Multiplicity-dependent properties of multipatcile production at high energy in extended multipomeron exchange model

The 7th international conference
on particle physics and astrophysics

ICPPA2024

22-25 October 2024

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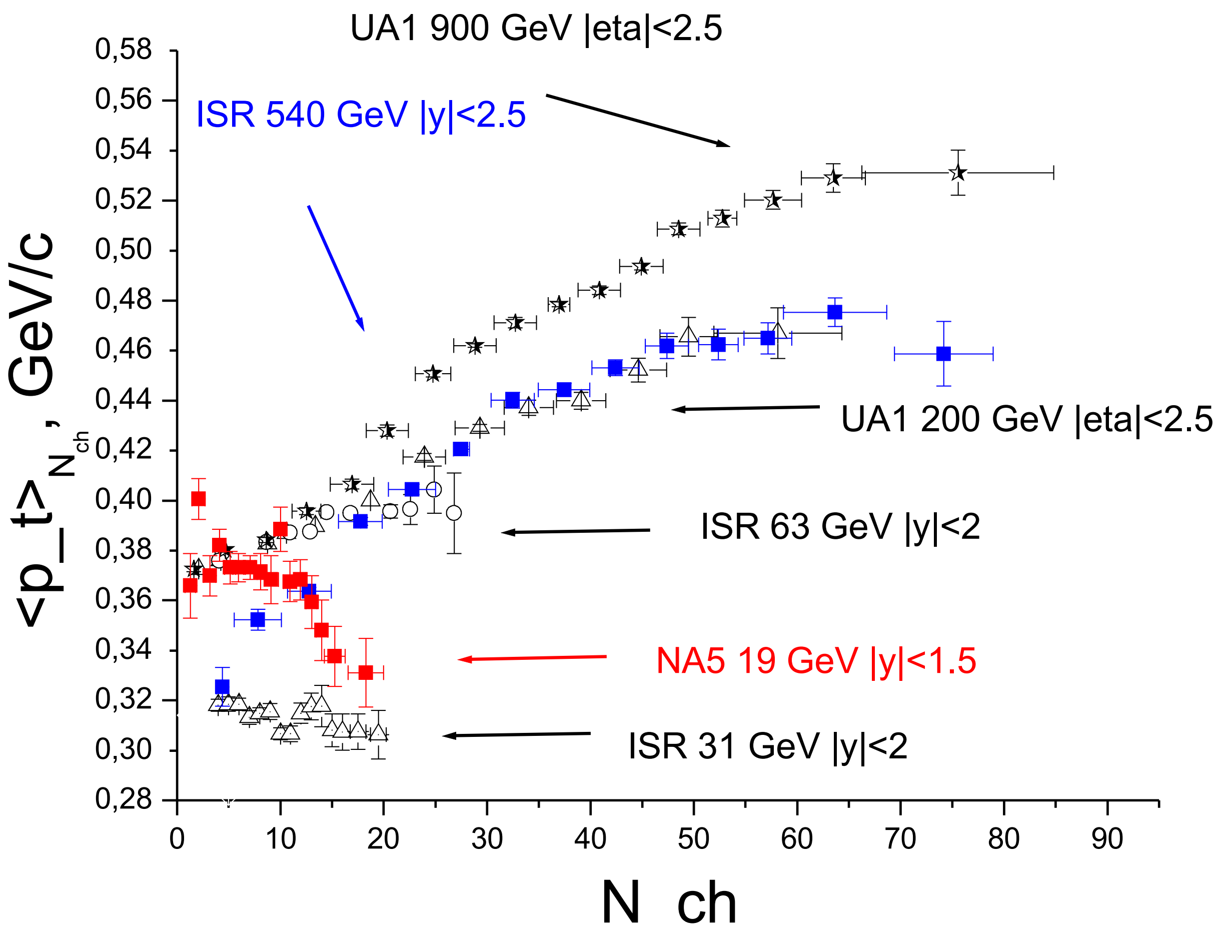
Supported by Saint Petersburg State University,
project ID: 95413904

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. Baryon number transfer in hadronic interactions. 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]:

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

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

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

Modified Schwinger mechanism

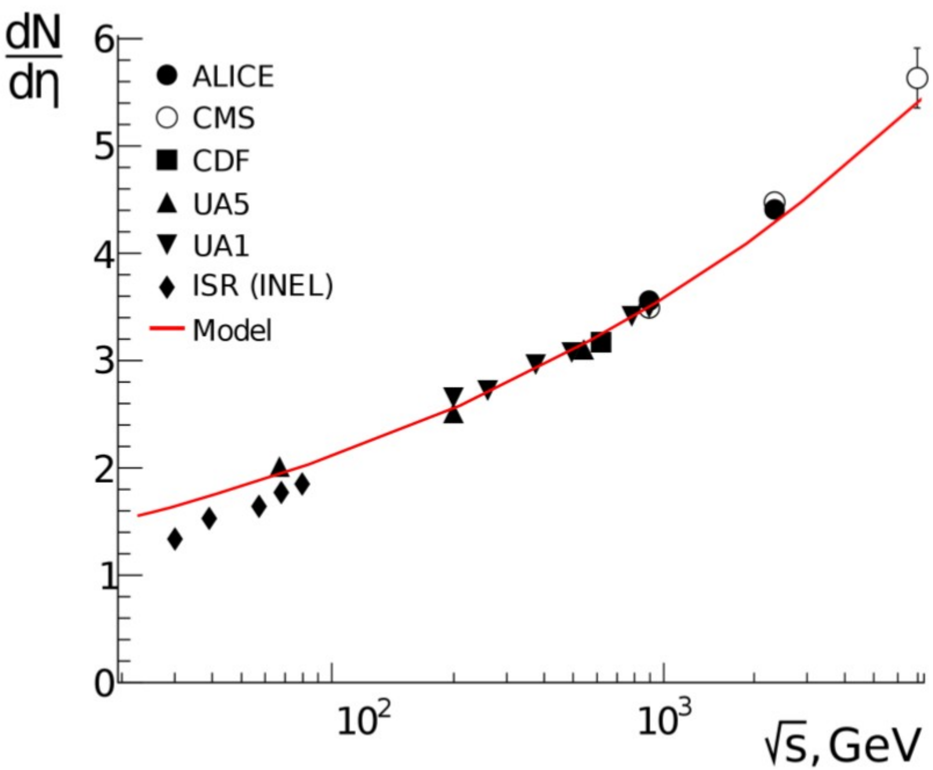
Bodnia, E.; Derkach, D.; Feofilov, G.; Kovalenko, V.; Puchkov, A. PoS QFTHEP2013 2013, 60. https://doi.org/10.22323/1.183.0060

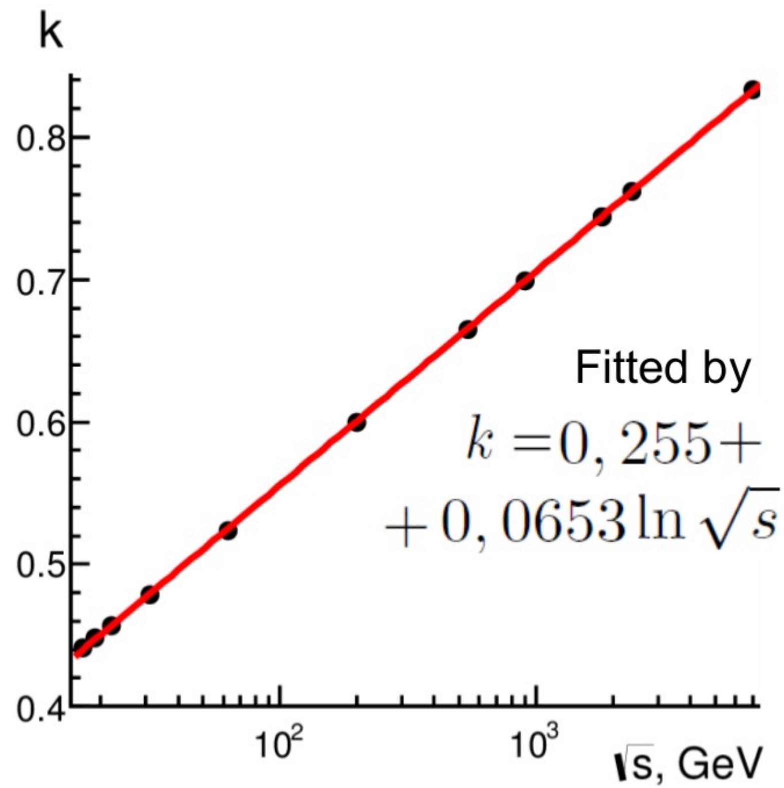
Kovalenko, V.; Feofilov, G.; Puchkov, A.; Valiev, F. . Universe 2022, 8, 246. https://doi.org/10.3390/universe8040246

Determination of the parameter k

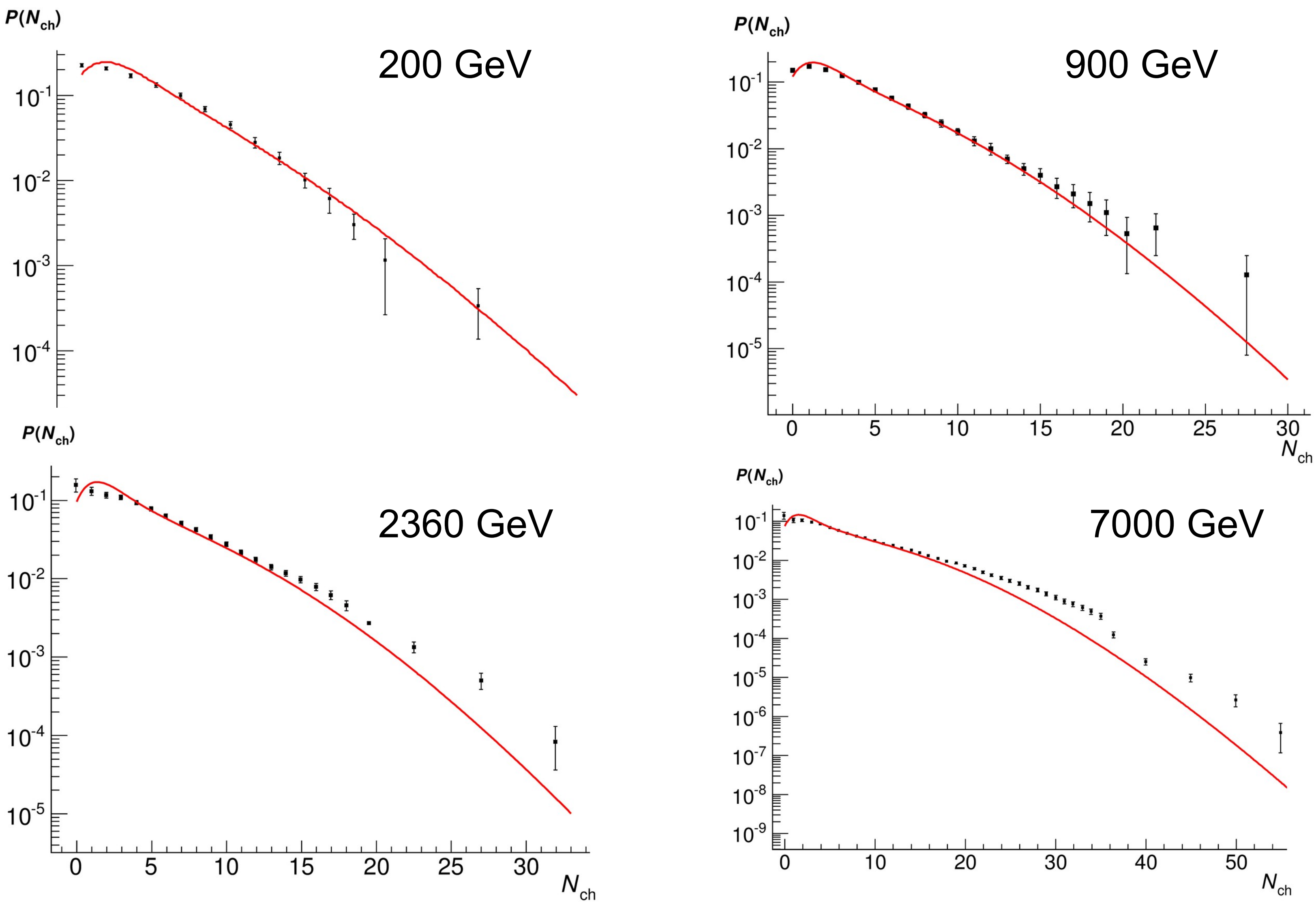
from experimental data on charged multiplicity:

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





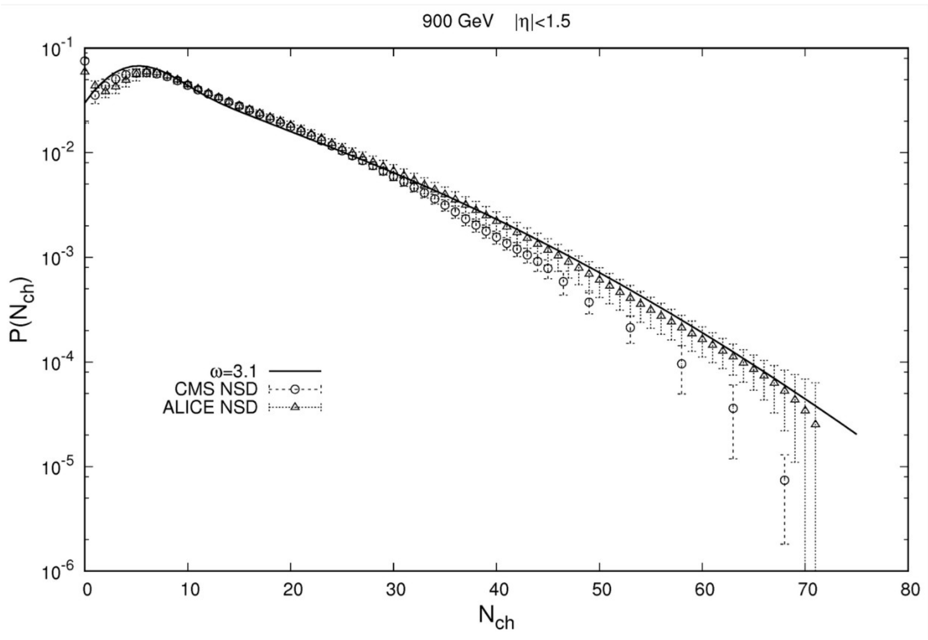
Distribution of N_{ch}

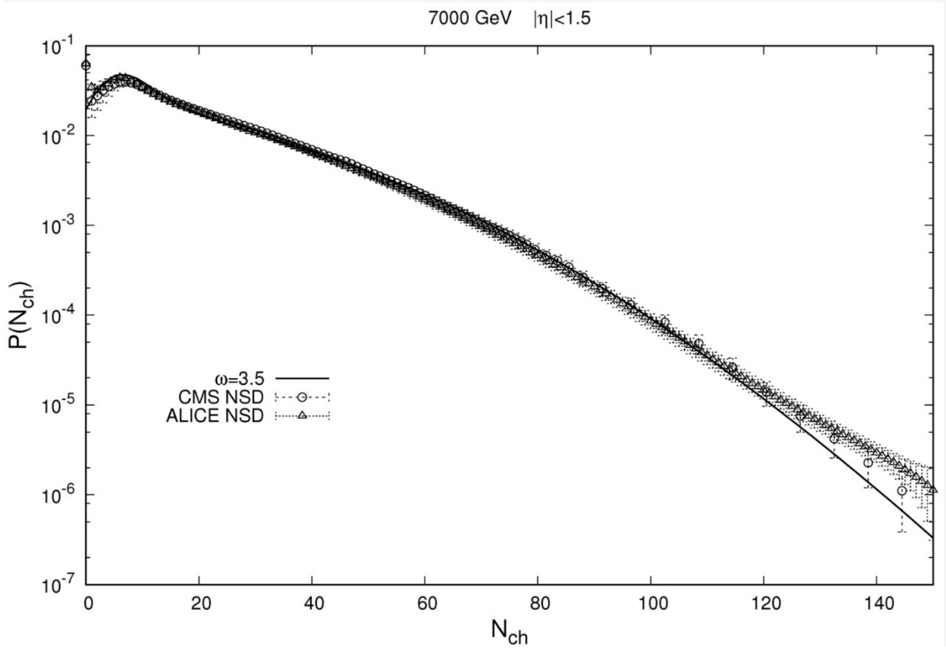


Distribution of N_{ch}

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

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





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

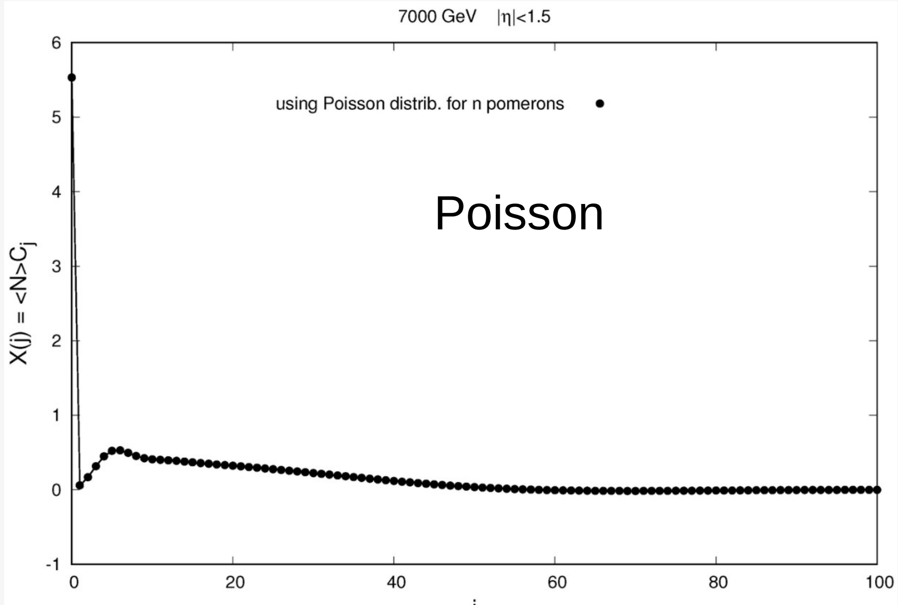
$$C(j) \equiv \frac{j+1}{\langle N\rangle} C^*(j+1), \qquad \text{where} \qquad \langle N\rangle = \sum_{N=1} N\, P(N)$$

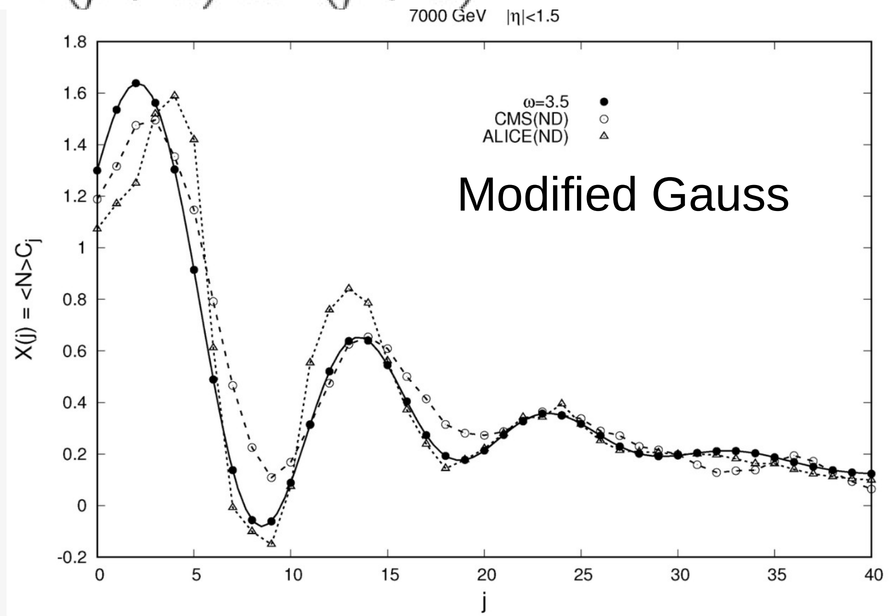
recursive relation

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

Final quantities

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

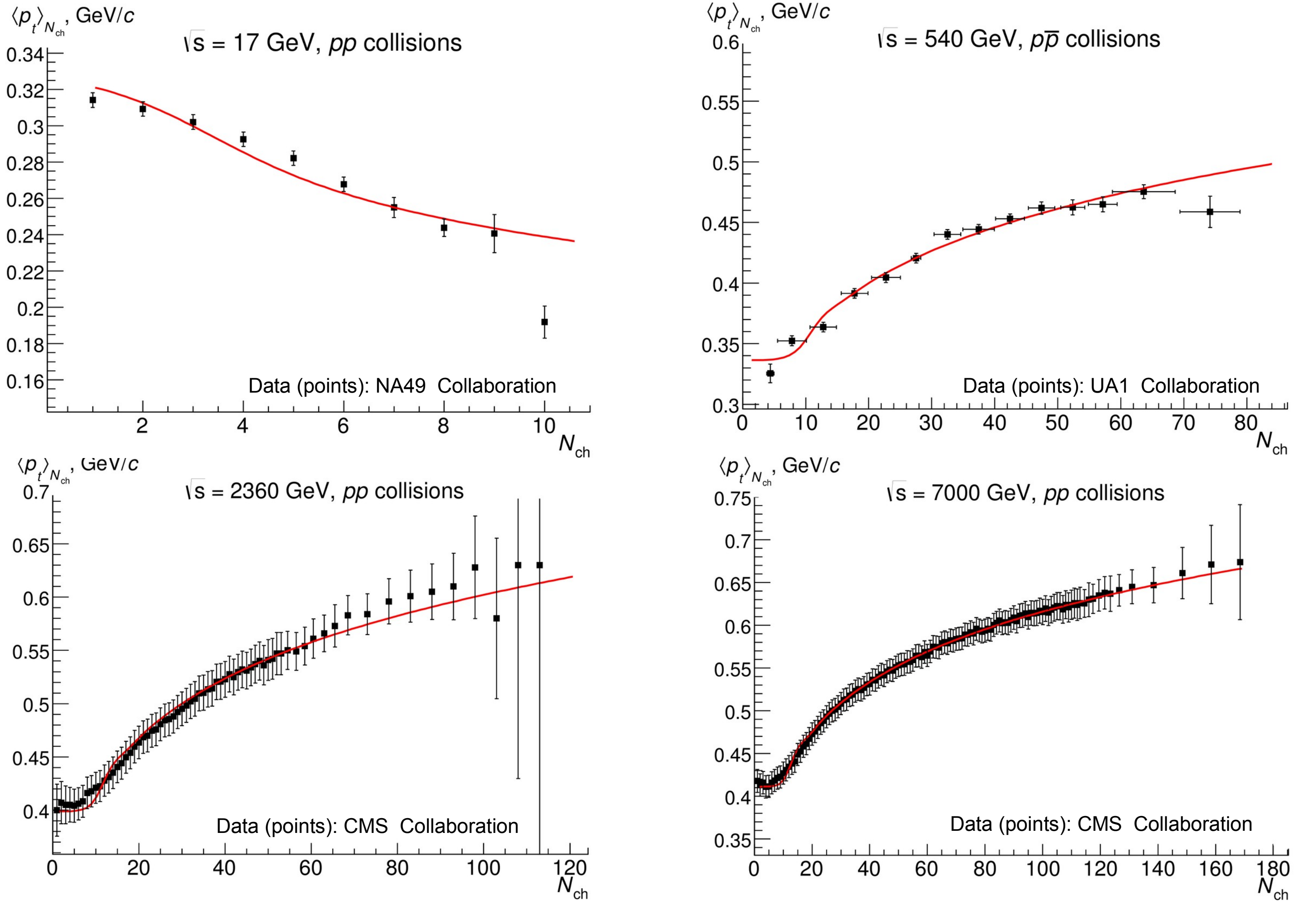




Vechernin, V.; Andronov, E.; Kovalenko, V.; Puchkov, A. . Universe 2024, 10, 56. https://doi.org/10.3390/universe10020056

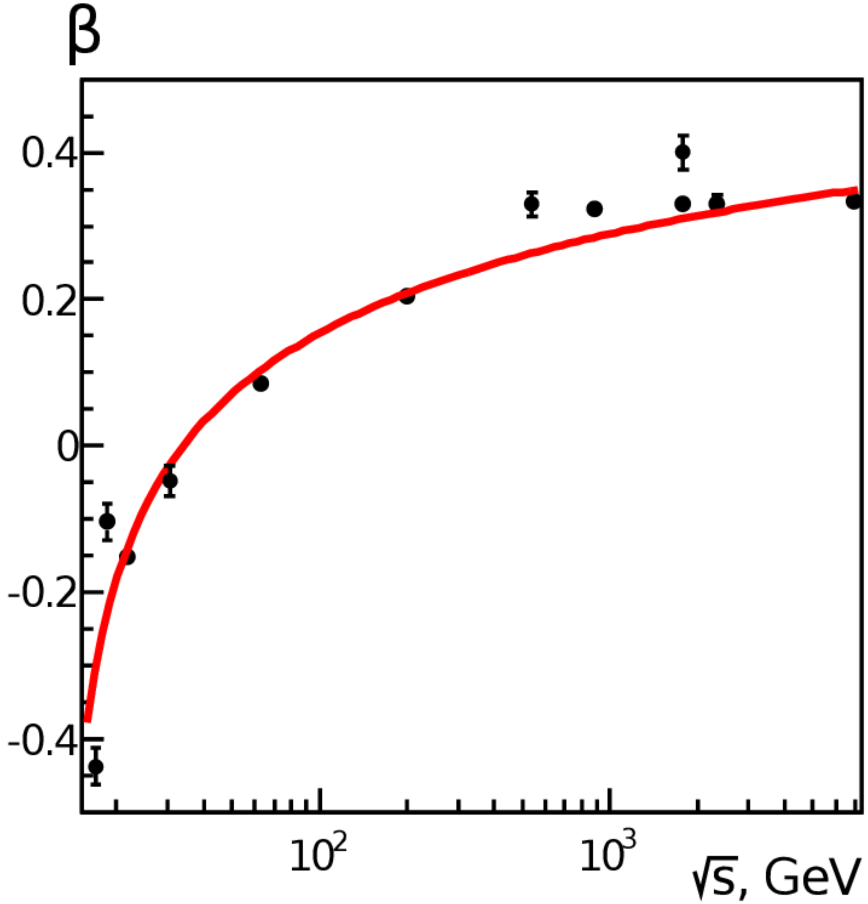
p_t-N_{ch} correlations

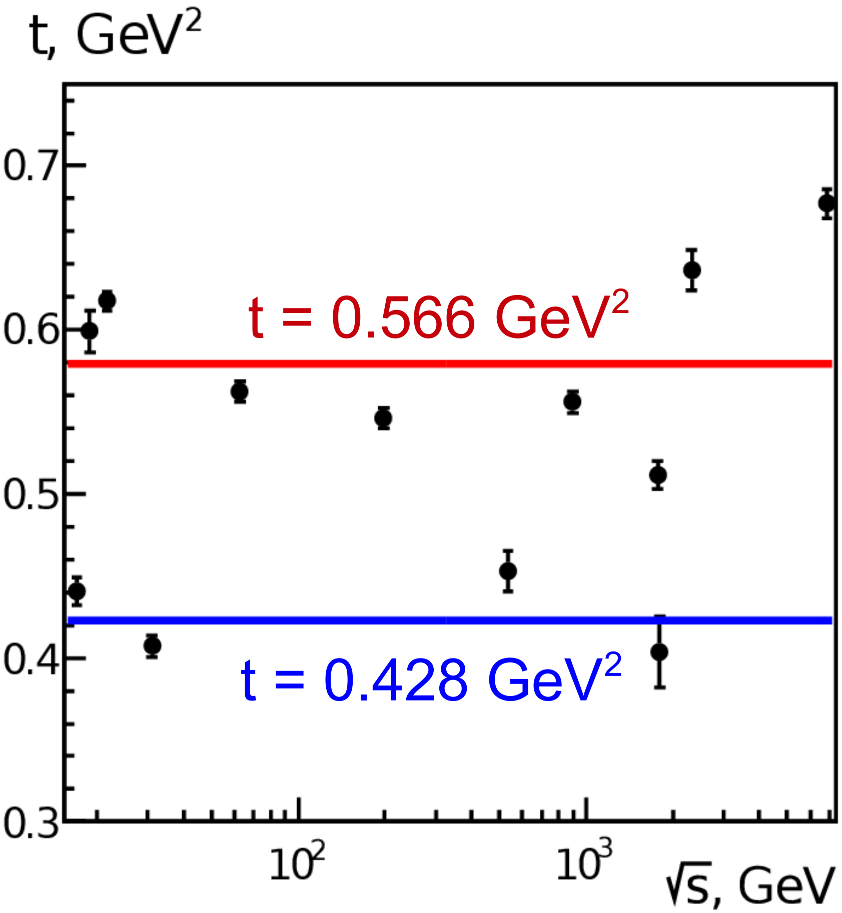
The data on p_t-N_{ch} correlations are analyzed in wide energy region: from 17 GeV to 7 TeV
Values of the parameters β and τ are obtained. Examples of fitting:



- 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

Dependence of the parameters β and t on collision energy





Fitted by

$$\beta = \beta_0 \left[1 - \left(\ln\sqrt{s} - \beta_2\right)^{-\beta_1}\right]$$

Fluctuation of string density

- Schwinger mechanism of particle production:

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

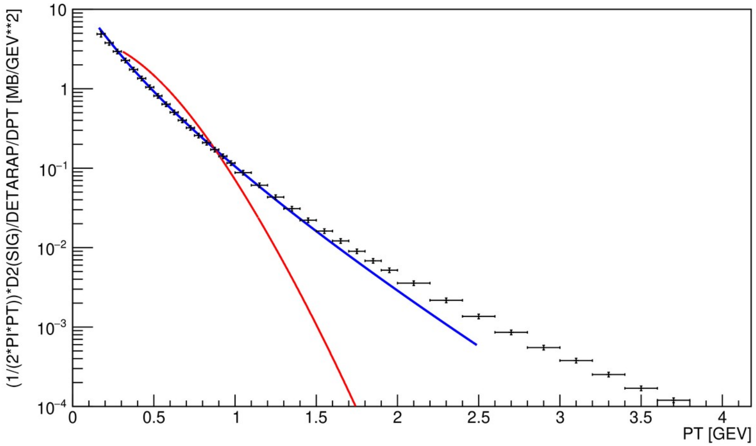
After averaging over string density fluctuations – thermal spectrum

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

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

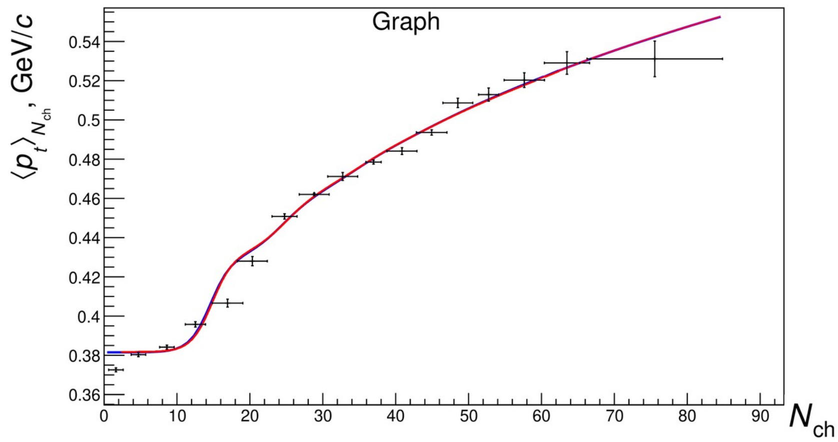
Results:

- Transverse momentum distributions and pt-Nch correlations



pp, 900 GeV

-- Schwinger
-- Thermal



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

Results:

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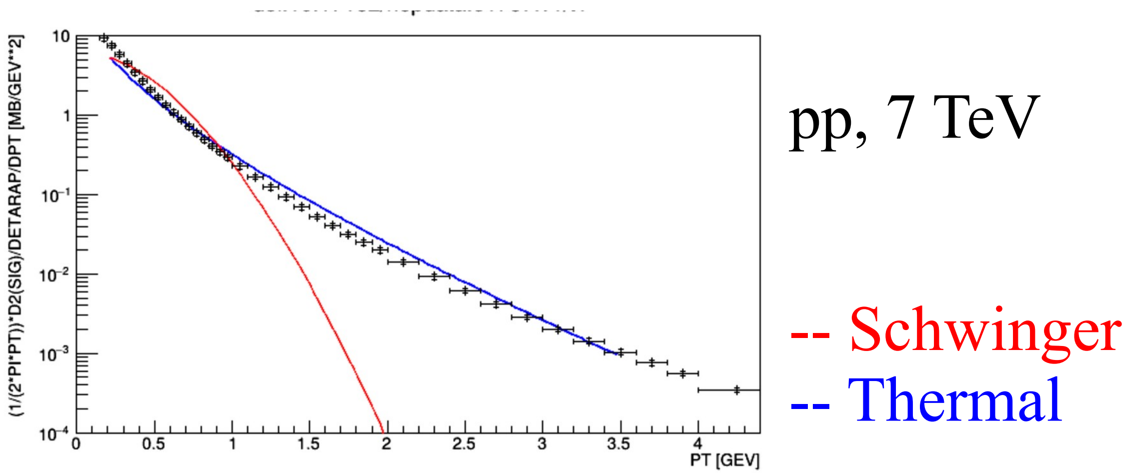
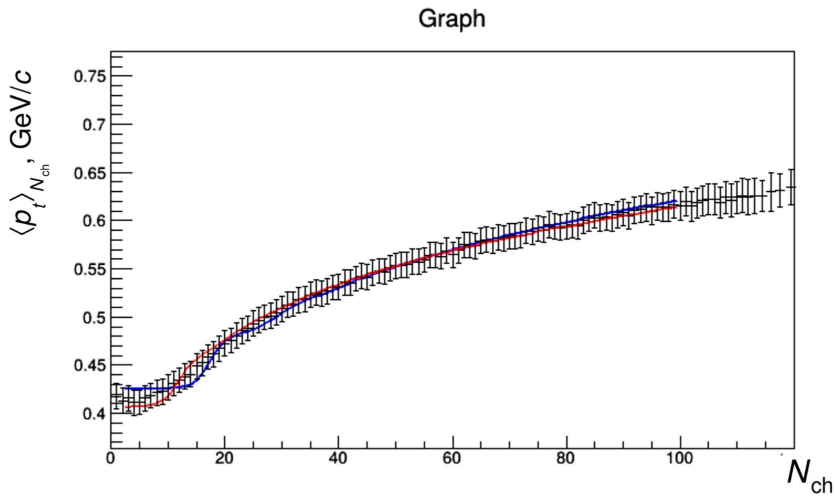
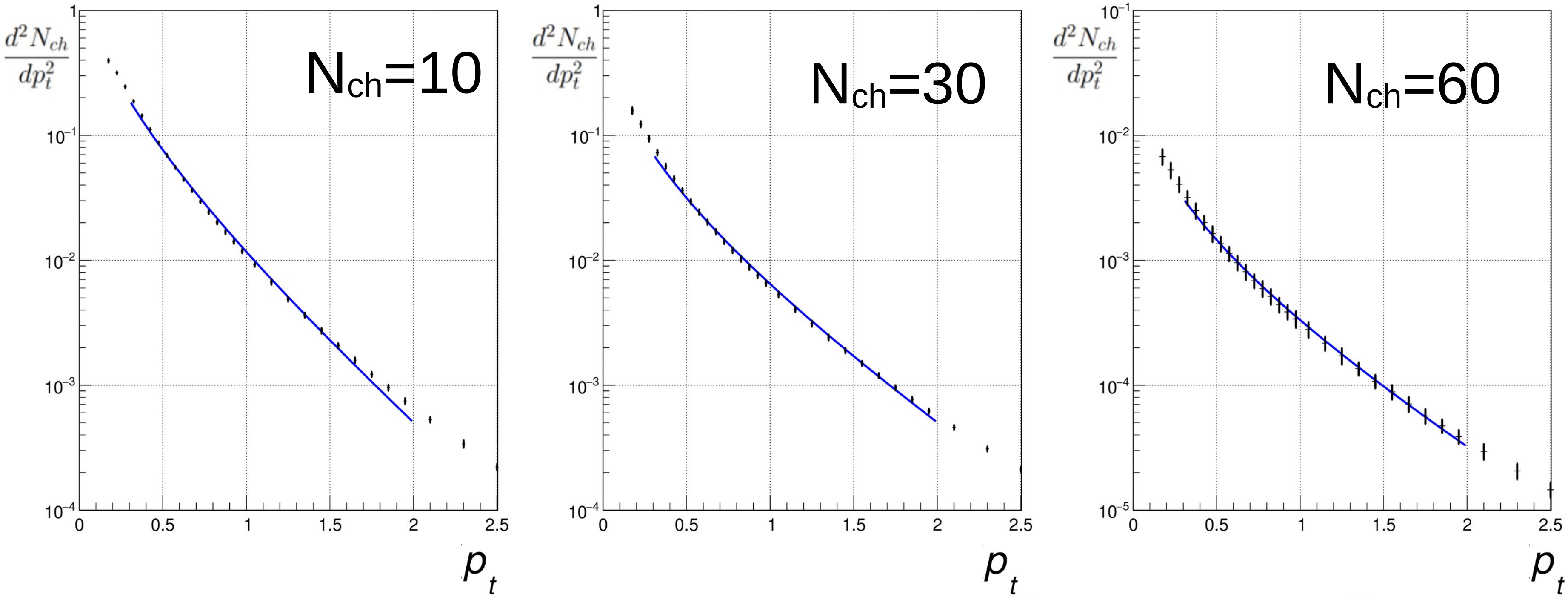




Experimental data ALICE, Eur.Phys.J.C 73 (2013) 2662, 2013. . Khachatryan et al. (CMS Collab.), JHEP 1101 (2011) 079

Multiplicity-dependent pt-spectrum

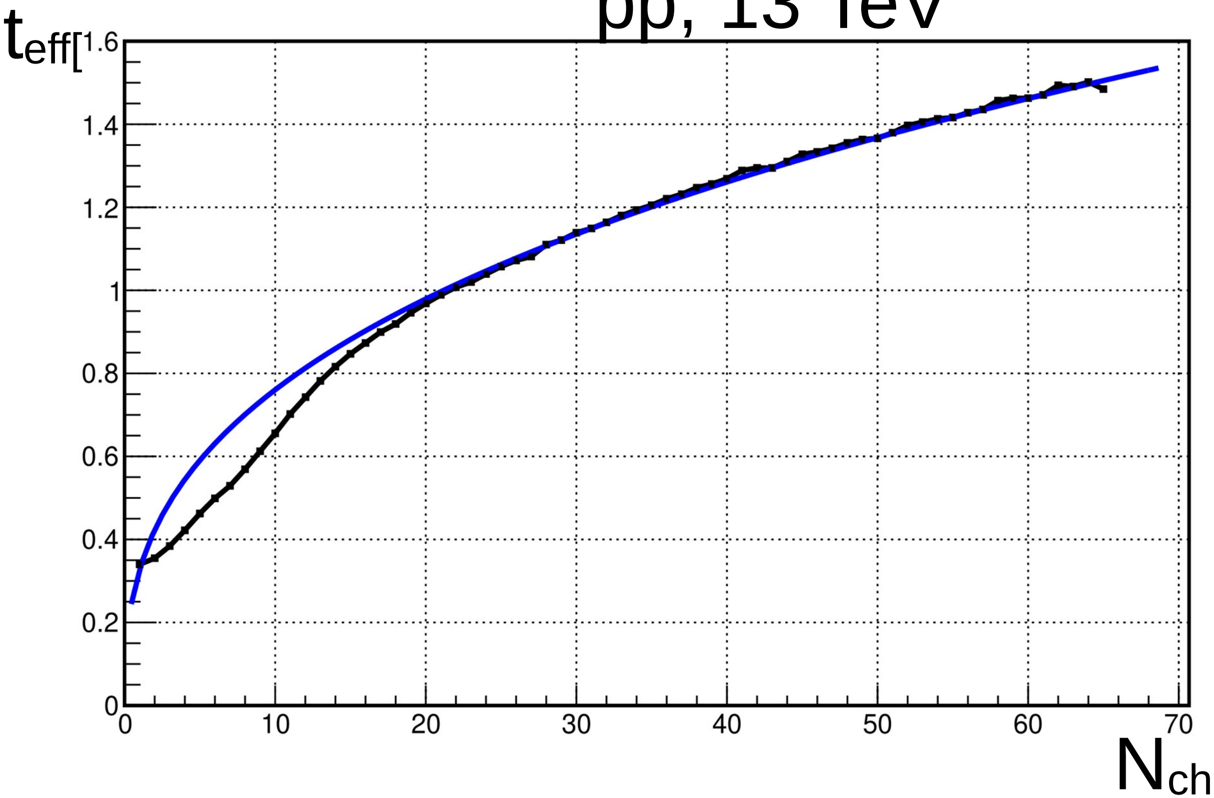
pp, 13 TeV



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

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

Multiplicity-dependent pt-spectrum



$t_{eff} = c\, N_{ch}^{\beta}$

c = 0.328

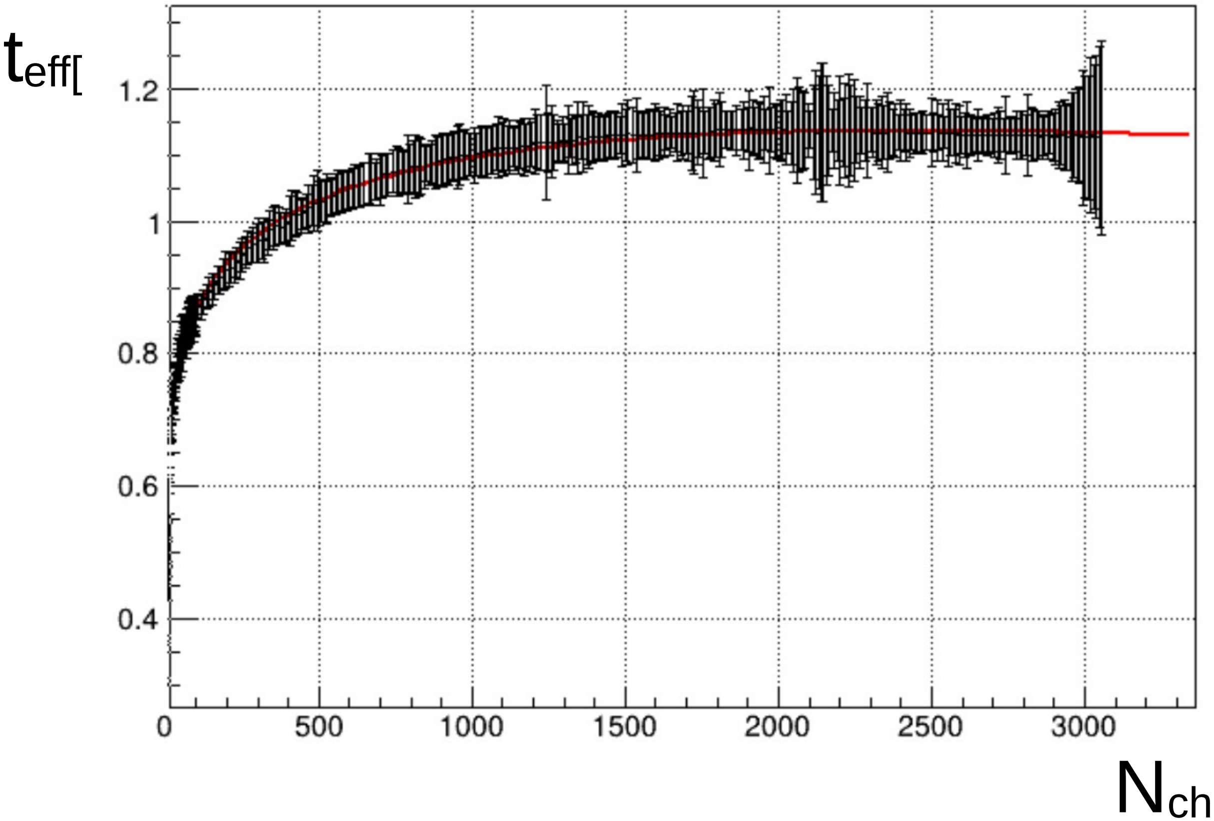
β = 0.365

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

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

Multiplicity-dependent pt-spectrum

Pb-Pb 5.02 TeV



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

c = 0.498

β = 0.121

γ = 0.00005

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

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

Conclusions:

- Thermal model for the description of pt-spectra allows not only to simultaneously describe pt-Ncb correlations and pt-spectra in min. bias pp collisions, but also pt-spectra in multiplicity bins.

- Emergence of the thermal model like pt-spectra can be related to fluctuations in the string tension fluctuations

- The dependence of the effective string tension on multiplicity can be describe with power low (which coincides with Extended multi-pomeron exchange model prescriptions
    - To be looked at more detailed in p-Pb and A-A collisions

Thank you