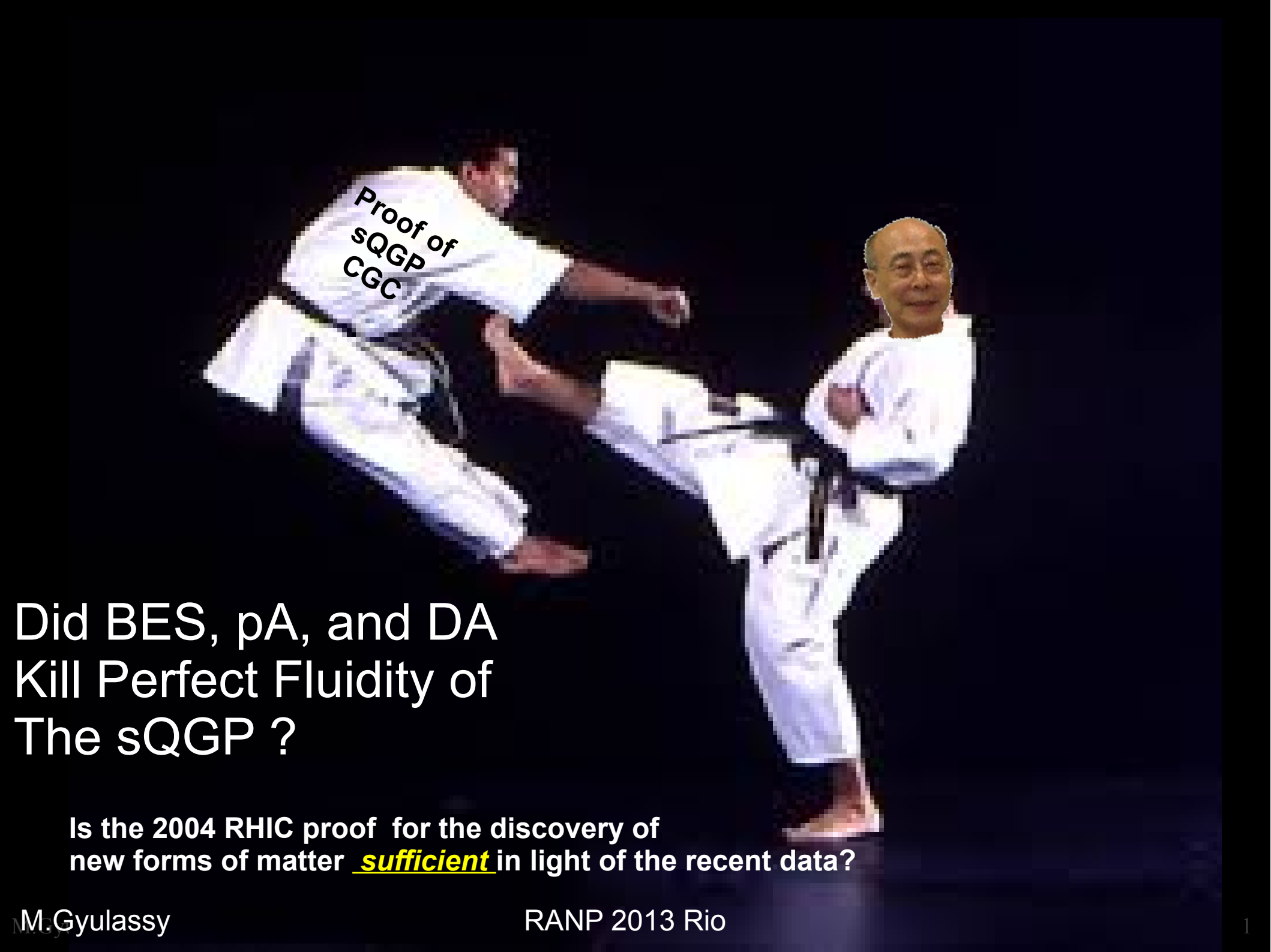


Did BES, pA, and DA Kill Perfect Fluidity of The sQGP ?

Is the 2004 RHIC proof for the discovery of new forms of matter *sufficient* in light of the recent data?

Unambiguous Evidence for Perfect Fluidity Found at RANP13

Thanks to Takeshi and

Organizing Committee:

Edivaldo Moura Santos (UFRJ)

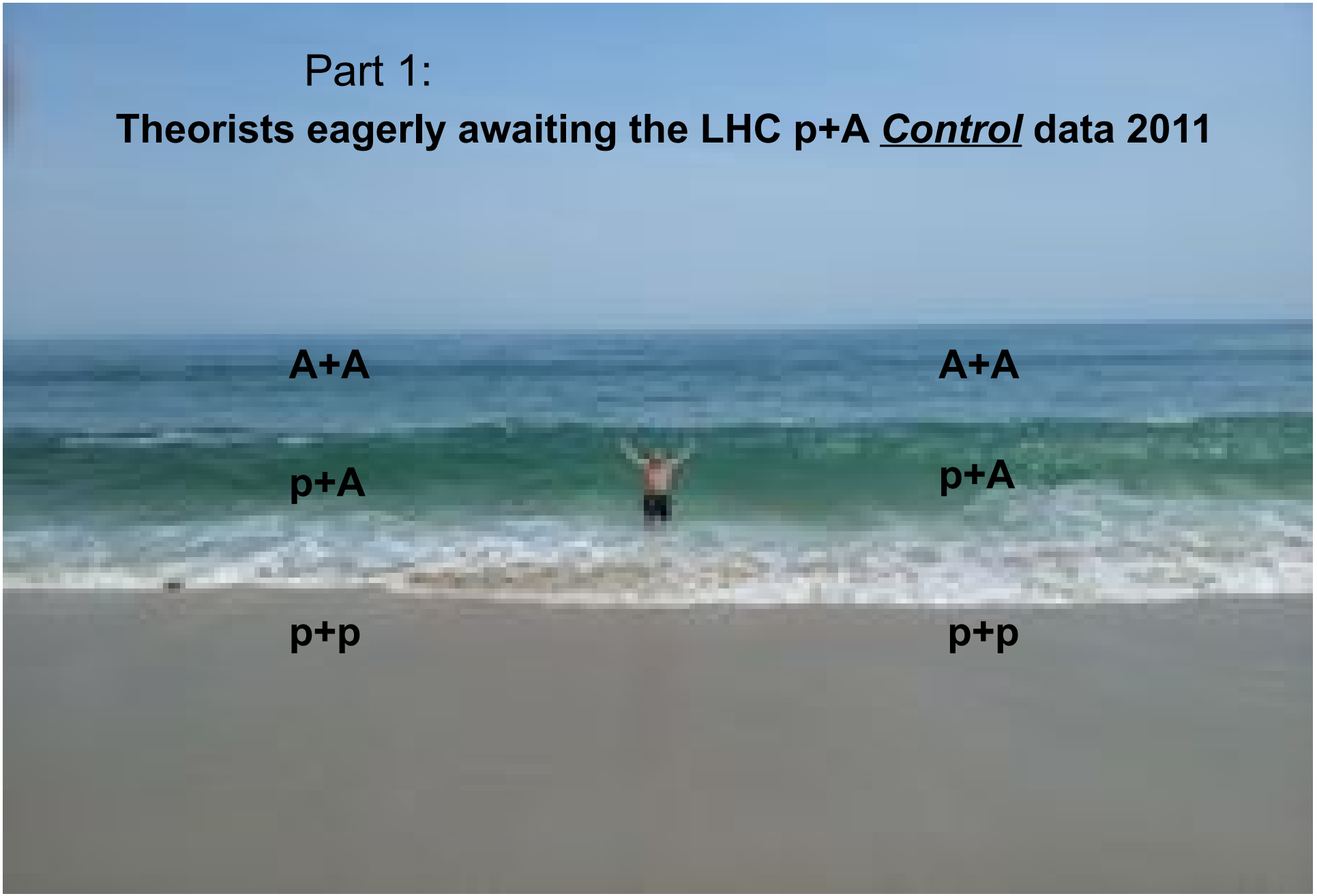
Eduardo Fraga - chair (UFRJ)

Jorge Noronha (USP)

Jun Takahashi - co-chair (UNICAMP)

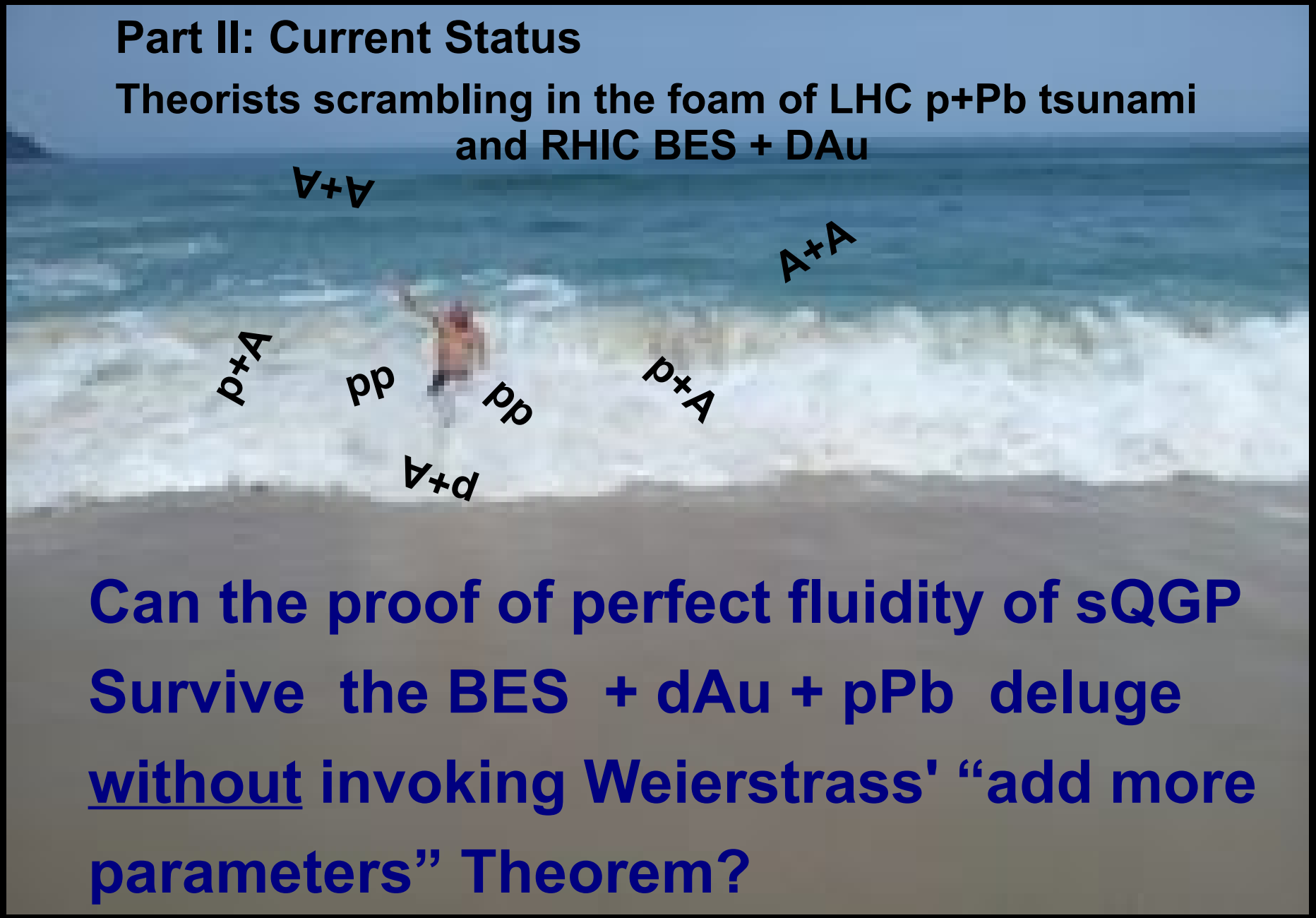
Sandra Padula (IFT-UNESP)

Sérgio Duarte (CBPF)


Part 1:
Theorists eagerly awaiting the LHC p+A *Control* data 2011
A+A
A+A
p+A
p+A
p+p
p+p

Part II: Current Status

Theorists scrambling in the foam of LHC p+Pb tsunami and RHIC BES + DAu



Can the proof of perfect fluidity of sQGP Survive the BES + dAu + pPb deluge without invoking Weierstrass' "add more parameters" Theorem?

Heretic Part 3: What IF there is NO flow?

Could most of vn(pT) be due to basic quantum interference phenomena in p+A?

Recalling the Good Old Days with Takeshi

3D Relativistic Hydrodynamic Computations Using Lattice-QCD-Inspired Equations of State

Nucl.Phys. A774 (2006) 169-178

Yogiro Hama, Rone P.G. Andrade, Frederique Grassia, Otavio Socolowski Jr., **Takeshi Kodama**, Bernardo Tavares and Sandra S. Padula

Nowadays, it is widely accepted that hydrodynamics is a successful approach for describing the bulk of the collective flow in high-energy nuclear collisions **[1].** The basic assumption in hydrodynamical models is the local thermal equilibrium. Once this condition is satisfied, all the thermodynamical relations should be valid in each space-time point. The properties of the matter formed in high-energy collisions are then specified by some equations of state (EoS). Thus, one of the main objects of hydrodynamical approach is to determine which are the EoS that consistently reproduce the observed quantities.

1. B. M¨uller, Quark Matter 2005

Early Universe was a liquid

Quark-gluon blob surprises particle physicists.

nature

by Mark Peplow
news@nature.com

The Universe consisted of a perfect liquid in its first moments, according to results from an atom-smashing experiment.

Scientists at the Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory on Long Island, New York, have spent five years searching for the quark-gluon plasma that is thought to have filled our Universe in the first microseconds of its existence. Most of them are now convinced they have found it. But, strangely, it seems to be a liquid rather than the expected hot gas.

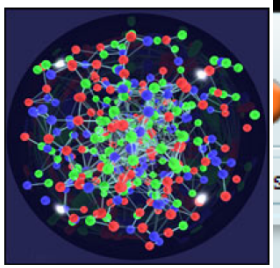
Early Universe was 'liquid-like'

Physicists say they have created a new state of hot, dense matter by crashing together the nuclei of gold atoms. BBC NEWS

The high-energy collisions prised open the nuclei to reveal their most basic particles, known as quarks and gluons.

The researchers, at the US Brookhaven National Laboratory, say these particles were seen to behave as an almost perfect "liquid".

The work is expected to help scientists explain the conditions that existed just milliseconds after the Big Bang.



The impression is of matter that is more strongly interacting than predicted

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Contact: Karen McNulty Walsh, (631) 344-8350 or Mona S. Rowe, (631) 344-5056

Print-friendly E-mail Article

RHIC Scientists Serve Up "Perfect" Liquid

New state of matter more remar many new questions

April 18, 2005

TAMPA, FL -- The four detector group Relativistic Heavy Ion Collider (RHIC the U.S. Department of Energy's Bro e of hot, de articles of markable t marizing th ead of behaving like a gas of free quarks and he matter created in RHIC's heavy ion collisions

New State of Matter Is 'Nearly Perfect' Liquid

Physicists working at Brookhaven National Laboratory announced today that they have created what appears to be a new state of matter out of the building blocks of atomic nuclei, quarks and gluons. The researchers unveiled their findings--which could provide new insight into the composition of the universe just moments after the big bang--today in Florida at a meeting of the American Physical Society. SCIENTIFIC AMERICAN

Image: BNL

There are four collaborations, dubbed BRAHMS, PHENIX, PHOBOS and STAR, working at Brookhaven's Relativistic Heavy Ion Collider (RHIC). All of them study what happens when two interacting beams of gold ions smash into one another at great velocities, resulting in thousands of subatomic collisions every second. When the researchers analyzed the patterns of the atoms' trajectories after these collisions, they found that the particles produced in the collisions tended to move collectively, much like a school of fish does. Brookhaven's associate laboratory director for high energy and nuclear physics, Sam Aronson, remarks that "the degree of collective interaction, rapid thermalization and extremely low viscosity of the matter being formed at RHIC make this the most nearly perfect liquid ever observed."

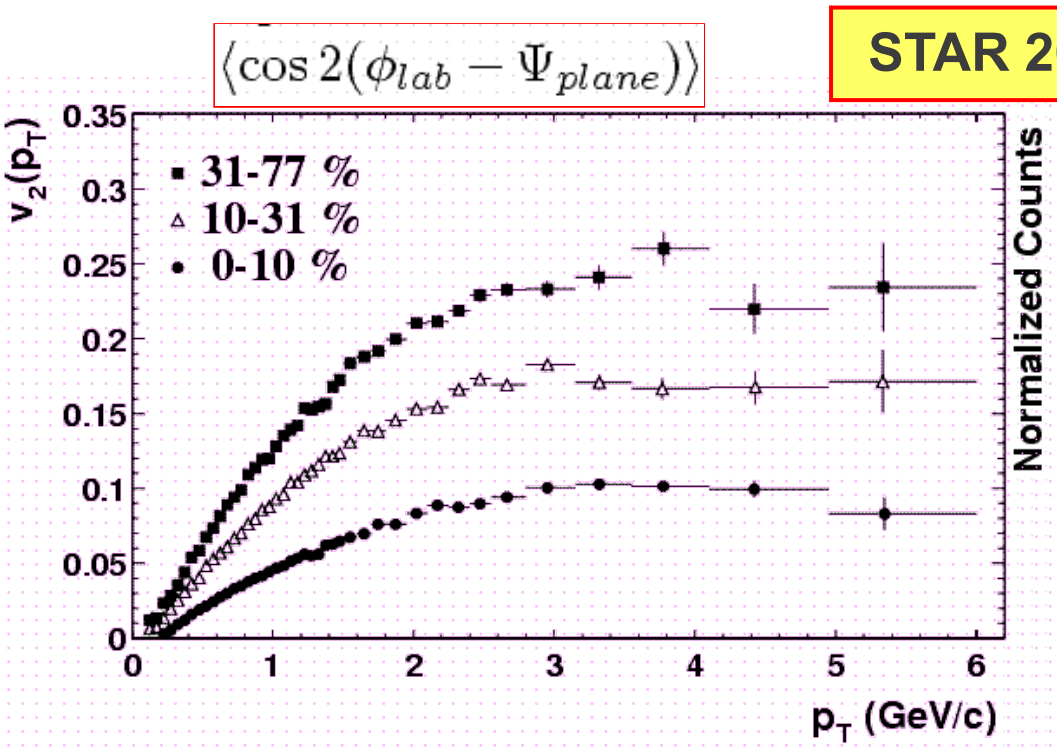
Universe May Have Begun as Liquid, Not Gas

Associated Press
Tuesday, April 19, 2005; Page A05

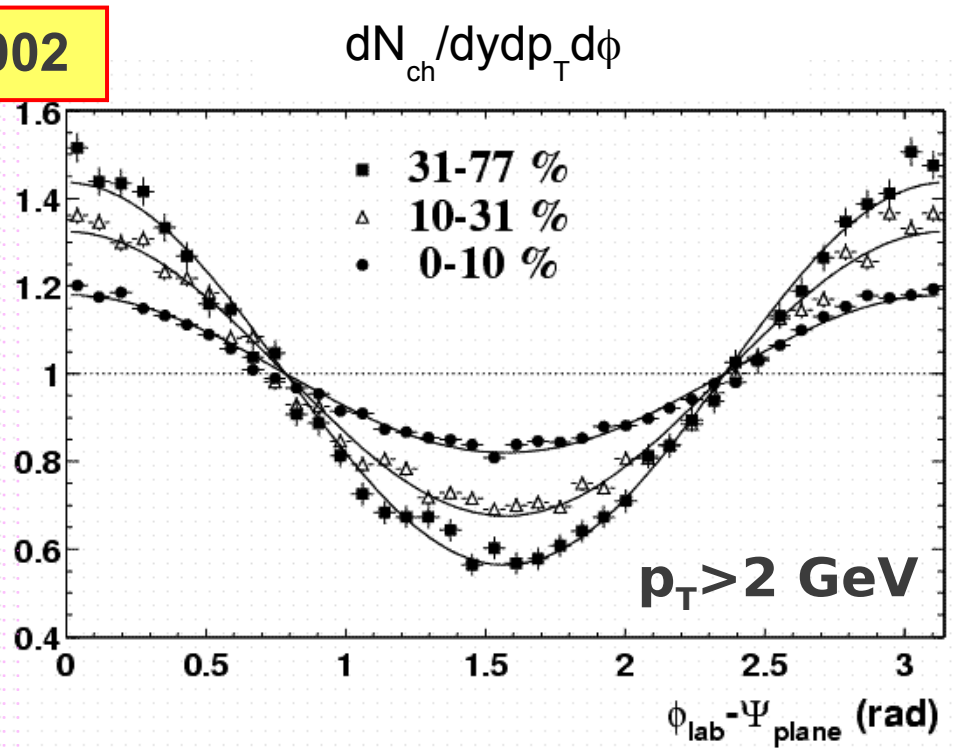
The Washington Post

New results from a particle collider suggest that the universe behaved like a liquid in its earliest moments, not the fiery gas that was thought to have pervaded the first microseconds of existence.

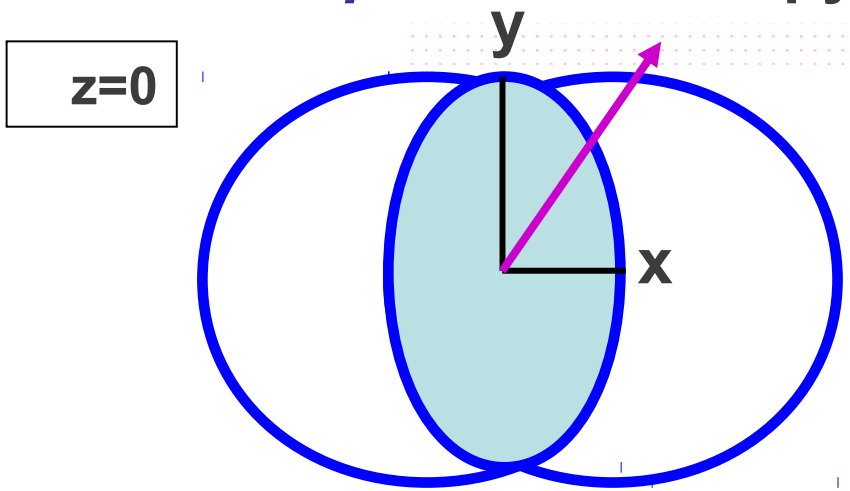
The Discovery of Transverse Elliptic Flow in Non-central Au+Au at RHIC



STAR 2002

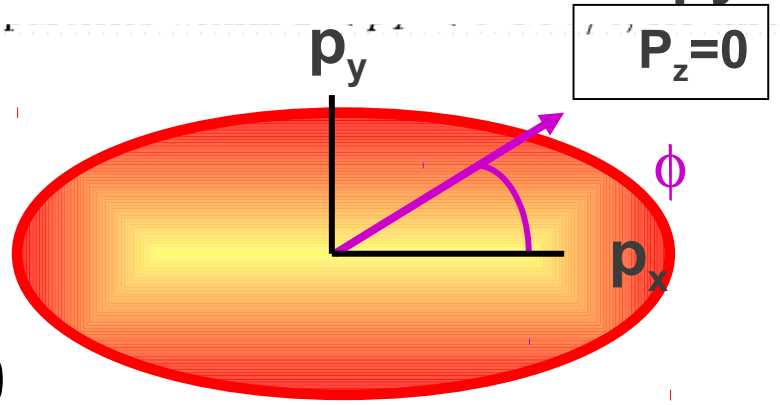


Initial *spatial* anisotropy



$$\partial_\mu T^{\mu\nu}(x) = 0$$

Final *momentum* anisotropy

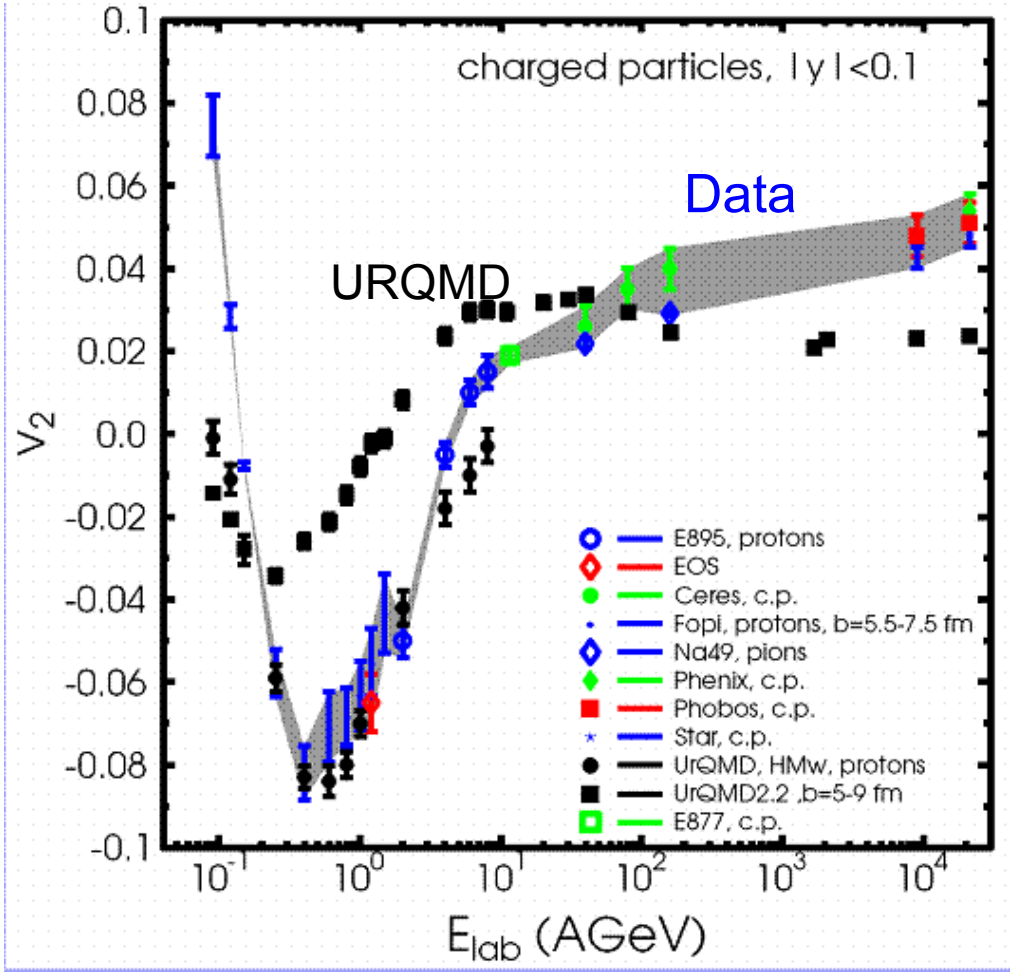


Stoecker, Greiner 84, Ollitrault 92

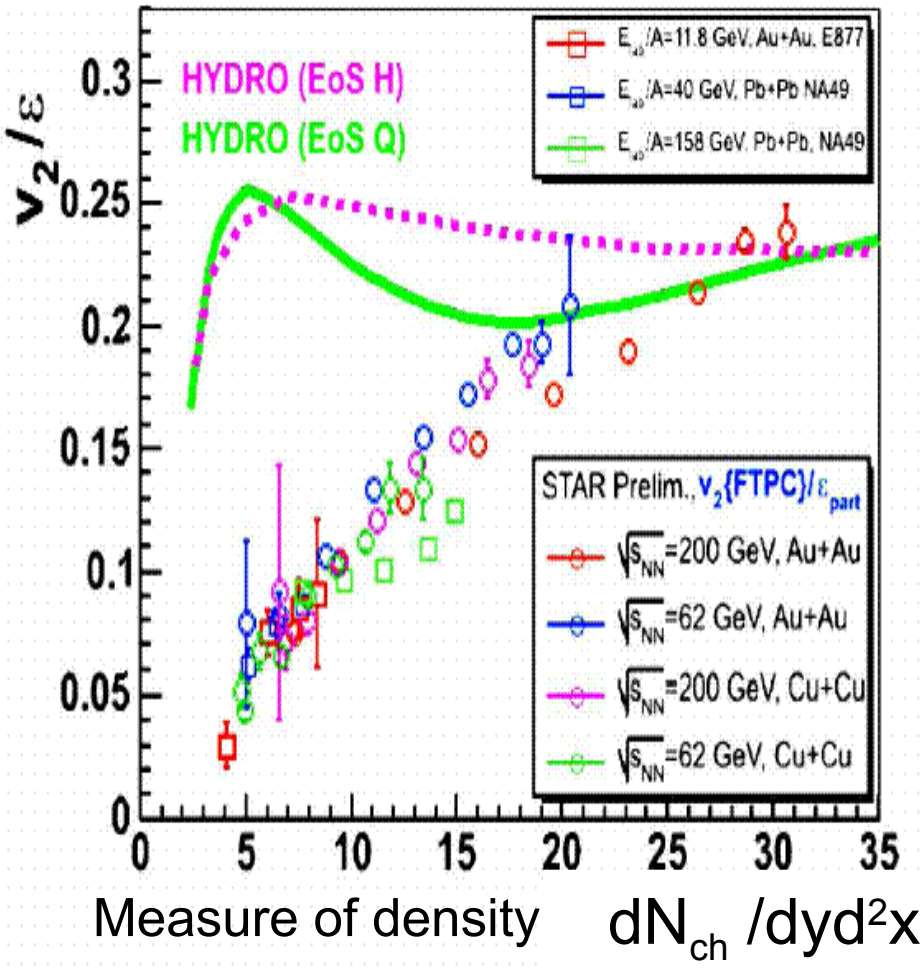
In 2004 it seemed Perfect Fluidity was finally observed at RHIC energies

But *perfect fluidity* appeared only at RHIC

Elliptic flow is a general feature of AA



Kolb, Heinz: Euler Hydrodynamics

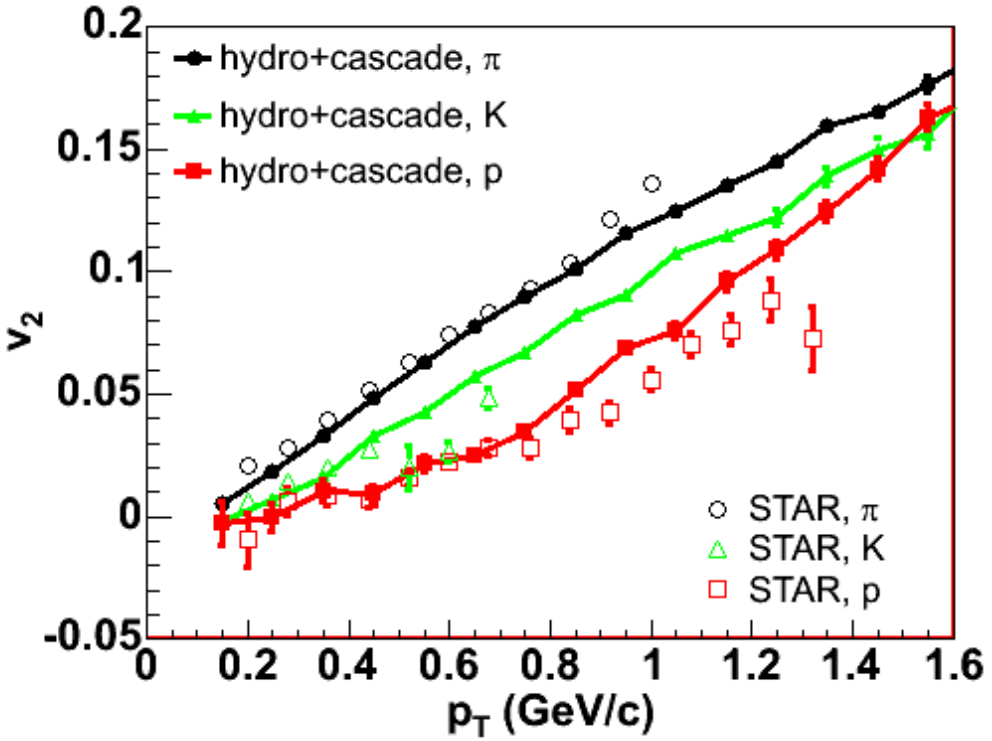


Ordinary hadron resonance gas (HRG) matter is was far from a perfect fluid

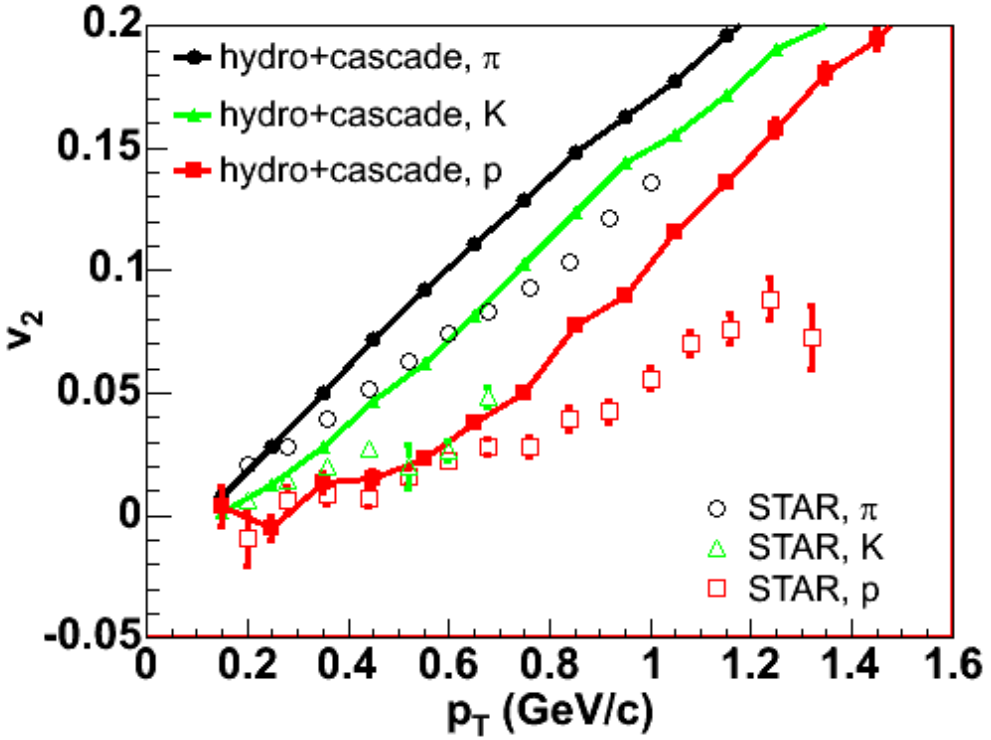
Hirano, Nara, et al 2005

Bulk $v_2(p_T, m)$ for identified hadrons was well understood in terms of near perfect QGP core + HRG corona

Glauber initial condition



KLN/CGC initial condition



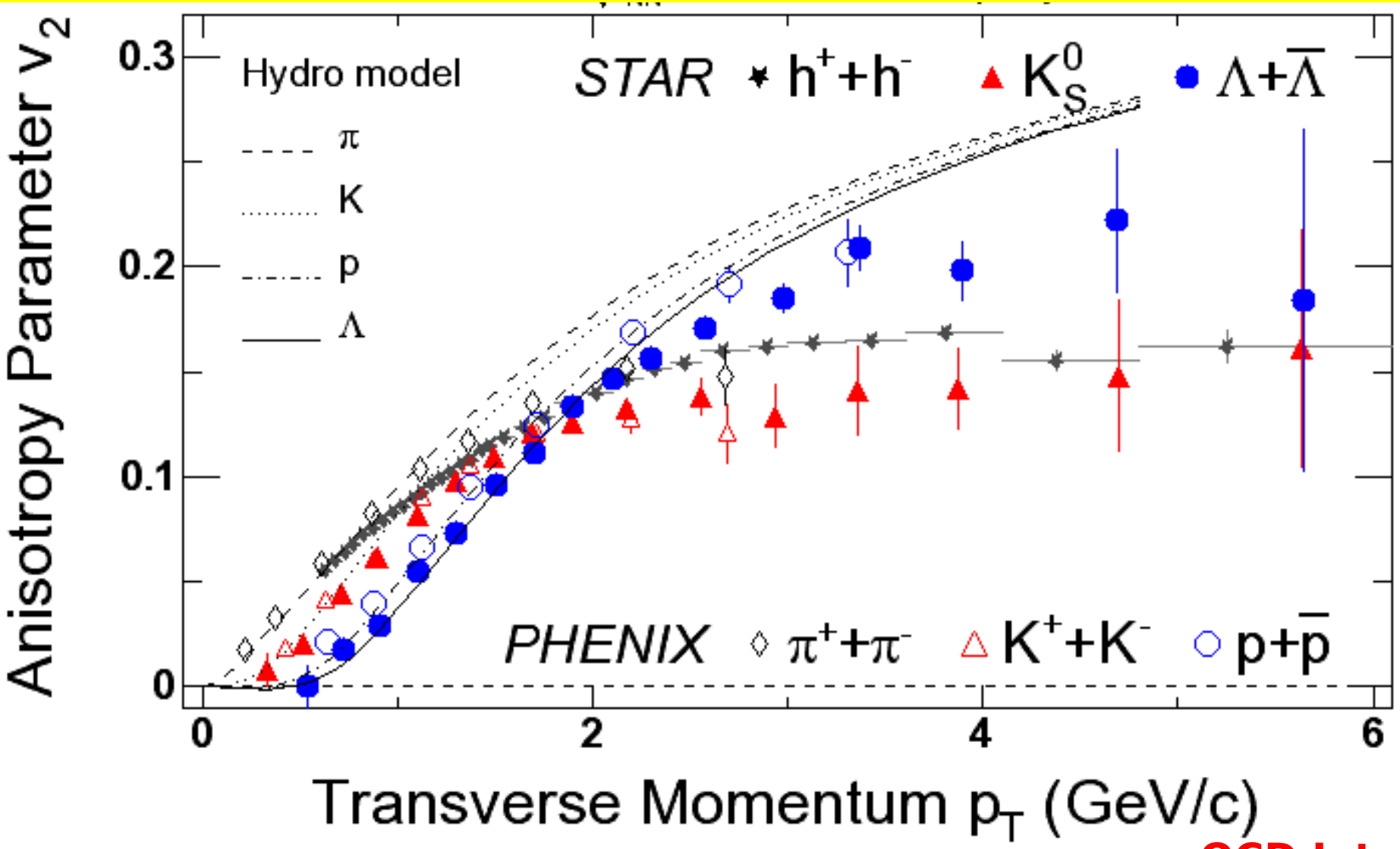
v_2(Glaub) ~ v_2(data)

v_2(CGC) > v_2(data) !!

Glauber+Data => "sQGP" is *Ideal* Fluid with a HRG corona

CGC+Data => "sQGP" is *almost* Perfect Fluid with a HRG corona

The QGP Fingerprint at RHIC = Fine Structure of collective flow $P_{QCD}(T)$



Bulk P_{QCD} Hydro

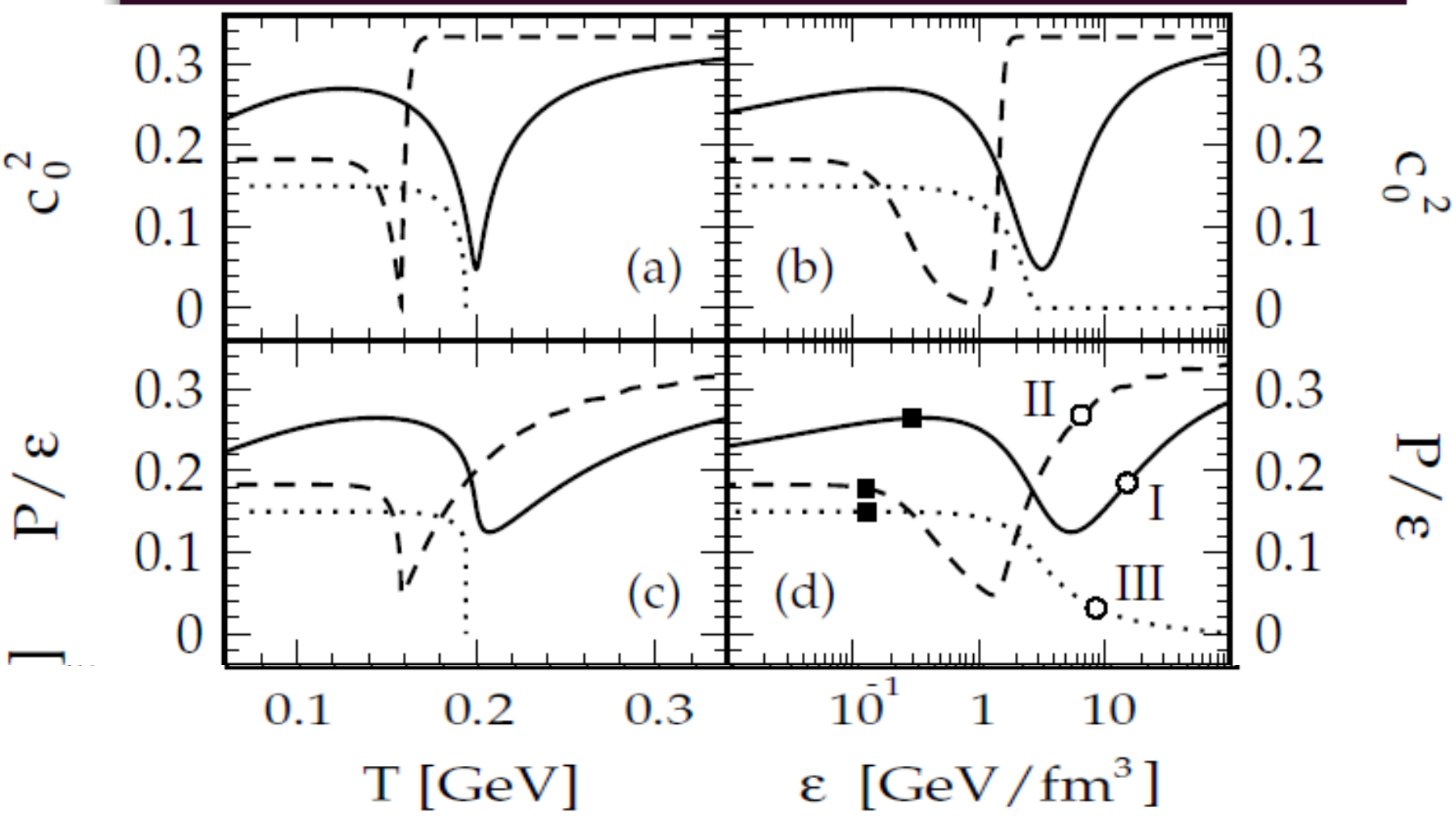
pQCD Jets

qqq Coalescence

[!WARNING!] **On the equation of state of nuclear matter in 158-GeV/A Pb + Pb**

B.R. Schlei, D. Strottman , N. Xu **Nucl-th/9801045; 9710047, 9706037**

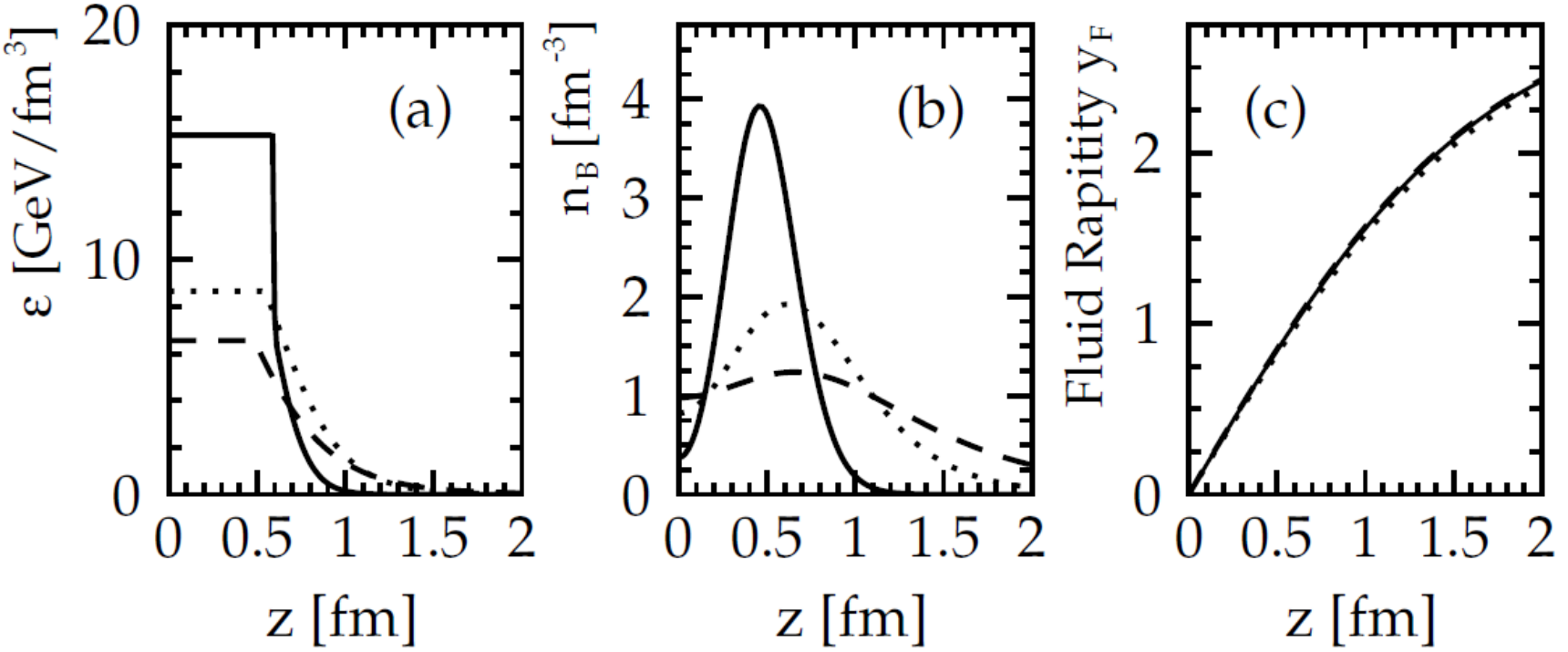
Landau 3D Hydro with model EOS I (solid) , II (dashed), III(dotted)



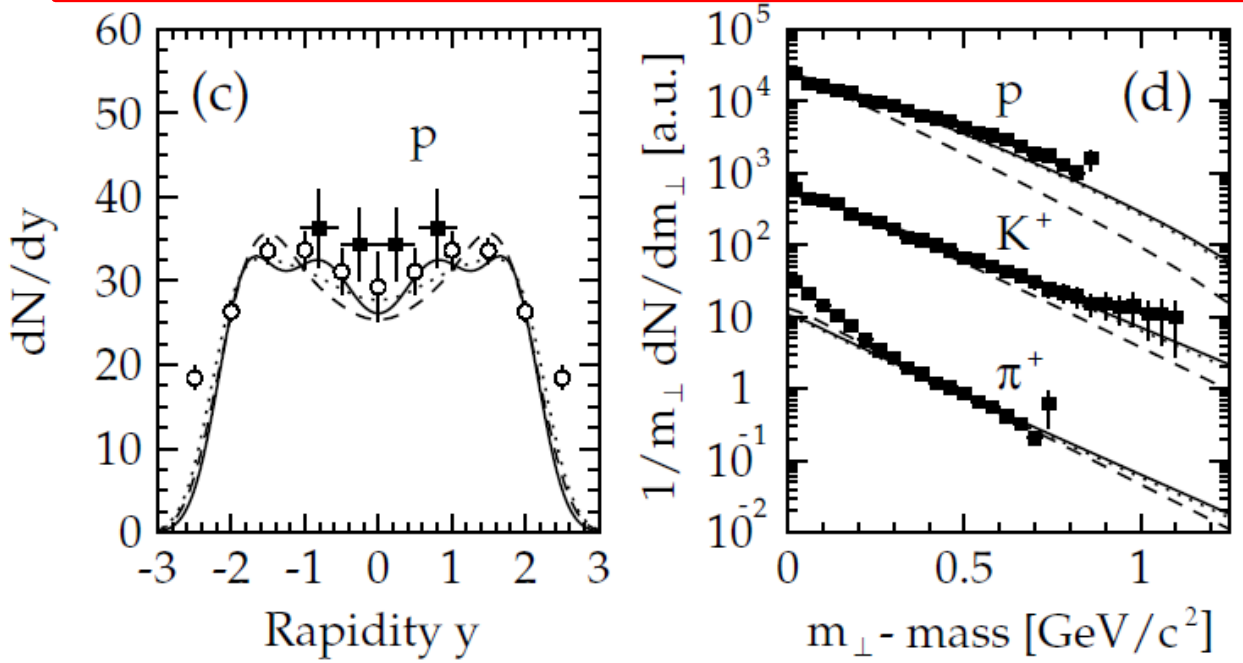
NA44 and NA49 data could be post-dicted with Ideal relativistic hydrodynamics with ***ANY Equation of State***

Provided that Initial and Freeze-out Conditions could be **arbitrarily adjusted!**

How to fit *ANY* data via ideal zero viscosity Landau hydrodynamics with any EOS



Adjust initial/final conditions until ideal hydro fits the data



K. Weierstrass (1885).

"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] × [c,d] and ε > 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

Ideal Fluidity vs Im-perfect Viscous Fluidity

$\partial(T+\Delta T)=0$ Navier Stokes

Inertial Shear Stress $T^{xy}=(\varepsilon+P)u^x u^y = s\,(T_{emp}\,u^x u^y)$

Viscous Shear Stress $\Delta T^{xy} \sim \eta\,\Delta u/\Delta L$ η=Shear viscosity

Reynolds Number (Laminar flow 1<< Re <<1000)

$$\mathrm{Re}=\frac{\text{Inertial}}{\text{Viscous}}=\left(\frac{s}{\eta}\div\right)(T\,R)\sim R/\lambda_{mfp}$$

$$R\sim \min[\,\tau, Rx(\tau), Ry(\tau)\,]$$

Bjorken 1+1 D Hubble expansion in high energy A+A

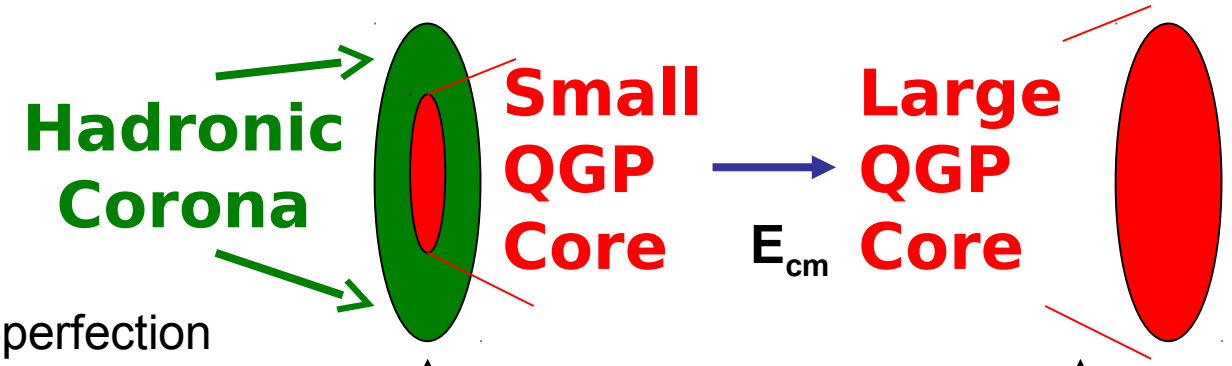
$$\frac{d\epsilon}{d\tau}=-\frac{\epsilon+P}{\tau}\left\{1-\frac{4}{3}\frac{\eta}{s}\frac{1}{T\tau}\right\}=-\frac{\epsilon+P}{\tau}\left\{1-\frac{1}{Re(\tau)}\right\}$$

Even "Flawed fluids" with $\eta/s>1$ can seem "Perfect" _

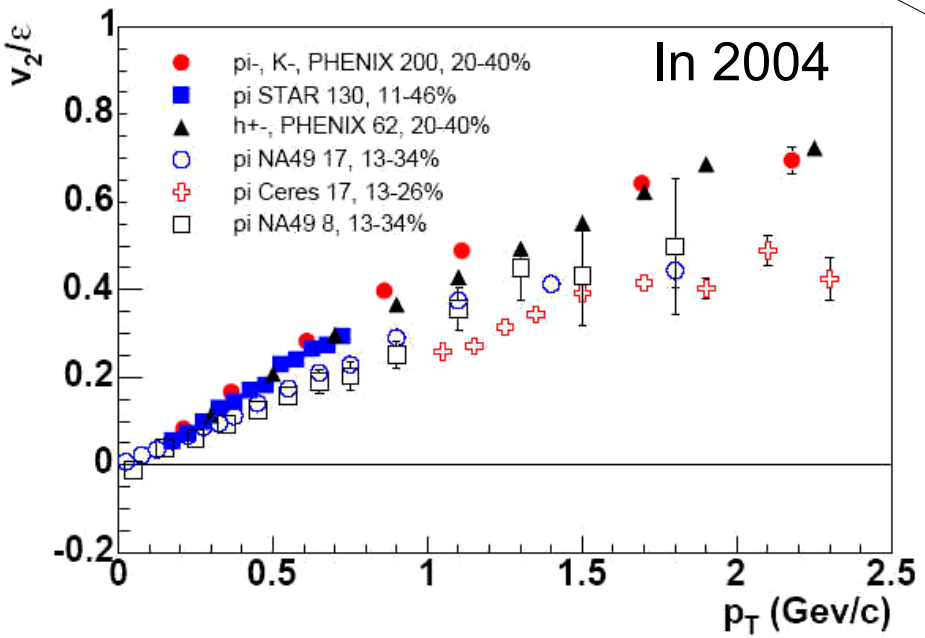
Iff TR remains large enough

At lower energies Perfect Fluidity seemed to be Hidden in the fog of the highly dissipative Hadron Resonance Gas Corona

Teaney, Shuryak
Bass, Dumitru
Hirano, Nara



Quantitative Explanation of SPS' sub-perfection



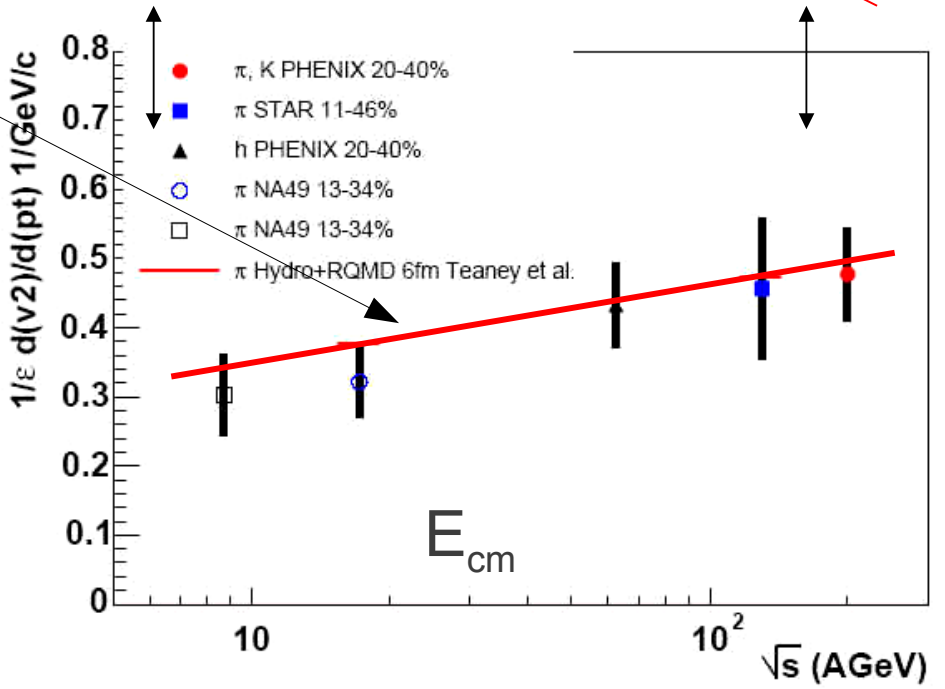
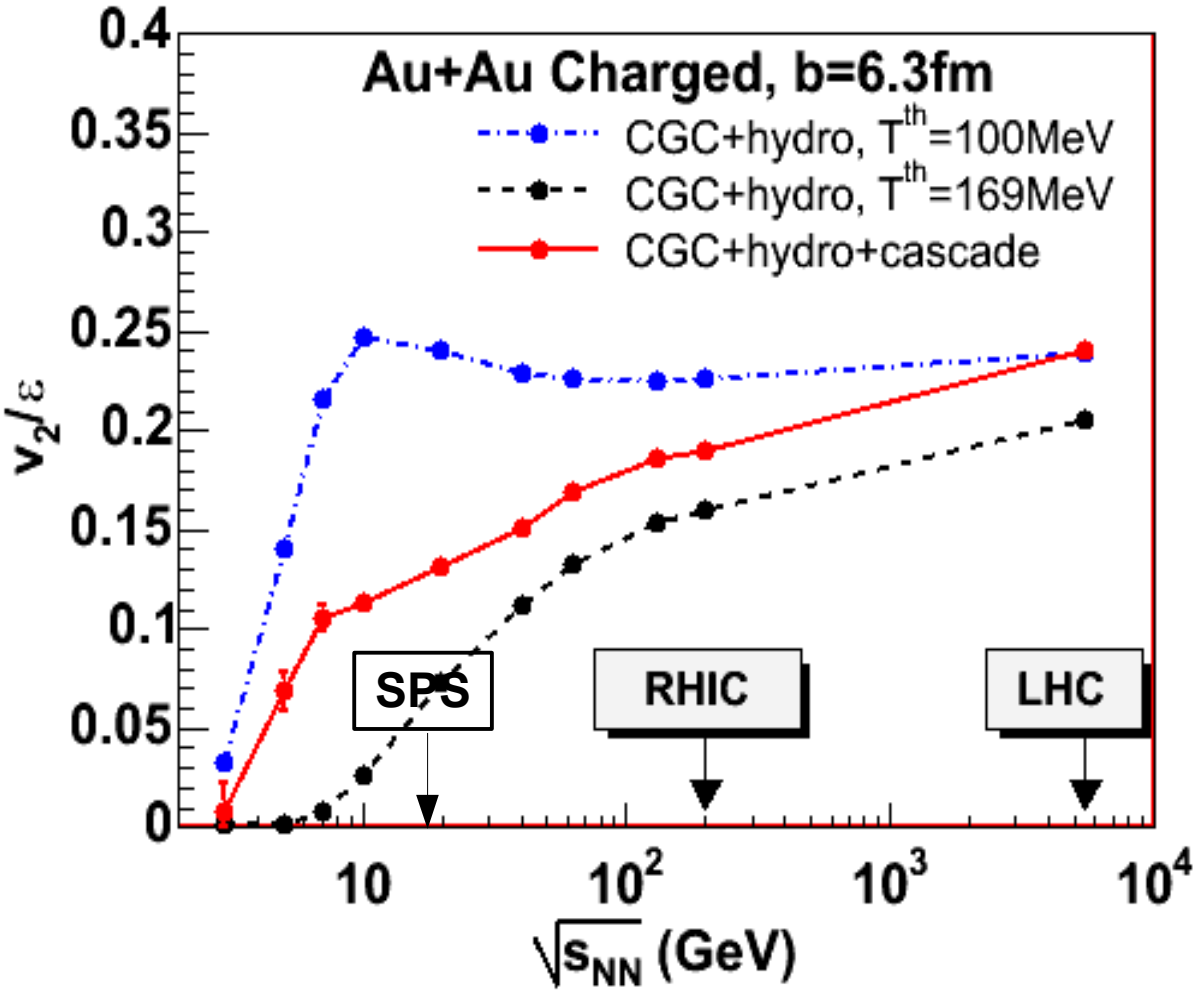


FIG. 16: $v_2(p_T)/\varepsilon$ versus p_T for mid-central collisions at RHIC (filled symbols) and SPS (open symbols). Dividing by eccentricity removes to first order the effect of different centrality selections across the experiments.

FIG. 17: The slope of the scaled elliptic flow, $(dv_2/dp_T)/\varepsilon$, for mid-central collisions at RHIC (filled symbols) and the SPS (open symbols). The slope is calculated for the data $p_T < 1$ GeV/c. The solid error bars are the systematic errors that include the systematic error on v_2 and ε.

Hirano et al *ideal* hydro core + Nara HRG corona (2005) confirmed Shuryak-Teaney hydro+RQMD analysis Of the core+corona explanation of Ecm dependence of <v2>



Competing effects ideal fluid radial and elliptic flow and dissipative HRG corona

Three Lines of Empirical Evidence seemed to converge to a new form of matter "QGP" in 2003

$QGP = P_{QCD} + pQCD + dA = v_2 + (R+I)_{AA} + (R+I)_{DA}$

- ***Unique* long wavelength collective properties**
  - **Elliptic flow ⇔ P_{QCD}**
- ***Unique* short wavelength dynamical properties**
  - **Jet Quenching ⇔ pQCD**
- **Critical Null Control : QGP could be turned off!**

(1) v2 SPS < RHIC due to HRG Corona

(2) R_{DAu} ~ 1 jet un-quenching in D+Au

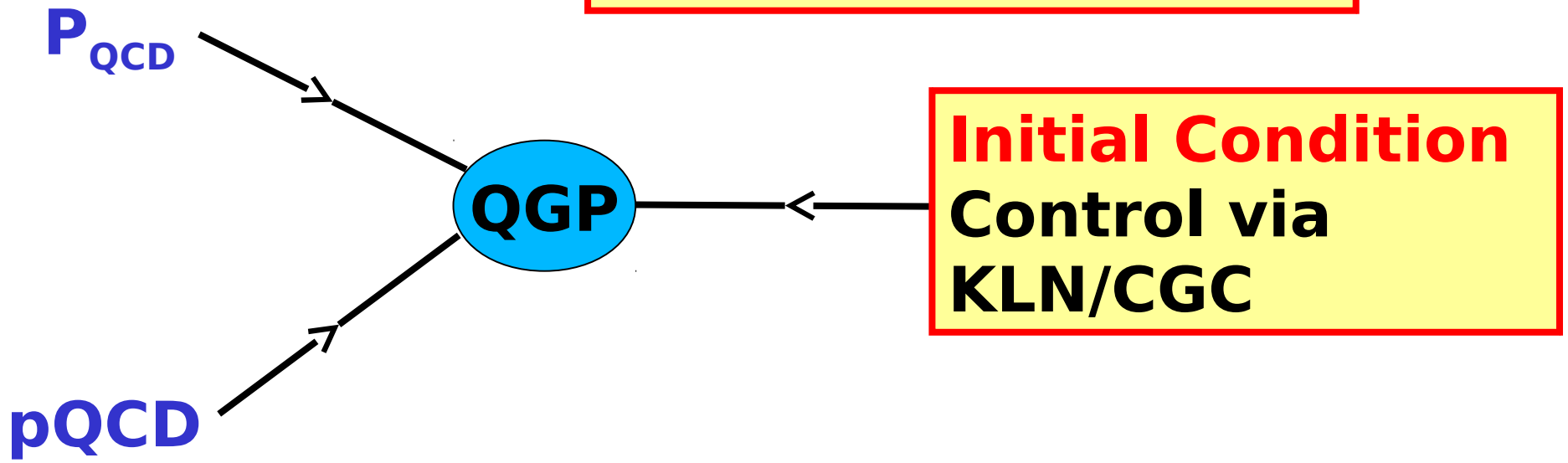
RBRC 2004 MG, L.McLerran

In addition to null control RHIC Ecm >100 AGeV It seemed that we had Initial Condition Control

(*essential to circumvent Weierstrass' 1885 Thm*)

$P_{QCD} = v_2(p_T, m_h, b)$

SPS and Centrality Corona HRG Control



$pQCD = R_{AA}(p_T, b) + I_{AA}(p_T, b)$

$D+A\ Control = (R_{DA}=1) + (I_{DA}=I_{pp})$

Part II: Current Status

Theorists scrambling in the foam of LHC p+Pb tsunami and RHIC BES + DAu

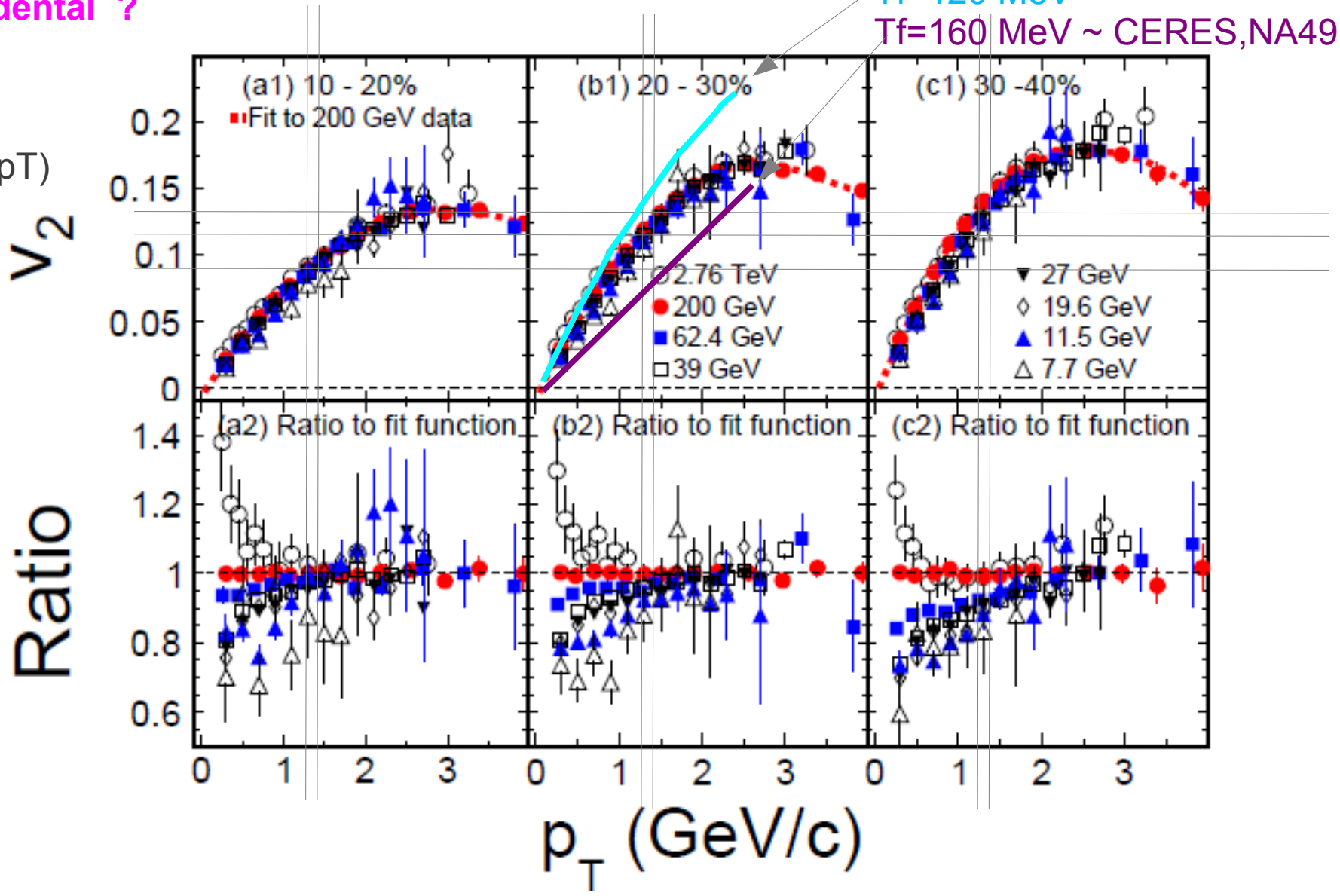
Can the proof of perfect fluidity of sQGP Survive the BES + dAu + pPb deluge without invoking Weierstrass' "add more parameters" Theorem?

RHIC **B**eam **E**nergy **S**can QM12, ***Contradicted*** **SPS' apparent HRG Corona Null Control !!**

Is apparent "Perfect fluidity" accidental ?

Ideal Hydro 17.2GeV: Huovinen
Tf=120 MeV
Tf=160 MeV ~ CERES,NA49 data

v2{4}(pT)

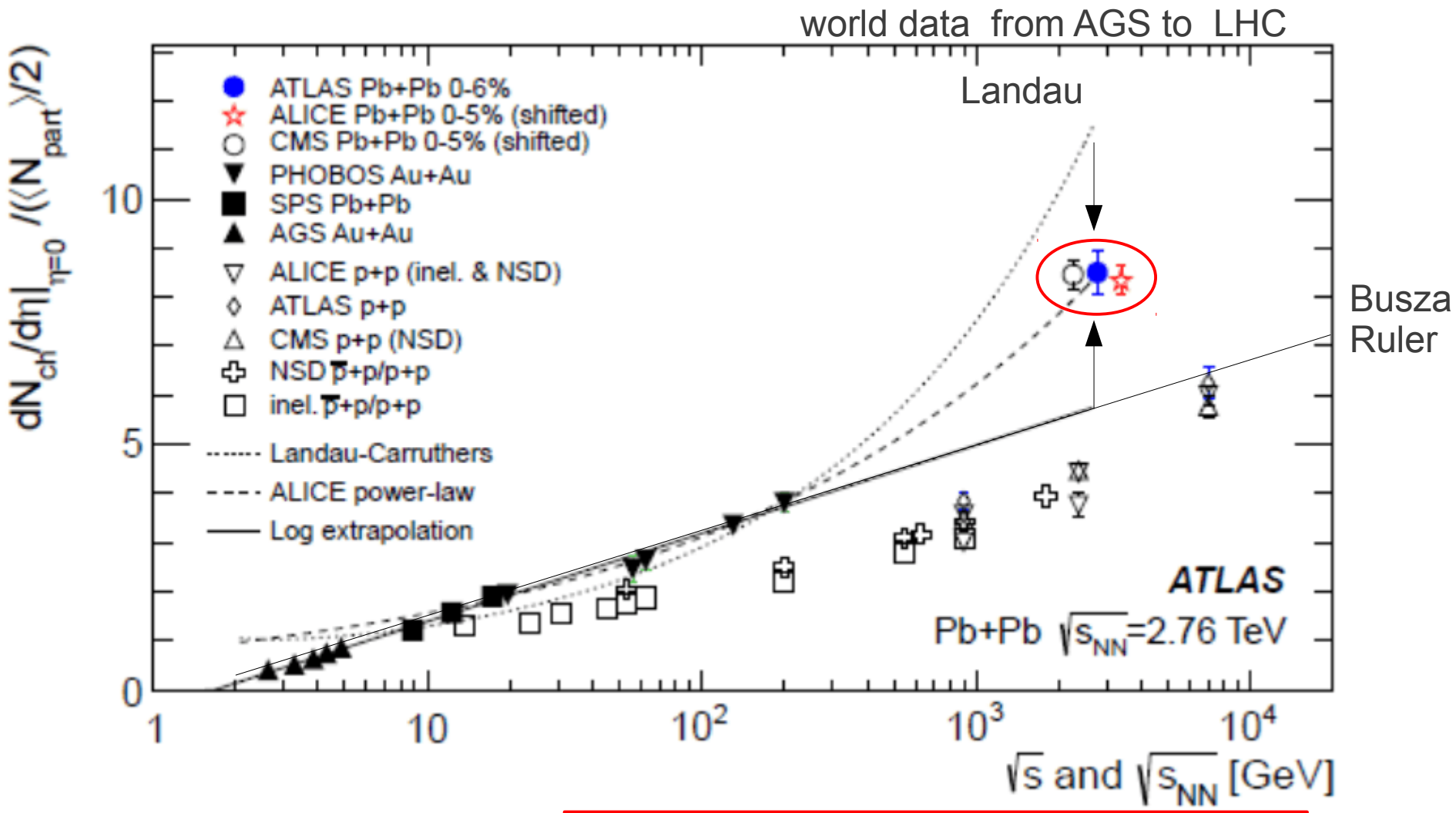


What happened to the HRG Corona ?

We have lost our A+A low Ecm Null control!

The v2{4}(pT) barometer appears stuck with very small sensitivity to huge variations of IC

Initial energy density $\epsilon_{Bjorken} = m_T\, dN/dy / \tau_0\, A_\perp$ increases by *at least* a factor ~ 10 from E_{cm} = 7 - 2760 AGeV !



CGC initial energy density $\epsilon_{CGC} = (m_T/\tau_0)\, dN/dy/A_\perp \propto (Q_s)^4$ could increase by factor -100 over this wide energy range.

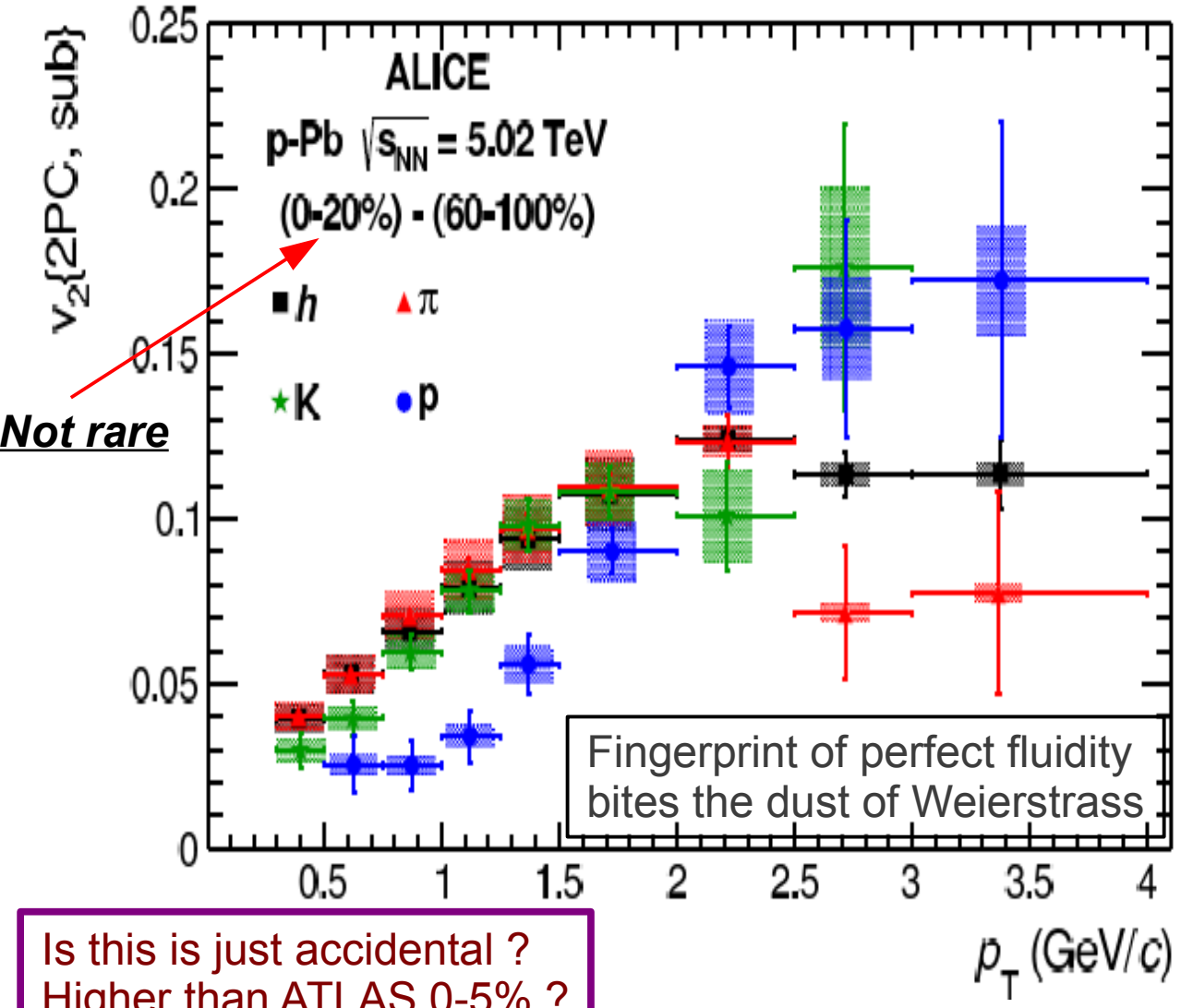
M.Gyulassy RANP 2013 Rio

How can v2(pT) vary by only 10% with >1000% variations of Initial Conditions ?

Long-range angular correlations of π, K and p in p–Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV

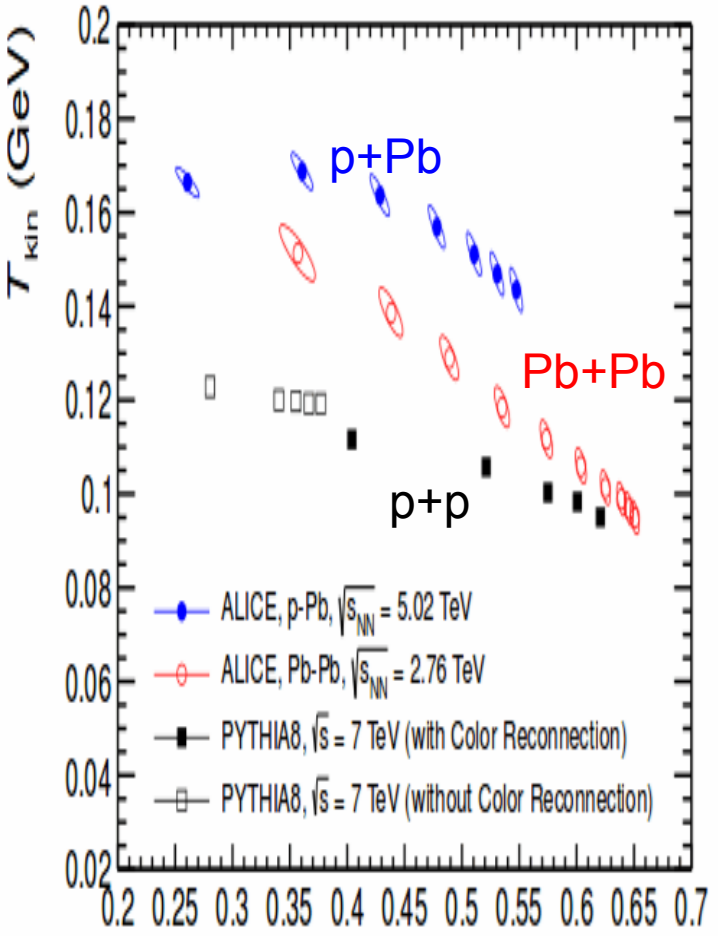
Hadron mass dependent fine structure of v2(pPb,pT, Mh) similar to A+A !!

But dissipative corrections should be ~ 5 X larger in p+Pb with R~ 1 fm



Not rare

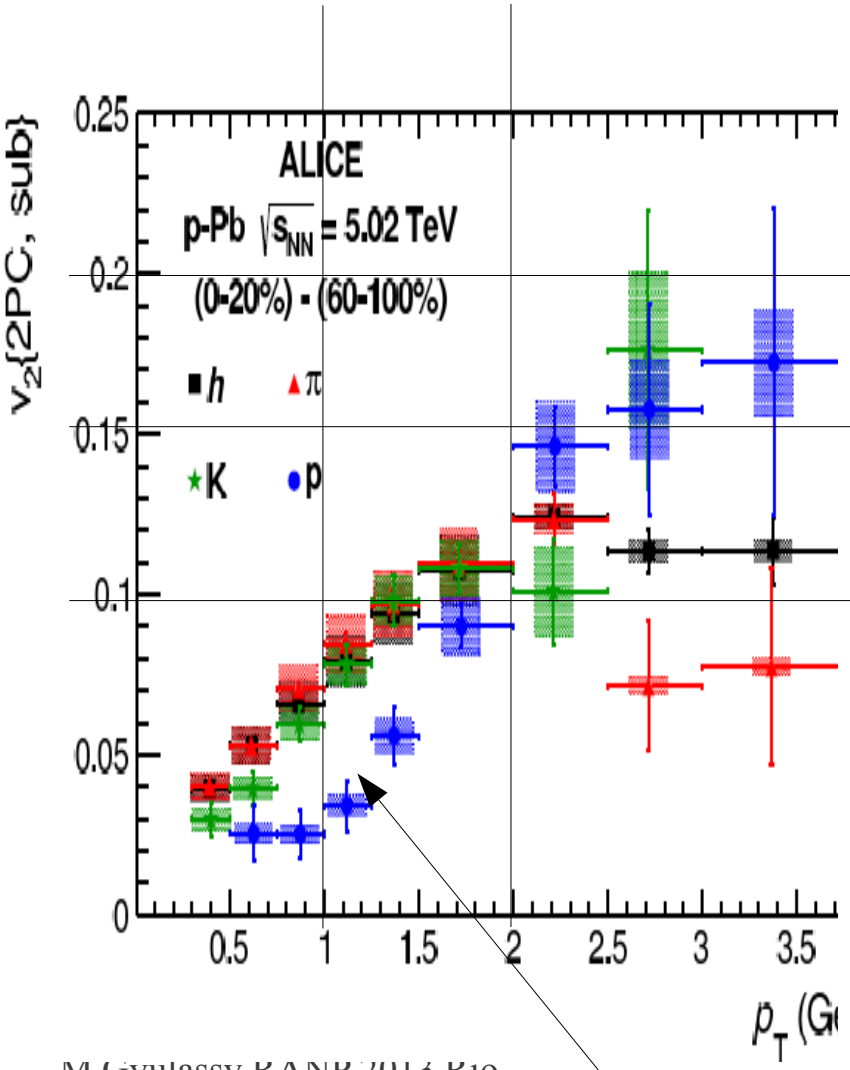
Is this is just accidental ?
Higher than ATLAS 0-5% ?

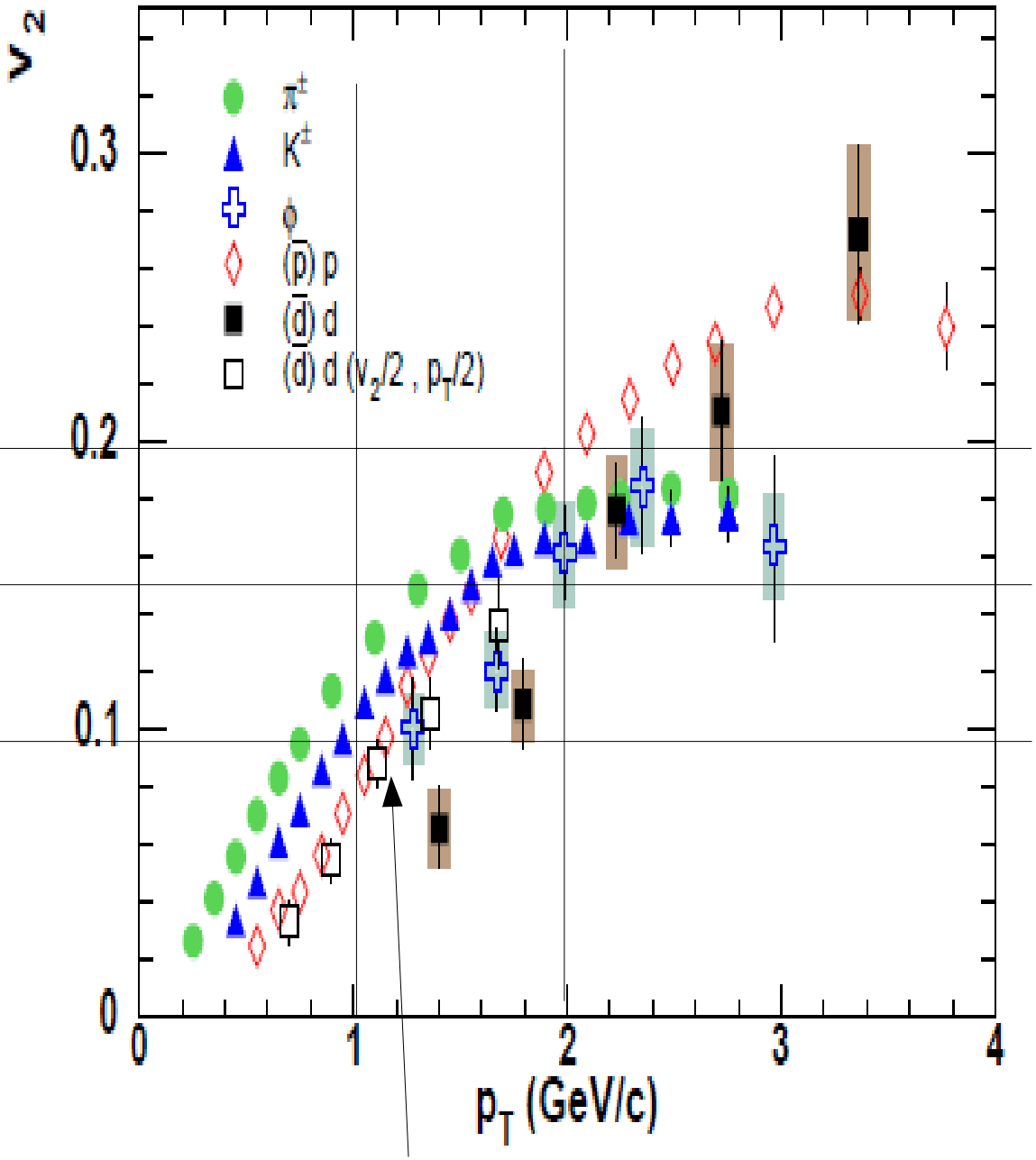


Radial flow in AA interpolates
Between pp and pA??.
Jets+Dissipation or Non-flow?

v2 p+Pb at LHC is not a Null QGP control
In spite of ~ 5 time smaller Re number

PHENIX/RHIC



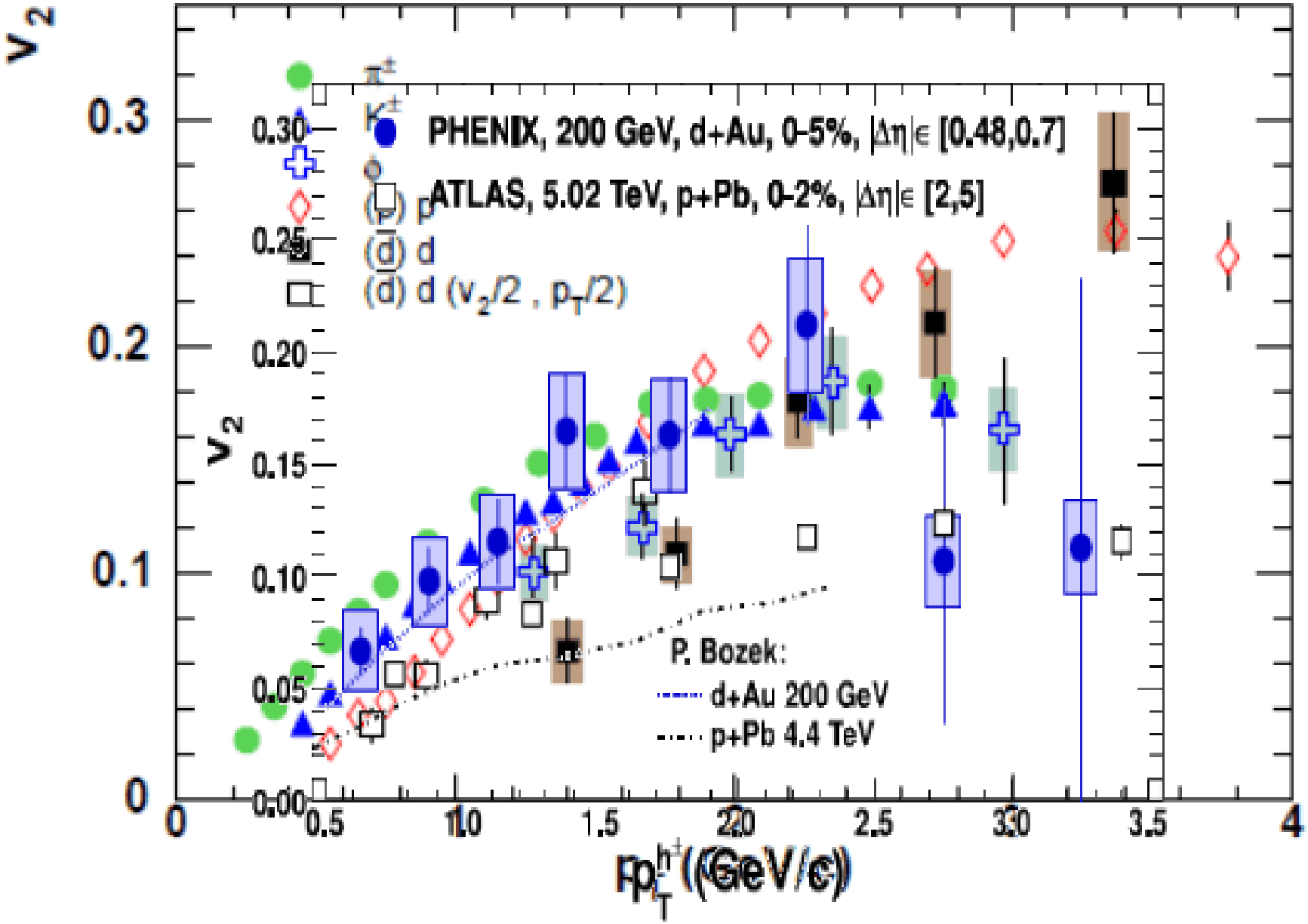


Higher baryon radial flow than in AA

v2(DAu,5%) ~ 2 v2(pPb,2%)

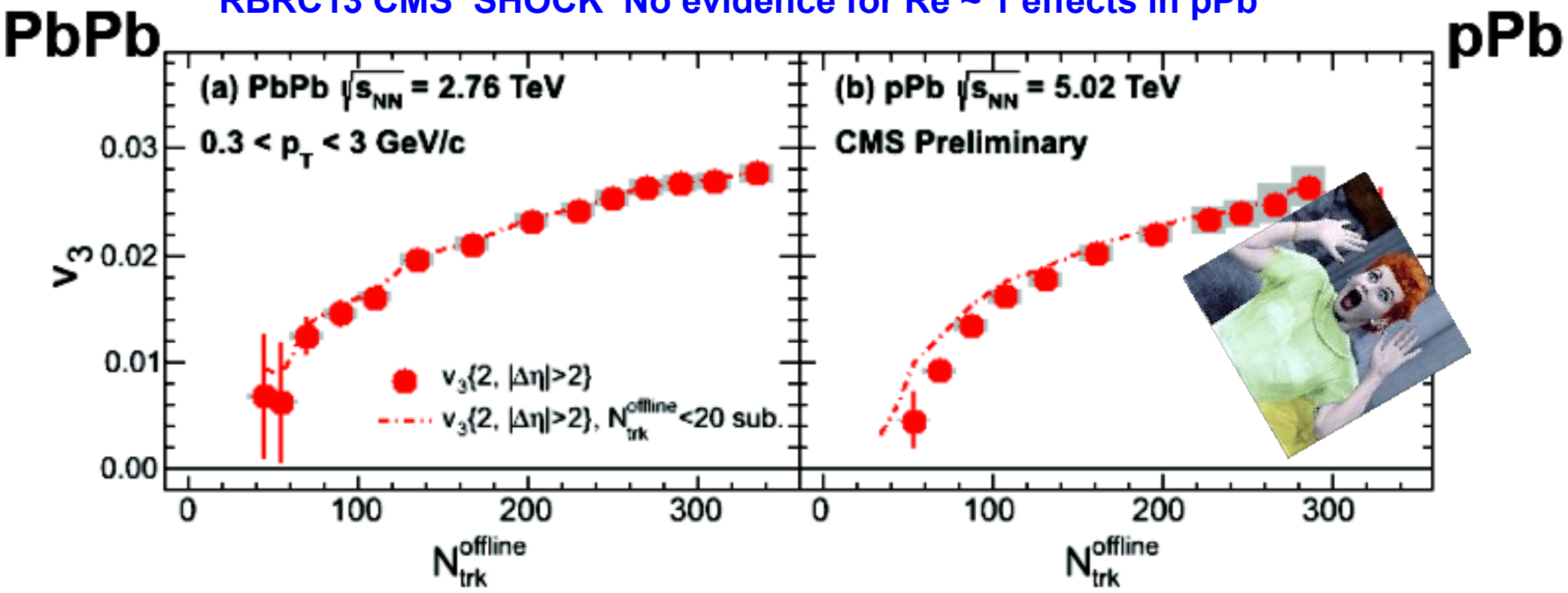
v2(pT) D+Au ch Blue rectangles = v2(pT) AuAu 20% pi,K p

3/7/13 The Day the XXX Hit the Fan at RHIC



v_3 in pPb and PbPb

RBRC13 CMS SHOCK No evidence for Re ~ 1 effects in pPb

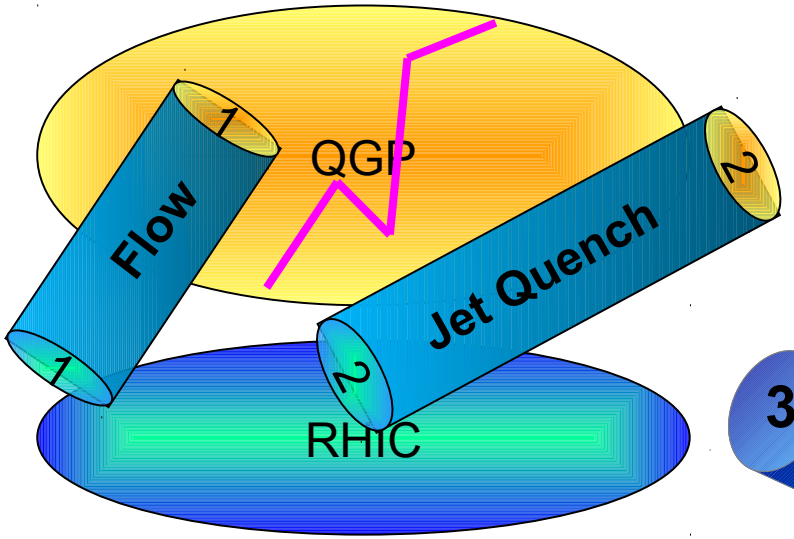


v_3 shows similar shape in pPb and PbPb; magnitude comparable

Can sQGP perfect fluidity survive the BES,D+Au,p+Pb tsunami
without invoking Weierstrass?

Necessary conditions satisfied but without control are insufficient

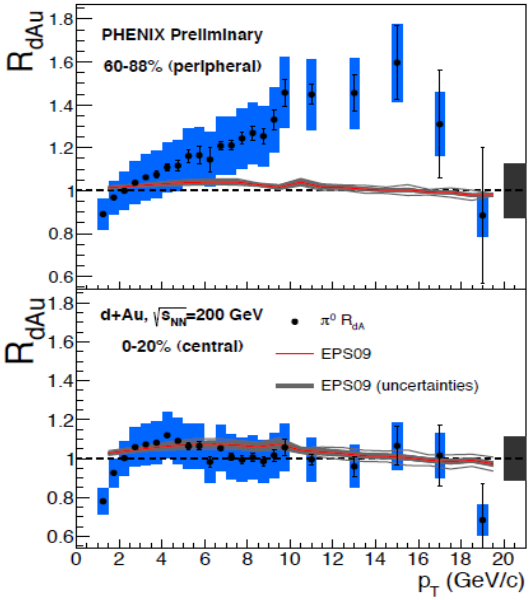
Broken
P_{QCD}
Barometer



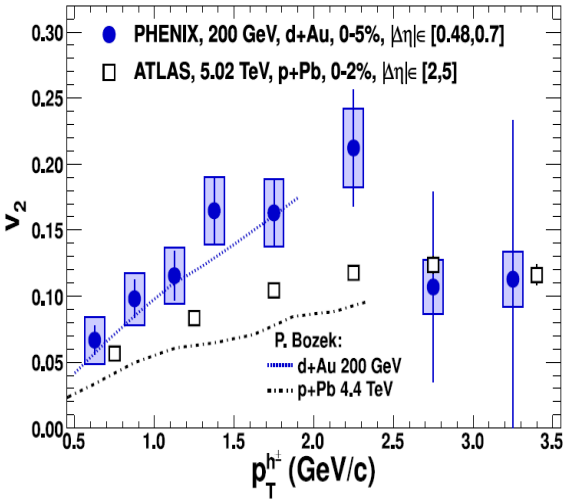
Broken
pQCD
Opacity gauge

The lights Remain ON Even in pA

R(DAu) ≠ 1



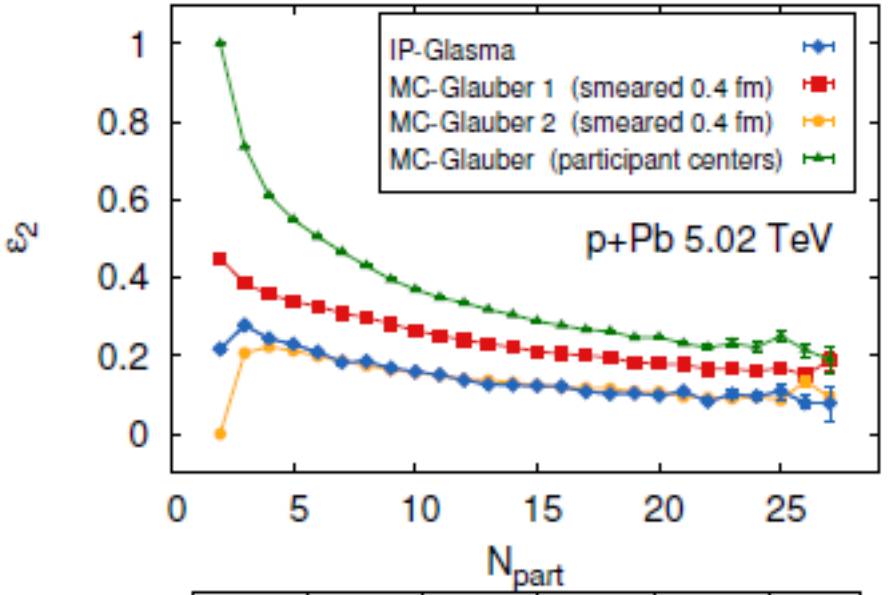
! v2(DAu,5%) = v2(AuAu,MB) ~ 2 v2(pPb,2%) !

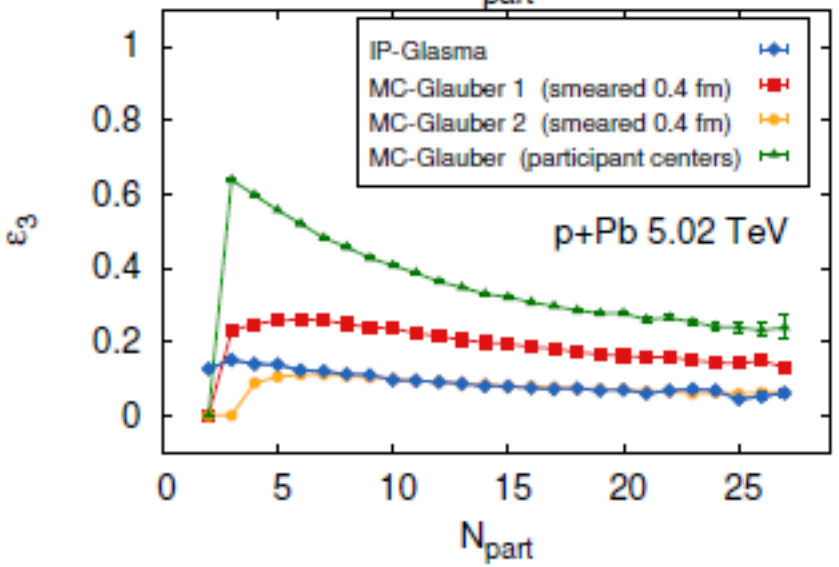


We can no longer turn QGP signatures "Off" That we thought Were Unique to the sQGP produced in AA

There is *Zero* control over hydro Initial Conditions in p+A

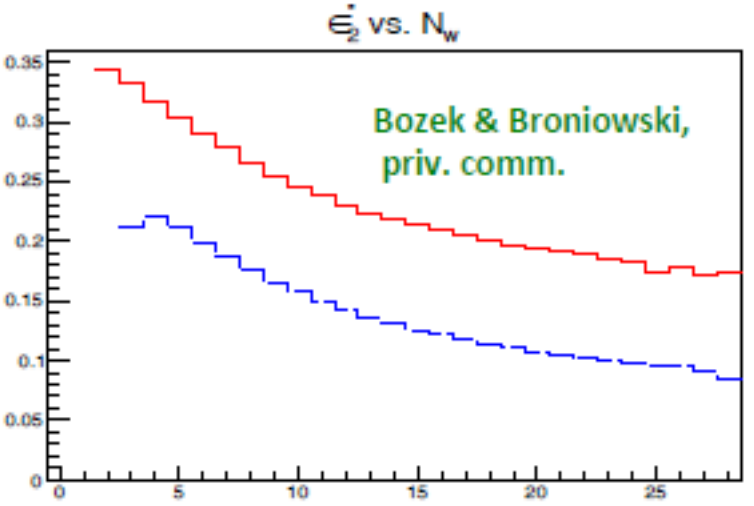
Initial conditions in p+A: IP-Glasma vs "Glauber"





Bzdak,Schenke,Tribedy,RV:1304.3403

MC-Glauber 1 MC-Glauber 2



In MC Glauber 1, big differences in hard sphere & Gaussian smearing

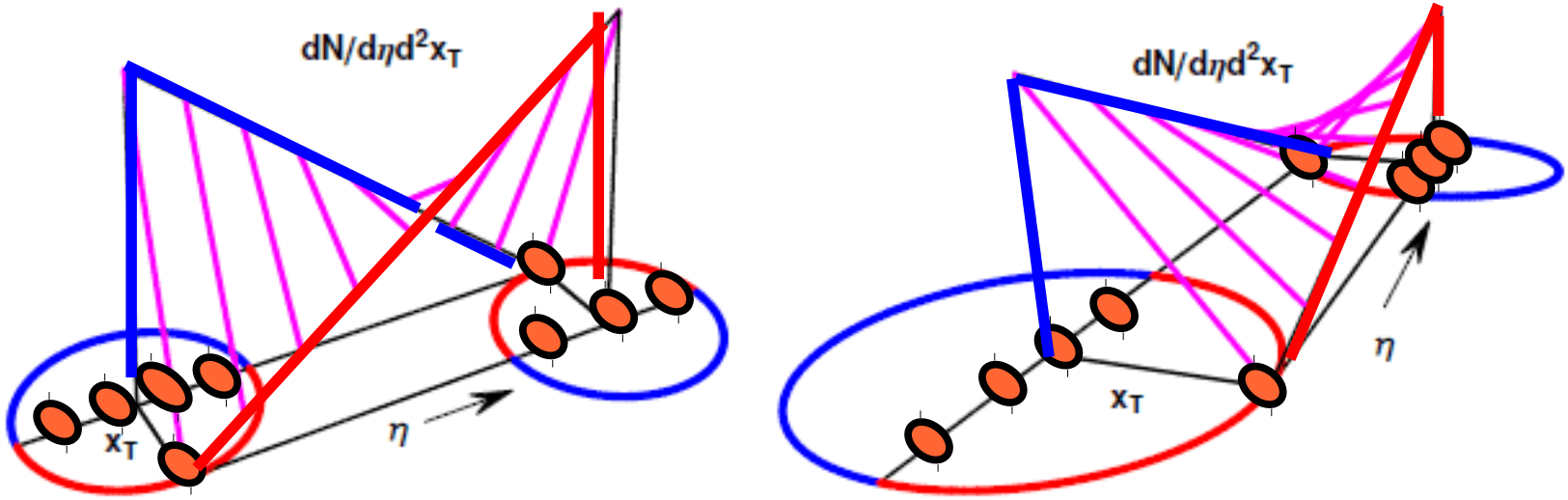
pA Hydro requires invoking Weierstrass' parametric guessing/fitting Thm !

Heretic Part 3: What IF there is NO flow?

Could most of vn(pT) be due to basic quantum interference phenomena in p+A?

3D jet tomography and the twisted color glass condensate
A. Adil, M. Gyulassy, T. Hirano , Nucl.Phys. A774 (2006) 593

$A+A = (p+A^{1/3}) + (A^{1/3}+p) + \text{Symmetric Stuff}(A-A^{1/3} + A-A^{1/3})$



AA has Triangular p+A edges

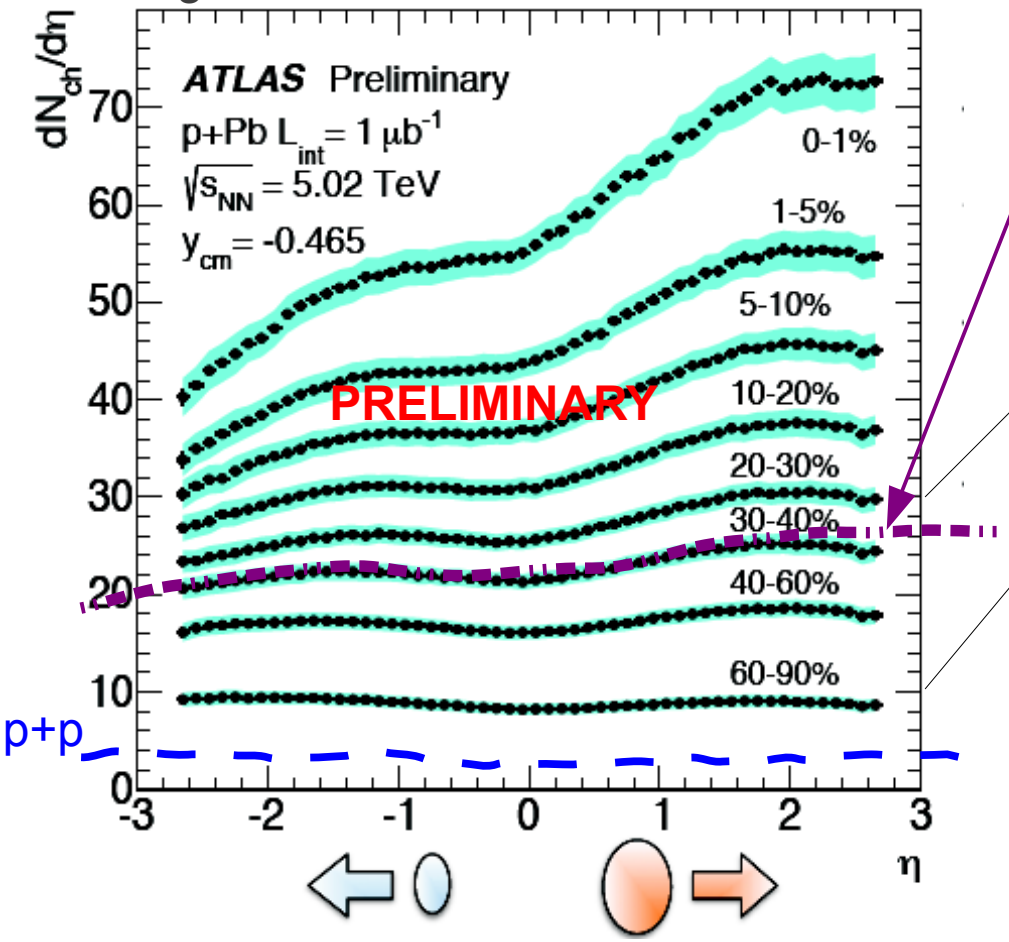
What ***IF*** there is No Hydro , No Flow??

But instead only Glasma like $\hbar$=c=1 Interference Phenomena especially in p+A edges ???

ATLAS-CONF-2013-096 shown at IC2013 by E. Shulga:

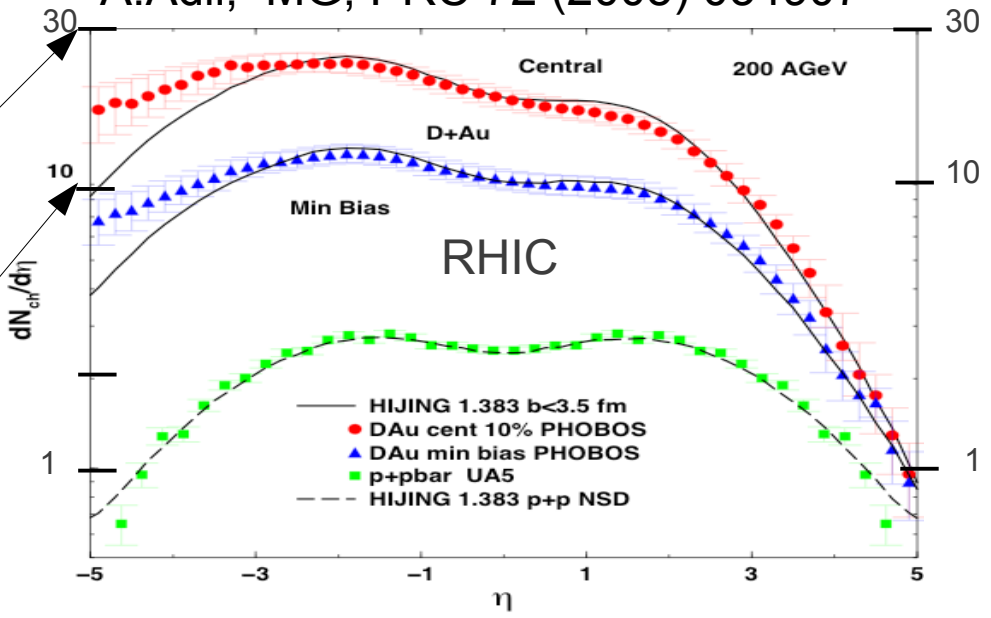
First clear evidence for "Triangular eta asymmetry" in P+Pb similar to D+Au @ RHIC

Fig.7 LHC

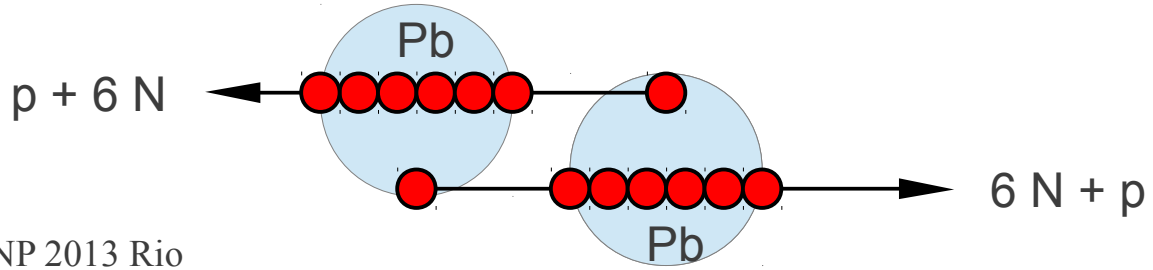


Topor Pop et al PRC85 (2012) 024903
HJ/BB2.0 pPb LHC (no Shadow) Ncol=6.4

A.Adil, MG, PRC 72 (2005) 034907



=> Large rapidity asymmetry "x-z shear twist " in b~R Pb+Pb @LHC



ATLAS-CONF-2013-096 shown at IC2013 by E. Shulga:

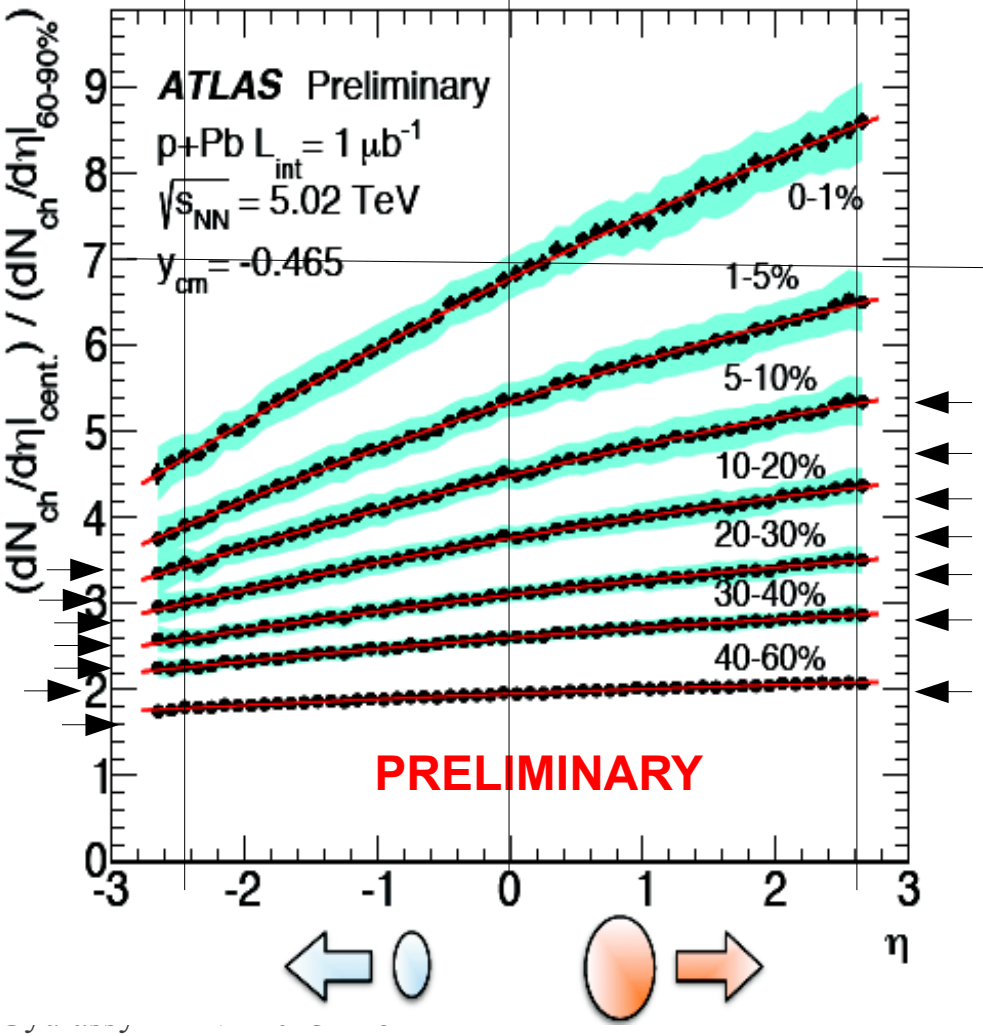
Remarkably linear pA/pp over -3<y<3

As first predicted by BGK 1977 and fit Busza pA

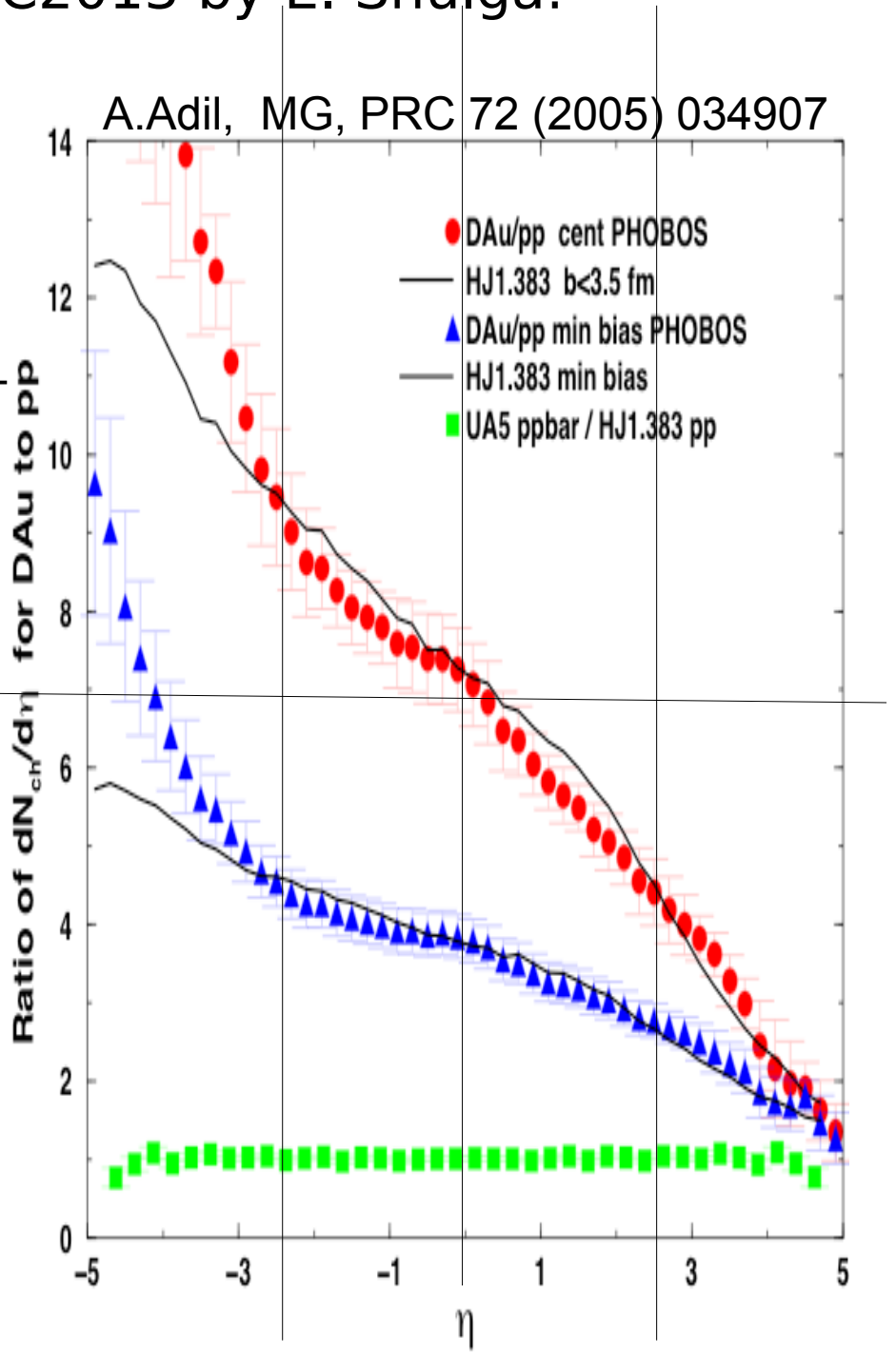
BGK(y,Y*,ν)=dNpA/dNpp = 1 + (ν-1)(y-Y*0)/2Y*

But y slope about ½ of LHC data

$\frac{R(3,6,\nu)}{R(3,6,3)}$



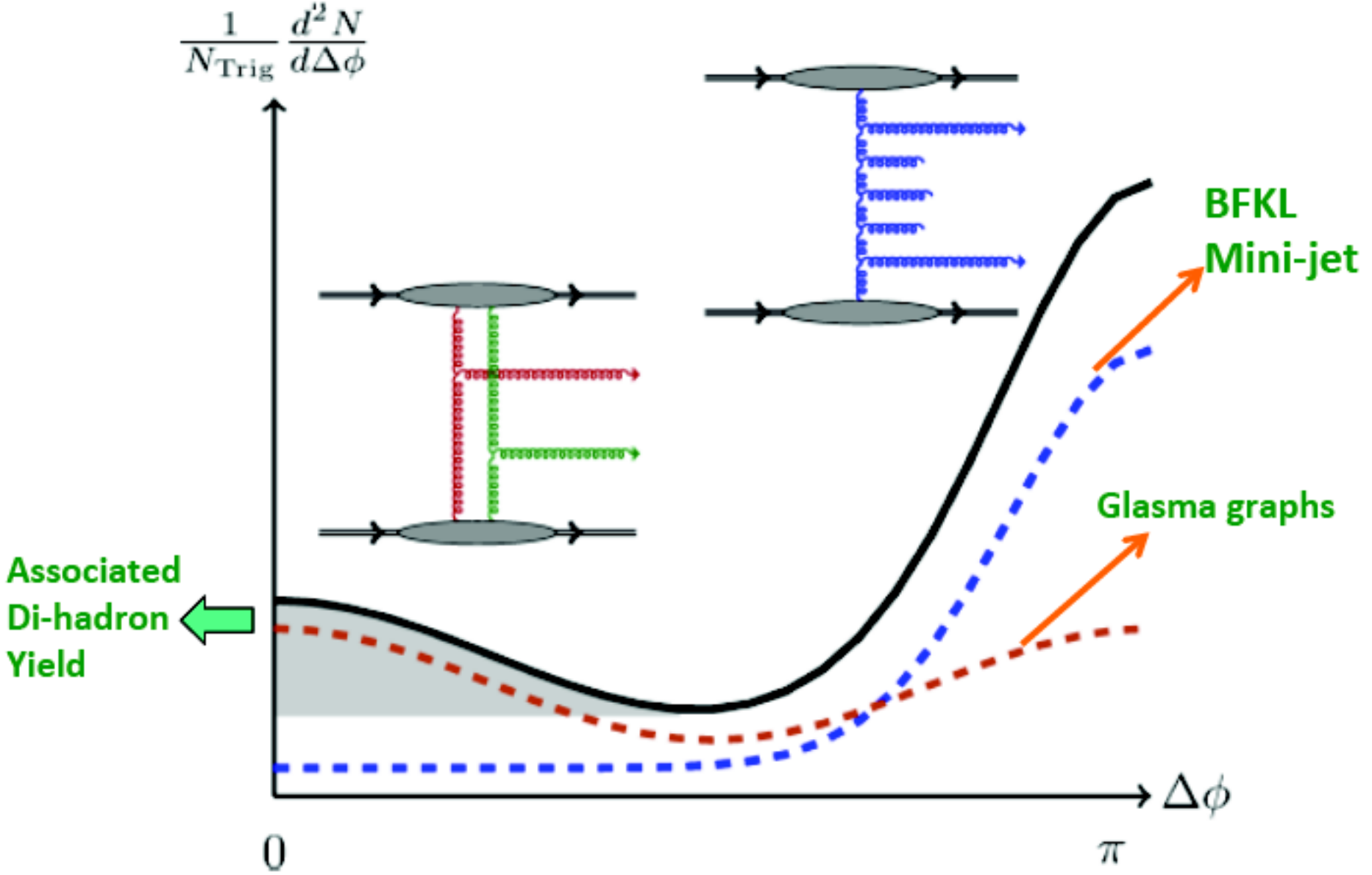
A.Adil, MG, PRC 72 (2005) 034907



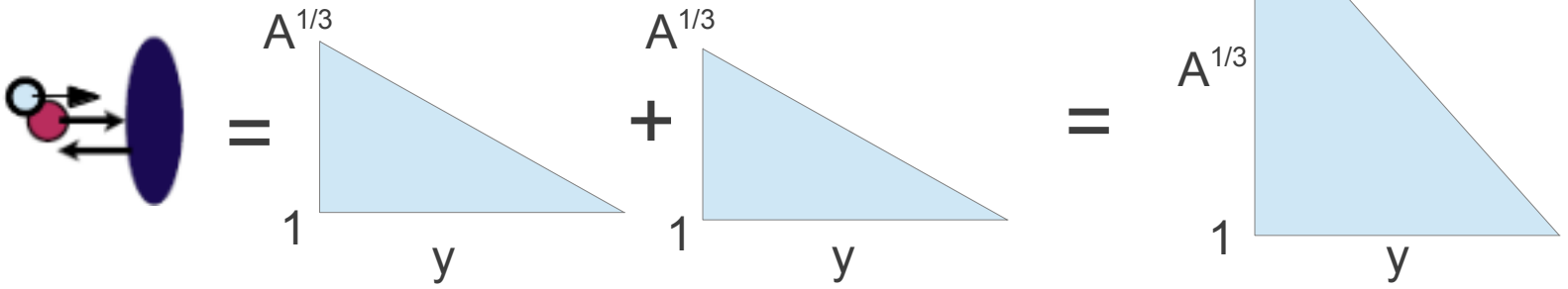
What else besides hydro can leads to “apparent vn flow” in p+A and A+A ??

hbar = 1 = c Crossing and Bose symmetrization effects also lead to multiparticle correlations

The Glasma Model illustrates this possibility: Venugopalan, McLerran et al



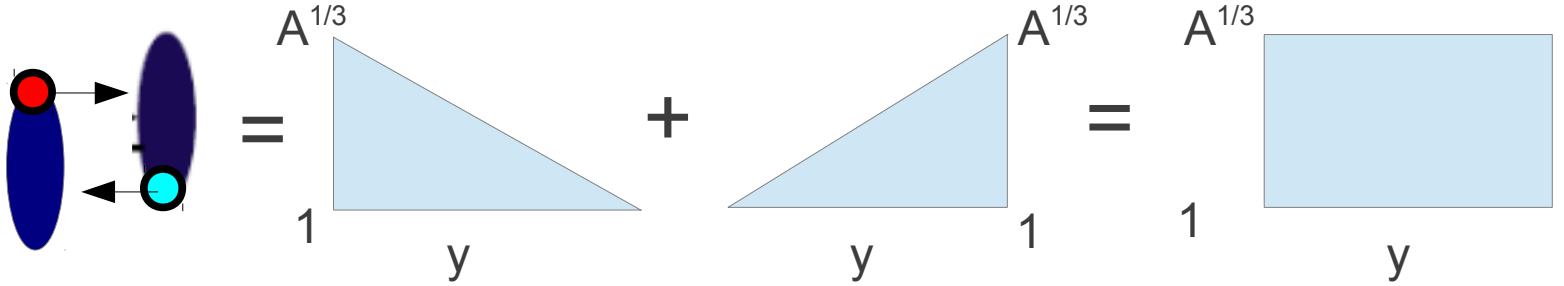
D+A central



<v2(y) v2(0)>
Correlation
strength

Au+Au central ~ p+A + A+p = triangle + anti-triangle Corona model

A+A central



<v2(y) v2(0)>
Correlation
strength

Falsifiable Prediction of this Heretic Non-Hydro BGK-like Flux Model of vn(y) systematics

v2(D+Au, y<0, cent) > v2(Au+Au, |y|, MB) > v2(D+Au,y>0,cent)

v2(D+Au, y , cent) = 2 X v2(p+Au, y, cent)

Exp facts 2013: v2(DAu , 5%) ~ v2(AuAu, 30%)
v2(AuAu, 7 AGeV) ~ v2(AuAu,200 AGeV) ~ v2(PbPb,2800 AGeV)

Could all B+A be controlled by quantum interferences in ~2 p+A triangles

MAYBE these point to more *basic* quantum/wave interference effects
That dominate high energy multiparticle production at all x!

p+A rapidity triangle just confirmed by ATLAS at LHC last week!

! PA BA and BES call for re-evaluation of our long held paradigms !

Is the hydro approximation washed up?
Will the ghost of Weierstrass
To haunt us into tweaking

continue
extra params?

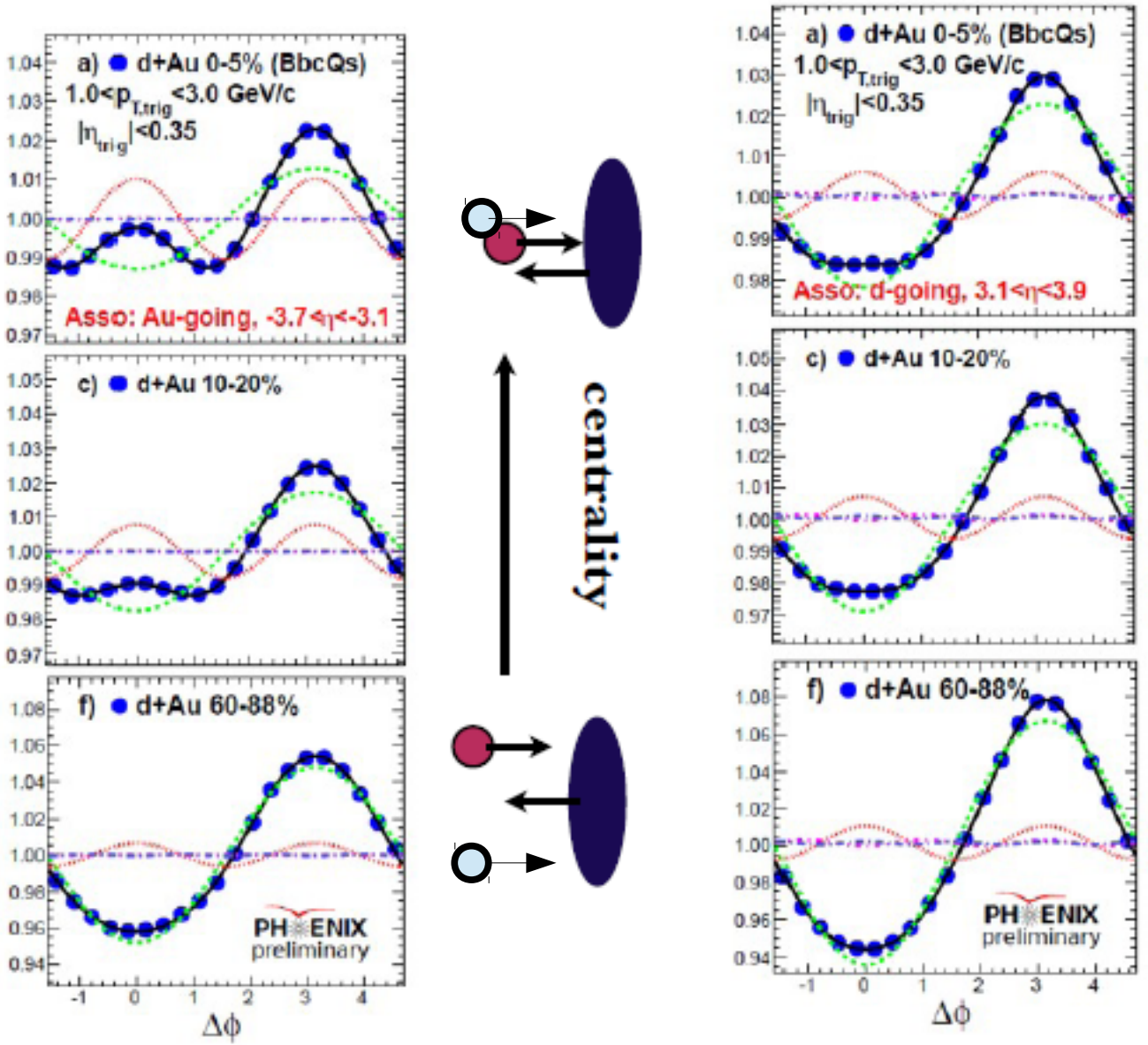
Clearly P+A @ RHIC and LHC are the critical missing links
That we must understand to resolve the new data anomalies.

Happy Birthday Takeshi. Your continued guidance is needed

Takeshi @ 70 and all of us have to cope with and learn from the 2013 pA, DA, and BES

(to be continued in Kyoto)

NEW! mid/Au-going correlations



Basic pA rapidity triangular flux density [MG]