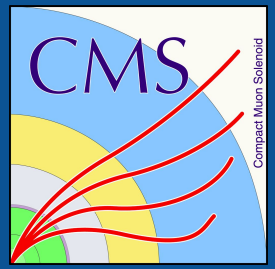
Search for elliptic azimuthal anisotropies in γ-proton interactions using rapidity gaps in pPb collisions with the CMS experiment

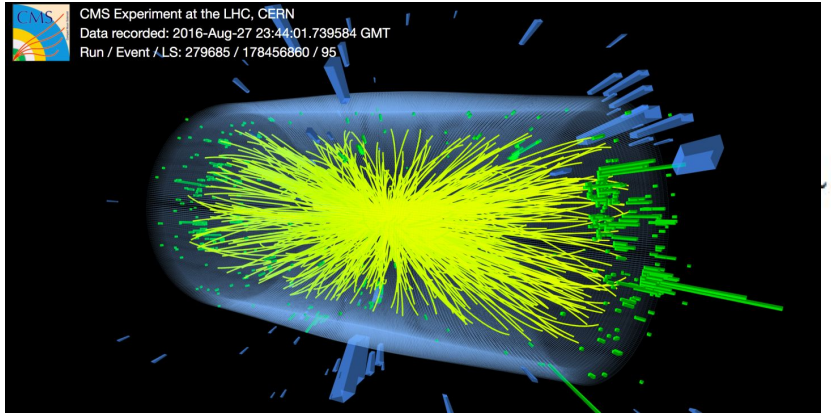


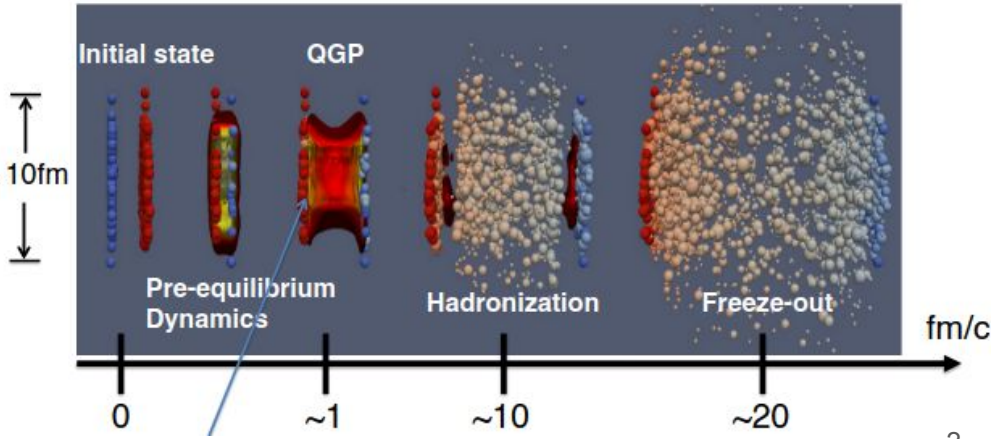
Moisés León Coello,
PhD student in Universidad de Sonora, on behalf of CMS collaboration

XXX International Workshop on Deep-Inelastic Scattering and Related Subjects

Collective phenomena in Heavy Ion Physics

- In heavy ion collisions different **collective phenomena** can occur
- Related to **hydrodynamic behavior** in the presence of **quark gluon plasma**
- A way of characterizing these phenomena is looking at **angular correlations between particles**

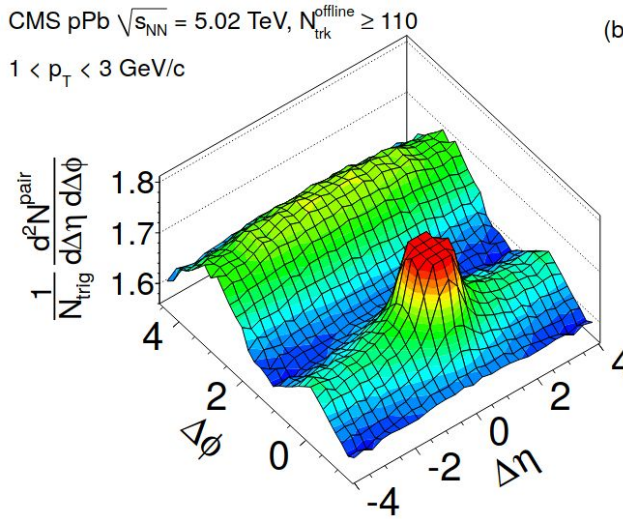


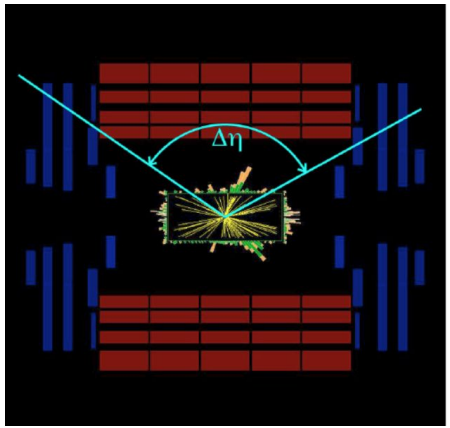


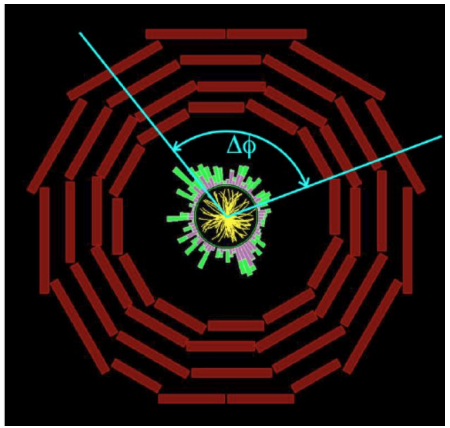
SOURCES: https://cds.cern.ch/record/2241144 https://madai.phy.duke.edu/indexaae2.html

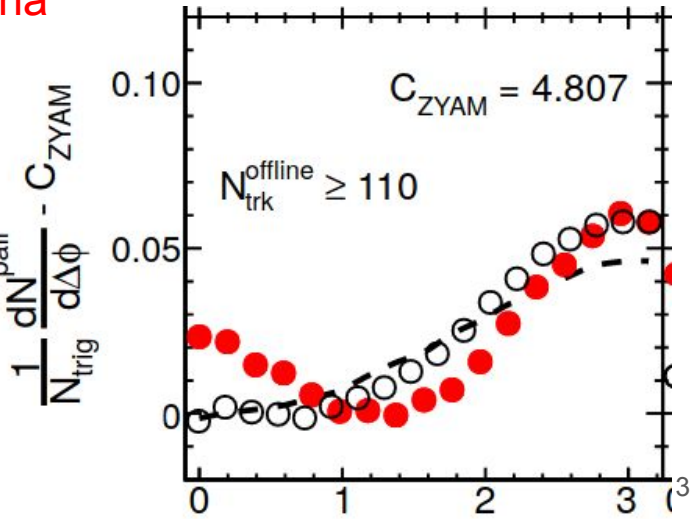
Two particle correlation distributions

- A tool for characterizing collective behavior are the **particle correlation distributions**
- "Ridge zone" is Δη>2, Δϕ~0 **(long range, near side)**
- Fourier fit gives V_N coefficients
  - $$\frac{1}{N_{trig}}\frac{dN^{pair}}{d\Delta\phi} = \frac{N_{assoc}}{2\pi}\sum[1 + 2V_{n\Delta}\cos(n\Delta\phi)]$$
- $V_{2\Delta}$ and $V_{3\Delta}$ > 0 indicates possible collective phenomena





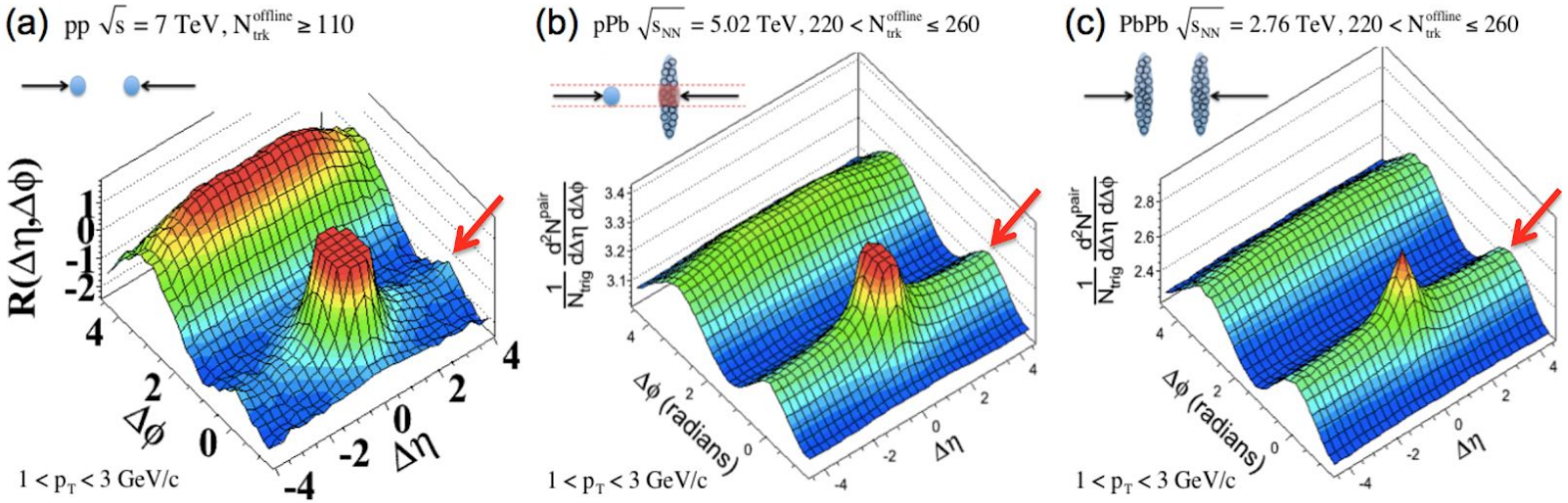




SOURCES: Phys. Lett. B 718 (2013) 795

Ridge also seen in small systems

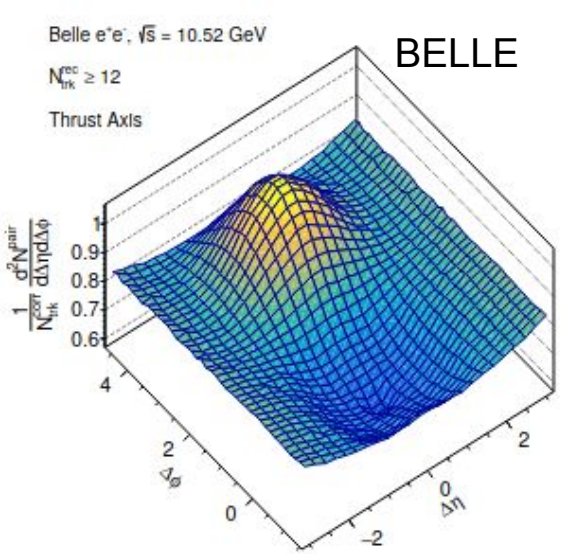
- Observed in pp and pPb
- Possible explanations in small systems:
  - Hydrodynamics of QGP droplets
  - Initial state correlations

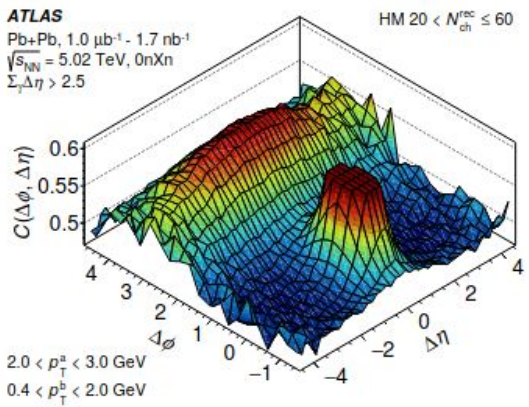


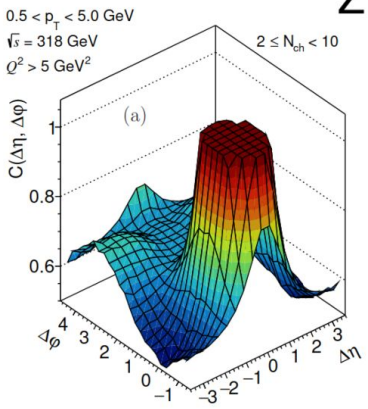
SOURCES: JHEP 1009:091,2010 Phys. Lett. B 718 (2013) 795 JHEP 7 (2011) 76

Latest probes in small systems

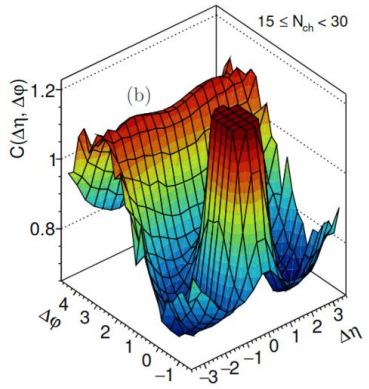
- This raises the question of the extent to which those models works
- Interest in measuring correlations in a variety of small systems
- Some of the last explored small systems:
  - e^+e^- , ep, γp (ZEUS)
  - e^+e^- (BELLE and ALEPH)
  - γPb (ATLAS)
- **Our goal:**
  - **γp**







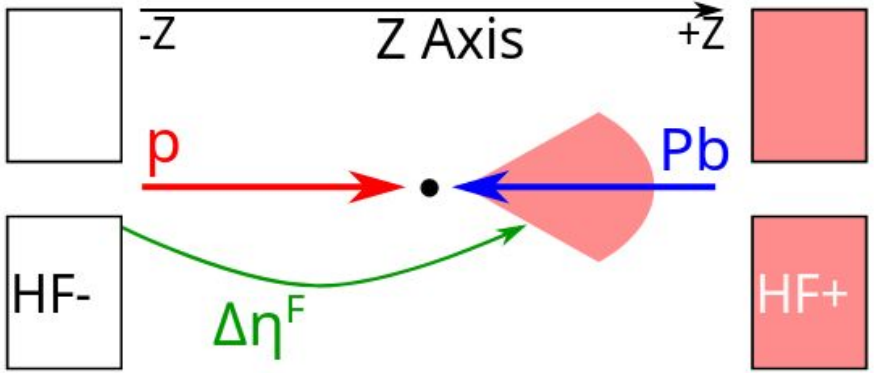
ZEUS

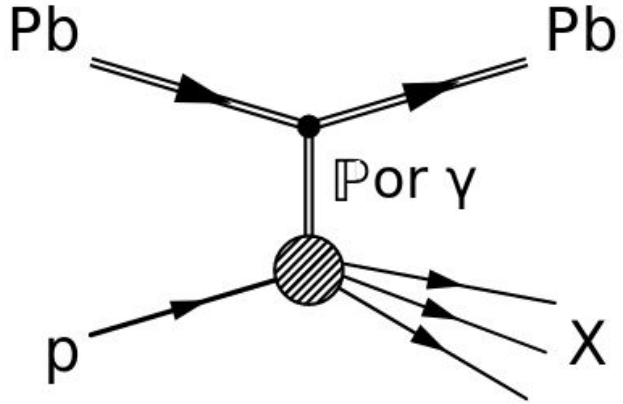


SOURCES: Phys. Rev. C 104, 014903 (2021) arXiv:2201.01694 J. High Energ. Phys. 2020, 70 (2020) J. High Energ. Phys. 2021, 102 (2021)

Two-particle correlations in γp interactions

- γp events from pPb collisions at $\sqrt{s_{NN}}$=8.16 TeV in CMS during run 2
- Selection studied in arXiv:2301.07630
- Selection enhances events where **Pb remains intact while p dissociates**
- γp and pomeron-p interactions can occur
- Activity expected in the proton side of the detector
- ZDC calorimeters ensure no neutrons from intact Pb

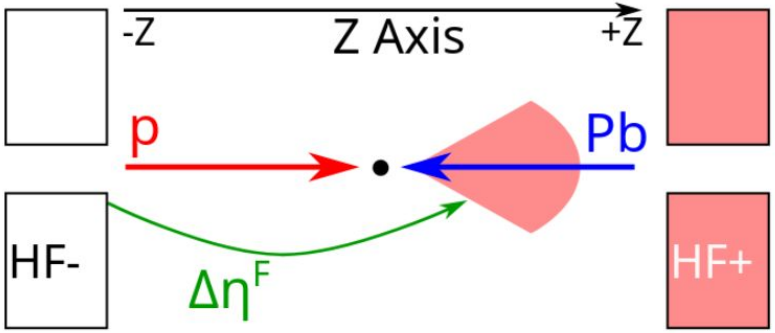


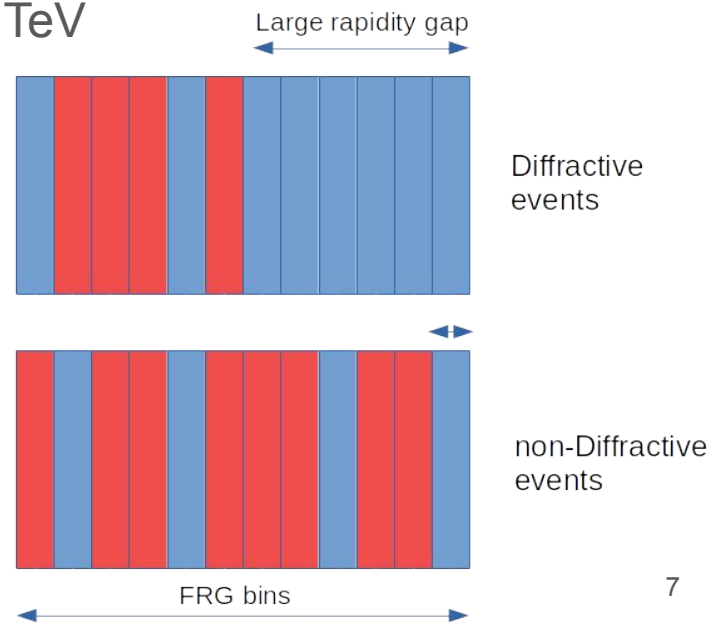


SOURCES: arXiv:2301.07630

Event selection

- Standard track selection were used:
  - Kinematic range: $\eta < 2.4$, $p_T > 0.4$ GeV
  - Significance of z separation between track and best vertex: $d_z/\sigma(d_z) < 3.0$
  - Impact parameter significance: $d_0/\sigma(d_0) < 3.0$
  - Relative momentum uncertainty: $\sigma(p_T)/p_T < 0.1$
- Energy sum on negative ZDC- Pb-going side < 1.0 TeV
- Energy in p-going HF > 10 GeV
- Forward rapidity gap within bins [5, 7.5)

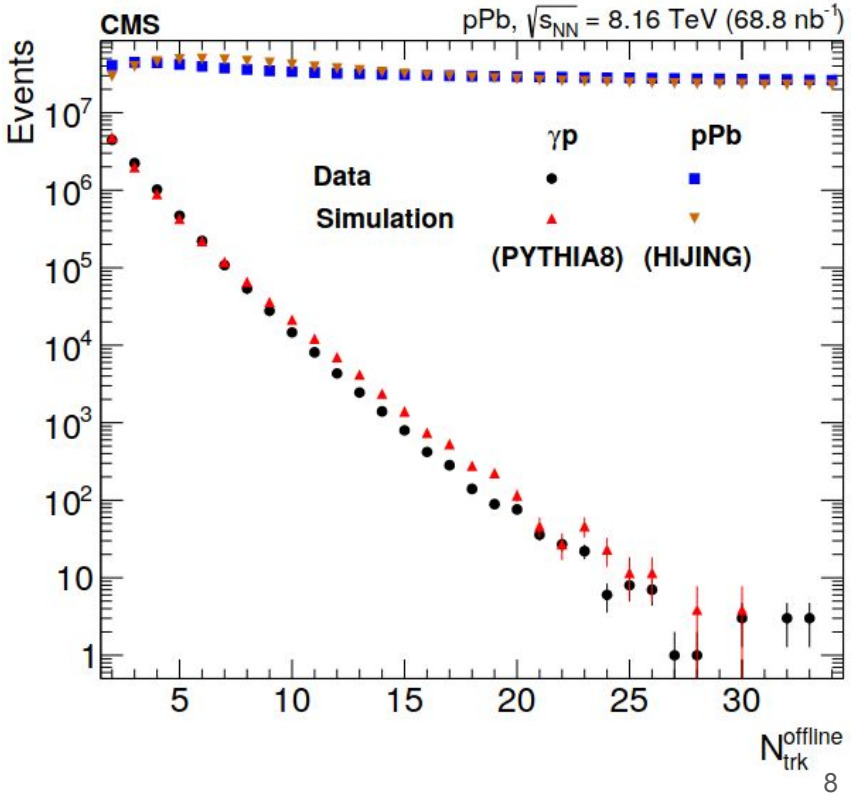




SOURCES: arXiv:2301.07630

N_{trk} distribution

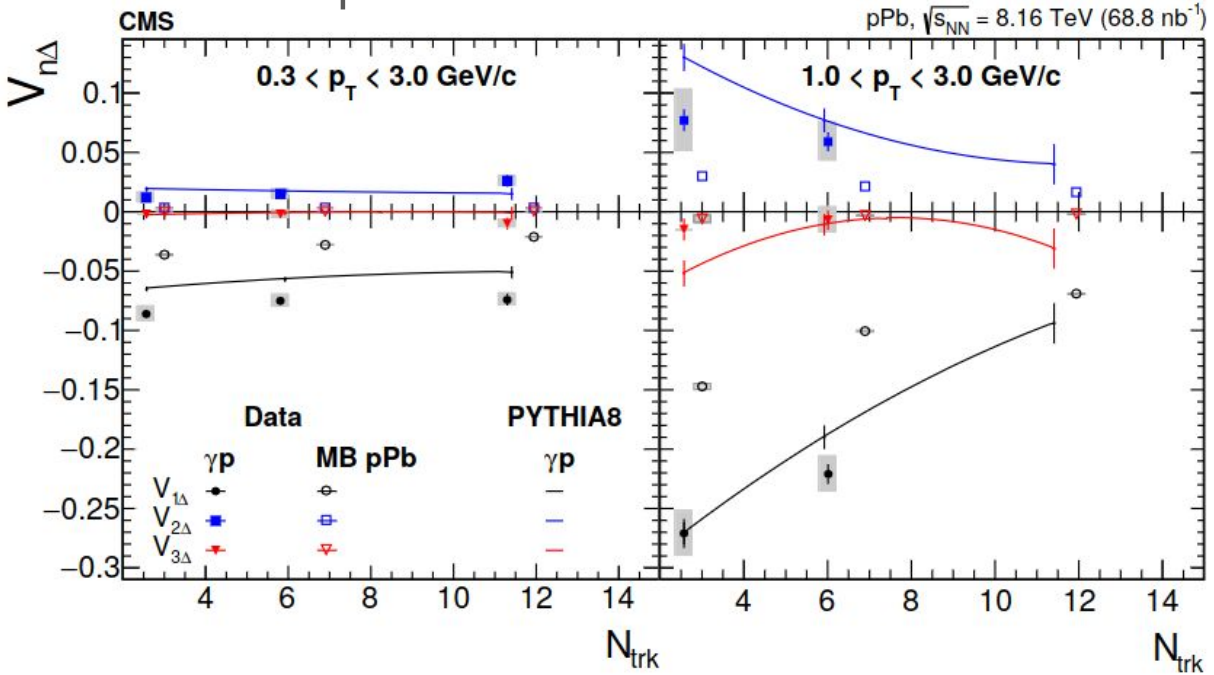
- Limited charged particle multiplicity N_{trk} with average ~2.9
- Pythia 8 added with **no flow effects**
- N_{trk} distribution from MC matches data
- Results are similar to e^+e^- and ep systems
- Analysis done in N_{trk} and track p_T categories



SOURCES: arXiv:2204.13486

Results (1/2)

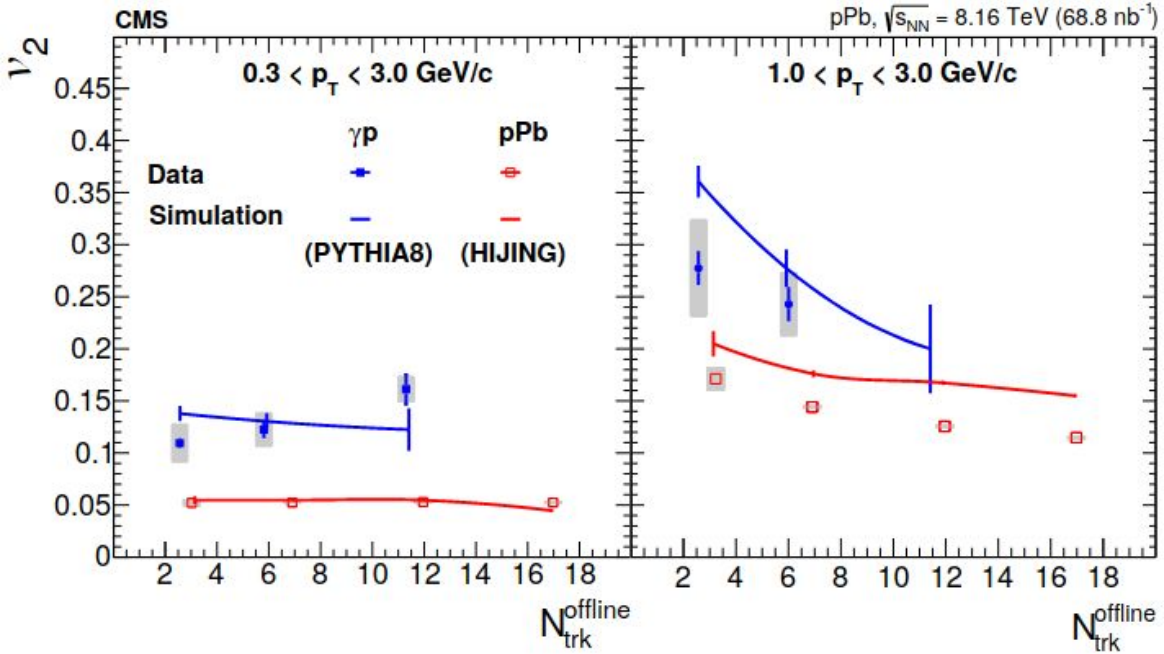
- Significant $V_{2\Delta}$ values observed
- $V_{3\Delta}$ values consistent with zero
- Consistency with non flow model (Pythia 8)
- Different results than in pPb case



SOURCES: arXiv:2204.13486

Results (2/2)

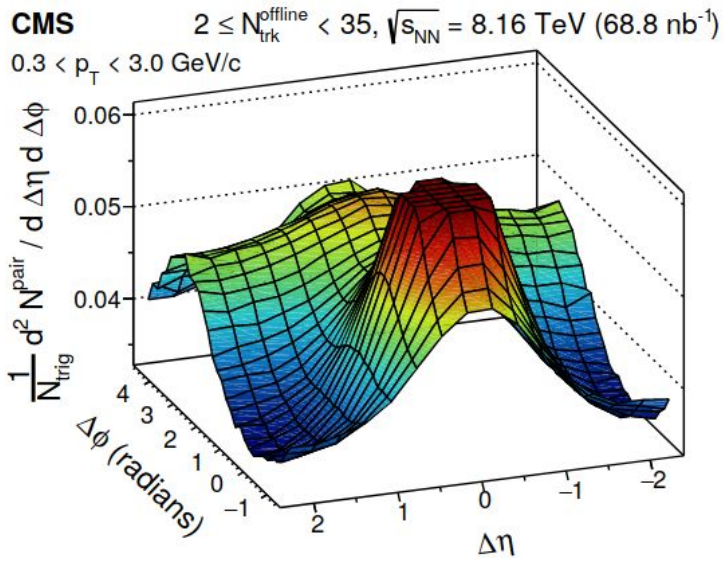
- Significant v_2 values observed
- Consistency with non flow model (Pythia 8)
- Values higher than in pPb case



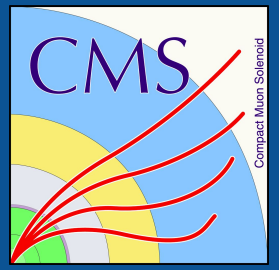
SOURCES: arXiv:2204.13486

Summary

- **First CMS measurements of two particle correlations in ɣ-proton**
  - Significant v_2 values consistent with non-flow model
  - No evidence of ridge structure in near-side, long-range region
- It adds to the plethora of small systems in which collectivity is being studied
- arXiv:2204.13486



Thanks for your attention!



Backup

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- CMS Collaboration, “Observation of long-range near-side angular correlations in pPb collisions at the LHC”, Phys. Lett. B 718 (2013) 795, doi:10.1016/j.physletb.2012.11.025, arXiv:1210.5482.
- Measurement of Two-Particle Correlations of Hadrons in e+e− Collisions at Belle. arXiv:2201.01694 [hep-ex]
- CMS Collaboration, “Two-particle azimuthal correlations in γp interactions using pPb collisions at $\sqrt{s_{NN}}$ = 8.16 TeV”, arXiv:2204.13486.
- CMS Collaboration, “Long-range and short-range dihadron angular correlations in central PbPb collisions at a nucleon-nucleon center of mass energy of 2.76 TeV”, JHEP 10 (2011) 076, doi:10.1007/JHEP07(2011)076, arXiv:1105.2438.
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References

- CMS Collaboration, “Observation of Long-Range, Near-Side Angular Correlations in Proton-Proton Collisions at the LHC”, JHEP 09 (2010) 091, doi:10.1007/JHEP09(2010)091, arXiv:1009.4122.
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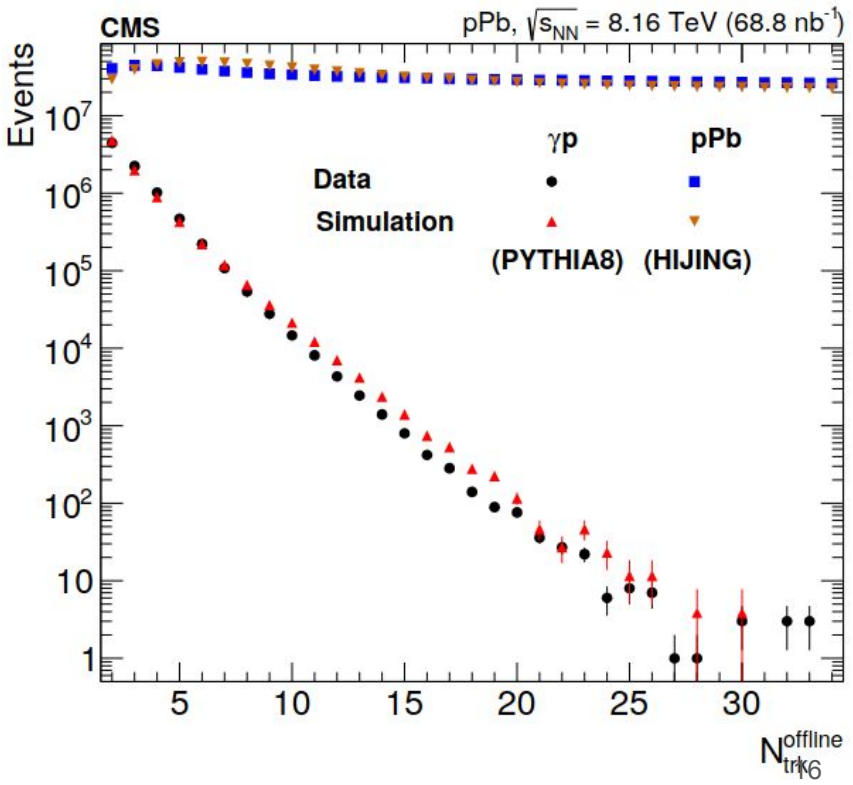
- T. Pierog et al., “EPOS LHC: Test of collective hadronization with data measured at the CERN Large Hadron Collider”, Phys. Rev. C 92 (2015) 034906, doi:10.1103/PhysRevC.92.034906, arXiv:1306.0121.

Two-particle correlations in γp interactions (1/2)

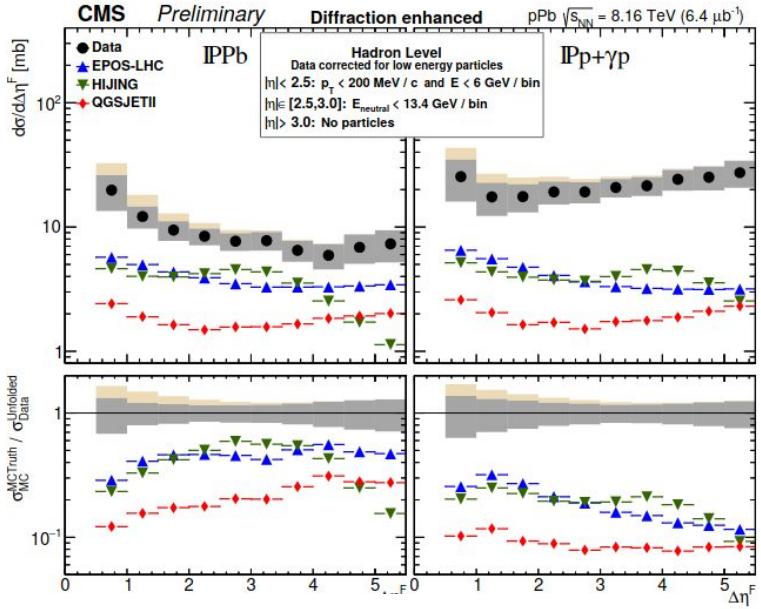
- Analysis done in N_{trk} and track p_T categories
  - For tracks $0.3 < p_T < 3.0$ GeV/c
    - $2 \leq N_{trk} < 5$
    - $5 \leq N_{trk} < 10$
    - $10 \leq N_{trk} < 35$
  - For tracks $1 < p_T < 3.0$ GeV/c
    - $2 \leq N_{trk} < 5$
    - $5 \leq N_{trk} < 35$

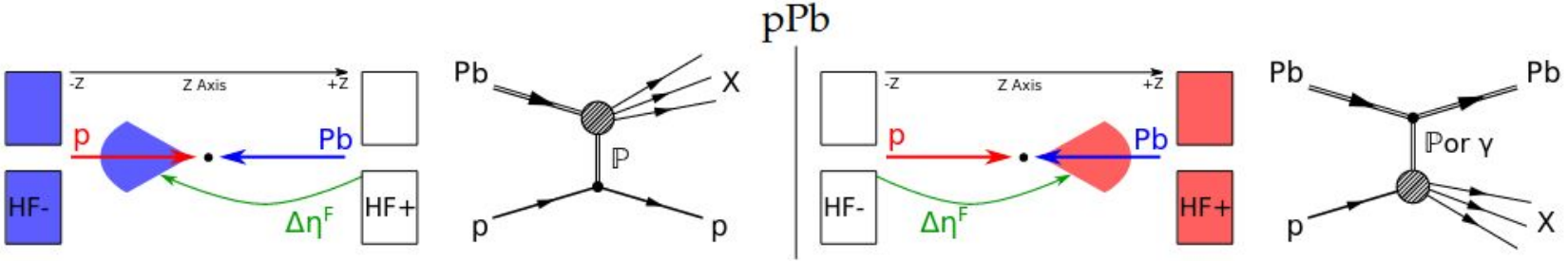


SOURCES: arXiv:2204.13486

Forward rapidity gap spectrum in pPb

- Run 2 collisions at 8.16 TeV
- Activity as a function of pseudorapidity using particle flow objects
- Results given in two directions of the interaction (ɣ-p and Pomeron-Pb sides)
- Provided a baseline for selecting ɣ-p and Pomeron-Pb events in pPb
- Submitted to Physical Review D

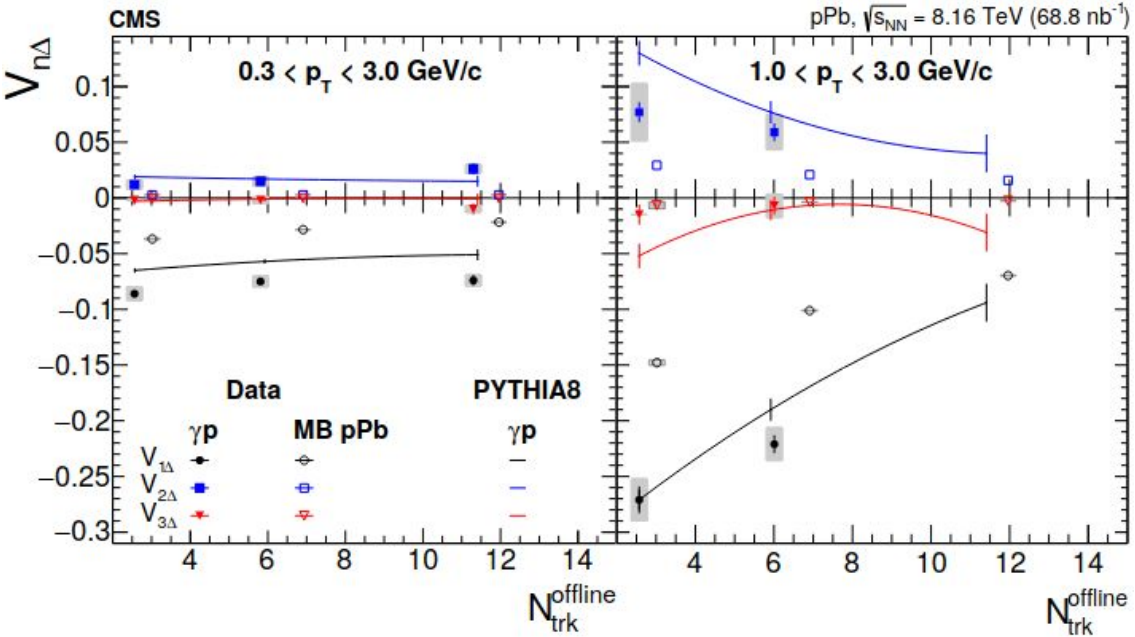




SOURCES: arXiv:2301.07630

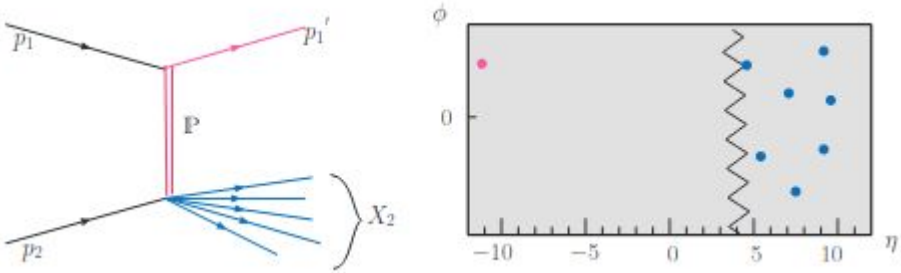
Two-particle correlations in γ-p interactions (2/2)

- Significant v_2 values observed
- $V_{3\Delta}$ values consistent with zero
- Consistency with non Flow model (Phythia 8)
- Different results than in pPb case

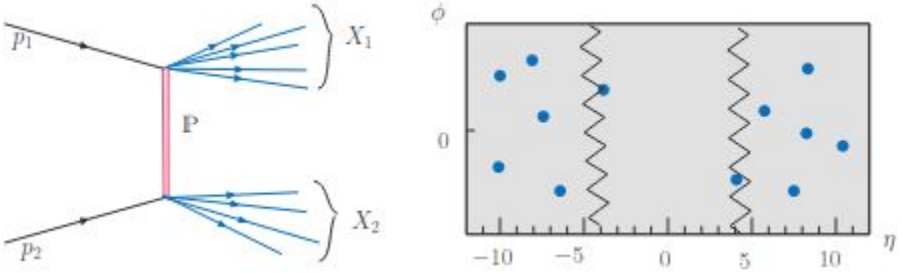


SOURCES: arXiv:2204.13486

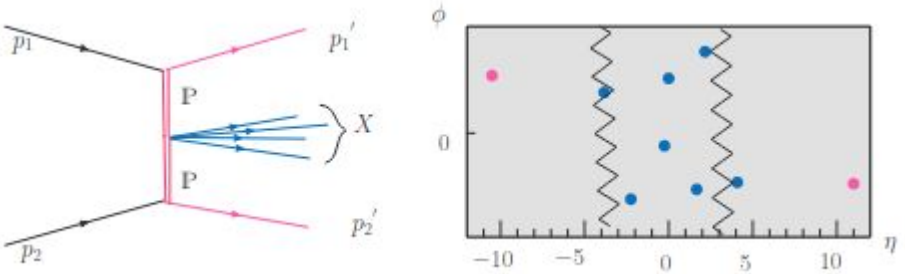
Topology of diffractive events



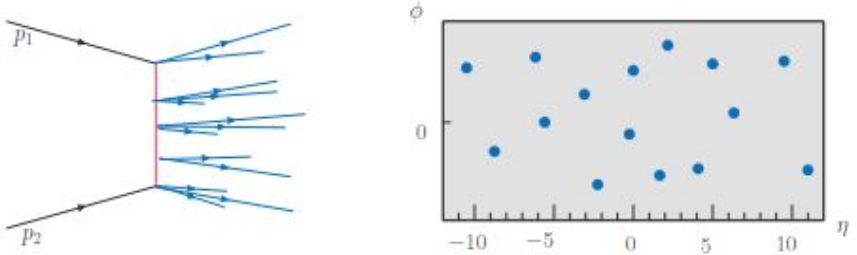
Single Diffractive



Double Diffractive



Central Diffractive

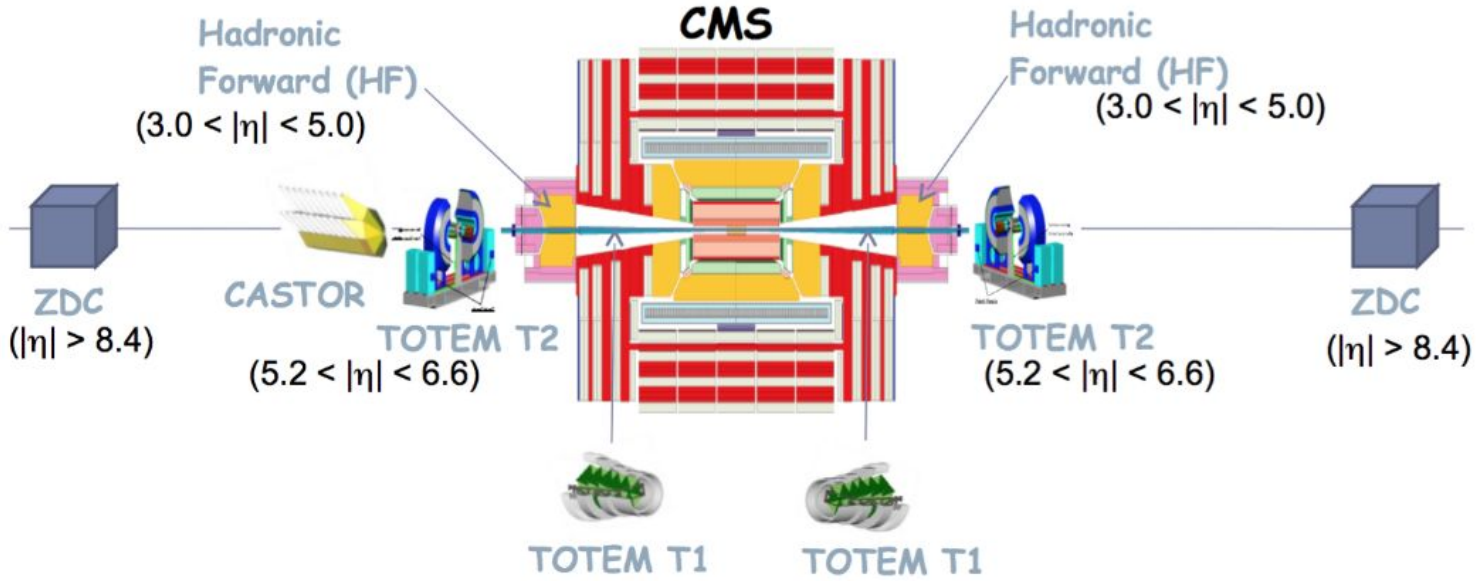


Non Diffractive

SOURCES: LUTP-09-23, MCnet/10/09

Zero Degree Calorimeter (ZDC) and Hadronic Forward Calorimeter (HF)

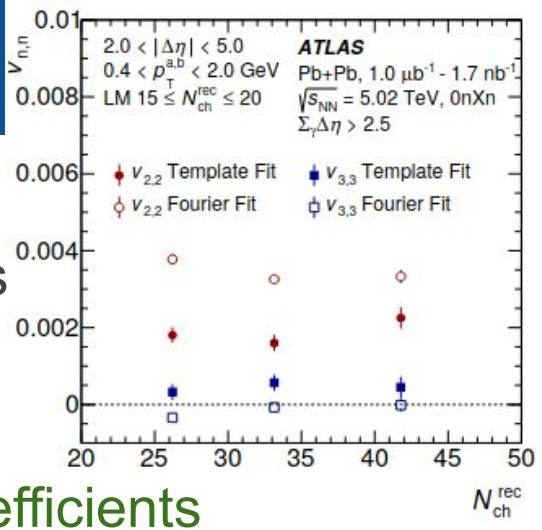
- Ideal for studying very forward events, including physics for peripheral and ultra-peripheral collisions
- ZDC located at 140 m from the interaction point
- HF ideal for detecting activity side in events with asymmetrical topology

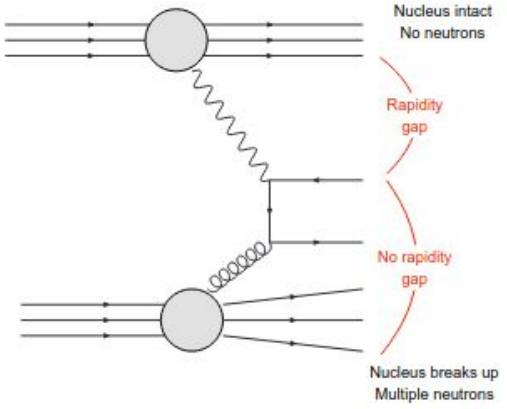


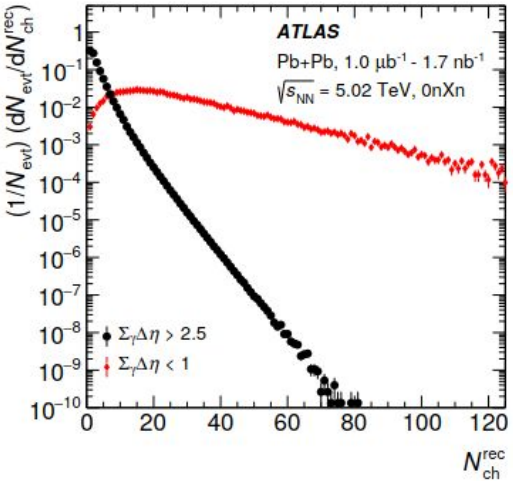
SOURCES: https://inspirehep.net/files/eccc173197ef02335f79bc831daf2fce

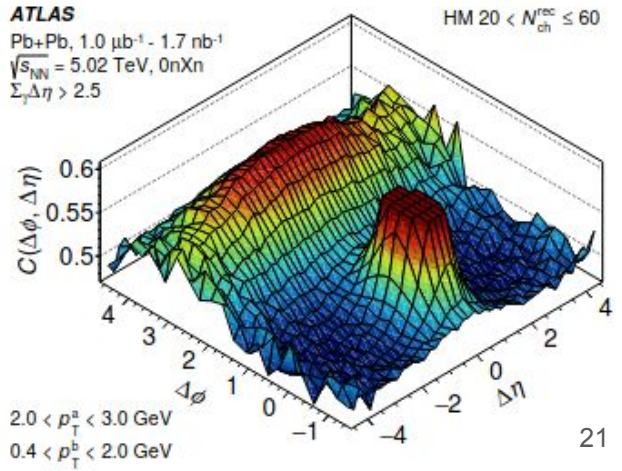
Recent probes on γ-Pb system

- γ-Pb events within PbPb collisions at 5.02 TeV
- Large rapidity gaps ($\Delta\eta_F$) expected at the events
- Upper N_{trk} limit at about 80
- Applied non-flow subtraction procedure
- Results consistent with significant v_2 and $V_{3\Delta}$ coefficients





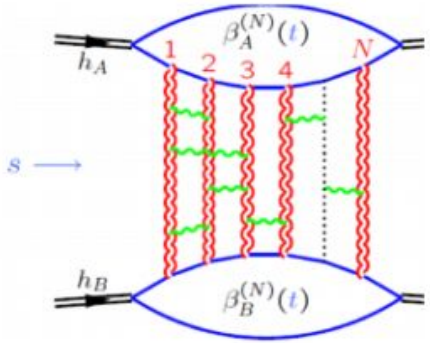


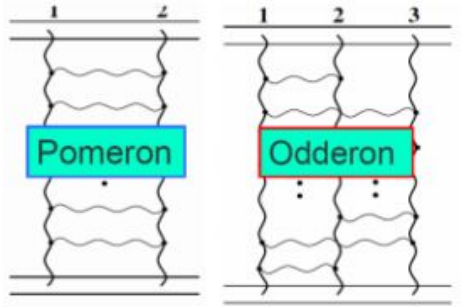


SOURCES: Phys. Rev. C 104, 014903 (2021)

Pomeron

- Pomeron is a Regge trajectory postulated to explain the slowly rising cross section of hadronic collisions at high energies
- These appear mostly in HEP events with a large rapidity gap
- In the SM era Pomeron is an state formed of a pair number of gluons exchanged in a diffractive event
- Interacting particles do not exchange quantum numbers
- Pomeron-Pb is a small system





SOURCES: https://indico.cern.ch/event/955960/contributions/4246688/

Zero Degree Calorimeter (ZDC)

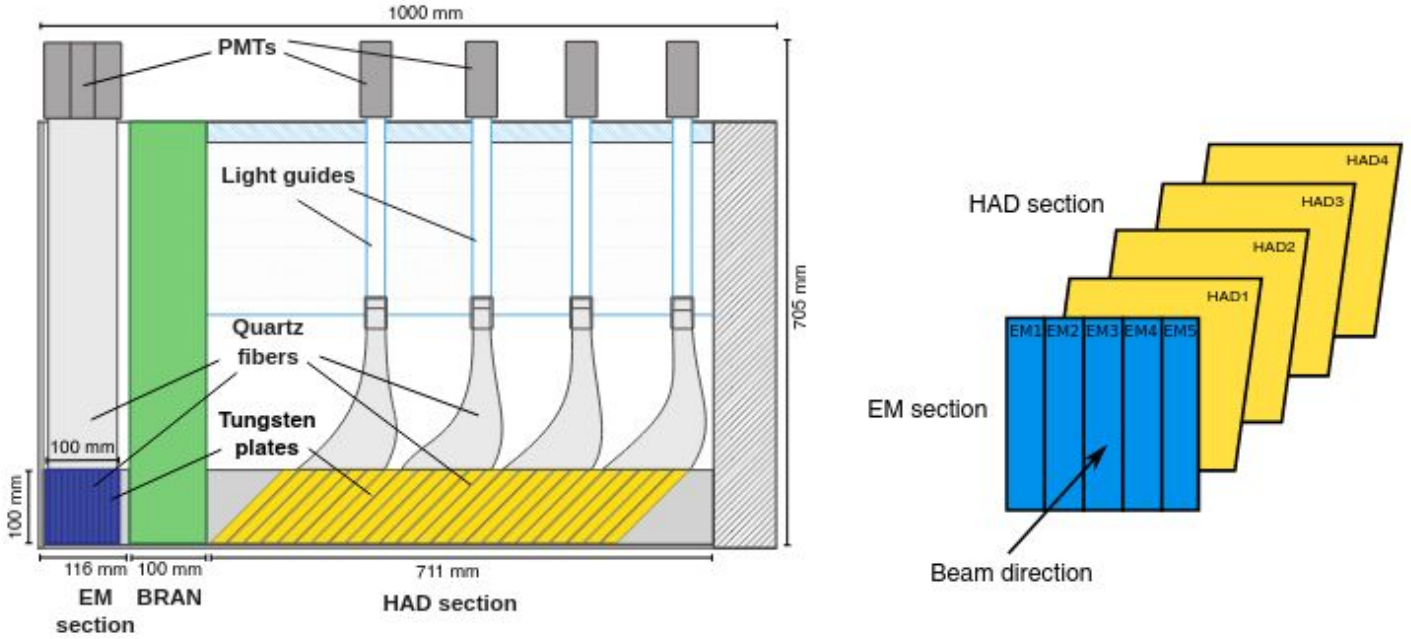
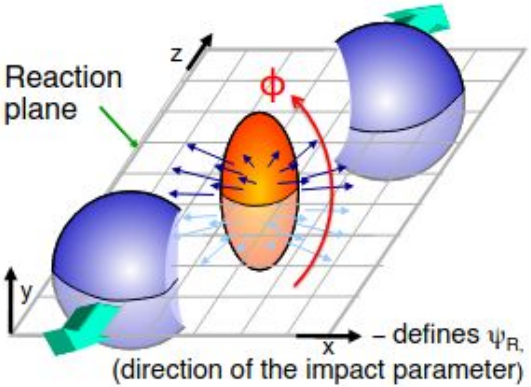


Figure 1: The schematic side-view (left) and segmentation (right) of the CMS ZDC.

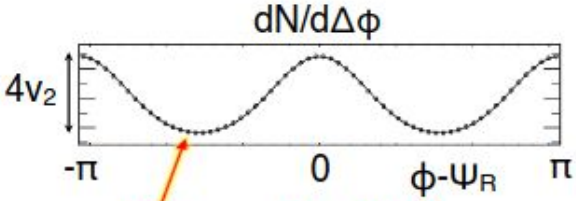
SOURCES: JINST 16 P05008 (2021)

Hydrodynamic behavior in correlation distributions

Initial-state asymmetry:



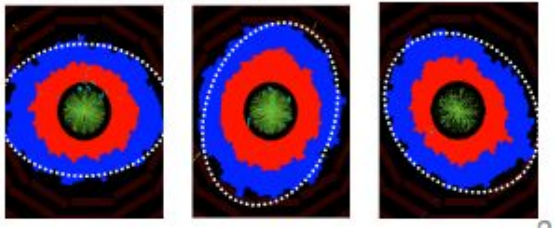
Final-state anisotropy:

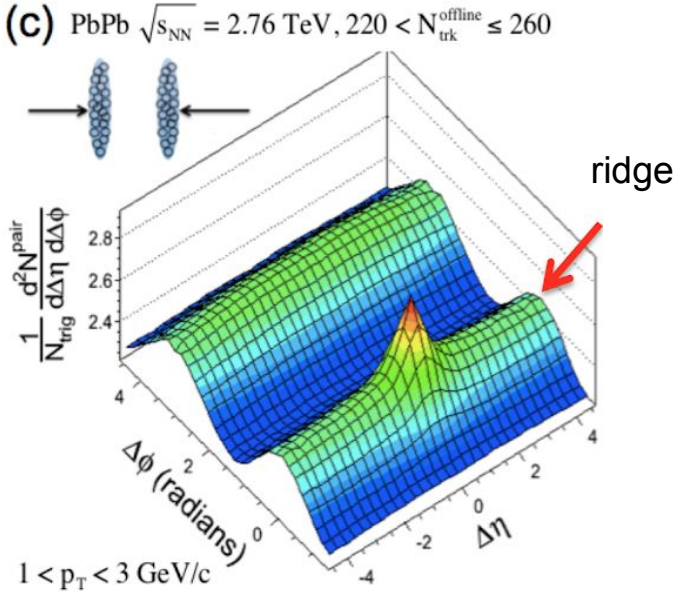


$\sim 1 + 2\, v_2 \cos[2(\phi - \Psi_R)]$

"elliptic flow"

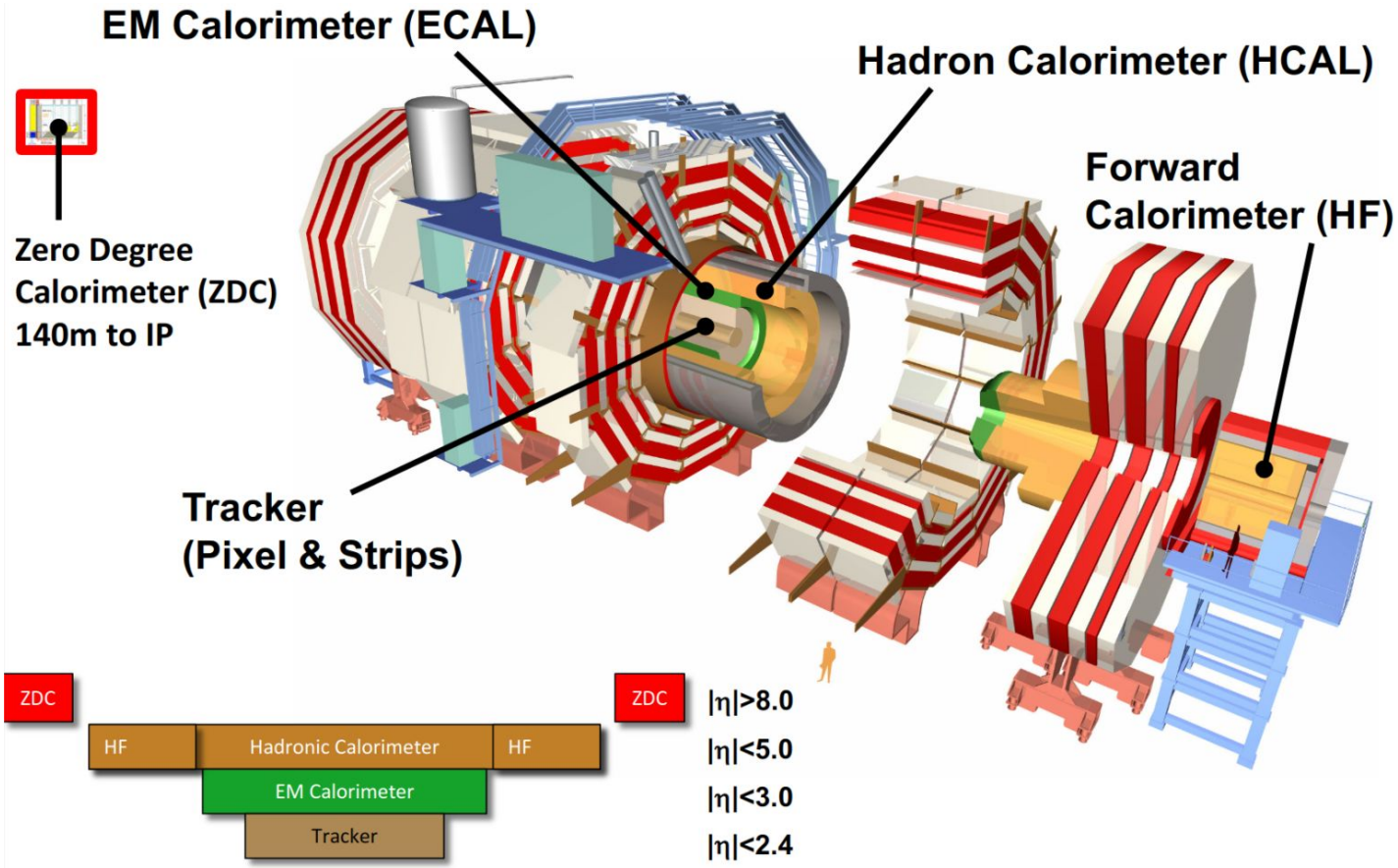
CMS event displays



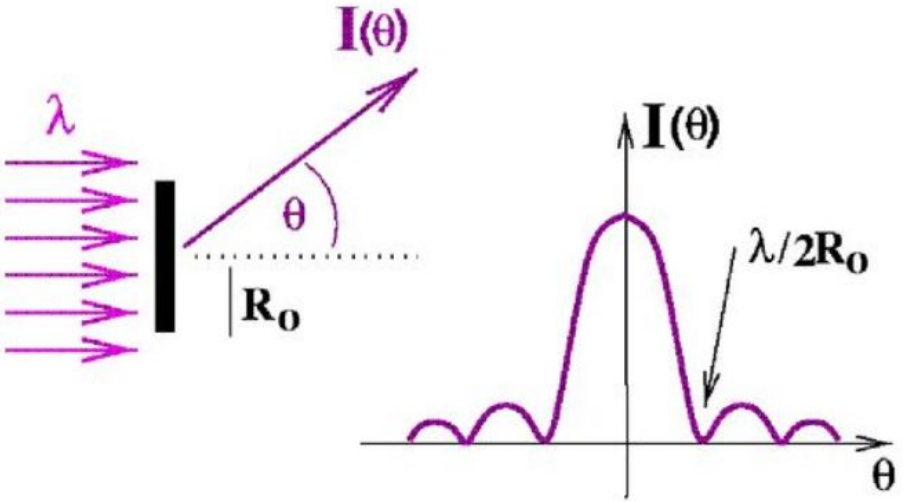


SOURCES: Collectivity in small systems, Wei Li. XIIth Quark Confinement and the Hadron Spectrum conference

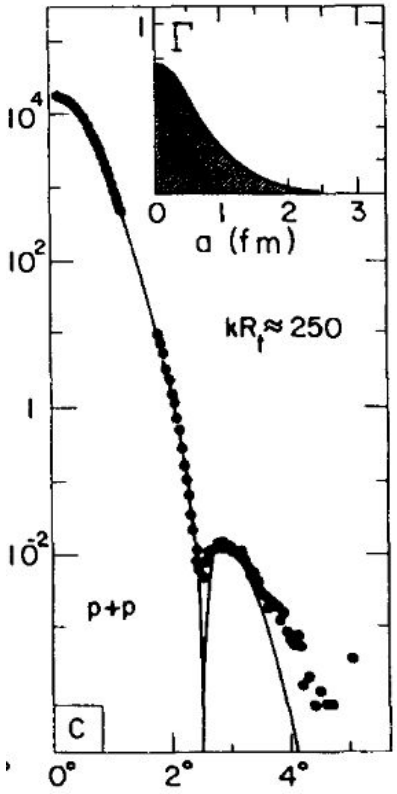
CMS

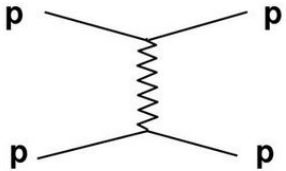

EM Calorimeter (ECAL)
Hadron Calorimeter (HCAL)
Forward Calorimeter (HF)
Zero Degree Calorimeter (ZDC) 140m to IP
Tracker (Pixel & Strips)
ZDC
HF
Hadronic Calorimeter
HF
EM Calorimeter
Tracker
ZDC
|η|>8.0
|η|<5.0
|η|<3.0
|η|<2.4

Diffractive collisions



Light diffraction in an obstacle





HEP interactions

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Forward rapidity gap (FRG)

- **Quantity indicative of the region in eta where the activity begins.** It can be thought of as a measure of frontality of the event
- Requires event reconstruction with particle flow (PF) algorithm
- 12 bins are defined in |η|<3 of 0.5 units width. Empty bins:
  - In |η|<2.5 (tracker) if there are no high-purity tracks with pt>200MeV and if the total energy sum of PF candidates (particle flow candidates) is <6GeV
  - In 2.5<|η|<3 if the energy of all hadronic PF candidates is <13.14GeV
- **The gap $\Delta\eta_F$ (FRG) is the number of empty bins from η=3 to the upper limit of the first non-empty bin**