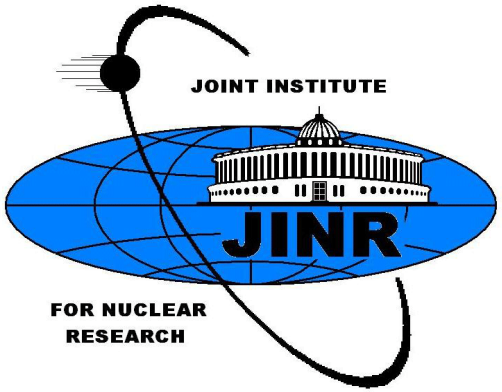
Performance study of the Beam-Beam Counters (BBC) for the dd – scattering at the Spin Physics Detector (SPD)

A.A Terekhin et al.
Joint Institute for Nuclear Research, Dubna, Russia

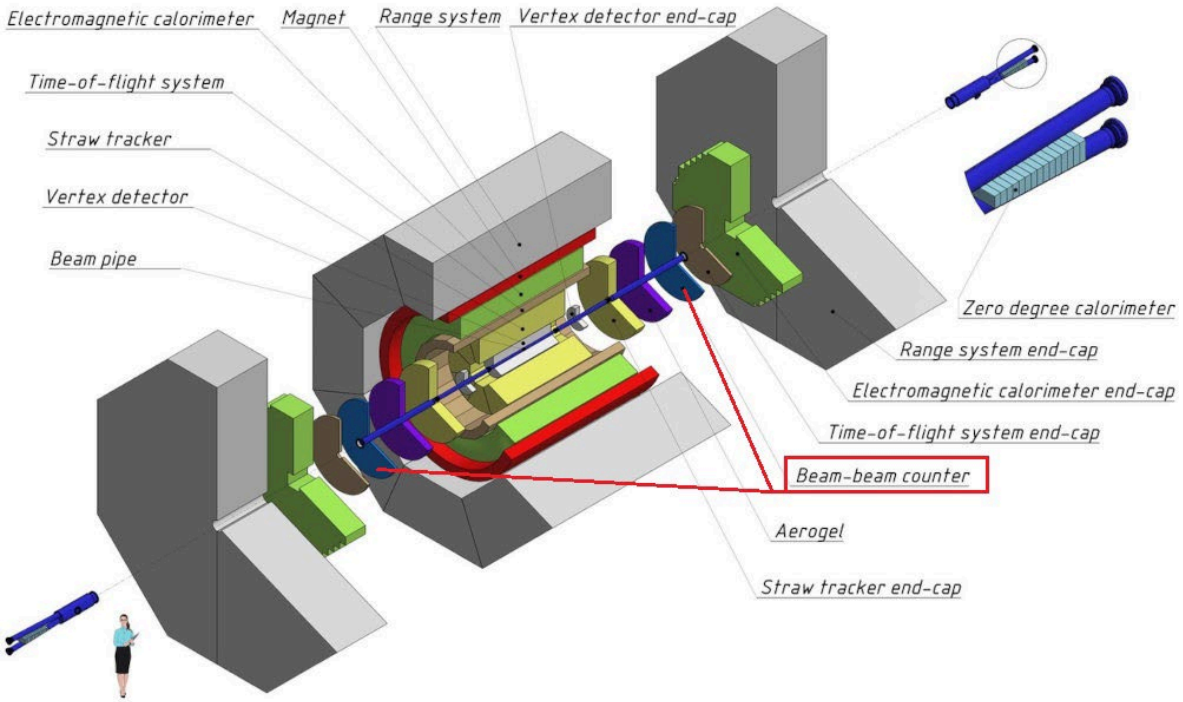


ICPPA – 2026
October 27-30

Beam-Beam Counters

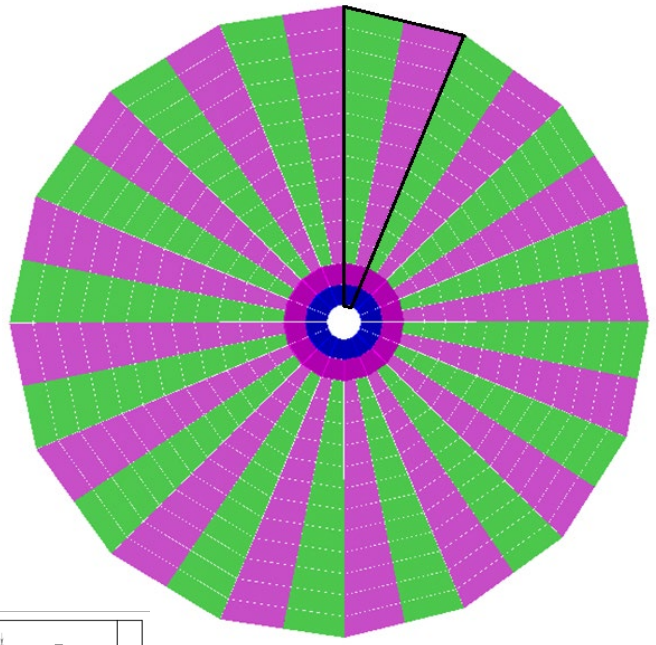
The two Beam-Beam Counters (BBC) are components of the Spin Physics Detector (SPD) at the NICA collider. They will be installed in to end-caps parts of SPD and are designed to perform local polarimetry of the colliding polarized proton and deuteron beams and luminosity control in the beam interaction region. BBCs detect all the charged particles produced in the forward direction within their acceptance.

Here, the MC simulation of the BBC operation for deuteron-deuteron collisions is presented. The simulations are performed at the center-of-mass energy $\sqrt{s}$ = 12 GeV using the SpdRoot framework. The results are compared for the following event generators/models: Geant4 FTF, PYTHIA 8.3, UrQMD, and DCM.



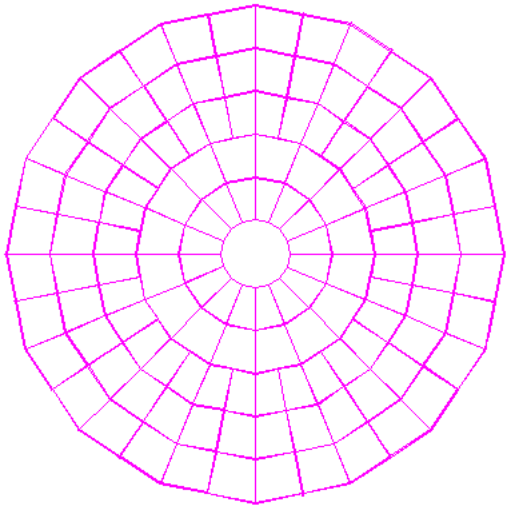
BBC - detector

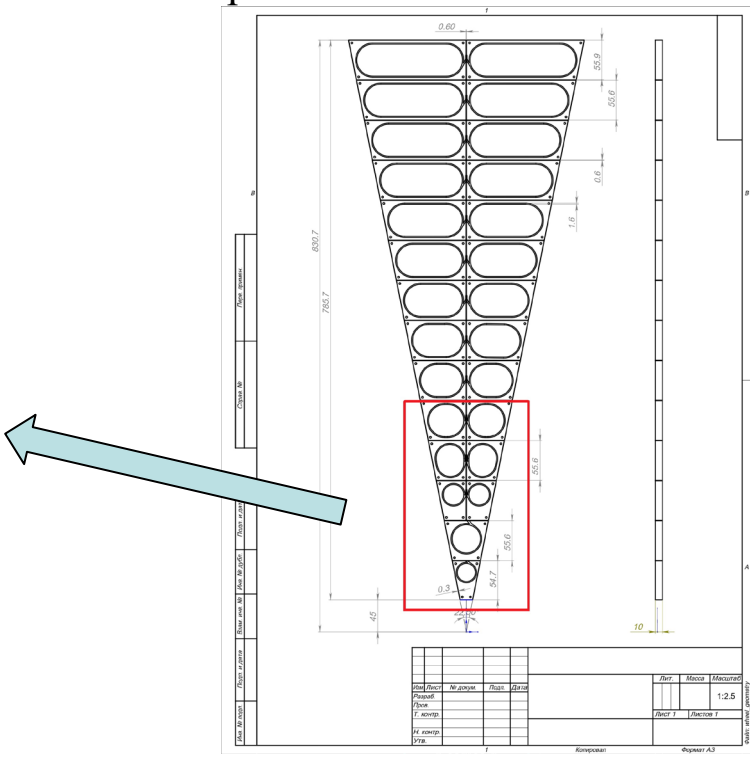
TDR design 2023



- 416 scintillation tiles
- 14 concentric layers with 16 azimuthal sectors each
- The distance between tiles is bullet points 1 mm.
- The tile thickness is bullet points 10 mm.
- The diameter will be bullet points about 1650 mm.
- The distance between each detector and SPD center is bullet points Z = 1793 mm.
- The uncertainty of location of the interaction point is expected to be ΔZ ~ ±300 mm.

The BBC prototype will be used in the zero SPD phase.





Study of the *dd* – collisions at SPD

- **Understanding of the nucleons structure and the nature of the strong interaction**
- **Information on the short-range structure of the deuteron** (Non-nucleonic degrees of freedom in the deuteron, test of the theoretical models)
- **Gluon contribution in the nucleon spin** (study of the TMD PDF)
- **Color transparency phenomenon**
- **Test the Standard Model** (Search for time-invariance violation parity violation in single-polarized scattering)

***dd* – inelastic scattering**

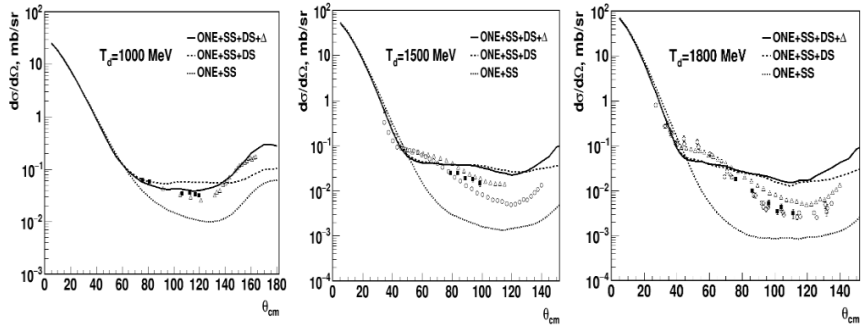
***dd* – elastic scattering**

***pd* – quasi-elastic scattering**

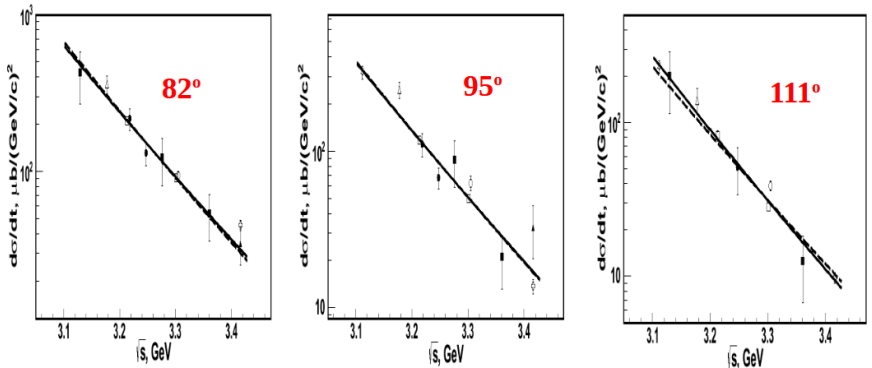
Study of the *dp* – collisions at Nuclotron

- dp-elastic scattering cross section at 500, 750 and 900 MeV/n.
- Energy dependence of the vector A_y and tensor A_{yy} analyzing powers in dp-elastic scattering at 350-900 MeV/n.
- The results obtained at Nuclotron demonstrate the power law scaling behavior for the cross section as well as the asymptotic values for the A_y and A_{yy} analyzing powers in dp- elastic scattering at large transverse momenta (>600 MeV/c). This can be due to the manifestation of the fundamental degrees of freedom.

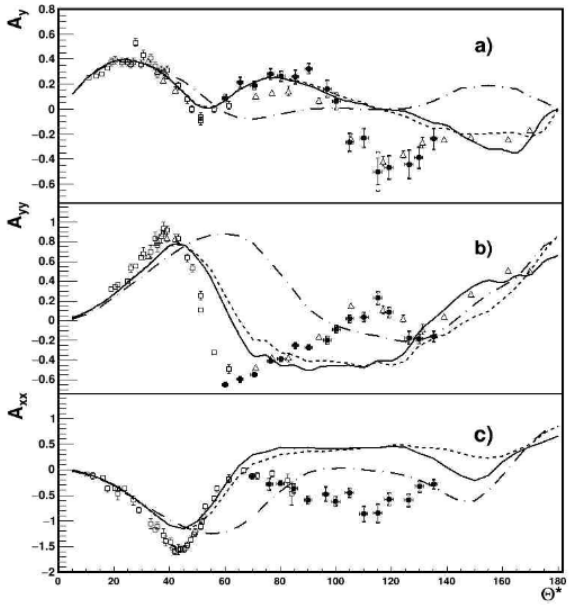
dp- elastic scattering cross section at 1000, 1500 and 1800 MeV



CCR for dp- elastic scattering cross section

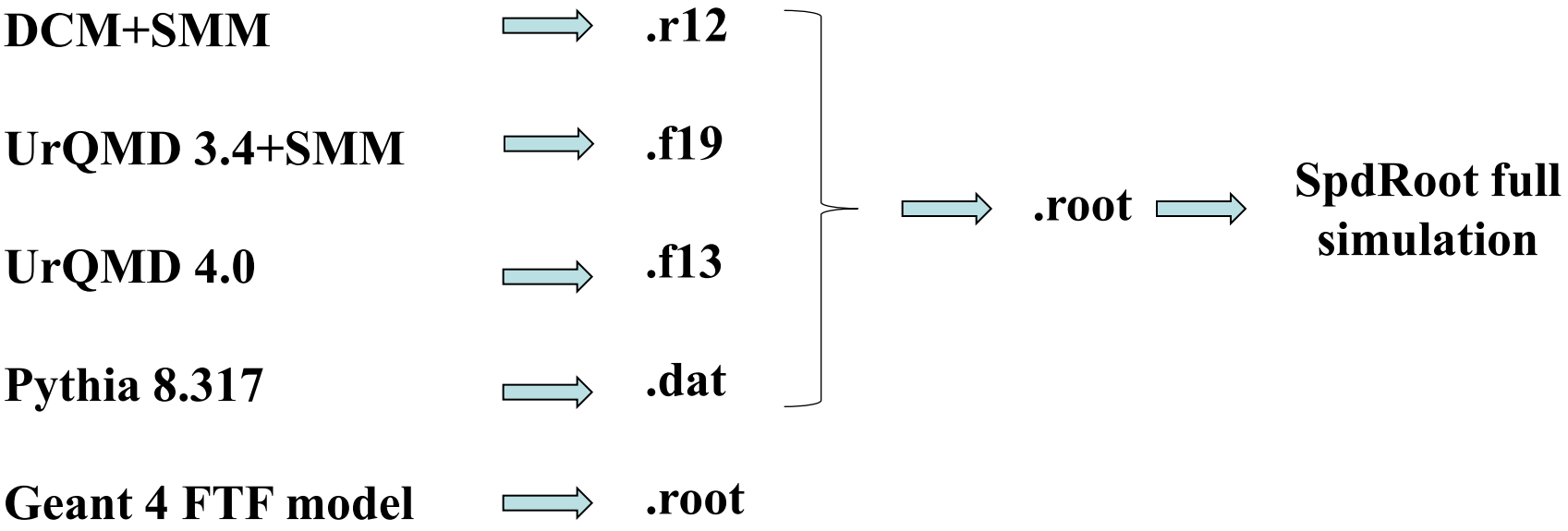


Angular dependencies of the vector Ay and tensor Ayy and Axx analyzing powers in dp-elastic scattering at 1300 MeV



dd – scattering simulation

Generators and models



DCM – Dubna Cascade Model
SMM – Statistic Multifragmentation Model

dd – scattering simulation

Generators and models

$$d + d \rightarrow \begin{cases} d + d \rightarrow d + d \\ d + d \rightarrow d + p + n \\ d + d \rightarrow d + p + n + \pi^0 (\pi^+ + \pi^-) \\ d + d \rightarrow 2p + 2n \\ d + d \rightarrow 2p + 2n + 2\pi^0 \\ d + d \rightarrow 3p + n + \pi^- \\ \ldots \end{cases}$$

dd – scattering simulation

Generators and models

Geant4 FTF Model:

- A. Galoyan et al. *"Production of Charmed Particles in Proton-Proton and Light Nucleus-Nucleus Interactions in the Geant4 FTF Model" //* **Phys.Part.Nucl. 57 (2026) 5, 1141**.
- A. Galoyan et al. *"Possible Studies of Two-Particle Transverse Momentum Correlations in Proton–Proton and Deuteron–Deuteron Interactions at NICA Energies" //* **Bull.Russ.Acad.Sci.Phys. 88 (2024) 11, 1782**.

UrQMD 3.4 + SMM:

- A. Galoyan et al. *"Coupling of UrQMD 3.4 and SMM Models for Simulation of Neutron and Nuclear Fragment Productions in Nucleus–Nucleus Interactions" //* **Phys.Part.Nucl. 56 (2025) 6, 1433**.

Pythia 8:

- D. S. Shapaev et al. *"Simulation of Direct Photon Production in d+d Collisions at* $\sqrt{s_{NN}} = 13.5$ *GeV and* $\sqrt{s_{NN}} = 27$ *GeV" //* **Phys.Atom.Nucl. 88 (2025) 5, 1043 (St.Petersburg Polytech.Univ.J.Phys.Math. 17 (2024) 4, 138)**.

dd – scattering simulation

UrQMD 4.0 + Coalescence

- **Phase-space box coalescence:** Protons and neutrons that are close to each other in phase space (after collision end), with a certain probability form a new deuteron [1].
  - Search of pair proton-neutron
  - Checking of conditions: $r_p - r_n < \Delta r$; $(p_p - p_n)/2 < \Delta p$
  - The pair "binds" into a deuteron with a probability of 3/8 (spin-isospin factor)

    Δr = 3.575 fm – maximum p-n spatial separation

    Δp = 0.285 GeV/c – maximum p-n momentum difference

[1] S. Sombun et al., *Deuteron production from phase-space coalescence in the UrQMD approach* // Phys. Rev. C 99, 014901 (2019)

- **Wigner coalescence:** The sharp box is replaced by a smooth probability, derived from the deuteron internal wave function [2].
  - Search of pair proton-neutron
  - Calculation of the relative coordinate r and relative momentum k in the pair rest frame: $r = r_p - r_n$, $k = (p_p - p_n)/2$
  - The deuteron formation probability is taken as: $P_d^w = g_d \cdot 8 \cdot exp\left(-\frac{r^2}{\sigma_d^2} - \frac{\sigma_d^2 k^2}{hc}\right)$

g_d = 3/4 – spin factor

σ_d^2 = 3.2 fm – Wigner width

hc = 0.197 GeV· fm – unit conversion

[2] L. K. Liu et al., *Light and hyper nuclei formation at √sNN = 3 GeV Au+Au collisions using Wigner coalescence approach,* // Phys. Lett. B 855, 138853 (2024)

dd – scattering simulation

UrQMD 4.0 + Coalescence

The UrQMD4 input file controls only whether coalescence is enabled, but not the method.

- **Phase-space box coalescence:** CTOption 64 *(cto 64 1)* activates the standard build-in box algorithm. Also, can be implemented as external code.
- **Wigner coalescence:** can be implemented only as external code.

In according with [3] both coalescence methods gives the similar results.

Pythia 8.317 + Coalescence

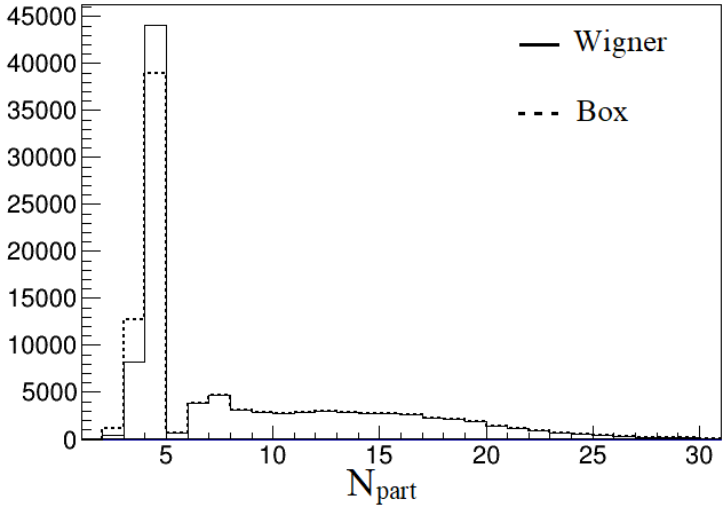
Both coalescence methods can be implemented only as external codes. According present simulation the box and Wigner coalescences gives the differenced results.

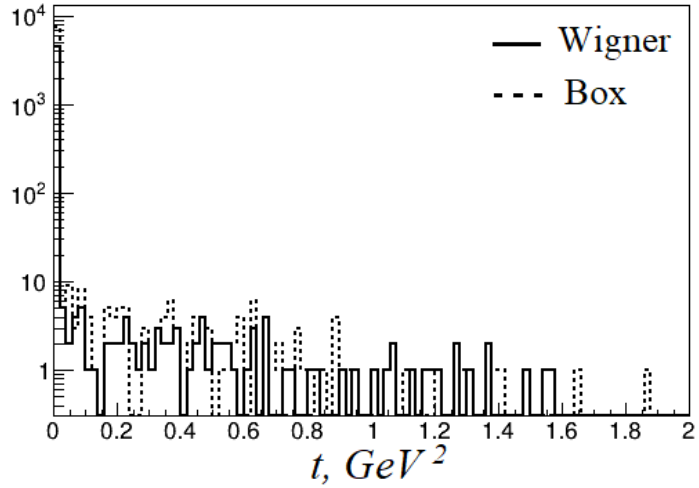
[3] Debasish Mallick., *UrQMD + Coalescence model study*
https://indico.ihep.ac.cn/event/11687/sessions/18658/attachments/103913/140100/DtrnFluct_Checks_4p5GeV_DM_240626.pdf#1#1

dd – scattering simulation

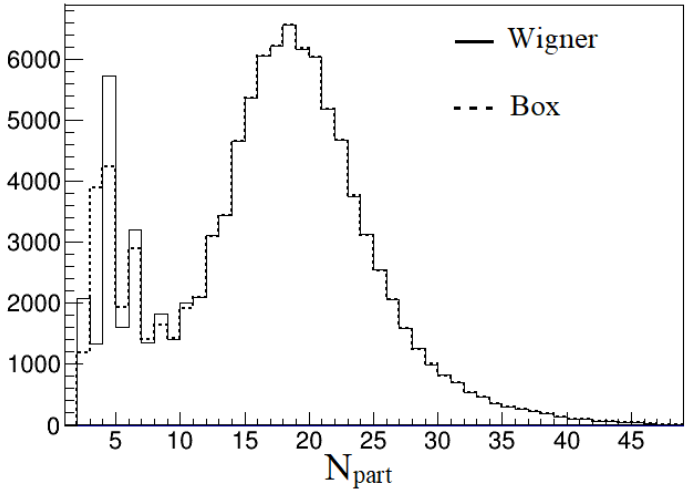
$\sqrt{s} = 12$ GeV $N_{events} = 10^5$

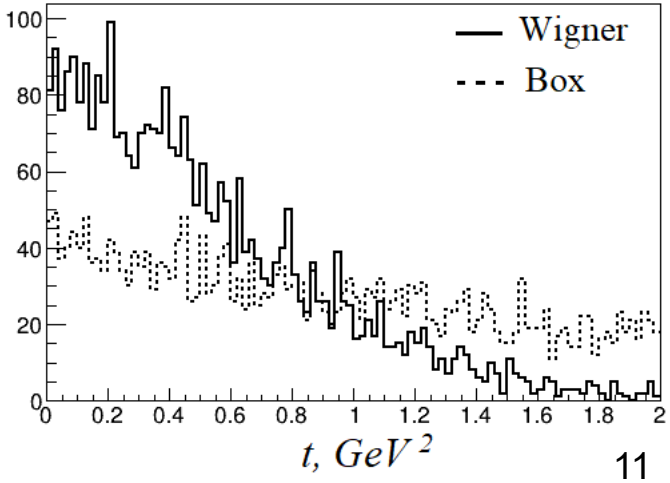
UrQMD 4.0 + Coalescence





Pythia 8.317 + Coalescence



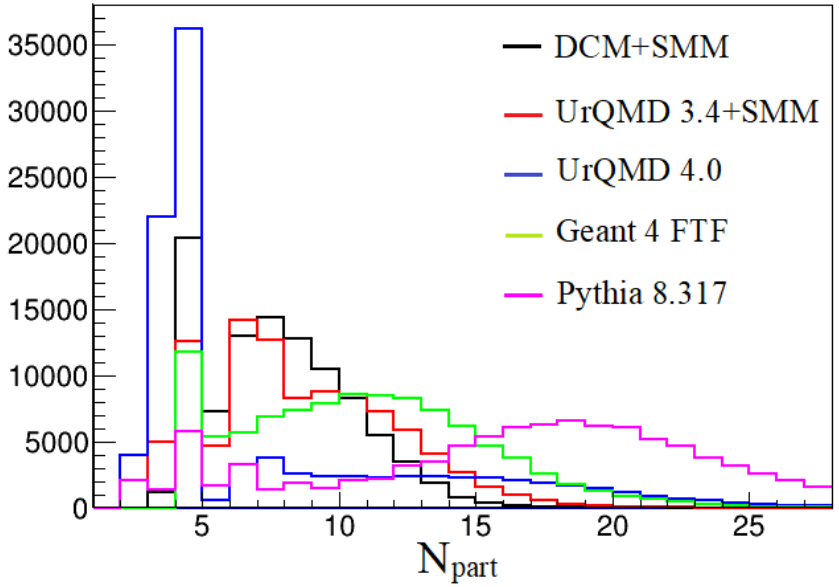


dd – scattering simulation

Generators and models

Multiplicity

$\sqrt{s} = 12$ GeV $N_{events} = 10^5$



Generator	Npart = 2	Npart = 3
DCM+SMM	0	1160
UrQMD 3.4+SMM	2085	4993
UrQMD 4.0	3990	21958
Pythia 8.317	2085	1332
Geant 4 FTF model (only inelastic)	0	0

Npart = 2: $d + d \rightarrow d + d$

Npart = 3: $d + d \rightarrow d + p + n$

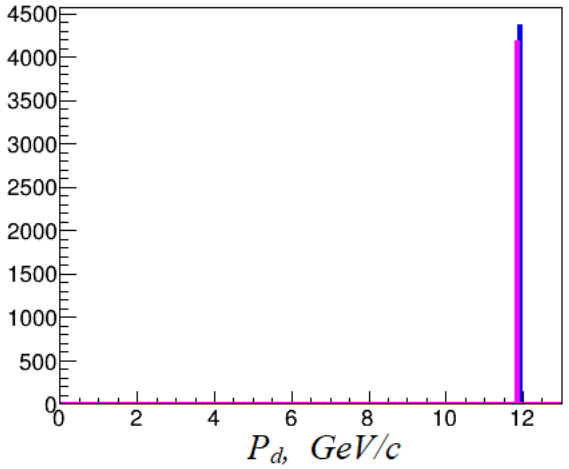
dd – scattering simulation

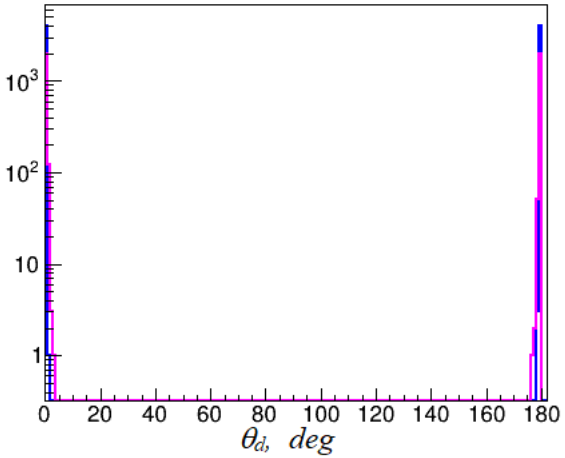
P - and θ - distribution

Npart = 2:

UrQMD 4.0

Pythia 8.317





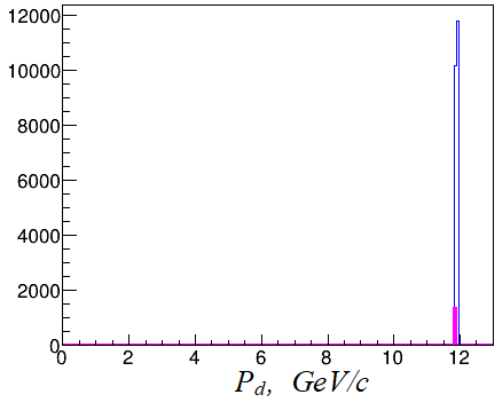
dd – scattering simulation

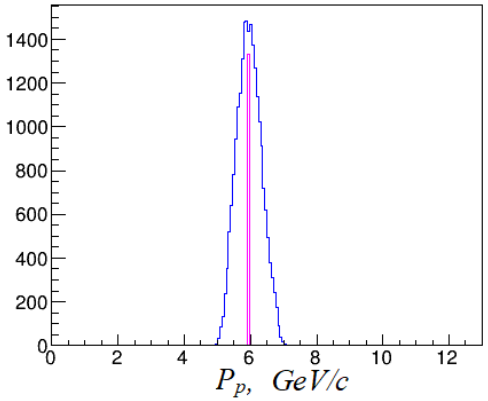
P - and θ - distribution

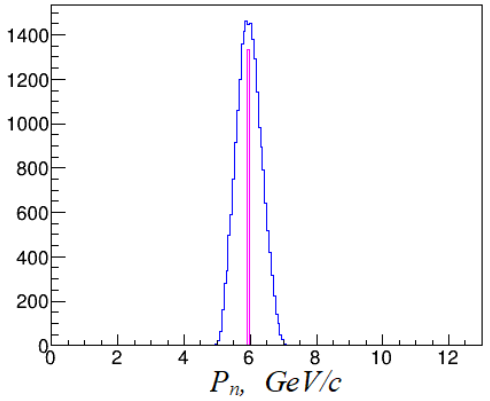
Npart = 3:

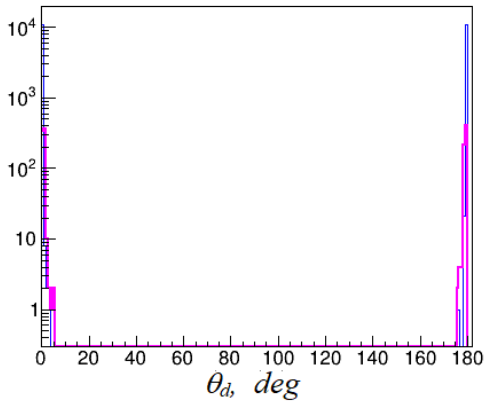
UrQMD 4.0

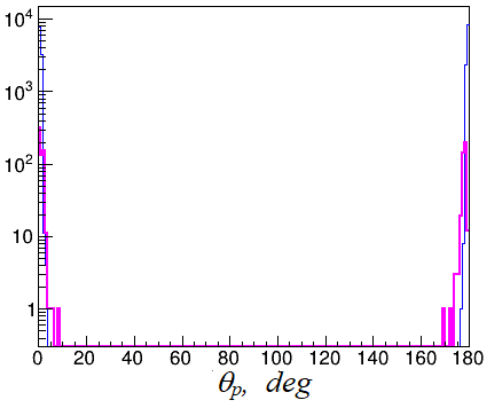
Pythia 8.317

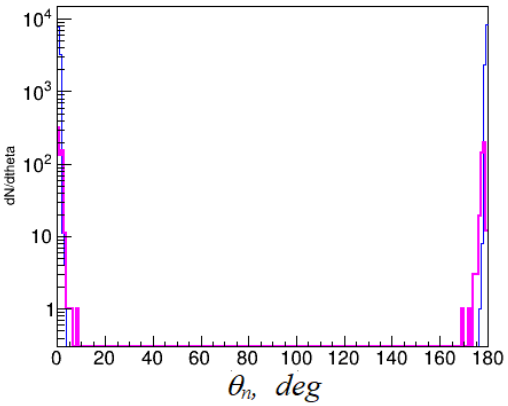












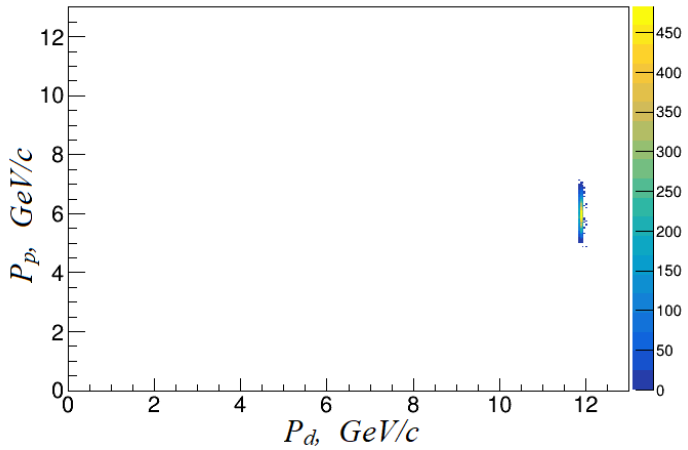
dd – scattering simulation

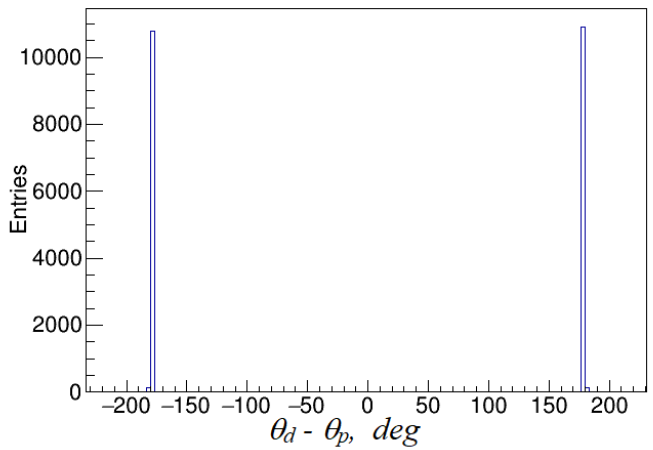
P - and $\Delta\theta$ - distribution

$\sqrt{s}$ = 12 GeV

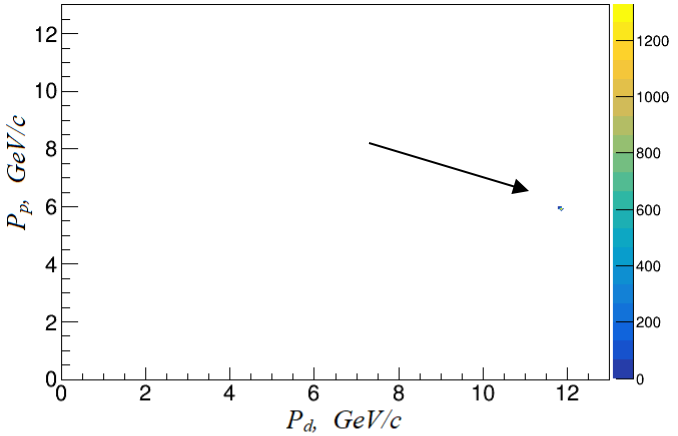
Npart = 3

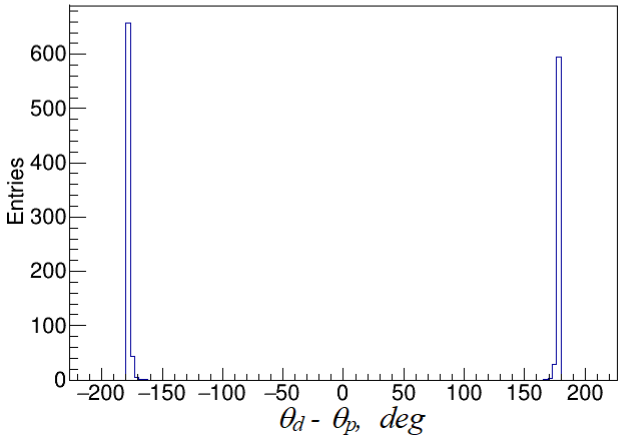
UrQMD 4.0





Pythia 8.317





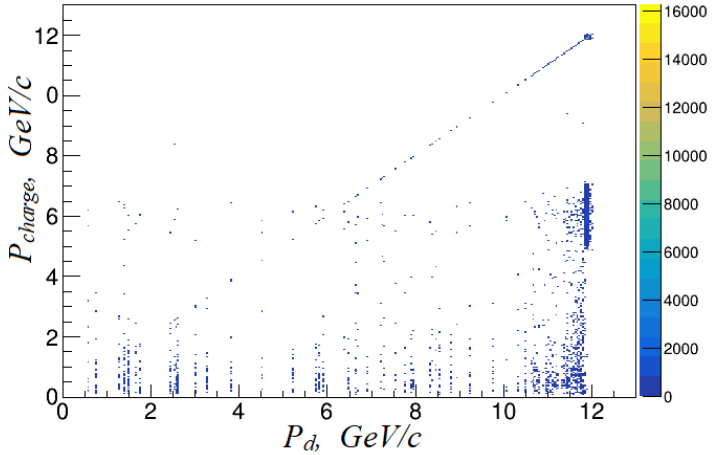
dd – scattering simulation

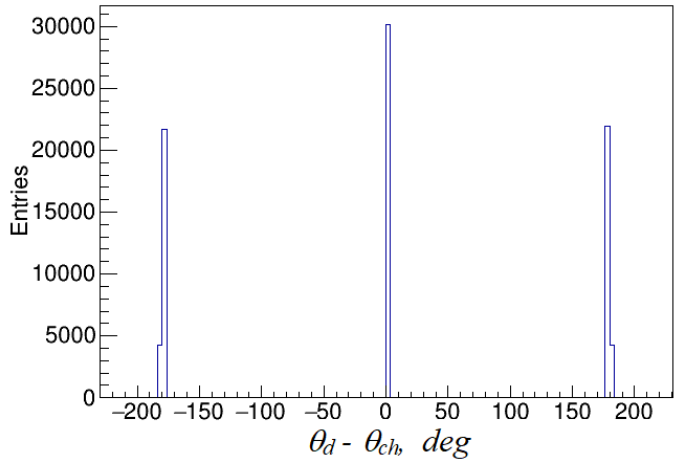
P - and $\Delta\theta$ - distribution

$\sqrt{s}$ = 12 GeV

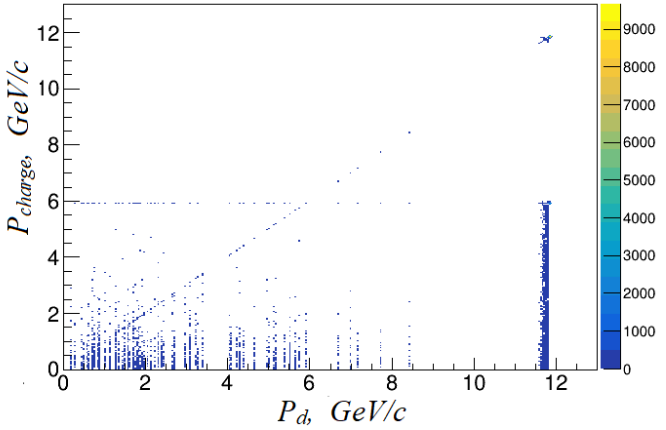
Npart >= 2

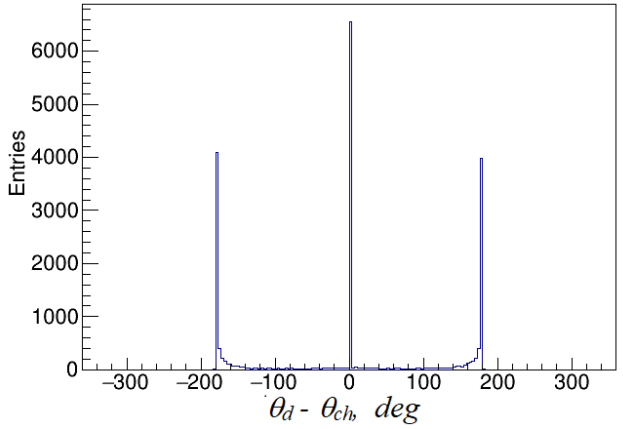
UrQMD 4.0





Pythia 8.317





dd – scattering SpdRoot simulation

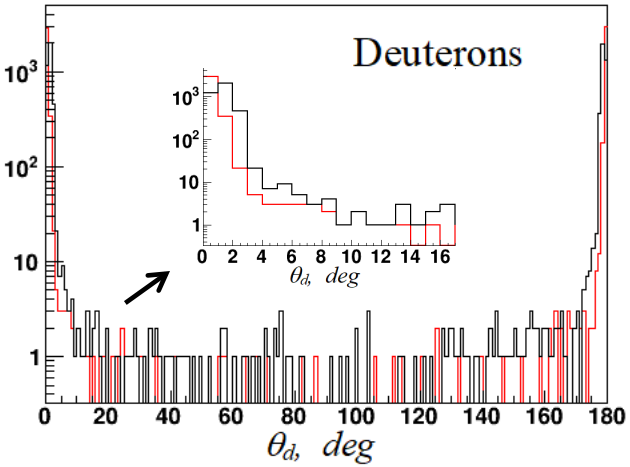
Pythia 8.317

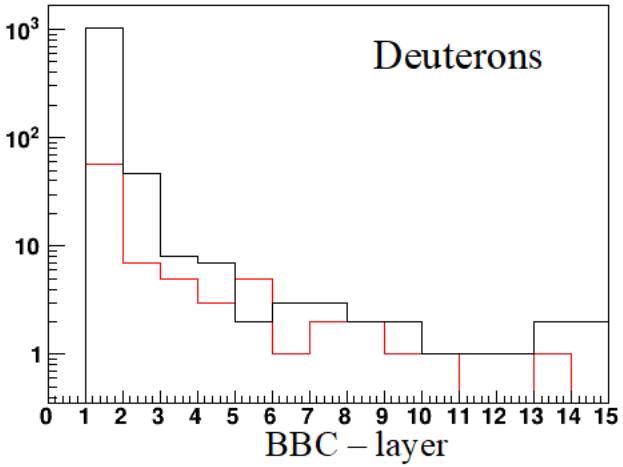
$N_{events} = 10^5$

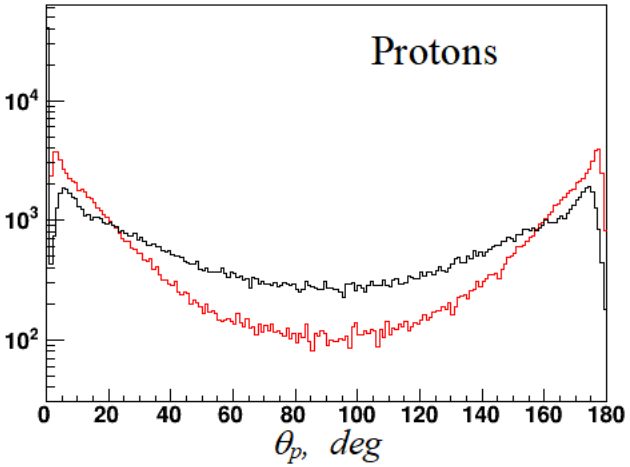
G1 – primary particles

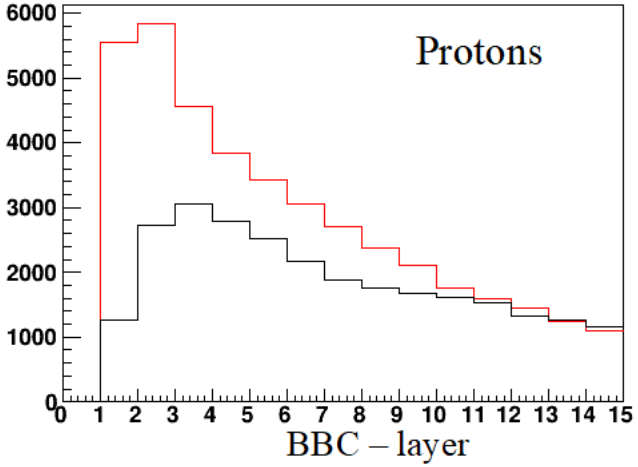
Black – $\sqrt{s}$ = 6 GeV

Red – $\sqrt{s}$ = 12 GeV









dd – scattering SpdRoot simulation

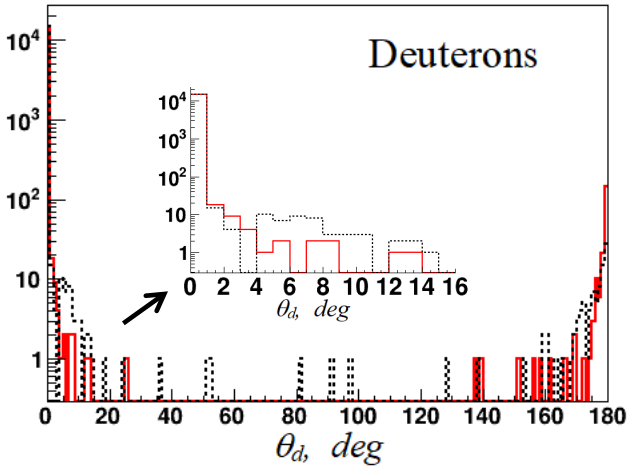
UrQMD 4.0

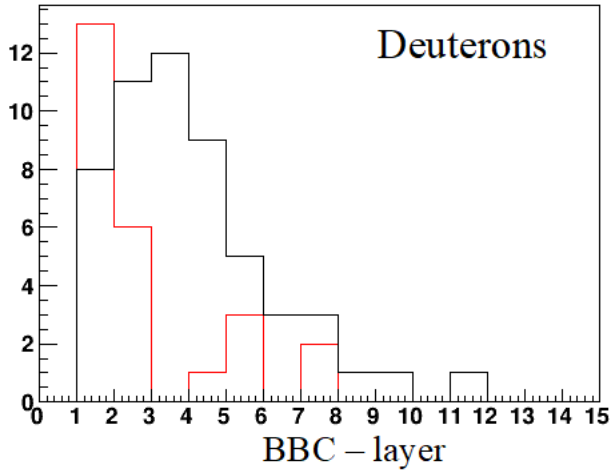
$N_{events} = 10^5$

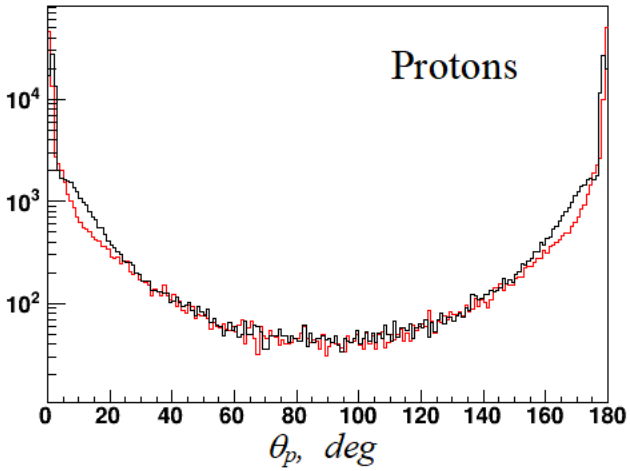
G1 – primary particles

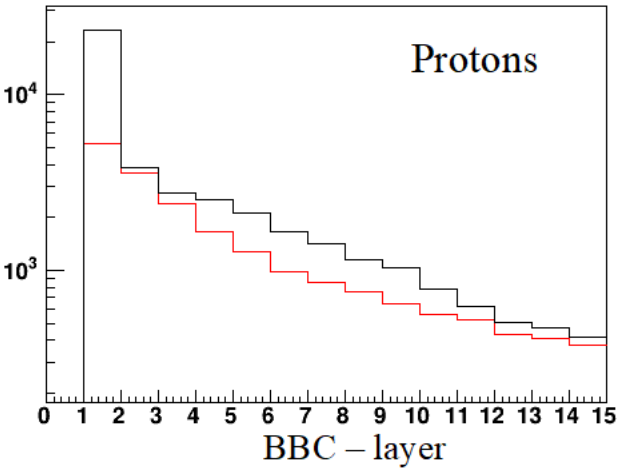
Black – $\sqrt{s}$ = 6 GeV

Red – $\sqrt{s}$ = 12 GeV









Results

- MC simulation have been performed for dd-scattering at energies $\sqrt{s}$ = 6 and 12 GeV. The the following event generators/models have been used: Geant4 FTF, PYTHIA 8.3, UrQMD, and DCM.
- The account of the different interaction channels was analyzed.
- The preliminary analysis of the momentum and polar scattering angle distributions was performed.
- The first spectra for BBC have been obtained.

Next plans

- Next comparison of the generators.
- Clarification of the coalescence mechanisms in the UrQMD and Pythia8.
- The estimation of the account of the different interaction channels to more accuracy simulation. The creation of the dd-scattering file with account all interaction channels.
- The possibility estimate of the deuterons and protons separation with BBC.

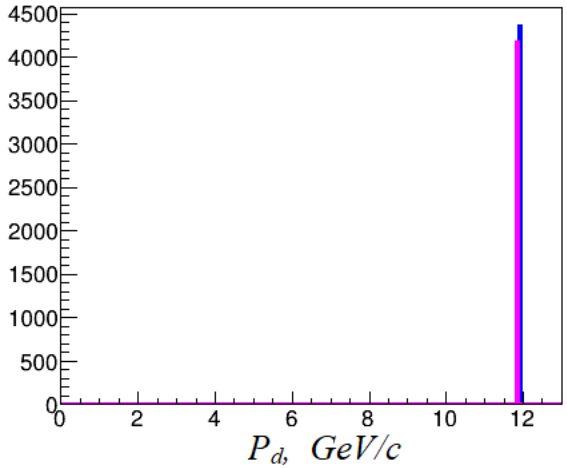
dd – scattering simulation

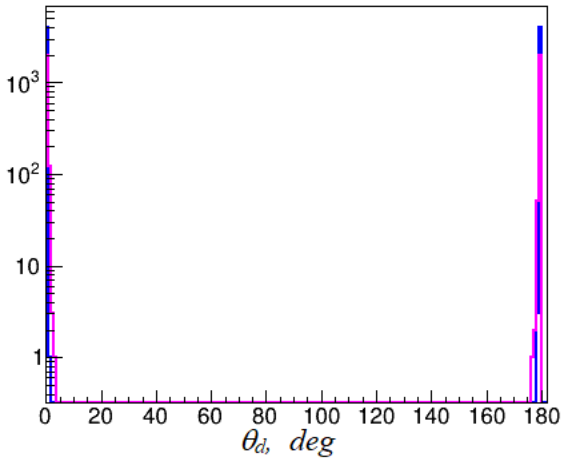
P - and θ - distribution

Npart = 2:

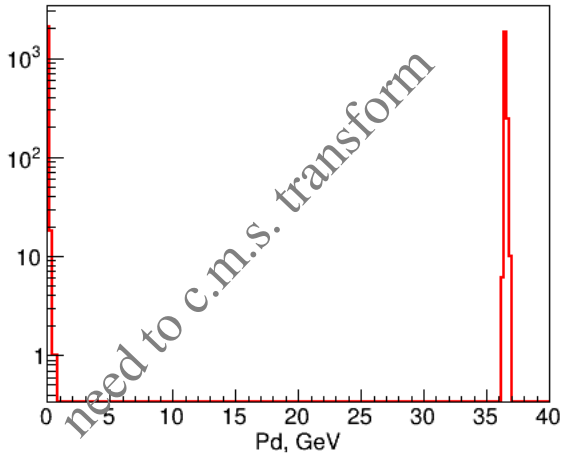
UrQMD 4.0

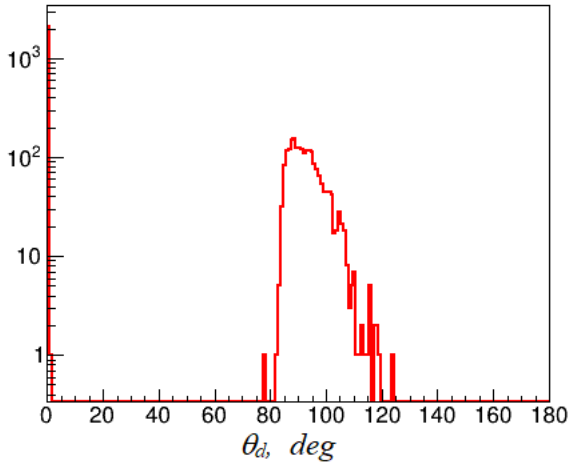
Pythia 8.317





UrQMD 3.4 + SMM





dd – scattering simulation

P - and θ - distribution

Npart = 3:

UrQMD 3.4 + SMM

DCM + SMM

