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Hadron production at RHIC energies towards polarization studies using Therminator.

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Abstract

In this talk we report on a calculation for particle hadronization after heavy ion collisions using both the Siemens-Rassmusen and the Schnederman-Sollfrank-Heinz freeze-out models. We compare the transverse momentum spectra of pions and protons using these models with RHIC data. Furthermore, we use Therminator generator to simulate Au+Au collisions at 200 GeV, and also we compare with RHIC data. We highlight the different freeze-out models and lay the road ahead for future polarization studies using Therminator.

Therminator

Therminator (THERMal heavy-IoN generATOR) is a Monte Carlo event-generating program designed for the study of particle production in heavy ion collisions. The program implements thermal models of particle production with single freeze-out:

- Cracow single freeze-out
- Blast wave model

Therminator is controlled by the following parameters

- **NumberOfEvents**
- **Randomize**
- **InputDirShare**
- **EventOutputFile**
- **FreezeOutModel**
- **BWVt**
- **Tau, RhoMax**
- **Temperature, MiuI, MiuS, MiusB**
- **AlphaRange, RapidityRange**
- **NumberOfIntegrateSamples**

A run in `Therminator` for Au+Au ions at $\sqrt{s_{NN}} = 200$ Gev with the following parameters:

NumberOfEvents	2000
Randomize	1
FreezeOutModel	SingleFreezeOut
Tau	9.74 fm
RohMax	7.74 fm
Temperature	0.1656 GeV
MiuI	-0.0009 GeV
MiuS	0.0069 Gev
MiuB	0.0285 Gev
AlphaRange	8.0
RapidityRange	4.0

Table: Parameters for the `Therminator` simulation for Au+Au at $\sqrt{s_{NN}}$ GeV

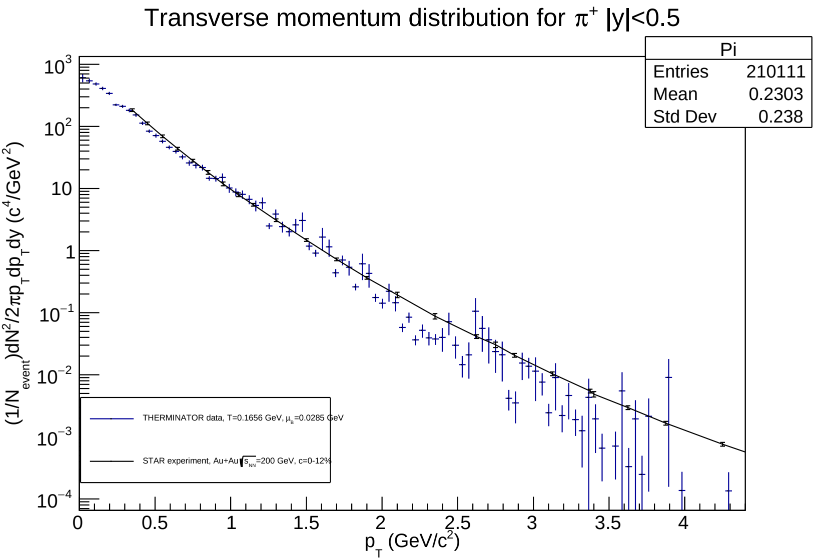

Figure: Comparison of the transverse momentum distribution at $|y| < 0.5$ for the π^+ obtained in Therminator with parameters showed in 1 for the Cracow single freeze-out model with 1000 events with the data reported (Phys. Rev. Lett. 97, 152301).

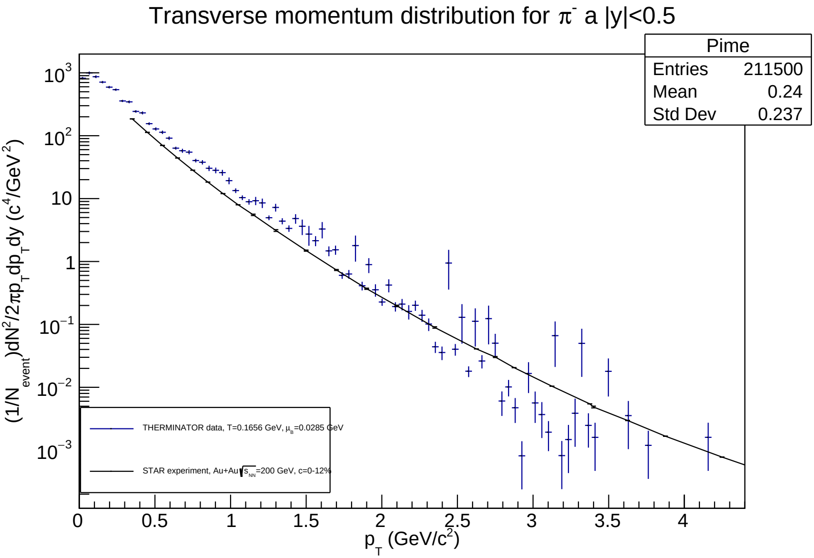

Figure: Comparison of the transverse momentum distribution at $|y| < 0.5$ for the π^- obtained in Therminator with parameters showed in 1 for the Cracow single freeze-out model with 1000 events with the data reported (Phys. Rev. Lett. 97, 152301).

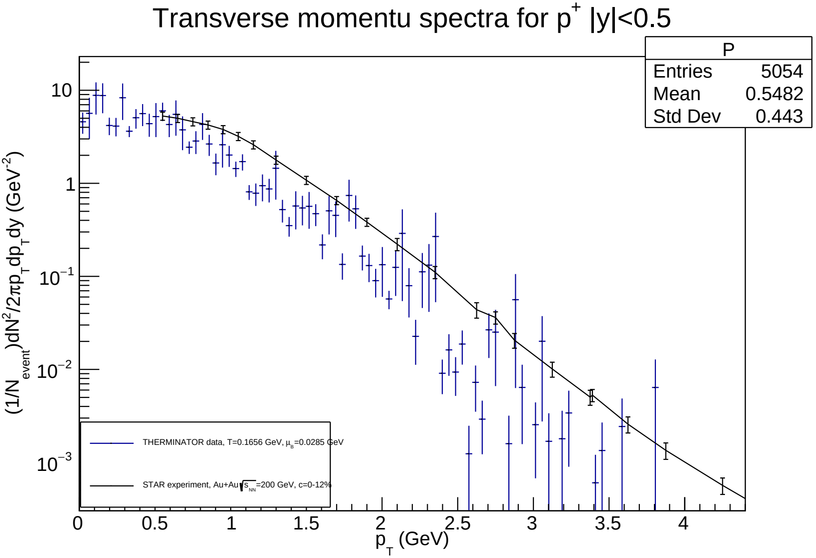

Figure: Comparison of the transverse momentum distribution at $|y| < 0.5$ for p obtained in Therminator with parameters showed in 1 for the Cracow single freeze-out model with 1000 events with data reported (Phys. Rev. Lett. 97, 152301).

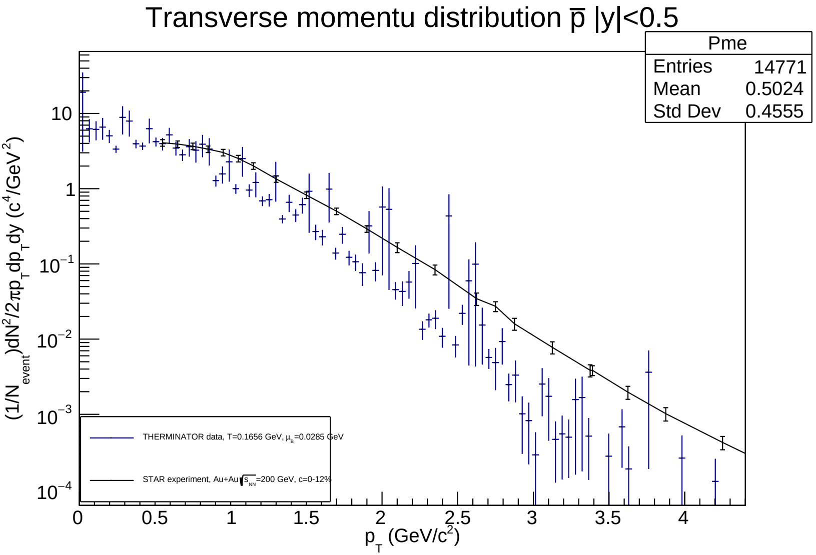

Figure: Comparison of the transverse momentum distribution at $|y| < 0.5$ for $\bar{p}$ obtained in Therminator with parameters showed in 1 for the Cracow single freeze-out model with 1000 events with data reported (Phys. Rev. Lett. 97, 152301).

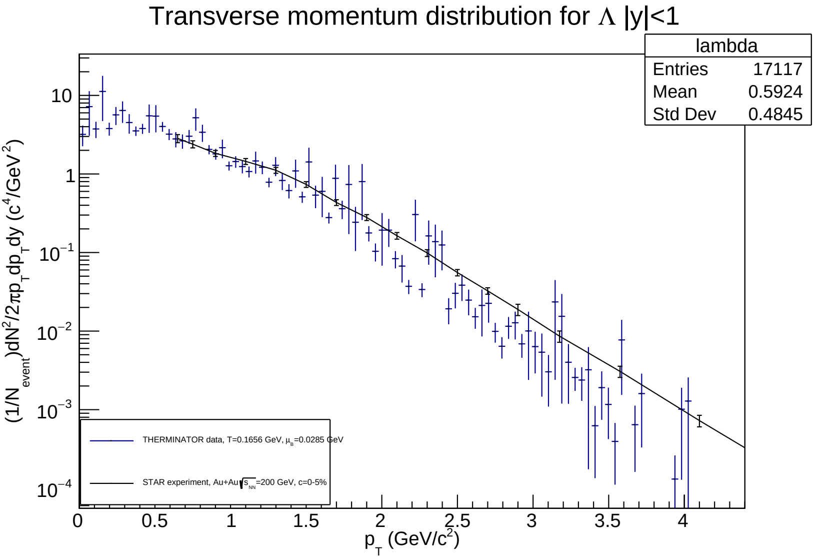

Figure: Comparison of the transverse moment distribution at $|y| < 1$ for Λ obtained in `Therminator` with parameters showed in 1 for the Cracow single freeze-out model with 1000 events with the data reported (Phys. Rev. Lett. 98, 062301)

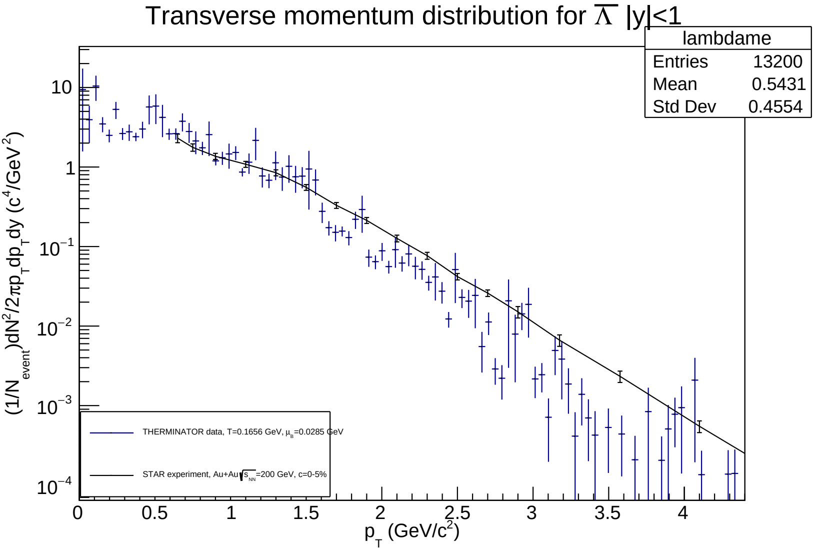

Figure: Comparison of the transverse moment distribution at $|y| < 1$ for $\bar{\Lambda}$ obtained in `Therminator` with parameters showed in 1 for the Cracow single freeze-out model with 1000 events with the data reported (Phys. Rev. Lett. 98, 062301)

The main goal of this work is to implement a polarization mechanism in `therminator`. In order to achieve it , the first step is studying freeze-out conditions used in the program. In this way, the freeze-out conditions that will be discussed are

- Siemens-Rassmusen model
- Schnedermann-Sollfrank-Heinz model

Freeze-Out model

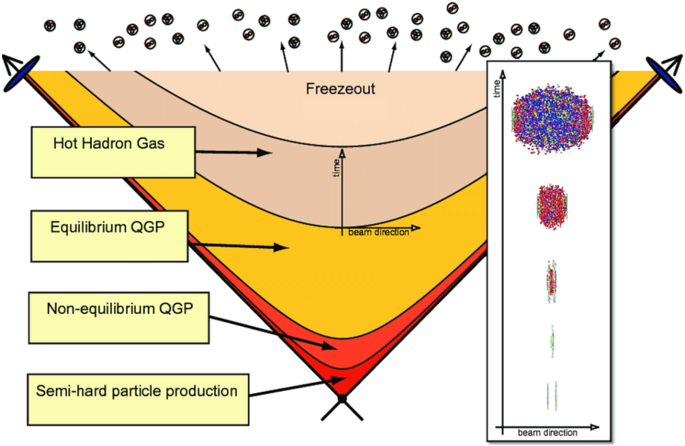

Figure: cartoon depicting the space-time history of the QGP asgenerated in a heavy ion collision at LHC energies. The overlay on the right showsthe lab-frame evolution (Acta Physica Polonica B, vol. 45, no. 12, p. 2355, 2014)

Cooper-Frye formalism

For an energy $E = \sqrt{m^2 + p^2}$, Cooper-Frye formula give us the particle distribution through an freeze-out hypersurface, that we call $d\Sigma_\mu$.

$$E\frac{dN}{d^3p} = \int d\Sigma_\mu p^\mu f(x,p) \tag{1}$$

With p^μ the four-moment and $f(x,p)$ the probability distribution. The hypersurface differential is

$$d\Sigma_\mu = \varepsilon_{\mu\alpha\beta\gamma}\frac{dx}{d\alpha}\frac{dx}{d\beta}\frac{dx}{d\gamma}d\alpha d\beta d\gamma \tag{2}$$

Where $\varepsilon_{\mu\alpha\beta\gamma}$ is the four rank Levi-Civita tensor and α,β,γ are the parameters which define the hypersurface.

Calculations for Siemens-Rassmusen model

An usual parametrization for spherical hypersurfaces is

$$x^\mu = (t(\zeta), r(\zeta)\cos\phi\sin\theta, r(\zeta)\sin\theta\sin\phi, r(\zeta)\cos\theta) \qquad (3)$$

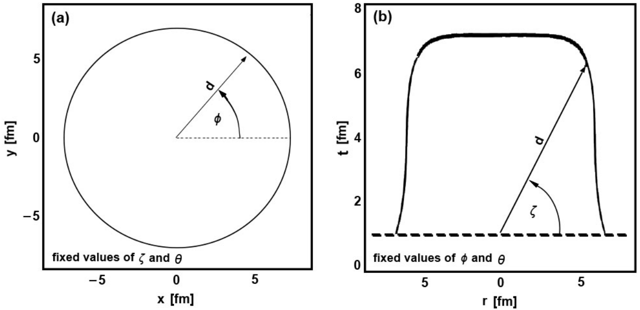

Figure: Parameterization of the freeze-out hypersurface. Part (a) shows the view in the x-y plane with a fixed value of ζ. Part (b) represents the view in the τ-r plane with a fixed value of ϕ (Phenomenology of ultra-relativistic heavy-ion collisions, World Scientific Publishing Company).

Assuming that the freeze-out curve in the t-r plane satisfies

$$dt = vdr, \quad t = t_0 + vt \tag{4}$$

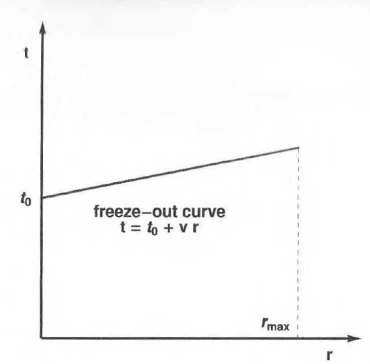

Figure: The time-like freeze-out curve assumed in the Siemens Rasmussen model represented by the solid line (Phenomenology of ultra-relativistic heavy-ion collisions, World Scientific Publishing Company).

With these two equations and assuming a Boltzmann distribution, is possible to write

$$E\frac{\mathrm{dN}}{d^3P} = \frac{e^{-(\gamma E-\mu)/T}}{2\pi^2}[E\frac{\sinh(a)}{a} + T\frac{(\sinh a - a\cosh a)}{a\gamma}]$$

$$\times \int_0^1 r' r^2(\zeta)d\zeta \tag{5}$$

Just is need to solve

$$\int_0^1 r' r^2(\zeta)d\zeta = \int_0^{r_{max}} r^2 dr = \frac{r_{max}^3}{3} \tag{6}$$

where a is an adimensional parameter defined as $a = \frac{\gamma vp}{T}$ and r_{max} denotes the maximum radio of the system, which can be associated to the volume

$$V = \frac{4}{3}\pi r_{max}^3 \tag{7}$$

Calculations for Schnederman-Sollfrank-Heinz model

The Schnederman-Sollfrank-Heinz model takes a boost invariant cylindrical hypersurface. Such hypersurface is defined with these three parameters: the azimuthal angle ϕ, the spacetime rapidity $\eta_{\|}$ and the ζ parameter which defines the curve $\tau - \rho$.

$$x^{\mu} = (\tau(\zeta) \cosh \eta_{\|}, \rho(\zeta) \cos \phi, \rho(\zeta) \sin \phi, \tau(\zeta) \sinh \eta_{\|}) \qquad (8)$$

Then

$$d\Sigma^{\mu} = (\rho' \cosh \eta_{\|}, \tau' \cos \phi, \tau' \sin \phi, \rho' \sinh \eta_{\|}) \qquad (9)$$

As before, the prime denotes the derivative respect to ζ.

In analogy to the Siemens-Rassmusen model, the $\tau - \rho$ plane curve is assumed constant

$$\tau(\zeta) = \tau_f = constant \tag{10}$$

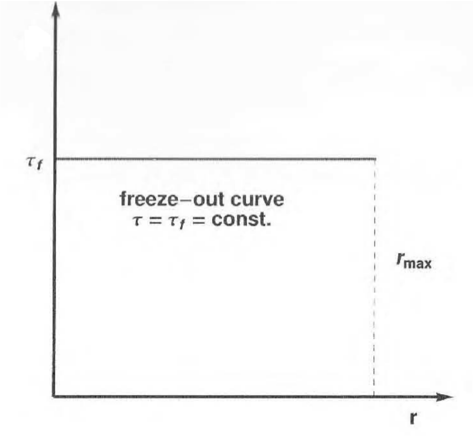

Figure: The freeze-out curve assumed in this model (Phenomenology of ultra-relativistic heavy-ion collisions, World Scientific Publishing Company)

Also, assuming a Boltzmann distribution Then equation (1) becomes

$$\frac{dN}{dyd^2p_\perp} = \frac{e^{\mu/T}}{4\pi^2}\tau_f \rho^2_{max} m_\perp K_1[\frac{m_\perp}{T\sqrt{1-v_\perp^2}}]I_0[\frac{p_\perp v_\perp}{T\sqrt{1-v_\perp^2}}] \quad (11)$$

Where K_0 and I_1 are the modified Bessel function of first and second kind and $v_\perp$ is the transverse velocity.

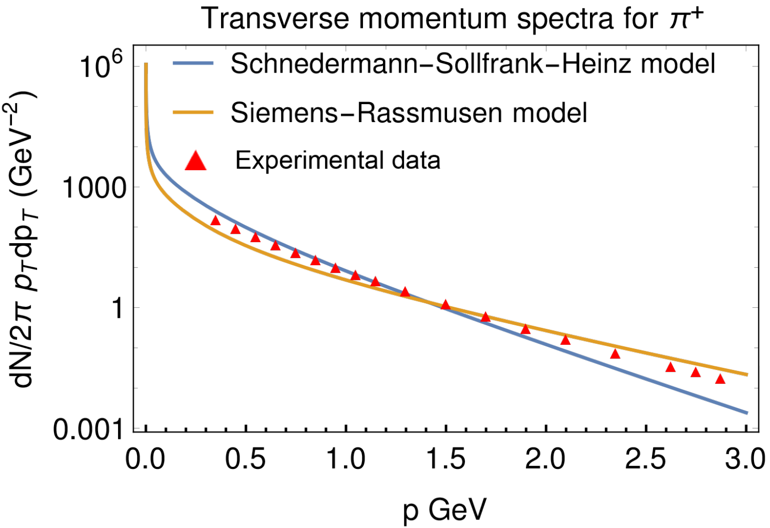

Figure: Comparison of the transverse momentum spectra for π^+ between Siemens-Rassmusen spherical model and Schnedermann-Sollfrank-Heinz cylindrical model using the parameters showed in table 1 with STAR data (Phys. Rev. Lett. 97, 152301).

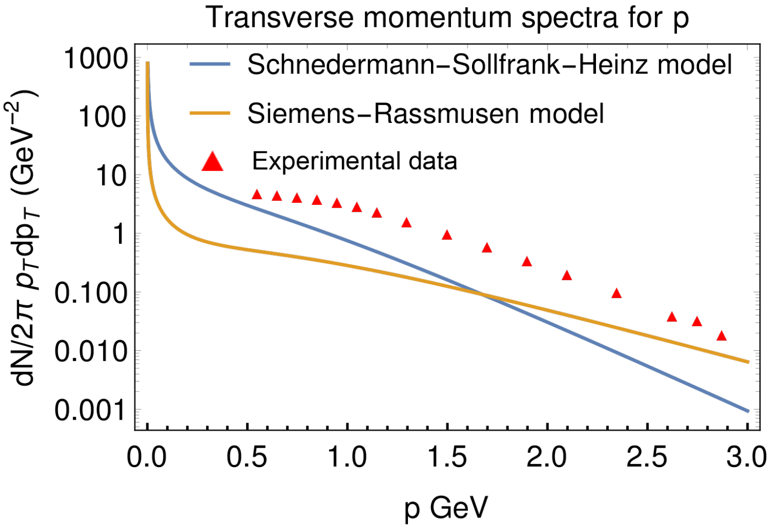

Figure: Comparison of the transverse momentum spectra for p between Siemens-Rassmusen spherical model and Schnedermann-Sollfrank-Heinz cylindrical model using the parameters showed in table 1 with STAR data (Phys. Rev. Lett. 97, 152301).

Conclusions

Several freeze-out parameterizations have been discussed. Schnedermann-Sollfrank-Heinz model showed a boost invariance, what makes it a good model to describe the hadronization after heavy-ions collisions. For studying these models, `Therminator` is a good tool capable to realize calculations for transverse momentum distribution.

Future work

- Studying polarization mechanism in heavy-ion collisions
- Include a polarization term in the freeze-out models
- Modify `Therminator` for including this polarization therm