Article

Excitation function of freeze-out parameters in Nucleus-Nucleus and proton-proton collisions at the same collision energy

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In case, the $\boxed{\text{hard process } (p_T < 3 \text{ GeV/c})}$ is taken into account, then the power law distribution is found to be more prominent and is given as

- Large than 3 or peripheral

$$f(p_T) = \frac{1}{N}\frac{dN}{dp_T} = Ap_T\left(1 + \frac{p_T}{p_0}\right)^{-n}, \tag{4}$$

Where A denotes the normalization constant and n and p_0 are the free parameters.

We can use the $\boxed{\text{superposition principle}}$ when the hard scattering is involved which is as

$$f(p_T) = \frac{1}{N}\frac{dN}{dp_T} = kf_S(p_T) + (1-k)f_H(p_T). \tag{5}$$

Where f_H and f_S represent soft and hard processes and k is the contribution fraction of the soft process to the hard process.

- More parameters, better fitting results, consistent phenomenological concepts
- Neither part is linear, especially the hard processes (QM ~ linear; QFT ~ non)

Fit results（Fig.1， Fig.2, Tab.1）

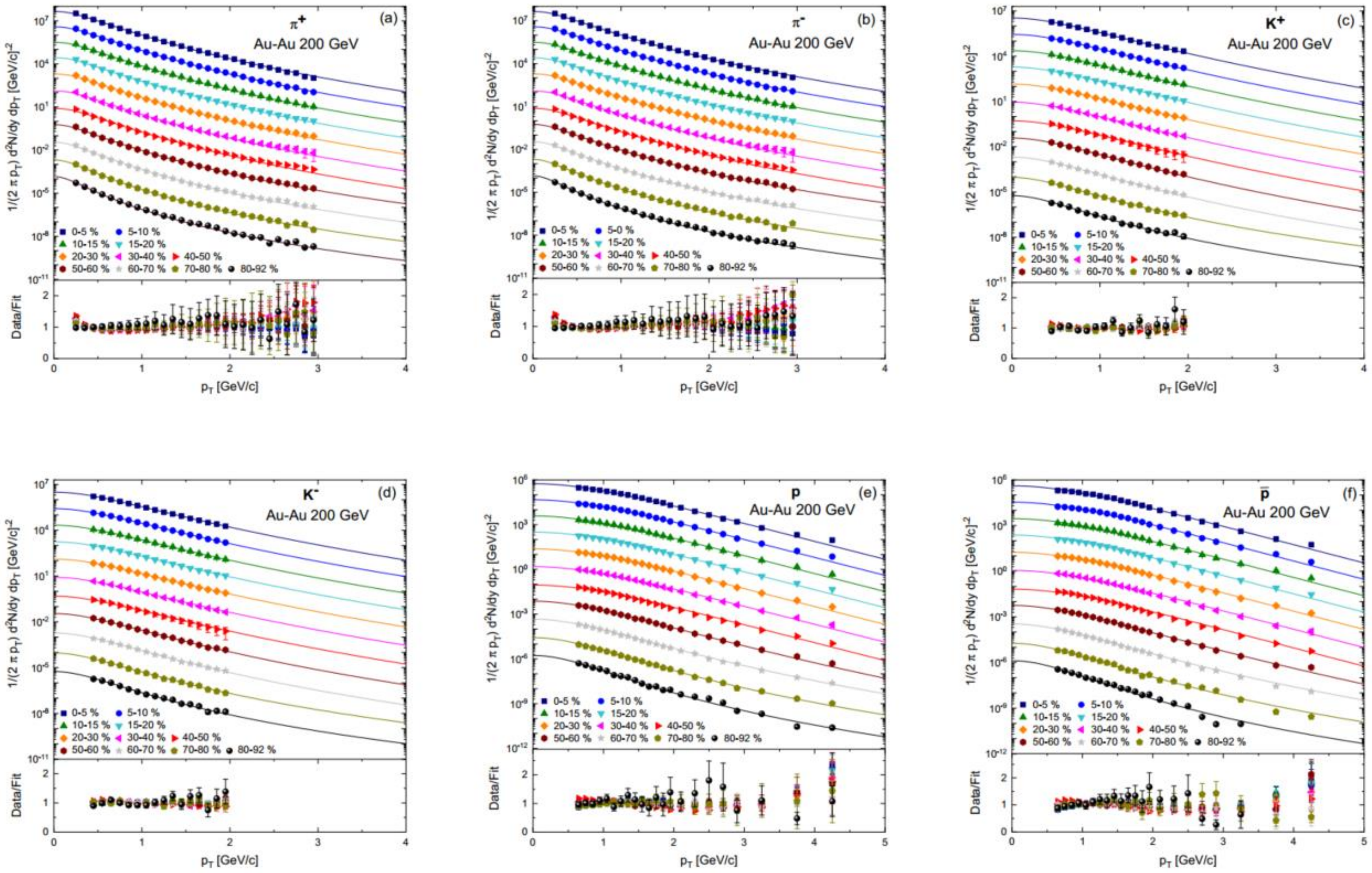


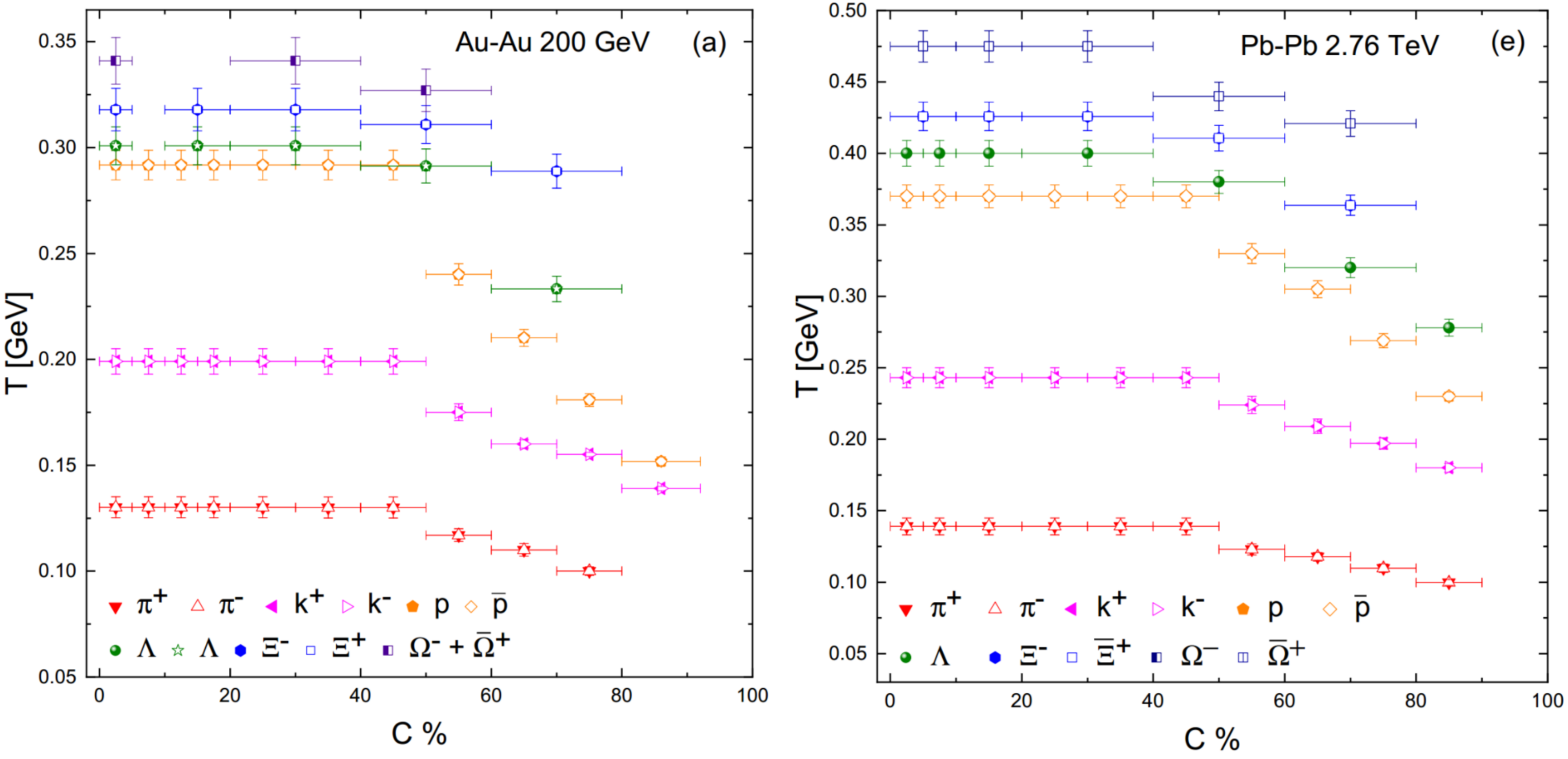
Table 1. Values of free parameters T and q, N_0, $< p_T >$ and χ^2/NDF extracted from the Tsallis-Pareto type function given in Eq.3

Collision	Particle	Centrality	Scaling factor	T [GeV]	q	$< p_T >$ [GeV/c]	N_0	χ^2/NDF
Fig.1		0-5%	10^5	0.120±0.005	1.093±0.003	0.248±0.013	18002.8±500	21.146/25
Au-Au		5-10%	10^4	0.120±0.005	1.093±0.003	0.248±0.013	15202.8±200	21.920/25
200 GeV		10-15%	10^3	0.120±0.005	1.093±0.003	0.248±0.013	12912.8±150	23.199/25
		15-20%	10^2	0.120±0.005	1.093±0.003	0.248±0.013	10932.7±150	26.539/25
		20-30%	10	0.120±0.005	1.093±0.003	0.248±0.013	8132.8±140	35.312/25
	π^+	30-40%	1	0.120±0.005	1.093±0.003	0.248±0.013	5842.5±120	83.160/25
		40-50%	10^{-1}	0.120±0.005	1.093±0.003	0.248±0.013	3472.9±100	61.810/25
		50-60%	10^{-2}	0.110±0.004	1.110±0.004	0.232±0.012	2079.8±90	17.099/25
		60-70%	10^{-3}	0.103±0.004	1.118±0.004	0.220±0.012	1160.8±30	9.500/25
		70-80%	10^{-4}	0.093±0.003	1.125±0.005	0.200±0.011	604.9±10	5.473/25
		80-92%	10^{-5}	0.081±0.003	1.135±0.005	0.176±0.009	396.5±5	15.930/25
Fig.1		0-5%	10^5	0.120±0.005	1.093±0.003	0.248±0.013	18002.8±500	25.491/25
Au-Au		5-10%	10^4	0.120±0.005	1.093±0.003	0.248±0.013	15202.8±200	27.524/25
200 GeV		10-15%	10^3	0.120±0.005	1.093±0.003	0.248±0.013	12912.8±150	32.500/25
		15-20%	10^2	0.120±0.005	1.093±0.003	0.248±0.013	10932.7±150	33.872/25
		20-30%	10	0.120±0.005	1.093±0.003	0.248±0.013	8132.8±140	37.682/25
	π^-	30-40%	1	0.120±0.005	1.093±0.003	0.248±0.013	5642.5±120	77.190/25
		40-50%	10^{-1}	0.120±0.005	1.093±0.003	0.248±0.013	3372.9±100	63.068/25
		50-60%	10^{-2}	0.110±0.004	1.110±0.004	0.232±0.012	2079.8±90	19.137/25
		60-70%	10^{-3}	0.103±0.004	1.118±0.004	0.220±0.012	1160.8±30	10.345/25
		70-80%	10^{-4}	0.093±0.003	1.125±0.005	0.200±0.011	604.9±10	4.824/25
		80-92%	10^{-5}	0.081±0.003	1.135±0.005	0.176±0.009	396.5±5	27.306/25
Fig. 1		0-5%	10^5	0.199±0.006	1.060±0.003	0.399±0.020	1880.8±90	40.931/13
Au-Au		5-10%	10^4	0.199±0.006	1.060±0.003	0.399±0.020	1540.7±70	23.196/13
200 GeV		10-15%	10^3	0.199±0.006	1.060±0.003	0.399±0.020	1290.8±50	18.055/13
		15-20%	10^2	0.199±0.006	1.060±0.003	0.399±0.020	1060.8±30	17.045/13
		20-30%	10	0.199±0.006	1.060±0.003	0.399±0.020	779.9±20	21.988/13
	K^+	30-40%	1	0.199±0.006	1.060±0.003	0.399±0.020	495.8±10	30.512/13
		40-50%	10^{-1}	0.199±0.006	1.060±0.003	0.399±0.020	291.5±7	79.333/13
		50-60%	10^{-2}	0.175±0.004	1.070±0.004	0.360±0.018	189.1±7	43.277/13
		60-70%	10^{-3}	0.160±0.004	1.081±0.005	0.337±0.018	98.9±4	69.408/13
		70-80%	10^{-4}	0.155±0.003	1.111±0.006	0.336±0.017	41.9±2	14.914/13
		80-92%	10^{-5}	0.139±0.003	1.122±0.007	0.310±0.016	23.8±1	18.862/13
Fig. 1		0-5%	10^5	0.199±0.006	1.070±0.003	0.402±0.020	1740.7±80	18.282/13
Au-Au		5-10%	10^4	0.199±0.006	1.070±0.003	0.402±0.020	1440.7±50	16.330/13
200 GeV		10-15%	10^3	0.199±0.006	1.070±0.003	0.402±0.020	1180.8±30	16.330/13
		15-20%	10^2	0.199±0.006	1.070±0.003	0.402±0.020	971.6±15	25.125/13
		20-30%	10	0.199±0.006	1.070±0.003	0.402±0.020	719.8±10	27.379/13
	K^-	30-40%	1	0.199±0.006	1.070±0.003	0.402±0.020	453.8±7	71.082/13
		40-50%	10^{-1}	0.199±0.006	1.070±0.003	0.402±0.020	266.6±6	99.387/13
		50-60%	10^{-2}	0.175±0.004	1.080±0.004	0.363±0.018	174.2±4	22.910/13
		60-70%	10^{-3}	0.160±0.004	1.088±0.005	0.339±0.018	89.7±3.7	88.802/13
		70-80%	10^{-4}	0.155±0.003	1.111±0.006	0.336±0.017	40.9±2	14.391/13
		80-92%	10^{-5}	0.139±0.003	1.122±0.007	0.310±0.016	23.1±1	17.794/13
Fig. 1		0-5%	10^5	0.291±0.007	1.011±0.003	0.586±0.029	471.8±20	78.267/19
Au-Au		5-10%	10^4	0.291±0.007	1.011±0.003	0.586±0.029	394.8±15	59.704/19
200 GeV		10-15%	10^3	0.291±0.007	1.011±0.003	0.586±0.029	325.9±13	39.207/19
		15-20%	10^2	0.291±0.007	1.011±0.003	0.586±0.029	270.3±10	31.674/19
		20-30%	10	0.291±0.007	1.011±0.003	0.586±0.029	202.2±7	33.076/19
	p	30-40%	1	0.291±0.007	1.011±0.003	0.586±0.029	130.3±5	56.559/19
		40-50%	10^{-1}	0.291±0.007	1.011±0.003	0.586±0.029	76.3±3	137.801/19
		50-60%	10^{-2}	0.240±0.005	1.041±0.003	0.513±0.026	54.3±2	10.924/19
		60-70%	10^{-3}	0.210±0.004	1.071±0.004	0.472±0.024	31.1±1.5	5.877/19
		70-80%	10^{-4}	0.180±0.003	1.089±0.005	0.430±0.022	16.1±0.6	7.078/19
		80-92%	10^{-5}	0.151±0.003	1.105±0.007	0.381±0.019	9.1±0.4	7.293/19
Fig. 1		0-5%	10^5	0.291±0.007	1.011±0.003	0.586±0.029	345.8±17	127.757/19
Au-Au		5-10%	10^4	0.291±0.007	1.011±0.003	0.586±0.029	291.8±12	105.070/19
200 GeV		10-15%	10^3	0.291±0.007	1.011±0.003	0.586±0.029	242.8±11	75.153/19
		15-20%	10^2	0.291±0.007	1.011±0.003	0.586±0.029	202.8±10	59.718/19
		20-30%	10	0.291±0.007	1.011±0.003	0.586±0.029	148.3±7	63.202/19
	$\bar{p}$	30-40%	1	0.291±0.007	1.011±0.003	0.586±0.029	96.1±3	69.226/19
		40-50%	10^{-1}	0.291±0.007	1.011±0.003	0.586±0.029	57.0±2	127.930/19
		50-60%	10^{-2}	0.240±0.005	1.041±0.003	0.513±0.026	41.6±1.3	9.229/19
		60-70%	10^{-3}	0.210±0.004	1.071±0.004	0.472±0.024	[illegible]	6.521/19
		70-80%	10^{-4}	0.180±0.003	1.089±0.005	0.430±0.026	11.1±0.4	12.705/19
		80-92%	10^{-5}	0.151±0.003	1.105±0.007	0.381±0.019	7.1±0.2	10.149/17

Fig. 1 Au-Au 200 GeV	Λ	0-5%	10^2	0.300±0.009	1.009±0.003	0.622±0.031
		10-20%	10	0.300±0.009	1.009±0.003	0.622±0.031
		20-40%	1	0.300±0.009	1.009±0.003	0.622±0.031
		40-60%	10^{-1}	0.291±0.008	1.019±0.004	0.611±0.031
		60-80%	10^{-2}	0.233±0.006	1.055±0.005	0.522±0.026

Collision	Particle	Centrality	Scaling factor	T [GeV]	q	$< p_T >$ [GeV/c]
Fig. 1 Au-Au 200 GeV	$\bar{\Lambda}$	0-5%	10^2	0.300±0.009	1.009±0.003	0.622±0.031
		10-20%	10	0.300±0.009	1.009±0.003	0.622±0.031
		20-40%	1	0.300±0.009	1.009±0.003	0.622±0.031
		40-60%	10^{-1}	0.291±0.008	1.019±0.004	0.611±0.031
		60-80%	10^{-2}	0.233±0.006	1.055±0.005	0.522±0.026
Fig. 1 Au-Au 200 GeV	Ξ^-	0-5%	10^2	0.317±0.010	1.007±0.003	0.675±0.034
		10-20%	10	0.317±0.010	1.007±0.003	0.675±0.034
		20-40%	1	0.317±0.010	1.007±0.004	0.675±0.034
		40-60%	10^{-1}	0.310±0.009	1.009±0.005	0.665±0.033
		60-80%	10^{-2}	0.288±0.008	1.039±0.006	0.637±0.032
Fig. 1 Au-Au 200 GeV	$\bar{\Xi}^+$	0-5%	10^2	0.317±0.010	1.007±0.003	0.675±0.034
		10-20%	10	0.317±0.010	1.007±0.003	0.675±0.034
		20-40%	1	0.317±0.010	1.007±0.003	0.675±0.034
		40-60%	10^{-1}	0.310±0.009	1.009±0.004	0.665±0.033
		60-80%	10^{-2}	0.288±0.008	1.039±0.005	0.637±0.032
Fig. 1 Au-Au 200 GeV	$\Omega^- + \bar{\Omega}^+$	0-5%	10	0.340±0.011	1.005±0.003	0.756±0.038
		20-40%	1	0.340±0.011	1.005±0.003	0.756±0.038
		40-60%	10^{-1}	0.326±0.010	1.020±0.004	0.740±0.037

Fig.4



- L138 **“more collision energy is deposited in a larger volume rather than higher temperature”** （40-50% to the most central collisions show a smooth behavior for T. It tends to be in thermal equilibrium and reaches a maximum temperature in 40-50%）
- pT~(0,3) hadronization together for pi/k/p, so in principle fit simultaneously(In particular, it is necessary to obtain changes with the center, and the control variable method should also be fitted simultaneously). If perform fits like this, then the above can be drawn for AuAu and PbPb systems and correspond energies.
- T extracted from pion spctra is consistent between auau and pbpb, soft hadrons can directly flect system evoluation. However, the other particle cases are significantly larger in PbPb than in AuAu.

L139-145

“The region from 0 - 40% centrality is <u>meson dominated</u> region where QGP is produced while the region beyond this to the most periphery is <u>baryon dominated</u>. ”

(pion+) 2.18+ 1.36+ 8.36E-01+ 5.29E-+01+ 3.51E-01+ 2.21E-01+ 1.51E-01+ 1.10E-01+ 7.17

(pion-) 2.16E+00+ 1.30E+00+ 8.30E-01+ 5.26E-01+ 3.45E-01+ 2.32E-01+ 1.47E-01+ 1.05E-

(k+) 4.81E-01+ 3.40E-01+ 2.33E-01+ 1.69E-01+ 1.19E-01+ 7.84E-02+ 5.43E-02+ 3.85E-02+

(k-) 4.43E-01+ 3.16E-01+ 2.31E-01+ 1.56E-01+ 1.09E-01+ 7.06E-02+ 5.72E-02+ 3.67E-02+ 2.38E-02

(p+) 2.04E-01+ 1.65E-01+ 1.27E-01+ 1.00E-01+ 7.43E-02+ 5.88E-02+ 3.98E-02+ 3.41E-02+ 2.41E-02

(p-) 1.58E-01+ 1.25E-01+ 9.50E-02+ 7.38E-02+ 5.50E-02+ 4.34E-02+ 3.19E-02+ 2.40E-02+ 1.90E-02

(60-70% pT~(0.6, 1.5))

(60-80%) (Λ |y|<1) 0.168534+0.143039+0.082781+0.0542705+0.0333924+ 0.0199942

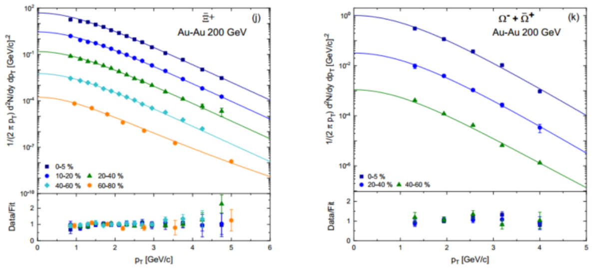


Figure 1. Plots (a) - (k) represent the event centrality-dependant double differential p_T spectra of identified particles at $|\eta| < 0.35$ measured by PHENIX Collaboration at RHIC [51] and strange, at $|y| < 1$ for Λ and $\bar{\Lambda}$ and $|y| < 0.5$ for Ξ, $\bar{\Xi}$ and $\Omega^- + \bar{\Omega}^+$ measured by STAR at RHIC [52] hadrons at $\sqrt{s}$ = 200 GeV in Au-Au collision. The data for these particles have been analyzed at all available centrality events indicated in each plot. Different symbols with different colors are used for different centralities, while the solid lines are the results of our fit by using Eq. 3. Each plot has the Data/Fit ratio at its bottom, which shows the fit quality.

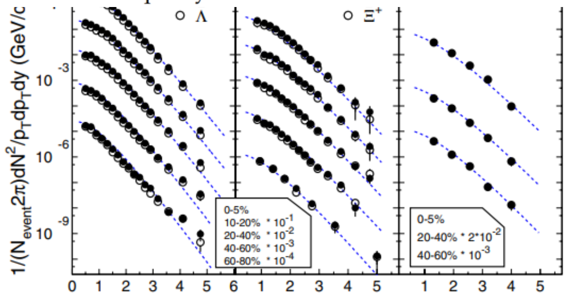


FIG. 1 (color online). Transverse momentum distributions of (a) $\Lambda(\bar{\Lambda})$ for $|y| < 1.0$, (b) $\Xi^-(\bar{\Xi}^+)$ for $|y| < 0.75$, and (c) $\Omega^- + \bar{\Omega}^+$ for $|y| < 0.75$ in Au + Au collisions at $\sqrt{s_{NN}}$ = 200 GeV as a function of centrality. Scale factors were applied to the spectra for clarity. Only statistical errors are shown. The dashed curves show a Boltzmann fit to the Λ, Ξ^-, and $\Omega^- + \bar{\Omega}^+$ data; the fits to the $\bar{\Lambda}$ and $\bar{\Xi}^+$ are omitted for clarity.

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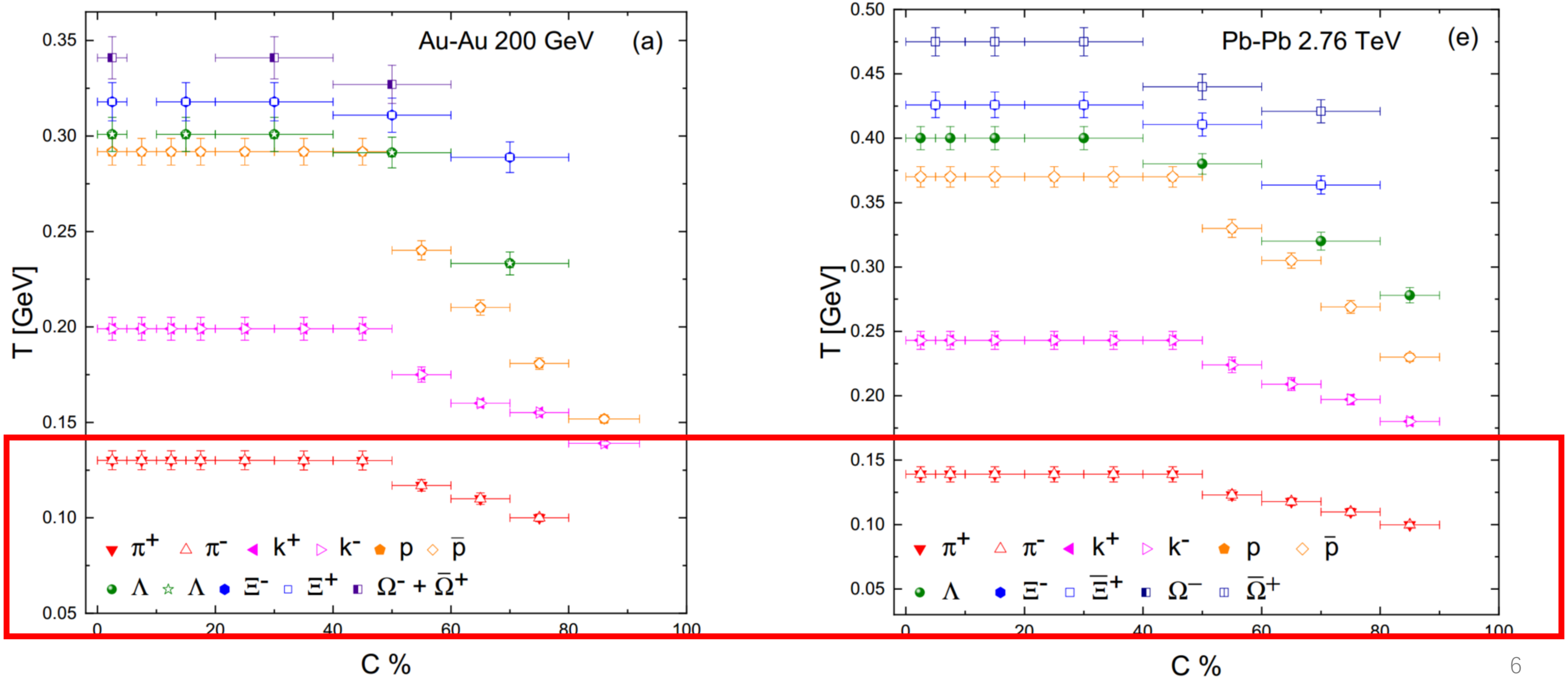
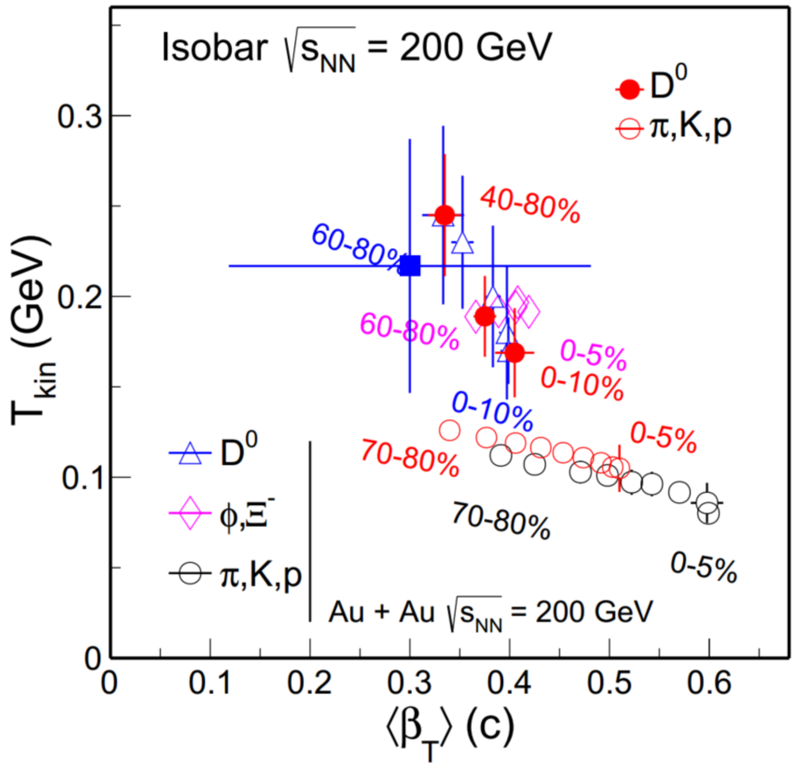
From the above results, we also reported that T, $< p_T >$ and N_0 are dependent on the size of the system. Larger the system, the larger they are. As a larger collision system has large participants involved in the interaction, it experiences an intense reaction, where more energy is deposited in the system, which corresponds to a large transfer of momentum in the system which naturally leads the system to be highly excited, and due to large transfer of energy (momentum), further multiple scattering happens and results in larger N_0 (multiplicity).



- Fig.7 does not appear in the text
- Kinematic Freeze-out Temperature is different between previous results.
- T is different from temperature in Boltzmann's thermodynamic statistics. How does the $T_{thermal}$ depend on centrality classes?



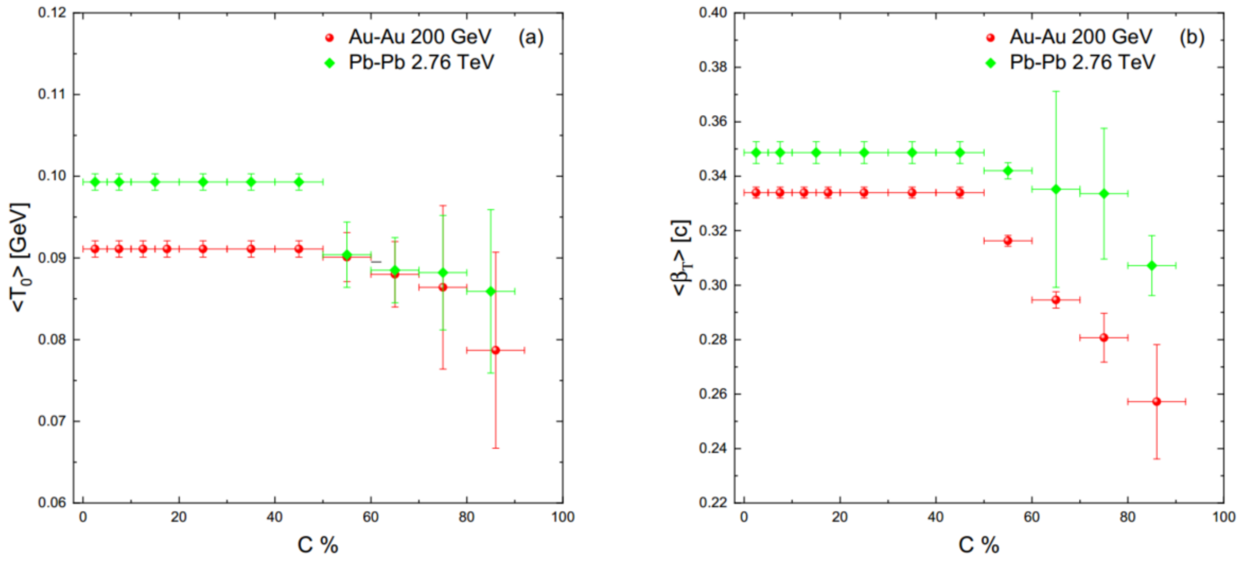


Figure 7. Dependence of (a) $< T_0 >$ and (b) $< \beta_T >$ on centrality in Au-Au and Pb-Pb collisions respectively.

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$$T = T_{fro} + m \langle u_t \rangle^2 , \tag{33}$$

where T_{fro} is the hadron kinetic freeze-out temperature and $\langle u_t \rangle$ is the measure of the strength of the average radial transverse flow, which is connected to the averaged transverse velocity via

$$\langle v_t \rangle = \frac{\langle u_t \rangle}{\sqrt{1 + \langle u_t \rangle^2}}. \tag{34}$$

$$T_{thermal} = T \sqrt{\frac{1 - v_t}{1 + v_t}}$$

Some other conflicts

work. But to show the extraction of the kinetic freeze-out temperature T_0 and transverse flow velocity β_T from T, we took the particles with same centrality and extracted the two

The following abbreviations are used in this manuscript:

p_T	**transverse momentum**
T_{eff}	**kinetic freeze-out temperature**
$< T_{eff} >$	**effective temperature**
β_T	**transverse flow velocity**
$< \beta_T >$	**average transverse flow velocity**

from these systems. The present work extracts the effective temperature T, non-extensivity parameter (q), the mean transverse momentum spectra ($< p_T >$), the multiplicity parameter (N_0), kinetic freeze-out temperature (T_0) and transverse flow velocity (β_T). We reported a plateau structure of p_T,