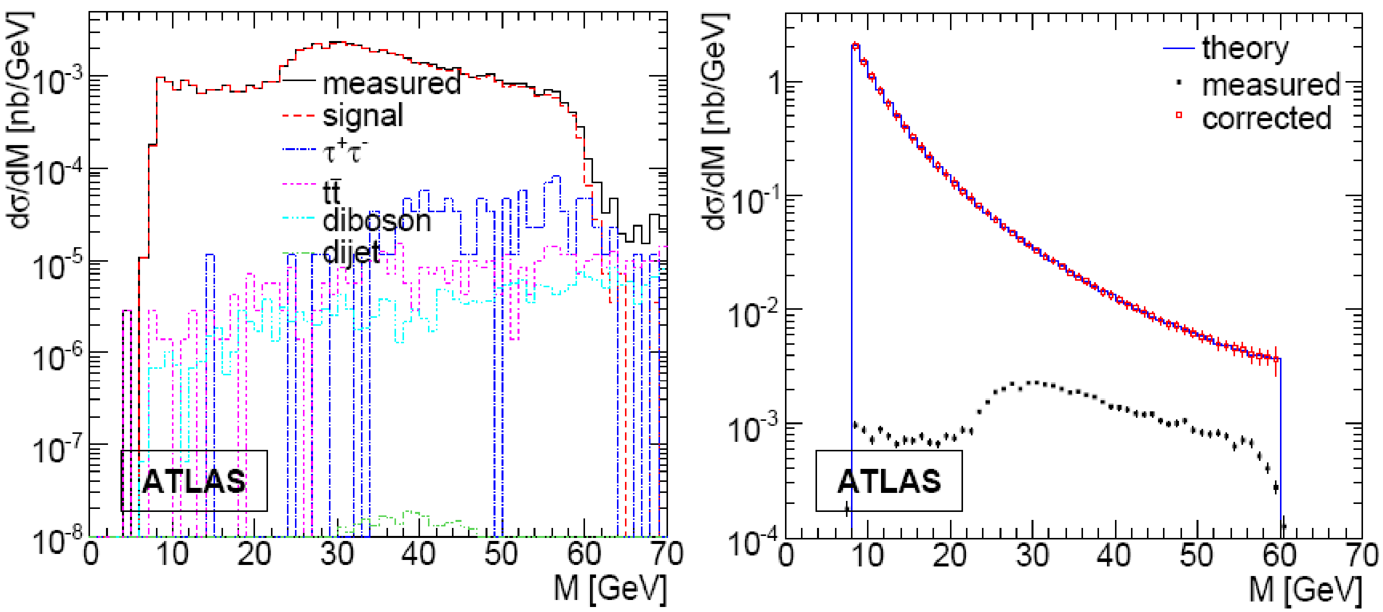
High-mass Drell-Yan

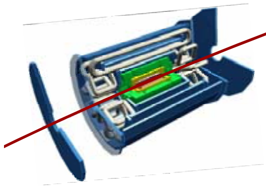


High-mass Drell-Yan

- Measured quantities:
  - dσ/dy (Z) already shown too much ()
  - dσ/dm at low mass:

ATLAS CSC





Summary & Conclusions

- Cross-section measurements
  - Complete program : a challenge in every aspect
    - dL/L : luminosity program well underway
    - Efficiency, scale, resolution : many auxiliary measurements
    - Need to measure distributions to minimize acceptance effects
  - Ratios : a possible simplification (normalization, or data-driven predictions)
    - Need to be defined carefully : eliminating L can easily introduce other, possibly larger sources of uncertainty
    - A good reference process should be correlated theoretically and experimentally to the target. And SM-certified

- SM cross-sections : not just background control

- LHC physics and PDFs : Intrinsically tied

- PDF uncertainty sets : a great tool
  - Most important application : more than error estimation, investigation of correlations among different physics processes