1.

7th International Conference on Particle Physics and Astrophysics

Open and hidden strangeness in central A+A collisions: ratios of the averagetransverse energy density for ϕ –meson and Ω –hyperons in the range $\sqrt{S_{NN}}$ =39 GeV -2,76 TeV

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Interesting strangeness

Hadrons with (multiple) strange quarks

Small hadronic cross section	Sensitive to dynamics of the medium	Can be easily reconstructed and identified in experiment!

→ Systematic study of medium properties!

φ -meson (1020)

The lightest meson with hidden flavor. Contains only strange quarks.

→ A dramatic increase prediction in the φ -meson after the formation of the quark-gluon plasma (QGP). [1]

[1] - Asher Shor , PHYSICAL REVIEW LETTERS, 25.70.Np, 12.35.Ht, 21.65 (1985)

Motivation

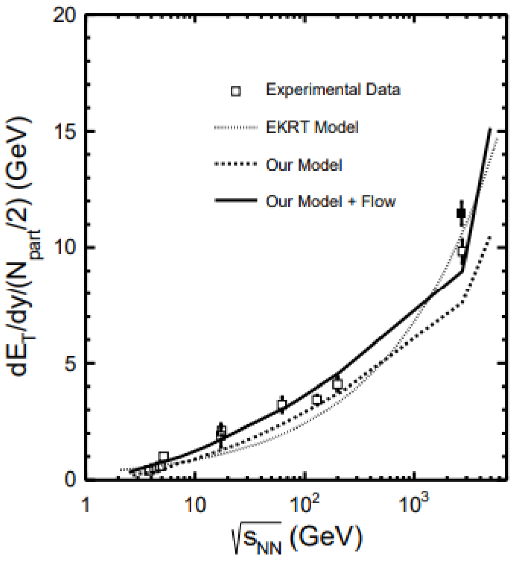
The ratio of particles with different strangeness can indicate whether there is an increased production of φ mesons.

Particle	кварковый состав	m, MeV	τ, c
φ	$s\bar{s}$	1020	$1{,}54 \cdot 10^{-22}$
Ω	sss	1672	$8{,}21 \cdot 10^{-11}$

φ, Ω, Ω^{-}

Transverse energy

$$< m_\perp > = \sqrt{m^2 + < p_\perp >^2}$$



[3]

[2]

$$\frac{d < E_\perp >}{dy} = < m_\perp > \frac{dN}{dy}$$

$S_\perp$ - is the transverse overlap area of the colliding nuclei

τ – is the formation time

[2] - J.T. Mitchell (for the PHENIX Collaboration), Transverse Energy Measurements from the Beam Energy Scan in PHENIX, Nuclear Physics A 00 (2022)

Calculating the average $p_\perp$

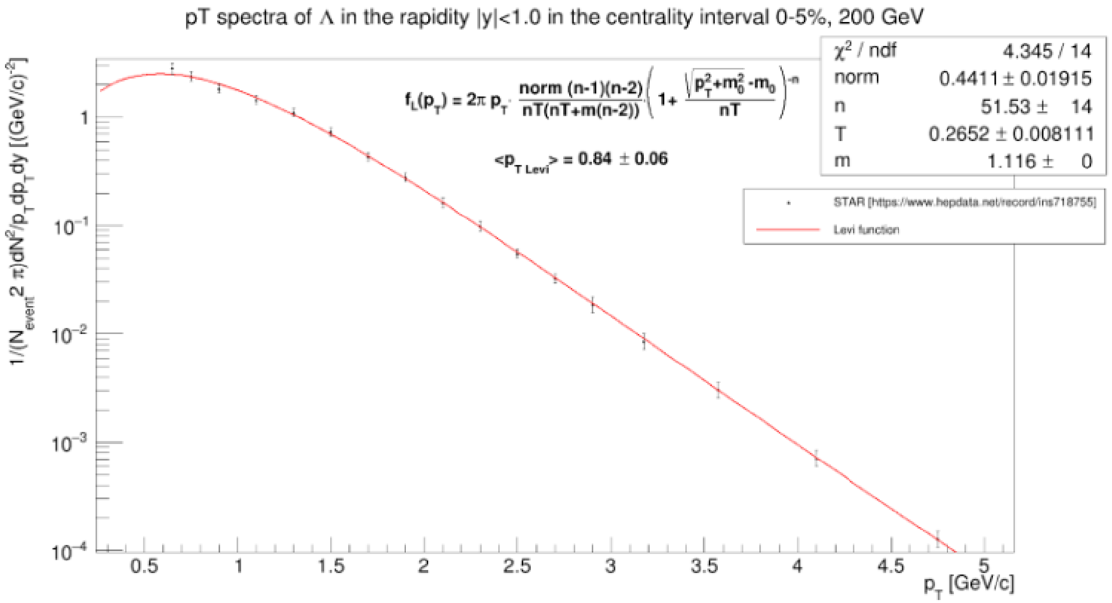
The Levy function:

$$f_L(p_\perp) = \frac{norm \cdot (n-1)(n-2)}{nT(nT + m_0(n-2))} \cdot p_\perp \left(1 + \frac{\sqrt{{m_0}^2 + {p_\perp}^2} - m_0}{nT}\right)$$

n, T, and m_0 - fitting parameters

Average transverse momentum:

$$< p_\perp > = \frac{\int_a^b f(p_\perp) p_\perp dp_\perp}{\int_a^b f(p_\perp) dp_\perp}$$



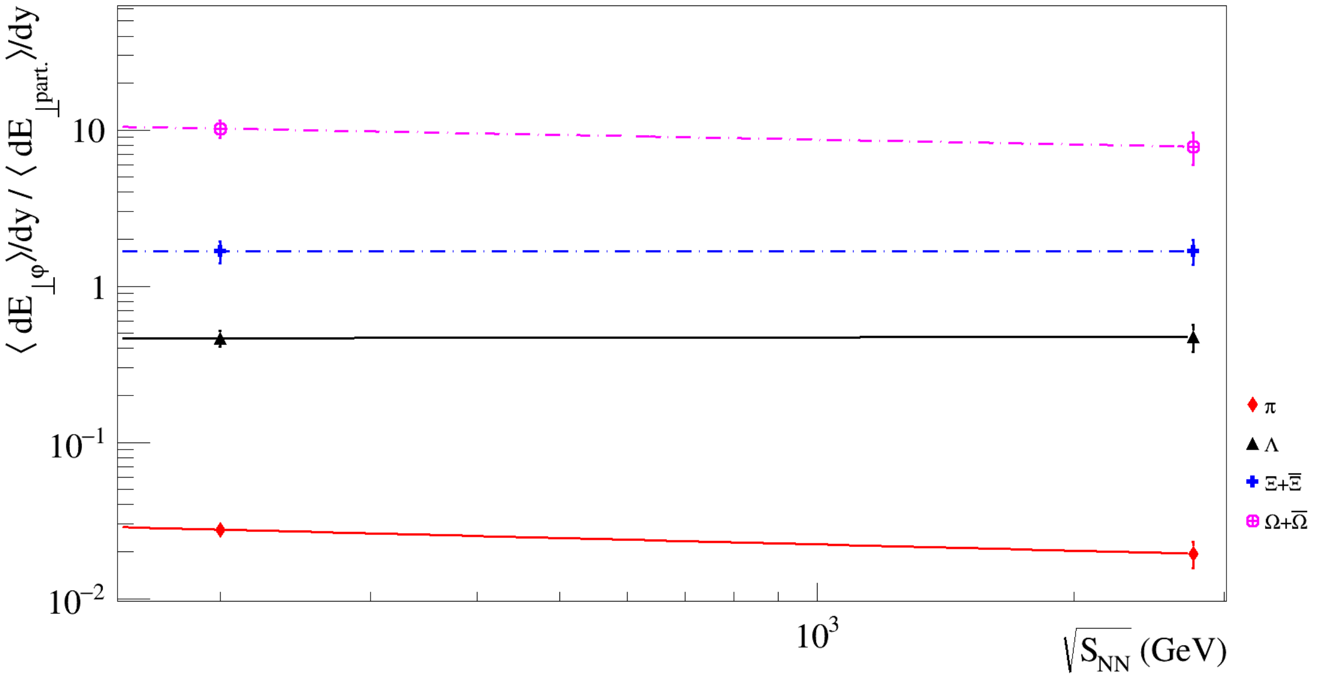
a and b are extended intervals over the entire range of $p_\perp$

To estimate systematic errors we used the blast-wave function.

10.

$<dE_{\perp}/dy>_{\varphi}/<dE_{\perp}/dy>_{particles}$

$$<dE_{\perp}/dy>_{\varphi}/<dE_{\perp}/dy>_{particles} = Q*(\sqrt{S_{NN}})^{n}$$



A different energies, the fractions of energy expended on the prodaction of varios particles with strangeness remain constant.

Предлагаю вставить картинку только с фи-мезон и омега

Theoretical models

Schwinger-like formula

$$|\mu^2| \sim \exp\left(\frac{-\pi m^2}{k}\right)$$

k is the string tension [10]

where M gives the matrix-element for the production of a quark-antiquark pair.

k ≈ 1 GeV/fm

[10] S.A. Bass et al. "Microscopic Models for Ultrarelativistic Heavy Ion Collisions", Nuclear Theory (nucl-th); High Energy Physics - Phenomenology

Thermal model

$$\left(\frac{dE_m}{dy}\right)_{y=0} = \frac{g_m V \lambda_m}{(2\pi)^2} \int \frac{m_T^3\, dm_T}{\left[\exp\left(\frac{m_T}{T}\right)\right]}.$$

T – is temperature

$\langle p \rangle$ — mean string tension. [11]

[11]V.V.Vechernin, Physics of Particles and Nuclei, 2023, Vol. 54, No. 3, pp. 528–535, 2023.

Schwinger-like formula

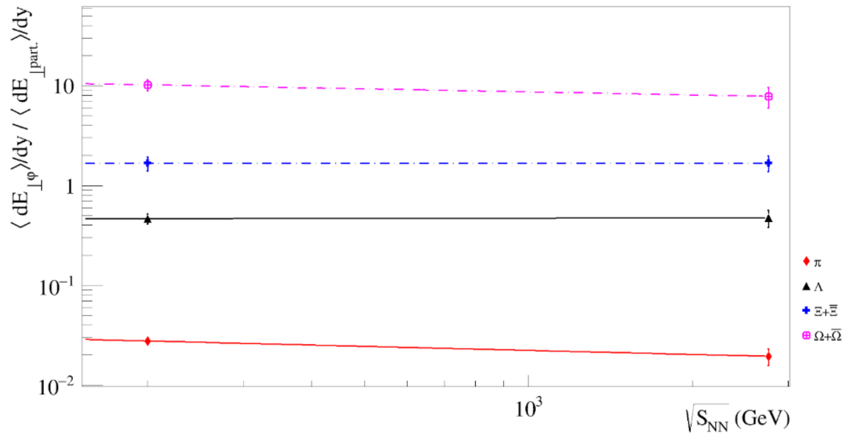
$$\frac{dN}{dy} \sim |\mu|^2 \sim \exp\left(-\frac{\pi < m_T >^2}{k}\right)$$

$$\frac{< \frac{dE_\varphi}{dy} >}{< \frac{dE_\Omega}{dy} >} = \frac{\frac{dN_\varphi}{dy} < m_T >_\varphi}{\frac{dN_\Omega}{dy} < m_T >_\Omega} = \frac{(2S_\varphi + 1)}{(2S_\Omega + 1)} \cdot \frac{< m_T >_\varphi}{< m_T >_\Omega} \exp\left(\frac{< m_T >_\Omega{}^2 - < m_T >_\varphi{}^2}{k} \cdot \pi\right) = 10$$

$$\exp\left(\frac{< m_T >_\Omega{}^2 - < m_T >_\varphi{}^2}{k} \cdot \pi\right) = \frac{10\,(2S_\Omega + 1) < m_T >_\Omega}{(2S_\varphi + 1) < m_T >_\varphi}$$

$$k = \frac{\pi(< m_T >_\Omega{}^2 - < m_T >_\varphi{}^2)}{\ln\left(\frac{10\,(2S_\Omega + 1) < m_T >_\Omega}{(2S_\varphi + 1) < m_T >_\varphi}\right)}$$

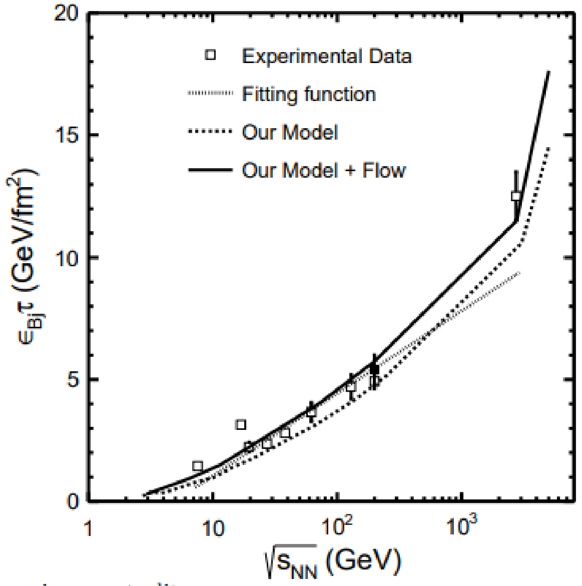
$\sqrt{S_{NN}}$	k
39	3,13
200	2,82
2760	4,69



Thermal model

$$\left(\frac{dE_m}{dy}\right)_{y=0} = \frac{g_m V \lambda_m}{(2\pi)^2} \int \frac{m_T^3 \, dm_T}{\left[\exp\left(\frac{m_T}{T}\right)\right]}.$$

$$\langle E_T \rangle = \left(\frac{\pi}{8} + \frac{1}{4}\right)\left[\langle E \rangle - m_N \langle N_B - N_{\bar{B}} \rangle\right].$$



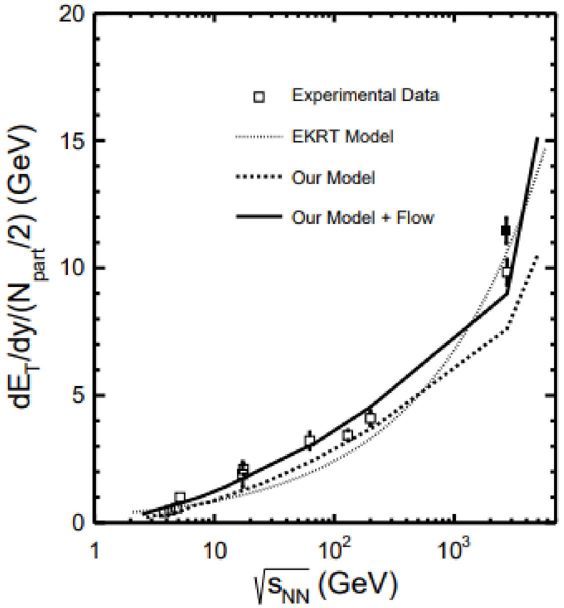


Table 2: Temperature and Baryon Chemical Potential extracted after fitting the particle ratios for various centrality at $\sqrt{s_{NN}}$ = 200 GeV and 2.76 TeV. Most-central, mid-central and peripheral are defined in the text for both energies.

Centrality	$\sqrt{s_{NN}}$ = 200 GeV		$\sqrt{s_{NN}}$ = 2.76 TeV	
	T (MeV)	μ_B (MeV)	T (MeV)	μ_B (MeV)
Most-central	169	23.5	169	1.7
Mid-central	168.5	17	168.5	1.0
Peripheral	168	5.5	168	0.5

[1] - Swatantra Kumar Tiwari , Raghunath Sahoo, "Transverse Energy per Charged Particle in Heavy-Ion Collisions: Role of Collective Flow", Eur. Phys. J. A (2018) 54: 39

Что есть на данный момент?

generacy factor:

$$g_i = (2s+1)(2I+1).$$

fugasity:

$$\lambda_m = \exp\left(\frac{\mu_m}{T}\right)$$

$$\mu_h = B_h \mu_{Bh} + Q_h \mu_{Qh} + S_h \mu_{Sh},$$

Фактор вырождения g для частицы i учитывает все возможные внутренние степени свободы, которые могут влиять на её состояние.

Формула, используемая в модели SHGM:

$$\left(\frac{dE_m}{dy}\right)_{y=0} = \frac{g_m V \lambda_m}{(2\pi)^2} \int \frac{m_T^3 \, dm_T}{\left[\exp\left(\frac{m_T}{T}\right)\right]}.$$

Преобразованная формула:

$$\left(\frac{dE_m}{dy}\right)_{y=0} = \frac{g_m V \lambda_m}{(2\pi)^2} \cdot \left(e^{\frac{-m_T}{T}}(-m_T{}^3 T - 3m_T{}^2 T^2 - 6m_T T^3 - 6T^4) + e^{\frac{-m_T}{T}} \cdot const\right)$$

Для отношения φ к Ω:

$$\frac{dE_\phi}{dy} \Big/ \frac{dE_\Omega}{dy} = \frac{g_\varphi \lambda_\varphi}{g_\Omega \lambda_\Omega} \cdot \frac{\left(e^{\frac{-m_{T\varphi}}{T}}\left(-m_{T\varphi}{}^3 T - 3m_{T\varphi}{}^2 T^2 - 6m_{T\varphi} T^3 - 6T^4\right) + e^{\frac{-m_{T\varphi}}{T}} \cdot const\right)}{\left(e^{\frac{-m_{T\Omega}}{T}}\left(-m_{T\Omega}{}^3 T - 3m_{T\Omega}{}^2 T^2 - 6m_{T\Omega} T^3 - 6T^4\right) + e^{\frac{-m_{T\Omega}}{T}} \cdot const\right)}$$

Некоторые преобразования ф-лы

$$\frac{dE_\phi}{dy}\Bigg/\frac{dE_\Omega}{dy} = \frac{g_\varphi \lambda_\varphi}{g_\Omega \lambda_\Omega} \cdot \frac{\left(e^{\frac{-m_{T\varphi}}{T}}\left(-m_{T\varphi}{}^3T - 3m_{T\varphi}{}^2T^2 - 6m_{T\varphi}T^3 - 6T^4\right) + e^{\frac{-m_{T\varphi}}{T}} \cdot const\right)}{\left(e^{\frac{-m_{T\Omega}}{T}}\left(-m_{T\Omega}{}^3T - 3m_{T\Omega}{}^2T^2 - 6m_{T\Omega}T^3 - 6T^4\right) + e^{\frac{-m_{T\Omega}}{T}} \cdot const\right)}$$

Используемые допущения и значения T(статья) и $\sqrt{S_{NN}}$:

$$\mu_\varphi = \mu_\Omega = \mu_B \rightarrow \lambda_\varphi = \lambda_\Omega$$

$$\frac{dE_\phi}{dy}\Bigg/\frac{dE_\Omega}{dy} = 1$$

$$\frac{g_\Omega \cdot exp(\mu_\Omega/T)}{g_\varphi} = \frac{e^{\frac{-m_{T\varphi}}{T}}\left(-m_{T\varphi}{}^3T - 3m_{T\varphi}{}^2T^2 - 6m_{T\varphi}T^3 - 6T^4\right)}{e^{\frac{-m_{T\Omega}}{T}}\left(-m_{T\Omega}{}^3T - 3m_{T\Omega}{}^2T^2 - 6m_{T\Omega}T^3 - 6T^4\right)} = 8{,}9514$$

$$const = 0$$

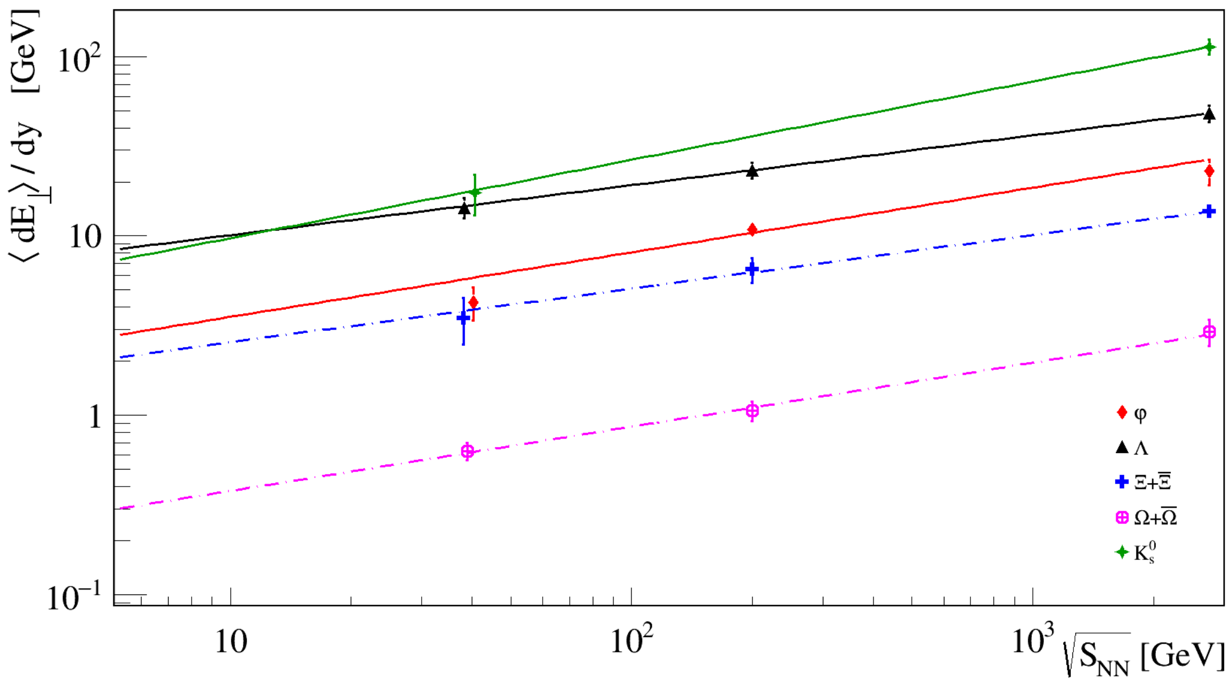
$$T = 169\ MeV$$

$$\sqrt{S_{NN}} = 200GeV$$

Back-up

Back-up Back-up Back-up Back-up Back-up Back-up Back-upvvvvvvv Back-up

$\langle dE_\perp/dy \rangle$ vs. $\sqrt{S_{NN}}$, very central (0-5 %) $|\eta| < 0.5$



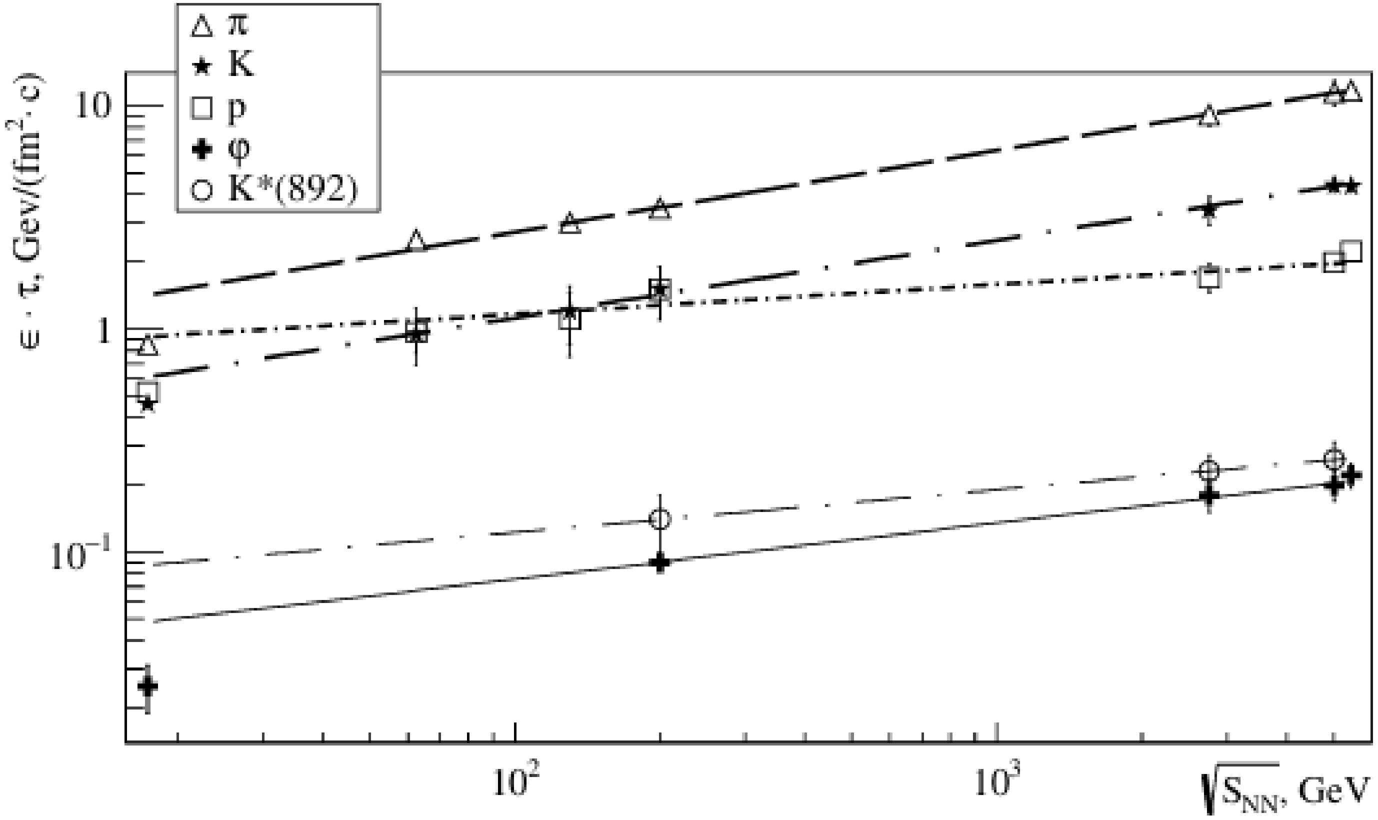
The dependence of $\langle dE_\perp/dy \rangle$ on $\sqrt{S_{NN}}$ for the most central collisions (0-5%) at energies of 39, 200, and 2760 GeV.

Approximation function: $\langle dE_\perp/dy \rangle = Q * (\sqrt{S_{NN}})^n$

Particles	n
φ	0.36±0.04
$\Xi + \Xi^-$	0.30±0.05
Λ	0.28±0.04
$\Omega + \Omega^-$	0.39±0.08
K_0^s	0.44±0.06

Similar functional dependencies for different particles.

φ -meson and particles with u- and d- quarks [9]



Approximation function: <dE⊥/dy> = Q *(√S_{NN})^n

Particles	n/2
φ	0.18±0.02
π	0.184±0.05

The slope of the function for π mesons is similar from that of strange hadrons.

[9] Shaposhnikova, Marova, Feofilov, “Open and hidden strangeness with kaons and ϕ-mesons in Bjorken energy density approach for central A+A collisions from SPS to LHC”, Physics of Particles and Nuclei

Thermal model: dN/dy

Baryon

$$\left(\frac{dN_i}{dy}\right)_{th} = \frac{g_i V \lambda_i}{(2\pi^2)} \left[\left((1-R) - \lambda_i \frac{\partial R}{\partial \lambda_i}\right) \int_0^\infty \frac{m_T^2 \, coshy \, dm_T}{\left[exp\left(\frac{m_T \, coshy}{T}\right) + \lambda_i\right]} - \lambda_i (1-R) \int_0^\infty \frac{m_T^2 \, coshy \, dm_T}{\left[exp\left(\frac{m_T \, coshy}{T}\right) + \lambda_i\right]^2}\right].$$

Meson

$$\left(\frac{dN_m}{dy}\right)_{th} = \frac{g_m V \lambda_m}{(2\pi^2)} \int_0^\infty \frac{m_T^2 \, coshy \, dm_T}{\left[exp\left(\frac{m_T \, coshy}{T}\right) - \lambda_m\right]}.$$

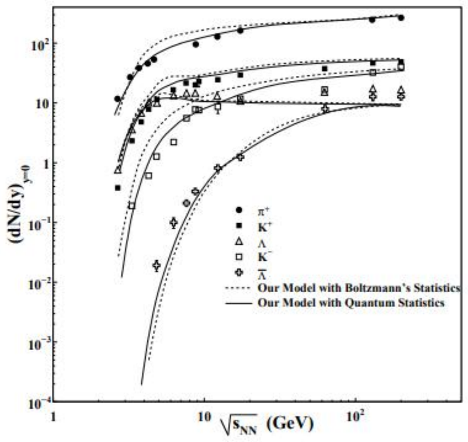


FIG. 3: Variation of rapidity distributions of various hadrons with respect to $\sqrt{s_{NN}}$ at midrapidity. Lines show our model calculation. Symbols are the experimental data [9, 49, 50].

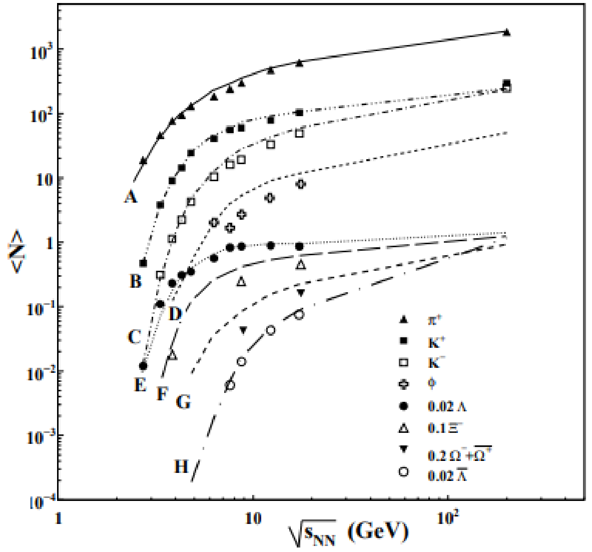


FIG. 2: Variations of total multiplicities of π^+, K^+, K^-, ϕ, Λ, Ξ^-, $(\Omega^- + \bar{\Omega}^+)$, and $\bar{\Lambda}$ with respect to center-of-mass energy predicted by our model. Experimental data measured in central $Au-Au/Pb-Pb$ collisions [31–47] have also been shown for comparison. In this figure, A, B, C, D, E, F, G, and H represent the multiplicities of π^+, K^+, K^-, ϕ, Λ, Ξ^-, $(\Omega^- + \bar{\Omega}^+)$, and $\bar{\Lambda}$, respectively.

$$\frac{dN_i}{dy} = \int_{-\eta_{max.}}^{\eta_{max.}} \left(\frac{dN_i}{dy}\right)_{th} (y-\eta) \, d\eta,$$

The resulting rapidity spectra of ith hadron, after incorporation of the flow velocity in the longitudinal direction is [11, 12]:

[2] - S. K. Tiwari ∗ , P. K. Srivastava, and C. P. Singh, “The effect of flow on Hadronic Spectra in an Excluded-Volume Model”, J. Phys. G : Nucl. Part. Phys. 40, 045102 (2013)

±

5.

Sources of experimental data used

, GeV	Particles	, GeV/c		π^+, K+, p,	π^-, K−, p−	, GeV/c	, GeV This work		, GeV/fm² This work		
62.4	Pions	0.4 [1]		237 ± 17 [1]	233 ± 17 [1]		298.7 ± 14.3		2.5 ± 0.14		
	Kaons	0.6-0.65 ± 0.05 [1]		32.4 ± 2.3 [1]	37.6 ± 2.7 [1]		111.5 ± 16.2		0.94 ± 0.16		
	Protons	0.95 ± 01 [1]		13.6 ± 1.7 [1]	29.0 ± 3.8 [1]		113.8 ± 26.8		0.96 ± 0.27		
130	Pions	0.4 [1]		280 ± 25 [1]	278 ± 25 [1]		355 ± 21		2.99 ± 0.2		
	Kaons	0.65-0.7 ± 0.05 [1]		42.7 ± 6.2 [1]	46.3 ± 6.5 [1]		145.8 ± 35.3		1.2 ± 0.35		
	Protons	1 ± 01 [1]		20.0 ± 3.4 [1]	28.2 ± 4.4 [1]		132.2 ± 35.4		1.1 ± 0.35		
200	Pions	0.4 [1]		327 ± 25 [1]	322 ± 25 [1]		392 ± 24		392 ± 24		
	Kaons	0.7-0.8 ± 0.05 [1]		49.5 ± 6.2 [1]	51.3 ± 6.5 [1]		181 ± 40.8		181 ± 40.8		
		1.08 [2]		10.482.4 [2]			14.74.3		14.74.3		
	Protons	1.1 ± 01 [1]		26.7 ± 3.4 [1]	34.7 ± 4.4 [1]		177.6 ± 41.3		177.6 ± 41.3		
		0.970.02 [3]		7.70.3 [3]			10.840.5		10.840.5		
		0.95±0.12 [8]	0.9±0.1 [8]	1.83±0.2 [6]	2.17±0.19 [6]		2.98±0.5	3.5±0.5			
		0.84±0.06 [8]	0.85±0.06 [8]	16.7±1.1 [6]	12.7±0.9 [6]		23.3±2.4	17.8±1.9			
		1.095±0.111 [8]		0.53±0.04 [6]			1.06±0.13				
2760	Pions	0.517+-0.019 [4]	0.520+-0.018 [4]	733 ± 54 [4]	732 ± 52 [11]		1179.96 ± 110.7		9.1 ± 1.0		
	Kaons	0.876+-0.026 [4]	0.867+-0.027 [4]	109 ± 9 [4]	109 ± 9 [11]		436.7 ± 56.5		3.4 ± 0.5		
		1.310.06 [5]		19.562.6 [5]			30.95.09		0.230.04	30.95.09	0.230.04
	Protons	1.333+-0.033 [4]	1.353+-0.034 [4]	34 ± 3 [4]	33 ± 3 [4]		219.5 ± 27.1		1.7 ± 0.24		
		1.310.07 [6]		13.81.8 [6]			22.93.8		0.180.03	22.93.8	0.180.03
		1.57±0.04 [10]	1.56±0.04 [10]	6.67±0.47 [3]			13.66±1.02				
		1.48±0.04 [4]		26±3 [4]			48.19±5				
		1.8±0.1 [10]		1.19±0,19 [3]			2.92±0.49				
5020	Pions	0.5682 [7]		1699.80 [7]			1491.8 ± 167.2		11.5 ± 1.5		
	Kaons	0.9177 [7]		273.41 [7]			569.8 ± 34.8		4.4 ± 0.3		
		1.460.07 [8]		19.72.8 [8]			37.54 6.5		0.290.05		
	Protons	1.4482 [7]		74.56 [7]			257 ± 18		1.99 ± 0.16		
		1.4 0.02 [8]		14.9 1.2 [8]			29.83.9		0.23		
5044	Pions	0.530.02 [9]		1002.6757.2 [9]			826.6551.5		11.4 0.7		
	Kaons	0.90.03 [9]		149.3714.07 [9]			308		4.20.3		
	Protons	1.40.02 [9]		46.214.7 [9]			156.9		2.150.1		
		1.330.03 [9]		9.271 [9]			31.51.9		0.430.03		

Я таки не знаю как её вставлять

Индусы, статья 3.0

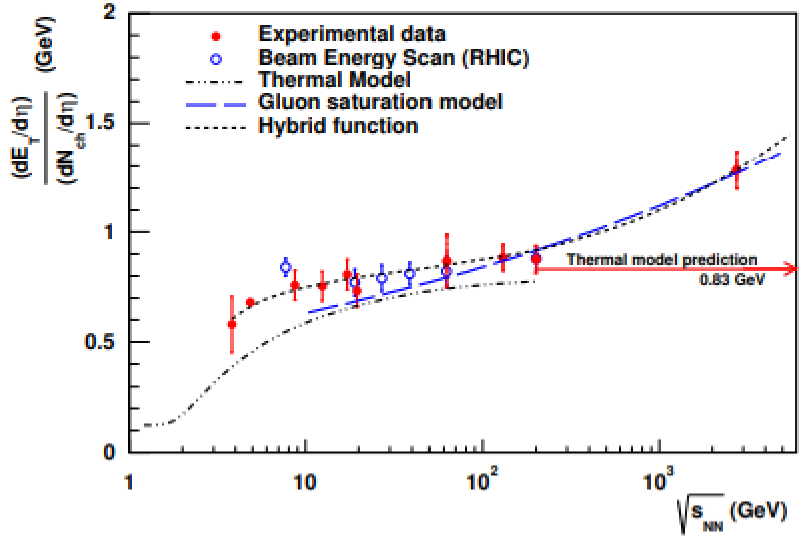


FIG. 42: The ratio of $\frac{dE_T}{d\eta}$ and $\frac{dN_{ch}}{d\eta}$ at midrapidity, as a function of center of mass energy. Experimental data are compared to the predictions from thermal model, gluon saturation model and the estimations obtained in the framework of the hybrid model fitting to transverse energy and charged particle data.

Нормальный слайд давай сделаем

Тезисы введения:

1) Есть модель SHGM -Statistical Hadron Gas Model
2) Для энергий RHIC она хорошо описывает некоторые эффекты???
3) Для энергий LHC наблюда.тся отклонения, например отклонения зависимости $dN_{ch}/d\eta$ от энергии от логарифмической
4) Встатье используется модель SHGM с включенным потоком, для объяснения этих эффектов.

모든 종류의 헛소리

Freeze-Out Parameters in Heavy-Ion Collisions at AGS, SPS, RHIC, and LHC Energies

"Relativistic Heavy-Ion Physics" by Reinhard Stock:

????

$$\langle E_T \rangle = \left(\frac{\pi}{8} + \frac{1}{4}\right)\left[\langle E \rangle - m_N \langle N_B - N_{\bar{B}} \rangle\right].$$

$$\mu_h = B_h \mu_{Bh} + Q_h \mu_{Qh} + S_h \mu_{Sh},$$

$$m_T = \sqrt{m^2 + p_T{}^2}$$

$$\left(\frac{dE_m}{dy}\right)_{y=0} = \frac{g_m V \lambda_m}{(2\pi)^2} \int \frac{m_T^3 \, dm_T}{\left[\exp\left(\frac{m_T}{T}\right)\right]}.$$

$$g_i = (2s_i + 1)(2I_i + 1),$$

Centrality	$\sqrt{s_{NN}} = 200$ GeV T (MeV)	μ_B (MeV)	$\sqrt{s_{NN}} = 2.76$ TeV T (MeV)	μ_B (MeV)
Most-central	169	23.5	169	1.7
Mid-central	168.5	17	168.5	1.0
Peripheral	168	5.5	168	0.5

$$z_i = e^{\mu_i / T}.$$

$$-x^3 \cdot T \cdot e^{-\frac{x}{T}} - T^2 \cdot 3 \cdot x^2 \cdot e^{-\frac{x}{T}} - T^3 \cdot 6 \cdot x \cdot e^{-\frac{x}{T}} - T^4 \cdot 6 \cdot e^{-\frac{x}{T}} + Const$$