The 26 International Symposium
on Spin Physics,
Qingdao, Shandong, China
September 22-26, 2025

Budker Institute of Nuclear Physics

Status of experiments with polarized deuteron target at VEPP-3 electron storage ring

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for the DEUTERON collaboration

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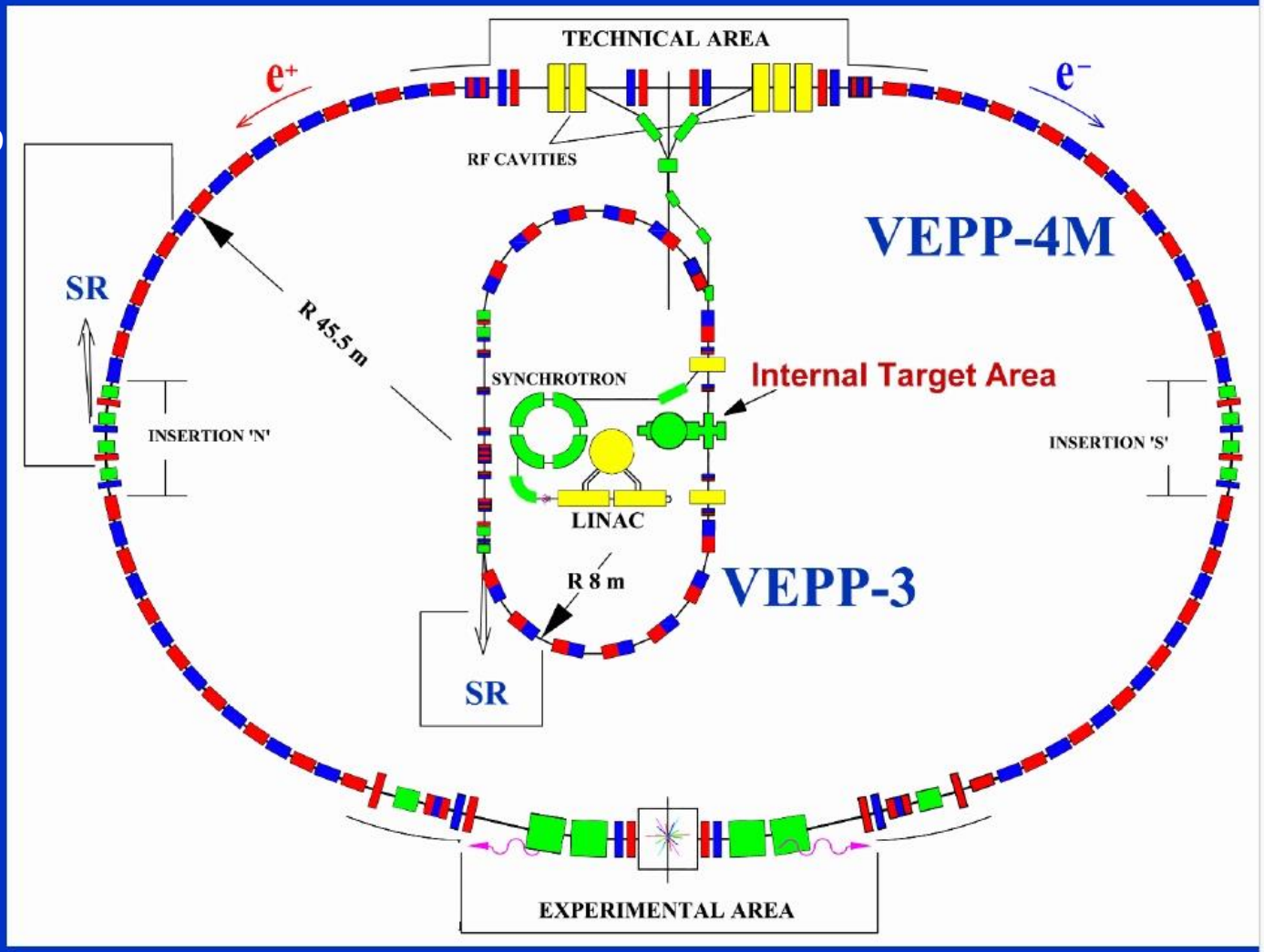
- Conclusion

Novosibirsk electron-positron facility

Experiments with POLARIZED deuteron target and UNPOLARIZED hydrogen target were conducted from mid of 80 years of last centure



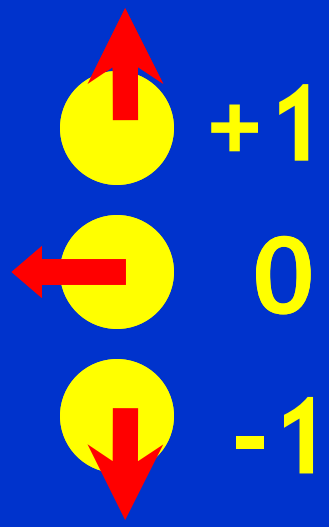
VEPP-3

Energy : 2000 MeV
Lifetime : 20000 s
Av. current : 100 mA
Bunch : 0.7x0.3 mm

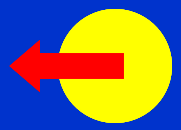
Polarization of sample of spin 1 particles

$$P_z = \frac{N_\uparrow - N_\downarrow}{N_\uparrow + N_0 + N_\downarrow} = n_\uparrow - n_\downarrow$$

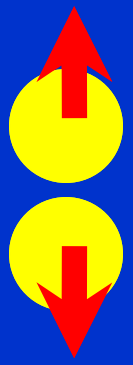
$$P_{zz} = \frac{N_\uparrow + N_\downarrow - 2N_0}{N_\uparrow + N_0 + N_\downarrow} = 1 - 3n_0$$



Tensor polarized target allows to measure tensor-polarization observables in e-d scattering even with electron beam is not polarized

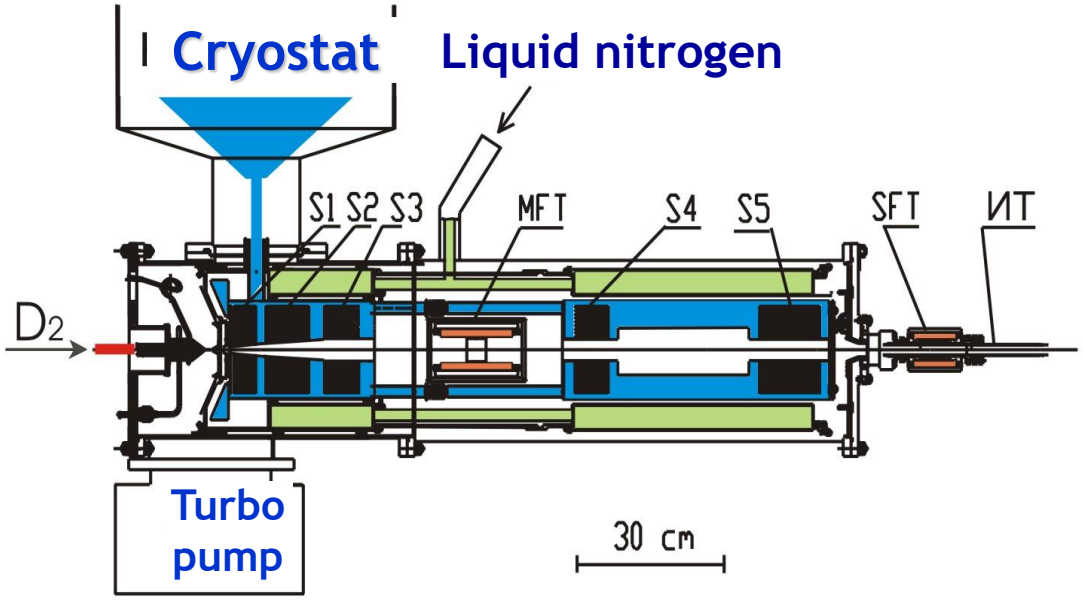


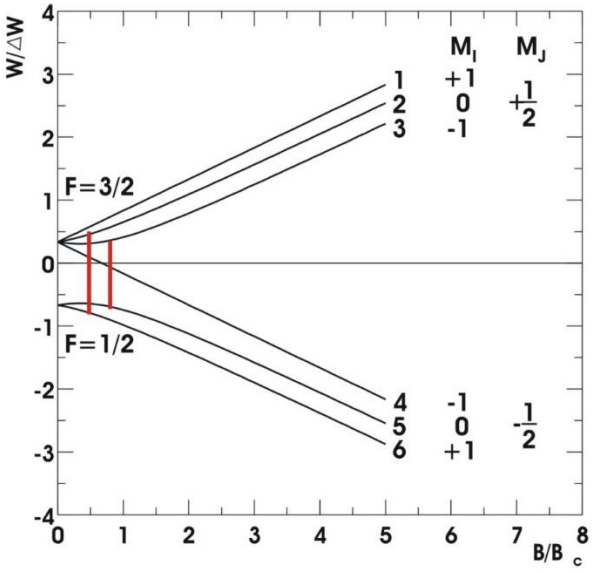
$P_{zz}=-2$

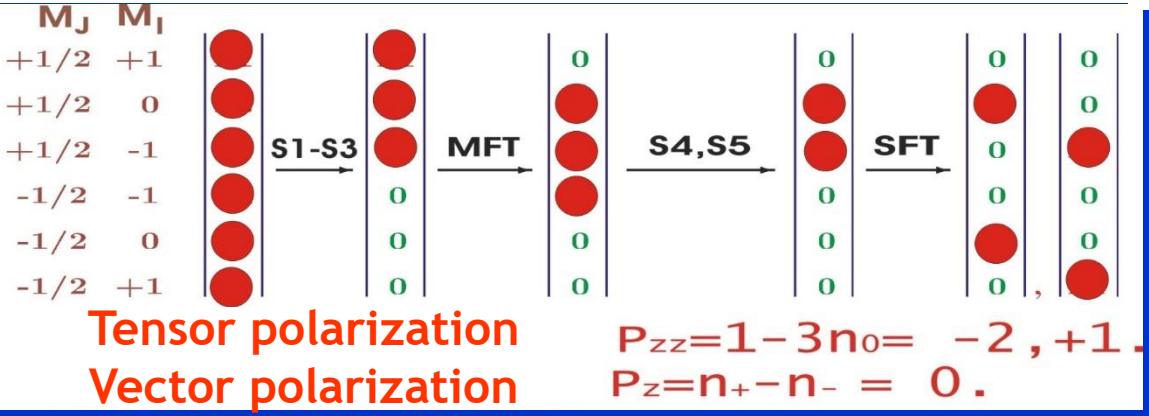


$P_{zz}=1$

Cryogenic Source of Polarized Atomic Beam



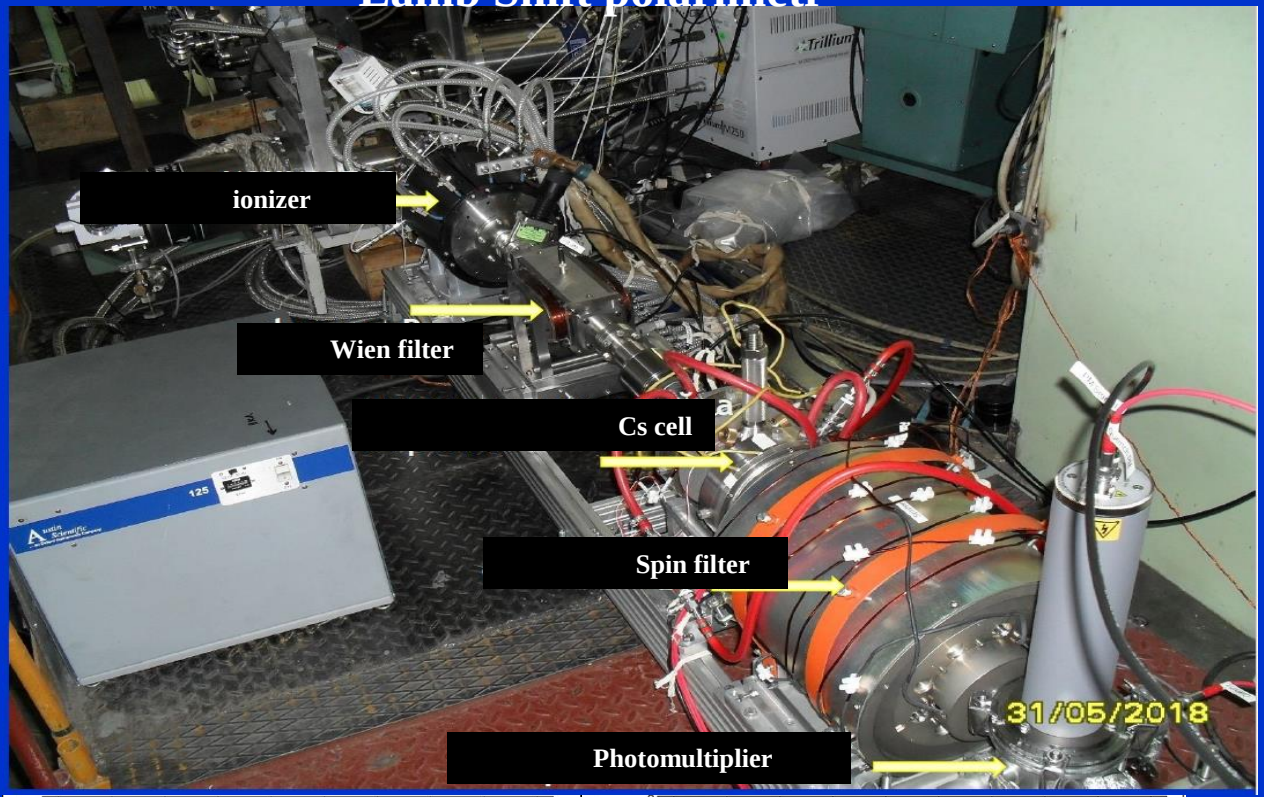


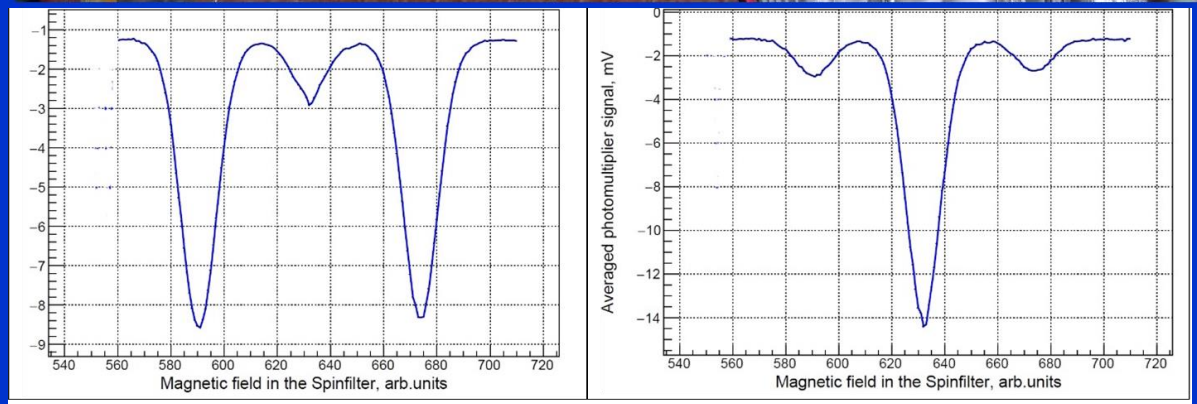


Superconducting magnets

Current, Am	Magnetic field, kGs 1-st magnet	Magnetic field, kGs 2-nd magnet	Magnetic field, kGs other magnets
10	3.25 – 3.75	4.1 – 4.5	2.2
20	6.5 – 7.5	8.1 – 9.0	4.5
30	9.2 – 10.8	10.8 – 12.0	7.0
50	12 .0 – 14.0	15.3 – 17.0	11.0
100	15.6 – 18.4	20.7 – 23.0	16.0
150	19.3 – 22.7	24.3 – 27.0	20.0
200	23.0 – 27.0	30.0 – 34.0	24.0
220	-	-	25.5
250	-	-	28.0
300	-	-	31.0
350	-	-	35.0

Lamb Shift polarimetr

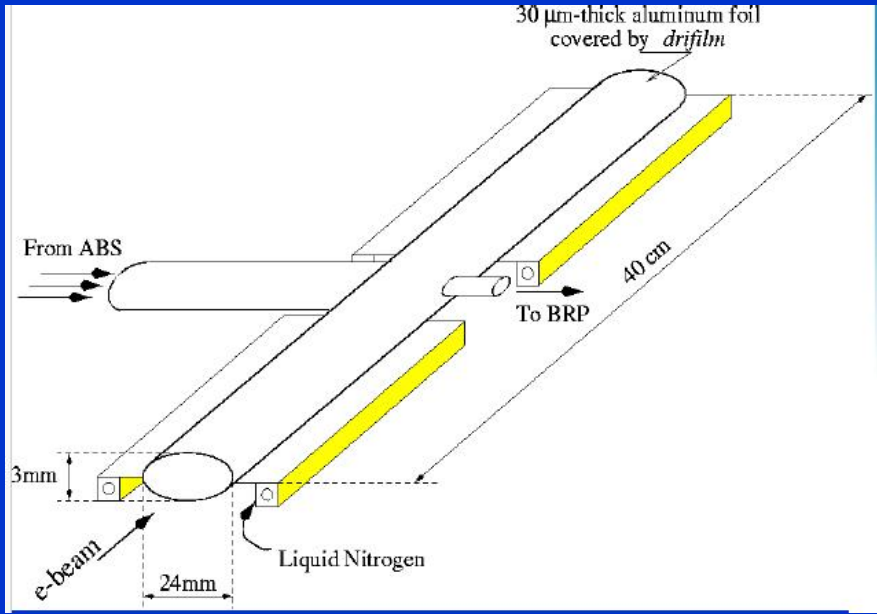




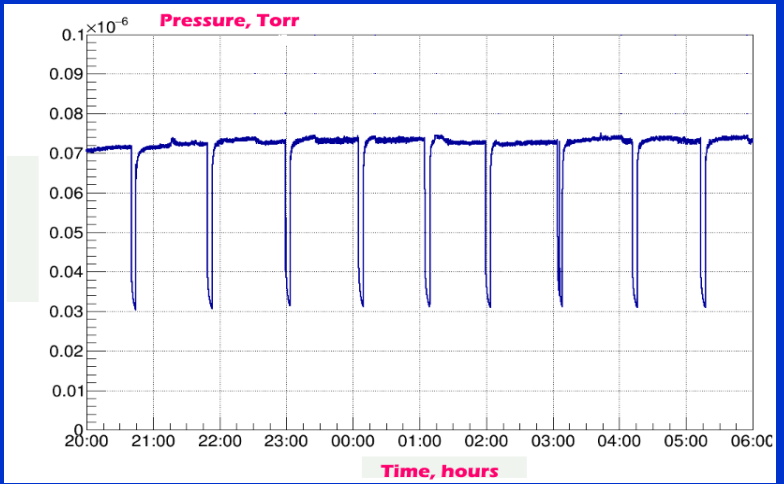
Pzz = 0.91+-0.03

Pzz = -1.77+-0.03

Storage cell for polarized atoms



Depolarization of atoms inside the cell

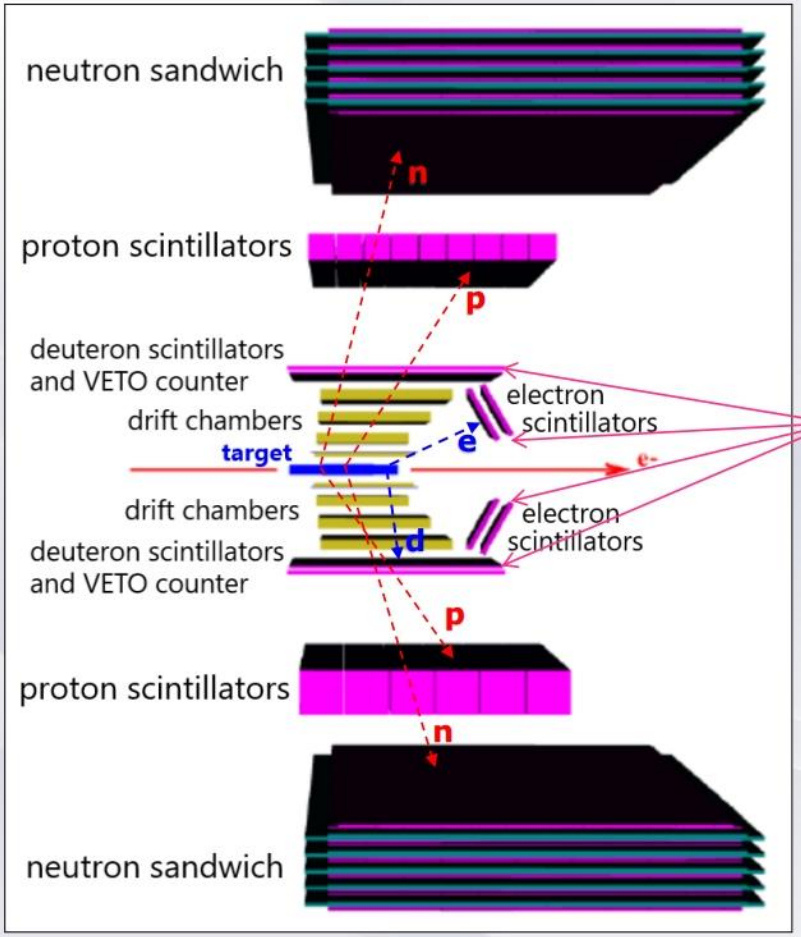


Target polarization measurement - elastic ed scattering at low momentum transfer

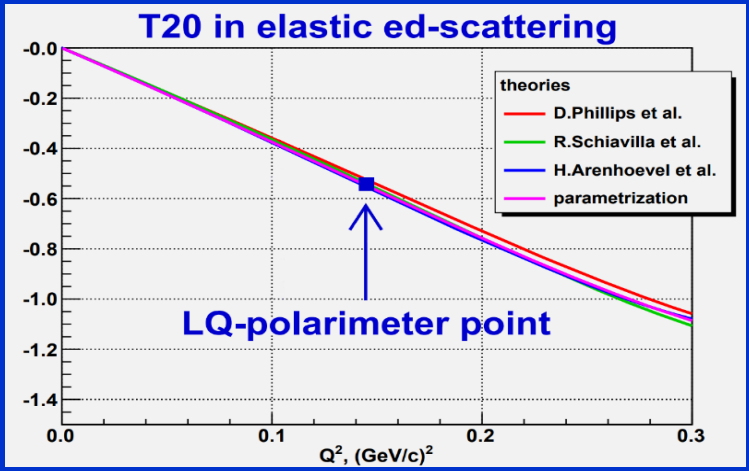
The detector system consists of two symmetrical arms for detecting proton and neutron in coincidence.

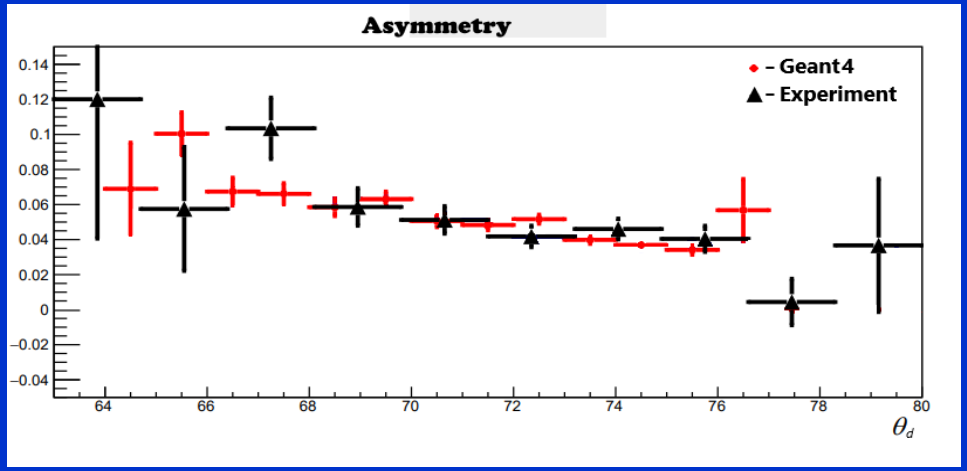
The tensor polarization of the target is measured using a LQ polarimeter.

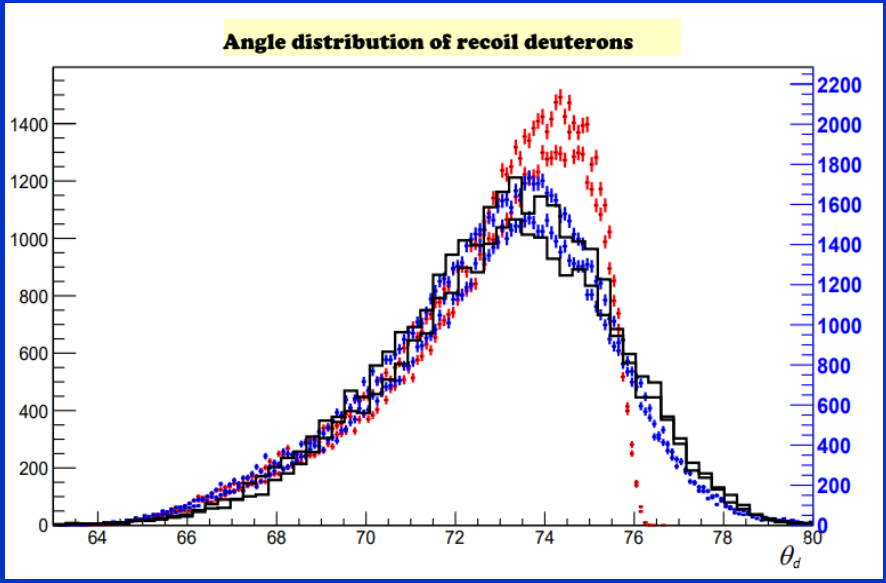
It consists of two symmetrically located sets of scintillation counters for detecting electron and deuteron in the process of elastic e-d scattering.



The results of target tensor polarization measurement



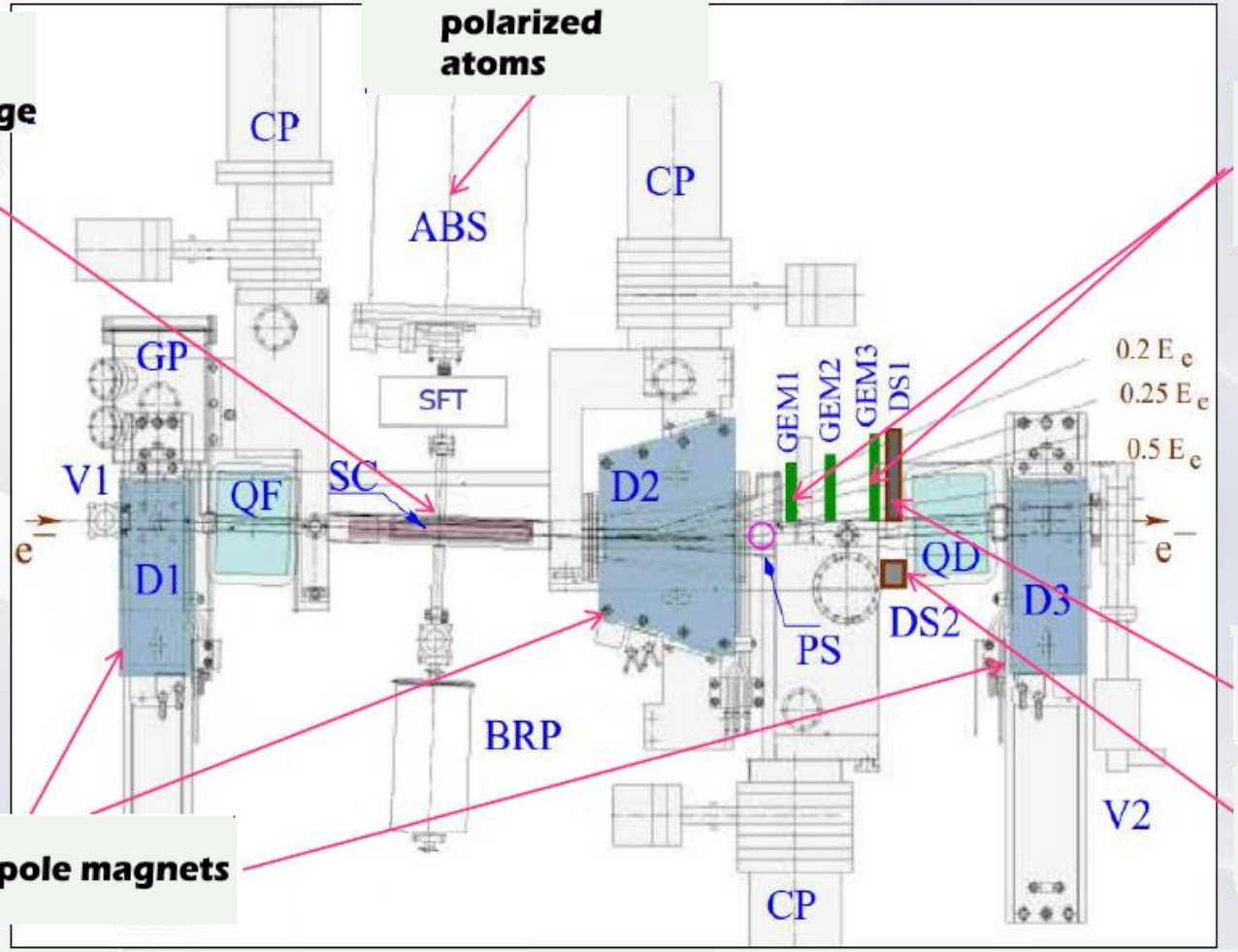




The tensor polarization is a free parameter in the simulation and shosen so that the calculated asymmetry coincides with the experimentally measured one.

Pzz = 0.39 +- 0.03 for one state and
Pzz = -0.66 +- 0.06 for the other

System of tagging photons



The reported measurements were done using a polarized deuterium target and unpolarized photons.

The incident photons of the photoproduction reaction $\gamma d \rightarrow d\pi 0$, $pn\pi 0$, $pp\pi$-, pn are the quasi-real virtual photons arising from the electron scattering at small angle in these reaction.

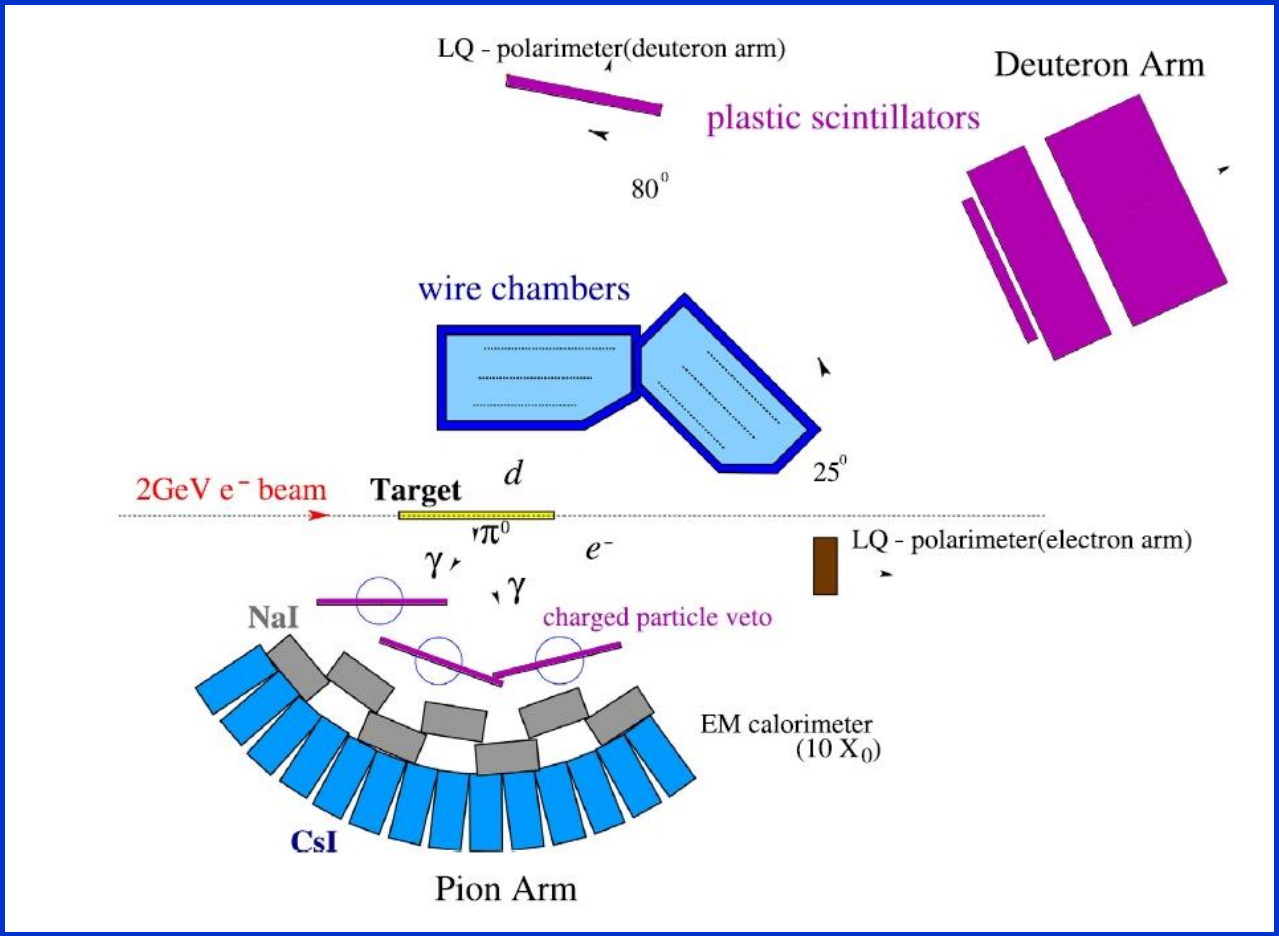
The general expression for the differential cross section in this case is given by

$$\frac{d\sigma}{d\Omega} = \frac{d\sigma_0}{d\Omega}\left\{1 - \sqrt{\frac{3}{4}}\,\mathbf{P_z}\sin\theta_H\sin\phi_H\cdot\mathbf{T_{11}}(E\gamma,\theta_\pi^{CM}) + \sqrt{\frac{1}{2}}\,\mathbf{P_{zz}}\left[\frac{3\cos^2\theta_H - 1}{2}\cdot\mathbf{T_{20}}(E\gamma,\theta_\pi^{CM})\right.\right.$$
$$\left.\left. - \sqrt{\frac{3}{8}}\sin 2\theta_H\cos\phi_H\cdot\mathbf{T_{21}}(E\gamma,\theta_\pi^{CM}) + \sqrt{\frac{3}{8}}\sin^2\theta_H\cos 2\phi_H\cdot\mathbf{T_{22}}(E\gamma,\theta_\pi^{CM})\right]\right\},$$

$$A^t = \sum_{i=0}^{2} d_{2i}T_{2i} \qquad A^t = \sqrt{2}\,\frac{(N^+ - N^-)}{(N^- P_{zz}^+ - N^+ P_{zz}^-)}$$

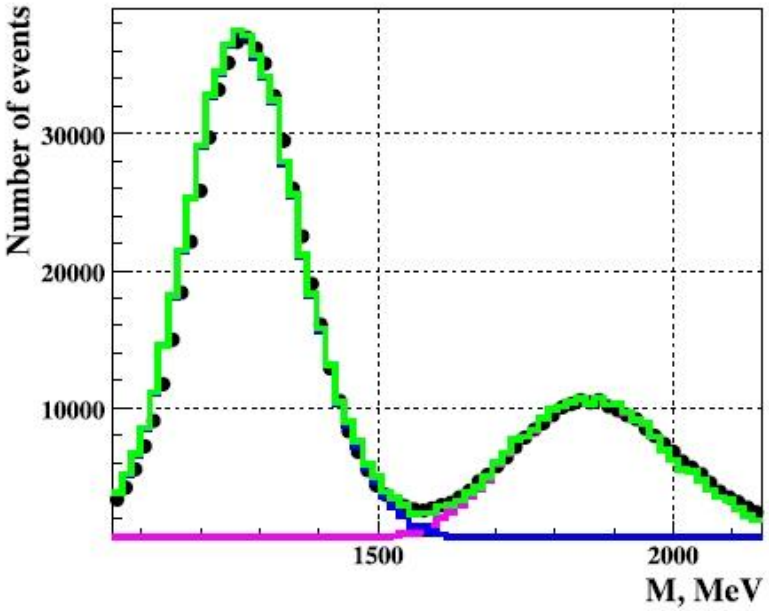
Coherent photoproduction of a $\pi 0$-meson on a deuteron $\vec{e}\vec{d} \rightarrow ed\pi 0$

Eur. Phys. J. A (2020) 56:169

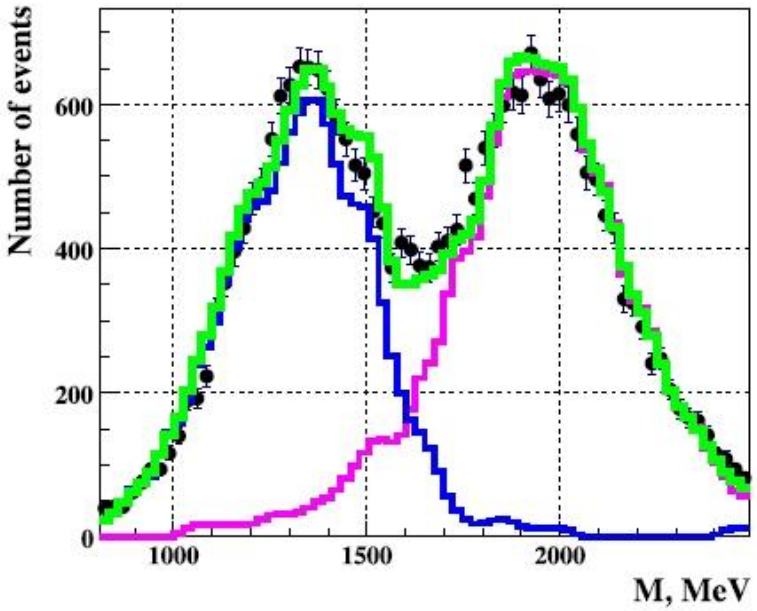


Scheme of the experiment 2013

Reconstructed particle masses distribution for the first (the left pane) and second (the right pane) scintillator. The points correspond to the experimental data, the magenta (blue) curve correspond to the GEANT4 simulation of the $\gamma d \to d\pi 0$ reaction (background reactions).



First scintillator



Second scintillator

Measurement of the tensor analyzing power T20 for the reaction γd → dπ0 Eur. Phys. J. A (2020) 56:169

Dependences of the T20 component of tensor analyzing power of the reaction γ d → dπ0 on the photon energy for the polar angle of pion emission in the center-of-mass system of 110◦ and 130◦. Theoretical calculations:

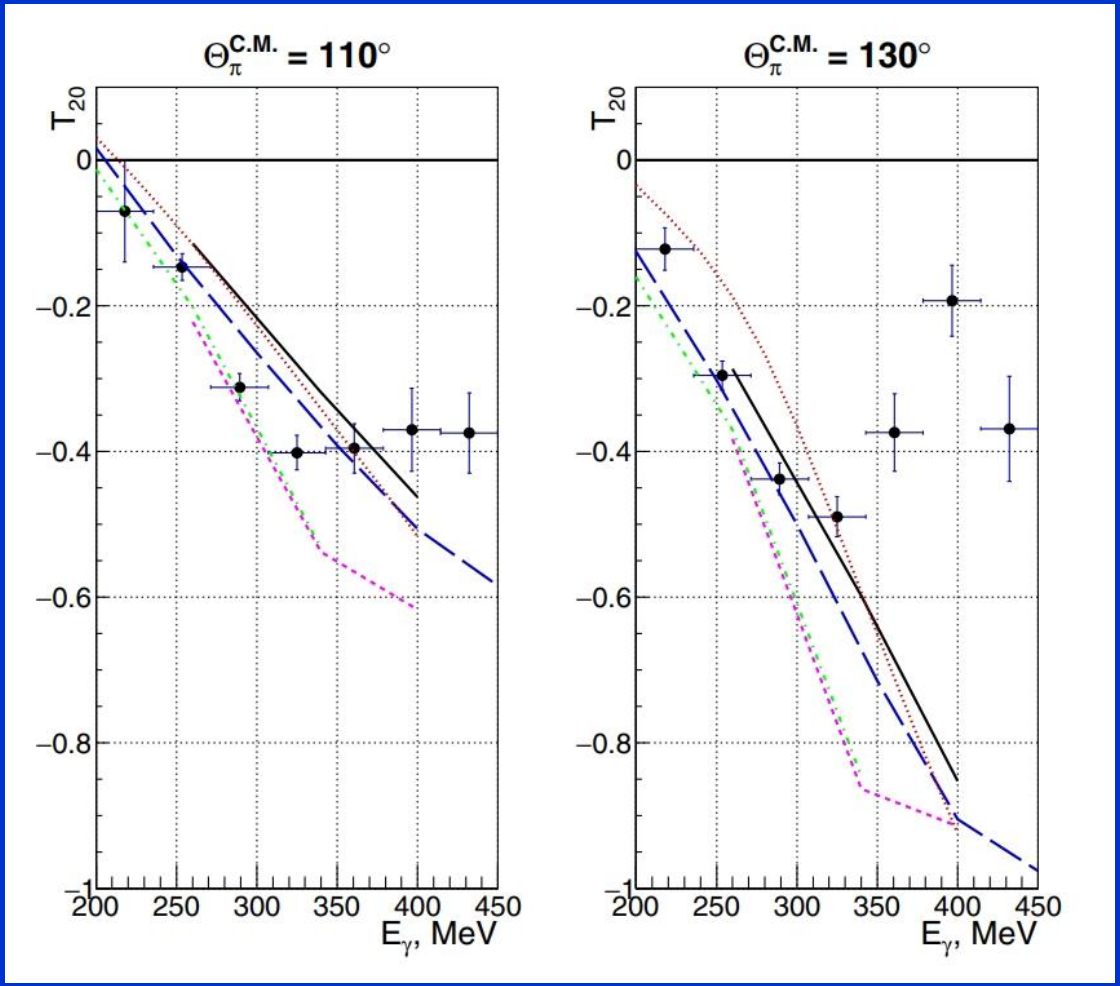
magenta (short-dashed) – P. Wilhelm, H. Arenhövel, Nucl. Phys. A 609, 469 (1996) ,

green (dash-dotted) – S.S. Kamalov et al. L. Phys. Rev. C 55, 98 (1997)

red (dotted) – E.M. Darwish et al. Mosc. Univ. Phys. Bull. 74, 595 (2019)

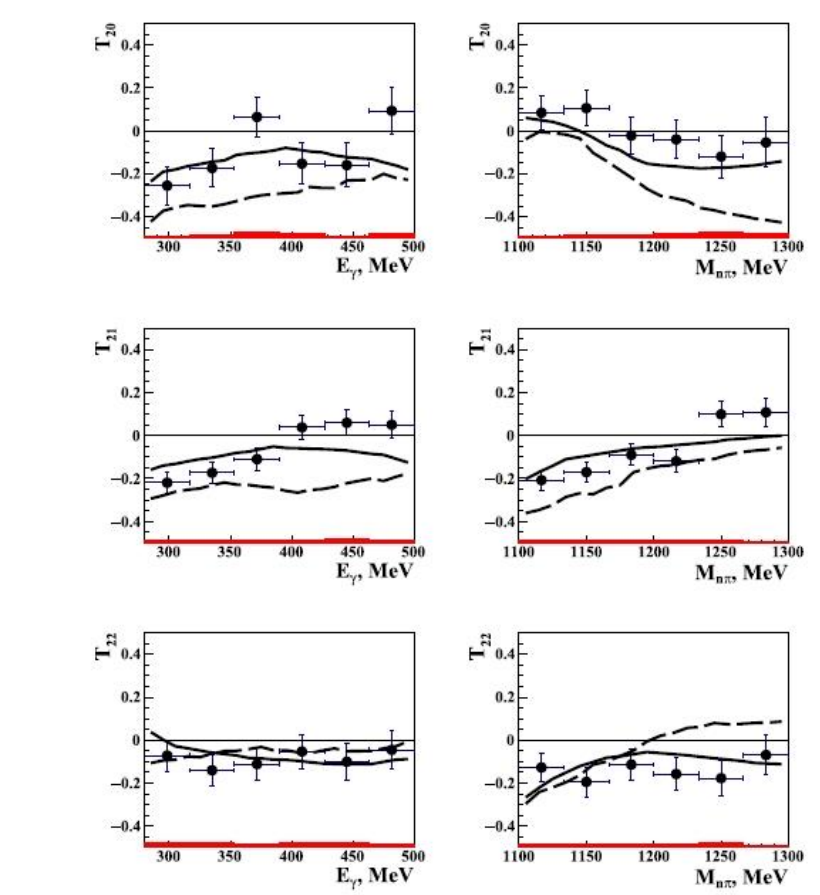
black (solid) – M.I. Levchuk, Private communication, (2013)

blue (long-dashed) – A.I. Fix, Private communication, (2013)



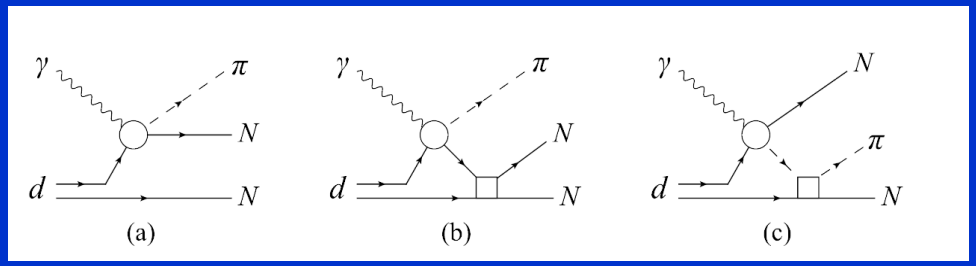
Measurement of the tensor analyzing power T20 for the reaction $\gamma\vec{d} \rightarrow pn\pi 0$

The role of final-state interaction in tensor polarization effects of the reaction $\gamma d \rightarrow pn\pi 0$



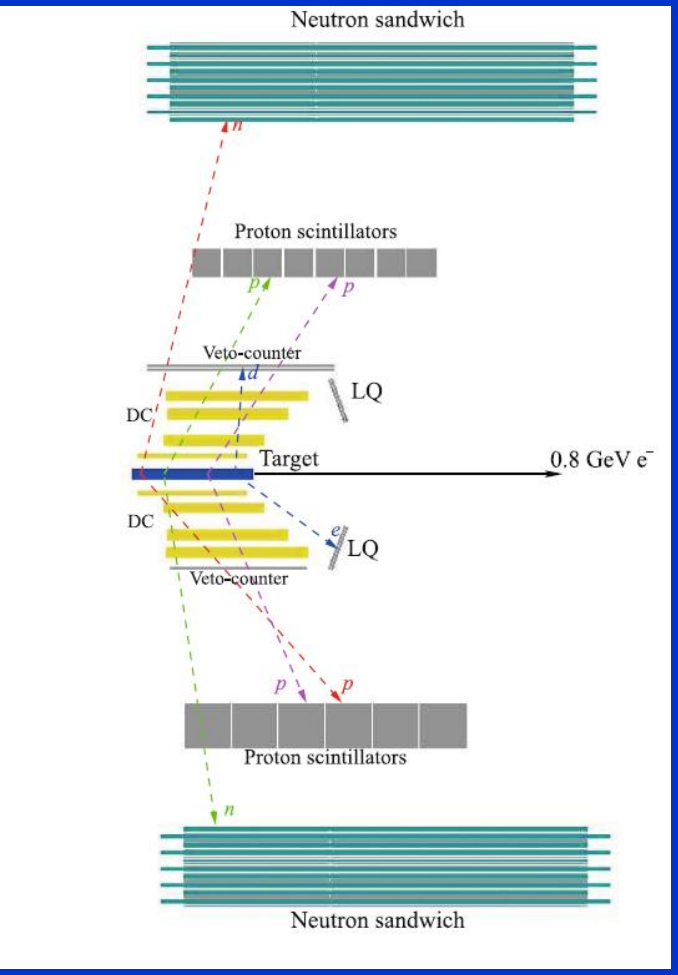
Scientific Reports (2023) 13:7532
experiment 2002 -2003

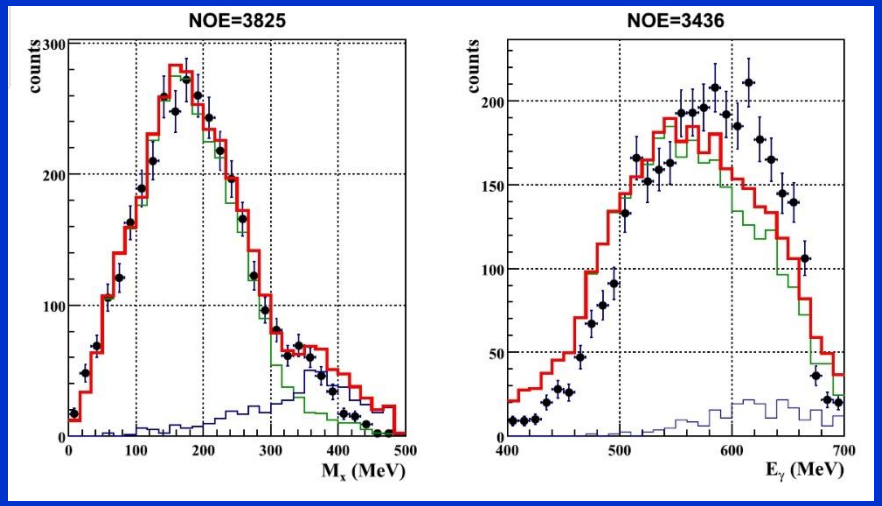
The tensor analyzing-power components T20 , T21 , and T22 for γ d $\rightarrow$ npπ0 as functions of the photon energy Eγ (left panels) and the pion-neutron invariant mass Mπn (right). The data points shown by filled circles represent experimental results of the experiment, with their error bars are reflecting statistical uncertainties. The red bars underneath each data point reflect its systematic uncertainty. The solid (dashed) curves correspond to the results of simulation with (without) taking into account πN and *NN* rescattering in the final-state



Measurement of the $T20$ Component of the Tensor Analyzing Power of the Incoherent Photoproduction $\gamma d \to pp\pi^-$ of a $\pi-$ Meson on a Deuteron for photon energies 400 −700 MeV (exp 2023)

Phys. Lett. B 860 (2025) 139166

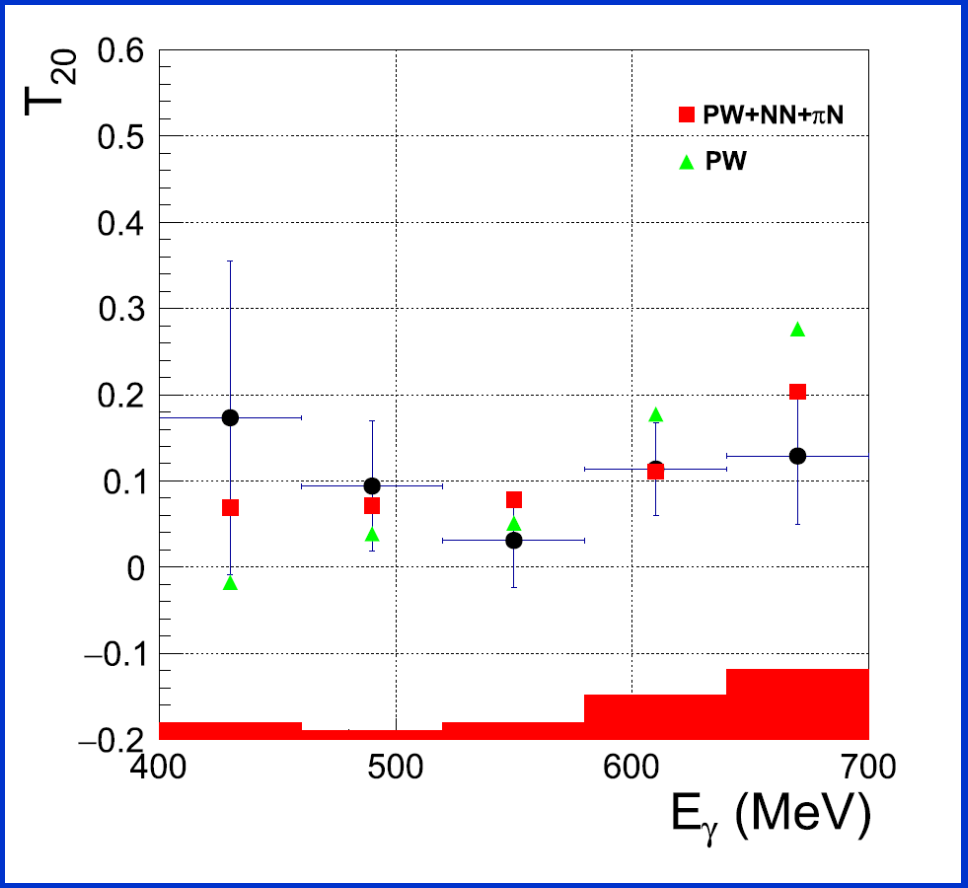




Distribution of the reconstructed missing mass Mx (leftpanel) and the initial photon energy Ey (right panel). The Ey data refer to Mx < 340 MeV. The points are the experimental data, the color curves represent the GEANT4 simulation: the green curve is the reaction $\gamma d \to pp\pi-$, the blue curve is the background reactions, and the red curve shows the sum of all reactions.

The experiment was carried out with the use of **tagged quasi-real photons and two-proton coincidence.** For determination of $T20$, the asymmetry caused by a change of the sign of the tensor polarization of the deuteron target was measured. The data are compared with the results of theoretical calculations based on the quasi-free approximation including πN and NN rescattering effects.

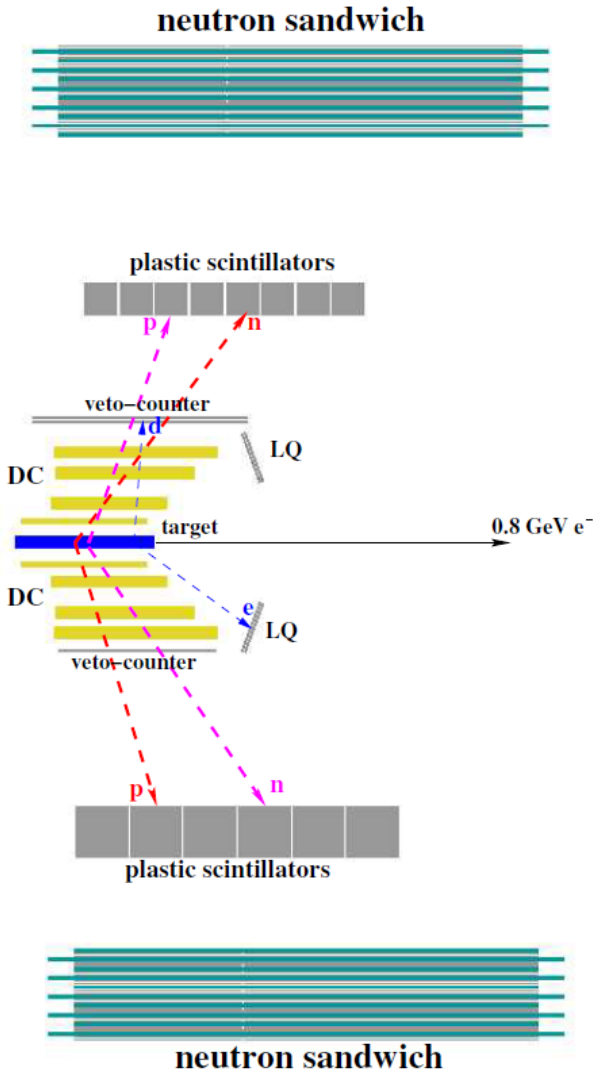
Phys. Lett. B 860 (2025) 139166

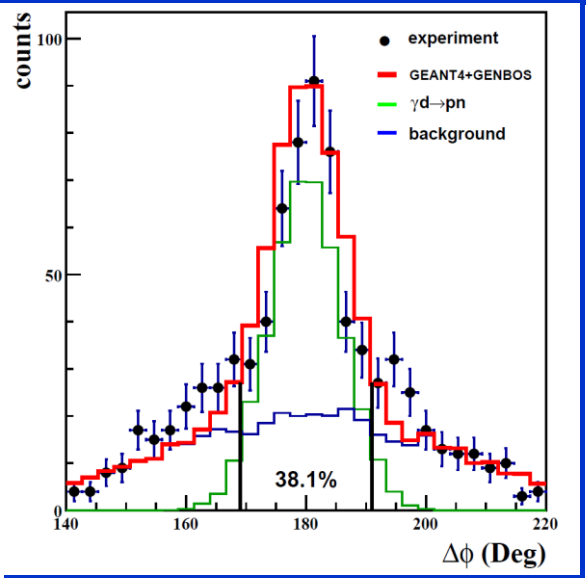


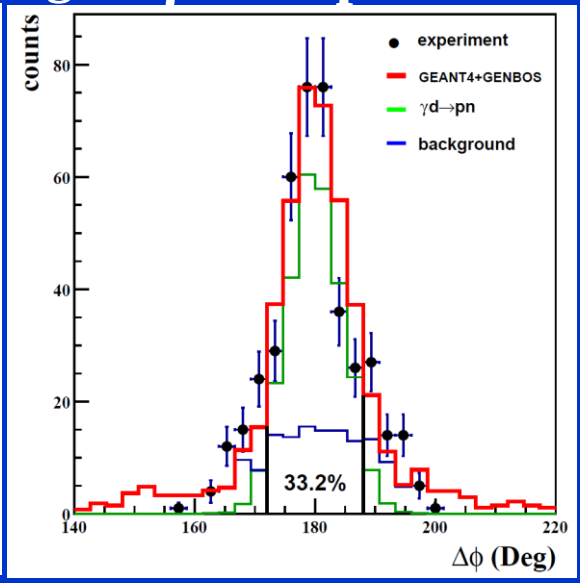
Component T_{20} of the tensor analyzing power for $\gamma d \to pp\pi^-$ as function of the lab photon energy E_γ. The filled circles are the present experiment. The error bars show the statistical uncertainties. The systematic uncertainties are represented by the red bars at the bottom of the plot for each data point. The data are compared with the results of a simulation using the plane-wave approximation (green triangles) and including πN and NN rescattering (red squares).

The $\gamma d \to pn\pi^0$ and $\gamma d \to pn$ reactions can contribute to the inseparable background because neutrons can knock out protons, which are then detected by the proton detectors.

Measurement of the tensor analyzing power T20 for a deuterons photodisintegration above the first resonance region $\gamma d \longrightarrow pn$



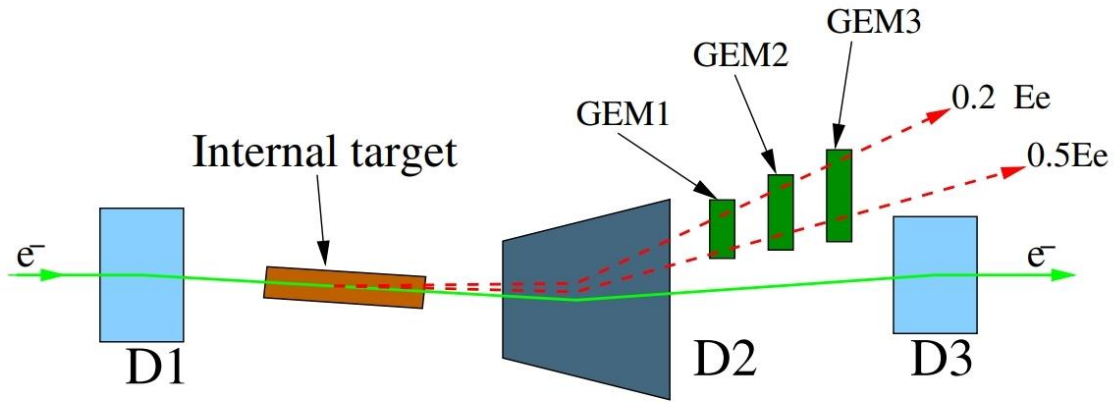




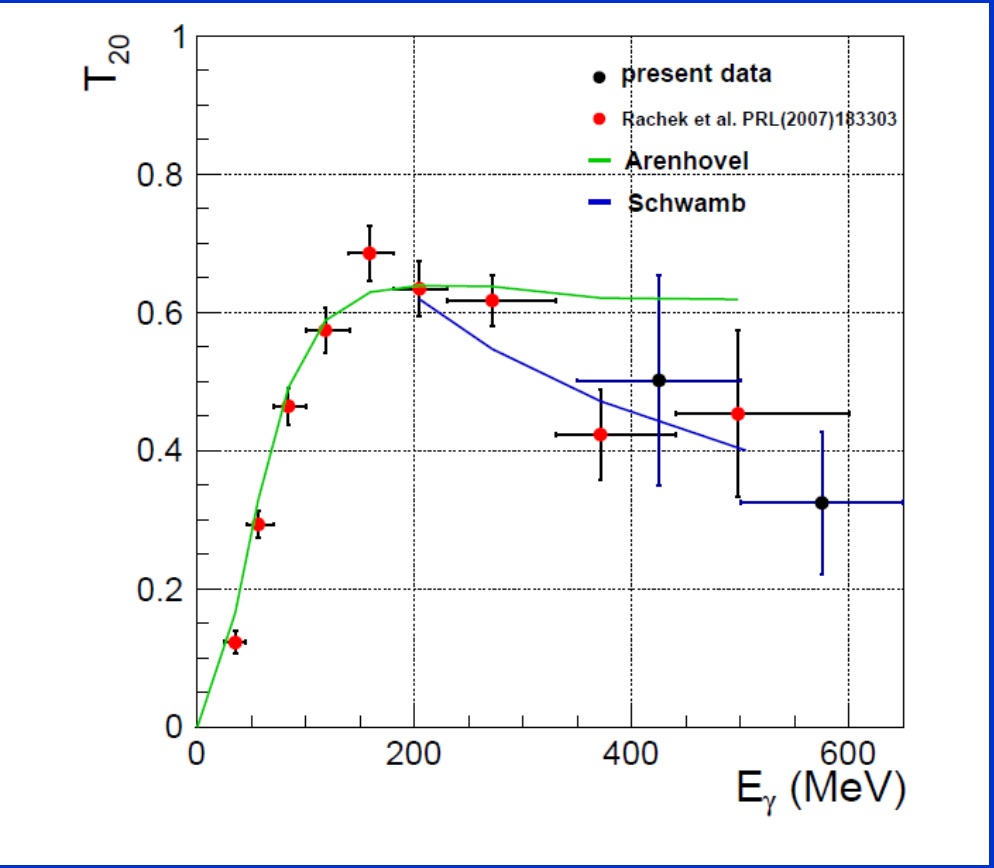
Tagged quasi-real photons, proton and neutron were detected in coincidence.

Distribution of $\Delta\varphi = \varphi p - \varphi n$ in the case where the proton is registered by the lower arm and the neutron by the upper arm (left panel) and where the proton is registered by the upper arm and the neutron by the lower arm (right panel). The points show the experimental data. The GEANT4 simulations are plotted by the curves: the green curve is the $\gamma d \rightarrow pn$ reaction, the blue curve shows the contribution of the background reactions ($\gamma d \rightarrow pn\pi^-\pi^+$, $\gamma d \rightarrow pn\pi^0$ and $\gamma d \rightarrow pn\pi^0\pi^0$), and the red curve is the sum of all reactions.

The Photons Tagging System



The photon tagging system, top view. D1, D2, D3: dipole magnets, GEM1, GEM2, GEM3: tracking detectors.



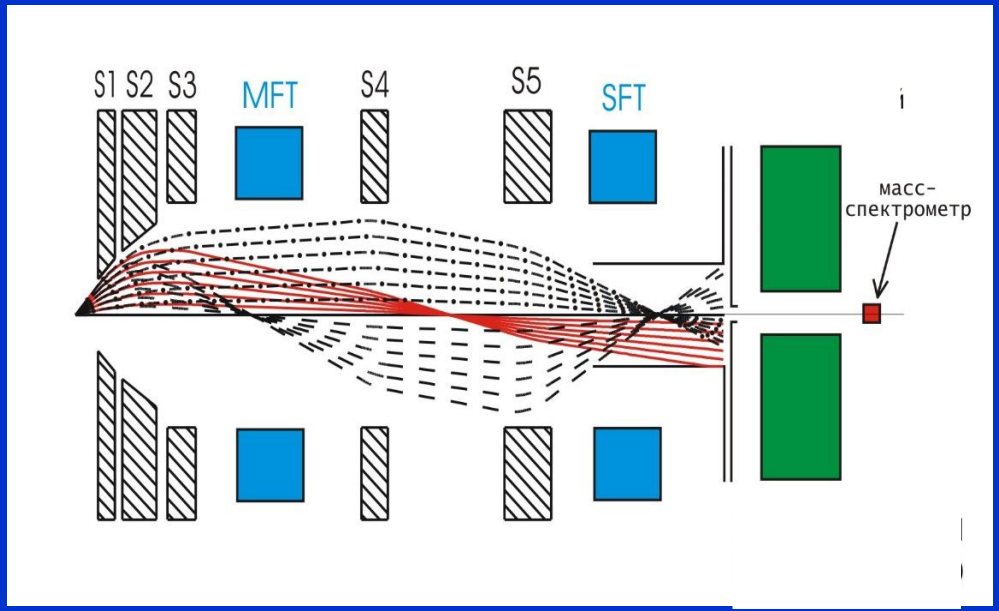
T20 component of the tensor analyzing power for γd → pn averaged in the proton angular range θp = 70° − 102° as function of the lab photon energy Eγ. The black circles show the present data. The red circles are the results of the earlier experiment carried out in 2002-2003. The error bars show the statistical uncertainties. The data are compared with the theoretical predictions from Arenh¨ovel and Schwamb

Nearest plans

1. Continue processing data of the experiment $\gamma d \longrightarrow pn$, including information from neutron calorimeters.
2. Continue the experiment for the energy of γ in the range 700 – 1000 MeV at the energy of electron beam 1250 MeV.

Thank for your attention

Focusing magnets

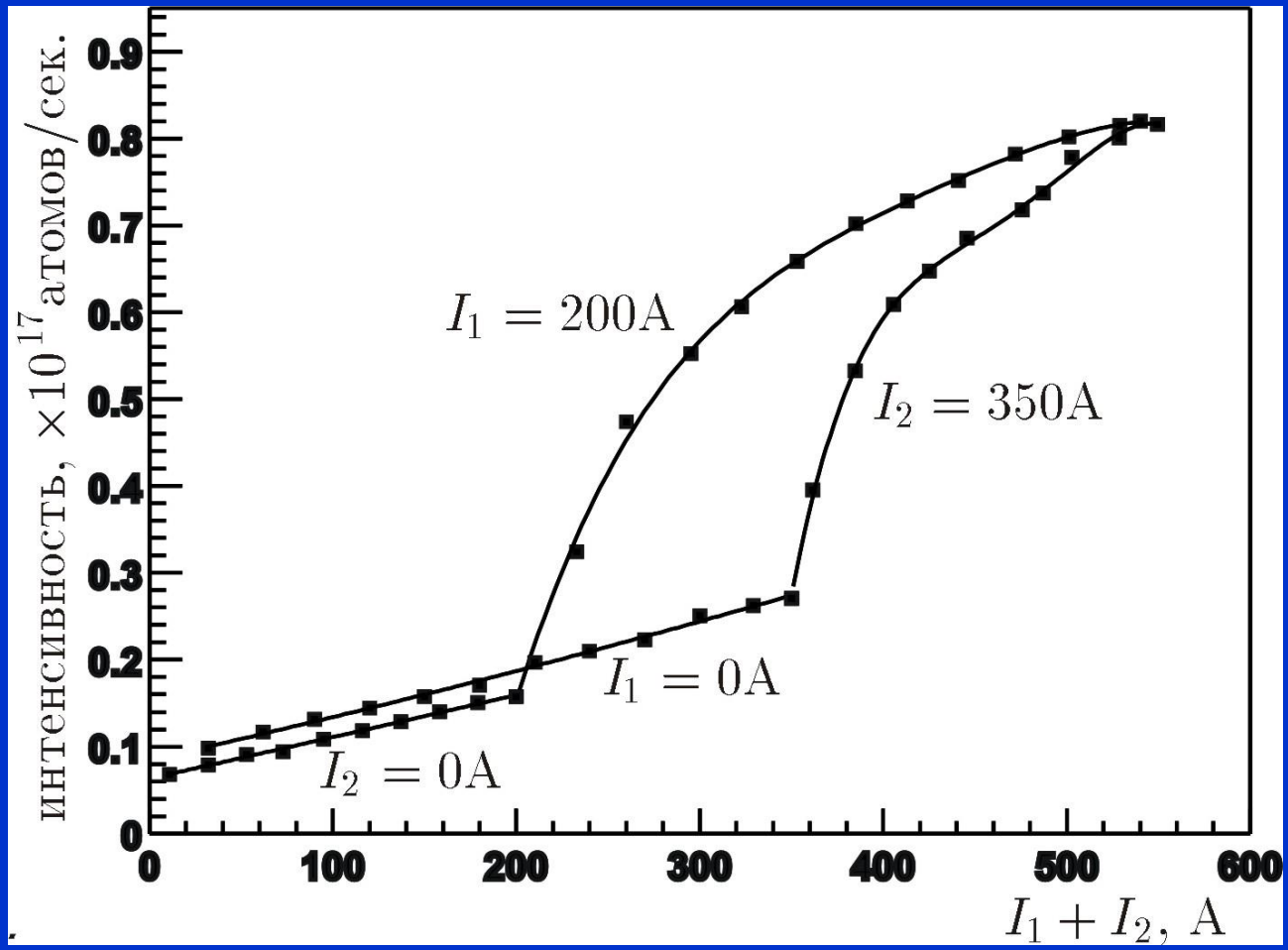


Permanent magnets
B=1.6 T
Superconducting
B=4.8 T

$\Delta\Omega = \pi*\alpha^2 = \pi*\mu*B/\kappa T$

B = 1.6 T $\Delta\Omega \sim 1.5*10^{-2}$ sr $\alpha \sim 0.07$ rad

B = 4.8 T $\Delta\Omega \sim 4.5*10^{-2}$ sr $\alpha \sim 0.21$ rad


интенсивность, $\times 10^{17}$ атомов/сек.
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
100
200
300
400
500
600
$I_1 + I_2$, A
$I_1 = 200$A
$I_2 = 350$A
$I_1 = 0$A
$I_2 = 0$A