Probing the Pre-equilibrium QGP with jets and jet correlations

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Early-Time-Dynamics in Heavy-Ion Collisions, McGill, Jul 15-19 2007

Outline

- ***Models of the matter @ RHIC,***
- ***Use of hard jets as probes,***
- ***The space-time picture,***
- ***The momentum space picture,***
- ***Use of medium response as probes,***
- ***Comparing models.***

The matter formed @ RHIC

2 (3) signatures of early dense matter

1) Modification of hard jets,

- Produced matter very dense, >1GeV^2/fm
- Quenching @ early times, < 5 fm/c

2) Large elliptic flow, almost ideal-Hydro!

- Matter thermalizes rapidly ~ 0.6 fm/c
- Very low viscosity, $\eta/s \geq 0.08$

3) In-Medium Jet correlations,

Cone structure on away side

Ridge structure on near side

The models!
1 macroscopic, 3 microscopic

Viscous Hydrodynamics:
finite no. of parameters from micro-theories

1) Bound states:

2) QCD Quasi-Particle (HTL, Mean-field theories)

3) ADS/CFT !!

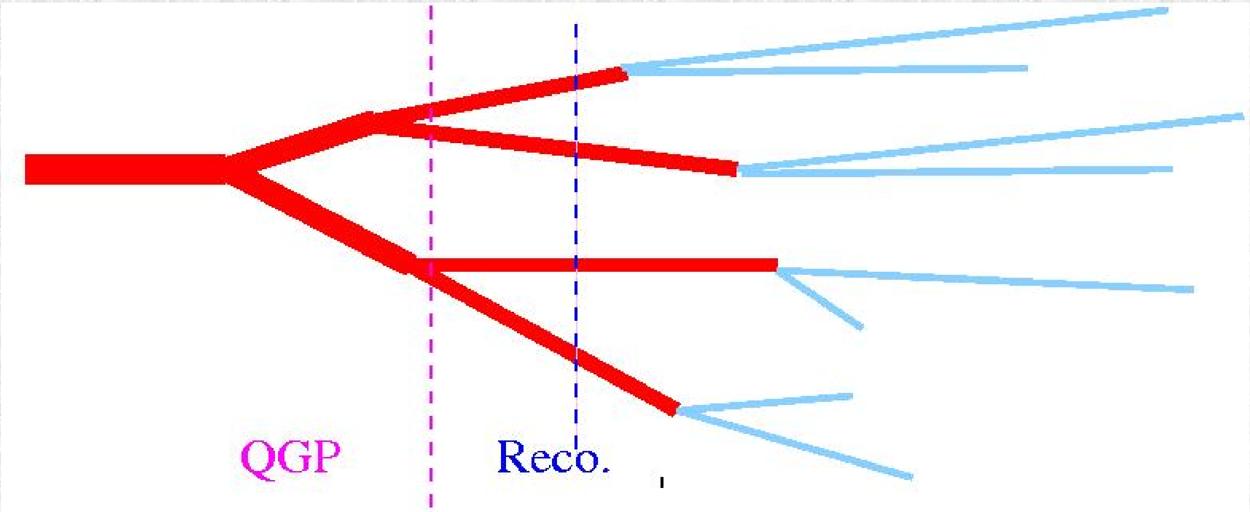
Jets (short distance processes)
direct probe of microscopic dynamics

Jet propagation & transverse broadening

Jet propagates in a medium with fluctuating color fields

Feels medium through Lorentz force correlation.

$$\int dt \left\langle F^{\mu\alpha}(t) v_\alpha F^{\beta}_{\mu}(0) v_\beta \right\rangle$$



$$\hat{q} = \frac{p_\perp^2}{t} = \frac{2\pi^2 \alpha_s C_R}{N_c^2 - 1} \int dt \left\langle F^{\mu\alpha}(t) v_\alpha F^{\beta}_{\mu}(0) v_\beta \right\rangle$$

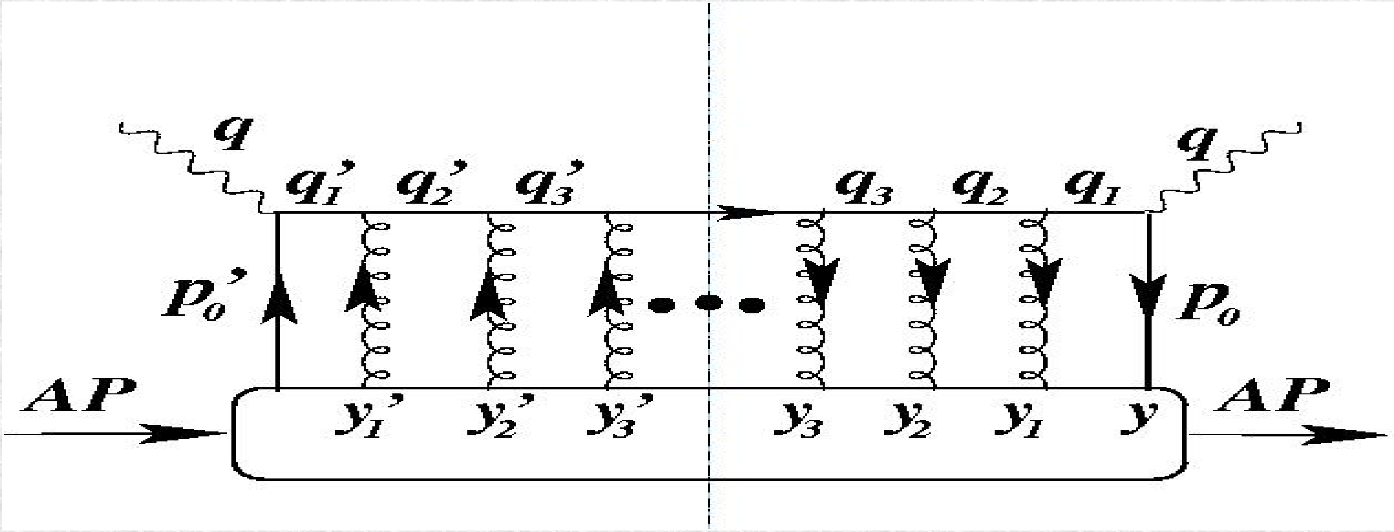
This influences both the energy loss and transverse broadening

In H-T formalism,

only assume correlation is short distance dominated

Extending higher twist to all-twist

Step 1) No radiation = transverse momentum broadening



Get a 2-D p_T diffsn eqn. $$\frac{\partial f(p_\perp, t)}{\partial t} = \nabla_{p_\perp} \cdot D \cdot \nabla_{p_\perp} f(p_\perp, t)$$

with the solution $$f(p_\perp, t) = \frac{1}{8\pi D t} e^{-\frac{p_\perp^2}{8Dt}}$$

$$p_\perp^2 = 4Dt$$

$$\hat{q} = \frac{p_\perp^2}{t} = \frac{2\pi^2 \alpha_s C_R}{N_c^2 - 1} \int d\tau \left\langle F^{\mu\alpha}(t+\tau) v_\alpha F_\mu^\beta(t) v_\beta \right\rangle$$

A. Majumder, B. Müller, arXiv:0705:1147 [nucl-th]

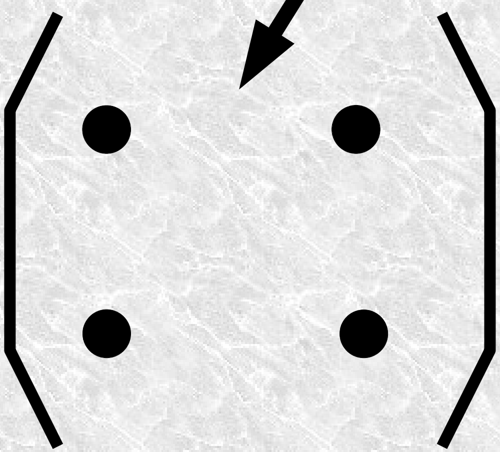
The need for a multidimensional $\hat{q}$

A full study of the medium requires a comprehensive probe

$$\hat{q}^{\mu\nu} = \hat{q}_0 f^{\mu\nu}(x, y, z, t, \gamma_{flow}; \mu^2, p_{jet})$$

Medium parameters

Jet parameters



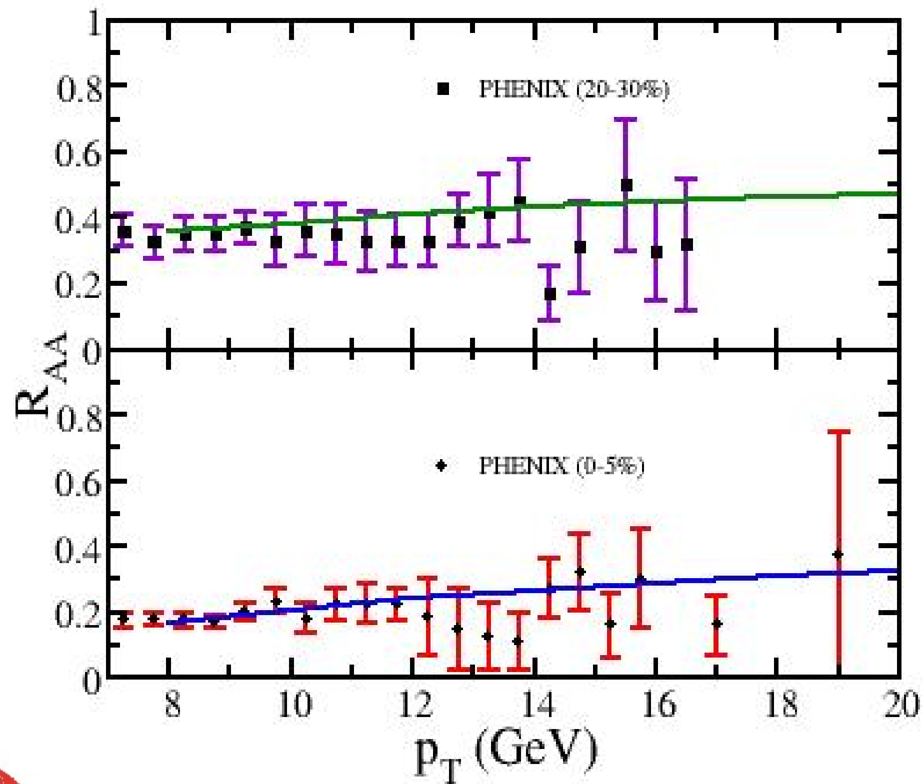
Macroscopic models test the space time dependence

Microscopic models can give $\hat{q}$ directly!

An example: the space-time profile

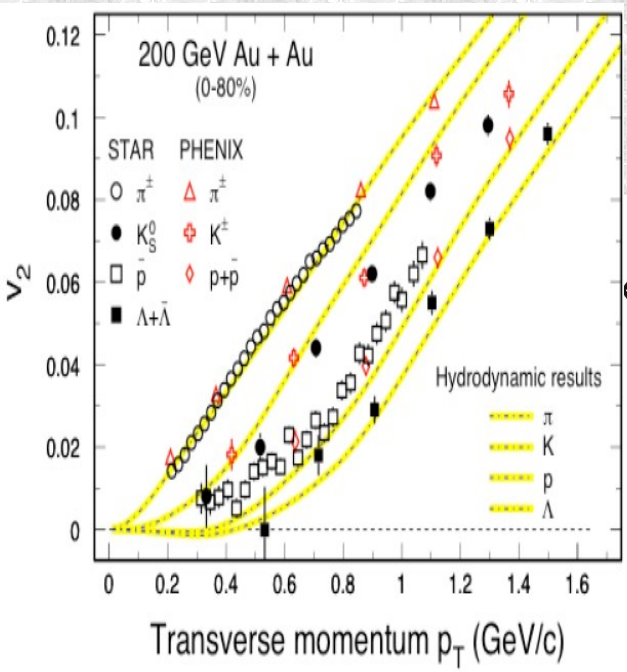
$$\hat{q}^{\mu\nu} = \hat{q}_0(f)\,\delta^{\mu\nu}\,\frac{\gamma_\perp(x,y,z,t)\,T^3(x,y,z,t)}{T_0^3(x,y,z,t)}$$

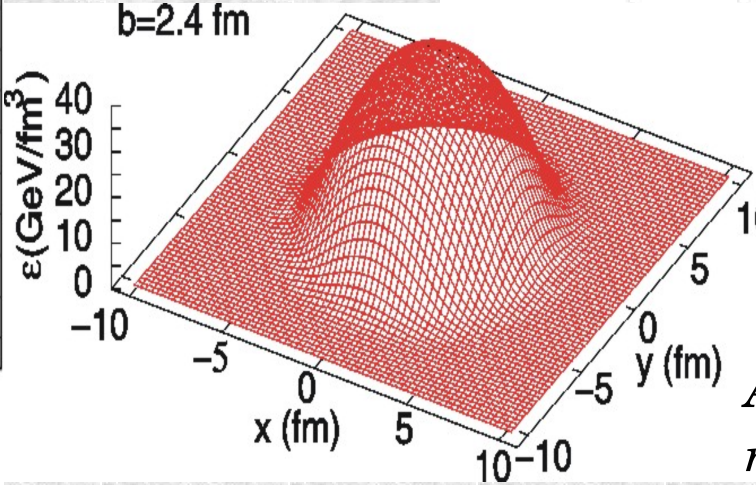
$$\hat{q}_0(quarks) = 1.3\,GeV^2/\,fm$$



Test of the hydro model!

Use the same hydrodynamic model that predicted the soft spectra

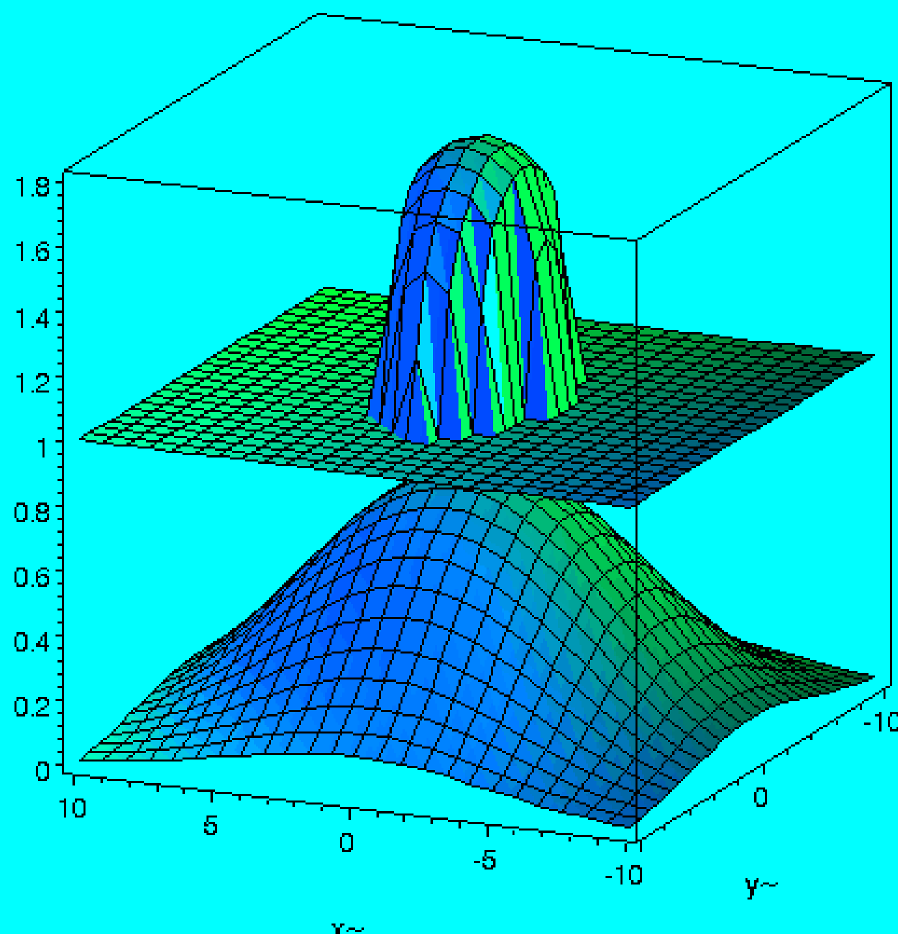


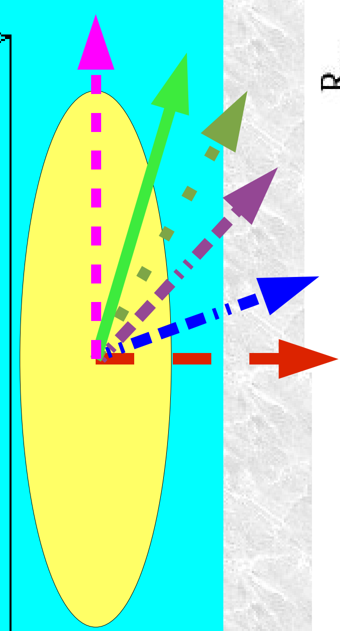


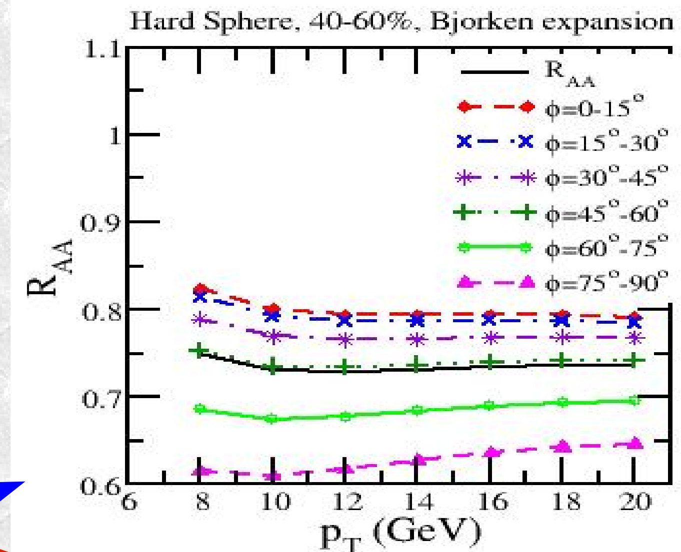
A. Majumder, C. Nonaka, S. Bass, nucl-th/0703019

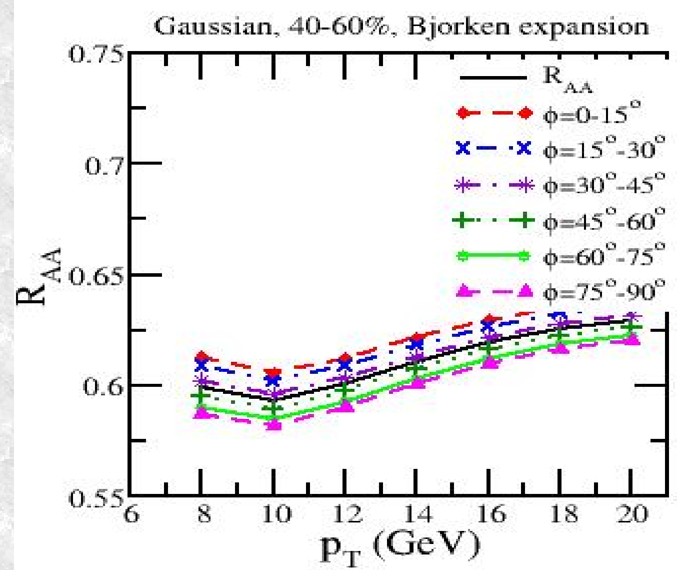
Need (x,y,z,t) dependent $\hat{q}$ for differential spectra

- ***Azimuthally dependent R_{AA} can distinguish***
- ***Look at two extreme cases, with Bjorken exp.***







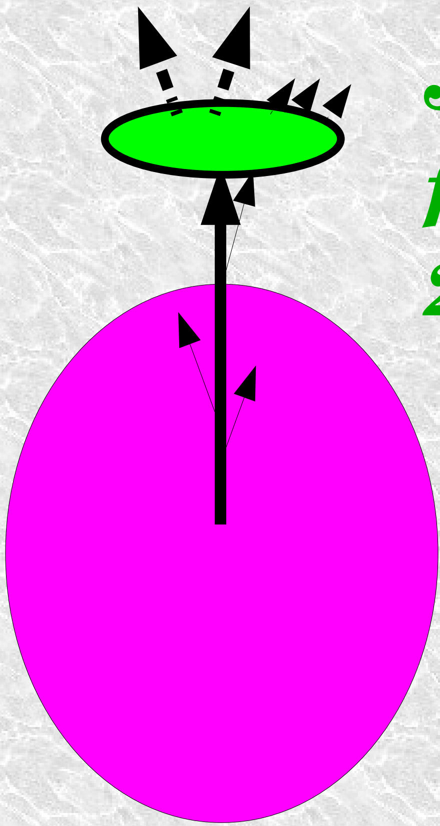


A. Majumder,PRC 75:021901,2007.

Probing microscopic structure

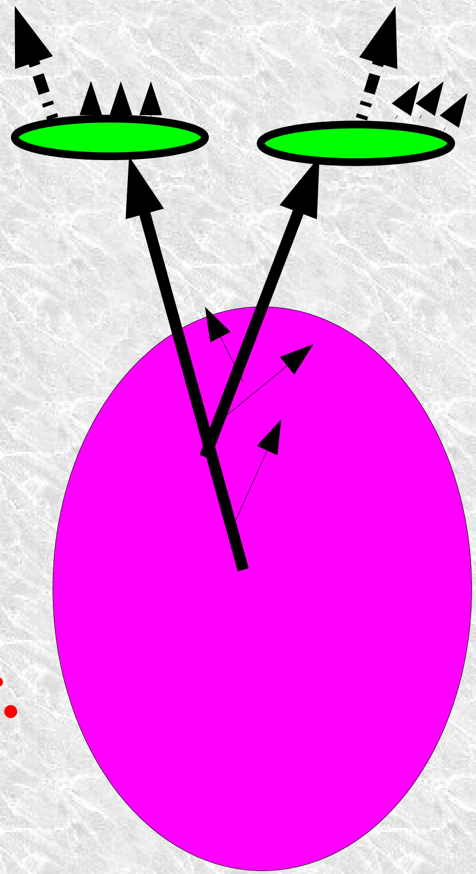
Need very differential probes: modification of jet structure,
Modification of near side correlation!

Can be decomposed into two components



Jet loses energy,
fragments outside,
2 h from vac. frag.

Jet radiates gluon,
Gluon escapes,
Assoc. h from glue frag.



gluon may thermalize, may hadronize by ReCo.

Comparing to the vacuum

Differential predictions from JETSET, compare with d-Au
Set Base-line

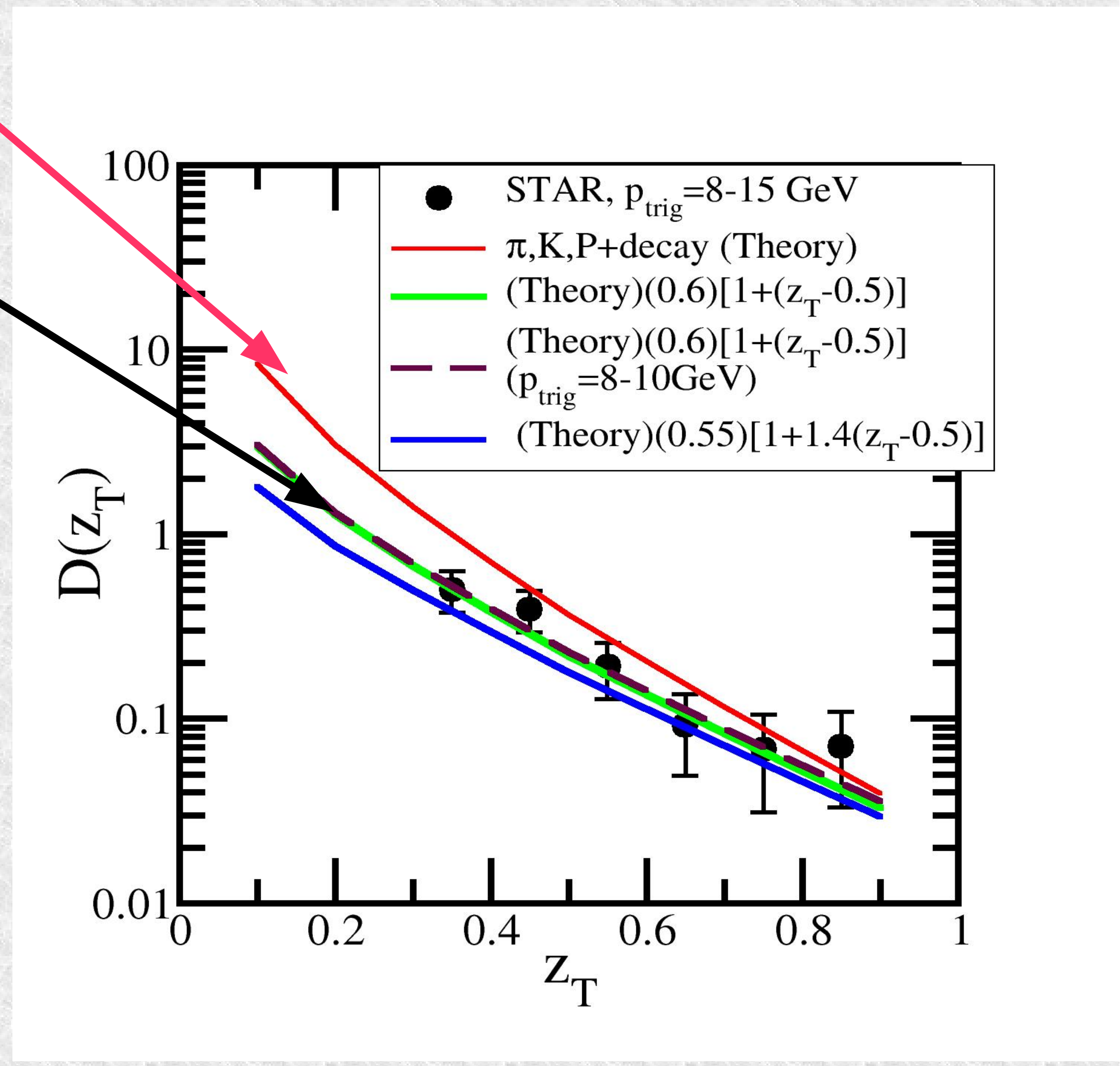
Bare JETSET prediction

Optimal decay correction

d-Au is not vacuum

Vacuum profile should be steeper

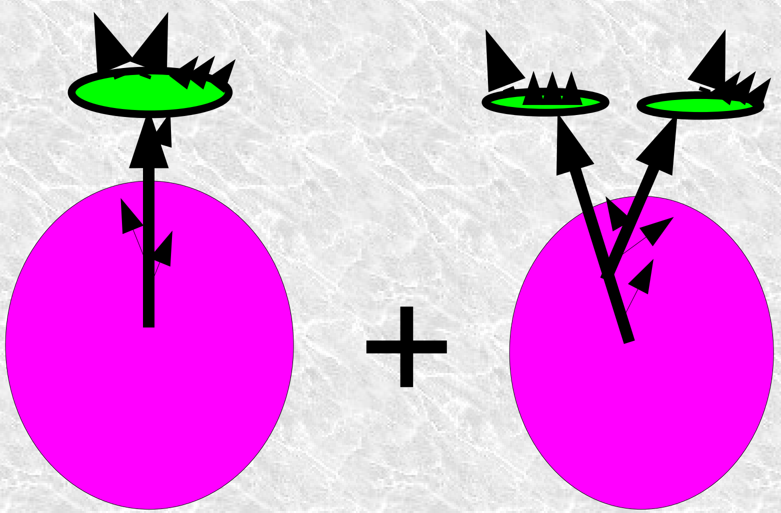
$$z_T = \frac{p_{T,\,Assoc.}}{p_{T\,,Trig.}}$$



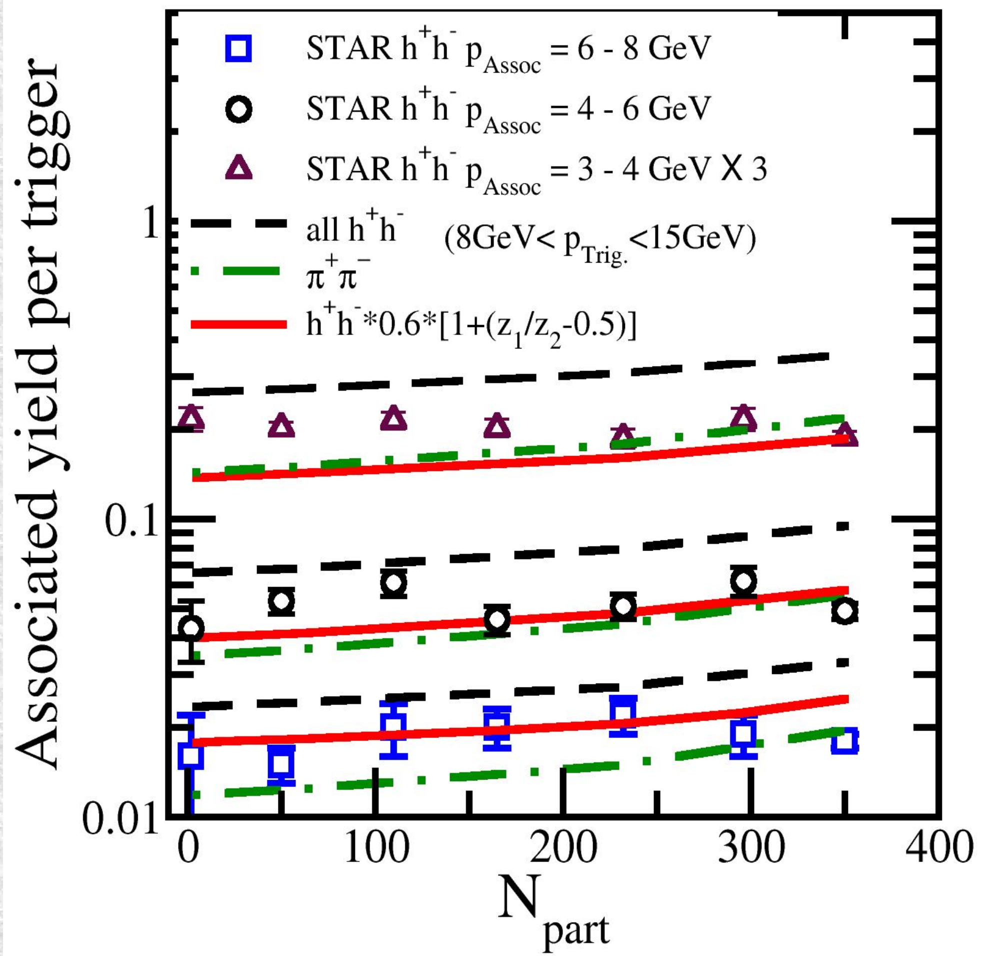
Does the whole thing add up?

Can we account for the near side associated yield in this 2-part formalism ?

At high trigger p_T, Yes!
low trigger p_T, Sort of!

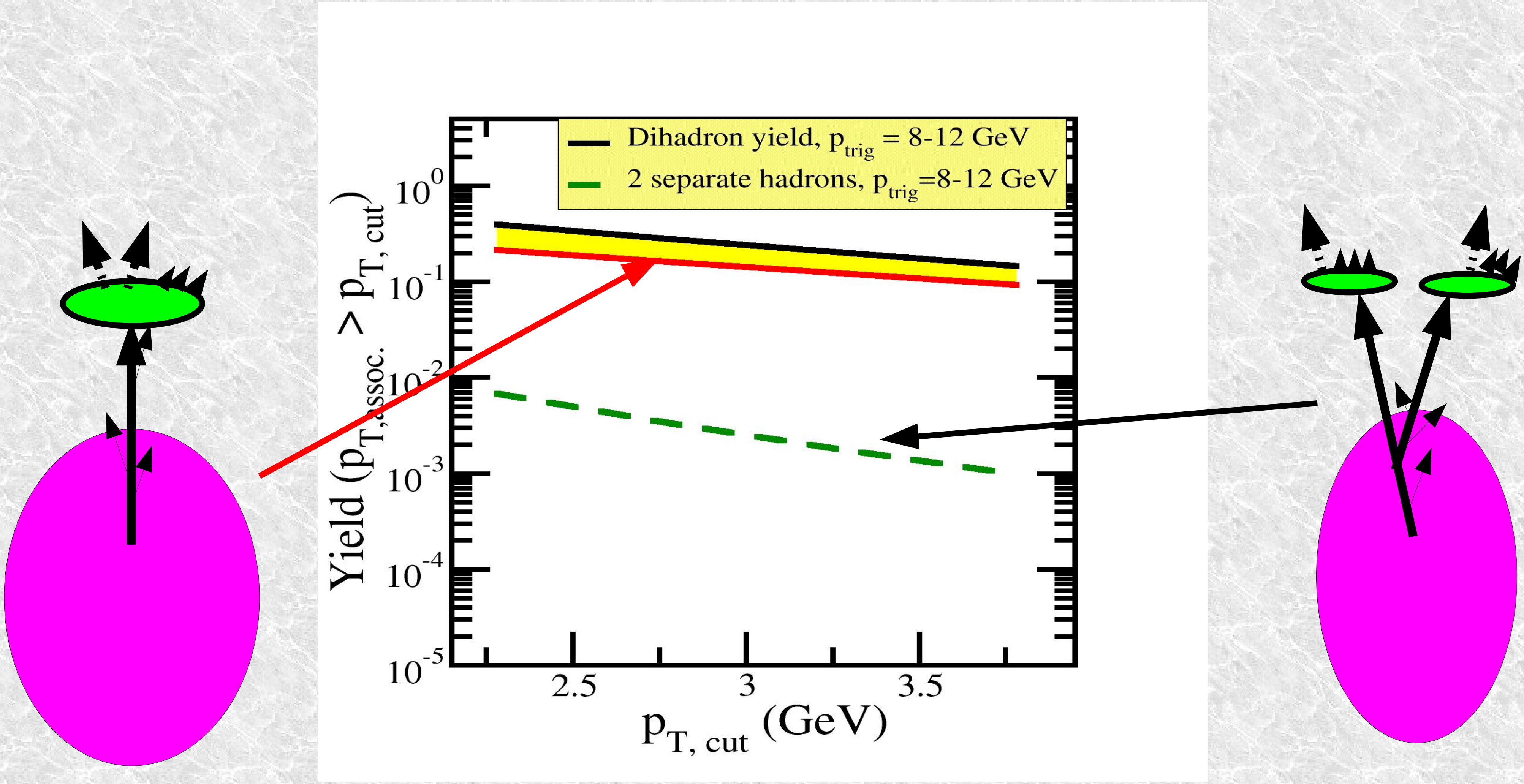


A. Majumder, E. Wang and X. N. Wang, nucl-th/0412061

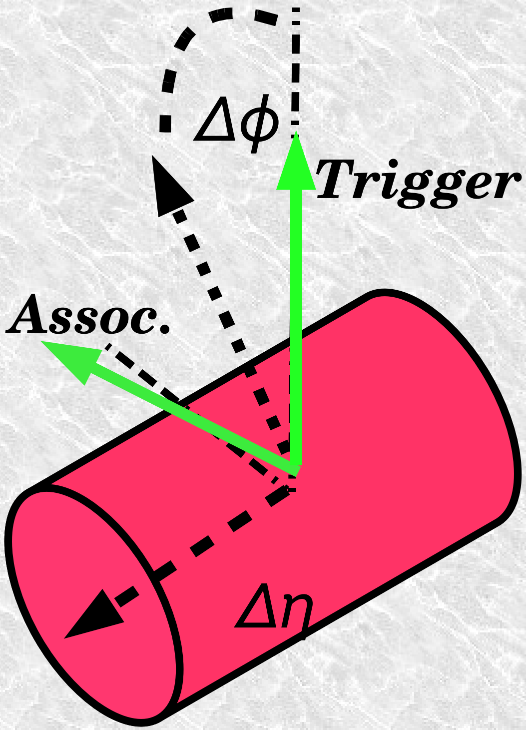


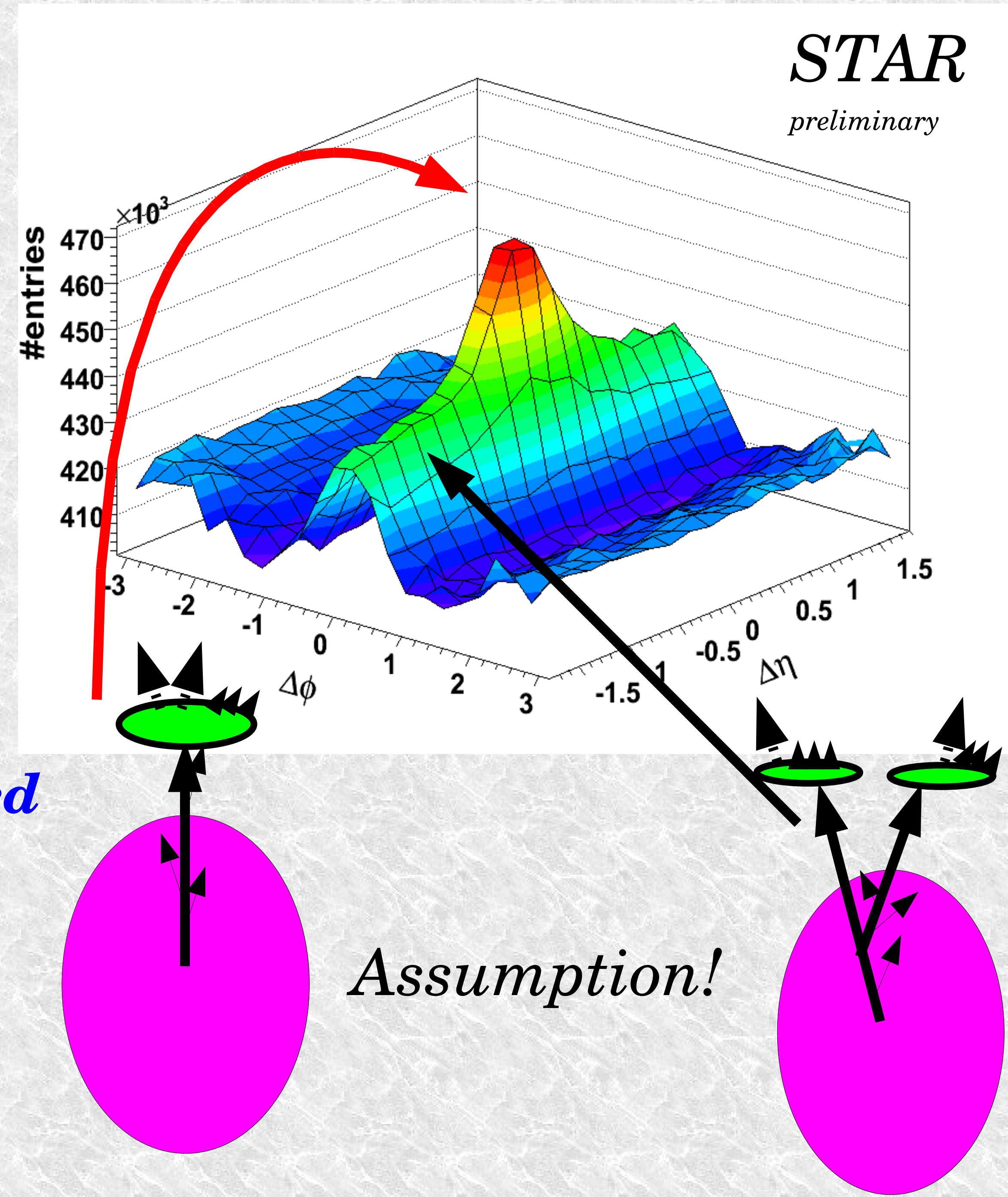
How much is each ?

- *Energy loss on the near side is small,*
- *Leads to small multiplicity*
- *How can experiment pick up this little bit ??*



They live in a different phase space



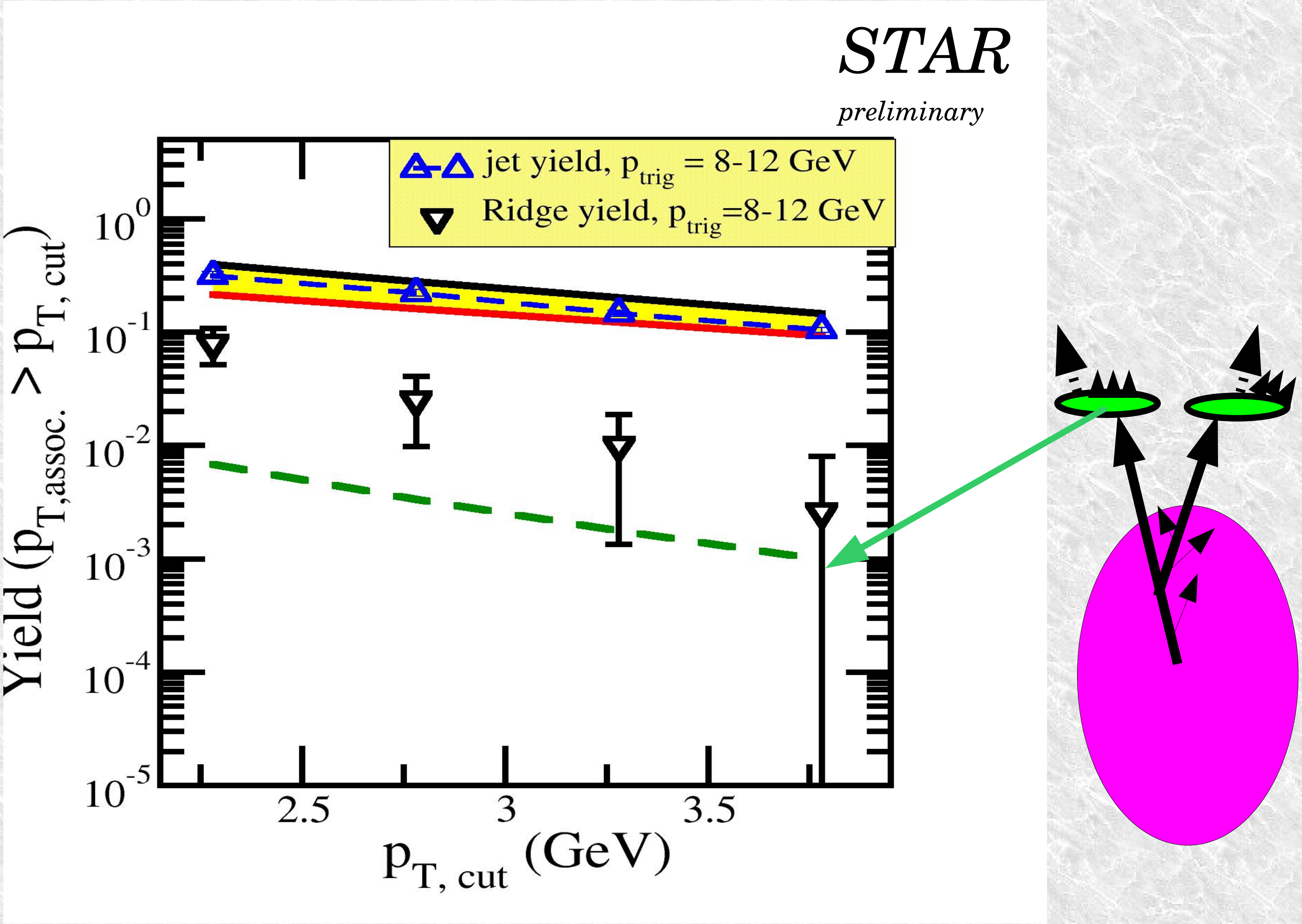


- ***Radiated gluon broadened in η, tensor q***
- ***Why broadened? Microscopic theory !***

Comparing theory to experiment

Vacuum fragmentation explains high assoc. p_T

Excess at lower p_T, must be due to medium effects: thermalization, recombination!

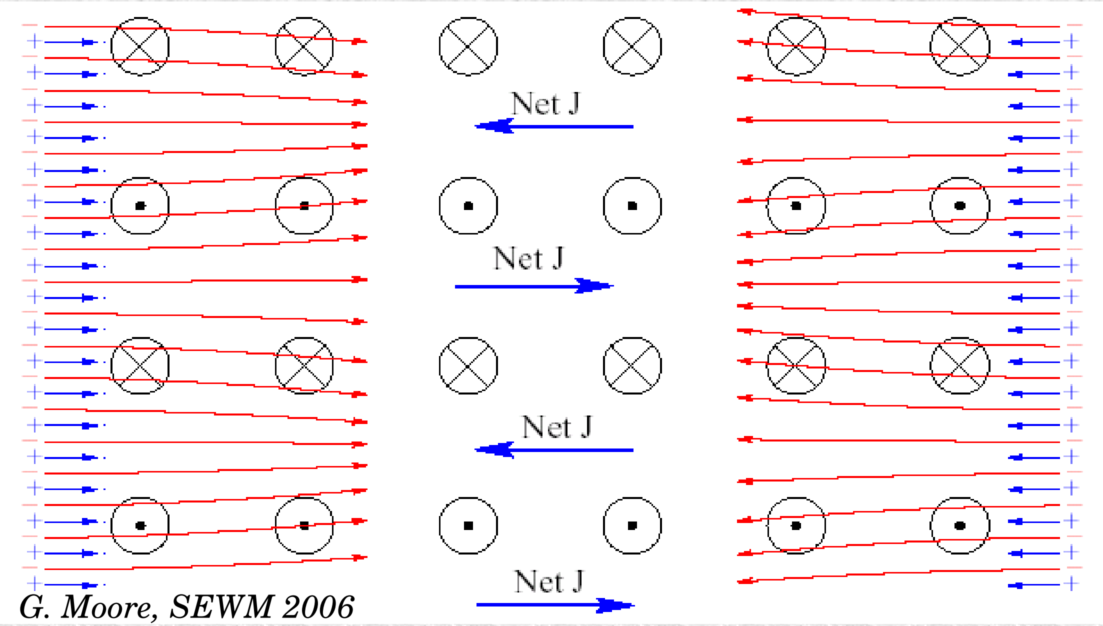


Both vacuum frag. piece and medium frag. piece are broadened in rapidity, why? *Microscopic theory!*

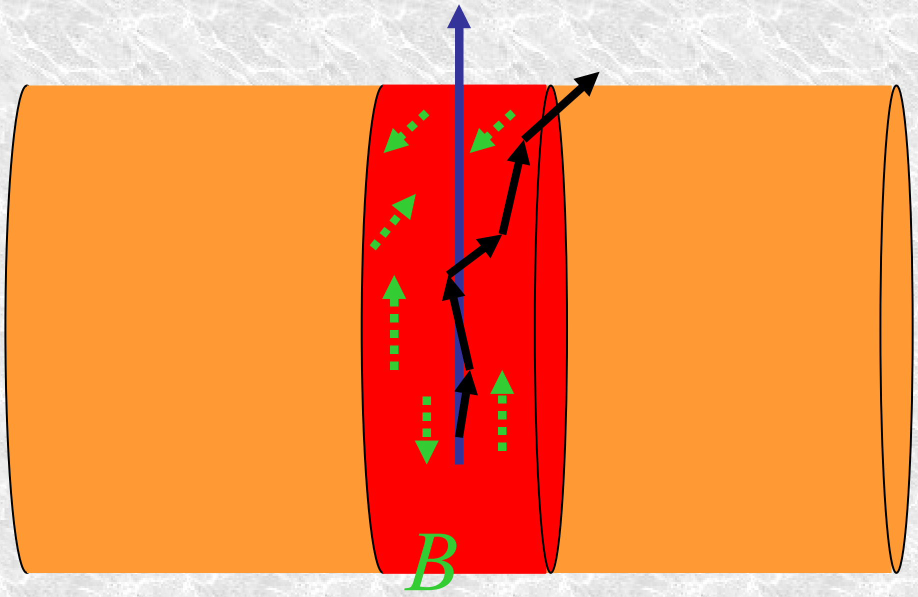
The quasi-particle model with large fields ! (pre-equilibrium QGP)

$$\hat{q}^{\mu\nu} = \frac{p_\perp^\mu p_\perp^\nu}{t} = \frac{2\pi^2 \alpha C_R}{N_c^2 - 1} \int dt \left\langle F^{\mu\alpha}(t) v_\alpha F^{\nu\beta}(0) v_\beta \right\rangle$$

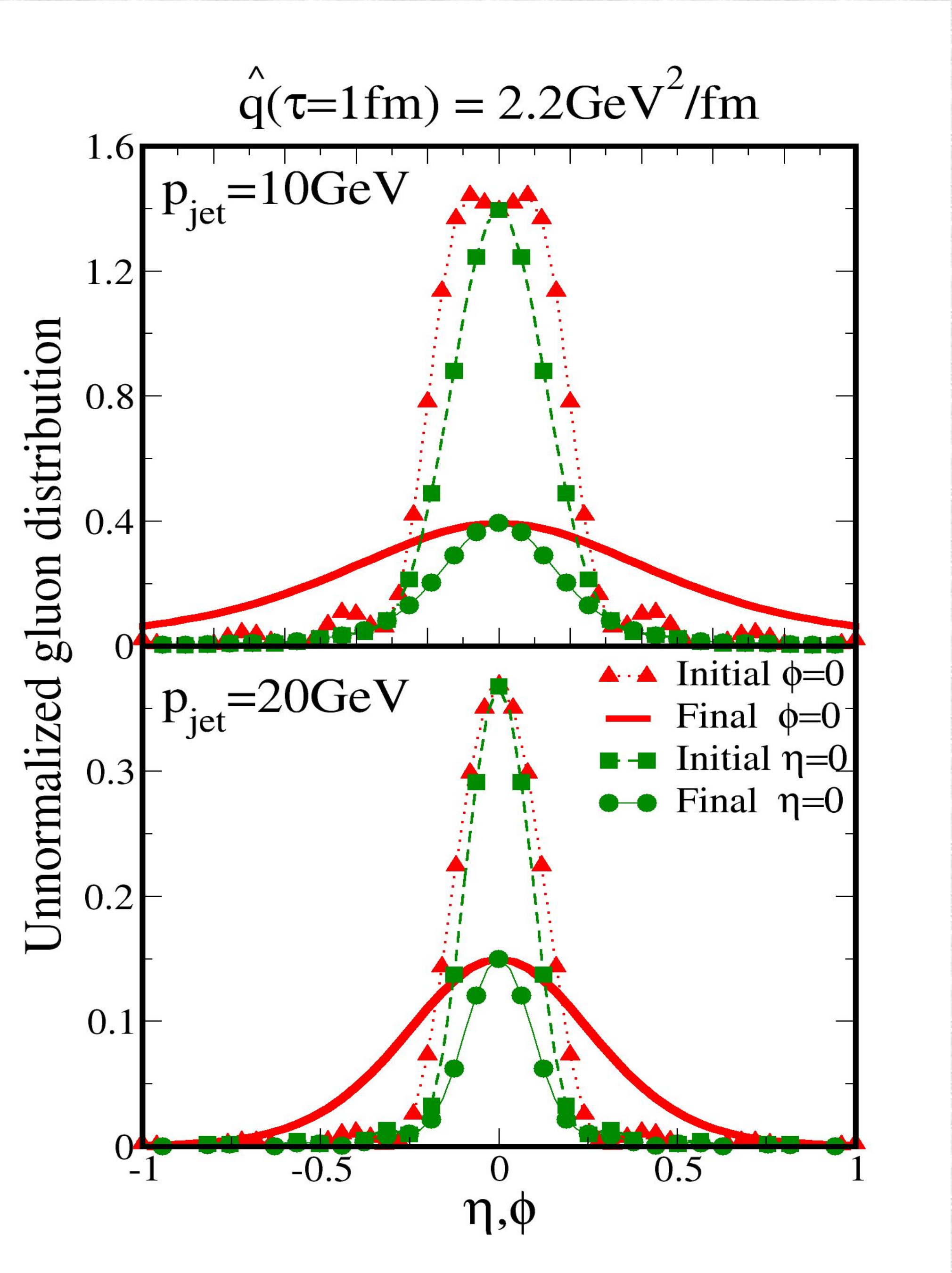
- ***If original particle density distributions anisotropic***
- ***Can lead to the production of a Weibel instability***
- ***This leads to large transverse color magnetic fields***

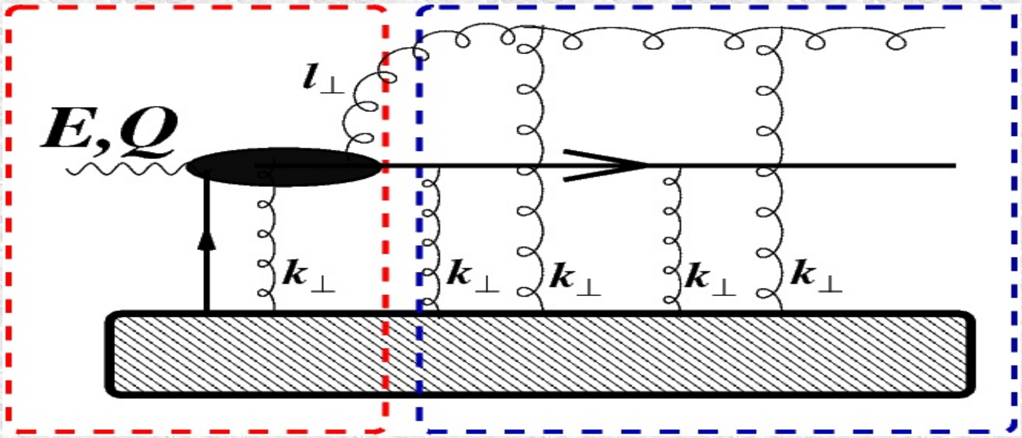


G. Moore, SEWM 2006



The diffusion of soft gluons





We use a factorized form:

1) Radiation formed in Mult. scat.

2) Soft gluon separates and multiply scatters.

3) Use the diffusion equation.

$$\frac{\partial f(p_\perp, t)}{\partial t} = \nabla_{p_\perp} \cdot D \cdot \nabla_{p_\perp} f(p_\perp, t)$$

Procedure completely partonic

How to hadronize the soft mode?

A.Majumder, B. Mueller, S. A. Bass, hep-ph/0611135

The quasi-particle model

+

instabilities

How does it stack up ?

- Instabilities ➔ fast thermalization (see talk by P. Arnold)
- Large fields ➔ small viscosity
- Large fields ➔ more``perturbative'' jet quenching (see talk by B. Müller)
- Large transverse fields ➔ Ridge on near side
- Supported by lattice susceptibilities (BS corr.)

- Microscopic explanation of cone on away side !

- Can a theory be setup without T ➔ ∞

Bound state picture?

- Large resonance scattering ➔ fast thermalization
- Small viscosities
- More jet quenching !! not pertubatively ➔ see talk by R. Rapp

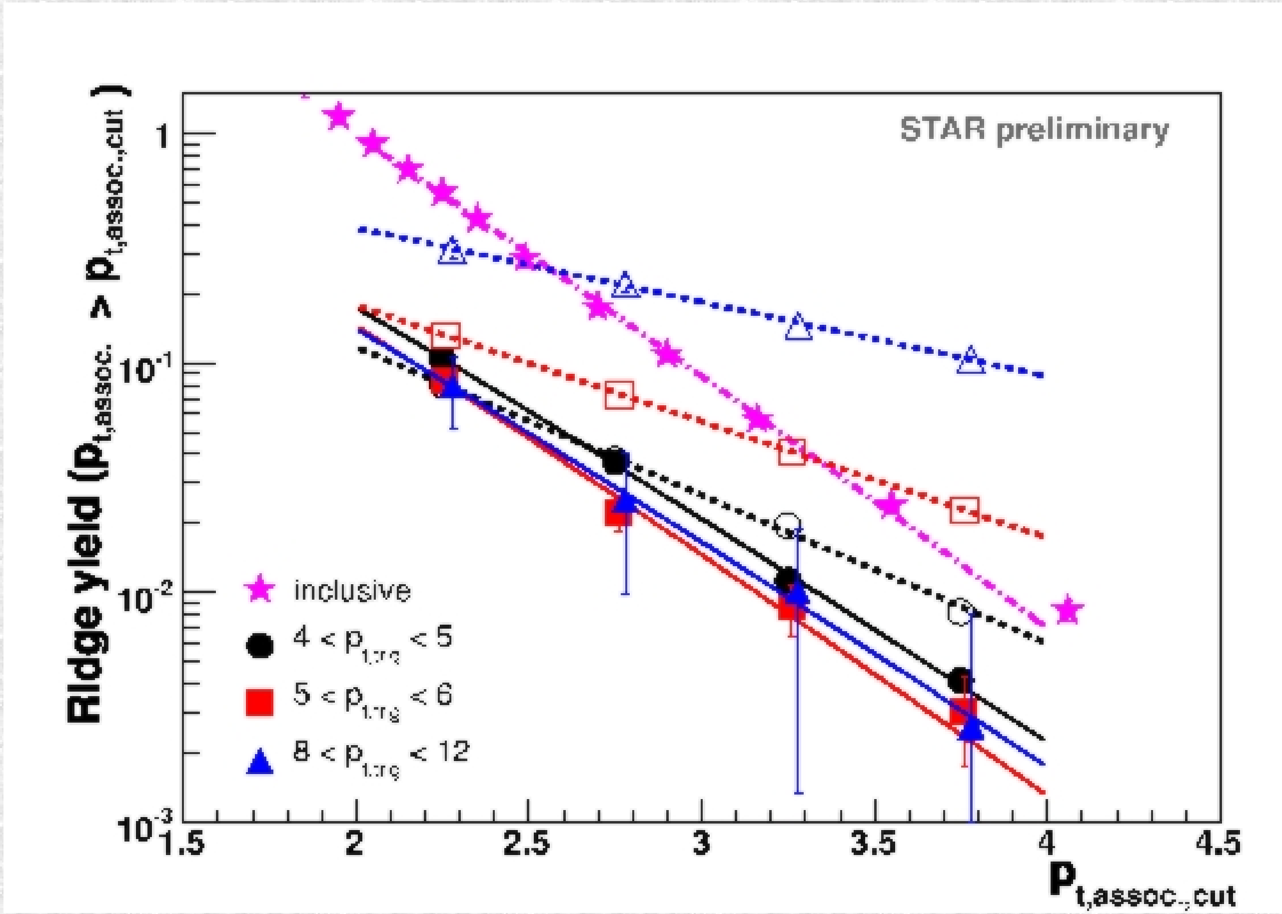
- No Ridge
- Not supported by lattice susceptibilities(flavor sec.)
- No derivation from first principles QCD.

- Microscopic explanation of away side cone: Cherenkov radiation

Conclusions and open issues

- *Need to weed down the microscopic model of the medium*
- *Theoretically or even phenomenologically*
- *Need a short distance, descriptive and differential probe*
- *Jet modification, is such a probe*
- *Need to extend qhat to full tensor structure*
- *Multiple phenomenological evidence for quasi-particle picture of QCD*
- *Can all the major observables be described in this model*
- *Can the quasi-particle picture be justified at $T \geq T_c$*

back up!


STAR preliminary
Ridge yield ($p_{t,assoc.} > p_{t,assoc.,cut}$)
$p_{t,assoc.,cut}$
inclusive
$4 < p_{t,trg} < 5$
$5 < p_{t,trg} < 6$
$8 < p_{t,trg} < 12$
1
10^{-1}
10^{-2}
10^{-3}
1.5
2
2.5
3
3.5
4
4.5