Study of multiquark fluctons in dd collisions at SPD"

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SPD First Stage Physics

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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:

$p+p \rightarrow \pi+X$

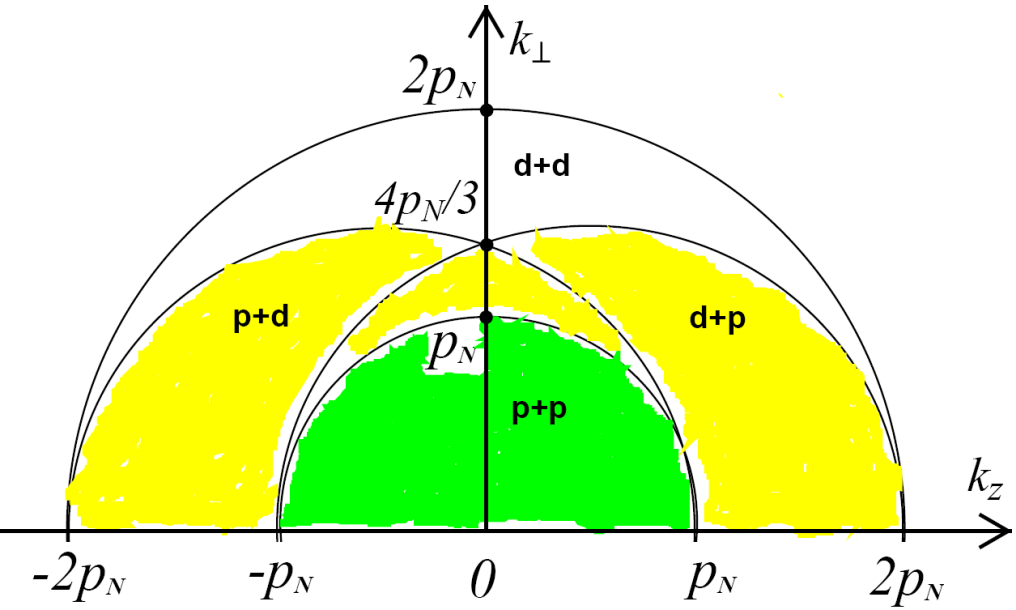
$p+p \rightarrow p+X$

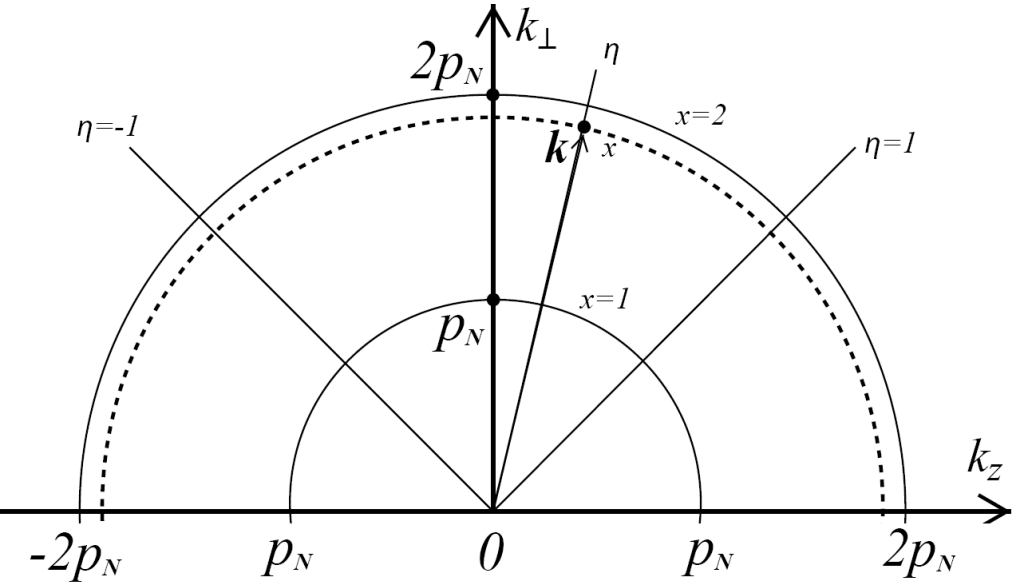
proton-proton interaction 3q+3q

This is possible only due 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

MC simulations of the particle production in cumulative region in dd collisions

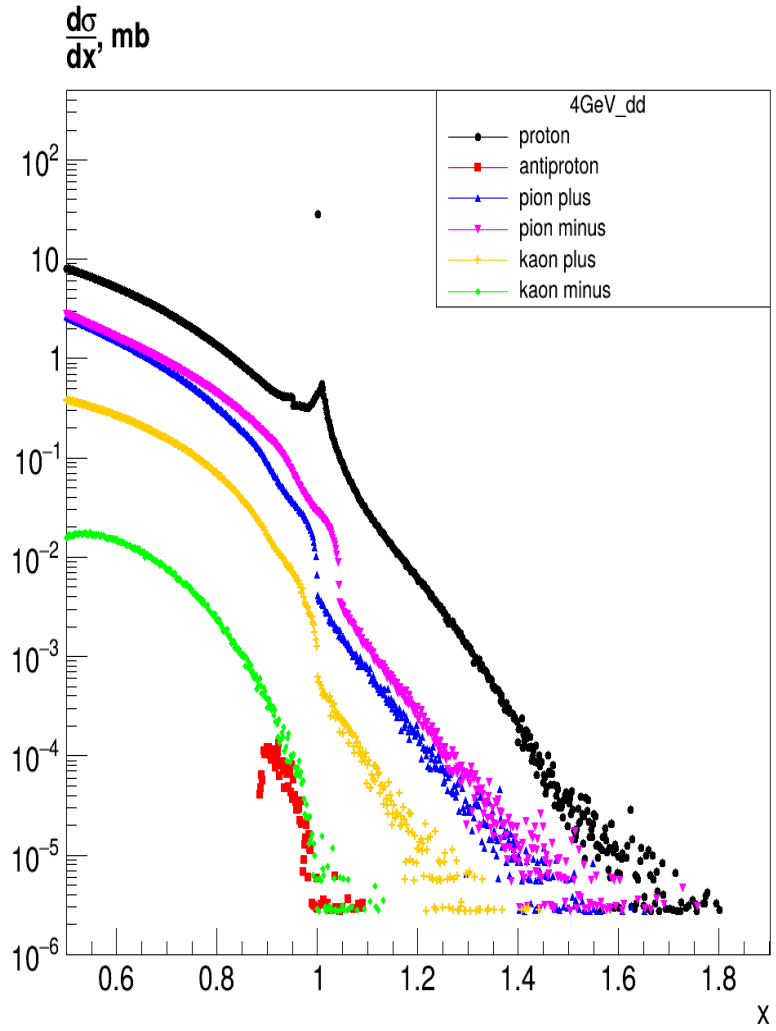
S. Yurchenko, Phys. Part. Nucl. (2026) [in press].

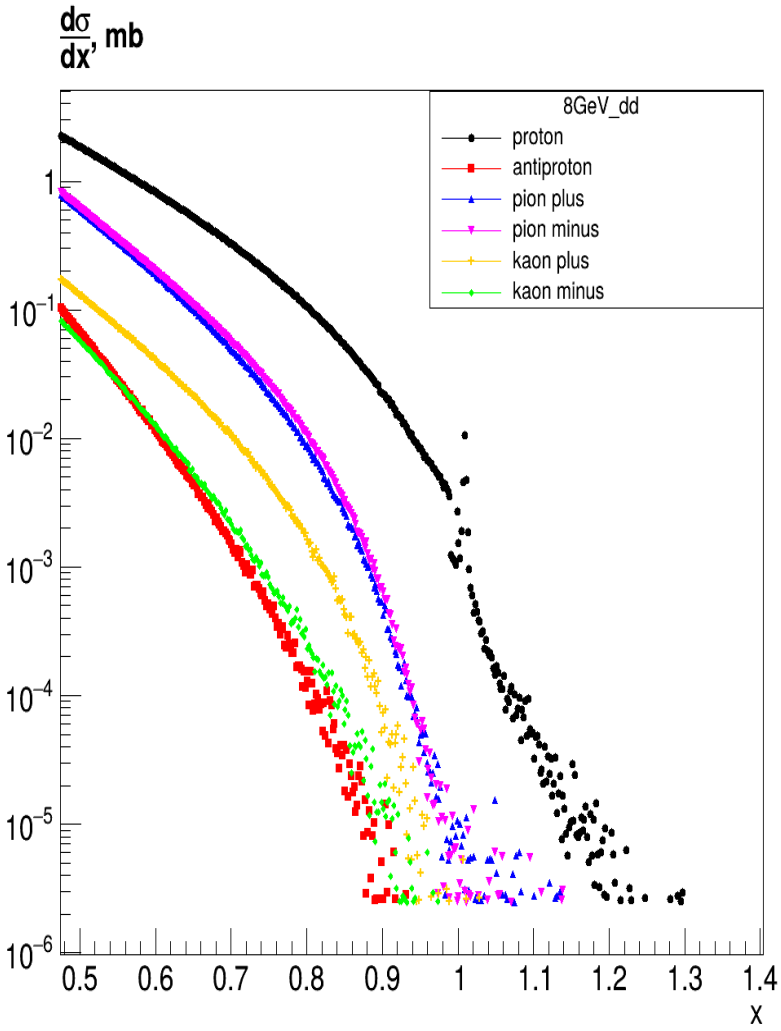
Simulations with Pythia8

- 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!

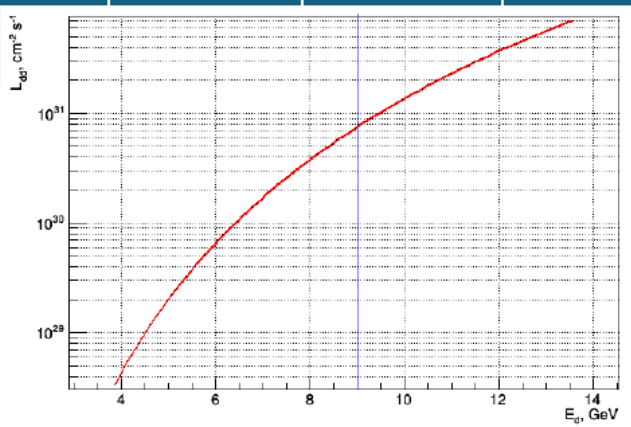
All particles in dd at 4 and 8 GeV



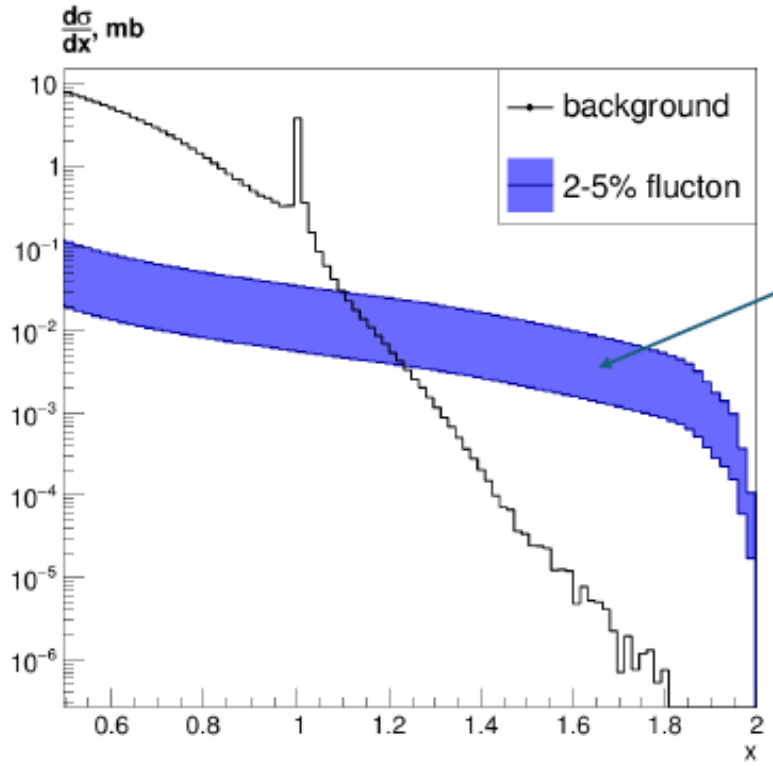


Yields of particles: dd with $x > 1$

	$\sqrt{S_{NN}} = 4\ GeV$			$\sqrt{S_{NN}} = 6\ GeV$			$\sqrt{S_{NN}} = 8\ GeV$		
Particle type	**Per sec**	**Per day**	**Per month**	**Per sec**	**Per day**	**Per month**	**Per sec**	**Per day**	**Per month**
p	$2.9 \cdot 10^{0}$	$2.5 \cdot 10^{5}$	$7.5 \cdot 10^{6}$	$1.2 \cdot 10^{0}$	$1 \cdot 10^{5}$	$3.1 \cdot 10^{6}$	$2.9 \cdot 10^{-1}$	$2.5 \cdot 10^{4}$	$7.5 \cdot 10^{5}$
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

$(0.02)^2 = 4\ 10^{-4}$

$(0.05)^2 = 2.5\ 10^{-3}$

Disadvantages of Pythia8:

1) **It is difficult to introduce non-nucleonic components as fluctons into a nucleus.**
   General problem for all MC event generators: We need to introduce the flucton distribution and fragmentation functions, which specify the probability of finding the flucton in the nucleus and the probabilities of its fragmentation into all other particles.

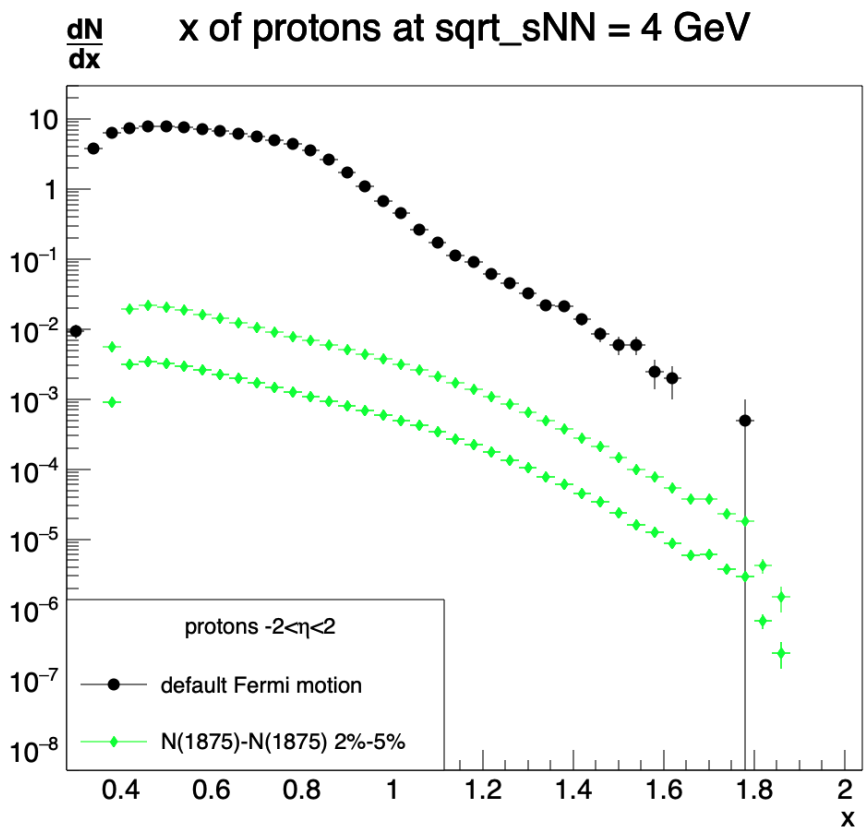
2) **No relative motion of nucleons (Fermi motion) is taken into account.**

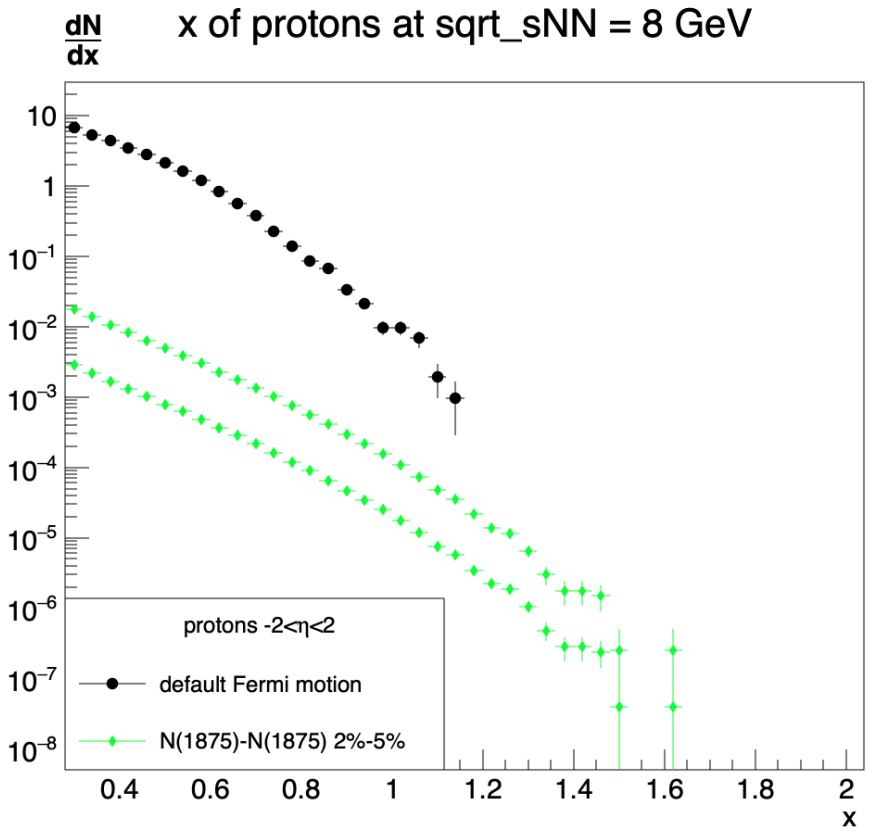
MC simulations with SMASH

1) **Using 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)].**

Using a heavy nucleon resonance (1875 MeV) to imitate fluctuon contribution with SMASH





Using a high relative momentum of nucleons for the particle production in cumulative region with SMASH

Relative motion of nucleons in a nucleus:

1) Low relative momentum motion (Fermi motion) driven by Fermi-Dirac statistics based on the Pauli exclusion principle. This corresponds to typical nuclear distances between nucleons in coordinate space.

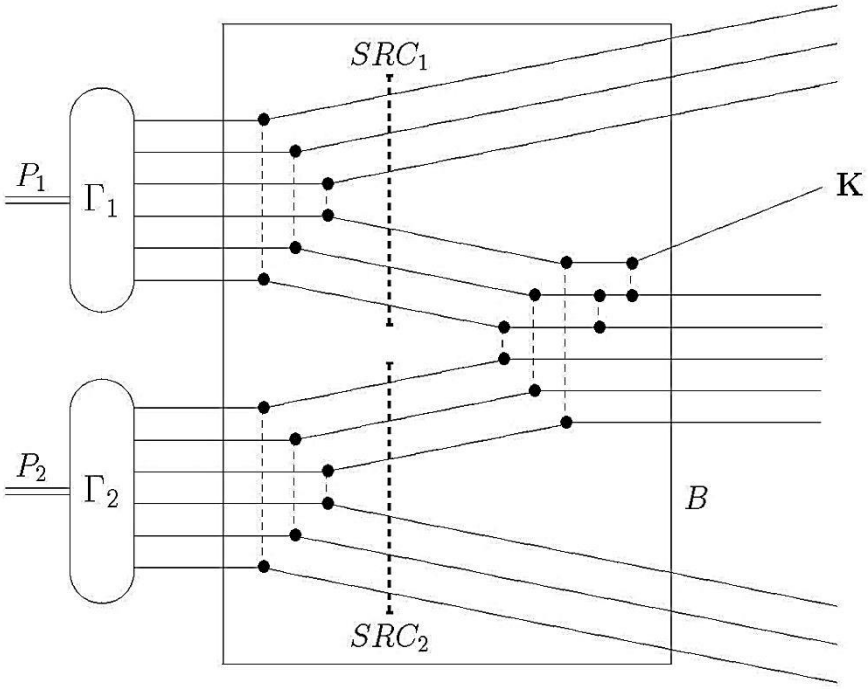
2) High relative momentum of nucleons corresponds to the formation of short-range correlation (SRC) of nuclons [L.L. Frankfurt, M.I. Strikmann, Phys. Rep. 76, 215(1981); ibid 160, 235 (1988)].

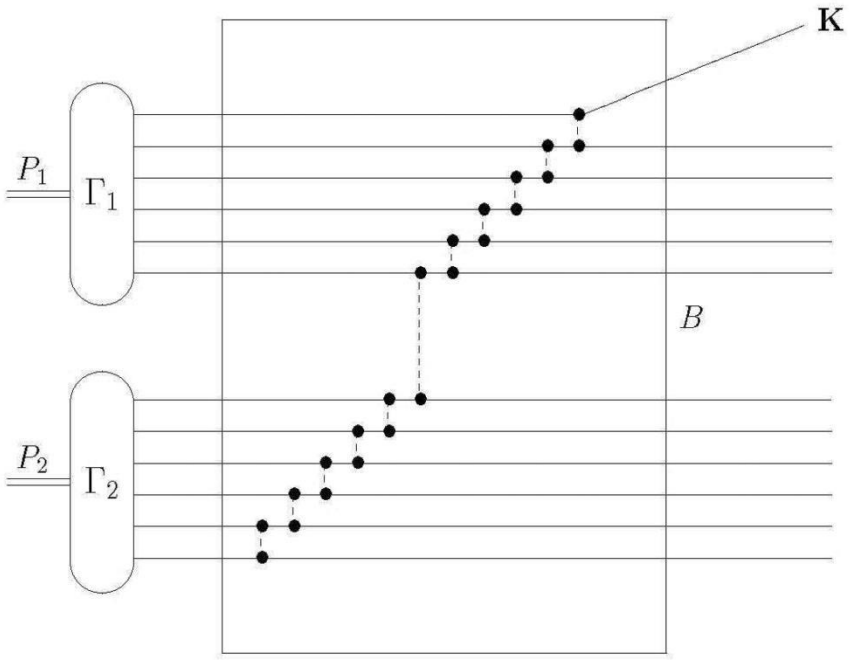
In the latter case, the distance between the centers of the nucleons turns out to be less than the nucleon radius, which allows us to consider such a pair as a flucton.

Fermi motion (incorporated in SMASH) =>
Add a component with higher relative nucleon momentum
(actually corresponds to the contribution of the flucton to the particle production in cumulative region)

Correspondence between the SRC approach and the diagrammatic picture of multiquark fluctons

For the production of pions





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

→ QCR

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

Contribution of Fermi motion does not decrease with increasing initial collision energy

Weakly coupled systems:

$$M = n(m - \varepsilon)$$

Small parameter:

$$\alpha = \sqrt{\frac{\varepsilon}{m}} \simeq \frac{1}{10} \triangleright \frac{1}{20}$$

$$Q_{\perp}^{*(i)} = Q_{\perp}^{(i)} \simeq \sqrt{m\varepsilon} = m\,\alpha$$

$$Q_{z}^{*(i)} = \gamma\, Q_{z}^{(i)} \simeq \gamma \sqrt{m\varepsilon} = E_p\,\alpha$$

$$\gamma = \frac{E_p^*}{m}$$

$$E_p^* = \sqrt{\mathbf{p}^{*2} + m^2}$$

$$\mathbf{P}^{*(i)} = \mathbf{p}^* + \mathbf{Q}^{*(i)}$$

$$E_p = 7000\ GeV$$

$$Q_{\perp}^{*(i)} = Q_{\perp}^{(i)} \simeq 50 \triangleright 90\ MeV$$

$$Q_{z}^{*(i)} \simeq 350 \triangleright 700\ GeV\ (!)$$

The compression of the wave function of the nucleus in coordinate space corresponds to its expansion in momentum space.

Energy non-conservation in SMASH when taking into account the Fermi motion

Generation of initial states of colliding nuclei in SMASH taking into account the Fermi motion:

1) Generation of the Fermi momenta for each nucleus in the rest frame.

$$\sum_{i=1}^{A} \mathrm{Q}_i^{(1)} = 0 \quad \sum_{i=1}^{A} \mathrm{Q}_i^{(2)} = 0$$

2) Boost to the center of mass system with v and -v, corresponding to

$$E_1^* = \gamma E_1 \qquad P_{1z}^* = \gamma\, v\, E_1$$

$$E_2^* = \gamma E_2 \qquad P_{2z}^* = -\gamma\, v\, E_2$$

$$\gamma = \frac{\sqrt{s_{AA}}}{2M} = \frac{\sqrt{s_{NN}}}{2m}$$

3) Treating later the collisions of the nucleons with these momenta as being on their mass shell.

$$E_1 = \sum_{i=1}^{A} E_i^{(1)} = \sum_{i=1}^{A} \sqrt{m^2 + \mathrm{Q}_i^{(1)2}}$$

$$E_2 = \sum_{i=1}^{A} E_i^{(2)} = \sum_{i=1}^{A} \sqrt{m^2 + \mathrm{Q}_i^{(2)2}}$$

This leads to

$$E^*_{final} = E^*_1 + E^*_2 > \sqrt{s_{AA}} \equiv A\sqrt{s_{NN}}$$

$$E^*_{final} = \sum_{i=1}^{n} \sqrt{m_i^2 + \mathbf{k}_i^2}$$

Preparation of the initial state in SMASH taking into account the Fermi motion and energy conservation

Using its own boost for each nucleus:

$$E^*_1 = \gamma_1 E_1 \qquad P^*_{1z} = \gamma_1 \, v_1 \, E_1$$

$$E^*_2 = \gamma_2 E_2 \qquad P^*_{2z} = -\gamma_2 \, v_2 \, E_2$$

To fulfill two conditions:

$$P^*_{1z} + P^*_{2z} = 0$$

$$E^*_1 + E^*_2 = \sqrt{s_{AA}} \equiv A\sqrt{s_{NN}}$$

In this case we have:

$$E^*_{final} = E^*_1 + E^*_2 = \sqrt{s_{AA}} \equiv A\sqrt{s_{NN}}$$

This leads to the equation for P_z^* :

$$\sqrt{P_z^{*2}+E_1^2}+\sqrt{P_z^{*2}+E_2^2}=\sqrt{s_{AA}}$$

$$P_z^* \equiv P_{1z}^* = -P_{2z}^*$$

Recall that

$$E_1=\sum_{i=1}^{A} E_i^{(1)}=\sum_{i=1}^{A}\sqrt{m^2+\mathbf{Q}_i^{(1)2}}$$

$$E_2=\sum_{i=1}^{A} E_i^{(2)}=\sum_{i=1}^{A}\sqrt{m^2+\mathbf{Q}_i^{(2)2}}$$

which has the explicit solution:

$$P_z^*=\frac{1}{2}\sqrt{s_{AA}-2(E_1^2+E_2^2)+(E_1^2-E_2^2)^2/s_{AA}}$$

Then we find

$$\gamma_1=\frac{E_1^*}{E_1}=\sqrt{1+P_z^{*2}/E_1^2} \qquad \gamma_2=\sqrt{1+P_z^{*2}/E_2^2}$$

$$v_1=\sqrt{1-1/\gamma_1^2} \qquad v_2=\sqrt{1-1/\gamma_2^2}$$

Finally we calculate the momenta of all nucleons in the center of mass system:

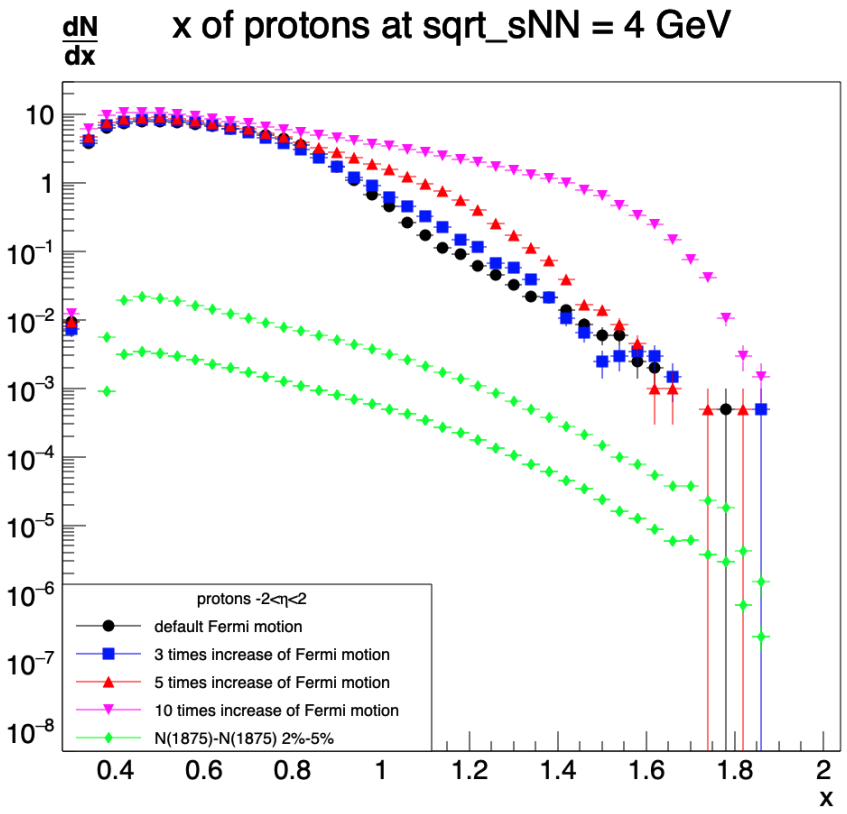
$$P_{iz}^{*(1)}=\gamma_1\left(Q_{iz}^{(1)}+v_1\sqrt{m^2+\mathbf{Q}_i^{(1)2}}\right) \qquad \mathbf{P}_{i\perp}^{*(1)}=\mathbf{Q}_{i\perp}^{(1)}$$

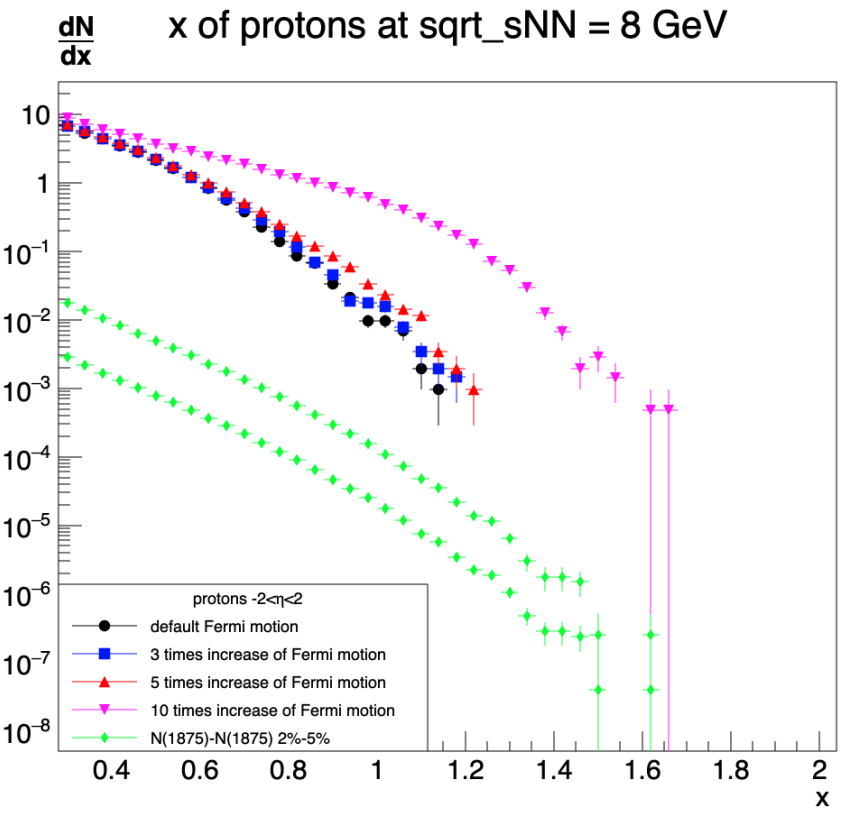
$$P_{iz}^{*(2)}=\gamma_2\left(Q_{iz}^{(2)}-v_2\sqrt{m^2+\mathbf{Q}_i^{(2)2}}\right) \qquad \mathbf{P}_{i\perp}^{*(2)}=\mathbf{Q}_{i\perp}^{(2)}$$

$$\sum_{i=1}^{A} P_{iz}^{*(1)}=P_{1z}^*=P_z$$

$$\sum_{i=1}^{A} P_{iz}^{*(2)}=P_{2z}^*=-P_z$$

Using a high relative momentum of nucleons (SRC) to imitate fluctuon contribution with SMASH





To do:
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)

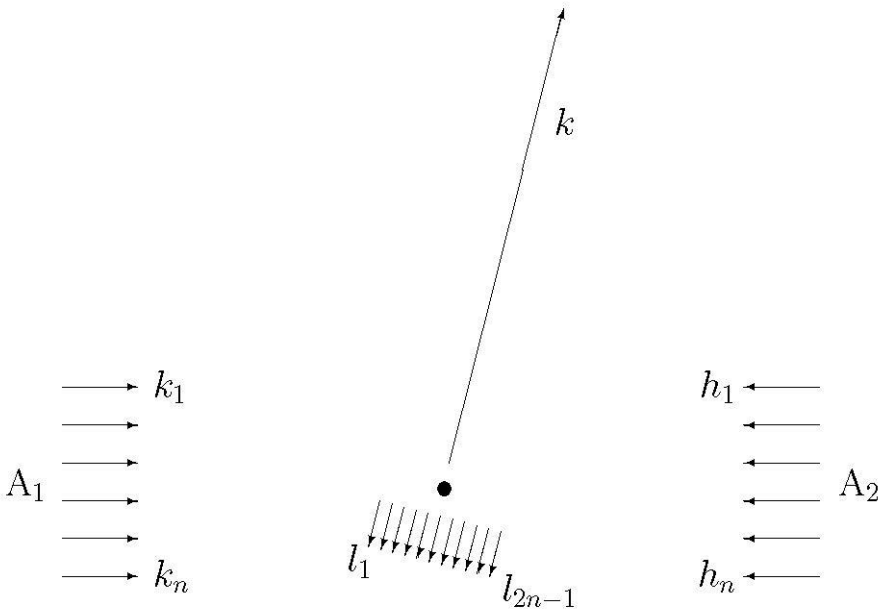
3. V. Vechernin, S. Yurchenko, Phys. Part. Nucl. 57 (5) (2026) [in press].

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

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

Kinematics



d+d → π+X at quark level
($A_1 = A_2 = A = 2$, $n = 6$)

$p_N = P_A/A \qquad p_N \gg m_N$

Initial state:

$k_i \sim P_A/n = p_N/3$
$h_i \sim -P_A/n = -p_N/3$

$n = 3A$

Final state:

$k \sim P_A = A\,p_N = n\,p_N/3$

$l_i \sim -P_A/(2n-1) = -\frac{n}{3(2n-1)}p_N$

First small parameter: $\frac{m_N}{p_N} = \frac{2m_N}{\sqrt{s_{NN}}} \ll 1$

Second small parameter: $1 - \frac{k}{k_{max}} \ll 1$

$k \to k_{max} \Rightarrow M_X{}^2 = (\sum_{i=1}^{2n-1} l_i)^2 \to M_{Xmin}{}^2$

$l_1 = l_2 = \ldots = l_{2n-1} = -\frac{k_{max}}{2n-1}$

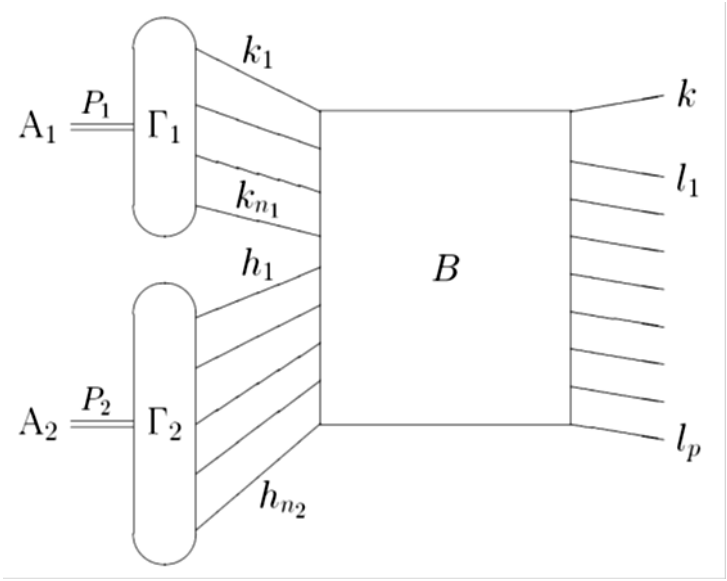
V. Vechernin, S. Yurchenko
Int.J.Mod.Phys. E, 2441022,
DOI: 10.1142/S0218301324410222

$s = s_{NN}$

Progress in theoretical motivation

pion production:

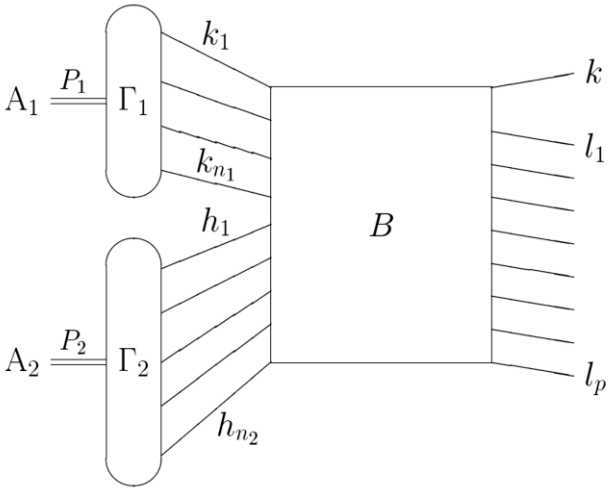
Standard Quark Counting Rules (based on production from one point) were generalized to the case of inclusive cross-section of pion production in the new cumulative region (central rapidities, large transverse momenta), which depends on two asymptotic parameters $s \gg m^2$ and $(x_{max} - x) \ll 1$.



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

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

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*)



$$p = n_1 + n_2 - 1$$

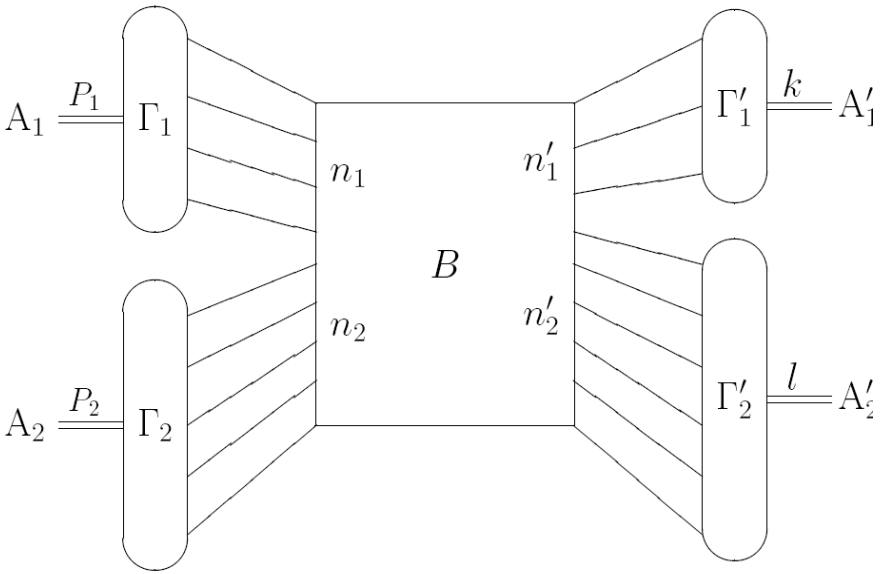
To evaluate this behavior and find asymptotes at s>>m and (2-x)<<1 we need to generalize the quark counting rules, known now only for a) the inclusive cross sections in the fragmentation region (|t|<<s) and b) the elastic and quasielastic cross sections in the high pT region (|t|~s), to the case of inclusive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

Comparison with Quark Counting Rules for Quasi-Elastic Processes

one small parameters: $m/\sqrt{s} \ll 1$



$$\frac{d\sigma}{dt} \sim \frac{1}{s^{n_1+n_2+n'_1+n'_2-2}}$$

Matveev V.A., Muradyan R.M., Tavkhelidze A.N., Lett. Nuovo Cimento 7 (1973) 719

Brodsky S., Farrar G., Phys.Rev.Lett. 31 (1973) 1153

Brodsky S., Chertok B.T., Phys.Rev. D14 (1976) 3003

Uzikov Yu. N., JETP Lett. 81 (2005) 303

$$\frac{d\sigma}{dt} = \frac{1}{16\pi\, s^2_{A_1A_2}} |T_{2\to 2}|^2 = \frac{1}{16\pi\, A_1^2 A_2^2 s^2} |T_{2\to 2}|^2$$

$$T_{2\to 2} = J_{n_1}\, J_{n_2}\, B\, J_{n'_1}\, J_{n'_2}$$

$$\frac{d\sigma}{dt} = \frac{C'}{s^{2n-2}\, m^{2n-4} R_1^{3(n_1-1)} R_2^{3(n_2-1)} R_1'^{3(n'_1-1)} R_2'^{3(n'_2-1)}}$$

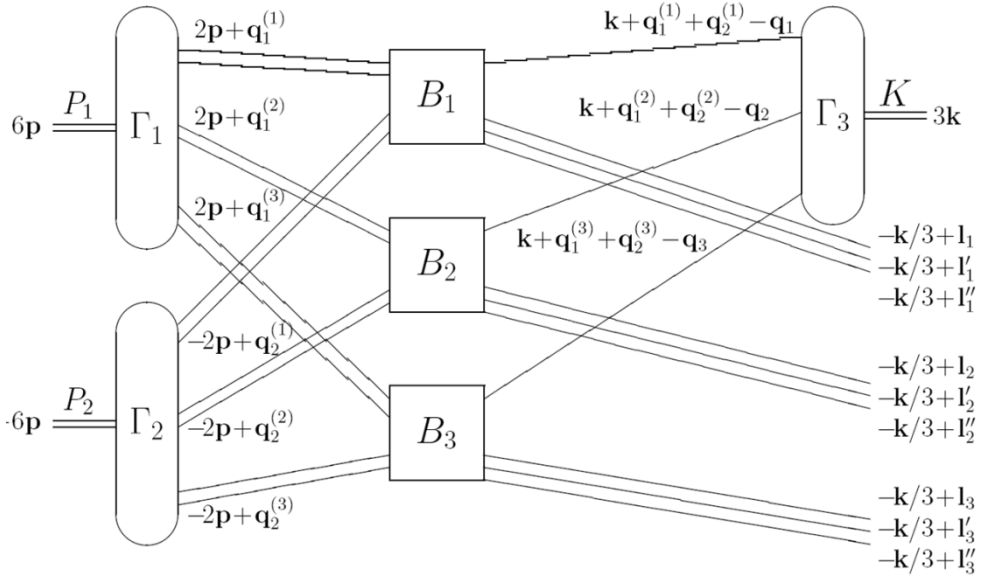
$n = n_1 + n_2$
$= n'_1 + n'_2$

Yu.L. Dokshitzer, QCD Phenomenology, Lectures at the CERN–Dubna School, Pylos, August 2002

Early validity of QCR in the deuteron break-up by a photon, $\gamma + D \to p + n$

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!

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:

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

Weakly coupled systems

Third small parameter: $\alpha = \sqrt{\frac{\varepsilon}{m}} \ll 1$

$$M = n(m - \varepsilon)$$

$$\left\langle \frac{\mathbf{q}^{*2}}{2m} \right\rangle \simeq \varepsilon \qquad |\mathbf{q}^*| \simeq \sqrt{m\varepsilon} = m\,\alpha$$

- in the rest frame

$$\gamma = \frac{E_p}{m}$$

$$|\mathbf{q}_\perp| \simeq \sqrt{m\varepsilon} = m\,\alpha$$

$$|q_z| \simeq \gamma |q_z^*| \simeq \gamma\sqrt{m\varepsilon} = \frac{E_p}{m}\sqrt{m\varepsilon} = E_p\,\alpha$$

$$E(\mathbf{p}+\mathbf{q}) \equiv \sqrt{(\mathbf{p}+\mathbf{q})^2 + m^2}$$

$$E(\mathbf{p}+\mathbf{q}) = E_p \left\{ 1 + \frac{(\mathbf{qp})}{E_p^2} + \frac{1}{2E_p^2}\left[\mathbf{q}^2 - \frac{(\mathbf{qp})^2}{E_p^2} \right] + O(\alpha^3) \right\}$$

$$E_p \equiv E(\mathbf{p}) = \sqrt{\mathbf{p}^2 + m^2}\ , \quad E_k \equiv E(\mathbf{k})$$

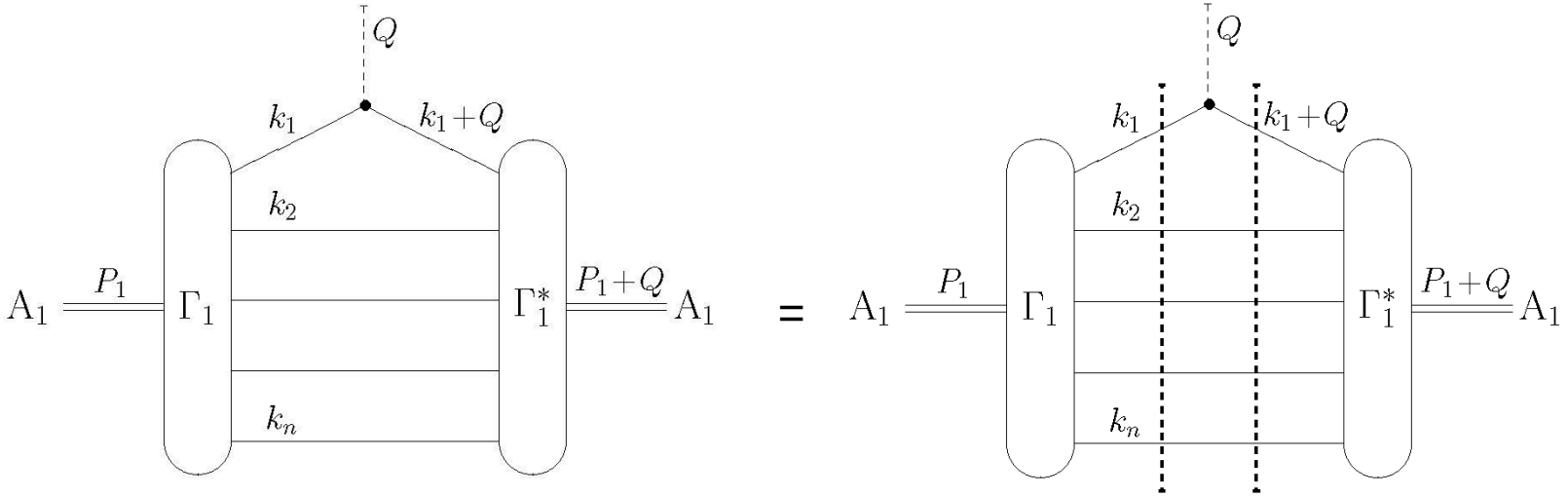
It is **not assumed** here that **|p|>>*m* !**

Valid both in the rest frame of the nucleus (p=0) and in the frame in which the nucleus moves with relativistic momentum *n*p or *n*k (|p|>>*m*, |k|>>*m*)

$$\frac{(\mathbf{qp})}{E_p^2} = \frac{q_z|\mathbf{p}|}{E_p^2} \simeq \frac{E_p\,\alpha\,|\mathbf{p}|}{E_p^2} = \frac{|\mathbf{p}|}{E_p}\alpha$$

Connection of vertices Γ_i with wave functions. Normalization.

$F(Q^2) =$



$$Q^2 \to 0 \quad \Rightarrow \quad F(Q^2) \to 1$$

$$\varphi_{n\mathbf{p}}(\mathbf{q}^{(i)}) = \frac{\Gamma_{n\mathbf{p}}(\mathbf{q}^{(i)})}{\sqrt{n}2E_p\left[\sum_{i=1}^{n} E(\mathbf{p}+\mathbf{q}^{(i)}) - E_{init} - \mathrm{i}\epsilon\right]}$$

$$\int |\varphi_{n\mathbf{p}}(\mathbf{q}^{(i)})|^2 \prod_{i=1}^{n-1} \frac{d^3\mathbf{q}^{(i)}}{2E_p(2\pi)^3} = 1$$

Connection of vertices Γ_i with wave functions. Normalization.

In the rest frame of the nucleus (p=0):

$$\varphi_0(\mathbf{q}^{*(i)}) = \frac{\Gamma_0(\mathbf{q}^{*(i)})}{\sqrt{n}2m\left[\sum_{i=1}^{n}\frac{\mathbf{q}^{*(i)2}}{2m} - n\varepsilon - \mathrm{i}\epsilon\right]} = \frac{\Gamma_0(\mathbf{q}^{*(i)})}{\sqrt{n}\left[\sum_{i=1}^{n}\mathbf{q}^{*(i)2} - n2m\varepsilon - \mathrm{i}\epsilon\right]}$$

$$\int |\varphi_0(\mathbf{q}^{*(i)})|^2 \prod_{i=1}^{n-1}\frac{d^3\mathbf{q}^{*(i)}}{2m(2\pi)^3} = 1$$

In the frame in which the nucleus moves with relativistic momentum *n*p :

$$\varphi_{n\mathbf{p}}(\mathbf{q}^{(i)}) = \frac{\Gamma_{n\mathbf{p}}(\mathbf{q}^{(i)})}{\sqrt{n}\left[\sum_{i=1}^{n}\mathbf{q}_\perp^{(i)2} + (q_z^{(i)}/\gamma)^2 - n2m\varepsilon - \mathrm{i}\epsilon\right]}$$

$$\int |\varphi_{n\mathbf{p}}(\mathbf{q}^{(i)})|^2 \prod_{i=1}^{n-1}\frac{d^3\mathbf{q}^{(i)}}{2m\gamma(2\pi)^3} = 1$$

$$\gamma = \frac{E_p}{m}$$

$$\mathbf{q}_\perp^{(i)} = \mathbf{q}_\perp^{*(i)} \simeq \sqrt{m\varepsilon} = m\,\alpha$$
$$q_z^{(i)} = \gamma q_z^{*(i)} \simeq \gamma\sqrt{m\varepsilon} = E_p\,\alpha$$

$$\alpha = \sqrt{\frac{\varepsilon}{m}}$$

MC simulations of the particle production in cumulative region in pp collisions

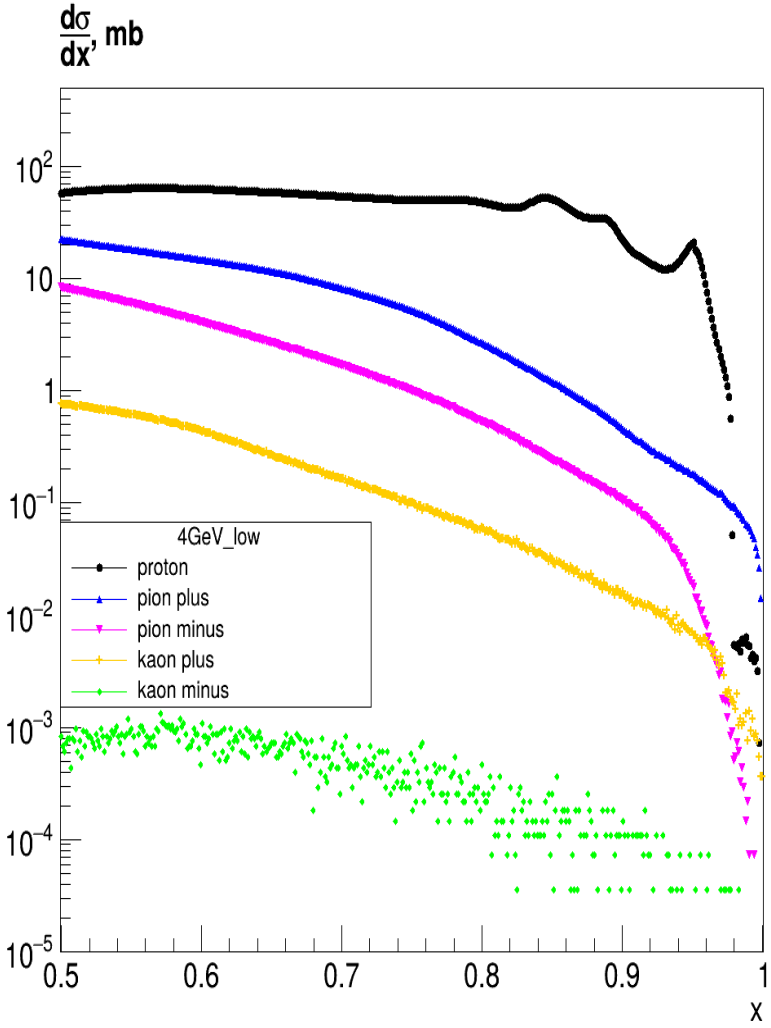
S. Yurchenko, Phys. Part. Nucl. (2026) [in press].

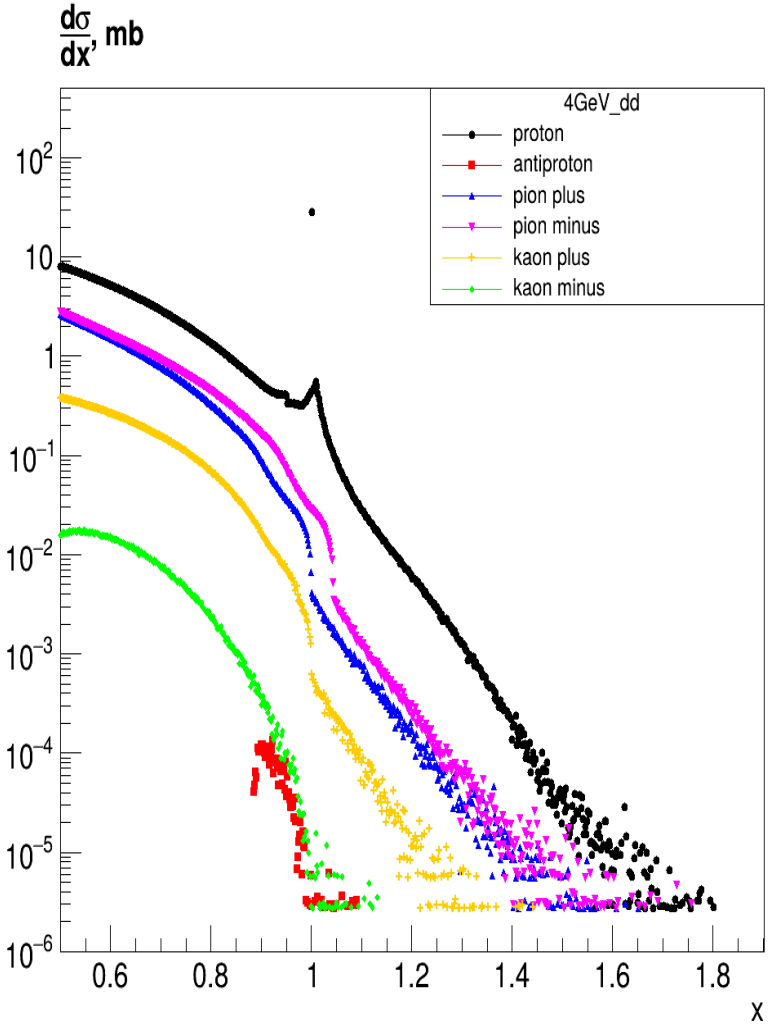
Simulations with Pythia8

- 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: $p, \bar{p}, \pi^+, \pi^-, K^+, K^-$

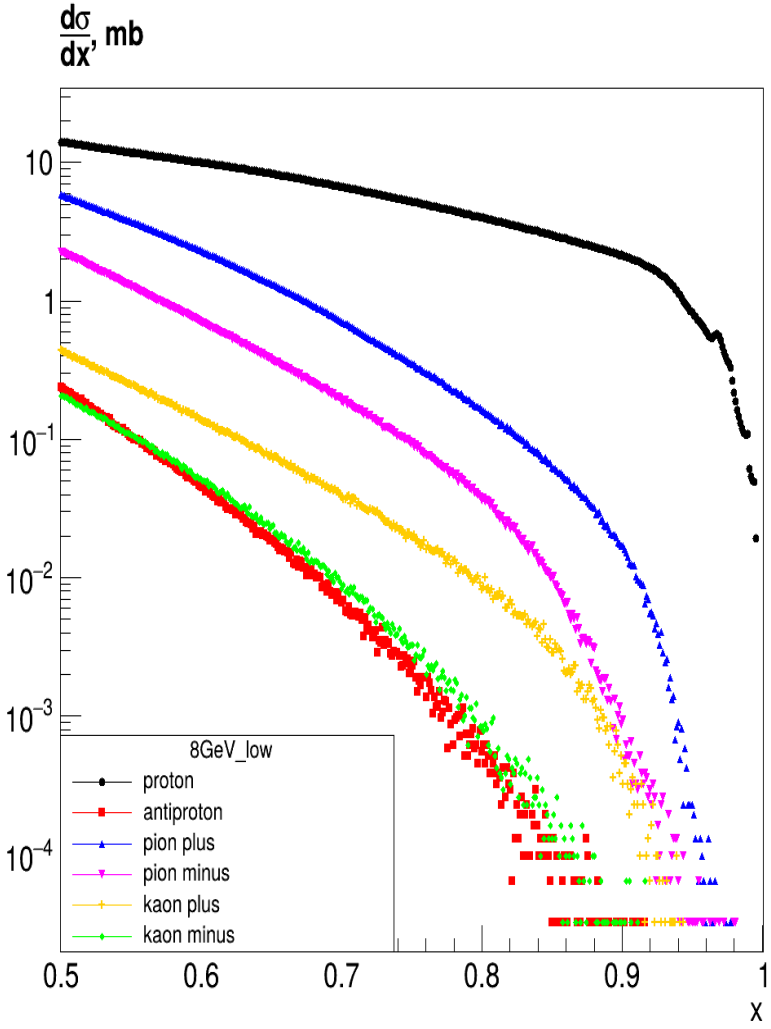
No propagation through detector material were done!

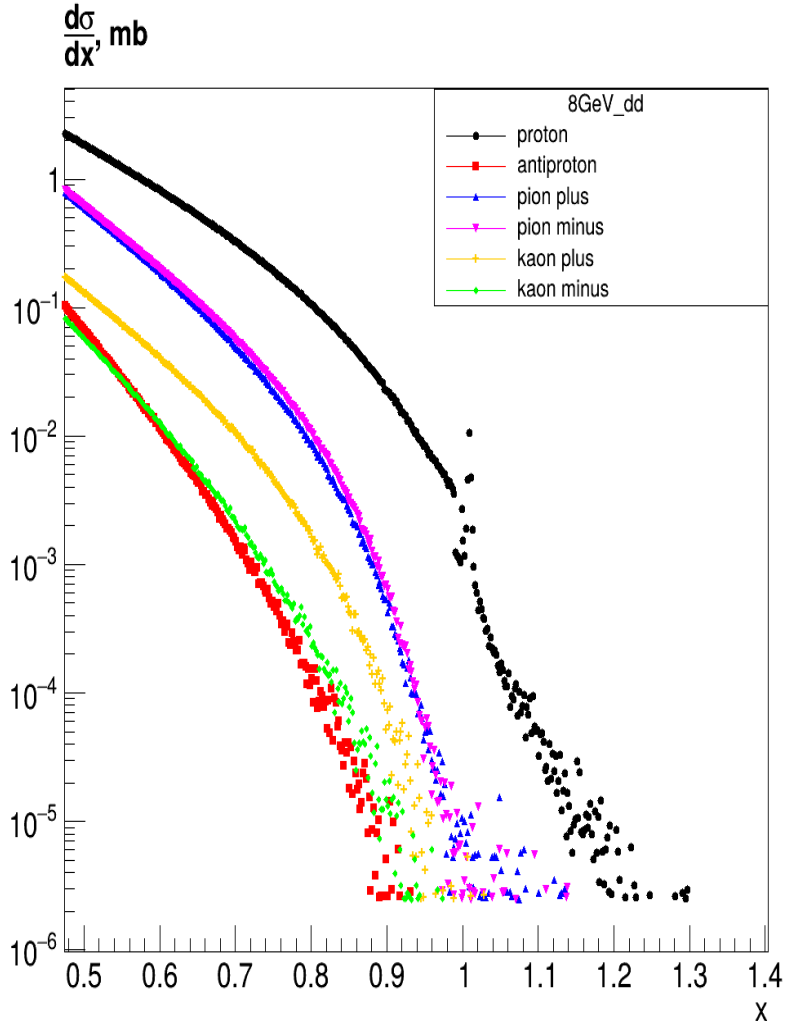
All particles, 4 GeV, pp and dd



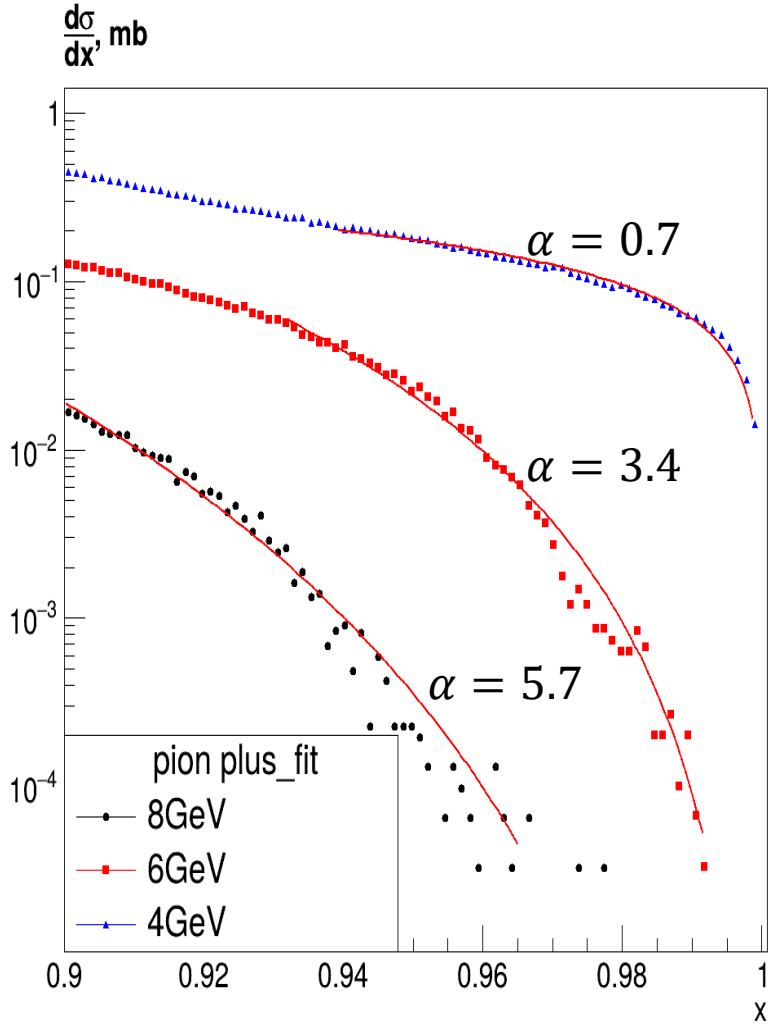


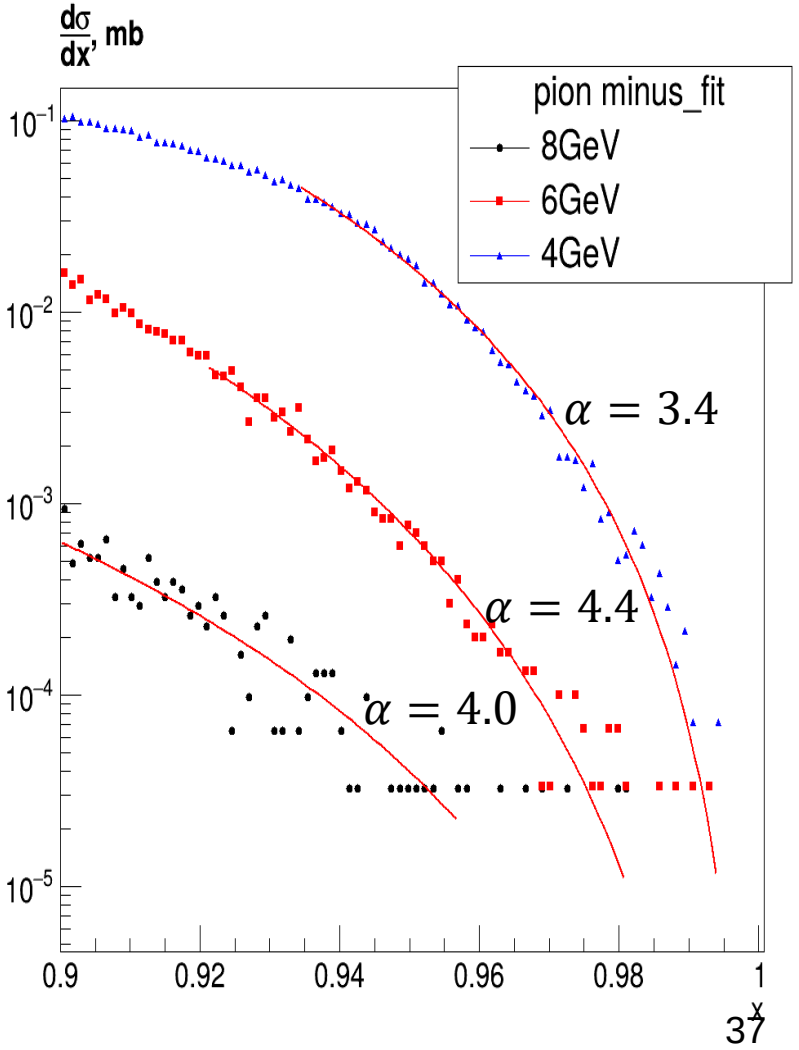
All particles, 8 GeV, pp and dd





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





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

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	$8.6 \cdot 10^2$	$7.4 \cdot 10^7$	$2.2 \cdot 10^9$	$2.6 \cdot 10^3$	$2.3 \cdot 10^8$	$6.8 \cdot 10^9$	$1.5 \cdot 10^3$	$1.3 \cdot 10^8$	$4 \cdot 10^9$
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	$1.7 \cdot 10^5$	$1.5 \cdot 10^{10}$	$4.4 \cdot 10^{11}$	$8.8 \cdot 10^5$	$7.6 \cdot 10^{10}$	$2.3 \cdot 10^{12}$	$3.1 \cdot 10^6$	$2.7 \cdot 10^{11}$	$8.2 \cdot 10^{12}$

