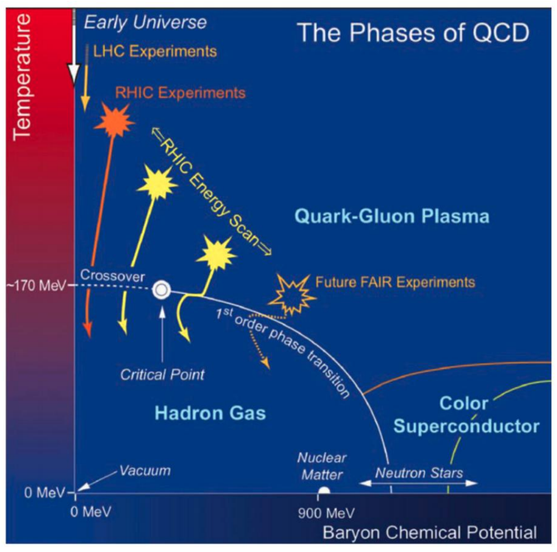
Measuring the spatio-temporal characteristics of meduim produced in heavy-ion collisions

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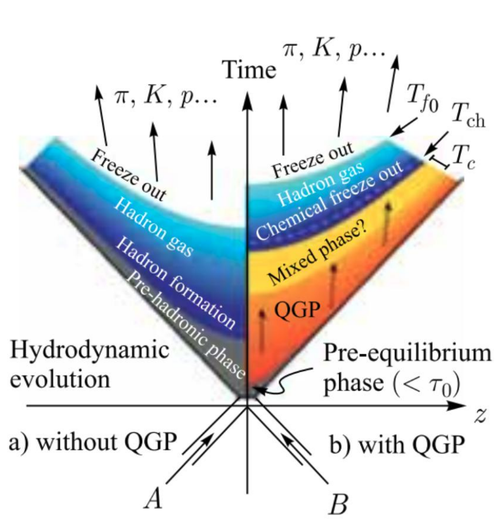
Abstract

One of the main interests of high-energy physics is the study of the phase diagram and the localization of phase transitions from hadronic to quark–gluonic matter. There are different techniques to study the hot matter. One of them is femtoscopy, which uses two-particle correlations to extract spatiotemporal characteristics of the emission source. Another approach is based on the analysis of momentum spectra of produced particles and the extraction of thermodynamic parameters. In this work, we perform a comparative analysis of the system volume obtained using the Blast-Wave model with finite size and the cylindrical freeze-out volume calculated from femtoscopic correlation radii.

Introduction

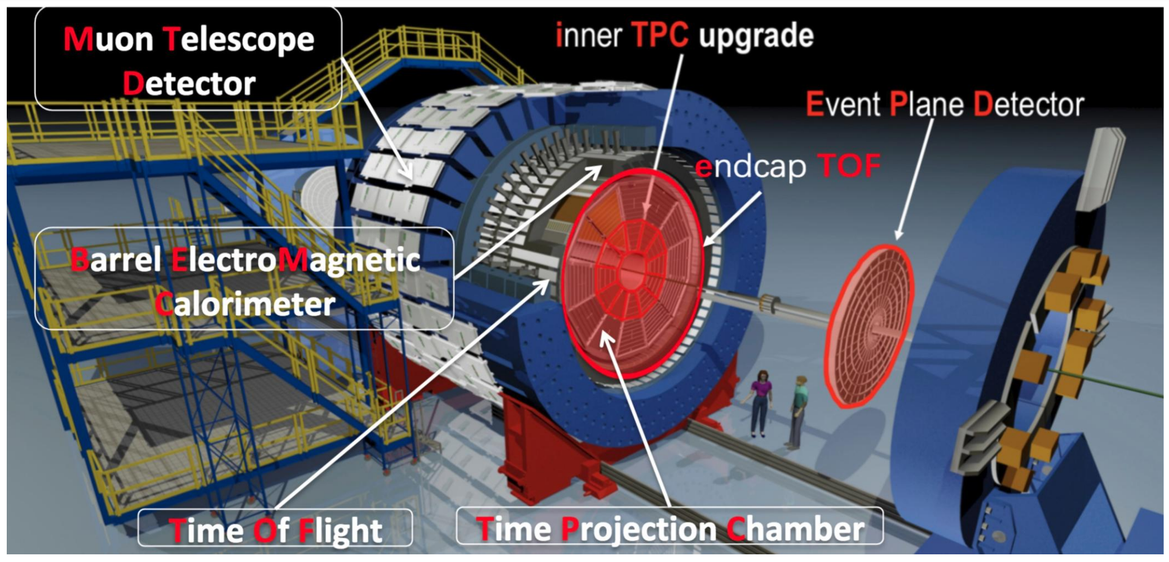


- QCD phase diagram in terms of temperature T and baryonic chemical potential μ_B
  - Crossover
  - 1 order phase transition
  - Critical point



- Stages of ultrarelativistic nuclear collision
  - Expansion
  - Formation of hot matter
  - Hadron gas
  - Final particles

The STAR experiment



- TPC (Time Projection Chamber)
  - Tracking and identification
  - Length 4.2 m, diameter 4 m
  - Azimuthal angle 2π
  - Pseudorapidity range $|\eta| < 1$
  - In a magnetic field 0.5 Tesla

Blast-Wave with finite volume

Transverse momentum distribution:

Particles are radiated from cylindrical fireball, we can calculate volume at kinetic freeze-out

$$\frac{d^2N}{dp_T dy} = \frac{g e^{\frac{\mu_0}{T_0}}}{2\pi}\, p_T m_T \frac{R}{v_{Tf}} \int_0^R r dr \int_{-\eta_{max}}^{\eta_{max}} d\eta_{\parallel}$$

$$\times \cosh(\eta_{\parallel} - y)\; e^{-\frac{m_T}{T_0}\cosh\rho(r)\cosh(\eta_{\parallel}-y)}\; I_0\left(\frac{p_T}{T_0}\sinh\rho(r)\right)$$

$$V \equiv \int d\Sigma^0 = \int_0^R r dr \int_{-\eta_{max}}^{\eta_{max}} d\eta_{\parallel} \cosh\eta_{\parallel} \int_0^{2\pi} d\phi\; \tau_f$$

$$= 2 z_{max} \pi R^2, \quad z_{max} = \tau_f \sinh\eta_{max} = \frac{R}{v_{Tf}} \sinh\eta_{max}.$$

Femtoscopic radii:

$$R^2_{\rm long} = \langle (z - \beta_L t)^2 \rangle - \langle (z - \beta_L t) \rangle^2, \; R^2_{\rm side} = \langle y^2 \rangle,$$

$$\langle \xi \rangle = \langle \xi \rangle (K) = \frac{\int d^4x\, \xi\, S(x,K)}{\int d^4x\, S(x,K)}.$$

$$S(x,K) = \frac{m_T \cosh(\eta - Y)}{(2\pi)^3}\, \delta(\tau - \tau_0) \times$$

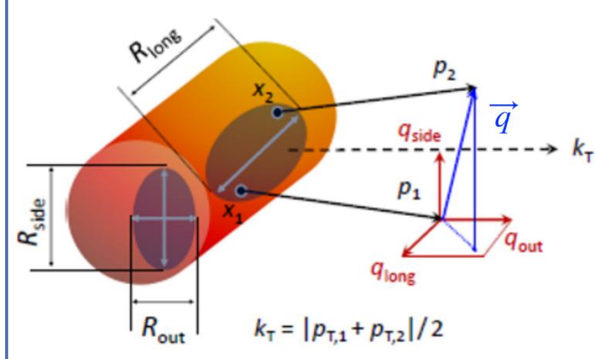
$$\exp\left[-\frac{m_T \cosh\rho(r)\cosh(\eta - Y) - K_T \sinh\rho(r)\cos(\phi - \Phi_K) - \mu}{T}\right]$$

$$\int d^4x = \int_{-\infty}^{\infty} \tau d\tau \int_0^R r\, dr \int_0^{2\pi} d\phi \int_{-\eta_{max}}^{\eta_{max}} d\eta.$$

We can compare with analytical results:

$$R_{\rm side} = \frac{R}{\sqrt{1 + \rho_0^2 (m_T/T)}} \quad R_{\rm long} = \tau \sqrt{\frac{T}{m_T} \frac{K_2(m_T/T)}{K_2(m_T/T)}}$$

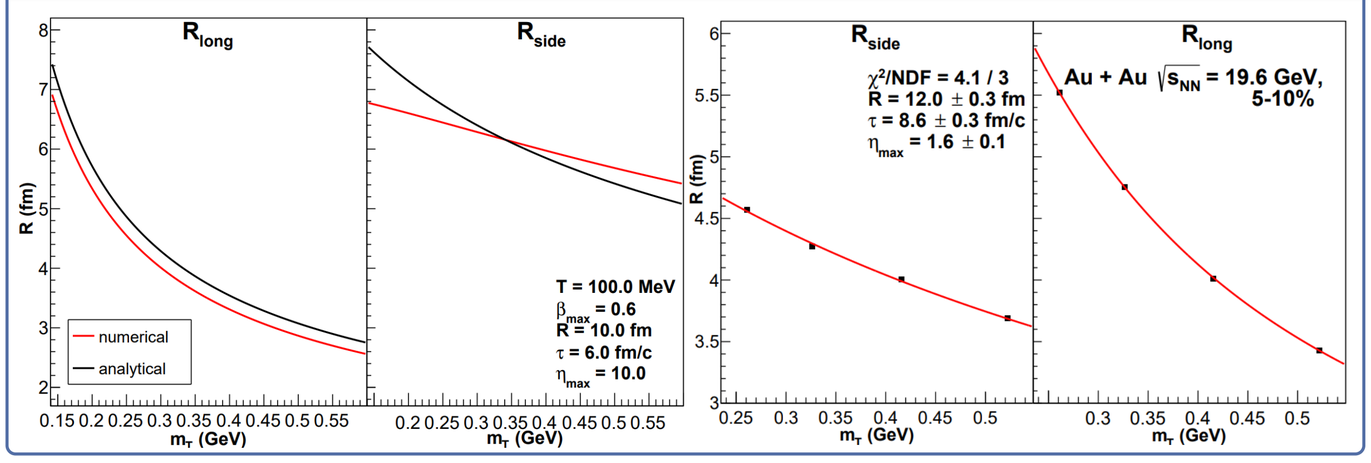
Freeze-out cylinder



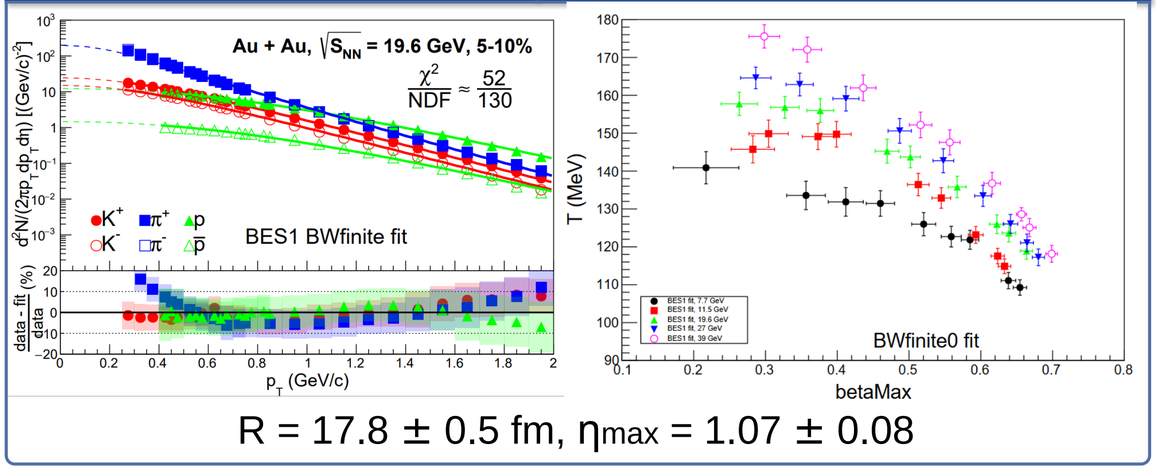
Bertsch-Pratt out-side-long coordinate system:

- $q_{\rm out}$ along k_T
- $q_{\rm long}$ along beam axis
- $q_{\rm side}$ perpendicular to other directions

Femtoscopic radii calculation



p_T fit



R = 17.8 ± 0.5 fm, η_{max} = 1.07 ± 0.08

Conclusion

We observe that femtoscopic volume is smaller, than volume, obtained from transverse momentum spectra. This can be explained by several factors:

- Femtoscopic correlations measure only the region of homogeneity, while in the statistical approach we obtain the volume of the whole system. If the collective expansion is strong, the region of homogeneity can be smaller than the entire source volume.
- The correlation function may deviate from a Gaussian shape due to exponential tails caused by resonance decay contributions. This can lead to an underestimation of the femtoscopic radii.

In the future, these results can help to combine these two different methods and provide a more comprehensive picture of the fireball.

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