p–Pb Collisions at the LHC: a brief overview

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13 experimental papers: ALICE (7), ATLAS (2), CMS (3), LHCb (1)

(...and "innumerable" theoretical ones :)

- Initial state (shadowing/saturation) ...reference measurements

  IS2013, `http://indico.cern.ch/conferenceTimeTable.py?confId=239958`

- Final state? (to flow or not to flow?)

Reference measurements

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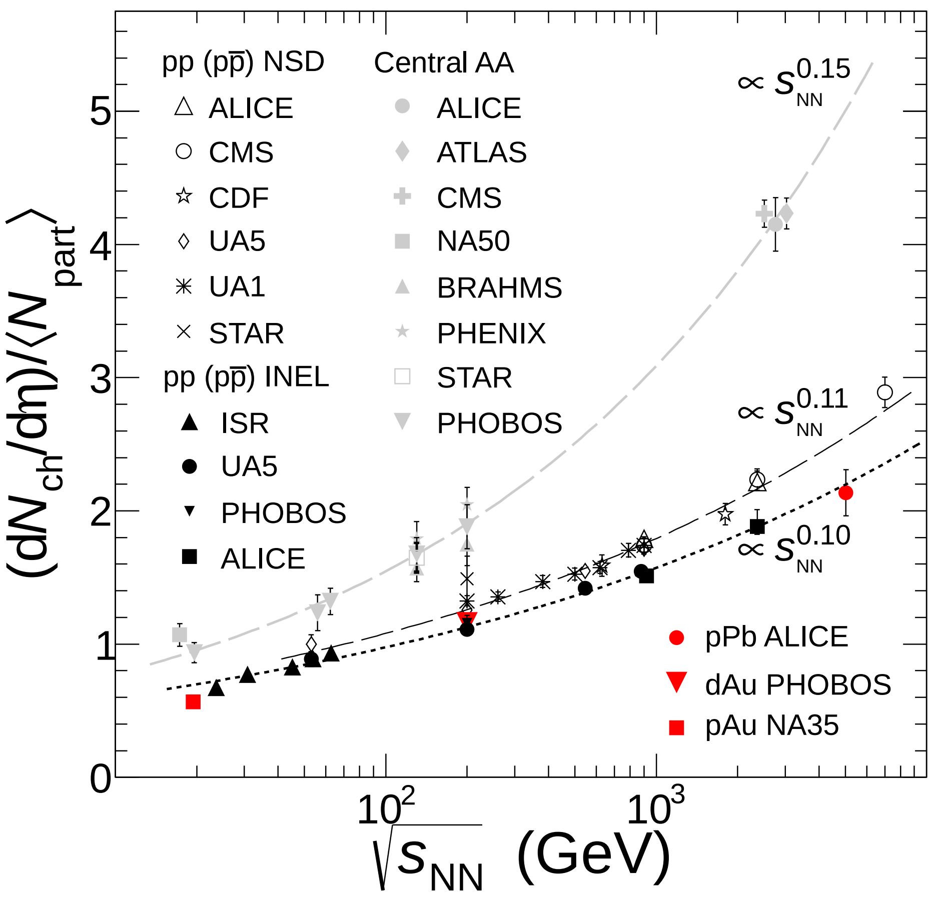
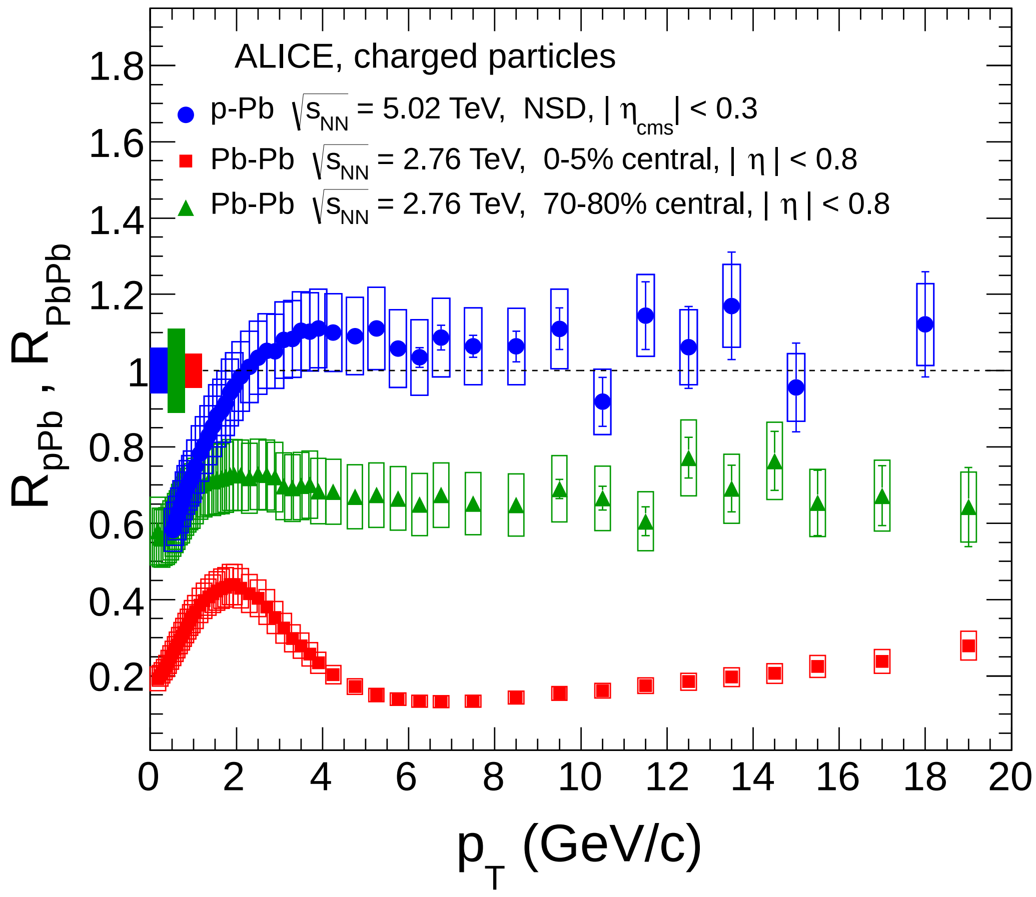
ALICE, PRL 110 (2013) 032301
30 citations



PRL 110 (2013) 082302
32 citations



p-Pb data exhibit generic features of (gluon) saturation (NB: N_{coll} (p-Pb) $= 8$)

Reference measurements + theory

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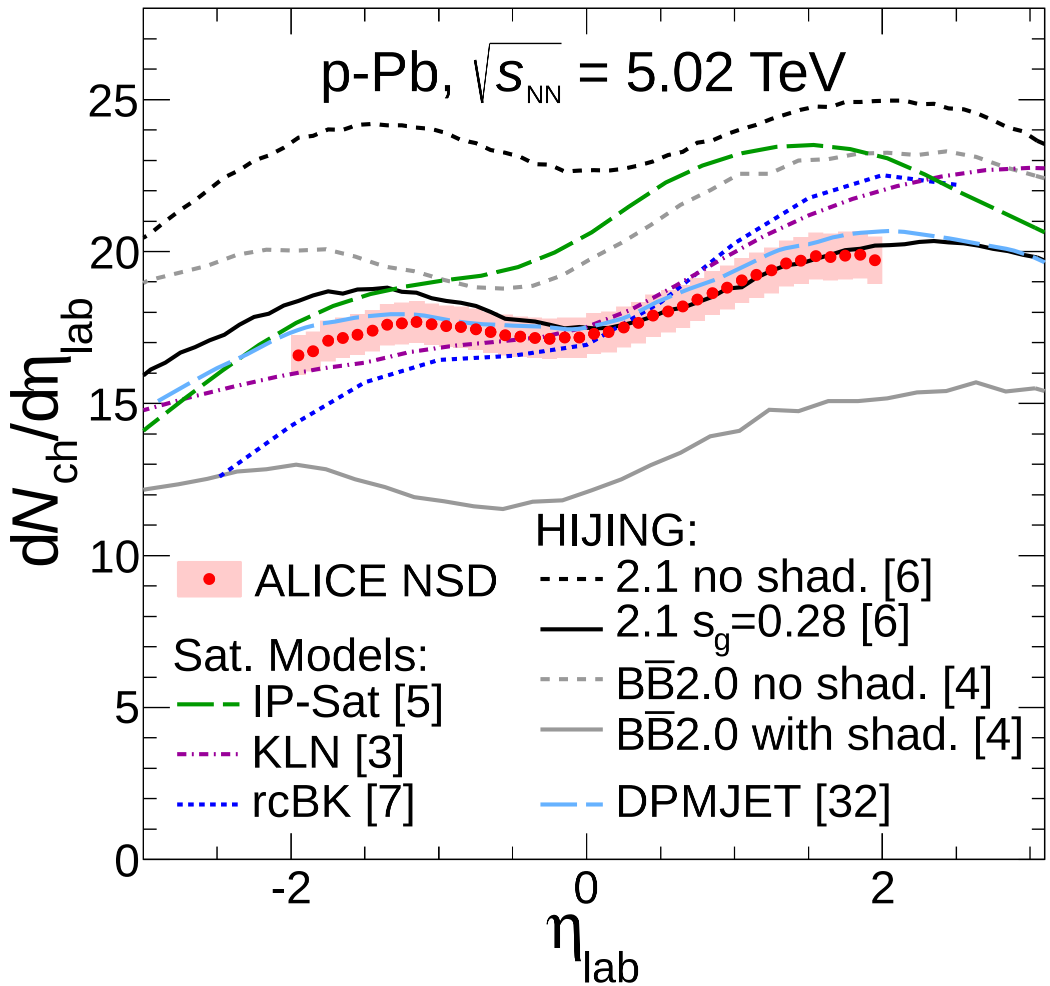
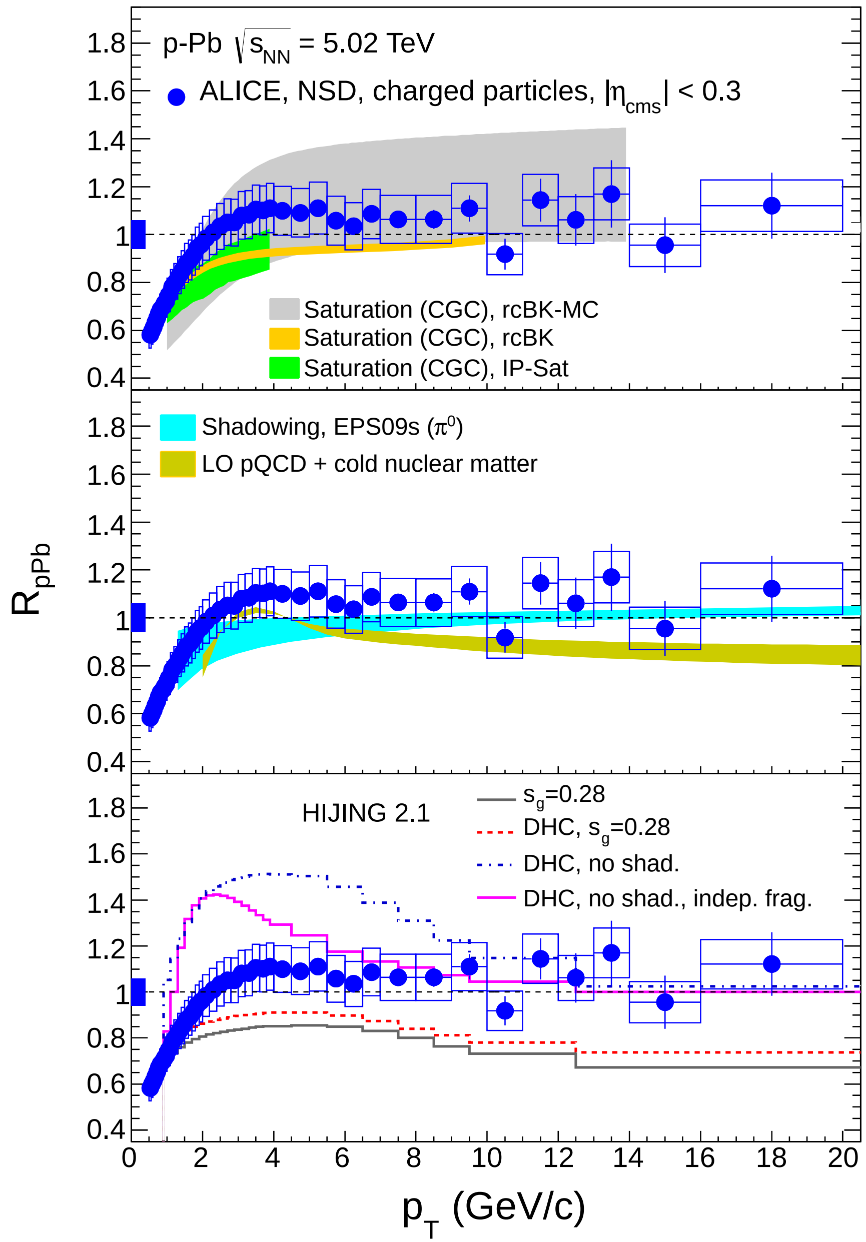
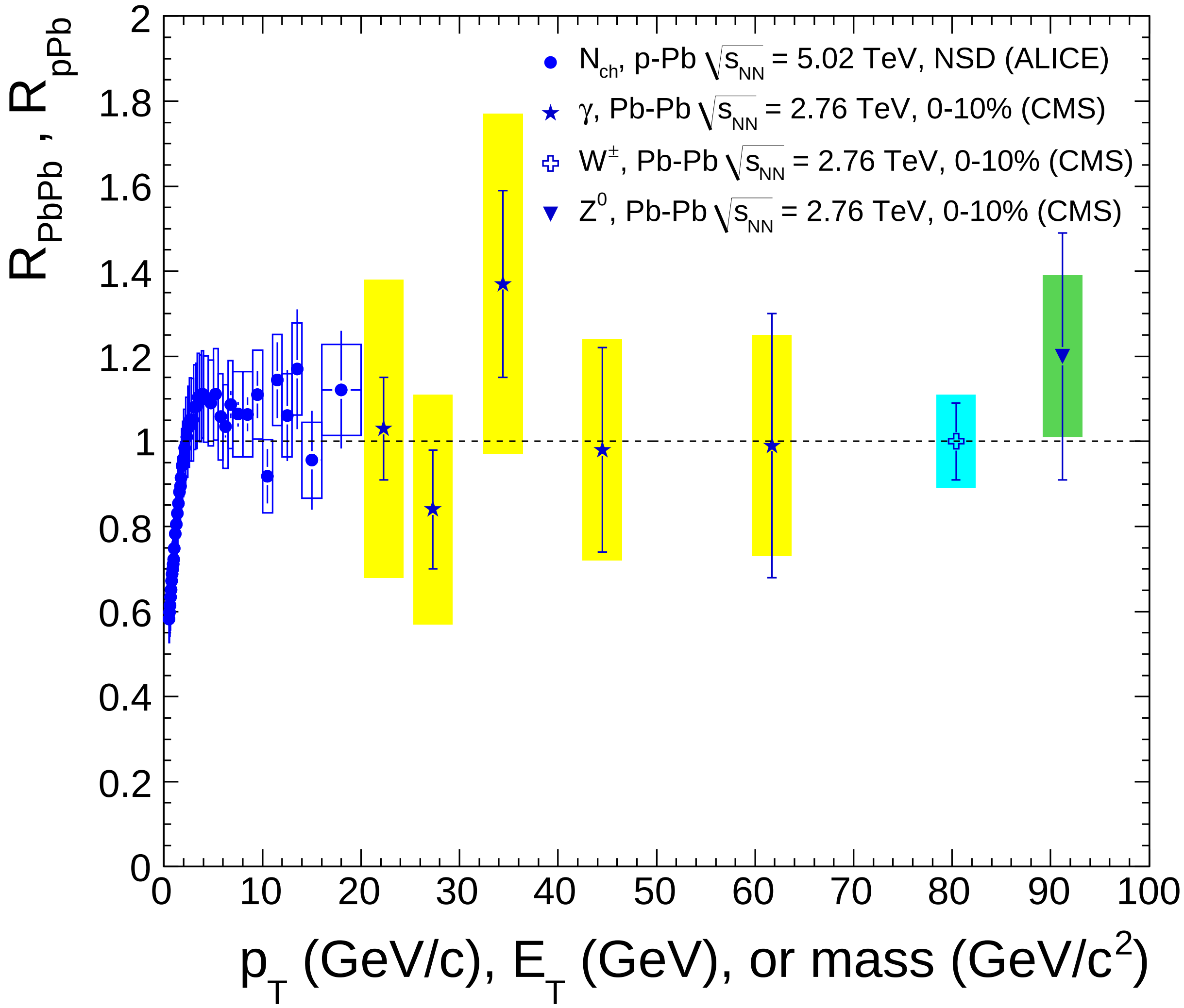
ALICE, PRL 110 (2013) 032301



PRL 110 (2013) 082302





"cold" nuclei (p–Pb):
shadowing / saturation
(gluon distr. func.) ...at low-x

binary coll. scaling, $p_{\mathrm{T}} > 2$ GeV/c

exhibited by various observables

ALICE, PRL 110 (2013) 082302

CMS
γ, PLB 710 (2012) 256
$W^{\pm}$, PLB 715 (2012) 66
Z^0, PRL 106 (2011) 212301

ATLAS: PRL 110 (2013) 002301

...and relevance to jet quenching at the LHC

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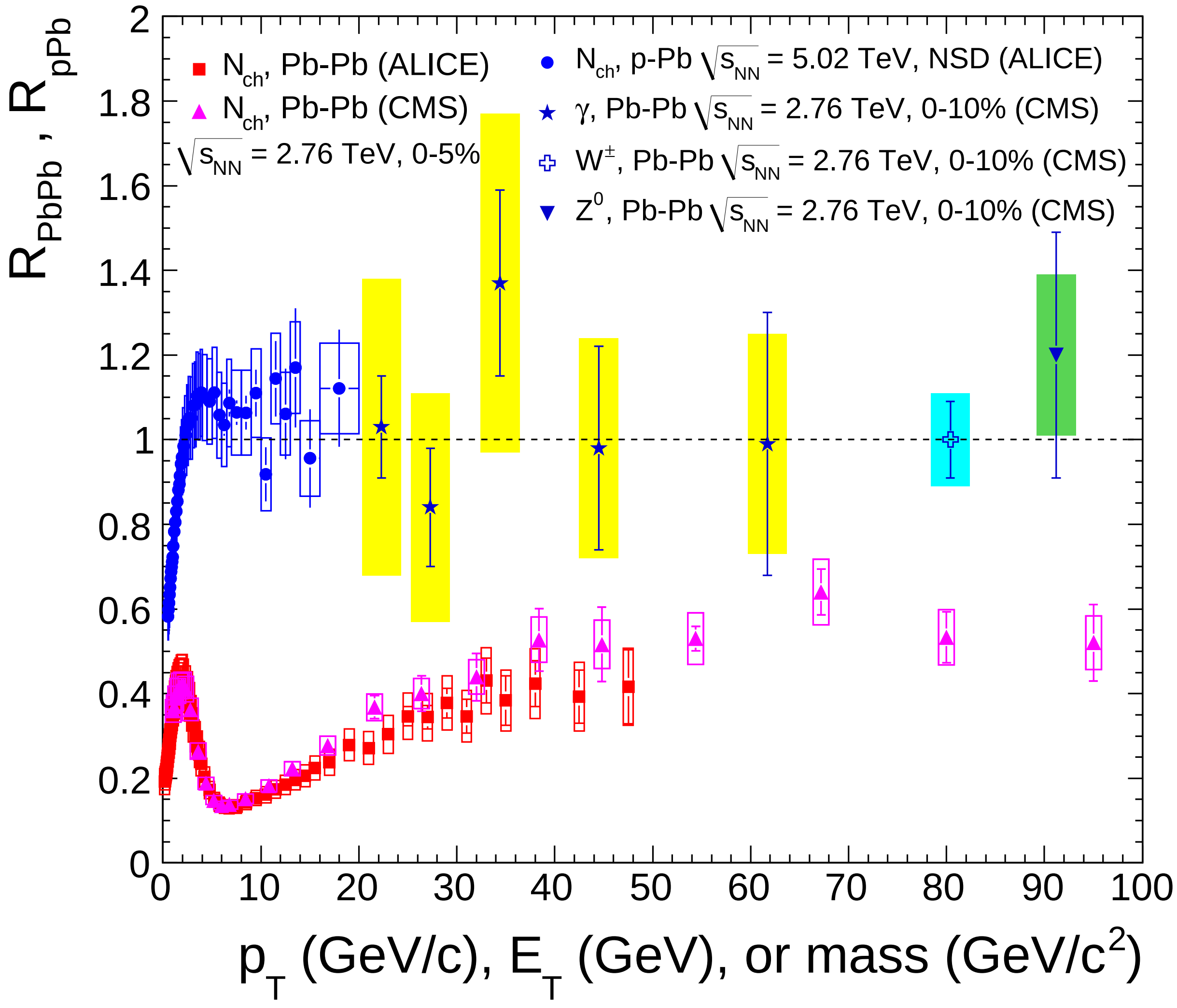

reaches a factor of about 7 around p_T=7 GeV/c

(stronger than previously measured at RHIC, $\sqrt{s_{NN}}$=200 GeV)

remains substantial even at 50-100 GeV/c

ALICE, PLB 720 (2013) 52

CMS, EPJC (2012) 72

seen also with jets

ATLAS, PLB 719 (2013) 220

CMS, PLB 712 (2012) 176
PLB 718 (2013) 773 (γ-jet)

ALICE preliminary

Long-range correlations

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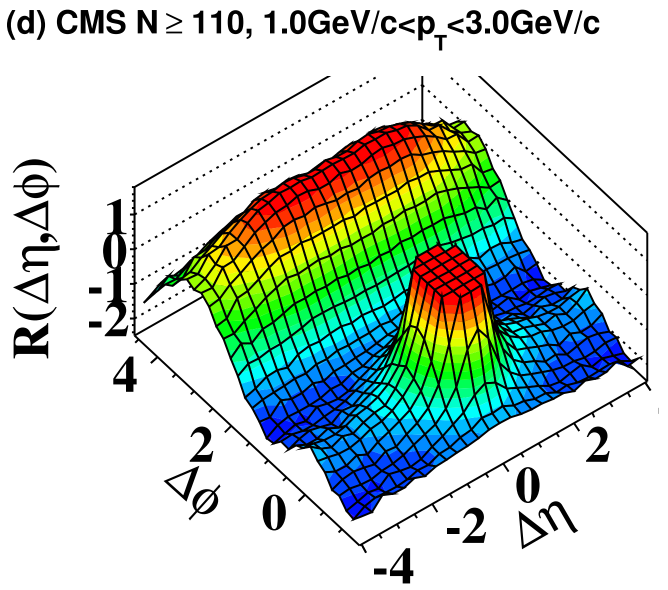
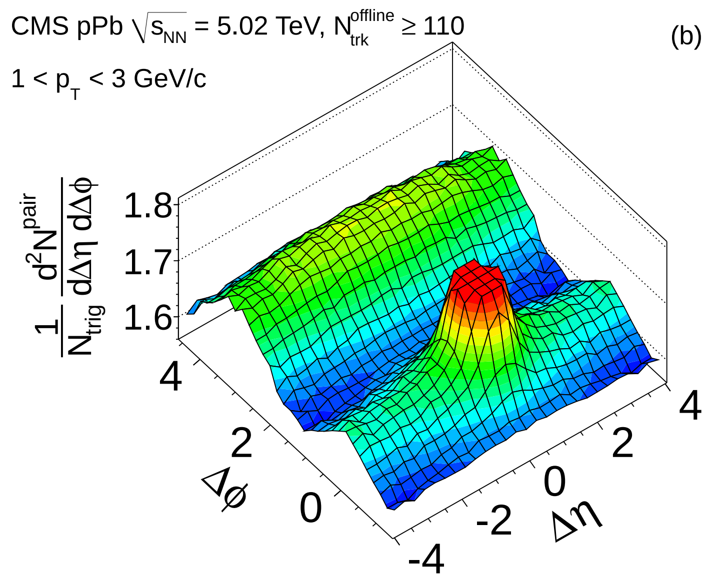
pp　　　　　　　　p-Pb





long range in η

CMS, JHEP 1009 (2010) 091, PLB 718 (2013) 795, ALICE, PLB 719 (2013) 29

Interpretations (long range in η): flow (EPOS MC), initial state (CGC/Glasma)

Werner et al., PRL 106 (2011) 122004; Dusling, Venugopalan, PRL 108 (2012) 262001

aligned flux tubes connecting valence quarks (pp), Bjorken, Brodsky, Goldhaber, arXiv:1308.1435

Long-range correlations

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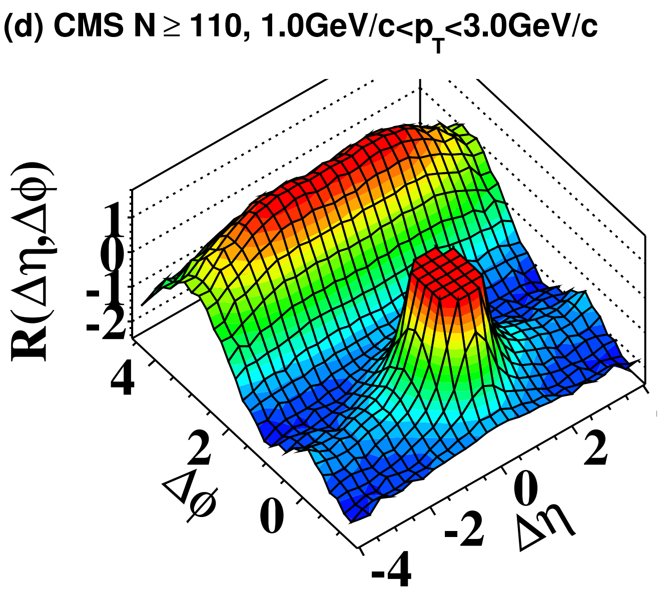
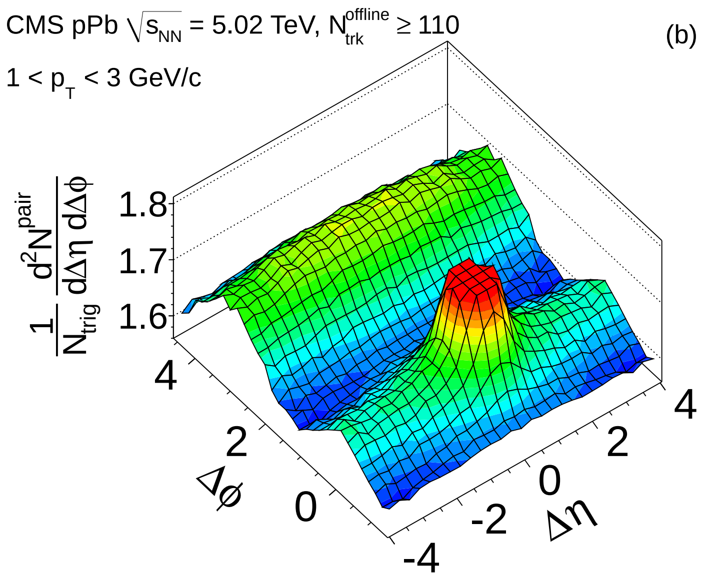
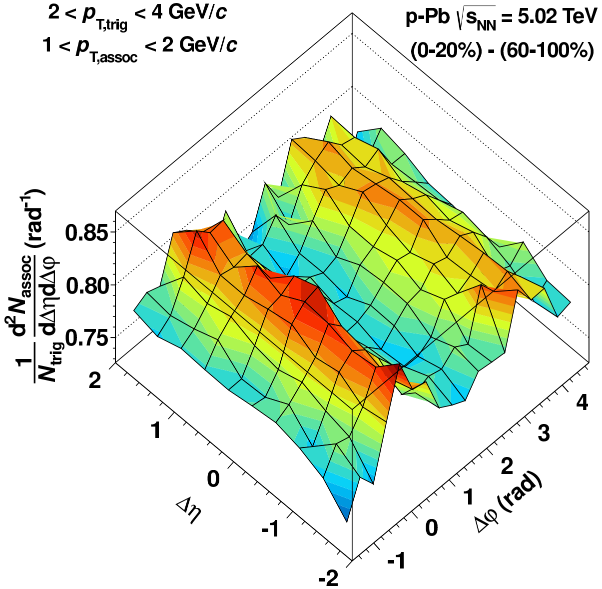
pp | p-Pb | p–Pb







long range in η ...and in ϕ (jet-subtracted distr.)

CMS, JHEP 1009 (2010) 091, PLB 718 (2013) 795, ALICE, PLB 719 (2013) 29

Interpretations (long range in η): flow (EPOS MC), initial state (CGC/Glasma)

Werner et al., PRL 106 (2011) 122004; Dusling, Venugopalan, PRL 108 (2012) 262001

aligned flux tubes connecting valence quarks (pp), Bjorken, Brodsky, Goldhaber, arXiv:1308.1435

Initial state model (CGC) vs. data

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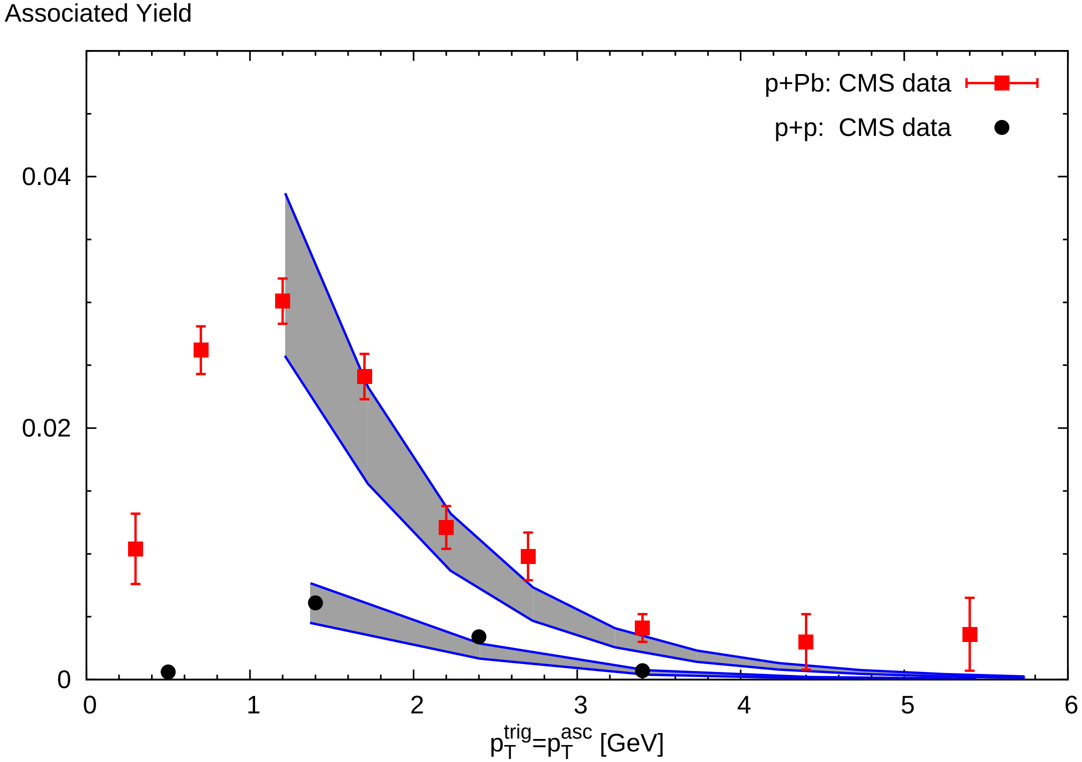
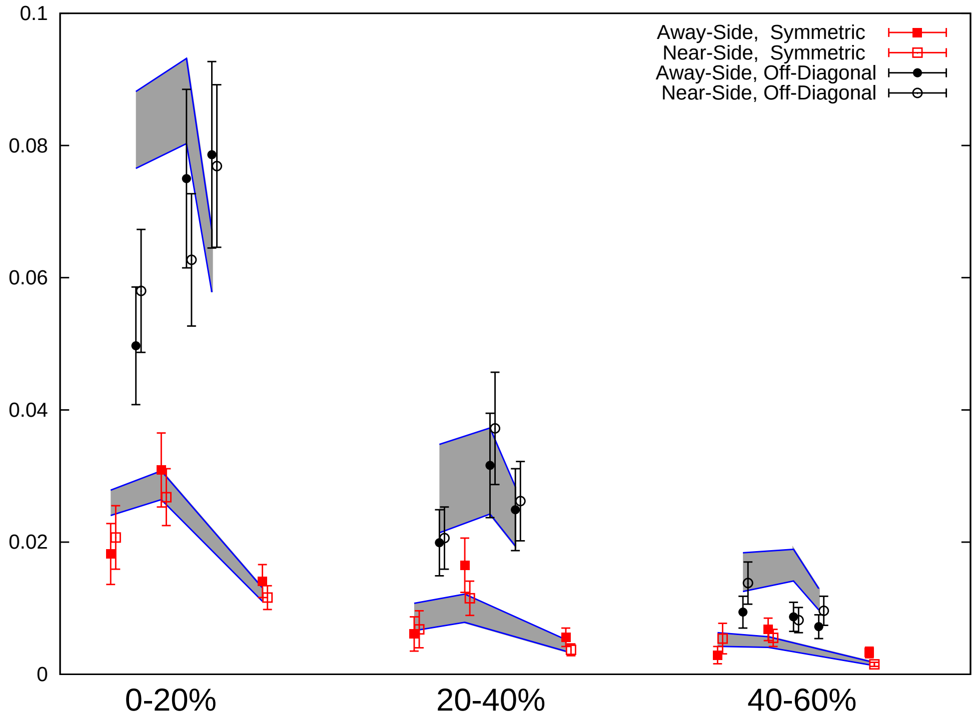
near side (CMS)



near and away side (ALICE)



Dusling, Venugopalan, PRD 87 (2013) 094034

the saturation model (CGC) is successful

Collective flow in p–Pb collisions?

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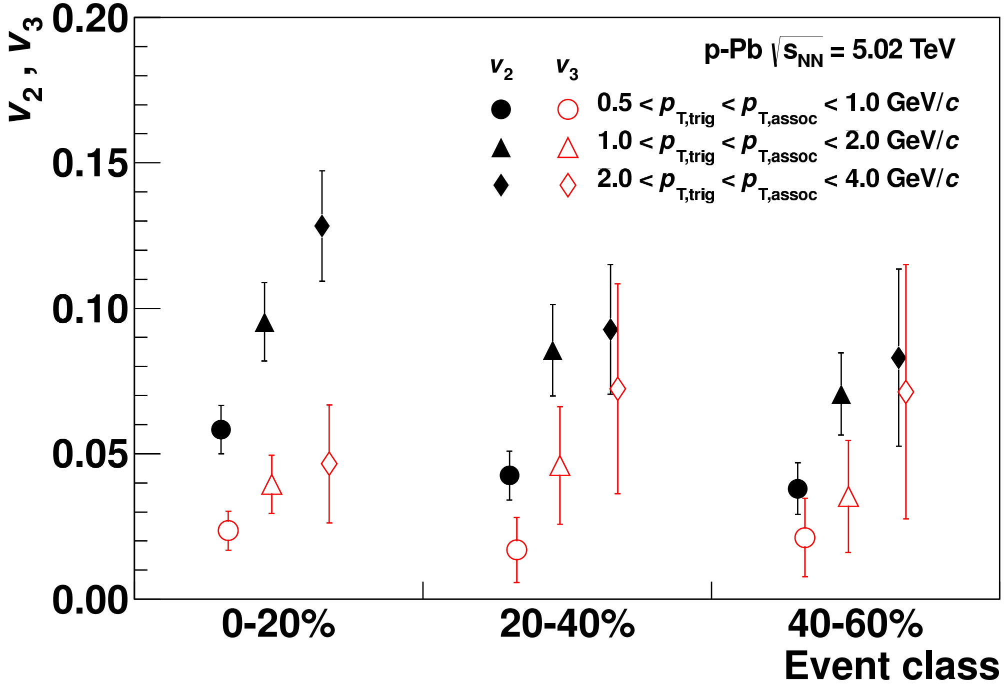

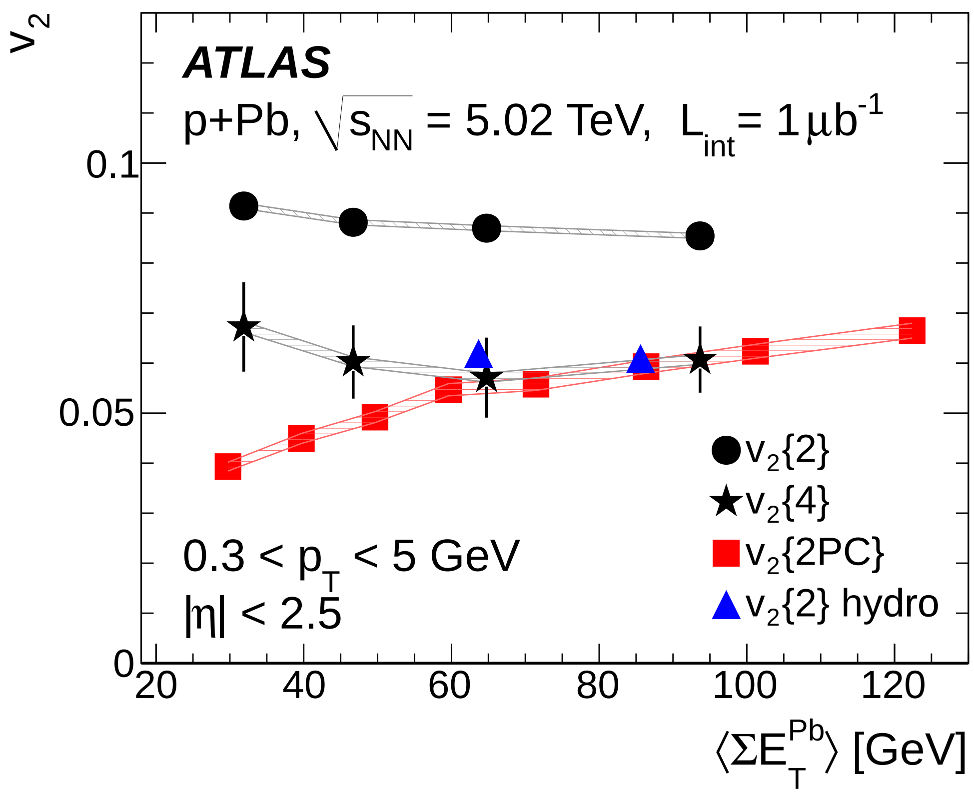

ALICE, PLB 719 (2013) 29

ATLAS, PLB 725 (2013) 60

ATLAS, PRL 110 (2013) 182302; CMS, arXiv:1305.0609

also hydrodynamics can explain data

...a heated saturation/hydrodynamics debate (and pursuit with data and models)

Flow in p–Pb (d–Au) collisions?

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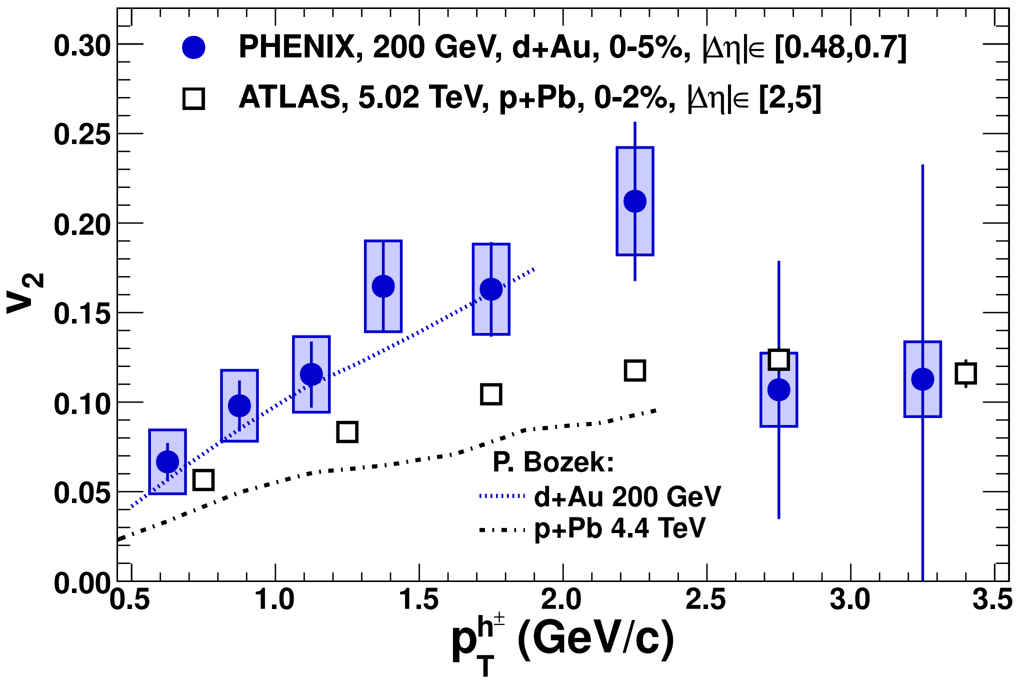
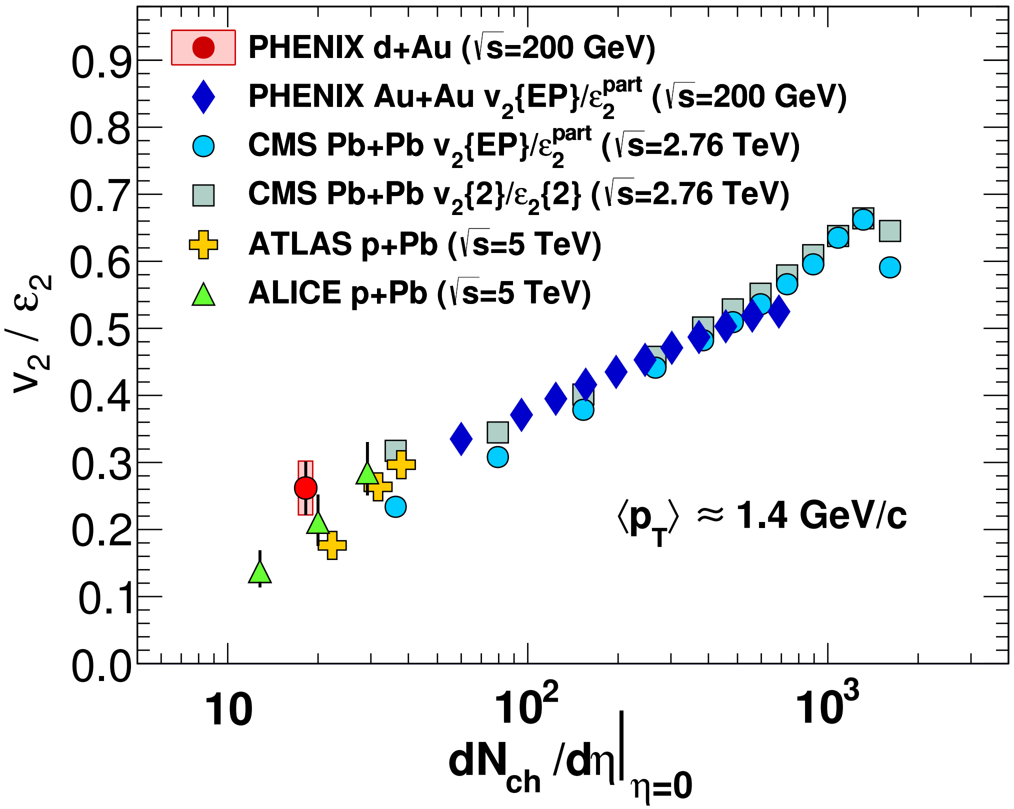


P.Bozek, PRC 85 (2012) 014911 (hydrodynamics)



ε_2, initial eccentricity, from MC Glauber

PHENIX, arXiv:1303.1794

Pushing the frontiers of deconfined matter?

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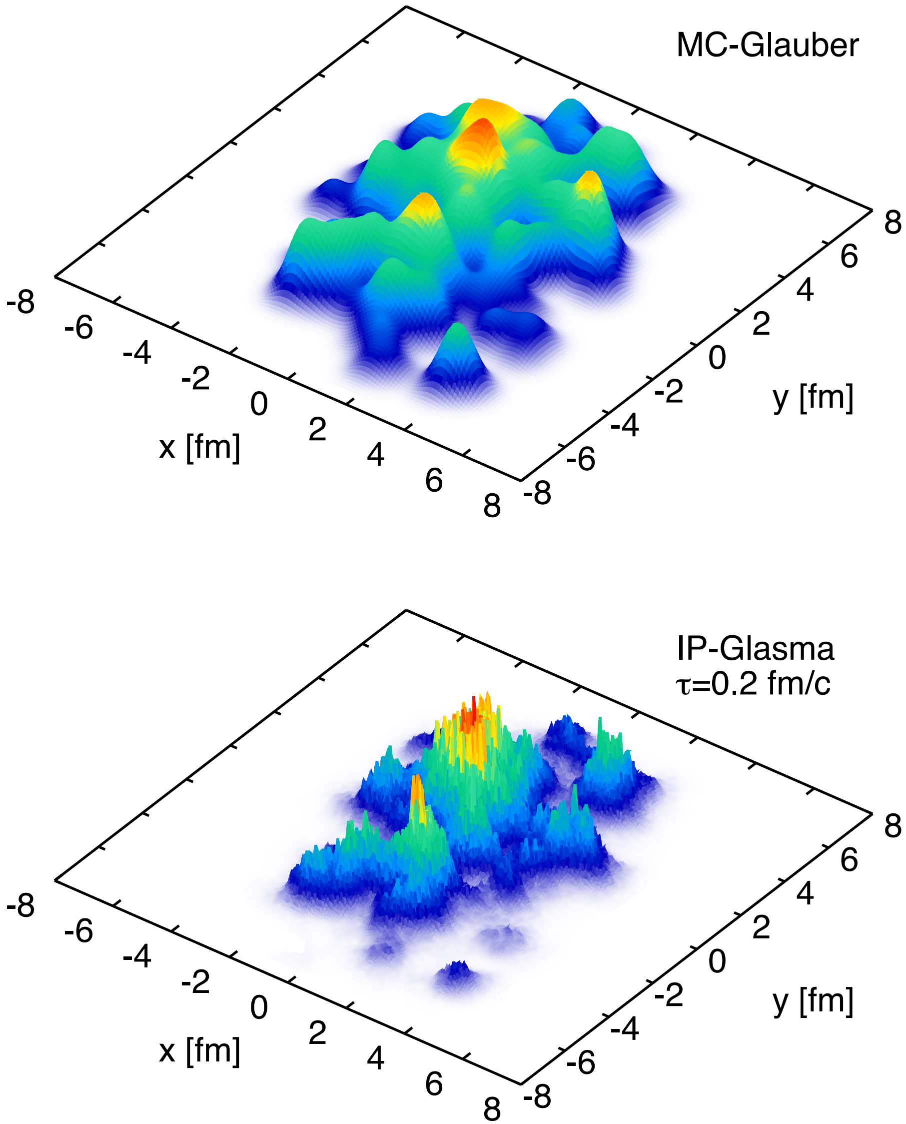
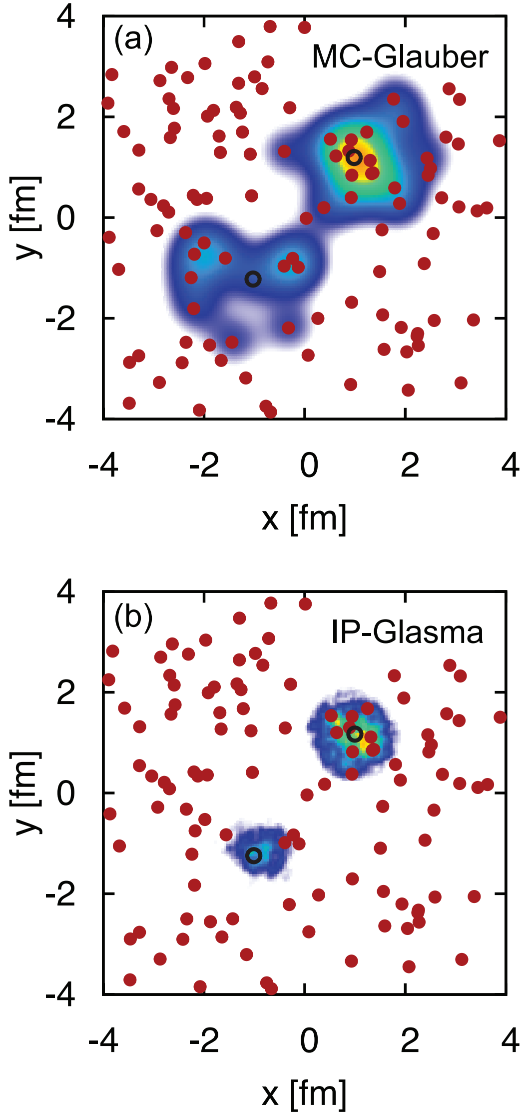
Au–Au, b=4 fm



d–Au



Gale, Jeon, Schenke, arXiv: 1301.5893; Bzdak et al., arXiv:1304.3403

Collective flow in p–Pb collisions?

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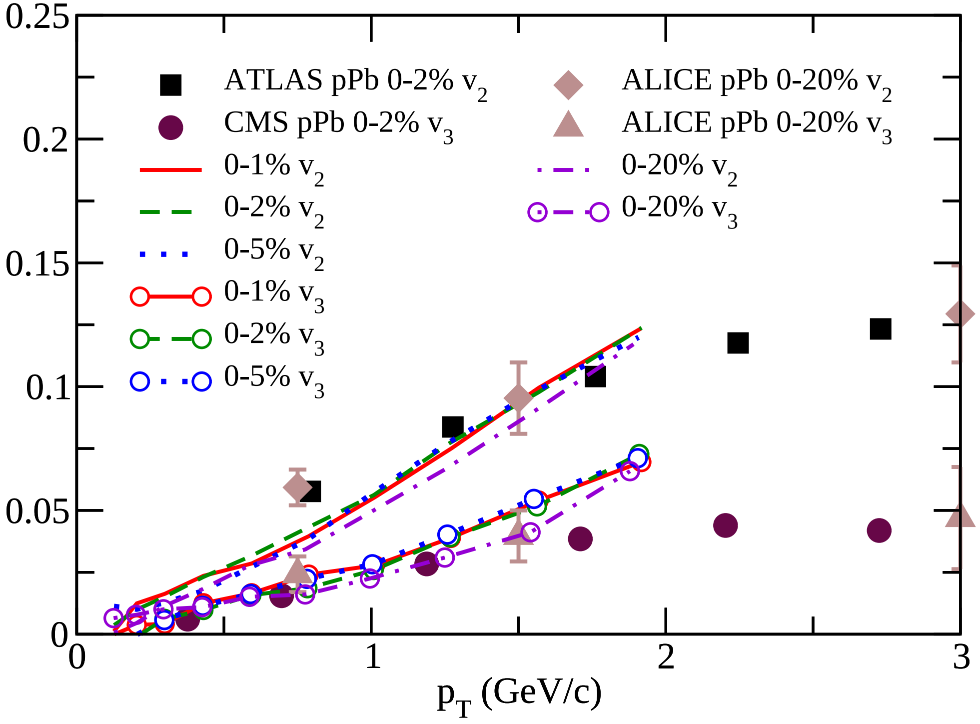
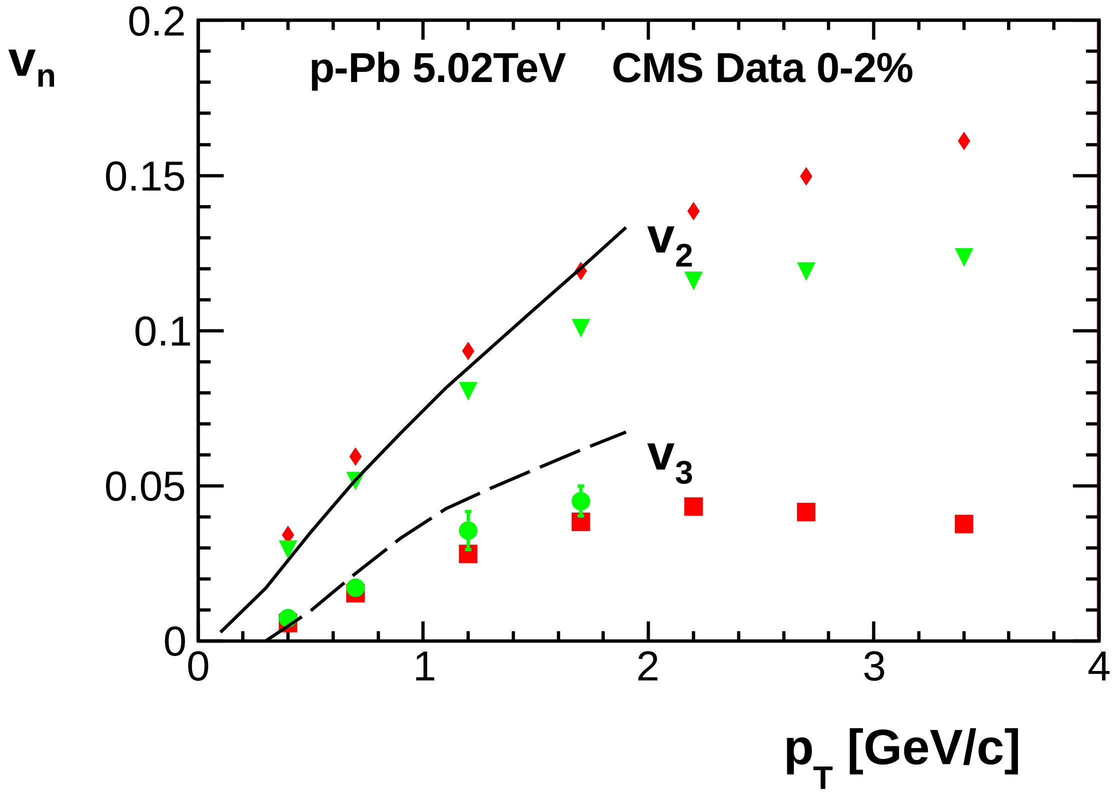
hydrodynamics makes large strides...



Qin, Müller, arXiv:1306.3439



Bozek, Broniowski, Torrieri, arXiv:1307.5060

...after it trully predicted collective flow (v_2, v_3)
Bozek, Broniowski, arXiv:1211.0845, PLB 718 (2013) 1557

Collective flow in p–Pb collisions?

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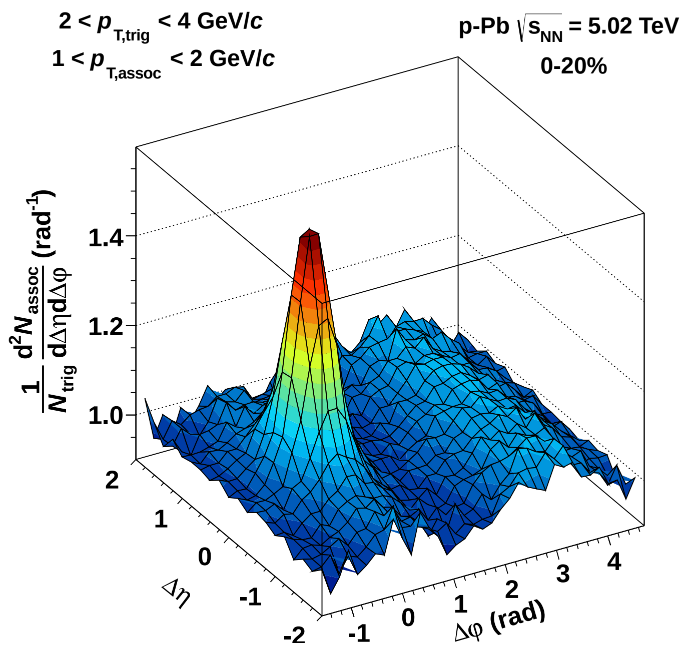

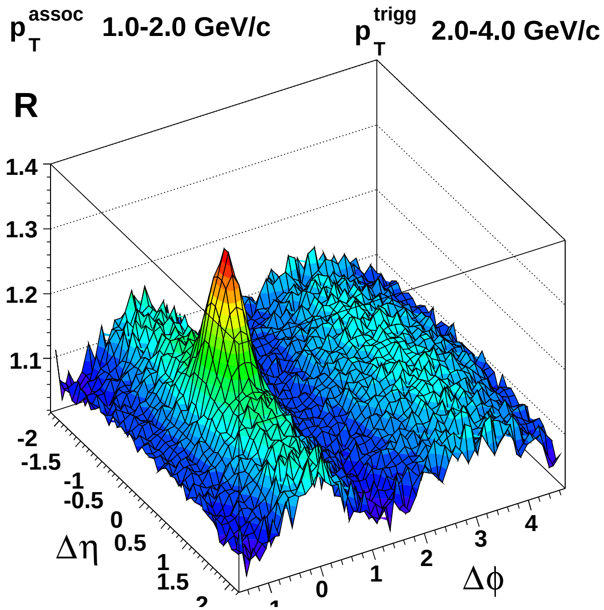

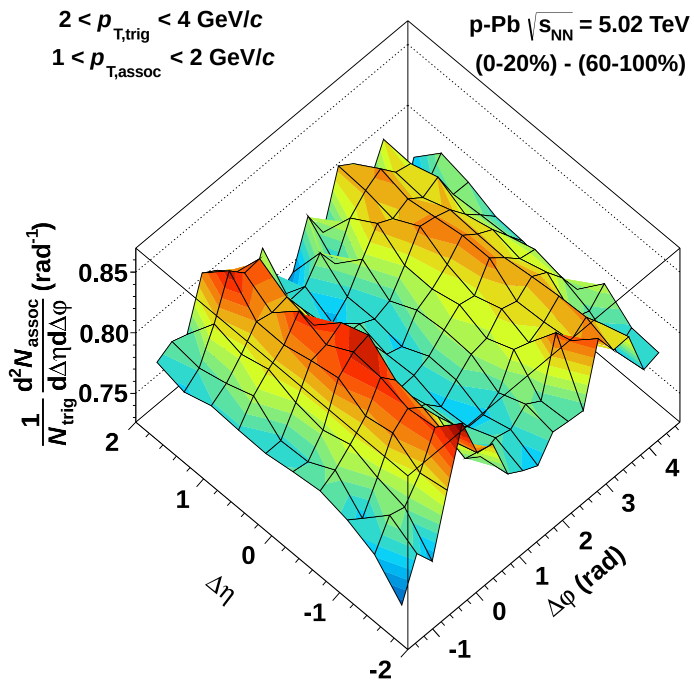

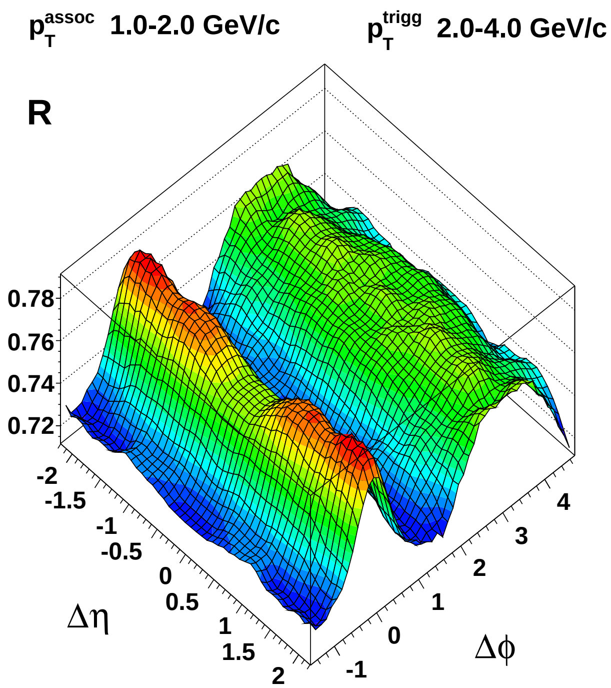

EPOS3.074

Collective flow in p–Pb collisions?

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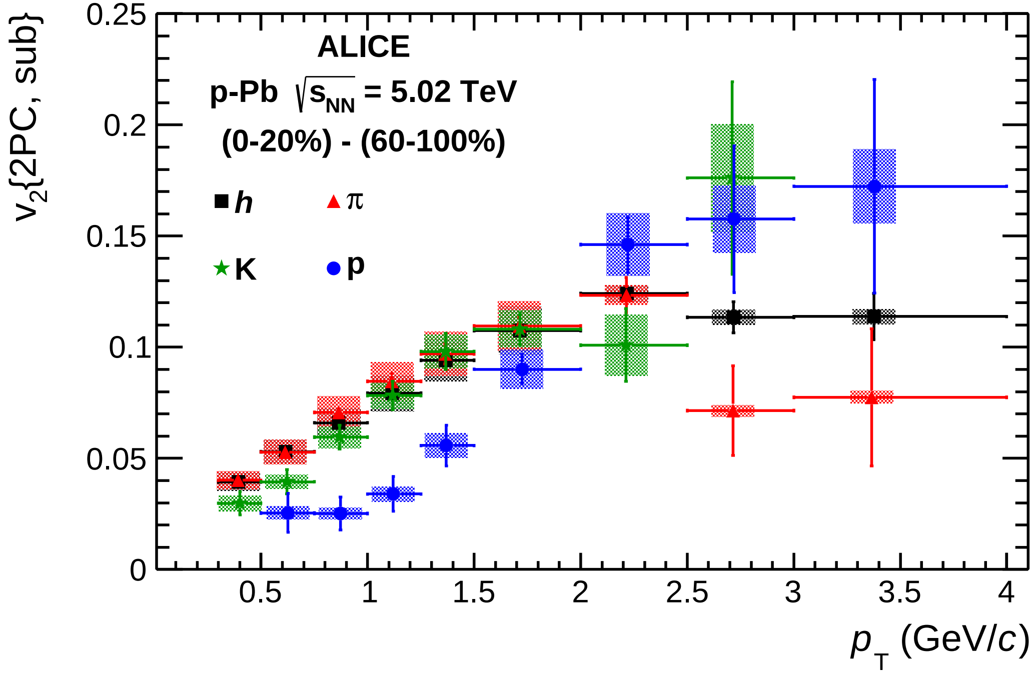
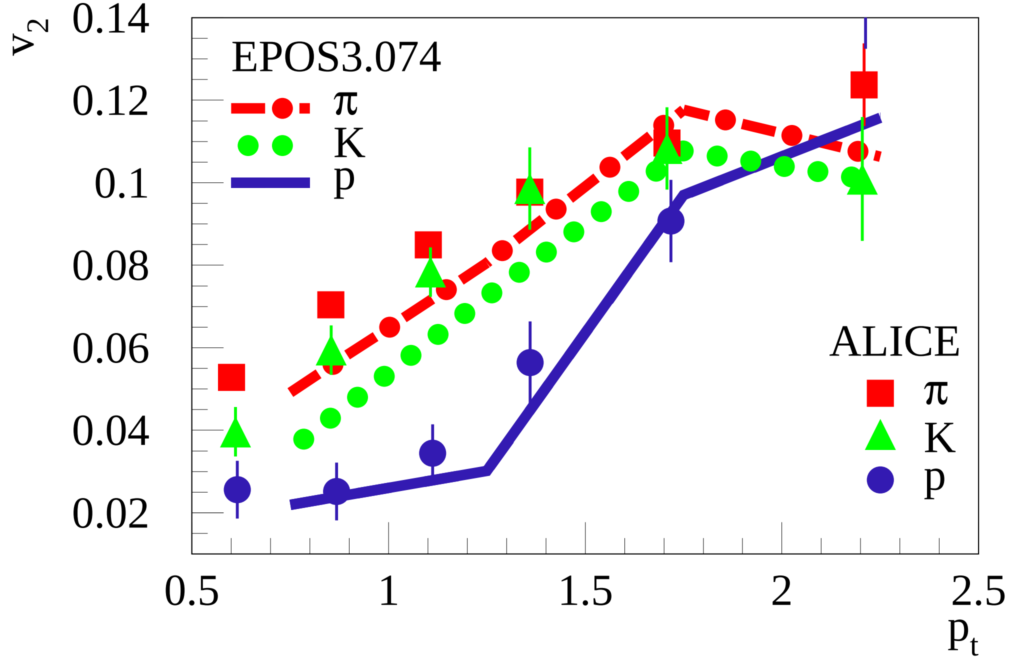
experiment makes strides ...and theory great claims





ALICE, 1307.3237

Werner et al., arXiv:1307.4379

EPOS 3.074: full hydrodynamical treatment (+Pomerons:)

Collective flow in p–Pb collisions?

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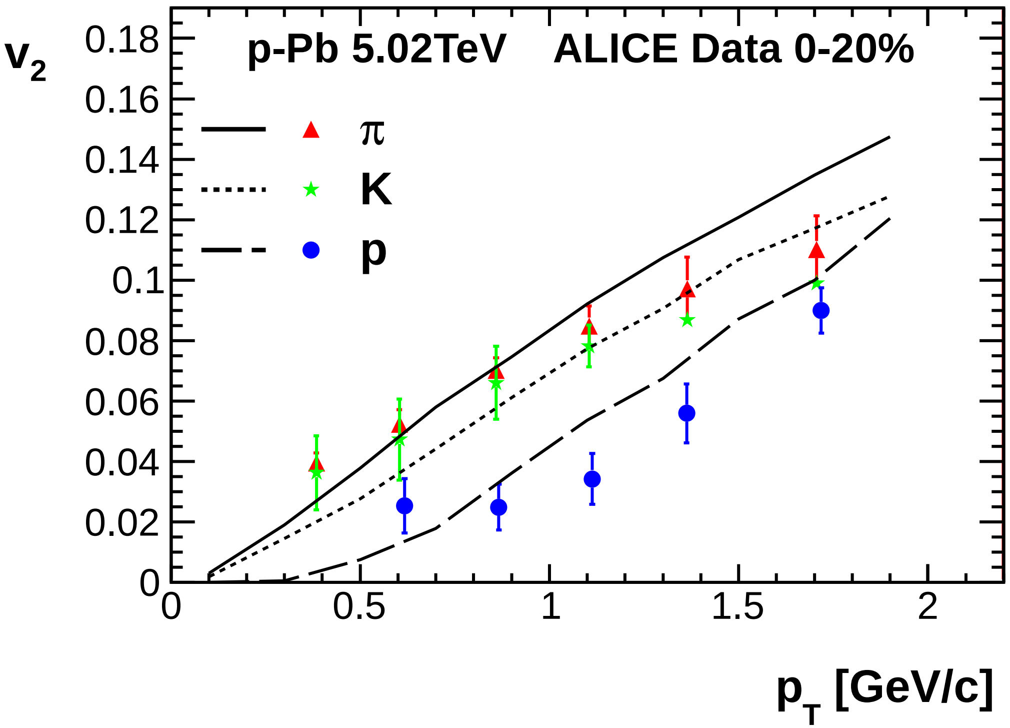
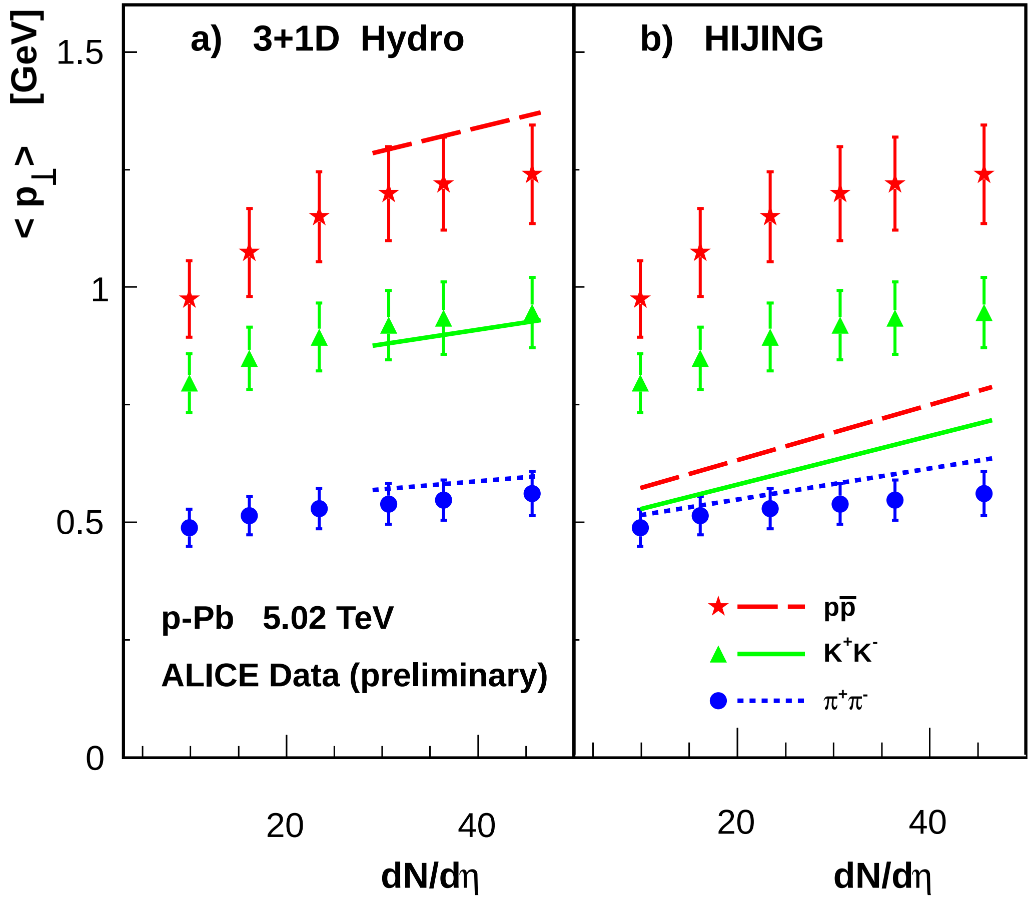
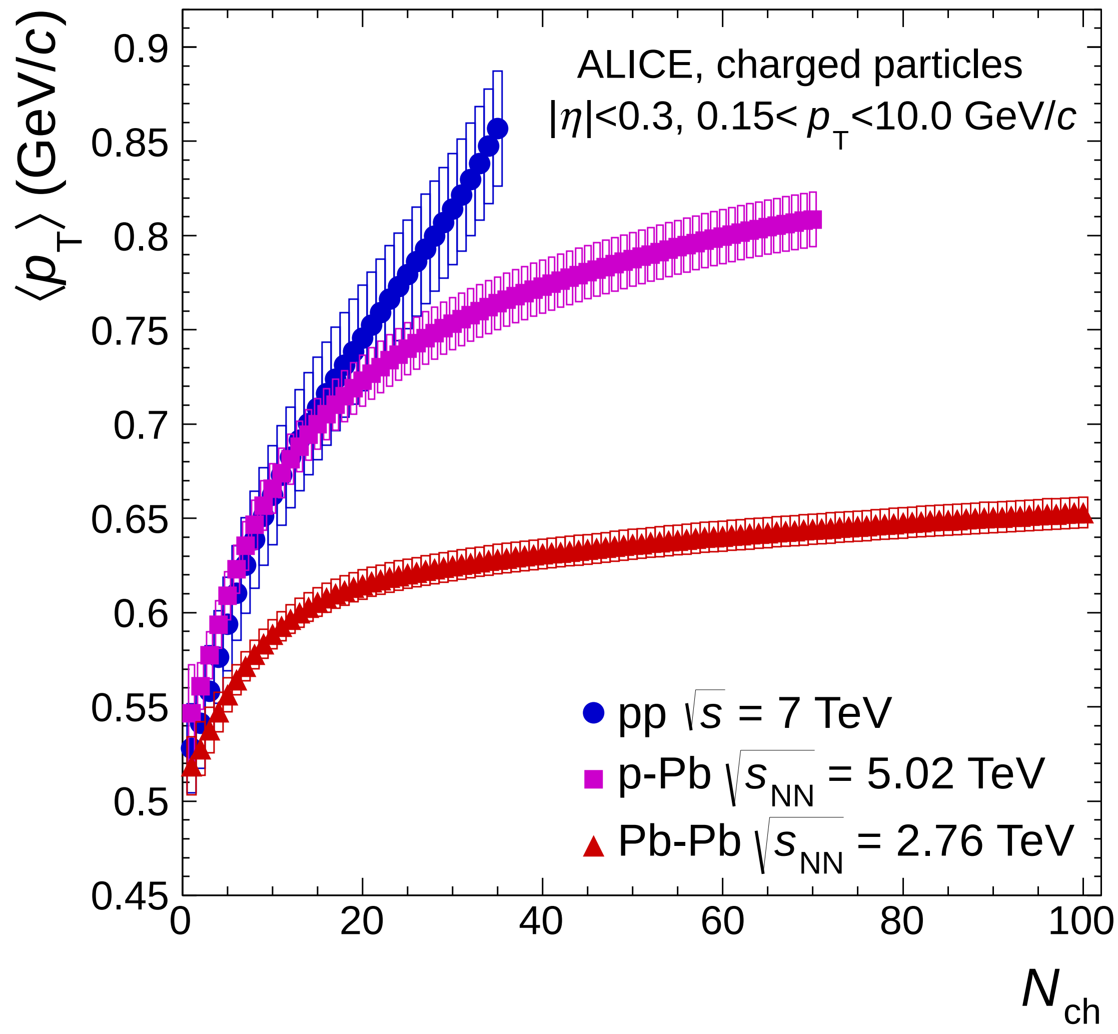
more points to hydrodynamics ...





(ALICE, 1307.3237)

Bozek, Broniowski, Torrieri, arXiv:1307.5060



p–Pb exhibits features of both pp and Pb–Pb

system	$\sqrt{s_{NN}}$ (TeV)	$\langle N_{ch} \rangle$	$\langle p_T \rangle$ (GeV/c)
pp	7	4.42±0.22	0.622±0.021
p–Pb	5.02	11.9±0.5	0.696±0.024
Pb–Pb	2.76	259.9±5.9	0.678±0.007

NB:

$N_{ch} > 14$ corresp. to 10%, 50%, 82% upper cross section for pp, p–Pb, Pb–Pb

$N_{ch} > 40$ corresp. to upper 1% (70%) of the cross section p–Pb (Pb–Pb)

ALICE, 1307.1094

p–Pb in perspective

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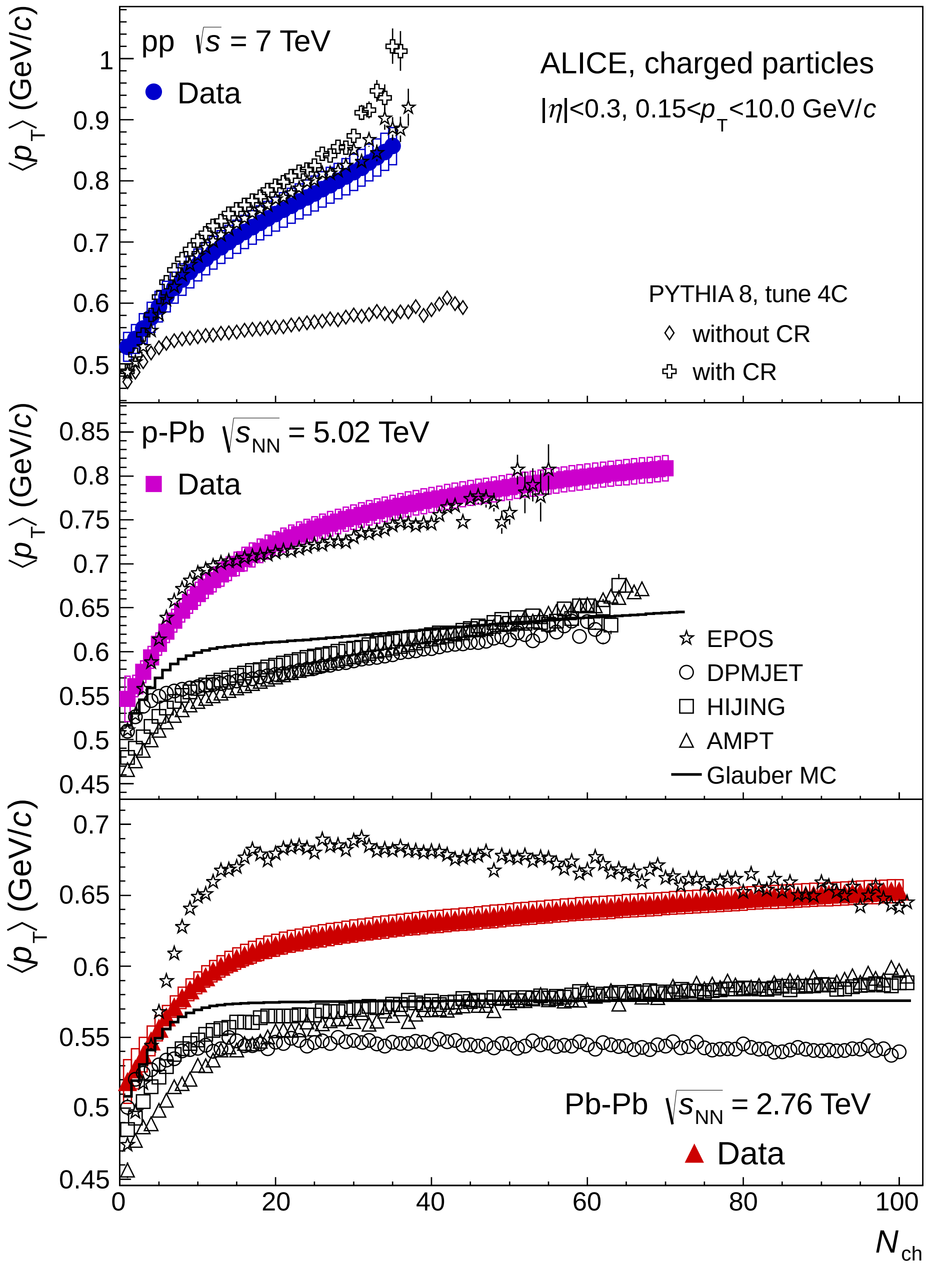
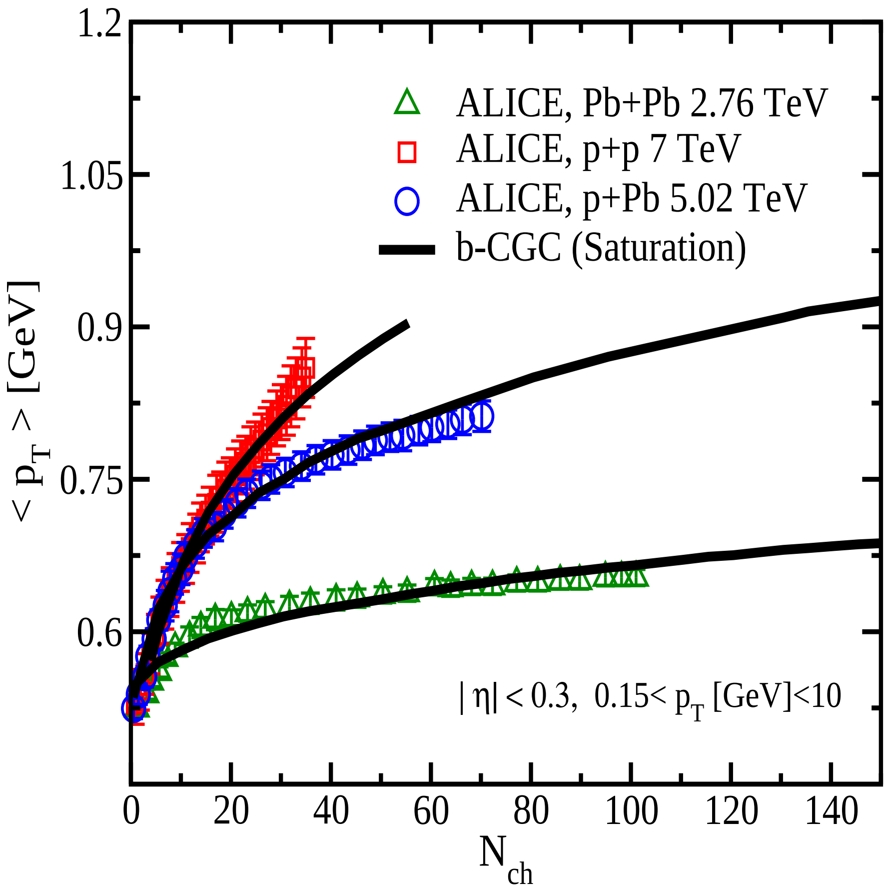


ALICE, 1307.1094

CR: color reconnection - a “collective” effect of hadronizing strings (a probability parameter)

EPOS LHC: parametrized flow (pp, p–Pb, Pb–Pb)
Pierog et al., arXiv:1306.0121



Rezaeian, 1308.4736 (3 parameters)

CGC strikes back

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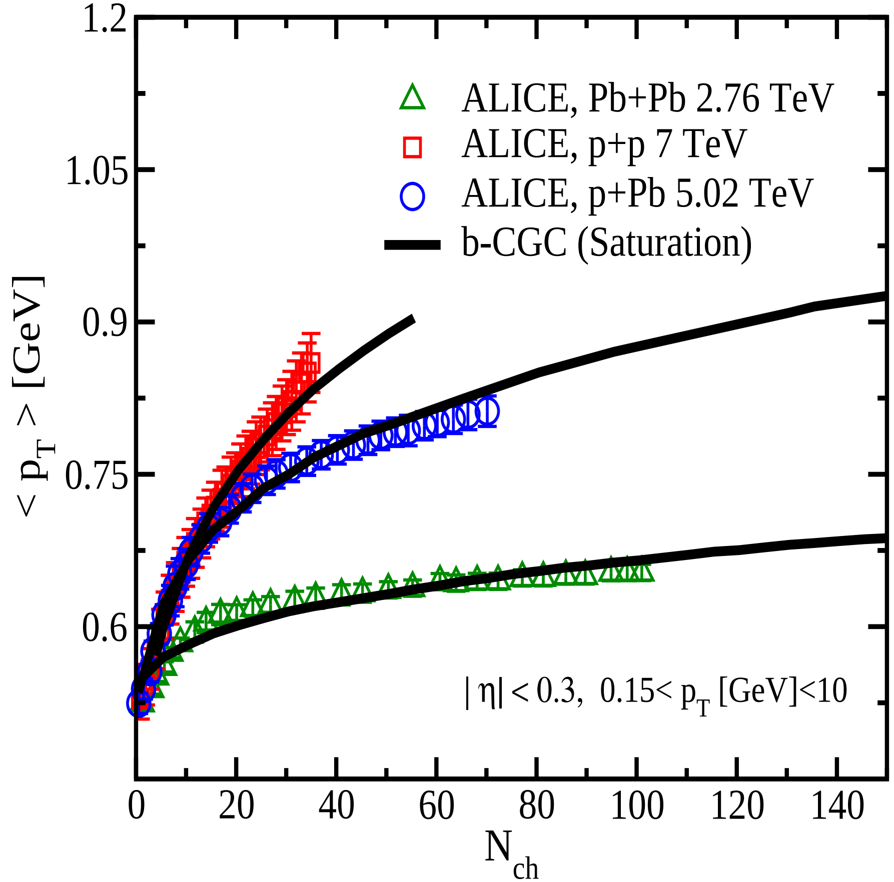
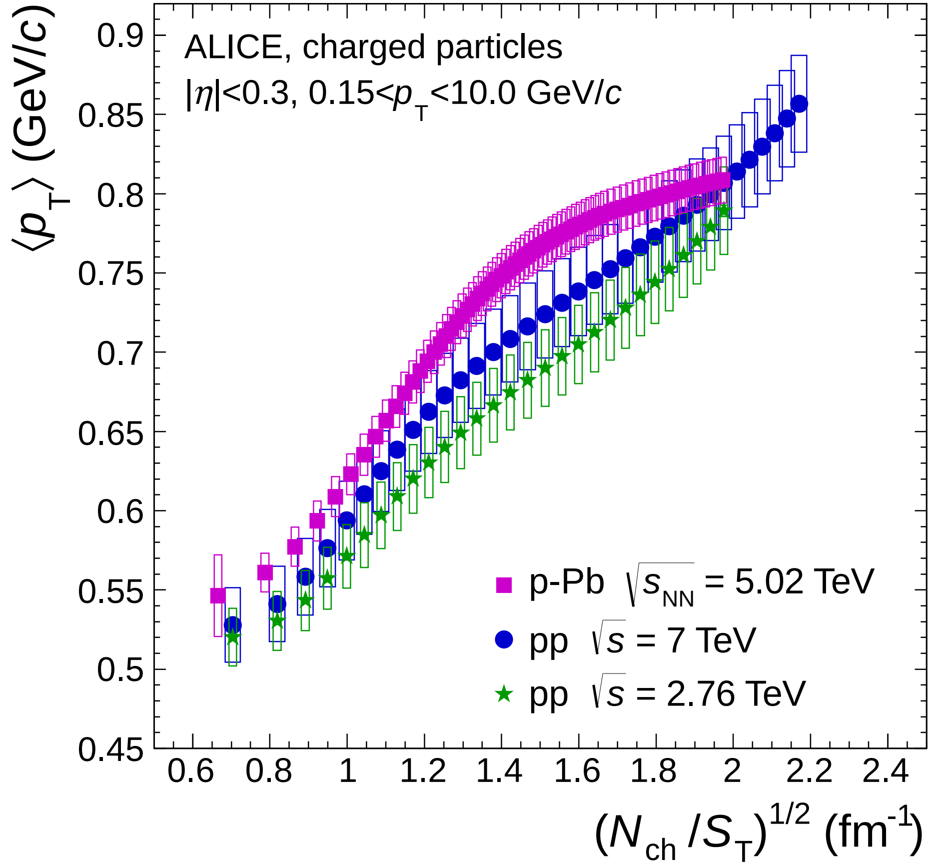
...or does it?



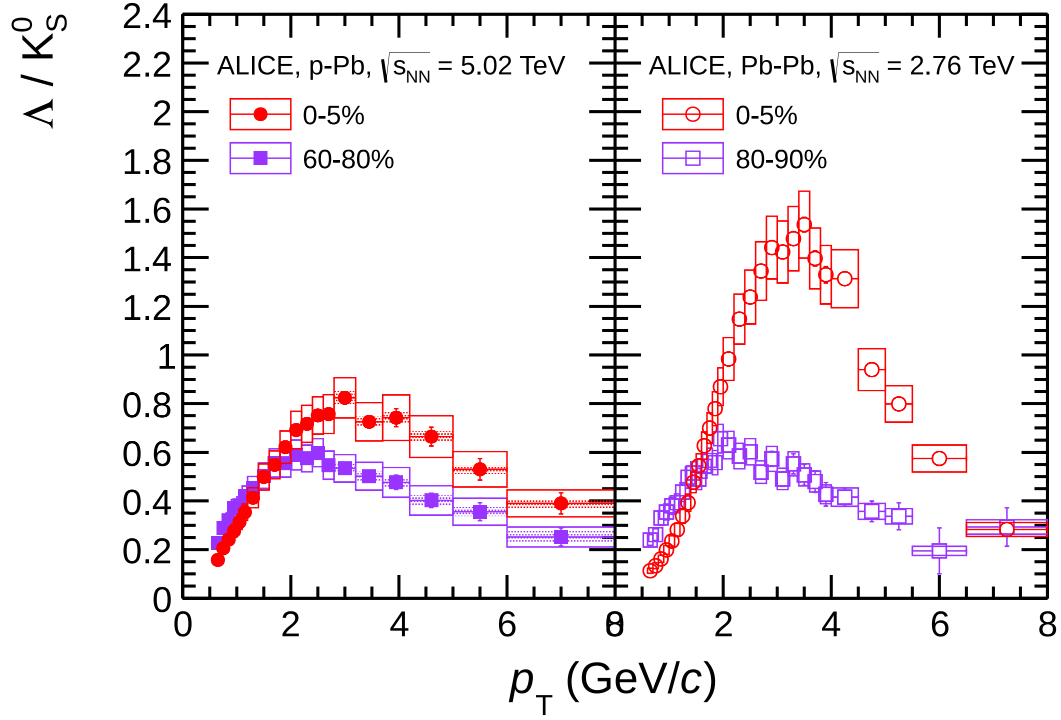


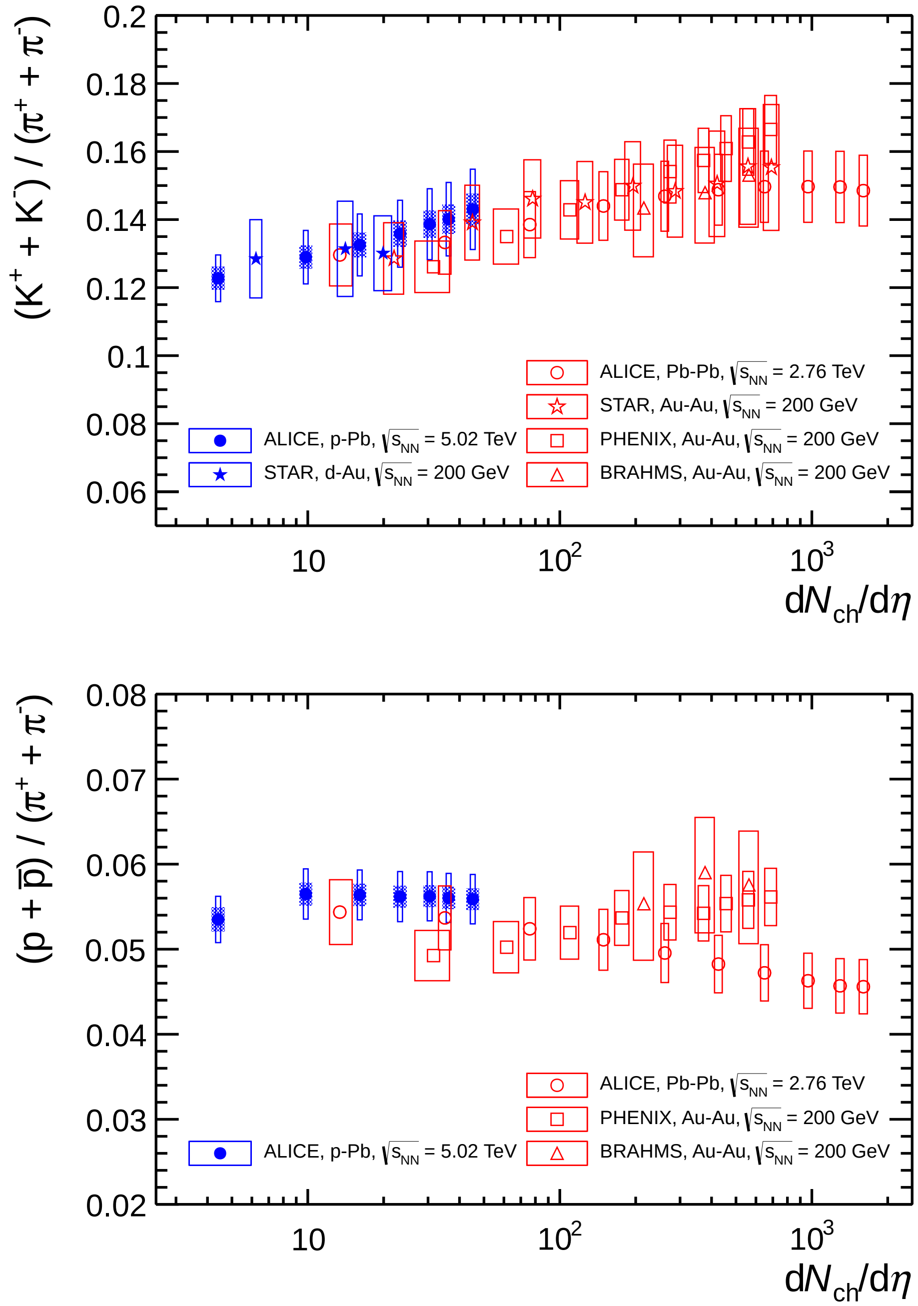
Rezaeian, 1308.4736 (3 parameters) ALICE, 1307.1094

geometric scaling ($S_\mathrm{T} = \pi R^2$), McLerran et al., arXiv:1306.2350;
$R \sim (dN_g/dy)^{1/3} \simeq (1.5 \cdot dN_{ch}/d\eta)^{1/3}$, sat. at 1.54 (2.39) fm for pp (p–Pb)

claim of success based on CMS data, arXiv:1307.3442 ...in a smaller N_{ch} range

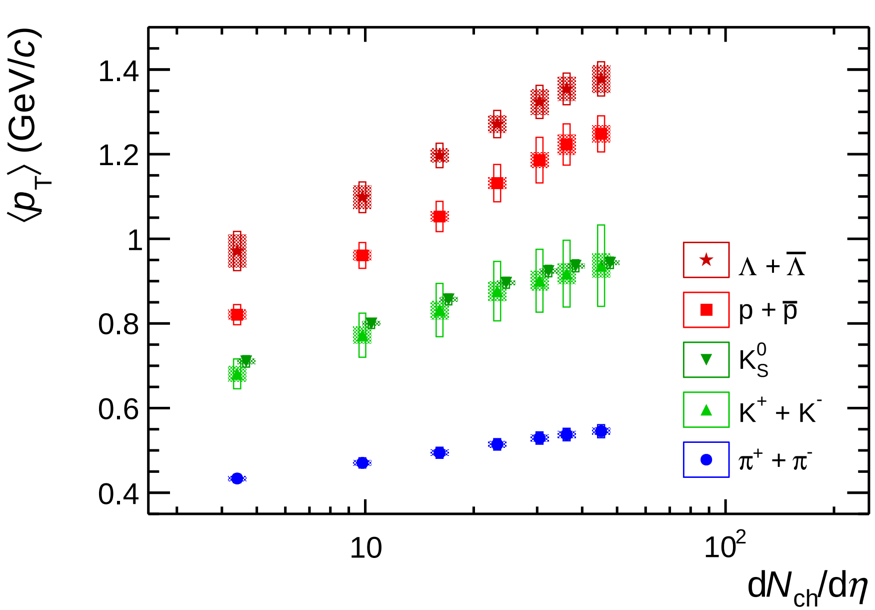
p–Pb in perspective

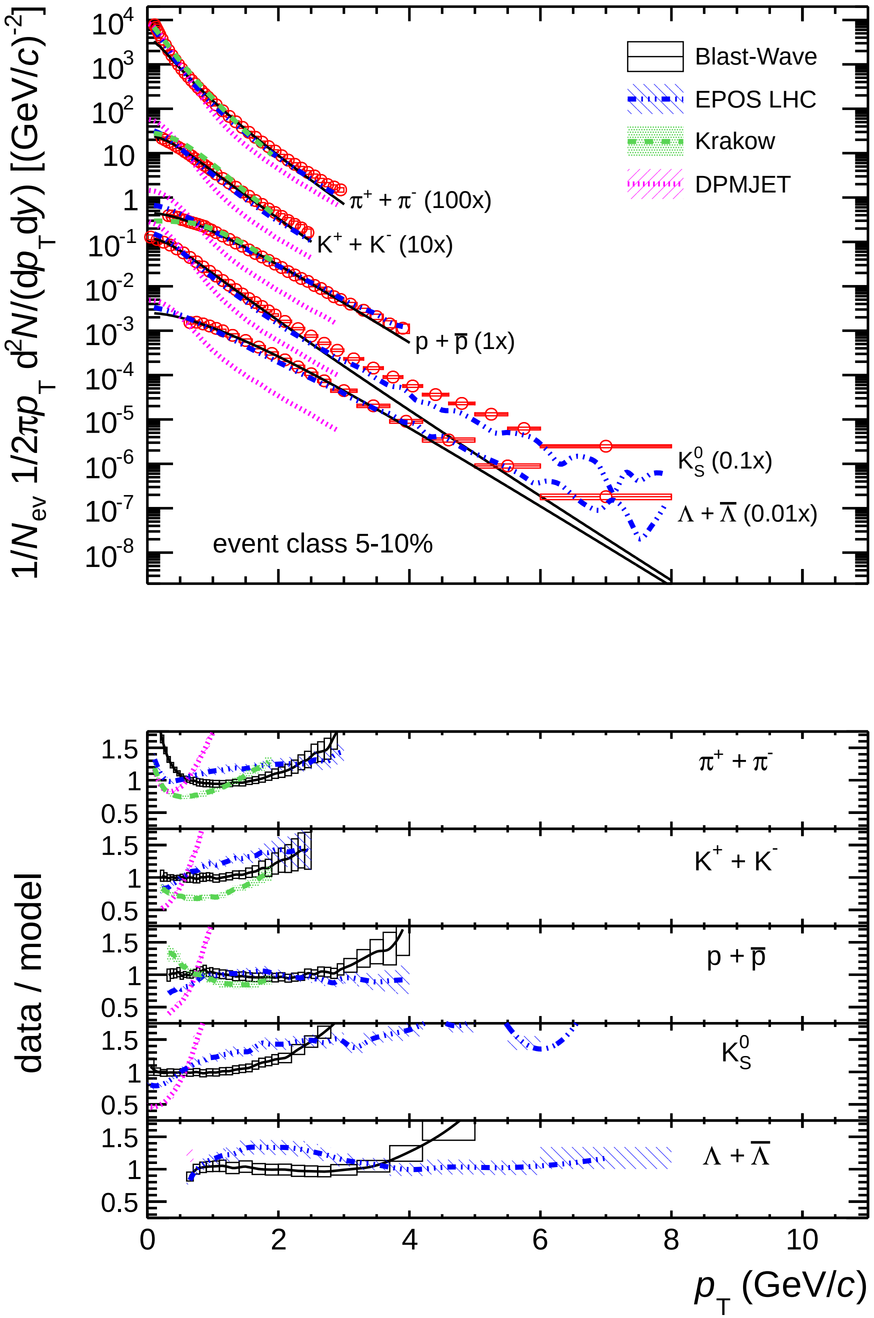


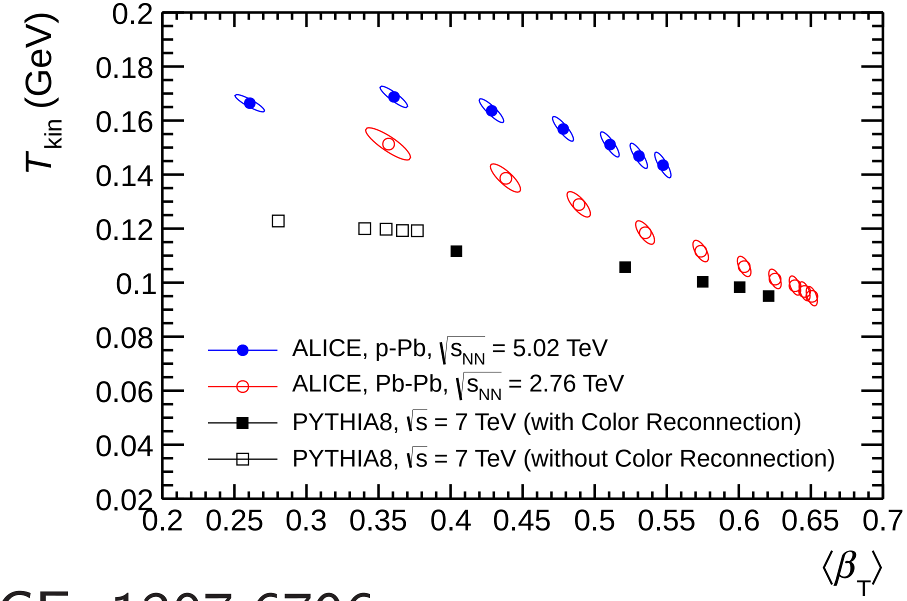


0-5% central p–Pb collisions look like 60-70% central Pb–Pb
($dN_{ch}/d\eta$ ~1.7 lower)
ALICE, arXiv:1307.6796

More flow arguments







ALICE, 1307.6796

Flow or Cronin effect or saturation?

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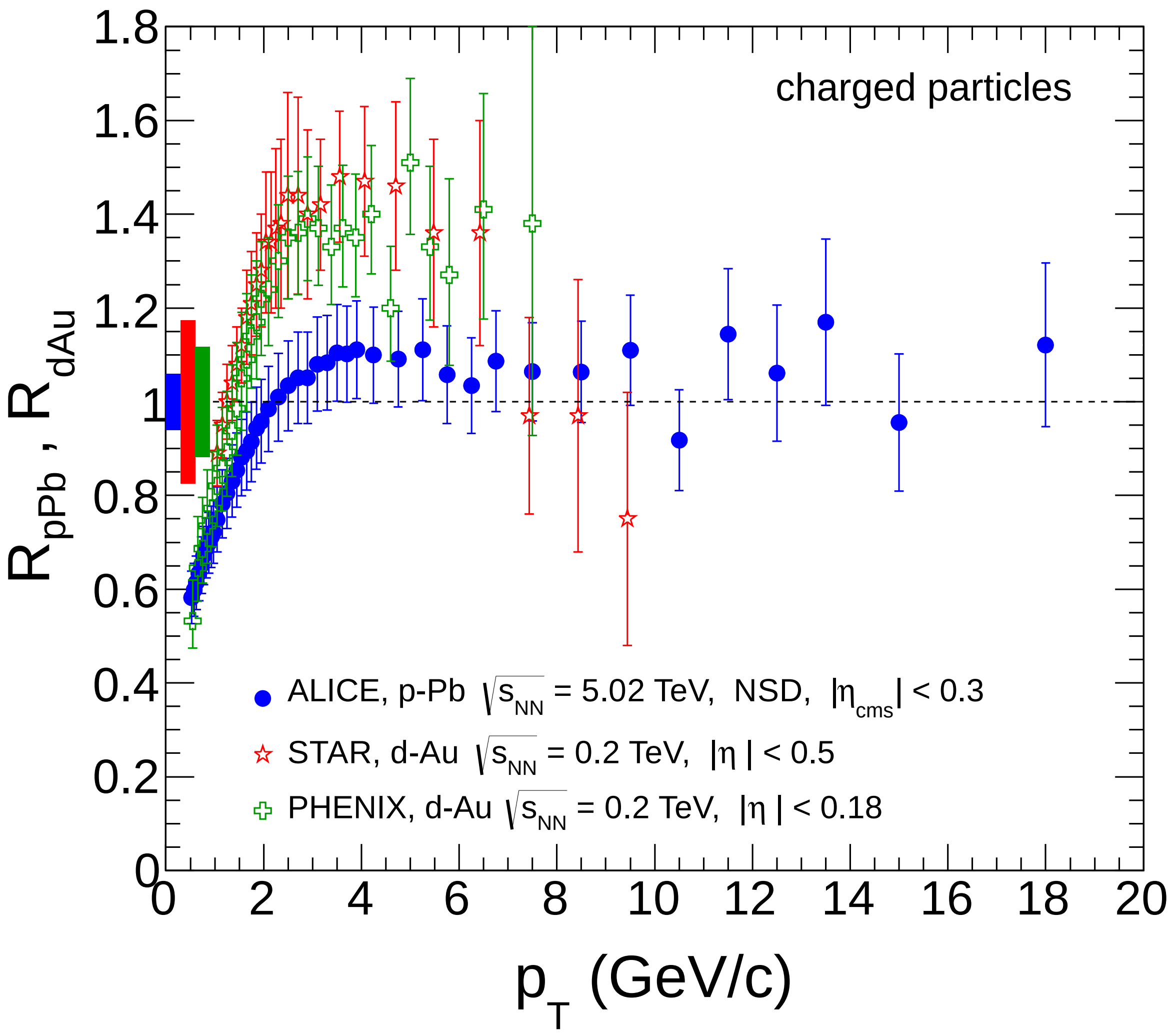


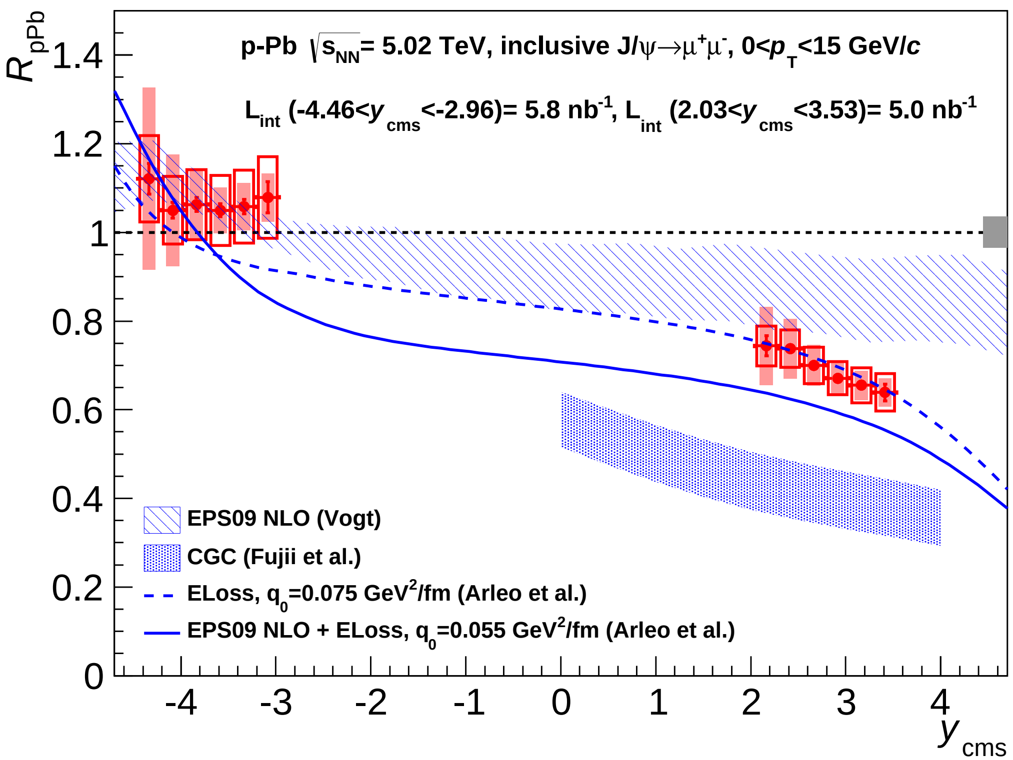
LHC vs. RHIC data

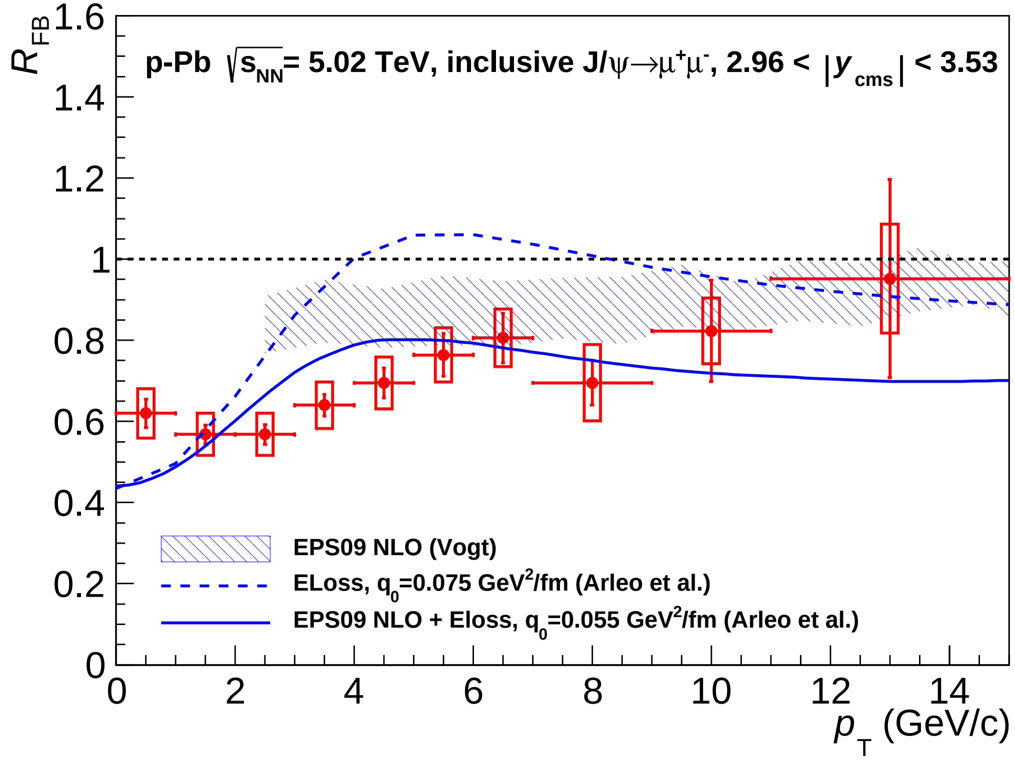
ALICE, PRL 110 (2013) 082302

- flow: blue-shift of spectra
  larger at LHC
- Cronin effect: "re-distribution" of low-p_{T} hadrons at higher p_{T} due to multiple (parton) scattering
  larger at RHIC
- saturation: depletion of spectra at low p_{T}
  larger at LHC

still need some strategy to distinguish
...a challenge: reduce (dominant) systematic uncertainties (?)

ALICE, arXiv:1308.6726; LHCb, arXiv:1308.6729





theory (nobody's perfect:) shadowing and Eloss ∼ OK ...CGC seems ruled out

tantalizing implication for Pb–Pb: $R_{AA} > 1$ (at low p_{T}) *if-no-shadowing*
...cannot turn off shadowing, but means we may see this at the top LHC energy

Summary

- interesting / puzzling features in p–Pb collisions
- both initial state and final state (collective flow?) play a role

  ... would we be able to disentangle them?

  ...(if so) is CGC the correct description of the initial state?
- what are the implications for Pb–Pb?

  ...normalize Pb–Pb to p–Pb(min.B)?
- would p–Pb (and pp) help elucidating thermalization and hadronization?

Extra slides

X

Elliptic flow (non-central collisions)

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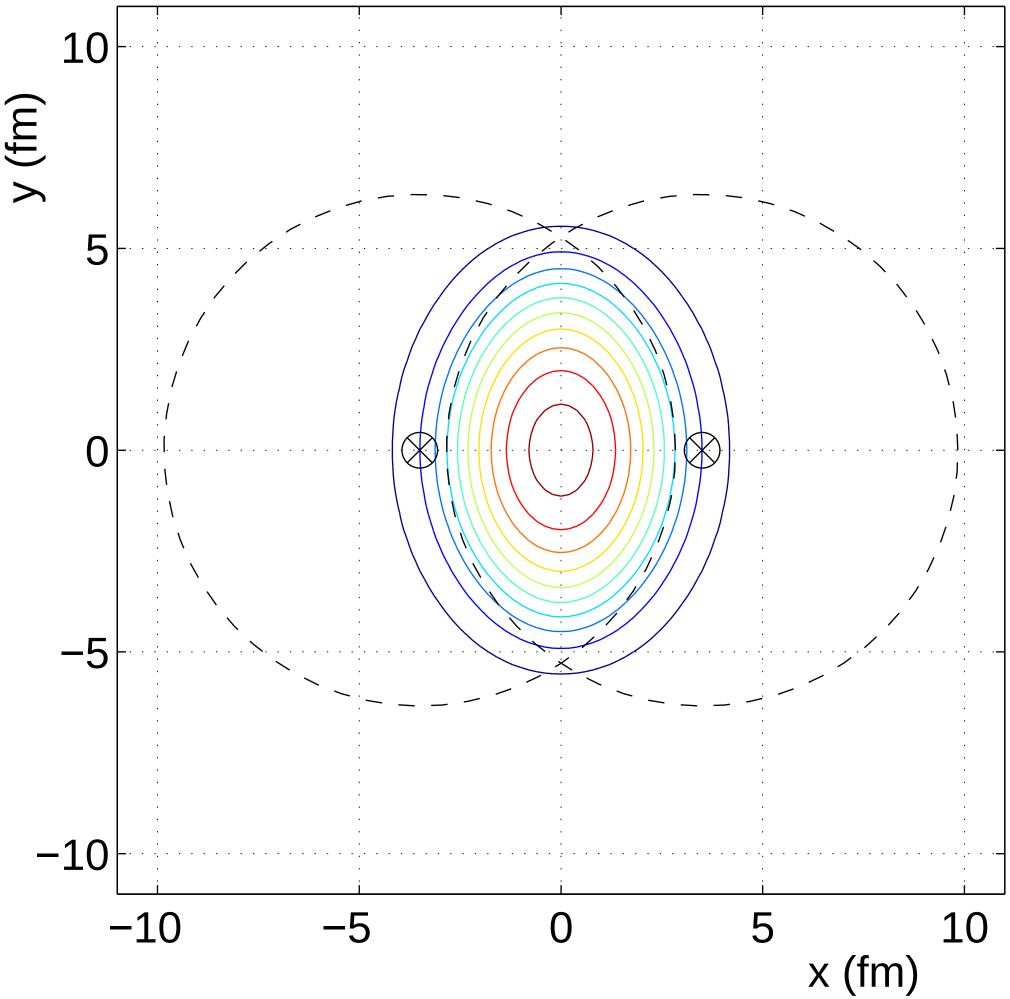
density of binary collisions
U.Heinz, arXiv:0901.4355



...arising from different initial gradients along x and y

"self-quenching" (develops early)

determined by the spatial eccentricity

$$\varepsilon(b) = \frac{<y^2 - x^2>}{<y^2 + x^2>}$$

with energy dens. as weight

...transformed into momentum anisotropy in ϕ (wrt reaction plane)

Fourier coef. $v_2 = \langle \cos(2(\phi - \Psi_{RP})) \rangle$

quantifies collective (elliptic) flow

Higher order harmonics (central collisions)

x2

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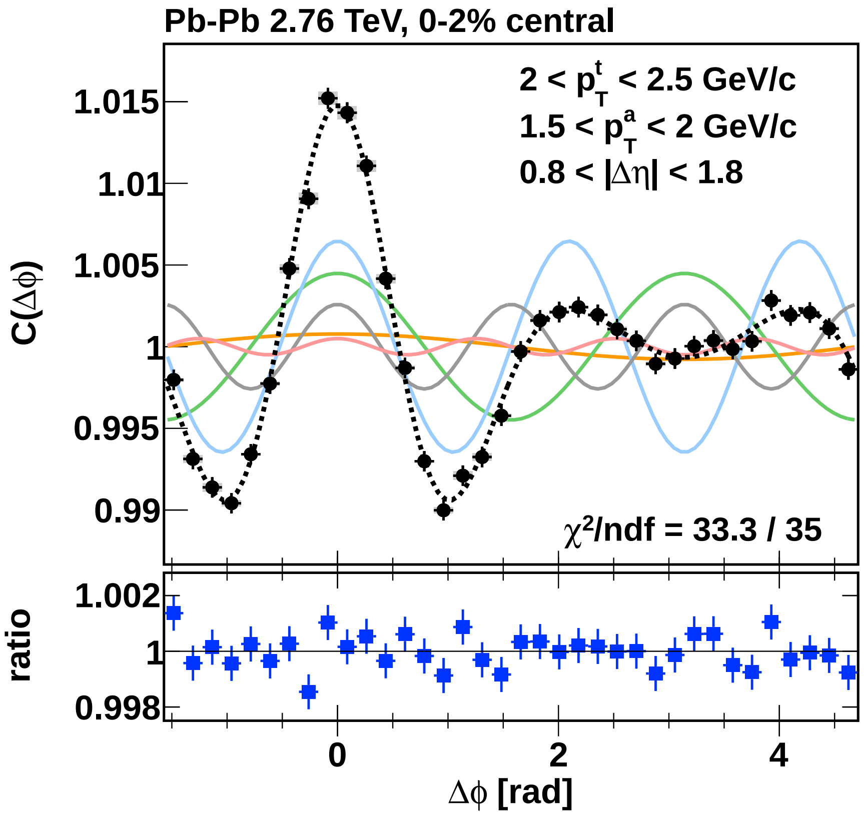
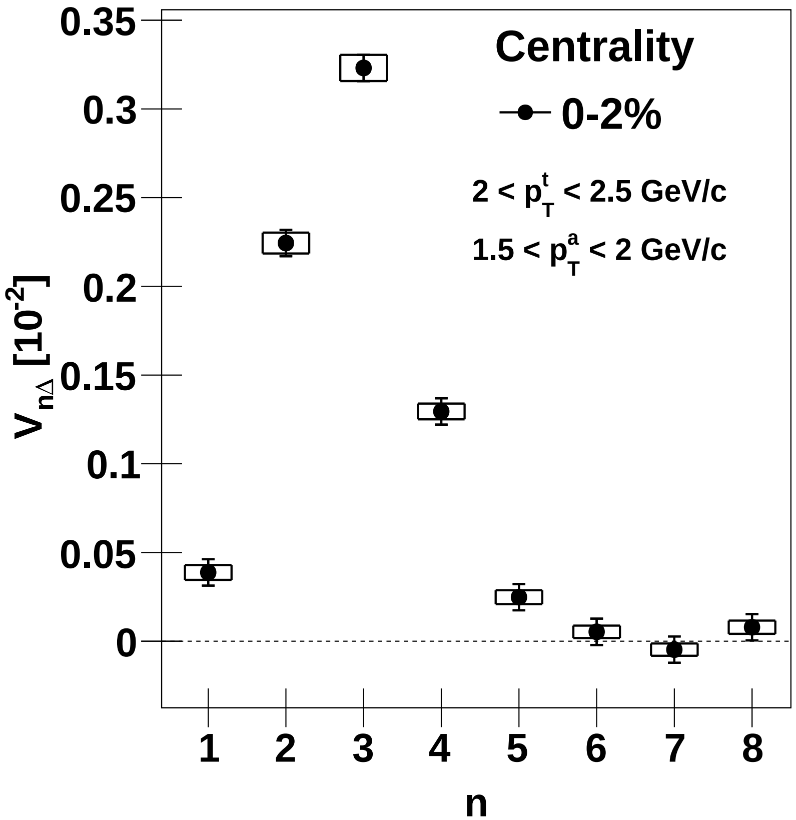
Sorensen, JPG 37 (2010) 094011; Alver, Roland, PRC 81 (2010) 054905 ...collision geometry fluctuations





ALICE, PLB 708 (2012) 032301; PRL 107 (2011) 032301

ATLAS, PRC 86 (2012) 014907 ; PHENIX, PRL 107 (2011) 252301

event-by-event distributions: ATLAS, arXiv:1305.2942

constrain initial state and η/s (small) in hydrodynamic models

Identified hadrons at the LHC

x3

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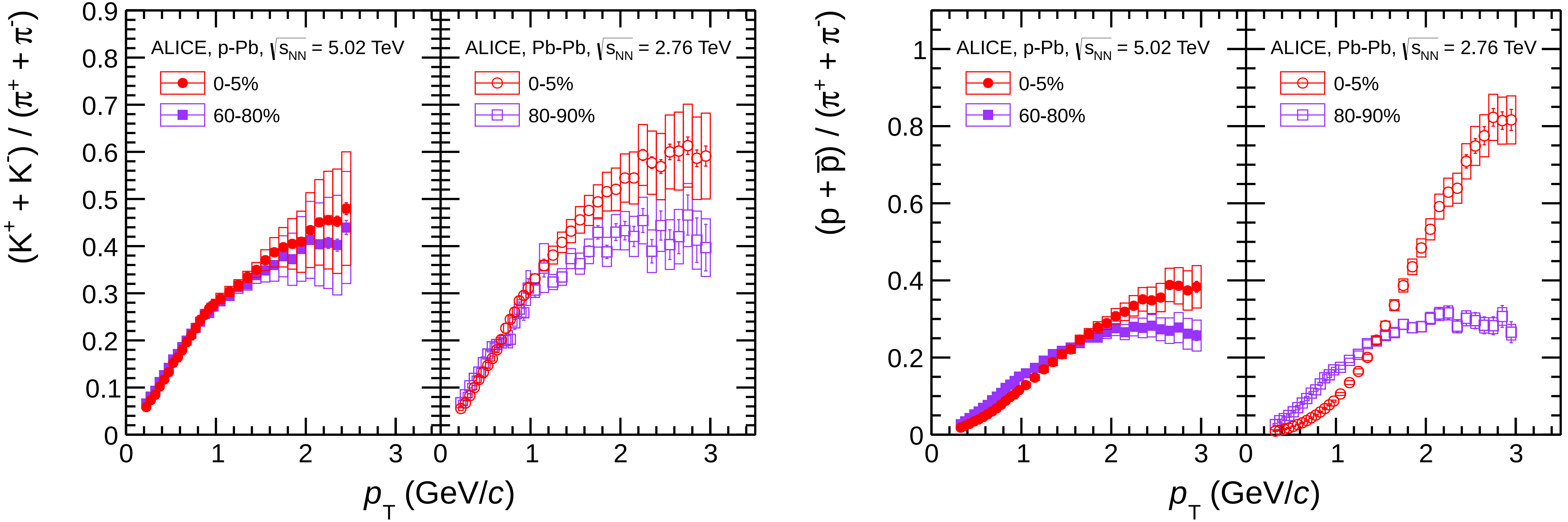

ALICE, 1307.6796 ...

0-5% central p–Pb collisions look like 60-70% central Pb–Pb

Identified hadrons at the LHC

x4

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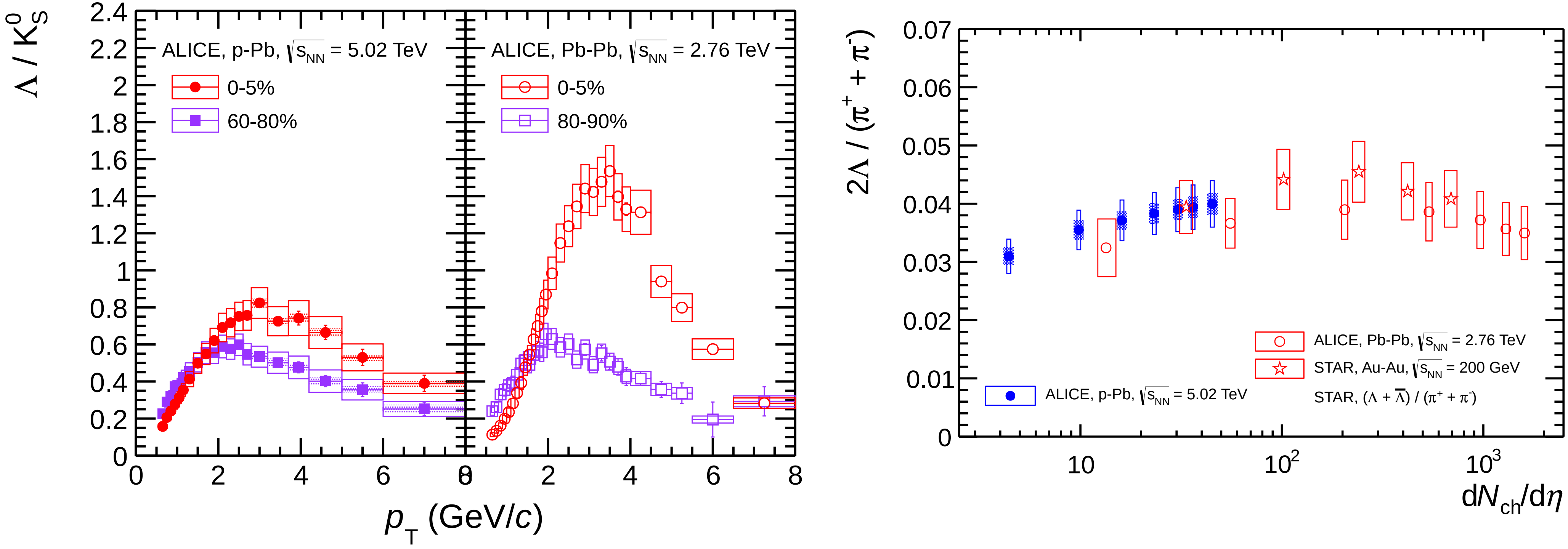

ALICE, 1307.6796 ...

0-5% central p–Pb collisions look like 60-70% central Pb–Pb ($dN_{ch}/d\eta$ ∼1.7 lower)

Identified hadrons at RHIC (d–Au collisions)

x5

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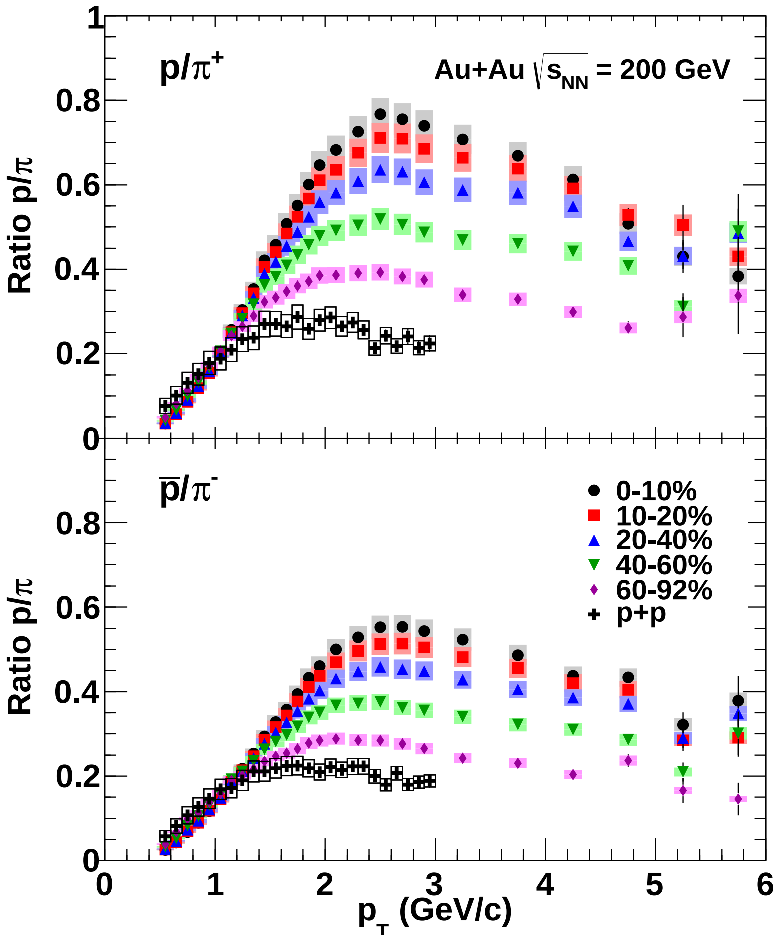

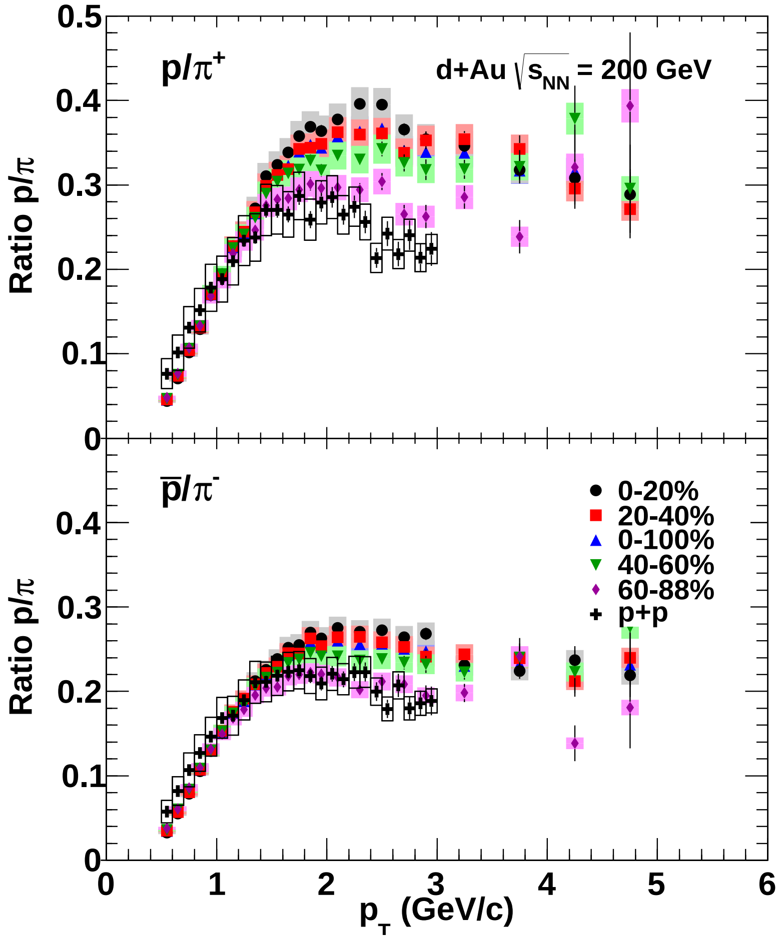

PHENIX, arXiv:1304.3410

... 0-20% central d–Au collisions look like 60-92% central Au–Au