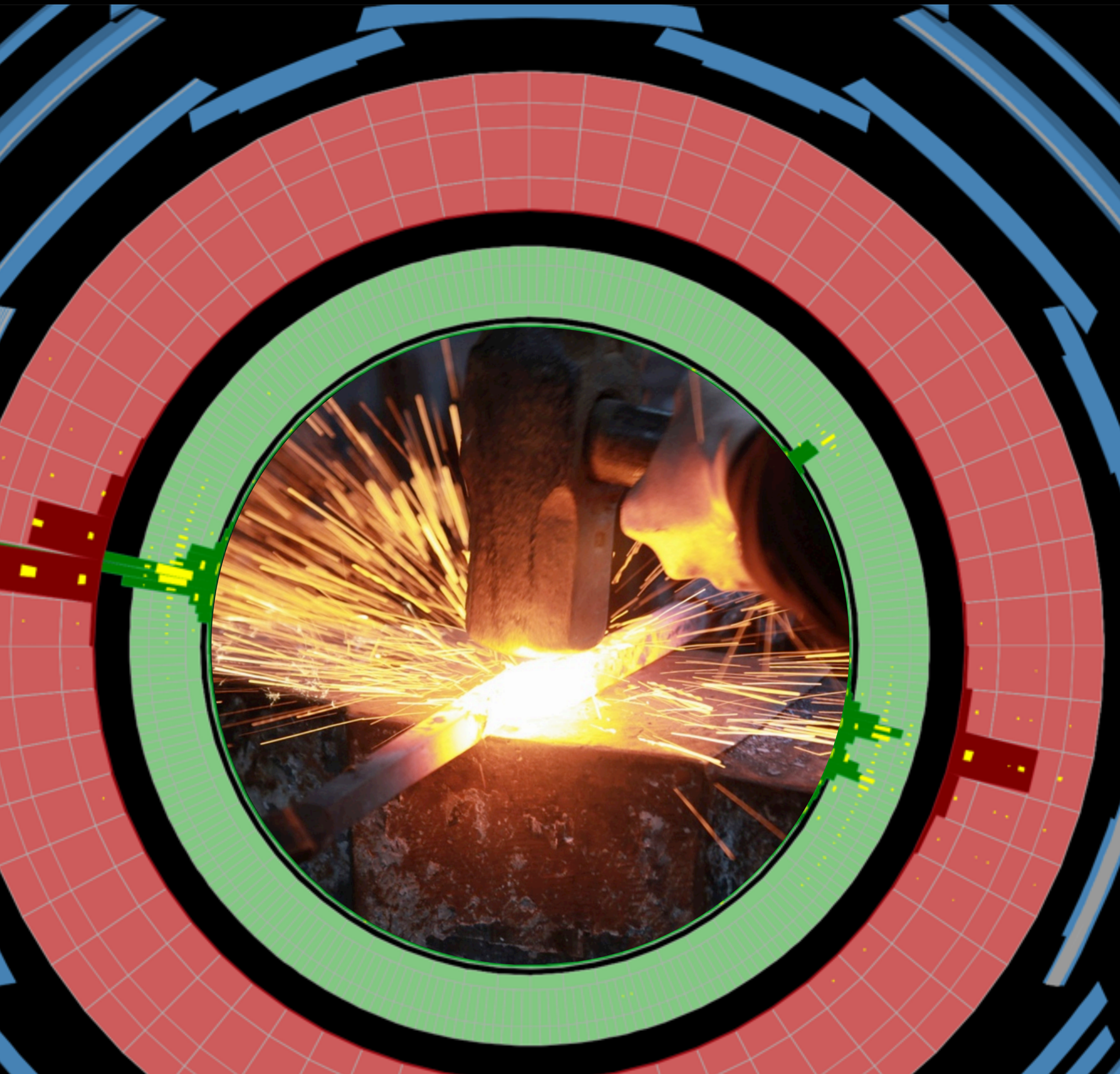
Pheno 2016 Forging new physics

May 9-11, 2016 University of Pittsburgh

Latest topics in **particle physics** and related issues in **astrophysics** and **cosmology**



Vector boson measurements @ ATLAS

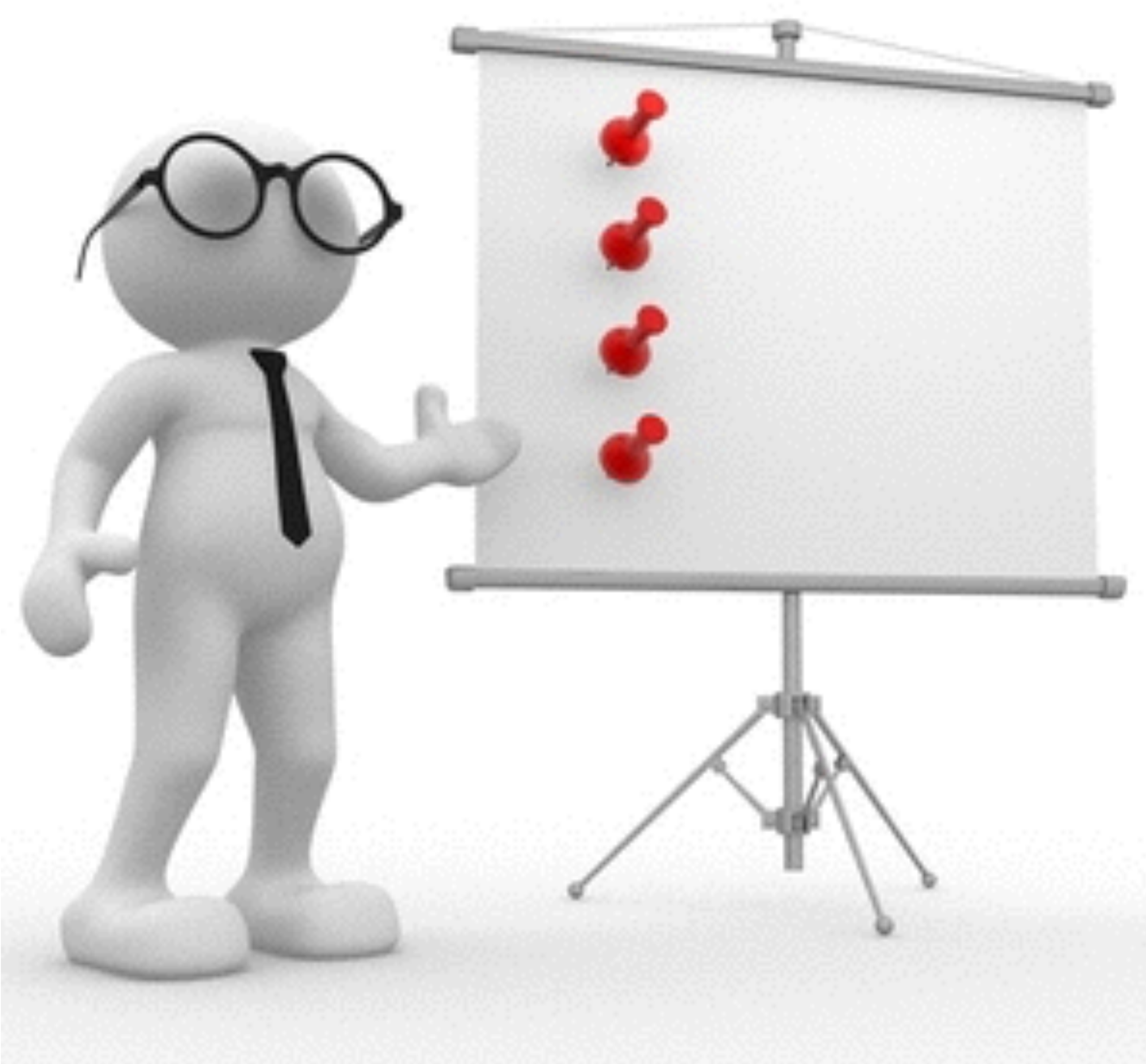
Chiara Debenedetti

UCSC, SCIPP

on behalf of the ATLAS collaboration

UNIVERSITY OF CALIFORNIA SANTA CRUZ

Outline



- ***Drell-Yan pairs transverse momentum and Φ^*_η precision measurement @ 8 TeV*** - arXiv: 1512.02192
- ***Measurement of angular coefficients in Z-boson events @ 8 TeV*** - still no arXiv record
- ***W,Z cross section and cross-section ratio measurement @ 13 TeV*** - arXiv:1603.09222

arXiv:1512.02192 - accepted by EPJC

Drell-Yan lepton pairs transverse momentum and ϕ_η^* precision measurement

L=20.3 fb^{-1}

Data collected by ATLAS @ 8 TeV in 2012

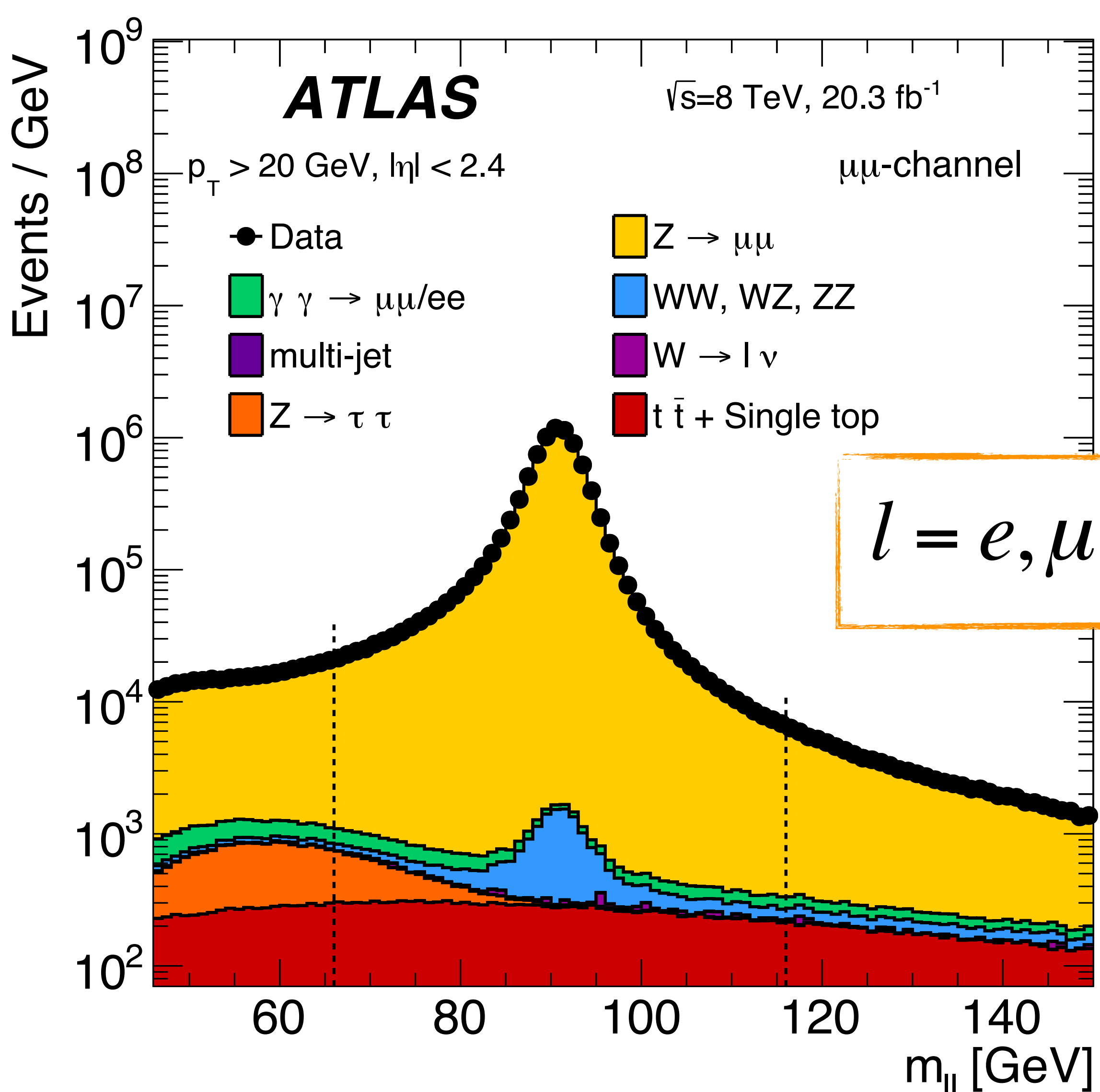
Motivation

- **_Testing different aspects of QCD:_**
  - soft gluon resummation
  - fixed-order perturbative QCD predictions
  - parton shower models

⇒ Study $d\sigma/dp_T^{\ell\ell}$ and $d\sigma/d\Phi^*_\eta$ in bins of $m_{\ell\ell}$ and $|y_{\ell\ell}|$

$$\phi^*_\eta = \tan\left(\frac{\pi - \Delta\phi}{2}\right)\cdot\sin(\theta^*_\eta) \qquad \cos(\theta^*_\eta) = \tanh[(\eta^- - \eta^+)/2]$$

Φ^*_η only direction dependent → no resolution effects present at low $p_T^{\ell\ell}$

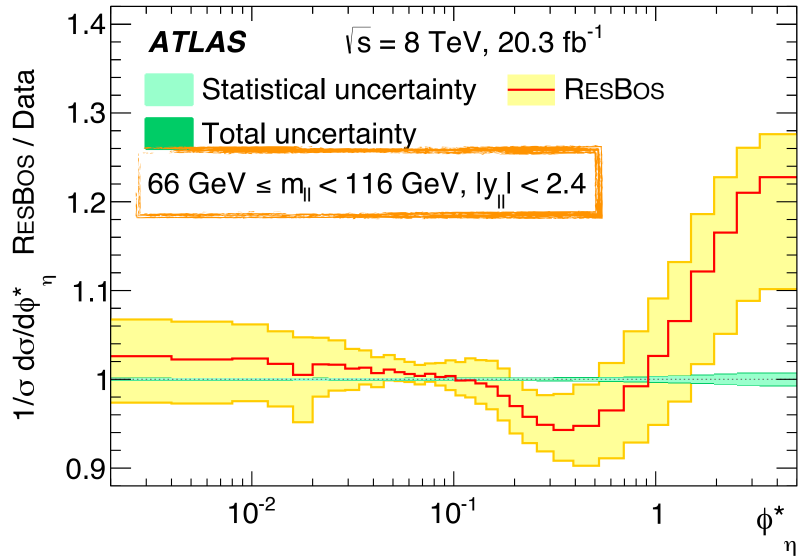


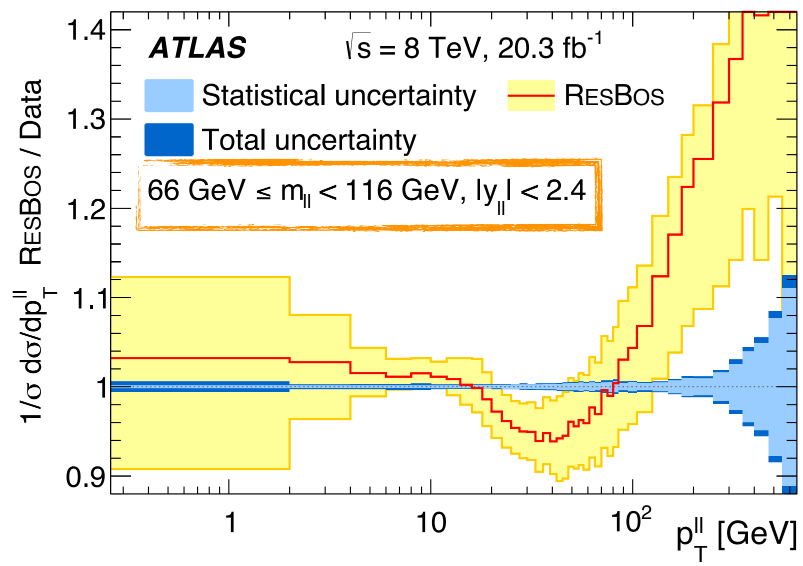
$l = e, \mu$

- Fiducial volume defined as: p_T^ℓ>20 GeV, $|\eta_\ell|$<2.4
- MC signal: Powheg+Pythia
- Backgrounds: multi-jet data-driven and others from MC

combination @ Born level

Results: QCD predictions comparison





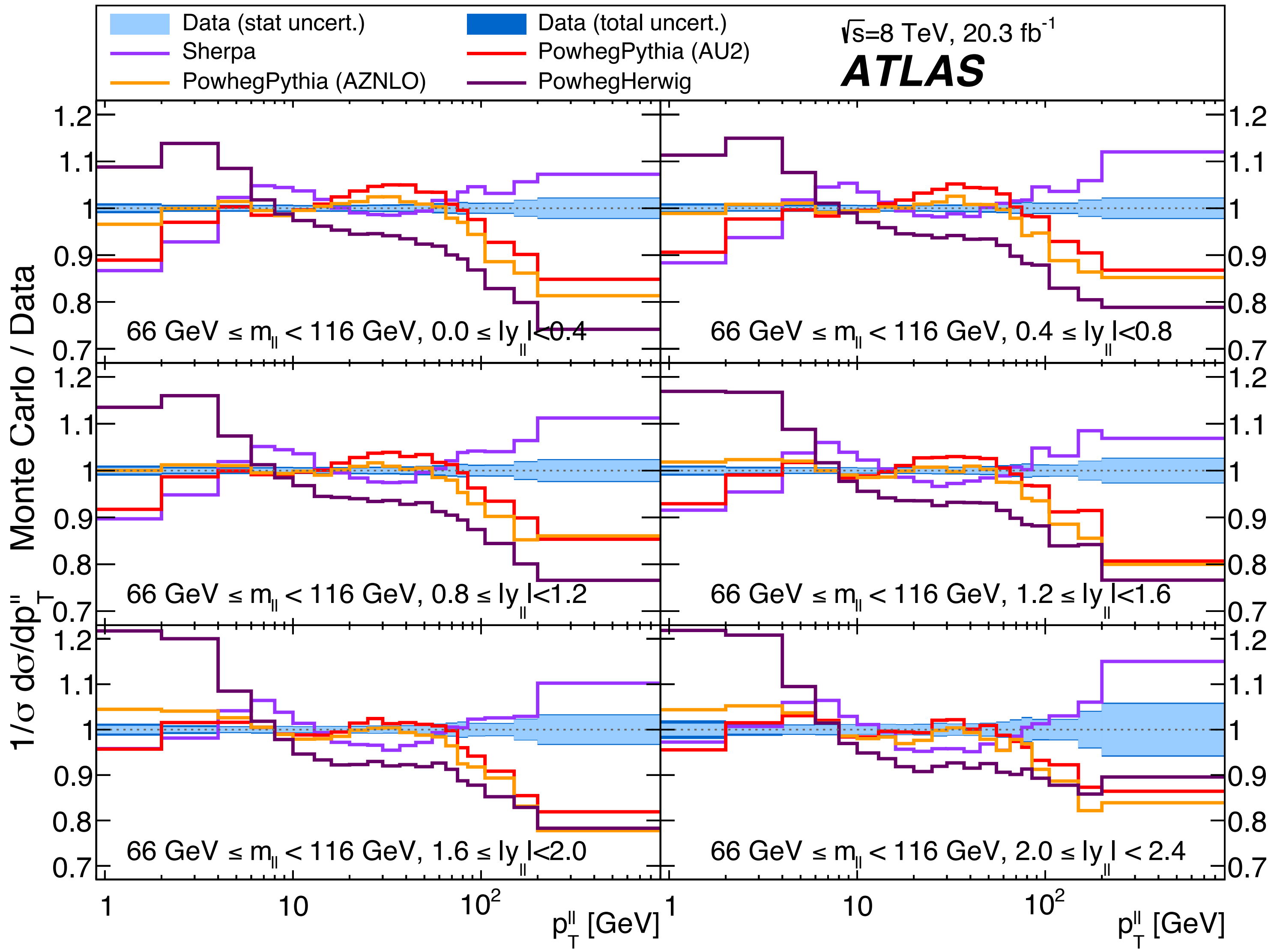
Known: RESBOS lacking NNLO QCD corrections for γ^* and Z/γ^* interference

- Comparisons with RESBOS under Z $m_{\ell\ell}$ peak and for integrated rapidity:
  - Low Φ^*_η and $p_T^{\ell\ell}$: dominated by soft-gluon-resummation effects → ***RESBOS predictions consistent with the data within theoretical uncertainties***
  - High Φ^*_η and $p_T^{\ell\ell}$: sensitive to hard parton emissions → *RESBOS differs from data*
- Detailed comparisons with RESBOS in bins of rapidity and invariant mass for Φ^*_η:
  - in Z peak region disagreement for Φ^*_η≳2
  - low $m_{\ell\ell}$ disagreement for Φ^*_η≳0.4
  - ***good agreement in other regions***
  - ratio of high $m_{\ell\ell}$ to low $m_{\ell\ell}$ shows disagreement above Φ^*_η ~0.5

Good description of RESBOS in evolution of the $(1/\sigma)d\sigma/d\Phi^*_\eta$ measurement with $|y_{\ell\ell}|$

More plots in the backup slides!

Results: comparison to PS approach



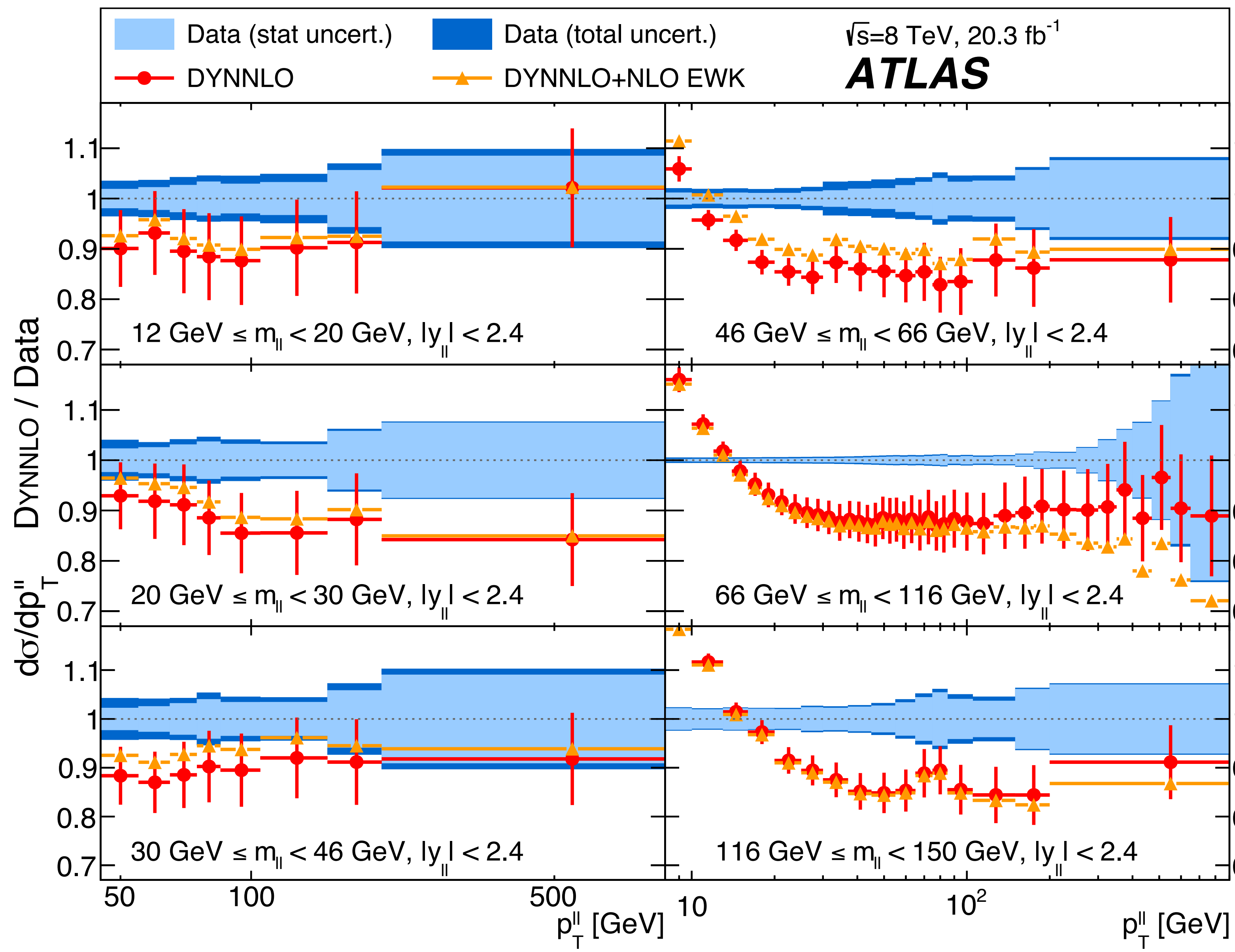
- In the Z mass peak region and above, for $p_T^{\ell\ell}$ within 5 and 100 GeV ***description of MC's compatible with data at 10% level***
- Low mass and high $p_T^{\ell\ell}$ → worse agreement
- *Powheg+Pythia tuned with AZNLO tune (using 7 TeV ATLAS data) provides best description under the Z mass peak for $p_T^{\ell\ell}$ <50 GeV*
- Sherpa differences with respect to data have same size of Powheg, but opposite trend

- Same study performed for $(1/\sigma)d\sigma/d\Phi^*_\eta$ show similar behaviour for the different mass bins
- PS MC's describe well (maximal discrepancies of 5%) the evolution of $(1/\sigma)d\sigma/dp_T^{\ell\ell}$ over $|y_{\ell\ell}|$

More plots in the backup slides!

Results: compare to fixed-order QCD

- Low $p_T^{\ell\ell}$ discrepancies ***expected*** because soft gluon emissions dominant
- Good shape description for $p_T^{\ell\ell}$ >30 GeV, but ***normalisation systematically 15% lower than data***
- Recent ***NNLO calculations*** (http://moriond.in2p3.fr/QCD/2016/TuesdayMorning/Huss.pdf) show ***improved agreement with data***



Not sensitive to EW corrections (much smaller than data/DYNNLO discrepancy)

Not yet on arXiv - hot from the press!!!

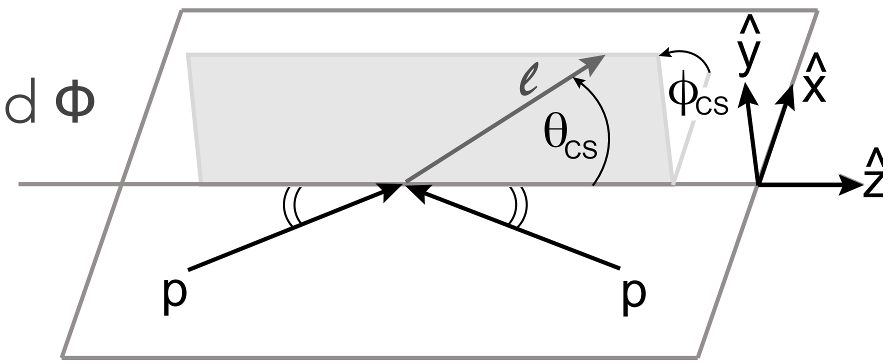
Measurement of angular coefficients in Z-boson events

$L = 20.3\ fb^{-1}$

Data collected by ATLAS @ 8 TeV in 2012

Analysis motivation

- Measurement of production dynamics through a spin 1 Z via spin correlation between initial and final state partons
- Use ***Collins-Soper (CS) reference frame*** → defines lepton θ and Φ



- The fully differential DY cross section can be reorganised by factorising the dynamic of the boson production, and the kinematic of the decay → *very precise measurement of A_i coefficients, that can be expressed as a function of θ and Φ*

$$\langle \frac{1}{2}(1-3\cos^2\theta)\rangle = \frac{3}{20}(A_0 - \frac{2}{3}); \quad \langle \sin 2\theta \cos\phi \rangle = \frac{1}{5}A_1; \quad \langle \sin^2\theta \cos 2\phi \rangle = \frac{1}{10}A_2;$$

$$\langle \sin\theta\cos\phi \rangle = \frac{1}{4}A_3; \quad \langle \cos\theta \rangle = \frac{1}{4}A_4; \quad \langle \sin^2\theta \sin 2\phi \rangle = \frac{1}{5}A_5;$$

$$\langle \sin 2\theta \sin\phi \rangle = \frac{1}{5}A_6; \quad \langle \sin\theta \sin\phi \rangle = \frac{1}{4}A_7.$$

- ***Lam-Tung relationship*** predicts $A_0=A_2$ up to NLO QCD (expect $A_0>A_2$ @ higher orders)
- ***$A_{5,6,7}$*** expected to be 0 up to NLO QCD, and slightly divergent from zero @ high p_T for NNLO QCD

Analysis strategy

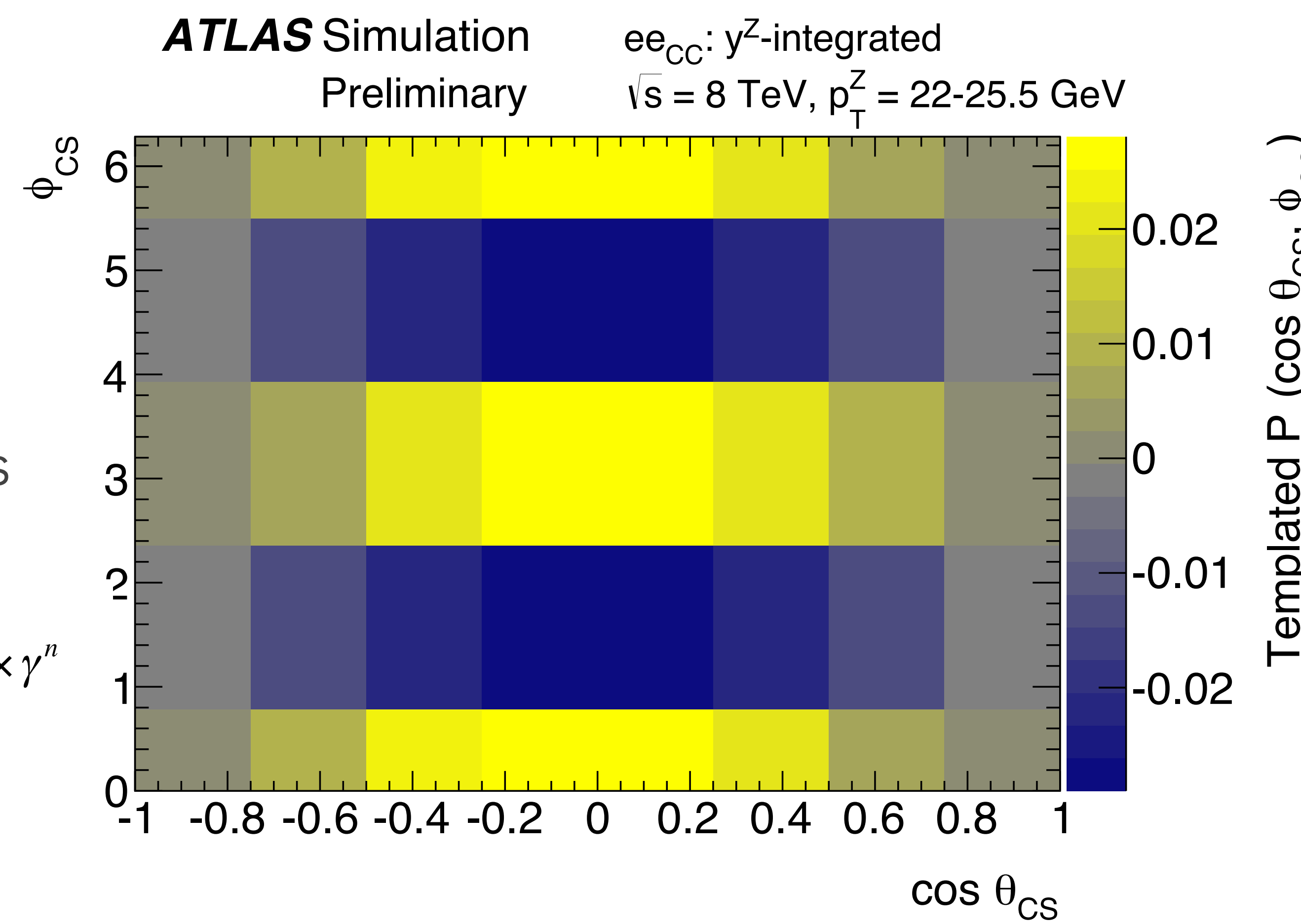
- Select ***three different lepton pair combinations***:
  - 2 central electrons (e_{CC}), two central muons (μ_{CC}), one forward and one central electron (e_{CF})
- Fiducial volume:
  - p_T^{ℓ} >25 GeV and $|\eta_{\ell}|$<2.4 (central leptons)
  - p_T^{e} >20 GeV, 2.5<$|\eta_{e}|$<4.9 (forward electrons)
  - ***80<$m_{\ell\ell}$<100 GeV, measurement functions of p_T^{Z} and also binned in y_Z***

- Signal MC: Powheg+Pythia
- Backgrounds estimated from MC, but multijet data-driven

Analysis strategy

- Select ***three different lepton pair combinations***:
  - 2 central electrons (e_{CC}), two central muons (μ_{CC}), one forward and one central electron (e_{CF})
- Fiducial volume:
  - p_{T_ℓ} >25 GeV and $|\eta_\ell|$<2.4 (central leptons)
  - p_{T_e} >20 GeV, 2.5<$|\eta_e|$<4.9 (forward electrons)
  - ***80<$m_{\ell\ell}$<100 GeV, measurement functions of p_T^Z and also binned in y_Z***

- Signal MC: Powheg+Pythia
- Backgrounds estimated from MC, but multijet data-driven



- *Fold polynomials* to reco phase space (t_{ij}) and fit them to reco data to the full phase space A_i's

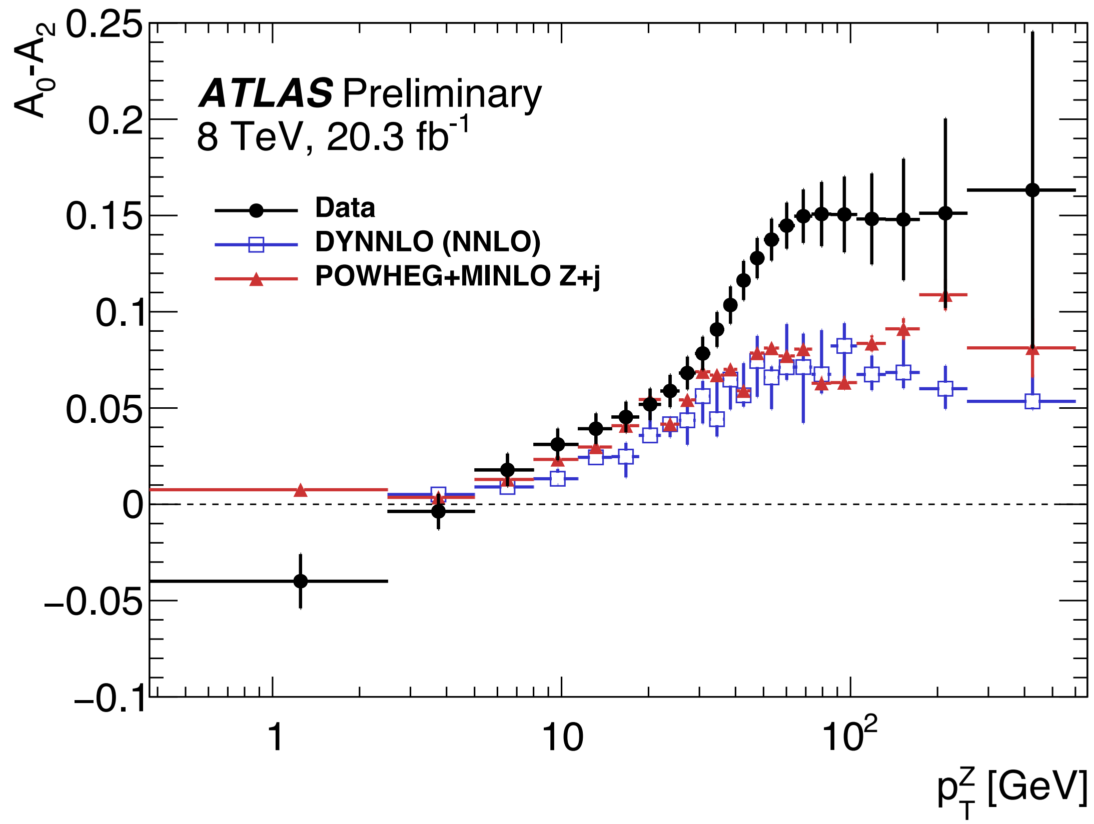
$$N^n_{\exp}(A,\sigma,\theta) = \left\{ \sum_{j=1}^{23} \sigma_j \times L \times \left[t_{8,j}(\beta) + \sum_{i=0}^{7} A_{i,j} \times t_{i,j}(\beta) \right] + \sum_{B}^{bkgs} T_B(\beta) + T_{Fakes} \right\} \times \gamma^n$$

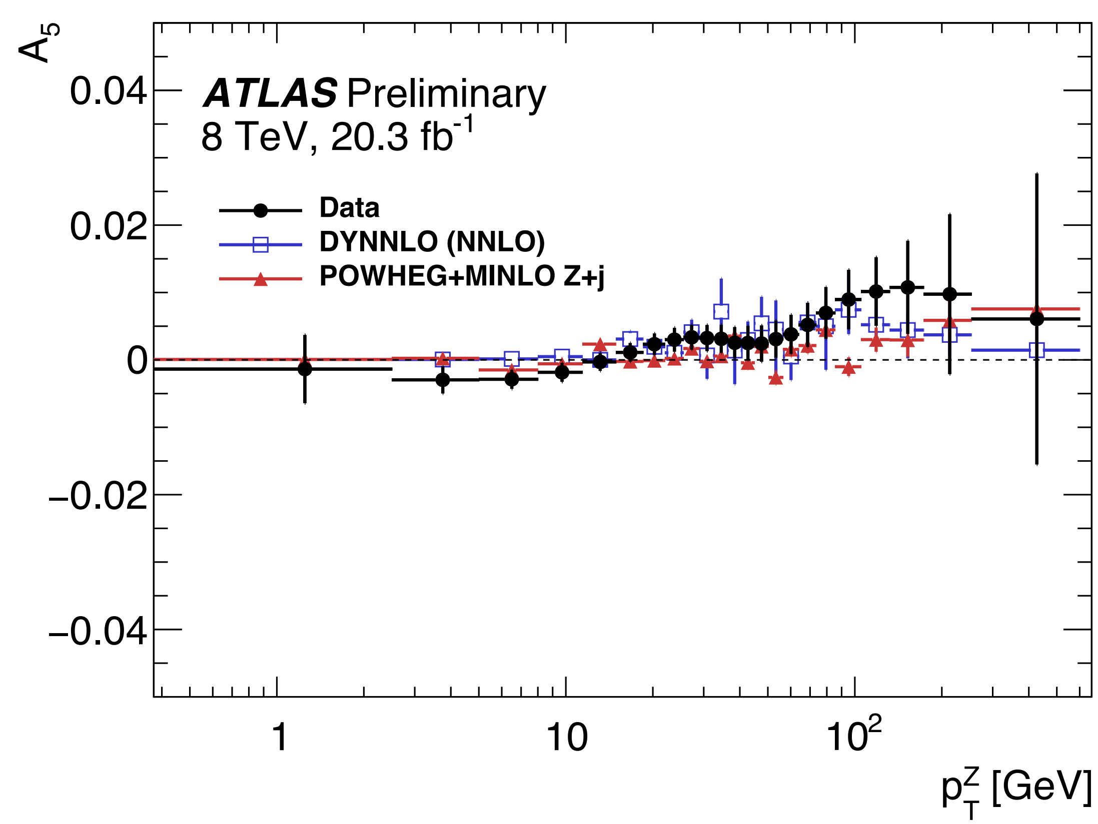
Perform maximum likelihood fit on the reco data to extract the A_i's:

$$\mathcal{L}(A_{i,j}, \sigma_j^{\Phi} \mid N) = \prod_{n}^{Nbins} \left\{ P(N^n_{obs}) \mid N^n_{\exp}(A,\sigma,\theta) P(N^n_{eff} \mid \gamma^n N^n_{obs}) \right\} \times \prod_{m}^{M} G(0 \mid \beta^m, 1)$$

Results

- In general ***comparison with Powheg+MINLO and DYNNLO (both $O(\alpha_S)$ for A_i vs p_T^Z predictions) show good agreement with data***
- A_2 has slower rise in data in p_T^Z than predictions
- *A_0-A_2, confirms Lam-Tung breaking @ higher orders than NLO* → ***very sensitive probe of higher order QCD corrections!***
  - For p_T^Z > 50 GeV a factor of 2 higher than predictions (PDF cannot cover for this, probably due to higher order effects)
- *$A_{5,6,7}$ all deviate from 0* @ high p_T, compatible with predictions within the errors but limited sensitivity





arXiv:1603.09222 - submitted to Phys. Lett. B

W,Z cross sections and cross-section ratios

L = 81 pb^{-1} @ 13 TeV

Data taken with 50 ns bunch spacing in early Summer 2015

Motivation and strategy

- Benchmark for understanding of EW and QCD processes
  - Precise *predictions available @ NNLO QCD with NLO EW corrections* (DYNNLO+FEWZ +SANC)

- High precision in the measurement reachable because of leptonic final states, and large production cross sections

- ***First tests of PDF's @ 13 TeV***
  - Cancellation of experimental uncertainties in the ratios providing constraints on the PDF's

- Calculate total and fiducial cross sections, and fiducial-cross-section ratios

$$\sigma^{fid}_{W,Z} \times BR(W,Z \to l\nu, ll) = \sigma^{tot}_{W,Z} \times BR(W,Z \to l\nu, ll) \cdot A_{W,Z} = \frac{N-B}{C_{W,Z} \cdot \mathcal{L}_{W,Z}}$$

Fiducial phase space: ***ℓ=μ,e***

Motivation and strategy

- Benchmark for understanding of EW and QCD processes
  - Precise *predictions available @ NNLO QCD with NLO EW corrections* (DYNNLO+FEWZ +SANC)
- High precision in the measurement reachable because of leptonic final states, and large production cross sections
- ***First tests of PDF's @ 13 TeV***
  - Cancellation of experimental uncertainties in the ratios providing constraints on the PDF's
- Calculate total and fiducial cross sections, and fiducial-cross-section ratios

$$\sigma^{fid}_{W,Z} \times BR(W,Z \rightarrow l\nu, ll) = \sigma^{tot}_{W,Z} \times BR(W,Z \rightarrow l\nu, ll) \cdot A_{W,Z} = \frac{N-B}{C_{W,Z} \cdot \mathcal{L}_{W,Z}}$$

geometric and phase space fiducial acceptance

Fiducial phase space: ***ℓ=μ,e***

Motivation and strategy

- Benchmark for understanding of EW and QCD processes
  - Precise *predictions available @ NNLO QCD with NLO EW corrections* (DYNNLO+FEWZ +SANC)
- High precision in the measurement reachable because of leptonic final states, and large production cross sections
- ***First tests of PDF's @ 13 TeV***
  - Cancellation of experimental uncertainties in the ratios providing constraints on the PDF's
- Calculate total and fiducial cross sections, and fiducial-cross-section ratios

$$\sigma^{fid}_{W,Z} \times BR(W,Z \to l\nu, ll) = \sigma^{tot}_{W,Z} \times BR(W,Z \to l\nu, ll) \cdot A_{W,Z} = \frac{N - B}{C_{W,Z} \cdot \mathcal{L}_{W,Z}}$$

candidate signal events in data (N)

geometric and phase space fiducial acceptance ($A_{W,Z}$)

Fiducial phase space: ***ℓ=μ,e***

Motivation and strategy

- Benchmark for understanding of EW and QCD processes
  - Precise *predictions available @ NNLO QCD with NLO EW corrections* (DYNNLO+FEWZ +SANC)
- High precision in the measurement reachable because of leptonic final states, and large production cross sections
- ***First tests of PDF's @ 13 TeV***
  - Cancellation of experimental uncertainties in the ratios providing constraints on the PDF's
- Calculate total and fiducial cross sections, and fiducial-cross-section ratios

$$\sigma^{fid}_{W,Z} \times BR(W,Z \to l\nu, ll) = \sigma^{tot}_{W,Z} \times BR(W,Z \to l\nu, ll) \cdot A_{W,Z} = \frac{N-B}{C_{W,Z} \cdot \mathcal{L}_{W,Z}}$$

N: candidate signal events in data

$A_{W,Z}$: geometric and phase space fiducial acceptance

B: estimated background events

Fiducial phase space: ***ℓ=μ,e***

Motivation and strategy

- Benchmark for understanding of EW and QCD processes
  - Precise *predictions available @ NNLO QCD with NLO EW corrections* (DYNNLO+FEWZ +SANC)
- High precision in the measurement reachable because of leptonic final states, and large production cross sections
- ***First tests of PDF's @ 13 TeV***
  - Cancellation of experimental uncertainties in the ratios providing constraints on the PDF's
- Calculate total and fiducial cross sections, and fiducial-cross-section ratios

$$\sigma^{fid}_{W,Z} \times BR(W,Z \to l\nu, ll) = \sigma^{tot}_{W,Z} \times BR(W,Z \to l\nu, ll) \cdot A_{W,Z} = \frac{N-B}{C_{W,Z} \cdot \mathcal{L}_{W,Z}}$$

- N: candidate signal events in data
- B: estimated background events
- $A_{W,Z}$: geometric and phase space fiducial acceptance
- $C_{W,Z}$: correction to experimental phase space

Fiducial phase space: ***ℓ=μ,e***

Motivation and strategy

- Benchmark for understanding of EW and QCD processes
  - Precise *predictions available @ NNLO QCD with NLO EW corrections* (DYNNLO+FEWZ +SANC)
- High precision in the measurement reachable because of leptonic final states, and large production cross sections
- ***First tests of PDF's @ 13 TeV***
  - Cancellation of experimental uncertainties in the ratios providing constraints on the PDF's
- Calculate total and fiducial cross sections, and fiducial-cross-section ratios

$$\sigma^{fid}_{W,Z} \times BR(W,Z \to l\nu, ll) = \sigma^{tot}_{W,Z} \times BR(W,Z \to l\nu, ll) \cdot A_{W,Z} = \frac{N - B}{C_{W,Z} \cdot \mathcal{L}_{W,Z}}$$

- N: candidate signal events in data
- $A_{W,Z}$: geometric and phase space fiducial acceptance
- $C_{W,Z}$: correction to experimental phase space
- B: estimated background events
- $\mathcal{L}_{W,Z}$: integrated luminosity

Fiducial phase space: ***ℓ=μ,e***

Motivation and strategy

- Benchmark for understanding of EW and QCD processes
  - Precise *predictions available @ NNLO QCD with NLO EW corrections* (DYNNLO+FEWZ +SANC)
- High precision in the measurement reachable because of leptonic final states, and large production cross sections
- ***First tests of PDF's @ 13 TeV***
  - Cancellation of experimental uncertainties in the ratios providing constraints on the PDF's
- Calculate total and fiducial cross sections, and fiducial-cross-section ratios

Fiducial phase space: ***ℓ=μ,e***

$$\sigma^{fid}_{W,Z} \times BR(W,Z \to l\nu, ll) = \sigma^{tot}_{W,Z} \times BR(W,Z \to l\nu, ll) \cdot A_{W,Z} = \frac{N - B}{C_{W,Z} \cdot \mathcal{L}_{W,Z}}$$

- N: candidate signal events in data
- $A_{W,Z}$: geometric and phase space fiducial acceptance
- $C_{W,Z}$: correction to experimental phase space
- B: estimated background events
- $\mathcal{L}_{W,Z}$: integrated luminosity

- Top-quark and EW backgrounds
  - estimated ***from simulation***
  - dominant contributions:
    - W analysis: Z→μμ 5%, W→τν 2%, Z→ee, ttbar 1%
    - Z analysis: ttbar 0.5%, EW background 0.2%
- ***QCD multijet background → data driven***
  - in Z channel negligible (<0.1%)
  - in W channel evaluated wth repeated template fit approach in slices of isolation, and extrapolated to the signal region: ~10% in electron channel and ~4% in muon channel

Combination and xsec measurement

Combination of the different channels

➡ Use HERAverager and *account for correlations* in the systematics and for MJ use: $\delta(W^{\pm})^2 = \delta(W^{+})^2 + \delta(W^{-})^2 + 2\rho\delta(W^{+})\delta(W^{-})$

Channel	Predicted cross section × BR($W \to \ell\nu, Z \to \ell\ell$) [nb] (value ± PDF ± scale ± other)		Measured cross section × BR($W \to \ell\nu, Z \to \ell\ell$) [nb] (value ± stat ± syst ± lumi)	
	Fiducial	Total	Fiducial	Total
W^-	$3.40^{+0.09}_{-0.11} \pm 0.04 \pm 0.06$	$8.54^{+0.21}_{-0.24} \pm 0.11 \pm 0.12$	$3.48 \pm 0.01 \pm 0.07 \pm 0.17$	$8.75 \pm 0.02 \pm 0.24 \pm 0.44$
W^+	$4.42^{+0.13}_{-0.14} \pm 0.05 \pm 0.08$	$11.54^{+0.32}_{-0.31} \pm 0.15 \pm 0.16$	$4.51 \pm 0.01 \pm 0.09 \pm 0.23$	$11.78 \pm 0.02 \pm 0.32 \pm 0.59$
$W^\pm$	$7.82^{+0.21}_{-0.25} \pm 0.09 \pm 0.13$	$20.08^{+0.53}_{-0.54} \pm 0.26 \pm 0.28$	$7.99 \pm 0.01 \pm 0.16 \pm 0.40$	$20.55 \pm 0.03 \pm 0.55 \pm 1.03$
Z	$0.74^{+0.02}_{-0.03} \pm 0.01 \pm 0.01$	$1.89 \pm 0.05 \pm 0.03 \pm 0.03$	$0.775 \pm 0.003 \pm 0.006 \pm 0.039$	$1.97 \pm 0.01 \pm 0.04 \pm 0.10$
	Predicted ratio (value ± PDF)		Measured ratio (value ± stat ± syst)	
W^+/W^-	1.30 ± 0.01	–	$1.295 \pm 0.003 \pm 0.010$	–
$W^\pm/Z$	10.54 ± 0.12	–	$10.31 \pm 0.04 \pm 0.20$	–

Good agreement with predictions!

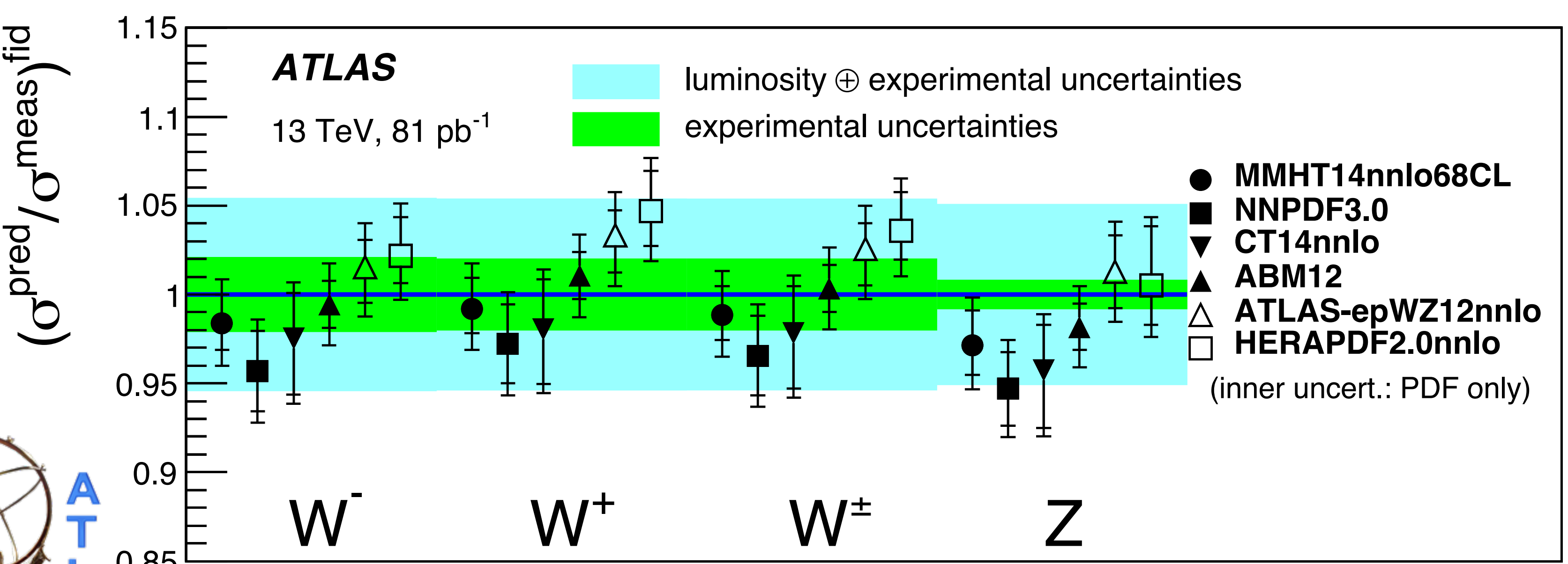
Combination and xsec measurement

Combination of the different channels

- Use HERAverager and account for correlations in the systematics and for MJ use: $\delta(W^{\pm})^2 = \delta(W^+)^2 + \delta(W^-)^2 + 2\rho\delta(W^+)\delta(W^-)$

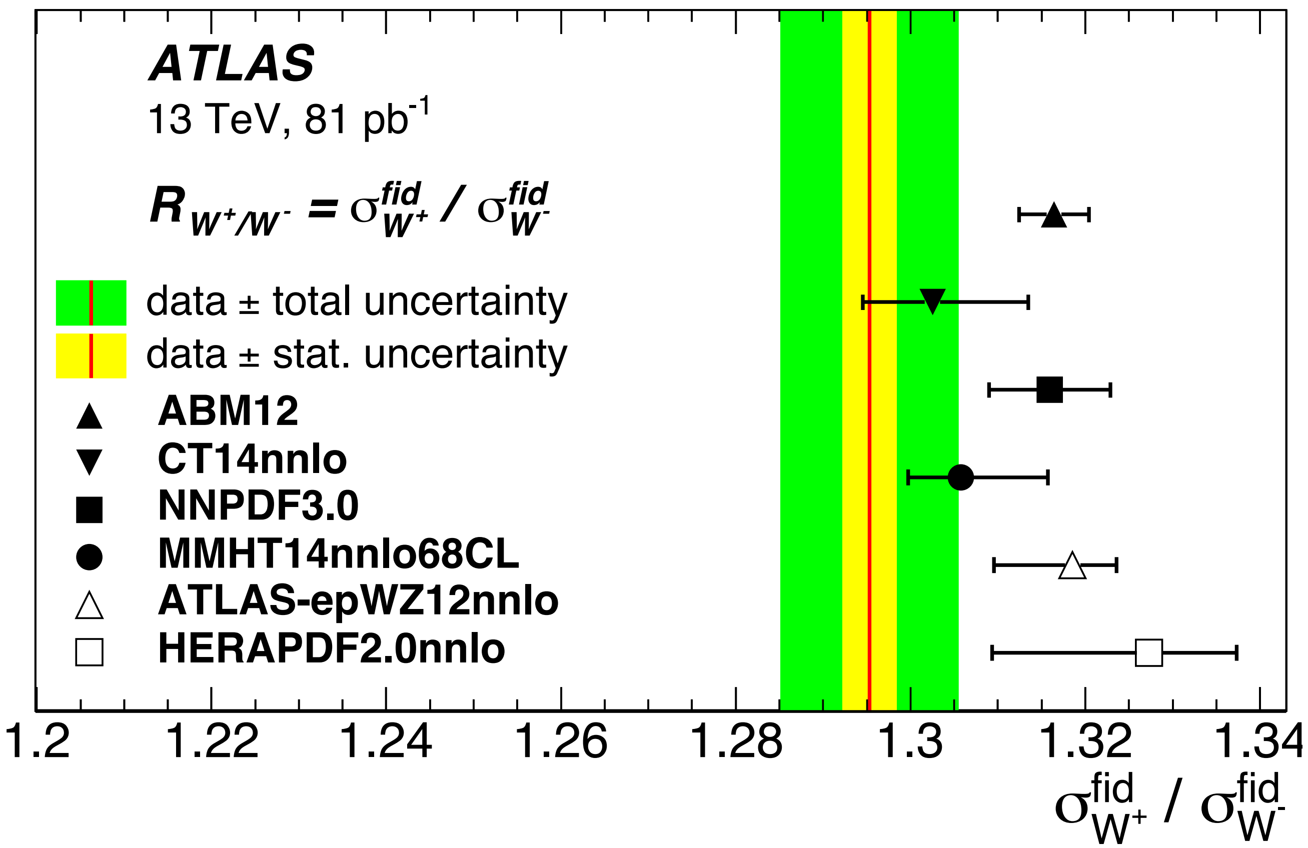
Channel	Predicted cross section × BR($W \to \ell\nu, Z \to \ell\ell$) [nb] (value ± PDF ± scale ± other) Fiducial	Total	Measured cross section × BR($W \to \ell\nu, Z \to \ell\ell$) [nb] (value ± stat ± syst ± lumi) Fiducial	Total
W^-	$3.40^{+0.09}_{-0.11} \pm 0.04 \pm 0.06$	$8.54^{+0.21}_{-0.24} \pm 0.11 \pm 0.12$	$3.48 \pm 0.01 \pm 0.07 \pm 0.17$	$8.75 \pm 0.02 \pm 0.24 \pm 0.44$
W^+	$4.42^{+0.13}_{-0.14} \pm 0.05 \pm 0.08$	$11.54^{+0.32}_{-0.31} \pm 0.15 \pm 0.16$	$4.51 \pm 0.01 \pm 0.09 \pm 0.23$	$11.78 \pm 0.02 \pm 0.32 \pm 0.59$
$W^{\pm}$	$7.82^{+0.21}_{-0.25} \pm 0.09 \pm 0.13$	$20.08^{+0.53}_{-0.54} \pm 0.26 \pm 0.28$	$7.99 \pm 0.01 \pm 0.16 \pm 0.40$	$20.55 \pm 0.03 \pm 0.55 \pm 1.03$
Z	$0.74^{+0.02}_{-0.03} \pm 0.01 \pm 0.01$	$1.89 \pm 0.05 \pm 0.03 \pm 0.03$	$0.775 \pm 0.003 \pm 0.006 \pm 0.039$	$1.97 \pm 0.01 \pm 0.04 \pm 0.10$
	Predicted ratio (value ± PDF)		Measured ratio (value ± stat ± syst)	
W^+/W^-	1.30 ± 0.01	–	$1.295 \pm 0.003 \pm 0.010$	–
$W^{\pm}/Z$	10.54 ± 0.12	–	$10.31 \pm 0.04 \pm 0.20$	–

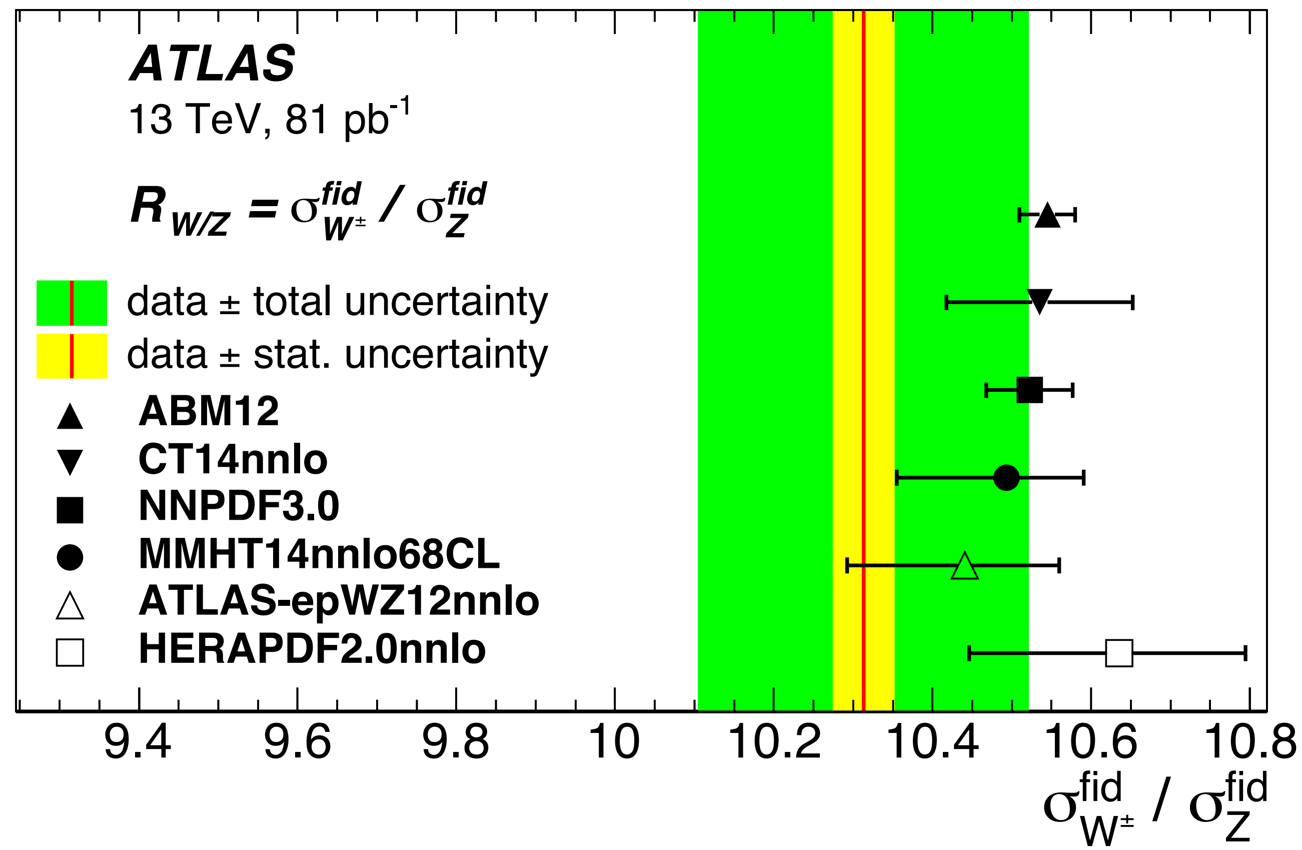
Good agreement with predictions!



- DYNNLO compared to data considering different PDF choices
- ***Agreement with NNLO predictions***, lumi uncertainty is large, covering all the PDFs spread

Cross-section ratios





- (partial) ***cancellation of some uncertainties*** (lumi, lepton ID and trigger systematics)
  - improved discriminating power between different pdf predictions
- Sensitivity to different aspects:
  - W^+/W^- to u_v-d_v at low x
  - $W^\pm/Z$ to strange quark distribution
- W^+/W^- more discriminant power, *favours CT14nnlo and MMHT14nnlo PDFs*
- W/Z compatible with all PDFs within uncertainties

Conclusions

- ***Drell-Yan pairs transverse momentum and Φ^*_η precision measurement @ 8 TeV*** - arXiv:1512.02192
  - Good agreement with RESBOS until high $p_T^{\ell\ell}$ or Φ^*_η, where divergences start
  - Powheg+Pythia with AZNLO tune provides best description of $p_T^{\ell\ell}$ in Z mass peak region
  - Fixed order NNLO QCD predictions systematically show 15% difference in normalisation to data, and no sensitivity to EW correction is observed
- ***Measurement of angular coefficients in Z-boson events @ 8 TeV*** - coming soon on arXiv!
  - Good agreement between data and $O(\alpha_S)$ predictions
  - A_0-A_2 sensitive to higher order corrections (confirmed Lam-Tung breaking @ NLO)
  - $A_{5,6,7}$ different from 0 @ high p_T^Z and consistent with predictions
- ***W,Z cross section and cross-section ratio measurement @ 13 TeV*** - arXiv:1603.09222
  - Fiducial and total cross sections in agreement within uncertainties with predictions, and different PDF choices
  - Cross-section ratio W^+/W^- favours CT14nnlo and MMHT14nnlo PDF's
  - Cross-section ratio $W^\pm/Z$ compatible with all PDF choices

Conclusions

- ***Drell-Yan pairs transverse momentum and Φ^*_η precision measurement @ 8 TeV*** - arXiv:1512.02192
  - Good agreement with RESBOS until high $p_T^{\ell\ell}$ or Φ^*_η, where diverge
  - Powheg+Pythia with AZNLO tune provides best description … region
  - Fixed order NNLO QCD predictions systematically … normalisation to data, and no sensitivity to EW correction is observed
- ***Measurement of angular coeffic… events @ 8 TeV*** - coming soon on arXiv!
  - Good agreement … α_S) predictions
  - A_0-A_2 sensi… corrections (confirmed Lam-Tung breaking @ NLO)
  - A_5 … high p_T^Z and consistent with predictions
- ***W,Z cr…tion and cross-section ratio measurement @ 13 TeV*** - arXiv:1603.09222
  - Fiducial and total cross sections in agreement within uncertainties with predictions, and different PDF choices
  - Cross-section ratio W^+/W^- favours CT14nnlo and MMHT14nnlo PDF's
  - Cross-section ratio $W^\pm/Z$ compatible with all PDF choices

Thanks for Listening!!

BACKUP

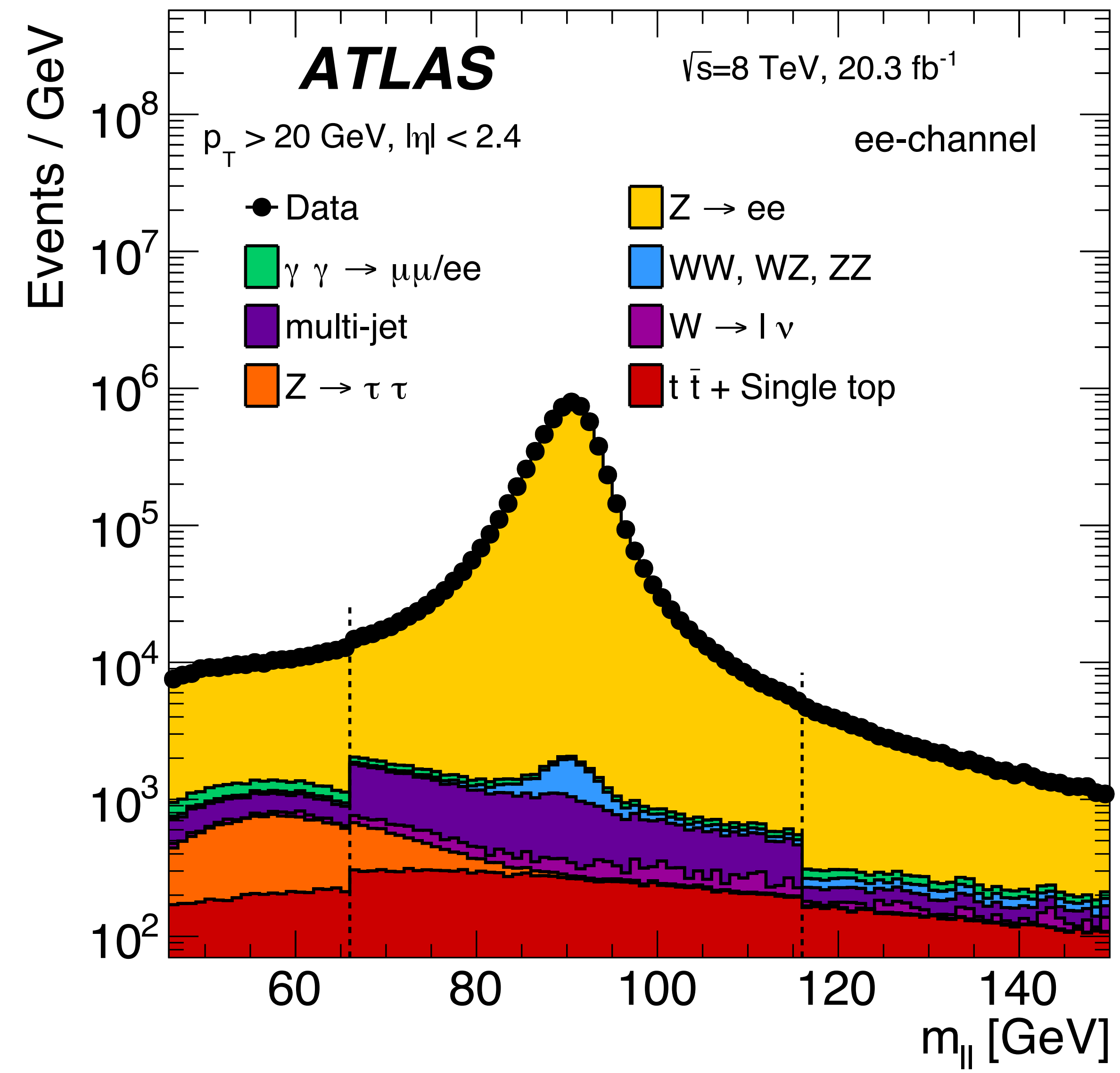
arXiv:1512.02192 - accepted by EPJC

Drell-Yan lepton pairs transverse momentum and ϕ_η^* precision measurement

L=20.3 fb^{-1} collected by ATLAS @ 8 TeV

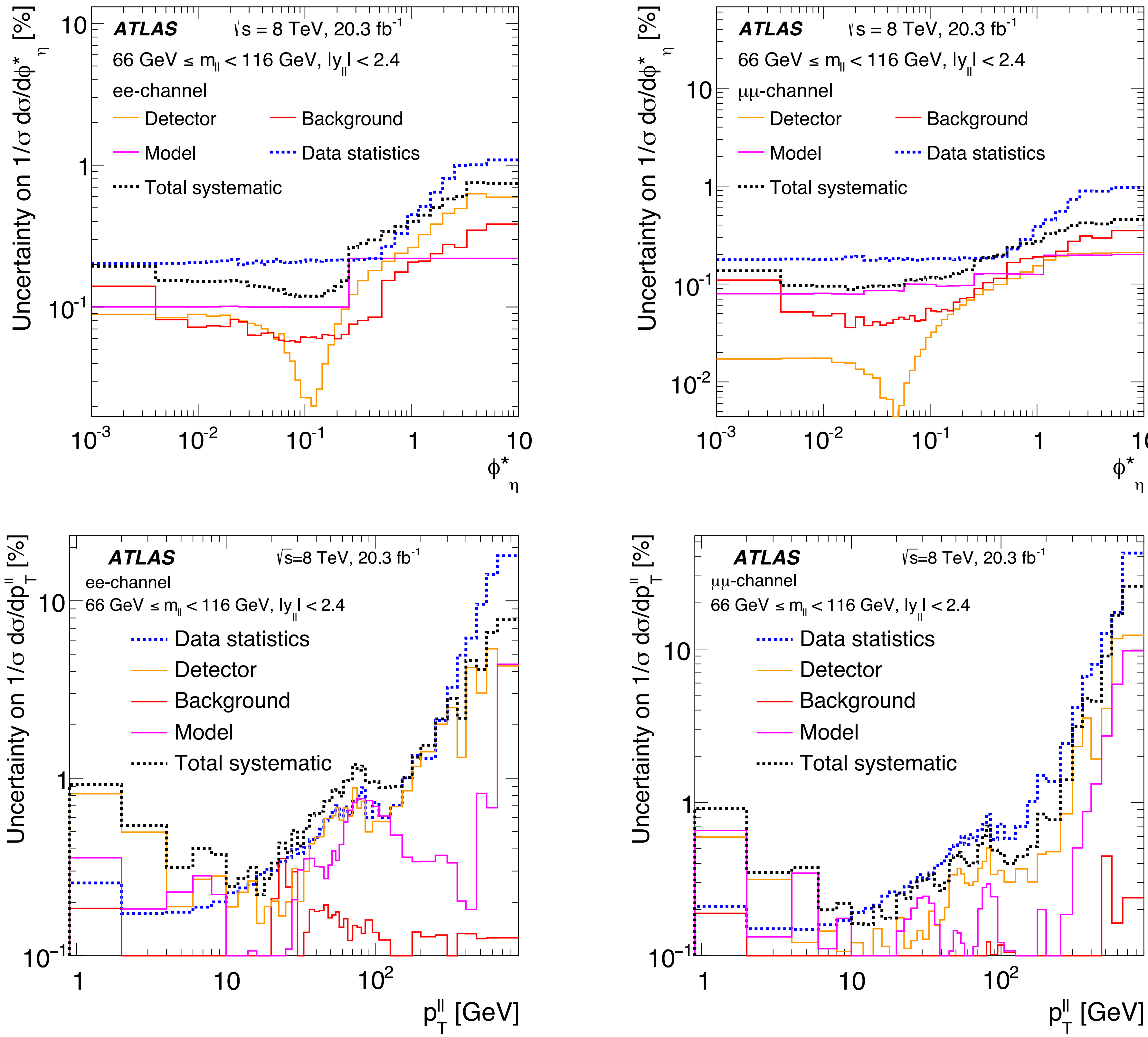
Background composition

- ***Under the Z peak*** dominated by $\gamma\gamma \to \ell\ell$ and multijet ~1%
- ***Low*** $m_{\ell\ell}$
  - high $p_T^{\ell\ell}$ and Φ^*_η dominated by tt and VV ~20%
  - low $p_T^{\ell\ell}$ dominated by $Z \to \tau\tau$ and multijet ~20%
- ***High*** $m_{\ell\ell}$
  - high $p_T^{\ell\ell}$ and Φ^*_η dominated by tt ~30%
  - low $p_T^{\ell\ell}$ dominated by $\gamma\gamma \to \ell\ell$ ~20%

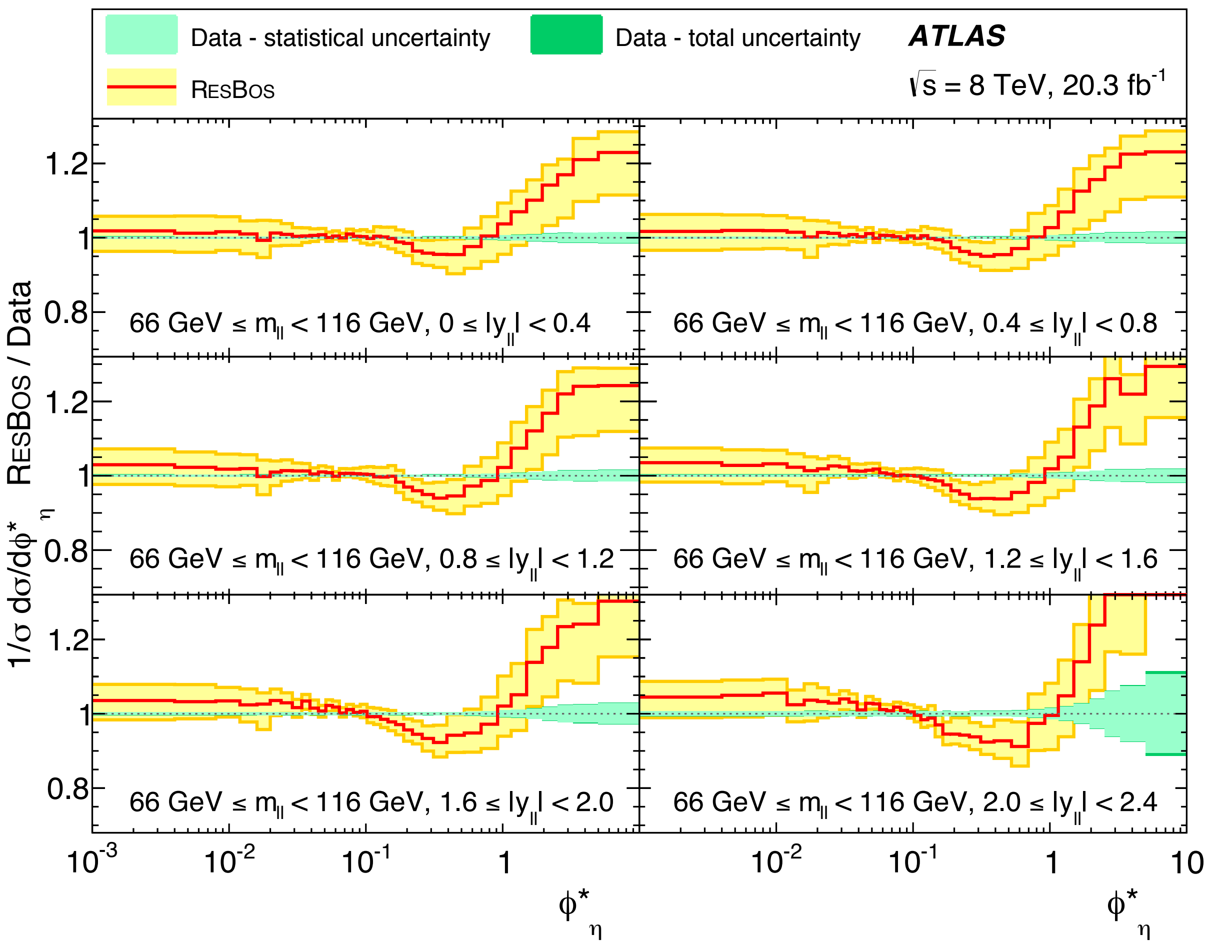


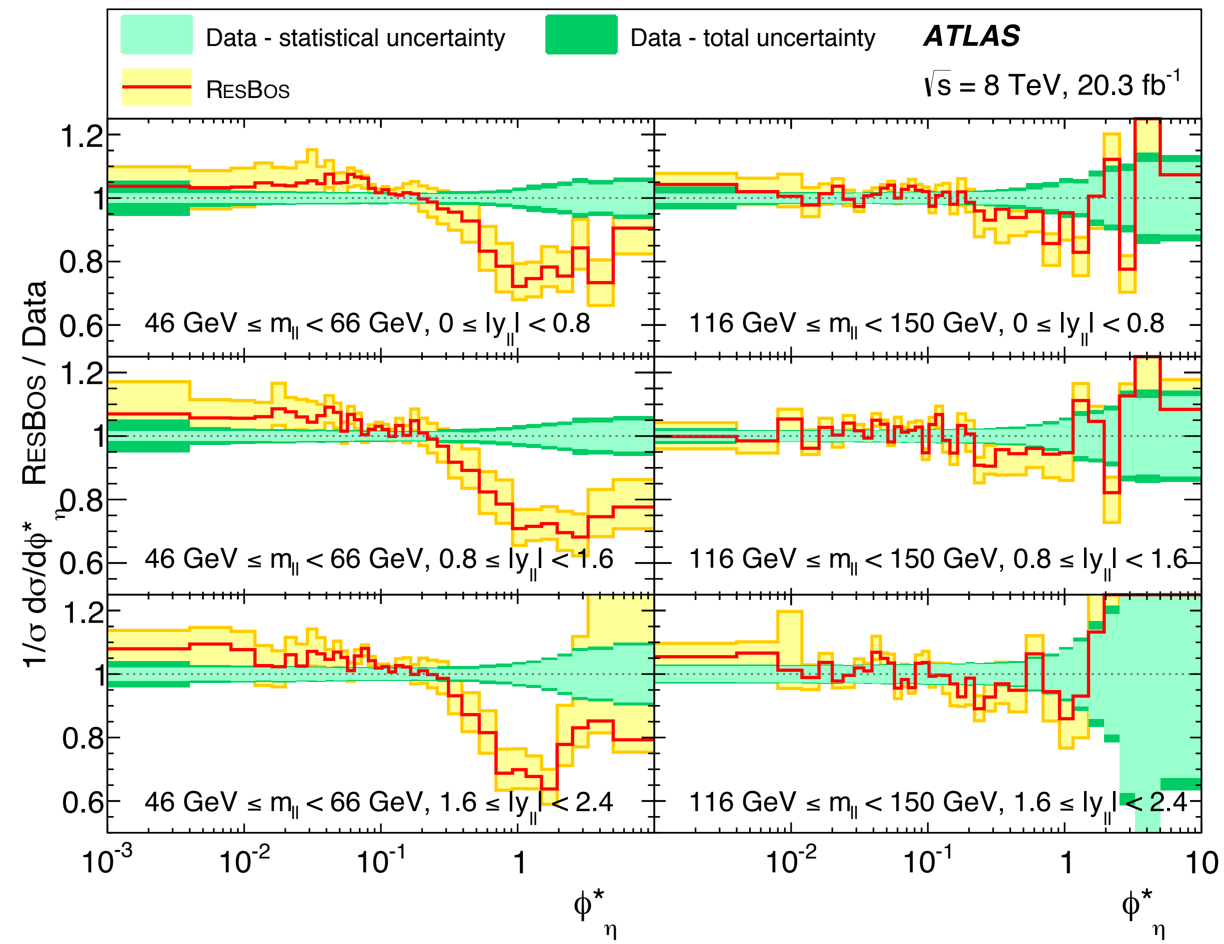
Systematic uncertainties

- ***Data statistical uncertainty is dominant***
- Lumi uncertainty 2.8%

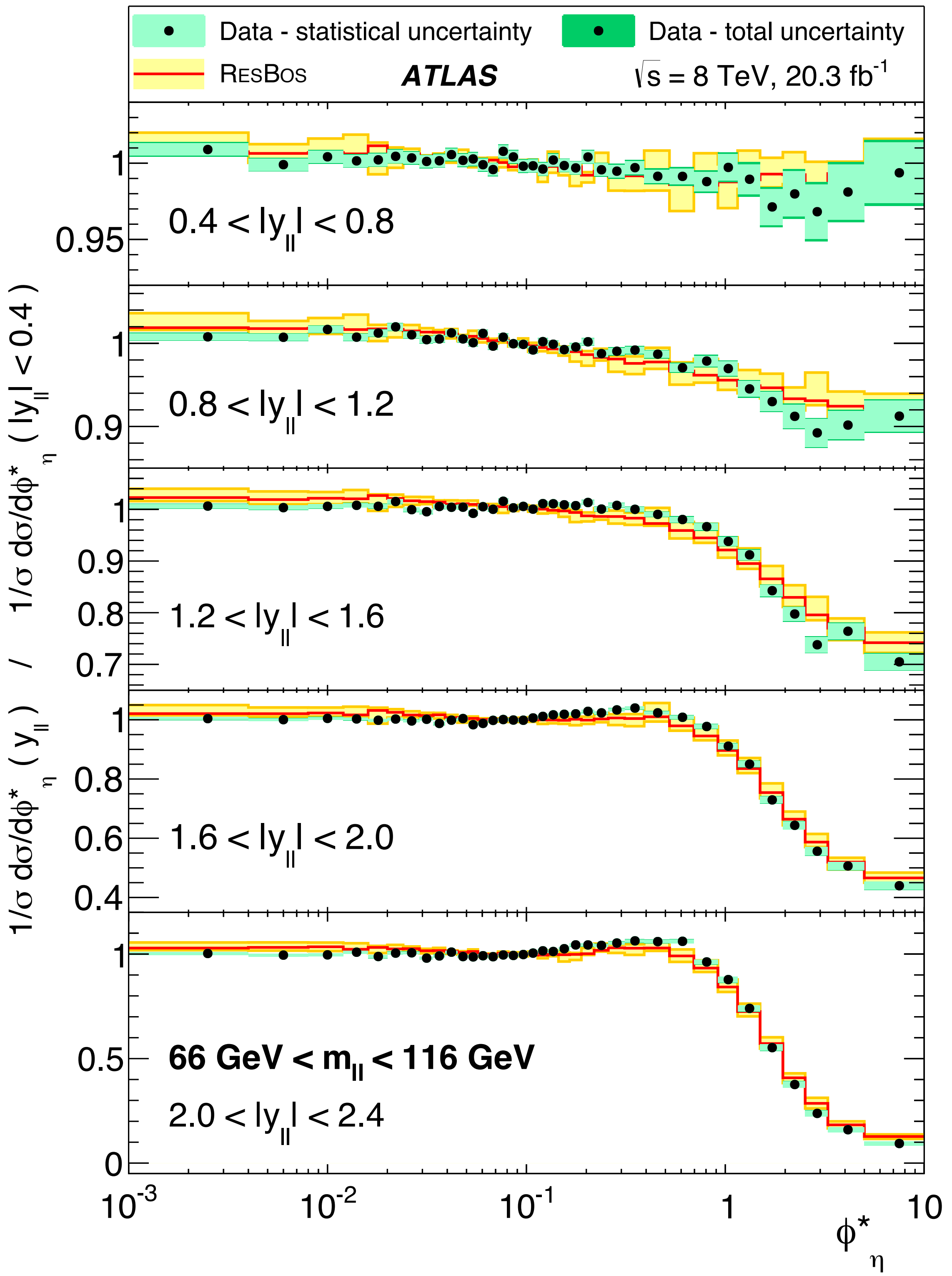


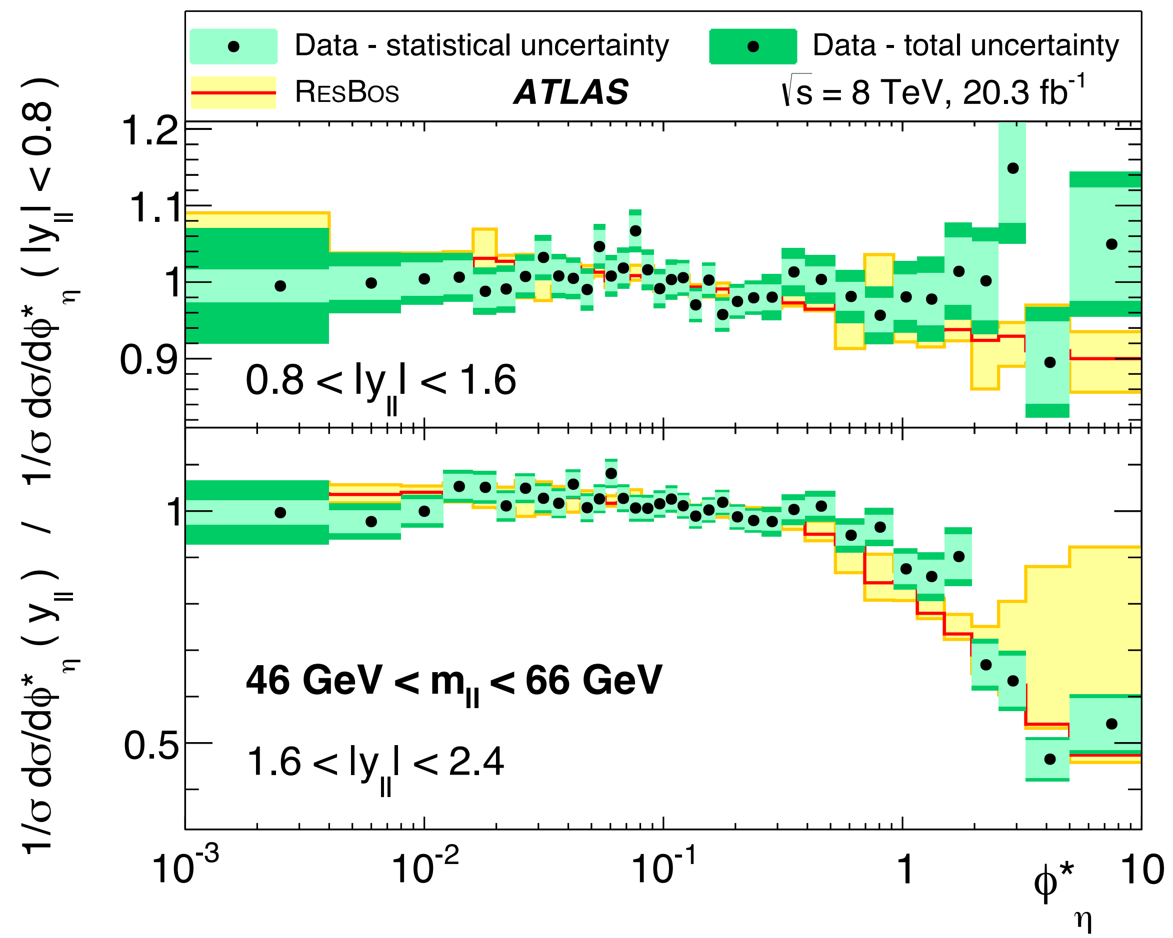
Data vs RESBOS (i)



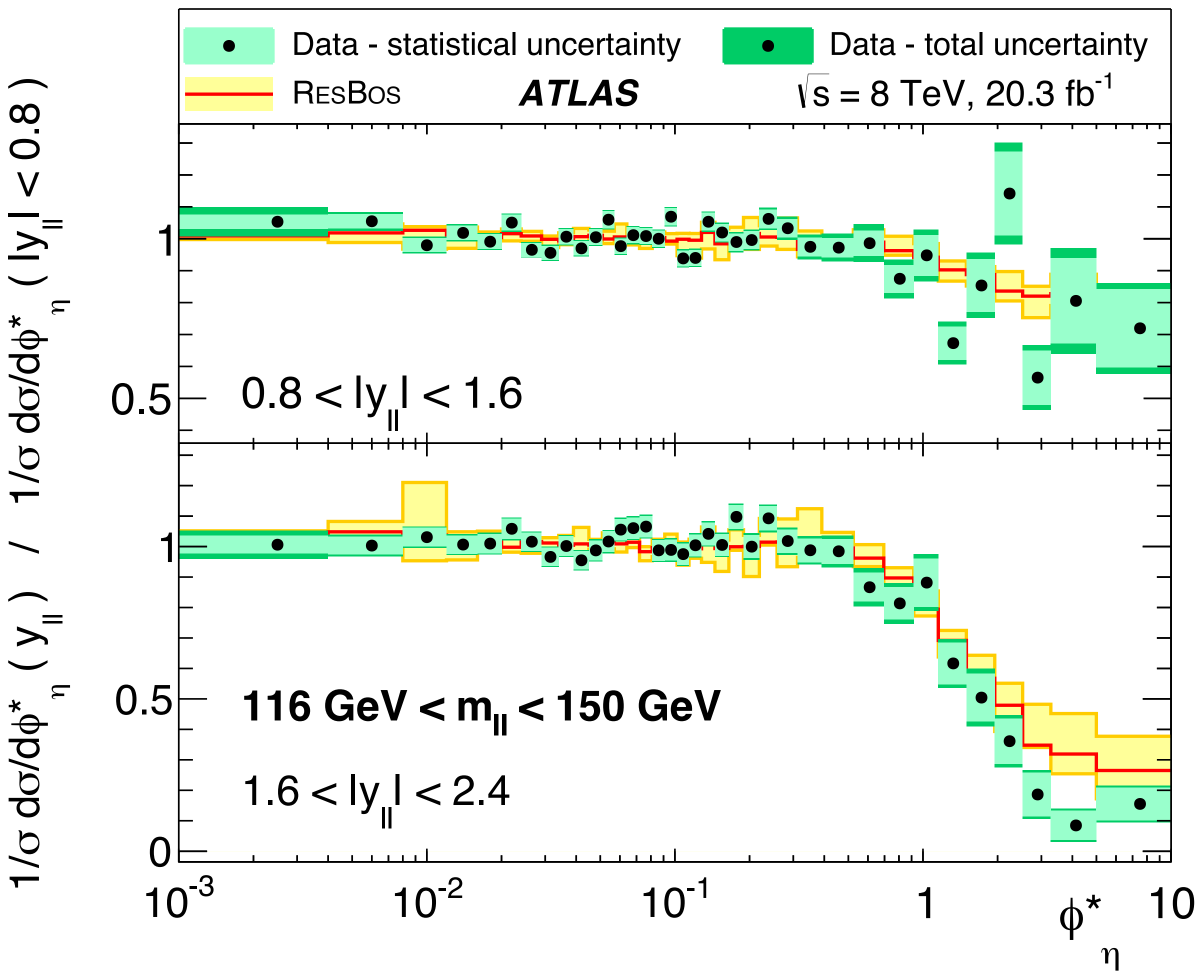


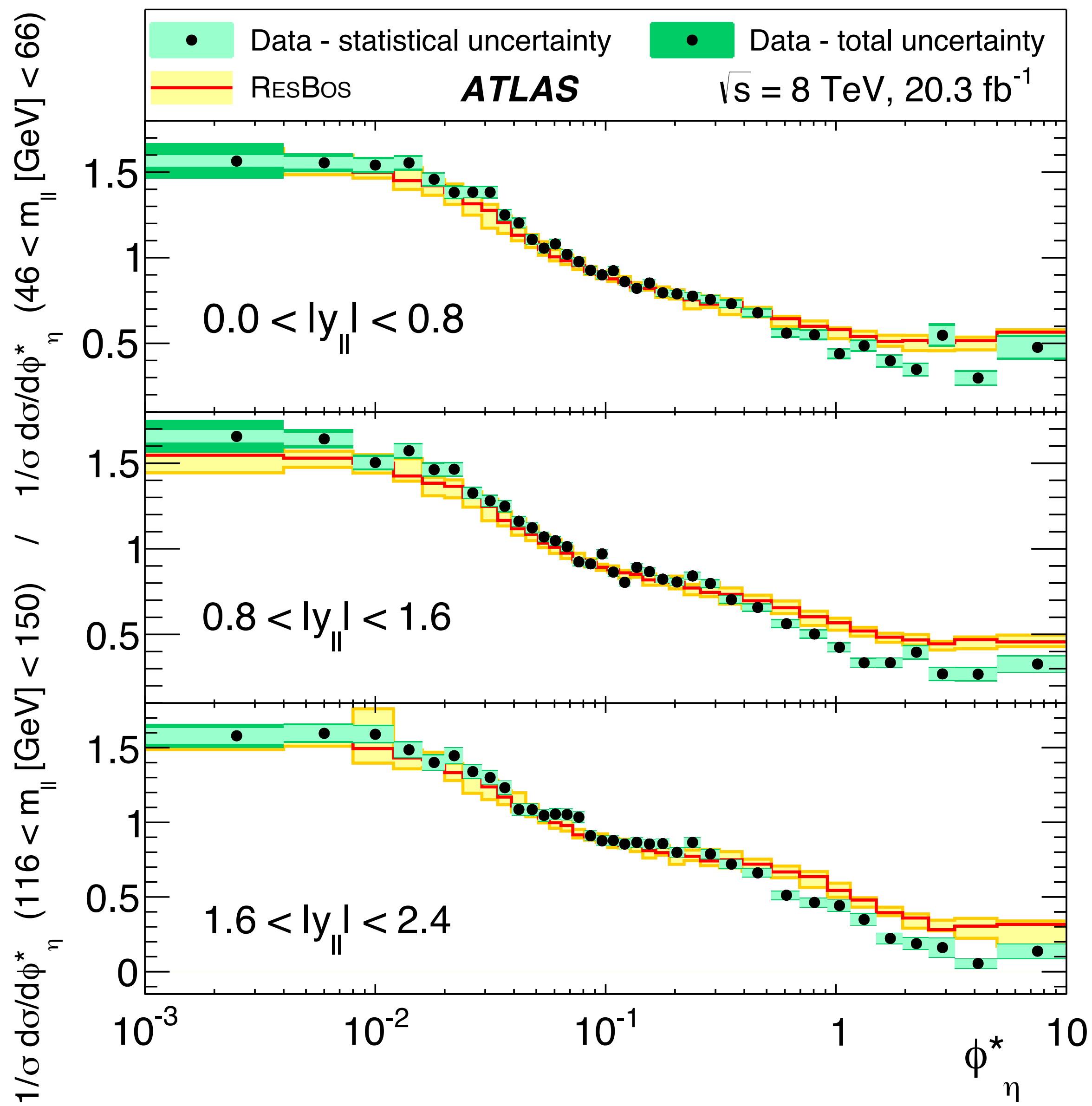
Data vs RESBOS (ii)



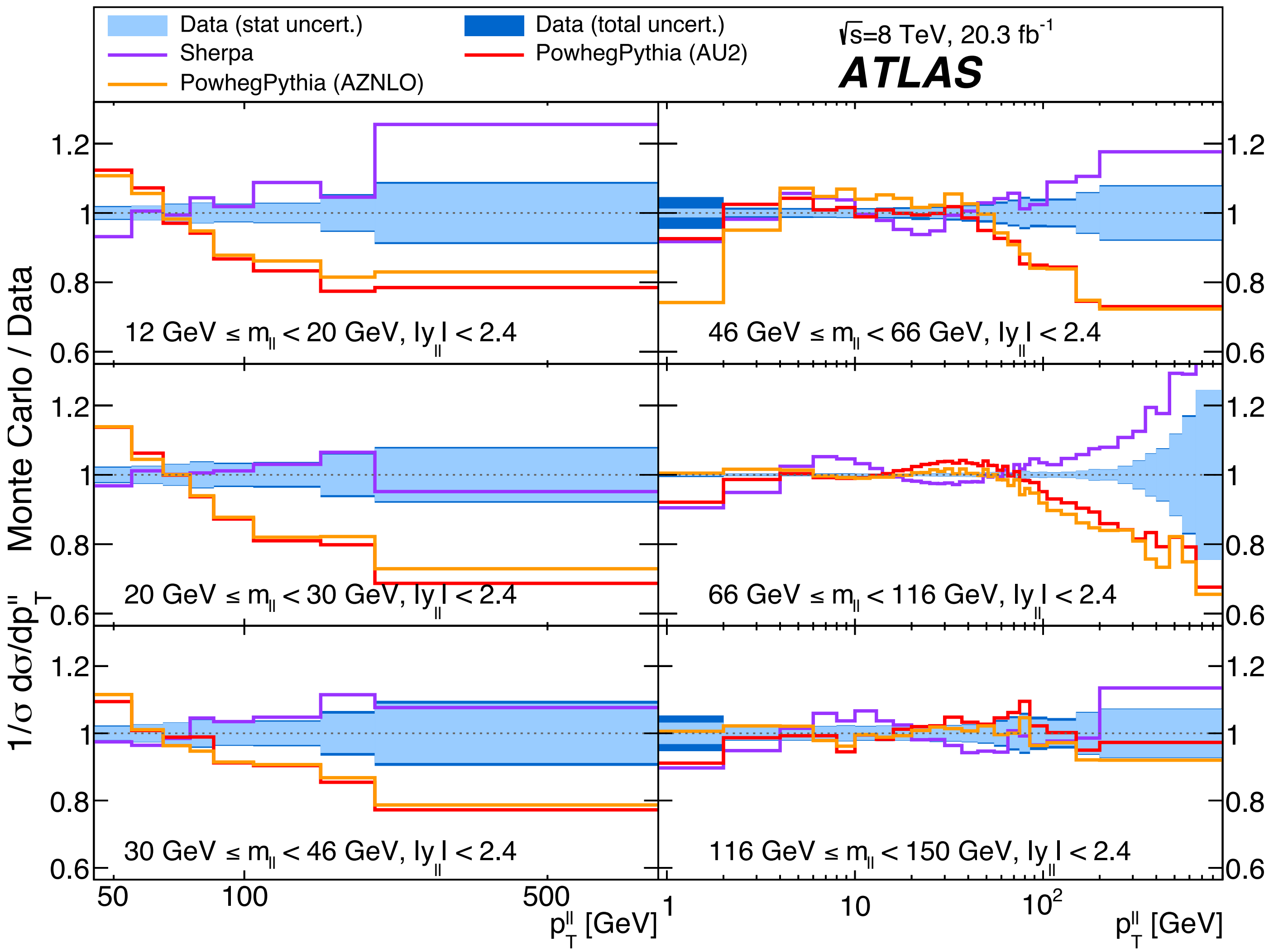


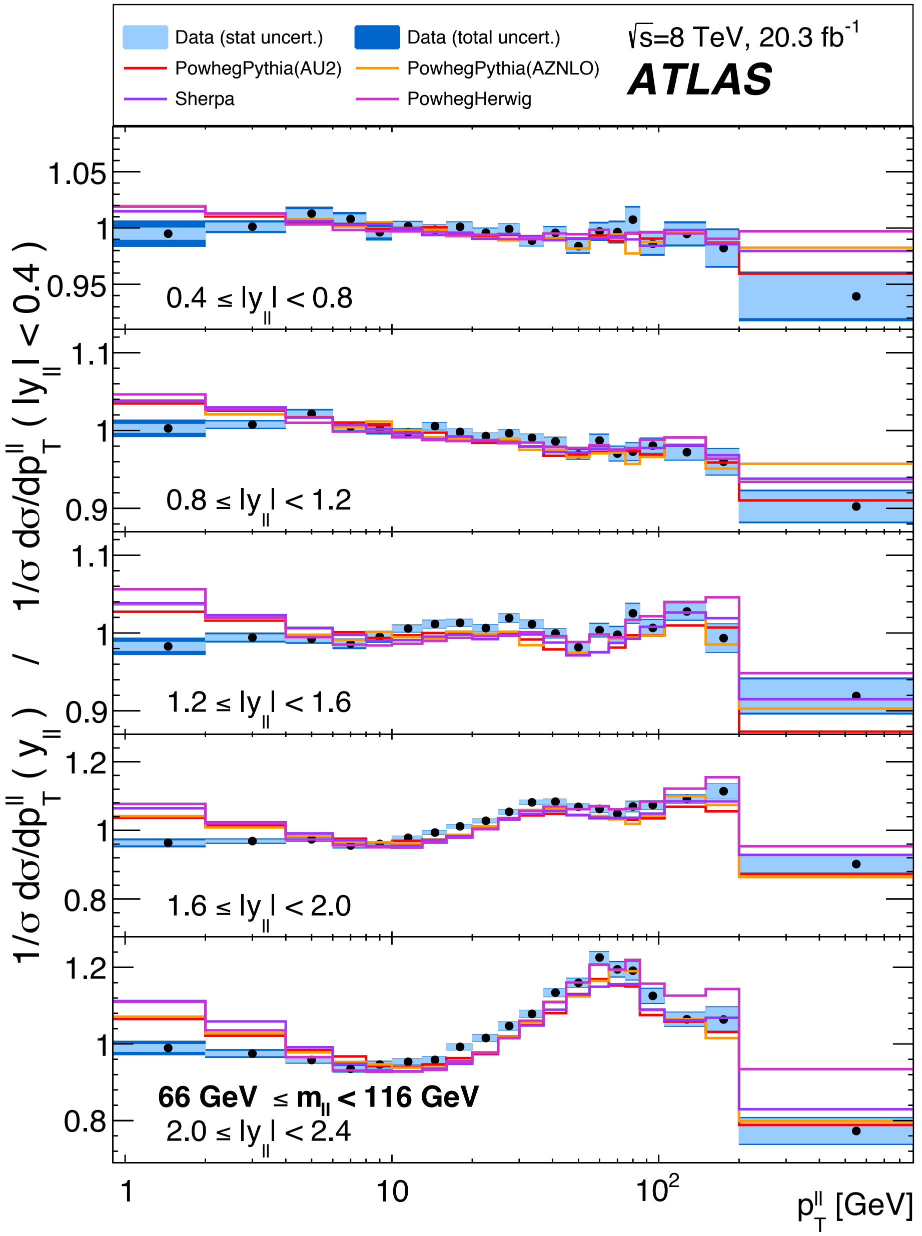
Data vs RESBOS (iii)



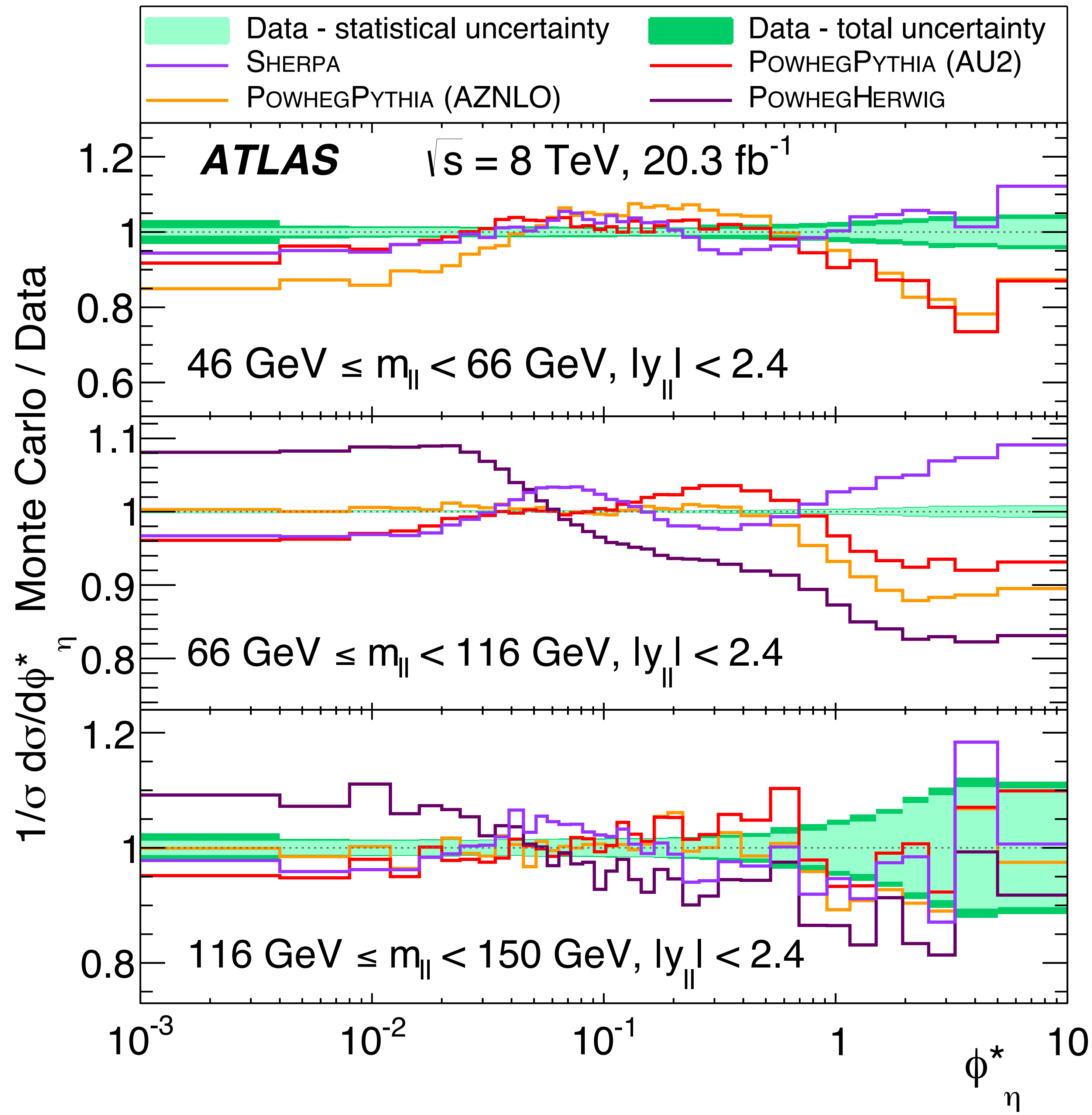


Results: comparison to PS approach



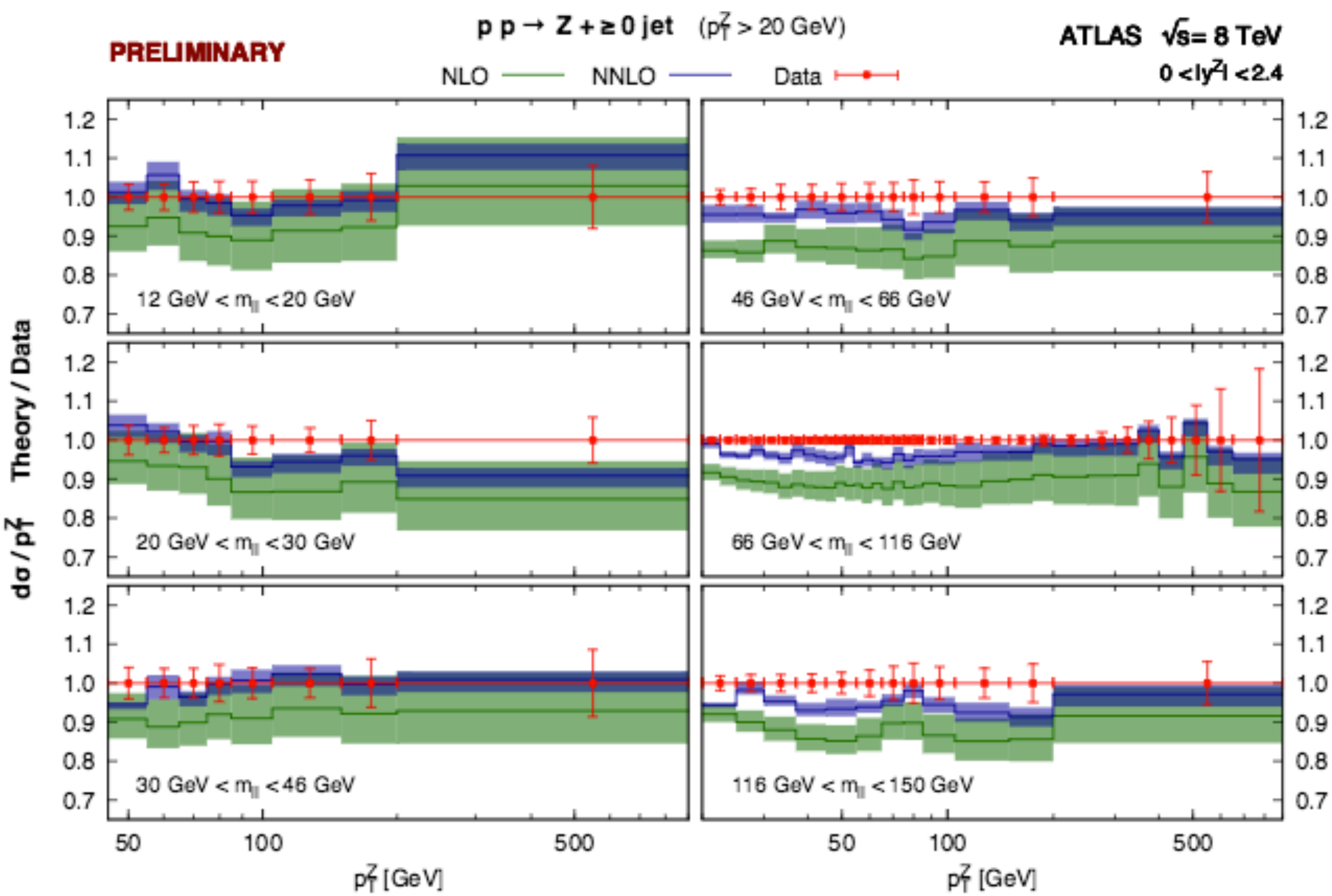


Data vs PS MC's for phi*eta



NNLO predictions comparison

- New NNLO available predictions (http://moriond.in2p3.fr/QCD/2016/TuesdayMorning/Huss.pdf) show ***improved agreement with the data***
  - *Up to 5-10%*



Not yet on arXiv - hot from the press!!!

Measurement of angular coefficients in Z-boson events

L=20.3 fb^{-1} collected by ATLAS @ 8 TeV in 2012

Analysis motivation

$$\langle \frac{1}{2}(1-3\cos^2\theta)\rangle = \frac{3}{20}(A_0 - \frac{2}{3}); \quad \langle \sin 2\theta \cos\phi\rangle = \frac{1}{5}A_1; \quad \langle \sin^2\theta \cos 2\phi\rangle = \frac{1}{10}A_2;$$

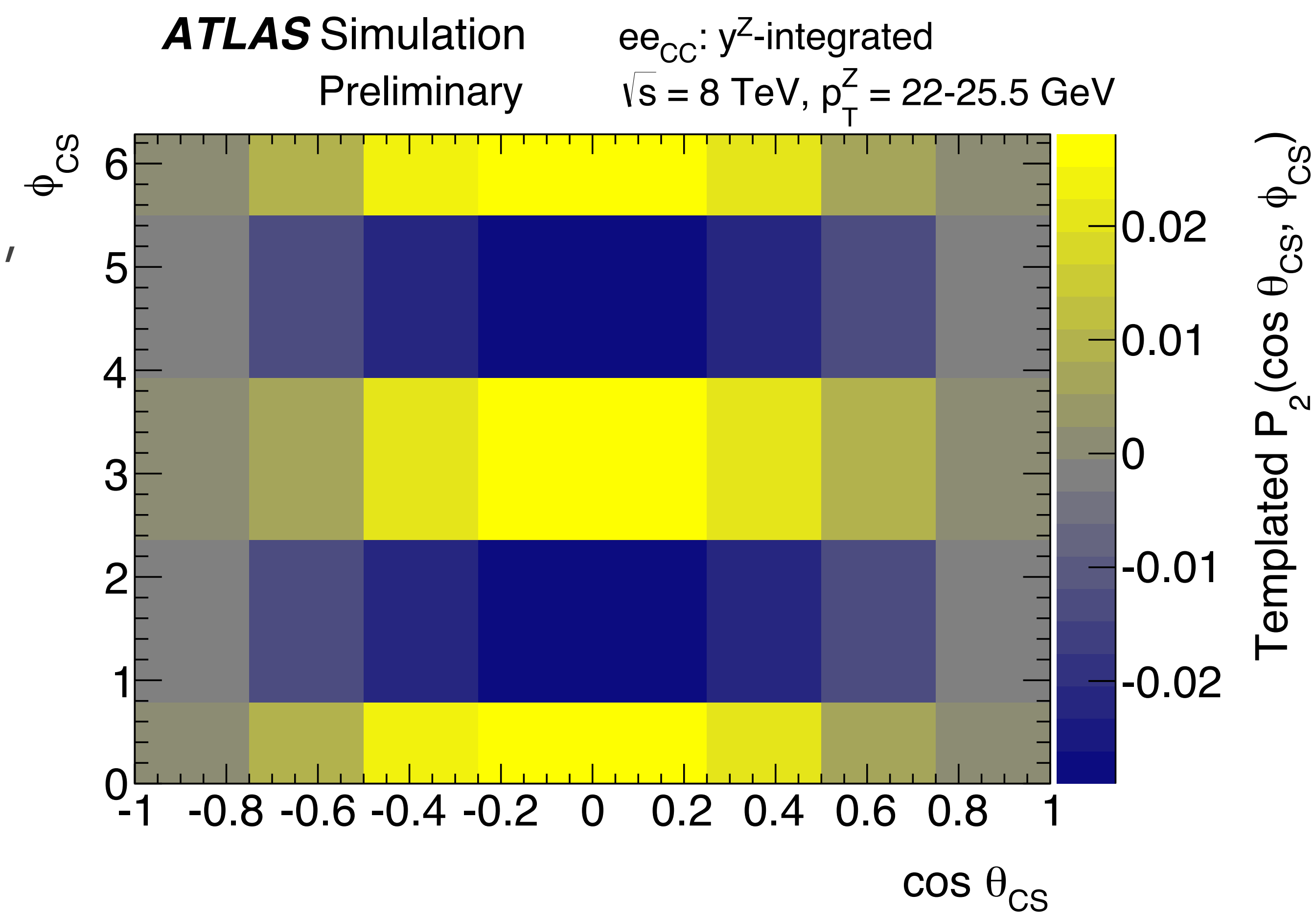
$$\langle \sin\theta \cos\phi\rangle = \frac{1}{4}A_3; \quad \langle \cos\theta\rangle = \frac{1}{4}A_4; \quad \langle \sin^2\theta \sin 2\phi\rangle = \frac{1}{5}A_5;$$

$$\langle \sin 2\theta \sin\phi\rangle = \frac{1}{5}A_6; \quad \langle \sin\theta \sin\phi\rangle = \frac{1}{4}A_7.$$

- ***A_0 and A_2***: fractions of transverse and longitudinal polarisations
  - ***Lam-Tung relationship*** predicts A_0=A_2 up to NLO QCD (expect A_0>A_2 @ higher orders)
- ***A_1***: interference between transverse and longitudinal polarisation
- ***A_3 and A_4***: product of vector-axial couplings, sensitive to $\sin^2\theta_W$
  - A_4 only one present @ LO QCD
- ***$A_{5,6,7}$*** expected to be 0 up to NLO QCD, and slightly divergent from zero @ high p_T for NNLO QCD

Analysis strategy

- Lepton selections sculpt A_i distributions → *fold polynomials* to reco phase space, modelling acceptance, efficiencies and migration effects with MC → t_{ij}
- Build also *background templates* T_B
- Fit folded templates to reco data to the full phase space A_i's

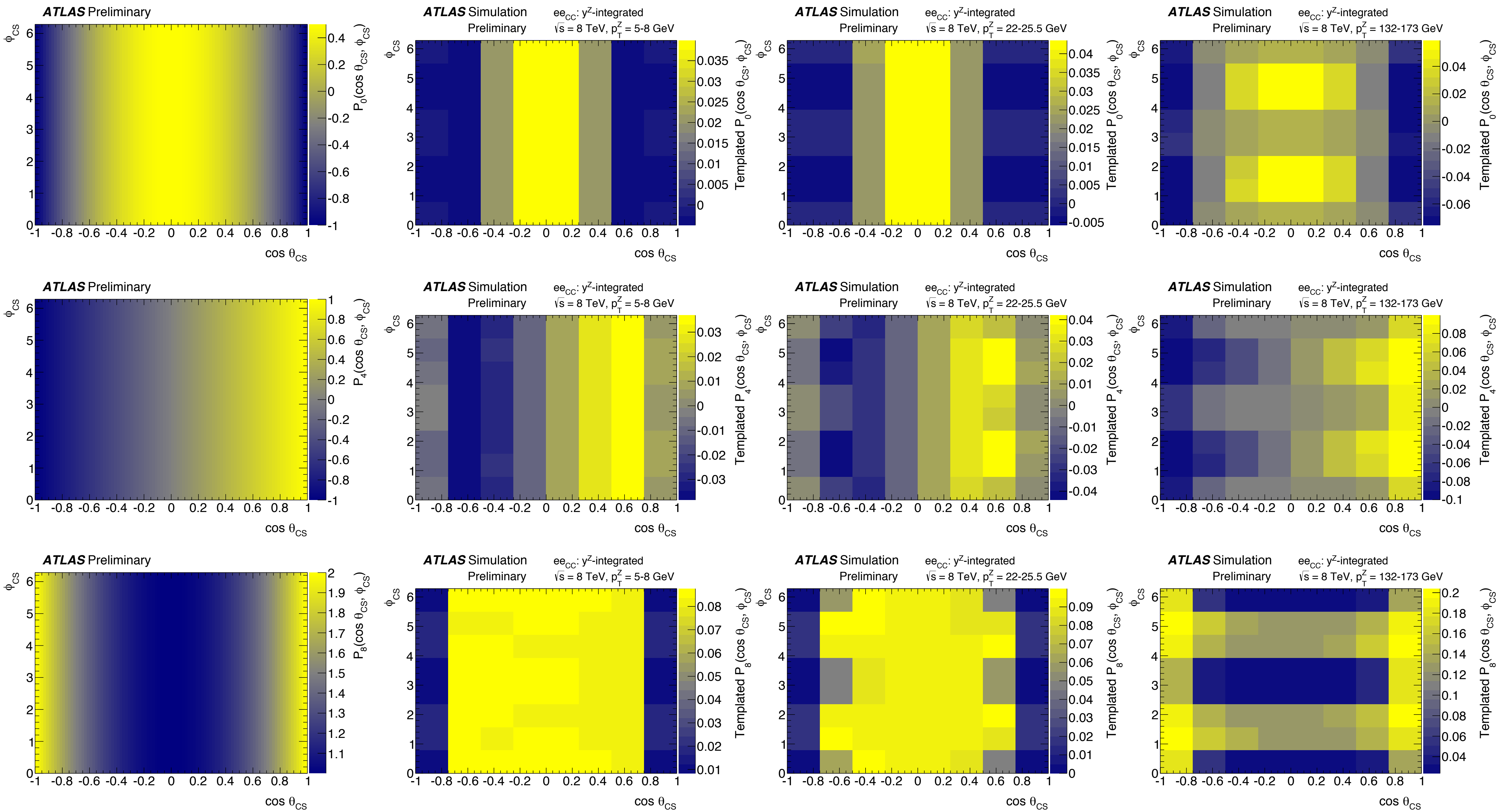


$$N_{\exp}^{n}(A,\sigma,\theta)=\left\{\sum_{j=1}^{23}\sigma_j\times L\times\left[t_{8,j}(\beta)+\sum_{i=0}^{7}A_{i,j}\times t_{i,j}(\beta)\right]+\sum_{B}^{bkgs}T_B(\beta)+T_{Fakes}\right\}\times\gamma^n$$

Perform maximum likelihood fit on the reco data to extract the A_i's:

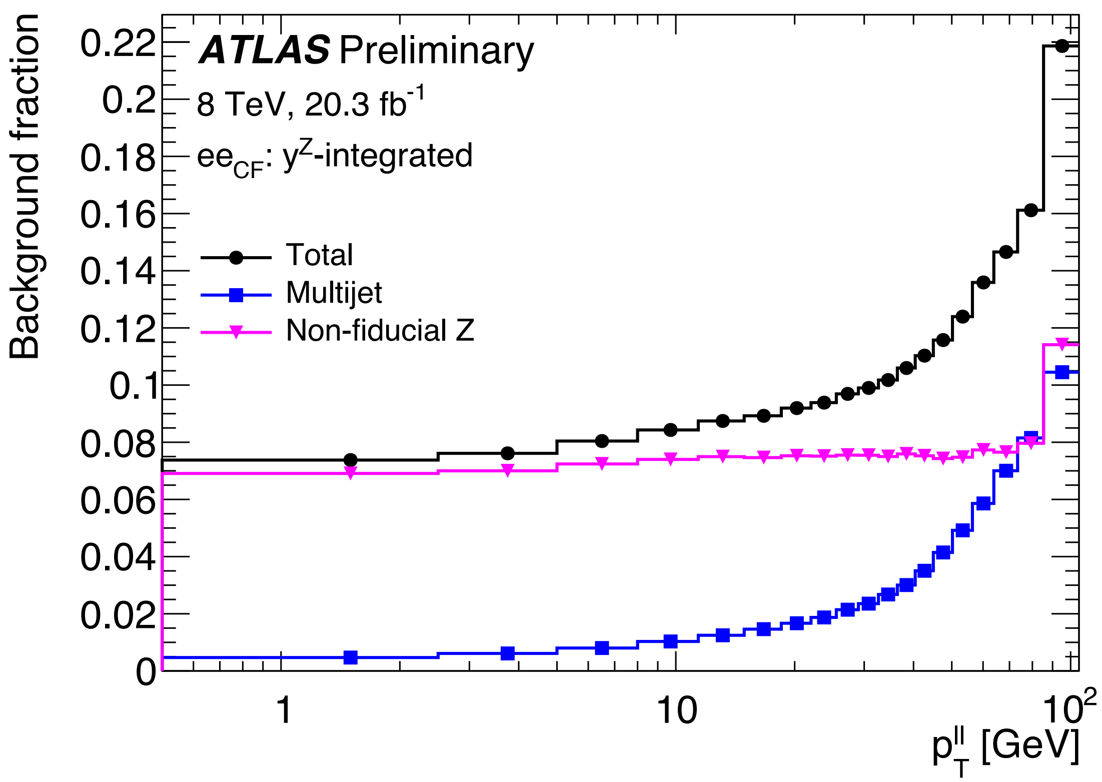
$$\mathcal{L}(A_{i,j},\sigma_j^{\Phi}\,|\,N)=\prod_{n}^{Nbins}\left\{P(N_{obs}^{n})\,|\,N_{\exp}^{n}(A,\sigma,\theta)P(N_{eff}^{n}\,|\,\gamma^{n}N_{obs}^{n})\right\}\times\prod_{m}^{M}G(0\,|\,\beta^{m},1)$$

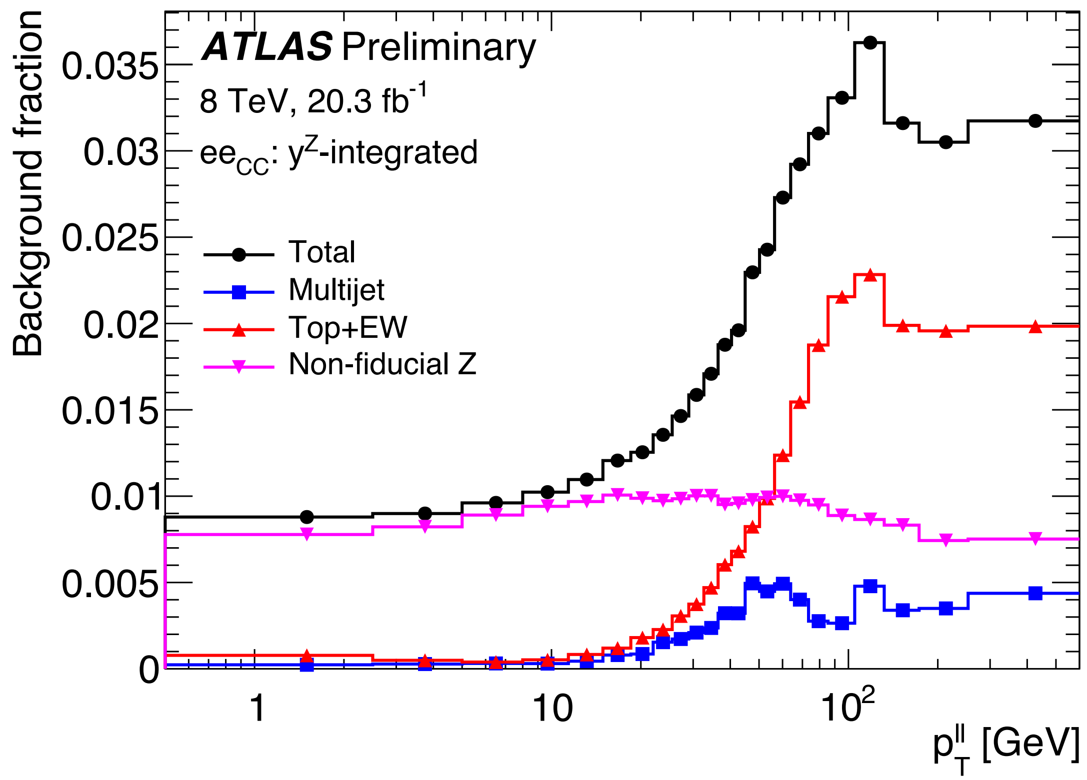
$P_{0,4,8}$

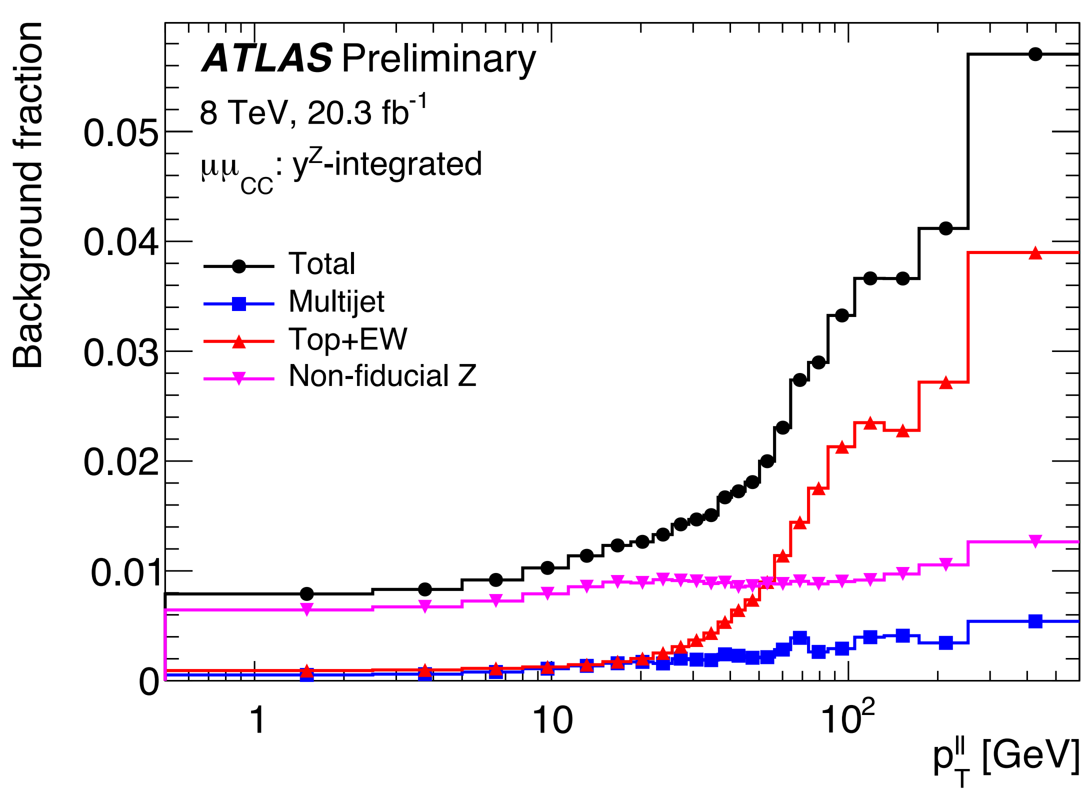


ATLAS Preliminary
ATLAS Simulation Preliminary
ee_{CC}: y^Z-integrated
$\sqrt{s}$ = 8 TeV, p_T^Z = 5-8 GeV
$\sqrt{s}$ = 8 TeV, p_T^Z = 22-25.5 GeV
$\sqrt{s}$ = 8 TeV, p_T^Z = 132-173 GeV
ϕ_{CS}
cos θ_{CS}
$P_0(\cos\theta_{CS}, \phi_{CS})$
$P_4(\cos\theta_{CS}, \phi_{CS})$
$P_8(\cos\theta_{CS}, \phi_{CS})$
Templated $P_0(\cos\theta_{CS}, \phi_{CS})$
Templated $P_4(\cos\theta_{CS}, \phi_{CS})$
Templated $P_8(\cos\theta_{CS}, \phi_{CS})$

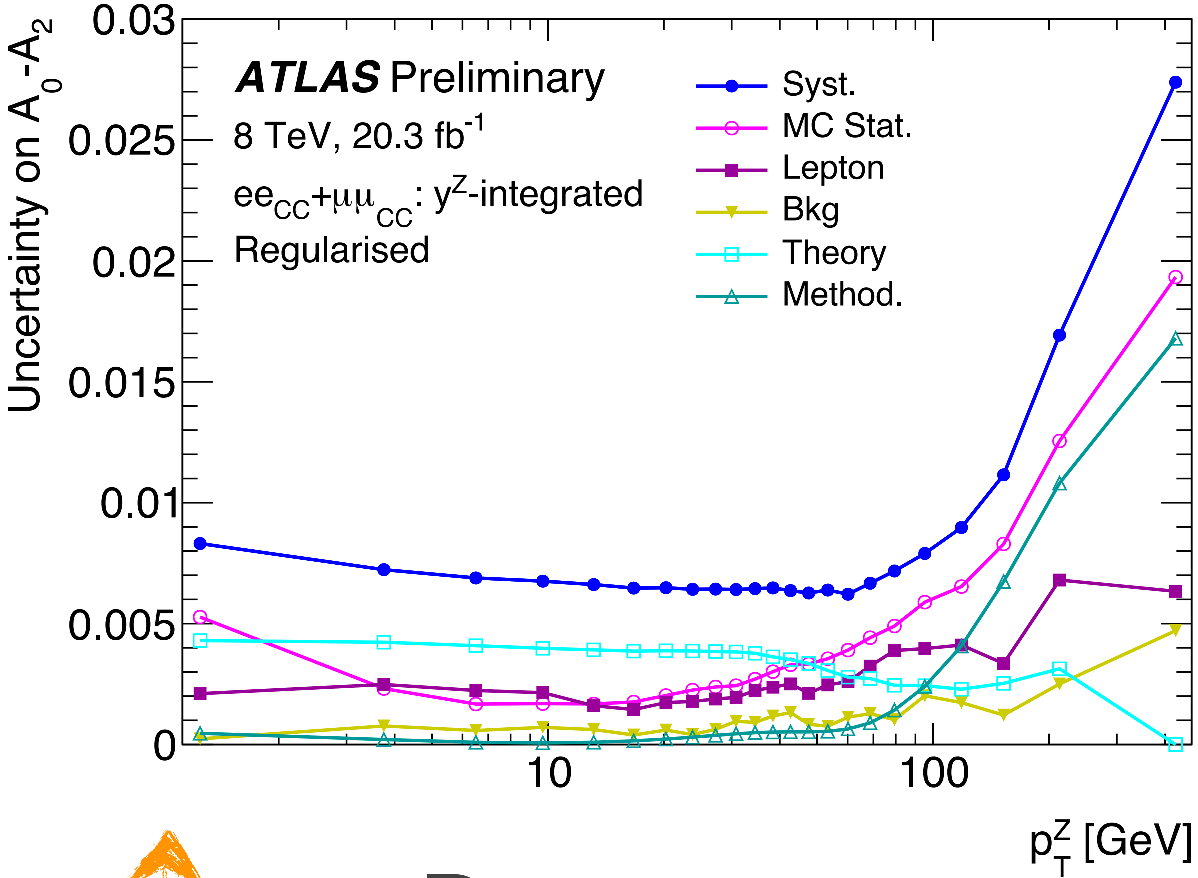
Background fractions







Systematic uncertainties

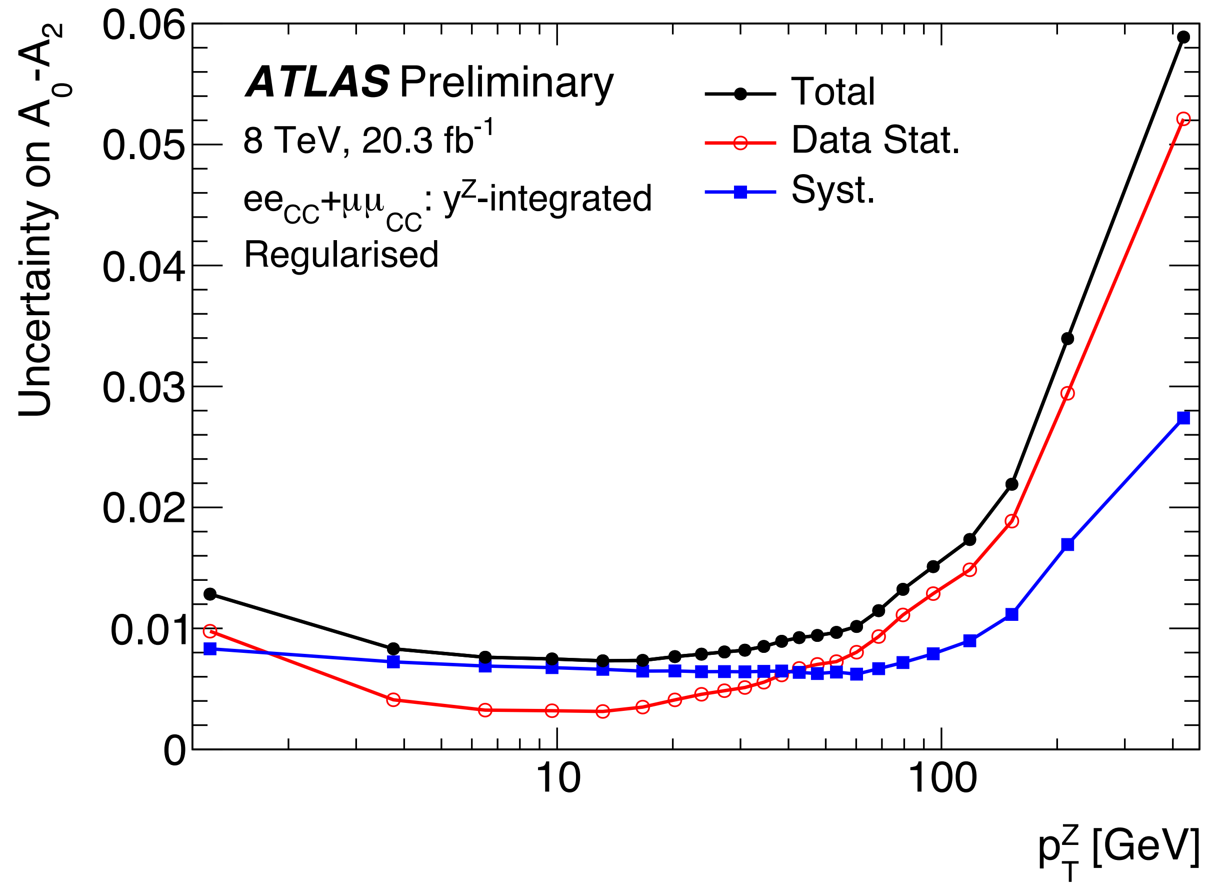


Data stat

Lepton systematics

PDF uncertainty

MC signal statistics



arXiv:1603.09222 - submitted to Phys. Lett. B

W,Z cross sections and cross-section ratios

$L = 81\ pb^{-1}$ @ 13 TeV

Data taken with 50 ns bunch spacing in early Summer 2015

Event selection - or "how to get N and B"

Event selection:

Primary vertex: hard scatter vertex with at least 2 tracks associated

Trigger (e): isolated electron with p_T>24 GeV OR electron with p_T>60 GeV

Trigger (μ): isolated muon with p_T>20 GeV OR muon with p_T>50 GeV

Good electron:

Pass likelihood medium ID

Isolation: 90% efficient track-calo combined working point

p_T>25 GeV, $|\eta|$<2.47, excluding calorimeter crack region ($1.37<|\eta|<1.52$)

Good muon:

Pass medium ID

Isolation: 90% efficient track-calo combined working point

p_T>25 GeV, $|\eta|$<2.4

W selection:

Only one good electron or muon

Calibrated missing energy > 25 GeV

m_T^W>50 GeV

Z selection:

Exactly two good electron or muon

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

NB: uniform cuts across the channels (important for uncertainty reduction in ratio)

Multijet background extraction in W analysis

QCD multijet background:

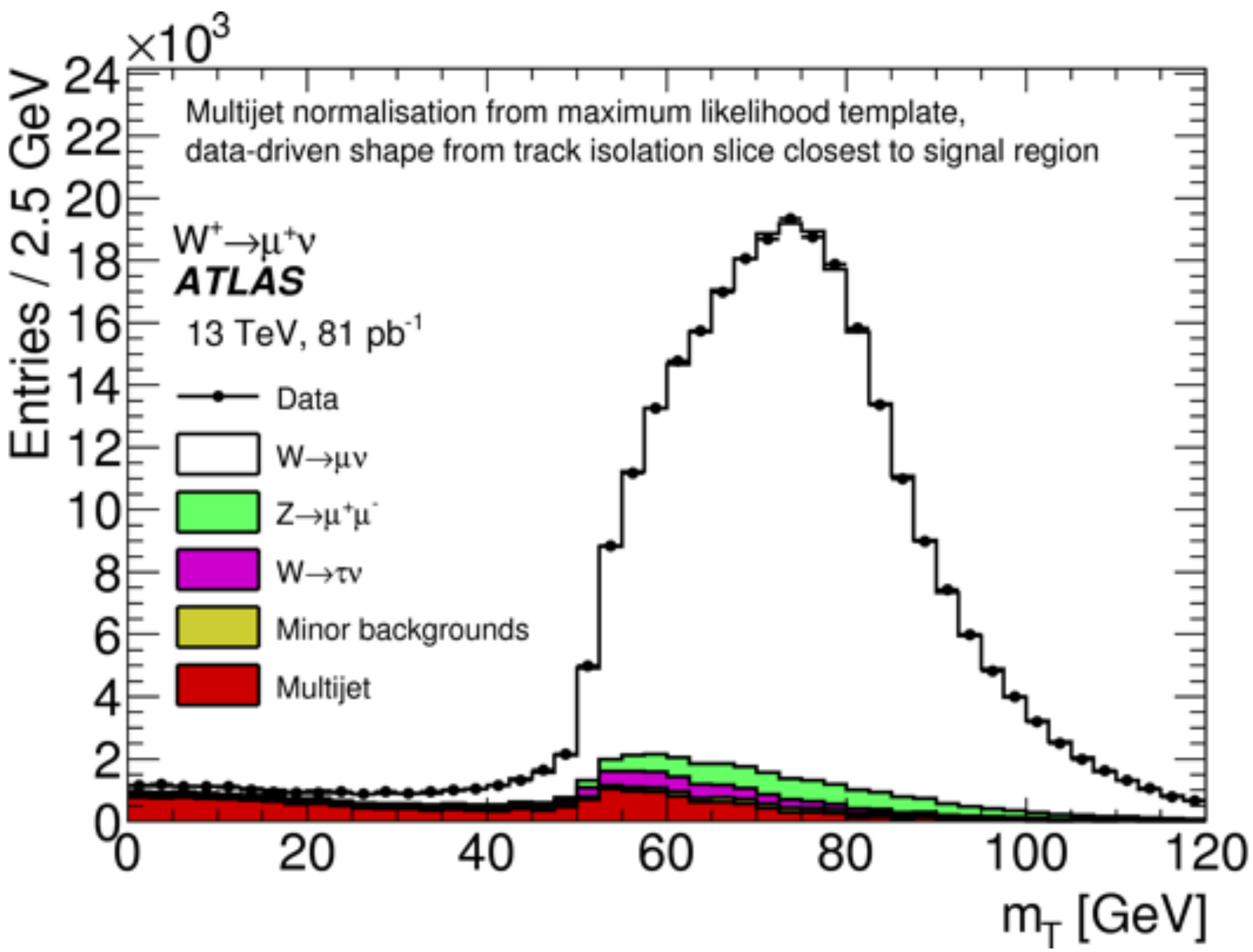
- in Z analysis negligible (<0.1%), in W analysis sizeable contribution, estimated using data

Use repeated template fit approach

- slice in intervals of isolation, to obtain *statistically independent templates*

- Evaluation performed in *2 Fit Regions* (m_T relaxed, E_T^{miss} relaxed), for *different kinematic distributions* (E_T^{miss}, m_T, p_T^{ℓ}, $d\Phi(E_T^{miss},\ell)$) → extract yields

- Different extracted ***yields extrapolated to signal region*** (small isolation values)



Multijet background extraction in W analysis

QCD multijet background:

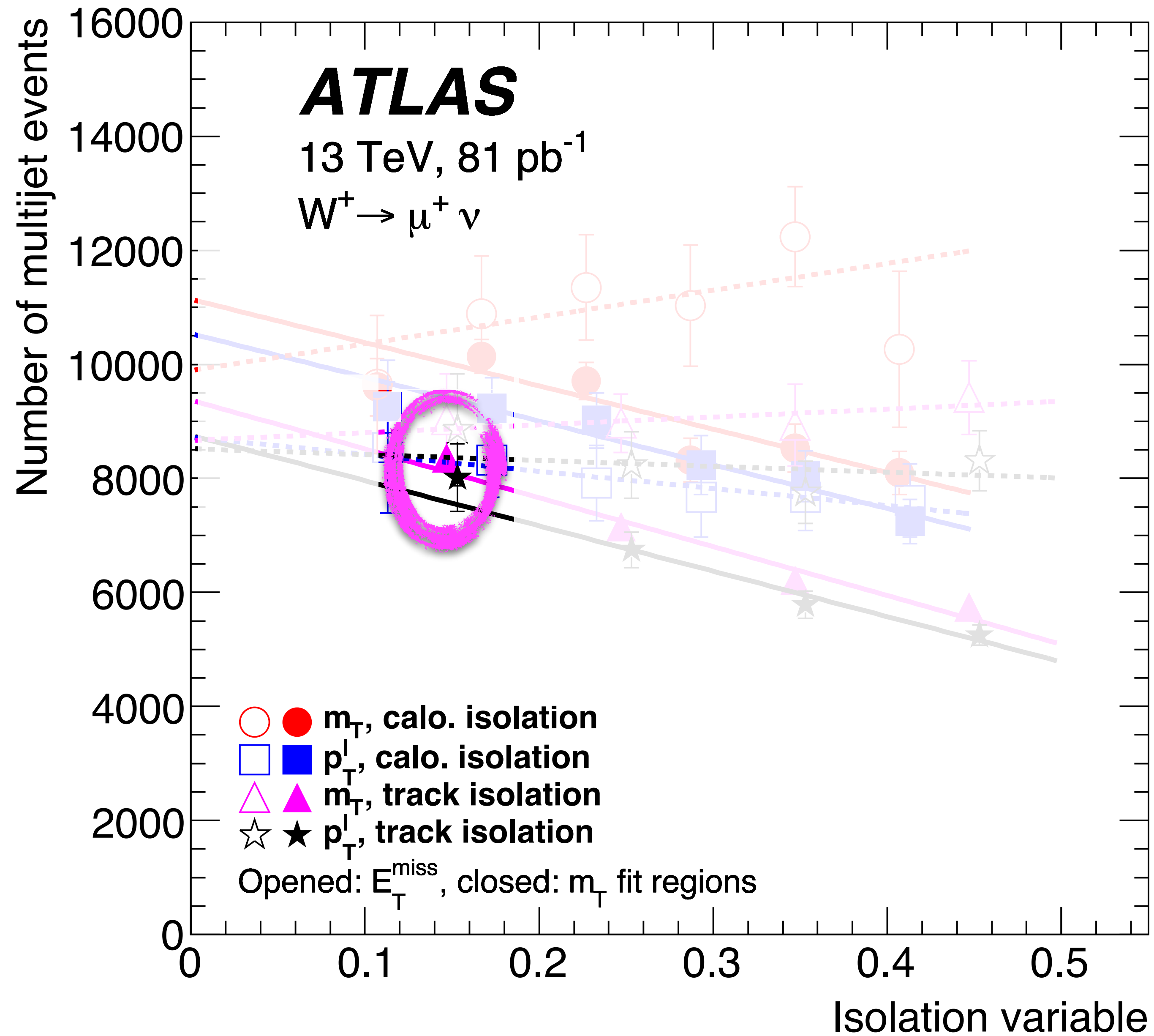
➡ in Z analysis negligible (<0.1%), in W analysis sizeable contribution, estimated using data

Use repeated template fit approach

➡ slice in intervals of isolation, to obtain *statistically independent templates*

➡ Evaluation performed in *2 Fit Regions* (m_T relaxed, E_T^{miss} relaxed), for *different kinematic distributions* (E_T^{miss}, m_T, p_T^{ℓ}, $d\Phi(E_T^{miss},\ell)$) → extract yields

➡ Different extracted ***yields extrapolated to signal region*** (small isolation values)



Multijet background extraction in W analysis

QCD multijet background:

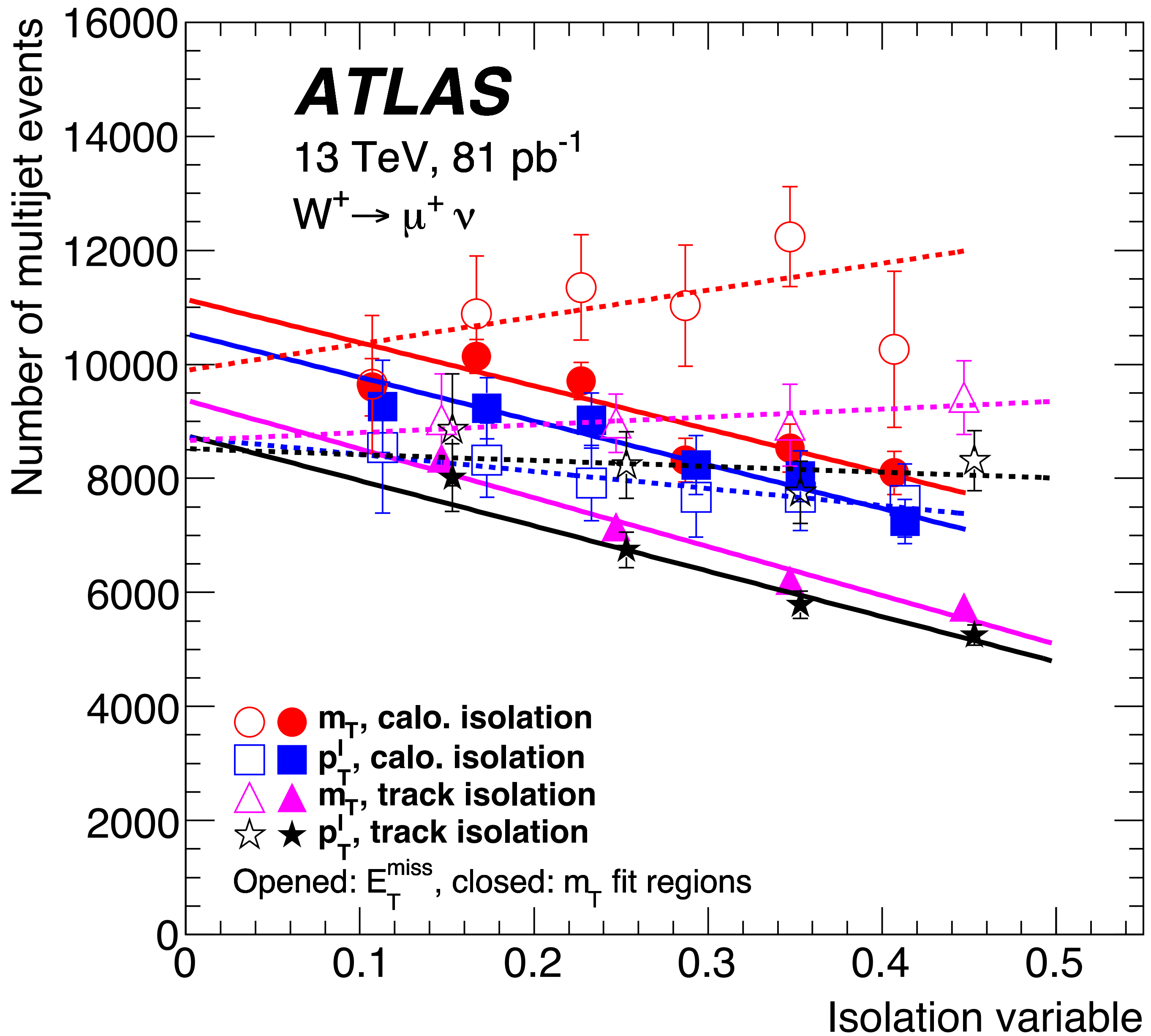
- in Z analysis negligible (<0.1%), in W analysis sizeable contribution, estimated using data

Use repeated template fit approach

- slice in intervals of isolation, to obtain *statistically independent templates*

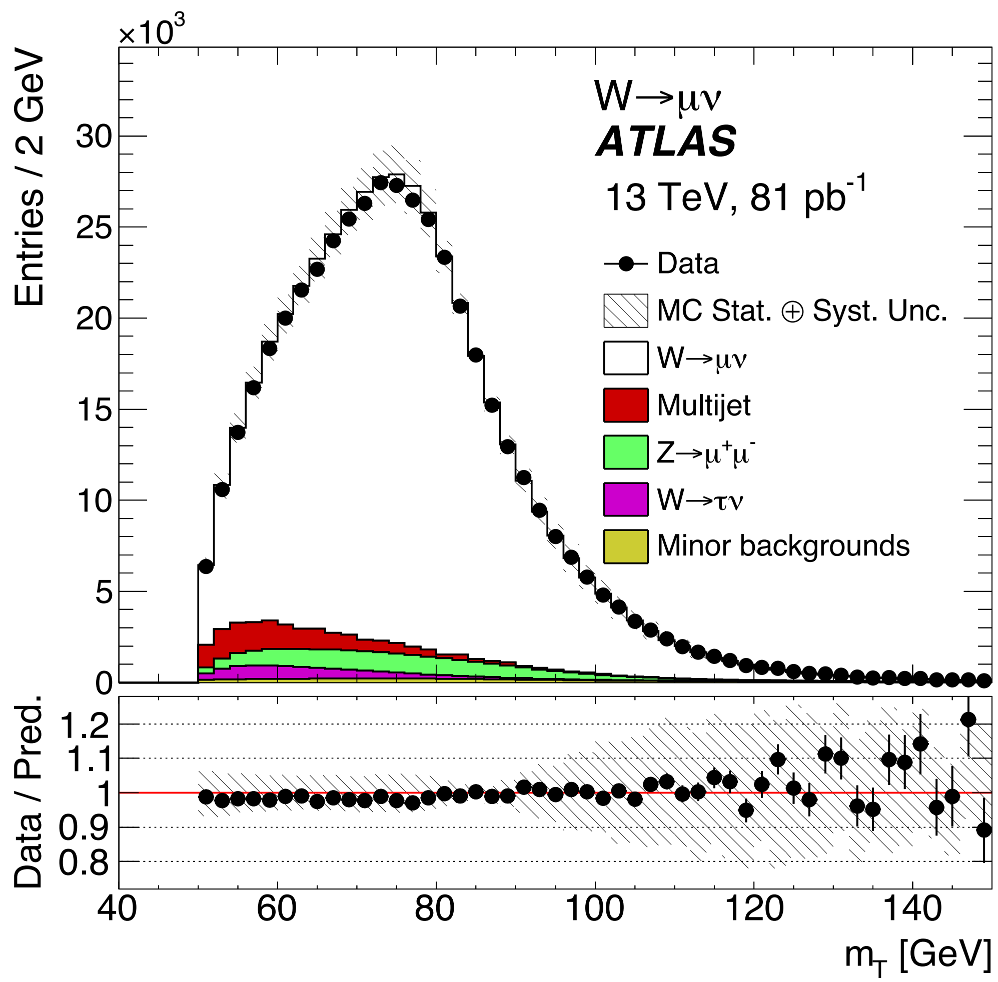
- Evaluation performed in *2 Fit Regions* (m_T relaxed, E_T^{miss} relaxed), for *different kinematic distributions* (E_T^{miss}, m_T, p_T^{ℓ}, $d\Phi(E_T^{miss},\ell)$) → extract yields

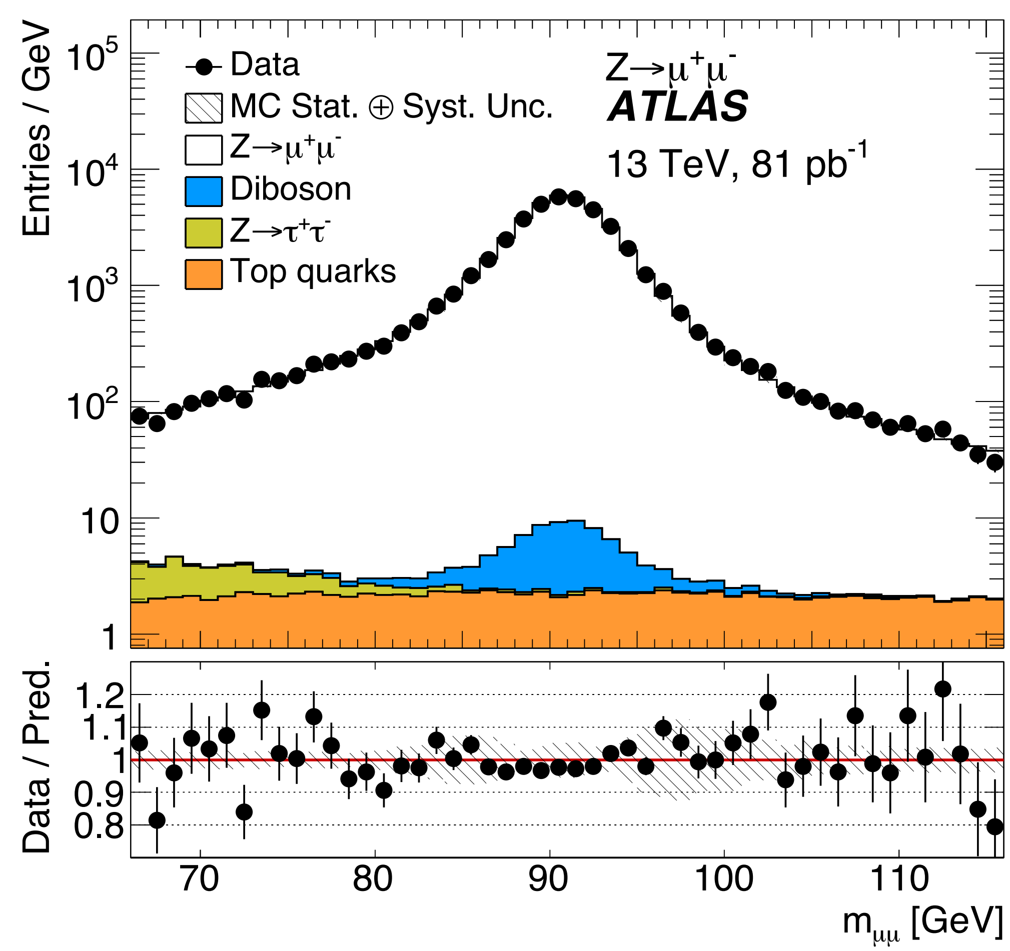
- Different extracted ***yields extrapolated to signal region*** (small isolation values)



Kinematic distributions

- No differential cross section evaluated:
  - plots only illustrative of the data/MC agreement
- Signal modelled with Powheg+Pythia8, MJ shape and yield from data-driven estimate, other backgrounds from simulation (Powheg+Pythia - check ttbar)
- Systematic band shows experimental uncertainties, but does not include 5% luminosity uncertainty





Systematic uncertainties

$\delta C/C$ [%]	$Z \to e^+e^-$	$W^+ \to e^+\nu$	$W^- \to e^-\overline{\nu}$	$Z \to \mu^+\mu^-$	$W^+ \to \mu^+\nu$	$W^- \to \mu^-\overline{\nu}$
Lepton trigger	0.1	0.3	0.3	0.2	0.6	0.6
Lepton reconstruction, identification	0.9	0.5	0.6	0.9	0.4	0.4
Lepton isolation	0.3	0.1	0.1	0.5	0.3	0.3
Lepton scale and resolution	0.2	0.4	0.4	0.1	0.1	0.1
Charge identification	0.1	0.1	0.1	–	–	–
JES and JER	–	1.7	1.7	–	1.6	1.7
$E_{\mathrm{T}}^{\mathrm{miss}}$	–	0.1	0.1	–	0.1	0.1
Pile-up modelling	< 0.1	0.4	0.3	< 0.1	0.2	0.2
PDF	0.1	0.1	0.1	< 0.1	0.1	0.1
Total	1.0	1.9	1.9	1.1	1.8	1.8

➡ Contribute to the cross-section measurement via the C factor mainly

➡ ***Lumi uncertainty 5%***

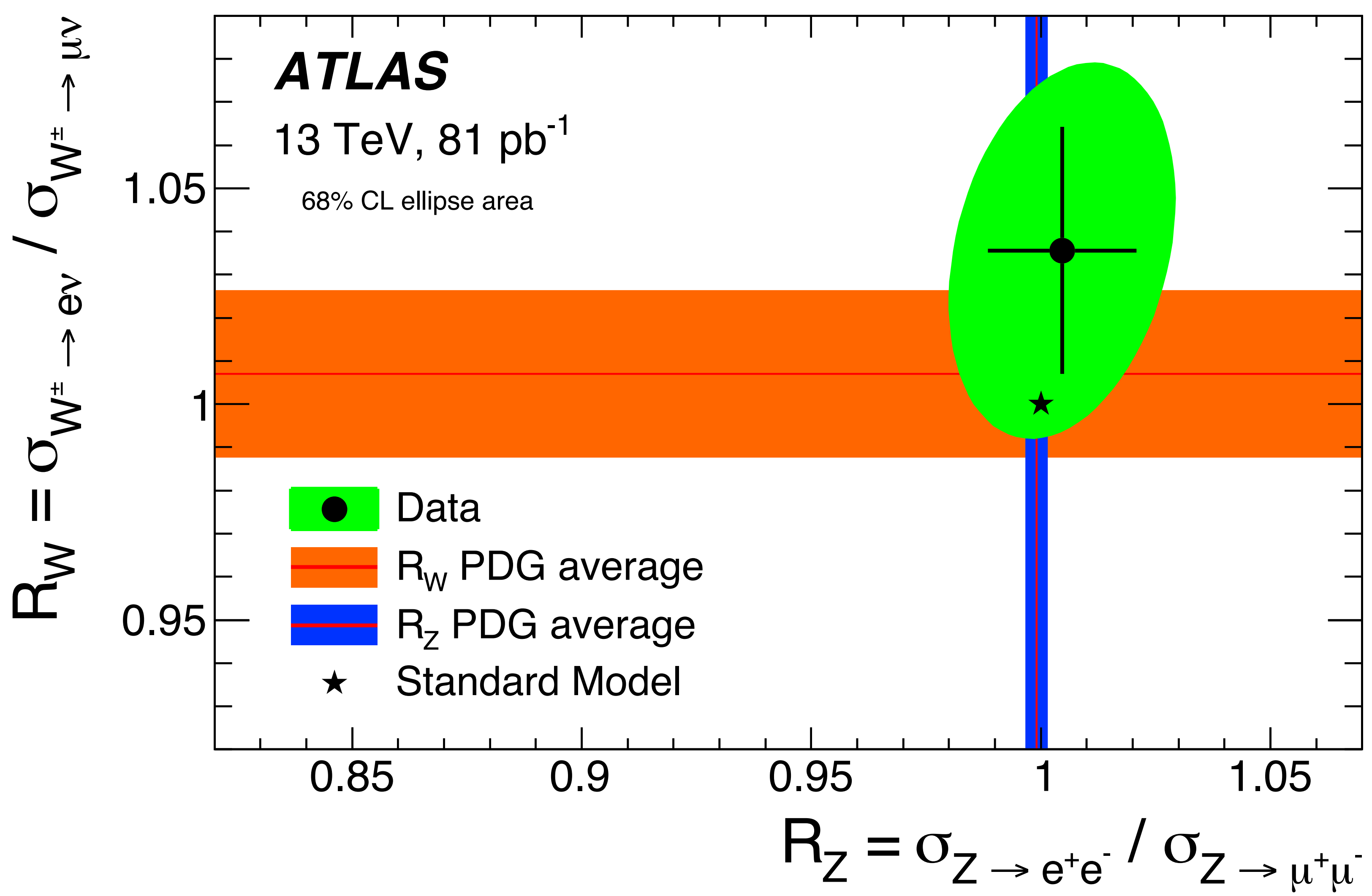
Putting everything together..

	W^+	W^-	Z
	Electron channel (value ± stat ± syst ± lumi)		
Signal events	228060 ± 510 ± 4920 ± 480	177890 ± 450 ± 6110 ± 430	34865 ± 187 ± 10 ± 7
Correction C	0.602 ± 0.012	0.614 ± 0.012	$0.552^{+0.006}_{-0.005}$
σ^{fid}[nb]	4.66 ± 0.01 ± 0.13 ± 0.24	3.57 ± 0.01 ± 0.14 ± 0.19	0.777 ± 0.004 ± 0.008 ± 0.039
Acceptance A	0.383 ± 0.007	0.398 ± 0.007	0.393 ± 0.007
σ^{tot}[nb]	12.18 ± 0.03 ± 0.41 ± 0.63	8.96 ± 0.02 ± 0.38 ± 0.47	1.98 ± 0.01 ± 0.04 ± 0.10
	Muon channel (value ± stat ± syst ± lumi)		
Signal events	237721.3 ± 516 ± 2209.6±970	183182.5 ± 457 ± 2520.1±870	44706 ± 212 ± 13 ± 10
Correction C	0.653 ± 0.012	0.650 ± 0.012	0.711±0.008
σ^{fid}[nb]	4.48 ± 0.01 ± 0.09 ± 0.24	3.47 ± 0.01 ± 0.08 ± 0.19	0.774 ± 0.004 ± 0.008 ± 0.039
Acceptance A	0.383 ± 0.007	0.398 ± 0.007	0.393 ± 0.007
σ^{tot}[nb]	11.70 ± 0.02 ± 0.32 ± 0.63	8.71 ± 0.02 ± 0.25 ± 0.48	1.97 ± 0.01 ± 0.04 ± 0.10

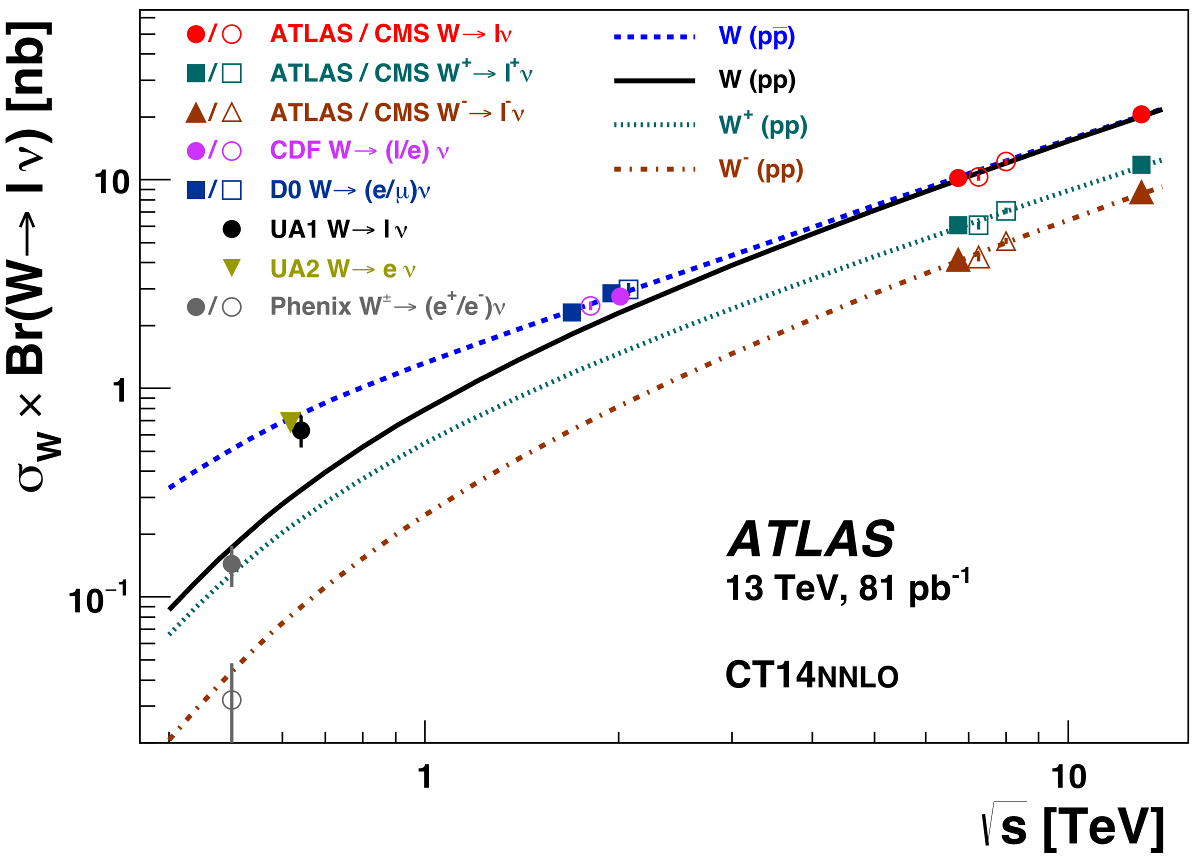
- ***A factors obtained at Born level with DYNNLO***
  - *dominant uncertainty from different PDF sets* (CT14nnlo, NNPDF3.0, MMHT14nnlo68CL, ABM12)
- Measurement in electron channel higher for W, but larger uncertainties, and *within 1σ*

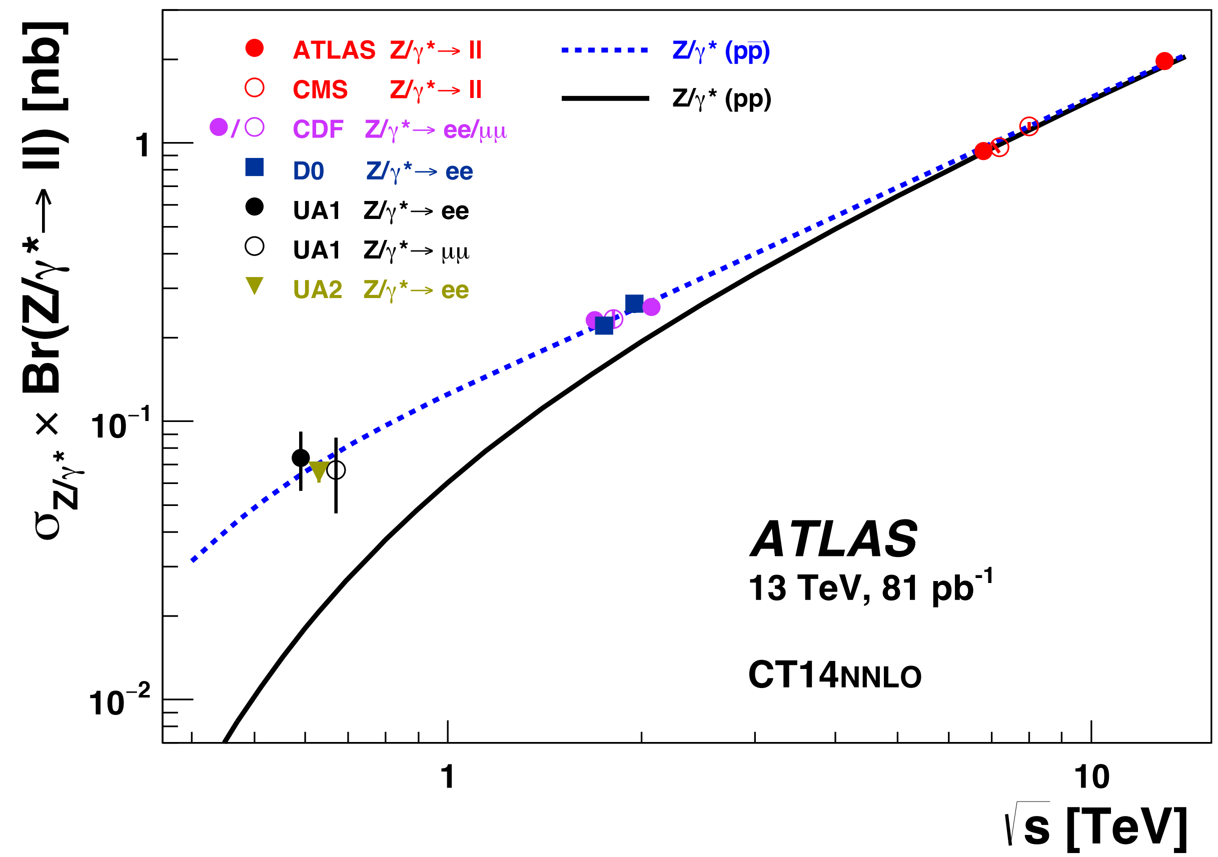
Lepton universality

- Check of lepton universality: good ***agreement with SM expectations and previous precision measurements***



Cross-section dependence on sqrt(s)





Consistent with NNLO QCD

ATLAS-CONF-2015-041

Z+jets cross section

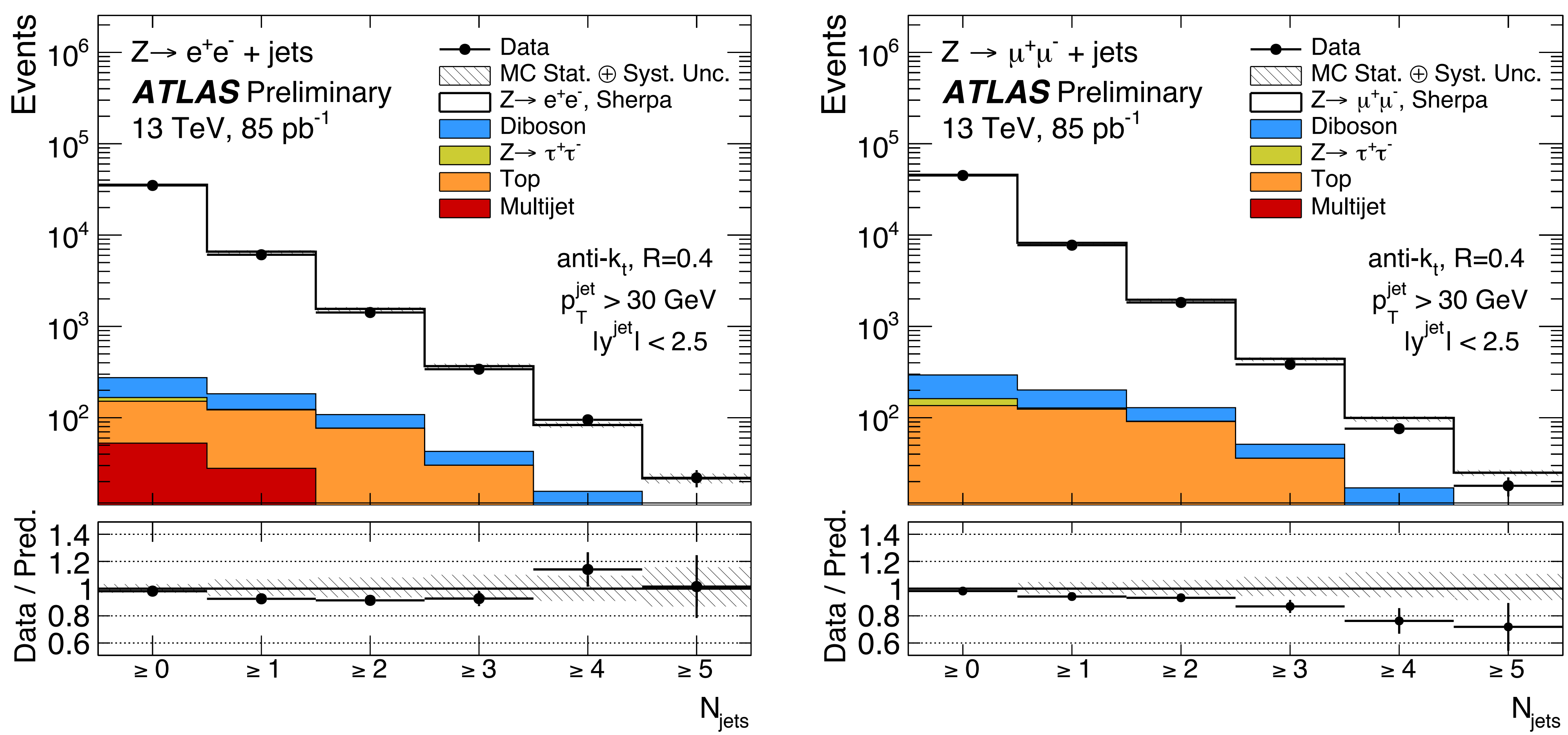
L = 81 pb^{-1} @ 13 TeV

Data taken with 50 ns bunch spacing in early Summer 2015

Motivation and strategy

- Helps to understand ***QCD effects in high-multiplicity final states***
- Z+jets important background to several searches, Higgs boson and top quark production
- Same fiducial phase space as Z inclusive analysis for leptons, with extra *jets requirement of p_T>30 GeV and |y|<2.5*
  - Look at ***events with up to 4 jets in the final state***

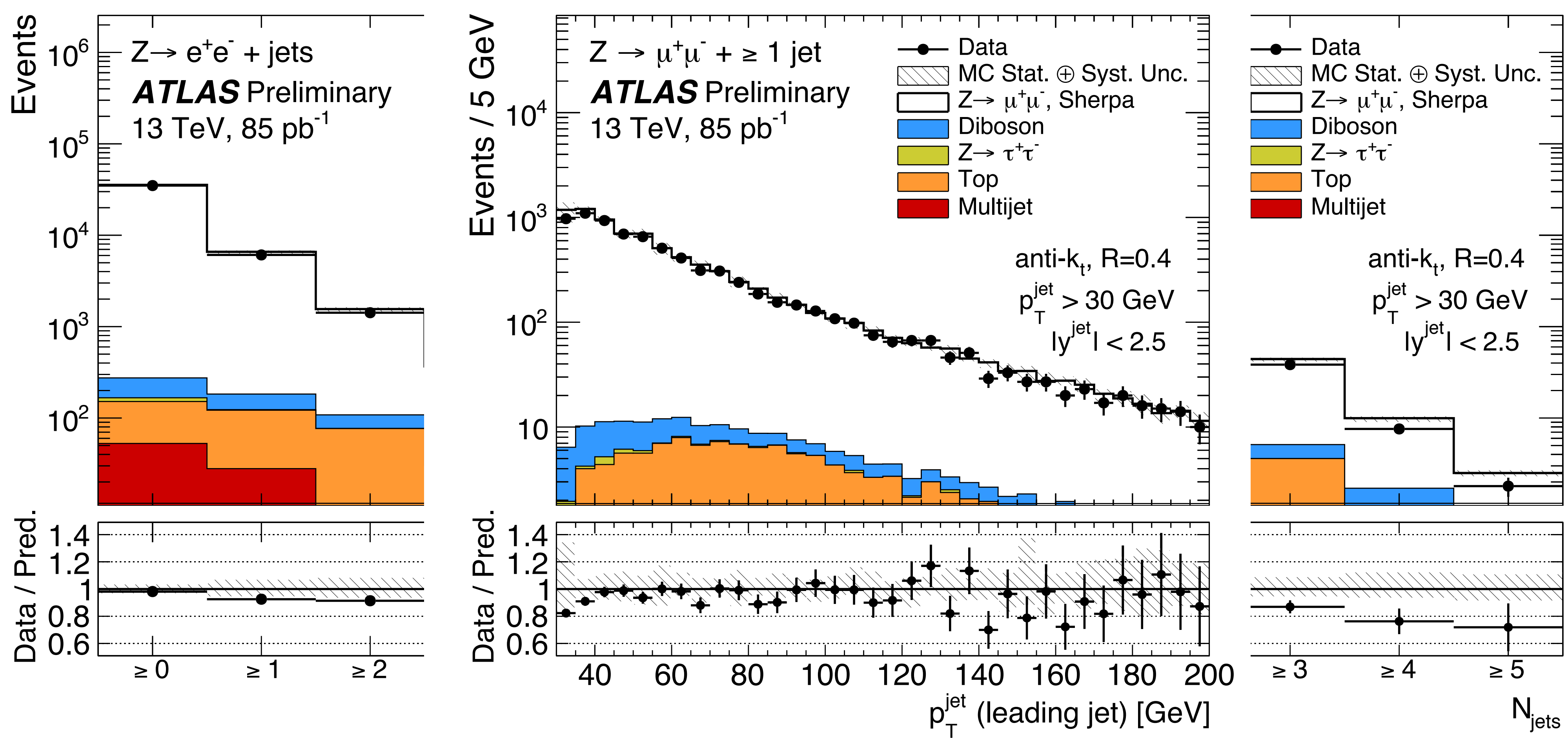
- Sherpa 2.1 signal MC
- MC-based background estimate



Motivation and strategy

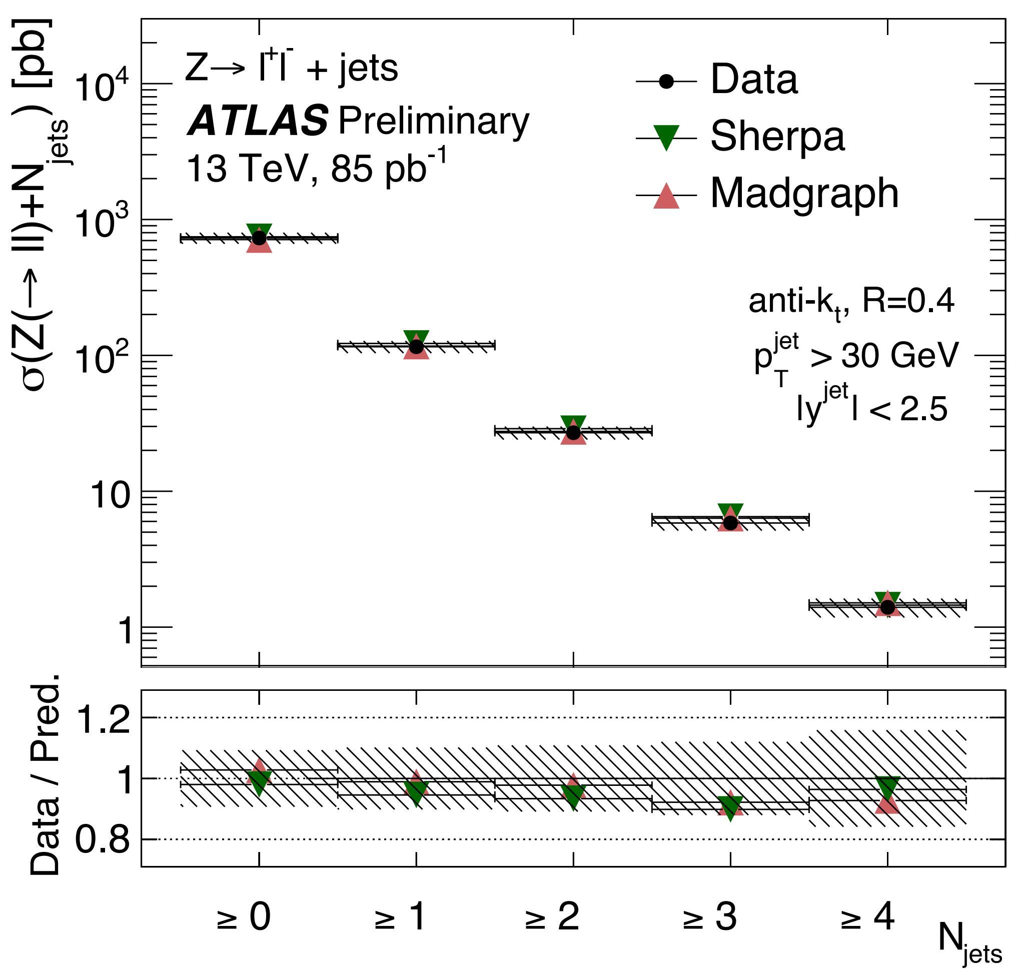
- Helps to understand ***QCD effects in high-multiplicity final states***
- Z+jets important background to several searches, Higgs boson and top quark production
- Same fiducial phase space as Z inclusive analysis for leptons, with extra *jets requirement of p_T>30 GeV and |y|<2.5*
  - Look at ***events with up to 4 jets in the final state***

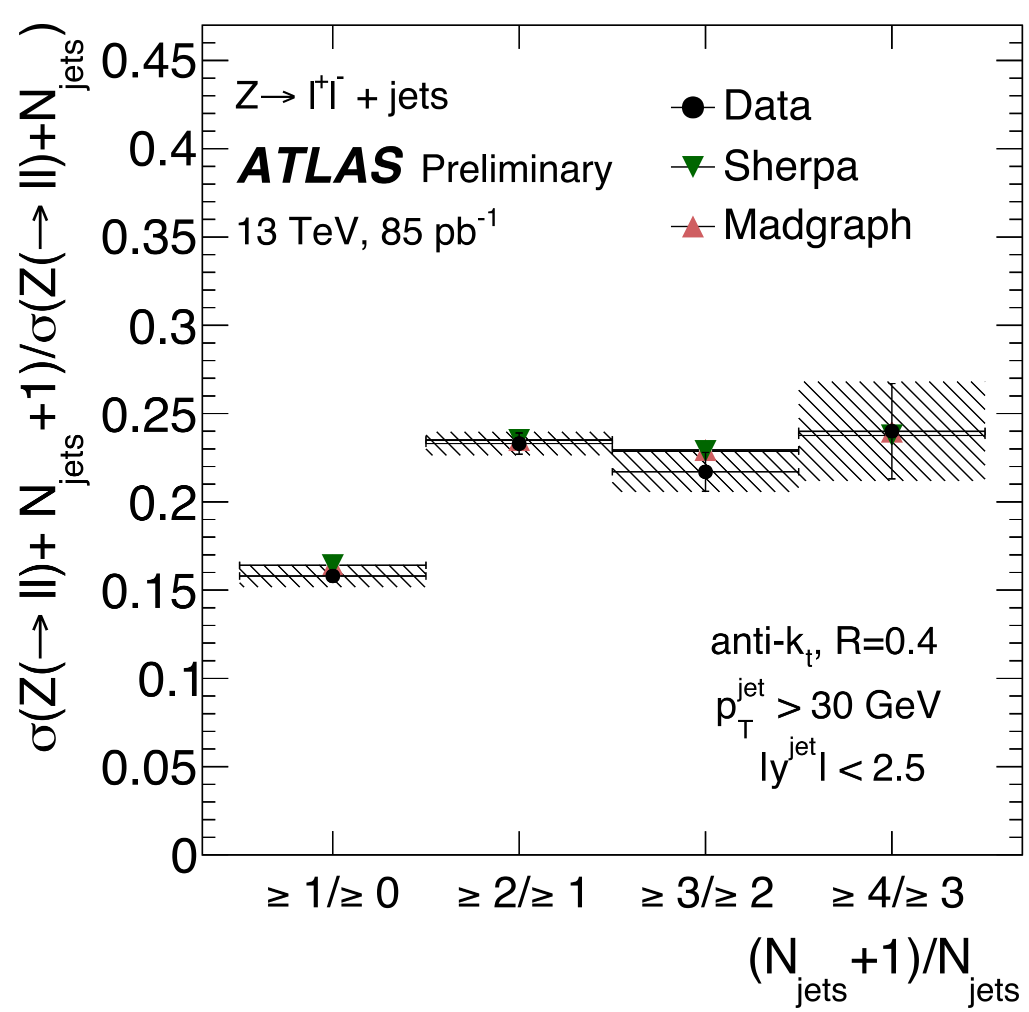
- Sherpa 2.1 signal MC
- MC-based background estimate



Results

- *Bin-by-bin extraction of fiducial cross sections at particle level* (see inclusive analysis)
  - Combination of lepton channels using HERAverager
- Comparison to Sherpa (NLO) and Madgraph (LO) → ***good agreement*** also in ratio
- ***Reach precision of 10-20% up to 4 jets***





Results: lepton breakdown