Measurements of long-range correlations in small systems with ATLAS

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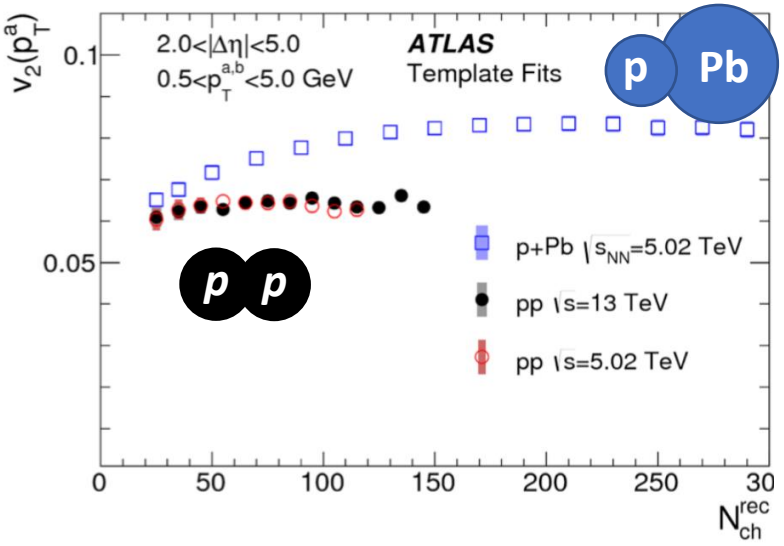
for the ATLAS collaboration

Hard Probes 2020, June 2nd

Introduction

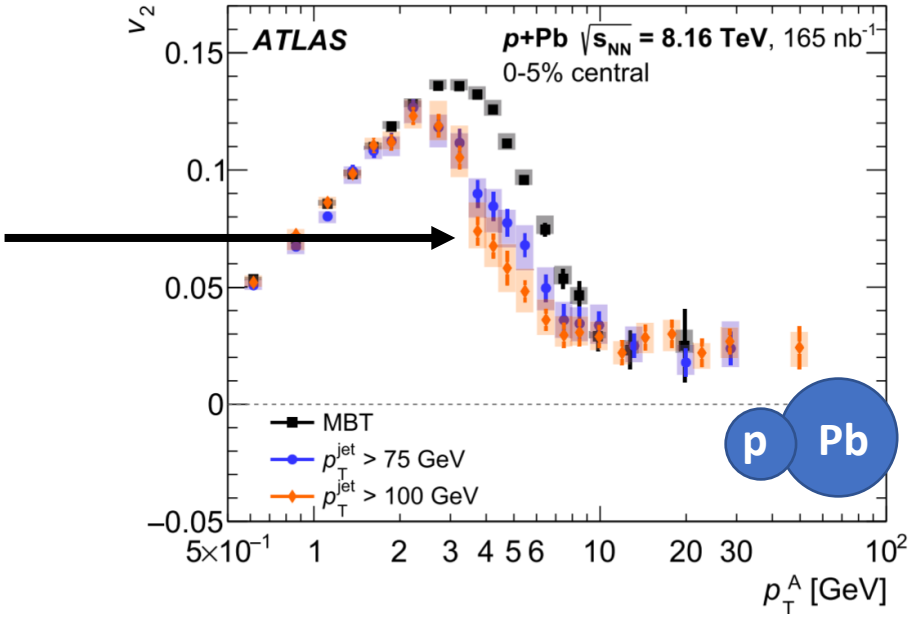


Phys. Rev. C 96 (2017) 024908

No centrality dependent v_2 observed in *pp*

Importance of particle origin
From jet or underlying event

[Eur. Phys. J. C 80 (2020) 73]



Outline

1. Collectivity in *pp* collisions tagged by Z-boson production
   Eur. Phys. J. C 80 (2020) 64

2. Collectivity in *pp* collisions when controlling particle origin.
   ATLAS-CONF-2020-018

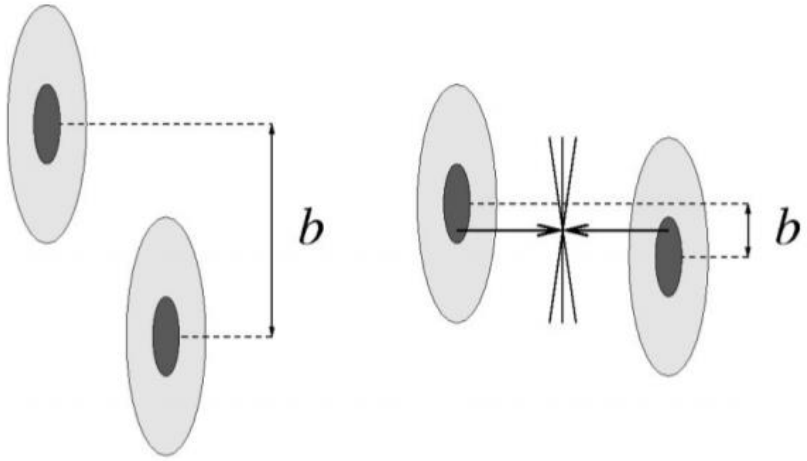
3. Evidence of collectivity in photo-nuclear collisions
   ATLAS-CONF-2019-022

Origin of v_2 in *pp*?

- In large systems, the impact parameter is strongly correlated with v_2
- Maybe impact parameter is important in pp v_2
- Multiplicity is not well correlated with impact parameter

- Large Q^2 (short distance scales) interactions
  - Smaller impact parameter
  - More MPIs

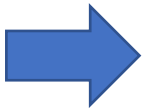
- Require Z-boson: $Q^2 \sim (90\ \text{GeV})^2$



Phys. Rev. D 69, 114010 (2004)
Phys. Rev. C 94, 024919 (2016)

v_2 in Z-tagged *pp* events vs. inclusive *pp*

Select events with a Z-boson identified by the presence of two high-p_T muons with invariant mass between 80-100 GeV



Correlate other particles in the event

v_2 in Z-tagged *pp* events vs. inclusive *pp*

Select events with a Z-boson identified by the presence of two high-p_T muons with invariant mass between 80-100 GeV

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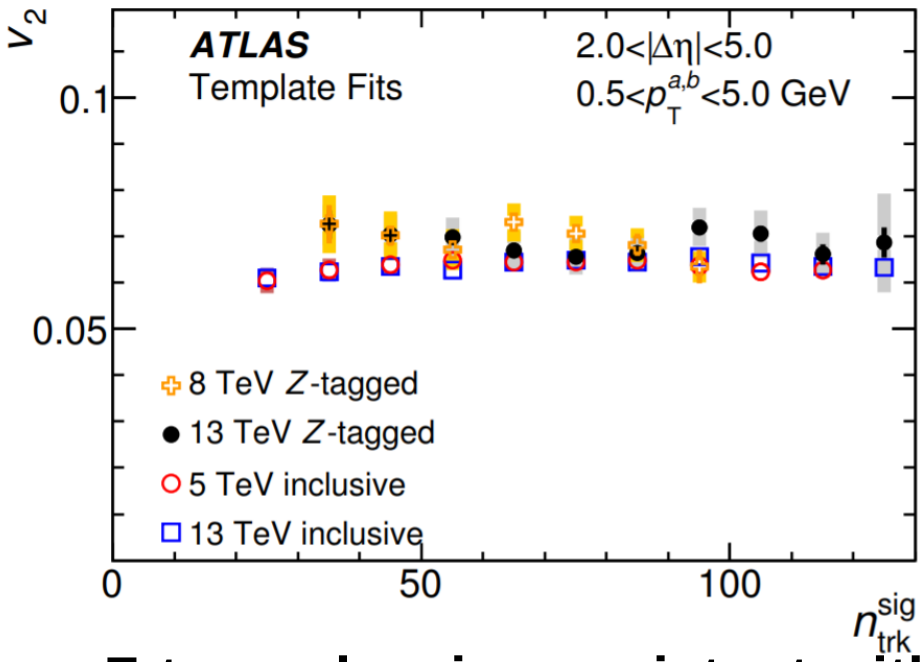

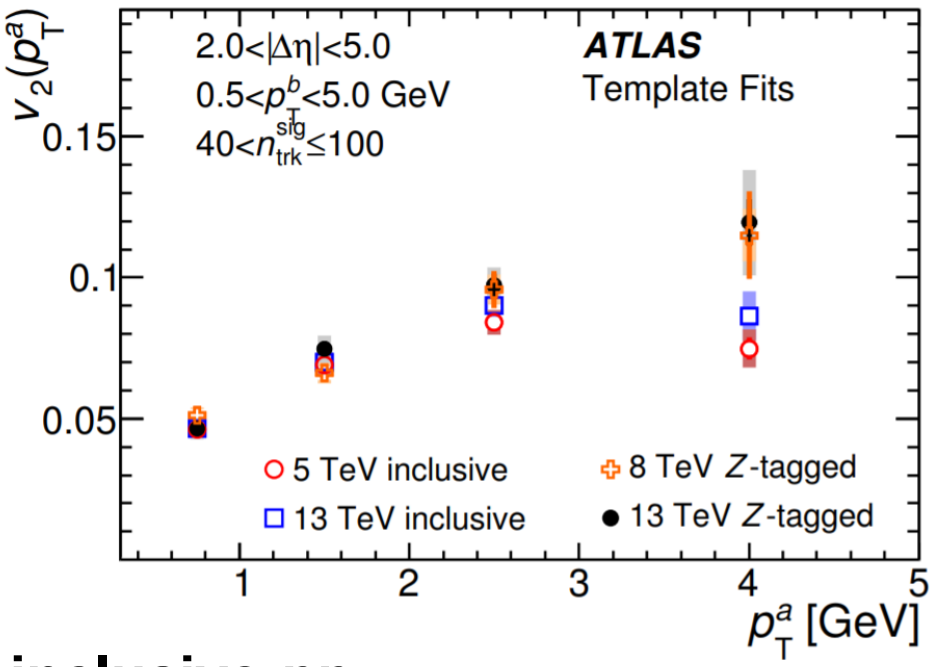

Z-tagged v_2 is consistent with inclusive *pp*.

Expansion of experimental techniques for doing correlations studies in a high pile-up environment.

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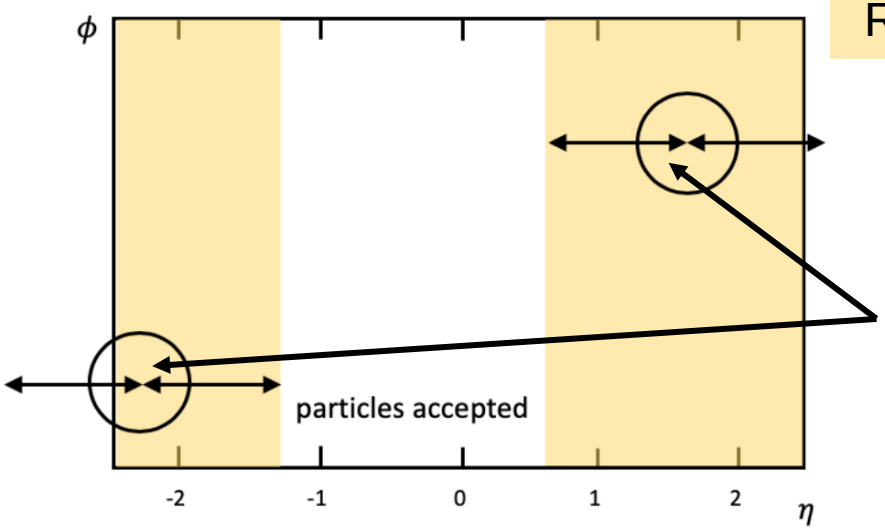
Selecting jet particle/events in *pp* collisions



Rejection region

NEW

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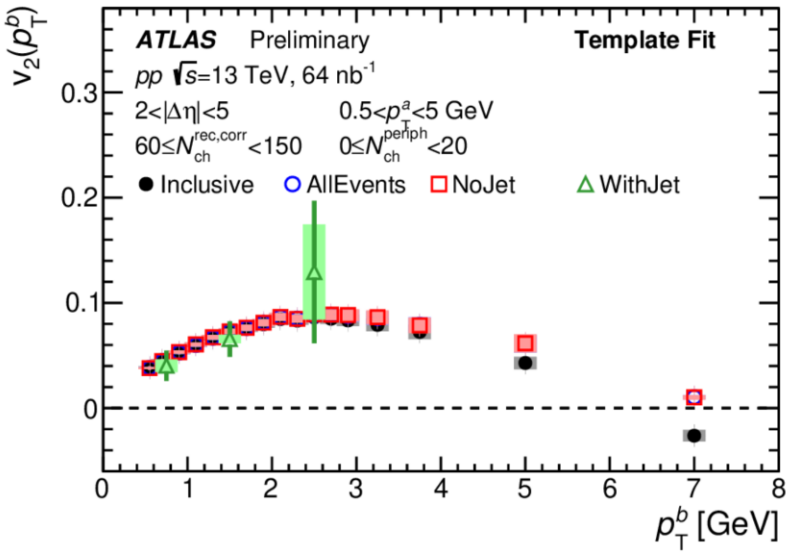
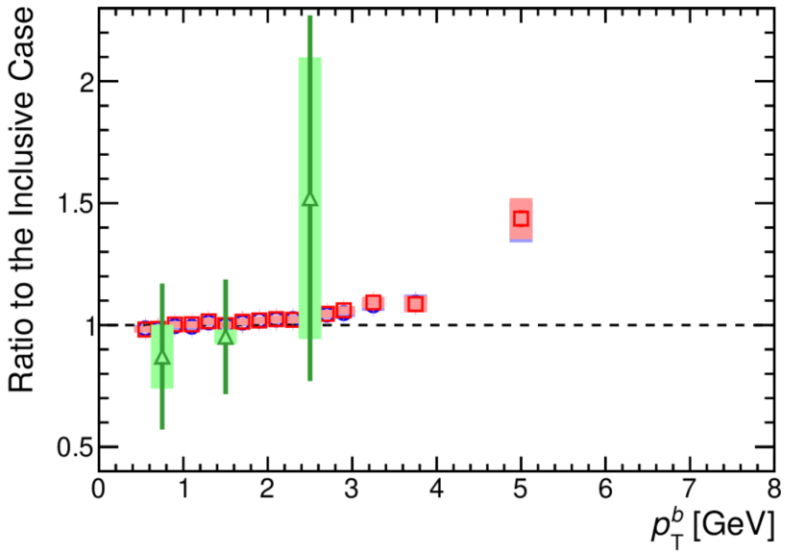
Anti-k_t R=0.4 track jets

- p_T > 10 GeV
- Jet p_T and multiplicity corrected for underlying event contributions
- Jets utilizing charge particle tracks of p_T > 0.5 GeV

Category	Marker	Jet-rejection	Events with jets	Events with no jets
Inclusive		✗	✓	✓
All Events		✓	✓	✓
No Jets		NA	✗	✓
With Jets		✓	✓	✗

v_2 when selecting on particle origin

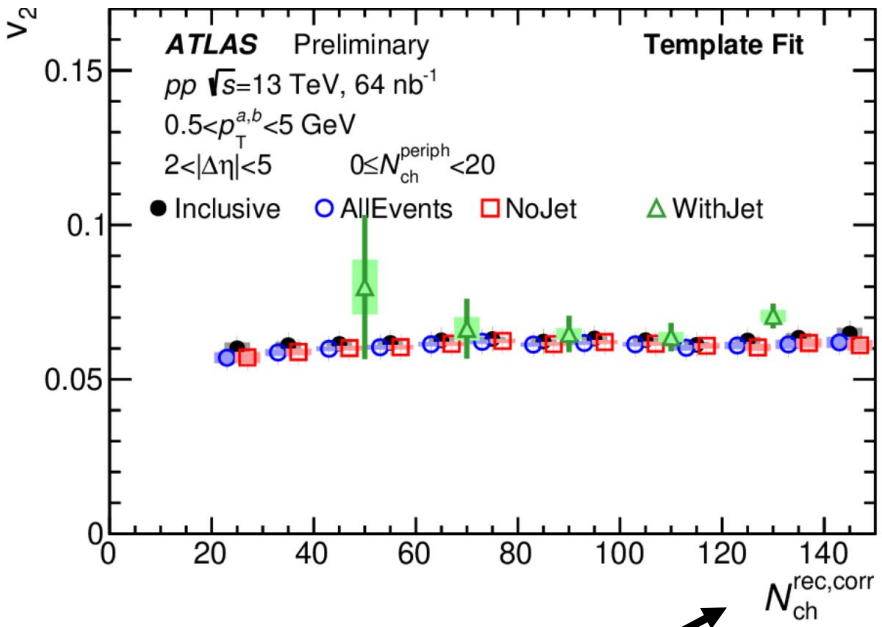


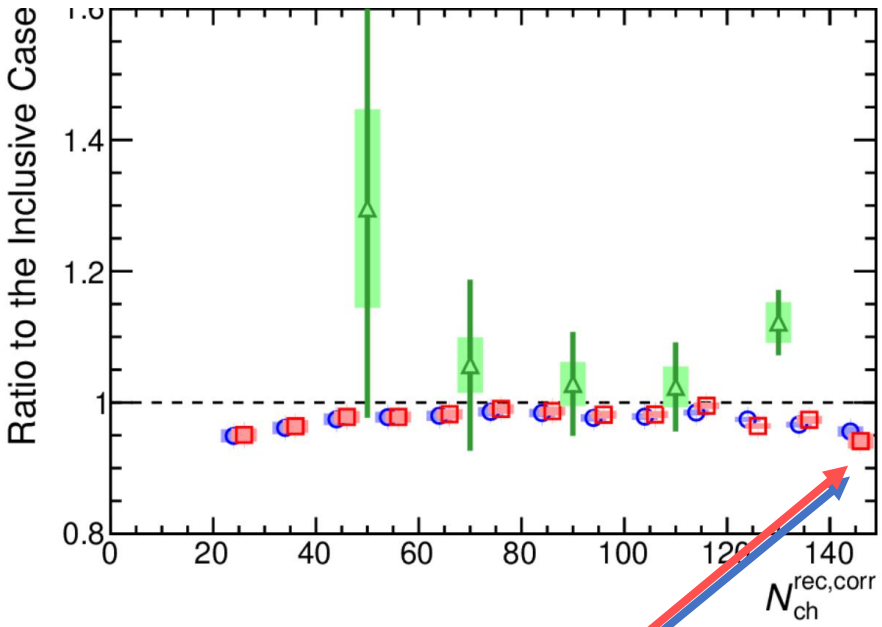


Jet-rejected v_2 is consistent at $p_T < 2.5$ GeV, larger v_2 at higher p_T

Category	Marker	Jet-rejection	Events with jets	Events with no jets
Inclusive		✗	✓	✓
All Events		✓	✓	✓
No Jets		NA	✗	✓
With Jets		✓	✓	✗

v_2 when selecting on particle origin





Multiplicity corrected back to number of primary charged particles from the underlying event .

V_2 (2-5%) lower in jet-rejected correlations due to **lower $\langle p_T \rangle$.**

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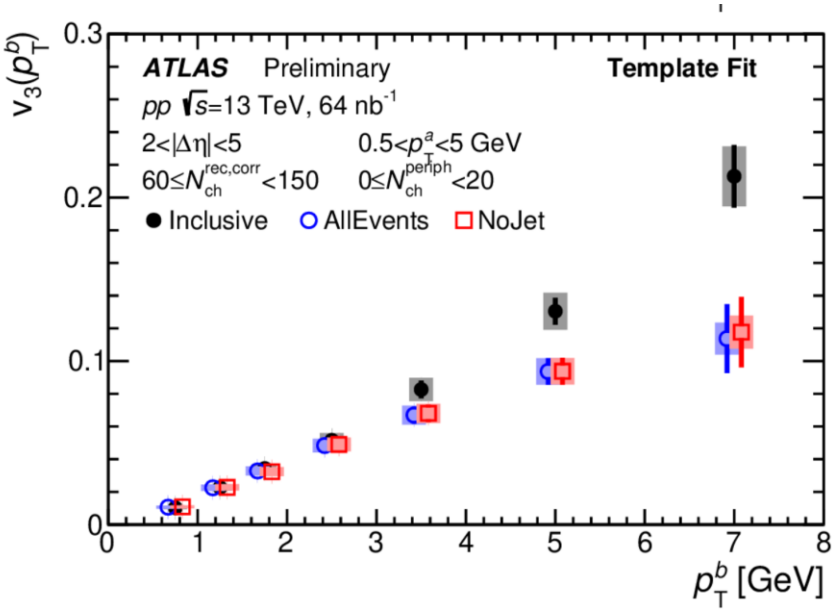
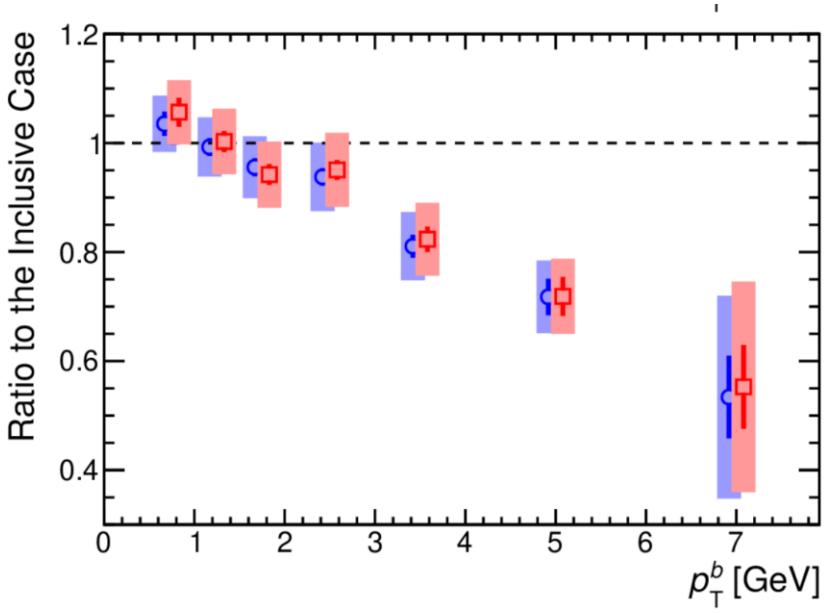
v_3 when rejecting jet particles





v_3 in no-jet and jet particle rejection correlations is

- Consistent at lower p_T 0.5-3 GeV
- Lower > 3 GeV

The high p_T increase in v_2 and decrease in v_3 in jet-rejected results relative to the inclusive indicates that the template-based removal of the away-side jet correlation is the source of the discrepancy. One would expect nonflow biases to be smaller in the jet-rejected selection.

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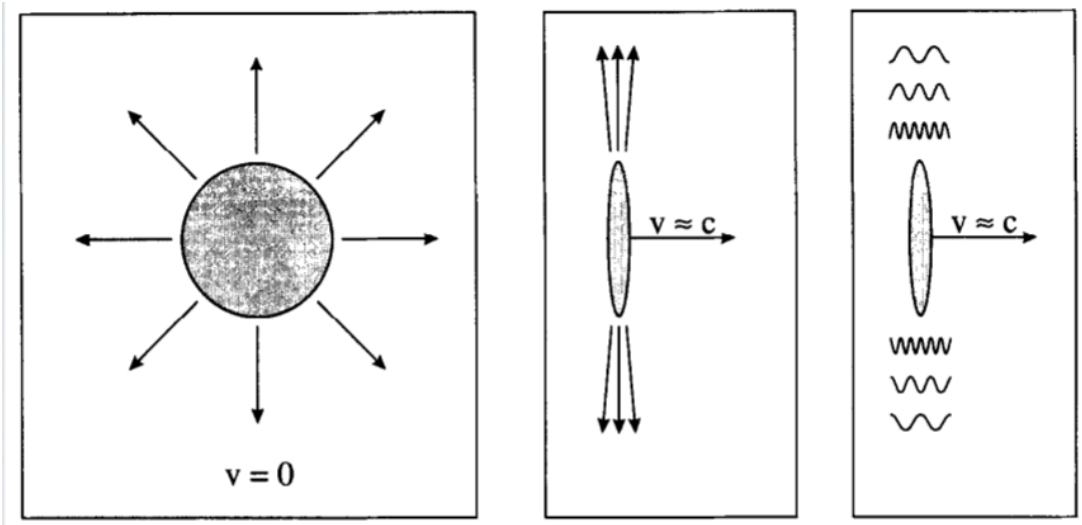
pp correlations summary

In both measurements, the presence of a hard or semi-hard process shows no significant impact on the observed correlation coefficients of other particles in the event.

Ultra-peripheral collisions with ATLAS



Coulomb fields of moving charges can be treated as an equivalent flux of photons which are boosted to high energies

Photons reach energies of 10s of GeV at the LHC

Two categories

- Pure EM processes (ATLAS-CONF-2016-025 & arXiv:1904.03536)
- Photo-nuclear interactions

All processes “may” also include one or both nuclei breaking up, due to additional soft photon exchange

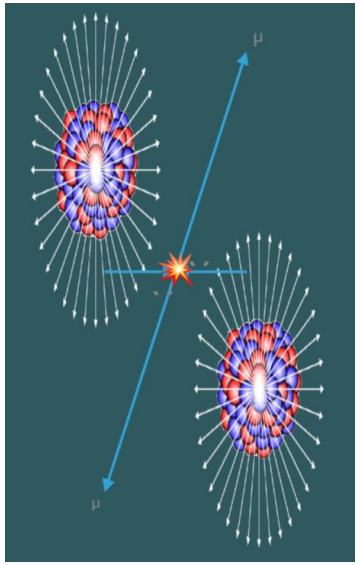
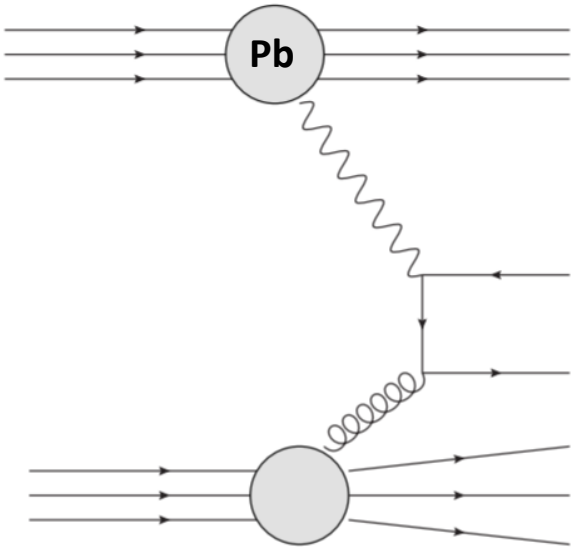


Photo-nuclear interactions

Direct γA collisions

Photon couples directly to nuclear parton



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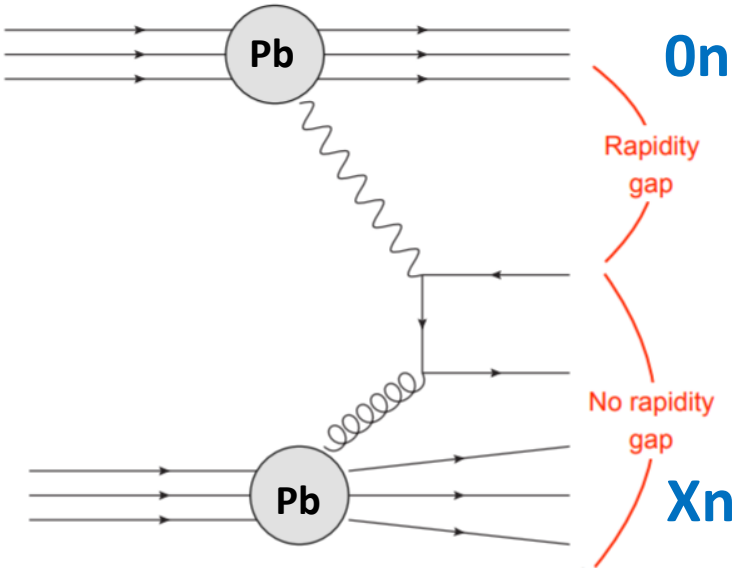

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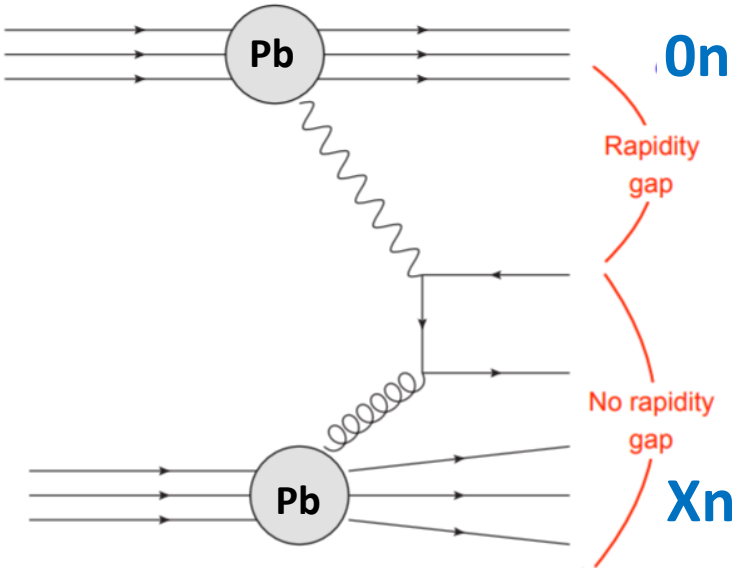
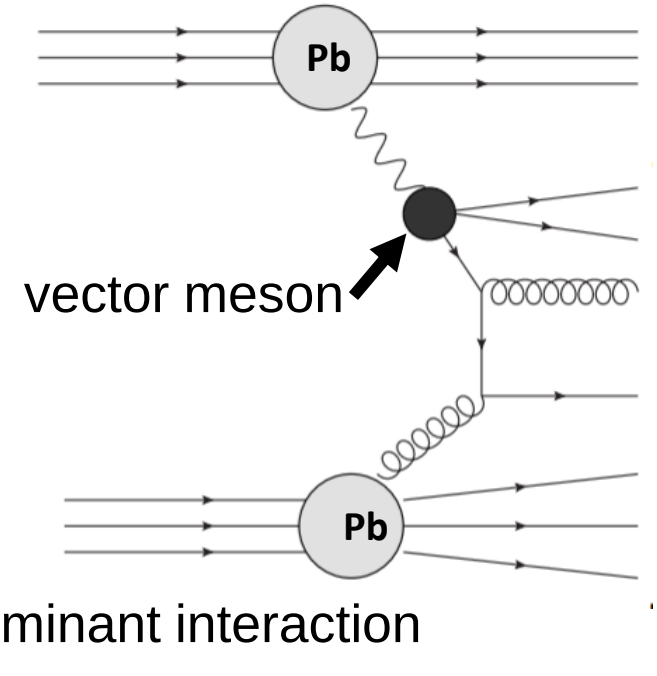


Resolved γA collisions

photon virtually resolved into hadronic state

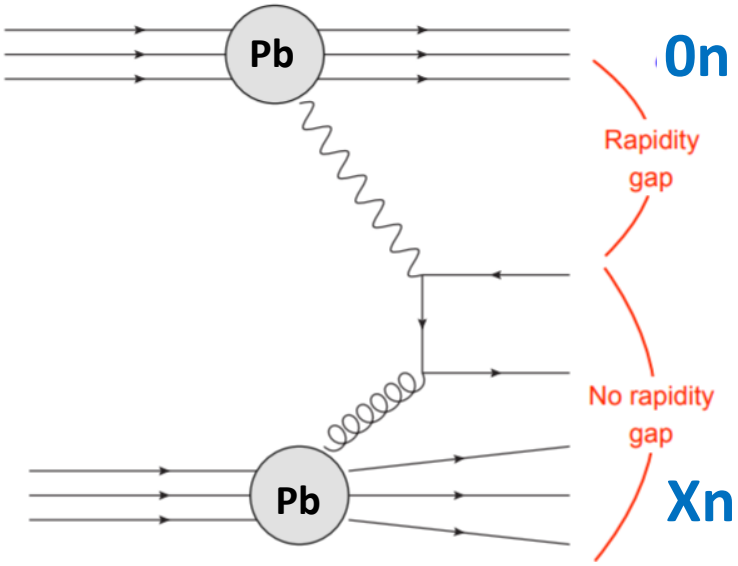


Dominant interaction

Photo-nuclear interactions

Direct γA collisions

Photon couples directly to nuclear parton



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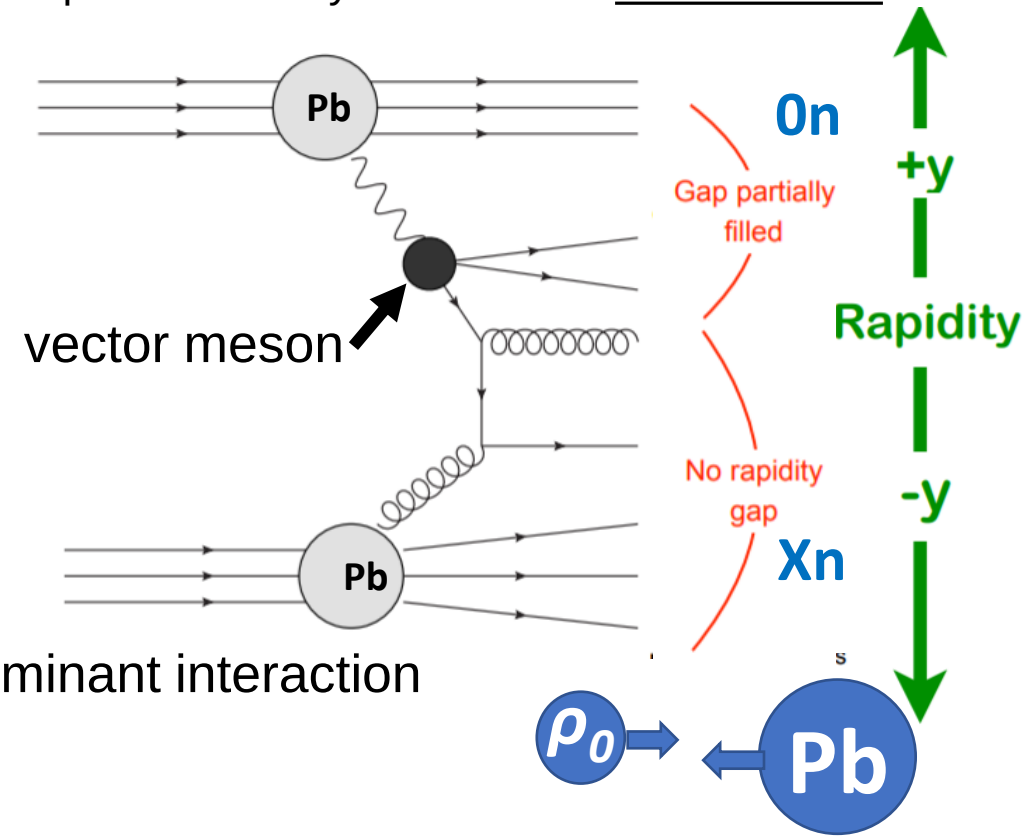


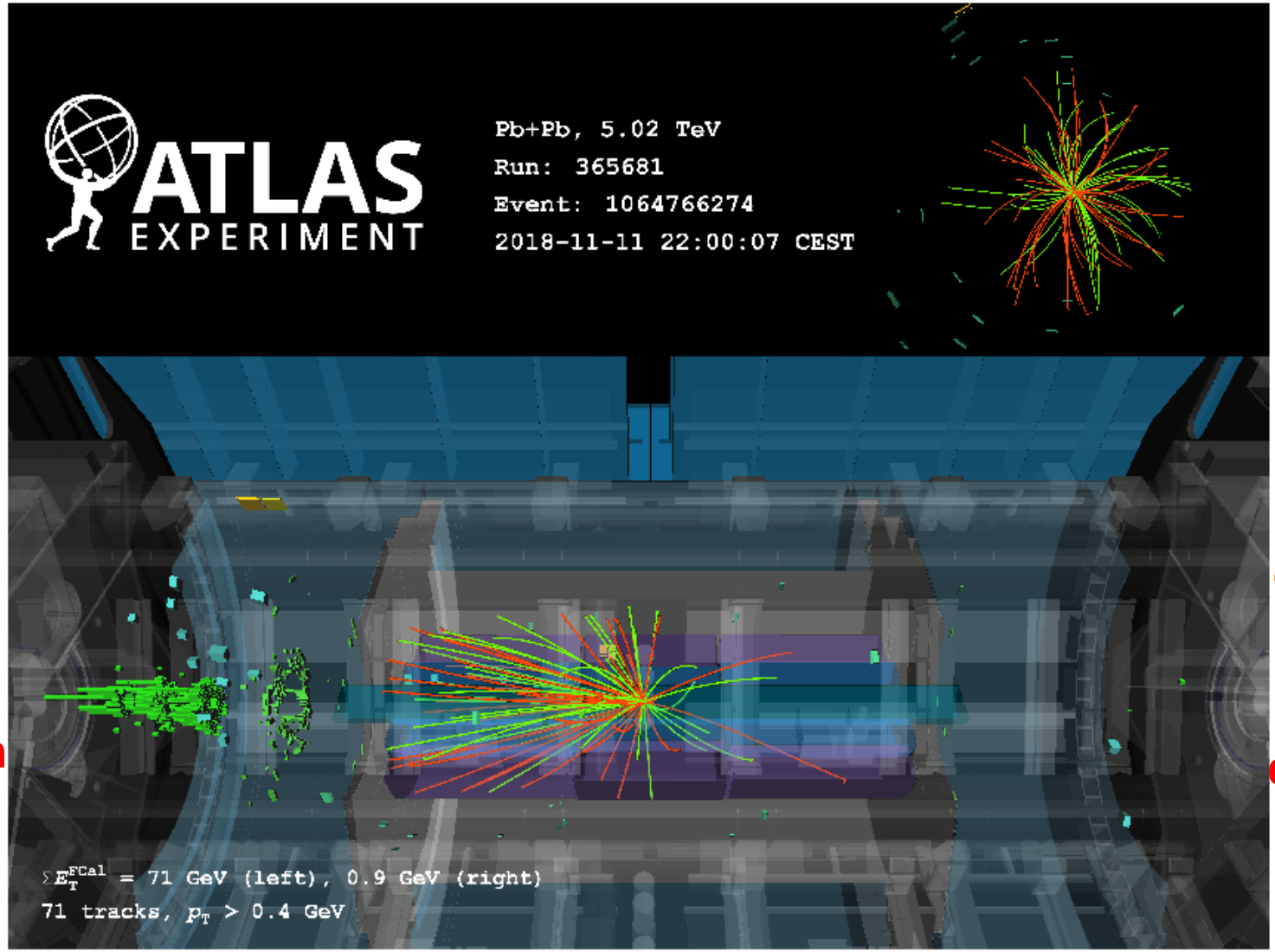
Dominant interaction

Select events based on primarily

- One-sided nuclear fragmentation (zero-degree calorimeter ZDC)
- Rapidity gaps

We have contributions from both diagrams

“High”-multiplicity photo-nuclear collisions

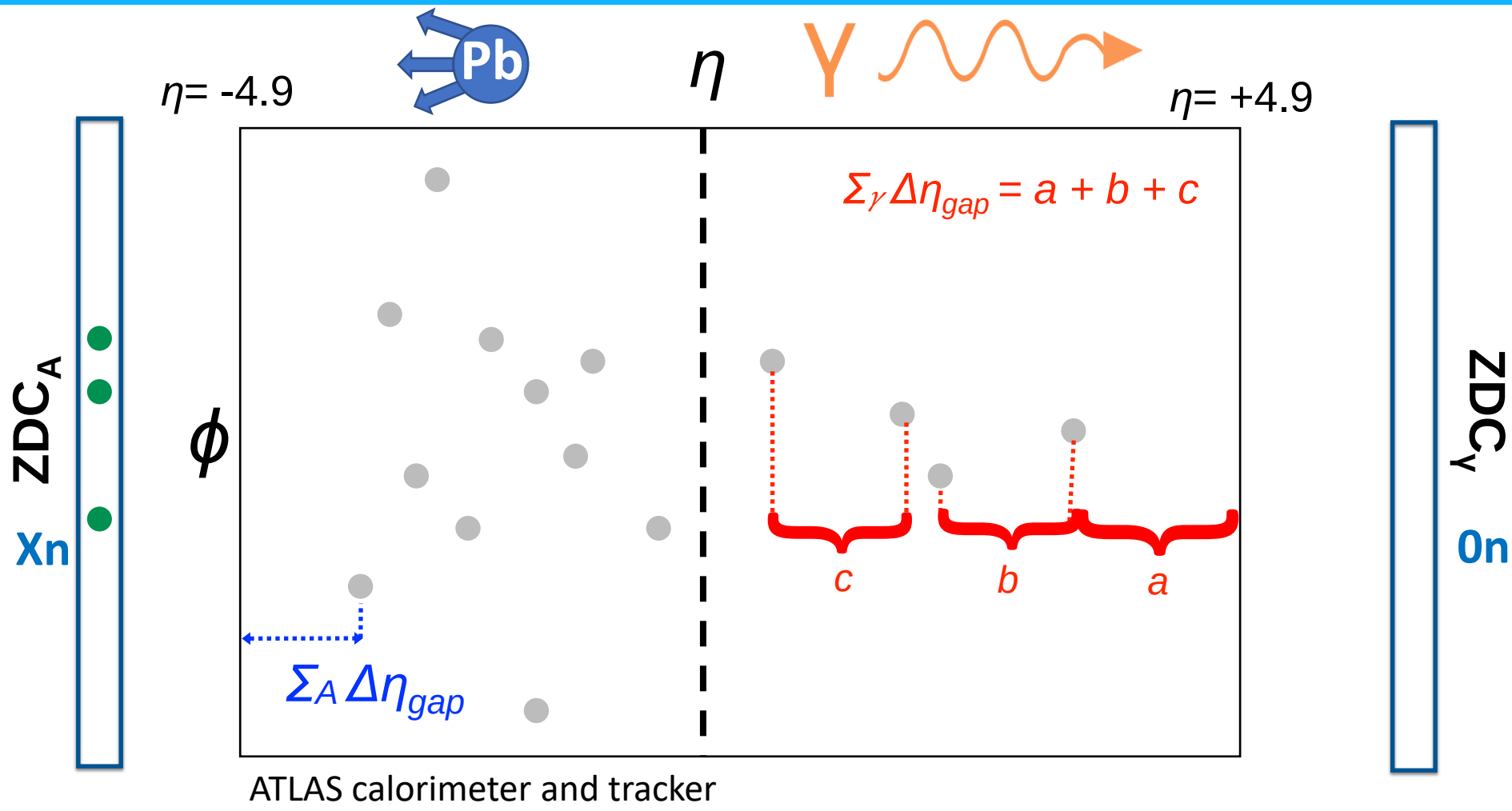


Pb

Pb Going direction

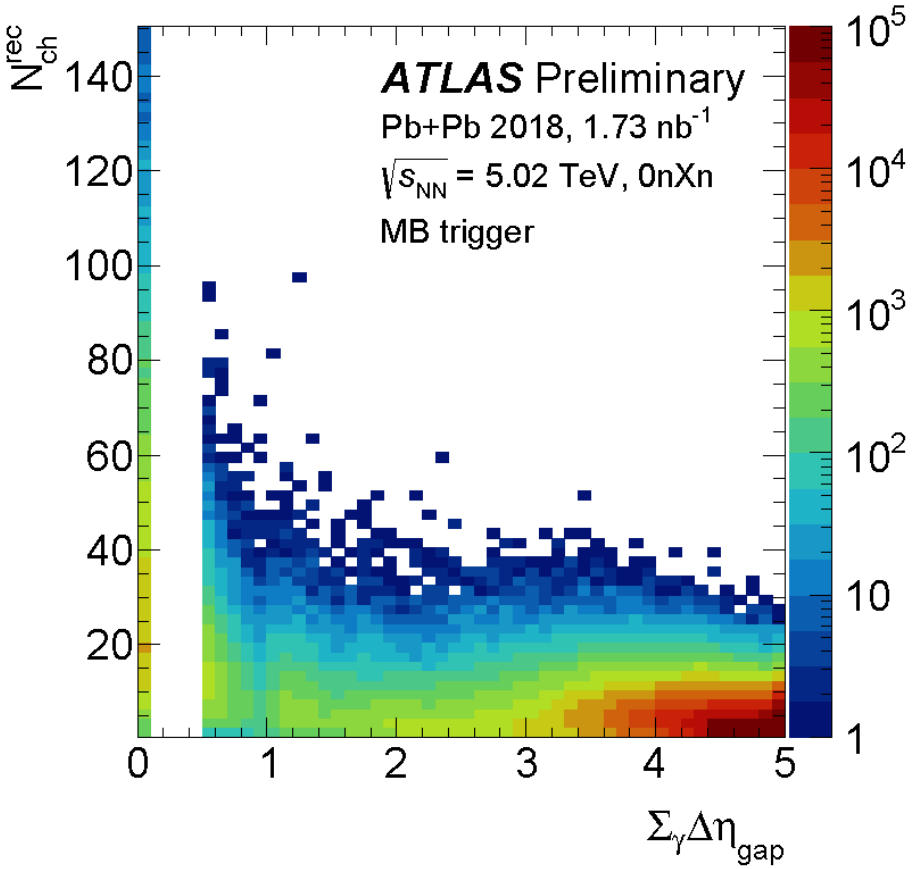
Photon Going direction

Gap definition (detector roll-out)



Event Selection: $\Sigma_A \Delta\eta_{gap} < 3$ $\Sigma_\gamma \Delta\eta_{gap} > 2.5$

Rapidity gaps $\Sigma_\gamma \Delta\eta_{gap}$ and N_{ch}



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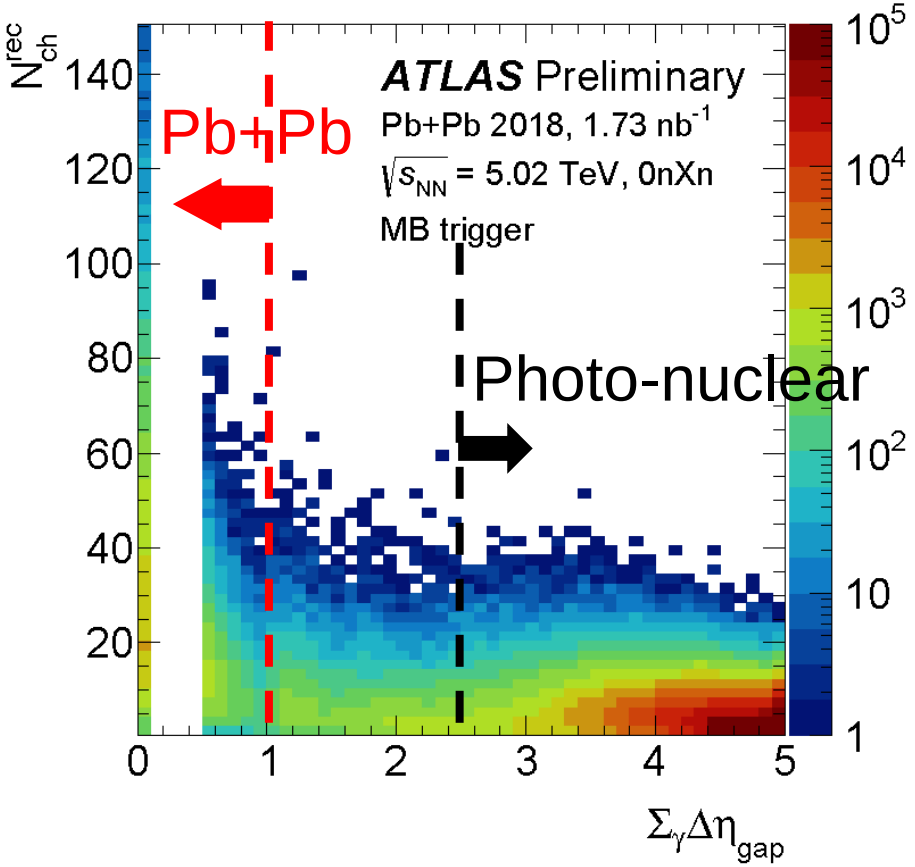
Rapidity gaps $\Sigma_\gamma \Delta\eta_{gap}$ and N_{ch}



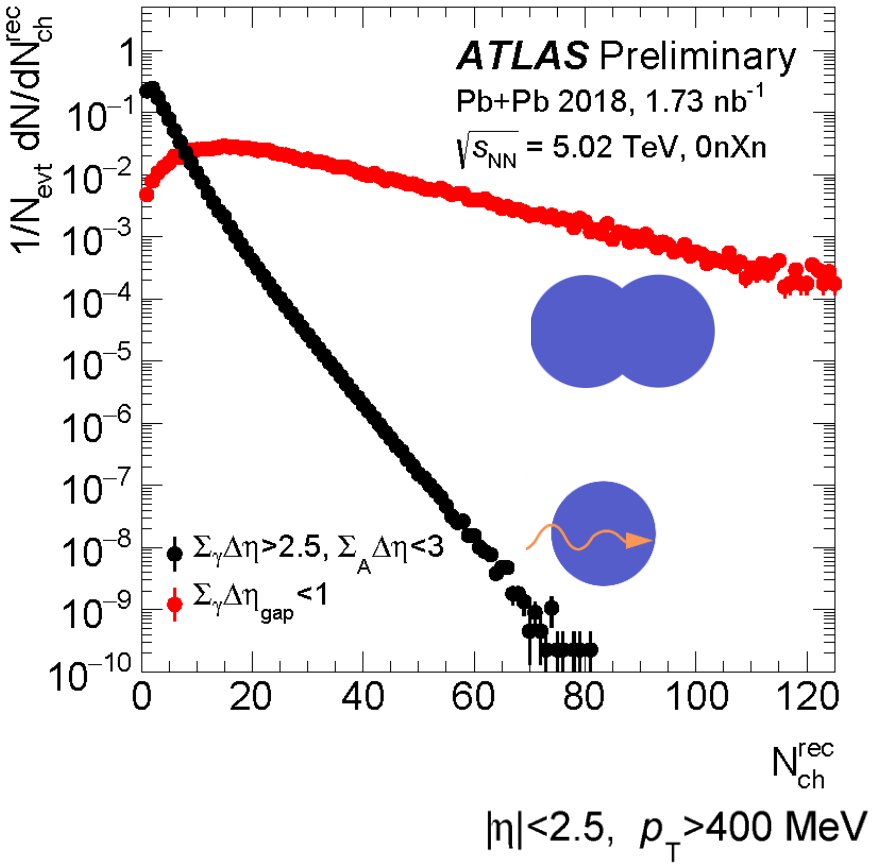


Photo-nuclear events have large rapidity gaps in the photon going direction and steeply falling multiplicity distribution.

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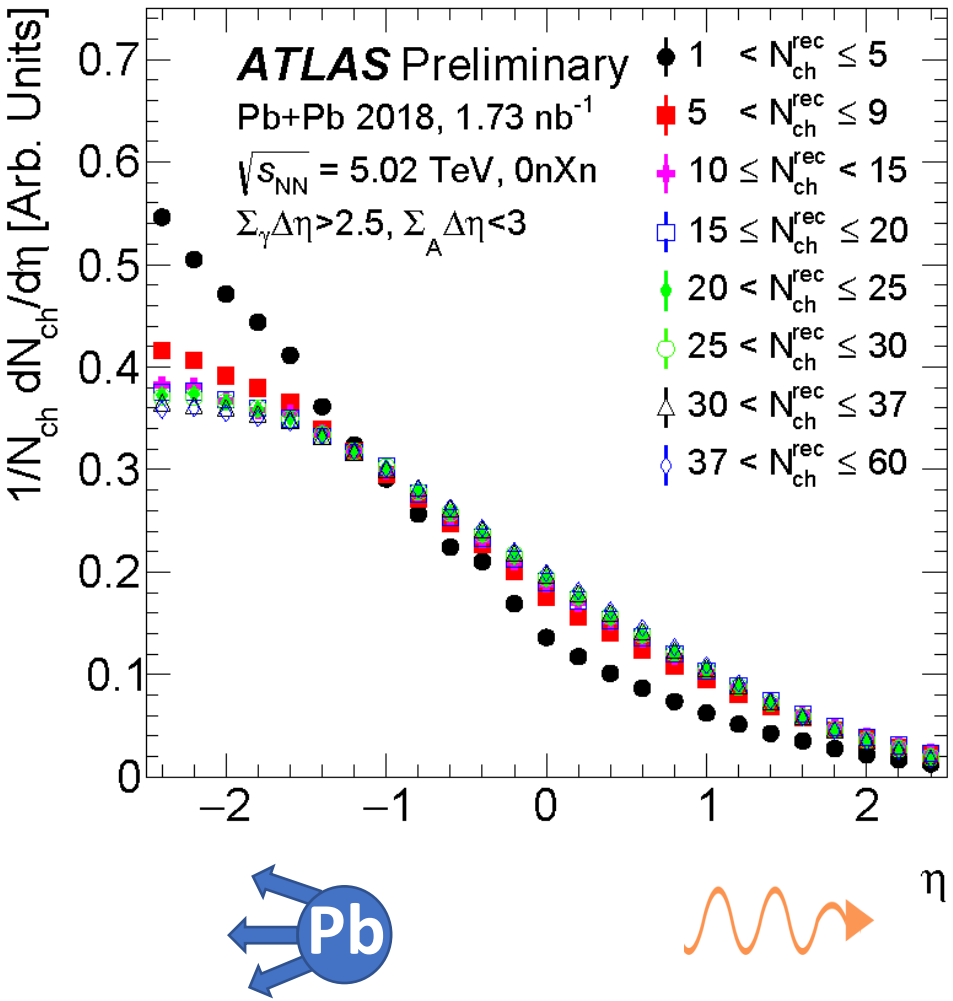
$dN_{ch}/d\eta$ in γA collisons



- $dN_{ch}/d\eta$ of events passing the photo-nuclear event selection.
- Very similar shape $dN_{ch}/d\eta$ for events with $N_{ch}^{rec} \geq 10$.

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ATLAS template fits to γA correlations

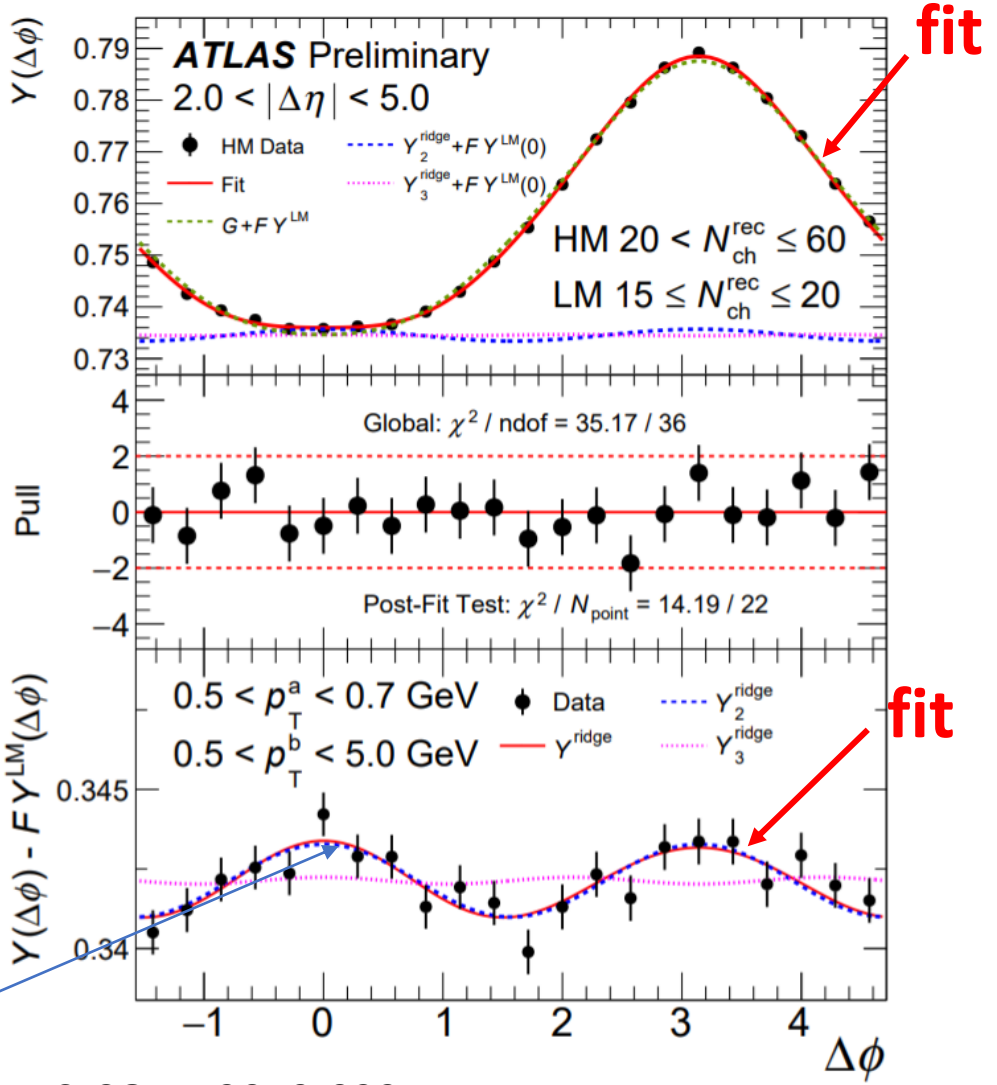
High-multiplicity (HM) correlation data

Low Multiplicity (LM) template for jet correlation

$$Y^{\mathrm{HM}}(\Delta\phi) = FY^{\mathrm{LM}}(\Delta\phi) + G\left\{1 + 2\sum_{n=2}^{3} v_{n,n}\cos(n\Delta\phi)\right\}$$

HM – (scaled LM)

Clear cos(2Δϕ) modulation!



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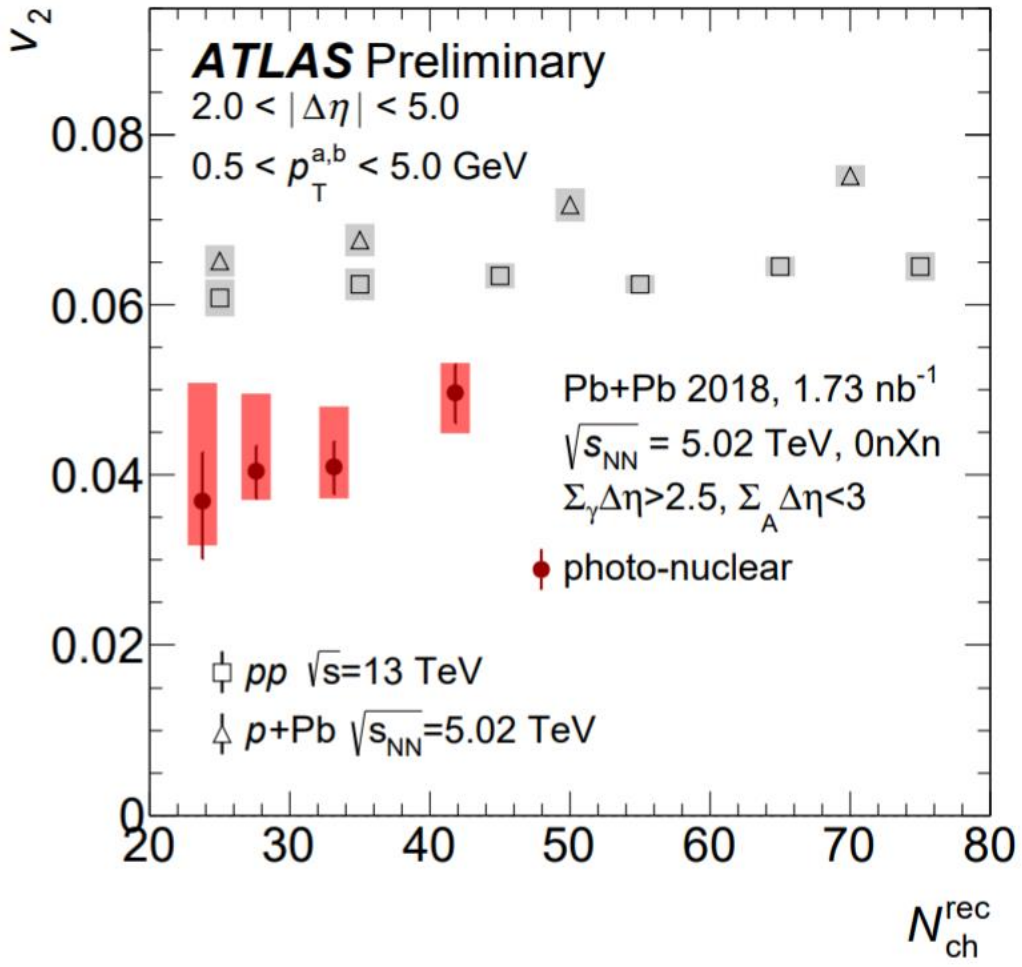
v_2 in photo-nuclear collisions



Significant v_2 in photo-nuclear collisions!

Photo-nuclear v_2 is smaller than v_2 inclusive *pp* and *p*+Pb

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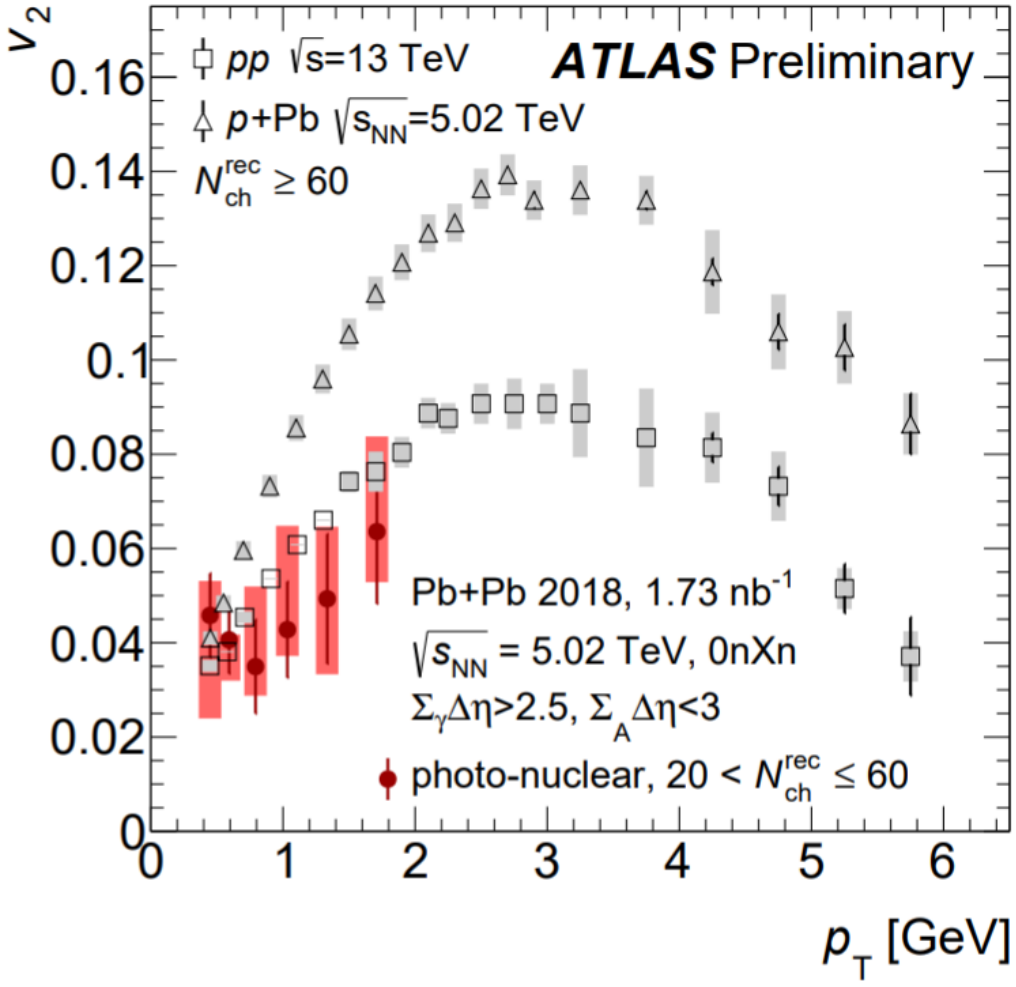
p_T dependence



Similar p_T dependence to hadronic collisions systems

Photo-nuclear central values are lower than *pp* and *p*+Pb (with larger uncertainties)

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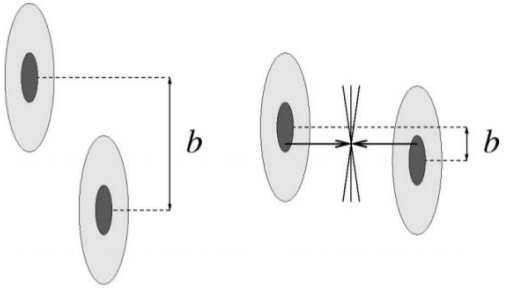
Conclusions

Z-tagged and inclusive *pp* v_2 are consistent.

- New: 13 TeV measurement and p_T dependence



New preliminary analysis: Long-range correlations arise from the underlying event in *pp* collisions.

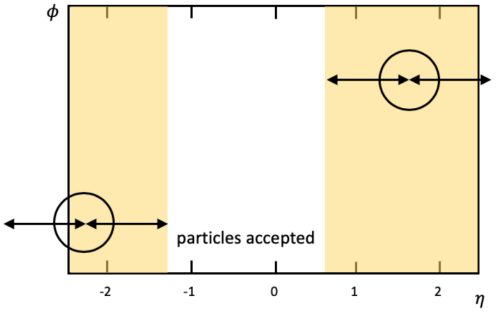
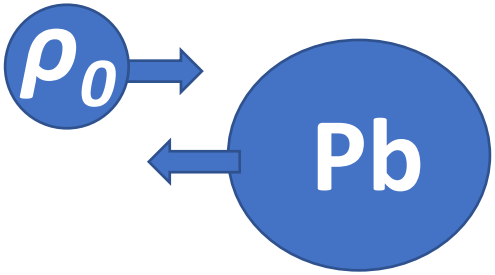


Photo-nuclear v_2 has a similar order of magnitude and trends as other previously measured hadronic systems

- Intuitive property of hadronic-like photo-nuclear collisions (photon → vector meson).

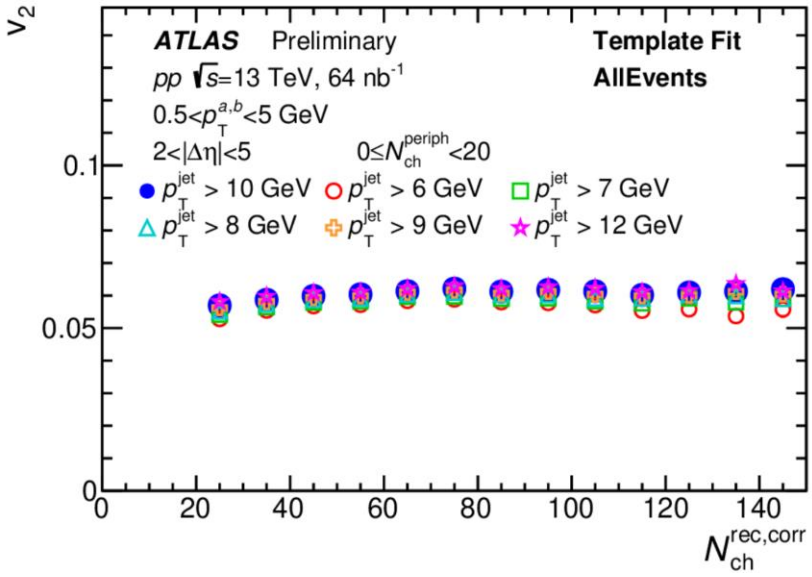


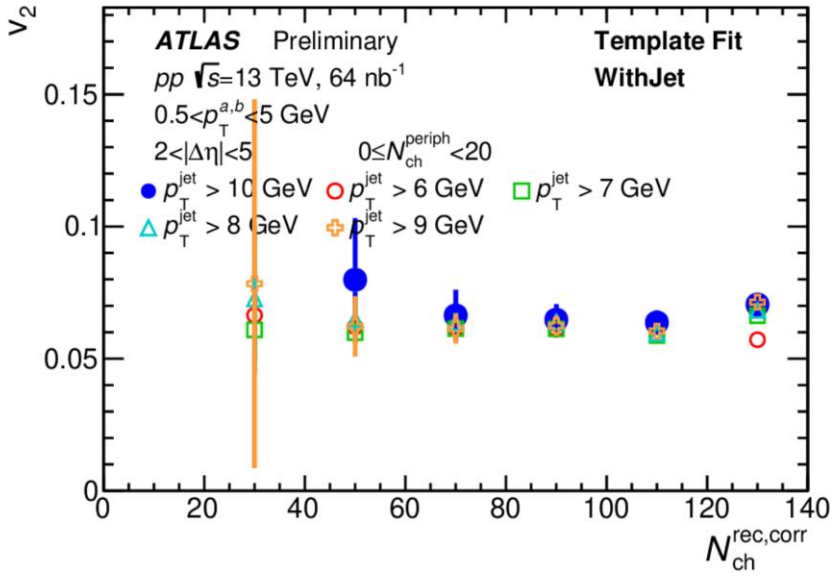
Thank you

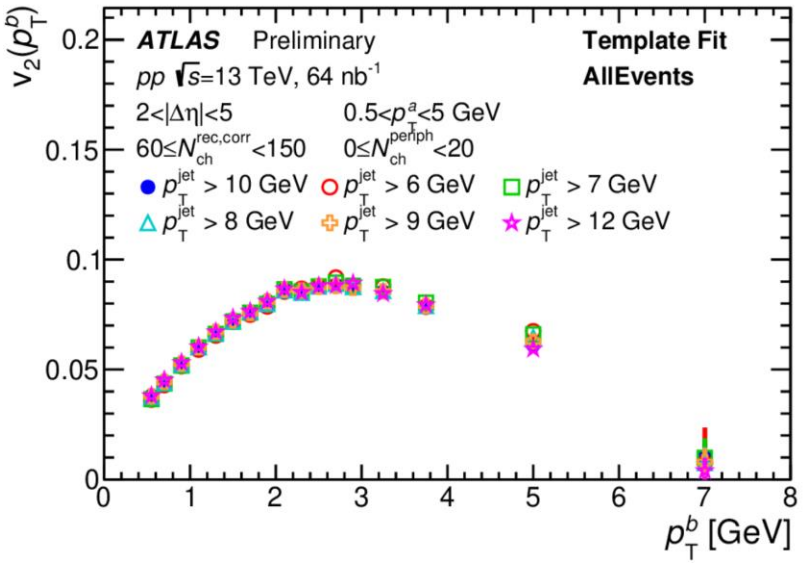
High-multiplicity photo-nuclear trigger

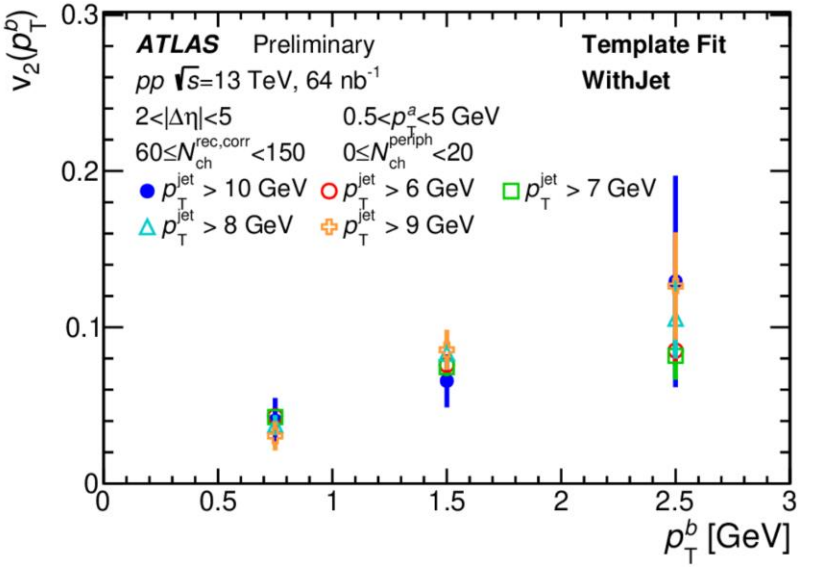
- Zero Degree Calorimeter: Xn0n
- Energy in the entire detector: 5-200 GeV
- Charged particle tracks: > 35 tracks
- Photon going forward calorimeter: < 5 GeV

Sensitivity to jet p_T

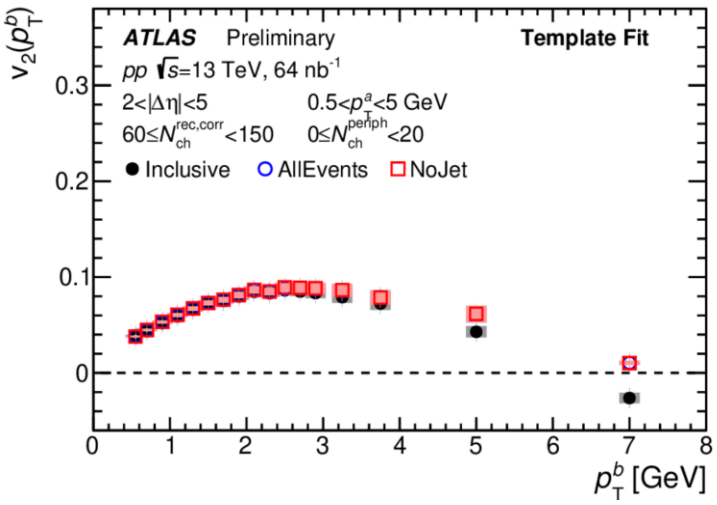


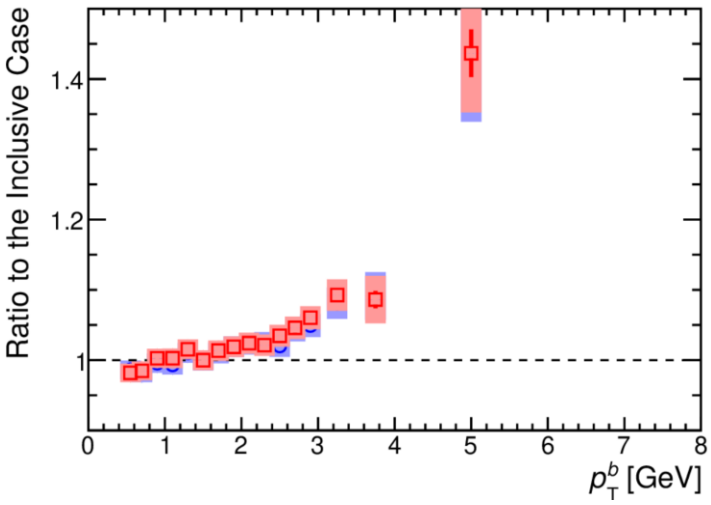


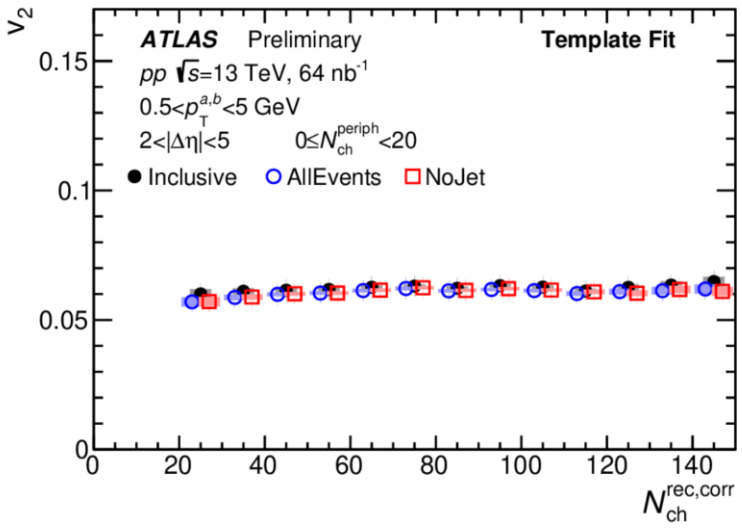


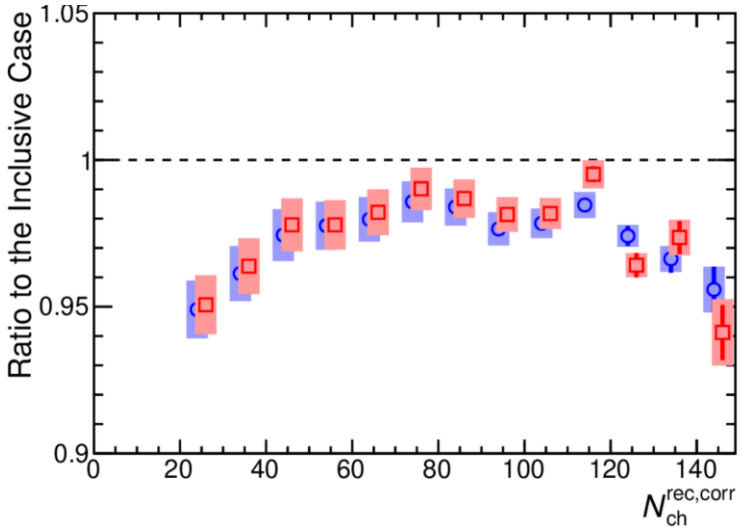


V_2 in *pp* events with jets

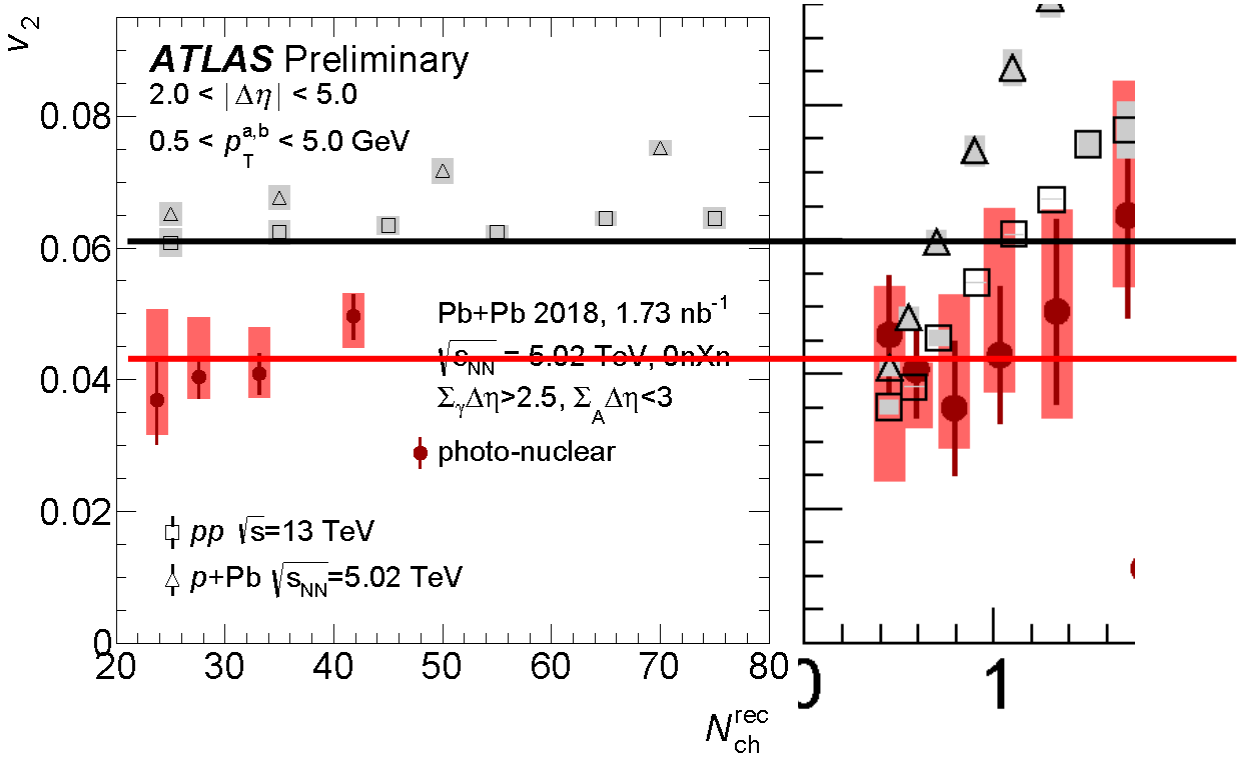








Consistency of N_{ch} and p_T in γA



Now on same y-axis scale

ATLAS template fitting method *pp*

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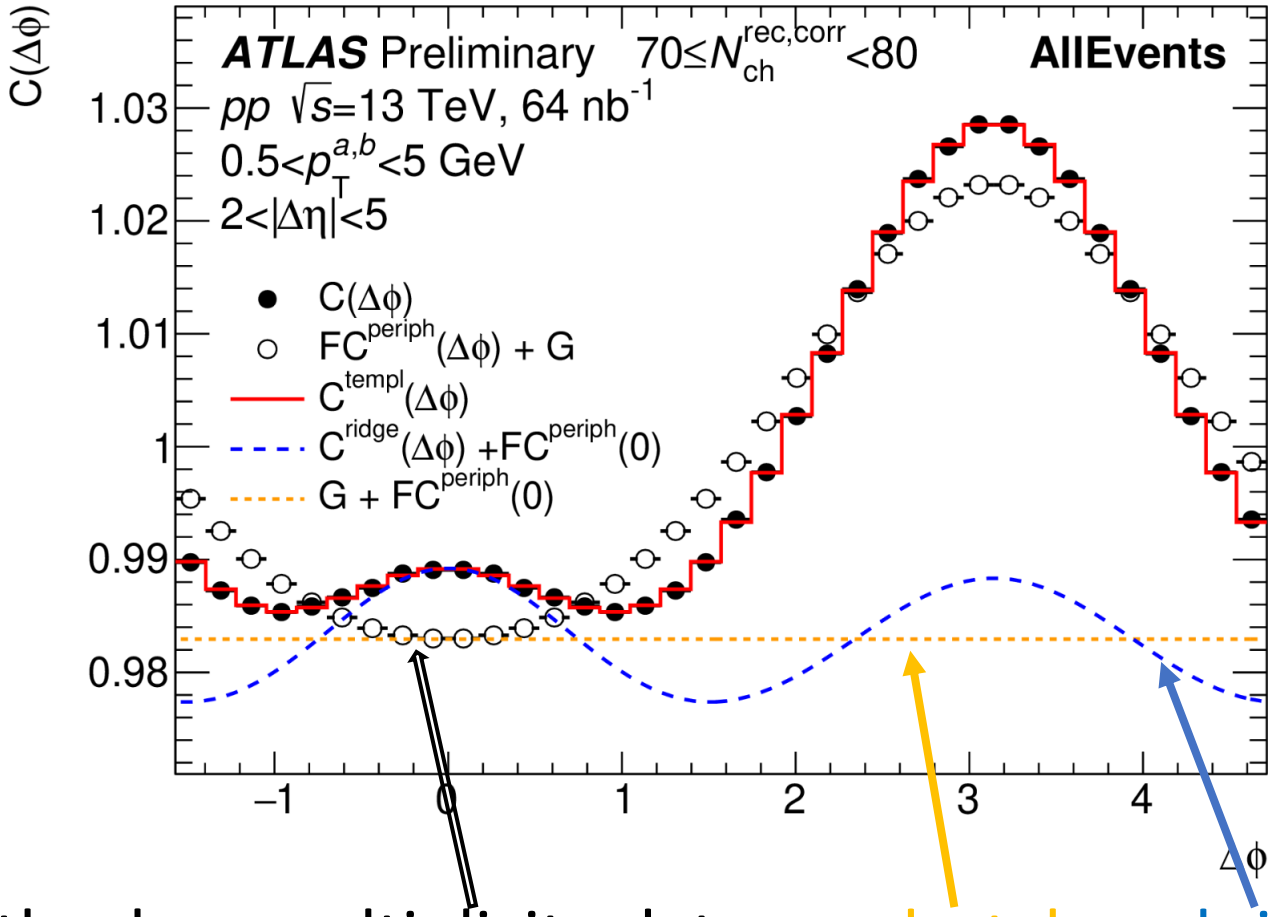

Fit with: low-multiplicity data, pedestal, and ridge

Low-multiplicity in a “template” for non-flow.