Olena Mezhenska

Investigation of the *dp*-breakup reaction at intermediate energies at Nuclotron

Motivation

Understanding the nature of the nuclear force is one of the most important questions in nuclear physics.
The detailed knowledge of the nuclear forces provides description of the nuclear properties and their reactions.

Two Nucleon Force (2NF)

1935 Yukawa's meson theory (2NF)

Theory :
- ✓ One Pion Exchange Model
- ✓ One Boson Exchange Model

π,ρ,ω

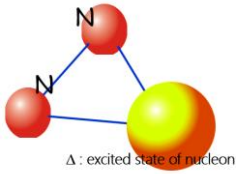
1990's Realistic Modern NN Force CD Bonn, AV18, Nijmegen I,II,93

Three Nucleon Force (3NF)

1957 Fujita-Miyazawa 3NF

2π-exchange 3NF :
- Main Ingredients :

Δ - isobar excitations in the intermediate

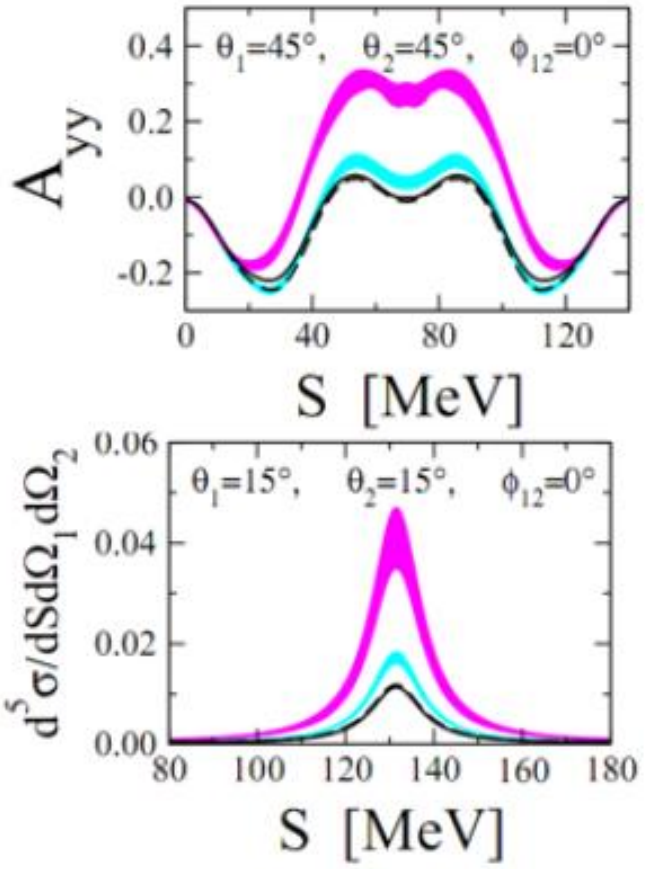


Tucson-Melbourne (TM) , Urbana IX, etc…

2NF and 3NF effects can be studied in *dp–> dp* and *dp->ppn*.

The dp breakup reaction has been investigated at the angles of 19 – 54 degrees in the laboratory frame at the energy of 300 - 500 MeV in a various detector configurations, in which the sensitivity to the three nucleon correlations and relativistic effects are assumed.

Motivation



Tensor analyzing power A_{yy} and differential cross section at 200 MeV.

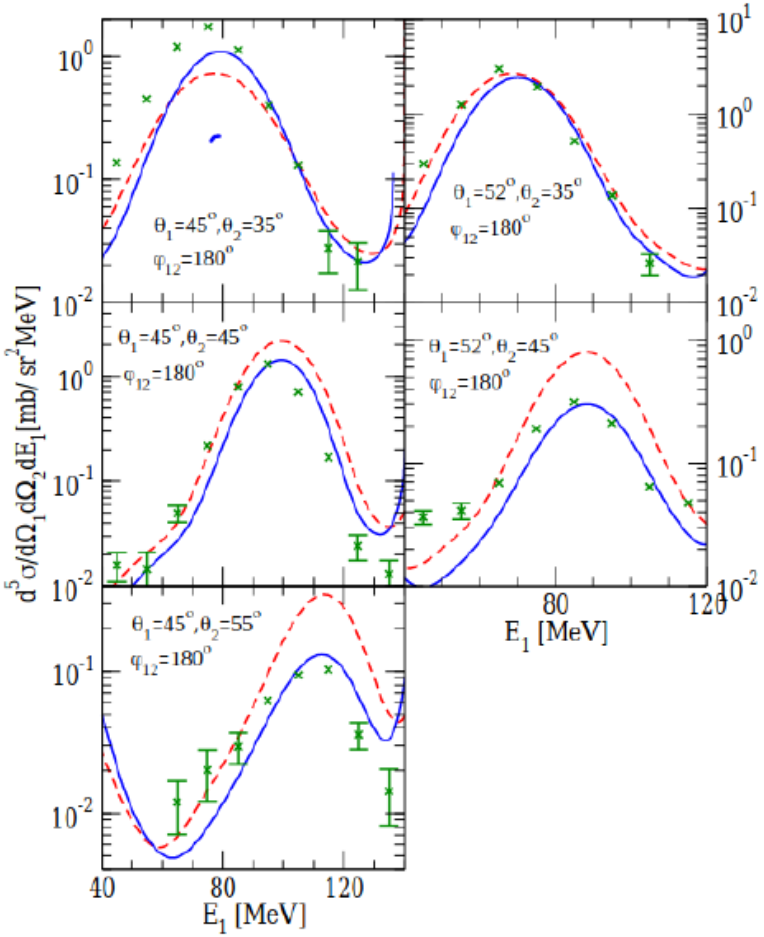
The light blue band contains theoretical predictions on CD-Bonn, AV18, Nijm I, II and Nijm 93;

The darker magenta band represents predictions NN + 3NF;

The solid line is for AV18+Urbana IX and the dashed line for CD Bonn+TM.

One can see that the inclusion of 3NF have great impact on the values of the analyzing power and cross section.

Motivation



H. Witala, Few Body Syst. (2011) 49, 61.

The cross section of the dp-brekup reaction at 200 MeV.

The red curve is the non relativistic CD Bonn potential prediction;

the blue one is the corresponding relativistic results.

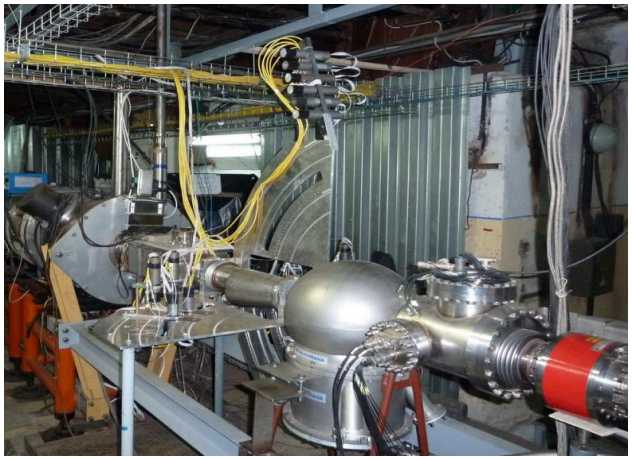
Important contribution comes from relativistic effects.

DSS Deuteron Structure

The purpose of the DSS experimental program is to obtain the information about 2NF and 3NF from two processes:

- ✓ dp-elastic scattering at the energies between 300 - 2000 MeV
- ✓ dp-breakup with registration of two protons at deuteron energies of 300 - 500 MeV

The experimental data were obtained at the ITS at Nuclotron at the Veksler and Baldin Laboratory of High Energy Physics of Joint Institute for Nuclear Research (JINR).

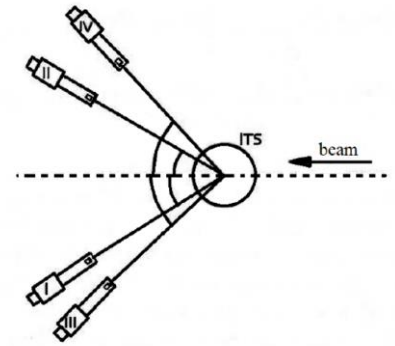


Internal Target Station is very well suited for the measurements of the deuteron induced reactions observables at large scattering angles.

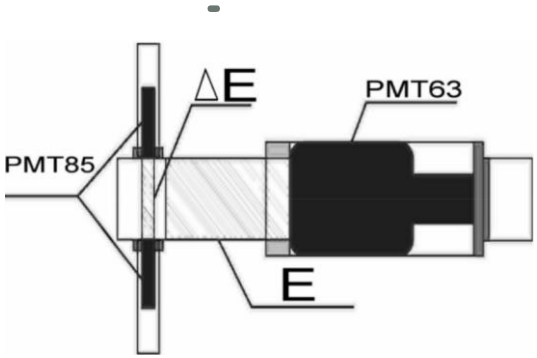
ITS consists of

- ✓ Spherical chamber;
- ✓ Target sweeping system

Particle detection system for dp-breakup



The view of the detector positions relative to the beam direction.



Schematic view of ΔE – E detector

- Protons in coincidences using ΔE – E detectors;
- Data collection for CH_2 and C targets, LED;
- Calibration measurement at 300, 400, 500 MeV;

E_d, MeV	Θ_1°	Θ_2°	E_1, MeV	E_2, MeV
300	43.5	43.5	73.9	73.9
400	43.3	43.3	98.9	98.9
500	43.0	43.0	123.9	123.9

Tab.1: Kinematic configurations for pp-quasi elastic reaction for three deuteron energies (E_d). θ_1° and θ_2° are the polar scattering angles; E_1 and E_2 are the scattered particle energies.

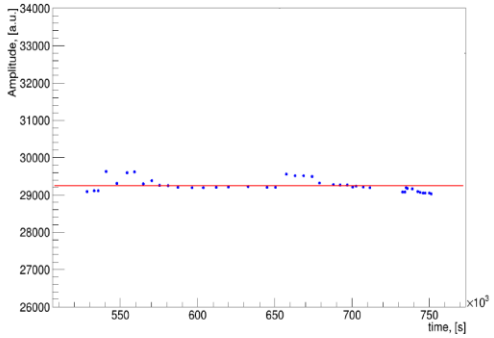
- Physical measurement at 300 MeV.

Configuration No.	α_1, [°]	α_2, [°]	β_1, [°]	β_2, [°]	θ_1, [°]	θ_2, [°]	ϕ_{12}, [°]
1	1.2	1.2	23.7	23.7	23.1	23.1	180
2	10.2	10.2	25.1	25.1	27	27	180
3	14	14	27.4	27.4	30.5	30.5	180
4	16.2	16.2	30.3	30.3	34	34	180
5	1.6	20.8	23.2	37.5	23.3	42.1	152.1
6	7.8	27.9	25.3	30	26.9	40.1	152.1
7	10.4	30	28.8	23	30.5	37.1	145

Tab.2: Detector location is determined by the polar and azimuthal angles. Angles α and β are the angles of mechanics.

Amplitude corrections

Using LED amplitude information

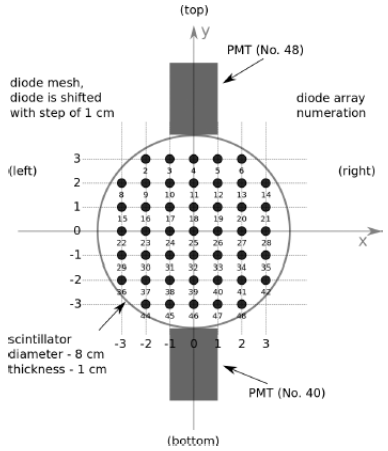


LED's amplitude mean value of first ΔE detector vs time for each run (blue dots). By fitting a constant (red line).

The average amplitude value correction for each run is extracted.

Positional dependence correction of PMT's amplitude of the Δ*E* detector.

Methodical measurement:



Setup setting: scintillator, photomultiplier tubes (No. 40, No. 48), LED positions.

from methodical measurement

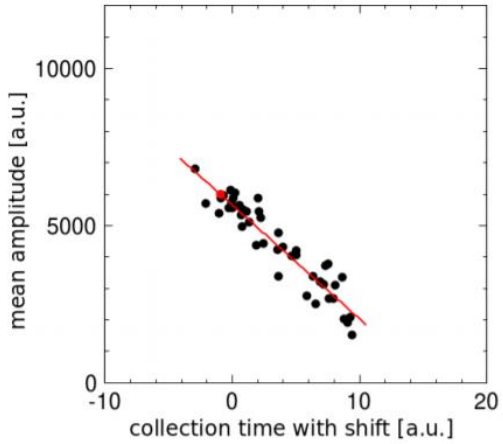
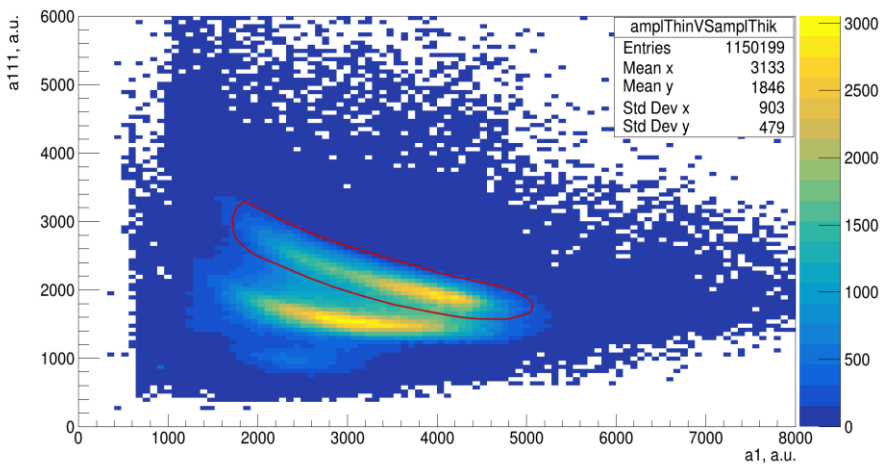


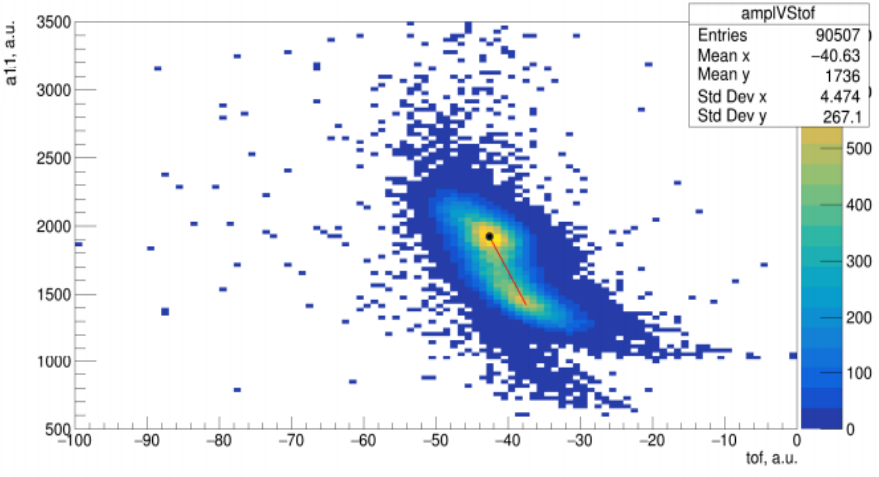
Fig.13: Mean amplitude vs collection time.

Mean amplitude: $samp = \sqrt{amp40 * amp48}$.
Red dot - amplitude value for the central geometrical point of scintillator and collected time ($stime = \sqrt{t40 * t48} - const$) value = zero.
Dependency has been fitted by straight line to obtain constant and slope values. To obtain true amplitude means to remove position amplitude dependence. The rotation about the red dot does this job.

Amplitude corrections



ΔE – E correlation.



Samp vs. stime correlation + fit (|a1 – 4000| < 125).

$$a11_{cor} = a11 - tg\alpha * (tof_{up} - tof_{measured})$$

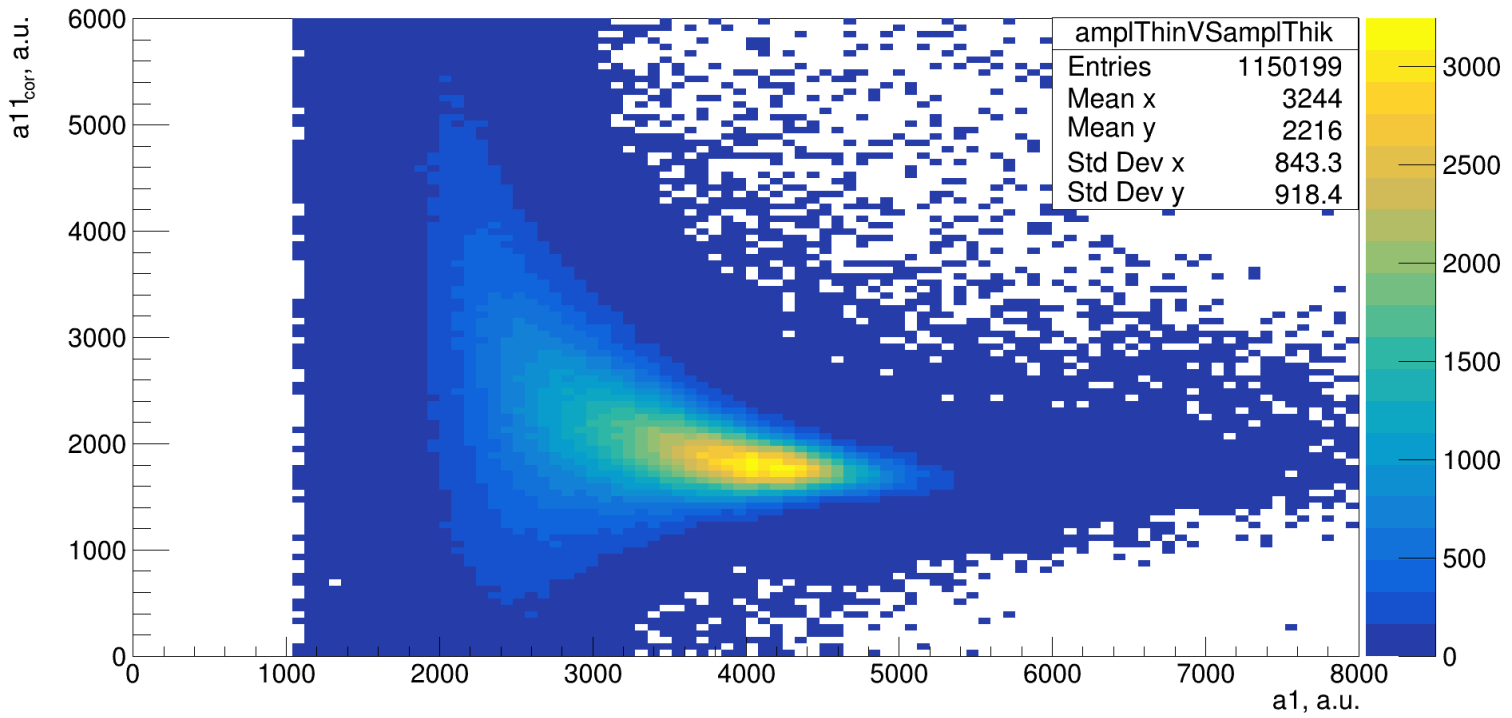
$a11_{cor}$ - the corrected amplitude,

α - the slope angle of the red line,

$tof_{measured}$ is the particle's time of flight - the time difference of register signal between *E* and *E* detector,

tof_{up} is the time difference of register signal between PMTs-85 positioned at thin scintillator.

Amplitude corrections



ΔE – E correlation with using rotation to remove position dependence.

Energy calibration

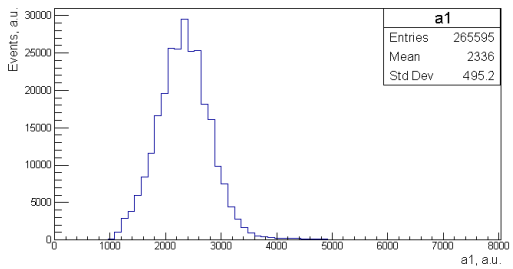
Multiplication of the calibration coefficient to the amplitude gives the information about the energy losses in the corresponding detector.

$$\begin{cases} k_i^1 am_i + k_i^2 A_i = 75 \\ k_i^1 am_i + k_i^2 A_i = 100 \\ k_i^1 am_i + k_i^2 A_i = 125 \end{cases}$$

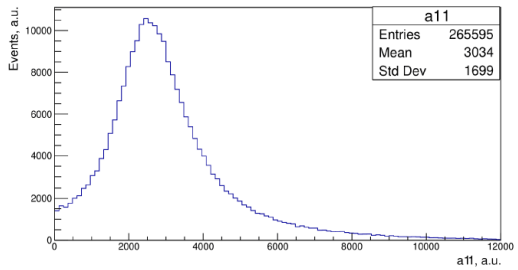
The method of least squares

Detector No.	k_1, a.u.	δk_1, a.u.	k_2, a.u.	δk_2, a.u.
I	0.0034	0.00017	0.028	0.002
II	0.0042	0.0002	0.028	0.003

Tab.3: The calibration coefficients (k_1 and k_2) for ΔE and E scintillators.

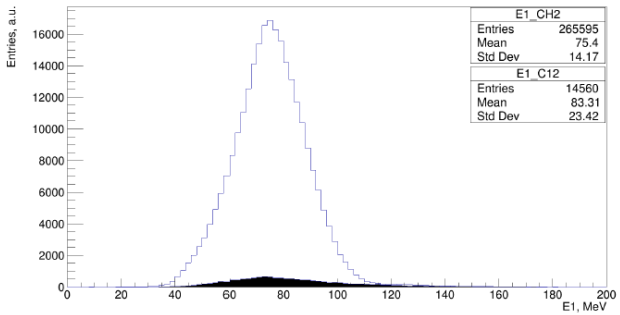


a)

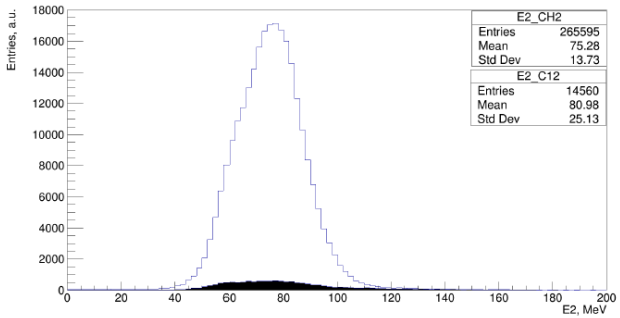


b)

Amplitude spectra for the E PMT-85 (a) and the E PMT-63 (b) for the first E – E detector at the deuterons beam energy of 300 MeV in case of pp-quasi reaction.

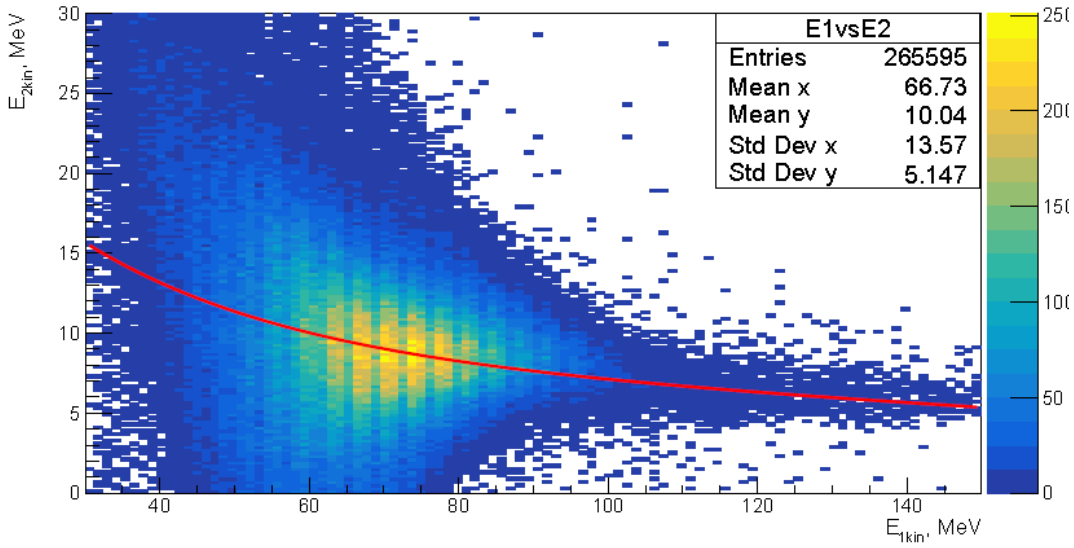


a)

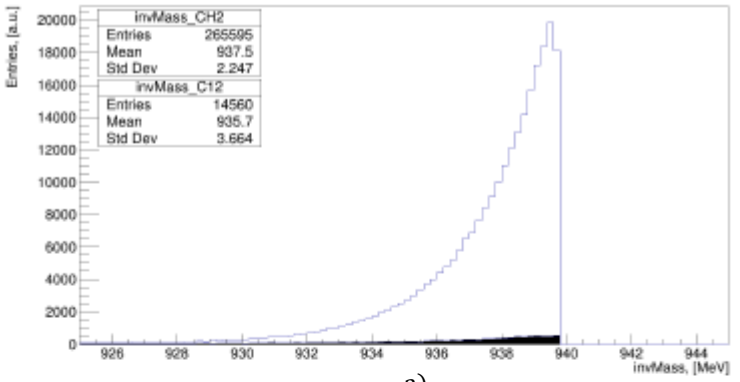


b)

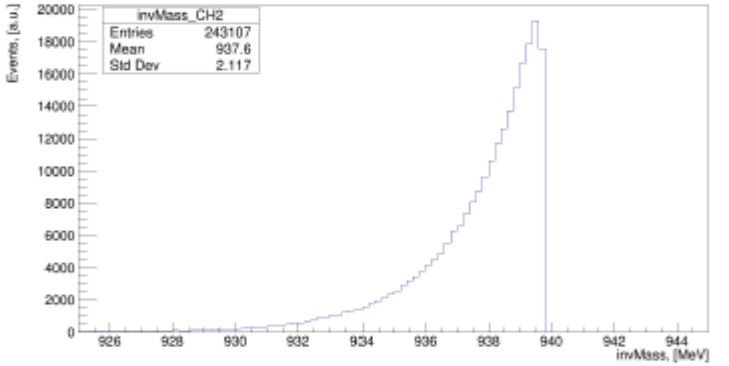
Energy calibration



Correlation of the energy losses signal in E (Y-axis) and E (X-axis) detectors. The red curve represents the results of Geant4 simulation.

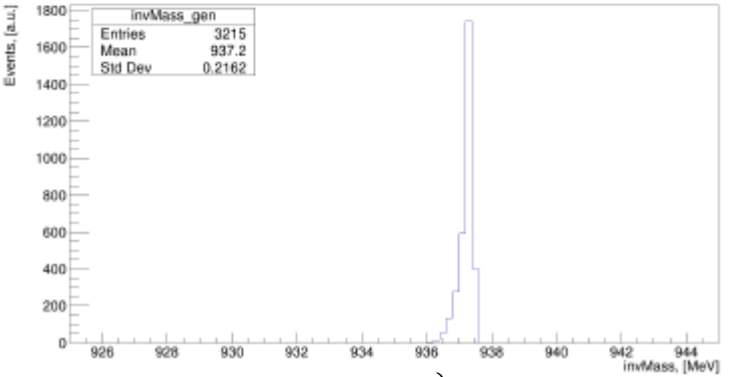


a)



b)

The missing mass spectra obtained for calibration data (a, b) and the results of TGenPhaseSpace simulation (c). Upper panel shows the missing mass spectra for CH_2 (nonshaded histogram) and ^{12}C (shaded histogram) targets. The spectrum obtained by subtracting of Carbon content from Polyethylene one is presented in b).

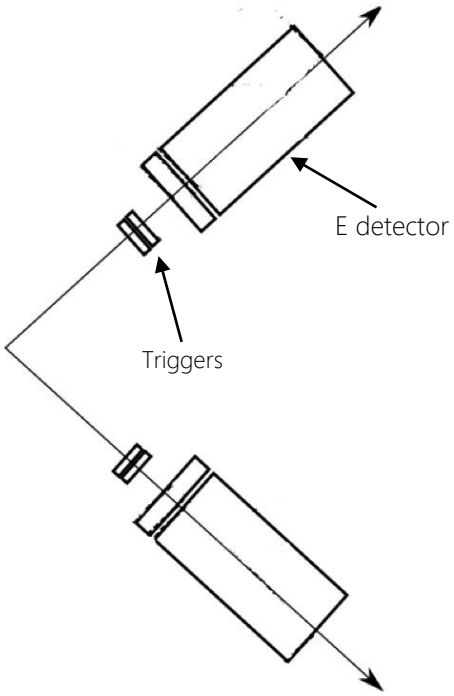


c)

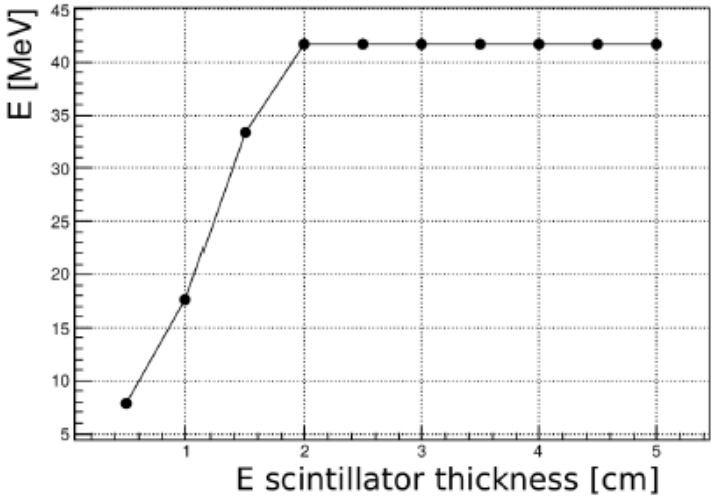
Detector efficiency

The various data files are used:

- ✓ Methodical longitudinal measurement angles at 43.9° (55 MeV);
- ✓ calibration data (75, 100, 125 MeV);
- ✓ data file from another *pp*-quasi elastic experiment at 110° (180 MeV).



Detector placement for longitudinal measurements.



Monte Carlo simulation in case of longitudinal measurement. The energy of the protons is 75 MeV. The the trigger thickness is 1 cm, E detector thickness of 1 cm, thicknesses of E scintillator = 0.5, 1, 1.5, 2, 2.5, 3, 3.5, 4, 4.5, 5 cm. Various thicknesses of E detector we used in order to find the depth of particles penetration in E detector.

Detector efficiency

$$N^{123} = \epsilon_1\epsilon_2\epsilon_3 N^{in},$$
$$N^{12} = \epsilon_1\epsilon_2 N^{in},$$
$$N^{13} = \epsilon_1\epsilon_3 N^{in},$$
$$N^{23} = \epsilon_2\epsilon_3 N^{in},$$

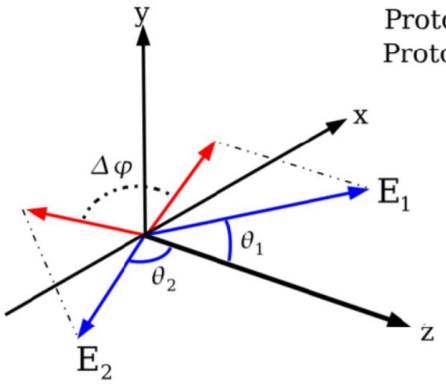
ε_1, ε_2, and ε_3 correspond to the efficiency of the first, second triggers and E detector, respectively.
N_{123} is the number of counts detected by the three detectors in coincidence;
N_{12}, N_{13}, N_{23} are the number of events detected by two counters and detector, respectively;
N_{in} represents the number of "incident" events.

energy, [MeV]	55	75	100	125	180
efficiency	0.407±0.0097	0.998±0.017	0.997±0.013	0.976±0.011	0.97±0.01

Tab.4: The detector efficiency for selected particles energies.

The detector efficiency correction needs to be applied to obtain the proper number of protons passing through the detector

S – curve



$\text{Proton1}(E_1, \theta_1, \varphi_1)$
$\text{Proton2}(E_2, \theta_2, \varphi_2)$

The final state particles can be determined using

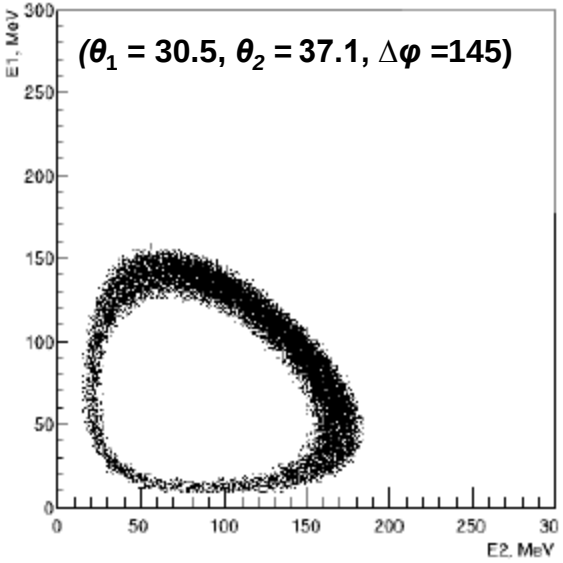
$$(E_1, \theta_1, \phi_1)_{p_1}, (E_2, \theta_2, \phi_2)_{p_2}, (E_3, \theta_3, \phi_3)_n;$$

\+ four momentum conservation law:

$$Q + 2[(E_1 + E_2)(E_p + m_d) - \sqrt{(E_1^2 - m_1^2)(E_p^2 - m_p^2)}cos\theta_1 - \sqrt{(E_2^2 - m_2^2)(E_p^2 - m_p^2)}cos\theta_2 + \sqrt{(E_1^2 - m_1^2)(E_2^2 - m_2^2)}cos\theta_{12} - E_p m_d - E_1 E_2] = 0,$$

$$Q = m_3^2 - m_1^2 - m_2^2 - m_d^2 - m_p^2$$

The dependence of E_2 on E_1 is the S - curve

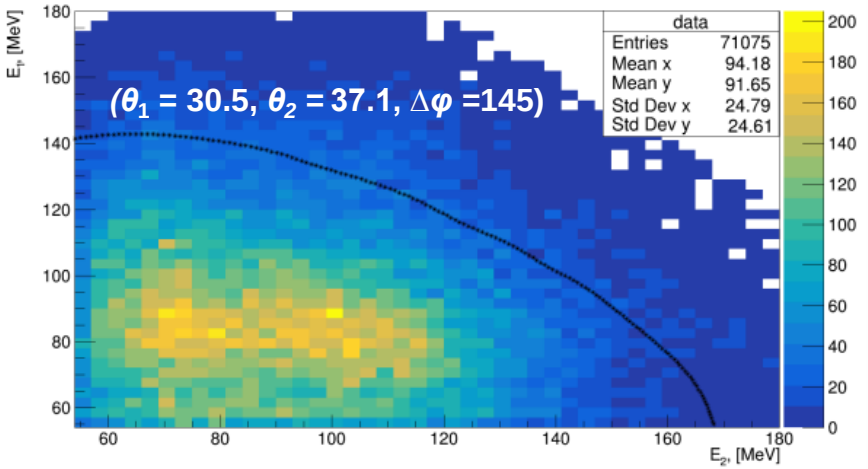


The correlation of the energy of protons (S - curve) obtained from phase space simulation performed in ROOT. Angular coverage of detector is taking into account.

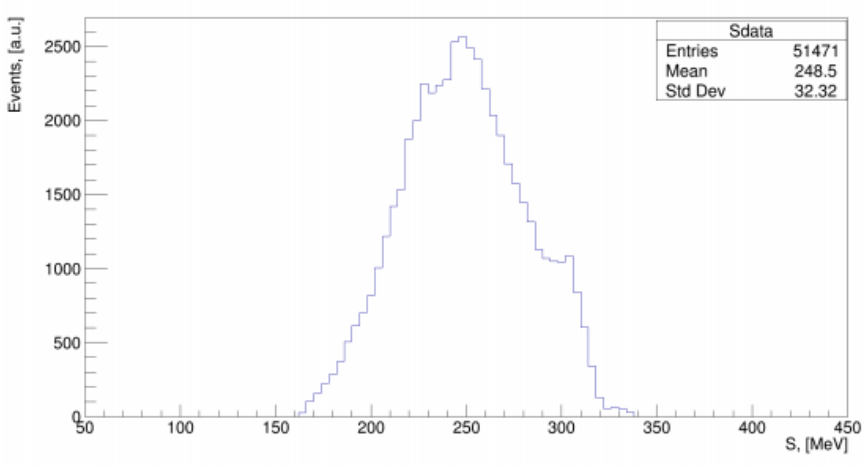
The S-curve contains all the kinematically allowed combinations

S – curve

The experimental data are projected onto the S - curve points to obtained the number of events for each point of the kinematical curve.



The correlation between the energy of the outgoing protons in the breakup. The relativistic S - curve is added as a dots with the step of 1 MeV.



The results of the experimental points projection into S - curve within acceptance of the detector.

The number of breakup events in each point of S - curve is needed for calculation of the differential cross section in future.

Summary and conclusions

Investigation of dp-breakup reaction was performed at the kinetic energy of the deuteron beam of 300, 400, 500 MeV. Processing of the dp → ppn reaction can be divided into three main steps:

- The particles amplitude is corrected using information from
  – measurement with LED during data taking,
  – positional dependencies of PMT's amplitude of ΔE detector.
- The energy calibration of the ΔE – E detector has been performed at 300, 400, and 500 MeV. The calibration coefficients for ΔE and E detectors are calculated by solving the system of linear equation.
- Detector efficiencies of ΔE-E were obtained.
- Studies of the deuteron proton breakup reaction in the space star configuration were performed at 300 MeV. Distribution of events along the kinematical S - curve has been obtained taking into account detector efficiency.

These results will be used for the calculation of the cross section of the breakup reaction.

Thank you for your attention