Study of multiquark fluctons in dd collisions

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Introduction

Study of inclusive production cross-sections

of pions and protons in a new cumulative region:

central rapidities, large transverse momenta

$$d+d \rightarrow \pi+X$$

$$d+d \rightarrow p+X$$

flucton-flucton interaction
6q+6q

outside (and inside) p+p kinematics:

$$p+p \rightarrow \pi+X$$

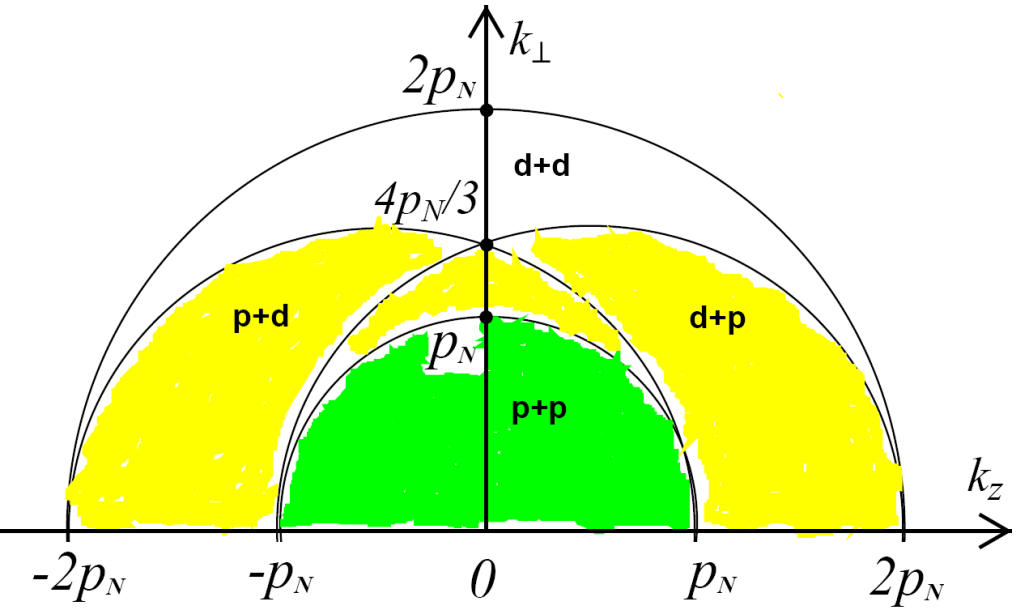
$$p+p \rightarrow p+X$$

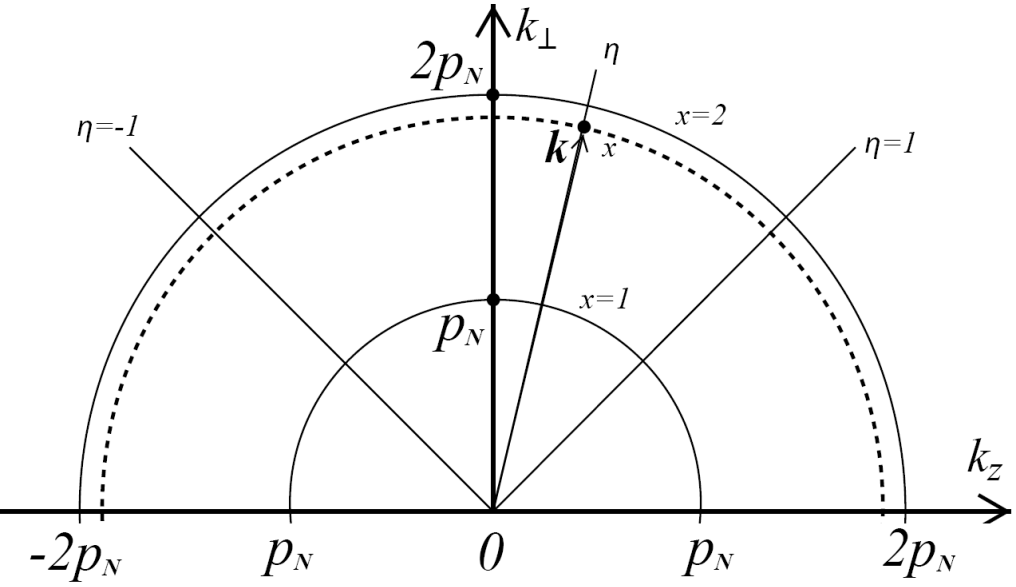
proton-proton interaction
3q+3q

This is only possible thanks to the moderate energy of the NICA collider
(completely impossible at ultrahigh energies of the RHIC and LHC)

The mechanisms of pion and proton production are different!

Asymptotic form of the inclusive cross-section at mid-rapidities near kinematic thresholds





$p_N >> m_N$ $\quad p_N \approx \sqrt{s}/2$

We expect
for the inclusive cross-section
of the production of particles with large transverse momenta at midrapidities:

$$\frac{k_0\, d^3\sigma}{d^3\mathbf{k}} = f(x,\eta) = C\, s^{-q_1}\, (f-x)^{q_2}\, F(\eta)$$

Quark Counting Rules with two asymptotic parameters:
$s >> m^2$ and $(f-x) << 1$
at f=1 (pp) and f=2 (dd)

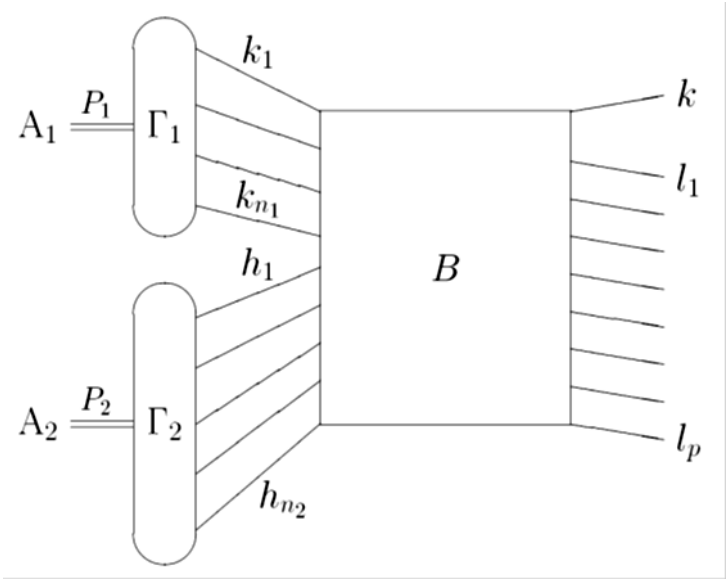
q_1, q_2 are different for production of pions and protons!

x - cumulative number
$\eta = -\ln \mathrm{tg}\, \frac{\theta^*}{2}$ - pseudorapidity

Progress in theoretical motivation

pion production:

Standard Quark Counting Rules (based on production from one point) were generalized to the case of inclusive cross-section of pion production in the new cumulative region (central rapidities, large transverse momenta), which depends on two asymptotic parameters $s \gg m^2$ and $(x_{max} - x) \ll 1$.

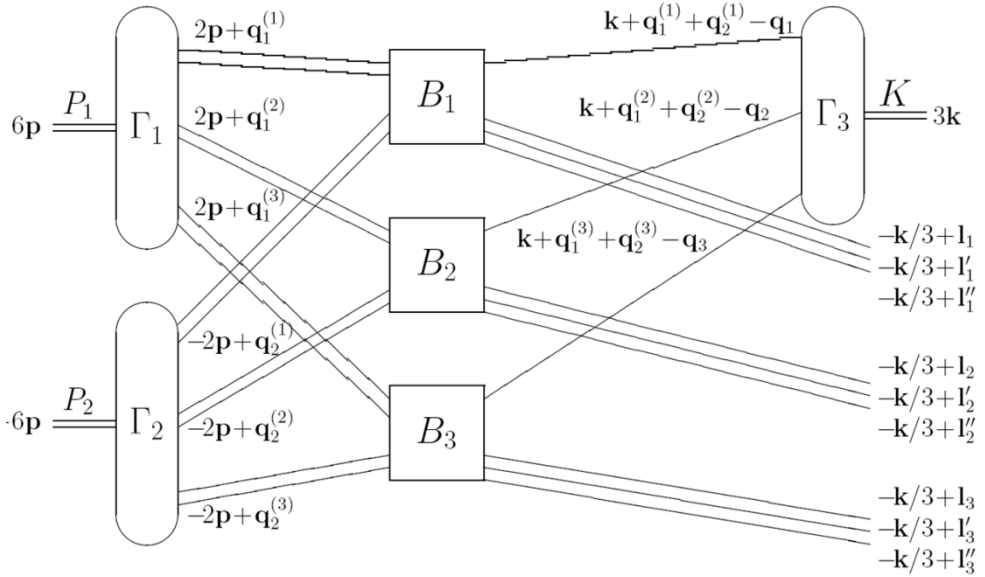


$$r_B \sim \frac{1}{\sqrt{s}}$$

V.Vechernin, S.Yurchenko, Int. J. Mod. Phys. E 33, 2441022 (2024)
S.Yurchenko, V.Vechernin, Phys. Atom. Nucl. 88, 349 (2025)

proton production:

Mechanism of Coherent Coalescence of Quark dominates the proton production in the new cumulative region. This leads to Modified Quark Counting Rules (due to production from few points) and changes the dependence of inclusive cross-section on two asymptotic parameters $s \gg m^2$ and $(x_{max} - x) \ll 1$.



$$r_N \sim r_f \gg r_B \sim \frac{1}{\sqrt{s}}$$

V. Vechernin, S. Yurchenko, Phys. Part. Nucl. 57 (5) (2026) [in press].

So, the asymptotic behaviour of cross-sections depends on details of flucton-flucton interaction!

Progress in MC simulations

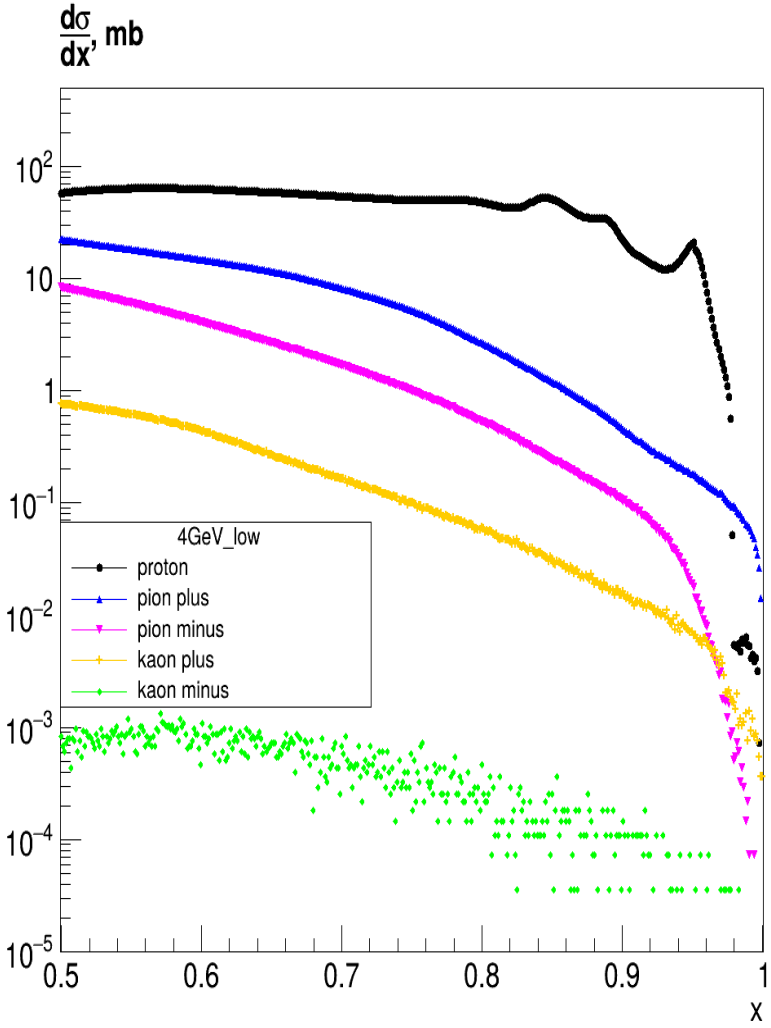
S. Yurchenko, Phys. Part. Nucl. (2026) [in press].

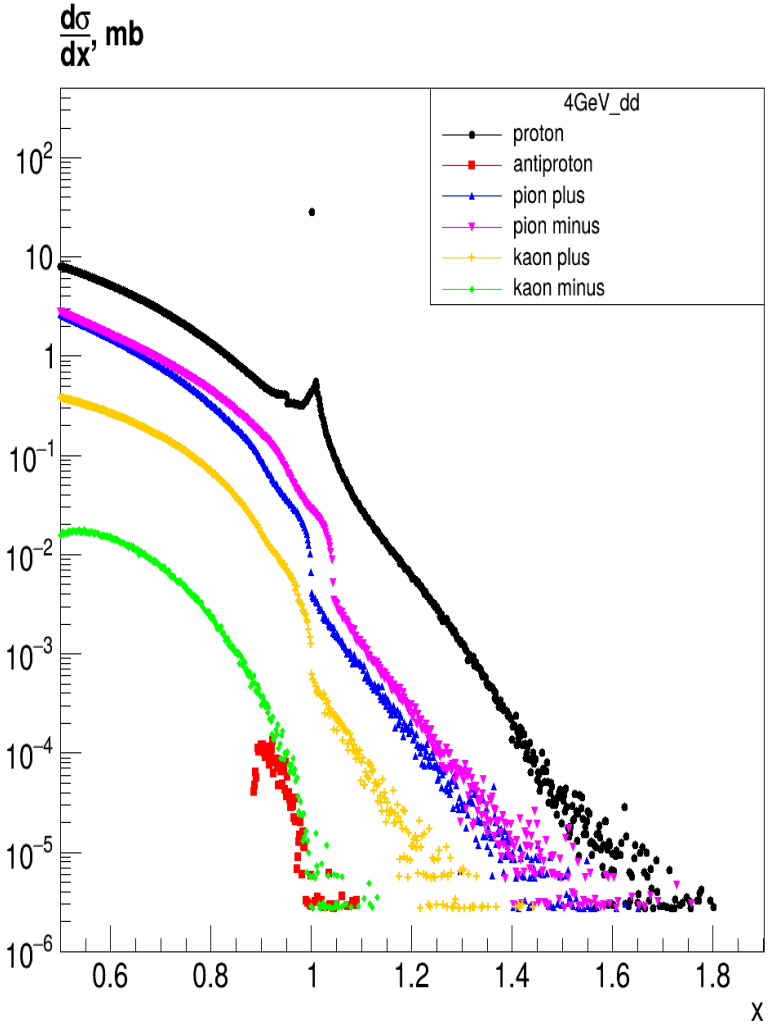
Simulations with Pythia8

- LowEnergyQCD: all = on. $\mathrm{N_{ev}} = 10^9$
- Heavylons: mode = 1. $\mathrm{N_{ev}} = 5 \cdot 10^8$
- Pseudorapidity interval: $-2 < \eta < 2\ (15^\circ < \theta < 165^\circ)$
- Particle types: $p, \bar{p}, \pi^+, \pi^-, K^+, K^-$

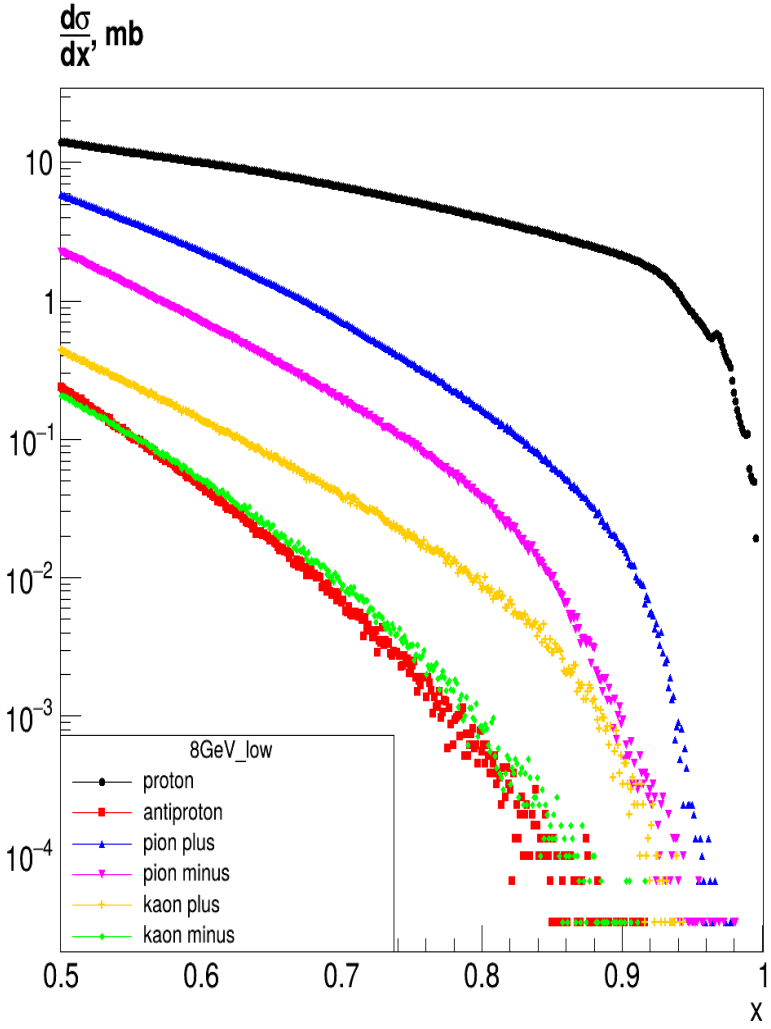
No propagation through detector material were done!

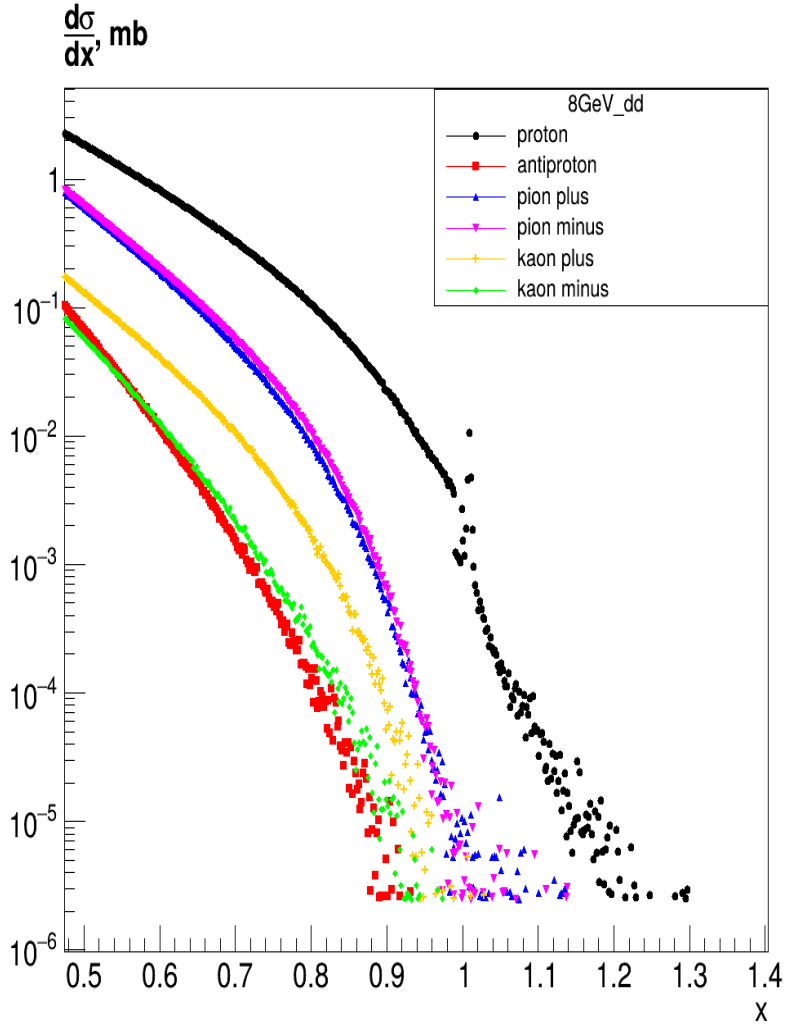
All particles, 4 GeV, pp and dd



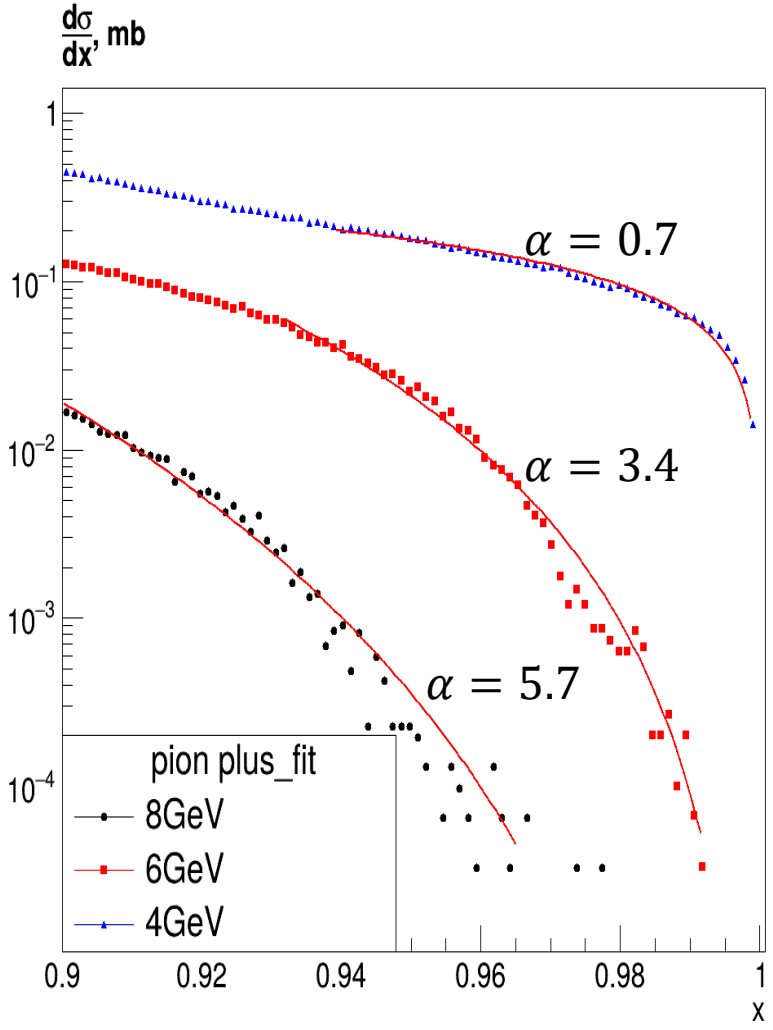


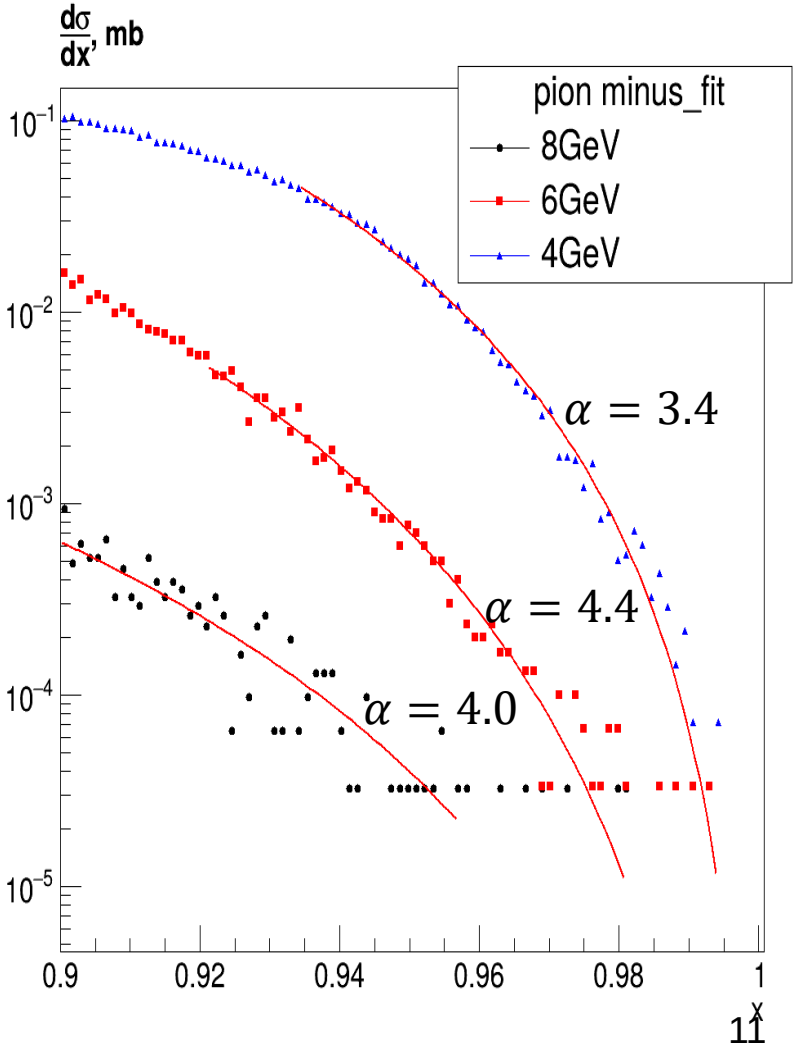
All particles, 8 GeV, pp and dd





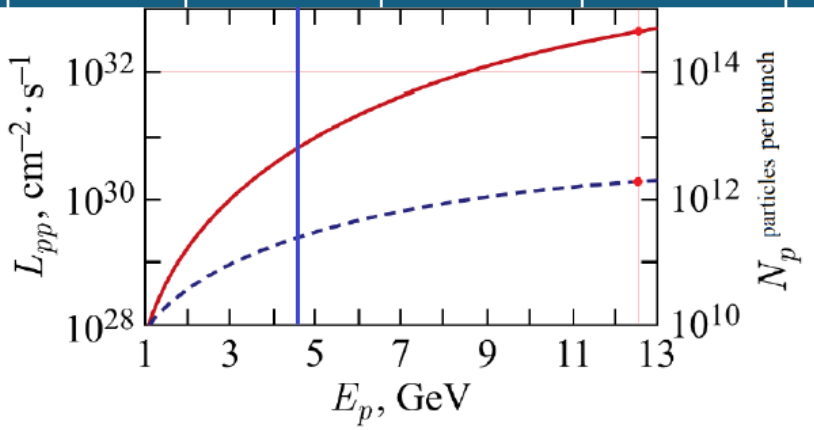
Fits of π^+ and π^- with $C \cdot (1-x)^{\alpha}$





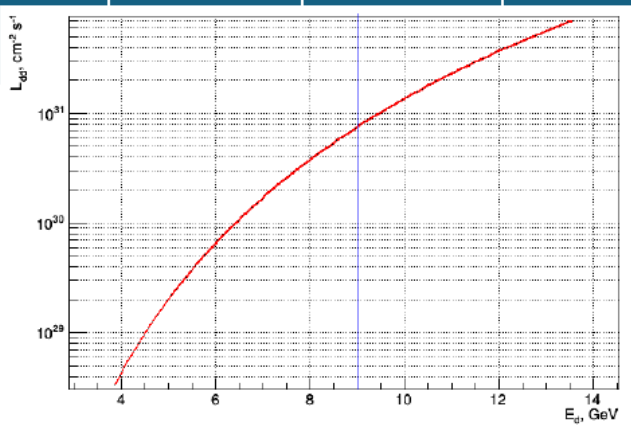
Yields of particles: pp with $0.95 < x < 1$

	$\sqrt{S_{NN}} = 4\ GeV$			$\sqrt{S_{NN}} = 6\ GeV$			$\sqrt{S_{NN}} = 8\ GeV$		
Particle type	**Per sec**	**Per day**	**Per month**	**Per sec**	**Per day**	**Per month**	**Per sec**	**Per day**	**Per month**
p	$8.6 \cdot 10^{2}$	$7.4 \cdot 10^{7}$	$2.2 \cdot 10^{9}$	$2.6 \cdot 10^{3}$	$2.3 \cdot 10^{8}$	$6.8 \cdot 10^{9}$	$1.5 \cdot 10^{3}$	$1.3 \cdot 10^{8}$	$4 \cdot 10^{9}$
π^{+}	$2.1 \cdot 10^{1}$	$1.8 \cdot 10^{6}$	$5.4 \cdot 10^{7}$	$5.8 \cdot 10^{0}$	$5 \cdot 10^{5}$	$1.5 \cdot 10^{7}$	$1.3 \cdot 10^{-1}$	$1.1 \cdot 10^{4}$	$3.3 \cdot 10^{5}$
π^{-}	$8.1 \cdot 10^{-1}$	$5.4 \cdot 10^{4}$	$2.1 \cdot 10^{6}$	$1.6 \cdot 10^{-1}$	$1.4 \cdot 10^{4}$	$4.1 \cdot 10^{5}$	$4.4 \cdot 10^{-2}$	$3.8 \cdot 10^{3}$	$1.2 \cdot 10^{5}$
Number of collisions	$\mathbf{1.7 \cdot 10^{5}}$	$\mathbf{1.5 \cdot 10^{10}}$	$\mathbf{4.4 \cdot 10^{11}}$	$\mathbf{8.8 \cdot 10^{5}}$	$\mathbf{7.6 \cdot 10^{10}}$	$\mathbf{2.3 \cdot 10^{12}}$	$\mathbf{3.1 \cdot 10^{6}}$	$\mathbf{2.7 \cdot 10^{11}}$	$\mathbf{8.2 \cdot 10^{12}}$

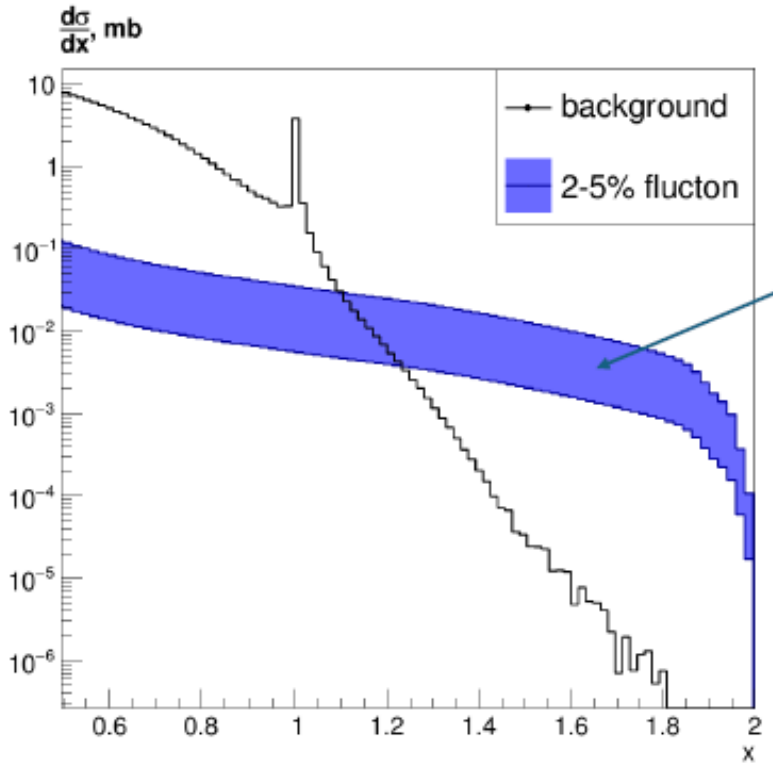


Yields of particles: dd with $x > 1$

Particle type	$\sqrt{S_{NN}} = 4\ GeV$ Per sec	Per day	Per month	$\sqrt{S_{NN}} = 6\ GeV$ Per sec	Per day	Per month	$\sqrt{S_{NN}} = 8\ GeV$ Per sec	Per day	Per month
p	$2.9 \cdot 10^{0}$	$2.5 \cdot 10^{5}$	$7.5 \cdot 10^{6}$	$1.2 \cdot 10^{0}$	$1 \cdot 10^{5}$	$3.1 \cdot 10^{6}$	$2.9 \cdot 10^{-1}$	$2.5 \cdot 10^{4}$	$7.5 \cdot 10^{5}$
π^{+}	$9.1 \cdot 10^{-3}$	$7.9 \cdot 10^{2}$	$2.4 \cdot 10^{4}$	$1.8 \cdot 10^{-3}$	$1.5 \cdot 10^{2}$	$4.6 \cdot 10^{3}$	$1.2 \cdot 10^{-3}$	$1.1 \cdot 10^{2}$	$3.2 \cdot 10^{3}$
π^{-}	$4.1 \cdot 10^{-2}$	$3.6 \cdot 10^{3}$	$1.1 \cdot 10^{5}$	$2.5 \cdot 10^{-3}$	$2.2 \cdot 10^{2}$	$6.5 \cdot 10^{3}$	$7 \cdot 10^{-4}$	$6 \cdot 10^{1}$	$1.8 \cdot 10^{3}$
Number of collisions	$5 \cdot 10^{3}$	$4.3 \cdot 10^{8}$	$1.3 \cdot 10^{10}$	$7.5 \cdot 10^{4}$	$6.5 \cdot 10^{9}$	$2 \cdot 10^{11}$	$4.2 \cdot 10^{5}$	$3.6 \cdot 10^{10}$	$1.1 \cdot 10^{12}$



Protons in dd collisions at $\sqrt{s_{NN}} = 4$ GeV



Flucton-flucton contribution is modeled as pp collisions at doubled energy $\sqrt{s_{NN}} = 8$ GeV

Incorporating fluctons into MC generators

Disadvantages of Pythia8:

1) It is difficult to introduce non-nucleonic components into a nucleus.
2) No Fermi motion (relative motion of nucleons) is taken into account.

Simulations with SMASH are now in progress:

[Semion Yurchenko].

1) Incorporation of a heavy nucleon resonance with a mass of about $2m_N$ into the nucleus to simulate a flucton.
2) Inclusion of a high relative momentum component in the deuteron wave function. Replacement of a flucton by a pair of nucleons with short-range correlation [L.L. Frankfurt, M.I. Strikmann, Phys. Rep. 76, 215(1981); ibid 160, 235 (1988)].

URQMD also enables to incorporate fluctons into a nucleus

[the student of Farhat Valiev].

MC simulations with the installation influence

To register extremely rare particle formation events in the cumulative region and reliably identify their tracks, the generated signal must be above the background level of various detector noises.

Passing the signal through the installation:
pure MC data => GEANT4 - propagation through detector material => reconstruction => reconstructed MC data
Typically, these two MC datasets are generated centrally in advance and are available for use in various analyses.

The problem in our case is that in standard MC generators, fluctons are not taken into account in dd collisions.

Possible solutions [Igor Denisenko]:
1) All contributions in the reconstructed MC pp data that appeared in the cumulative domain due to various detector noises can be used to estimate the background noise level.
2) To improve the signal-to-noise ratio, it was proposed to use the coincidence of the cumulative particle production with the formation of a jet in the opposite direction due to the fragmentation of flucton residues.

Reports:

1) V.V. Vechernin, S.V. Yurchenko,
IX SPD Collaboration Meeting, Yerevan (Armenia), 12-16 May, 2025.

2) V.V. Vechernin, S.V. Yurchenko,
LXXV International Conference «NUCLEUS-2025», St-Petersburg, 1-6 July, 2025.

3) V.V. Vechernin.
XXXVII International Workshop on High Energy Physics, Protvino, 22–24 July, 2025.

4) V.V. Vechernin, S.V. Yurchenko. & 5) S.V. Yurchenko.
(2 reports)
XXVI International Baldin Seminar on High Energy Physics Problems, Dubna,
15-20 September 2025.

6) V.V. Vechernin, S.V. Yurchenko,
VIII International Conference “Models in Quantum Field Theory” (MQFT-2025),
St-Petersburg, 6-10 October, 2025.

7) V.V. Vechernin, S.V. Yurchenko. & 8) S.V. Yurchenko.
(2 reports)
X SPD Collaboration Meeting, Dubna, 20-23 October, 2025.

Recent publications:

1. V.Vechernin, S.Yurchenko, Int. J. Mod. Phys. E 33, 2441022 (2024)

2. S.Yurchenko, V.Vechernin, Phys. Atom. Nucl. 88, 349 (2025)

3. V. Vechernin, S. Yurchenko, Phys. Part. Nucl. 57 (5) (2026) [in press].

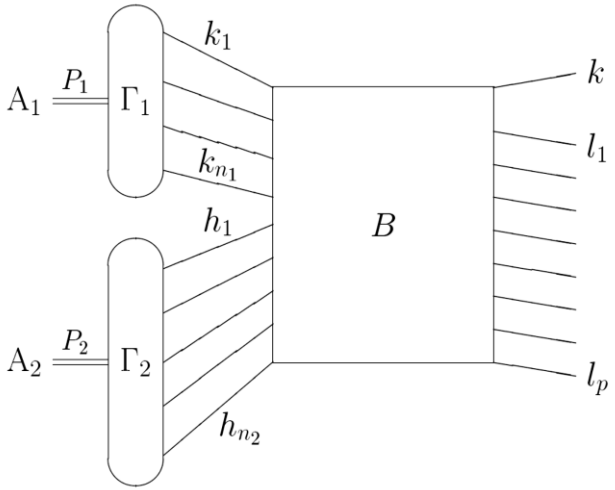
4. S. Yurchenko, Phys. Part. Nucl. (2026) [in press].

Detailed information and further progress will be presented at the "SPD first stage physics meeting" on 5 May 2026.

An important problem:
Currently, SPbSU does not receive any funding for the NICA project at all (including from the Ministry of Science and Higher Education).

Backup slides

Quark counting rules for the inclusive cross sections of pion production in a region of large transverse momenta at mid-rapidities (the decrease with both the initial energy s and the cumulative number *x*)



$$p = n_1 + n_2 - 1$$

To evaluate this behavior and find asymptotes at s>>m and (2-x)<<1 we need to generalize the quark counting rules, known now only for a) the inclusive cross sections in the fragmentation region (|t|<<s) and b) the elastic and quasielastic cross sections in the high pT region (|t|~s), to the case of inclusive cross sections in the high pT region (|t|~s).

$$I(x) \equiv (2\pi)^3 \, 2k_0 \frac{d^3\sigma}{d^3\mathbf{k}} = \frac{C(A-x)^{\frac{3}{2}p-\frac{5}{2}}}{(m^2R^3)^{p-1}s^{(p+3)/2}}$$

V. Vechernin, S. Yurchenko
Int.J.Mod.Phys.E, Vol. 33, No. 11, 2441022 (2024).

Asymptotic behaviour of inclusive cross sections

n=2, q+(qq):

Coalescence:

$$I_{\mathrm{pp}\to\mathrm{p}}(x) = C\frac{m^2}{R}\frac{(1-x)^{0.5}}{s^{3.5}}F(\theta)$$

Quark fragmentation:

$$I_{\mathrm{pp}\to\pi}(x) = C'\frac{1}{(m^2R^3)^2}\frac{(1-x)^2}{s^3}$$

n=3, q+q+q:

Coalescence:

$$I_{\mathrm{pp}\to\mathrm{p}}(x) \sim (1-x)^2$$

Quark fragmentation:

$$I_{\mathrm{pp}\to\pi}(x) = C''\frac{1}{(m^2R^3)^4}\frac{(1-x)^5}{s^4}$$