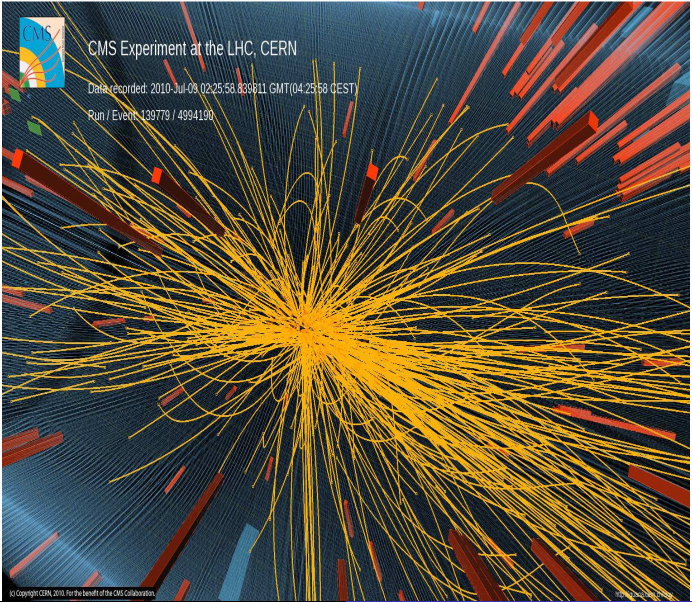
Limits of fluid dynamics in small systems

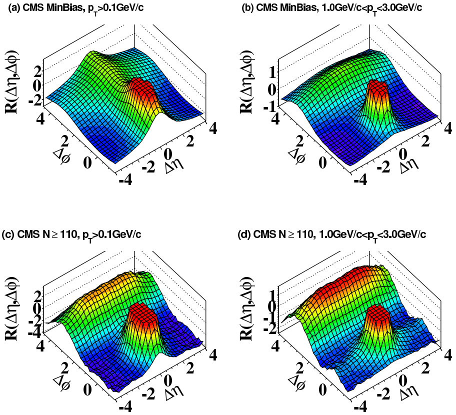
Piotr Bożek

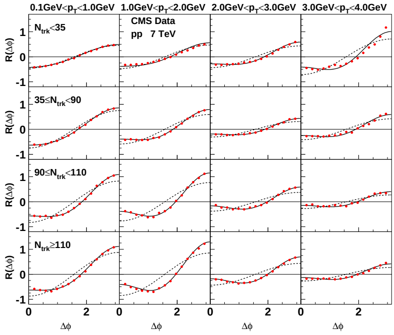
AGH and Institute of Nuclear Physics, Kraków

High multiplicity events in pp



Ridge in pp

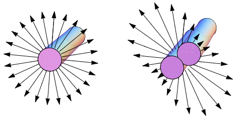


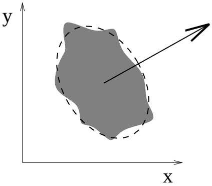


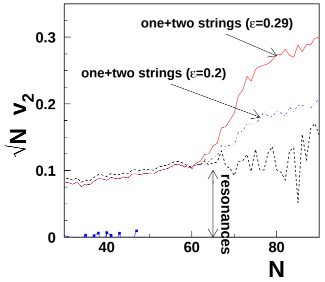
PB arXiv:1010.0405

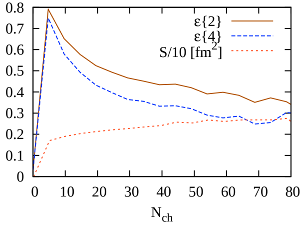
can we measure (calculate) v_2

Fireball shape in pp









E.Asar et al., 1009.5643

Casalderrey-Solana, Wiedemann, 0911.4400

Bozek, 0911.2397

p-Pb reference system - No FSI expected

CERN-PH-TH/2011-119
LHC-Project-Report-1181

arXiv:1105.3919v1 [hep-ph] 19 May 2011

Proton-Nucleus Collisions at the LHC: Scientific Opportunities and Requirements

Editor: *C. A. Salgado*[1]
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Abstract
Proton-nucleus (p+A) collisions have long been recognized as a crucial component of the physics programme with nuclear beams at high energies, in particular for their reference role to interpret and understand nucleus-nucleus data as well as for their potential to elucidate the partonic structure of matter at low parton fractional momenta (small-x). Here, we summarize the main motivations that make a proton-nucleus run a decisive ingredient for a successful heavy-ion programme at the Large Hadron Collider (LHC) and we present unique scientific opportunities arising from these collisions. We also review the status of ongoing discussions about operation plans for the p+A mode at the LHC.

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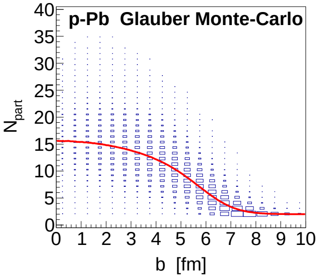
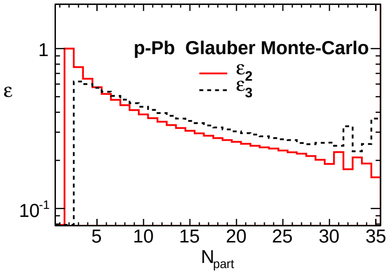
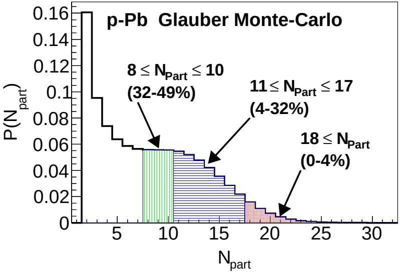
Contents

Fireball in p-Pb



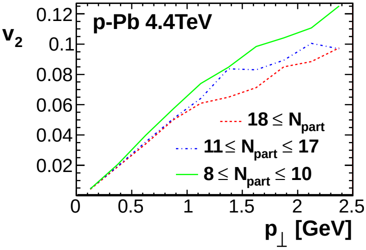


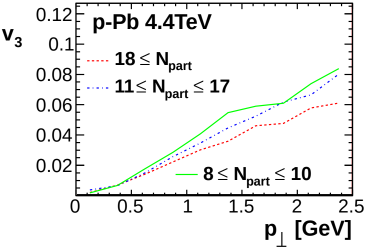


PB, arXiv:1112.0912

Collective elliptic flow in p-Pb? in p-p?

	p-Pb	p-p
Large enough density?	yes	yes (high mult.)
Large enough eccentricity	yes?	(?)
Large enough size?	(?) but should and can be tested	(???)
Small enough gradients? - beyond viscous hydro	no	no!

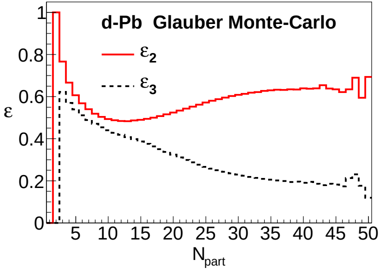


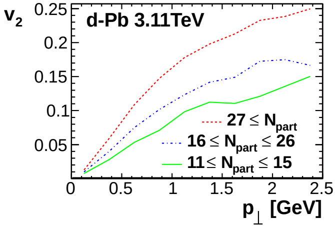


elliptic flow in p-Pb

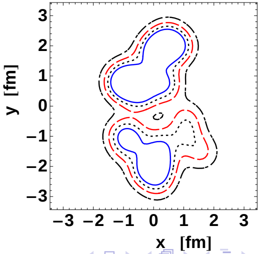
triangular flow

PB, arXiv:1112.0912





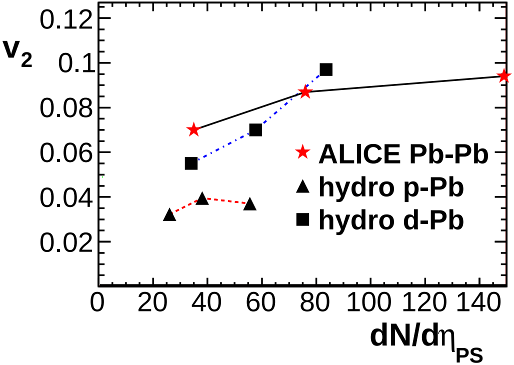
large elliptic flow



PB, arXiv:1112.0912

. . . it seems very interesting to look for collective effects in d-Au collisions at $\sqrt{s_N} = 200$GeV in RHIC experiments . . .

prediction 12.2011



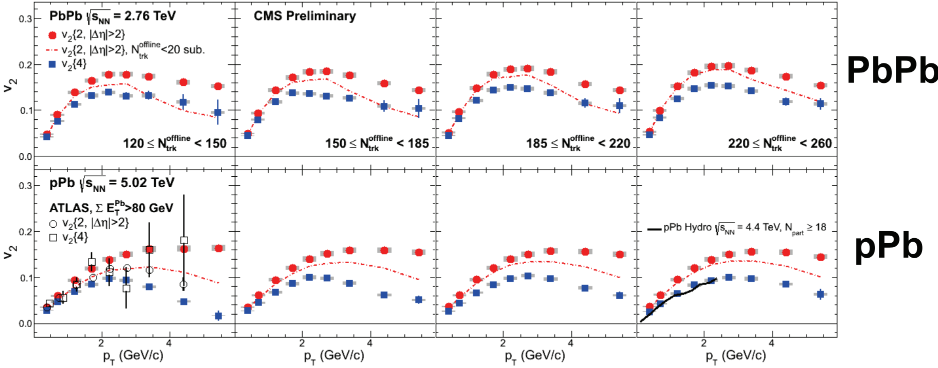
- collective flow effects $\simeq$ peripheral Pb-Pb
- can be observed
- p-Pb (d-Pb) is not p-p superposition
- only p-p as baseline

PB, arXiv:1112.0912

v_2 in pPb and PbPb

Dash-dot line: peripheral subtracted

multiplicity →



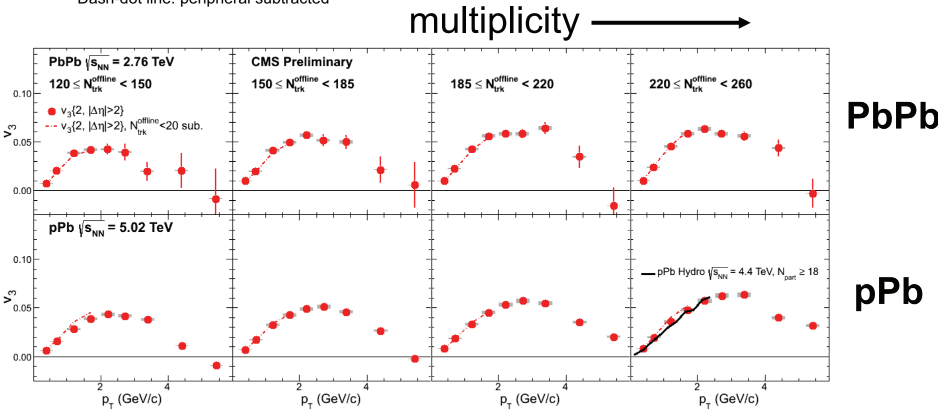
v_2 shows similar shape in pPb and PbPb, but is smaller in pPb

$v_2\{4\}$ is only 20% smaller than $v_2\{2\}$ below 2 GeV/c

"Peripheral subtraction" has small effect at high multiplicity

v_3 in pPb and PbPb

Dash-dot line: peripheral subtracted

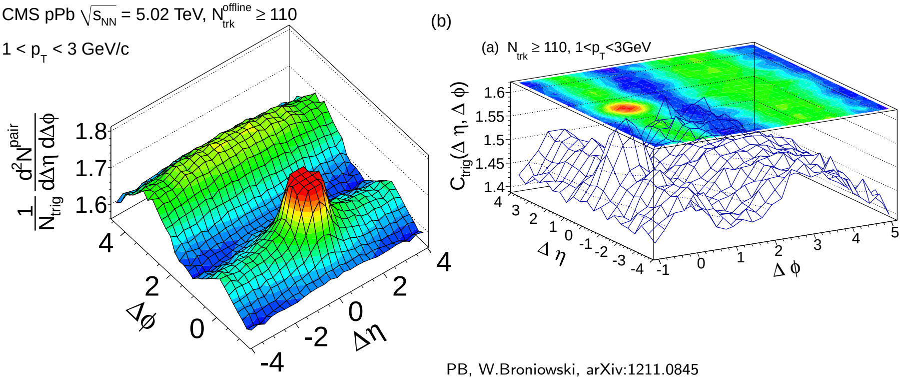


v_3 has similar shape in pPb and PbPb; magnitude comparable

"Peripheral subtraction" makes essentially no difference

Hydro prediction: Bozek, $v_3\{PP\}$, not including fluctuations

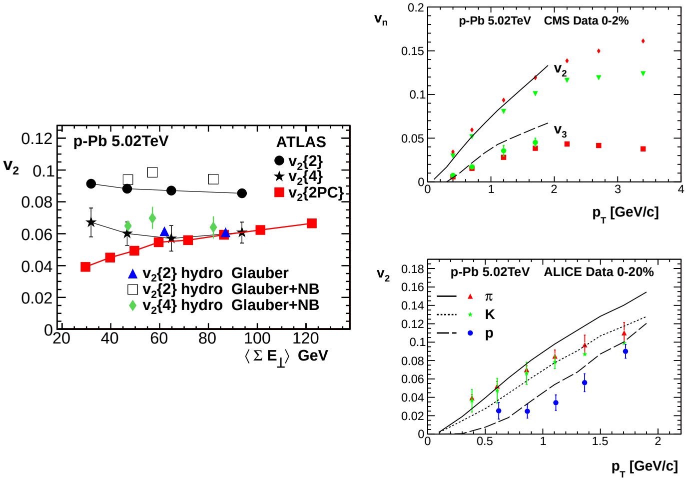
Ridge in p-Pb



PB, W.Broniowski, arXiv:1211.0845

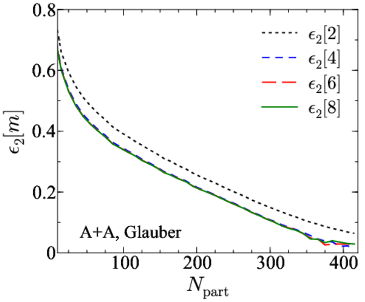
symmetric ridge also from CGC, K.Dusling, R. Venugopalan, arXiv:1210.3890, 1211.3701, 1302.7018

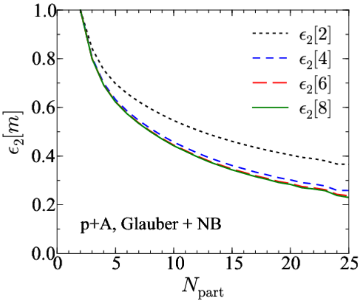
Elliptic and triangular flow



PB, W.Broniowski, G. Torrieri arXiv:1306.5442

Higher cumulants

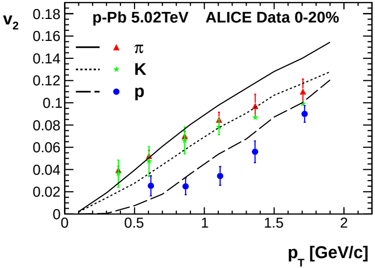


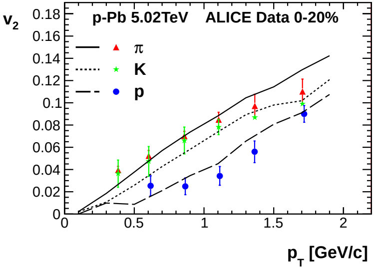


$v_2\{2\}^2 \simeq v_2^2 + \delta^2 \quad v_2\{4\} = v_2\{6\} = v_2\{8\} \simeq v_2$
Bzdak,PB, McLerran

$v_2\{4\} \simeq v_2\{6\} \simeq v_2\{8\} < v_2\{2\}$

v_2 from late stage





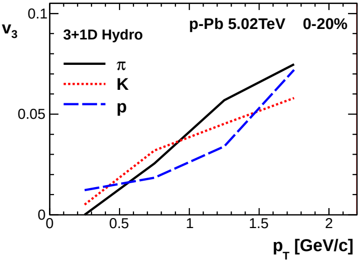
$T_f = 150$MeV

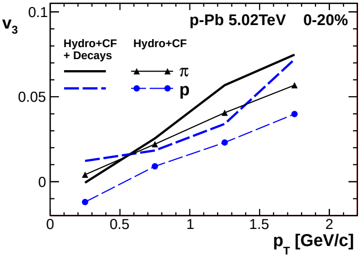
- pions : 0.75 collisions after emission

$T_f = 140$MeV

- pions : 0.65 collisions after emission

v_3 - small mass splitting

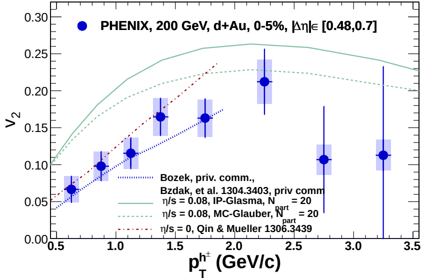


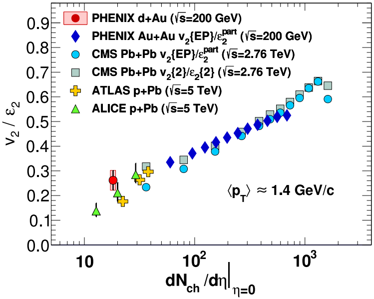


limited mass splitting

resonance decays spoil mass ordering

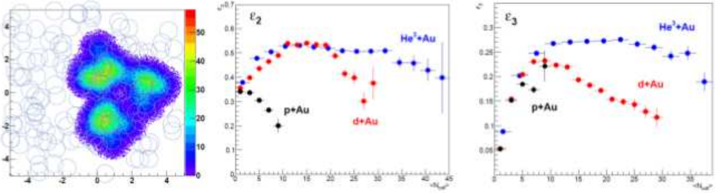
d-Au at 200GeV

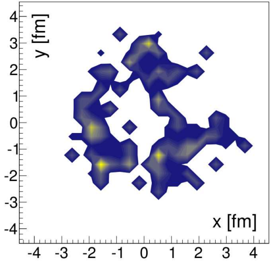




^{3}He-Au $\quad$ ^{12}C-Pb

PHENIX proposal $\rightarrow v_3$

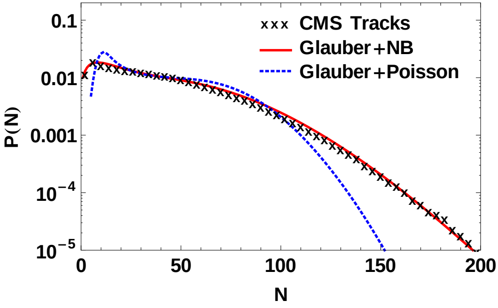




α clusters in ^{12}C Broniowski, Arriola 1312.0289

Glauber+NB

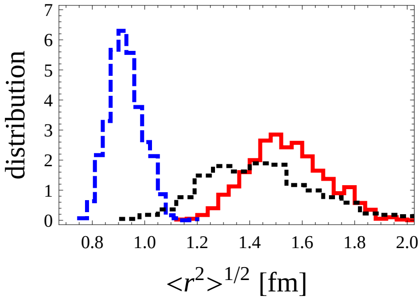
fluctuations from subnuclear dynamics



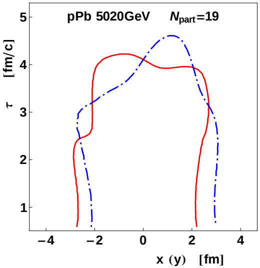
$$P(n) = \sum_i P_{part}(i) Np\lambda i, \kappa i(n)$$

Additional fluctuations of density (compared to Glauber)

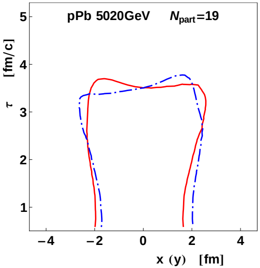
very different source sizes



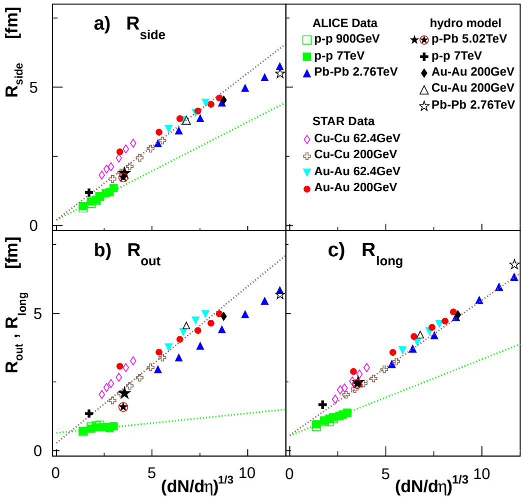
large source (standard)



compact source



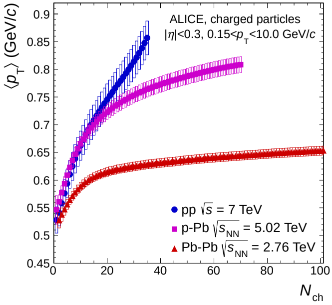
HBT systematics

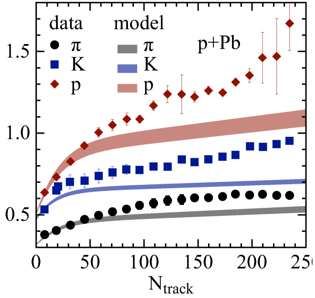


PB, W.Broniowski, arXiv:1301.3314

small system corrections!- Sinyukov, Shapoval - arXiv:1209.1747

Spectra - $< p_\perp >$

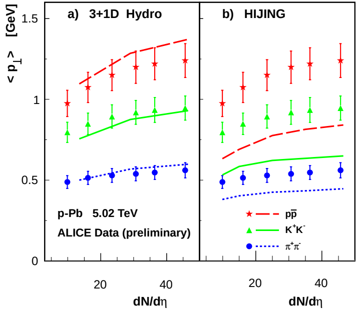


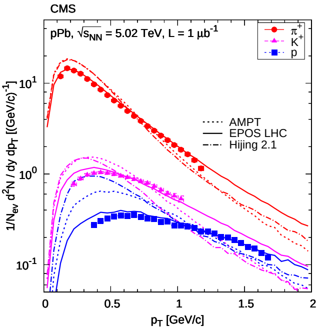


larger $< p_\perp >$ in smaller systems

Bzdak, Skokov, arXiv:1306.5442

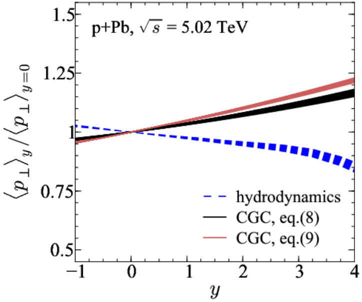
Spectra - $< p_\perp >$





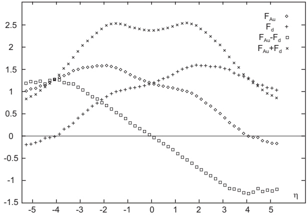
PB, W.Broniowski, G. Torrieri arXiv:1306.5442

$< p_\perp >$ rapidity dependence



different prediction of CGC and hydro

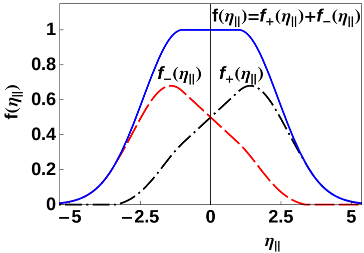
PB, Bzdak, Skokov, 1309.7358

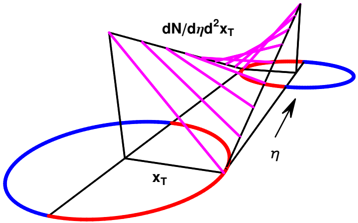


Asymmetric emission

(Białas, Czyż, Acta Phys.Polon.B36, 905 (2005)

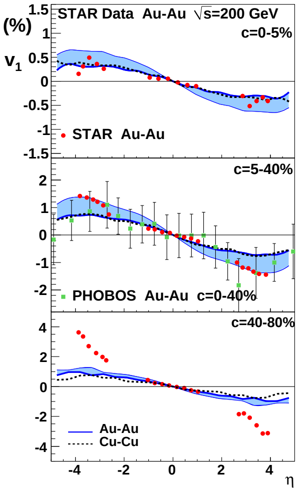
$$\rho(\eta, x, y) \propto f_+(\eta)N_+(x,y) + f_-(\eta)N_-(x,y)$$

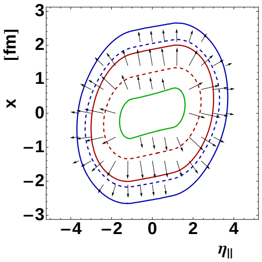




bremsstrahlung (Adil Gyulassy, Phys. Rev. C72, 034907 (2005)

Directed flow- tilted source





Bozek, Wyskiel, Phys. Rev. C81, 054902 (2010)

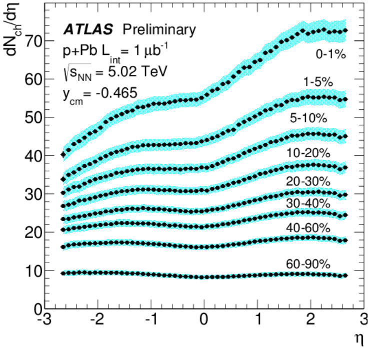
$$\partial_\tau u_x = -\frac{\partial_x p_\perp}{p+\epsilon}$$

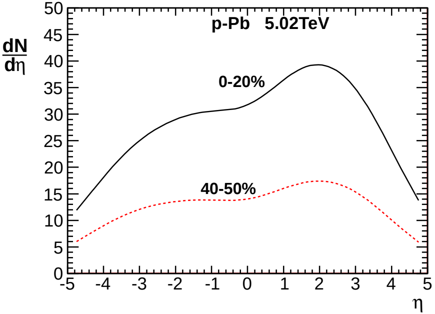
$$\partial_\tau Y = -\frac{\partial_\eta p_{||}}{\tau(p+\epsilon)}$$

tilted source $\rightarrow$ transverse pressure + longitudinal pressure

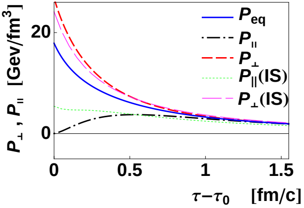
Glauber model

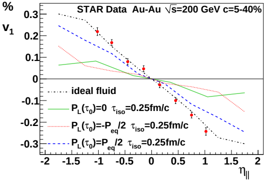
Asymmetric distributions

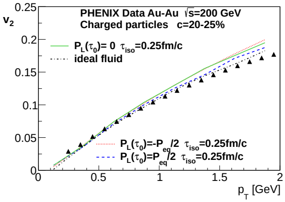


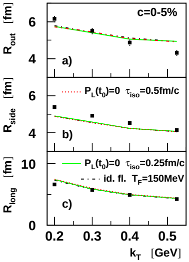


pressure anisotropy









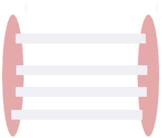
PB, I. Wyskiel - arXiv:1009.0701

- early pressure anisotropy irrelevant!

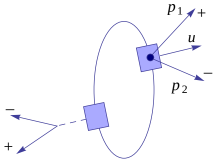
FSI scenarios

fields+thermalization

color fields

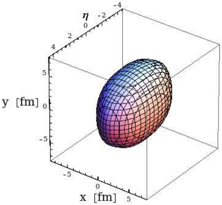


local thermalization → hadronization

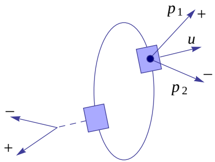


hydrodynamics

hydrodynamic expansion

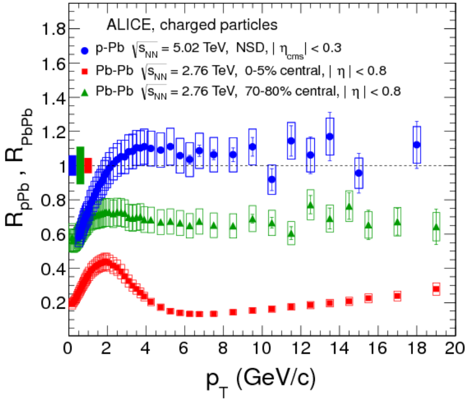


hadronization, statistical emission



Give similar flow

Flow without jet quenchinq?



Summary

- Collectivity in pPb@LHC explains v_2, v_3, ridge, $< p_\perp >$
- Observations consistent with collective flow
  many exp. results; several calculations
- Limits of hydro!

Final State Interactions in p-Pb !

- Why hydrodynamics would work?
- **Effective theory for transverse expansion**
- We need observables for longitudinal pressure

energy-momentum tensor

$$T^{\mu\nu} = \begin{pmatrix} \epsilon & 0 & 0 & 0 \\ 0 & p+\Pi & 0 & 0 \\ 0 & 0 & p+\Pi & 0 \\ 0 & 0 & 0 & p+\Pi \end{pmatrix} + \pi^{\mu\nu}$$

- shear viscosity

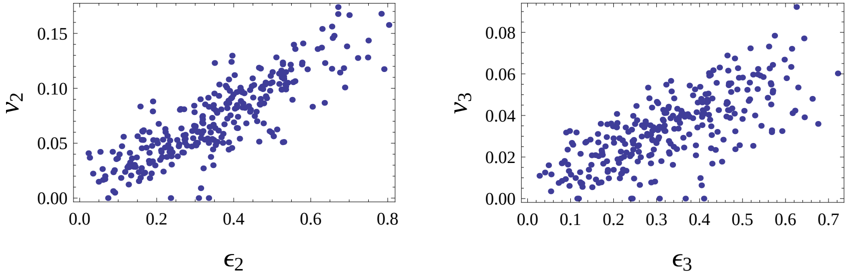
$$\Delta^{\mu\alpha}\Delta^{\nu\beta}u^\gamma\partial_\gamma\pi_{\alpha\beta} = \frac{2\eta\sigma^{\mu\nu} - \pi^{\mu\nu}}{\tau_\pi} - \frac{1}{2}\pi^{\mu\nu}\frac{\eta T}{\tau_\pi}\partial_\alpha\left(\frac{\tau_\pi u^\alpha}{\eta T}\right)$$

- bulk viscosity

$$u^\gamma\partial_\gamma\Pi = \frac{-\zeta\partial_\gamma u^\gamma - \Pi}{\tau_\Pi} - \frac{1}{2}\Pi\frac{\zeta T}{\tau_\Pi}\partial_\alpha\left(\frac{\tau_\Pi u^\alpha}{\zeta T}\right)$$

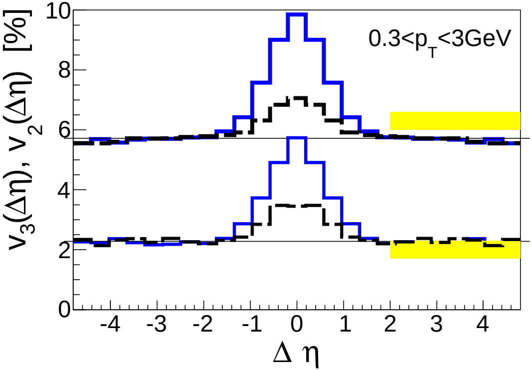
- viscosity corrections from velocity gradients
- **initial** stress tensor - pressure anisotropy
- equation of state

fireball asymmetry - flow asymmetry



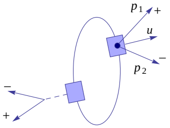
- Ev-by-Ev hydro response to geometry valid
- response strength depends on details

Extracting the flow correlations

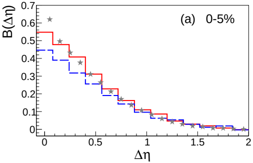


Charge balancing

local charge conservation

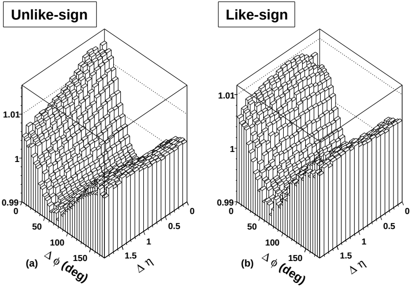


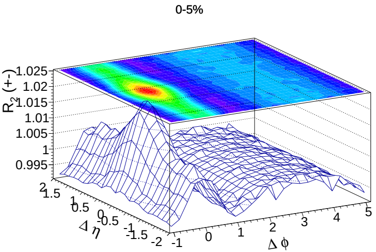
charge balance function



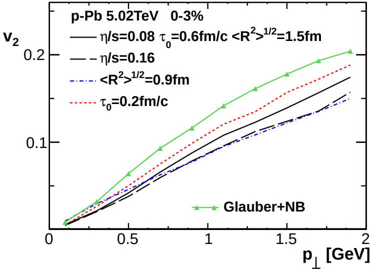
PB, W.Broniowski, arXiv: 1204.3580

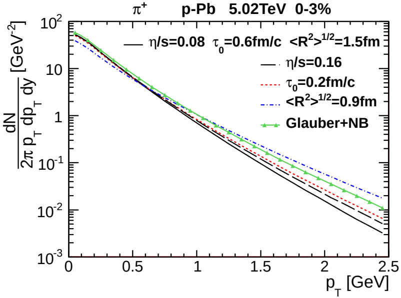
STAR data





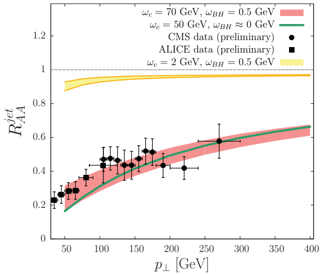
dependence on model details



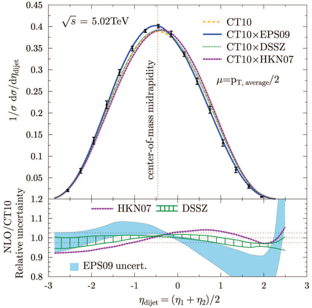


- response strength depends on details, initial eccentricity

No final-state effects



Eskola, Paukkunen, Salgado, arXiv:1308.6733



- Excellent situation to extract initial-state effects

also see H. Paukkunen's and J. Qiu's talks yesterday