

# Collectivity in UPC

Peter Steinberg (BNL) for ATLAS & CMS / LHCP 2021 / 7-12 June 2021



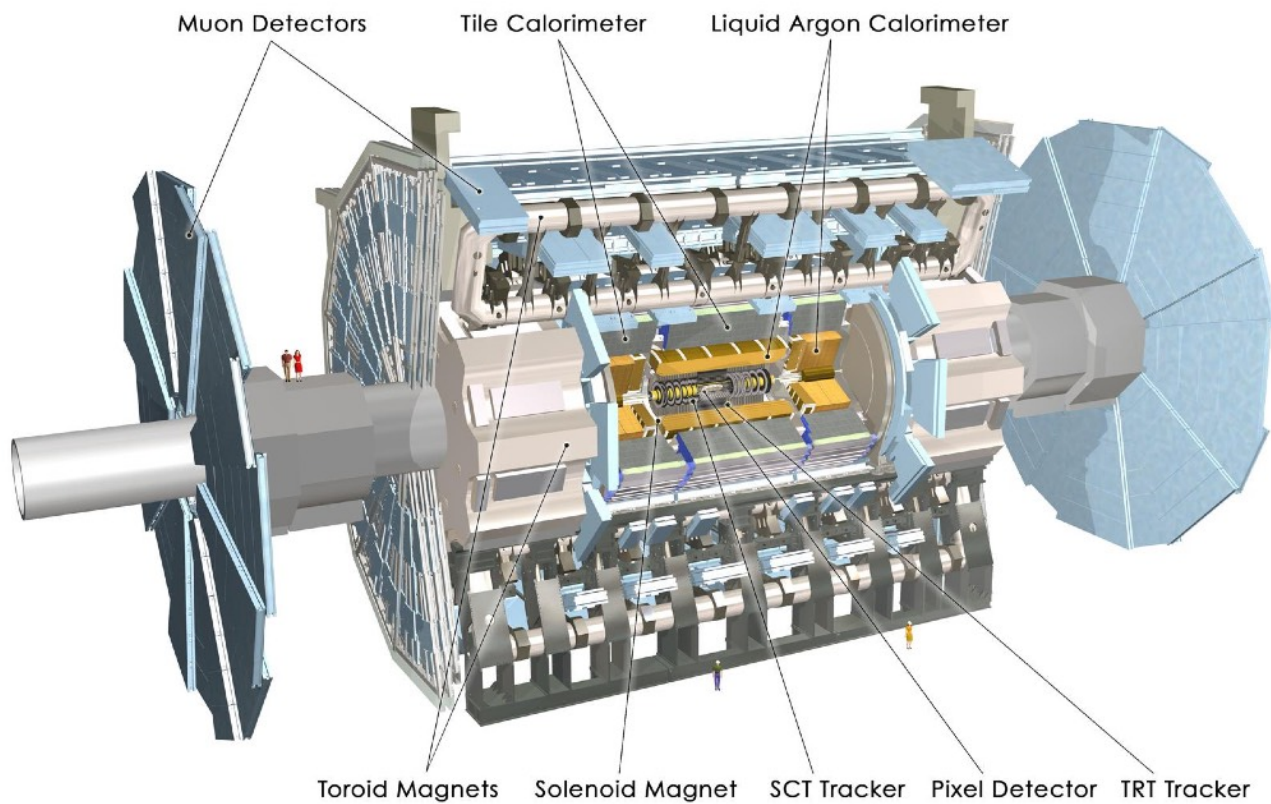
**LHCP2021**  
The Ninth Annual Conference on Large Hadron Collider Physics

**Online**

7-12 June 2021 ~~Paris (France), Sorbonne Université~~ (IN2P3/CNRS, IRFU/CEA)

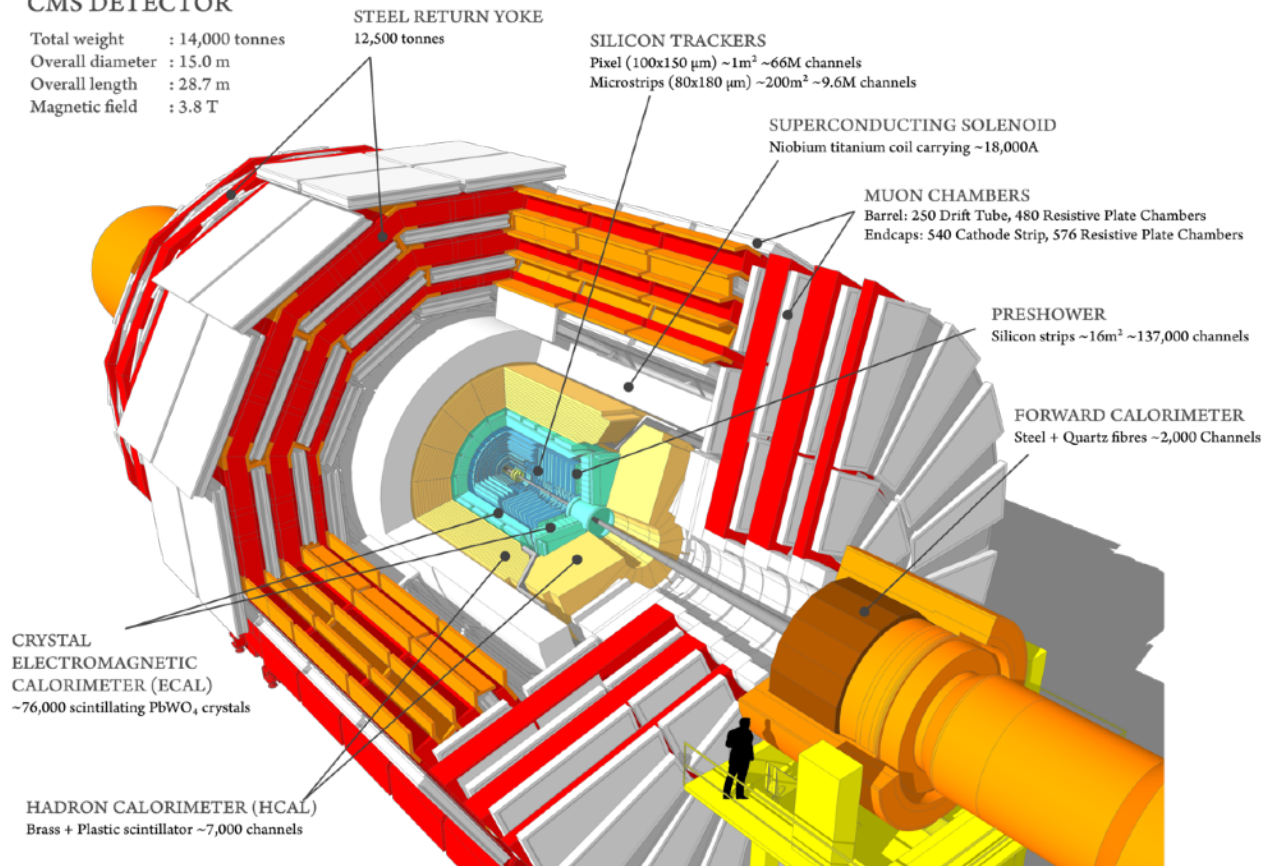
D. Longieras UCLab 2021

# ATLAS & CMS



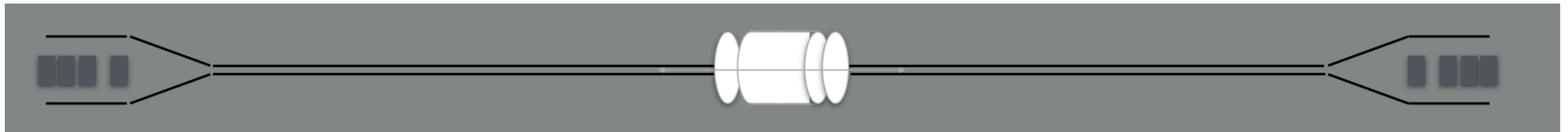
## CMS DETECTOR

Total weight : 14,000 tonnes  
Overall diameter : 15.0 m  
Overall length : 28.7 m  
Magnetic field : 3.8 T



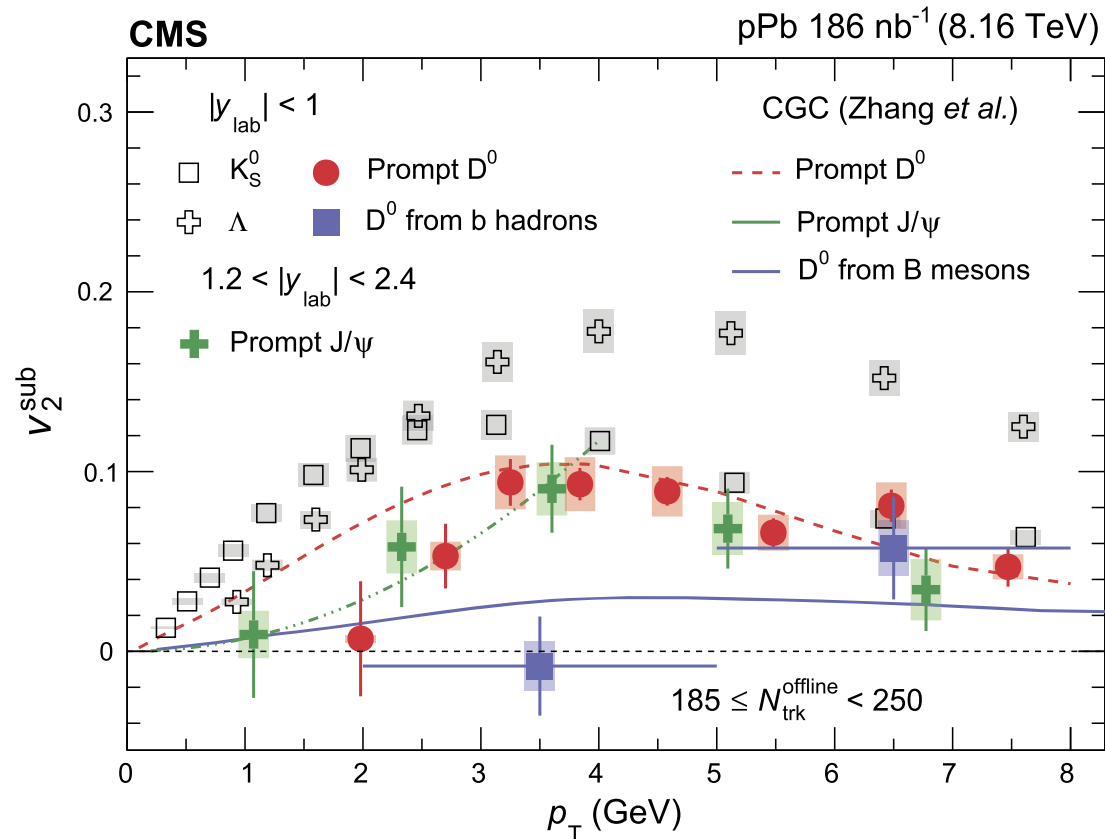
Large, hermetic detectors with precise spectrometers

Zero degree calorimeters  $z=\pm 140\text{m}$ : neutrons & photons  $|\eta|>8.3$

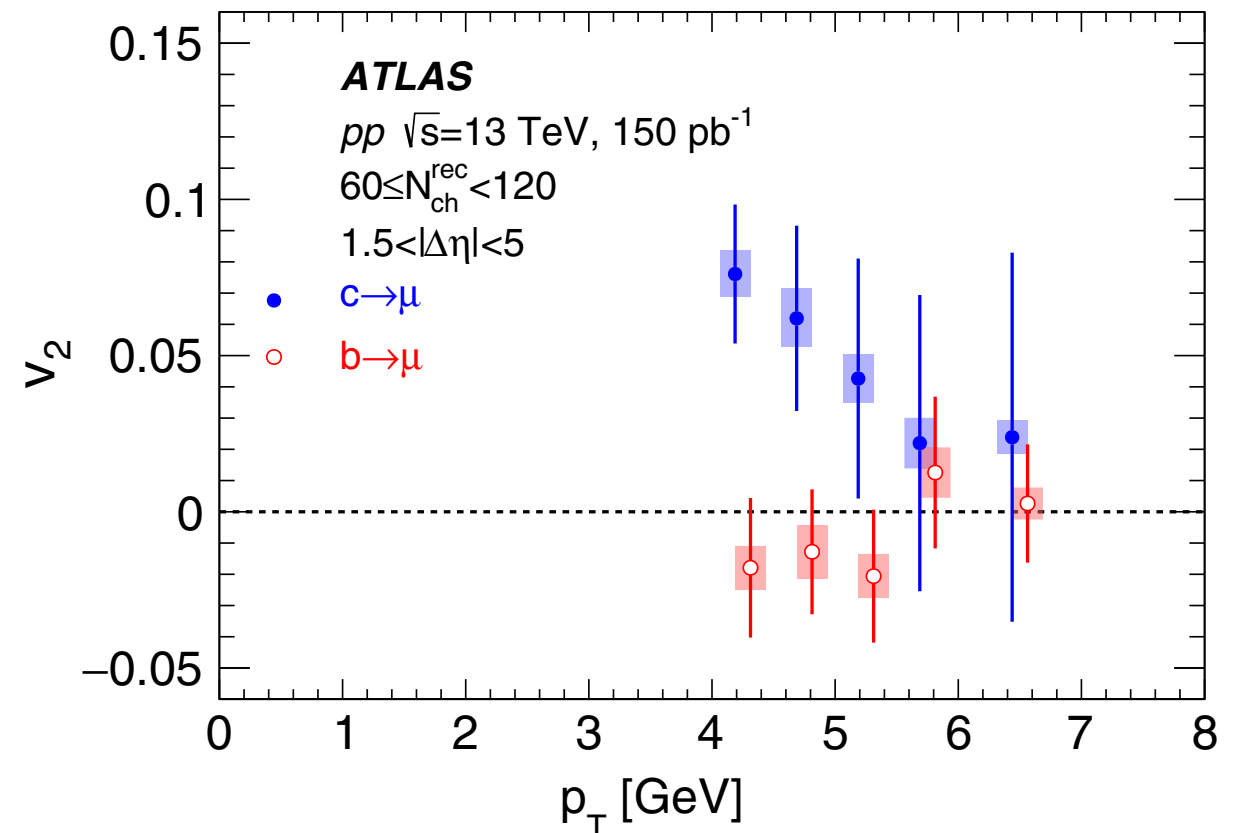


# Golden age for small system collectivity!

Physics Letters B 813 (2021) 136036



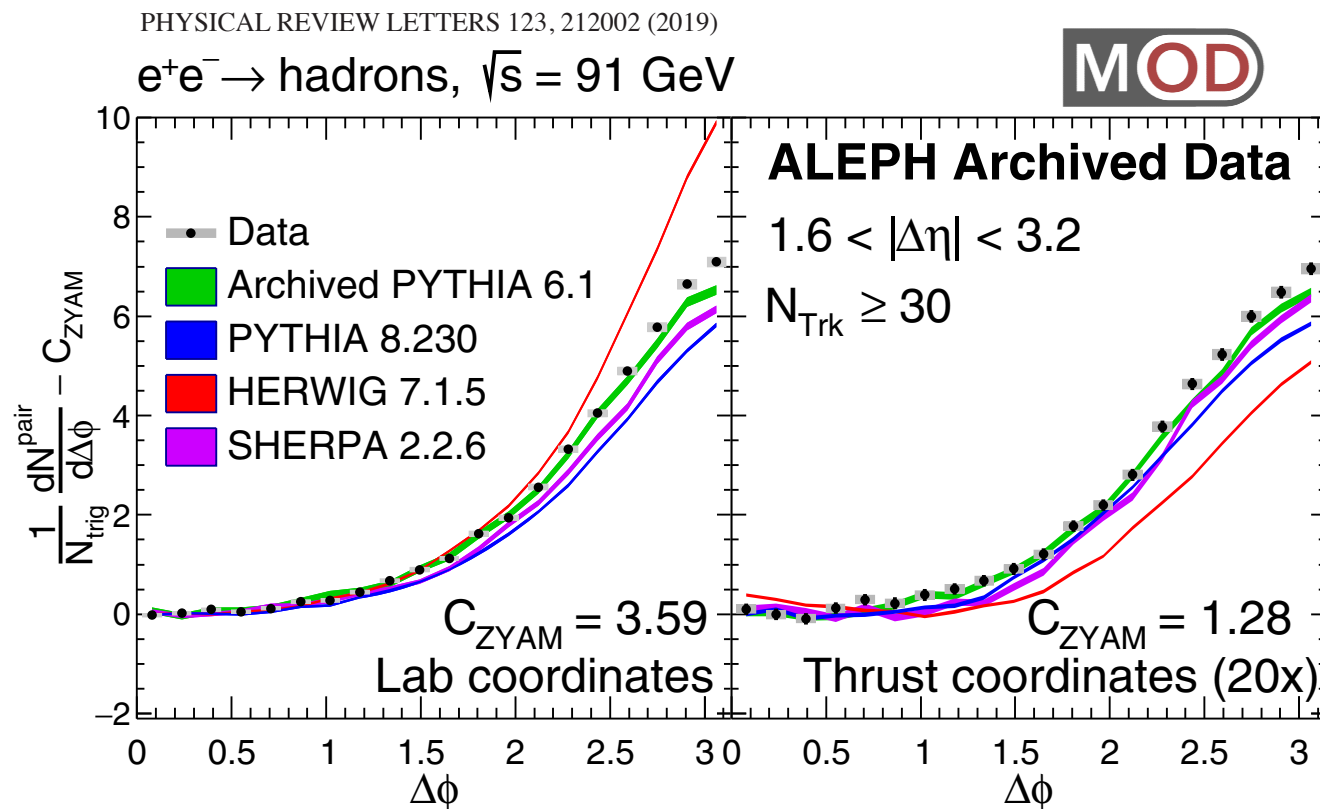
PHYSICAL REVIEW LETTERS **124**, 082301 (2020)



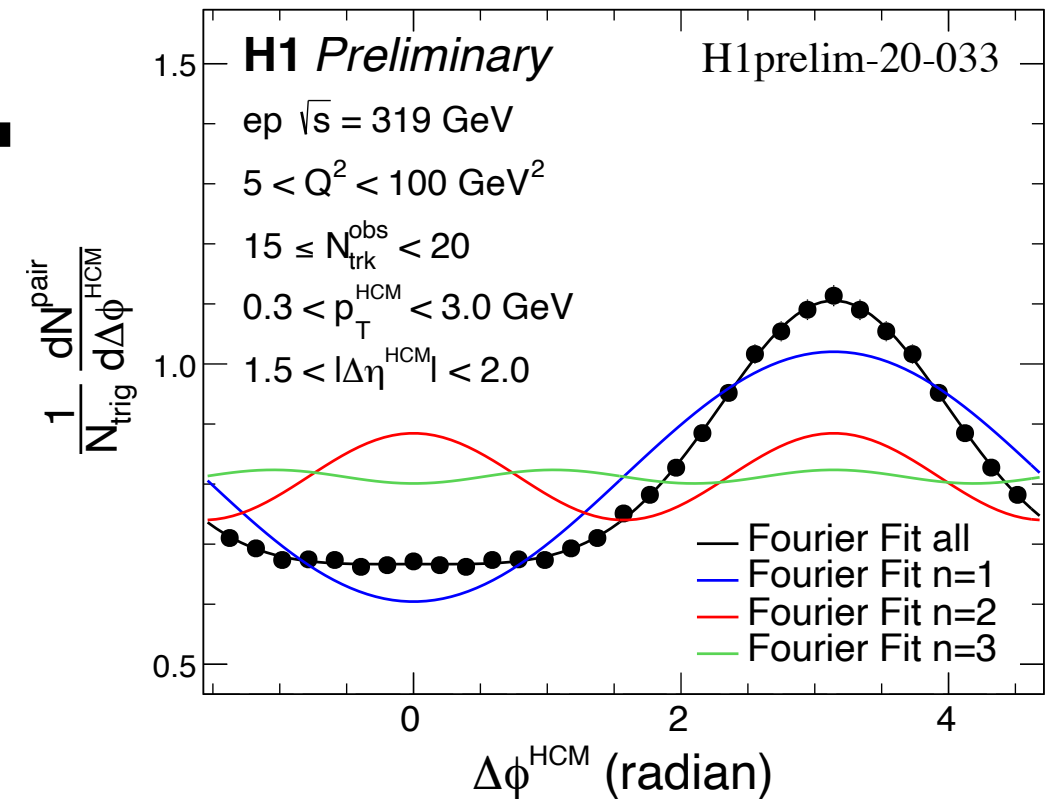
Flow-like signals identified in p+Pb almost 9 years ago!

By now we have observed similar effects in pp with strangeness and heavy flavor!

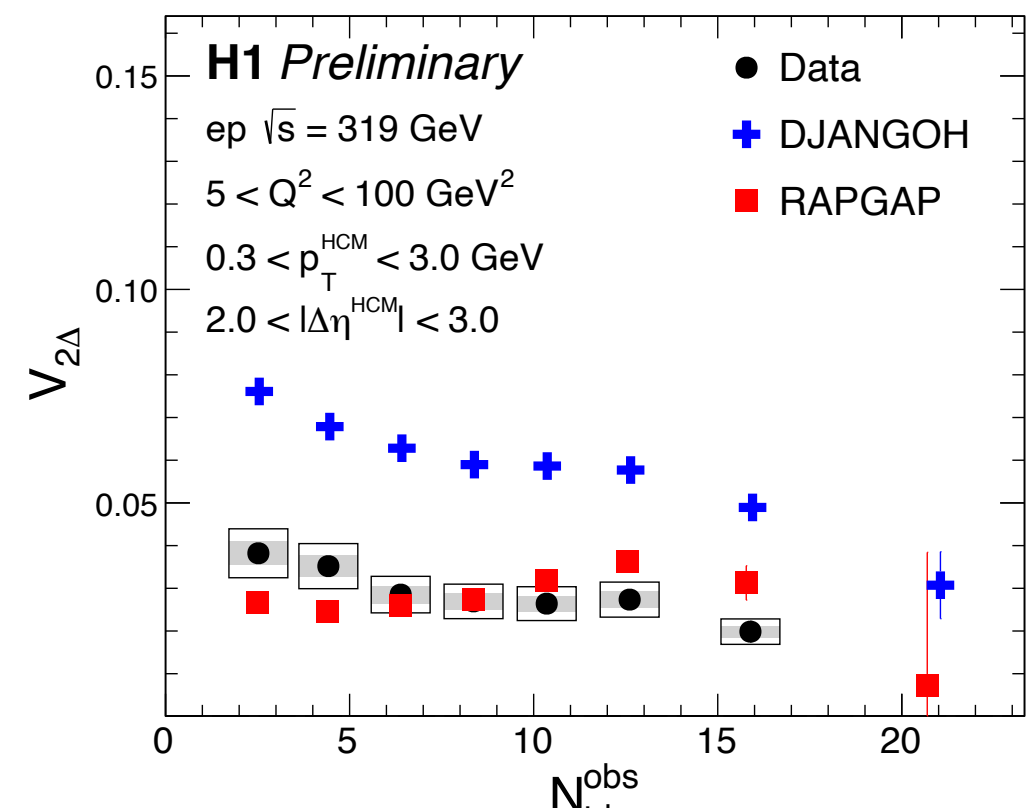
# But not too small...



archived  $e^+e^-$  data shows  
 no obvious “ridge” and good  
 consistency with generators

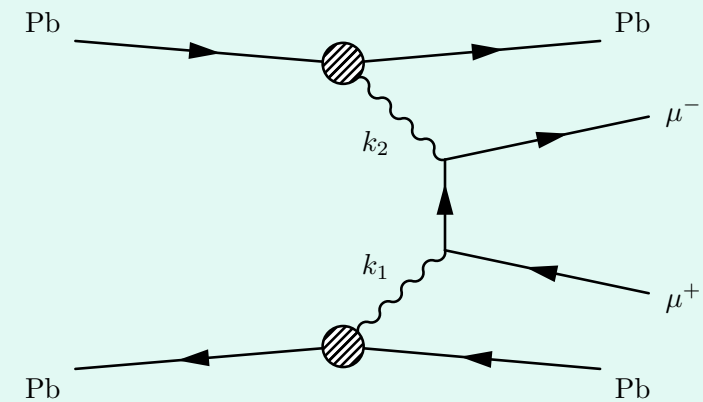
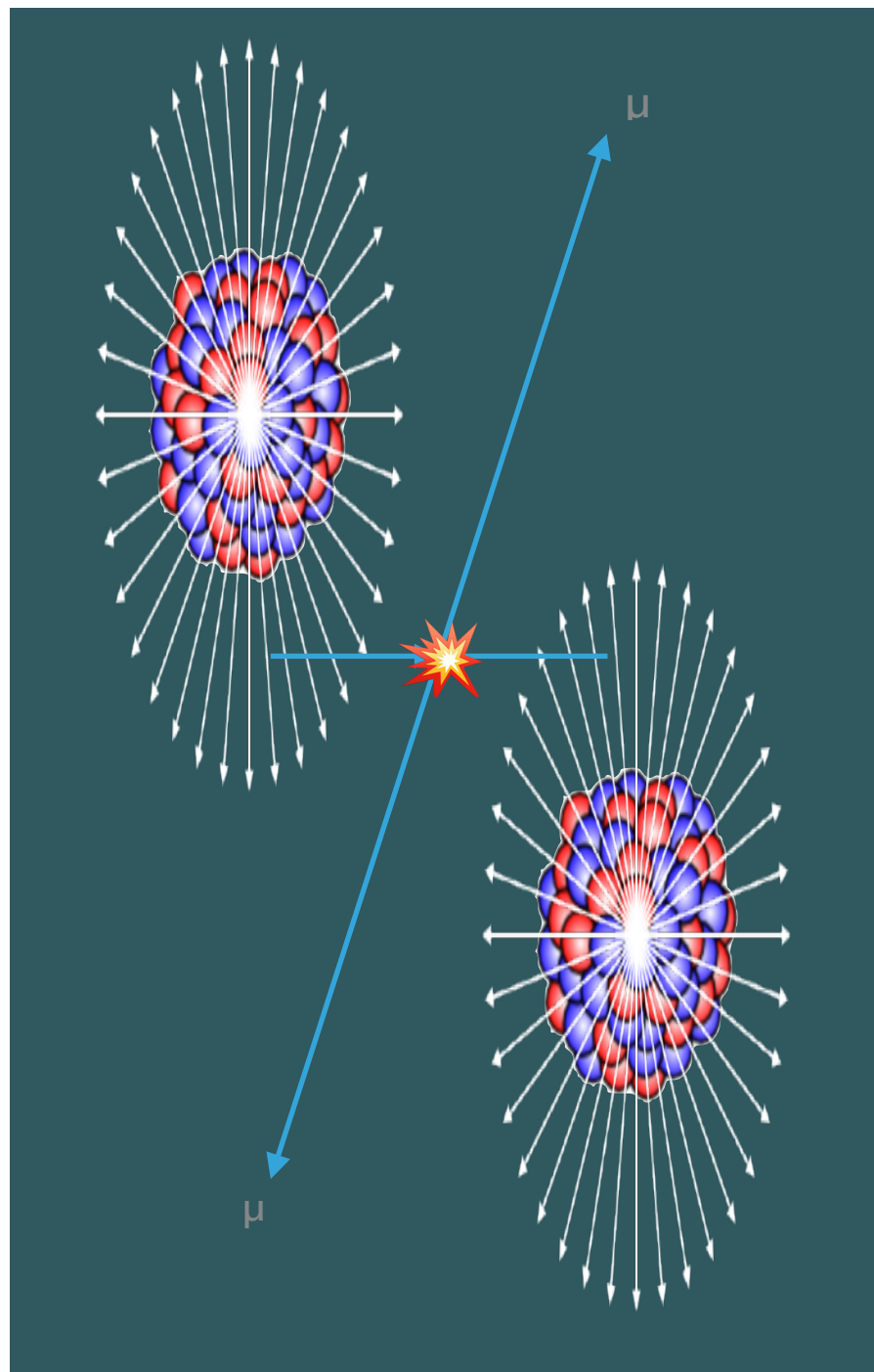


Archived H1 (& ZEUS) DIS data  
 also is consistent with models,  
 with no obvious contribution  
 from collectivity



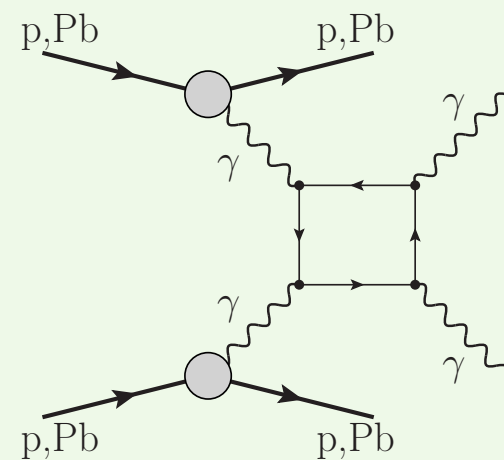


# A golden (or lead) age for UPC @ LHC!



lepton pair production

(Breit-Wheeler formula, Brodsky et al 1971)

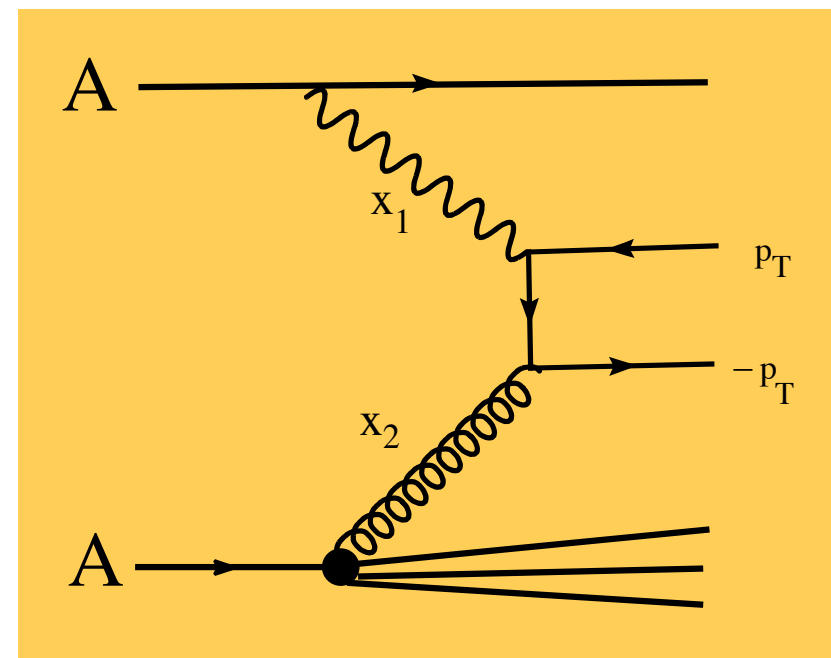
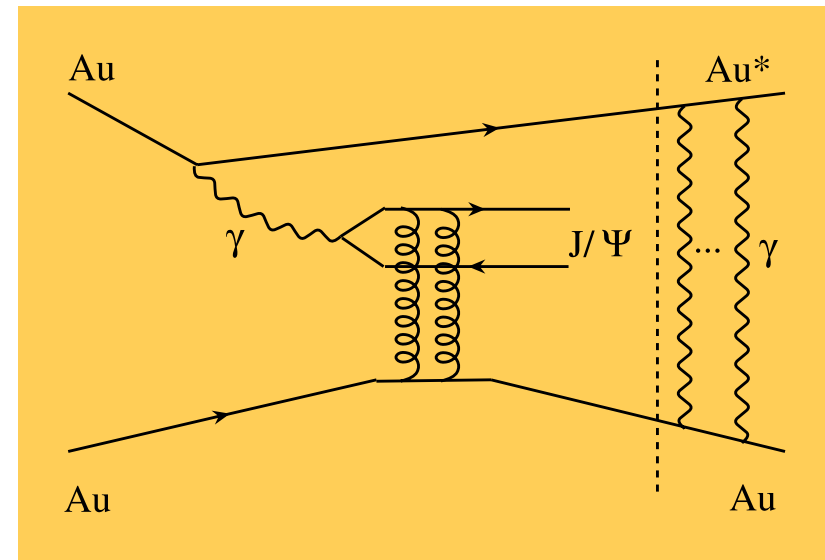
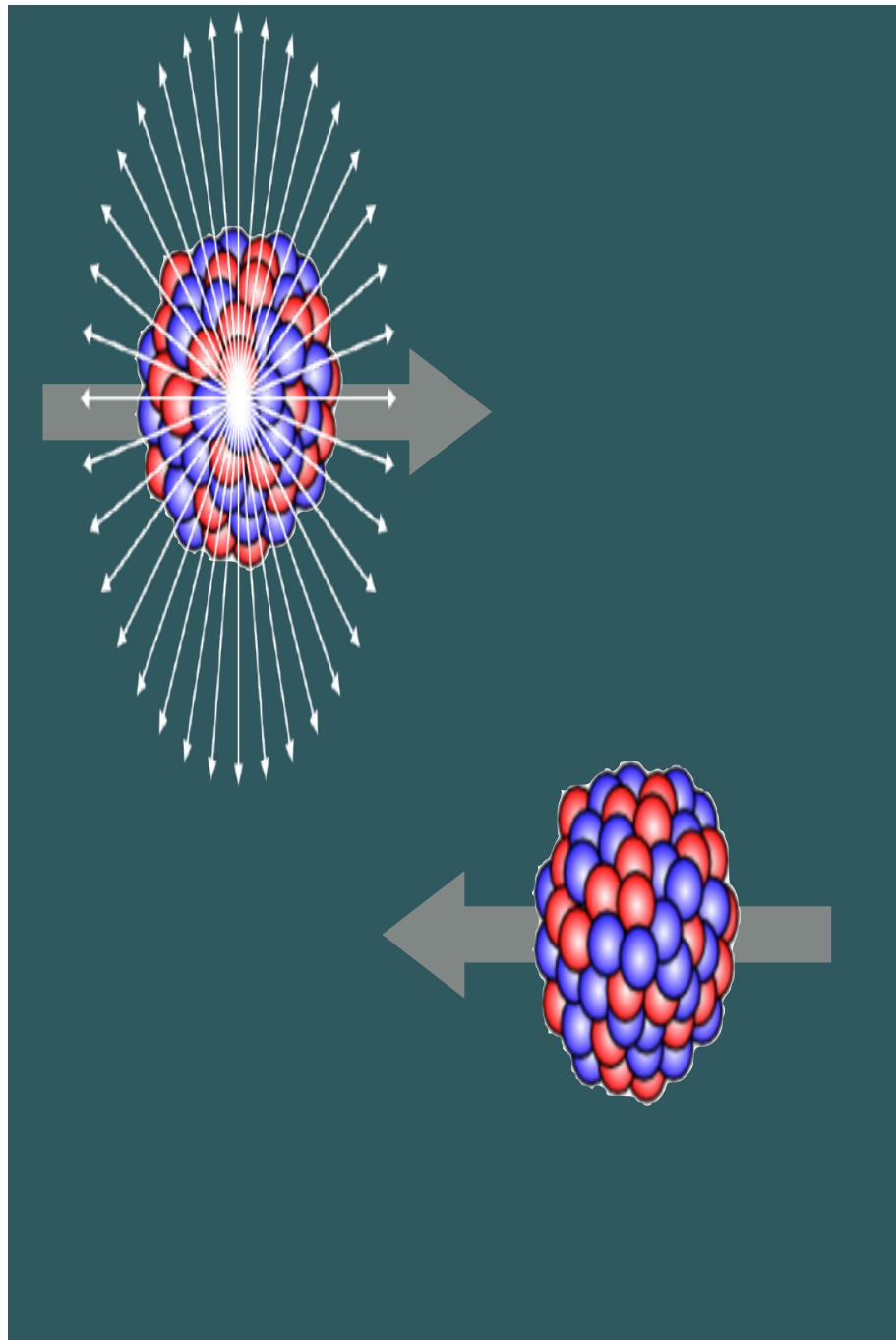


photon pair production

(via quark, lepton, W, BSM? loops)

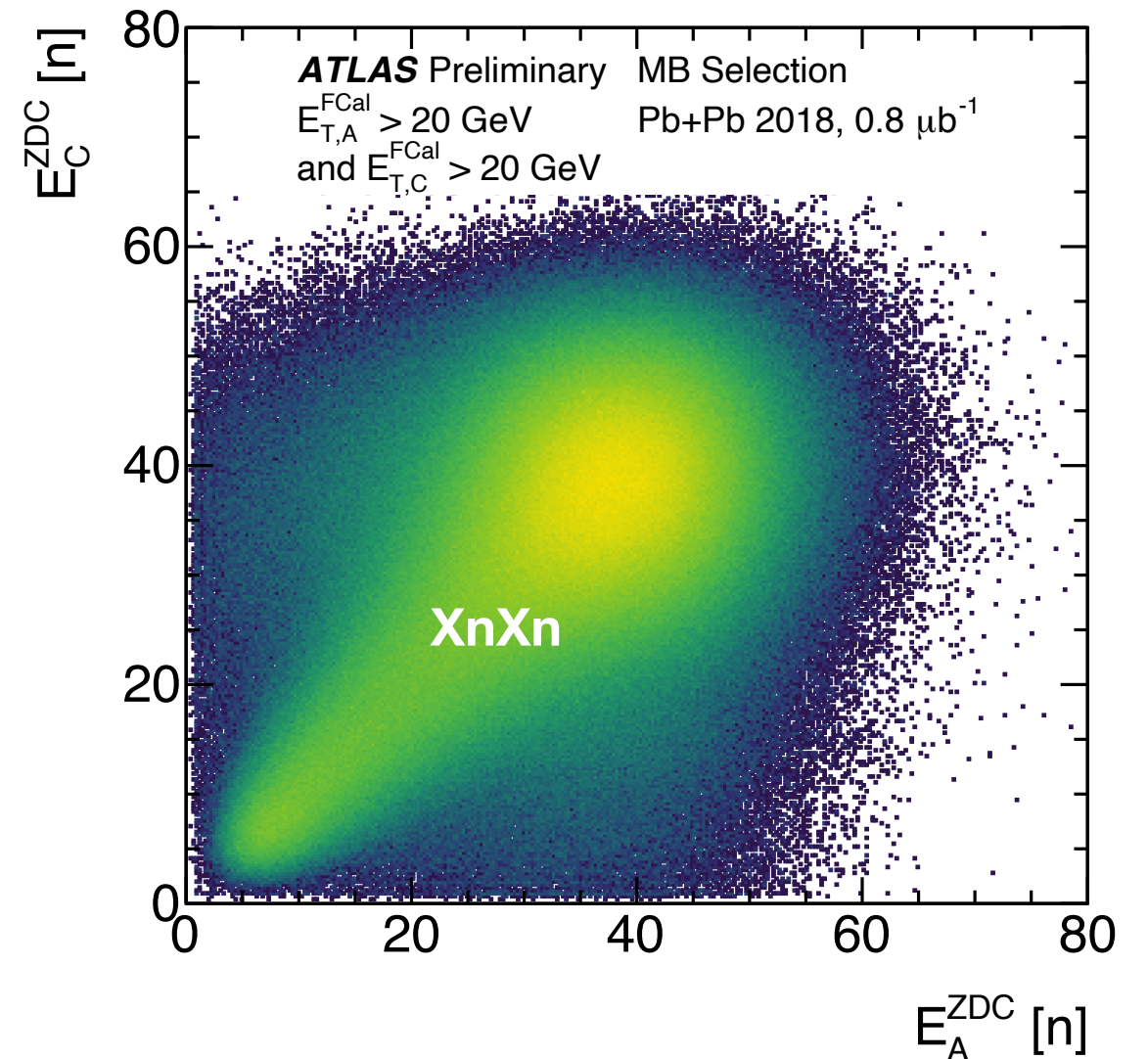
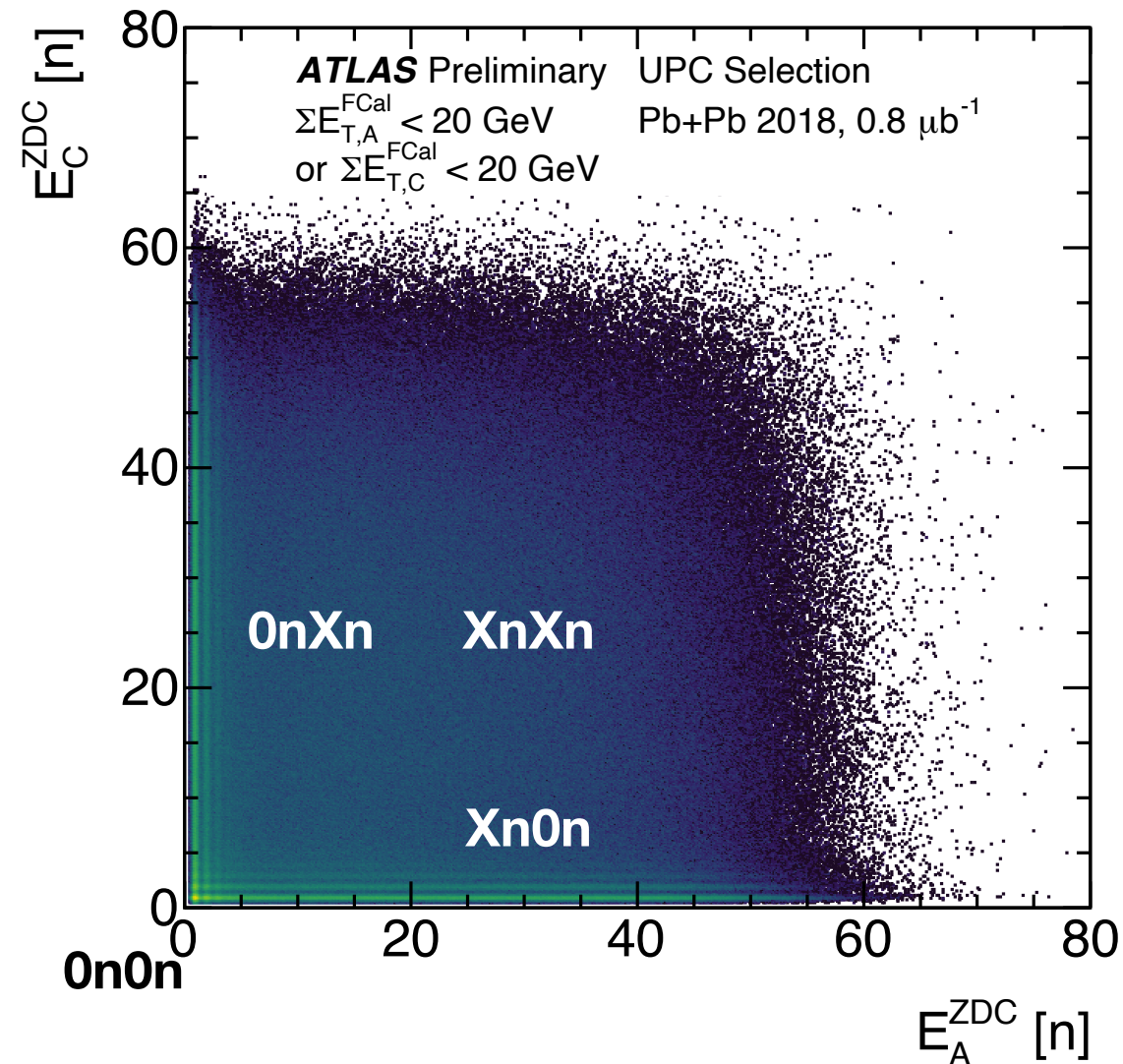
Exclusive  $\mu\mu$  &  $\gamma\gamma$  production are pure QED processes,  
one photon from each nucleus

# A golden (or lead) age for UPC @ LHC!

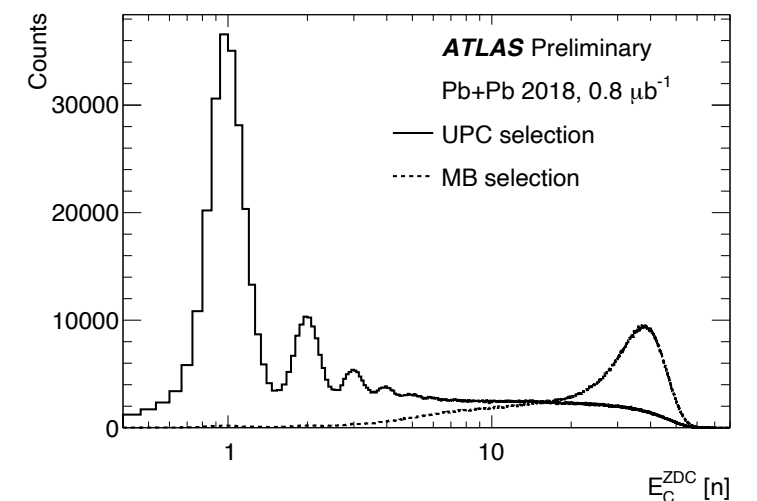


Exclusive J/psi and photonuclear processes involve just one photon

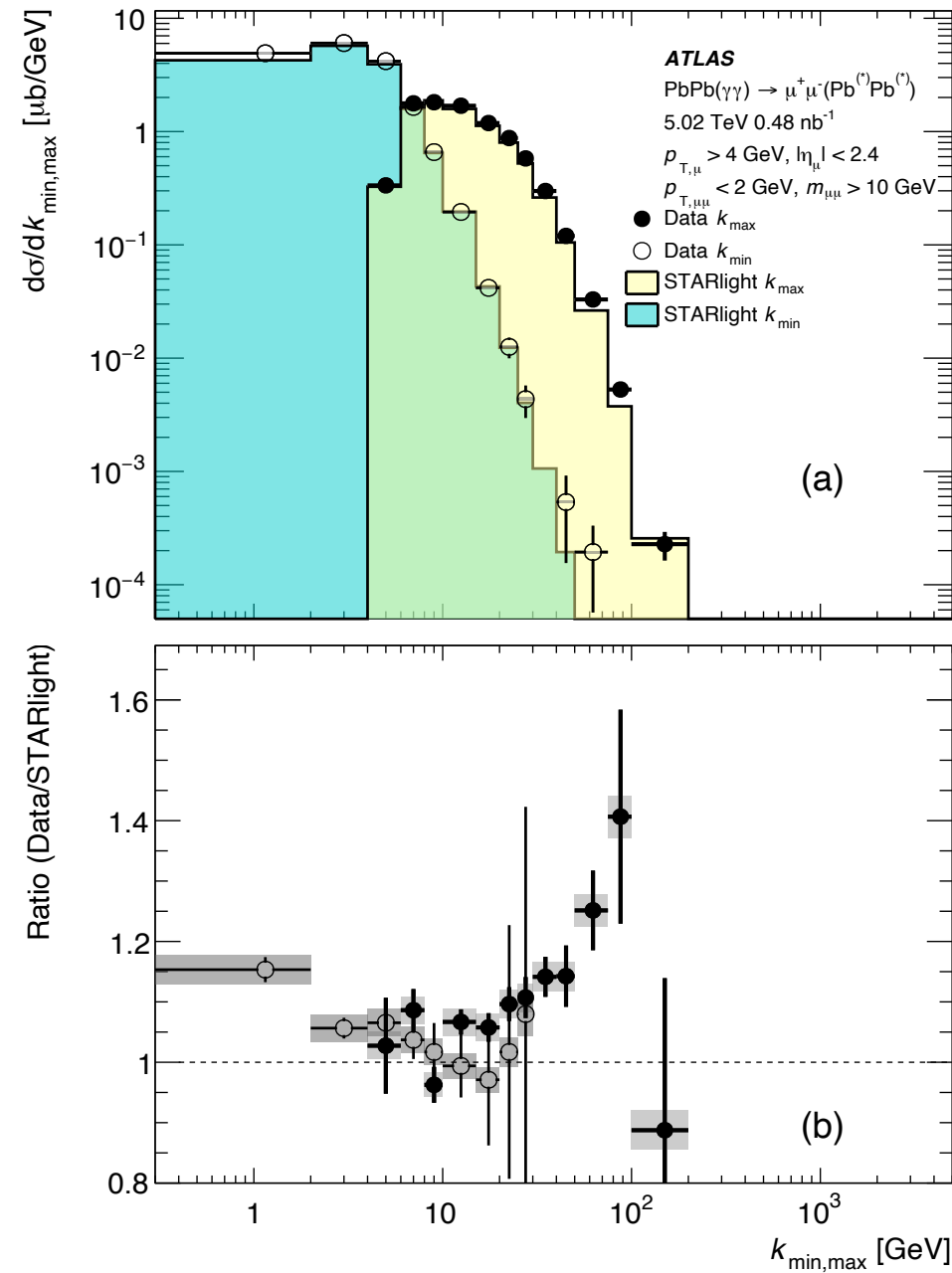
# ZDC correlations in Pb+Pb



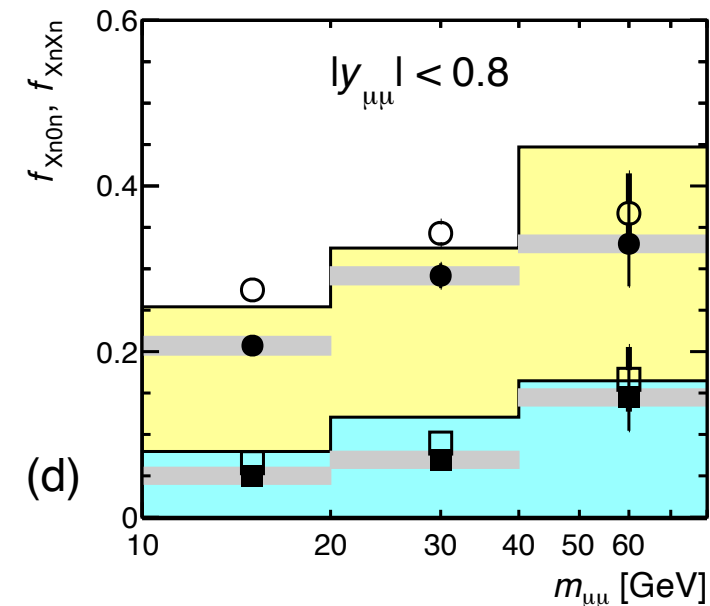
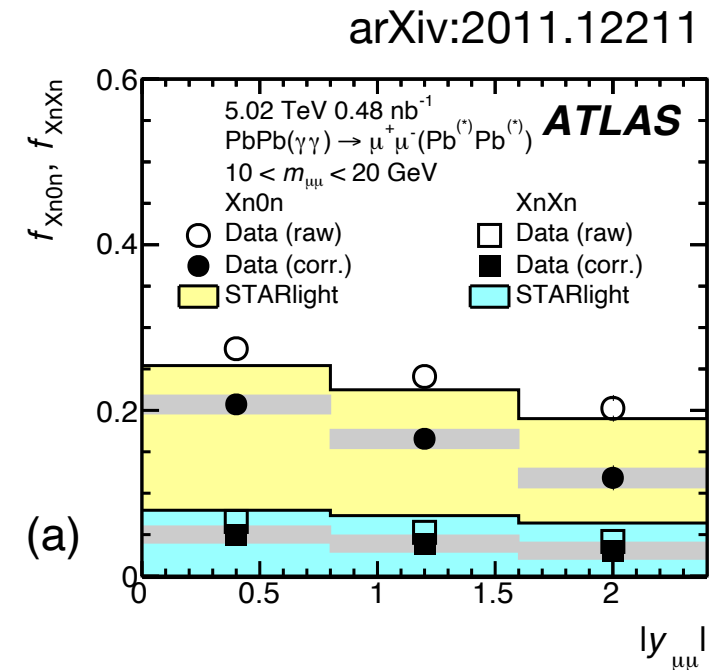
- **ZDC “counts” forward neutrons**
  - Use measured FCal ET to define MB & UPC (when one side  $< 20 \text{ GeV}$ )
  - Clear separation of "Glauber" (right) and EM (left) with one and two-side ZDC topology
- **Use of ZDC topology allows distinct class of UPC triggers**



# Recent photon-photon results



Measured dimuon cross sections show an enhancement of high momentum photons compared to STARlight

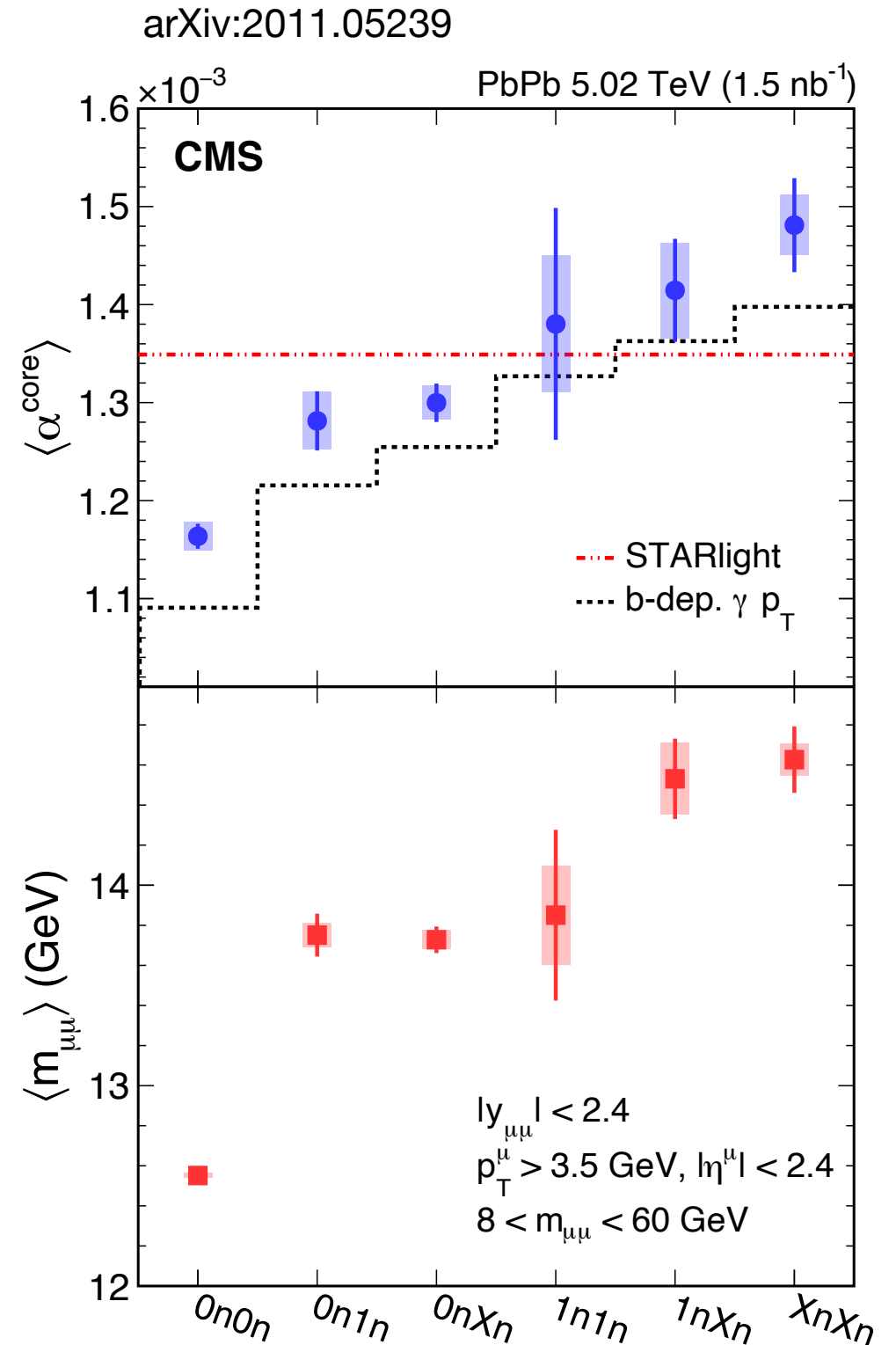
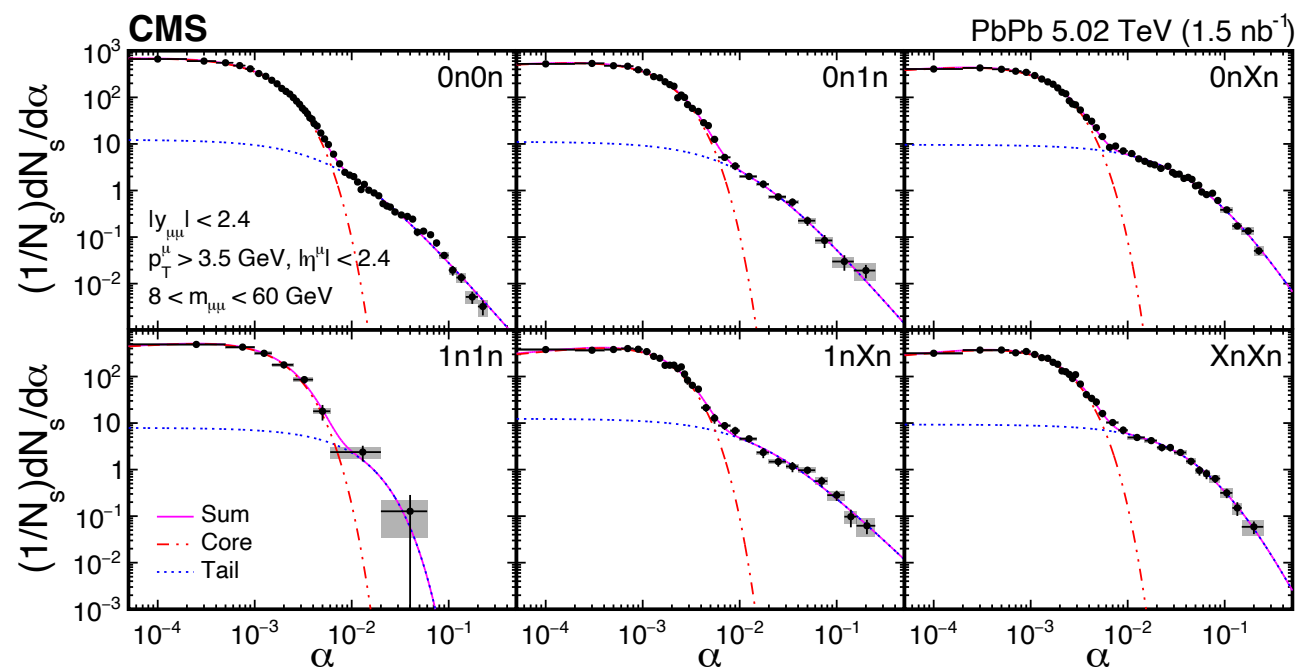


Fraction of events with Xn0n or XnXn rises with  $m_{\mu\mu}$  and decreases with  $|y_{\mu\mu}|$



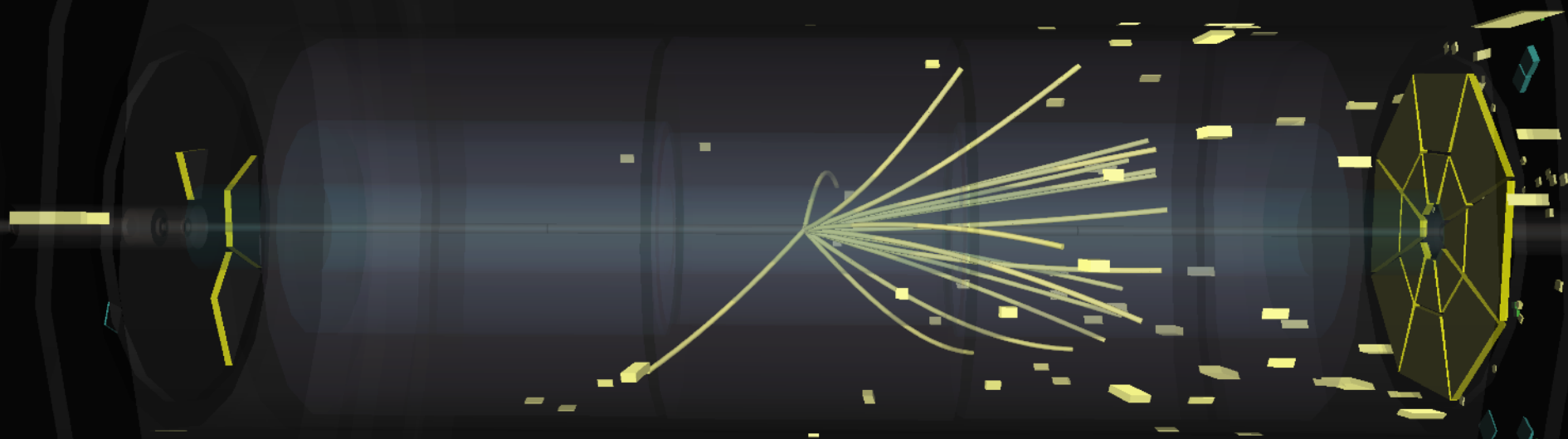
# Recent photon-photon results

Recent CMS results on acoplanarity as a function of the ZDC forward neutron topology reveals coupling between impact parameter and photon transverse momentum



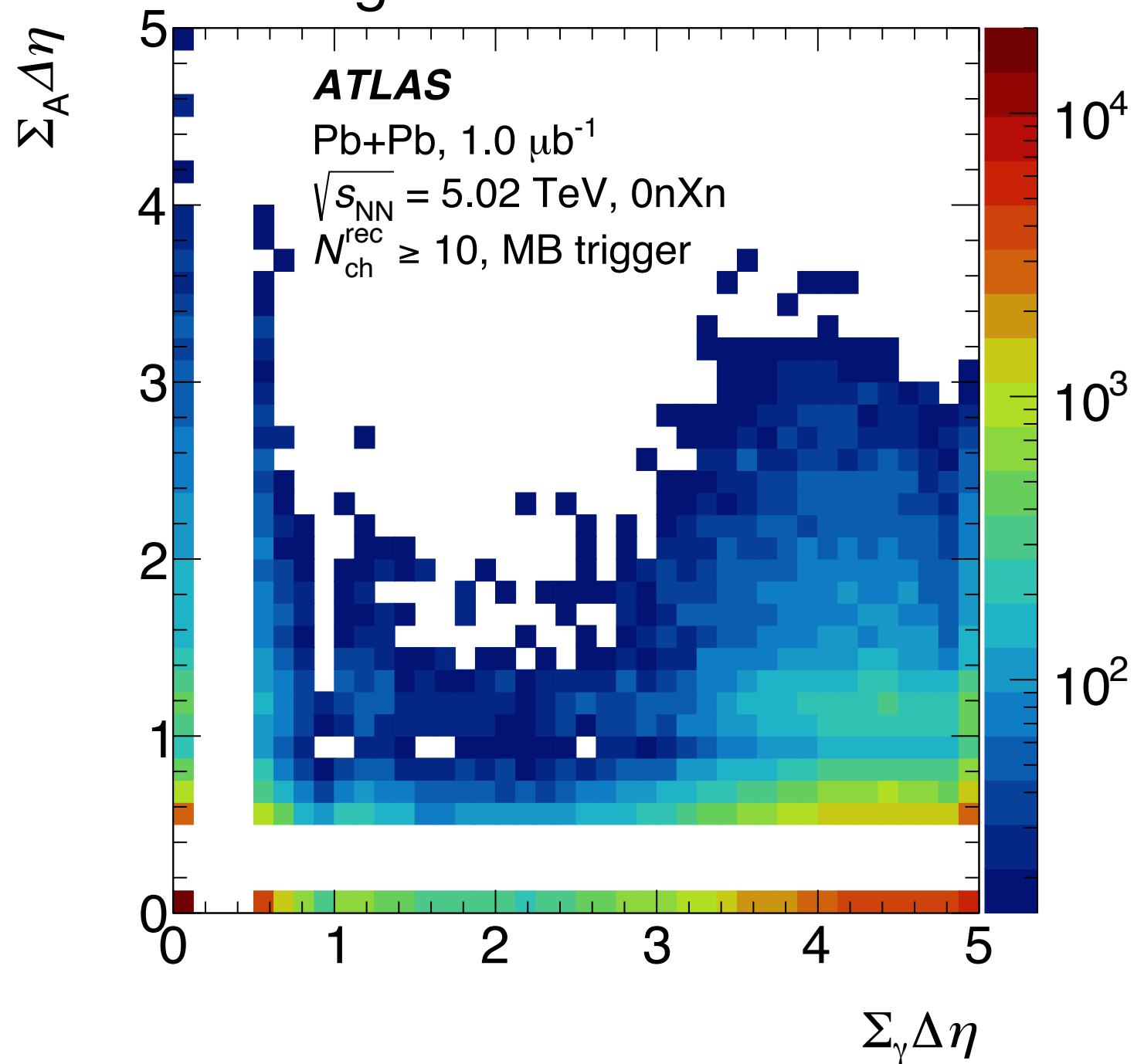


Run: 286717  
Event: 43643466  
2015-11-26 09:53:40 CEST  
Pb+Pb,  $\sqrt{s_{NN}} = 5.02$  TeV

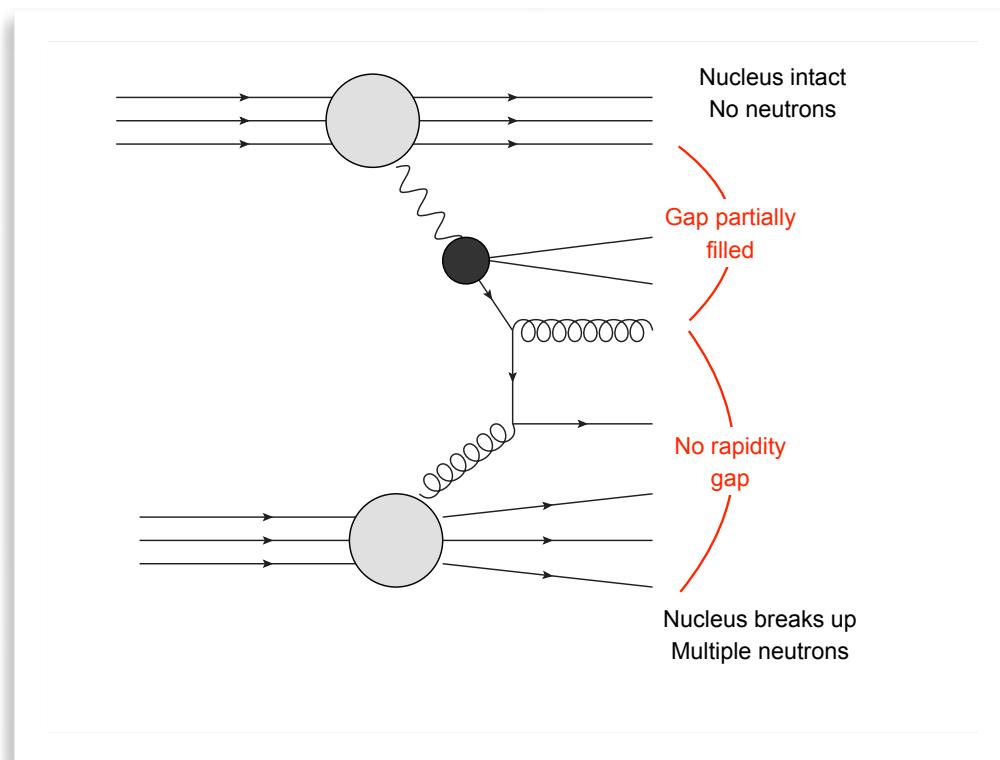
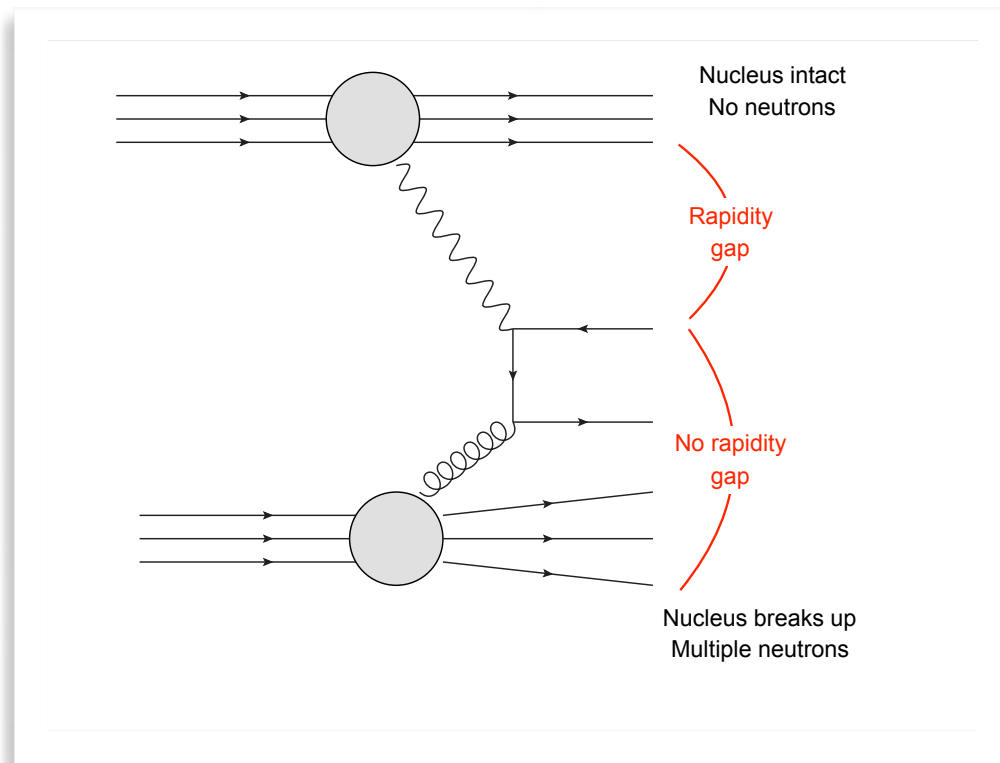


# Gap distributions

single-sided ZDC events

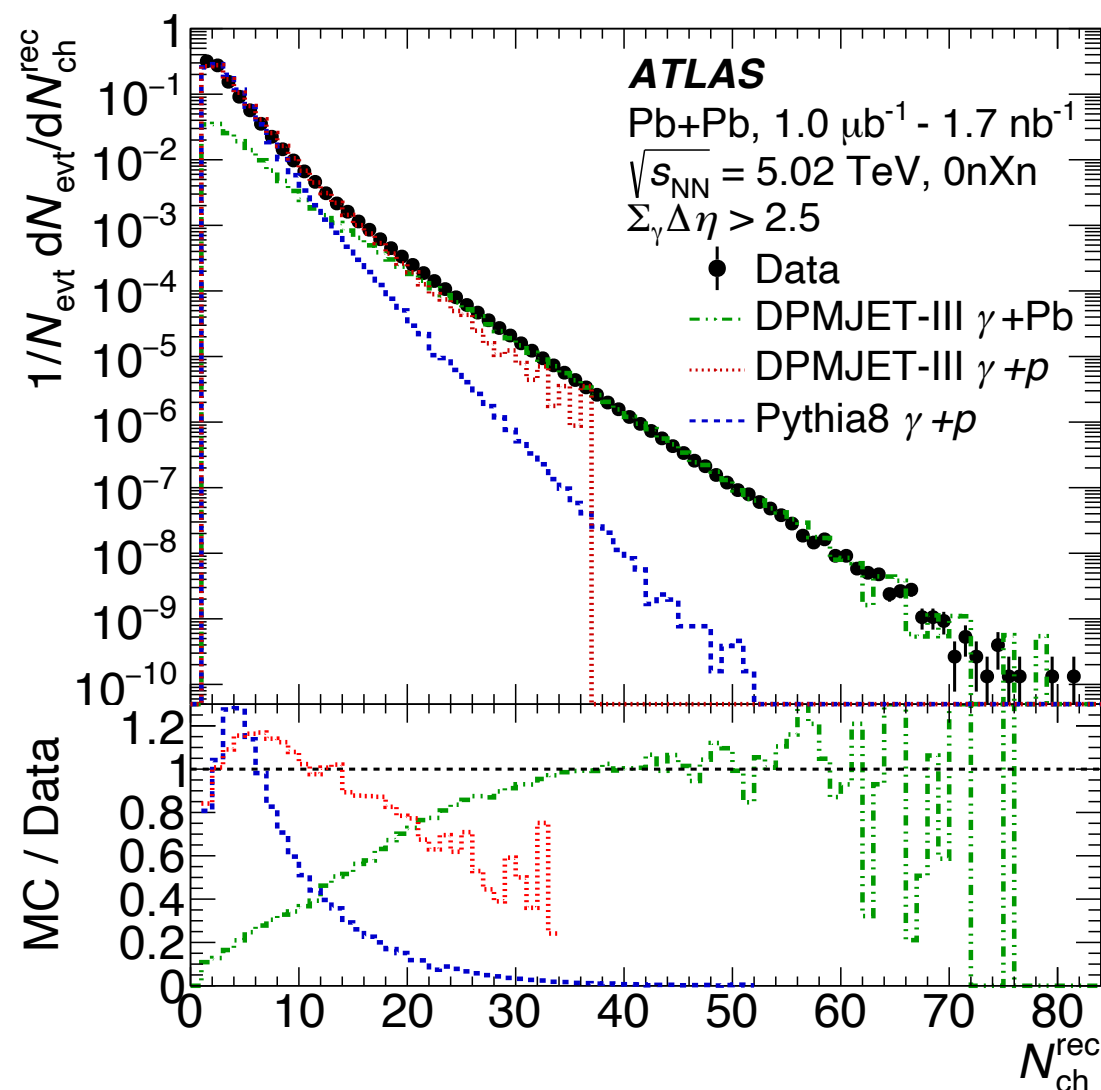


“Sum of gaps” allows some particle production by adding gaps above  $\Delta\eta=0.5$  between calorimeter clusters

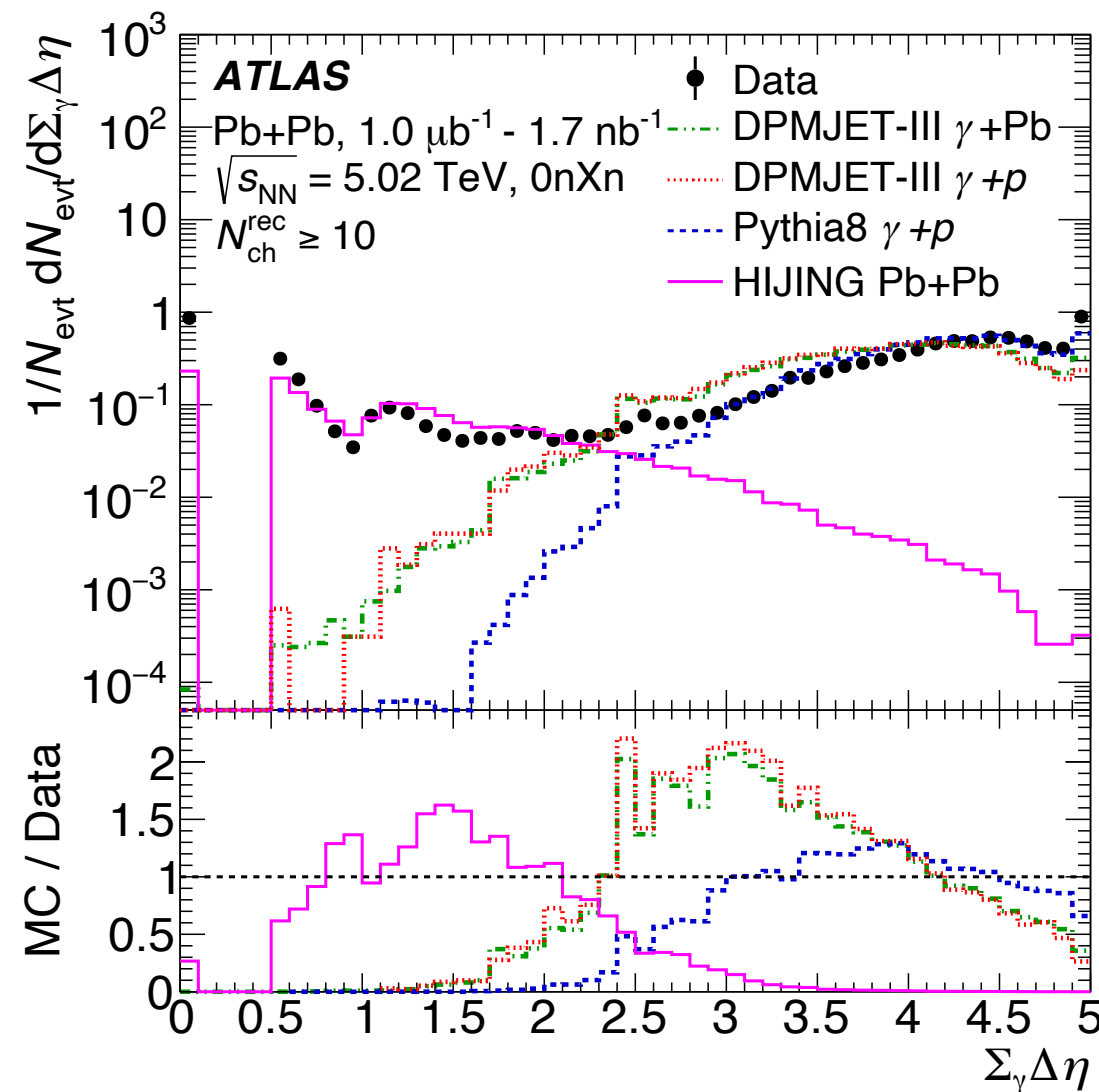


resolved processes can partially fill expected gap

# Diagnosing photonuclear collisions



Reconstructed charged multiplicity distribution can be described of superposition of photonucleon (low  $N_{\text{ch}}$ ) and photonuclear (higher  $N_{\text{ch}}$ )



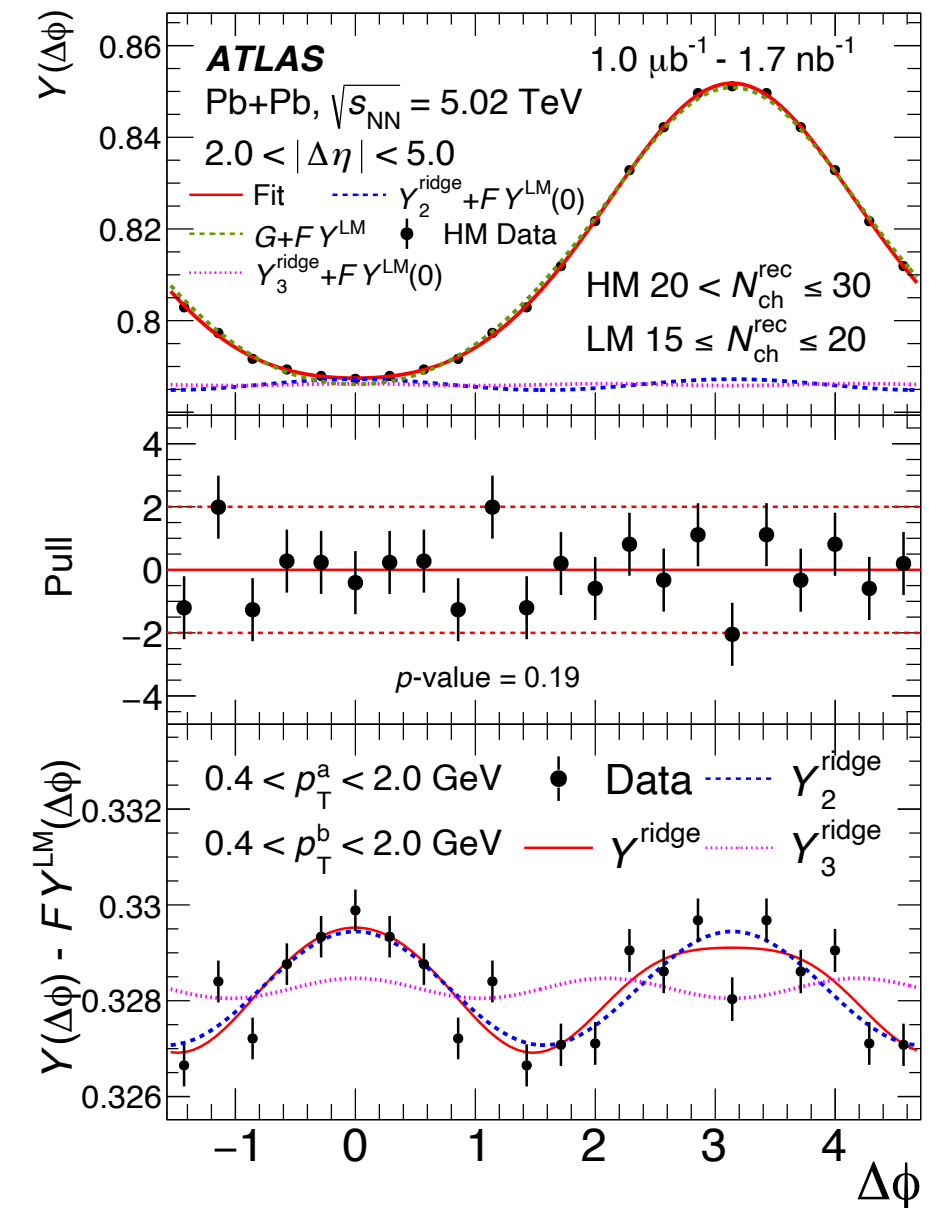
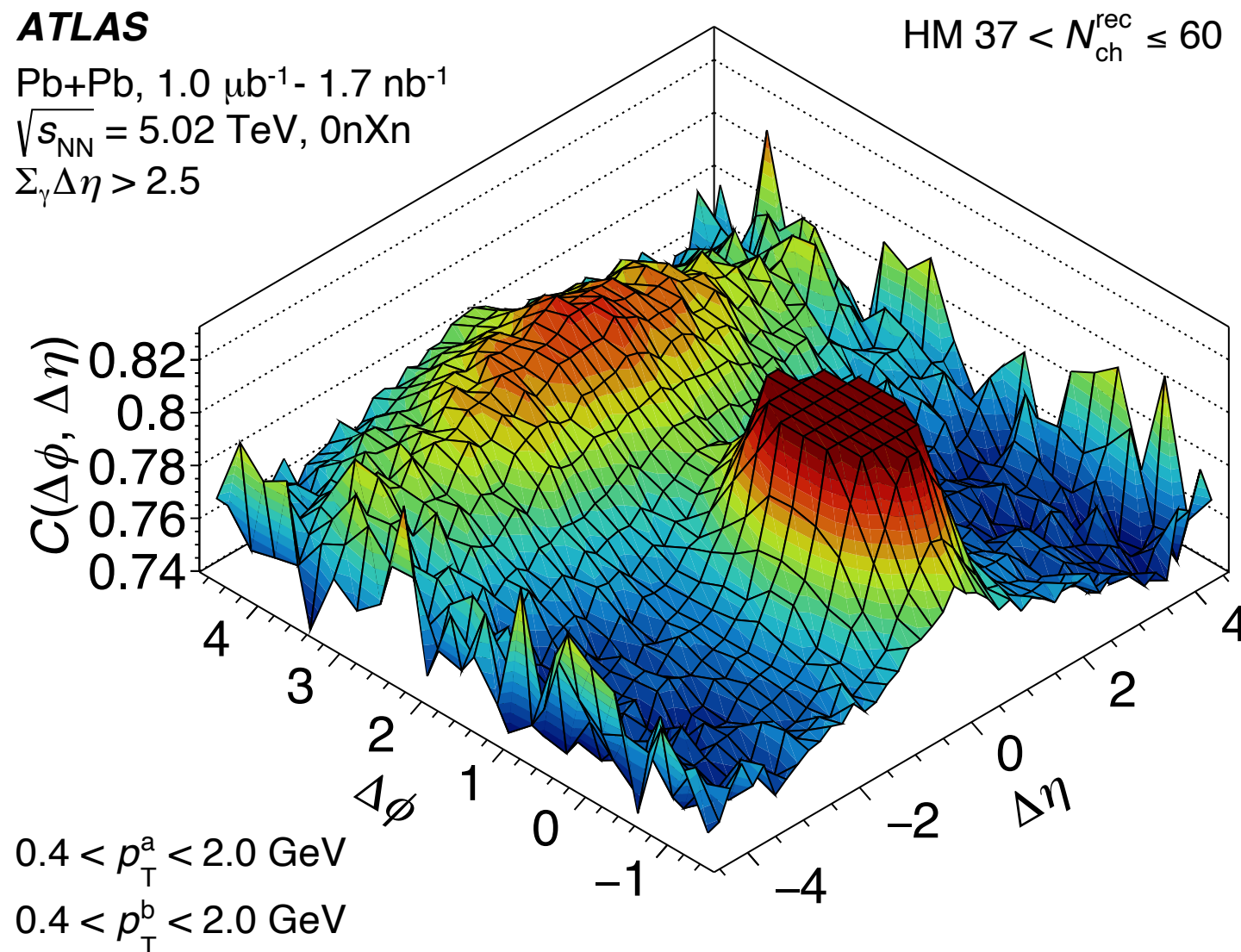
Reconstructed sum-of-gap distribution roughly described of superposition of photonucleon/nuclear (large gap) and peripheral Pb+Pb (smaller gap): crossover around 2-2.5  
→ More work needed for generators!



# Extracting flow contributions

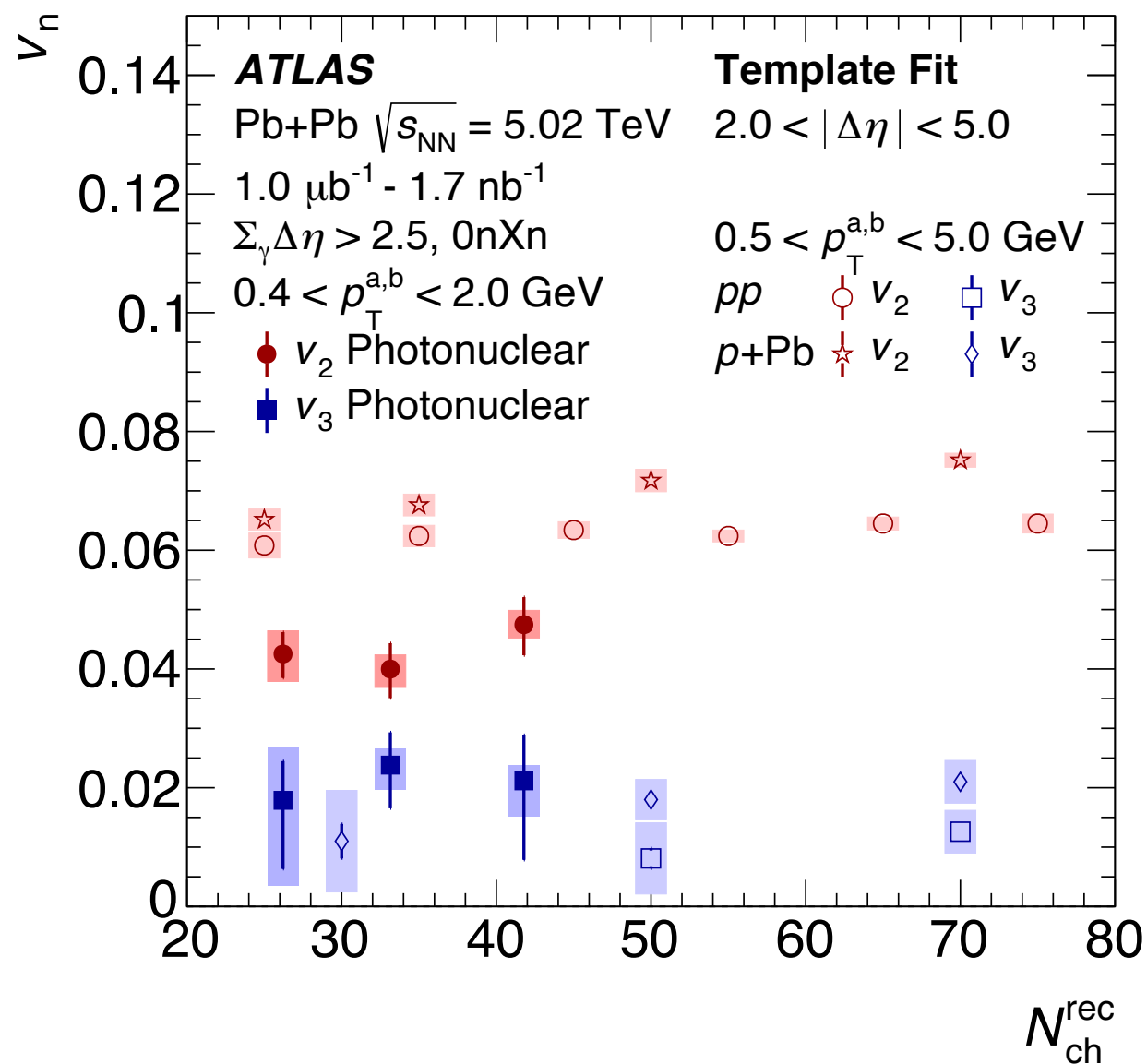
**ATLAS**

Pb+Pb,  $1.0 \mu\text{b}^{-1} - 1.7 \text{nb}^{-1}$   
 $\sqrt{s_{\text{NN}}} = 5.02 \text{ TeV}$ , 0nXn  
 $\Sigma_Y \Delta\eta > 2.5$

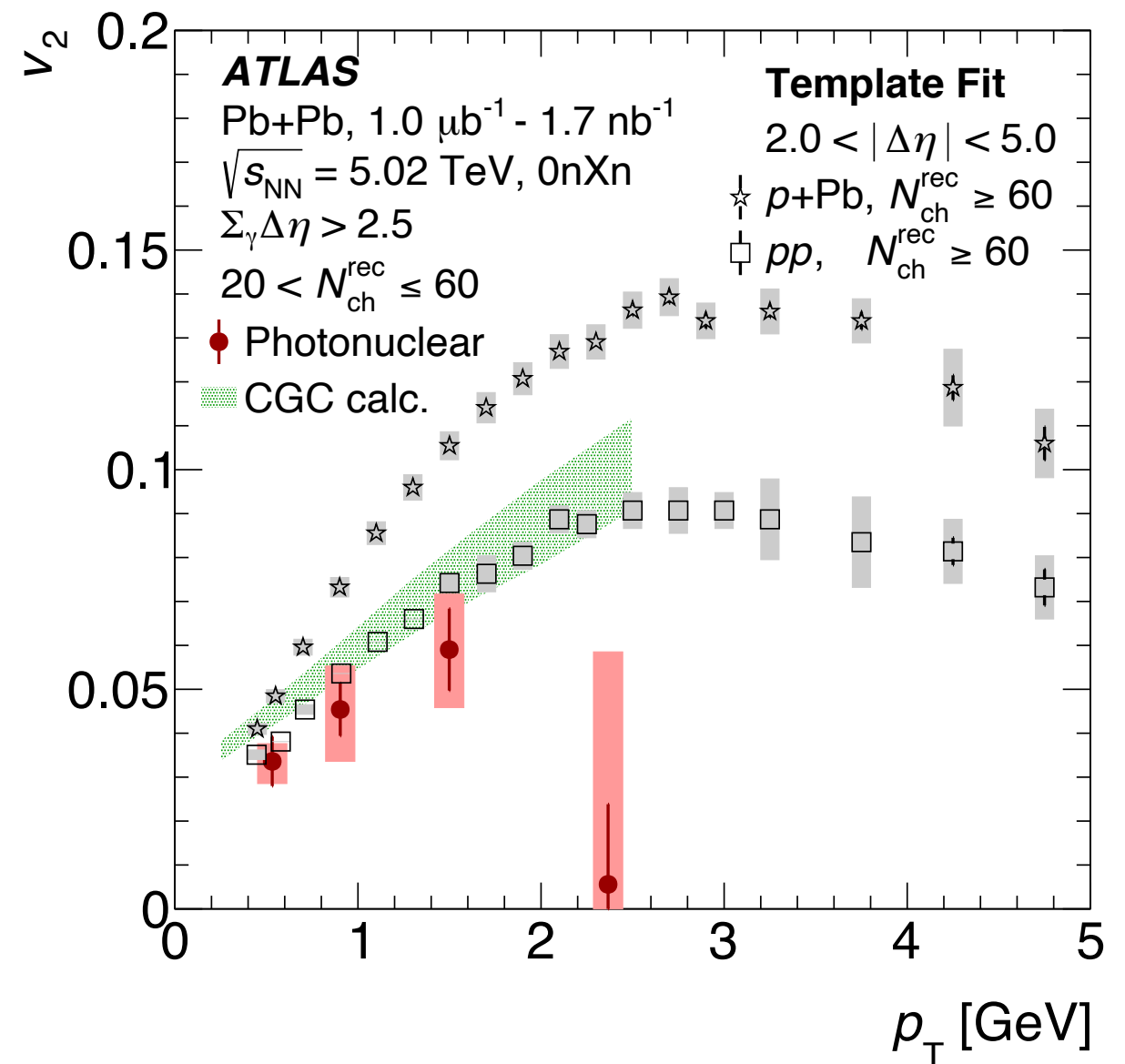


Template method has been successfully used to extract flow coefficients from pp data, based on use of a lower multiplicity sample

# Flow coefficients in $\gamma+A$

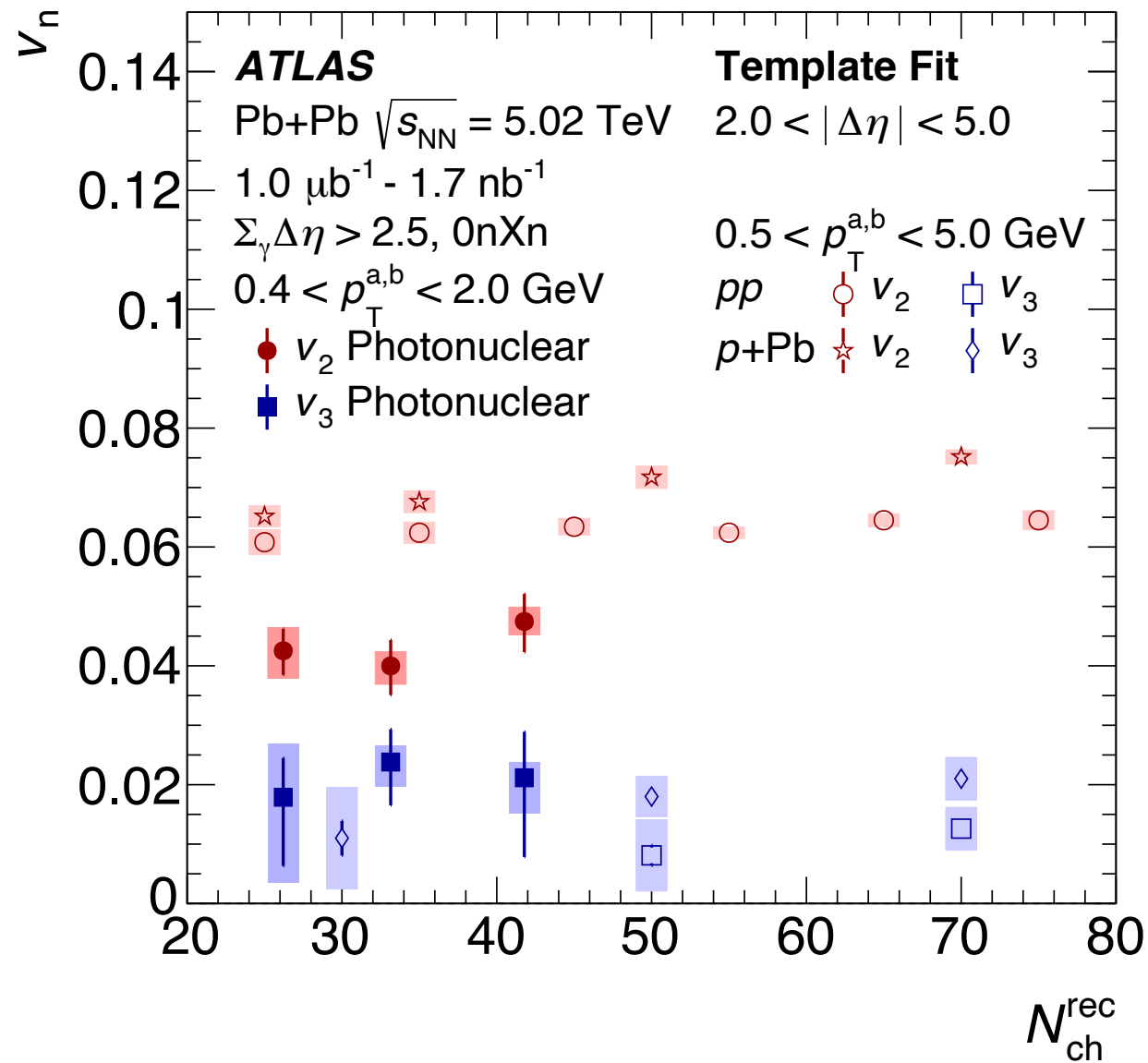


$v_2$  and  $v_3$  observed - with no observed multiplicity dependence

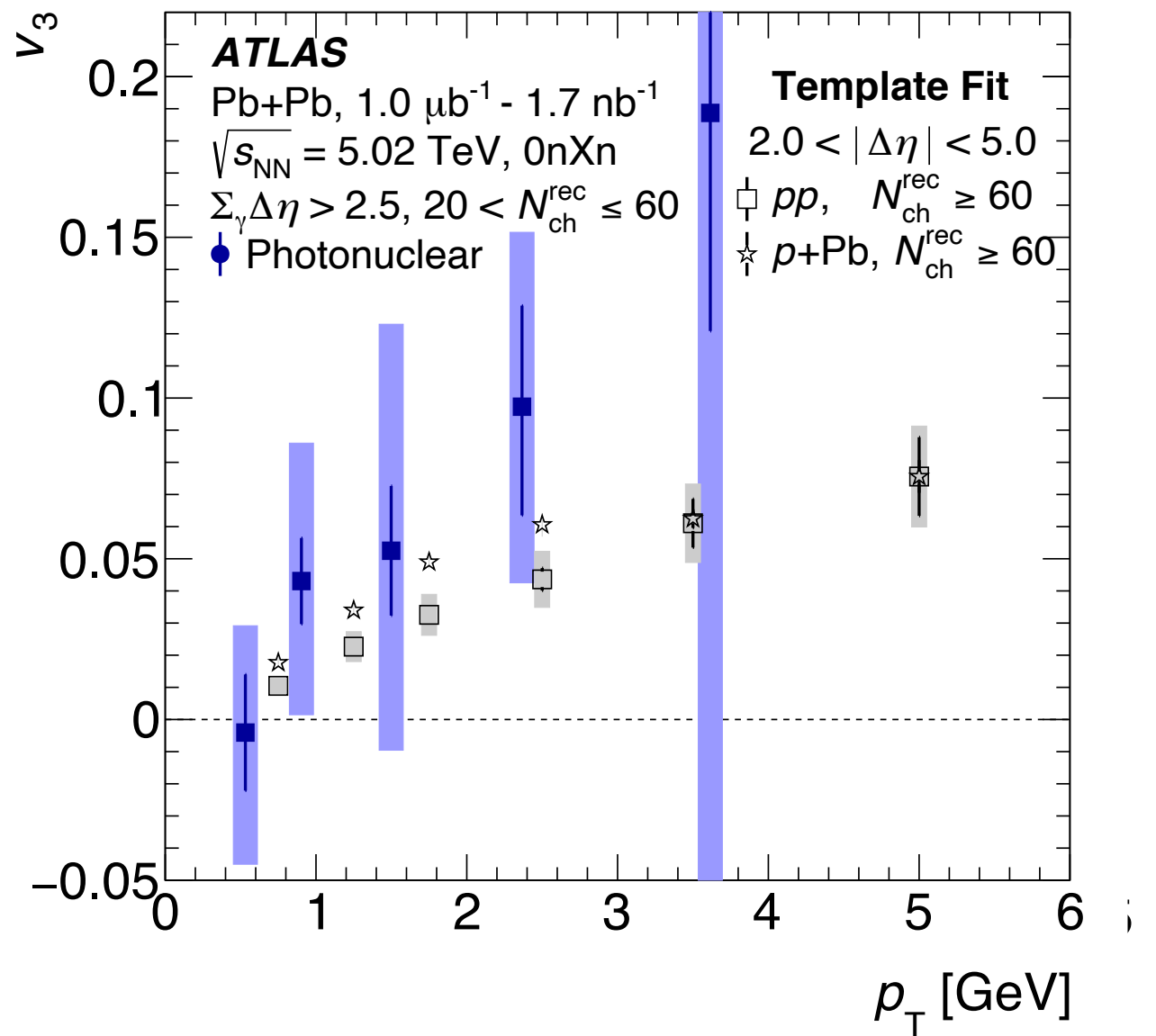


Significant  $v_2$  signal, lower than pp.  
CGC calculation (Shi et al) has also been applied to EIC kinematics

# Flow coefficients in $\gamma+A$



$v_2$  and  $v_3$  observed - with no observed multiplicity dependence

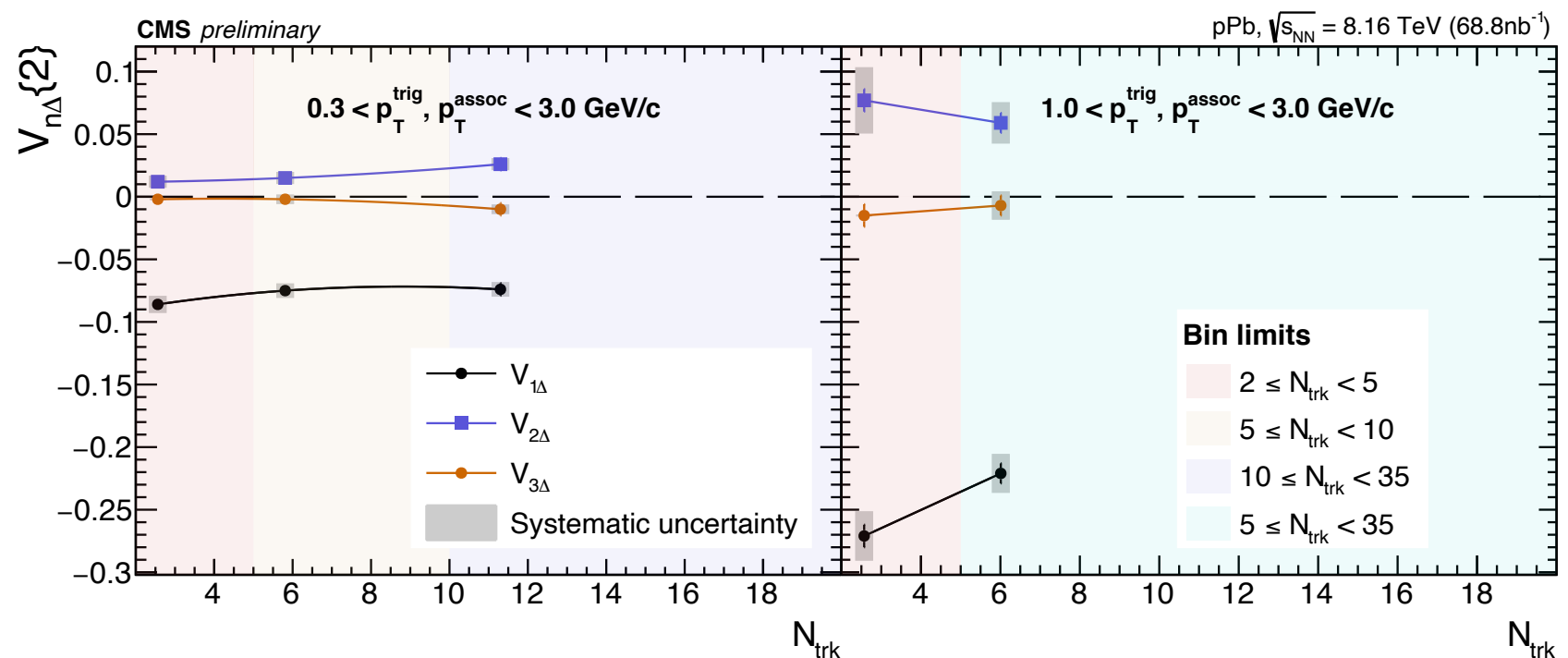
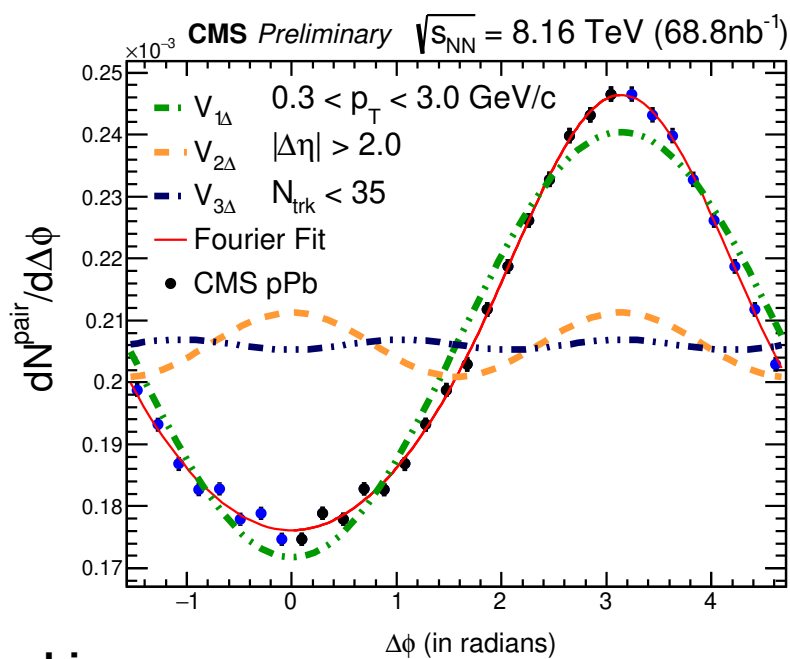
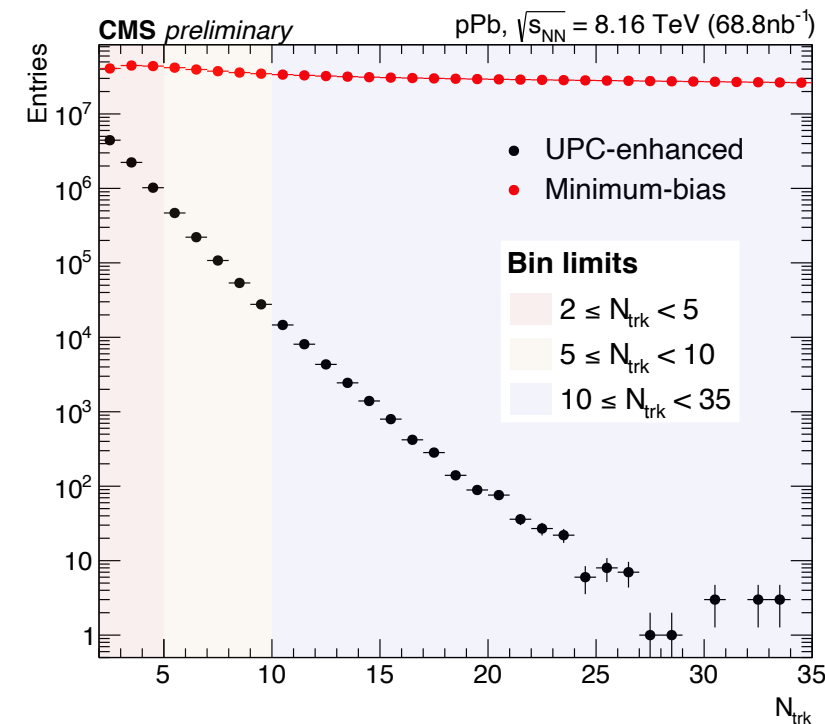


Differential  $v_3$  limited by statistics

# Collectivity in $\gamma p$ ?

p+Pb collisions provide a source of  $\gamma+p$  collisions, as a good comparison system, using selection based on ZDC and gap.

Correlation functions do not show obvious ridge contribution, so comparisons made between Fourier coefficients: patterns suggestive of jet production, and no information on collectivity provided.





# Conclusions

- **Golden age for collectivity and UPC**
  - Flow signals observed in pp, but not e+e- and DIS ep
  - Many new UPC measurements, both for photon-photon and photonuclear processes
- **Collectivity observed in  $\gamma$ A from ATLAS**
  - Event selection based on presence of photon-going sum-of-gaps
  - Template analysis, previously used in pp, used to extract a significant  $v_2$  signal: no multiplicity dependence, magnitude lower than pp/pPb
- **CMS measurements of  $\gamma$ p show no obvious contribution from collectivity**
  - negative  $v_1$  and positive  $v_2$  indicative of jet production
- **LHC Run 3 offers many exciting possibilities!**



# Summary and outlook: $\gamma\gamma$ & $\gamma A$

- **Light by light in Pb+Pb (JHEP 03 (2021) 243)**
  - Measured in 2015+2018 Pb+Pb data
  - Wide range in  $m_{\mu\mu}$ ,  $y_{\mu\mu}$
  - Data unfolded for experimental resolution
  - Good comparisons with Superchic 3.0
  - New, stringent limits set on ALP
- **Correlations in photonuclear collisions (NEW arXiv:2101.10771)**
  - Measured with 2018 dataset
  - Photonuclear processes isolated using (sum) gap selections
    - *Still need more work for theory on details of gap distributions*
  - Ridge signal extracted, using ATLAS template method
    - *Observe significant  $v_2$  and  $p_T$ -integrated  $v_3$*
    - *$v_3$  similar in magnitude, but  $v_2$  is smaller than  $pp$  and  $p+Pb$*
  - Interesting prospects for similar studies at the EIC