Search for collectivity in diffractive collisions at the LHC

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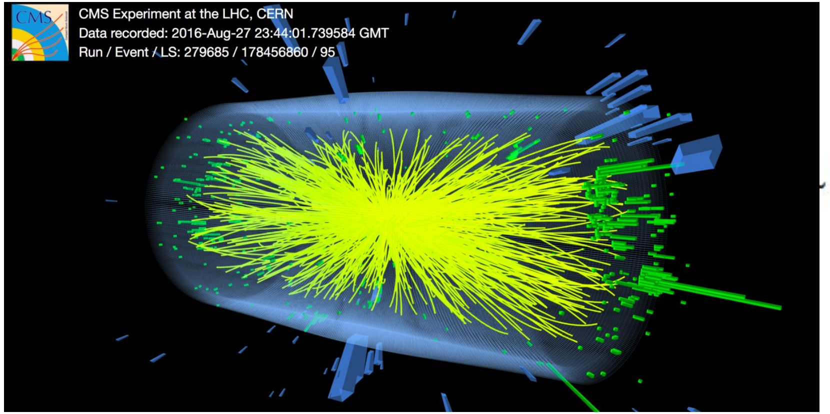
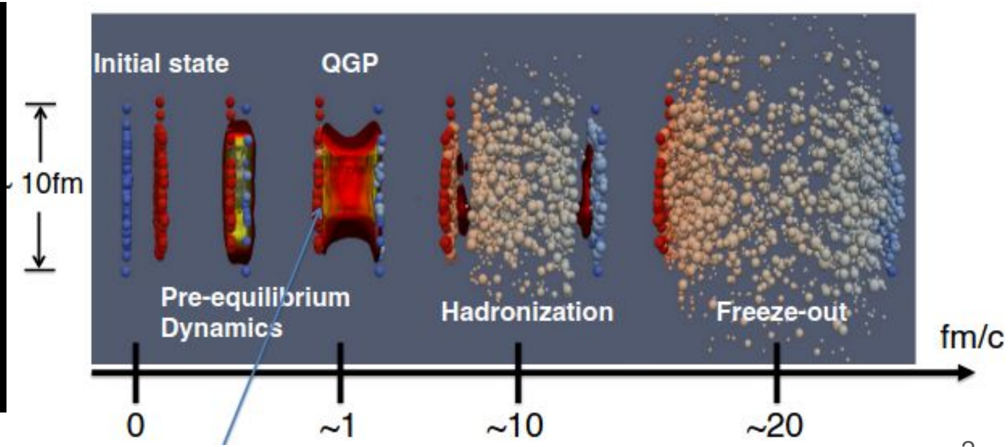
Workshop on medical and high energy physics at Sonora, Mexico

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**

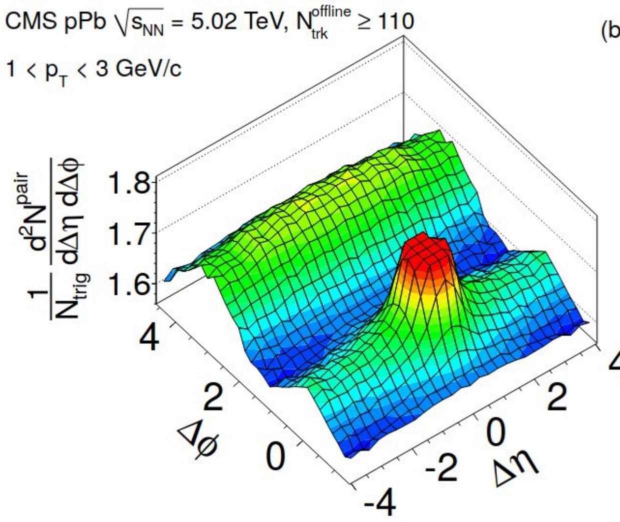


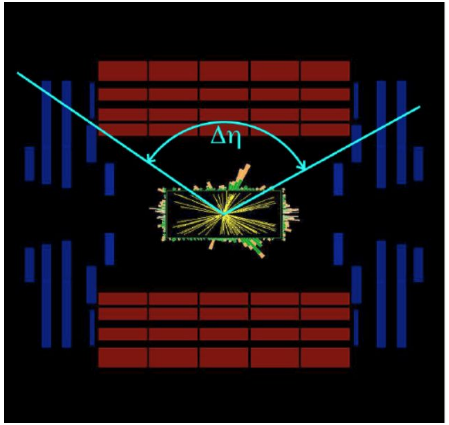


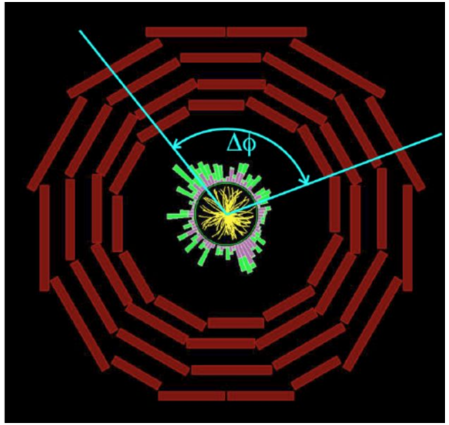
SOURCES: https://cds.cern.ch/record/2241144 https://madai.phy.duke.edu/indexaae2.html

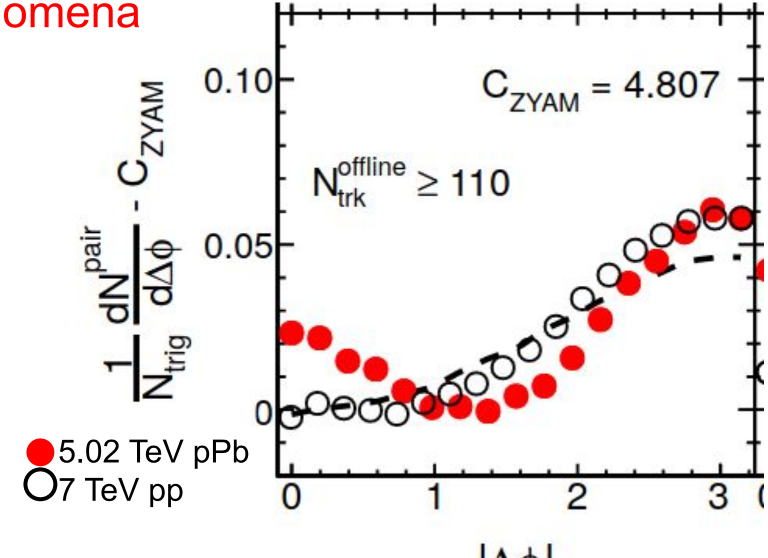
Two particle correlation distributions

- **A tool for characterizing collective behavior is the particle correlation distribution**
- "Ridge zone" is Δη>2, Δϕ~0 **(long range, near side)**
- Fourier fit gives VN 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





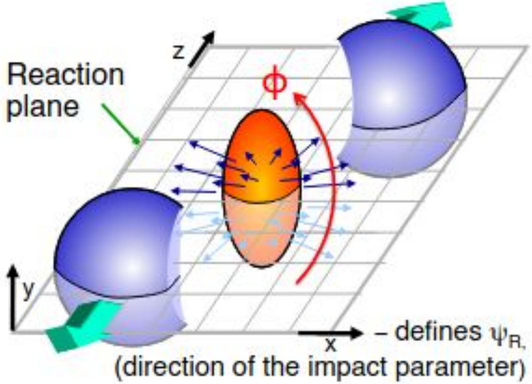




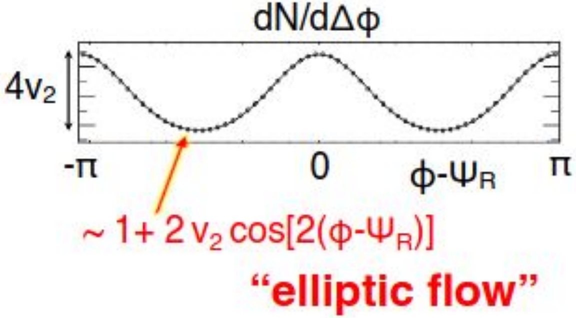
SOURCES: Phys. Lett. B 718 (2013) 795

Hydrodynamic behavior in correlation distributions

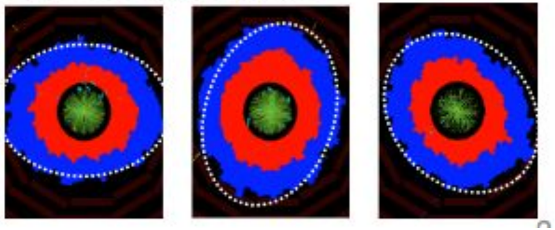
Initial-state asymmetry:

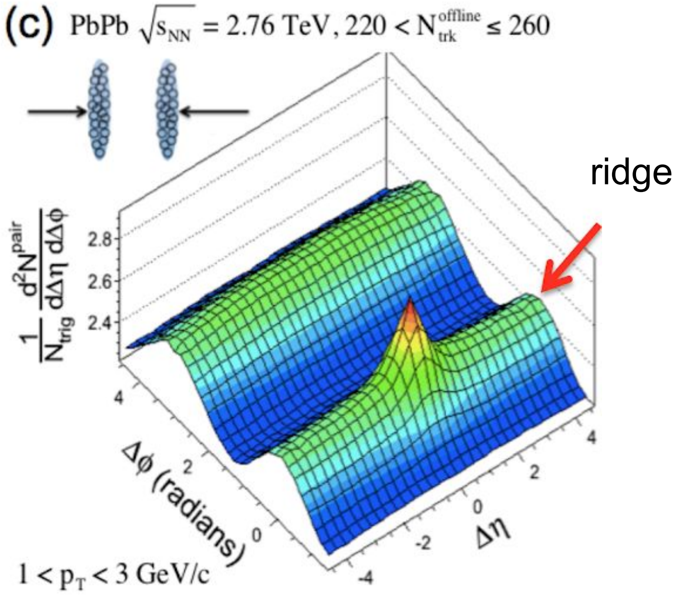


Final-state anisotropy:



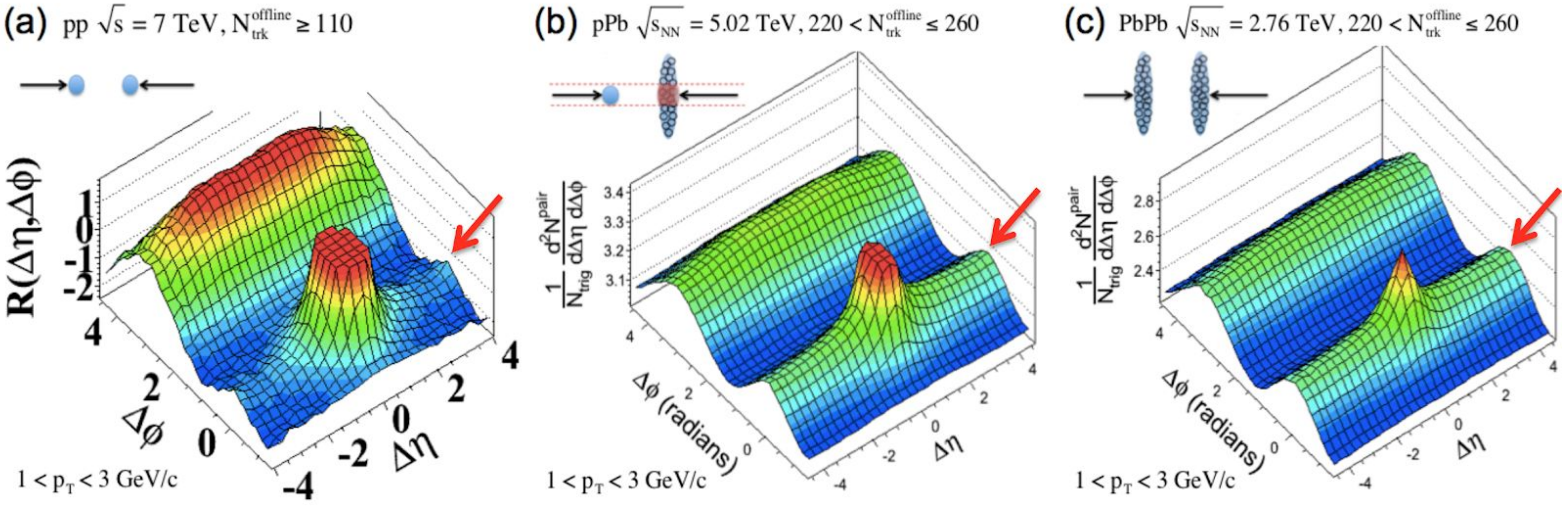
CMS event displays





Ridge also seen in small systems

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

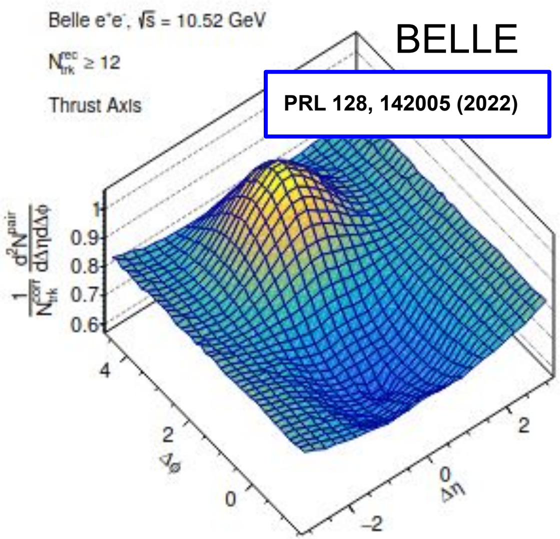


SOURCES: JHEP 1009:091,2010 Phys. Lett. B 718 (2013) 795 JHEP 7 (2011) 76

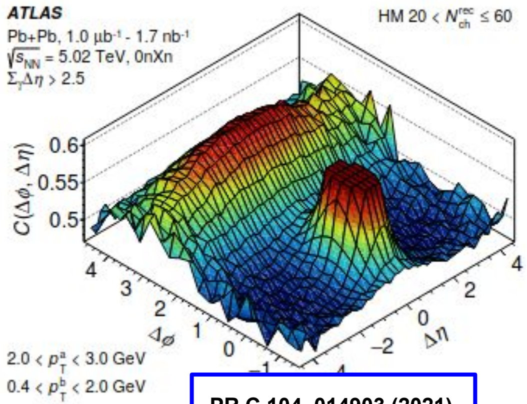
Latest probes in small systems

- 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 recently explored small systems:
  - e^+e^- , ep, ɣp (ZEUS)
  - e^+e^- (BELLE and ALEPH)
  - ɣPb (ATLAS)
  - ɣp (CMS)
  - Jets (CMS)

BELLE

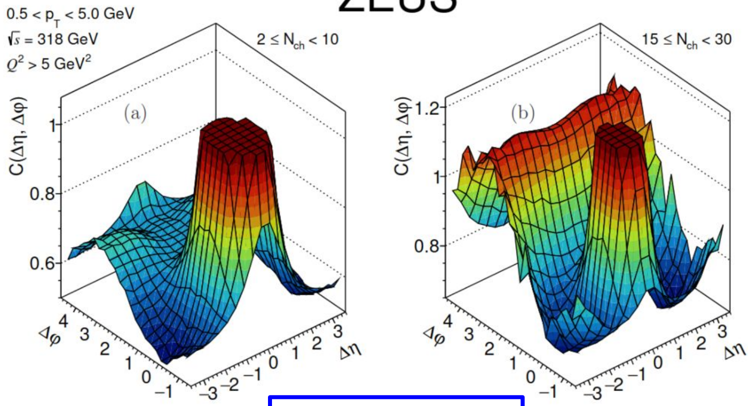


PRL 128, 142005 (2022)



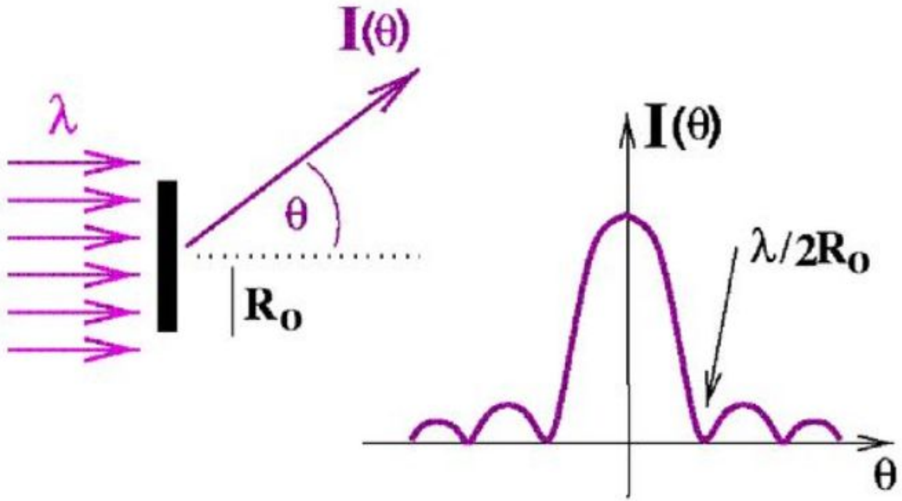
PR C 104, 014903 (2021)

ZEUS

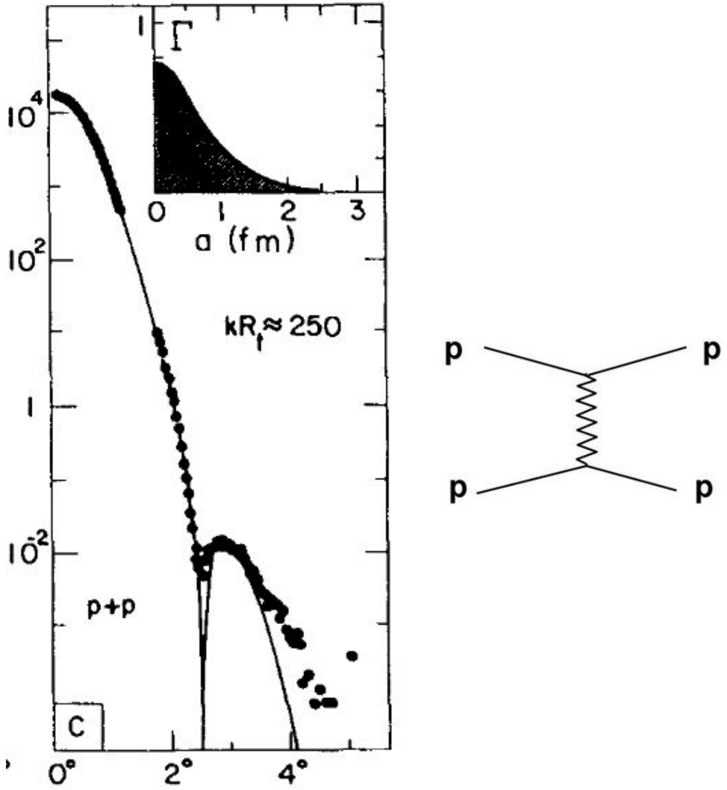


JHEP 04 (2020) 070

Diffractive collisions

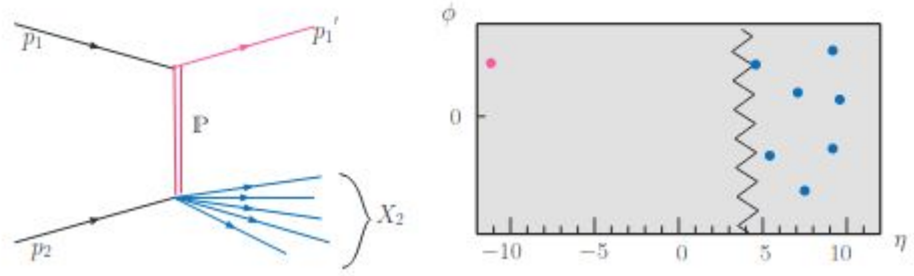


Light diffraction in an obstacle

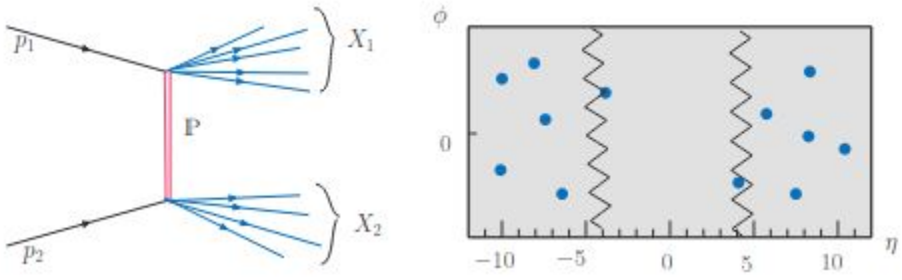


HEP interactions

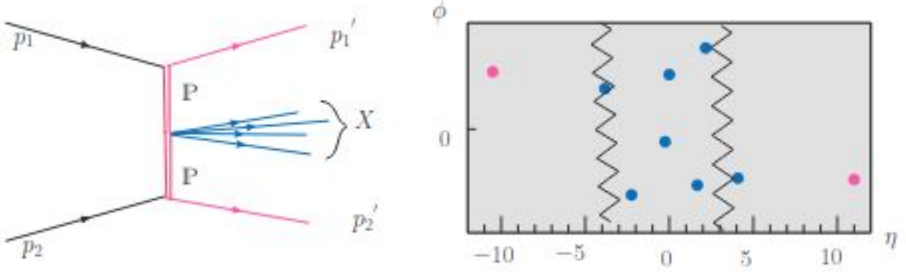
Topology of diffractive events



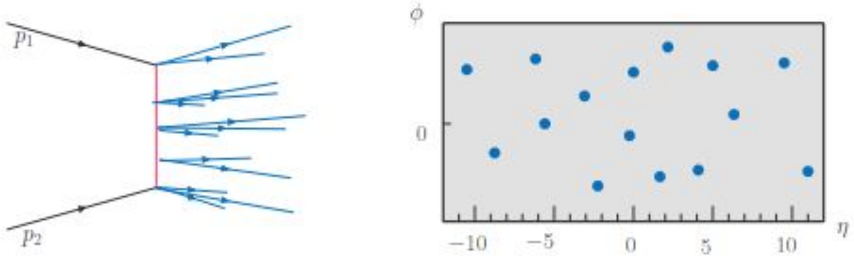
Single Diffractive



Double Diffractive



Central Diffractive

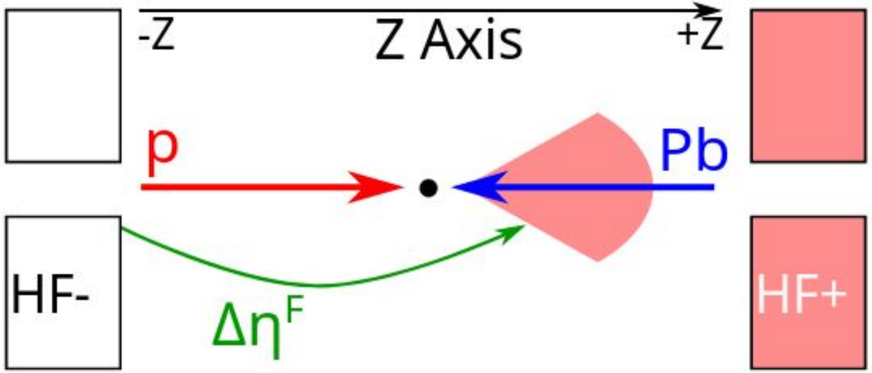


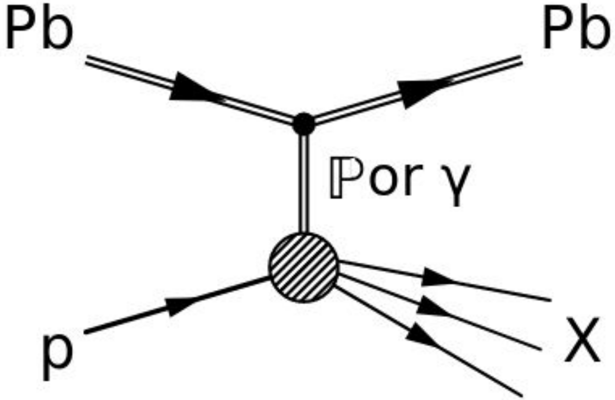
Non Diffractive

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

Two-particle correlations in ɣp interactions

- ɣp events from pPb collisions at $\sqrt{s_{NN}}$=8.16 TeV in CMS during run 2
- Rapidity gap studied in Phys.Rev. D108(2023)092004
- Selection enhances events where **Pb remains intact while p dissociates**
- ɣp and pomeron-p interactions can occur
- Activity expected in the proton side of the detector
- ZDC calorimeters ensure no neutrons from intact Pb

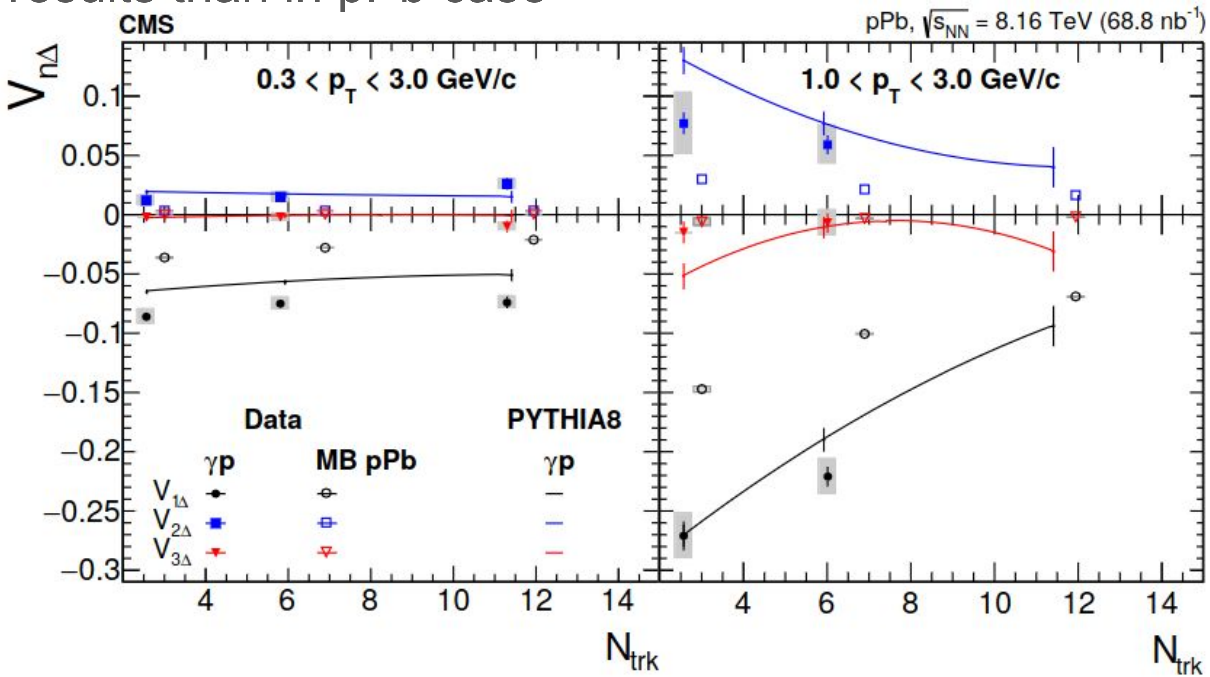




SOURCES: arXiv:2301.07630

Results (1/2)

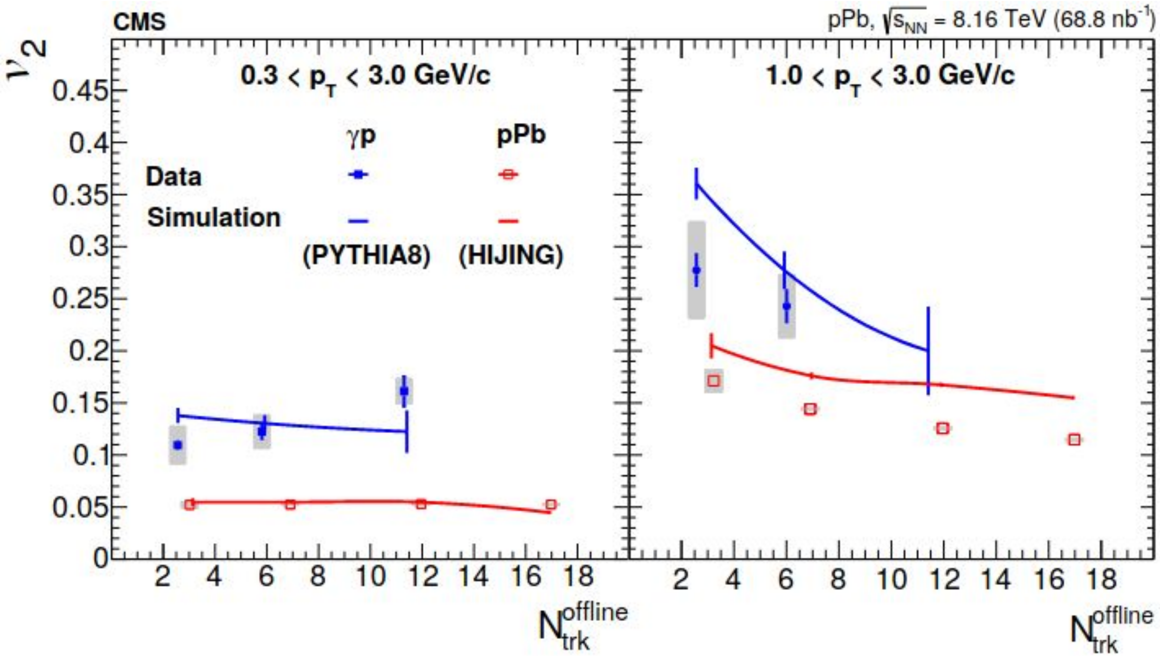
- Significant $V_{2\Delta}$ values observed
- $V_{3\Delta}$ values consistent with zero
- Consistency with non flow model (Pythia 8)
- Different results than in pPb case



SOURCES: arXiv:2204.13486

Results (2/2)

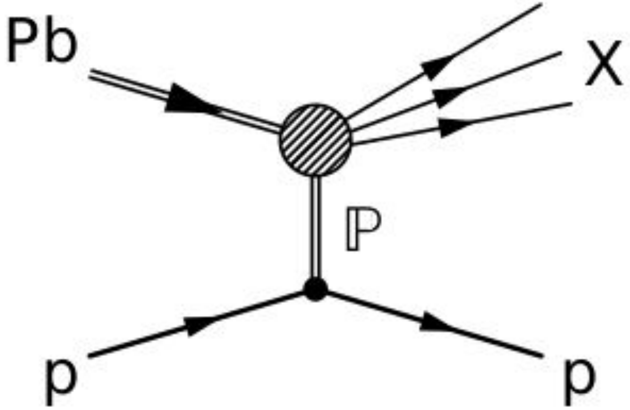
- Significant v_2 values observed
- Consistency with non flow model (Pythia 8)
- Values higher than in pPb case

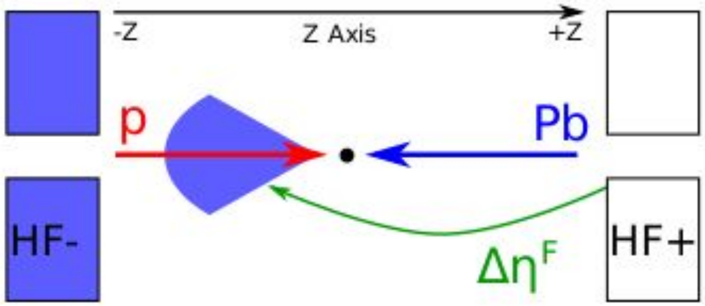


SOURCES: arXiv:2204.13486

What happens when the activity is on the Pb side?

- Phys.Rev. D108(2023)092004 also study what happen when also studies what happens when activity is on the other side
- Selection enhances events where **p remains intact while Pb dissociates**
- Activity expected in the lead side of the detector
- pomeron-Pb, γPb and nondiffractive interactions can occur

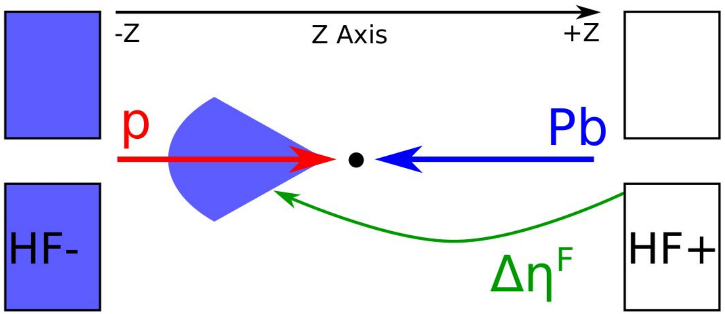


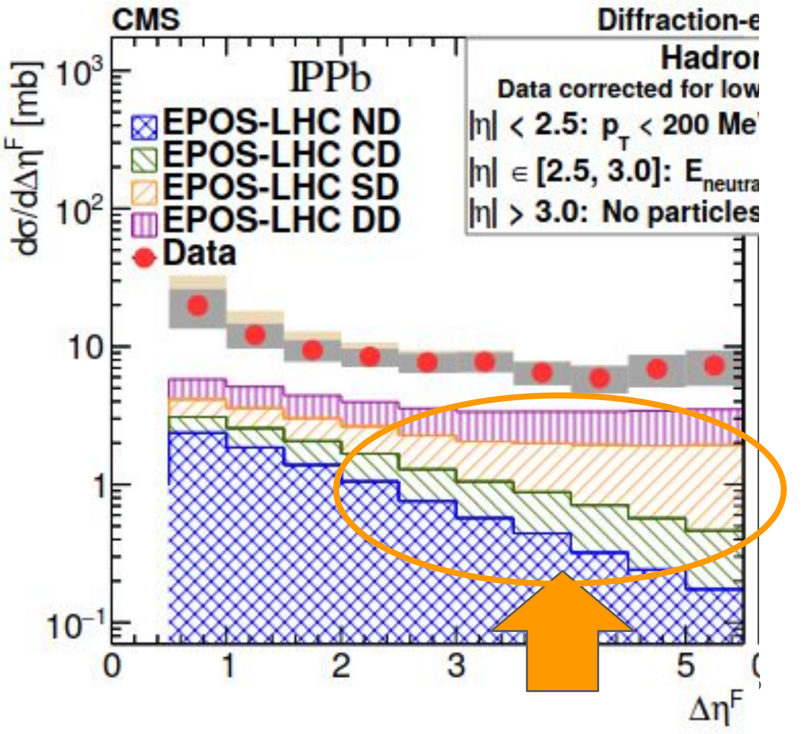


SOURCES: arXiv:2301.07630

Sample under study

- **This analysis studies pPb interactions with different levels of Forward Rapidity Gap ($\Delta\eta_F$)**
  - Activity goes to direction of Pb beam
- **Sample includes Pomeron-Pb, γPb and Nondiffractive interactions**
- From Phys.Rev. D108(2023)092004:
  - EPOS models diffractive and non-diffractive processes accounting for up to ~43% of data sample yield
- According to PYTHIA 8.3 model, an ~8% yield corresponds to γPb processes
- For larger $\Delta\eta_F$ the fraction of Pomeron-Pb contribution increases





Pythia 8.3 simulation

Samples were produced using Pythia 8.3

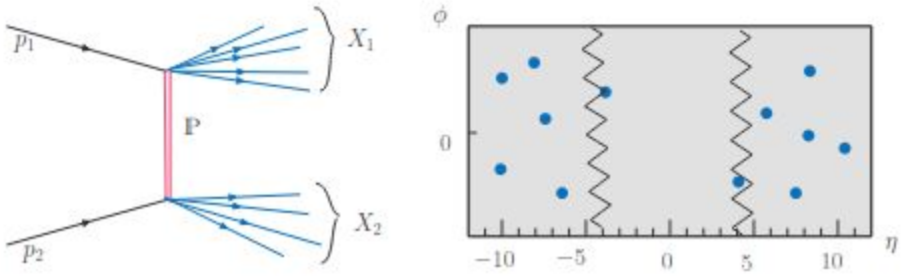
- **Angantyr model**
- **Based on example main112.cc**

Categories:

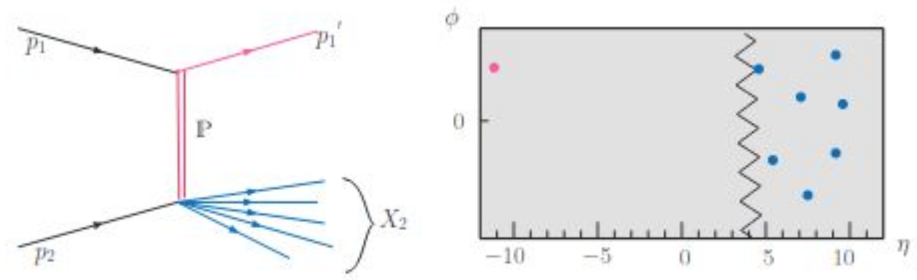
- **Nominal selection:**
  - **Varying gap width from 0 to 2.5 with 0.3<Pt<3:**
    - $\Delta\eta_F$ bins ∈ [0.0−0.5, 0.5-1.0, 1.0-1.5, 1.5-2.0, 2.0-2.5, >2.5]
- **Diffraction enhanced as function of charged track multiplicity ($N_{trk}^{offline}$):**
  - **For 0.3<Pt<3:**
    - $N_{trk}^{offline}$ bins ∈ [2−5, 5−7, 7−40, 2-40]
- In all $V_{n\Delta}$ measurements $N_{trk}^{offline}$ range was limited to [2-40]

Processes produced in Pythia 8.3

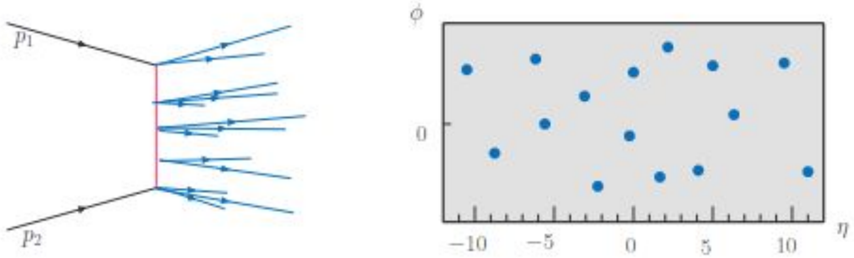
- **Processes produced were as follows:**
  - **Nondiffractive (ND)**
  - **Single-diffractive (SD)**
  - **Double-diffractive (DD)**
- **About 4 million of events produced per bin (previous slide) and per process**



Double Diffractive



Single Diffractive

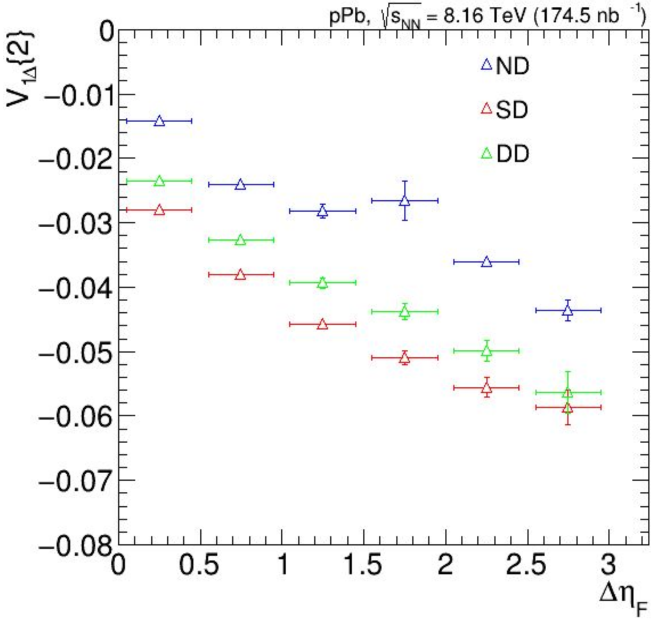


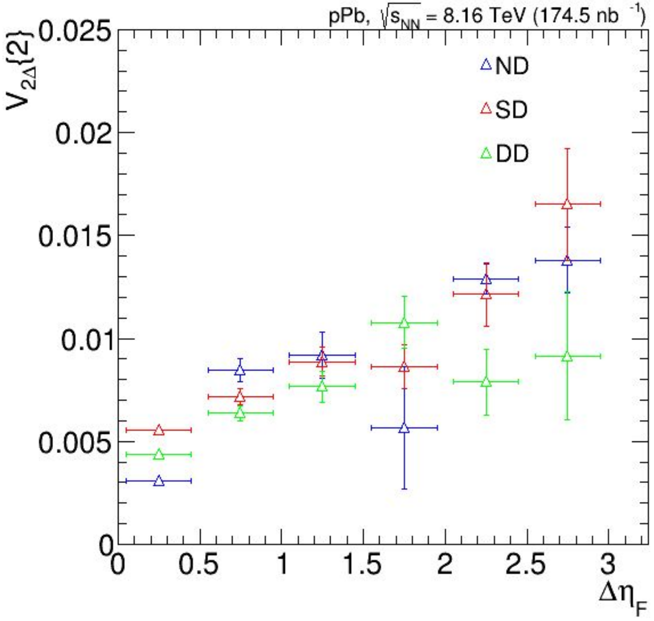
Non Diffractive

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

$V_{n\Delta}$ as function of $\Delta\eta_F$

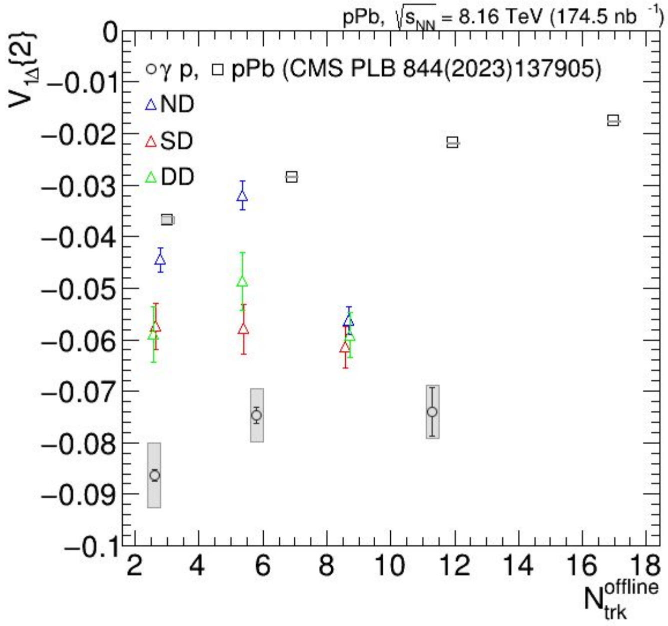
- $V_{1\Delta}$ decreases for all components with $\Delta\eta_F$
  - ND processes are predicted to be higher than SD and DD
- $V_{2\Delta}$ increases for all components with $\Delta\eta_F$ (no clear differences)
- Small nonmonotinic behavior in ND distribution in bin (1.5-2]

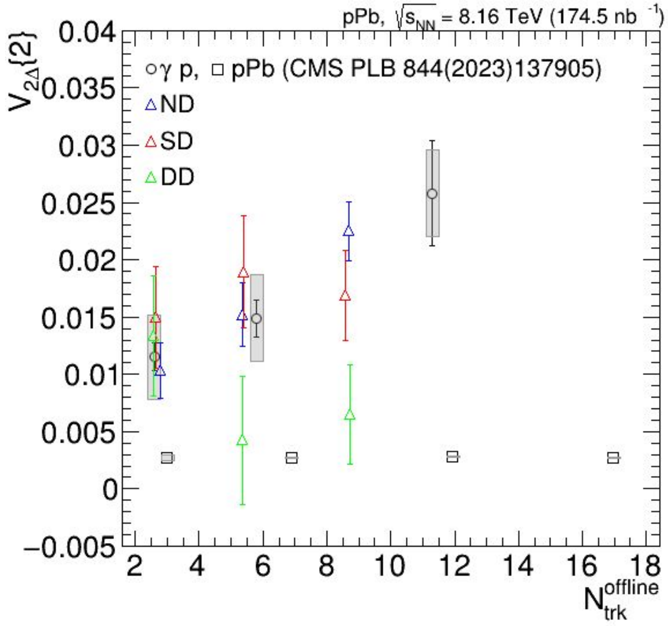




$V_{n\Delta}$ as function of $N_{trk}^{offline}$

- $V_{1\Delta}$ and $V_{2\Delta}$ remains flat across $N_{trk}^{offline}$
  - No clear tendency on different processes
- Results for $V_{1\Delta}$ tends to be lower than pPb but higher than in γPb
- Results for $V_{2\Delta}$ in ND and SD tends to be similar than in γPb
- Results for $V_{1\Delta}$ in DD tends to be similar than in γPb in first bin and similar to pPb in the rest





Summary

- **Simulations of the dependence of two-particle azimuthal correlations on the forward rapidity gap width**
- Simulations done with Pythia 8.3 (Angantyr model)
- Results of $V_{1\Delta}$ as function of $\Delta\eta_F$ are negative for all components
  - ND results are higher than the rest of the components
- Results of $V_{2\Delta}$ grows as function of $\Delta\eta_F$
  - No clear difference between simulation components
- Results of $V_{1\Delta}$ as function of Ntrk are smaller than in pPb but larger than γp
  - No clear difference between simulation components
- Results of $V_{2\Delta}$ as function of $N_{trk}^{offline}$ are similar to γp for ND and SD
  - DD component similar to pPb for larger $N_{trk}^{offline}$
- Not an obvious way to differentiate diffractive clases using $V_{2\Delta}$ and $V_{1\Delta}$ measurements
- Ongoing work in CMS to provide data points in such measurements

Thanks for your attention!

Backup

References

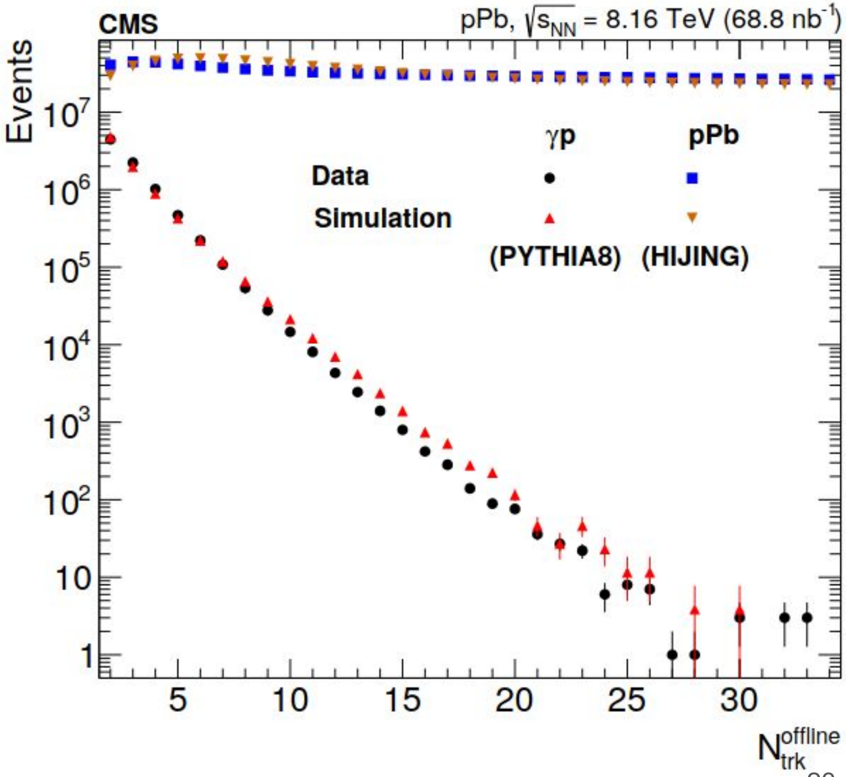
- CMS Collaboration, “Observation of Long-Range, Near-Side Angular Correlations in Proton-Proton Collisions at the LHC”, JHEP 09 (2010) 091, doi:10.1007/JHEP09(2010)091, arXiv:1009.4122.
- CMS Collaboration, “Observation of long-range near-side angular correlations in pPb collisions at the LHC”, Phys. 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.
- ATLAS Collaboration Collaboration, “Two-particle azimuthal correlations in photonuclear ultraperipheral Pb + Pb collisions at 5.02 tev with atlas”, Phys. Rev. C 104 (Jul, 2021) 014903, doi:10.1103/PhysRevC.104.014903.
- ZEUS Collaboration, “Two-particle azimuthal correlations as a probe of collective behaviour in deep inelastic ep scattering at HERA”, JHEP 04 (2020) 070, doi:10.1007/JHEP04(2020)070, arXiv:1912.07431.

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.
- P. D. B. Collins, “An Introduction to Regge Theory and High-Energy Physics”. Cambridge Monographs on Mathematical Physics. Cambridge Univ. Press, Cambridge, UK, 5, 2009. doi:10.1017/CBO9780511897603, ISBN 978-0-521-11035-8.
- E. Martynov and B. Nicolescu, “Did totem experiment discover the odderon?”, Physics Letters B 778 (2018) 414–418, doi:https://doi.org/10.1016/j.physletb.2018.01.054.
- CMS Collaboration, “First measurement of the forward rapidity gap distribution in pPb collisions at $\sqrt{s_{NN}}$ = 8.16 TeV”, Technical Report CMS-PAS-HIN-18-019, CERN, Geneva, 2020.
- CMS Collaboration, “Particle-flow reconstruction and global event description with the CMS detector”, JINST 12 (2017) P10003, doi:10.1088/1748-0221/12/10/P10003, arXiv:1706.04965.
- CMS Collaboration, “The CMS experiment at the CERN LHC”, JINST 3 (2008) S08004, doi:10.1088/1748-0221/3/08/S08004.
- 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.

N_{trk} distribution

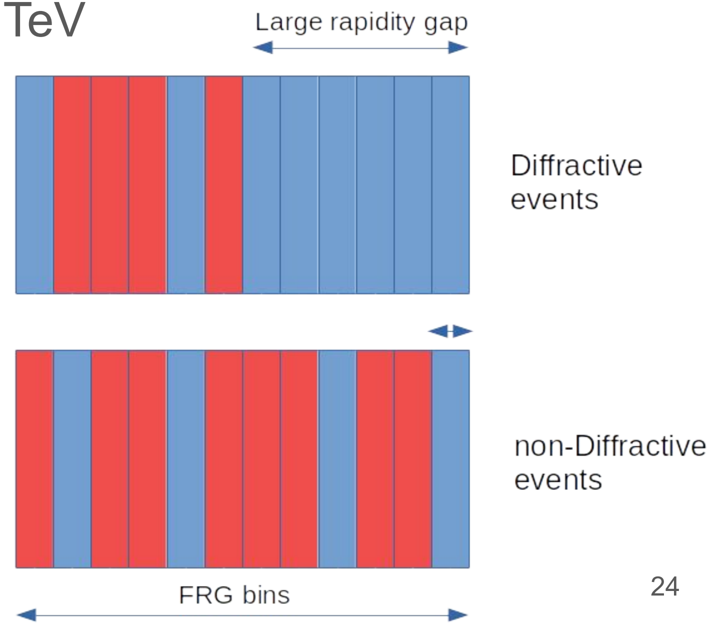
- Limited charged particle multiplicity N_{trk} with average ~2.9
- Pythia 8 added with **no flow effects**
- N_{trk} distribution from MC matches data
- Results are similar to e^+e^- and ep systems
- Analysis done in N_{trk} and track p_T categories

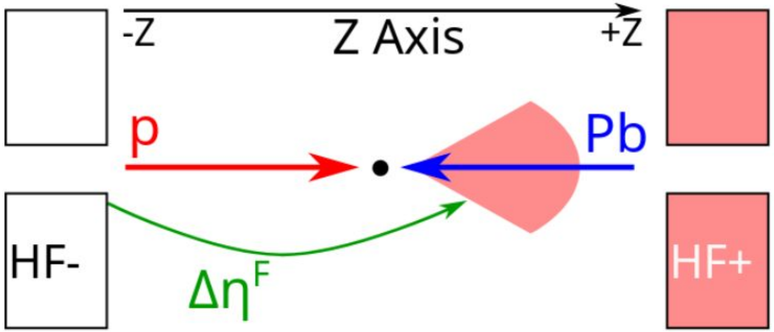


SOURCES: arXiv:2204.13486

Event selection for γp paper

- Standard track selection were used:
  - Kinematic range: η < 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

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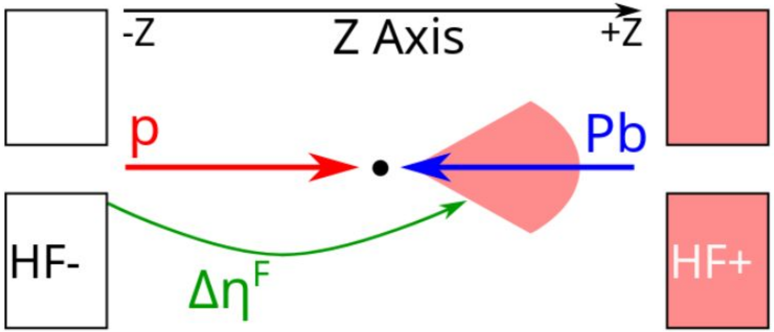
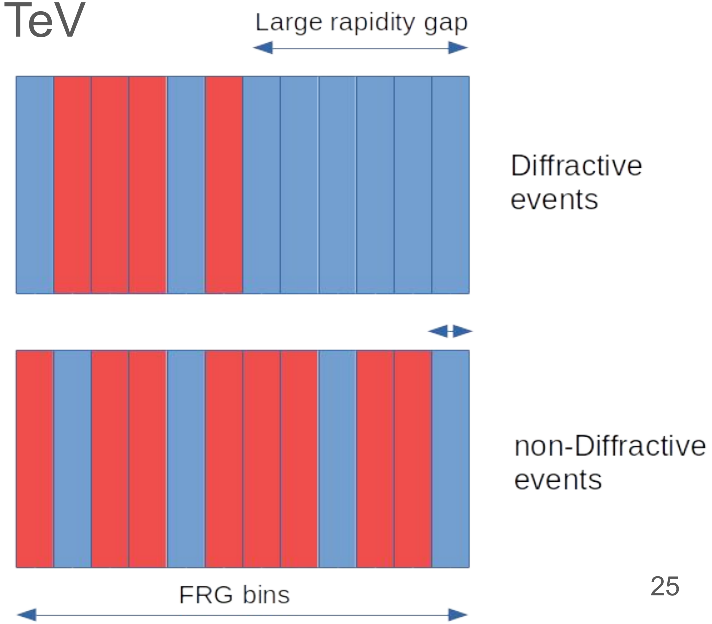
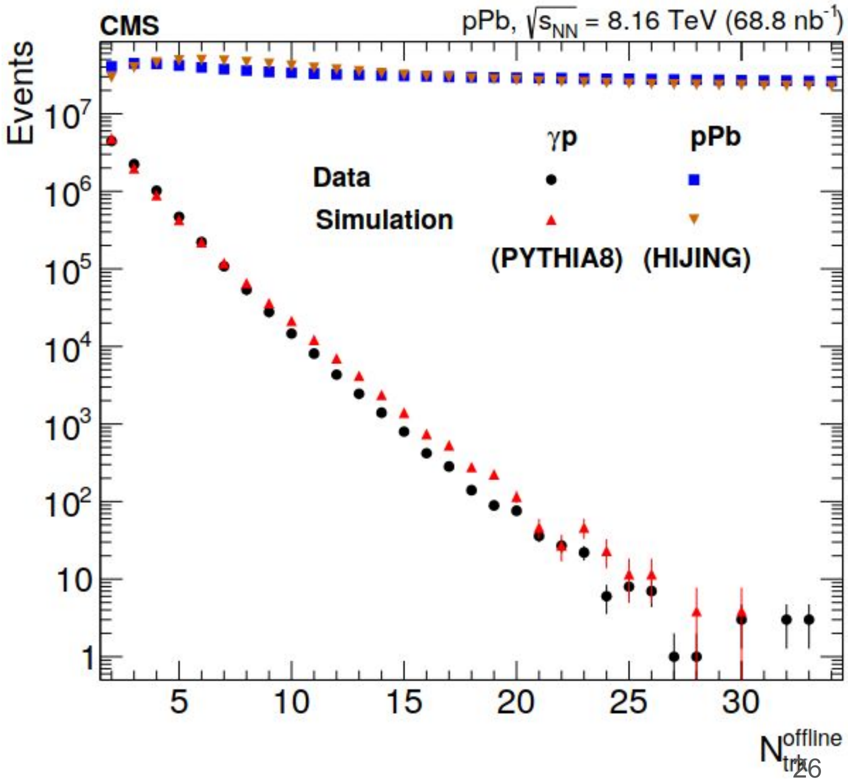




SOURCES: arXiv:2301.07630

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

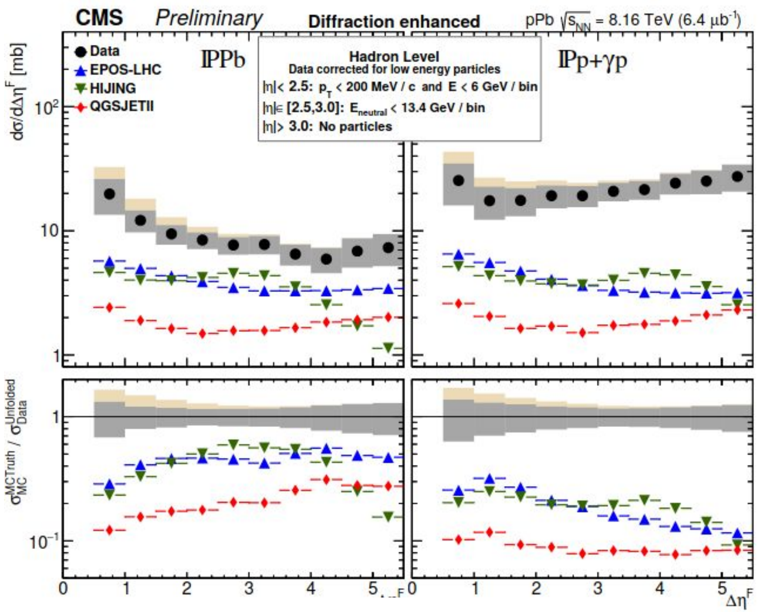
- Analysis done in N_{trk} and track p_T categories
  - For tracks $0.3 < p_T < 3.0$ GeV/c
    - $2 \leq N_{trk} < 5$
    - $5 \leq N_{trk} < 10$
    - $10 \leq N_{trk} < 35$
  - For tracks $1 < p_T < 3.0$ GeV/c
    - $2 \leq N_{trk} < 5$
    - $5 \leq N_{trk} < 35$

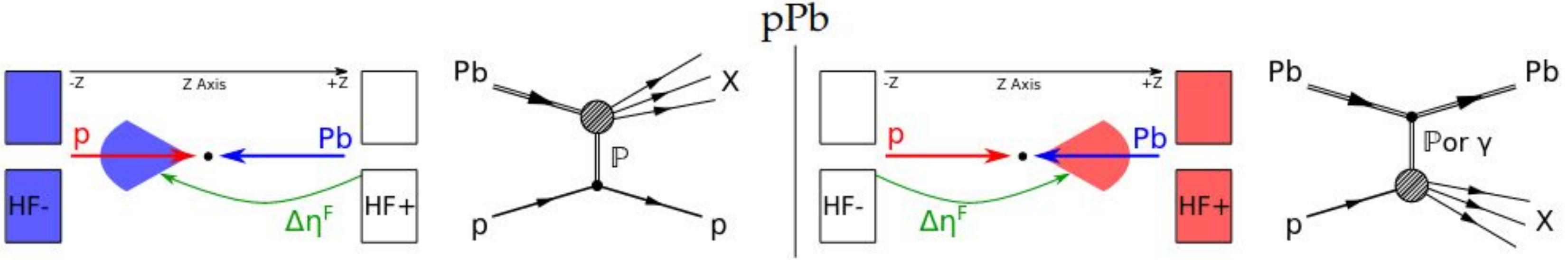


SOURCES: arXiv:2204.13486

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

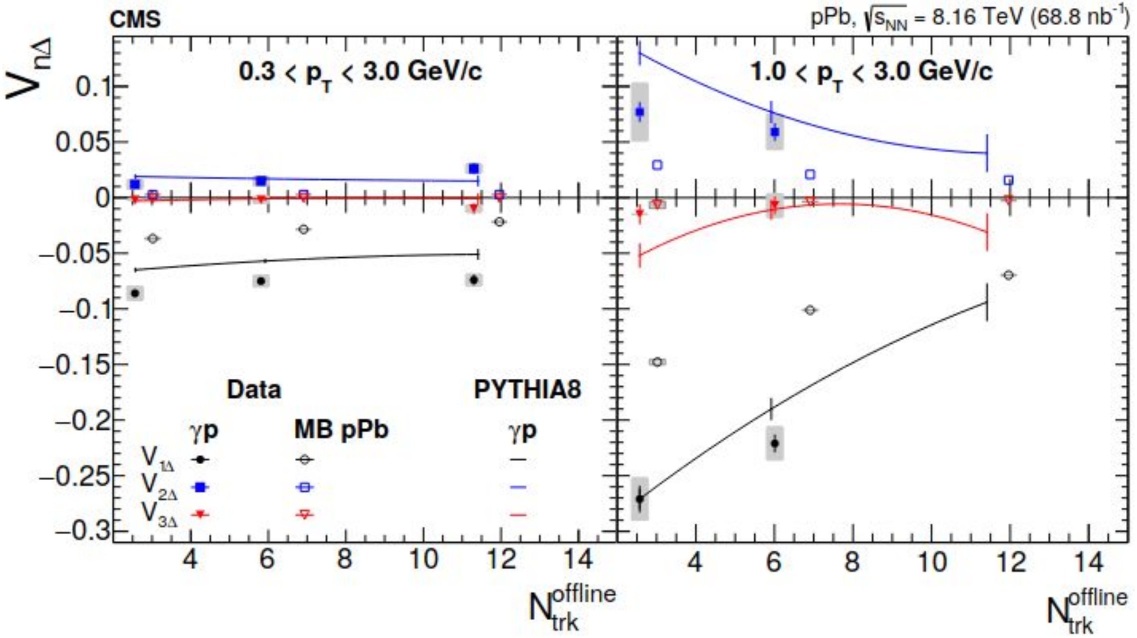




SOURCES: arXiv:2301.07630

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

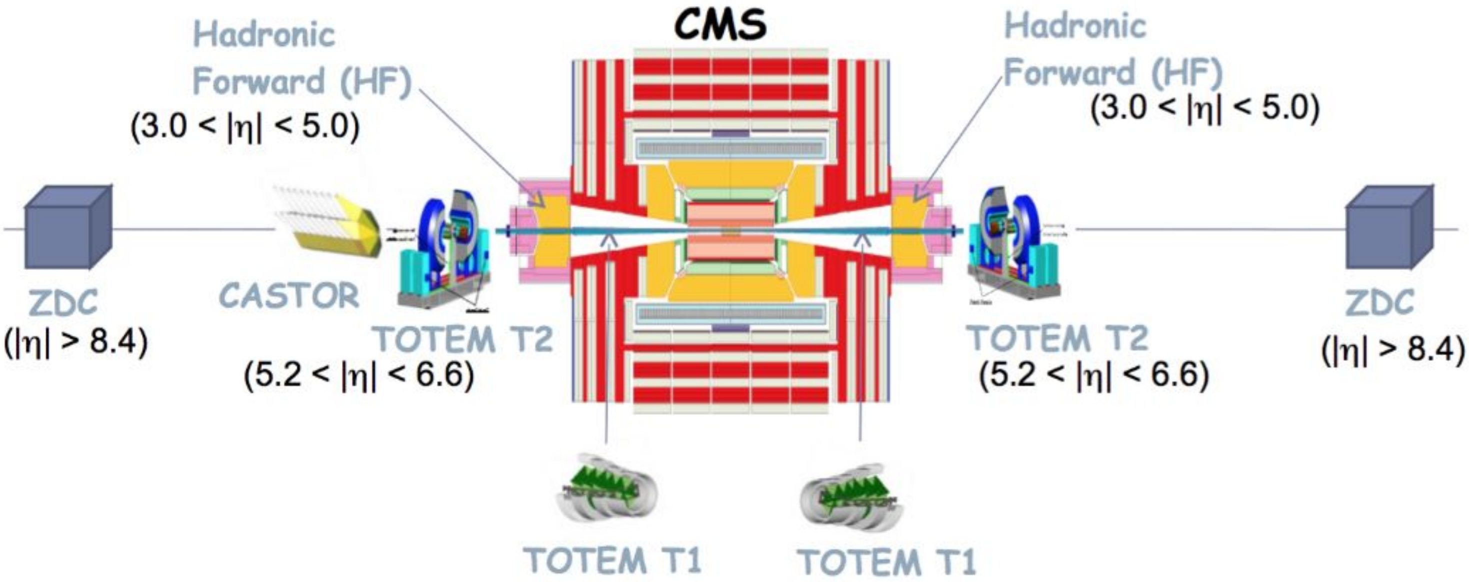
- Significant v_2 values observed
- $V_{3\Delta}$ values consistent with zero
- Consistency with non Flow model (Phythia 8)
- Different results than in pPb case



SOURCES: arXiv:2204.13486

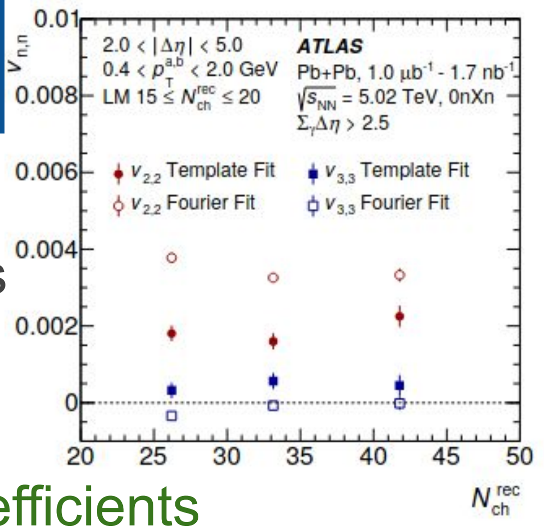
Zero Degree Calorimeter (ZDC) and Hadronic Forward Calorimeter (HF)

- 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

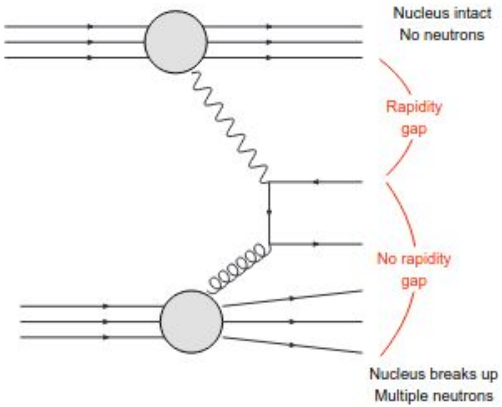


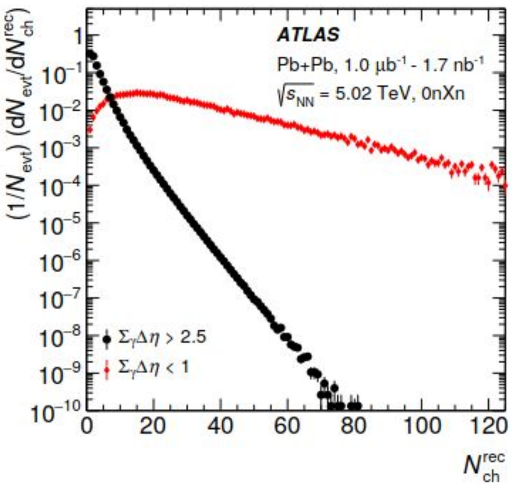
SOURCES: https://inspirehep.net/files/eccc173197ef02335f79bc831daf2fce

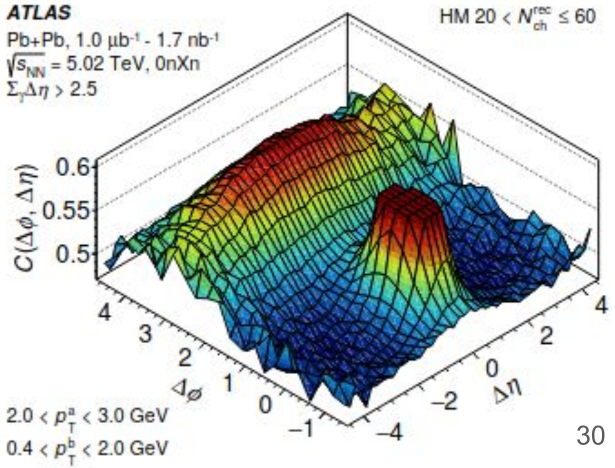
Recent probes on γ-Pb system



- 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



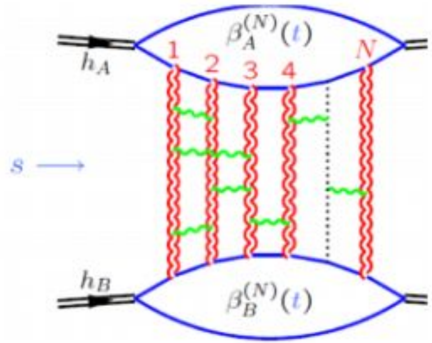


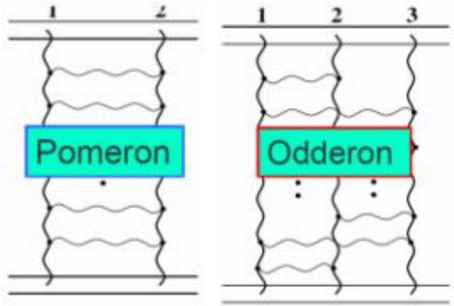


SOURCES: Phys. Rev. C 104, 014903 (2021)

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)

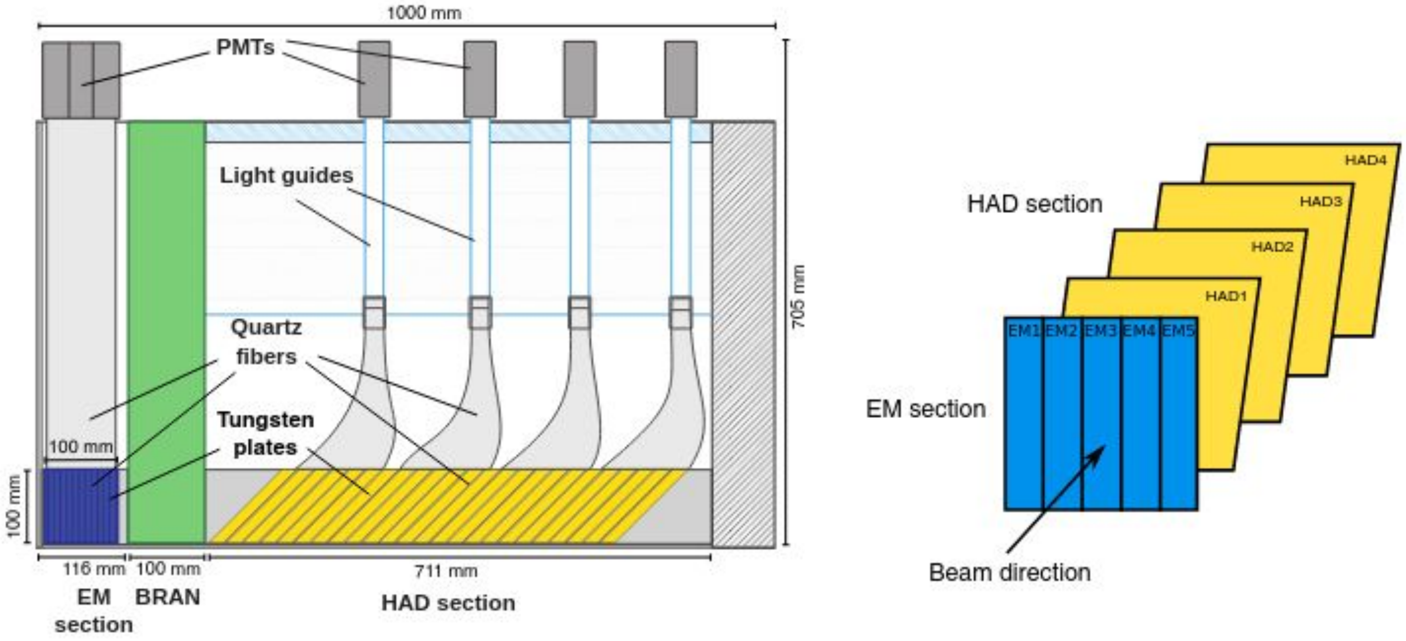
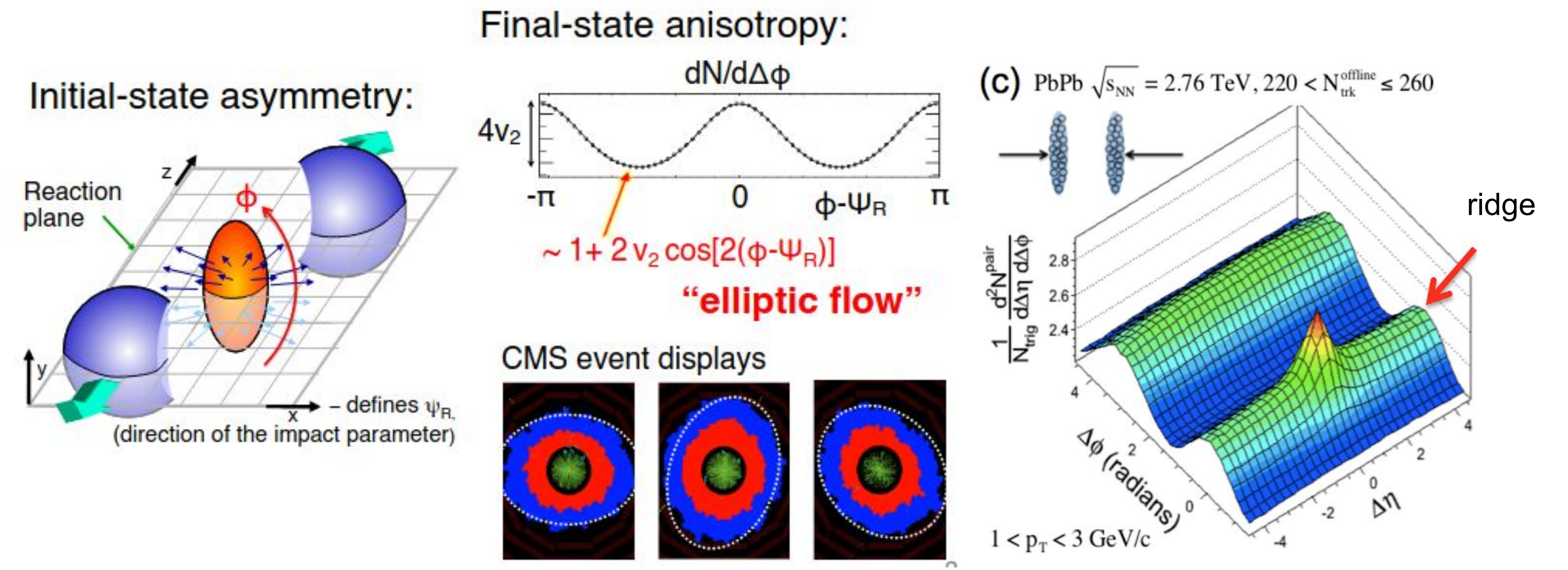


Figure 1: The schematic side-view (left) and segmentation (right) of the CMS ZDC.

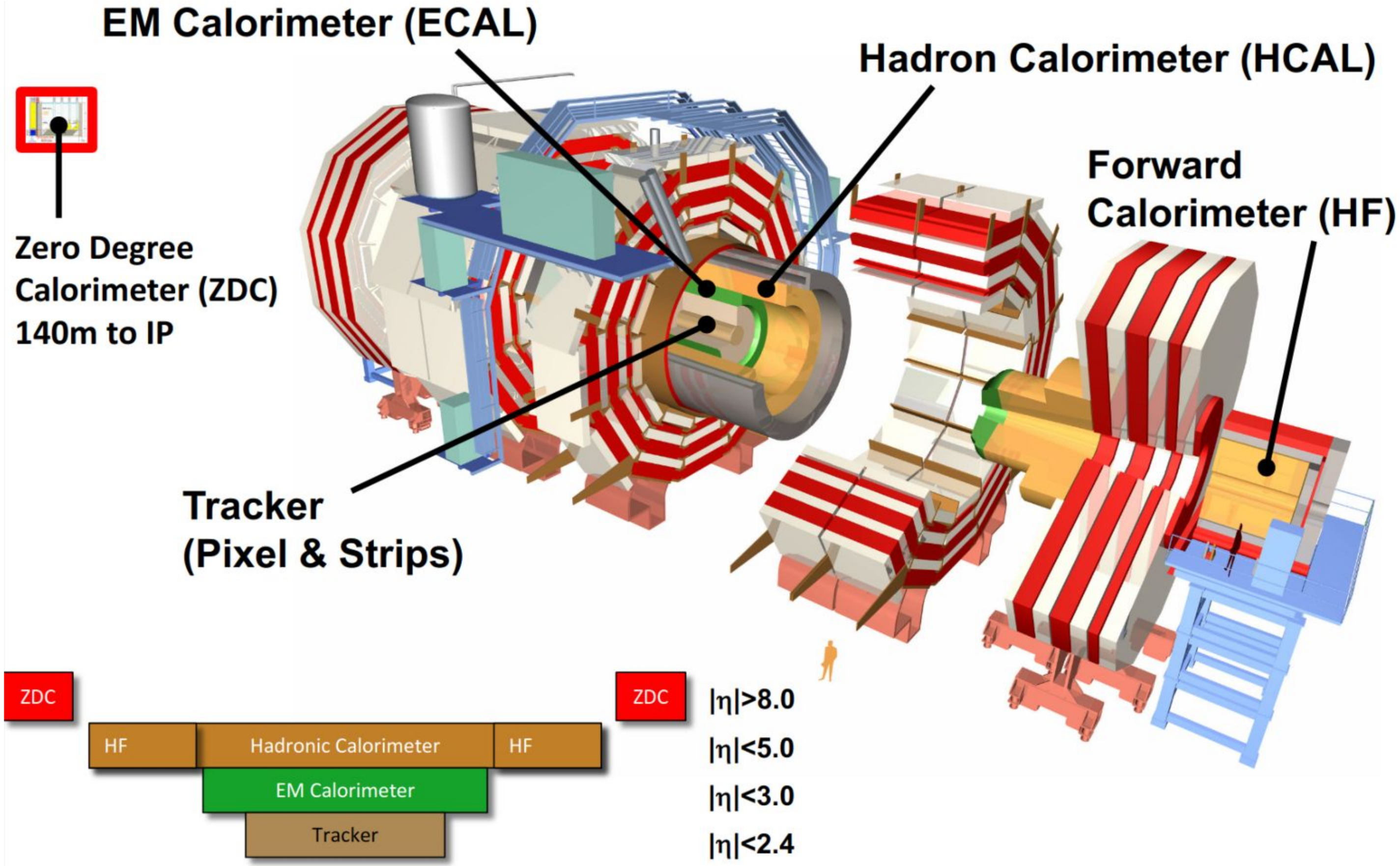
SOURCES: JINST 16 P05008 (2021)

Hydrodynamic behavior in correlation distributions



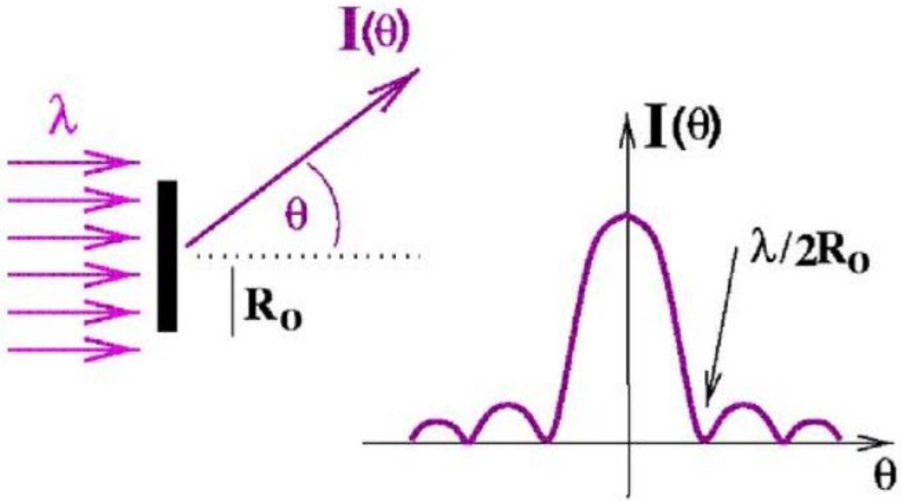
SOURCES: Collectivity in small systems, Wei Li. XIIth Quark Confinement and the Hadron Spectrum conference

CMS

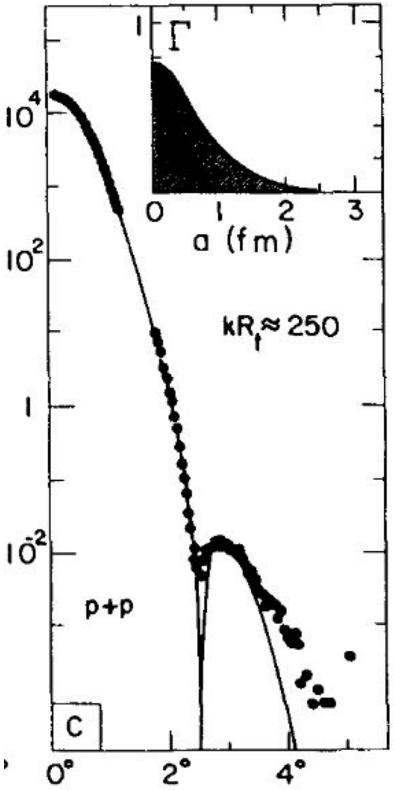


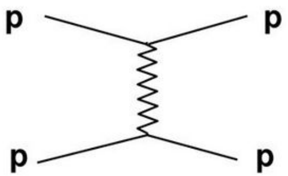
EM Calorimeter (ECAL)
Hadron Calorimeter (HCAL)
Forward Calorimeter (HF)
Zero Degree Calorimeter (ZDC) 140m to IP
Tracker (Pixel & Strips)
ZDC
ZDC
HF
Hadronic Calorimeter
HF
EM Calorimeter
Tracker
|η|>8.0
|η|<5.0
|η|<3.0
|η|<2.4

Diffractive collisions



Light diffraction in an obstacle





HEP interactions

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

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 $|\eta|<3$ of 0.5 units width. Empty bins:
  - In $|\eta|<2.5$ (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 $2.5<|\eta|<3$ if the energy of all hadronic PF candidates is <13.14GeV
- **The gap $\Delta\eta_F$ (FRG) is the number of empty bins from $\eta=3$ to the upper limit of the first non-empty bin**