Theory Summary

Tetsufumi Hirano

Dept. of Physics, Sophia Univ.

ΣΟΦΙΑ

φύσις

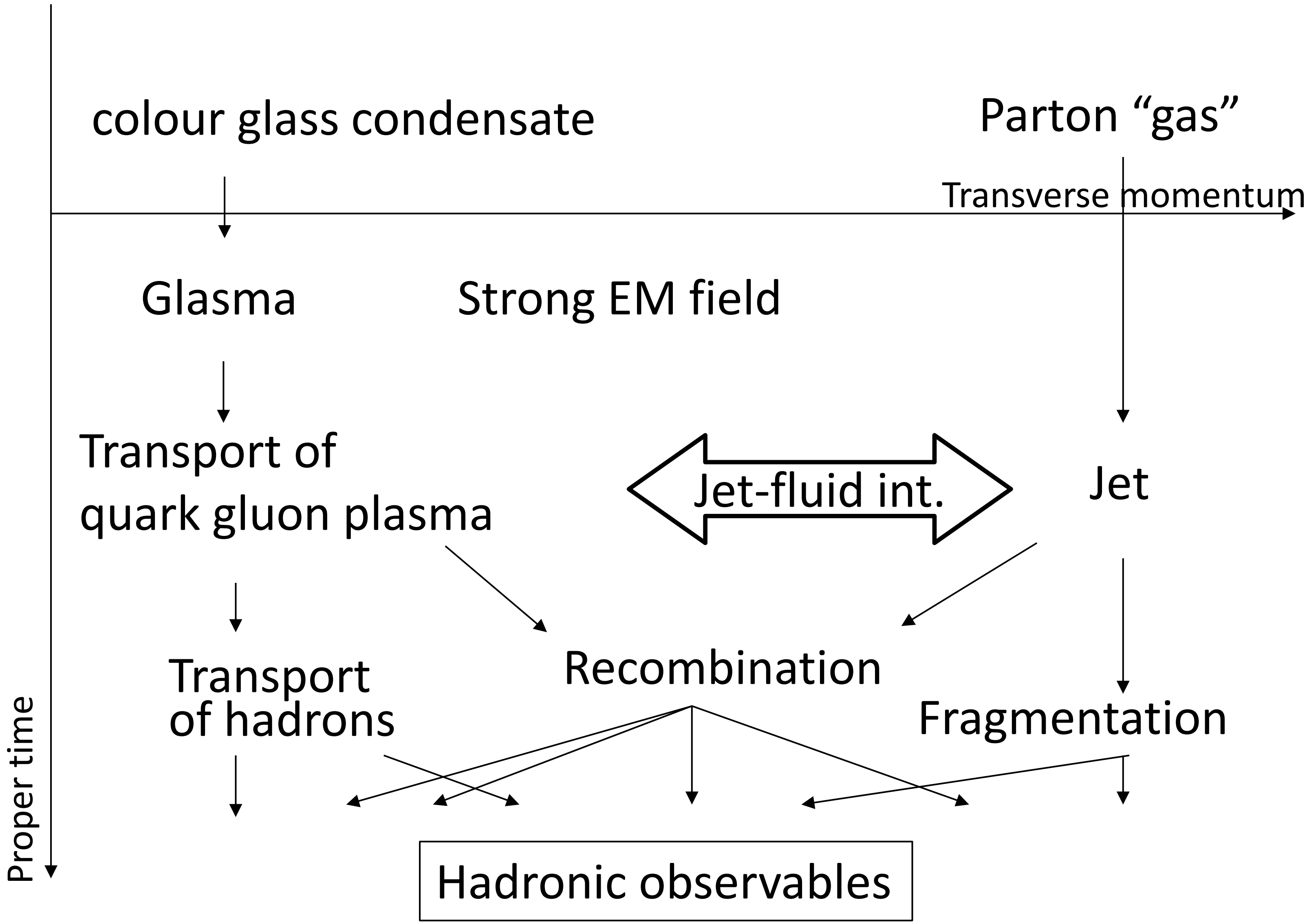
International Conference on the Initial Stages in High-Energy Nuclear Collisions

Illa da Toxa (Galicia-Spain), September 8-14, 2013

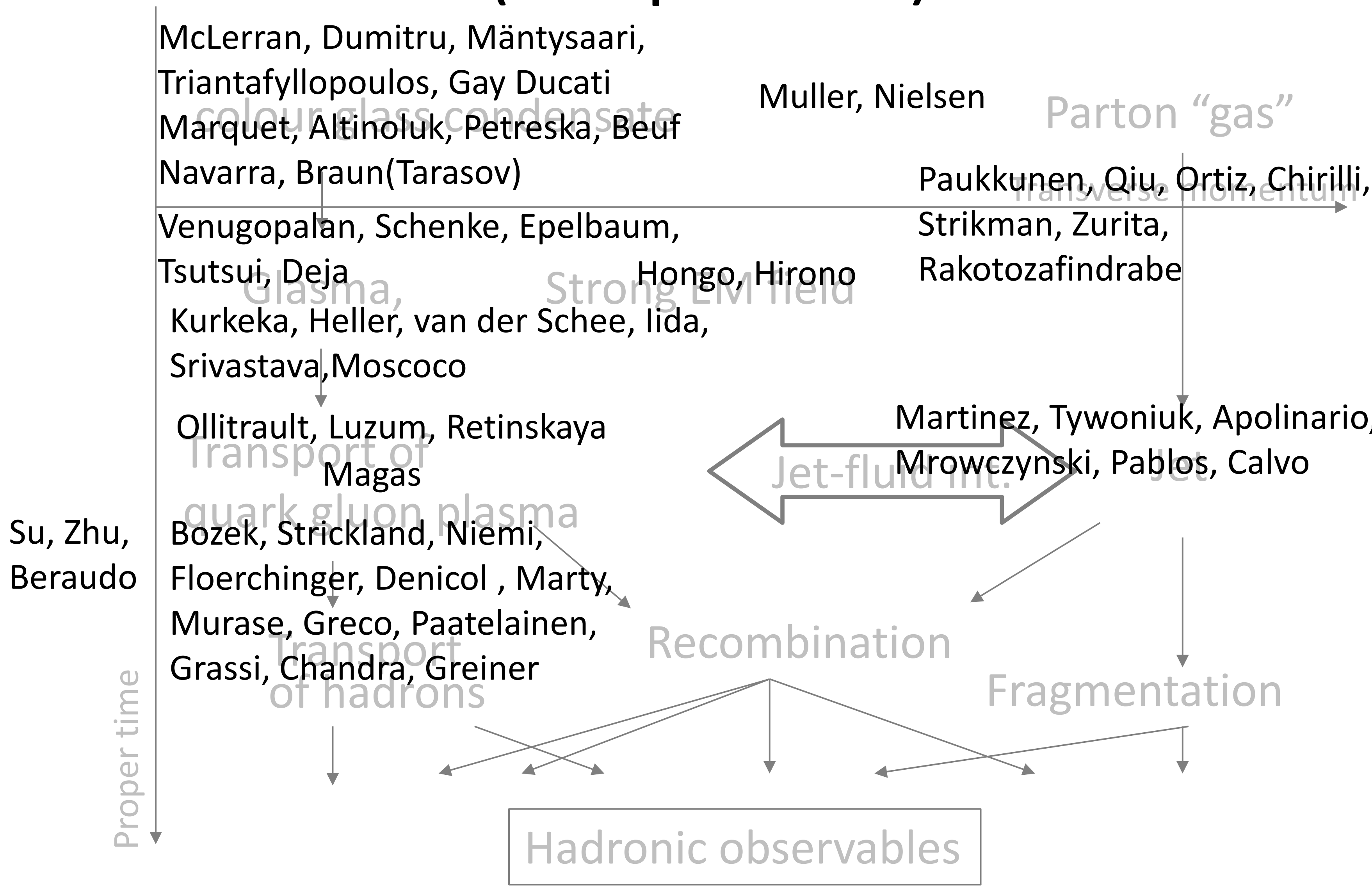
Before start

- Disclaimer…
  - 25 plenary and 33 parallel theory talks
  - Impossible to summarize all of them in 30 minutes
  - Highly biased summary
  - **Important**: Do not get angry ;-) if your work (from theory community) does not appear! This does not mean less important.

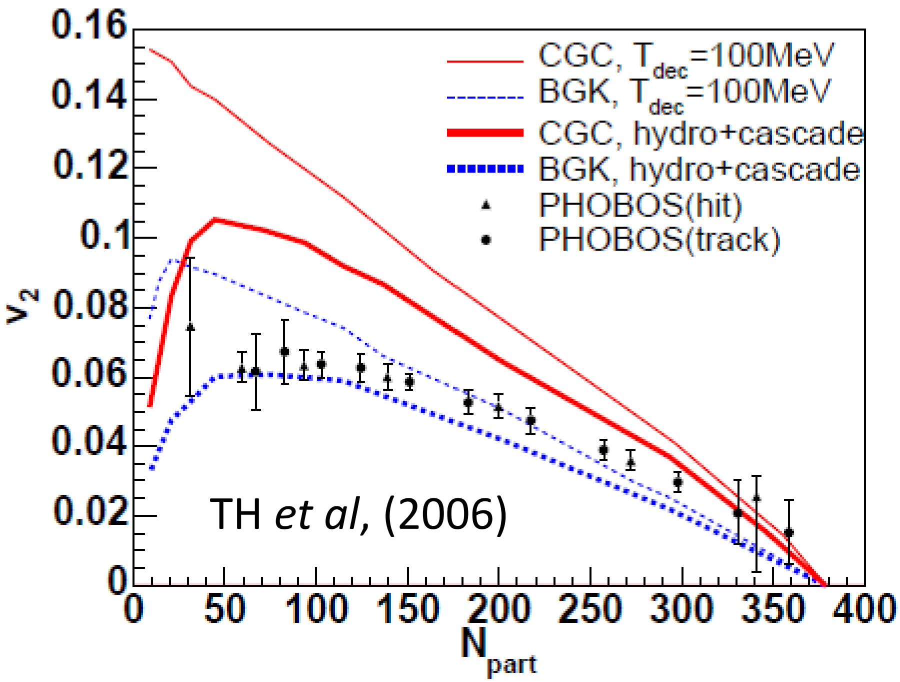
Schematic picture of H.I.C.



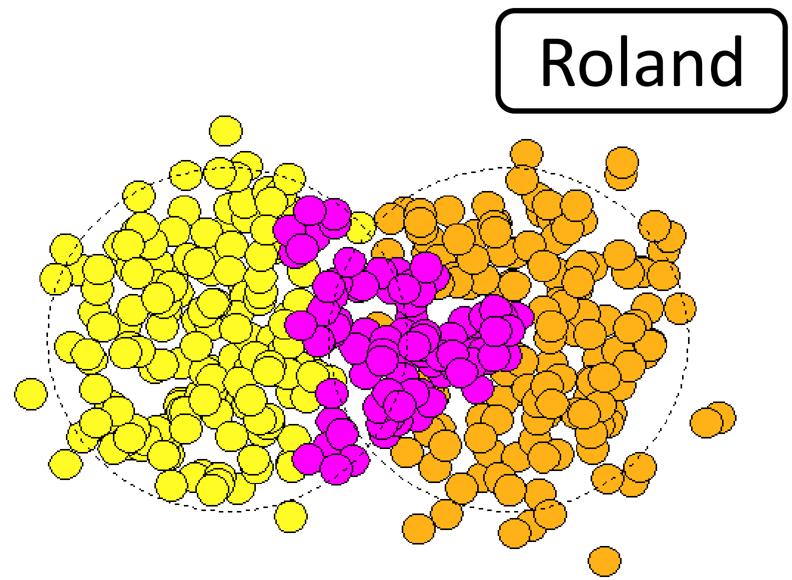
Theorist Map at IS2013 (58 speakers)



Two Results to Start with…



Hydro v_2 depends highly on initial model → Perfect fluidity?
TH as an "iconoclast"
Larry called me a "trouble maker".

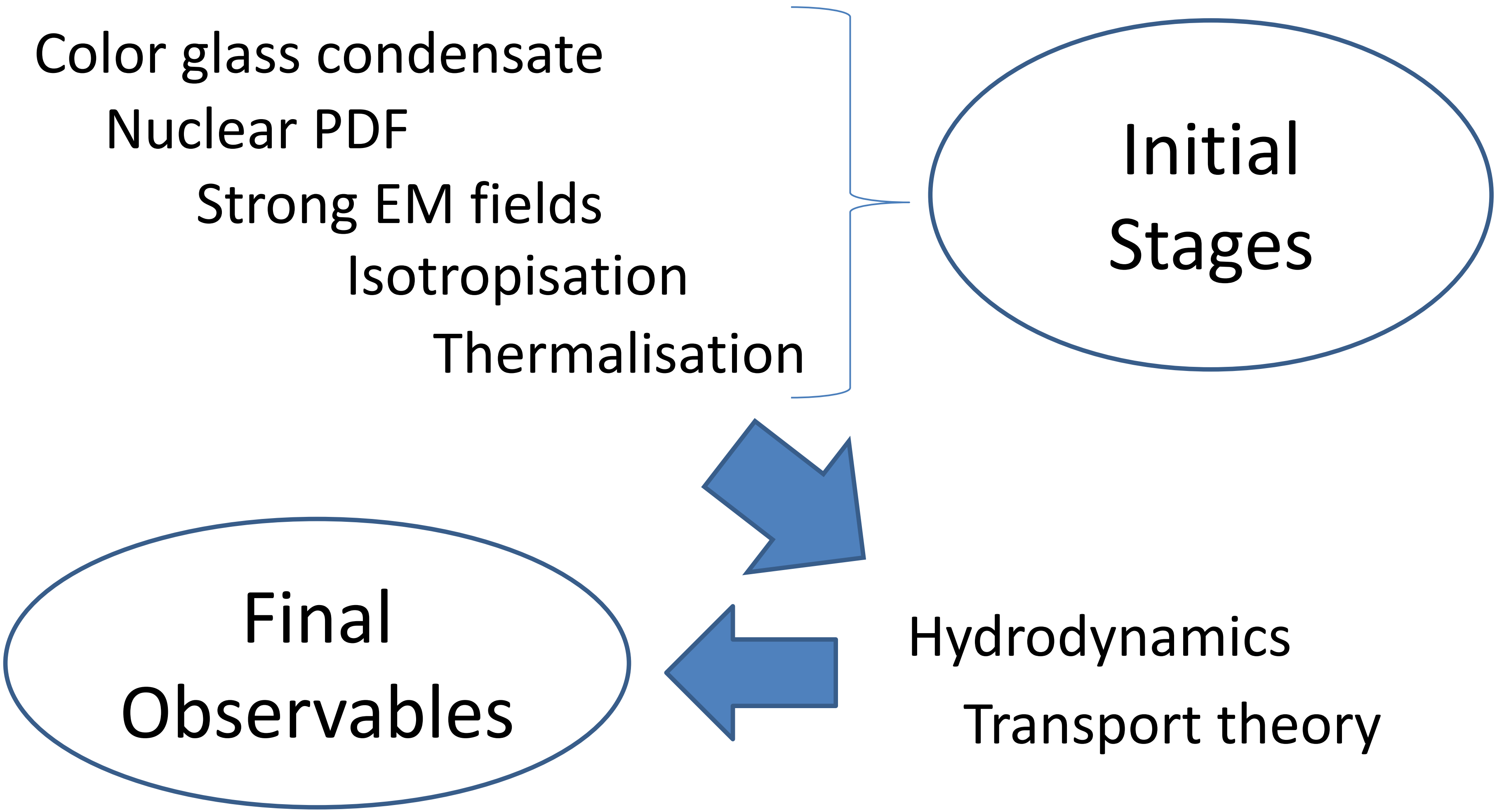


B.Alver and G. Roland (2010)

ε_3 resolves ridge and Mach cone.
See also, Gyulassy et al. ('97)
and Aguiar et al. ('02-)

A part of the main reasons why we are here to discuss "Initial Stages in high energy nuclear collisions"

Main Focus of the Conference



Old and New Picture: Paradigm change?

~2005

- Reference, baseline

- Control experiment
- Initial state effects
- Cold matter effects

- QGP creation
- Final state effects
- Hot matter effects

Old and New Picture: Paradigm change?

~2005

- Reference, baseline

???

- Control experiment
- Initial state effects
- Cold matter effects

- QGP creation
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- Hot matter effects

2012-2013

- Reference, baseline?

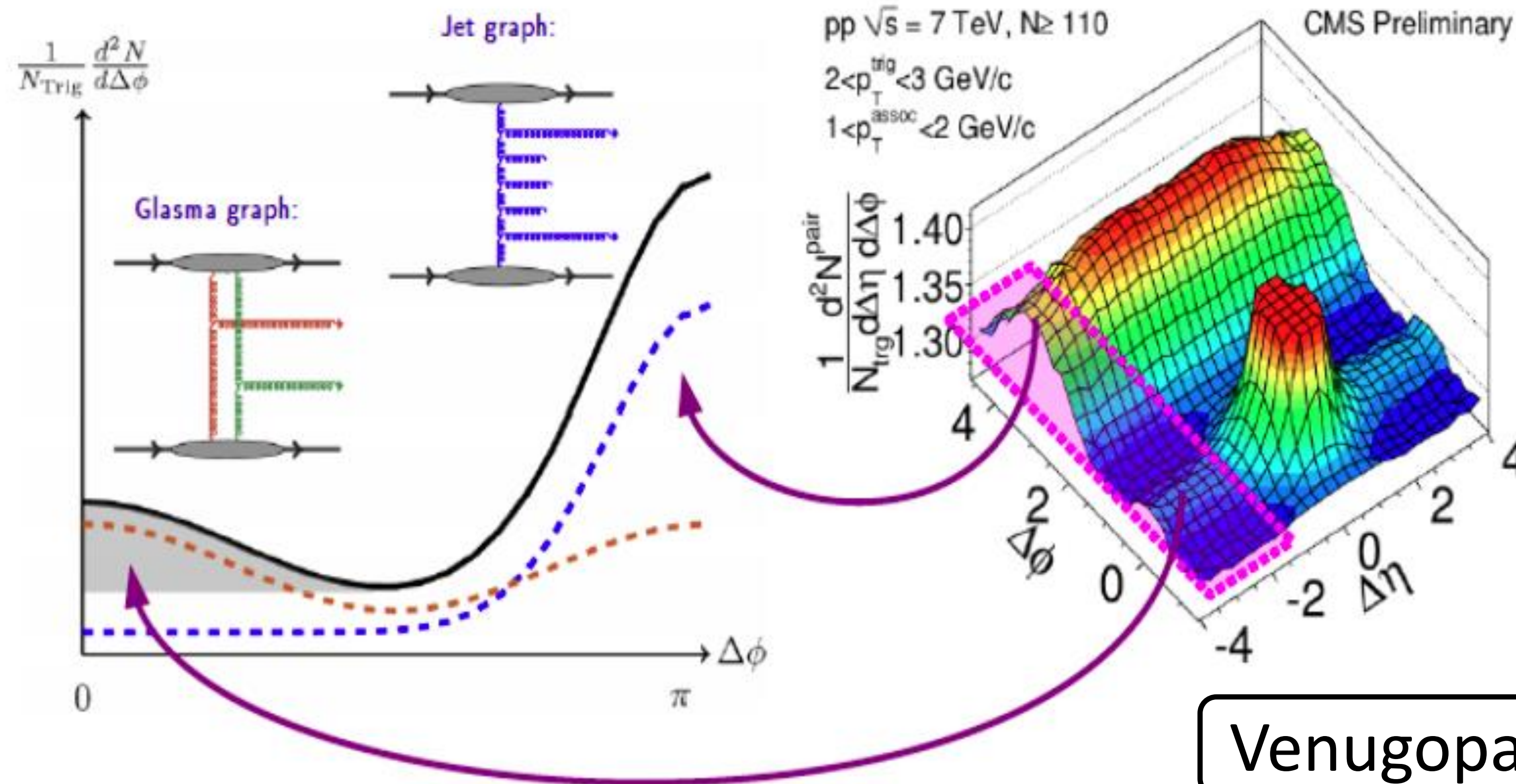
- Control experiment?
- Initial state effects?
- Cold matter?

- QGP creation
- Final state effects
- Hot matter effects
- **Strong EM field effects**

P/D-A COLLISIONS

Purpose: To understand initial state
Outcome: Non-trivial final state effects?

Interpretation from CGC

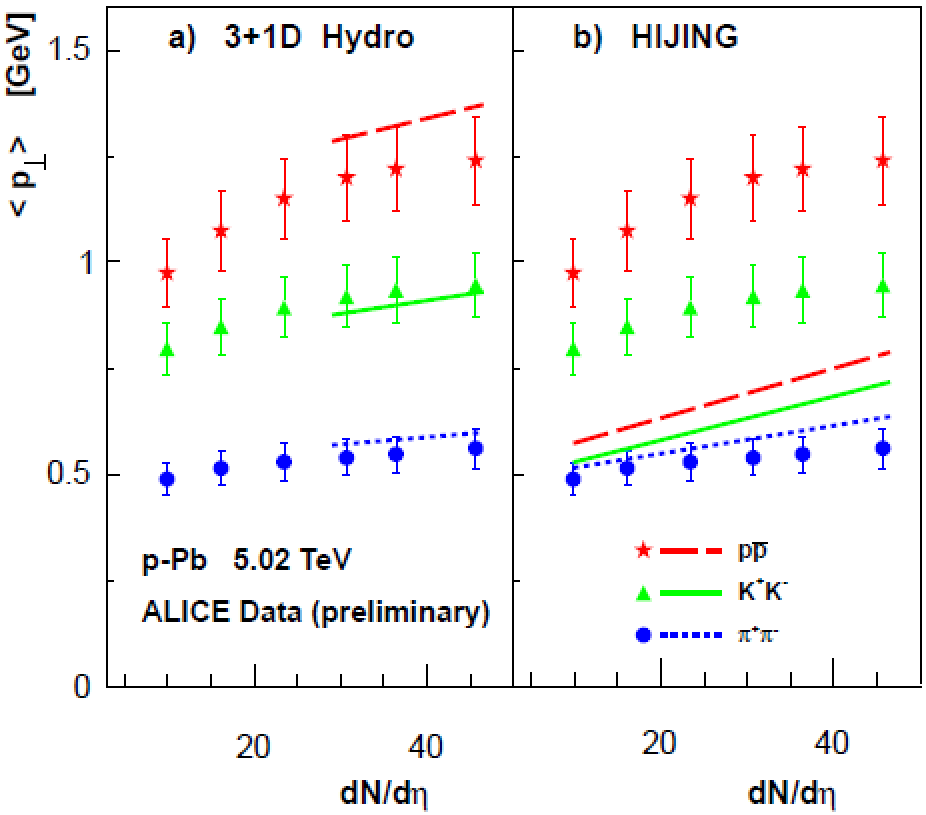


Venugopalan

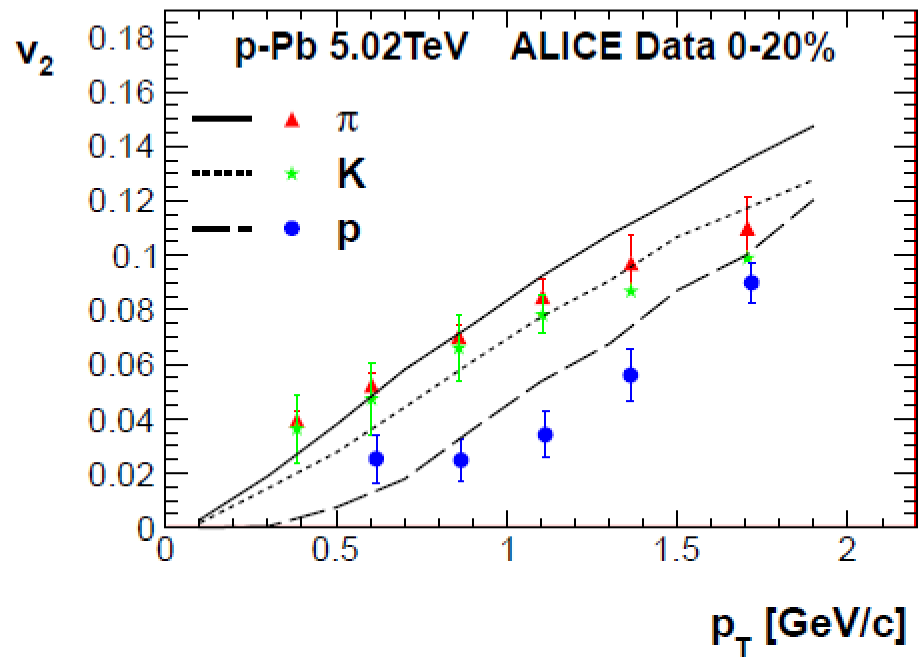
Mass Ordering in pA

Bozek

Radial flow



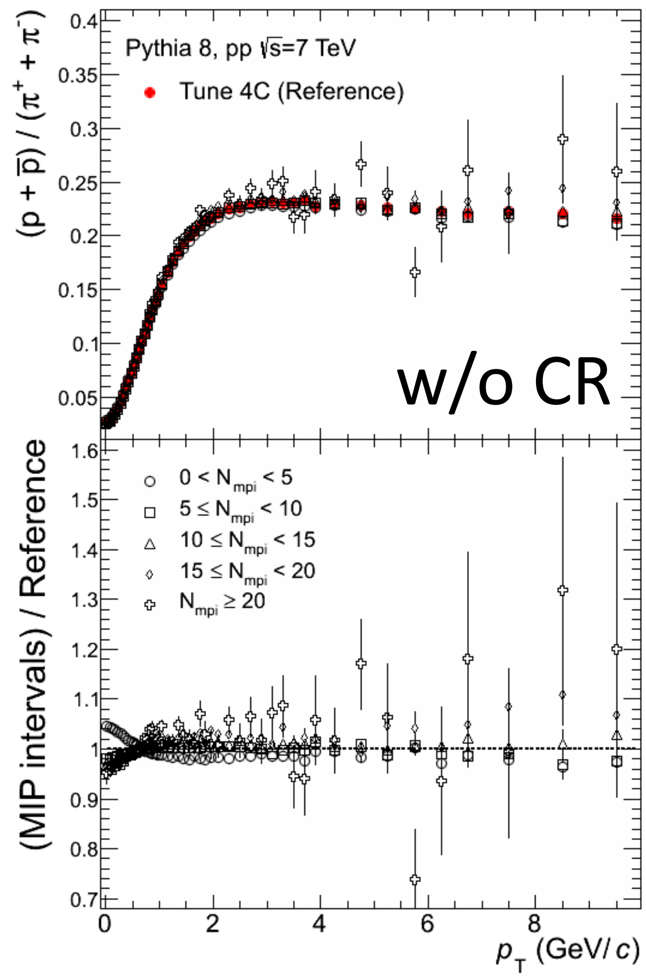
Elliptic Flow

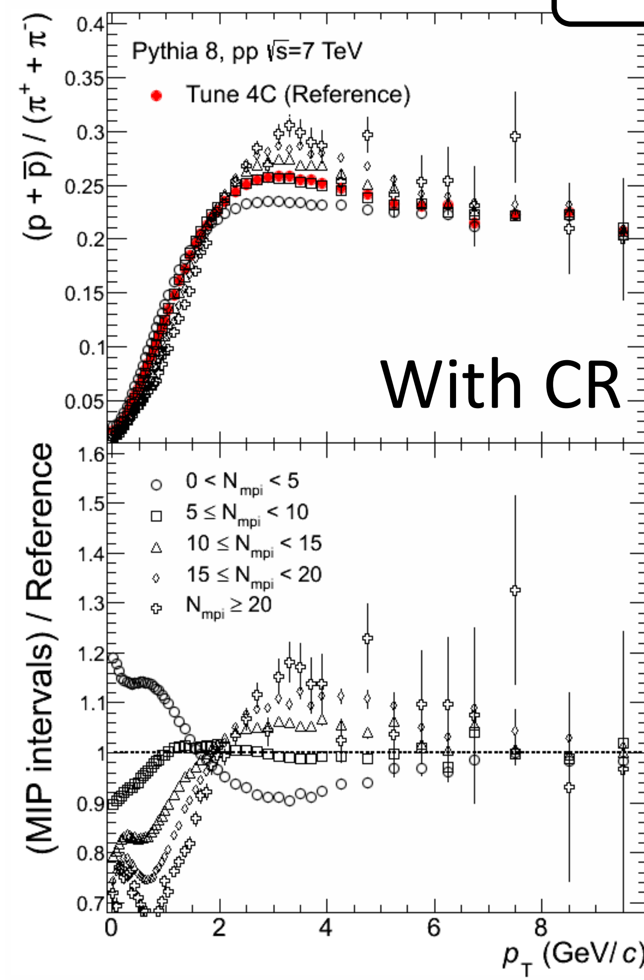


Strong indication of collectivity in pA

Color Reconnection

Ortiz





Color reconnection option in PYTHIA apparently induces flow-like effect → Ridge structure?

Marquet

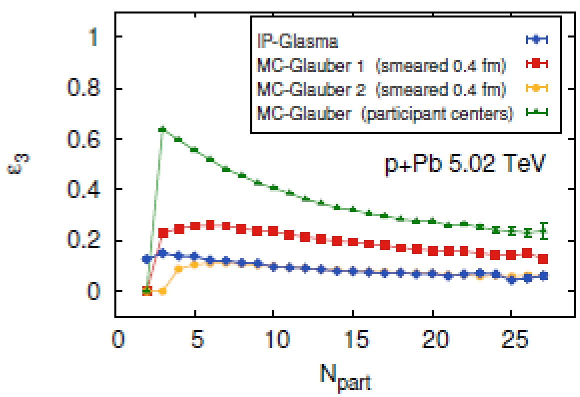
CGC or CGC+hydro ?

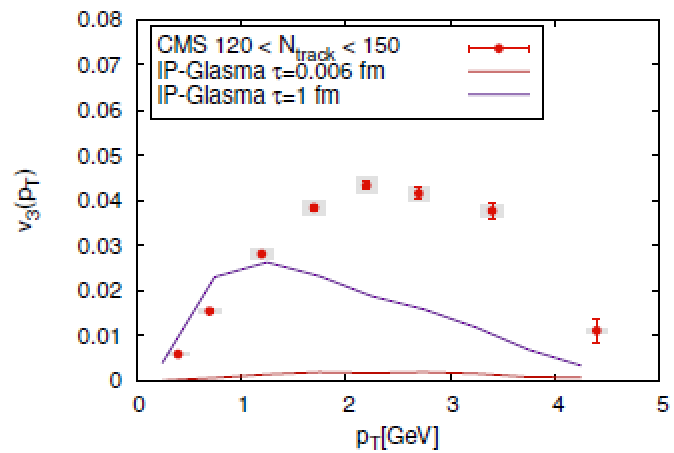
the question is not CGC or hydro, the question is CGC only, or CGC+hydro ?

- in the presence of the flow

one still needs to describe the nature and dynamics of the pre-hydro fluctuations, and the Glauber model is not enough anymore, QCD cannot be ignored

MC-Glauber 1 MC-Glauber 2



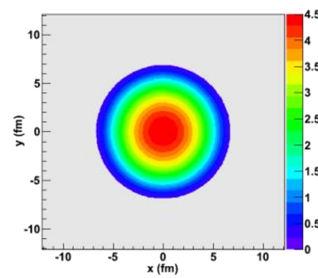
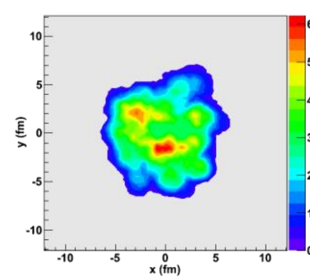


Bzdak, Schenke, Tribedy and Venugopalan (2013)

- other options to access the QCD momentum correlations ?

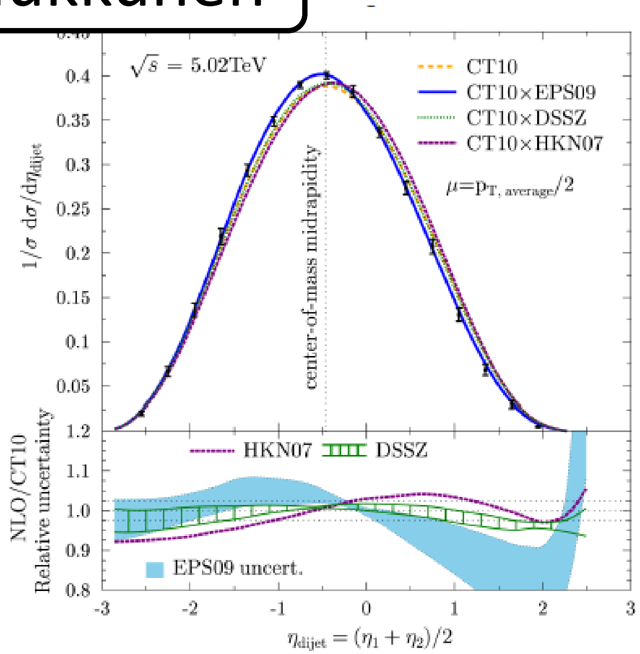
e+A collisions, and maybe p+A in the forward region

Interpretation of data using hydro

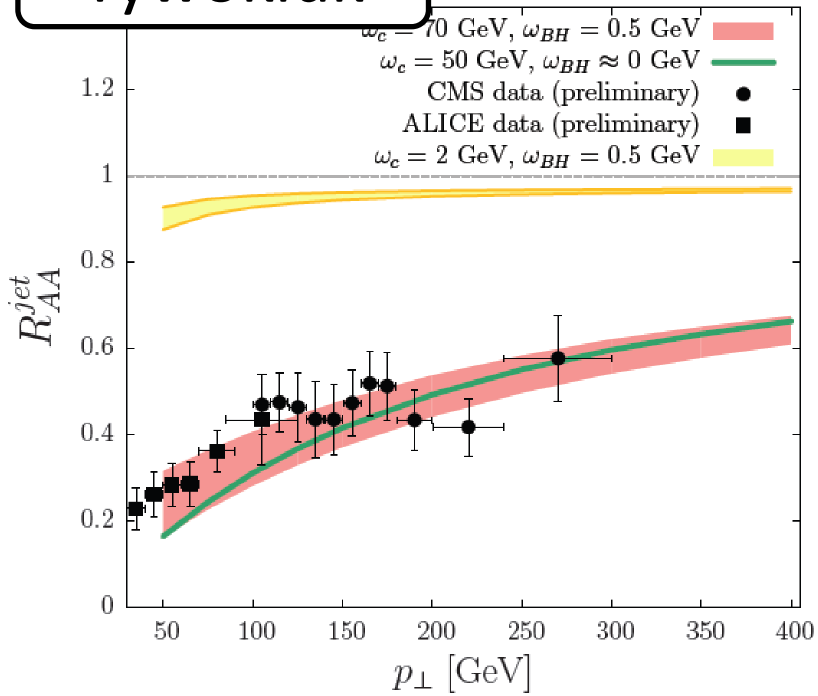
	coarse graining size	initial profile
• Most of the people did not believe hydro description of the QGP (~ 1995)		
• Hydro at work to describe elliptic flow (~ 2001)	$d \lesssim 5$ fm	
• E-by-e hydro at work to describe higher harmonics (~ 2010)	$d \lesssim 1$ fm	
• Even in p+p and/or p+A?	$d \lesssim 1$ fm?	?

Hard Probes in pA

Paukkunen



Tywokiuk



Successfull pQCD description of nuclei in DGLAP region

Almost no jet quenching in pPb

Talks by Qiu, Zurita, Rakotozafindrabe,...

ISOTROPISATION, THERMALISATION, ANISOTROPIC HYDRO

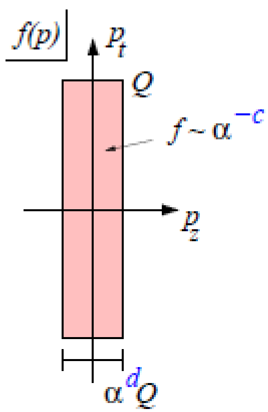
Isotropisation/Themalisation

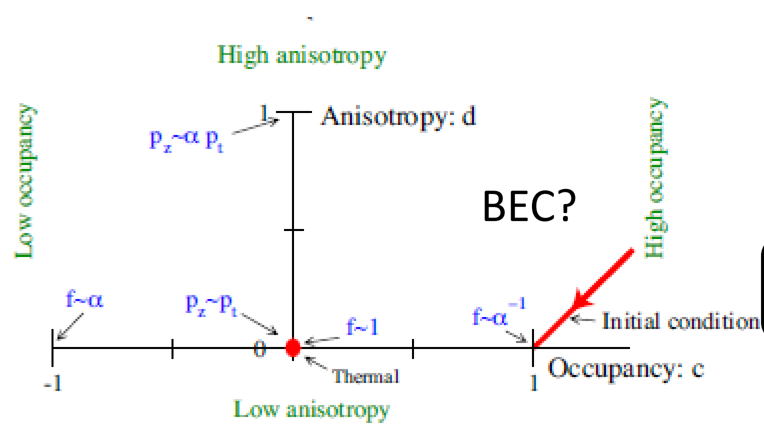
$$T^{\mu\nu} = \mathrm{diag}(\epsilon(0^+), \epsilon, \epsilon, -\epsilon)$$

Negative pressure
→ Negaive pdV work
→ Energy stored in the system
→ Something like an elastic body

$$T^{\mu\nu} = \mathrm{diag}\big(\epsilon\big(\tau_{\mathrm{iso/therm}}\big), P_T, P_T, P_L\big)$$

with $P_T \approx P_L$



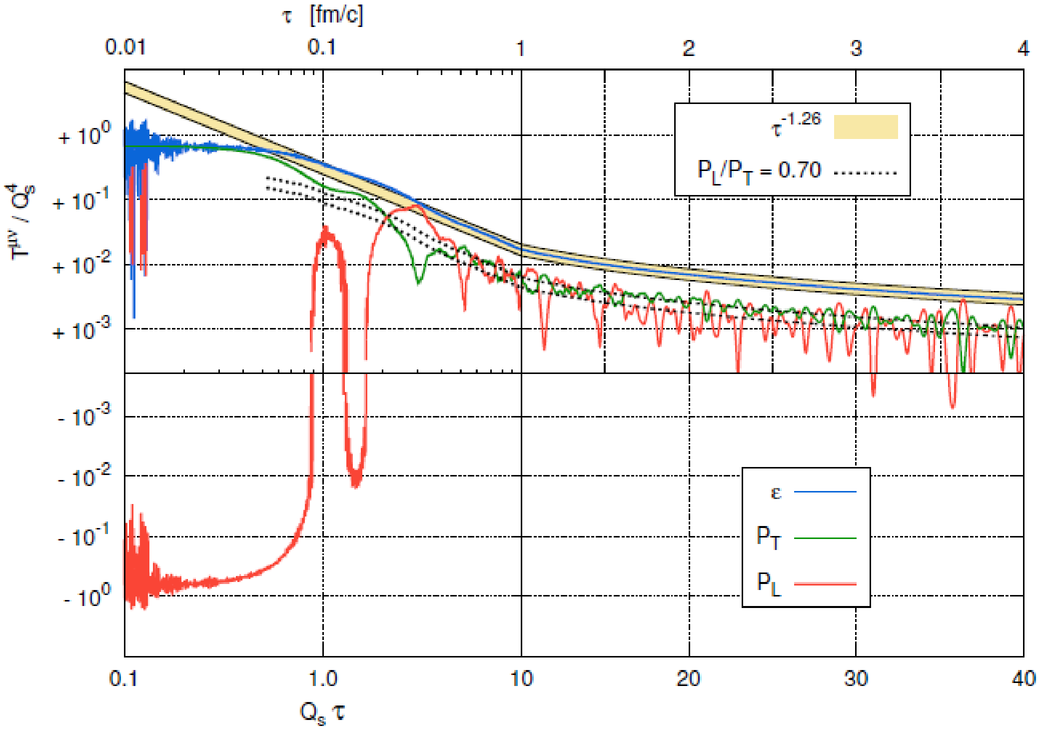


Kurkela

Talks by McLerran, Venugopalan, Schenke, Epelbaum, Kurkeka, Heller, Van der Schee, Iida, Srivastava, Tsutsui ,…

Longitudinal and transverse pressure vs. proper time

Epelbaum



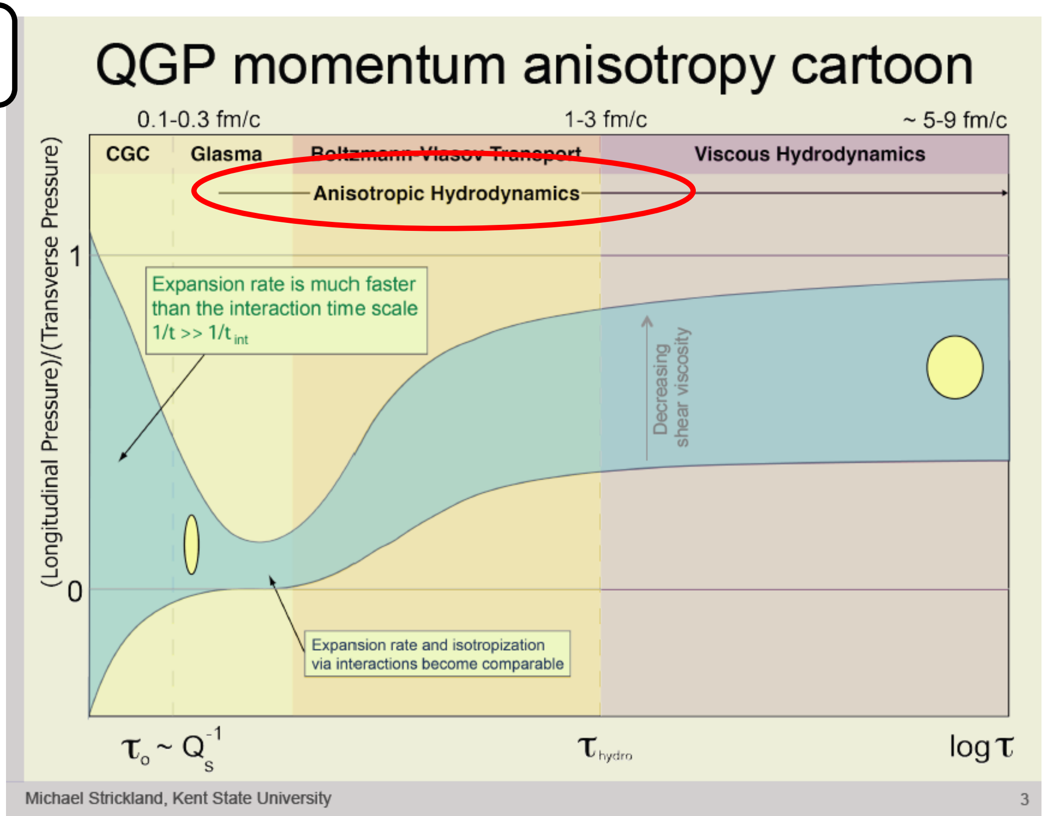
System reaches a hydrodynamic regime at ~ **0.4 fm/c**! even for small coupling (α_s ~10^{-2})

AdS/CFT: Heller, van der Schee, pQCD: Kurkela, CYM: Iida, Abellian Higgs: McLerran

Anisotropic Hydro

Anisotropic hydro can help to describe $P_T > P_L$

Strickland



Applicability of hydro → Extended to earlier stage

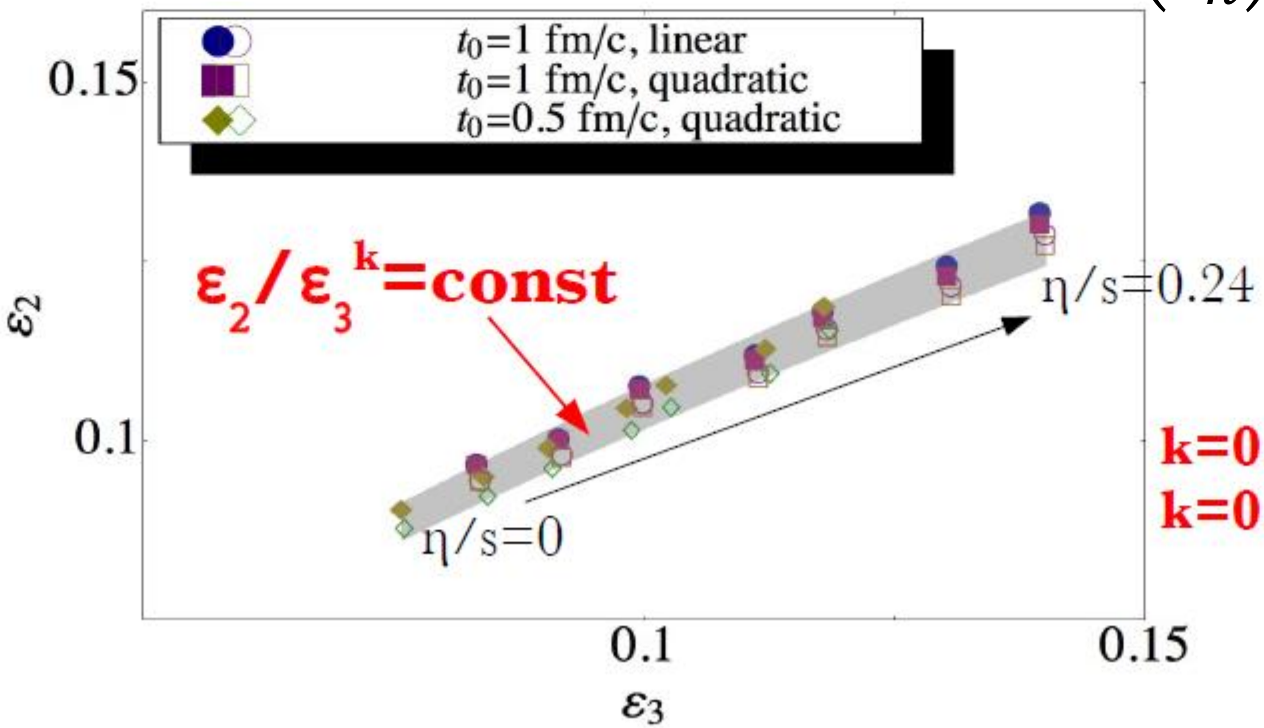
Talks by Mrowczynski, Deja

FLUCTUATION, FLUCTUATION, …

Initial Fluctuation and Harmonics

Retinskaya

Inverse problem $$v_n(\text{exp. data}) = \left(\frac{v_n}{\varepsilon_n}\right)_{\text{hydro}} \varepsilon_n$$



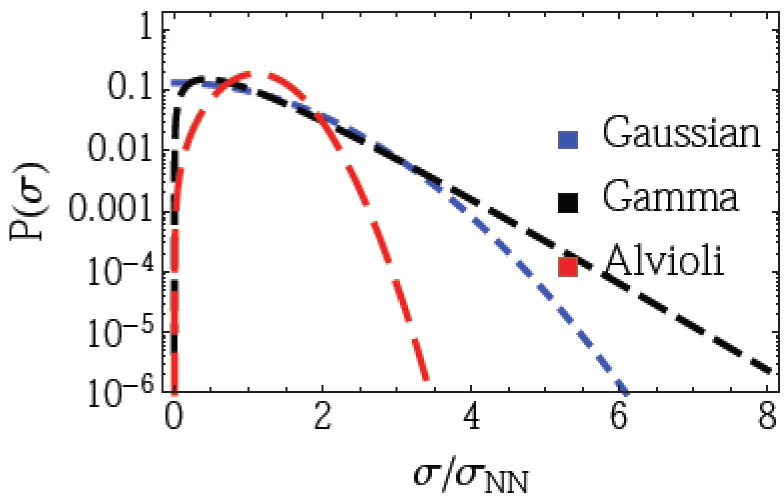
k=0.6 (LHC)
k=0.5 (RHIC)

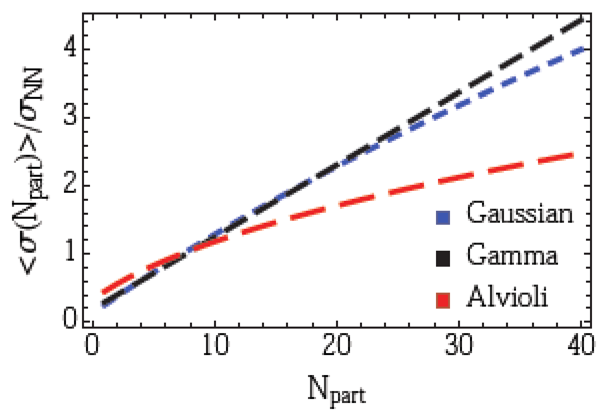
Talks by Ollitrault, Luzum, Retinskaya, Schenke, Niemi, Floerchinger, Marty,…

Fluctuation, fluctuation, …

Mueller

Fluctuation of NN inelastic cross section → "Fat" proton

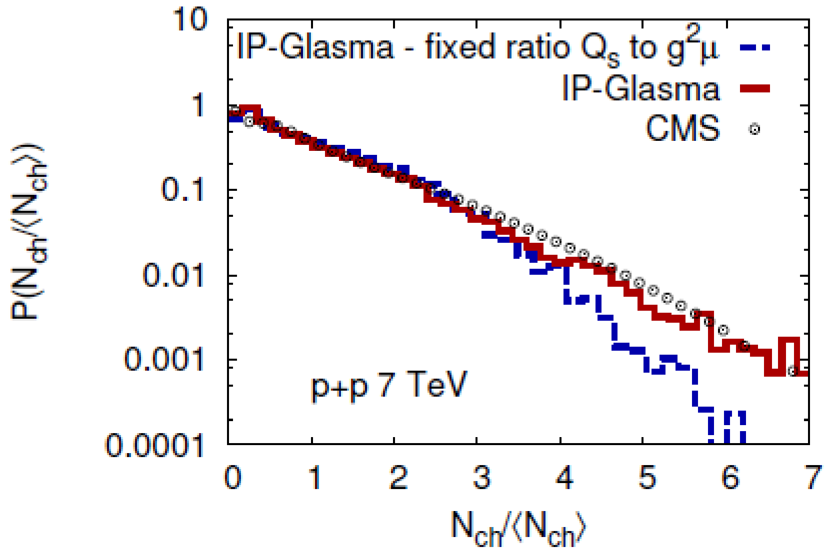




Large N_{part} and high multiplicity events
→ Sufficient deposited energy and reasonable gradient
→ Hydro applicable even in pp/pA collisions

Fluctuation, fluctuation, …

Fluctuation of saturation scale



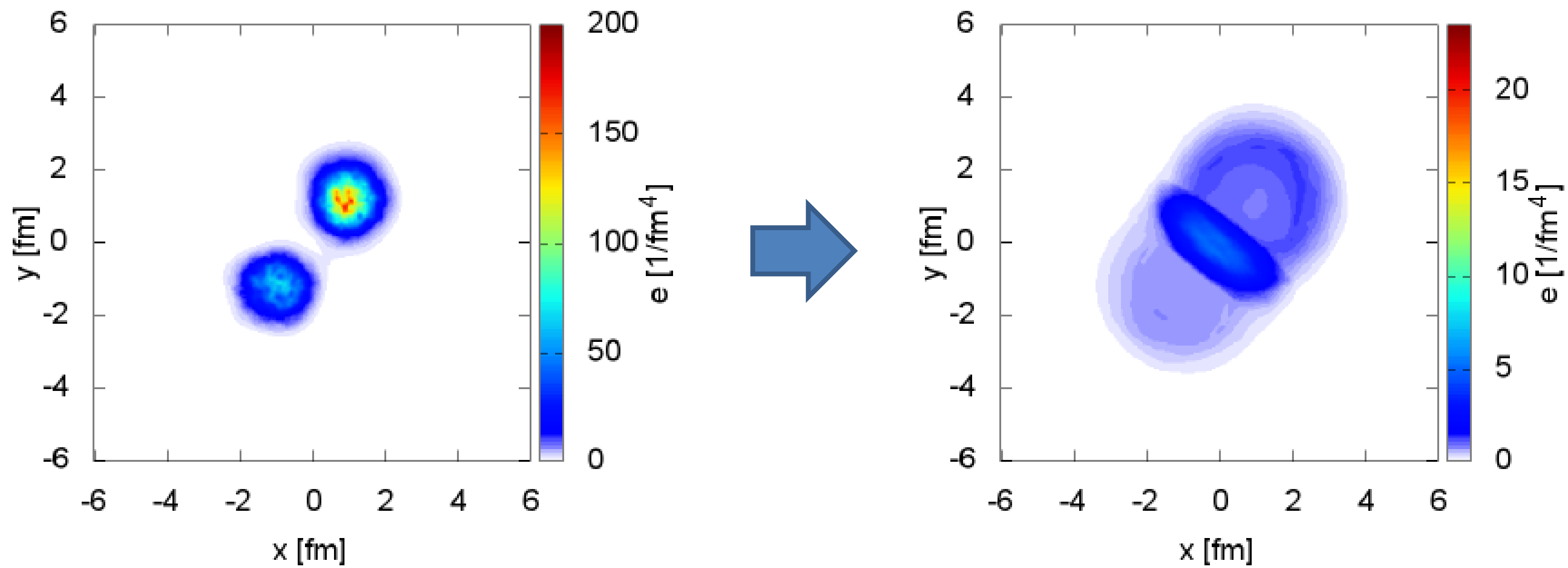
Schenke

→ Important in high multiplicity events in CGC

Fluctuation in quantum evolution: Dumitru, Triantafyllopoulos

Shock Wave in dA (and AA?)

Schenke



Squeeze-out in perpendicular direction?

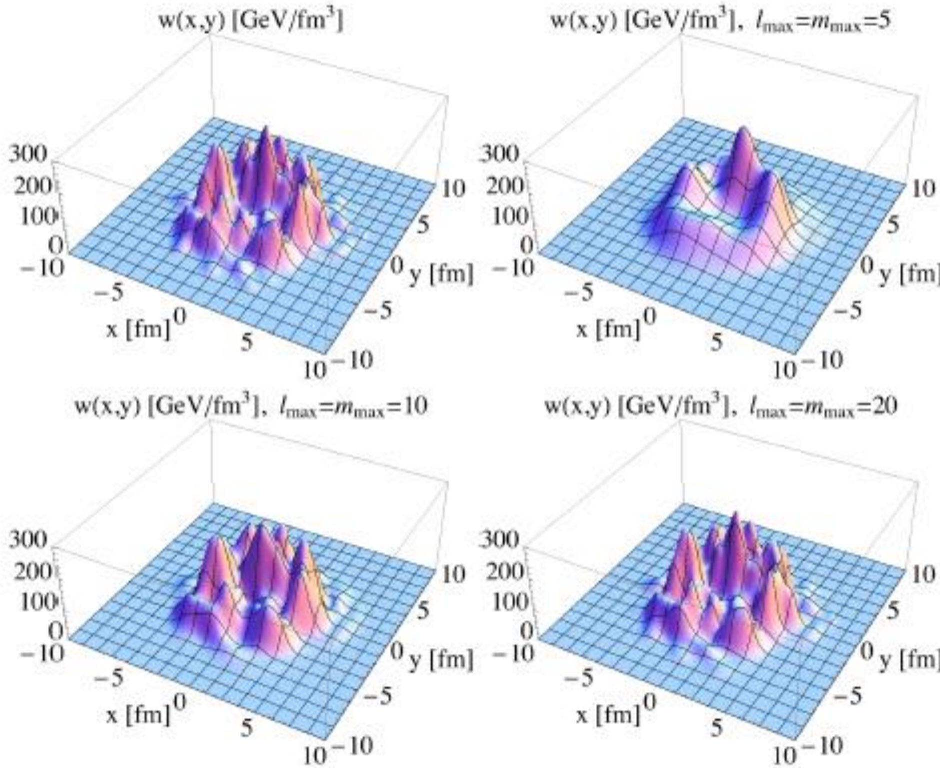
Any implication in observables?

See also, Volcano scenario: T.D.Lee, CU–TP–226 (1982)

Gyulassy, Rischke, Zhang, Nucl.Phys. A613 (1997) 397

Fluctuation, fluctuation, …

Initial enthalpy fluctuation and its expansion in 2D space



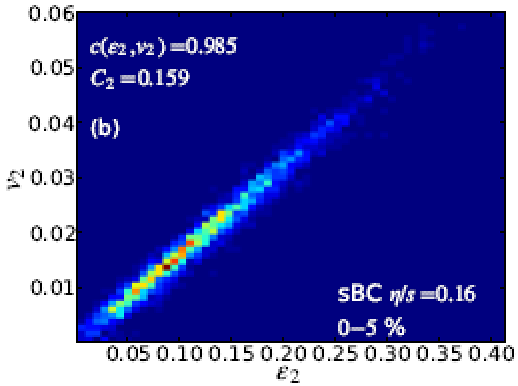
Floerchinger

New technique:
"Perturbative" hydrodynamics/
background field method

Fluctuation, fluctuation, …

Niemi

Final state



Initial state

$$v_2 \propto \varepsilon_2$$

Almost one-to-one mapping in viscous hydro

See also, Ollitrault, Luzum, Retinskaya,…

Murase

Fluctuating causal hydro

thermal fluctuation

$$\Pi(x) = \int d^4x' G_R(x, x') F(x') + \delta\Pi(x)$$

How much one-to-one mapping affected?

HYDRO AND TRANSPORT THEORY

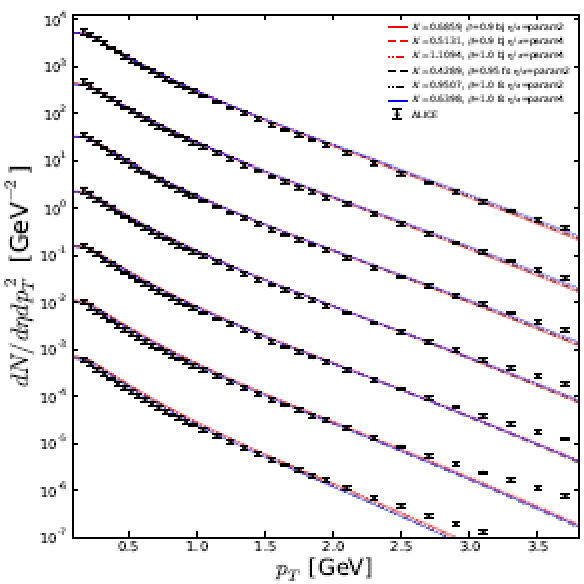
pQCD + final state saturation +(2+1)D viscous hydro

Paatelainen

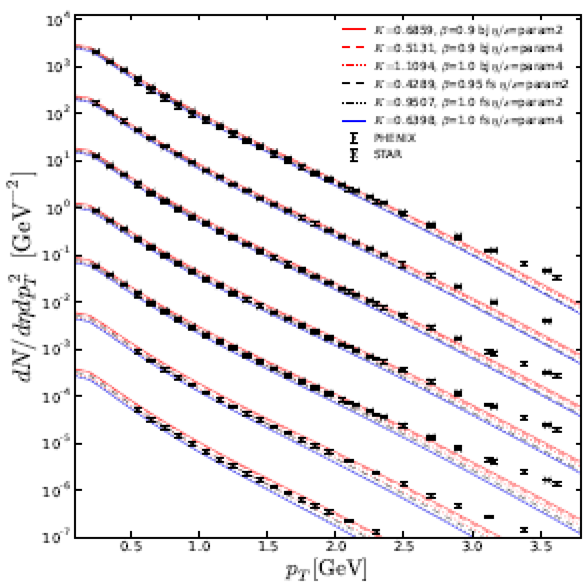
Charged particle p_T spectra VS Data at the LHC and RHIC

- T_{chem} determines the low p_T shape of the spectra (better shape with PCE 175 MeV than 150 MeV)

LHC



RHIC

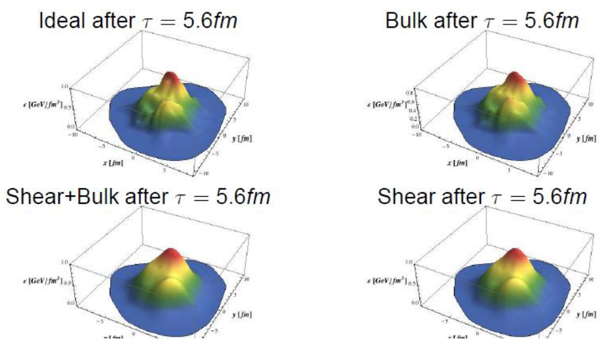


Brand-New Viscous Hydro Codes

Grassi

v-USPhydro

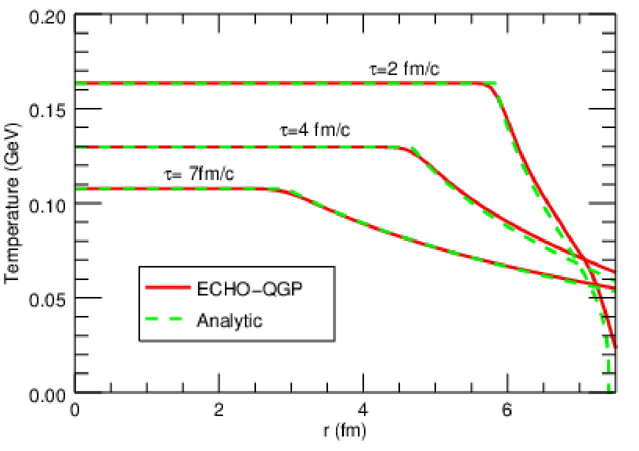
← Successor of NeXSPheRIO



Effect of bulk viscosity

Chandra

ECHO-QGP



Numerical test done

→ Data analysis

*USP=Ultrarelativistic Smooth Particle
=Universidade de São Paulo

*ECHO=Eulerian Conservative High-Order Code

Full 2nd Order

Denicol

Compare

wo/ nonlinear terms

$$\tau_\pi \dot{\pi}^{\langle\mu\nu\rangle} + \pi^{\mu\nu} = 2\eta\sigma^{\mu\nu} - \frac{4}{3}\tau_\pi \pi^{\mu\nu}\theta$$

w/ nonlinear terms

$$\tau_\pi \dot{\pi}^{\langle\mu\nu\rangle} + \pi^{\mu\nu} = 2\eta\sigma^{\mu\nu} + 2\pi_\alpha^{\langle\mu}\omega^{\nu\rangle\alpha} - \frac{4}{3}\tau_\pi \pi^{\mu\nu}\theta + \frac{18}{35}\tau_\pi \frac{\pi_\alpha^{\langle\mu}\pi^{\nu\rangle\alpha}}{\varepsilon_0 + P_0} - \frac{10}{7}\tau_\pi \pi_\alpha^{\langle\mu}\sigma^{\nu\rangle\alpha}.$$

what is the difference?

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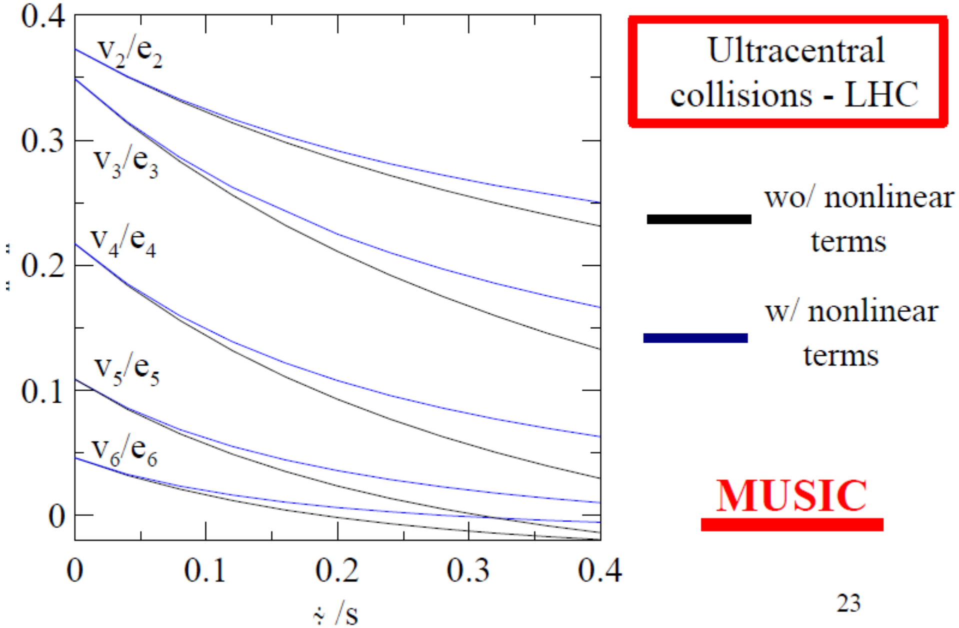
Effect of nonlinear terms



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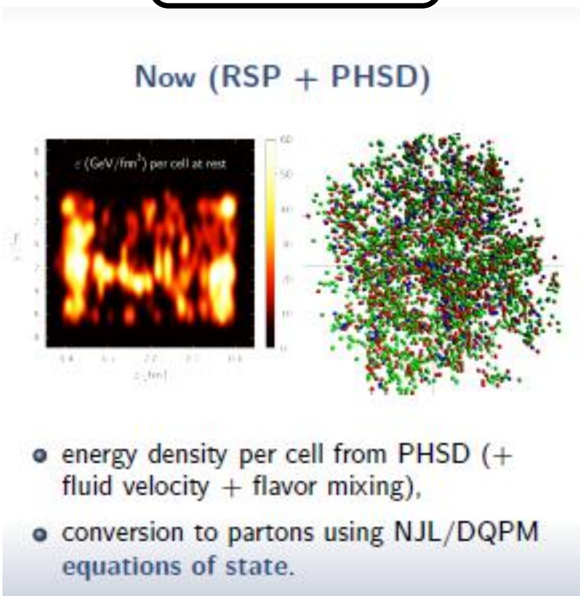
Need to implement of full 2nd order terms in codes in the next generation

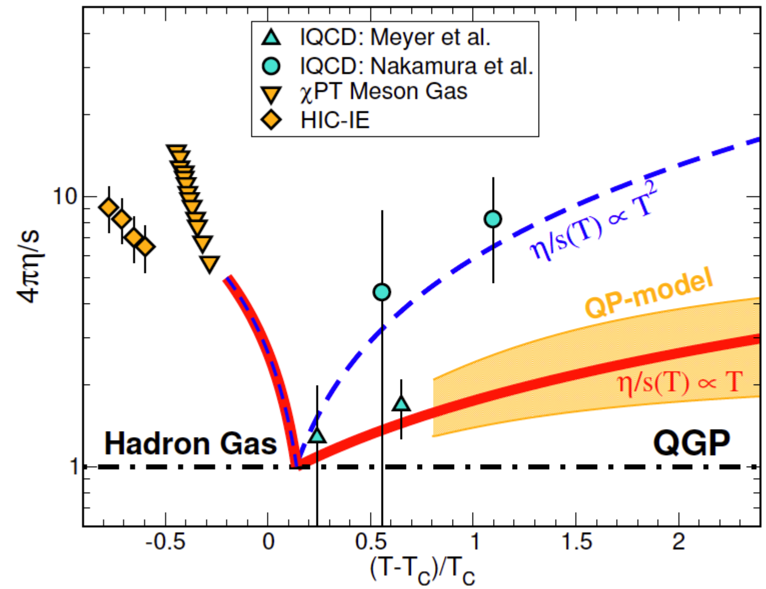
Kinetic Approaches

Marty



kinetic + NJL
→ phase transition behaviour

Greco



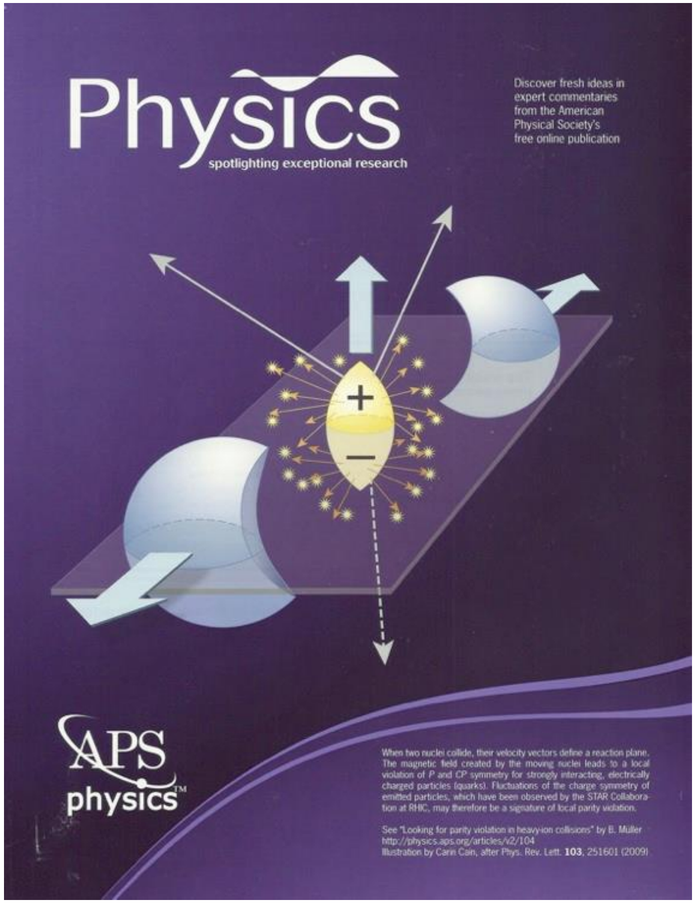
Implement wanted η/s in transport model

Kinetic approaches → Non-eq. + Hydro-like behaviour

See also talk by Greiner on BAMPS

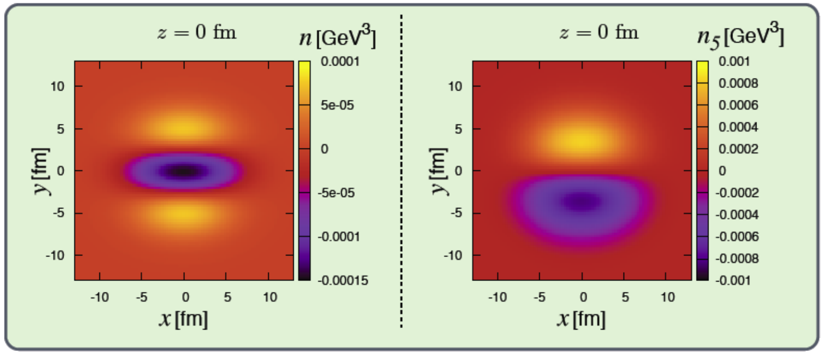
Strong EM fields

Voloshin



$eB \sim 10^{17}$ Gauss

Hongo



Chiral magnetic wave in expanding background

Charge dep. v_2?→ Alternative interpretation by Bozek

Hirono

Strong E-field in Cu+Au collisions

→ Measure E-field?

Summary of Summary

- p/d-A collisions provide us with a new opportunity to learn novel aspects of high energy hadron/nuclear reaction in a unified picture.
- Let us keep in touch with each other between sub-communities of initial stages (CGC, nuclear PDF, …) and final evolution (hydro, …).
- Future e-A program should shed light on more precise structure of hadrons/nuclei at very high energy.

Before the End…


Let's thank
Carlos^2, Nestor and
local organisers
for excellent
organisation
of the conference!