Multiplicity dependent transverse momentum distributions of hadrons of different species in the extended multipomeron exchange model

V. N. Kovalenko

E.V.Andronov,
A. M. Puchkov, V.V.Vechernin

Saint Petersburg State University, Russia

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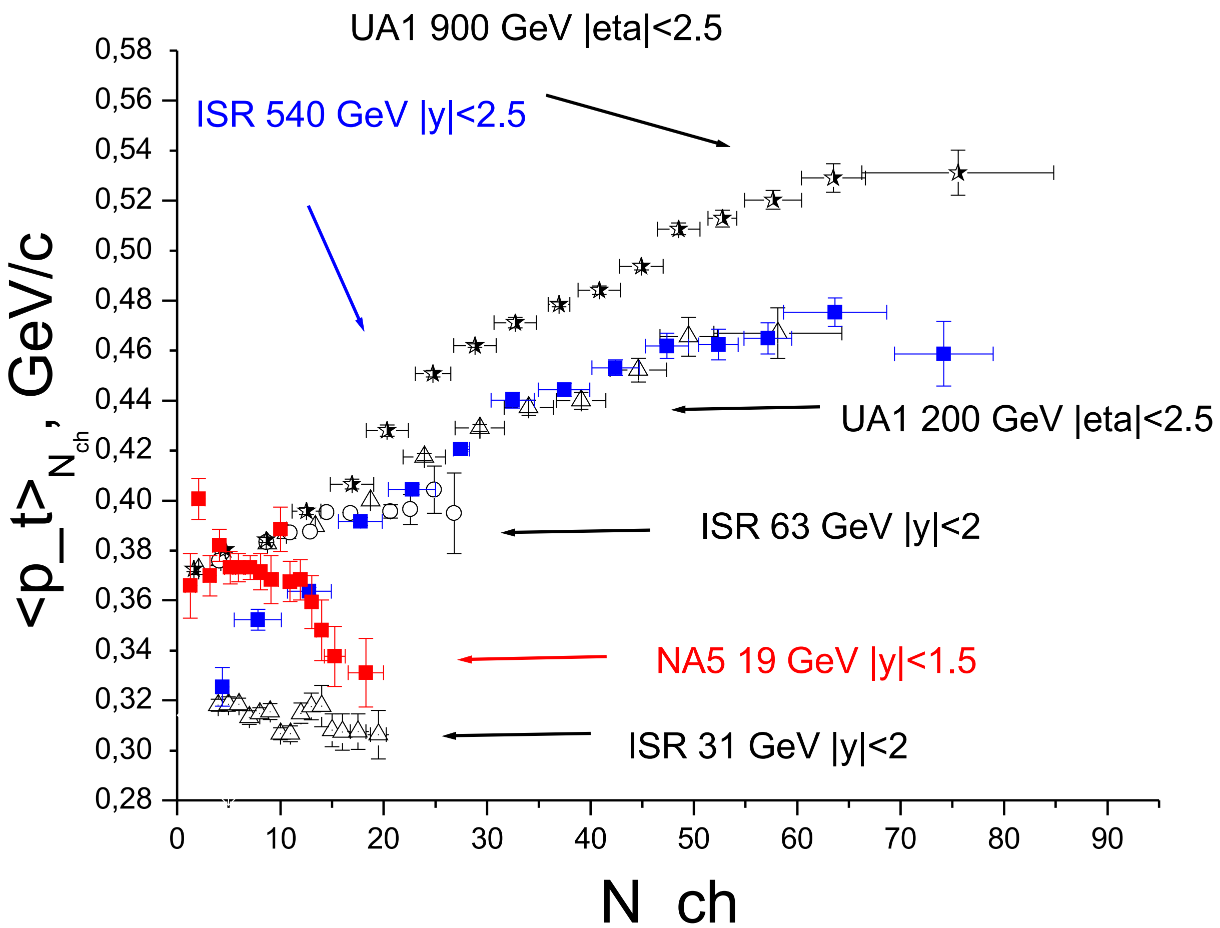
Experimentally Observed p_t-N_{ch} Correlations



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

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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

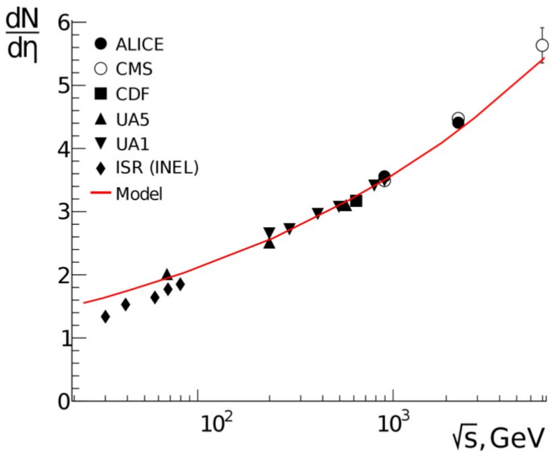
$$\times \frac{1}{n^{\beta} t} \exp\left(-\frac{\pi p_t^2}{n^{\beta} t} \right)$$

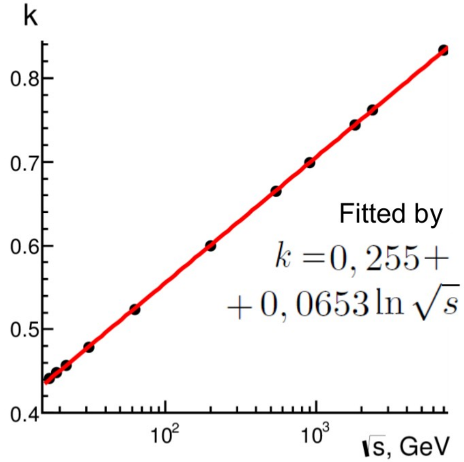
Modified Schwinger mechanism

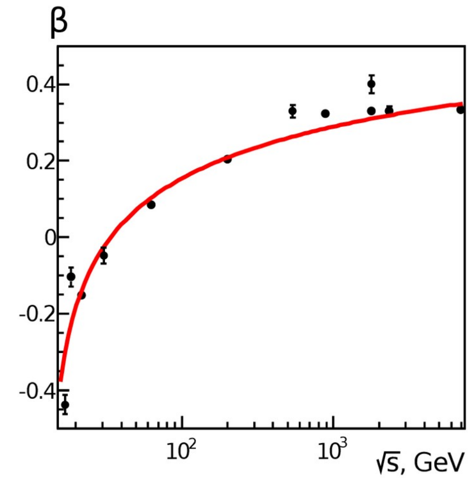
Bodnia, E.; Derkach, D.; Feofilov, G.; Kovalenko, V.; Puchkov, A. PoS QFTHEP2013 2013, 60. https://doi.org/10.22323/1.183.0060

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

Parameters determination

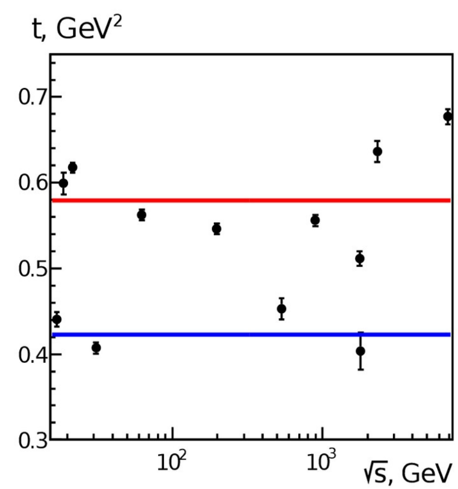


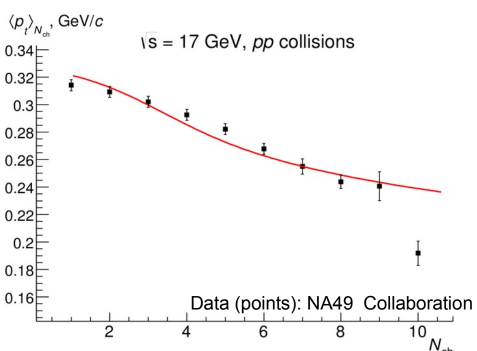


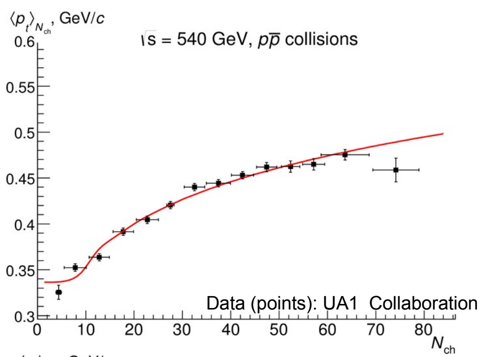


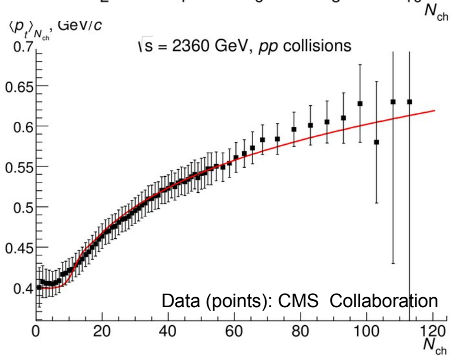
Fitted by

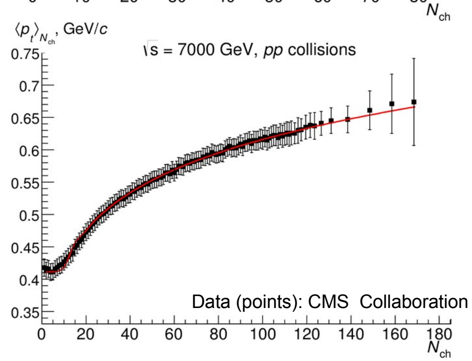
$$\beta = 1.16\left(1 - \left(ln\sqrt{s} - 2.52\right)^{-0.19}\right)$$







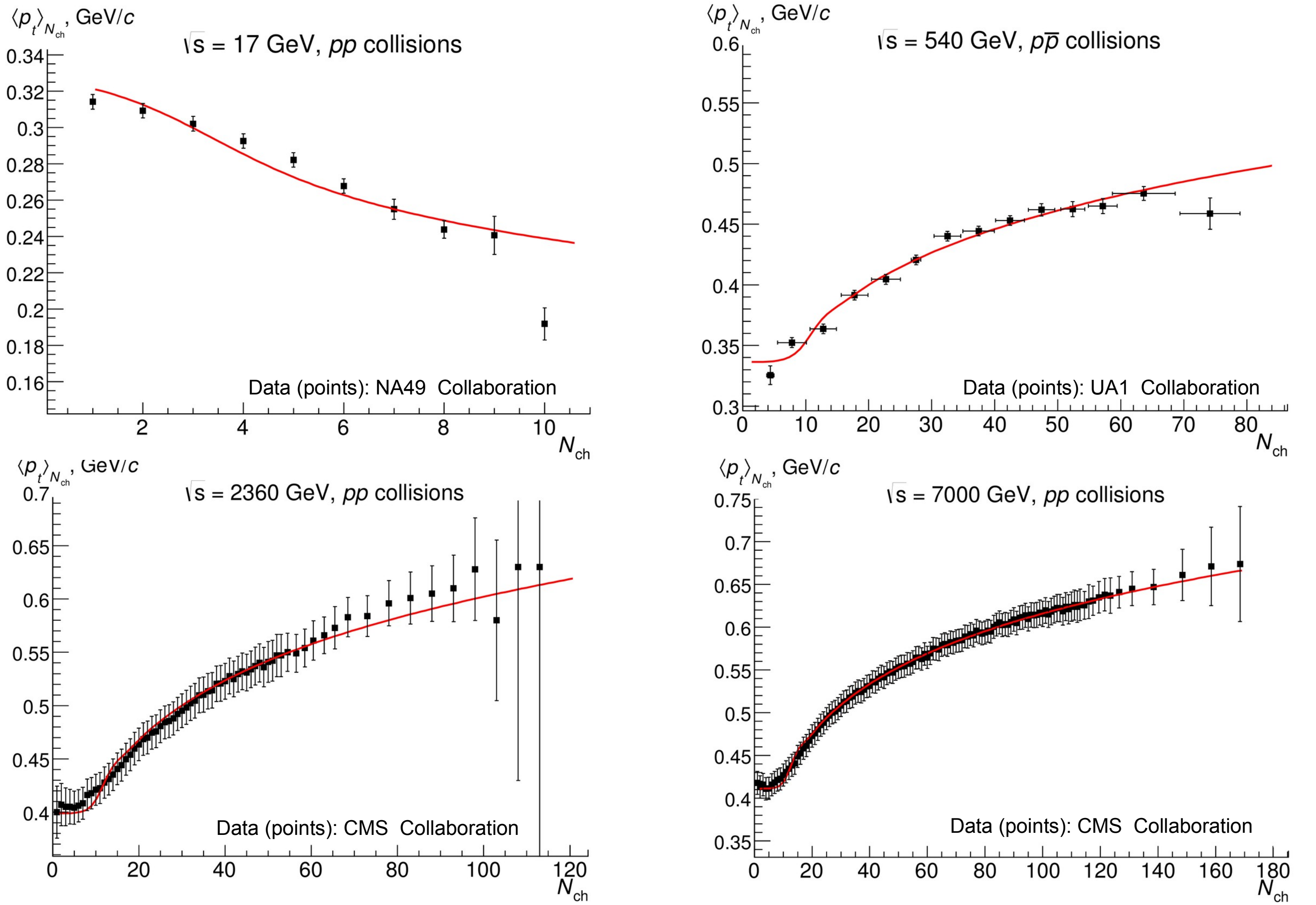




p_t-N_{ch} correlations

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

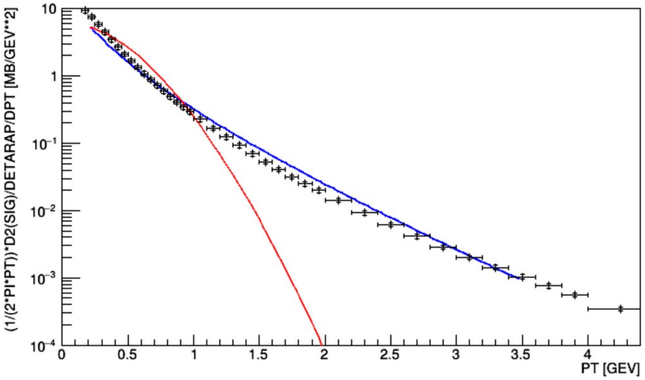
- Schwinger mechanism of particle production:

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

After averaging over string density fluctuations – thermal spectrum

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

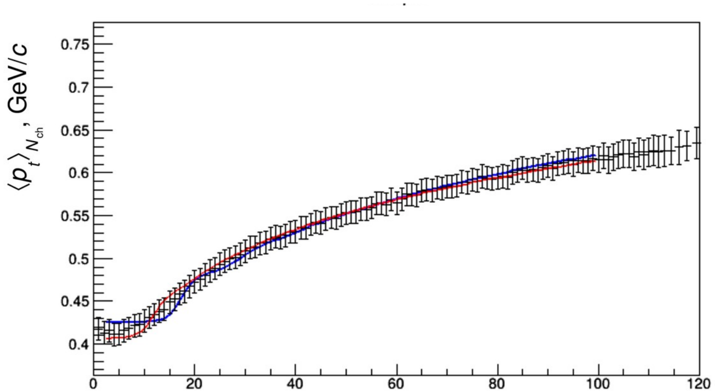
Bialas, A. Fluctuations of the string tension and transverse mass distribution. Phys. Lett. B. 1999, 466, 301–304



pp, 7 TeV

– Schwinger

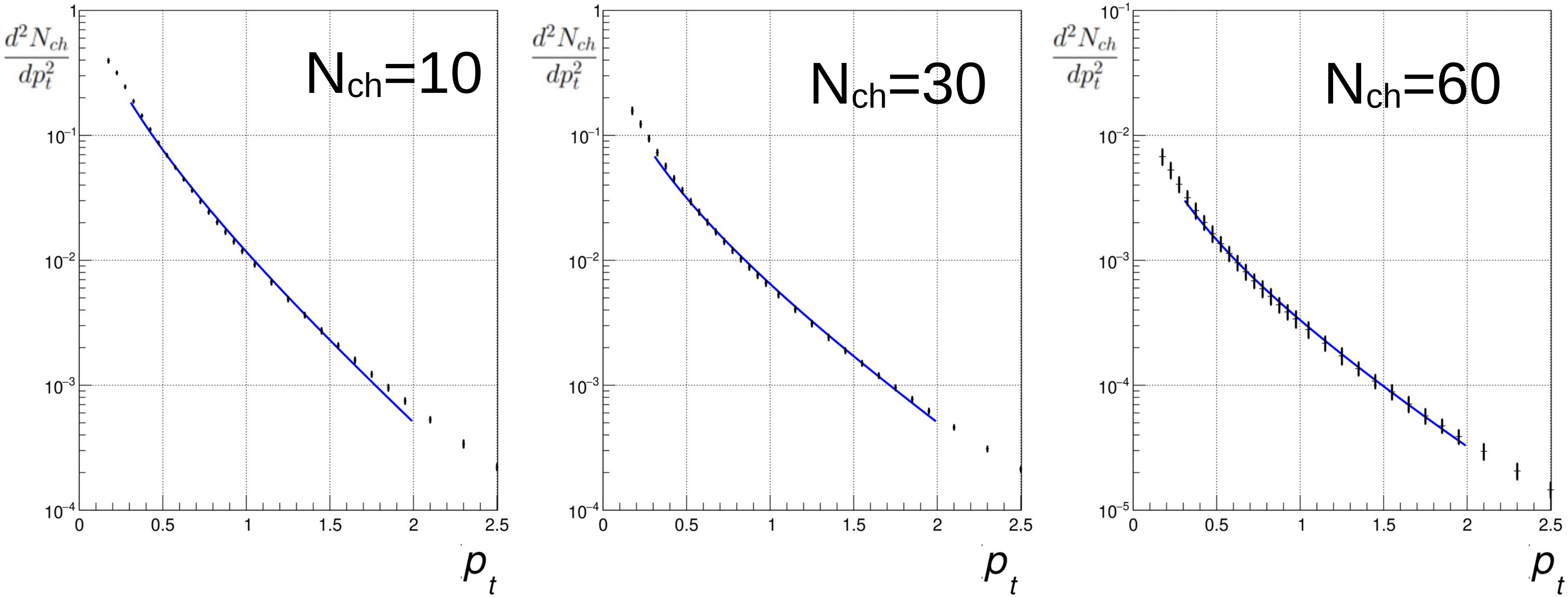
– Thermal



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

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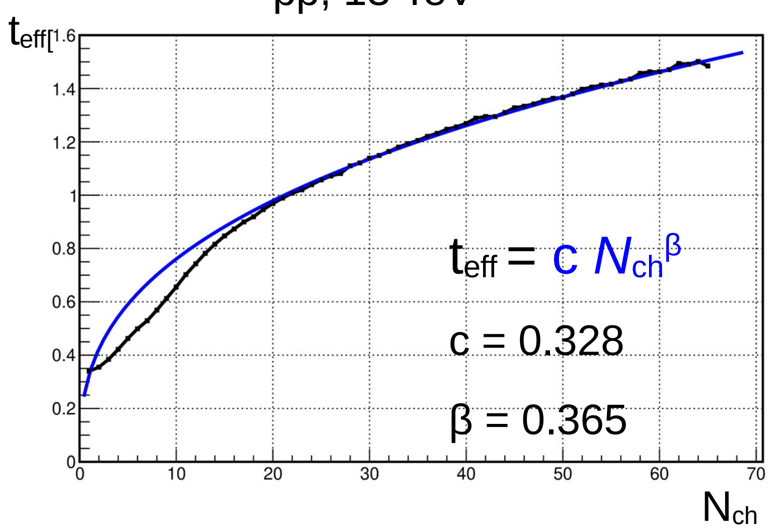
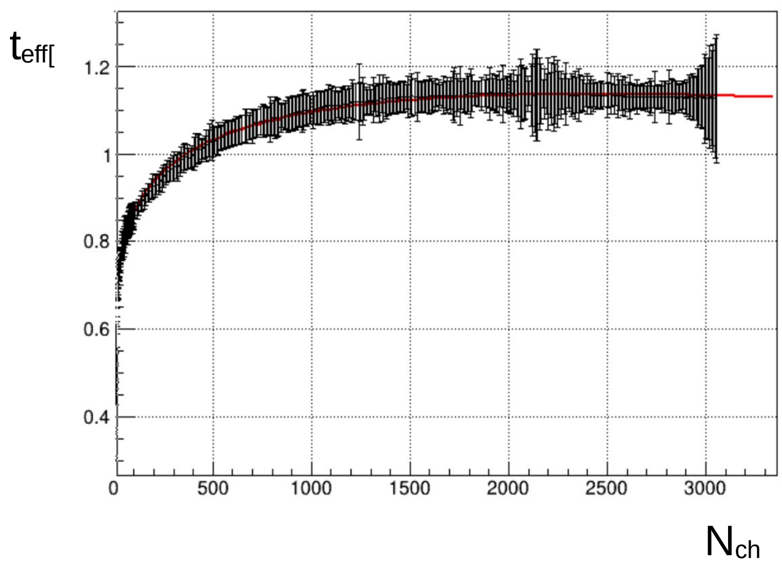
pp, 13 TeV



Pb-Pb 5.02 TeV



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

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

c = 0.498

β = 0.121

γ = 0.00005

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

Particle differentiation

- Schwinger or thermal mechanism of particle production:

$$Y_\nu \sim \exp\left(\frac{\pi\left(p_t^2+m_\nu^2\right)}{n^\beta t}\right) \quad \text{or} \quad Y_\nu \sim \exp\left(-2\frac{\left(\sqrt{p_t^2+m^2}-m\right)}{\sqrt{t_{\text{eff}}}}\right)$$

  - Naive approach: take only major particles: pions, kaons, protons
  - Better: include rho-meson: decays into pions: $\rho^0 \rightarrow \pi^+ + \pi^-$, $\rho^\pm \rightarrow \pi^\pm + \pi^0$
  - Best: take all light hadrons and correct for their cascade decays (feed down)

then

$$Y_\nu \sim \sum_\mu M_{\mu\nu} \cdot (2S_\mu+1) \cdot \exp\left(\frac{\pi\left(p_t^2+m_\mu^2\right)}{n^\beta t}\right),$$

$$Y_\nu \sim \sum_\mu M_{\mu\nu} \cdot (2S_\mu+1) \cdot \exp\left(-2\frac{\left(\sqrt{p_t^2+m^2}-m\right)}{\sqrt{t_{\text{eff}}}}\right)$$

where S_μ – spin of particle type μ

$M_{\mu\nu}$ – effective branching ration matrix, i.e. the yield of particles from cascade decays of a particle μ

- The particle lists and the effective branching ration is extracted from Therminator 2 particle decayer (M. Chojnacki, et al, Comput. Phys. Commun. 183, 746 (2012), arXiv:1102.0273 [nucl-th])

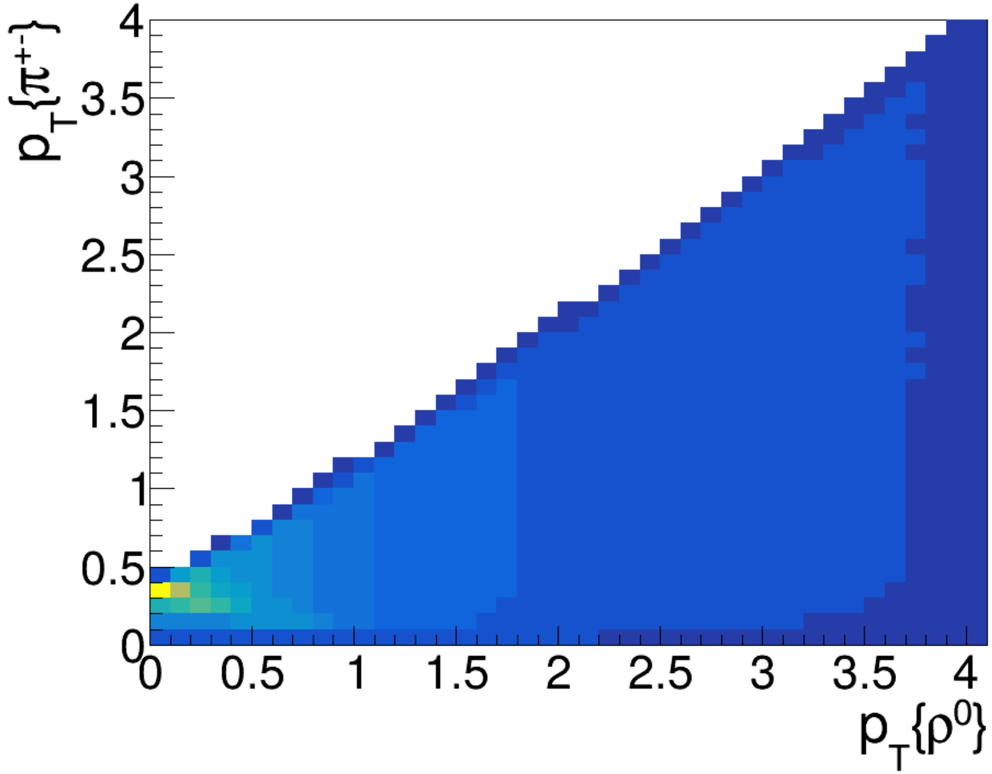
$M_{\mu\nu}$ Has to be also pt-dependent

Contribution of different particle species and resonance decays

Transverse-momentum dependent decay matrix

$M_{\mu\nu}(p_T[\rho^0], p_T[\pi^{+-}])$

145161 2d histograms



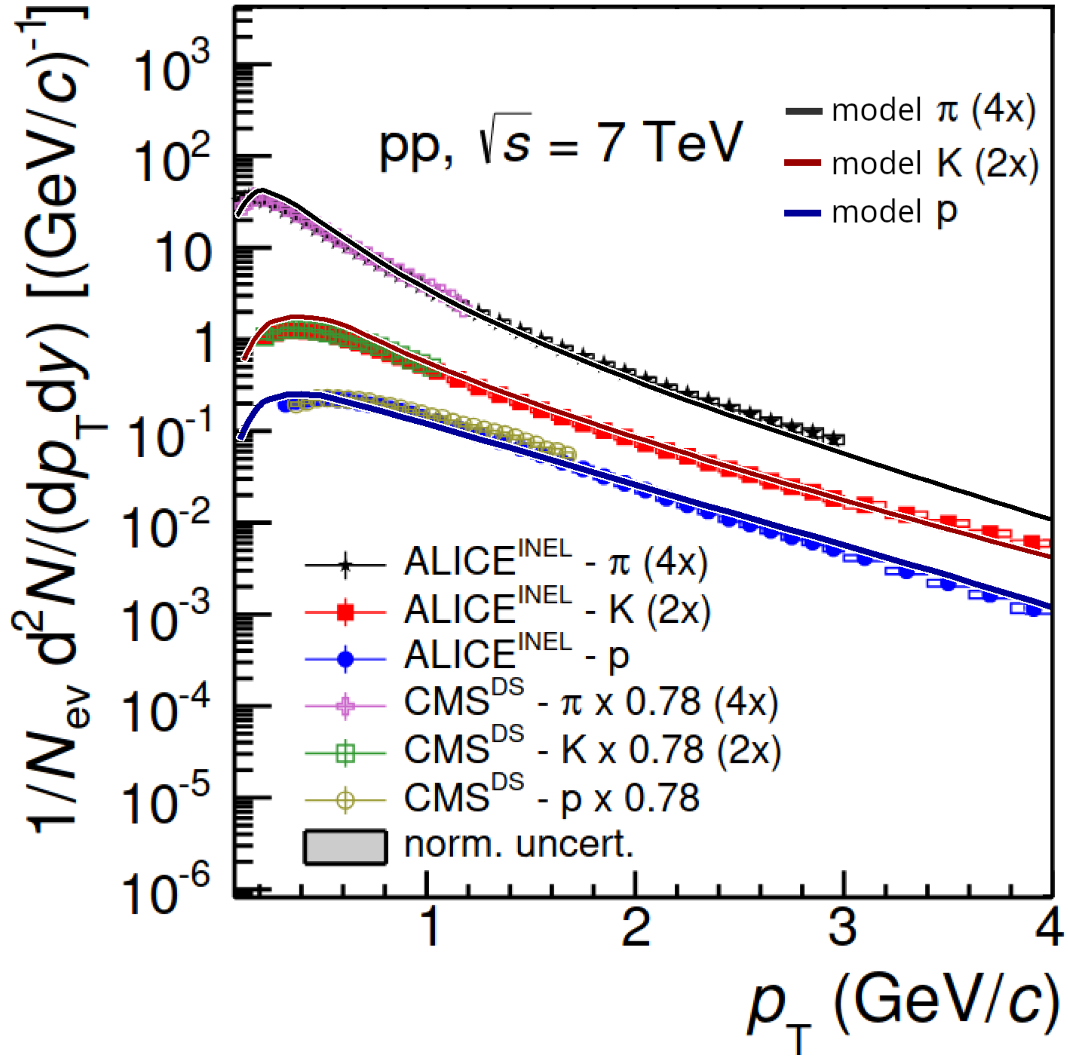
At large transverse momentum the spectra becomes softer due to resonance decays

Results: pt-distributions for pions, kaons and protons

$$Y_\nu \sim \exp\left(-2\frac{\left(\sqrt{p_t^2+m^2}-m\right)}{\sqrt{t_{\text{eff}}}}\right)$$

Resonance decays.
Transverse-momentum dependent decay matrix

t=2.5 GeV², β=0.4, k=0.3



Lines - current model
Experimental data: ALICE Collab, Eur.Phys.J.C 75 (2015) 5, 226

Conclusions:

- A new generalization of the Multipomeron exchange model is proposed with thermal spectrum due to event-by-event string tension fluctuations
- This allowed to describe the thermal-like behavior p_T-distributions
- For the particle specie differentiation the Schwinger-like and Thermal-like mechanism can be applied
- The contributions of resonances is essential at LHC energy to the production of pions, kaons and protons
- The pt-dependent decay matrix is implemented
- The spectra becomes softer due to resonance decays
- The approach allowed to describe simultaneously the p_T-spectra of different particle species

Thank you