Prospects for ATLAS hard probes measurements in Run 2

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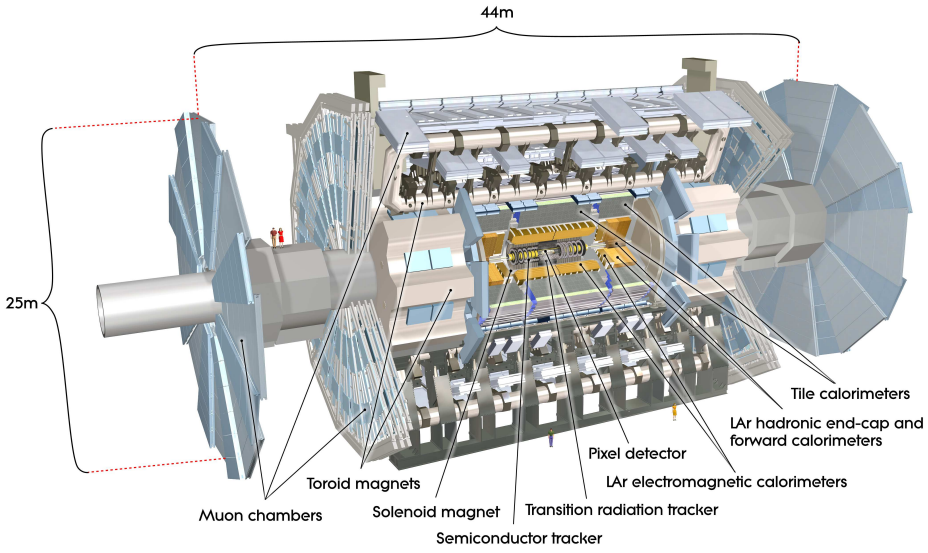
Short overview of run 1

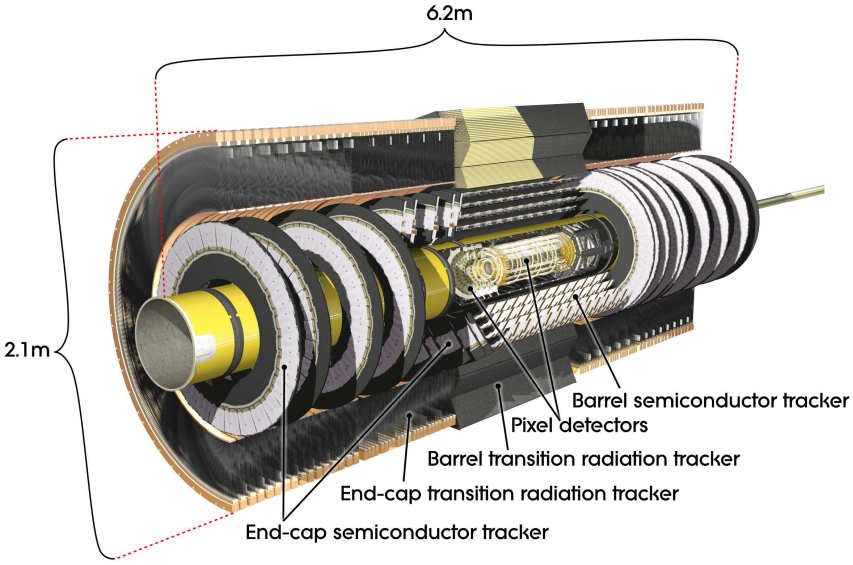
- In run 1, ATLAS collected $L_{\mathrm{int}}^{\mathrm{PbPb}} = 0.15$ nb^{-1} of Heavy-Ion (HI) and $L_{\mathrm{int}}^{pp} = 4.2$ pb^{-1} of pp data at $\sqrt{s_{\mathrm{NN}}} = 2.76$ TeV
- Many interesting studies published: (di)jets, W and Z bosons, J/ψ's, photons and charged tracks
- All of these measurements provided information on HP production rates, parton energy loss and medium properties
- Physics impact of some measurements was reduced by the large statistical errors, some measurements were impossible to do

Run 2

- The main advantage of the new data is the large increase in integrated luminosity ($L_{\mathrm{int}}^{\mathrm{PbPb,run1}} = 0.15$ nb^{-1} vs $L_{\mathrm{int}}^{\mathrm{PbPb,run2}} = 0.515$ nb^{-1})
- Along with the increased cross section for some processes this will provide opportunity to improve statistical precision
- New channels become feasible
- All the possible collision systems, *pp*, p+Pb and Pb+Pb measured at the same energy

ATLAS experiment



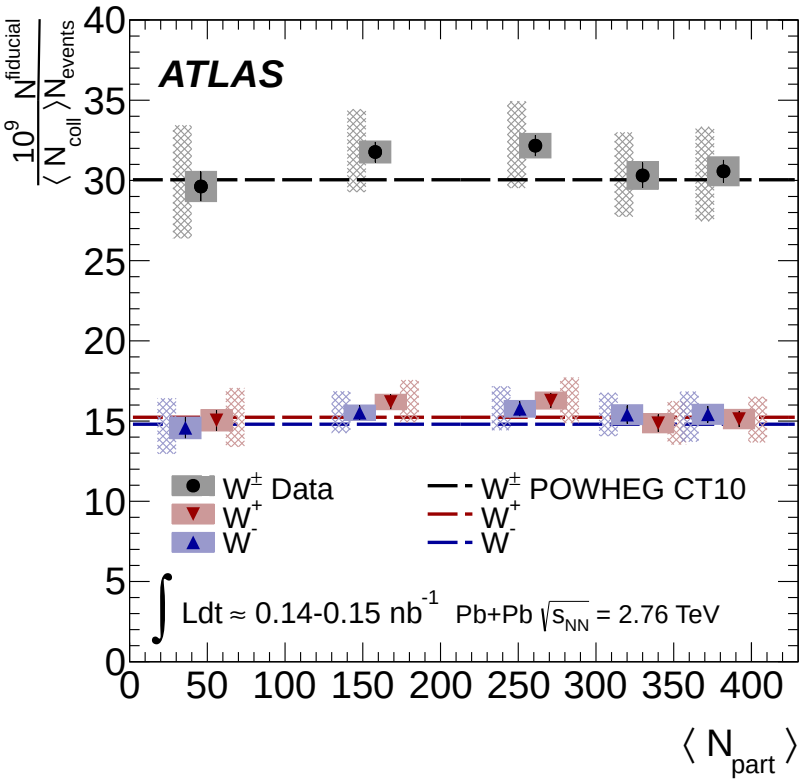


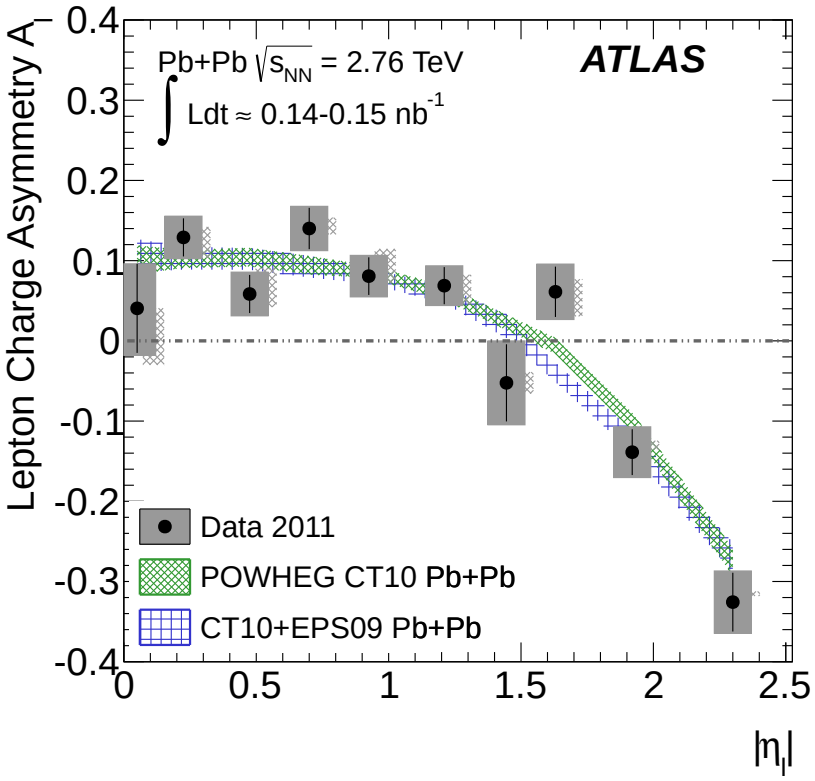
- ATLAS is multi-purpose detector with excellent performance for measurements of heavy-ion collisions
- Precise tracking within $|\eta| < 2.5$. Combination of silicon pixel and strip detectors and transition radiation tracker.
- Large acceptance calorimeter system with fine granularity covers $|\eta| < 4.9$, surrounded by muon spectrometer covering $|\eta| < 2.7$

Electroweak bosons

- Electroweak bosons are a useful channel to test the production rates in HI collisions, it's clear signal being the large advantage
- Statistical uncertainties have been a limiting factor for some channels, e.g. Z+jet
- New data opens possibility to measure jets and electroweak probes simultaneously and differentially

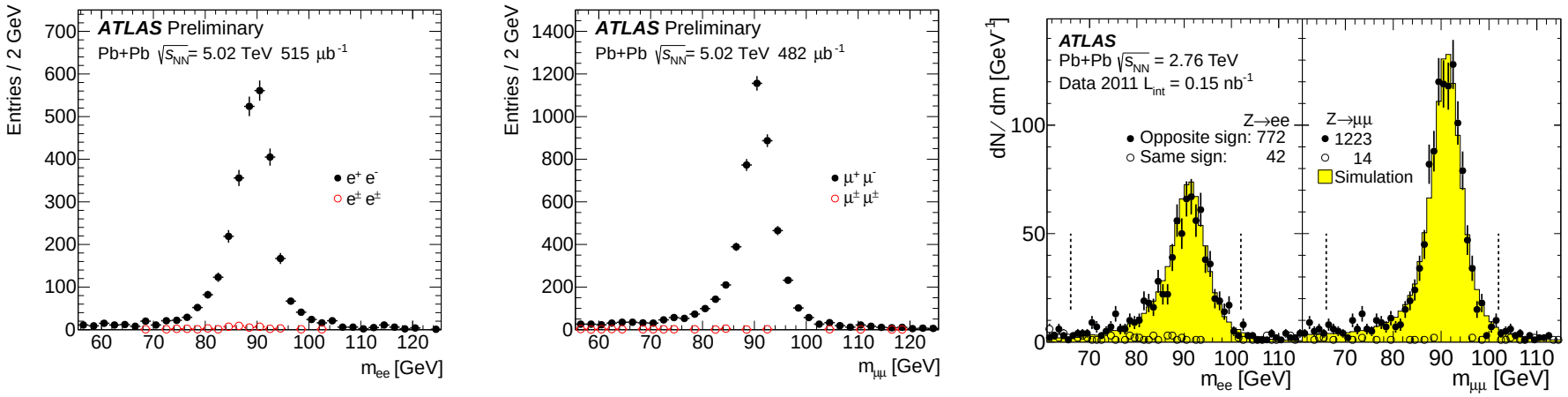
W bosons





- W production yield per binary collision shows no significant dependence on $\langle N_{\mathrm{part}} \rangle$ and is consistent with POWHEG prediction
- Lepton charge asymmetry agrees with theoretical predictions incorporating no nuclear modifications, as well as the small EPS09 modifications

Z mass peaks



- Dielectron (left) and dimuon (right) invariant mass distributions centered around Z peak for opposite and like-sign pairs
- Run 2 measurements left and middle, run 1 on the right
- ≈10 times more Z's with the new data

Charged particle R_{AA}

JHEP09(2015)050

- Variable that expresses the size of the suppression/enhancement is the R_{AA} defined as

$$R_{\mathrm{AA}} = \frac{\frac{1}{N_{\mathrm{evt}}} \frac{\mathrm{d}^2 N_{\mathrm{Pb+Pb}}}{\mathrm{d}p_{\mathrm{T}}\mathrm{d}y}\Big|_{\mathrm{centr}}}{\langle T_{\mathrm{AA}} \rangle \frac{\mathrm{d}^2\sigma_{pp}}{\mathrm{d}p_{\mathrm{T}}\mathrm{d}y}}$$

- R_{AA} is the nuclear suppression factor, which characterizes the modification of the spectrum due to the nuclear environment
- Data are corrected for tracking efficiency, contributions from fake tracks, and momentum resolution

Charged particle R_{AA}

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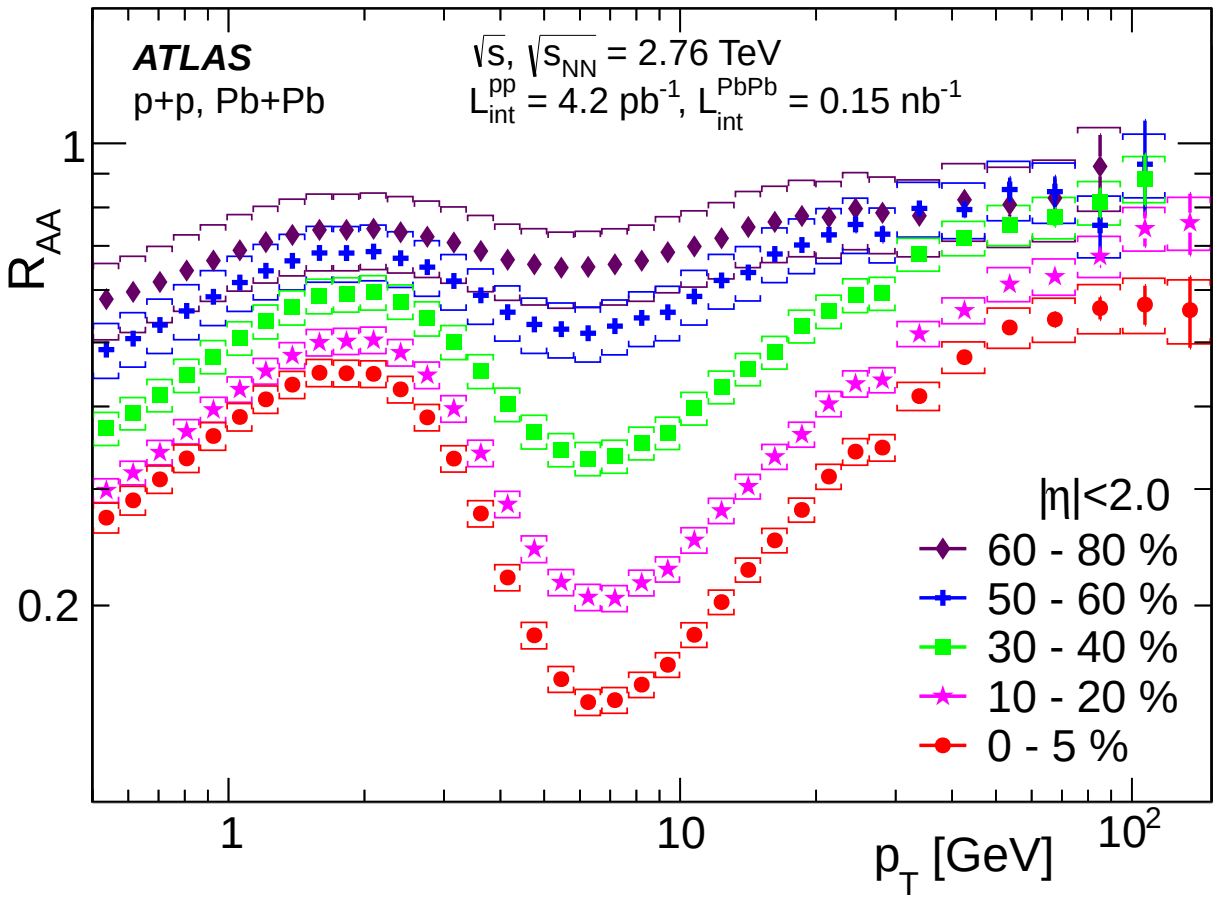
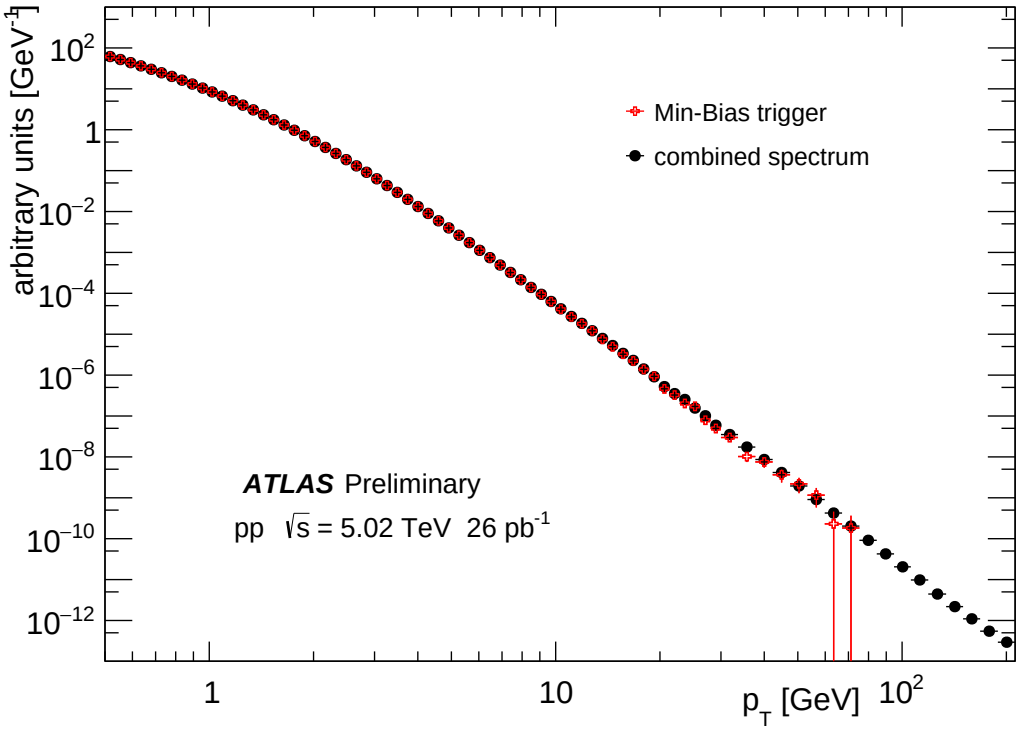
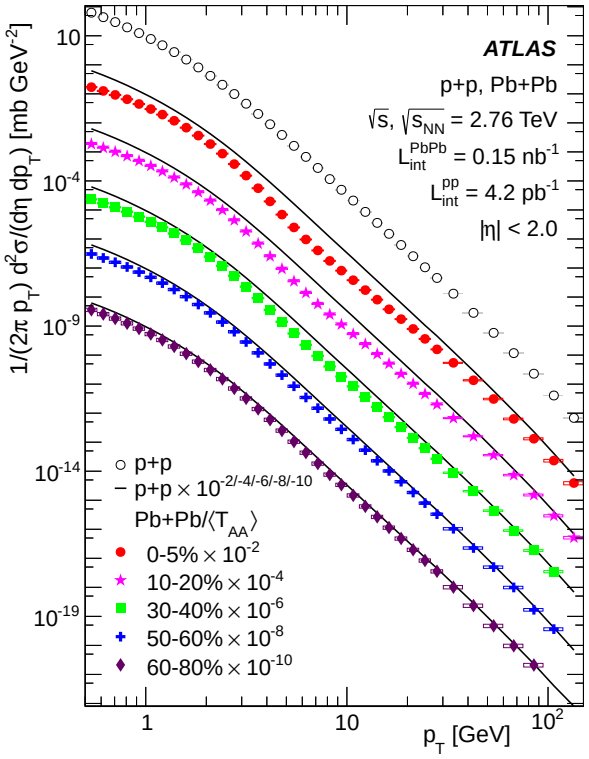


- Very strong suppression at intermediate p_{T}, hint of presence of plateau at $p_{\mathrm{T}} \approx 60$ GeV

Run 2 charged particles

- Uncorrected charged particle spectra from pp at $\sqrt{s} = 5.02$ TeV (left)
- Charged tracks spectra used for R_{AA} measurement in run 1 (right)
- Measurement was possible up to p_{T}=150 GeV, new data should allow to reach at least 200 GeV and possibly higher



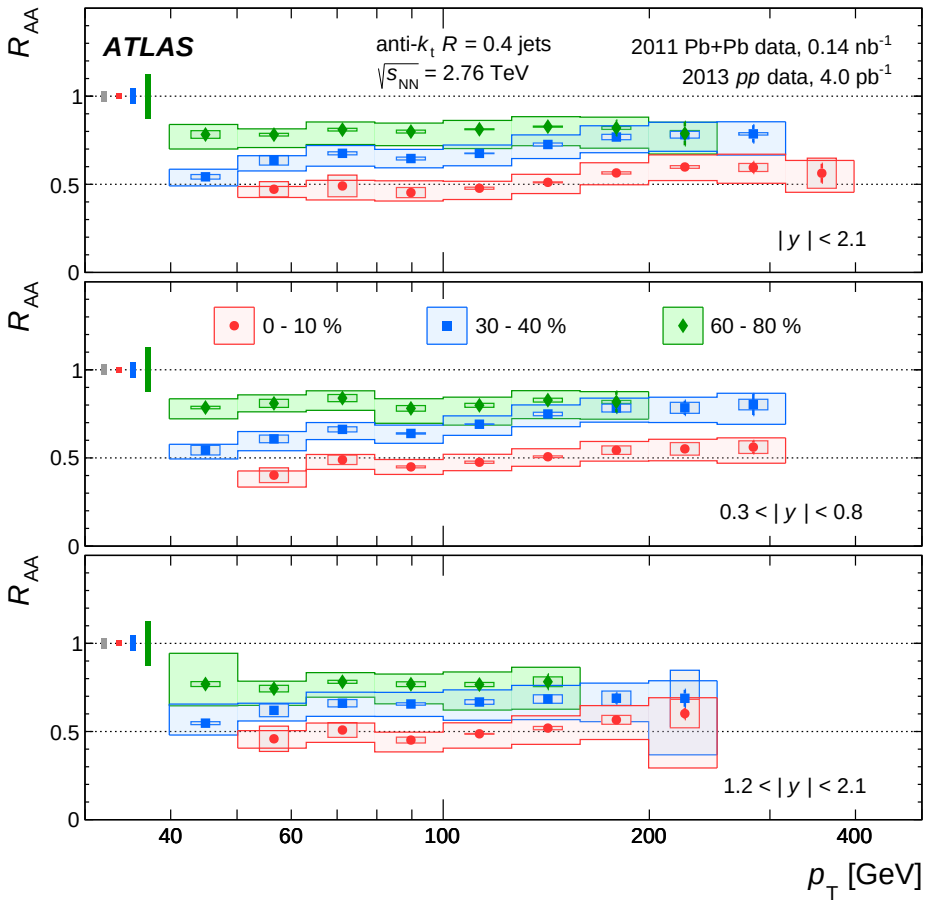


Jets

- Jets probe the medium created in the Pb+Pb collisions
- ATLAS has published results from run 1 on dijet asymmetry, jet R_{AA}, jet fragmentation and production of nearby jets
- New data will allow significant improvements relative to the older measurements, mainly:
  - extended p_{T} reach for jet R_{AA} (measured up to $\approx$ 300 GeV in run 1)
  - differential measurements of jet fragmentation functions
  - reduced statistical uncertainties in measurement of nearby jets

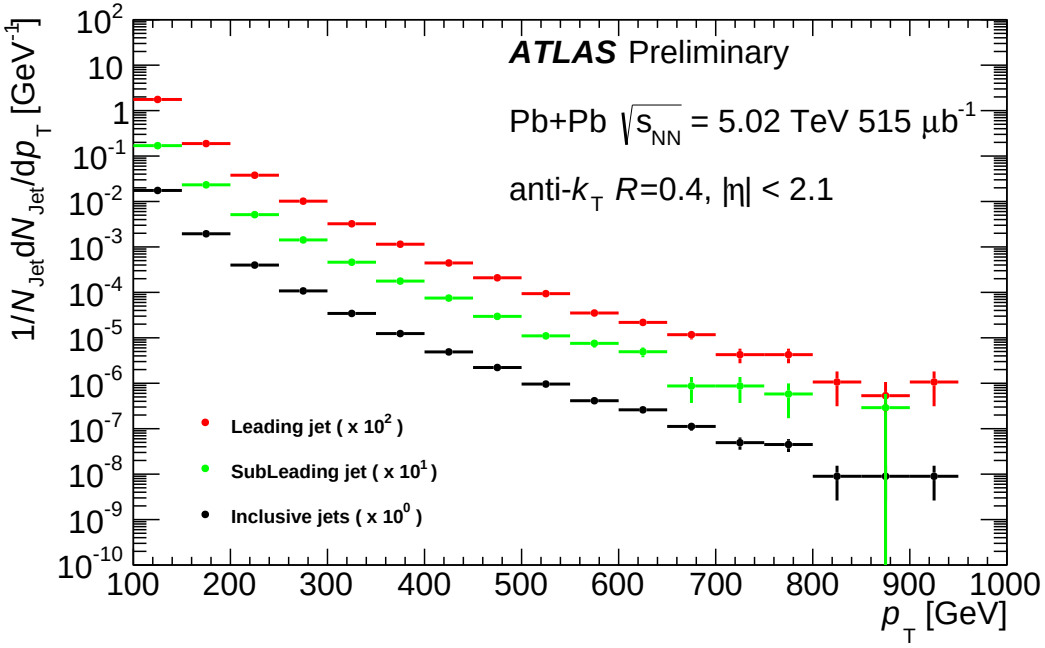
Jet R_{AA}

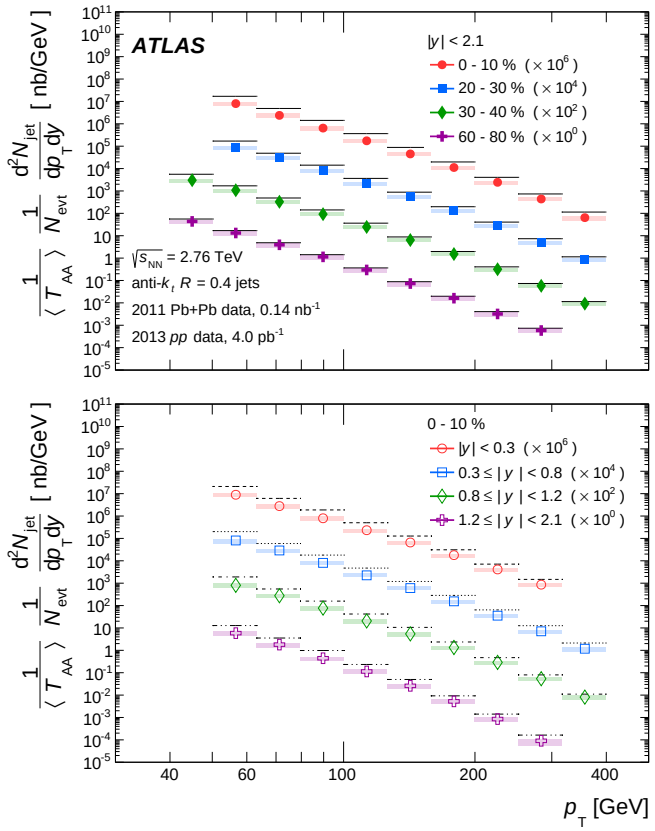
Phys.Rev.Lett. 114 (2015)



- R_{AA} plots clearly show suppression down to ≈ 0.5 for the most central collisions
- Weak dependence of R_{AA} on the p_{T} and rapidity

Jet yields in run 2





- Uncorrected yields of inclusive, leading and subleading jets in Pb+Pb collisions at $\sqrt{s} = 5.02$ TeV as a function of p_{T}, $|\eta| < 2.1$
- Run 1 jet spectra as a function of p_{T} for different centrality and rapidity bins

Fragmentation functions

ALTAS-CONF-2015-055

- Jet Fragmentation Functions (FF) $D(p_{\mathrm{T}})$ and $D(z)$ are defined as

$$D(p_{\mathrm{T}}) = \frac{1}{N_{\mathrm{jet}}} \frac{\mathrm{d}N_{\mathrm{ch}}}{\mathrm{d}p_{\mathrm{T}}^{\mathrm{ch}}} \qquad D(z) = \frac{1}{N_{\mathrm{jet}}} \frac{\mathrm{d}N_{\mathrm{ch}}}{\mathrm{d}z} \qquad z = \frac{p_{\mathrm{T}}}{p_{\mathrm{T}}^{\mathrm{jet}}} \cos \Delta R$$

- Run 1 FF measurement at $\sqrt{s_{\mathrm{NN}}} = 2.76$ TeV of $R = 0.4$ jets done differentially in η and $p_{\mathrm{T}}^{\mathrm{jet}}$
- Jet substructure measured using charged tracks starting at $p_{\mathrm{T}} = 1$ GeV
- FF are background subtracted, efficiency corrected and fully unfolded with 2-D Bayesian unfolding

$D(p_{\mathrm{T}})$ Ratios

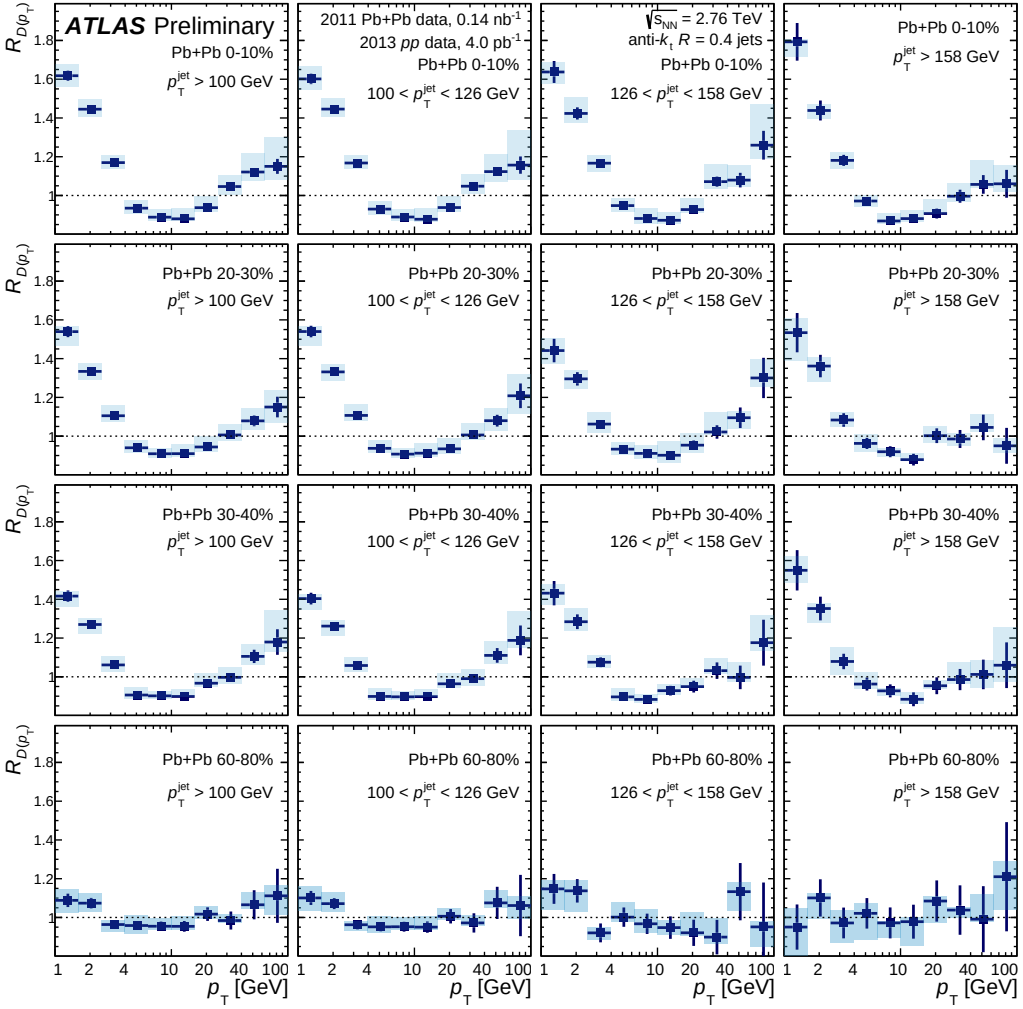
ALTAS-CONF-2015-055

inclusive low $p_{\mathrm{T}}^{\mathrm{jet}}$ → high $p_{\mathrm{T}}^{\mathrm{jet}}$

central

↓

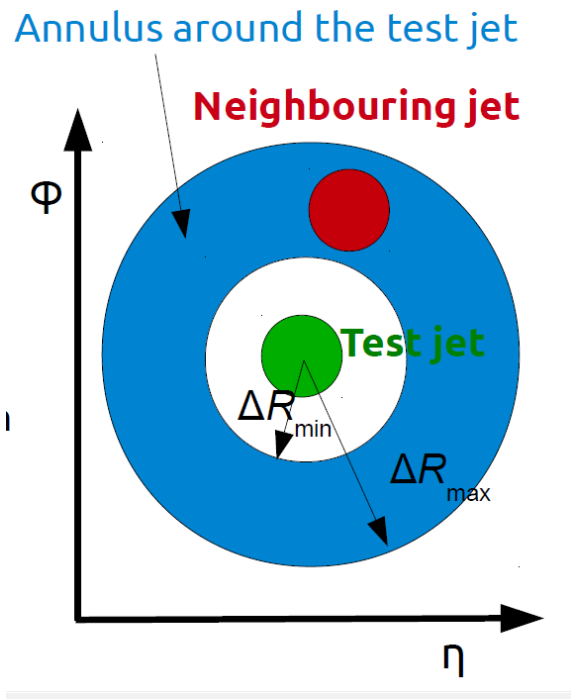
peripheral



- $R_{D(p_{\mathrm{T}})}$ for 4 centralities in 4 $p_{\mathrm{T}}^{\mathrm{jet}}$ bins
- No dependence on $p_{\mathrm{T}}^{\mathrm{jet}}$ observed except change of trends at highest p_{T}

Nearby jets (1)

Phys.Lett. B 751 (2015)

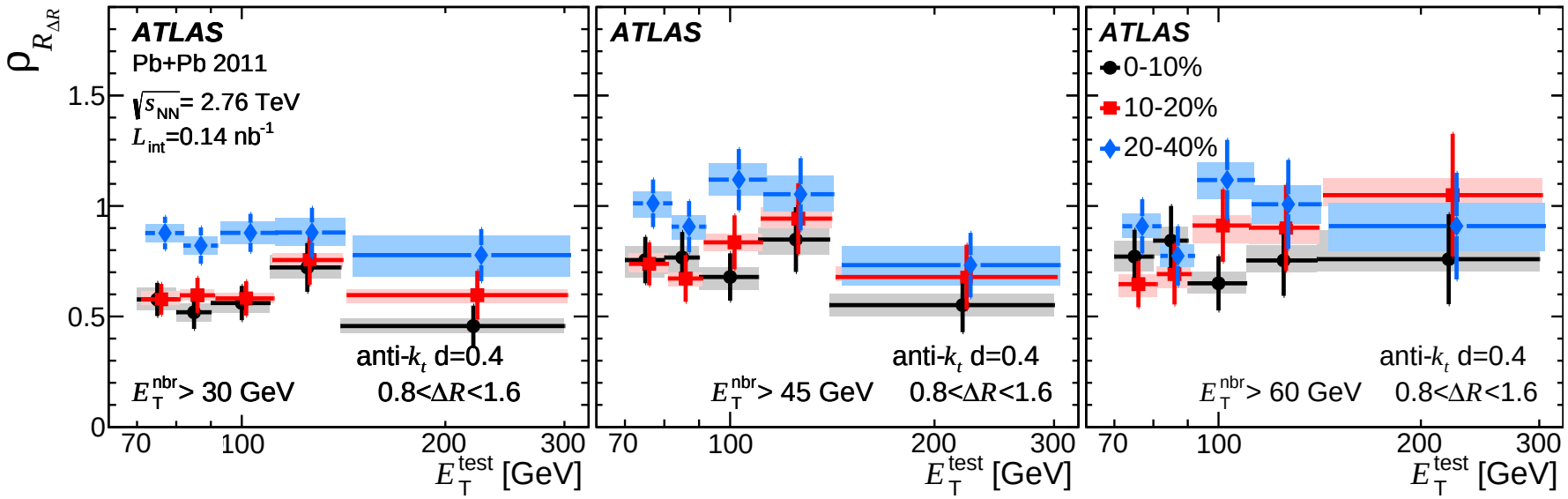


- The rate of the neighbouring jets that accompany a test jet was measured in run 1
- $R_{\Delta R}$ is defined as

$$R_{\Delta R} = \frac{1}{\mathrm{d}N_{\mathrm{jet}}^{\mathrm{test}}/\mathrm{d}E_{\mathrm{T}}^{\mathrm{test}}} \sum_{i=1}^{N_{\mathrm{jet}}^{\mathrm{test}}} \frac{\mathrm{d}N_{\mathrm{jet},i}^{\mathrm{nbr}}}{\mathrm{d}E_{\mathrm{T}}^{\mathrm{test}}}(E_{\mathrm{T}}^{\mathrm{test}}, E_{\mathrm{T,min}}^{\mathrm{nbr}}, \Delta R)$$

Nearby jets (2)

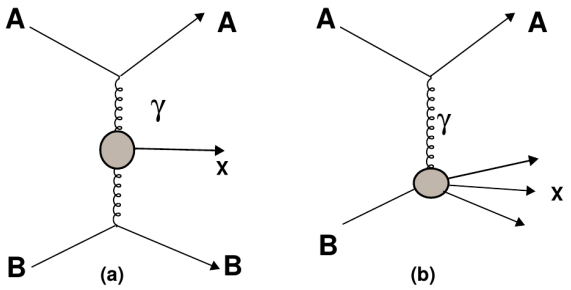
Phys.Lett. B 751 (2015)



- The ratio of $R_{\Delta R}$ for three centrality bins to 40-80% centrality bin
- Suppression by a factor ≈ 2 in central collisions, no strong E_{T} dependence observed
- With increased statistics in Run 2, expect significant reduction in statistical uncertainties
- Moreover new type of jet substructure measurements possible

UPC collisions

ALTAS-CONF-2016-025



- Ultra Peripheral Collisions (UPC) are collisions at large impact parameter where strong interaction is not possible; nuclei interact via photons (photon-photon (a) or photon-ion (b)) emitted coherently from the entire nucleus
- One way to better understand the photon flux induced by the electromagnetic fields surrounding heavy nuclei is to measure high-mass dimuon pairs
- In the presented measurement, cross section for exclusive dimuon pairs with $M_{\mu\mu} > 10$ GeV is compared with STARLIGHT 1.1 calculations
- Measured cross section was corrected for muon trigger efficiency, muon reconstruction efficiency and vertex reconstruction efficiency

High-mass dimuon pairs in UPC

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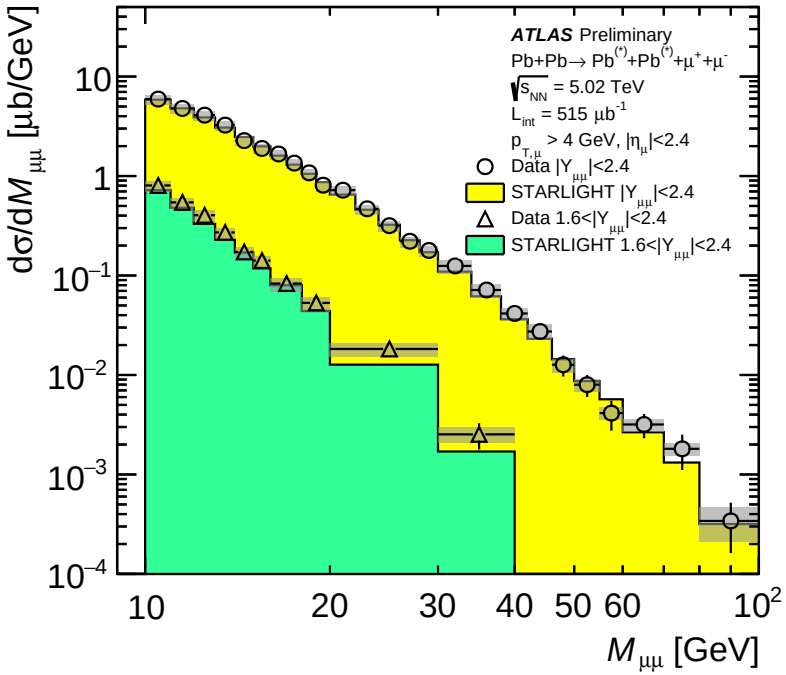

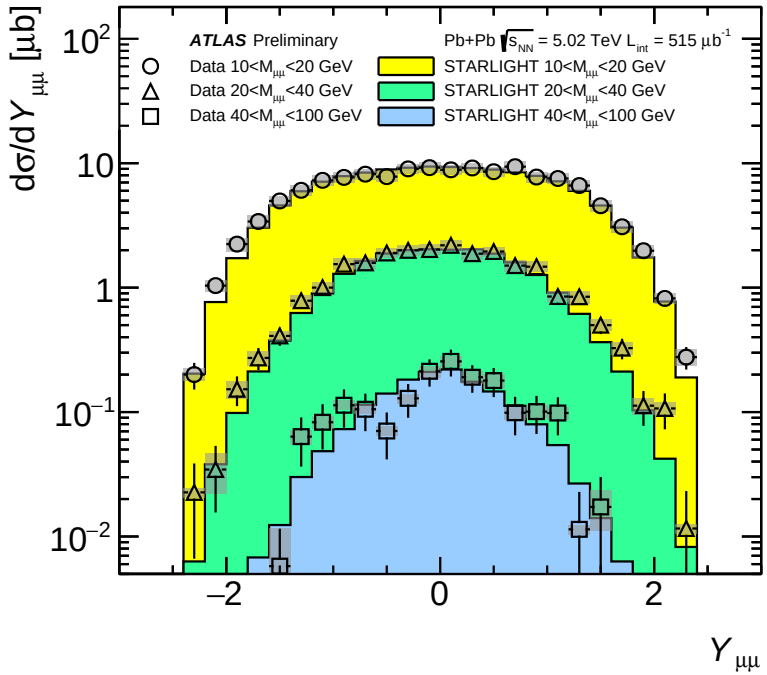

- Cross section for dimuon production in UPC as a function of pair mass (left) and pair rapidity (right)
- Mass distribution provided for two rapidity regions $|Y_{\mu\mu}| < 2.4$ and $|Y_{\mu\mu}| > 1.6$
- Rapidity distribution provided for three mass ranges $10 < M_{\mu\mu} < 20$ GeV, $20 < M_{\mu\mu} < 40$ GeV, $40 < M_{\mu\mu} < 100$ GeV

Summary

- Results from run 1 show that production of EW bosons is not influenced by the medium created in HI collisions
- But strong suppression of charged particles and jet production in central collisions, suppression of nearby jets and modest but significant modification of jet FF is observed
- With the new data we'll be able to extend old measurements, do them more differentially and with higher precision; new measurements will be possible with increased statistics
- High-mass dimuon pairs measurement shows good agreement between data and STARLIGHT calculations, enabling precise future measurements of UPC collisions

Backup

High-mass dimuon pairs in UPC

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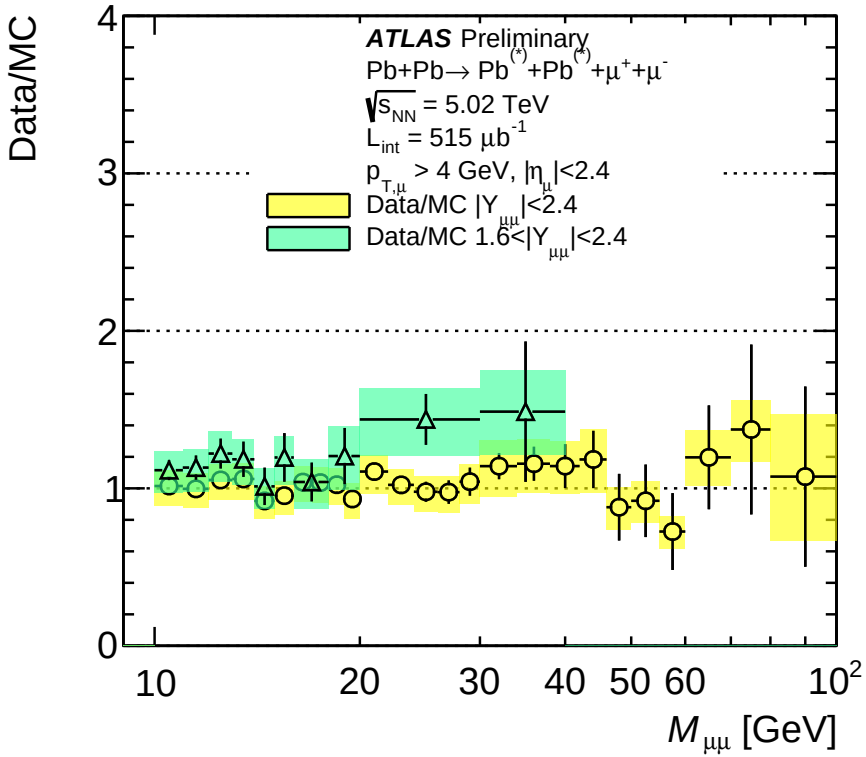

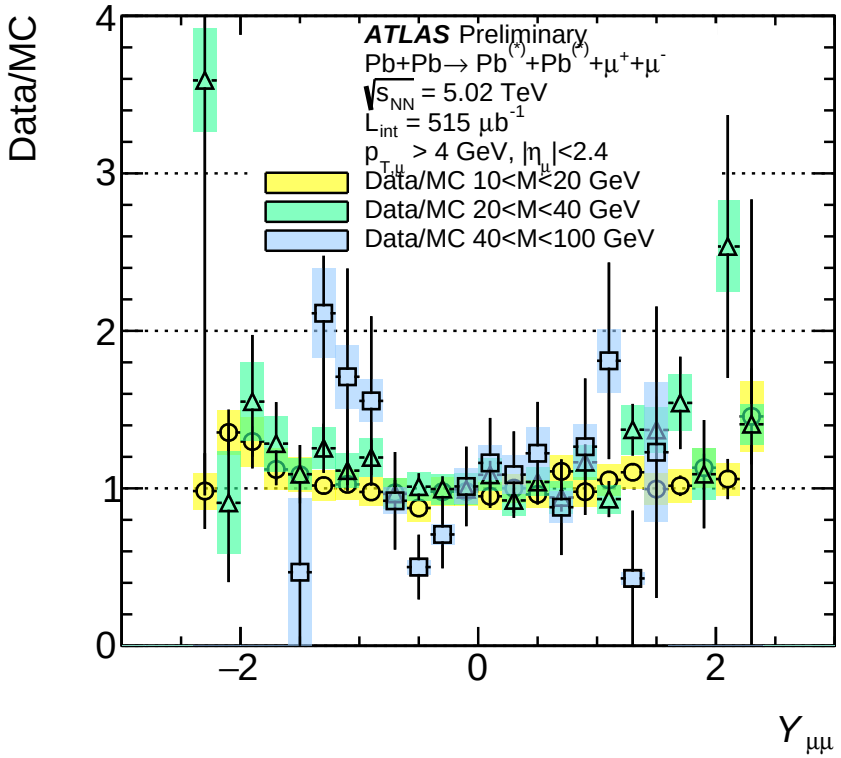

- The ratios of data and STARLIGHT calculations
- Good agreement between calculations and data