The XXVIth International Baldin Seminar on High Energy Physics Problems "Relativistic Nuclear Physics and Quantum Chromodynamics"

MC modeling of high transverse momentum particle production in pp and dd collisions at NICA energies

Yurchenko Semyon

Laboratory of ultra-high energy physics, Saint Petersburg State University

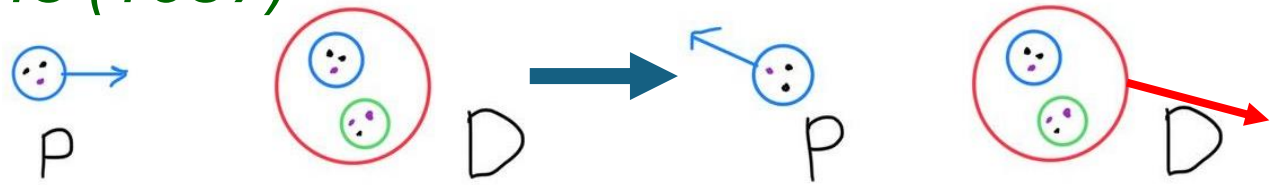
18.09.2025

Outline

- Introduction
- Motivation
- Definition of cumulative number x
- Pythia8 simulation results
- Conclusions

Introduction

- 1957 – The 1st experimental observations of the backward particle production in p+A collisions on a fixed target nucleus: *G.A. Leksin, ZhETF 32, 445 (1957)*



- 1957 – Flucton – intrinsic droplet of dense cold nuclear matter in a nucleus (2N flucton – 6 quark state) *Blokhintsev D.I., JETP 33 (1957) 1295*



Cumulative pion production

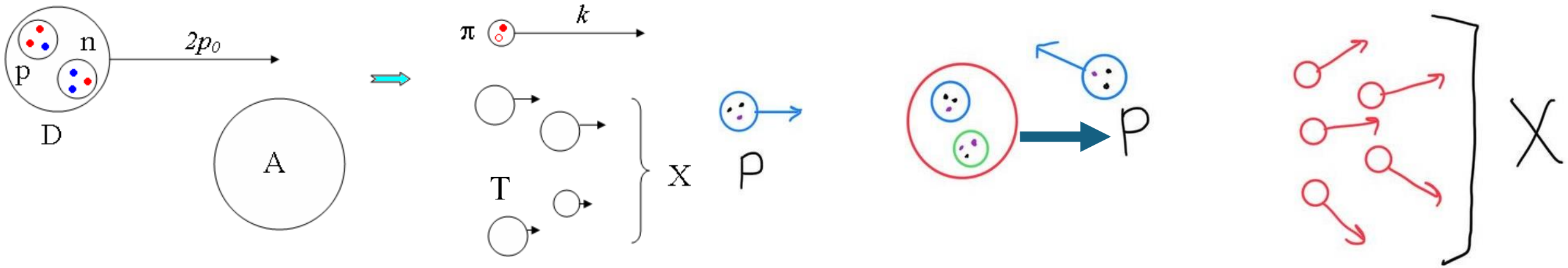
Production of particles from nuclei in a region, kinematically forbidden for reactions with free nucleons.

1970 - Nuclotron@Dubna – beams of relativistic deutrons (p_0=5 *GeV/c/nucleon*)
Stavinskiy V.S. → Fragmentation of projectile deuterons, D, on some target, T.
*Baldin A.M. et al., Yad.Fiz.**18** (1973) 79*

D + T → π + X

$p_0 >> m_N$: $p_0 < k < 2p_0$ - cumulative pions

The Rutherford-like experiments indicating the presence of droplets of dense nuclear matter in a target nucleus (fluctons).
Yu.D. Bayukov et al., Izv. AN SSSR 30, 521 (1966)



Fragmentation of projectile nucleus ↔ Fragmentation of target nucleus
(the same phenomenon in different frames of reference)

Flucton-flucton interaction in dd collisions

f+f in dd collisions - New and Clear!

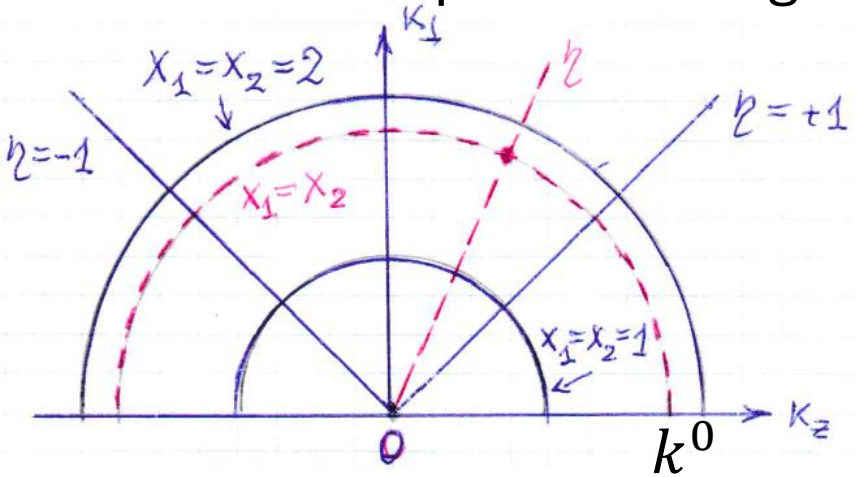
- It can be studied only in new cumulative region of large transverse momenta in mid-rapidity region at NICA (not in the traditional cumulative region of fragmentation of one of the nuclei).
- There are no additional interactions in dd collision, compared with collisions of heavier nuclei, if both deuterons are in flucton configuration at the moment of collision.
- The possibility to register, in addition to the cumulative particle, the particles formed from fragmentation of the flucton residue.
- The studies in new cumulative region becomes possible due to the moderate energy of the NICA collider and is completely impossible at ultrahigh energies of the RHIC and LHC.

Definition of x

For each reaction it is possible determine maximal momentum of particle.

$$k^0_{max} = \frac{S_{AA} + \mu^2 - \left(M_X^{min}\right)^2}{2\sqrt{S_{AA}}} = \frac{A\sqrt{S_{NN}}}{2} + \frac{\mu^2 - \left(M_X^{min}\right)^2}{2A\sqrt{S_{NN}}}$$

Then we set $A = x$ and parametrize M_X^{min} for different reactions, so that when x is positive integer it gives proper kinematic boundaries:



$$M_X^p = (2x-1)m_p$$
$$M_X^{\pi^+} = 2xm_p$$
$$M_X^{\pi^-} = 2xm_p + m_\pi$$

For given momentum k we find x, such that this momentum equals to maximal

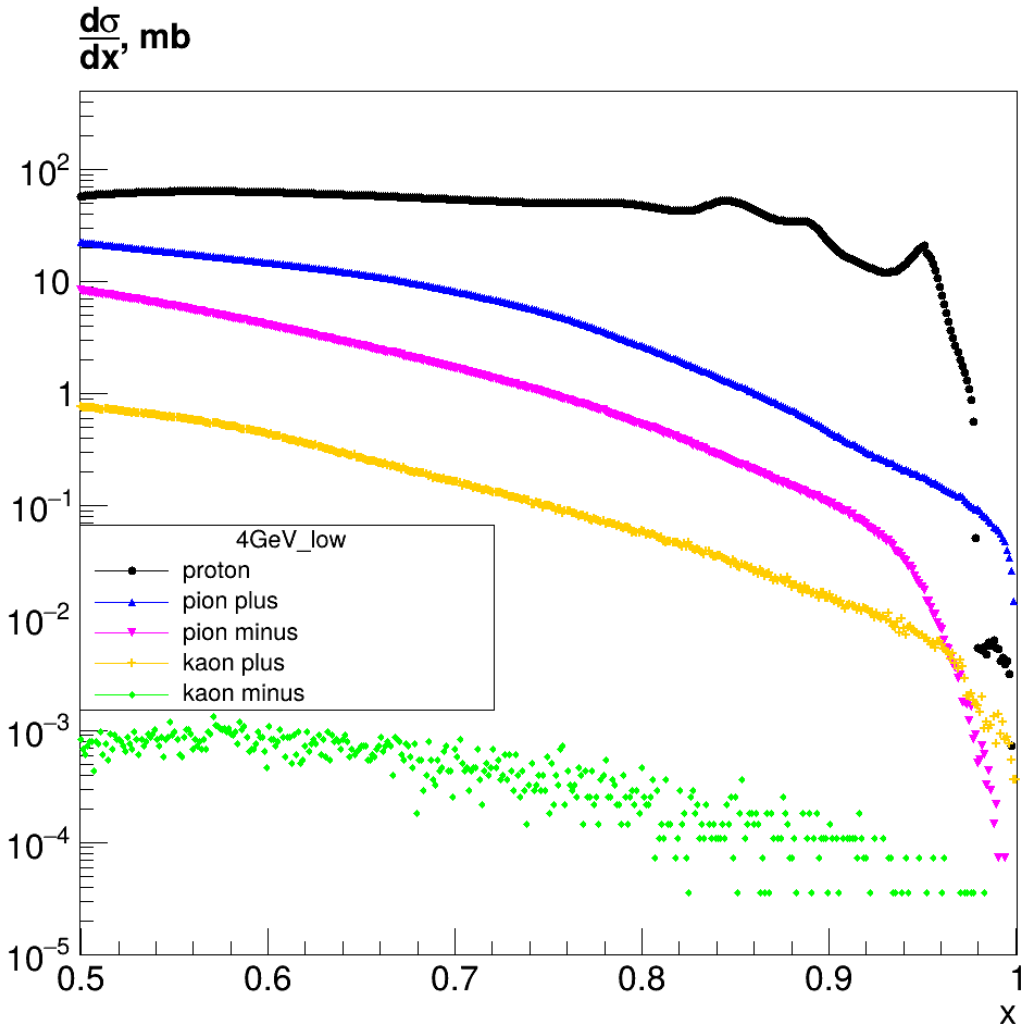
$$1 = \frac{k^0}{k^0_{max}(x, \sqrt{S_{NN}})} \quad \Leftrightarrow \quad k^0_{max}\left(x, \sqrt{S_{NN}}, M_x^{min}(x)\right) = k^0$$

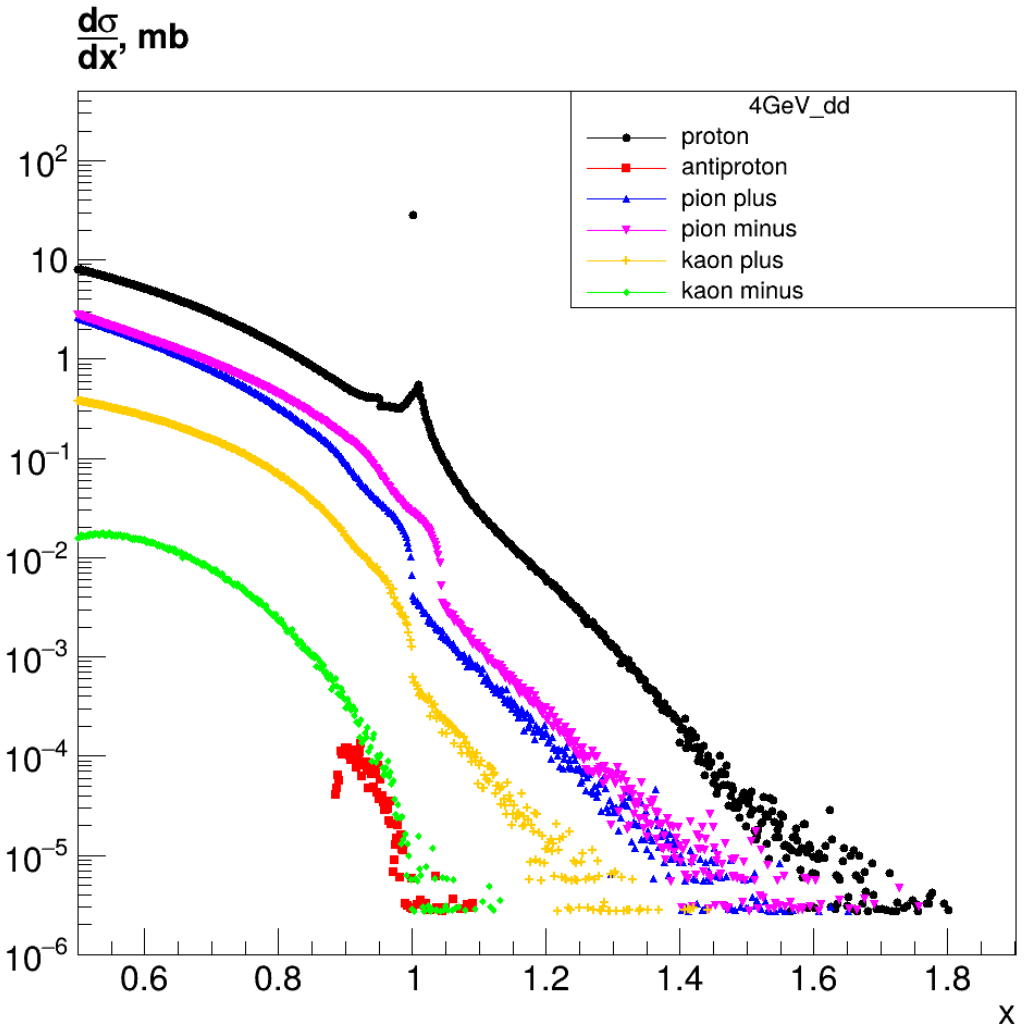
Pythia8 data

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

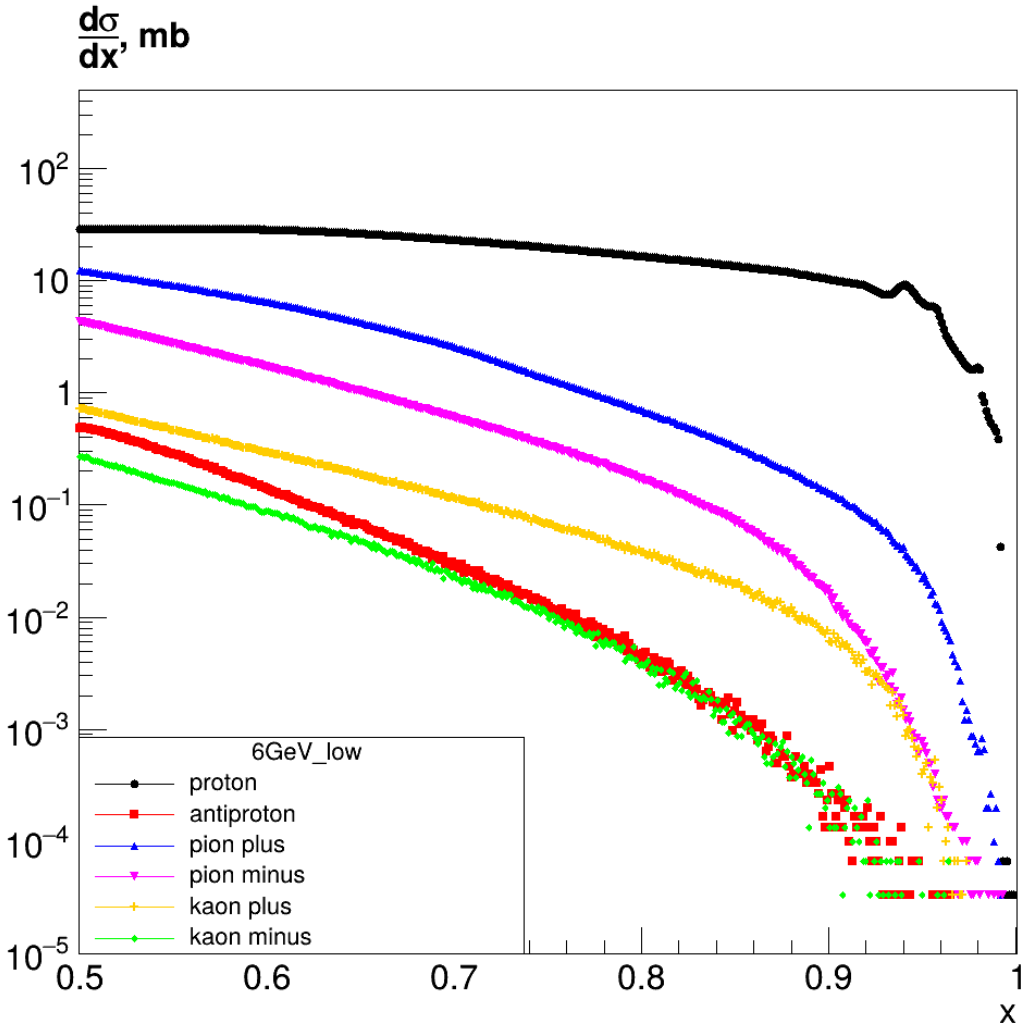
No propagation through detector material were done!

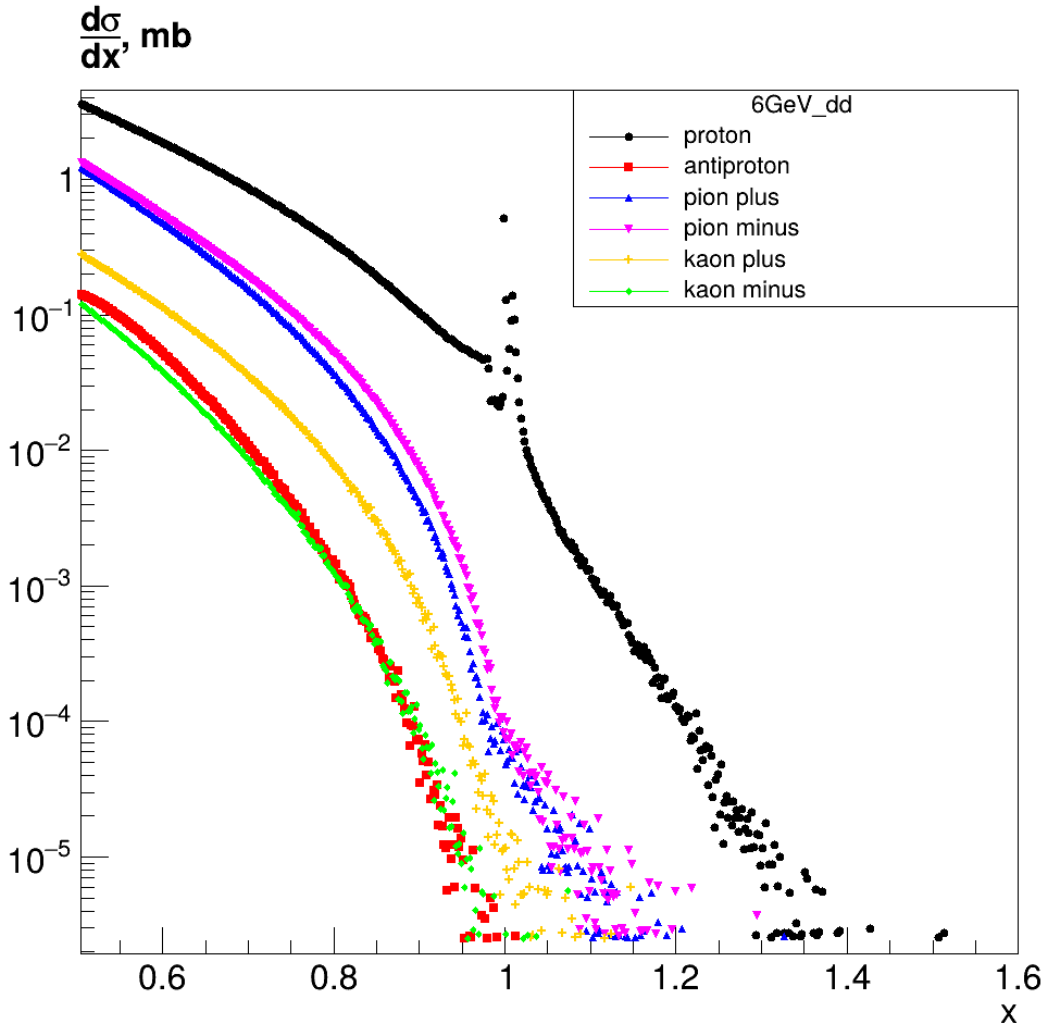
All particles, 4 GeV, pp and dd



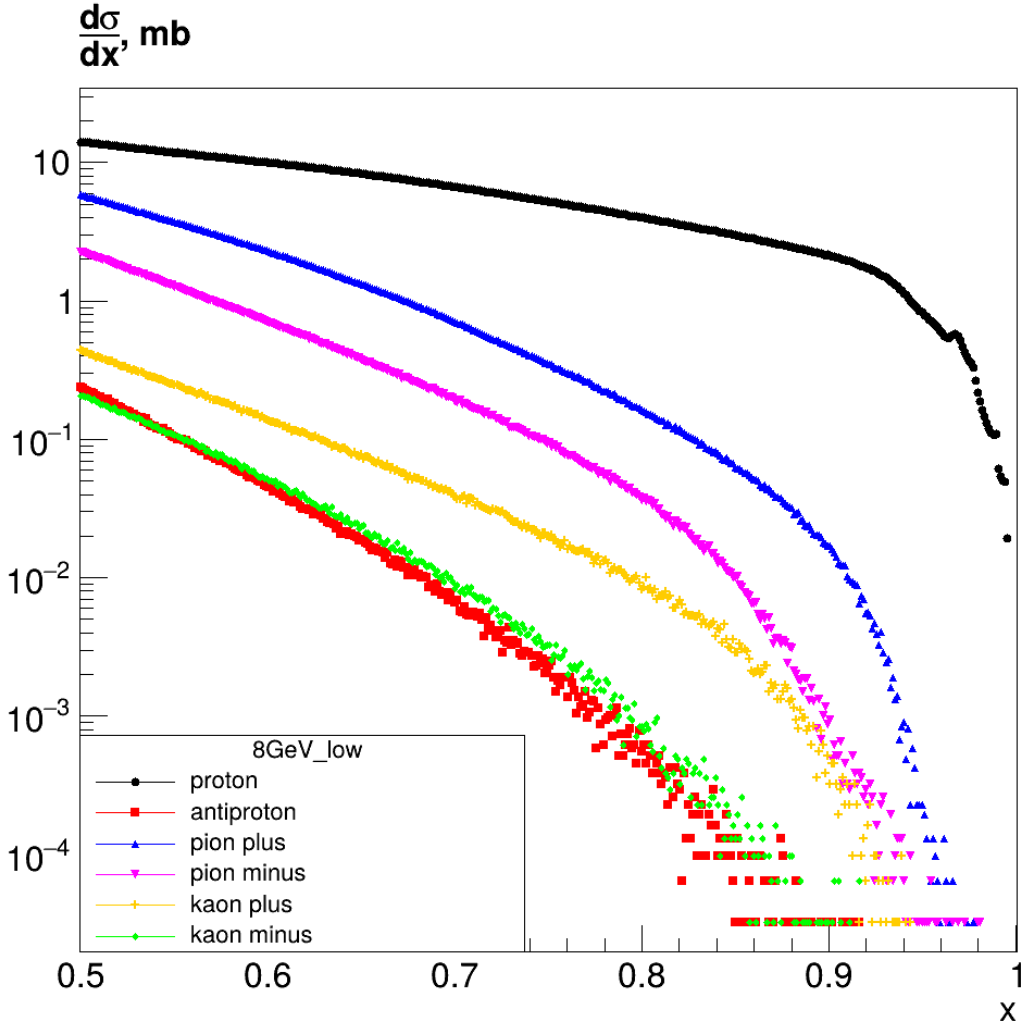


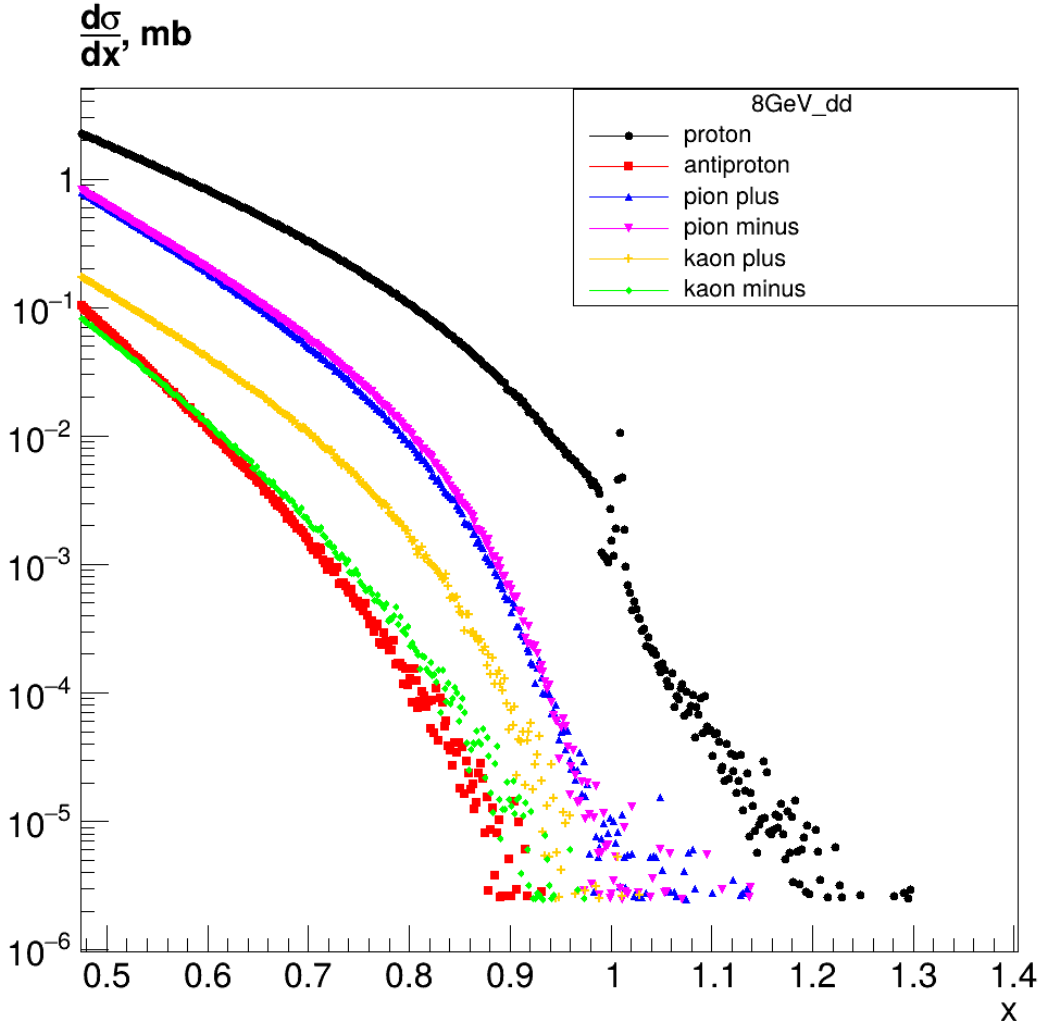
All particles, 6 GeV, pp and dd



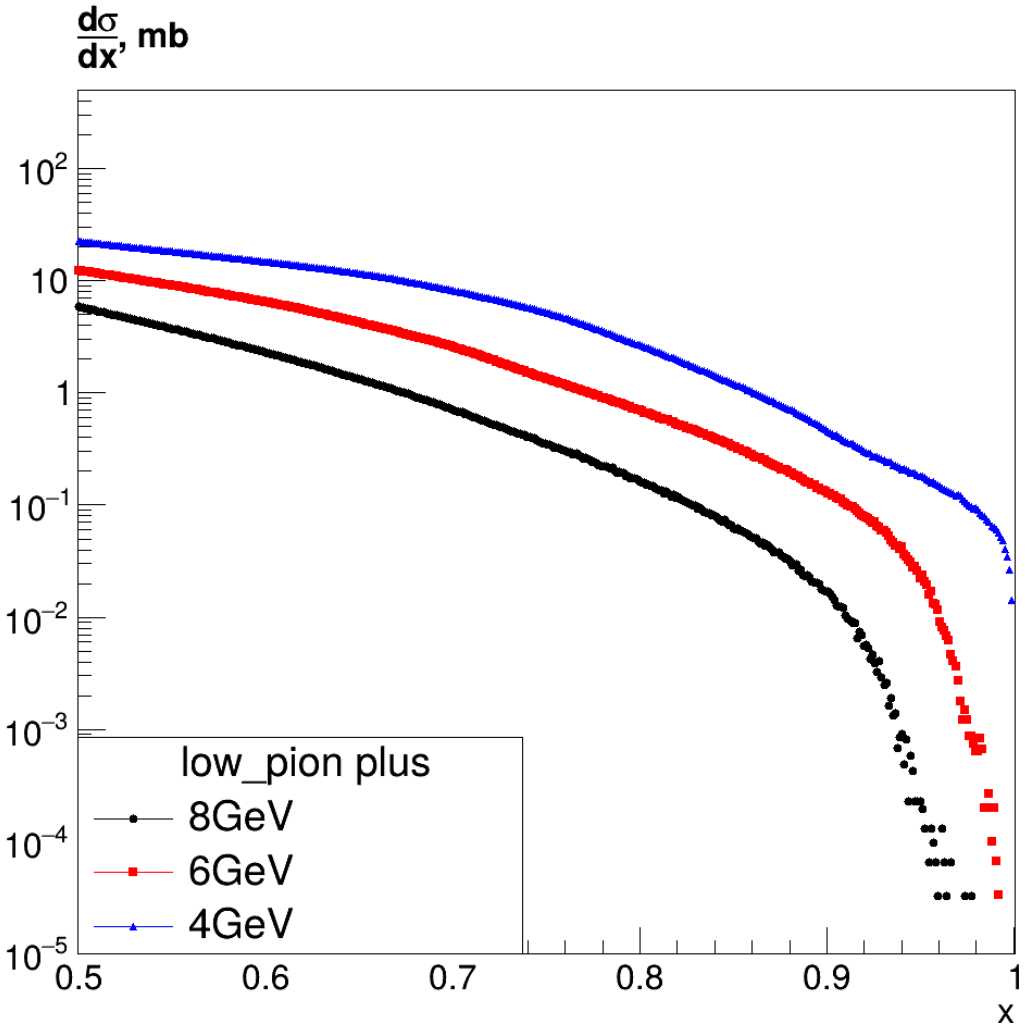


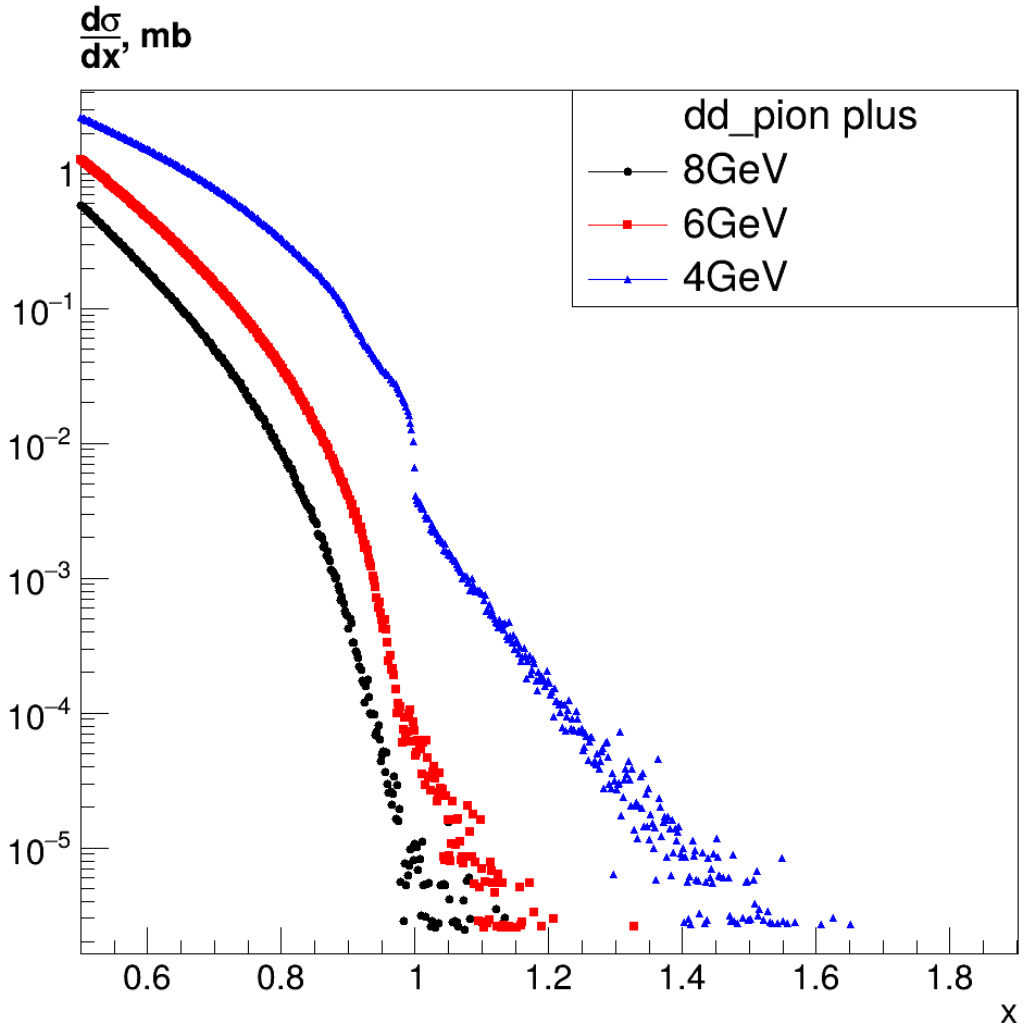
All particles, 8 GeV, pp and dd



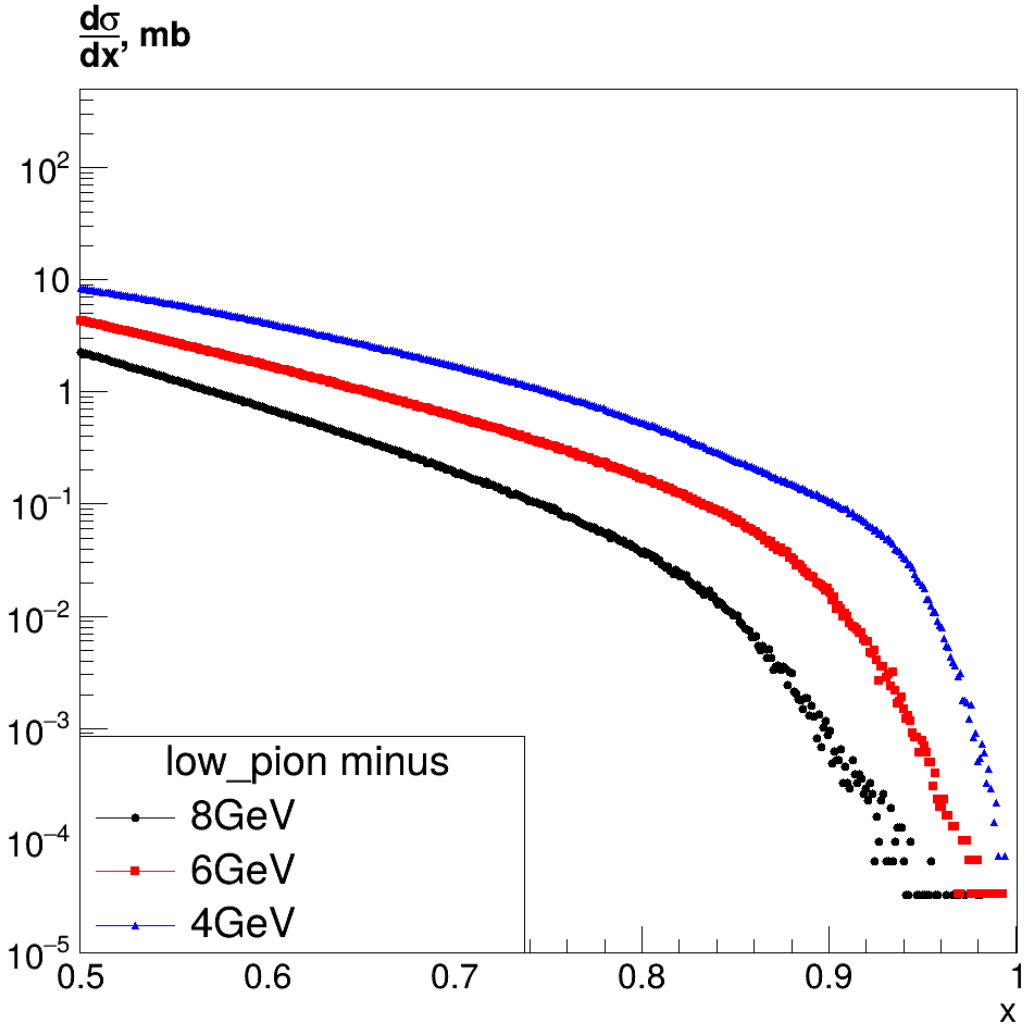


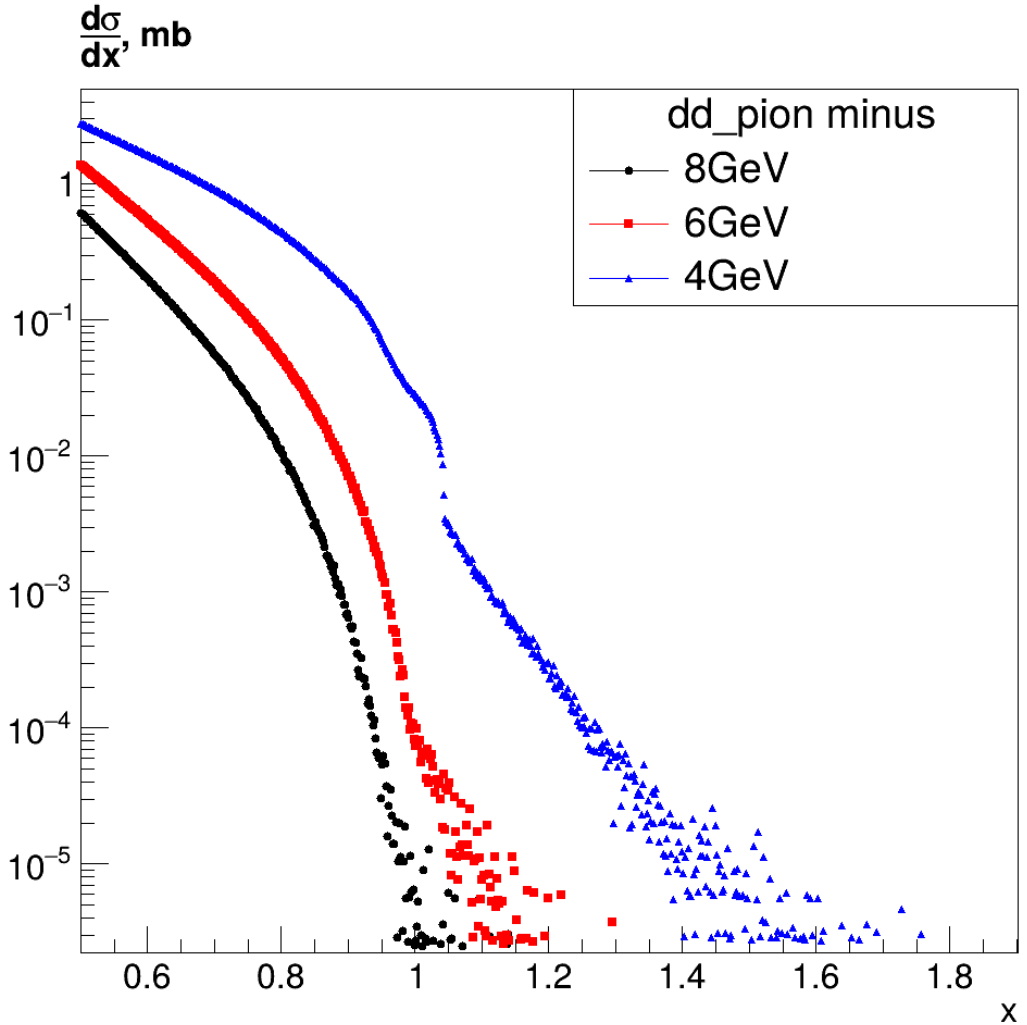
Pion plus, pp and dd



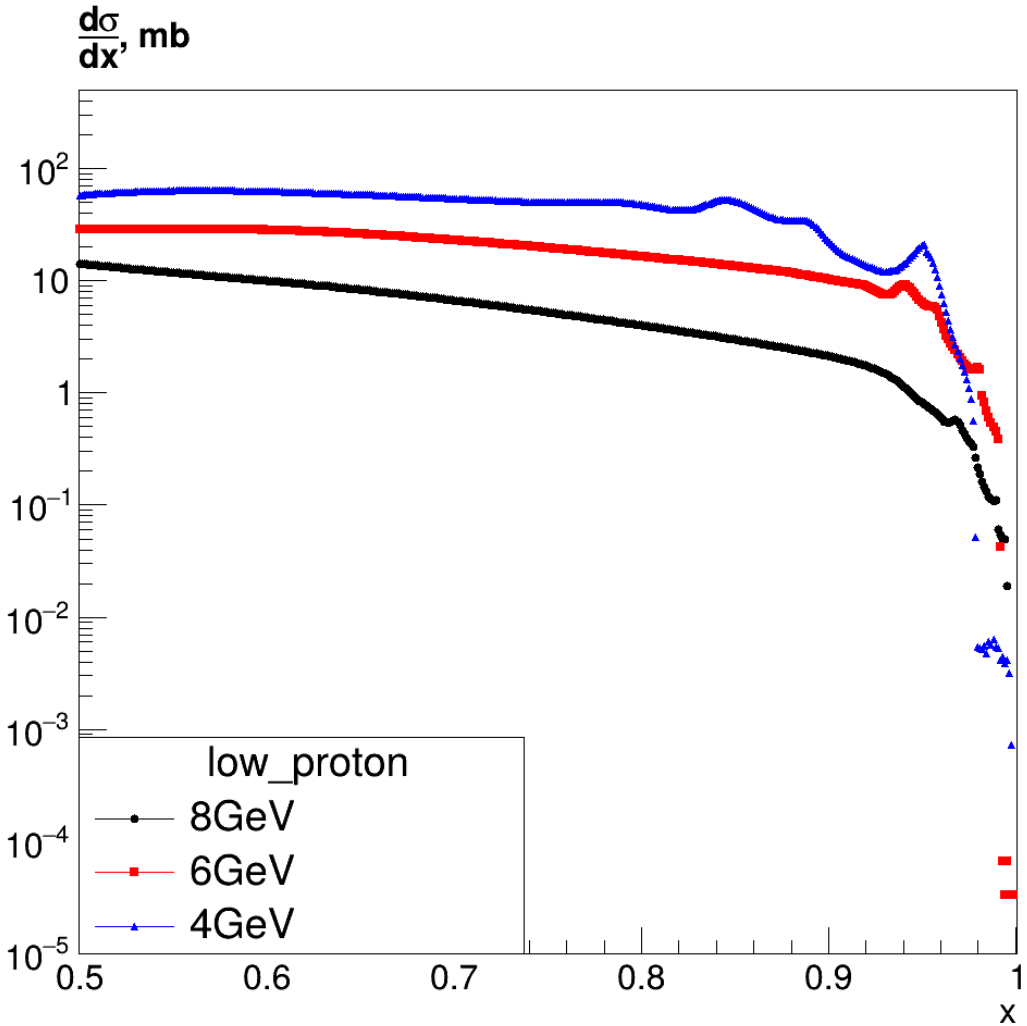


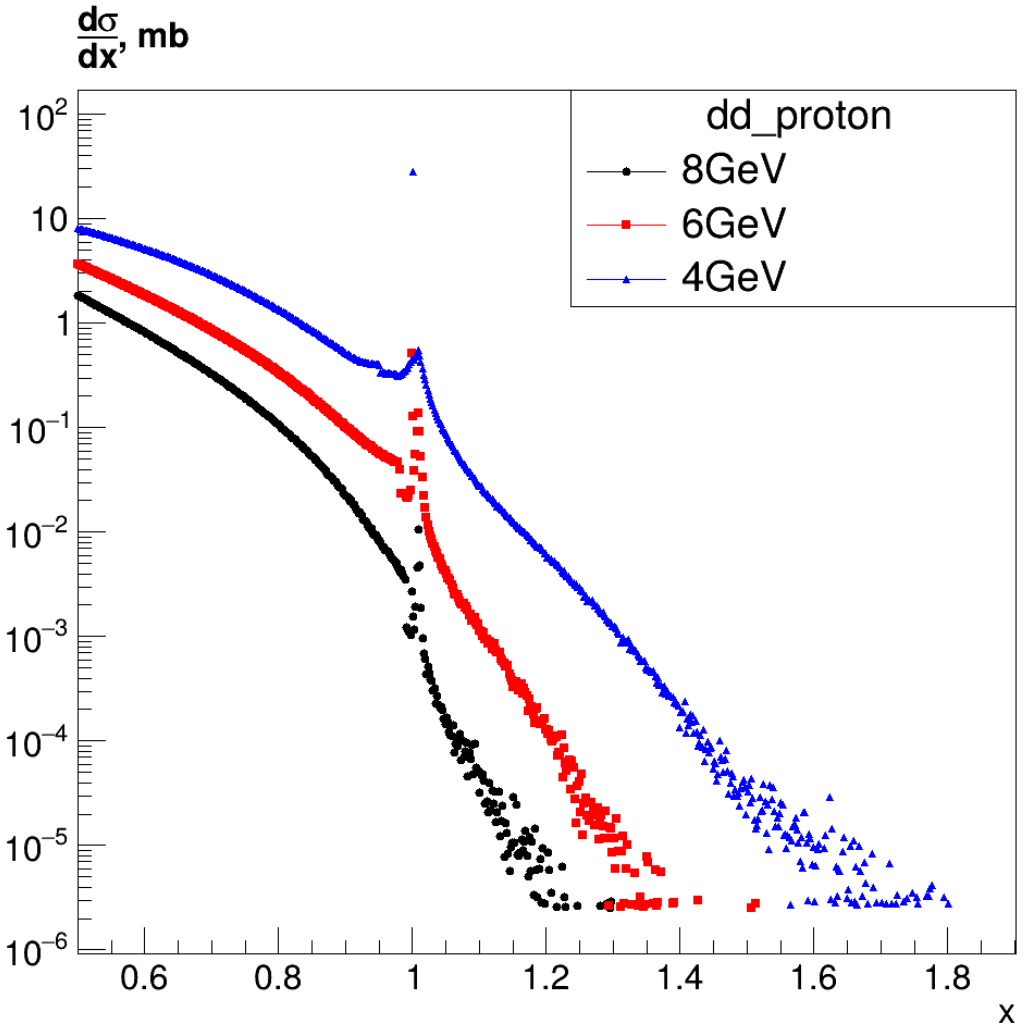
Pion minus, pp and dd



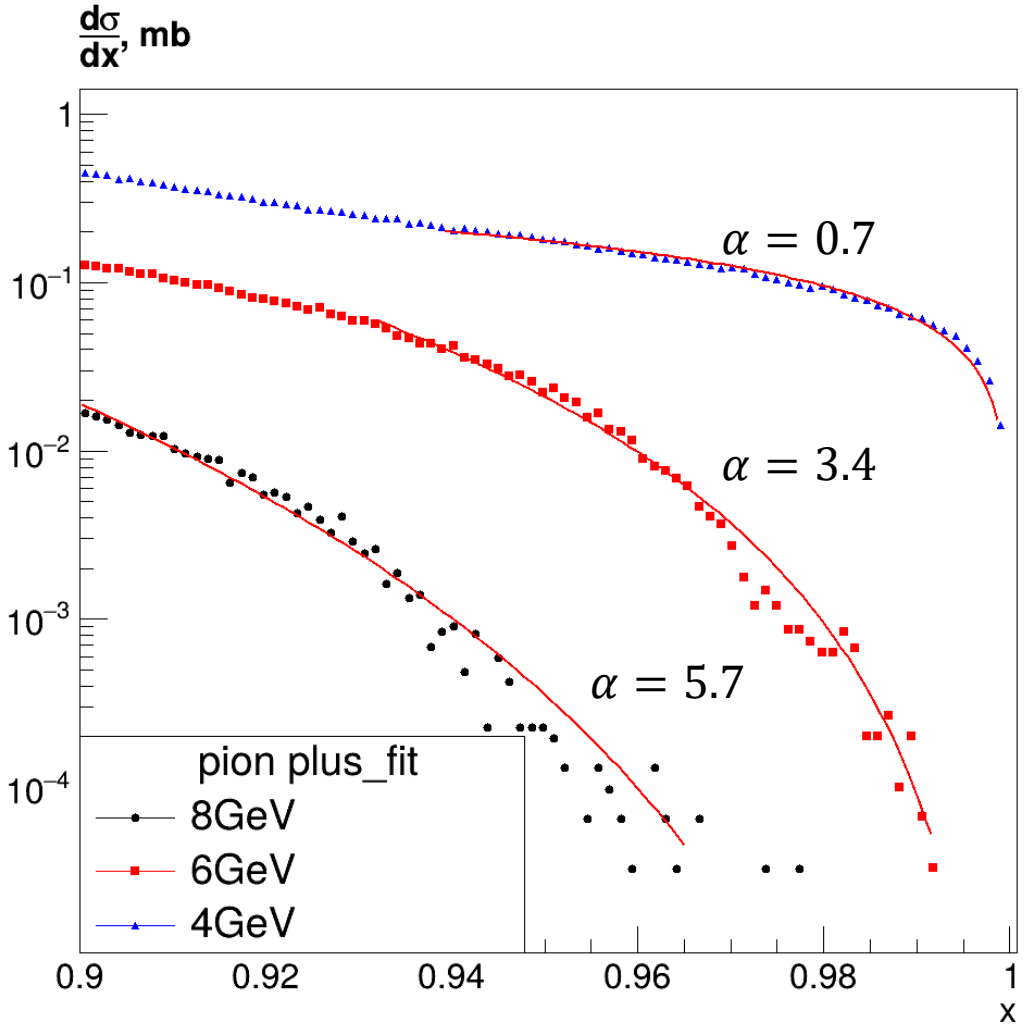


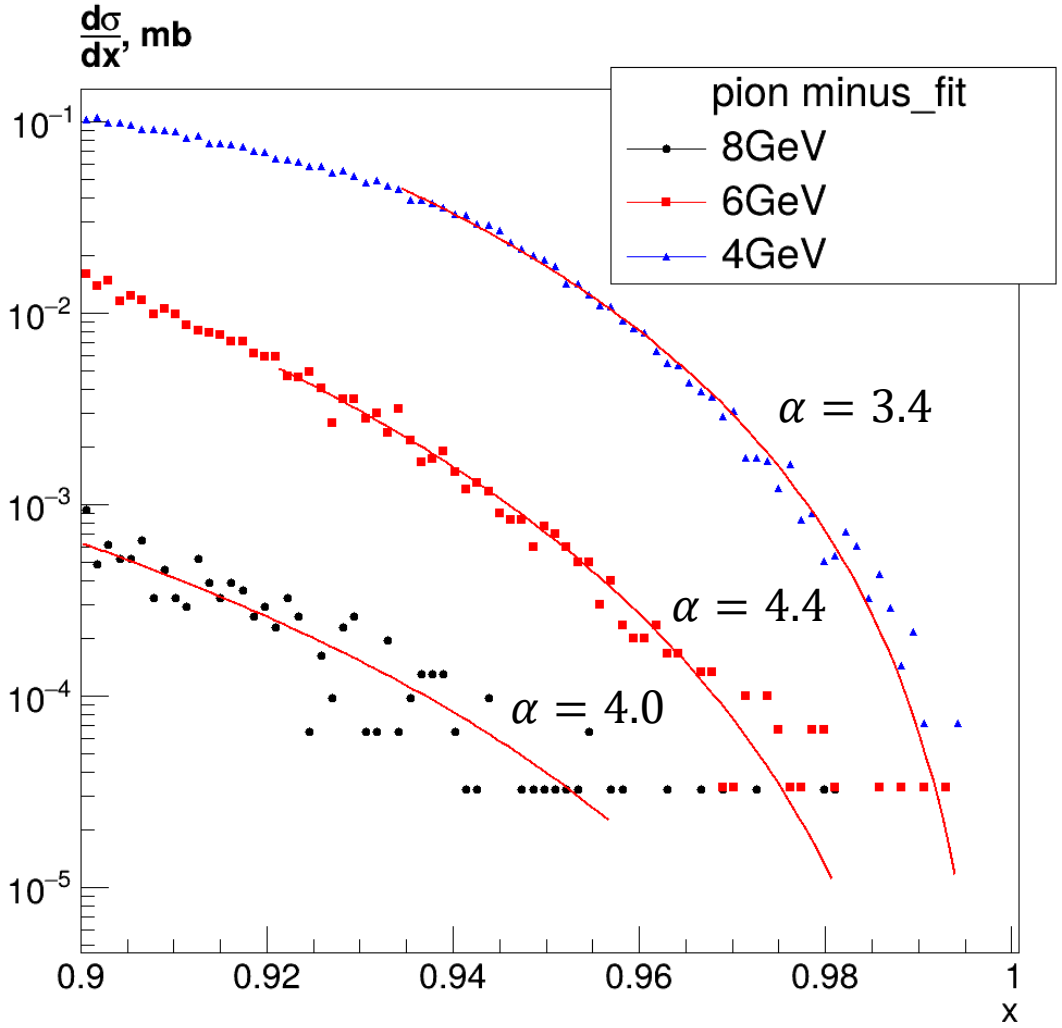
Protons, pp and dd





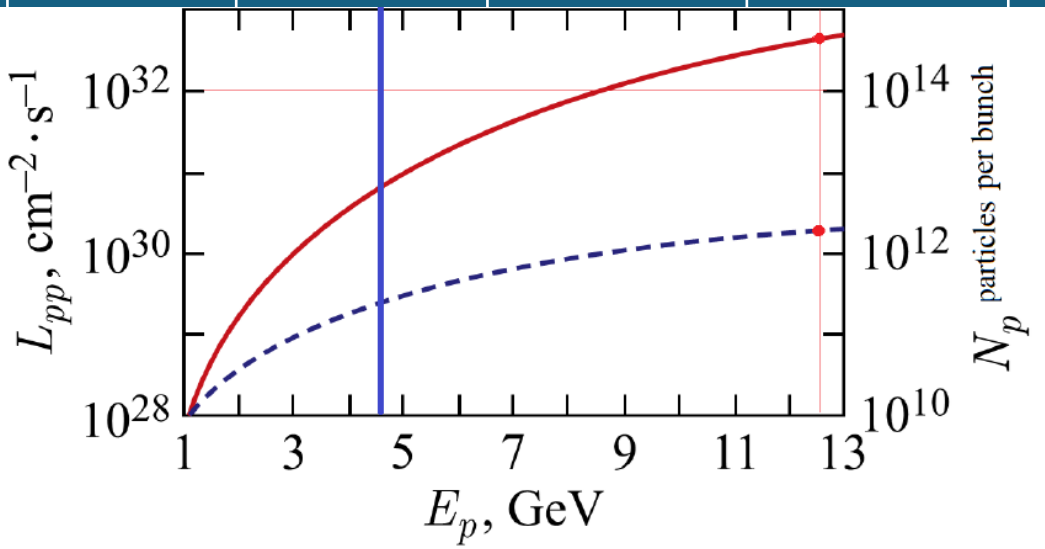
Fits of π^+ and π^- with $C \cdot (1-x)^{\alpha}$





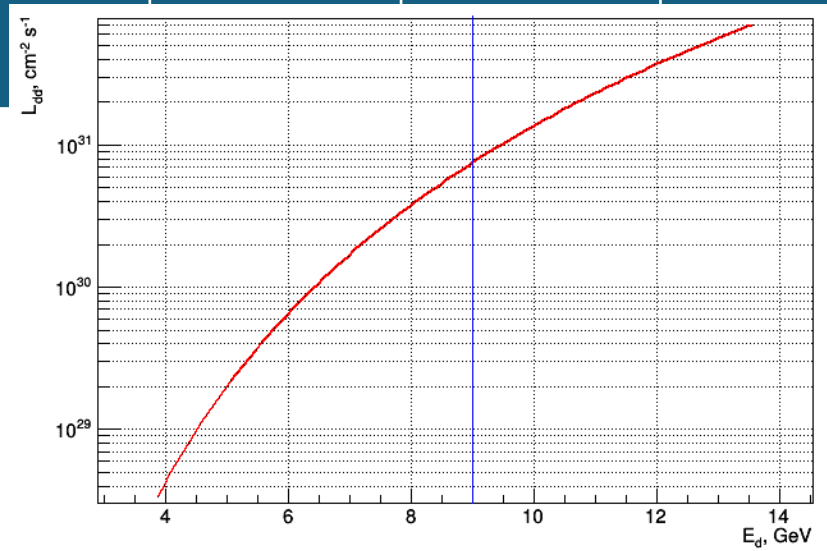
Yields of particles: pp with $0.95 < x < 1$

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	$1.7 \cdot 10^5$	$1.5 \cdot 10^{10}$	$4.4 \cdot 10^{11}$	$8.8 \cdot 10^5$	$7.6 \cdot 10^{10}$	$2.3 \cdot 10^{12}$	$3.1 \cdot 10^6$	$2.7 \cdot 10^{11}$	$8.2 \cdot 10^{12}$



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	$5 \cdot 10^{3}$	$4.3 \cdot 10^{8}$	$1.3 \cdot 10^{10}$	$7.5 \cdot 10^{4}$	$6.5 \cdot 10^{9}$	$2 \cdot 10^{11}$	$4.2 \cdot 10^{5}$	$3.6 \cdot 10^{10}$	$1.1 \cdot 10^{12}$



To Do

1) Repeat this analysis on other generators
2) Add other sources (fluctons, SRC) of cumulative effect to some generator (probably Pythia8)

Conclusions

- x-spectra of different particles were obtained using Pythia8 for pp and dd collisions.
- Pythia8 has capability of producing cumulative particles using rescattering mechanism
- Prediction of particles yields were made at NICA collider luminosities
- Increase of luminosity compensates decrease of cross section. This allows us to study cumulative effect in 4-8 GeV energy range.

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Thank you for your attention!