# Tale of the Tails

Imprints of QCD

Heidelberg, April 2015

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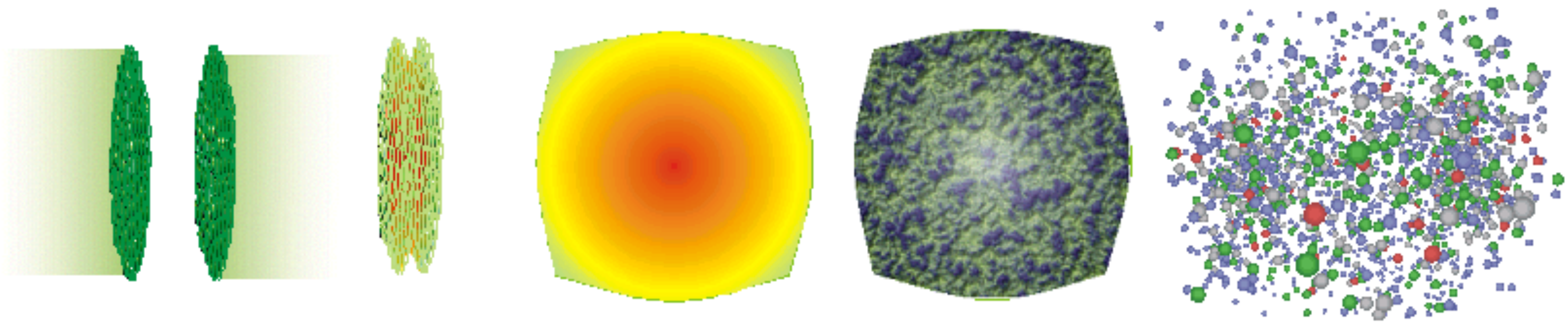
A story I think will make Johanna happy, at least the ending



CGC | Initial Singularity | Glasma | Thermalized QGP | Hadron Gas

**$\leftarrow$ Strongly Interacting QGP $\rightarrow$**

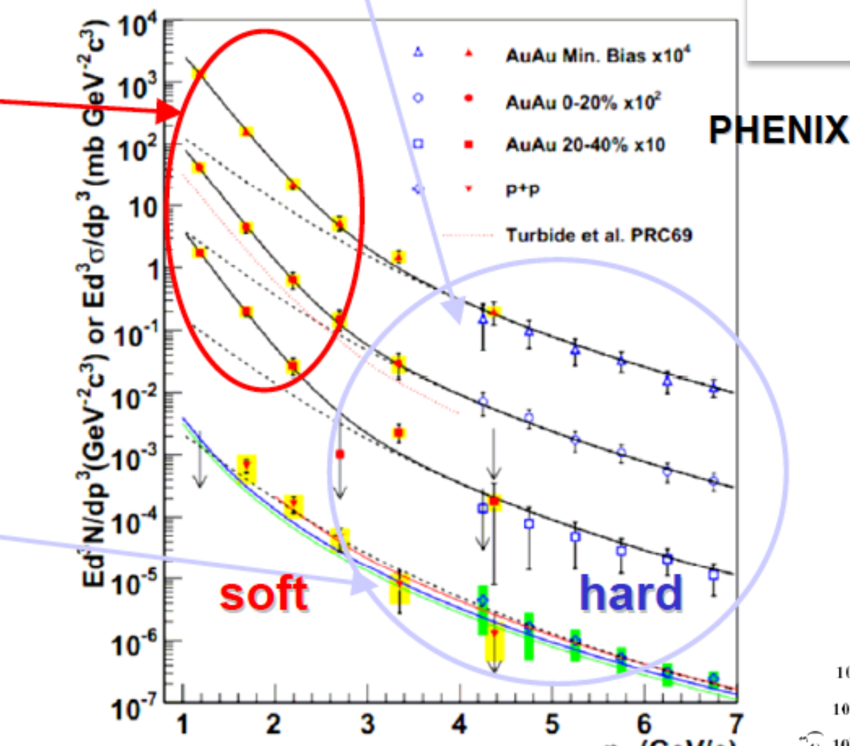
If there were no tails:

Bridges would not fall

Trains would not crash

Cats would not land on their feet

Would photons flow?




Phys. Rev. C 81, 034911 (2010)

Problems with photon emission:

Rates typically higher than computed from first principles hydrodynamical computations

Photon flow observed and too large for first principles computations

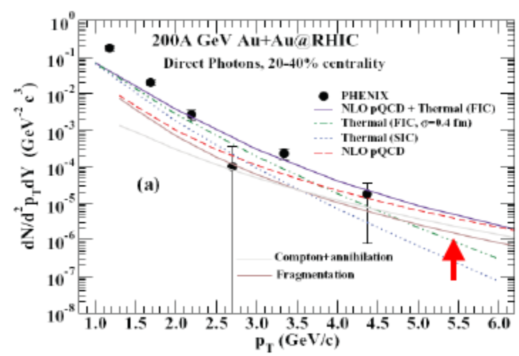
Maybe some hope from late time emission of boosted pions?

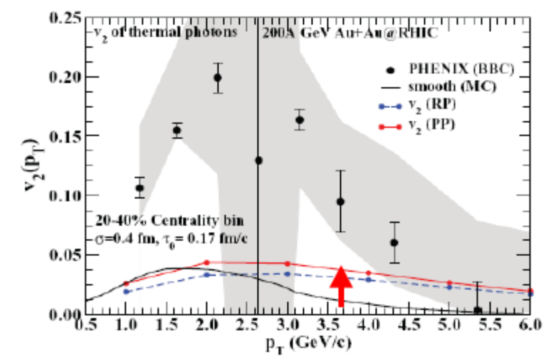
Rates computed fall short in low pt region

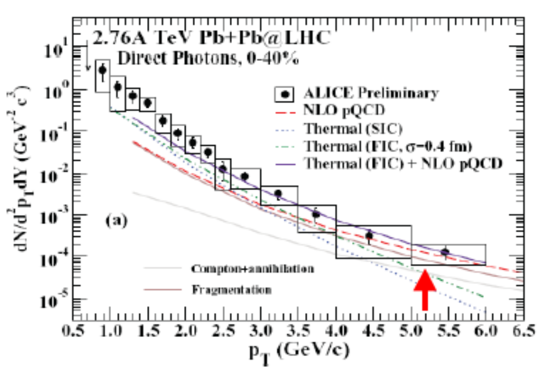
Flow is generically way too small

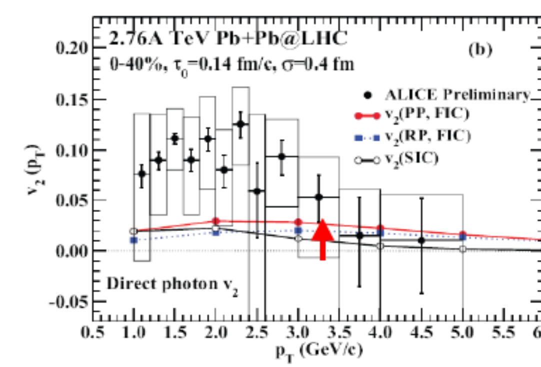
Only success models to date need very large rates at late times for pions

(Bratkovskaya et al, Zahed et. Al.)



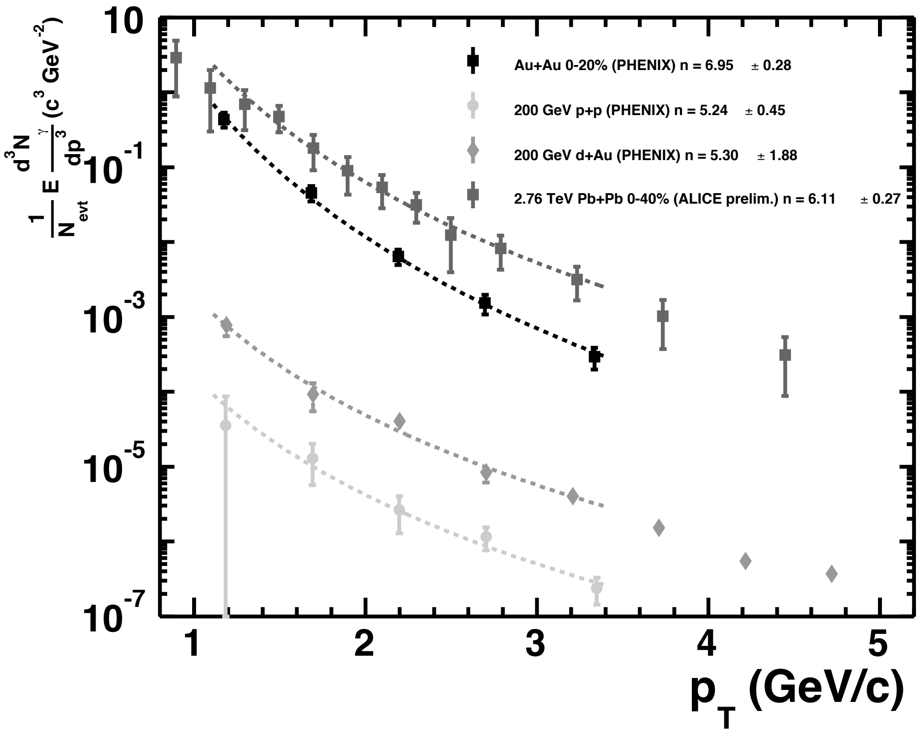



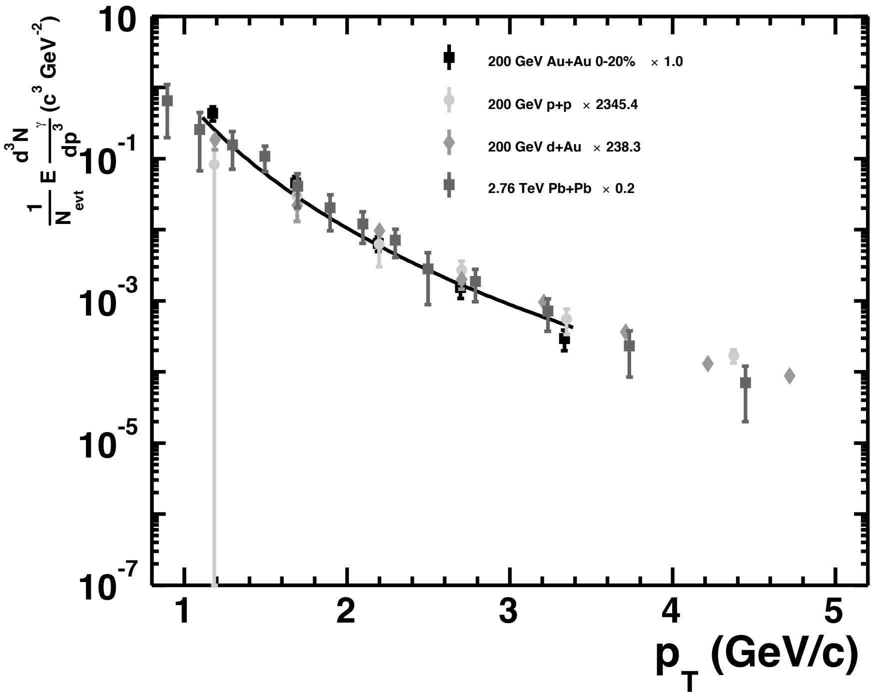



There is geometric scaling of the p_t spectrum for pp, dAu, A-A at RHIC and LHC

Golec- Biernat, Statso Kwieczinski; Praszalowicz and McLerran




$$Q_{sat}^2 = \frac{\kappa}{\pi R^2} \frac{dN}{dy} \qquad \frac{1}{\pi R^2} \frac{dN_\gamma}{dy d^2 p_T} = F\left(\frac{Q_{sat}}{p_T}\right)$$

Also agrees with the multiplicity dependence seen in Phenix

LDM and Christian Klein –Boesing

Suggests an early time explanation before there is breaking of scale invariance

Attempts by Glasma, Semi-QGP:

Both methods suppress the quark production until late time therefore suppressing the rate of photon production until that late time. Improves but does not solve the photon flow problem.

Greatly suppresses the overall rates!
Gives about an order of magnitude suppression relative to data

Lattice Monte-Carlo computations of rates are good to within a factor of two and agree with estimates from hard thermal loop computations

Jets?

Hard to get the rates correct. Jets in general for these smallish pt are not so simple.
In LHC, that saturation momentum is several GeV, so that the jets effective mass is huge.
This allows lowish momentum "jets" and their decay product to scatter in the media. In effect, the 'jets' at several GeV behave like they are part of the media.

So what might be wrong?

For a photon at momentum k, what is the typical temperature it is emitted from?

Shuryak; McLerran, Toimela

$$E\frac{dN_{\rm th}}{d^4x d^3p} = \frac{5}{9}\frac{\alpha_s\alpha}{2\pi^2}T^2 e^{-E/T}\ln\left(\frac{2.912}{4\pi\alpha_s}\frac{E}{T}\right)$$

Kapusta Lichard and Seibert

$$T/T_0 = (t_0/t)^{1/3}$$

$$\int tdt \sim \int \frac{dT}{T}\frac{1}{T^6}$$

$$R \sim \int \frac{dT}{T}\frac{1}{T^4}e^{-k/T}$$

Rate integral peaked at k ~ 4T, which is in the tail of the distribution

What happens for a distribution with a power law tail?

$$f(k) = (1 + k/aT)^{-a}$$

$$k << aT$$ exponential; a ~ 6

T is temperature, aT saturation momentum?

Note that as system cools, the center of the distribution stays fixed, but the tail

$$f \sim (aT/k)^6$$

Glasma computations suggest that evolution should be shape conserving

The tail quickly falls, and there is a rapid dependence upon the number of participants through T. Will lead to geometric scaling.

Maximum of emission rate then

$$k/T \sim 4a/(a-4) \sim 12$$

HUGE factor of time! $t \sim T^3$

The over all rate is about a factor of 4 larger than for the thermal case

This example is a bit of an exaggeration but illustrates the main point:

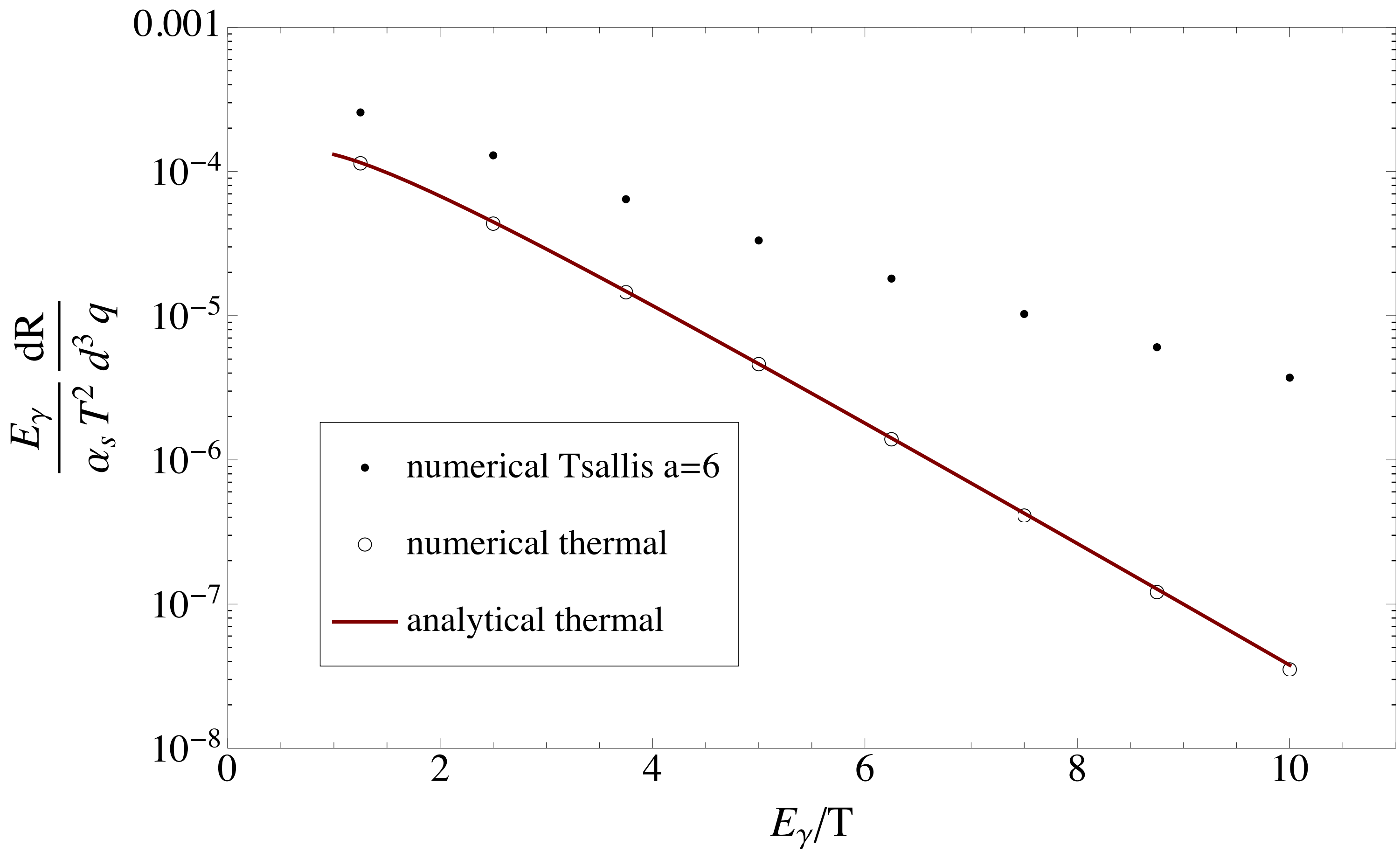
Tails are important and they can STRONGLY modify expectations from fully thermalized computation

# What we did:

Mclerran Schenke

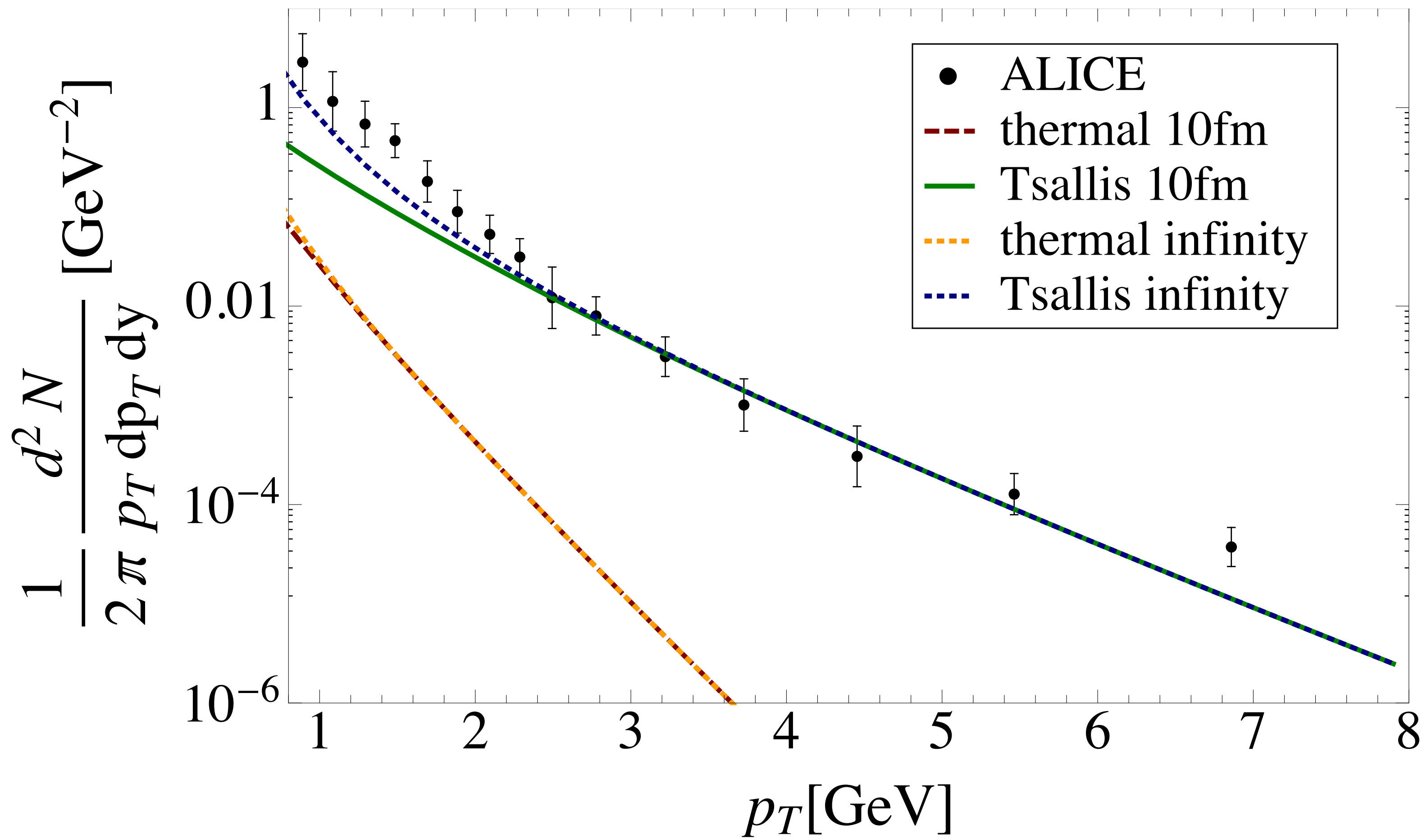
Replace the Bose-Einstein and Fermi Dirac distributions in the rate formula for photons by Tsallis distributions with a = 6

Generalize the emission rate formula



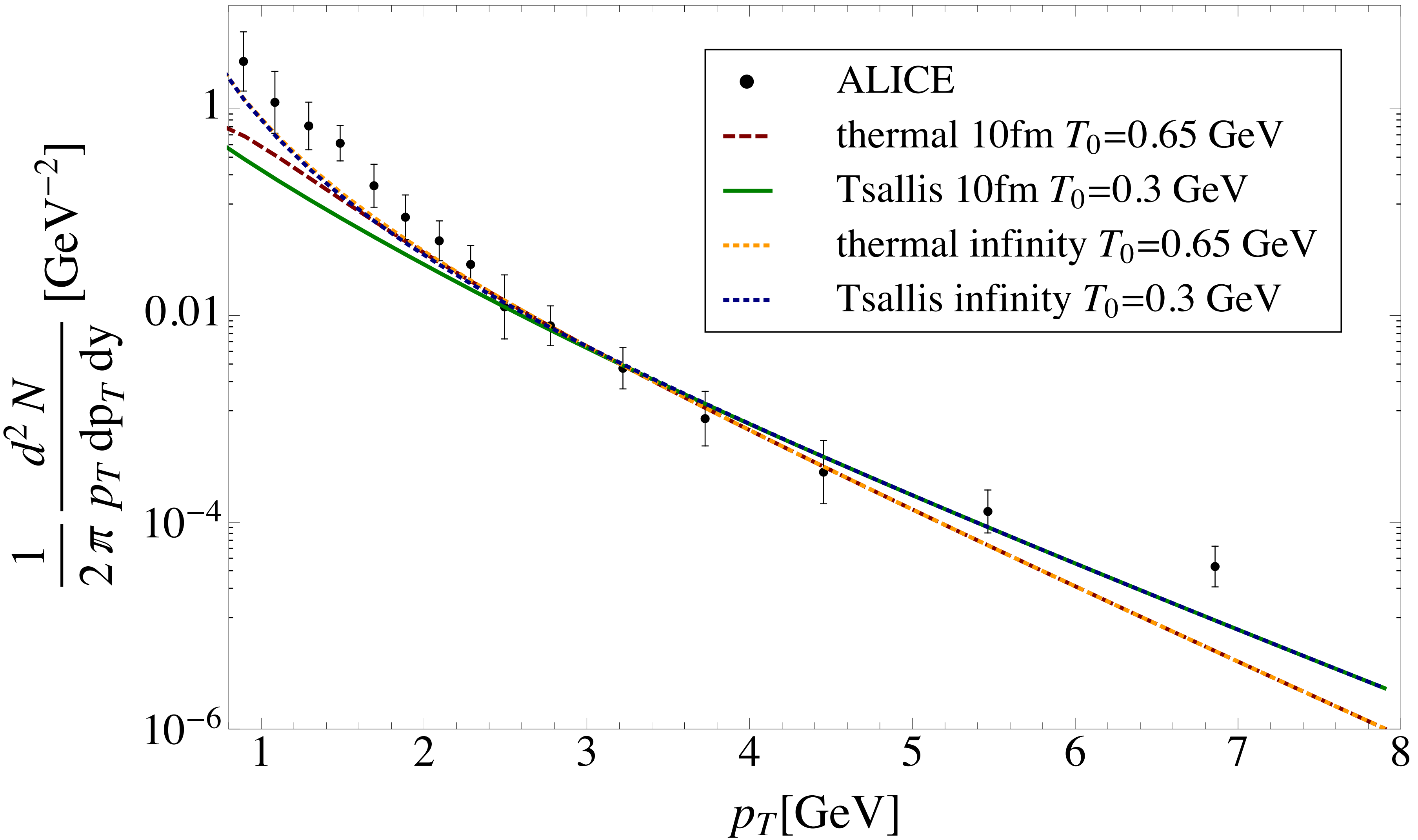
Insert into a 1+1 D hydro computation to compute the rates
No k factor or tuning of the fits. No contributions from jets or hadron gas

Initial temperature in all plots is T = .3 GeV

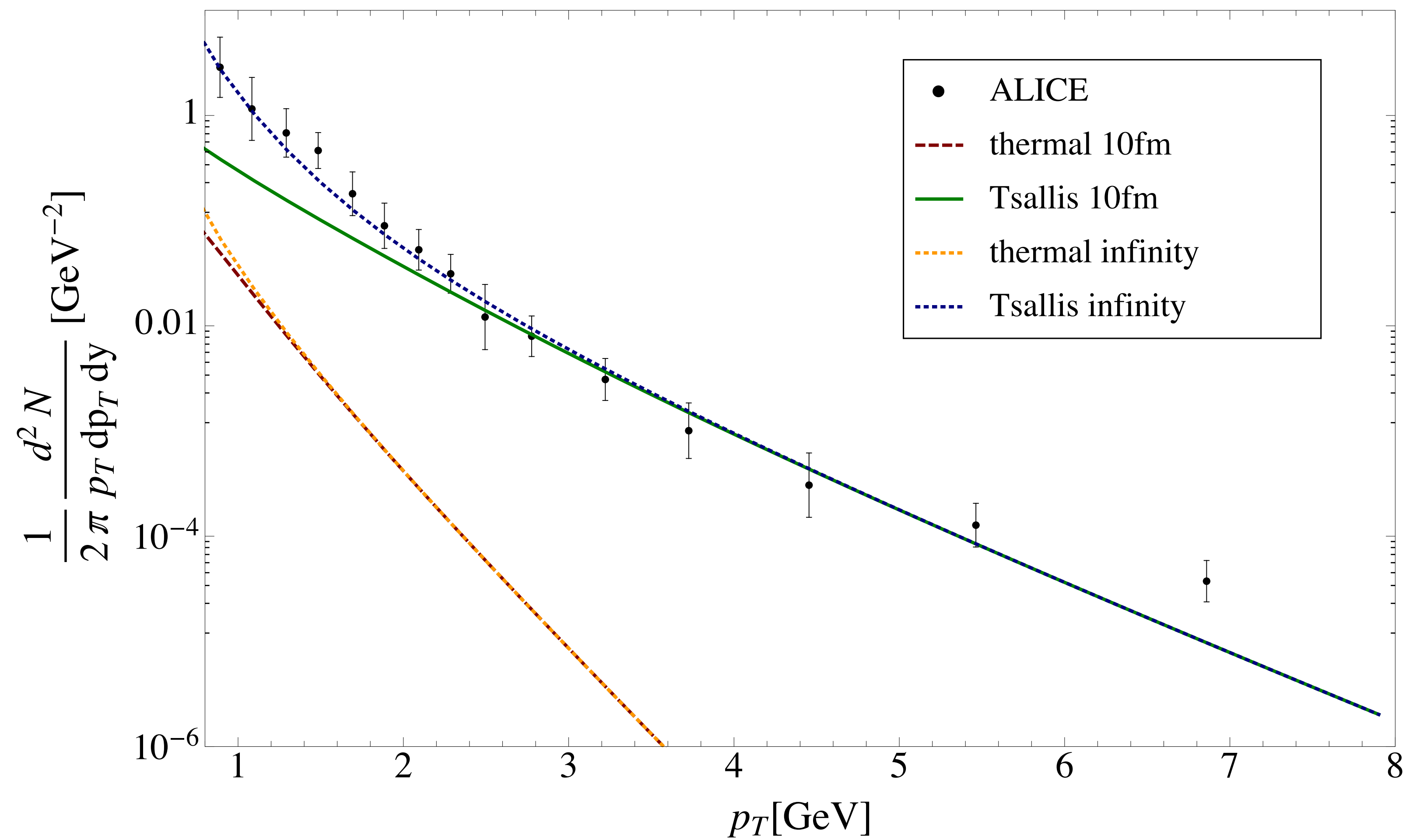



Shape of Tsallis curve is for an ideal gas. More realistic equations of state will make it a bit steeper. Also including hadron gas ....

Insert into a 1+1 D hydro computation to compute the rates
No K factor or tuning of the fits. No contributions from jets or hadron gas
Comparison with increased initial temperature for thermal (Tsallis is the same as before)



Small changes in the sound velocity squared (10%) make big difference in photon spectra shape, but not overall magnitude nor time of emission



| $\langle t \rangle$ [fm/c] | th. ($T_0 = 300\,\mathrm{MeV}$) | th. ($T_0 = 650\,\mathrm{MeV}$) | Tsallis ($T_0 = 300\,\mathrm{MeV}$) |
|---|---|---|---|
| $p_T = 1\,\mathrm{GeV}$ | 4.4 | 16.6 | 44.5 |
| $p_T = 2\,\mathrm{GeV}$ | 1.4 | 2.4 | 6.9 |
| $p_T = 3\,\mathrm{GeV}$ | 1 | 1.1 | 2.9 |

Emission times were GREATLY lengthened while the overall rate increase to an acceptable level (Even compared with the very high early temperature thermal case)

What needs doing:
Microscopic treatment of the tail
Proper 3+1 d hydro
Glasma
Jet contribution
Hadron Gas

Bottom line:

*A man who carries a cat by the tail learns something he can learn in no other way*
*Mark Twain*