Differential Cross Section for Proton Induced Deuteron Breakup at 108 MeV

Angelina Łobejko

Institute of Physics, University of Silesia, Katowice for Few Nucleon System Collaboration:

1) Institute of Nuclear Physics, PAN, Kraków, Poland

2) KVI-CART, University of Groningen, Groningen, The Netherlands

3) Institute of Physics, Jagiellonian University, Kraków, Poland

4) Faculty of Physics, University of Warsaw, Warsaw, Poland

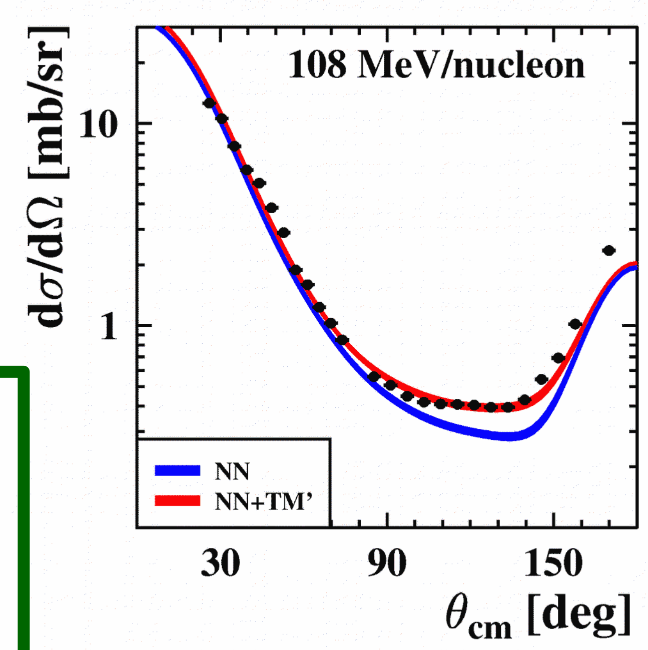
UNIWERSYTET ŚLĄSKI W KATOWICACH

EFB

UNIVERSITY OF SURREY

Three nucleon System

- Prediction of NN potentials alone:
  - ➔ Fail to reproduce binding energies of 3N, 4N and heavier system
  - ➔ Fail to reproduce minimum of the d(N,N)d elastic scattering cross section



- introducing concept of three-nucleon forces: genuine (irreducible) interaction of three nucleons – direct consequence of internal structure of nucleons
- Systematic approach within ChPT

Why to Study System of 3N?

- Observables can be calculated in ab-inito regime
- the environment is non-trivial as compared to NN systems and probably reacher in dynamics
- The nuclear potentials tested in those simple systems can be used in more complicated ones
- TO LEARN ABOUT NUCLEAR INTERACTIONS

Studies of 3N System with BINA@CCB

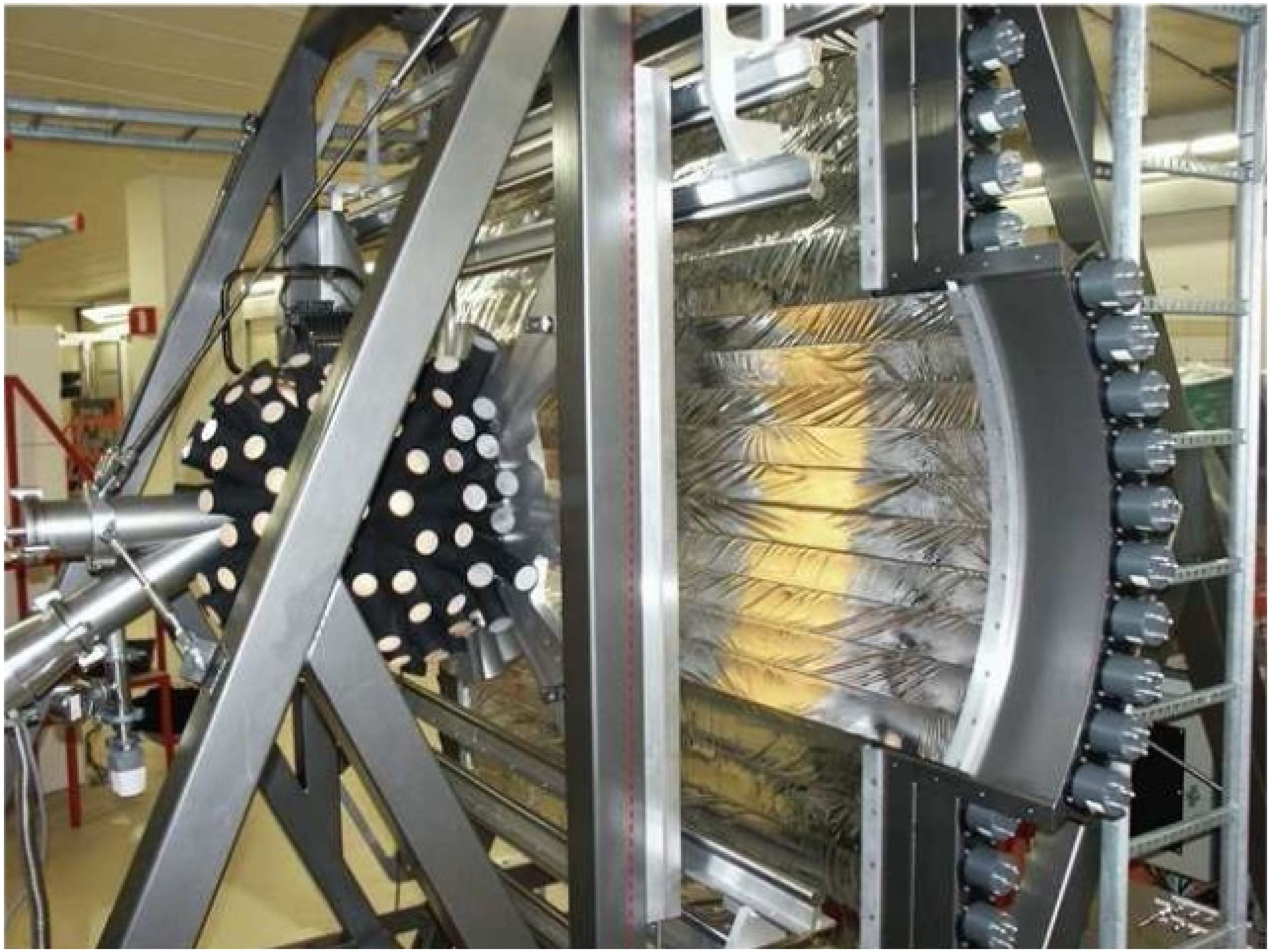
BINA – Big Instrument for Nuclear-Polarization Analysis

1) Experimental program:

- Measurement of **^{2}H(p,pd)** elastic scattering at 108, 135 and 160 MeV
- Measurement of **^{2}H(p,pp)n** breakup reaction at 108 and 160 MeV for over 100 kinematic configurations

2) Aim:

- Studies of **3NF**
- Verification of predicted **Coulomb** and **relativistic effects**
- Tests of upcoming **ChPT** calculations

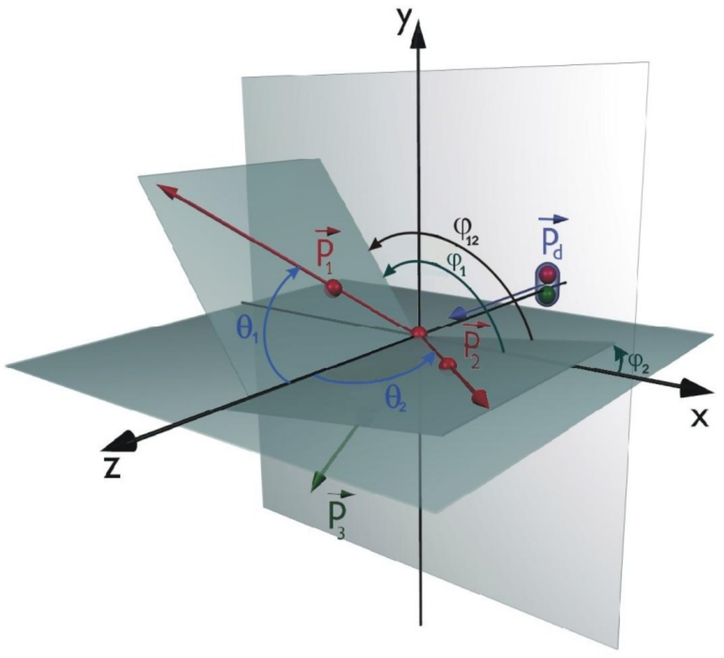


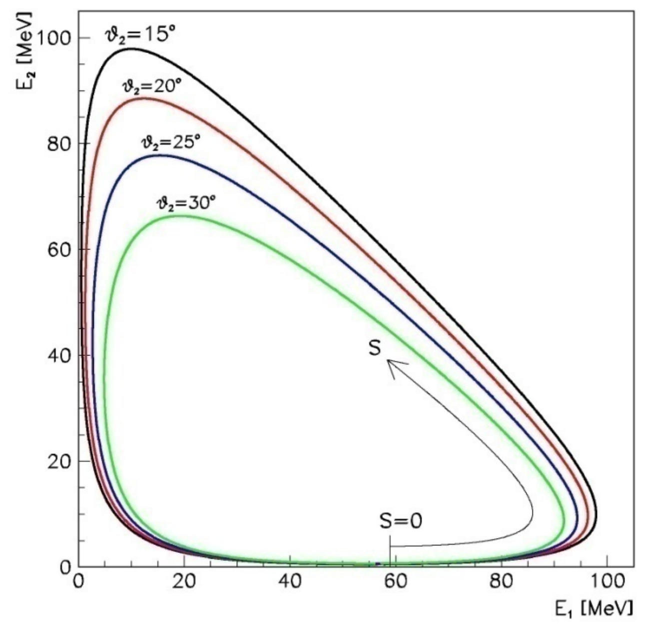
Breakup Reaction

- **Three nucleon** (p,p,n) in the final state; nucleons are defined by its momenta → 9 kinematic variables;
- Energy-momentum conservation → **five independent kinematic variables**;
- **$^{2}H(p,pp)n$** was measured:
  - ➔ Energies
  - ➔ Directions

  } **of two protons**
- With absence of polarization the system is axially symmetric;
- $\theta_1, \varphi_1, E_1, \theta_2, \varphi_2, E_2$

  → $\theta_1, \theta_2, S, \varphi_{12}\ (\varphi_1 - \varphi_2)$



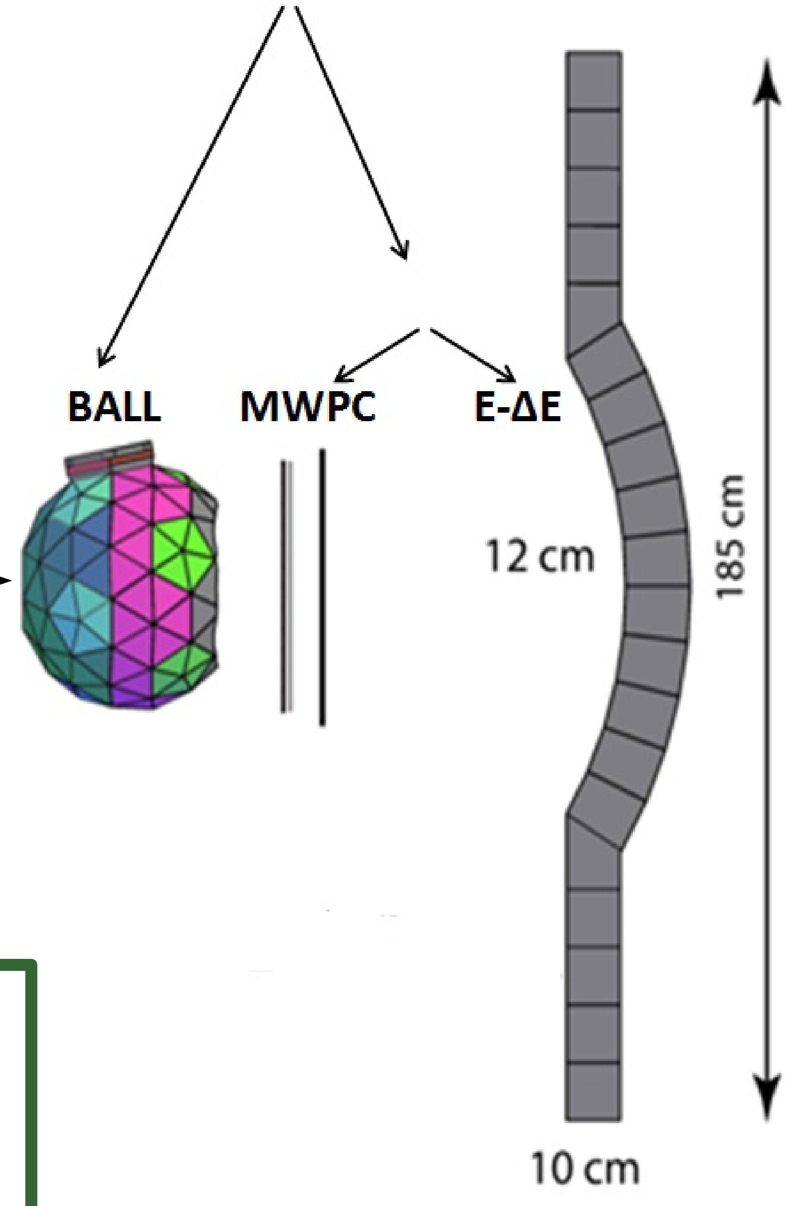


Experimental Setup

A) **The Forward Part of detector (Wall):**

- **Multi-Wire Proportional Chamber**
- **The E-ΔE telescopes**

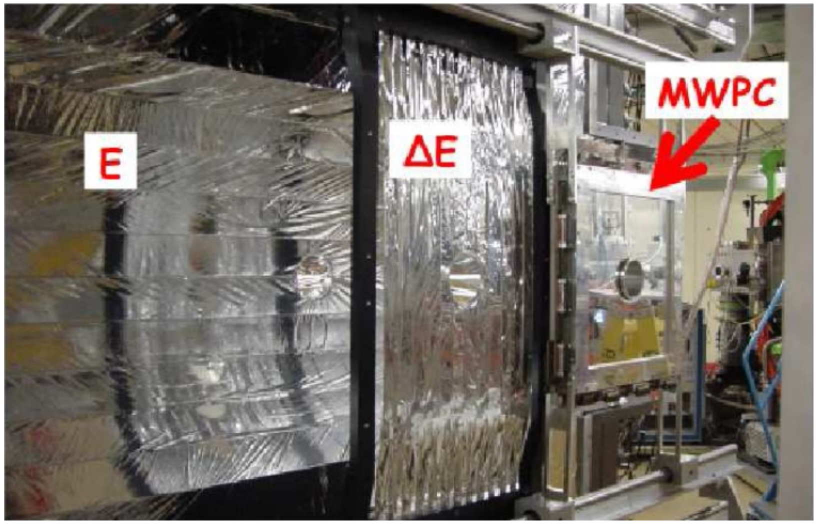
B) **The Central-Backward Part - Ball**

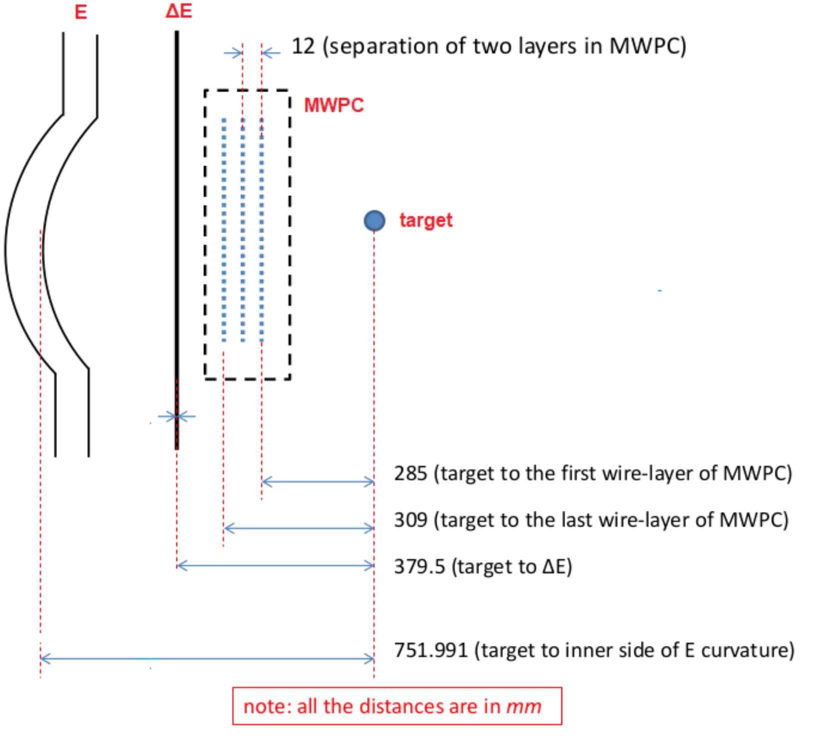


FIRST RUN -
ONLY THE FORWARD PART

MWPC + E-ΔE telecopes

- **MWPC** – 3 planes wires allowing reconstruct of the emission angle of a charged particle;
- the efficiency of **MWPC** is about 90%;
- **ΔE-E hodoscopes** are made of plastic scintillator material;
- **ΔE-E – Particle Identifications.**





- Angular acceptance of Wall:

  $\theta \in (10° - 35°)$

  $\varphi \in$ (full φ)

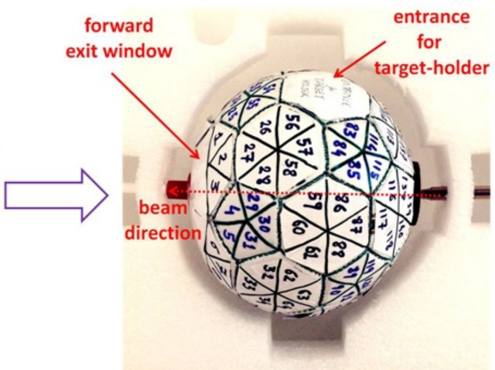
- Angular resolution:

  $\Delta\theta \approx 0.5°$

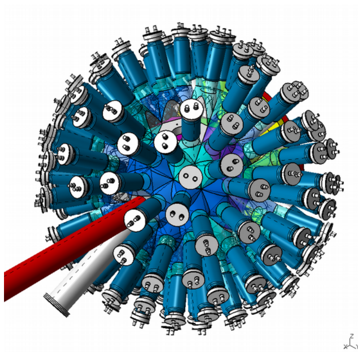
  $\Delta\varphi \approx 0.5° - 3°$

The Backward Part of Detector - Ball

a soccer ball



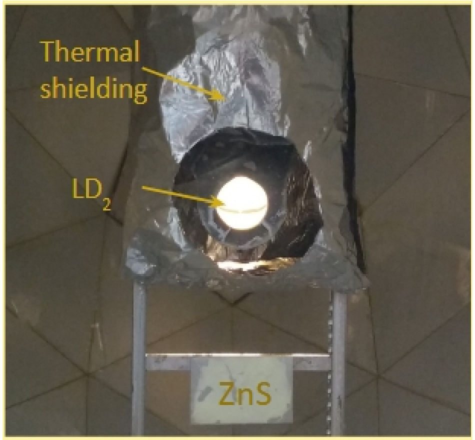
backward ball

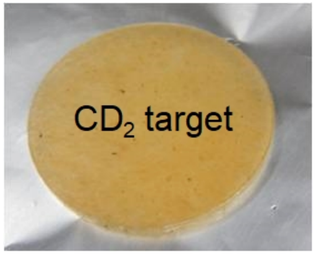


System of 149 **phoswitches**

(phosphor sandwich) is a combination of scintillators with dissimilar pulse shape characteristics optically coupled to each other and to a common PMT.

- The shape and the construction — **20 identical hexagon** and **12 identical pentagon structures** which are further divided into **identical triangles** (represents here a single ball element)



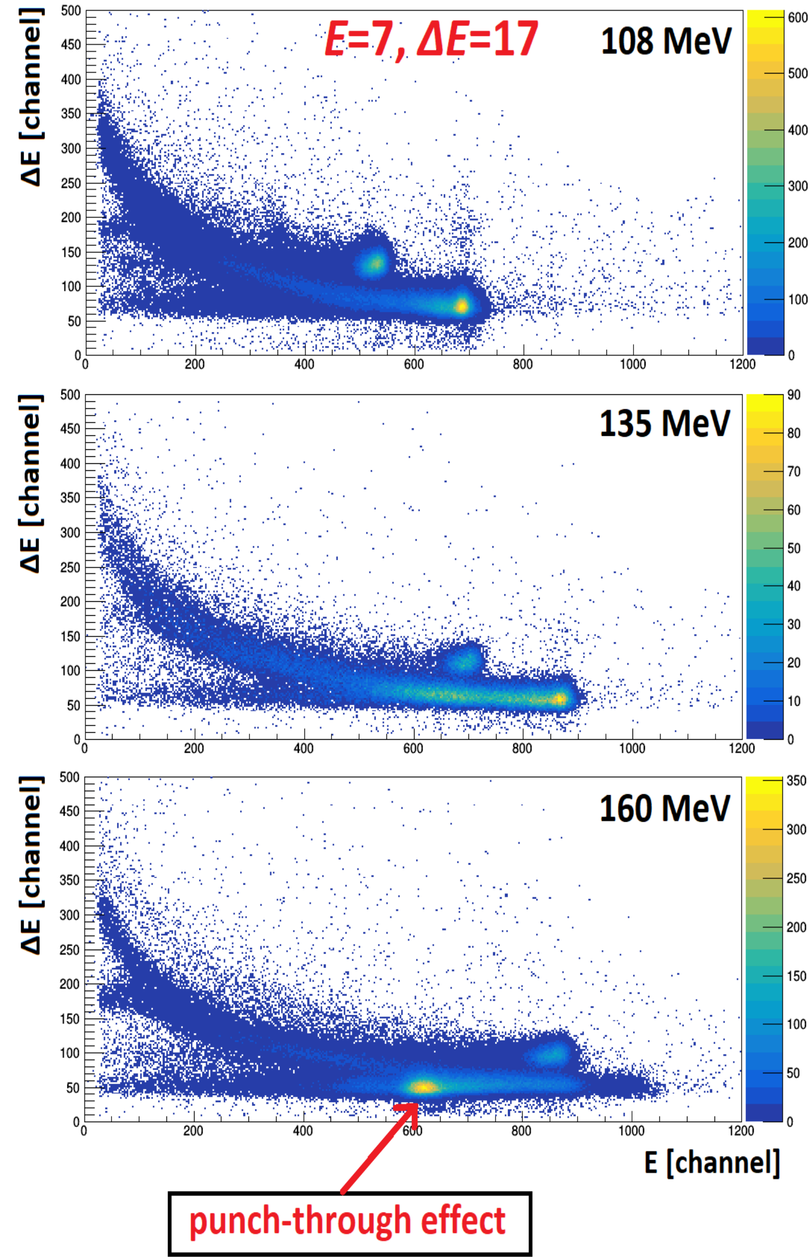


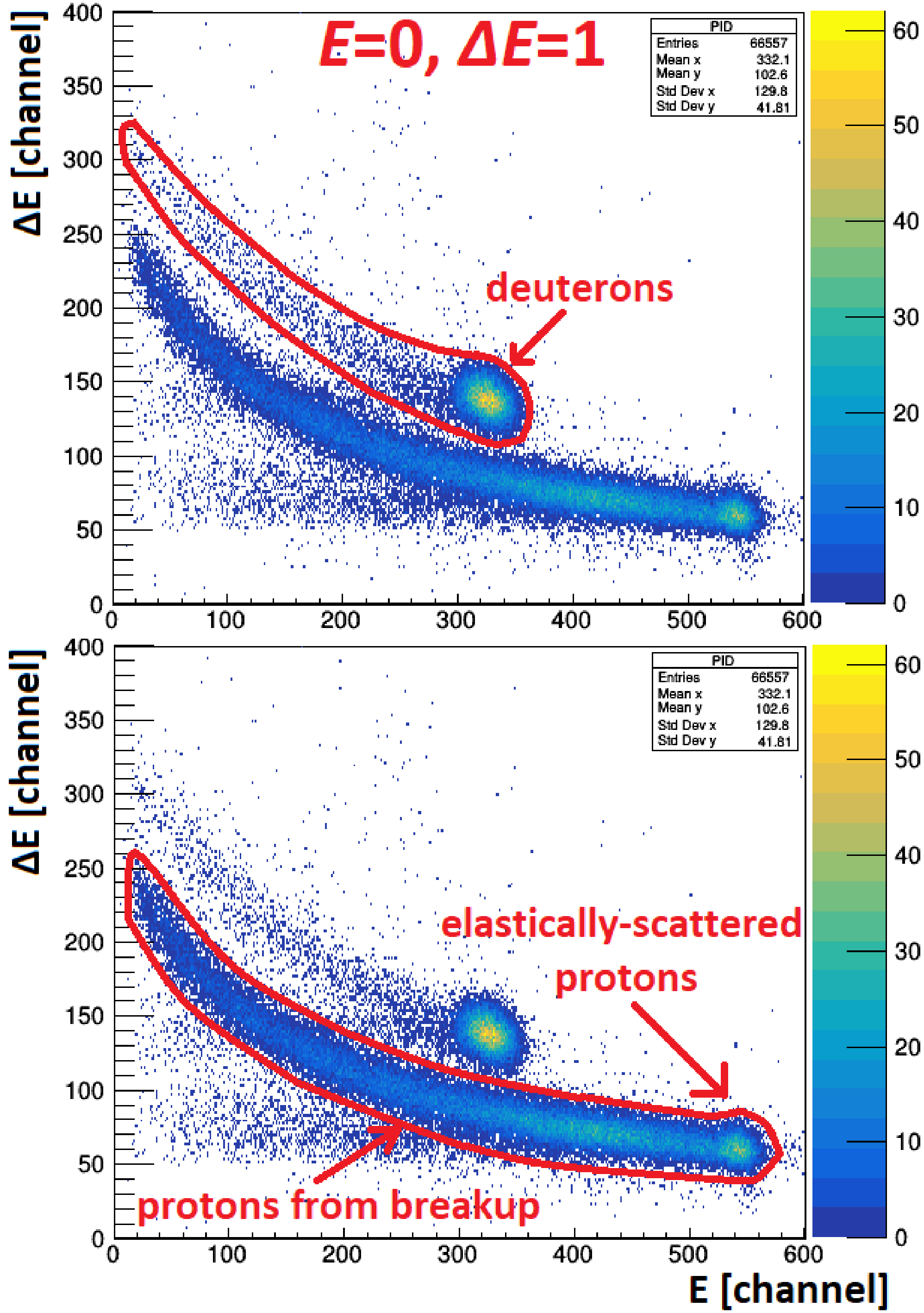
- The **target system** inside the Ball:
  1) Liquid Deuterium Target **LD_2 –** relative measurement of breakup cross section
  2) Solid Target **CD_2 –** absolute measurement of elastic scattering cross section
- Together with Wall - angular acceptance of nearly **4π**

Particle Identification (PID)

- Based on ***ΔE-E* technique**;
- The events of interest are the **coincidences of two charged particles:**
  1) pp (breakup reaction),
  2) pd (elastic scattering),
- allows us to identify **protons and deuterons**;

FIRST DATA (2016)





- **Graphical cuts** (“gates”) were defined **for each individual *ΔE-E* telescope;**
- Small overlap of gates is allowed;
- **three groups of events** are well visible:
  - ➔ the **spot of deuterons** coming from the elastic scattering,
  - ➔ the long **branch of protons** coming from the breakup reaction,
  - ➔ the **spot of elastically-scattered protons**.

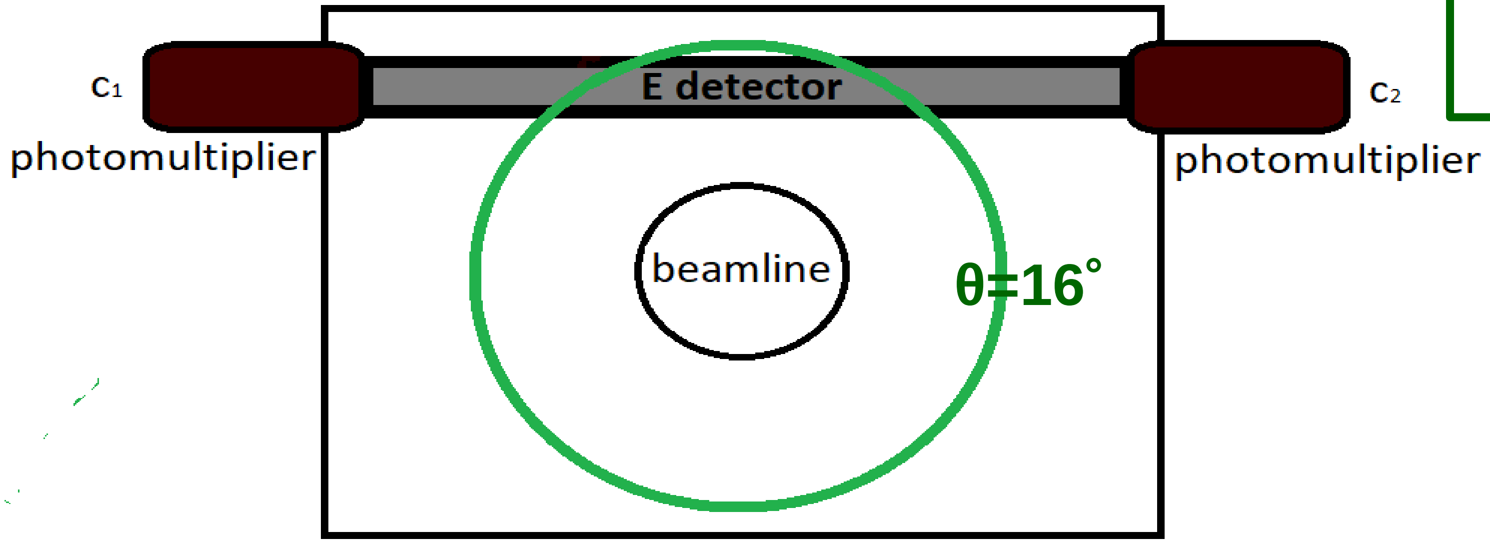
Calibration of deposited energy

- **Proton beam** energies: **70, 83, 97, 108, 120** MeV;
- **Al(p,p)Al** scattering.

- **Events are defined by**:
  - ➔ the **side** (S = right / left),
  - ➔ the ***E* detector number** (N = 0, 1, …, 9),
  - ➔ the **polar angle** (θ = 12° - 34°; step = 2°).

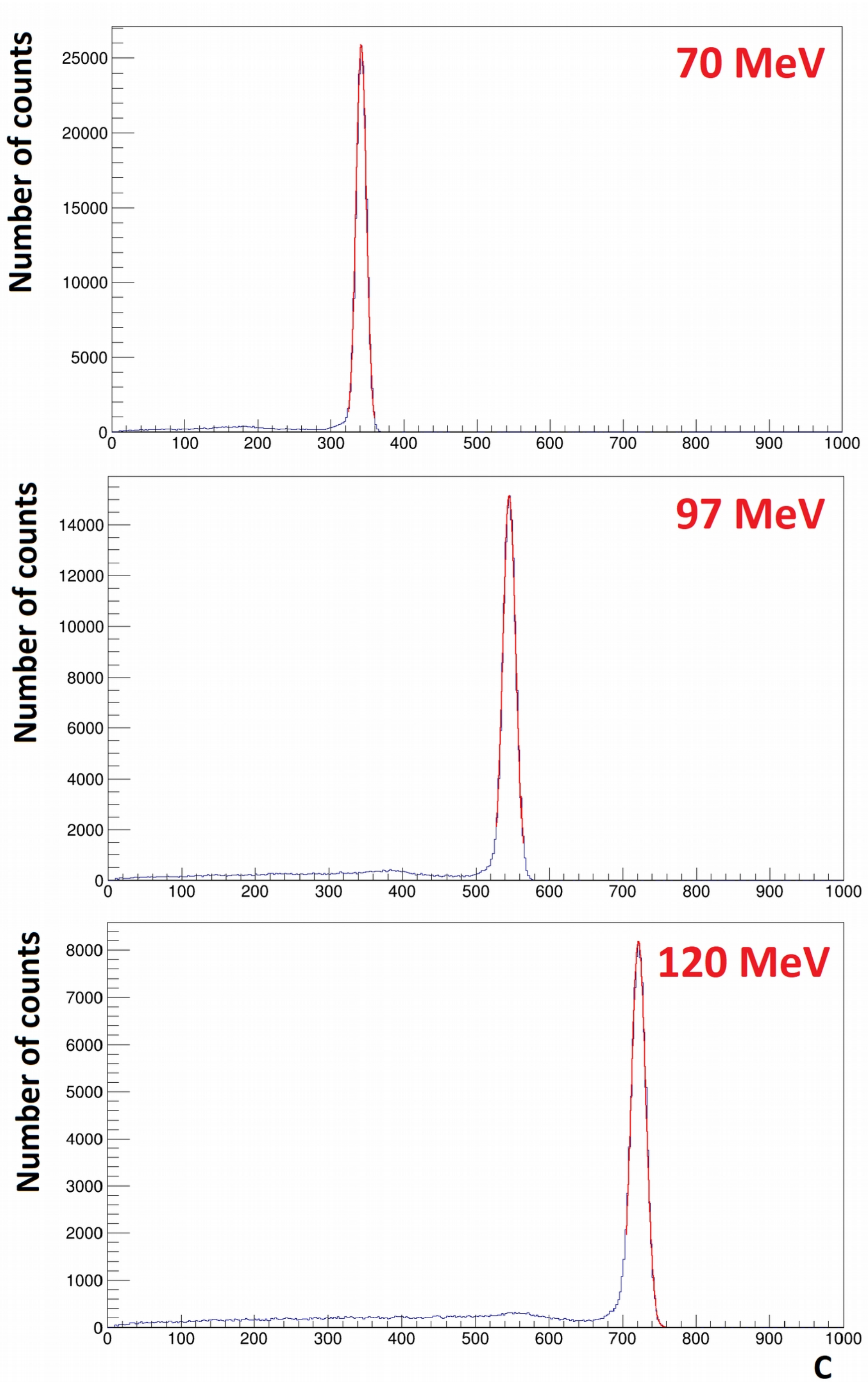
- Energy for each detector:

$$C=\sqrt{c_1 * c_2}$$

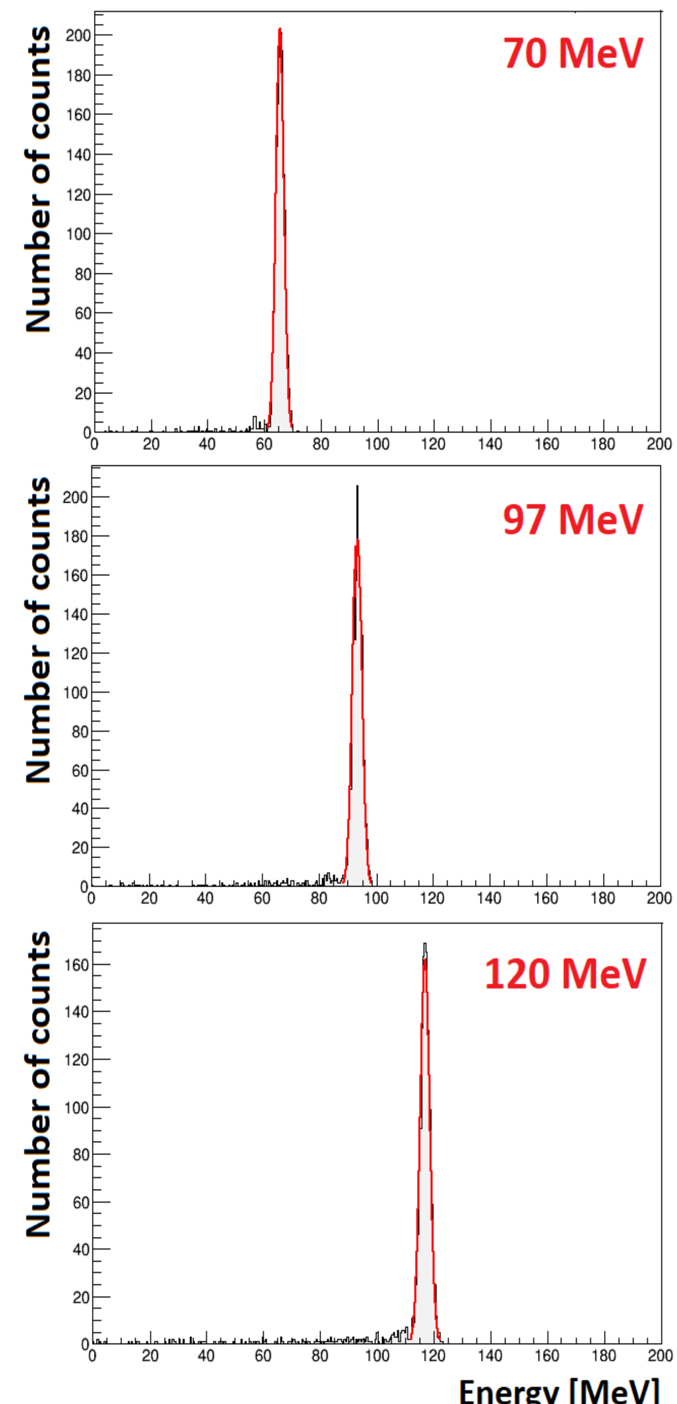


supress effects of light attenuation along the bar

Experimental data



Monte Carlo Simulation

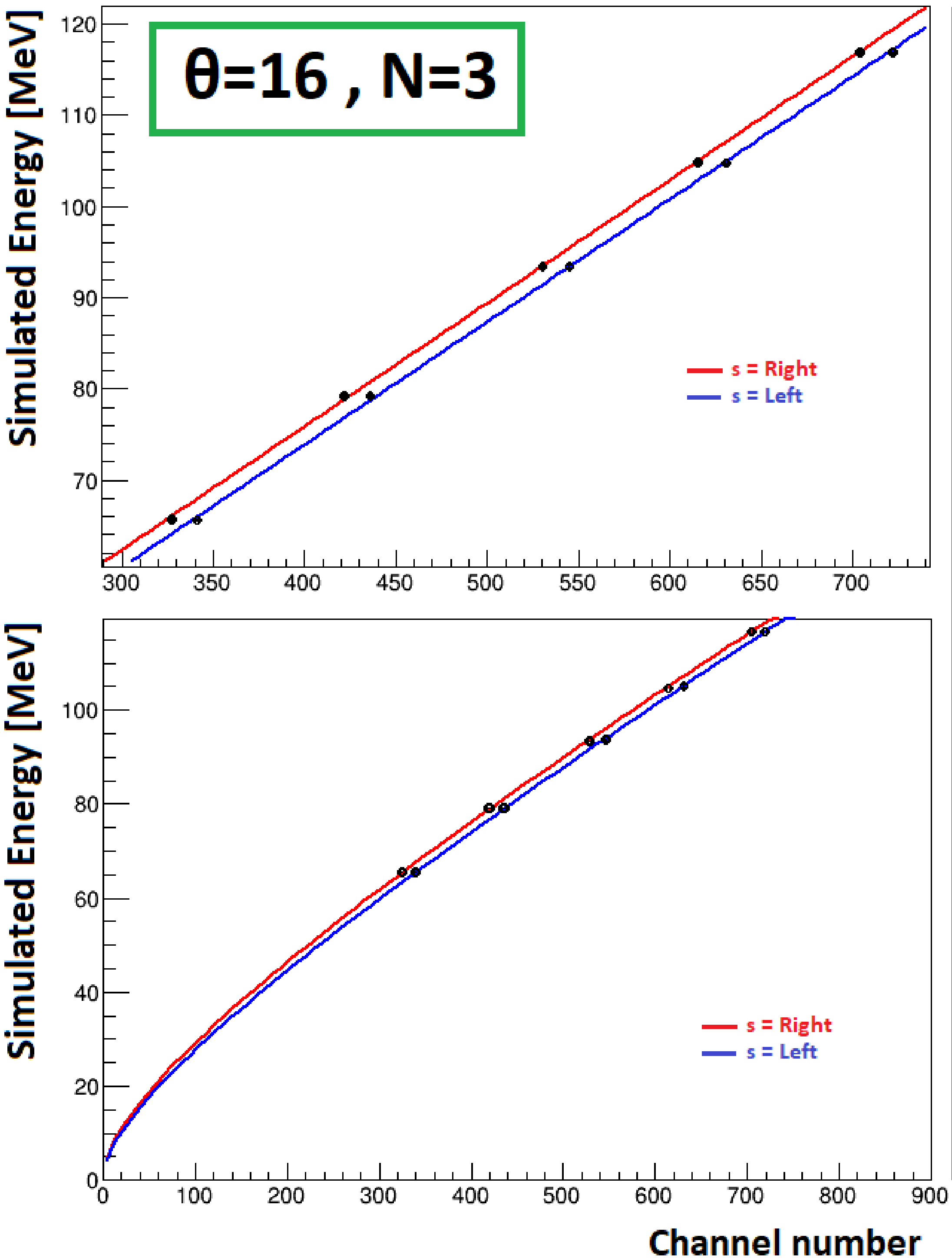


Al(p,p)Al
scattering

E detector number:
N=3

Theta angle:
$\theta = 16^{\circ} \pm 1^{\circ}$

Side:
S=left



1. Linear calibration

- y = aC + b
- Range: > 50 MeV

$$C = \sqrt{c_1 * c_2}$$

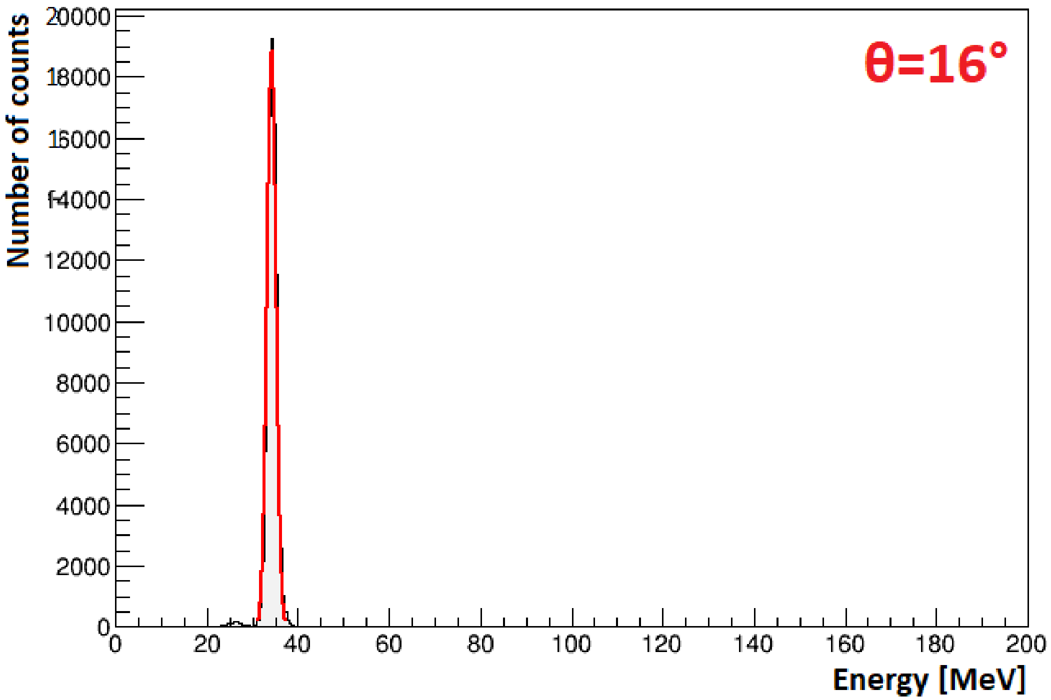
2. Light quenching effect

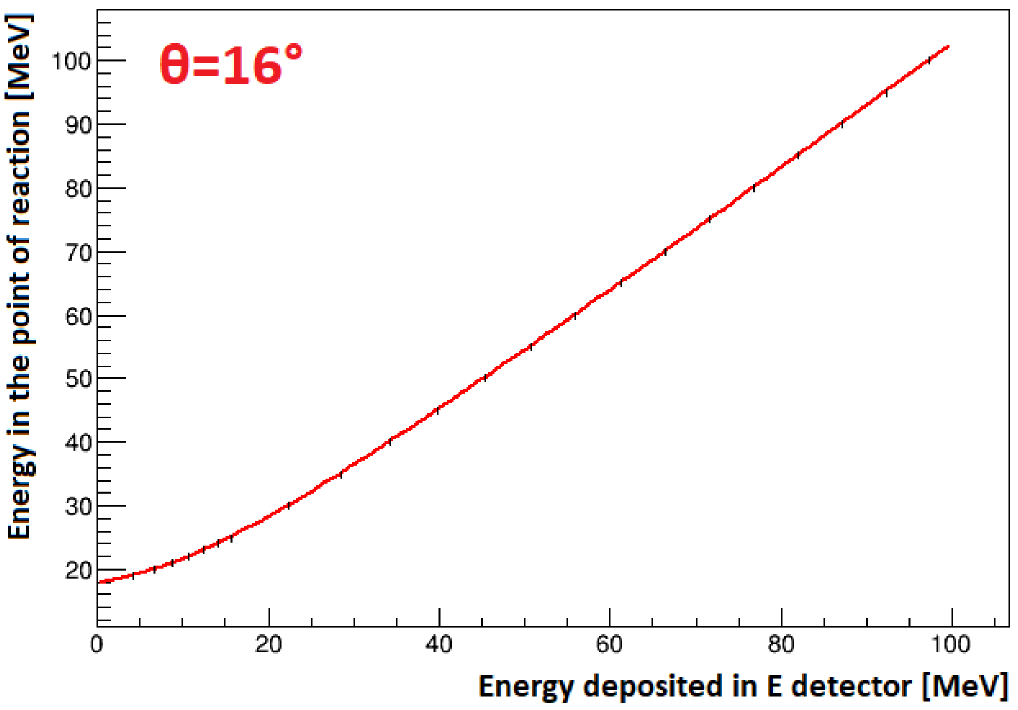
- $y = aC + b\sqrt{C}$
- Departure from linearity for energies 0-50 MeV

Calibration - LD_2 target

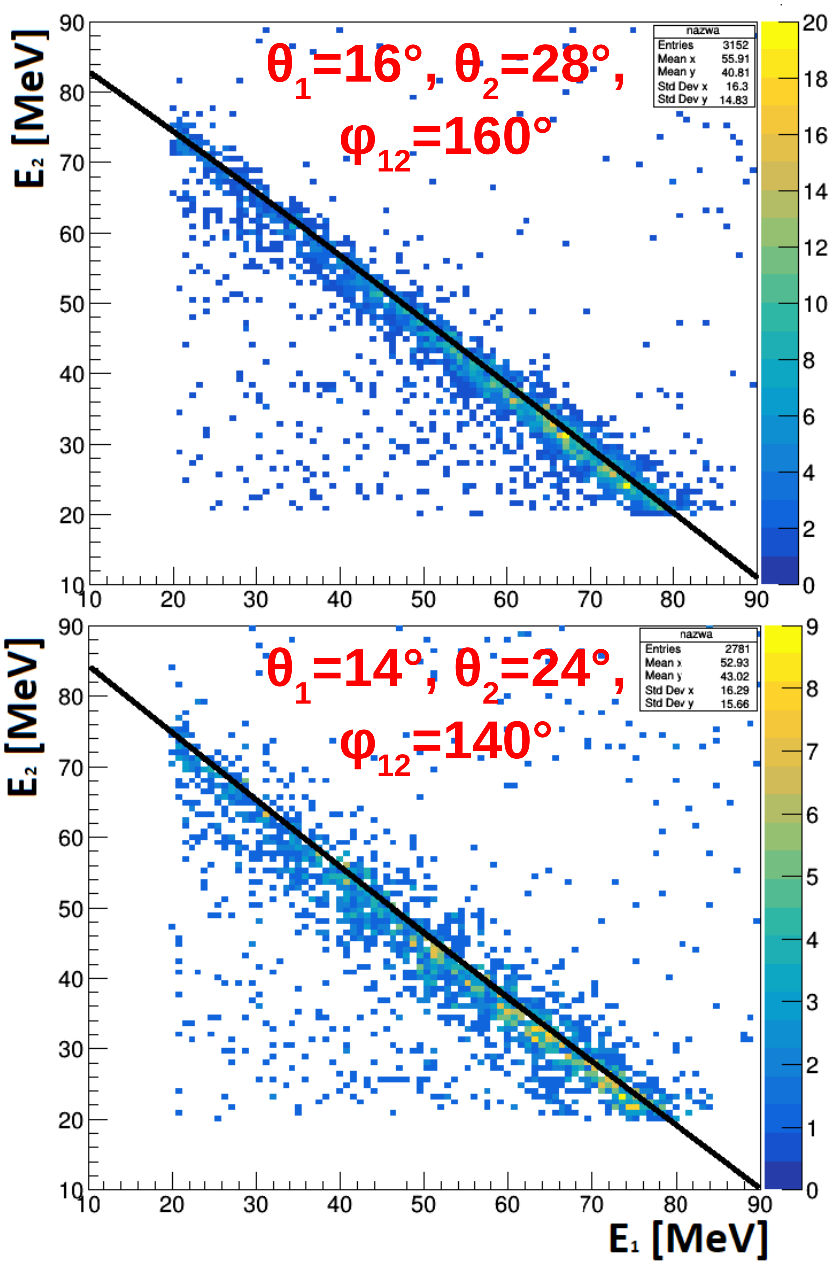
- Transformation of deposited energy to initial energy
- Monte Carlo simulations of E_{loss} between the reaction point and *E* detector

- Simulation:
  - → proton energy (15-100 MeV),
  - → proton θ angle (12°-34°).





Kinematical configuration



- ^{2}**H(p,pp)n** reaction kinematics determined by proton momenta $\vec{p}_1, \vec{p}_2$
- Configuration was defined by emission angles of two outgoing protons:

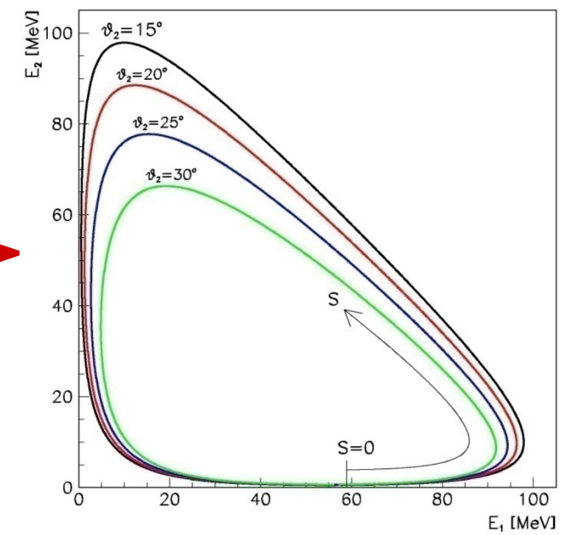
  ➔ $\theta_1 \pm 1°$, $\theta_2 \pm 1°$, $\varphi_{12} \pm 5°$,

- The central line of the experimental band is lying on the theoretical kinematics

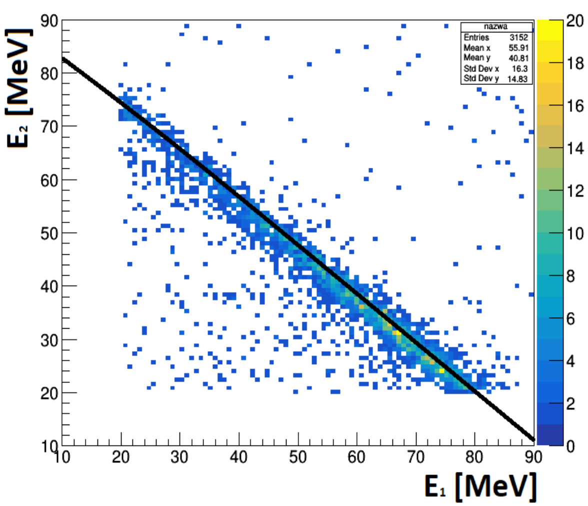
It confirms the correct energy calibration

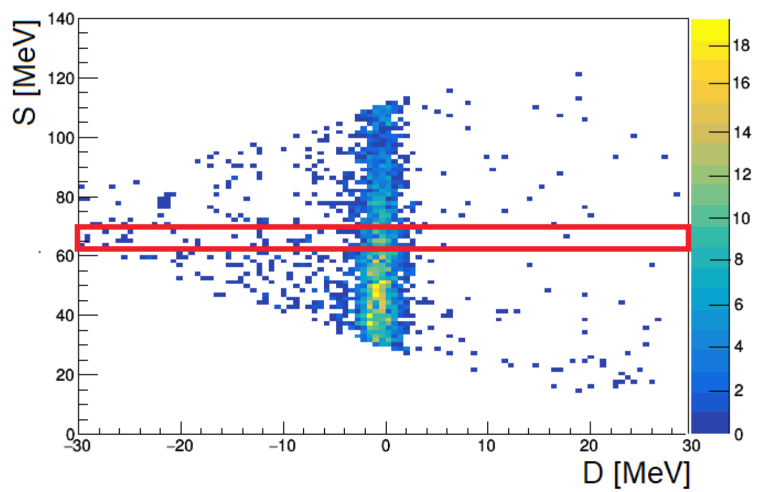
Background Subtraction

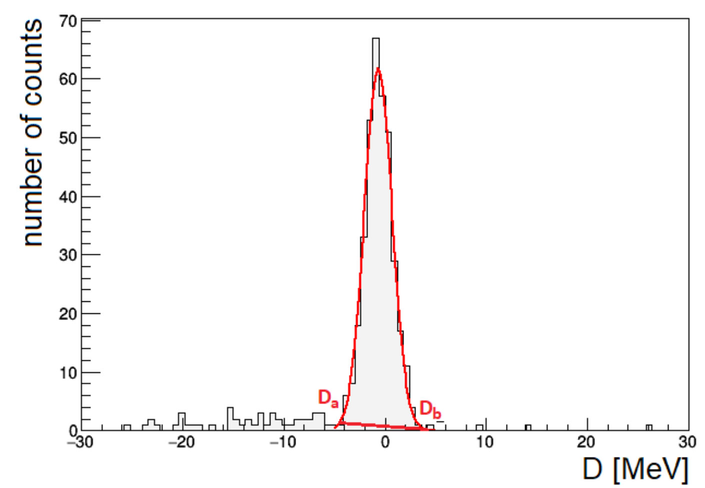
- Transformation of E_2 vs E_1 spectrum to S (**arclength variable**) vs Distance of the points from kinematical curve;
- Each slice on the S vs D – distance spectrum is treated separately;
- The background is approximated by a linear function between the two limits of integration;
- The events below linear function are subtracted;



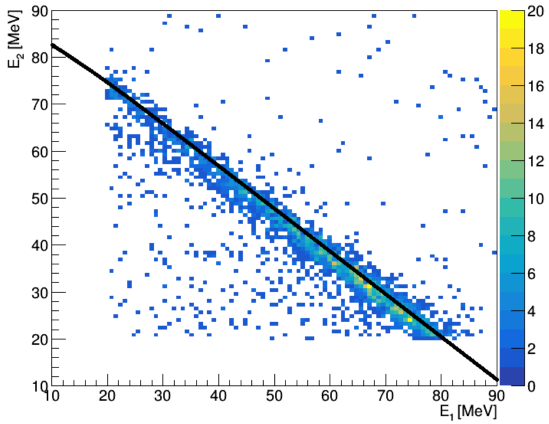
θ_1=16°, θ_2=28°, φ_{12}=160°

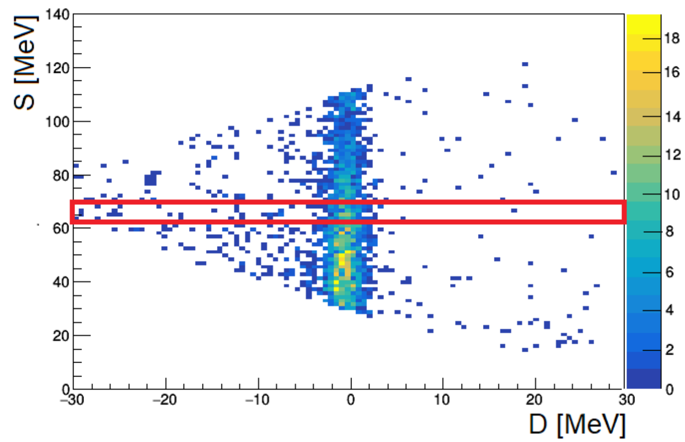


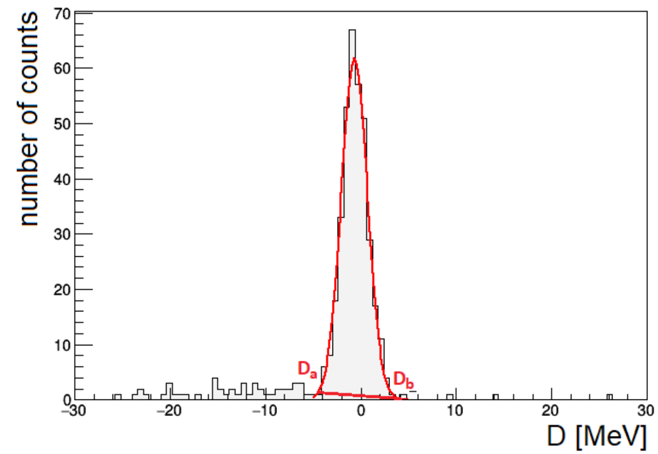




θ_1=16°, θ_2=28°, φ_{12}=160°



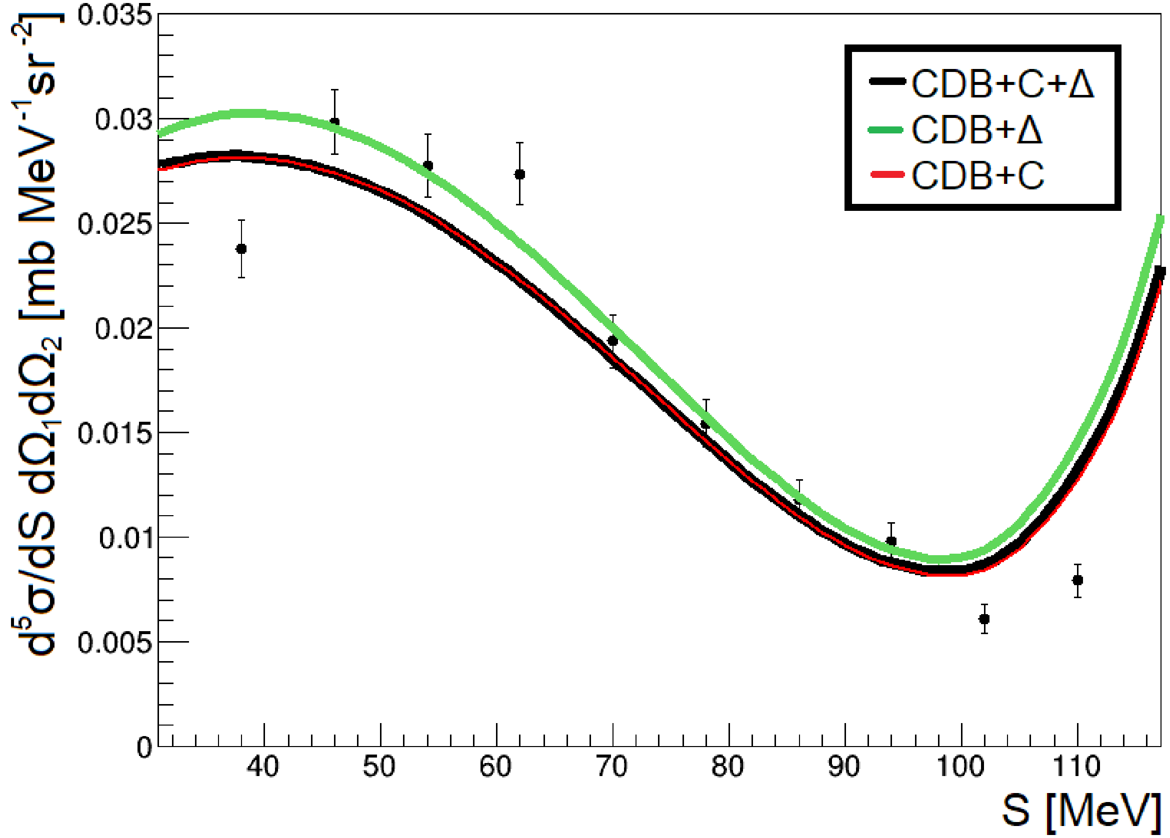




Arbitrary

Data

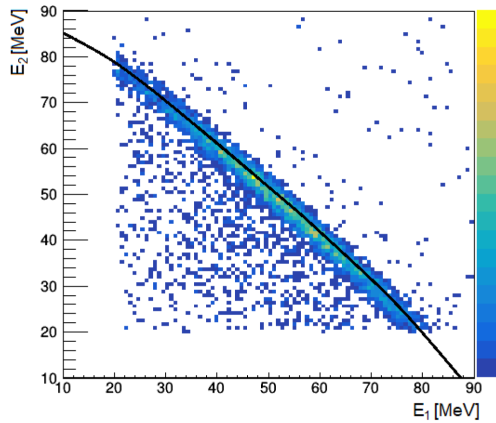
Normalization

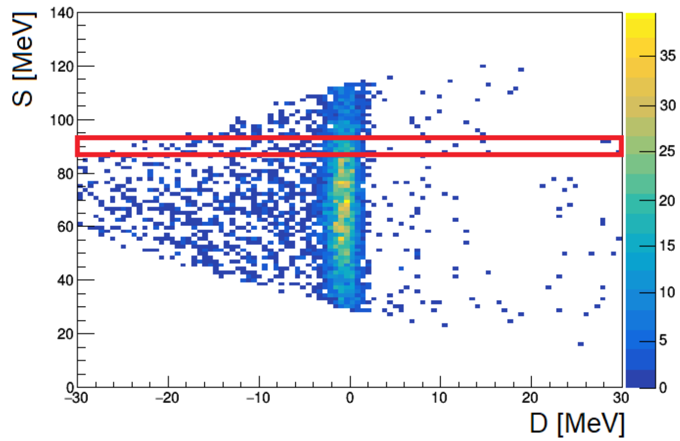


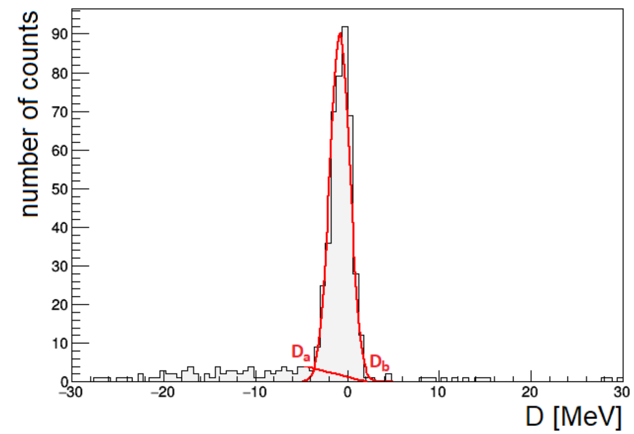
averaged theories:

$\theta_1 \pm 1°$, $\theta_2 \pm 1°$, $\varphi_{12} \pm 5°$

θ_1=28°, θ_2=30°, φ_{12}=180°



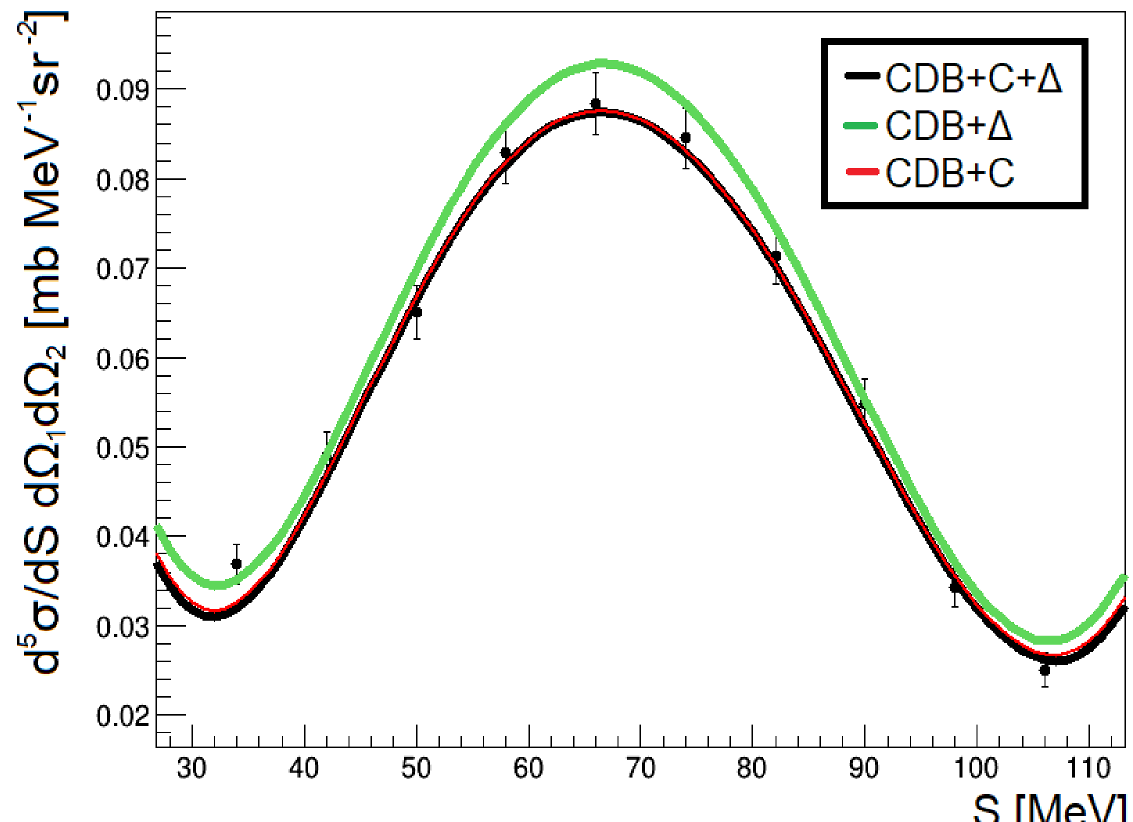




Arbitrary

Data

Normalization



averaged theories:

θ_1±1°, θ_2±1°, φ_{12}±5°

Summary of Data Analysis

1. Particle Identification
2. Energy Calibration
3. Selection of Kinematics Configuration of Breakup Reaction
4. Background subtraction

DONE ☺

5. Determination of Detection Effficiency → **IN PROGRESS**

6. Normalization to Cross Section of Elastic Scattering
7. Comparison of Differential Cross Section for $^{2}H(p,pp)n$ Reaction at 108 MeV

TO DO !

Outlook

- The preliminary analysis of the data taken with the **BINA detector at CCB** demonstrates a proper and efficient functioning of the forward part of this detector;
- **New data will be collected** with high statistics for 108, 135 and 160 MeV.

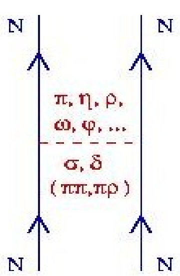
Thank you for your attention!

Theoretical calculations – Two Nucleons

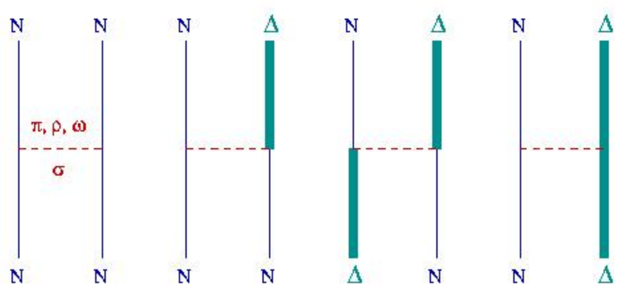
1) **Realistic Potentials** – meson exchange theory of NN forces – ph*enomenological* short range part (CD Bonn, Nijm I, Nijm II, AV18);

2) **Coupled-Channel Potential** with Δ-isobar excitation – CD Bonn + explicit treatment of a single Δ-isobar degrees of freedom;

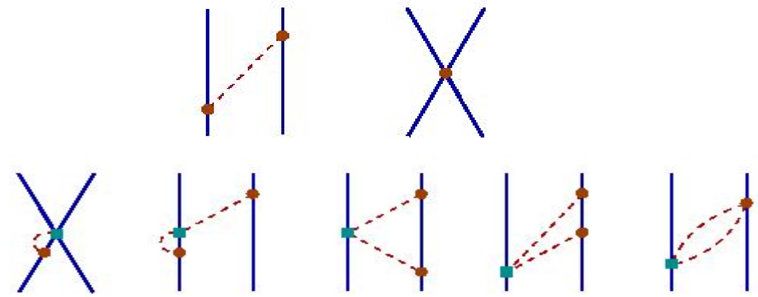
3) **Ch**iral **P**erturbation **T**heory (ChPT) – expansion of potential in powers ν of small external momenta Q, $(Q/\Lambda_\chi)^\nu$, with $\Lambda_\chi \approx 1$ GeV;



Realistic Potentials



Coupled-Channels Potential (single Δ)



Chiral Perturbation Theory Potential (2π exchanges & contact terms)