QCD物理暨国家自然科学基金重大项目交流会

Charge dependent flow and the search for the chiral magnetic wave at RHIC and LHC

Qiye Shou 寿齐烨
Fudan University

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Chiral anomaly in heavy-ion collisions

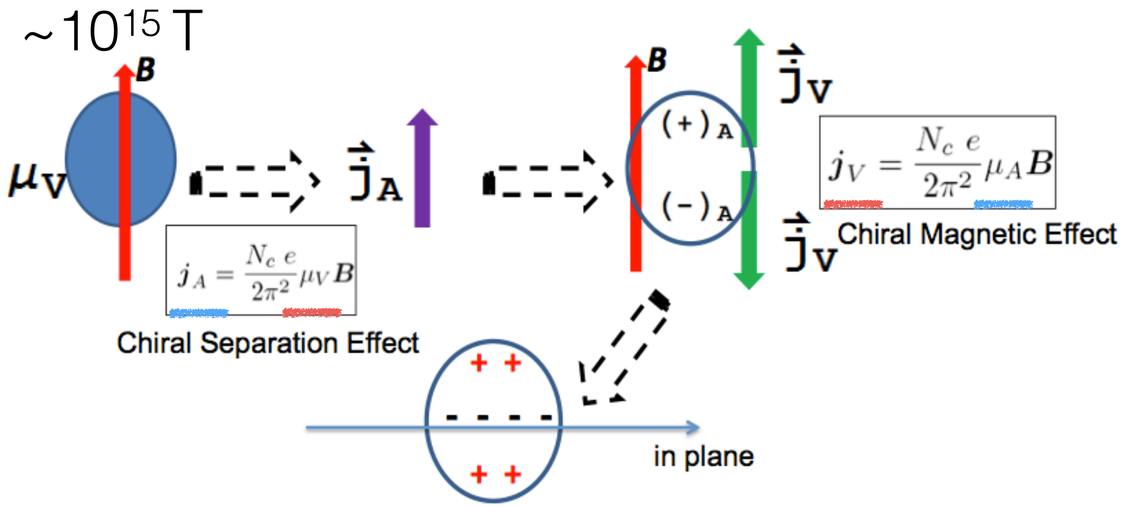
- In non-central heavy-ion collisions an unprecedented intense magnetic field (~10^{18} G) is generated by the movement of the spectator protons

- In the presence of such magnetic field, several anomalous chiral effects, such as
- Chiral Magnetic Effect,
- Chiral Magnetic Wave, etc, have been theorized to be created in QGP
  - Possible local CP violation in strong interactions
  - The novel topological nature of the QCD vacuum

  …

Chiral magnetic wave

Y. Burnier, D. E. Kharzeev, J. Liao, and H.-U. Yee, Phys. Rev. Lett. 107, 52303 (2011).



asymmetry in the azimuthal distributions of h+ and h-

$$N_+(\phi) - N_-(\phi) = (\bar{N}_+ - \bar{N}_-)[1 - r\cos(2\phi)] \longleftarrow r \equiv \frac{2q_e}{\bar{\rho}_e}$$

monopole, nonzero net charge density

$$q_e = \int RdRd\phi \cos(2\phi)[j^0_e(R,\phi) - j^0_{e,B=0}(R,\phi)]$$

quadrupole, CMW contribution

$$\bar{\rho}_e = \int RdRd\phi j^0_{e,B=0}(R,\phi)$$

$$\frac{dN_\pm}{d\phi} = N_\pm[1 + 2v_2\cos(2\phi)]$$

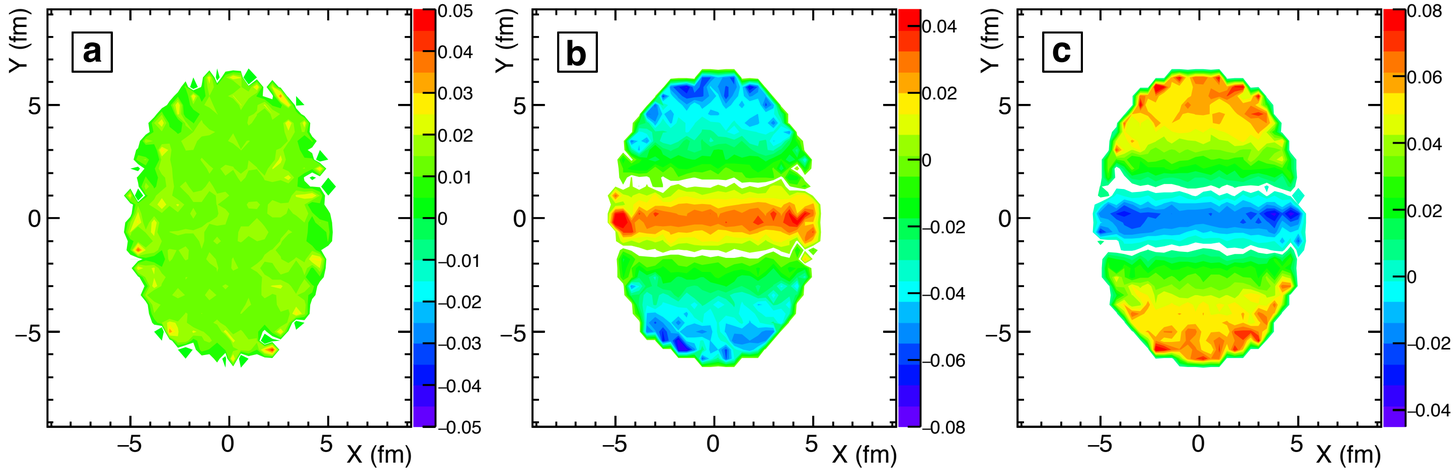
$$\approx \bar{N}_\pm[1 + 2v_2\cos(2\phi) \mp A_\pm r\cos(2\phi)] \longleftarrow A_\pm \equiv (\bar{N}_+ - \bar{N}_-)/(\bar{N}_+ + \bar{N}_-)$$

$$v_2^\pm = v_2 \mp \frac{rA_\pm}{2} \longleftrightarrow \boxed{\Delta v_2 = v_2^- - v_2^+ \approx rA}$$

Chiral magnetic wave

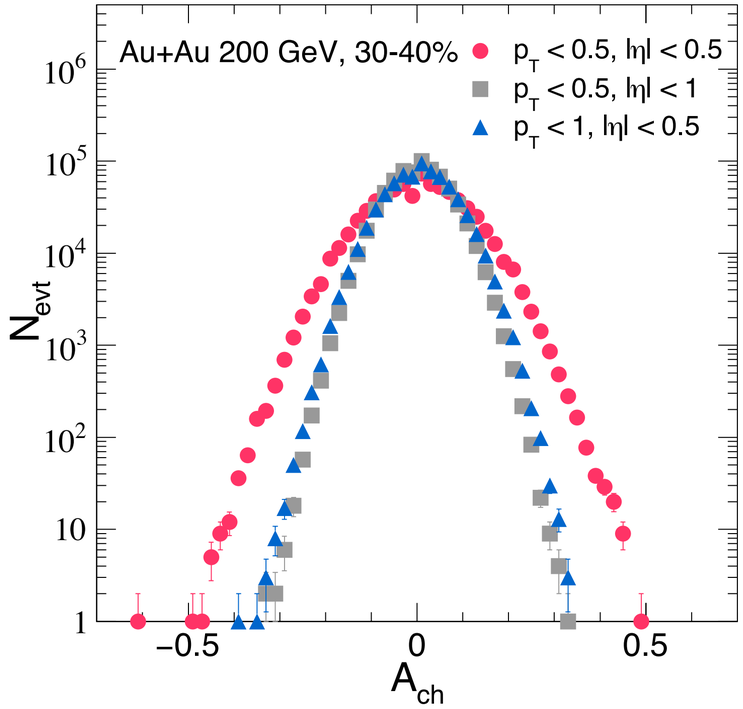
Y. Burnier, D. E. Kharzeev, J. Liao, and H.-U. Yee, Phys. Rev. Lett. 107, 52303 (2011).

AMPT simulation with imported quadrupole



$$\Delta v_2 = v_2^- - v_2^+ \approx rA$$

Negative binomial distr.



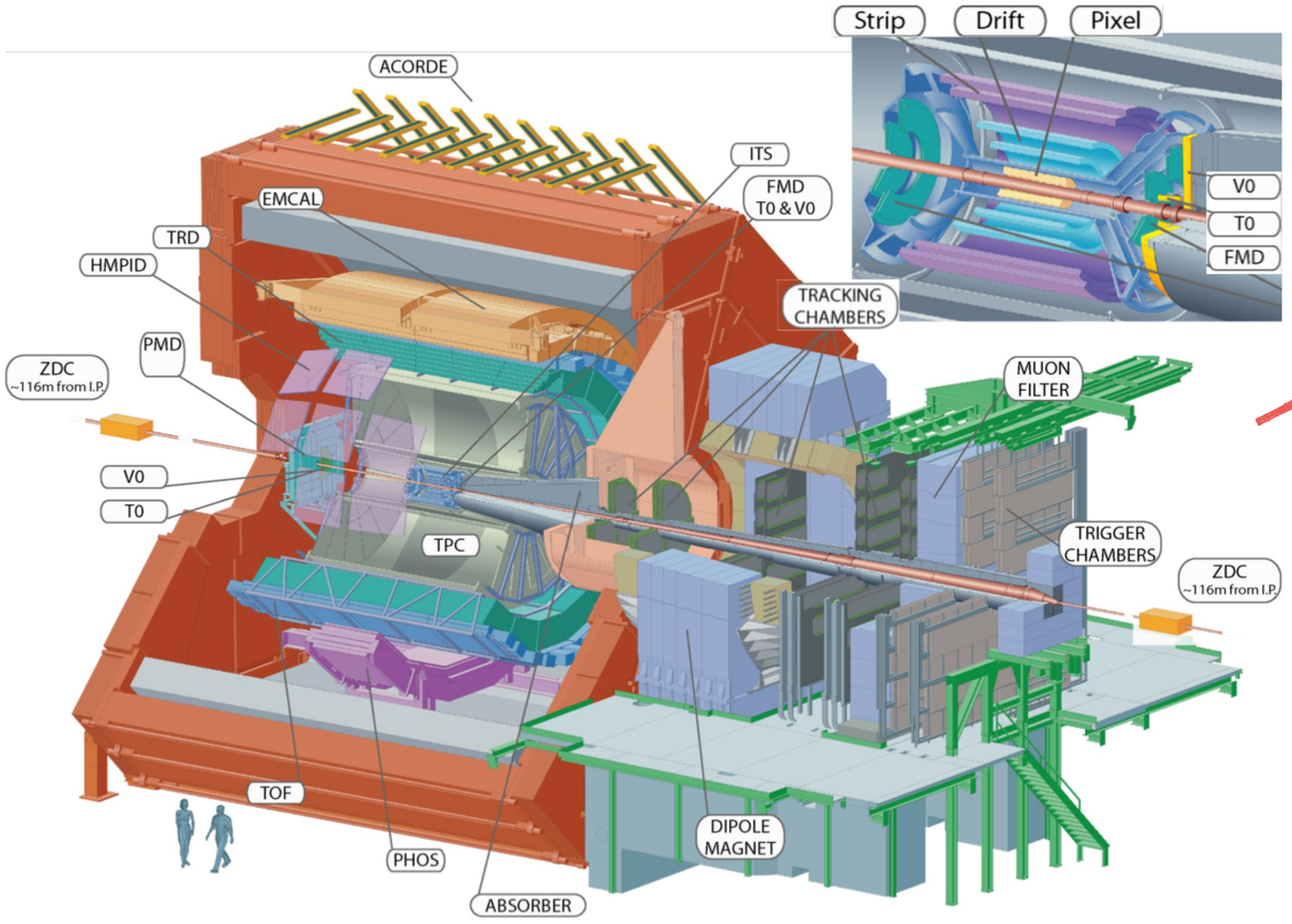
ALICE, CMS and STAR experiments put efforts into such studies for more than a decade

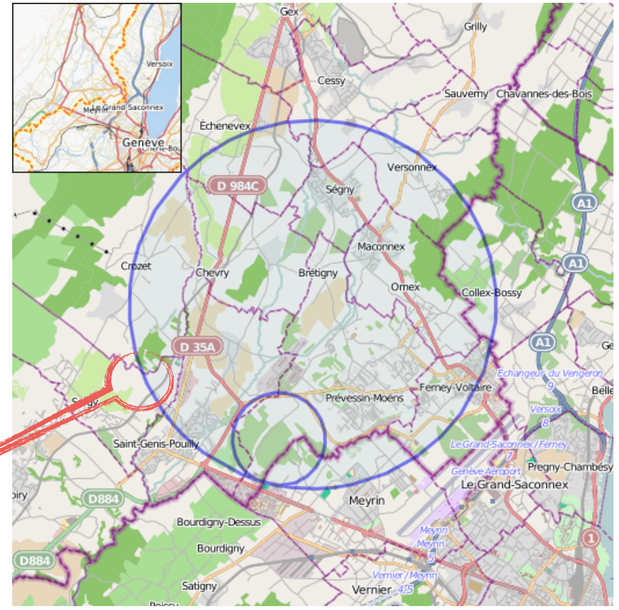
Experimental setup

- Collision systems and energies
  - Pb-Pb, p-Pb, Xe-Xe ➔ 2.76 TeV, 5.02 TeV, 5.44 TeV at LHC
  - Au+Au, p(d)+Au, U+U ➔ BES (7-62 GeV), 200 GeV, 193 GeV at RHIC

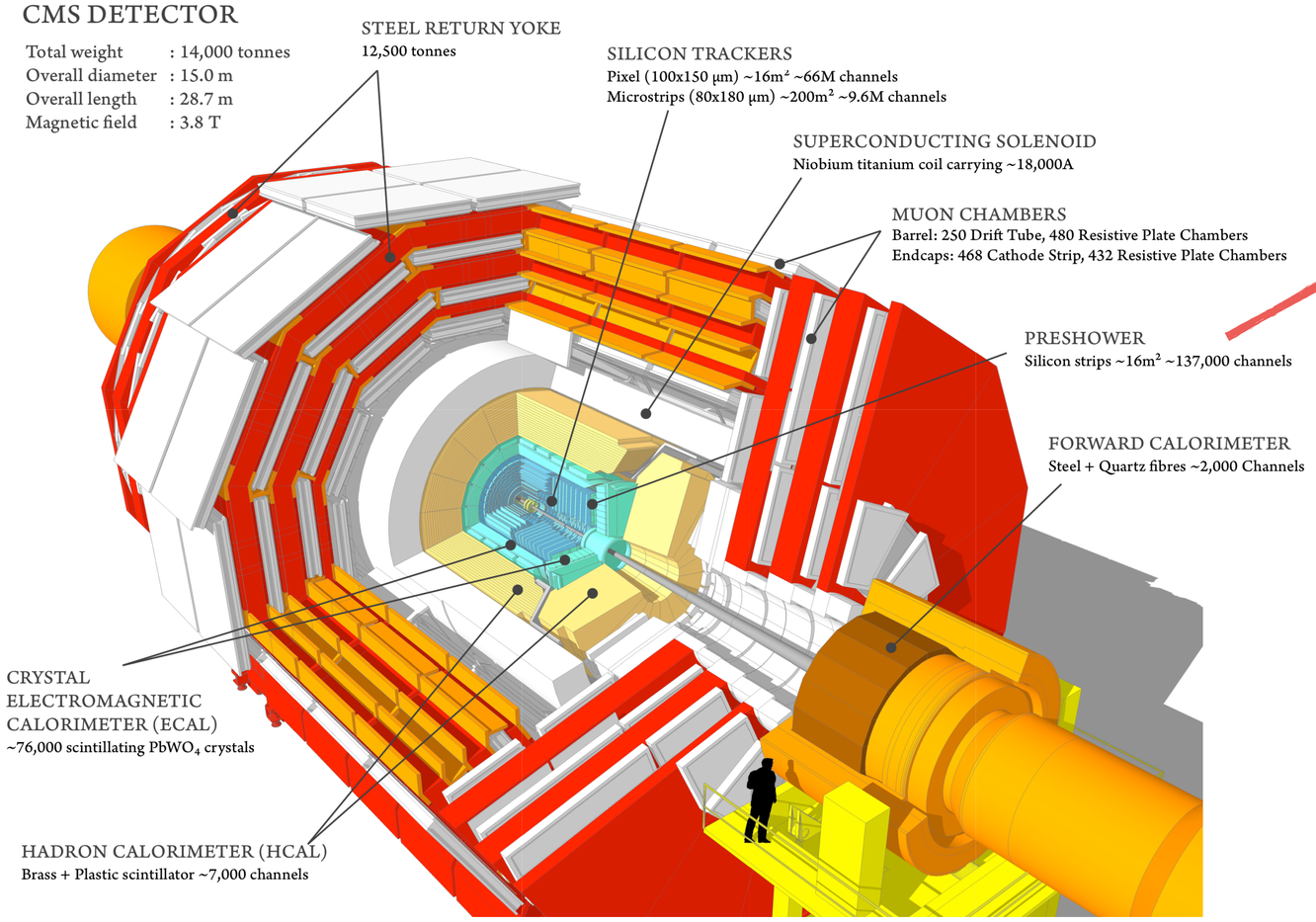
- Particle of interest
  - Inclusive charged particles
  - Identified particles: π, K, p, heavy-flavour, etc at various kinematic windows (p_T, η, etc)

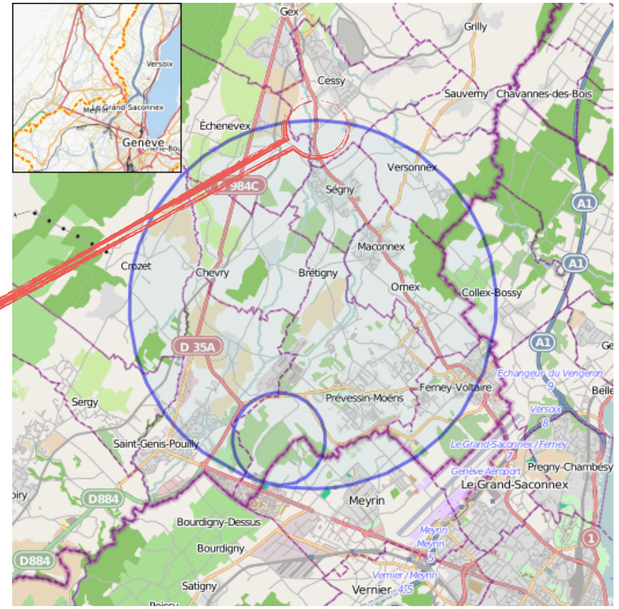
LHC-ALICE


Strip
Drift
Pixel
ACORDE
ITS
FMD
T0 & V0
EMCAL
TRD
HMPID
PMD
ZDC
~116m from I.P.
V0
T0
TPC
TRACKING
CHAMBERS
MUON
FILTER
TRIGGER
CHAMBERS
ZDC
~116m from I.P.
V0
T0
FMD
TOF
PHOS
ABSORBER
DIPOLE
MAGNET


Gex
Grilly
Cessy
Sauverny
Chavannes-des-Bois
Echenevex
Genève
Versonnex
Ségny
D 984C
A1
Maconnex
Crozet
Chevry
Brétigny
Omex
Collex-Bossy
D 35A
Prévessin-Moëns
Ferney-Voltaire
Saint-Genis-Pouilly
Le Grand-Saconnex
Pregny-Chambésy
Meyrin
D884
Bourdigny-Dessus
Bourdigny
Satigny
Vernier

LHC-CMS


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 μm) ~16m² ~66M channels
Microstrips (80x180 μm) ~200m² ~9.6M channels
SUPERCONDUCTING SOLENOID
Niobium titanium coil carrying ~18,000A
MUON CHAMBERS
Barrel: 250 Drift Tube, 480 Resistive Plate Chambers
Endcaps: 468 Cathode Strip, 432 Resistive Plate Chambers
PRESHOWER
Silicon strips ~16m² ~137,000 channels
FORWARD CALORIMETER
Steel + Quartz fibres ~2,000 Channels
CRYSTAL ELECTROMAGNETIC CALORIMETER (ECAL)
~76,000 scintillating $PbWO_4$ crystals
HADRON CALORIMETER (HCAL)
Brass + Plastic scintillator ~7,000 channels


Gex
Grilly
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Chavannes-des-Bois
Echenevex
Genève
Versonnex
Ségny
Maconnex
Crozet
Chevry
Bretigny
Omex
Collex-Bossy
Sergy
Prévessin-Moëns
Ferney-Voltaire
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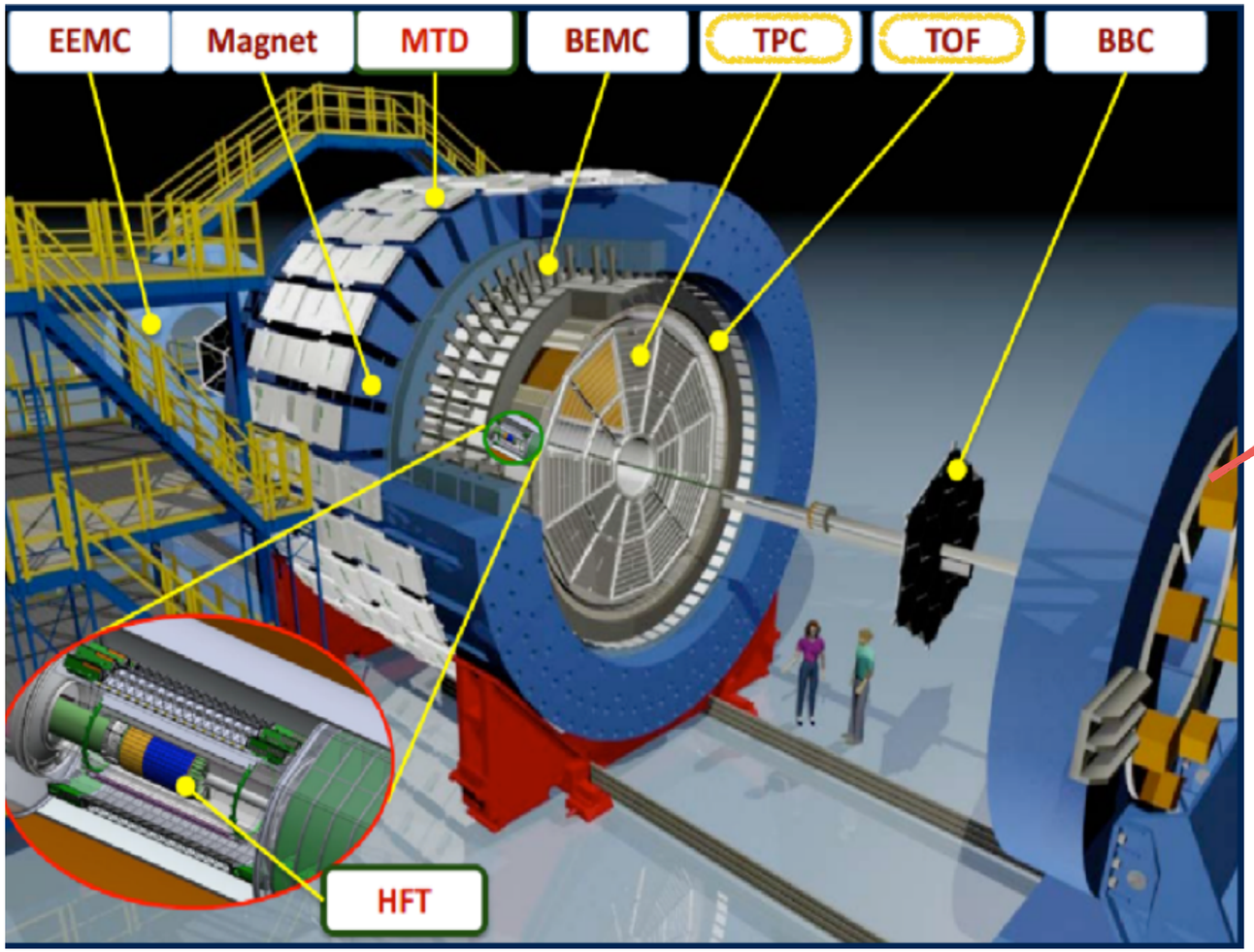
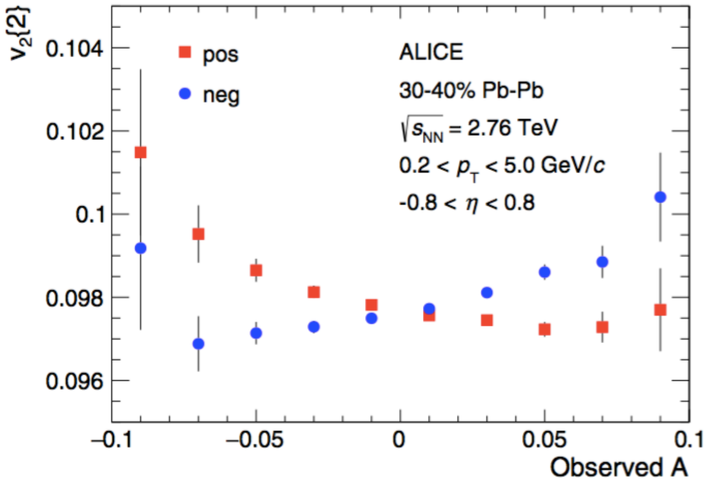
Le Grand-Saconnex
Pregny-Chambésy
Meyrin
Bourdigny-Dessus
Bourdigny
Satigny
Vernier
D 35A
D884
A1

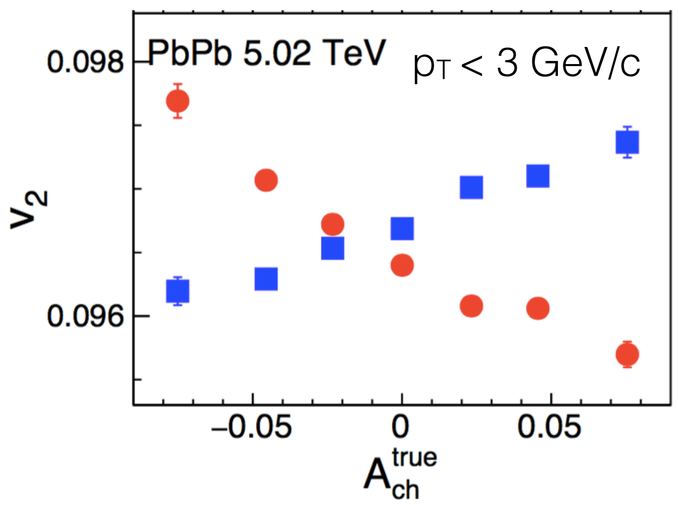
RHIC-STAR



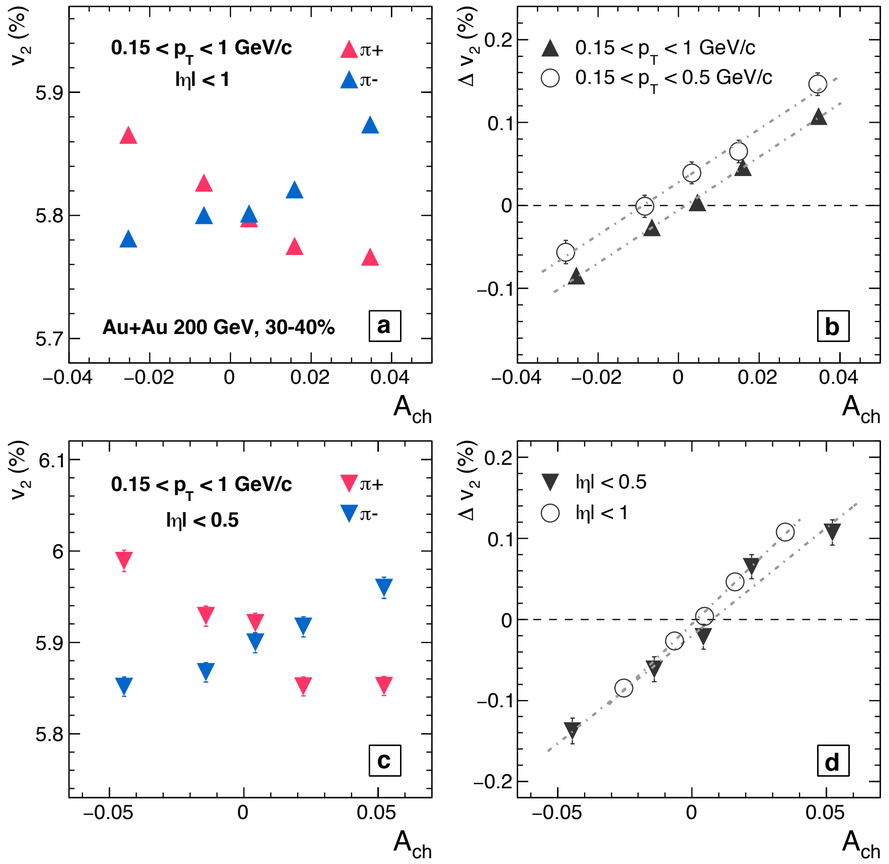
Experimental measurement of A_{ch} dependent v_2



CMS

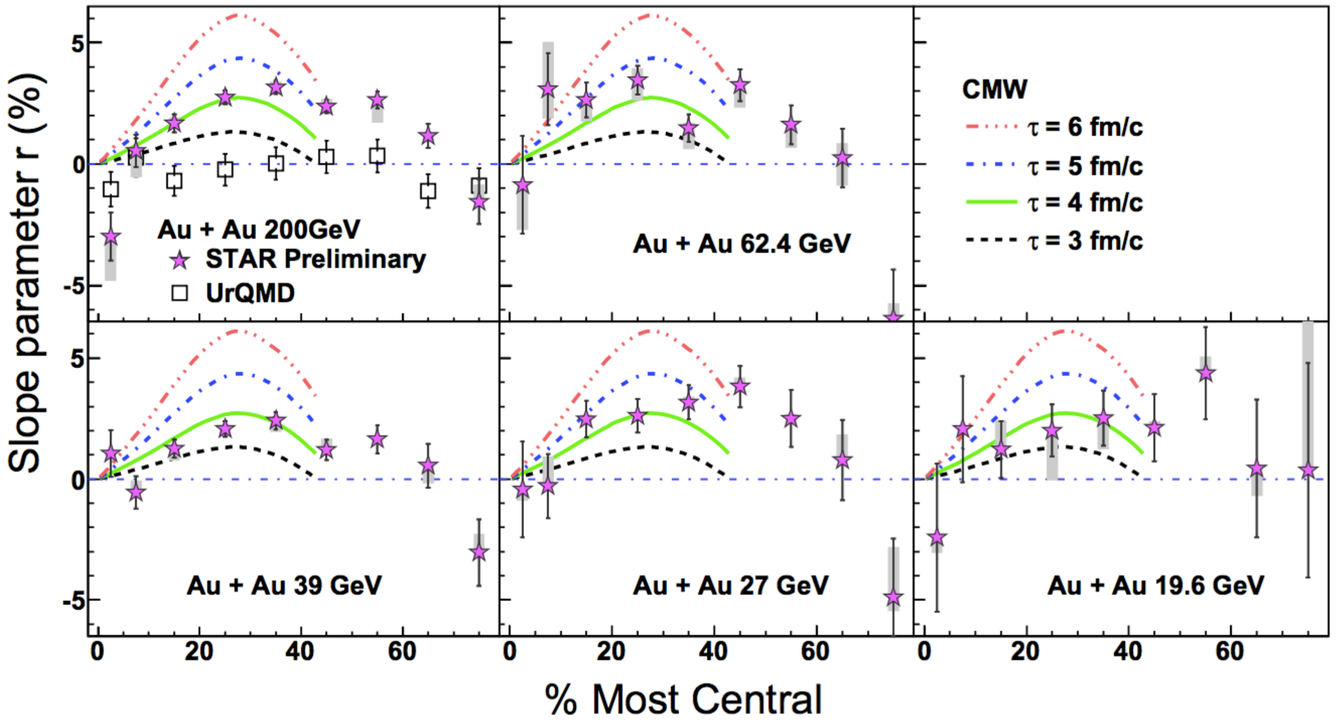


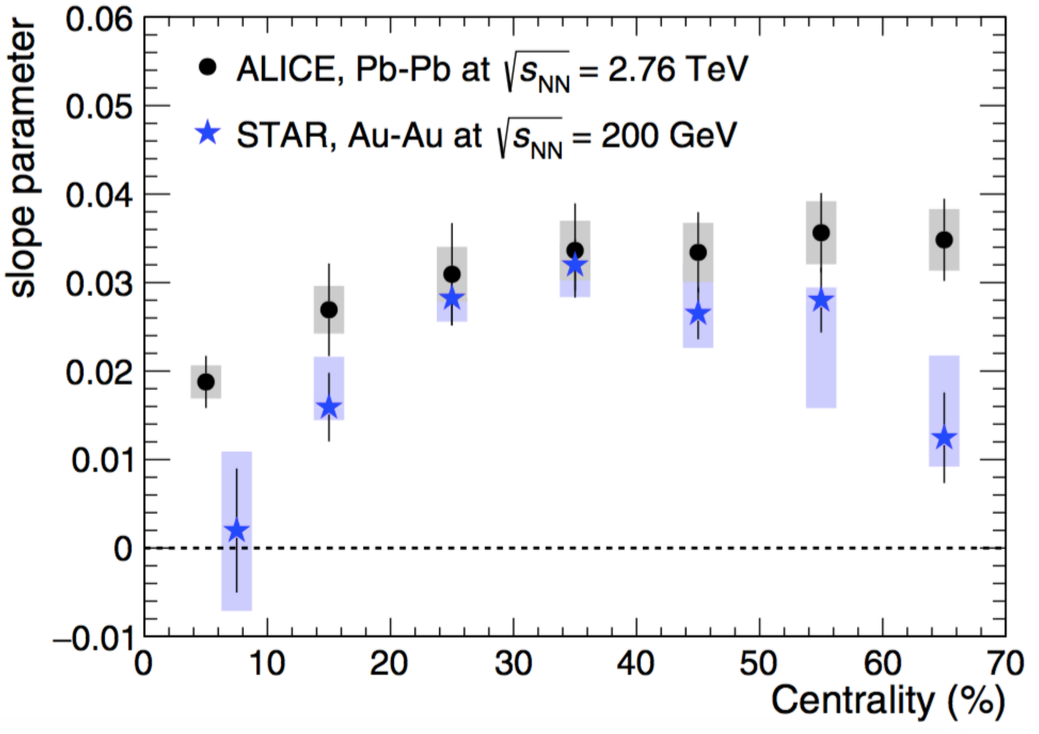
STAR



- A clear linear dependence between v_2 and A_{ch} is observed in all experiments

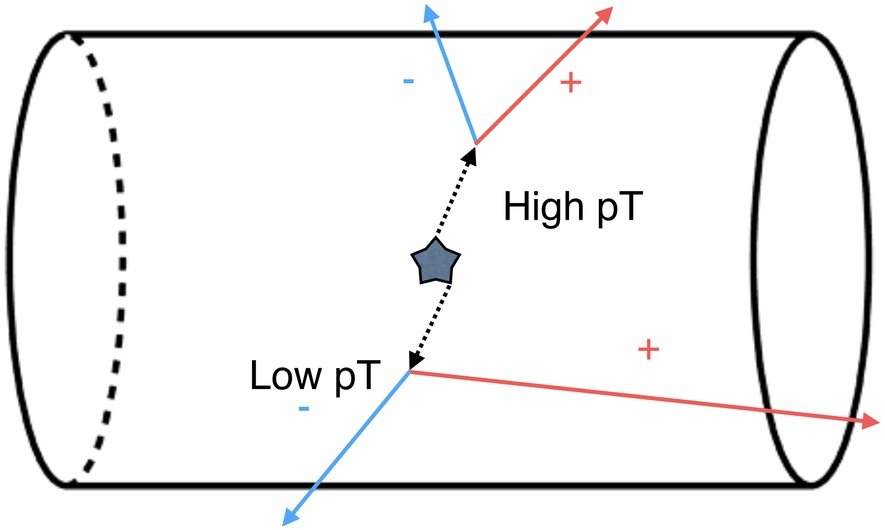
Slope of v_2 vs Centrality



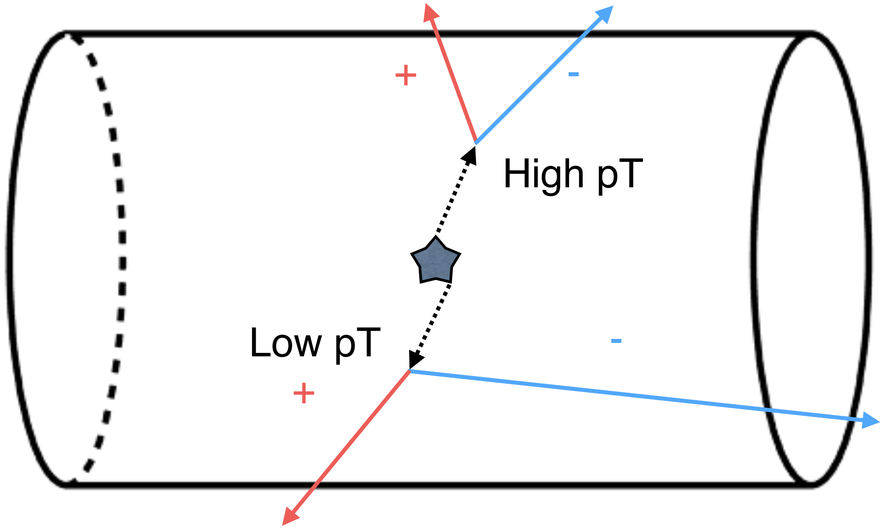


- At GeV scale, data are consistent with the qualitative expectations from the CMW picture, and the slope parameter follows a centrality dependence qualitatively similar to the theoretical calculations of the CMW
- At TeV scale, the slopes remain the same, however, with weaker centrality dependence

Possible background — Local Charge Conservation



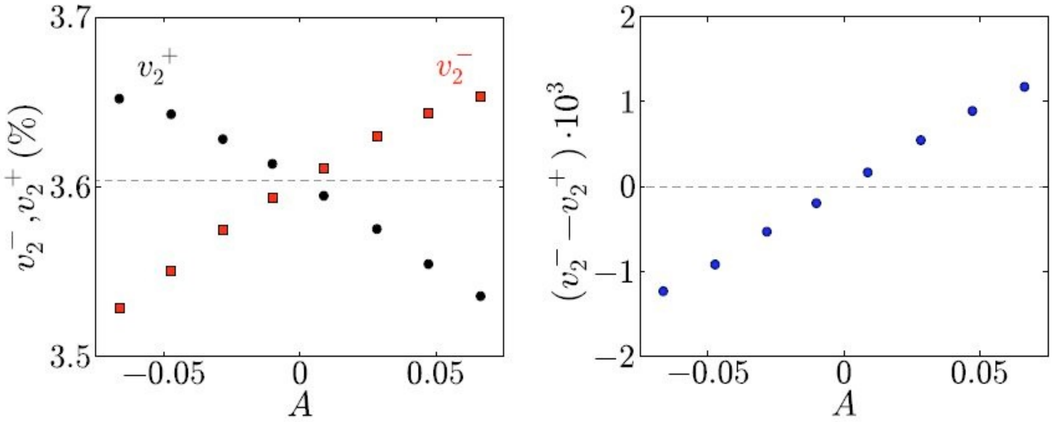
A_{ch} decrease
mean p_T (-) < mean p_T (+)
v_2 (-) < v_2 (+)



A_{ch} increase
mean p_T (-) > mean p_T (+)
v_2 (-) > v_2 (+)

A. Bzdak, P. Bożek / Physics Letters B 726 (2013) 239–243

Possible background — Local Charge Conservation



Local charge conservation (LCC) at freeze-out, when folded with the characteristic shape of v2(η) and v2(p_T) at RHIC energies, can be manifested in the measurement of v_2, v_3 and different η coverage

$$\Delta v_3/\Delta v_2 \sim v_3/v_2$$

How to examine LCC?

- Check <p_T> vs A_{ch}
- Investigate the v_3 slope
- Perform the measurement in the small system collisions

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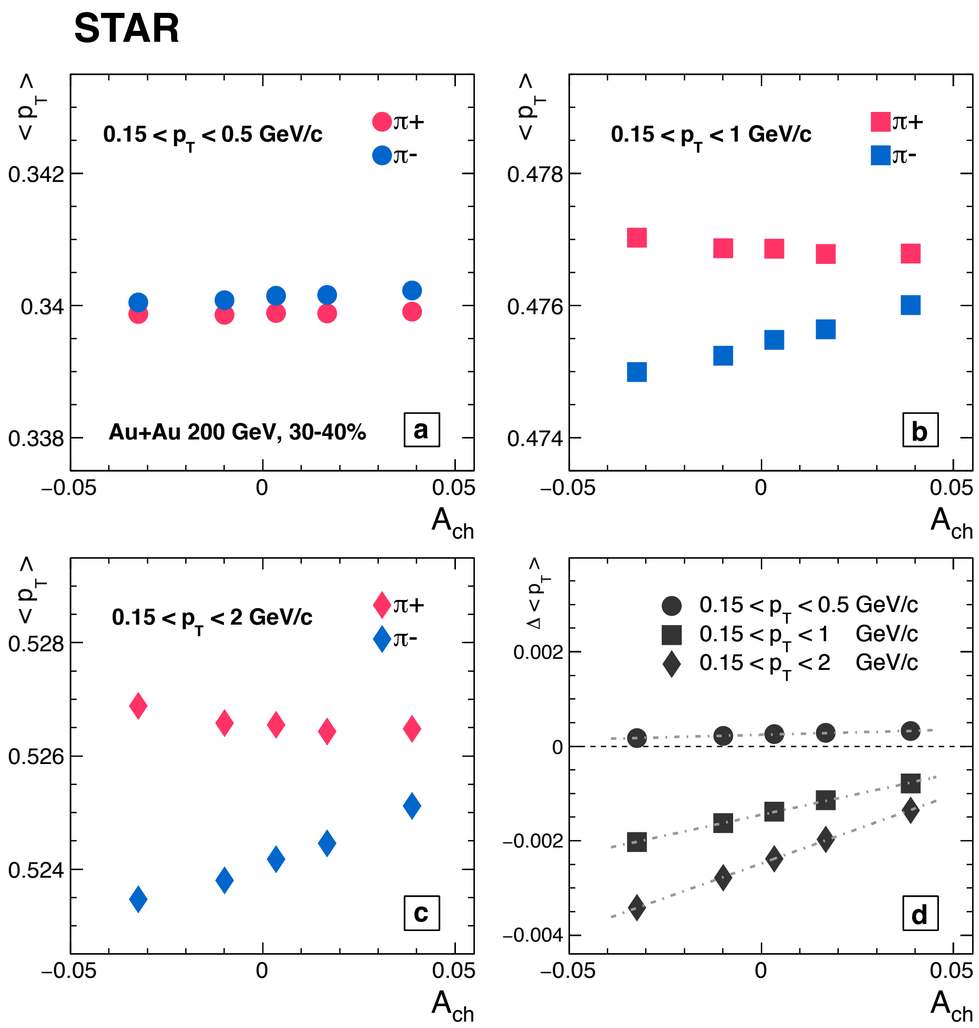
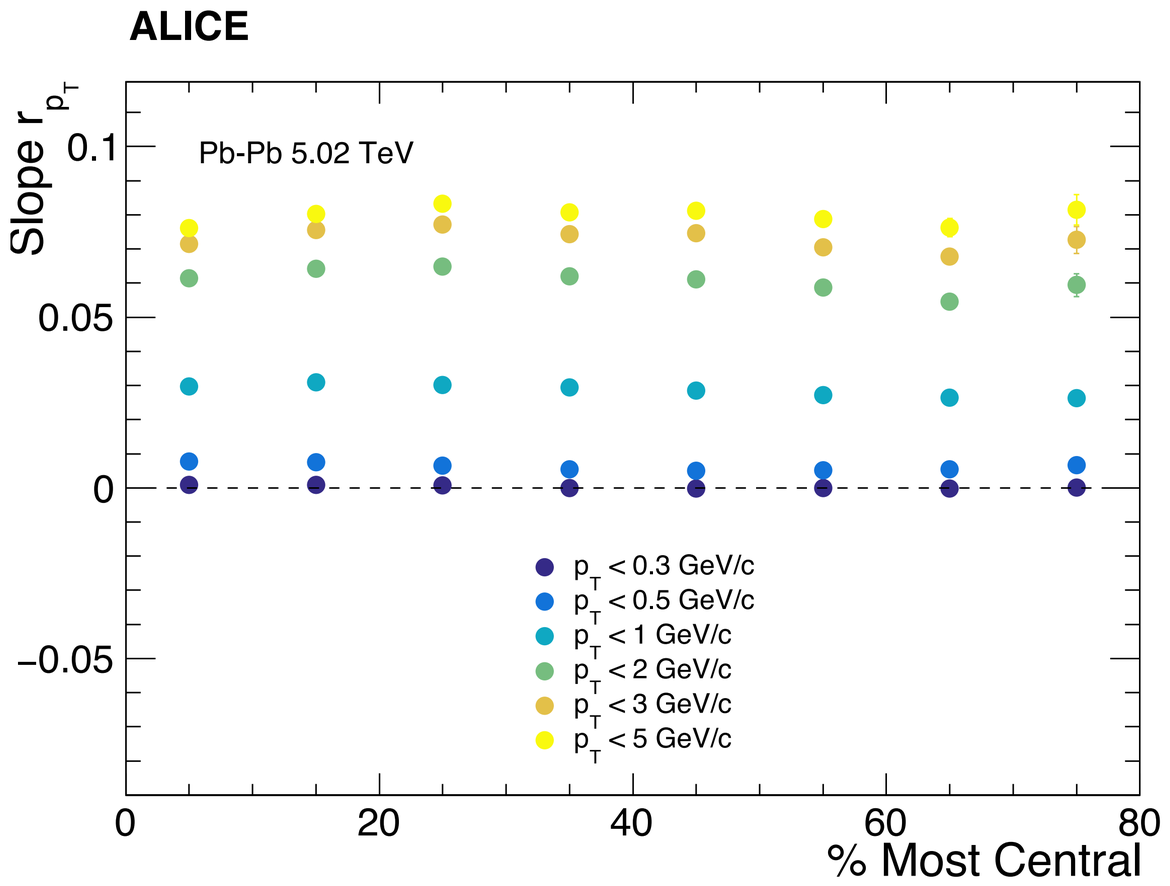
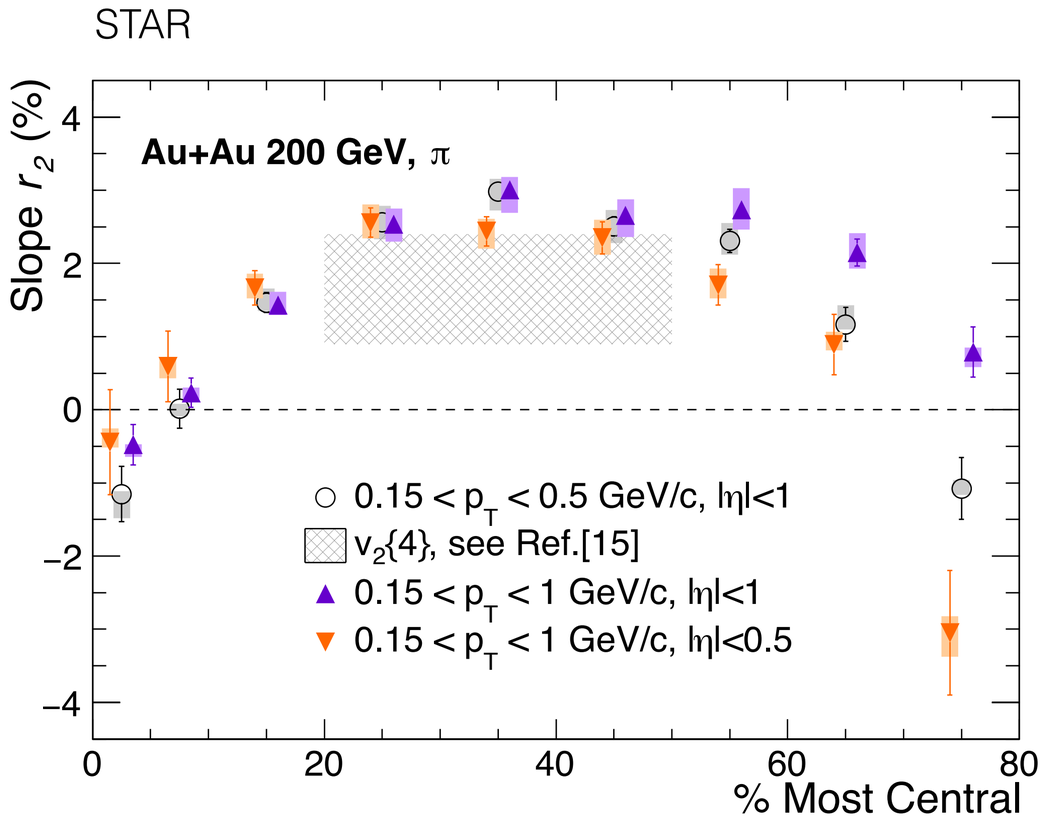
<p_T> vs A_{ch}

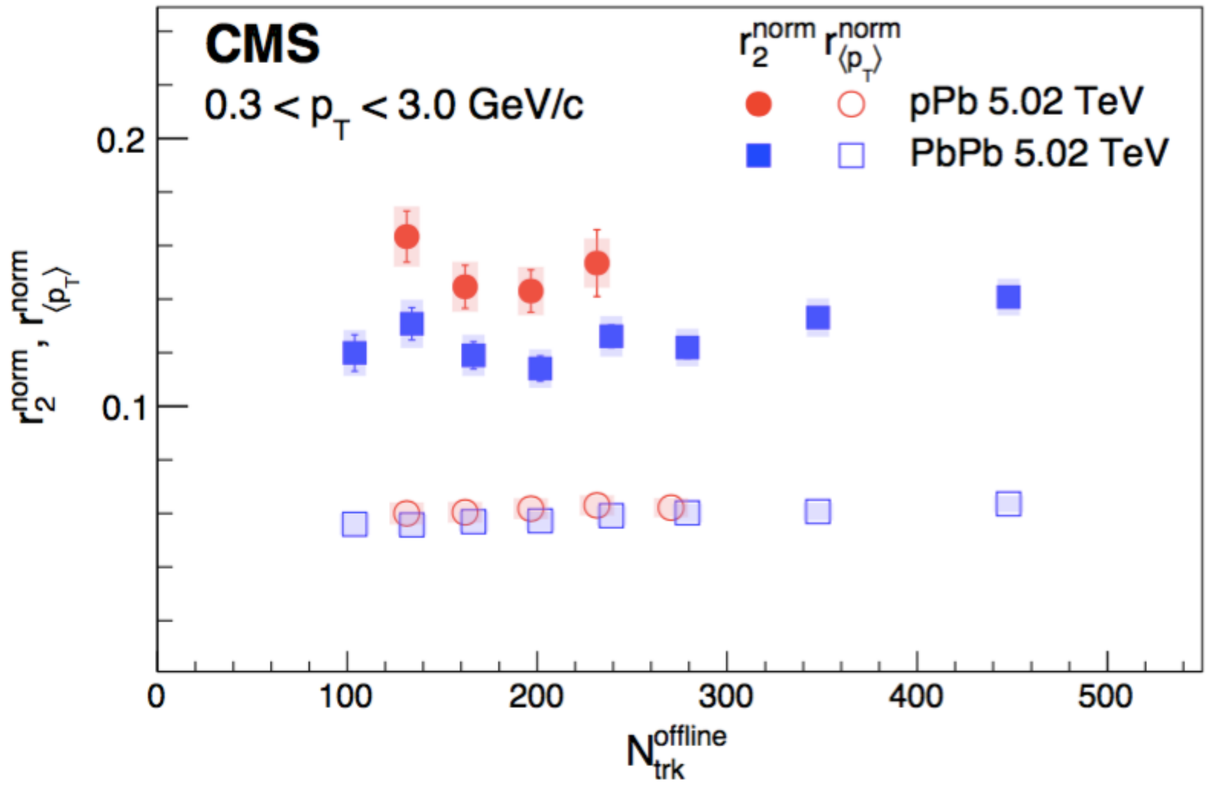




- In a widened p_T coverage, the dependence between <p_T> vs A_{ch} get stronger

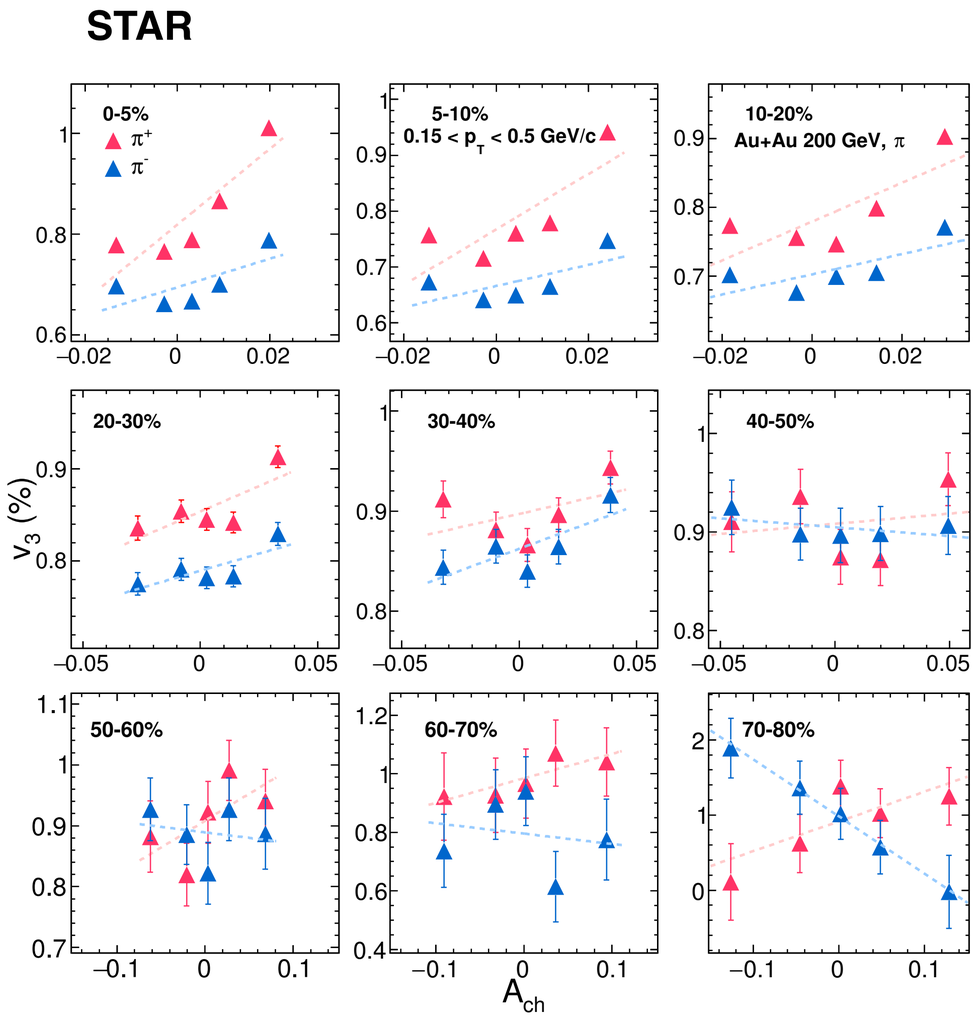
Slope of v_2 and p_T vs centrality (N_{trk})

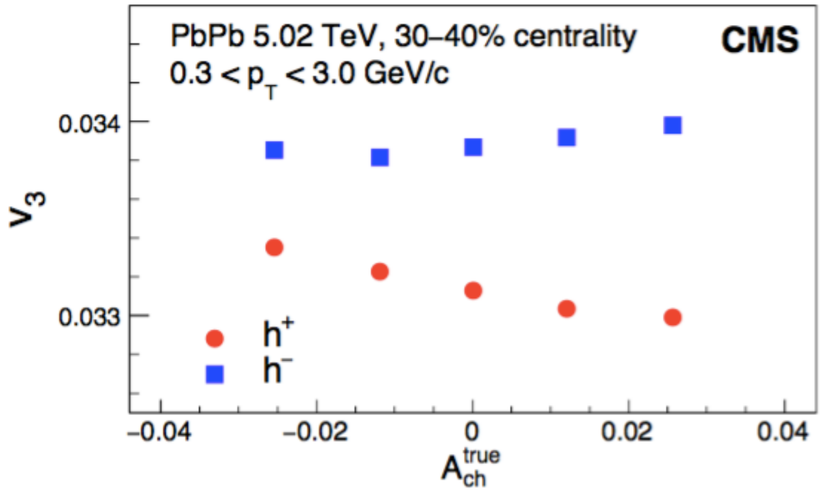


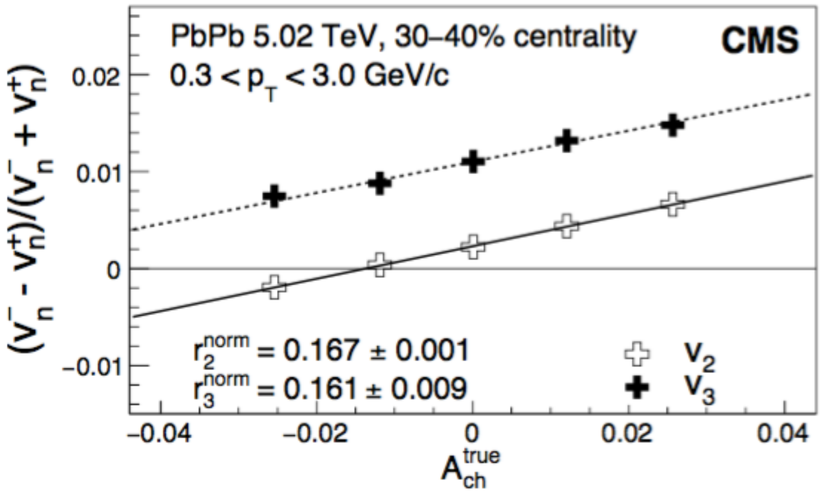


- To remove the contamination from <p_T> vs A_{ch}, one should keep the p_T coverage as low as possible

Experimental measurement of A_{ch} dependent v_3

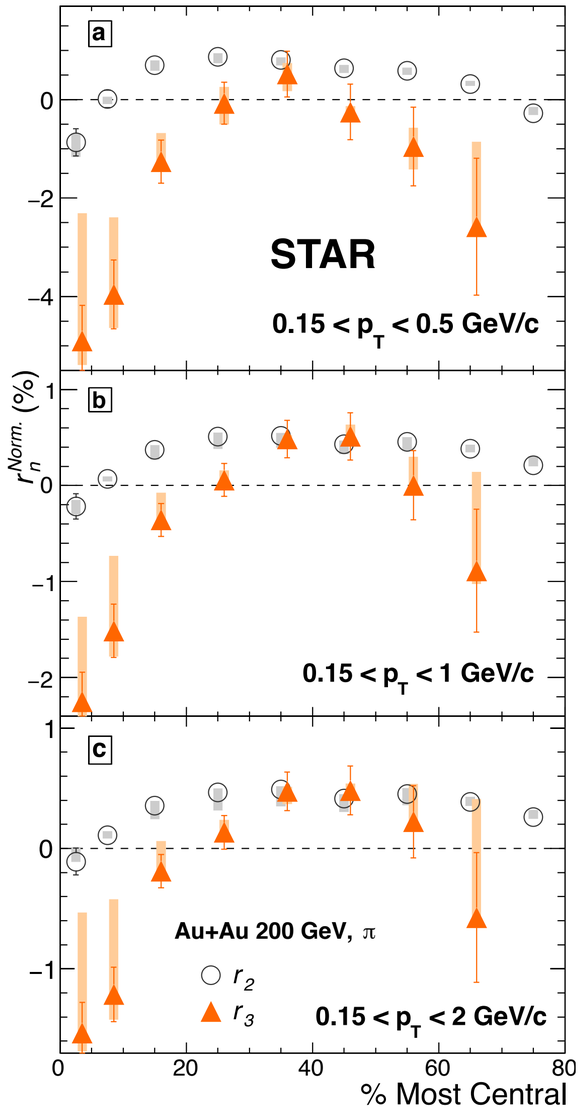


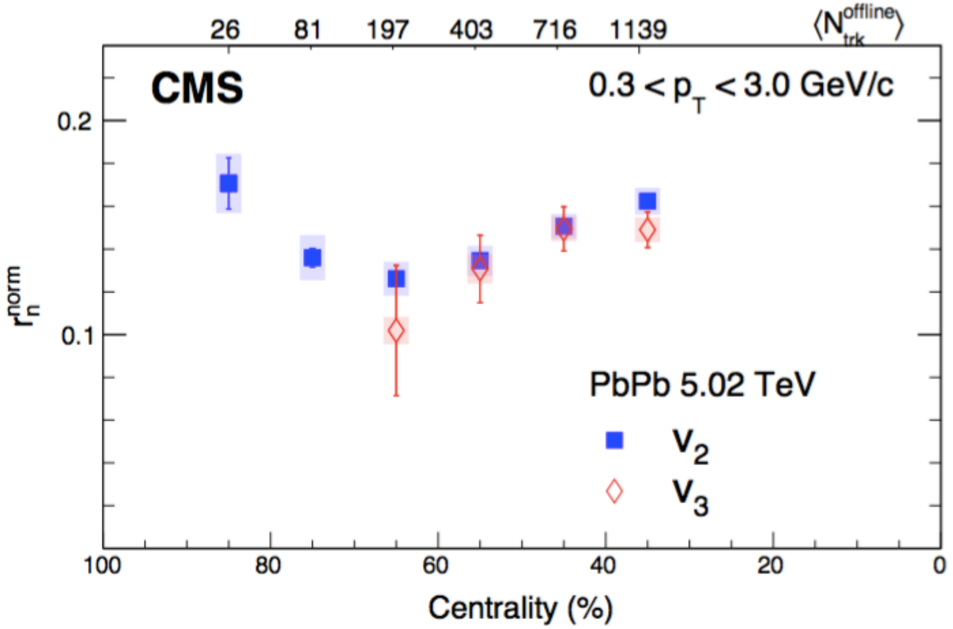




- The linear dependence between v_3 and A_{ch} gets weaker at STAR, however, remains unchanged at CMS

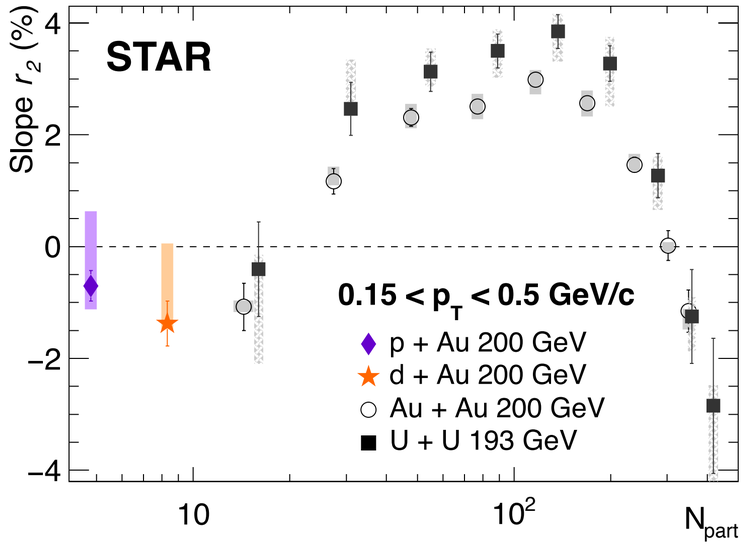
Slope of v_3 vs centrality

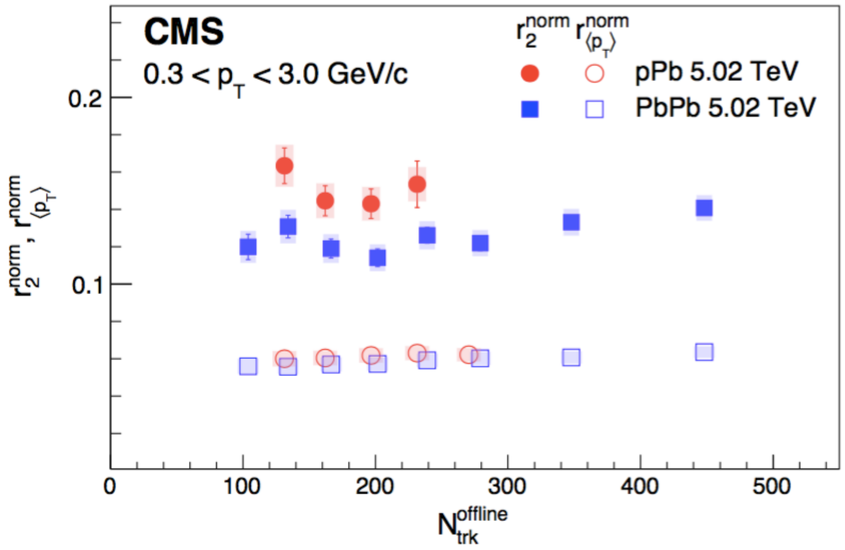


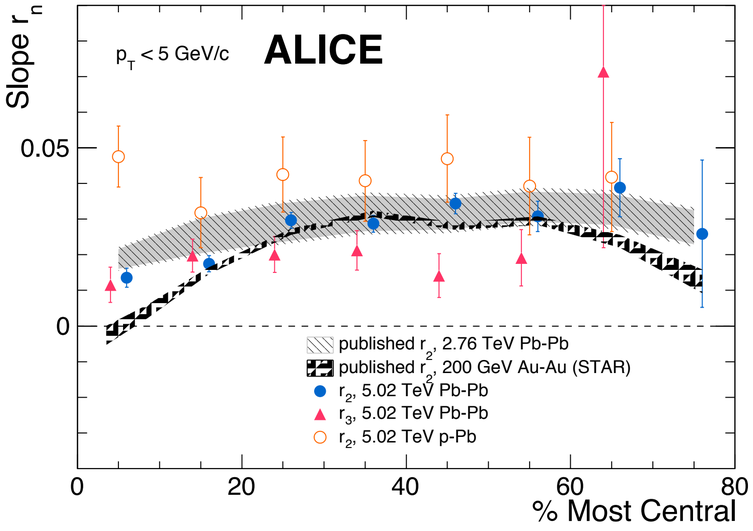


- For STAR data, the normalized slopes of v_2 and v_3 are basically consistent with each other at semi-central collisions, however, behave differently in most central and peripheral collisions, which can be explained by the non-flow contribution (expected to be presented at QM19)
- Consistent with each other in CMS data

Slope vs centrality in small system collisions







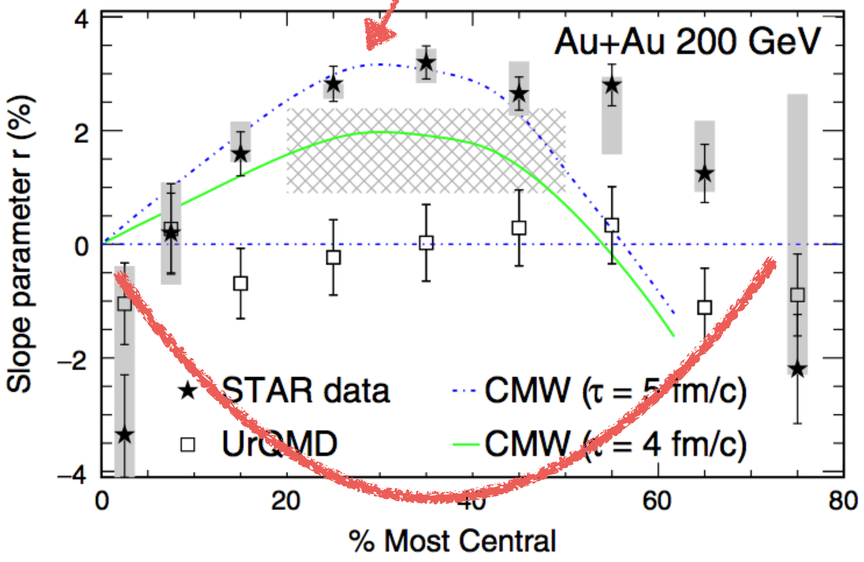
- The slopes in pAu and dAu are consistent with zero at STAR
- Similar slopes (positive) are observed in pPb collisions at both CMS and ALICE, however, in a wider p_T range

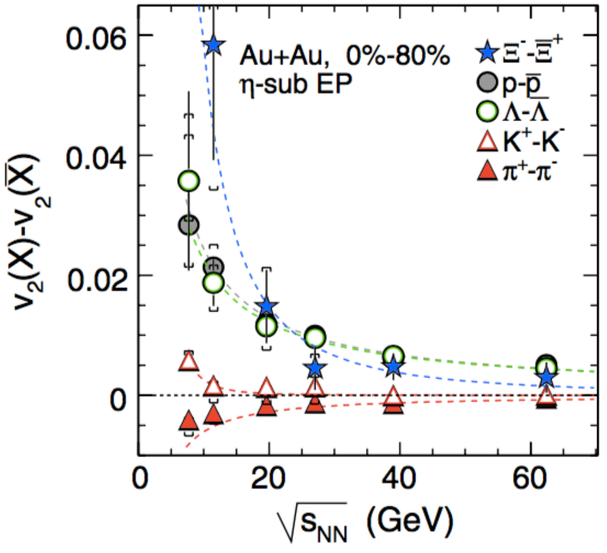
Possible background — Isospin+hydrodynamics

"… We demonstrate that the STAR results can be understood within the standard viscous hydrodynamics without invoking the CMW…"

$$\Delta v2 \propto -\mu_I;\ A_{ch} \propto -\mu_I \text{ (assumed)};\ \Rightarrow \Delta v2 \propto A_{ch}$$

"… the slope r for the kaons should be negative, in contrast to the pion case, and the magnitude is expected to be larger… Note that in these predictions are integrated over $0 < p_T < \infty$. In order to properly test them, a wider p_T coverage is necessary…"



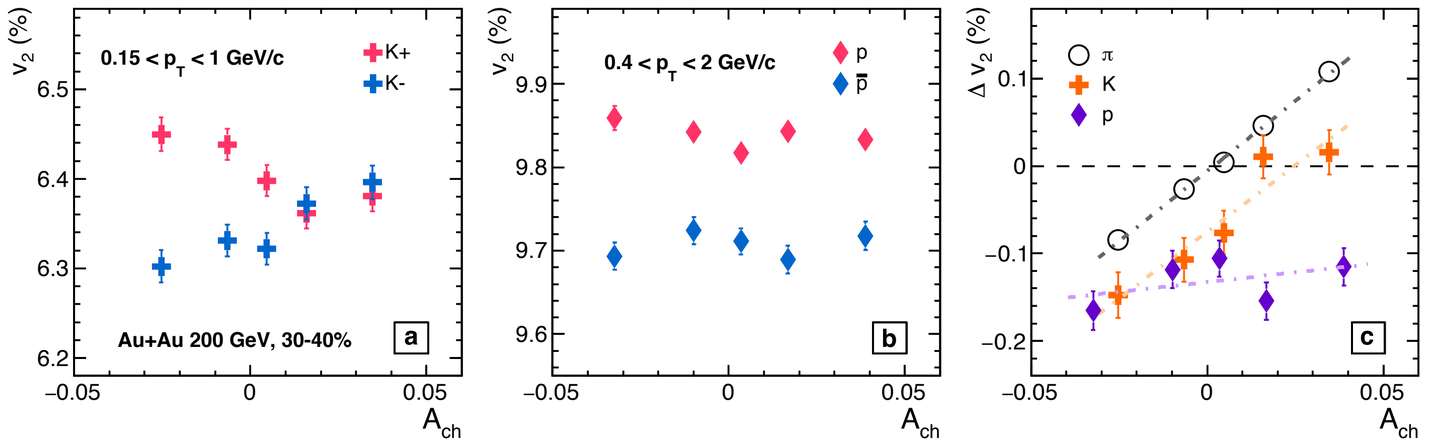


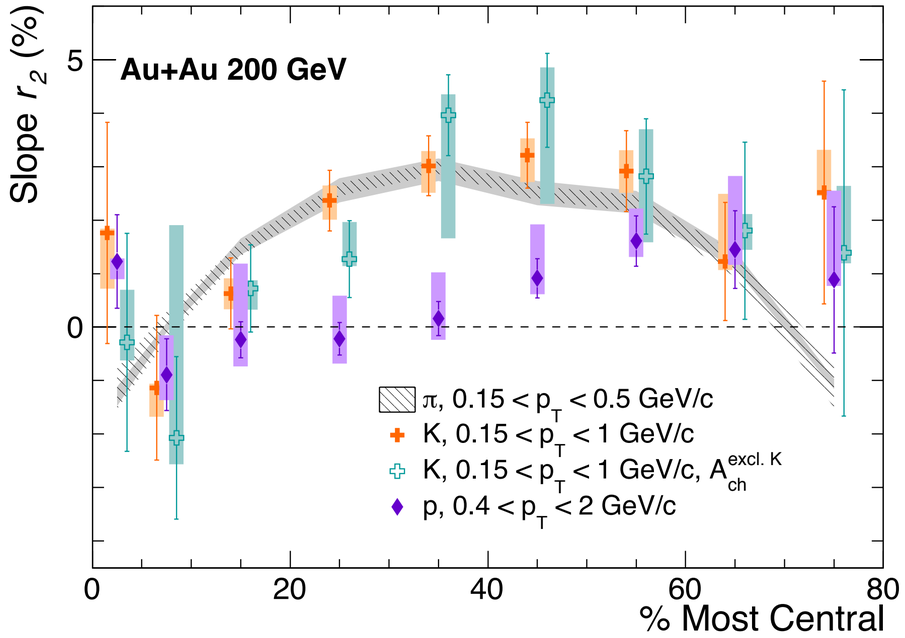
Hydrodynamics study suggests that, with wider p_T coverage, K slope should be opposite to π slope with larger magnitude, since

$v_2(\pi^+) < v_2(\pi)$, $v_2(K^+) > v_2(K^-)$

Y. Hatta et al. / Nuclear Physics A 947 (2016) 155–160

Measurements with identified K and p





- Centrality dependence of slope parameters for K behave similarly to that of π
- Intercepts for kaons K negative, while intercepts for pions are consistent with zero
- The p slopes are smaller than that of pions and kaons, except in the most peripheral collisions. Such discrepancy motives future studies

Summary

- The existence of Chiral Magnetic Wave has been searched for at ALICE, CMS and STAR
- The clear linear relationship between v_2 and A_{ch}, usually considered as a possible evidence, is observed at all experiments, however, is this a signal?
- The background effect of LCC is examined with different measurements
- The isospin effect gives the wrong prediction.
- More inputs from theoretical experts are expected. Any other background source?
- Any other observable besides the slope?
- More updated experimental results will be presented at QM19