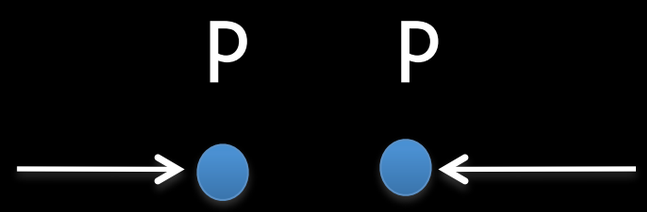
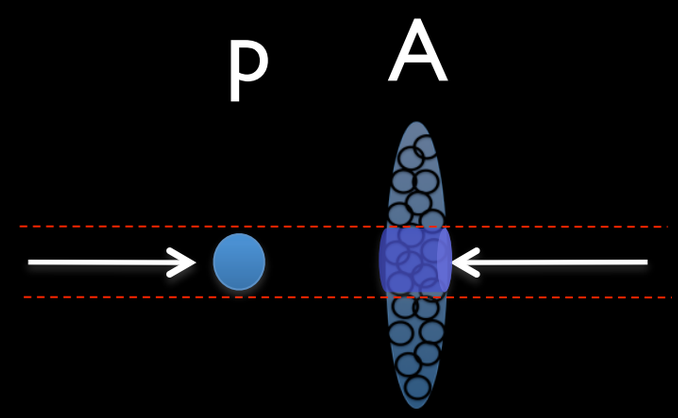
Initial state, an experimental perspective

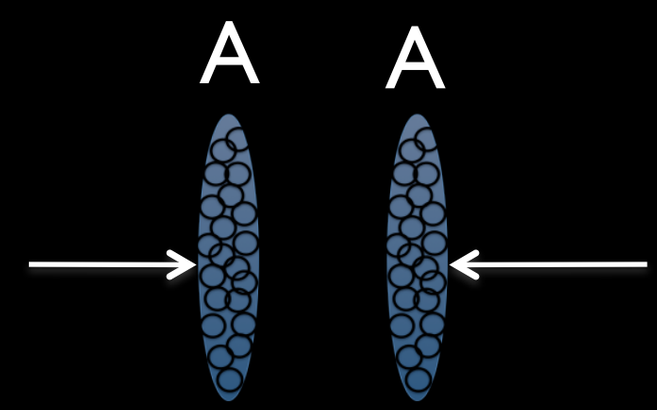
historical

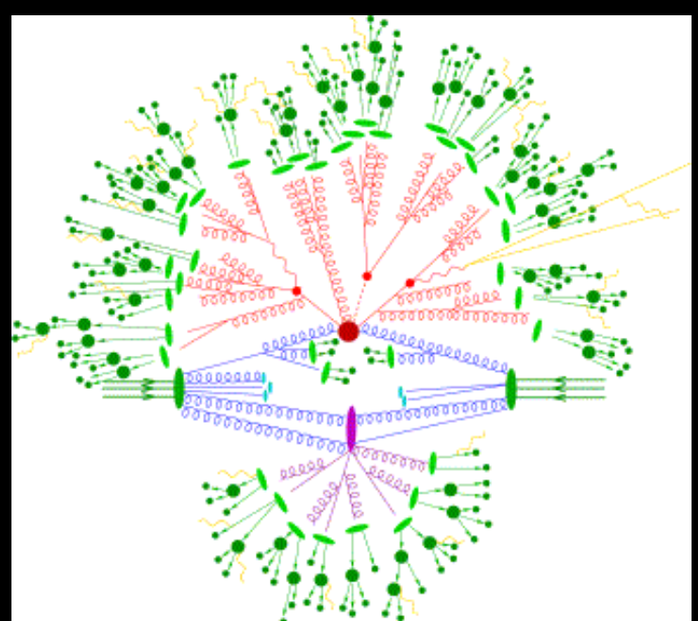
Gunther Roland

Using pp and pA to cleanse AA from initial state physics (early 2000's)

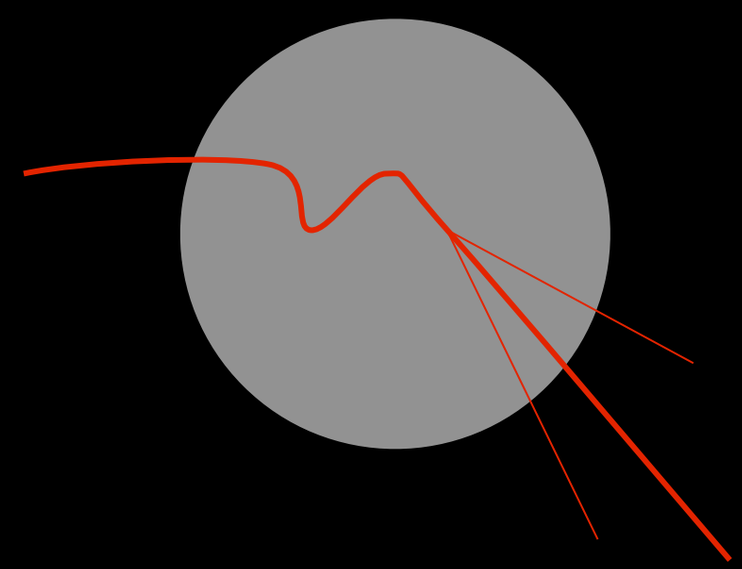




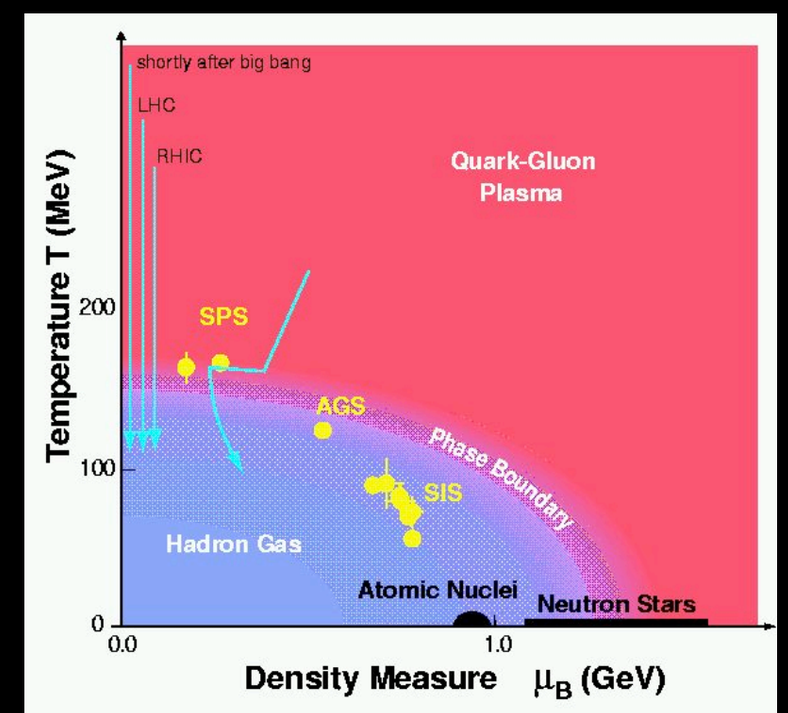




Local structure of QCD vacuum

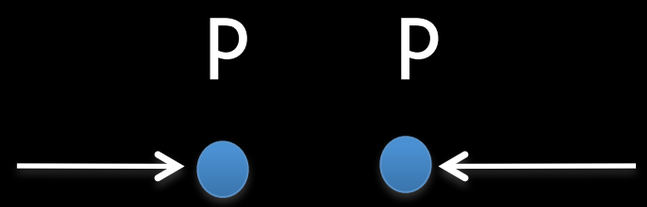


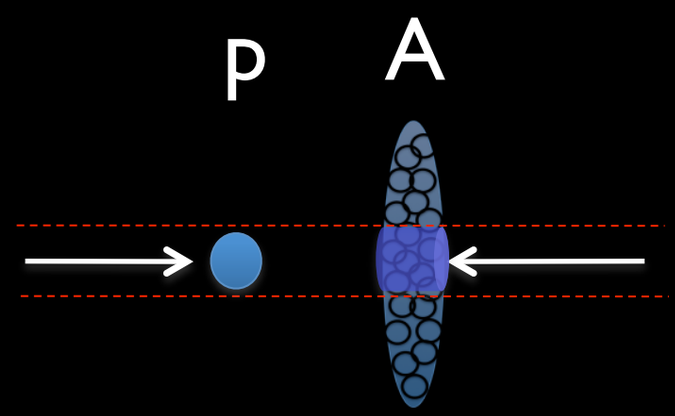
Local QCD
+
initial state/cold nuclear matter

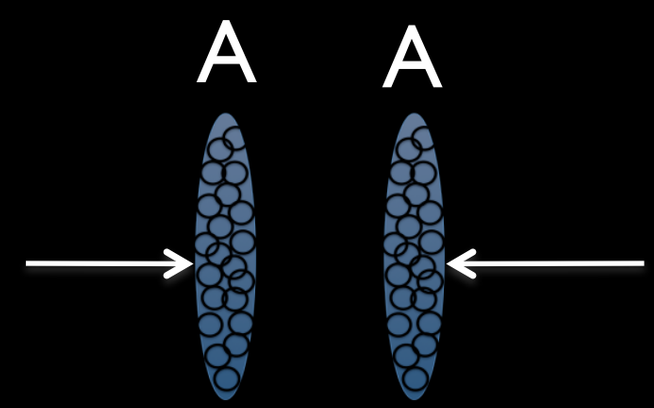


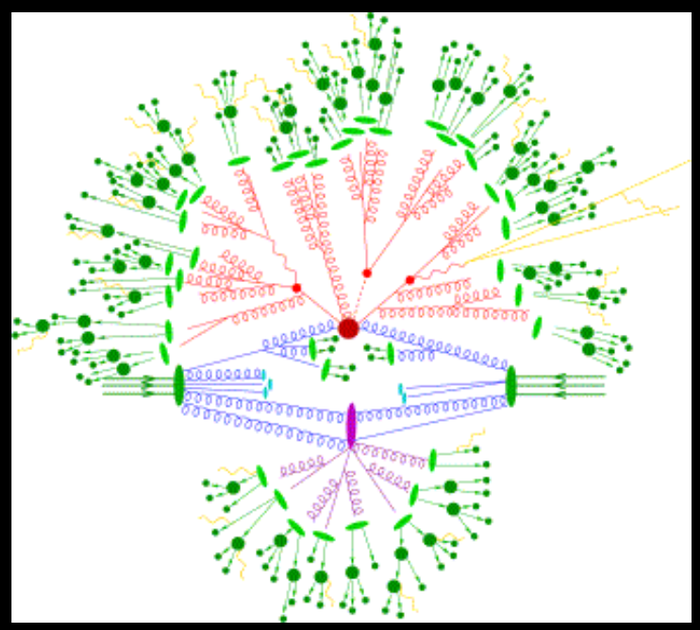
Local QCD
+
initial state/cold nuclear matter
+
Quark-Gluon Plasma

Using pp and pA to cleanse AA from initial state physics (early 2000's)

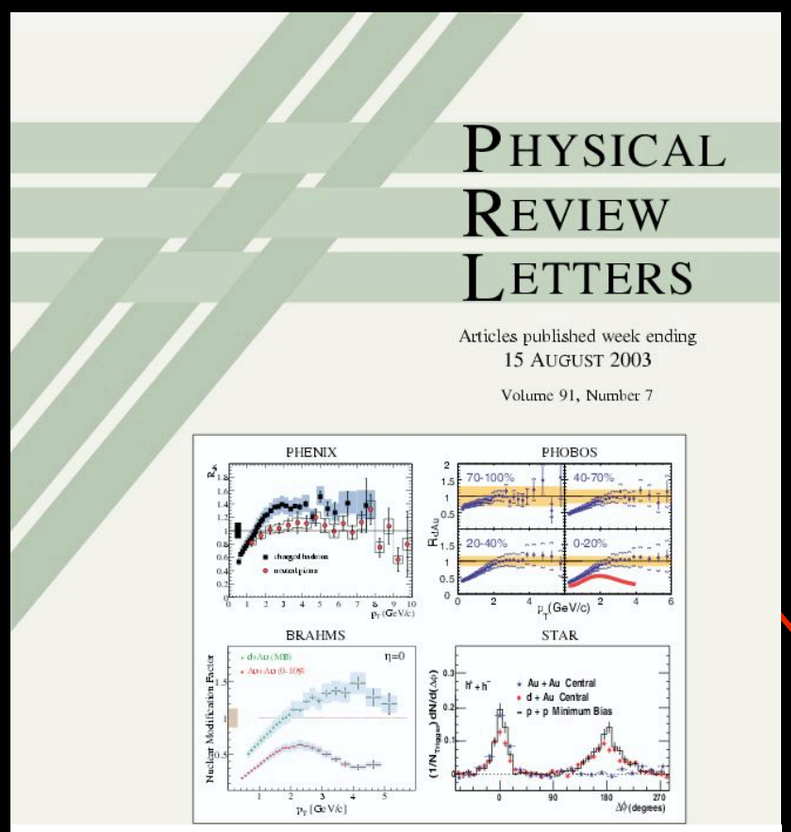




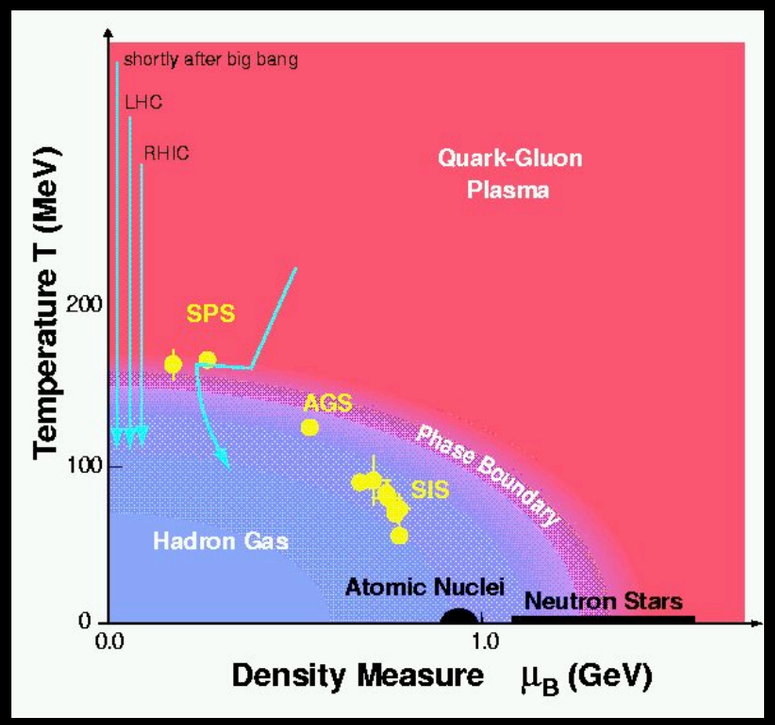




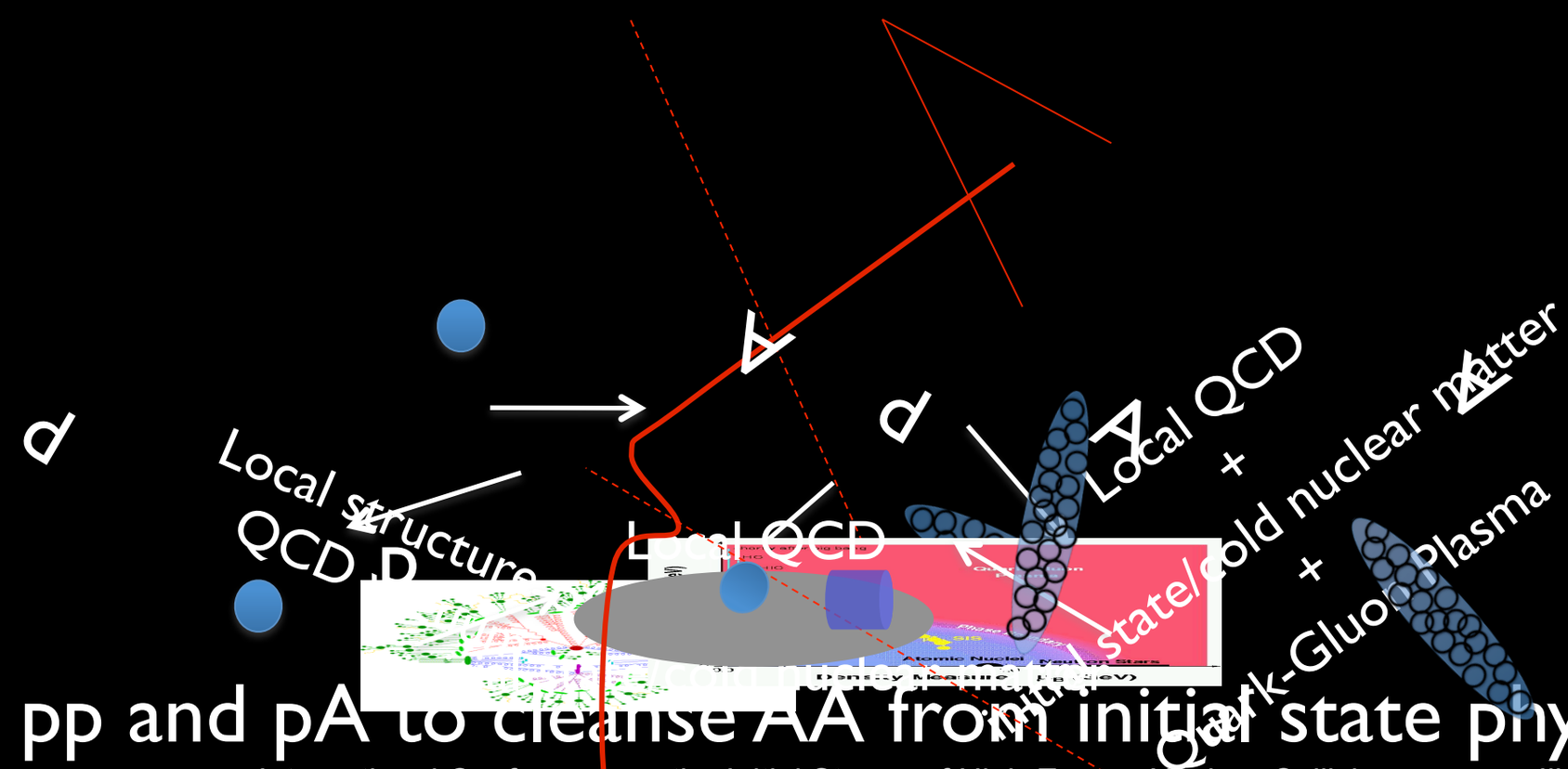
Local structure of QCD vacuum



2003 dAu run shows that jet quenching is a final state effect

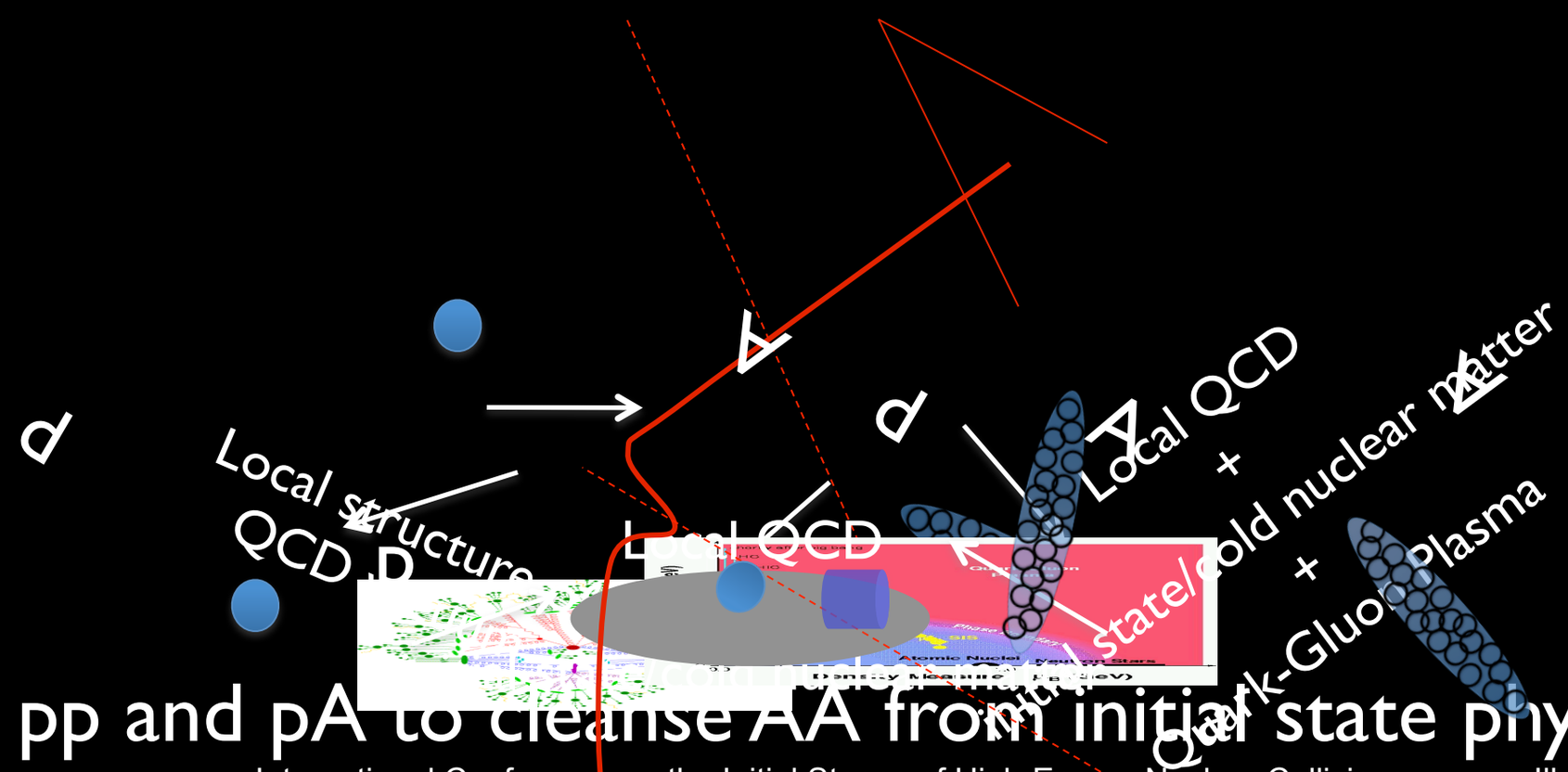


Local QCD
+
initial state/cold nuclear matter
+
Quark-Gluon Plasma



Using pp and pA to cleanse AA from initial state physics

Initial state,
an ~~experimental~~ perspective
iconoclastic



Using pp and pA to cleanse AA from initial state physics

i·con·o·clast (ī-kŏn′ə-klăst′)

n.

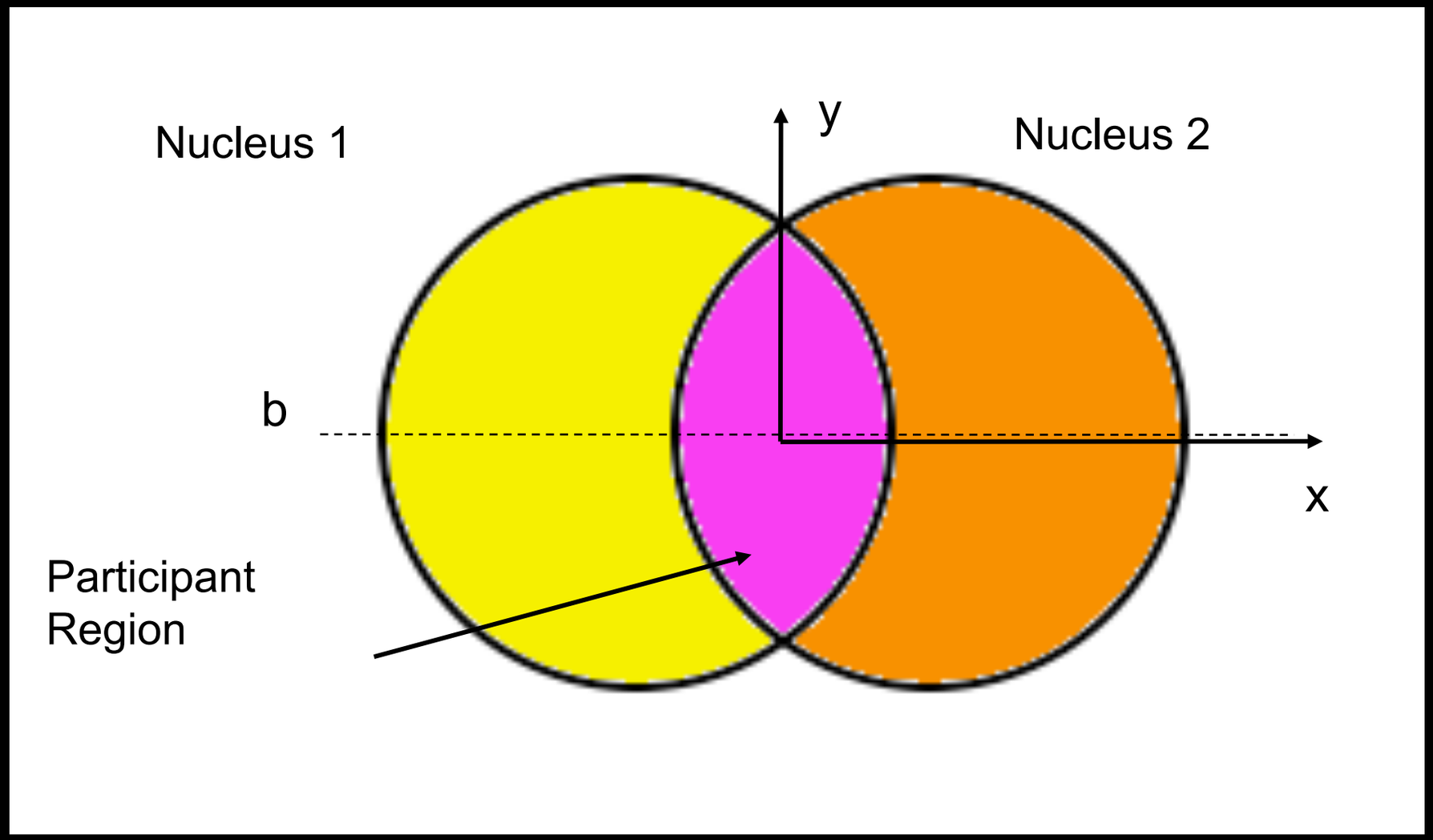
1. One who attacks and seeks to overthrow traditional or popular ideas or institutions.
2. One who destroys sacred religious images.

Warning:

i·con′o·clas′ti·cal·ly *adv.*

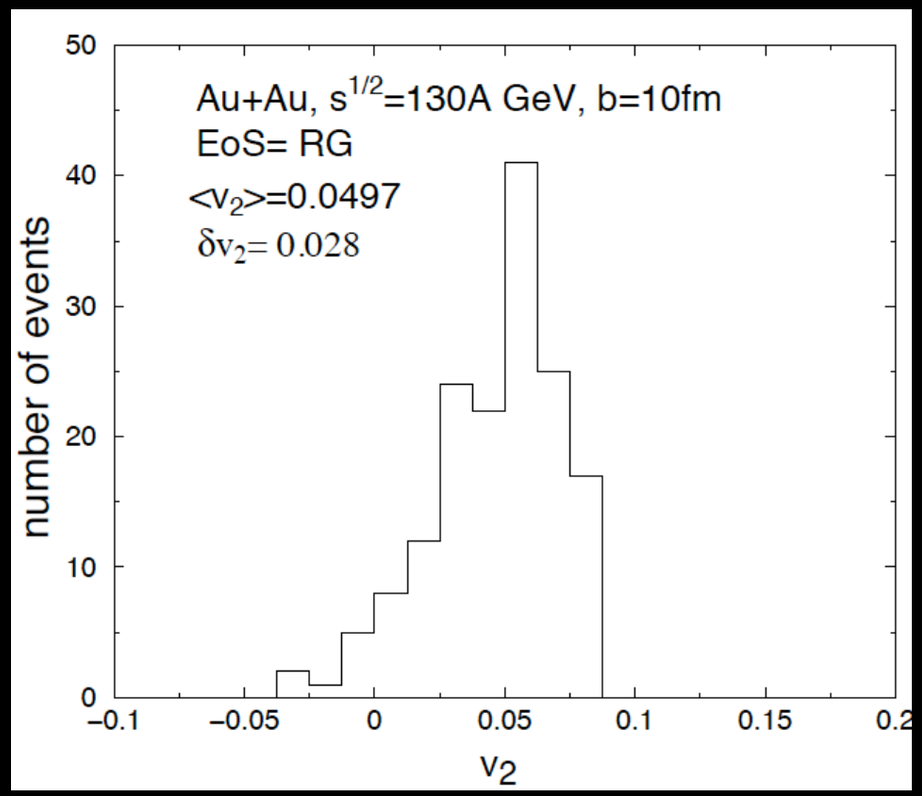
Word History: An iconoclast can be unpleasant company, but at least the modern iconoclast only attacks such things as ideas and institutions. The original iconoclasts destroyed countless works of art.

Geometry



this is what nuclei looked like in early 2000's

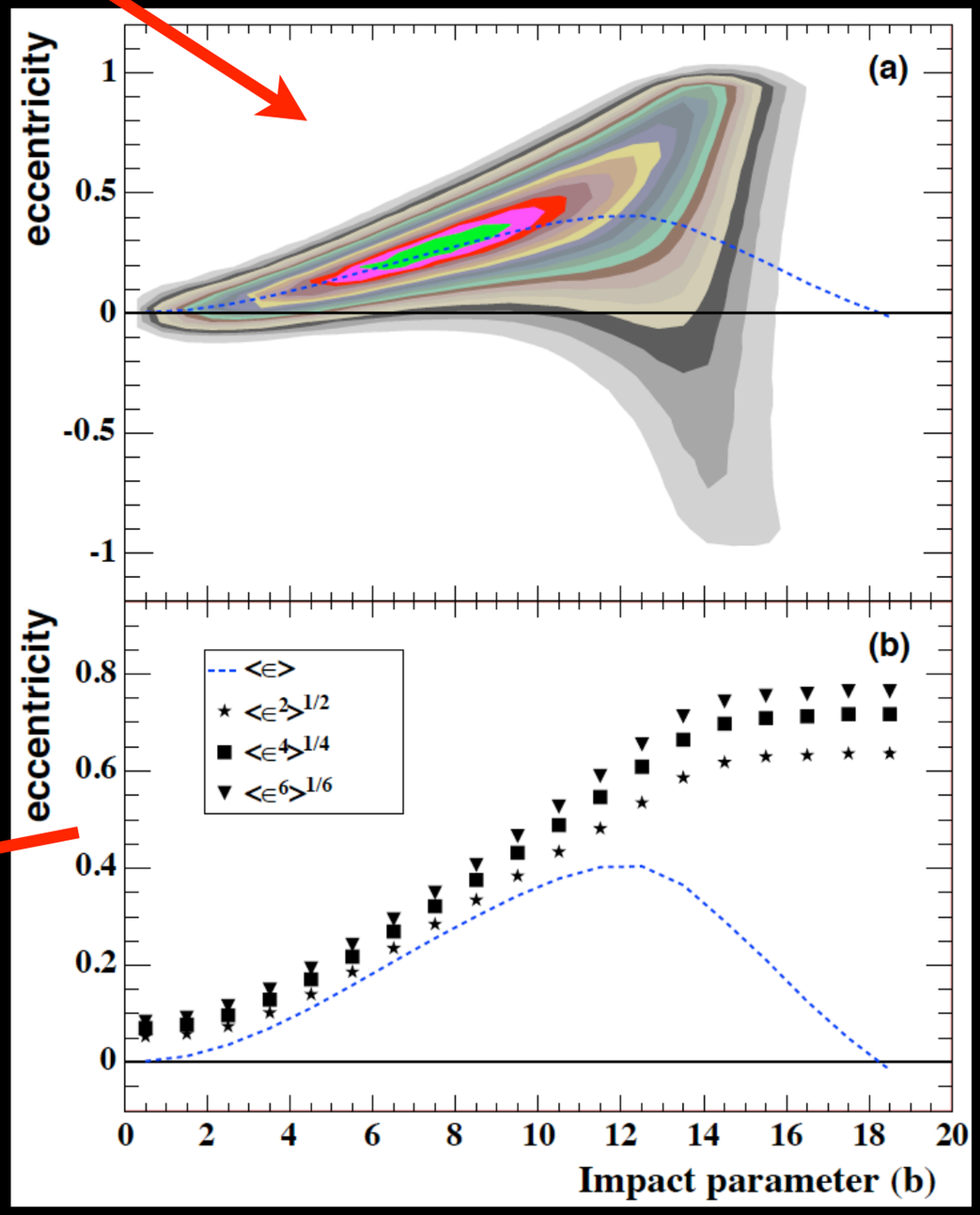
Aguiar, Hama et al
Nucl.Phys.A698 (2002) 639-642



Hydro-dynamics with
fluctuating initial conditions

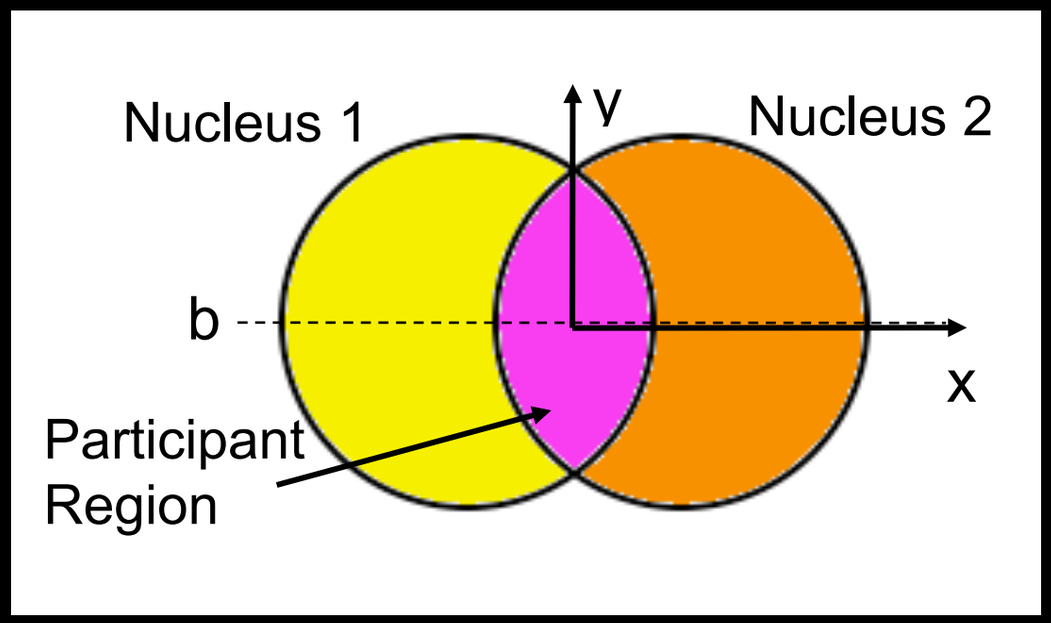
Miller, Snellings
nucl-ex/0312008

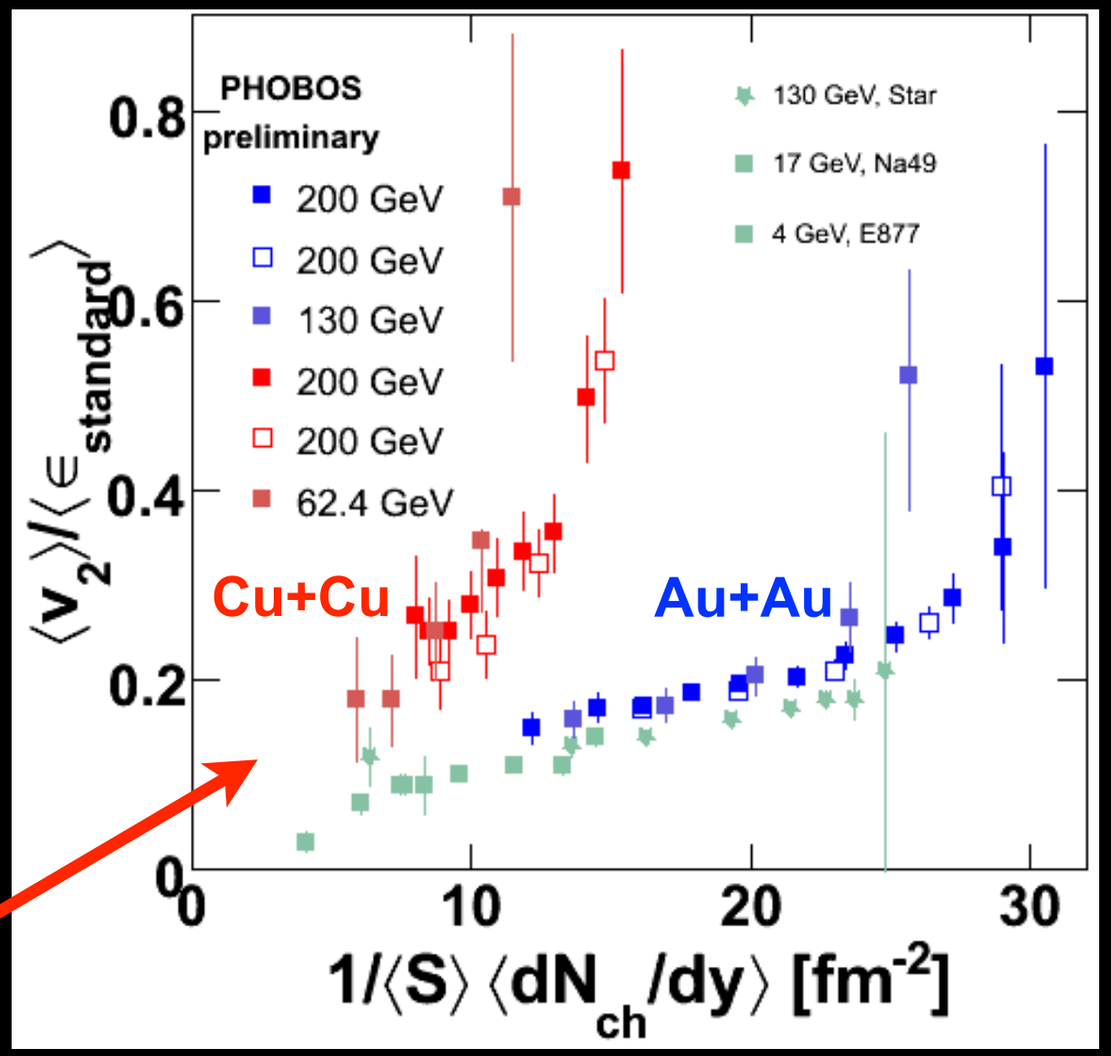
MC Glauber eccentricity fluctuations
relative to the reaction plane



In summary, experimental measurements of elliptic flow (v_2) might be affected by fluctuations.

But: Geometry fluctuations still treated as a perturbation of reaction plane eccentricity



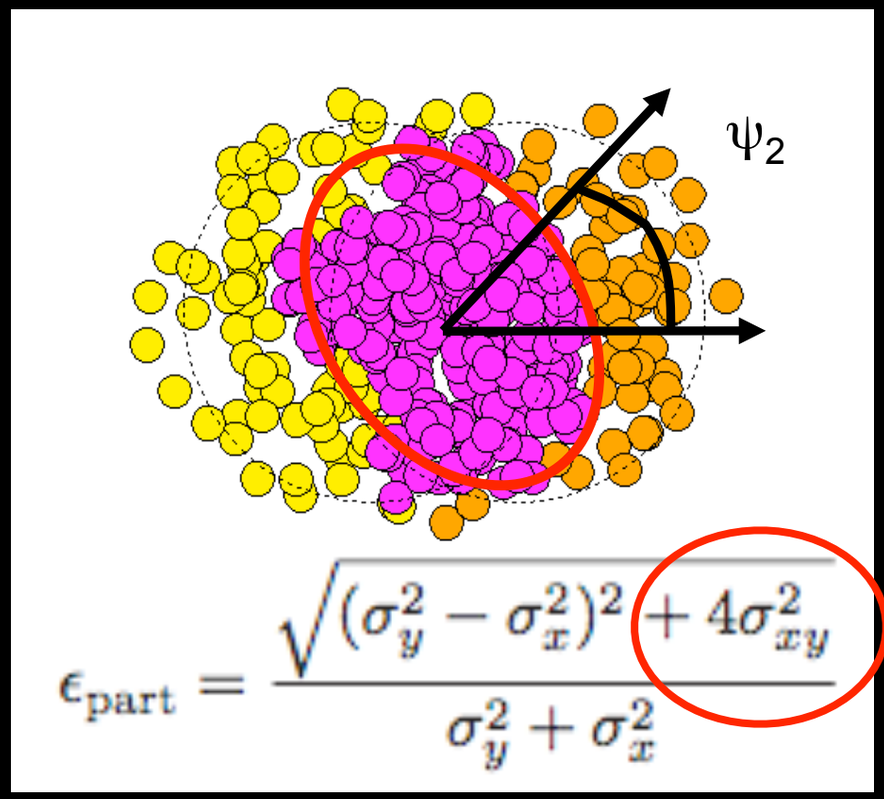


QM'05: First results on v2 in CuCu from PHENIX, PHOBOS, STAR

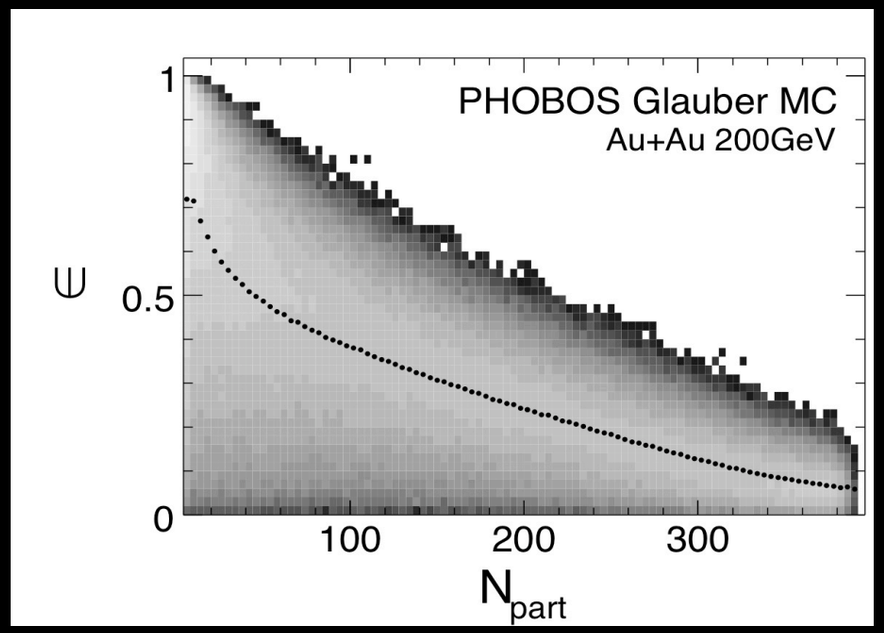
In the pre-2005 view, density-scaling of v_2/ϵ broken in Cu+Cu vs Au+Au

Geometry Fluctuations and Participant Eccentricity

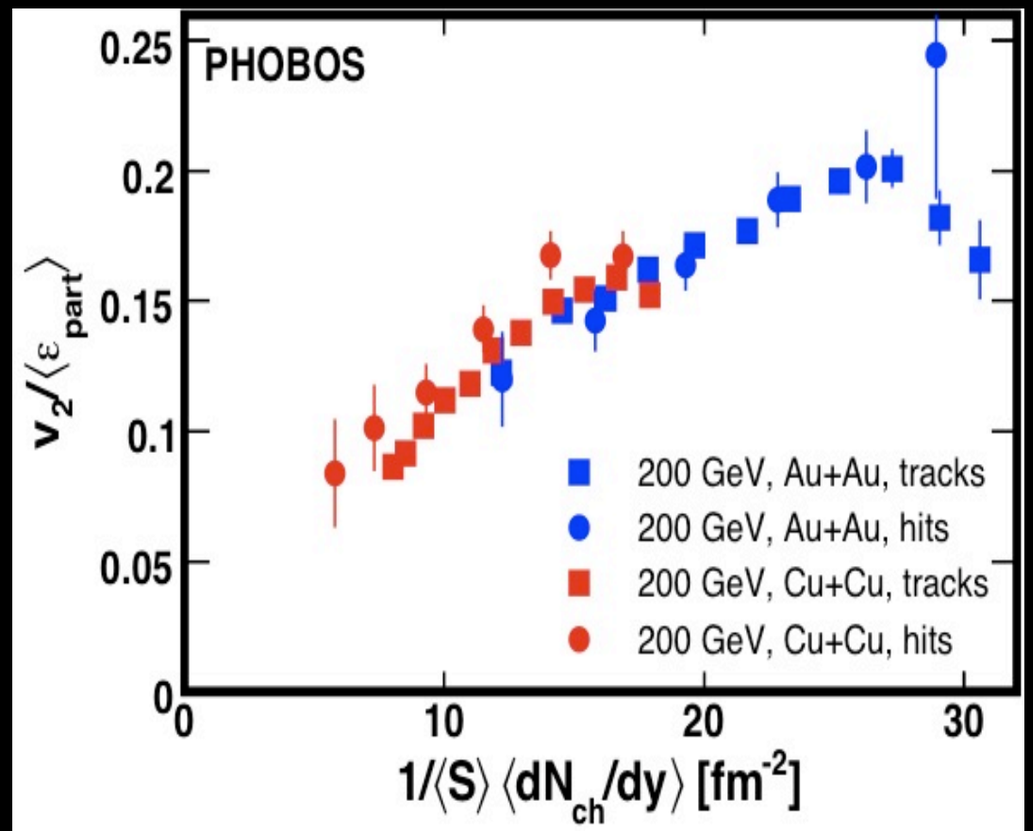
Participant Eccentricity



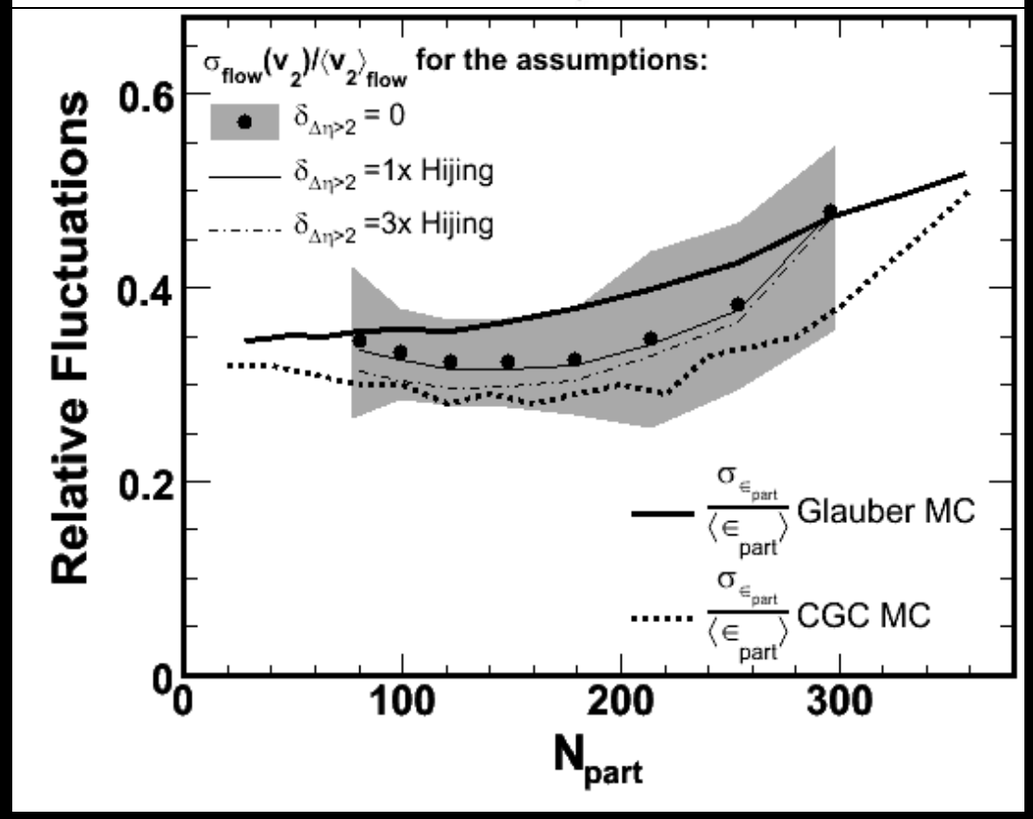
$$\epsilon_{\rm part} = \frac{\sqrt{(\sigma_y^2 - \sigma_x^2)^2 + 4\sigma_{xy}^2}}{\sigma_y^2 + \sigma_x^2}$$



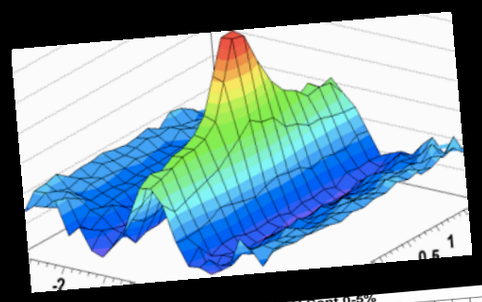
PHOBOS
QM2005
PRL 98, 242302 (2007)



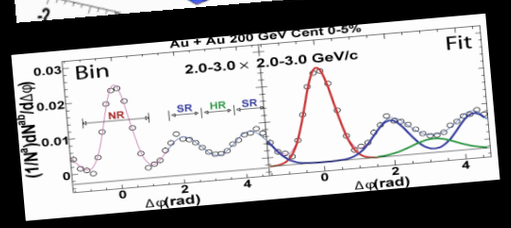
PHOBOS
PRL 104, 142301 (2010)
PHOBOS
PRC81, 034915 (2010)



Ridge



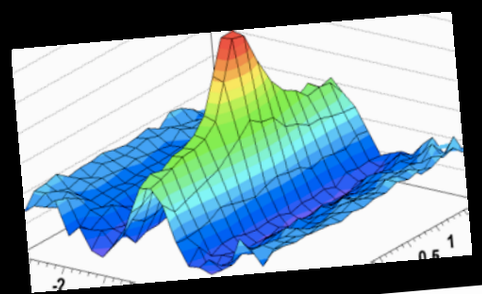
STAR Phys.Rev. C80 (2009) 064912
PHOBOS Phys.Rev.Lett. 104 (2010) 062301



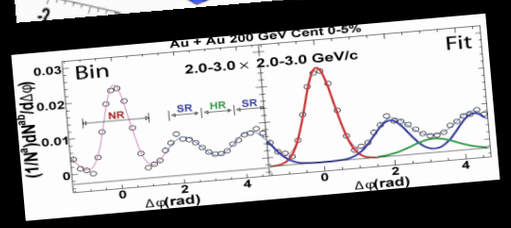
PHENIX Phys.Rev.Lett.98:232302,2007

Mach cones

Ridge



STAR Phys.Rev. C80 (2009) 064912
PHOBOS Phys.Rev.Lett. 104 (2010) 062301



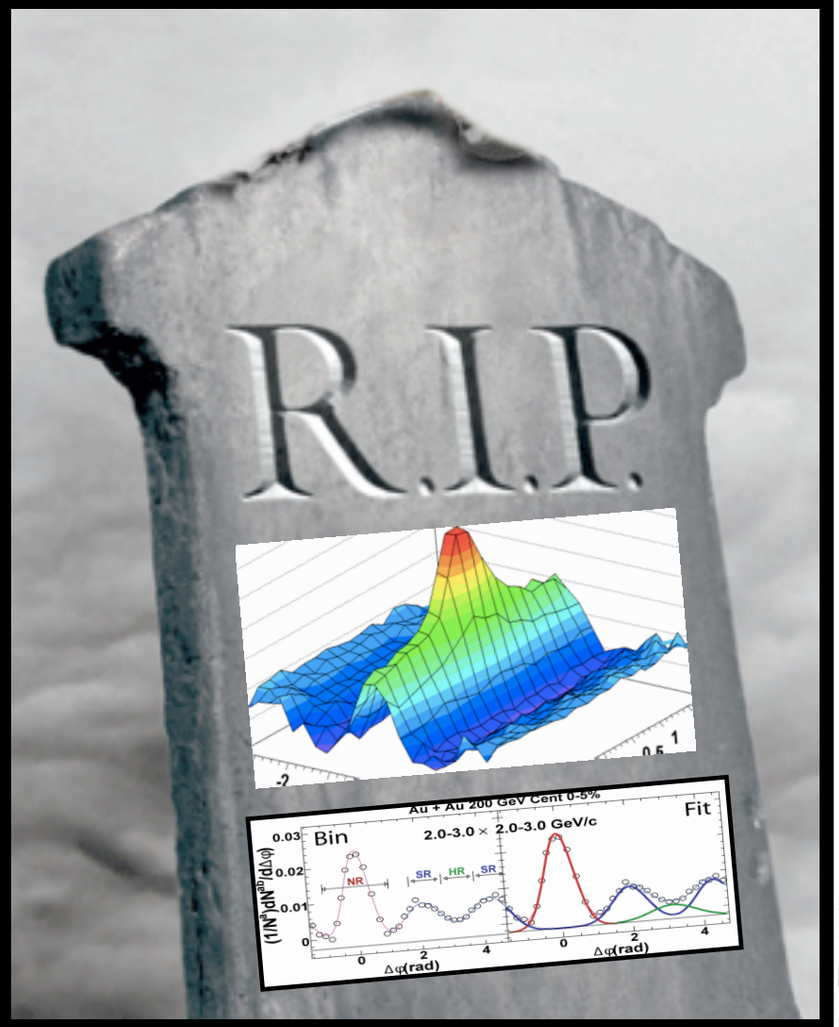
PHENIX Phys.Rev.Lett.98:232302,2007

Mach cones

Geometry fluctuations and final state correlations:

Mishra et al arXiv:0711.1323
Takahashi et al, arXiv:0902.4870
Sorensen, arXiv:1002.4878

Demise of Ridge and Mach Cones



"Triangular flow"
and
"Participant triangularity"

No ridge, no mach cone, just flow

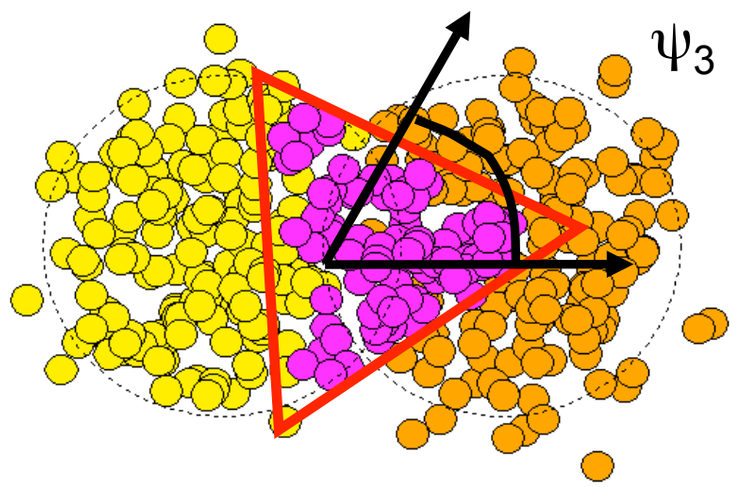
Burak Alver
Mithig meeting
10/13/2009

Geometry fluctuations and final state correlations:

Mishra et al arXiv:0711.1323
Takahashi et al, arXiv:0902.4870
Sorensen, arXiv:1002.4878

Geometry Fluctuations and Higher Order Harmonics

Participant Triangularity
(2010)



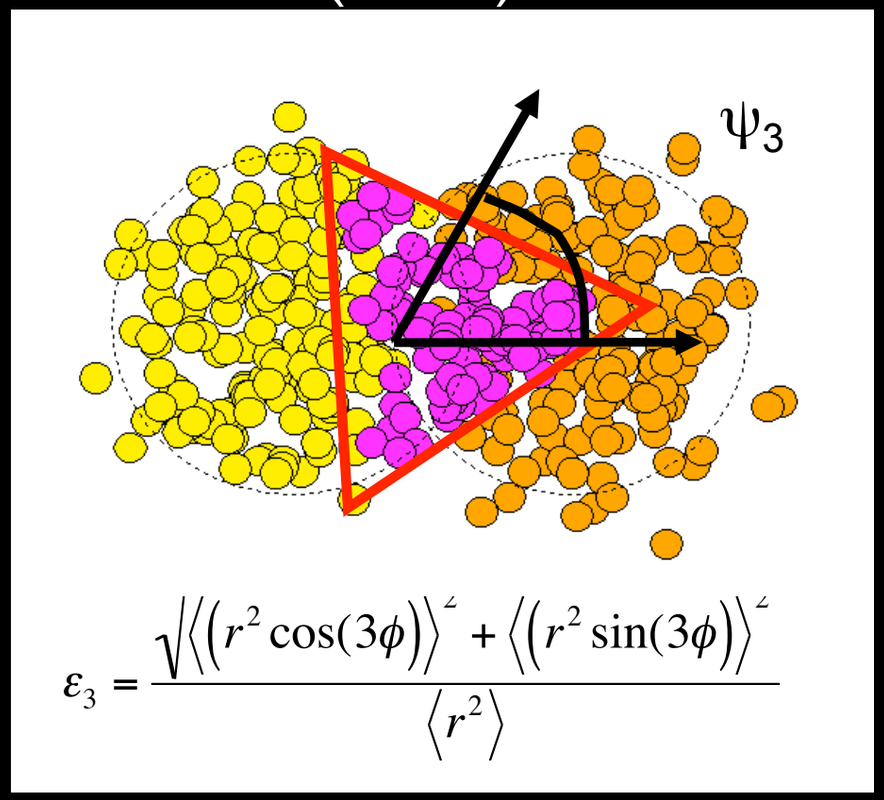
$$\varepsilon_3 = \frac{\sqrt{\left\langle \left(r^2 \cos(3\phi)\right)\right\rangle^2 + \left\langle \left(r^2 \sin(3\phi)\right)\right\rangle^2}}{\left\langle r^2 \right\rangle}$$

Alver, Roland
Phys.Rev.C81:054905,2010

Just like elliptic flow reflects event-by-event eccentricity, "triangular flow" (v_3) reflects event-by-event "triangularity" (ε_3)

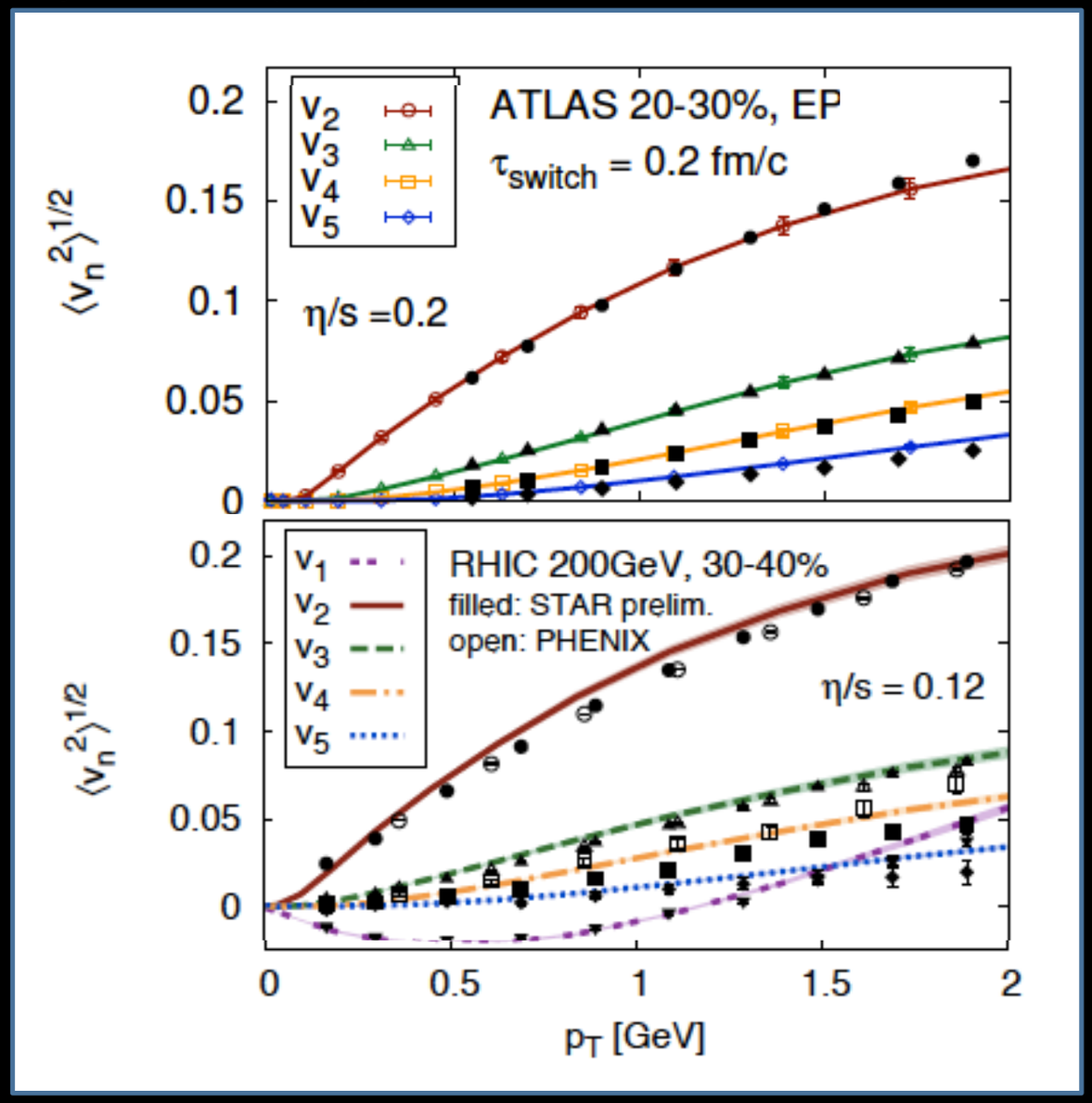
Geometry Fluctuations and Higher Order Harmonics

Participant Triangularity (2010)



Alver, Roland
Phys.Rev.C81:054905,2010

Bjoern Schenke et al
Phys.Rev. C85 (2012) 024901



Just like elliptic flow reflects event-by-event eccentricity, "triangular flow" (v_3) reflects event-by-event "triangularity" (ε_3)

Single calculation describes Fourier coefficients at RHIC and LHC (2012) (small change in η/s from RHIC to LHC)

September 2010

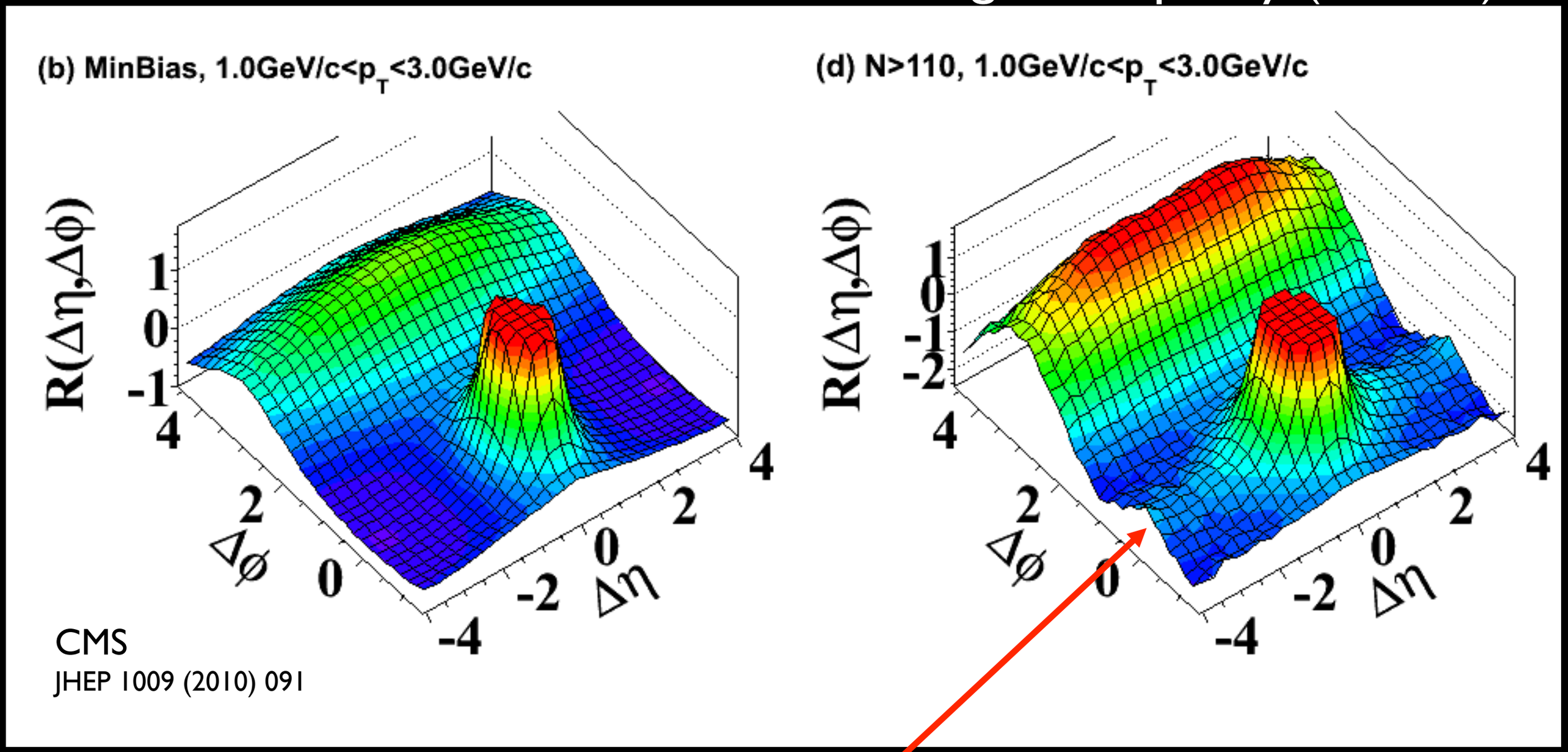
Two-Particle Correlations in pp (Sep 2010)

Results based on $1fb^{-1}$,
i.e. sampling 50billion pp events
with high multiplicity trigger

Intermediate p_T: 1-3 GeV/c

MinBias

high multiplicity (N>110)

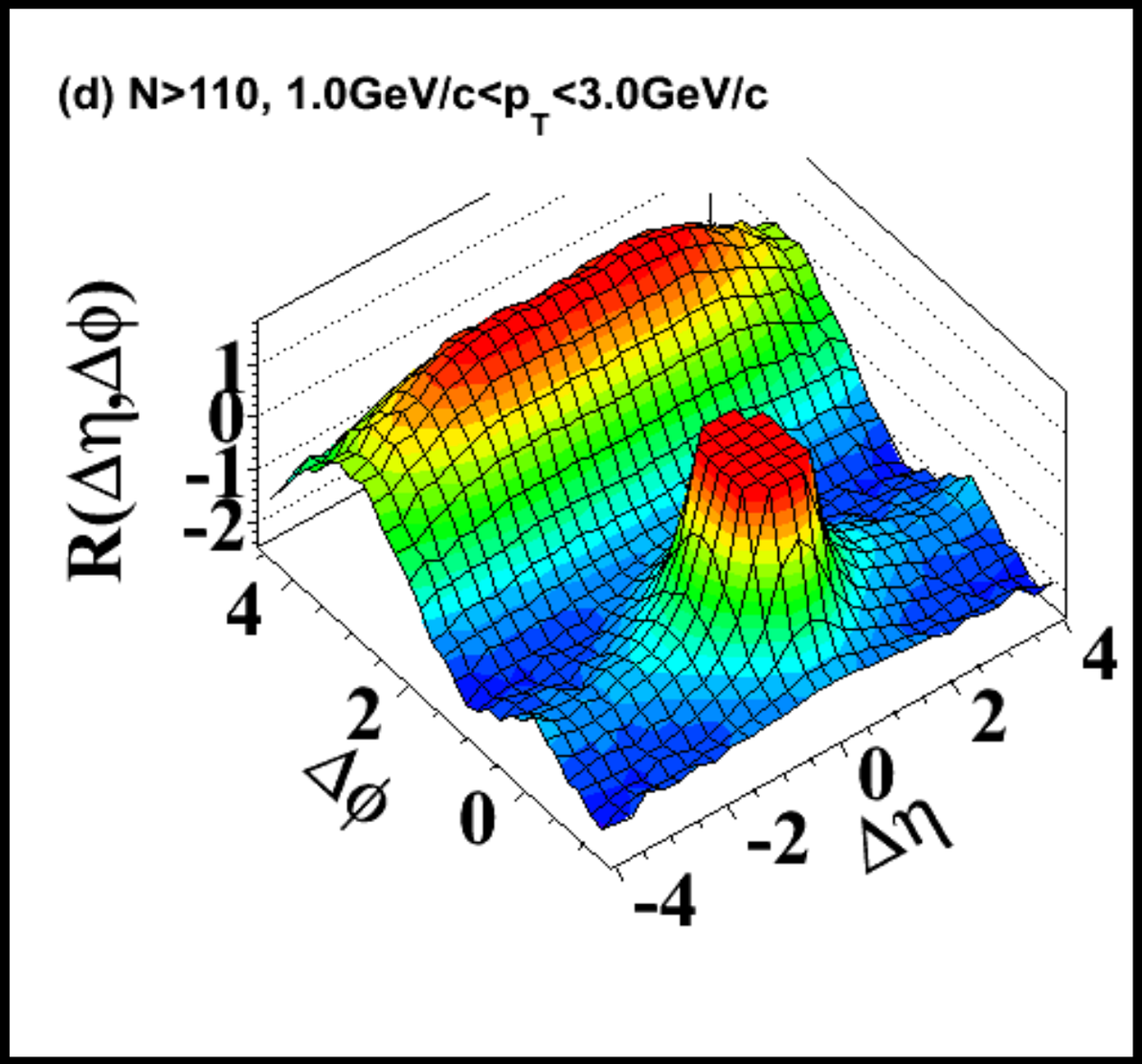


Pronounced structure at large $\delta\eta$ around $\delta\phi \sim 0$!

Two-Particle Correlations in pp (Sep 2010)

High multiplicity (N>110)

~100 citations within a year



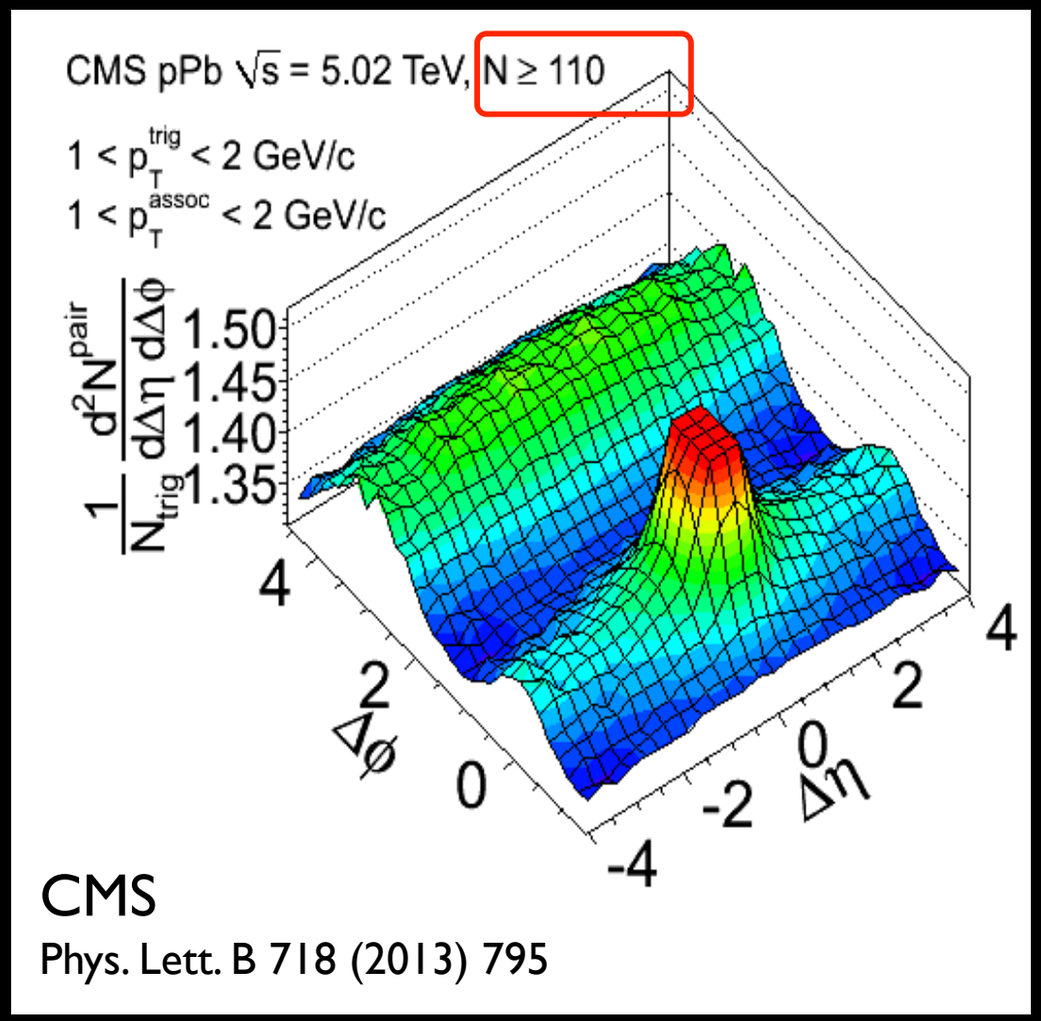
Multiplicity in these events is dominated by jet contribution.

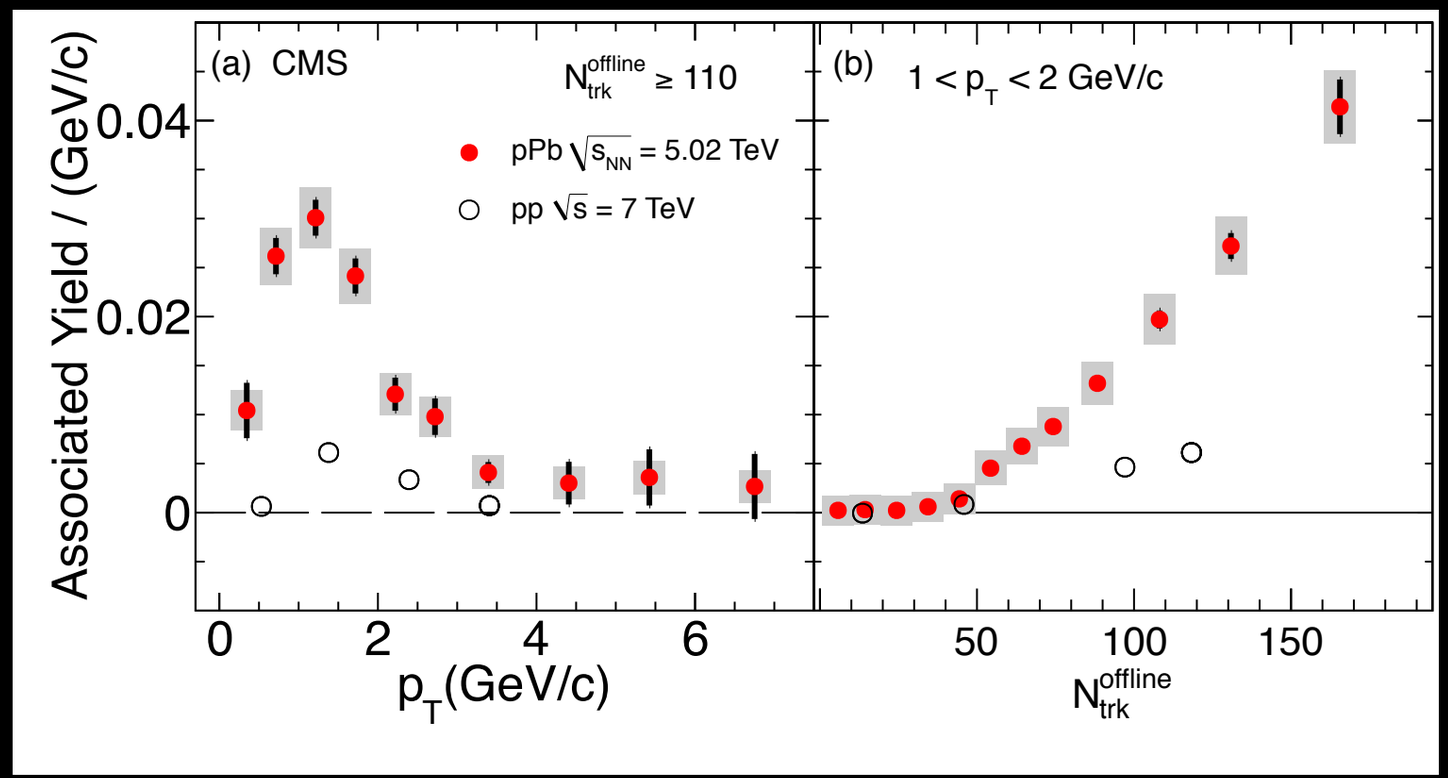
Interpretation:

Multi-jet correlations
Jet-Jet color connections
Jet-proton remnant color connections
Jet-remnant connections + medium
Glasma correlations
Quantum entanglement
Angular momentum conservation
Angular momentum conservation + medium
Hydrodynamic flow

?

Two-Particle Correlations in pPb (Oct 2012)





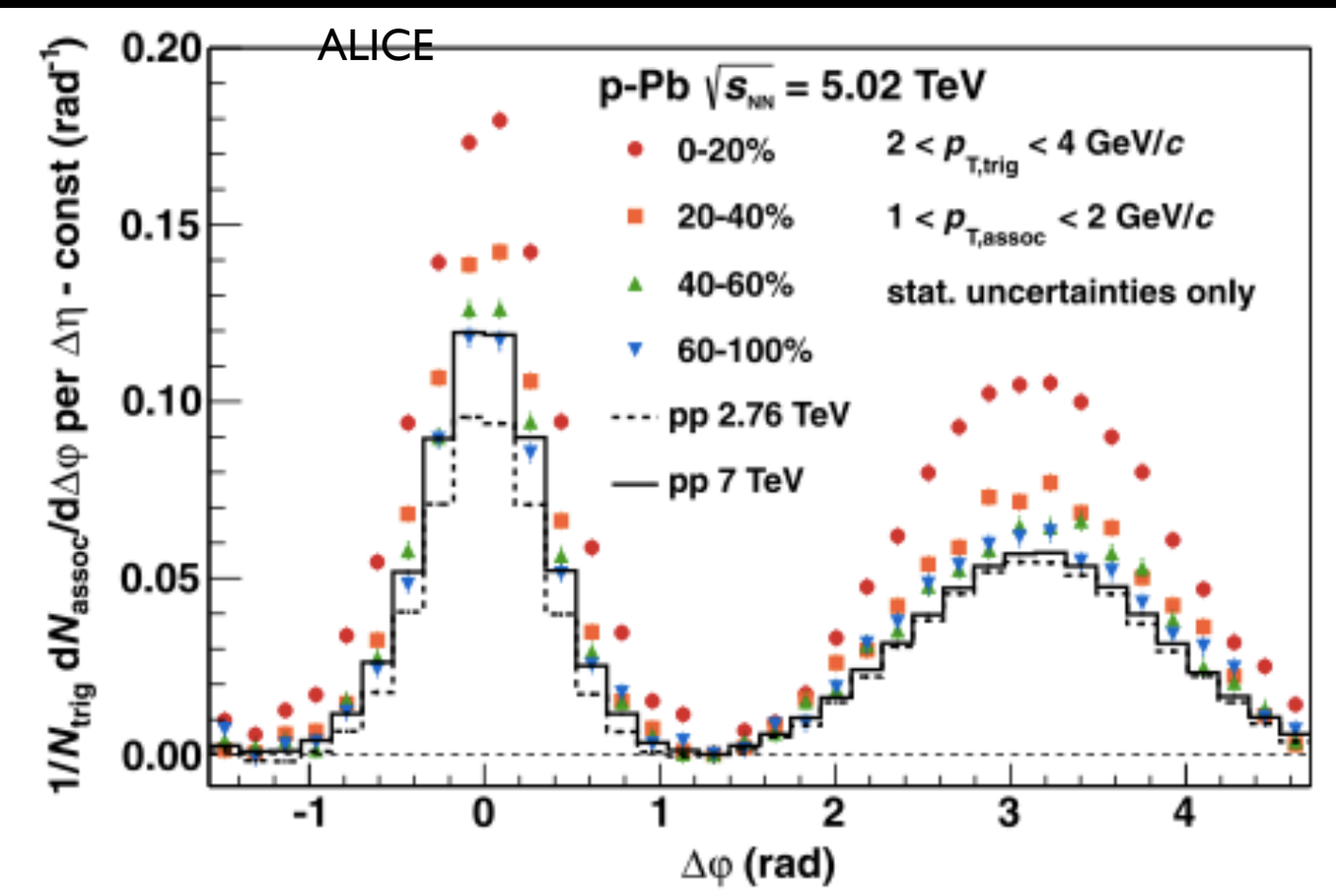
Similar correlations as in high-multiplicity pp, but larger strength (associated yield)

Opinion:
Phenomenology very similar in pp and pPb - same underlying physics

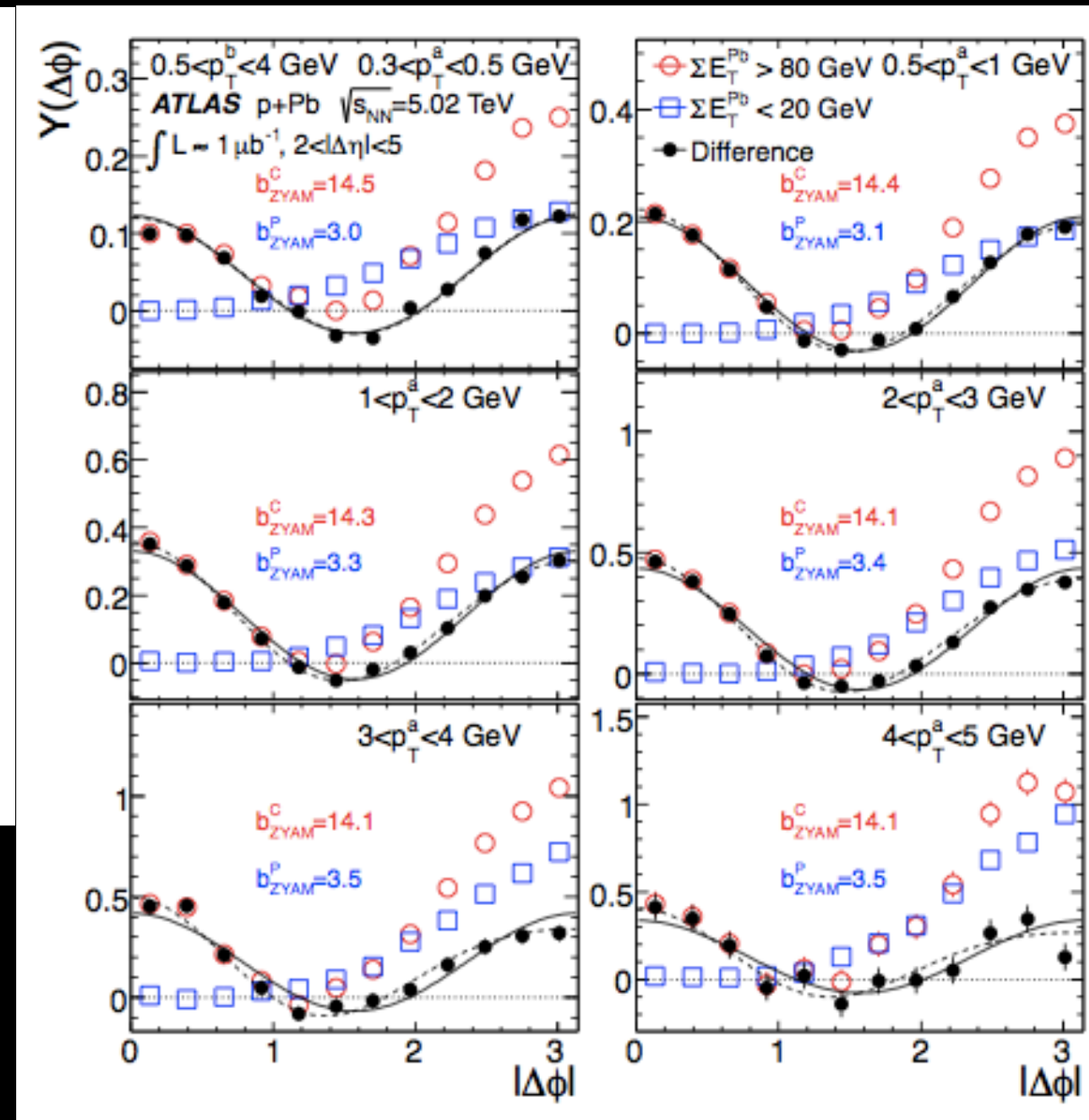
Most models of pp-ridge immediately ruled out

Peripheral subtraction in ALICE and ATLAS

ALICE Phys.Lett. B719 (2013) 29-41



ATLAS Phys. Rev. Lett. 110, 182302 (2013)

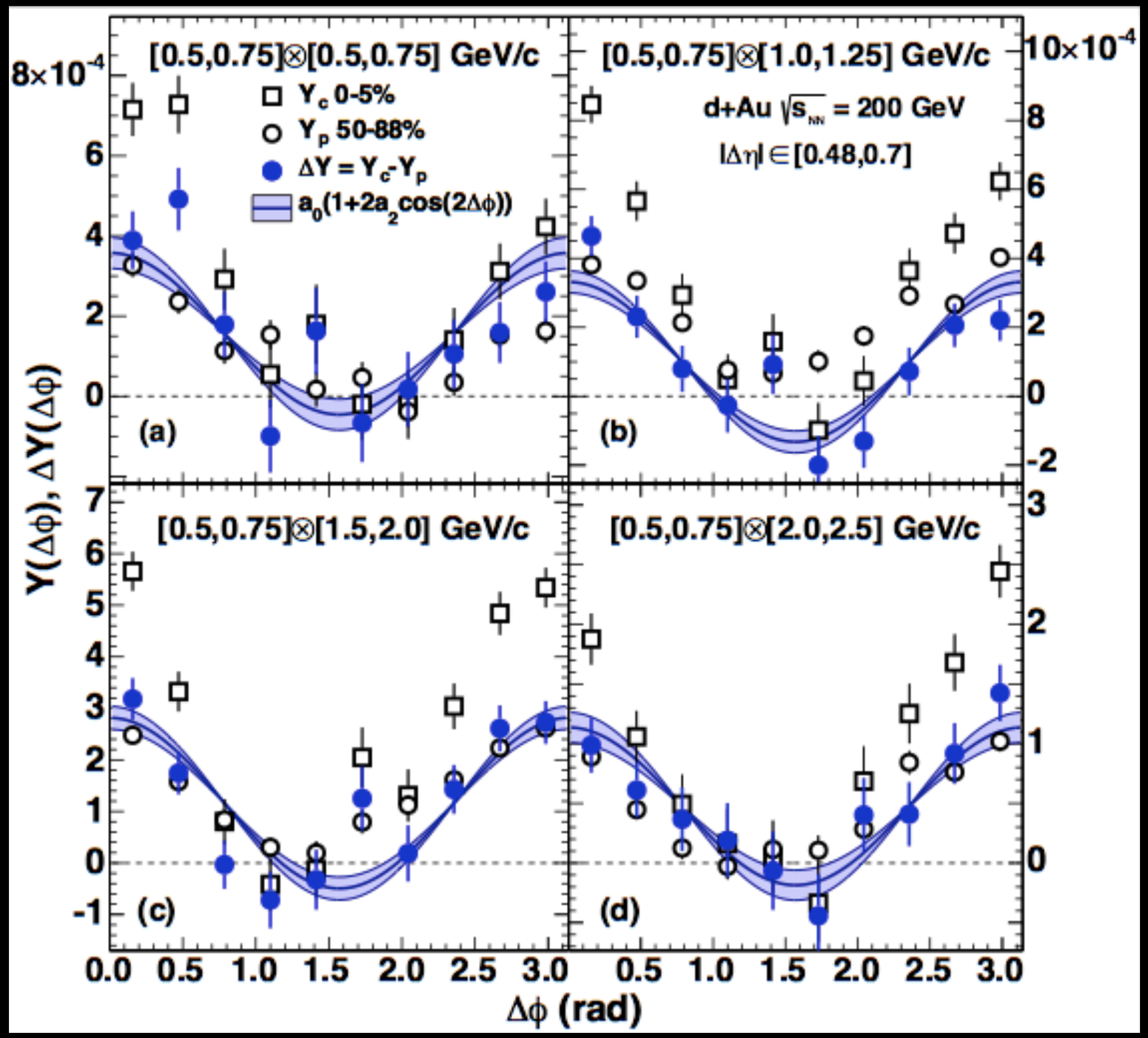


Away side yield in pp and peripheral pPb is very similar (away-side jet)

Subtraction of peripheral pPb correlations reveals nearly symmetric "double-ridge" structure

PHENIX dAu correlations

PHENIX
arXiv:1303.1794

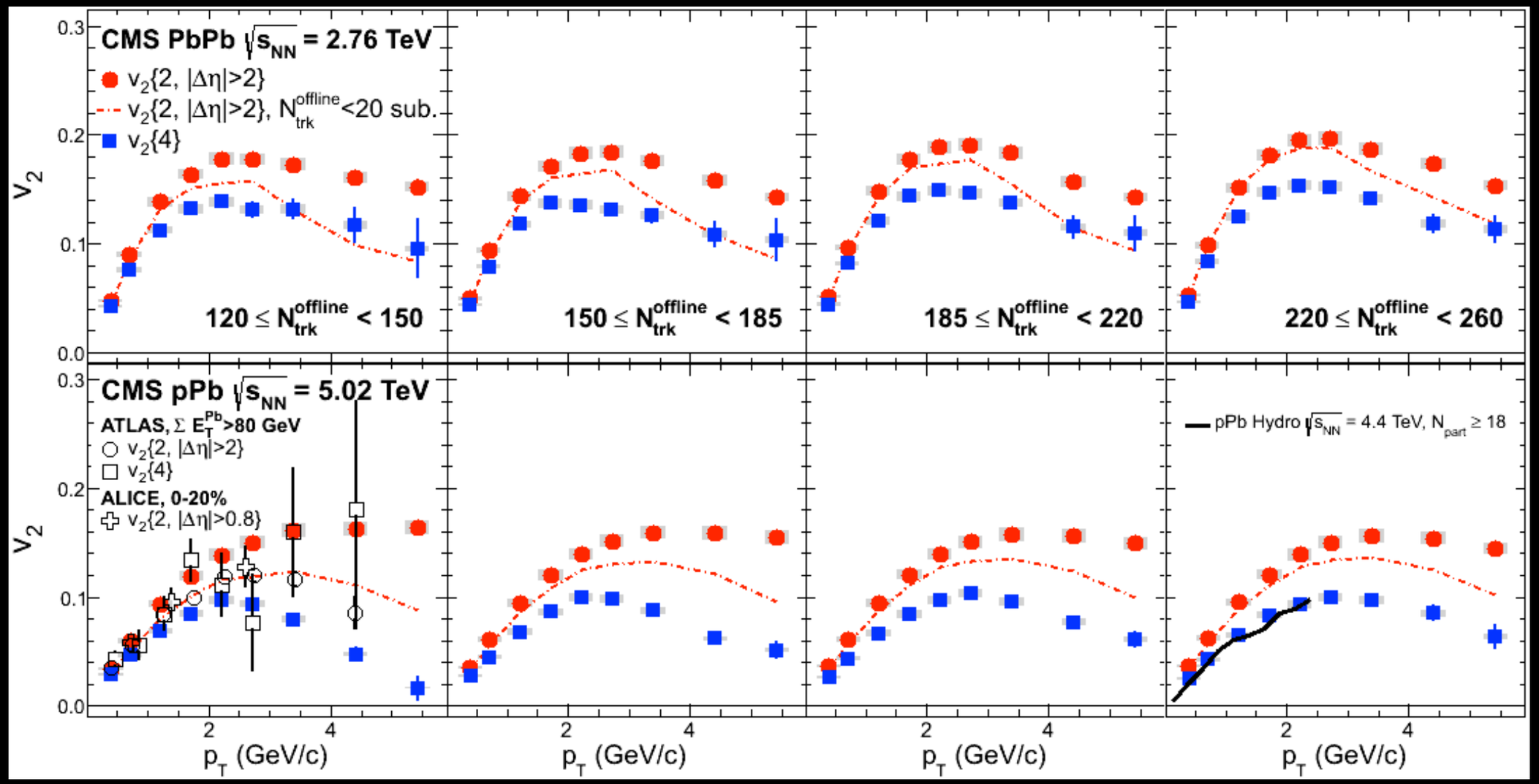


"Quadrupole correlations" seen in dAu as well

Direct comparison of v_2 in pPb and PbPb

CMS Phys. Lett. B 724 (2013) 213

ATLAS $v_2\{4\}$: Phys. Lett. B 725 (2013)

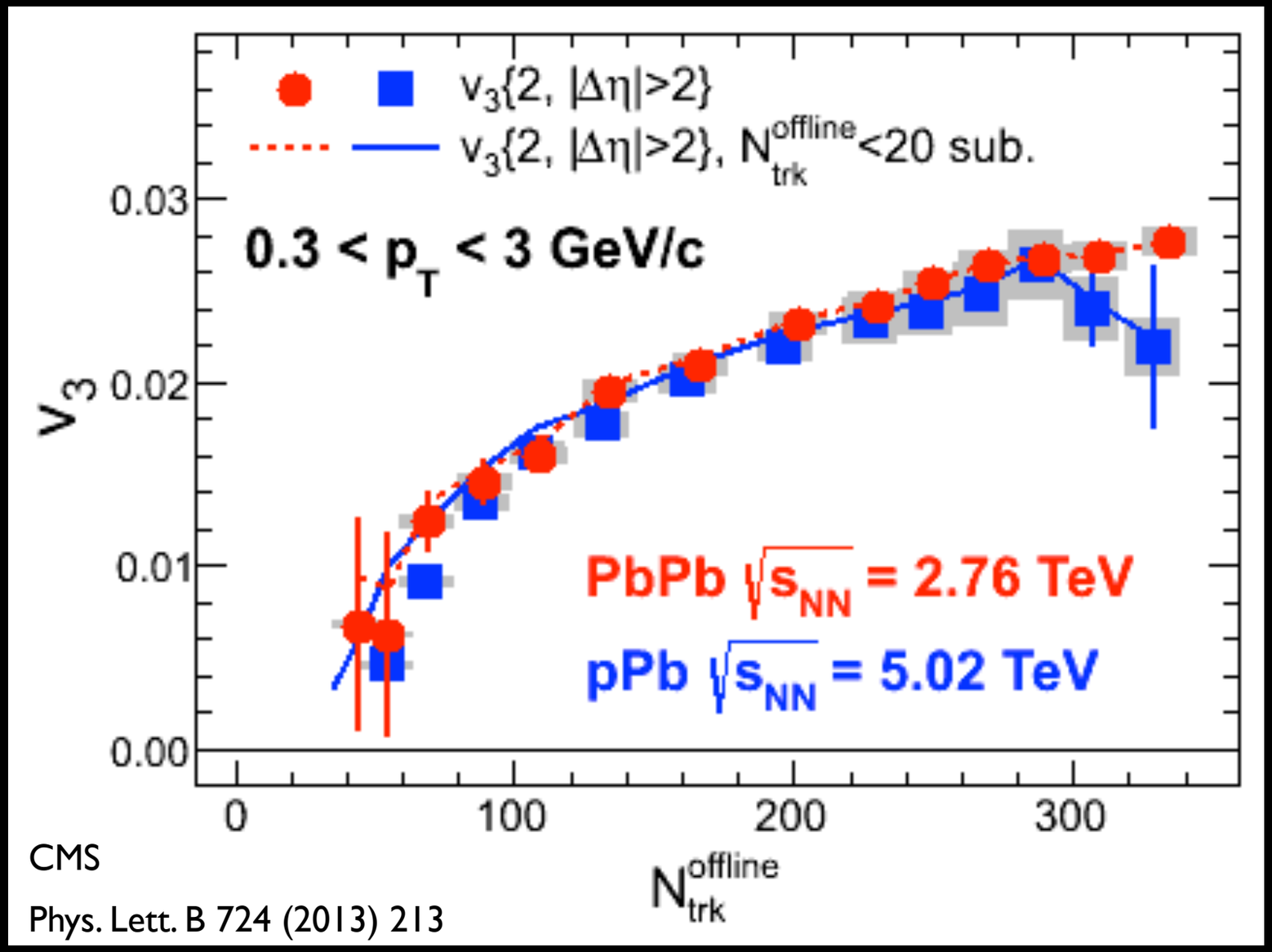


v_2 shows similar shape in pPb and PbPb, but is smaller in pPb

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

"Peripheral subtraction" has small effect at high multiplicity

Direct comparison of v_3 in pPb and PbPb

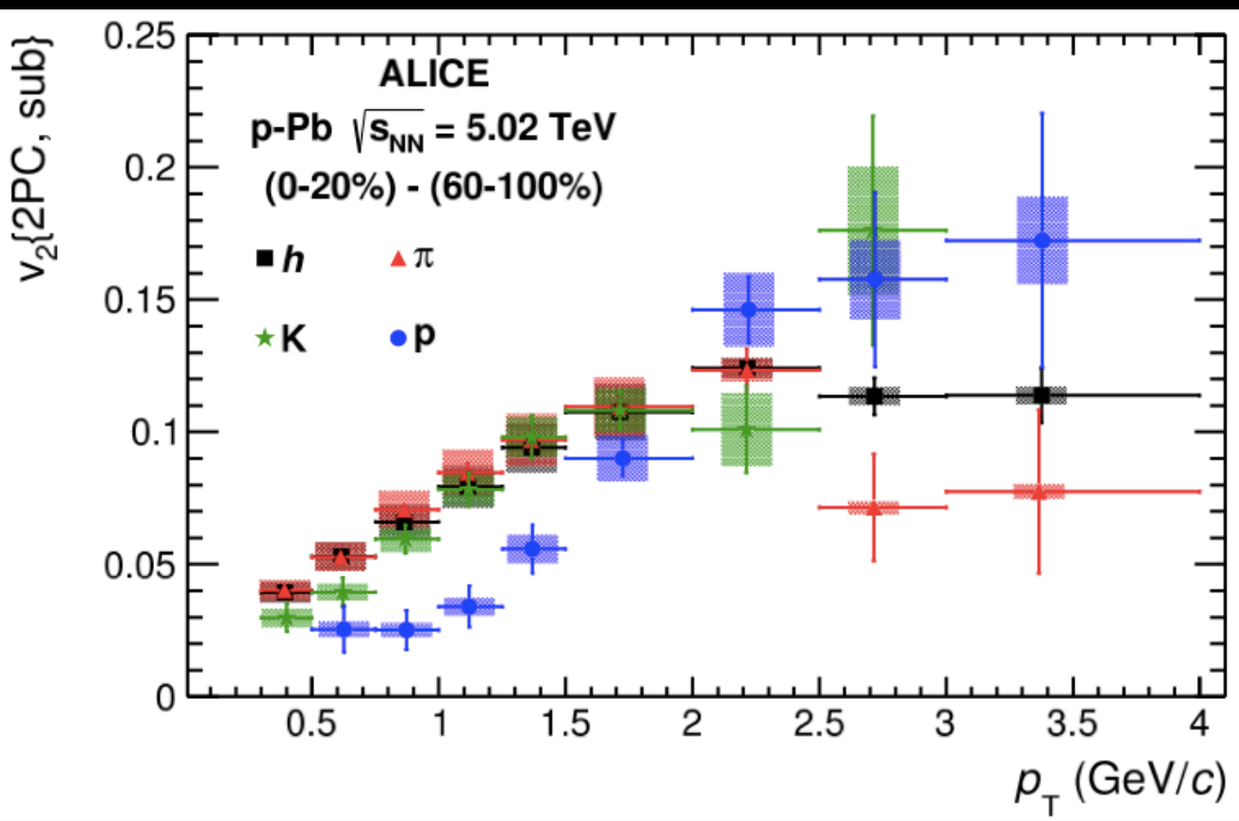


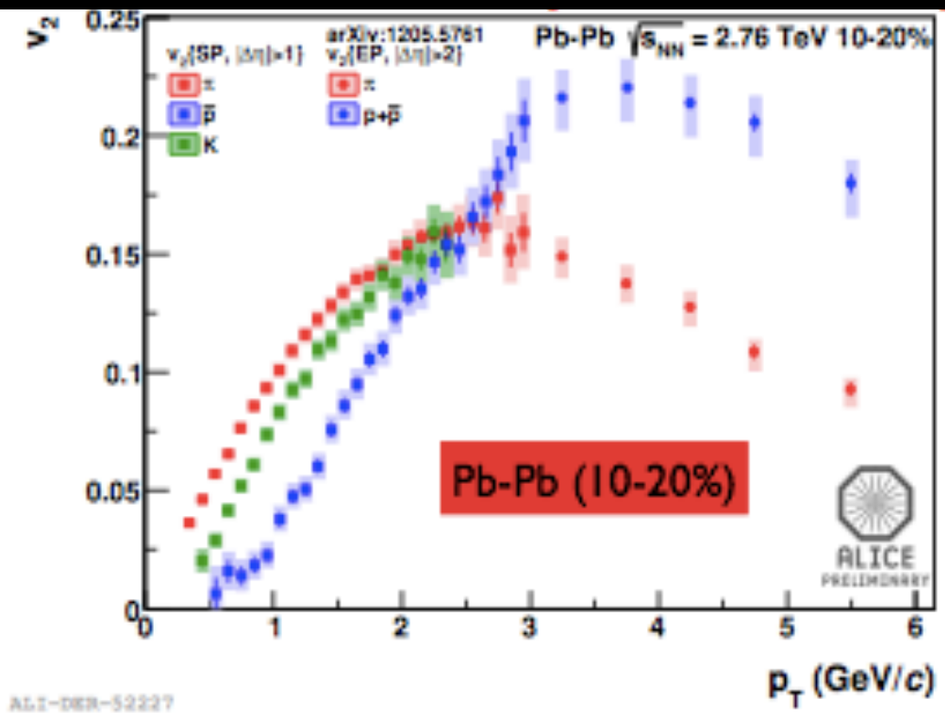
Triangular flow vs multiplicity rather similar in pPb vs PbPb

PID correlations in pPb vs PbPb

ALICE

arXiv:1307.3237



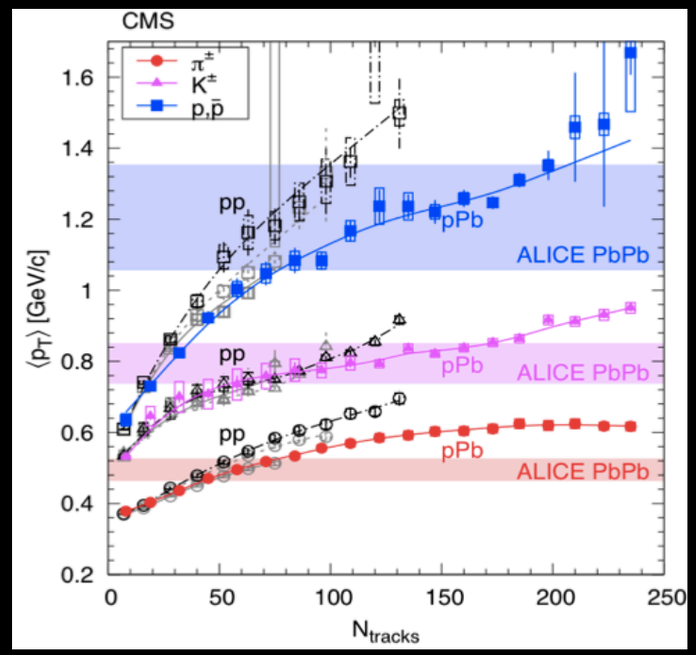


Mass-ordering of v_2 vs p_T seen in pPb, similar to PbPb

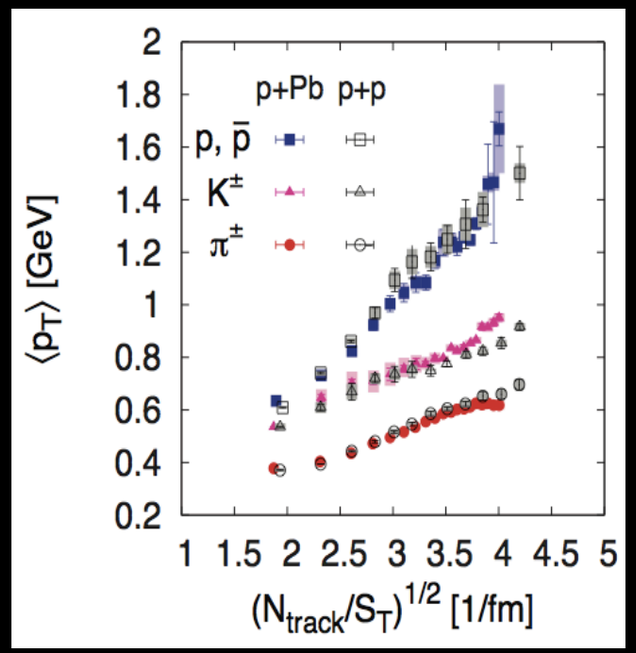
p_T Spectra in pp, pPb and PbPb

McLerran, Praszalowicz, Schenke

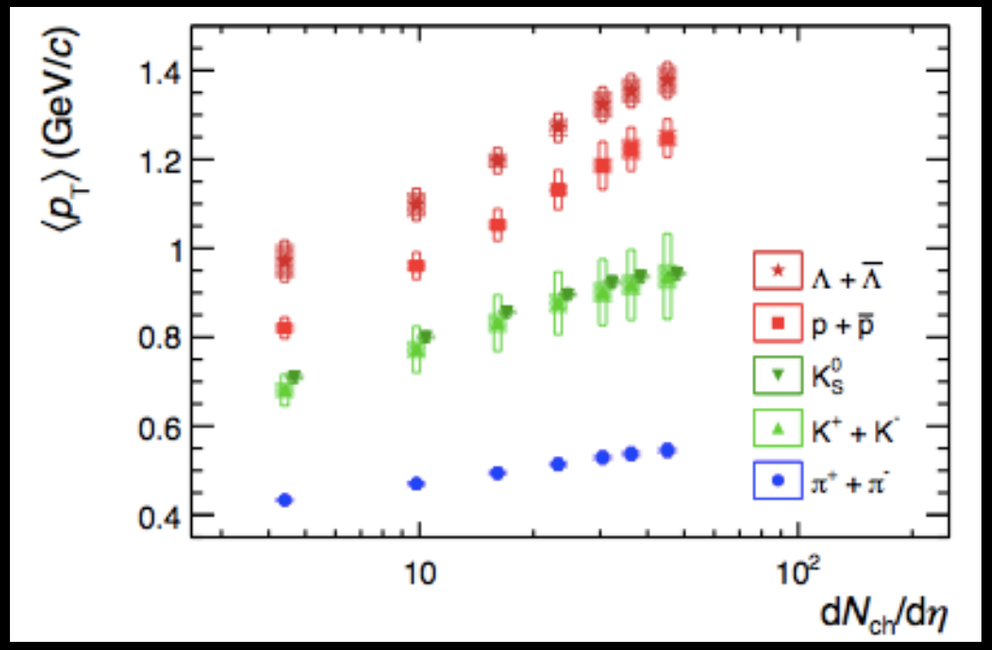
CMS arXiv:1307.3442



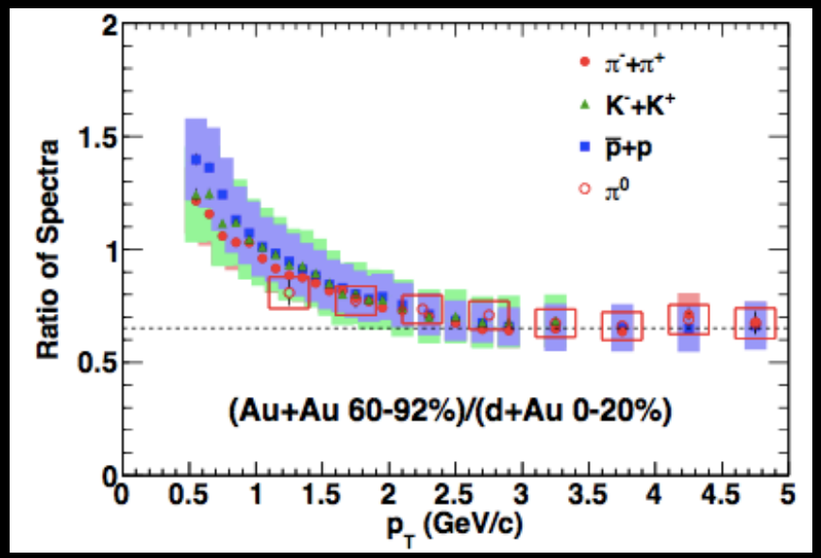
arXiv:1306.2350



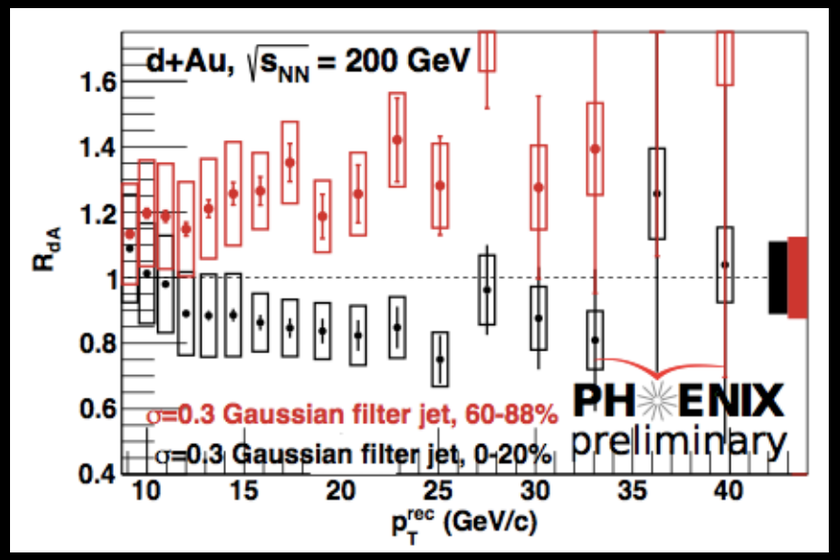
ALICE arXiv:1307.6796



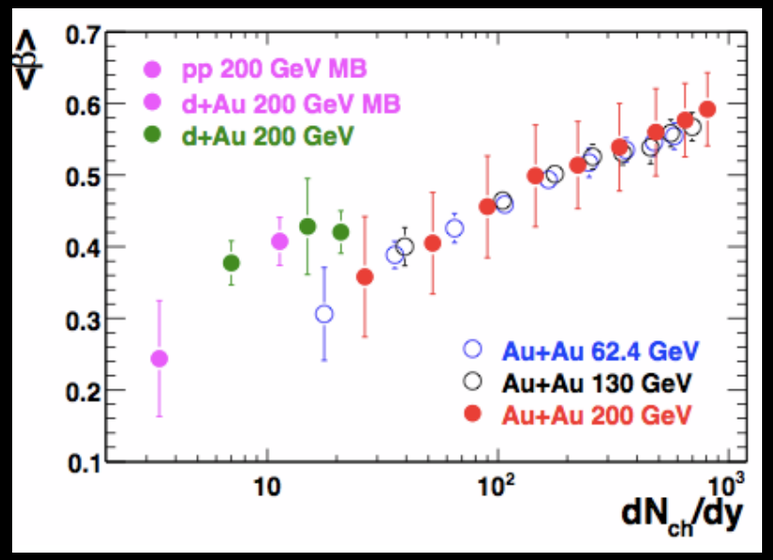
Radial flow, mini-jets, Cronin effect, Geometric Scaling, Recombination,....



PHENIX PRC 88, 024906 (2013)



PHENIX QM'12



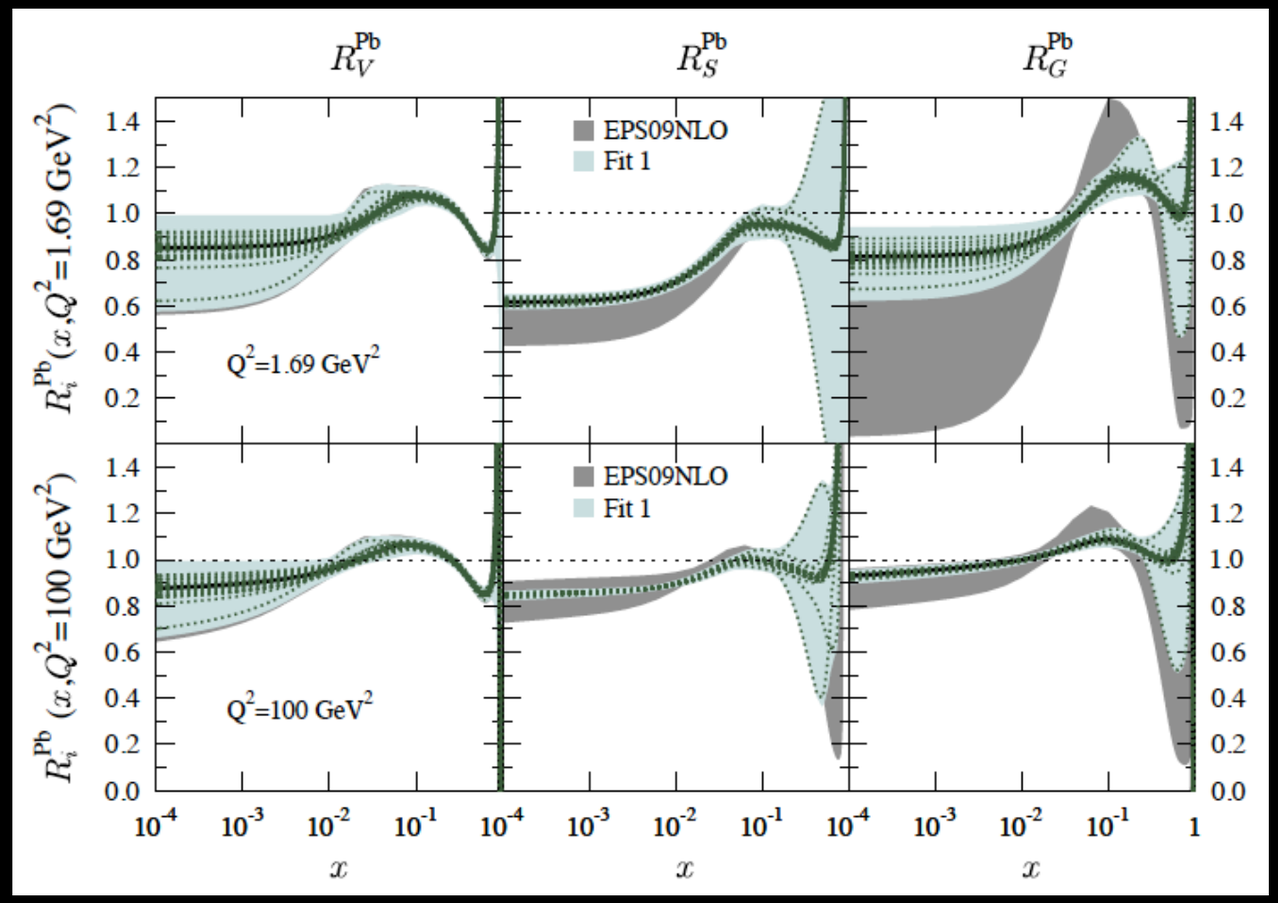
STAR Phys.Rev. C79 (2009) 034909

Azimuthal Correlations in pp, pA and AA

- "Glauber+Hydro" dominant source of AA azimuthal correlations
- Important questions not settled:
  - Glasma/KLN/Glauber
  - Existence of other non-trivial azimuthal correlations
- Striking similarity of p(d)A and AA azimuthal correlations
  - v_2, $v_2\{4\}$, v_3 vs p_T, multiplicity, PID v_2
  - Relative magnitude understood in "Glauber+Hydro" picture
  - if pp fits in there as well: sub-nucleonic geometry fluctuations
- **But, is this picture physical? Thermalization**

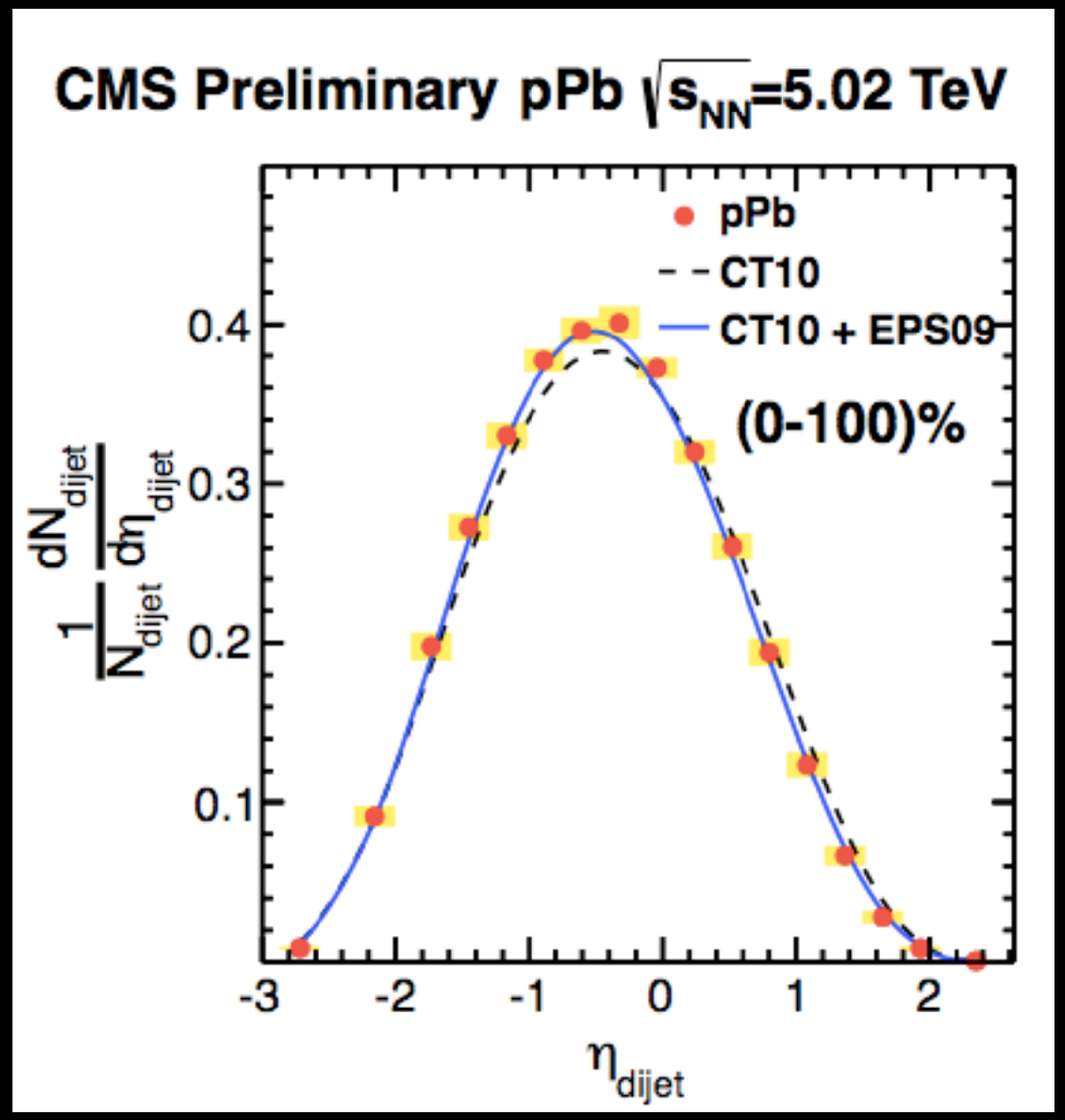
Spectra: pp vs p(d)A vs AA - a mess or interesting physics in search of a big idea?

Momentum space



Dijet dN/dη in pPb and nuclear PDFs

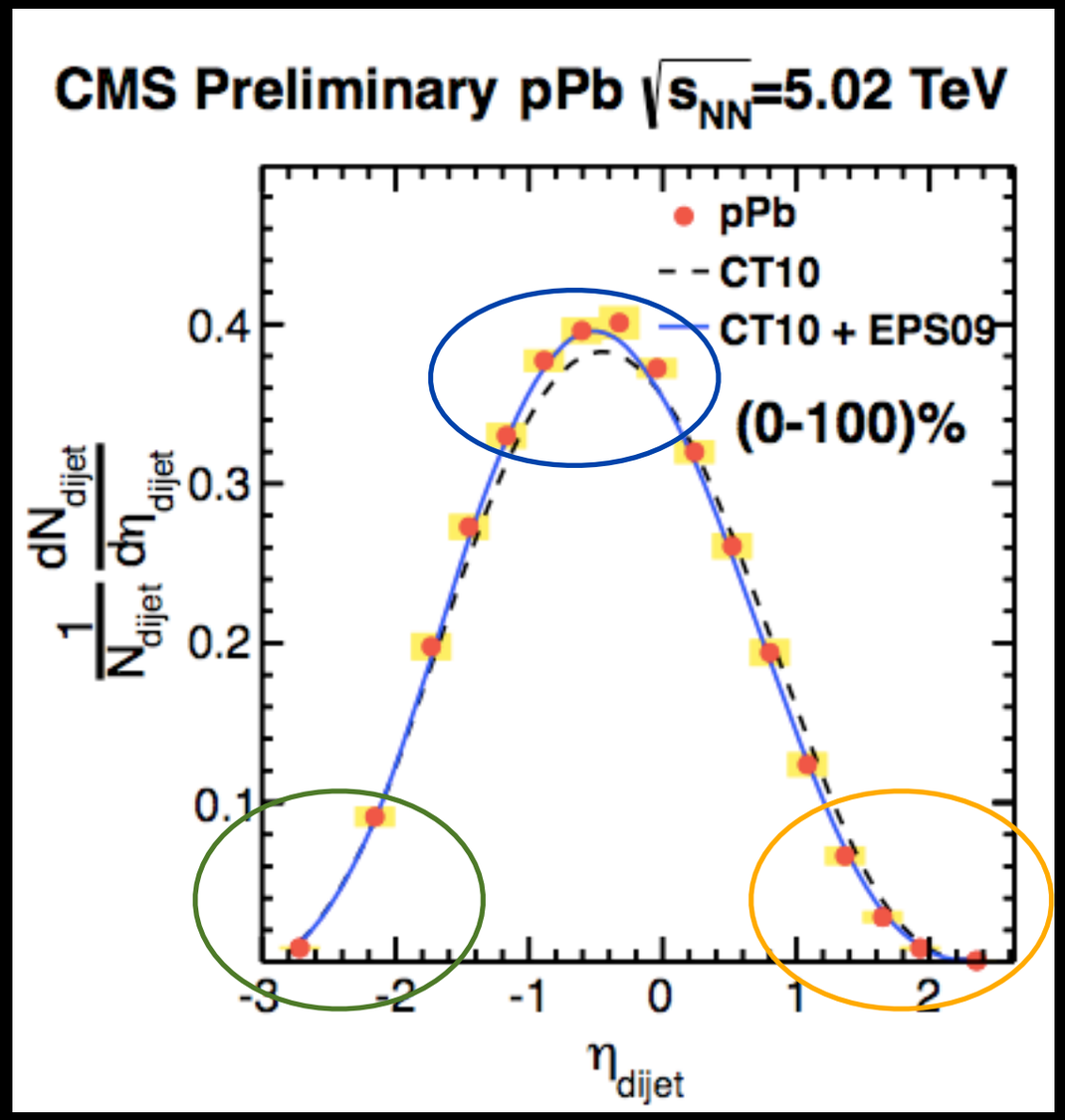
CMS PAS HIN-13-001

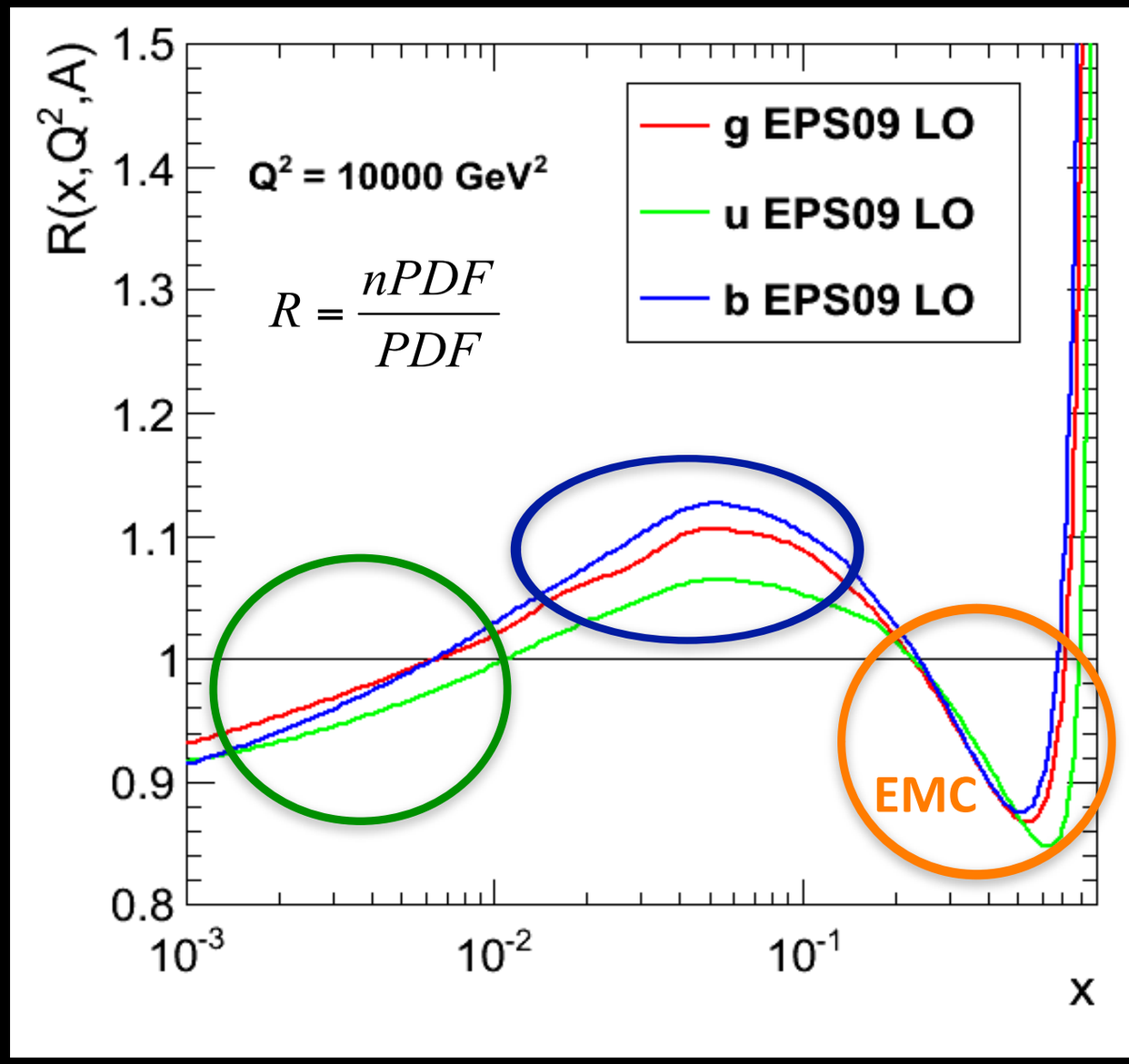


see talks by Yaxian Mao (plenary)
and Doga Gulhan (parallel)

Dijet dN/dη in pPb and nuclear PDFs

CMS PAS HIN-13-001



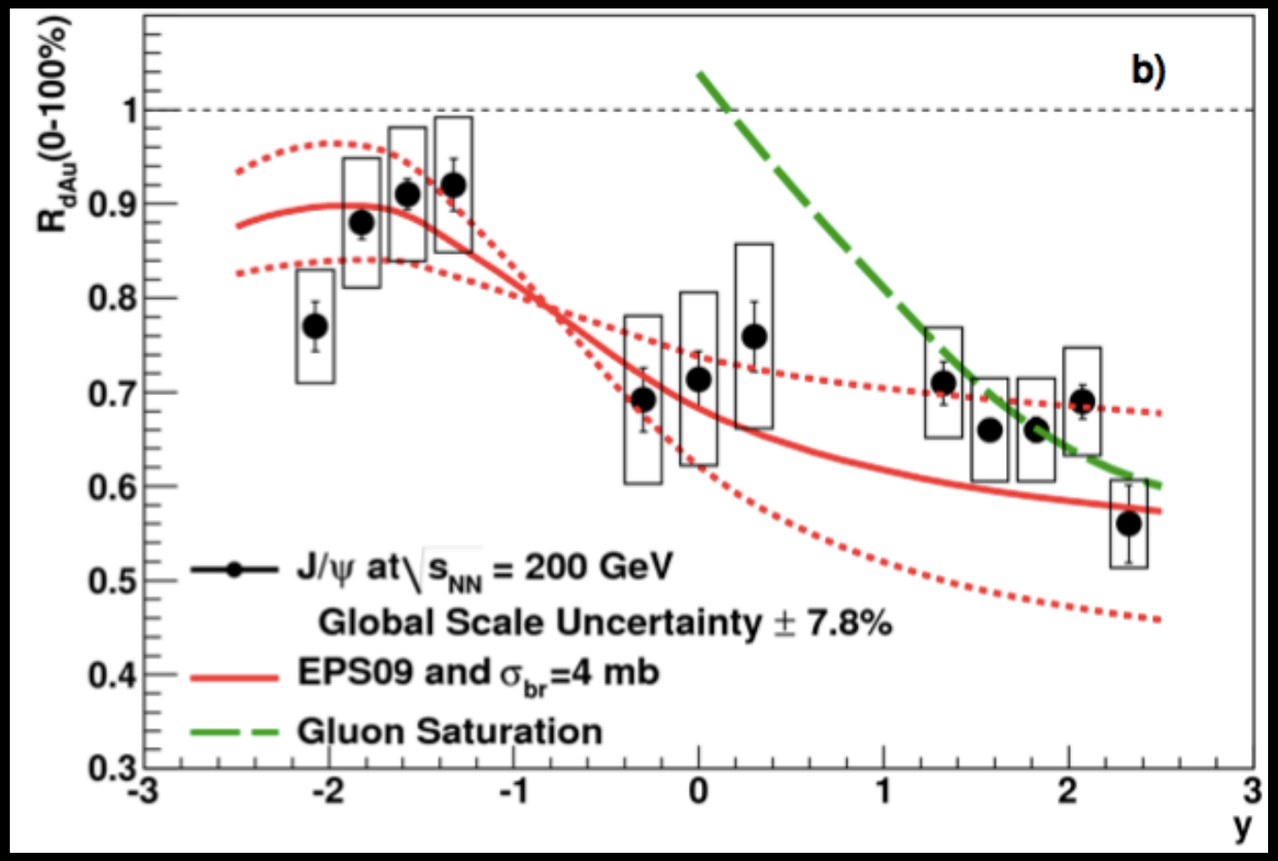


Modification vs Pythia of pPb dijet dN/dη matches nuclear PDF

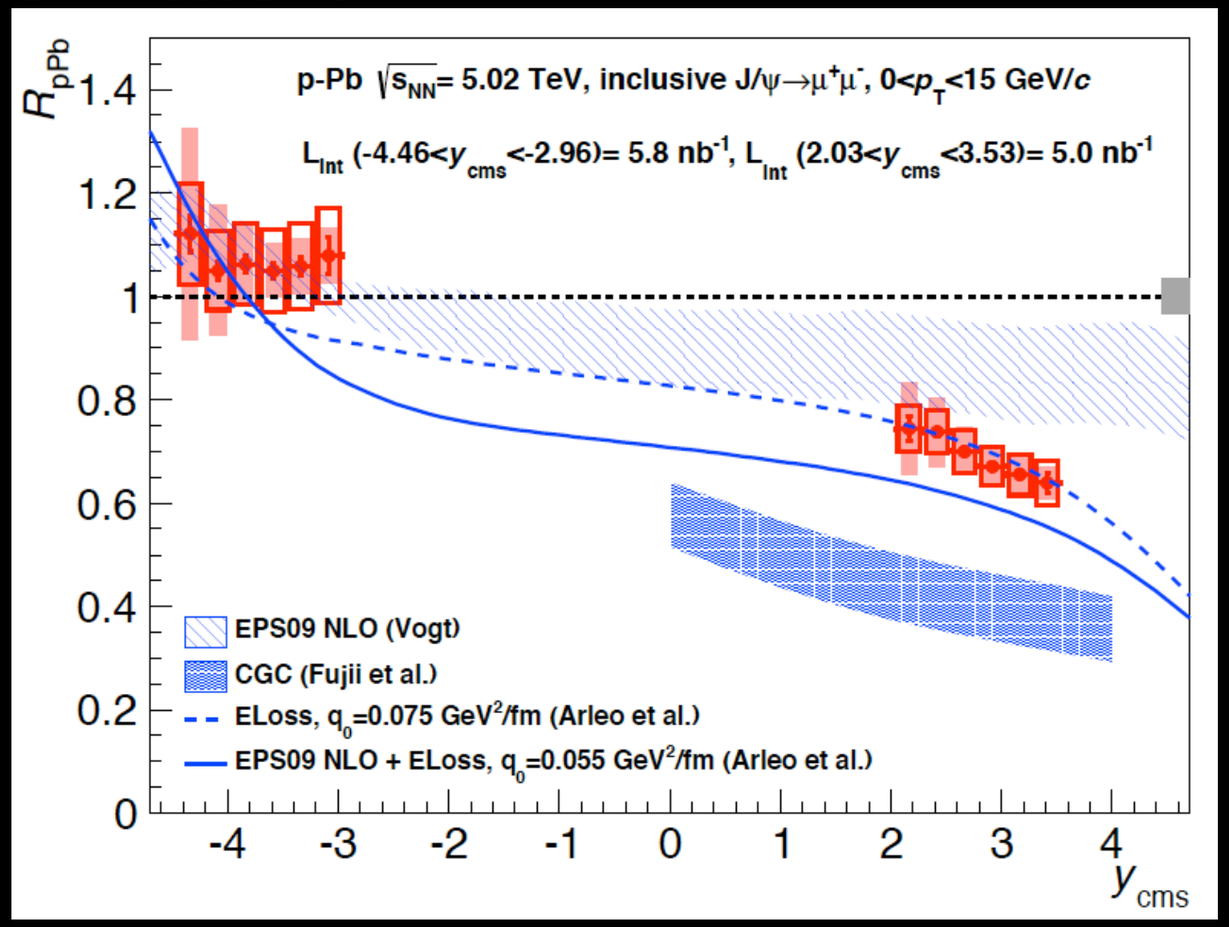
see talks by Yaxian Mao (plenary)
and Doga Gulhan (parallel)

Charmonium $R_{p(d)A}$ and nuclear PDFs

PHENIX
Phys.Rev.Lett. 107 (2011) 142301



ALICE
arXiv:1308.6726

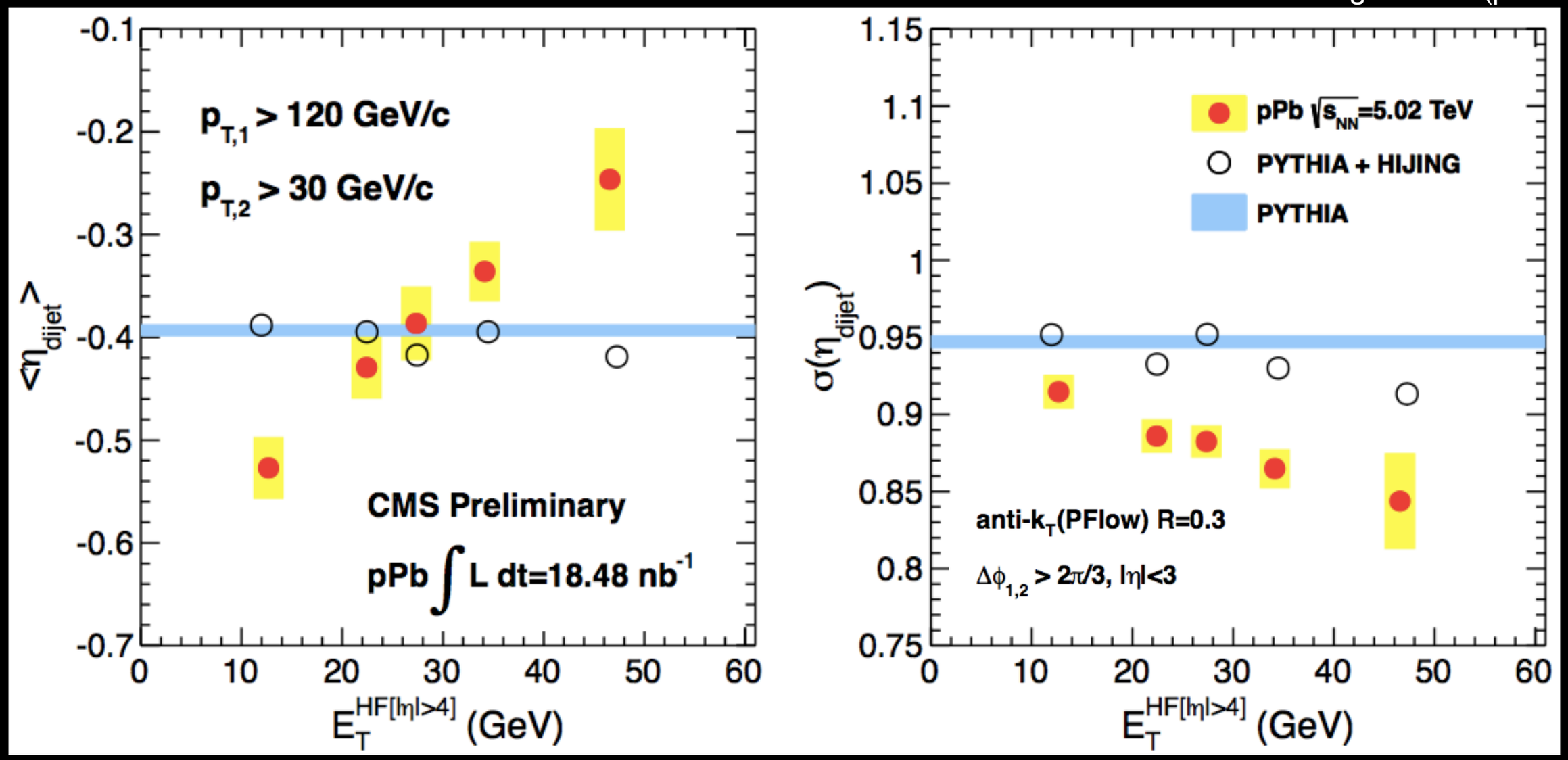


Much of the rapidity dependence
can be understood in terms of nPDFs

"Centrality" (not really) dependence of dijet η

CMS PAS HIN-13-001

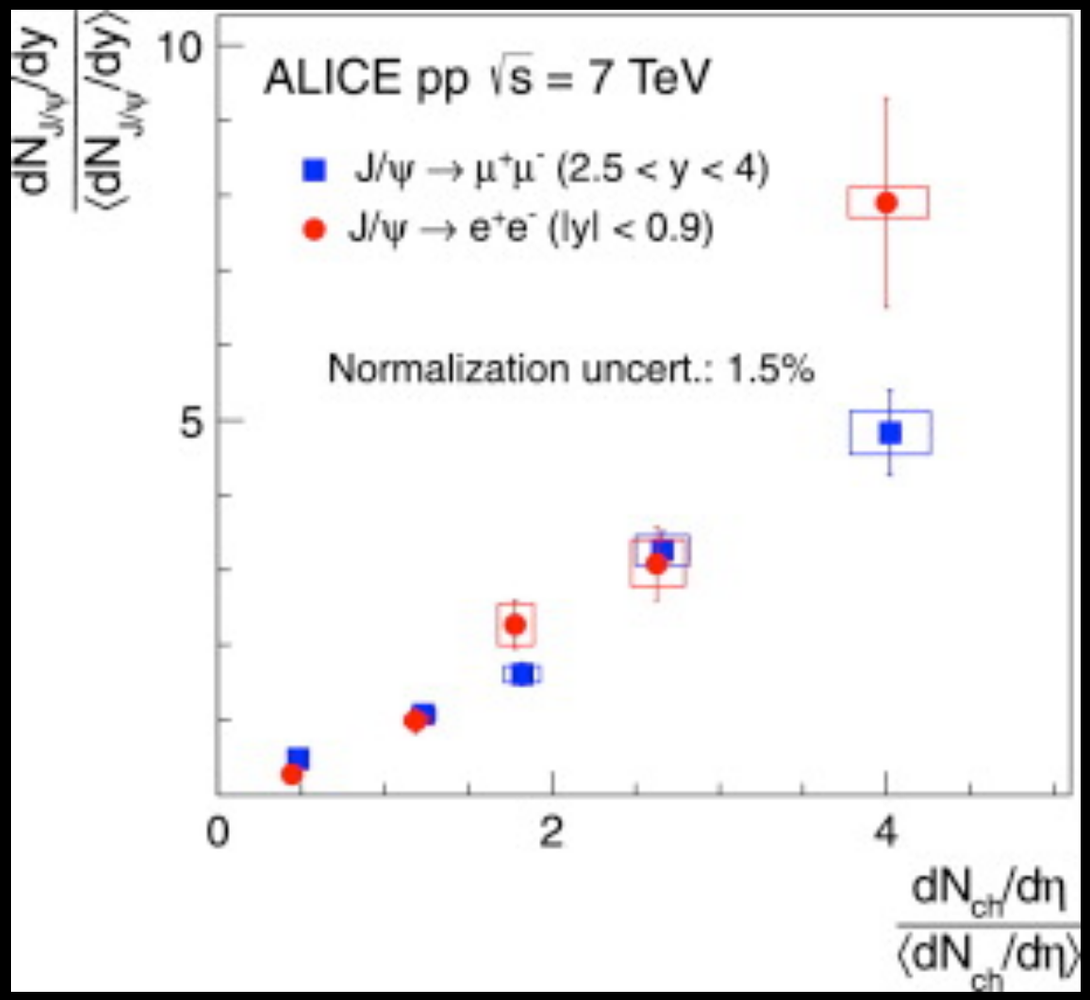
see talks by Yaxian Mao (plenary) and Doga Gulhan (parallel)

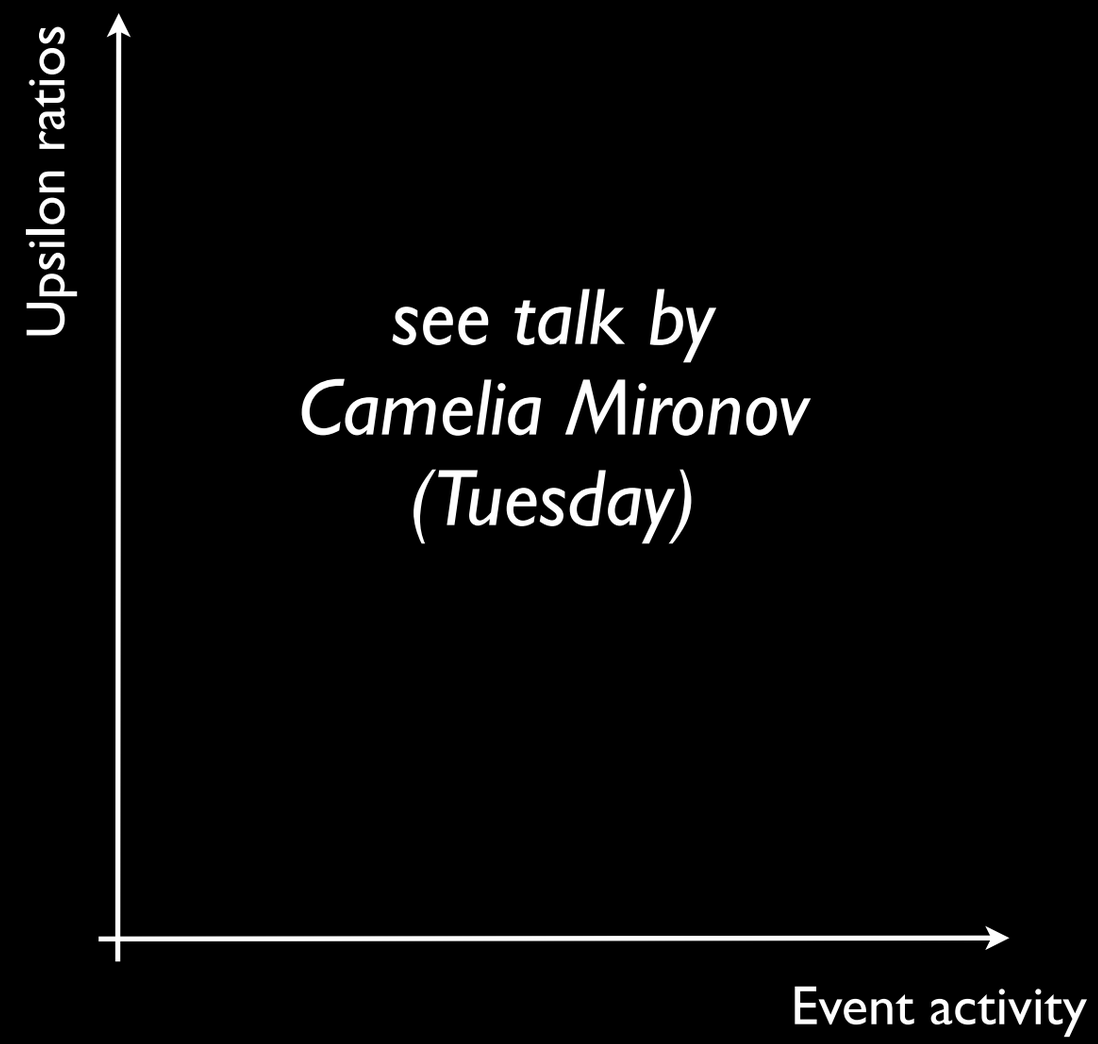


Correlation between dijet system and underlying event introduces "rapidity shift" that is much larger than nPDF effects

Quarkonia yield and event activity

ALICE
Phys.Lett. B712 (2012) 165-175



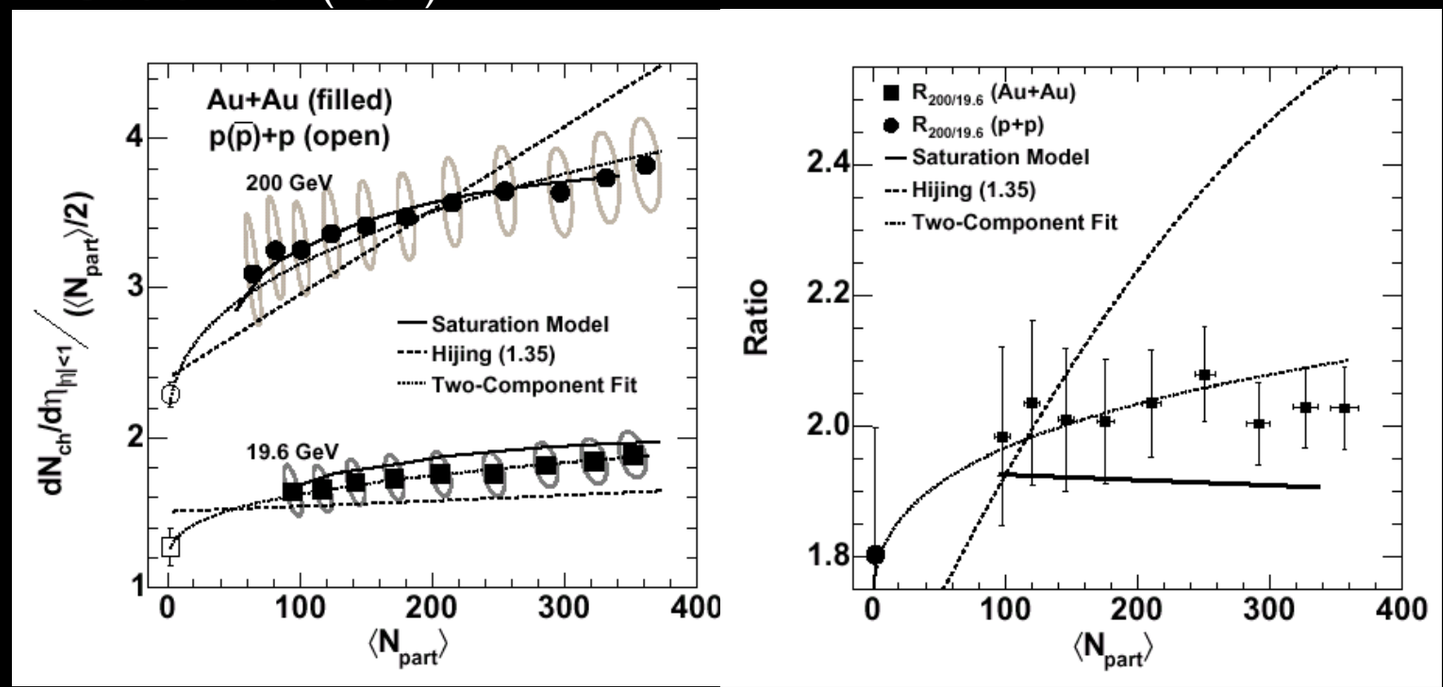


see talk by Camelia Mironov (Tuesday)

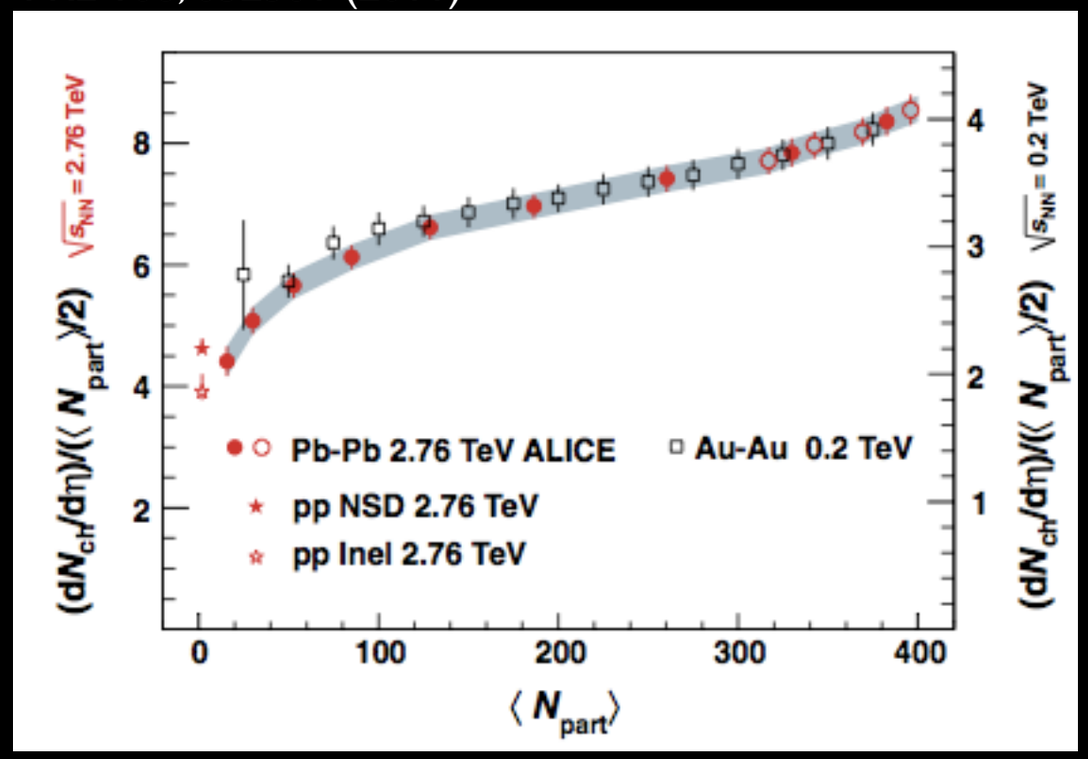
Similar to dijets, strong correlation of hard probe and event activity

Recall: Factorization of centrality vs √s

PHOBOS
PRC 70 021902 (2004)



PHOBOS
PRL 106, 032301 (2011)



Centrality dependence from mid-peripheral to central collisions similar from 0.02 to 2.76TeV

N_{coll}/N_{part} for central events changes by more than 2 over this energy range

This cannot be understood in incoherent superposition of hard/soft processes

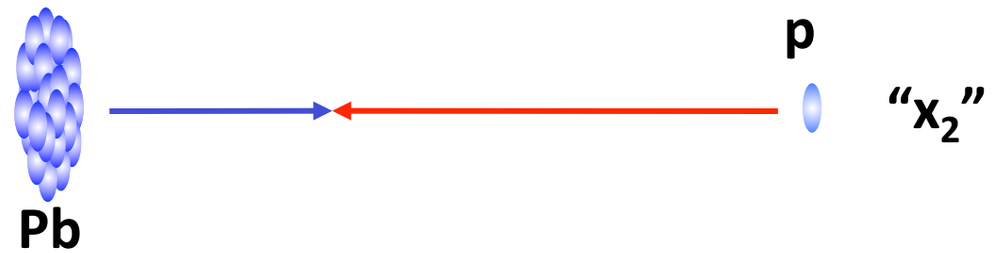
$dN/d\eta = x*N_{coll} + (x-1)*N_{part}$ **? NO!**

Summary

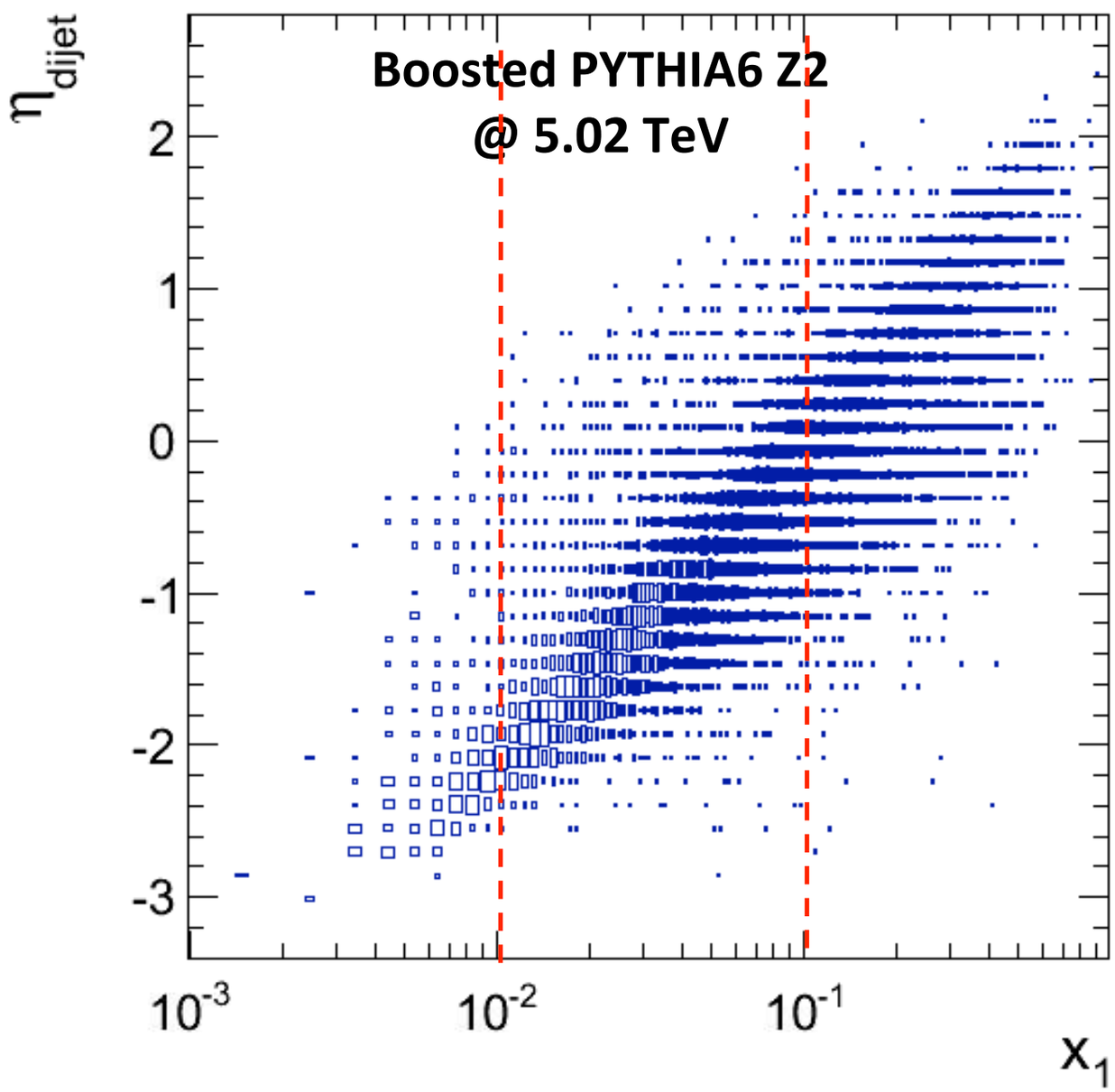
- Last decade has seen a dramatic evolution of our understanding of the initial state in nuclear collisions
- Unified picture of the bulk of correlations in pp, pPb and PbPb in terms of hydrodynamics
  - Is this picture *physical*?
- Hard probes in pA show significant nuclear effects
  - nPDFs, saturation, cold (hot?) matter e-loss?
- Strong correlations between hard scattering system and underlying event cannot be ignored

Dijet η and nuclear PDFs

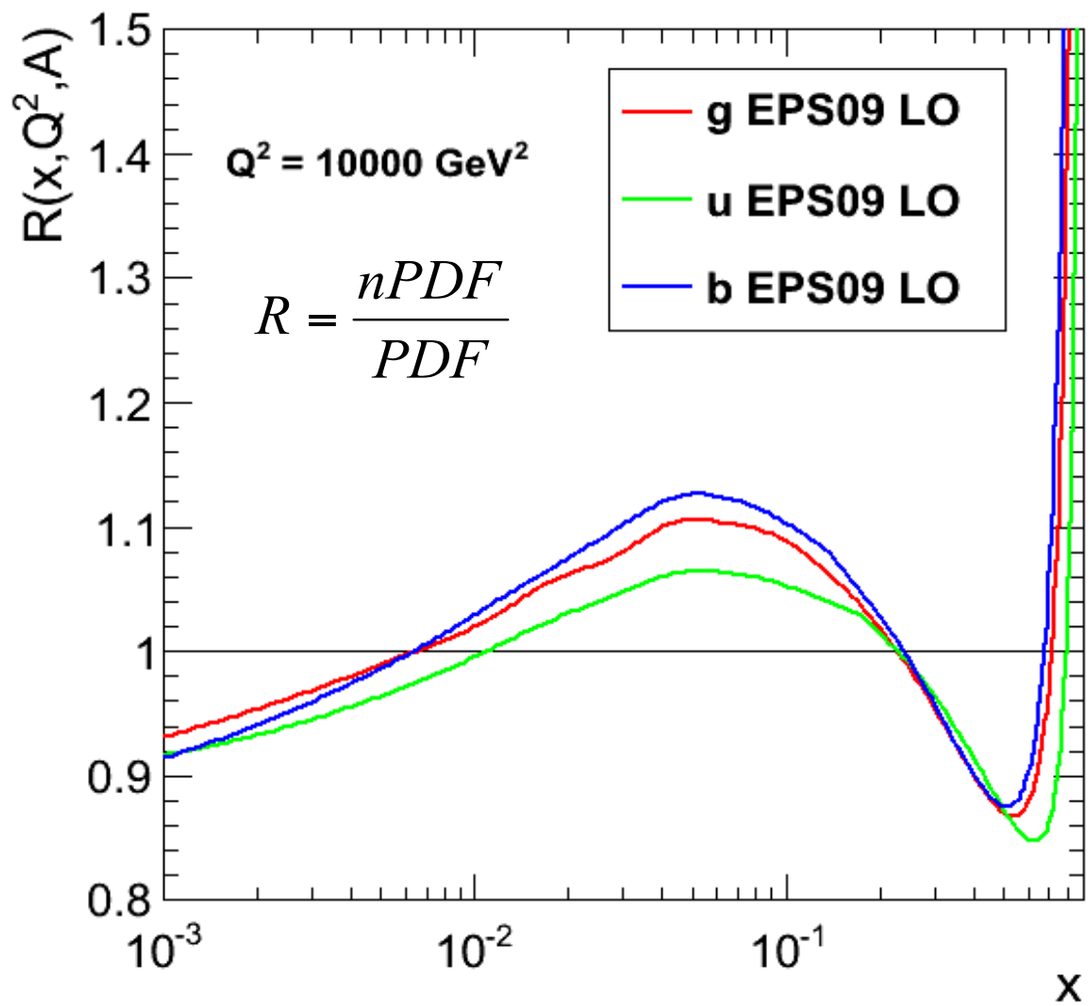
Leading jet $p_{T,1}$ > 120 GeV/c
subleading jet $p_{T,2}$ > 30 GeV/c
$|\Delta\varphi_{12}| > 2\pi/3$



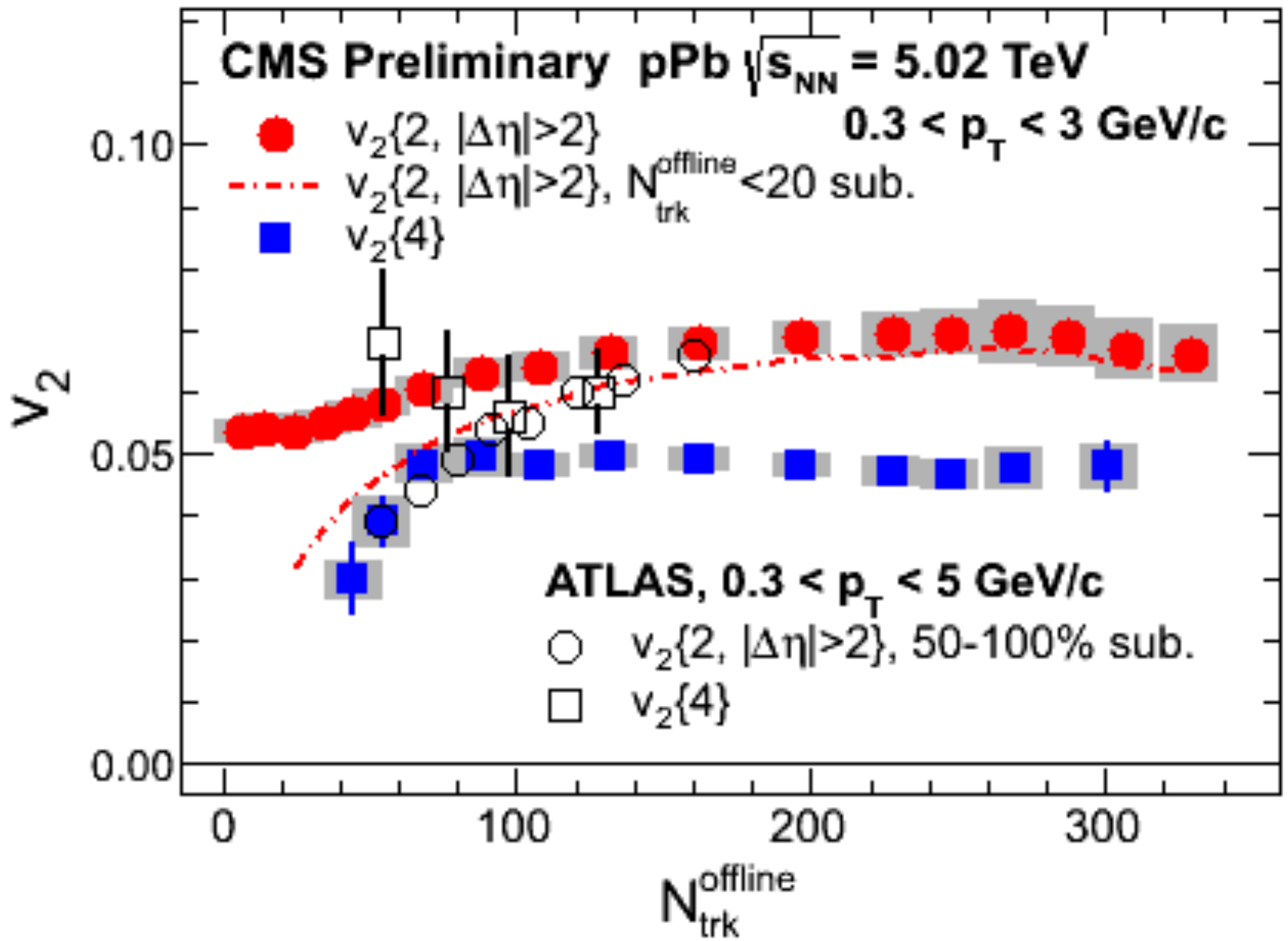
$$\eta_{dijet} = \frac{\eta_1 + \eta_2}{2}$$



Translation from η_{dijet} to x_1



v_2 comparison with ATLAS in pPb



pPb

ATLAS: arXiv: 1303.2084

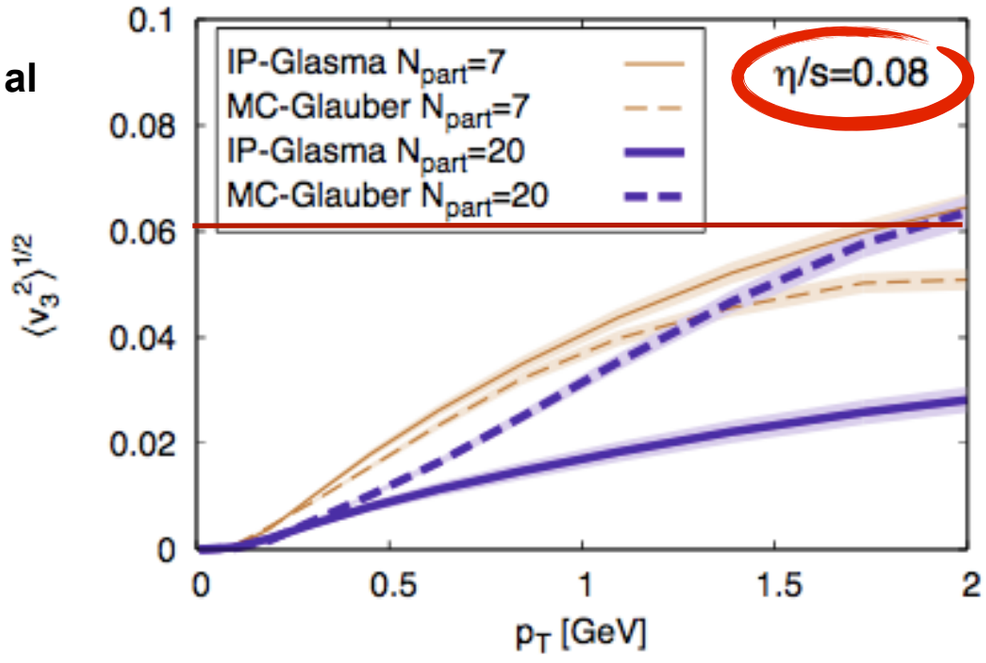
Subtract $N_{trk}^{offline}$<20 (70-100%) to avoid removing signal

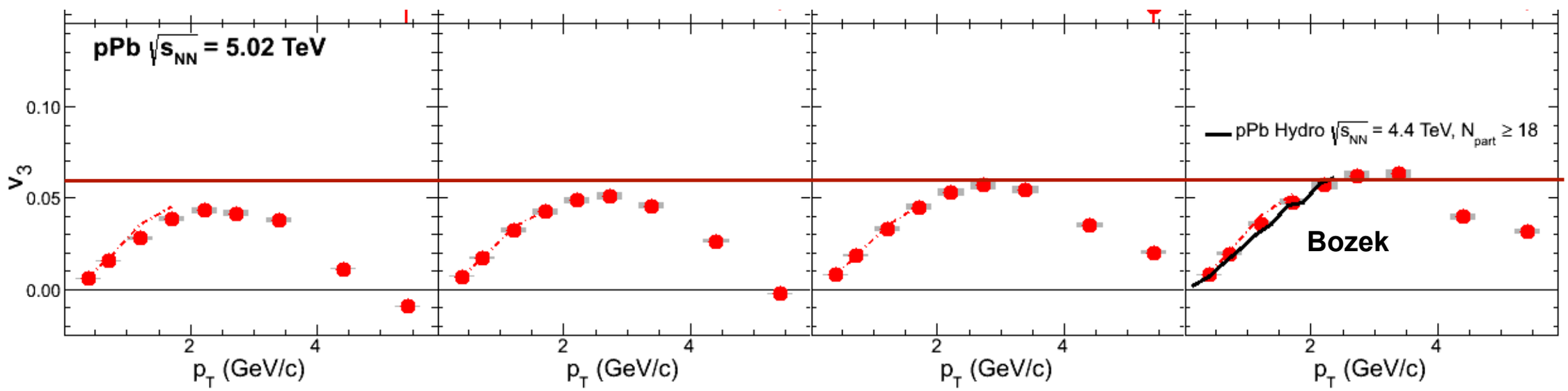
- ATLAS subtract 50-100%; forward-calorimeter centrality

Some difference vs ATLAS in $v_2\{4\}$: multiplicity fluctuations?

v_3 in pPb compared to hydro

Schenke et al





pPb

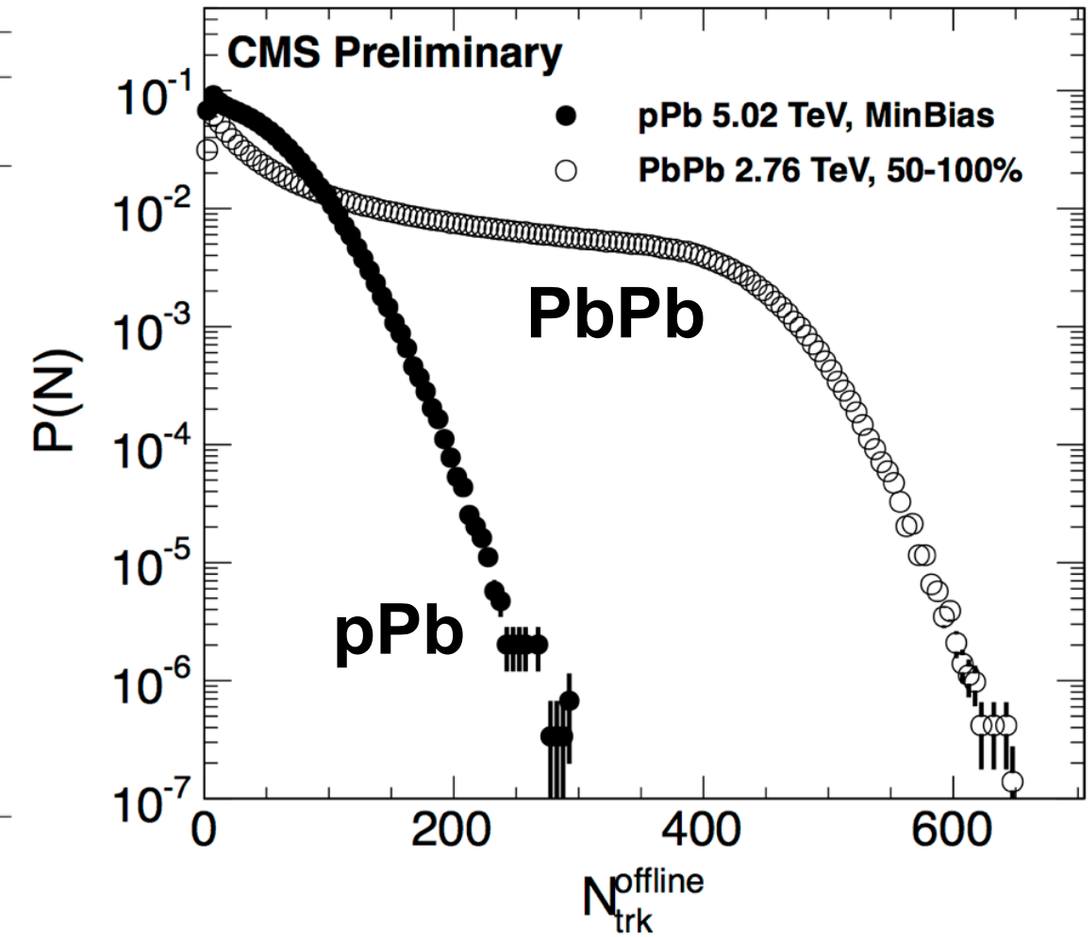
multiplicity →

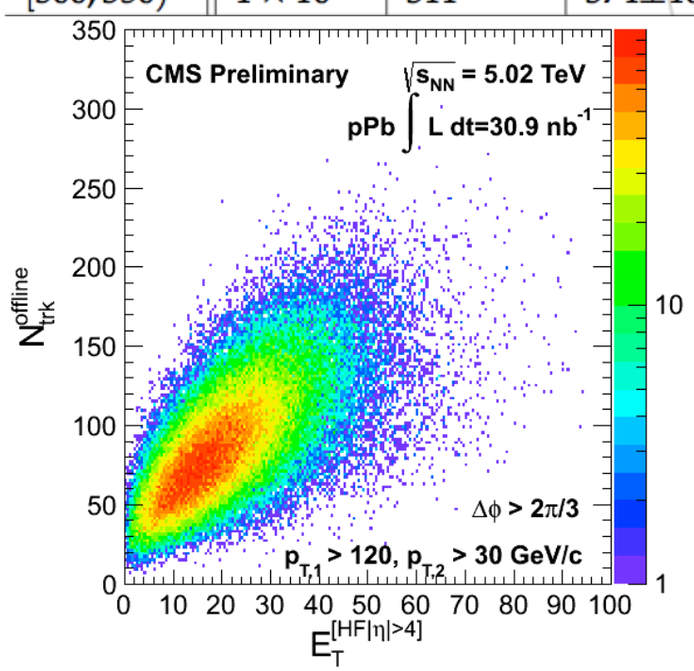
Perfect liquid (η/s = 1/4π) in pPb collisions?

“Centrality” (multiplicity density) binning

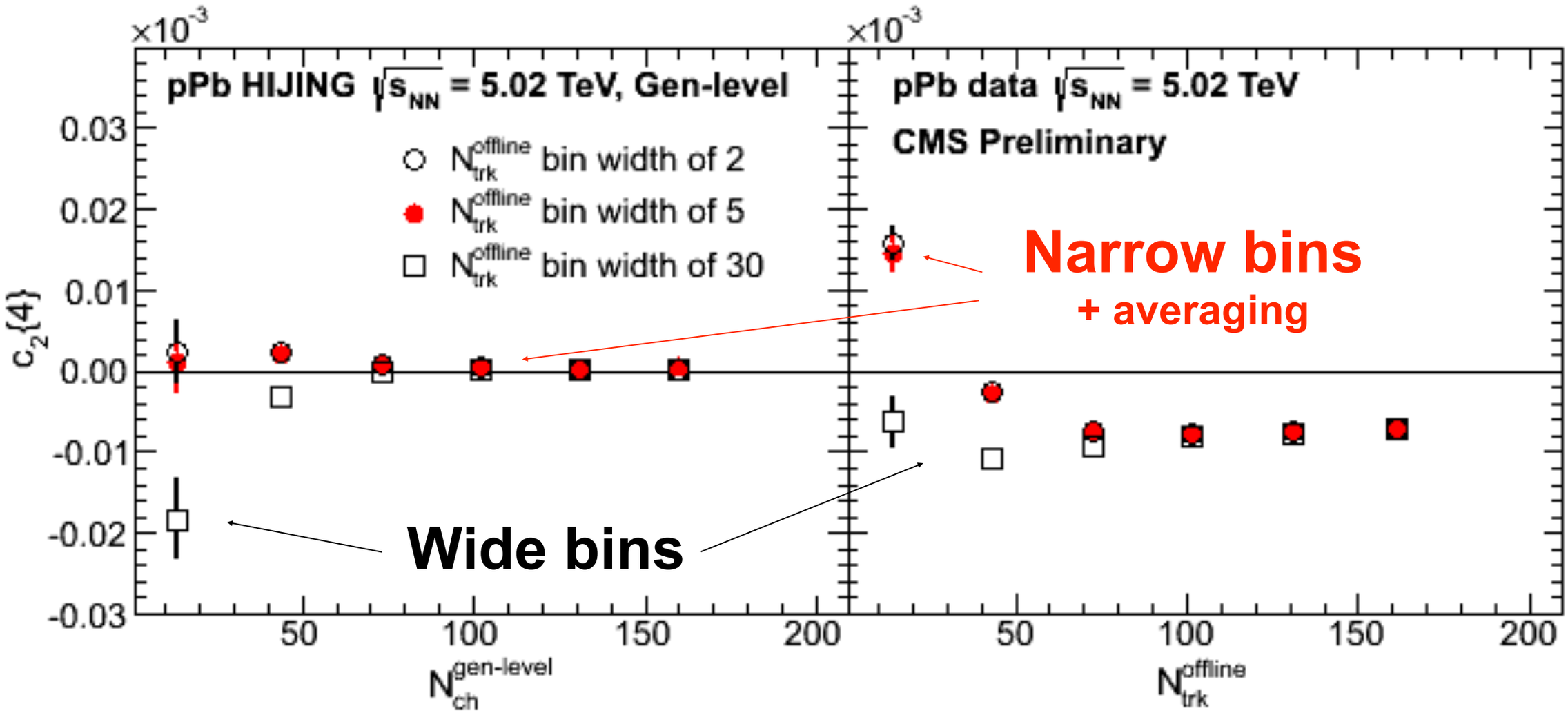
n.b., particles are counted for p_T > 0.4GeV/c, |η| < 2.4

	pPb data			PbPb data		
$N_{trk}^{offline}$ bin	Fraction	$\langle N_{trk}^{offline} \rangle$	$\langle N_{trk}^{corrected} \rangle$	<Centrality> ± RMS (%)	$\langle N_{trk}^{offline} \rangle$	$\langle N_{trk}^{corrected} \rangle$
$[0,\infty)$	1.00	40	50±2			
[0,20)	0.31	10	12±1	92±4	10	13±1
[20,30)	0.14	25	30±1	86±4	24	30±1
[30,40)	0.12	35	42±2	83±4	34	43±2
[40,50)	0.10	45	54±2	80±4	44	55±2
[50,60)	0.09	54	66±3	78±3	54	68±3
[60,80)	0.12	69	84±4	75±3	69	87±4
[80,100)	0.07	89	108±5	72±3	89	112±5
[100,120)	0.03	109	132±6	70±3	109	137±6
[120,150)	0.02	132	159±7	67±3	134	168±7
[150,185)	4×10^{-3}	162	195±9	64±3	167	210±9
[185,220)	5×10^{-4}	196	236±10	62±2	202	253±11
[220,260)	6×10^{-5}	232	280±12	59±2	239	299±13
[260,300)	3×10^{-6}	271	328±14	57±2	279	350±15
[300,350)	1×10^{-7}	311	374±16	55±2	324	405±18





4th order cumulants in multiplicity bins



Cumulant analysis in bins of multiplicity
Need to consider bin widths carefully
CMS analysis: (narrow bins + averaging)