Correction to Bjorken energy density calculations for central A-A collisions

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Bjorken's formula

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

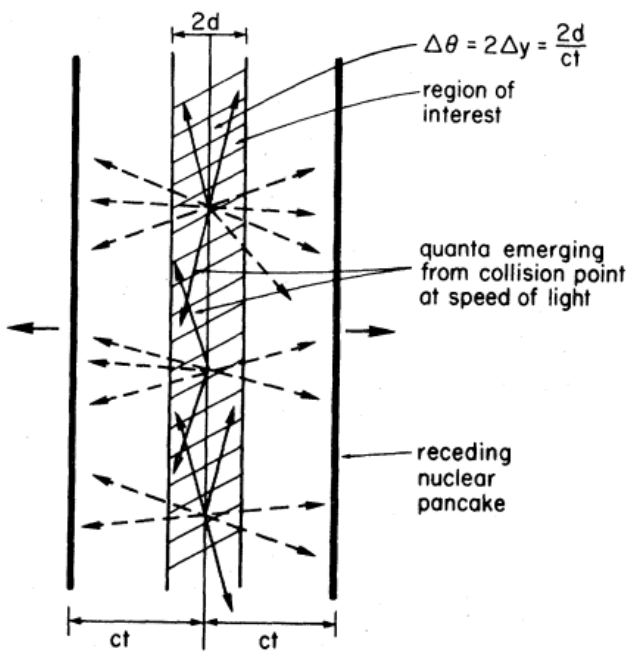
E⊥ – is the total transverse energy

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

τ - is the formation time

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

[1]



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

[2]

ε≈ 1 GeV/fm³

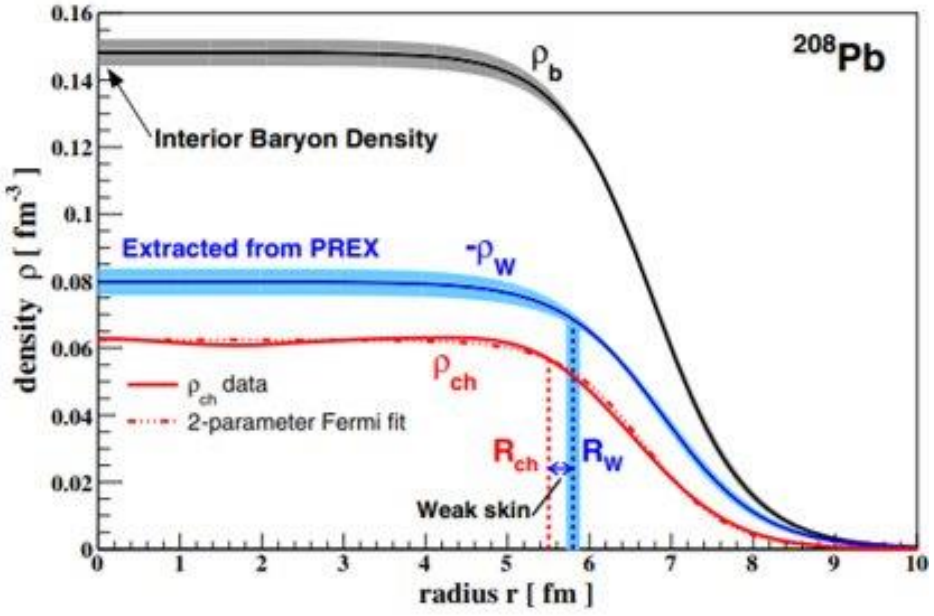
The factors 3/2 and 2 compensate for the neutral particles.

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)

Usually used quantities:

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

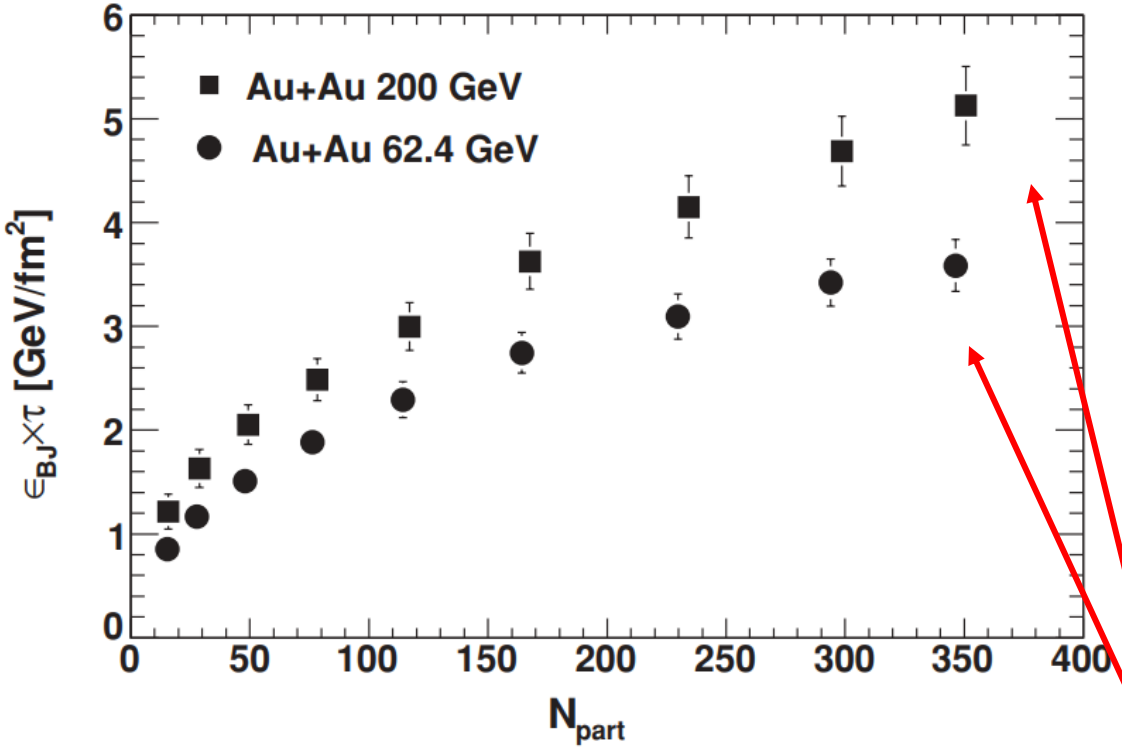


Nuclear density profile

$$S_\perp = \pi R^2$$

Here R – the radius of nucleas taken at 90% density

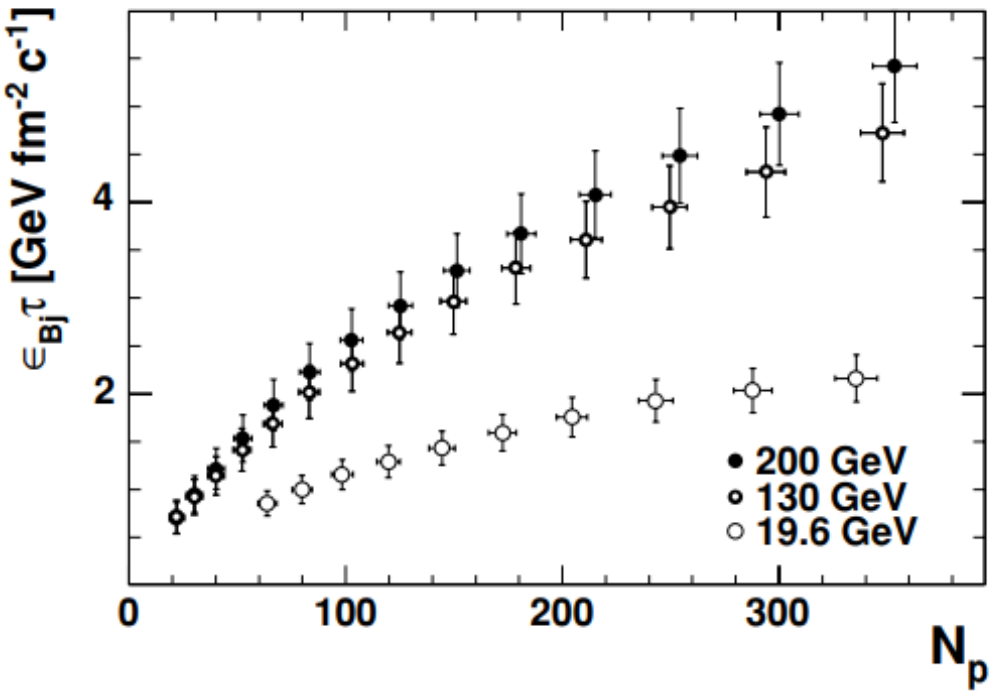
Some results obtained so far: $\varepsilon \cdot \tau$ vs. centrality most (0-5%)



B. I. Abelev, M. M. Aggarwal et al.

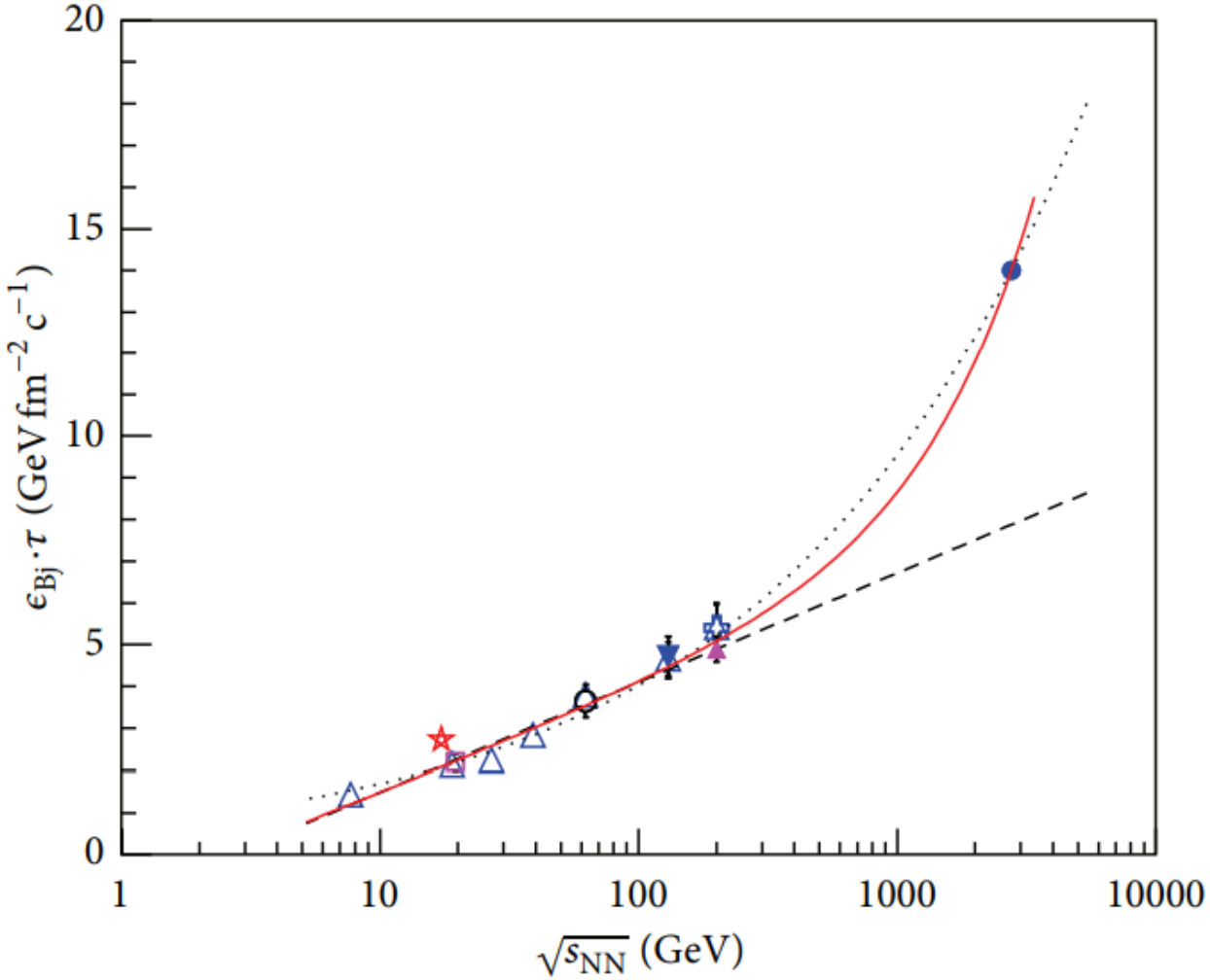
PHYSICAL REVIEW C 79, 034909 (2009)

0-5%



S. S. Adler,5 S. Afanasiev, et al. PHYSICAL REVIEW C 71, 034908 (2005)

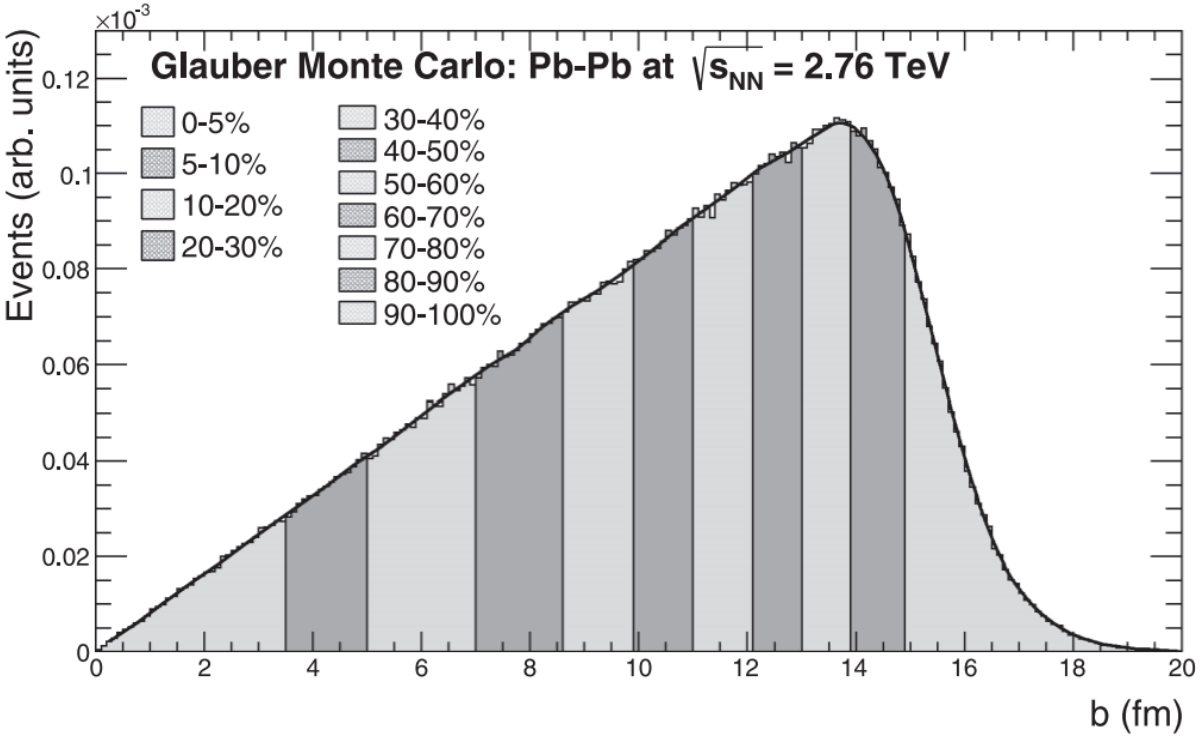
The results obtained by CMS: $\varepsilon \cdot \tau$ vs. collision energy for very central(0-5%)

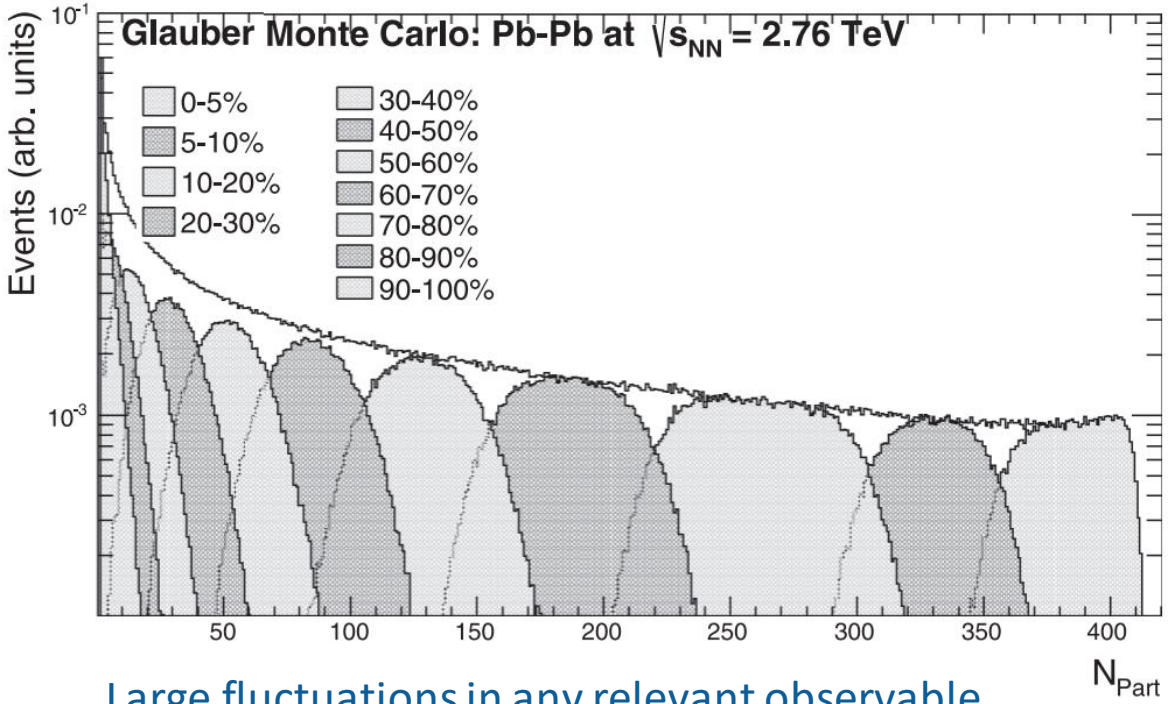


- CMS (Pb+Pb, $\sqrt{s_{NN}}$ = 2.76 TeV)
- PHENIX (Au+Au, $\sqrt{s_{NN}}$ = 200 GeV)
- STAR (Au+Au, $\sqrt{s_{NN}}$ = 200 GeV)
- PHENIX (Au+Au, $\sqrt{s_{NN}}$ = 130 GeV)
- STAR (Au+Au, $\sqrt{s_{NN}}$ = 62.4 GeV)
- PHENIX (Au+Au, $\sqrt{s_{NN}}$ = 19.6 GeV)
- NA49 (Pb+Pb, $\sqrt{s_{NN}}$ = 17.2 GeV)
- PHENIX beam energy scan
- $A + B \ln \sqrt{s_{NN}}$
- $P + Q(\sqrt{s_{NN}})^n$
- $\alpha + \beta \ln \sqrt{s_{NN}} + \gamma(\sqrt{s_{NN}})^n$

From: Raghunath Sahoo, Aditya Nath Mishra et al. Review Article 612390 -22(2015)

Methodology: centrality class 0-5%





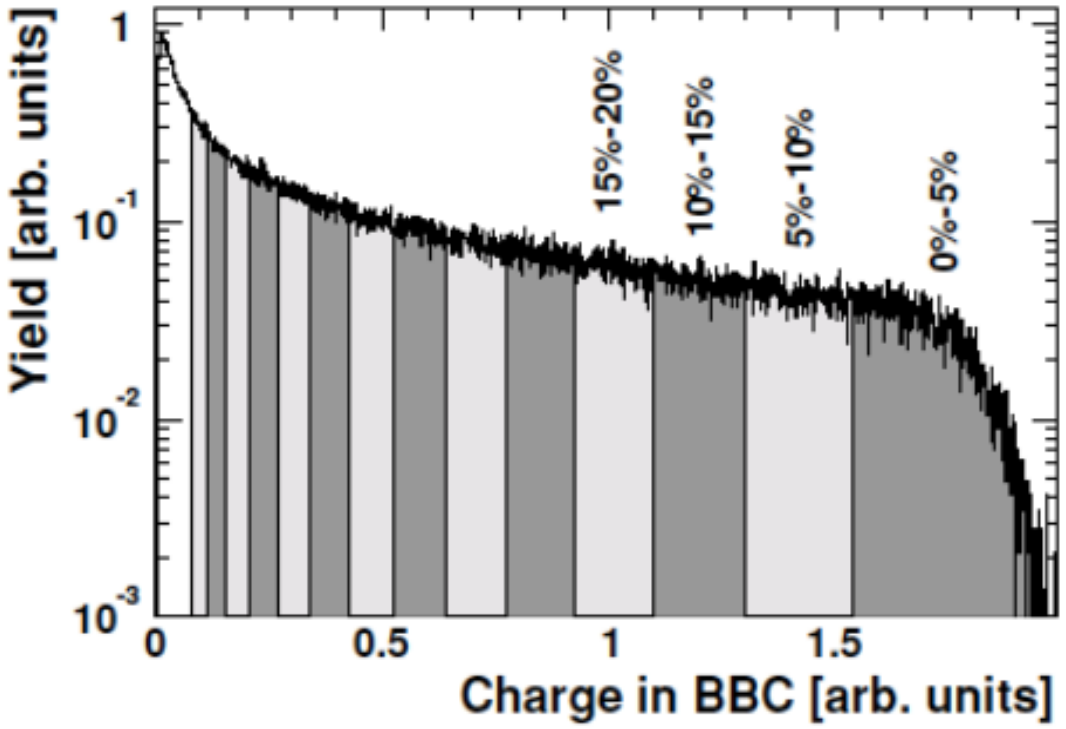
Large fluctuations in any relevant observable

Geometric properties of Pb-Pb collisions at √sNN = 2.76 TeV obtained from a Glauber Monte Carlo calculation: impact parameter distribution (left), sliced for percentiles of the hadronic cross section, and distributions of the number of participants (right) for the corresponding centrality classes.

B. ABELEV et al. PHYSICAL REVIEW C 88, 044909 (2013)

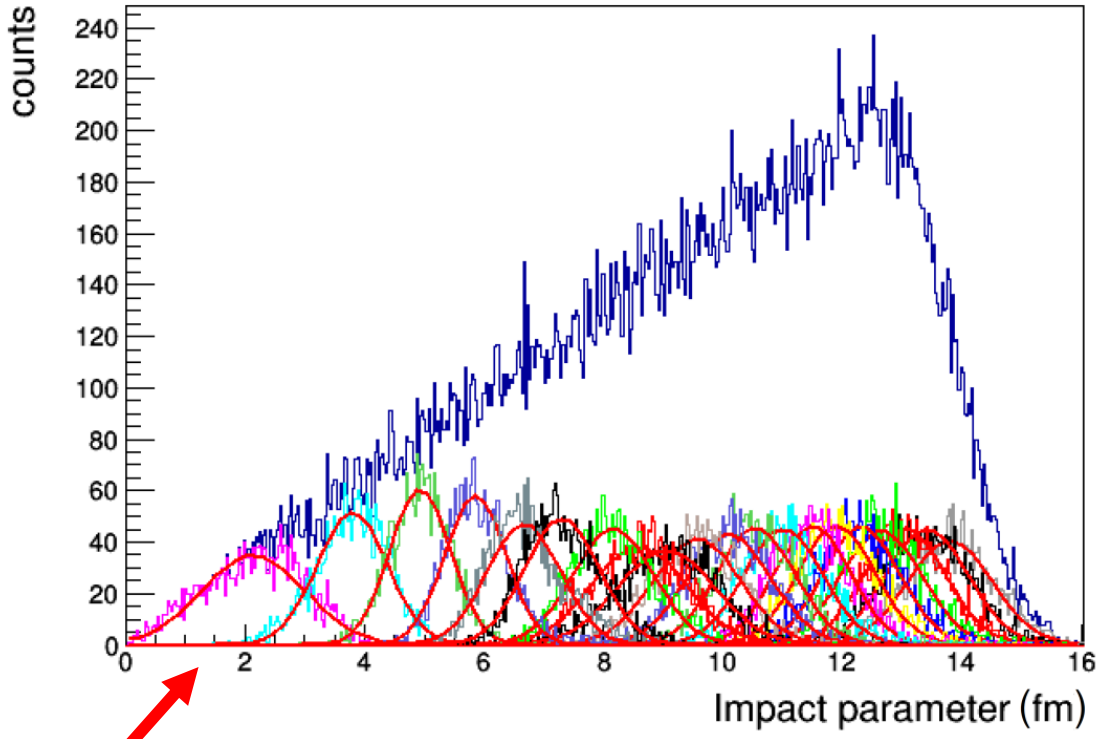
0-5% classes of "very central " collisions

Example of different centrality classes by PHENIX[1]



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

Example of *b* distributions from MC calculations



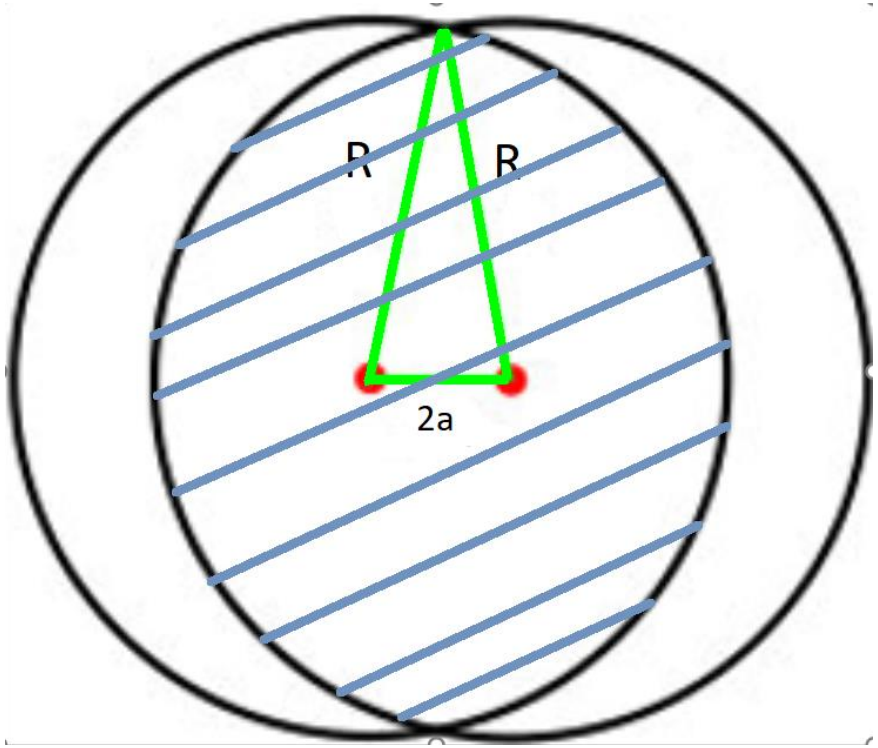
[2] Eur. Phys. J. A (2022) **58**: 140

Evident shift in 2 fm for mean impact parametr 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

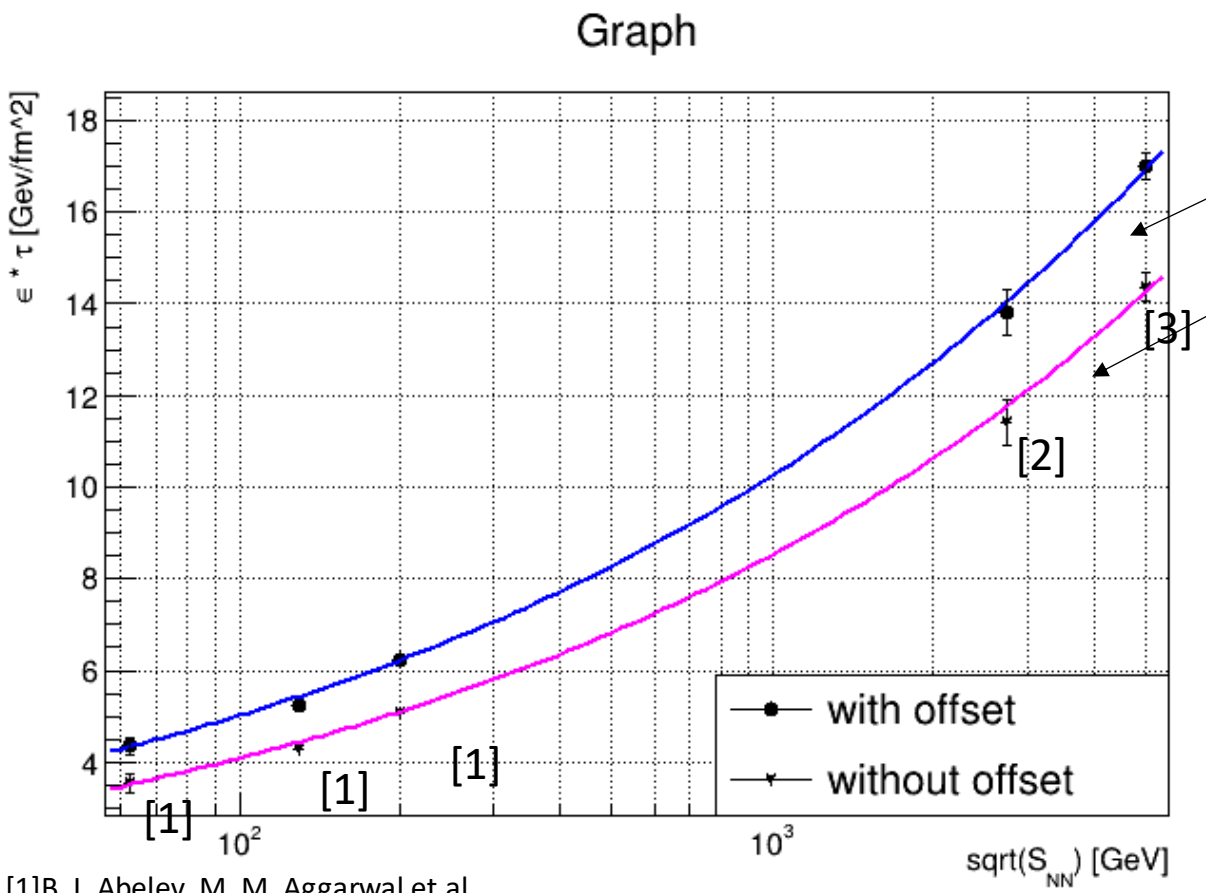
The shift in <b> is here denoted as 2a



The new area is smaller than πR^2

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

$\varepsilon \cdot \tau$ vs. $\sqrt{SNN}$ results for 0-5% classes



Our results(fits by MINUT[4])

Old results([1],[2],[3])

Parametrisation:

$$\varepsilon \cdot \tau = \alpha \cdot \left(\sqrt{S_{NN}}\right)^{\beta}$$

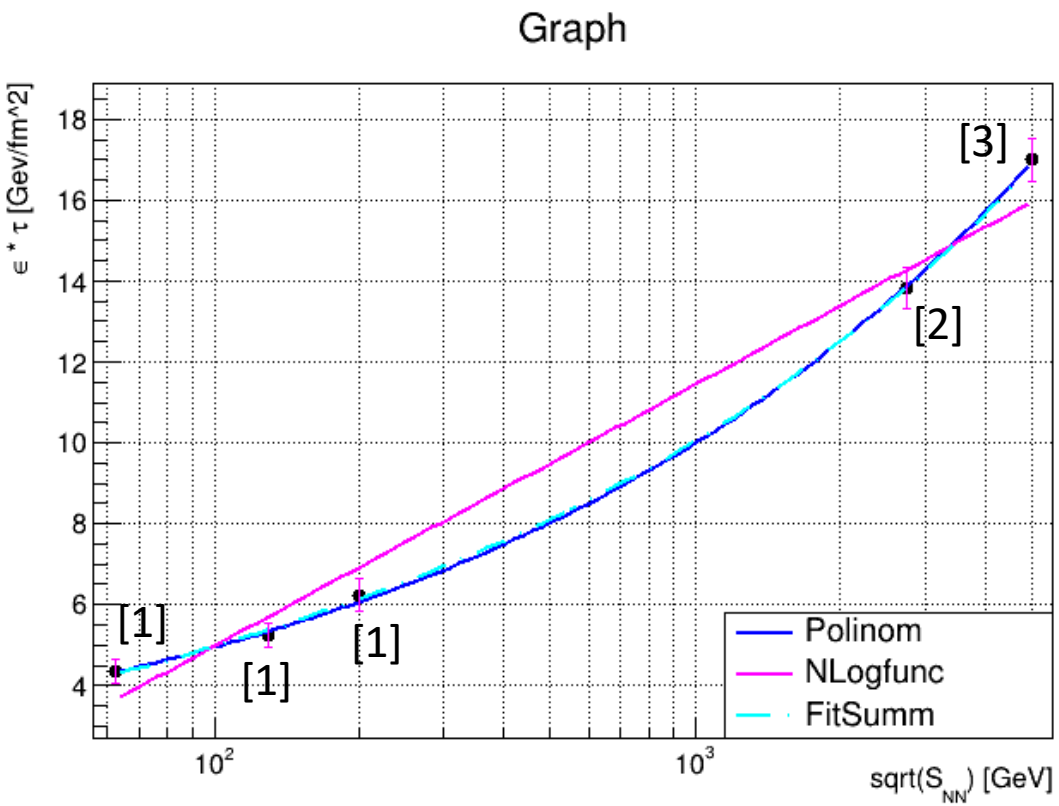
	α	β
Old	0.94±0.1	0.32±0.01
New	1.2±0.1	0.31±0.01

[1]B. I. Abelev, M. M. Aggarwal et al.
PHYSICAL REVIEW C 79, 034909(2009)
[2] ALICE Collaboration Phys. Rev. C 88, 044910 (2013)
[3] ALICE Collaboration Phys. Rev. C 101, 044907 (2020)
[4] Comput. Phys. Commun. 10 (1975) 343

1) The resulting energy density is higher

2) Different energy depencies

Varios approximations for energy dependence



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

$$\varepsilon \cdot \tau = \mathrm{A} + \mathrm{B}\ln\left(\sqrt{S_{NN}}\right)$$

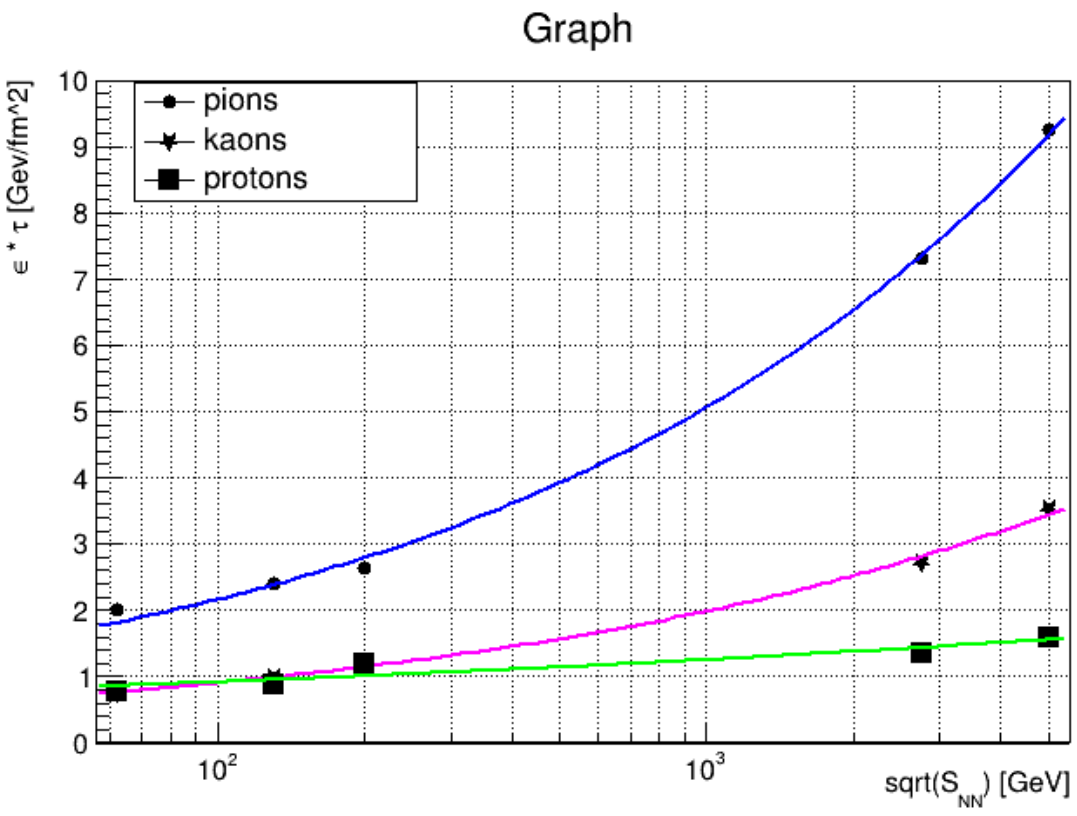
$$\varepsilon \cdot \tau = \alpha + \beta\ln\left(\sqrt{S_{NN}}\right) + \gamma\left(\sqrt{S_{NN}}\right)^m$$

	P	Q	n	A	B	α	β	γ	m
Old	1.27± 1.64	0.44± 0.55	0.39± 0.13	-6.9± 0.62	2.38± 0.11	1±0.58	0.01± 0.007	3	4.3
New	0.94± 1.37	0.79± 0.8	0.35± 0.1	-7.95± 0.62	2.8± 0.1	$3*10^{-7}$± 1.96	0.6± 0.03	3	4.3

[1]B. I. Abelev, M. M. Aggarwal et al. PHYSICAL REVIEW C 79, 034909(2009)
[2] ALICE Collaboration Phys. Rev. C 88, 044910 (2013)
[3] ALICE Collaboration Phys. Rev. C 101, 044907 (2020)

For approximations, it is better to take the power or the sum of the power and logarithmic

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

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

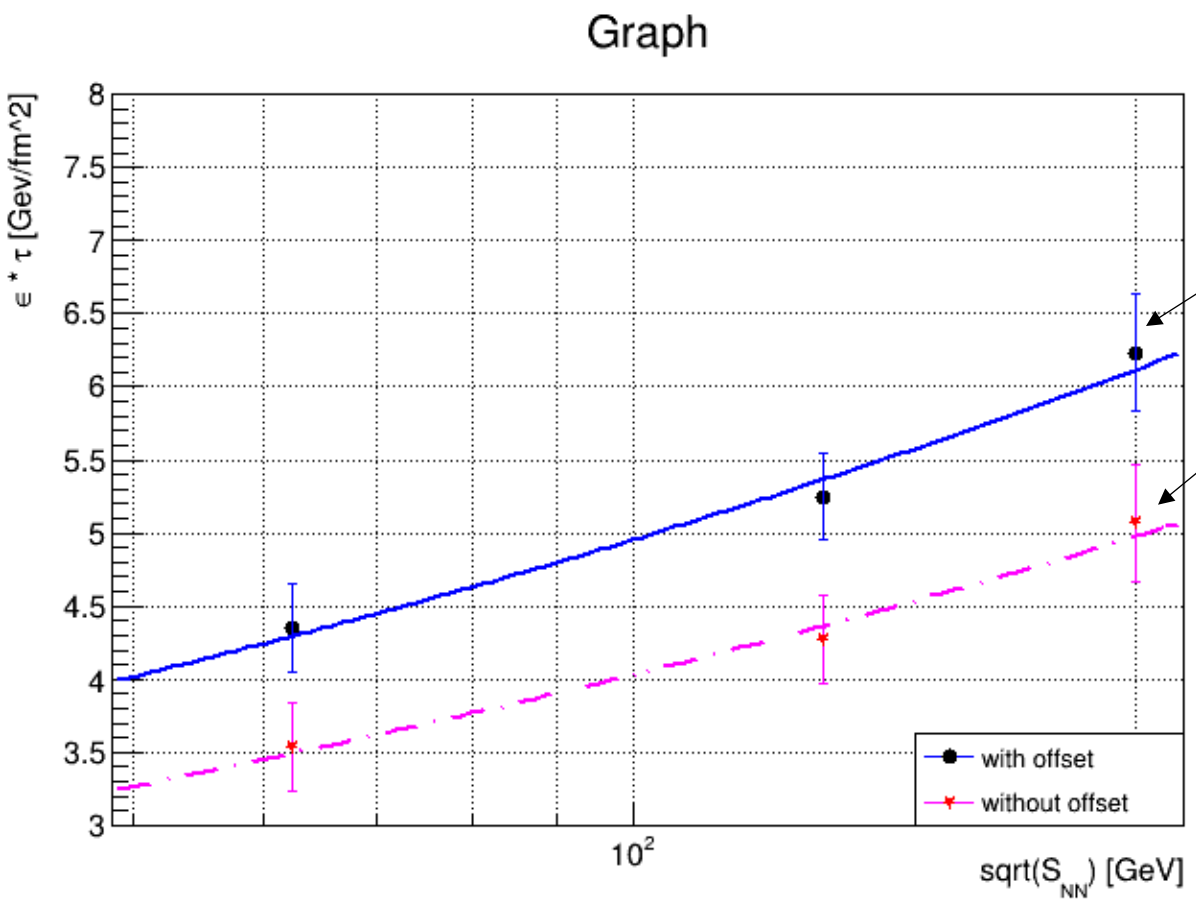
Our corrections to experimental on 0-5% classes data:

[1]B. I. Abelev, M. M. Aggarwal et al. PHYSICAL REVIEW C 79, 034909 (2009)

[2] ALICE Collaboration Phys. Rev. C 88, 044910 (2013)

[3] ALICE Collaboration Phys. Rev. C 101, 044907 (2020)

Extrapolation to region of RHIC energies



Our results(preliminary)

Old results([1])

$$\varepsilon \cdot \tau = \alpha \cdot \left(\sqrt{S_{NN}}\right)^{\beta}$$

	α	β
Old	0.94±0.1	0.32±0.01
New	1.2±0.1	0.31±0.01

Work is in progress

Hovewer, one has to be careful becous Bjorken energy density extrapolation is not quite justified

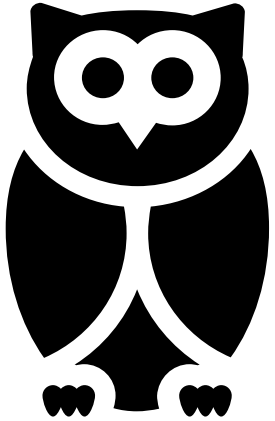
[1]B. I. Abelev, M. M. Aggarwal et al.
PHYSICAL REVIEW C 79, 034909 (2009)

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. In connection with this, the collision overlap area decreases, and consequently the density increases at these energies.

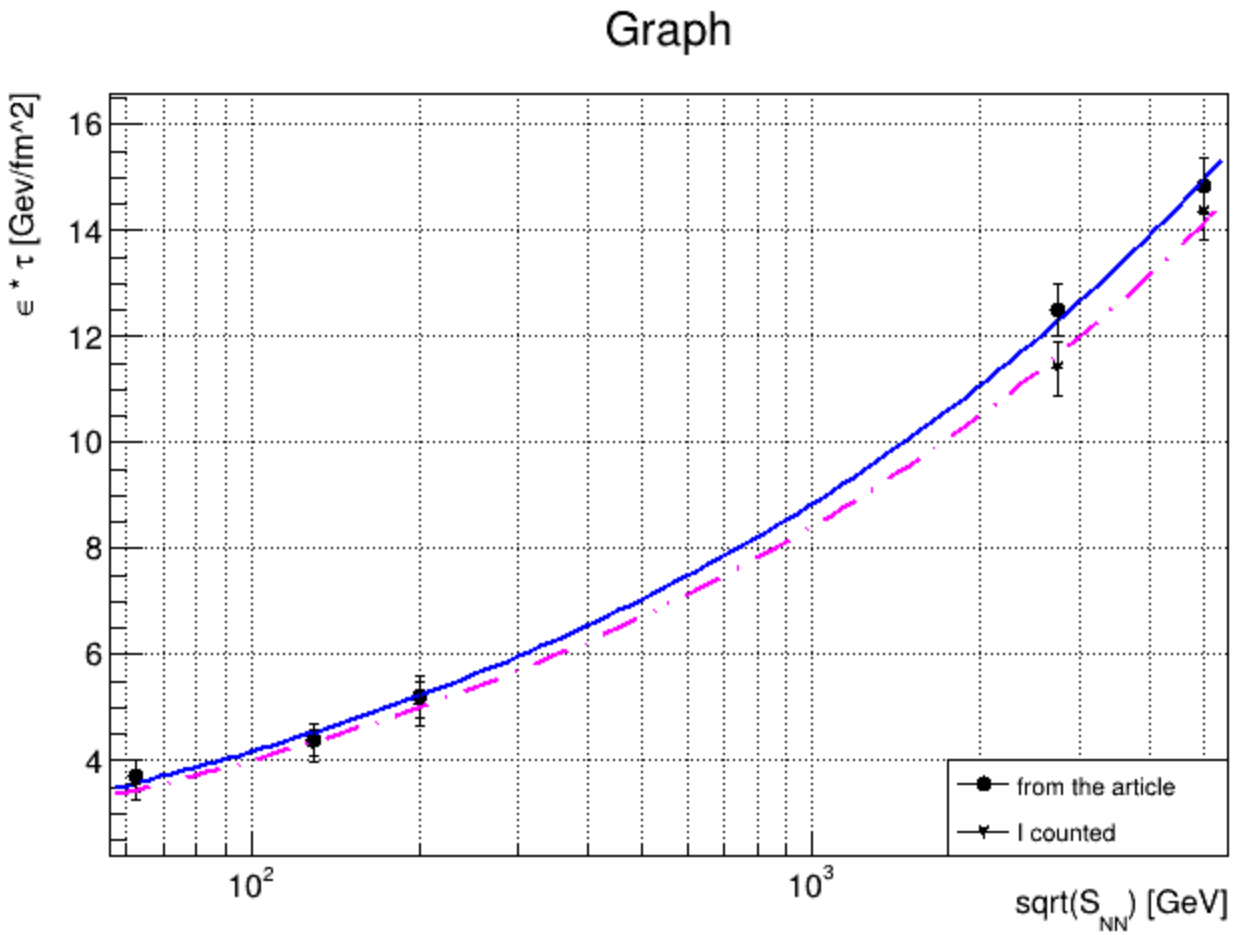
2) The results of recalculation of available data on $\varepsilon \cdot \tau$ are presented. Various approximations to the excitation function of $\varepsilon \cdot \tau$ vs. (√SNN) are tested.

3) The results show that lower energies of A-A collisions could be expected to reach the region of critical Bjorken's energy. More studies are planned for these lower energy region.



BACK-UP SLIDES

Checking the formula



62.4, 130, 200 GeV – (STAR, Au+Au, B. I. Abelev,9 M. M. Aggarwal et al. PHYSICAL REVIEW C 79, 034909 (2009))

2760, 5020 GeV – (RHIC, Pb+Pb, Ze –Fang Jiang et al.)