Study of initial conditions in *pp* collisions at LHC energies in String Percolation Model

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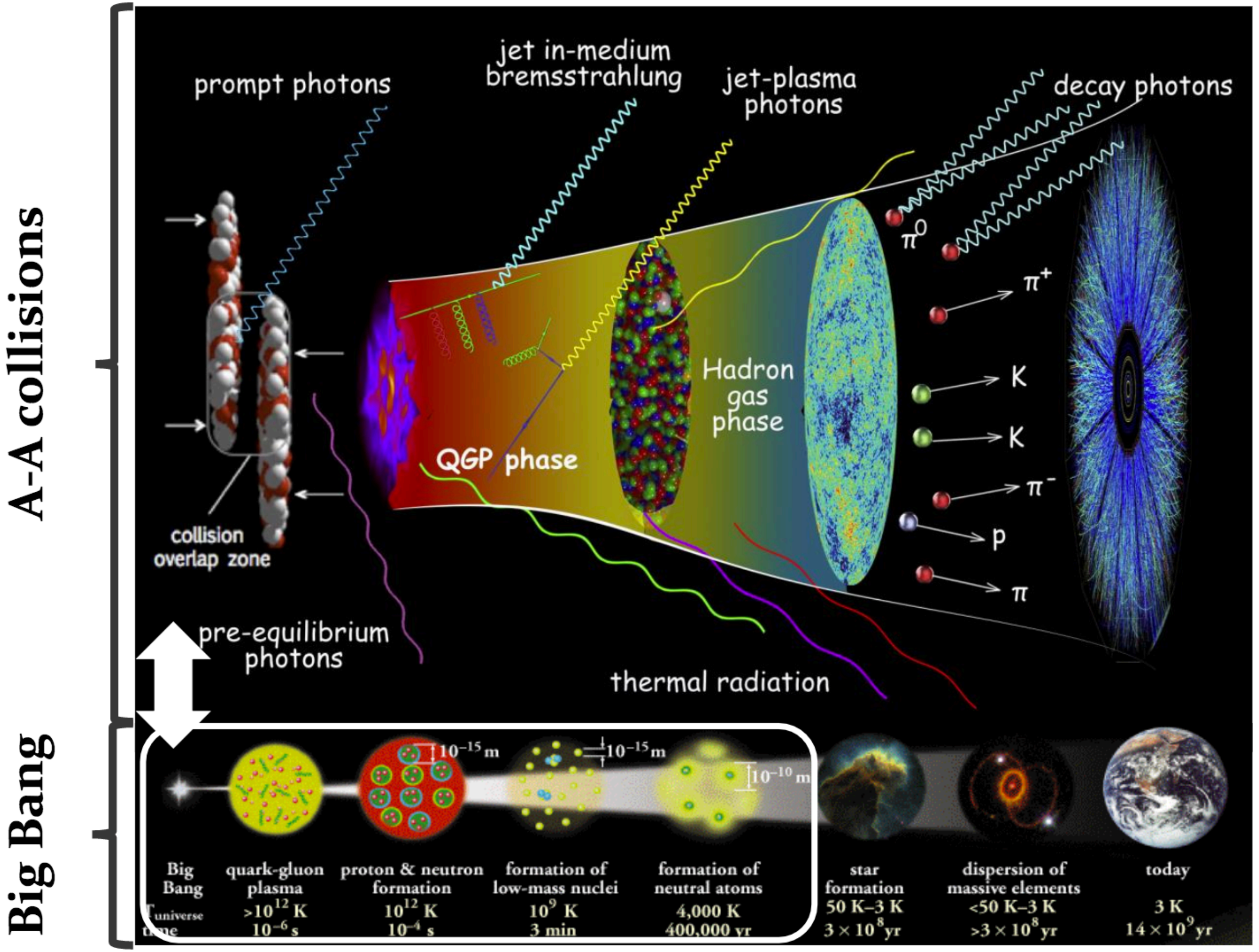
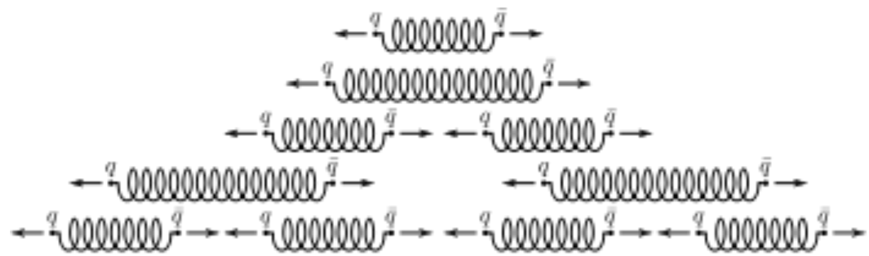
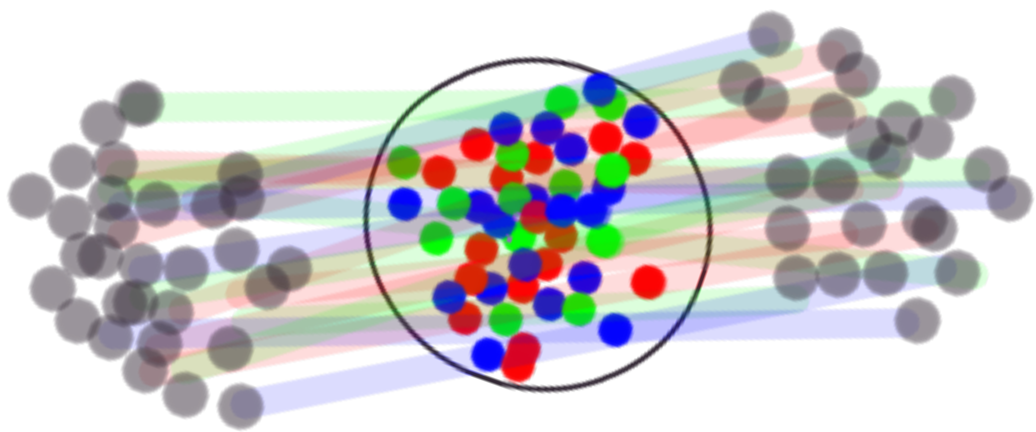
Outline

- Motivation
  - Quark-Gluon Plasma
- String Percolation Model
  - Parameters
  - Thermodynamic Quantities
- Results
- Conclusions


A-A collisions
Big Bang
prompt photons
jet in-medium bremsstrahlung
jet-plasma photons
decay photons
π^0
π^+
K
K
π^-
p
π
Hadron gas phase
QGP phase
collision overlap zone
pre-equilibrium photons
thermal radiation
10^{-15} m
10^{-15} m
10^{-10} m
Big Bang
quark-gluon plasma
proton & neutron formation
formation of low-mass nuclei
formation of neutral atoms
star formation
dispersion of massive elements
today
$T_{universe}$
time
$>10^{12}$ K
10^{-6} s
10^{12} K
10^{-4} s
10^9 K
3 min
4,000 K
400,000 yr
50 K–3 K
3×10^8 yr
<50 K–3 K
$>3 \times 10^8$ yr
3 K
14×10^9 yr

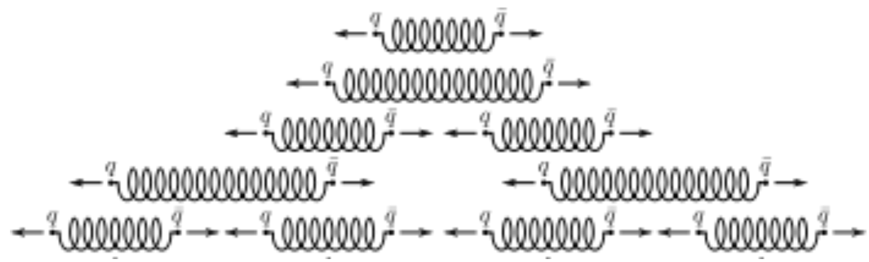
Color String Percolation Model

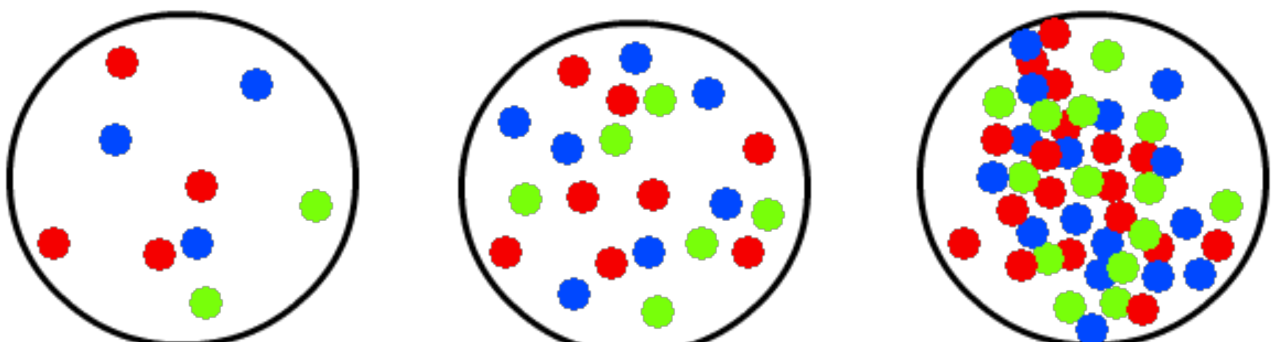




* Braun, M. A. Dias de Deus, J. Hirsch, A. S. Pajares, C. Scharenberg, R. P. and Srivastava, B. K., arXiv 1501.01524 [nucl-th].

Color String Percolation Model





* Braun, M. A. Dias de Deus, J. Hirsch, A. S. Pajares, C. Scharenberg, R. P. and Srivastava, B. K., arXiv 1501.01524 [nucl-th].

Model Parameters

The two cardinal parameters of the model are the transverse string density

$$\xi^t = \frac{S_0}{S}\bar{N}_s \,, \tag{1}$$

and the color suppression factor

$$F(\xi^t) = \sqrt{\frac{1 - e^{-\xi^t}}{\xi^t}} \;. \tag{2}$$

* Braun, M. A. Dias de Deus, J. Hirsch, A. S. Pajares, C. Scharenberg, R. P. and Srivastava, B. K., arXiv 1501.01524 [nucl-th].

We make a global fit with the relation

$$\left.\frac{dN}{d\eta}\right|_{\eta=0} \equiv \mu = kF(\xi^t)\bar{N}_s\,, \qquad (3)$$

$$\bar{N}_s = 2 + 4\left(\frac{S_0}{S_\epsilon(b)}\right)\left(\frac{\sqrt{s}}{m_p}\right)^{2\lambda}\,, \qquad (4)$$

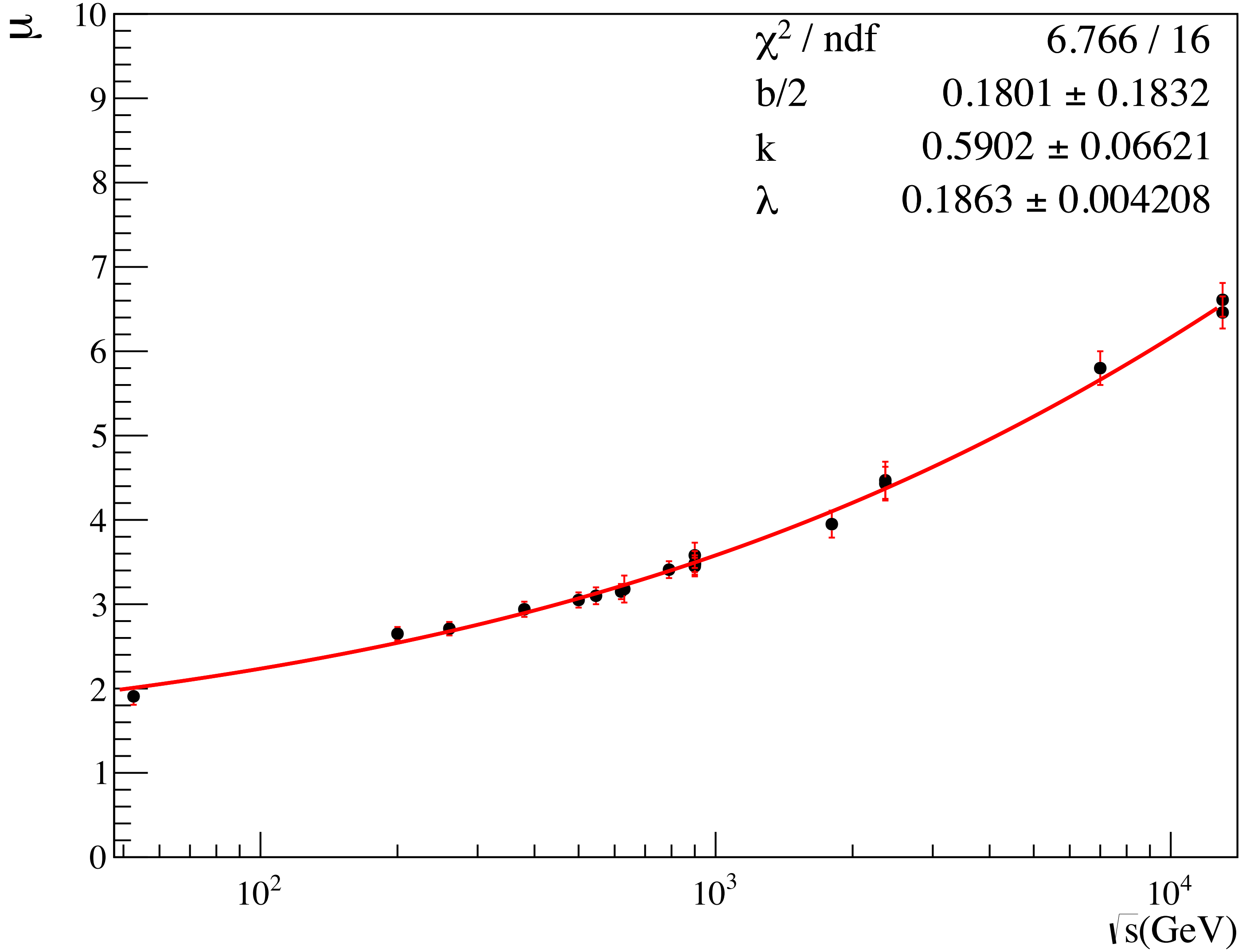
where $S_0=\pi r_0^2$ the mean color interaction transverse area and

$$S_\epsilon(b) = \pi\sqrt{1-(b/2)^2}(1-b/2)\,, \qquad (5)$$

the cross-sectional area parameterized by the impact parameter.

* Bautista, I. Milhano, J. G. Pajares, C. 2012. and Dias de Deus. J.Phys.Lett.,B715,230

Multiplicity dependence of $\sqrt{s}$



- J. Adam et al. [ALICE Collaboration], Phys. Lett. B 753 (2016) 319
- V. Khachatryan et al. [CMS Collaboration], Phys. Lett. B 751, 143 (2015)
- Bautista, I. Milhano, J. G. Pajares, C. 2012. and Dias de Deus. J.Phys.Lett.,B715,230

With those values we can calculate the average minimum bias parameters from pp collisions at central rapidity region for the energies of interest

$\sqrt{s}$(TeV)	N_s	ξ^t	$F(\xi^t)$
7	*10.85516256*	*0.678447660*	*0.852093488*
2.76	*8.091336298*	*0.505708519*	*0.885936059*
0.9	*5.882152711*	*0.367634544*	*0.914757690*

Table 1: *Minimum bias values of average number of strings, string density and color reduction factor.*

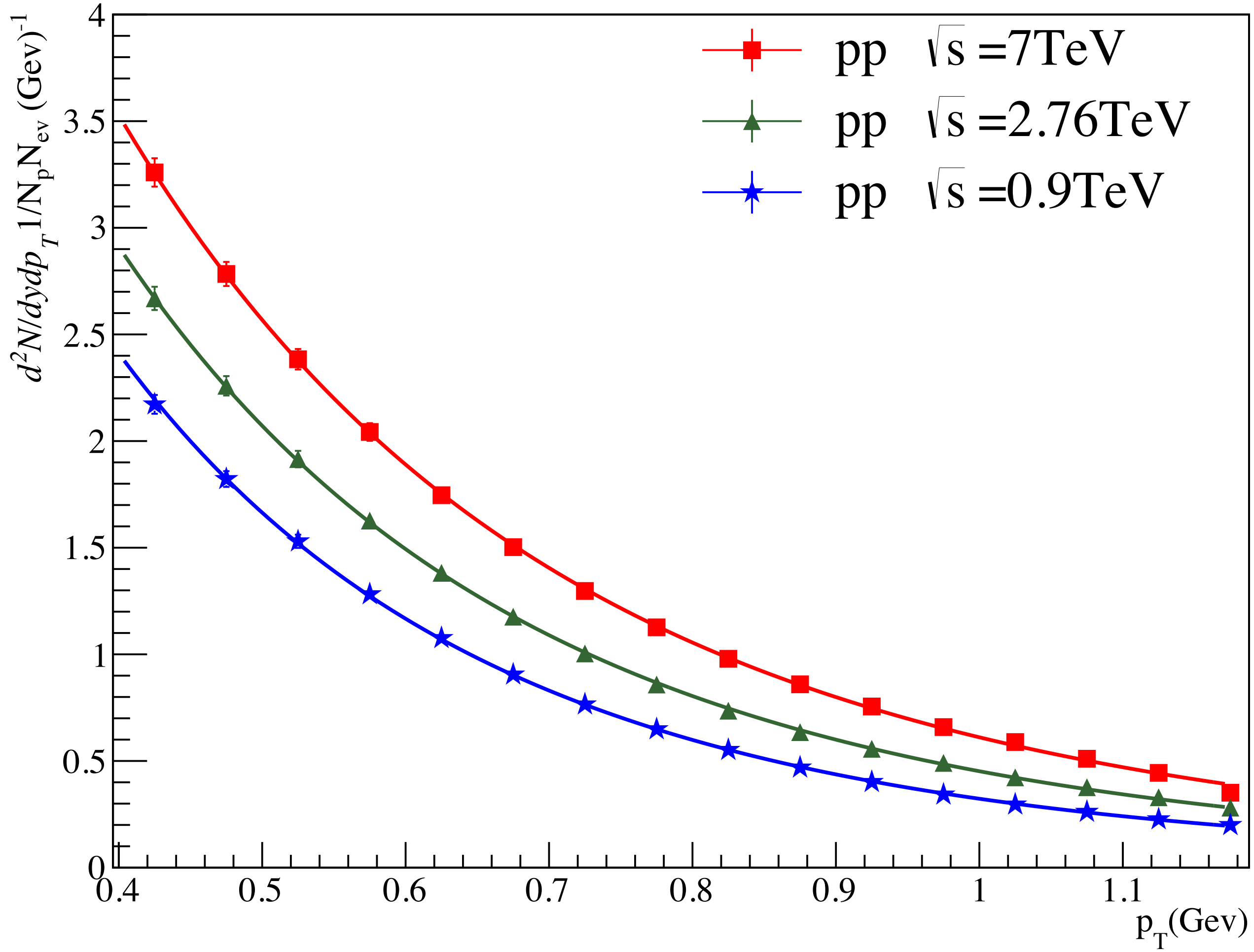
To determine the value of the parameters for each energy we use the invariant spectrum of transverse moment that follows the power law

$$\frac{d^2N}{d\eta dp_T} \sim \frac{(\beta p_0)^{\alpha-2}}{[\beta p_0 + p_T]^{\alpha-1}}, \qquad (6)$$

with

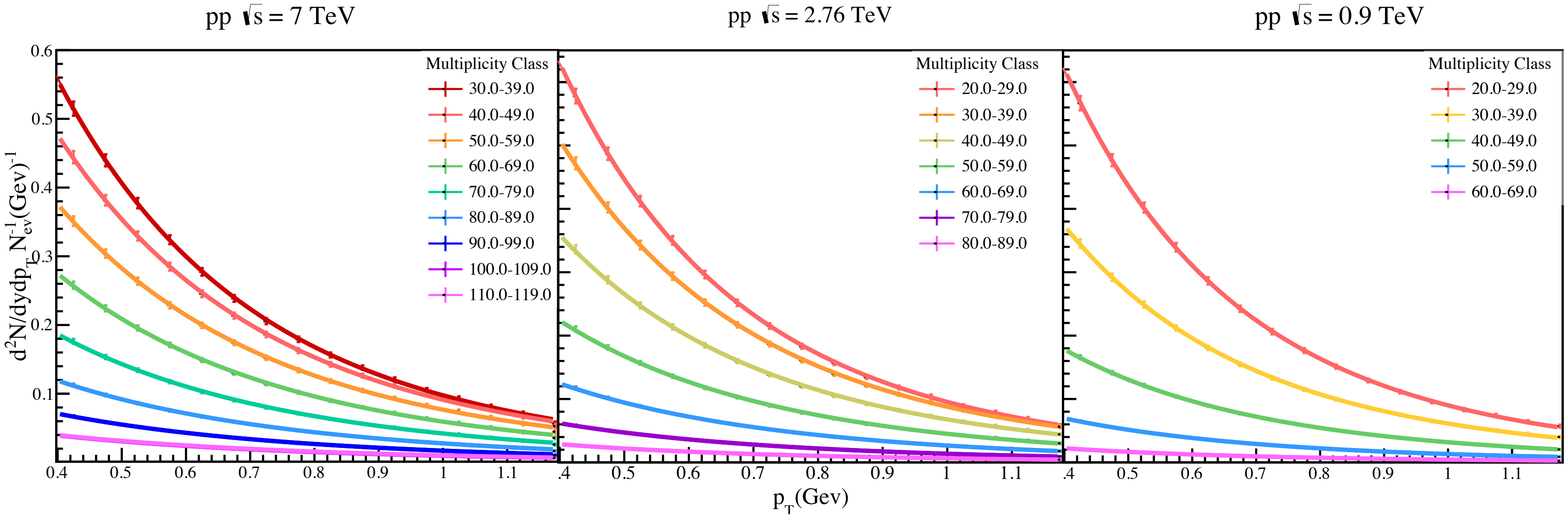
$$\beta = 1 \to \sqrt{\frac{F(\xi^t_{MB})}{F(\xi^t_{HM})}}. \qquad (7)$$

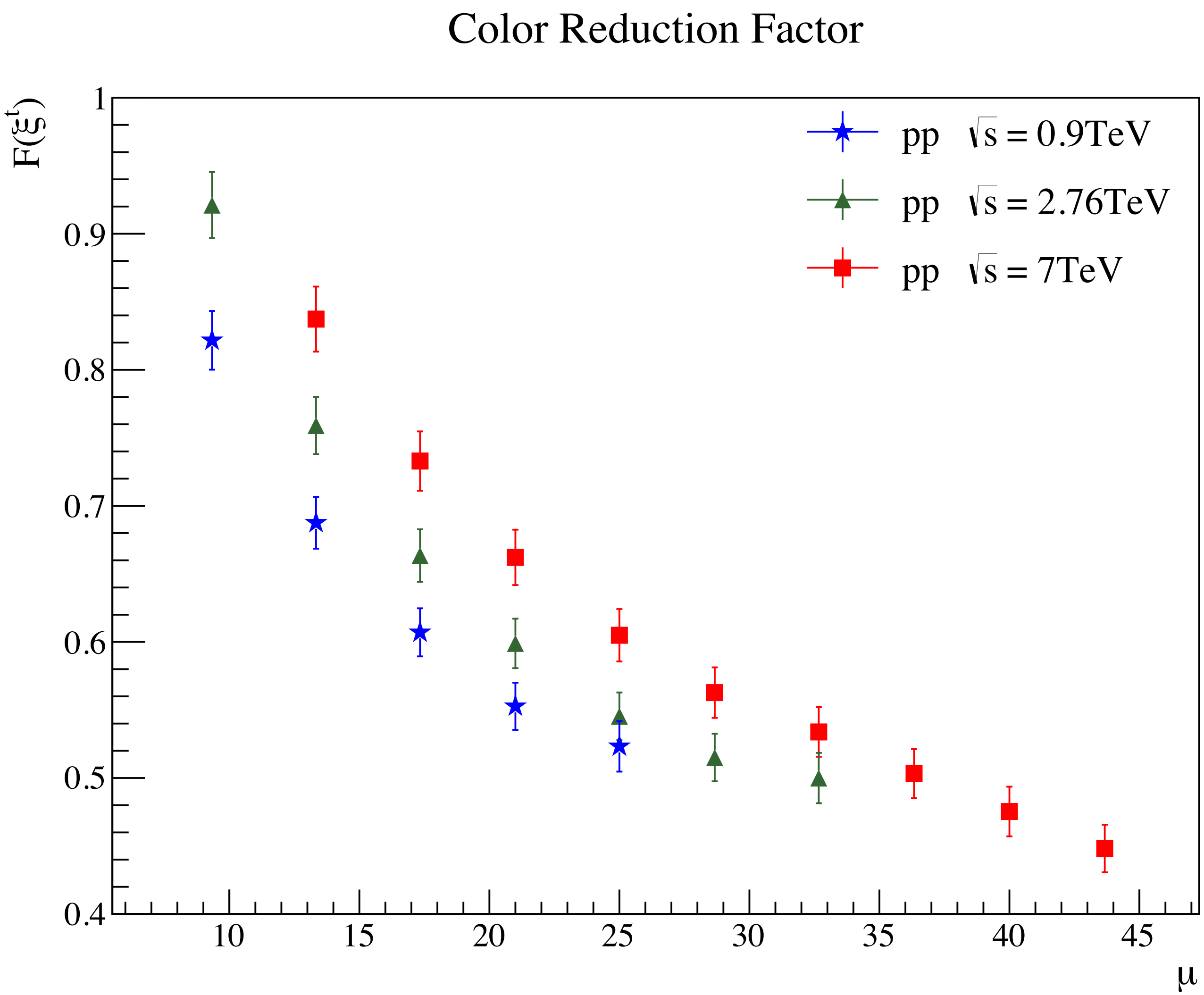
*Braun, M. A. Dias de Deus, J. Hirsch, A. S. Pajares, C. Scharenberg, R. P. and Srivastava, B. K., arXiv 1501.01524 [nucl-th].



*S. Chatrchyan et al. [CMS Collaboration], Eur. Phys. J. C 72 (2012) 2164.

For each multiplicity class we use the deviation of beta and we calculate the different color reduction factors




Color Reduction Factor
$F(\xi^t)$
μ
pp $\sqrt{s}$ = 0.9TeV
pp $\sqrt{s}$ = 2.76TeV
pp $\sqrt{s}$ = 7TeV
1
0.9
0.8
0.7
0.6
0.5
0.4
10
15
20
25
30
35
40
45

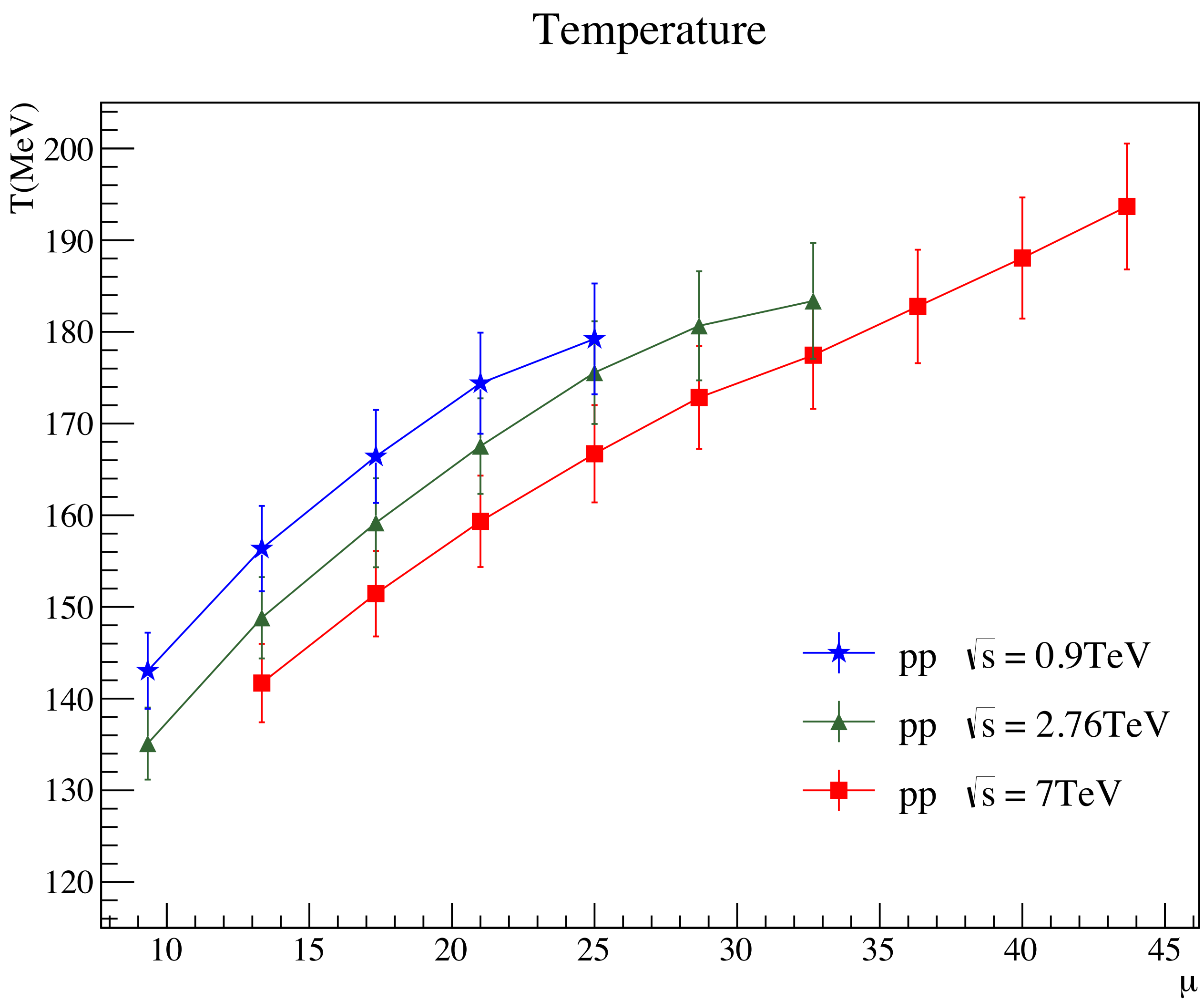
Thermodynamic Quantities

The effective system temperature is obtained by the Schwinger mechanism for massless particles; a non-Gaussian distribution of the tension fluctuations of the strings gives a thermal distribution related to the color reduction factor

$$T(\xi^t) = \frac{\langle p_T \rangle}{\sqrt{2F(\xi^t)}}, \tag{8}$$

where $\langle p_T \rangle$ = 190.25±11.12MeV.

* J. S. Schwinger, Phys. Rev. 128 (1962) 2425. doi:10.1103/PhysRev.128.2425
* I. Bautista, A. Fernadez, P. Ghosh, Phys. Re D 92 (2015) 7


Temperature
T(MeV)
200
190
180
170
160
150
140
130
120
10
15
20
25
30
35
40
45
μ
pp √s = 0.9TeV
pp √s = 2.76TeV
pp √s = 7TeV

Energy density

In cSPM we can define an average temperature in analogy to the one defined in hydro from the local thermal equilibrium. After the initial temperature $T > T_c$ the perfect fluid may expand according to Bjorken formula

$$\varepsilon = \frac{3\mu\langle p_T\rangle}{2S\tau}, \tag{9}$$

where $\tau = 0.89$fm.

* J. D. Bjorken, Phys. Rev. D 27 (1983) 140.

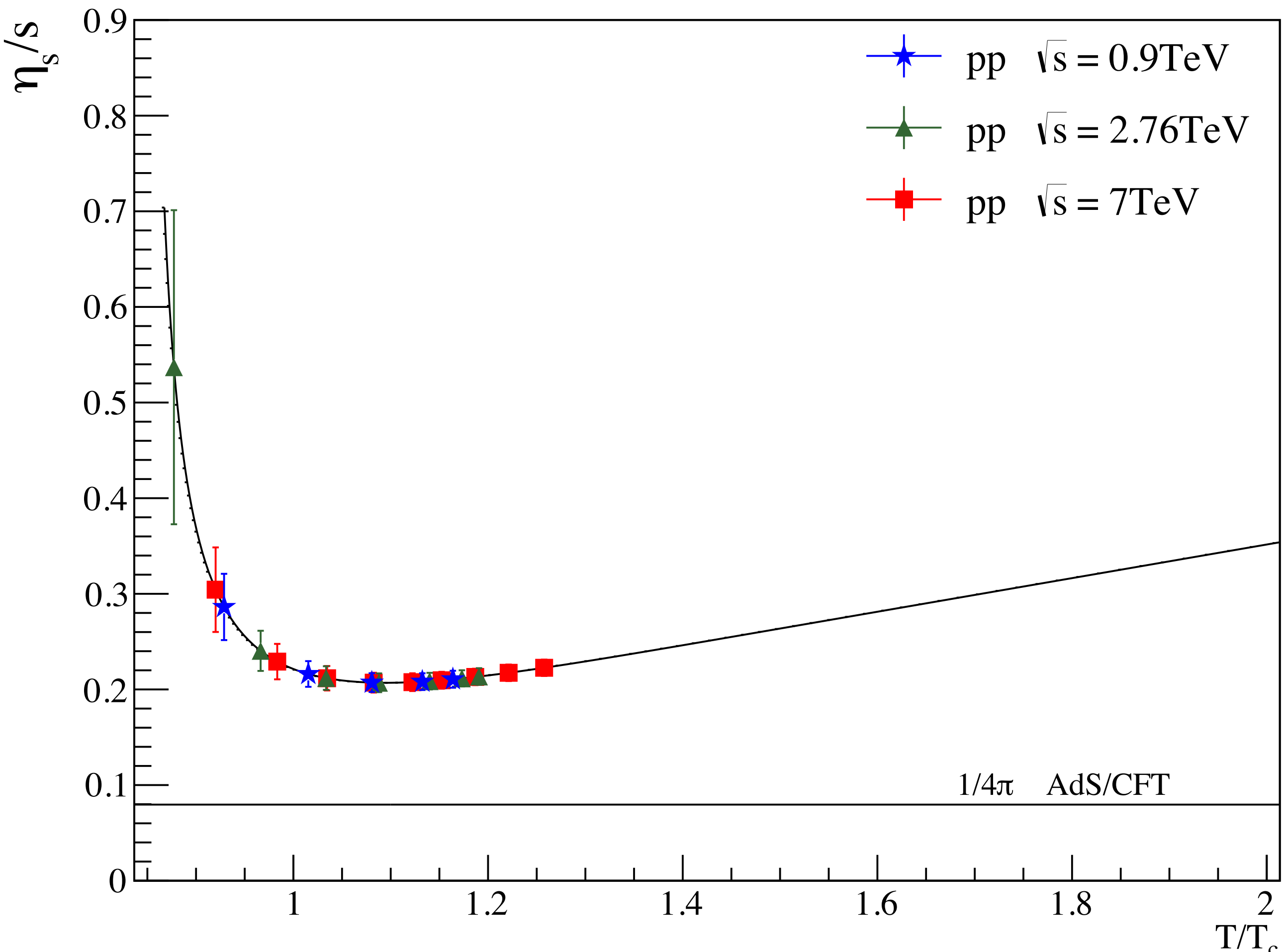
Shear Viscosity

In the relativistic kinetic theory the shear viscosity is proportional to the mean free path $\eta_s/s \simeq T/5n\sigma$, where the mean free path is inverse to the effective number of sources per unit volume and the transport cross section, we consider that it is inverse to $(1-e^{-\xi^t})/L$, with L the longitudinal extension of the source (1fm)

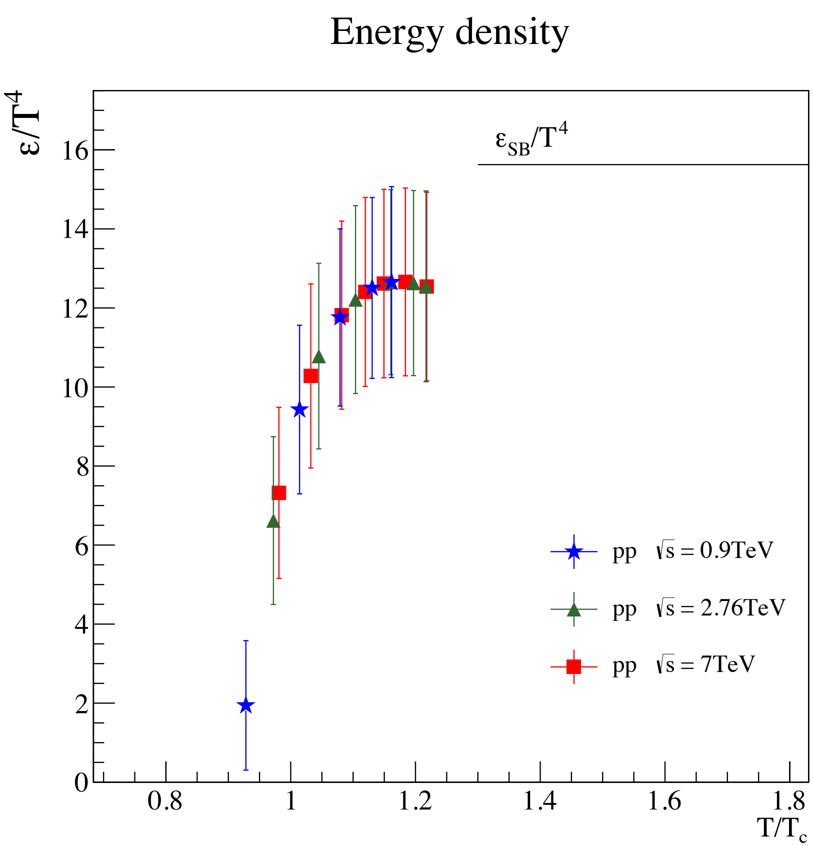
$$\frac{\eta_s}{s} = \frac{TL}{5(1-e^{-\xi^t})} \, . \tag{10}$$

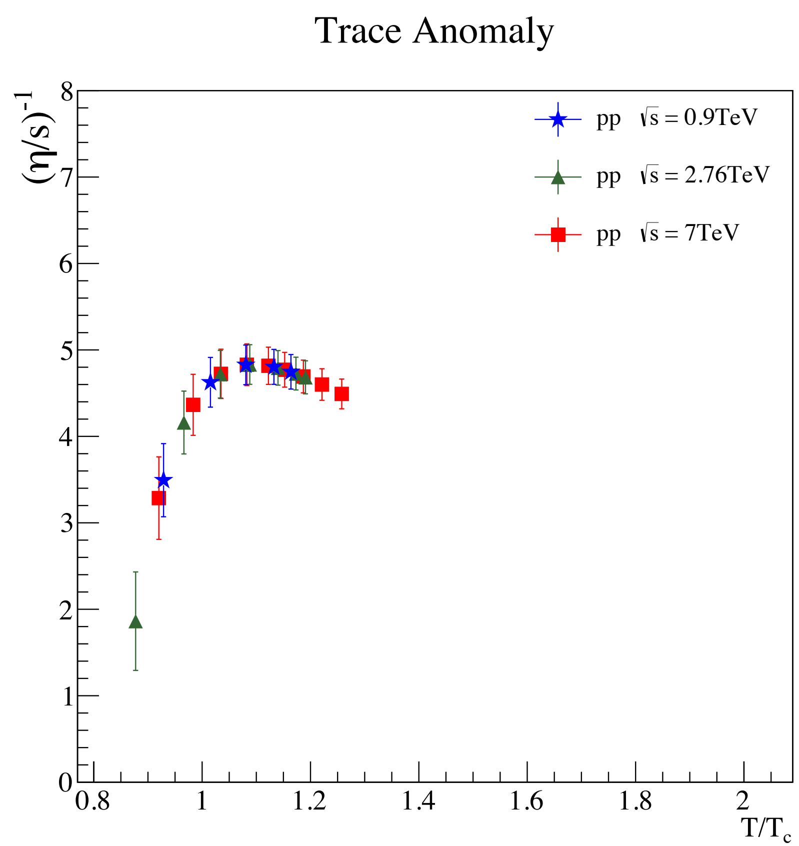
* I. Bautista, A. Fernadez, P. Ghosh, Phys. Re D 92 (2015) 7

Shear Viscosity

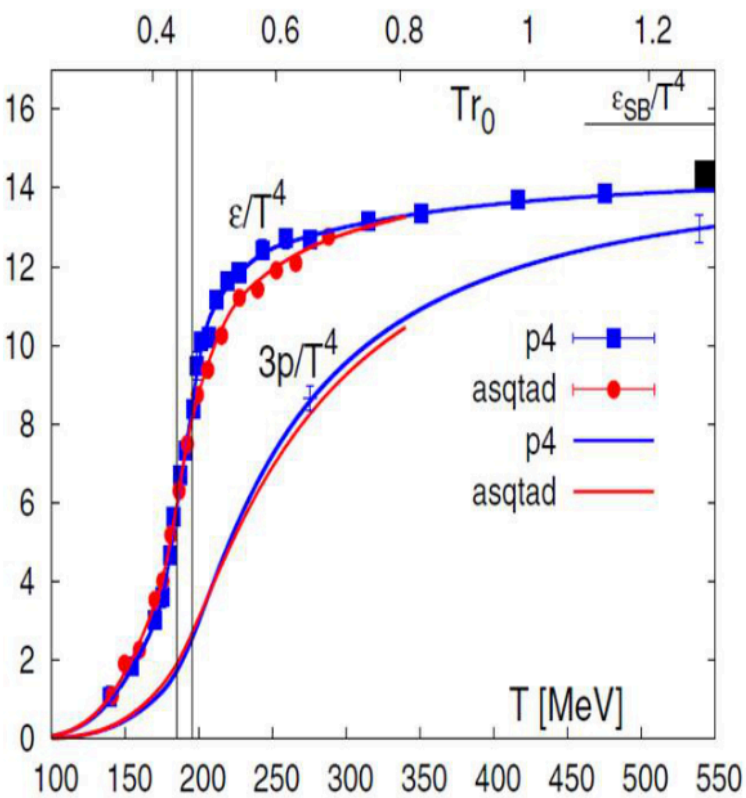


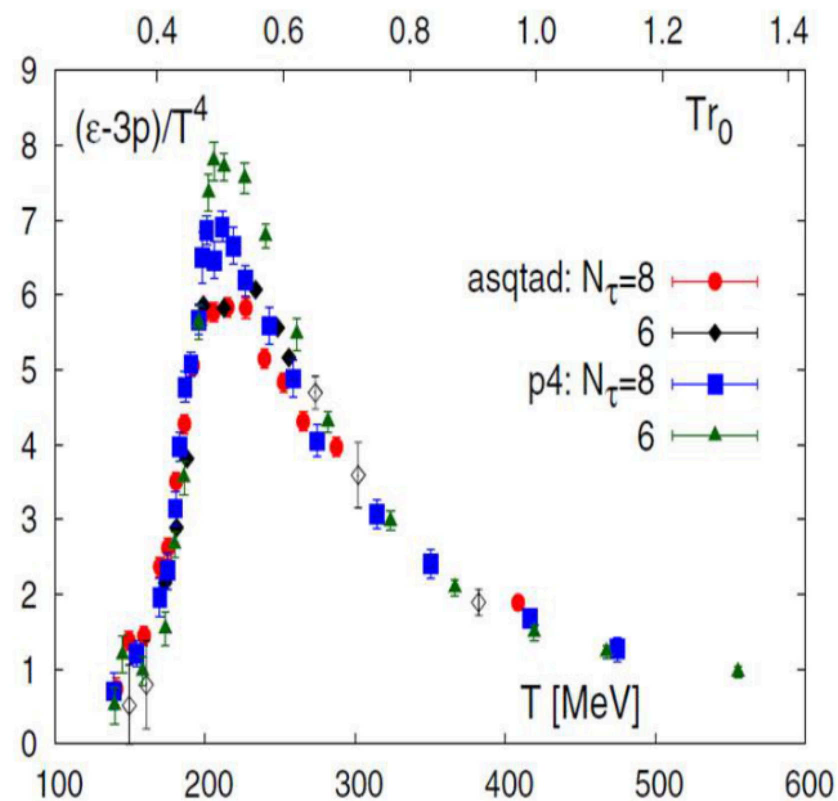
* P. Kovtun, D. T. Son and A. O. Starinets, Phys. Rev. Lett. 94 (2005) 111601 doi:10.1103/PhysRevLett.94.111601 [hep-th/0405231].





* S. Borsanyi, G. Endrodi, Z. Fodor, A.~Jakovac, S. D. Katz, S. Krieg, C. Ratti and K. K. Szabo, JHEP 1011, 077 (2010)





* P. Petreczky, J. Phys. G: Nucl. Part. Phys. 39 (2012) 093002.

Speed of Sound

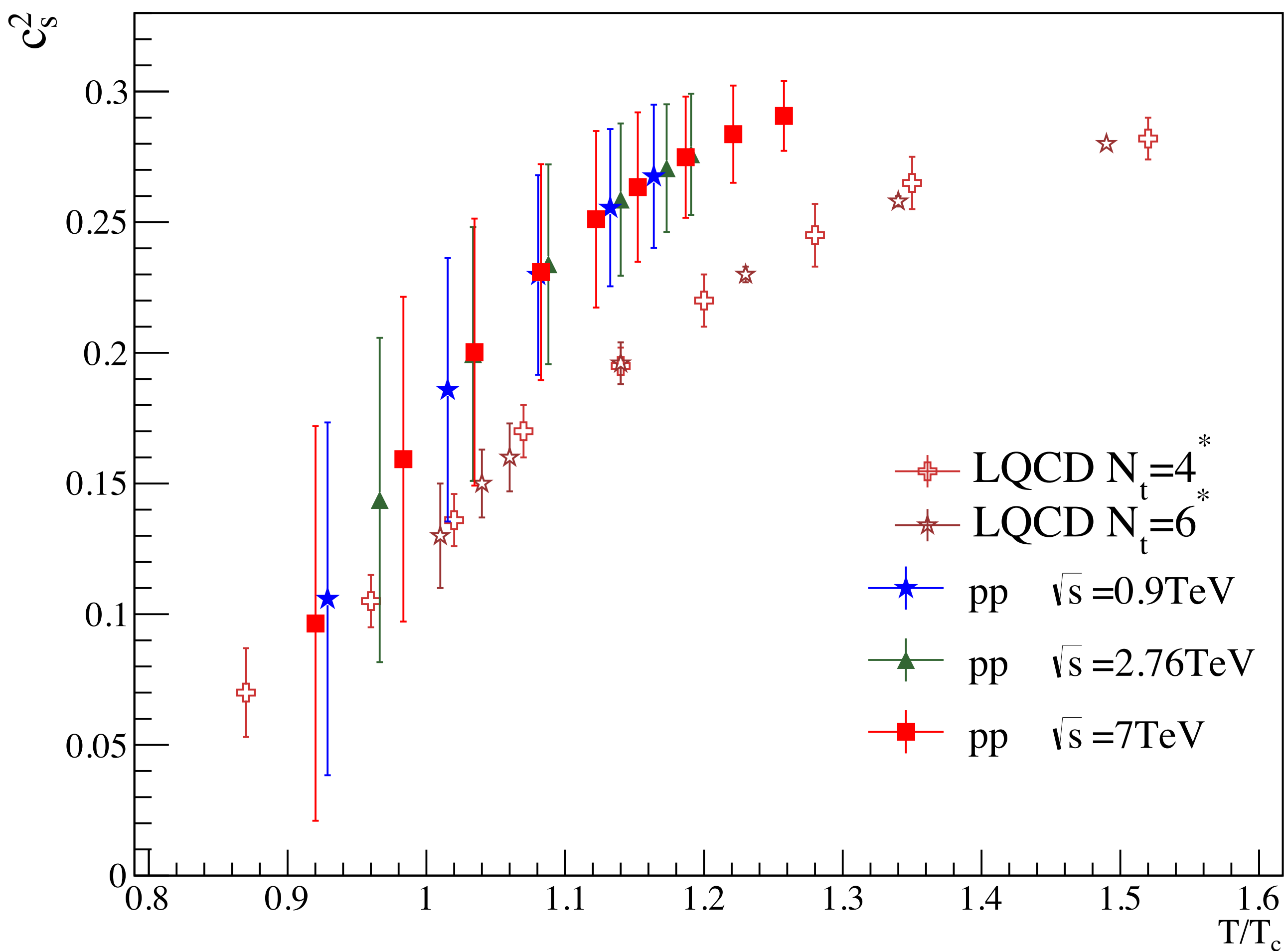
The Bjorken 1D expansion gives the sound velocity in terms of the model parameters,

$$c_s^2 = \left(\frac{\xi^t e^{-\xi^t}}{1 - e^{-\xi^t}} - 1 \right) \left(\frac{0.019\Delta}{3(1 - e^{-\xi^t})} - 0.33 \right) \quad (11)$$

with the assumption $\Delta = (\varepsilon - 3P)/T^4 \approx (\eta/s)^{-1}$.

* Braun, M. A. Dias de Deus, J. Hirsch, A. S. Pajares, C. Scharenberg, R. P. and Srivastava, B. K., arXiv 1501.01524 [nucl-th].

Speed of Sound



* S. Borsanyi, G. Endrodi, Z. Fodor, A.~Jakovac, S. D. Katz, S. Krieg, C. Ratti and K. K. Szabo, JHEP 1011, 077 (2010)

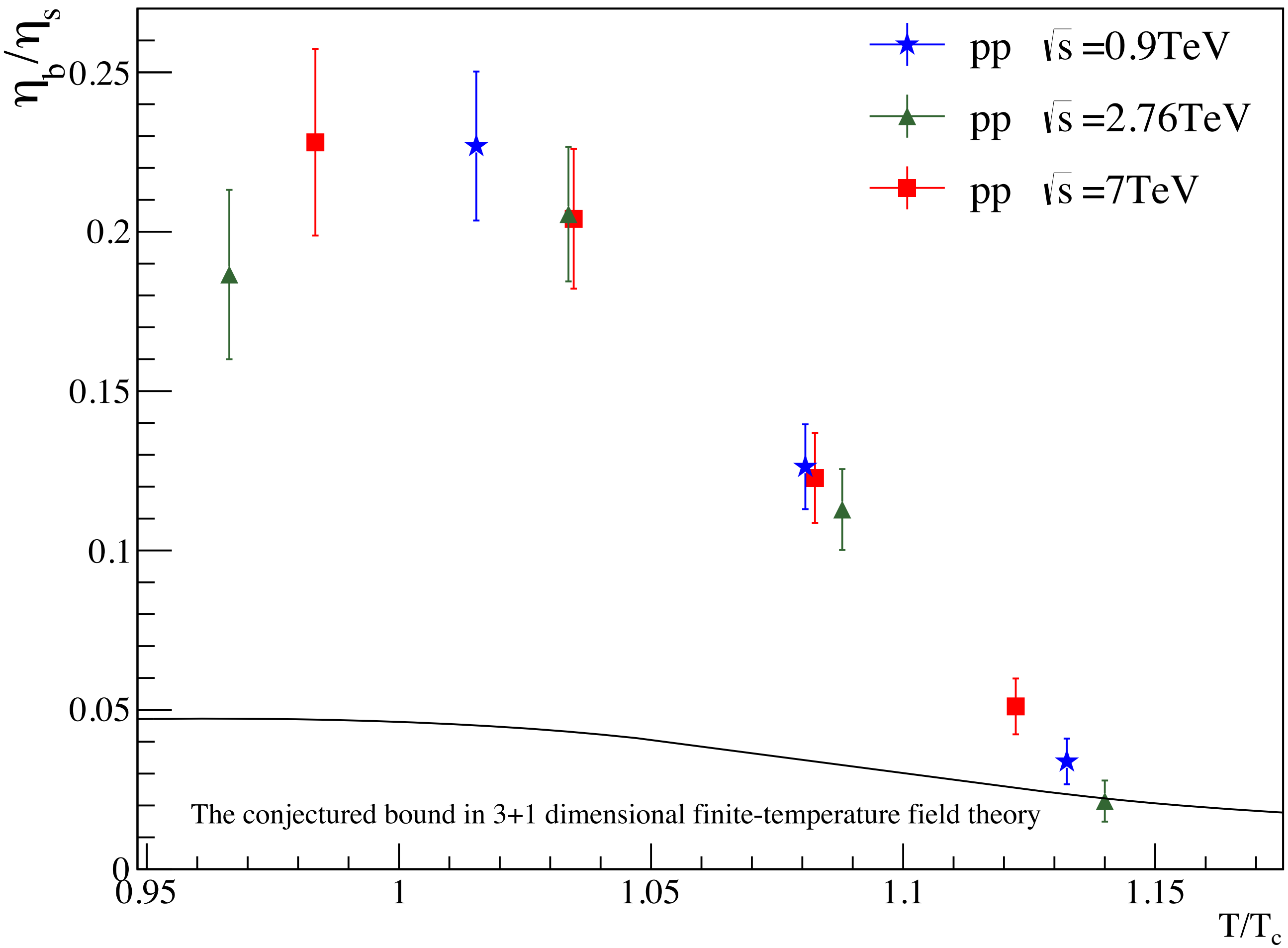
Bulk Viscosity

The bulk viscosity characterizes the internal properties of the fluid, the microscopic formula of the bulk viscosity over the corresponding relaxation time of causal dissipative relativistic fluid-dynamics are obtained at finite temperature and chemical potential by using the projection operator method

$$\frac{\eta_b}{\tau_\Pi} = \left(\frac{1}{3} - c_s^2\right)(\varepsilon + P) - \frac{2}{9}(\varepsilon - 3P). \quad (12)$$

* X. G. Huang and T. Koide, Nucl. Phys. A 889 (2012) 73

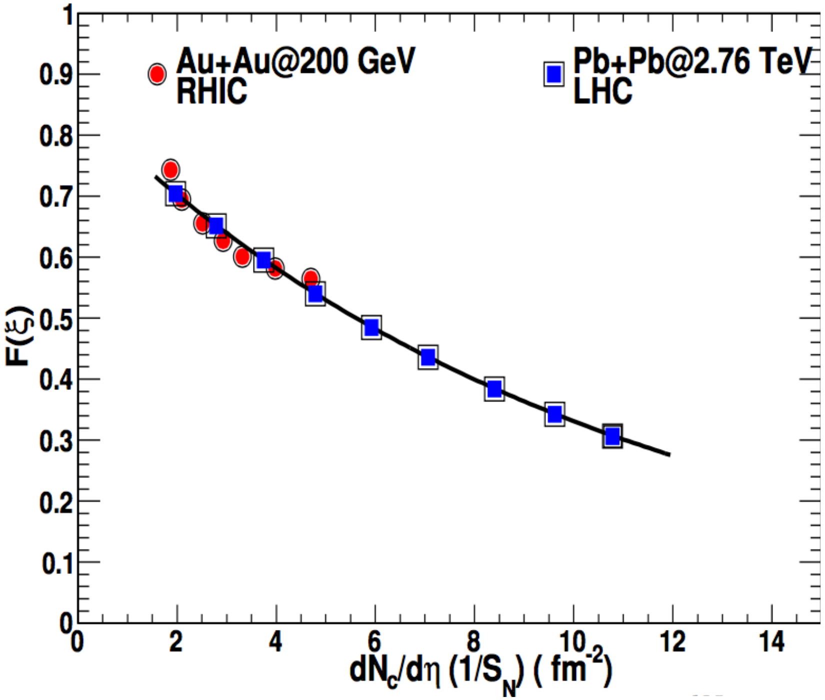
Bulk-Shear viscosity ratio

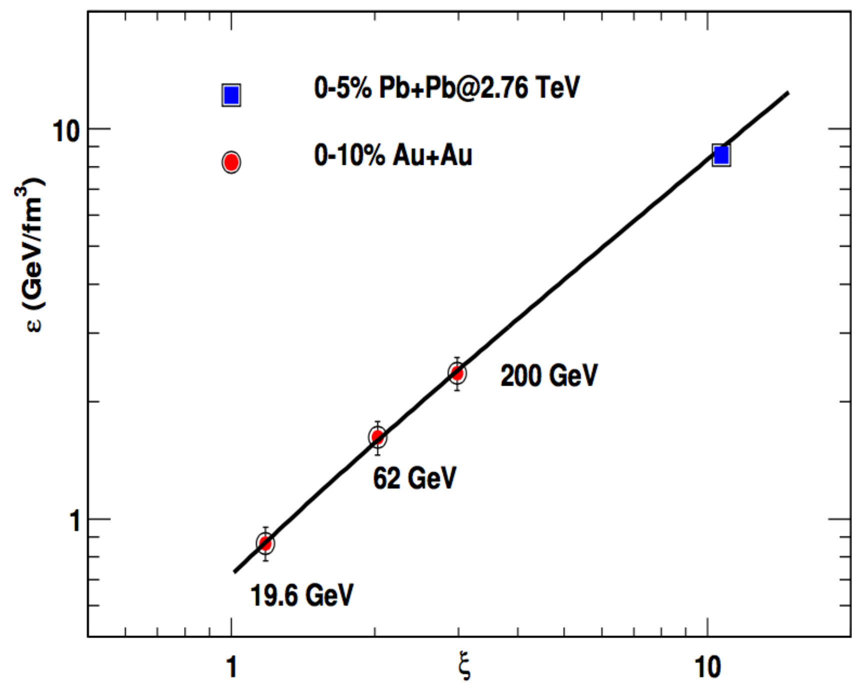


* A. Buchel, Phys. Lett. B 663 (2008) 286

Previous results show that the dependence of the color reduction factor and the multiplicity per transverse area unit is exponential.

And energy density is proportional to the string density parameter.





* Braun, M. A. Dias de Deus, J. Hirsch, A. S. Pajares, C. Scharenberg, R. P. and Srivastava, B. K., arXiv 1501.01524 [nucl-th].

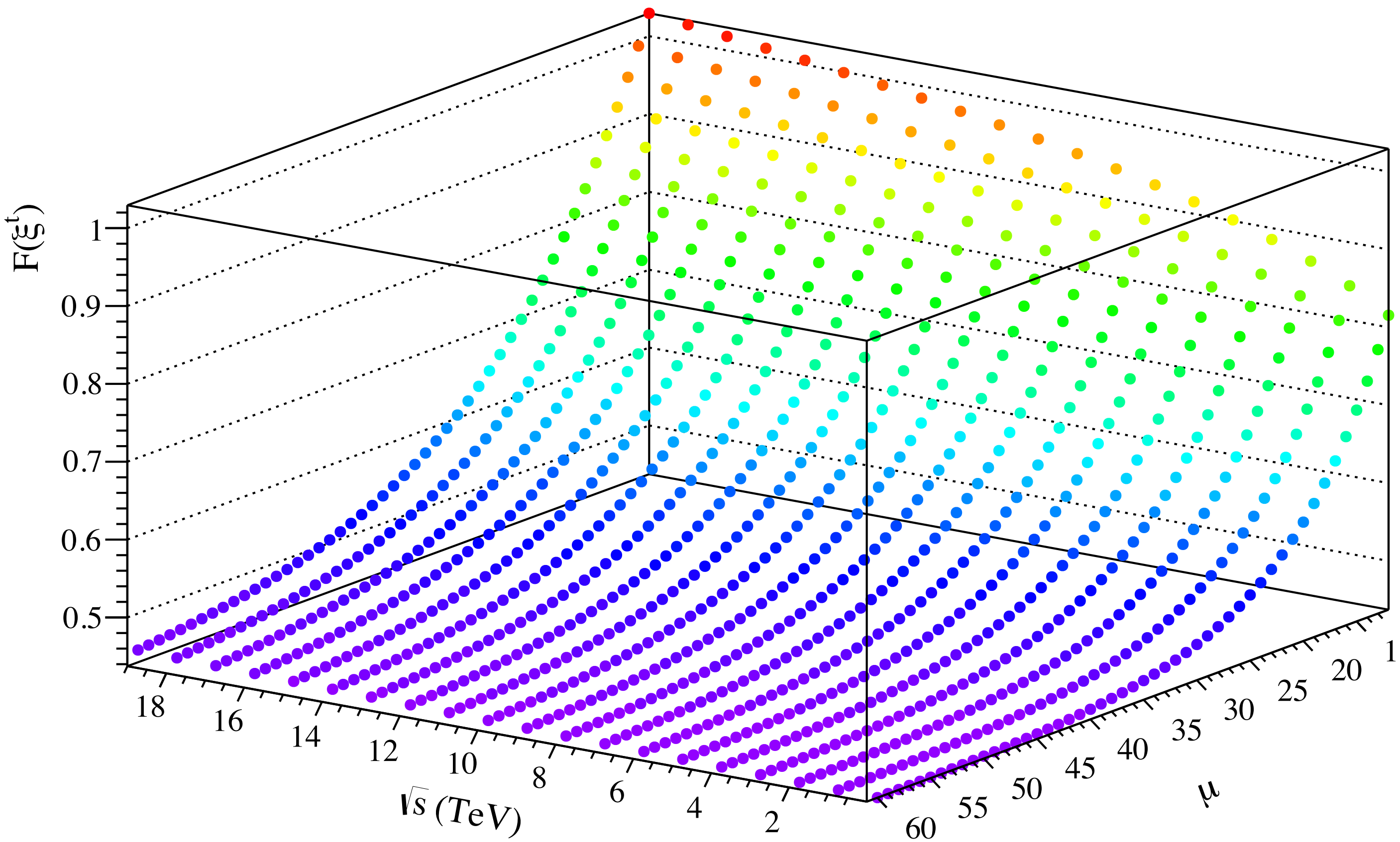
To fit data we use the scaling $1 - e^{p(\mu)}$, where $p(\mu)$ is a polynomial in multiplicity considering a limit for very high multiplicities, F_0 is the limit on saturation scale and we have a logarithmic dependence on the ratio of the energy over the threshold $\sim 1/ln(s_0/s)$ of gluon saturation

$$F(\xi^t) = F_0 + \frac{1 - \exp\left[\left(\frac{\mu(\xi^t)}{\mu_0} + a_1\right)^{\frac{\sqrt{s}}{\sqrt{s_0}}}\right]}{a_0 \ln\left(\frac{\sqrt{s_0}}{\sqrt{s}}\right)}. \quad (13)$$

* R. Conceicao, J. Dias de Deus and M. Pimenta, Nucl. Phys. A 888 (2012) 58

	Value	Error
F_0	0.435241	0.0503243
$\sqrt{s_0}(10^3\ \mathrm{TeV})$	1.40030	1.49161

	Value	Error
μ_0	54.468	16.2556
a_1	0.00258187	0.00470024
a_0	0.119777262	0.026209073



Conclusions

- There is a global saturation scale for all systems as the multiplicity grows.
- The gluon saturation scale appears at higher energy and multiplicity.
- There is a limit of minimum multiplicity for the formation of clusters.

Thanks a lot!

Percolation

- Percōlāre: "to filter" or "trickle through". Refers to the movement and filtering of fluids through porous materials.