HELMHOLTZ | GEMEINSCHAFT

HGS-HIRe for FAIR
Helmholtz Graduate School for Hadron and Ion Research

GOETHE UNIVERSITÄT FRANKFURT AM MAIN

Shear viscosity and entropy in SMASH

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FIAS Frankfurt Institute for Advanced Studies

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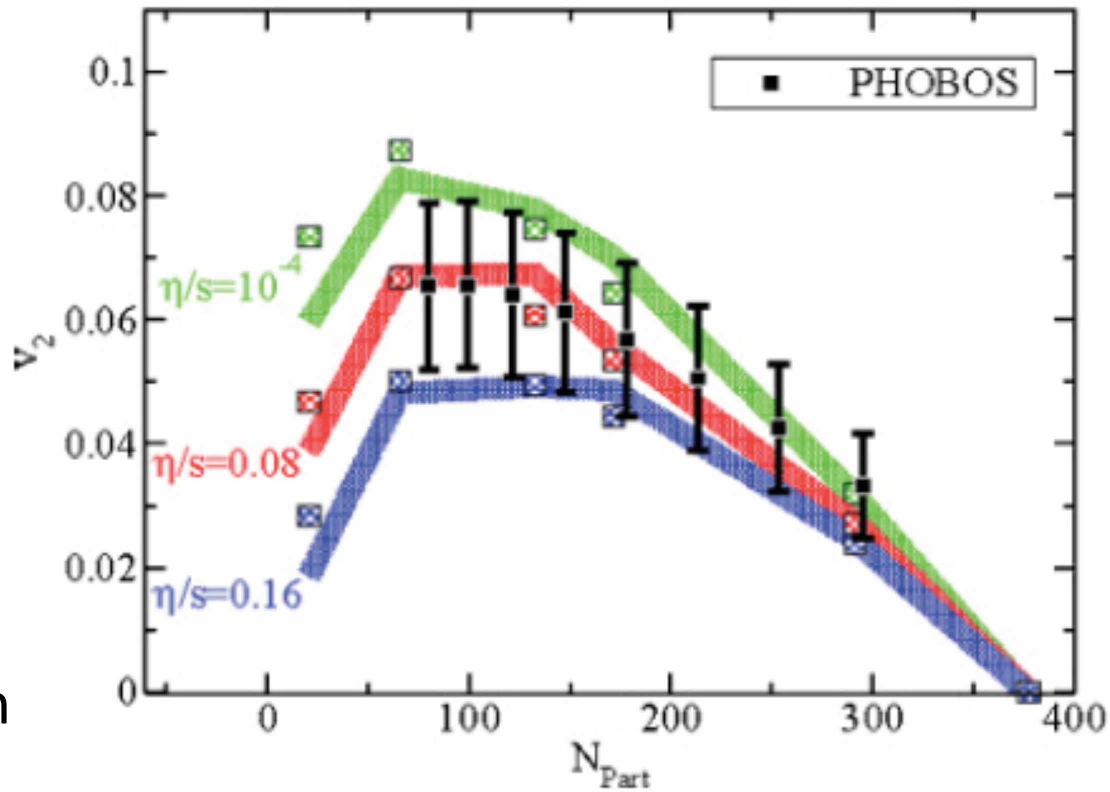
Introduction

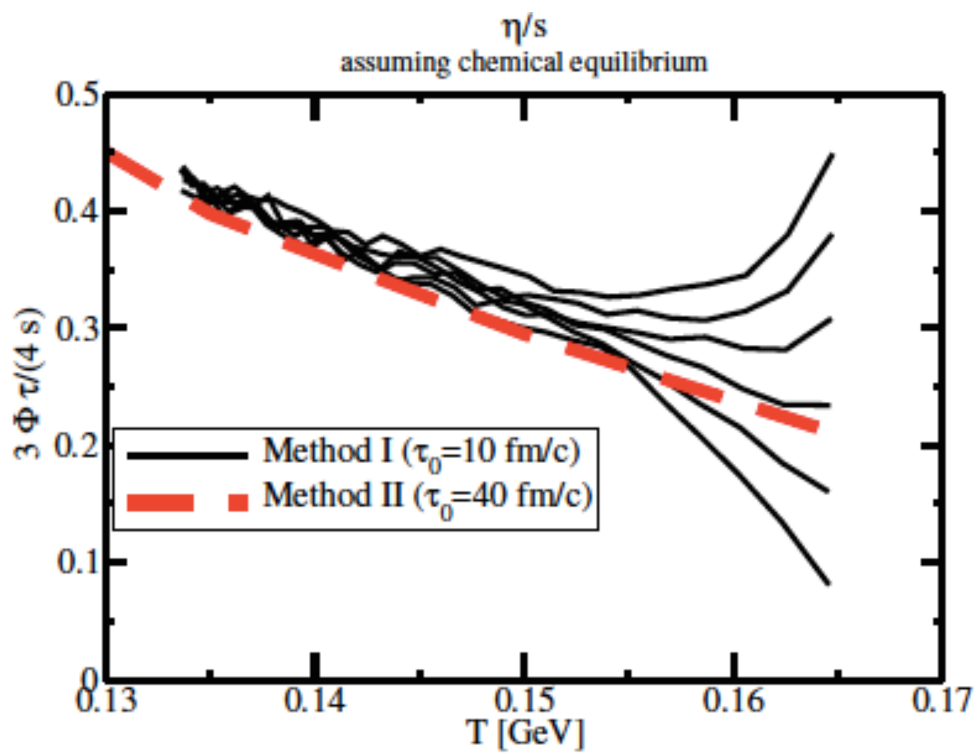
- RHIC and LHC measured unprecedented levels of elliptic flow at the high energies corresponding to what is thought to be QGP
- Hydrodynamics have been relatively successful at explaining this with the inclusion of a small η/s ratio (slightly larger than 1/4π)
- What about the viscosity at lower energies, such as will occur in FAIR, or in late stages of RHIC/LHC?



Luzum & Romatschke 10.1103/PhysRevC.78.034915

Viscosity in the Hadron gas

What about low temperatures?



- Cascade code B3D, initialize over large 2D area at mid rapidity, with $T^{\mu\nu}$ modified such that

$$T_{ij} = \sum_{species\ l} \int \frac{d^3p}{(2\pi)^3} \frac{p_i p_j}{E(p)} f_l(p)$$

$$f(p) = f_{eq}(p)\left[1 + C(p) p_i p_j \pi_{ij}^{(s)}\right]$$

- Writing evolution equation using Muronga's $\Phi = -\pi^{zz}$

$$\Phi = \frac{1}{3}(T_{xx} + T_{yy} + T_{zz}) - T_{zz} = \frac{4\eta}{3\tau} + \dots$$

initialized where $d\Phi/d\tau = 0$.

Romatschke & Pratt, arXiV:1409.0010v1

Viscosity in the Hadron gas

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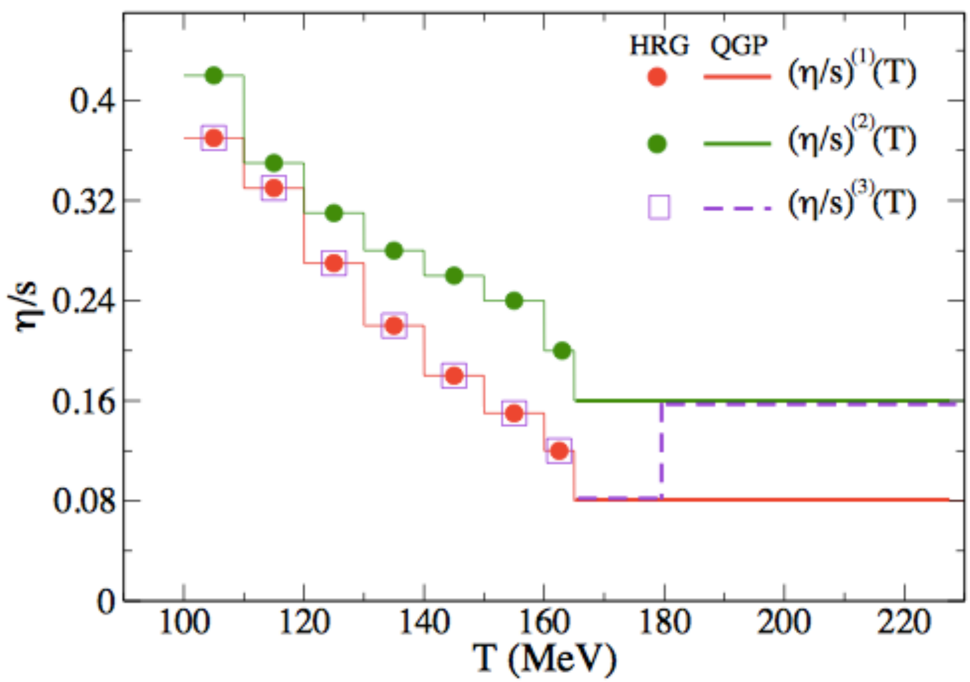

- UrQMD coupled with VISH2+1
- Progressively lowering the coupling temperature
- Each step, the η/s of VISH2+1 is adjusted so that there is no pion v_2 buildup
- Take this η/s to be the effective UrQMD η/s at this temperature
- Non-universal: changing the QGP η/s changes the results

Song, Bass & Heinz, arXiV:1012.0555

Viscosity in the Hadron gas

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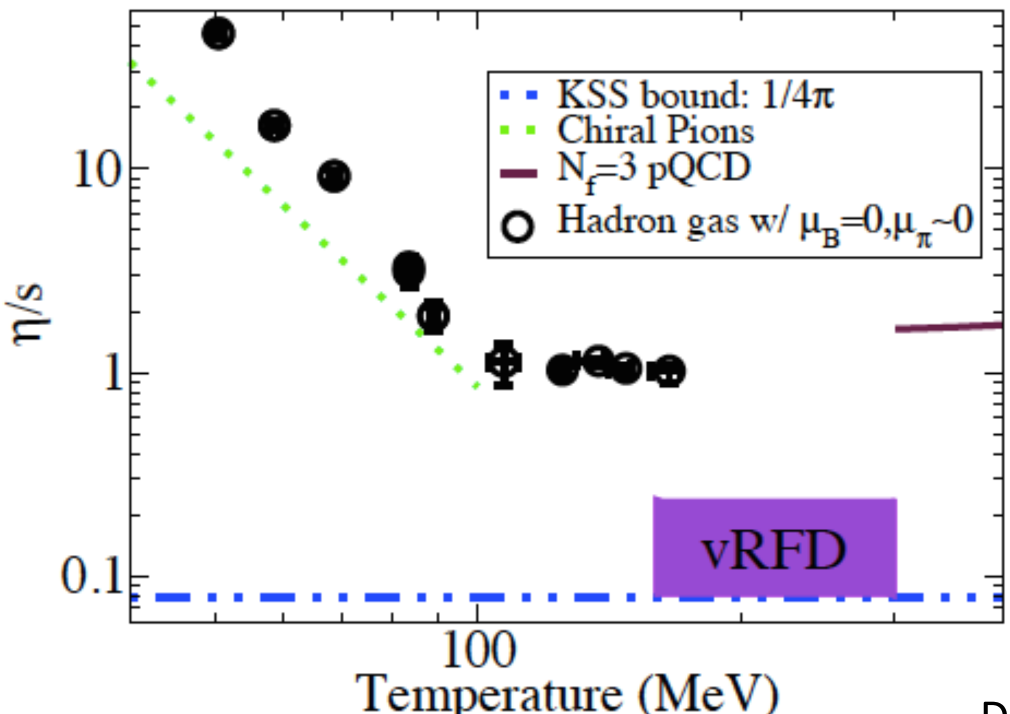
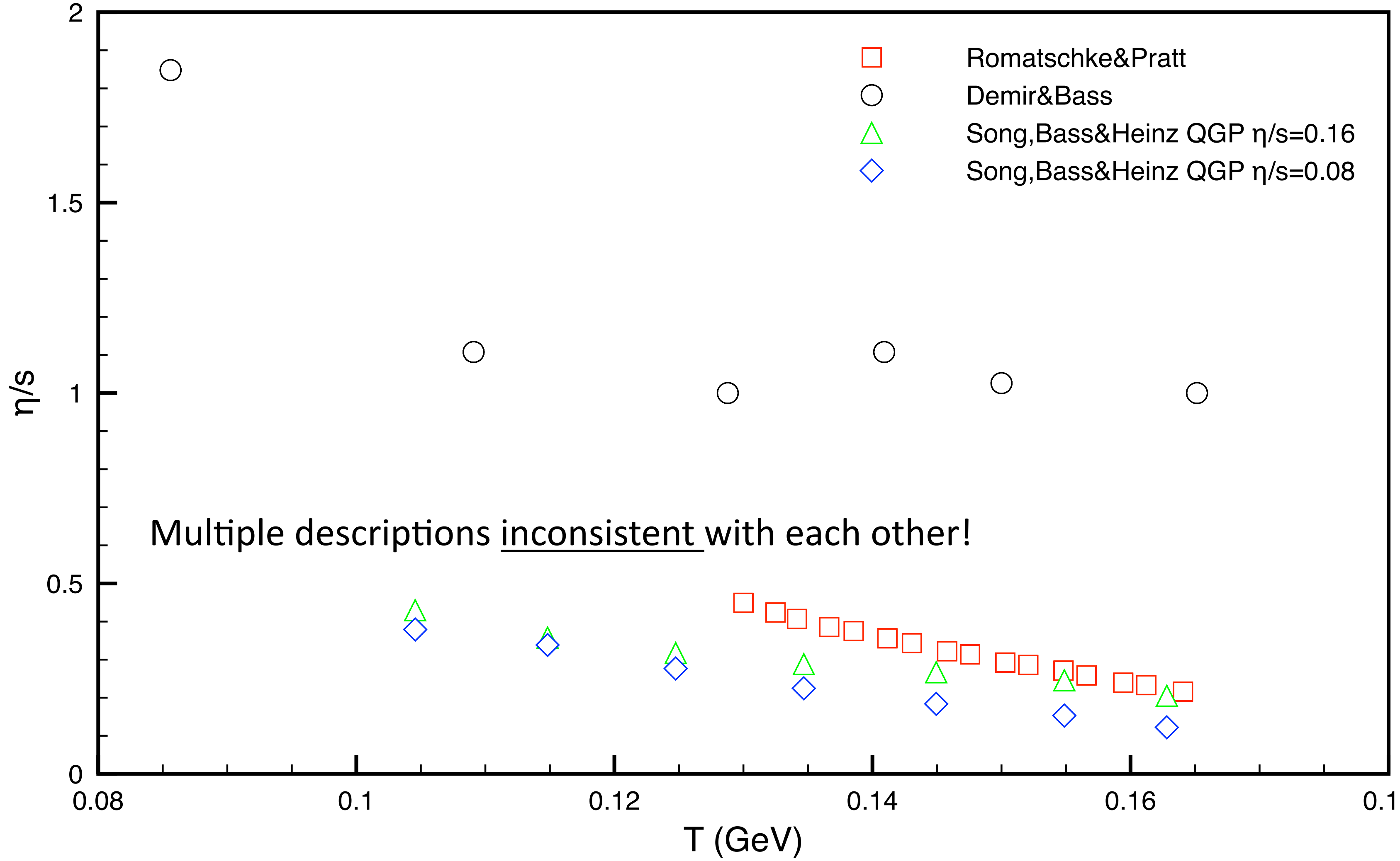


- UrQMD
- Box calculation
- Green-Kubo formalism
- Essentially the same procedure that we used

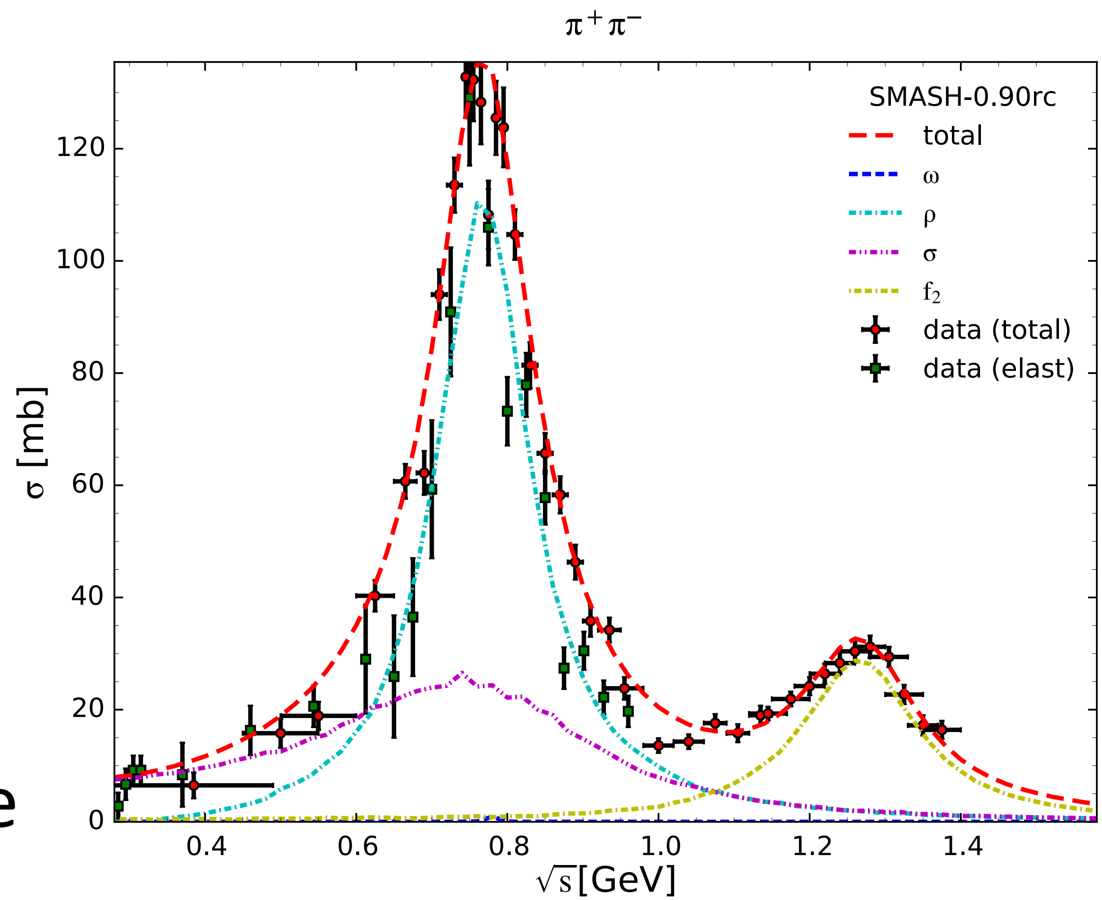
Demir & Bass, arXiV:0812.2422v4

So... is anyone right?



Viscosity in SMASH

- SMASH is a new transport code
  - Includes all resonances up to 2 GeV
  - 2-to-1 and 2-to-2 collisions, eventually 3-to-1
- Box calculations simulating infinite matter to apply the Green-Kubo procedure



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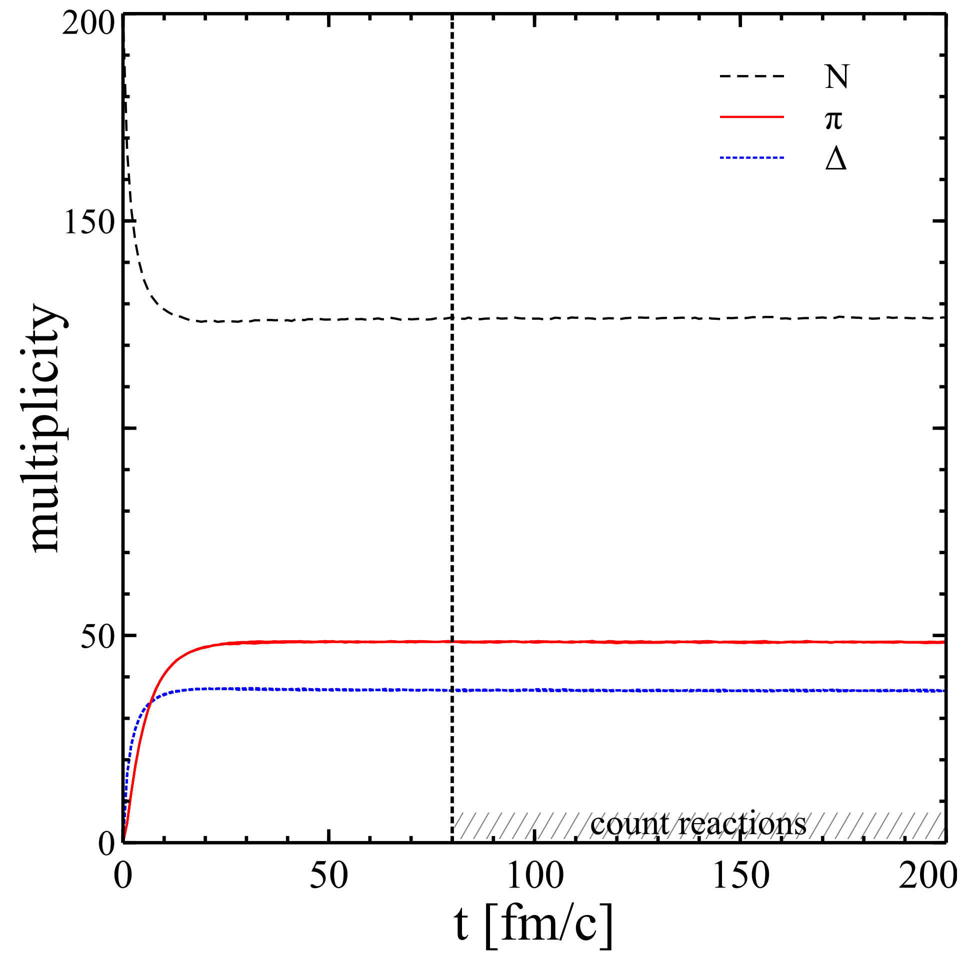
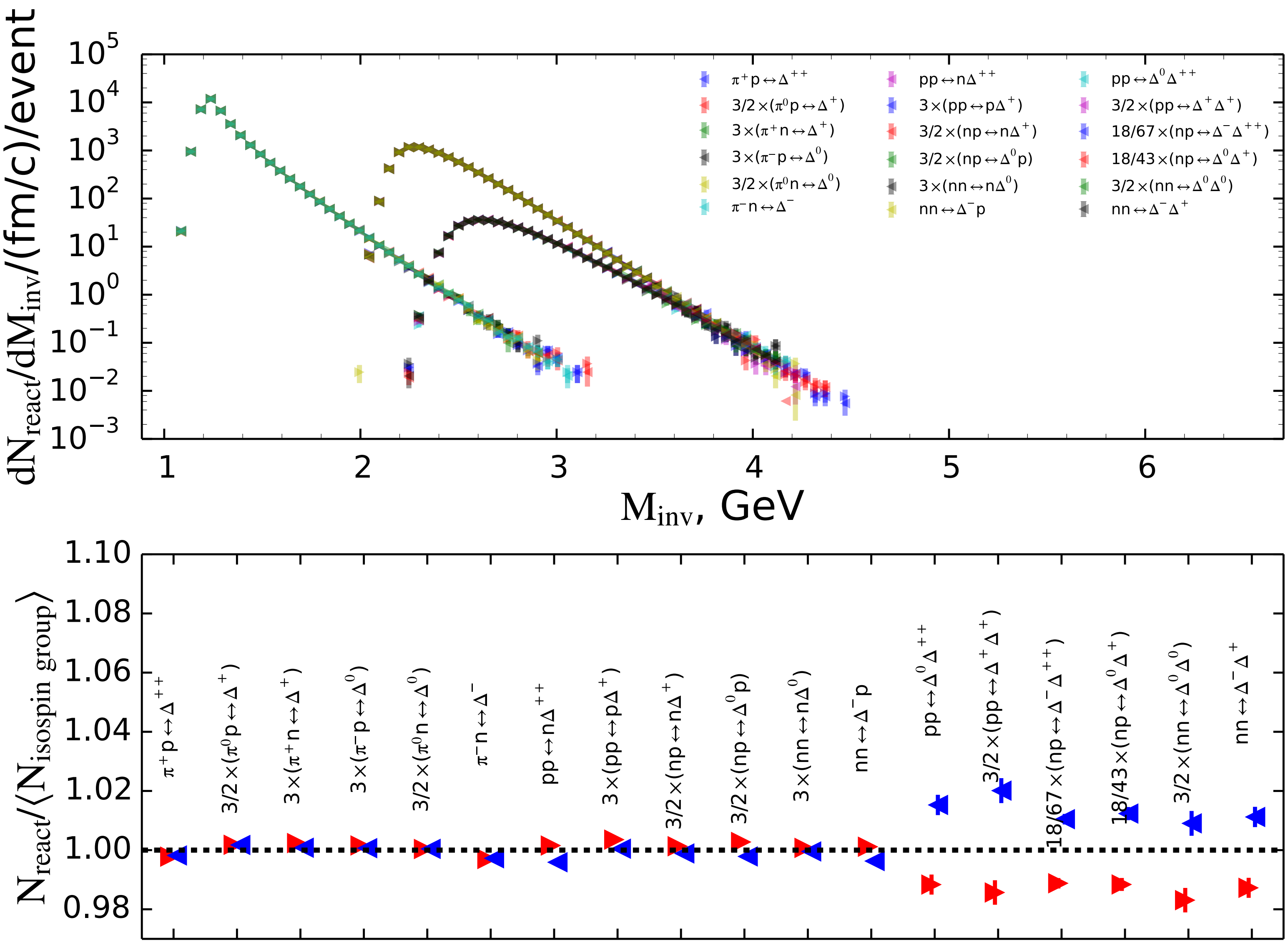


Detailed balance in SMASH



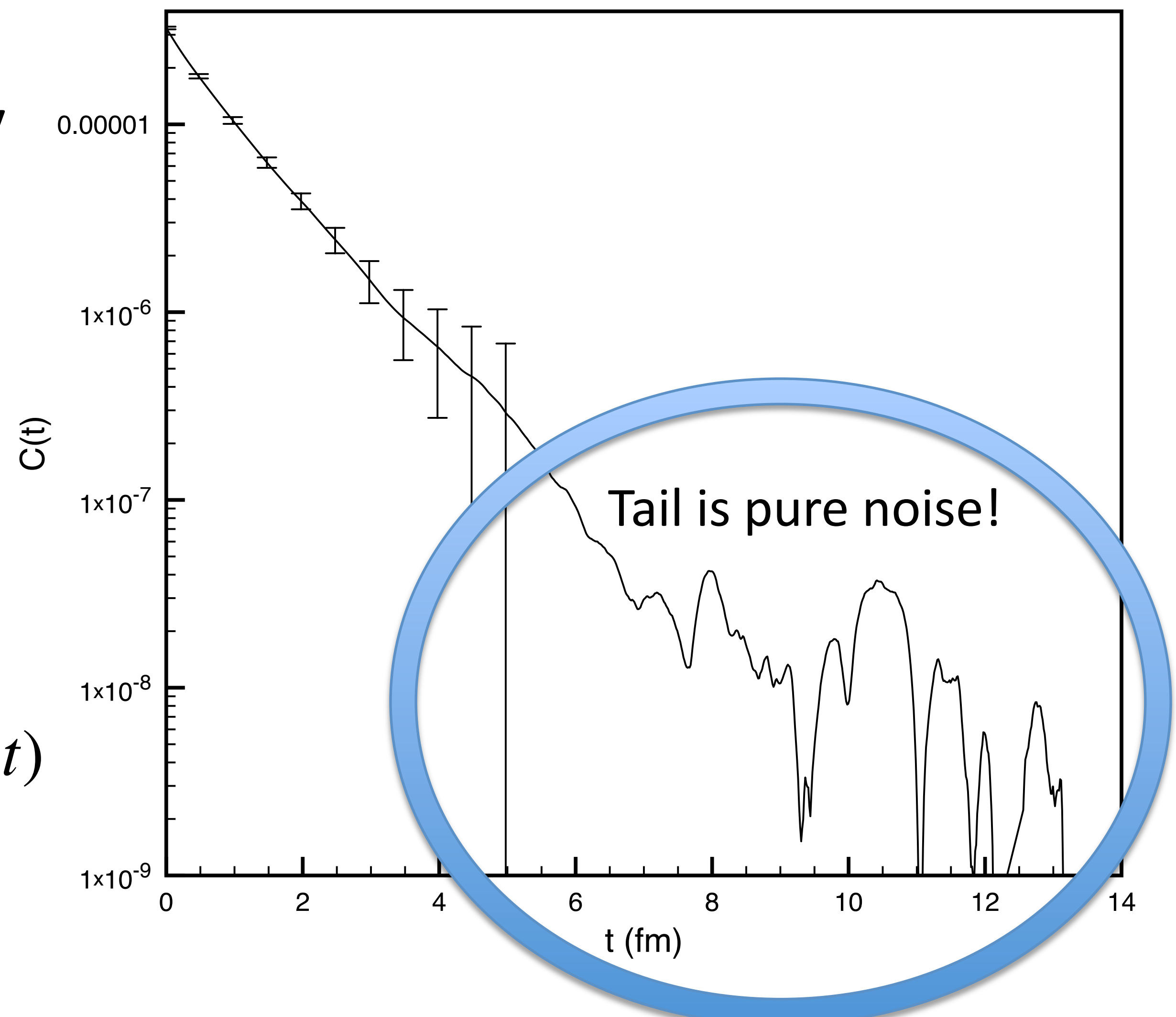
Green-Kubo Formalism

The shear viscosity is calculated from

$$\eta = \frac{V}{T}\int_0^\infty C^{xy}(t)\,dt$$

where

$$C^{xy}(t) = \frac{1}{N}\sum_s^N T^{xy}(s)T^{xy}(s+t)$$



Green-Kubo Formalism

It has been shown that the correlation function in

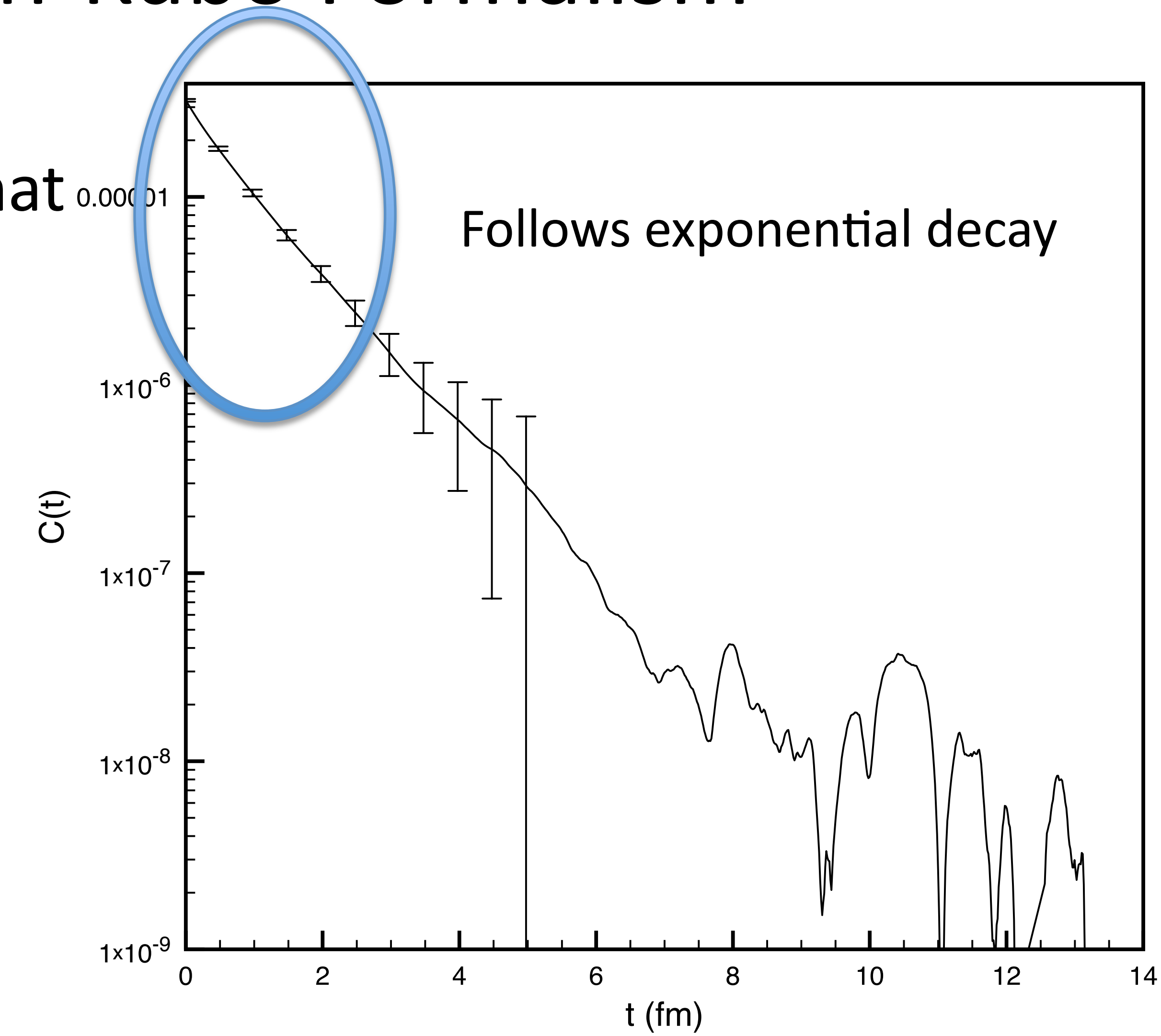
$$\eta = \frac{V}{T}\int_0^\infty C^{xy}(t)dt$$

follows

$$C^{xy}(t) = C^{xy}(0)\exp\left(-\frac{t}{\tau}\right)$$

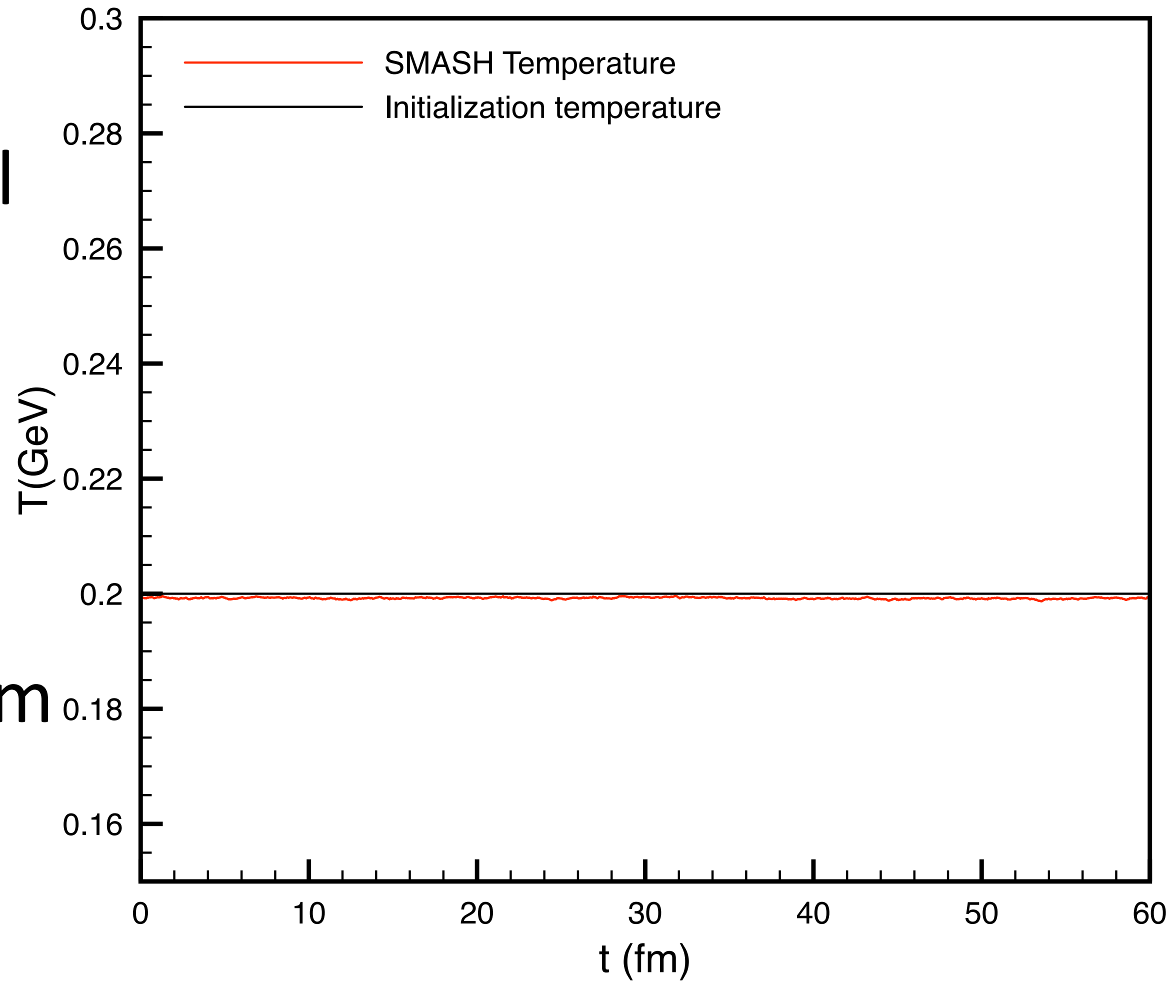
So that

$$\eta = \frac{VC^{xy}(0)\tau}{T}$$

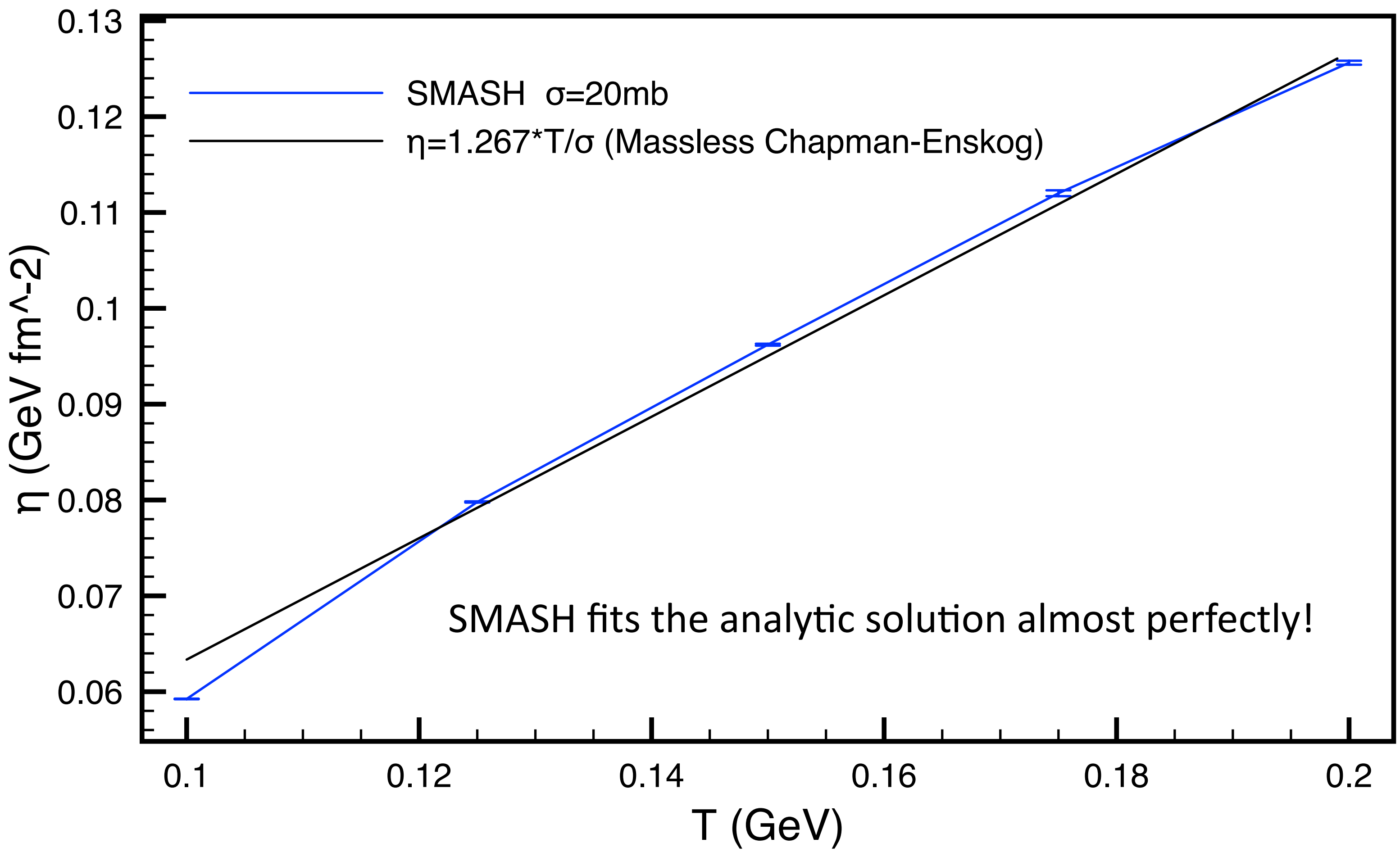


Massless particles : Elastic collisions

- Pions in the chiral limit in a (50 fm)^3 box simulating infinite matter
- Constant σ
- Runs for t_{max}=60fm



Massless particles

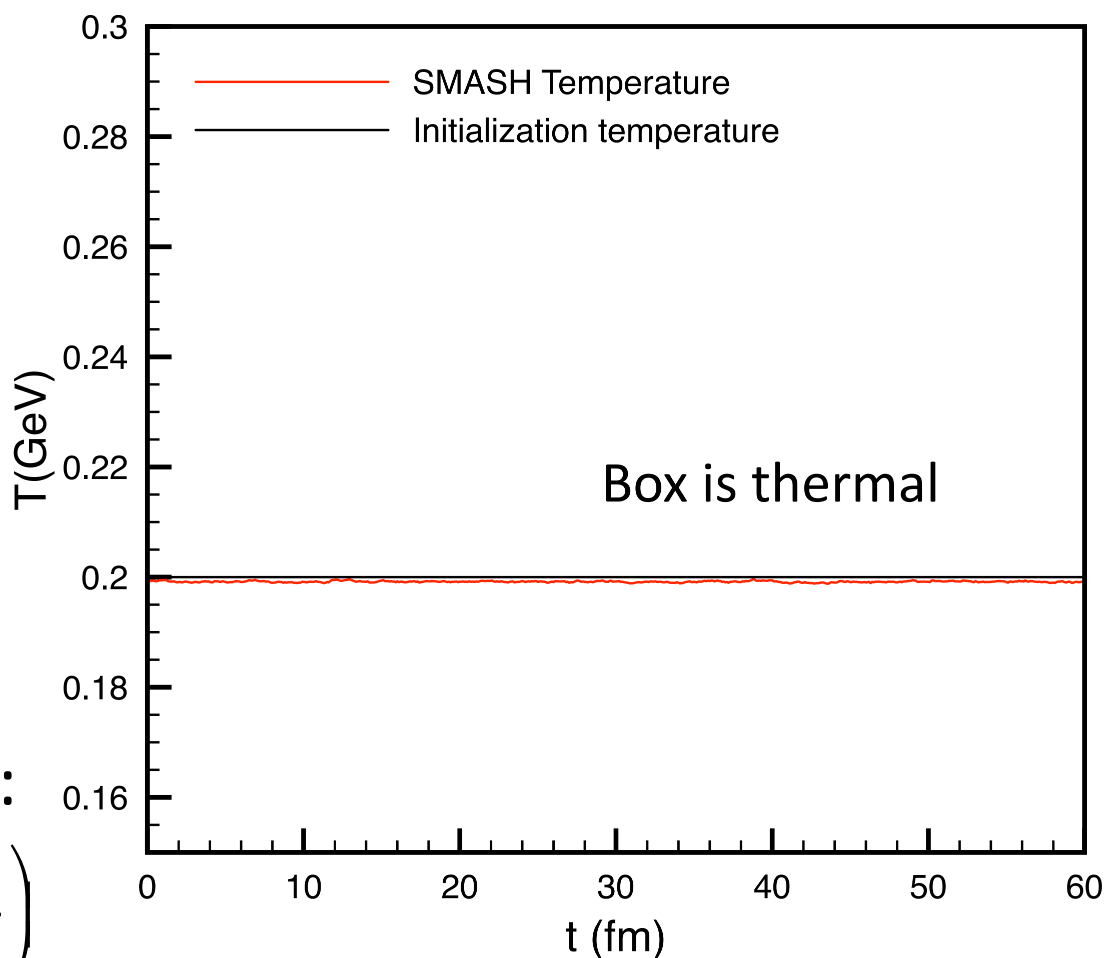


Plumari et al., arXiV:1208.0481v2

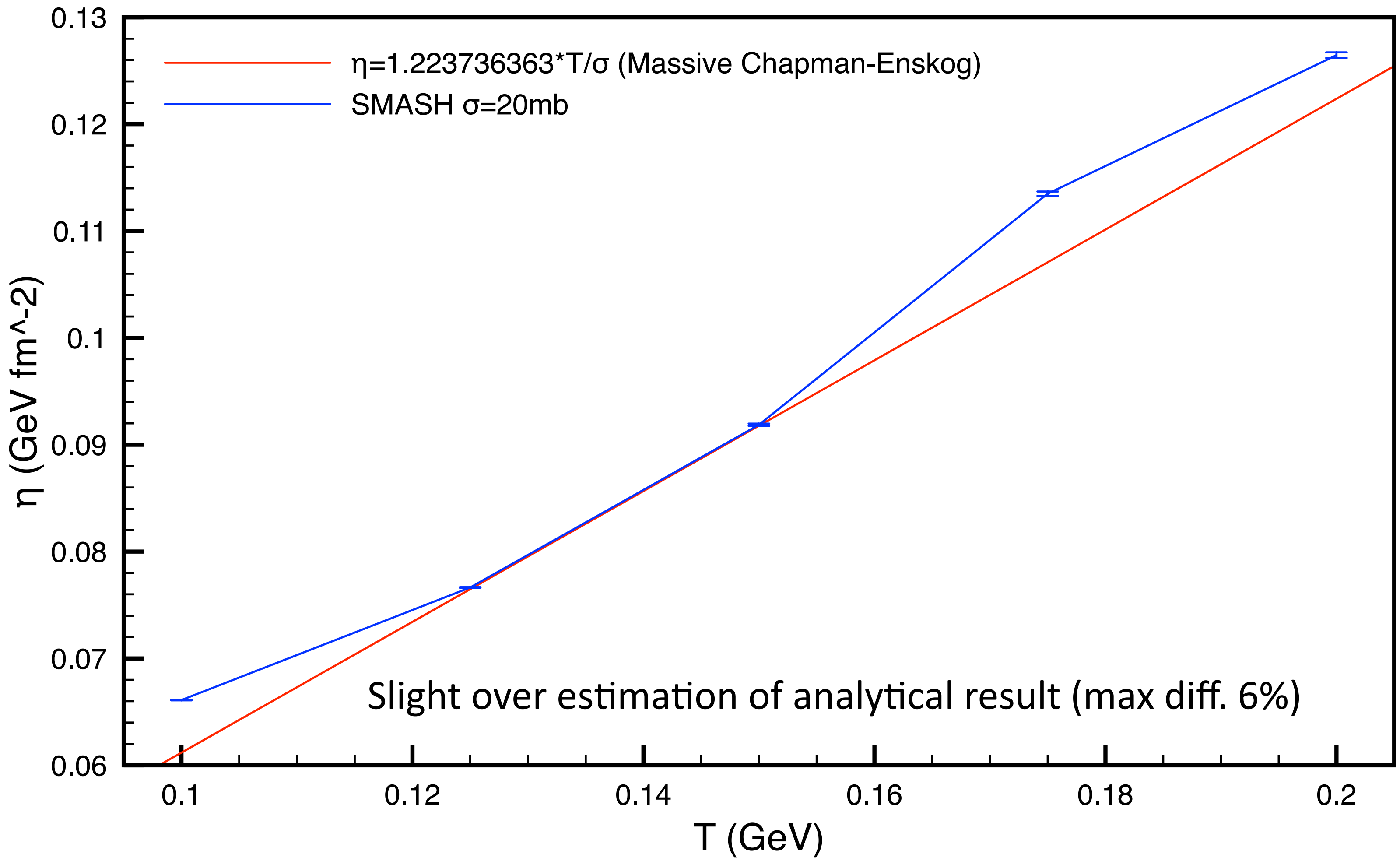
Massive pion box : Elastic collisions

- Pions in a (50 fm)^3 box simulating infinite matter
- Constant σ
- Runs for t_{max}=60fm
- Initialized with initial densities consistent with Boltzmann ideal gas:

$$\frac{dN}{dp} = \frac{g}{2\pi^2} V p^2 \exp\left(-\frac{\sqrt{p^2+m^2}}{T}\right)$$

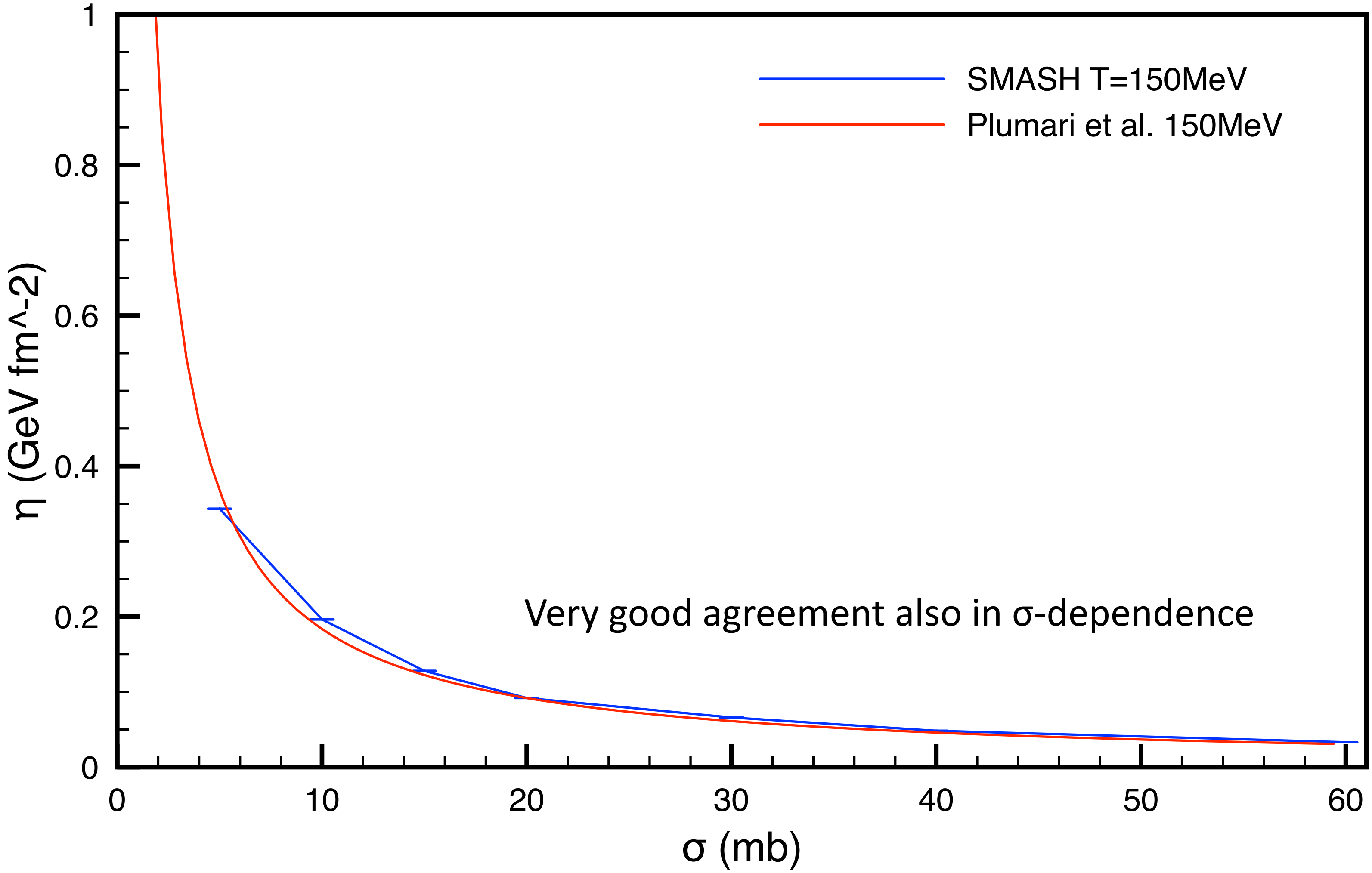


Pion box : Temperature dependence



Plumari et al., arXiV:1208.0481v2

Pion box : Cross-section dependence



Plumari et al., arXiV:1208.0481v2

Entropy

The entropy density can be calculated from the Gibbs formula:

$$s = \frac{e + p - \mu n}{T}$$

where e and p can be taken from the shear-stress tensor according to:

$$T^{\mu\nu} = diag(e, p, p, p)$$

What about T, μ and n? Assuming that we are dealing with a nearly ideal gas, one can fit T and μ using a multiplicity distribution:

$$\frac{dN}{dp} = \frac{g}{2\pi^2} V p^2 \exp\left(-\frac{\sqrt{p^2 + m^2} - \mu}{T}\right)$$

Entropy

However:

- How does one account for particle decay widths, i.e. that most particles are not on shell?

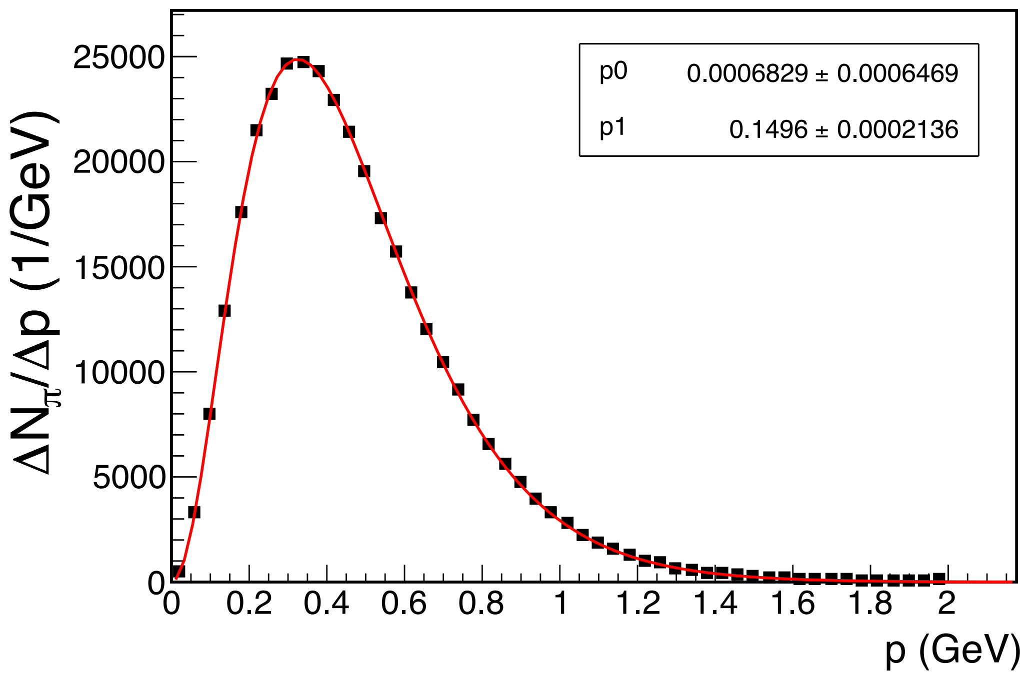
$$\frac{dN_i}{dp} = \frac{g_i}{2\pi^2} V p^2 \int_0^\infty \frac{dm}{N} \frac{\Gamma_i}{\left(m-m_i\right)^2 + \frac{\Gamma_i^2}{4}} \exp\left(-\frac{\sqrt{p^2+m^2}}{T}\right)$$

- How can one check the temperature and chemical potentials of a non-trivial system after a Boltzmann initialization?

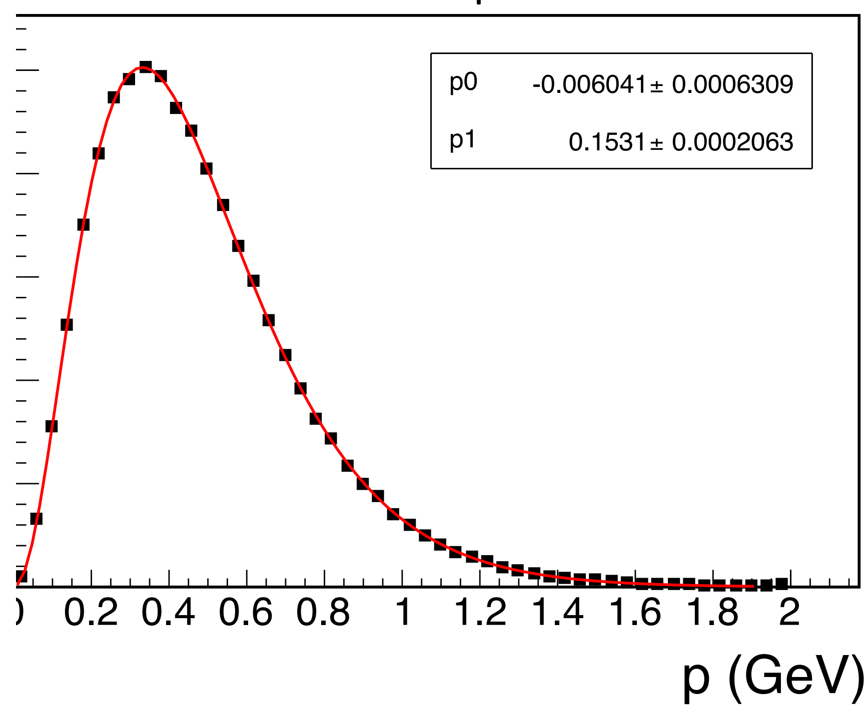
π-ρ-σ mesonic system

Supposing that the system remains close to an ideal Boltzmann gas, one can check the temperature and chemical potentials by fitting.

Pions: Initial



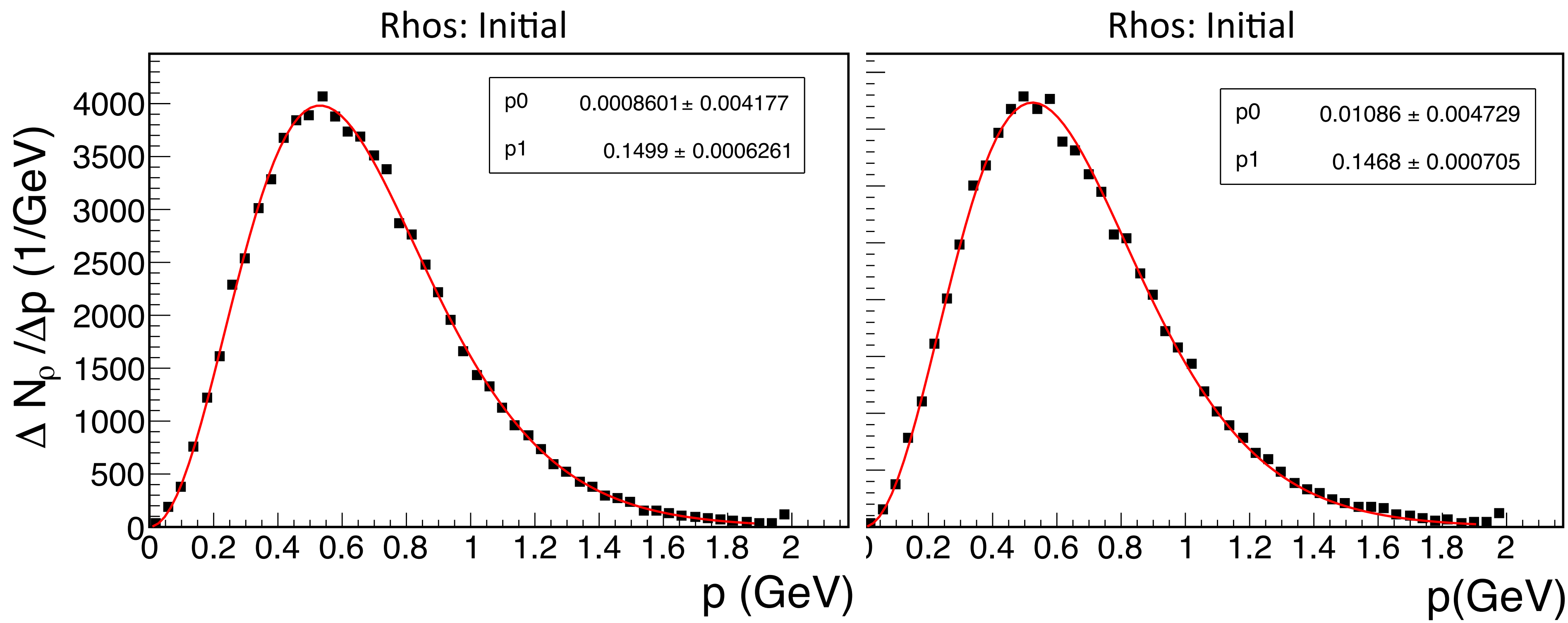
Pions: Equilibrium



Temperature stays **constant**, and chemical potential varies little

π-ρ-σ mesonic system

Supposing that the system remains close to an ideal Boltzmann gas, one can check the temperature and chemical potentials by fitting.



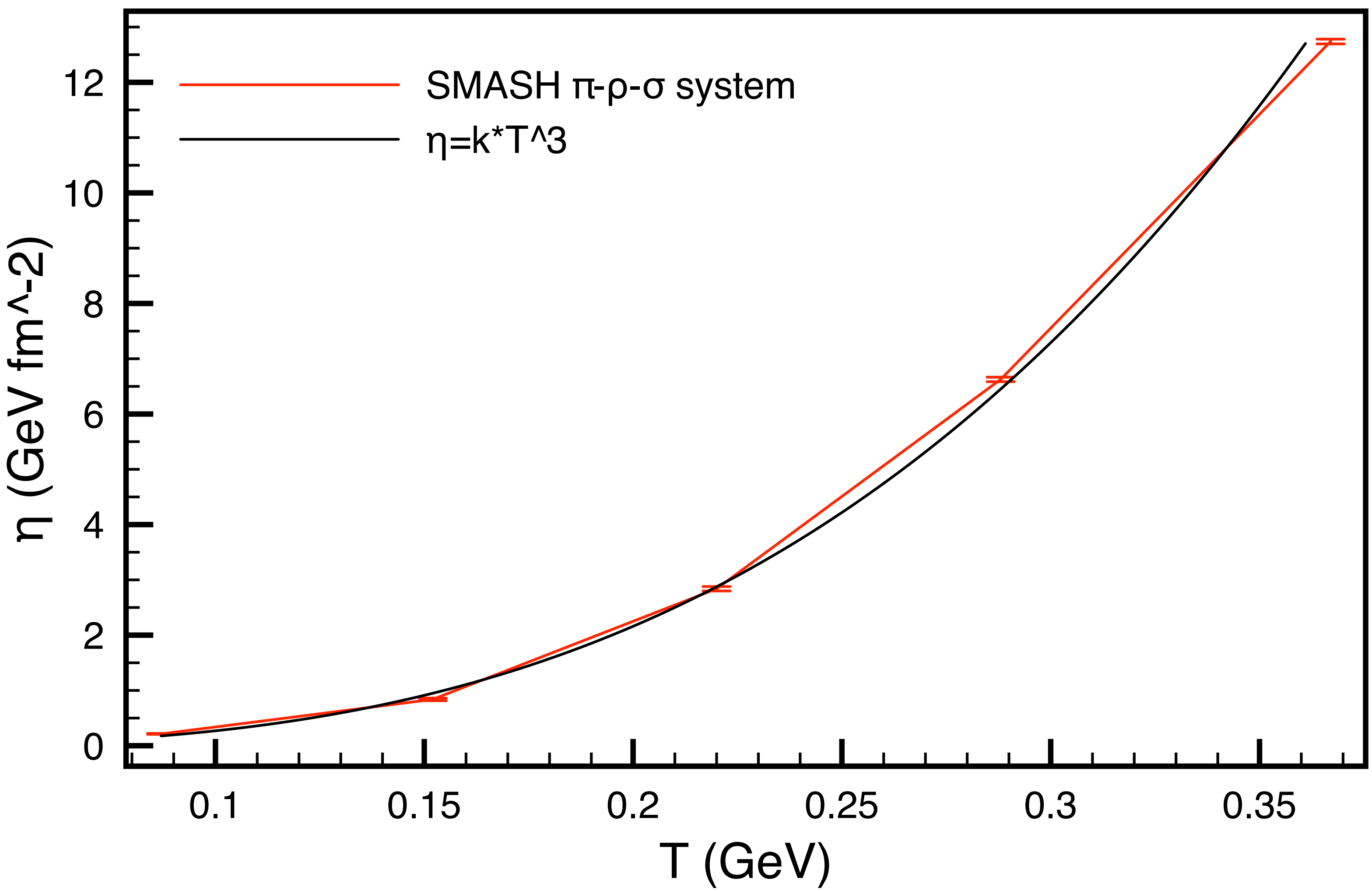
Both temperature and chemical potential vary little; might be an effect from decay widths

π-ρ-σ mesonic system

- Box starts according to Boltzmann distribution (might need Bose for pions)
- Temperature stays constant within 2%
- At equilibration, chemical potential stays small compared to temperature
- μn/T terms contribution to entropy negligible

	Pions	Rhos
Initial (GeV)	T=.1496 μ_π=.0007	T=.1499 μ_ρ=.0009
Equilibrium (GeV)	T=.1531 μ_π=-.006	T=.1468 μ_ρ=.0109

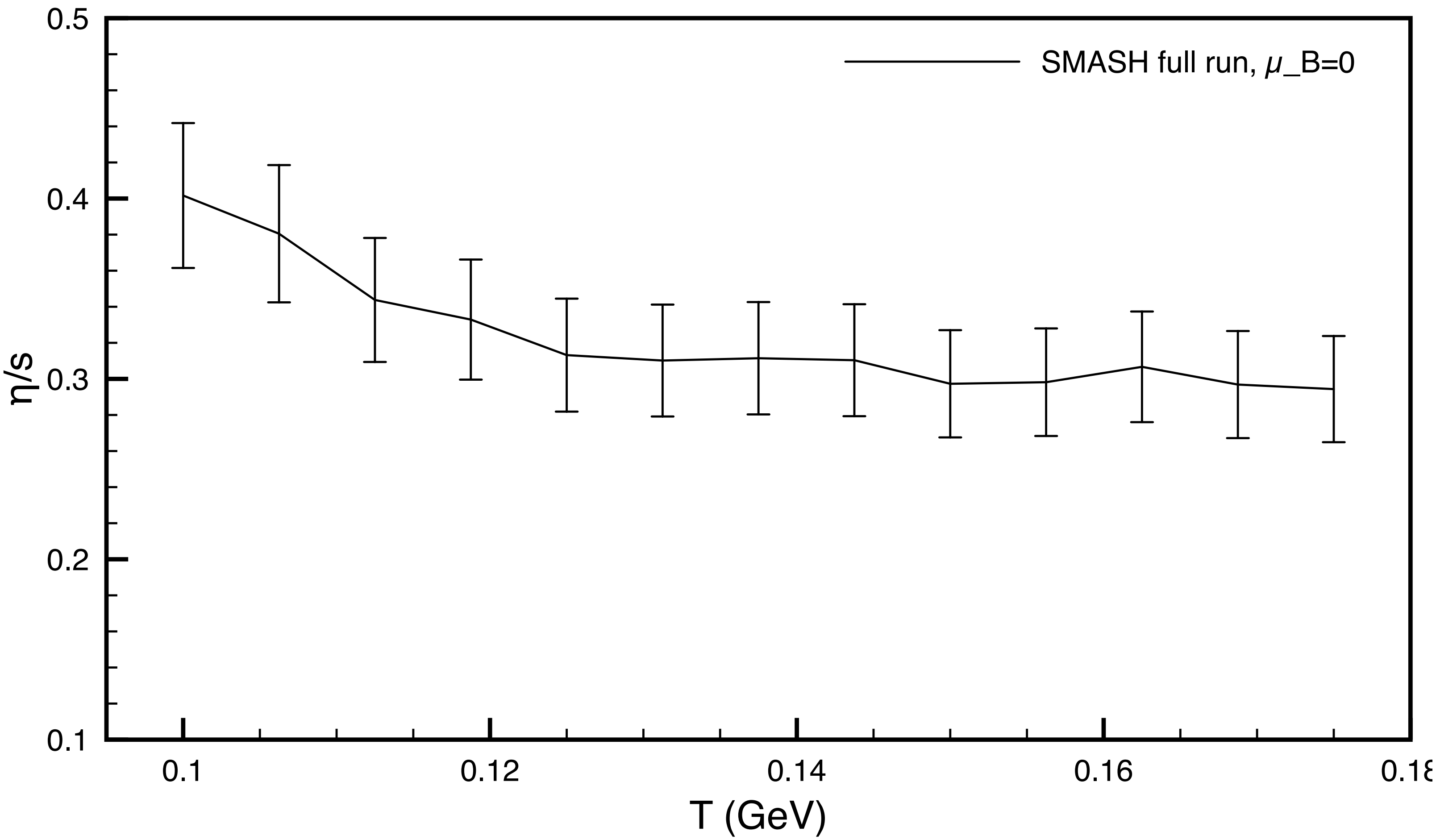
π-ρ-σ mesonic system : Temperature dependence



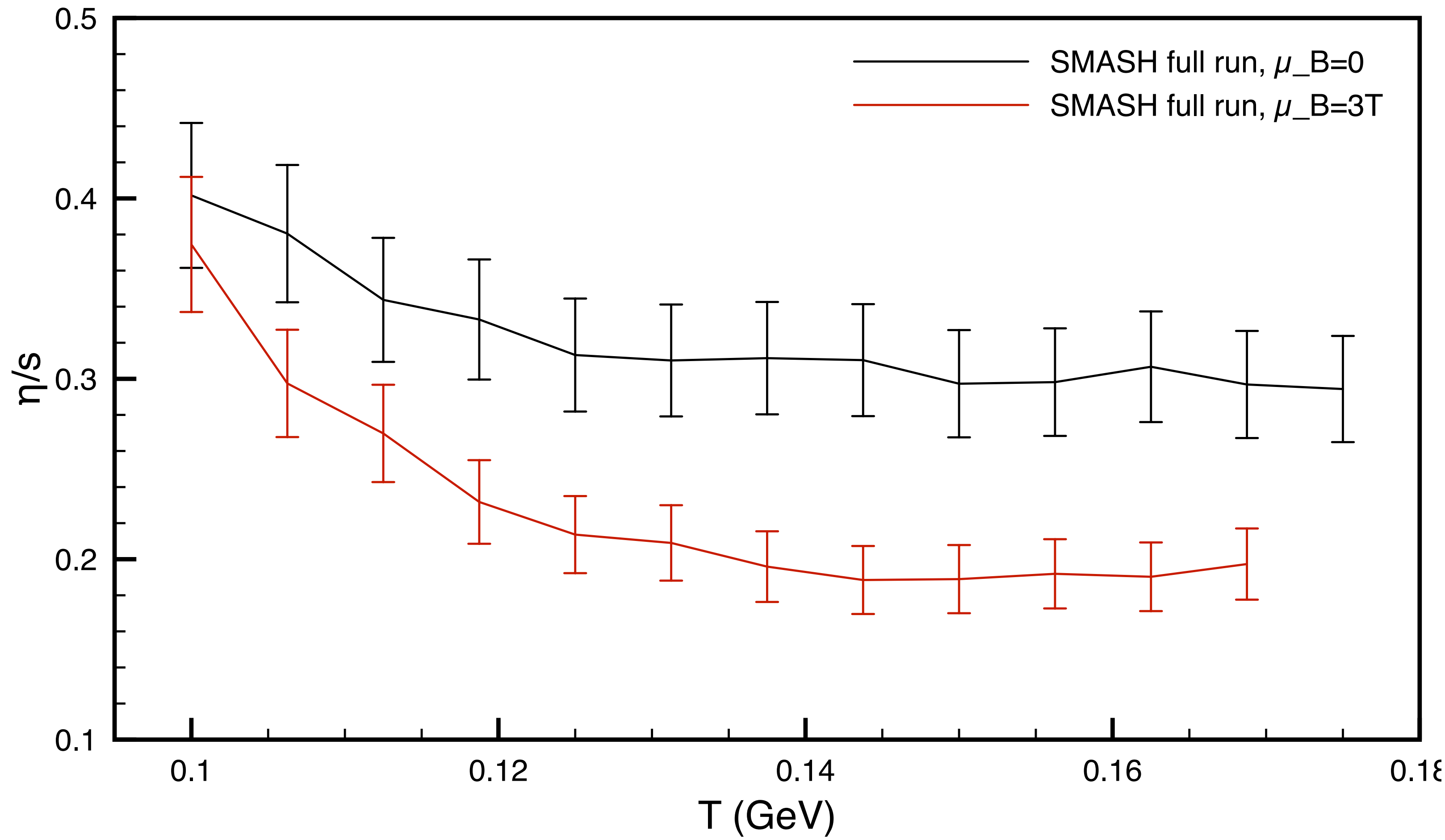
Full Hadron resonance gas

- Mesons:
  - π, ρ, η, ω, ϕ, σ, f_2
  - K, K*(892), K*(1410)
- Baryons:
  - N, N*, up to 2.25 GeV
  - Δ, Δ*, up to 1.95 GeV
  - Λ, Λ*, up to 1.89 GeV
  - Σ, Σ*, up to 1.915 GeV
  - Ξ, Ω
- All particles initialized using thermal densities

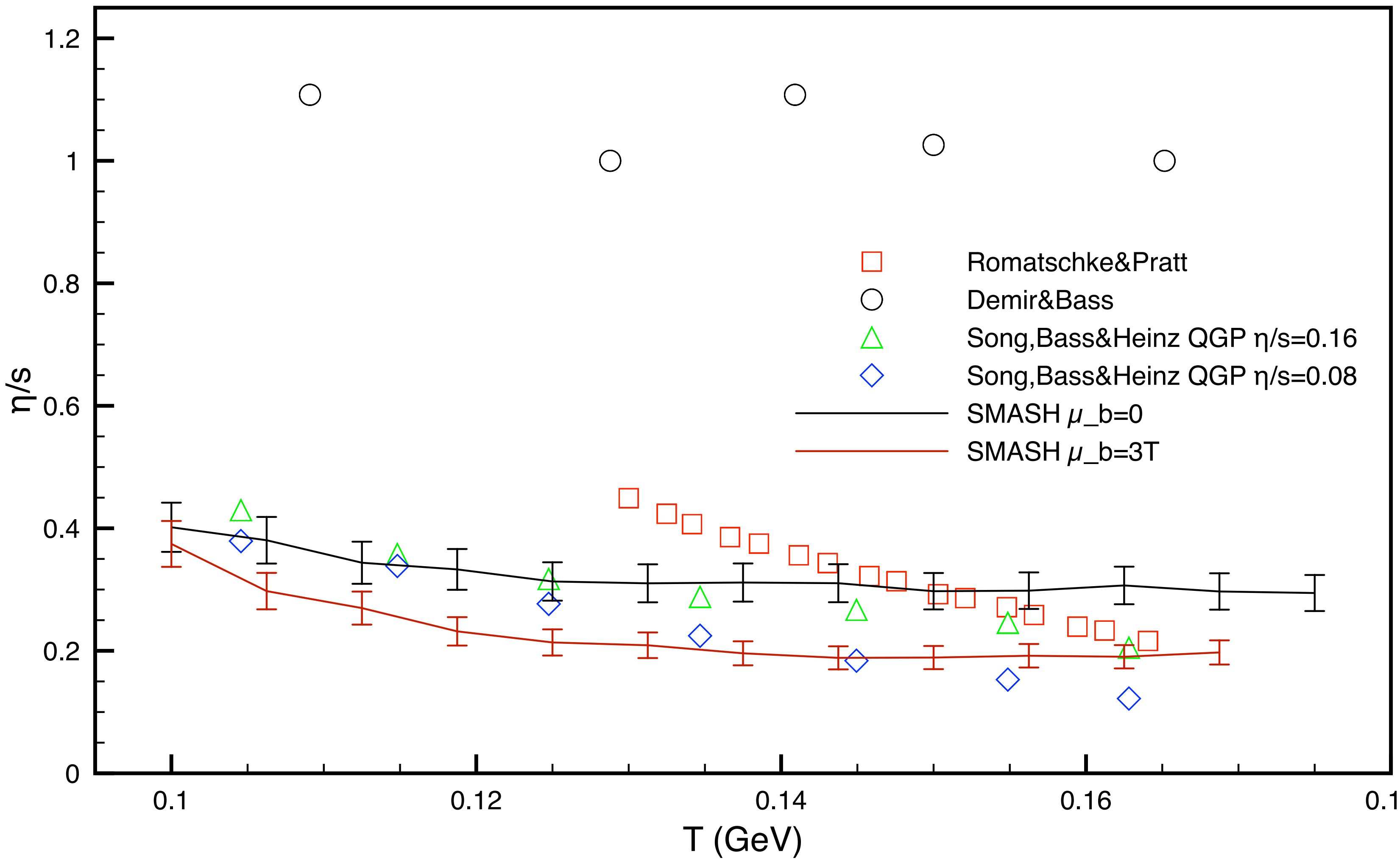
Full Hadron resonance gas



Full Hadron resonance gas



Comparison with previous calculations



Summary & outlook

- Investigated temperature and cross-section dependence of the shear viscosity in elastic massless and mesonic systems
  - Thermal particle densities
  - Slight over estimation of the analytic curves (within 5%)
- Calculation of the entropy of a non-trivial mesonic system
  - Temperature remains constant within a 2% error margin
  - Chemical potentials appear not to develop a lot during equilibration
  - Ansatz : one can use the initial T and μ to get good approximated values for T and μ after equilibration
- Full SMASH η/s calculated
  - Has the expected decreasing profile
  - Order of magnitude in agreement with most other simulations, but not in full agreement with any
- Outlook:
  - Improve calculation of T, μ and entropy (decay widths, equi-partition theorem..?)
  - More thorough investigation of the μ_B, μ_S parameter space (inclusion of μ_I?); strange cross-sections have to be verified
  - Other transport coefficients (electrical conductivity, bulk viscosity, etc.)