The ``ridges" and large jet v_2 are explained by magnetic plasma near Tc

(“CGC workshop, BNL, May 11th 2010)

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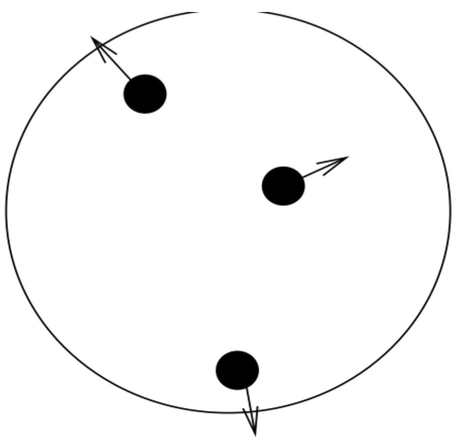
Outlook:

- the ridges: not just flow but

(quite robust) flux tubes!

- ``tomography” (v2) of the jets show that it happens near Tc
- “magnetic” (color monopole) plasma near Tc to explain them, as well as deconfinement!

Three main observations from jet correlations may be explained by:



- ``cone” on the away side => hydro flow

(H.Stoecker,J.Casalderrey+ES, 2005)

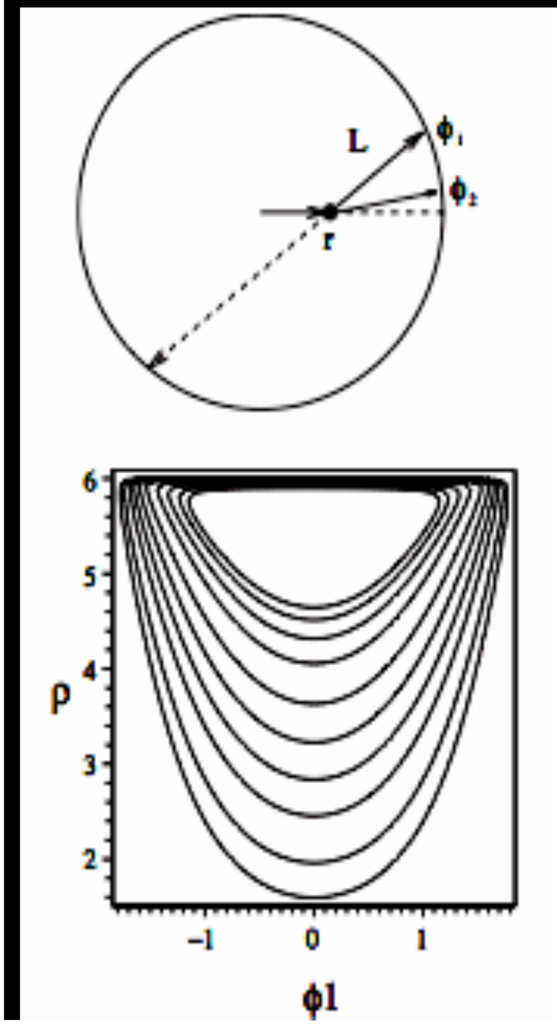
- ``Hard ridge” => forward-backward bremmstrahlung cones kicked out by hydro radial flow **(4 jets!)**

(Shuryak 0706.3531, PRC76)

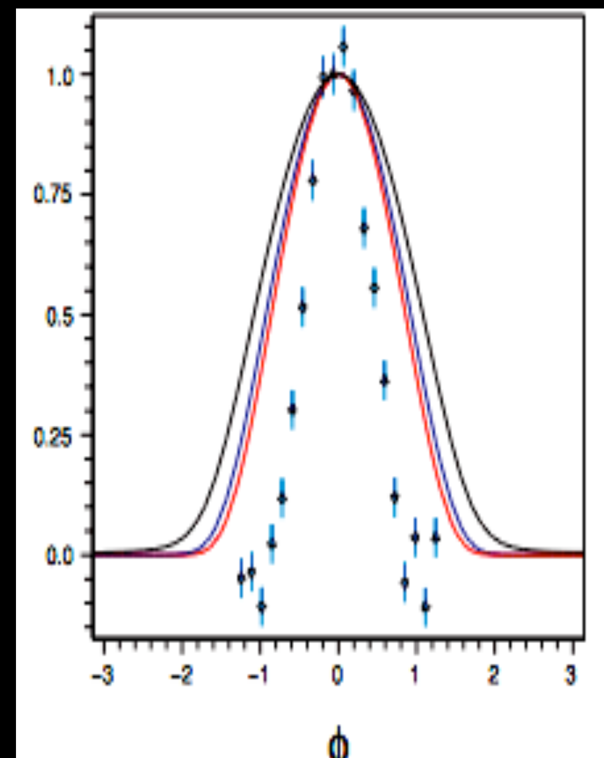
- ``Soft ridge” => initial stage fluctuation of the color changes, also carried by flow

(Dumitru,Gelis,McLerran,Venugopalan, 0804.3858, Gavin et al 0806.4718)

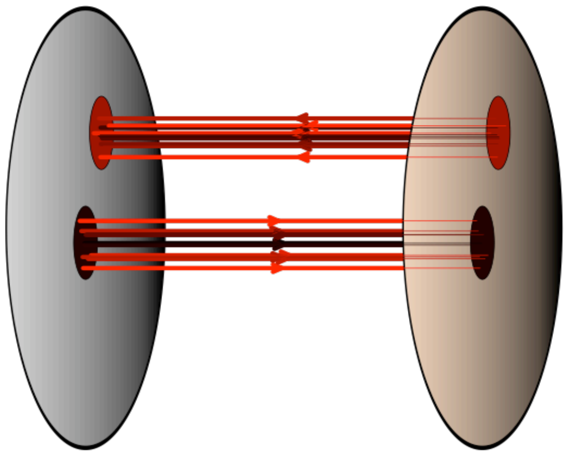
The jets we trigger on are biased to be near the nuclear surface:



- thus their phi is correlated with the flow
- Forward-backward jets deposite several extra particles into the fireball
- Those gets carried by the flow and seen as a ridge, in a wide rapidity range

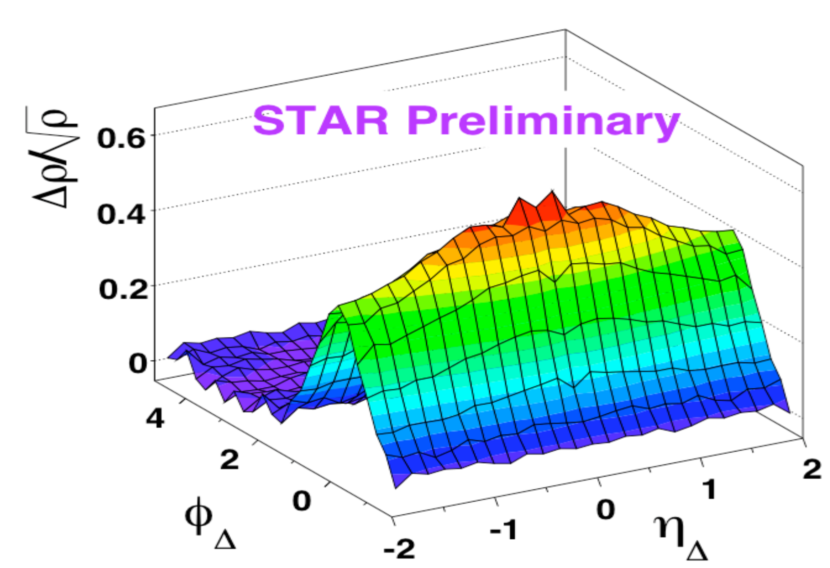


the``soft ridge" exists even **without** any hard trigger



McLerran et al:
Fluctuations of
Color charges
At early time

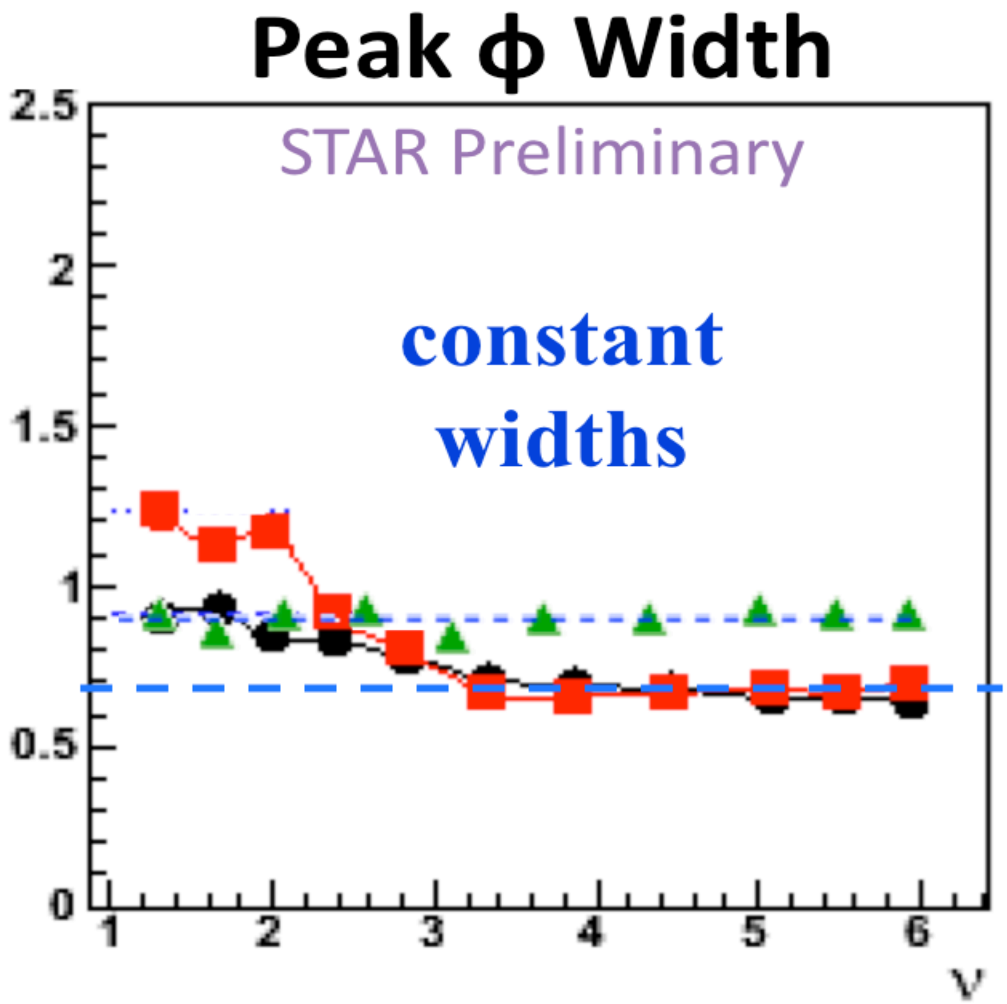
$$1/Q_s \sim .2fm/c$$



(Phobos further observed that ridge extends at least till |y|=4)

What happens next, till freezeout (>10 fm), is quite nontrivial

The peak width decreases for central collisions



- L.Ray

PHYSICAL REVIEW C **80**, 054908 (2009)

Fate of the initial state perturbations in heavy ion collisions

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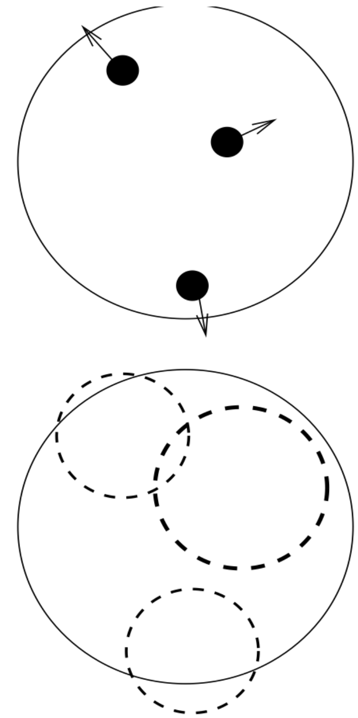
(Received 20 July 2009; revised manuscript received 14 October 2009; published 13 November 2009)



Naively, ``spots" should excite a wave and get expanded to a spherical (or conical, or cylindrical) wave

Like in the case of stone thrown into the pond, nothing is left at the original position: **so how can they be observed?**

Its size =>the sound horizon => is comparable to fireball size 6-8 fm/c

$$R_h = \int_0^{\tau_f} d\tau c_s(\tau)$$

And thus large angular size

If one wants to get large radial flow, one has to wait the time needed for it to develop. The sound speed during this time creates large rings.

Can we restrict its size (at freezeout) from the data?

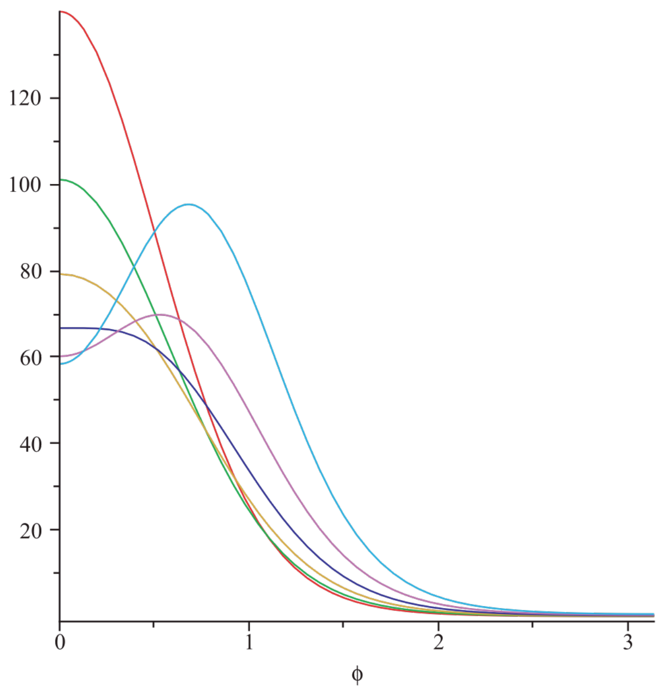


FIG. 5. (Color online) Dependence of the visible distribution in the azimuthal angle on the width of the (semi)circle at the time of freeze-out. Six curves, from the most narrow to the widest ones, correspond to the radius of the circle of 1, 2, 3, 4, 5, and 6 fm, respectively. The original spot position is selected to be at the edge of the nuclei. The distribution is calculated for a particle of $p_t = 1$ GeV and fixed freeze-out $T_f = 165$ MeV.

- This is how azimuthal distribution would look like:
- comparing with data, we concllude

$$R(\tau_{\text{freeze-out}}) < 3\,\text{fm} \;\text{ or }\; \text{so.}$$

The decay products of the ridge are clusters which are larger than in pp!

they have up to 10 pions and they decay unisotropically

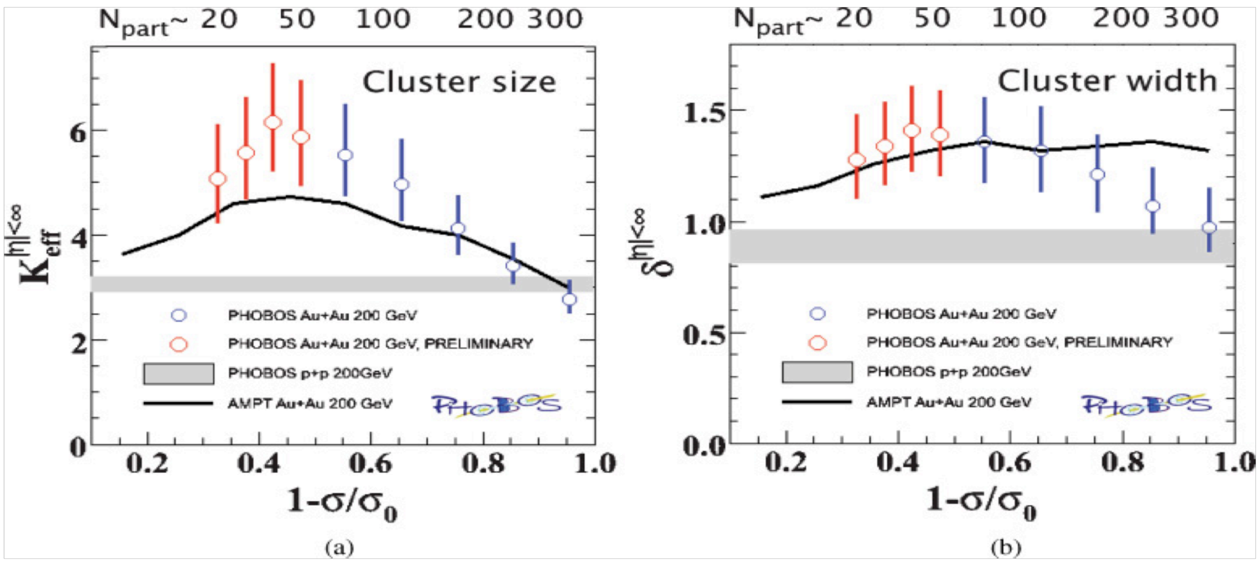
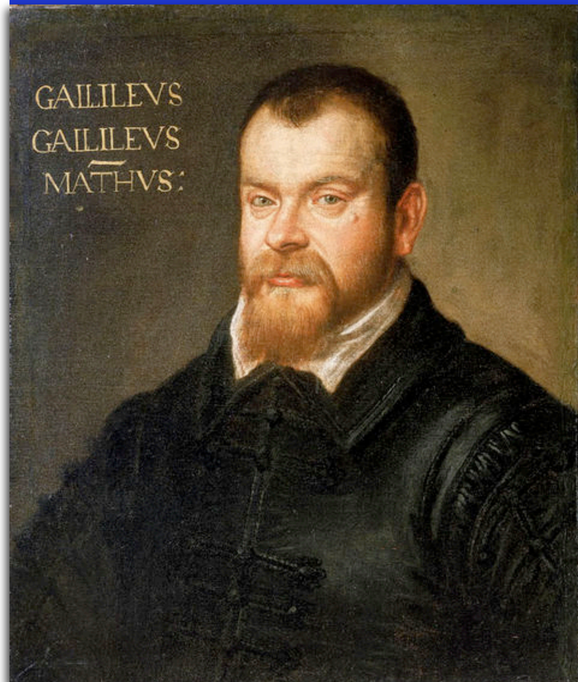
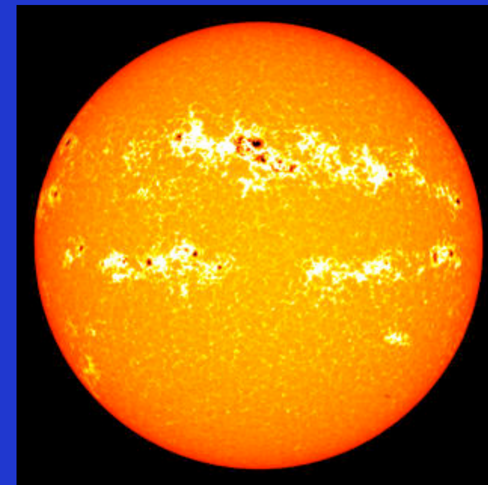


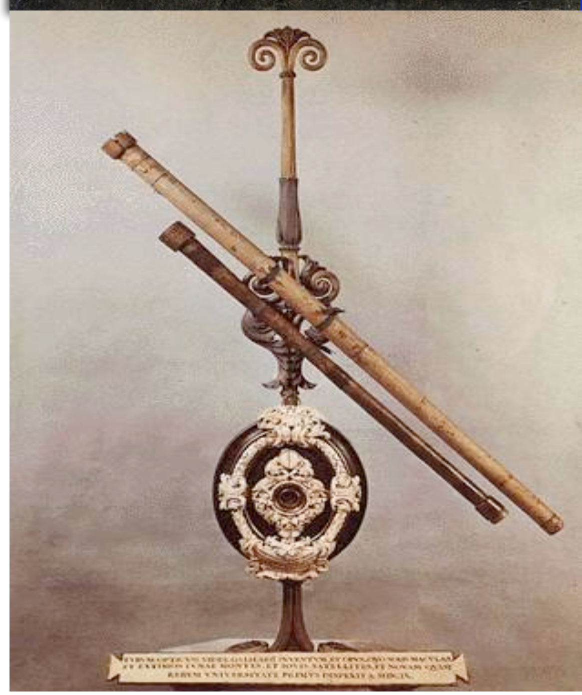
FIG. 13. (Color online) Cluster size (a) and width (b) as functions of centrality (cross section fraction) in Au-Au collisions at RHIC full energy, from PHOBOS [41]. The size is the number of charged particles associated with the cluster, and the width is in rapidity.

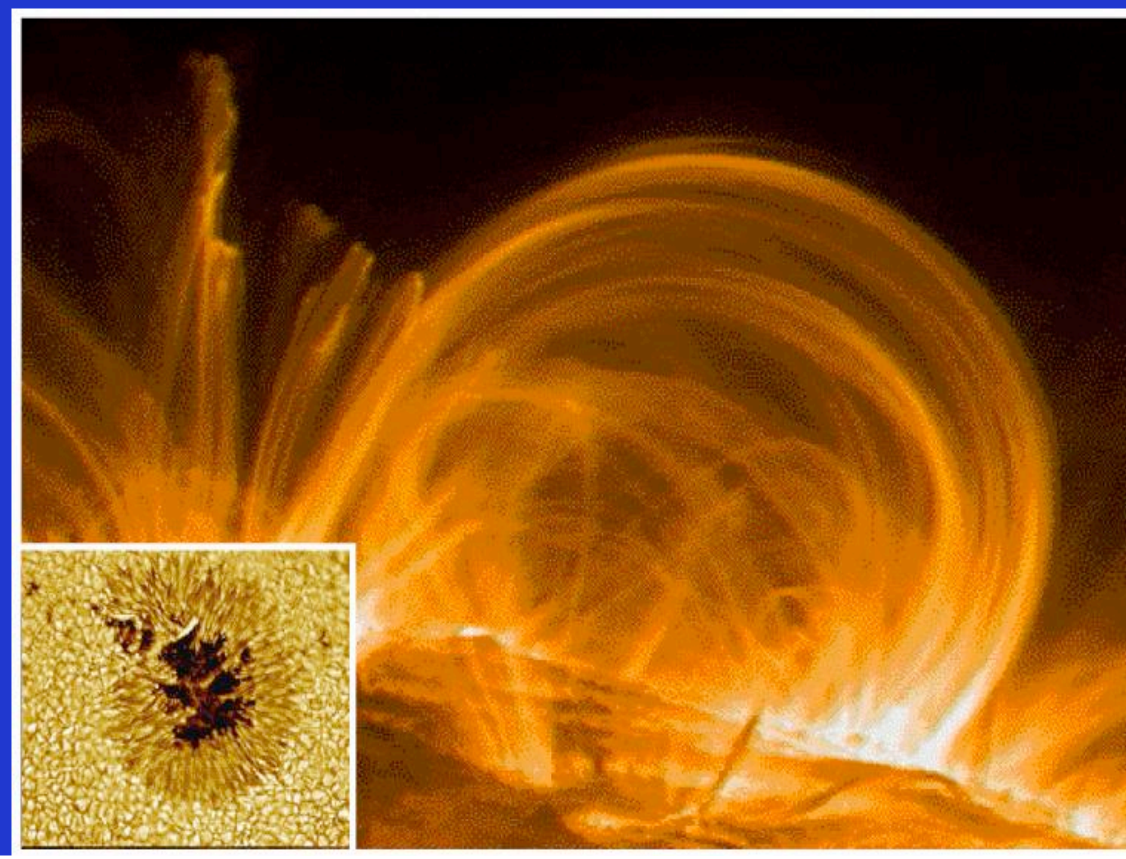
G.Stephens



1612: Galileo discovered what we now call solar corona







Here is my view of the "QGP corona"

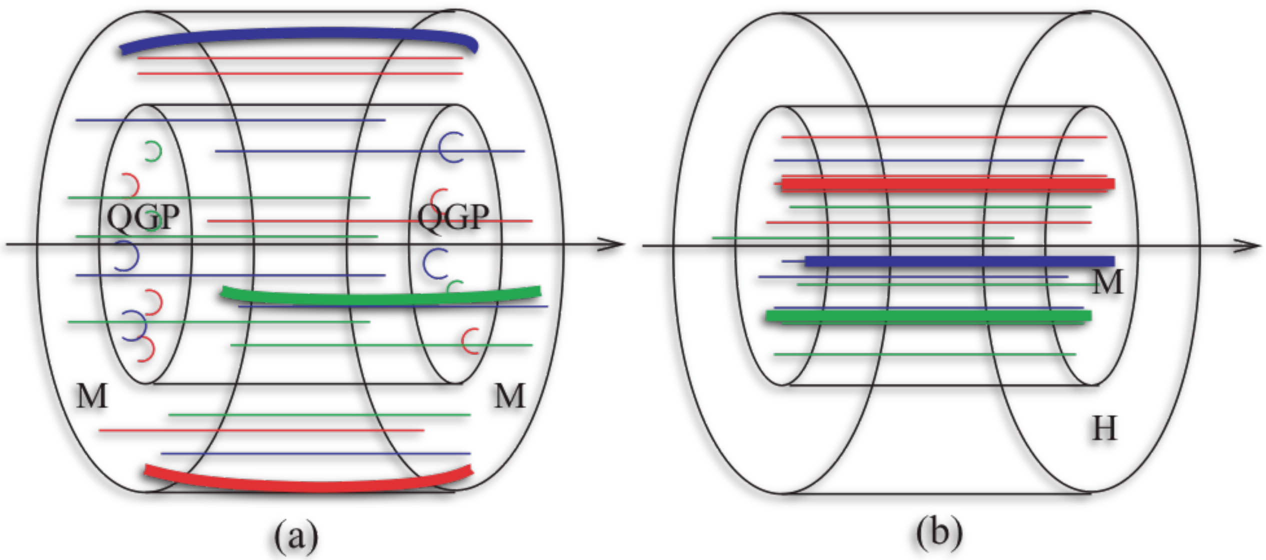
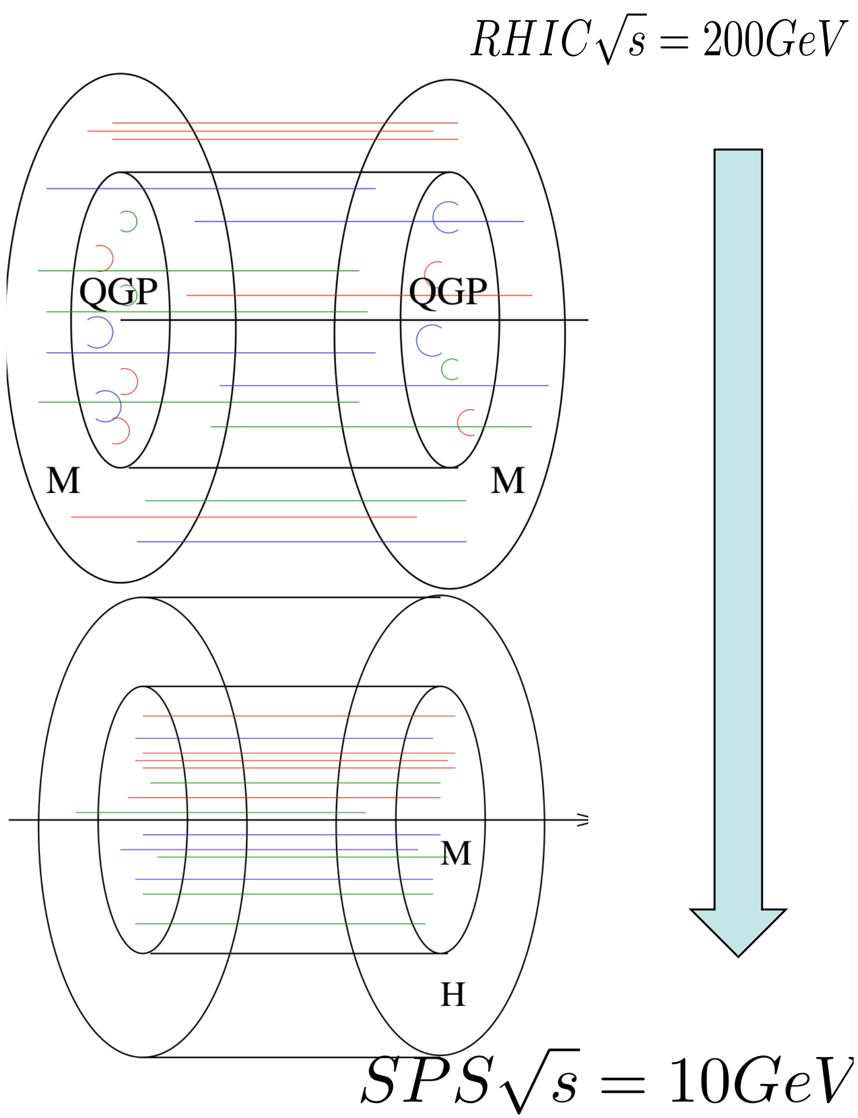
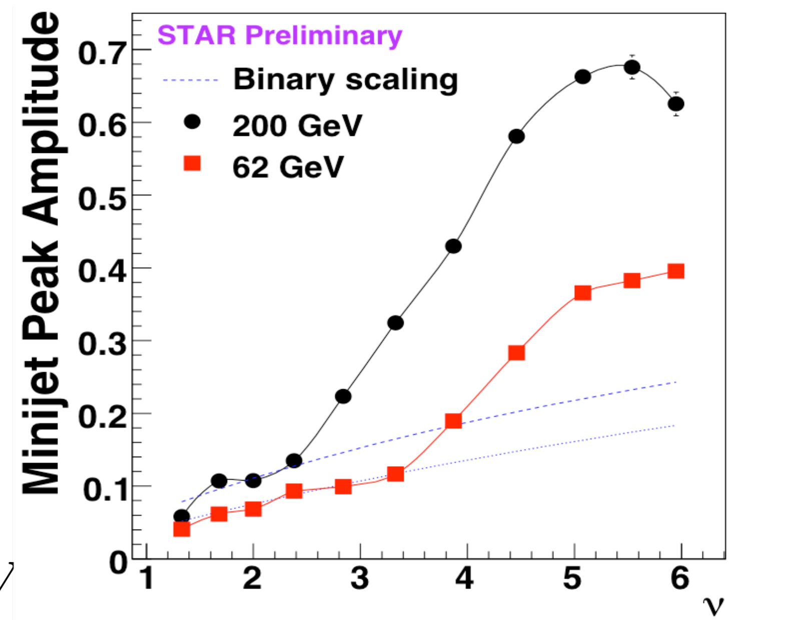


FIG. 1. (Color online) Snapshot of unscreened electric (dual-magnetic) field in the M (near-T_c) region of the fireball. (a) Full RHIC energy; (b) reduced energy (analogous to SPS).

Predictions for energy dependence: ridges



As energy decreases, M phase
Goes inside the fireball =>
Much smaller radial flow =>
Disappearance of the ridge
at fixed matter density



L.Ray

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The Azimuthal Asymmetry at large p_t seem to be too large for a pure "Jet Quenching"

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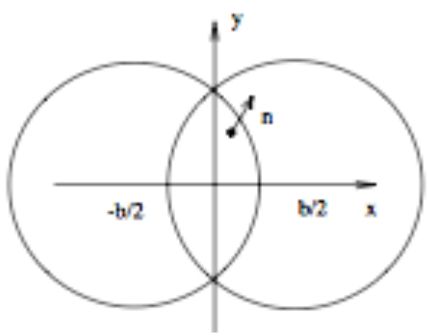
(February 8, 2008)

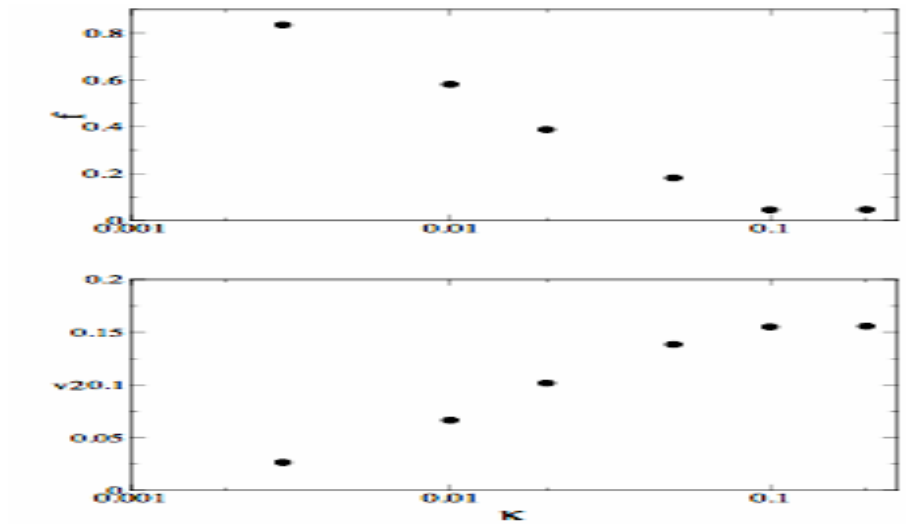
We discuss simple generic model of "jet quenching" in which matter absorption is defined by one parameter. We show that as absorption grows, the azimuthal asymmetry parameter v_2 grows as well, reaching the finite limit v_2^* which has a simple geometric interpretation. We show that this limit is still below the experimental values for $6 > p_t > 2\,GeV$, according to preliminary data from STAR experiment at RHIC. We thus conclude that "jet quenching" models alone cannot account for the observed phenomenon, and speculate about alternative scenarios.

azimuthal asymmetry, $v_2(\kappa = 0) = 0$, while increasing absorption creates increasing v_2. Interestingly, in the limit of very strong absorption the asymmetry reaches a *finite limit*, denoted by asterix below

$$v_2(b, \kappa \to \infty) \to v_2^*(b) \quad (2)$$

The reason for that is that in this case all the emitted partons/hadrons originate from the thin surface of the almond (see below). Even in this case, however, partons have half solid angle open for them: thus $v_2^*(b)$ has direct geometric interpretation. The main point of this letter is that, after evaluating $v_2(b)$ values for the experimental conditions and comparing it with data we have found that even the limiting ones, $v_2^*(b)$, are below the data.





Centrality %	$< f >$	v_2^*/s_2	v_2^*	v_2^{STAR}
0-11	.018	.32	.042	.12± 0.02
11-34	.027	.35	0.12	.16± 0.02
34-85	.046	.31	0.16	.22± 0.02

TABLE I. The limiting momentum/spatial asymmetry for three different centrality selections of STAR, given as v_2 versus the percentage of total AuAu cross section. The quantity $< f >$ is the escape probability (5) averaged over produced jets in the collisions, with all directions and origin points.

Medium induced jet absorption in relativistic heavy ion collisions

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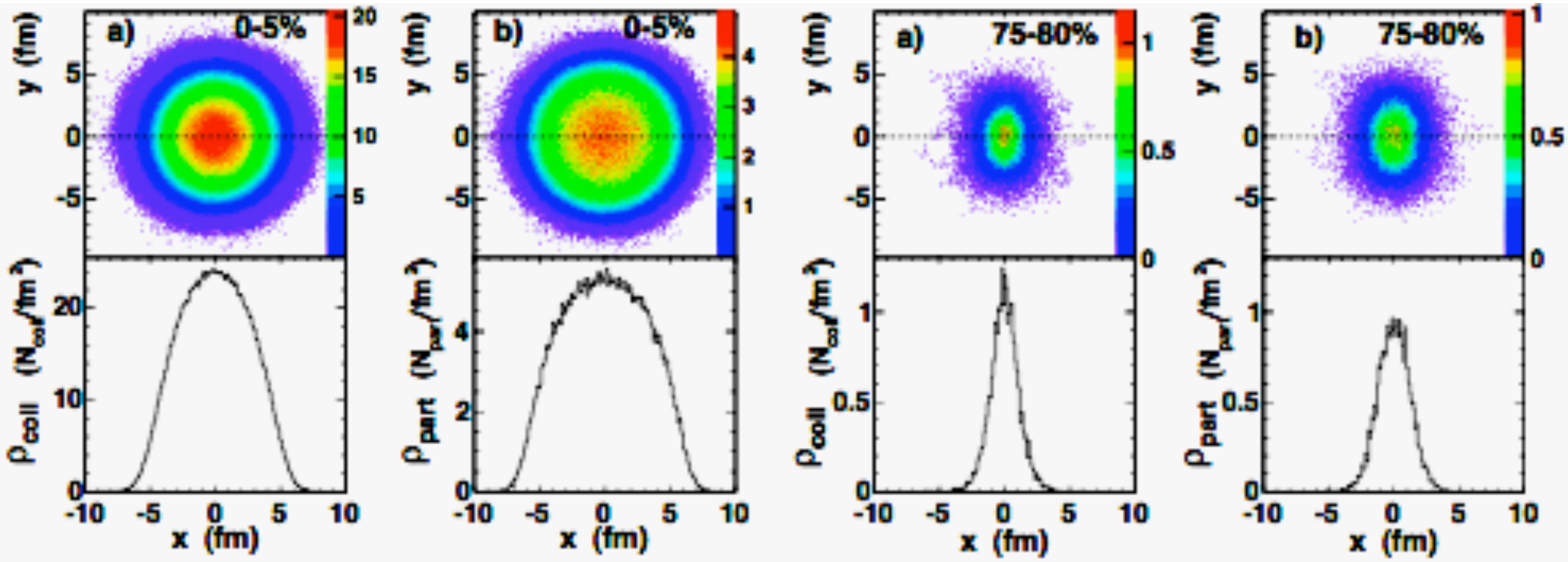


FIG. 1: (Color online) Collision density $\rho_{\text{coll}}(x, y)$ (a) and participant density $\rho_{\text{part}}(x, y)$ (b) in transverse plane for central (0–5%) and peripheral (75–80%) collisions. The bottom panels are the average density along the impact parameter axis, which is indicated by the dashed line in the top panels.

Realistic geometry made the ``standard predictions" even lower!

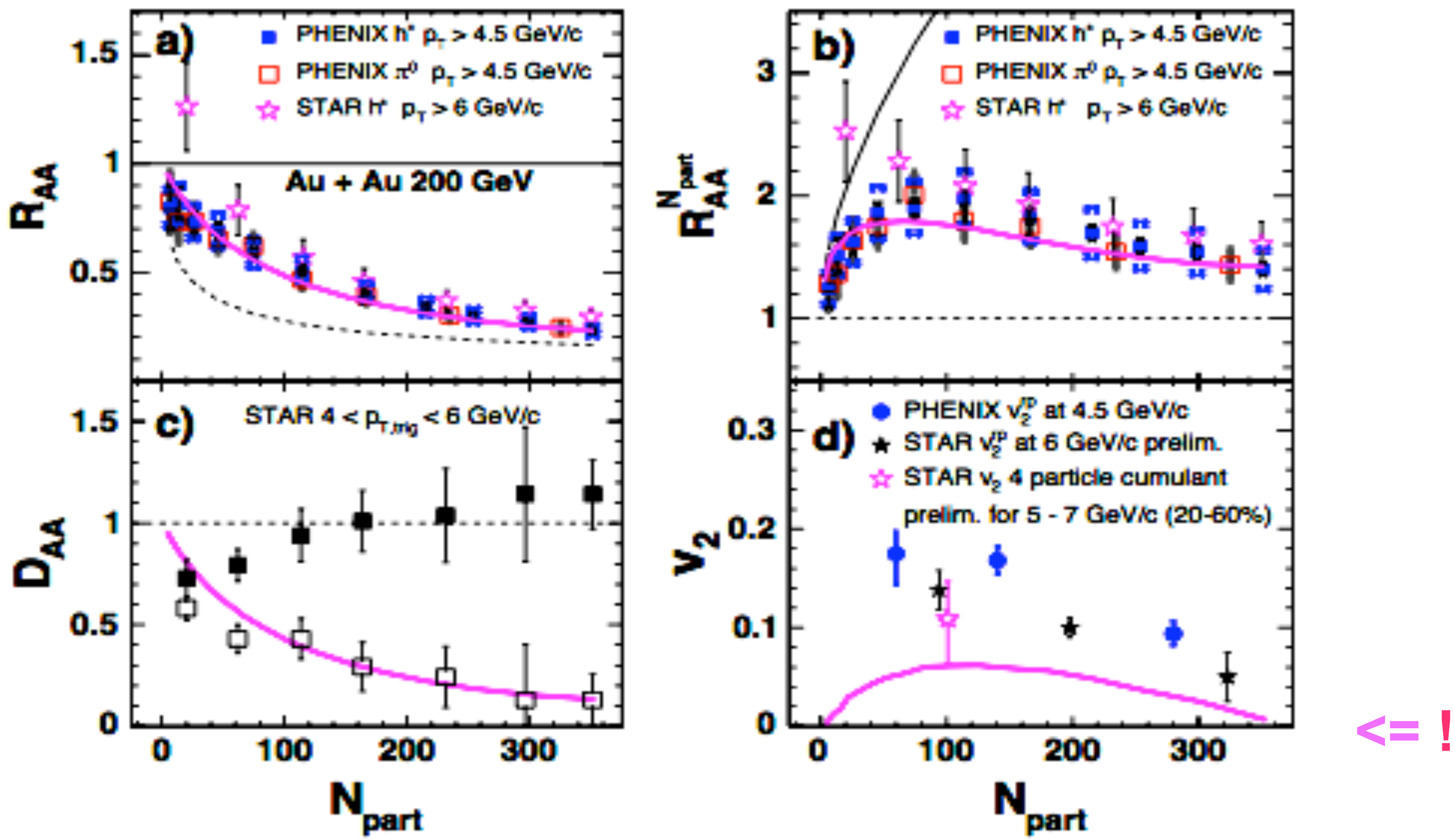
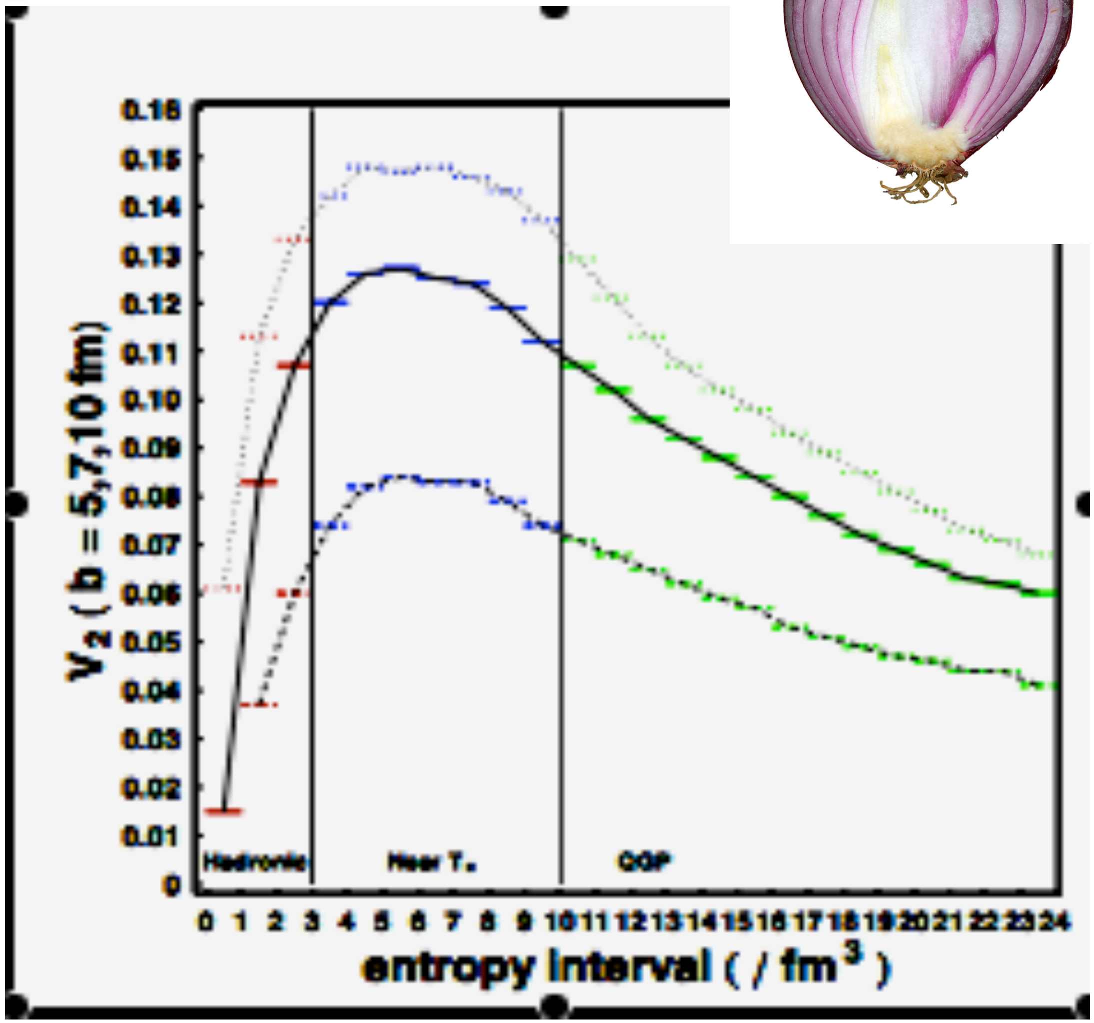


FIG. 3: (Color online) Centrality dependence of normalized yield of high p_T hadrons (a and b), back-to-back correlation strength (c), and v_2 (d) at high p_T. In all four panels, the thick solid line indicates the result of our calculations based on

"Onionization" (slicing matter into shells/bins of the same entropy density then adjusting quenching to reproduce the $R_{AA}(b)$ and predicting v_2)

- Glauber matter distribution, as above
- Hard jets by binary scaling, as above
- Calculated v_2 for each shell (b=5,7,10 fm)
- The maximum $v_2^{max}(b)$ is the absolute geometric limit
- It happens to be at RHIC at the near-Tc matter - known as the M (mixed or magnetic) phase

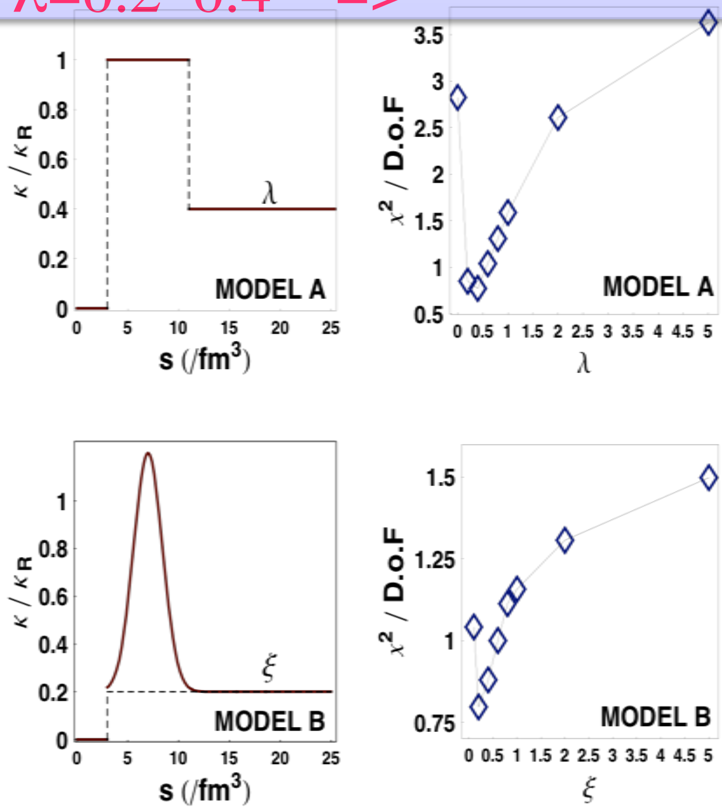


Liao,ES: Resolution of the old puzzle of large v2(large pt): **Phys.Rev.Lett.102:202302,2009.**

two different quenching in QGP and M phases (zero in H)

λ=quenching(QGP)/quenching(M)

λ=0.2−0.4 =>



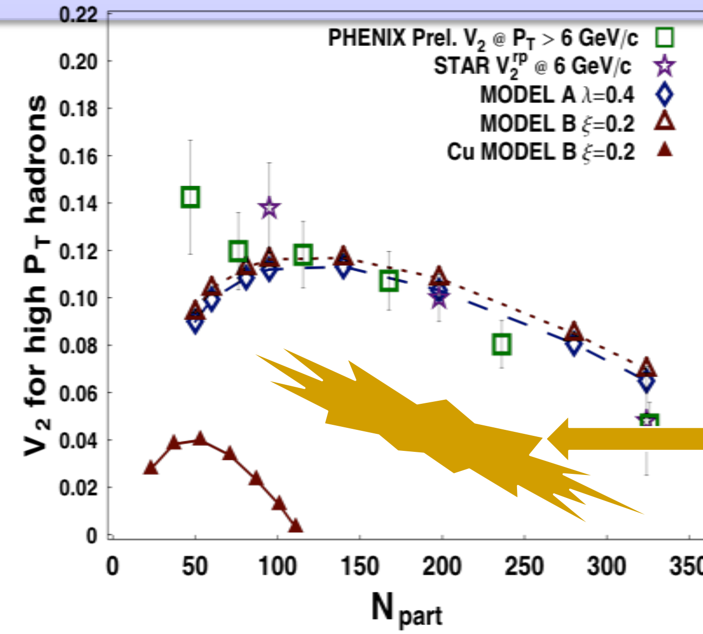


FIG. 3: (color online) Comparison between v_2 experimental data and v_2 calculated from our models, see text.

Other Models with quench. going as density

- **M-region (near Tc) quenched jets stronger**
- **Because light monopoles are there**

The solution: (color) magnetic monopoles are important excitations near Tc

Four lectures on strongly coupled Quark Gluon Plasma. Edward Shuryak, (SUNY, Stony Brook) . 2009. 46pp. Published in Nucl.Phys.Proc.Suppl. 195:111-156,2009.

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  Liao,ES, Phys.Rev.C75:054907,2007.
  hep-ph/0611131
- **Magnetic component of Yang-Mills plasma**,M.N.Chernodub and V.I.Zakharov, 98, 082002 (2007) [arXiv:hep-ph/0611228].
- **Electric Flux Tube in Magnetic Plasma.**
  Liao,ES, Phys.Rev.C77:064905,2008.
  arXiv:0706.4465
- Magnetic monopoles in the high temperature phase of Yang-Mills theories, A.D'Alessandro and M.D'Elia, Nucl.Phys.B 799, 241 (2008) [arXiv:0711.1266
- **Magnetic Component of Quark-Gluon Plasma is also a Liquid!** Liao,ES,
  Phys.Rev.Lett.101:162302,2008.
  e-Print: arXiv:0804.0255
- **Angular Dependence of Jet Quenching Indicates Its Strong Enhancement Near the QCD Phase Transition. Jinfeng Liao,, Edward Shuryak Phys.Rev.Lett. 102:202302,2009.**
  e-Print: arXiv:0810.4116
- **Thermal Monopole Condensation and Confinement in finite temperature Yang-Mills Theories.**
  Alessio D'Alessandro, Massimo D'Elia, Edward Shuryak, . Feb 2010. 17pp.

Thermal Monopole Condensation and Confinement in finite temperature Yang-Mills Theories

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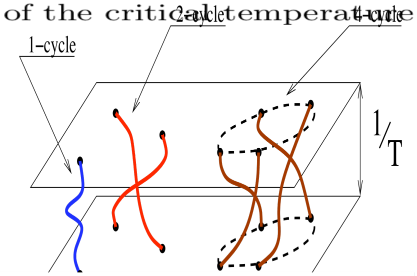
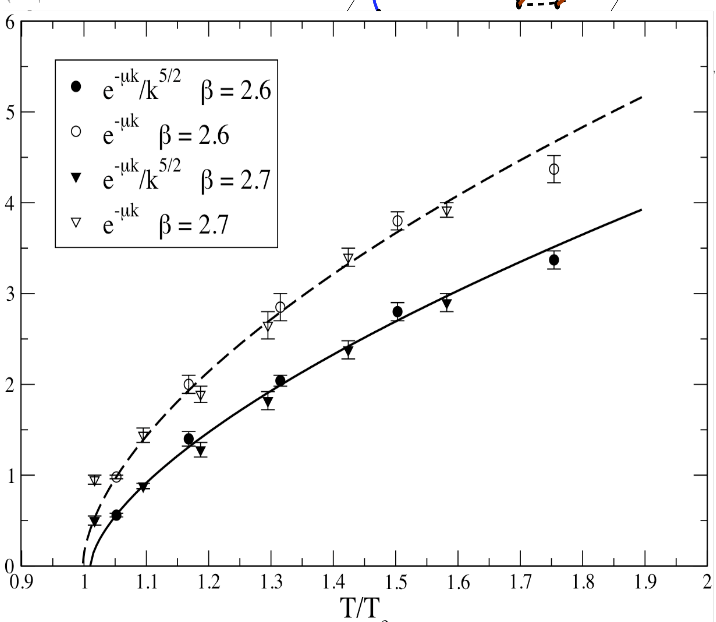
[2] *Department of Physics and Astronomy, State University of New York, Stony Brook NY 11794-3800, USA*
(Dated: February 22, 2010)

We investigate the connection between Color Confinement and thermal Abelian monopoles populating the deconfined phase of SU(2) Yang-Mills theory, by studying how the statistical properties of the monopole ensemble change as the confinement/deconfinement temperature is approached from above. In particular we study the distribution of monopole currents with multiple wrappings in the Euclidean time direction, corresponding to two or more particle permutations, and show that multiple wrappings increase as the deconfinement temperature is approached from above, in a way compatible with a condensation of such objects happening right at the deconfining transition. We also address the question of the thermal monopole mass, showing that different definitions give consistent results only around the transition, where the monopole mass goes down and becomes of the order of the critical temperature itself.





, in which

FIG. 4: Chemical potentials reported in Table II for $\alpha = 0$ and $\alpha = 2.5$ and two different lattice spacings, together with a fit of them according to Eq. (24).

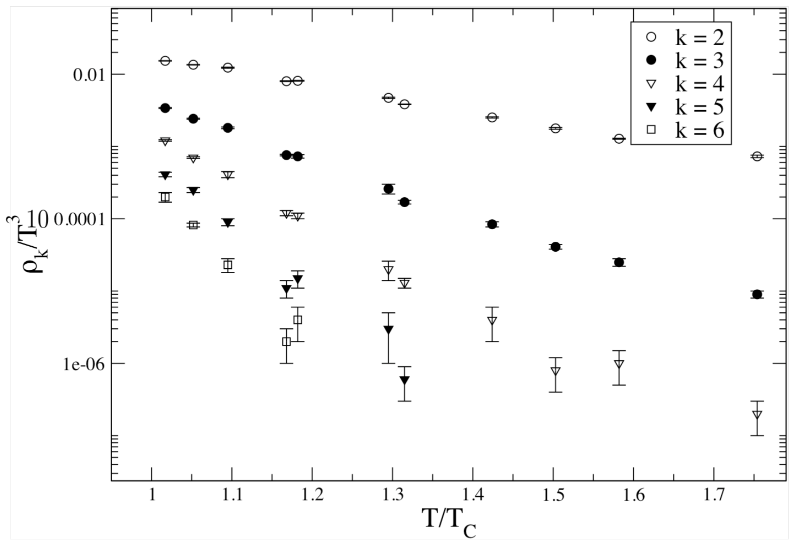
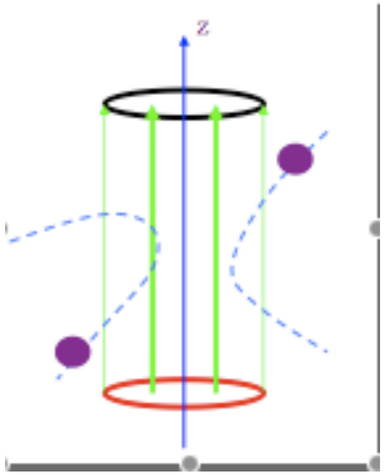


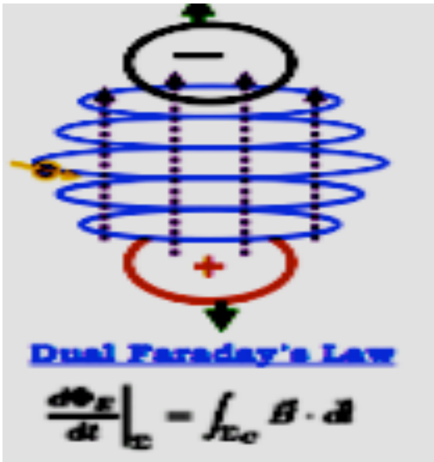
FIG. 2: Normalized densities ρ_k/T^3 as a function of T/T_c.

The lesson: monopoles at T_c, behave as He^4 =>Bose-Einstein condensation



Moving e-charge leads to magnetic coil => e-flux tubes above Tc?

(with J.F.Liao, archive 0706.4465)



- **Dual superconductivity** at T<Tc as a confinement mechanism ('tHooft, Mandelstam 1980's) => monopole Bose condensation => electric flux tubes (dual to Abrikosov-Nielsson-Olesen vortices)
- **Dual magnetohydrodynamics** at T>Tc ? Electric flux tubes in magnetic plasma (M=phase)
- monopoles are reflected from E field => pressure => metastable flux tubes

(Dual) magnetohydrodynamics

Ideal if conductivity => infinity,

Viscosity => 0

Dual(H) = E

$$div\vec{\tilde{H}} = 0 \quad (3.2)$$

$$\frac{\partial \tilde{H}}{\partial t} = curl[\vec{v}\vec{\tilde{H}}]$$

complemented by Euler eqn of hydrodynamics

$$\frac{\partial \rho v_i}{\partial t} = -\frac{\partial \Pi_{ik}}{\partial x_k} \quad (3.3)$$

$$\Pi_{ik} = \rho v_i v_k + p\delta_{ik} - \frac{1}{4\pi}\left(\tilde{H}_i\tilde{H}_k - (1/2)\vec{\tilde{H}}^2\delta_{ik}\right) \quad (3.4)$$

appended by the magnetic stress tensor, as well as the usual matter continuity eqn

$$\frac{\partial \rho}{\partial dt} + \frac{\partial \rho v_i}{\partial dx_i} = 0 \quad (3.5)$$

The expression for the velocities of the "magnetosounds" or Alfven waves is

$$v_{1,2}^2 = (\frac{1}{2})\left[\frac{\tilde{H}^2}{4\pi\epsilon} + c_s^2\right] \pm (\frac{1}{2})\left[(\frac{\tilde{H}^2}{4\pi\epsilon} + c_s^2)^2 - \frac{\tilde{H}_{||}^2 c_s^2}{\pi\epsilon}\right]^{1/2} \quad (3.6)$$

For weak field
Splitting into two
cones

For H||=0 (wave normal to H)
One velocity =0, stabilization

``metastable flux tube” option for ``cone” and ``ridge”:

- there are enough monopoles to stabilize the flux tubes mechanically up to 1.4Tc:
- They can **survive for a long time**, 5-10 fm/c due to **heavy electric quasiparticles (q,g,dyons) at Tc**

$$P_{breaking} \sim exp(-\frac{\pi M^2}{E})$$

Mq=300 MeV at T=0 but about 800 MeV at Tc

Summary

- Flow makes the “QGP corona” visible as ridges. They seem to be rather stable flux tubes
- Their existence is only possible in magnetic plasma (M-phase)
- **Mixed phase => monopole plasma** (near Tc) should be described by dual magnetohydrodynamics <= nonzero E
- Confinement is BEC of magnetic charges! They do make a liquid! And they seem to quench the jets!