Jet Production in ultra-peripheral collisions @ LHC (with ATLAS)

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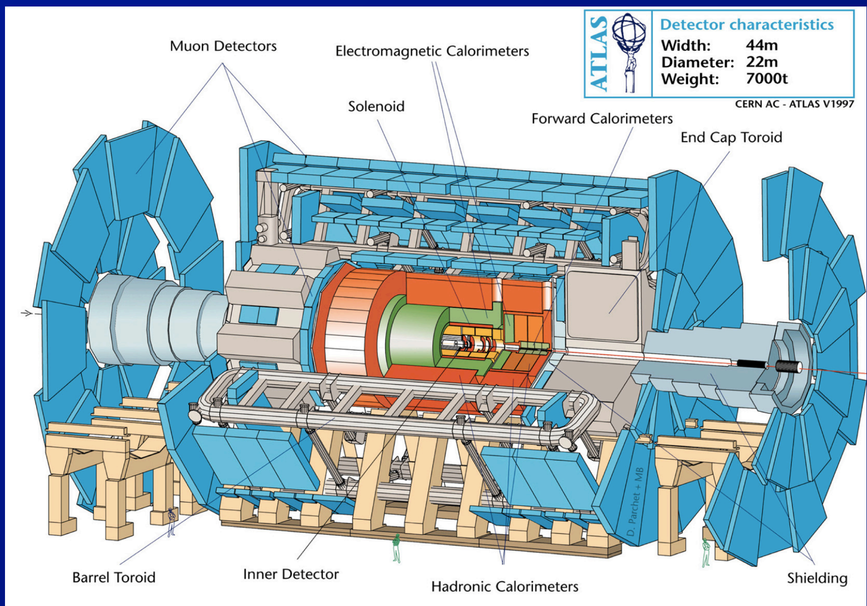
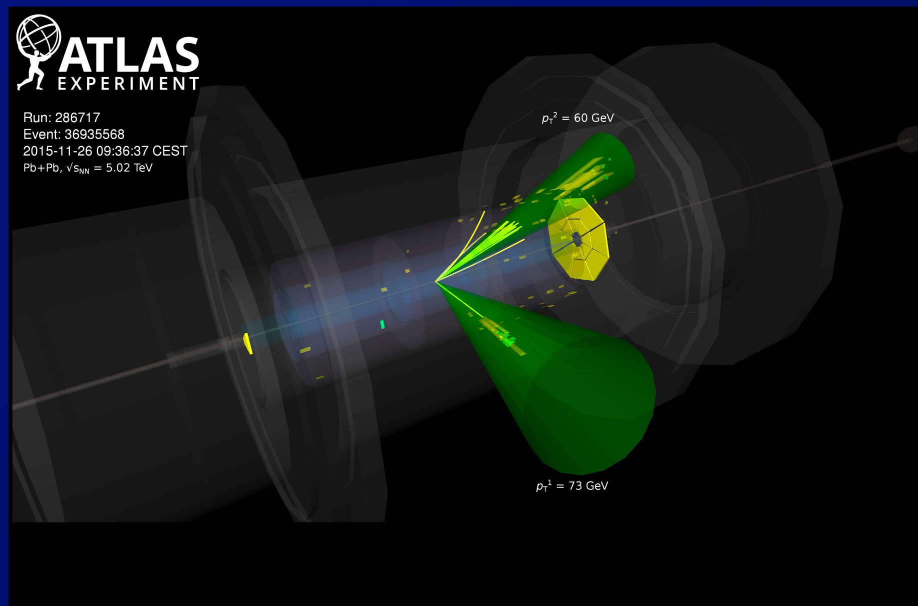
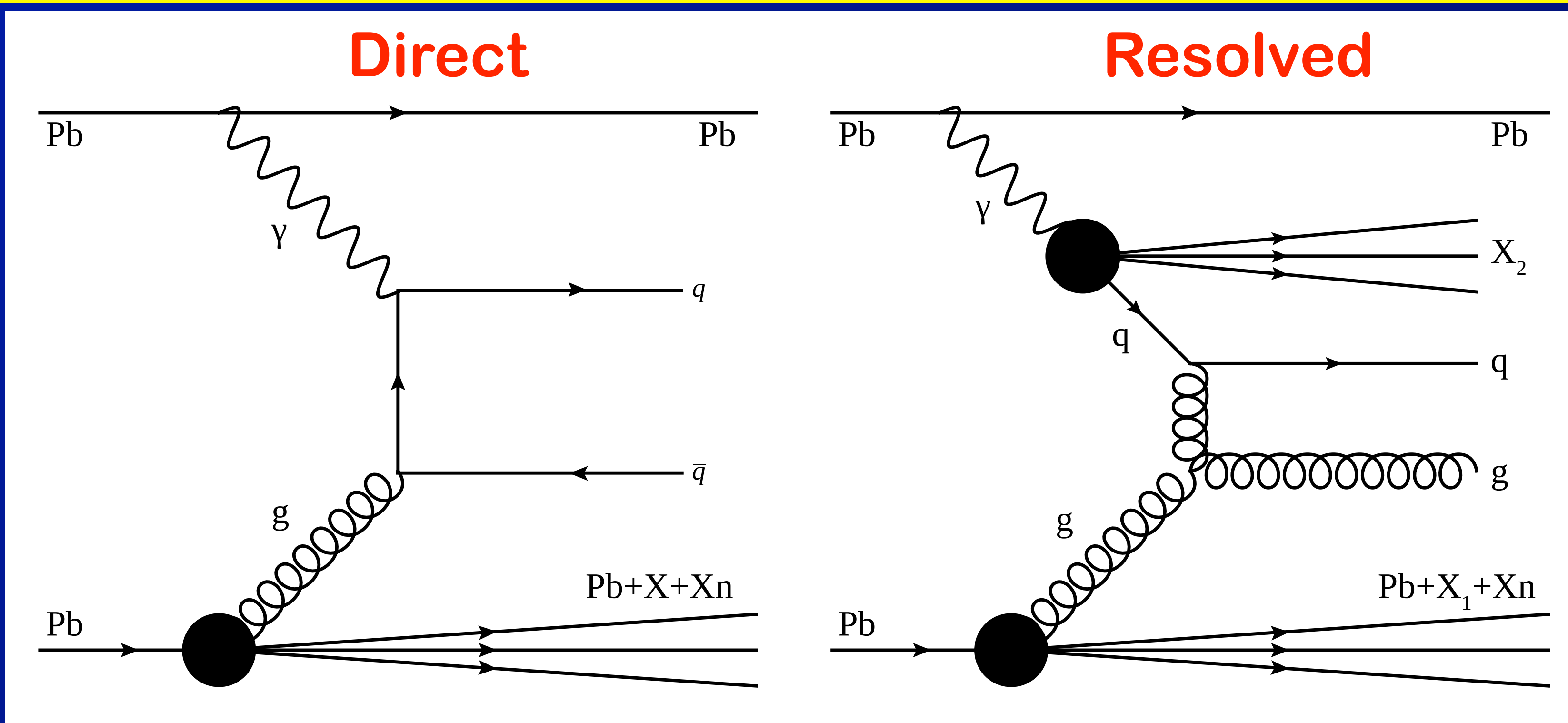




Outline

- Start with focus on (non-diffractive?) γ+A
  - Provide framework for discussing experimental aspects of the measurement(s)
  - Results relevant for/complementary to EIC program
- Discuss issues related to nuclear breakup
- Discuss "0n0n" measurements
  - $\gamma+\gamma$ contribution
  - Diffractive photo production
  - Photo-nuclear processes w/o Pb breakup?
- Gap survival, resolved photons
  - Hadronic y and x_γ measurement
- Summary/discussion

UPC photo nuclear jet production



- (Mostly) coherent photons from one nucleus
  - scatters off a Parton from the other (direct)
  - breaks up, parsons scatters of other (resolved)

⇒Old idea (Strikman, Frankfurt) to use photo-nuclear collisions to measure nuclear PDFs

UPC photo nuclear jet production

- Rough acceptance using kinematics of preliminary 2015 analysis
  - Jet $|\eta| < 4.5$
  - Leading jet $p_T > 20$ GeV

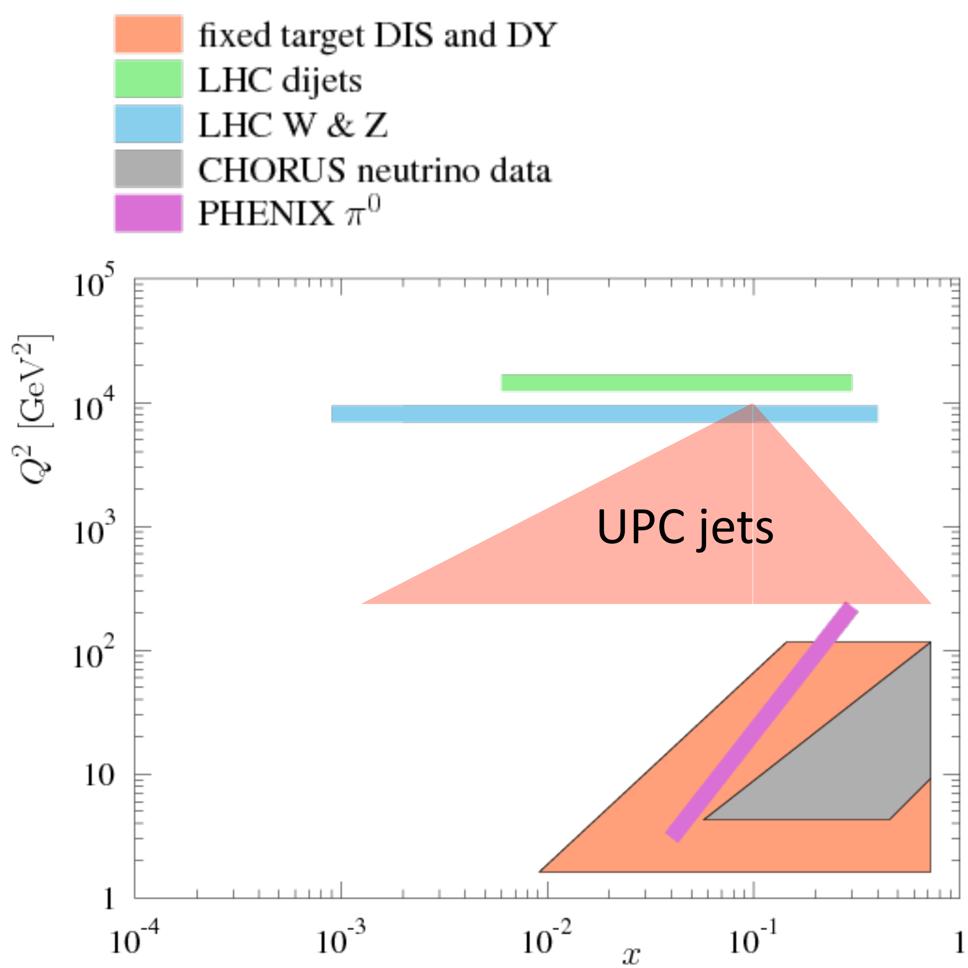
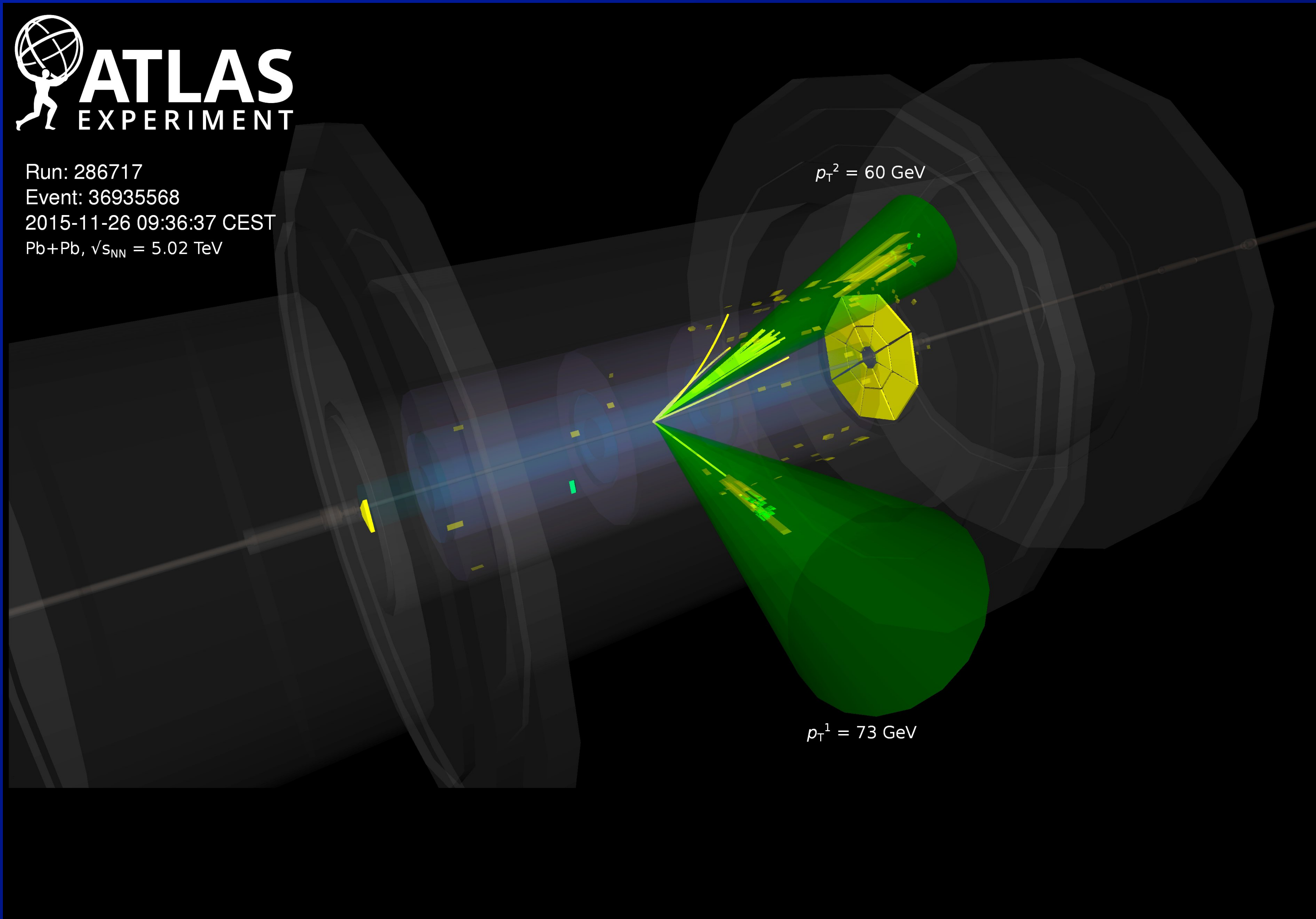
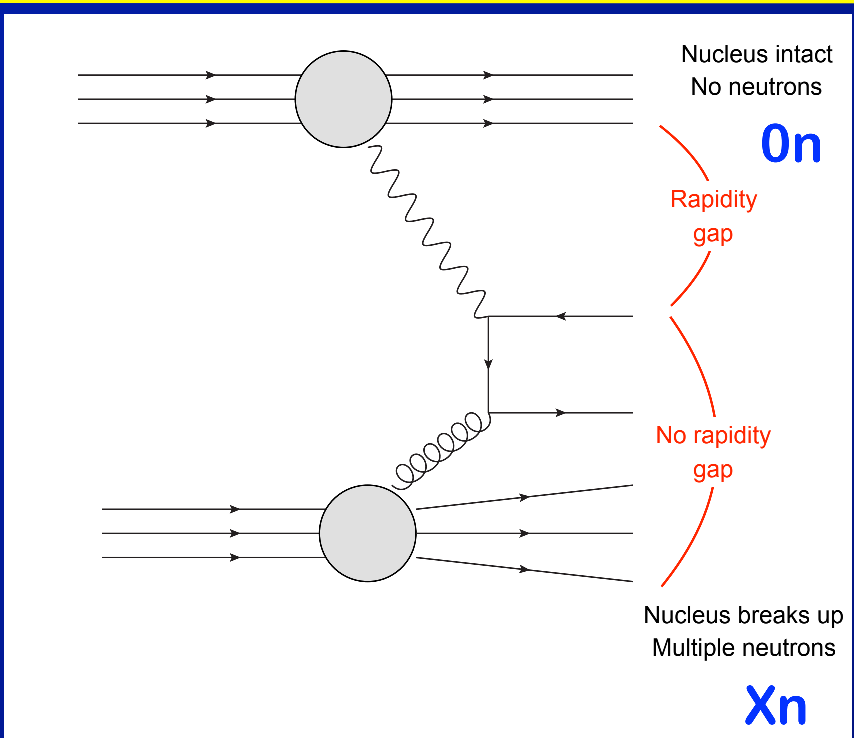


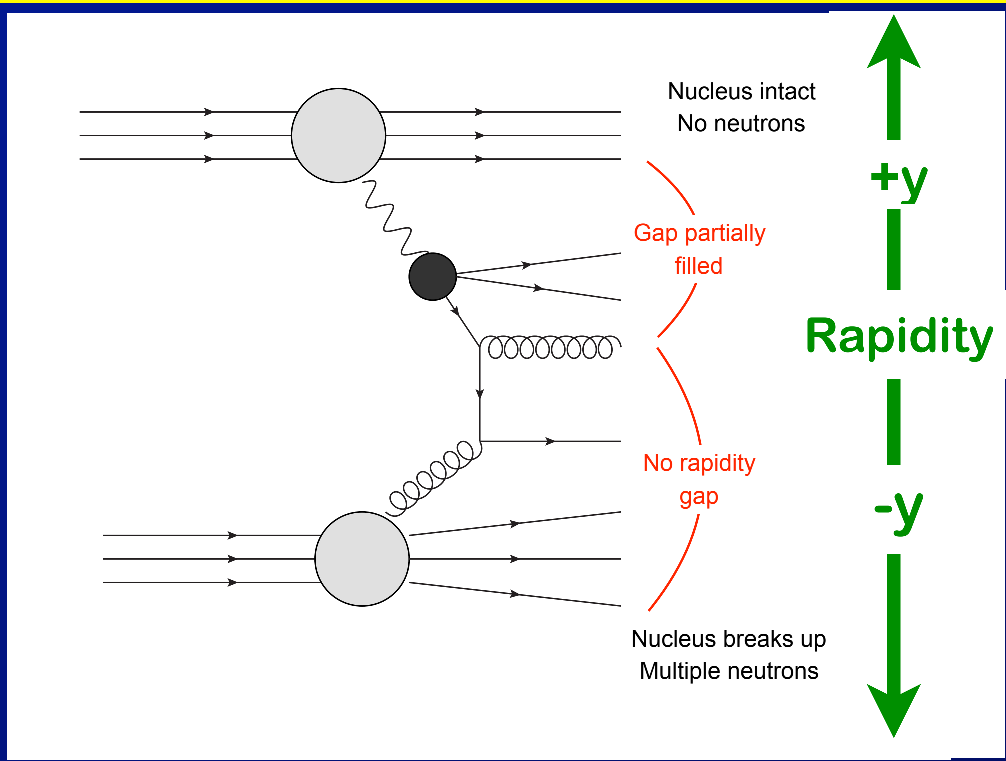
Figure adapted from EPPS16 1612.05741 [hep-ph]

UPC dijet event display



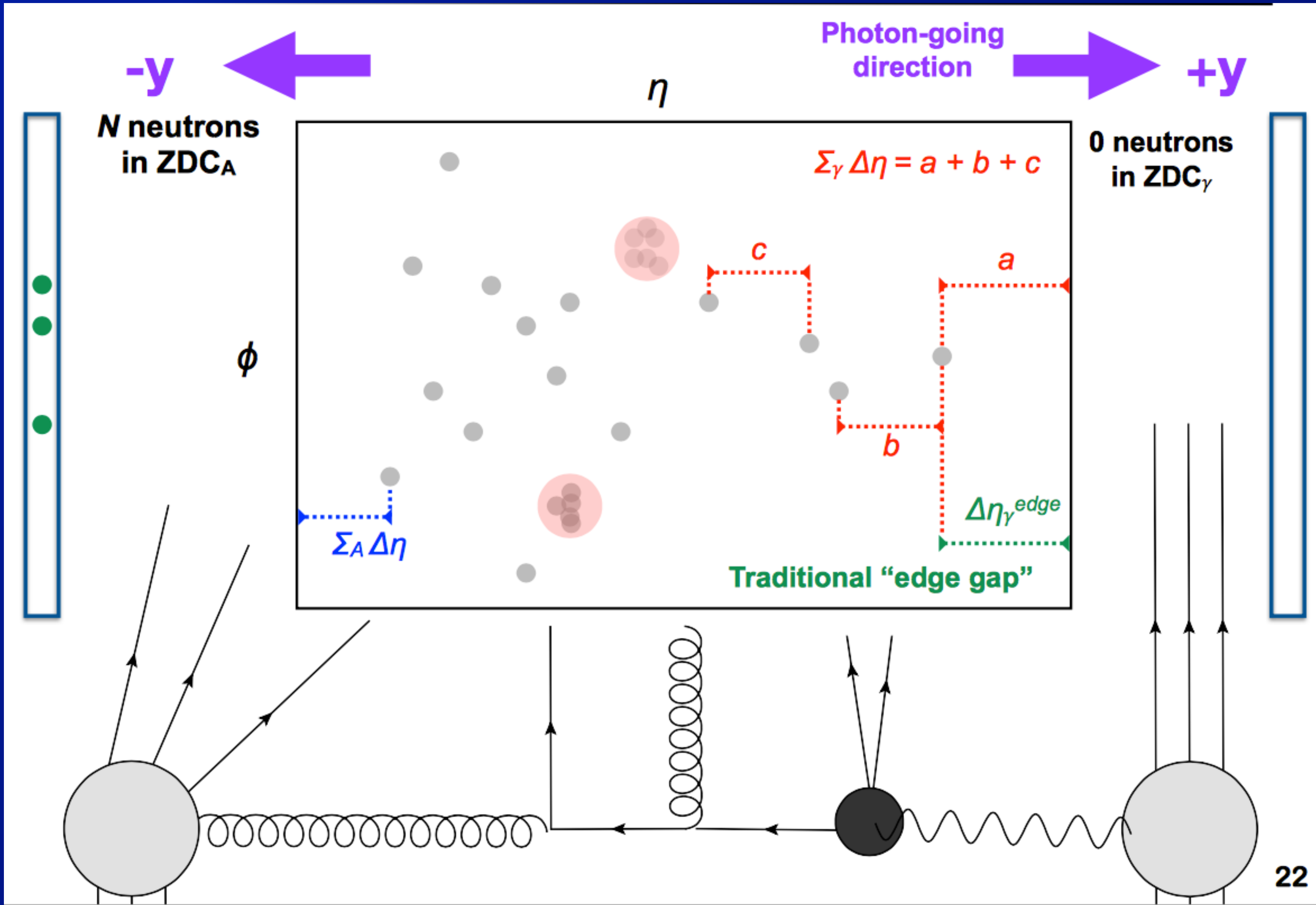
Event selection





- Two experimental handles: ZDC energy, gaps
  - no neutrons in photon-going direction
    - ⇒Except for Coulomb excitation-induced breakup
  - Rapidity gap in photo-going direction
    - ⇒Partially filled by photon remnant

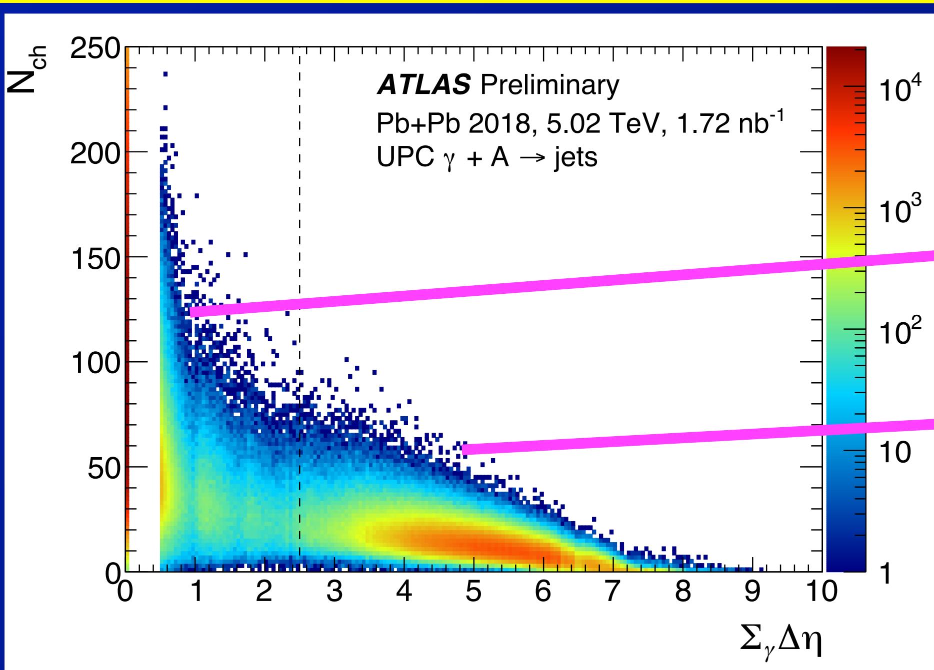
Gap analysis

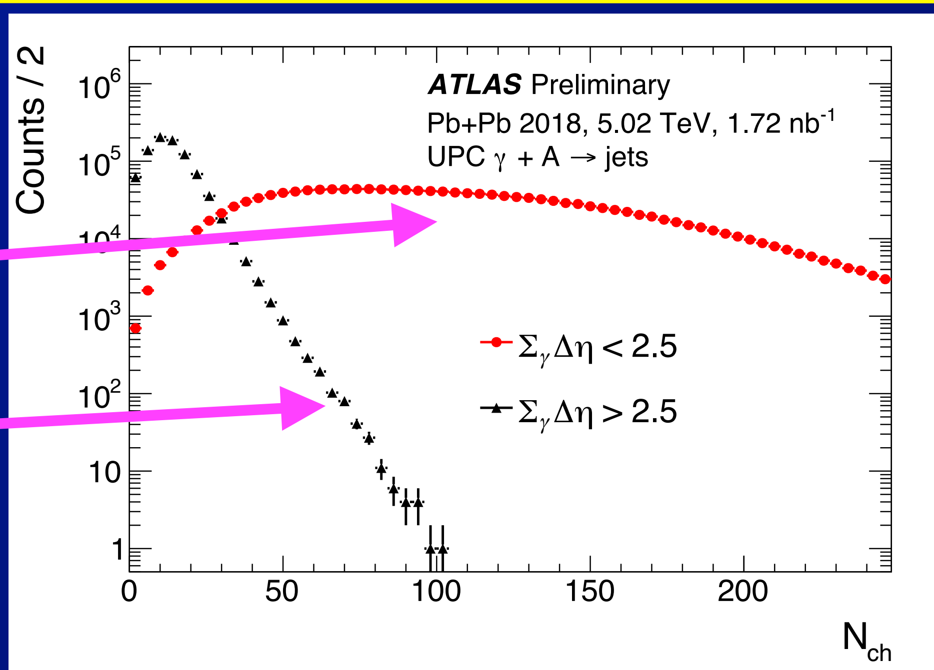


- To handle resolved contribution:
  - sum gaps greater than some size (currently 0.5)

  ⇒ optimize resolved γ efficiency and hadronic rejection

(Sum) gap selection in γ direction



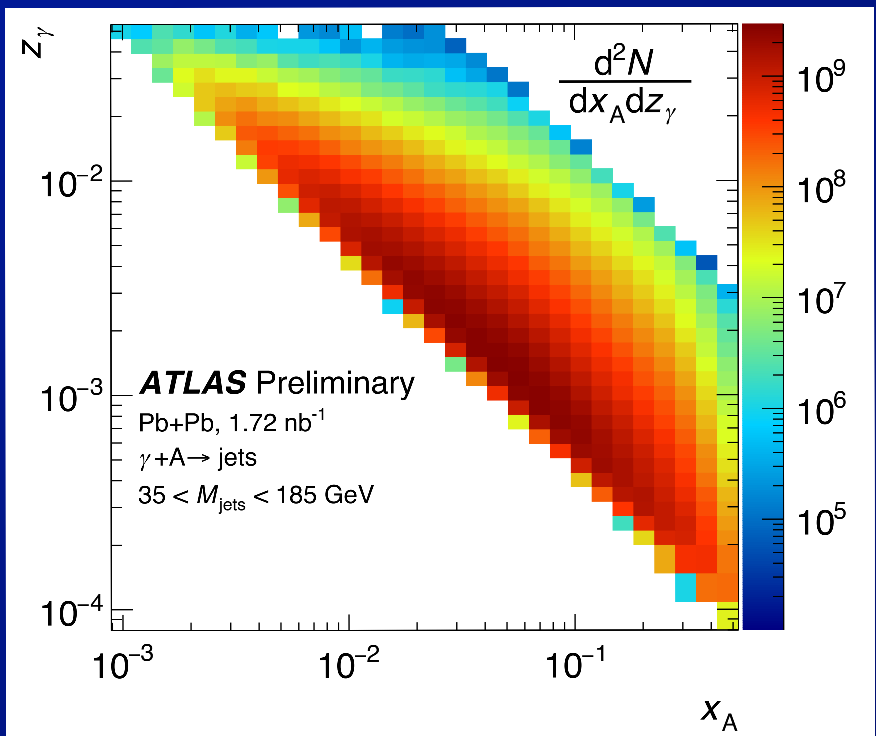


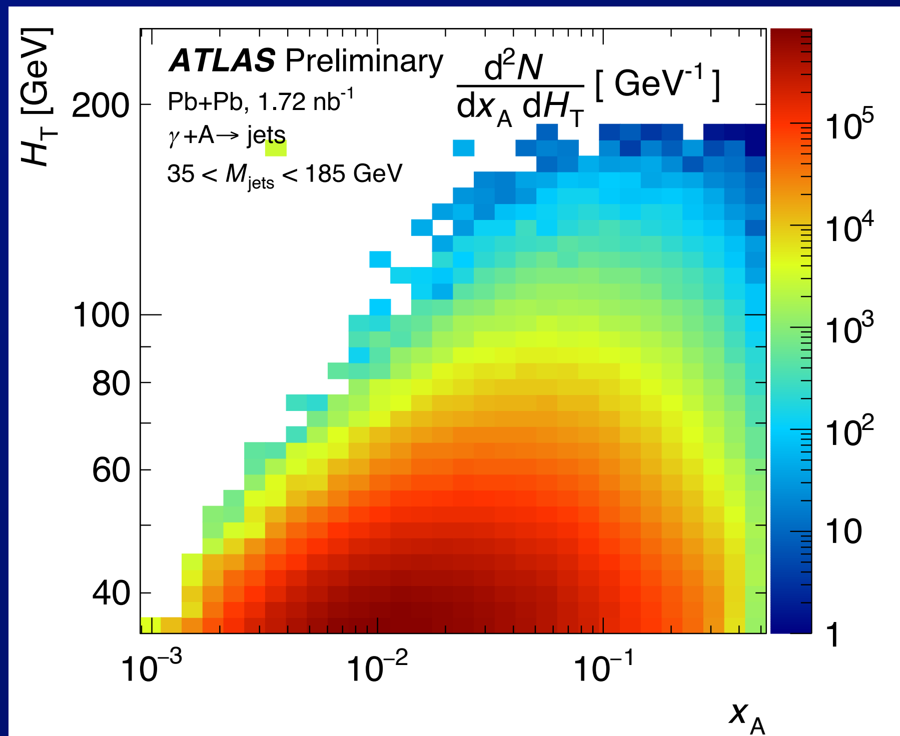
- Select γ direction using ZDC (0n)
  - Define as +y (+η) direction
- Evaluate ΣΔη between most forward jets and detector edge (4.9)
  - Plot versus charge particle multiplicity ($|\eta_{ch}|<2.5$)

⇒Clear** separation between photonuclear events and hadronic background

Photonuclear kinematics

- From the dijet (or N jet) mass and rapidity, reconstruct LO kinematics:
  - $H_T = \sum_{\text{jets}} p_T \approx Q$
  - $x_A = \dfrac{m_{\text{jets}}\, e^{-y_{\text{jets}}}}{\sqrt{S}}$
  - $z_\gamma = y_\gamma \times x = \dfrac{m_{\text{jets}}\, e^{+y_{\text{jets}}}}{\sqrt{S}}$ → energy of parton from photon entering the hard scattering



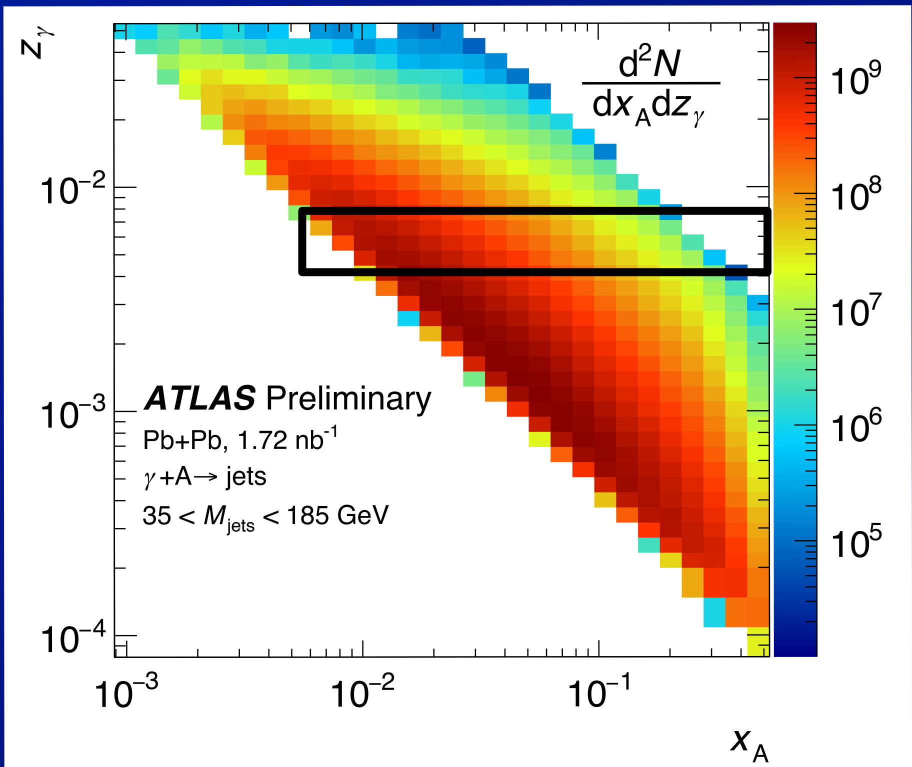


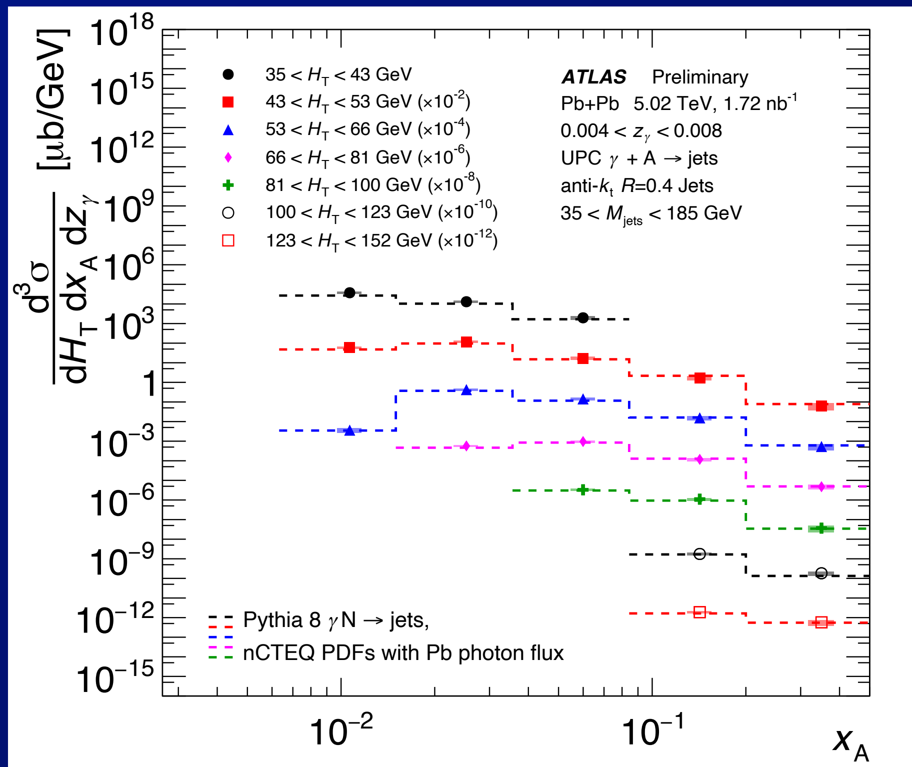
Cross-sections

- **Measure triple-differential cross-section:**
  - Unfolded to particle level (mostly jet response)

$$\Rightarrow \frac{\mathrm{d}^3\sigma}{\mathrm{d}H_T\,\mathrm{d}x_A\,\mathrm{d}z_\gamma} = \frac{1}{\mathcal{L}}\,\frac{N_{\mathrm{evt}}}{\Delta H_T\,\Delta x_A\,\Delta z_\gamma}$$

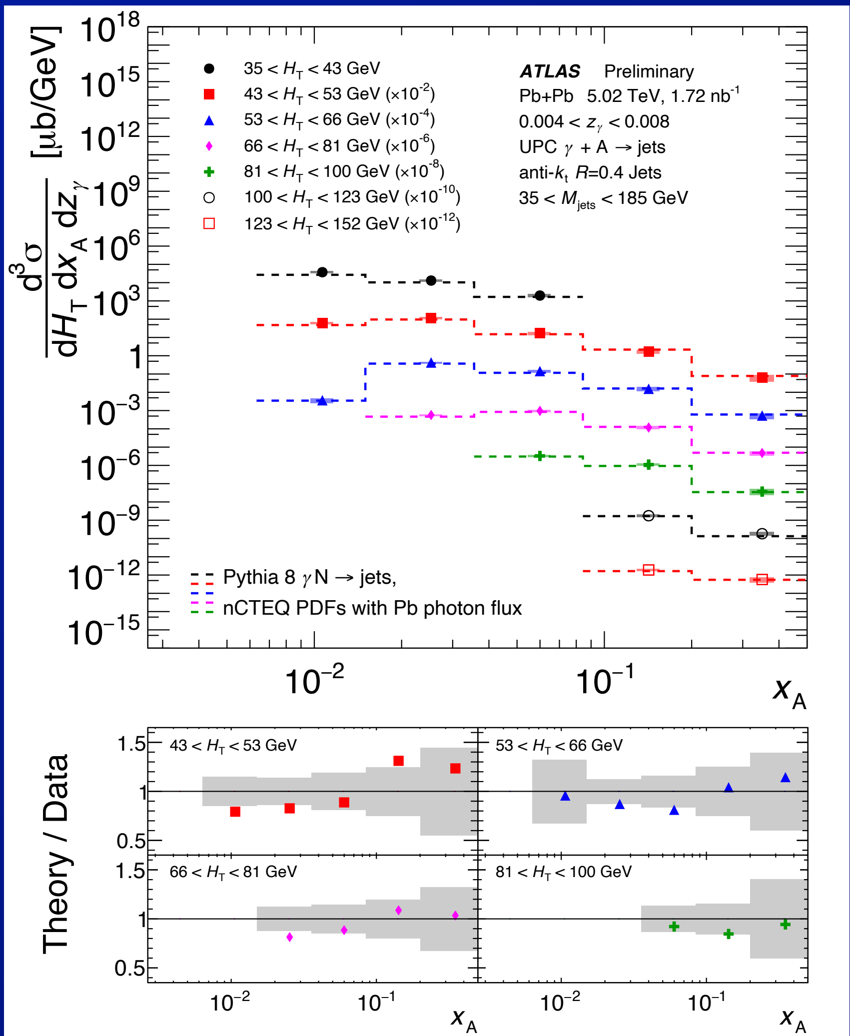
- **Measure in slices (e.g. in z_γ)**

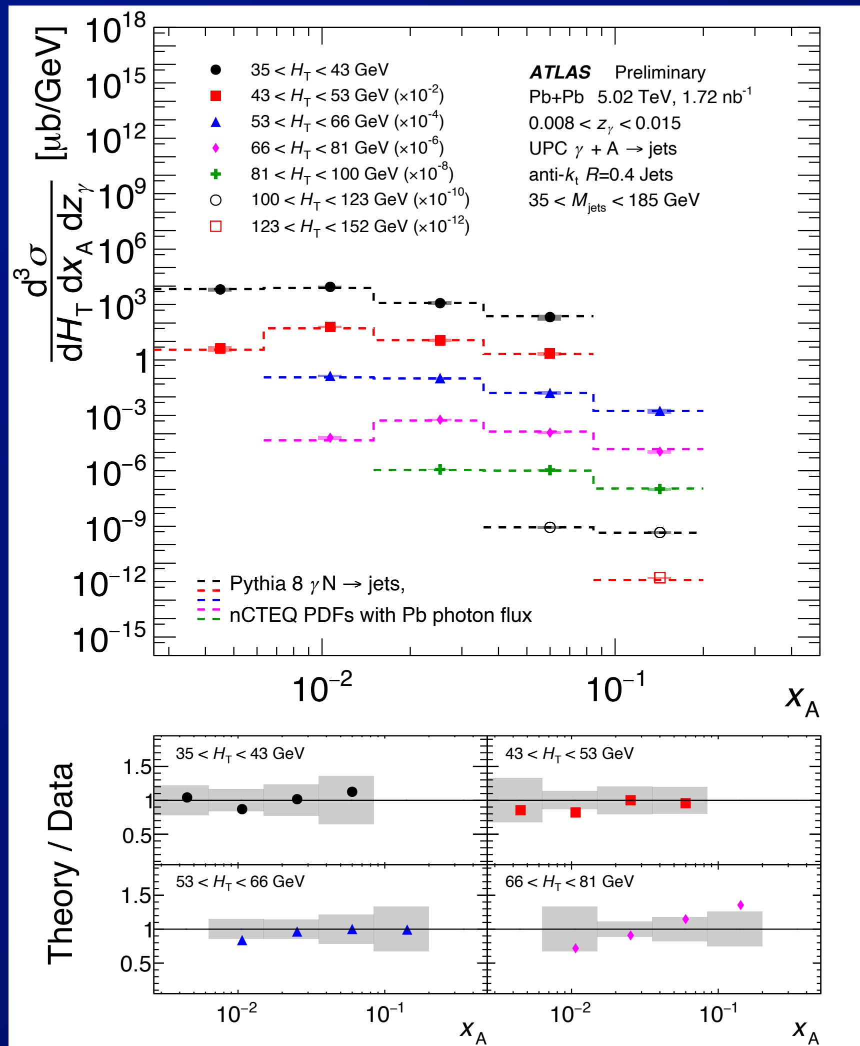




Compare to Pythia8 + breakup

- Pythia8 MC: γ+A w/ nuclear photon flux + nCTEQ15 PDFs, corrected (down) to 0nXn
  - ⇒ See reasonable agreement w/ data

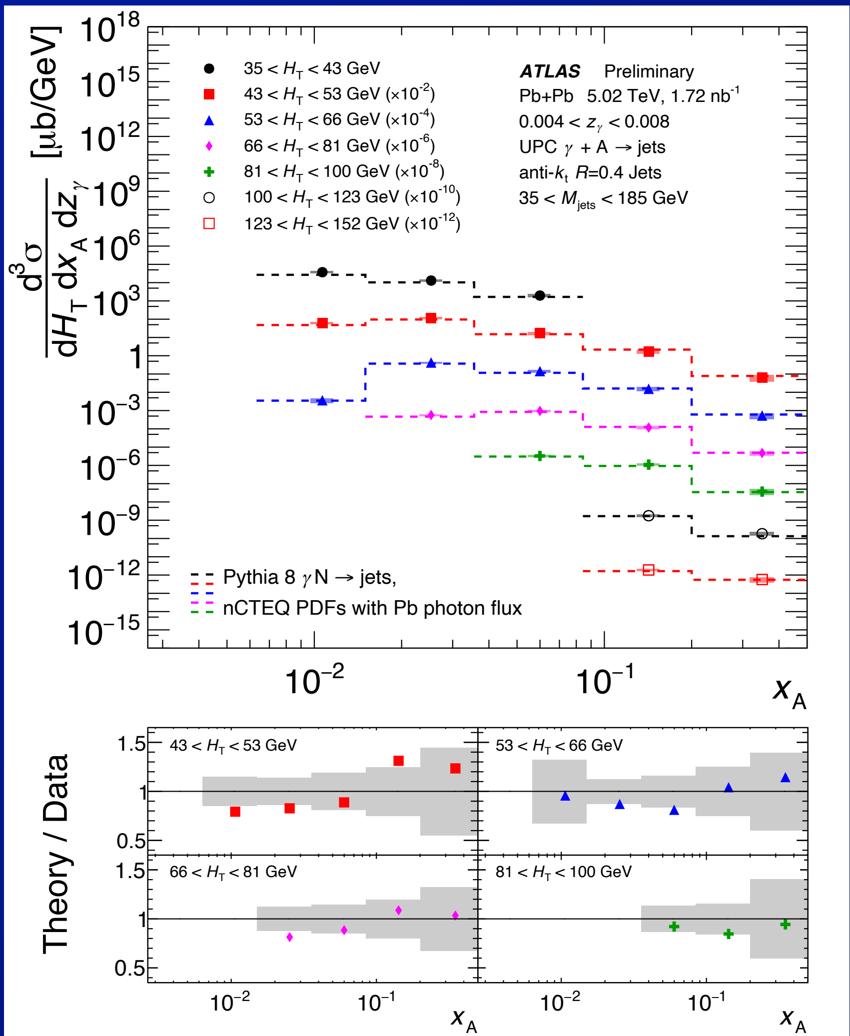


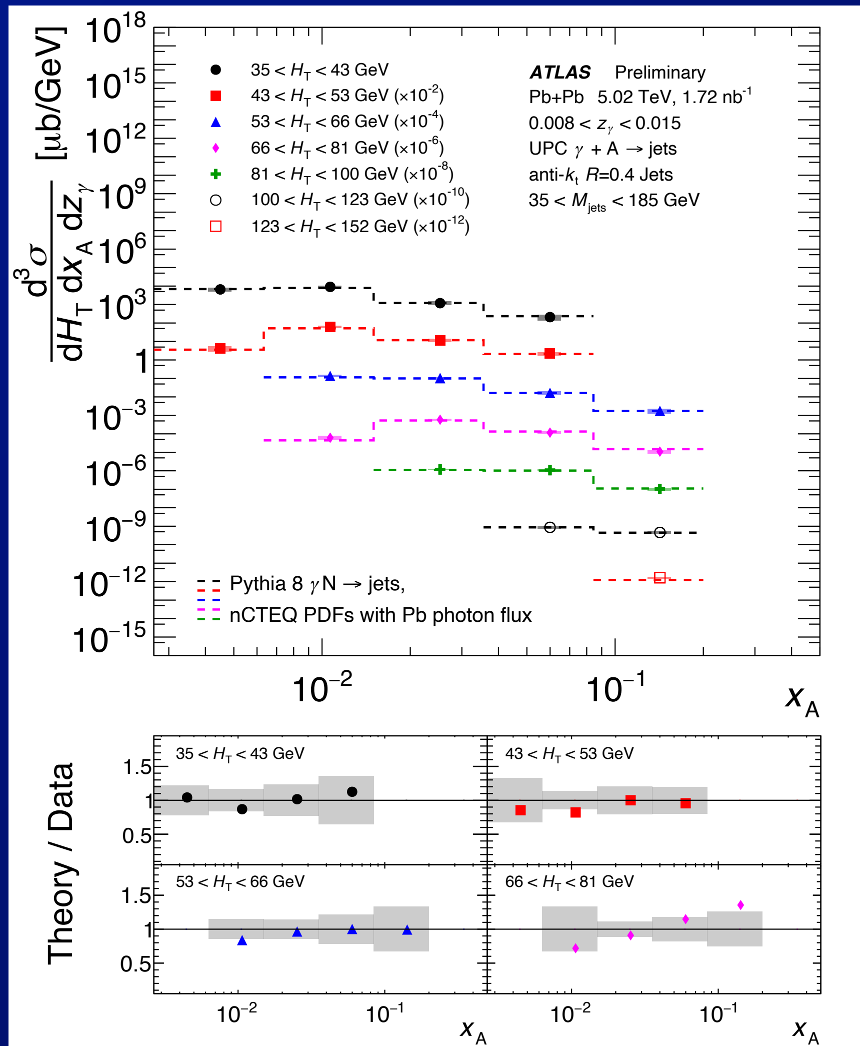


Compare to Pythia8 + breakup

- Systematic uncertainties will decrease significantly in final measurement

⇒expected September 2023

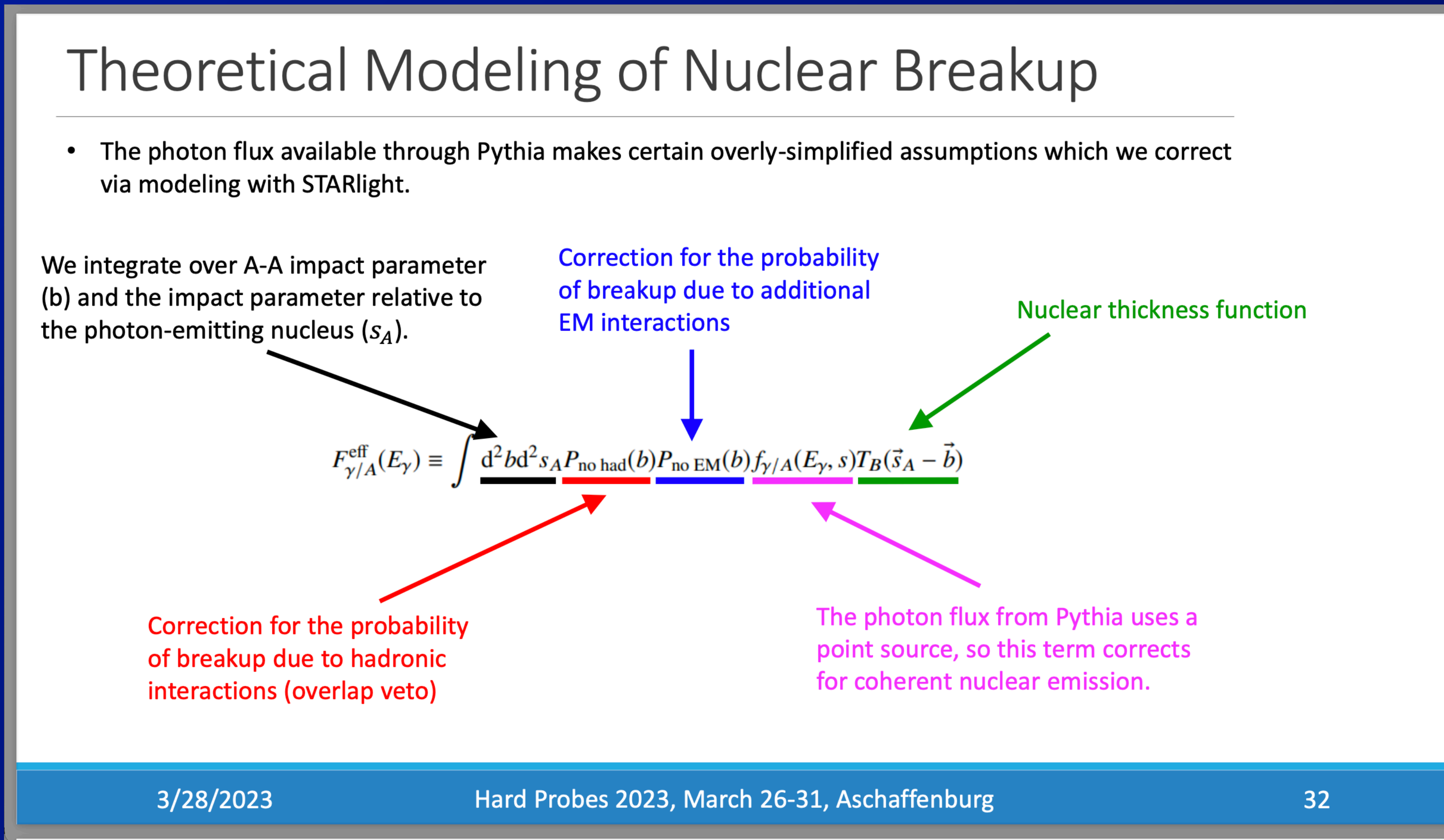




Nuclear breakup

- **Nuclear breakup probability is process-dependent, must evaluate for γ+A**
  - Express in terms of survival probability

⇒ From B. Gilbert's Hard Probes 2023 talk



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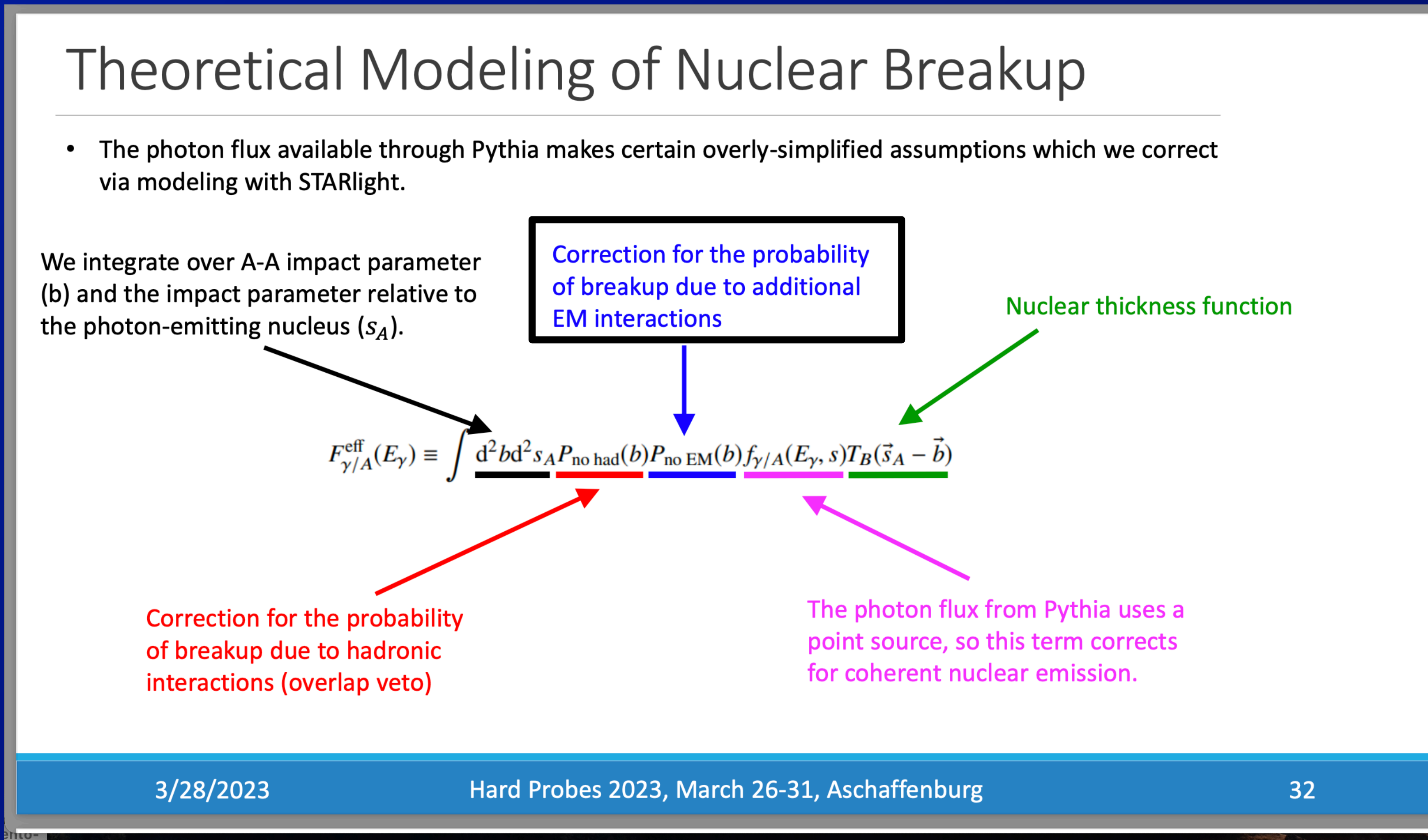
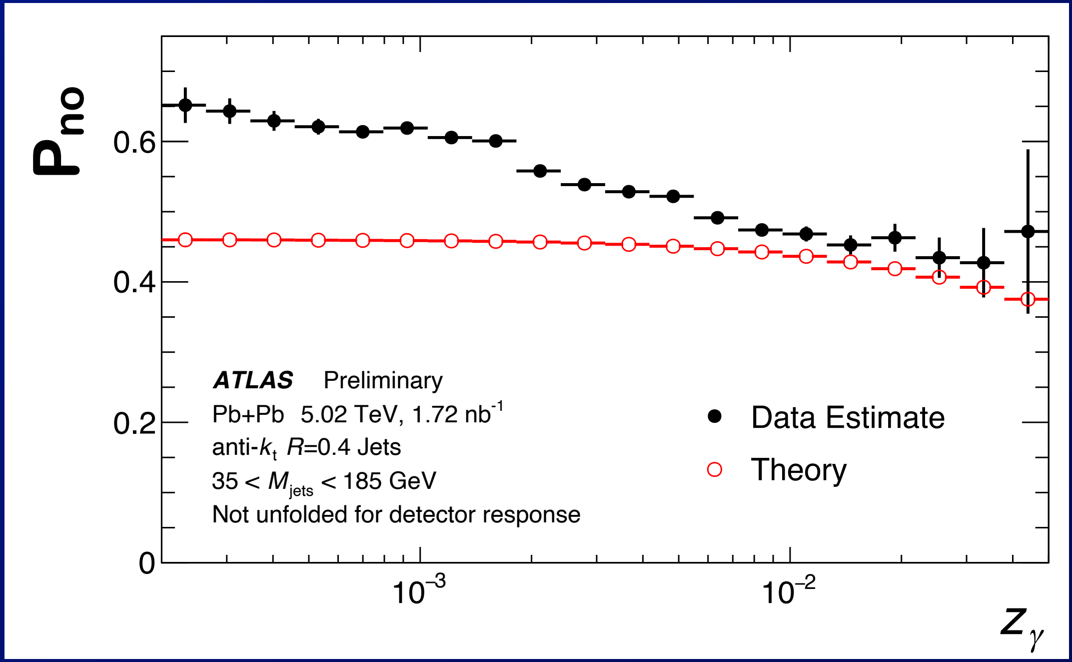


Nuclear breakup: experimentally

- In Run 2, we required 0nXn condition in trigger
  - Able to sample the full luminosity
- Use separate trigger w/o 0nXn condition to measure γ+A events with XnXn topology
  - Sampled small fraction (~1/1000) of luminosity
- Estimate breakup survival probability

⇒ Not great agreement with improved STARlight

⇒ Controlling the breakup important for measurement



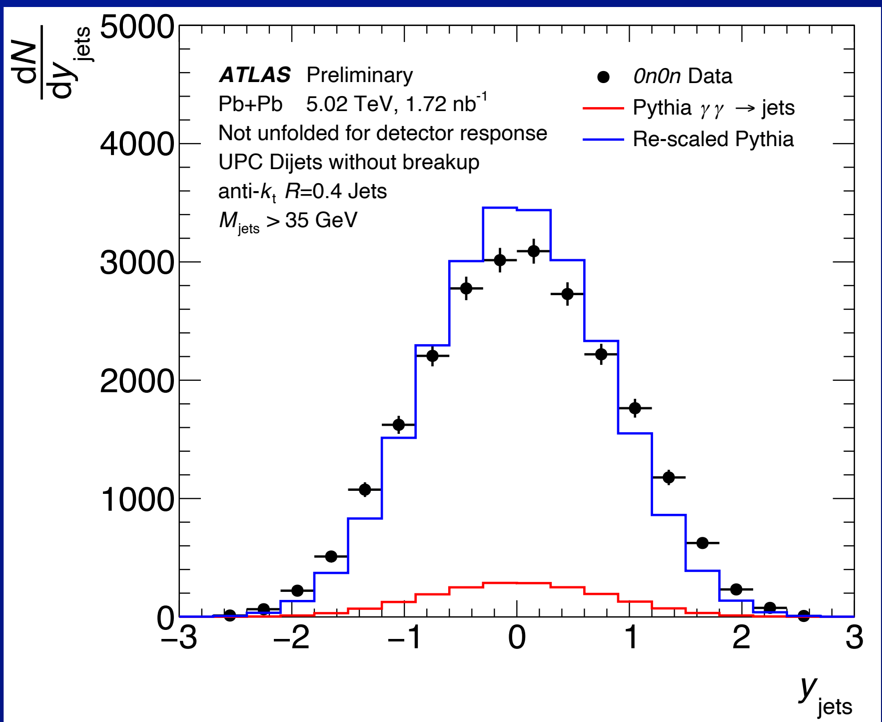
γ+A in 0n0n UPC collisions

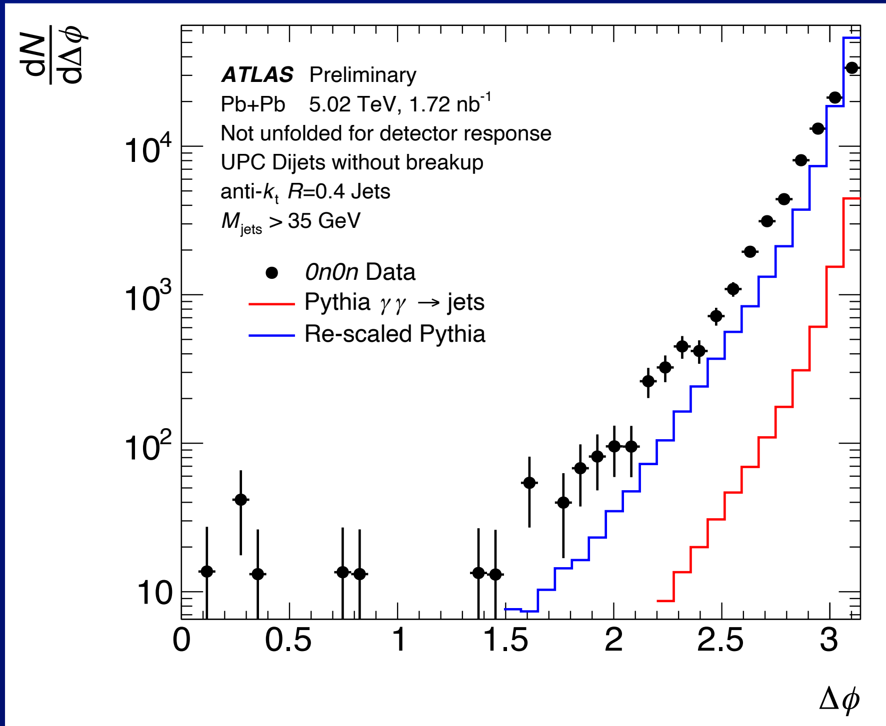
- In Run 2 (2018) we had trigger specifically to measure 0n0n jet events — neither nuclear breaks up
  - Until recently, only relevant MC generator was Pythia8 γ+γ — used as baseline to compare to data

  ⇒ In this case, data not unfolded (yet)
- Compare reconstructed Pythia8+GEANT to data (counts)

  ⇒ Observe 10x more events in data than γ+γ MC

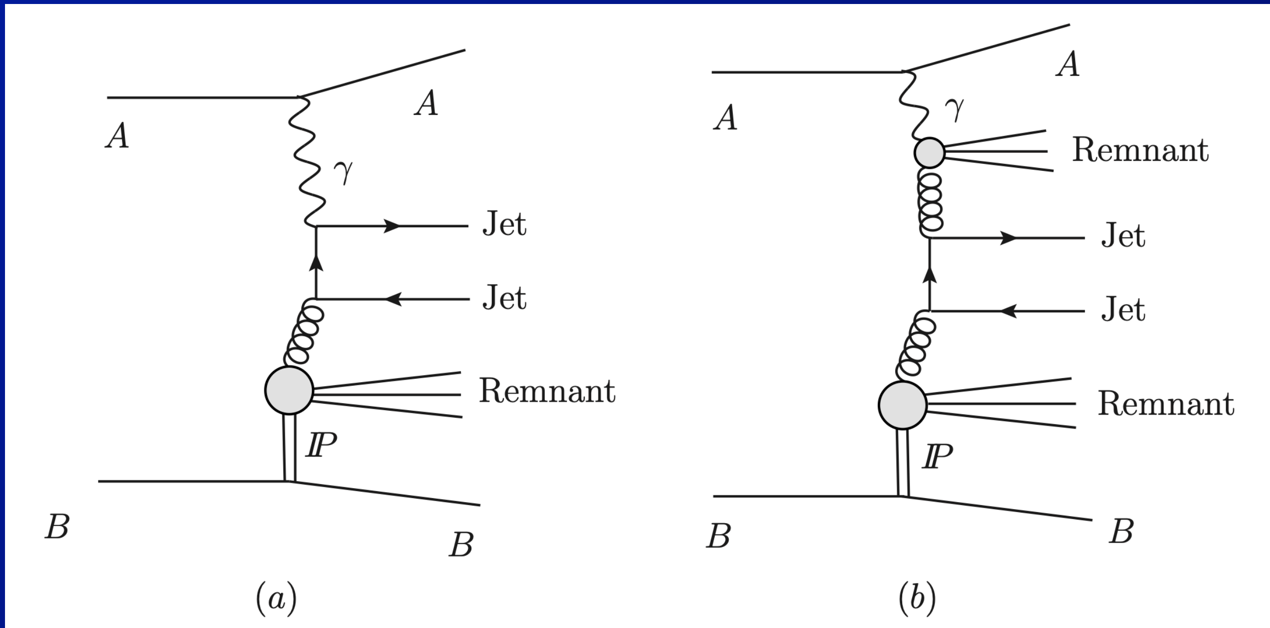
  ⇒ Even scaled by x10, kinematic distributions don't match





Diffractive photo production

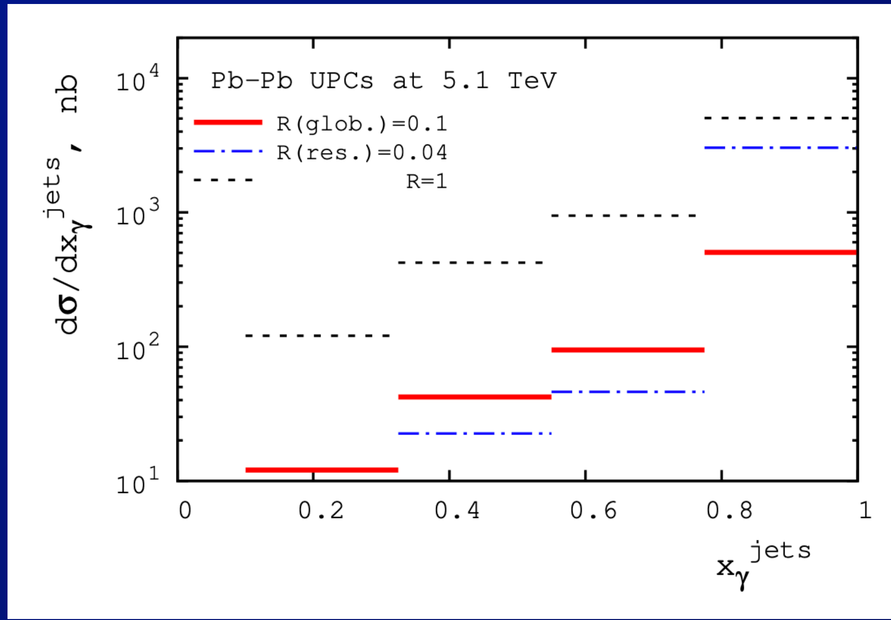
- From Guzey & Klasen (JHEP 04 (2016) 158, arXiv: 1603.06055)
  – LO photo-diffraction diagrams



- For (dominant) coherent Pomeron, no nuclear breakup(?)
  – Coherent Pomeron consistent with y_{jets} peaked near 0
  ⇒ Coherence condition ~same for photon and pomeron
- (Private) comparisons of $d\sigma/dy_{jets}$ to data "plausible"
  ⇒ Photo-diffractive jet measurement underway, but early
  ⇒ In discussions with Mueller, Iancu, re: "cgc topology" (BGU+CU)

Diffractive photo production

- From Guzey & Klasen (arXiv: 2106.16084)
  - Gap survival in UPC photo-diffraction smaller than in HERA data
    - ⇒ But, for all events, or resolved photon only?
  - Propose measuring cross-section vs x_γ
    - ⇒ Fraction of photon energy entering hard scattering



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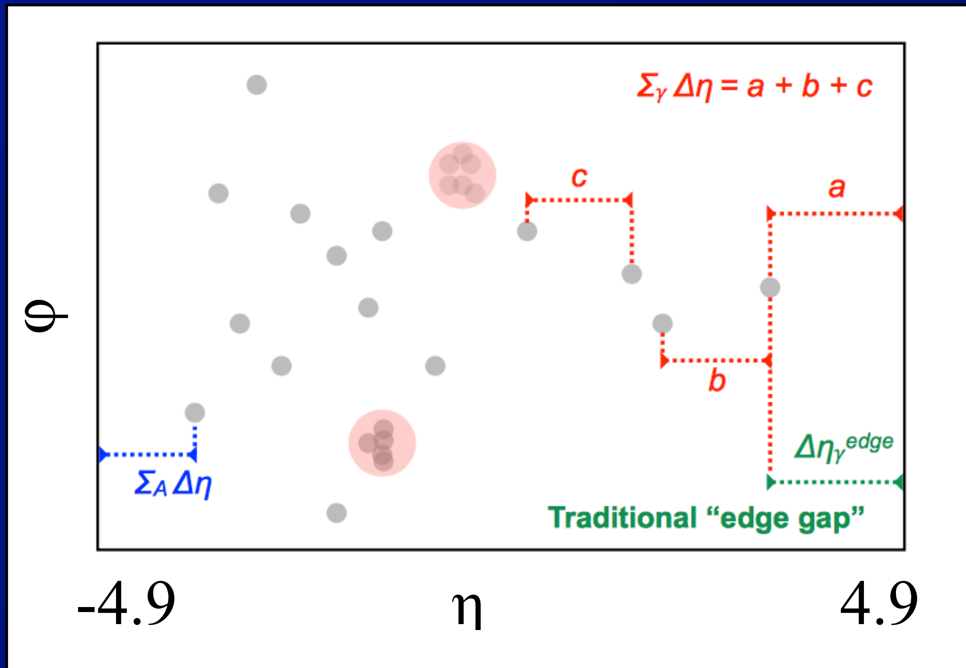
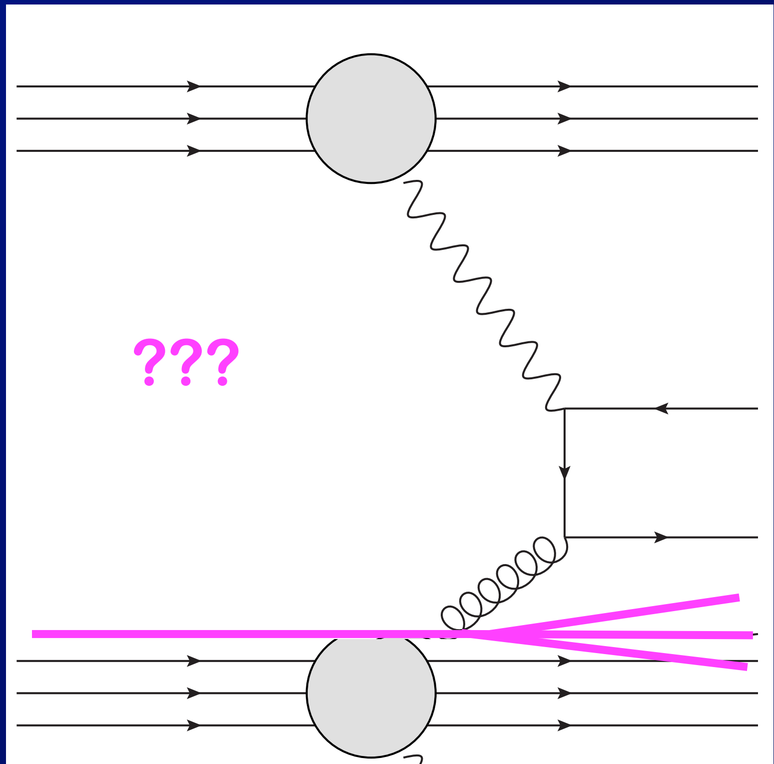


- Experimentally can measure "hadronic y"
  - energy of photon from sum over particle energies
    ⇒ ~ 20% resolution
  - We also directly extract $z = y * x$ from jet kinematics
    ⇒ In principle, possible to measure cross-section vs x_γ

Non-diffractive γ+A w/o breakup

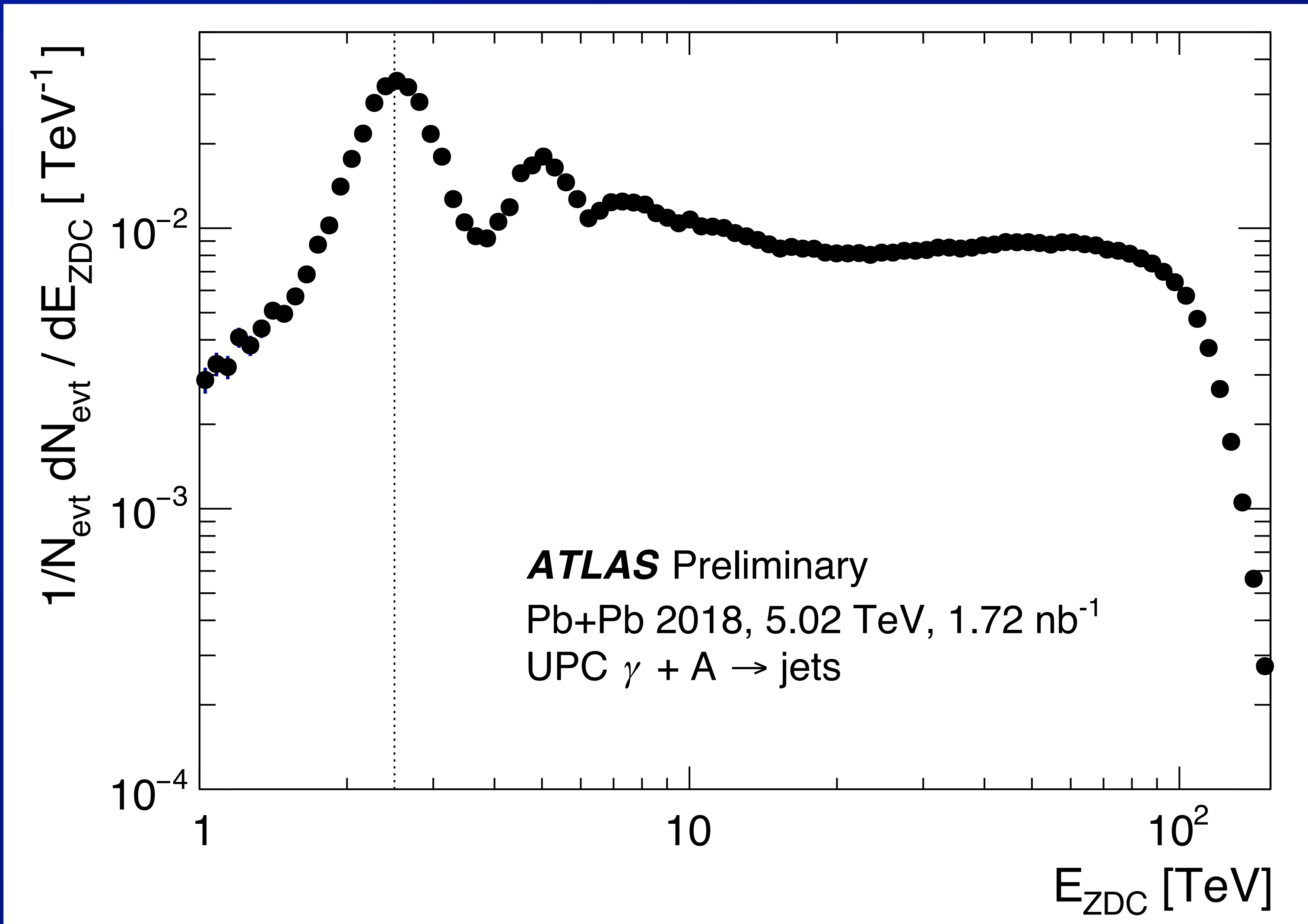
- See indications in 0n0n sample of a non-diffractive photo-nuclear contribution:
  - Asymmetric rapidity distribution, no gap on one side, …
  - ⇒ Suggests that there is a measurable rate for γ+A without nuclear breakup
- Also see hints of differences in x_A distribution
  - ⇒ Events where the photon scatters off "skin" neutron??
- Such a contribution would also be present in DIS
  - ⇒ Would be an interesting problem to address theoretically



Summary

- Measurements of (non-diffractive) γ+A can probe nuclear PDFs in kinematic range that will not be accessible @ EIC
  – $1\times10^{-3} < x < 0.5$, $Q^2 > 200$ GeV^2
- Results from ATLAS in few months
  – With improved systematics compared to prelim.
  ⇒ Final "low-μ" jet energy scale calibration
- Diffractive photo-production next
  – "Vanilla" or CGC?
  ⇒ MC would help evaluate sensitivity to CGC
  – Interesting problem of gap survival
- Control over nuclear breakup crucial
  – e.g. breakup makes diffractive γ+A and γ+γ a background to non-diffractive γ+A

Backup



$1/N_{evt}\ dN_{evt}\ /\ dE_{ZDC}$ [TeV^{-1}]
10^{-2}
10^{-3}
10^{-4}
1
10
10^{2}
E_{ZDC} [TeV]
ATLAS Preliminary
Pb+Pb 2018, 5.02 TeV, 1.72 nb^{-1}
UPC $\gamma + A \rightarrow$ jets