Particle correlations in small systems

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Saturation and Diffraction at the LHC and the EIC

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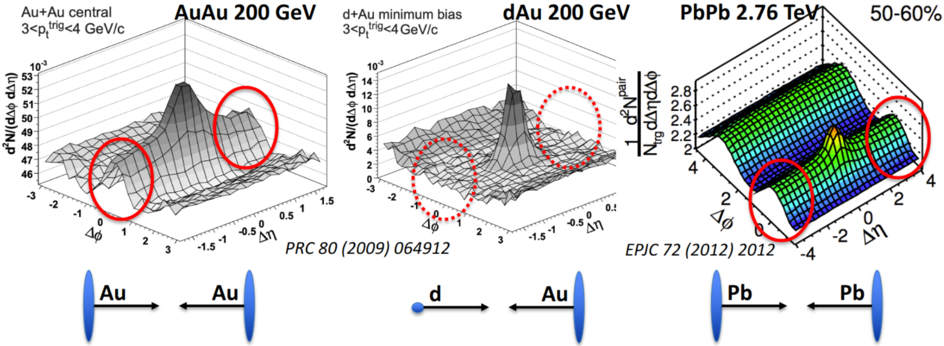
Overview

Long-range, near-side ridge structure

- Emerges in the two-particle correlation functions
  - High energy nuclear collisions
  - Observed in large collision systems (AA)
  - Absent in MB small collision systems (dAu)
- Evidence of collectivity and one of the features of QGP



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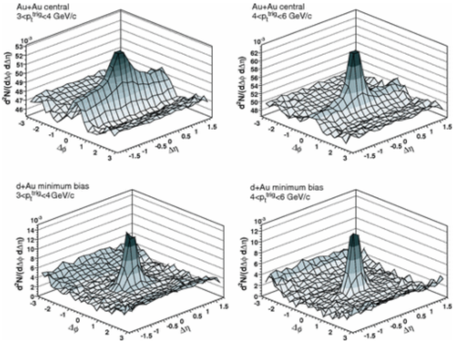
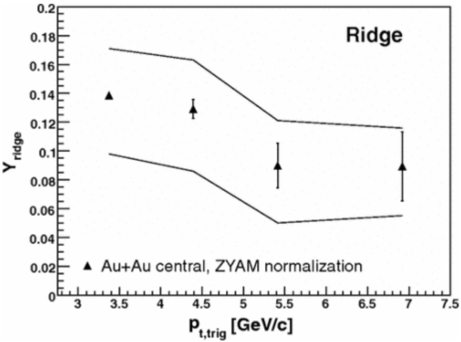
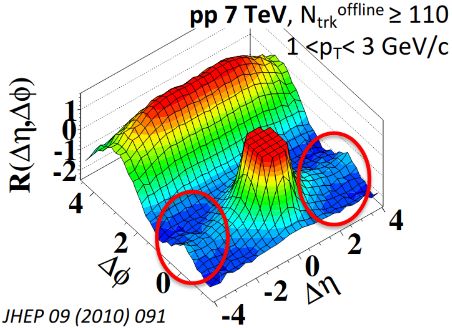


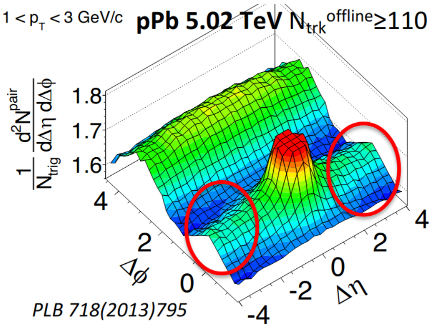


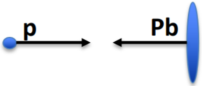
PRC 80 (2009) 064912

Discovery; strong collectivity found in small systems

- Ridge: near-side long-range 2-particle correlations
  - Observed also in small collision systems (pp, pPb) with high event multiplicity
  - Predicted by Color Glass Condesate (CGC) effective models



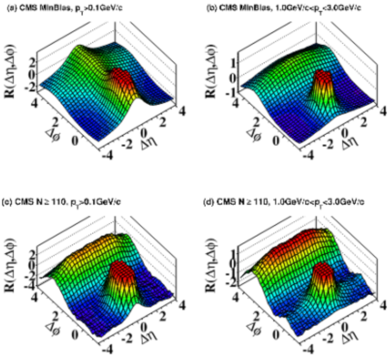


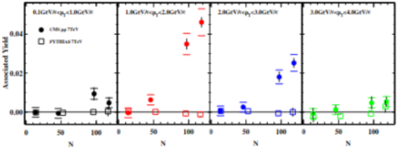


DOI: 10.1016/j.physletb.2011.01.024

Discovery; strong collectivity found in small systems

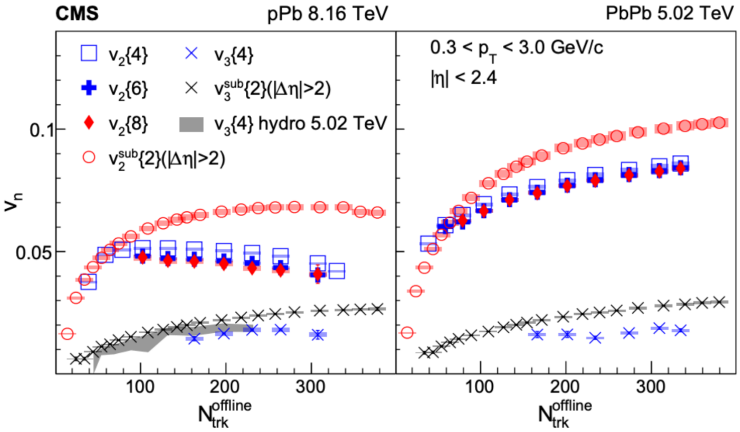
- Ridge: only seen in intermediate p_T categories





Small vs large collision systems

- Origin of the ridge in small systems?
  - Natural question is whether such signatures persist in even smaller collision systems
  - Final state effect?, Pure fluctuations? CGC?

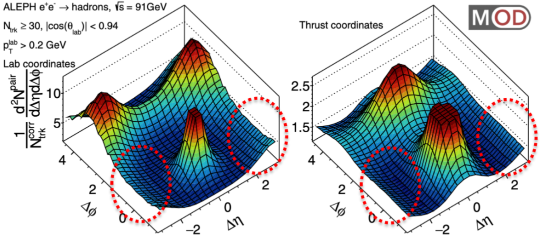


PRC 101 (2020) 014912

Recent explorations with small systems

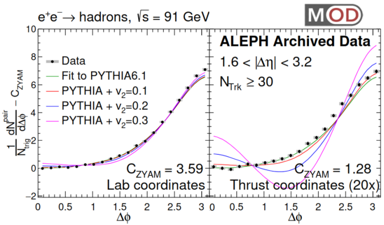
First measurement with e^+e^- system at $\sqrt{s} = 91$ GeV

- **ALEPH e^+e^-**
  - Sharp near-side peaks arise from jet-like (non-flow) correlations
  - No significant long-range correlations; better consistency with Pythia and Sherpa than Herwig
  - Confidence limits on associated yield as a function of N_{trk} have been set



PRL 123 (2019) 212002

N_{trk} range	Fraction of data (%)	$\langle N_{trk} \rangle$	$\langle N_{trk}^{corr} \rangle$
[5, 10)	3.1	8.2	8.9
[10, 20)	59.2	15.2	15.8
[20, 30)	34.6	23.1	23.4
[30, ∞)	3.1	32.4	32.6
[35, ∞)	0.5	36.9	37.2



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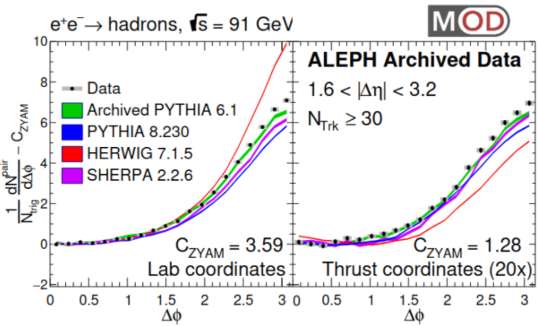
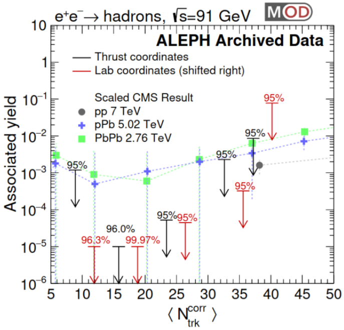
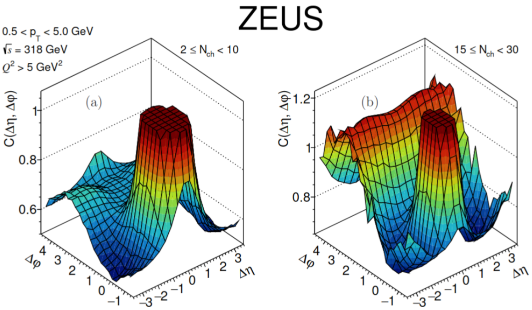
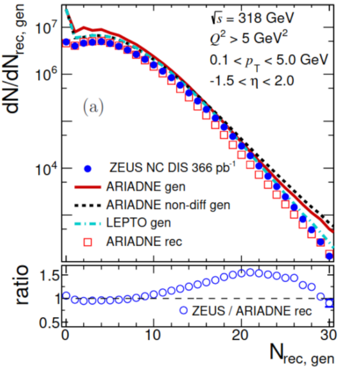




Deep inelastic ep scattering with ZEUS at HERA ($\sqrt{s} = 318$ GeV)

- Dominated by contributions from multijet production
  - $\langle N_{\rm trk} \rangle \approx 5$
  - No indication of same collective behaviour observed in high-multiplicity hadronic collisions





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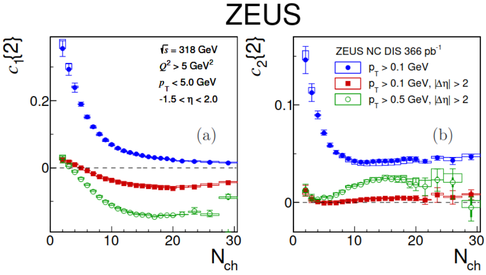

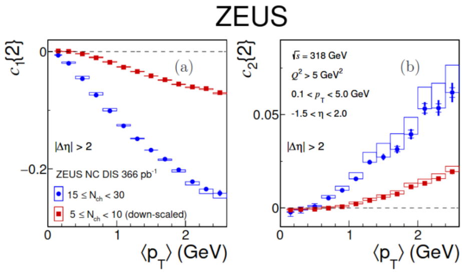

Deep inelastic ep scattering with H1 at HERA ($\sqrt{s} = 318$ GeV)

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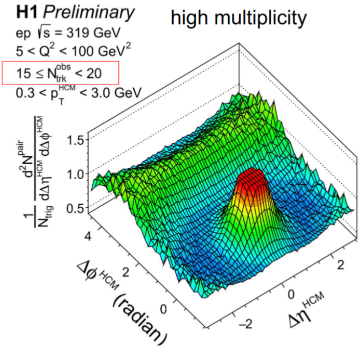
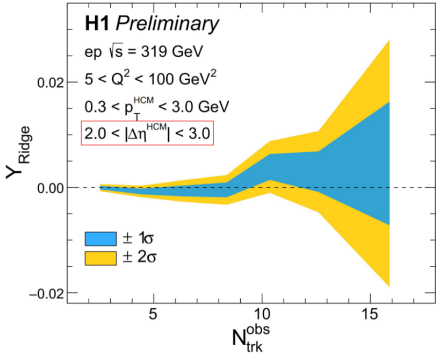
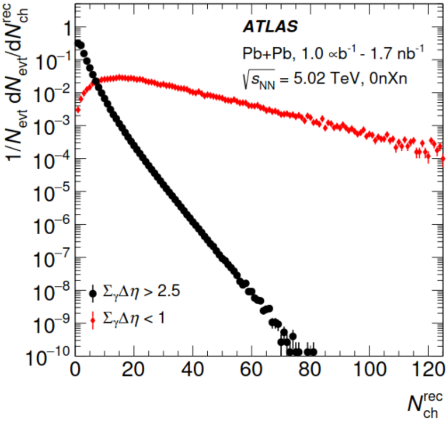
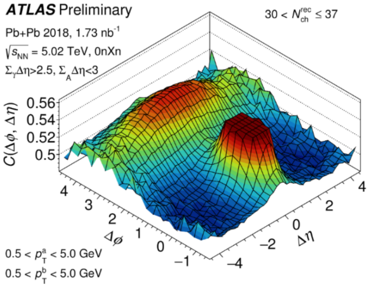




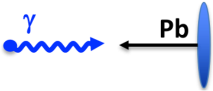
photonuclear ultraperipheral PbPb at 5.02 TeV with ATLAS

- Significant non-zero v_2
  - Substracting non-flow contribution using template fitting method





ATLAS-CONF-2019-022



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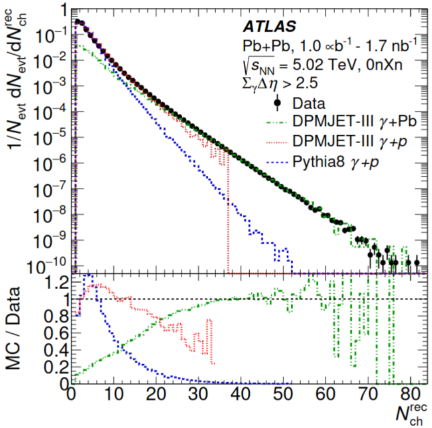
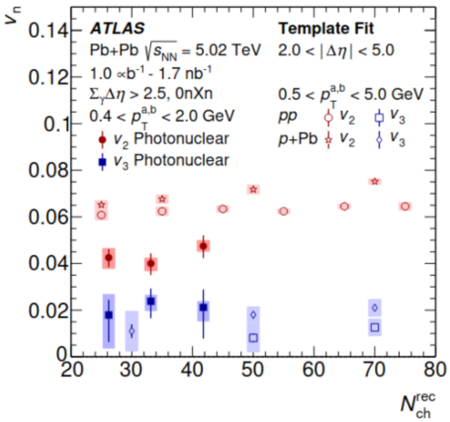
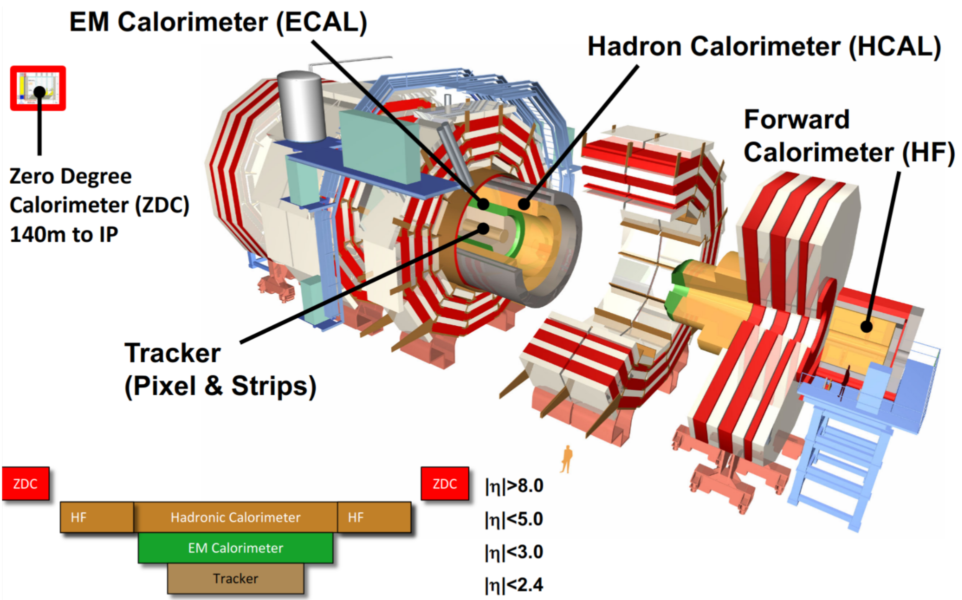




Crucial CMS detector subsystems



γp interactions within ultra-peripheral pPb collisions

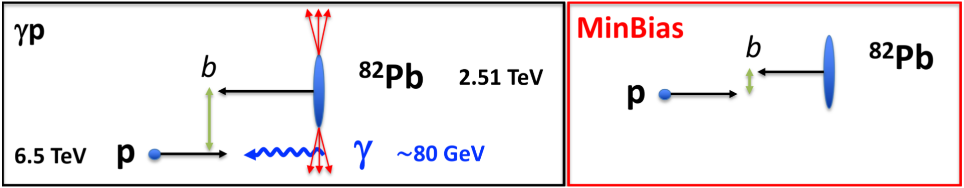
- CMS-PAS-HIN-18-008

  J. A. Murillo Quijada, Quan Wang, Michael Murray et al. "Search for elliptic azimuthal anisotropies in γp interactions within ultra-peripheral pPb collisions at $\sqrt{s_{\rm NN}} = 8.16$ TeV"

  - Being submitted to Physics Letters B (PLB)

- γ-proton interactions (b>$R_{\rm Pb}$)

  - Minimum-bias (b<$R_{\rm Pb}$))



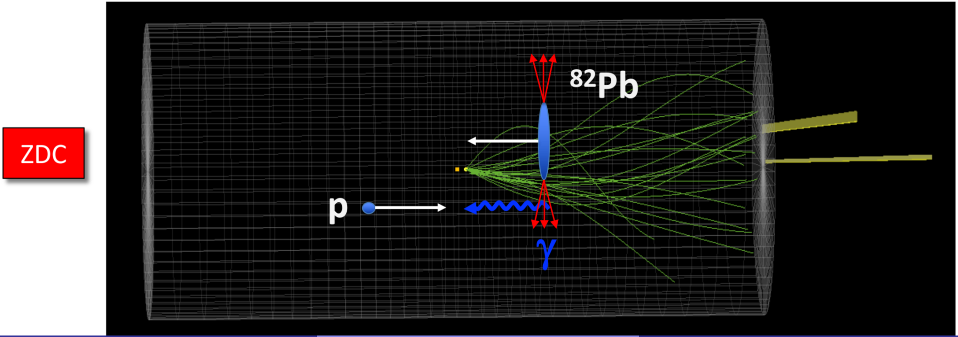
https://cds.cern.ch/record/2725477/

Selection requirements; 95% γp purity

- Pb-going side quiet;
  - $\rightarrow$ No neutrons detected by Zero Degree Calorimer (Pb nucleus is not broken)
  - $\rightarrow$ Rapidity Gap; No activity in Pb-going side using Particle Flow and tracks
- Activity in proton-going side; HF+ calorimeter with at least one tower with energy $>$ 10 GeV

Tracks satisfying following requirements:

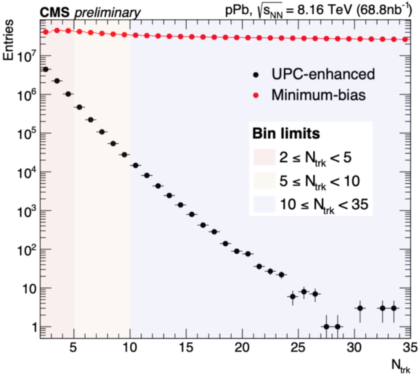
- Kinematic range: $\eta < 2.4$, $p_T > 0.4$ GeV
- Significance of z separation between track and best vertex: $d_z/\sigma(d_z) < 3.0$
- Impact parameter significance: $d_0/\sigma(d_0) < 3.0$, Momentum uncertainty: $\sigma(p_T)/p_T < 0.1$



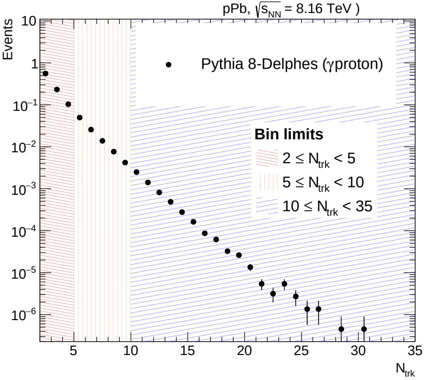
Available MC for signal γ-proton in pPb

- Recent addition to Pythia8 simulation: Standard Equivalent Photon Approximation (EPA) flux model with low-virtuality γp in pPb collisions[1]
- Comparison with montecarlo is being added to final paper
  - It reproduces N_{trk} distribution with limit up to $\sim$ 35 as data sample

CMS Data



Pythia8 + detector fast simulation



[1] Ilkka Helenius, Christine O. Rasmussen, "Hard diffraction in photoproduction with Pythia 8", Eur.Phys.J.C 79 (2019)

Signal pair distribution:

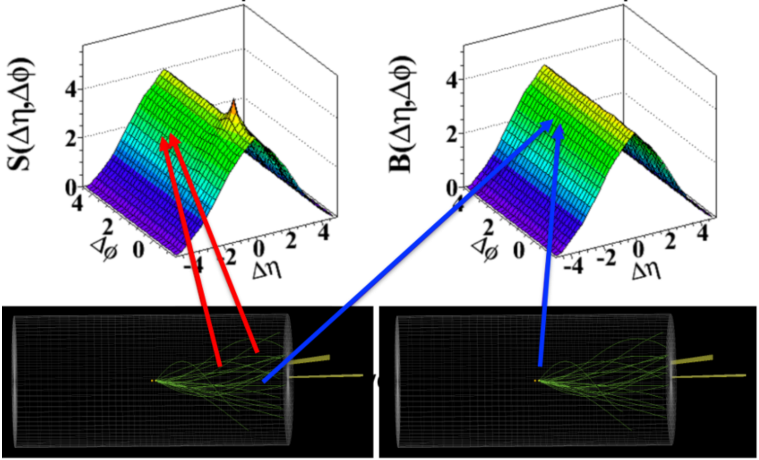
$$S(\Delta\eta,\Delta\varphi) = \frac{1}{N_{trig}} \frac{d^2N^{same}}{d\Delta\eta d\Delta\varphi}$$

Background pair distribution:

$$B(\Delta\eta,\Delta\varphi) = \frac{1}{N_{trig}} \frac{d^2N^{mix}}{d\Delta\eta d\Delta\varphi}$$

same event pairs

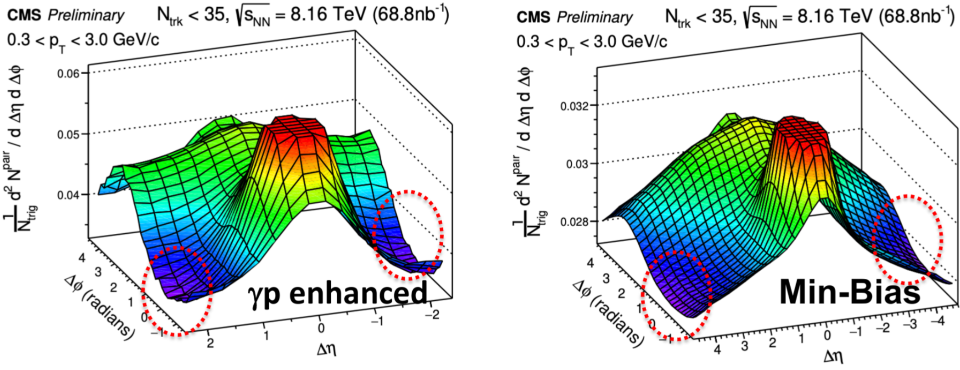
mixed event pairs



2D ratio distribution

- 2D correlations for γp enhanced and Minimum-bias
  - N_{trk} limited up to $\sim$35 for γp $\rightarrow$ divided in different bins for two p_{T} categories
  - No evidence of ridge-like correlations

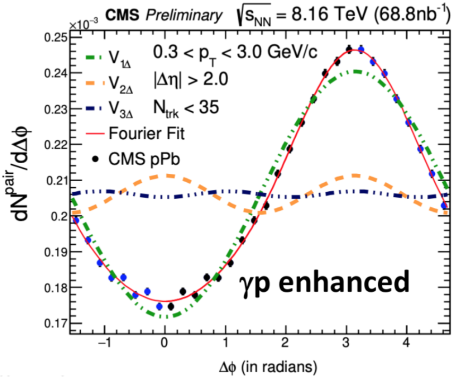
$$\frac{1}{N_{trig}}\frac{d^2N^{pair}}{d\Delta\eta d\Delta\phi} = B(0,0)\frac{S(\Delta\eta,\Delta\phi)}{B(\Delta\eta,\Delta\phi)}$$

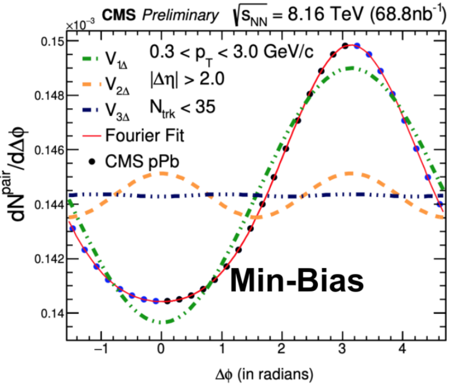


1D Long-range projection

- Azimuthal distributions for $|\Delta\eta| > 2.0$
- $V_n\Delta$ Fourier coefficients obtained from the decomposition fit:

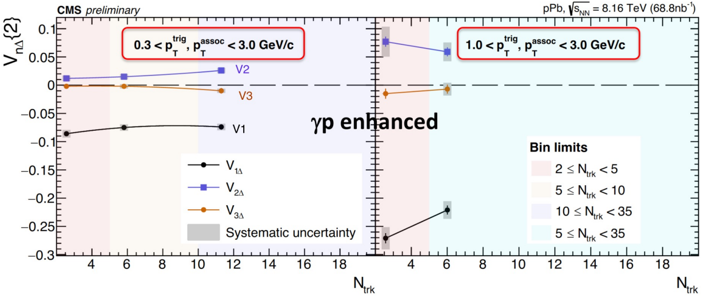
$$\frac{1}{N_{\mathrm{trig}}}\frac{dN^{\mathrm{pair}}}{d\Delta\phi} = \frac{N_{assoc}}{2\pi}[1 + \sum_n 2V_{n\Delta}cos(n\Delta\phi)]; \qquad n = 1, 2, 3$$



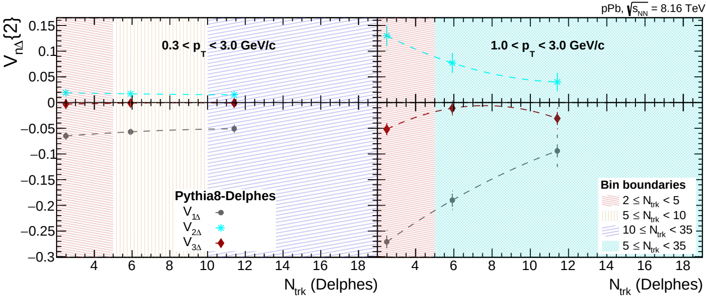


- Results on two-particle Fourier coefficient; $V_{n\Delta}$
  - $V_{1\Delta}$ negative, $V_{2\Delta}$ positive and $V_{3\Delta}$ consistent with zero

- Measurements with γp-enhanced dataset



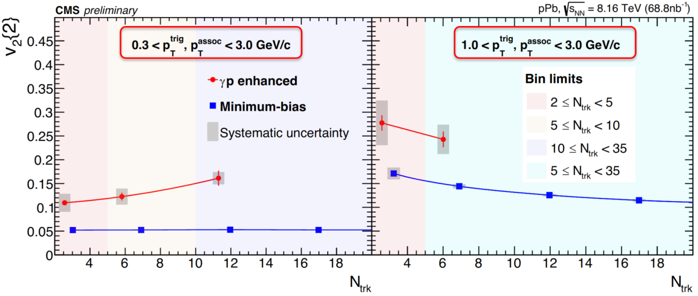
- Predictions from Pythia8 + Delphes fast simulation



- Single-particle v_2 coefficient, $v_2 = \sqrt{V_{n\Delta}}$; consistent with non-flow effects

- Measurements with γp-enhanced dataset

  Comparison with simulation and Minimum-bias to appear in final paper



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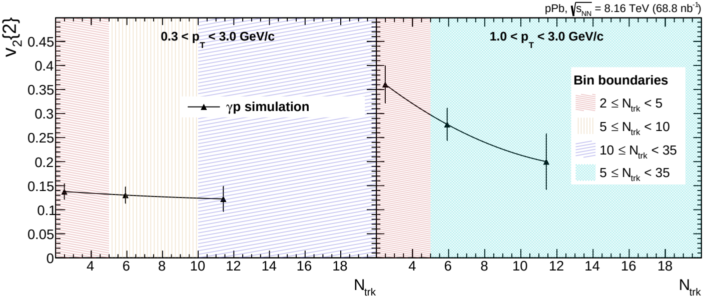
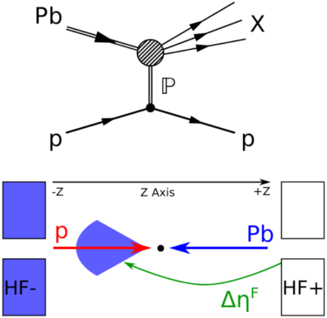
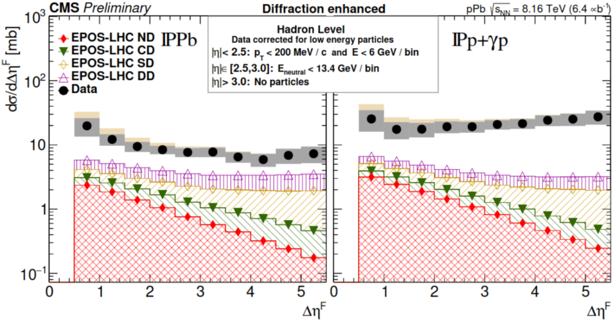


Other systems

Pomeron-Pb system within pPb 8.16 TeV collisions

- **Large rapidity gaps**
  - Generator predictions: Non (ND), Central (CD), Single (SD) and Double Diffractive (DD)

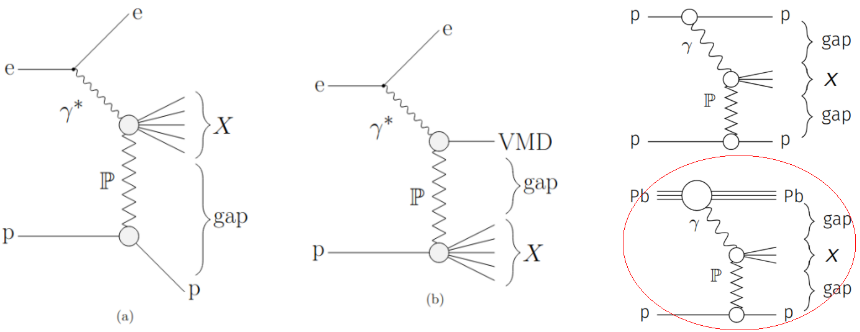




CMS-PAS-HIN-18-019

Pomeron-photon system within pPb 8.16 TeV collisions

- Hard diffraction with photons
  - Large rapidity gaps



[1] Ilkka Helenius, Christine O. Rasmussen, "Hard diffraction in photoproduction with Pythia 8", Eur.Phys.J.C 79 (2019) 5, 413

Summary

- Study of two-particle correlations ($V_{1\Delta}$, $V_{2\Delta}$,$V_{3\Delta}$) and azimuthal anisotropies (v_2) in small systems has been expanded to e^+e^-, ep, γ-proton

  - Limited N_{trk} range; confirmed by signal Monte Carlo
  - $V_{1\Delta}$ negative, $V_{2\Delta}$ positive and $V_{3\Delta}$ consistent with zero
  - No evidence of ridge-like correlations observed

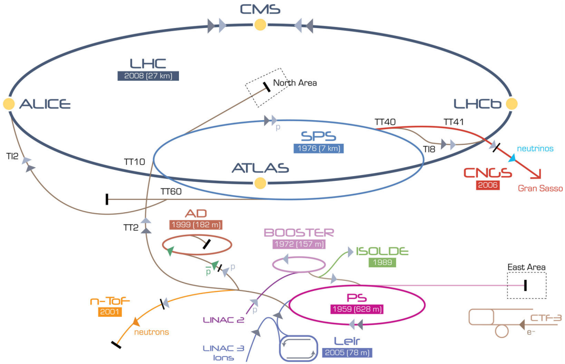
- More systems such as pomeron-Lead or Pomeron-photon can be studied

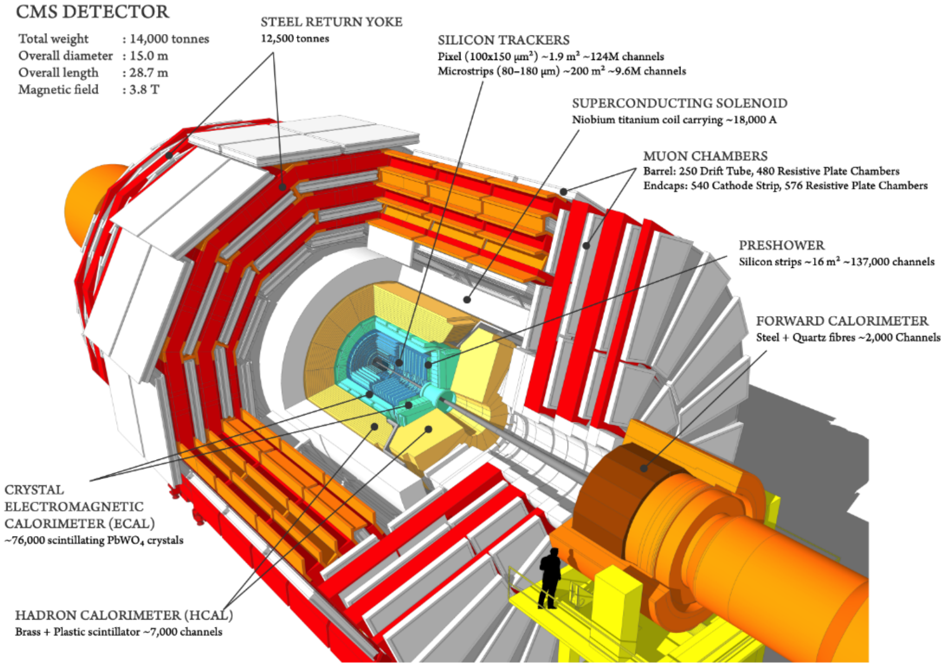
- Results providing insights to the origin of ridge-like structures

Backup

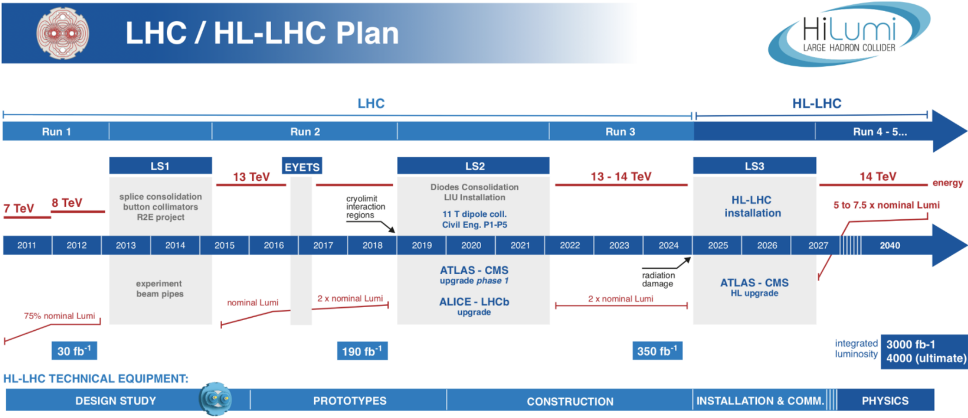
Acceleration complex at CERN

- The LHC extends to both sides of the border between France and Switzerland
- Proton bunches are produced, split and accelerated sequentially through different accelerators before injection into the LHC
- Done with Run 2 at 13 TeV (2015-2018) → several analyses ongoing
- Preparation for Run 3 (2021 to 2023/24) and HL-LHC
(at least 160 fb^{-1} for ATLAS and CMS at $\sqrt{s}$ = 13-14 TeV)




CMS DETECTOR
Total weight : 14,000 tonnes
Overall diameter : 15.0 m
Overall length : 28.7 m
Magnetic field : 3.8 T
STEEL RETURN YOKE
12,500 tonnes
SILICON TRACKERS
Pixel (100x150 μm²) ~1.9 m² ~124M channels
Microstrips (80–180 μm) ~200 m² ~9.6M channels
SUPERCONDUCTING SOLENOID
Niobium titanium coil carrying ~18,000 A
MUON CHAMBERS
Barrel: 250 Drift Tube, 480 Resistive Plate Chambers
Endcaps: 540 Cathode Strip, 576 Resistive Plate Chambers
PRESHOWER
Silicon strips ~16 m² ~137,000 channels
FORWARD CALORIMETER
Steel + Quartz fibres ~2,000 Channels
CRYSTAL ELECTROMAGNETIC CALORIMETER (ECAL)
~76,000 scintillating PbWO₄ crystals
HADRON CALORIMETER (HCAL)
Brass + Plastic scintillator ~7,000 channels

LHC / HL-LHC Plan with extended LS2



Hydrodynamic flow in A-A collisions

- Azimuthal anisotropy Fourier coefficients v_n well understood in A-A collisions in the context of hydrodynamical model
  - Mass ordering dependence at low p_T
  - Quark content grouping at high p_T