Multi-jet production in ultra-peripheral lead-lead collisions with ATLAS experiment

ATLAS-CONF-2017-011

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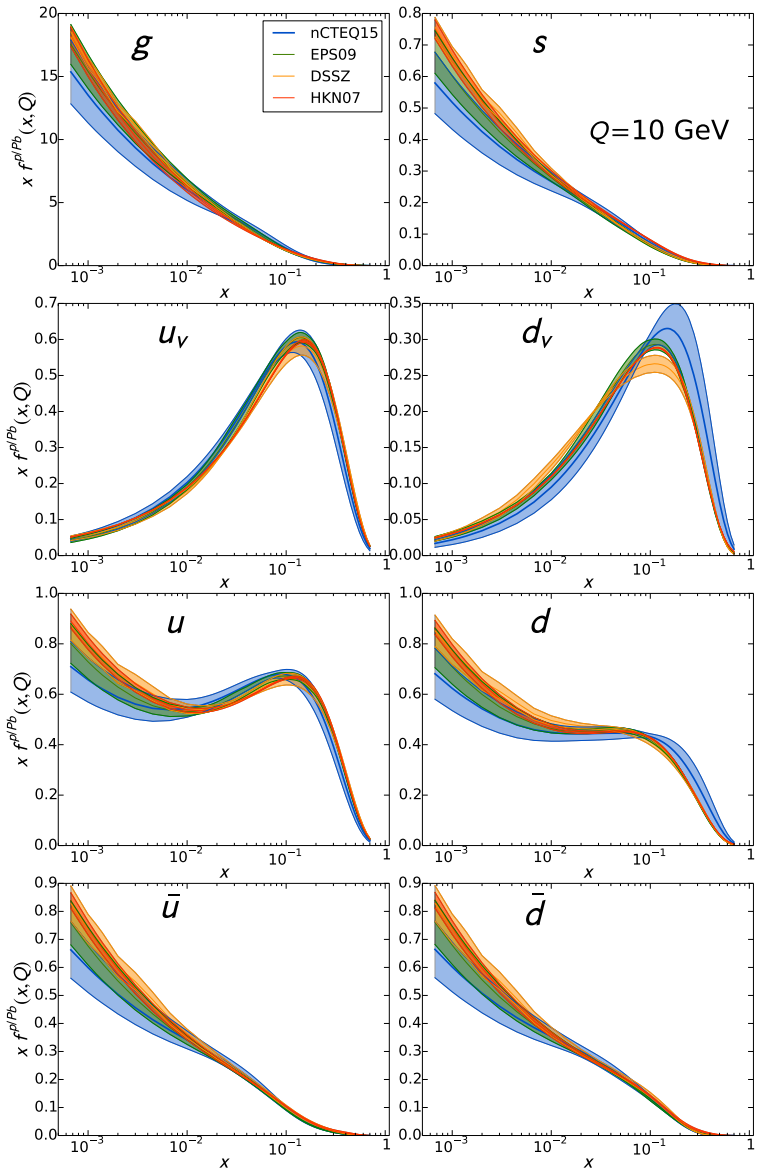
Measurement motivation

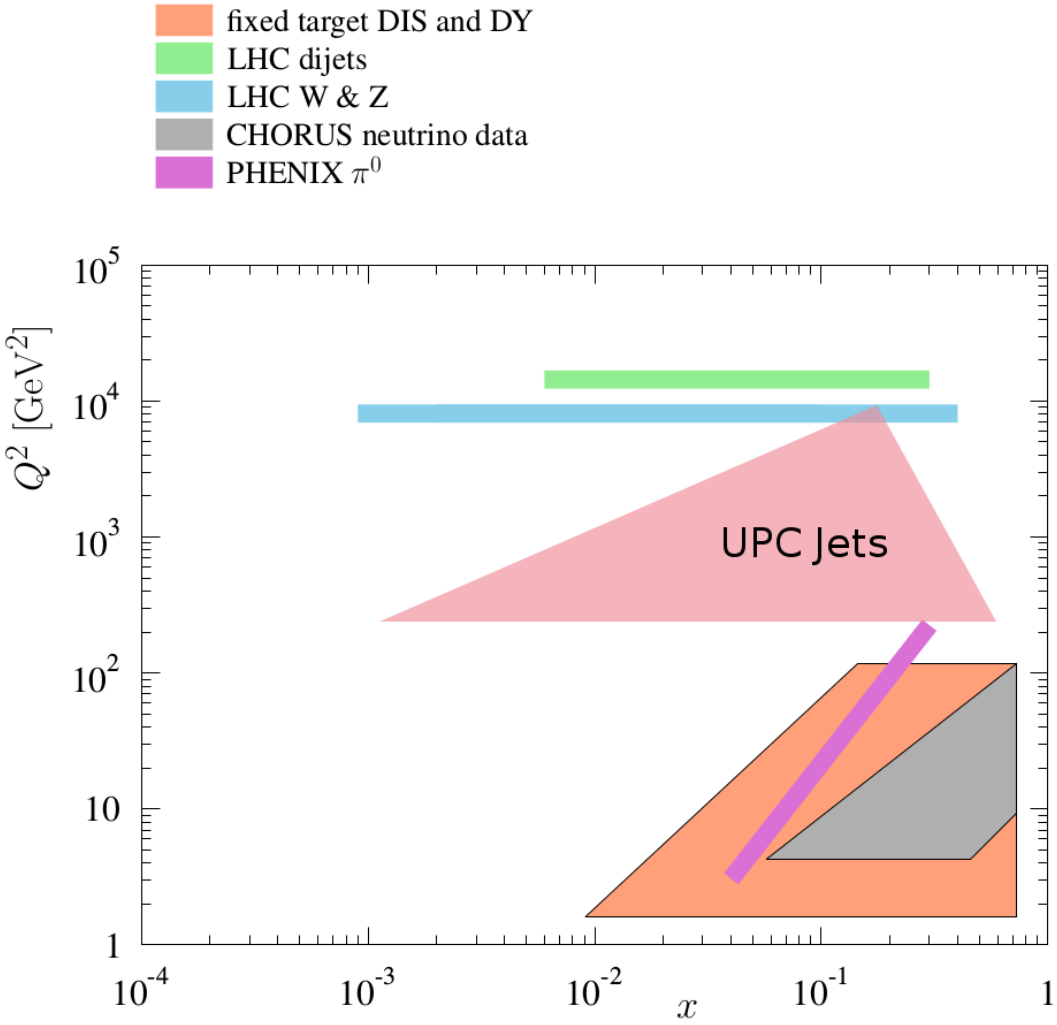
- Recent CTEQ analysis of nuclear PDF compared with other fits
- Large uncertainty especially at low-x
- See talks by H. Paukkunen (EPPS16) and F. Olness (nCTEQ15) on Tuesday

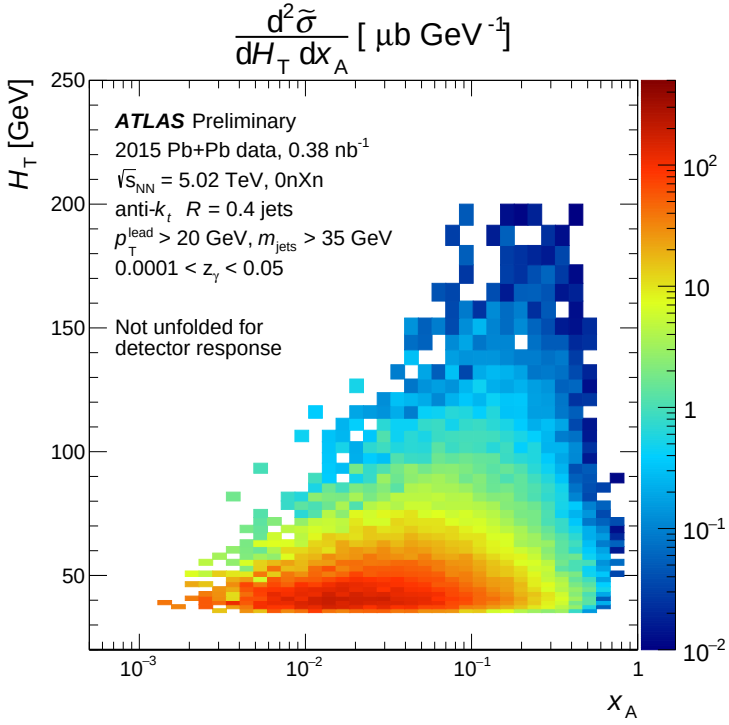


- Measurement of photo-production of dijets in ultra-peripheral (UPC) ion collisions proposed in 2005
- Photons emitted by entire nucleon, enhancement Z^2
- UPC collision occure at large impact parameter, qualitatively different than AA

Kinematic coverage

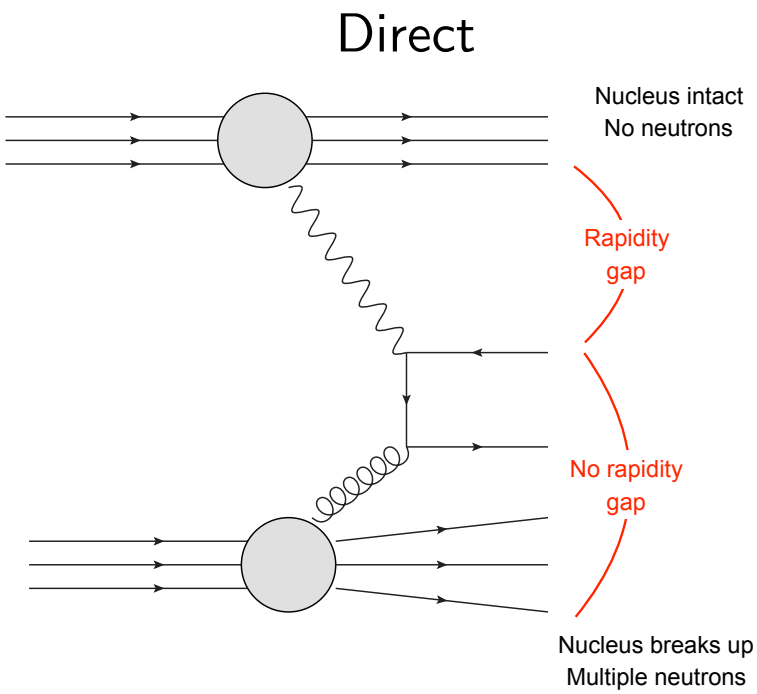
- LHC data opens up previously unexplored region

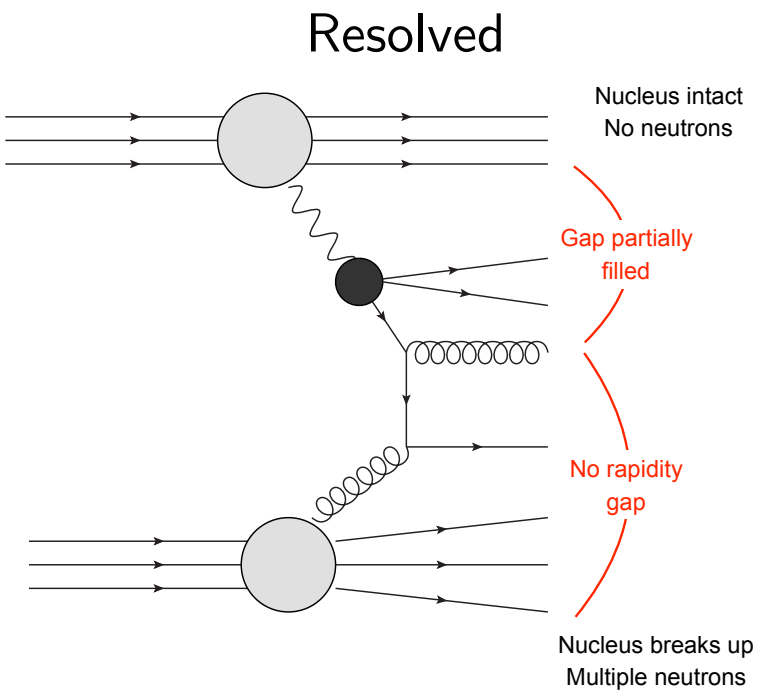




Adapted from EPPS16

Direct and resolved topology

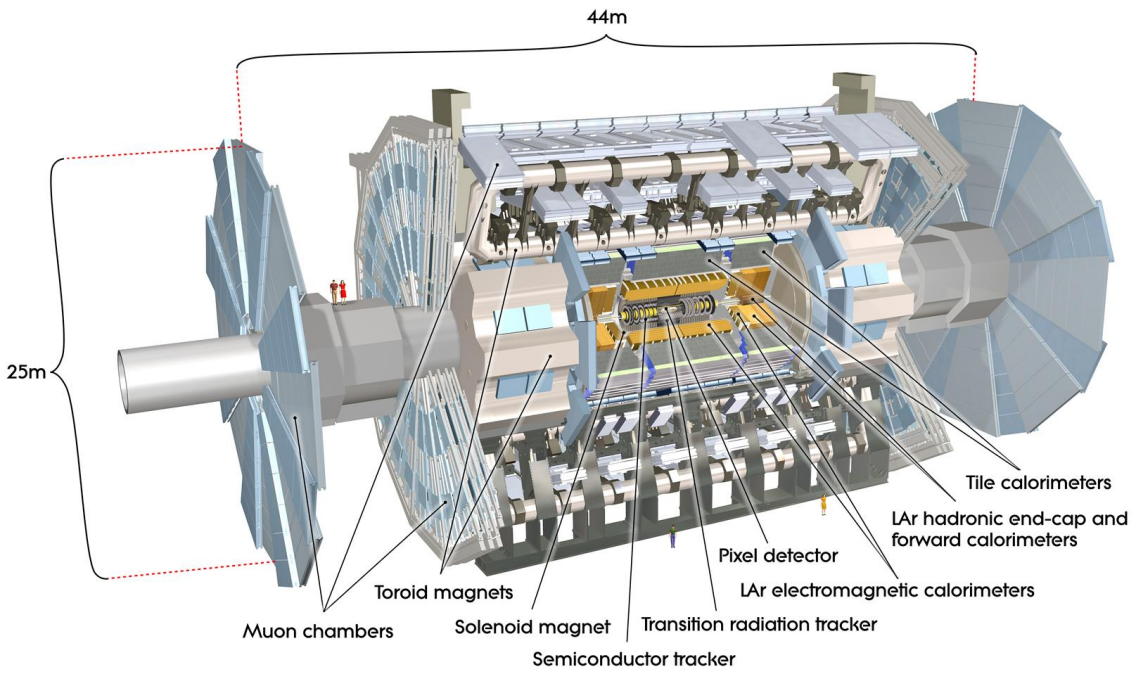


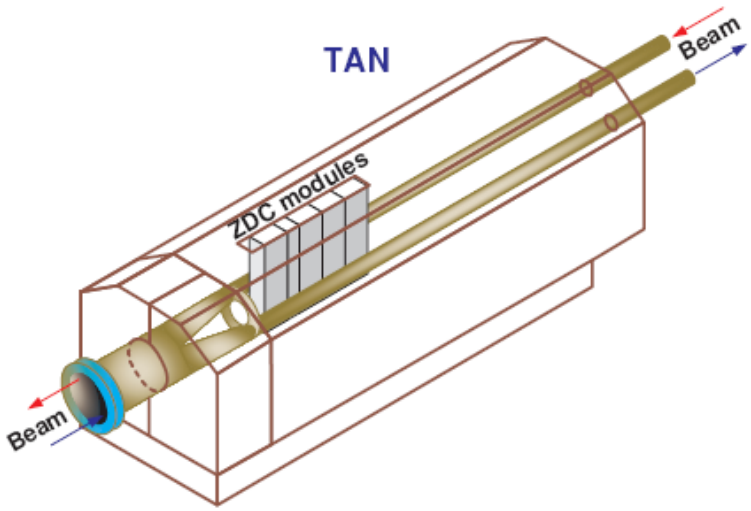


- About 1/3 of the contribution

- Depends on the structure of the photon
- Photon fluctuates to vector meson or virtual $q\bar{q}$
- Gap partially filled by particles

Detection technique



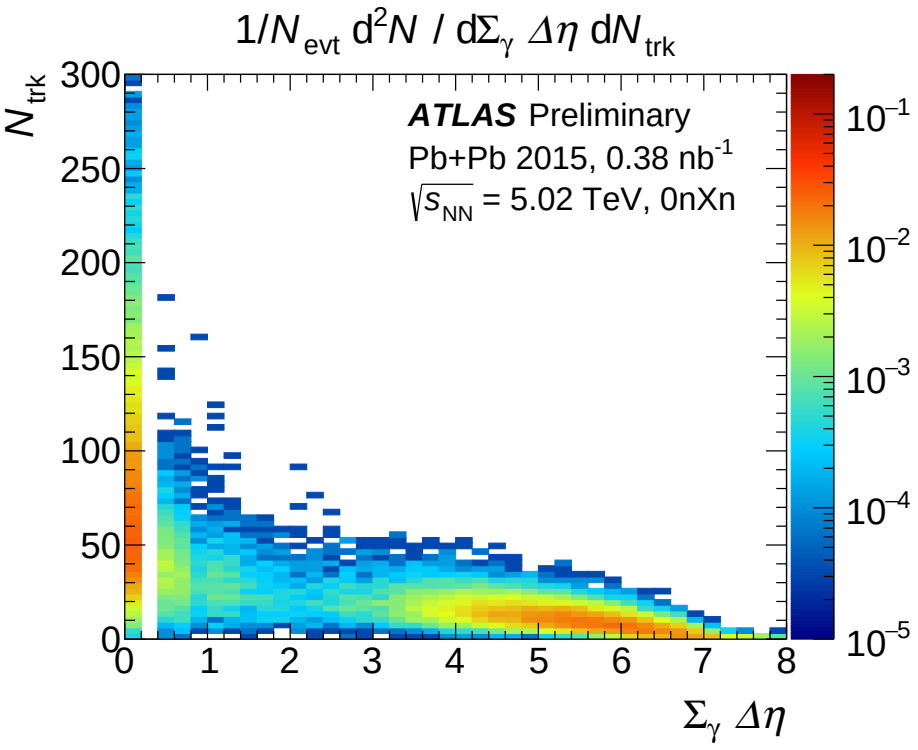


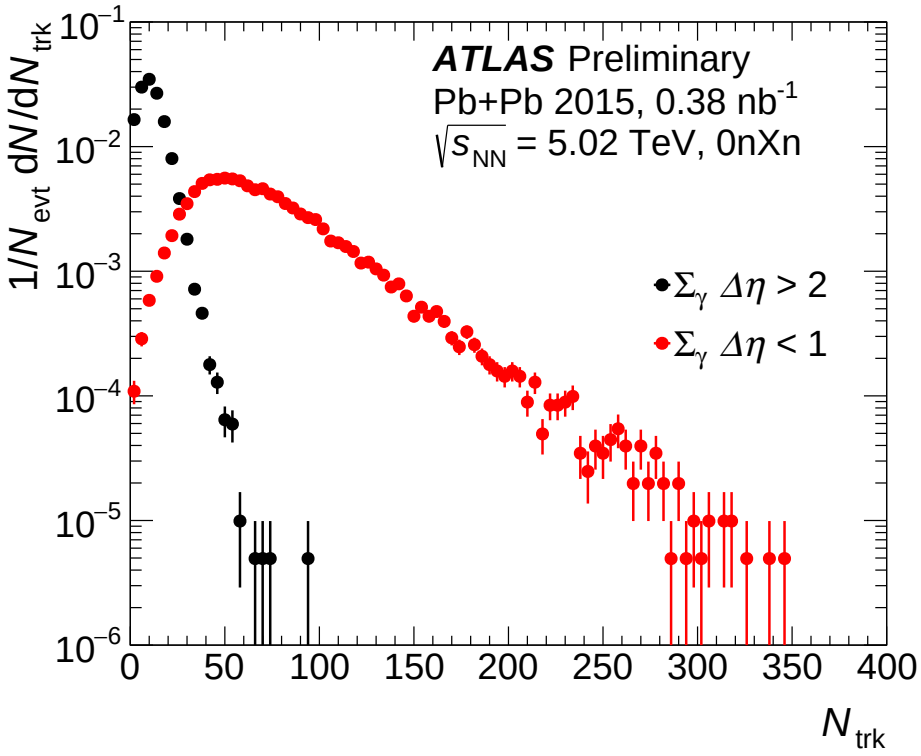
- ZDC - located 140 m from IP in both directions, detects neutral energy, effectively counts number of incident neutrons
- Rapidity gaps reconstructed as empty regions in the EM calorimeters $|\eta| < 4.9$, no energy deposition above expected detector noise
  - "Sum gap" - $\sum \Delta\eta$ - a sum of all empty region with $\Delta\eta > 0.5$ between calorimeter edge and the jets
- Distinguish γ-going ("0n" in ZDC) and Pb-going directions -$\sum_\gamma \Delta\eta$, $\sum_A \Delta\eta$

Event selection

- Using 2015 data Pb+Pb data at $\sqrt{s} = 5.02$ TeV
- Use ZDC to select "0nXn" event topology
  - No correction made for photon emitter breakup
- Selections to suppress backgrounds:
  - Regular dijet production in PbPb:
    - Require minimal gap on the γ direction: $\sum_\gamma \Delta\eta \geq 2$
  - $\gamma\gamma \to e^+e^-, \tau^+\tau^-, q\bar{q}$ or central diffraction
    - Typically not 0nXn topology
    - Remove with maximum gap requirement on Pb-going side: $\sum_A \Delta\eta \leq 3$
- Measurement corrected for events lost due to the gap requirement

Event topology





- Events with 0nXn and dijet topology
- Events with large gaps have much smaller track multiplicity
- $\sum_\gamma \Delta\eta \geq 2$ to select UPC events

Jets and kinematics

- Jet selection
  - Anti-kt $R = 0.4$ jets with $|\eta| < 4.4$
  - $p_{\mathrm{T}}^{\mathrm{lead}} > 20\,\mathrm{GeV}$
  - $p_{\mathrm{T}}^{\mathrm{sublead}} > 15\,\mathrm{GeV}$
  - $m_{\mathrm{jets}} > 35\,\mathrm{GeV}$
- Measure differential cross-section as a function of x_A, z_γ, H_{T}

$$H_{\mathrm{T}} \equiv \sum_{\mathrm{jets}} p_{\mathrm{Ti}}$$

$$m_{\mathrm{jets}} = \left((\sum E_i)^2 - (\sum \vec{p}_i)^2\right)^{1/2} \qquad y_{\mathrm{jets}} = \frac{1}{2}\ln\left(\frac{\sum_i E_i + \sum_i p_{zi}}{\sum_i E_i - \sum_i p_{zi}}\right)$$

$$x_A = \frac{m_{\mathrm{jets}}}{\sqrt{s}} e^{-y_{\mathrm{jets}}} \qquad z_\gamma = \frac{m_{\mathrm{jets}}}{\sqrt{s}} e^{+y_{\mathrm{jets}}}$$

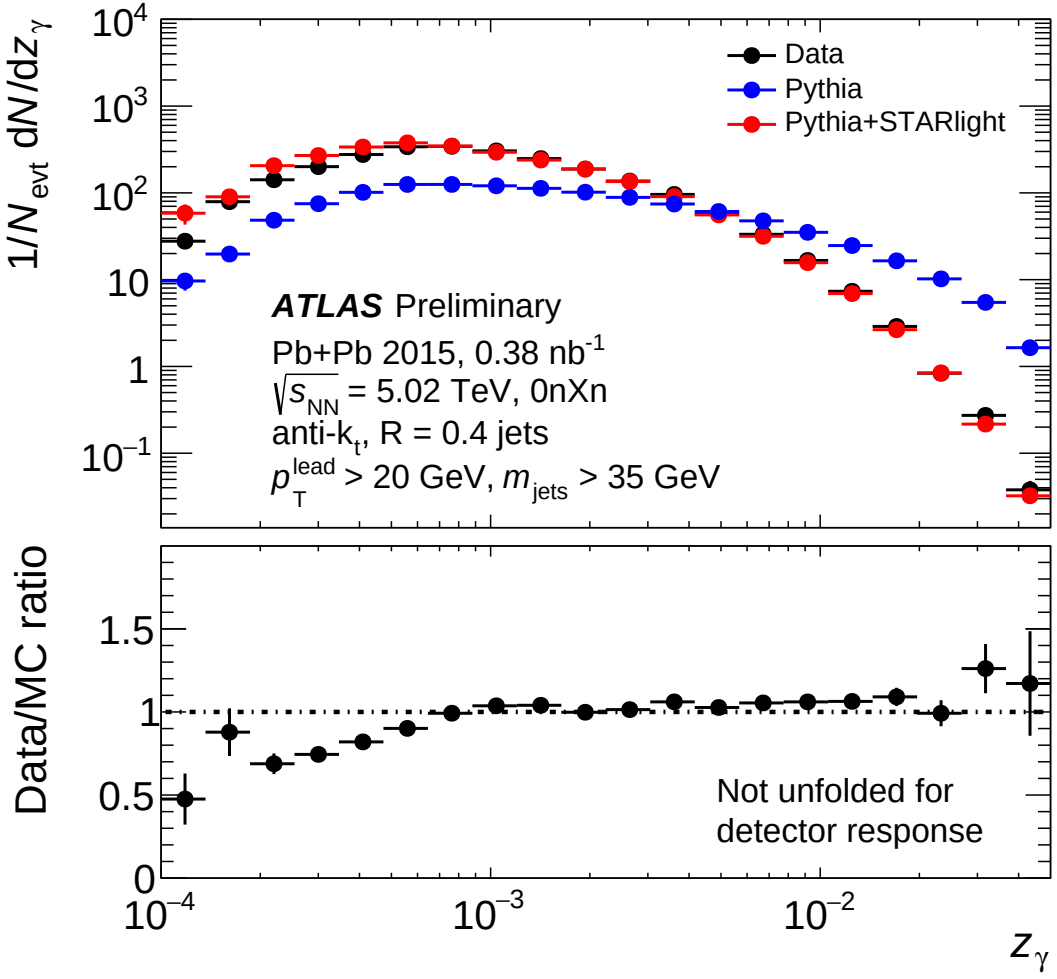
- Observables generalized to n jet final states
- For $2 \to 2$ scattering:
  - x_A - energy fraction of struck parton in the nucleon
  - $z_\gamma = x_\gamma y_\gamma$ (x_γ energy fraction of parton in the photon, $x_\gamma = 1$ for direct processes)
  - $H_{\mathrm{T}} = 2 \times p_{\mathrm{T}} = 2Q$

Signal modelling

- PYTHIA6 can be run in $\mu(\mu \to \mu\gamma)p$ mode to generate photo-nuclear events
  - Mixture of direct and resolved photon processes
  - Wrong photon flux
- STARLIGHT provides the nuclear photon flux
  - found to describe well two-photon initiated events in AA
  - need to integrate flux over nuclear target
  - need to integrate over $P_{\mathrm{UPC}}(b)$, prb. of no hadronic interaction
    - at small b, additional hadronic interactions breaks the nucleon
    - cannot separate photo-nuclear events from regular PbPb collisions
    - $P_{\mathrm{UPC}}(b)$ obtained from the model of nucleon geometry and hadronic interaction model implemented in the generator
- Use modified STARLIGHT to calculate weights, applied to PYTHIA6 on event-by-event basis

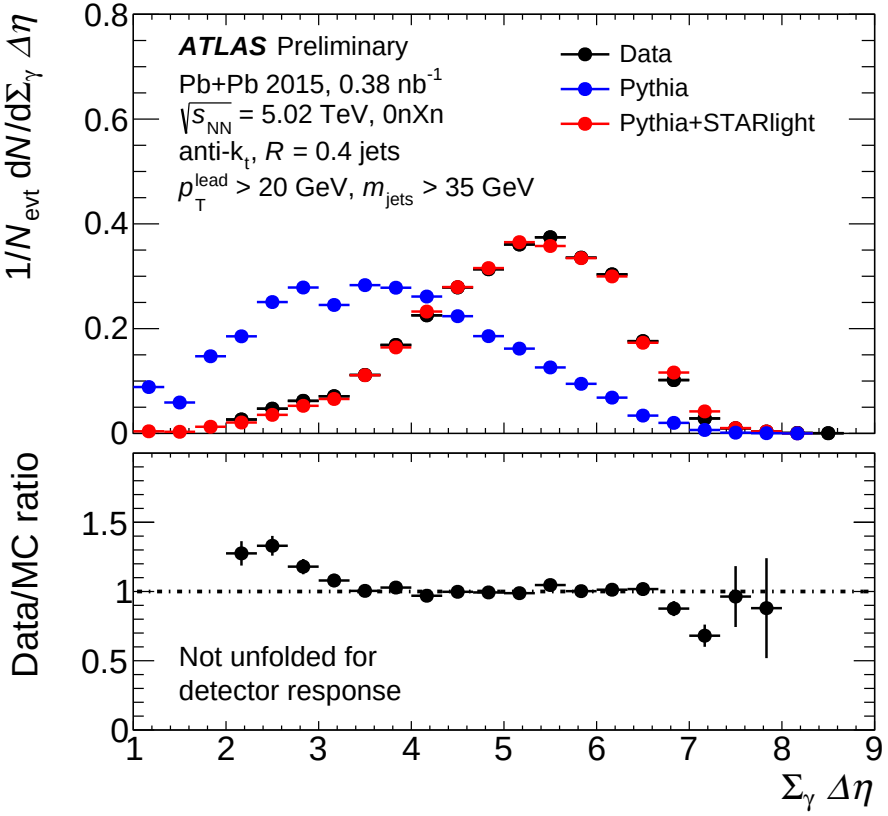
$$\frac{\mathrm{d}\sigma_{\mathrm{UPC}}^{\mathrm{Pb+Pb}}}{\mathrm{d}E} = 2\int \mathrm{d}^2 b\, P_{\mathrm{UPC}}(b) \int \mathrm{d}^2 r_{\mathrm{B}}\, \frac{\mathrm{d}^2 N_\gamma^{\mathrm{Pb}}}{\mathrm{d}E\, \mathrm{d}^2 r_{\mathrm{A}}}\bigg|_{\vec{r_{\mathrm{A}}}=\vec{b}-\vec{r_{\mathrm{B}}}} T_{\mathrm{Pb}}(r_{\mathrm{B}})\sigma^{\gamma N} \equiv \frac{\mathrm{d}N_\gamma^{\mathrm{eff}}}{\mathrm{d}E}\sigma^{\gamma N}$$

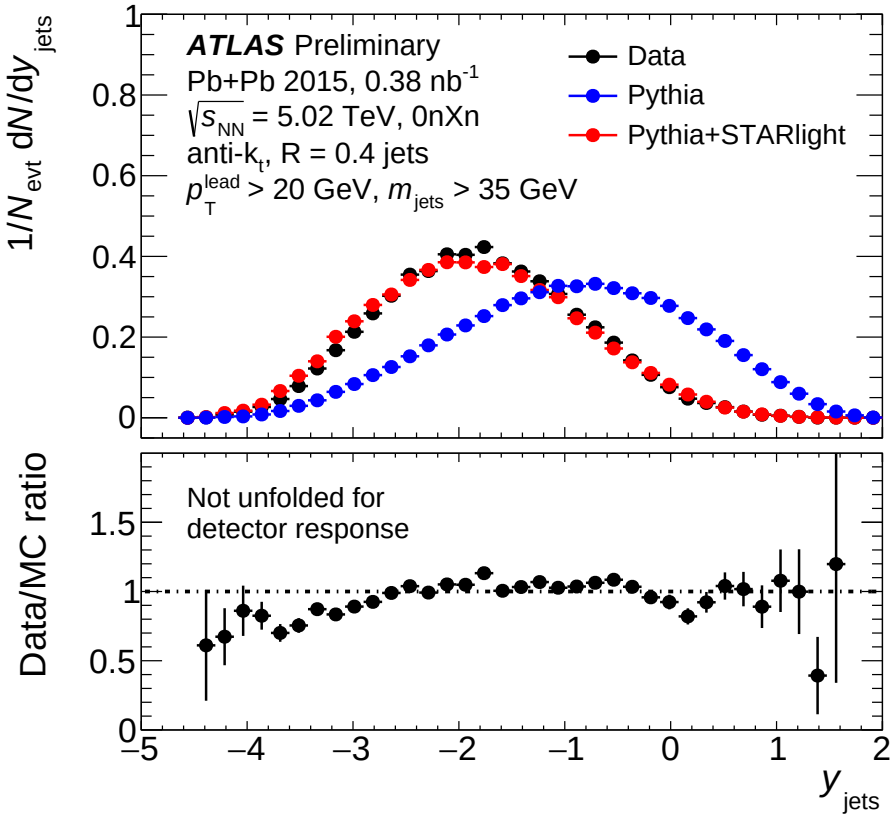
Monte-Carlo re-weighting



- PYTHIA6 in good (not perfect) agreement with data after re-weighting

Data/MC comparisons





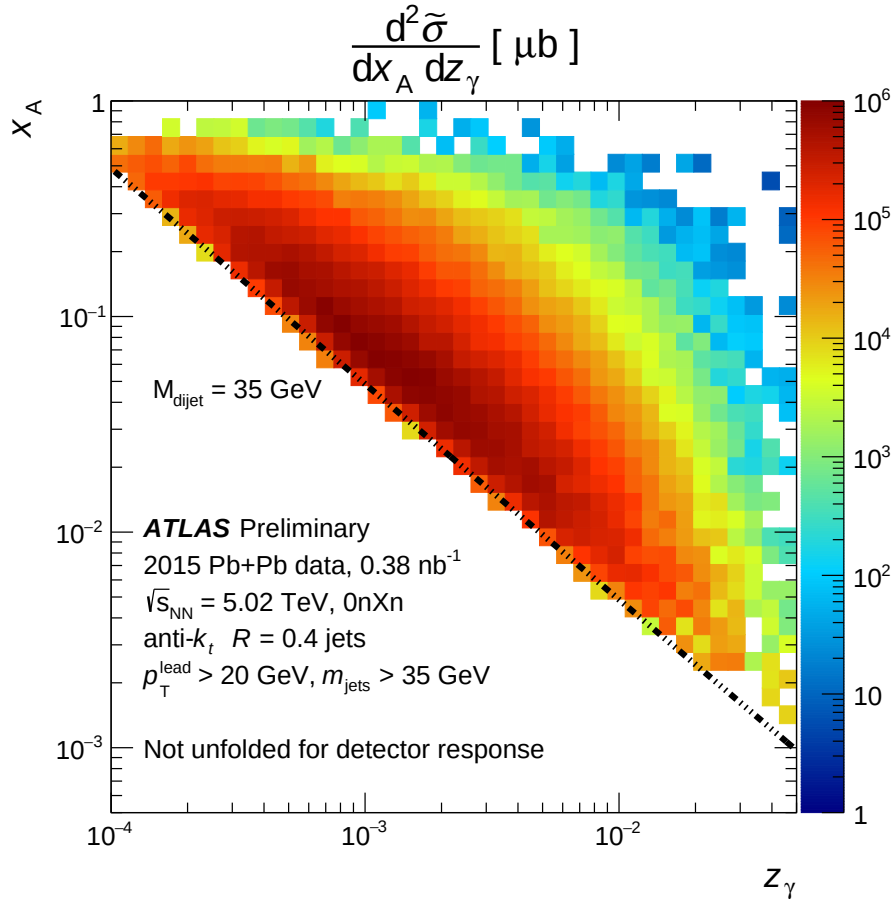
- Sign of p_z fixed to be positive for γ-going direction
- $y_{\text{jets}} < 0 \ \rightarrow z_\gamma < x_A$
- Satisfactory modelling of the gap and jet kinematics after re-weighting

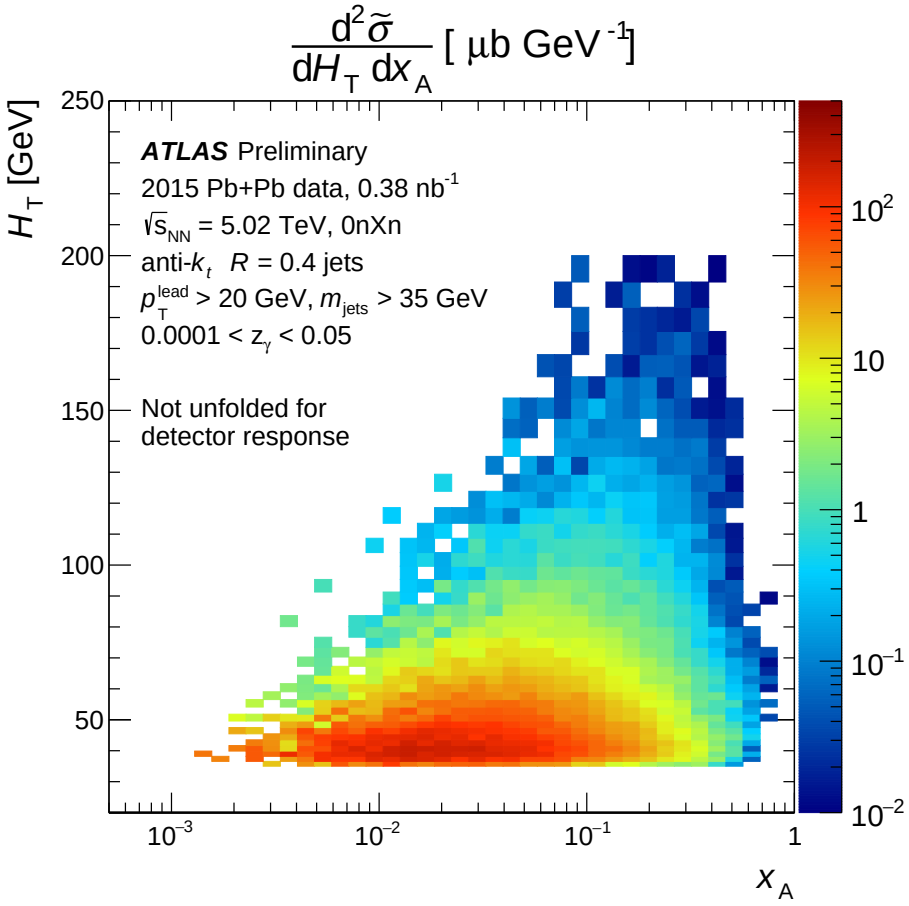
Fiducial cross-section and systematic uncertainties

$$\frac{\mathrm{d}^3\widetilde{\sigma}}{\mathrm{d}H_\mathrm{T}\mathrm{d}x_A\mathrm{d}z_\gamma} = \frac{1}{\mathcal{L}}\frac{N_\mathrm{Data}}{\Delta H_\mathrm{T}\Delta x_A\Delta z_\gamma}\frac{1}{\epsilon_\mathrm{trig}\epsilon_\mathrm{sel}}$$

- ZDC inefficiency to loose 0nXn configuration
  - $\sim 2\%$, independent of the jet kinematics
- Inefficiency due to gap requirement
  - mostly $\sim 1\%$ except for large z_γ and small x_A: correction up to 30% implying 10-25% systematic uncertainty
- EM dissociation from additional PbPb collisions, producing extra neutrons in γ-going direction
  - $5\% \pm 0.5\%$ on overall normalisation (from RELDIS)
- Luminosity: 6.1% uncertainty
- Jet response not unfolded $\rightarrow \widetilde{\sigma}$
  - Jet scale and resolution uncertainties propagated

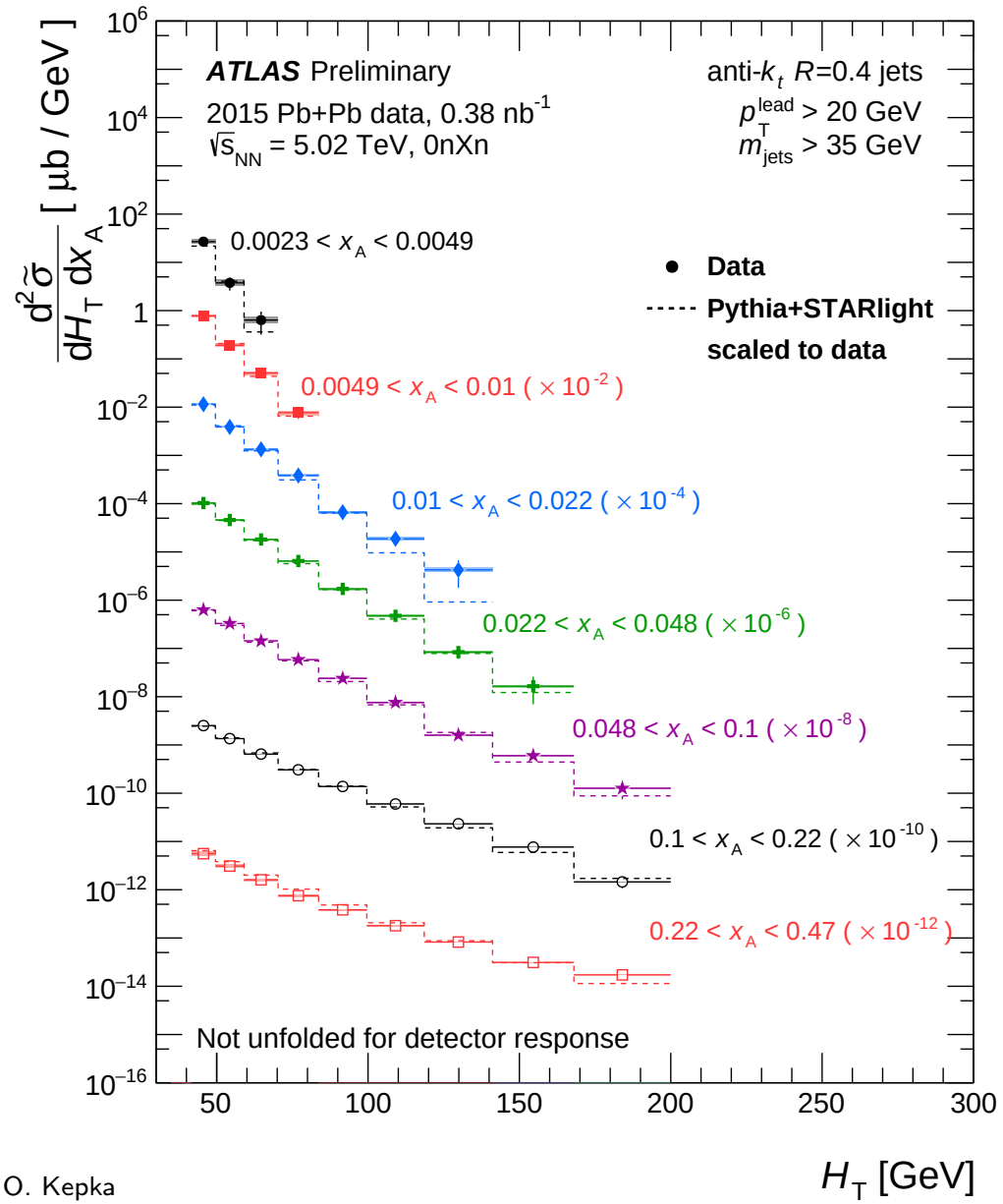
2D cross section





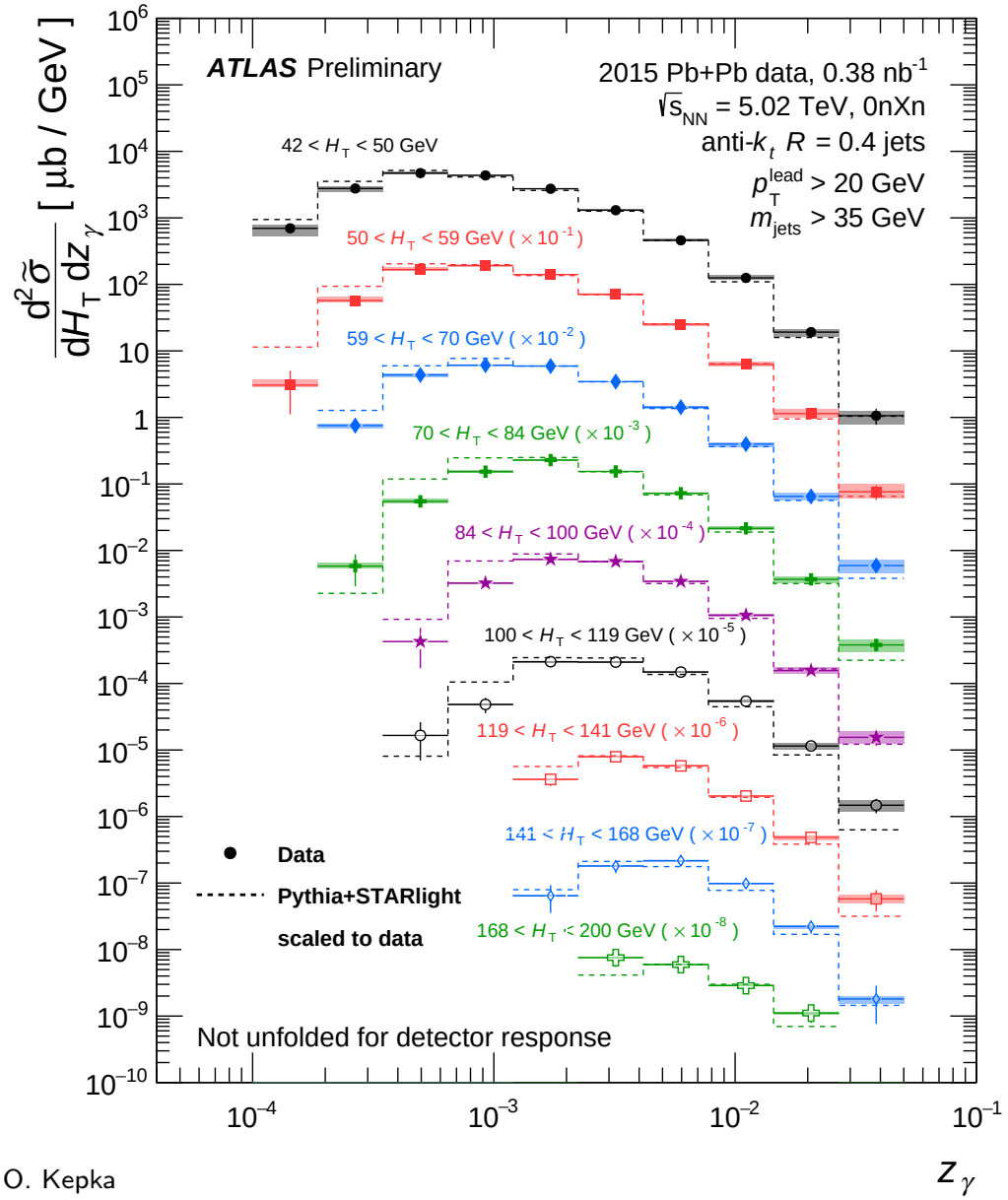
- The x_A and z_γ reach depends strongly on the minimum mass of jet system
- Small x_A requires large z_γ

Results: H_{T} dependence



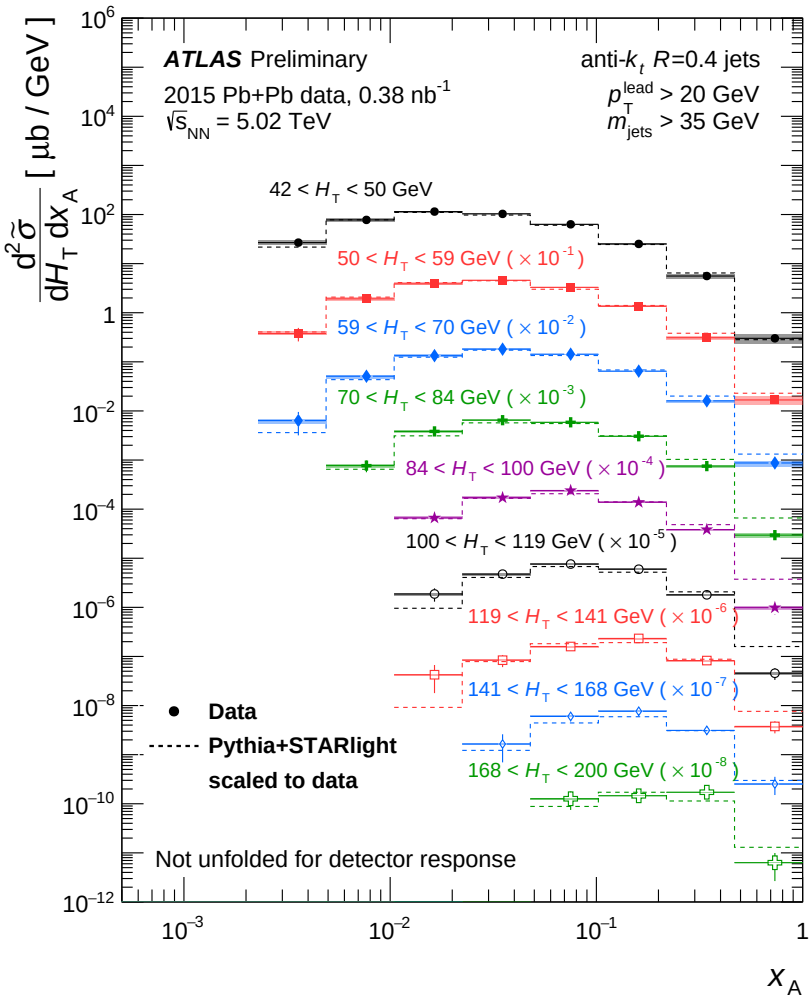
- Slices of x_A
- Theory prediction normalized to data in the measured kinematic range
- Theoretical uncertainty does not include luminosity uncertainty (6.1% constant effect)
- $F(x, Q^2)$ like plot, however, z_γ photon kinematics included in the cross-section

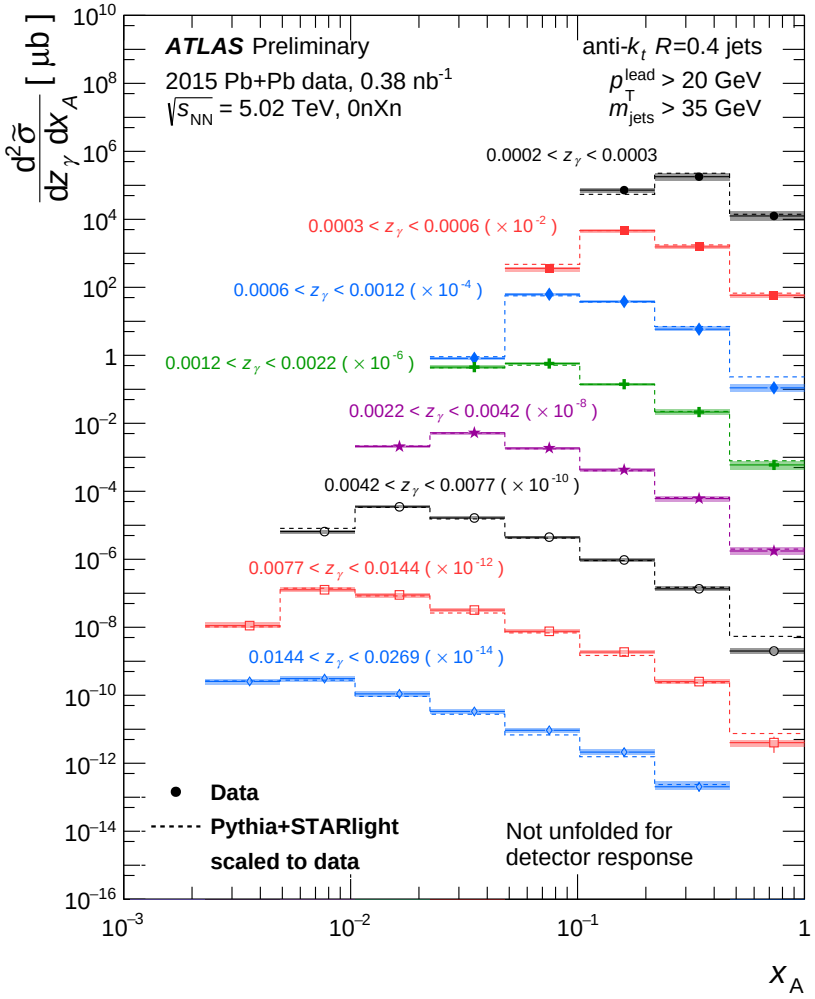
Results: z_γ dependence



- Slices of H_T
- Largest disagreement for large and small z_γ where re-weighting is most important

Results: x_A dependence





- Slices of H_{T}
- Slices of z_γ

Conclusion

- First measurement of photo-nuclear dijets in PbPb collisions
- UPC events selected
  - by requiring rapidity gap on γ-going side and leading neutrons on Pb-going side
  - $\gamma - \gamma$ background suppressed by limiting the gap on Pb-going side

- Prove that UPC events can be selected from regular HI collision
- Opens up a new possibility to study nucleon structure at LHC
- New coverage in terms of (x_A, Q^2), input for determination of nPDF
- Smaller x_A can be reached with future PbPb data in 2018

- Preliminary result needs to be unfolded for detector effects
- More rigorous comparison to theory needed

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EDS Blois 2017

17th International Conference on Elastic and Diffractive Scattering
Prague, Czech Republic, 26-30 June 2017

Topics

- Elastic scattering and total cross section
- Hard diffraction and exclusive production
- Soft QCD and soft diffraction
- Heavy ions
- Cosmic rays
- Forward physics (low-x QCD)
- Theory developments in forward physics

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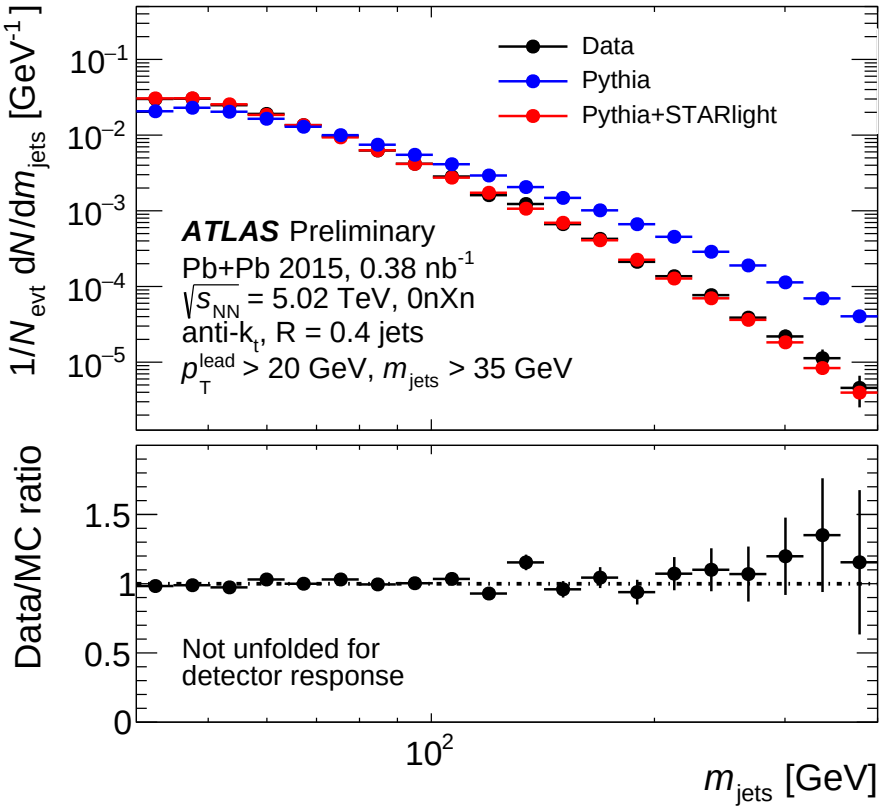
Backup

Data/MC comparisons



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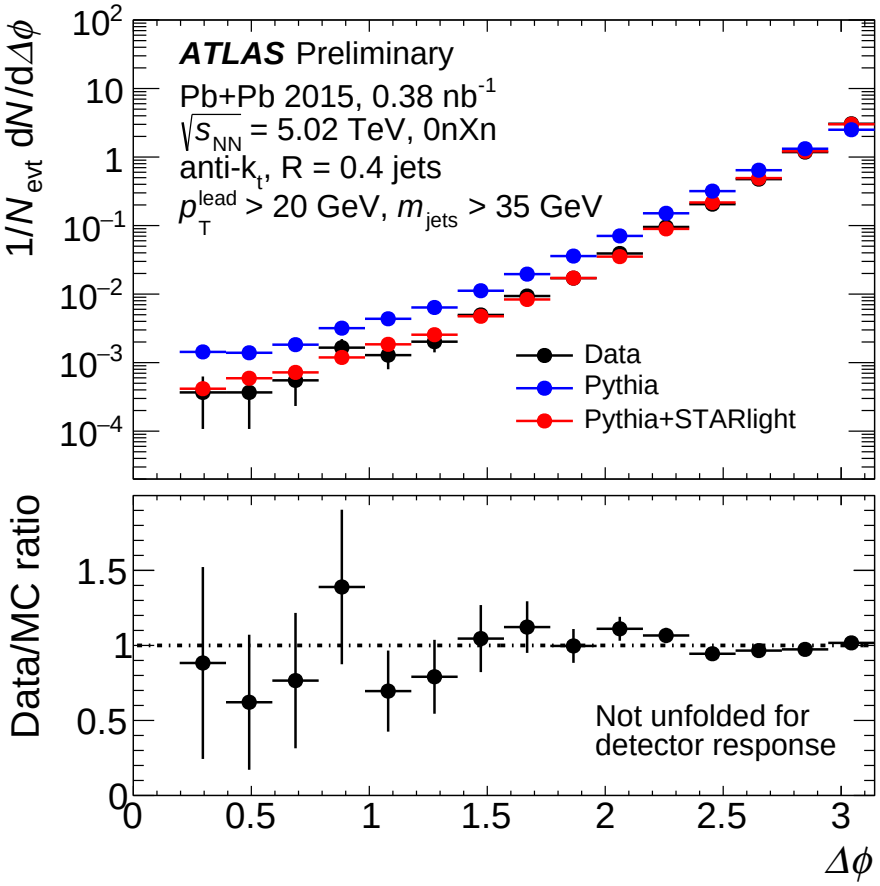
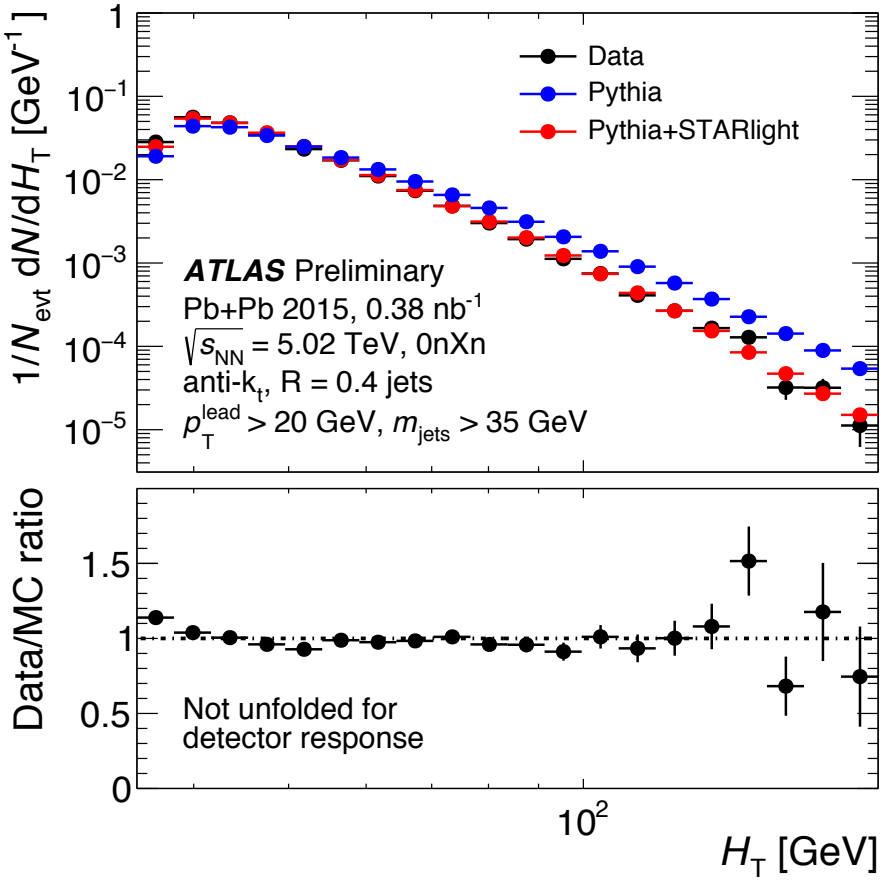
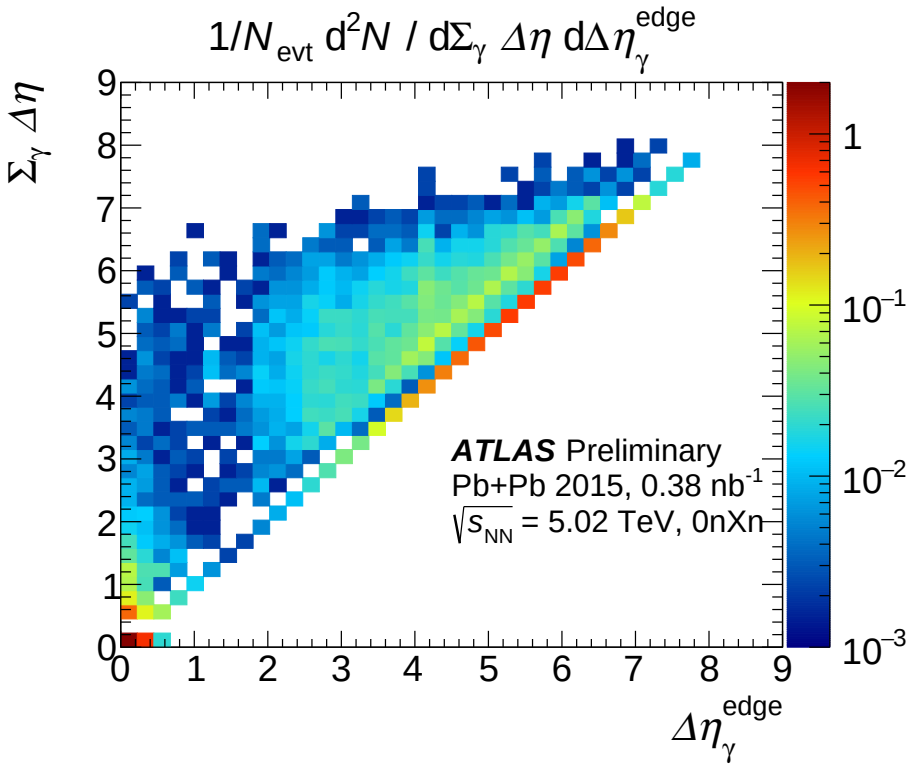
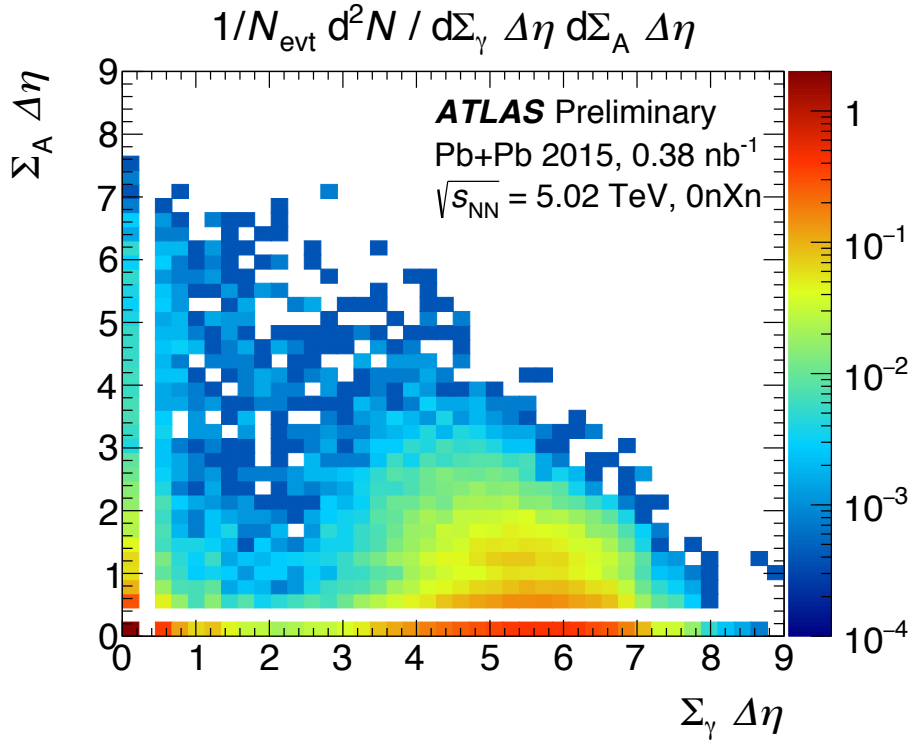




Event topology: edge and sum gap





- indication of resolved contribution in edge and sum gap correlation