Open and hidden strangeness with kaons and ϕ-mesons in Bjorken energy density approach for central A+A collisions from SPS to LHC

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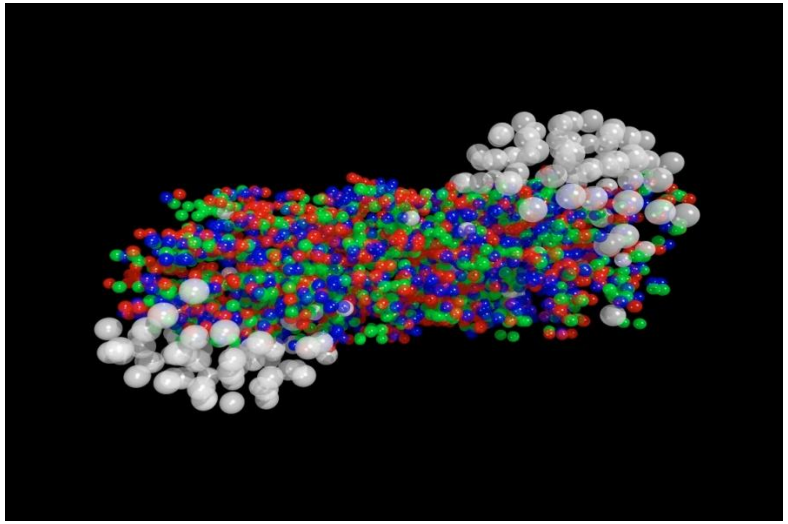
Strangeness in particle yields.

$$\varphi(1020) - meson$$
$$s\bar{s} - \ quark$$

$$K^*(892) - meson$$
$$\bar{d}s - \ quark$$

$$K(495) - meson$$
$$su - \ quark$$



Rafelski, and Muller have shown that a plasma created in nuclear collisions would result in an enhanced production of strange quarks, possibly at a level 10—50 times that in ordinary hadronic collisions.

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

φ – meson

$$\varphi(1020) - meson$$
$$s\bar{s} - \; quark$$

In a plasma, strange and antistrange quarks would be produced primarily by gluon-gluon interactions.

During the hadronization phase, s and $\bar{s}$ quarks from the plasma form ϕ – mesons could be also produced via coalescence .

The lack of OZI suppression, in addition to the large abundance of strange quarks predicted to exist in the plasma, may provide for a dramatic increase in the production of the ϕ-meson following the formation of a QGP.

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

Bjorken's formula

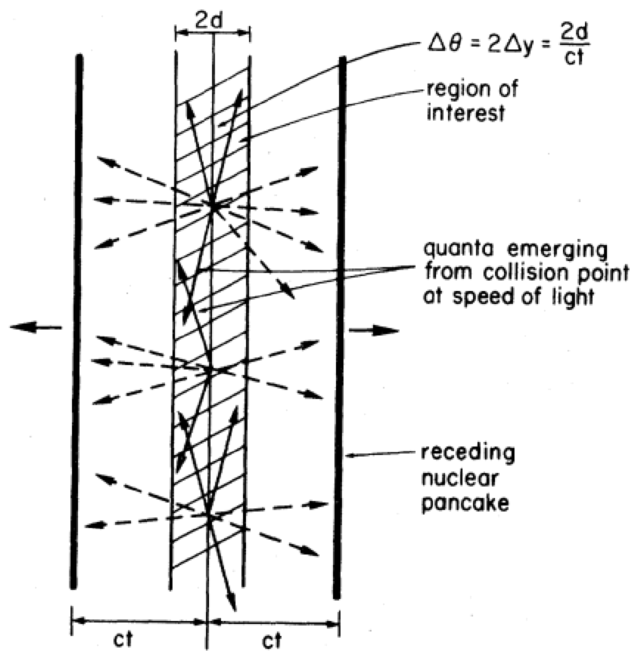
S⊥ – is the transverse overlap area of the colliding nuclei

$$\langle m_\perp \rangle = \sqrt{\langle p_\perp \rangle^2 + m^2}$$

$$\varepsilon \cdot \tau = \frac{dE_\perp}{dy} \frac{1}{S_\perp}$$

$$\varepsilon = \frac{dE_\perp}{dy} \frac{1}{S_\perp \cdot \tau}$$

[1]



E⊥ – is the total transverse energy

τ - is the formation time

$$\tau \sim 1\ fm/c$$

[2]

$$\frac{d\langle E_\perp \rangle}{dy} \approx \frac{3}{2}\left(\langle m_\perp \rangle \frac{dN}{dy}\right)_{\pi^\pm} + 2\left(\langle m_\perp \rangle \frac{dN}{dy}\right)_{K^\pm, p, \bar{p}}$$

The factors 3/2 and 2 compensate for the neutral particles.

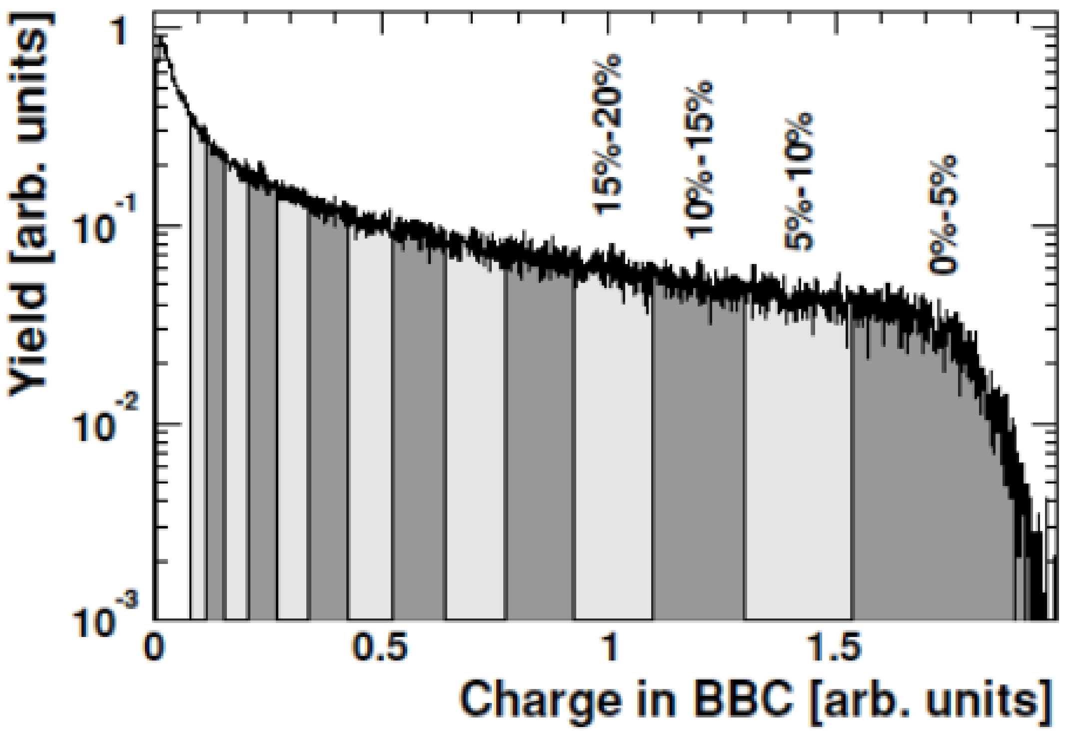
ε≈ 1 GeV/fm³

is critical energy density

[1] J. D. Bjorken, Phys. Rev. D 27, 140 (1983)
[2]B. I. Abelev, M. M. Aggarwal et al. PHYSICAL REVIEW C 79, 034909 (2009)

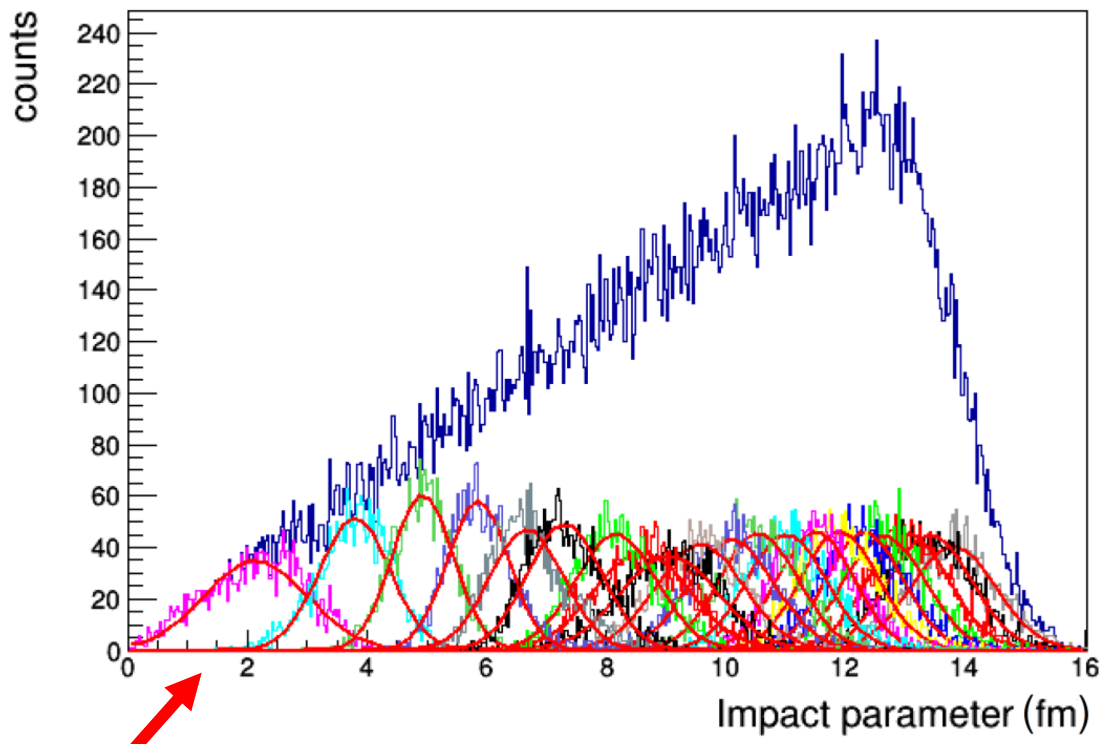
0-5% classes of "very central " collisions

Example of different centrality classes by PHENIX[1]



[1] PHYSICAL REVIEW C 71, 034908 (2005)

Example of *b* distributions from MC calculations



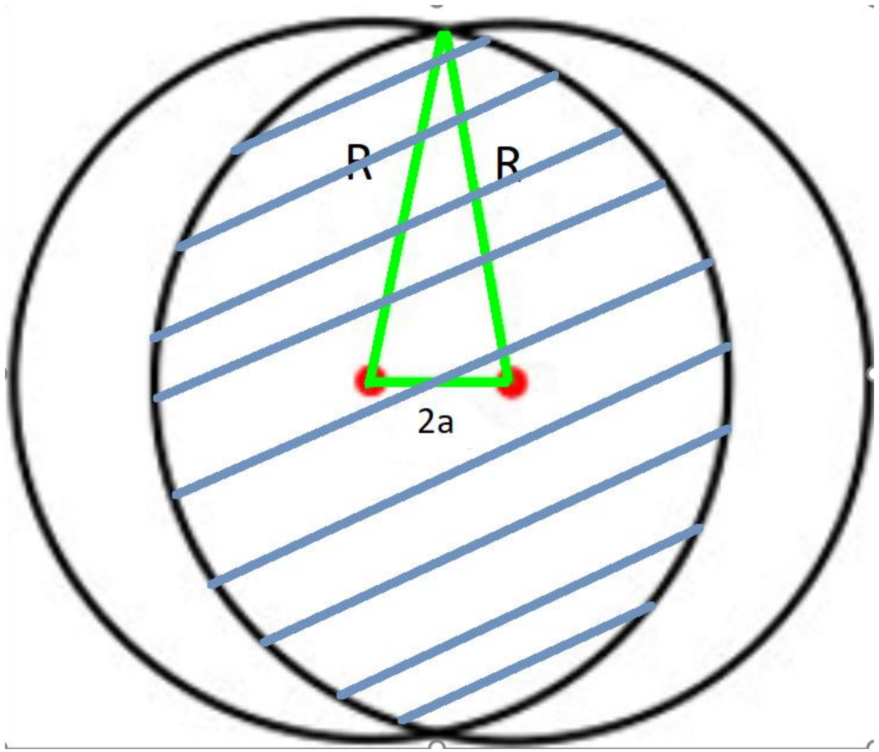
[2] Eur. Phys. J. A (2022) 58: 140

Evident shift in 2 fm for mean impact parameter for majority or events in 0-5% centrality class

S. S. Adler, S. Afanasiev,et al. PHYSICAL REVIEW C 71, 034908 (2005)!!!

<b> shift and area S⊥ of central (0-5%) collisions

The shift in <b> is here denoted as 2a



The new area is smaller than πR^2

$$S_\perp = 2 \cdot \left(\frac{2\pi R^2 \cdot \arccos \frac{a}{R}}{360^\circ} - a \cdot \sqrt{R^2 - a^2} \right)$$

Contribution of pions, kaons, and protons to the mean per unit rapidity and to the product

<table>
<tr><th rowspan="2">$\sqrt{S_{NN}}$ GeV</th><th rowspan="2">Particles</th><th rowspan="2" colspan="2">$< p_\perp >$, GeV/c</th><th colspan="2">$< \frac{dN}{dy} >$</th><th rowspan="2">$< \frac{dE_\perp}{dy} >$, GeV This work</th><th rowspan="2">$\varepsilon \cdot \tau$, GeV/fm^2 This work</th></tr>
<tr><th>π+, K+, p</th><th>π⁻, K⁻, p⁻</th></tr>
<tr><td rowspan="3">62.4</td><td>Pions</td><td colspan="2">0.4 [1]</td><td>237 ± 17 [1]</td><td>233 ± 17 [1]</td><td>298.7 ± 14.3</td><td>2.5 ± 0.14</td></tr>
<tr><td>Kaons</td><td colspan="2">0.6-0.65 ± 0.05 [1]</td><td>32.4 ± 2.3 [1]</td><td>37.6 ± 2.7 [1]</td><td>111.5 ± 16.2</td><td>0.94 ± 0.16</td></tr>
<tr><td>Protons</td><td colspan="2">0.95 ± 01 [1]</td><td>13.6 ± 1.7 [1]</td><td>29.0 ± 3.8 [1]</td><td>113.8 ± 26.8</td><td>0.96 ± 0.27</td></tr>
<tr><td rowspan="3">130</td><td>Pions</td><td colspan="2">0.4 [1]</td><td>280 ± 25 [1]</td><td>278 ± 25 [1]</td><td>355 ± 21</td><td>2.99 ± 0.2</td></tr>
<tr><td>Kaons</td><td colspan="2">0.65-0.7 ± 0.05 [1]</td><td>42.7 ± 6.2 [1]</td><td>46.3 ± 6.5 [1]</td><td>145.8 ± 35.3</td><td>1.2 ± 0.35</td></tr>
<tr><td>Protons</td><td colspan="2">1 ± 01 [1]</td><td>20.0 ± 3.4 [1]</td><td>28.2 ± 4.4 [1]</td><td>132.2 ± 35.4</td><td>1.1 ± 0.35</td></tr>
<tr><td rowspan="3">200</td><td>Pions</td><td colspan="2">0.4 [1]</td><td>327 ± 25 [1]</td><td>322 ± 25 [1]</td><td>392 ± 24</td><td>3.3 ± 0.23</td></tr>
<tr><td>Kaons</td><td colspan="2">0.7-0.8 ± 0.05 [1]</td><td>49.5 ± 6.2 [1]</td><td>51.3 ± 6.5 [1]</td><td>181 ± 40.8</td><td>1.5 ± 0.4</td></tr>
<tr><td>Protons</td><td colspan="2">1.1 ± 01 [1]</td><td>26.7 ± 3.4 [1]</td><td>34.7 ± 4.4 [1]</td><td>177.6 ± 41.3</td><td>1.5 ± 0.4</td></tr>
<tr><td rowspan="3">2760</td><td>Pions</td><td>0.517+-0.019 [2]</td><td>0.520+-0.018 [2]</td><td>733 ± 54 [2]</td><td>732 ± 52 [2]</td><td>1179.96 ± 110.7</td><td>9.1 ± 1.0</td></tr>
<tr><td>Kaons</td><td>0.876+-0.026 [2]</td><td>0.867+-0.027 [2]</td><td>109 ± 9 [2]</td><td>109 ± 9 [2]</td><td>436.7 ± 56.5</td><td>3.4 ± 0.5</td></tr>
<tr><td>Protons</td><td>1.333+-0.033 [2]</td><td>1.353+-0.034 [2]</td><td>34 ± 3 [2]</td><td>33 ± 3 [2]</td><td>219.5 ± 27.1</td><td>1.7 ± 0.24</td></tr>
<tr><td rowspan="3">5020</td><td>Pions</td><td colspan="2">0.5682 [3]</td><td colspan="2">1699.80 [3]</td><td>1491.8 ± 167.2</td><td>11.5 ± 1.5</td></tr>
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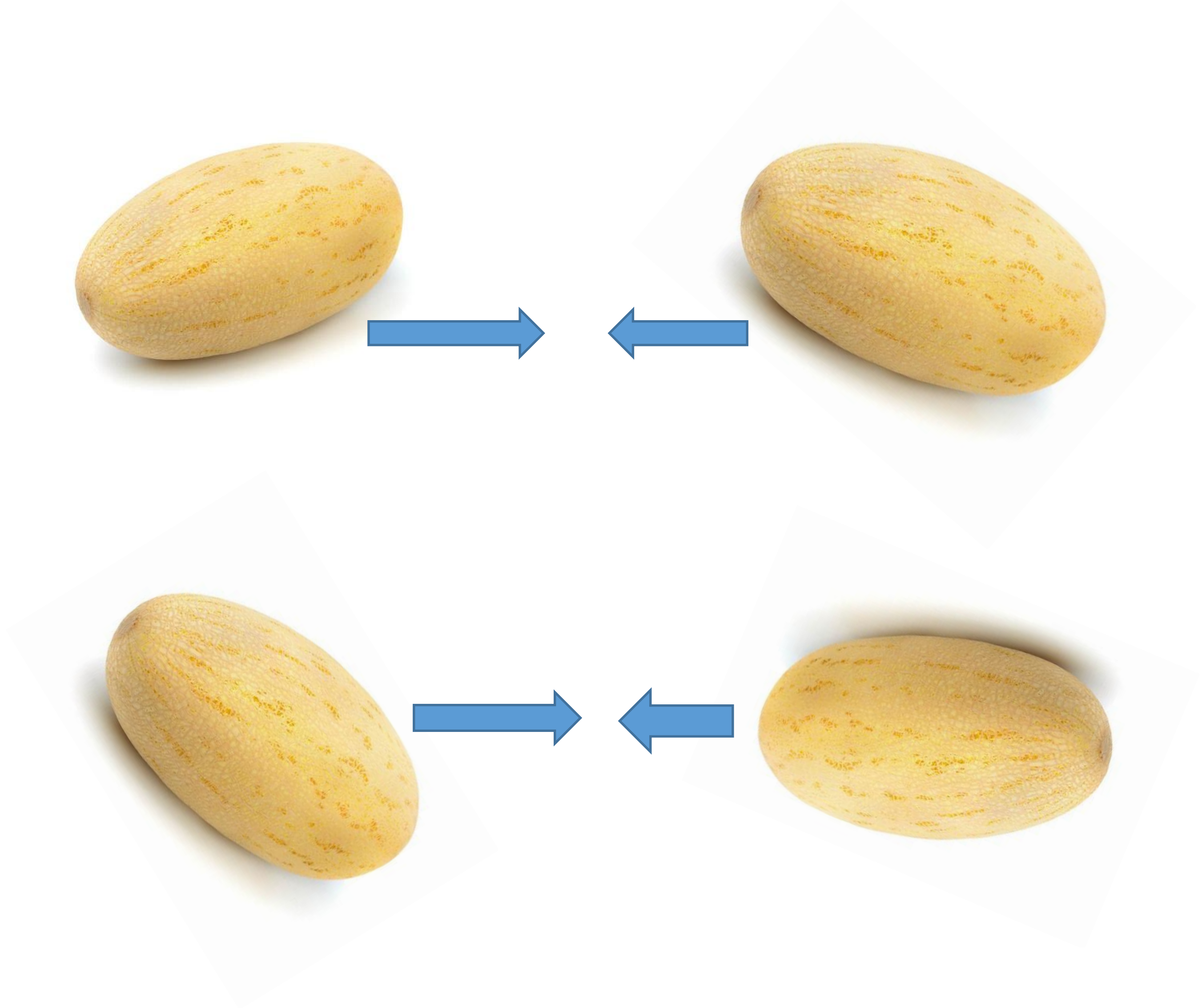
<tr><td>Protons</td><td colspan="2">1.4482 [3]</td><td colspan="2">74.56 [3]</td><td>257 ± 18</td><td>1.99 ± 0.16</td></tr>
</table>

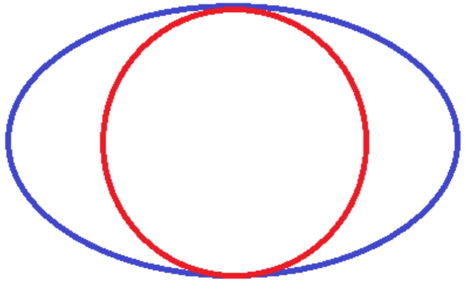
1. B. I. Abelev et al. (STAR Collab.), Phys. Rev. C 79, 034909 (2009).
2. B. Abelev et al. (ALICE Collab.), Phys. Rev. C 88, 044910 (2013).
3. S. Acharya *et al.* (ALICE Collab.), Phys. Rev. C 101, 044907(2020).

On the orientations of nuclei in space



There are much more options for the development of events for deformed nuclei than for undeformed ones

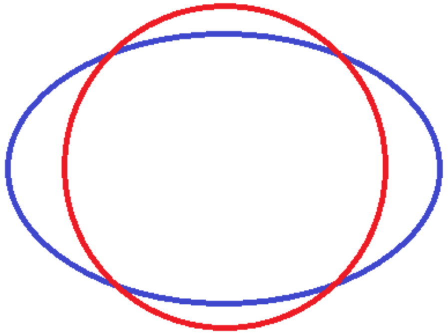
Xenon area for the most central events



$$\bar{R} = (b + a)/2,$$

$$\beta = \frac{b - a}{\frac{1}{2}(b + a)} = \frac{1}{2}\frac{b^2 - a^2}{\bar{R}^2}$$

R	$S_{\perp}$(taking into account the targeting parameter)
5.4	70.1
4.9	54.05



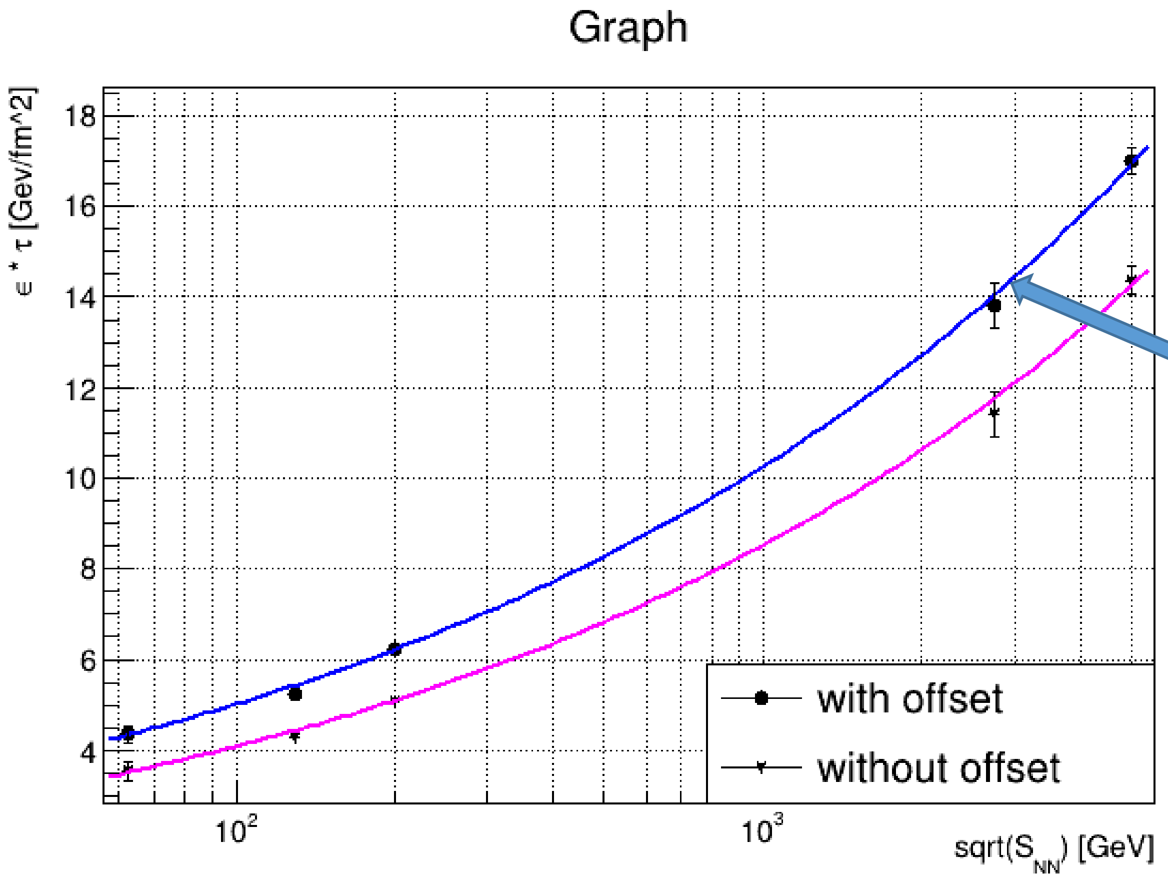
$$\rho(r, \vartheta) = \rho_0 \frac{1}{1 + \exp\left(\frac{r - R(\vartheta)}{a}\right)}$$ [1]

$$Y_{20} = \sqrt{\frac{5}{4\pi}}\left(\frac{3}{2}\cos^2\theta - \frac{1}{2}\right)$$ [1]

R = 5.4 fm

[1] - Phys. Lett. B 790 (2019) 35

$S_{\perp eff.}$



Different methods for calculating area give very different results, so we use a fictitious area obtained from extrapolation of previously obtained results.

$$\varepsilon \cdot \tau = 1.12 \cdot (\sqrt{S_{NN}})^{0.162}$$

$$\sqrt{S_{NN}} = 5440\ GeV$$

$$S_{\perp eff.} = 72.7$$

Correction to Bjorken energy density calculations for central A-A collisions, repoted O.Shaposhnikova et ICPPA 2022 (to be published)

Contribution of pions, kaons, and protons to the mean per unit rapidity and to the product (new results)

$\sqrt{S_{NN}}$, GeV	Particles	$<p_\perp>$, GeV/c	$<\frac{dN}{dy}>$ $\pi+$, K+, p	$<\frac{dN}{dy}>$ π^-, K^-, p^-	$<\frac{dE_\perp}{dy}>$, GeV This work	$\varepsilon \cdot \tau$, GeV/fm^2 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
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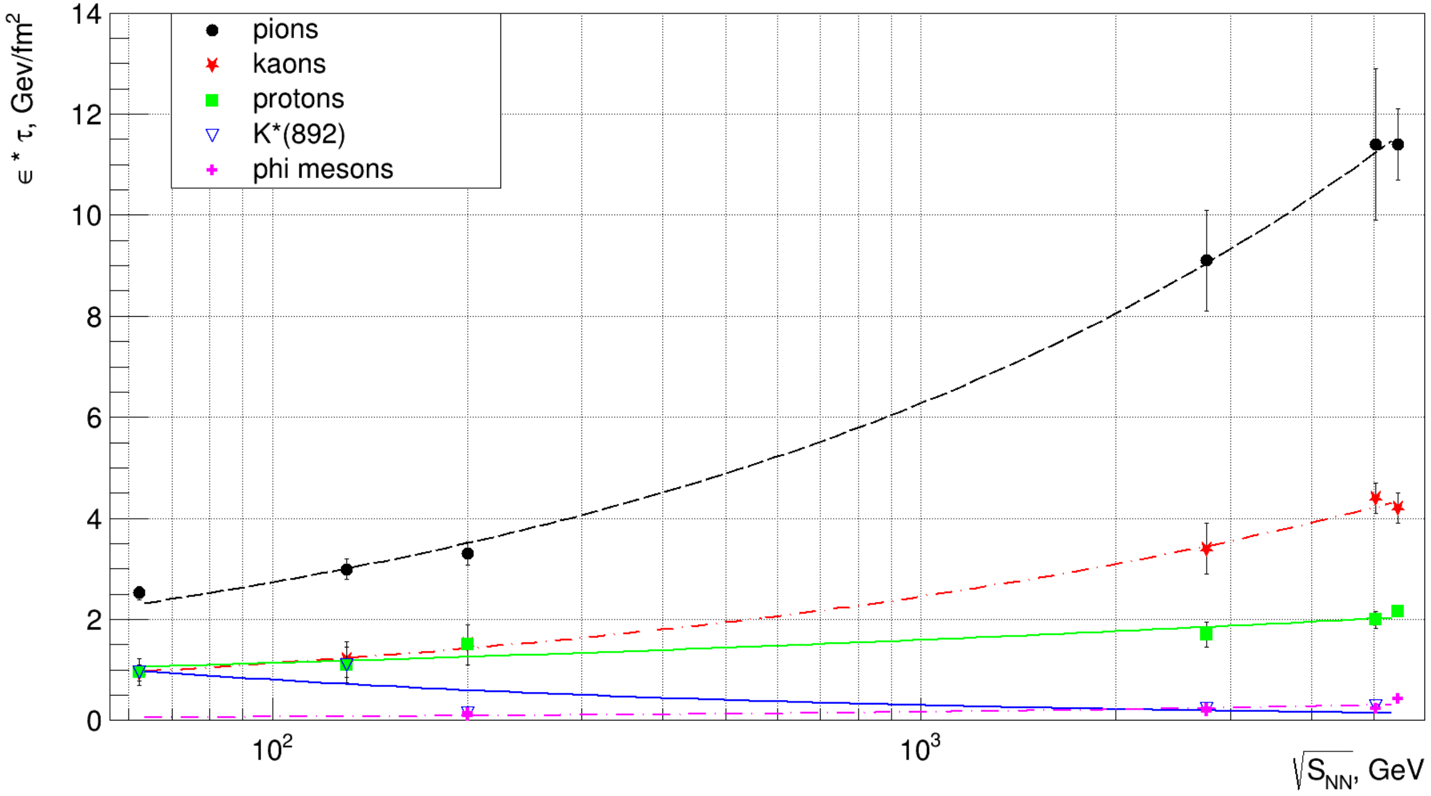
	Protons	1 ± 01 [1]	20.0 ± 3.4 [1]	28.2 ± 4.4 [1]	132.2 ± 35.4	1.1 ± 0.35
200	Pions	0.4 [1]	327 ± 25 [1]	322 ± 25 [1]	392 ± 24	3.3 ± 0.23
	Kaons	0.7-0.8 ± 0.05 [1]	49.5 ± 6.2 [1]	51.3 ± 6.5 [1]	181 ± 40.8	1.5 ± 0.4
	K^*	10.48±2.4 [2]	1.08±0.12 [2]		14.7±4.3	0.14±0.04
	Protons	1.1 ± 01 [1]	26.7 ± 3.4 [1]	34.7 ± 4.4 [1]	177.6 ± 41.3	1.5 ± 0.4
	φ	0.97±0.02 [3]	7.7±0.3 [3]		10.84±0.5	0.09±0.004
2760	Pions	0.517+-0.019 [4] / 0.520+-0.018 [4]	733 ± 54 [4]	732 ± 52 [4]	1179.96 ± 110.7	9.1 ± 1.0
	Kaons	0.876+-0.026 [4] / 0.867+-0.027 [4]	109 ± 9 [4]	109 ± 9 [4]	436.7 ± 56.5	3.4 ± 0.5
	K^*	19.56±2.6 [5]	1.31±0.06 [5]		30.9±5.09	0.23±0.04
	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
	φ	1.31±0.07 [6]	13.8±1.8 [6]		22.9±3.8	0.18±0.03
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
	K^*	1.46±0.07 [8]	19.7±2.8 [8]		37.54±6.5	0.29±0.05
	Protons	1.4482[7]	74.56[7]		257 ± 18	1.99 ± 0.16
	φ	1.4±0.02 [8]	14.9±1.2 [8]		29.8±3.9	0.23±0.03
5044	Pions	0.53±0.02[9]	1002.67±57.2 [9]		826.65±51.5	11.4 ±0.7
	Kaons	0.9±0.03 [9]	149.37±14.07[9]		308±19	4.2±0.3
	Protons	1.4±0.02 [9]	46.21±4.7 [9]		156.9	2.15±0.1
	φ	1.33±0.03 [9]	9.27±1 [9]		31.5±1.9	0.43±0.03

1. B. I. Abelev et al. (STAR Collab.), Phys. Rev. C 79, 034909 (2009).
2. J. Adams et al. (STAR Collab.) Physics Letters B 612 (2005) 181–189
3. J. Adams et al. (STAR Collab.) Phys.Rev.C71:064902,2005
4. B. Abelev et al. (ALICE Collab.), Phys. Rev. C 88, 044910 (2013).
5. J. Adams et al. (STAR Collab.) PHYSICAL REVIEW C 95, 064606 (2017)
6. B. Abelev et al. (ALICE Collab.) PHYSICAL REVIEW C 91, 024609 (2015)
7. S. Acharya *et al.* (ALICE Collab.), Phys. Rev. C 101, 044907(2020).
8. S. Acharya et al.∗ (ALICE Collaboration) Phys. Rev. C 106, 034907 (2022)
9. (ALICE Collab.),)Eur. Phys. J. C 81 (2021) 584

Contributions of pions, kaons and protons

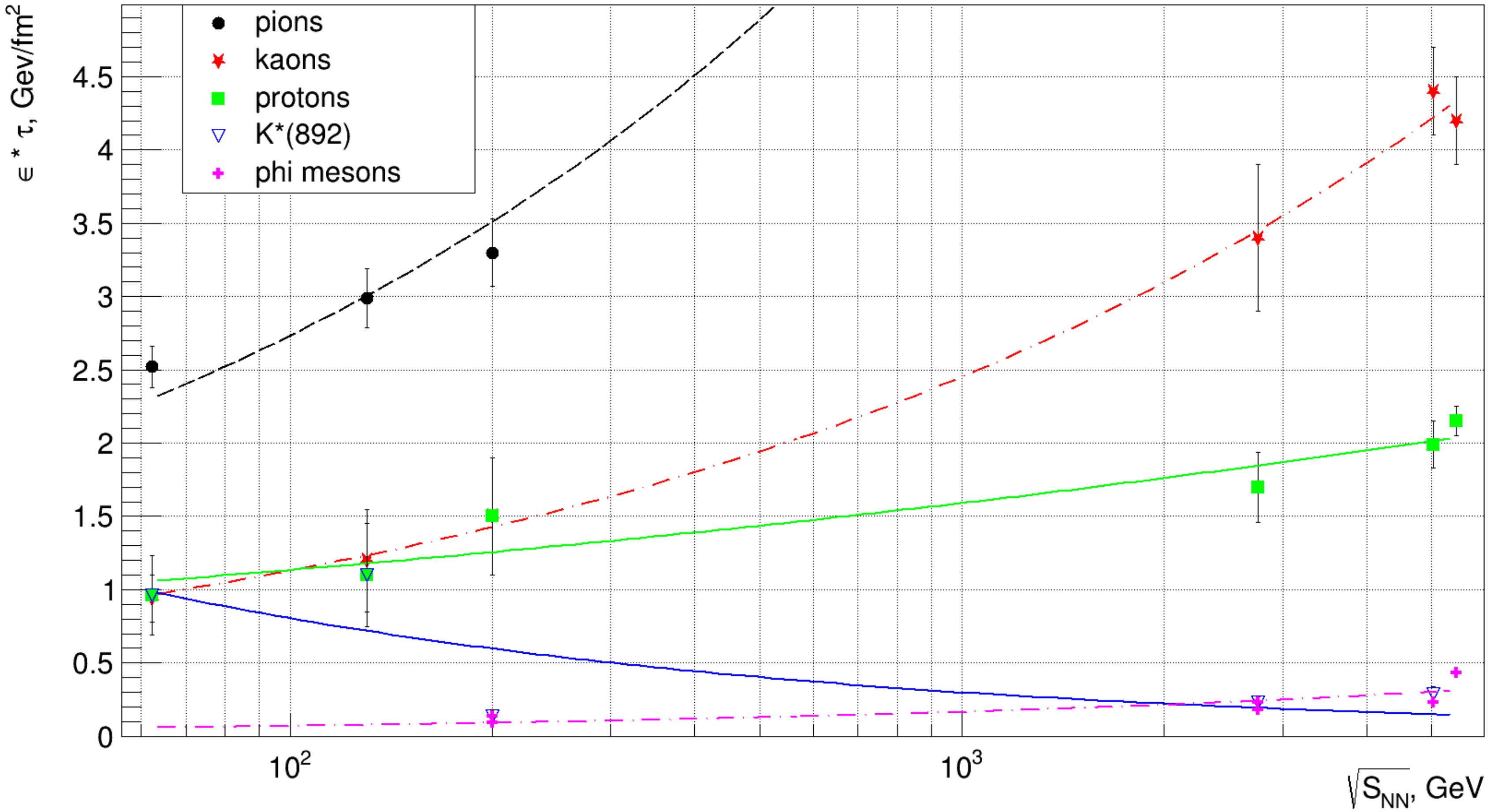


1) It can be seen that the greatest contribution is made by pions and kaons, but protons also cannot be neglected.
2)Slower energy dependence for heavy particles
3) The yield of K^* -mesons and phi-mesons remains virtually unchanged and constitutes a very small fraction of the Bjorken energy density.

Our corrections to experimental on 0-5% classes data
(Statistical errors are not shown)

Parametrisations

		K	p	K*(892)	ϕ
n	0.36±0.01	0.34±0.02	0.15±0.03	-0.43±0.375	0.37±0.23
Q	0.51±0.04	0.24±0.03	0.58±0.12	5.83±10.35	0.01±0.02
χ^2/NDF	0.15/4	0.06/4	0.11/4	0.38/3	0.03/4



$$\varepsilon \cdot \tau = Q \cdot (\sqrt{S_{NN}})^n$$

Conclusions:

1) For the most central A-A collisions 0-5 %, we take into account the dominance of events with an average impact parameter of ~2 fm. So - the mean collision overlap area decreases, and consequently the energy density is increased.

2) The fraction of Bjorken energy of particles with open and hidden strangeness was studied in wide energy range of A-A collisions.

3) The particle, which has a hidden strangeness, the phi meson, makes virtually no contribution.

4) K^* *-mesons have a different dependence. The energy spent on their birth decreases with increasing energy.*

5) Future plants: the fractions of Bjorken energy density for Λ *and* Ξ, Ω *hiperons.*

BACK-UP SLIDES