Charge dependent 3 particle correlation as a probe for jet-medium interaction in high multiplicity classes of small collision systems

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Plan of the Talk

a) Motivation

b) Possible nature of Jet-medium interaction in small collision systems

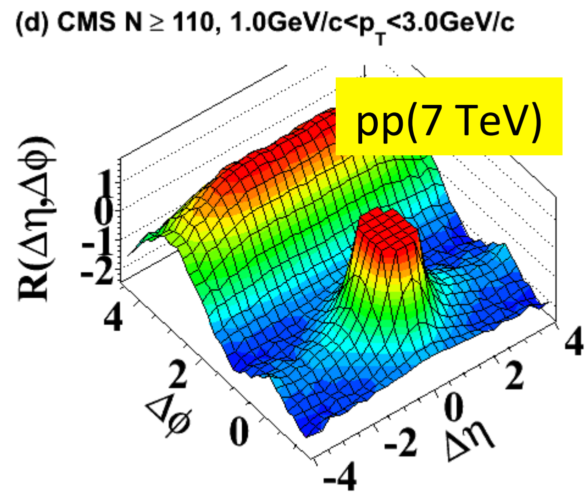
c) 3 particle correlation results from EPOS and AMPT

d) Summary

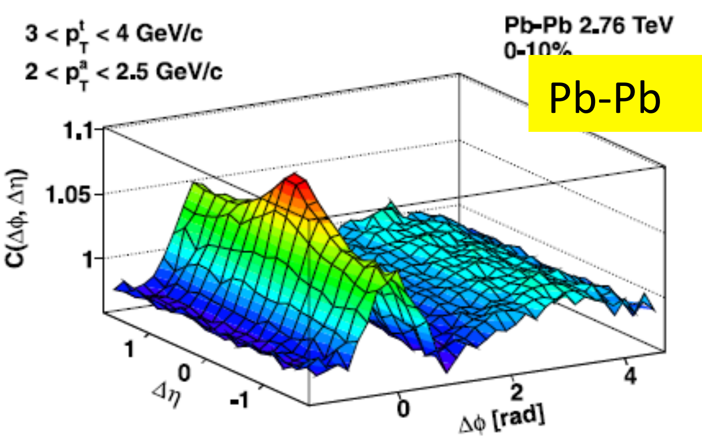
The Near-Side Ridge in pp and p-Pb!!

- Observed in high-multiplicity pp and p-Pb collisions

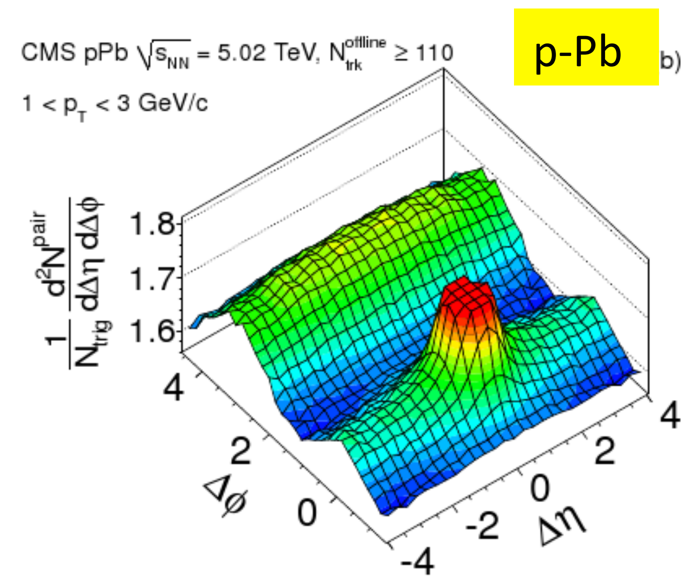
- Well known feature from Pb-Pb collisions (→ collective flow)



CMS, JHEP09(2010)091

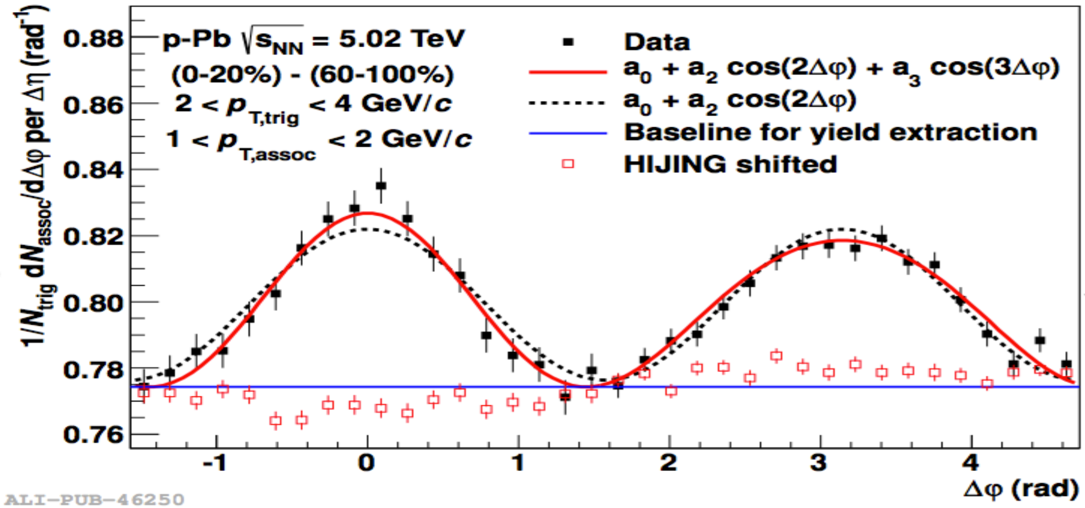


ALICE, PLB708 (2012) 249

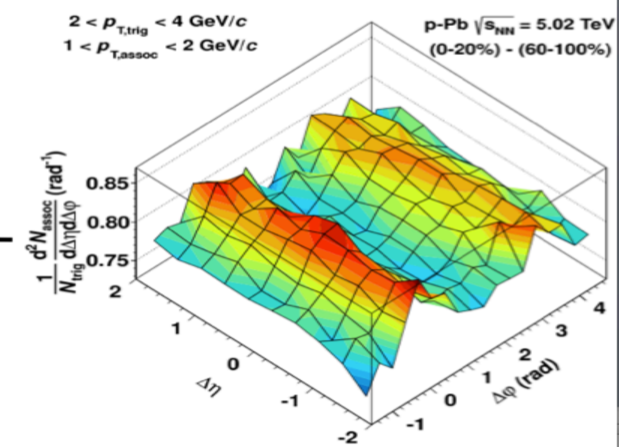


CMS, PLB718 (2013) 795

Collectivity in small systems!!

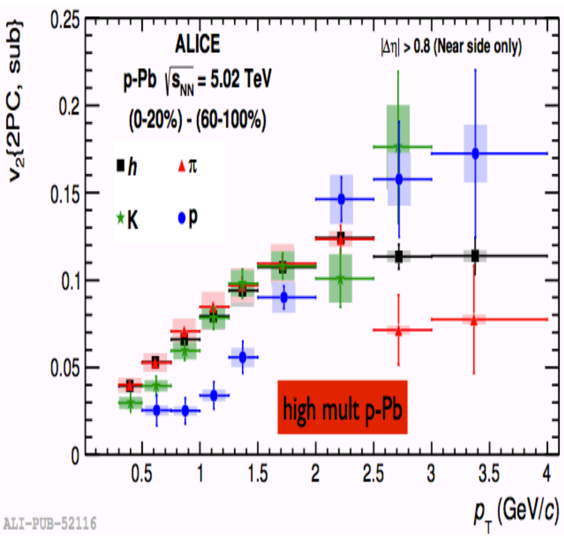


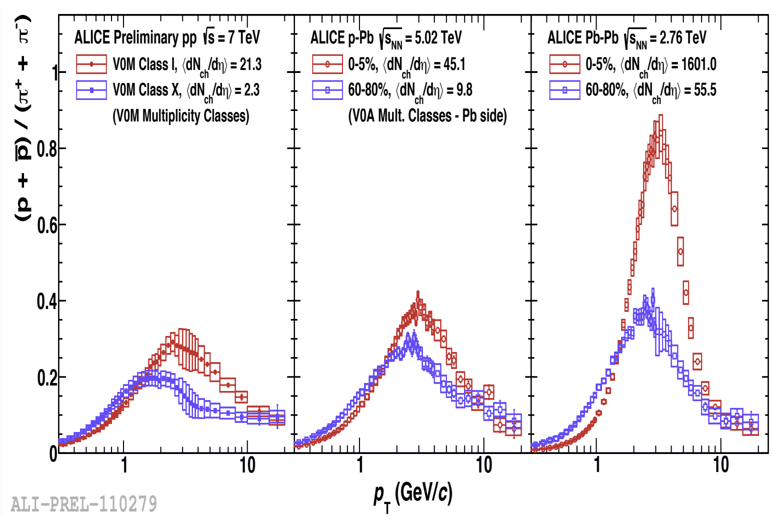
Phys. Lett. B 719 (2013) 29-41



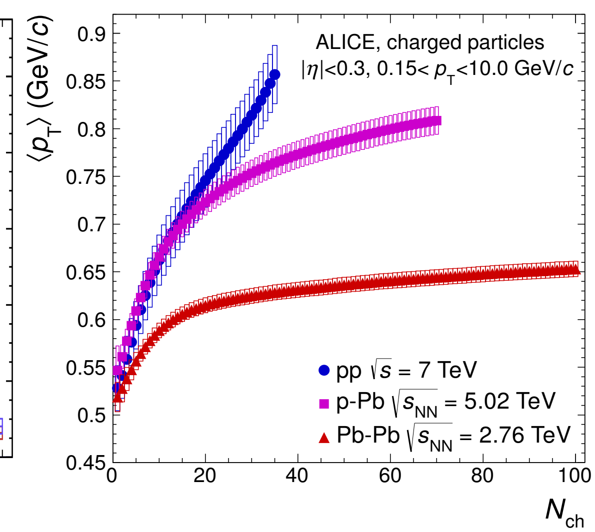
Hint of Collectivity…!!

Phys. Lett. B 719 (2013) 29-41





Physics Letters B [727, 4–5](),



Final state collectivity in *small* collision systems OR some other physics mechanisms are mimicking final state collectivity in small systems??

- ❑ ***Observables to probe final state collectivity*** **– Ridge, elliptic flow (V_2), mass ordering of V_2, hardening of Spectra, baryon to meson enhancement at intermediate p_T, mass and multiplicity dependence of <p_T>…**

- ❑ **A possible way to deal with this issue - Comparison of the data results (in terms of the above mentioned observables) with the output of different event generators (include different physics mechanisms).**

Issue: Different physics mechanisms can mimic the flow like effects (at least qualitatively) as observed in small collision systems (pp and p-Pb collisions) at LHC energies.

- ***Parton cascade + Coalescence + Hadronic Transport** – explains ridge, V_2, mass ordering of V_2, Spectra, baryon to meson enhancement at intermediate p_T (at least qualitatively)*

G-L Ma and A Bzdak - PLB 739 (2014) 209-213; A Bzdak and G-L Ma - PRL 113, 252301(2014); Liang He et al - PLB 753 (2016) 506-510; Y. Zhou et al - PRC 91, 064908 (2015); ***D. S, S.C, S.C – PRC 94, 044919 (2016)*** ; ***D. S, S. C, S.C – PRC 94, 044909 (2016)***

- ***MPI +Color Reconnection - explains mass and multiplicity dependence of <p_T>, flattening of Spectra, baryon to meson enhancement at intermediate p_T (at least qualitatively), narrowing of balance function width with multiplicity***

A Ortiz Velasquez et al Phys. Rev. Lett. 111, 042001 (2013); C. Bierlich and J. R. Christiansen, Phys. Rev. D 92, 094010 (2015); ***D. S, S. C –*** arXiv:1710.09785 [hep-ph]

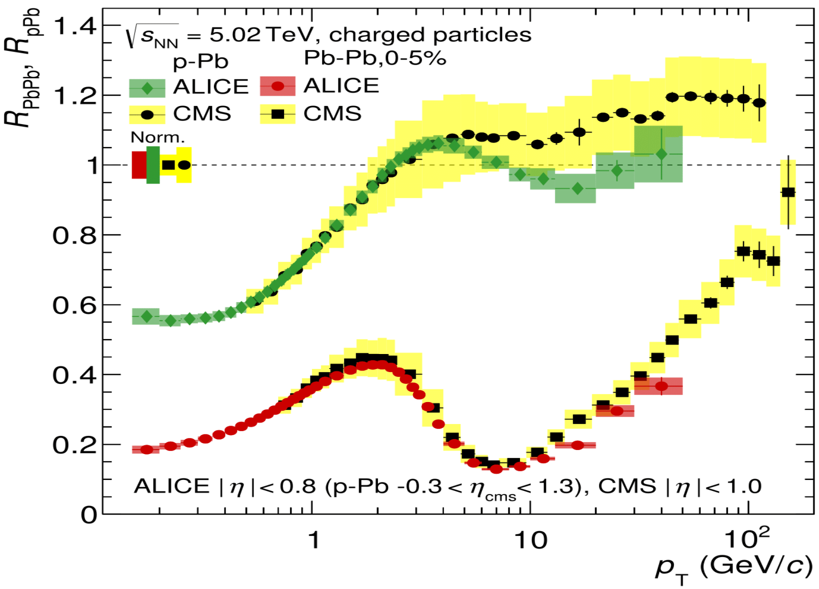
- ***3+1 D Hydro – explains all of the above mentioned observables (at least qualitatively)***

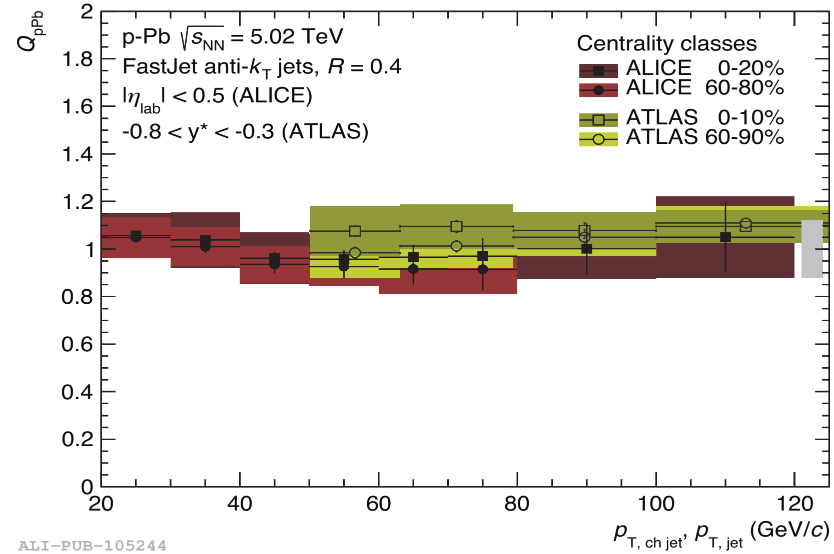
K. Werner et al - PRL. 112 (2014) 23, 232301; K. Werner et al – PRL 106 (2011) 122004; K. Werner et al – PRC 89 (2014) 6, 064903; P Bożek et al -Phys. Rev. Lett. 111, 172303 (2013), ***D. S, S.C, S.C – PLB 760 (2016) 763 – 768, D. S, S.C, S.C –PRC 95, 044906 (2017), D. S- Phys. Rev. D 97, 034036 (2018)***

- ***Possible Solution: Jet quenching can be the smoking gun!!...***

A Twist….

arXiv:1802.09145 [nucl-ex]

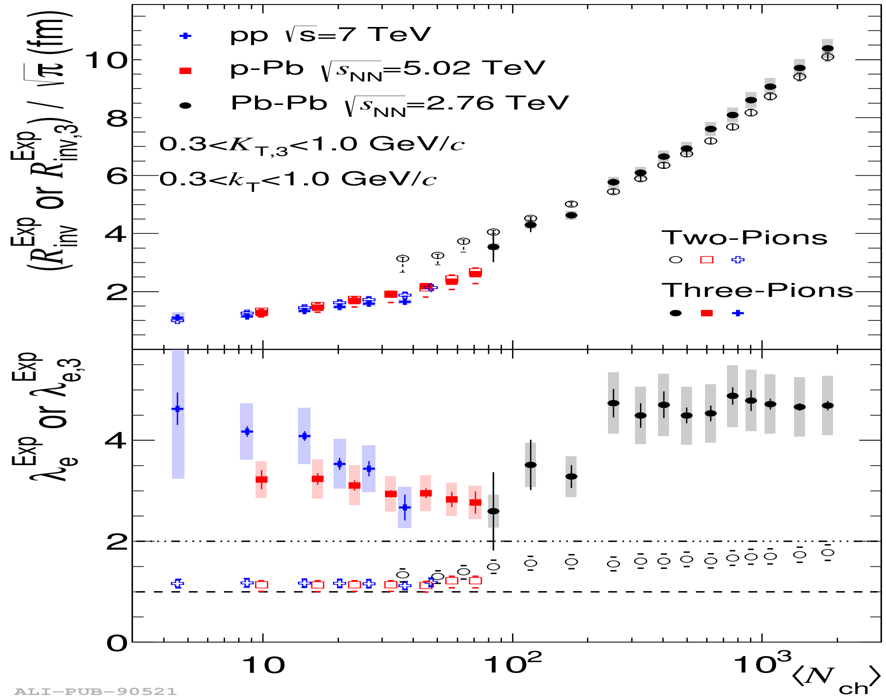




EPJ Web of Conferences 71, 00101 (2014)
DOI: 10.1051/epjconf/20147100101

- ***No Jet Quenching in p-Pb BUT significant Jet Quenching in Pb-Pb!!***
- ***The interplay between the intrinsic momentum scale of the jet and characteristic scales of the medium (size, density etc) decides the kinematic range of the jets which are most affected by the fluid-jet interaction…***
- ***For PbPb, the medium is large and dense - quenching exists upto very high p_T particles (upto 100 GeV/c)***
- ***What about p-Pb??. Are we looking at the relevant kinematic range??***

Jet-medium interaction depends on system size



Phys. Lett. B 739 (2014) 139-151

❖ *The size of the emitting source can be estimated from interferometric two/three particle Correlations:*

$$R \propto \left(\frac{dN_{ch}}{d\eta}\right)^{1/3} \quad dN_{ch}^{pPb}/d\eta \sim 225$$

$$dN_{ch}^{PbPb}/d\eta \sim 1600$$

Konrad Tywoniuk,
Nuclear Physics A 926 (2014) 85-91

❖ *The active systems size (L) can be approximated as the size of the emitting source (R):*

$$L|_{pPb} = \frac{1}{2} L|_{PbPb}$$

Jet-medium interaction depends on transport coefficient of the medium (qhat)

❖ *qhat is a measure of the typical transverse momentum broadening of the jet per unit length traversed in the plasma…*

❖ *qhat in association with the typical length scales of the system gives rise to characteristic momentum scales which compete with the intrinsic momentum scales of the jet:*

Konrad Tywoniuk,
Nuclear Physics A 926 (2014) 85-91

$$\hat{q} \propto \#\text{D.O.F.} \times \frac{\mathrm{d}N_{\text{ch}}}{\mathrm{d}\eta}.$$

❖ *Experimental observations indicate the release of partonic degrees of freedom in p-Pb collisions similar to the Pb-Pb collisions but at a smaller scale…*

$$\hat{q}|_{\text{pPb}} = \frac{1}{7}\hat{q}|_{\text{PbPb}}.$$

$$\mathrm{d}N_{\text{ch}}^{\text{pPb}}/\mathrm{d}\eta \sim 225$$

$$\mathrm{d}N_{\text{ch}}^{\text{PbPb}}/\mathrm{d}\eta \sim 1600$$

❖ *The energy loss by jets is dominated by the hardest gluon emissions—with the characteristic gluon frequency:*

$$\omega_c \equiv \frac{1}{2}\hat{q}L^2$$

$$\hat{q}|_{\text{pPb}} = \frac{1}{7}\hat{q}|_{\text{PbPb}}.$$

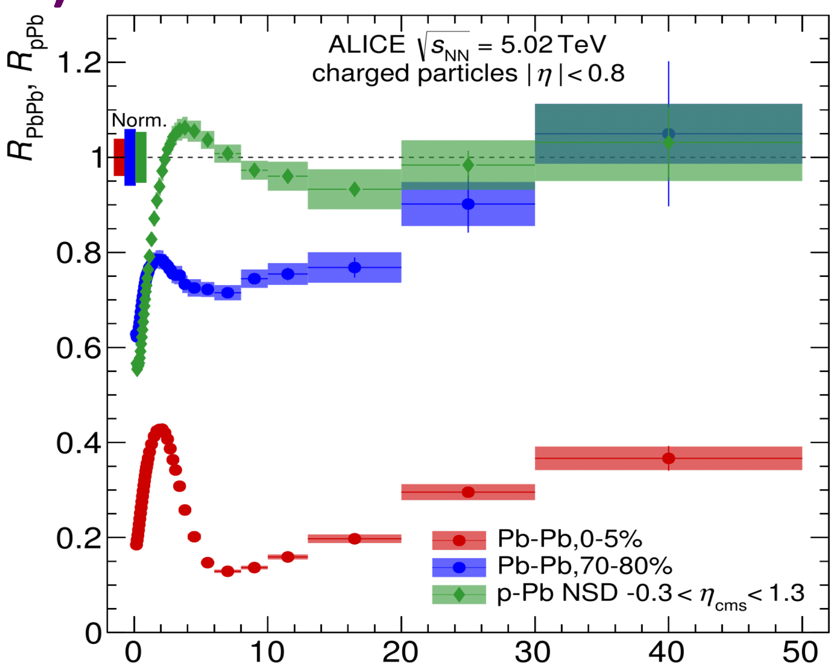
$$L|_{\text{pPb}} = \frac{1}{2}L|_{\text{PbPb}}.$$

$\omega_c^{pPb} \approx (1/30)\omega_c^{PbPb}$

So, the jet energy loss in p-Pb systems is ≈30 times less probable than Pb-Pb collisions!!

Jet-Medium interaction in small collision systems

a)



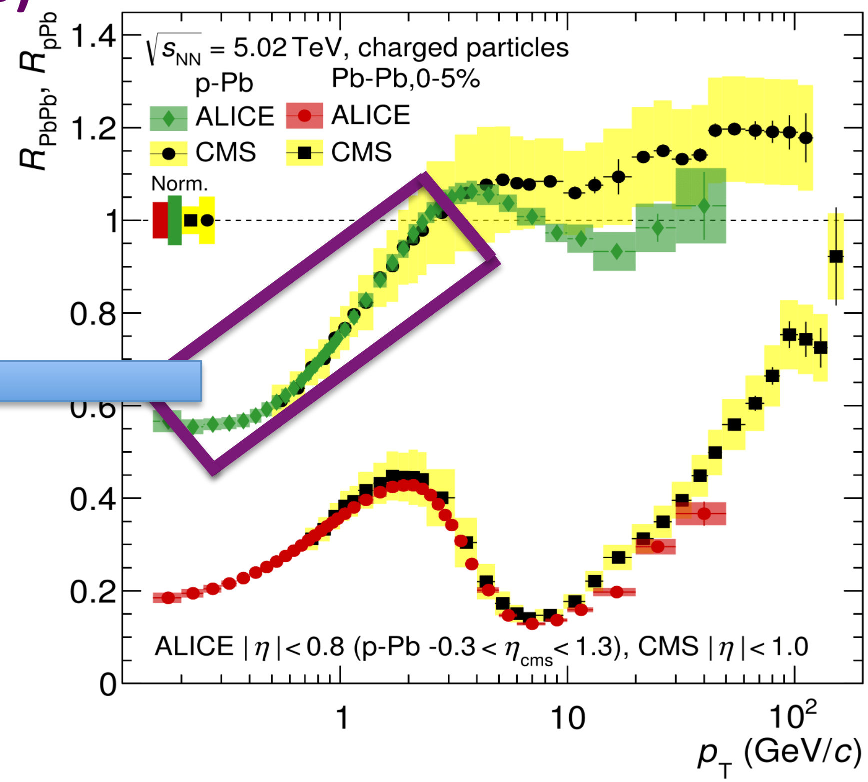
arXiv:1802.09145 [nucl-ex]

$R_{pPb} \approx 1$ for $p_T > 10$ GeV/c indicates:

a) High p_T region is free from final state Interactions in small collision systems.

b) But, this is NOT a concrete evidence for absence of Jet-medium interaction in small systems.

b) *arXiv:1802.09145 [nucl-ex]*



Kinematic region sensitive to Jet-medium interaction in small collision systems.

Konrad Tywoniuk, Nuclear Physics A 926 (2014) 85-91

Jet-Medium interaction in small collision systems

❖ ***The medium formed in p-Pb collisions may act as transparent one to the higher p_T jets.***

❖ ***The lower p_T jets (mini jets) have a larger probability to interact with the smaller and dilute medium formed in high multiplicity p-Pb collisions.***

BUT, There are issues with low p_T jets (mini jets):

1) The perturbative calculation fails. The approaches become highly model dependent.

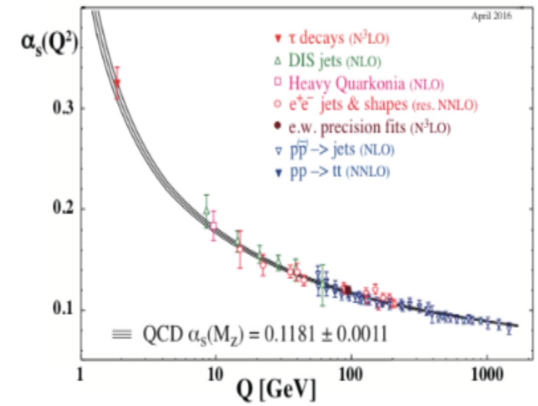
2) The jet reconstruction is complicated because of large background.

❖ ***So, we need a tool which doesn't depend on the background subtraction and also sensitive to the jet-medium interplay!!***

The charge dependence of 3 particle correlation may shed some light…

❖ ***But, at first we need to know about how the jet and the jet-medium interaction are designed in the event generators.***

Jet Fragmentation in event generators

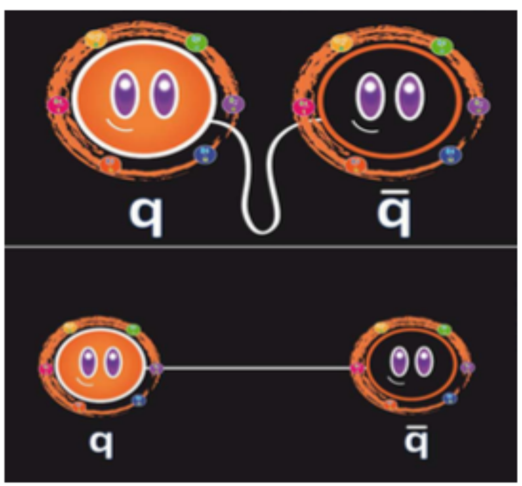


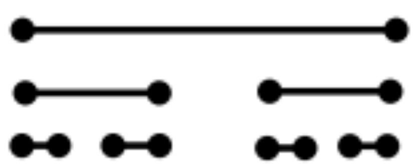
❖ ***Based on experimentally observed information :***

1) Quarks have never been observed as free.

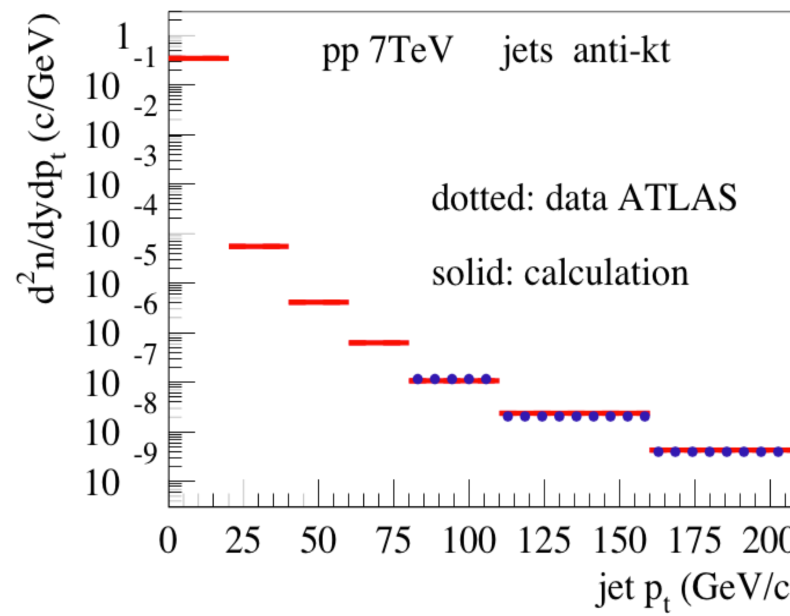
2) Asymptotic freedom (quarks behave as free for large momentum transfer i.e when they are spatially very close).

These two features can be implemented using string dynamics (F=-Kr) and can explain the jet spectra in pp collisions at the LHC energies.





Phys. Rev. C 85, 064907 (2012)



Jet-medium interaction: PYTHIA jet fragmentation in the hydrodynamic background - EPOS

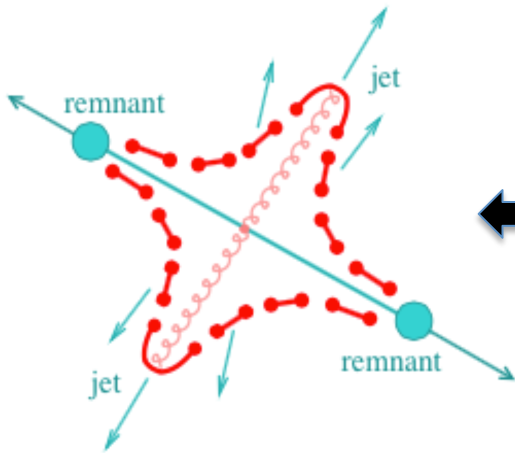


Figure 2: (Color online) Flux tube breaking via $q-\bar{q}$ production, which screens the color field (Schwinger mechanism).

Lowest Multiplicity class

String fragmentation in low density region following usual Schwinger mechanism- creating Jet hadrons (corona).

Highest Multiplicity class

String fragmentation/flux tube breaking using partons from the bulk/core. These jet hadrons(corona) will carry fluid information and eventually be correlated with the bulk(core) part of the system.

The low and intermediate p_T string segments are most affected by this interaction

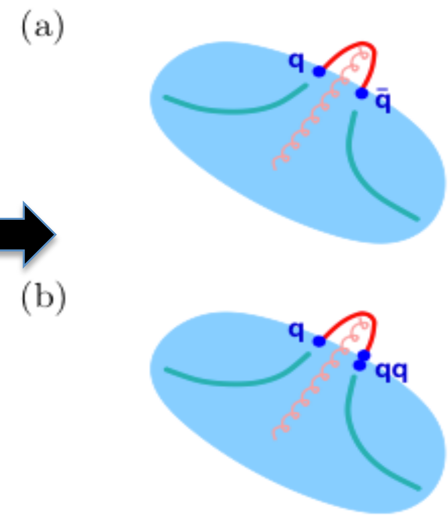
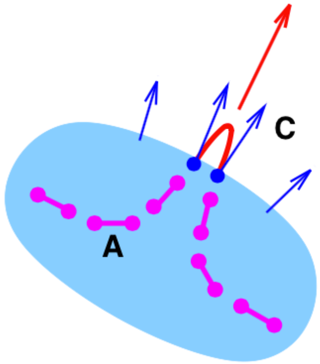


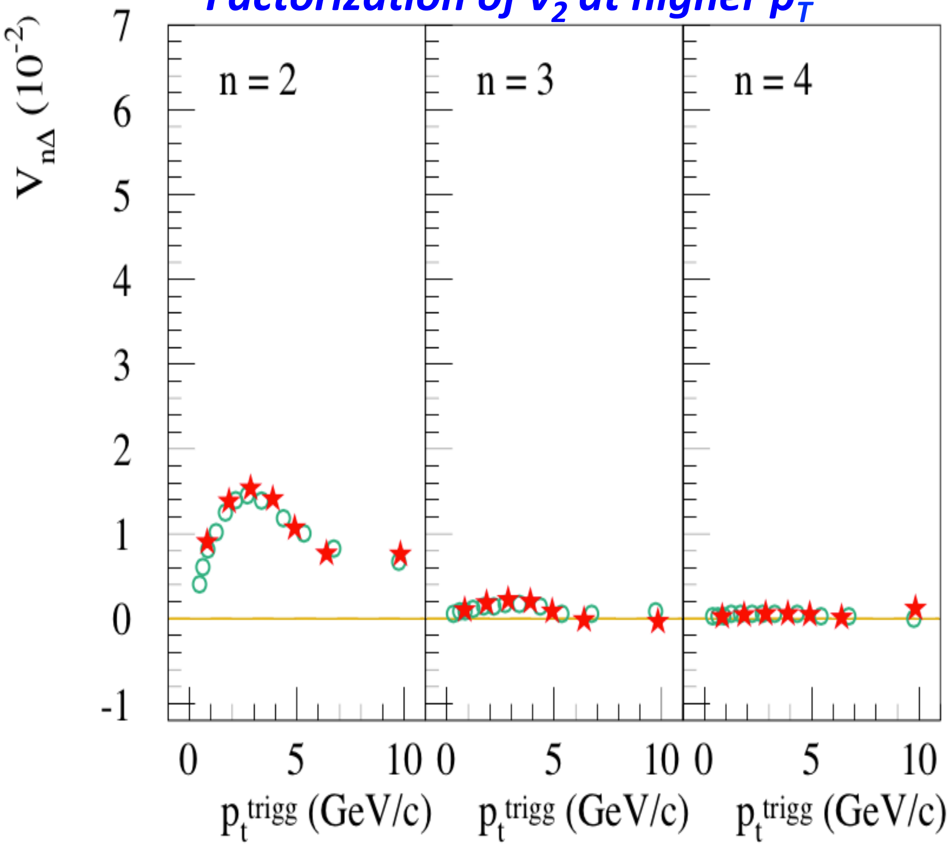
Figure 3: (Color online) Escaping string segment, getting it's endpoint partons from the fluid. We show the case of a quark and an antiquark (a) and of a quark and a diquark (b). The rest of the string dissolves in matter.

Phys. Rev. Lett. 109, 129903 (2012)

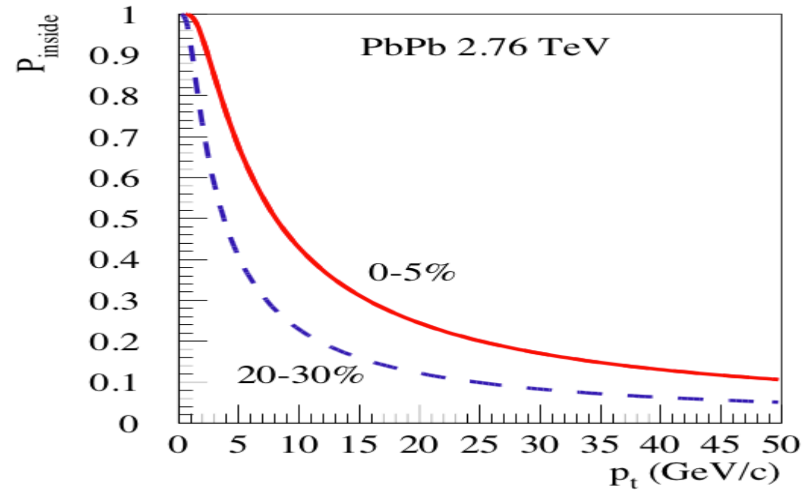
Effect of Jet-Fluid interaction on final state observables



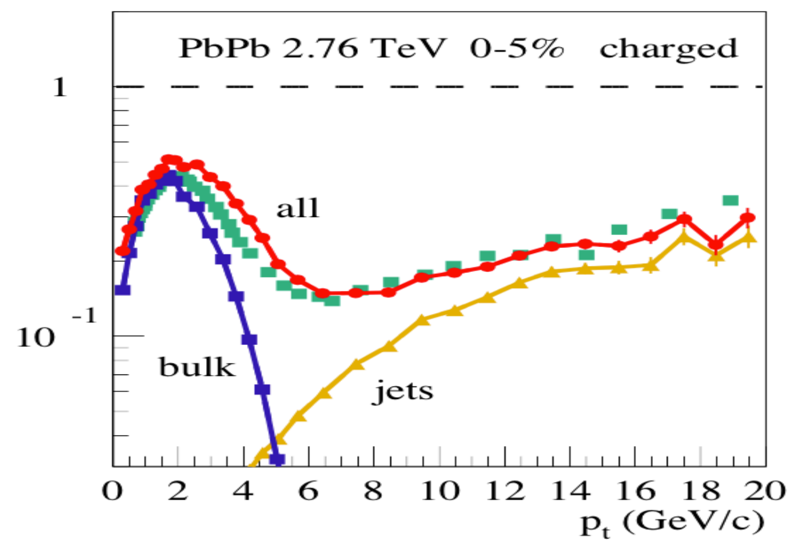
Factorization of v_2 at higher p_T



Phys. Rev. C 85, 064907 (2012)



Nuclear modification factor



Does it affect the charge dependence of 3 particle correlation ??

3 particle correlation in small collision systems

Observables :

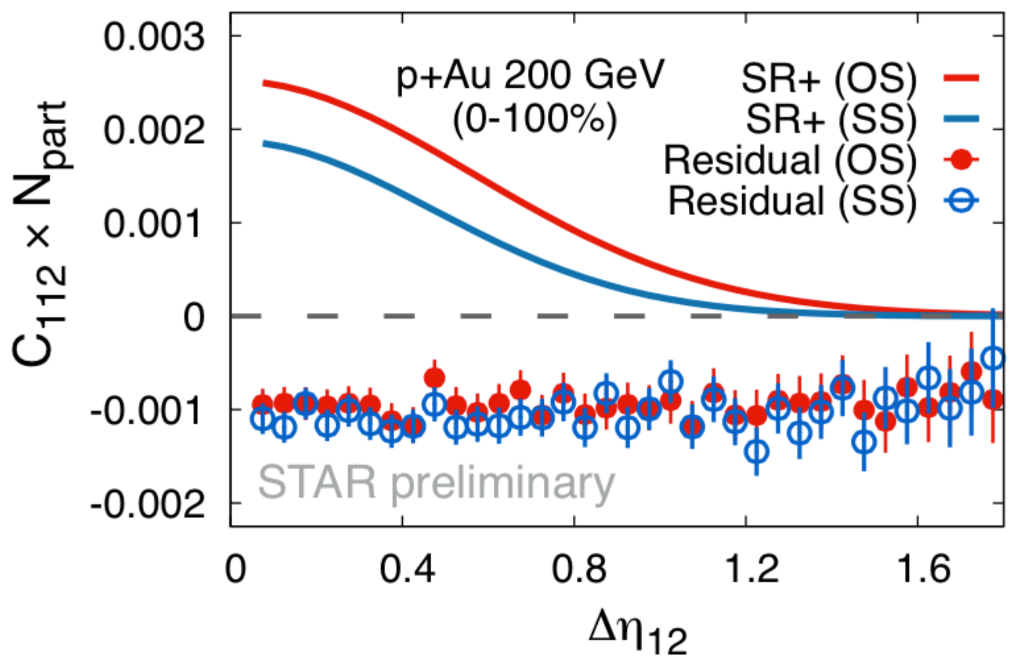
Voloshin, PRC 70 (2004) 057901

Three particle correlator : $C_{112} = \langle \cos(\phi_1 + \phi_2 - 2\phi_3) \rangle$

$$\gamma^{a,b} = \langle \cos(\phi_1^a + \phi_2^b - 2\Psi_2) \rangle$$

a,b → same sign
a,b → opposite sign

❖ ***This observable describes the two particle correlation with respect to the event plane. Initially designed to study Chiral Magnetic Effect (CME) in heavy ion collisions***

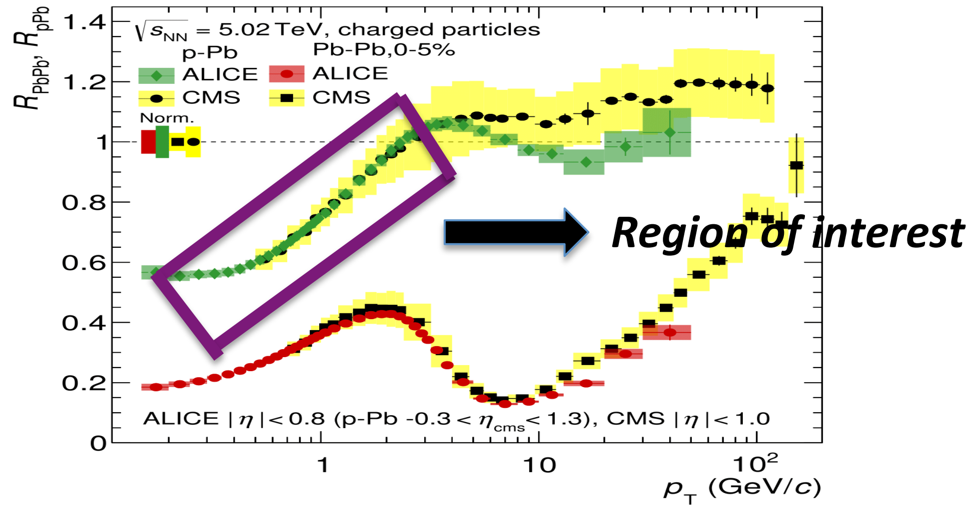


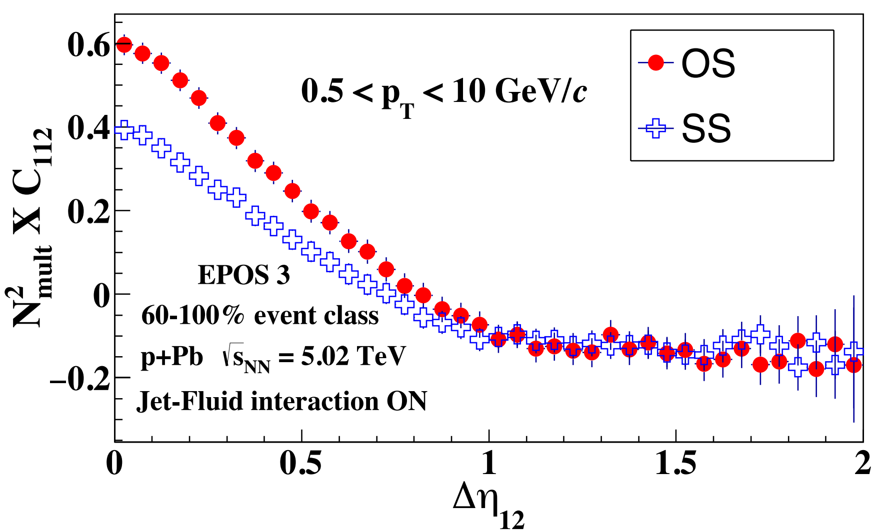
❖ ***The short range of the correlation is dominated by jets and has a characteristic charge dependence (experimentally observed).***

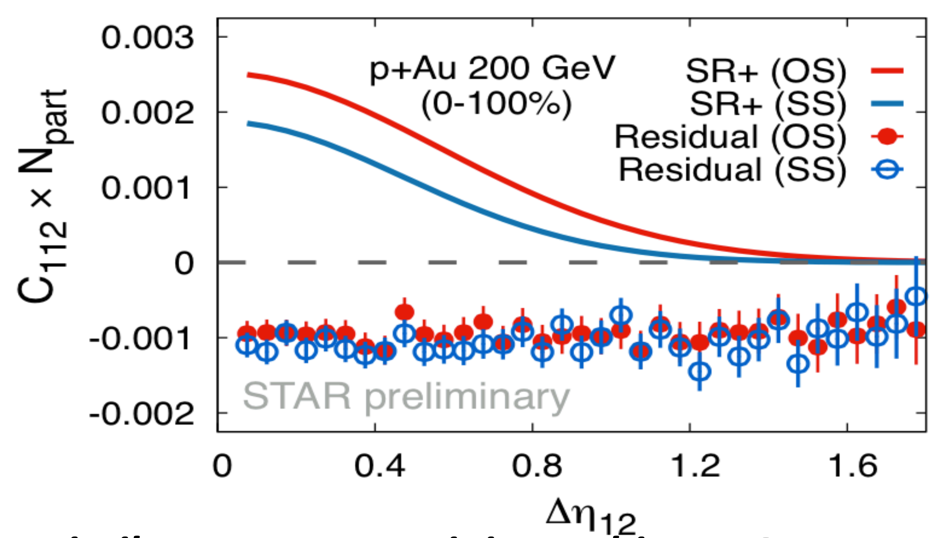
3 particle correlation in EPOS

Three particle correlation has been constructed using charged hadrons with 0.5 < p_T < 10.0 GeV/c

- ***EPOS takes into account hydrodynamically evolving bulk matter, jets and the interaction between the two.***

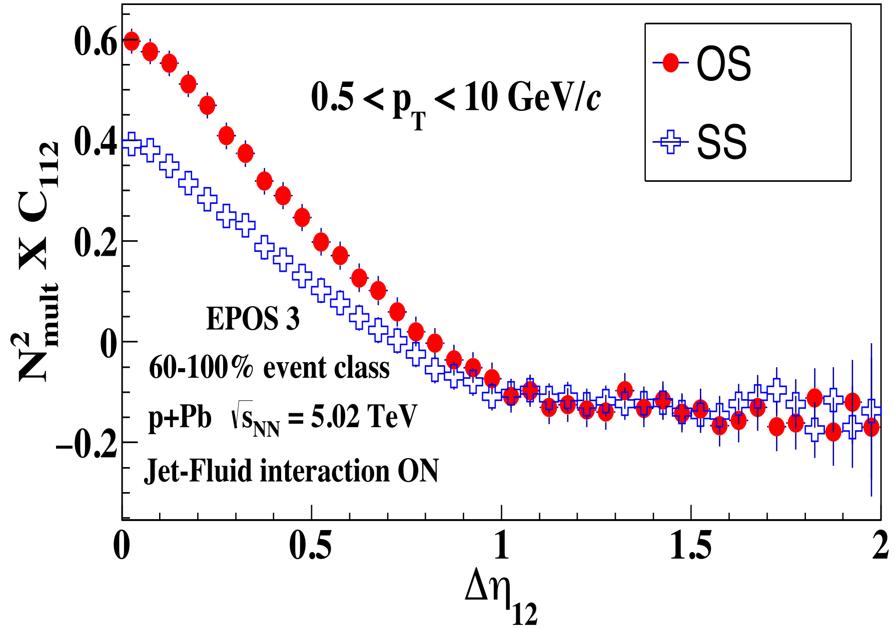


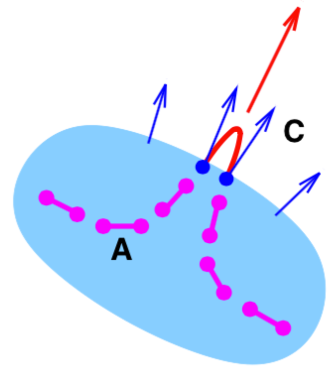


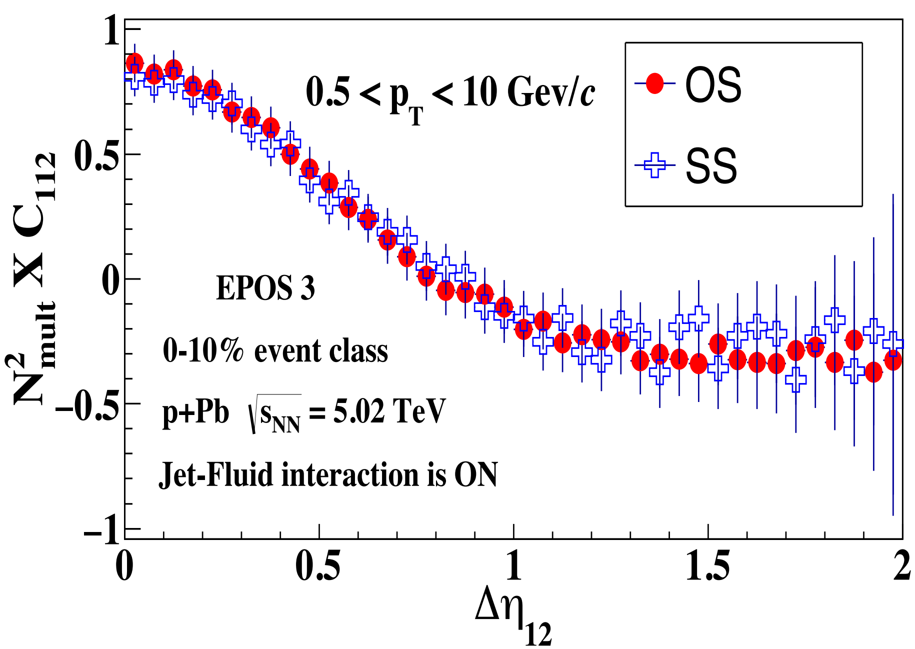


The lower multiplicity class of p-Pb collisions show similar pattern as minimum bias p+Au collisions at 200 GeV.

Jet-medium interaction is significant in higher multiplicity classes







- ❖ *System size increases with multiplicity*

⇓

- ❖ *Probability of jet-fluid interaction increases*

⇓

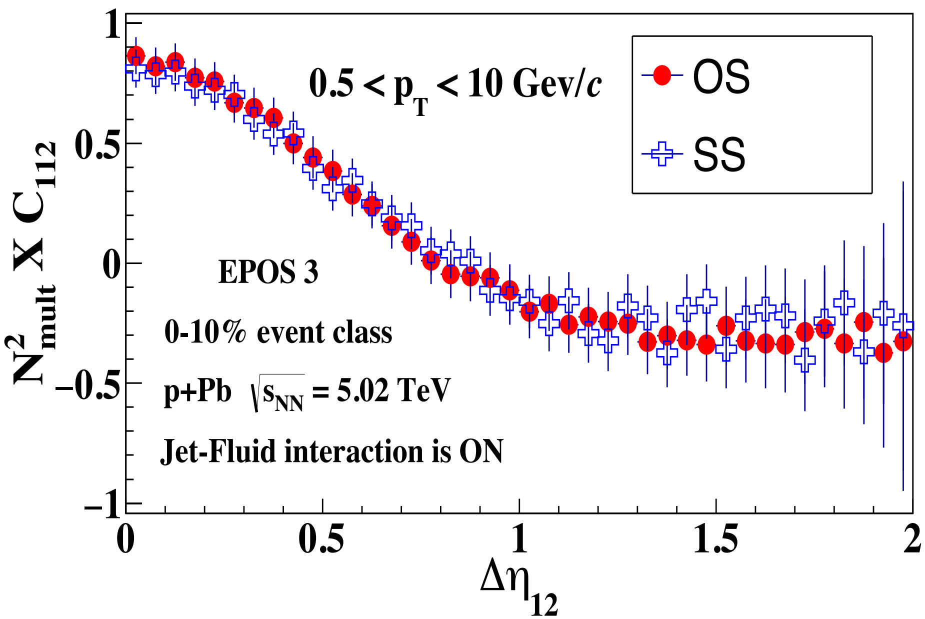
- ❖ *More string segments are carrying fluid properties (hydro current is charge blind).*

⇓

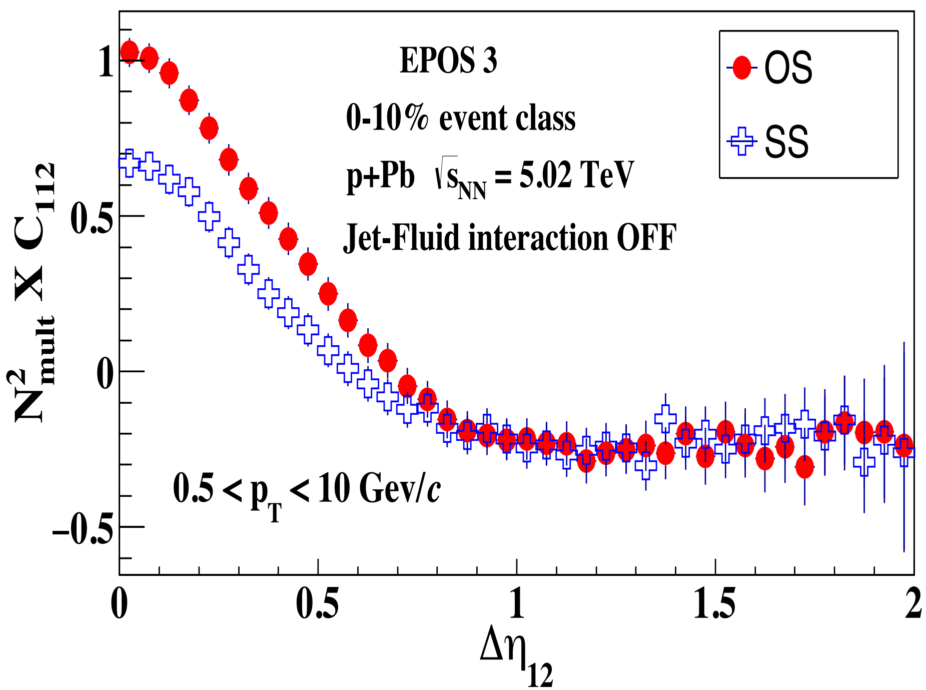
- ❖ *Charge dependence of C_{112} diminishes with increase in multiplicity*

❑ *Possible sign of jet-medium interaction in small systems ??*

Jet-medium interaction contributes to the charge dependence of C_{112}



❖ ***The jet-medium interaction has an effect in the charge dependence of C_{112}.***

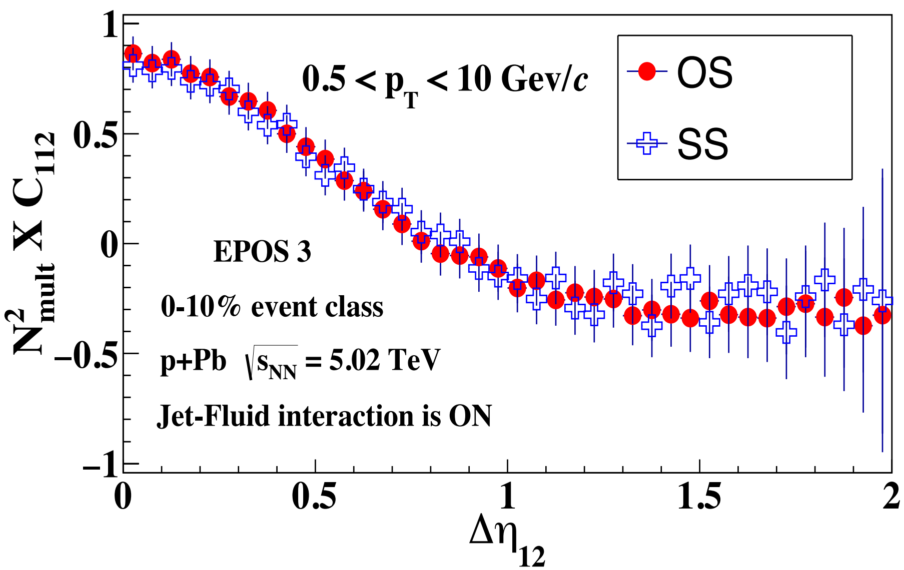


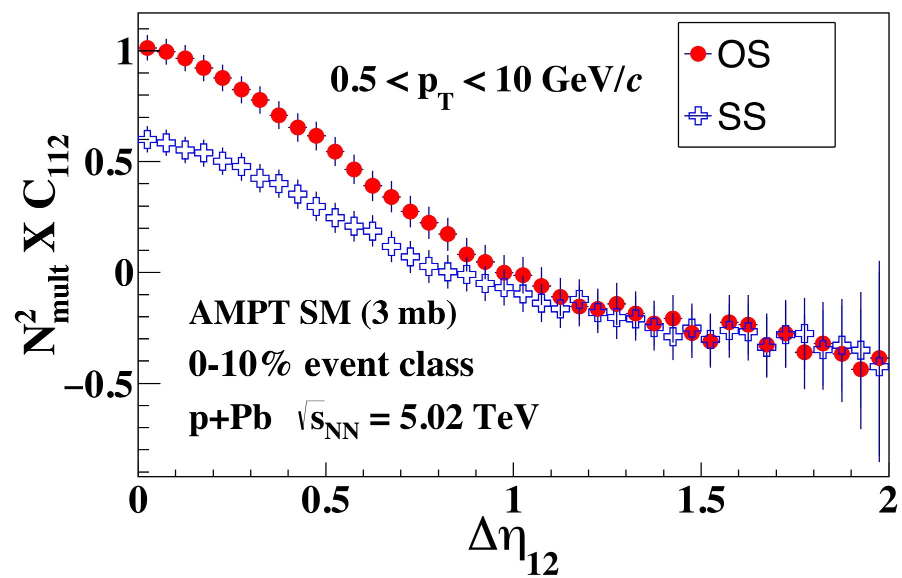
❖ ***The string segments carrying the fluid Properties in the higher multiplicity classes of p-Pb collision contributes to the reduction of the charge dependence of C_{112}***

Comparison with AMPT

❖ ***AMPT: The escape mechanism along with coalescence model of hadronizaion can describe the collective like behaviors in the high multiplicity p-Pb collisions at the LHC energies.***

G-L Ma and A Bzdak - PLB 739 (2014) 209-213; A Bzdak and G-L Ma - PRL 113, 252301(2014); Liang He et al - PLB 753 (2016) 506-510; Y. Zhou et al - PRC 91, 064908 (2015); ***D. S, S.C, S.C – PRC 94, 044919 (2016)*** ; ***D. S, S. C, S.C – PRC 94, 044909 (2016)***





❖ ***But AMPT doesn't take into account any realistic jet-medium interaction except he 2->2 elastic Scatterings at the parton cascade stage.***

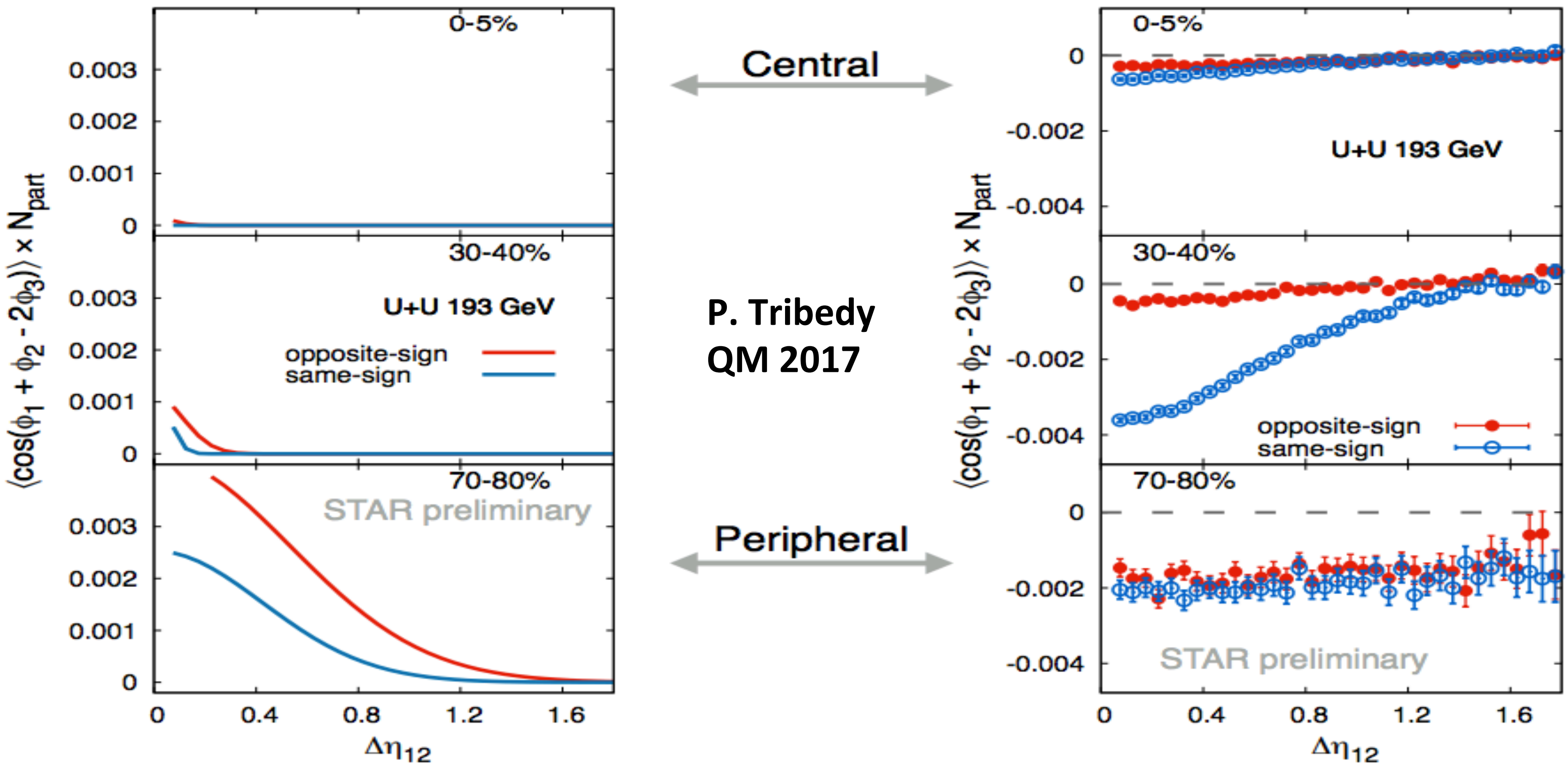
❖ ***The reduction of charge dependence of C_{112} in the higher multiplicity classes of p-Pb in EPOS can't be mimicked by AMPT!!***

Similar measurement in DATA (in U+U collisions at 193 GeV)

$$C_{112}(\Delta\eta_{12}) = A^{+}_{SR} e^{-(\Delta\eta)^2/2\sigma^2_{SR}} - A^{-}_{IR} e^{-(\Delta\eta)^2/2\sigma^2_{IR}} + A_{LR}$$

Short-range-positive Residual

Short-range-positive Residual



❖ ***The charge dependence of the short range of C_{112} diminishes in the more central collisions compared to the peripheral one- The pattern is similar to that observed in EPOS!!***

SUMMARY

a)This study shows that the short range of 3 particle correlation (C112) is dominated by jet-like Correlations and can be influenced by jet-medium interaction.

B) The jet-fluid interaction reduces the charge dependence of C112 (short range) in the central U+U collisions (193 GeV) compared to the peripheral ones.

c) The EPOS with Jet-medium interaction ON can mimic the pattern for p-Pb collisions at 5.02 TeV with particles $0.5 < p_T < 10.0$ GeV/c. The low and intermediate p_T particles are more effected by the jet-fluid interaction in small collision systems.

d) Data-Model comparisons with identified particles and different p_T bins may be helpful to understand the underlying dynamics of small collision systems in a better way.

Thank You…

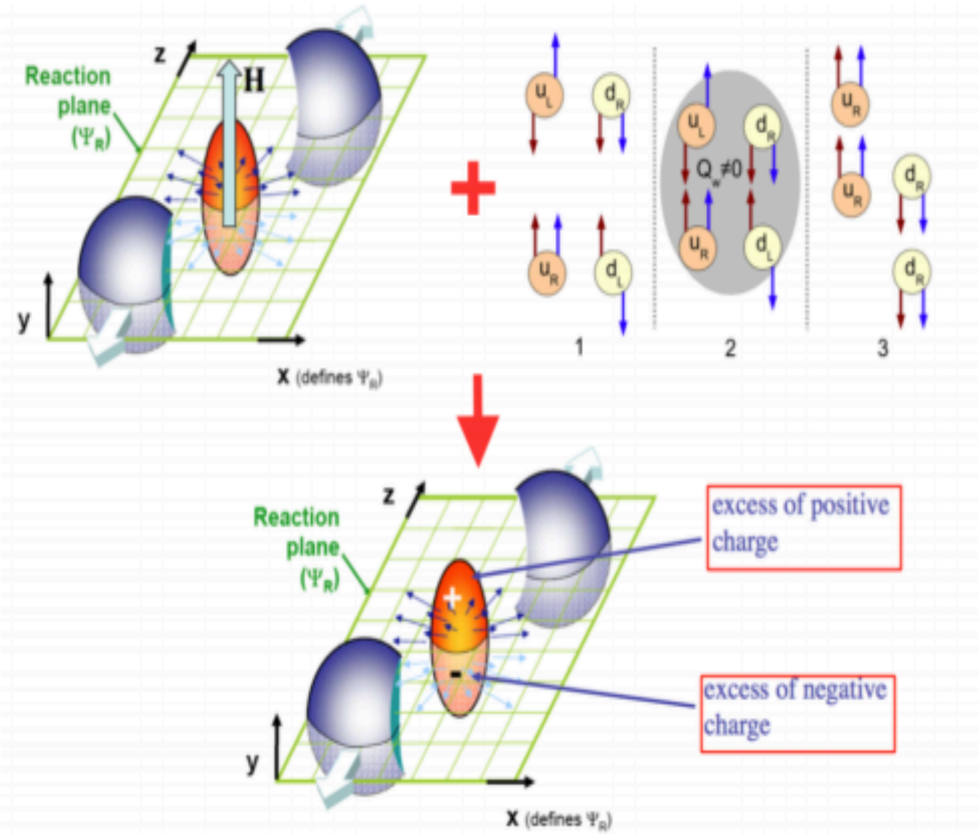
Multiplicity evolution of charge dependent 3 particle correlation as a probe to study jet-medium interaction in p-Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV

Debojit Sarkar* and Prithwish Tribedy

We present a unique way to detect the possible jet-medium interaction in small collision systems using the 3 particle correlation technique. The short range of the 3 particle correlation is dominated by the jet fragmentation and has a unique charge dependence as observed in the minimum bias p+Au collisions at the RHIC energy. The similar effect has been observed in case of EPOS in the lower muliplicity classes of p+Pb collisions at the LHC energy where jet fragmentation plays the dominant role. Interestingly, the charge dependence of the 3 particle correlator gets diminished in the higher multiplicity classes of p+Pb collisons where the jet-medium interplay as implemented in EPOS 3 plays an important role. The results from EPOS and AMPT will be presented and the effectiveness of this observable as a probe to study jet-medium interaction in small collision systems will be discussed.

PACS numbers:
Keywords: EPOS 3; core-corona separation; fluid-jet interaction; hydrodynamics, ridge

Chiral Magnetic Effect (CME)



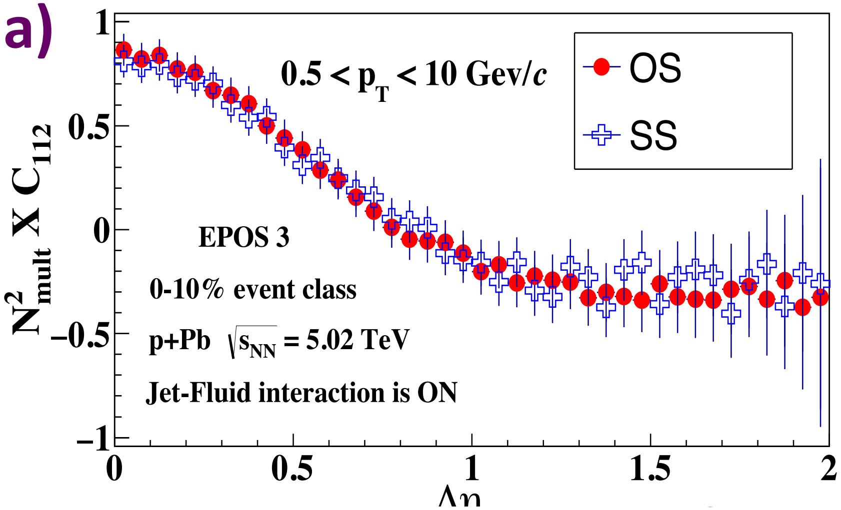
- Charged spectators create a strong (but short lived) magnetic field ($\vec{B}$), $\sim 10^{18}$ Gauss.
- The spins (momentum) of the right– and left–handed quarks are aligned along the $\vec{B}$ direction.
- In the presence of $\vec{B}$, net current in the hot and dense medium created in a heavy-ion collision becomes non-zero.

→ Charge separation in the QGP medium.

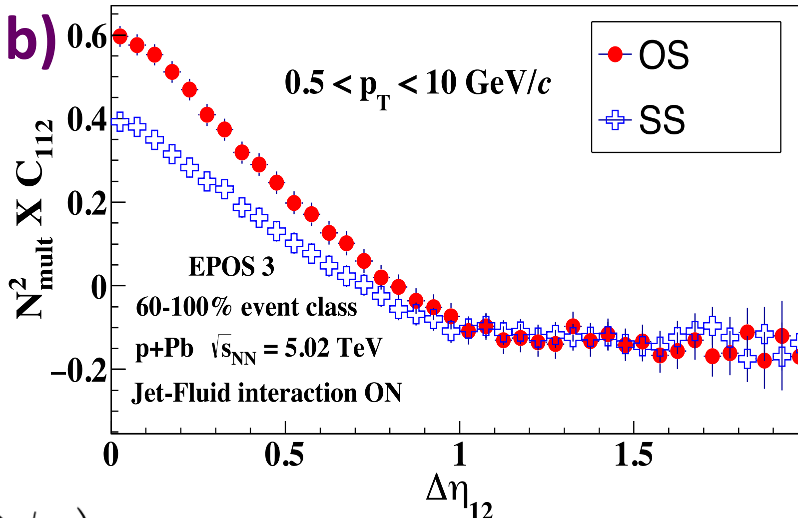
R. Haque, QM 2018

Jet-Medium interaction in small collision systems

a)



b)

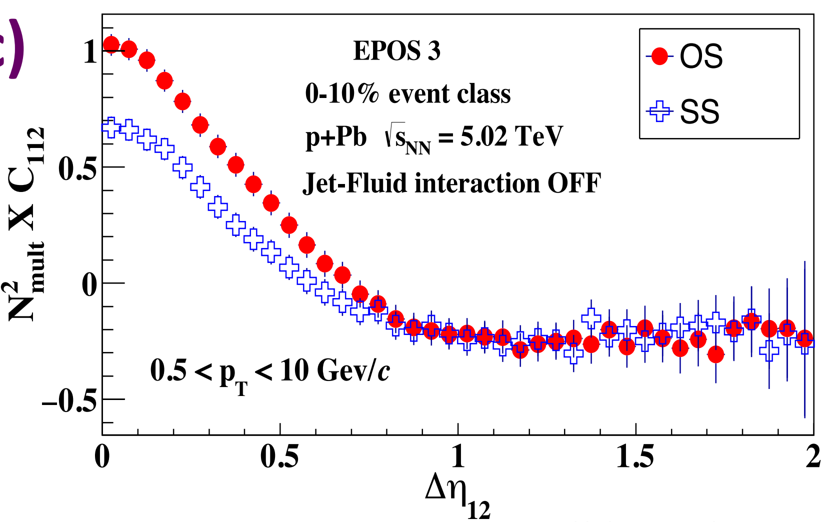


$$C_{112} = \langle \cos(\phi_1^a + \phi_2^b - 2\phi_3) \rangle$$

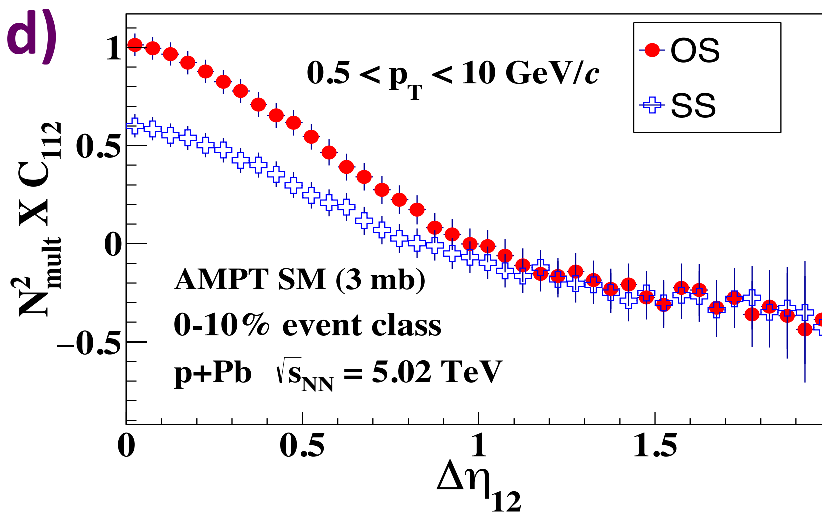
Where a, b = +-, -+ ; ++, --

- ***Charge dependence of C_{112} diminishes with increase in multiplicity – an indication of presence of jet-medium interaction in small collision systems…***

c)



d)



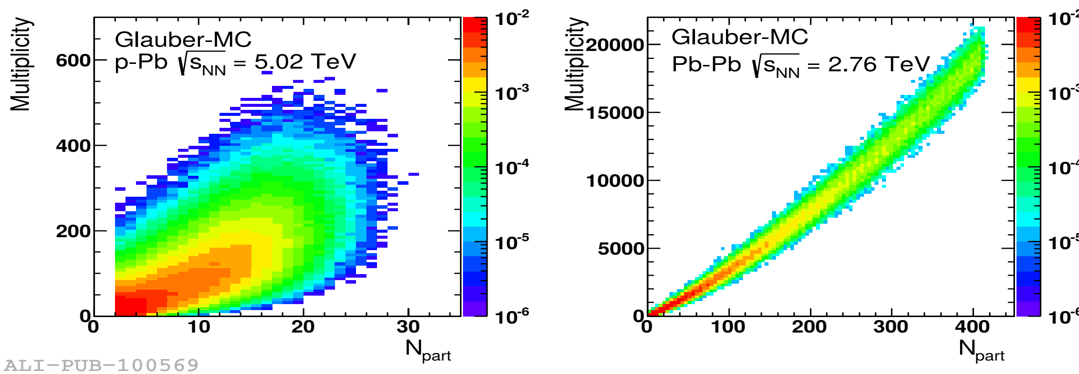
Will be submitted in Phys Lett B within a week…

Multiplicity(NOT centrality!!) class estimation in p-Pb collisions

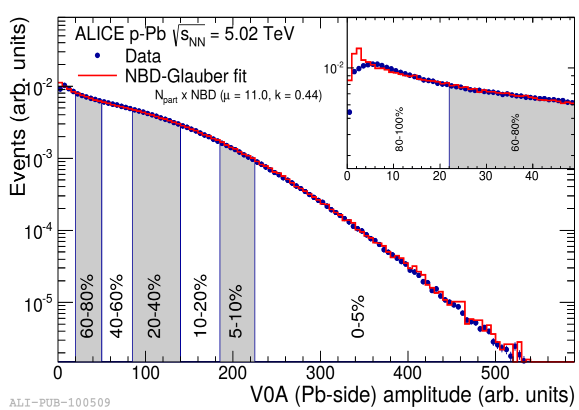
- In Pb–Pb collisions, the geometrical quantity N_{part} is extracted from Glauber_NBD fit to the multiplicity distribution (experimentally measured).

- In Pb–Pb collisions the fluctuations of the two quantities are smaller than the total range whereas in p–Pb collisions they are of the same size as the multiplicity range.

- This means that a fixed N_{part} is associated with a large range of multiplicity – generating multiplicity bias.

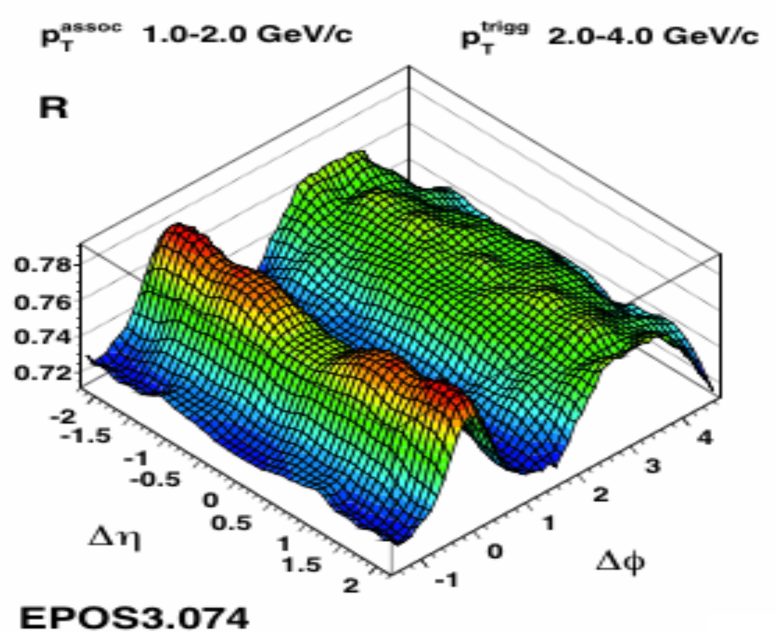


- The selected events are divided into 5 event classes (percentile ranges) based on the charge counted in the VZERO detector(V0A,(2.8< η <5.1)) – defined as V0A multiplicity classes.

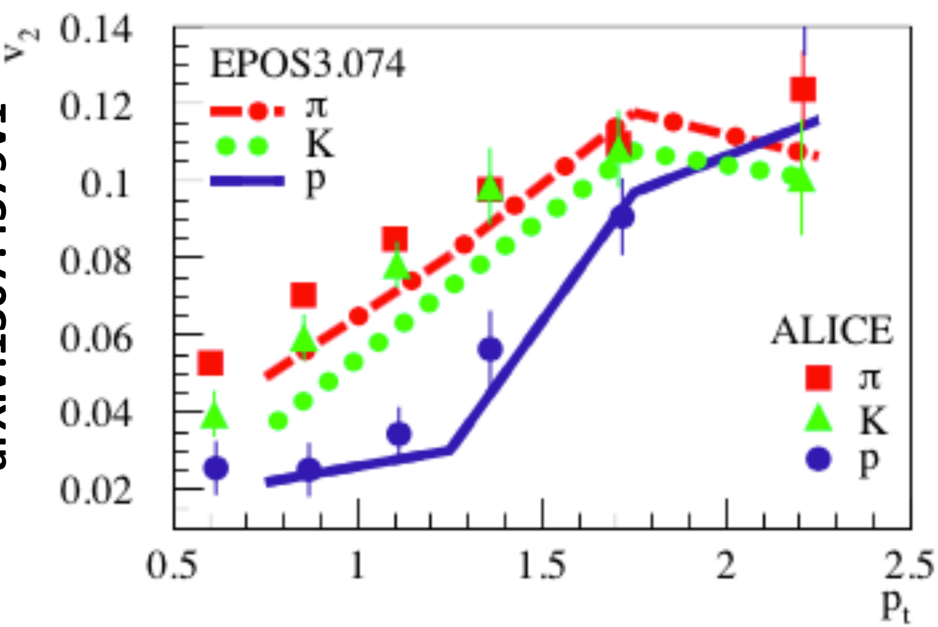


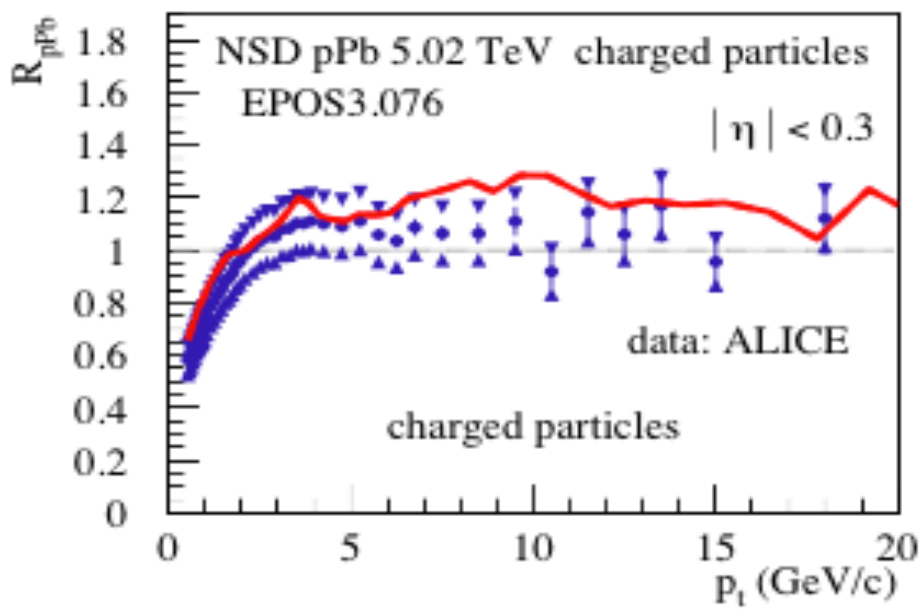
- The V0A detector is placed along the Pb going direction and therefore more sensitive to the fragmentation of the Pb nucleus in p-Pb collisions.

EPOS3 : 3+1 dim viscous EbyE hydro + hadronic afterburner



arXiv:1307.4379v1



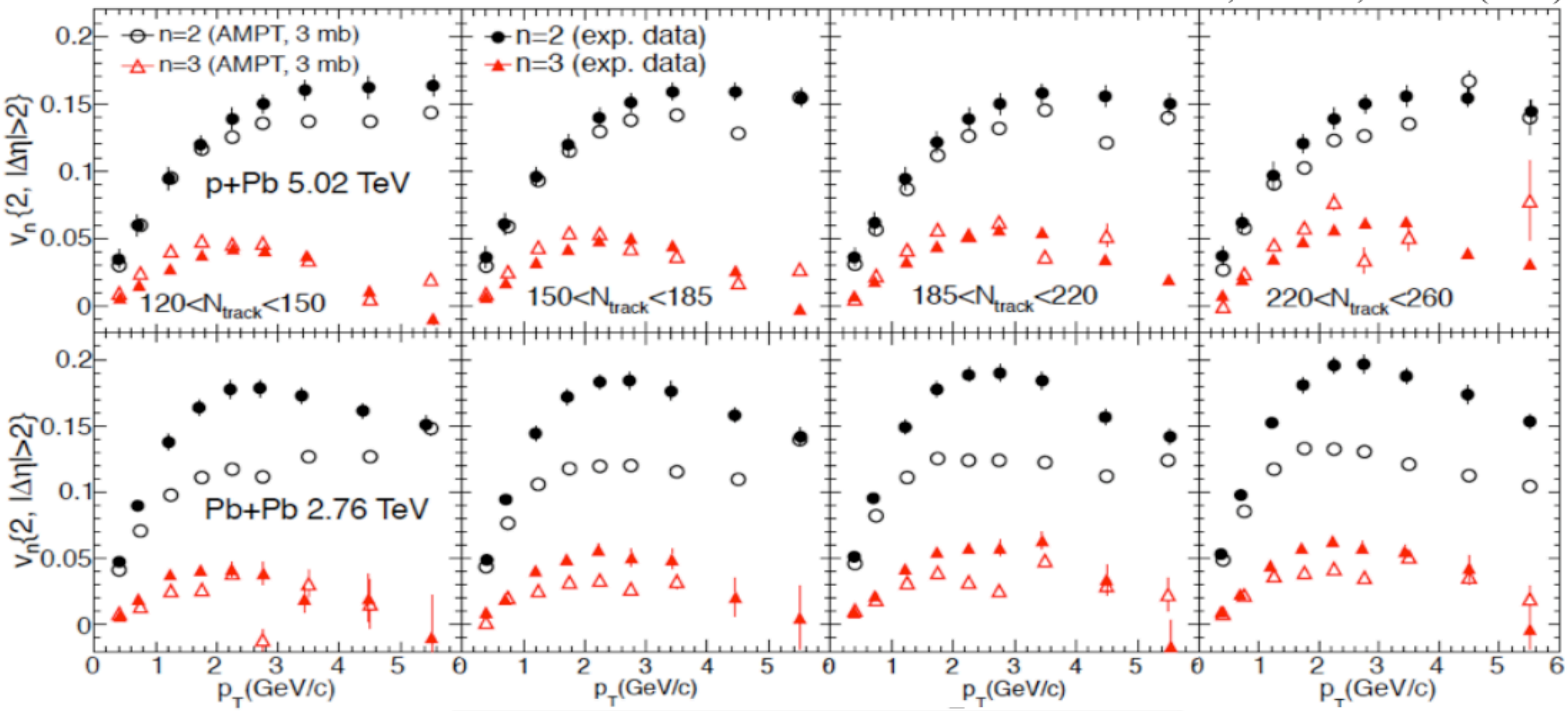


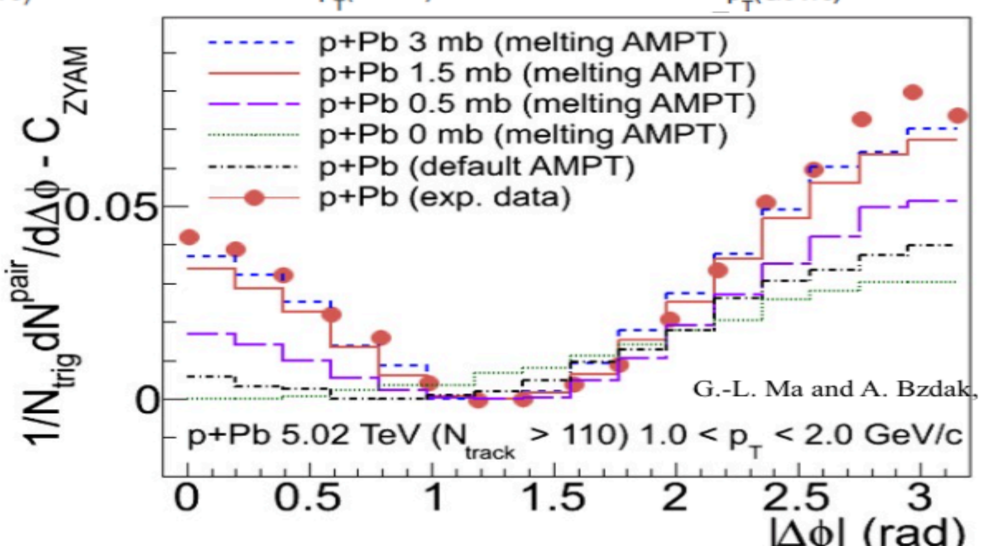
arXiv:1312.1233

EPOS3 describes well Double Ridge, Mass Ordering of V2 and absence of Jet Qurenching In p-Pb…

AMPT has done some Good Job in p-Pb case....

A. Bzdak and G.-L. Ma, PRL 113, 252301 (2014)





G.-L. Ma and A. Bzdak, PLB 739, 209 (2014)