The XXVth International Conference on Nucleus-Nucleus Collisions

Centrality dependence of low-p_T and high-p_T particle production in proton-lead collisions with ATLAS

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Introduction

p+A collisions at the LHC provide an opportunity to study the physics of the initial-state of ultra-relativistic A+A collisions

p+A multiplicity measurements:

- $dN_{ch}/d\eta$ − the most basic experimental probe which as a function of centrality can provide understanding of p+A interactions

Z-boson production:

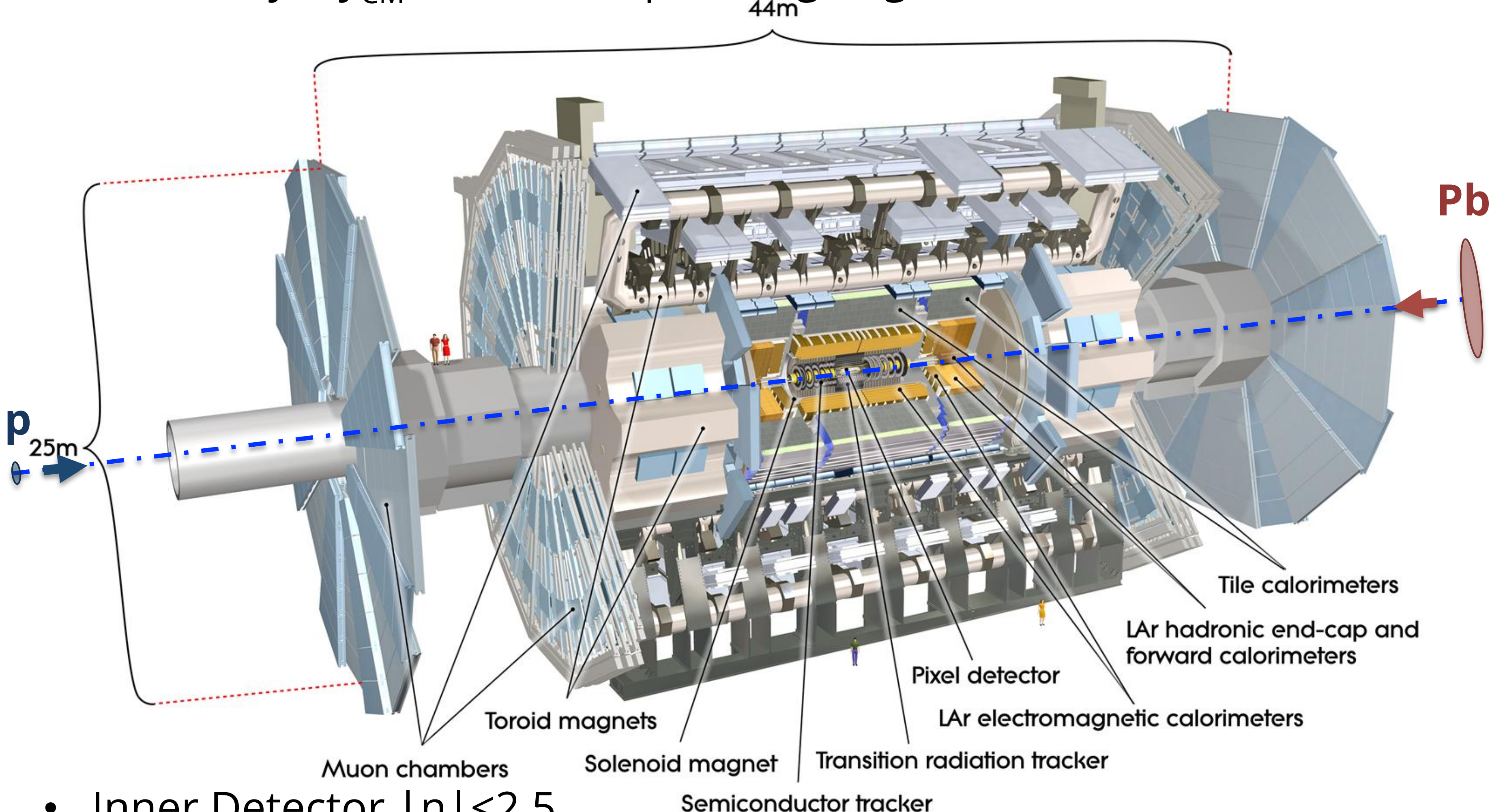
- Clean probe to better understand p+Pb particle production scaling properties and underlying nature of the collision

pp dijet measurements:

- provide a tool to test how underlying event activity correlates with hard scattering kinematics in p+Pb interactions

ATLAS detector

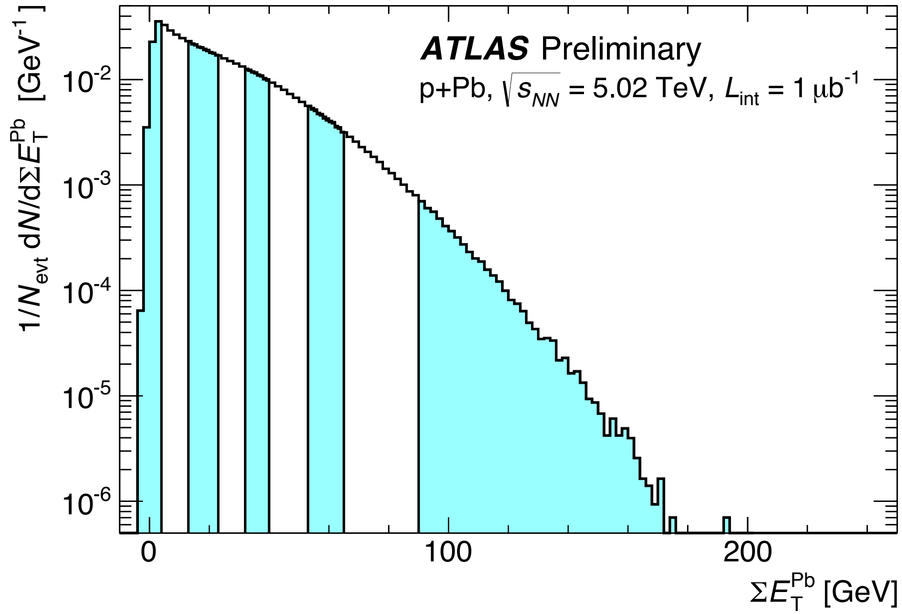
Convention: $y^{*}=y_{CM}-0.465>0$ is proton-going



- Inner Detector $|\eta|<2.5$
- EMCal+HCal system $|\eta|<4.9$
- Pb-going Forward Calorimeter $-4.9<\eta<-3.2$

Data

- Multiplicity analysis:
  - 2012 p+Pb pilot run is used for the measurements: Integrated Luminosity: 1 μb^{-1}



- Z-boson production analysis:
  - 29.1 ± 1.0 nb^{-1} for Z➔ee
  - 27.8 ± 0.9 nb^{-1} for Z➔μμ

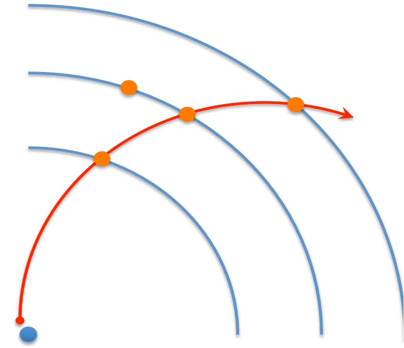
- Dijet analysis:
  - pp at 2.76 TeV collisions (2013) with integrated luminosity of 4 pb^{-1}

- Centrality:
  - Pb-going Fcal is used to characterize event centrality
  - Gribov extension is evaluated for the centrality estimations

Centrality and Multiplicity in p+Pb

Multiplicity reconstruction methods

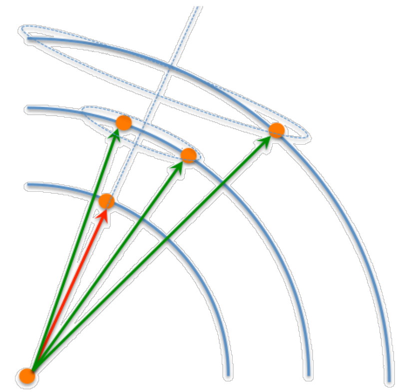
[arXiv:1508.00848]



Pixel tracks:

- $|\eta|<2.5$
- provide p_T of the particle
- used to reweight HIJING -> Data

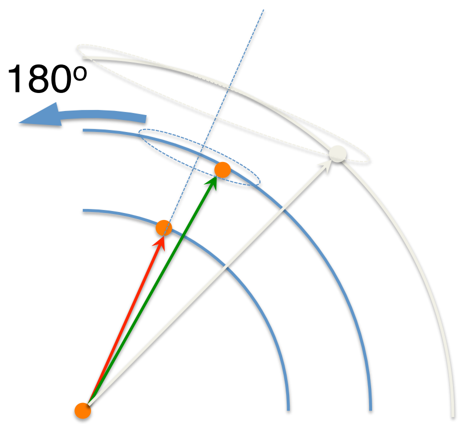
Pixel track method is used primarily as a consistency test



$$|\Delta\eta| < 0.015, \quad |\Delta\varphi| < 0.1, \quad |\Delta\eta| < |\Delta\varphi|$$

Method 1: tracklet = Vertex + 2 hits/clusters (3 layers)

- is chosen as the default result for $dN_{ch}/d\eta$

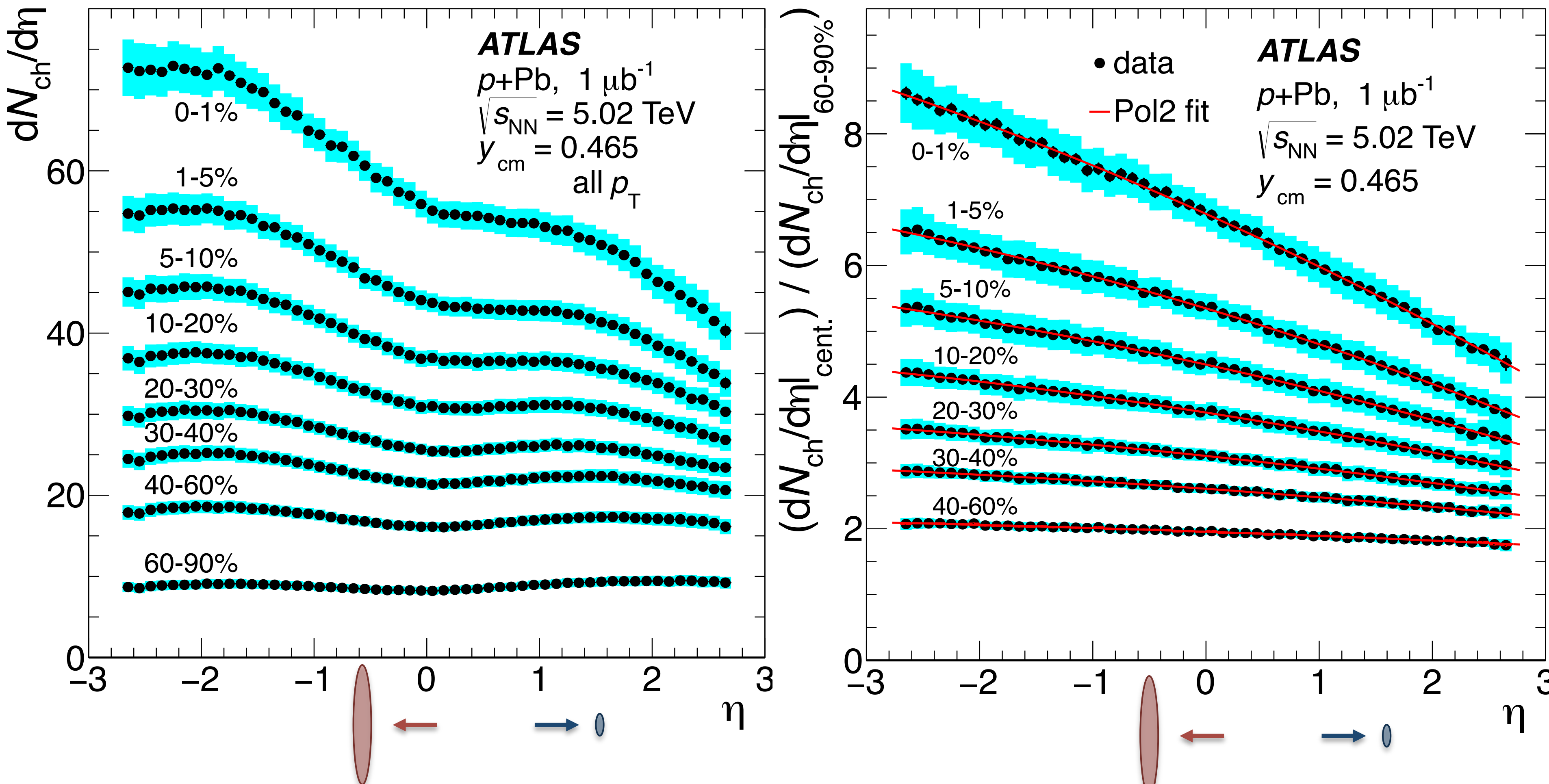


Method 2: tracklet = Vertex + 2 hits/clusters (2 layers)

- is used for systematic uncertainties

dN/dη for different centralities

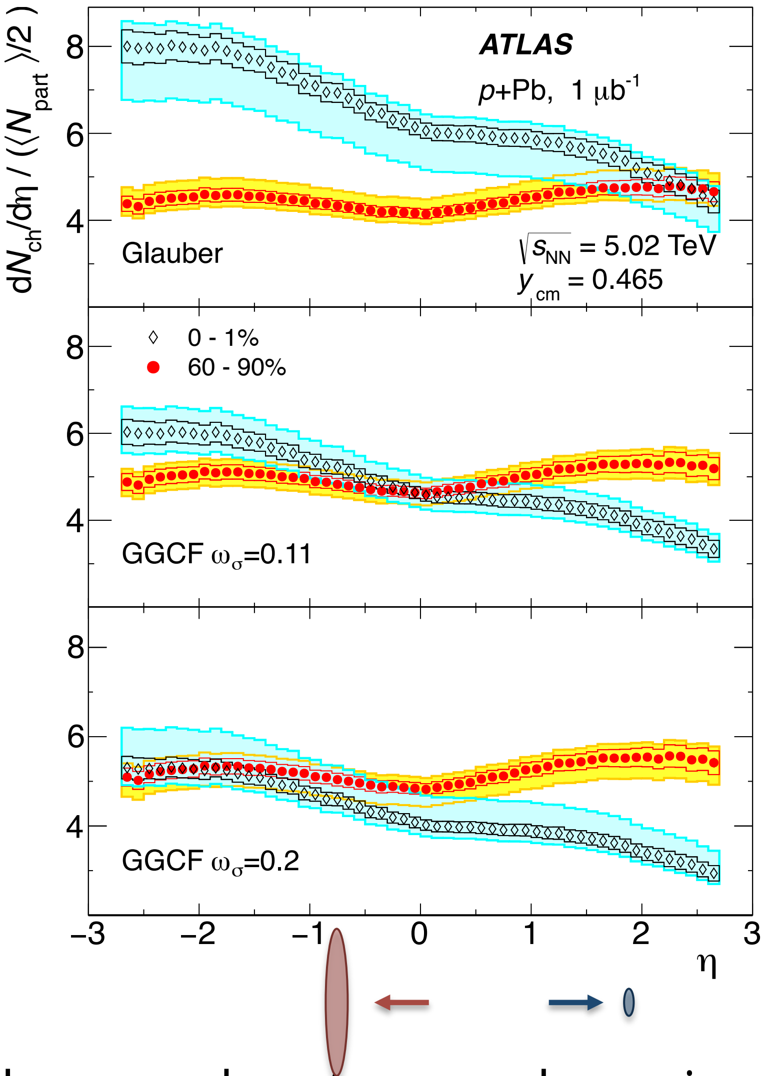
[arXiv:1508.00848]



- $dN_{ch}/d\eta$ is measured for $|\eta| < 2.7$ in eight centrality intervals
- Forward backward asymmetry between p and Pb going directions grows with centrality

dN/dη per pair of participants

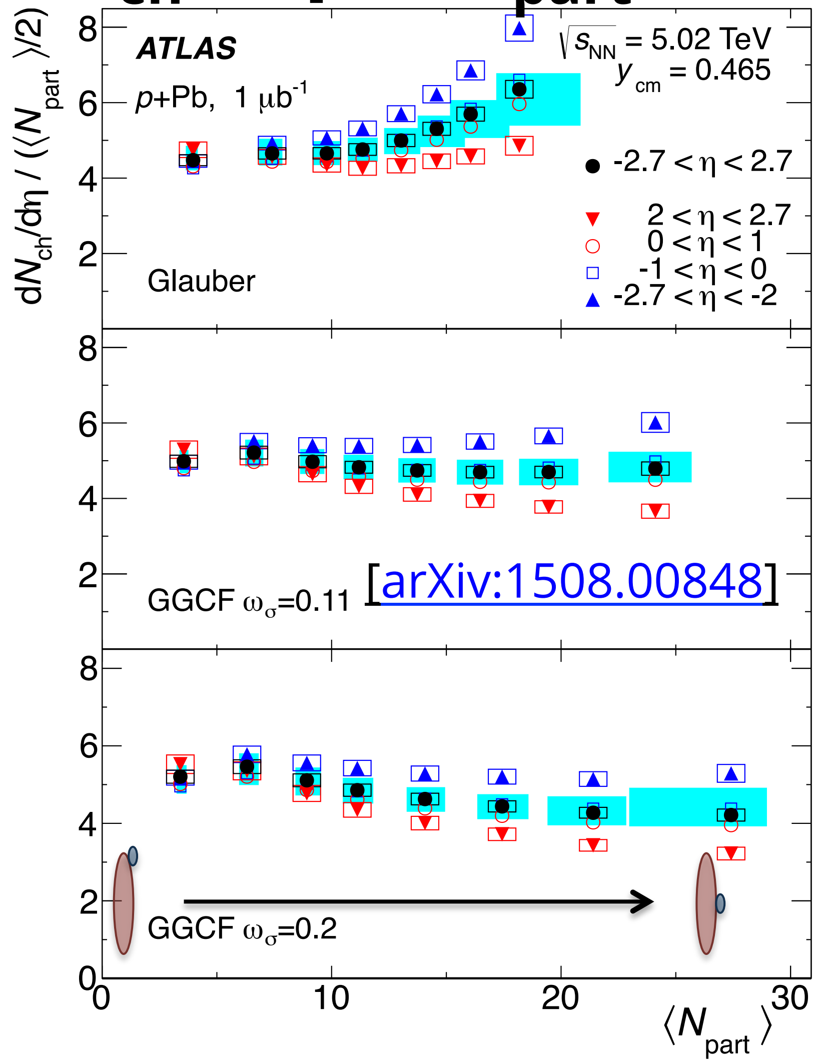
[arXiv:1508.00848]

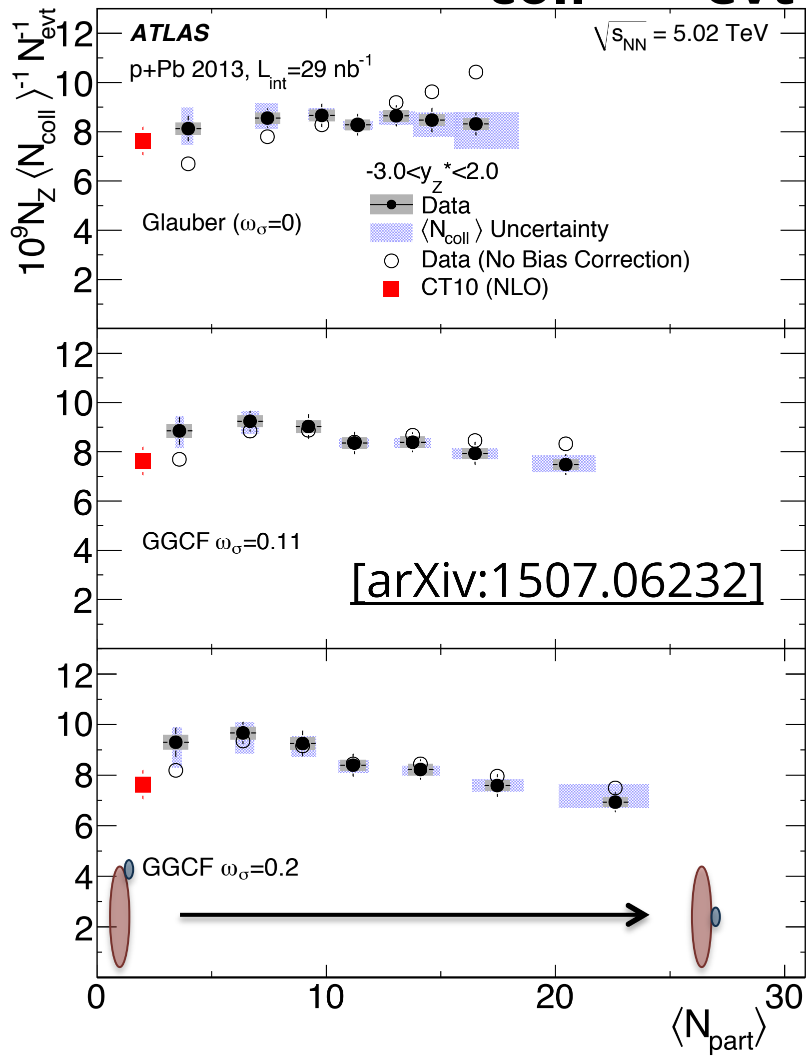


- To further investigate $dN_{ch}/d\eta$ scaling with N_{part} Z-bosons can be used

- Standard Glauber, used up to now shows increase with $\langle N_{part} \rangle$
- GGCF with ω_σ=0.11 is almost flat with ω_σ=0.2 even decreases

$dN_{ch}/d\eta/(<N_{part}>/2)$ & $10^9 N^Z/(<N_{coll}>N_{evt})$

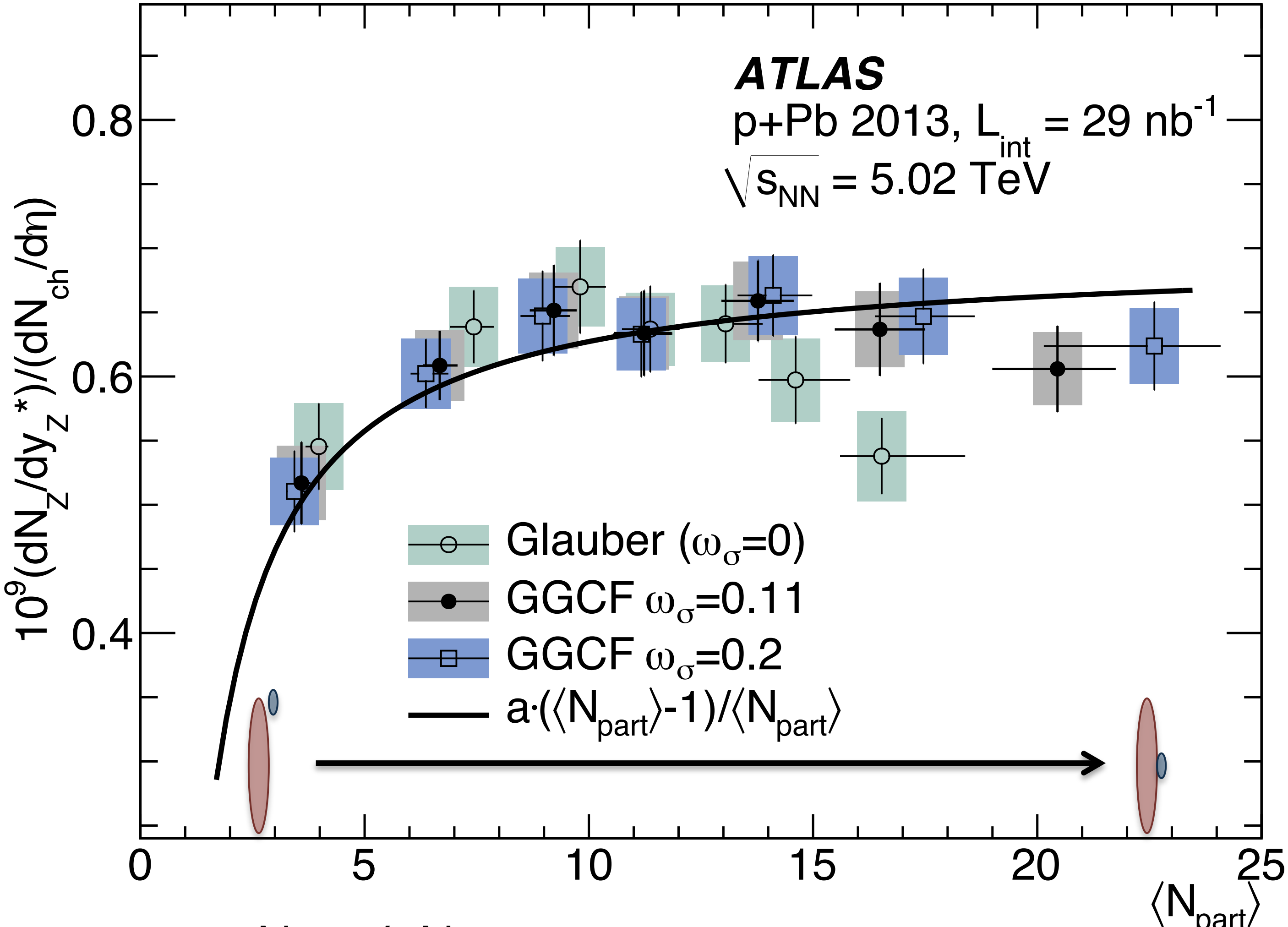




- Similar shape of charged multiplicity and Z-yield
- Agreement in the geometric scaling ➔ reflecting initial state conditions of the nucleus

Z-production

[arXiv:1507.06232]



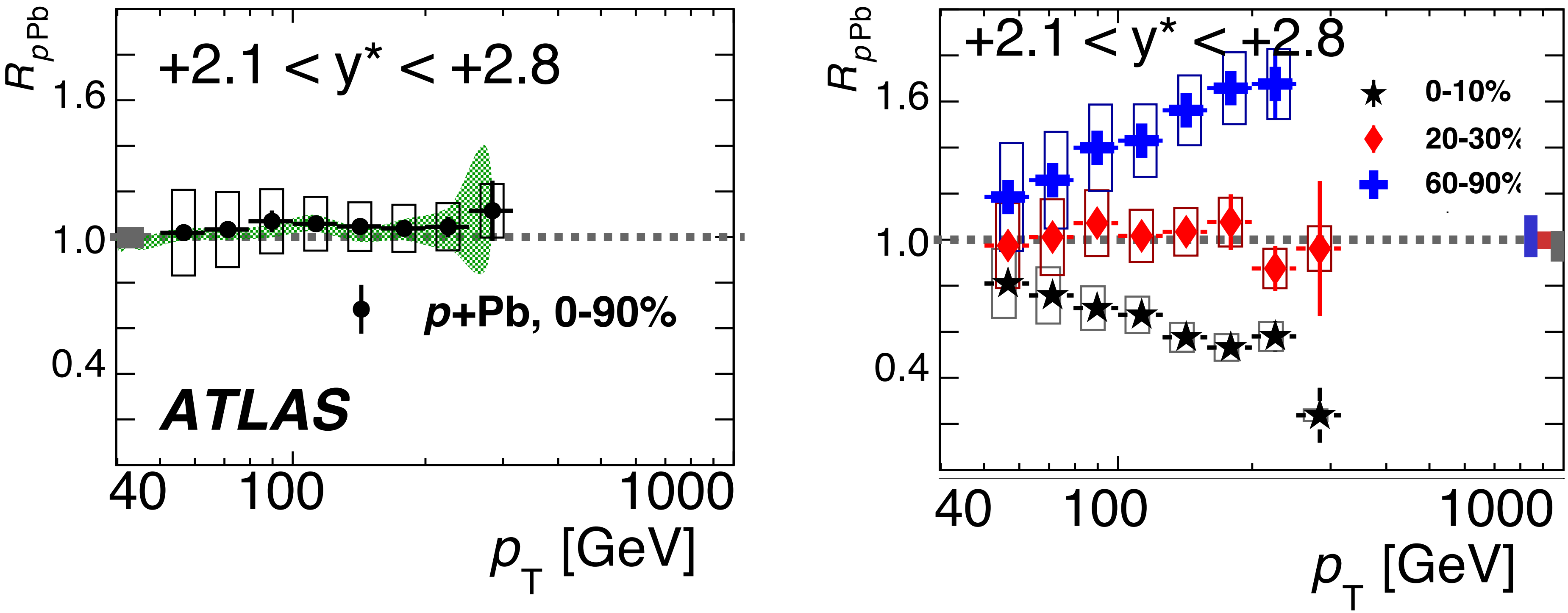
- Fit represents $<N_{coll}>/<N_{part}>$
- Agreement in the geometric scaling

➔ reflecting initial state conditions of the nucleus

Centrality and Jets in p+Pb:
switching to even higher p_T

Jet R_{pPb}

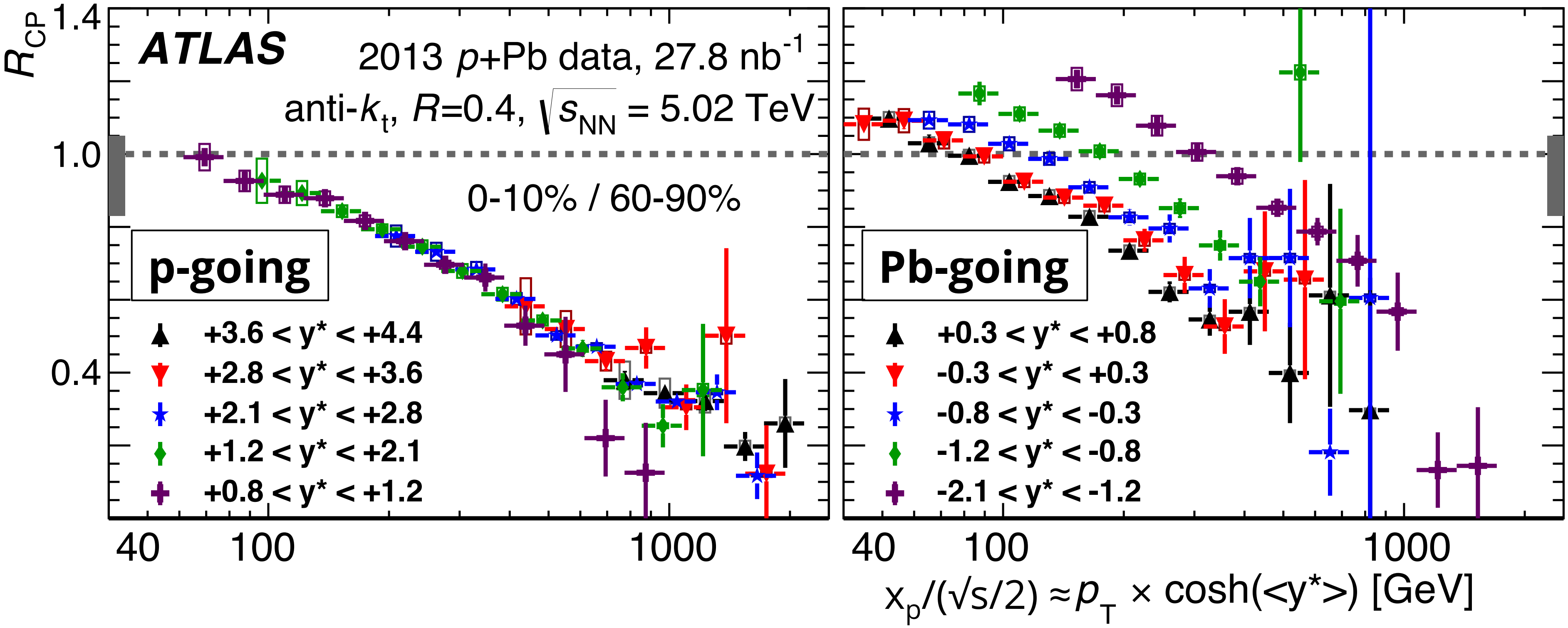
arXiv:1412.4092



- While the R_{pPb} is consistent with unity when evaluated inclusively in centrality, it is not unity when evaluated differentially in centrality

Jet R_{CP}

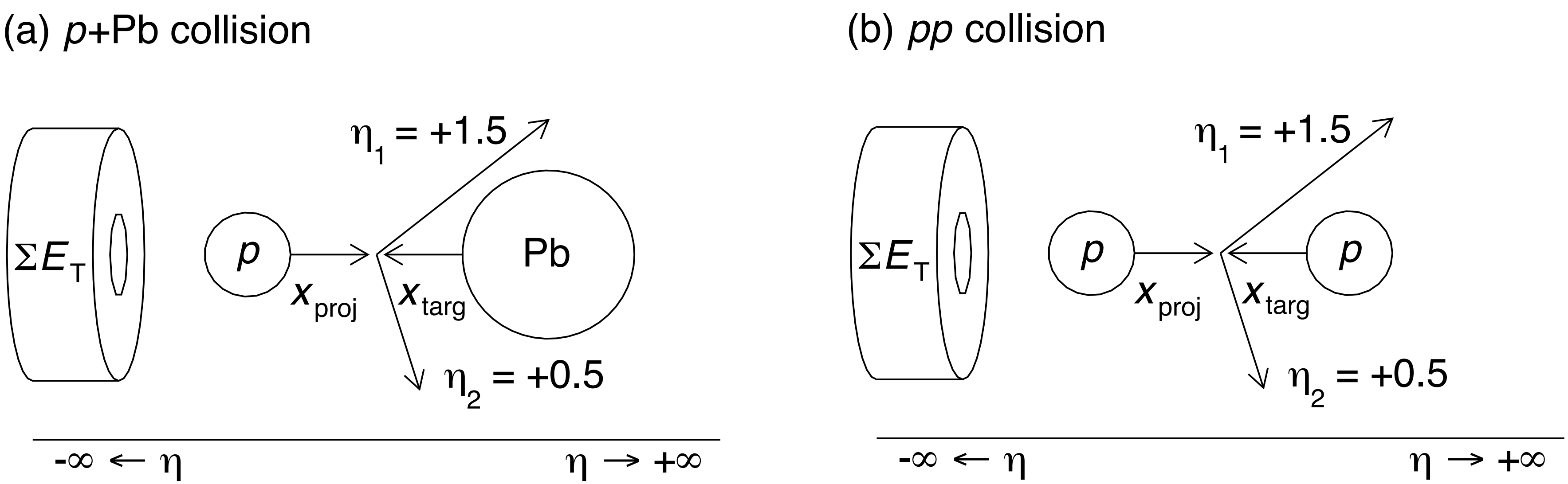
arXiv:1412.4092



- R_{CP}/R_{pPb} scales with the total momentum of a jet for jets in the positive forward region suggesting a dependence on x of parton in proton.
- How much of the centrality dependence (= dependence on ΣE_T in the negative forward region) comes from the dependence of ΣE_T on x in proton for individual NN collision?

pp and p+Pb

- **What is measured**: correlation between the dijet kinematics and the magnitude of the UE in the forward region **in p+p collisions**
- **Motivation**: modeling of particle production, reference measurement to **better understand the centrality in p+Pb**



Main measurement:

$\langle \Sigma E_T \rangle$ vs p_T^{avg}, η^{dijet}, x_{targ}, x_{proj}

Dijet kinematic variables

- ΣE_T corrected to full hadronic scale using a dedicated calibration procedure using PYTHIA8, which accounts for a small offset stemming primarily from out-of-time pileup

- Jets are reconstructed using anti-kt algorithm with R=0.4:
  - **p_{T1}>50 GeV, p_{T2}>20 GeV, p^{avg}_T >50 GeV**
  - **η_1 < 3.2** to match acceptance of jet trigger
  - **η_1, η_2 > -2.8** to avoid overlap with the FCal

- The kinematic variables:
  - average quantities for dijet measurements:

$$p_T^{\text{avg}} = (p_{T,1} + p_{T,2})/2 \qquad \eta^{\text{dijet}} = (\eta_1 + \eta_2)/2$$

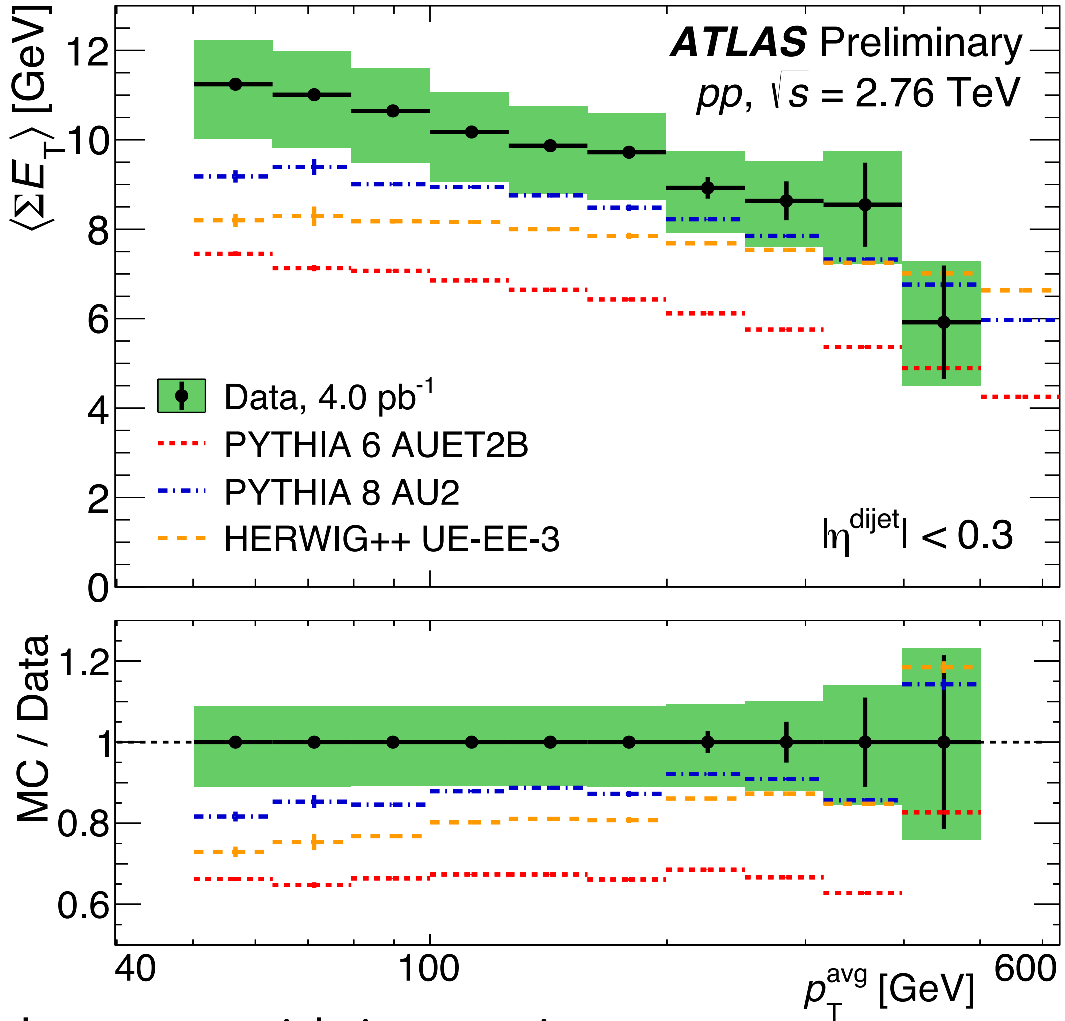
  - Bjorken x_{proj} and x_{targ} with the proton defined as the projectile:

$$x_{\text{proj}} = p_T^{\text{avg}}(e^{+\eta_1} + e^{+\eta_2})/\sqrt{s}$$

$$x_{\text{targ}} = p_T^{\text{avg}}(e^{-\eta_1} + e^{-\eta_2})/\sqrt{s}$$

Energy production

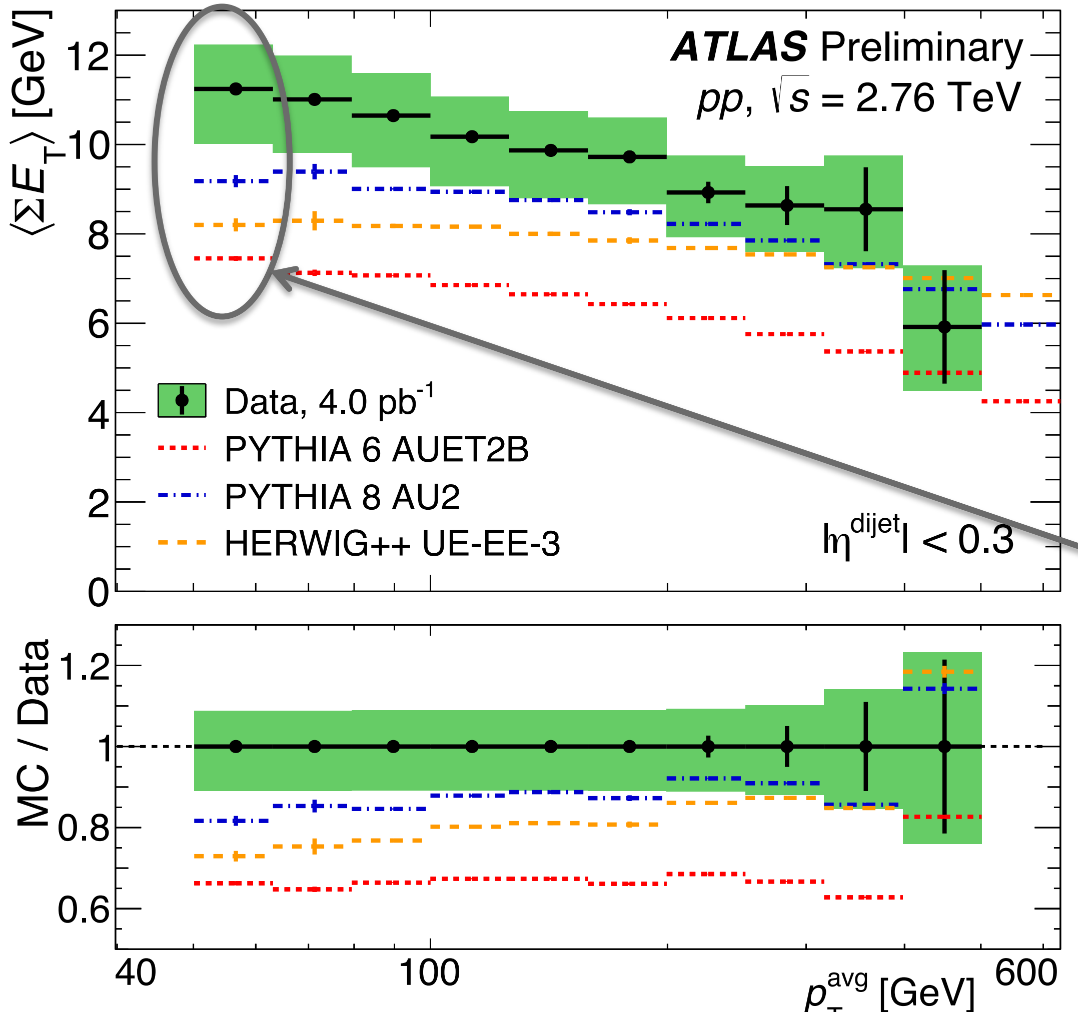
ATLAS-CONF-2015-019



- Steady decrease with increasing p_T^{avg}
- Generators have similar antycorrelation, but vary in overall magnitude

Energy production

ATLAS-CONF-2015-019

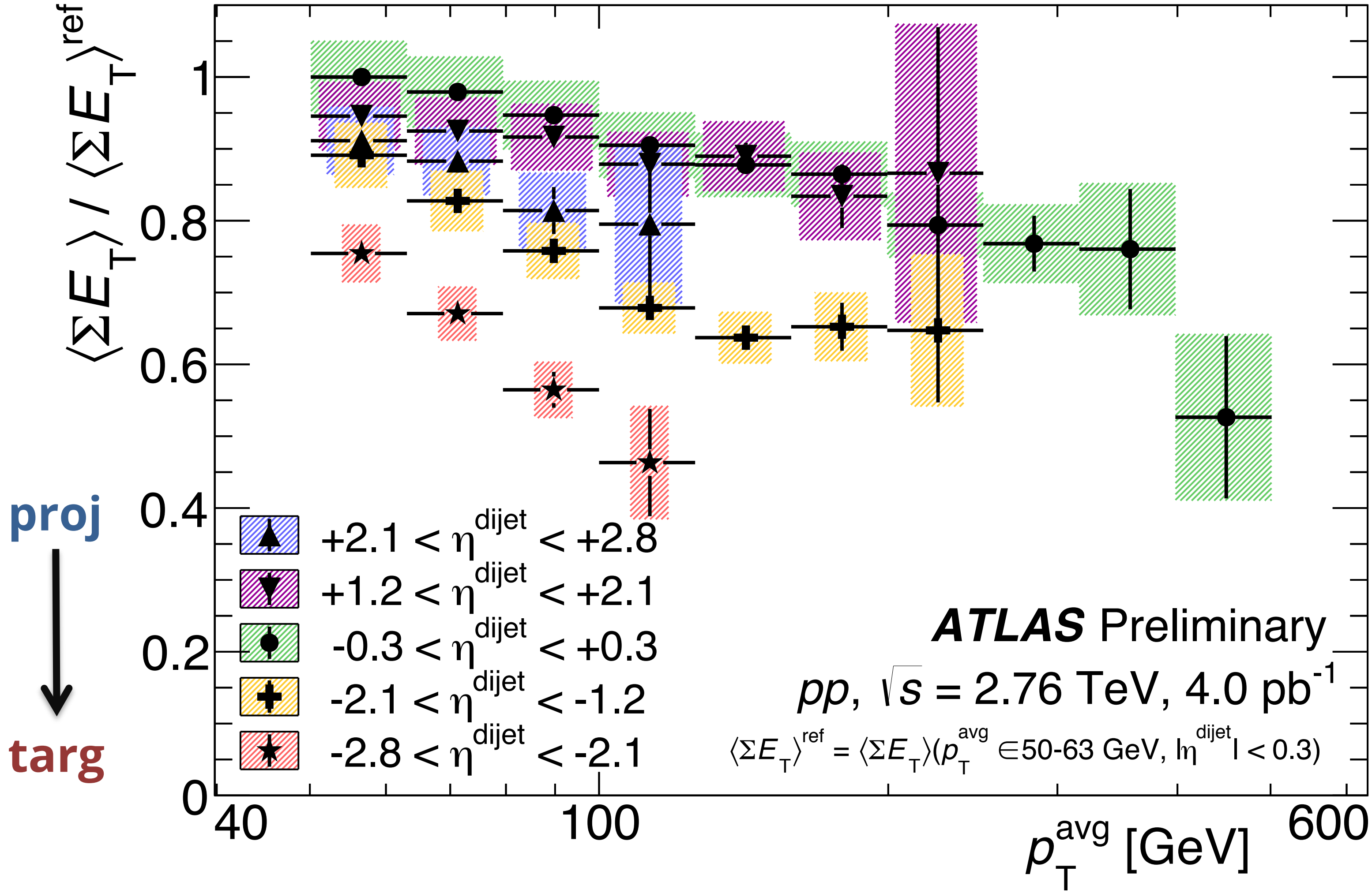


To better show dependence on the kinematics - $\langle \Sigma E_T \rangle^{ref}$ is used for scaling

- Steady decrease with increasing p_T^{avg}
- Generators have similar antycorrelation, but vary in overall magnitude

η^{dijet} dependence

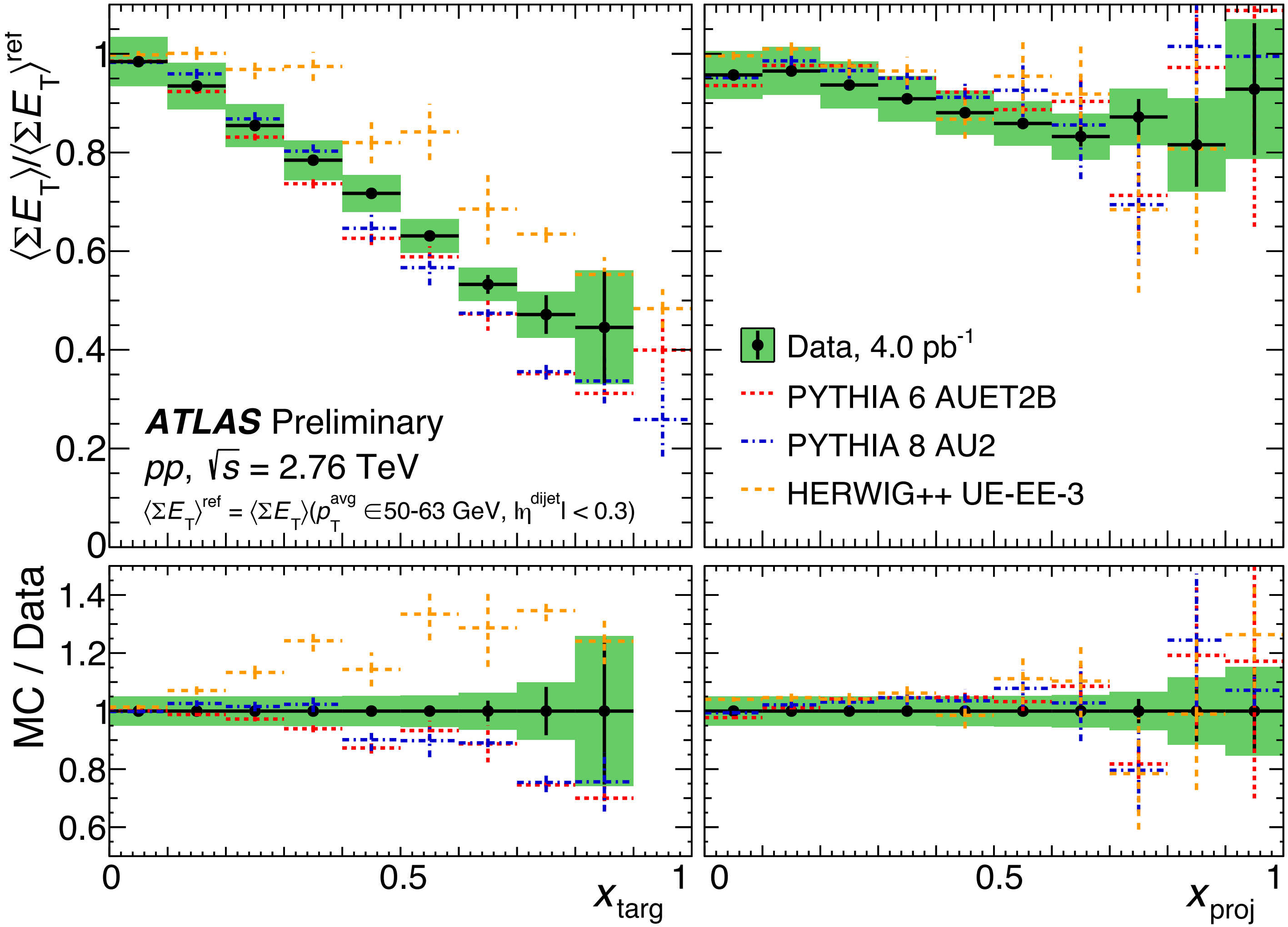
ATLAS-CONF-2015-019



- Anti-correlation is stronger when η^{dijet} approaches the ΣE_T measuring region
- This can be evaluated as a function of x_{targ} and x_{proj} (~ Bjorken x)

x_{proj} and x_{targ}

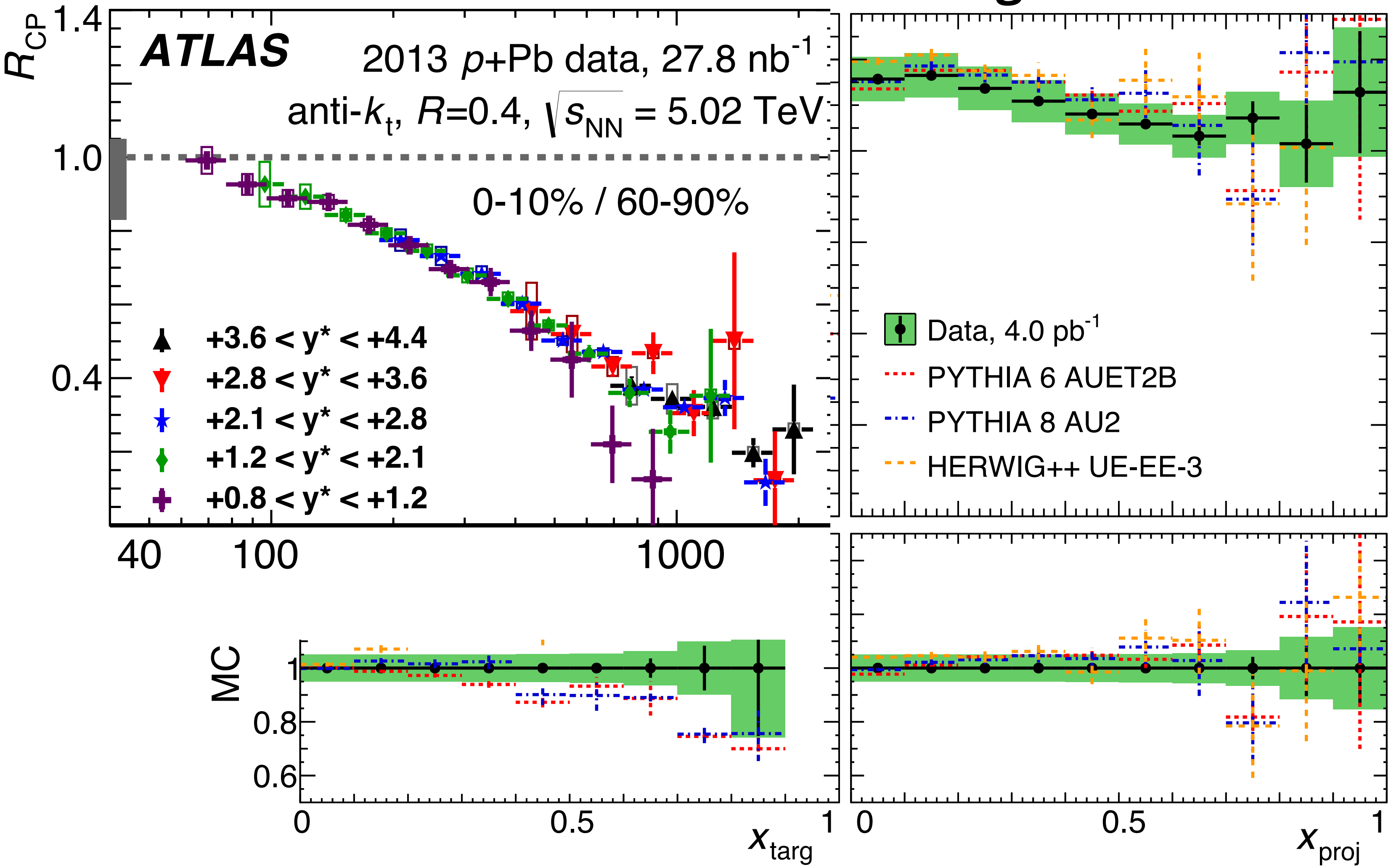
ATLAS-CONF-2015-019



- Small (10%) drop in ΣE_T ratio with x_{proj}
- Over a factor of two drop in ΣE_T ratio with x_{targ}
- Generators show qualitatively similar behavior

x_{proj} and x_{targ}

ATLAS-CONF-2015-019



- In pp collisions, <ΣE$_T$> falls with x_{targ}, mostly insensitive to x_{proj}
- Effects seen in p+Pb jets are not due to trivial anti-correlation in individual nucleon-nucleon collisions (e.g. “energy conservation”)

Conclusion

- ATLAS measurements of the centrality dependence of the charged particle pseudorapidity distribution, $dN_{ch}/d\eta$ shows:
  - Significant asymmetry in the rapidity
  - Centrality dependence of $dN_{ch}/d\eta/(\langle Npart \rangle/2)$ is sensitive to the model used for cenrality determination
  - Comparison to Z-bosons show intriguing similarities between p+Pb observables, and very good consistency with N_{part} and N_{coll} scaling

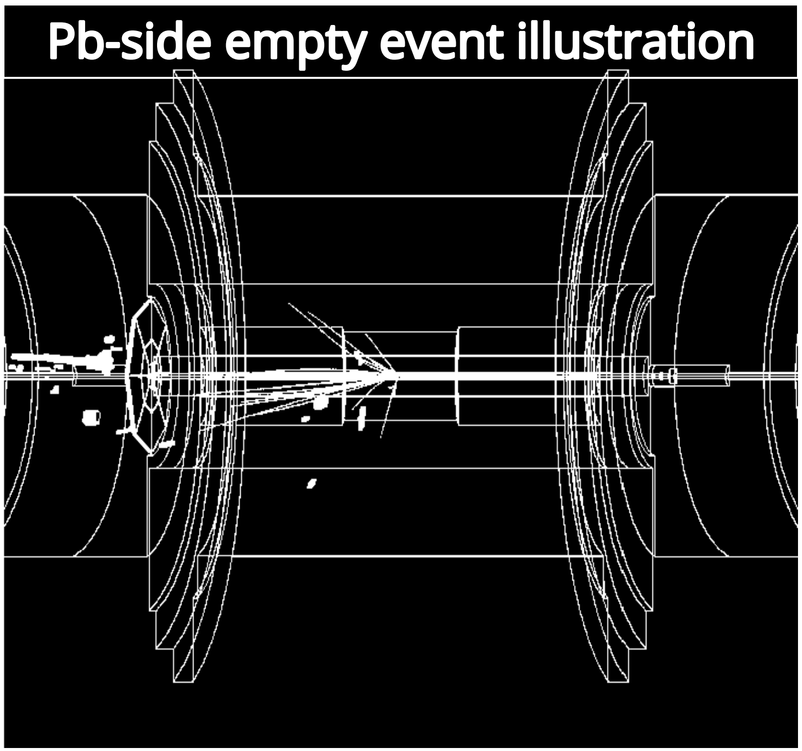
- Presented a measurement of correlation of the underlying event in the backwards region with hard scattering kinematic variables :
  - $\langle \Sigma E_T \rangle$ is strongly correlated with x_{targ}, but only weakly with x_{proj}
  - The results indicate that the p+Pb jet effect is not a trivial energy conservation

Thank You!

Back Up Slides

Removal of events with large η gaps

- pPb interactions produce an additional coherent and photo-nuclear component of events consistent with the excitation of the proton



- Full coverage $|\eta| < 4.9$ divided into $\Delta\eta = 0.2$ intervals
- Occupied interval , contains reconstructed tracks or calorimeter clusters with p_T **>** 200 MeV
- $\Delta\eta^{Pb}_{gap} = \Sigma\Delta\eta^{Pb}_{\text{Empty interval}}$
- Electromagnetic or diffractive excitation of the proton typically produce $\Delta\eta^{Pb}_{gap}>2$ (f_{gap} **=** 6%)

Glauber and Glauber-Gribov models

To model Npart distribution we used:

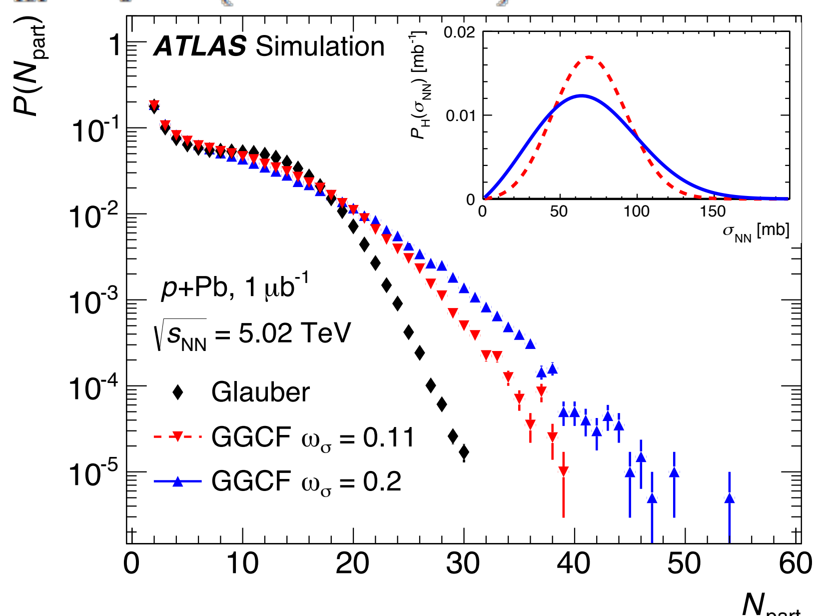
- standard Glauber with σ_{NN} cross section = 70±5mb
- Glauber-Gribov color fluctuation models, with $<\sigma_{NN}>$ cross section = 70±5mb

In Glauber-Gribov model:

- σ_{tot} is considered frozen for each event
- parameter Ω controls the amount of fluctuations
- Ω is extracted from experimental data: 0.55 [PLB633 (2006) 245–252] and 1.01 [PLB 722 (2013) 347–354]

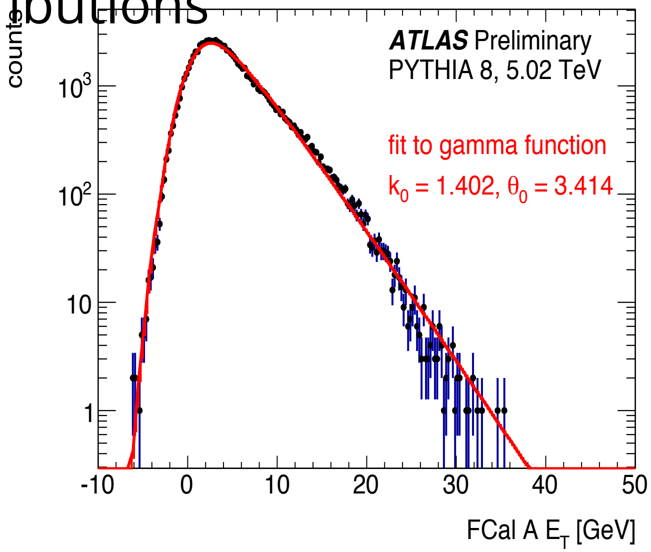
$$P_h(\sigma_{tot}) = \rho \frac{\sigma_{tot}}{\sigma_{tot} + \sigma_0} \exp\left\{-\frac{(\sigma_{tot}/\sigma_0 - 1)^2}{\Omega^2}\right\}.$$

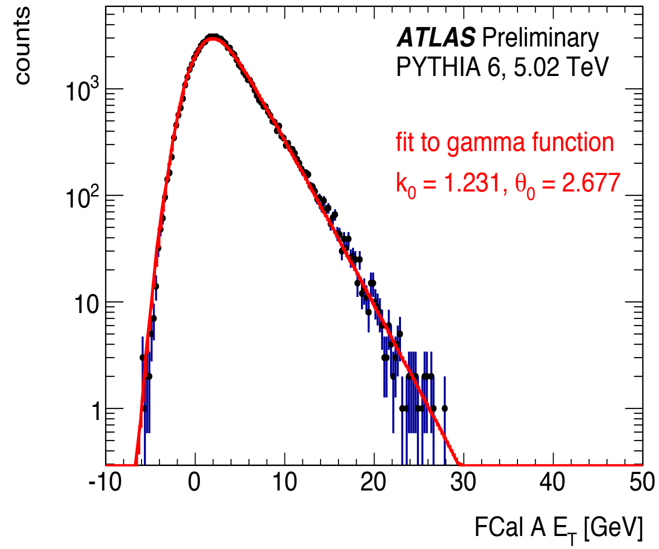
$$P_H(\sigma_{NN}) = \frac{1}{\lambda} P(\sigma_{NN}/\lambda)$$



Constructing FCal ΣE_T^{Pb} response

E_T distribution modeled by PYTHIA simulated taking into account FCal response in p+Pb configuration and were approximated by Gamma(k,θ) distributions





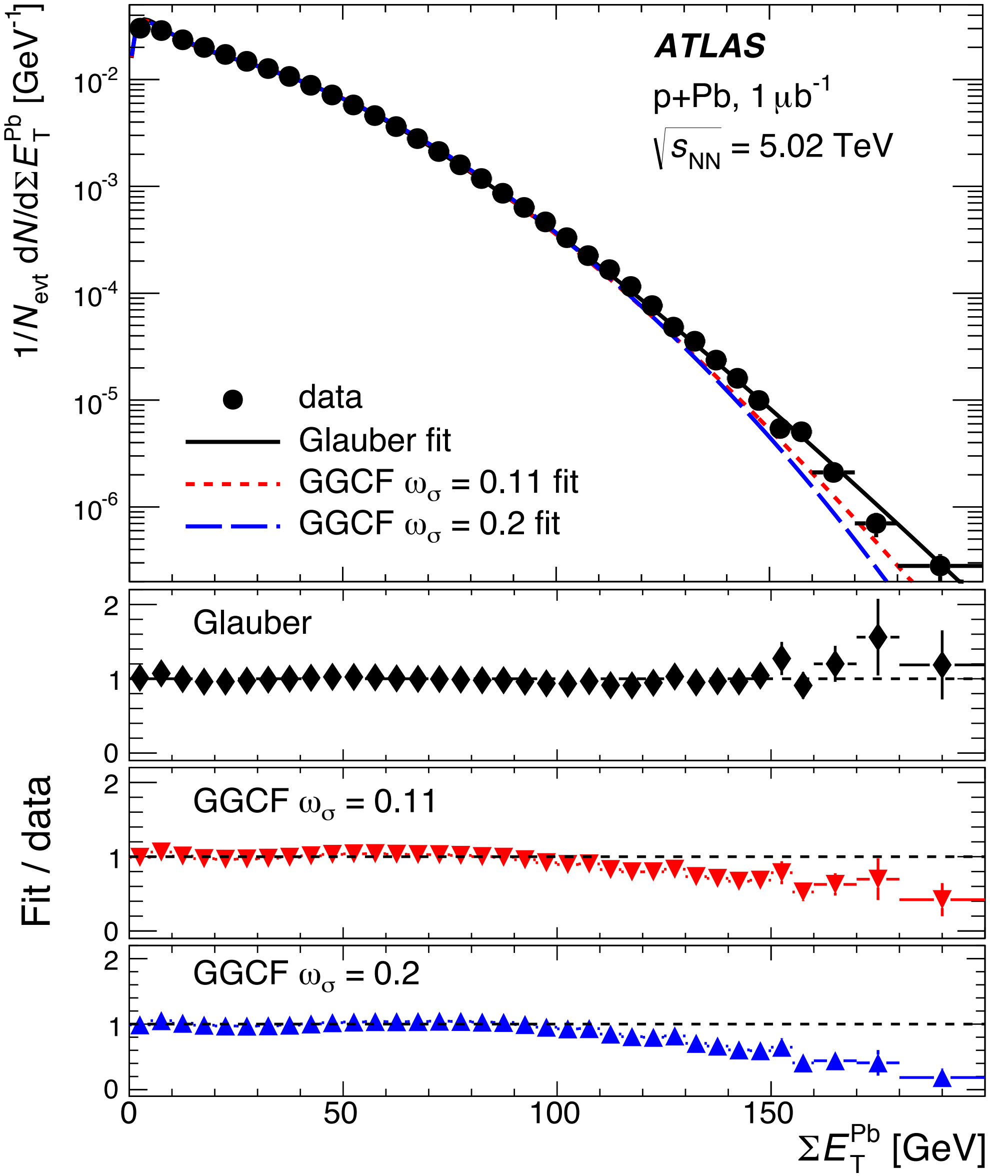
Convolution of N_{part} Gamma(k,θ) was taken as Gamma($k(N_{part})$,$\theta(N_{part})$)

We allowed: $k(N_{part}) = k_0+k_1*(N_{part}-2)$; $\theta(N_{part}) = \theta_0+\theta_1*(\log(N_{part}-1))$;

In WN : $k(N_{part}) = k*N_{part}$; $\theta(N_{part}) = \theta$;

E_T response for N_{part} was weigthed according to Glauber or Glauber-Gribov model and fitted to the data

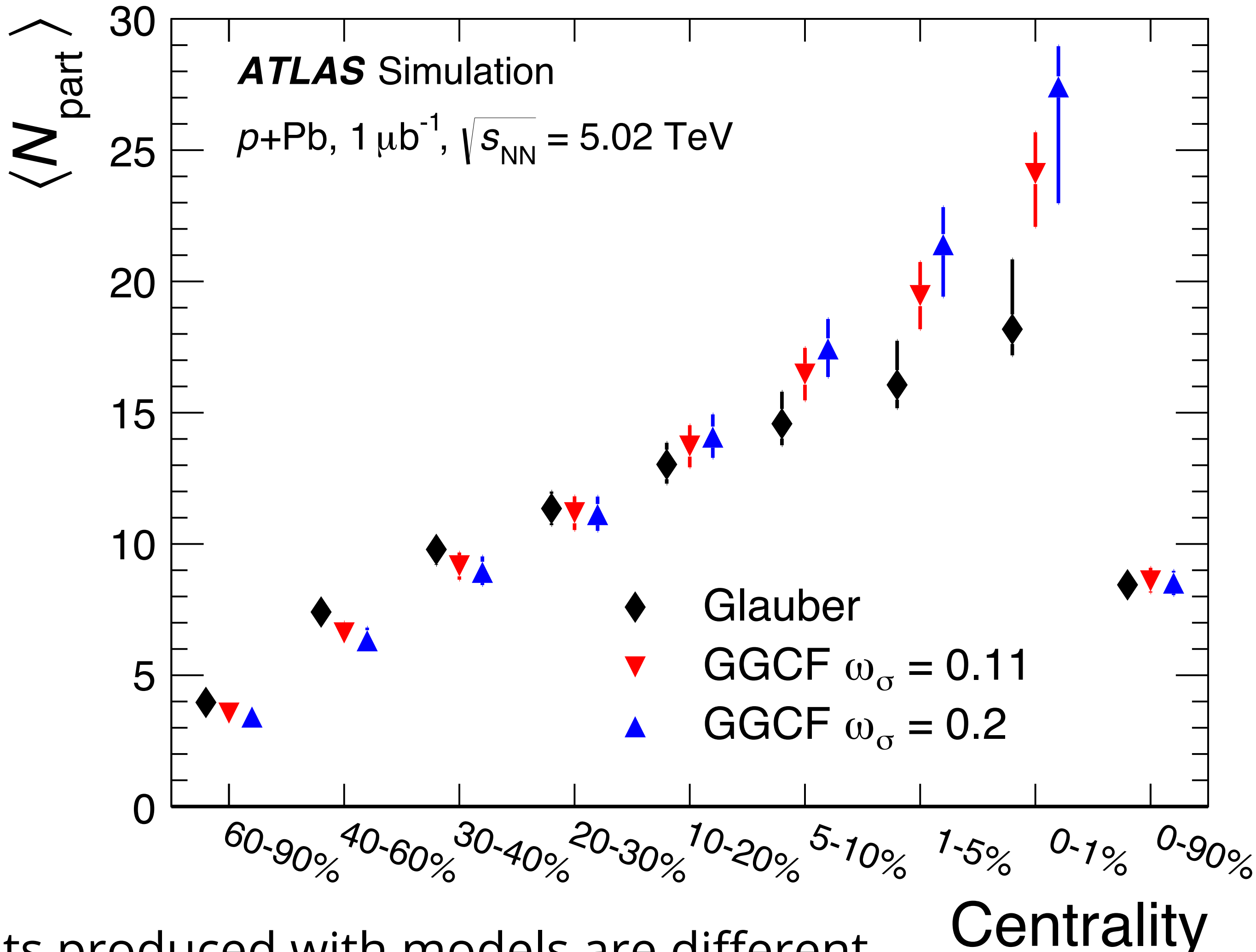
FCal E_T distribution fits



- dN_{evt}/dE_T obtained by summing the gamma distributions over different N_{part} values weighted by $P(N_{part})$

Fits to the measured E^{Pb}_T distributions show reasonable agreement over 3 orders of magnitude in E_T distribution.

N_{part} for different Glauber models

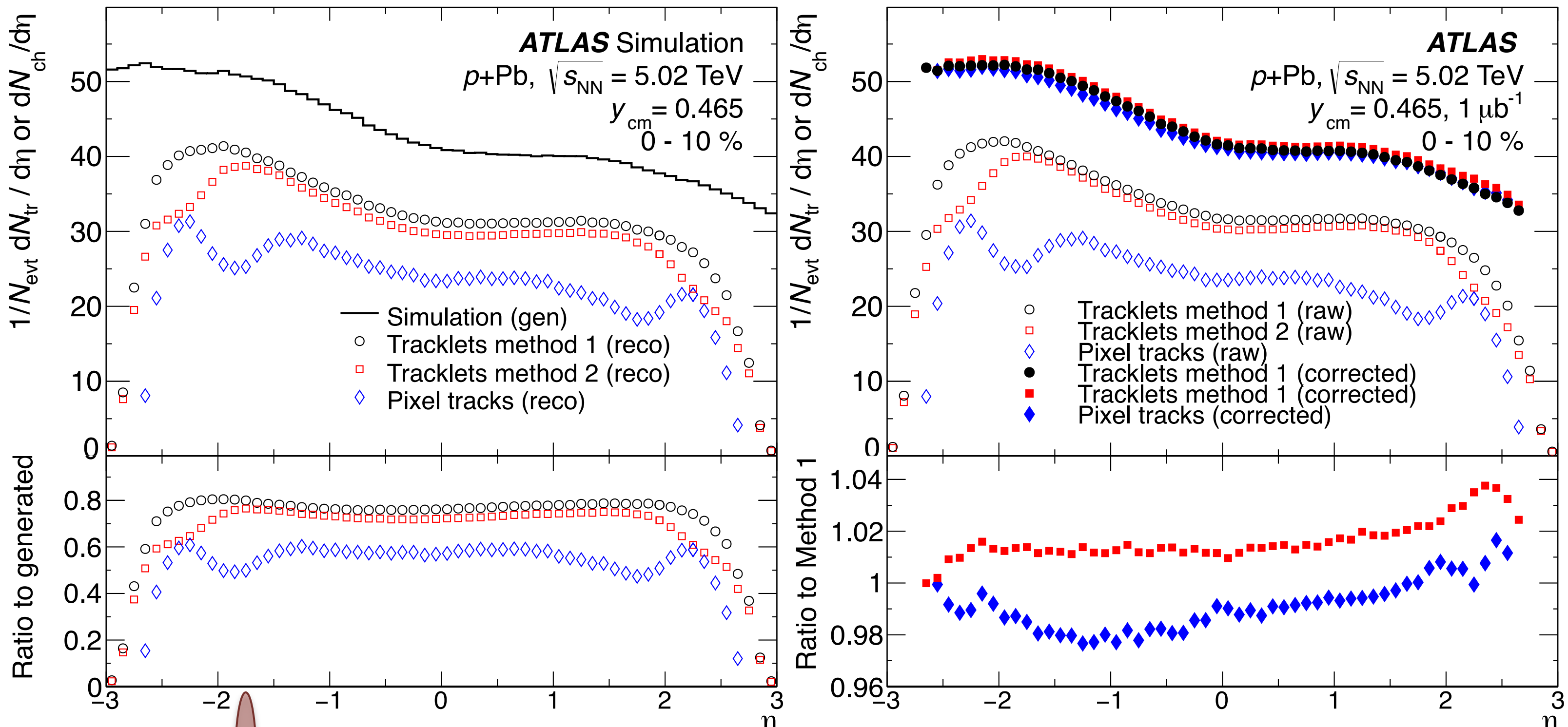


- Results produced with models are different
- Standard Glauber has highest fluctuations of produced E_T per participant
- Glauber-Gribov Ω=1.01 has less E_T fluctuation and therefore gives highest N_{part}

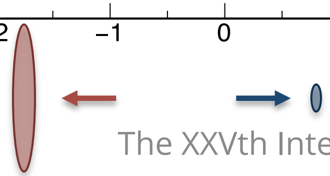
Multiplicity reconstruction methods

- Method 1 is chosen as the default result for $dN_{ch}/d\eta$
- Method 2 is used for systematic uncertainties
- Pixel track method is used primarily as a consistency test
- The correction factor is evaluated as a function of occupancy (O), event vertex (z_{vtx}), and η as:

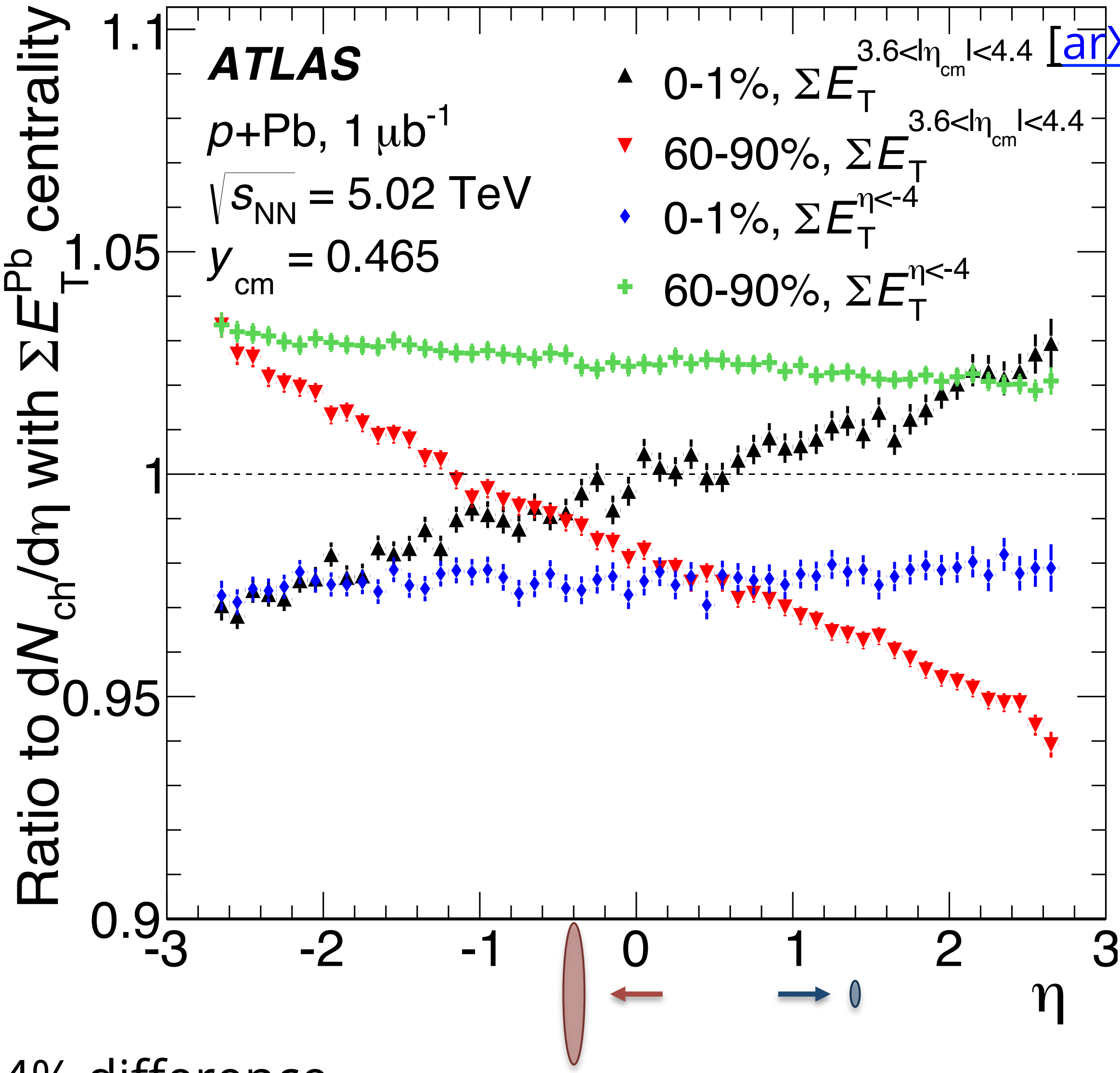
$$C(\mathcal{O}, z_{\text{vtx}}, \eta) \equiv \frac{N_{\text{pr}}(\mathcal{O}, z_{\text{vtx}}, \eta)}{N_{\text{rec}}(\mathcal{O}, z_{\text{vtx}}, \eta)} \qquad \frac{dN_{\text{ch}}}{d\eta} = \frac{1}{\Delta\eta} \frac{\sum \Delta N_{\text{tr}}(\mathcal{O}, z_{\text{vtx}}, \eta) C(\mathcal{O}, z_{\text{vtx}}, \eta)}{\sum N_{\text{evt}}(z_{\text{vtx}})}$$



CERN-PH-EP-2015-160 [arXiv:1508.00848]



$dN_{ch}/d\eta$ vs alternate centrality



[arXiv:1508.00848]

- Only up to 4% difference

Z-candidates

[arXiv:1507.06232]

- Electrons
  - Trigger e: E_T >20 GeV, |η|<2.47
  - Second e: E_T >10 GeV, |η|<2.47
  - Forward e: E_T >20 GeV, 2.5<|η|<4.9

Select candidates with:

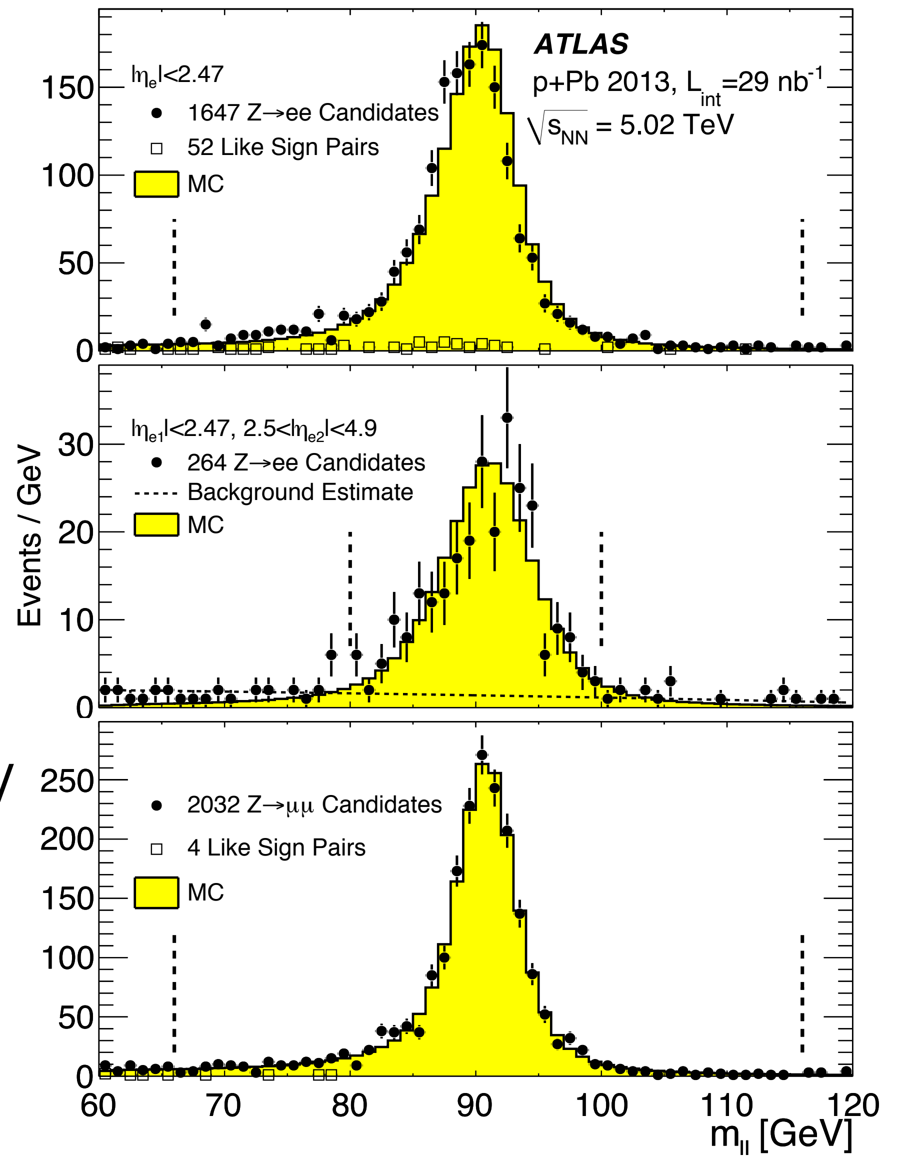
a) $66<m_{ee}<116$ GeV

b) $80<m_{ee}<100$ GeV

- Muons
  - Trigger μ: p_T > 20 GeV, |η|<2.4
  - Second μ: p_T > 10 GeV, |η|<2.47

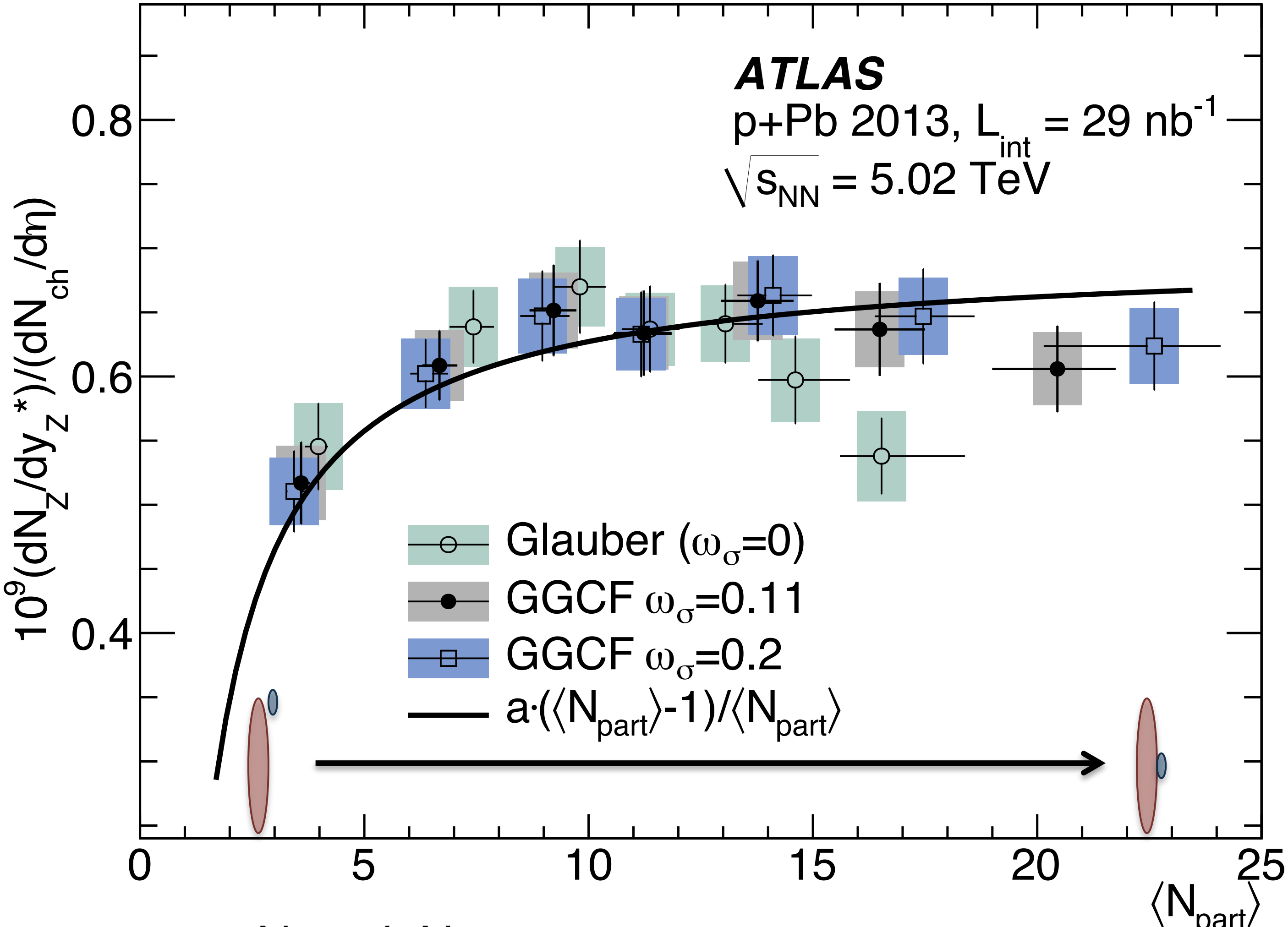
Select candidates with $66<m_{\mu\mu}<116$ GeV

- To further investigate $dN_{ch}/d\eta$ scaling with N_{part} Z-bosons can be used



Z-production

CERN-PH-EP-2015-146 [arXiv:1507.06232]

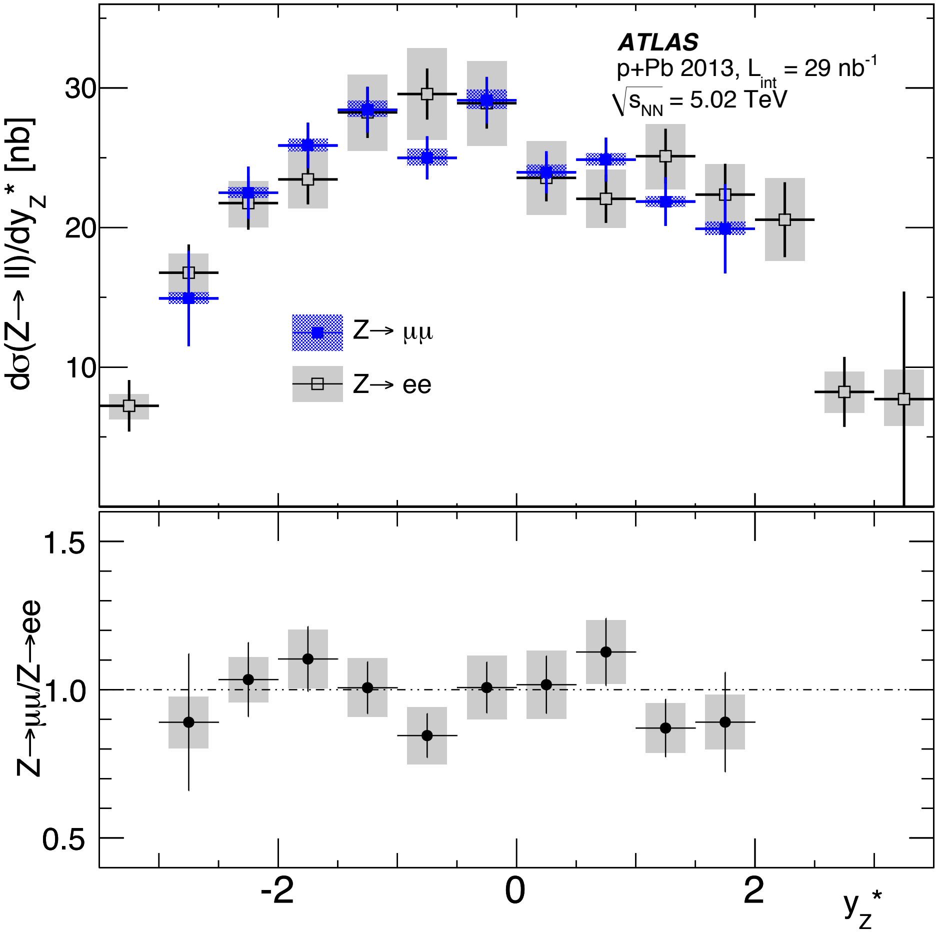


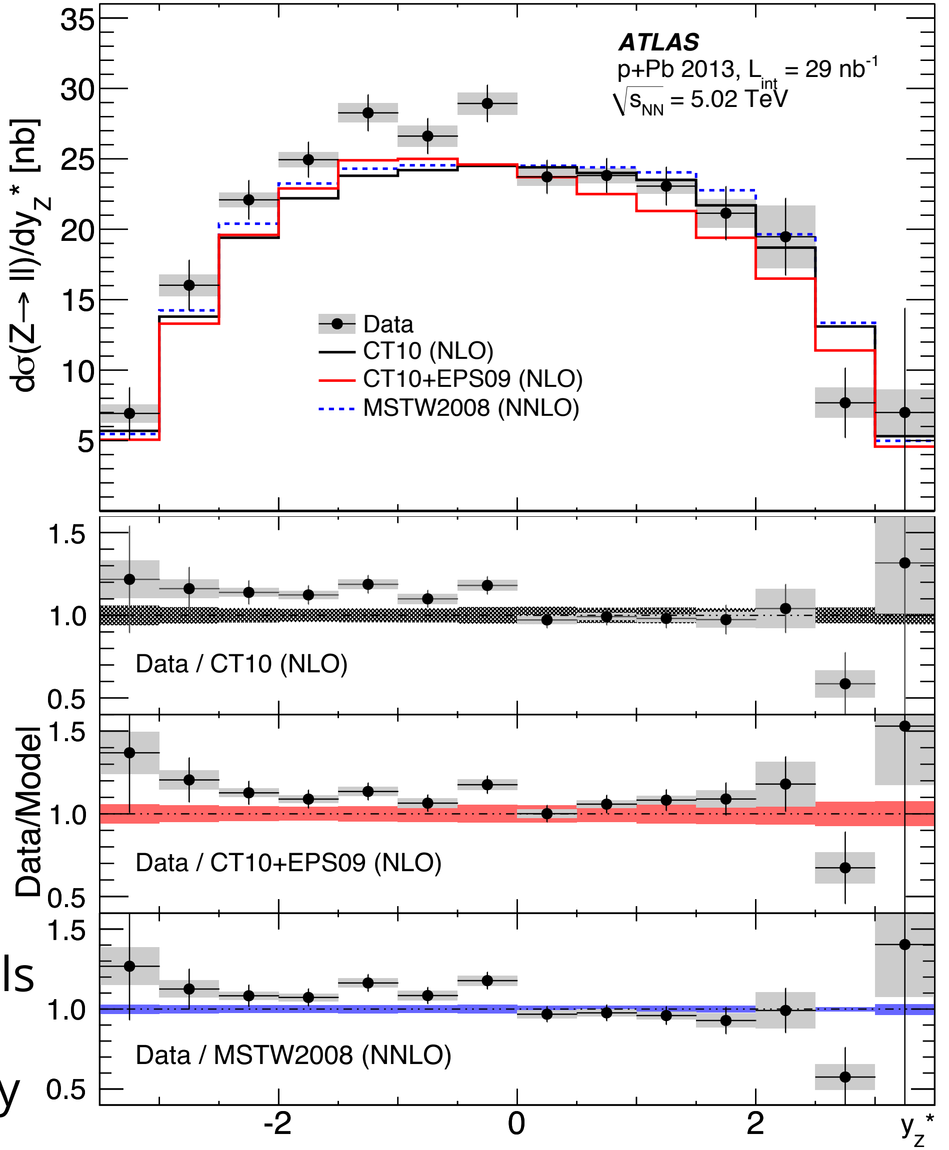
- Fit represents <N_{coll}>/<N_{part}>
- Agreement in the geometric scaling

➔ reflecting initial state conditions of the nucleus

Rapidity Differential Cross-Section

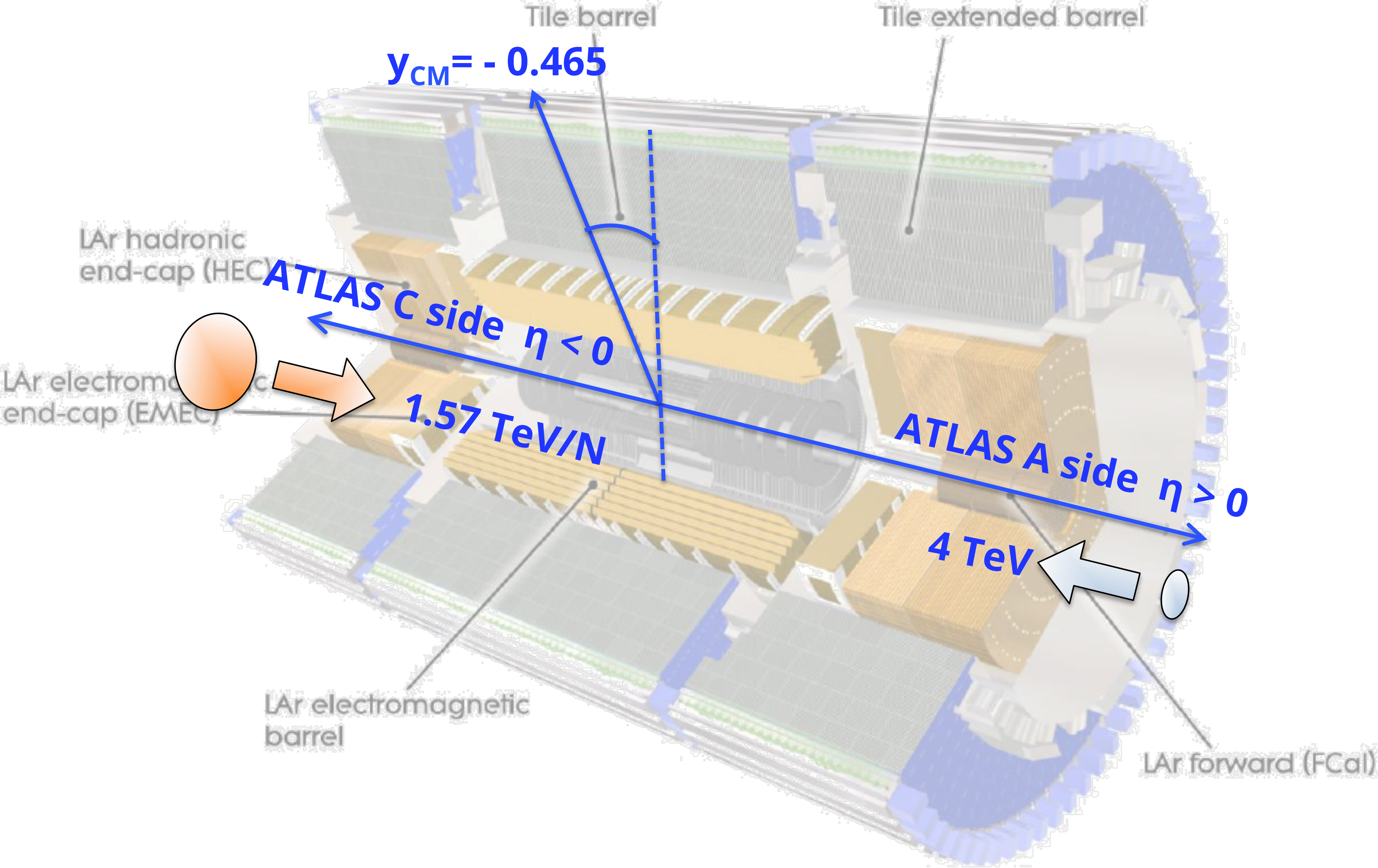
CERN-PH-EP-2015-146 [arXiv:1507.06232]



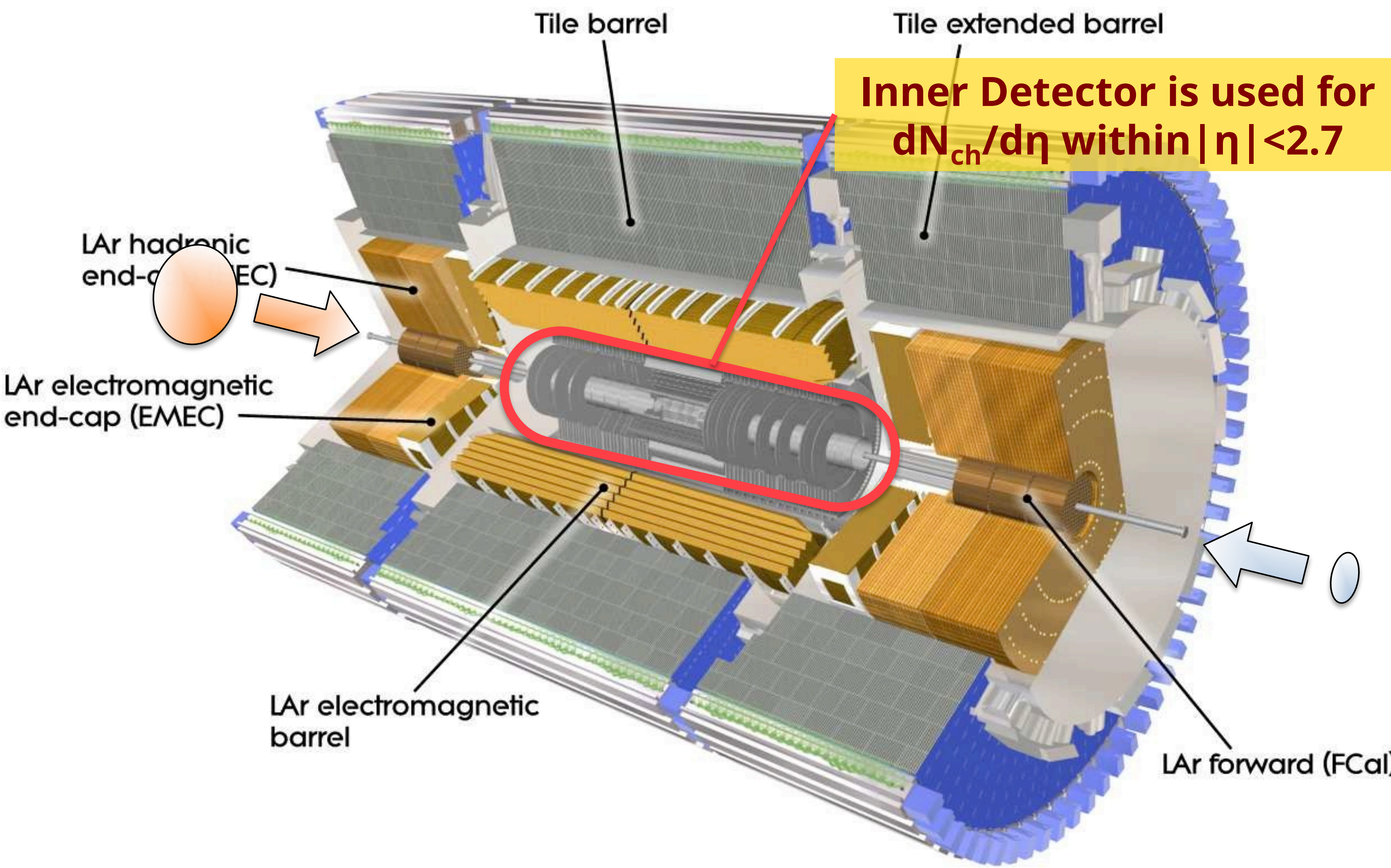


- Excellent agreement between channels
- y_Z* asymmetry observed in the data
- Significant excess at backward rapidity

p+Pb @ LHC and ATLAS



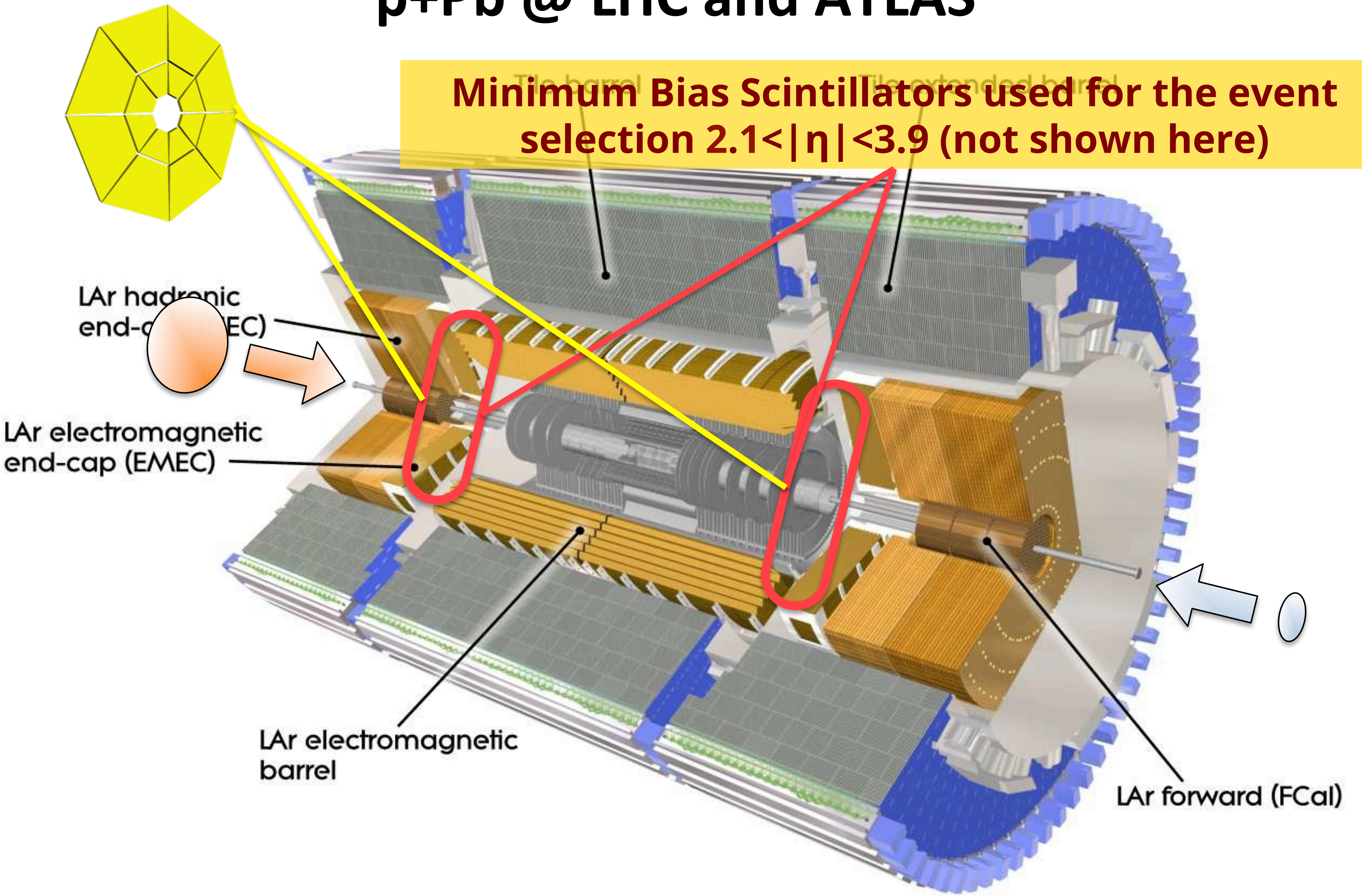
p+Pb @ LHC and ATLAS



Inner Detector is used for $dN_{ch}/d\eta$ within $|\eta|<2.7$

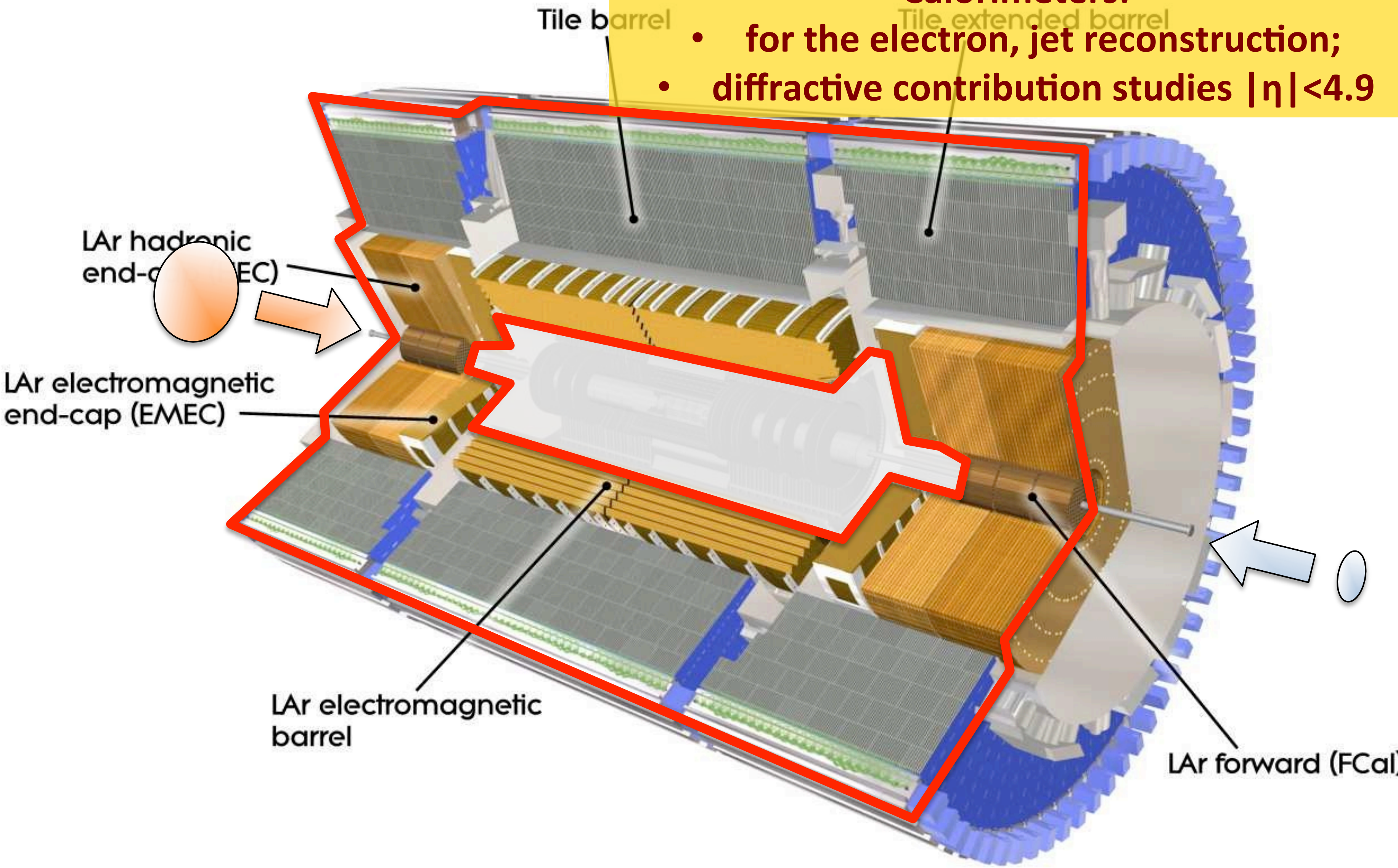
p+Pb @ LHC and ATLAS

Minimum Bias Scintillators used for the event selection 2.1<|η|<3.9 (not shown here)

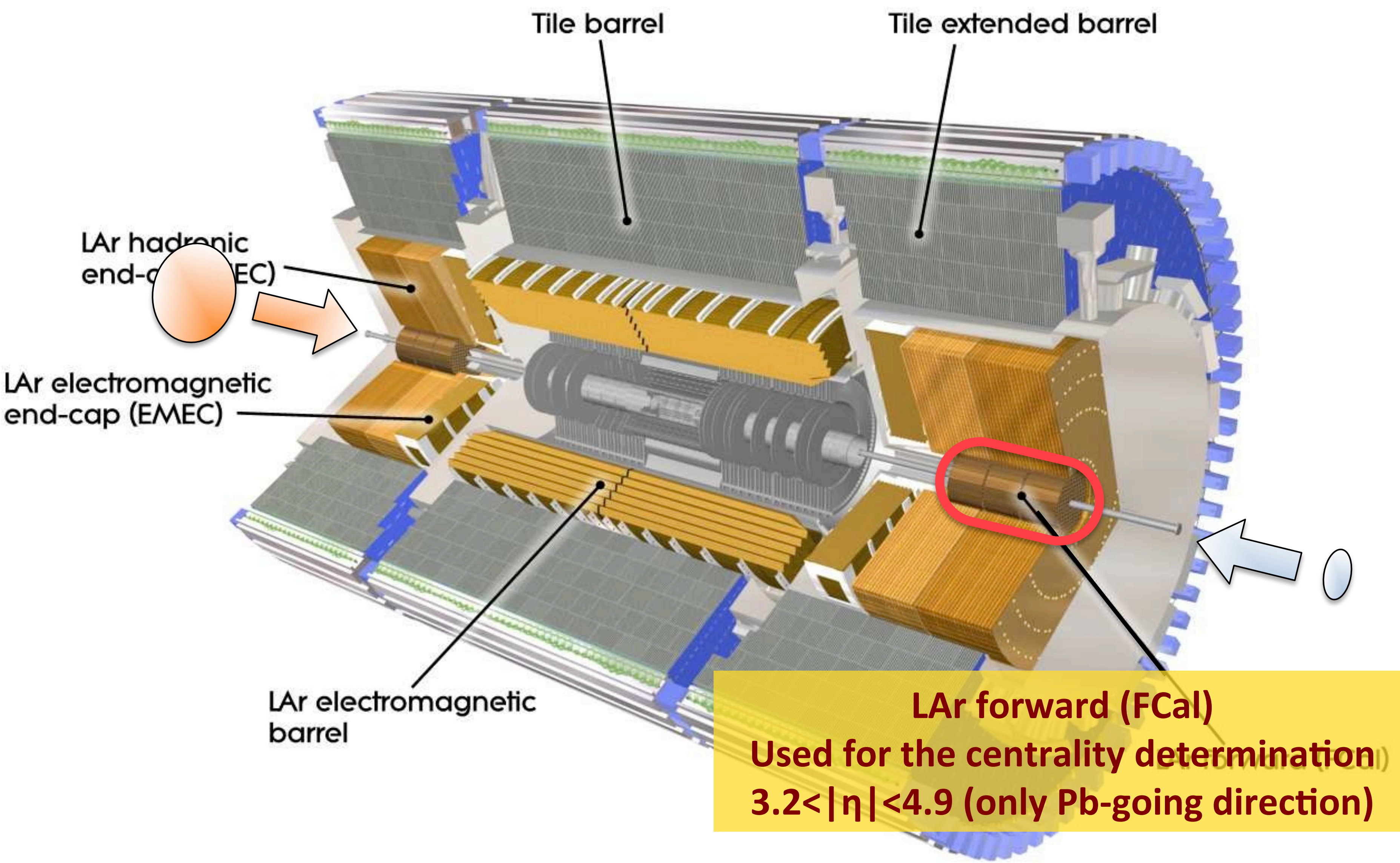


p+Pb @ LHC and ATLAS

Calorimeters:
- for the electron, jet reconstruction;
- diffractive contribution studies $|\eta|<4.9$



p+Pb @ LHC and ATLAS



LAr forward (FCal)
Used for the centrality determination
3.2<|η|<4.9 (only Pb-going direction)