W & Z production at ATLAS

Feedback to the theory of strong interactions

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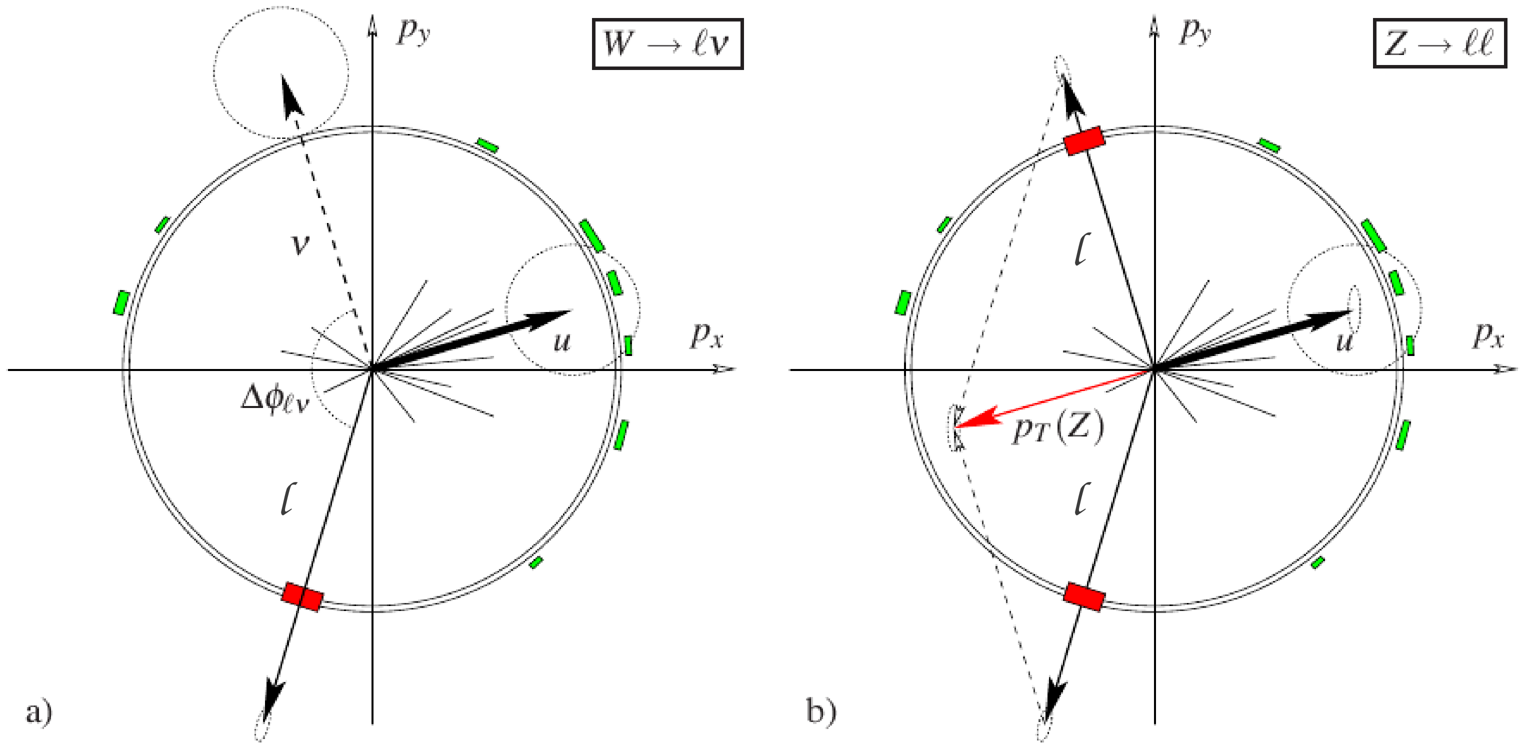
for the ATLAS Collaboration

W and Z production as a probe of strong interactions

- Event reconstruction, kinematics



$\mathbf{p_T^l}$, η^l

$\mathbf{p_T^l} + \mathbf{u} = E_T^{miss} \approx> p_T^\nu$

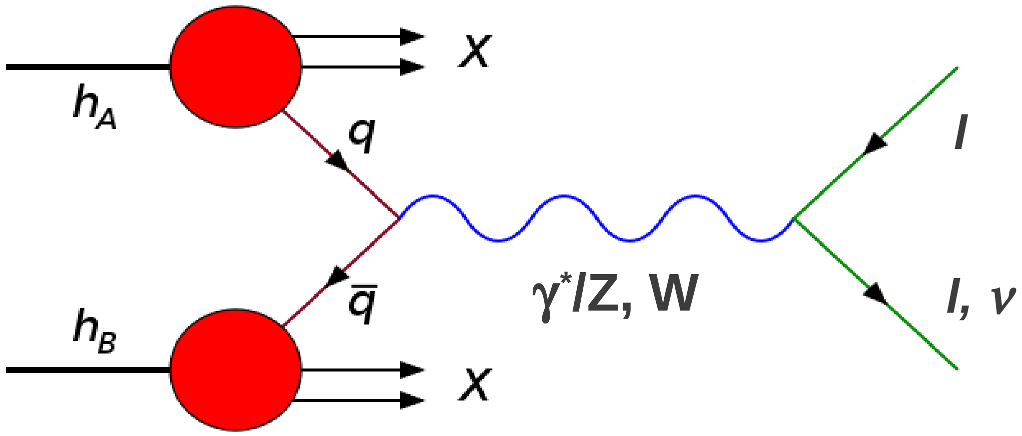
$M_T = [\, 2\, p_T^l\, p_T^\nu\, (1 - \cos\Delta\phi)\,]^{1/2}$

$\mathbf{p_T^1}$, η^1 ; $\mathbf{p_T^2}$, η^2

$M = [\, 2\, p_T^1\, p_T^2\, (\cosh\Delta\eta - \cos\Delta\phi)\,]^{1/2}$

W and Z production as a probe of strong interactions

- Probing the proton



$$\frac{d^2\sigma}{dQ^2 dx} \sim \Sigma_i q_i(x)\overline{q}_i(x)\hat{\sigma}(Q^2)$$

- From detector-level to parton-level kinematics:
  - **$\frac{1}{2}\ln(E^Z+p_L^Z)/(E^Z-p_L^Z) = y^Z = \frac{1}{2}\ln x1/x2$**

    → **$q_i(x)$? $\overline{q}_i(x)$?**
  - **$p_T^1 + p_T^2 \rightarrow p_T^Z = p_T$ imbalance of incoming partons (LO) + hard radiation (HO)**

    → **what generates the transverse momentum distribution?**

Discussed below:

- Measurements (2010, ~35 pb^{-1})
  - Inclusive W and Z cross sections : Phys. Rev. D85 (2012) 072004
  - W transverse momentum distribution : Phys.Rev. D85 (2012) 012005
  - Z transverse momentum distribution : Phys.Lett. B705 (2011) 415-434
- Interpretation
  - Monte Carlo tuning : ATL-PHYS-PUB-2011-015
  - PDF determination : arXiv:1203.4051

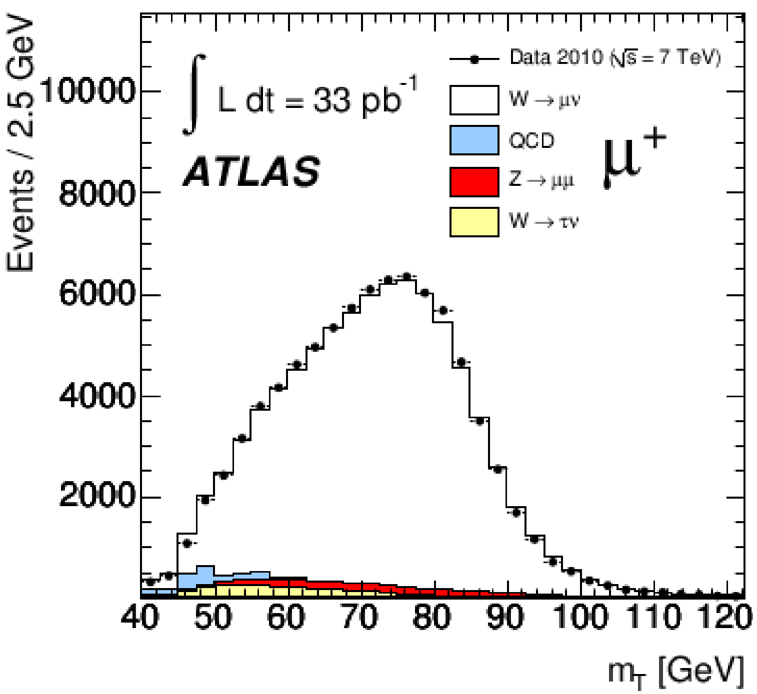
Cross sections (W)

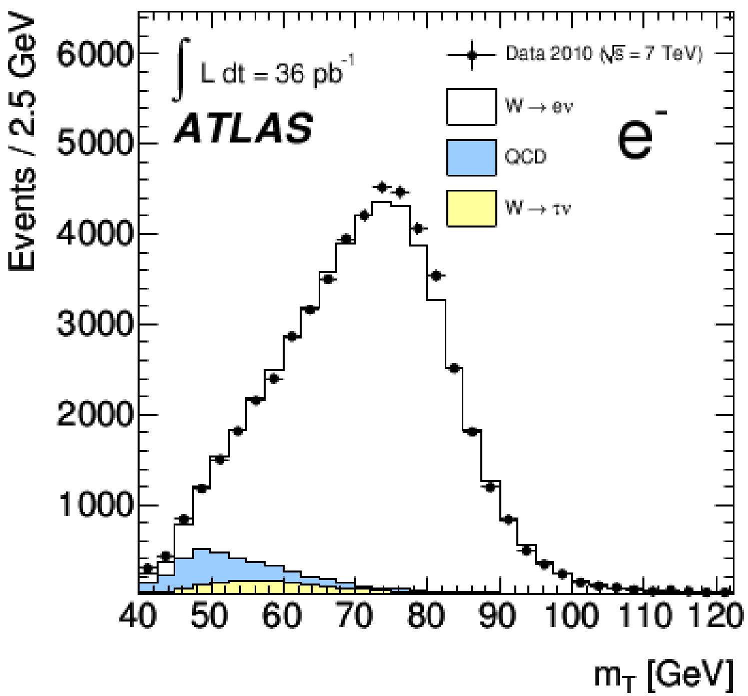
- Event selections :

$$W \to e\nu: \quad p_{T,e} > 20 \ \text{GeV}, \ |\eta_e| < 2.47, \ \text{excluding} \ 1.37 < |\eta_e| < 1.52, \ p_{T,\nu} > 25 \ \text{GeV}, \ m_T > 40 \ \text{GeV}$$

$$W \to \mu\nu: \quad p_{T,\mu} > 20 \ \text{GeV}, \ |\eta_\mu| < 2.4, \ p_{T,\nu} > 25 \ \text{GeV}, \ m_T > 40 \ \text{GeV}$$

- ~135k events selected per channel; W+ and W- measured separately
- Backgrounds subtracted using Monte Carlo or data-driven methods





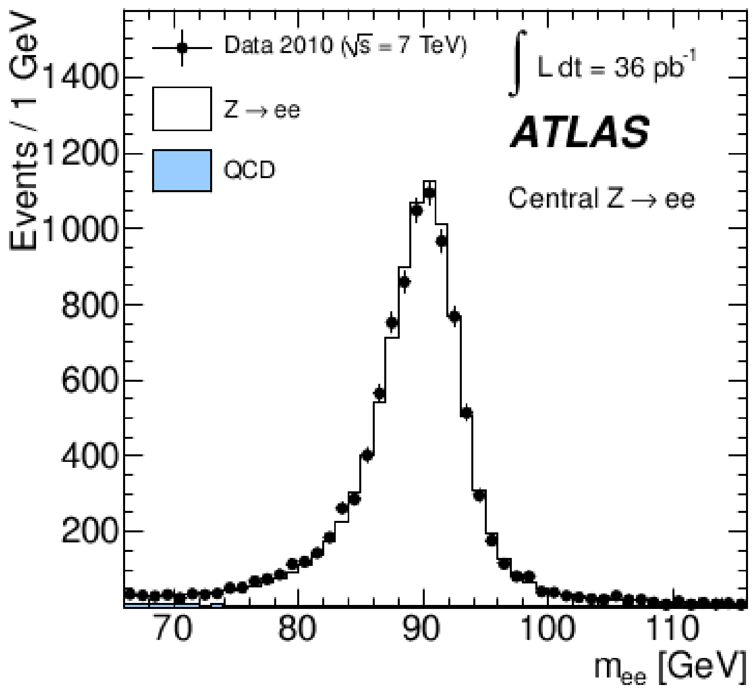
Cross sections (Z)

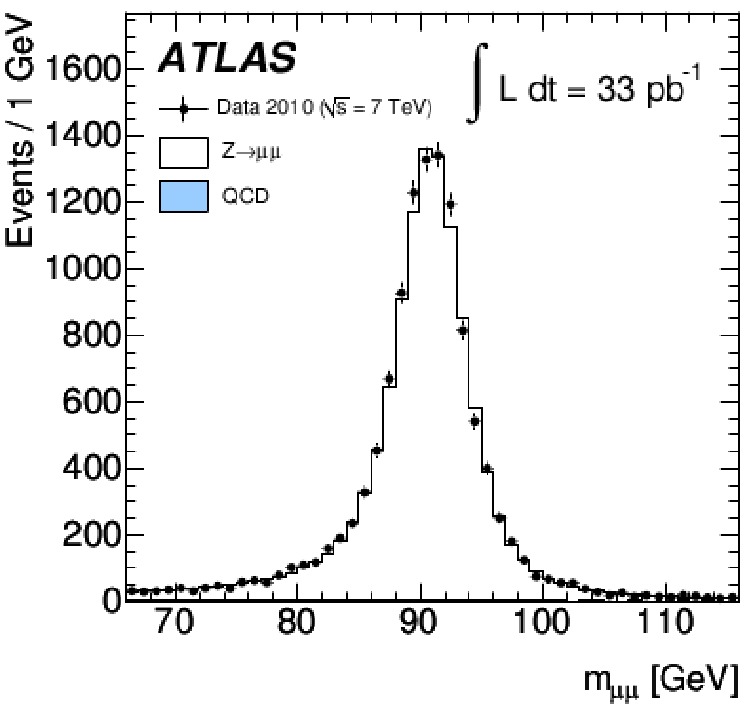
- Event selections :

$$Z \to ee: \quad p_{T,e} > 20 \text{ GeV}, \text{ both } |\eta_e| < 2.47, \text{ excluding } 1.37 < |\eta_e| < 1.52, \; 66 < m_{ee} < 116 \text{ GeV};$$

$$Z \to \mu\mu: \quad p_{T,\mu} > 20 \text{ GeV}, \text{ both } |\eta_\mu| < 2.4, \; 66 < m_{\mu\mu} < 116 \text{ GeV}.$$

  - ~10k events selected per channel
  - "forward Z selection" in the electron channel : $2.5 < \eta_2 < 4.9$





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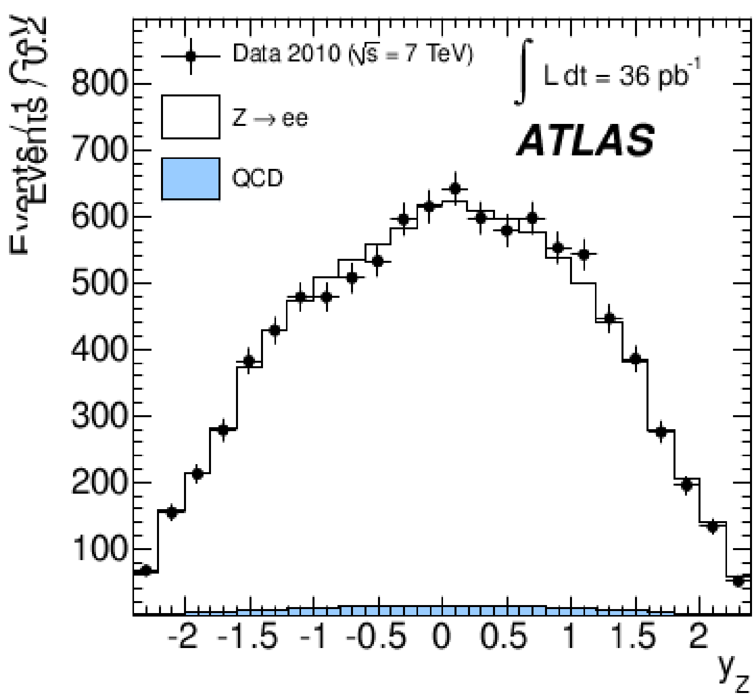
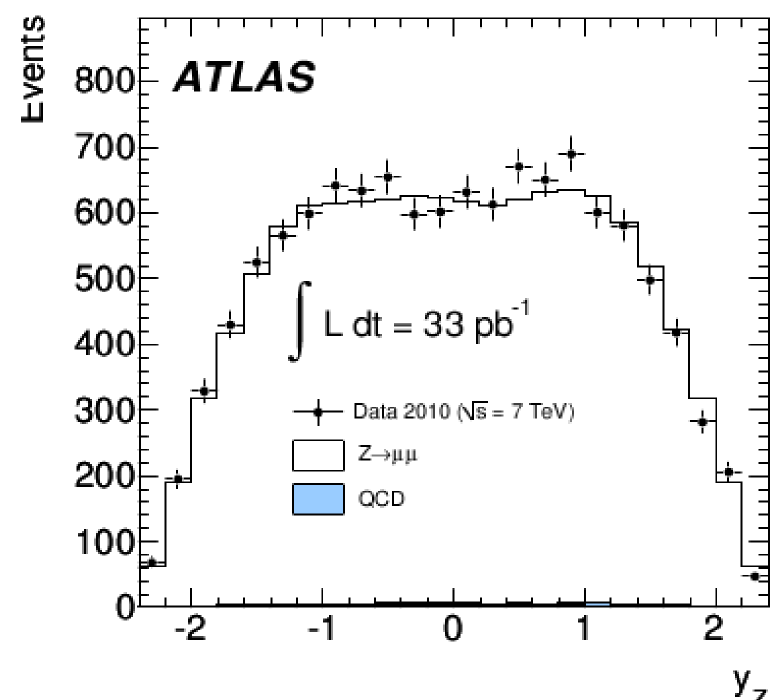




Cross sections

- Efficiency and acceptance corrections
  - Primary result : fiducial cross sections and distributions : efficiency/resolution corrected data, as close as possible to the experimental measurement. They feed the strong interaction studies downstream:

$$\sigma_{\rm fid} = \frac{N - B}{C_{W/Z} \cdot L_{\rm int}}$$

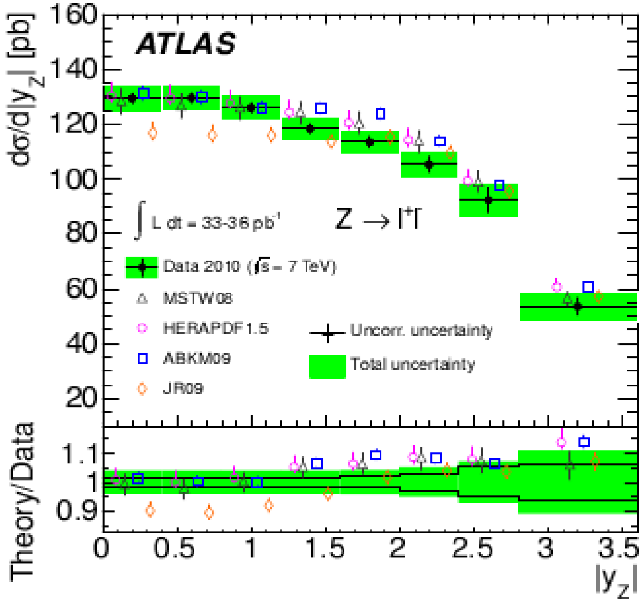
$$\begin{aligned} \eta_\ell &= [\,0.00\,,\,0.21\,,\,0.42\,,\,0.63\,,\,0.84\,,\,1.05\,,\,1.37\,,\,1.52\,, \\ &\quad 1.74\,,\,1.95\,,\,2.18\,,\,2.47\,(e)\ \text{or}\ 2.40\,(\mu)\,]\,; \\ y_Z &= [\,0.0\,,\,0.4\,,\,0.8\,,\,1.2\,,\,1.6\,,\,2.0\,,\,2.4\,,\,2.8\,,\,3.6\,]\,, \end{aligned}$$

  - Also extrapolated cross section (to full phase space), for comparison with existing theoretical calculations:

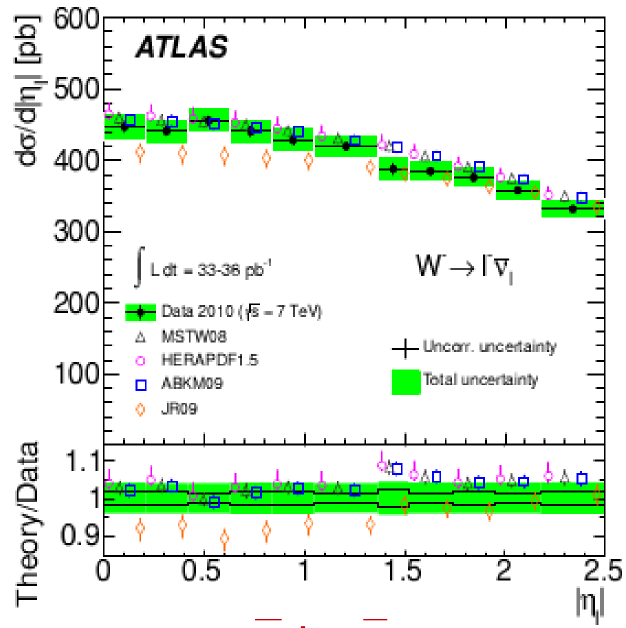
$$\sigma_{\rm tot} = \sigma_{W/Z} \times BR(W/Z \to \ell\nu/\ell\ell) = \frac{\sigma_{\rm fid}}{A_{W/Z}}$$

Experimental results

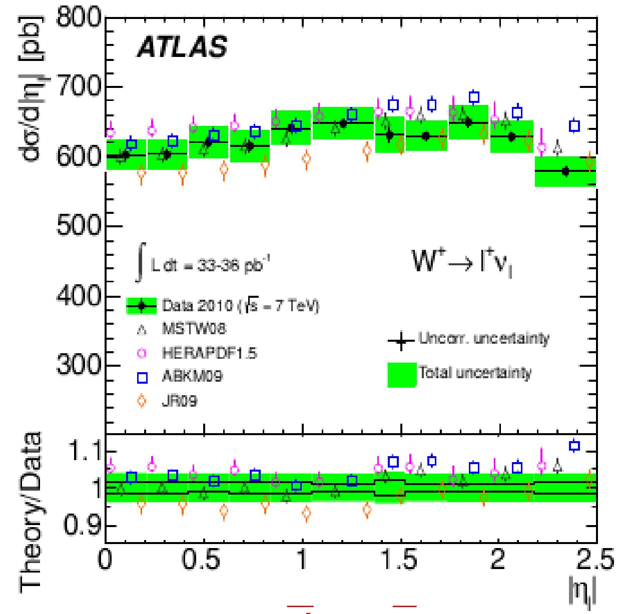
- Longitudinal distributions
  - Z rapidity
  - Decay lepton pseudorapidity for W+ and W-



$u\bar{u} + d\bar{d} + s\bar{s} + \ldots$



$\bar{u}d + \bar{c}s + \ldots$

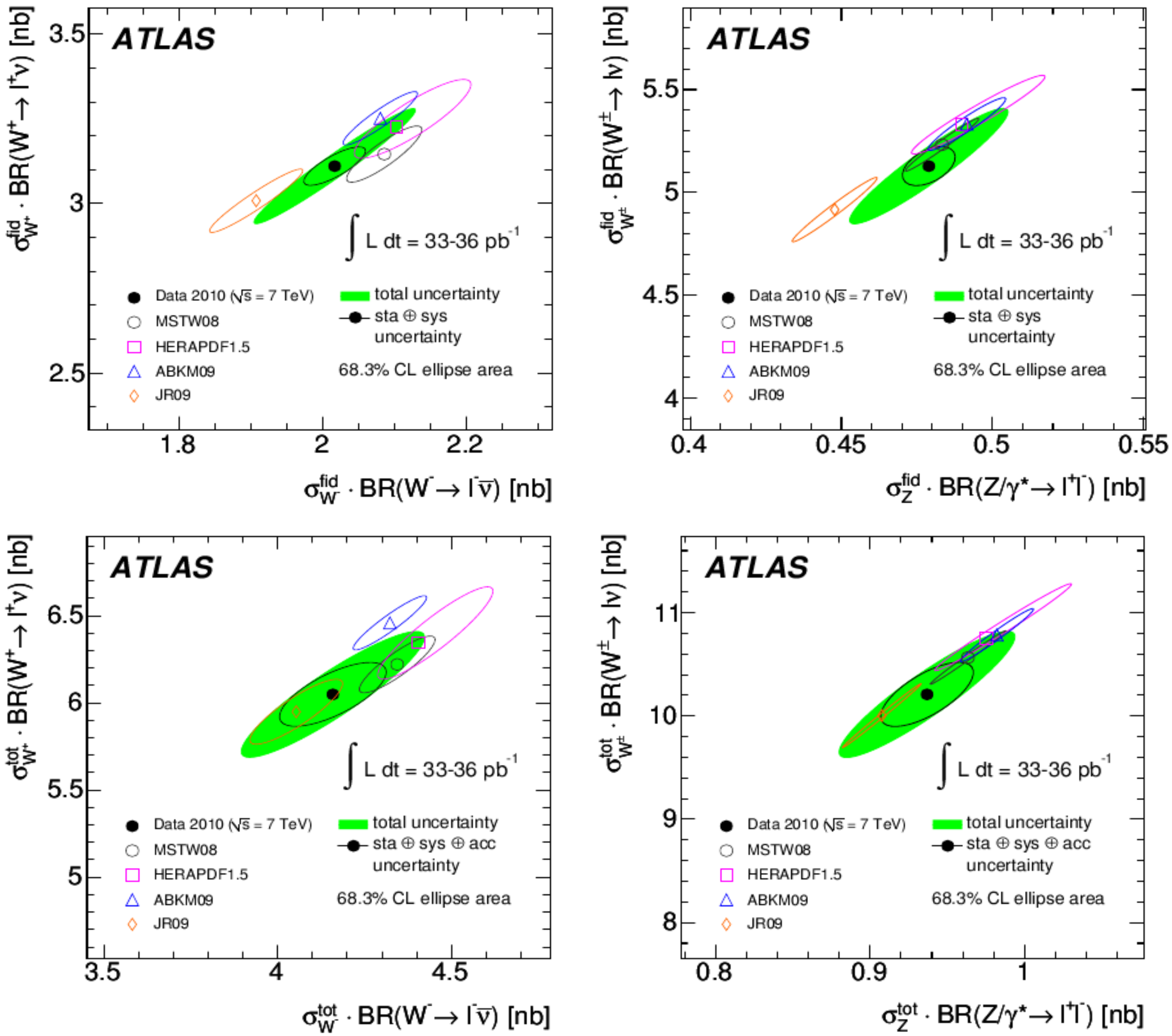


$u\bar{d} + c\bar{s} + \ldots$

- These processes are sensitive to different parton flavour configurations, which their combined interpretation allows to disentangle

Experimental results

- Fiducial → total (extrapolated) cross sections

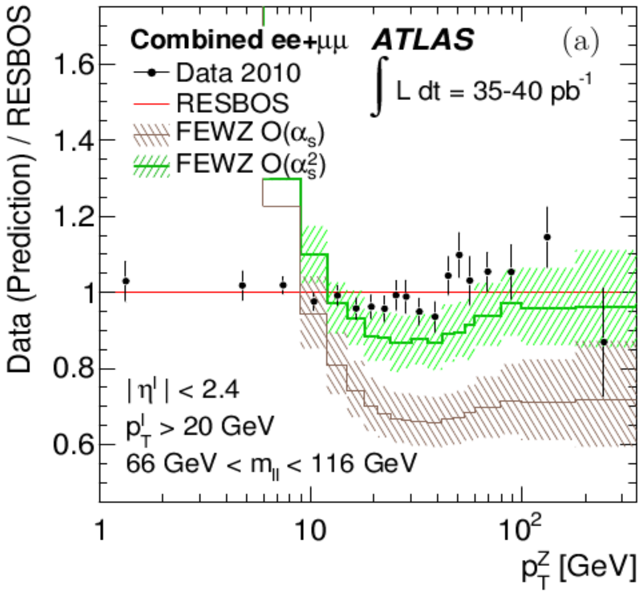


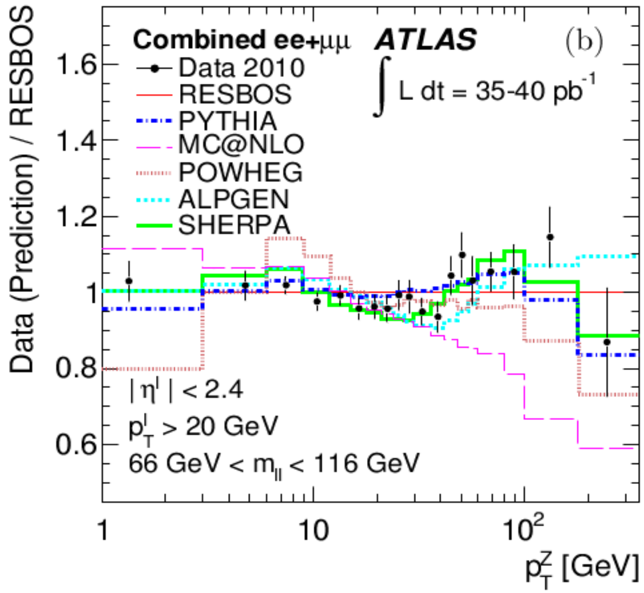
data are still less precise than single predictions, but more than differences among predictions : some model discrimination already

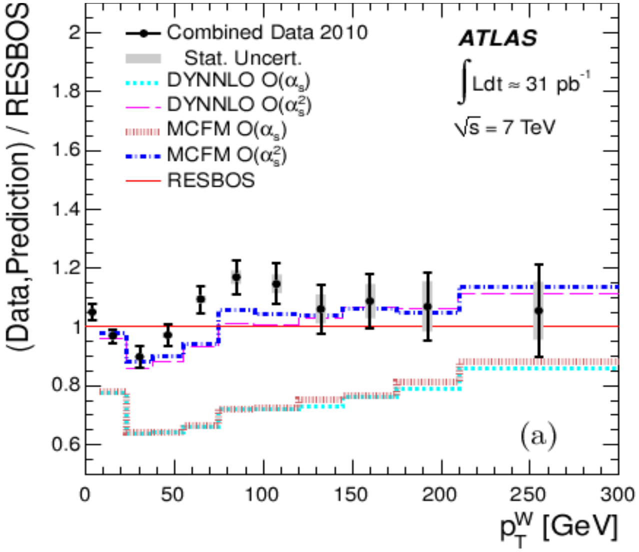
fiducial cross sections provide better model discrimination than total cross sections

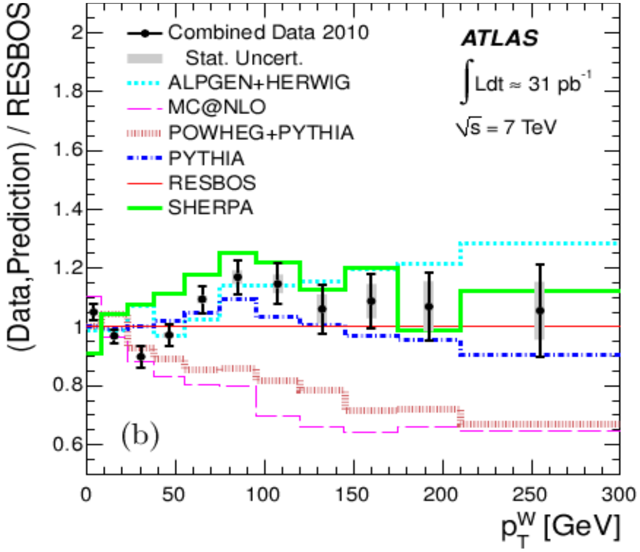
Experimental results

- Transverse momentum distributions
  - Z bosons
  - W bosons



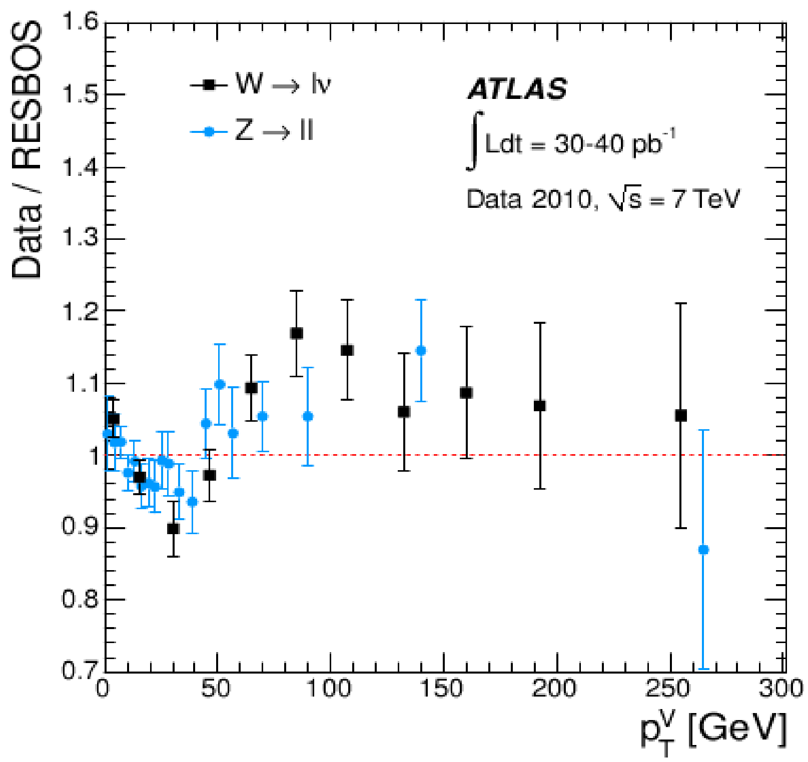


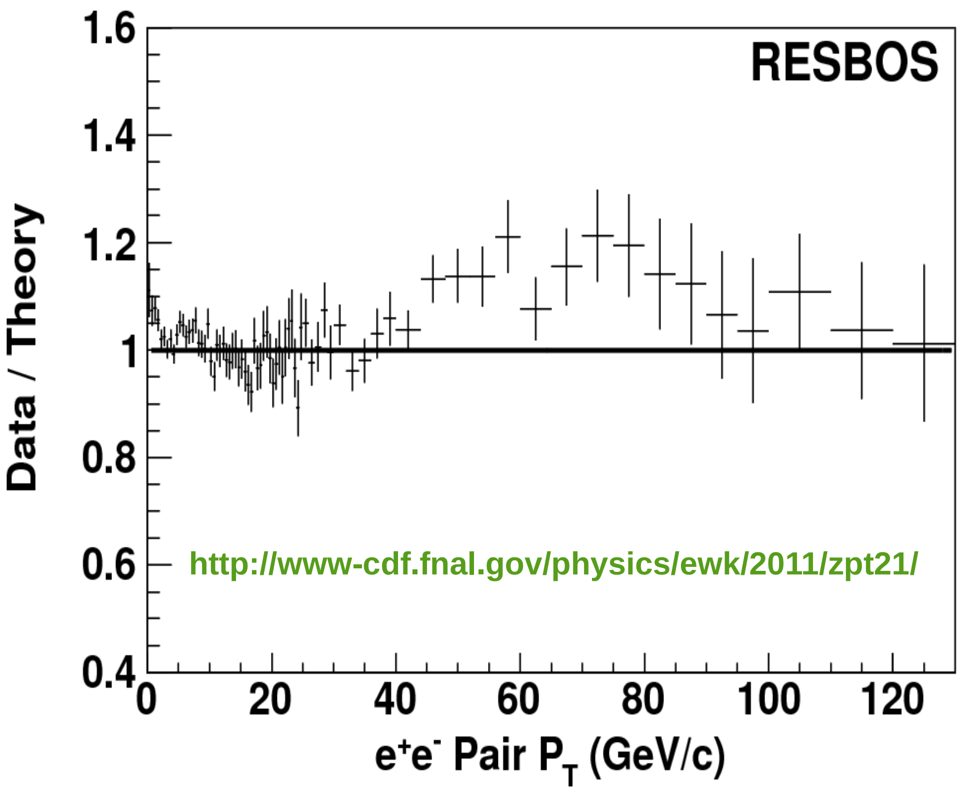




Experimental Results

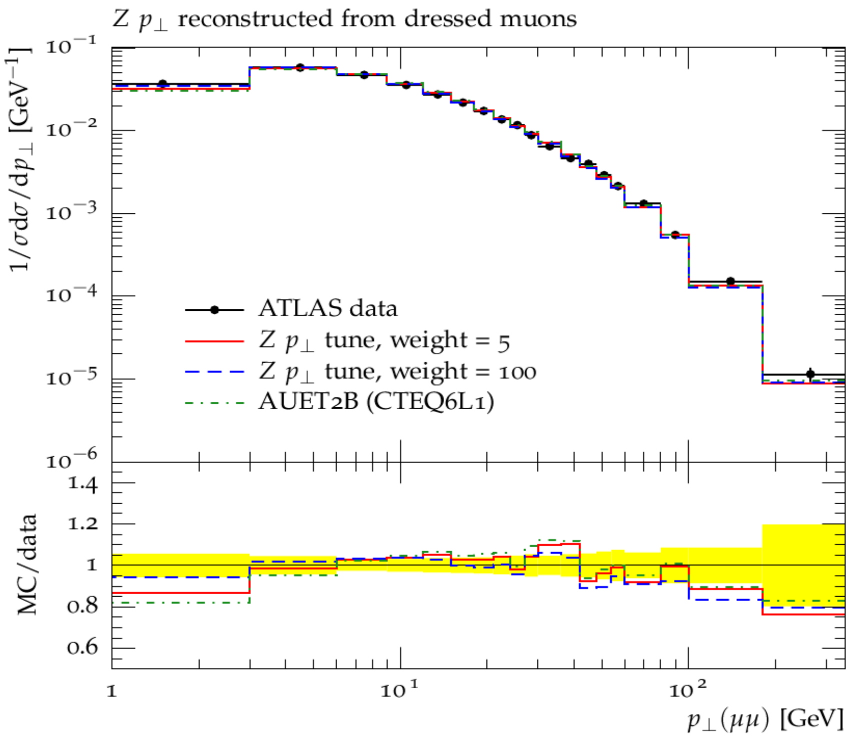
- Data seem to give a consistent picture
  - NLO predictions undershoot data at high $p_T^{W,Z}$, NNLO or higher-order ME predictions restore agreement: higher-order corrections to this distribution are important
  - Data allow to refine parton shower / resummation models (ATLAS W and Z channels compare consistently to ResBos, recently confirmed by CDF)

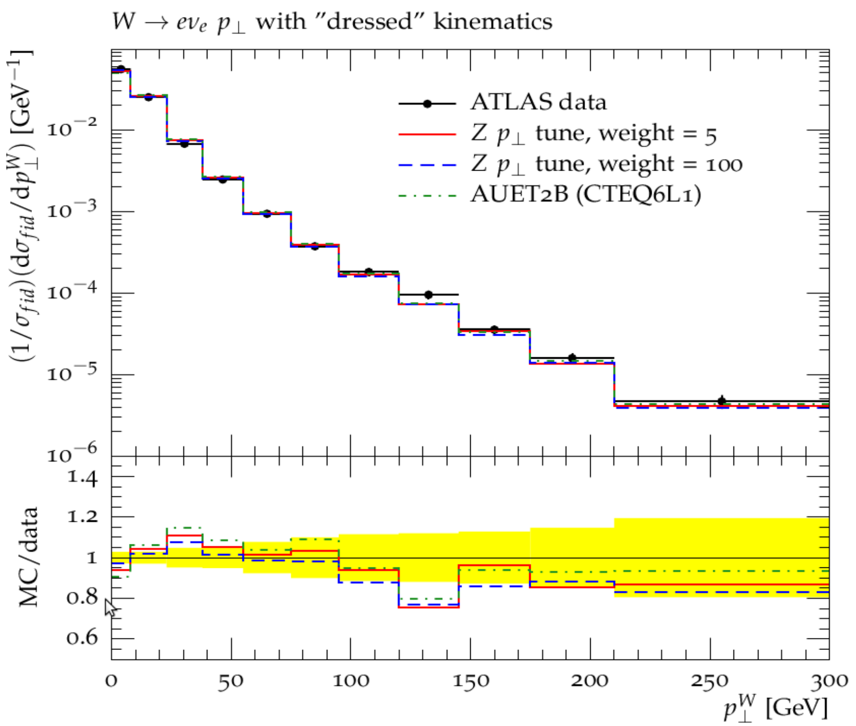




Applications : Monte Carlo tuning

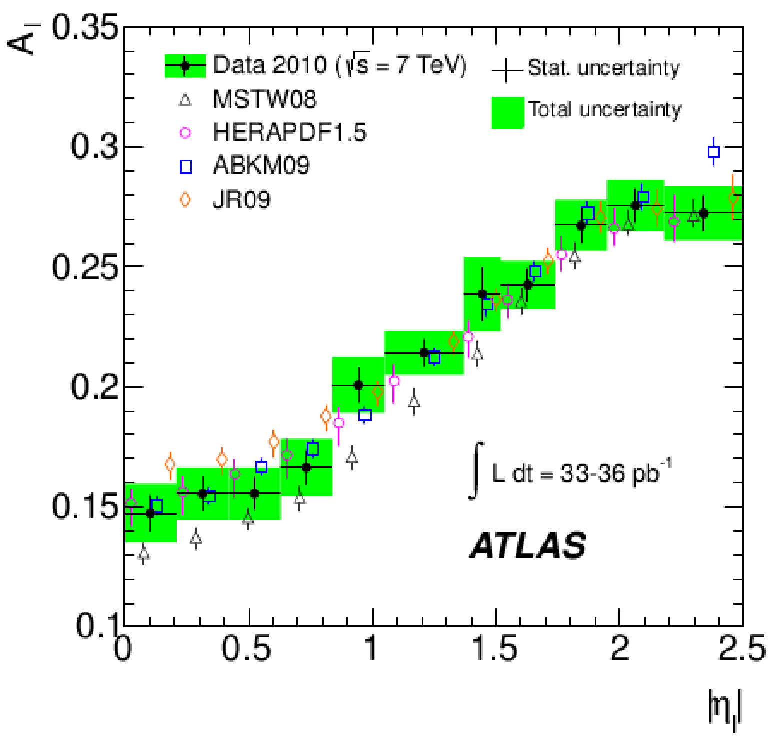
- Data are exploited to refine the “tuning” of non-perturbative parameters entering our Monte Carlo programs
  - Refines the description of transverse distributions in W and Z events
  - Implications for cross section measurements (acceptance), and precision electroweak (M_W, where the Jacobians peaks need accurate description in order to be interpreted properly)

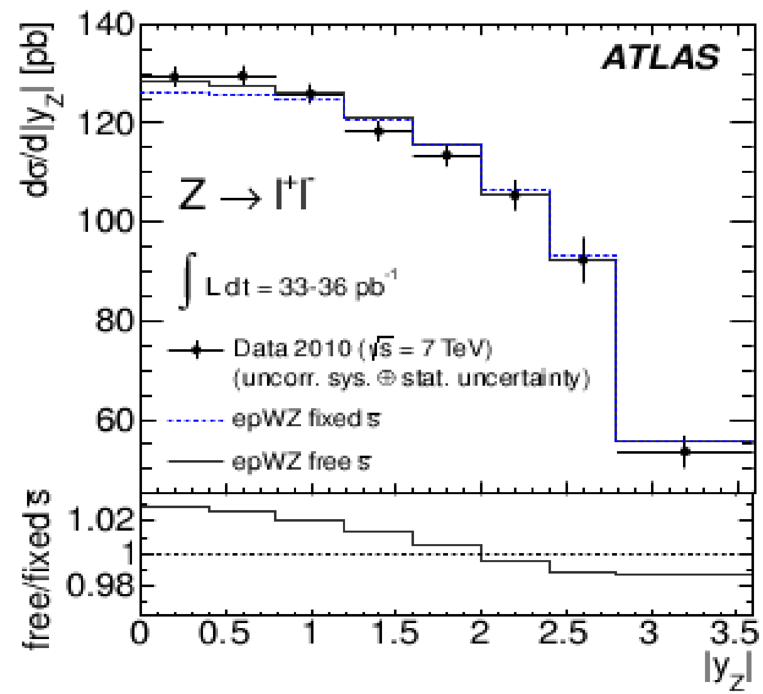




Applications : PDF fits

- A long-lasting mystery in the proton structure is the strange density
  - Poorly constrained at Hera, where F2 is mostly sensitive to the total (**u+c**) and (**d+s**) components
  - Particularly relevant at the LHC, where W & Z are produced in pp, and at low x, enhancing second generation contributions to the production rate
- ATLAS data (specifically, W asym and W/Z ratio) provide new insights on **s**:





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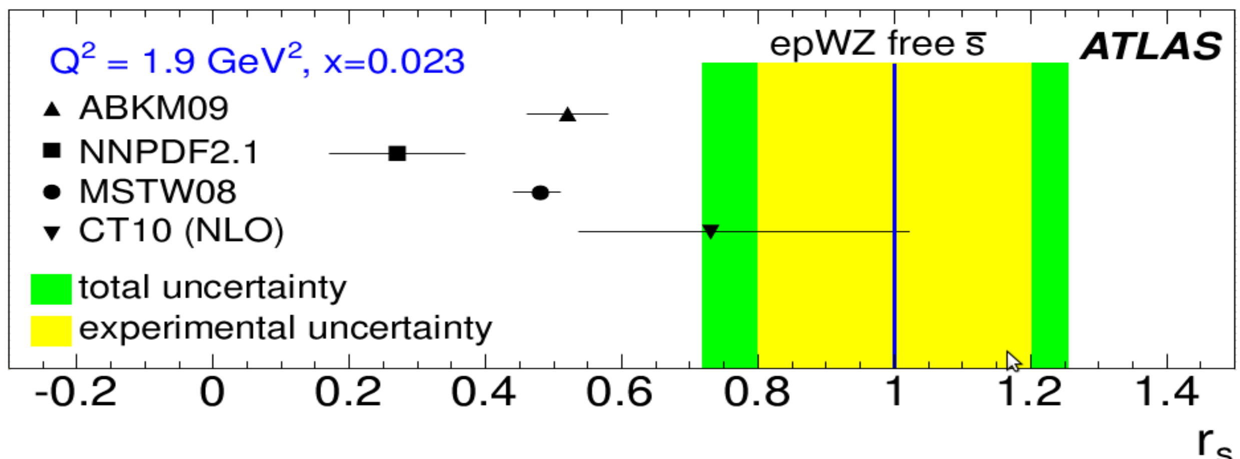
- ATLAS data provide new insights on **s**. Define $r_s = ½ (s + \bar{s})/\bar{d}$:

At Q = 1.9 GeV :



At Q = M_Z :

$$r_s = 1.00 \pm 0.07_{\mathrm{exp}} \pm 0.03_{\mathrm{mod}} {}^{+0.04}_{-0.06}{}_{\mathrm{par}} \pm 0.02_{\alpha_S} \pm 0.03_{\mathrm{th}}$$

- Atlas result based on Hera+W,Z data only, ~not affected by non-perturbative uncertainties (fragmentation, nuclear corrections)

Summary and perspectives

- 2010 data analyzed and digested : $\sqrt{s}$ = 7 TeV; $\mathcal{L}$ = 35 pb^{-1}
  - Percent level measurements, already constraining our uncertainties
  - Improved description of parton shower / resummation
  - New constraints on the strange density
- 2011 data measurements being finalized : $\sqrt{s}$ = 7 TeV; $\mathcal{L}$ = 5 fb^{-1}
  - Target precisions of few/mil, tightening the 2010 constraints
  - Major challenge to detector performance, in particular selection efficiencies
- 2012 : $\sqrt{s}$ = 8 TeV; $\mathcal{L}$ = 6 fb^{-1} and counting
  - Increase in energy provides new handles

"LHC Run1" will likely end with 20-30 fb^{-1} of data collected by ATLAS

Unseen samples : 10^8 selected W events, 10^7 Z events

Providing knowledge of our detector, of QCD, and – ultimately – EW symmetry breaking