Post-QM Theory Summary

Raju Venugopalan

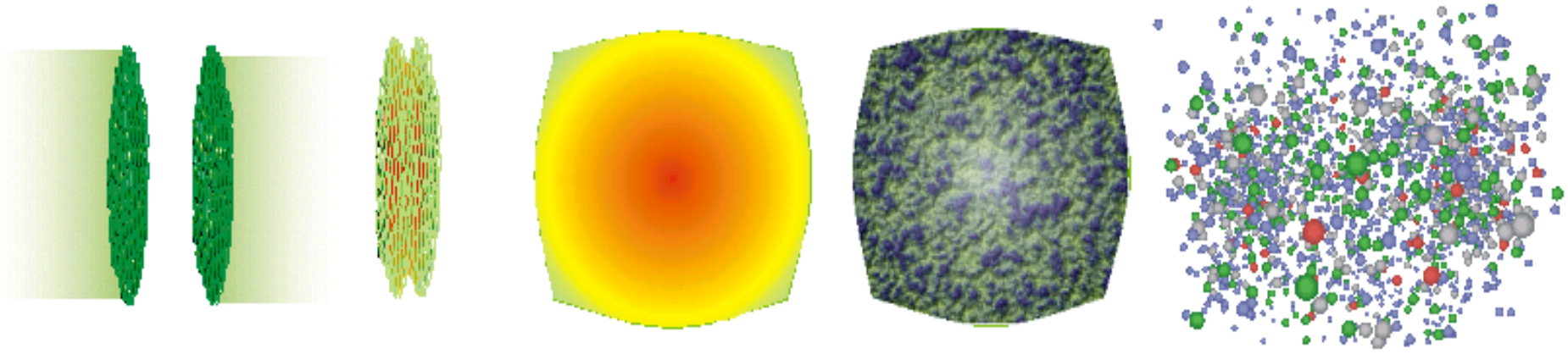
Theory at QM2006:

~ 20 theory plenary talks

~ 50 theory parallel talks

many posters…

Overview by Blaizot, summary by McLerran



CGC

Initial Singularity

Glasma

sQGP

Hadron Gas

- Initial State:
  Gelis, Strickland, Borghini, Venugopalan, Albacete, Armesto, Fries, Xu, Mrowczynski, Adil

- Hydro/Transport:
  Teaney, Nonaka, Ko, Kapusta, Son, Levai, Chaudhuri, Bass, Ma, Asakawa, Hirano, Bhalerao, Molnar, Kodama, Csernai, Gavin, Hwa

- Lattice:
  Hatsuda, Redlich, Karsch, Ipp, Petrov, Ratti, Maezawa,Ohnishi

- Jet quenching:
  Casalderry-Solana, Majumder, Liu, Wiedemann, Renk, Salgado, Vitev, Dremin, Wicks, Lokhtin, Salam, Turbide, Arleo, Alam, Stocker

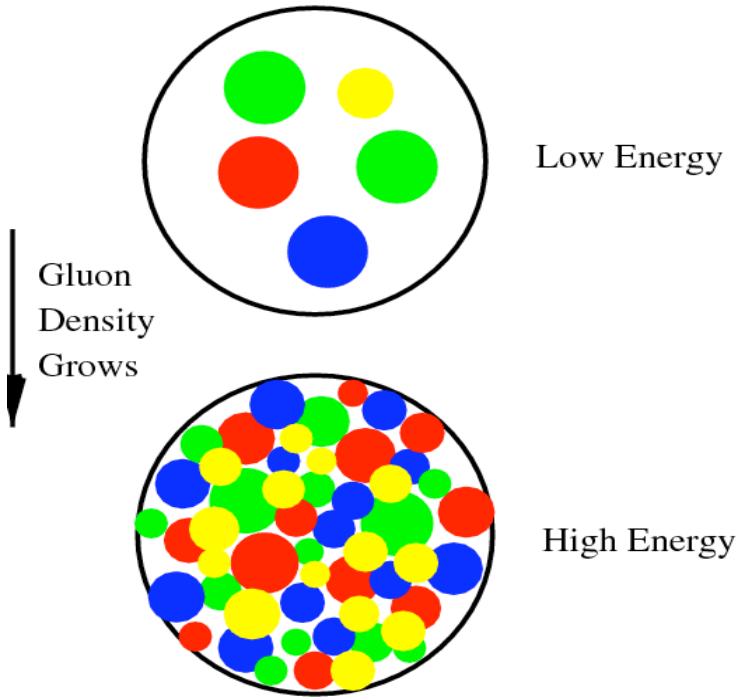
- Heavy & Light mesons properties in-medium:
  Rapp, Kharzeev, Cacciari, Zhuang, Braun-Munzinger, Lee, Mocsy, Vogt, van Hees, Ruppert, Granier de la Cassa

- QM at low T & large mu_B
  Prakash, Randrup, Huang, Wang, Yamamoto, Blaschke

The Unstable Glasma:

How and **when** does thermalization occur in HI collisions ?

The nuclear wavefunction at high energies:



Density of Gluons Grows

α_S becomes weak

Color Glass Condensate

Successes:

Geometric scaling in DIS

Diffractive DIS

Shadowing in dA

Multiplicity in AA

Limiting fragmentation

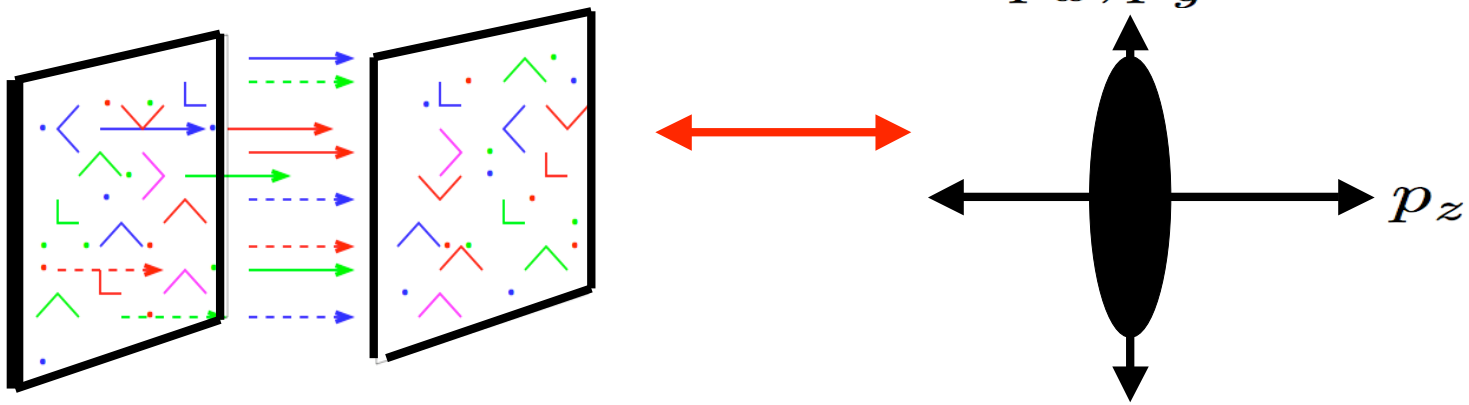
Long range correlations

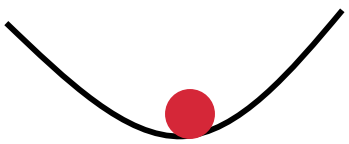
Total cross section

Pomeron, reggeon, odderon

Break down of factorization of pp to ep? Saturated hot spots?

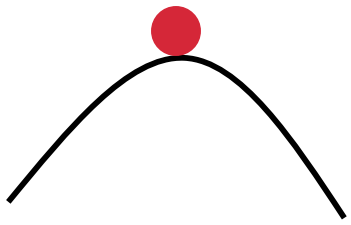
Before the collision, CGC fields are transverse E & B fields-a la Weizsacker-Williams:





Before collision, stability

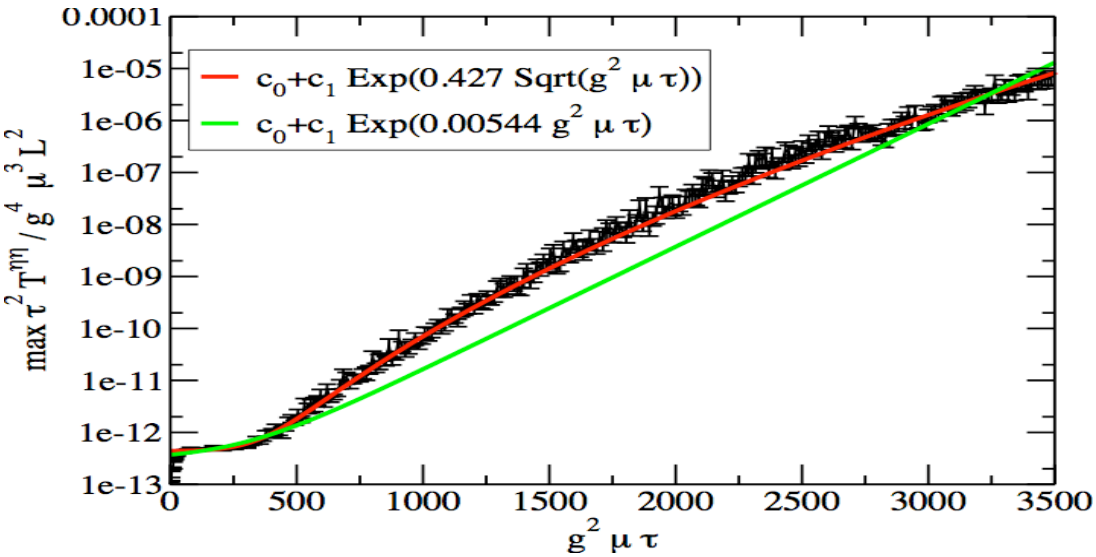
After the collision, in the Glasma, the ***boost invariant*** E and B fields are instead longitudinal…



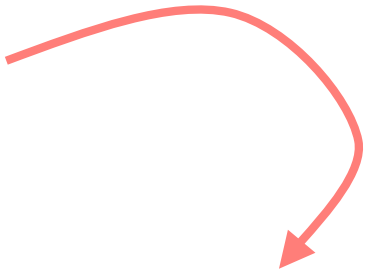
After collisions, unstable

- highly unstable to small ***rapidity dependent*** fluctuations…

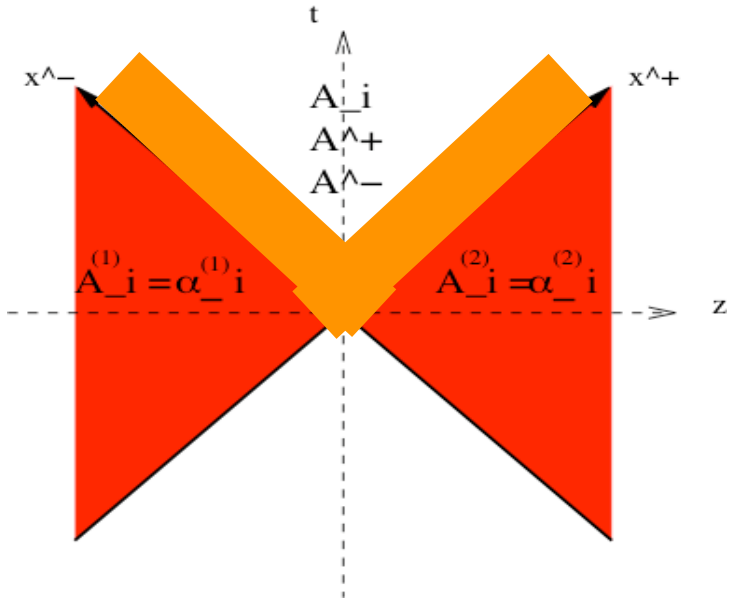
Weibel instability: explosive growth of transverse magnetic fields…(3+1-D numerical solns. of YM eqns.)



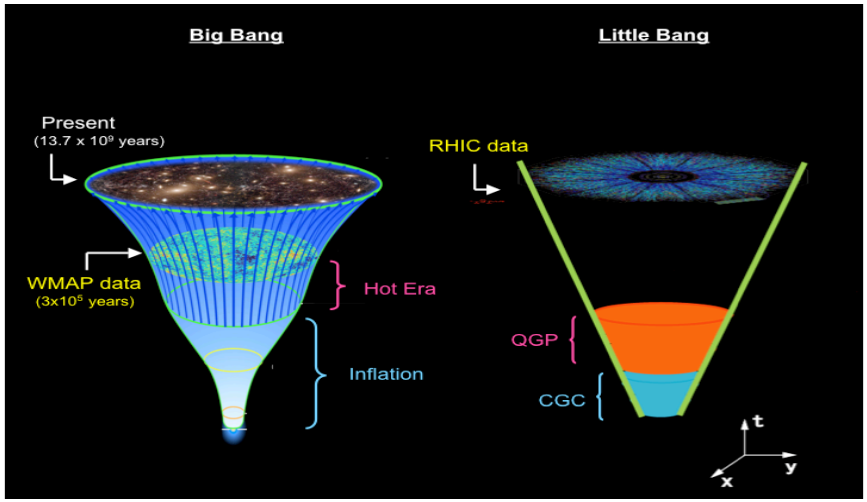
Can these isotropize the system quickly by “bending” transverse modes into the longitudinal direction ?



Answer sensitive to
spectrum of initial fluctuations
in the little bang:



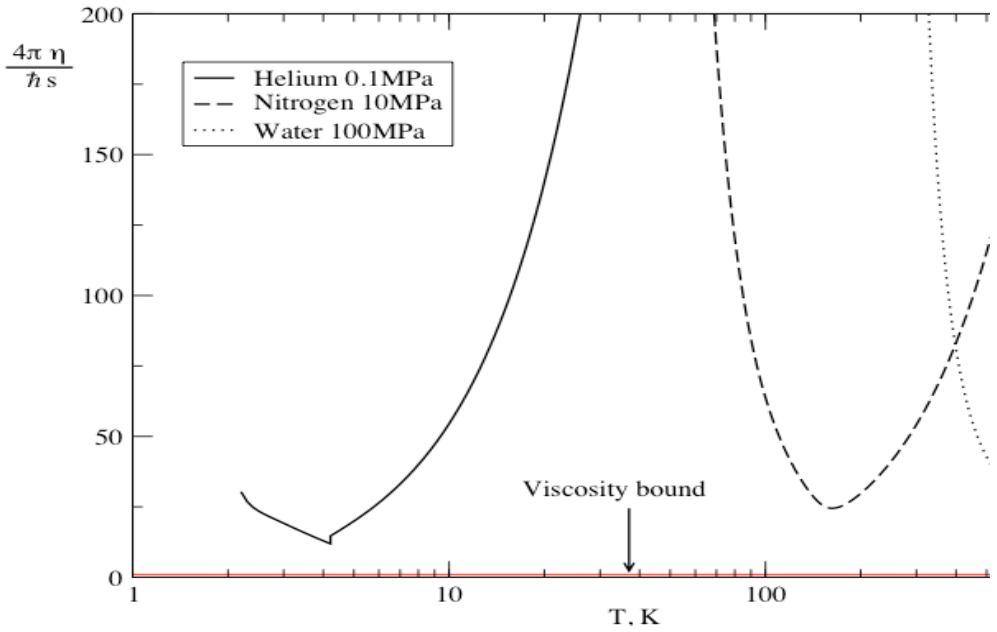
Analogy to spectrum
of density fluctuations
in inflationary
phase after the big bang

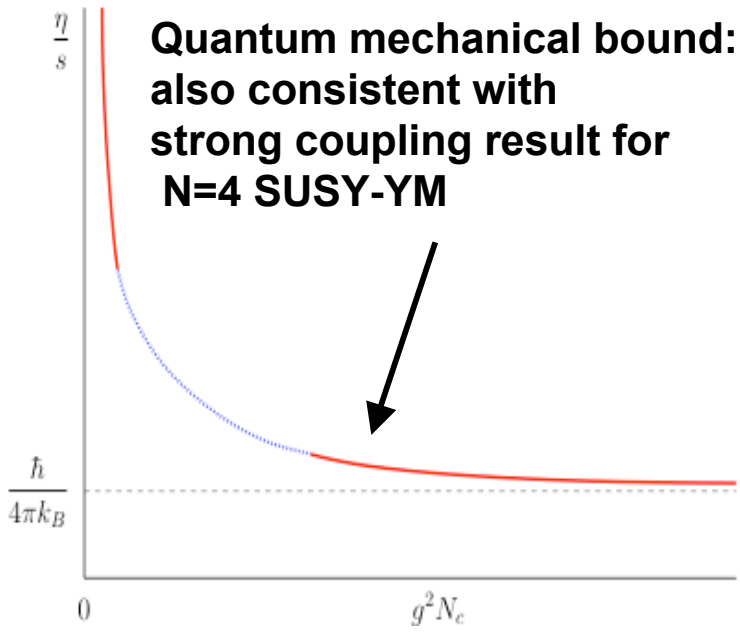


Do little bang fluctuations
survive in long range rapidity correlations ?

Hydrodynamics of the “perfect” fluid

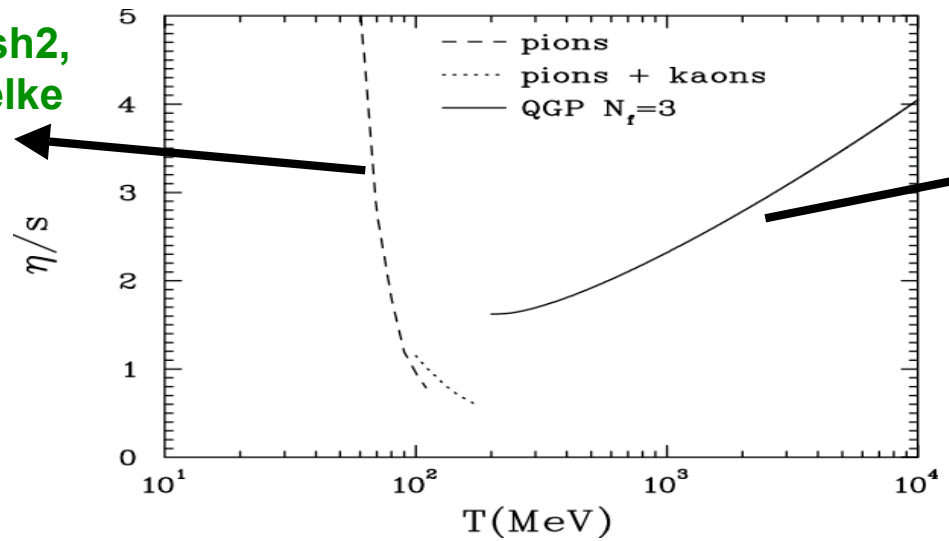
Conjecture: lowest possible in nature? Son, Starinets, Kovtun





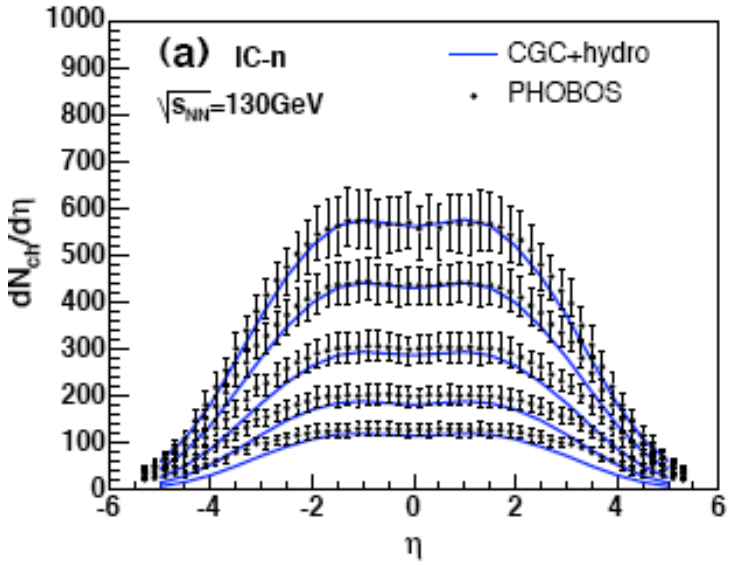
Quantum mechanical bound: also consistent with strong coupling result for N=4 SUSY-YM

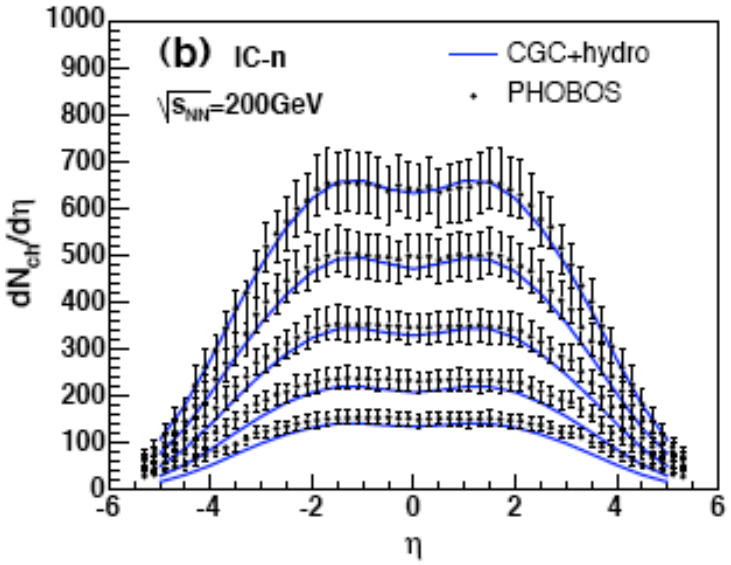
Prakash2, RV,Welke



Arnold,Moore,Yaffe

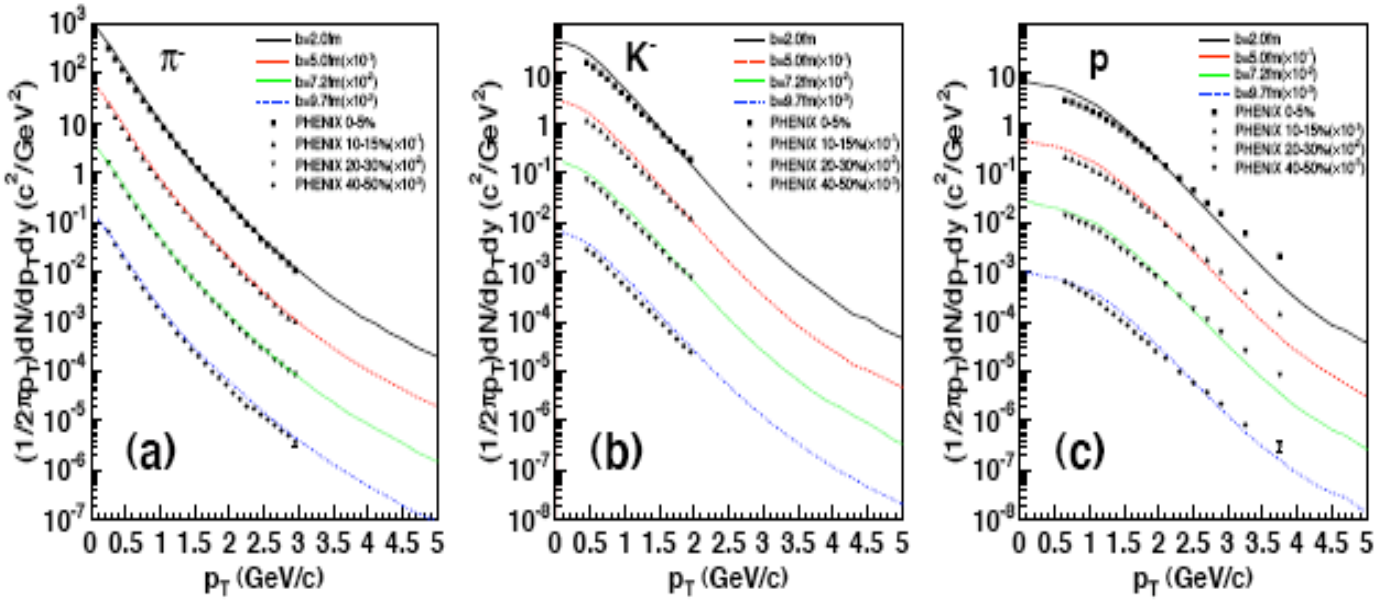
Csernai, Kapusta, McLerran





Hydro+ CGC Initial Conditions

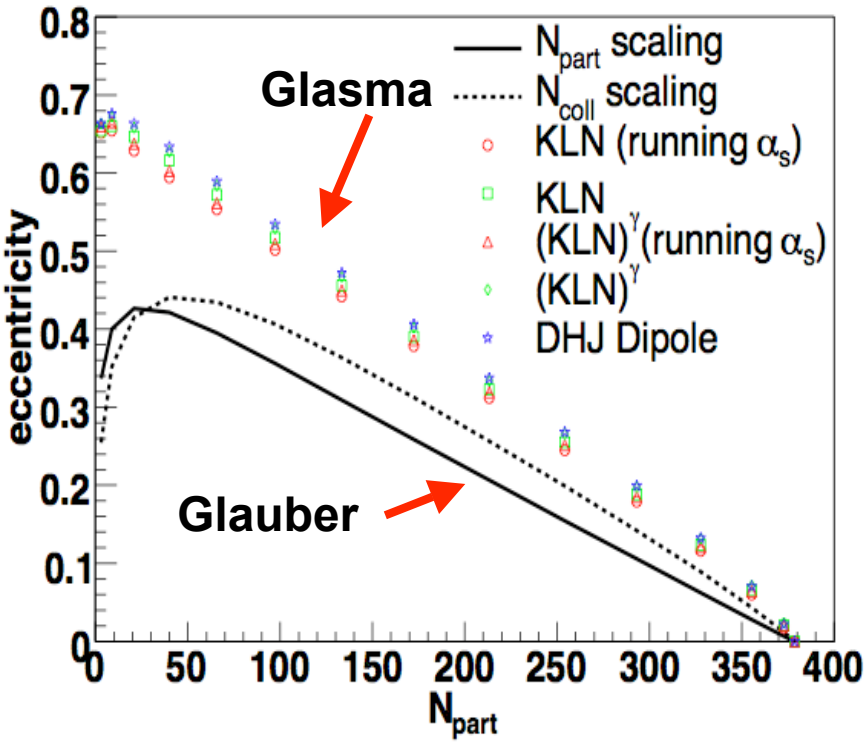
Good description of multiplicity and pT distributions



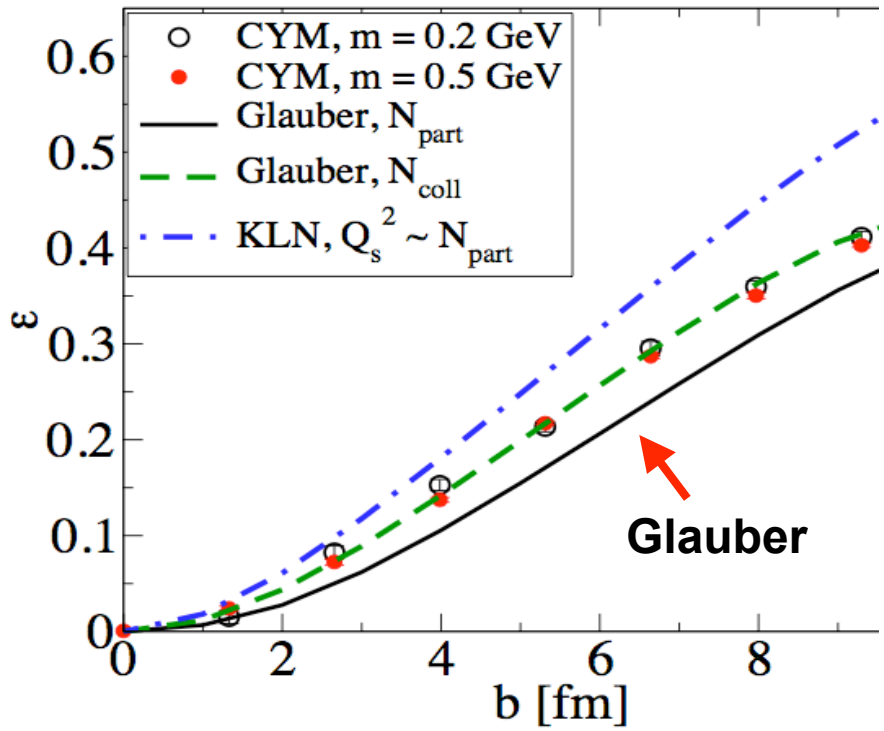
Hirano, Nara

Large eccentricity from Glasma initial conditions ?

Hirano et al., nucl-th/0511046;
Nara et al. nucl-th/0605012



Lappi, RV, nucl-th/0609021



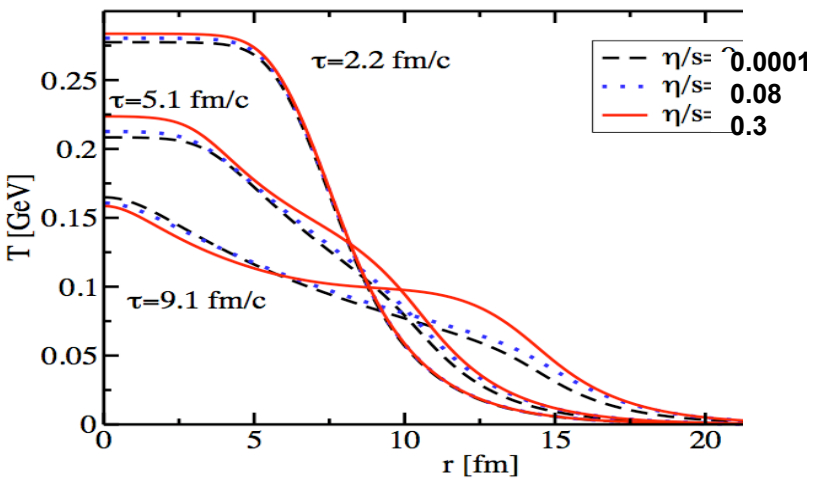
$v_2 \propto \varepsilon$ → exceeds the "hydro limit" ?

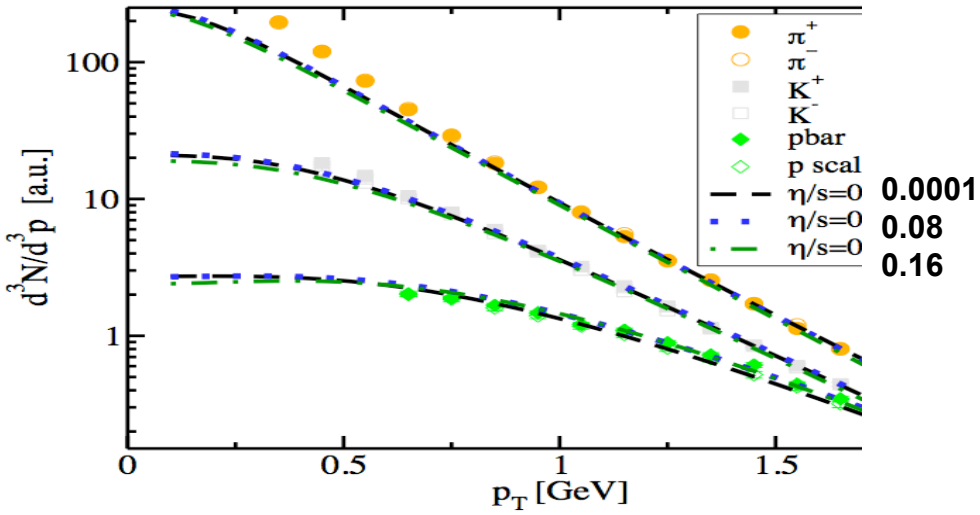
Excess => Viscosity

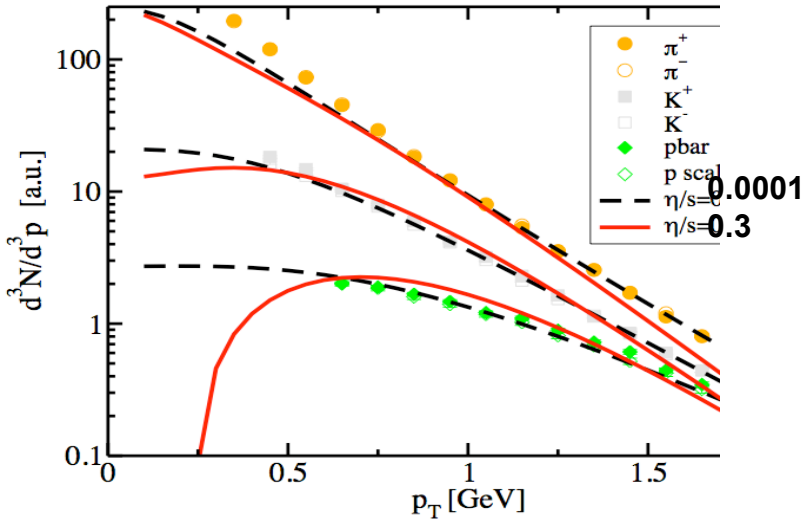
v2 fluctuations ?

Towards viscous hydro… 1+1 D simulations now available

Baier+Romatschke



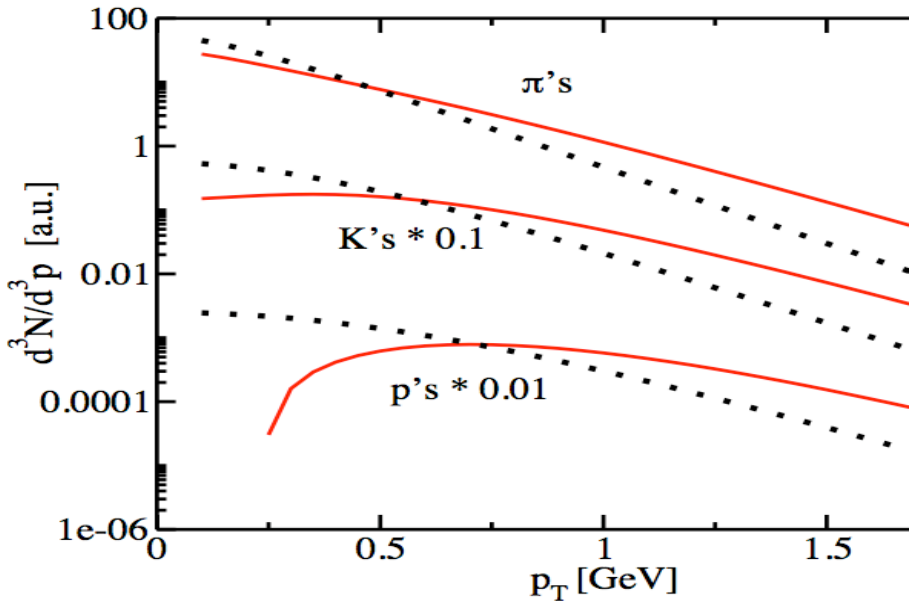




Does this mean that

$$\frac{\eta}{s} < 0.3\,?$$

Not necessarily…

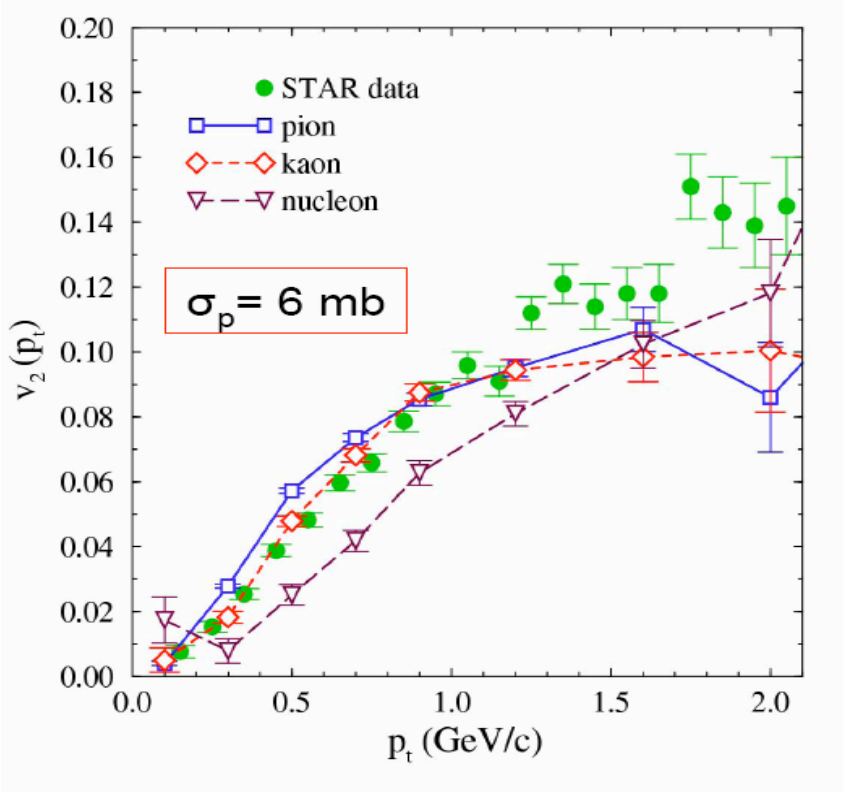


O(1) corrections mean that viscous hydro description of matter produced at RHIC is not valid…

-simulations will give the bound for which it is useful to define eta/s

-important to have independent theory (lattice?) insight into eta/s

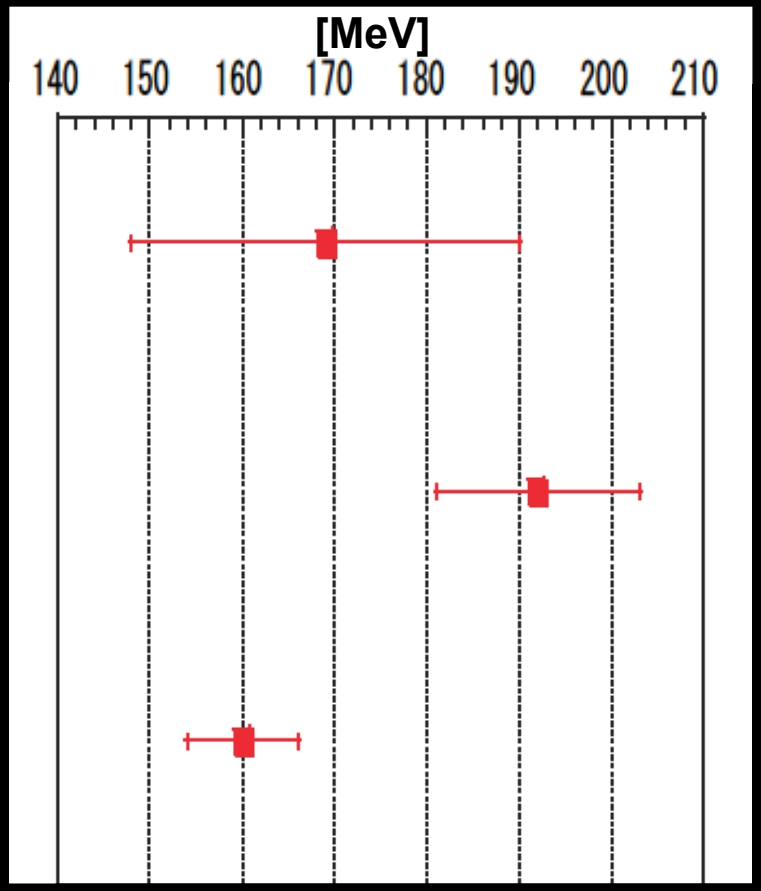
Note: transport models can also reproduce
v2 data-with smaller cross-sections than believed previously



Ko et al.

News from lattice QCD
+ relevance for finite T Onia

T_{pc} ($a \to 0$) in full QCD (N_f=2+1) from χ_m/T^2



Staggered fermion

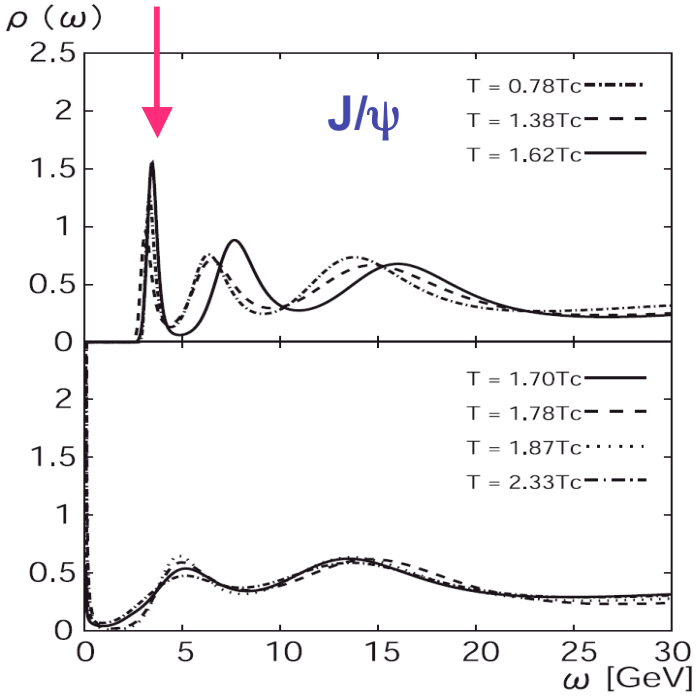
MILC Coll., hep-lat/0405029
169(12)(4)(5) MeV
Asqtad, Nt=4,6,8, Ns/Nt=2, r_1=0.317(7) fm

RBC-Bielefeld Coll., hep-lat/0608013
192(7)(4) MeV
P4fat3, Nt=4,6 Ns/Nt=2-4, r_0=0.469(7) fm

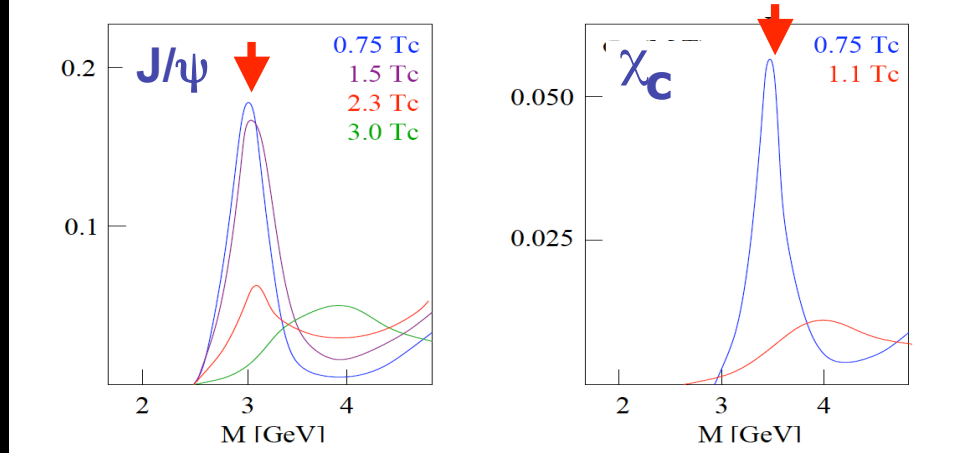
Wuppertal-Budapest Coll., hep-lat/0609068
151(3)(3) MeV + 9 MeV
stout, Nt=6,8,10, Ns/Nt=4, F_K scale

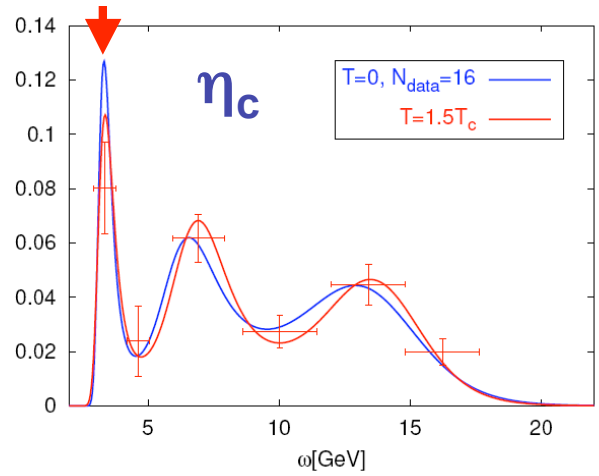
Charmonium spectra in quenched QCD

Asakawa & Hatsuda, hep-lat/0308034



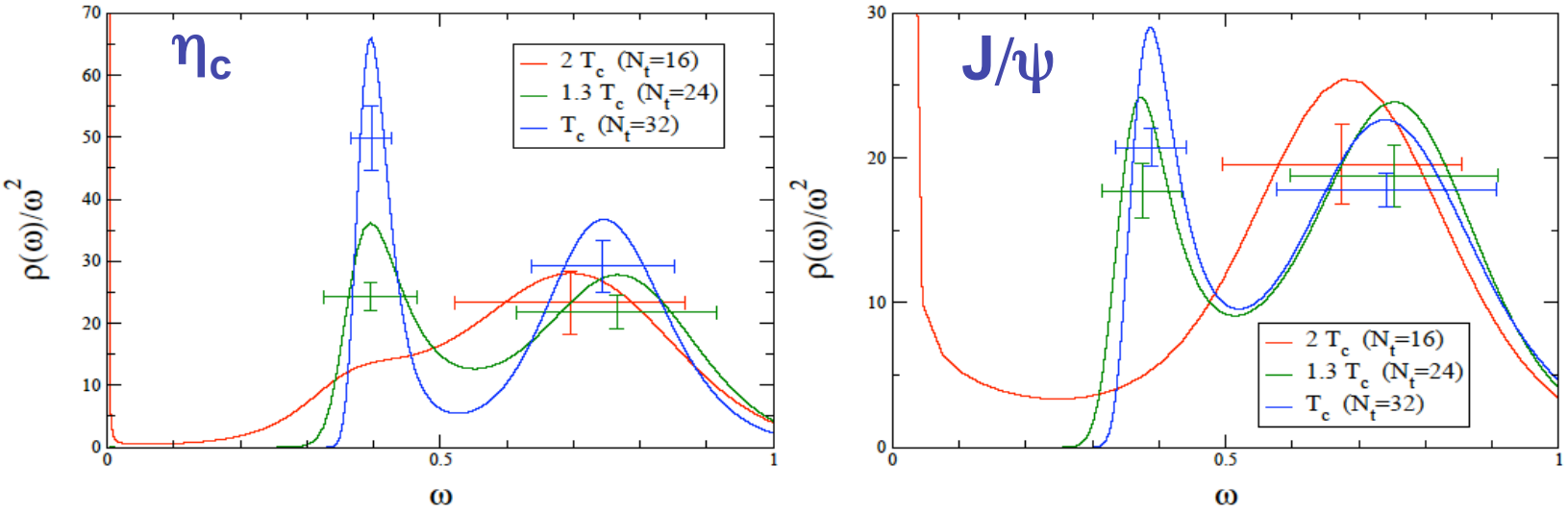
Datta, Karsch, Petreczky & Wetzorke, hep-lat/0312034





Jakovac, Petreczky, Petrov & Velytsky hep-lat/0611017

Charmonium spectra in full QCD (N_f=2)



Aarts et al., hep-lat/0610065

1S (eta_c, J/Psi) states exist as resonances to T~ 1.5 T_c

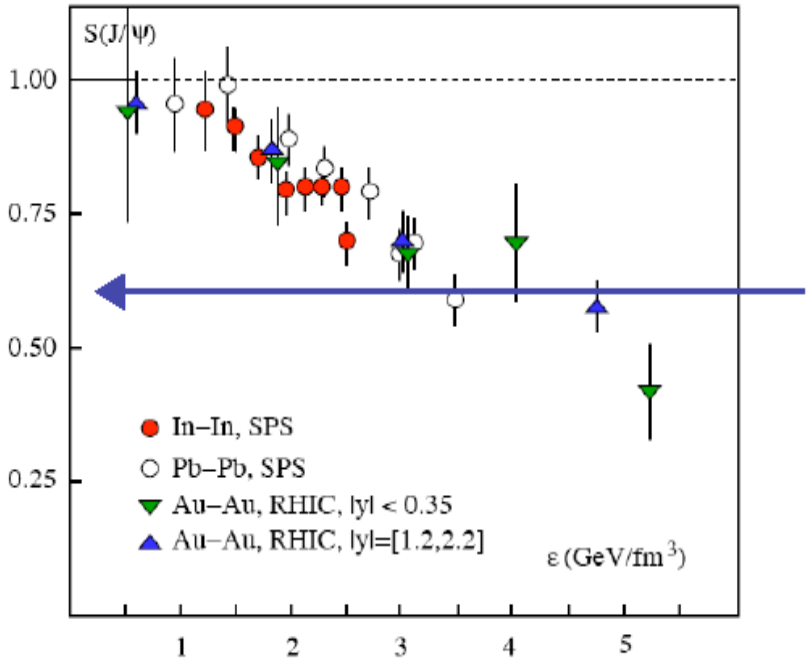
1P states dissolve at ~ 1.1 T_c

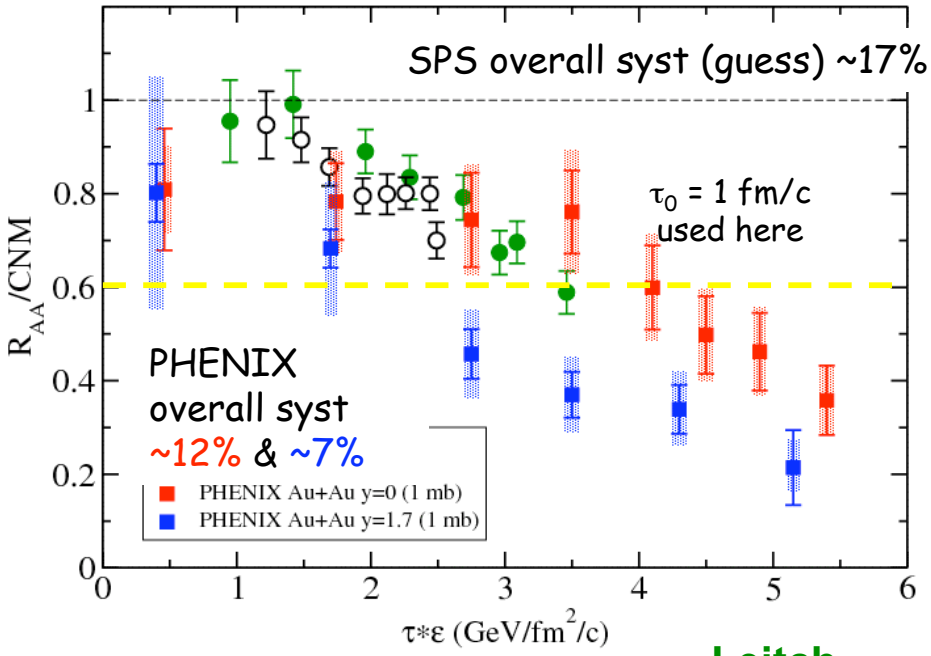
Lattice data not simply reproduced in potential models which mimic finite T behavior of heavy quark free energy

Mocsy, Petreczky

Basis of sequential screening scenario

Karsch,Kharzeev,Satz





Leitch

Alternative scenario-screening+regeneration

Thews et al.

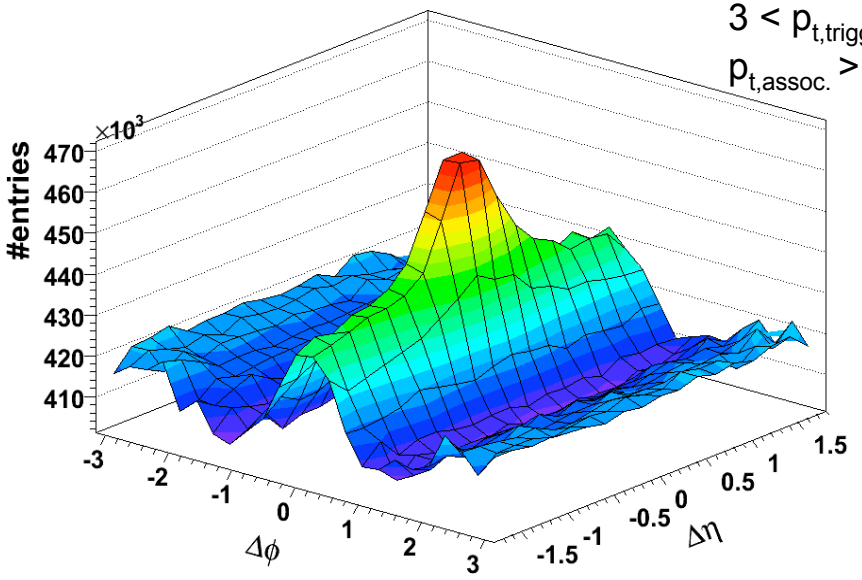
Detailed understanding of pt/rapidity systematics needed

Hard probes/Jet quenching

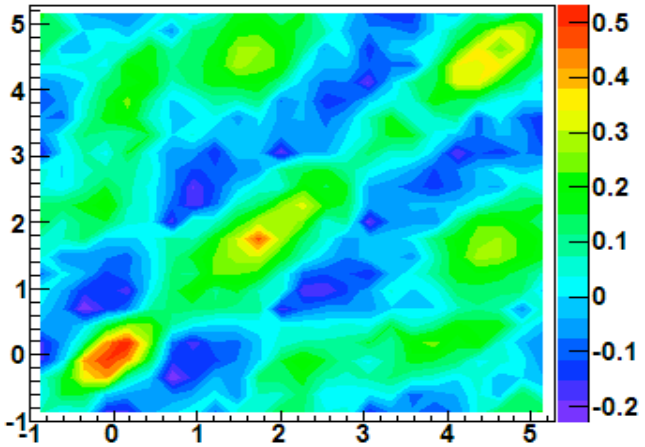
New era of jet studies…

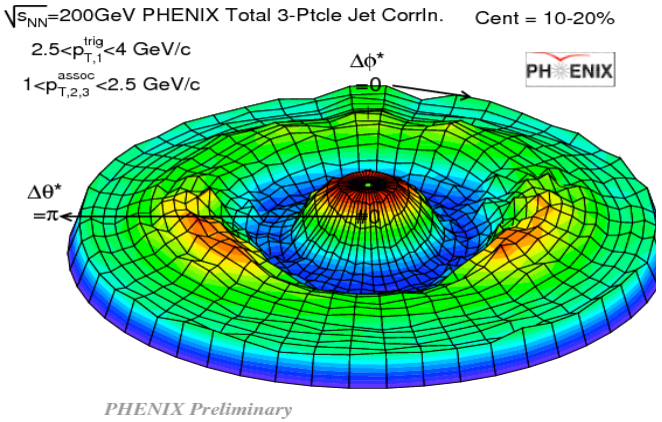
$3 < p_{t,trigger} < 4$ GeV

$p_{t,assoc.} > 2$ GeV



Near side peak+ridge



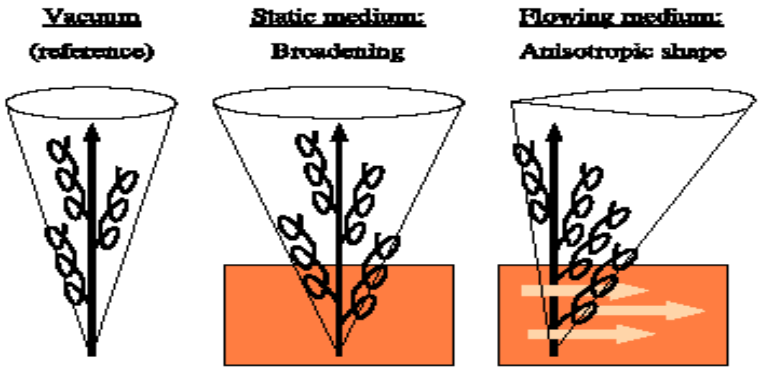


Away side correlations suggest conical structure…

The ridge:

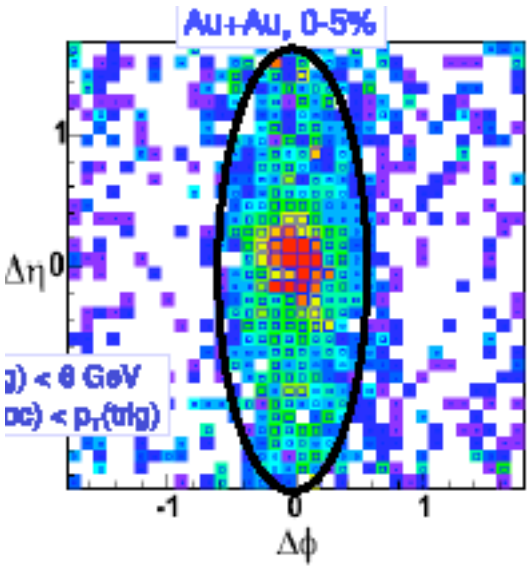
Broadening of jets due to collective flow ?

Armesto,Salgado,Wiedemann



Plasma Instabilities ?

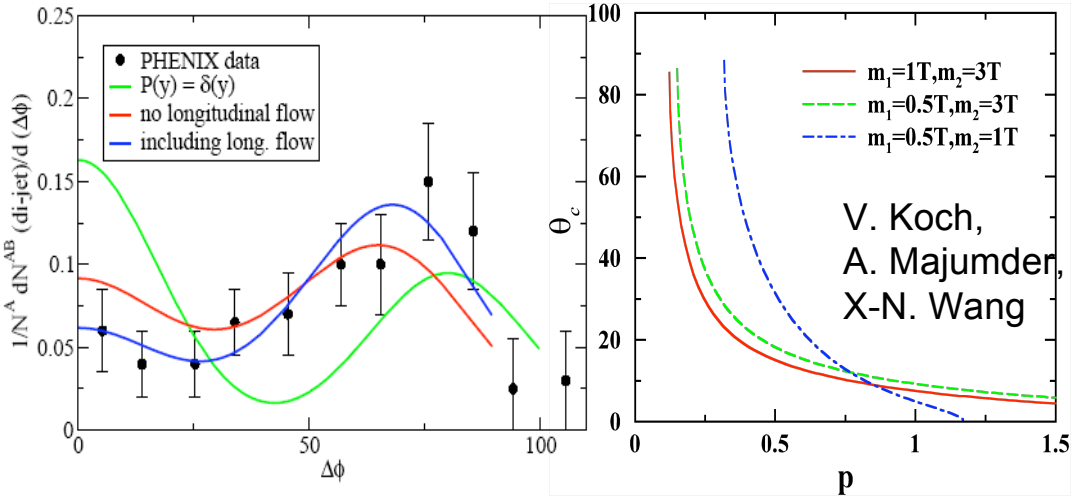
Romatschke



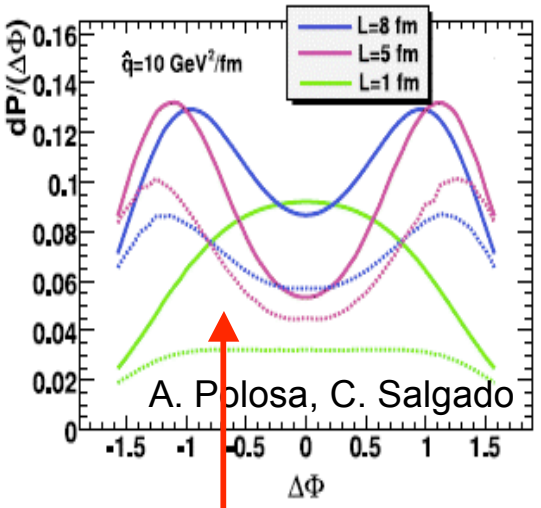
In both these scenarios, the width of the ridge should decrease rapidly with p_T

The away-side cone:

Mach Cone/Shock wave Cherenkov radiation Gluon rad+Sudakov

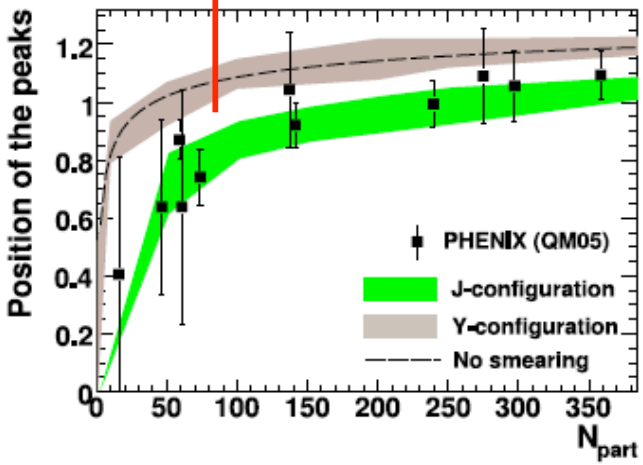


Stöcker, Casseldery-Solana et al



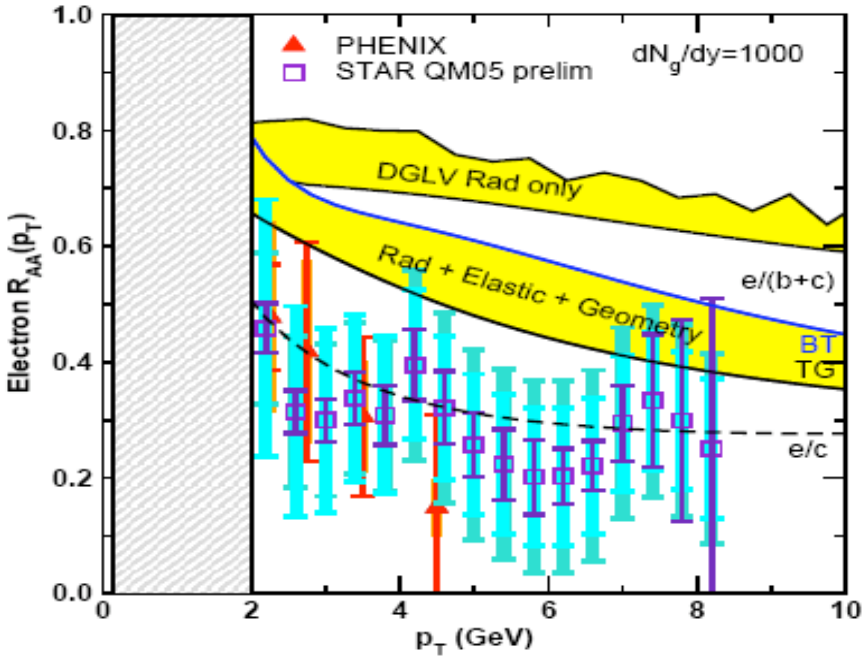
Also: Vitev, Phys. Lett. B630 (2005)

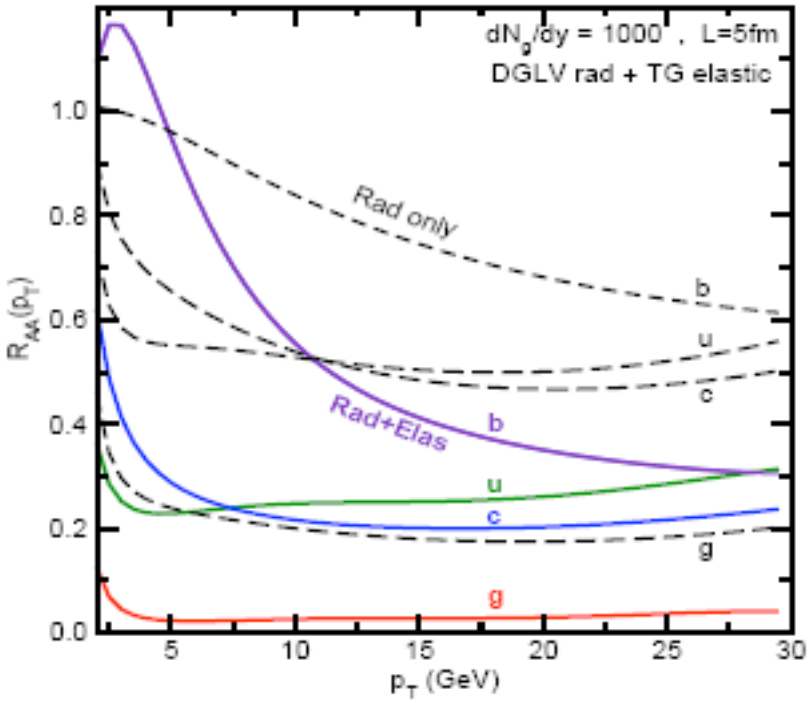
Many different explanations…



Collisional energy loss of heavy quarks ?

Mustafa; Djordevic, Gyulassy

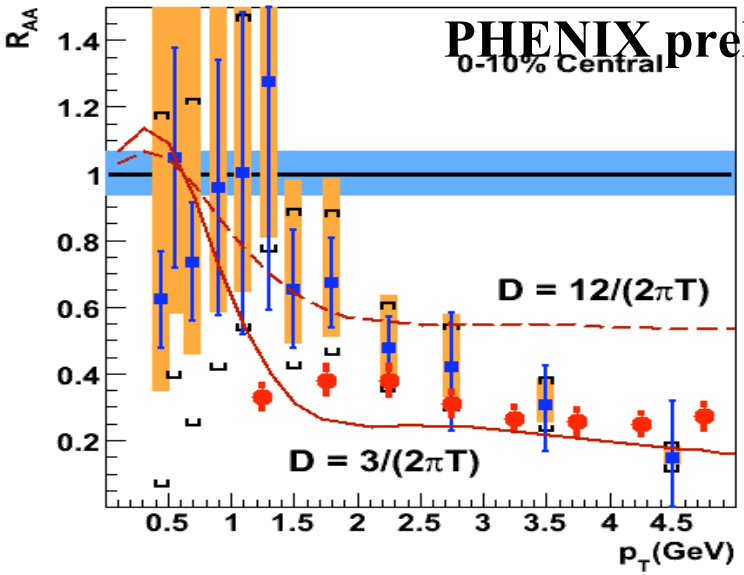




Wicks,Horowitz,Djordjevic,Gyulassy

Including both still off from data with FONLL b/c rations

Charm quark energy loss from Langevin dynamics ?



Moore & Teaney

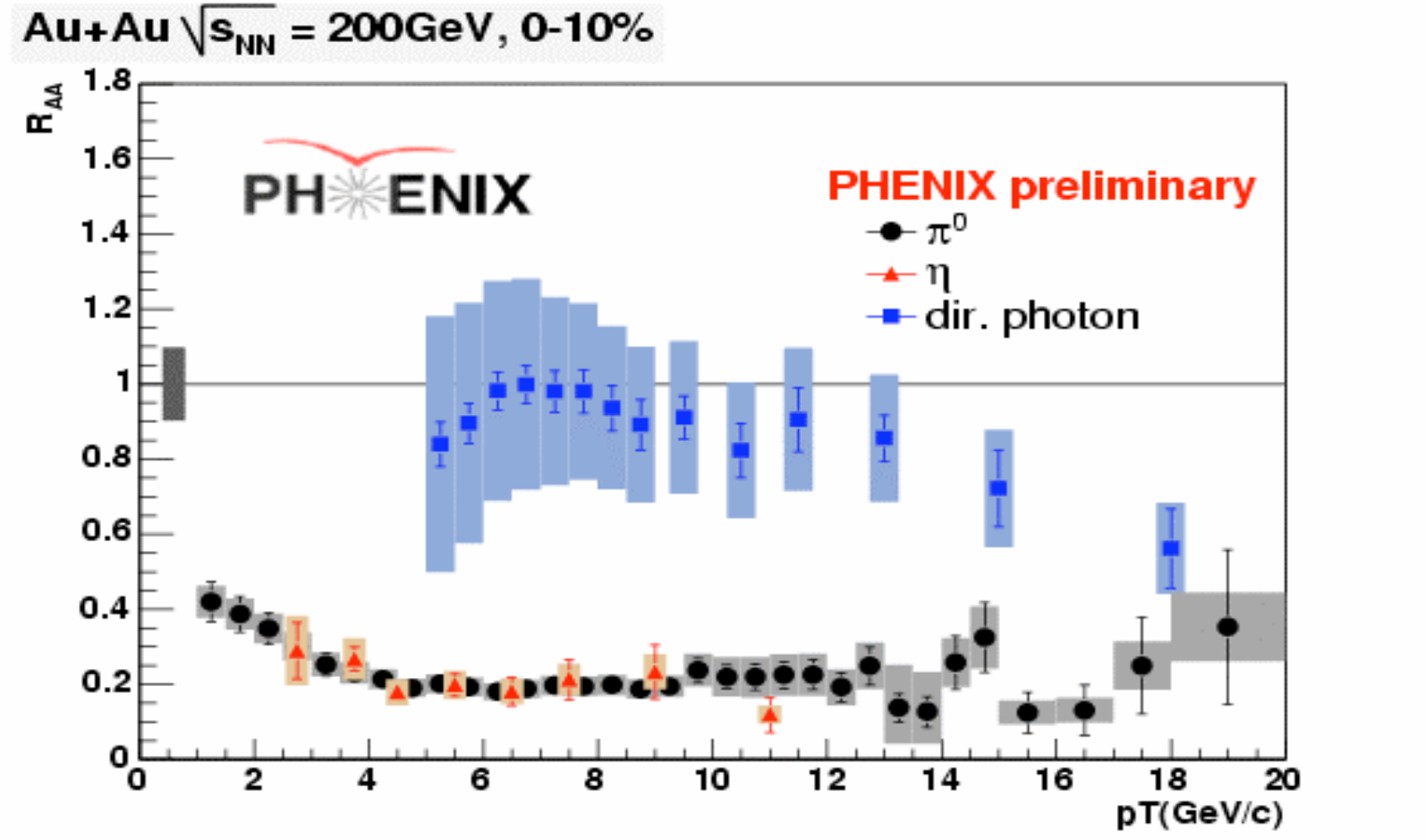
pQCD estimate: $D \approx \frac{6}{2\pi T}\left(\frac{1.5}{\alpha_S N_c}\right)^2$

ADS/CFT $D \approx \frac{0.9}{2\pi T}\left(\frac{1.5}{\alpha_{SYM} N_c}\right)^{0.5}$

(Teaney, Casalderry-Solana; Yaffe et al.; Gubser et al)

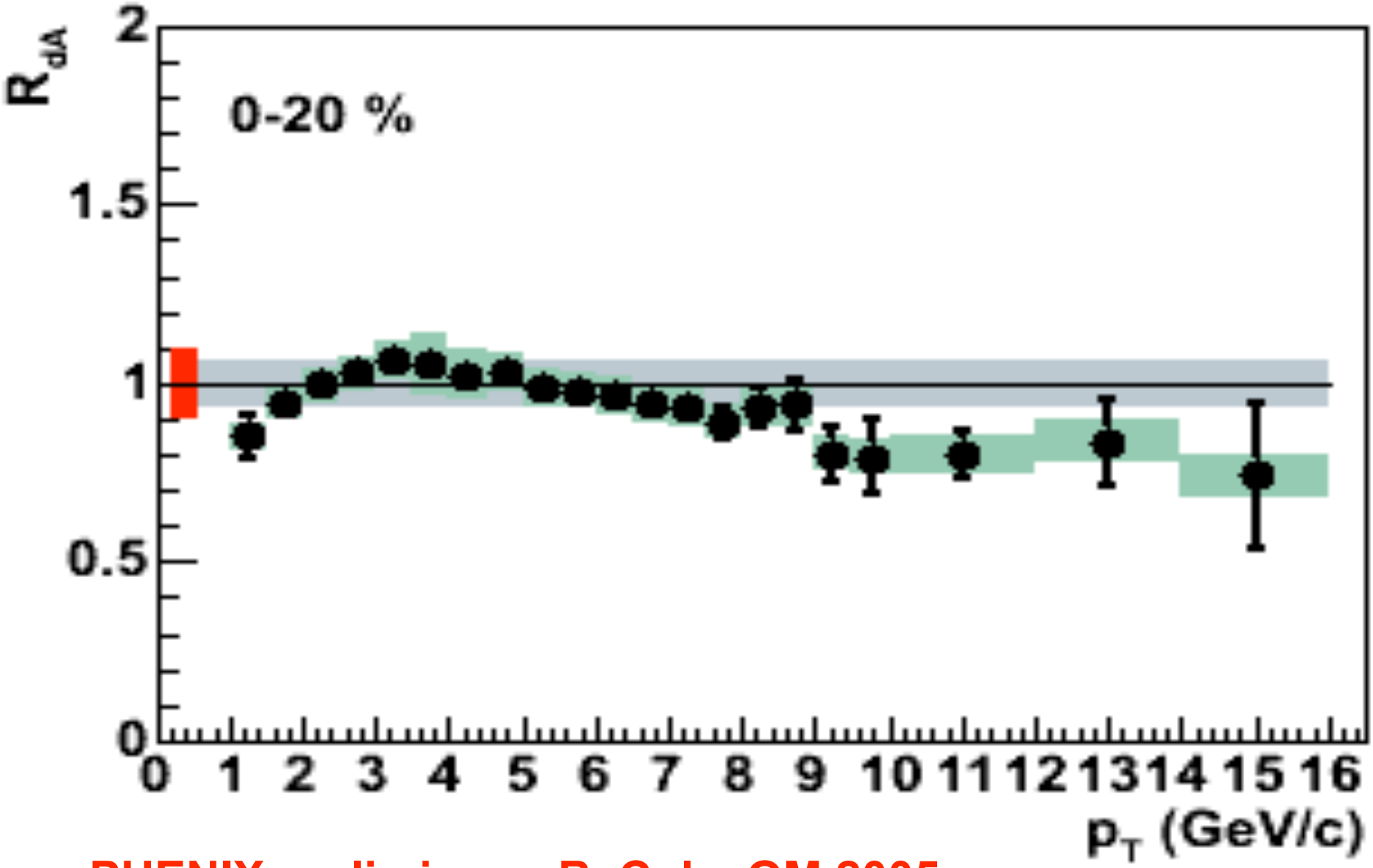
But AdS estimate reliable only for M >> 1.7 GeV

Very interesting R_AA for photons

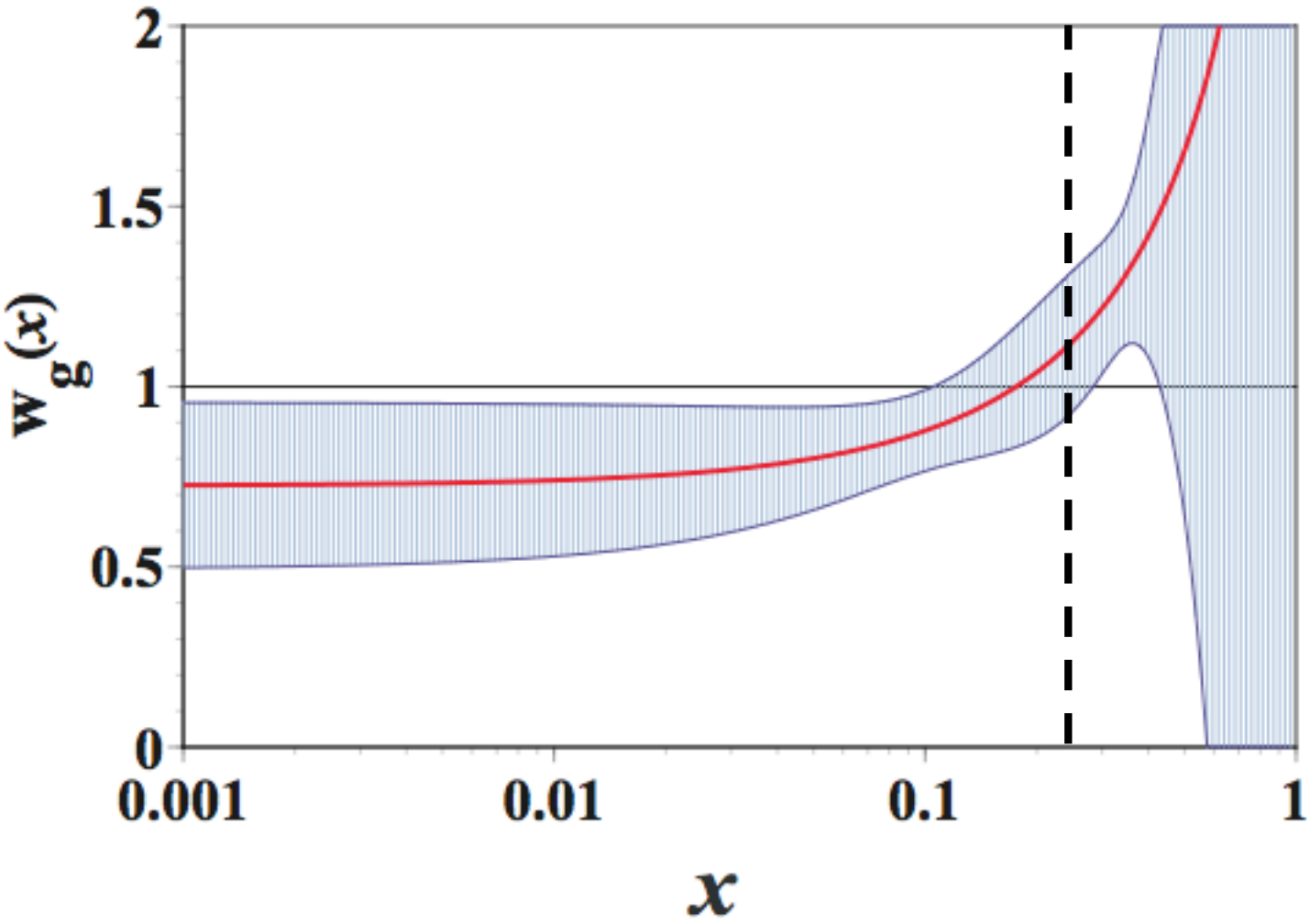


EMC effect ?

EMC effect at large p_T ?

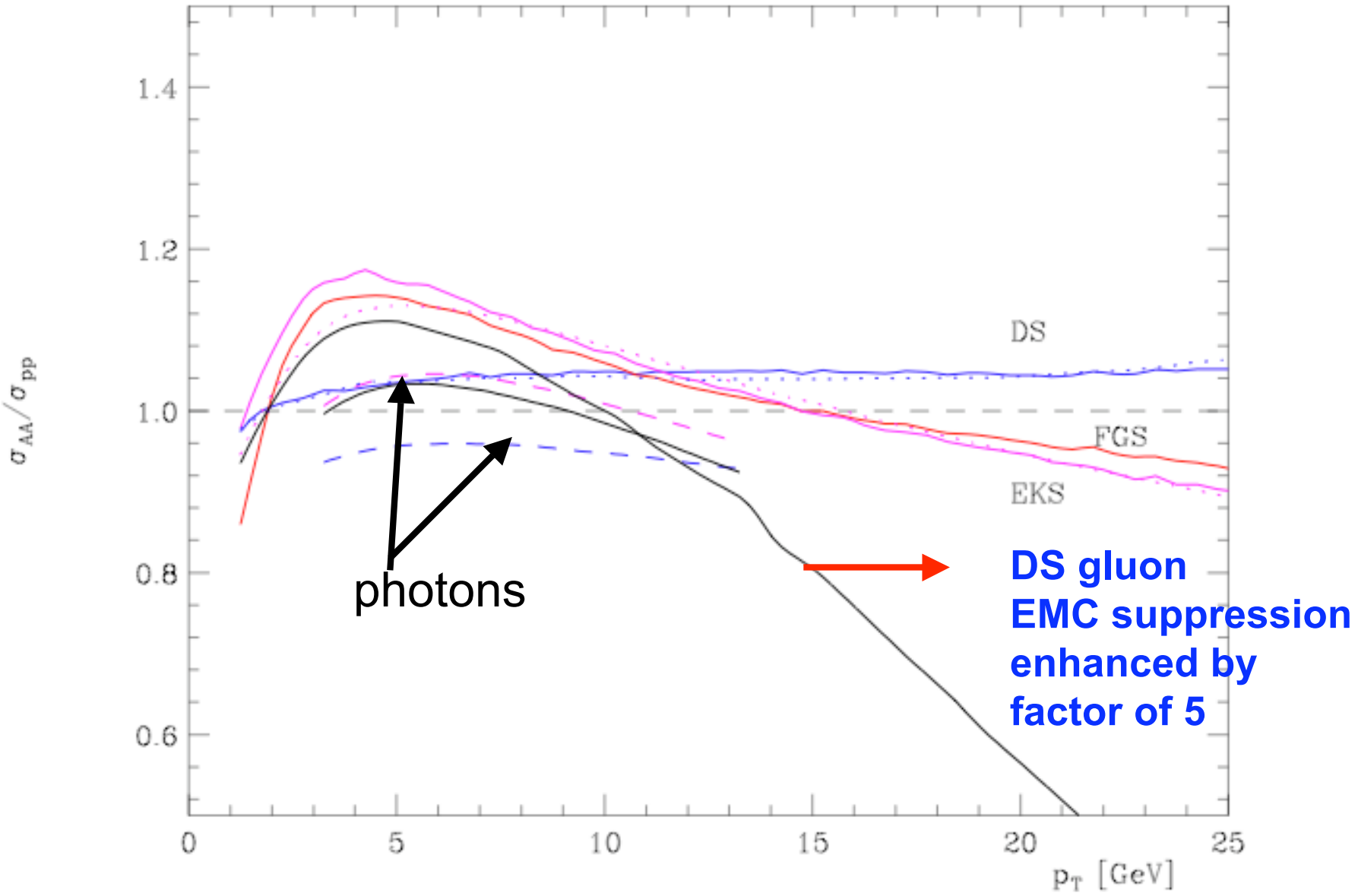


PHENIX preliminary, B. Cole, QM 2005



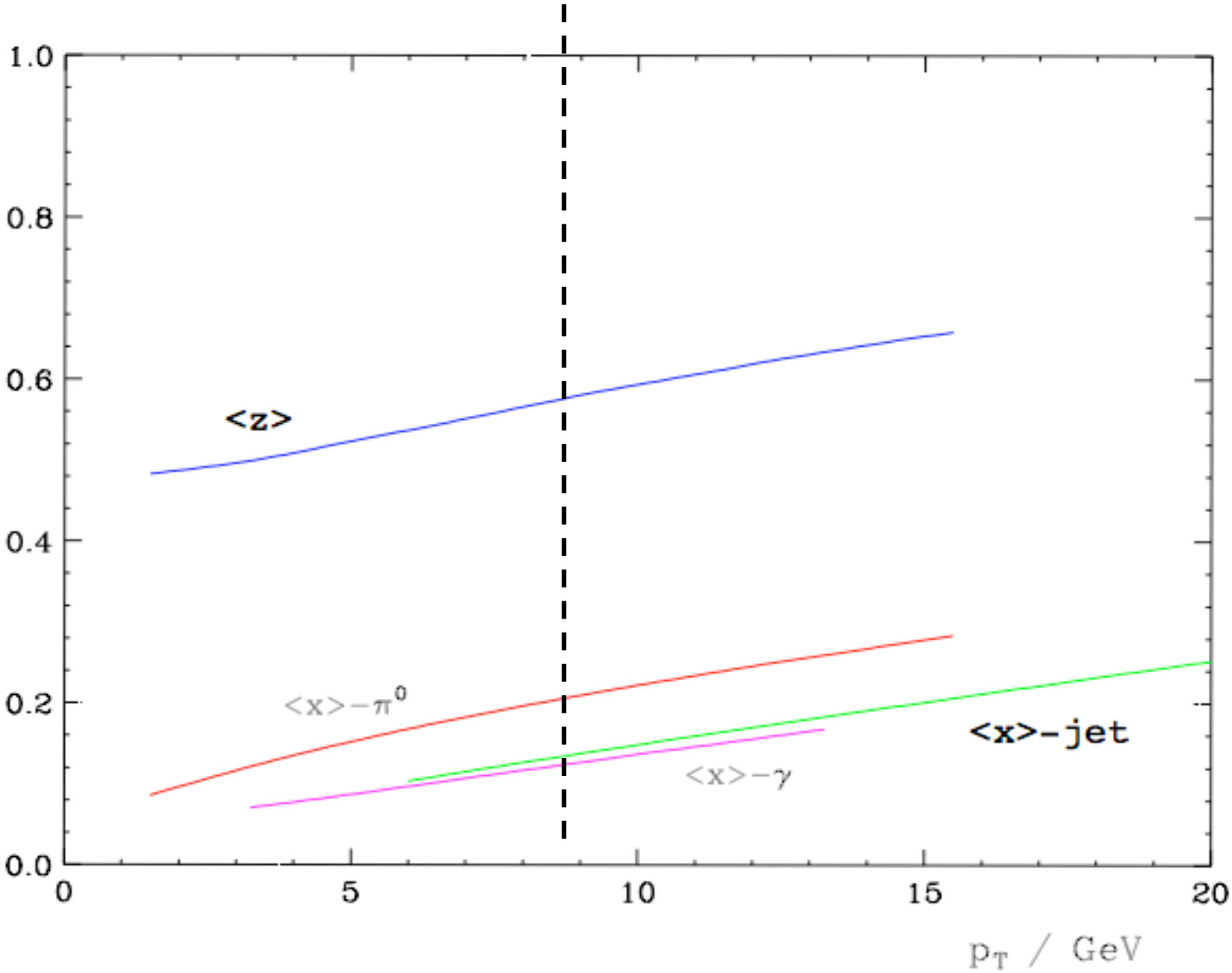
Uncertainity in ratio of Ca to nucleon gluon distributions

-from Hirai, Kumano, Nagai, hep-ph/0404093

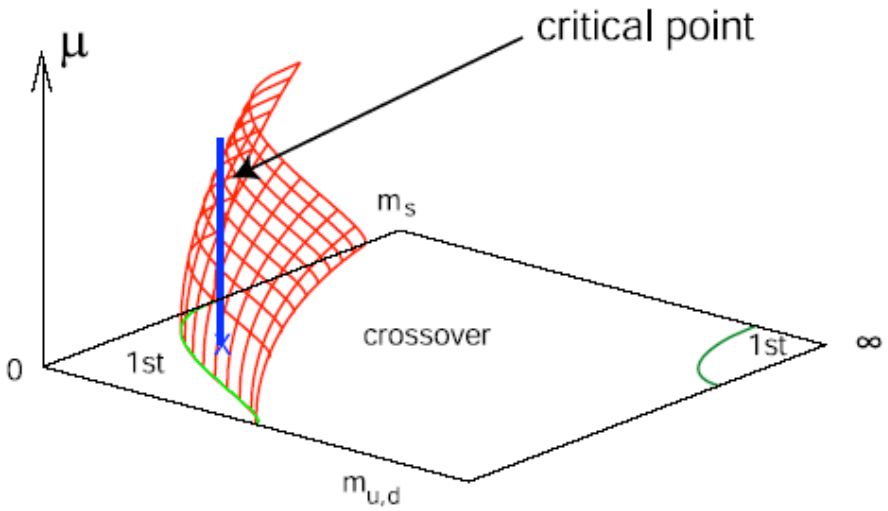

1.4
1.2
1.0
0.8
0.6
0
5
10
15
20
25
p_T [GeV]
σ_{AA}/σ_{pp}
DS
FGS
EKS
photons
DS gluon
EMC suppression
enhanced by
factor of 5

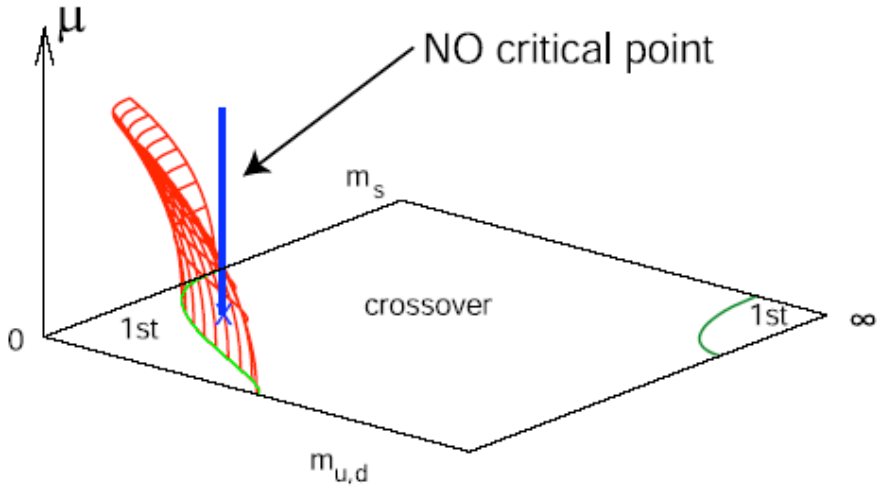
May you live in interesting times

Chinese proverb


1.0
0.8
0.6
0.4
0.2
0.0
0
5
10
15
20
<z>
<x>−π0
<x>−γ
<x>-jet
pT / GeV

Critical point





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