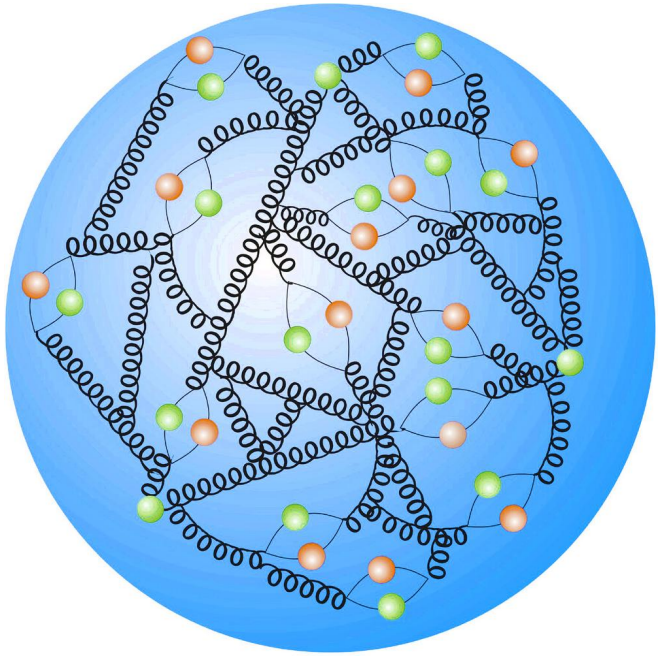
Precision measurements of single vector boson production at ATLAS

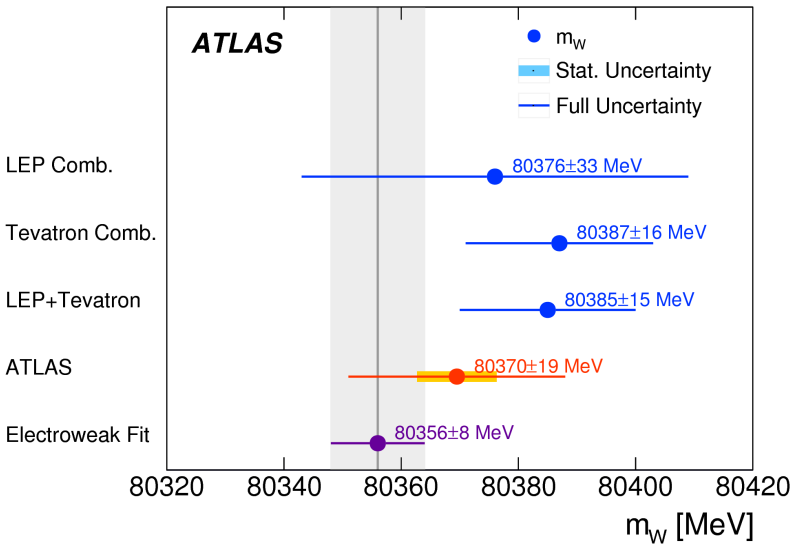


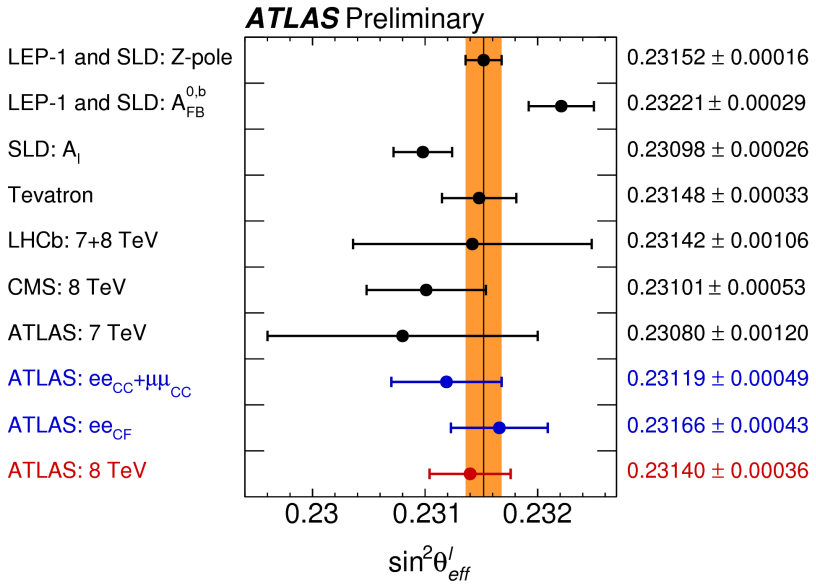
Kristin Lohwasser
University of Sheffield

40th International Conference on High Energy Physics, ICHEP, 28 July 2020

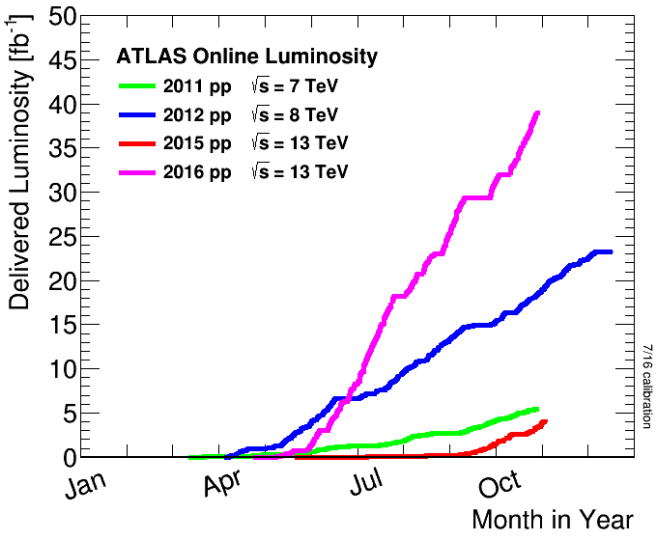
Precision at the LHC

- With or without further discoveries: LHC is currently the only machine to give more information about Higgs Boson or the Standard Model
  - Some theorists discuss 1% percent uncertainty – in the extreme hadron collider environment! [https://gsalam.web.cern.ch/gsalam/talks/repo/2016-03-SB+SLAC-Munich-precision.pdf]
- Precision of ATLAS W-mass and weak mixing angle measurements only slightly worse than TeVatron *combination*
- Uncertainties dominated by PDFs





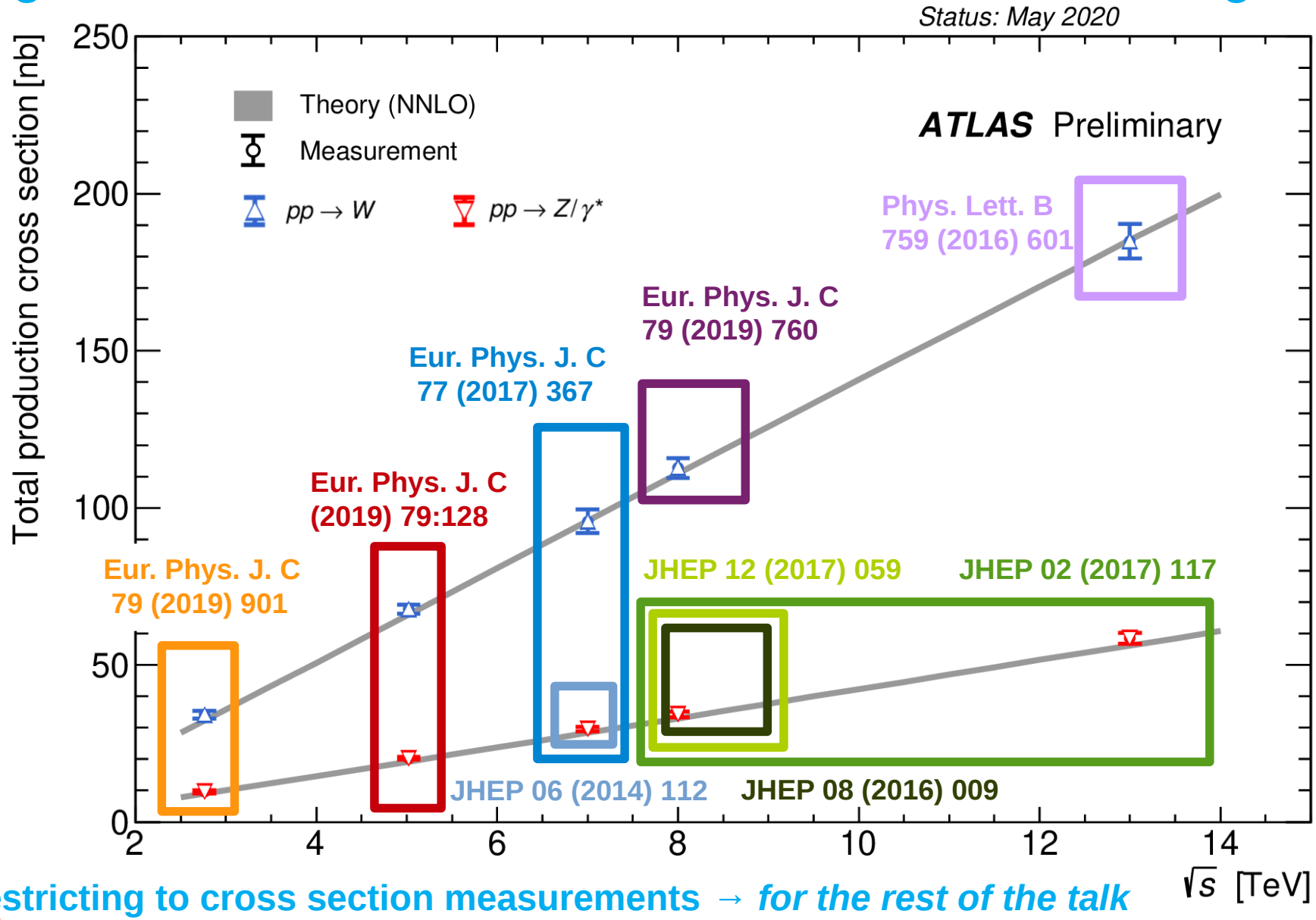
A wealth of data at the LHC



- Largest data set ever collected at hadron collider
- Luminosity uncertainty **around 2%** but largely uncorrelated between centre-of-mass energies
- **Unique opportunity to understand proton dynamics**

- $\sqrt{s}$ = 2.76 TeV — **5 pb^{-1}**
- $\sqrt{s}$ = 5 TeV — **25 pb^{-1}**
- $\sqrt{s}$ = 7 TeV — **4 fb^{-1}**
- $\sqrt{s}$ = 8 TeV — **20.3 fb^{-1}**
- $\sqrt{s}$ = 13 TeV — **139.0 fb^{-1}**

Single boson measurements for all centre-of-mass-energies*



*** restricting to cross section measurements → *for the rest of the talk***

Fiducial phase spaces

>Z Boson

- Lepton pT threshold
  $p_T(\ell)$>20 GeV
  (25 GeV – 8, 13 TeV)
- Maximal pseudo-rapidity
  $|\eta|$<2.5
  ($|\eta|$<2.4 – 2.76 TeV)
  ($|\eta|$<4.9 – 7 TeV)
  ($|\eta|$<4.9 – 8 TeV)
- Mass range
  66<$m_{\ell\ell}$<116 GeV
  (46 < $m_{\ell\ell}$ < 150 GeV – 7 TeV)
  (26 < $m_{\ell\ell}$ < 66 GeV – 7 TeV)
  (116 < $m_{\ell\ell}$ < 1500 GeV – 8 TeV)

>W Boson

- Lepton pT threshold
  $p_T(\ell)$>25 GeV
  (20 GeV – 2.76 TeV)
- Neutrino pT threshold
  $p_T(\nu)$>25 GeV
- Maximal pseudo-rapidity
  $|\eta|$<2.5
- Transverse Mass mT
  $m_T(W)$ > 40 GeV
  ($m_T(W)$ > 50 GeV – 13 TeV)

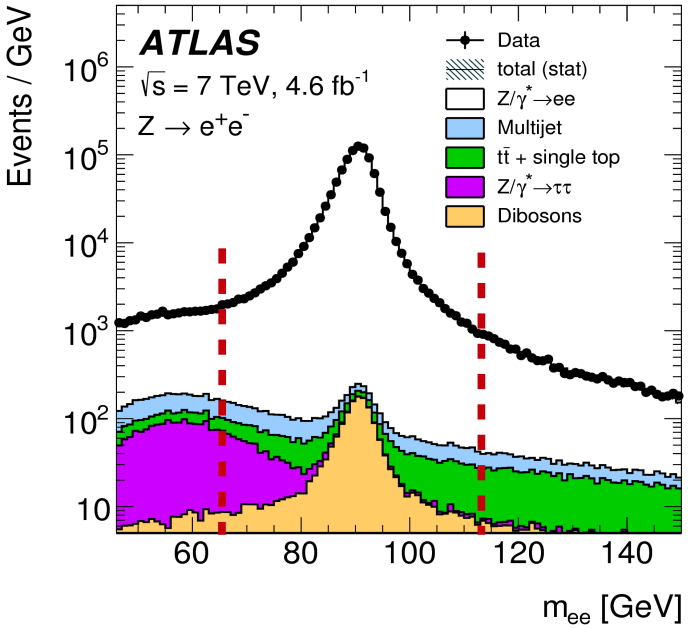
Fiducial phase spaces

> Z Boson

$p_T(\ell)$>20 GeV

$|\eta|$<2.5

66<$m_{\ell\ell}$<116 GeV



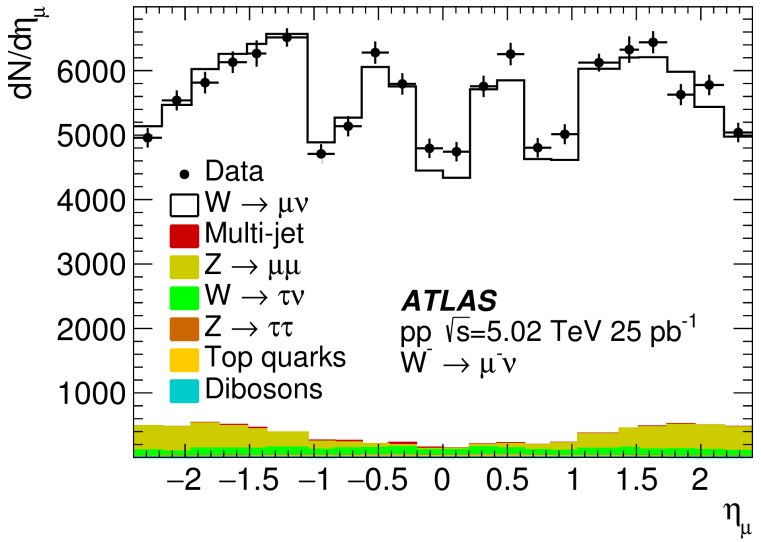
> W Boson

$p_T(\ell)$>25 GeV

$p_T(\nu)$>25 GeV

$|\eta|$<2.5

$m_T(W)$ > 40 GeV



Very clean signatures, low backgrounds

Dominated by lepton reconstruction uncertainties → correlated over channels

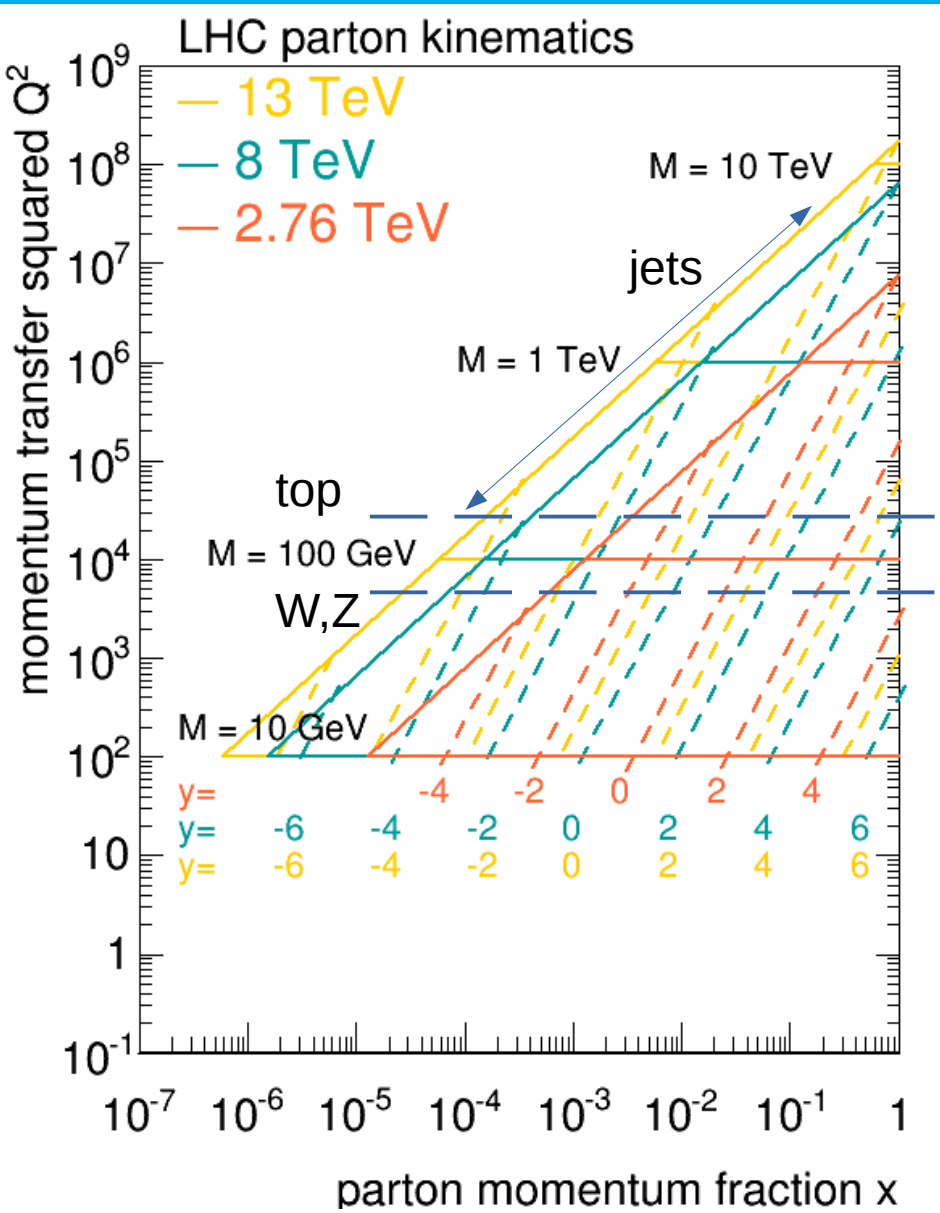
Phase space at the LHC

> **x-dependence:**
valence quarks carry higher momentum

> **Q^2 dependence:**
higher resolution,
more gluon and sea quark contributions

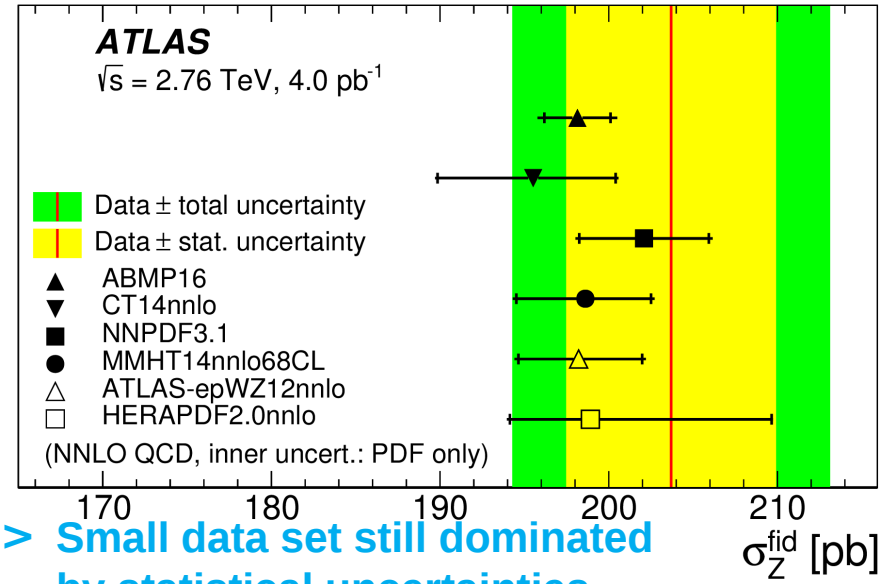
> **Kinematics are determined by centre-of-mass energy**

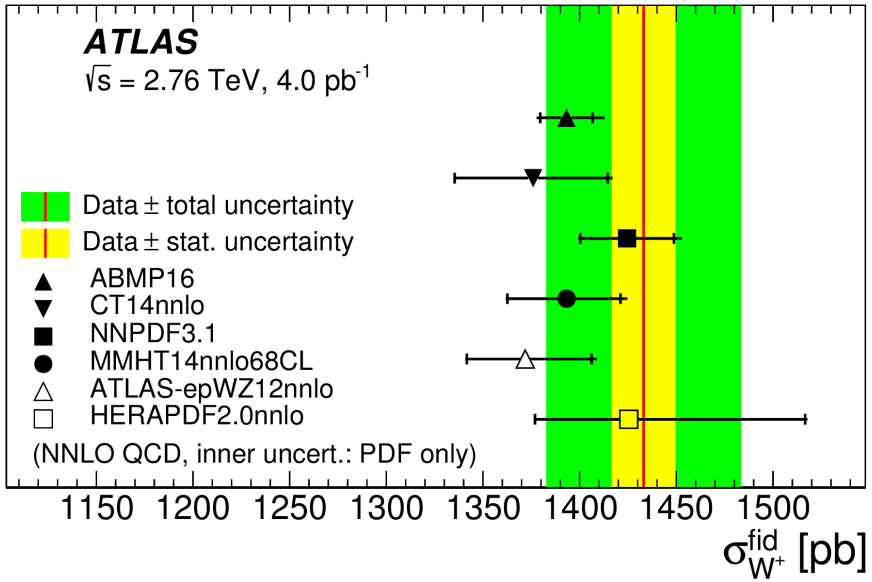
- $$x_{1,2} = \frac{M}{\sqrt{s}} e^{\pm y}$$
- For fixed mass and fixed y:
larger $\sqrt{s}$ → smaller x
- Has a distinct effect on composition of gluons, sea and valence quarks

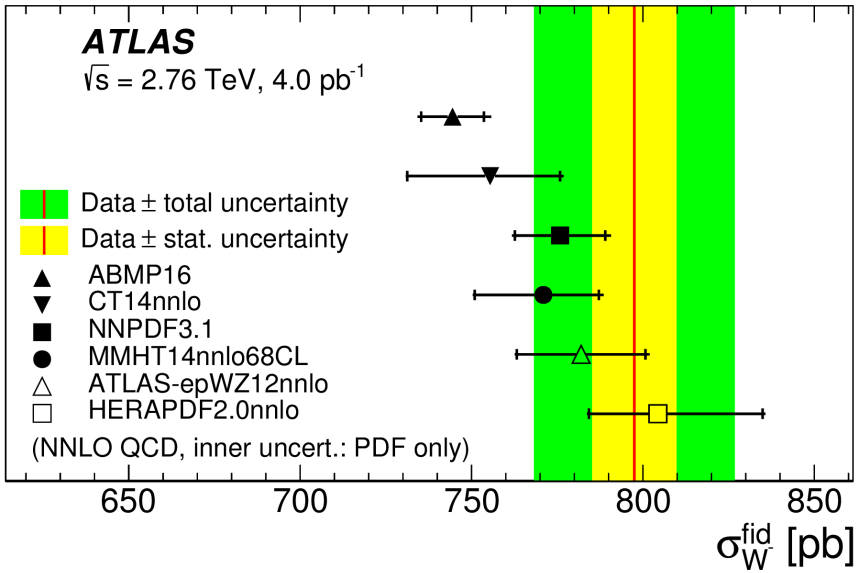


W/Z cross sections at $\sqrt{s}$ = 2.76 TeV

Eur. Phys. J. C 79 (2019) 901







> **Small data set still dominated by statistical uncertainties**

> **Reasonable agreement between data and predictions for Z cross-section**
- Slightly low for all PDFs

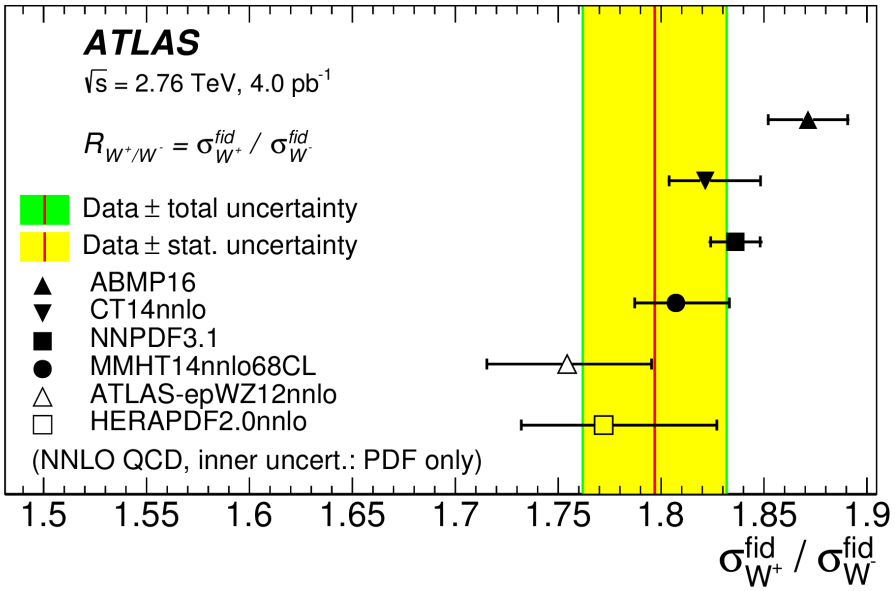
> **Larger disagreements between data and prediction for W cross-section**
- Best agreement with HERAPDF2.0nnlo only HERA data

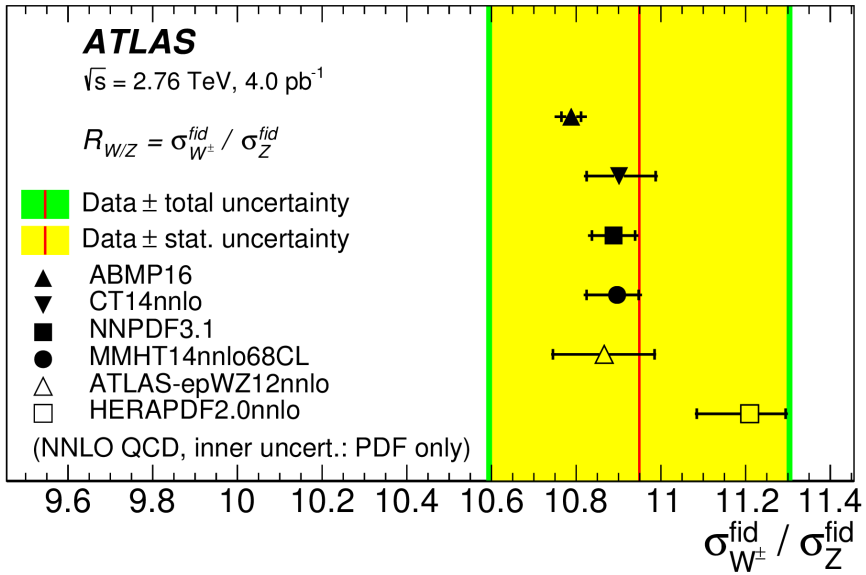
Predictions from DYNNLO 1.5 (NNLO, $O(\alpha_s^2)$) with full spin correlations, NLO EW effects with Fewz 3.1 (Z bosons) / Sanc (W bosons) in Gμ EW scheme (~ -0.25% effect). FEWZ used for PDF/scale uncertainty. Scales used: dynamic $m_{\ell\ell}$, fixed m_W.

Sheffield.

W/Z cross sections at $\sqrt{s}$ = 2.76 TeV

Eur. Phys. J. C 79 (2019) 901





> **Ratios significantly reduce systematic uncertainties due to systematics cancellations**

- Slight (<2σ) tension of W+/W- data ABMP16 PDF set
  contains 7+8 TeV LHC W,Z and top data

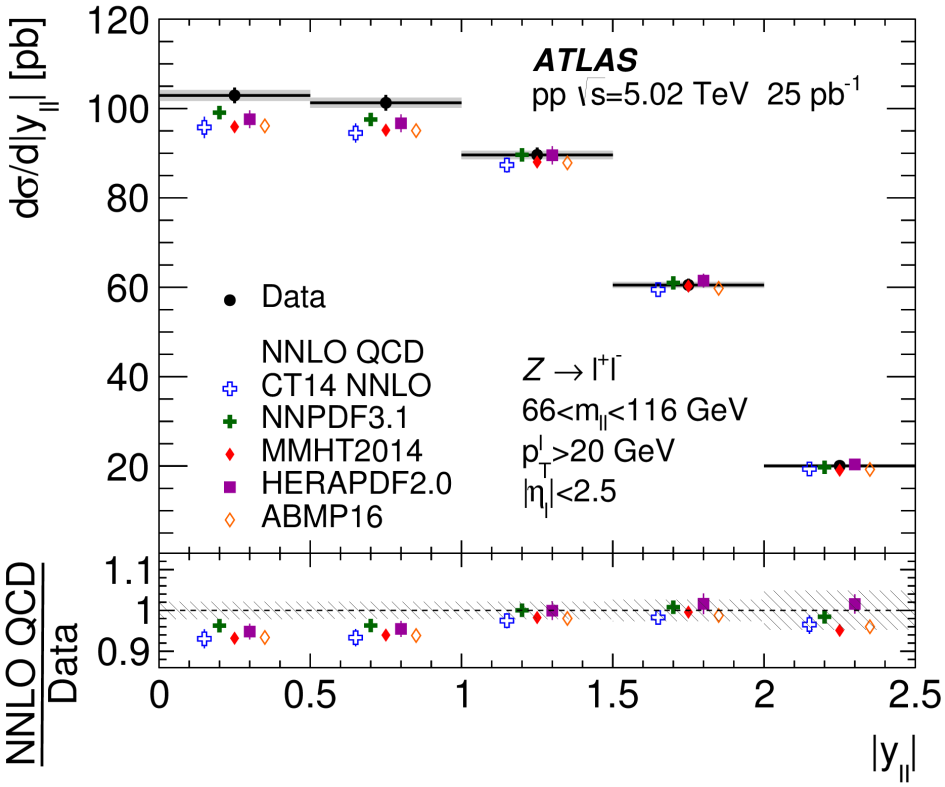
- MMHT14nnlo68CL and CT14nnlo good agreement in ratios
  include Tevatron as well as most LHC data (except top and W+c for CT14, except W+c for MMHT)

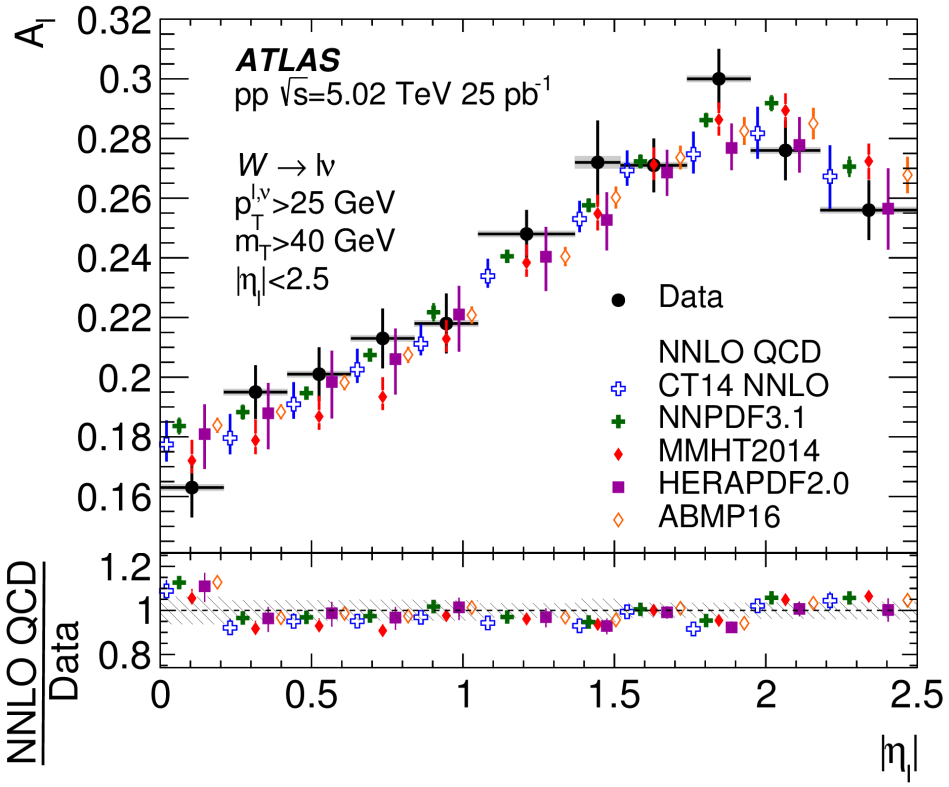
> **W/Z ratio sensitive to strange quark contents**

- HERAPDF2.0nnlo a bit high and generally different from other PDFs
  only HERA data (+LHC WZ 7 TeV data for ATLAS-epWZ12)

W/Z cross sections at $\sqrt{s}$ = 5 TeV

Eur. Phys. J. C (2019) 79:128



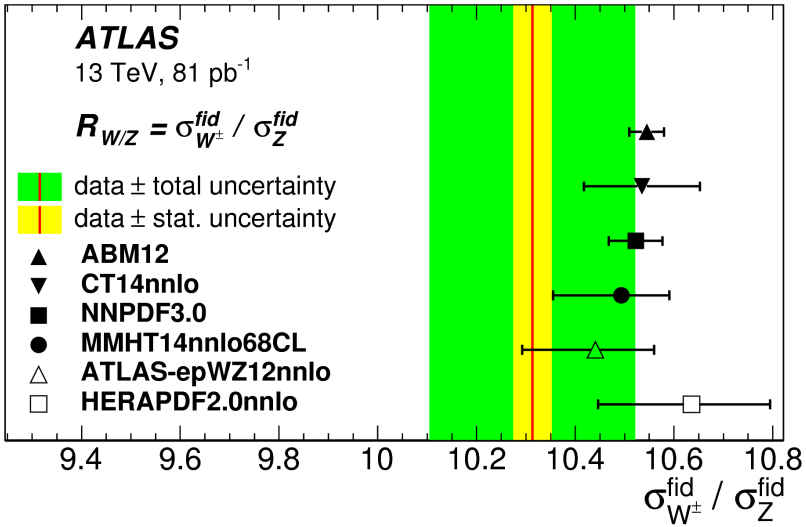


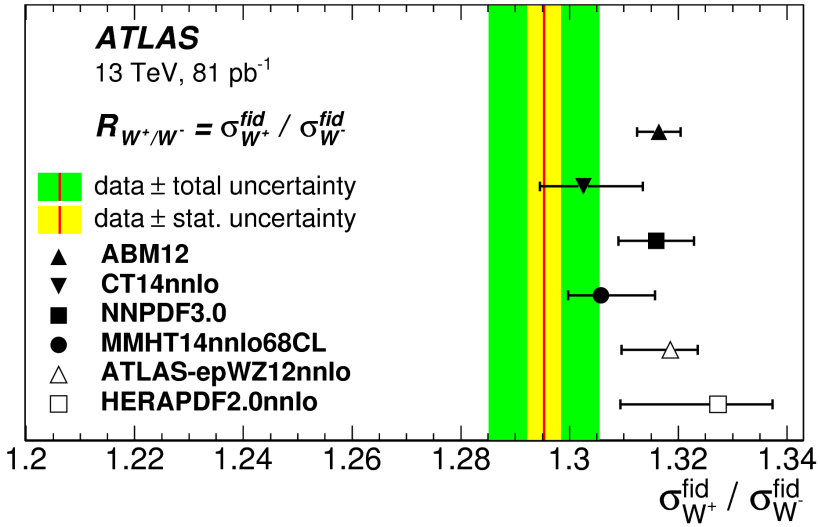
> Differential cross section with DYNNLO prediction

- Tendency of all PDFs to underestimate central Z rapidity range
  Best agreement with NNPDF3.1 which includes the high precision 7 TeV ATLAS data set
- W asymmetry also mostly slightly underestimated

W/Z: Cross section ratios at $\sqrt{s}$ = 13 TeV

JHEP 02 (2017) 117





> W/Z ratio

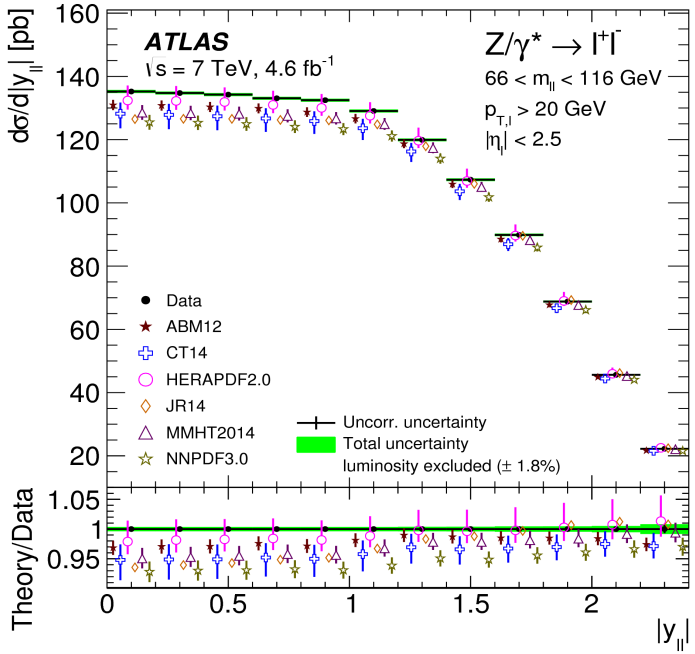
- Sensitive to valence to strange ratio
- Consistent with Run-1: preference for an enhanced strange content, though not visible for 2.76 TeV data

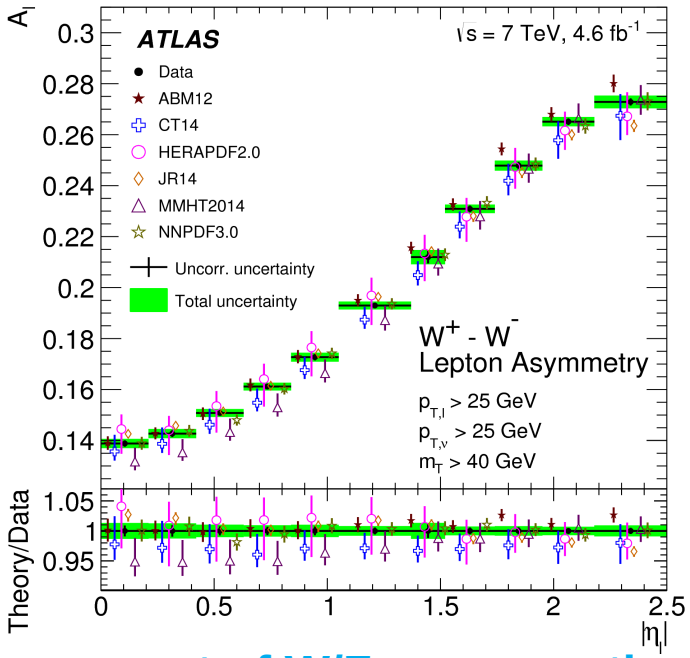
> W+/W- ratio

- Sensitive to u/d valence content of the proton
- Smaller ratio than predicted by most PDFs

Results from LHC Run-1 – cross-sections at 7 Tev

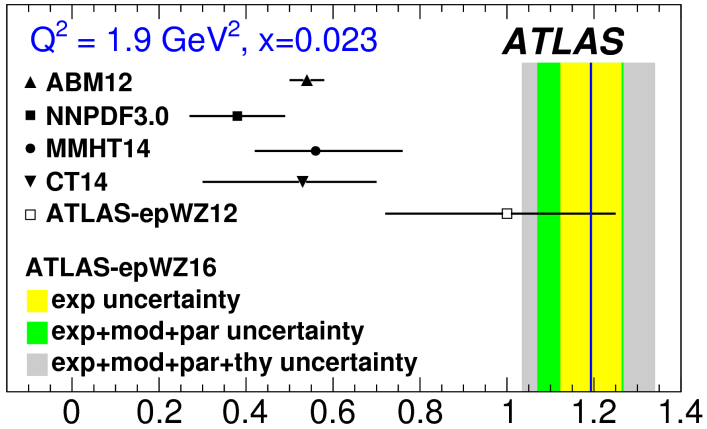
Eur. Phys. J. C 77 (2017) 367





> Consistent picture in the most precise measurement of W/Z cross sections

- 7 TeV data included in newest global PDF sets
- Interpreted by ATLAS as enhanced strange sea (strange-to-down sea quark fraction ~1, no strange sea suppression at low x)



$$r_s = \frac{s+\bar{s}}{2\bar{d}}$$

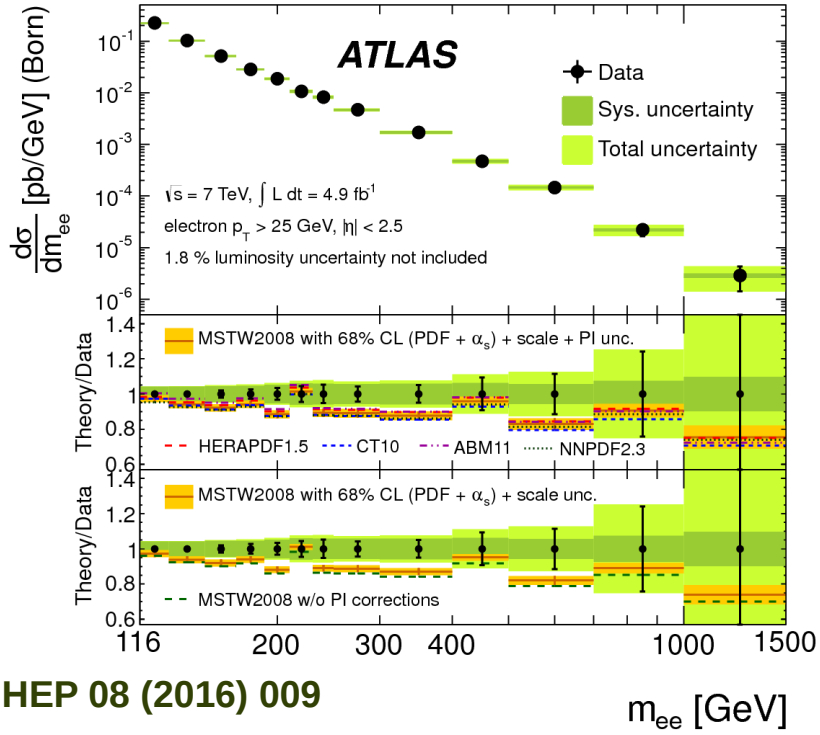
https://indico.cern.ch/event/868940/contributions/3814138/

Mark Sutton: Determination of the Parton Density Functions of the Proton with the ATLAS data
28 Jul 2020, 20:30

More information through very specific phase spaces

> High mass Drell–Yan

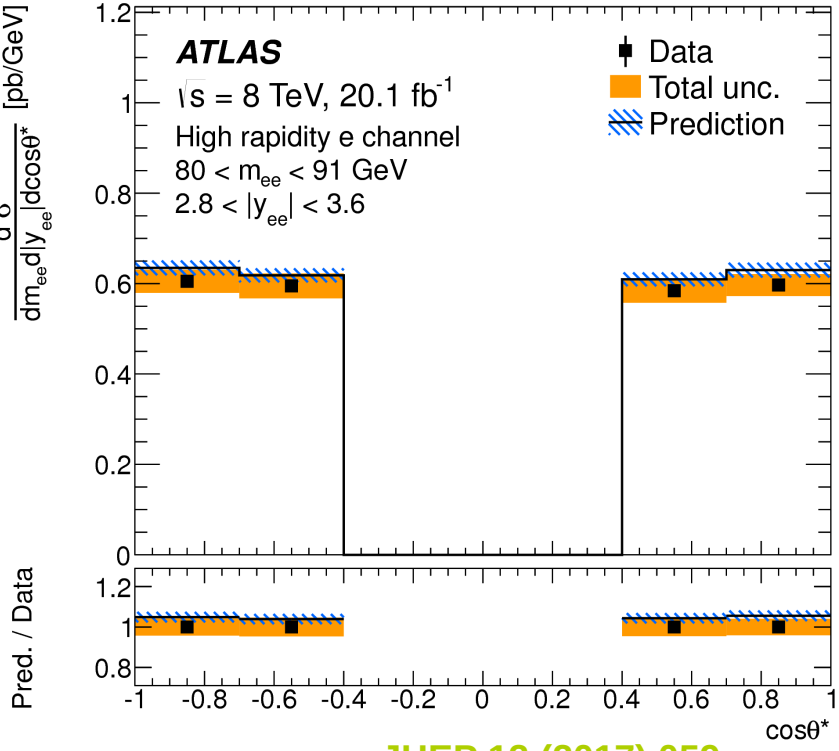
- Adding additional information on photon-induced processes



JHEP 08 (2016) 009

> Forward Z production

- Useful to go to lower values of x
- Also interesting for A_{FB} measurements



JHEP 12 (2017) 059

https://indico.cern.ch/event/868940/contributions/3814143/

Camilla Vittori: Measurements of W/Z boson production in association with jets at ATLAS
28 Jul 2020, 16:15

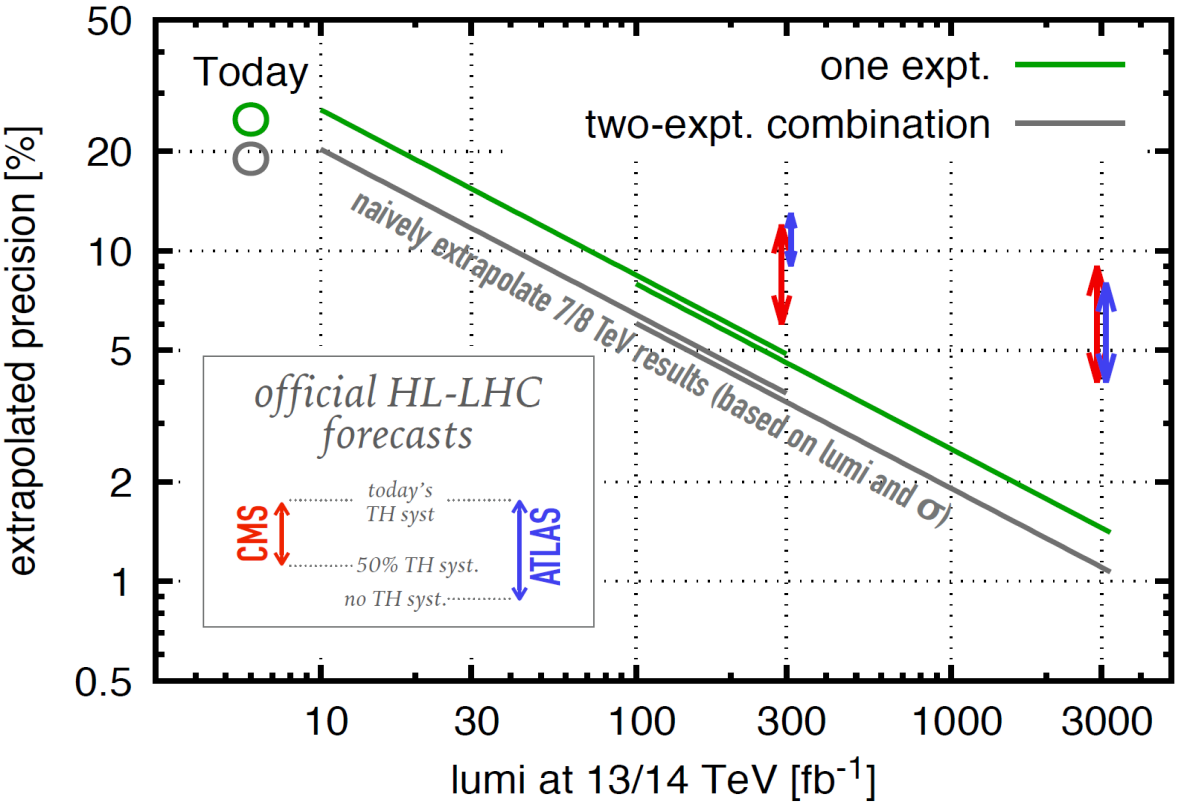
Conclusions

- A wealth of single-boson cross-section data is available at the LHC → all centre-of-mass energies
- Low uncertainties with full correlation information
- Looking forward to see this included in global interpretations

Backup slides.

Optimistic forecasts

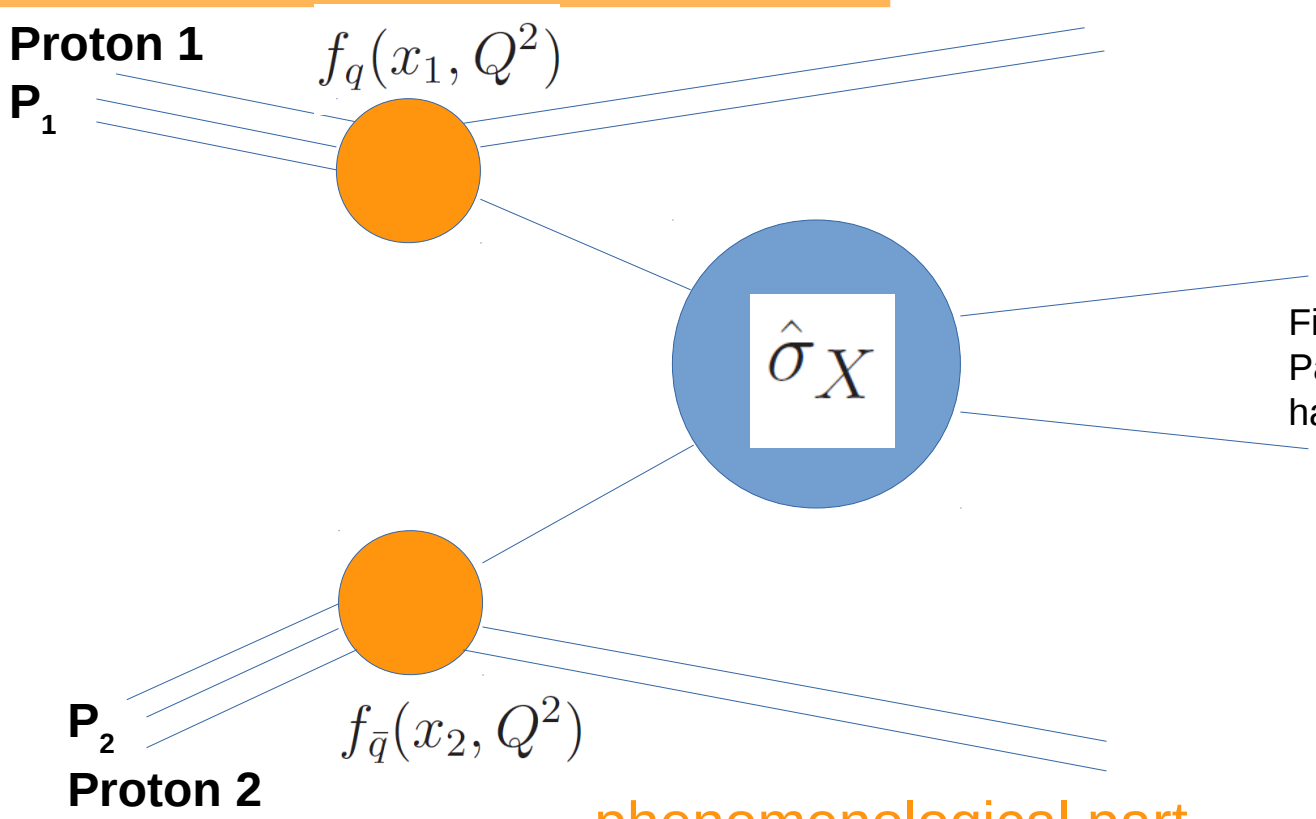
- Some theorists advertise 1% percent uncertainty – in the extreme hadron collider environment!
  - Gavin Salam: H→ γγ signal strength



https://gsalam.web.cern.ch/gsalam/talks/repo/2016-03-SB+SLAC-Munich-precision.pdf

Collisions at the LHC

$f_q(x_1, Q^2)$ Probability to find parton in proton with **momentum fraction x** to enter a collision at a **momentum transfer squared Q²**



Analytical part

phenomenological part

scale uncertainty, α_s,...

$$\sigma_{PP\to X} = PDF \otimes \sigma_{\text{hardscatter}} = \sum_q \int dx_1 dx_2 f_q(x_1, Q^2) f_{\bar{q}}(x_2, Q^2) \otimes \hat{\sigma}_{q\bar{q}\to X}(\alpha, Q^2)$$