International School of Nuclear Physics, Erice, Sicily, Sept. 2012

HYDRODYNAMIC EVENT GENERATOR AT LHC AND RHIC

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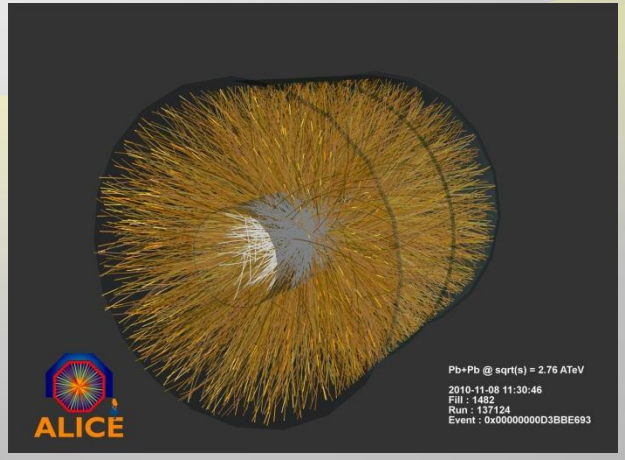
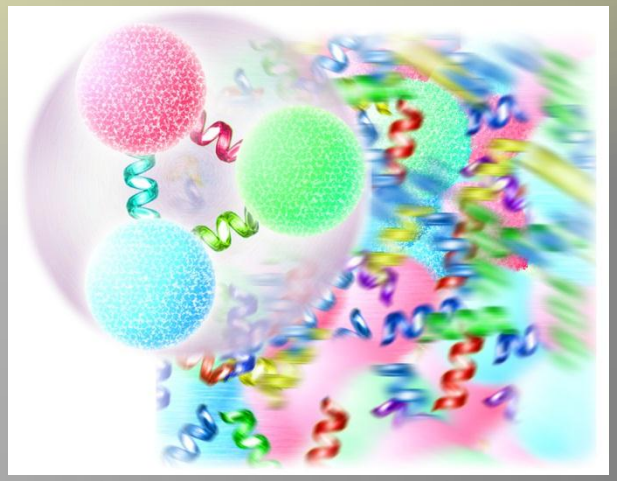
In collaboration with P. Huovinen, K. Murase and Y. Nara

T.Hirano, P.Huovinen, K.Murase and Y.Nara, arXiv:1204.5814

Introduction



ALICE event display



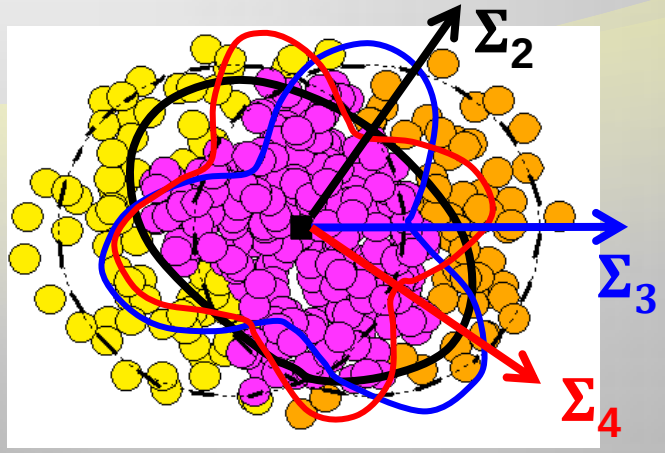
The Quark Gluon Plasma
(Taken from LBNL website)

Analysis tool(s)
to interpret data

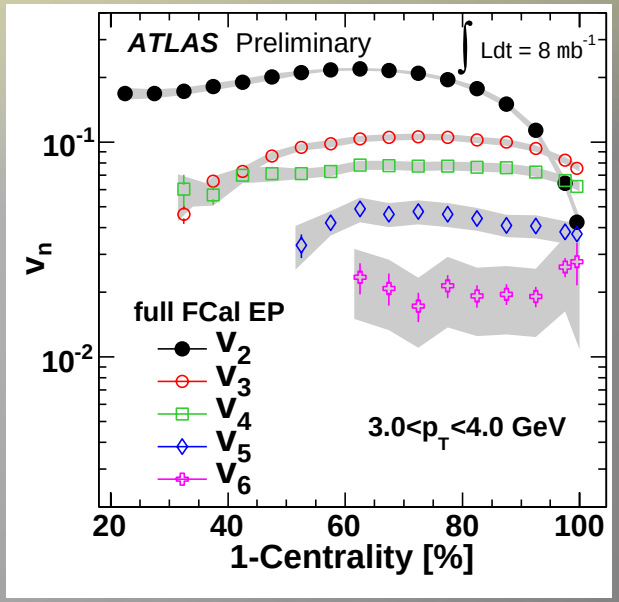
Properties of the QGP
e.g. EoS, transport coefficients

*Cosmic Microwave Background →Cosmological constants

Initial Fluctuation and Higher Harmonics



Adapted from talk by J.Jia at QM2011

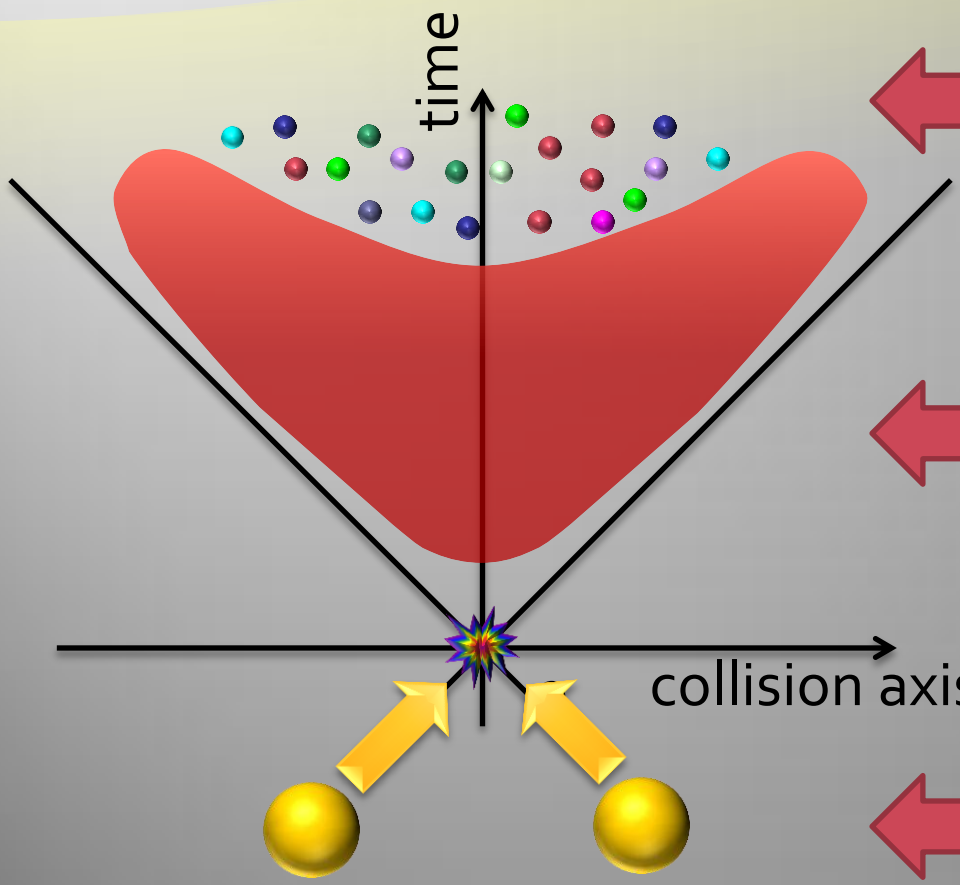


Initial fluctuation of profile → Higher harmonics

Necessity of event-by-event simulation

Impact of finite v_n (discussed later)

An Integrated Dynamical Model



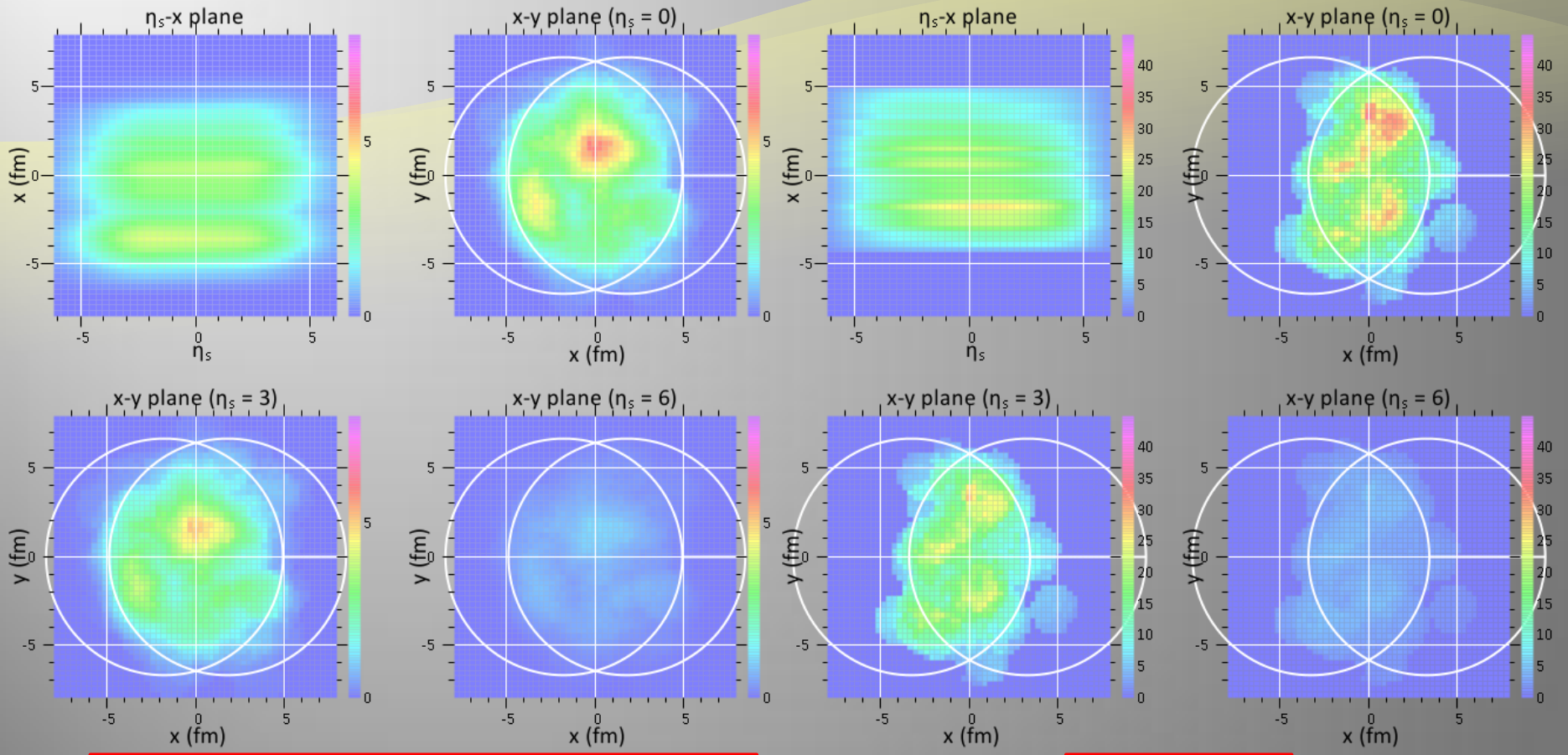
Current module

Hadron cascade (JAM)

3D Ideal hydro simulation with lattice EoS

Monte Carlo Glauber/CGC model

Initial Conditions



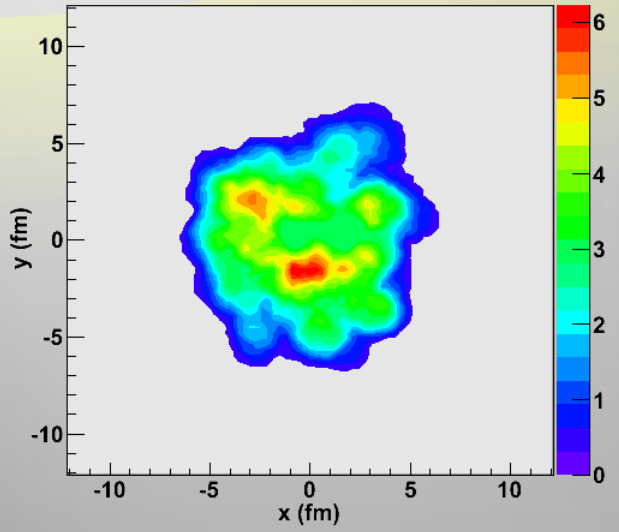
MC-Glauber + modified BGK

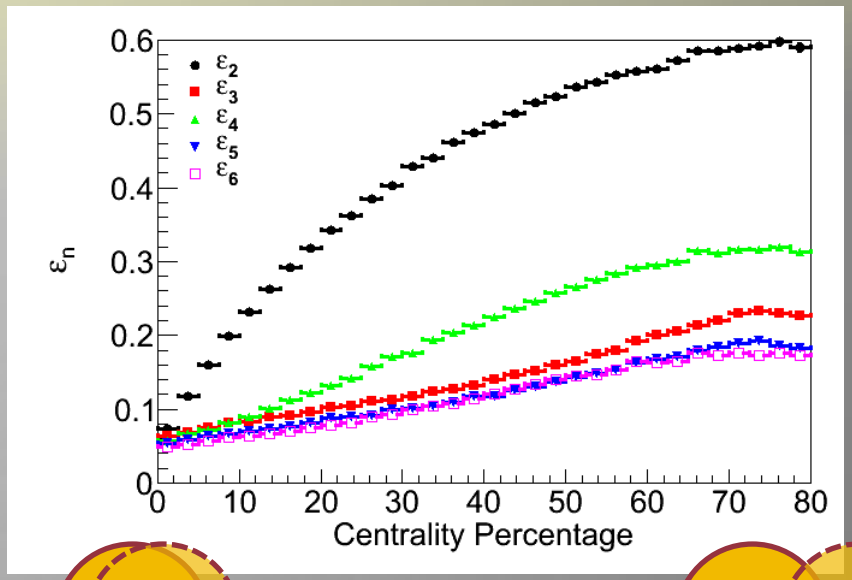
MC-KLN

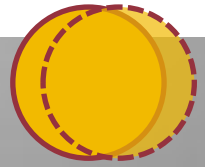
Longitudinally correlated structure (color flux tubes)

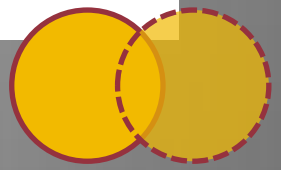
*No longitudinal fluctuation (open question)

Deformation in Initial Conditions





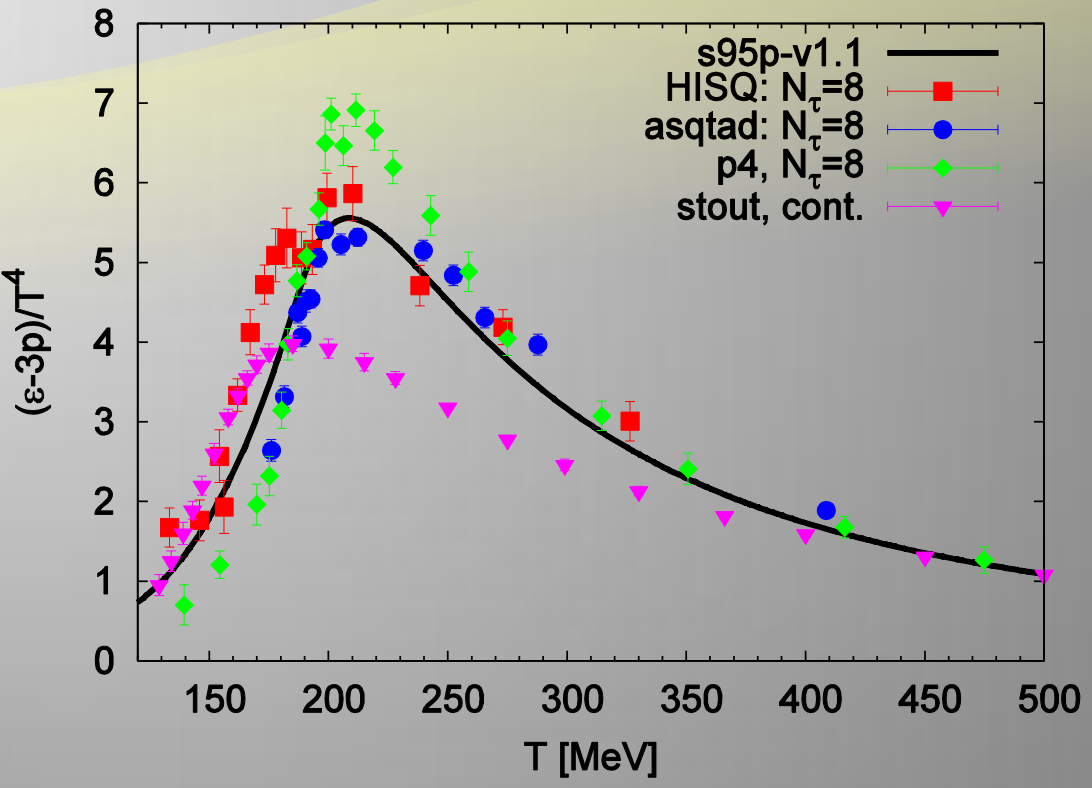




Sample of entropy density profile in a plane perpendicular to collision axis

$$\varepsilon_n = \frac{\left|\left\langle r^2 e^{in\phi}\right\rangle\right|}{\langle r^2\rangle}$$

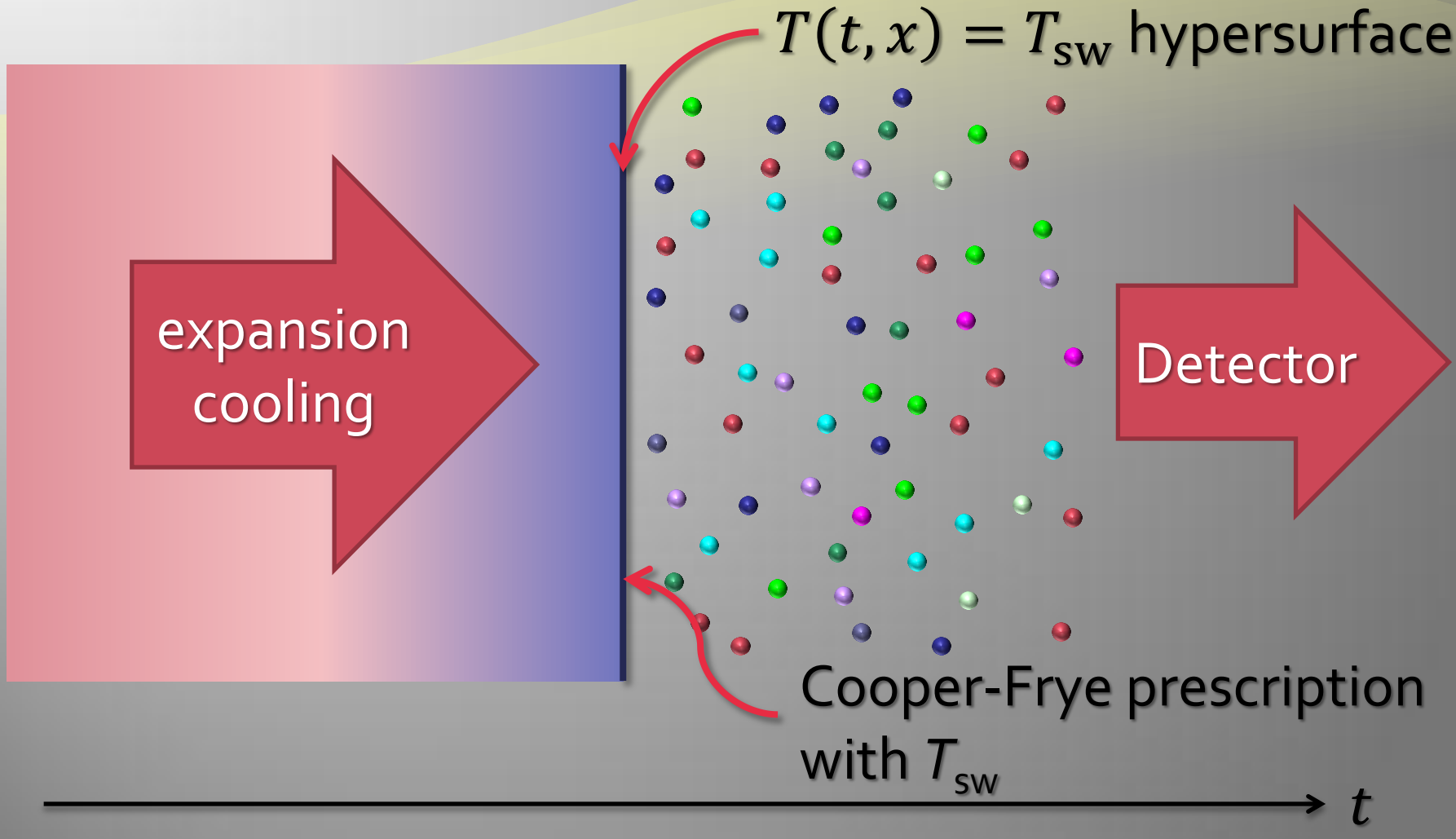
Equation of State



High temperature region: Lattice results

Low temperature region: Hadron resonance gas (JAM)

"Particlization" and Cascade

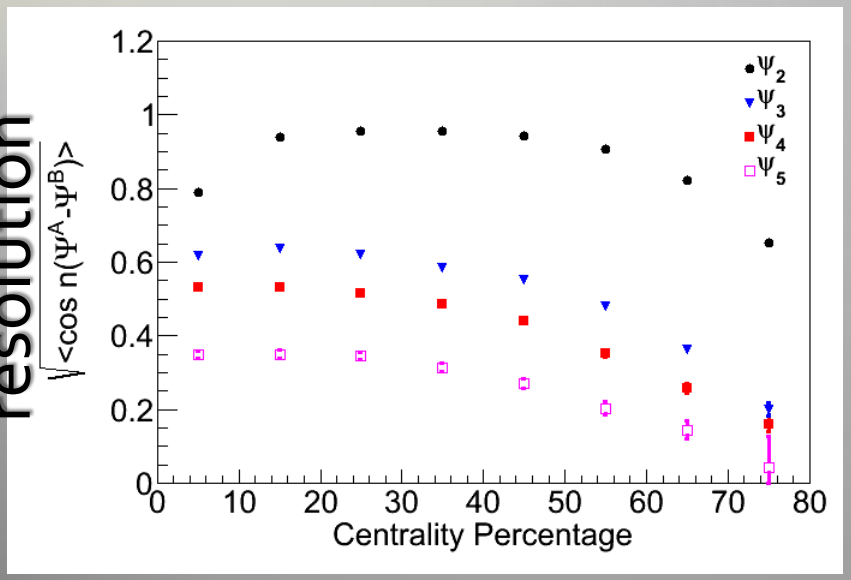


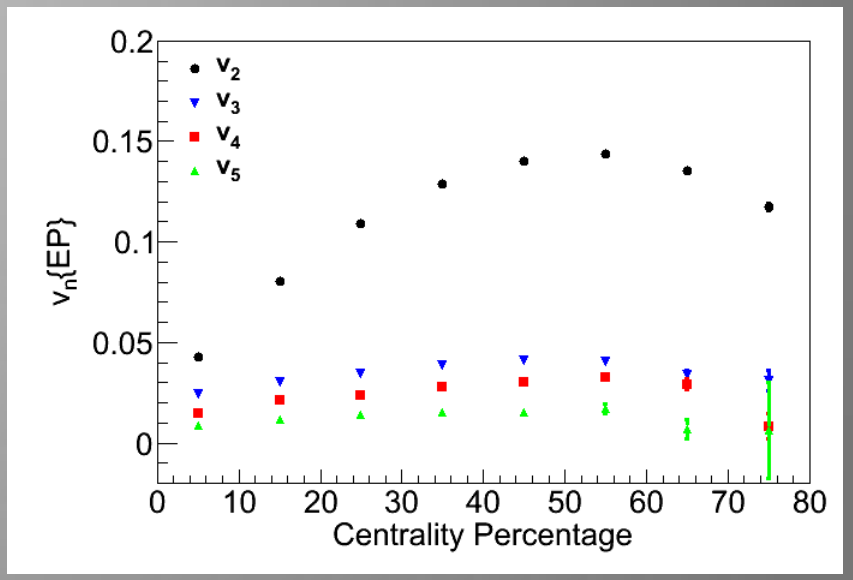
$T_{sw} = 155\text{MeV}$ determined from PHENIX PID p_T spectra

$v_n\{EP\}$ and Event Plane Resolution

$$v_n\{\mathrm{EP}\}(\eta, p_T) = \frac{1}{R}\langle\cos[n(\phi - \Psi_n{}^{P/N})]\rangle$$

MC-KLN, Pb+Pb@LHC, midrapidity





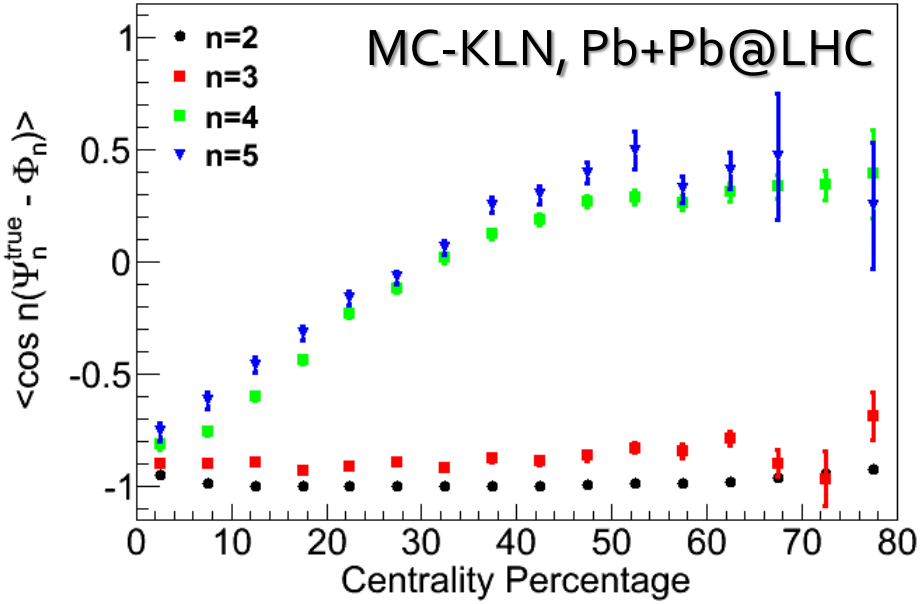
Assuming ATLAS Forward CAL region

*100K events

Finite v_n

→ What makes them finite?

Correlation between Participant Plane and Event Plane



Ψ_n: Event plane angle

Φ_m: Participant plane angle

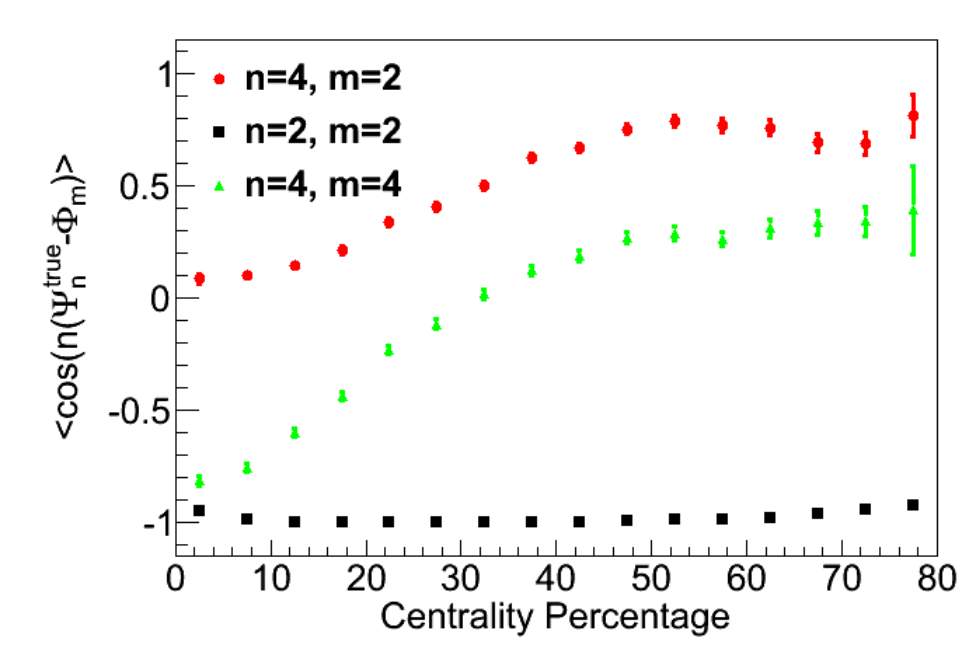
※Event plane angle corrected by its resolution

$\varepsilon_2 \rightarrow v_2$
$\varepsilon_3 \rightarrow v_3$
Intuitively understood

$\varepsilon_4 \rightarrow v_4$
$\varepsilon_5 \rightarrow v_5$
Only in central collisions

Ultra central collision?
Caveats: Deformation of Au and Cu?

Correlation btw. participant plane and event plane



Ψ_n: Event plane angle
Φ_m: Participant plane angle

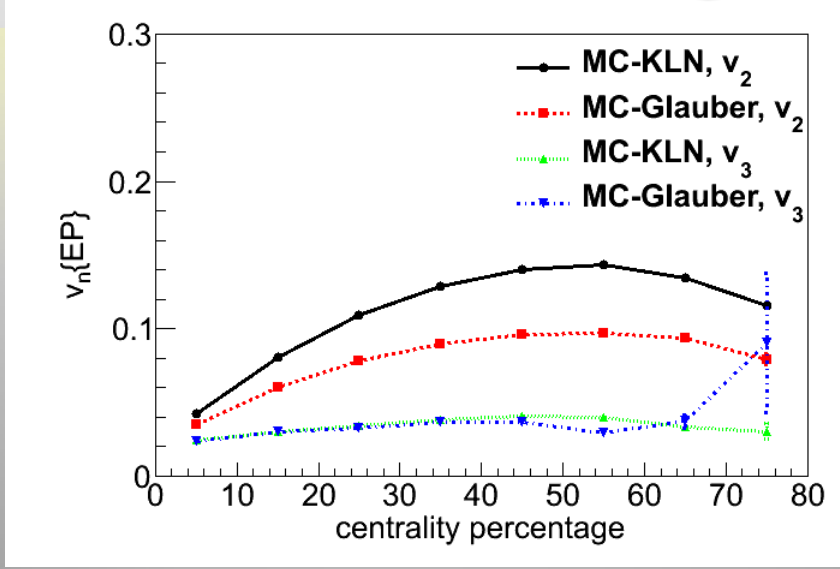
※Event plane angle corrected by its resolution

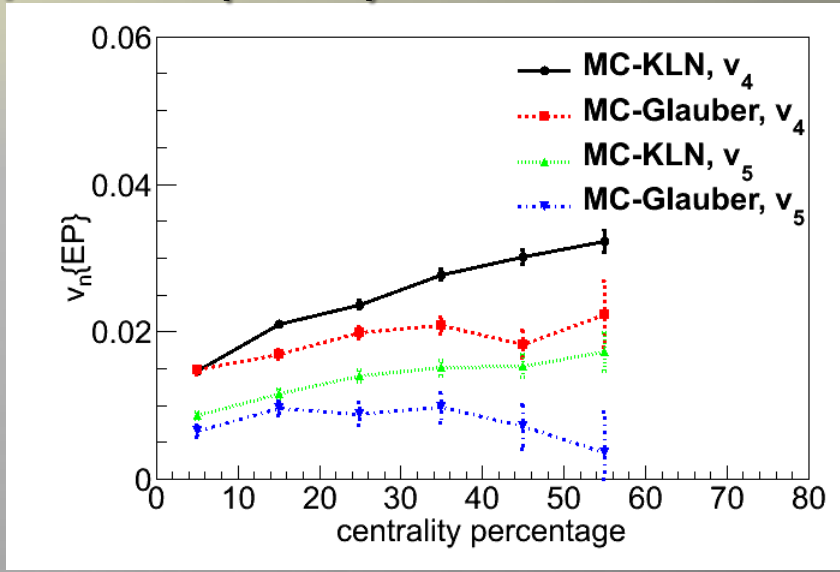
$\varepsilon_2 \rightarrow v_2$

$\varepsilon_4 \rightarrow v_4$ (central)
$\varepsilon_2 \rightarrow v_4$ (peripheral)

MC-KLN vs. MC-Glauber

Pb+Pb @ LHC, midrapidity





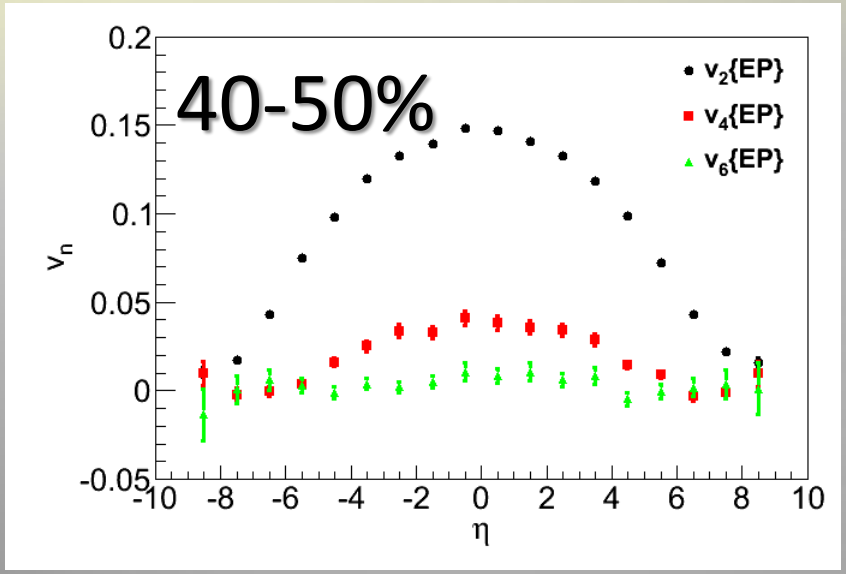
PHENIX* : Simultaneous analysis of v_2 and v_3

Our suggestion : Simultaneous analysis up to v_5

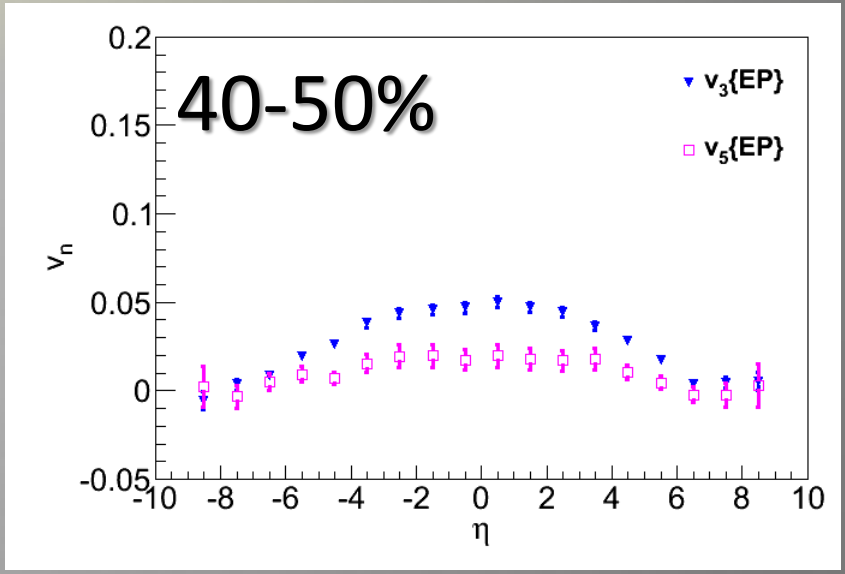
*A.Adare et al. [PHENIX], Phys. Rev. Lett. 107, 252301 (2011)

$v_n\{EP\}(\eta)$

Even Harmonics

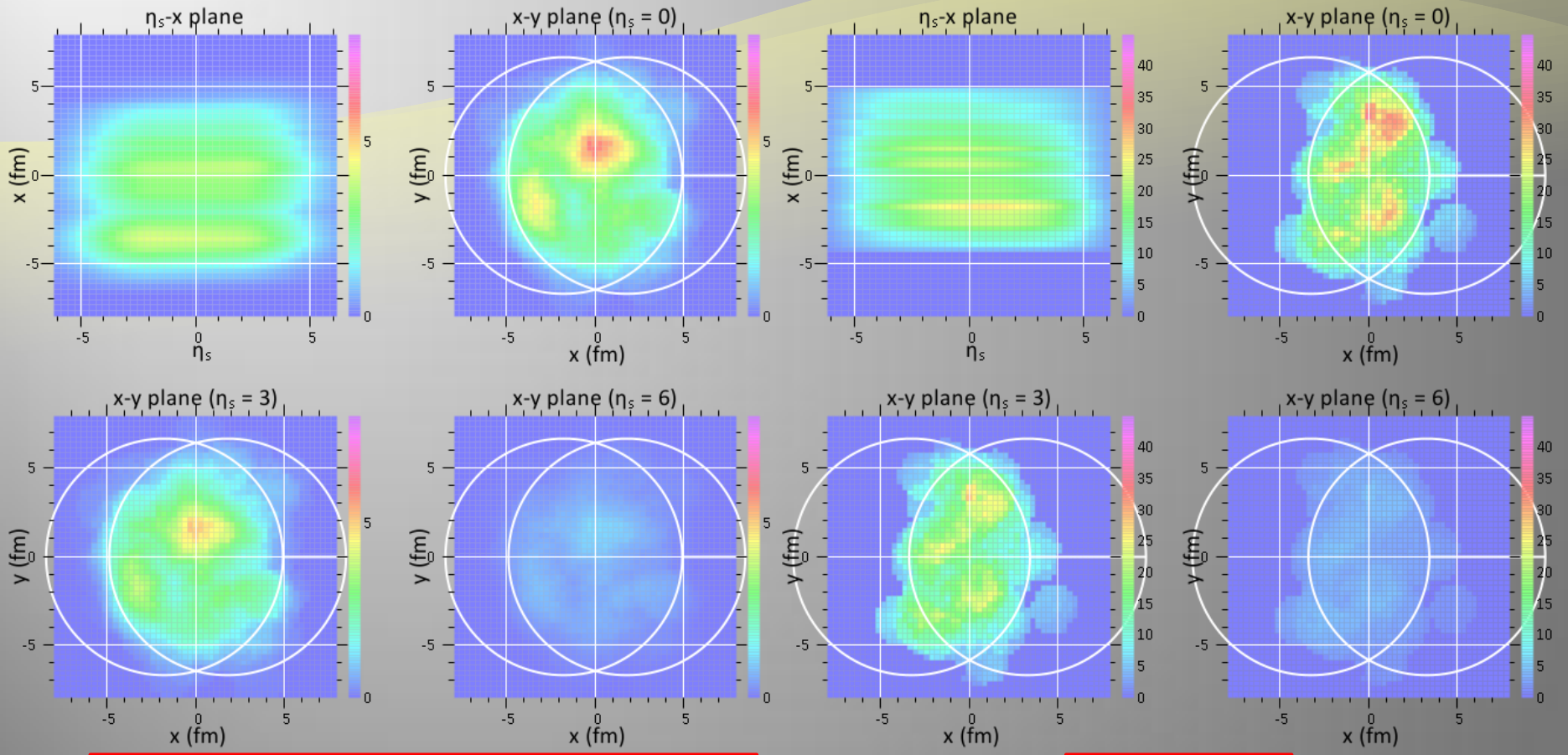


Odd Harmonics



Not boost inv. ←→almost boost inv. for epsilon
(Remember flux tube structure)

Initial Conditions



MC-Glauber + modified BGK

MC-KLN

Longitudinally correlated structure (color flux tubes)

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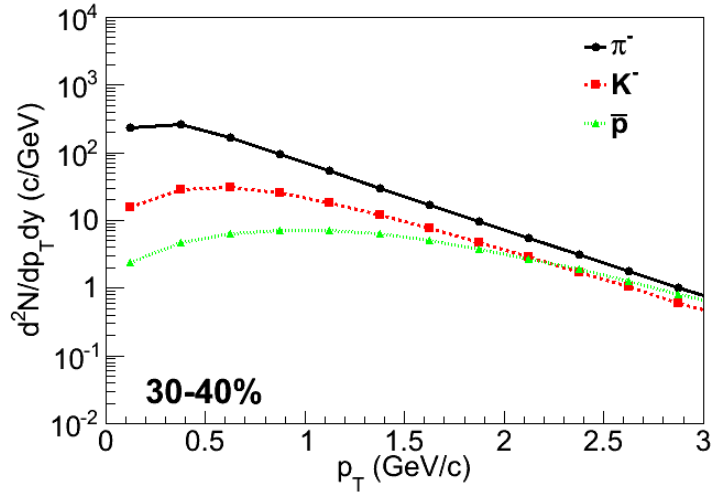
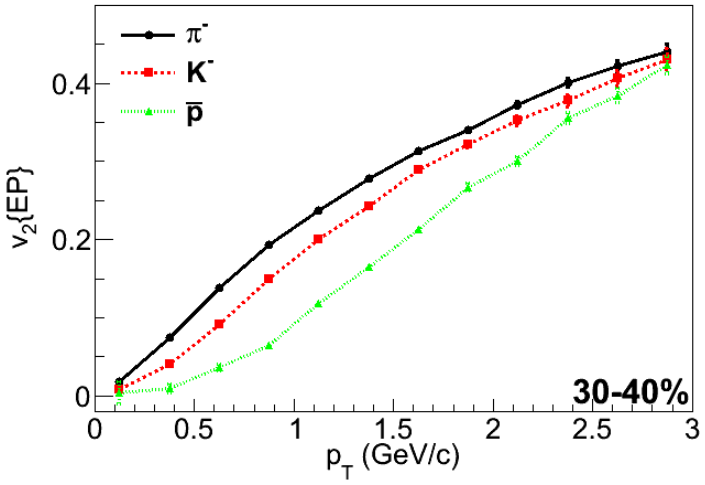
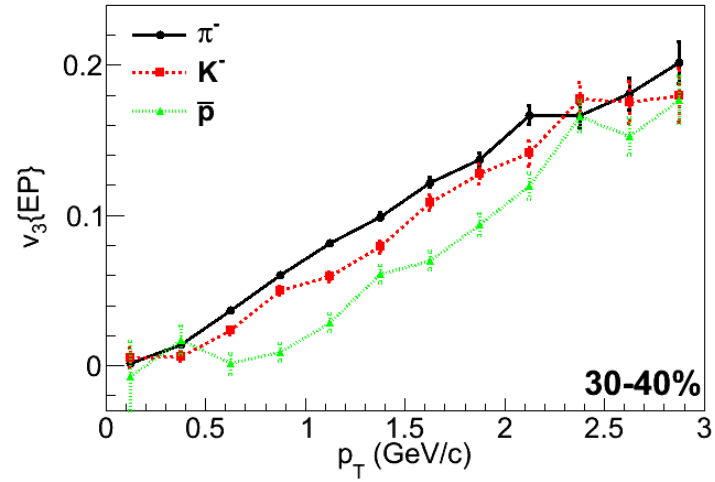
PID spectra, $v_2(p_T)$ and $v_3(p_T)$

MC-KLN, Pb+Pb @ LHC, midrapidity







Almost identical pattern between v_2 and v_3

*100K events

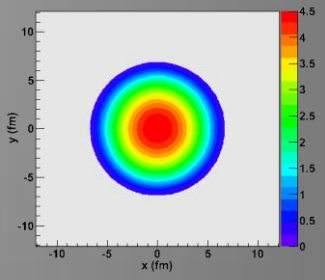
Impact of Finite Higher Harmonics

- Only few people (?) believed hydro description of the QGP (~ 1995)
- Hydro at work to describe elliptic flow (~ 2001)
- Hydro at work (?) to describe higher harmonics (~ 2010)

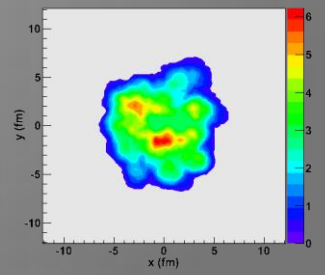
coarse graining size

initial profile

$d \lesssim 5$ fm



$d \lesssim 1$ fm



Outlook: Towards a more realistic event generator

- Dissipative effects
- Fluctuation appears everywhere
  - Multiplicity fluctuation (Negative Binomial Dist.)
  - Longitudinal fluctuation (Particle production in strong color fields)
  - Thermal fluctuation (a.k.a. hydrodynamic fluctuation)
  - Disturbed by jets (wake)

Hydrodynamic Fluctuation and Dissipation

Stochastic constitutive equation

$$\pi^{\mu\nu} = \int_{x^0 > x'^0} d^4x' G_\pi(x - x')^{\mu\nu}{}_{\alpha\beta}\, \partial^{<\mu} u^{\nu>}(x') + \delta\pi^{\alpha\beta}$$

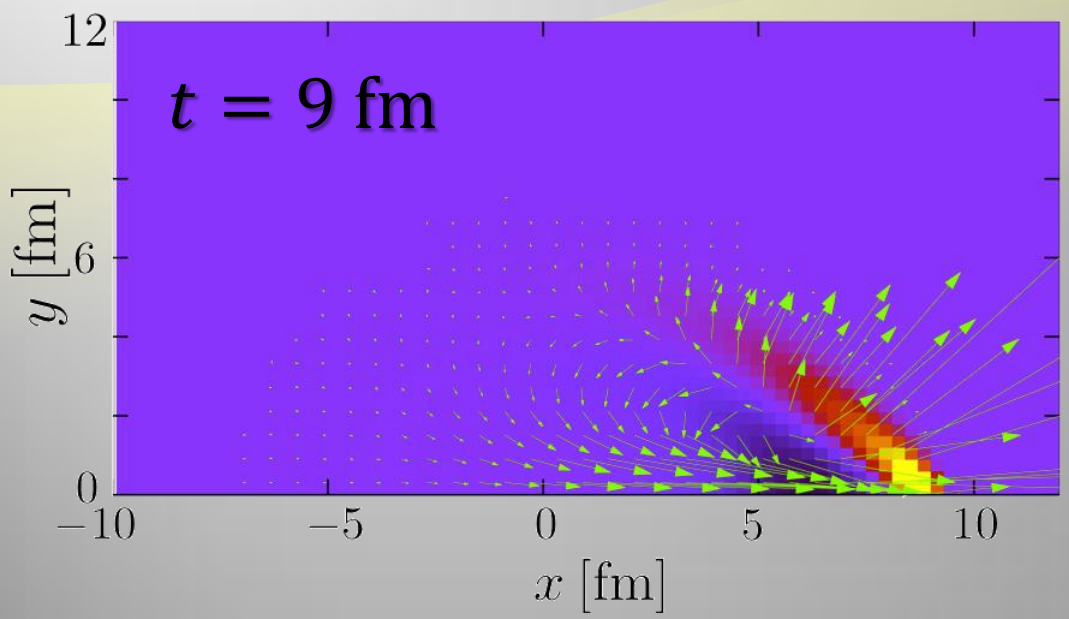
Fluctuation-Dissipation relation

$$\left\langle \delta\pi^{\mu\nu}(x)\delta\pi_{\alpha\beta}(x') \right\rangle = T G_\pi(x - x')^{\mu\nu}{}_{\alpha\beta}$$

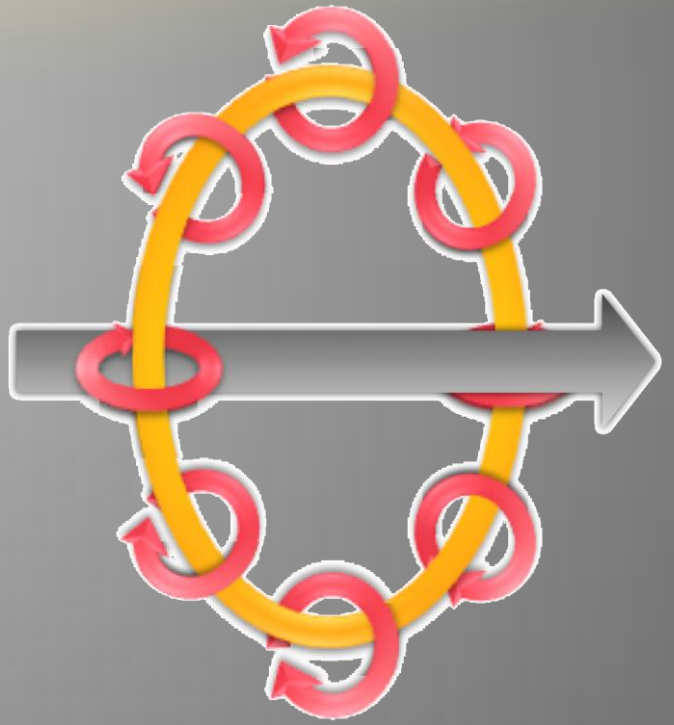
2nd order hydro including relaxation time
←→Colored noise

K.Murase and TH, in preparation

Vortex Ring



An energetic jet traveling through a uniform medium



Vortex ring

Y. Tachibana and TH, in preparation

Summary

- Development of event generator based on relativistic hydrodynamics and its application
  - MC-Glauber/KLN initialization
  - Full 3D ideal hydrodynamic simulation with lattice EoS
  - Hadronic afterburner

Outlook: Towards a more realistic event generator

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- Fluctuation appears everywhere
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