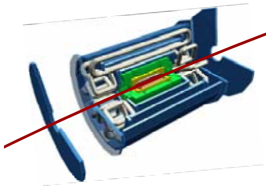
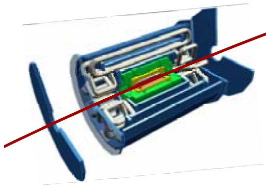


Luminosity Monitors and Standard Candles at ATLAS

Troels C. Petersen and Maarten Boonekamp
on behalf of ATLAS
Hera-LHC workshop, 28th of May 2008



Outline

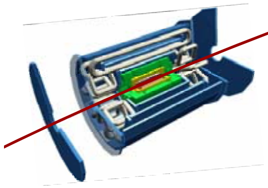
- Cross-sections : Single process
  - Luminosity
  - Efficiency (scale, resolution…)
  - Acceptance

- Cross-sections : Multiple processes (Ratios)
  - Cross-section normalizing - experiment
  - Cross-section normalizing - theory

- Data driven predictions :
  - Z as case study.
  - Applications to W, high-mass Drell-Yan, Higgs

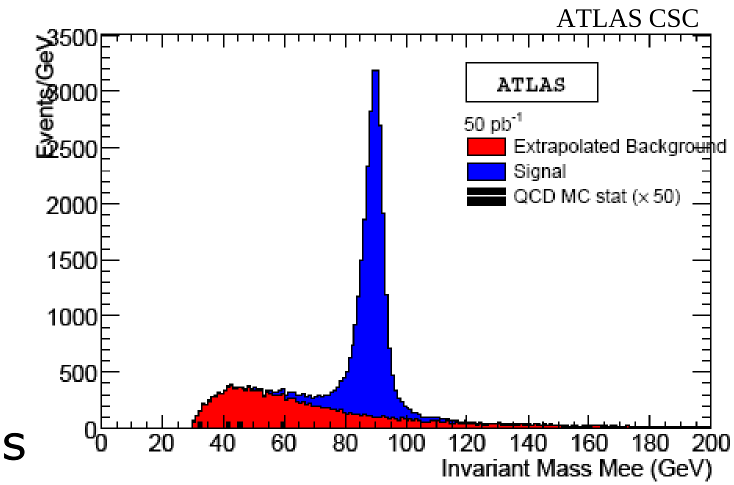
- Summary and Conclusion

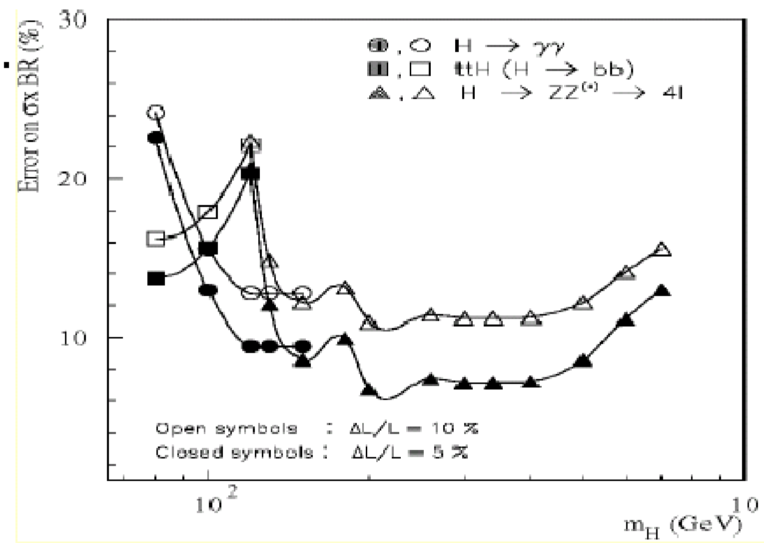
References: ATLAS CSC notes and Per Grafstrom (LHCC-2008-004)



Motivation

- Cross sections of Standard processes:
  - Z production (more later)
  - Top pair production (known to 10%)
  - Jet production
- New Physics manifestation in cross sections
  - Cross-section changes from SM prediction (important if New Physics not seen directly).
- New Physics directly observed:
  - Higgs production – check cross-section.
  - Cross-section useful for MSSM Higgs. (Measurement of tanβ).





Cross-section measurements

- Counting rate :

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

(function of) fundamental parameter(s) → σ

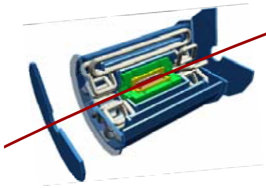
nuisance → $L \, \varepsilon \, A + B$

- 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



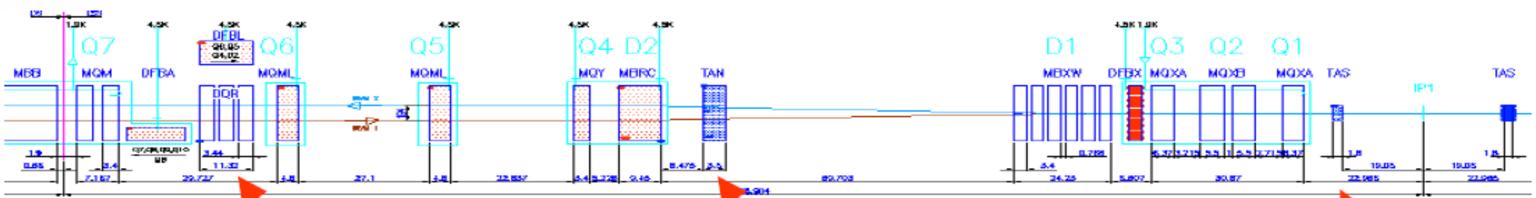
1 : Luminosity measurement

(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 luminosity detectors/experiments:
  - 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



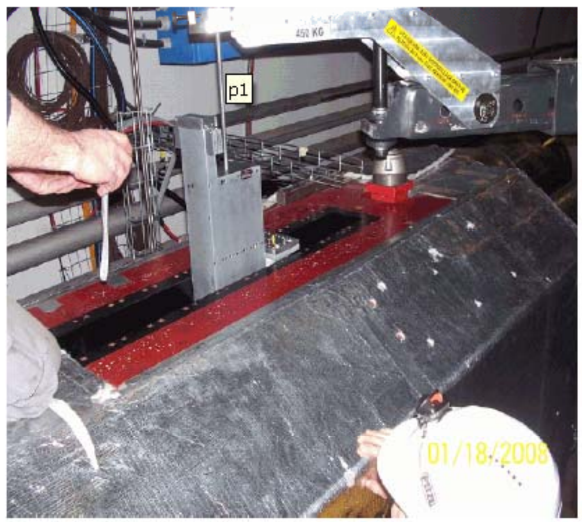
ALFA at 240 m

ZDC at 140 m

LUCID at 17 m

Absolute Luminosity for ATLAS

TDR submitted CERN/LHCC/2008-004

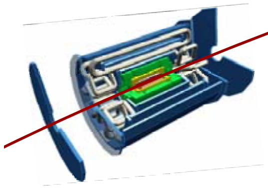


Zero Degree Calorimeter

Phase I (partially) installed

Luminosity Cerenkov Integrating Detector

Phase I ready for installation



Absolute luminosity from low-t elastic scattering

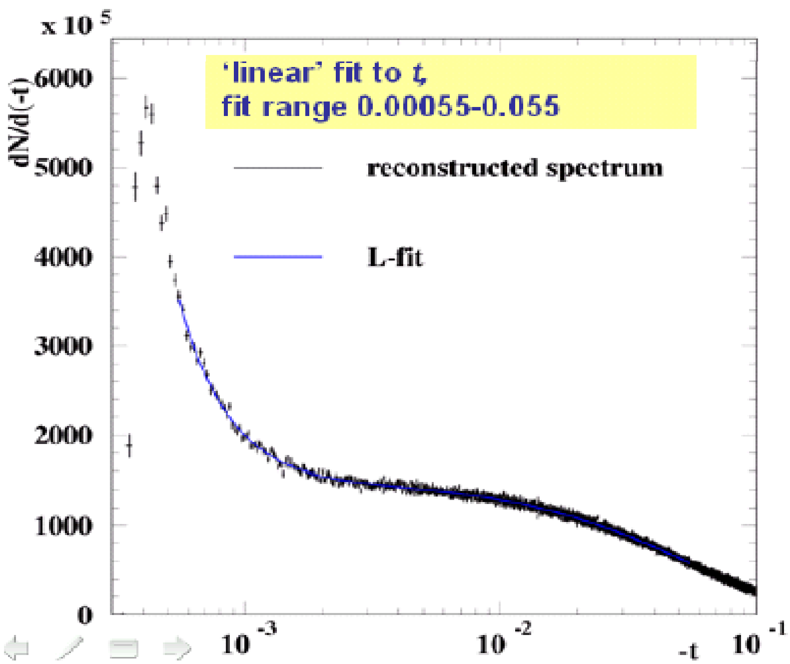
- General expression of the elastic cross-section at 0 angle:

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

- 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

Expected performance
~100 hours at 10^{27}

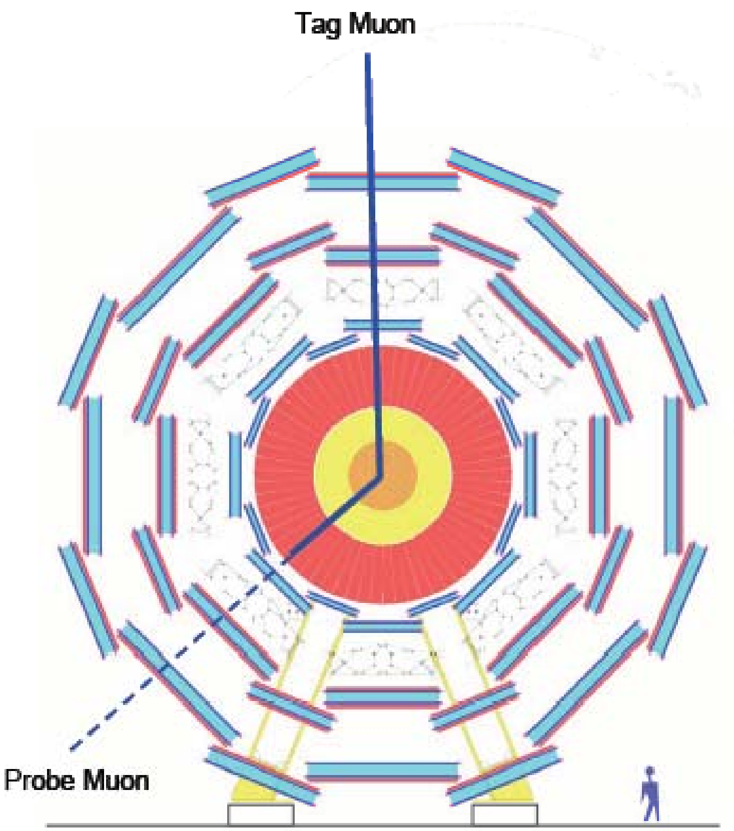


	Input	Lin.fit	Error (%)
L (10^{26} cm^{-2} s^{-1})	8.10	8.15	1.8
σ_{tot} (mb)	101	101.1	0.9
B (Gev^{-2})	18	17.9	0.25
ρ	0.15	0.14	4.3

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

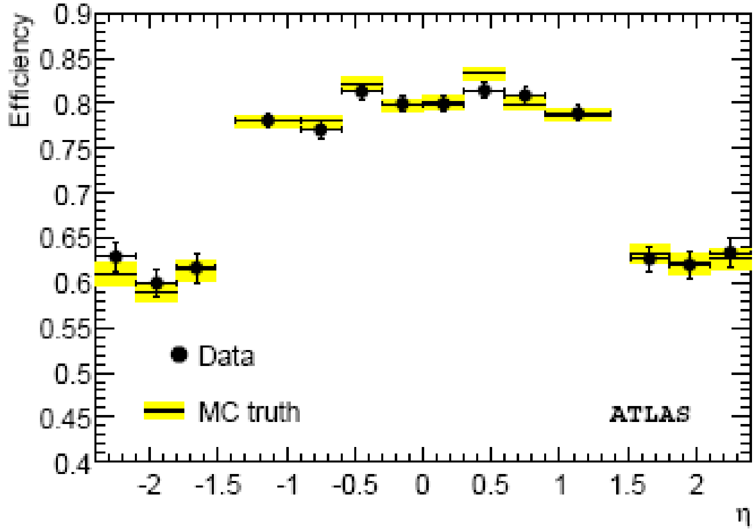
- Simplest example : Z production. Two isolated leptons – Tag & probe

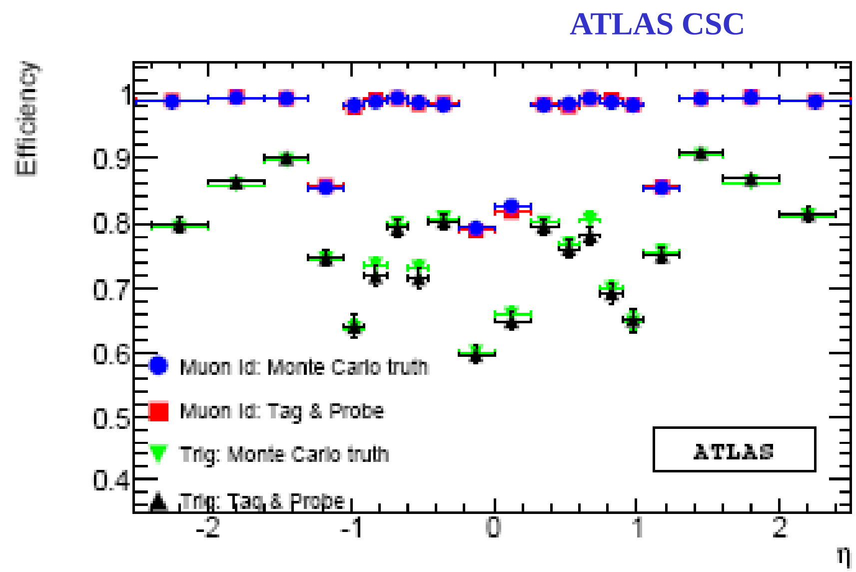


- Tag Muon: Track in Inner Detector AND Muon Spectrometer (+Isolation and pT-Cuts)
- Probe Muon: Track in Inner Detector (+Isolation and pT-Cuts)
- If this di-muon mass is near 91 GeV and $\Delta\varphi > 2$, then the probe muon is assumed to be a real muon
- muon efficiency is given by the fraction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

Efficiency results

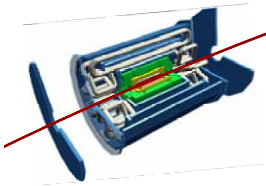
- Electron and muon channels





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

- Cross-section : $d\varepsilon_Z/\varepsilon_Z$ ~ 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 : **Production** - PDF(Z) and **decay** - PDF(e,μ | Z)

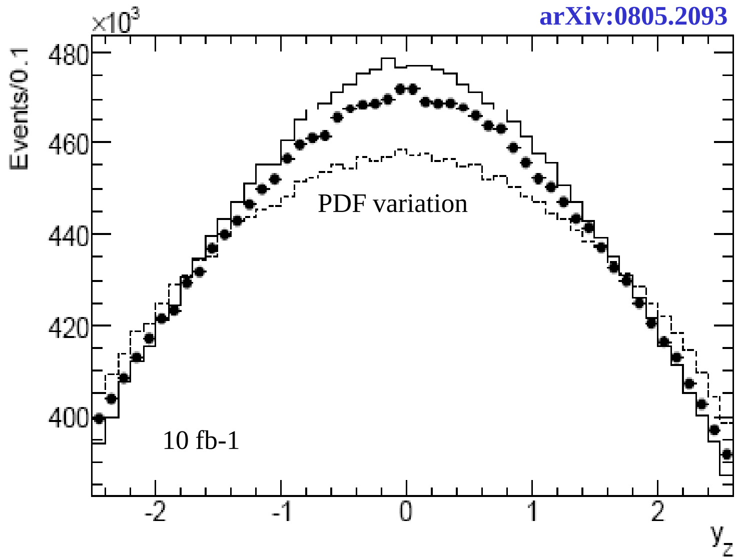
- **Production** : $d\sigma/dy$, $d\sigma/dp_T$, related to proton PDFs and parton showers.

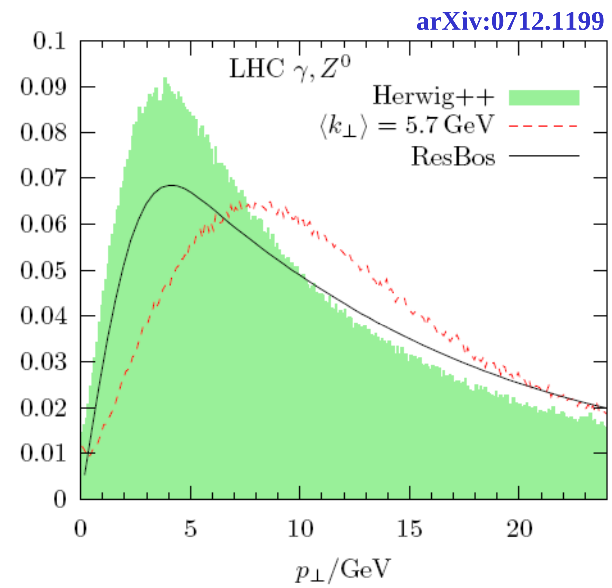
  Not well known!

- **Decay** : 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…)

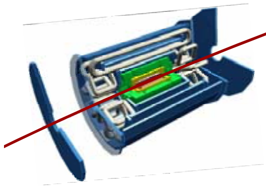
Acceptance





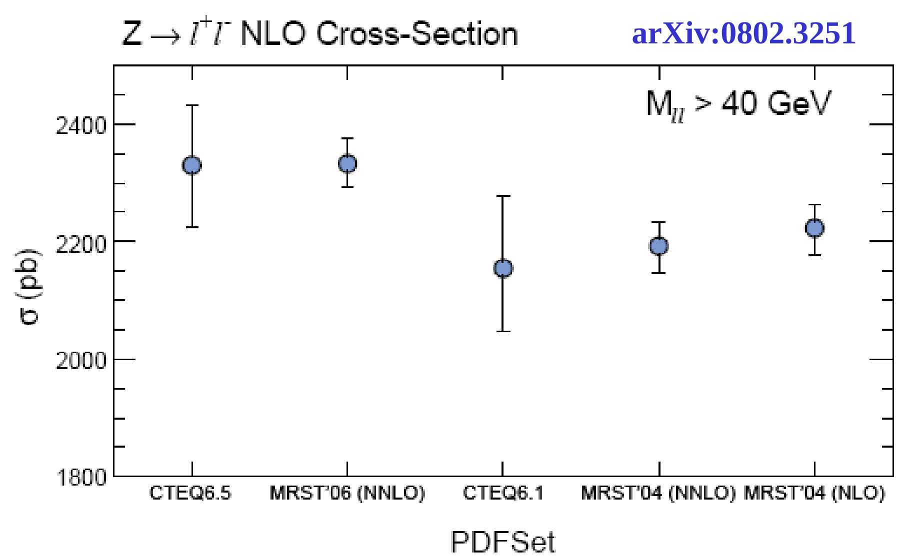
- Proton PDF induced uncertainty dA/A ~ 1%
- QCD higher orders and resummation contributes dA/A ~ 3%

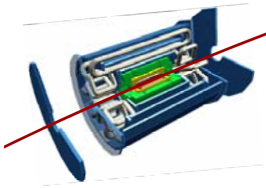
- Our ATLAS study; also CMS note 2006/082; Mangano, Frixione, 2004 (W production); Adam, Halyo, Yost, 2008 (Z production)



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.

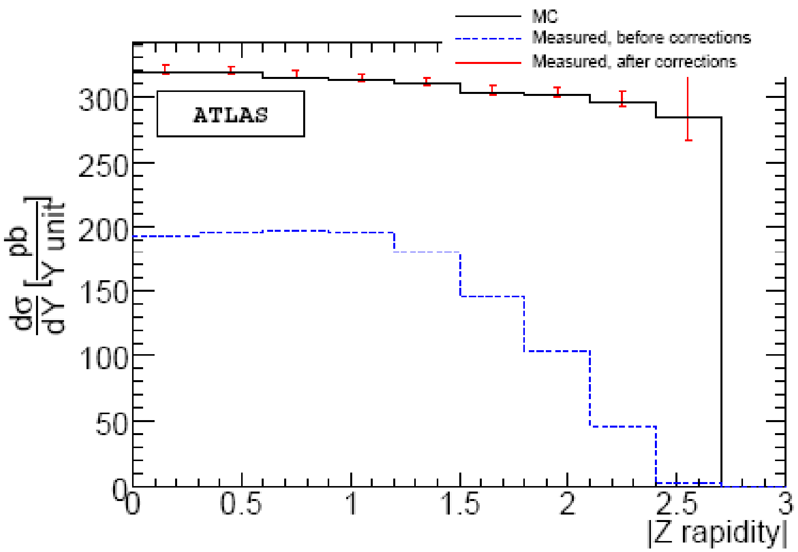


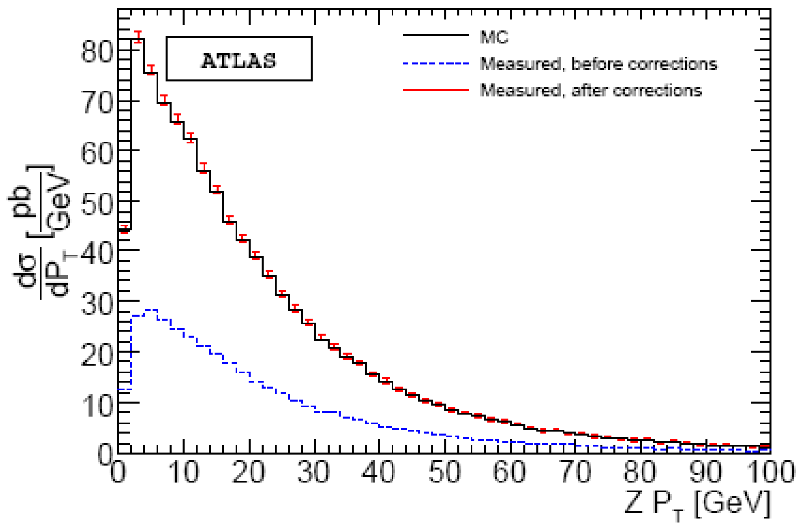


→ Differential cross-sections

- 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 12)

ATLAS CSC





~200 pb^{-1}

→ Differential cross-sections

- Total cross-section measurements are thus limited by the very effects we want to constrain!
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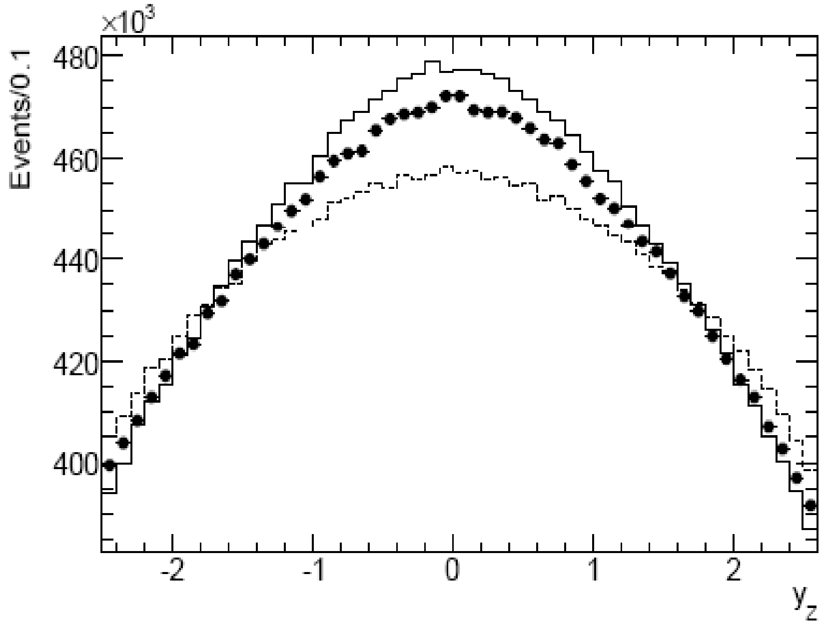
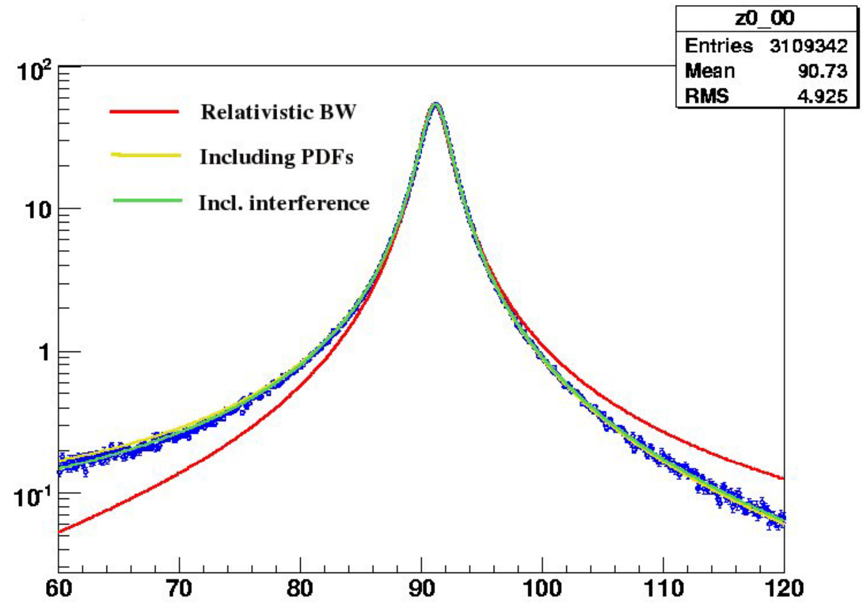
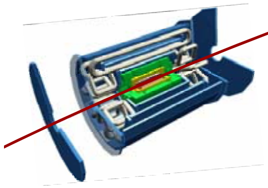




~10 fb^{-1}



Ratios : cross-normalizing experiment

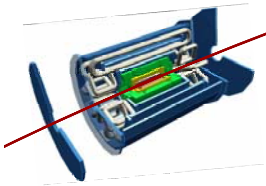
- Measure $R = \sigma / \sigma_{ref}$: $$\frac{dR}{R} = \frac{dN}{N} \oplus \frac{dN_{REF}}{N_{REF}} \oplus 0 \oplus \frac{d(\varepsilon/\varepsilon_{REF})}{(\varepsilon/\varepsilon_{REF})} \oplus \frac{d(A/A_{REF})}{(A/A_{REF})}$$

Statistical terms — No lumi term! — 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

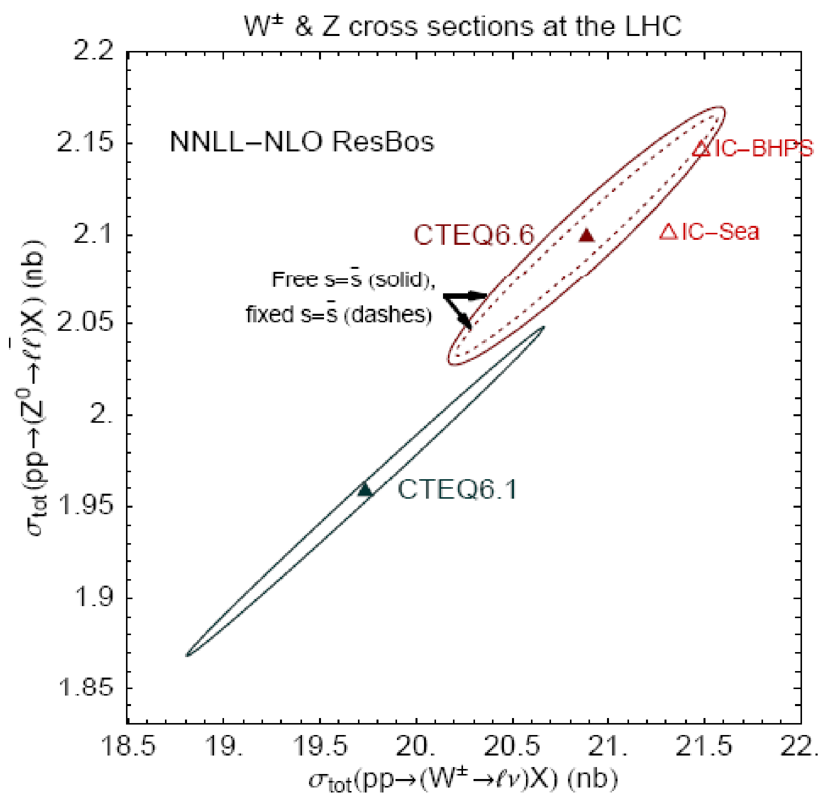
- Conversely : when possible, define R keeping this in mind, i.e maximize correlation with REF



Examples of ratios

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.

- Measurement also possible at 10 TeV!

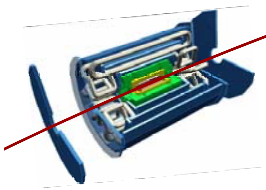
- Example of the contrary: σ_{tt}/σ_Z
  No useful correlations.
  Only adds Z rate uncertainty!!!

Ratios :
cross-normalizing theory

- Data-driven predictions :

$$\underbrace{\sigma_{pred}}_{\text{Poor prediction}} = \underbrace{\left(\frac{\sigma}{\sigma^{REF}}\right)_{pred}}_{\text{Precise prediction}} \underbrace{\left(\sigma^{REF}\right)_{meas}}_{\text{Measurement}}$$

- 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 $d\sigma_W/dy$

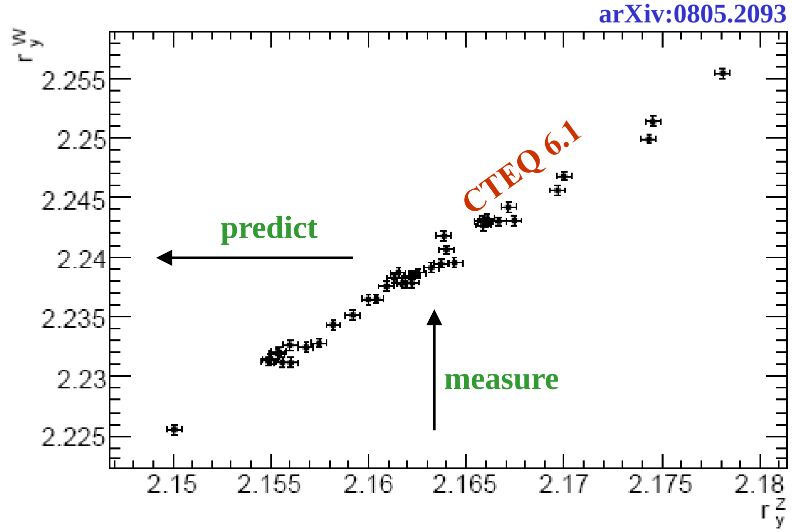
- Define :

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

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

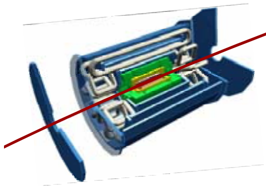
- Use RMS of rapidity distribution, $r_y^{W,Z}$, to quantify $d\sigma/dy$ and their variations (choice not unique)

arXiv:0805.2093



However, beware!!!

Different theoretical assumptions lead to 1% variations.

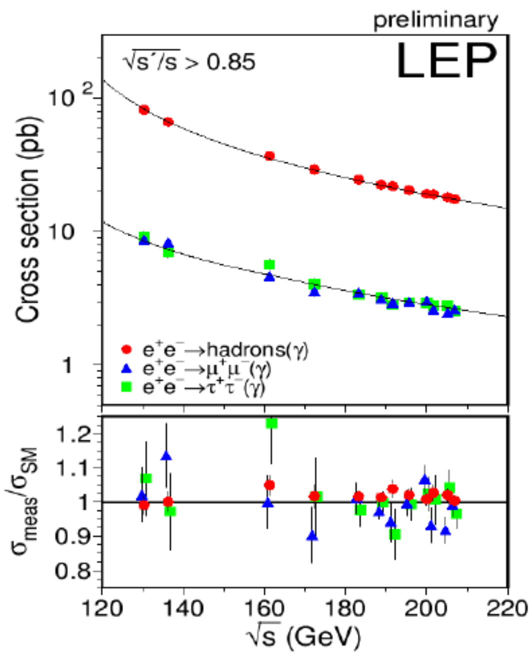


Data-driven predictions (2)

- Example : High-mass DY. Motivation:

Precision measurement above the Z. Cf. LEP2 :

- ~30 measurements, precision ~1-5%



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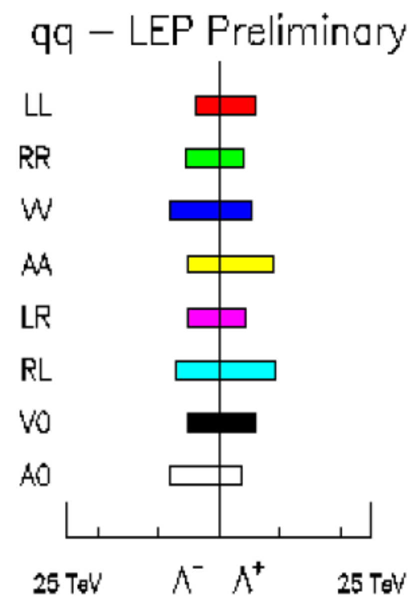
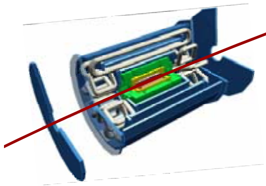




High-mass Drell-Yan

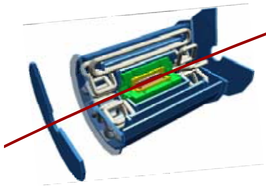
- Current LHC uncertainty : ~6-7% for 100 GeV < M < 1 TeV and y~0
- → Gain a factor ~5. To do this, relate:
  - $\sigma(m,y=0) \sim f^2(x,m)$ (at m [low-mass], **measure**)
  - $\sigma(m_Z,y\neq 0) \sim f(X,m_Z) \times f(x,m_Z)$ (at M_Z , **measure**)
  - $\sigma(M,y=0) \sim f^2(X,M)$ (at M [high-mass],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

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

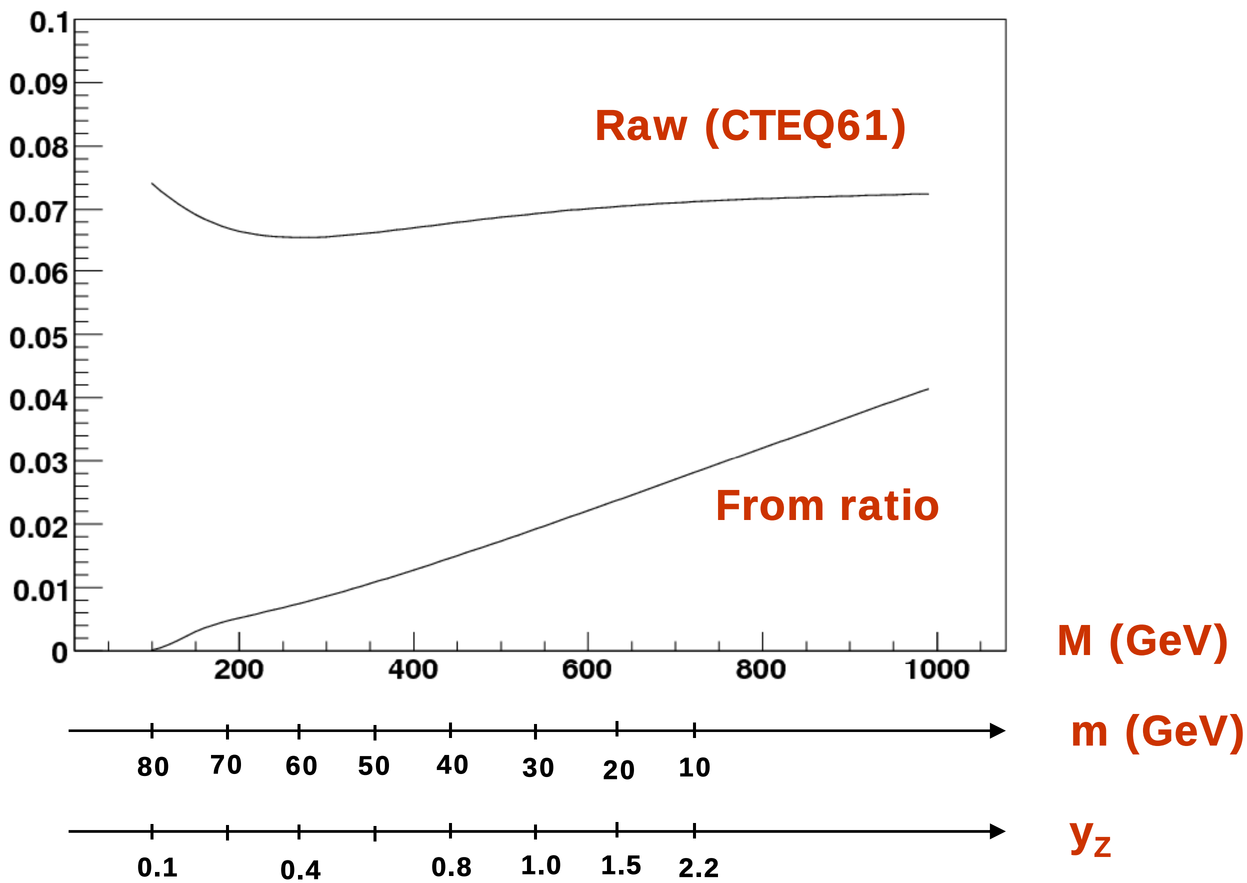
Raw prediction — **Smaller PDF dependence?** — **Measured**

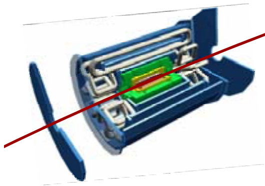
chosing m, M and y such that $m = M_Z\, e^{-y}$; $M = M_Z\, e^{+y}$

- Work by Maarten Boonekamp and Florent chevallier, in preparation.



High-mass Drell-Yan





Summary & Conclusions

- Cross-section measurements :
  - Complete program : A challenge in every aspect.
    - dL/L : Luminosity program well underway.
    - Efficiency, scale, and 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 : Eliminates L but introduces other uncertainties.
    - 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 connected.
  Major improvements expected.
- PDF uncertainty sets : A great tool.
  - Most important application : More than error estimation, investigation of correlations among different physics processes.