Photon and jet probes of small collision systems with ATLAS

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for ATLAS collaboration

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Prague

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of High-Energy Nuclear Collisions, Aix-Les-Bains, France

Introduction

- Original motivation for p+Pb collisions:
  - to calibrate Pb+Pb measurements,
  - to understand initial state effects,
  - to study nuclear PDFs, ...

- ATLAS results in p+Pb collisions:
  - Charged particle spectra, multiplicities, R_{pPb}
  - Ridge and flow, HBT correlations
  - Jet production and fragmentation
  - W and Z boson production, gamma production
  - Quarkonia and heavy flavor production

… quite a lot of unexpected seen! p+Pb is a non-trivial reference

Introduction

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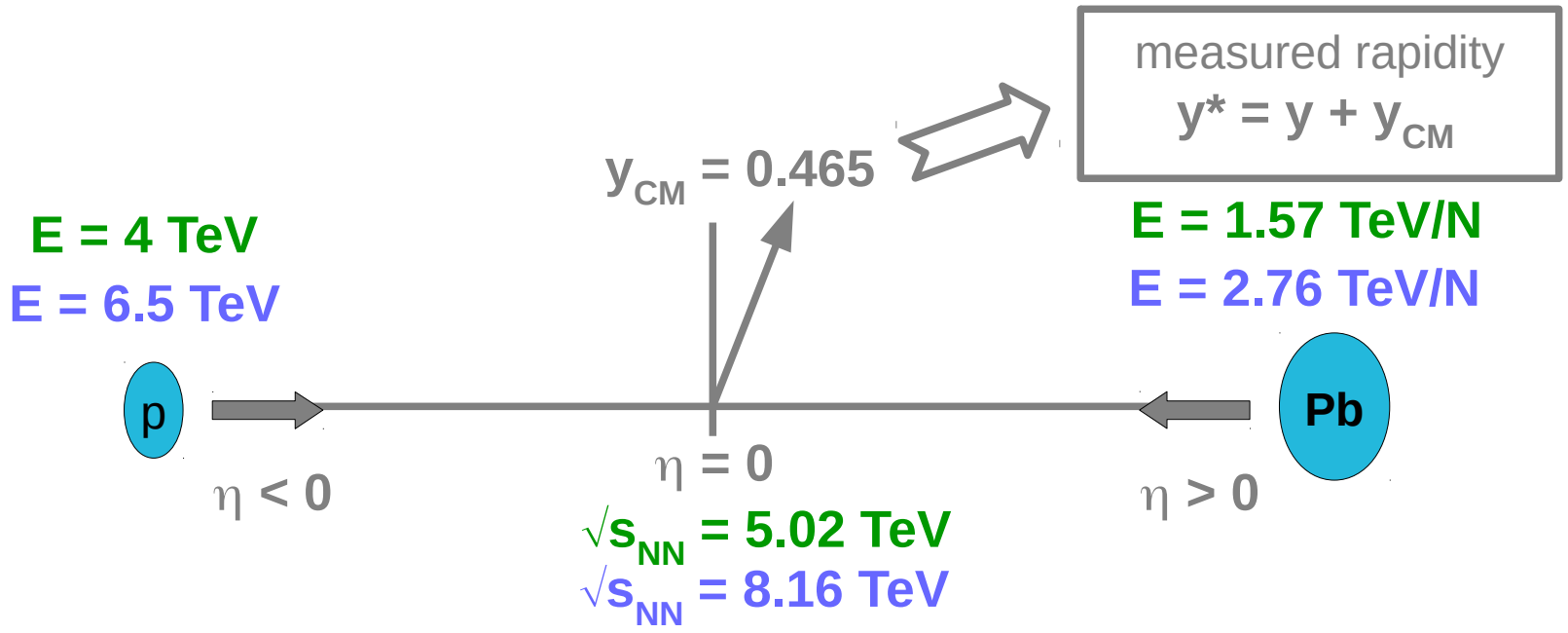
- ATLAS results in p+Pb collisions:
  - Charged particle spectra, multiplicities, R_{pPb}
  - ATLAS-CONF-2018-050 rrelations
  - **Jet production** and fragmentation ATLAS-CONF-2017-072
  - W and Z boson production, **gamma production**
  - Quarkonia and heavy flavor production

Talk by Sebastia Tapia Talk by Mirta Dumancic -trivial reference

- Here only selected new results on jets and photons.

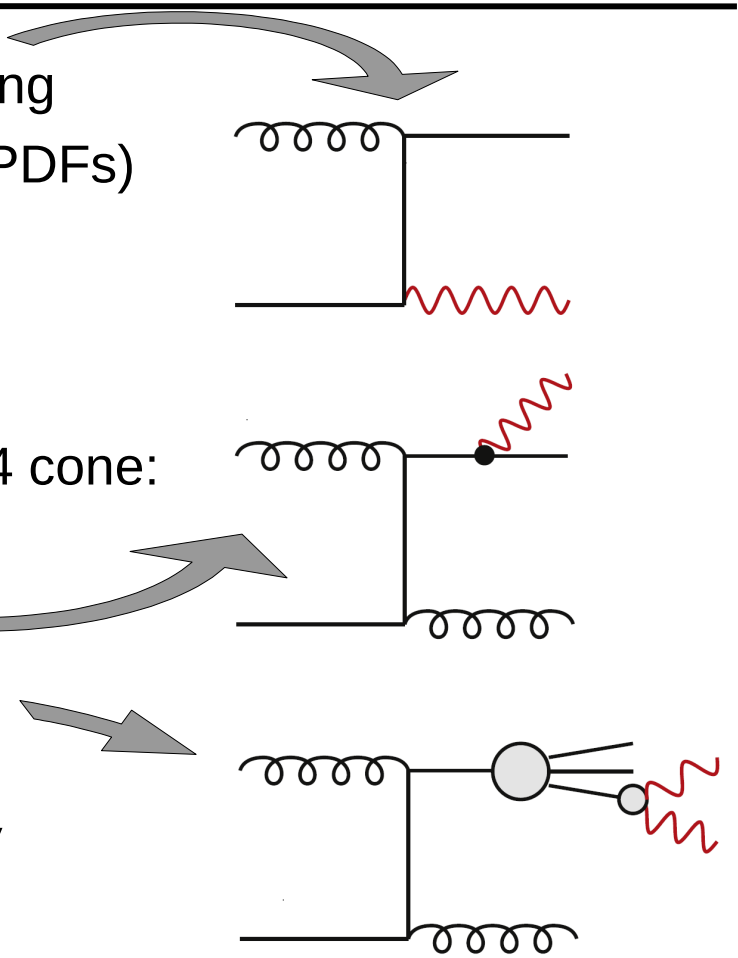
p+Pb datasets

System	Year	$\sqrt{s_{NN}}$ [TeV]	L_{int}
p+Pb	2012	5.02	1 μb^{-1}
p+Pb	2013	5.02	29 nb^{-1}
p+Pb	2016	5.02	0.5 nb^{-1}
p+Pb	2016	8.16	180 nb^{-1}



Prompt photons

- **Prompt photons** originate in initial hard scattering
  - Sensitive to initial state densities (nuclear PDFs) and potential initial state energy loss.
  - Insensitive to final state modification.
- **Isolation** requirement:
  - Reject photons w/ excess E_T within $\Delta R=0.4$ cone: $E_T > E_{T,iso} = 4.8 + 4.2 \times 10^{-3} E_{T\gamma}$ [GeV]
  - Suppresses of **fragmentation** photons
  - Suppresses photons from **vector mesons** decays
- Measurement performed for $25 < E_{T\gamma} < 500$ GeV in three bins of η^* between -2.83 and 1.91.
- First LHC measurement of isolated prompt (or direct) photons in p+Pb collisions.

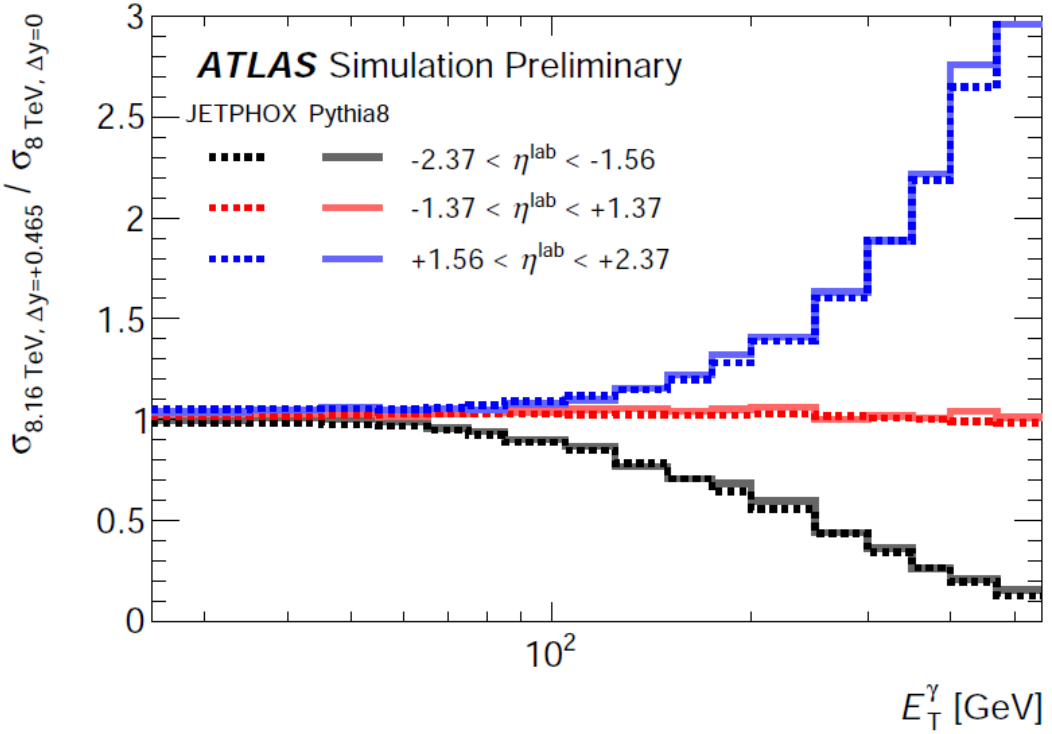


pp reference

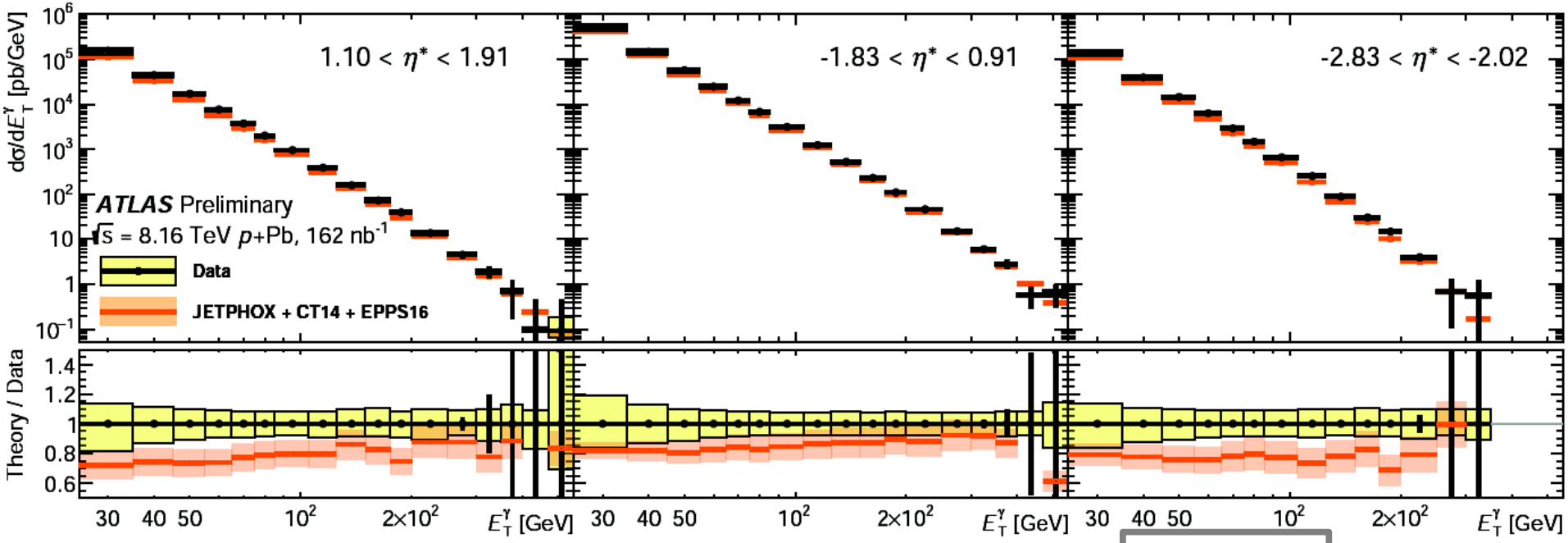
- No *pp* data exists at 8.16 TeV => **extrapolation**
- Photon cross-section calculated in **JETPHOX** for 8 TeV and 8.16 TeV
- Correction factors:

$$\sigma_{8.16\ \mathrm{TeV},\ \Delta y=+0.465} \ / \ \sigma_{8\ \mathrm{TeV},\ \Delta y=0}$$

… applied on **data from 8 TeV *pp*** collisions (JHEP 08 (2016) 005).



Cross-section



$$d\sigma/dE_{\mathrm{T}}^{\gamma} = \frac{1}{L_{\mathrm{int}}} \frac{1}{\Delta E_{\mathrm{T}}^{\gamma}} \frac{N_{\mathrm{sig}} P_{\mathrm{sig}}}{\epsilon^{\mathrm{sel}} \epsilon^{\mathrm{trig}}} C,$$

Purity

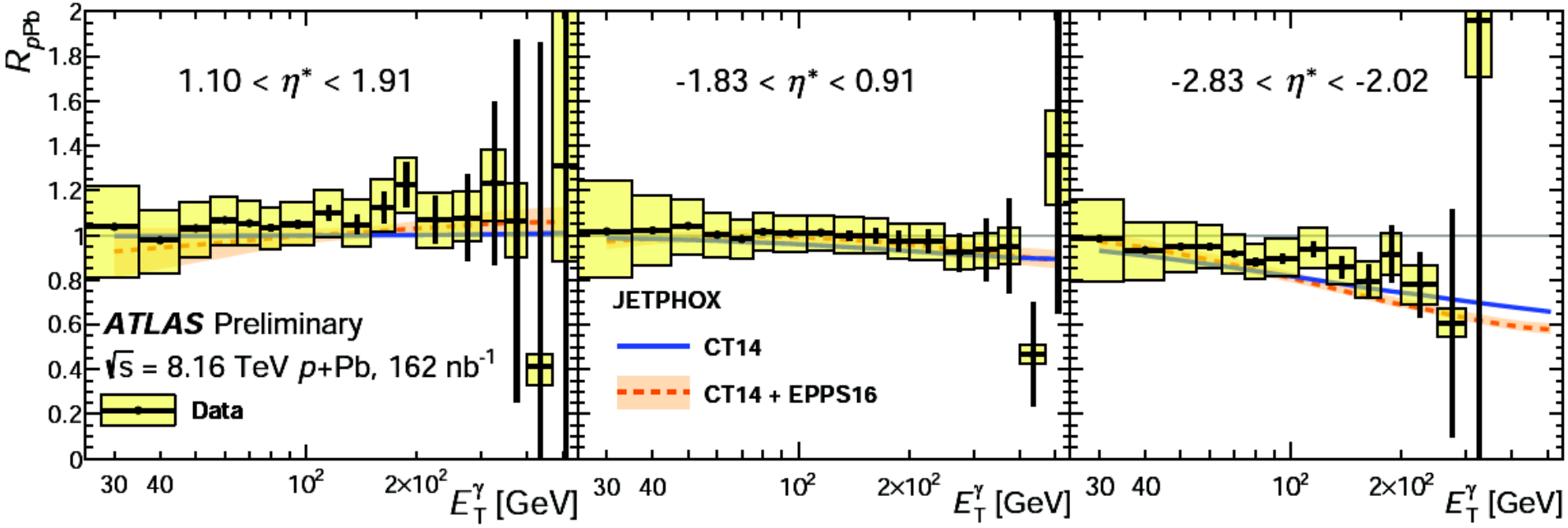
bin-by-bin

Efficiencies

Cross-section in *pp* compared to JETPHOX – similar level of **disagreement as in previous** *pp* photon measurement (JHEP 08 (2016) 005, PLB 770 (2017) 473).

R_{pPb}

$$R_{pPb} = (d\sigma^{p+\mathrm{Pb}\to\gamma+X}/dE_{\mathrm{T}}^{\gamma})/(A \cdot d\sigma^{pp\to\gamma+X}/dE_{\mathrm{T}}^{\gamma})$$



- Consistent with unity except for backward (Pb-going) direction: consistent with **expected isospin effects**.
- Data compared to two nPDF sets: **CT14+EPPS16**, nCTEQ15 – **no ability to distinguish**.

Thanks to I. Helenius and H. Paukunnen for nPDF calcuations

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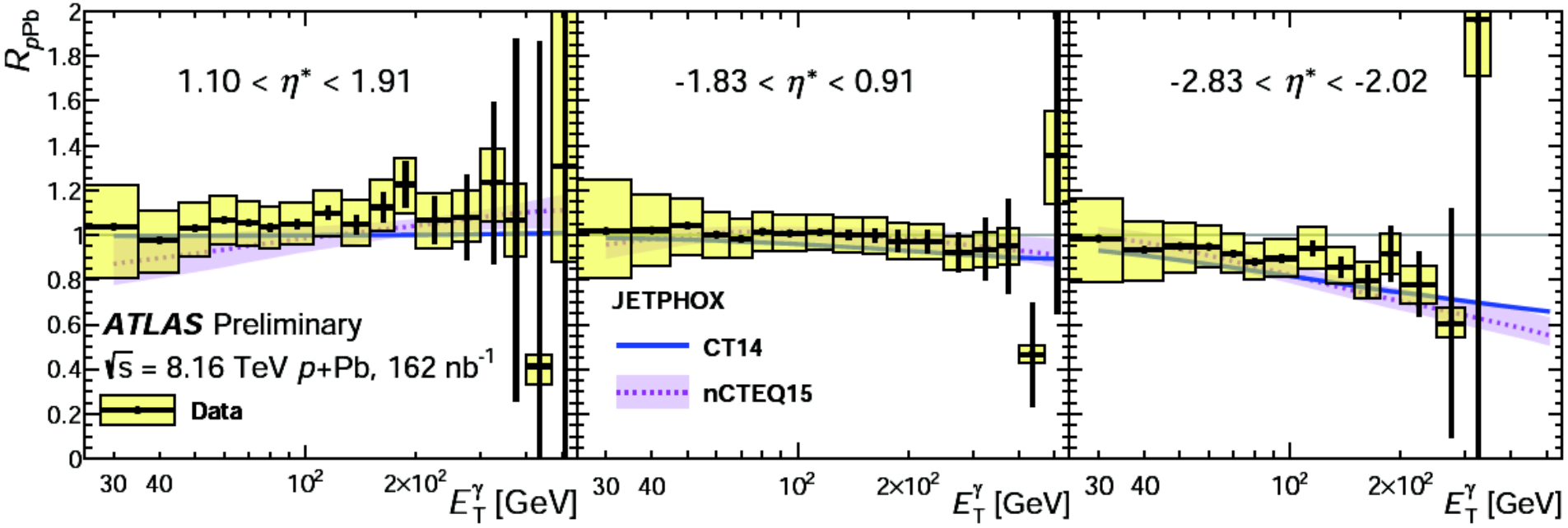

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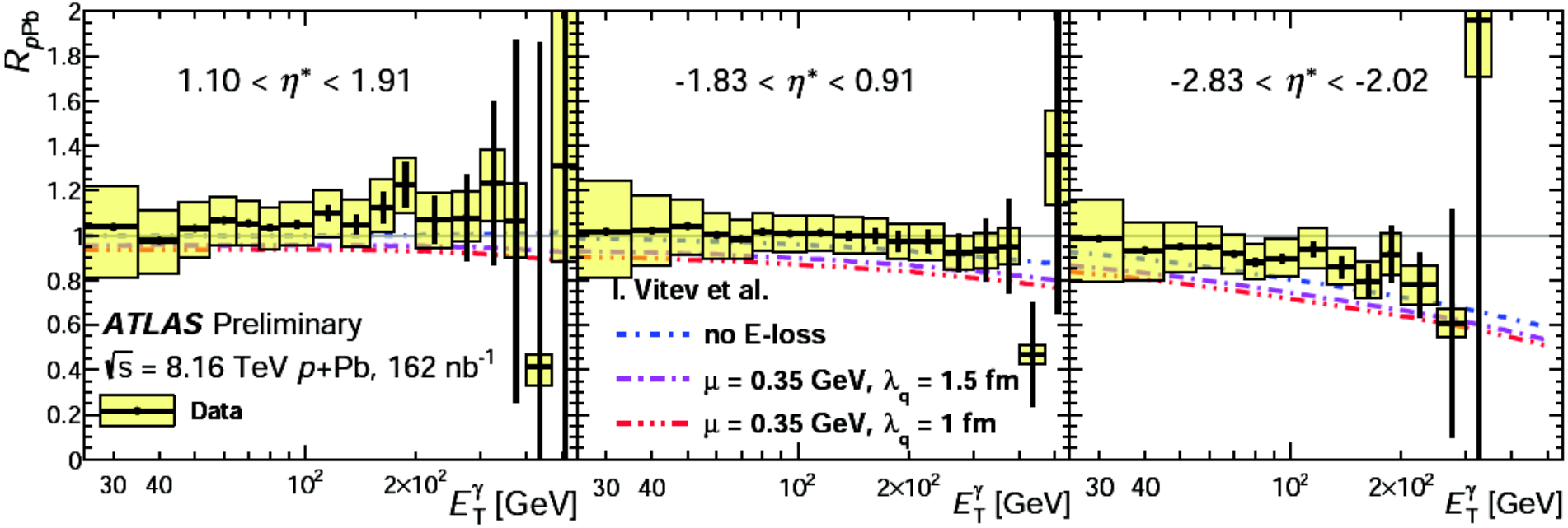
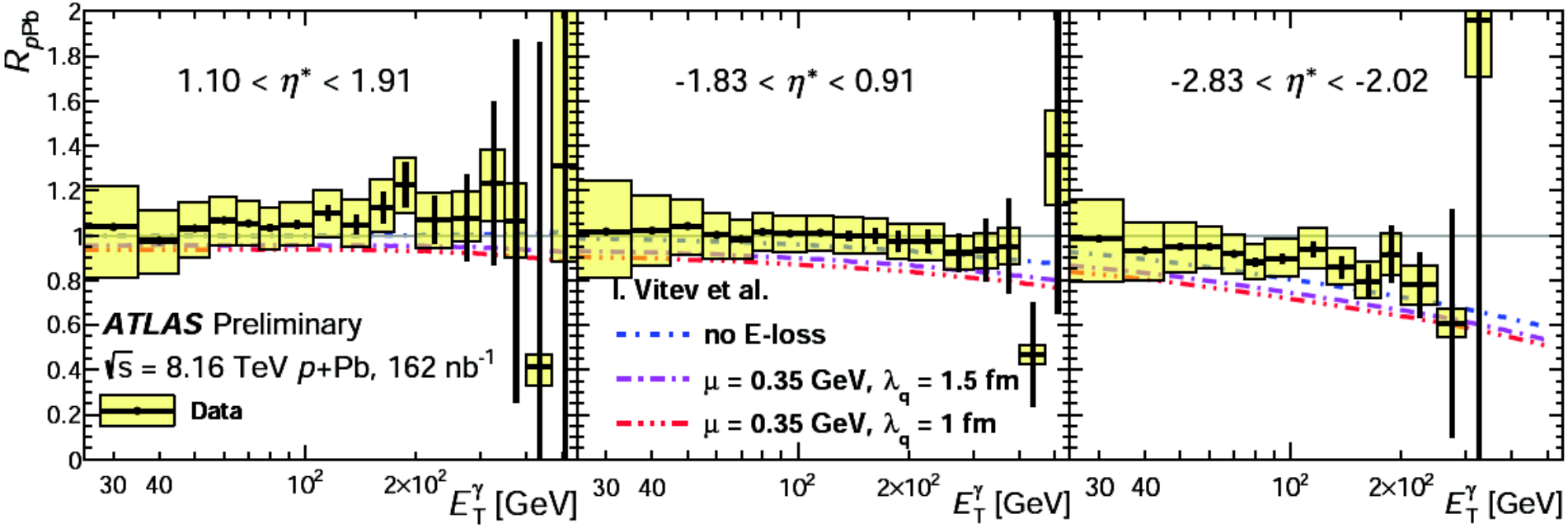


- Consistent with unity except for backward (Pb-going) direction = consistent with **expected isospin effects**.
- Data compared to two energy loss scenarios: **no sign of energy loss.**

R_{pPb}

$$R_{pPb} = (d\sigma^{p+\mathrm{Pb}\to\gamma+X}/dE_{\mathrm{T}}^{\gamma})/(A \cdot d\sigma^{pp\to\gamma+X}/dE_{\mathrm{T}}^{\gamma})$$

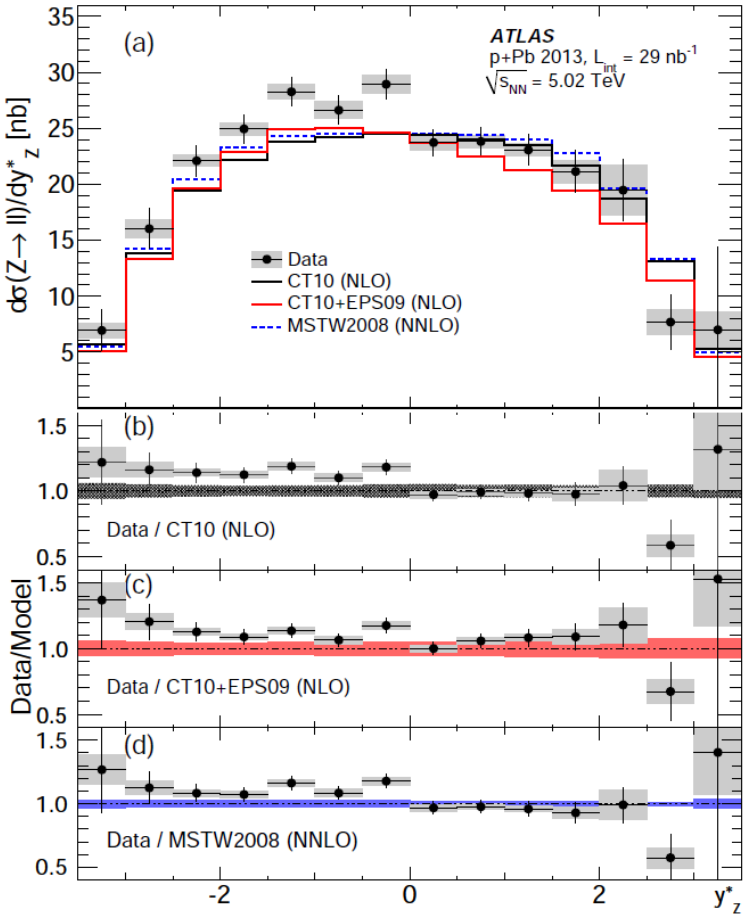


Outlook:

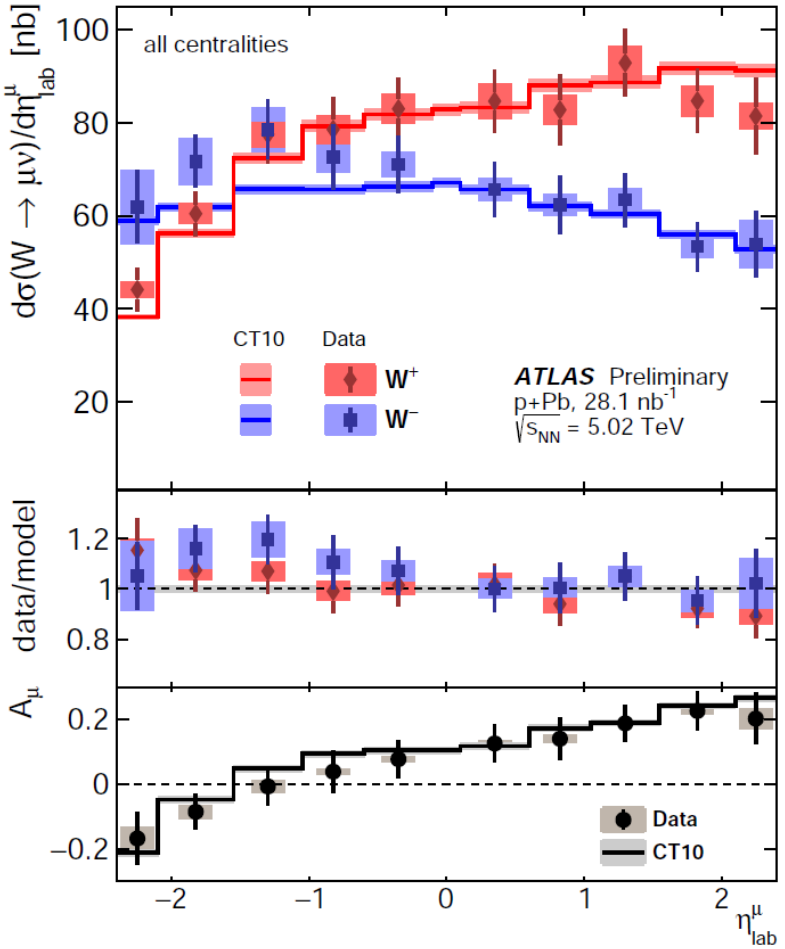
- Final results coming up soon with **significant reduction** of systematic uncertainties.
- **Forward-to-backward** ratio to be added.

Context: W and Z with 5.02 TeV p+Pb

Phys. Rev. C 92, 044915 (2015)



ATLAS-CONF-2015-056



… no ability to distinguish nPDF effects, data consistent with NLO pQCD

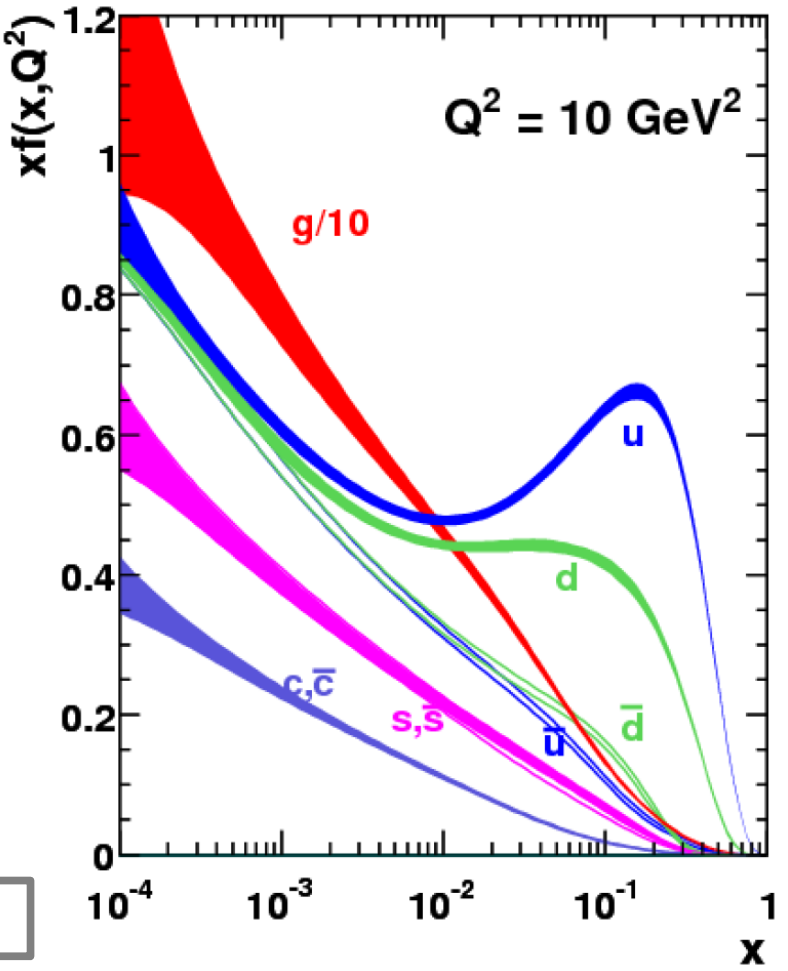
Dijet $\Delta\phi$ correlations

- **Steep rise** of gluon PDFs at low-x versus unitarity.
- **Saturation** can bring expected change of trend at low-x.
- Saturation studied **before**, e.g. using high-p_T charged particles.
- **Dijet $\Delta\phi$ correlations** sensitive to saturation effects.

$$\Delta\phi = |\phi_1 - \phi_2|$$

Leading jet

Sub-leading jet



Dijet $\Delta\phi$ correlations – observables

Correlation function

$$C_{12} = \frac{1}{N_1}\frac{\mathrm{d}N_{1,2}}{\mathrm{d}\Delta\phi}$$

$$W_{12} = \mathrm{RMS}(C_{12})$$

$$\rho_W^{\mathrm{pPb}} = \frac{W_{12}^{p+\mathrm{Pb}}}{W_{12}^{pp}}$$

Dijet conditional yield

$$I_{12} = \frac{1}{N_1}\frac{\mathrm{d}N_{1,2}}{\mathrm{d}y_1^*\mathrm{d}y_2^*\mathrm{d}p_{\mathrm{T},1}\mathrm{d}p_{\mathrm{T},2}}$$

$$\rho_I^{\mathrm{pPb}} = \frac{I_{12}^{p+\mathrm{Pb}}}{I_{12}^{pp}}$$

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$$W_{12} = \mathrm{RMS}(C_{12})$$

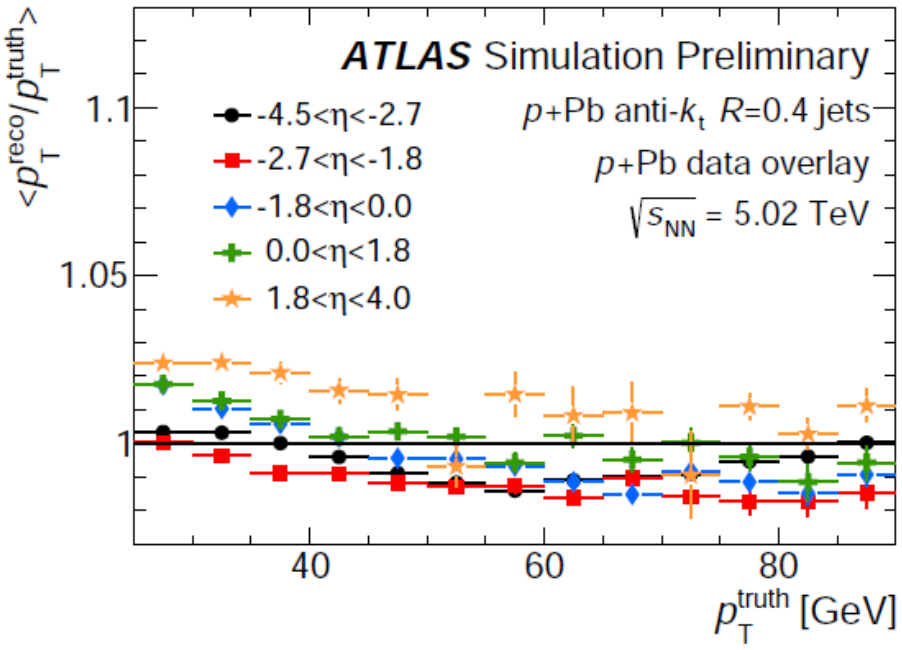
$$C_{12}(\Delta\Phi) = \int_{-\infty}^{\infty}\mathrm{d}\delta\,\frac{e^{-\delta^2/2\sigma^2}}{\sqrt{8\pi\sigma^2\tau^2}}e^{-|\Delta\Phi-\delta|/\tau}$$

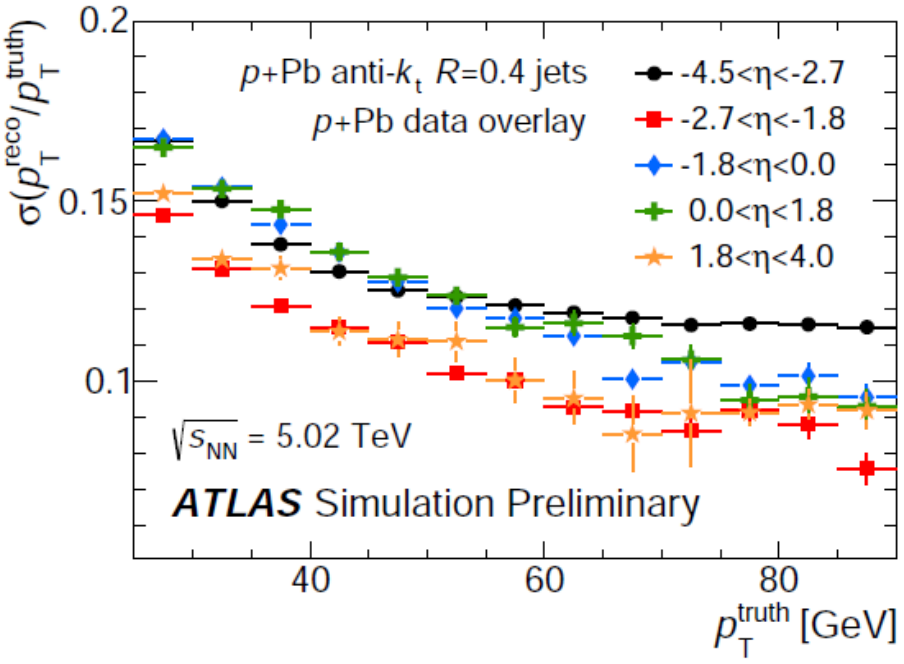
W_{12} fitted to reduce impact of statistical fluctuations

$$\rho_W^{\mathrm{pPb}} = \frac{W_{12}^{p+\mathrm{Pb}}}{W_{12}^{pp}}$$

$$\rho_I^{\mathrm{pPb}} = \frac{I_{12}^{p+\mathrm{Pb}}}{I_{12}^{pp}}$$

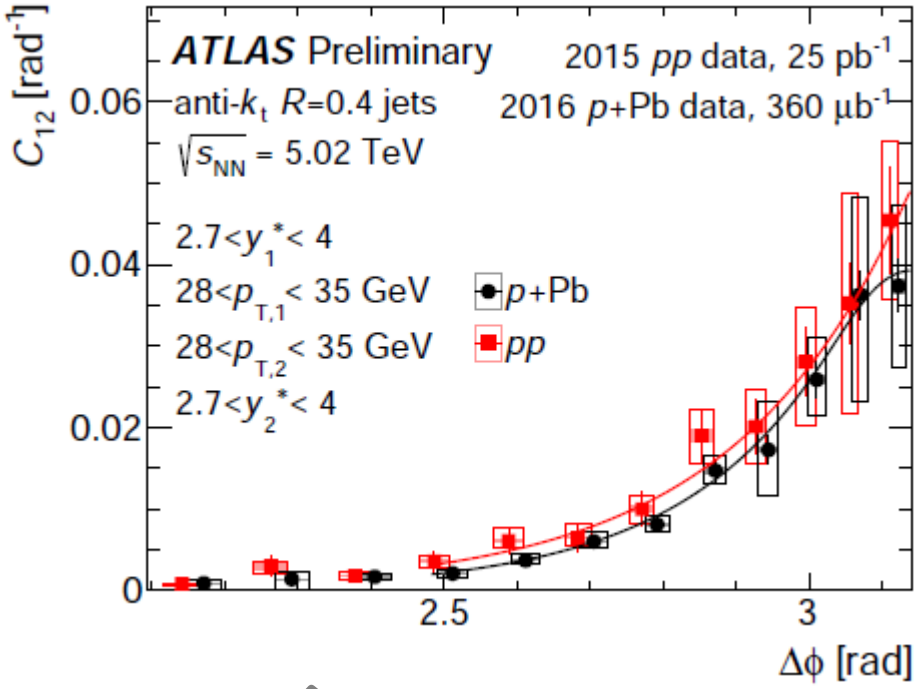
Performance

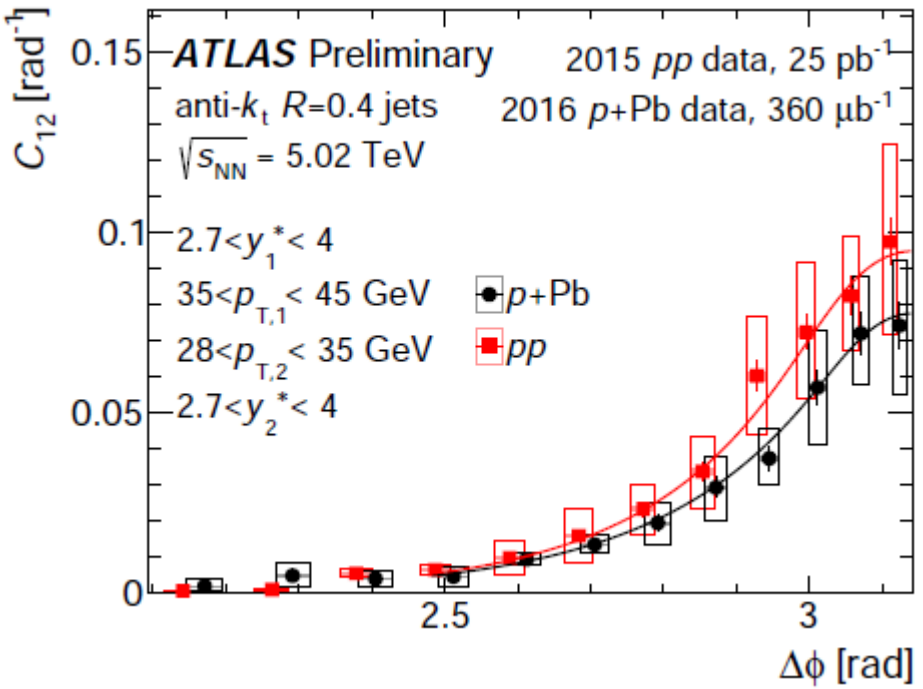




- Measurement performed in **-4.0 < y* < 4.0** and for **28 < p_T < 90 GeV**.
- Good jet reconstruction performance even in the forward region.
- Residual departure of JES from unity corrected by unfolding.

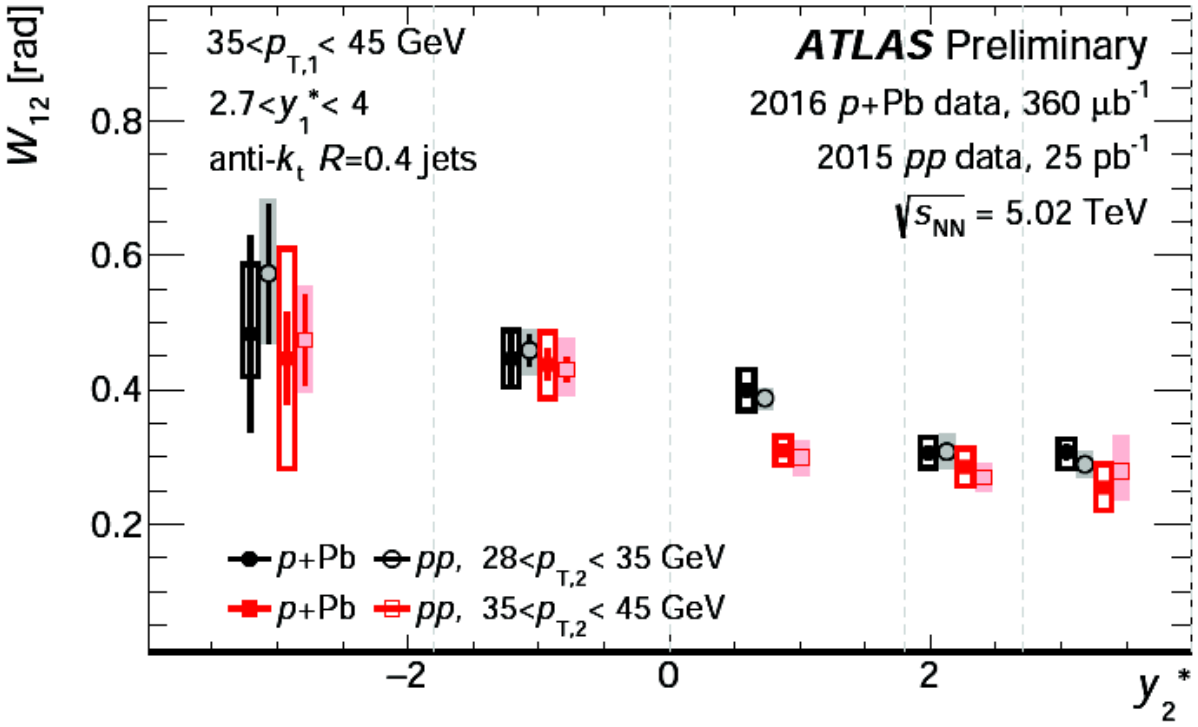
C_{12} distributions





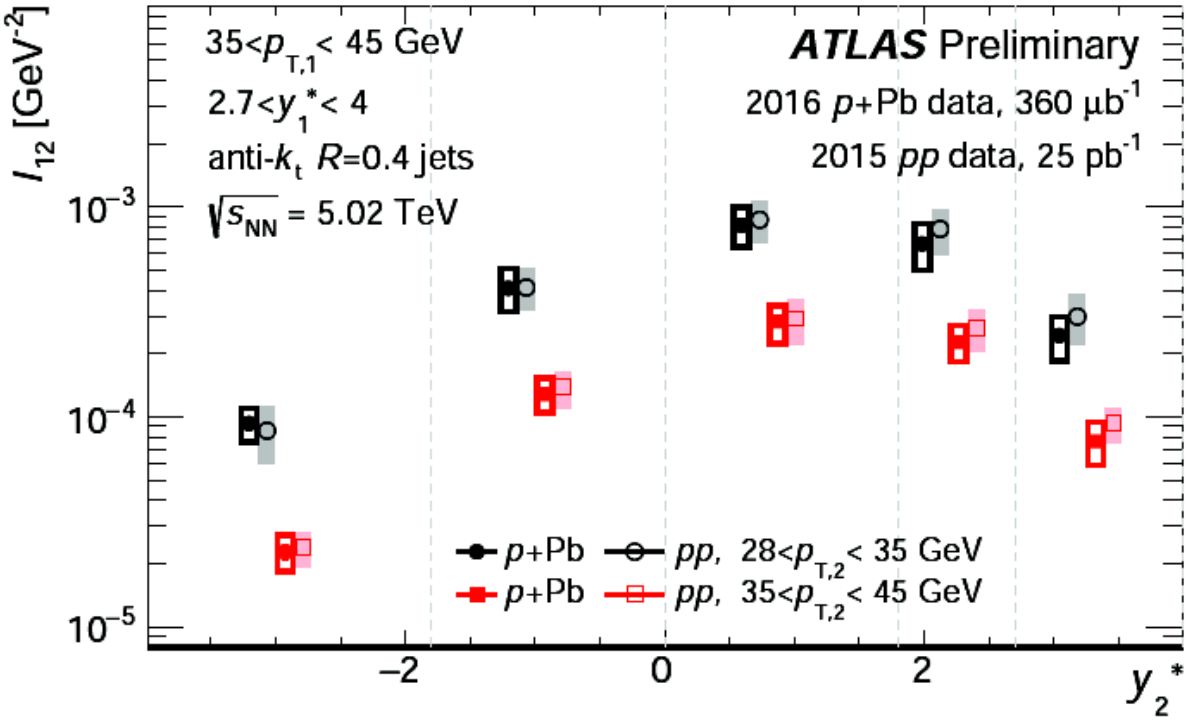
Lowest forward bin: kinematic selection corresponds to $1.5 \cdot 10^{-4} < x < 10^{-3}$

W_{12} distributions



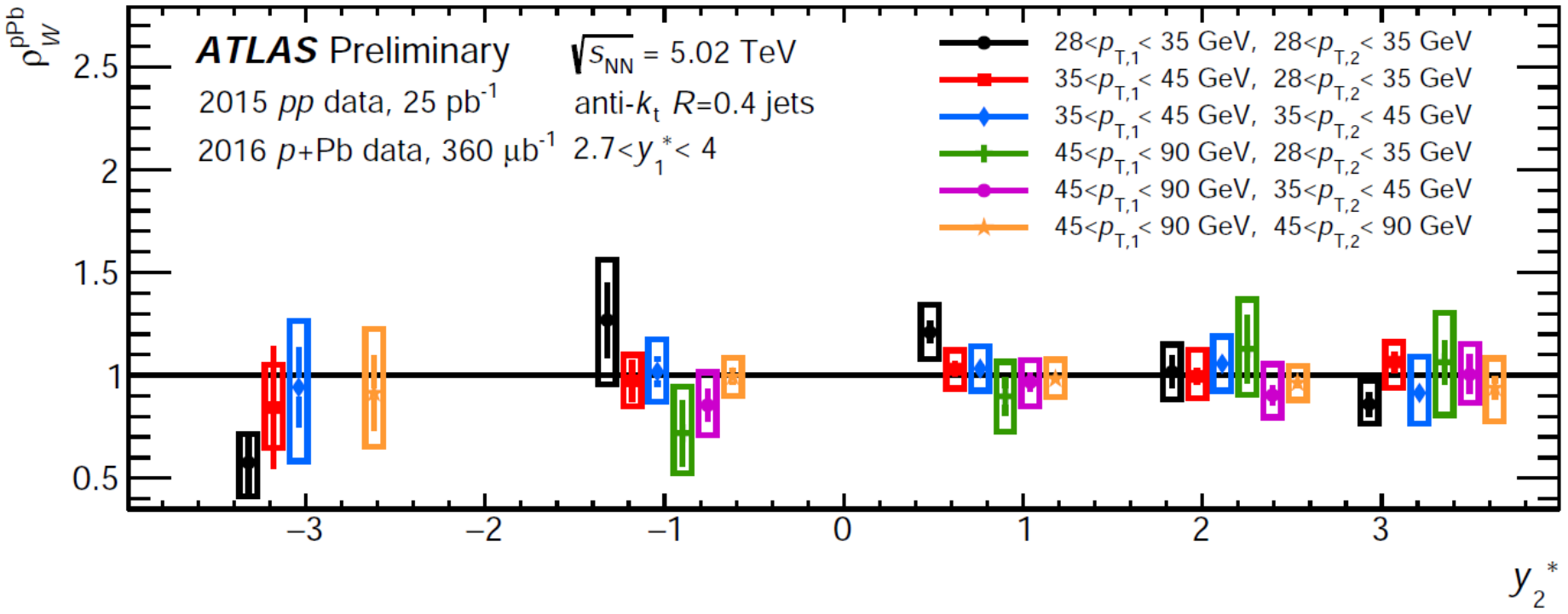
- Widths of azimuthal correlations **increase with increasing rapidity separation** between jets.
- Widths of azimuthal correlations **increase with increasing p_T imbalance** between jets.

I_{12} distributions



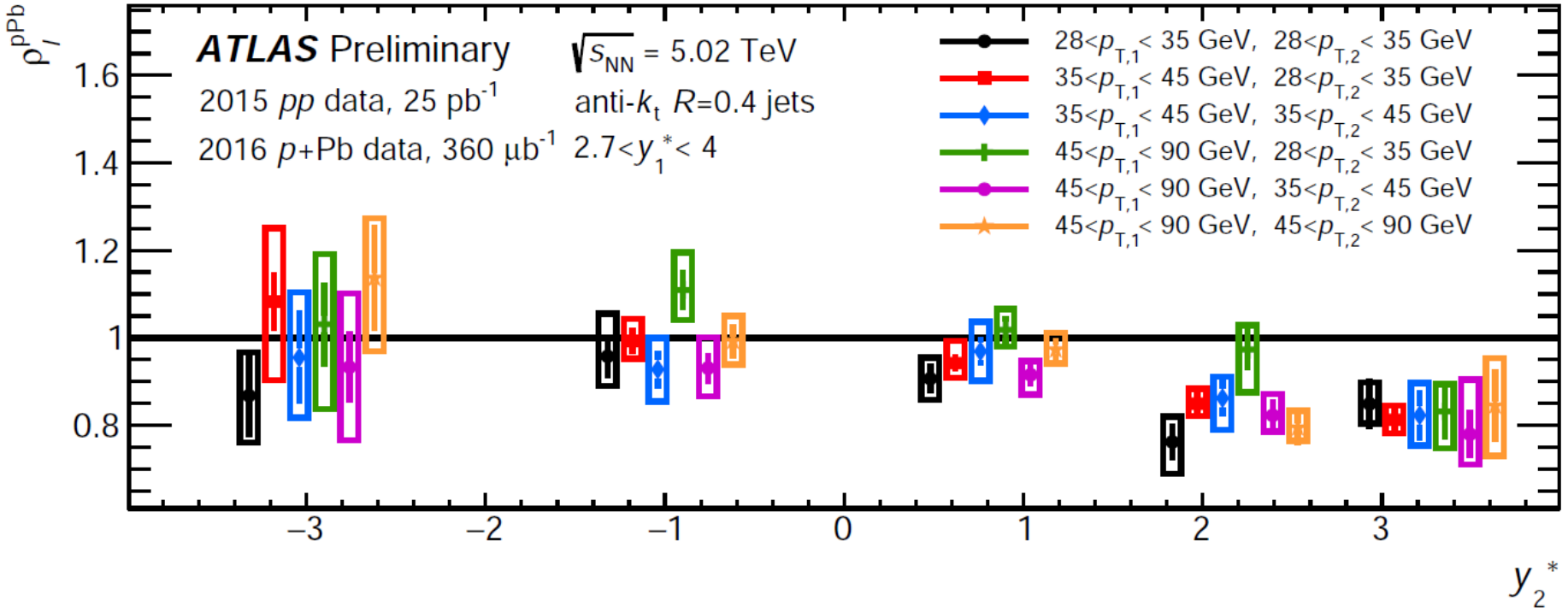
- Yields of jets: shape dictated by **faster fall-off of forward cross-section** as compared to inclusive cross-section.
- Measurement repeated also for a configuration with $\Delta p_T = p_{T,1} - p_{T,2} > 3$ GeV with the same conclusions.

ρ_W distributions



- No significant broadening of azimuthal correlations seen in p+Pb compared to *pp*.

ρ_l distributions



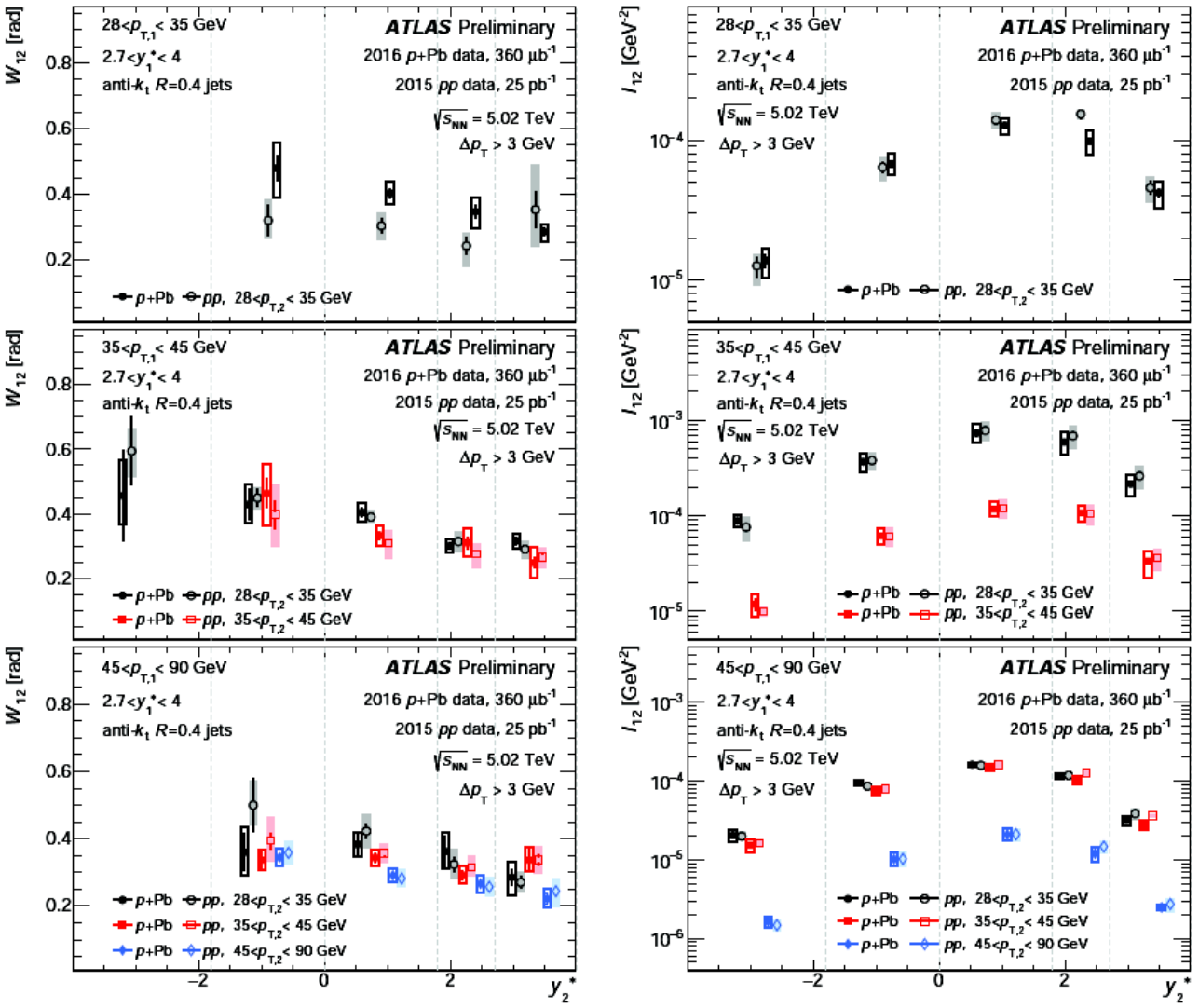
- 20% **suppression** in yield seen for **forward-forward** jets in p+Pb collisions in proton-going direction.

Summary

- Photons in *p*+Pb collisions at 8 TeV
  - Expected isospin effects seen.
  - No ability to distinguish nPDF effects.
  - No initial state energy loss observed in the data.
  - More *p*+Pb data needed to access nPDF effects with photons / electro-weak probes.
- Dijet $\Delta\phi$ correlations
  - No significant broadening of azimuthal correlations seen in *p*+Pb compared to *pp*.
  - 20% suppression in yield seen for forward-forward jets in *p*+Pb collisions compared to *pp*.
  - Should provide new input for saturation models.

Backup slides

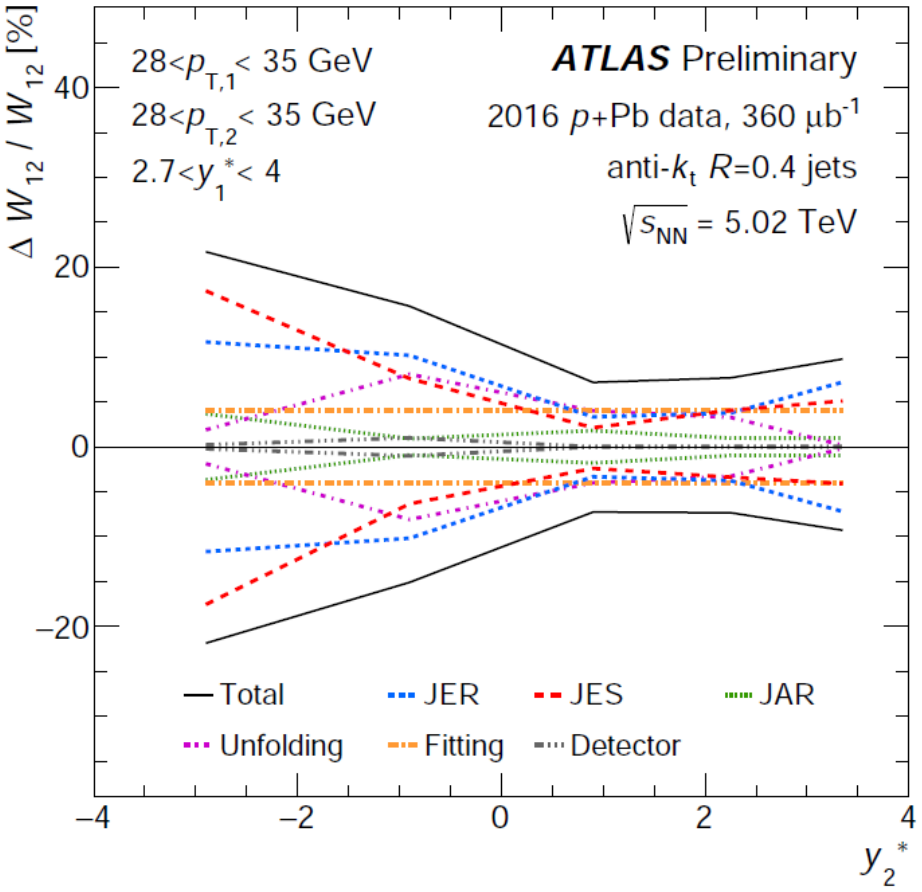
Full set of distributions

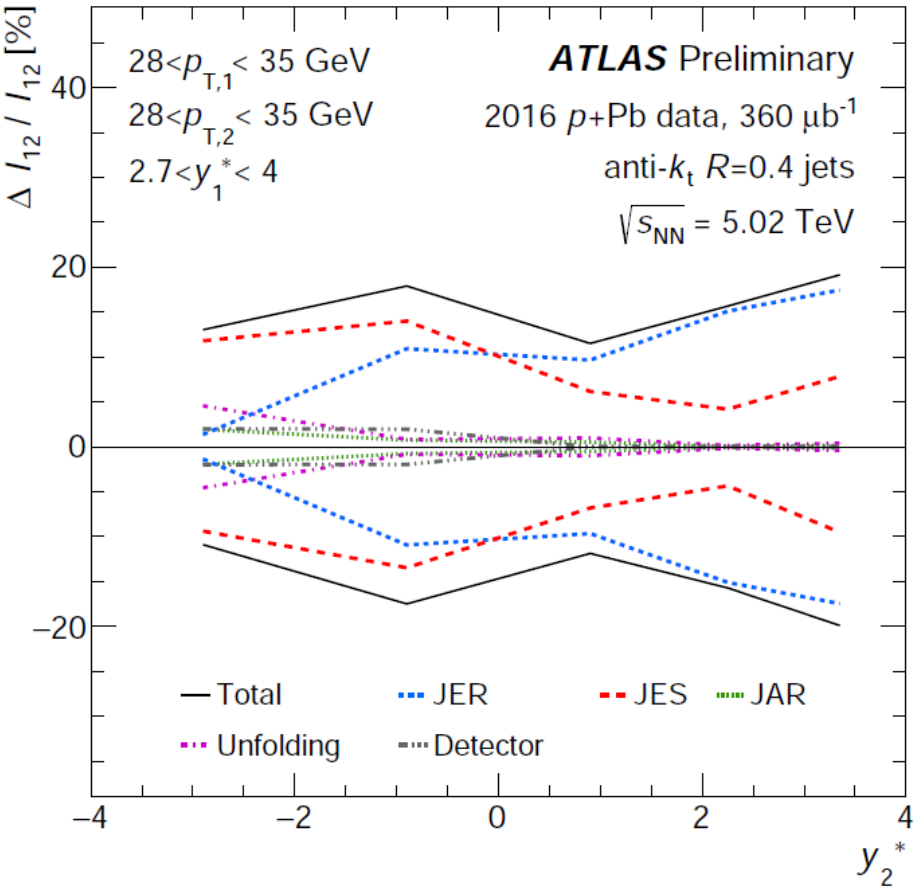


Systematic uncertainties

- Selection and purity of photons (10% at low E_T)
- Photon energy scale and resolution (5-10% at large E_T and eta)
- Extrapolation (<5%)
- Reference pp spectra for R_{pPb} (< 12%)
- Luminosity (6.2%)
- Other small sources of uncertainties:
  - Generator level vs detector level isolation (<2%)
  - Data-taking period (1%)
  - Direct / fragmentation photon ratio in MC (1%)
  - Contribution of mis-reconstructed electrons from W, Z (<1%)

Systematic uncertainties





Fitting function

$$C_{12}(\Delta\Phi) = \int_{-\infty}^{\infty} \mathrm{d}\delta \frac{e^{-\delta^2/2\sigma^2}}{\sqrt{8\pi\sigma^2\tau^2}} e^{-|\Delta\Phi-\delta|/\tau}$$

$$C_{12}(\Delta\Phi) = A\frac{e^{\sigma^2/2\tau^2}}{2\tau}\left(\frac{1}{2}e^{\Delta\Phi/\tau}\mathrm{Erfc}\left(\frac{1}{\sqrt{2}}\left[\frac{\Delta\Phi}{\sigma}+\frac{\sigma}{\tau}\right]\right)+e^{-\Delta\Phi/\tau}\left[1-\frac{1}{2}\mathrm{Erfc}\left(\frac{1}{\sqrt{2}}\left[\frac{\Delta\Phi}{\sigma}-\frac{\sigma}{\tau}\right]\right)\right]\right)$$

Bins in $p_{\mathrm{T},1}$[GeV]	Bins in $p_{\mathrm{T},2}$[GeV]	Bins in y_2^*
$28 < p_{\mathrm{T},1} < 35$	$28 < p_{\mathrm{T},2} < 35$	$2.7 < y_2^* < 4.0$
$35 < p_{\mathrm{T},1} < 45$	$35 < p_{\mathrm{T},2} < 45$	$1.8 < y_2^* < 2.7$
$45 < p_{\mathrm{T},1} < 90$	$45 < p_{\mathrm{T},2} < 90$	$0.0 < y_2^* < 1.8$
		$-1.8 < y_2^* < 0.0$
		$-4.0 < y_2^* < -1.8$