Theoretical developments on initial state and fluctuation (QM2014 Review)

Heavy Ion Meeting 2014-06
June 20 2012
Korea University

Sungtae Cho

YONSEI UNIVERSITY

Institute of Physics and Applied Physics
Yonsei University

Outline

– New universal parametrization of initial –state fluctuations and its application to event-by-event anisotropy … by L. Yan

– Multi-particle production and ridge structure in A+A, p+A, and p+p collisions … by B .Schenke

– Is perfect fluidity of the sQGP necessary in light of recent BES & D+Au & p+Au data from RHIC and LHC? … by M. Gyulassy

New universal parametrization of initial-state fluctuations and its application to event-by-event anisotropy

Li Yan[1], Jean-Yves Ollitrault[1] and Art Poskanzer[2]

[1]CNRS, Institut de Physique Théorique, Saclay

[2]Lawrence Berkeley National Laboratory

Quark Matter 2014, Darmstadt

Outline

- Introduce Elliptic Power and Power parameterizations of ε_n fluctuations.
- Apply Elliptic Power and Power to v_n data.

– Elliptic power distribution

L. Yan, J-Y. Ollitrault, and A. M. Poskanzer, arXiv:1405:6595

Eccentricity distributions in nucleus-nucleus collisions

Li Yan,[1] Jean-Yves Ollitrault,[1] and Arthur M. Poskanzer[2]
[1] *CNRS, URA2306, IPhT, Institut de physique théorique de Saclay, F-91191 Gif-sur-Yvette, France*
[2] *Lawrence Berkeley National Laboratory, Berkeley, California, 94720*
(Dated: May 27, 2014)

1) A parametrization of the distribution of the initial eccentricity in a nucleus-nucleus collisions at a fixed centrality

2) A two parameter distribution, where one of them corresponds to the intrinsic eccentricity, while the other controls the magnitude of eccentricity fluctuations.

– Eccentricity ε_2

1) v_2 is, to a good approximation, a linear response to the initial eccentricity ε_2 , which quantifies the spatial azimuthal anisotropy of the fireball

2) The initial eccentricity comes from two effects

i. The overlap area between the colliding nuclei has the shape of an almond in non-central collisions.
ii. There is a sizable eccentricity, even in central collisions , due to quantum fluctuations in wave functions of incoming nuclei

3) It is defined in every event from the initial energy density profile and thus carries information about how energy is deposited in the early stage of heavy ion collisions

– Models of the initial energy density profile and its fluctuation

1) The MC Glauber model in event-by-event hydrodynamics
: the energy is localized around each wounded nucelon
2) The MC+ saturation physics as an initial conditions in hydro

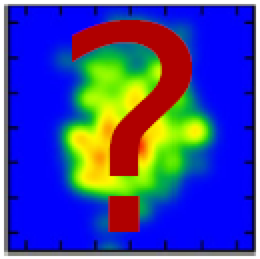
– Simple parametrization of ε_2

1) The Bessel-Gaussian distribution
: works well for nucleus-nucleus collisions at moderate impact parameters, but fails for more peripheral collisions and/or small systems such as proton-nucleus collisions
2) A new power distribution

Motivation: fluctuations of harmonics

XXIV QUARK MATTER DARMSTADT 2014

- Fluctuating initial state and harmonic flow v_n:



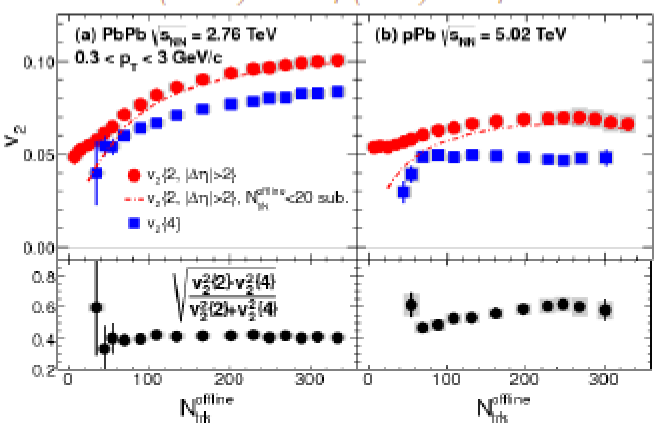
Glauber, KLN, IP-Glasma

$\Longleftrightarrow$ medium exp.

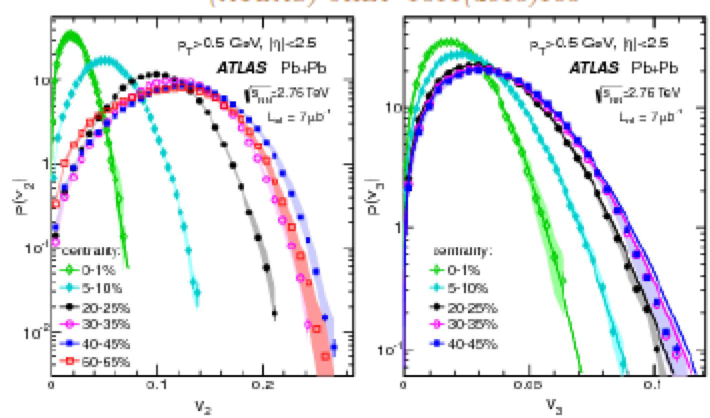
$$\frac{dN}{d\phi_p} \sim 1 + 2\sum_n v_n e^{in(\phi_p - \Psi_n)}$$

- Fluctuations of v_n in experiments:

(CMS)PLB724 (2013)213-240



(ATLAS) JHEP 1311(2013)183



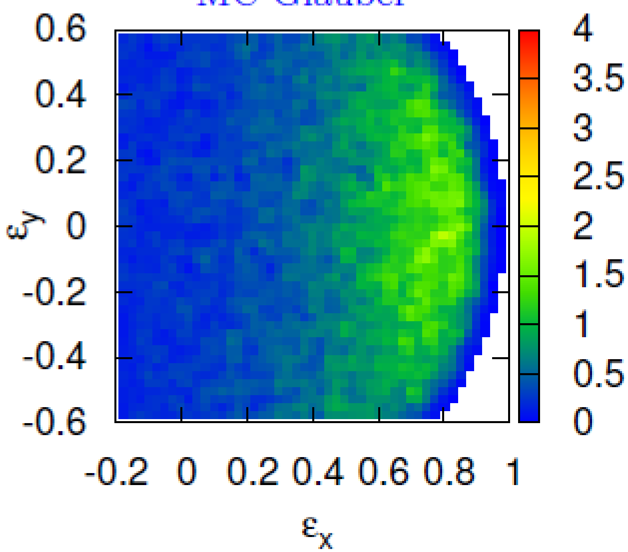
1. Significant $v_2\{4\}$ observed in p-Pb? Do we see collective expansion in p-Pb?
2. What can we learn from EbyE v_n distribution? In particular, η/s?

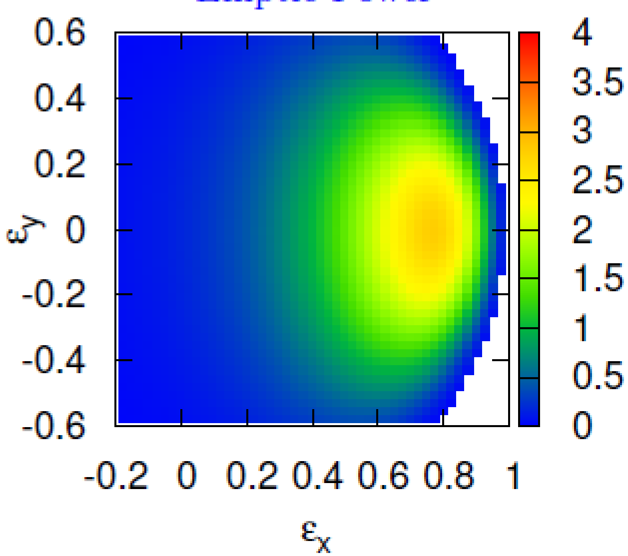
Elliptic Power distribution and Power distribution

- **Elliptic Power distribution** : (e.g. assuming N independent point-like sources)

$$P_{\rm EP}(\varepsilon_x,\varepsilon_y)=\frac{\alpha}{\pi}(1-\varepsilon_0^2)^{\alpha+\frac{1}{2}}\frac{(1-\varepsilon_x^2-\varepsilon_y^2)^{\alpha-1}}{(1-\varepsilon_0\varepsilon_x)^{2\alpha+1}},\qquad \text{with } \varepsilon_x^2+\varepsilon_y^2<1$$

$\alpha\sim N \Rightarrow$ fluctuations, $\varepsilon_0 \Rightarrow$ average reaction plane(RP) eccentricity





- **Power distribution** (e.g. ε_3 in AA, ε_n in p-Pb) : fluctuation-driven with $\varepsilon_0=0$

$$P_{\rm Power}(\varepsilon_x,\varepsilon_y)=\frac{\alpha}{\pi}(1-\varepsilon_x^2-\varepsilon_y^2)^{\alpha-1}\qquad\Leftarrow\qquad P_{\rm EP}(\varepsilon_0\to 0)$$

Applications to data

- With Elliptic Power and Power characterizing initial state fluctuations,

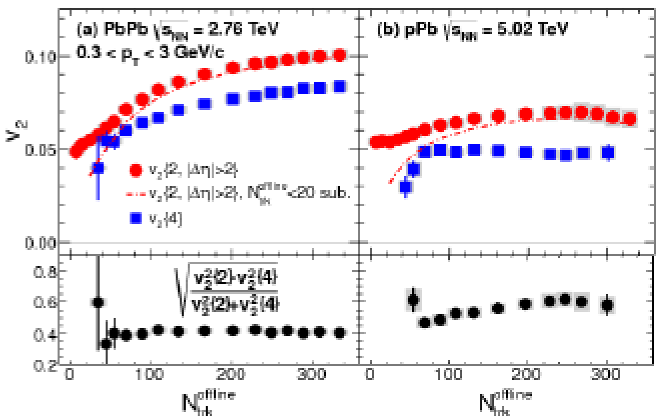
- Linear eccentricity scaling: $(n = 2 \text{ and } 3)$ *H.Niemi et al.,Phys.Rev. C87 (2013) 054901*

$$v_n = \underbrace{\kappa_n}_{\text{medium resp.: } \eta/s} \times \underbrace{\varepsilon_n}_{\text{Elliptic Power or Power}}$$

- Ignore fluctuations in medium response, i.e., κ_n does not fluctuate.

- Then distribution of v_n is rescaled Elliptic Power or Power distribution.

(CMS)PLB724 (2013)213-240



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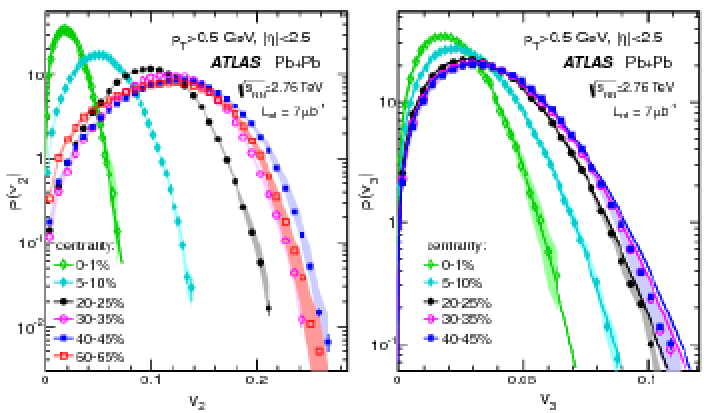
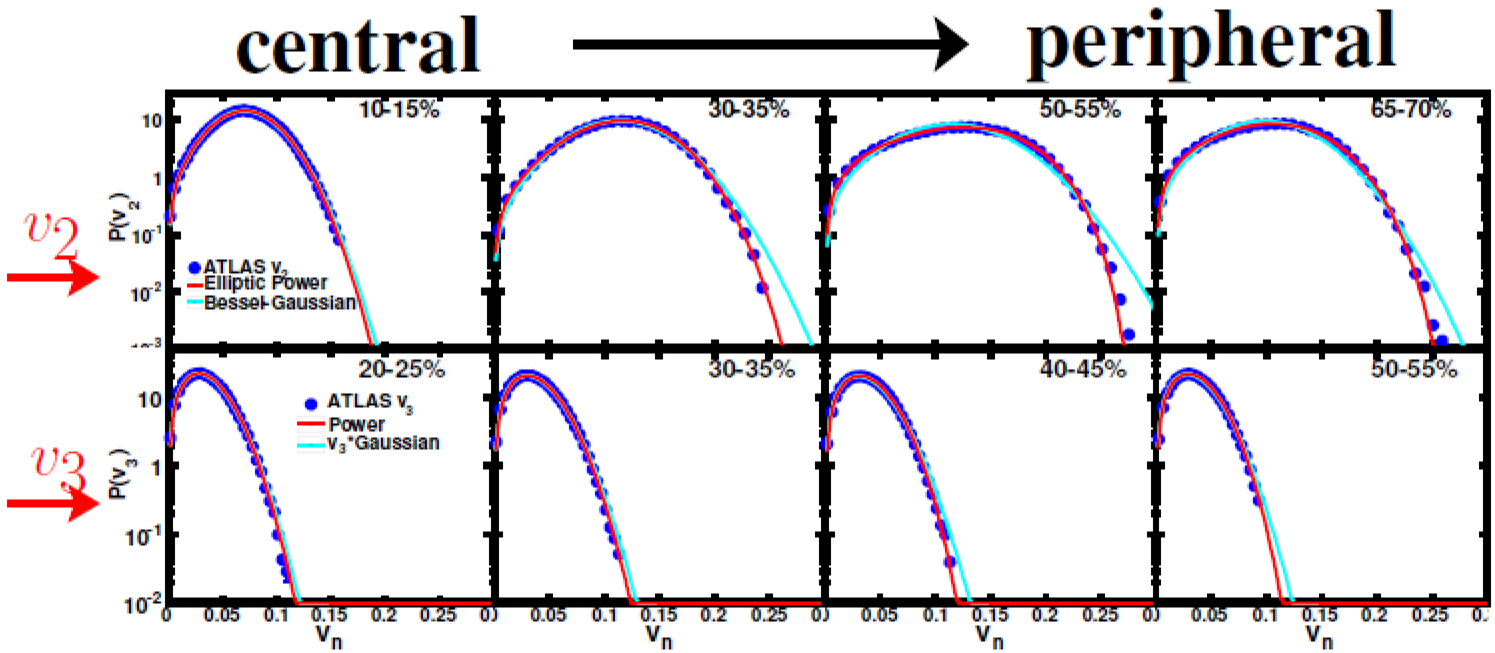


ATLAS EbyE v_n distribution



- Significant improvement with Elliptic Power and Power parameterization.
- Error of v_2 fit is dominated by systematic errors on $\sigma_v / < v >$ from ATLAS results.
- Error of v_3 fit is from statistical error of v_3 only. Systematic errors are too large.

Summary and conclusions

- New parameterizations of eccentricity fluctuations: Elliptic Power and Power
  1. Implement the condition $|\varepsilon_n| < 1$: large anisotropies are correctly modeled
  2. Fit all models of the initial state (Glauber, KLN, IP-Glasma, etc.)
  3. Reveals physical information of initial state: fluctuations (α) and average shape (ε_0).

- Applications
  1. Natually explains **large** $v_2\{4\}$ in p-Pb of LHC $\Rightarrow$ collective expansion of p-Pb system.
  2. Fits of ATLAS EbyE v_2 and v_3 distributions: we are able to disentangle for the first time the initial eccentricity from the hydrodynamic response **without assuming a particular model of initial conditions.**

     Info. of initial state $\Rightarrow$ Fluctuations and average eccentricity of initial state.

     Info. of the medium $\Rightarrow$ Extraction of $\eta/s \sim 0.18$.
  3. And more . . ..

MULTI-PARTICLE PRODUCTION AND RIDGE STRUCTURE IN A+A, p+A, AND p+p COLLISIONS

BJÖRN SCHENKE, BROOKHAVEN NATIONAL LABORATORY

QUARK MATTER 2014
DARMSTADT
MAY 21 2014

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B. Schenke and R. Venugopalan, arXiv:1405:3605

– IP-Glasma + MUSIC

B. Schenke and R. Venugopalan, arXiv:1405:3605

Eccentric protons? Sensitivity of flow to system size and shape in p+p, p+Pb and Pb+Pb collisions

Björn Schenke and Raju Venugopalan
Physics Department, Brookhaven National Laboratory, Upton, NY 11973, USA

1) Event-by-event fluid dynamics model
: The color glass condensate (CGC) based IP-Glasma model in combination with the viscous fluid dynamic simulation, MUSIC

2) The impact parameter dependent saturation model (IP-Sat) with the classical description of initial glasma fields
: includes the quantum fluctuation of color charges and produces initial energy fluctuation

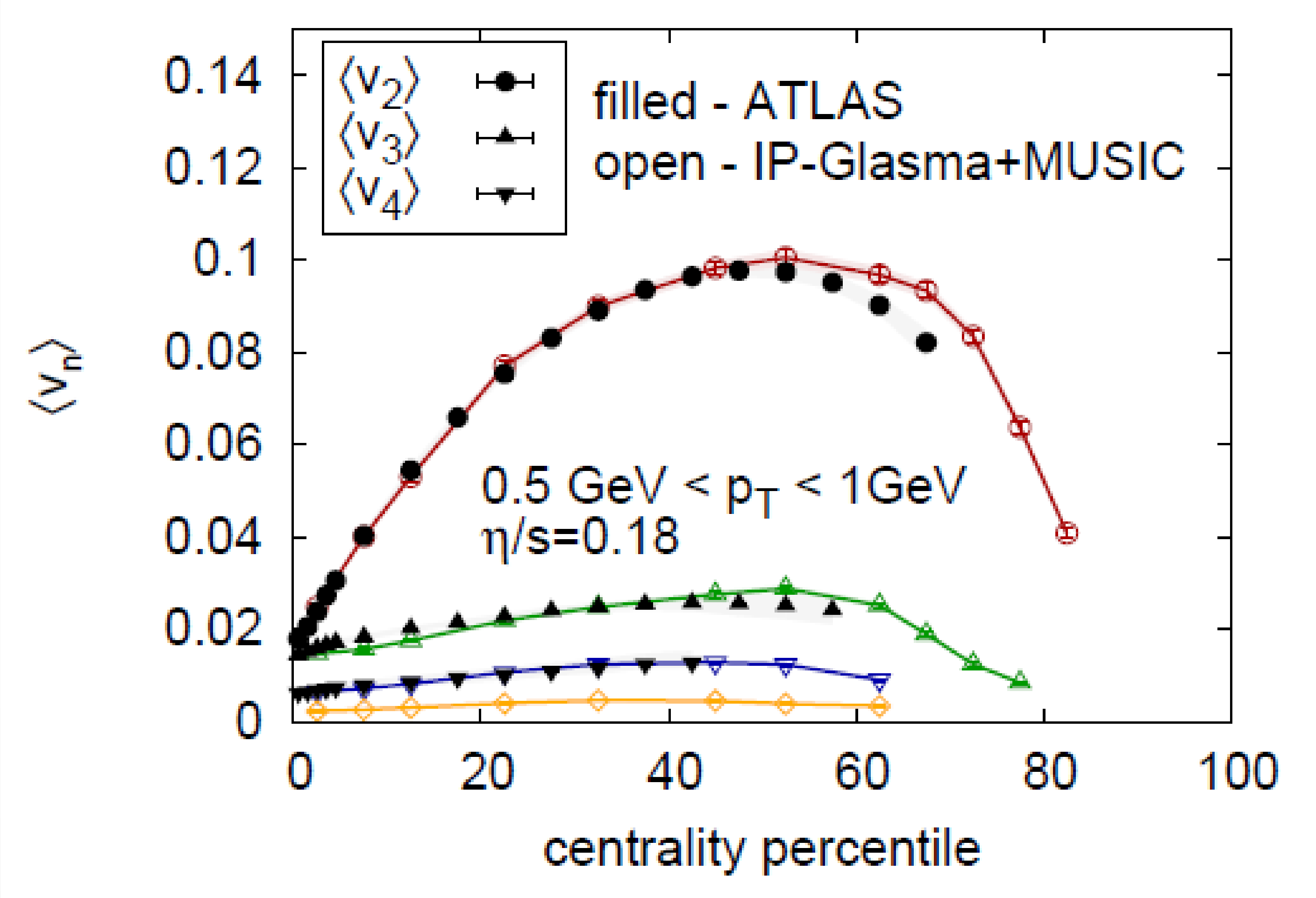
– Collective effects in pp, pA, and AA

1) Striking similarity in the structure of long range pseudo-rapidity correlation between high multiplicity d+Au, p+Pb collisions and peripheral heavy ion collisions with similar multiplicity

2) The observed mass splitting of elliptic flow has been qualitatively explained within the fluid dynamic model description

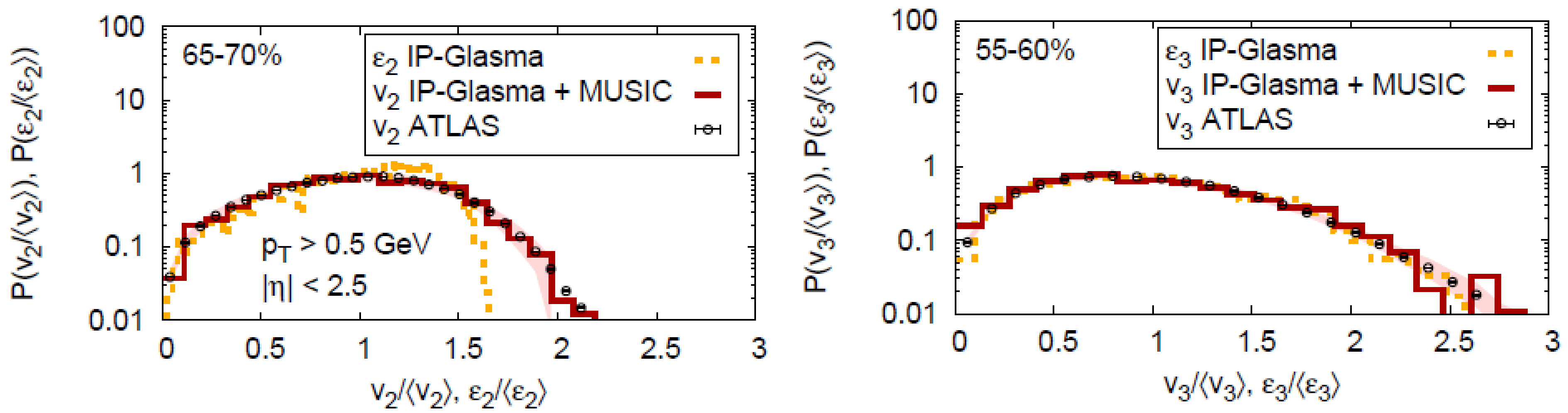
3) The v_n distribution are not well described by the initial state developed so far except IP-Glasma+MUSIC

– Average v_n



⟨v2⟩
⟨v3⟩
⟨v4⟩
filled - ATLAS
open - IP-Glasma+MUSIC
0.5 GeV < pT < 1GeV
η/s=0.18
⟨vn⟩
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
0
20
40
60
80
100
centrality percentile

– Event-by-event distribution of vn

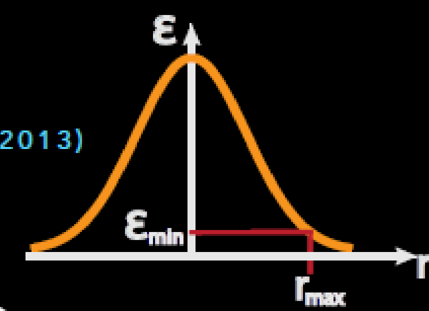


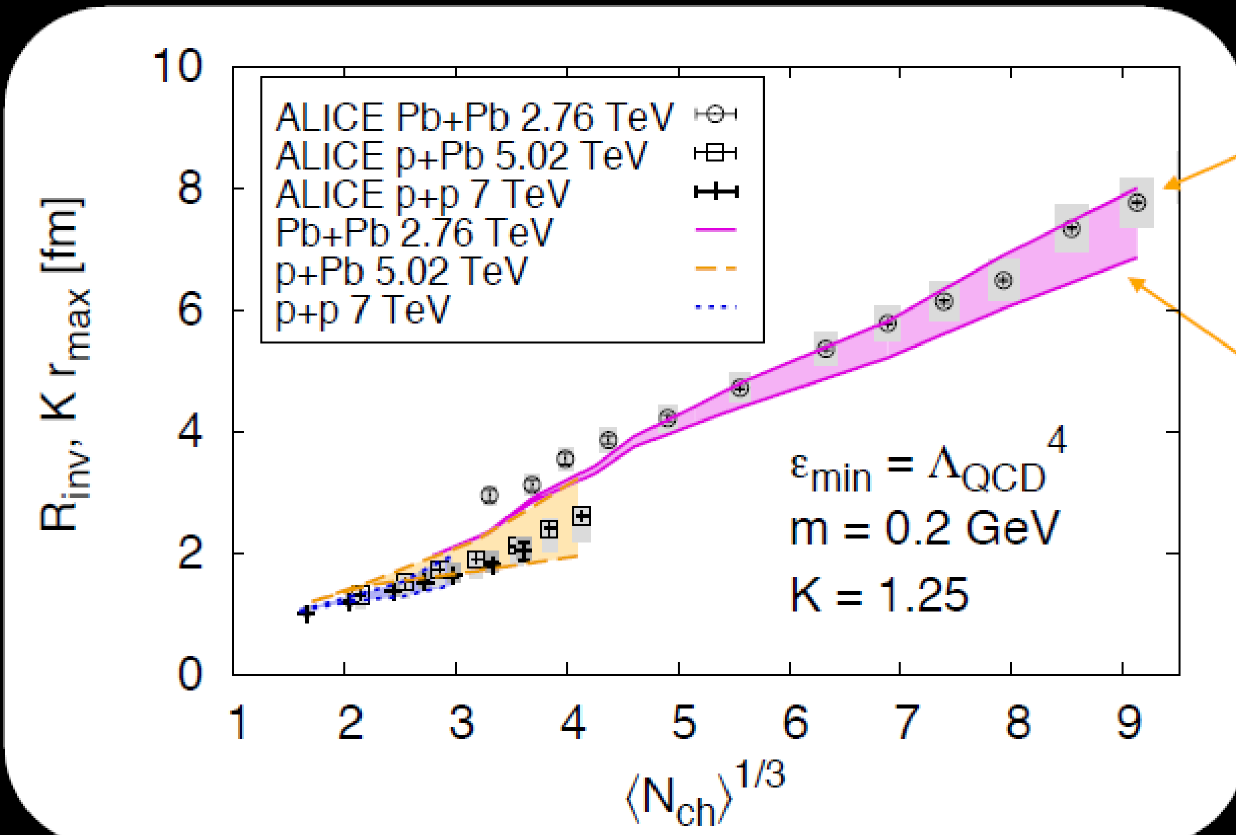
1) The initial state eccentricities εn
: quantifies the spatial azimuthal anisotropy of the fireball created right after the collisions

2) Nonlinearity effects in fluid dynamics evolution modify the shape of the distributions : the necessity of fluid dynamics

SYSTEM SIZE

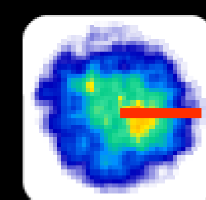
A. BZDAK, B. SCHENKE, P. TRIBEDY, R. VENUGOPALAN, PRC87, 064906 (2013)
AND B.SCHENKE, R.VENUGOPALAN, ARXIV:1405.3605 (2014)
HBT DATA: ALICE COLLABORATION, ARXIV:1404.1194





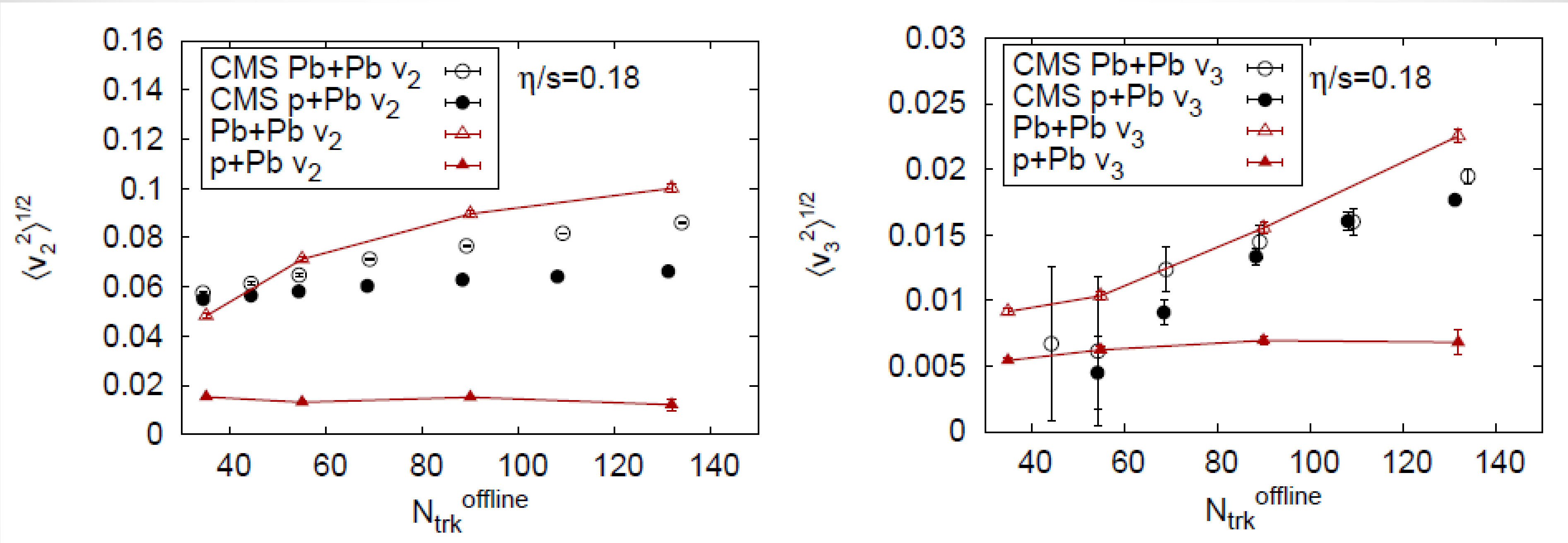
MAXIMAL SIZE DURING EVOLUTION

INITIAL SIZE



r_{max}

– Anisotropic flows in p+Pb collisions



1) $N_{trk}^{offline}$ =132 corresponds to 65-70% central Pb+Pb events

2) Pb+Pb data are well described while p+Pb data are not.

: No choice of parameters could achieve better agreement

FOURIER HARMONICS IN p+Pb

B.SCHENKE, R.VENUGOPALAN, ARXIV:1405.3605 (2014)

Why does it not work? Two possibilities:

a) We neglected correlations from the initial state

K. DUSLING, R. VENUGOPALAN, PHYS.REV. D87 054014 (2013)

They are there in IP-Glasma - just need to keep them

b) The proton is not spherical and its shape fluctuates

Other models:

MC-Glauber: similar fluctuations in p+Pb and Pb+Pb

P. BOZEK, G. TORRIERI, W. BRONIOWSKI, PHYS.REV.LETT. 111, 172303 (2013)

I. KOZLOV, M. LUZUM, G. DENICOL, S. JEON, C. GALE, ARXIV:1405.3976 (2014)

One challenge for MC-Glauber are the similar p+p and p+Pb HBT radii

EPOS: Fluctuations of "cut pomerons" - larger eccentricities

K. WERNER, M. BLEICHER, B. GUIOT, I. KARPENKO, T. PIEROG, ARXIV:1307.4379

SUMMARY

- IP-Glasma model + fluid dynamics does very good job in describing experimental data in A+A collisions out to very peripheral events
- Similar size in p+p and p+Pb agrees with ALICE HBT
- Within IP-Glasma+MUSIC model and ignoring initial state correlations, v_n in p+Pb are not well described
- If fluid dynamic picture holds we have access to shape fluctuations of the proton's gluon distribution

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WIGNER RESEARCH CENTRE FOR PHYSICS

Is Perfect Fluidity of the sQGP *necessary* in light of recent BES & D+Au & p+Au data from RHIC and LHC ?

Gyulassy Miklós
Wigner Research Center KFKI
(Columbia University)

Collaborators: Levai P, Vitev I, Biro T

Abstract:
Recent low pT<2 GeV azimuthal correlation data from the beam energy scan (BES) and D+Au at RHIC/BNL and the especially the surprising low pT azimuthal v_n(pT) in p+Pb at LHC challenge long held assumptions about the necessity of perfect fluidity (minimal viscosity to entropy ~ 1/4pi) to account for azimuthal asymmetric "flow" patterns in A+A.

Perfect fluidity is certainly sufficient to fit all A+A and even p+A, data,
but is it really necessary, i.e., is it a unique property of sQGP?

I discuss **basic** pQCD interference phenomena from beam jet color antenna arrays that may help unravel current BES+DA+pA vs AA puzzles without requiring perfect fluid hydrodynamic or CGC Glasma diagrams , but only LO Feynmann diagrams.

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– The color scintillation antenna (CSA)

M. Gyulassy, P. Levai, I. Vitev, and T. Biro, arXiv:1405:7825

Non-Abelian Bremsstrahlung and Azimuthal Asymmetries in High Energy p+A Reactions

M. Gyulassy,[1,2,*] P. Levai,[1] I. Vitev,[3] and T. Biro[1]

[1] *MTA WIGNER Research Centre for Physics, RMI, Budapest, Hungary*
[2] *Department of Physics, Columbia University, New York, NY 10027, USA*
[3] *Theoretical Division, Los Alamos National Laboratory, Los Alamos, NM 87545, USA*

(Dated: May 30, 2014)

1) Multiple resolved clusters of recoiling target beam jets together with the projectile beam produces color scintillation antenna (CSA) array

2) The scaling of intrinsically azimuthally and long range in η nature of the non-abelian breamsstrahlung leads to v_n moments, entirely due to non-ablelian wave interference phenomena sourced by CSA

– Vitev-Gunion-Bertch multiple interaction pQCD bremsstrahlung

1) The dynamical source that could partially account for the azimuthal moment systematics may be traced to a basic perturbative QCD feature

2) The pQCD based model, the opacity 1 Gunion-Bertch pQCD bremsstrahlung, has been extended to all orders in opacity

3) Vitev-Gunion-Bertch bremsstrahlung naturally leads on an event-by-event basis to a hierarchy of non-trivial azimuthal asymmetry moments similar to those observed in p+A and peripheral A+A at fixed $dN/d\eta$

slide of B. Schenke QM12

Higher harmonic flow

Fourier starts at n=1

$$\frac{dN}{d\phi} = \frac{N}{2\pi}\left(1 + \sum_{n=2} (2v_n \cos[n(\phi - \psi_n)]\right)$$

When including fluctuations, all moments appear:

$n=2$ $n=3$ $n=4$ $n=5$ $n=6$

also v_1 and $n > 6$

Compute $v_n = \langle \cos[n(\phi - \psi_n)] \rangle$
with the event-plane angle $\psi_n = \frac{1}{n} \arctan \frac{\langle \sin(n\phi) \rangle}{\langle \cos(n\phi) \rangle}$

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Part 1: case for perfect fluidity with CGC IS

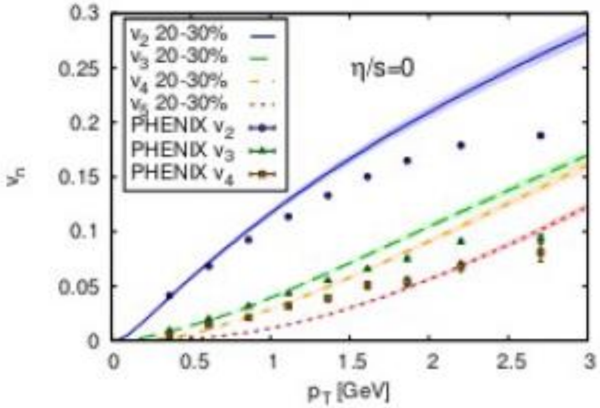
Using higher harmonics to determine η/s

Viscocity/entropy
Of perfect fluid QGP

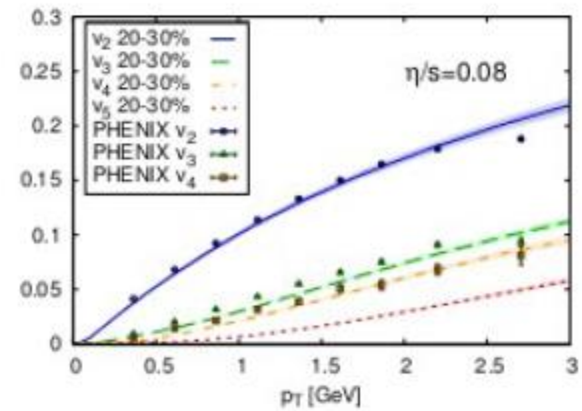
QM12

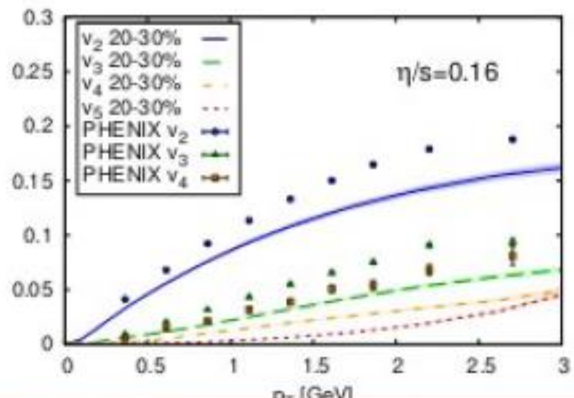
B. Schenke, S. Jeon, C. Gale, arXiv:1109.6289

Data is from event-plane method. Calculations are $\sqrt{\langle v_n^2 \rangle}$.



MC-Glauber initial conditions





This is promising.
Need systematic study of all v_n as function of initial conditions, granularity, η/s, ...

Experimental data: PHENIX, arXiv:1105.3928

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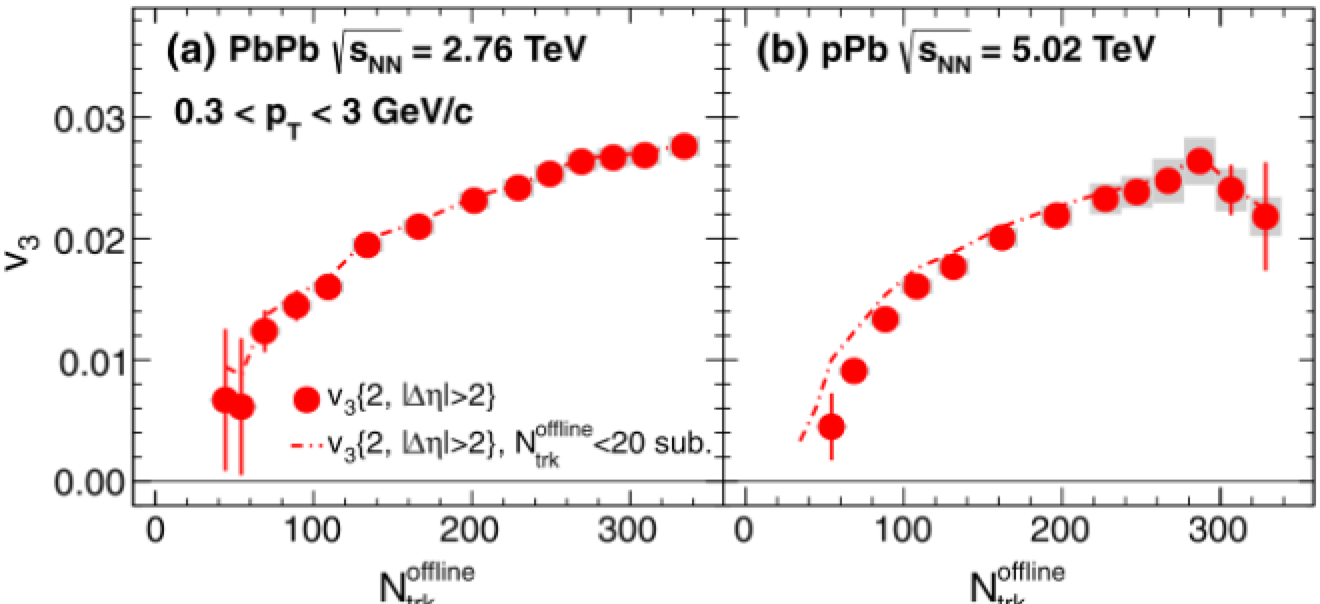
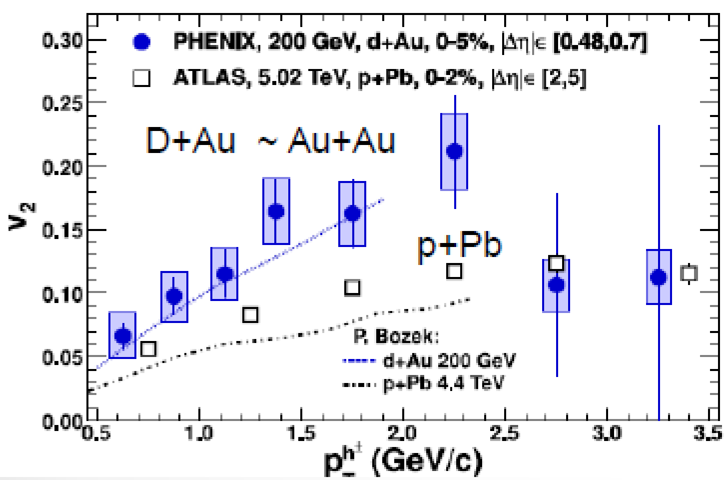
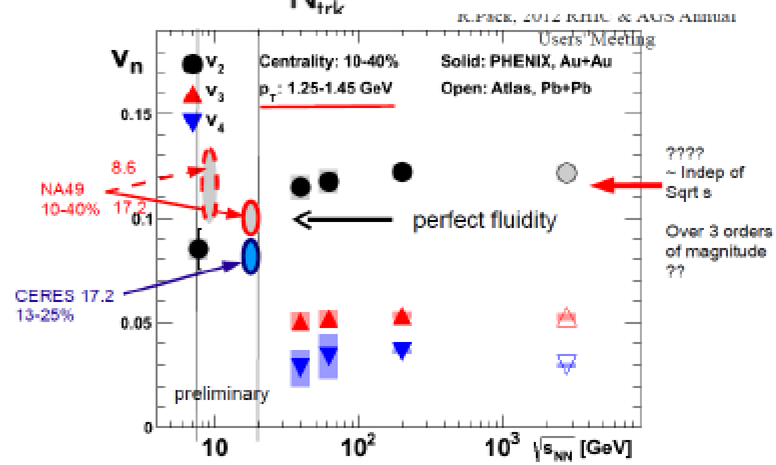
QM12 p(D) + A & BES surprises: v3(p+Pb) =v3(Pb+Pb) ; v2(D+Au)=v2(Au+Au) ; Ecm indepen





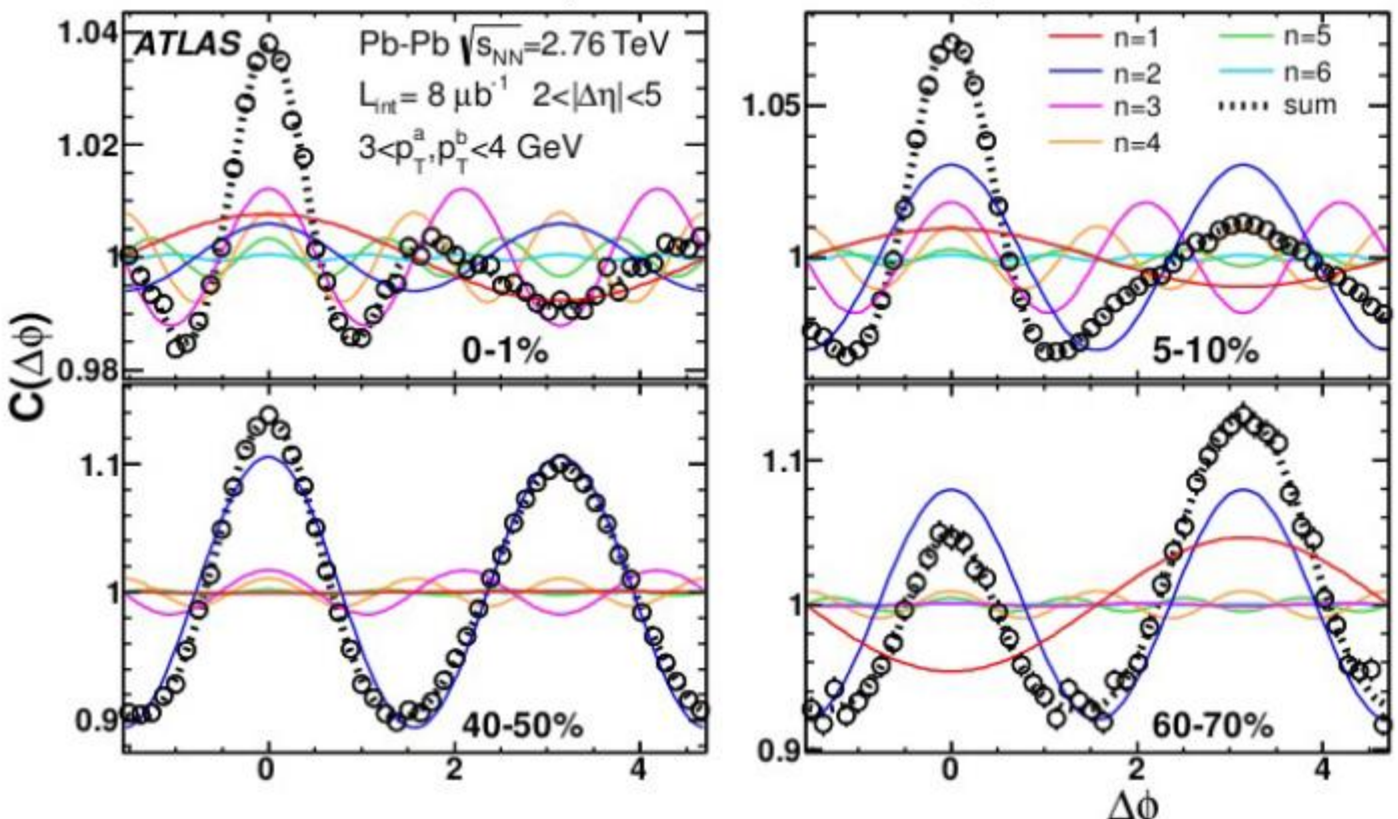


BES vn independent os Ecm

Another surprise : v1

[ATLAS Collaboration], PRC86, 014907 (2012)

PQCD Color Scintillations or Lumpy CGC perfect hydro response ? or complex combo of many effects?



The magnitude of v1,1=<Cos[φ1 - φ2]> Red is large for p1~p2~ 3-4GeV

After subtracting dijets and mom.consv a new rapidity even Dipole!

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MG QM14

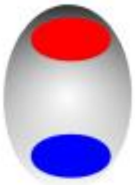
modified slide of B. Schenke QM12

Fuctuating Dipole can also appear

Higher harmonic flow **Fourier starts at n=1**

$$\frac{dN}{d\phi} = \frac{N}{2\pi}\left(1 + \sum_{n=1}(2v_n\cos[n(\phi - \psi_n)]\right)$$

When including fluctuations, all moments appear:



n=1 $n=2$ $n=3$ $n=4$ $n=5$ $n=6$

also v_1 and $n > 6$

Compute $v_n = \langle\cos[n(\phi - \psi_n)]\rangle$
with the event-plane angle $\psi_n = \frac{1}{n}\arctan\frac{\langle\sin(n\phi)\rangle}{\langle\cos(n\phi)\rangle}$

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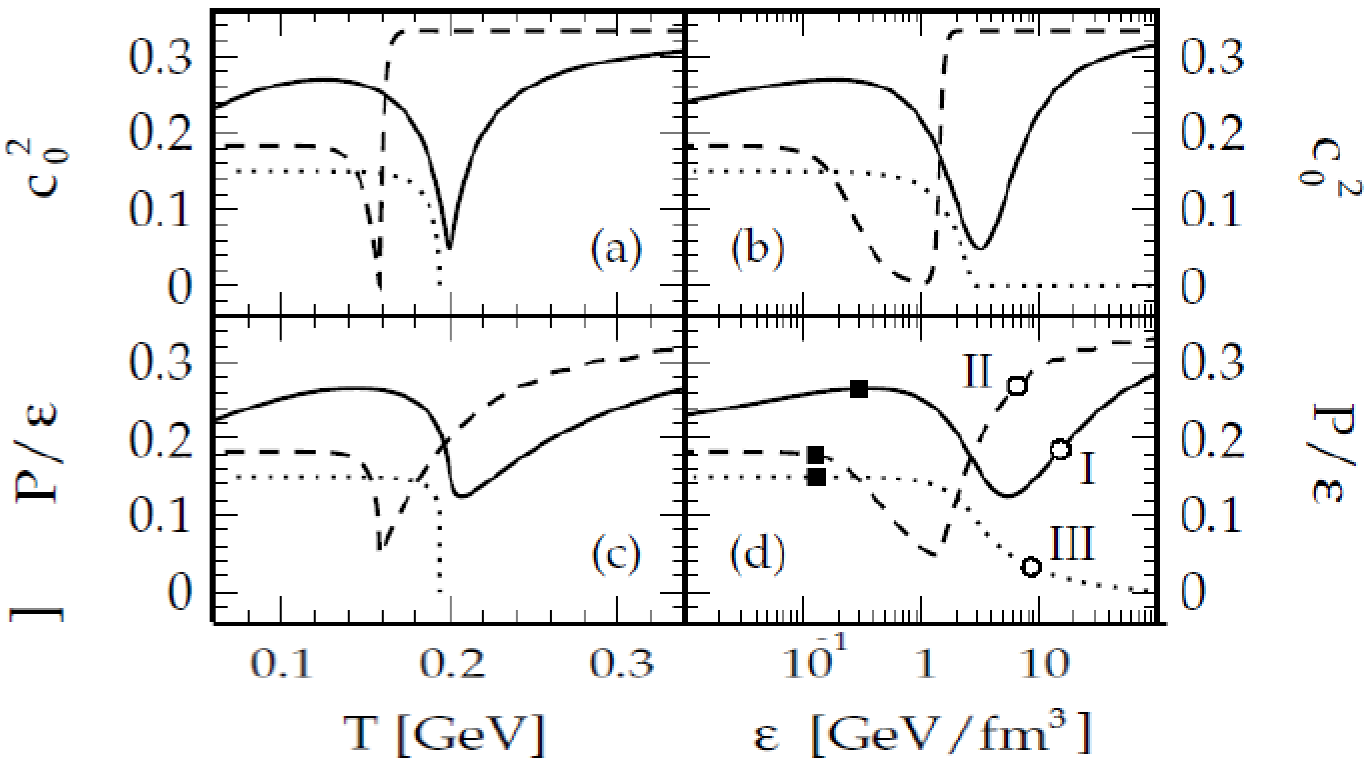
[! Danger ! Hydro can fit anything]

158-GeV/A Pb + Pb

B.R. Schlei, D. Strottman , N. Xu

Nucl-th/9801045; 9710047, 9706037

Ideal Landau 3D Hydro with different EOS I (solid) , II (dashed), III(dotted)



NA44 and NA49 data could be post-dicted with Ideal relativistic hydrodynamics with ***ANY Equation of State***

Given freedom to adjust **Initial** and Freeze-out Conditions

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Mathematician's delight can be Physicist's Nightmare

K. Weierstrass (1885) Theorem:

"Über die analytische Darstellbarkeit sogenannter willkürlicher Functionen einer reellen Veränderlichen'

Sitzungsberichte der Königlich Preußischen Akademie der Wissenschaften zu Berlin, 1885 (II).

If f is a continuous real-valued function defined on the set $[a,b] \times [c,d]$ and $\varepsilon > 0$, then **there exists a polynomial function** in two variables such that
$| f(x,y) - p(x,y) | < \varepsilon$
for all x in [a,b] and y in [c,d].

Corrolary 1: Fourier transforms exists

Corrolary 2: ideal hydro can fit anything

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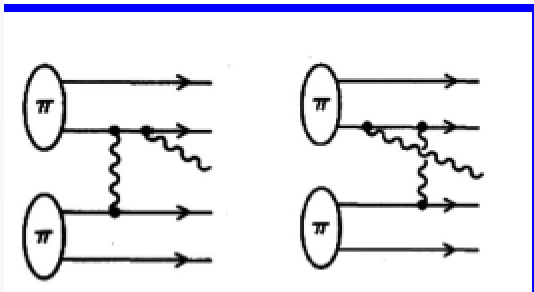
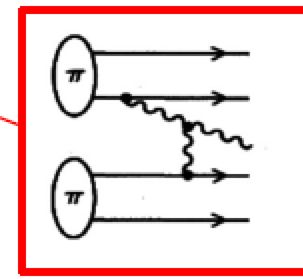
II. FIRST ORDER IN OPACITY (GB) BREMSSTRAHLUNG AND AZIMUTHAL ASYMMETRIES v_n

The above puzzles with BES and $D + Au$ at RHIC and with $p + Pb$ at LHC and models proposed so far motivate us to consider simpler more basic perturbative QCD sources of azimuthal asymmetries.The well known non-abelian bremstralung Gunion-Bertsch (GB) formula[29] for the soft gluon radiation single inclusive distribution is

Color Dipole
Form factor

$$\frac{dN_g^{(1)}}{d\eta d^2\mathbf{k} d^2\mathbf{q}} \equiv f(\eta, \mathbf{k}, \mathbf{q})$$
$$= \frac{C_R \alpha_s}{\pi^2 k^2} \frac{\mu^2}{(\mathbf{q}^2 + \mu^2)} \frac{P_\eta}{(\mathbf{k} - \mathbf{q})^2 + \mu^2}$$
$$\equiv \frac{F \cdot P}{A_{kq} - \cos(\phi - \psi)}$$





Gluon Bremsstrahlung peaks in transverse direction near net momentum transfer $\vec{Q}$ = (Q, Psi) that also defined reaction Event Plane (EP)

Basic Non-Abelian feature: uniform *rapidity-even* distributed (unlike QED)

Of course also peaks in beam direction 1/k^2 (as in QED)

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– Conclusions

M. Gyulassy, P. Levai, I. Vitev, and T. Biro, arXiv:1405:7825

1) The color scintillation antenna (CSA) arrays radiate gluons with characteristic boost non-invariant trapezoidal rapidity distributions in asymmetric nuclear collisions

2) Non-abelian beam jet CSA bremsstrahlung may provide a partial analytic solution to the beam energy scan discovery of the near energy independence of the azimuthal moments down to very low CM energy of ~ 10 AGeV, where large x valence quarks beam jet dominate inelastic dynamics

3) The uniqueness of the perfect fluid description of p+A cannot be taken for granted