"The emergence of QCD is a wonderful example of the evolution from farce to triumph" David Gross, from his Nobel Lecture

Recent Results on (d,Au) Collisions from PHENIX

Richard Seto

for the

PHENIX

Experiment

RHIC/AGS User's meeting

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Outline

- dAu collisions
  - Forward hadrons
  - forward J/psi
- a sort of Non Sequitur
  - An estimate of the NDOF (effective)
- Conclusions

- since I am completing my slides today (my sincere apologies – I also had to give another talk last week – and classes are still going at UCR) It was suggested to me to put on the web ASAP, the slides I would use to talk about looking at the values of ε/T^4, $3s/4T^3$ (aka – with caveats which I list, the $NDOF_{effective}$) Please look at the content. I will be improving the look and clarity of the slides.
- I hope to have the rest up late (tonight)

Preliminaries : thermo

$$\varepsilon_g = \frac{1}{2\pi^2}\int \frac{p^3 dp}{e^{\beta p}-1} \qquad \Rightarrow \varepsilon_g = \frac{\pi^2 T^4}{30}$$

$$\varepsilon_q = \frac{1}{2\pi^2}\int \frac{p^3 dp}{e^{\beta(p+\mu)}+1} \qquad \Rightarrow \varepsilon_q + \varepsilon_{\bar{q}} = \frac{7\pi^2 T^4}{120} + \frac{\mu^2 T^2}{4} + \frac{\mu^4}{8\pi^2}$$

melt the hadrons and liberate quark and gluon DOF?

Energy density (entropy density) for "g" massless d.o.f. (bosons)

$$\varepsilon = g\frac{\pi^2}{30}T^4 \qquad TS = \varepsilon + p \Rightarrow \qquad s = g\left(\frac{4}{3}\right)\frac{\pi^2}{30}T^3$$

$$\varepsilon = 3\cdot\frac{\pi^2}{30}T^4$$

Hadronic Matter: quarks and gluons confined
For T ~ 200 MeV, **3** pions with spin=0

$$\varepsilon = \left\{2_s\cdot 8_g + \frac{7}{8}\cdot 2_s\cdot 2_a\cdot 2_f(3)\cdot 3_c\right\}\frac{\pi^2}{30}T^4$$

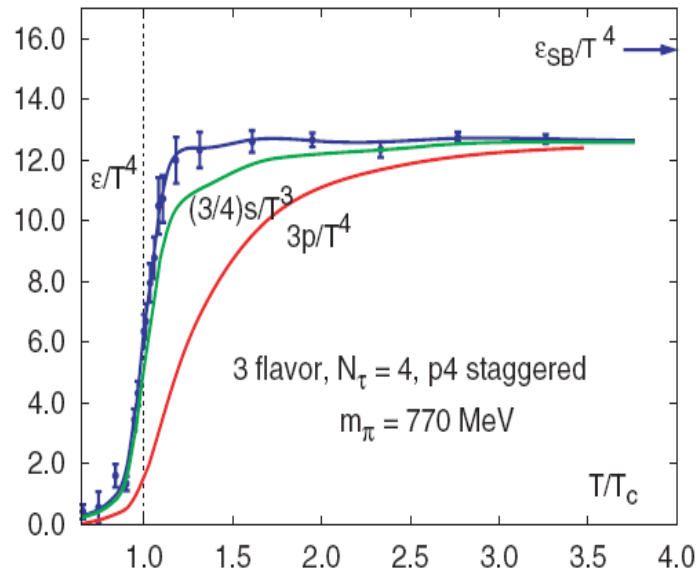
Quark Gluon Matter:
8 gluons;
2(3) quark flavors,
antiquarks,
2 spins, 3 colors

$$\varepsilon = 37(48)\cdot\frac{\pi^2}{30}T^4$$

Ndof~37 (48) !

Looking at ε/T^4, $3s/4T^3$ aka $NDOF_{effective}$

- PHENIX
  - energy density (ET)
  - T (photons)
  - entropy (dN/dy)
- Can we make a rough estimate from data of ε/T^4, $3s/4T^3$?
- For an ideal massless gas ε/T^4, $3s/4T^3 \sim NDOF$
- sQGP $\Rightarrow$ but we can look at the lattice for guidance



strategy~ fit ε, s, T a functions of τ

ref – see Enteria et al
Rajagopal, Mueller

what do we expect?

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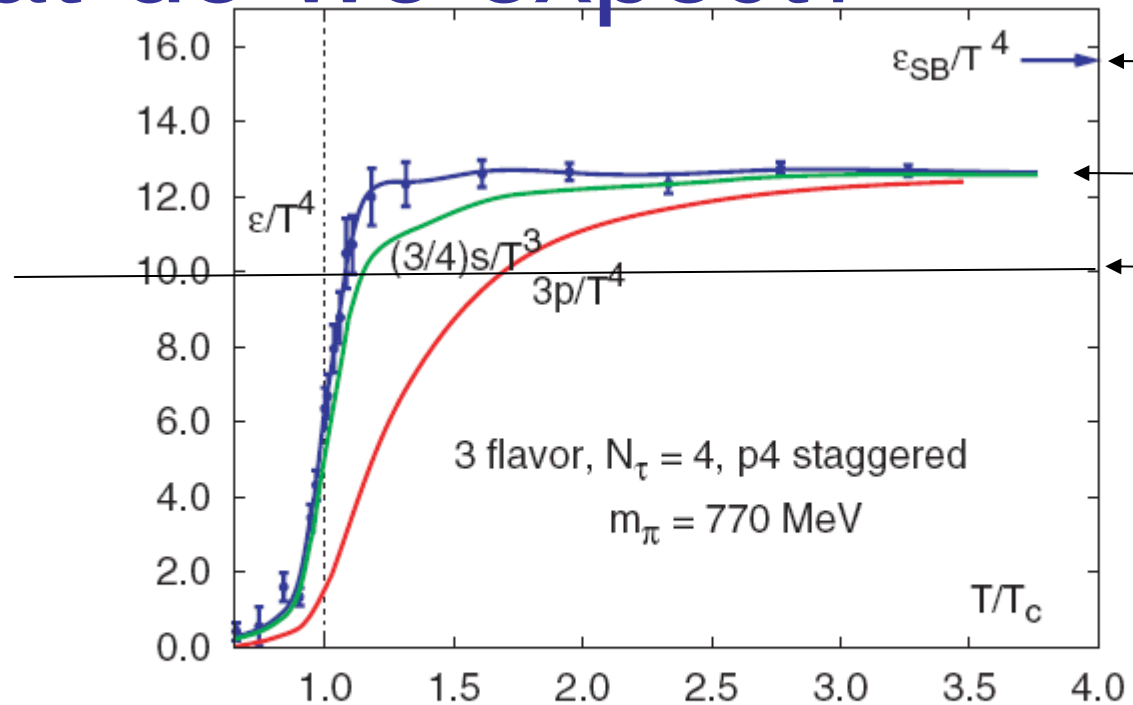


for 2 flavors

12 (ndof=37)

9.5 (ndof=29)

7.5 (ndof=23)

Figure 1 $\varepsilon(T)/T^4$, $P(T)/T^4$, and $s(T)/T^3$ for three light flavors of quarks on the lattice. SB, massless Bose field.

$$9.5\frac{30}{\pi^2} = 29 = ndof\,(effective)$$

37=ndof(effective 3 flavor)

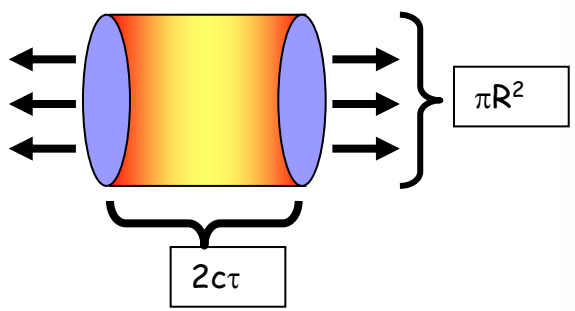
Expectaions								
	ndof(sb)	e/T^4(s	3s/4T^3(sb)	e/T^4(la	3s/4T^3(	ndof(effective)	3s/4T^3(near T	ndof(effective)
3 flavor	48	16.00	16	12.5	12.5	38.0	10.00	30.4
2 flavor	37	12.00	12	9.5	9.5	28.9	7.50	22.8

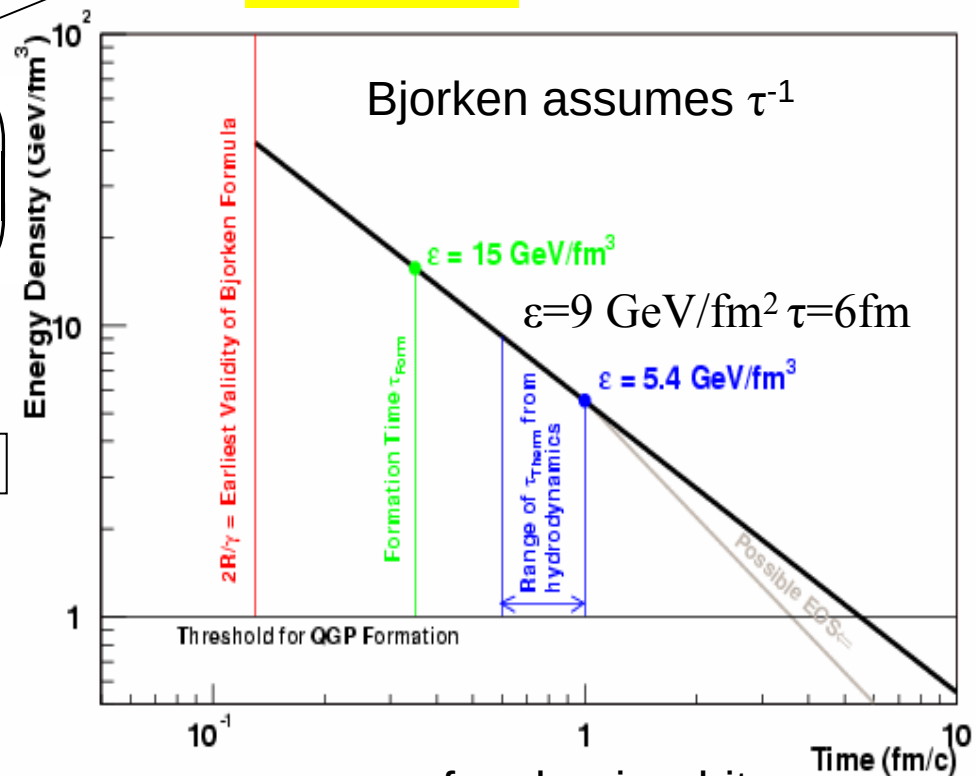
the data: Energy Density

$f(\tau) \sim \tau^{-1}$

$$\varepsilon_{Bj} = \frac{1}{\pi R^2}\frac{1}{2c\tau}\left(2\frac{dE_T}{dy}\right)$$

R~6.3fm



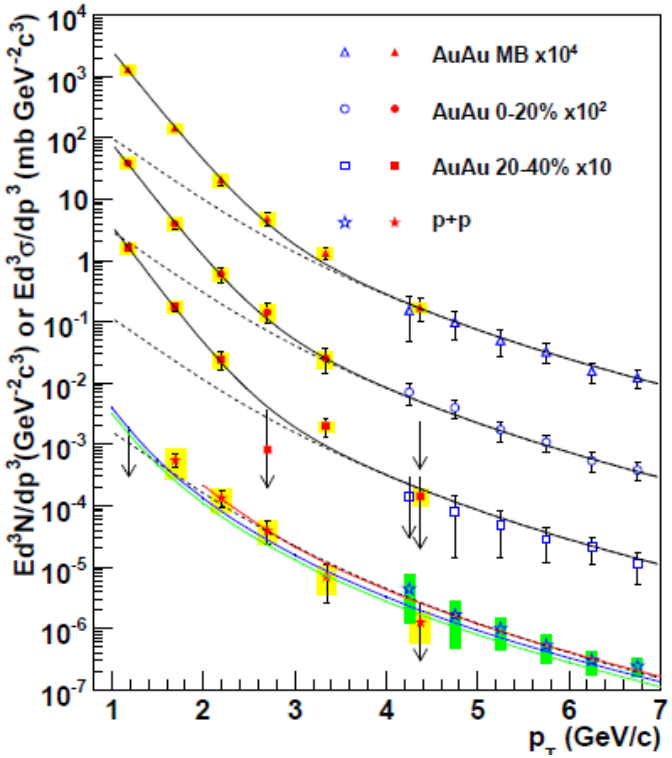


ref – phenix white paper

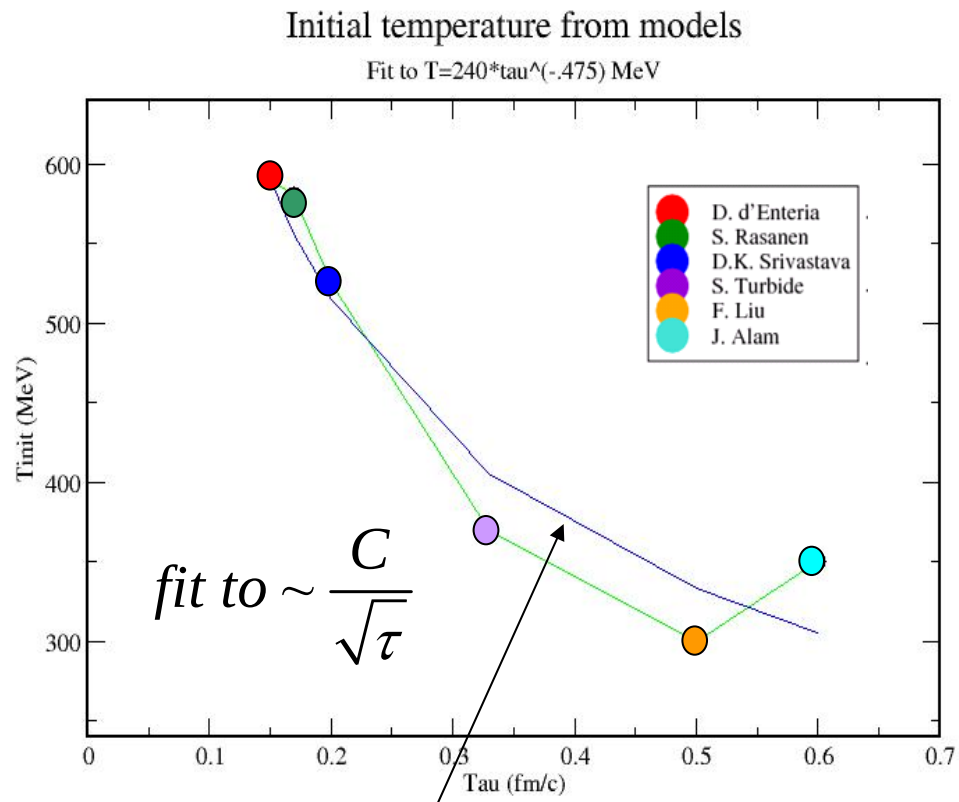
PHENIX: Central Au-Au yields

$$\left\langle \frac{dE_T}{d\eta} \right\rangle_{\eta=0} = 606 \pm 2\,GeV \quad \Rightarrow \quad \left\langle \frac{dE_T}{dy} \right\rangle_{y=0} = 760\,GeV$$

The data: Temperature - Photons



arXiv:0804.4168v1 [nucl-ex]



- Fit to the p_T slope in central collisions yields

  T_{avg} = 221 ±23 ±18 MeV

- Using models for the expansion

  T_{avg} = 221 → T_{init} > 300 MeV

fit to

$$T(GeV) = 0.240\tau^{-.475}\ GeV$$

The rough calculation
$NDOF_{effective}$ using ε/T^4 $3s/4T^4$

central

$$NDOF = \varepsilon \cdot \frac{30}{\pi^2 T^4} = \frac{1}{\pi R^2}\frac{1}{c\tau}\left(\frac{dE_T}{dy}\right)\frac{30(\hbar c)^3}{\pi^2 T^4} =$$

$$\frac{1}{\pi(6.6\,fm)^2}\frac{1}{\tau(\,fm)}(758GeV)\frac{30\,(0.197\,GeV\ \ fm)^3}{\pi^2(0.240\tau^{-.475}\ GeV)^4} = C\tau^{0.9}$$

$$NDOF = 39\tau^{0.9} \qquad dEt/dy = 760 \quad R = 6.6 = 1.18*(351/2)^{1/3}$$

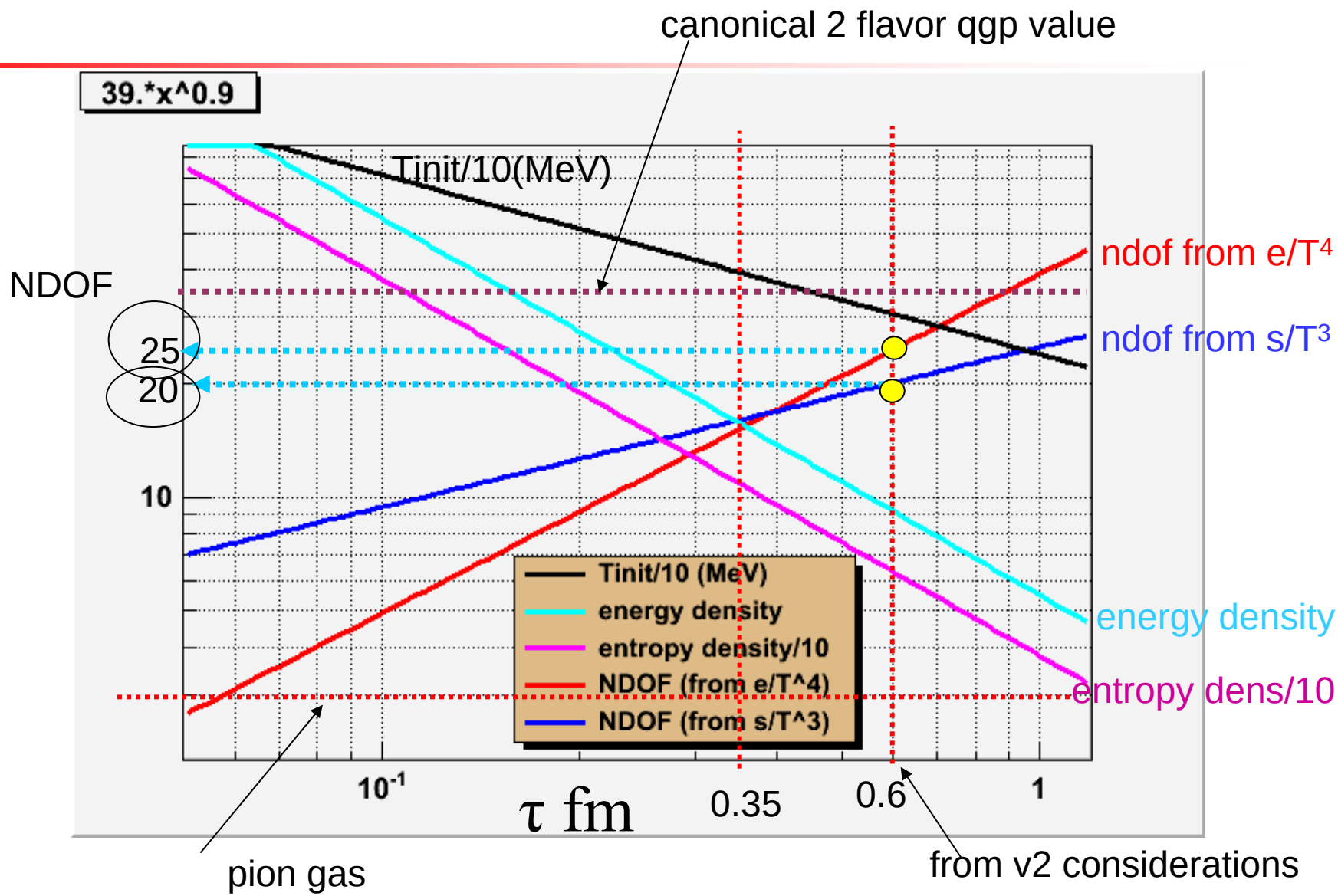
$$s = \frac{7.9}{\pi R^2}\frac{1}{c\tau}\left(\frac{dN_{ch}}{d\eta}\right)$$

from 1.1*7.25/1.04
ref –rajagopal/Mueller

$$NDOF = s\frac{45}{2\pi^2 T^3} = \frac{7.9}{\pi R^2}\frac{1}{c\tau}\left(\frac{dN_{ch}}{d\eta}\right)\frac{45\,(0.197\,GeV\ \ fm)^3}{2^2\pi^2(0.3\,GeV)^3} =$$

$$\frac{7.9}{\pi R^2}\frac{1}{c\tau}\left(\frac{dN_{ch}}{d\eta}\right)\frac{45\,(0.197\,GeV\ \ fm)^3}{2^2\pi^2(0.240\tau^{-.475}\ GeV)^3} = C\tau^{0.425}$$

$$NDOF = 25\tau^{0.425} \qquad dN/d\eta = 758 \quad R = 6.6 = 1.18*(350/2)^{1/3}$$



remember the expectations for 2 flavor QCD is 29(e/T^4) and 23(s/T^3)

What do we learn?

- Pretty hard to get NDOF=3 (i.e. need tau<0.1 fm)
- For reasonable tau ~0.35 to 1 fm (0.6 from v2 considerations) get NDOF= 25 using the energy density and 20 using the entropy
- a wQGP predicts ndof=37. If you use the lattice we see a value of 29 using the energy density. The entropy rises slower so right at Tc it would start out at about 23
- So what I would like to say is that
  - a) we see a e/T^4 and s/T^3 consistent (within the errors of this rough calculation) with the lattice
  - d) its much greater than 3
- This is a VERY rough estimate. Caveats about a hadron gas. But pressure arguments may be able to help