Experimental studies of the three nucleon system dynamics in the proton induced deuteron breakup at 108 MeV

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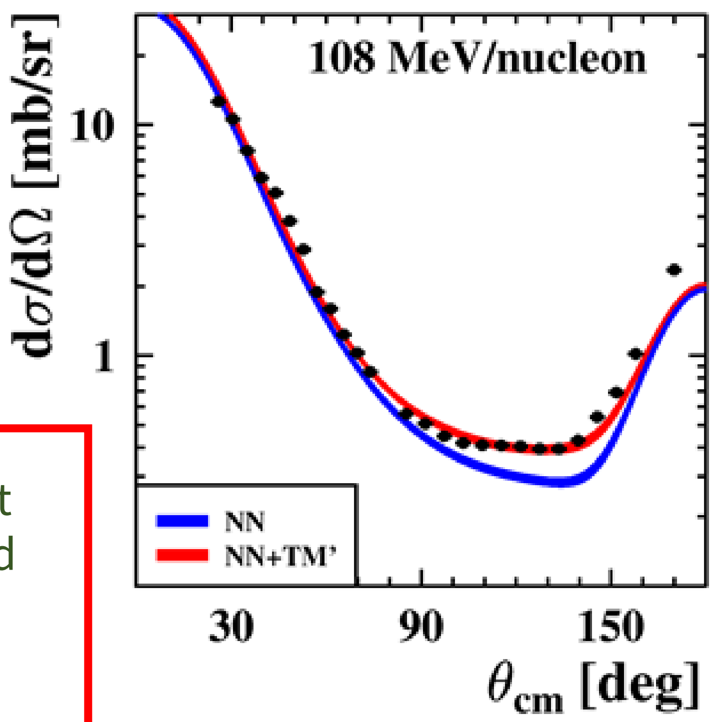
Three Nucleon (3N) System

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

- **Very well describe** the experimental data for the **2N system;**
- Do **not reproduce** even the **binding energy** of the ^{3}**H** and ^{3}**He** and heavier systems;
- **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;

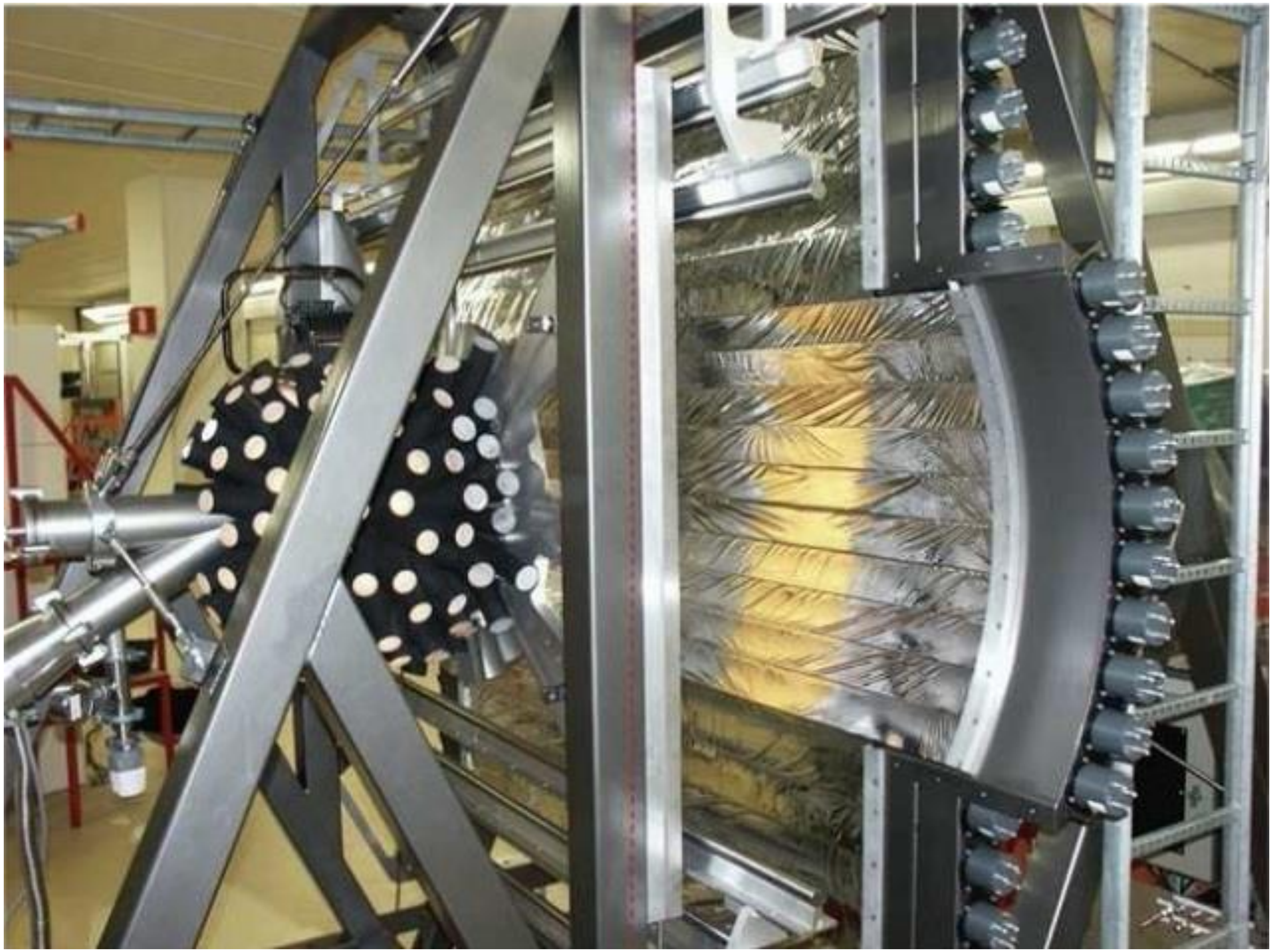
➢ The nuclear potentials tested in those simple systems can be used in more complicated ones;

➢ To learn about nuclear interactions.

Studies of 3N System with BINA@CCB

BINA – Big Instrument for Nuclear-Polarization Analysis

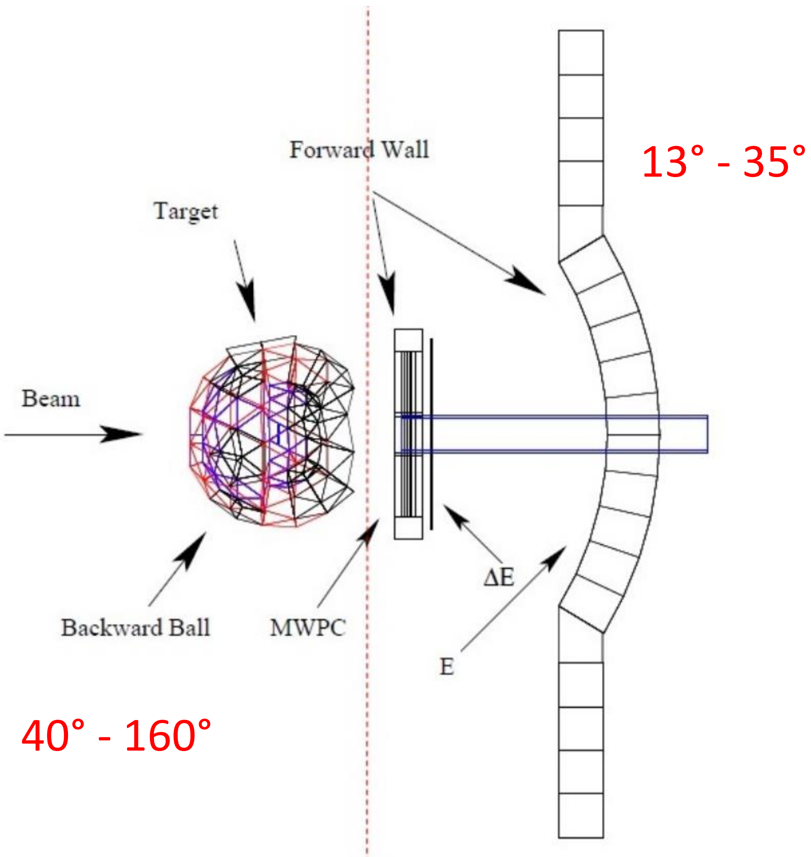
- Experimental program:
  - Measurement **of ^{2}H(p,pd)** elastic scattering at **108, 135 and 160 MeV;**
  - Measurement of **^{2}H(p,pp)n** breakup reaction at **108 and 160 MeV** for over 200 kinematic configurations;
- **The aim:**
  - Studies of **3NF**;
  - Verification of predicted **Coulomb**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



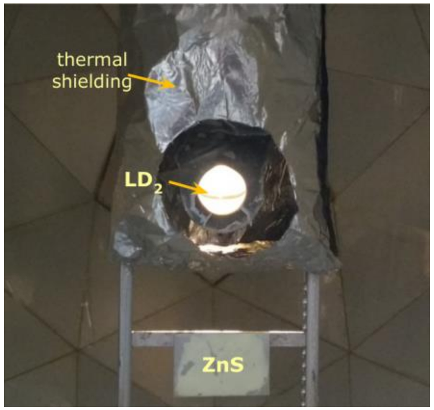
- **The backward part of detector (Ball):**

➢ 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:

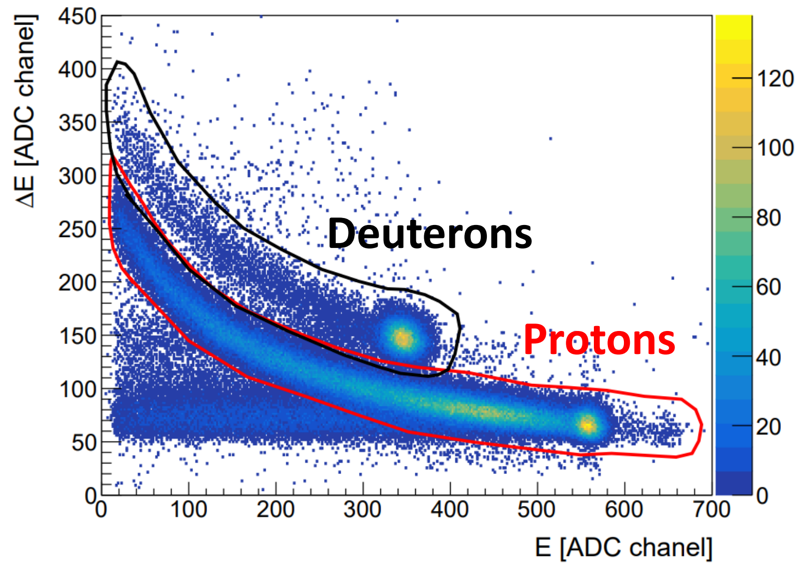
1) LD_2 target
2) Al target with a thin ZnS layer (callibration runs)

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

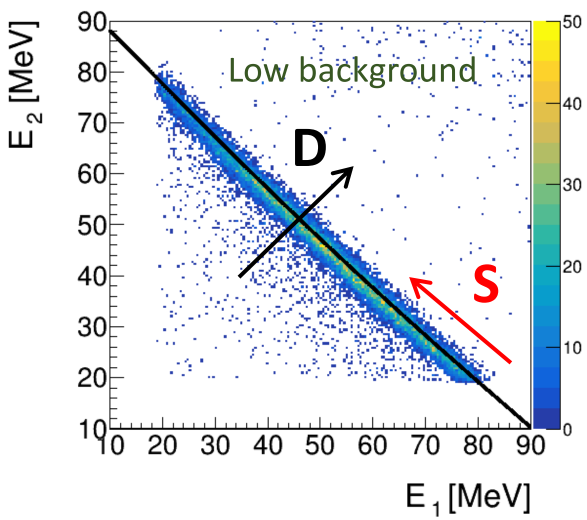


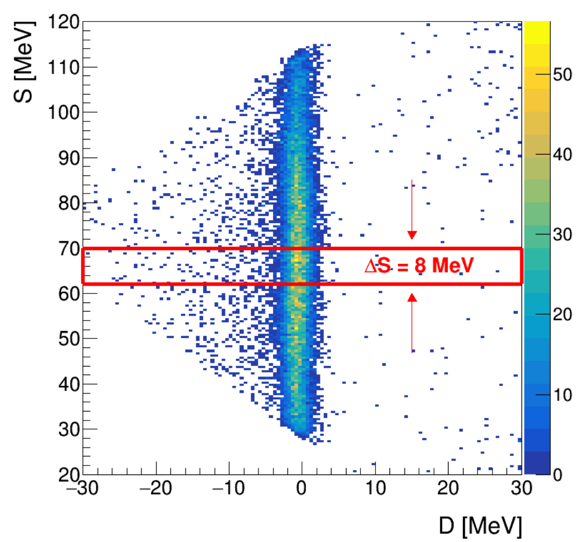
The measurement of the $^2H(p,pp)n$ at 108 MeV

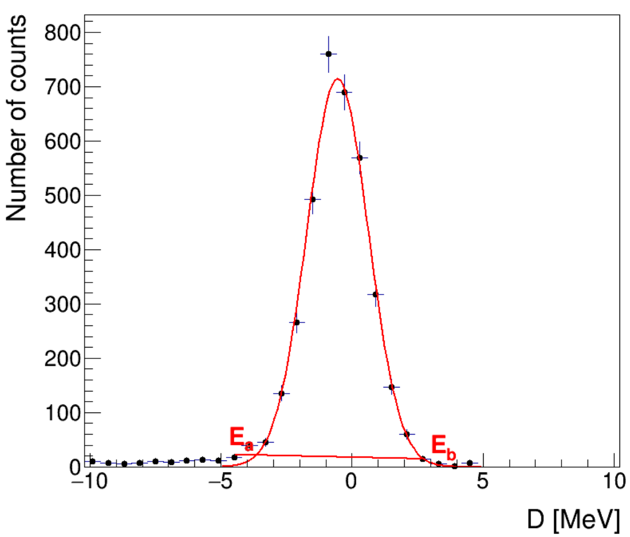
- Results of the **first experimental run** at 2016;
- Particle Identification procedure is based on the **ΔE-E technique**;
  - ➢ Perpendicular arrangment allows to build **two-dimmensional spectra** where **protons** and **deuterons** distribution can be **well distinguished**;
  - ➢ The gates are **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;



$$\theta_1 = 15°, \theta_2 = 19°, \varphi_{12} = 160°$$







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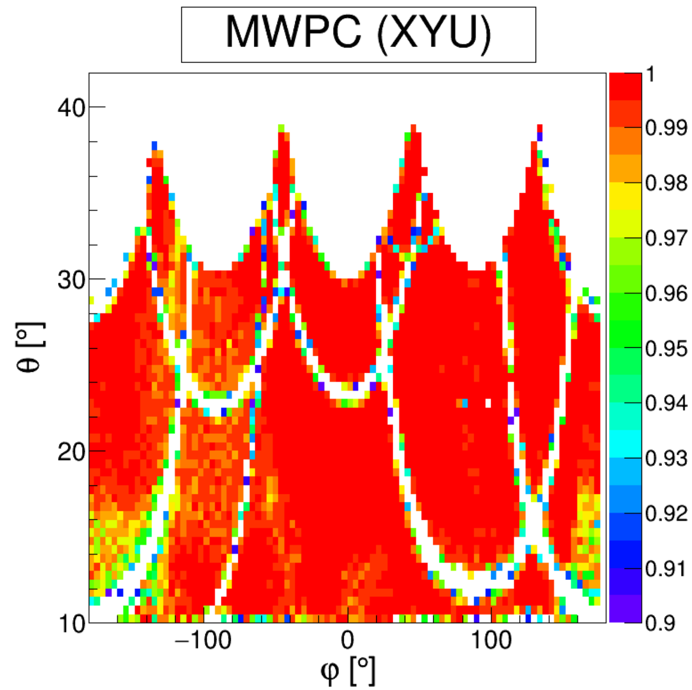

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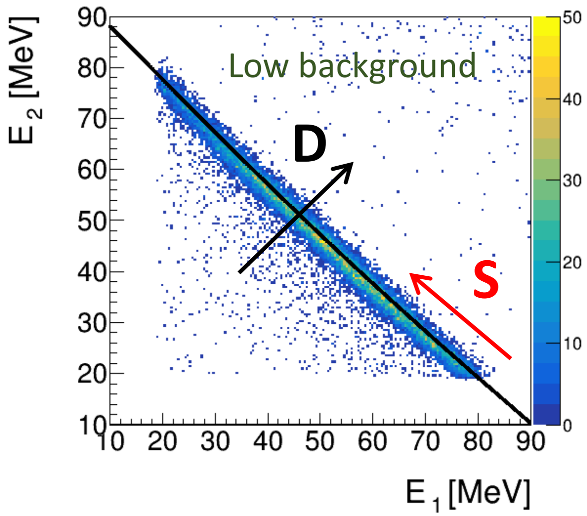
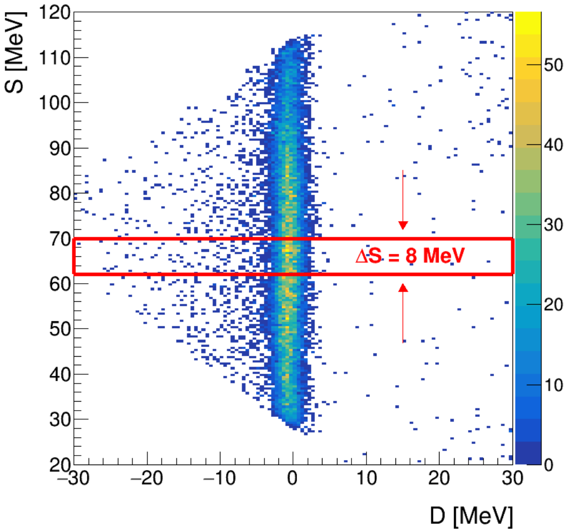
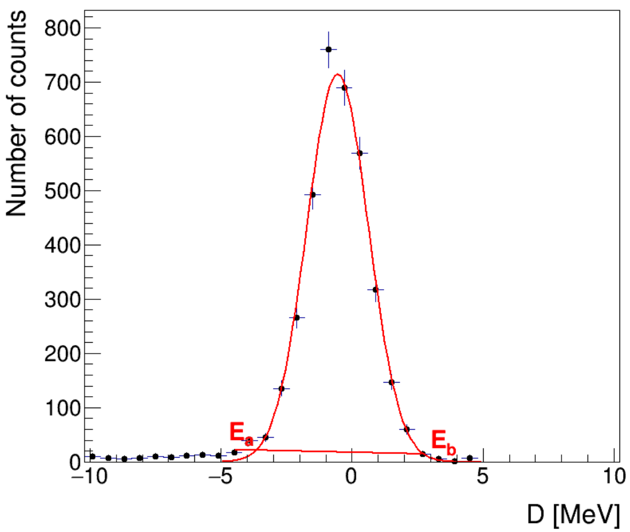
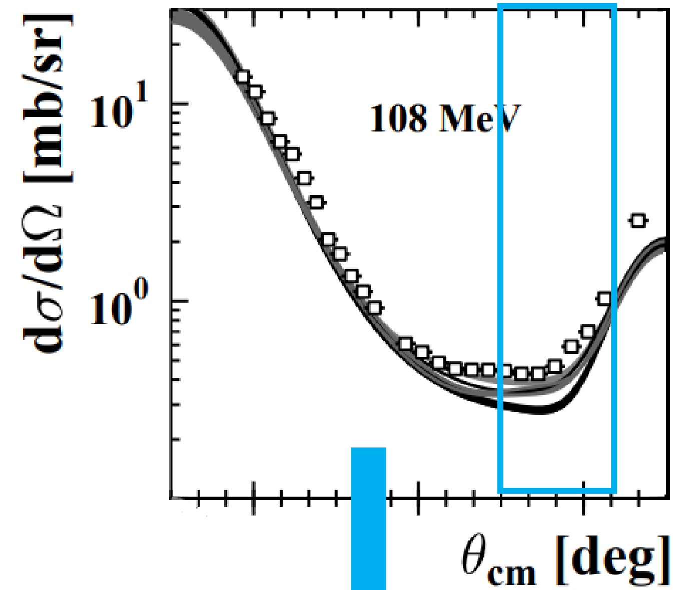






^{2}H(p,pp)n breakup cross section

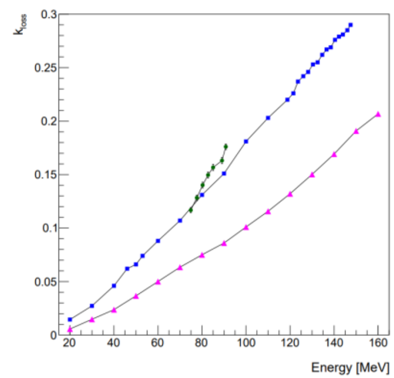
- Data analysis of the elastic scattering:
  - **Deuterons** from **elastic scattering** were the basis of the **normalization** procedure to a known cross section at 108 MeV – *Ermisch et al., Phys. Rev. C 71, 064004 (2005) – data with the systematic uncertainty between 4.4% - 6.5%*

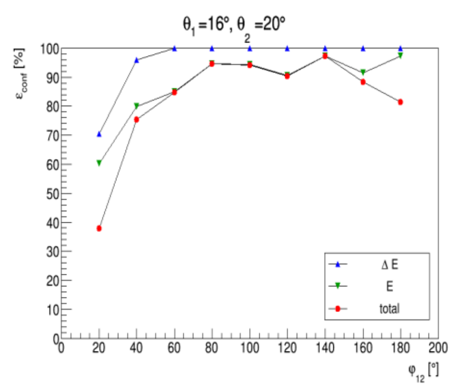


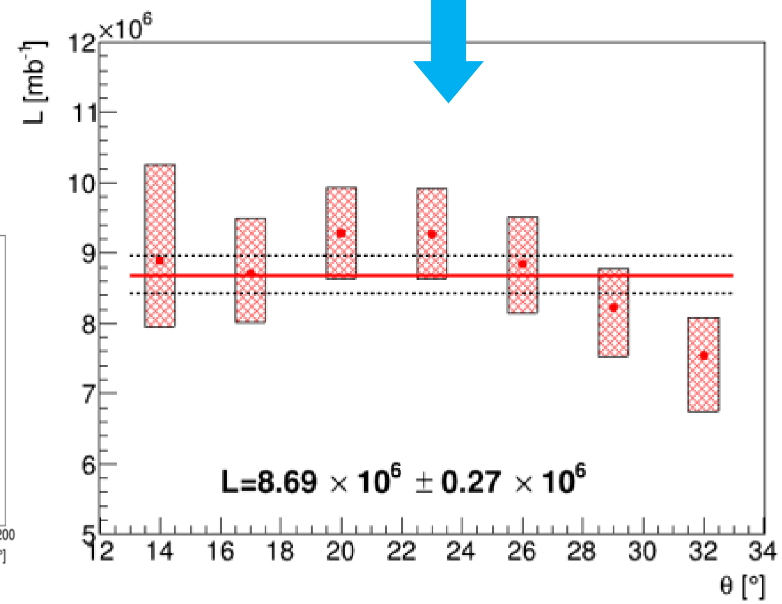
- Corrections: **hadronic interactions, Wall efficiency, Edge events, configurational efficiency;**

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

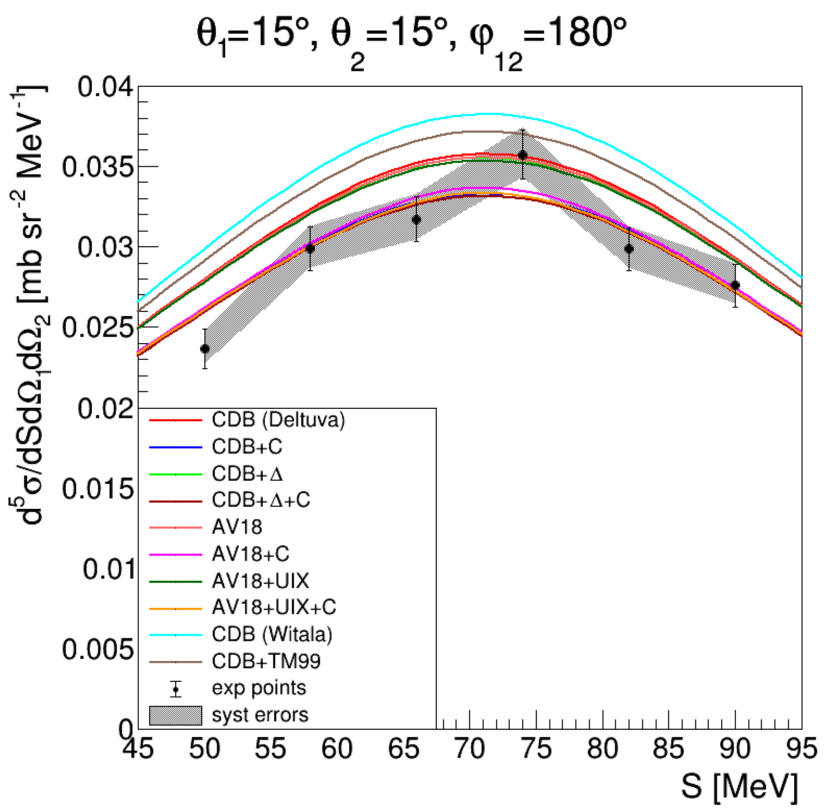
Sources of errors	The impact on breakup cross section [%]
Statistical uncertainties	2 – 11%
Total systematic error	3.9 – 8.5%
· Normalization	3%
· Particle identification	1%
· Configurational efficiency	0.01 – 7%
· Hadronic interaction	1%
· Energy calibration + angle reconstruction + detector efficiency	1%
· Trigger efficiency	3%

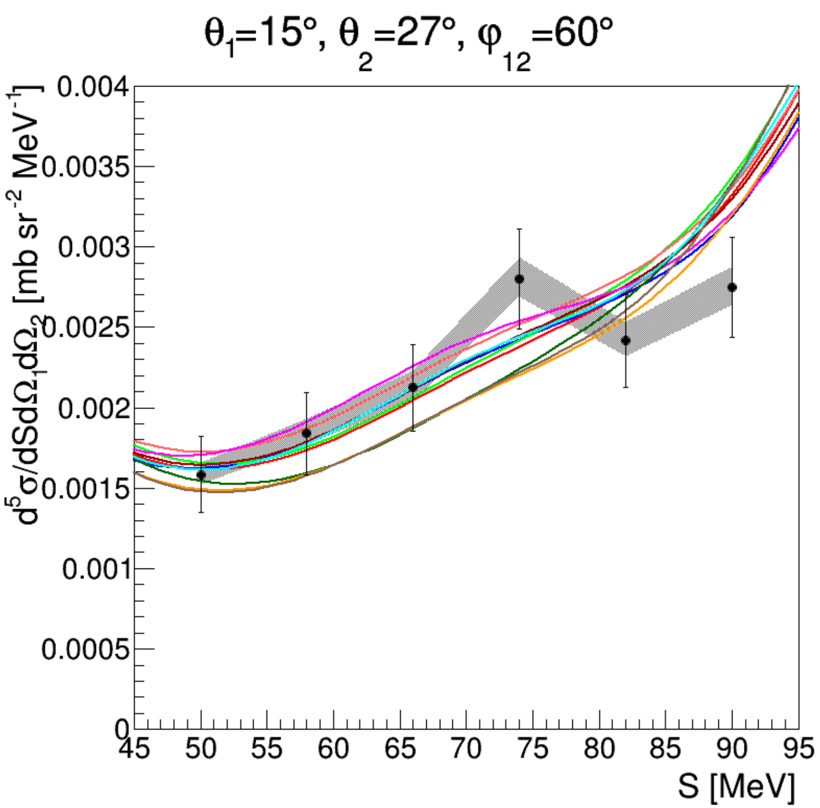






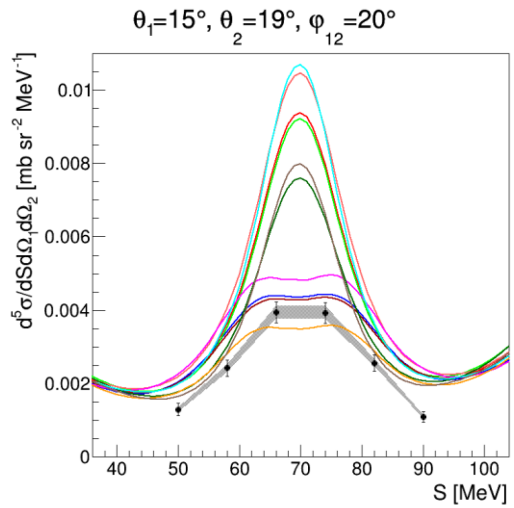
Results and comparison with theory





- The differential cross section obtained for a set of **84 angular configurations**; polar angles **θ from 13° to 33°,** and azimuthal angle **φ_{12} from 50° to 190°** ⟶ **503 data points**;

- **φ_{12} =20°** and **φ_{12} =40°** are **determined by Coulomb** interactions, so further **χ^2_{red}** analysis ignores these configurations;



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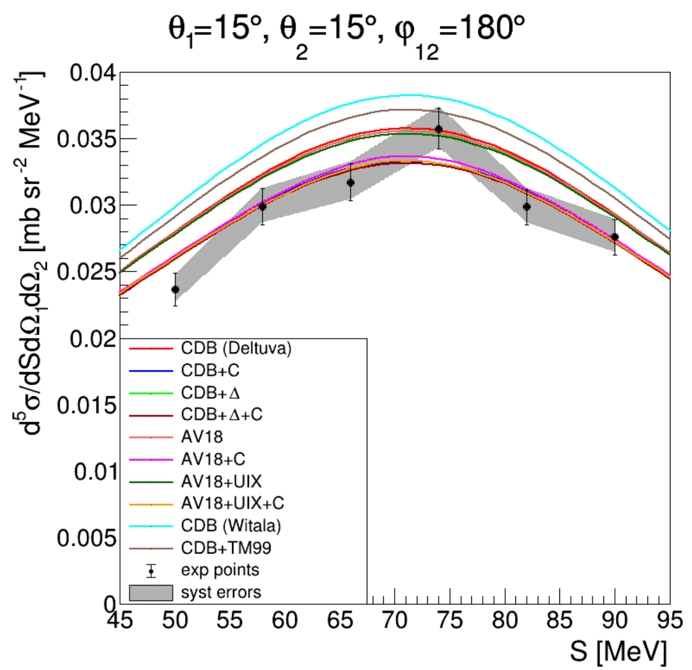
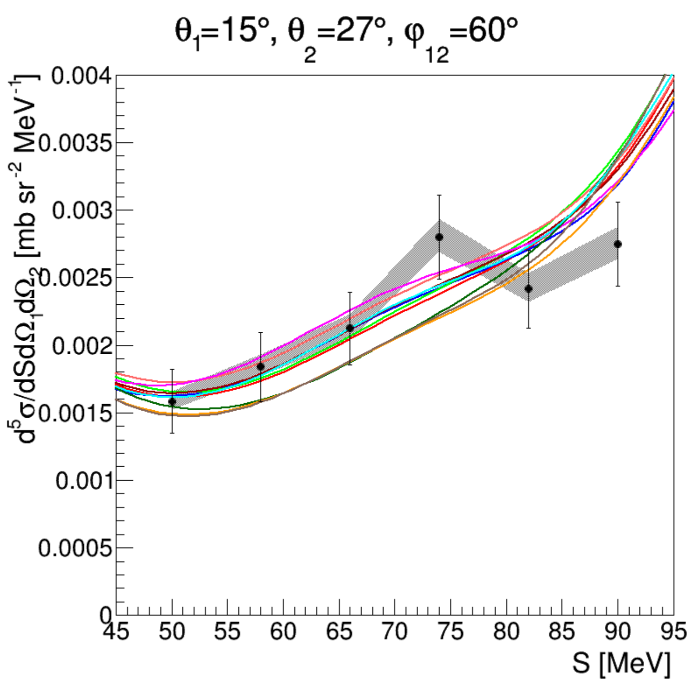
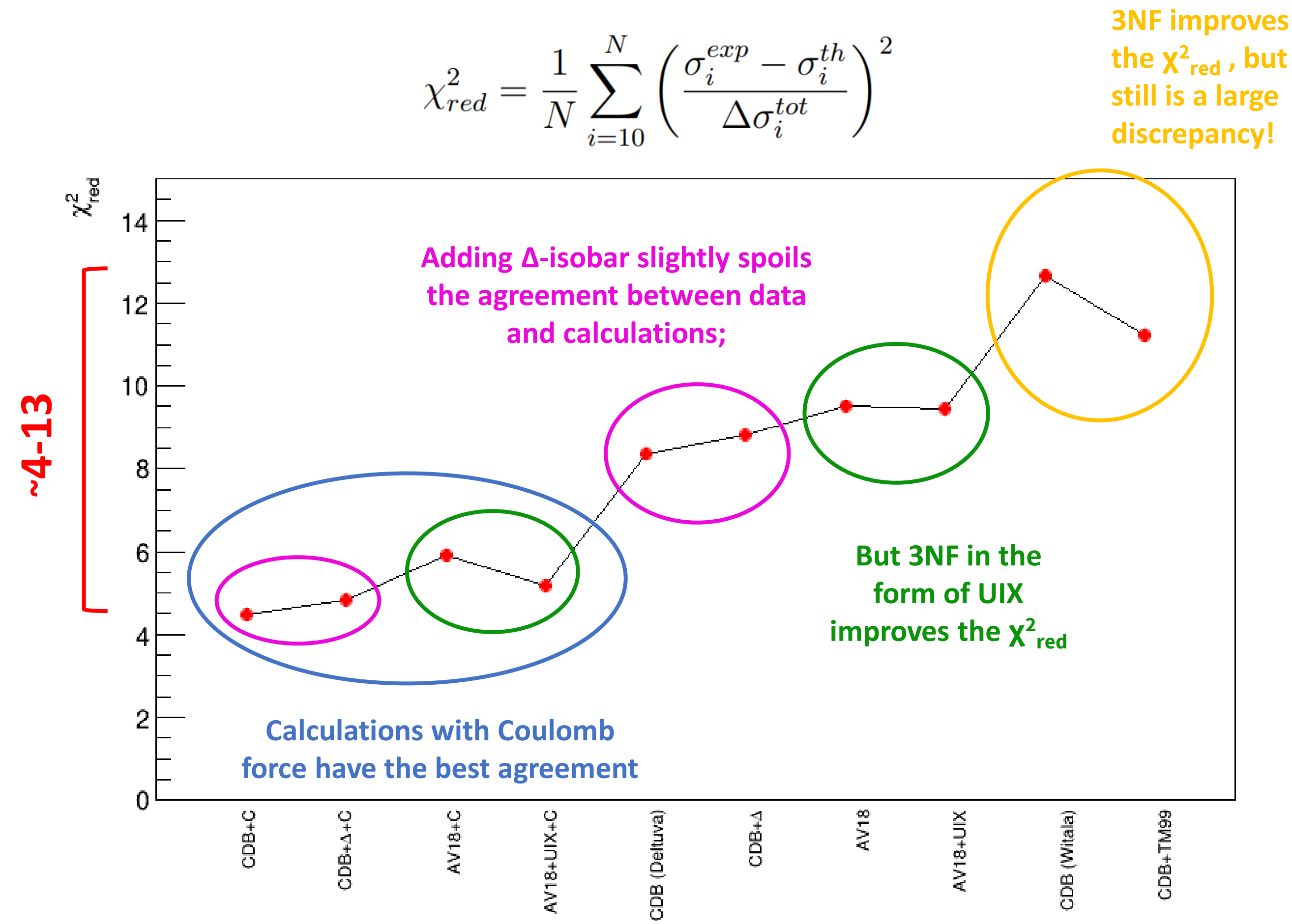




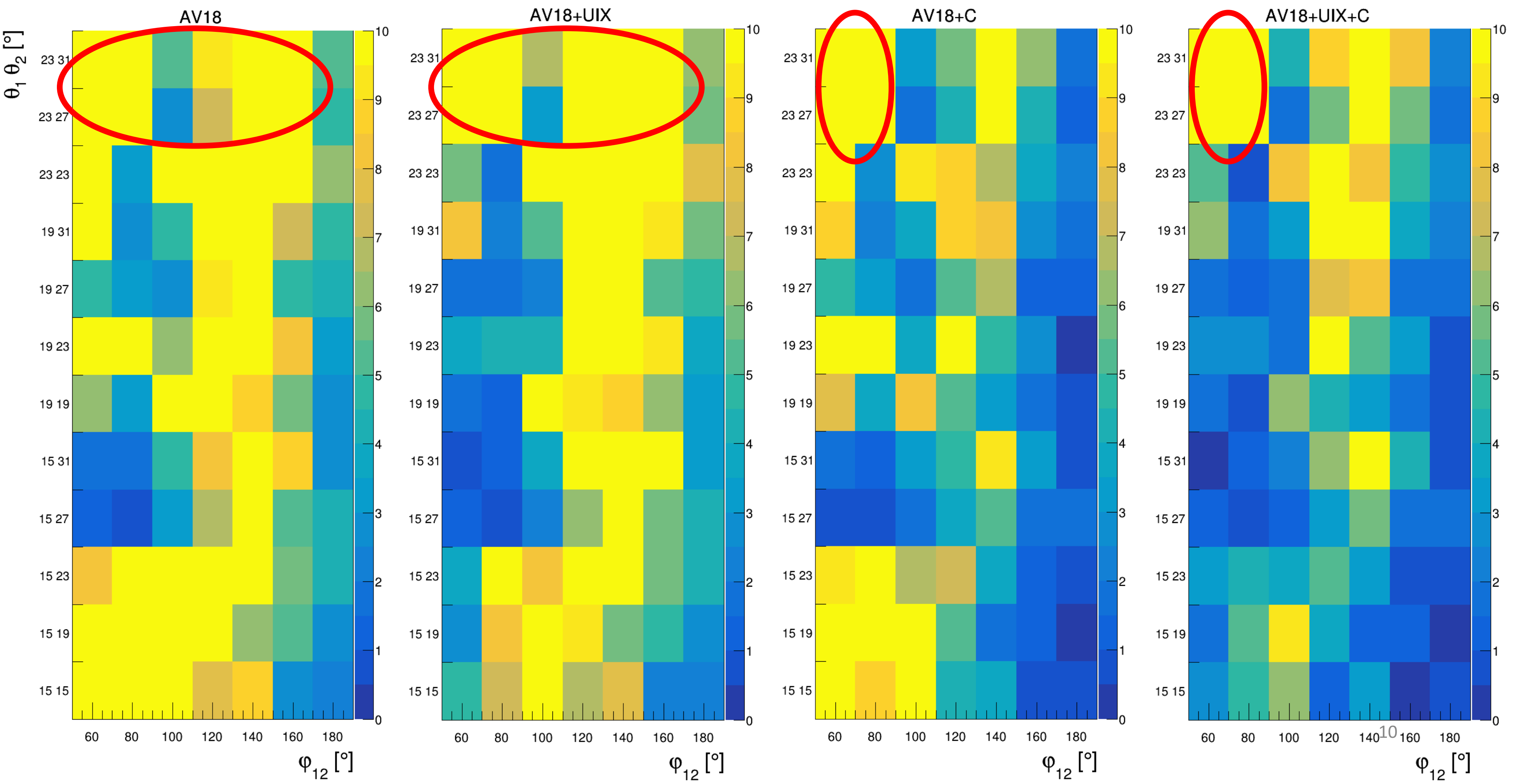
$$\chi^2_{red} = \frac{1}{N}\sum_{i=10}^{N}\left(\frac{\sigma_i^{exp} - \sigma_i^{th}}{\Delta\sigma_i^{tot}}\right)^2$$



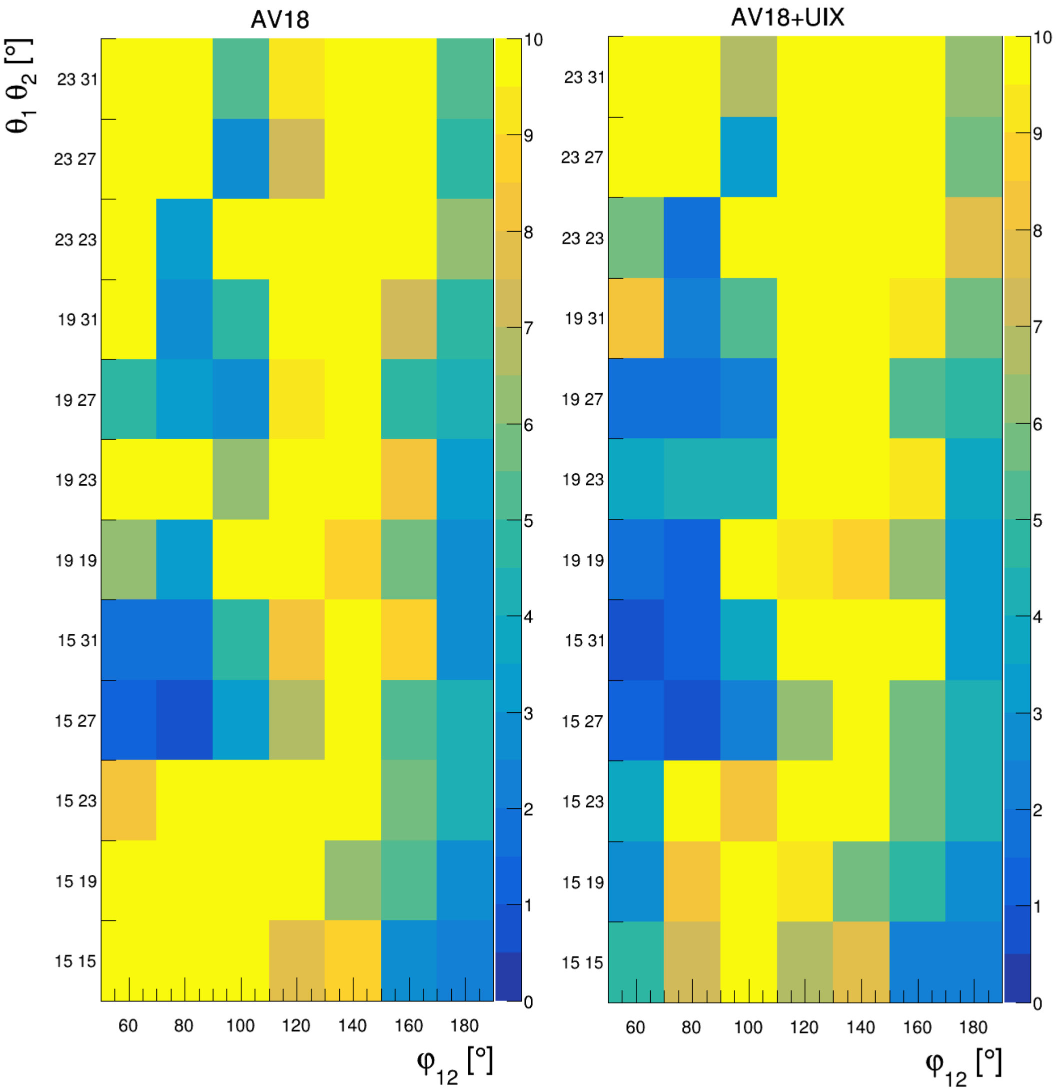
- The **global χ^2_{red}** results strongly **depend** on the **theoretical model;**
- Calculations **with Coulomb** force have the **best agreement**;
- The **effect of the 3NF** introduced **in Δ form is negligible**;
- The **TM99** and **UIX model of 3NF** introduce effects which are **more significant**.

Results and comparison with theory

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

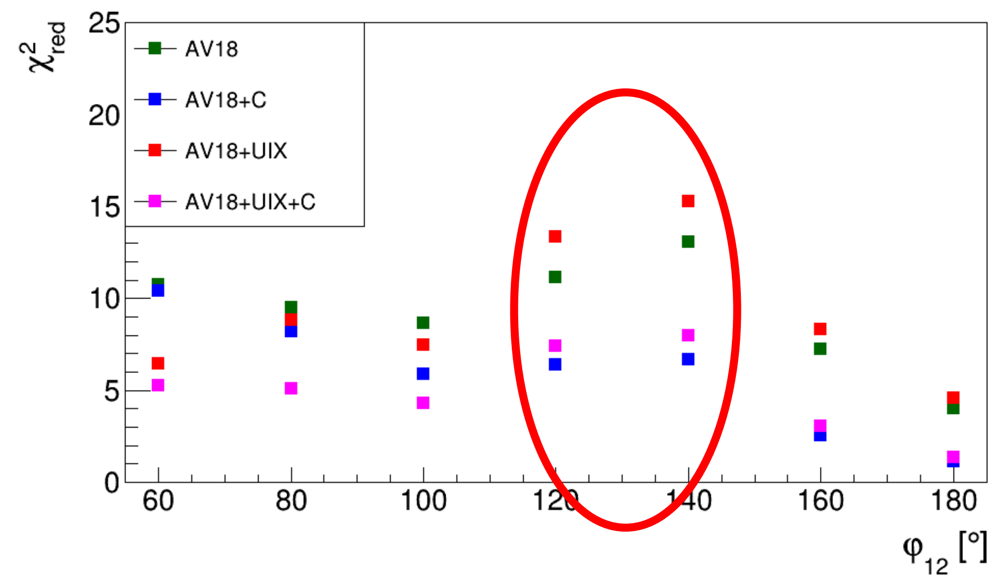


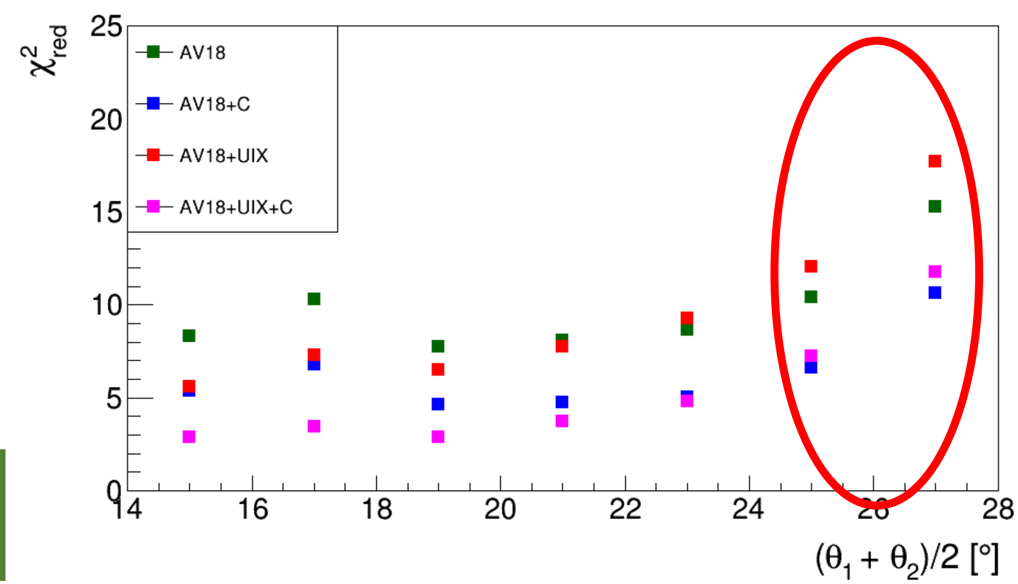
Results and comparison with theory



- **Problematic areas: correction related to configuration efficiency averaged over several configurations**

- The greatest discrepancy is for $\boldsymbol{\varphi_{12}=120°}$, $\boldsymbol{\varphi_{12}=140°}$

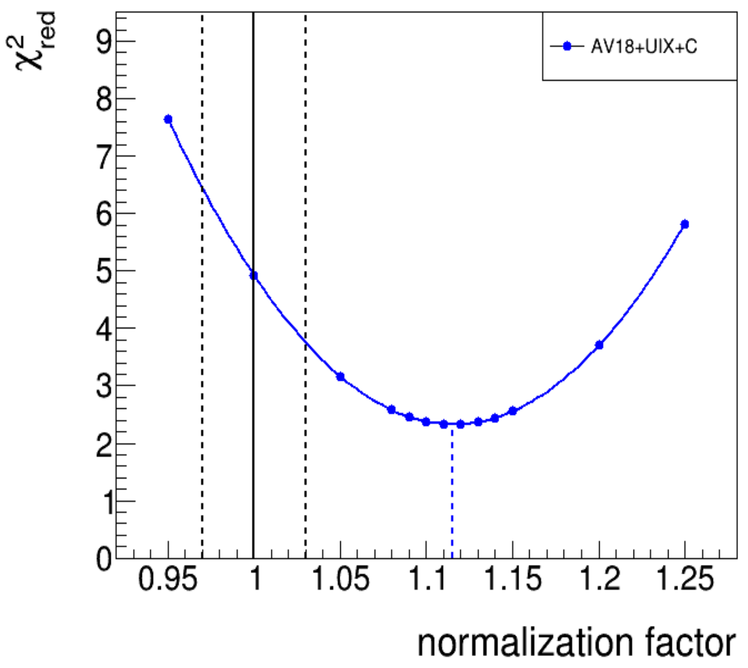




- The **higher** polar angles $\boldsymbol{\theta_1}$ and $\boldsymbol{\theta_2}$;

Discusion of the experimental results

Additional test

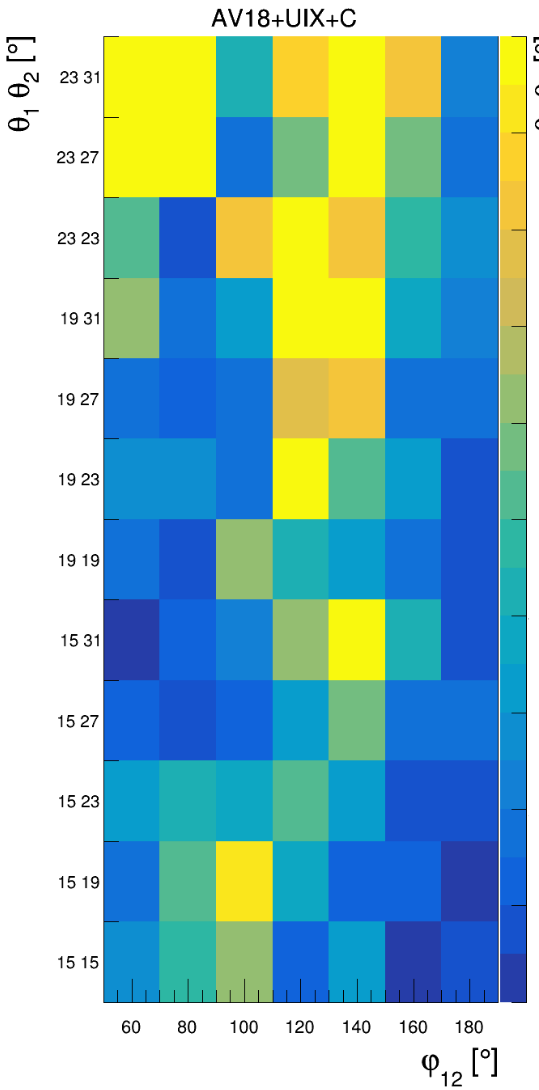


- The value of the cross section **multiplied by a factor** ranging from **0.95 to 1.25**, and the χ^2_{red} was again determined;
- By fitting a parabola we can find the **minimum chi-square** value:

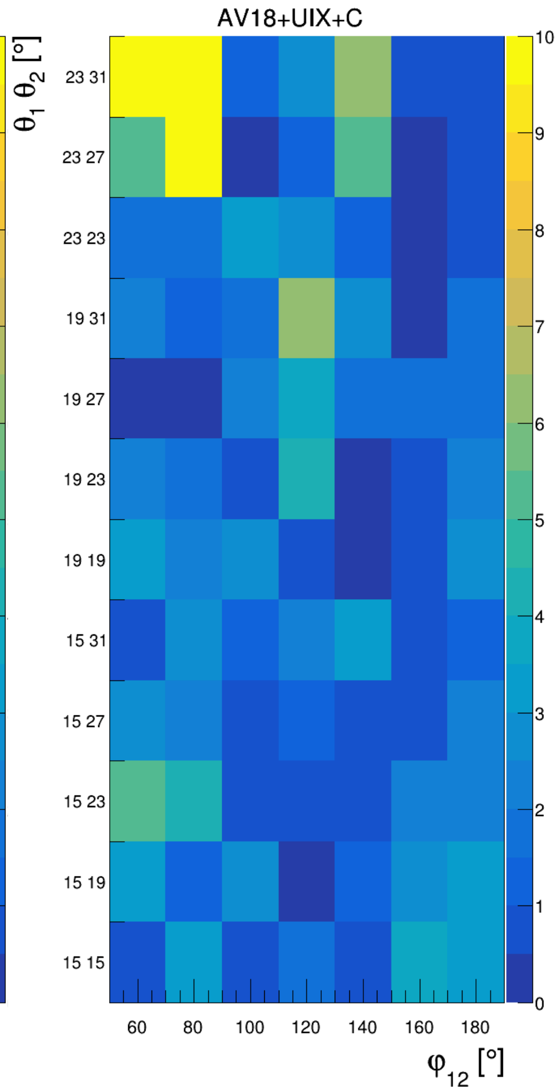
X^2_{red} = 2.332 for a factor of 1.12

The best agreement of cross-section distribution shapes is obtained for **normalization greater by 12%**

Before



After



Summary and outlook

- The **Coulomb** interaction has to be **necessarily included in the theoretical description**;
- The effect of the **3NF** introduced in **Δ** form **is negligible**; the **UIX model** of 3NF introduces effects which are **more significant** 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 12%**;
- **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 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!