η/s of a hot Hadron Gas

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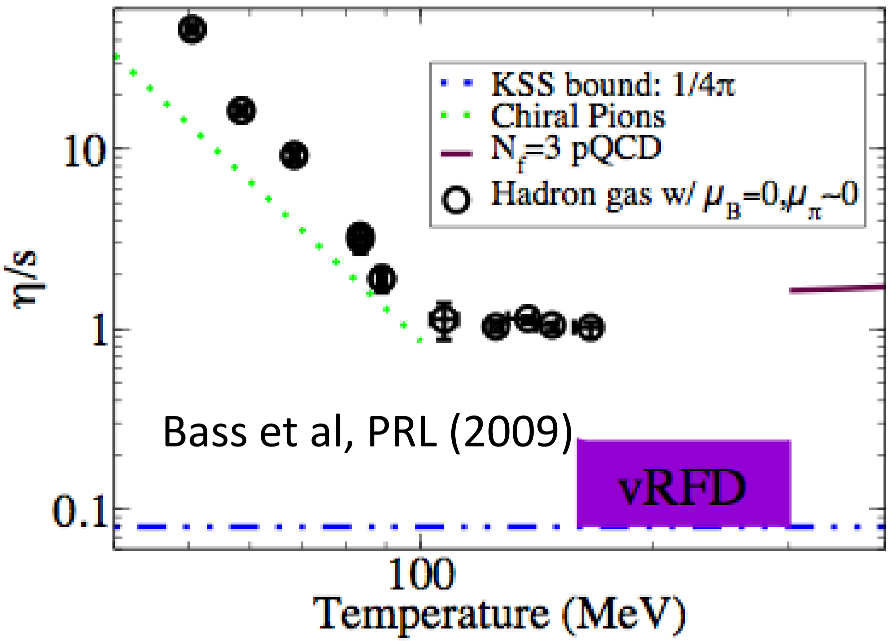
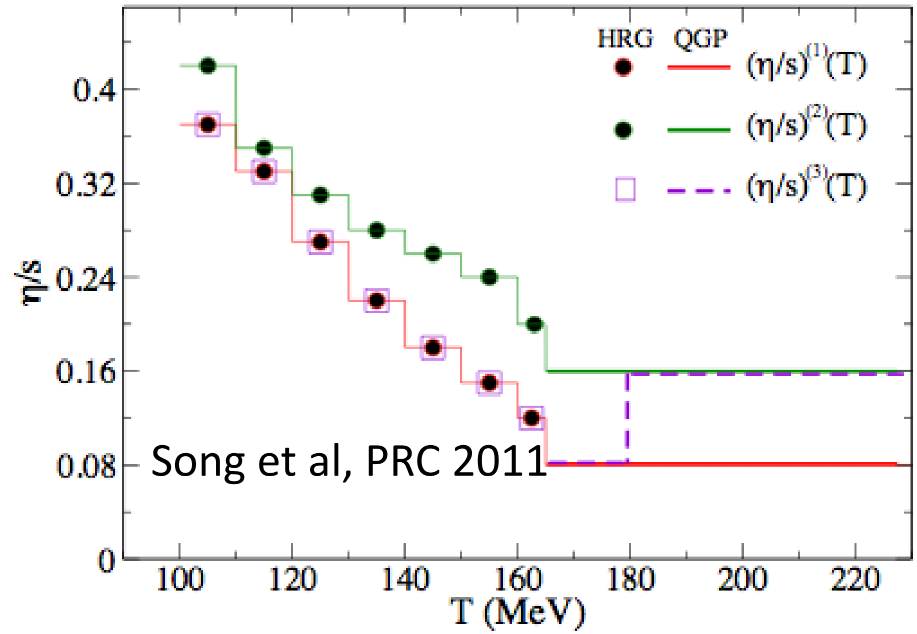
Why?



No (good) hydro @ 170 MeV!



No result for eta/s

Hadron Gas eta/s changes hydro model vn's (especially for p+A collisions). We need to know it in order for precision determination!

What we did

- Simulate hot hadron gas using a hadron cascade
- 2<->2 scatterings with fixed cross section (10 mb)
- Scattering through resonances
- All stable hadron resonances up to 2.2 GeV in PDG
- Set up system with boost invariance in z (large volume, translational symmetry in x,y)

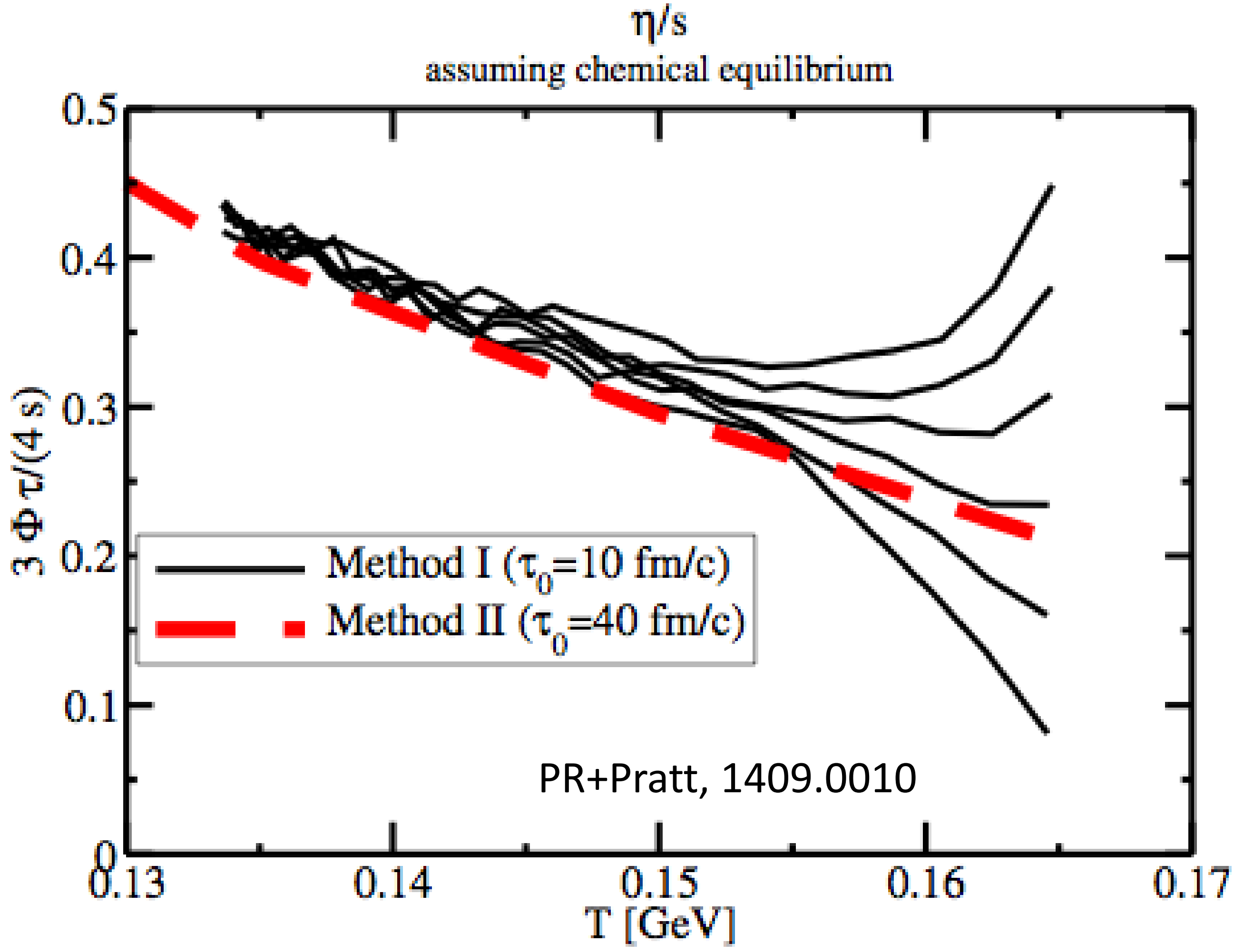
What we did

- System expands and cools, we ‘measure’ local energy-momentum tensor $T^{ab}(t)$ at midrapidity
- We decompose $T^{ab}(t)$ to extract shear tensor

$$T^{ab} = \epsilon u^a u^b - (P - \Pi)\Delta^{ab} + \pi^{ab}$$

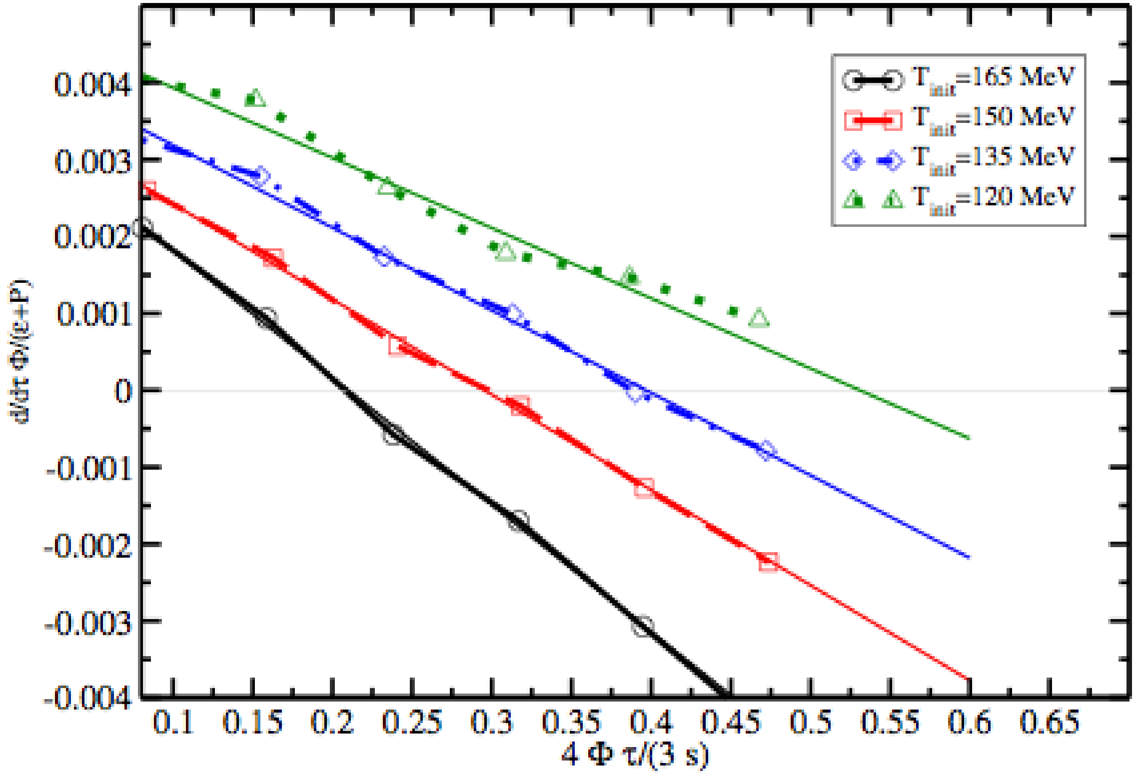
- Close to equilibrium $\pi_{zz}=-4\,\eta/3t$
- Assuming chemical equilibrium we can get entropy density from energy density: $s=s(T^{00})$, thus we have a handle on η/s (“Method I”)

What we observe



Different lines: different *initial* anisotropies

For experts: Method II



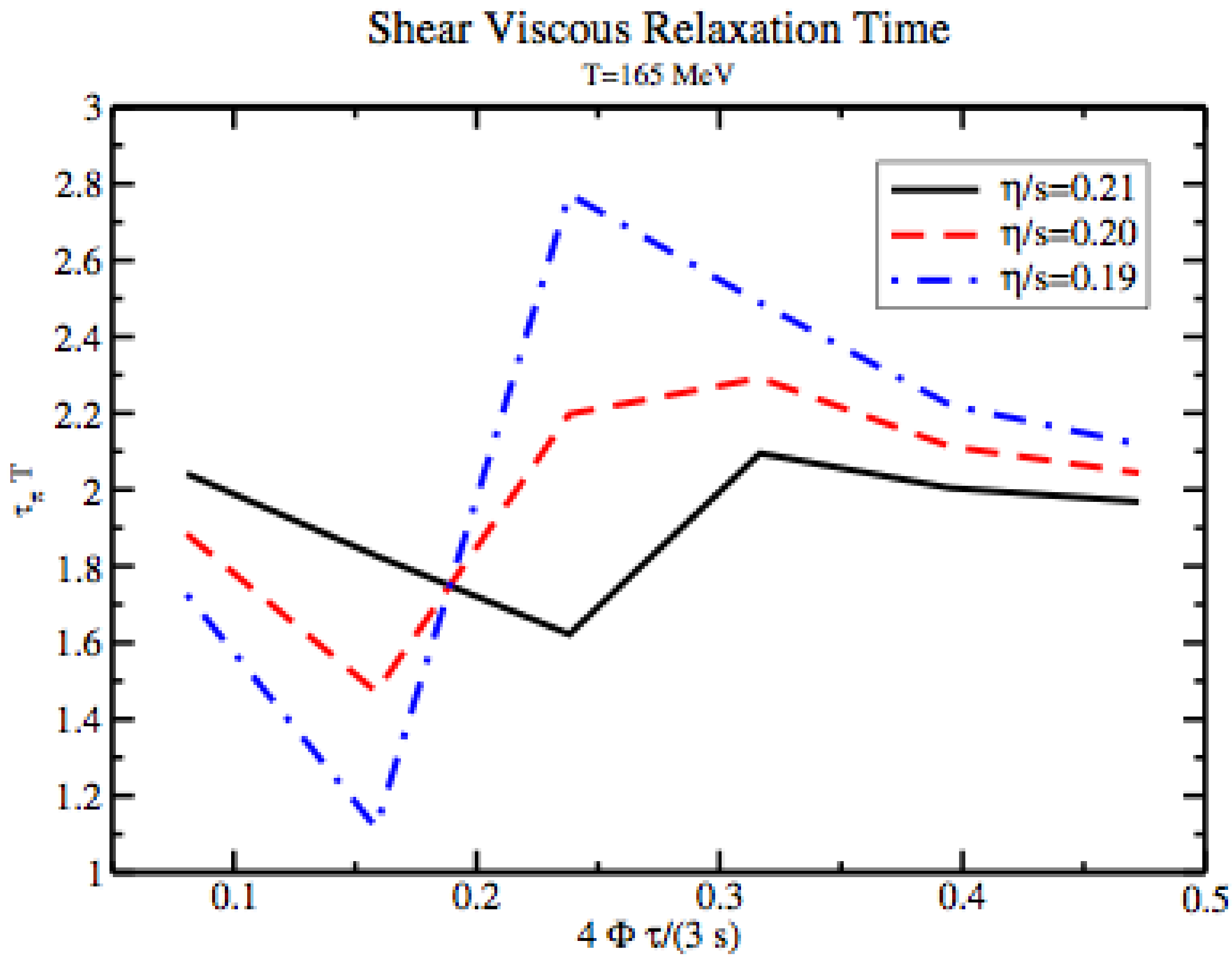
$$\partial_\tau \left(\frac{\Phi}{\epsilon + P} \right) = -\frac{1}{\tau_\pi} \left(\frac{\Phi - \frac{4\eta}{3\tau}}{\epsilon + P} \right) \left[1 + \mathcal{O}\left(\frac{1}{\tau T} \right) \right]$$

Our result

$$\frac{\eta}{s} \simeq 1.35(5) - 1.17(6)\,\frac{T}{170\,\mathrm{MeV}}$$

For 120<T<170 MeV

Bonus: 2nd order transport?



Summary & Conclusions

- We have extracted eta/s in hot hadron gas
- Result is ‘low’ eta/s close to T_c: ‘plausible’ for having hydro behavior in ‘early late stage’
- Result is growing for decreasing T: expected, but does it match up with analytic calc for pion gas?
- We also have first constraints on 2nd order transport coefficent τ_π

Outlook

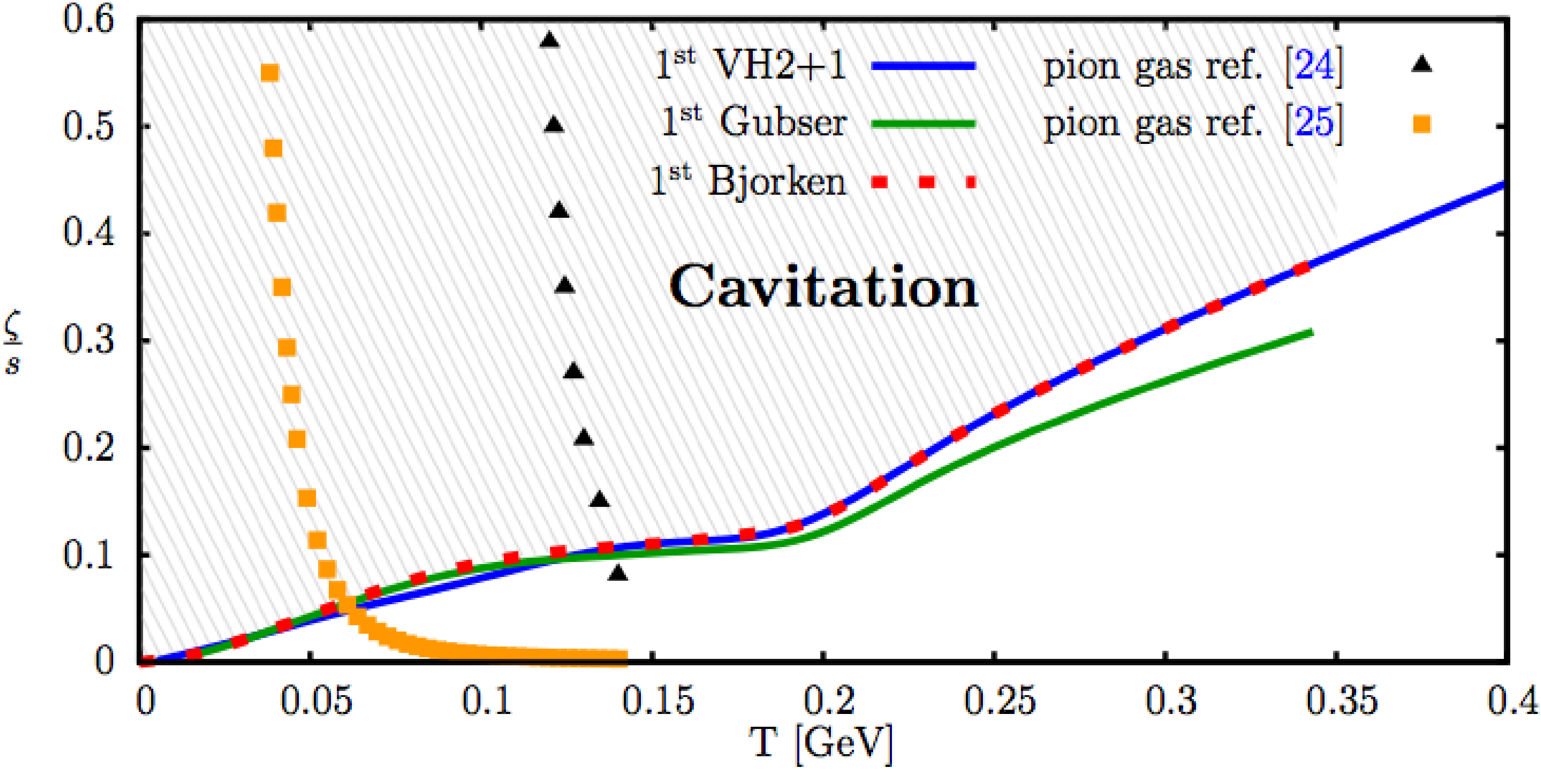
- We’ve set up a new method. This method can be presumably implemented in URQMD, URASIMA, SMASH, … and results can be cross-checked => Validating hadron cascade codes!!!
- One of our key assumptions was chemical equilibrium. This is probably fine for eta/s, but it prohibits us to study zeta/s!

Towards extracting ς/s

- Rather than extracting $T^{ab}(t)$, we could look at hadron spectra and (by fitting) extract both T(t) and μ(t)
- This would allow us to reconstruct the (chemically correct) pressure P, and hence get a handle on the bulk stress Π
- Similar to shear stress, we could then hope to extract ς/s by looking at

$$\Pi = \frac{\zeta}{\tau}$$

Bulk viscosity could pin down hydro freeze-out



Habich and PR, 1405.1978

That's it!