# Measurements of long-range correlations in small systems with ATLAS



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### Outline

1. Collectivity in *pp* collisions tagged by Z-boson production <u>arXiv:1906.08290</u>

2. Recent results from exploration of ultra-peripheral collisions arXiv:1904.03536 Phys. Rev. C 96 (2017) 024908



3. Evidence of collectivity is photo-nuclear collisions

#### **ATLAS-CONF-2019-022**S:

https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CONFNOTES/ATLAS-CONF-2019-022/

### What is the pp v<sub>2</sub> correlated with?

- In large systems, the impact parameter is strongly correlated with  $\rm v_2$
- Maybe impact parameter is important in pp  $\rm v_2$
- Multiplicity is not well correlated with impact parameter
- Large Q<sup>2</sup> (short distance scales) interactions
  - smaller impact parameter
  - More MPIs
- Require Z-boson: Q<sup>2</sup> ~ (90 GeV)<sup>2</sup>



Phys. Rev. D 69, 114010 (2004)

### **Analysis method**

- Event with Z-boson identified by presence of two high-pT muons with invariant mass between 80-100 GeV
- Correlate other particles in the event
- Pileup vertices can be very close to Z-event vertex (indistinguishable).
- Construct synthetic pileup contribution to Z-event correlations and subtract.



### v<sub>2</sub> in Z-tagged pp events versus inclusive pp



NEW: 13 TeV Z-tagged measurement and pT measurement

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

Expansion of experimental techniques to perform correlation studies in high pileup conditions

### **Ultra-peripheral collisions with ATLAS**



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

Photon max energy~ 80 GeV at LHC

Two categories

- Pure EM processes
- Photo-nuclear interactions

All processes "may" also include one or both nuclei breaking up, due to additional soft photo exchange

### **Pure EM processes**



Pure EM process: interactions of photons from each nucleus



lepton pair production ATLAS-CONF-2016-025



photon pair production Nature Physics 13 (2017) 852

### **Light-by-light scattering with ATLAS**

- Updated measurement with 1.7 nb<sup>-1</sup> 2018 data
- 8.2σ observation
- Clean system
- Limits couplings for photons to axion-like particles
- Active goal of the LHC in Run 3 and 4.



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arXiv:1904.03536

Direct γA collisions Photon couples directly to nuclear parton



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#### Resolved vA collisions photon virtually resolved into hadronic state



**Dominant interaction** 



- One-sided nuclear fragmentation (zero-degree calorimeter ZDC)
- Rapidity gaps
- We have contributions from both diagrams

### "High"-multiplicity photo-nuclear collisions



### Gap definition (detector roll-out)



Event Selection:  $\Sigma_A \Delta \eta_{gap} < 3$ 

 $Σ_γ Δη_{gap} > 2.5$ 

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



### 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<sub>ch</sub>/dη in γA collisons



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

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### ATLAS template fits to vA correlations



### v<sub>2</sub> in photo-nuclear collisions



Significant v<sub>2</sub> in photo-nuclear collisions!

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

### **p**<sub>T</sub> dependence



Similar  $p_{T}$  dependence to hadronic collisions systems

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

### Conclusions

Z-tagged and inclusive pp  $v_2$  are consistent. New: 13 TeV measurement and  $p_T$  dependence

 $8.2\sigma$  observation of light-by-light scattering

Photo-nuclear v<sub>2</sub> has a similar order of magnitude and trends as other previously measured hadronic systems

Intuitive property of hadronic-like photo-nuclear collisions (photo  $\rightarrow$  vector meson).







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# Thank you

### Consistency of $N_{ch}$ and $p_T$ in $\gamma A$



#### Now on same y-axis scale

### ATLAS template fitting method pp

ATLAS Phys. Rev. C 96 (2017) 024908

