

# Electroweak probes of small and large systems with the ATLAS detector



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QM 2017 Venice, 16 May

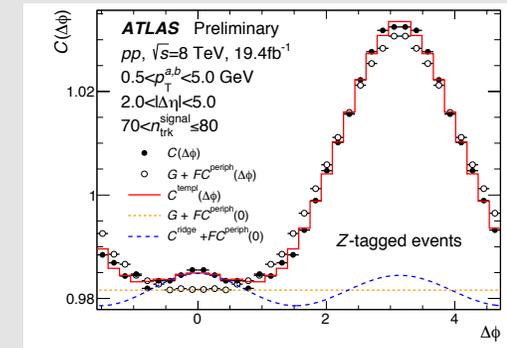
# Why Do We Measure EW Boson Yields?

- p+p
  - High precision test of pQCD
  - Baseline for p+Pb & Pb+Pb
- pPb
  - Study nuclear modification of PDF
- PbPb
  - ‘Standard candle’ to gauge QGP effects

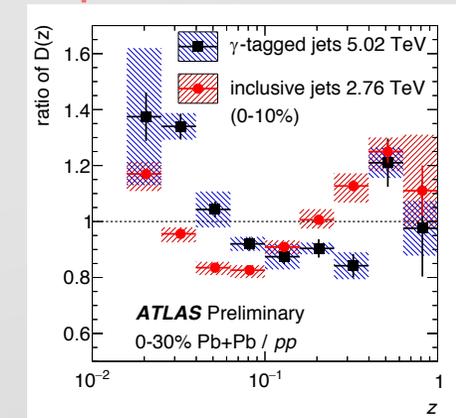
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(And other EW Boson Observables)  
See B. Cole’s Talk on Z+Ridge



See D. Perepelitsa’s Talk on  $\gamma$ +Jet

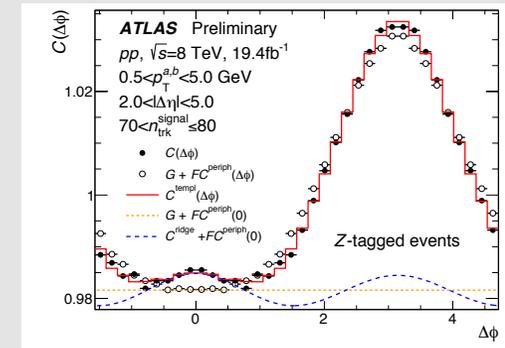


# Why Do We Measure EW Boson Yields?

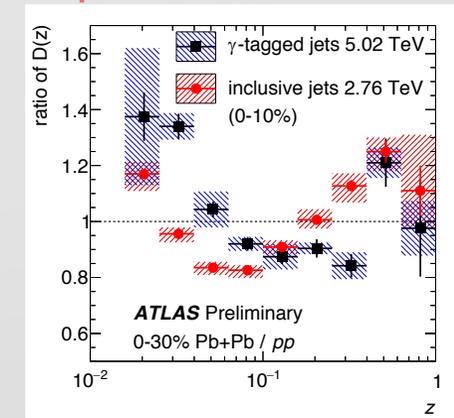
## This Talk!

(And other EW Boson Observables)  
See B. Cole's Talk on Z+Ridge

- p+p: **Z @ 5.02 TeV**
  - High precision test of pQCD
  - Baseline for p+Pb & Pb+Pb
- pPb: **Photons @ 8.16 TeV (and Z @ 5.02 TeV)**
  - Study nuclear modification of PDF
- PbPb: **W&Z @ 5.02 TeV**
  - 'Standard candle' to gauge QGP effects

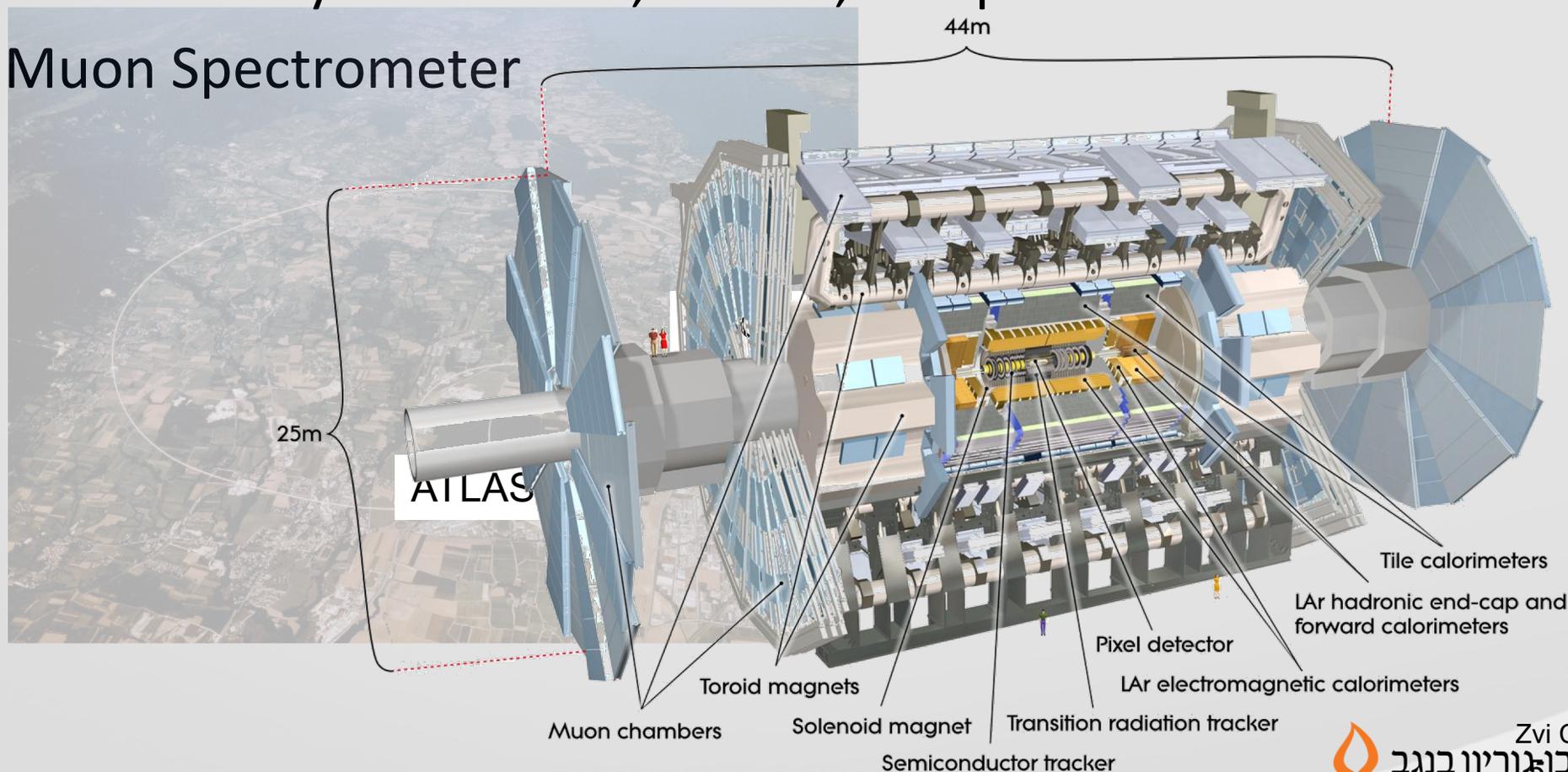


See D. Perepelitsa's Talk on  $\gamma$ +Jet



# ATLAS at the LHC

- ATLAS has:
  - Charged particle tracking → electrons and muons (photon veto)
  - Calorimetry → electrons, muons, and photons
  - Muon Spectrometer



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# Z Bosons in p+p @ 5.02 TeV

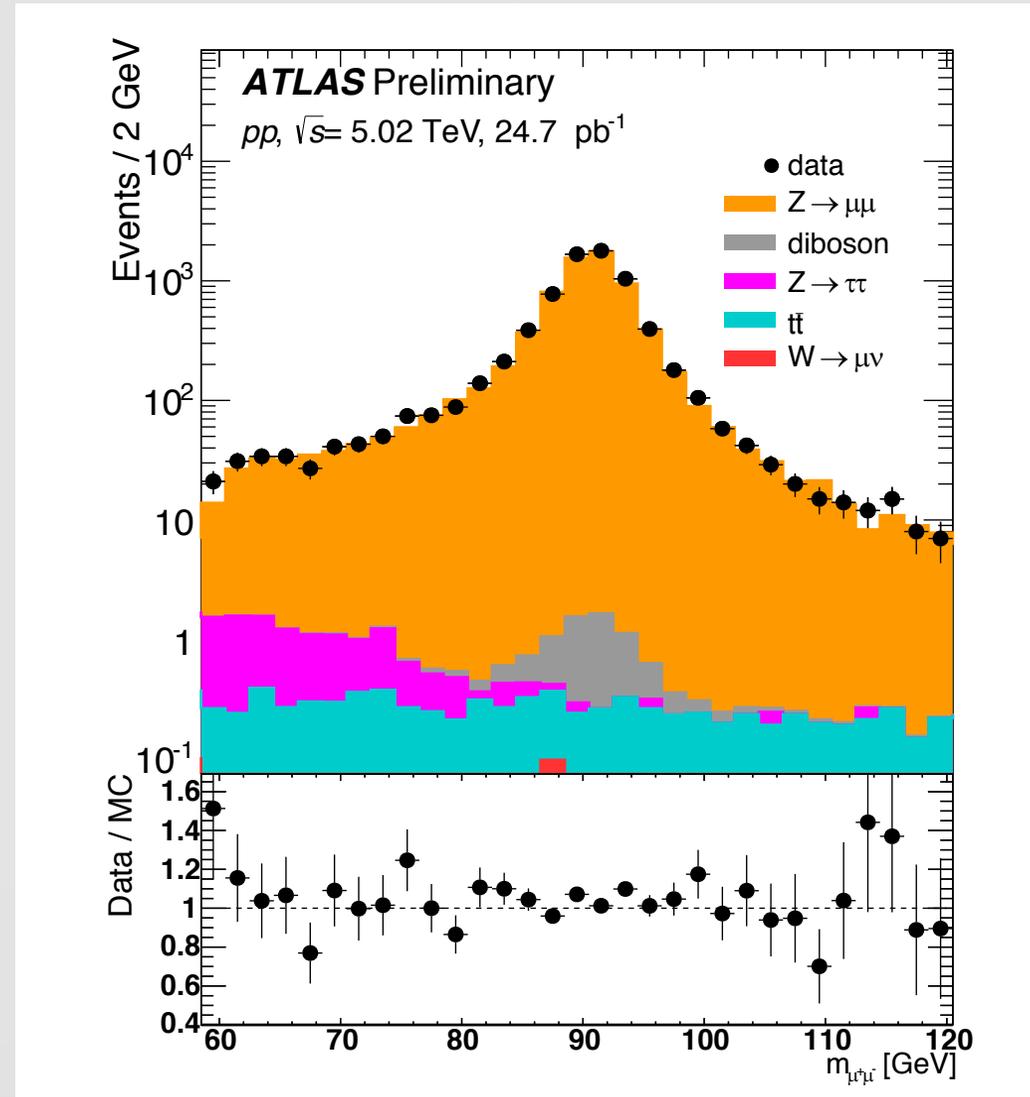
(ATLAS-CONF-2016-107)

**See Mirta Dumancic's Poster!**

# Event Selection

## Z $\rightarrow\mu\mu$

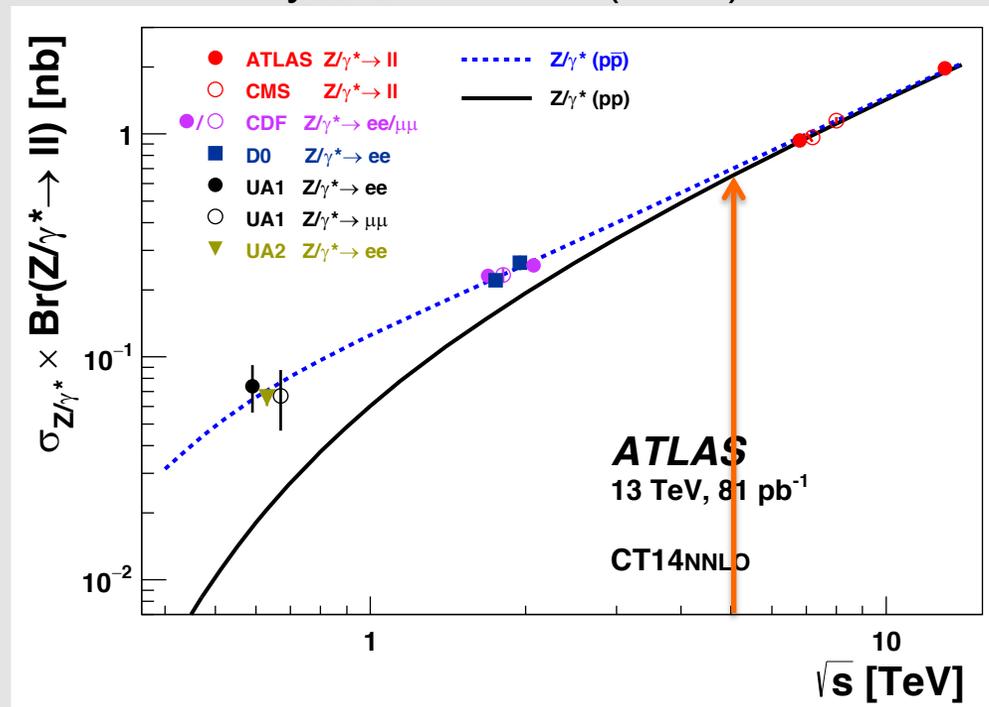
- $24.7 \pm 1.3 \text{ pb}^{-1}$  of data
- 14 GeV muon trigger
- Opposite charge muons
- $p_{\text{T}} > 20 \text{ GeV}$ ,  $|\eta| < 2.4$
- High quality muons
  - Good ID and MS signals
- Isolated muons
  - No close by energy in calorimeter
- $66 < m_{\mu\mu} < 116 \text{ GeV}$
- **7293** counts
- Background  $\approx 0.3\%$ 
  - subtracted



# Cross Section

Phys. Lett. B 759 (2016) 601

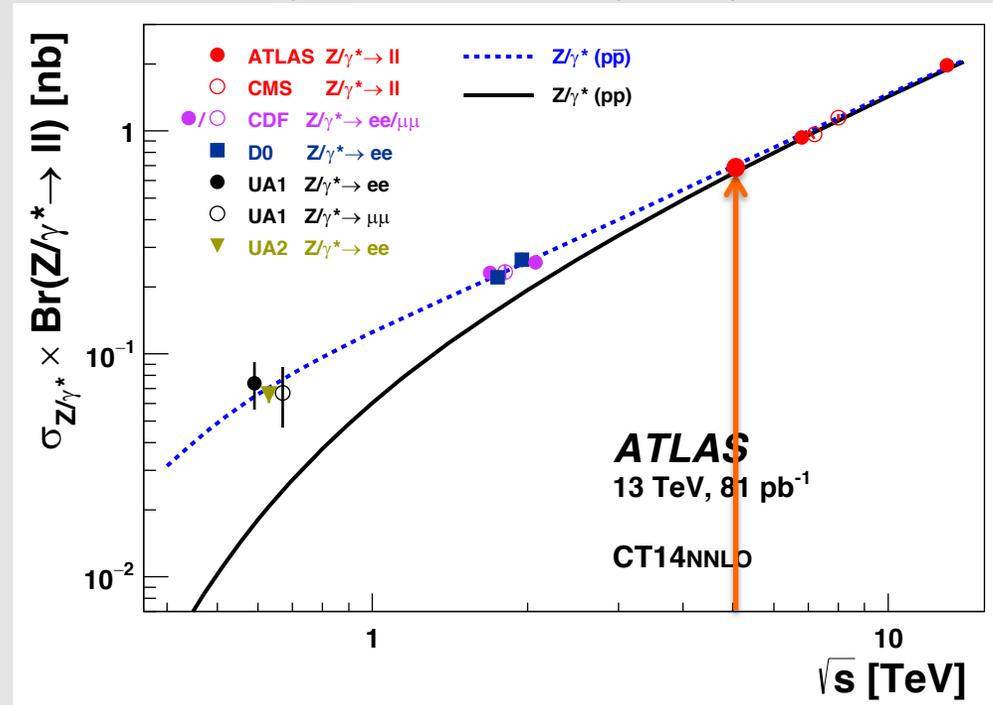
- Correct to fiducial volume:
  - $66 < m_Z < 116$  GeV
  - $|y_Z| < 2.5$
  - (all muon kinematics)
- Correct for detector/trigger efficiency
- Dominant uncertainty from luminosity – 5.4%
- Other uncertainties  $\approx 2\%$



# Cross Section

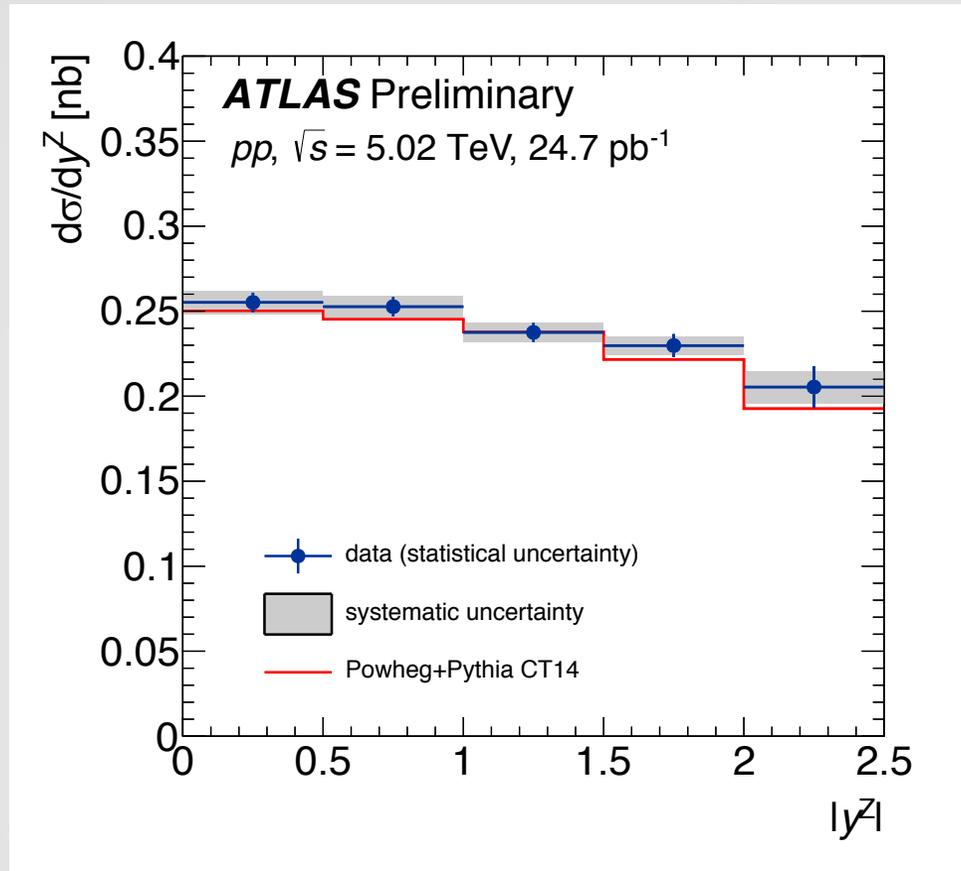
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  - (all muon kinematics)
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Measured cross section:  $590 \pm 9$  (stat)  $\pm 12$  (sys)  $\pm 32$  (lumi) pb

# Rapidity Differential Cross Section



Good shape agreement in rapidity

# Photons in p+Pb @ 8.16 TeV

(ATLAS-CONF-2017-072)

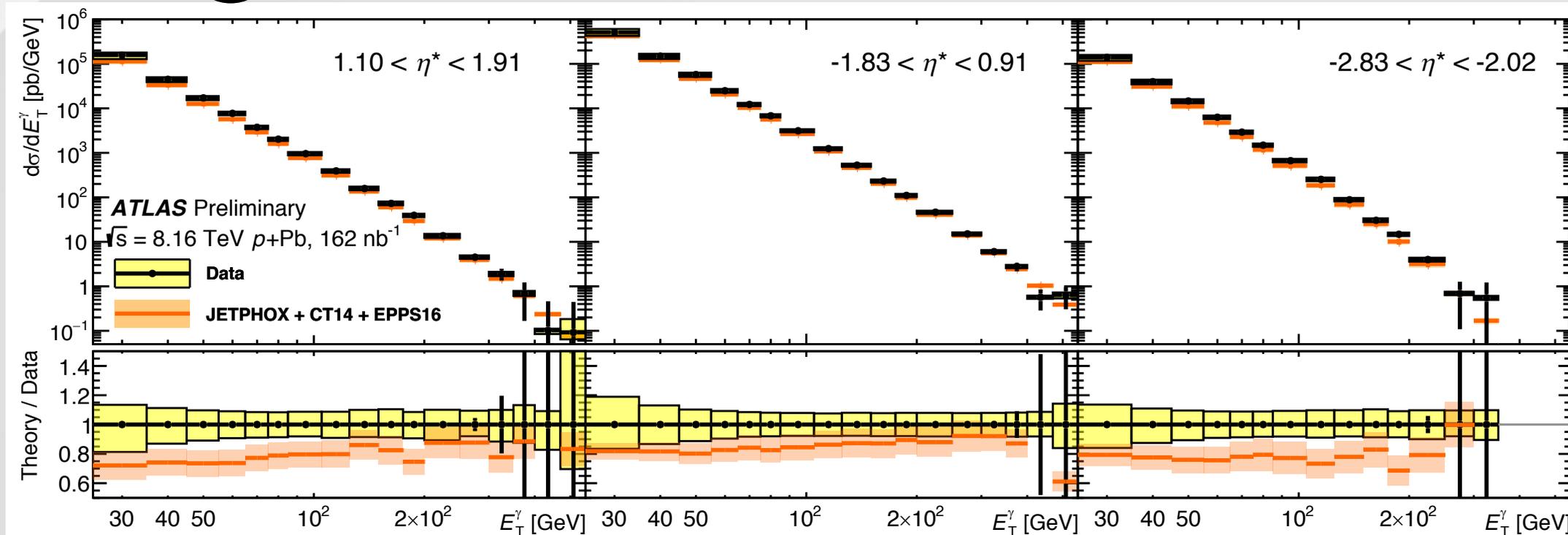
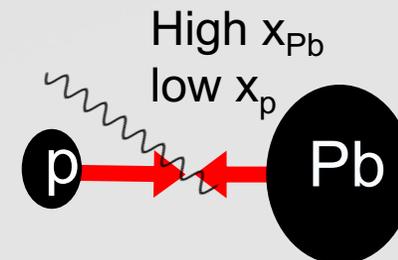
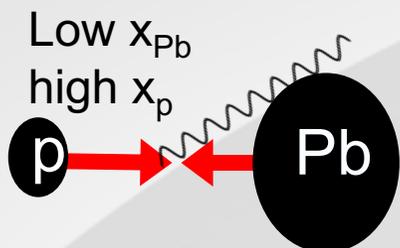
**See Kurt Hill's Poster!**

# Event Selection

- 162 nb<sup>-1</sup> of p+Pb data recorded (56 nb<sup>-1</sup>/106 nb<sup>-1</sup> p+Pb/Pb+p)
- $\sqrt{sNN} = 8.16$  TeV; Pb accelerated with 6.5TeV  $\times$  Z/A per nucleon  $\rightarrow y^* = y^{\text{lab}} + 0.465$
- Trigger on photon events selected in calorimeter,  $|\eta| < 2.37$
- Offline select:
  - $E_T^\gamma > 25$  GeV
  - Isolation selection tuned for this dataset:  $E_T^{\text{iso}} < 4.8\text{GeV} + 4.2 \times 10^{-3} E_T^\gamma$
- Correct for background with ‘double sideband’ method
  - Purity: 60% @ 25 GeV  $\rightarrow$  80% @ 100 GeV  $\rightarrow$  99% @ 300 GeV

Correct for efficiencies based on MC simulation

# Photon Cross-Section



## Photon spectra + pQCD calculation

Uncertainties include:

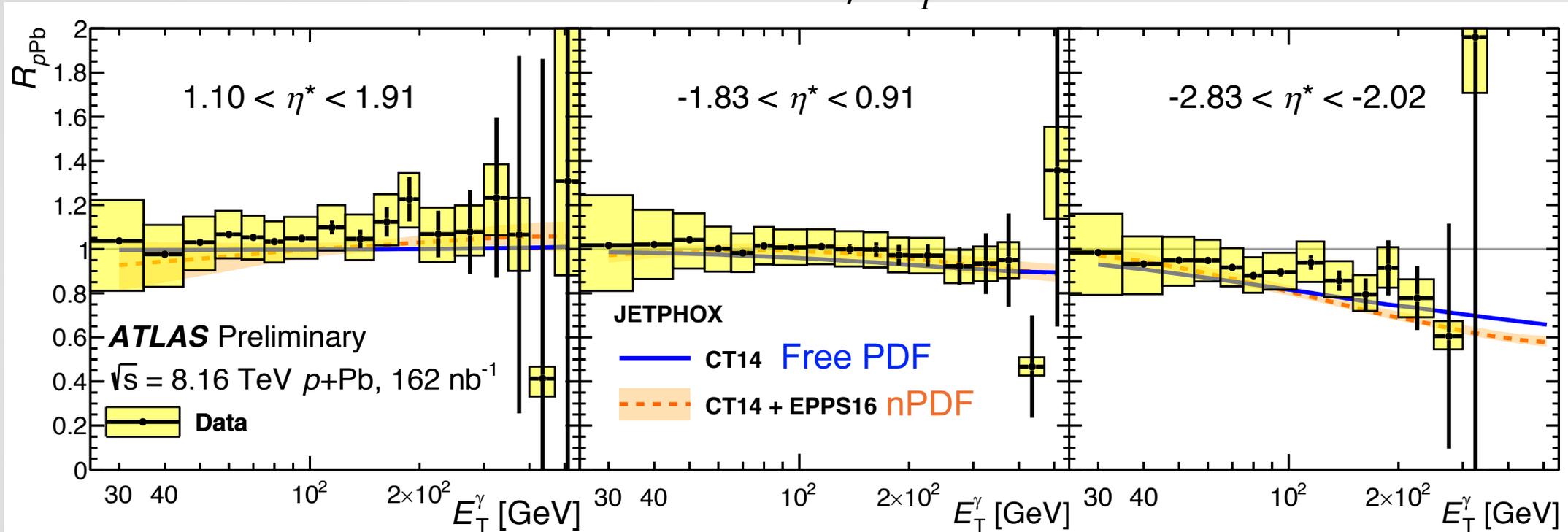
- Isolation & selection: 10% at lowest  $E_T$  and decreasing
- Energy scale 5-10% (higher at low  $E_T$  forward  $\eta$ )
- (Luminosity 6.2%)

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# Nuclear Modification Factor

$$R_{pPb} = \frac{d\sigma^{p+Pb \rightarrow \gamma+X} / dE_T^\gamma}{A \times d\sigma^{p+p \rightarrow \gamma+X} / dE_T^\gamma}$$

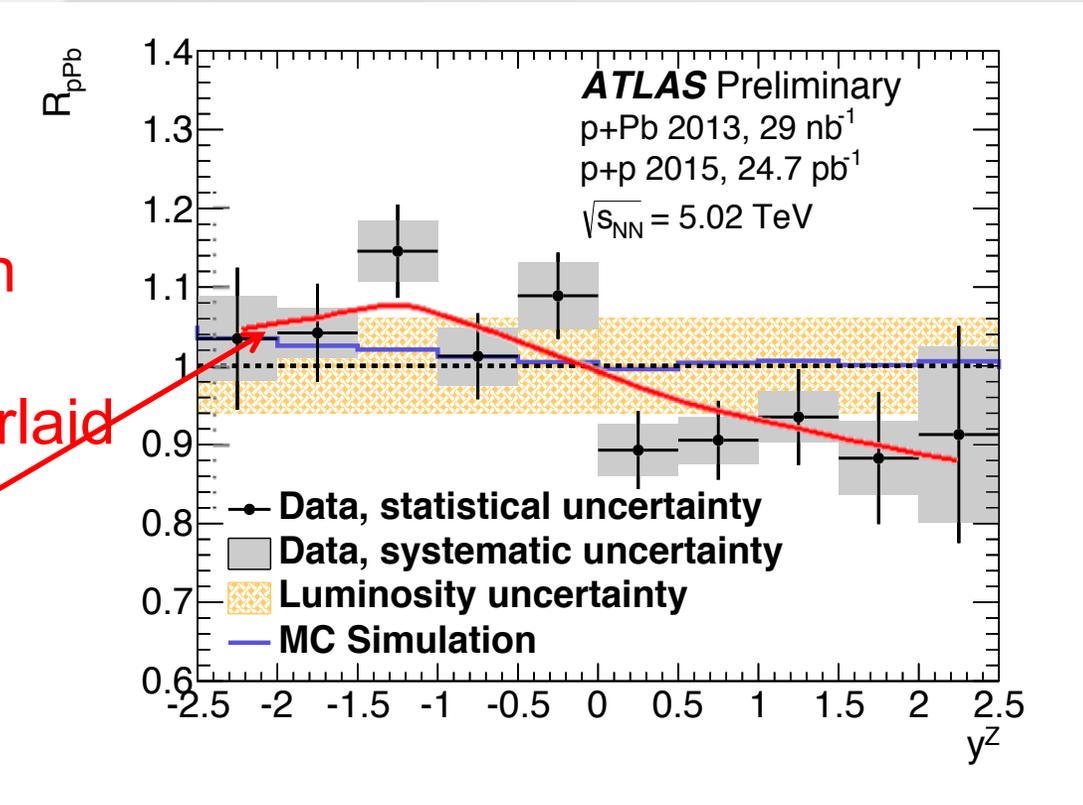


High precision probe of nucleus over a large kinematic range

Not (yet) sensitive to difference between modified  $n$ PDF and standard pQCD calculation with free PDF

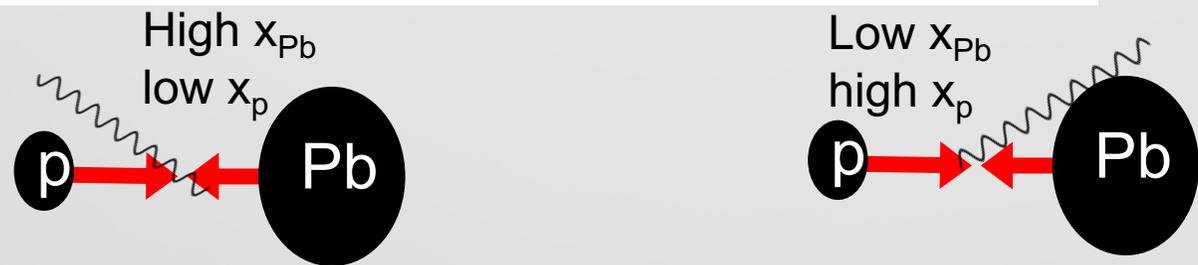
# (Some context from Z bosons @ 5.02 TeV)

ATLAS-CONF-2016-107



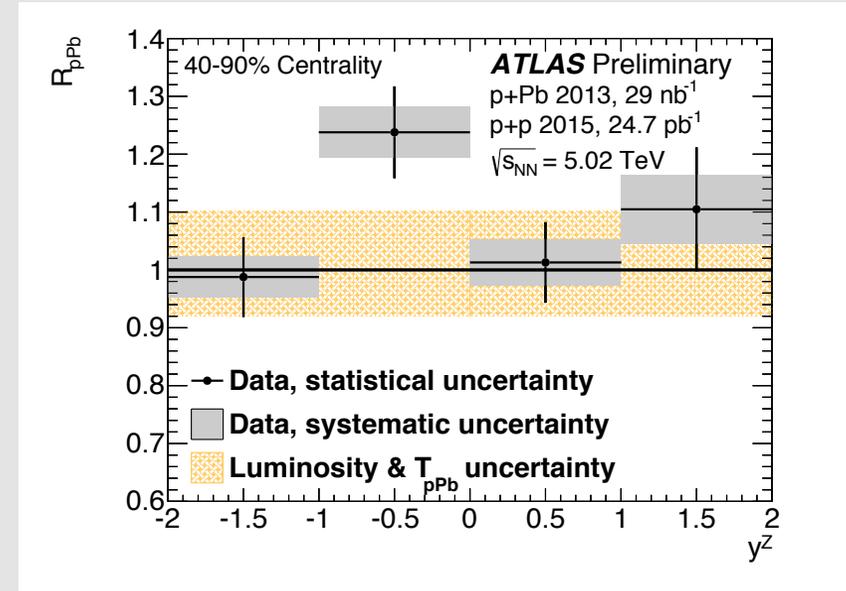
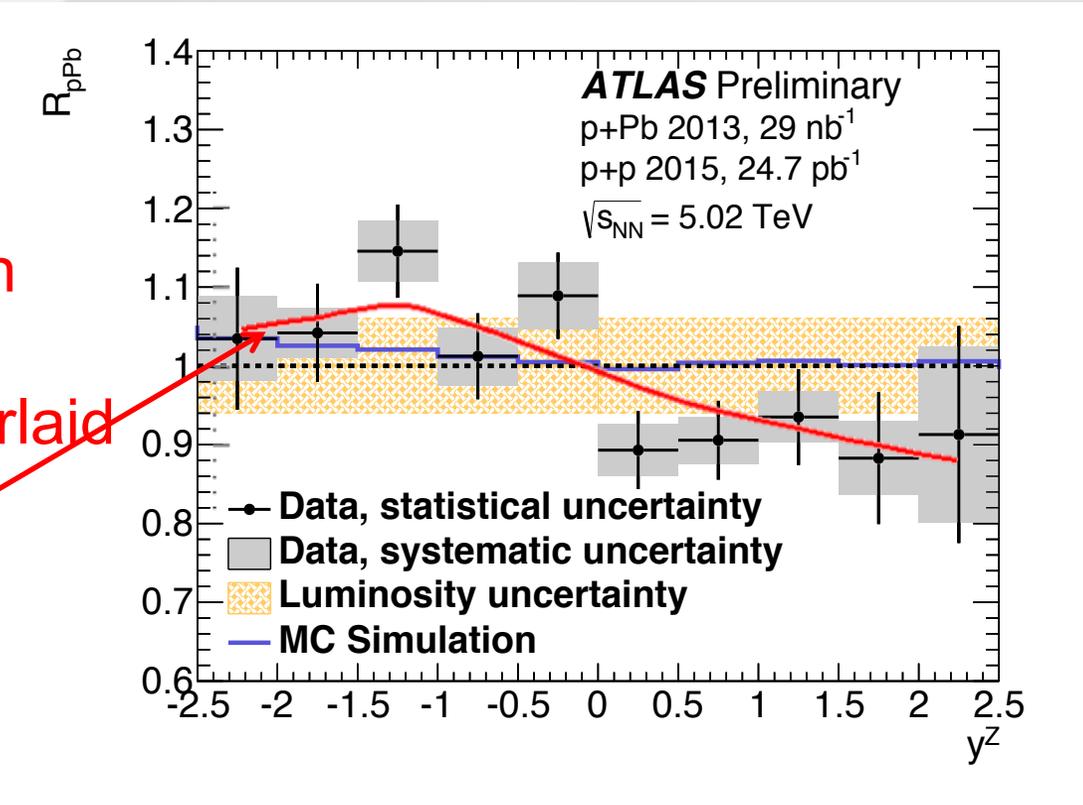
Calculation based on nPDF, overlaid onto  $R_{pPb}$

Phys. Rev. C 92, 044915



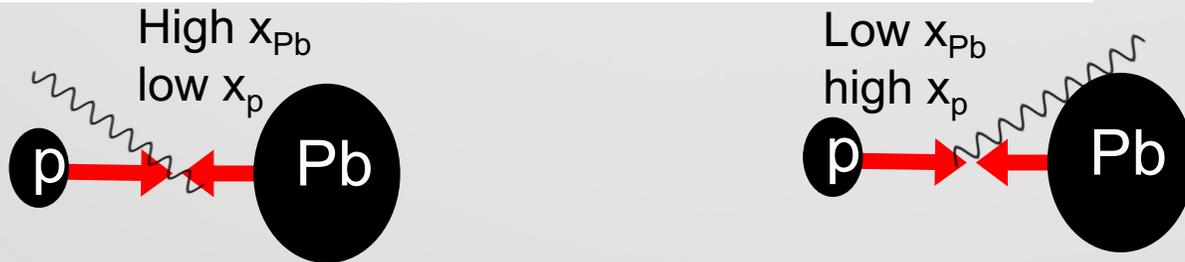
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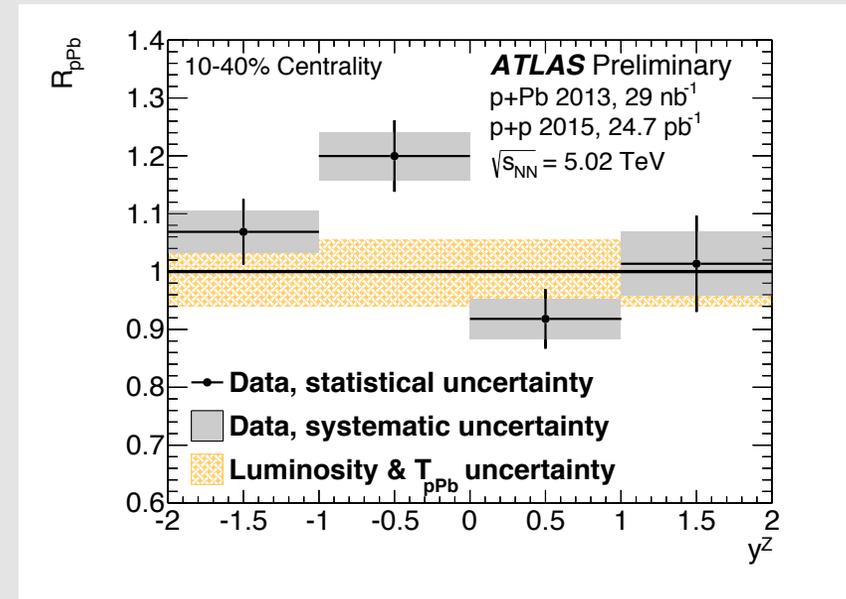
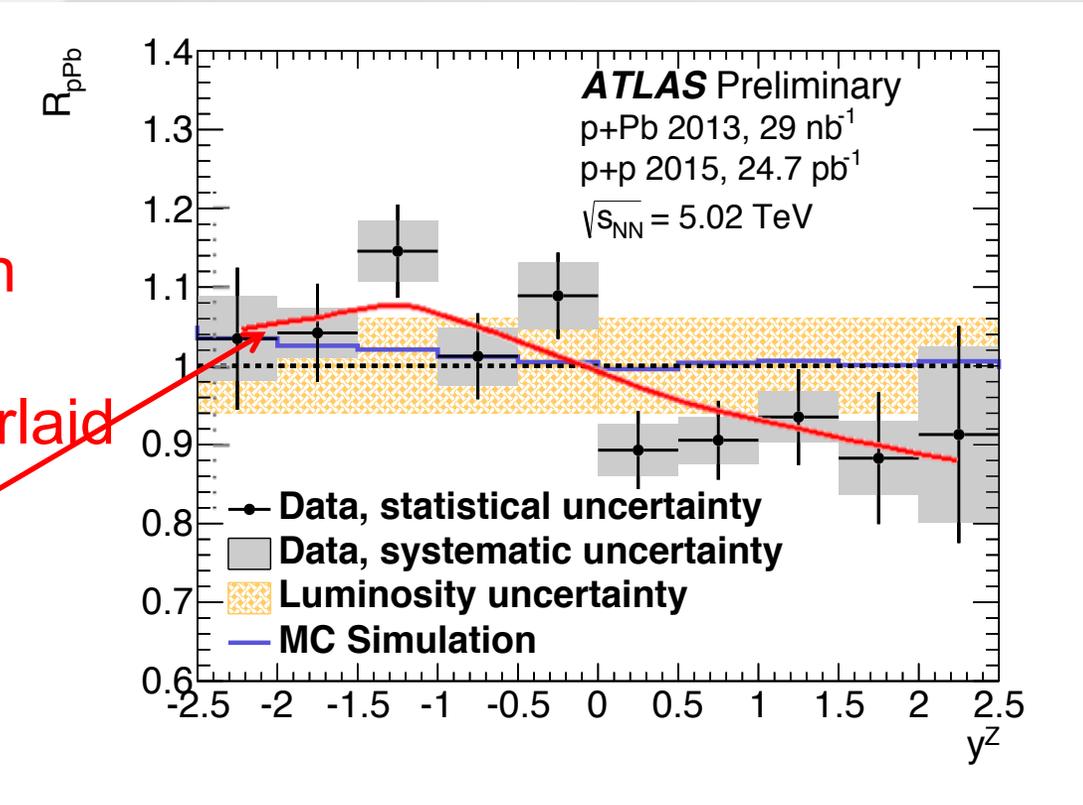
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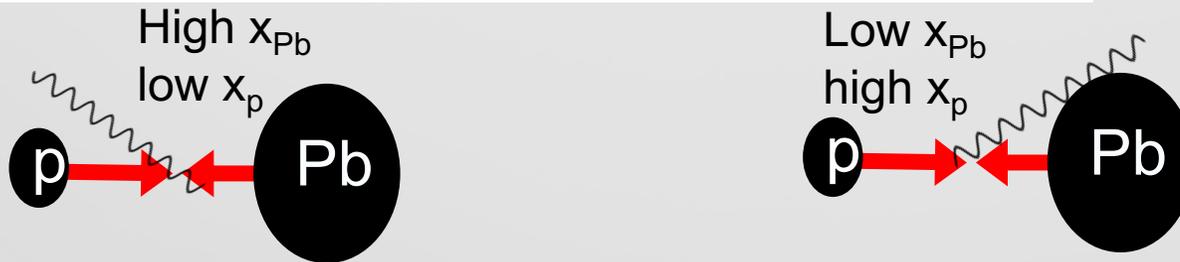
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ATLAS-CONF-2016-107



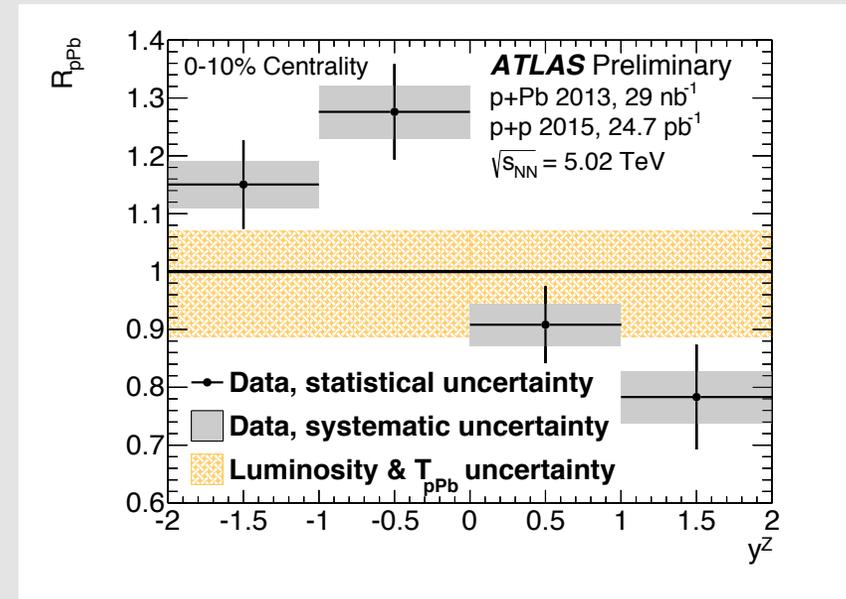
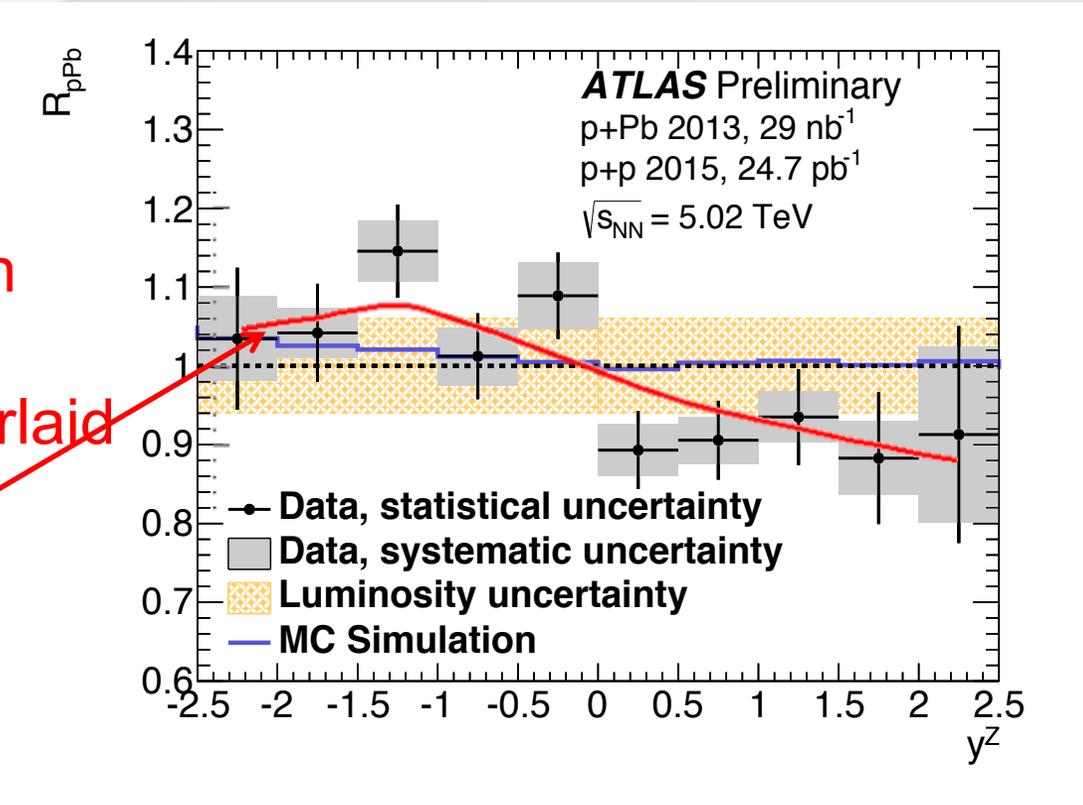
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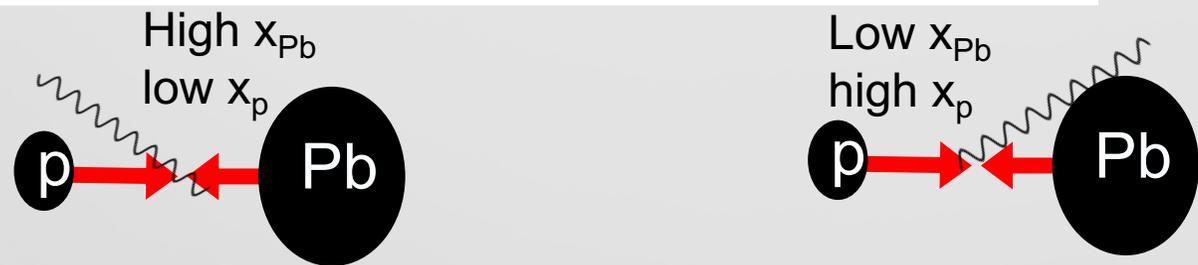
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ATLAS-CONF-2016-107



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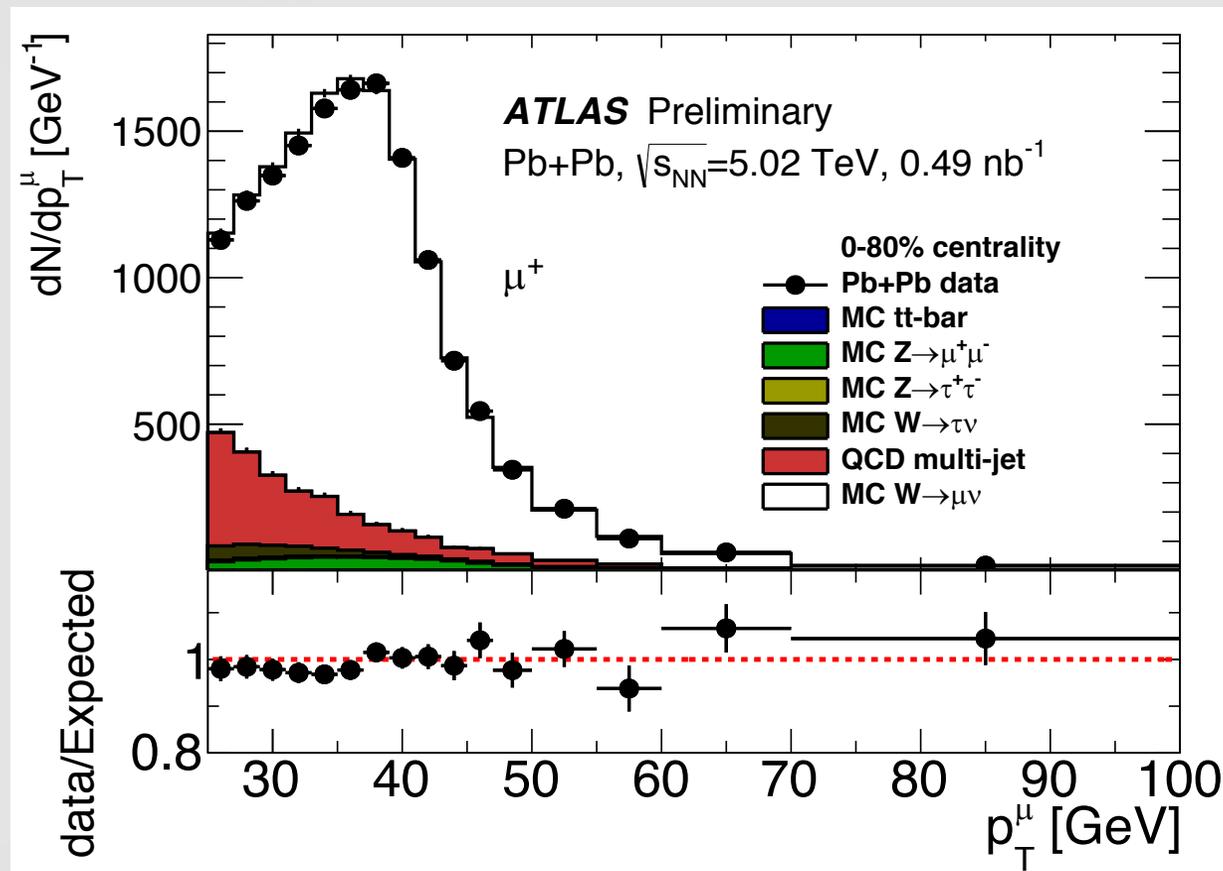
# W&Z Bosons in Pb+Pb @ 5.02 TeV

(ATLAS-CONF-2017-067 & ATLAS-CONF-2017-010)

# W Boson Event Selection

## $W \rightarrow \mu + \nu$

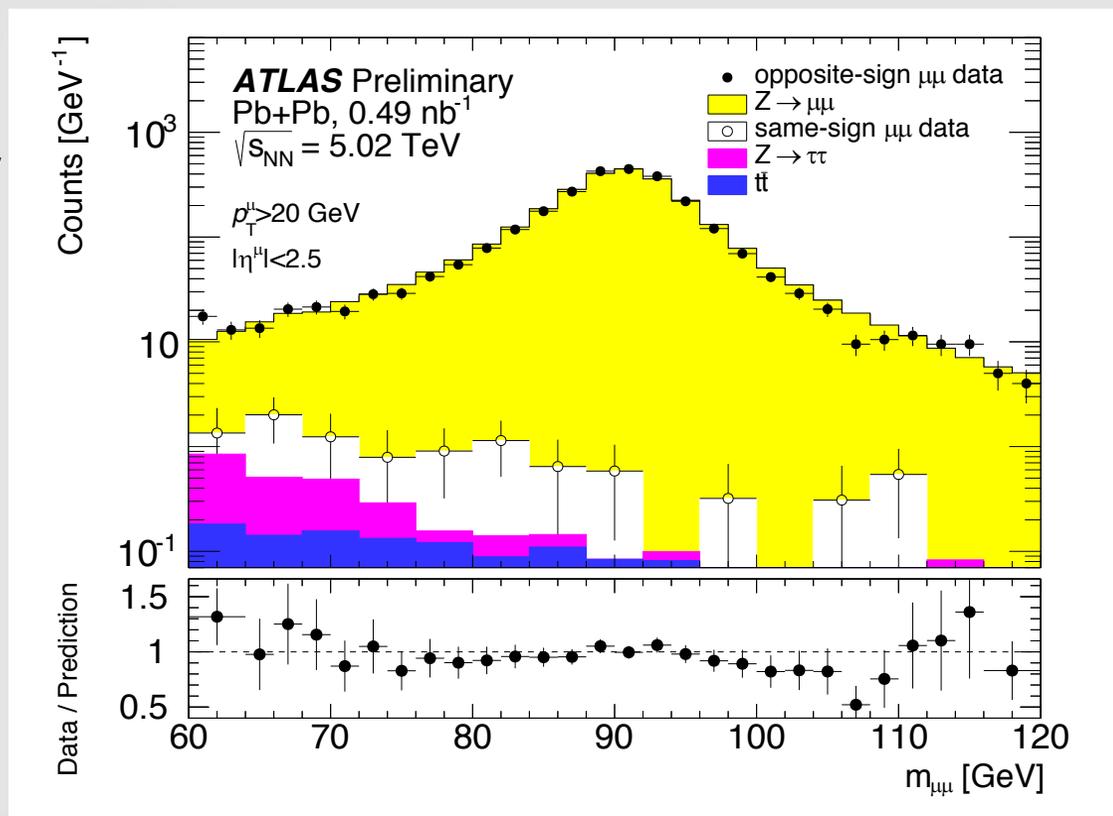
- $\approx 0.49 \text{ nb}^{-1}$  of data
- 8 GeV single muon trigger
- Exactly one muon
- $p_T > 25 \text{ GeV}$ ,  $0.1 < |\eta| < 2.4$
- High quality isolated muons
- **25245 (23123)  $W^{+(-)}$  candidates**
- Backgrounds subtracted:
  - 6-12% from multi-jet
  - $\sim 3\%$  from  $Z \rightarrow \mu\mu$
  - $< 1\%$  from  $Z \rightarrow \tau\tau$  and tops



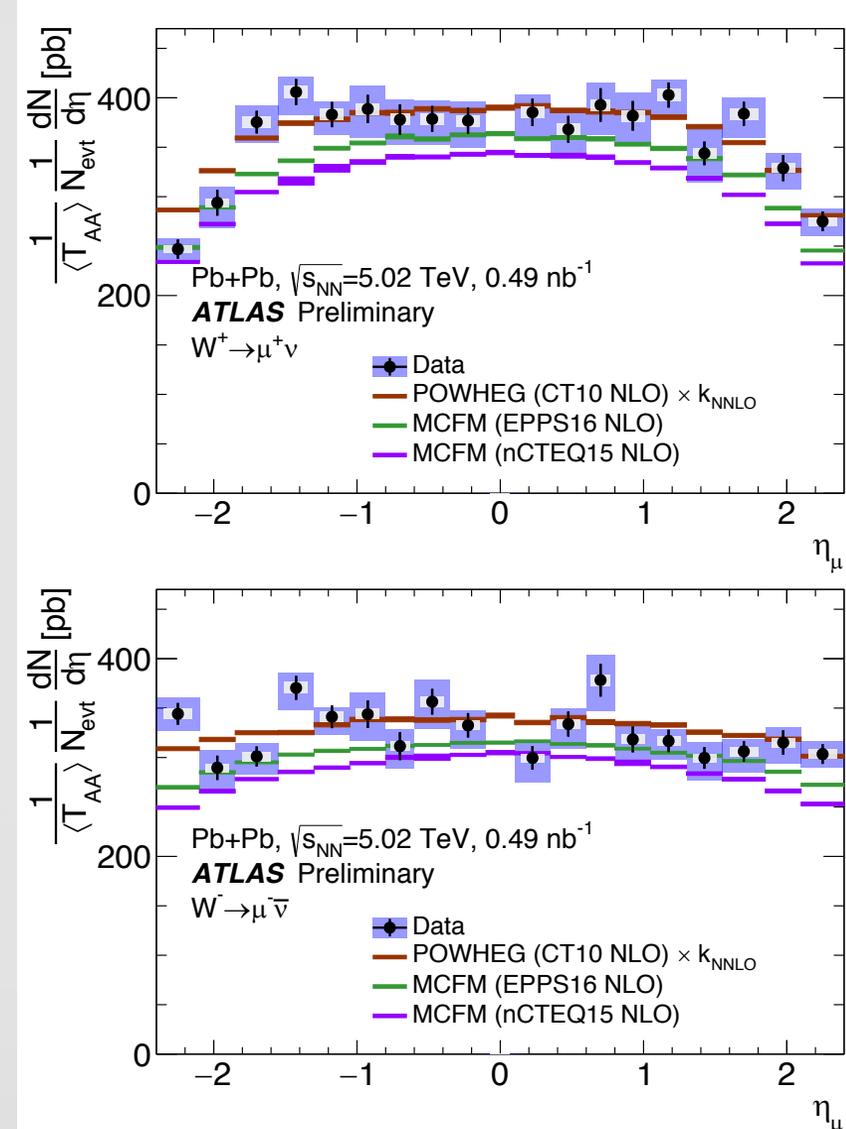
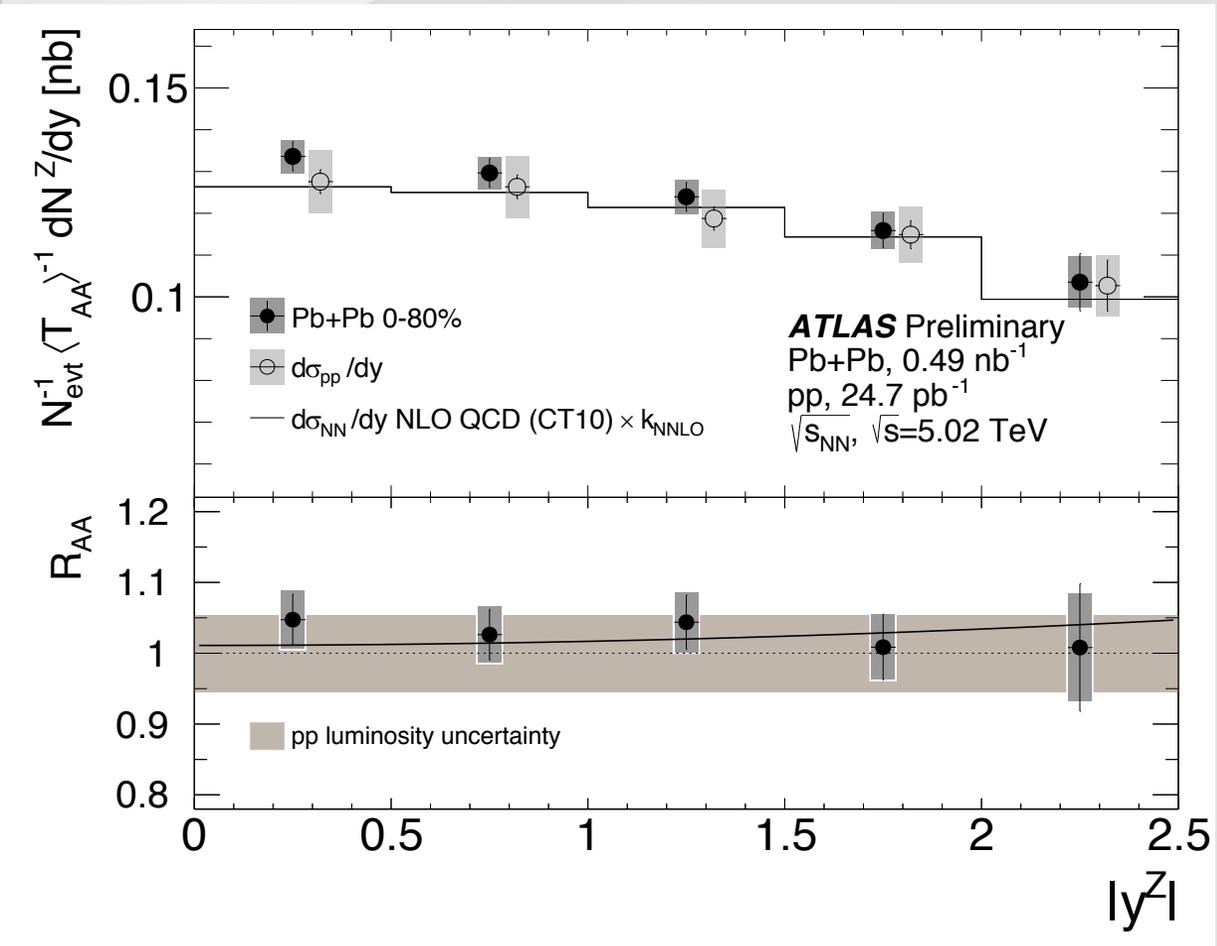
# Z Boson Event Selection

## Z → μμ

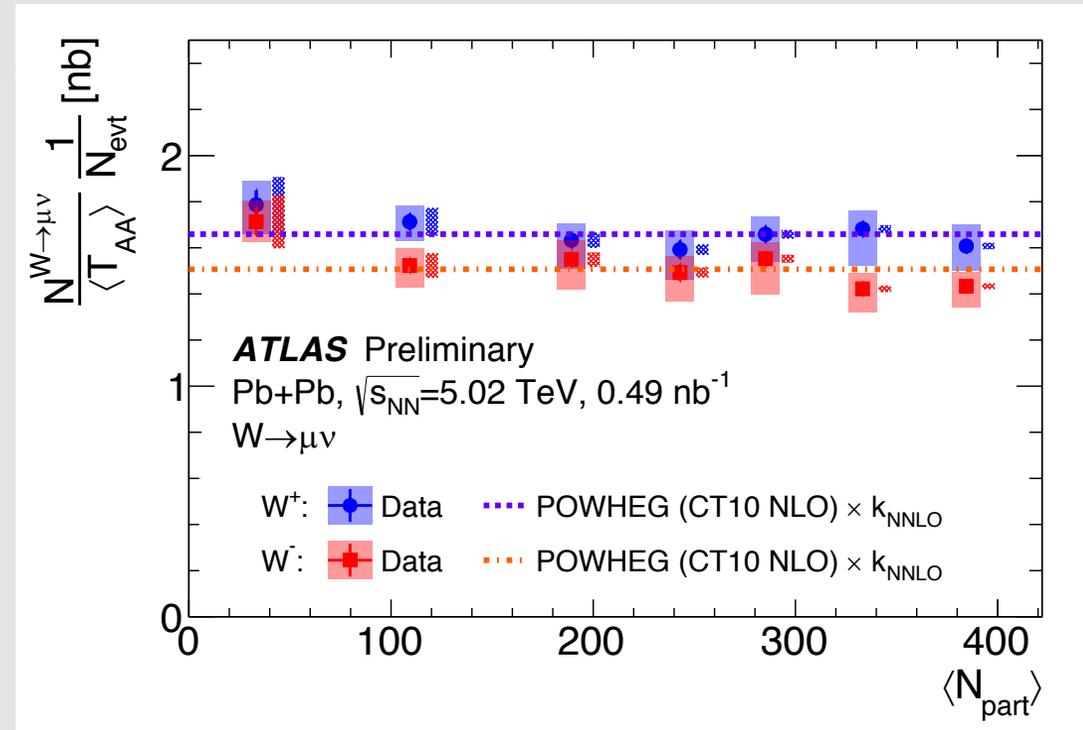
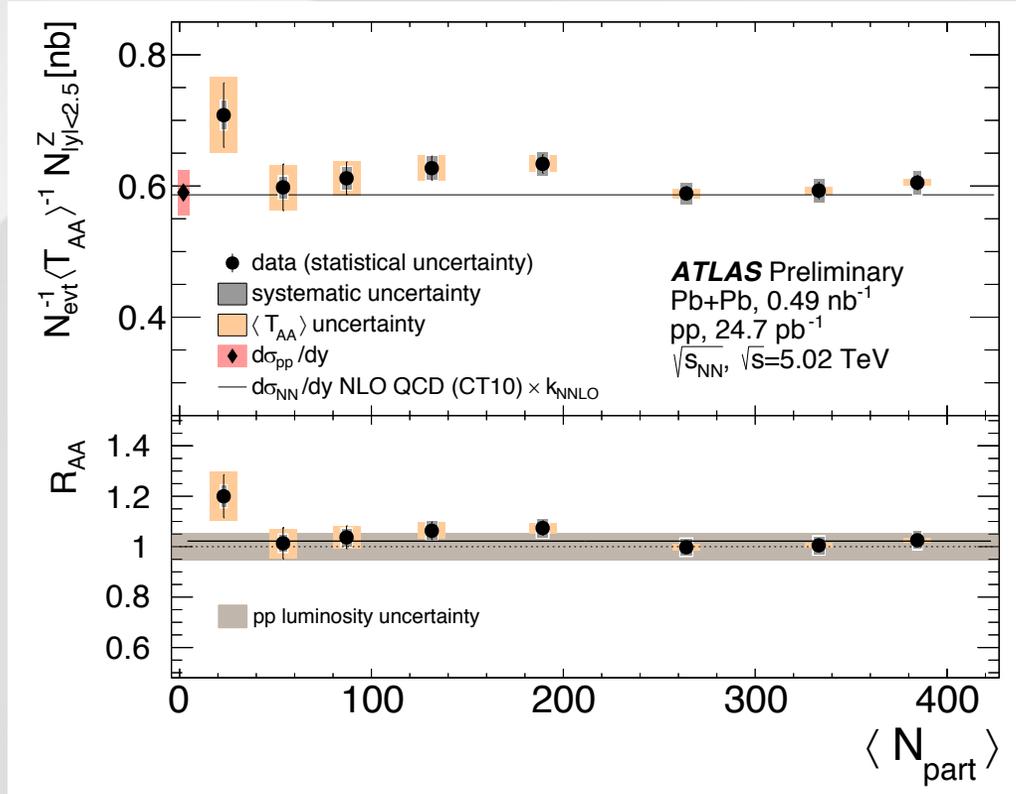
- $\approx 0.49 \text{ nb}^{-1}$  of data
- 8 GeV single muon trigger
- Opposite charge muons
- $p_T^{\mu} > 20 \text{ GeV}$ ,  $|\eta| < 2.5$
- High quality muons
- $66 < m_{\mu\mu} < 116 \text{ GeV}$
- **5326** counts
- Background  $\approx 0.5\%$ 
  - subtracted



# Rapidity Differential Yield



# Integrated Yield in Centrality



- Centrality trend consistent with expectations
  - (Peripheral is  $\sim 1.5$  sigma higher ...)
- High precision results: uncertainties are better on measuring EW bosons than on  $T_{AA}$  and luminosity
- Combined EW as a baseline for other hard probes?

$$Z_{AA} = \frac{R_{AA}(X)}{R_{AA}(EW)} = \frac{N_{Pb+Pb}^X}{\sigma_{Pb+Pb}^X} \times \frac{\sigma_{Pb+Pb}^{EW}}{N_{Pb+Pb}^{EW}}$$

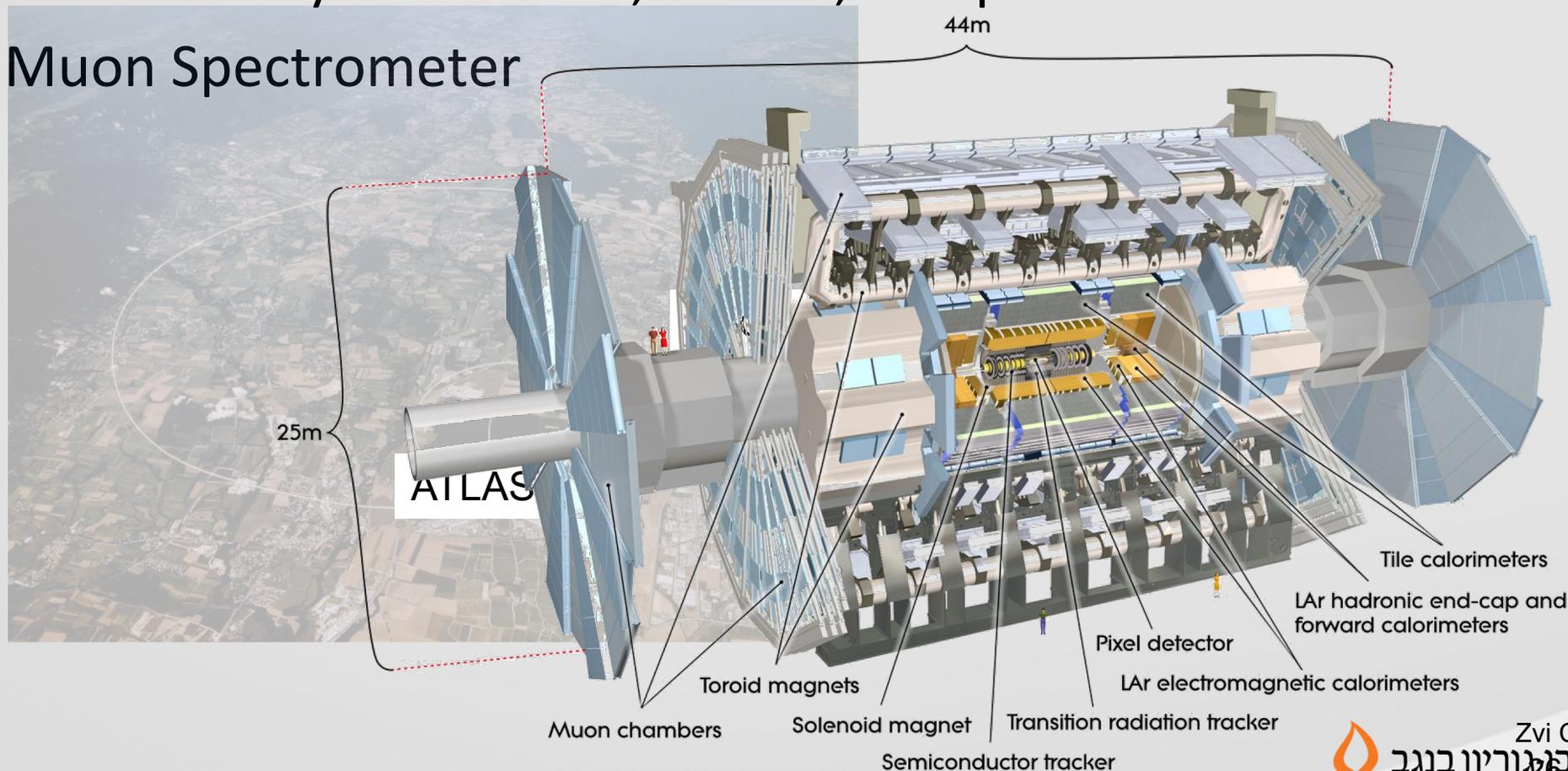
# Summary

- EW bosons in pp, pPb, and PbPb at 5.02,8.16 TeV
- pp serves as high precision baseline
- pPb displays evidence for nPDF modification in Z measurement, room to think some more about photons ...
- PbPb consistent with expectations (even w/out nPDF), high precision → new centrality paradigm?

# Backup Information

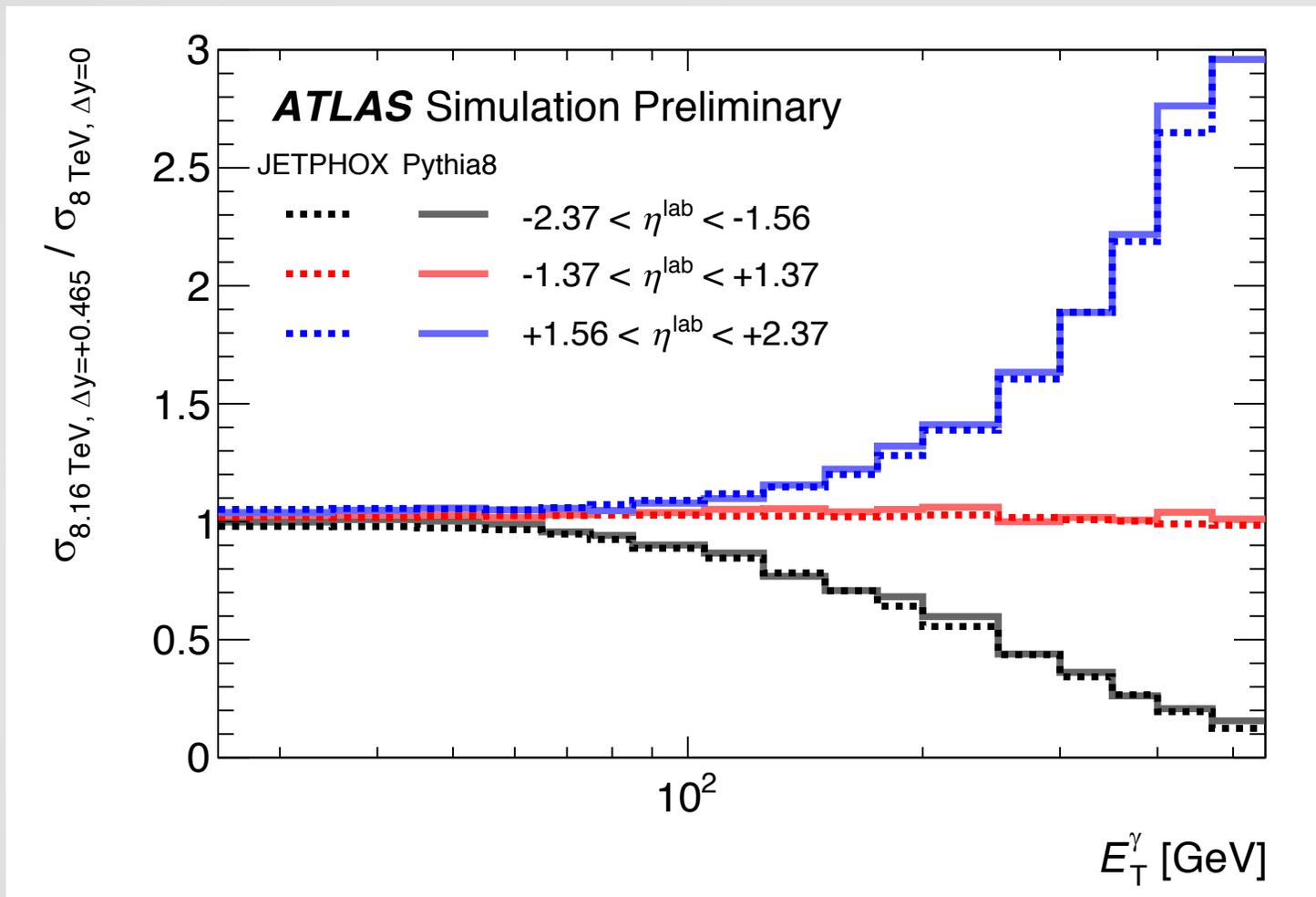
# ATLAS at the LHC

- ATLAS has:
  - Charged particle tracking  $\rightarrow$  electrons and muons (photon veto)
  - Calorimetry  $\rightarrow$  electrons, muons, and photons
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# Reference Spectra for photon $R_{pA}$



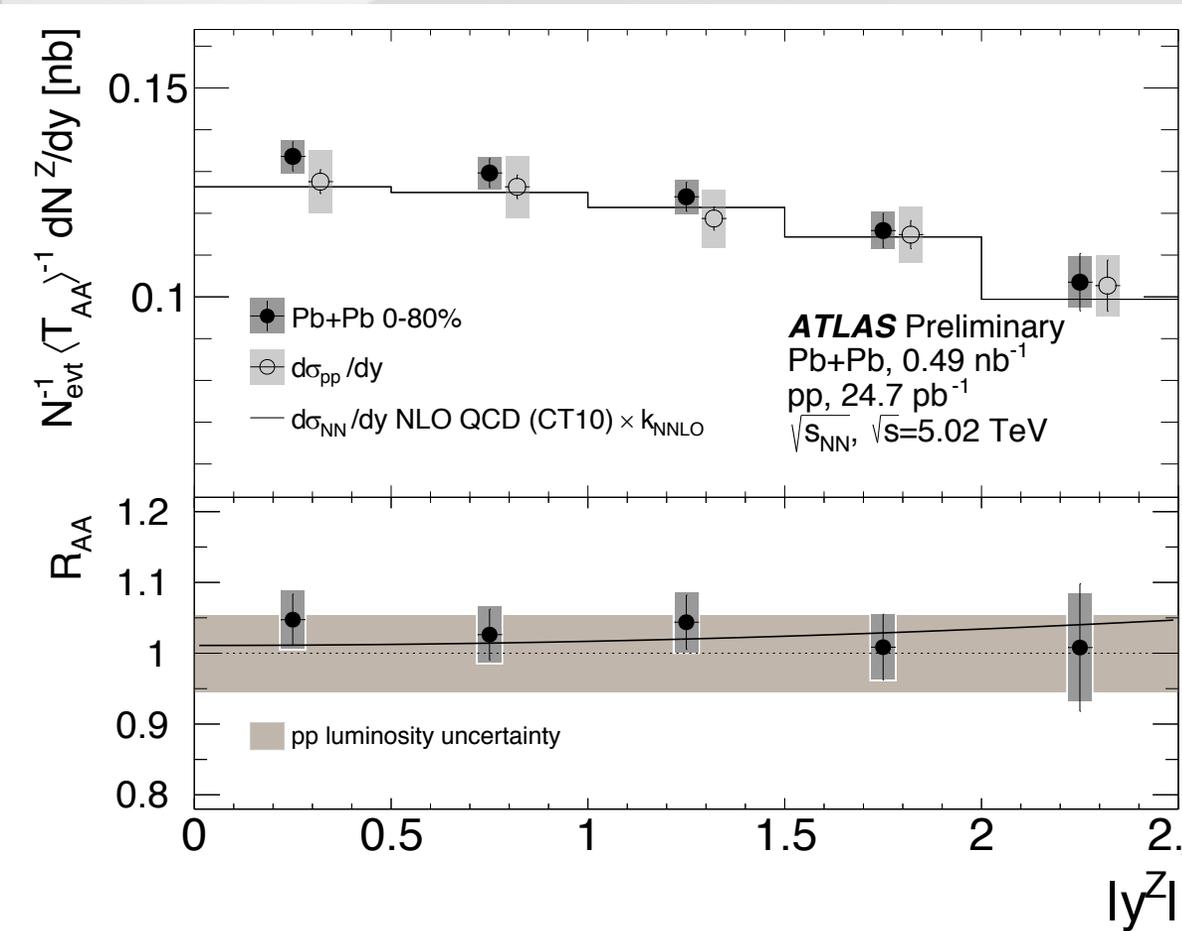
Start with 8 TeV pp data

Use simulation to define extrapolation factor in  $E_T$  and  $\eta$

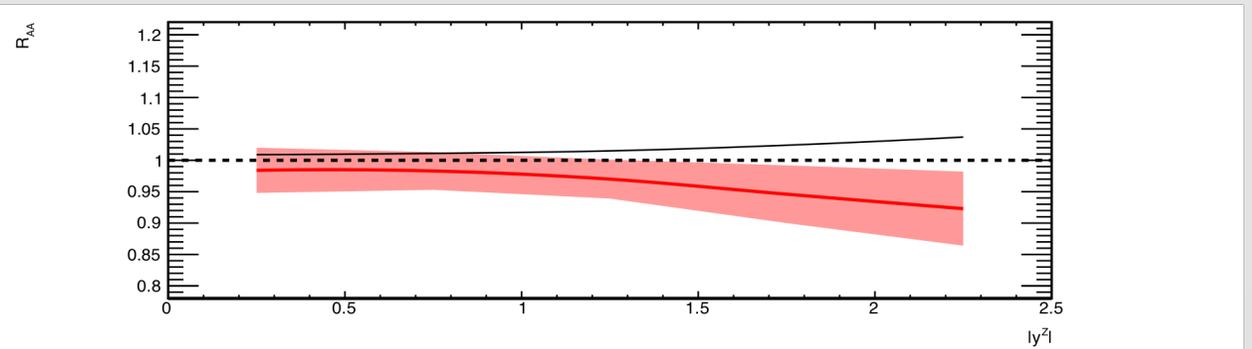
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# Rapidity Differential Yield



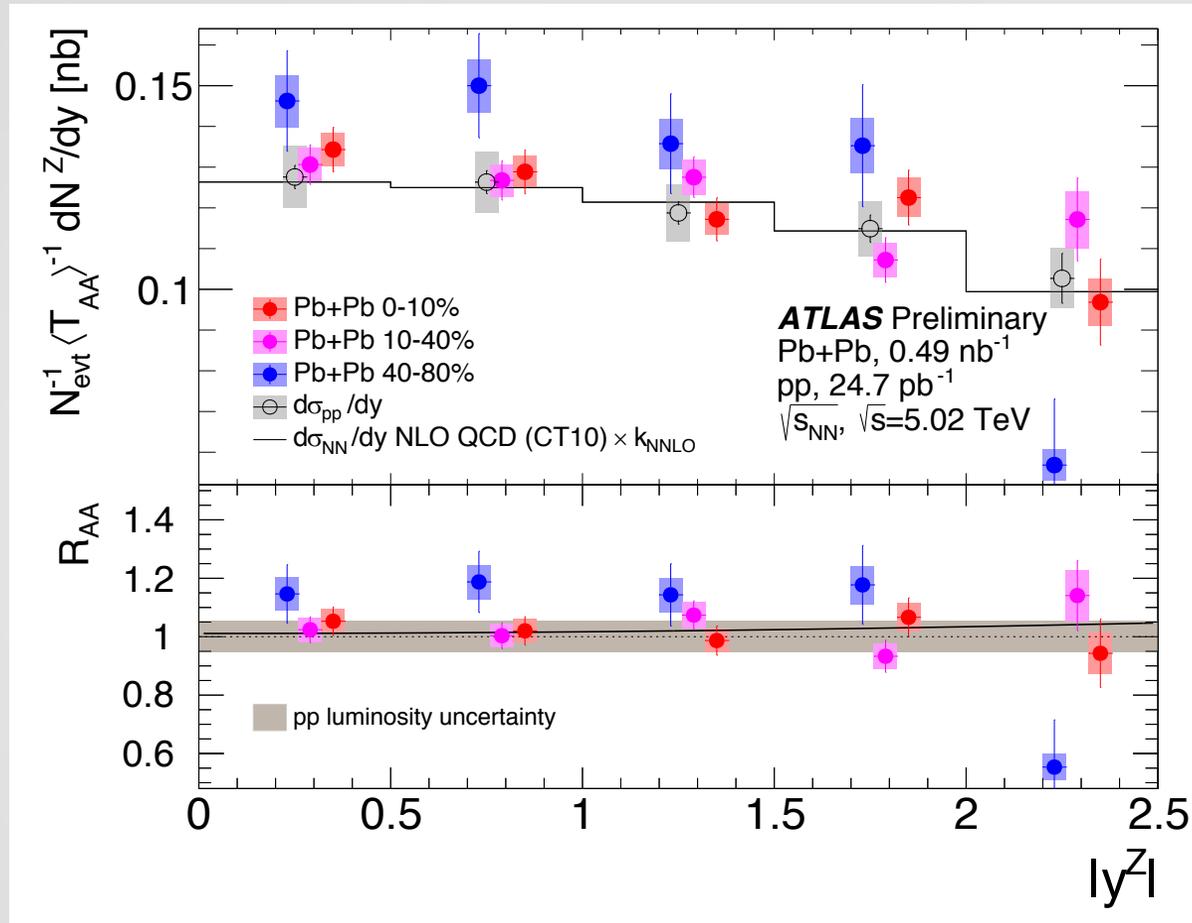
nPDF (EPS09)  
 expected  $R_{AA}$   
 (provided by H.  
 Paukkunen)



# *Yield per Minimum Bias Event*

- Correct for detector/trigger efficiency
- Divide by number of sampled minimum bias events in lieu of luminosity
- Divide by  $\langle T_{AA} \rangle$
- Uncertainty on  $\langle T_{AA} \rangle$  : 1-9%

# Rapidity Differential Yield in Centrality



Shown with comparison to pp data

Largely consistent with expectations (most peripheral bin is  $\sim 1.5$  sigma high)

# Photon-Model Comparisons

