π/K/p spectra in Ar+Ar, Kr+Kr and O+O collisions at SPD energies in UrQMD

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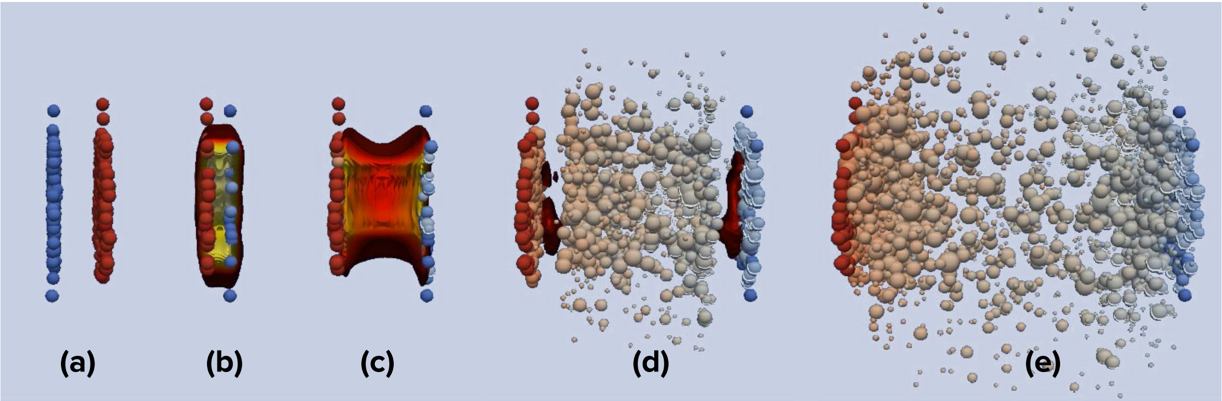
Collisions of nuclei of heavy ions in the experiment

1. The colliding nuclei fly towards each other **(a)**,
2. pass through each other, forming excited matter **(b)**.
3. The hot region expands and cools **(c)**,
4. a gas of interacting hadrons is formed **(d)**,
5. which expands, cools and disintegrates into final hadrons **(e)**

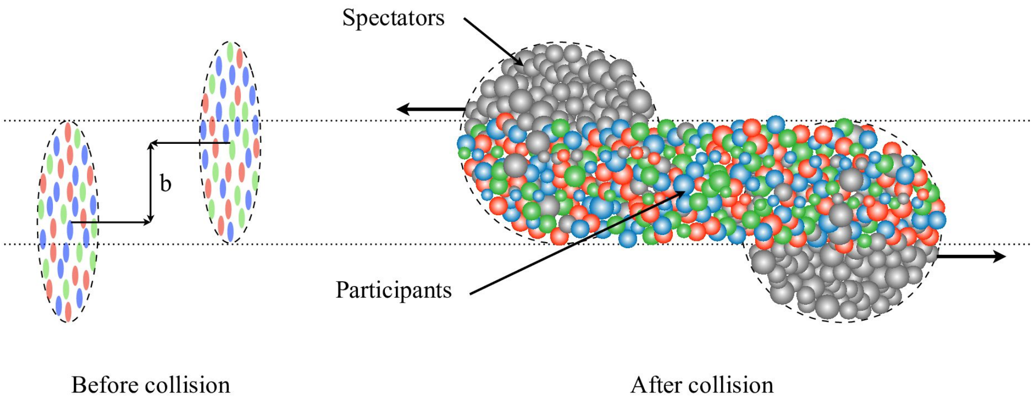


Schematic representation of a heavy ion collision.

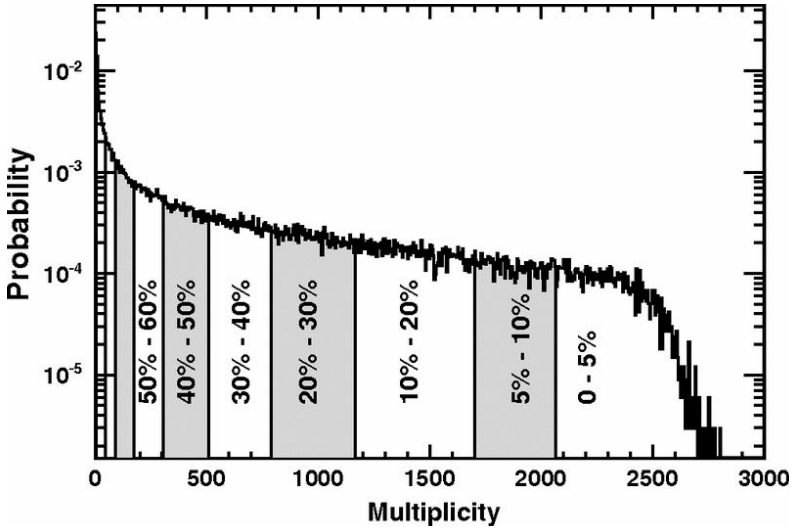
- **Chemical freeze-out** occurs at a temperature ($\mathbf{T_{ch}}$) when inelastic processes that convert one kind of hadronic species into a different one cease and the hadronic abundances stop changing.
- **Kinetic freeze-out** occurs at a temperature ($\mathbf{T_{kin}}$) when the momenta of the particles stop changing, i.e., elastic and inelastic scatterings cease

Collision centrality

- **Impact parameter b** represents a vector connecting the ion centers.
- Collision **centrality** was selected according to the fraction of integral of the impact parameter distribution.
- Central collisions correspond to the small length of b, while peripheral to the large length of impact parameter.



A schematic view of a heavy-ion collision.



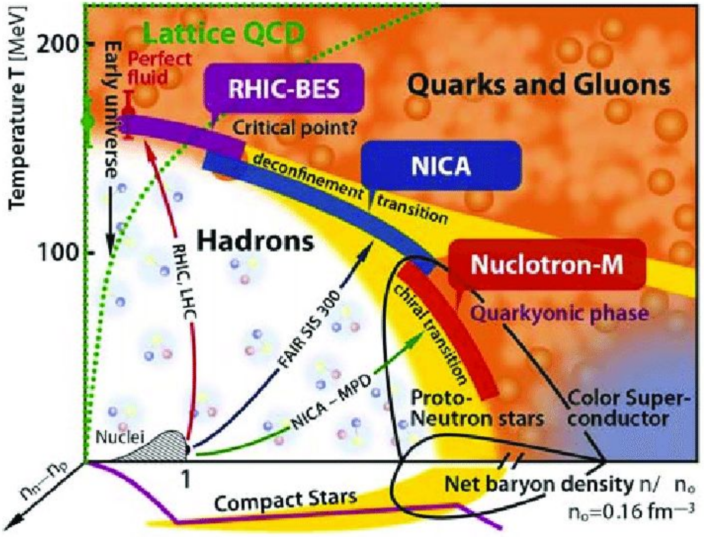
Example of multiplicity distribution of charged particles

What we want to estimate?

- Searching for the critical point and phase boundary in the QCD phase diagram is currently a focus of experimental and theoretical nuclear physics research.

- However, before looking for signatures, it is important to know the (T, µB) region of the phase diagram we can access. The spectra of produced particles allow us to infer the T and µB values at freeze-out.

- The systematic study of these bulk properties may reveal the evolution and change in behavior of the system formed in heavy-ion collisions as a function of collision energy



Blast-Wave fit of spectra

- The kinetic freeze-out parameters are obtained by fitting the spectra with a **Blast-Wave model**.
- The model assumes that the particles are locally thermalized at a kinetic freeze-out temperature (**T_{kin}**) and are moving with a common transverse collective flow velocity.
- Assuming a radially boosted thermal source, with **T_{kin}** and a transverse radial flow velocity **β**, the **p_T** distribution of the particles is given by equation:

$$\frac{dN}{p_T\,dp_T} \propto \int_0^R r\,dr\,m_T I_0\left(\frac{p_T \sinh\rho(r)}{T_{\rm kin}}\right) \times K_1\left(\frac{m_T \cosh\rho(r)}{T_{\rm kin}}\right),$$

m_T - transverse mass, **ρ (r)** = $\tanh^{-1}(\beta)$
I_0, K_1 - Bessel functions, **β** = $2 * \beta_S / (2+n)$
β_S - surface velocity, **n** - exponent of flow velocity profile
Fit parameters: T_{kin}, β

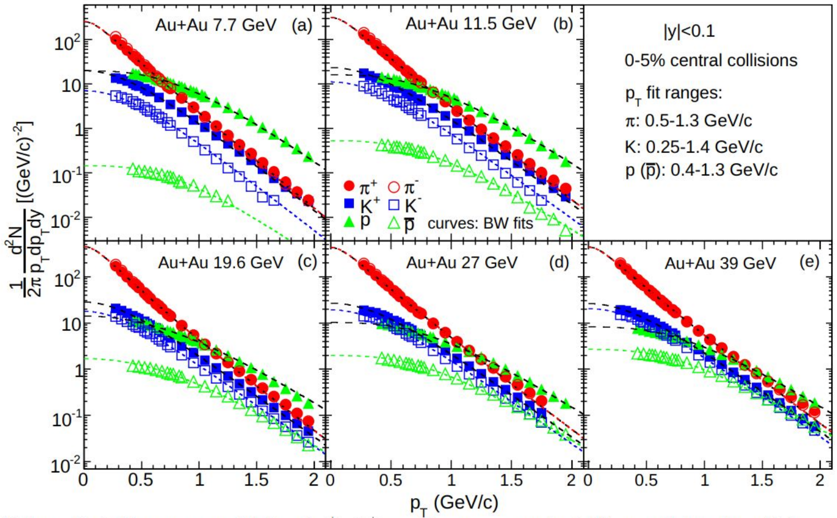


FIG. 36: (Color online) Blast wave model fits of $\pi^{\pm}$, $K^{\pm}$, p and $\bar{p}$ p_T spectra in 0–5% central Au+Au collisions at $\sqrt{s_{NN}}$ = (a) 7.7 GeV, (b) 11.5 GeV, (c) 19.6 GeV, (d) 27 GeV, and (e) 39 GeV. Uncertainties on experimental data represent statistical and systematic uncertainties added in quadrature. Here, the uncertainties are smaller than the symbol size.

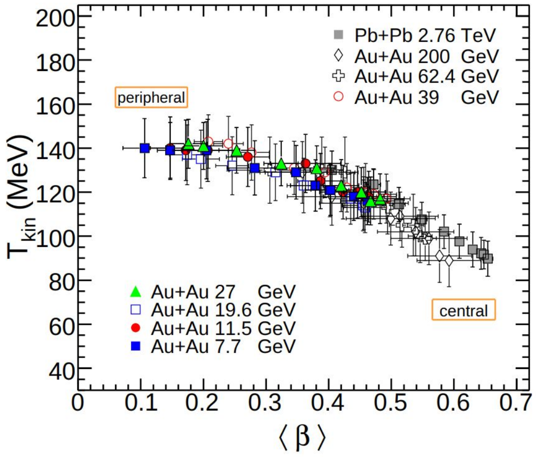


FIG. 37: (Color online) Variation of $T_{\rm kin}$ with $\langle\beta\rangle$ for different energies and centralities. The centrality increases from left to right for a given energy. The data points other than BES energies are taken from Refs. [43, 66]. Uncertainties represent systematic uncertainties.

Experimental results from: Phys. Rev. C 96, 044904 (2017)

UrQMD model

The UrQMD model is a microscopic transport approach that is based on the binary elastic and inelastic scattering of hadrons.

In our analysis it is utilized to simulate Ar+Ar, Kr+Kr, O+O collisions at $\sqrt{s_{NN}}$ = 6 and 12 GeV.

UrQMD provides a reasonable description of many observables (particle spectra and yields, flow, etc.) for hadron–hadron, hadron–nucleus and nucleus–nucleus reactions across a large range of beam energies.

The used UrQMD setup considers only elastic and inelastic scatterings and may reproduce particle multiplicities and collective motion measured by experiments

Statistics: ~2M events

Particle cuts:

- PDG ($\pi^{\pm}$ = ±211, $K^{\pm}$ = ±321, p (p-bar) = ±2212)
- $|y| < 0.1$

Centrality was calculated using multiplicity.

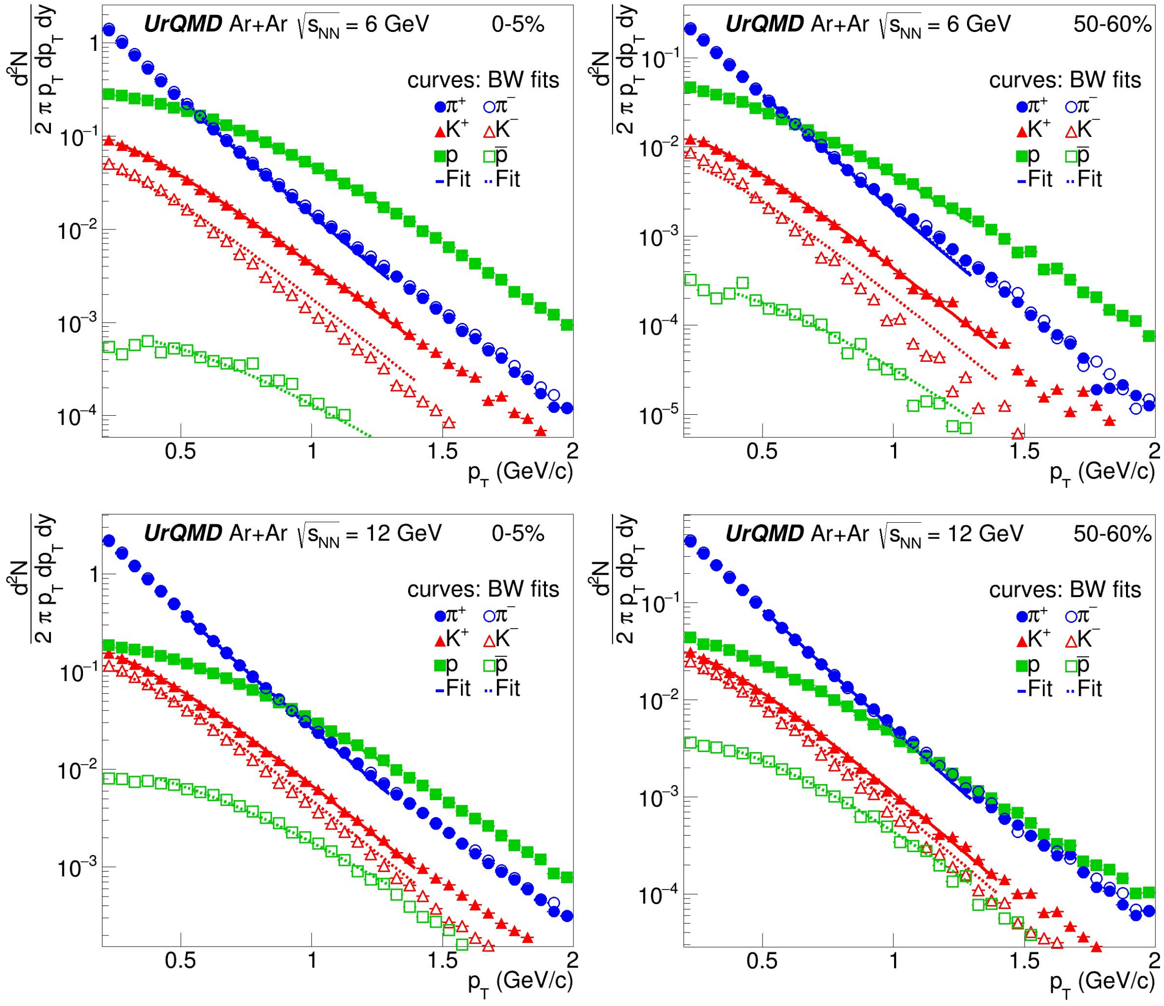
Blastwave fits of p_T spectra for Ar+Ar

Blast-Wave fits of $\pi^{\pm}$, $K^{\pm}$, p and pBar p_T spectra in 0-5% central Ar+Ar collision at $\sqrt{s_{NN}}$ = 6 and 12 GeV.

T_{kin} =

- 113 MeV at 0-5% at $\sqrt{s_{NN}}$ = 6 GeV
- 127 MeV at 50-60% at $\sqrt{s_{NN}}$ = 6 GeV

- 116 MeV at 0-5% at $\sqrt{s_{NN}}$ = 12 GeV
- 136 MeV at 50-60% at $\sqrt{s_{NN}}$ = 12 Gev



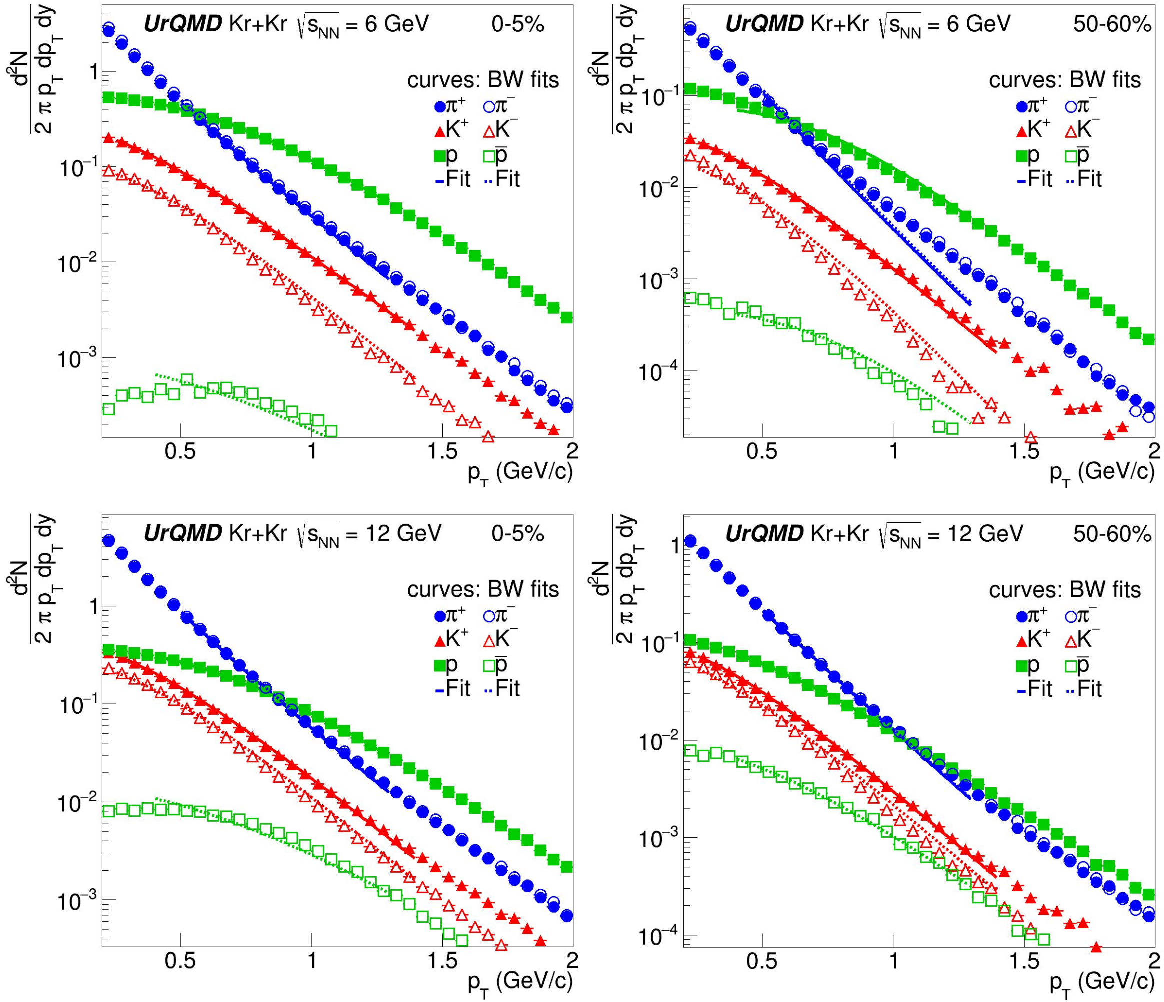
Blastwave fits of p_T spectra for Kr+Kr

Blast-Wave fits of $\pi^{\pm}$, $K^{\pm}$, p and pBar p_T spectra in 0-5% central Kr+Kr collision at $\sqrt{s_{NN}}$ = 6 and 12 GeV.

T_{kin} =

- 106 MeV at 0-5% at $\sqrt{s_{NN}}$ = 6 GeV
- 72 MeV at 50-60% at $\sqrt{s_{NN}}$ = 6 GeV

- 106 MeV at 0-5% at $\sqrt{s_{NN}}$ = 12 GeV
- 134 MeV at 50-60% at $\sqrt{s_{NN}}$ = 12 Gev



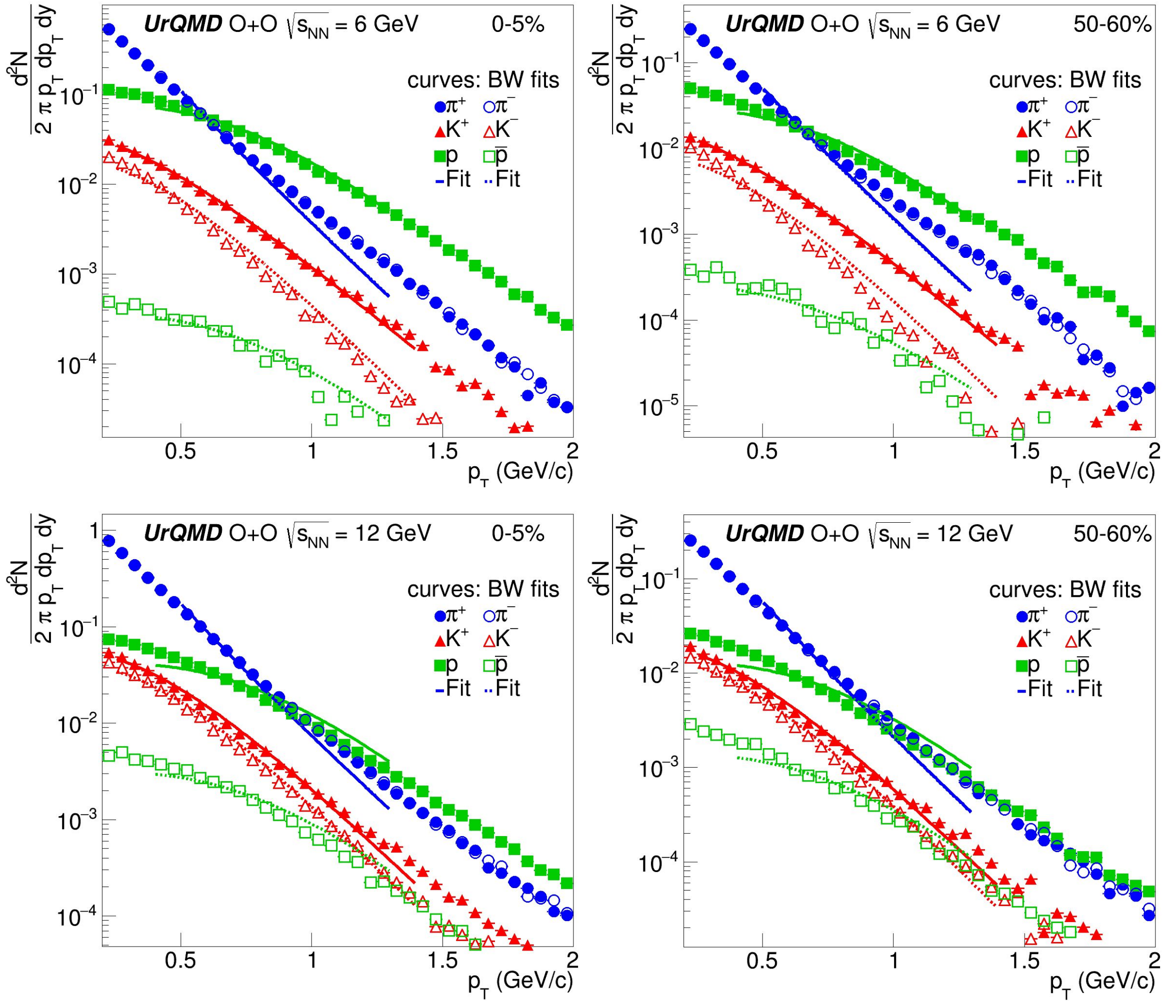
Blastwave fits of p_T spectra for O+O

Blast-Wave fits of $\pi^{\pm}$, $K^{\pm}$, p and pBar p_T spectra in 0-5% central O+O collision at $\sqrt{s_{NN}}$ = 6 and 12 GeV.

T_{kin} =

- 72 MeV at 0-5% at $\sqrt{s_{NN}}$ = 6 GeV
- 72 MeV at 50-60% at $\sqrt{s_{NN}}$ = 6 GeV

- 72 MeV at 0-5% at $\sqrt{s_{NN}}$ = 12 GeV
- 72 MeV at 50-60% at $\sqrt{s_{NN}}$ = 12 Gev



Conclusion

- Spectra for the $\pi^{\pm}$, $K^{\pm}$, p and pBar were constructed for Ar+Ar, Kr+Kr, O+O at SPD energies using UrQMD
  - The spectra were fitted using the BlastWave (BW) model
  - Extracted fit parameters T_{kin} and $\langle\beta\rangle$