ATLAS and CMS results on collectivity in small-systems

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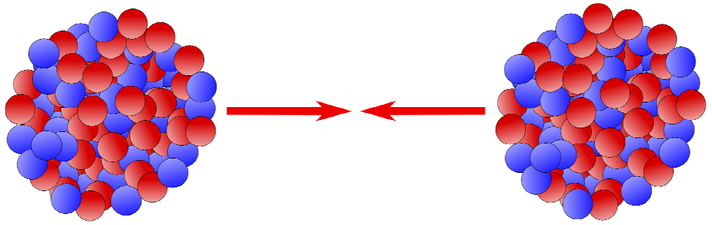
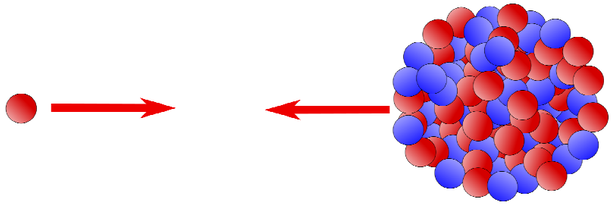
On behalf of the ATLAS and CMSCollaborations

QGP in small systems?

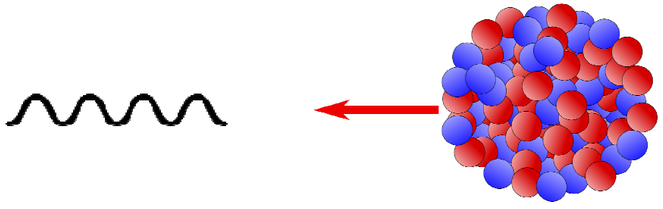


ion-ion QGP ✓



proton-ion QGP ✓

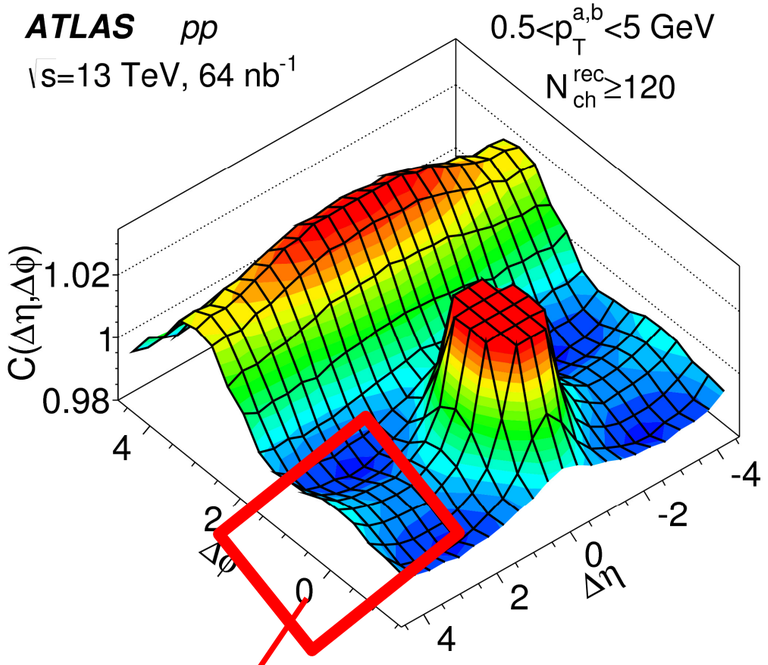
proton-proton QGP ?



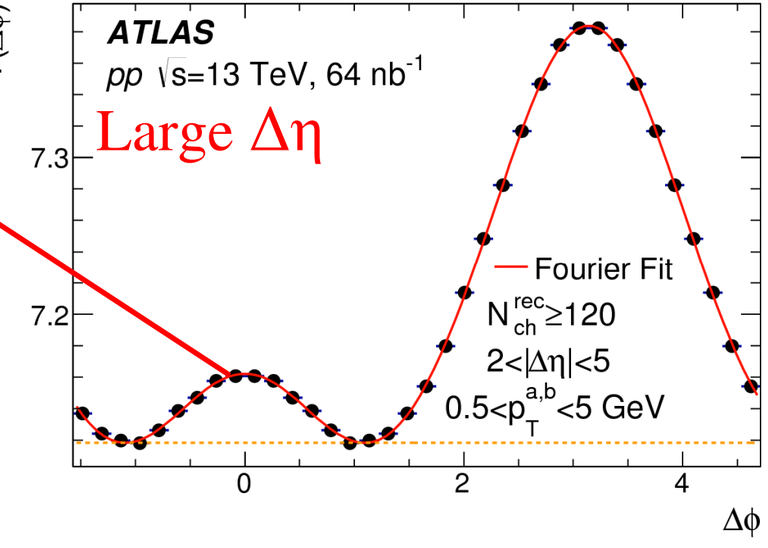
photon-ion

photon-proton

The ridge in *pp* collisions



pp ridge



- Try to further our understanding of the origin of the *pp* ridge.
  - Does it arise from collective (hydro) behavior?
  - Or is it driven by semi-hard processes? Perhaps related to gluon saturation.
- If latter, then actively selecting/rejecting events with semi-hard processes (low-p_T jets) should enhance/weaken the ridge.
- Is there any dependence of the ridge on the impact parameter of the *pp* collision?
- Do HF hadrons in *pp* collisions also show this feature?

Event classes

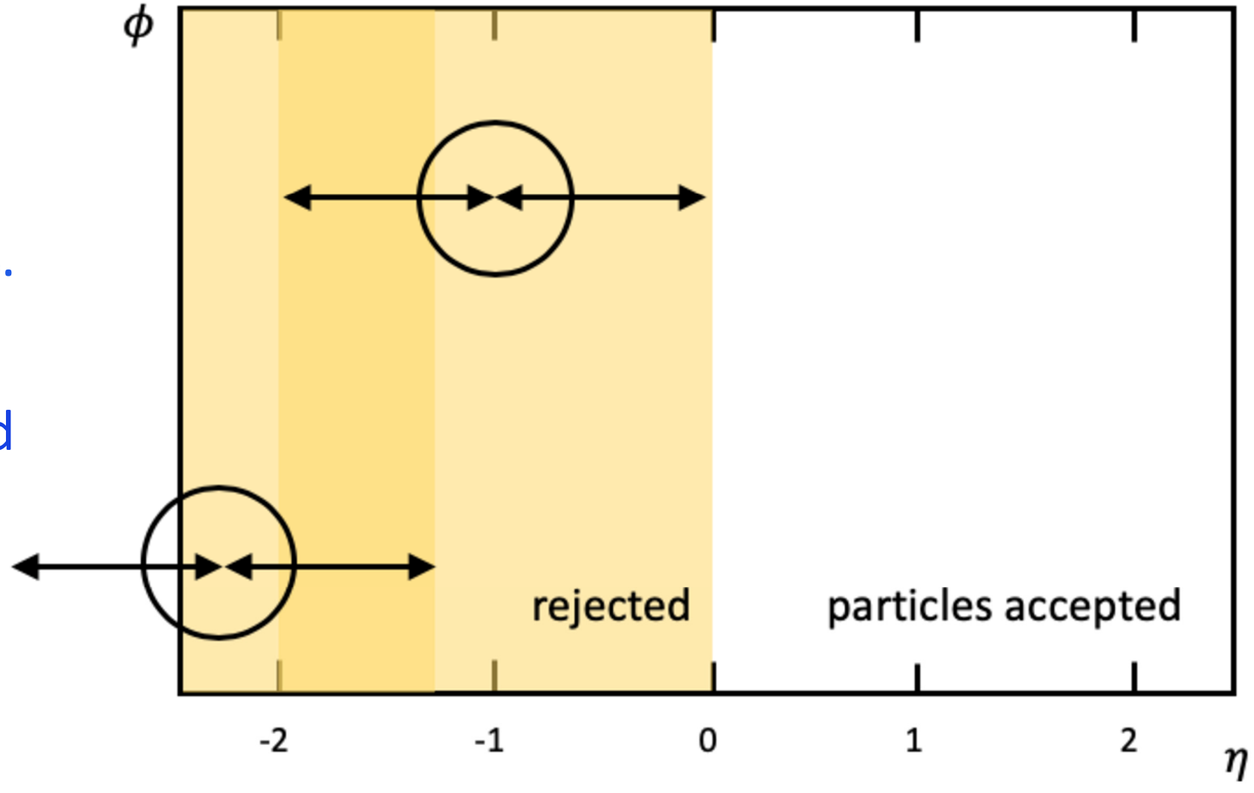
- *WithJet*: events that have a jet with p_T>10 GeV, but with tracks within $|\eta| \leq 1$ of the jet axis removed. Sample dominated by events having a semi-hard process.

- *NoJet*: events that do not have a p_T >10 GeV jet.
  - Event sample dominated by soft processes.

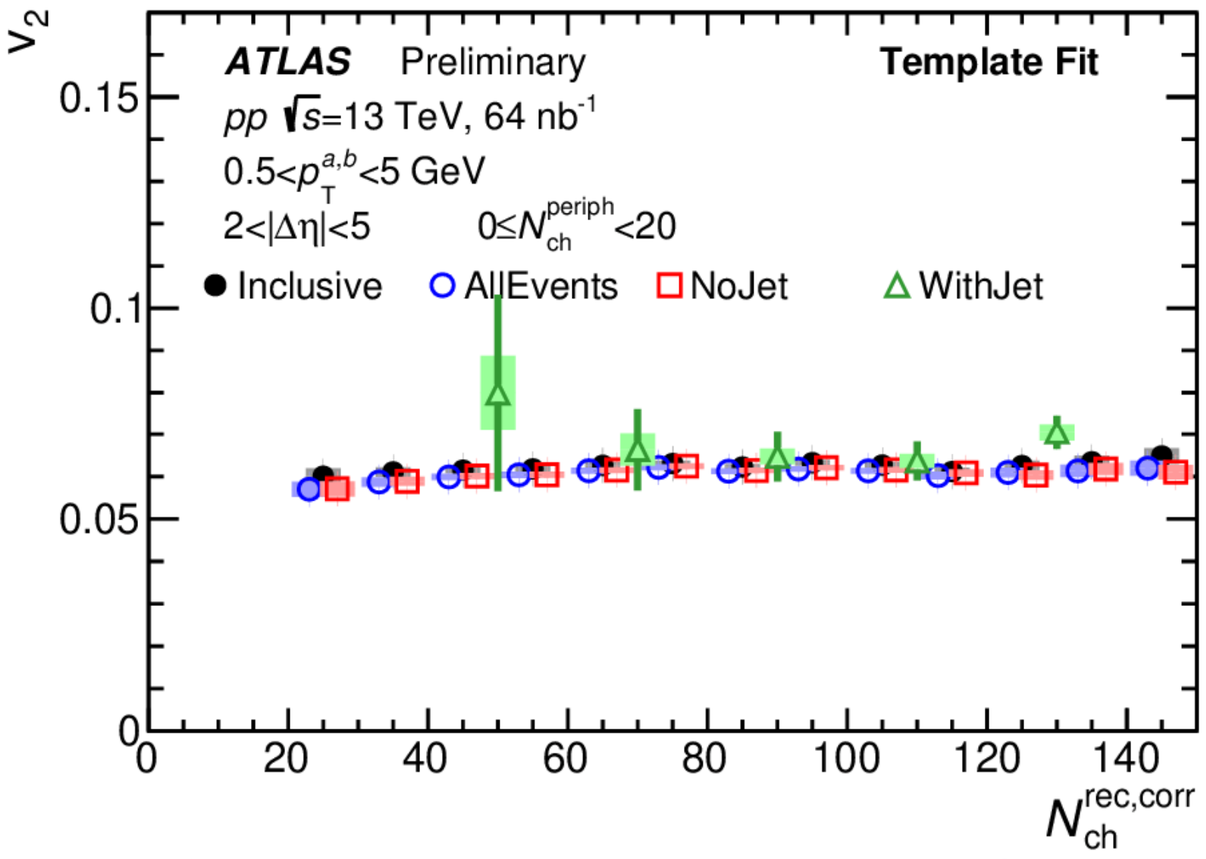
- *AllEvents*: Union of the *WithJet* and *NoJet* classes.

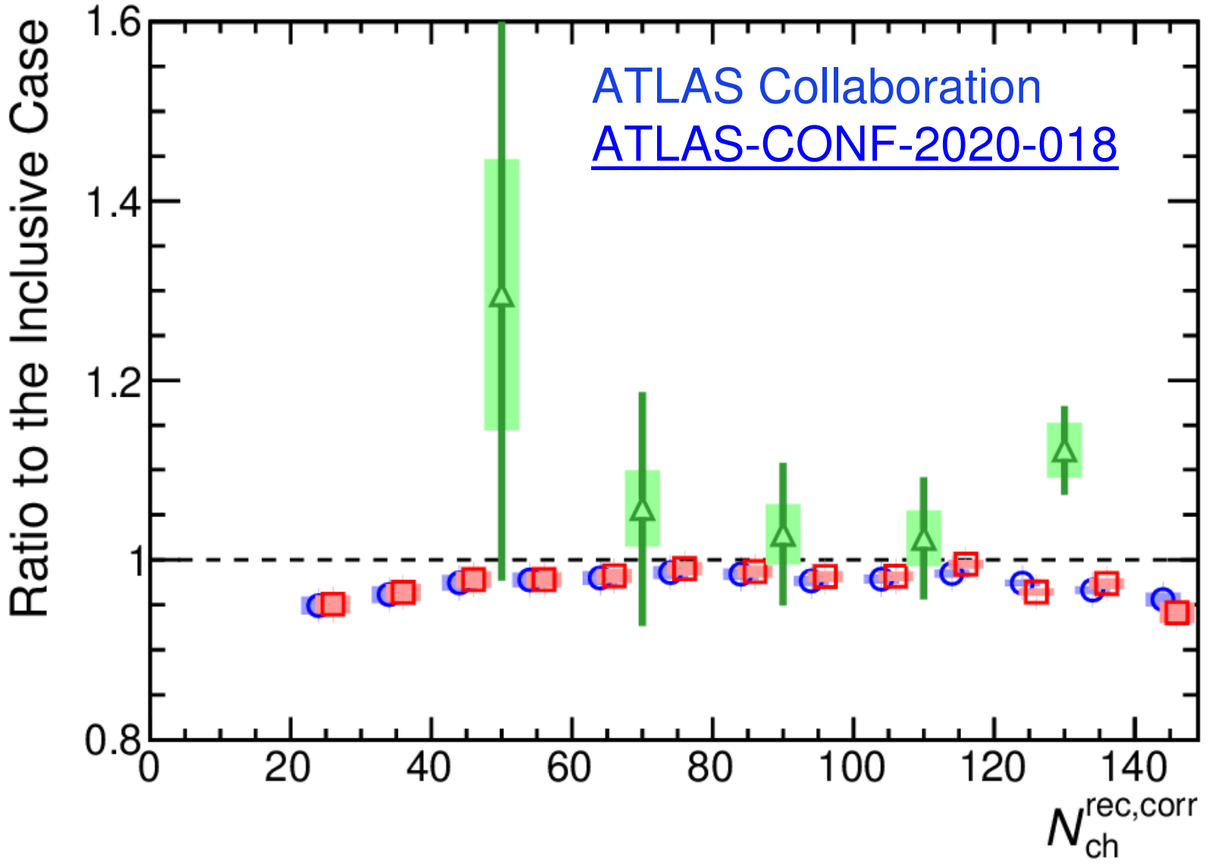
- *Inclusive*: Standard *pp* ridge analysis: no jet-based selection of events and no rejection of jet-associated tracks.

ATLAS Collaboration
ATLAS-CONF-2020-018



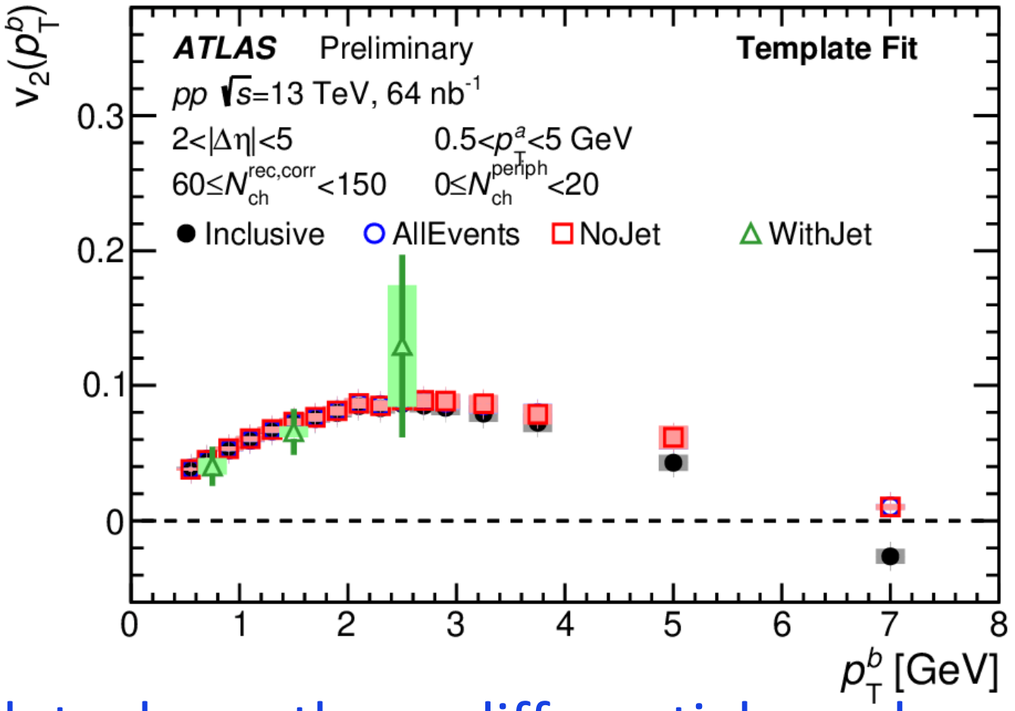
v_2 in different event classes: multiplicity dependence

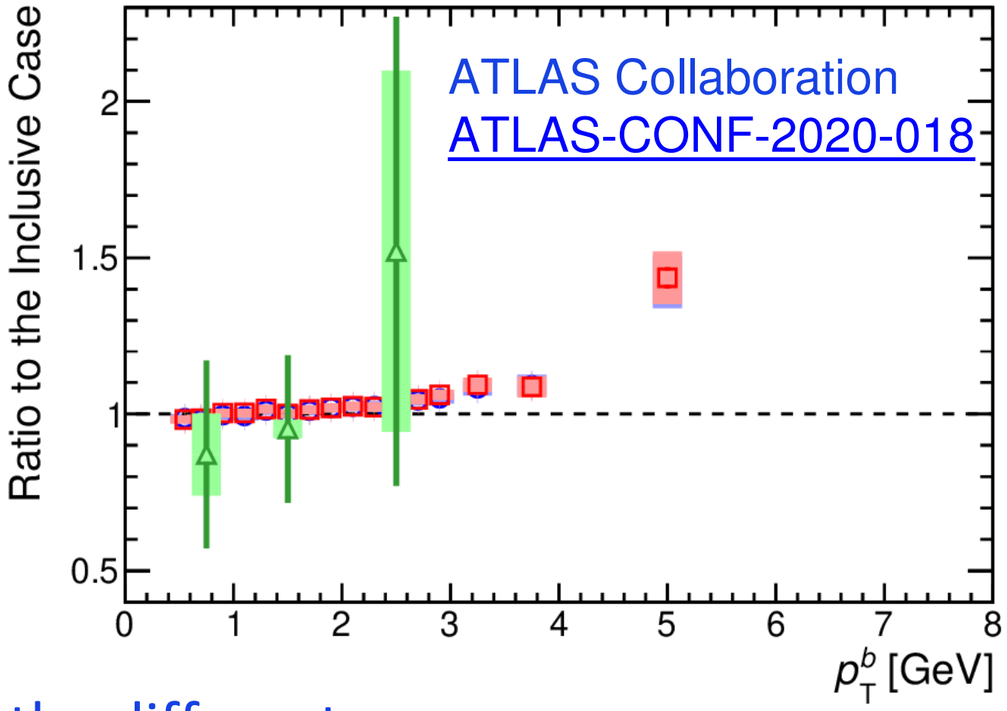




- Single-particle anisotropies extracted from the correlations using the ATLAS template-fit. procedure: Phys. Rev. C 96 (2017) 024908.
- Left panel : v_2 in the four different event classes vs event multiplicity.
- Right panel : ratio to the *Inclusive* case.
- Only a marginal reduction observed in the v_2 for the *AllEvents* and *NoJet* cases.

v_2 in different event classes: p_T dependence

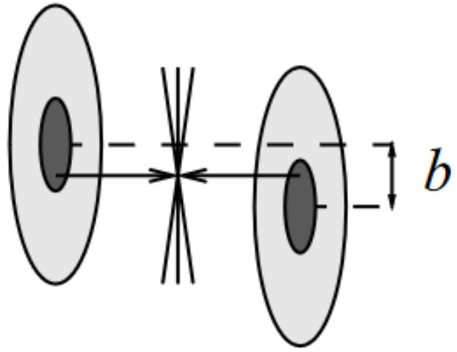




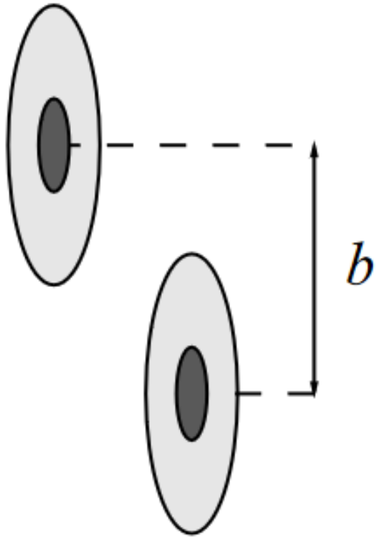
- Plots shows the p_T differential v_2 values for the different cases.
- Up to p_T =3 GeV all the *AllEvents* and *NoJet* cases have values similar to the *Inclusive* case.
- The *WithJet* case also consistent but with much larger statistical uncertainties.
- At higher p_T some significant differences are seen, but the *AllEvents* and *NoJet* cases are consistent with each other.
- Indicates that the *Inclusive* case has some bias at higher p_T , which is reduced when removing tracks associated with jets.

Selecting *pp* collisions based on impact parameter

Collision with small impact parameter

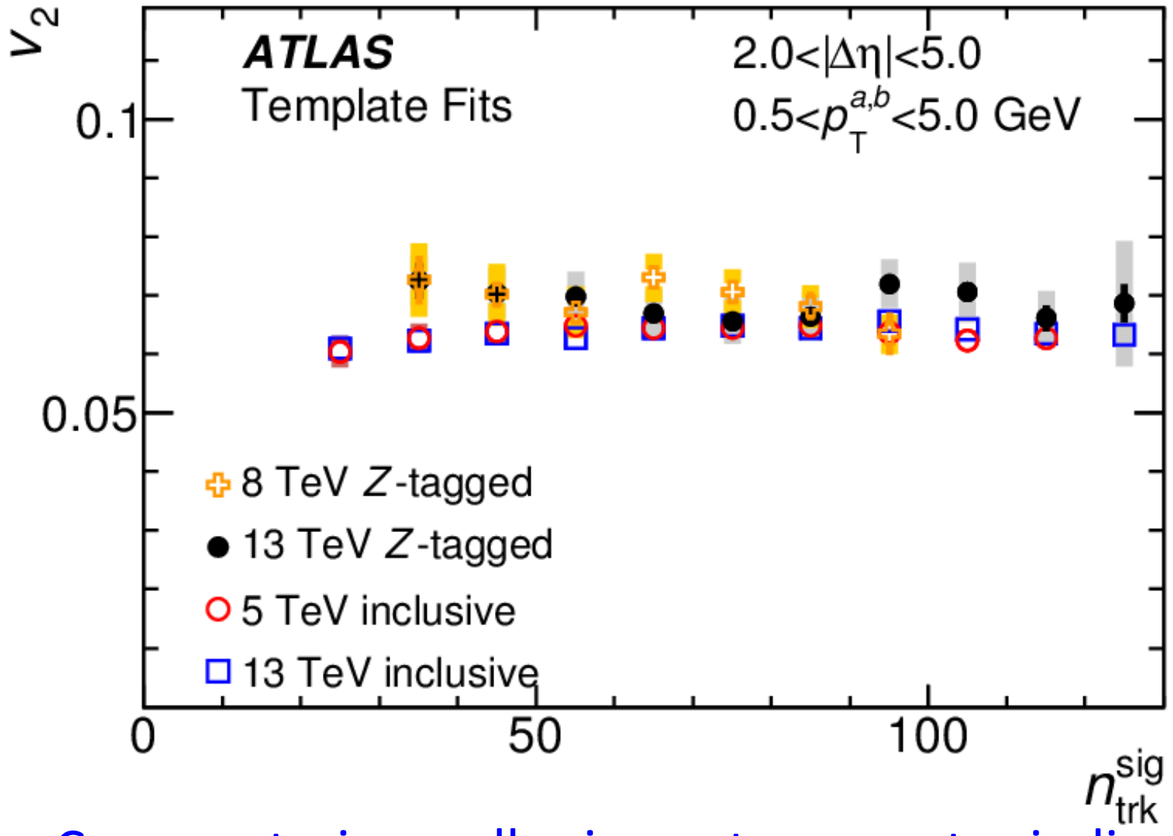


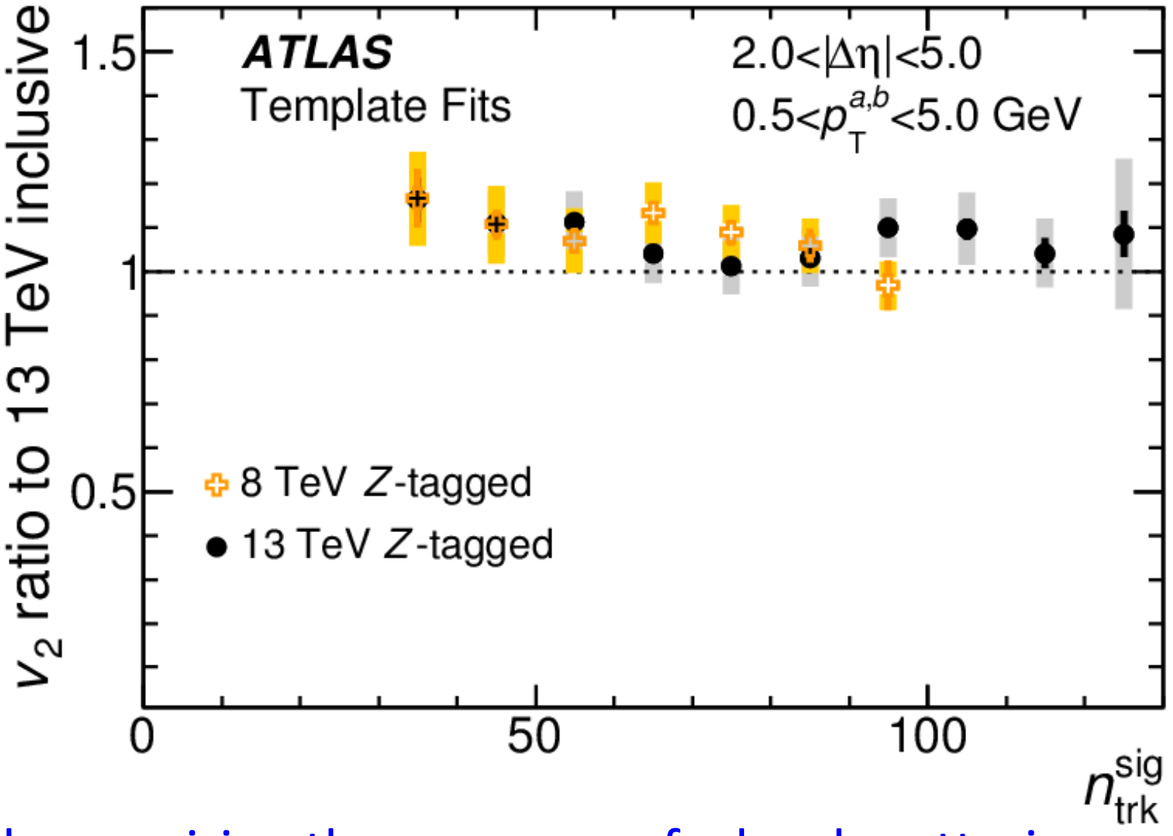
Collision with large impact parameter



- Is there a way to select *pp* events with small impact parameter?
  - i.e. events where the *pp* collision is more head-on?
- Darker regions indicate regions having partons with momentum-fraction x>0.01.
  - Figure from Phys. Rev. D 69 114010, (L. Frankfurt, M. Strikman, C. Weiss).
  - Note figure is a schematic only.
- Process with large momentum transfer (large $|q^2|$) implies smaller impact parameter.
- Can impose large q^2 requirement by requiring a Z-boson in the event : $|q^2| \sim (90\ \text{GeV})^2$.

v_2 in Z-boson tagged pp events (multiplicity dependence)

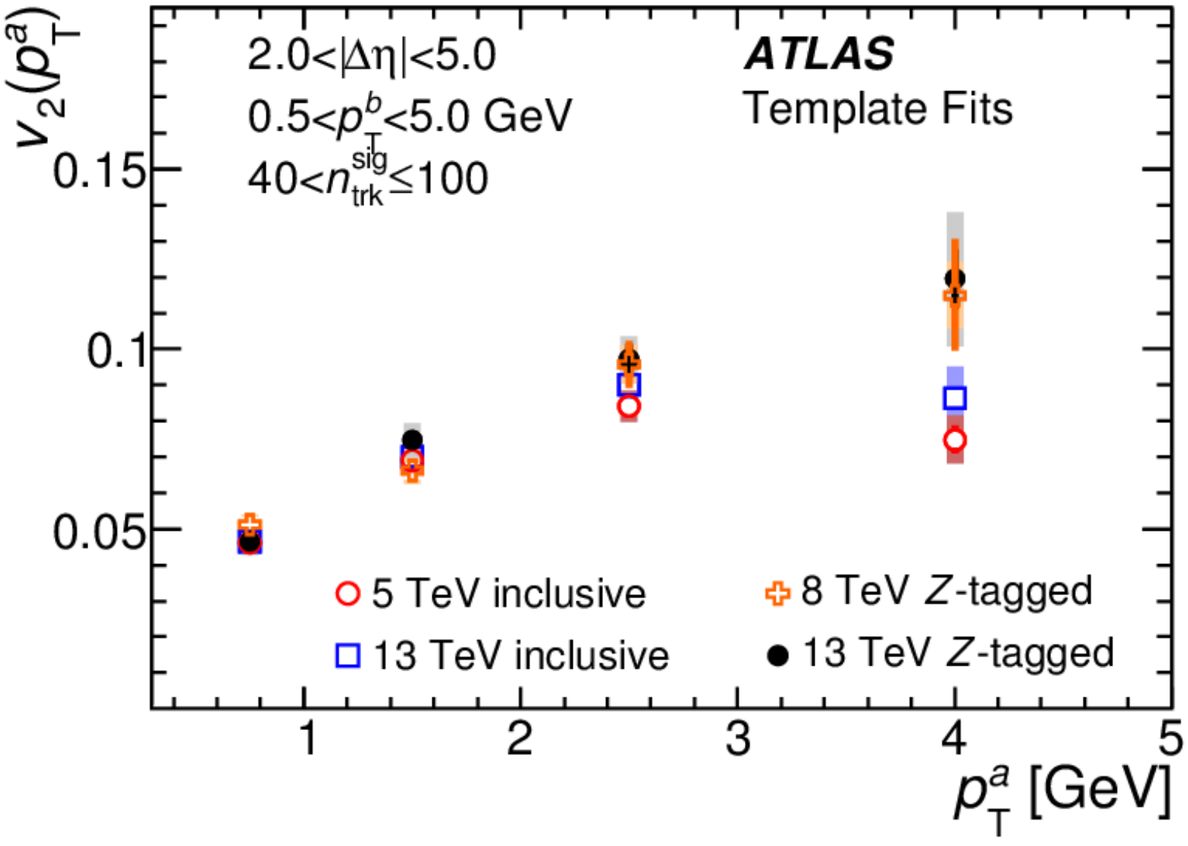


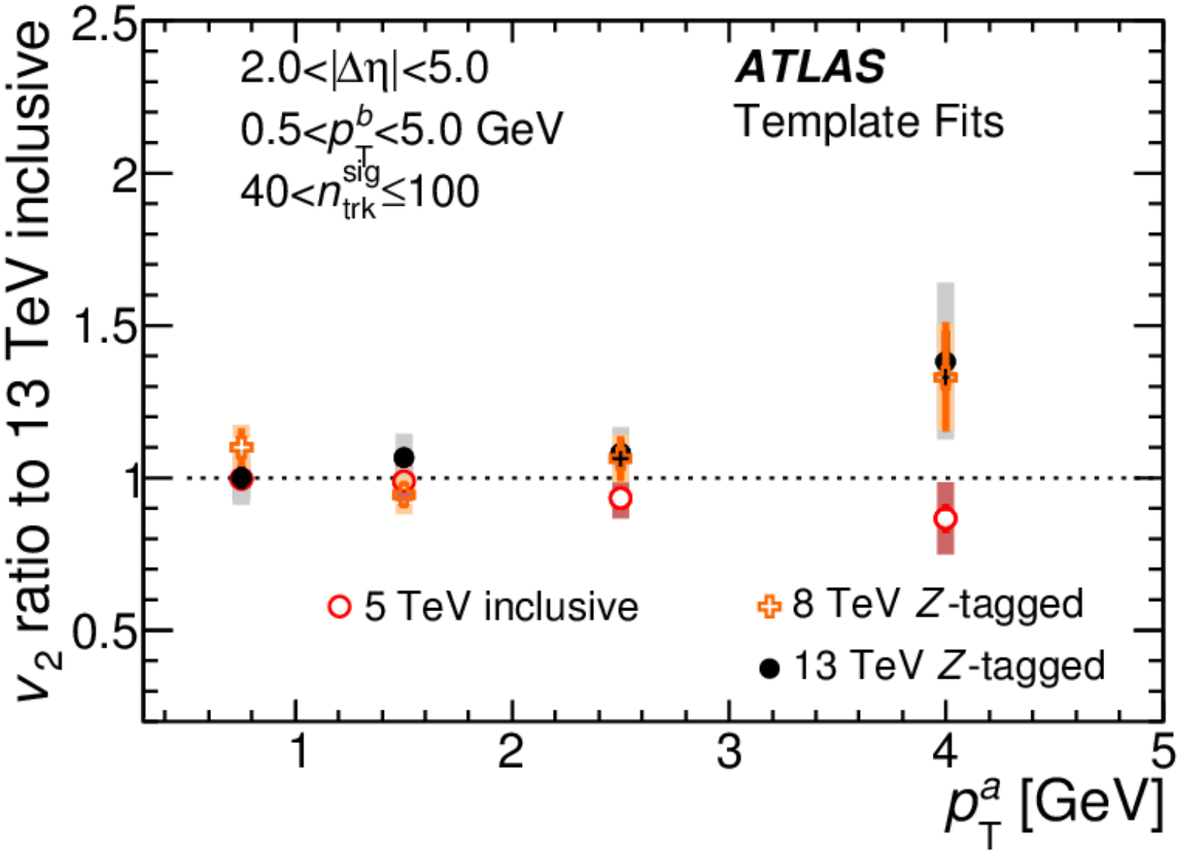


- Can constrain smaller impact parameter indirectly: by requiring the presence of a hard scattering, for example presence of a Z-boson.
- Use high-luminosity pp data at 8 and 13 TeV.
- The v_2 in Z-tagged events is consistent with inclusive events!

ATLAS Collaboration
Eur. Phys. J. C 80 (2020) 64

v_2 in Z-boson tagged pp events (p_T dependence)





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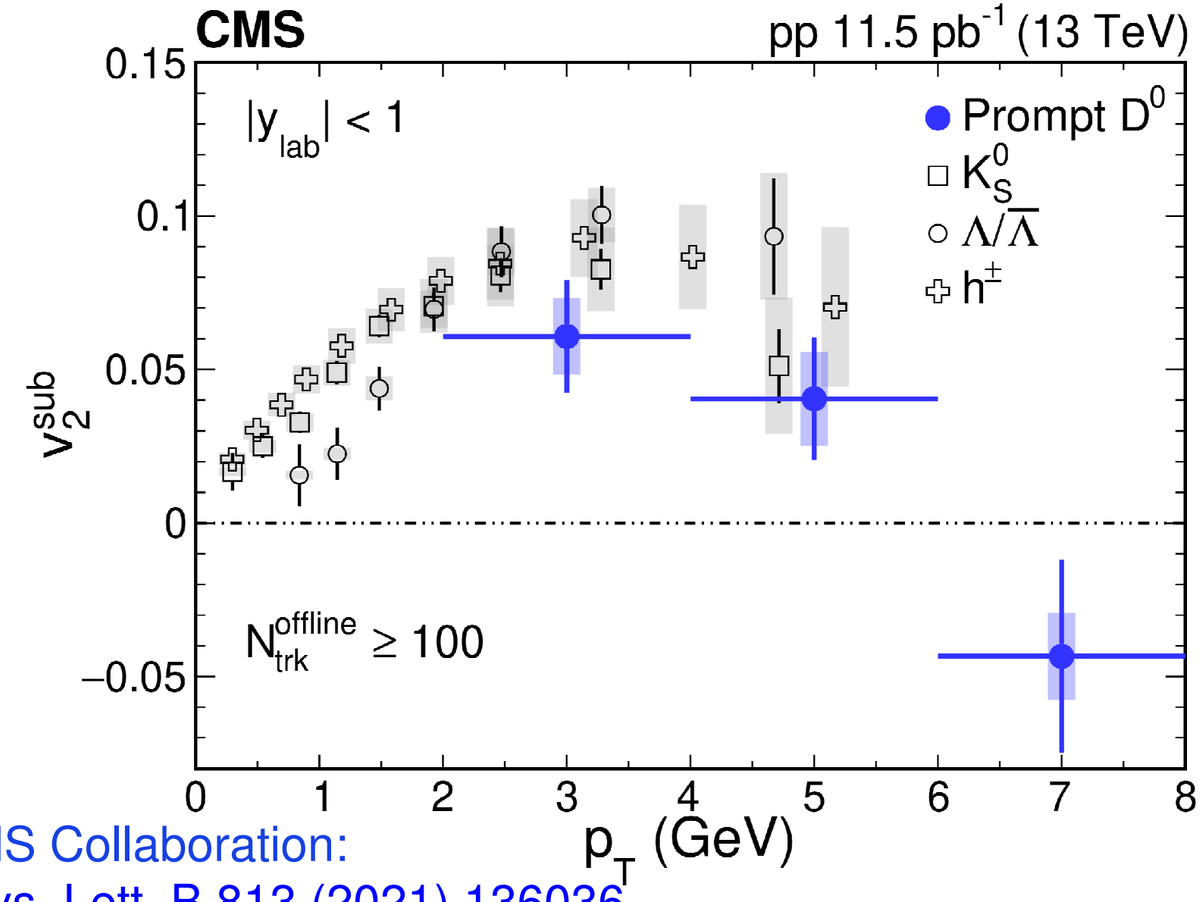
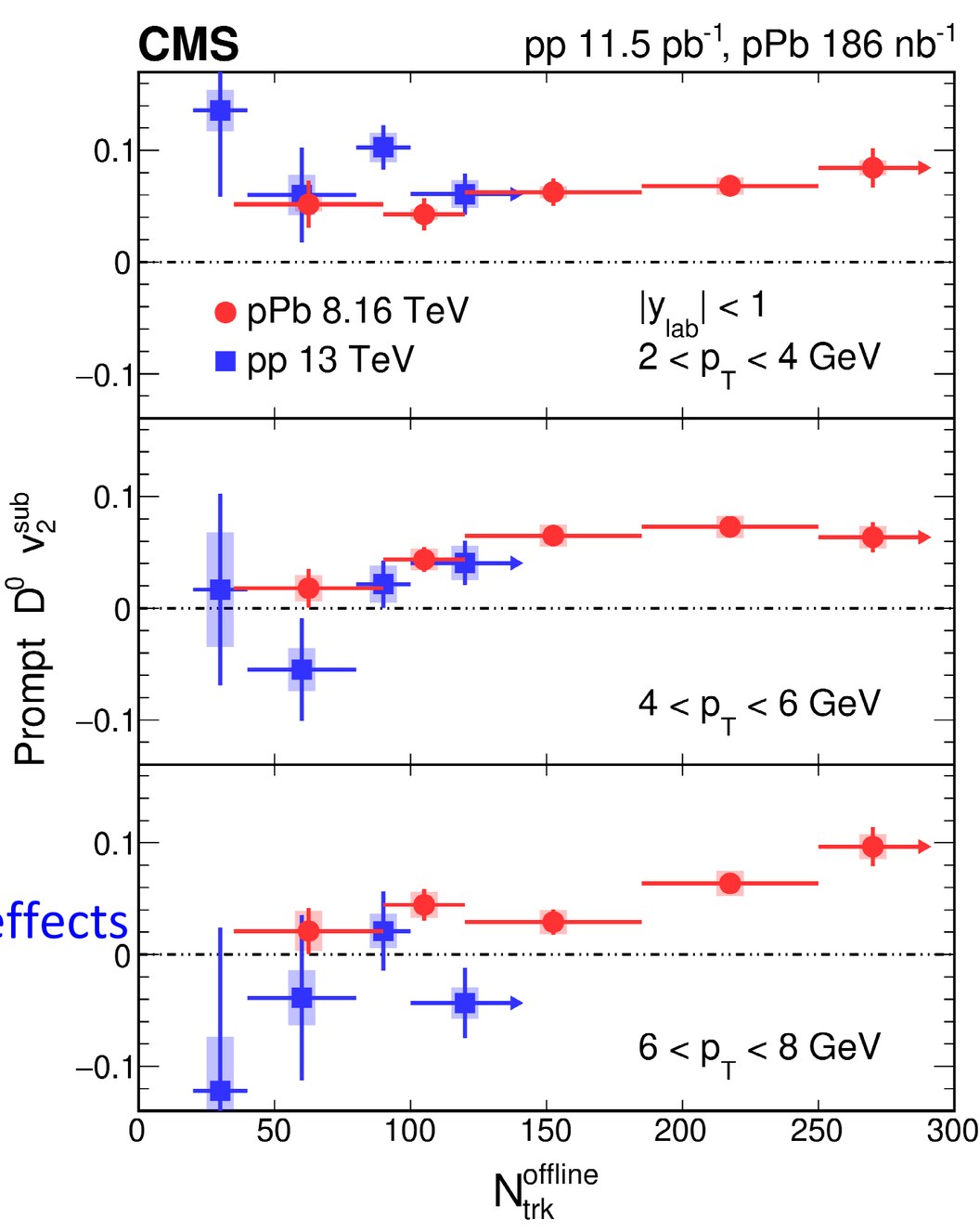
ATLAS Collaboration
Eur. Phys. J. C 80 (2020) 64

HF collectivity in *pp* collisions

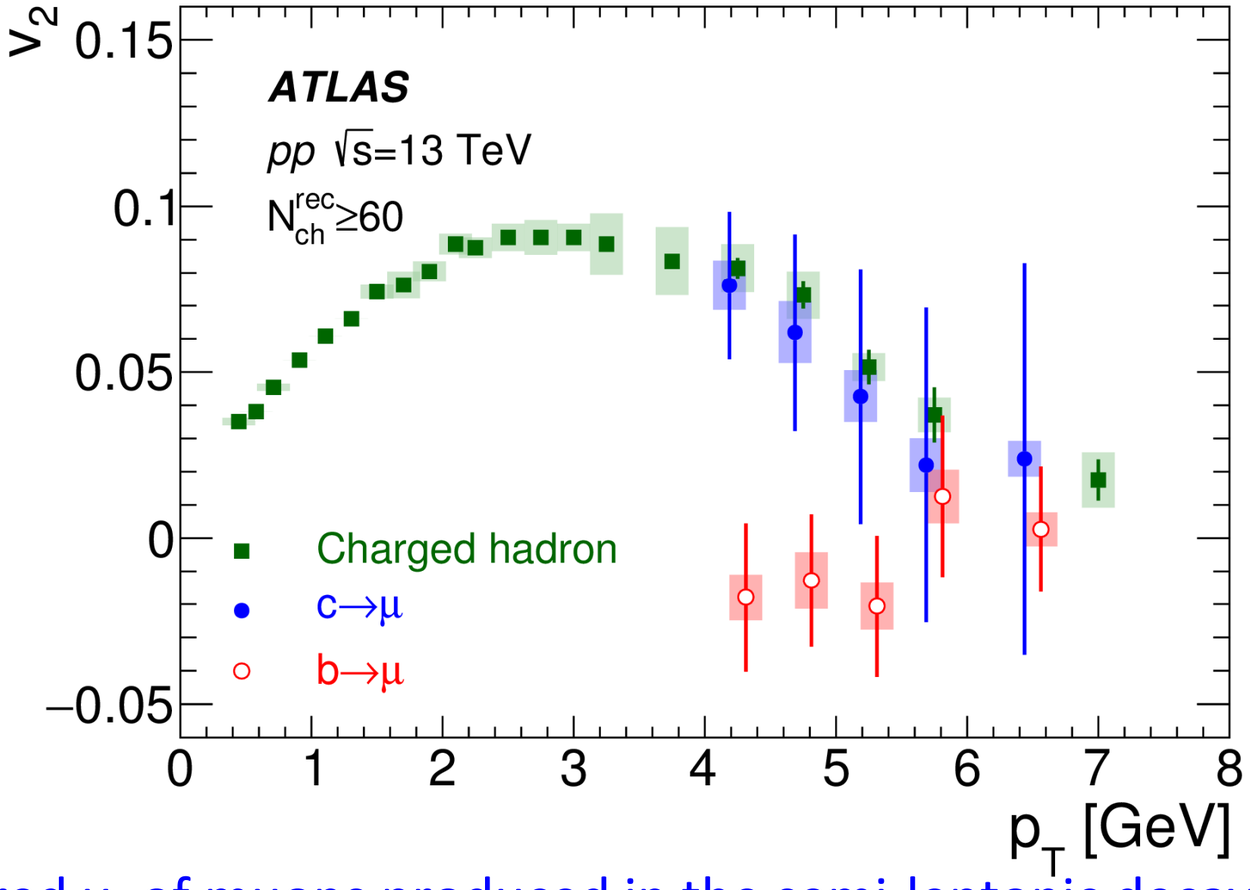




CMS Collaboration:
Phys. Lett. B 813 (2021) 136036

- HF collectivity can potentially separate initial vs final-state effects
- v_2 of prompt D^0 mesons in *pp* collisions.
- Significant anisotropy observed : Comparable to inclusive hadrons.
- Comparable to v_2 in *p*+Pb collisions at similar multiplicity

HF collectivity in *pp* collisions

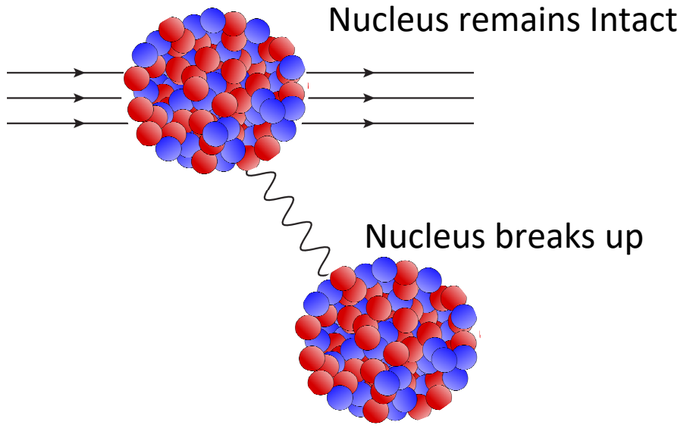


ATLAS Collaboration:
Phys. Rev. Lett. 124 (2020) 082301

- Measured v_2 of muons produced in the semi-leptonic decays of *b* and *c* hadrons.
- Significant anisotropy observed for muons from charm decay: consistent with inclusive hadrons.
- v_2 for muons from *b* decays consistent with zero.
- These HF anisotropy measurements can lead to further understanding of origin of the *pp* ridge.

Photon-ion and photon-proton collisions

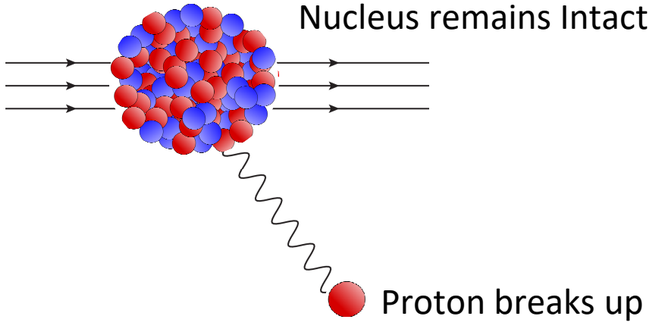
Ultra Peripheral Pb+Pb



EM fields of Lorentz contracted nuclei can be treated as flux of quasi-real photons.

In UPC Pb+Pb collisions, Photons coherently emitted from one Pb nuclei can interact with another: γ+Pb collisions

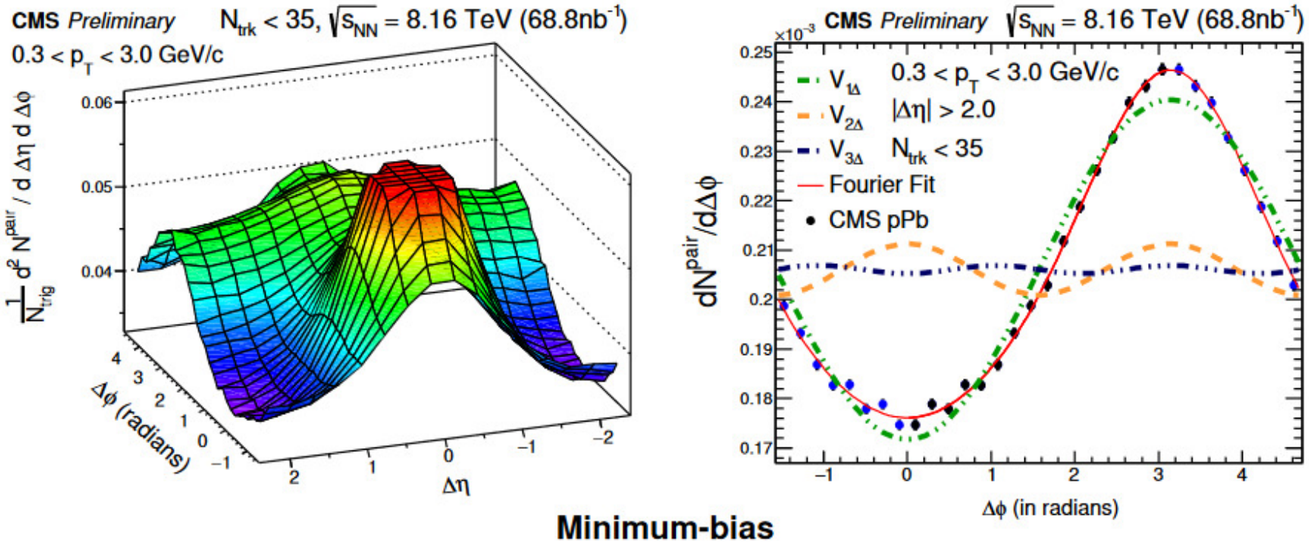
Ultra Peripheral Pb+p



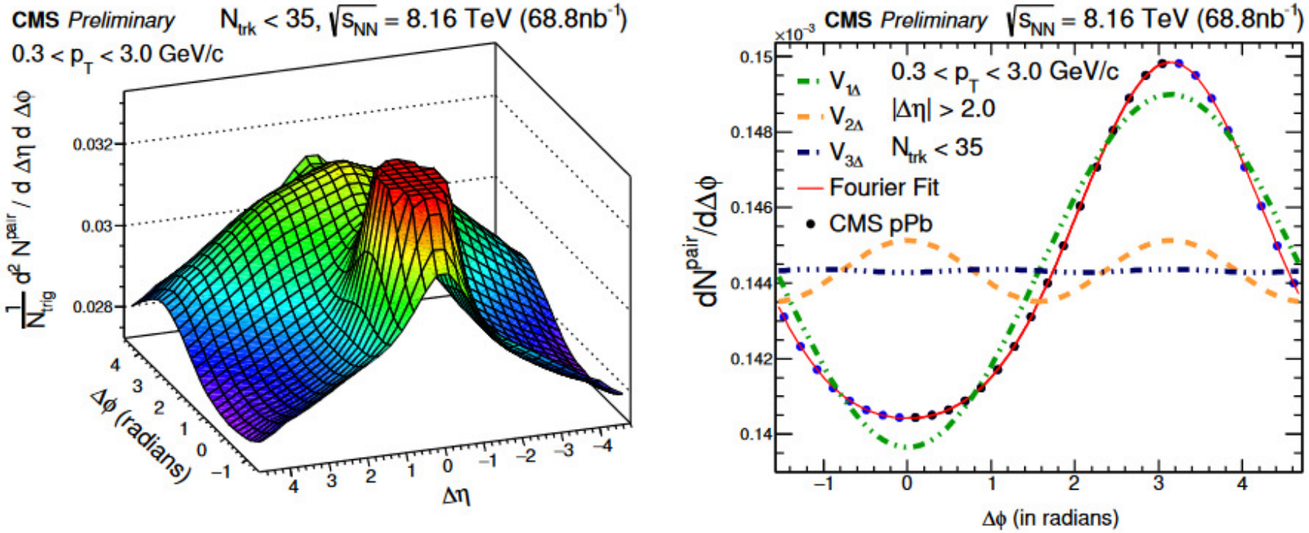
Similar process in UPC Pb+p : γ+p collisions

First look at *γ+p* collisions

γp enhanced



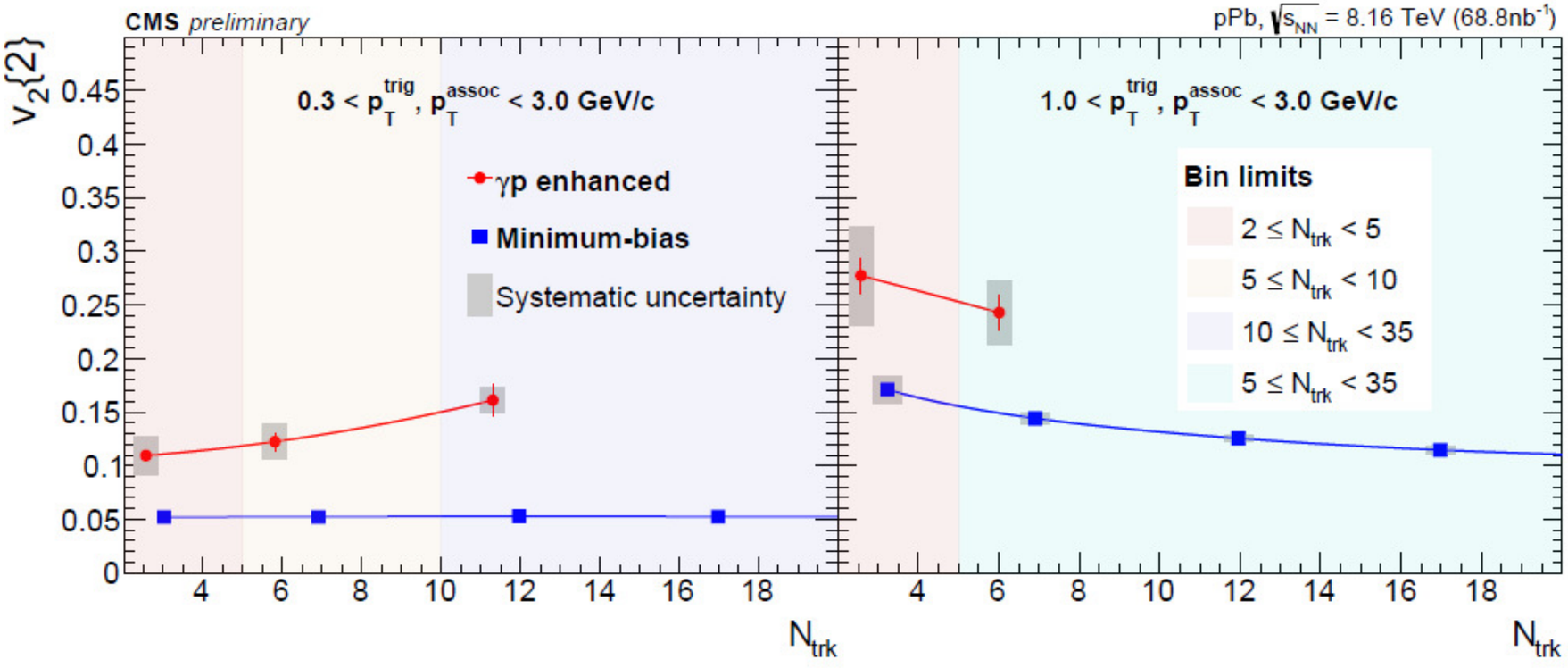
Minimum-bias



- Select enriched sample of *γ+p* events in UPC p+Pb collisions.
- Require no neutron on Pb-going size ZDC, as well as a large region with no detector activity on Pb going side.
- Plots show 2D and 1D 2PCs in *γ+p* events and min-bias *p*+Pb events.
- Stronger away-side correlation observed in *γ+p* events compared to min-bias *p*+Pb.

CMS Collaboration
CMS-PAS-HIN-18-008

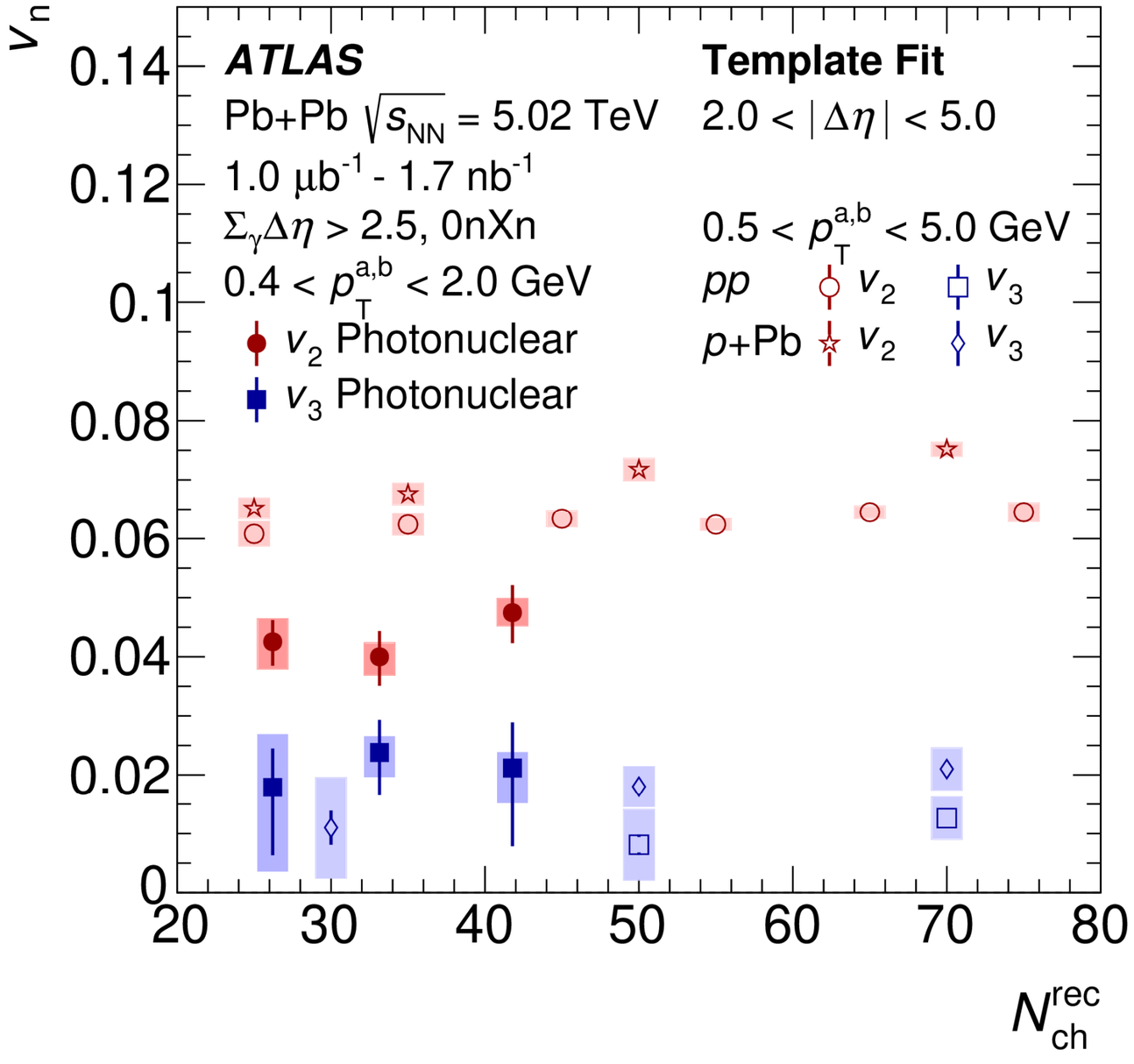
First look at *γ+p* collisions



CMS Collaboration
CMS-PAS-HIN-18-008

- Larger v_2 observed in *γ+p* events compared to min-bias events
  - Need to be careful as no "non-flow" subtraction is performed
  - i.e. jet-like correlations dominate the measurement.
- Measurements can extend search for collectivity to *γ+p* events

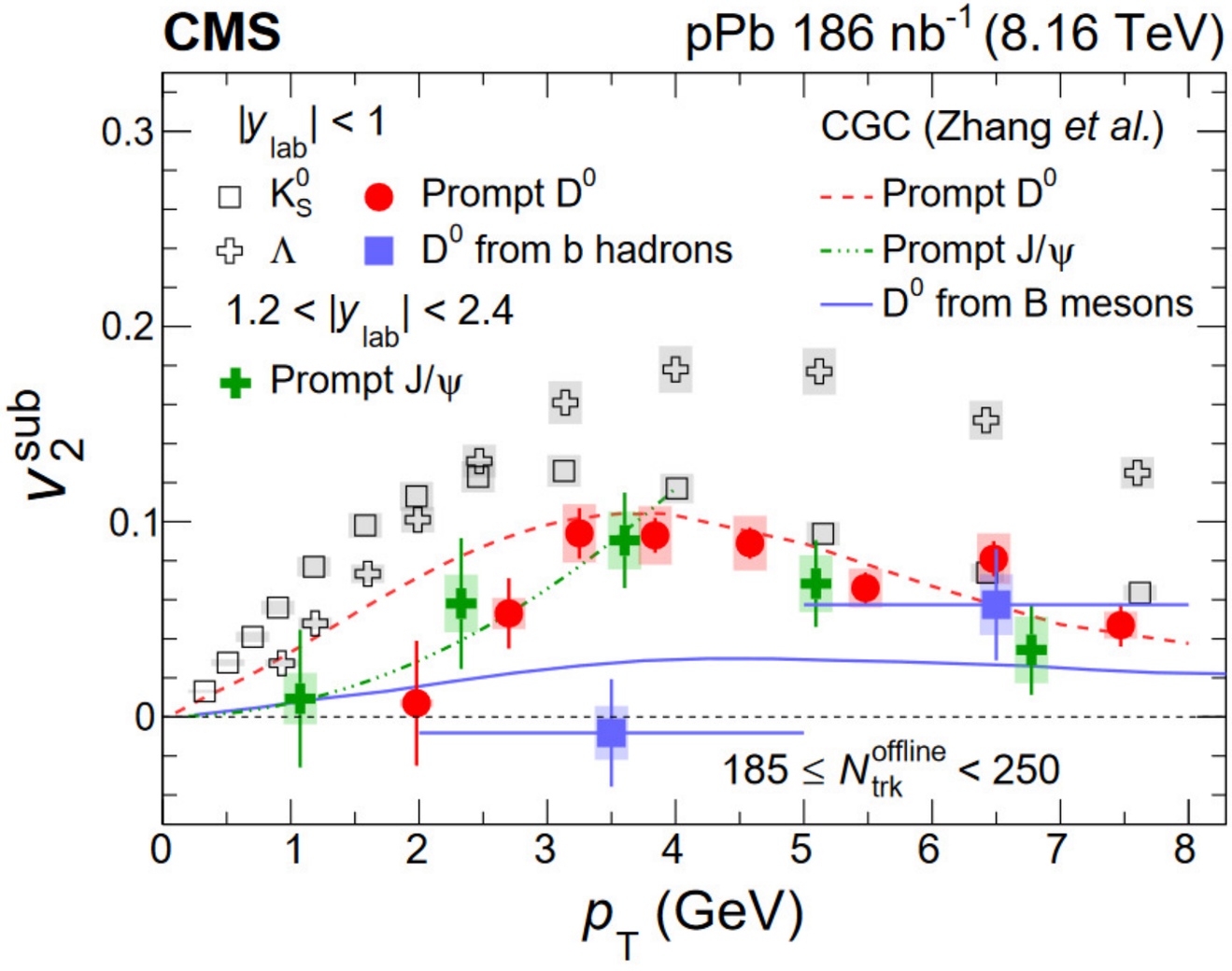
Collectivity in γ+Pb collisions



- Comparison of v_2 and v_3 measured in γ+Pb collisions to those in pp and p+Pb collisions
  - Done with "non-flow" subtraction.
- The v_2 in γ+Pb are systematically smaller than those in p+Pb and pp collisions at similar multiplicity

ATLAS Collaboration
Phys. Rev. C. 104 014903

More results for HF collectivity in *p*+Pb



The v_2 for prompt and non-prompt D^0 mesons in *p*+Pb collisions.

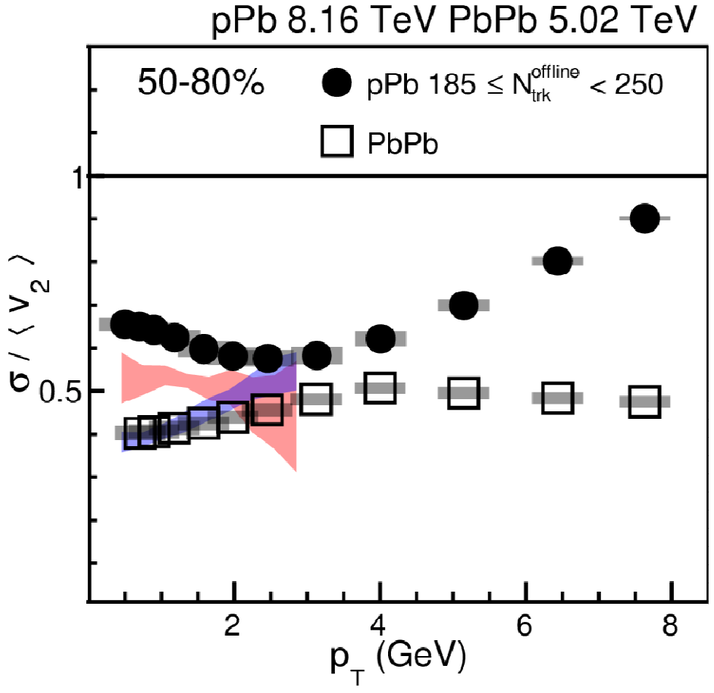
v_2 for non-prompt D^0 mesons smaller than for prompt D^0 mesons.

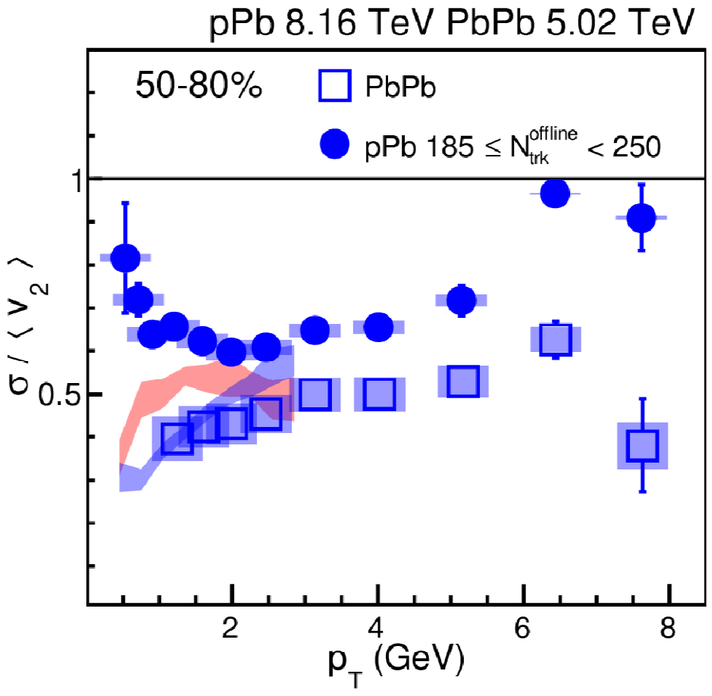
Mass dependence in v_2 observed between charm and beauty hadrons in *p*+Pb.

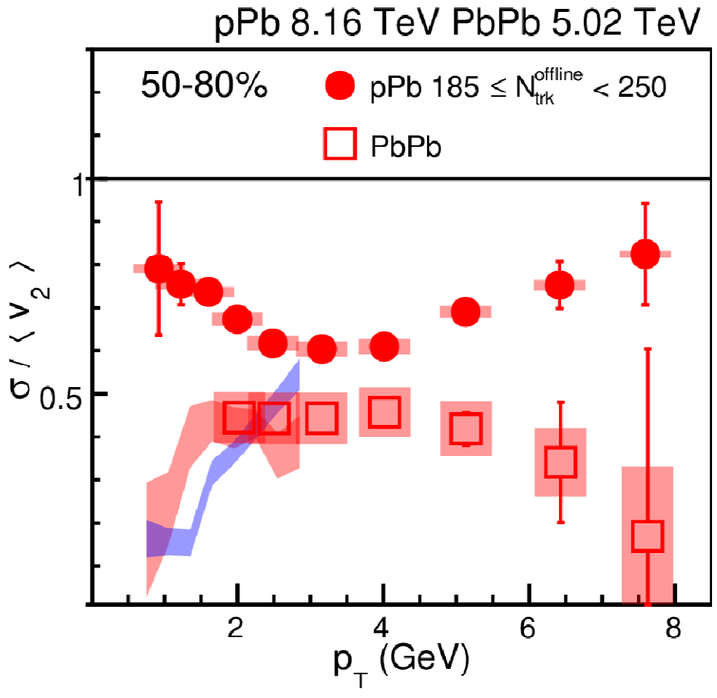
These results provide insights into the origin of heavy-flavor quark collectivity in small systems.

CMS Collaboration:
Phys. Lett. B 813 (2021) 136036

Strange particle flow fluctuations in *p*+Pb







- Flow fluctuation measurements for:
  - Inclusive hadrons (left), K^0_s (middle), and Λ (right)
  - Compared between *p*+Pb and Pb+Pb

CMS Collaboration
CMS-PAS-HIN-19-004

- Larger fluctuations seen in *p*+Pb than in Pb+Pb.
- No dependence of fluctuations on particle species.

Summary

- Multiple recent measurements from ATLAS and CMS investigate collectivity in small collision systems.
- ATLAS measured v_2-v_4 in *pp* collisions when rejecting tracks in the vicinity of low-p_T jets.
  - The p_T-integrated v_2 only decreases marginally (2-5%) when rejecting the jet associated tracks.
  - No significant change for p_T<3 GeV: low-p_T v_n not affected by presence/absence of jets.
- ATLAS measured v_2 in *pp* events tagged with a *Z*-boson.
  - Studies impact-parameter dependence of ridge.
  - No significant modification from *inclusive* events observed.
- ATLAS and CMS : also measured HF v_2 in *pp* events.
  - *charm* v_2 consistent with inclusive hadrons, *bottom* v_2 consistent with zero.
- CMS & ATLAS : 2PC measurements in *γ+p* and *γ*+Pb events.
  - Smallest collision systems at the LHC.
- CMS : multiple measurements of strange and HF collectivity in *p*+Pb