Measurements of collectivity in the forward region at LHCb

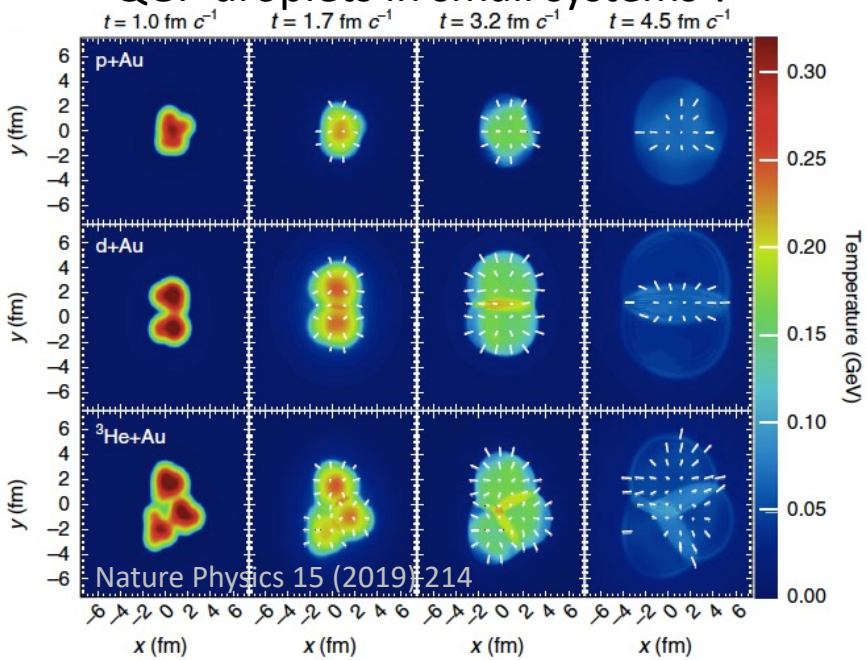
Cheuk-Ping Wong [cpwong@gmail.com]
on behalf of the LHCb collaboration

04-07-2022

LA-UR-22-23105

Particle Flow in Asymmetric Collisions

QGP droplets in small systems ?



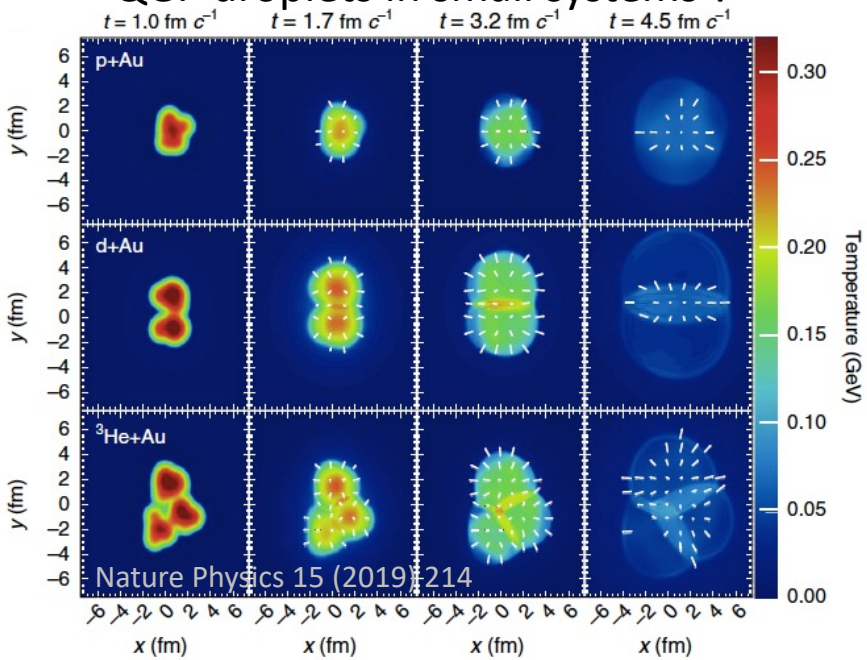
Nature Physics 15 (2019) 214

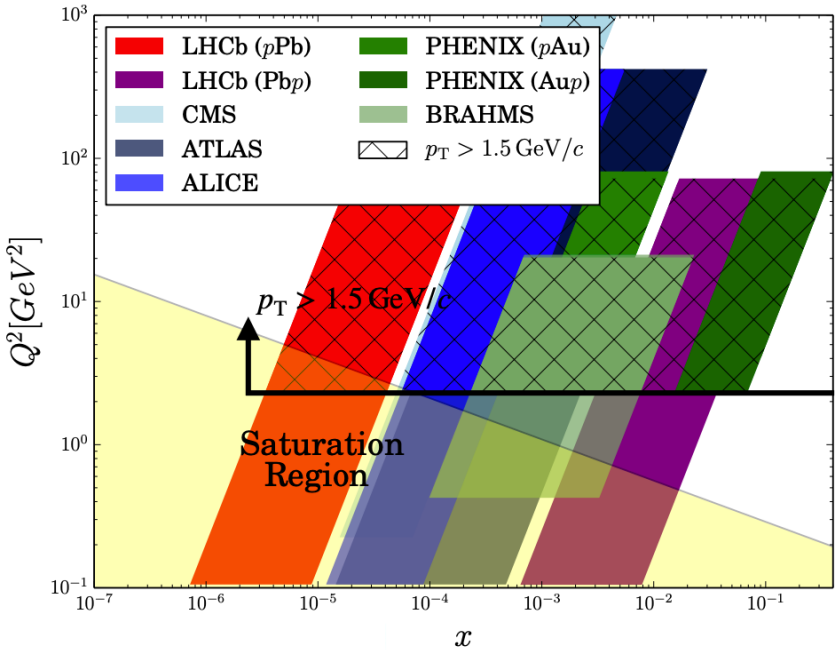
The highest particle densities and multiplicities reached in pPb at the LHC are of a similar size to those in peripheral AA collisions

→ looking for signatures which were so far mainly studied in AA collisions

Particle Flow in Asymmetric Collisions

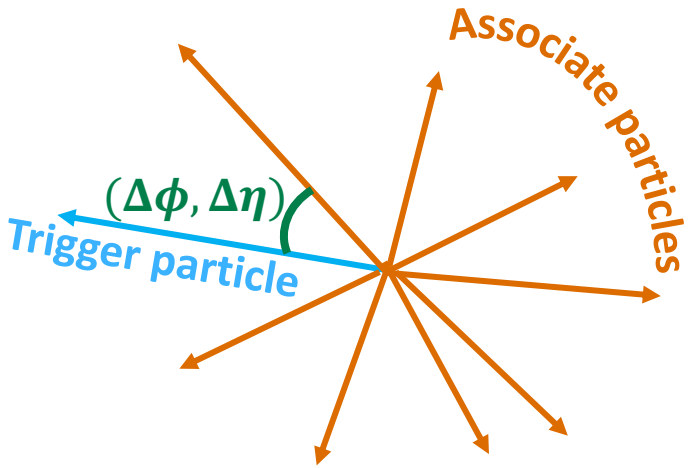
QGP droplets in small systems ?





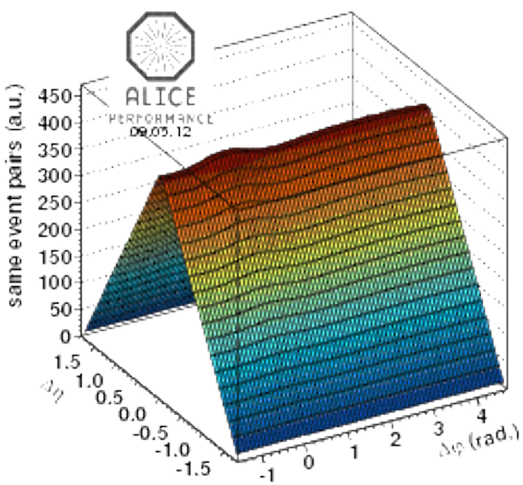
- LHCb can reach $x \approx 10^{-6}$ for pPb and $x \approx 10^{-2}$ for Pbp
- Forward region is sensitive to gluon saturation
  →Particle correlations induced by gluon saturation
  →Using **charged hadron correlations in pPb and Pbp at 5 TeV**

Charged Hadron Correlations



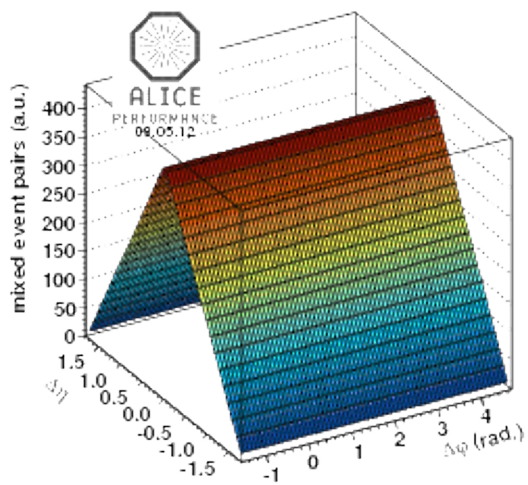
- Construct $(\Delta\phi, \Delta\eta)$ of charged hadron pair with the same p_T range in the same events
- Using mixed-event technique to correct for detector acceptance

Same events



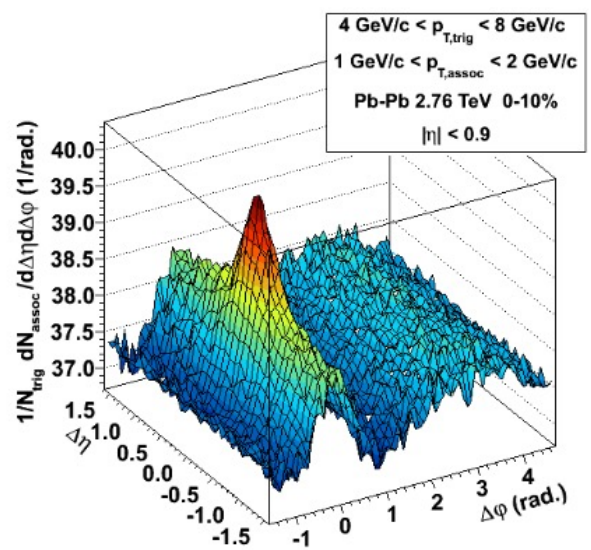
÷

Mixed events



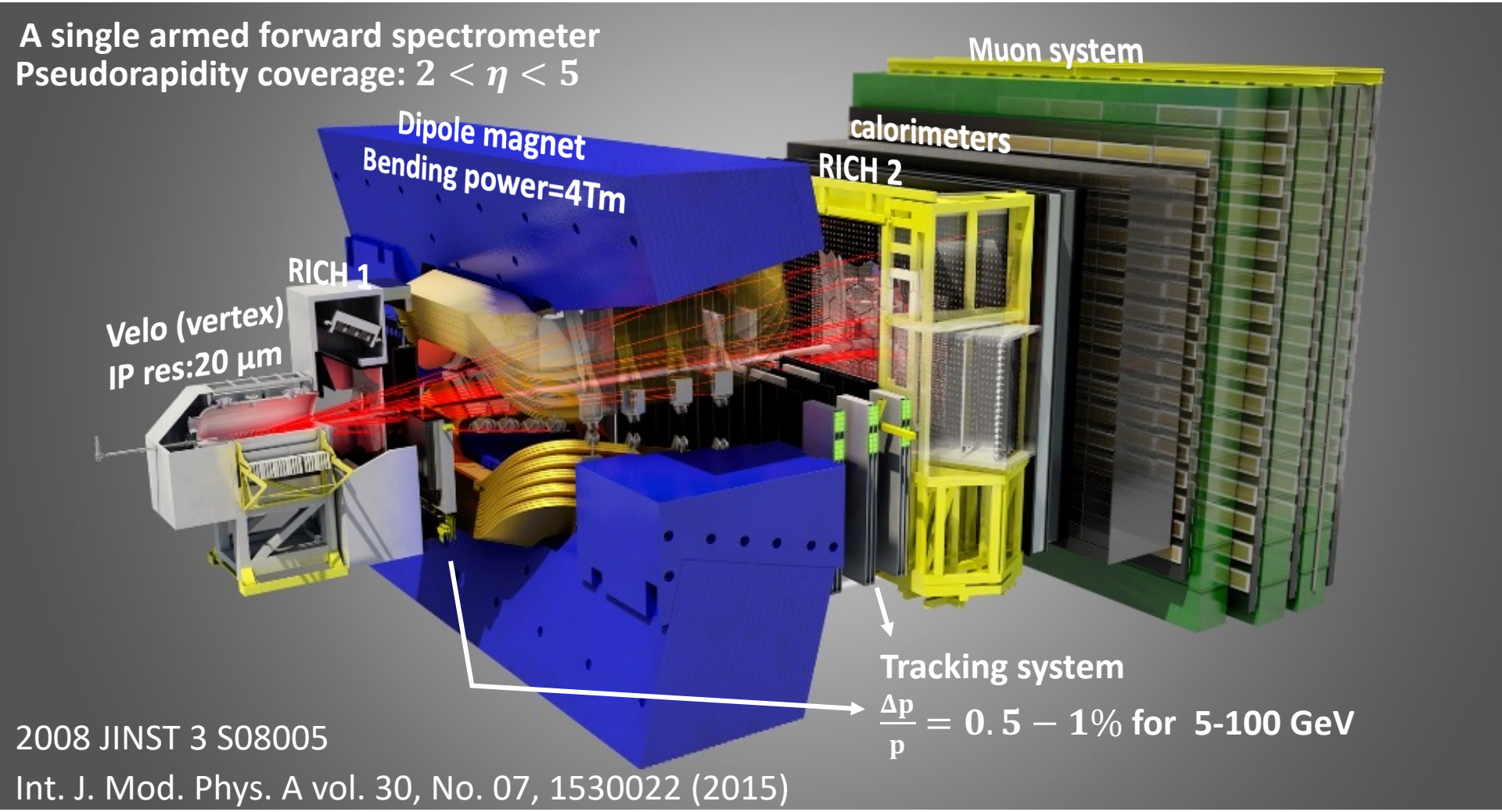
=

Correlation functions



Int. J. Mod. Phys. Conf. Ser. 29 (2014) 1460212

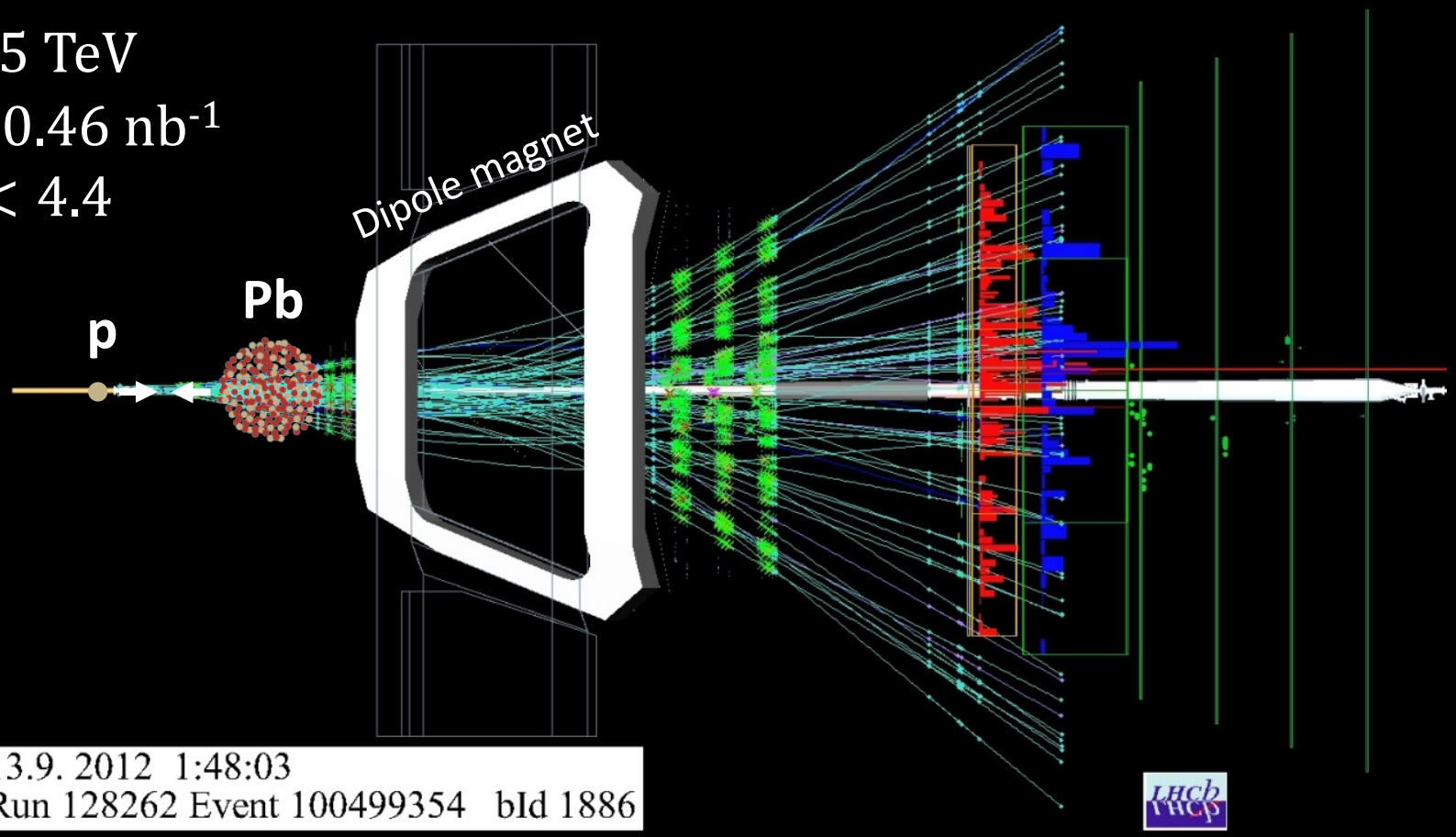
LHCb Detector



Beam Configurations

Event display of a pPb event

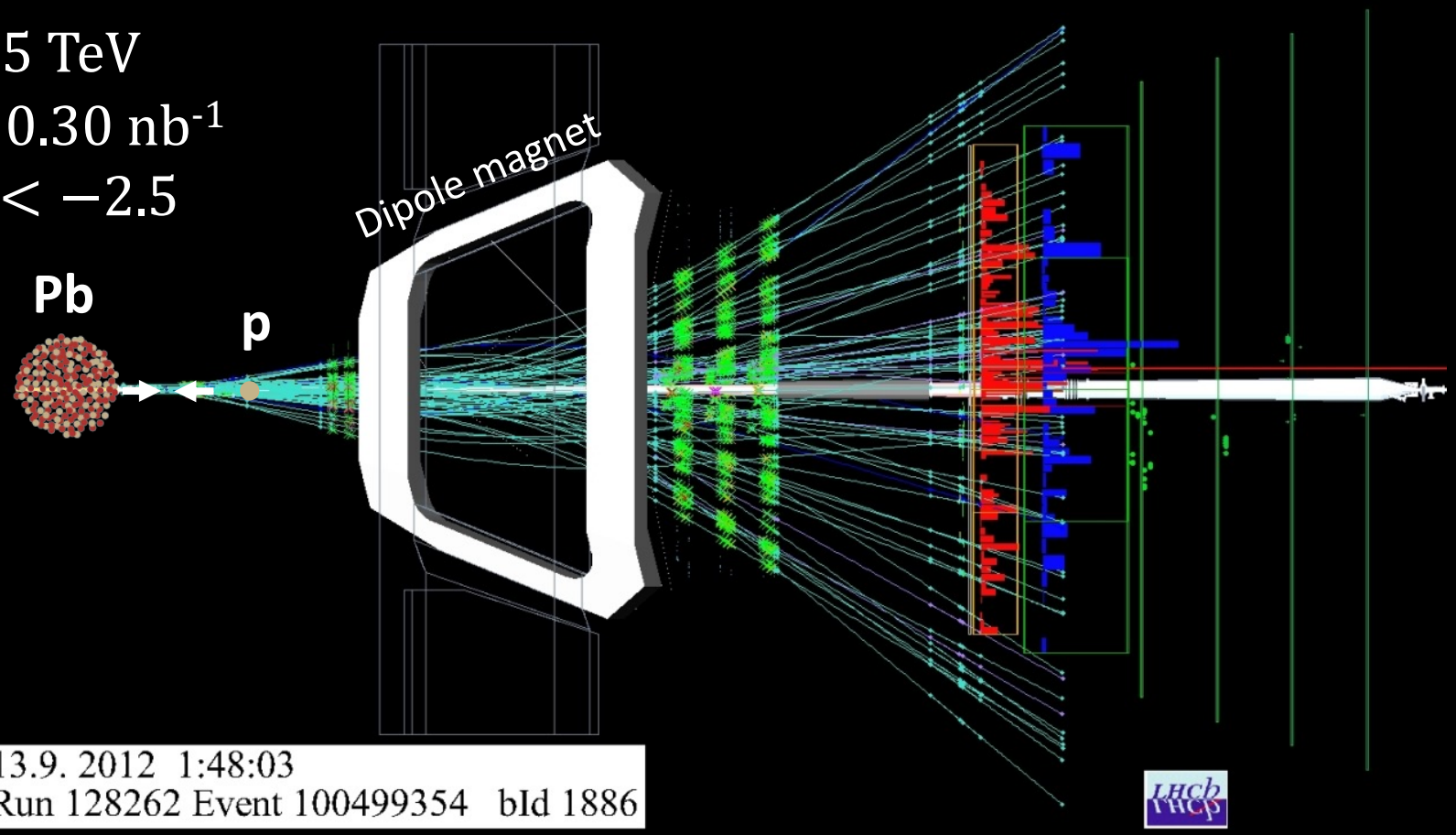
$\sqrt{s_{NN}} = 5$ TeV
$\int Ldt = 0.46$ nb^{-1}
$1.5 < y < 4.4$



Beam Configurations

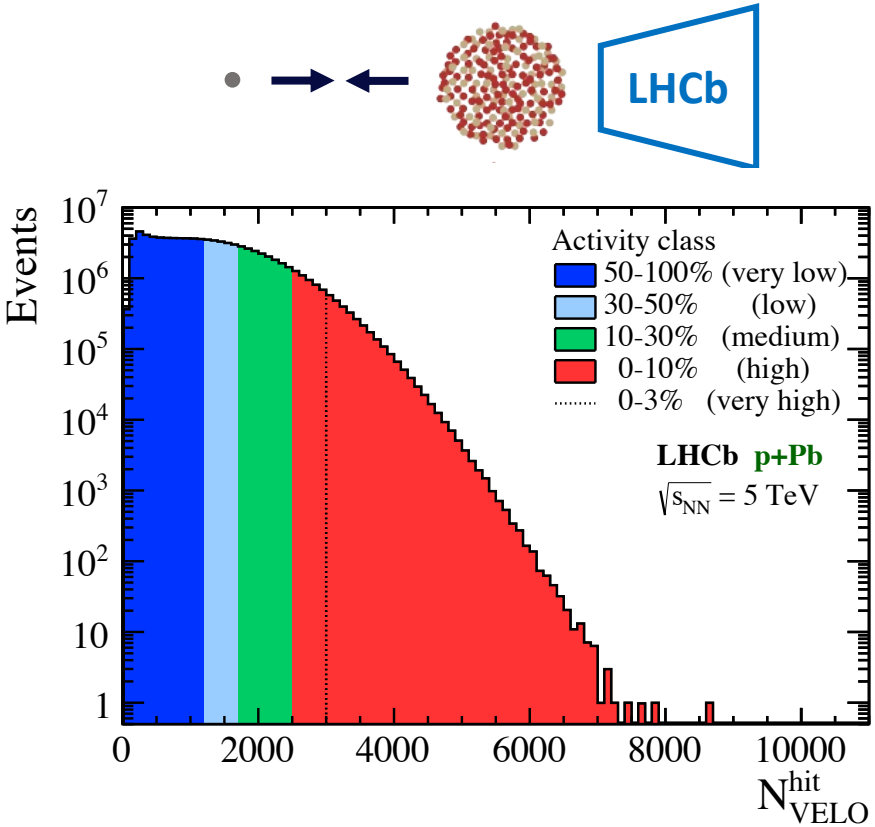
Event display of a pPb event

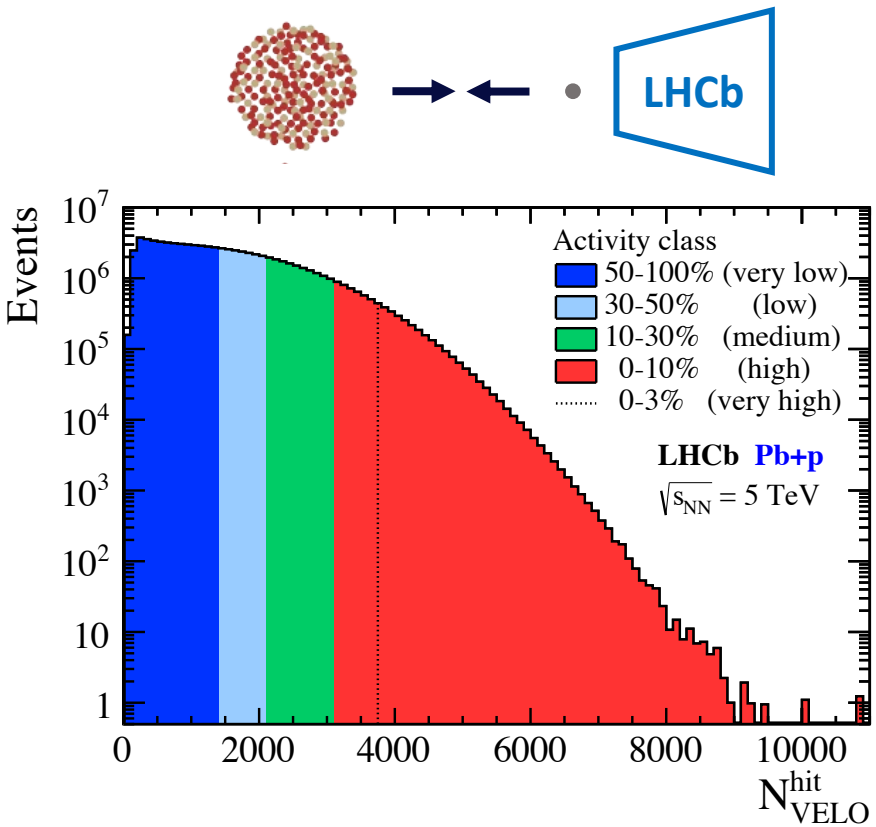
$\sqrt{s_{NN}} = 5$ TeV
$\int Ldt = 0.30$ nb^{-1}
$-5.4 < y < -2.5$



PLB 762 (2016) 473

Activity Class Determination

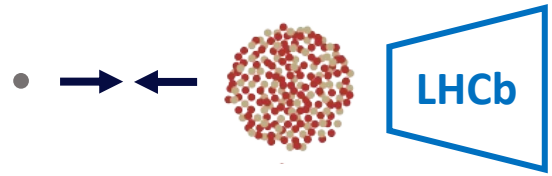


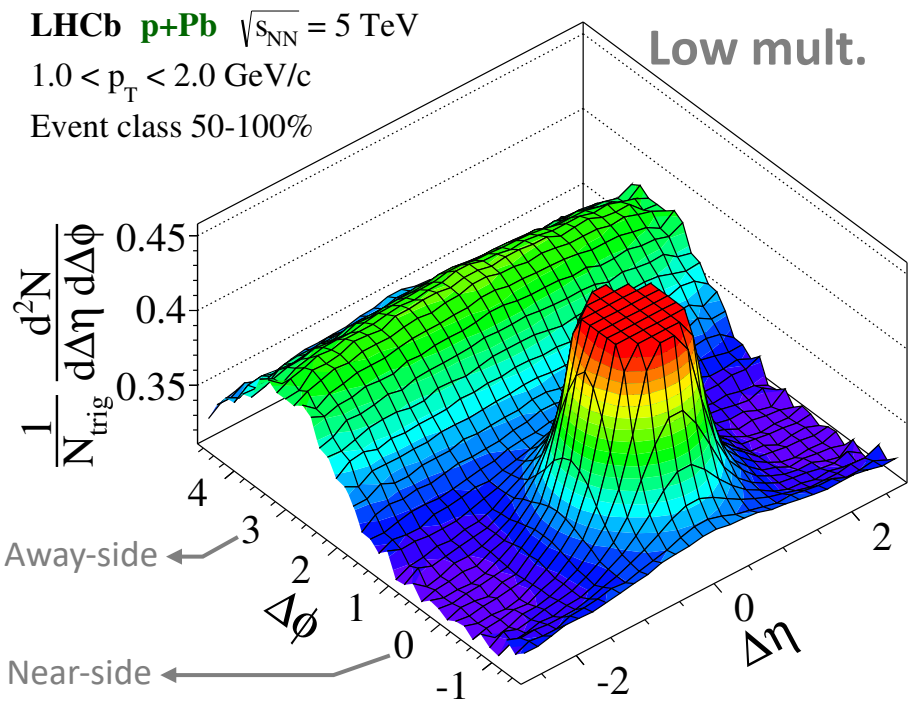


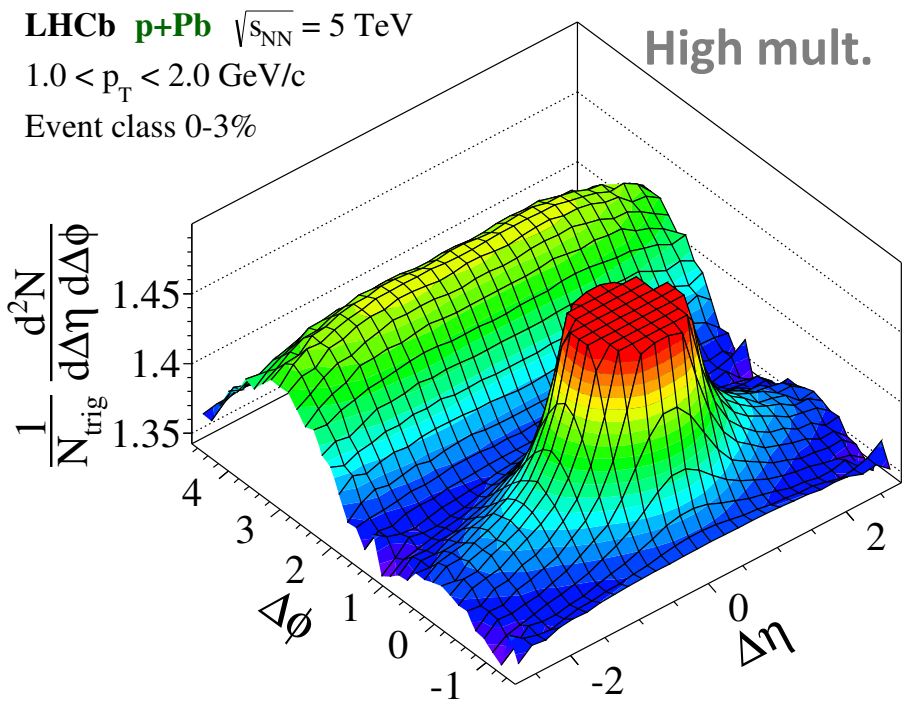
- Five activity classes determined using hit multiplicity in the Velo (vertex detector)
- Activity classes of Pbp have higher multiplicity than pPb

PLB 762 (2016) 473

Efficiency Corrected Two-Particle Correlations in p+Pb



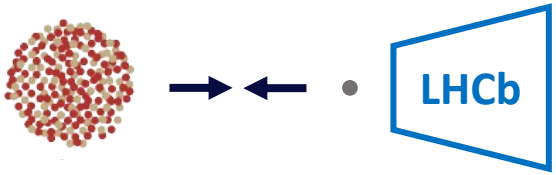


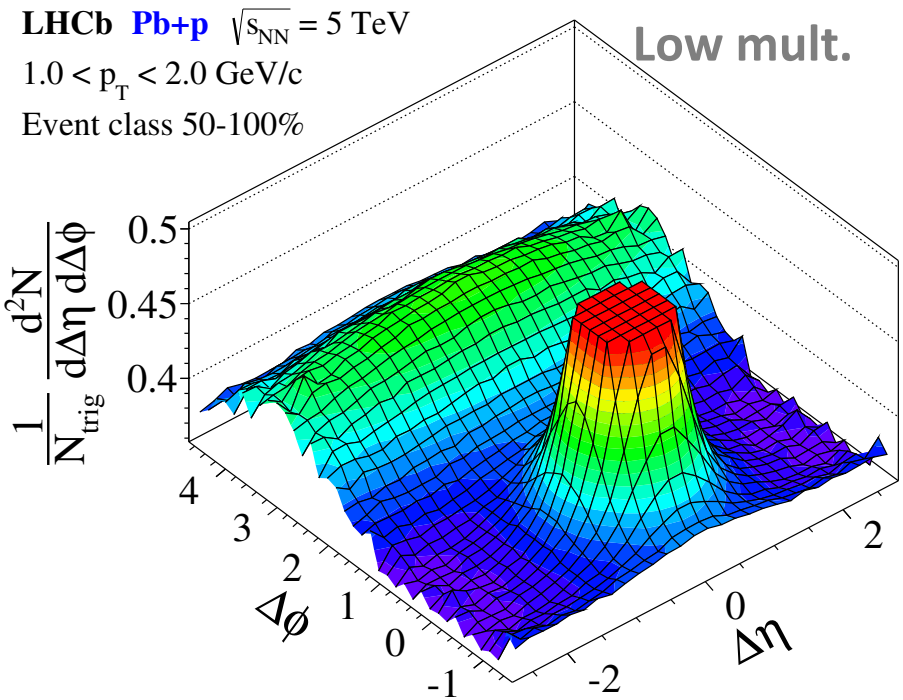


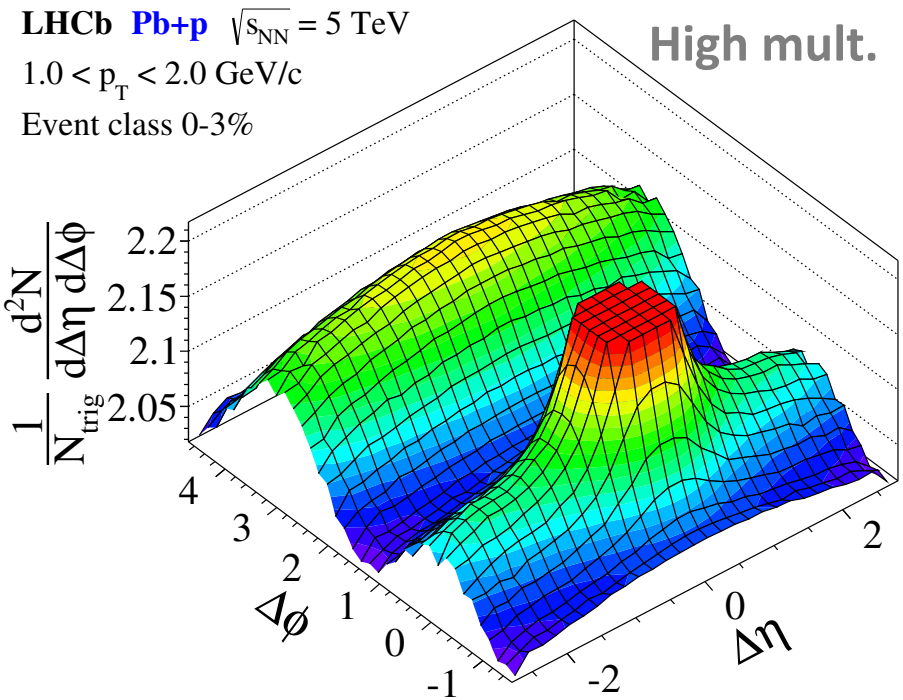
- Clear long-range away-side ($\Delta\phi \approx \pi$) structures in both activity classes
- Pronounced jet-like peaks in low and high multiplicity events
- Less pronounced long-range near-side ($\Delta\phi \approx 0$) structure appears in high multiplicity events

PLB 762 (2016) 473

Efficiency Corrected Two-Particle Correlations in Pb+p

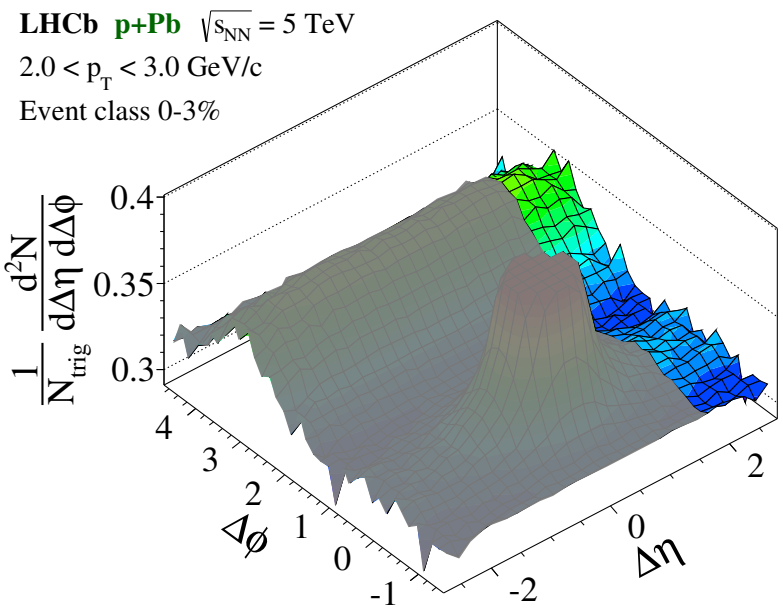


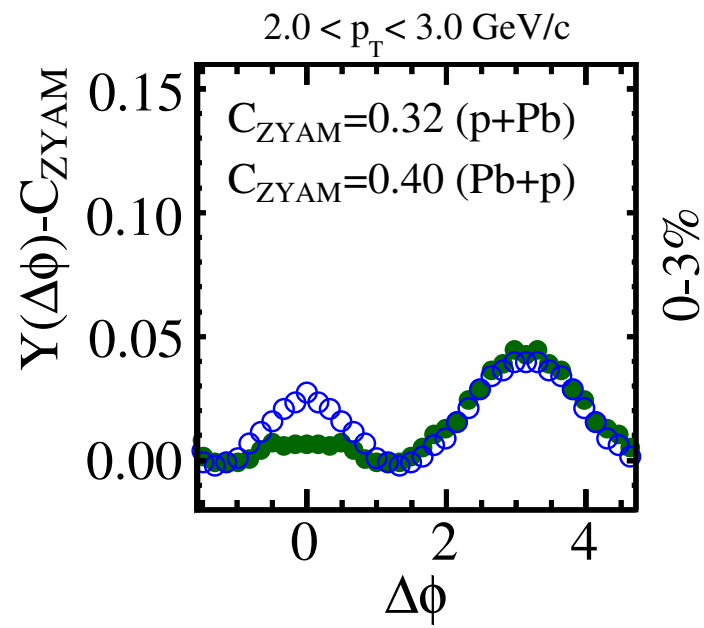




Similar long-range structures shown in Pb+p collisions in high multiplicity events

Quantitative Comparison

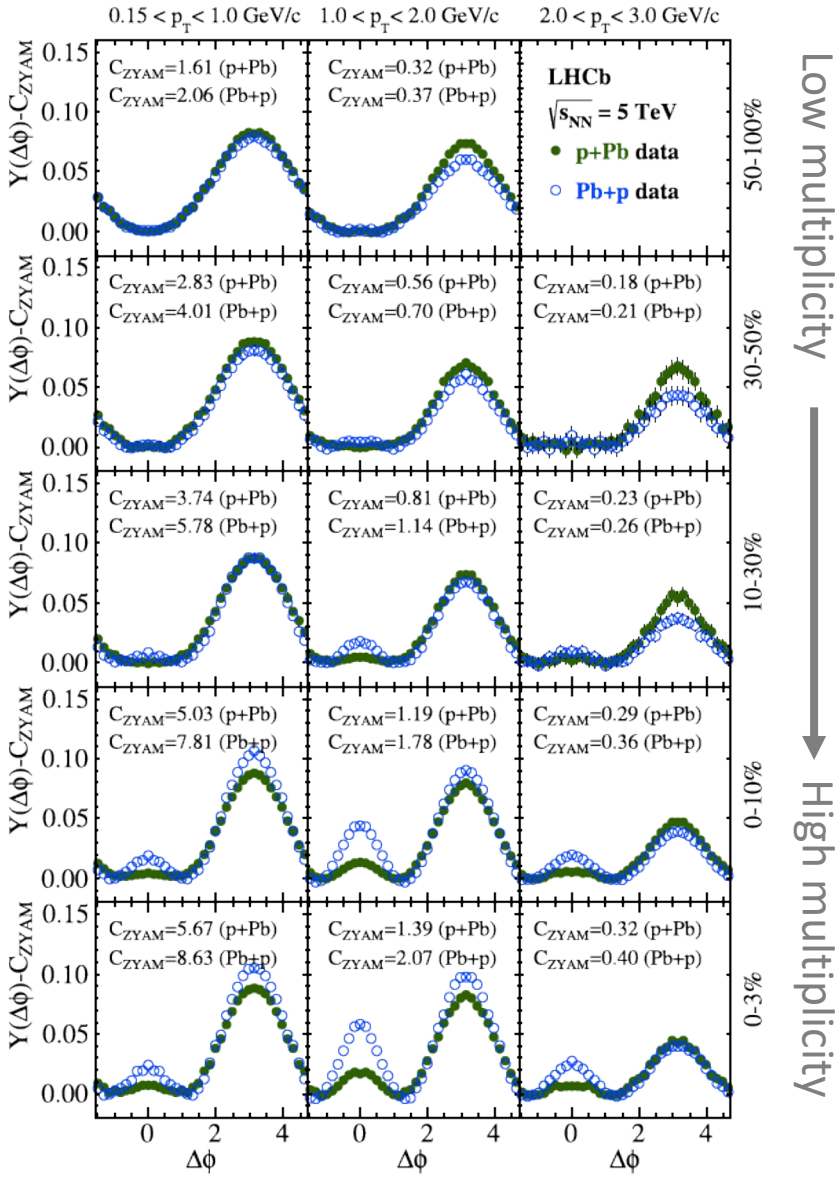




- Integrate over $2 < \Delta\eta < 2.9$ to avoid jet-like contributions
- Using zero-yield-at-minimum (ZYAM) to remove combinatorial background

PLB 762 (2016) 473

Correlations in Different Kinematic Range

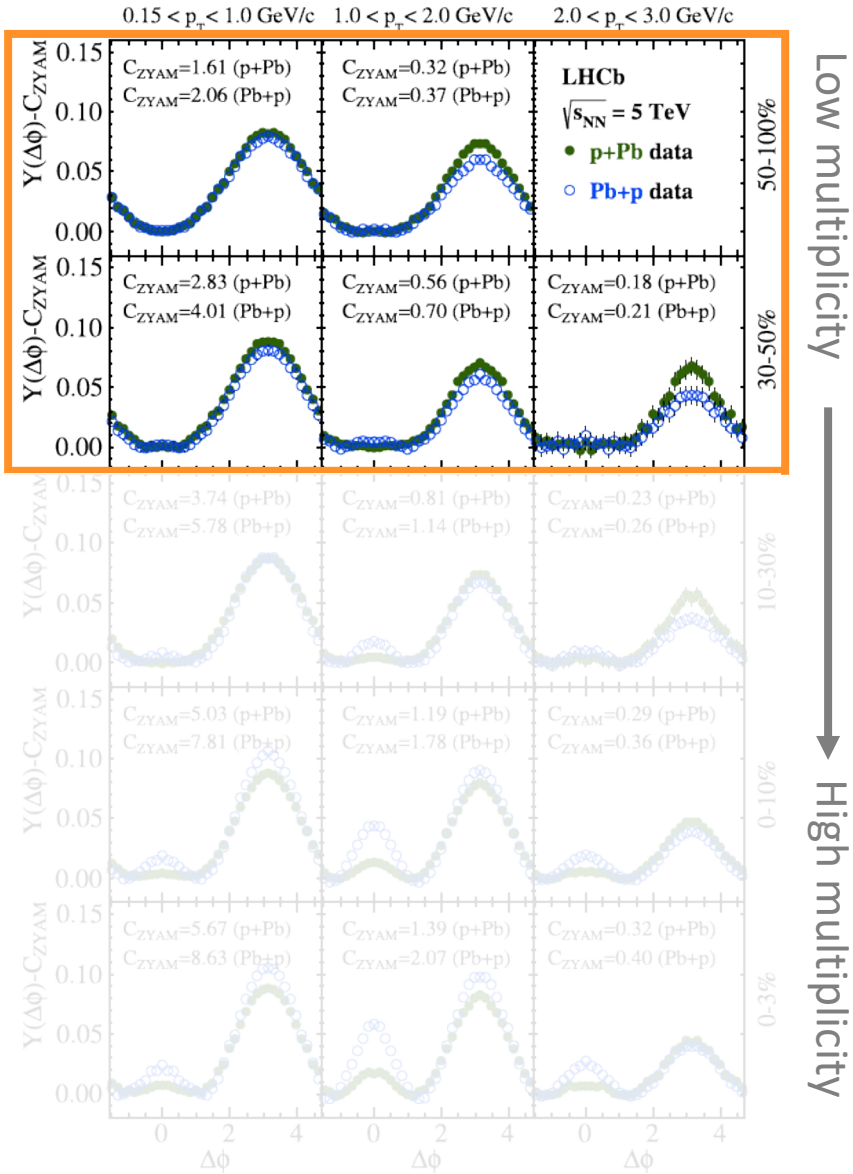


Low multiplicity

High multiplicity

PLB 762 (2016) 473

Correlations in Different Kinematic Range



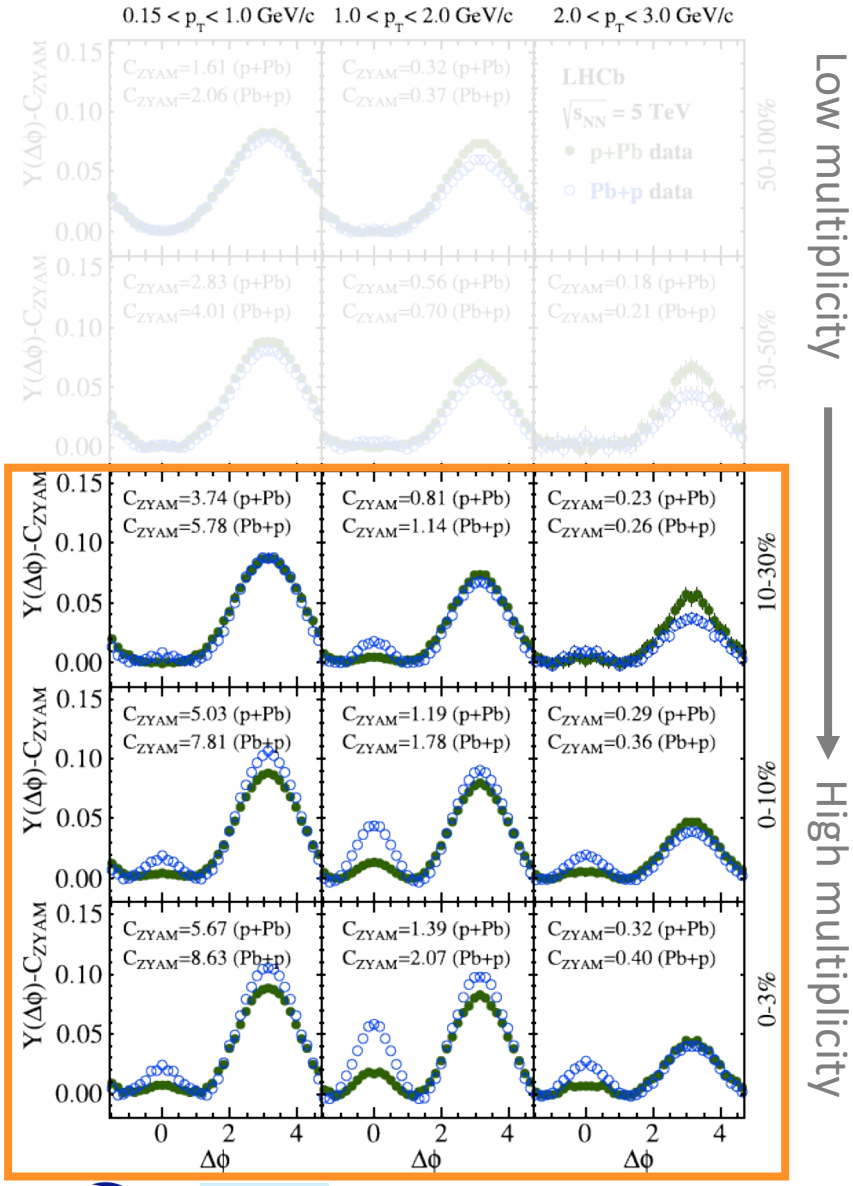
Low multiplicity → High multiplicity

Lower activity events (>30%)

- Pronounced away-side peaks in both pPb and Pbp data
- Away-side peaks reduce at higher p_T
- Away-side peaks are higher in pPb than in Pbp
- No significant near-side peak

PLB 762 (2016) 473

Correlations in Different Kinematic Range



Low multiplicity → High multiplicity

Lower activity events (>30%)

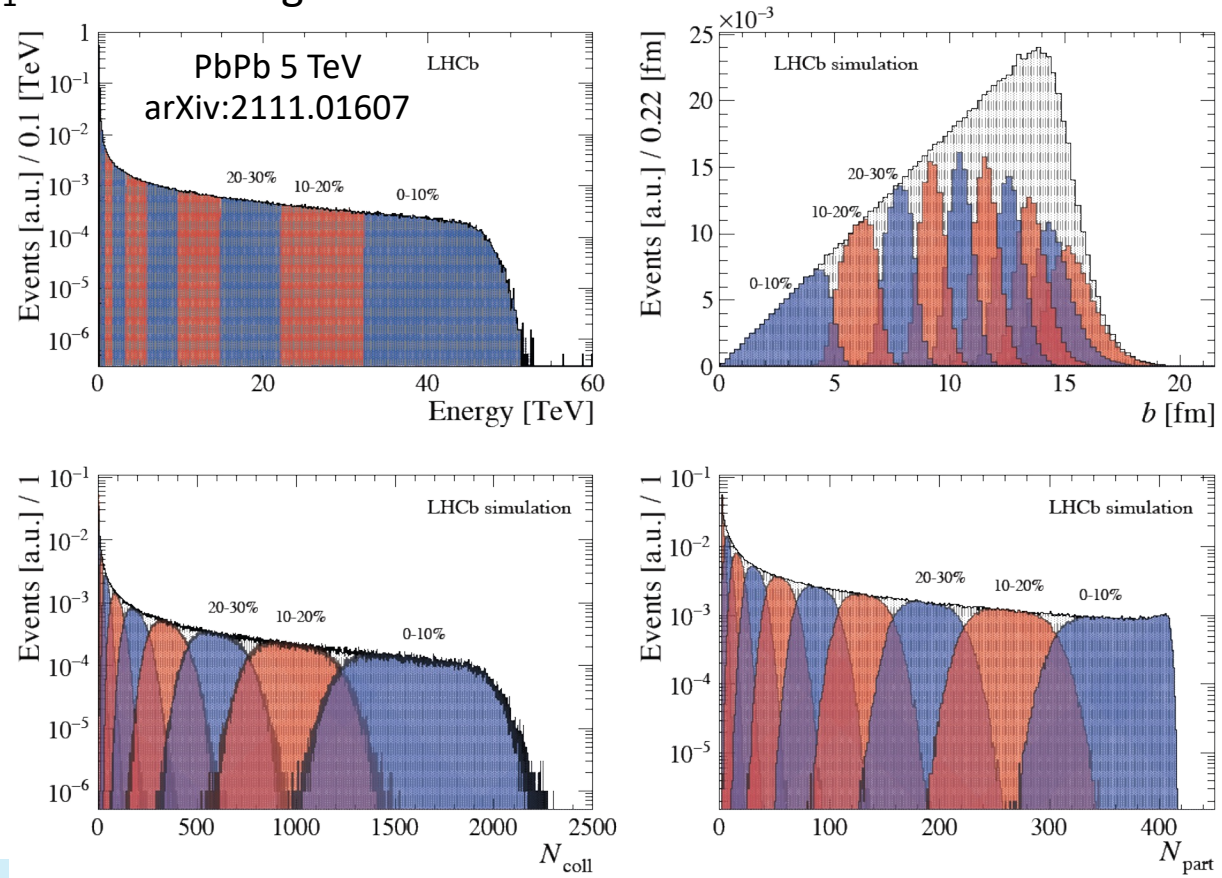
- Pronounced away-side peaks in both pPb and Pbp data
- Away-side peaks reduce at higher p_T
- Away-side peaks are higher in pPb than in Pbp
- No significant near-side peak

Higher activity events (<30%)

- Near-side peaks emerge in more central events
- Near-side peaks are higher in Pbp than in pPb
- Indication of p_T dependence for both near and away-side peaks

Current Flow Analyses at LHCb

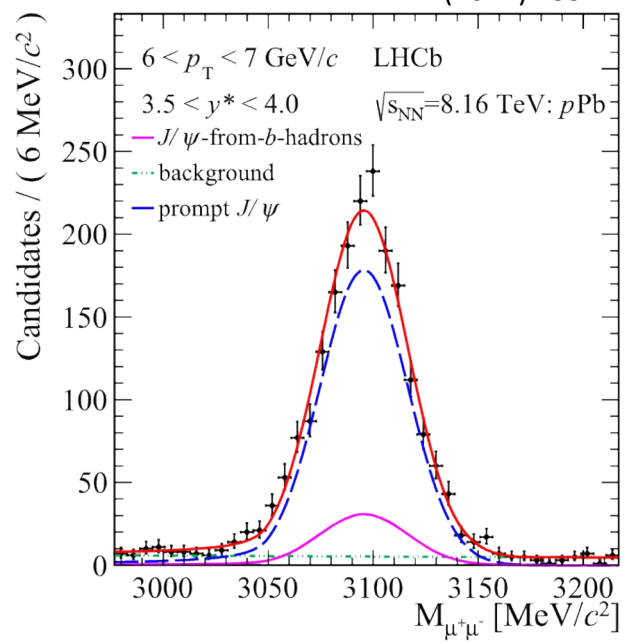
- **Charged hadron v_n in PbPb at 5 TeV**
  - $\int Ldt = 228\ \mu b^{-1}$
  - Centrality determination using calorimeter energy and Glauber model
  - Study v_1 in forward region



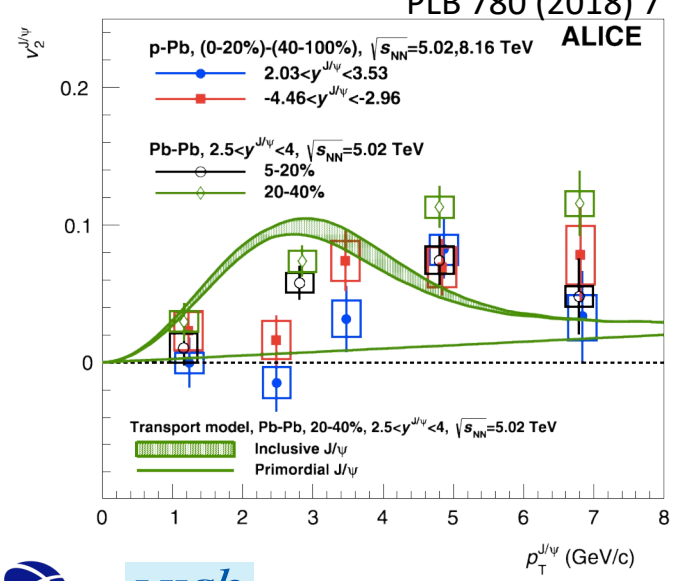
Current Flow Analyses at LHCb

- **Charged hadron v_n in PbPb at 5 TeV**
  - $\int Ldt = 228\ \mu b^{-1}$
  - Centrality determination using calorimeter energy and Glauber model
  - Study v_1 in forward region
- **Charged hadron & J/ψ v_n pPb and Pbp at 8 TeV**
  - Total $\int Ldt = 34.4\ nb^{-1}$
  - Finer activity classes
  - Study initial state effects at low x

PLB 774 (2017) 159



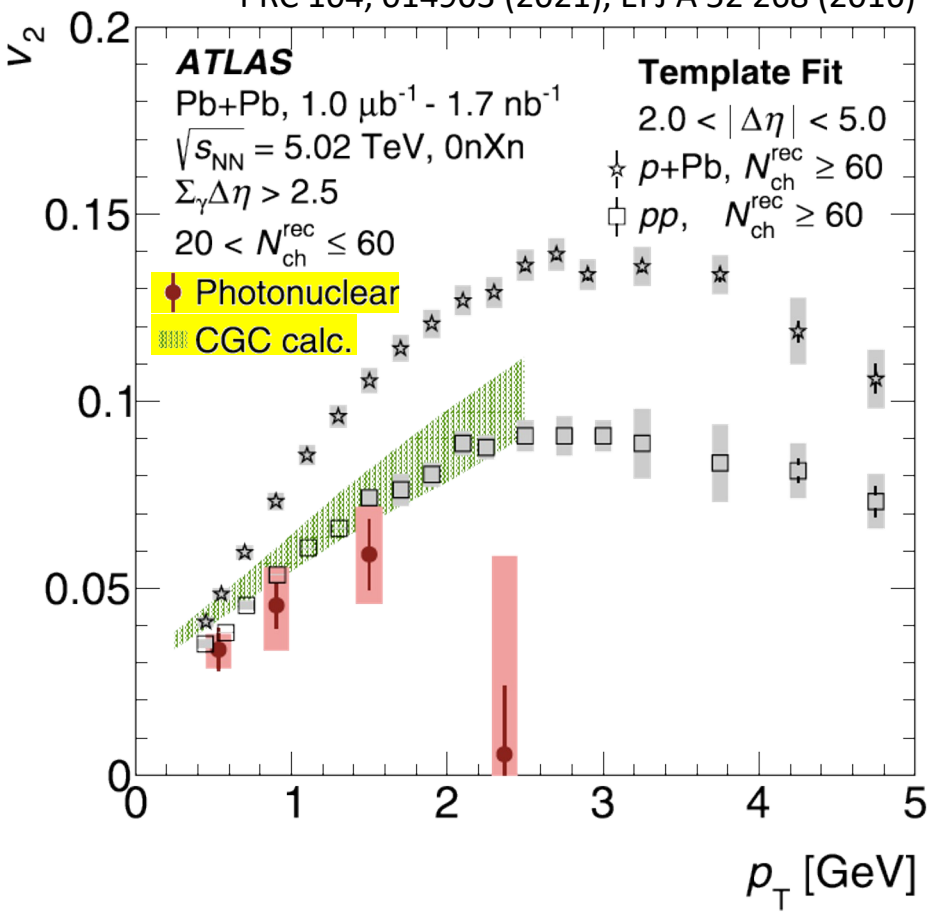
PLB 780 (2018) 7



- ALICE results show agreement of J/ψ v_2 in PbPb (black and green) and pPb (blue and red) with the sizable uncertainties
- LHCb has good statistics of J/ ψ which will help improve the measurements

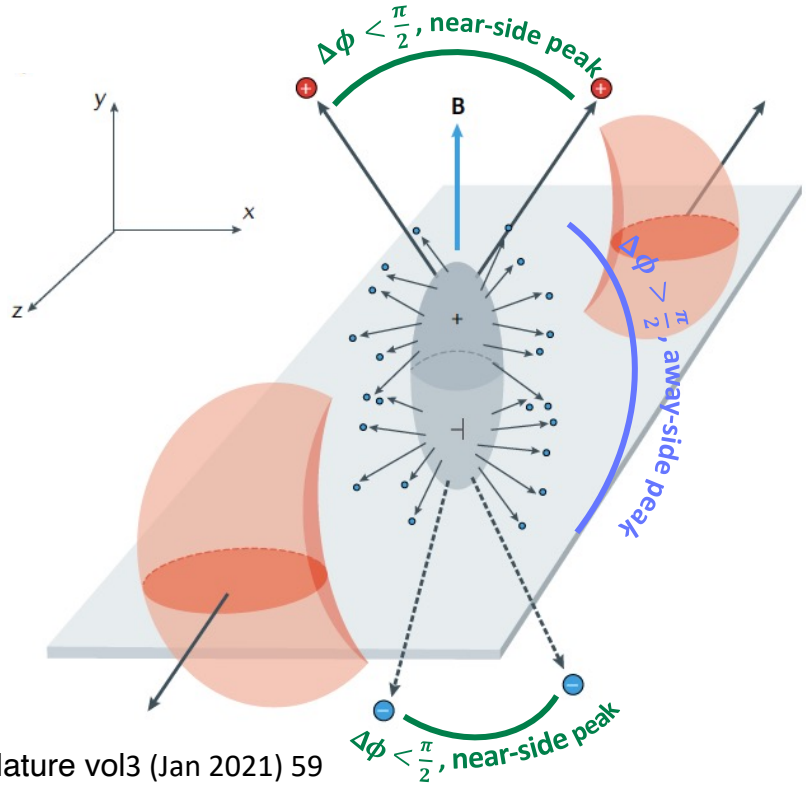
Potential Flow Analysis: Flow in UPC Events

PRC 104, 014903 (2021), EPJ A 52 268 (2016)



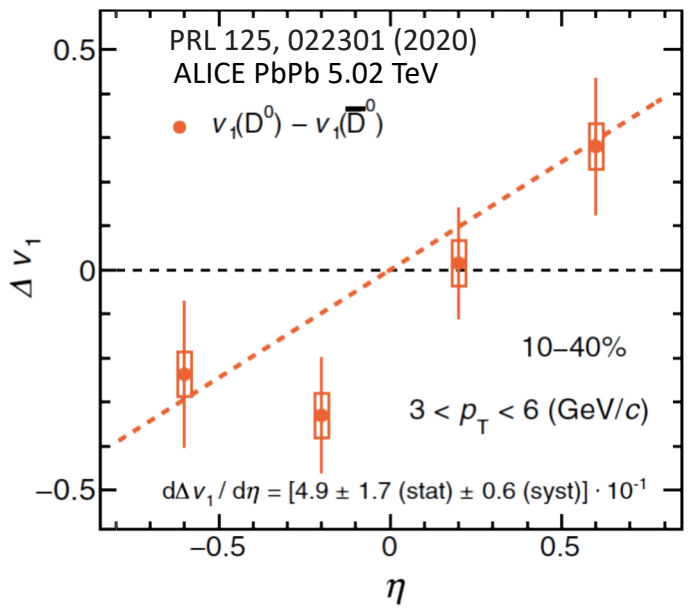
- Study particle flow induced by gluon saturation
- CGC calculation show agreements with photo-production events at low p_T
- More experimental results needed to constraint CGC models and provide reference for future EIC experiments

Potential Flow Analysis: Chiral Magnetic Effects

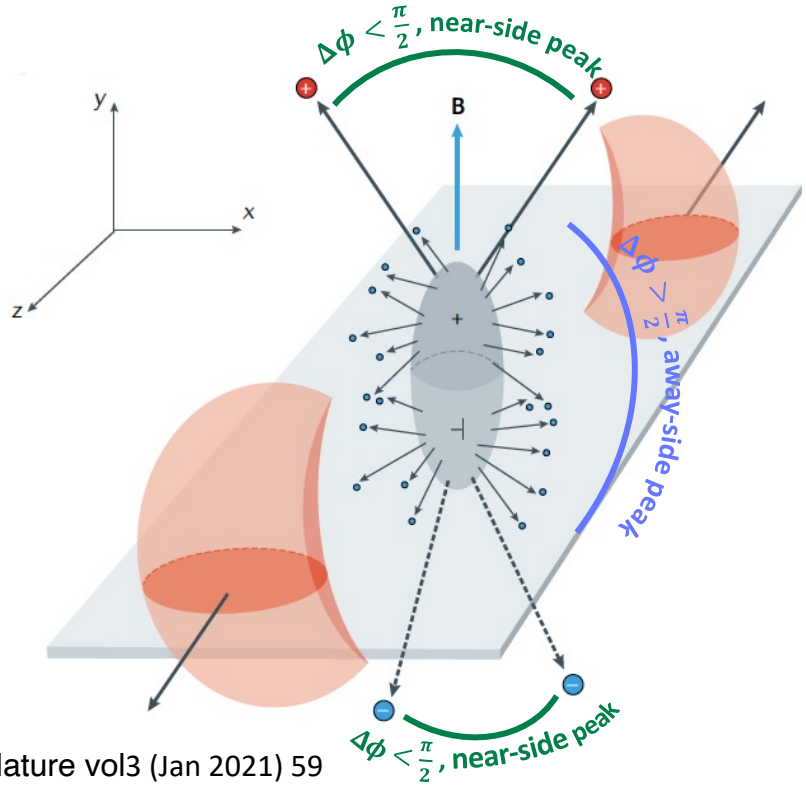


Nature vol3 (Jan 2021) 59

- Quarks in the QGP form an electric dipole due to the strong magnetic field from the spectator protons
  → charged hadrons emitted in different direction based on their signs
- In case of charge asymmetry, the charge imbalance transfer to Δv_1 between positive and negative tracks

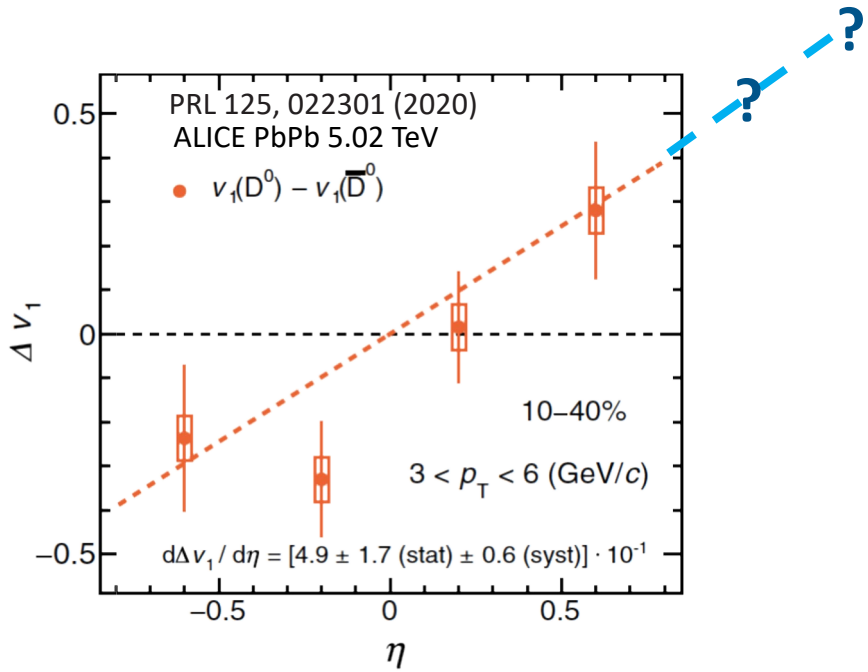


Potential Flow Analysis: Chiral Magnetic Effects



Nature vol3 (Jan 2021) 59

- Quarks in QGP form an electric dipole due to the strong magnetic field from the spectator protons
  → charged hadrons emitted in different direction based on their signs
- In case of charge asymmetry, the charge imbalance transfer to Δv_1 between positive and negative tracks

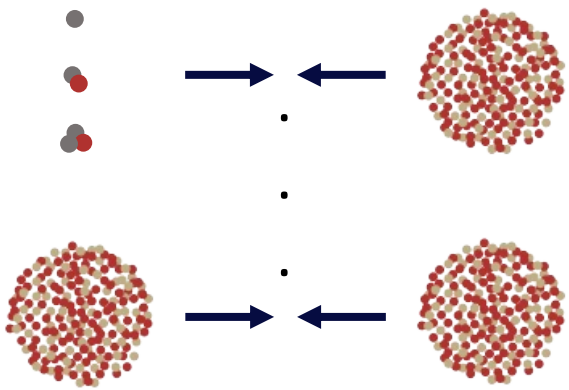


- Forward and backward results will help reduce the uncertainty of the fit
- Good statistics of D meson in LHCb [JHEP 10 (2017) 090]

LHCb SMOG Programs

- Rising interest in small systems
- But intermediate size systems are missing

Collisions systems at RHIC

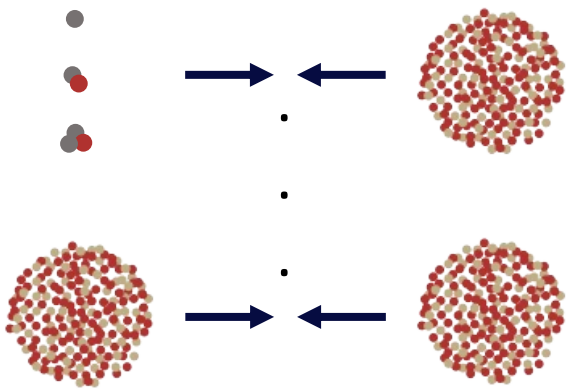


Look forward for the collider mode with the argon or oxygen beams in the future

LHCb SMOG Programs

- Rising interest in small systems
- But intermediate size systems are missing

Collisions systems at RHIC

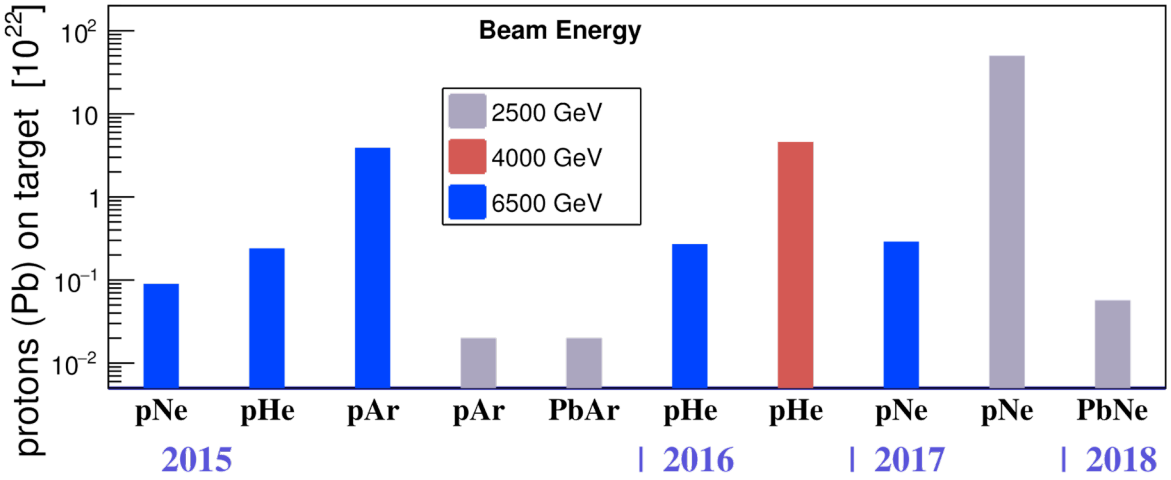


More SMOG talks

S. Mariani, T15, April 6th
J.Y. Sun, T11, April 7

Look forward for the collider mode with the argon or oxygen beams in the future

Or dive right in with LHCb SMOG datasets



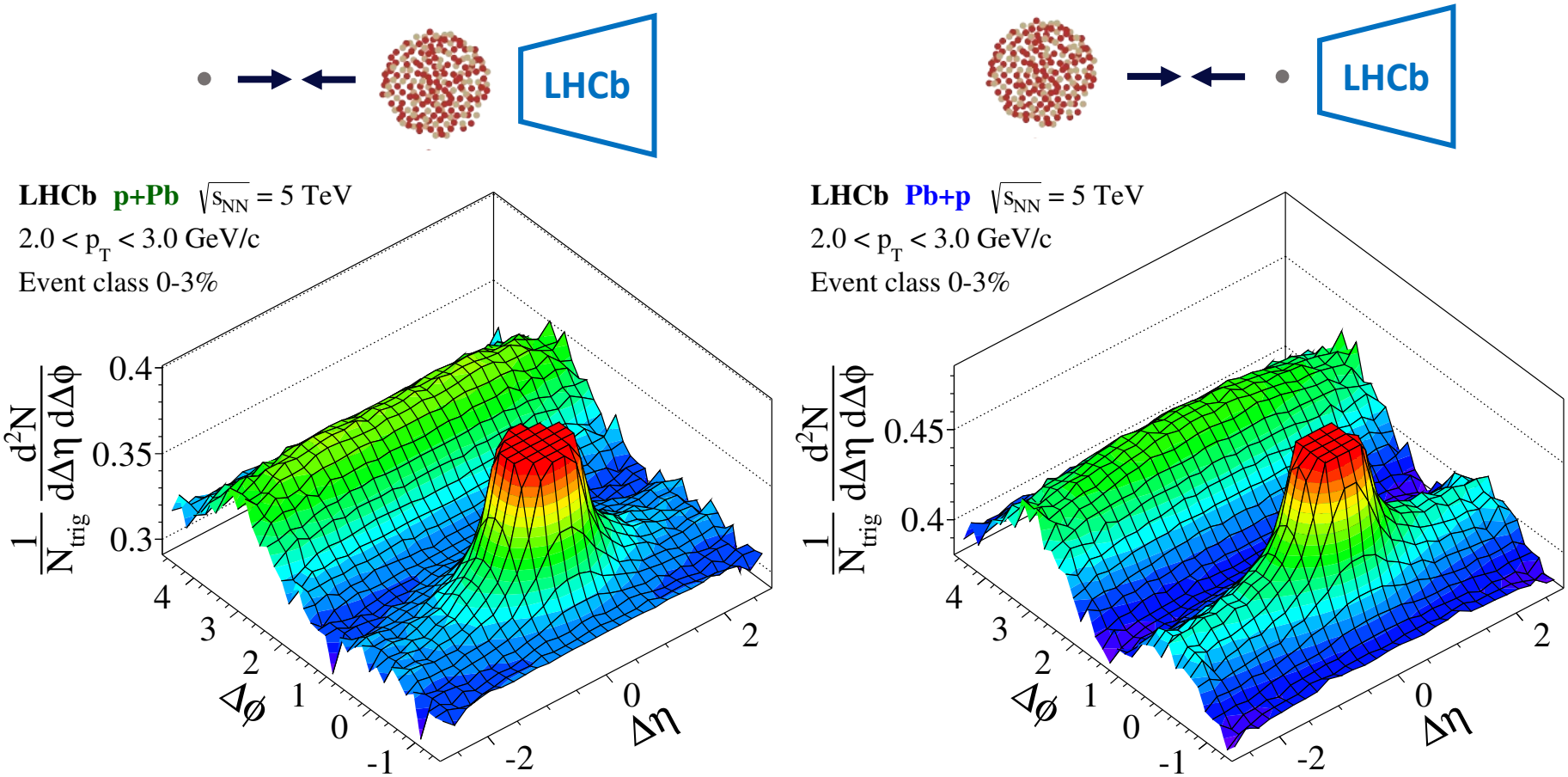
Summary

- Collectivity in the forward region at LHCb
  - Asymmetric collision at LHCb can benefit to both low and high-x physics
  - Two-particle correlation shows difference near-side structure between pPb and Pbp in high multiplicity events
- Coming flow analyses at LHCb
  - With pPb/Pbp and PbPb datasets
  - Flow harmonic coefficients of charged hadrons and J/ψ
  - Forward v_1
- Potential flow study in the future:
  - UPC events → CGC
  - Charged dependence v_1 → chiral magnetic effect
  - SMOG dataset → QGP in intermediate system size

Back Up

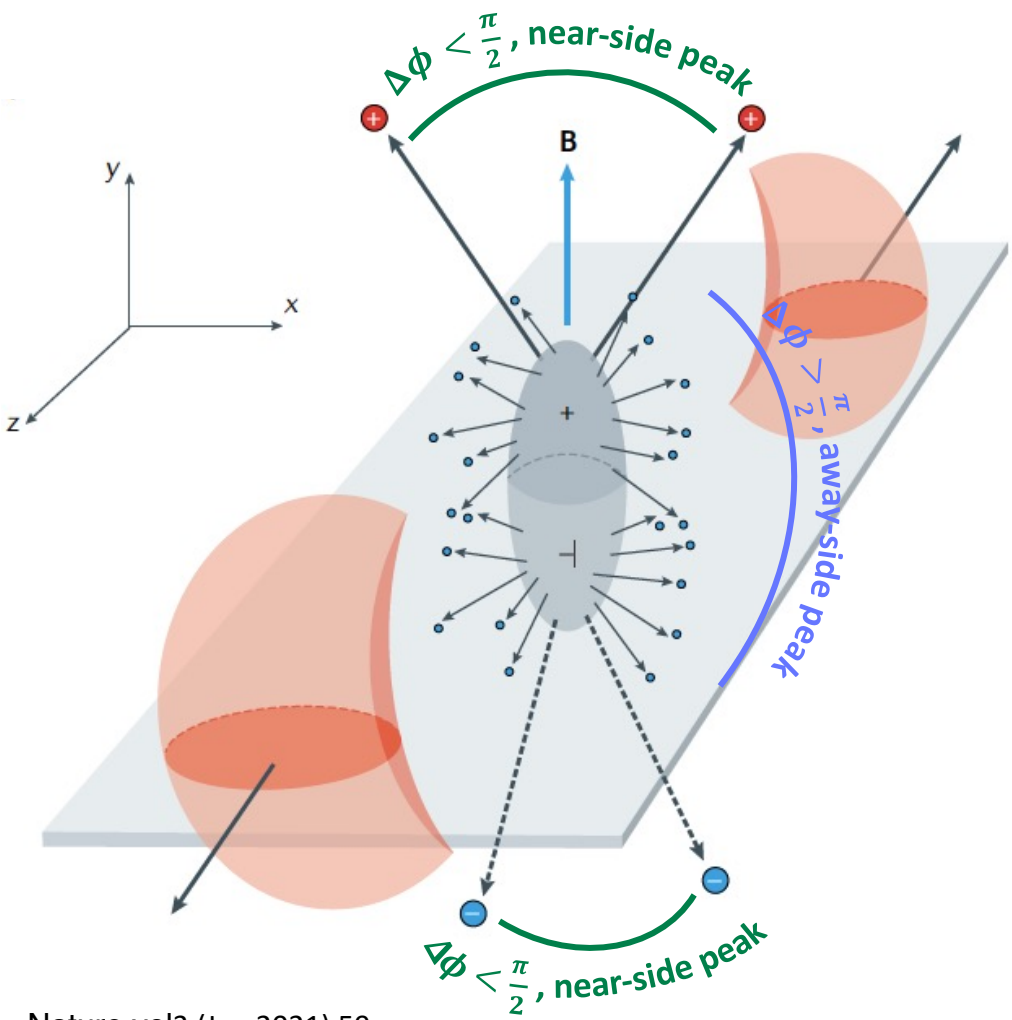
PLB 762 (2016) 473

p+Pb vs Pb+p



Clear near-side ridge in Pbp collisions

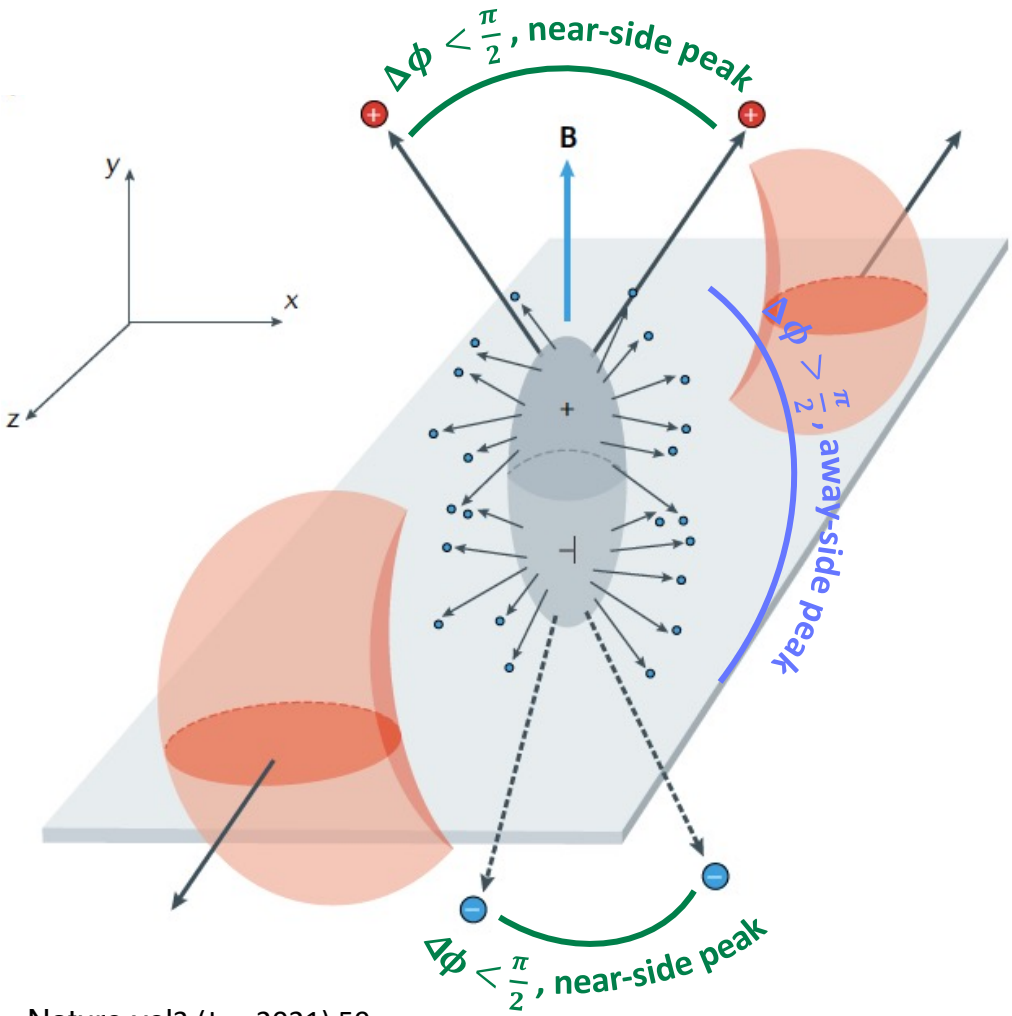
Potential Flow Analysis: Chiral Magnetic Effects



Nature vol3 (Jan 2021) 59

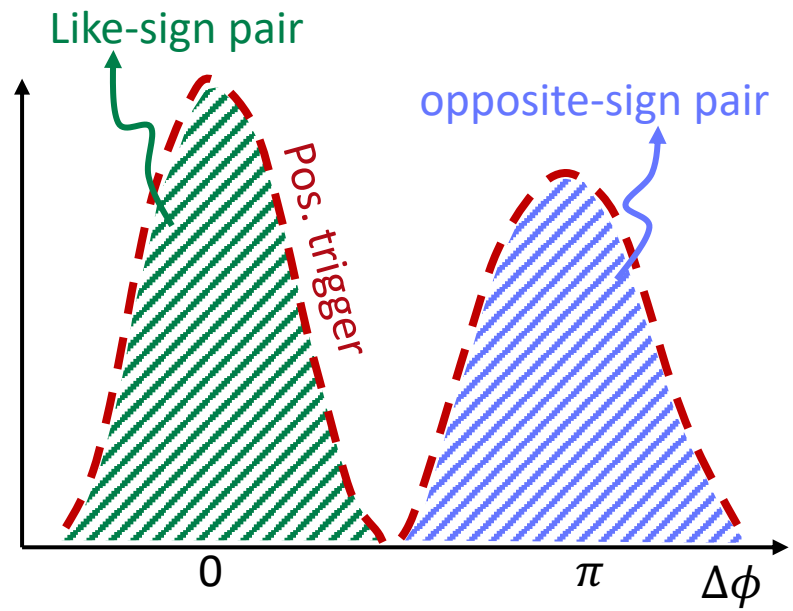
- A brief but strong magnetic field created by the spectator protons (red)
- Quarks inside the QGP form a dipole due to the strong magnetic field
- The angular correlations of the same-sign (opposite-sign) hadron pair at the final state are emitted in the same (opposite) side

Potential Flow Analysis: Chiral Magnetic Effects

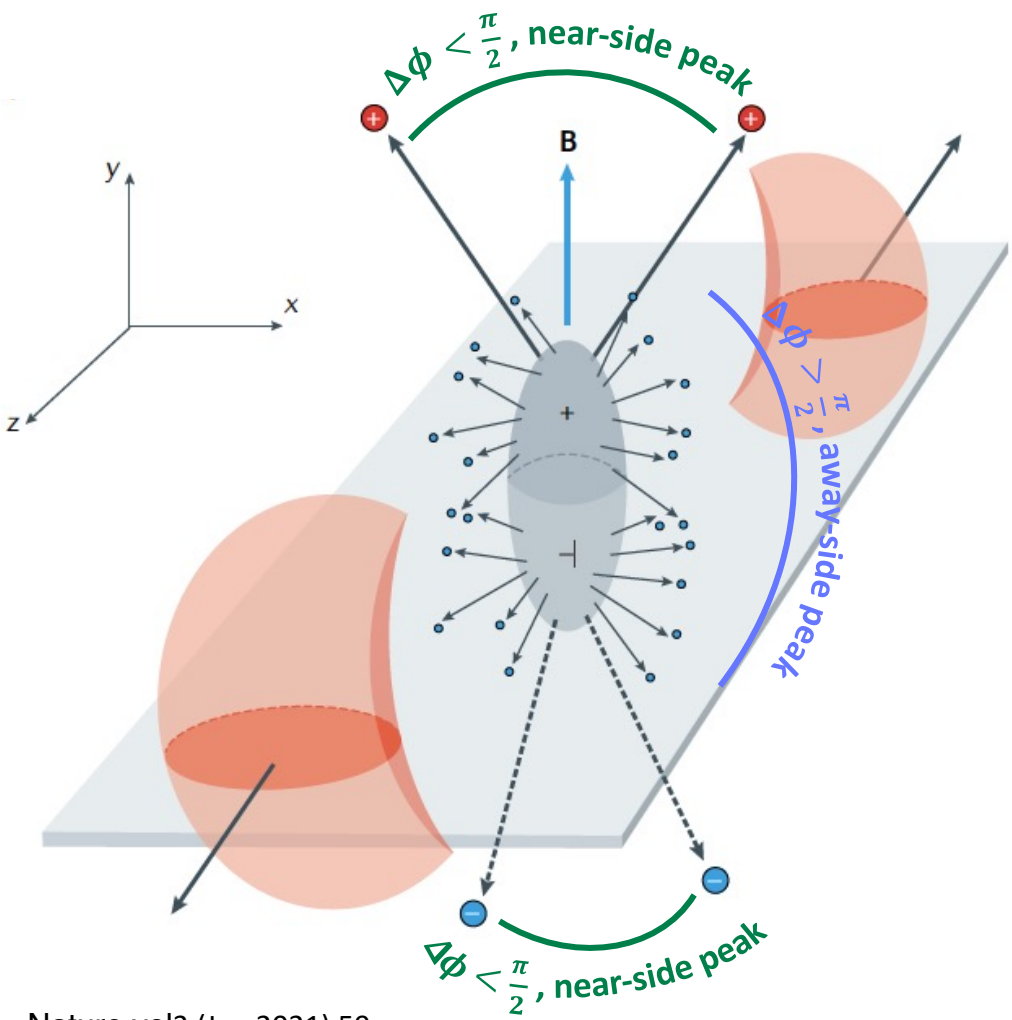


Nature vol3 (Jan 2021) 59

In case of symmetry breaking,
for example: more positive tracks

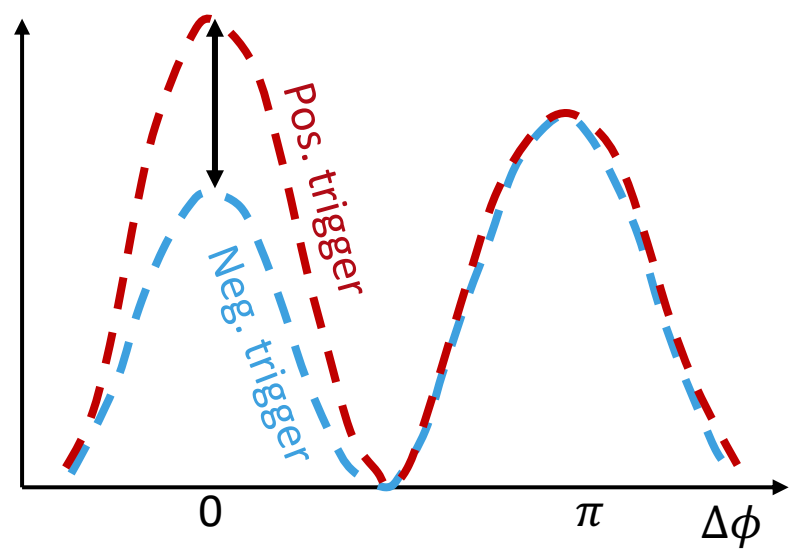


Potential Flow Analysis: Chiral Magnetic Effects



Nature vol3 (Jan 2021) 59

In case of symmetry breaking, for example: more positive tracks



Differences in v_1 between positive and negative trigger