PP – and DD – scattering simulation for Beam–Beam Counter of the Spin Physics Detector

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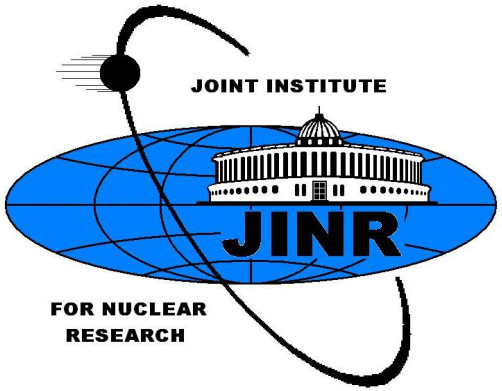
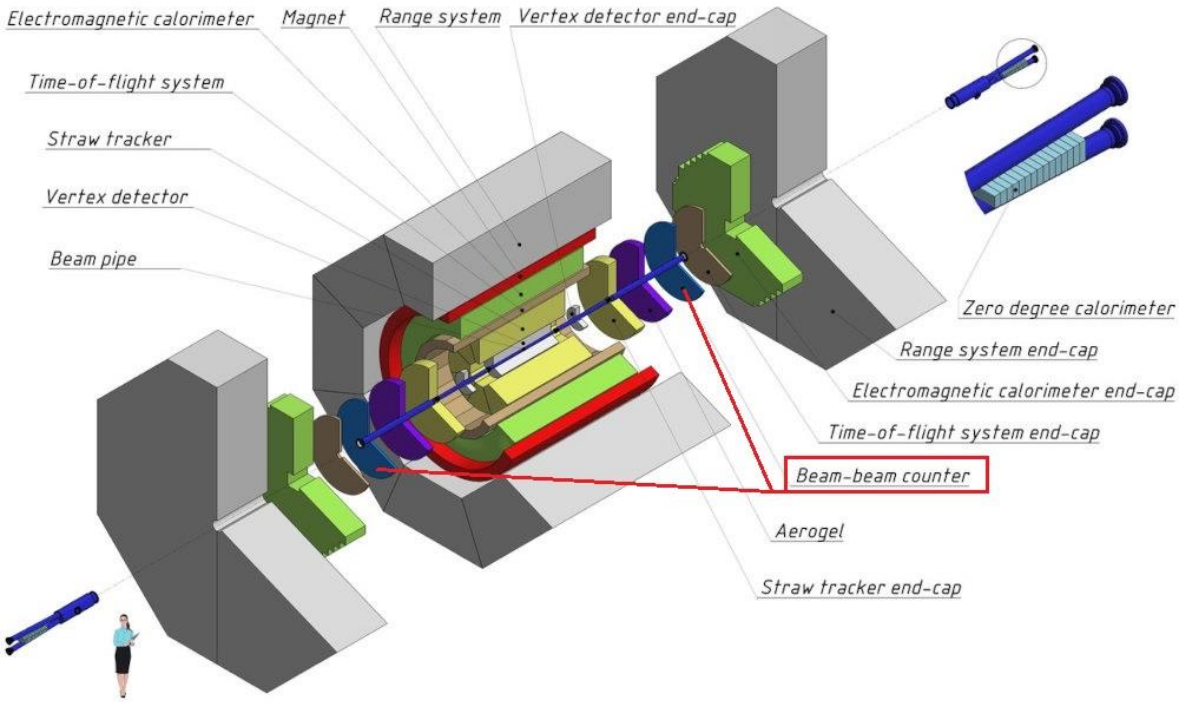


NUCLEUS – 2025
1–6 Jul 2025

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 proton-proton and deuteron-deuteron collisions is presented. The simulations are performed using the SpdRoot framework and the center-of-mass energies 6 and 10 GeV. The selection of the *pp*- and *dd*-elastic scattering events in the BBC is discussed.

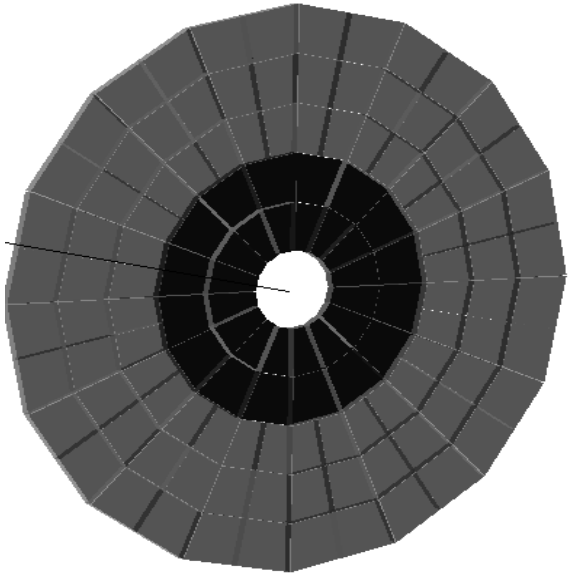


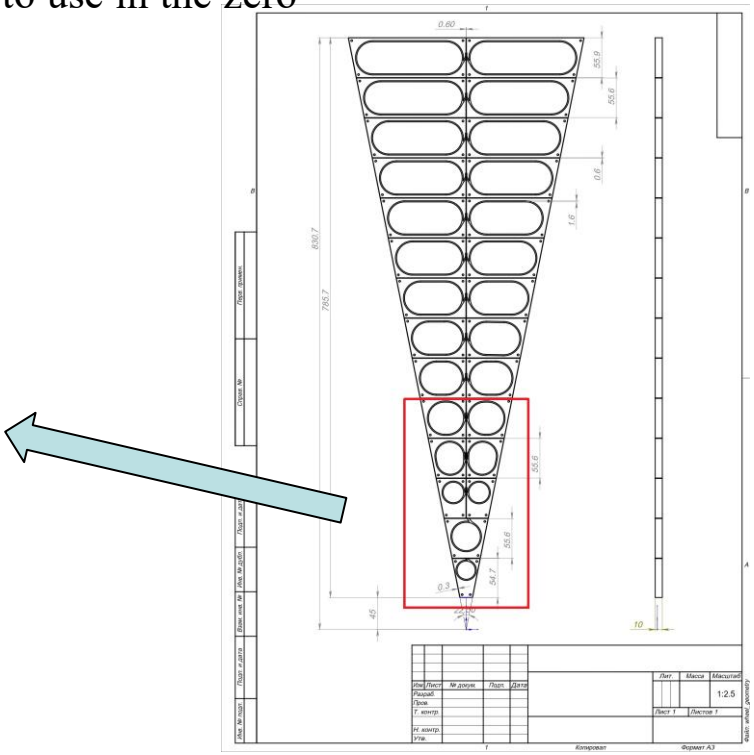
BBC - detector

TDR design 2023

- 416 scintillation tiles
- 14 concentric layers with 16 azimuthal sectors each
- The distance between tiles is equal 1 mm.
- The tile thickness is equal 10 mm.
- The diameter will be equal about 1650 mm.
- The distance between each detector and SPD center is equal Z = 1716 mm.
- The uncertainty of location of the interaction point is expected to be ΔZ ~ ±300 mm.

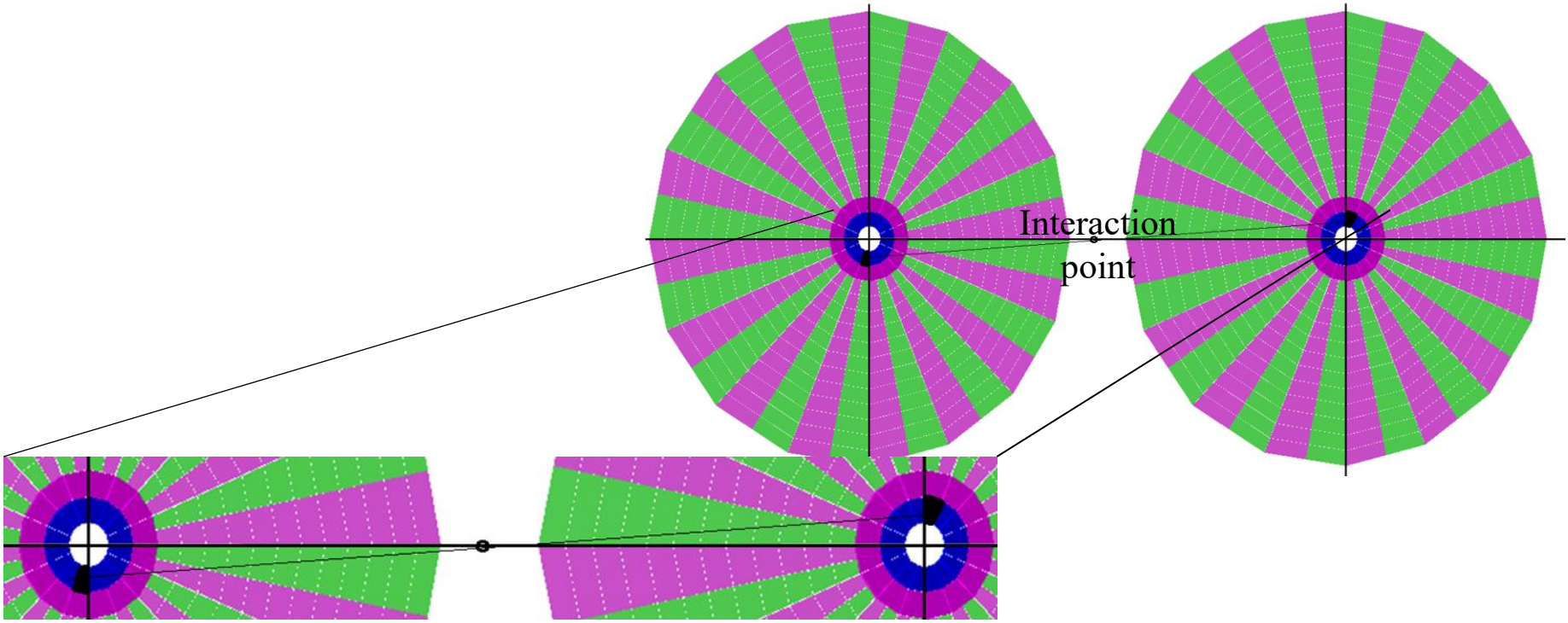
The BBC prototype will be planned to use in the zero phase of the SPD – experiment.





PP – elastic scattering selection

Elastic scattering of protons can be used for polarimetry control of the colliding beams. Also elastically scattered protons have large momentum and therefore small rotation angle $\Delta\varphi$ in the magnetic field. Preliminary analysis shows [1] that the elastic scattering plays a significant role at the energies $\sqrt{s} < 10$ GeV. The comparison of the proton and pion analyzing powers A_N [1] show that the behavior of A^{eff}_N is dominated by the A^{proton}_N. Therefore, the selection of the elastic channel is of interest to estimate its contribution to the behavior of A^{eff}_N. The timing information for each hit in the kinematically corresponding tiles can be used for this purpose. Two corresponding tiles of the BBC first layers have been selected in the figure below as an example. Elastic scattering events can be pre-selected by using the time information of the hits which are present simultaneously in the both BBCs.



[1] Terekhin A.A. Phys. of Atomic Nuclei, V 87, № 2, p. 44 (2024)

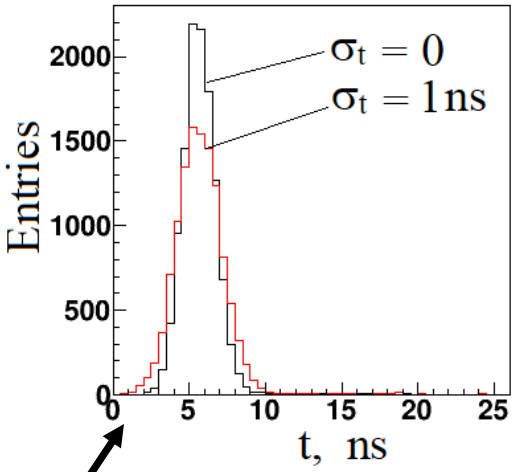
PP – elastic scattering selection

Generator: Pythia8, $\sqrt{s}$ = 10 GeV, B = 0, σ_z = 300mm

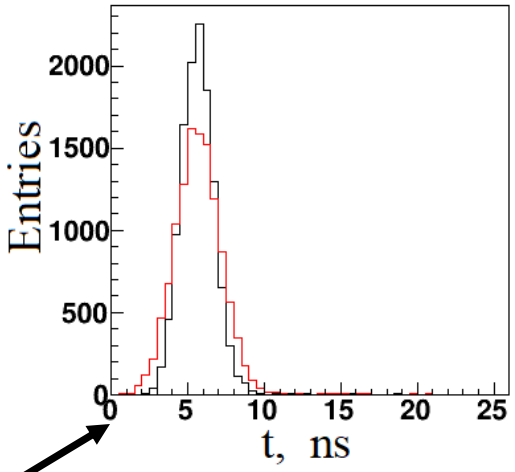
Time difference Δt

The timing distributions of hits have been obtained for each BBC. Also, the time difference distribution for hits, which are registered in the both BBC simultaneously is showed.

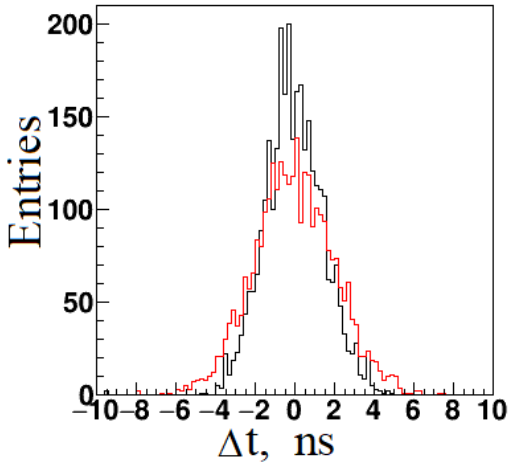
BBC 1



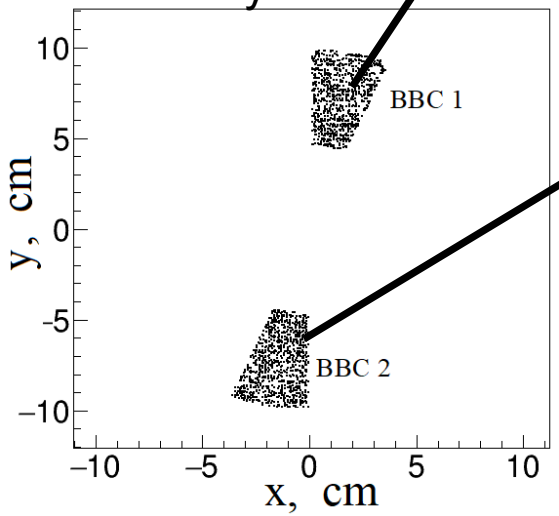
BBC 2



BBC 1 & BBC 2



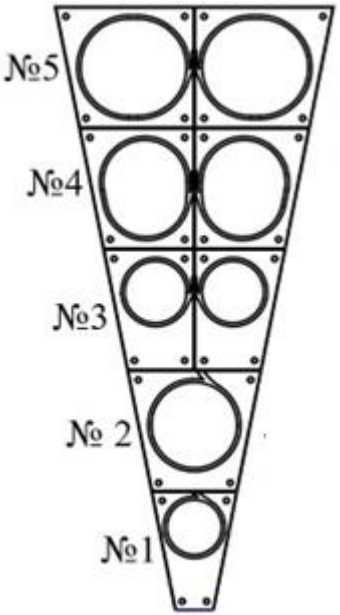
First layer



The total time resolution smeared the spectrum, but the main statistic part also is located in the domain ±4 ns.

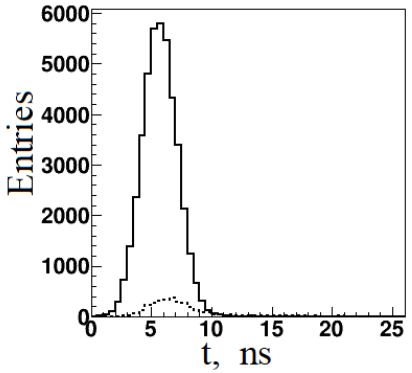
PP – elastic scattering selection

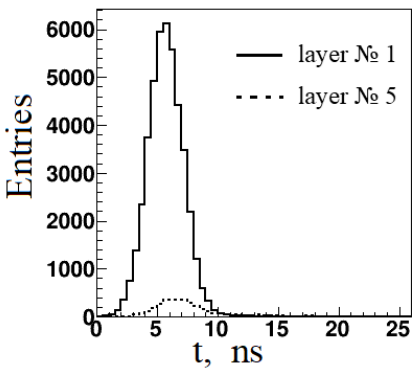
It due to the increasing of the background coincidences between BBC 1 and BBC 2. The simulation of the pp-elastic scattering only and pp-inelastic scattering only at 10 GeV have been performed to understand of the above obtained results.

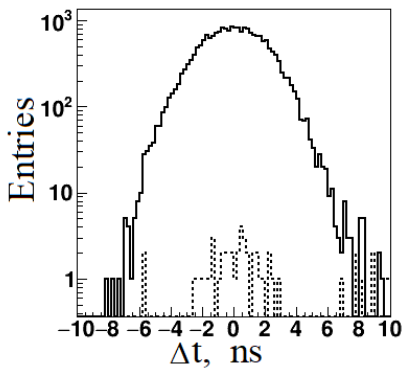


BBC 1 | BBC 2 | BBC 1 & BBC 2

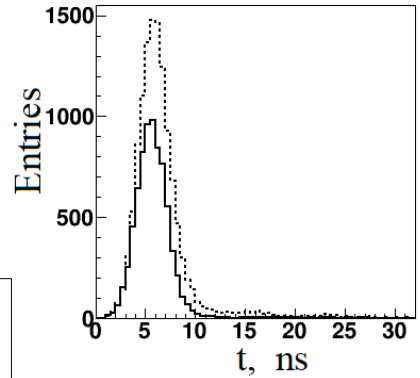
pp^{el}

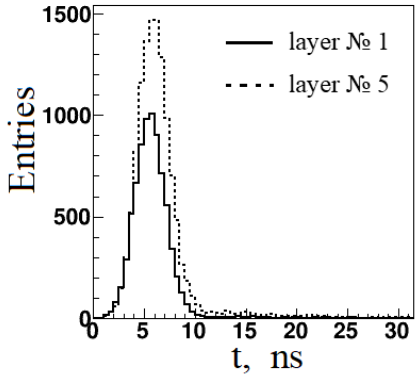


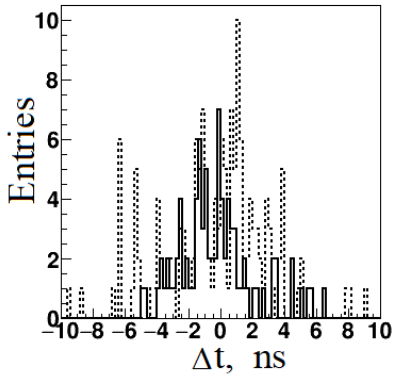


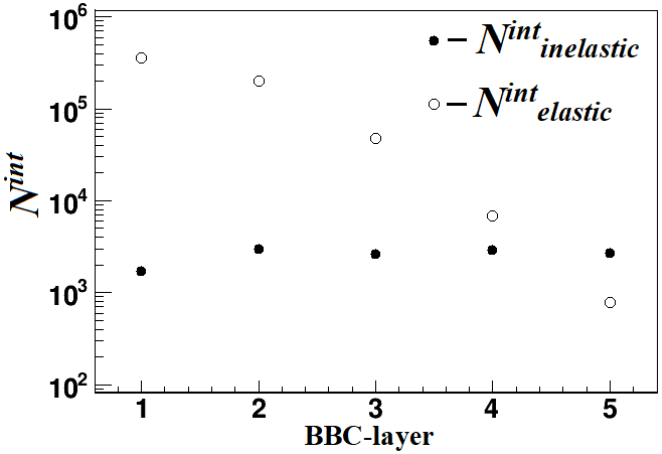


pp^{in}









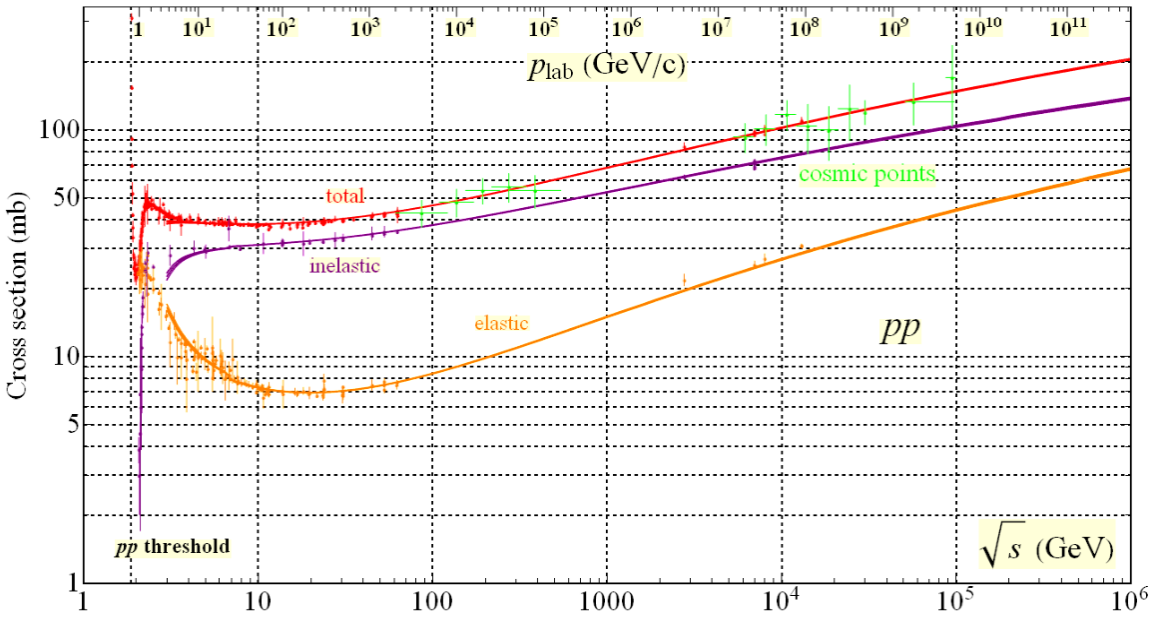
N^{int} – total selected events in the i-layer, $i = 1\ldots5$

PP – elastic scattering selection

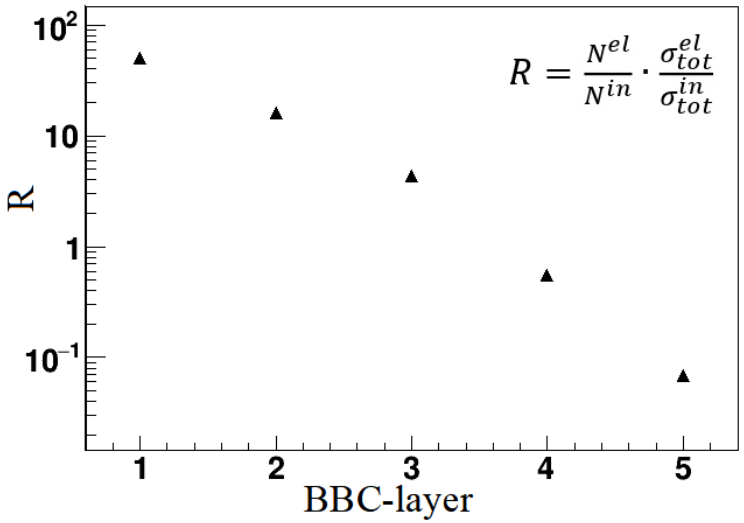
Pythia8 generator

$\sqrt{s} = 10$ GeV

$\frac{\sigma_{tot}^{el}}{\sigma_{tot}^{pp}} = 0.19$ $\frac{\sigma_{tot}^{in}}{\sigma_{tot}^{pp}} = 0.81$



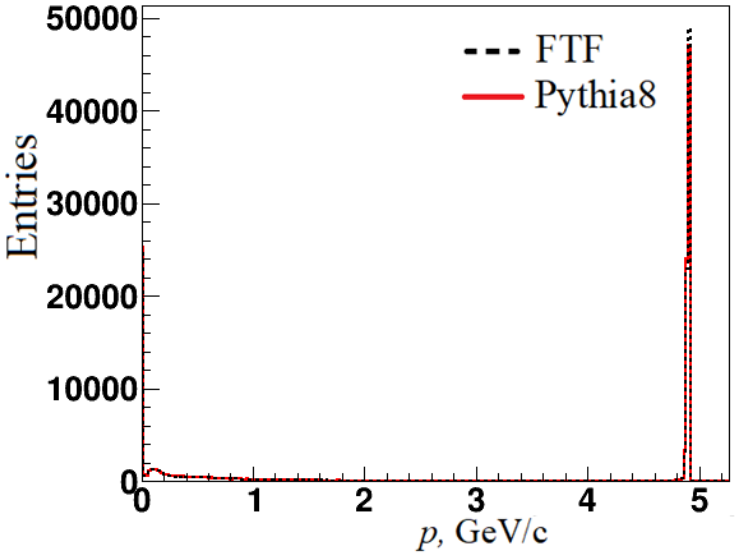
https://pdg.lbl.gov/2022/hadronic-xsections/

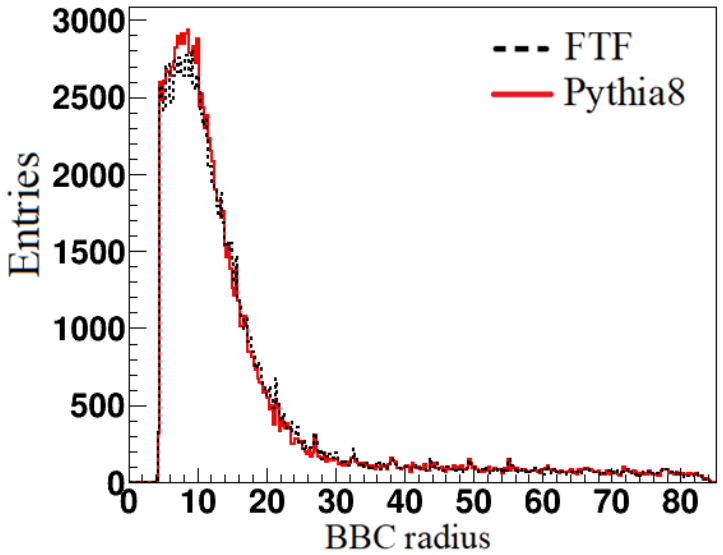


BBC-layer	Signal %	Background %
1	98.0	2.0
2	94.1	5.9
3	81.2	18.8
4	35.5	64.5
5	6.5	93.5

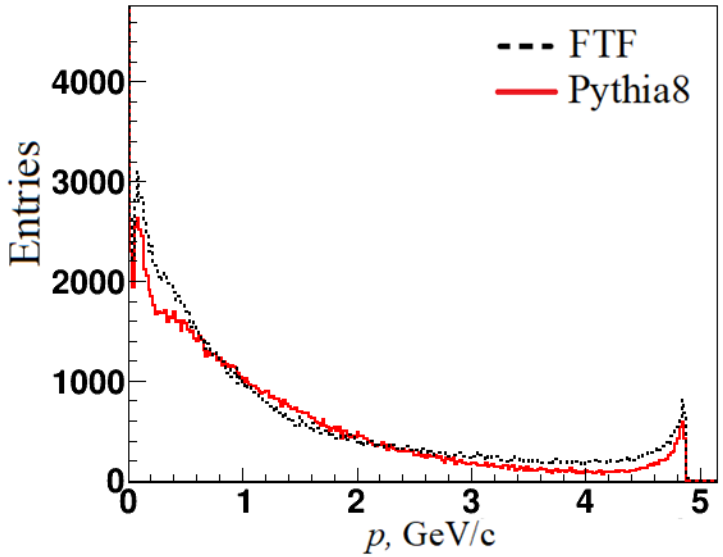
Comparison of the FRITIOFF and Pythia8 generators at √s = 10 GeV

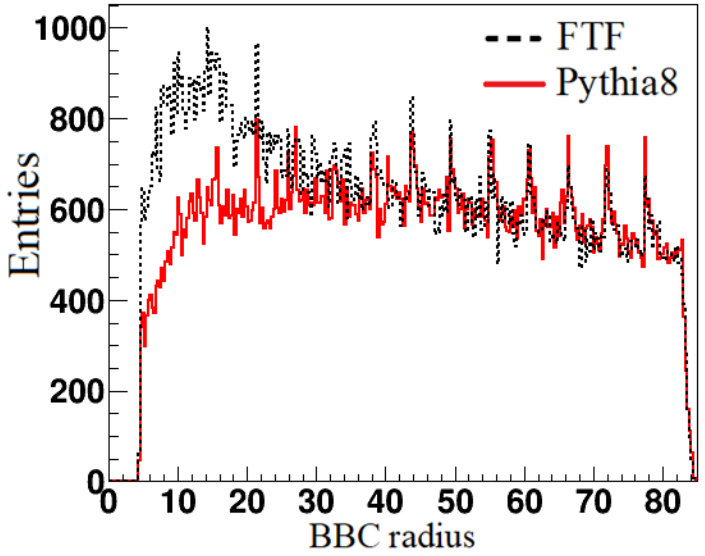
PP – elastic scattering selection





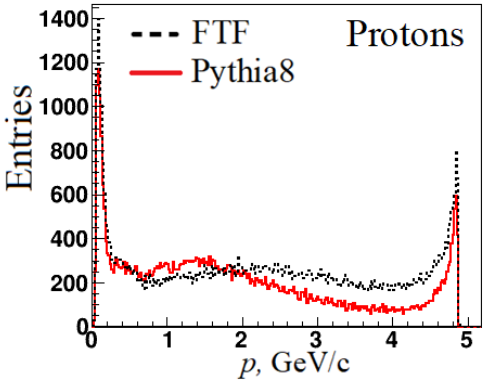
PP – inelastic scattering selection

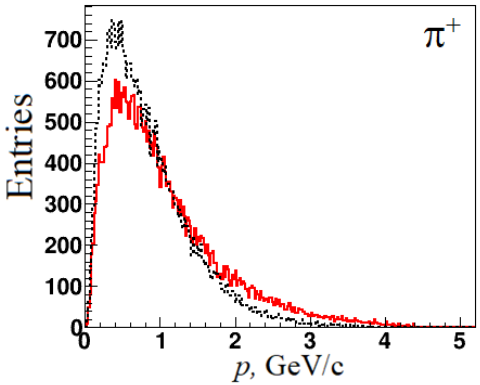


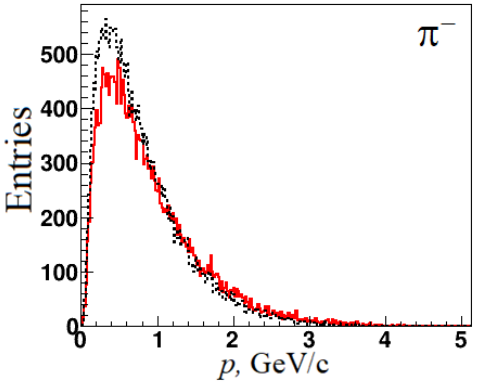


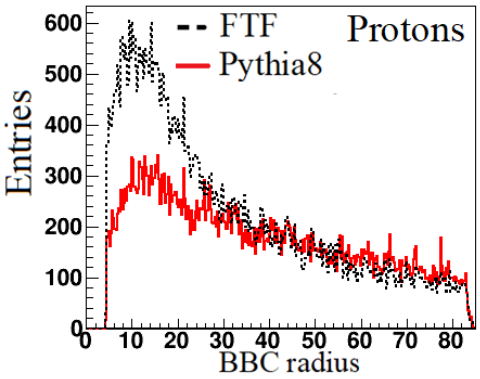
Comparison of the FRITIOFF and Pythia8 generators at √s = 10 GeV

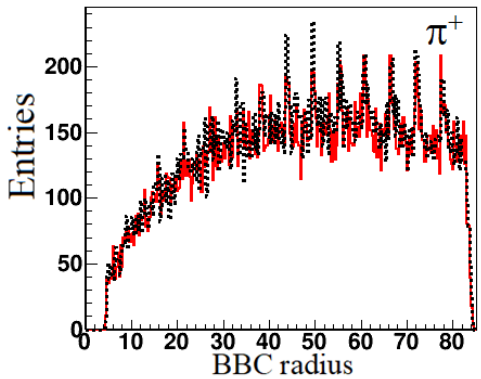
PP – inelastic scattering selection

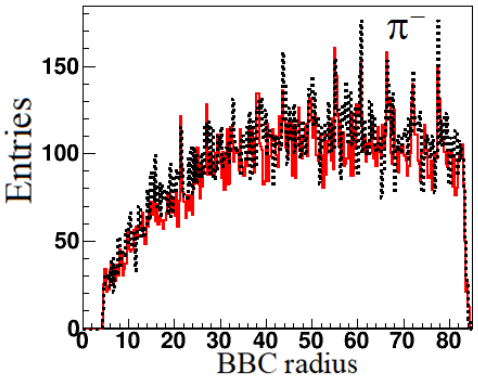


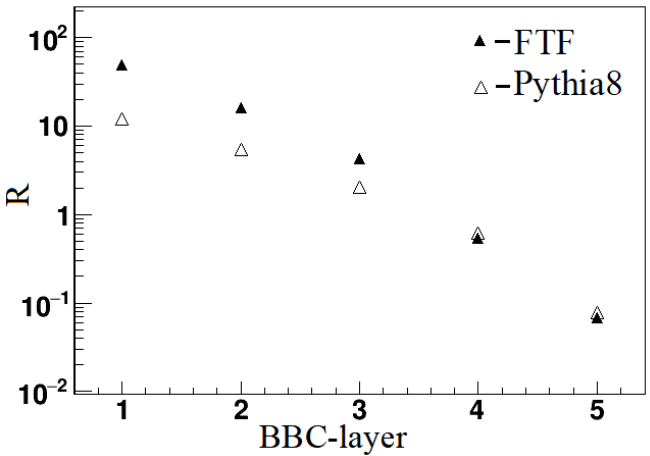








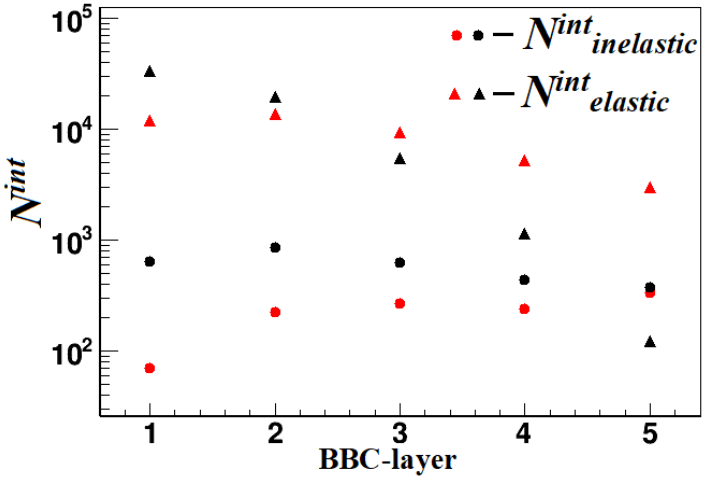


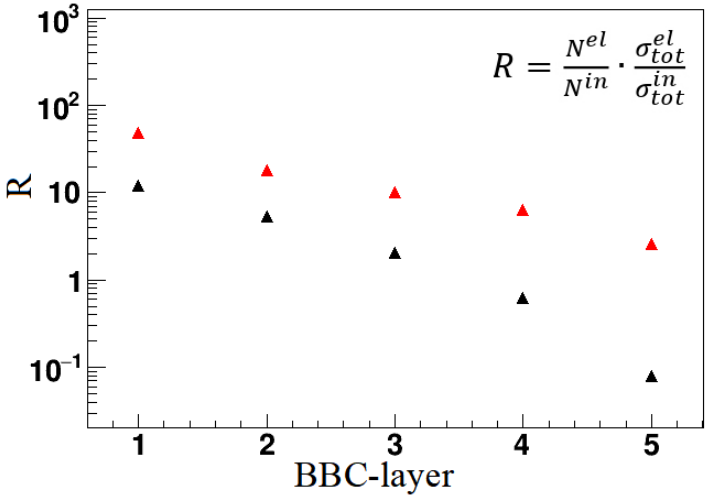


PP – elastic scattering selection

FRITIOFF generator, √s = 6 and 10 GeV

Black - √s = 10 GeV **Red - √s = 6 GeV**





√s = 10 GeV

BBC-layer	Signal %	Background %
1	92.5	7.5
2	84.4	15.6
3	67.2	32.8
4	38.0	62.0
5	7.3	92.6

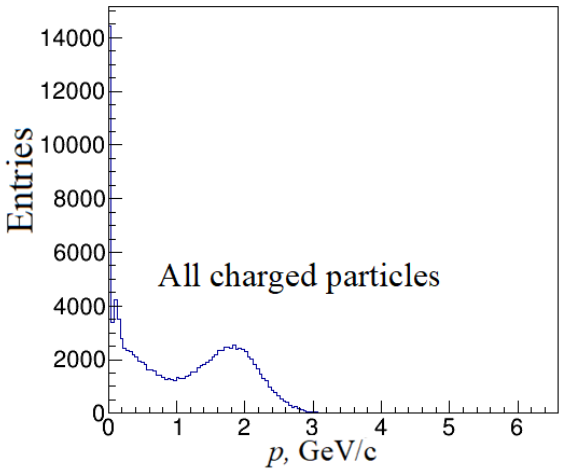
√s = 6 GeV

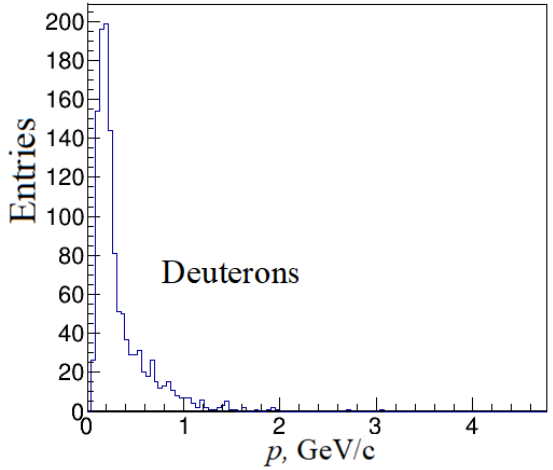
BBC-layer	Signal %	Background %
1	98.0	2.0
2	94.7	5.3
3	90.9	9.1
4	84.4	15.6
5	61.5	38.5

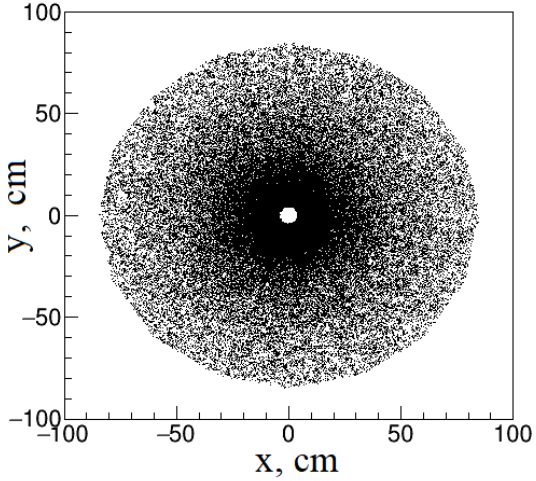
DD – scattering simulation

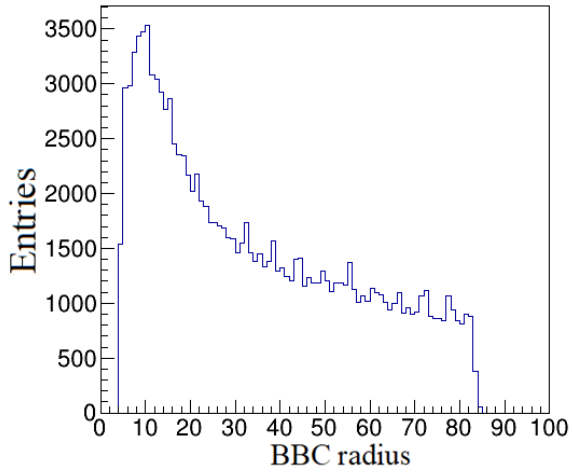
- The generators used for the simulation:
- **FRITIOFF** – inelastic scattering only
- **Pluto** – elastic scattering only

FRITIOFF, $\sqrt{s}$ = 6 GeV, 10^5 interactions







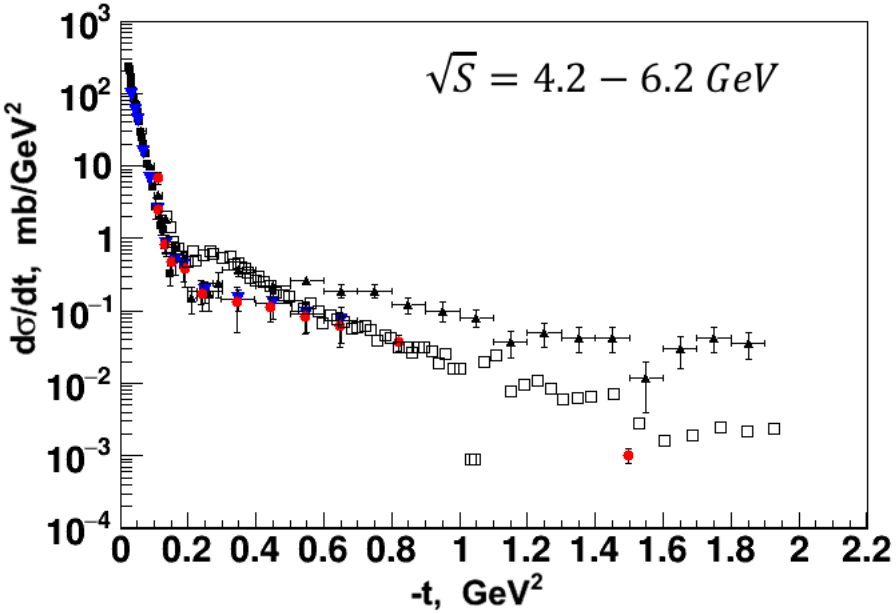


DD – elastic scattering simulation

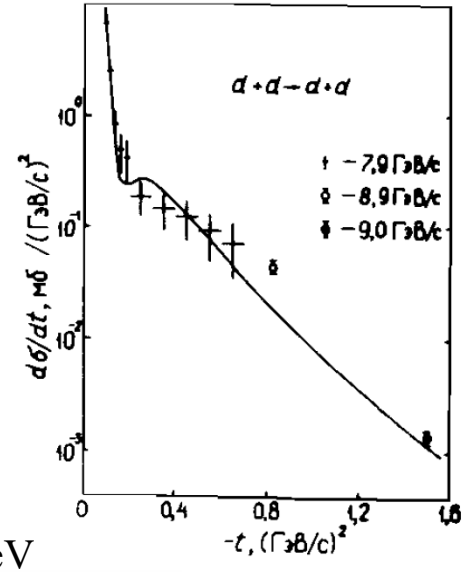
Pluto – generator, 10^5 interactions

The angle dependences of the differential cross section are using in the Pluto generator to simulation dd-elastic scattering.

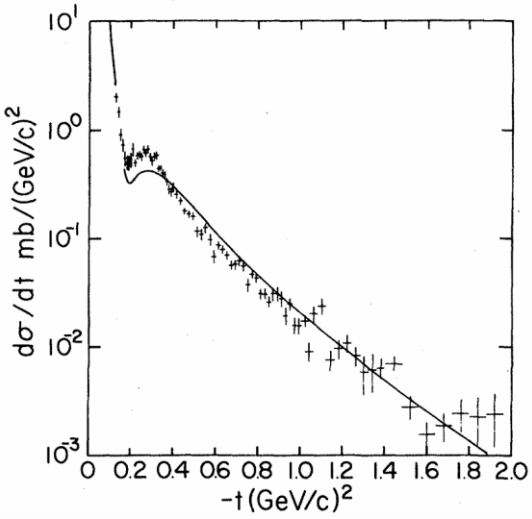
Experimental data for the differential cross section



√s = 6.1 – 6.4 GeV



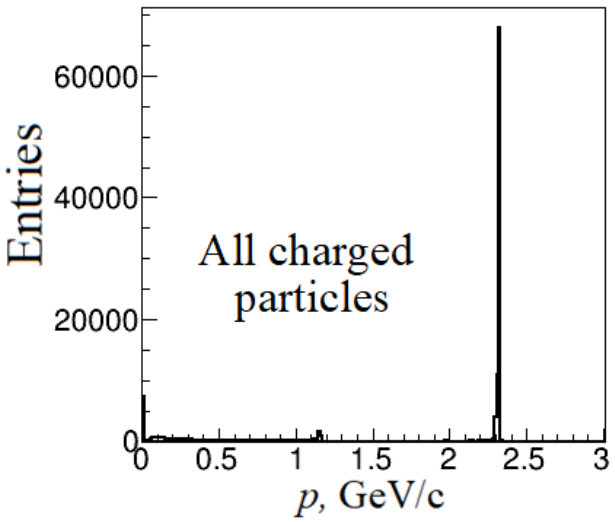
√s = 5.5 GeV

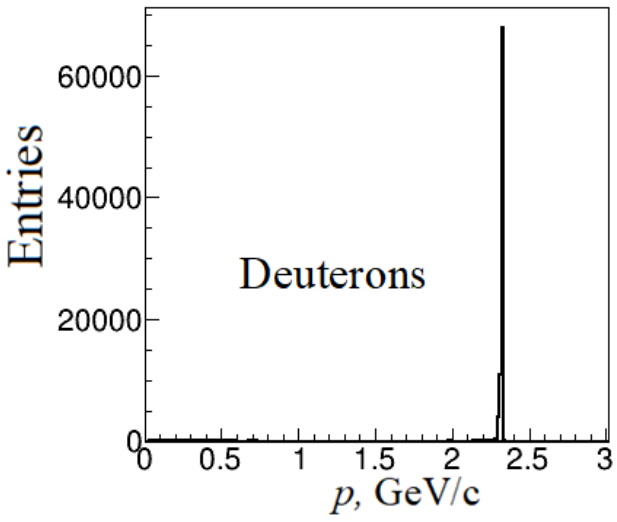


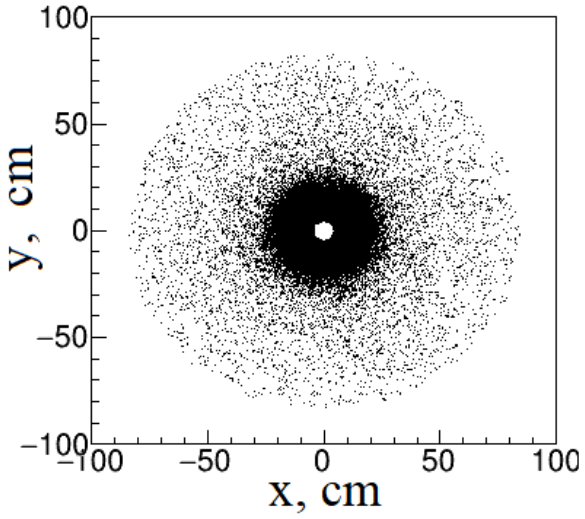
Goshaw A.T. et al. // Phys.Rev.Lett. 25, 249-253, 1970.
Devenski P.A. et al. // Yad.Fiz. 34, 1302, 1981.
Ashgirey L.S. et al. // Yad.Fiz. 30, 1538, 1979
Ashgirey L.S. et al. // Print JINR P1-88-23
Alberi G. et al. // Nucl.Phys.B 17. 621, 1970
Whipple E.T. Et al. // Phys.Rev.Lett. 47 (1981) 774

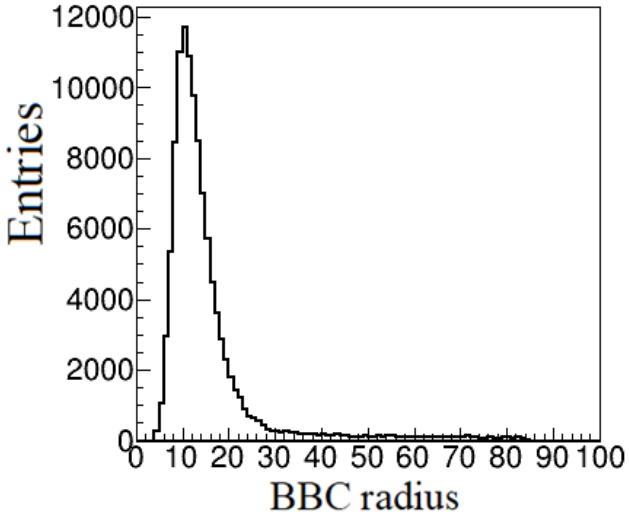
DD – elastic scattering simulation

Pluto, $\sqrt{s}$ = 6.1 GeV, 10^5 interactions

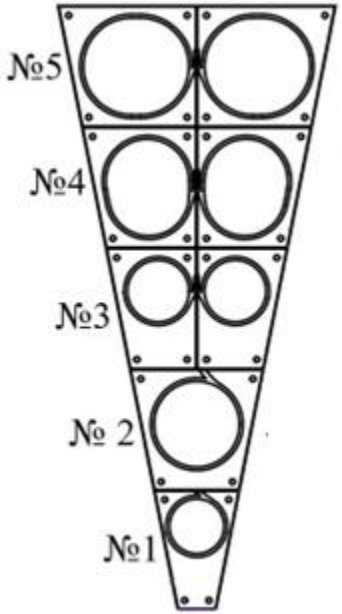




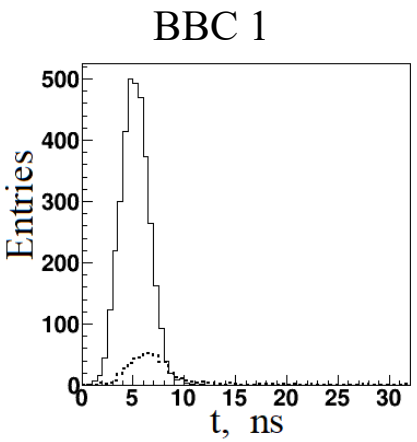


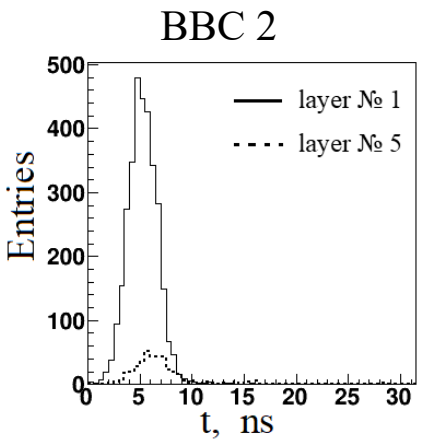


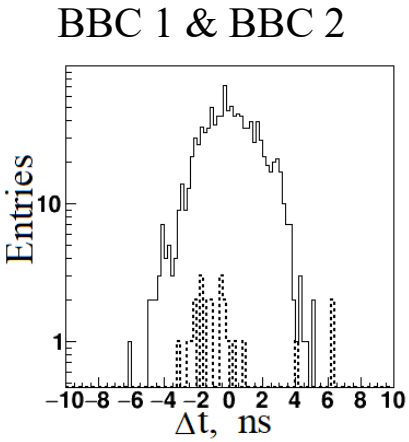
DD – elastic scattering simulation



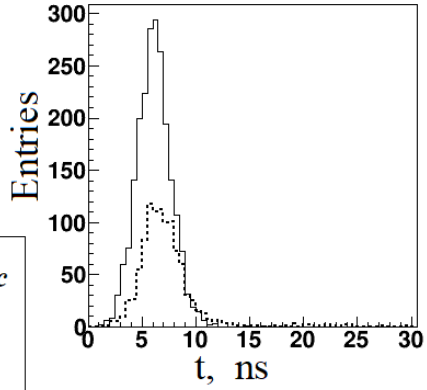
dd^{el}

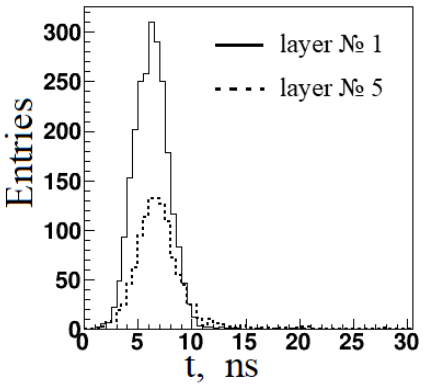


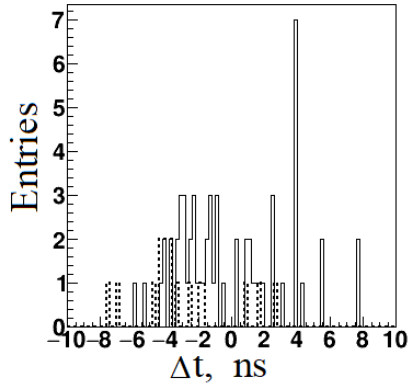


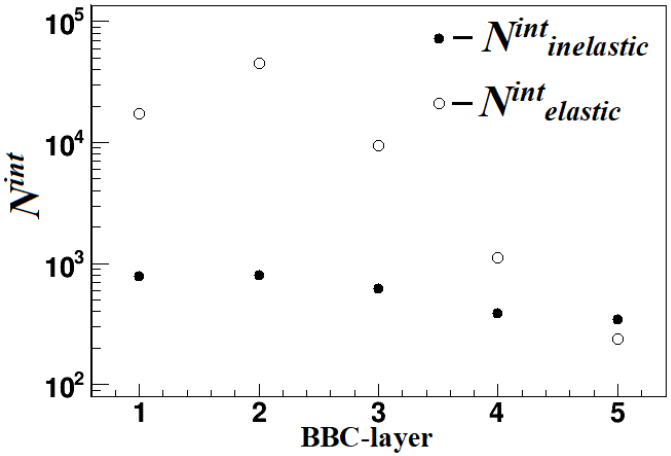


dd^{in}





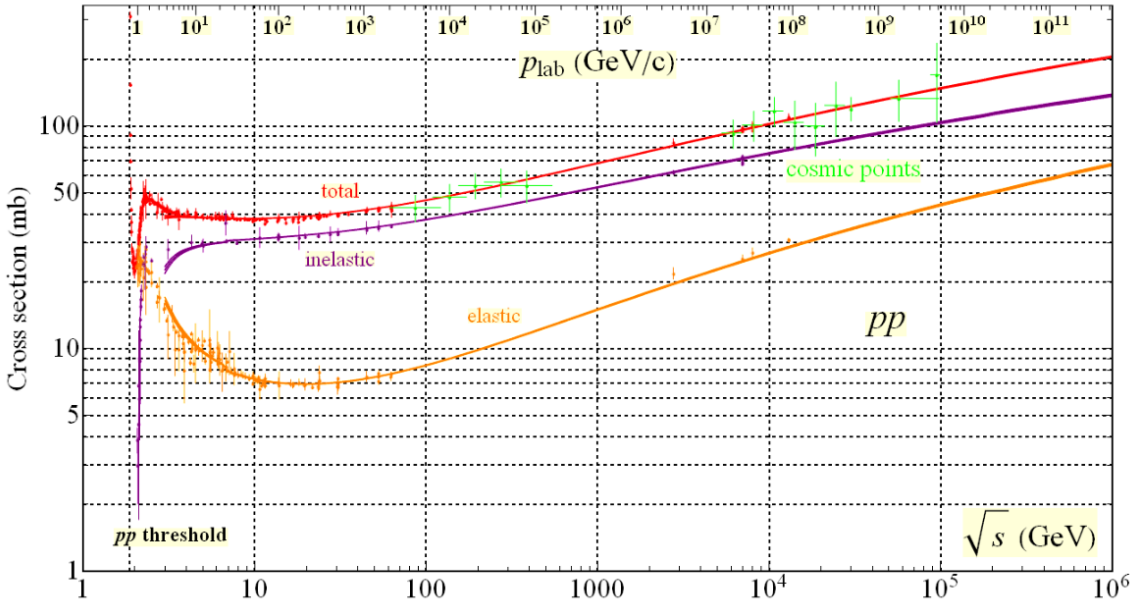




N^{int} – total selected events in the i-layer, $i = 1…5$

PP – elastic total cross section

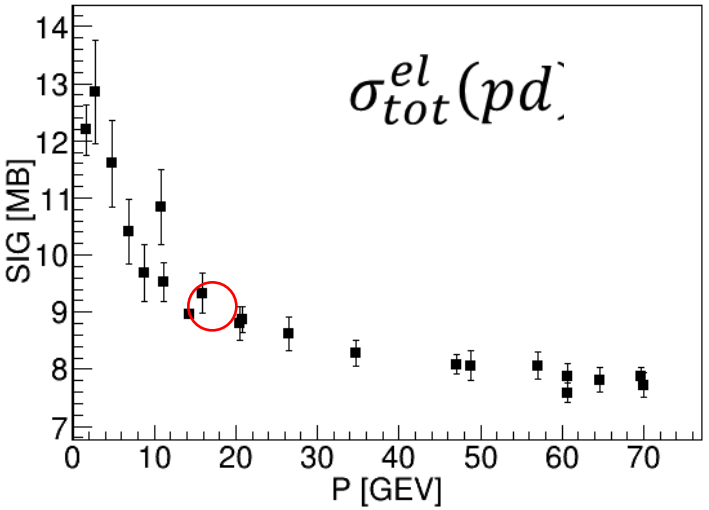
$\sqrt{s}$ = 6 GeV



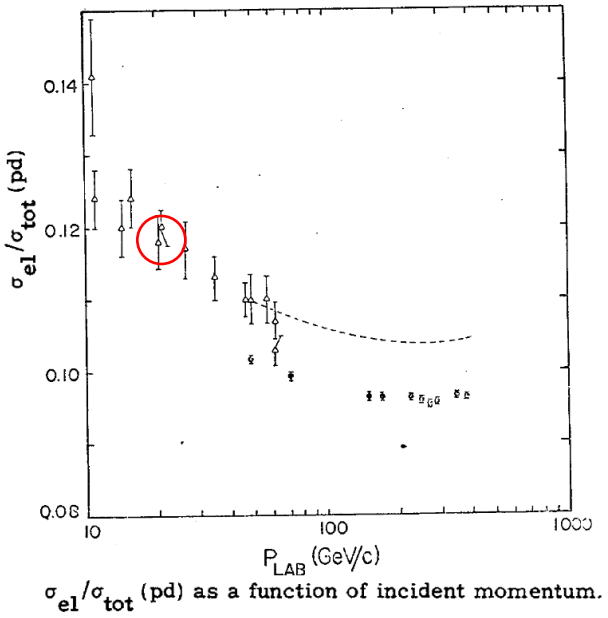
$$\sigma_{tot}(pp) \approx 40\ mb$$
$$\sigma_{tot}^{el}(pp) \approx 8.7\ mb$$

https://pdg.lbl.gov/2022/hadronic-xsections/

PD – elastic total cross section



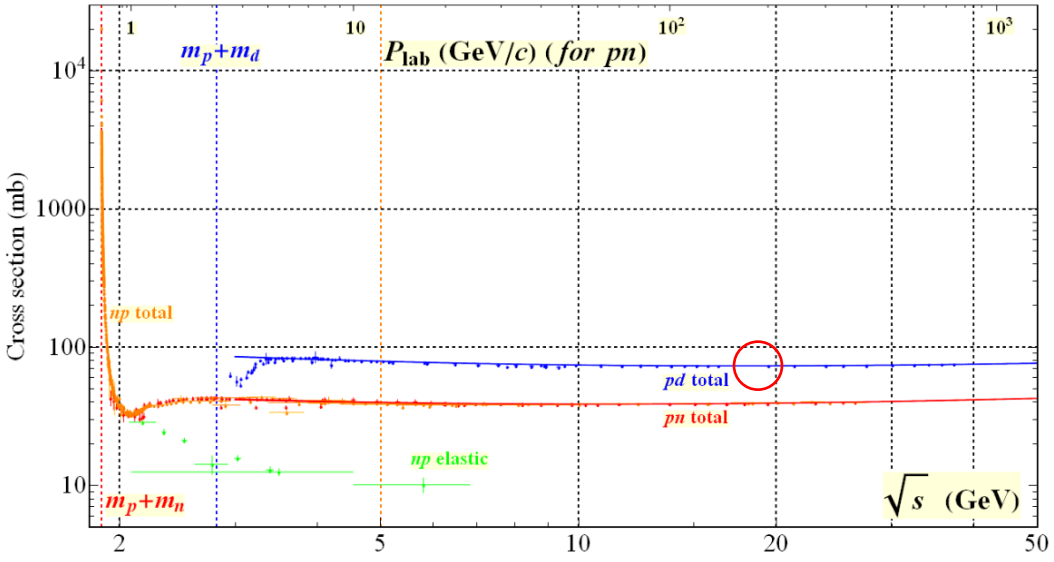
Phys.Lett.B 43 (1973) 85-88, 1973



σ_{el}/σ_{tot} (pd) as a function of incident momentum.

Phys.Rev.D 12 (1975) 3399, 1975

$\sqrt{s}$ = 6 GeV



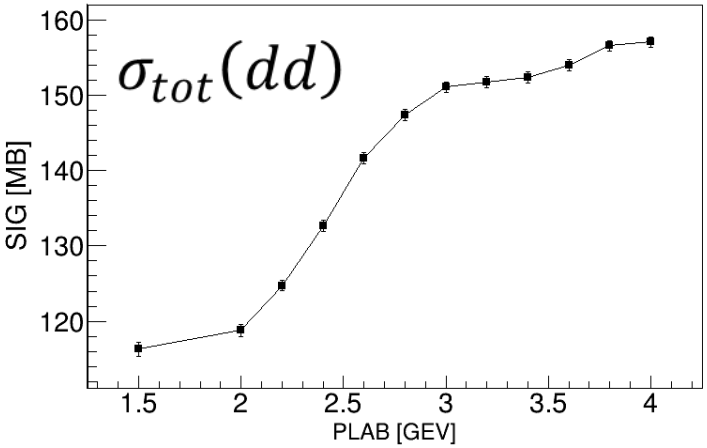
https://pdg.lbl.gov/2022/hadronic-xsections/

$\sigma_{tot}(pd) \approx 80\ mb$

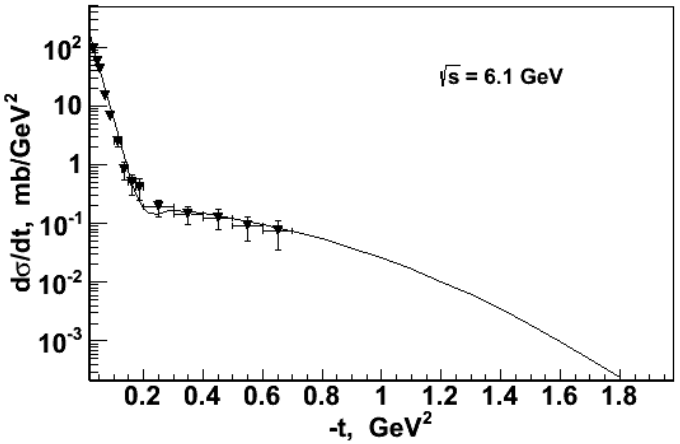
$\sigma_{tot}^{el}(pd) \approx 9\ mb$

DD – elastic total cross section

$\sqrt{s}$ = 6 GeV



Phys.Rev.C 41 (1990) 180-192



$\sigma_{tot}(dd) \approx 160\ mb$

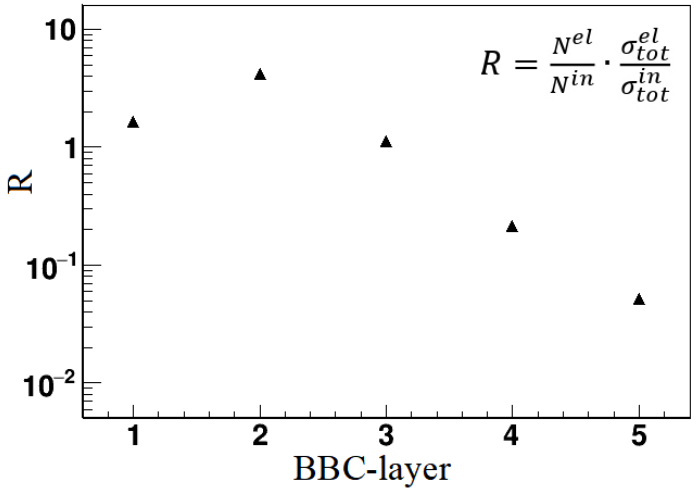
$\sigma_{tot}^{el}(dd) \approx 18\ mb$

P.A. Devenski et al., Yad. Fiz. 34, 1302 (1981).
A.T. Goshaw et al., Phys. Rev. Lett. 25, 249 (1970).

DD – scattering simulation

$\sqrt{s} = 6$ GeV

	pp	*pd*	*dd*
σ_{tot}	≈ 40 mb [1]	≈ 80 mb [1]	≈ 160 mb [4]
σ_{tot}^{el}	≈ 8.7 mb [1]	≈ 9 mb [2,3]	≈ 18 mb [5,6]
$\frac{\sigma_{tot}^{el}}{\sigma_{tot}^{in}}$	0.28	0.13	0.13



BBC-layer	Signal / Background
1	1.61
2	4.31
3	1.19
4	0.24
5	0.06

[1] https://pdg.lbl.gov/2022/hadronic-xsections/

[2] Phys.Lett.B 43 (1973) 85-88, 1973

[3] Phys.Rev.D 12 (1975) 3399, 1975

[4] Phys.Rev.C 41 (1990) 180-192

[5] Yad. Fiz. 34, 1302 (1981)

[6] Phys. Rev. Lett. 25, 249 (1970)

Conclusion

- The simulation of the proton-proton scattering at the total energies $\sqrt{s}$ = 6 and 10 GeV have been performed by the FRITIOF and Phytia8 generators in the SPDRoot framework.
- The possibility of the pp-elastic scattering selection using BBC was estimated. The candidates of the elastically scattering protons have been selected using the coincidences between kinematically corresponding tiles. The background contribution have been estimated by the simulation of the pp-elastic and pp-inelastic scattering separately. The true signal may be to selected for first three layers at energy $\sqrt{s}$ = 10 GeV. The background contribution is decreased at energy $\sqrt{s}$ = 6 GeV.
- The first stage of the deuteron-deuteron scattering simulation at the total energies $\sqrt{s}$ = 6 GeV have been performed by the FRITIOF and Pluto generators in the SPDRoot framework.
- The possibility of the dd-elastic scattering selection using BBC was estimated. The estimated background contribution is very big for all BBC-layers.
- The further simulation is necessary.

Thank you for attention!