Blast-Wave Analysis of Charged Hadron Spectra in Bi+Bi Collisions at $\sqrt{s_{NN}} = 9.2$ GeV

SPbPU Working Group

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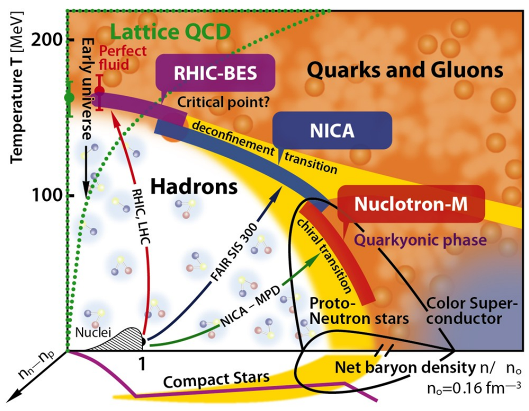
Introduction

Exploring the critical point and phase boundary in the QCD phase diagram is a key goal in experimental and theoretical nuclear physics.

To identify potential signatures, it is essential to determine the accessible (T, μ_B) region.

Particle spectra analysis based on Blast-Wave model allows estimate T and μ_B values at freeze-out.



Introduction

1. The charged hadron ($\pi^{\pm}$, $K^{\pm}$, p, $\bar{p}$) invariant spectra have been obtained in different centrality classes of Bi+Bi collisions at $\sqrt{s_{NN}} = 9.2$ GeV using the NucleiWagon by V. Kireyeu.
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2. These charged hadron spectra have been studied using the Blast-Wave model.
3. The $\bar{p}/p$ ratio was calculated in order to obtain value of baryon chemical potential.
4. Results are presented in the Phase Diagram.

Blast-Wave Model

The Blast-Wave model describes a boosted thermal source based on relativistic hydrodynamics

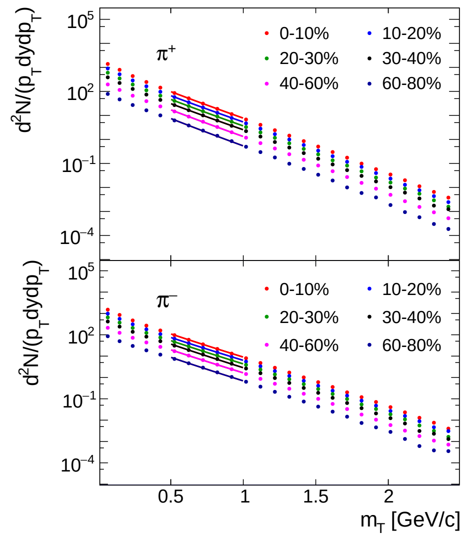
$$\frac{dN}{m_T dm_T} = C \int_0^R r dr \cdot m_T \cdot I_0 \left(\frac{p_T \sinh \rho}{T_0} \right) K_1 \left(\frac{p_T \cosh \rho}{T_0} \right)$$

- $m_T = \sqrt{p_T^2 + m_0^2}$
- β_T - radial flow velocity
- T_0 - freeze-out temperature
- R - maximum radius of the expanding source at freeze-out
- ρ - transverse boost depending on the radial position: $\rho(r) = \tanh^{-1}(\beta_T) \cdot \frac{r}{R}$
- I_0 and K_1 - modified Bessel functions

C, T_0, β_T - approximation parameters.

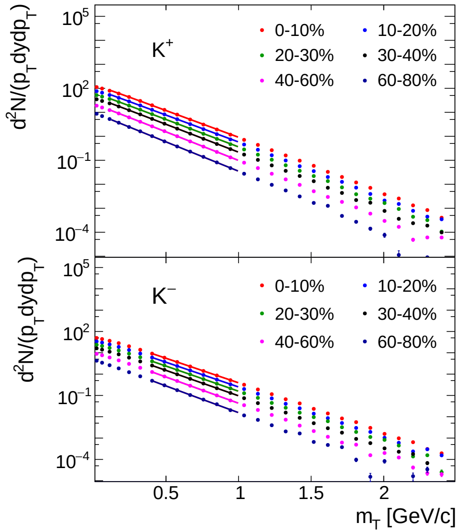
The $\pi^\pm$ invariant m_T spectra

centrality	T_0[MeV]	β_T
	π^+	
0-10%	121	0.57
10-20%	125	0.56
20-30%	120	0.58
30-40%	123	0.58
40-60%	117	0.60
60-80%	113	0.61
	π^-	
0-10%	120	0.59
10-20%	123	0.59
20-30%	119	0.60
30-40%	117	0.60
40-60%	121	0.61
60-80%	118	0.61



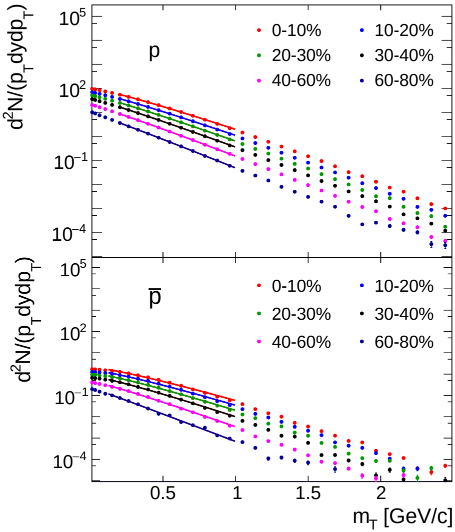
The $K^{\pm}$ invariant m_T spectra

centrality	T_0[MeV]	β_T
	K^+	
0-10%	101	0.61
10-20%	103	0.6
20-30%	99	0.6
30-40%	99	0.59
40-60%	97	0.59
60-80%	101	0.55
	K^-	
0-10%	101	0.59
10-20%	99	0.6
20-30%	95	0.6
30-40%	100	0.57
40-60%	99	0.56
60-80%	110	0.49



The p and $\bar{p}$ invariant m_T spectra

centrality	T_0[MeV]	β_T
	p	
0-10%	105	0.6
10-20%	108	0.57
20-30%	108	0.55
30-40%	111	0.52
40-60%	106	0.51
60-80%	109	0.47
	$\bar{p}$	
0-10%	101	0.63
10-20%	100	0.62
20-30%	99	0.6
30-40%	97	0.58
40-60%	100	0.53
60-80%	110	0.41



Fit details

Fitting ranges:

	π^+	π^-	K^+	K^-	p	$\bar{p}$
m_{Tmin}	0.5	0.5	0.12	0.4	0.2	0.12
m_{Tmax}	1.0	1.0	1.0	1.0	1.0	1.0

The Blast-Wave approximation uses an integral function and may exhibit instability. The fitting ranges were chosen arbitrarily to achieve optimal fitting results.

A common approach to evaluating the goodness of fit is by estimating χ^2/Ndf. However, it was found that the values of χ^2/Ndf range from approximately 5 in peripheral collisions to around 1000 in central collisions, indicating an underestimation of uncertainties.

Therefore, we evaluated the average differences between the fit function and simulation values, revealing that they do not exceed 1%.

Systematic uncertainties

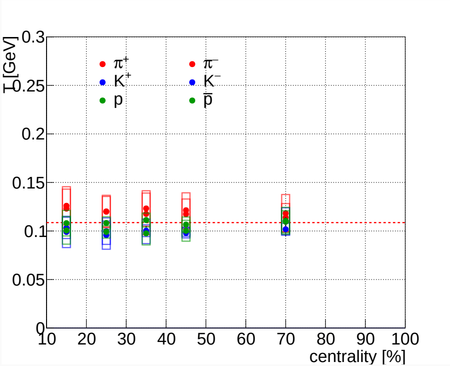
The fit parameters (C, T_0, β_T) are sensitive to the fit range, parameter limits, and initial values. These variations were taken into account by calculation of systematic uncertainties.

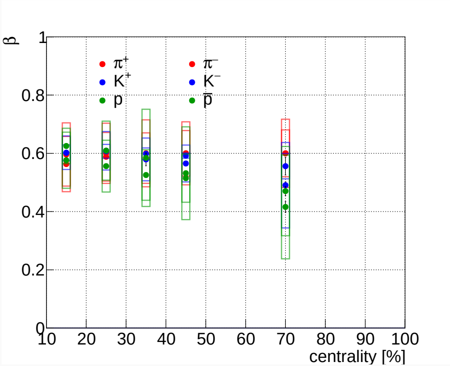
Systematic uncertainties were determined as the percentage difference between the final parameter values and those obtained under varied fit conditions.

To evaluate these uncertainties, we adjusted the fit conditions as follows:

- Fit ranges were varied by 10%.
- Initial parameter values were varied by 10%.
- Parameter limits were varied by 10%.

Blast-Wave Approximation Results





$T_0 = 0.109 \pm 0.002$ GeV

Boxes represent systematic uncertainties of approximation parameters and were obtained by varying initial parameters and the approximation range.

Results for different particles agree within uncertainties.

The $\bar{p}/p$ ratio and Phase Diagram

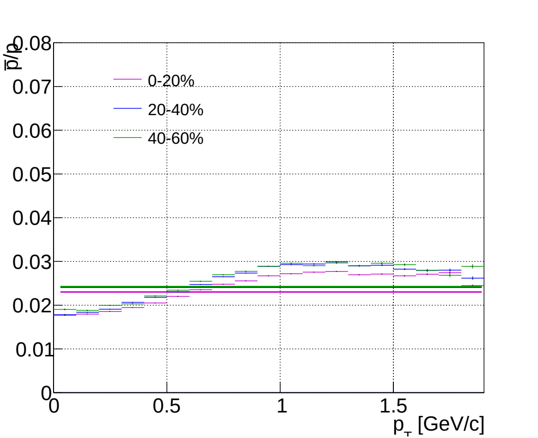
The boundary of the first-order phase transition can be described as follows:

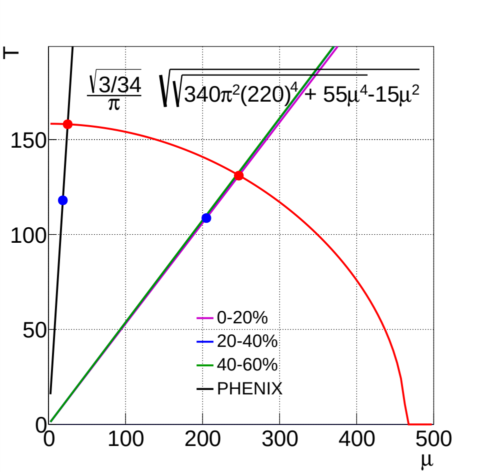
$$T_c(\mu) = \frac{1}{\pi}\sqrt{\frac{3}{34}}\sqrt{\sqrt{340\pi^2(220)^4 + 55\mu^4} - 15\mu^2}$$

The $\bar{p}/p$ ratio from the statistical model is given by:

$$\frac{\bar{p}}{p} = \exp\left(\frac{-2\mu_B}{T}\right) \Rightarrow T = \frac{-2\mu_B}{\ln\left(\frac{\bar{p}}{p}\right)}$$

The $\bar{p}/p$ ratio and Phase Diagram





MPD

Kinetic Freeze-out: $T_0 \approx 109$ MeV, $\mu_B \approx 205$ MeV

Chemical Freeze-out: $T_{ch} \approx 131$ MeV, $\mu_B \approx 247$ MeV

$$\mu_B = -1/2 \cdot T \cdot (\bar{p}/p)$$

Conclusion

- Charged hadron spectra have been studied in the frame of Blast-Wave model.
- Freeze-out temperatures (T) and radial velocities (β) have been calculated as a function of centrality.
- The value of chemical potential was calculated based on obtained values of $p/\bar{p}$ ratios.

  Kinetic Freeze-out: $T_0 \approx 109$ MeV, $\mu_B \approx 205$ MeV

  Chemical Freeze-out: $T_{ch} \approx 131$ MeV, $\mu_B \approx 247$ MeV

We want to thank V. Kireyeu for the help and detailed description of his wagon!

TO DO: Comparison Blast-Wave results with other approximation functions like Hagedorn and Levy.

Thank you for your attention!

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