Differential Cross Section for Proton Induced Deuteron Breakup at 108 MeV

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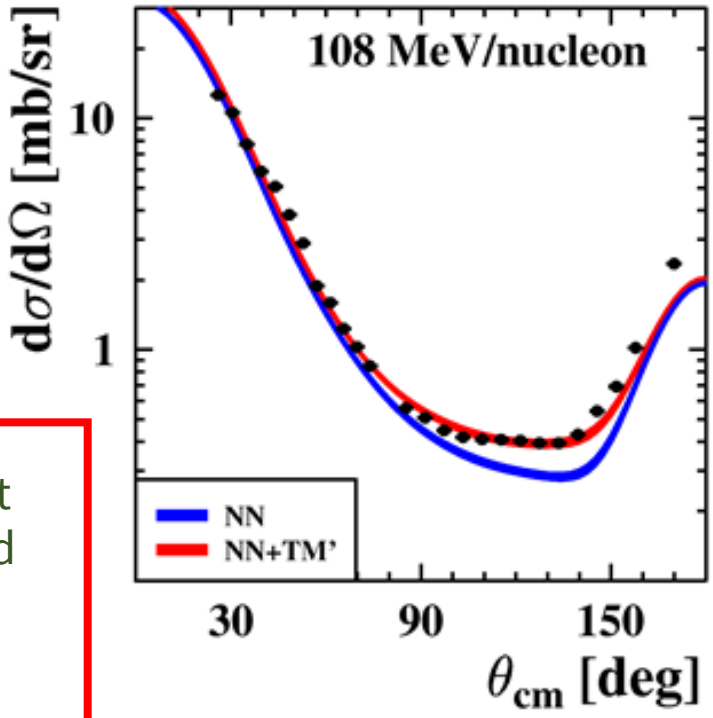
Three Nucleon (3N) System

➢ **Prediction of the nucleon-nucleon (NN) potentials:**

- **Very well describe** of the experimental data for the **2N system;**
- Do **not reproduce** even the **binding energy** of the **^{3}H** and **^{3}He** and heavier system;
- **Fail to reproduce** the **minimum** of **the d(N,N)d elastic scattering** cross section;



➢ **Introducing the Three-Nucleon Force (3NF)** as a concept **of additional dynamics** related to the presence of the third nucleon **solves these problems;**

➢ In **ChEFT**, the **3NF naturally appears** in the NNLO;

WHY DO WE WANT TO STUDY 3N SYSTEM

➢ Observables can be calculated in ab-inito regime;

➢ The environment is non-trivial as compared to NN systems and probably reacher in dynamics;

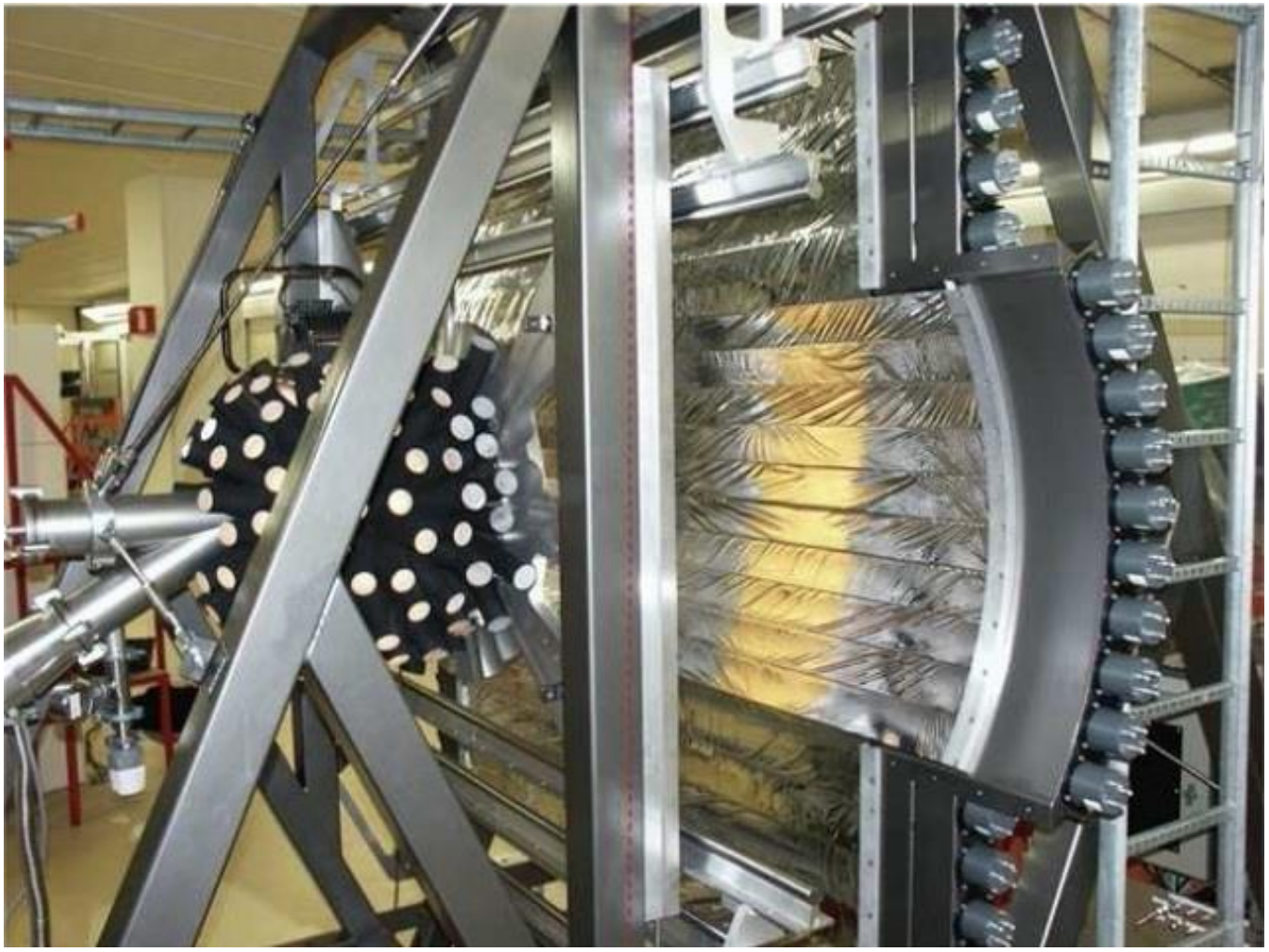
➢ The nuclear potentials tested in those simple systems can be used in more complicated ones;

➢ To learn about nuclear interactions.

Studies of 3N System with BINA@CCB

BINA – Big Instrument for Nuclear-Polarization Analysis

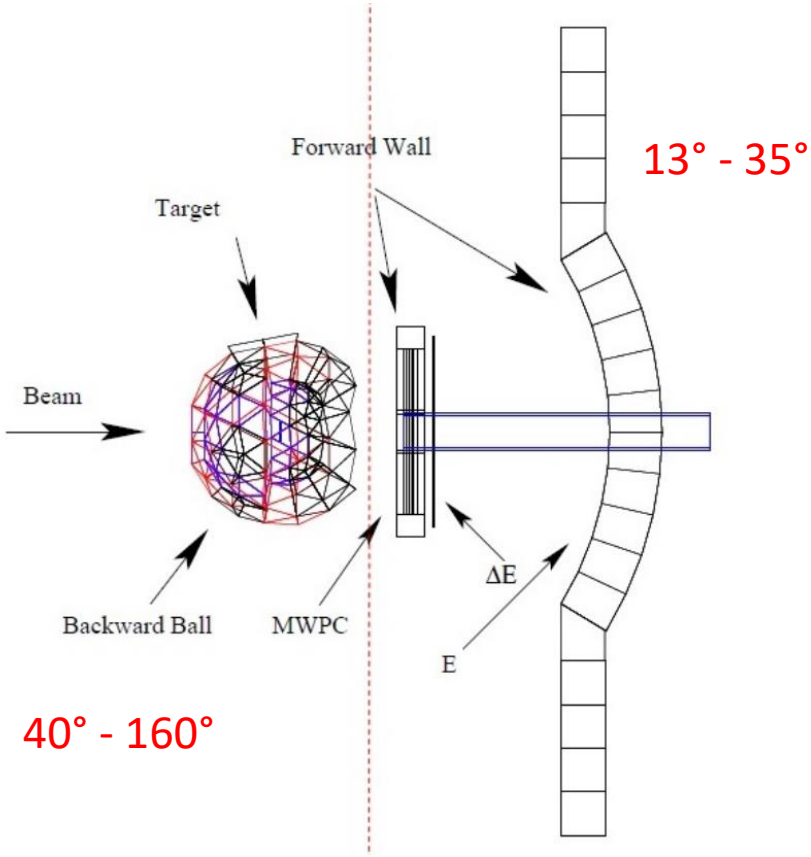
- Experimental program:
  - Measurement **of ^{2}H(p,pd)** elastic scattering at **108, 135 and 160 MeV;**
  - Measurement of **^{2}H(p,pp)n** breakup reaction at **108 and 160 MeV** for over 200 kinematic configurations;
- **The aim:**
  - Studies of **3NF**;
  - Verification of predicted **Coulomb** and **relativistic effects**;
  - Tests of upcoming **ChEFT calculations;**



Experimental setup

- **The forward part of detector (Wall):**

1. Multi-Wire Proportional Chamber (**MWPC**):
   - ➢ **3 anode wire plane** allowing recontruct the exact **information about emission angle** of the outgoing charged particles
2. **ΔE-E hodoscopes**:
   - ➢ Two layers of plastic scintillators: **24 vertically-placed** thin transmission-**ΔE strips** and **10 horizonally-placed** thick stopping-**E bars**

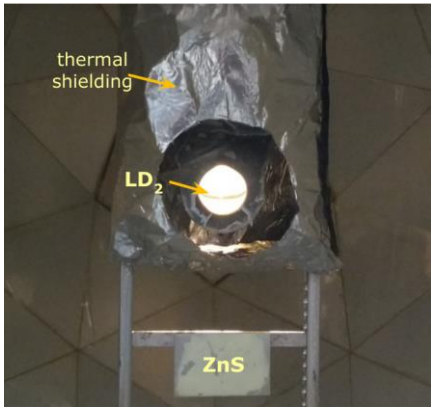


- **The backward part of detector (Ball):**

➢ System of **149 phoswitch** (phosfor sanwich) - combination of scintillators with **dissimilar pulse shape characteristics** optically coupled to each other and to a common PMT

➢ The target system located inside the Ball:

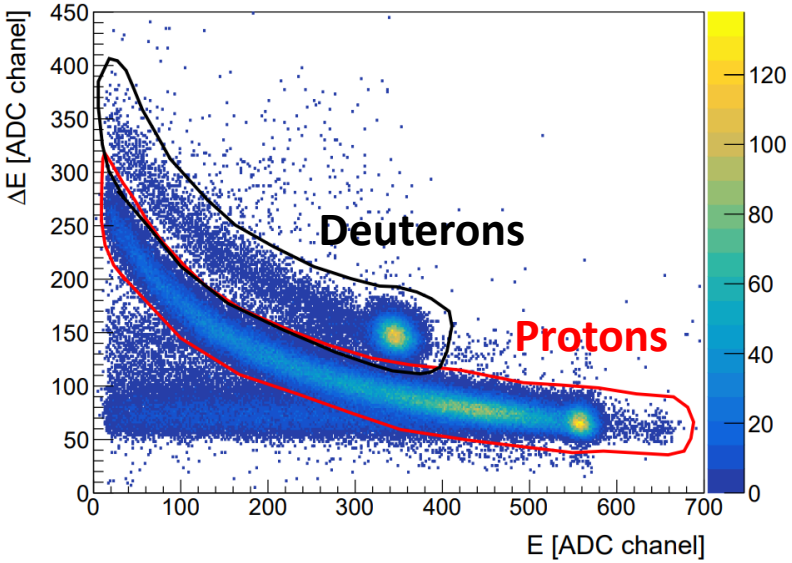
1) LD_2 target
2) Al target with a thin ZnS layer (callibration runs)



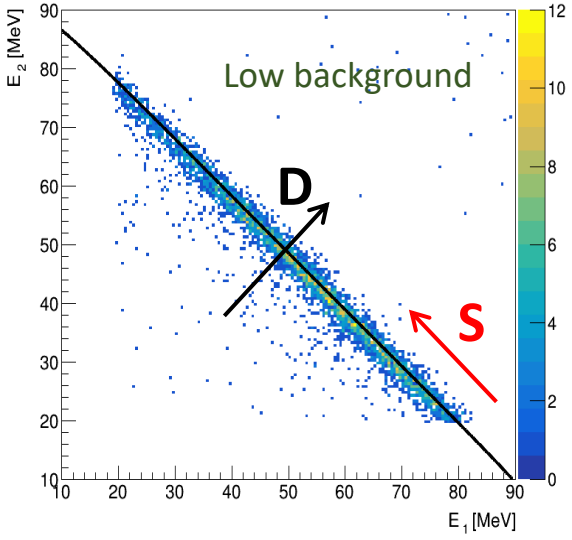
DATA REGISTERED **ONLY** BY THE **FORWARD WALL**!

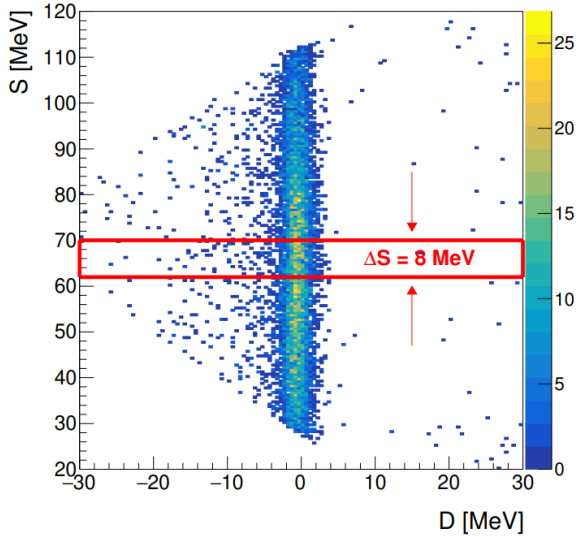
The measurement of the ^{2}H(p,pp)n at 108 MeV

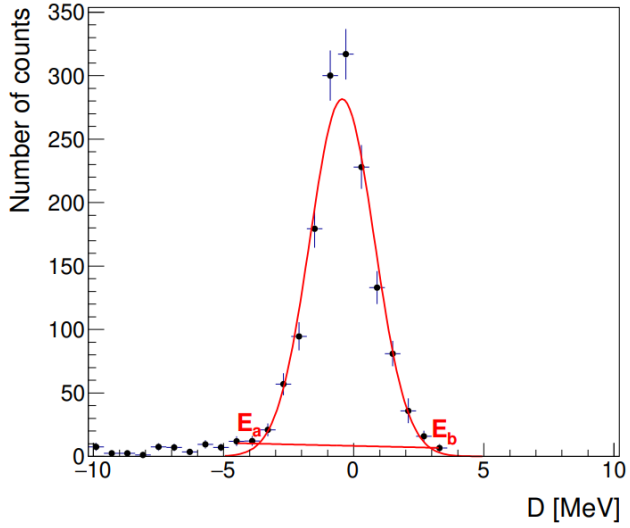
- Results of the **first experimental run** at 2016;
- Particle Identification procedure is based on the **ΔE-E technique**;
  - Perpendicular arrangment allows to build **two-dimmensional spectra** where **protons** and **deuterons** distribution can be **well distinguished**;
  - The gates are **wide enough** to **avoid a significant loss** of particles -> the slight overlap of them is allowed;
- The **excellent efficiency** of the Wall detectors;
- The events identified as **proton-proton coincidences** were analyzed event-by-event and sorted according to angular configurations;



$$\theta_1 = 20°, \theta_2 = 24°, \varphi_{12} = 160°$$







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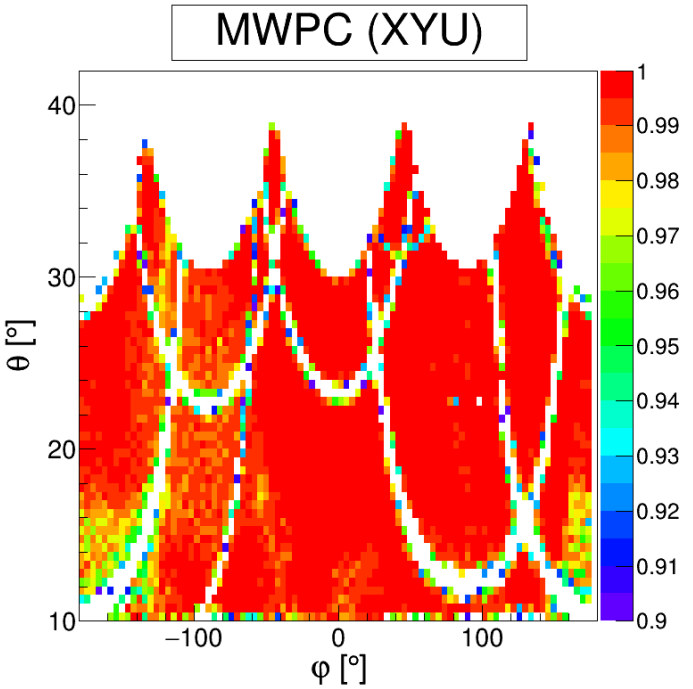

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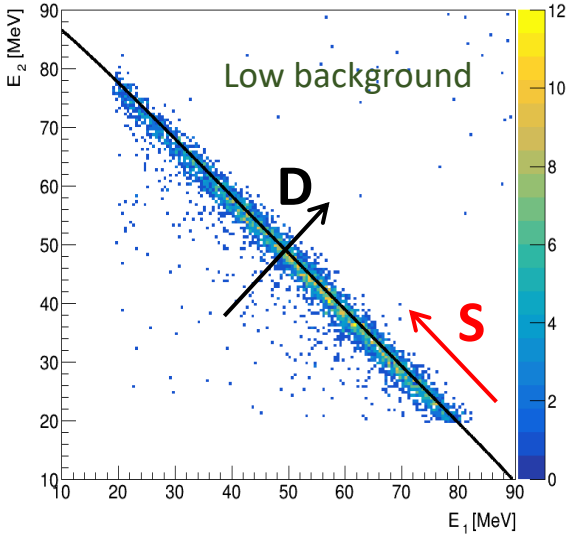
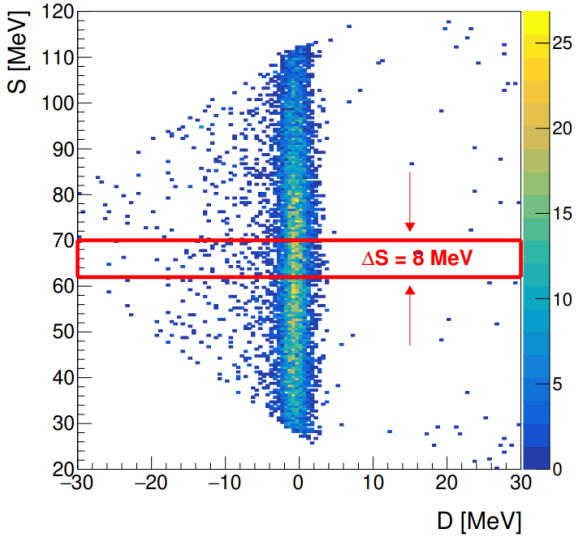
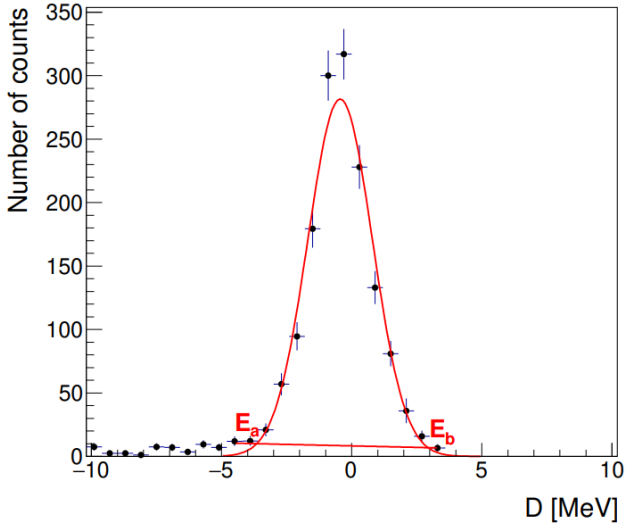




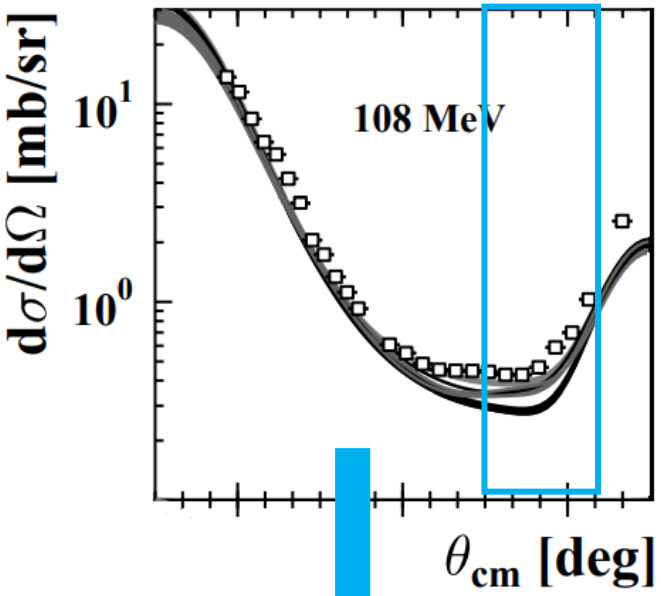


^{2}H(p,pp)n breakup cross section

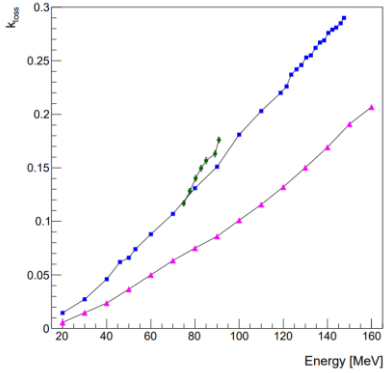
- Data analysis of the elastic scattering:
  - **Deuterons** from **elastic scattering** were the basis of the **normalization** procedure to a known cross section at 108 MeV – *Ermisch et al., Phys. Rev. C 71, 064004 (2005) – data with the systematic uncertainty between 4.4% - 6.5%*

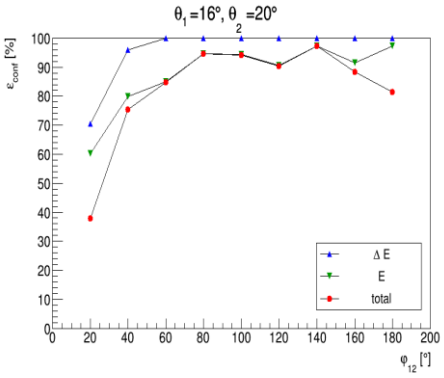
- Corrections: **hadronic interactions, Wall efficiency, Edge events, configurational efficiency;**

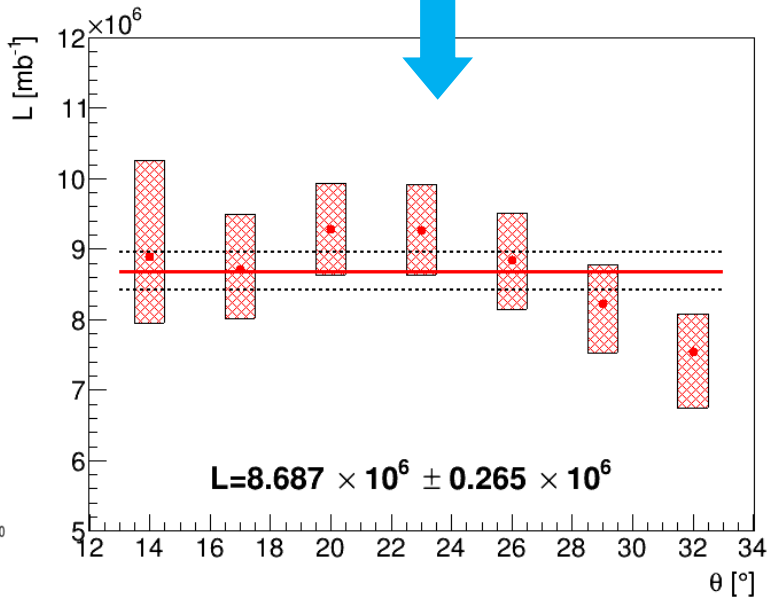
- **Statistical** and **systematic uncertainties** taken into account;



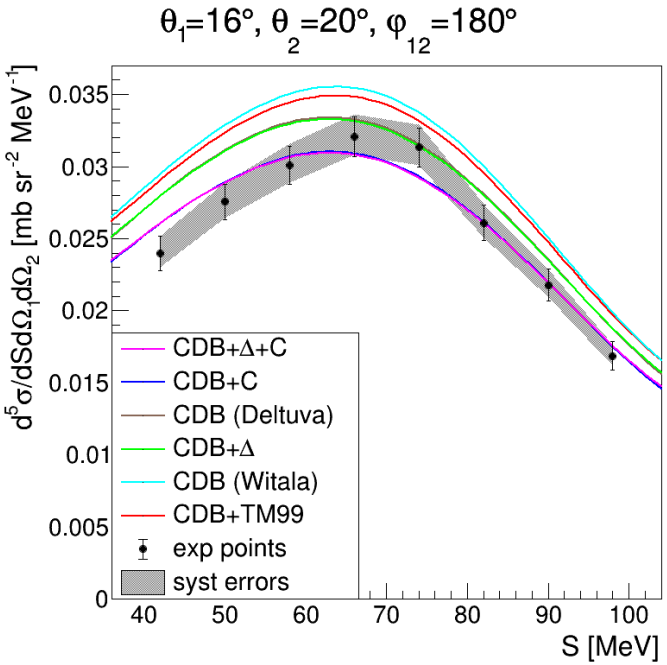
Sources of errors	The impact on breakup cross section [%]
Statistical uncertainties	$6-24\%$
Total systematic error	$3.9-8.5\%$
· Normalization	3%
· Particle identification	1%
· Configurational efficiency	$0.01-7\%$
· Hadronic interaction	1%
· Energy calibration	
+ angle reconstruction	
+ detector efficiency	1%
· Trigger efficiency	3%

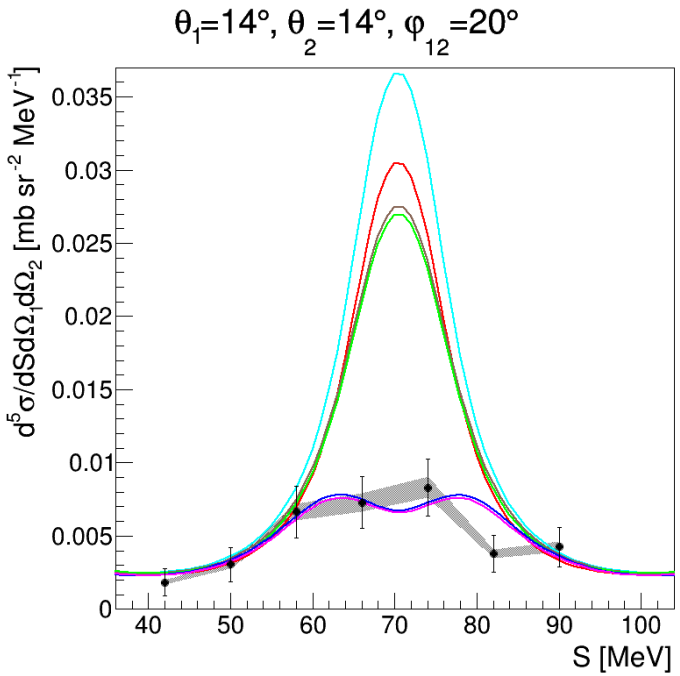






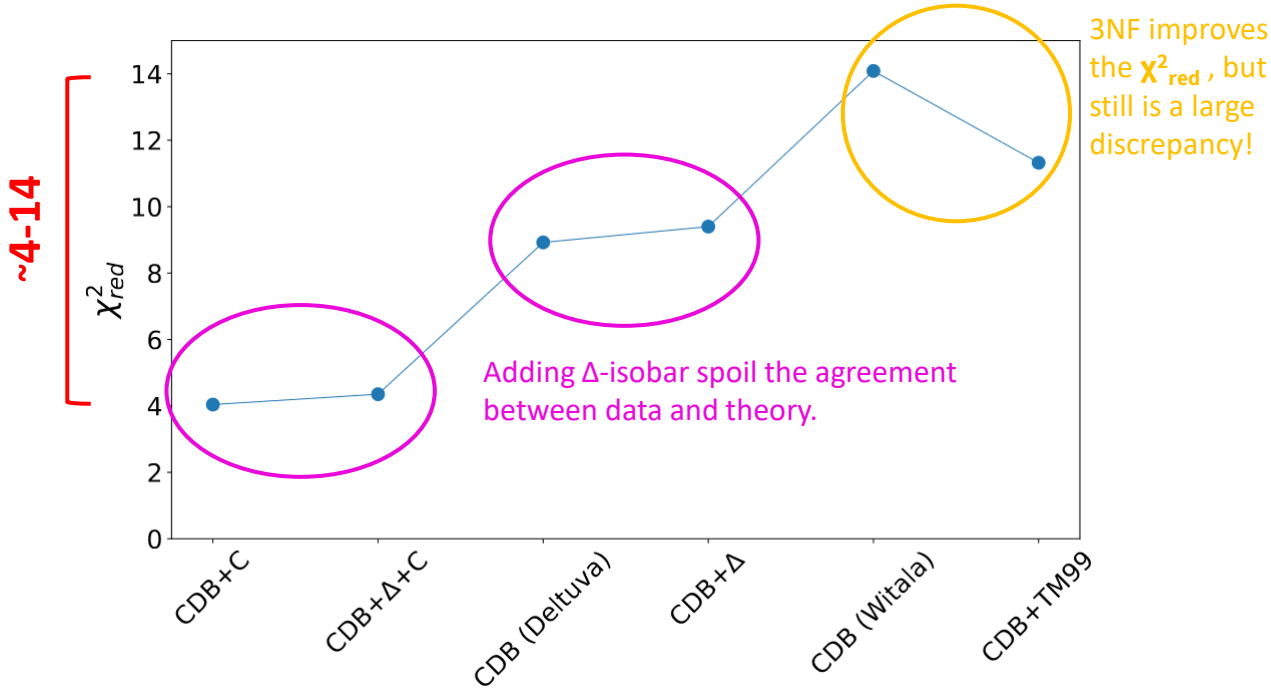
Results and comparison with theory





- The differential cross section obtained for a set of **252 angular configurations**; polar angles **θ from 13° to 27°,** and azimuthal angle **φ_{12} from 10° to 180°** ⟶ **1767 data points**;

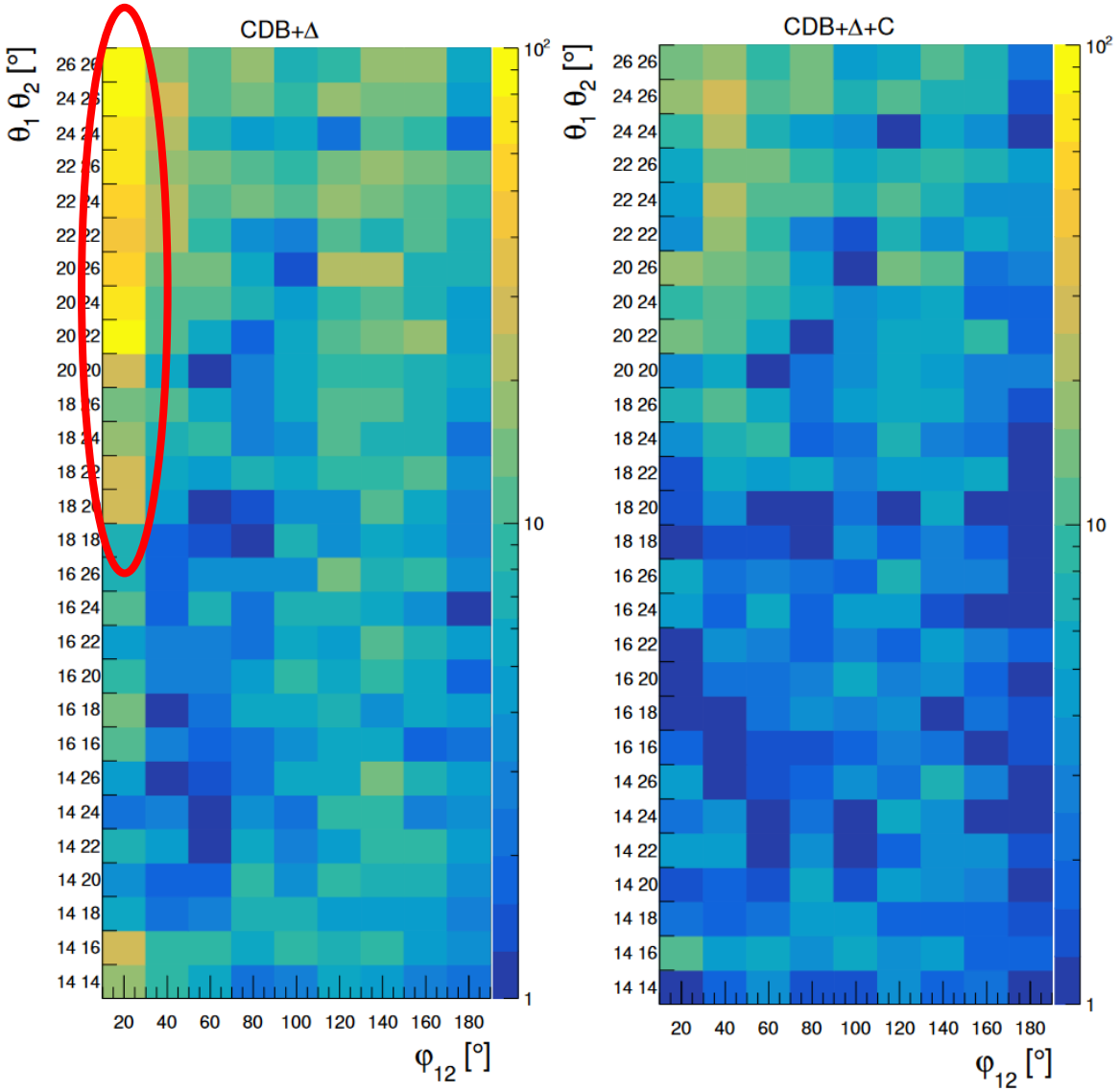
$$\chi^2_{red} = \frac{1}{N}\sum_{i=10}^{N}\left(\frac{\sigma_i^{exp} - \sigma_i^{th}}{\Delta\sigma_i^{tot}}\right)^2$$



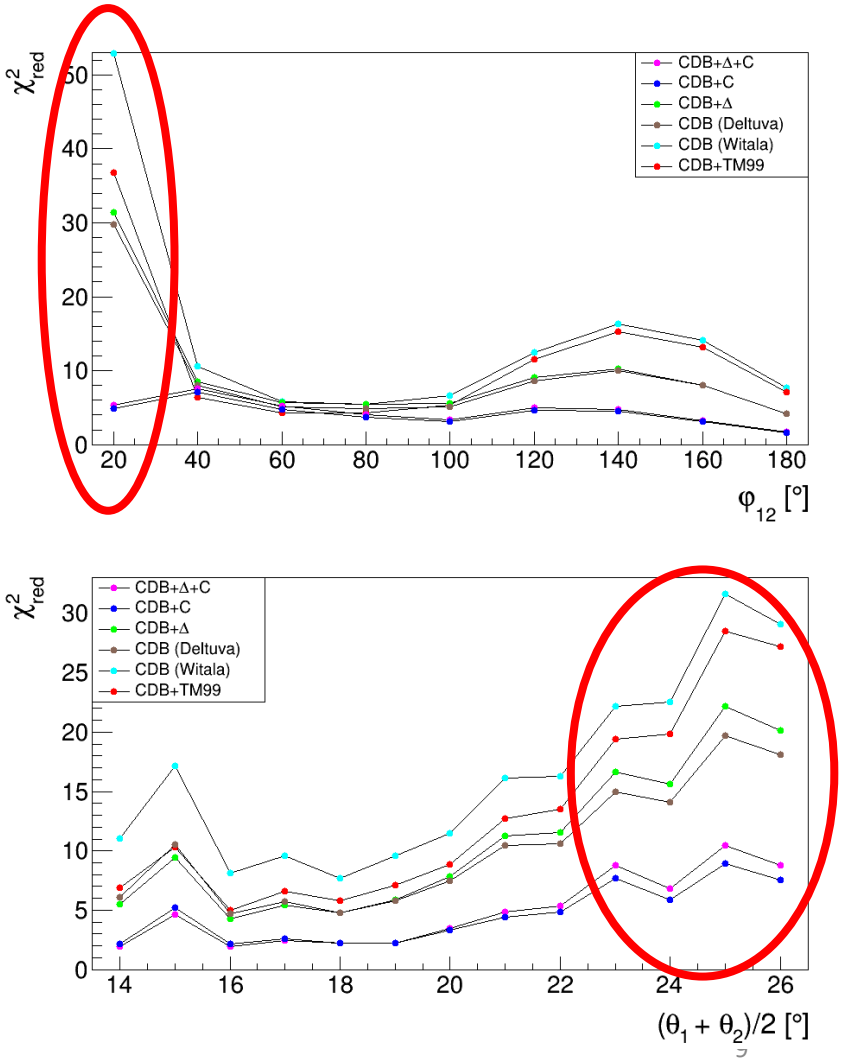
- The **global χ^2_{red}** results strongly **depend** on the **theoretical model;**
- Calculations performed by Witała have **the worst agreement**;
- The impact of the χ^2_{red} by **adding the Δ-isobar is very low and even spoil** the agreement;

Results and comparison with theory

- **Giant disagreement** between the data and theories
- **Significant improvement** in the description when the **Coulomb force is included**;

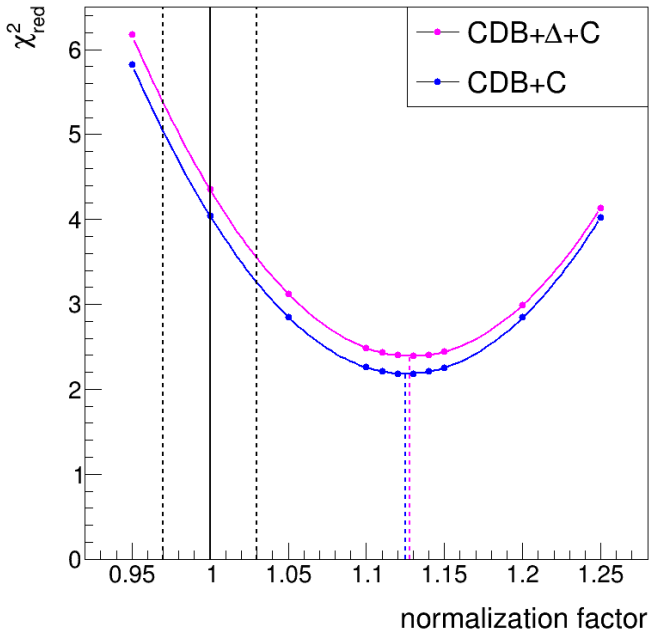


- The **smallest φ_{12}** in the upper part;
- The **higher** polar angles θ_1 and θ_2;
- The greatest discrepancy is for **φ_{12}=20°**



Discusion of the experimental results

Additional test



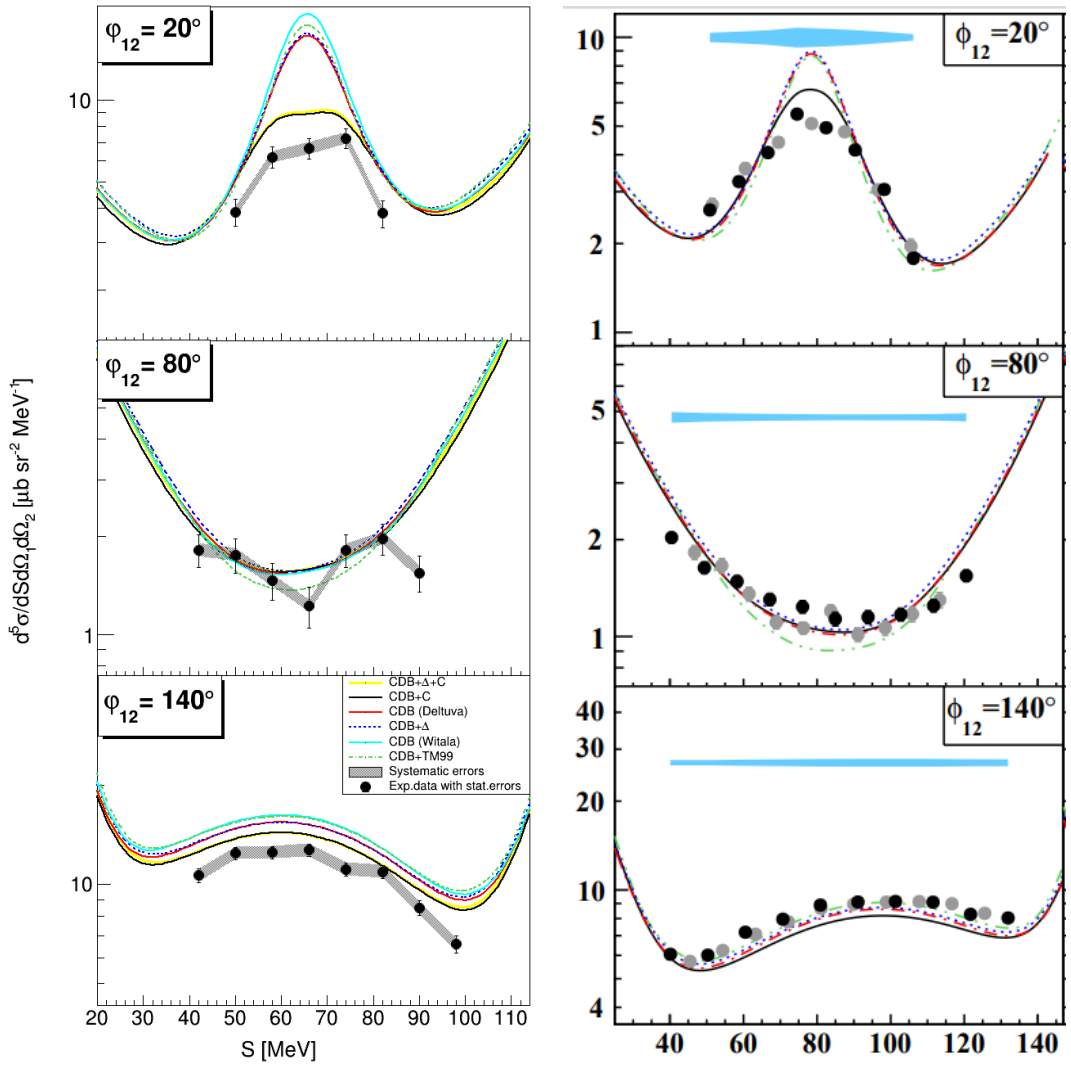
- The value of the cross section **multiplied by a factor** ranging from **0.95 to 1.25**, and the X^2_{red} was again determined;
- By a fitting the parabola we can find the **minimum chi-squere** value:

X^2_{red} = 2.395 for a factor of 1.128

X^2_{red} = 2.185 for a factor of 1.125

θ_1=20°, θ_2=24°,

CCB data, 108 MeV **KVI data, 135 MeV**



The best agreement of cross-section distribution shapes is obtained for **normalization greater by 13%**

Summary and outlook

- The **Coulomb** interaction has to be **necessarily included in the theoretical description**;
- The effect of the **3NF is negligible** in the presented data;
- Analysis of the global **chi-square** and the **additional test** suggest that **the best agreement** of cross-section distribution shapes is obtained **for normalization greater by 13%**;
- **Verification of normalization - direct measurement of the absolute value** of the differential cross-section by using the **solid CD_2 target** and determine the luminosity value;
- **Combining the current data** with the data set collected in **2019** which should **double our statistics**;
- Comparing the results with **other theoretical prediction** including Coulomb, based on the different NN potential (**Av18**) and the Urbana-Illinois X (**UIX**) 3NF model;
- Comparing our results with the **newly developed ChEFT** (only for the NNLO with the 3NF) **– the most interestig ideas**, but presented results indicates the necessity **to include the Coulomb** interaction into calculation.

Thank you for your attention!