Modeling collective effects in the extended multi-pomeron exchange model

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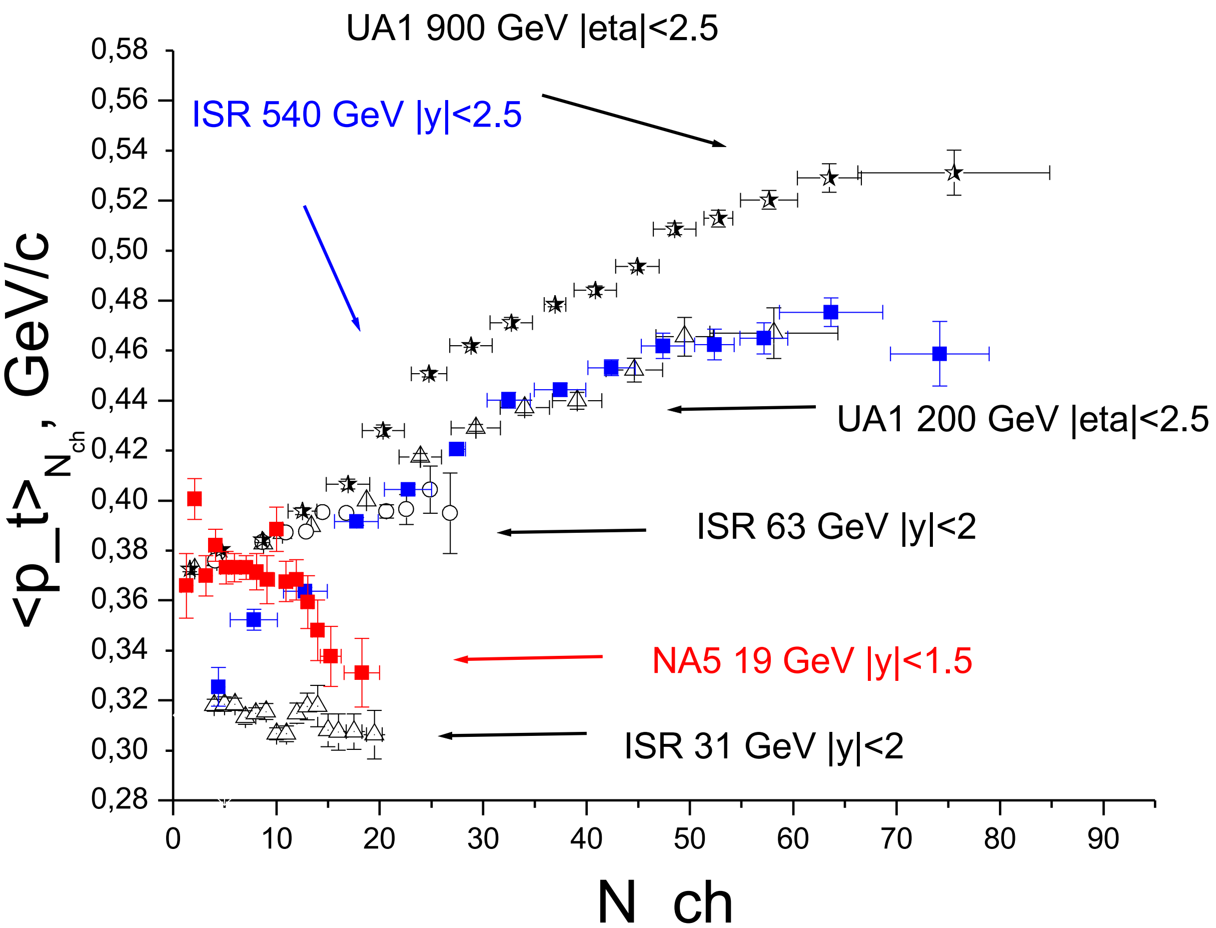
Experimentally Observed p_t-N_{ch} Correlations



summary plot - Armesto N., Derkach D., Feofilov G., Phys. Atom. Nucl. 71, 2087 (2008)

Regge-Gribov multipomeron approach

Probability of production of *n* pomerons

$$w_n = \sigma_n / \sum_{n'} \sigma_{n'},$$

where σ_n – cross section of n cut-pomeron exchange:

$$\sigma_n = \frac{\sigma_{\mathrm{P}}}{nz}\left(1 - e^{-z}\sum_{l=0}^{n-1}\frac{z^l}{l!}\right)$$

Each cut-pomeron corresponds to pair of strings

Regge-Gribov multipomeron approach

$$z = \frac{2C\gamma s^{\Delta}}{R_0^2 + \alpha' \ln(s)}$$

Numerical values of parameters used [1]:

$$\Delta = 0,139\,, \quad \alpha' = 0,21\ \mathrm{GeV}^{-2}\,,$$

$$\gamma = 1,77\ \mathrm{GeV}^{-2}\,, \quad R_0^2 = 3,18\ \mathrm{GeV}^{-2}\,,$$

$$C = 1,5\,.$$

[1] Arakelyan, G.H.; Capella, A.; Kaidalov, A.B.; Shabelski, Y.M.
Eur. Phys. J. C 2002, 26, 81.

Description of multiplicity

Probability for n strings to give N_{ch} particles:

$$P(n, N_{ch}) = \exp(-2nk\delta)\frac{(2nk\delta)^{N_{ch}}}{N_{ch}!},$$

where k – is mean multiplicity per rapidity unit from one pomeron;
δ – acceptance i.e. width of (pseudo-)rapidity interval

Probability to have N_{ch} particles in a given event:

$$\mathscr{P}(N_{ch}) = \sum_{n=1}^{\infty} w_n P(n, N_{ch})$$

Mean charged multiplicity:

$$\langle N_{ch}\rangle(s) = \sum_{N_{ch}=0}^{\infty} N_{ch}\mathscr{P}(N_{ch}) = 2\langle n\rangle \cdot k \cdot \delta$$

Description of transverse momentum

Schwinger mechanism of particles production from one string [2]:

$$\left.\frac{dN_{\mathrm{ch}}}{dy\,d^2p_T}\right|_{y=0} \sim \exp\left(\frac{-\pi\left(p_t^2+m^2\right)}{t}\right)$$

p_t-N_{ch} correlation function in the model is calculated as:

$$\langle p_t\rangle_{N_{ch}}(s) = \frac{\int\limits_0^\infty \rho(N_{ch}, p_t)\, p_t^2\, dp_t}{\int\limits_0^\infty \rho(N_{ch}, p_t)\, p_t\, dp_t}$$

[2] Schwinger J. Phys. Rev. 1951. Vol. 82, P. 664 – 679

Description of transverse momentum

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[2] Schwinger J. Phys. Rev. 1951. Vol. 82, P. 664 – 679

Distribution of N_{ch} and particles over p_t

$$\rho(N_{ch}, p_t) =$$

Probability distribution

$$= \frac{C_w}{z} \sum_{n=1}^{\infty} \frac{1}{n} \left(1 - \exp(-z) \sum_{l=0}^{n-1} \frac{z^l}{l!} \right) \times$$

Probability of production of *n* pomerons

$$\times \exp(-2nk\delta) \frac{(2nk\delta)^{N_{ch}}}{N_{ch}!} \times$$

Poisson distribution of the charged particles from 2*n* string

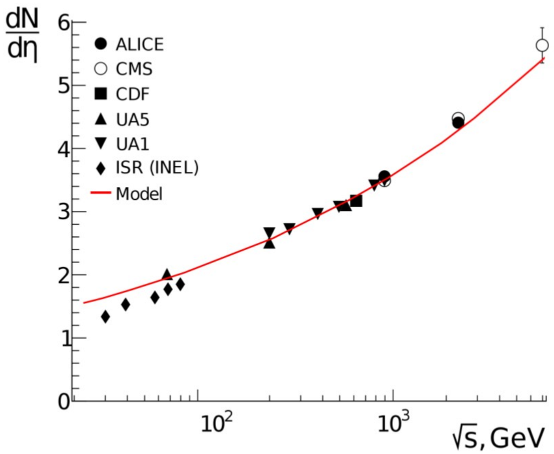
$$\times \frac{1}{n^{\beta} t} \exp\left(-\frac{\pi p_t^2}{n^{\beta} t} \right)$$

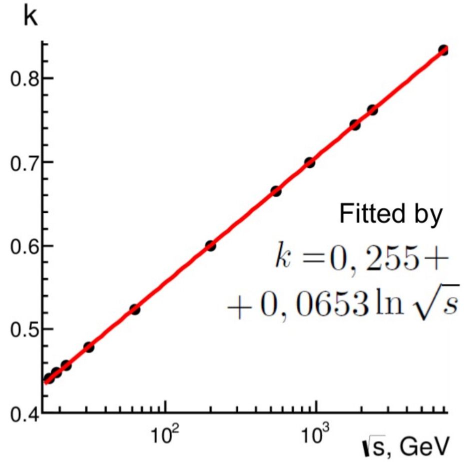
Modified Schwinger mechanism

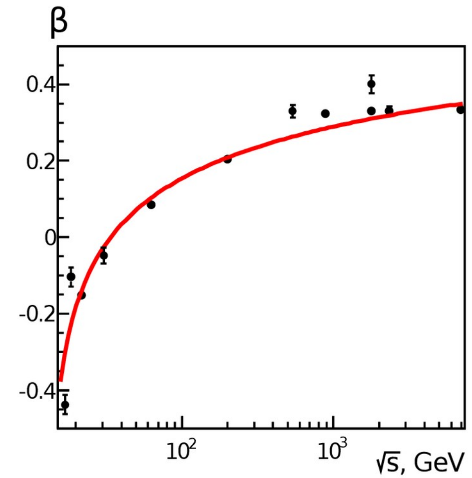
Bodnia, E.; Derkach, D.; Feofilov, G.; Kovalenko, V.; Puchkov, A. PoS QFTHEP2013 2013, 60. https://doi.org/10.22323/1.183.0060

Kovalenko, V.; Feofilov, G.; Puchkov, A.; Valiev, F. . Universe 2022, 8, 246. https://doi.org/10.3390/universe8040246

Parameters determination

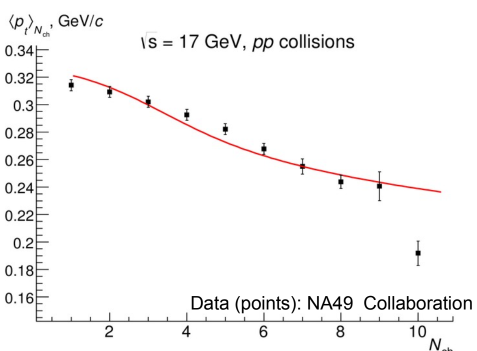


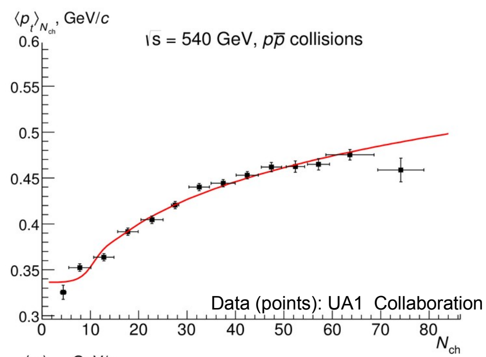


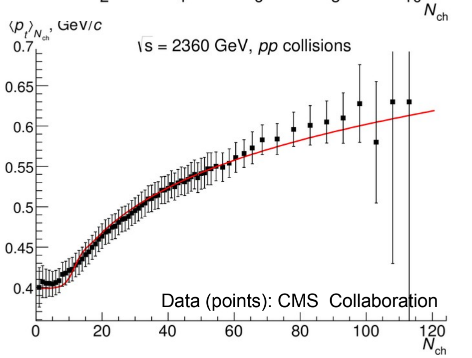


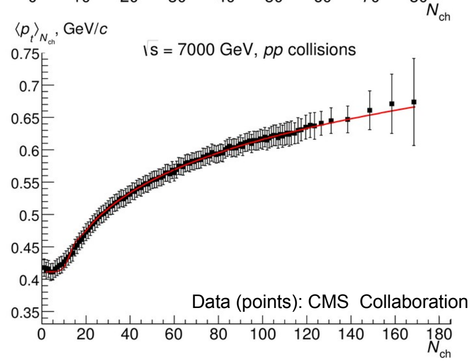
Fitted by

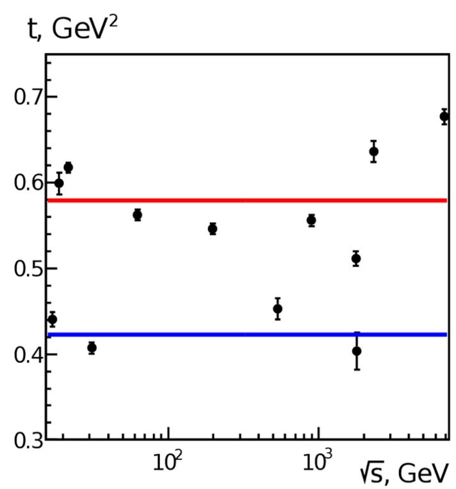
$$\beta = 1.16\left(1 - \left(ln\sqrt{s} - 2.52\right)^{-0.19}\right)$$







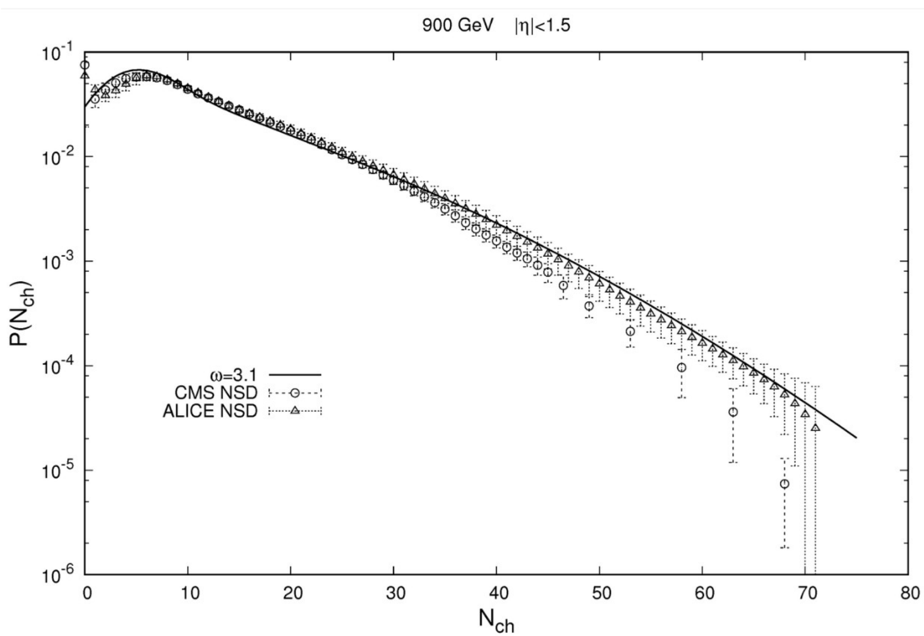


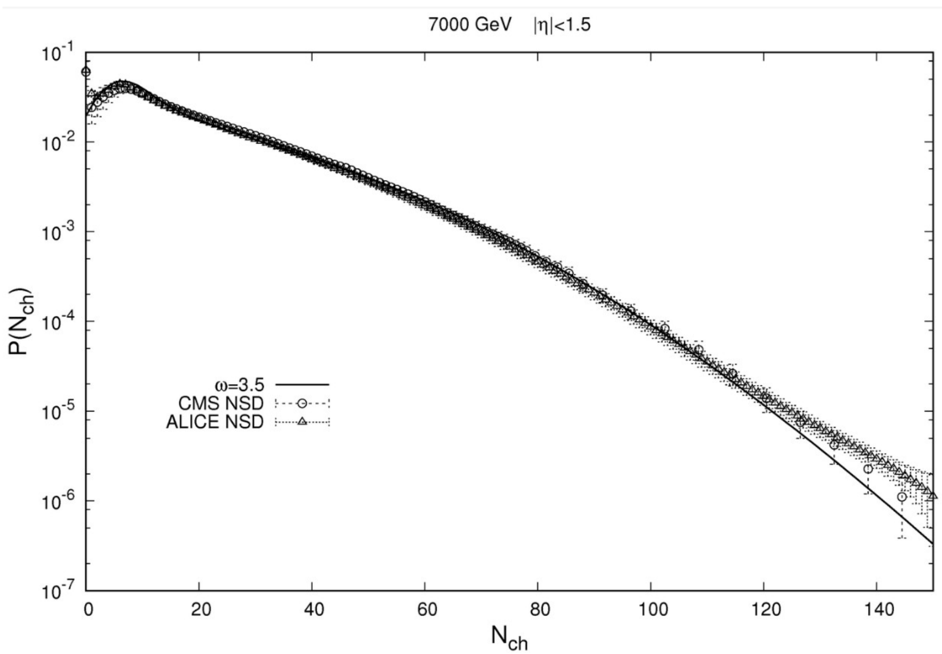


Distribution of N_{ch}

$$P_n(N) = e^{-\langle N\rangle_n} \frac{\langle N\rangle_n{}^N}{N!} \quad \text{----->} \quad P_n(N) = C \exp\left[-\frac{(N-2n\mu_{str})^2}{2\omega_{str}\, 2n\mu_{str}}\right],$$

$$\sum_{N=0}^{\infty} P_n(N) = 1, \qquad C^{-1} = \sum_{N=0}^{\infty} \exp\left[-\frac{(N-2n\mu_{str})^2}{2\omega_{str}\, 2n\mu_{str}}\right].$$





Vechernin, V.; Andronov, E.; Kovalenko, V.; Puchkov, A. . Universe 2024, 10, 56. https://doi.org/10.3390/universe10020056

Combinants of N_{ch}

generating function

$$G(t) = \sum_{N=0}^{\infty} P(N)\, t^N$$

generating function of combinants

$$F(t) = \ln G(t) = \sum_{j=0}^{\infty} C^*(j)\, t^j$$

modified combinants

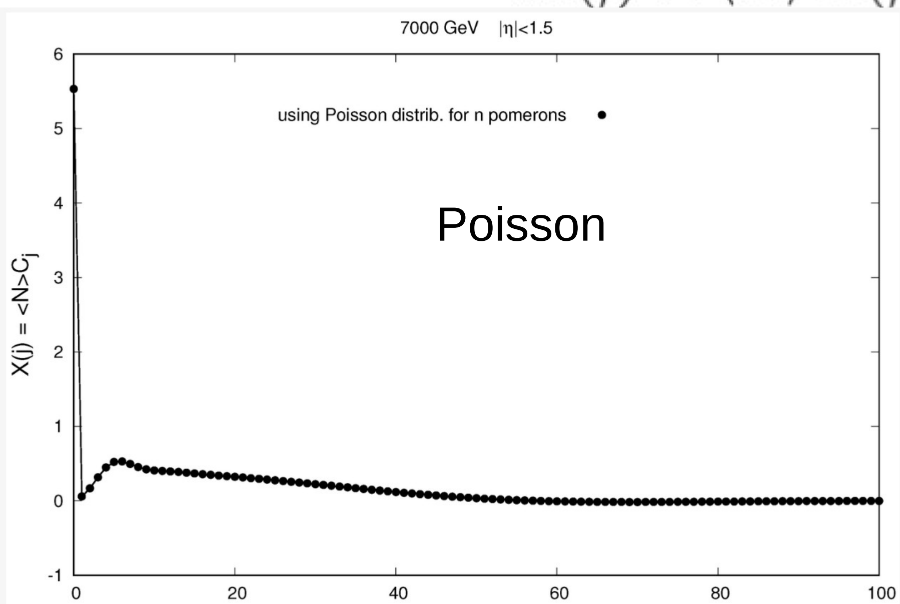
$$C(j) \equiv \frac{j+1}{\langle N \rangle} C^*(j+1), \qquad \text{where} \qquad \langle N \rangle = \sum_{N=1} N\, P(N)$$

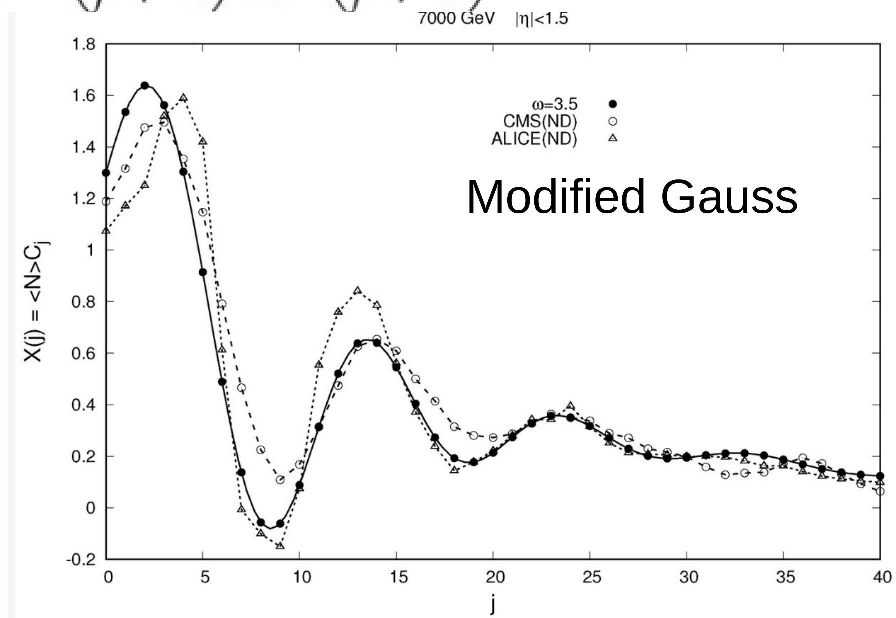
recursive relation

$$(N+1)\, P(N+1) = \langle N \rangle \sum_{j=0} C(j)\, P(N-j)$$

Final quantities

$$X(j) \equiv \langle N \rangle C(j) = (j+1)\, C^*(j+1)$$



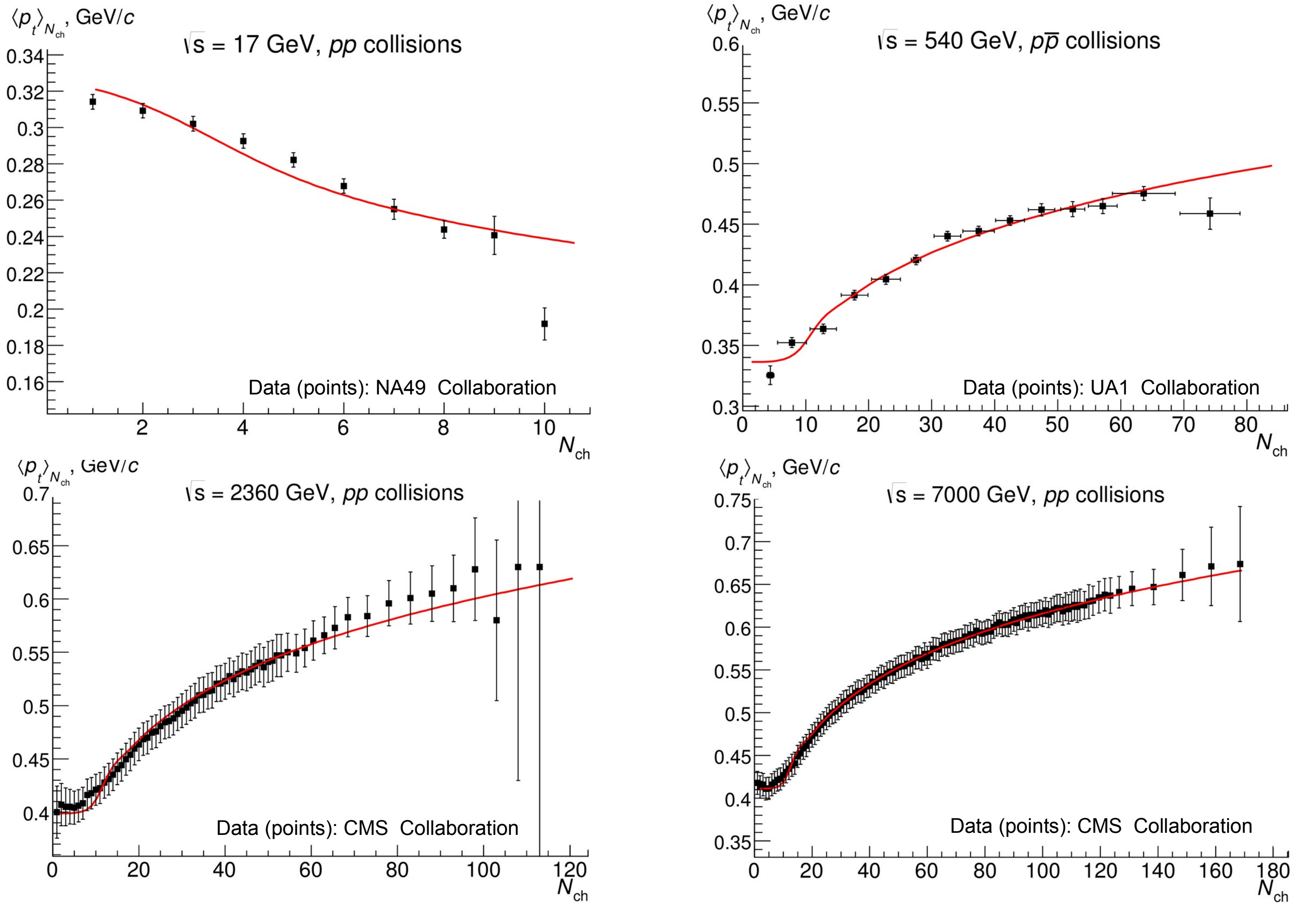


Vechernin, V.; Andronov, E.; Kovalenko, V.; Puchkov, A. . Universe 2024, 10, 56. https://doi.org/10.3390/universe10020056

p_t-N_{ch} correlations

The data on p_t-N_{ch} correlations are analyzed in wide energy region: from 17 GeV to 7 TeV

Values of the parameters β and t are obtained. Examples of fitting:



pp, 17 GeV

pp, 19 GeV

pp, 22 GeV

pp, 31 GeV

pp, 63 GeV

$p\bar{p}$, 200 GeV

$p\bar{p}$, 540 GeV

$p\bar{p}$, 900 GeV

$p\bar{p}$, 1800 GeV

$p\bar{p}$, 1800 GeV

pp, 2360 GeV

pp, 7000 GeV

Fluctuation of string density

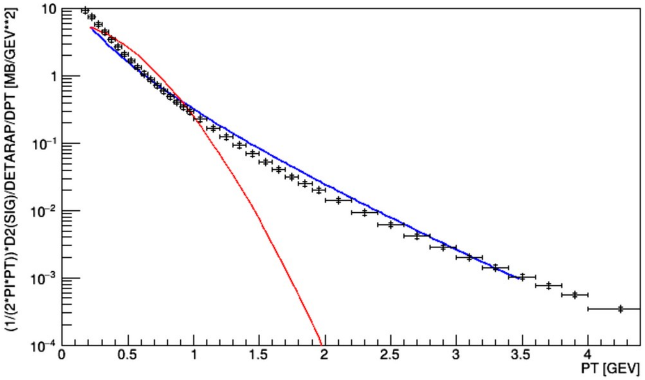
- Schwinger mechanism of particle production:

$$\frac{d^2 N_{ch}}{dp_t^2} \sim \exp\left(-\frac{\pi m_\perp^2}{\tau^2}\right) \qquad P(\tau) = \sqrt{\frac{2}{\pi \langle \tau^2 \rangle}} \exp\left(-\frac{\tau^2}{2\langle \tau^2 \rangle}\right)$$

After averaging over string density fluctuations – thermal spectrum

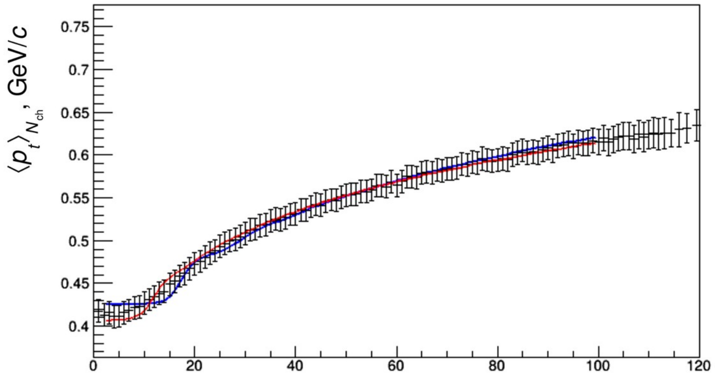
$$g(n, p_t; t, \beta) = \frac{1}{\pi\sqrt{n^\beta t}} \frac{1}{\sqrt{p_t^2 + m^2}} \exp\left(-2\frac{\left(\sqrt{p_t^2 + m^2} - m\right)}{\sqrt{n^\beta t}}\right)$$

Bialas, A. Fluctuations of the string tension and transverse mass distribution.
Phys. Lett. B. 1999, 466, 301–304



pp, 7 TeV

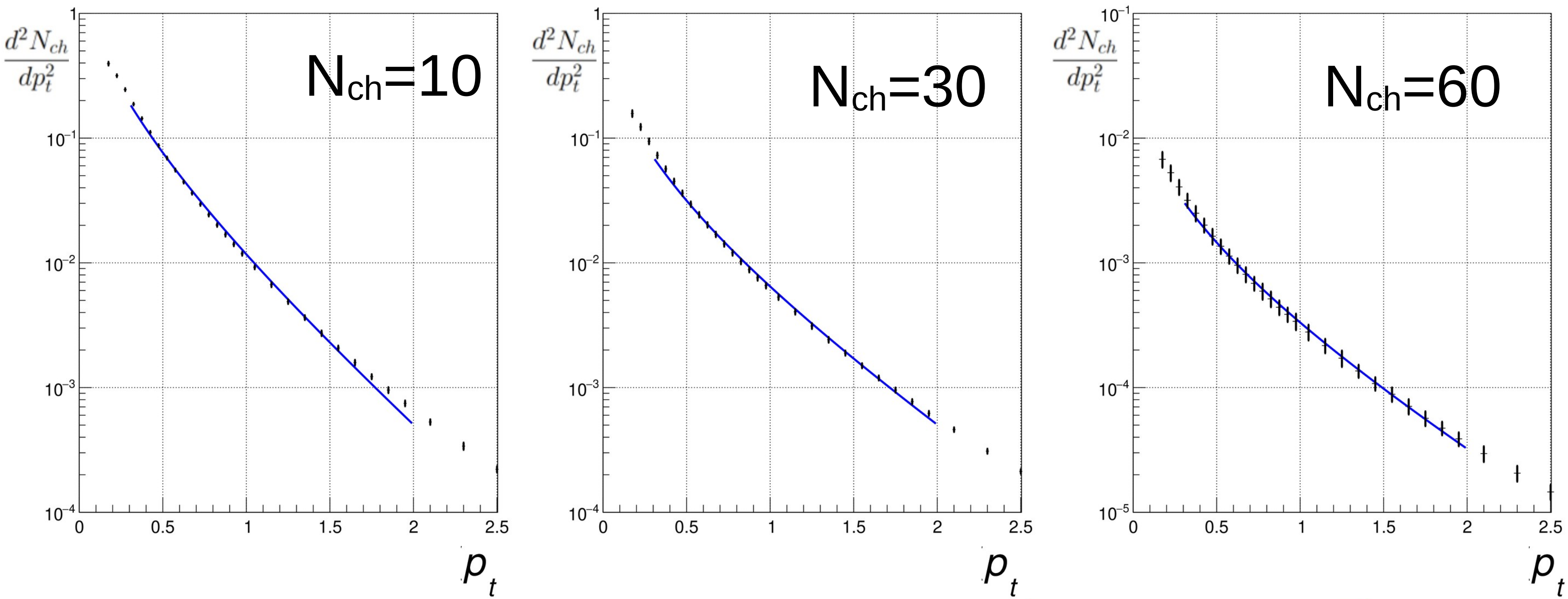
– Schwinger
– Thermal



Experimental data ALICE, Eur.Phys.J.C 73 (2013) 2662, 2013. . Khachatryan et al. (CMS Collab.), JHEP 1101 (2011) 079

Multiplicity-dependent pt-spectrum

pp, 13 TeV

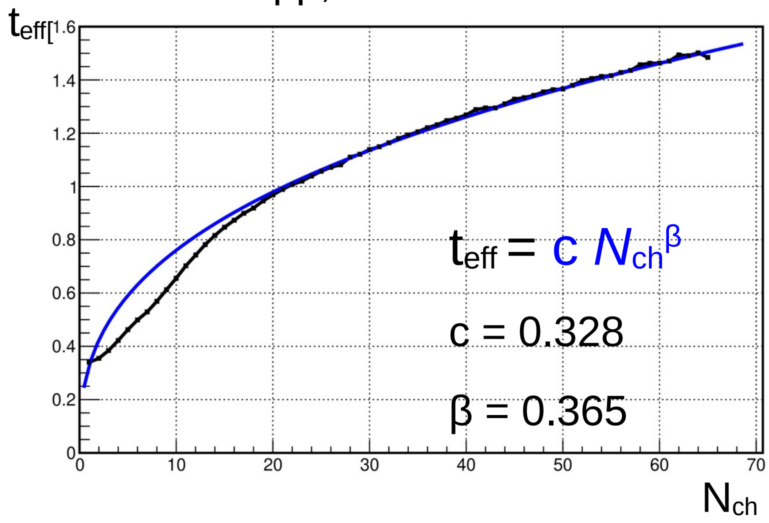


$$g(p_t; t_{\text{eff}}) = \frac{1}{\pi\sqrt{t_{\text{eff}}}} \frac{1}{\sqrt{p_t^2+m^2}} \exp\left(-2\frac{\left(\sqrt{p_t^2+m^2}-m\right)}{\sqrt{t_{\text{eff}}}}\right)$$

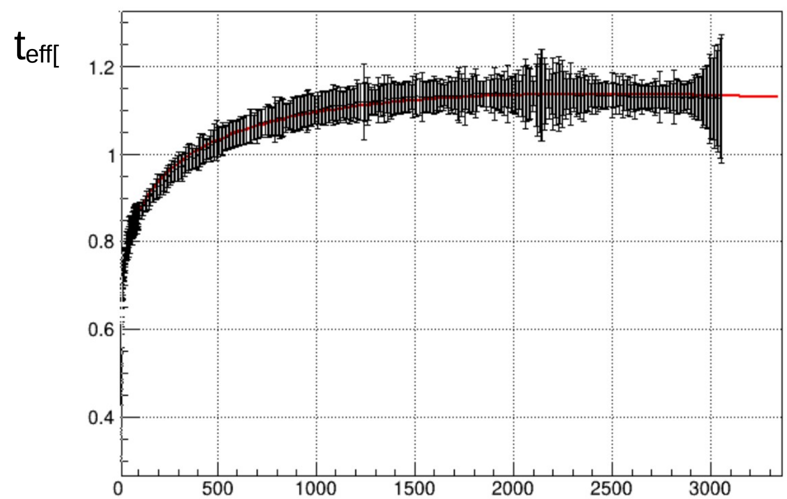
Exp data: S. Acharya et al (ALICE Collaboration) Phys.Lett.B 845 (2023) 138110

Multiplicity-dependent pt-spectrum

pp, 13 TeV



Pb-Pb 5.02 TeV



$$g(p_t; t_{eff}) = \frac{1}{\pi\sqrt{t_{eff}}} \frac{1}{\sqrt{p_t^2+m^2}} \exp\left(-2\frac{\left(\sqrt{p_t^2+m^2}-m\right)}{\sqrt{t_{eff}}}\right)$$

$t_{eff} = c\, N_{ch}^{\beta} \exp(-\gamma N_{ch})$

c = 0.498

β = 0.121

γ = 0.00005

Exp data: S. Acharya et al (ALICE Collaboration) Phys.Lett.B 845 (2023) 138110

Strongly-intensive variables

$$\Delta(P_{\rm t},N_{ch}) = \frac{1}{\langle N_{ch}\rangle \omega\langle\langle p_{\rm t}\rangle\rangle}\left[\langle N_{ch}\rangle\omega[P_{\rm t}] - \langle P\rangle_{\rm t}\omega[N_{ch}]\right],$$

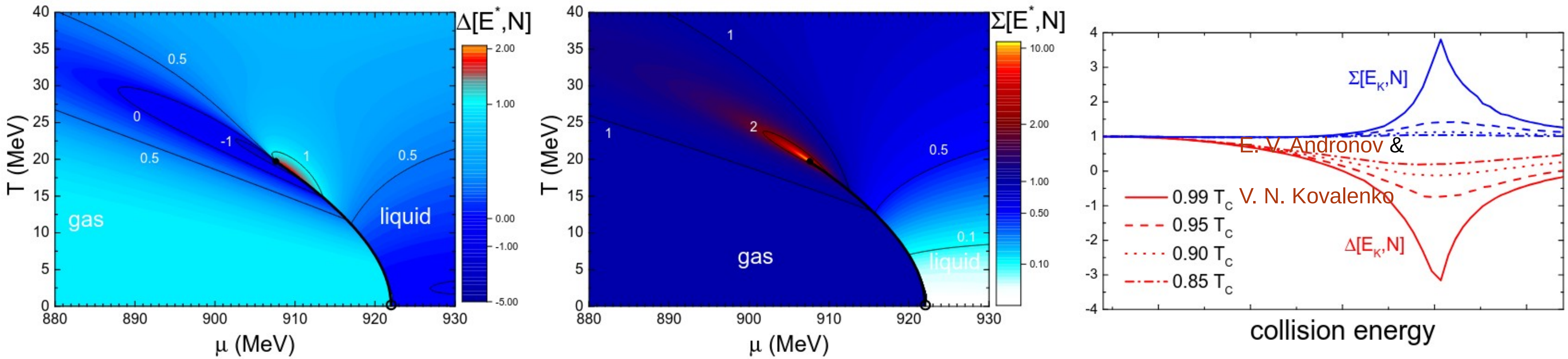
$$\Sigma(P_{\rm t},N_{ch}) = \frac{1}{\langle N_{ch}\rangle \omega\langle\langle p_{\rm t}\rangle\rangle}\left[\langle N_{ch}\rangle\omega[P_{\rm t}] + \langle P\rangle_{\rm t}\omega[N_{ch}] - 2\,\mathrm{cov}(P_{\rm t},N_{ch})\right].$$

Angle brackets denote averaging over events

$\omega[A] = (\langle A^2\rangle - \langle A\rangle^2)/\langle A\rangle$ scaled variance of variable A

$\omega\langle\langle p_{\rm t}\rangle\rangle = (\langle\langle p_{\rm t}^2\rangle\rangle - \langle\langle p_{\rm t}\rangle\rangle^2)/\langle\langle p_{\rm t}\rangle\rangle$ - scaled variance of the inclusive distribution of transverse momentum, double angle brackets – averaging over all particles.

Strongly-intensive variables for the search of the critical point



Vovchenko, Gorenstein, Stoecker, PRL 118: 182301, V. Vovchenko, D. V. Anchishkin, and M. I. Gorenstein, J. Phys. A 48, 305001 (2015); Phys. Rev. C 91, 14 (2015); V. Vovchenko, D. V. Anchishkin, M. I. Gorenstein, and R. V. Poberezhnyuk, Phys. Rev. C 92, 054901 (2015);V. Vovchenko, D.V. Anchishkin, M.I. Gorenstein, R.V. Poberezhnyuk, H. Stoecker, Acta Phys. Pol. B Proc. Suppl. 10, 753 (2017)

Strongly-intensive variables

$$\Delta(P_{\rm t},N_{ch}) = \frac{1}{\langle N_{ch}\rangle \omega\langle\langle p_{\rm t}\rangle\rangle}\left[\langle N_{ch}\rangle \omega[P_{\rm t}] - \langle P\rangle_{\rm t}\omega[N_{ch}]\right],$$

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E. V. Andronov, V. N. Kovalenko, Theoretical and Mathematical Physics, 2019, V. 200, Iss. 3, 1282–1293

Angle brackets denote averaging over events

$\omega[A] = (\langle A^2\rangle - \langle A\rangle^2)/\langle A\rangle$ scaled variance of variable A

$\omega\langle\langle p_{\rm t}\rangle\rangle = (\langle\langle p_{\rm t}^2\rangle\rangle - \langle\langle p_{\rm t}\rangle\rangle^2)/\langle\langle p_{\rm t}\rangle\rangle$ - scaled variance of the inclusive distribution of transverse momentum, double angle brackets – averaging over all particles.

For thermal spectrum the calculation gives

$$\Delta(P_{\rm t},N_{ch}) = 1 + k\delta\langle n^{1+0.5\beta}\rangle \frac{\langle n\rangle\omega[n^{1+0.5\beta}] - \langle n^{1+0.5\beta}\rangle\omega[n]}{\langle n\rangle\langle n^{1+\beta}\rangle - \langle n^{1+0.5\beta}\rangle^2\cdot(1/2)},$$

$$\Sigma(P_{\rm t},N_{ch}) = 1 + k\delta\langle n^{1+0.5\beta}\rangle \frac{\langle n\rangle\omega[n^{1+0.5\beta}] + \langle n^{1+0.5\beta}\rangle\omega[n] - 2\,\mathrm{cov}(n,\, n^{1+0.5\beta})}{\langle n\rangle\langle n^{1+\beta}\rangle - \langle n^{1+0.5\beta}\rangle^2\cdot(1/2)}.$$

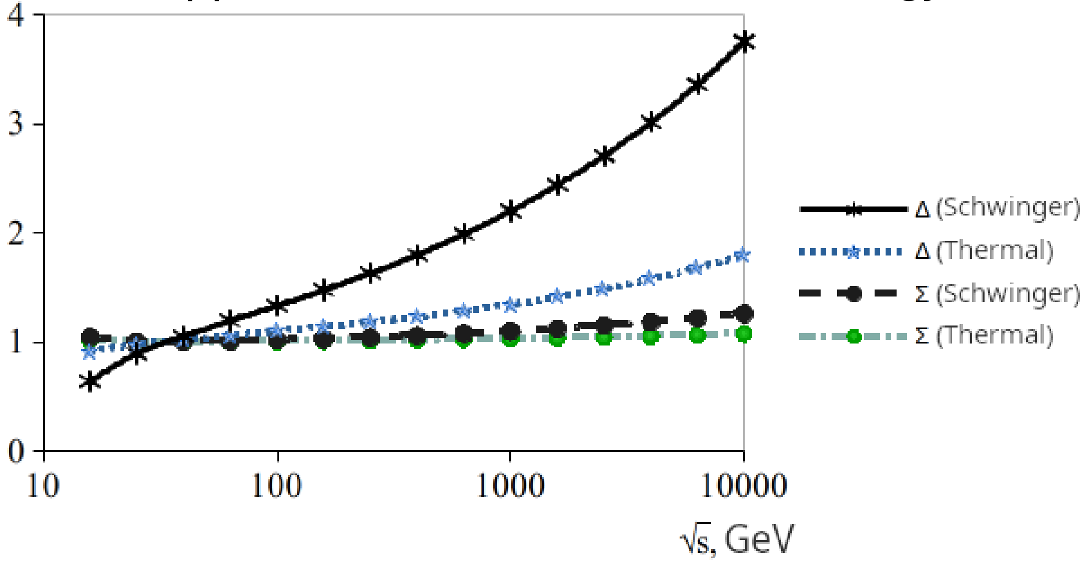
And for heavy-ion collisions there is a modification

$$\Delta(P_{\rm t},N_{ch}) = 1 + k\delta\langle n^{1+0.5\beta}\, e^{-2\gamma kn}\rangle \frac{\langle n\rangle\omega[n^{1+0.5\beta}e^{-2\gamma kn}] - \langle n^{1+0.5\beta}e^{-2\gamma kn}\rangle\omega[n]}{\langle n\rangle\langle n^{1+\beta}\, e^{-4\gamma kn}\rangle - \langle n^{1+0.5\beta}e^{-2\gamma kn}\rangle^2\cdot(1/2)},$$

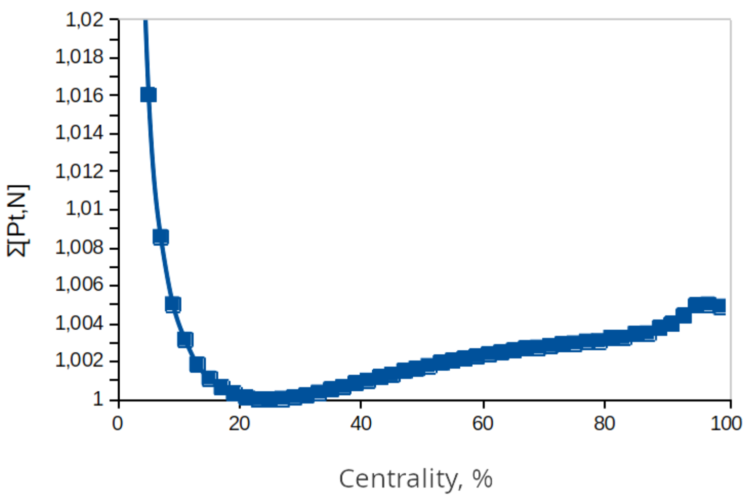
$$\Sigma(P_{\rm t},N_{ch}) = 1 + k\delta\langle n^{1+0.5\beta}\, e^{-2\gamma kn}\rangle \frac{\langle n\rangle\omega[n^{1+0.5\beta}e^{-2\gamma kn}] + \langle n^{1+0.5\beta}\, e^{-2\gamma kn}\rangle\omega[n] - 2\,\mathrm{cov}(n,\, n^{1+0.5\beta}\, e^{-2\gamma kn})}{\langle n\rangle\langle n^{1+\beta}\, e^{-4\gamma kn}\rangle - \langle n^{1+0.5\beta}e^{-2\gamma kn}\rangle^2\cdot(1/2)}.$$

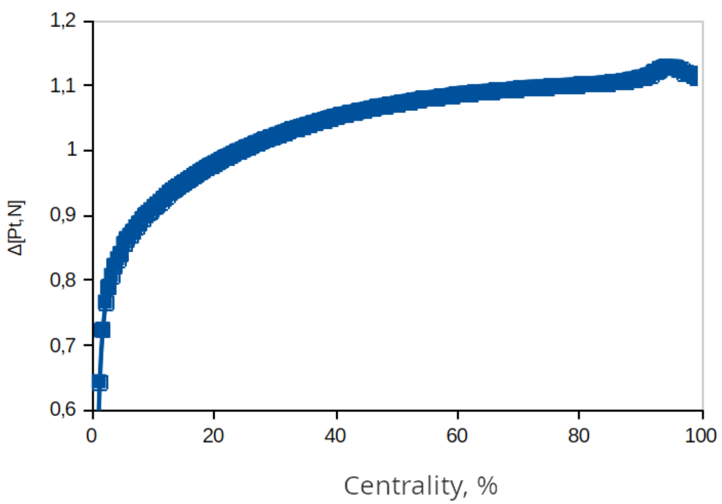
Results: Strongly-intensive variables

For the pp-collisions as a function of energy



For Pb-Pb collisions at 2.76 TeV, centrality class width 2%, Rapidity window width 0.5





Conclusions:

- A new generalization of the Multipomeron exchange model is proposed with thermal spectrum due to event-by-event string tension fluctuations
- For multiplicity, by replacing the Poisson distribution from one string with the discrete Gaussian distribution, the model correctly reproduces the characteristic oscillating behavior of modified combinants in pp collisions over a wide energy range
- Simultaneously, the p_T-multiplicity correlation functions described
- Using results of the Glauber model at the partonic level, the model is applied relativistic heavy-ion collisions
- Strongly intensive fluctuations are calculated for pp collisions as a function of energy, and in Pb-Pb collisions as a function of centrality.

Thank you