Differential Cross Section for Proton Induced Deuteron Breakup at 108 MeV

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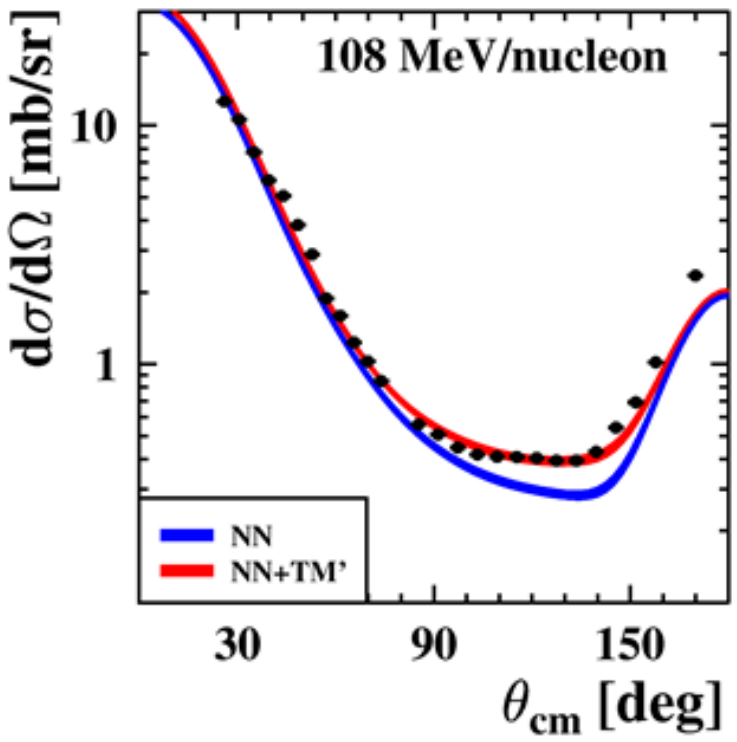
EuNPC

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) solves these problems;**
- In **ChEFT**, the **3NF naturally appears** in the NNLO;

	^{3}H	^{3}He	^{4}He
Experiment	8.48	7.72	28.3
CD Bonn	8.01	7.29	26.3
Av18	7.62	6.92	24.3
CD Bonn + TM99	8.48	7.73	29.2

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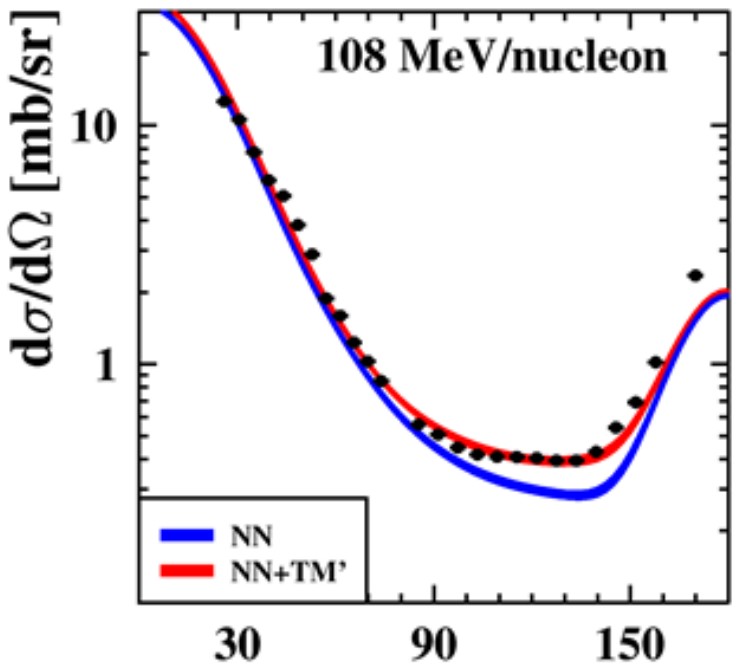

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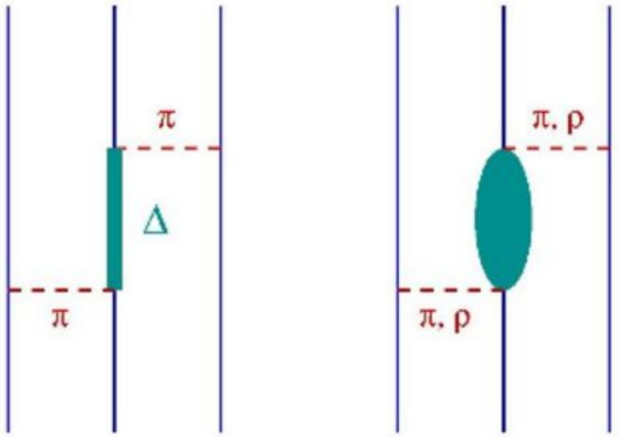
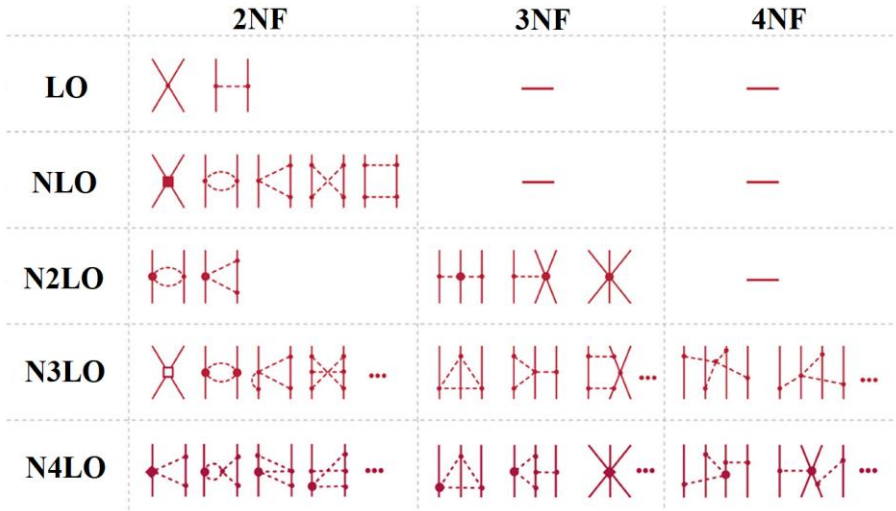
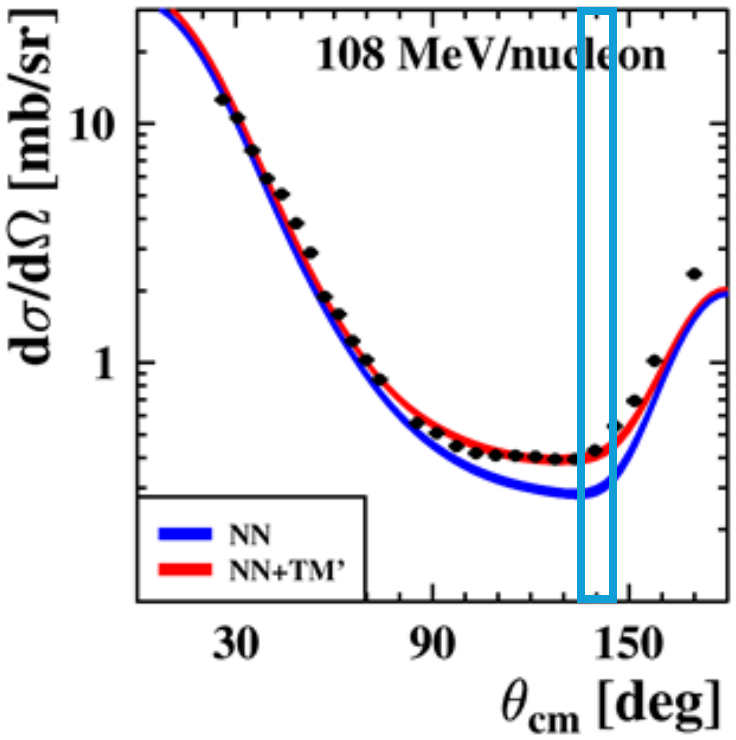
3NF MODELS



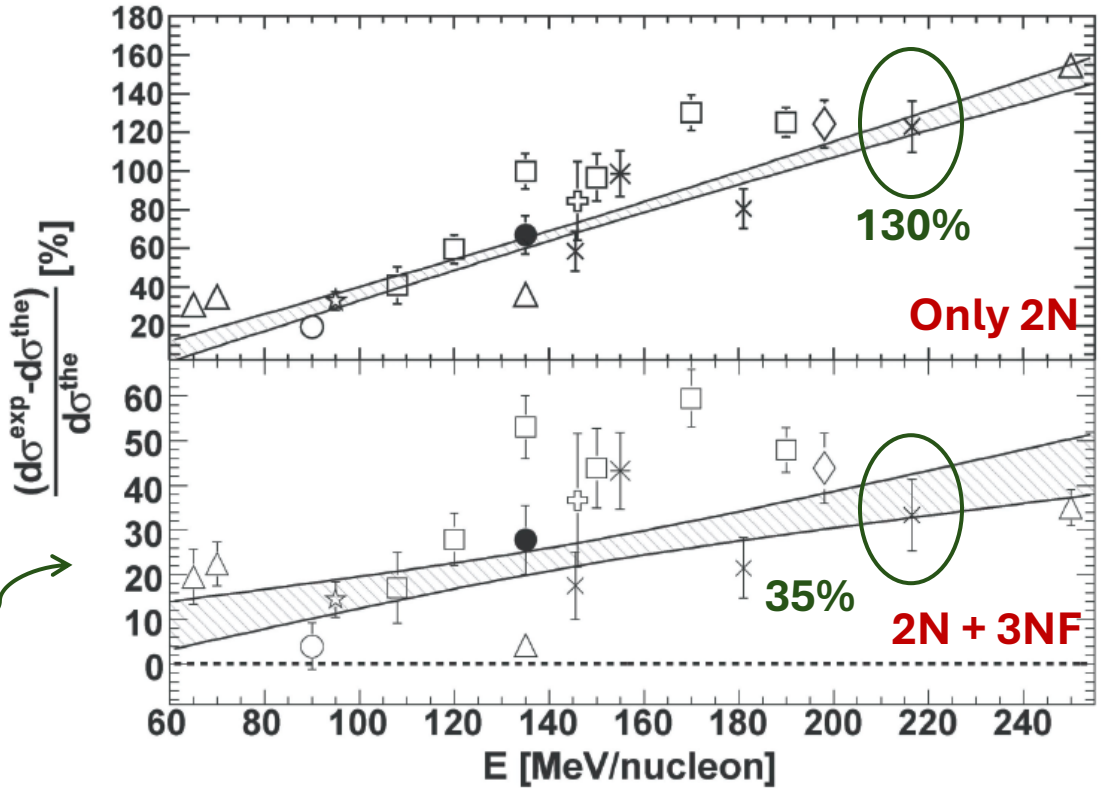


Motivation



$\theta_{cm} = 140°$

3 times smaller scale

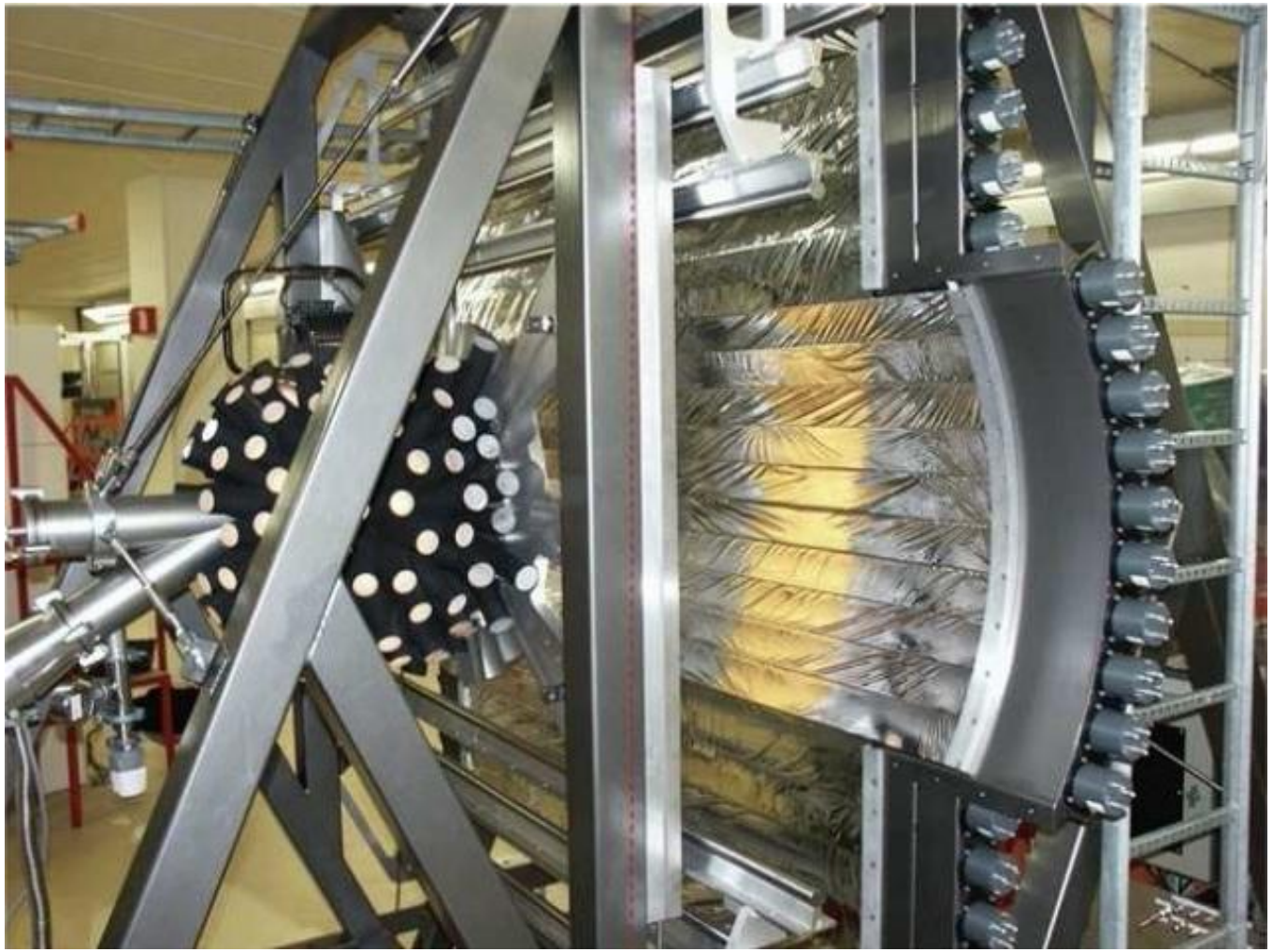


- p-d elastic scattering shows **significant sensitivity to 3NF** effects;
- calculations **based only on 2N interactions do not reproduce** experimental data at backward angles (θcm=140°);
- deuteron breakup reaction – the final state of three bodies **rich in kinematic configurations demonstrating different sensitivity to specific effect;**

Studies of 3N System with BINA@CCB

BINA – Big Instrument for Nuclear-Polarization Analysis

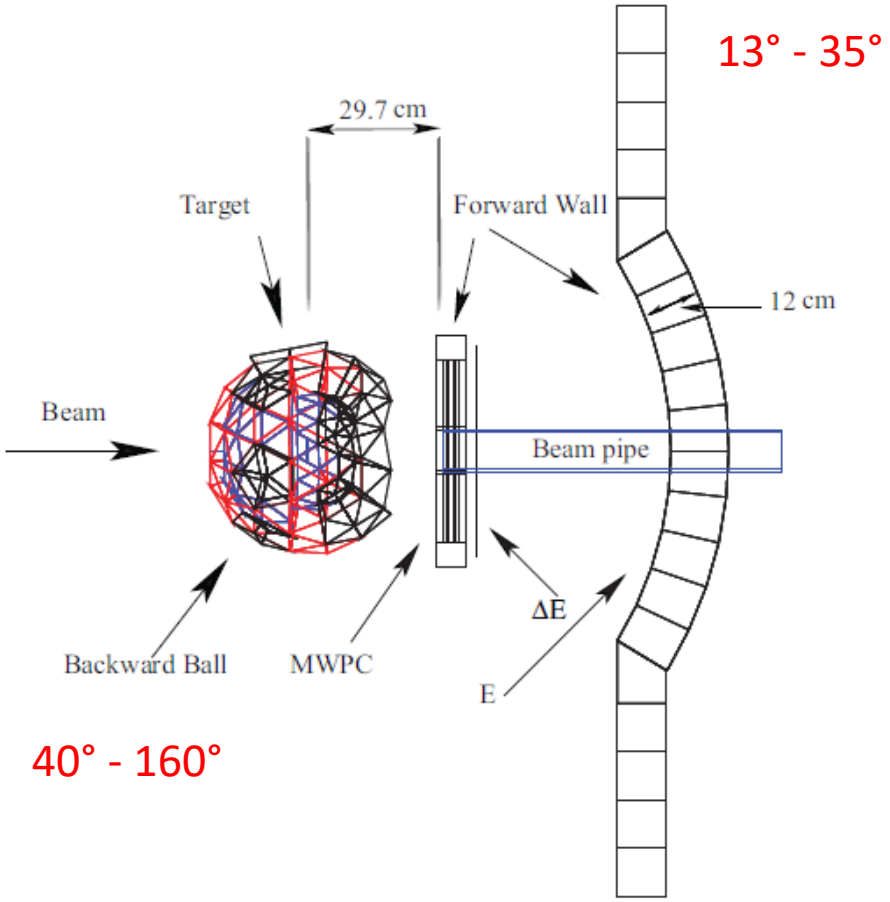
- Experimental program:
  - Measurement **of ^{2}H(p,pd)** elastic scattering at **108, 135 and 160 MeV;**
  - Measurement of **^{2}H(p,pp)n** breakup reaction at **108 and 160 MeV** for over 200 kinematic configurations;
- **The aim:**
  - Studies of **3NF**;
  - Verification of predicted **Coulomb**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



Experimental setup

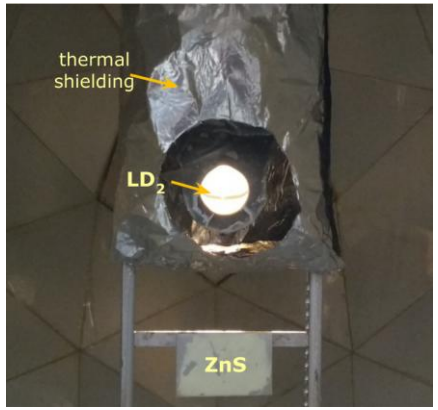
- **The forward part of detector (Wall):**

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**



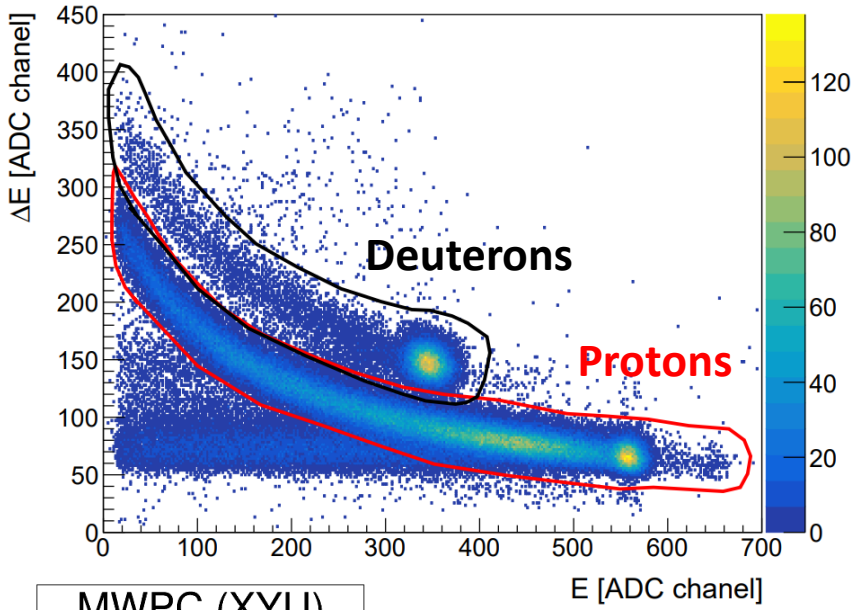
- **The backward part of detector (Ball):**

- ➢ System of **149 phoswitch**
- ➢ The target system located inside the Ball:
  1) LD_2 target
  2) Al target with a thin ZnS layer (callibration runs)

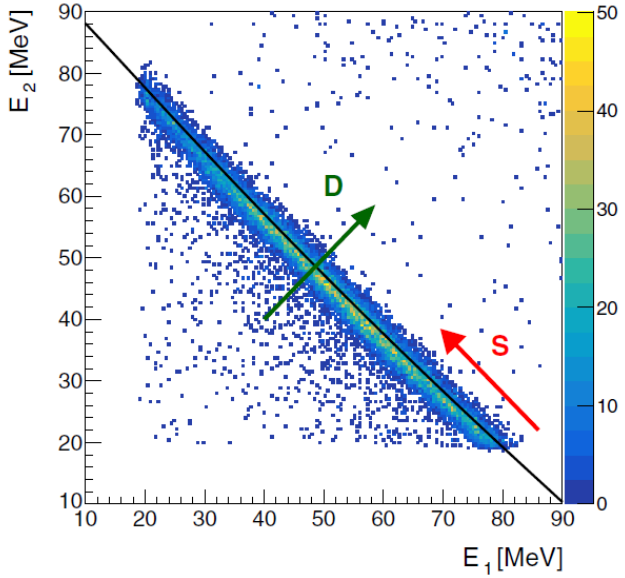


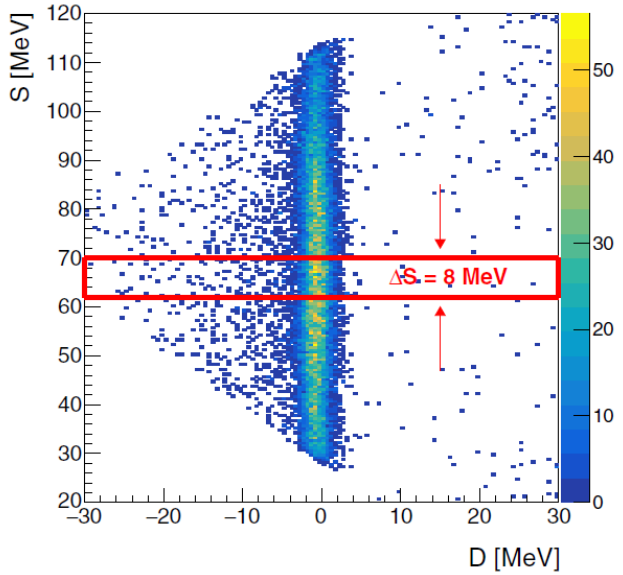
The measurement of the $^{2}H(p,pp)n$ at 108 MeV

- Results of the **first experimental run**;
- 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;

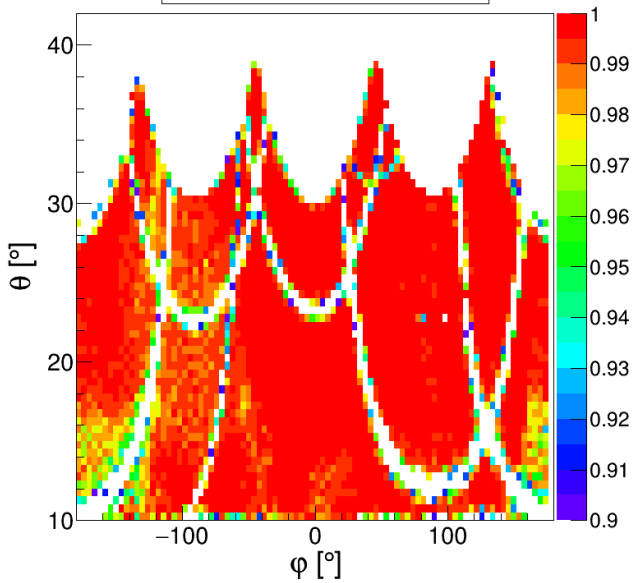


$$\theta_1 = 15°, \theta_2 = 19°, \varphi_{12} = 160°$$





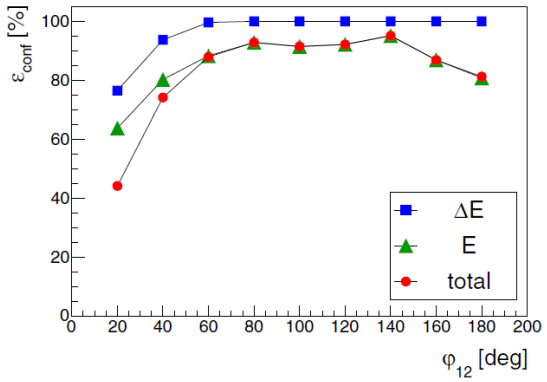
MWPC (XYU)

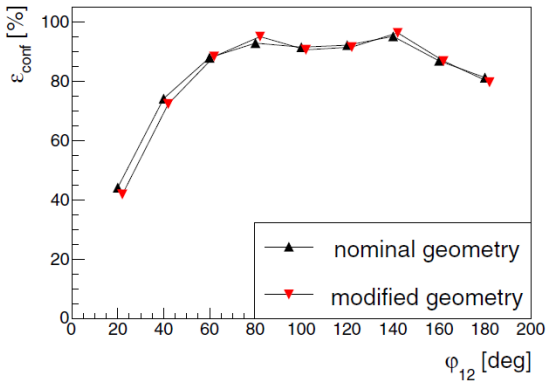


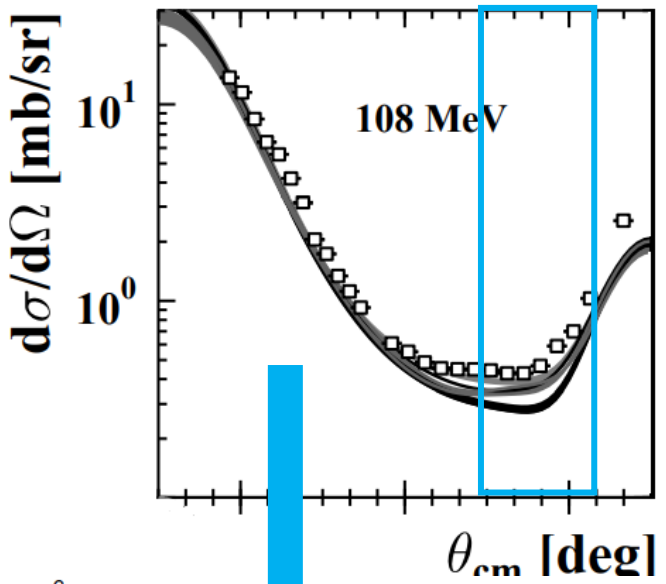
^{2}H(p,pp)n breakup cross section

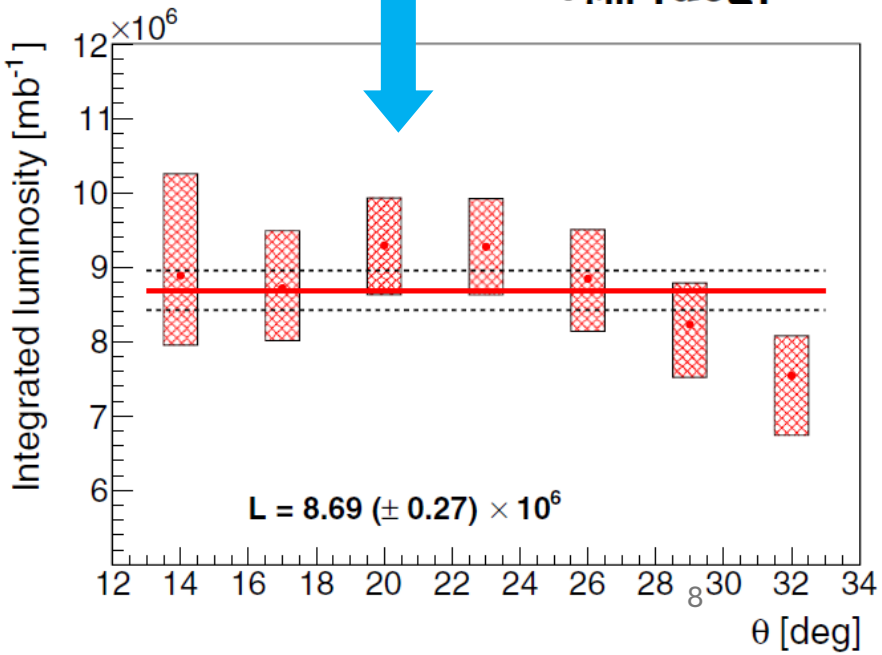
- **Normalization** procedure:
  - Based on **deuterons** from **elastic scattering;**
  - *Ermisch et al., Phys. Rev. C 71, 064004 (2005)* – data with the systematic uncertainty between 4.4% - 6.5%
- Corrections: **hadronic interactions, Wall efficiency, Edge events, configurational efficiency;**

Sources of errors	The impact on breakup cross section [%]
Statistical uncertainties	2.3–11.1%
Total systematic error	3.9–8.3%
1. Normalization	3.5%
2. Particle identification	1%
3. Configurational efficiency	0.01–6.8%
4. Energy calibration	
+ angle reconstruction	
+ detector efficiency	1%
5. Trigger efficiency	−0%, +3%
6. Hadronic interactions	1%

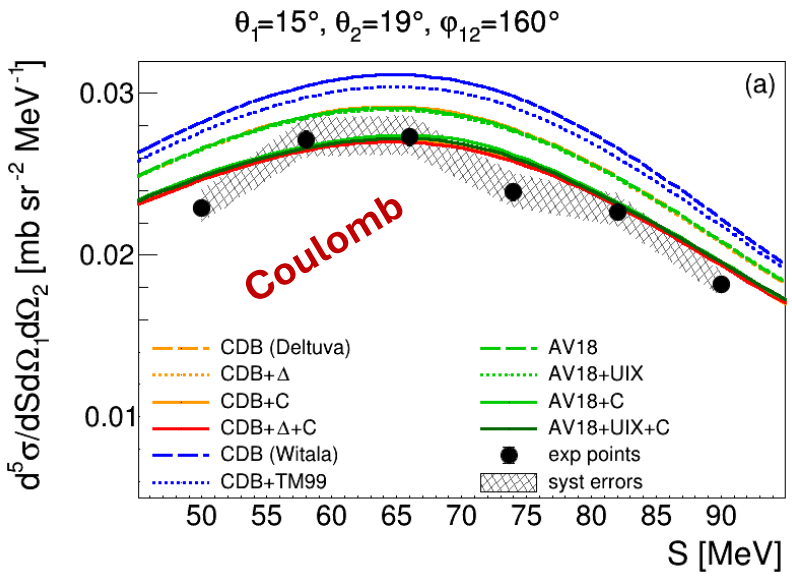


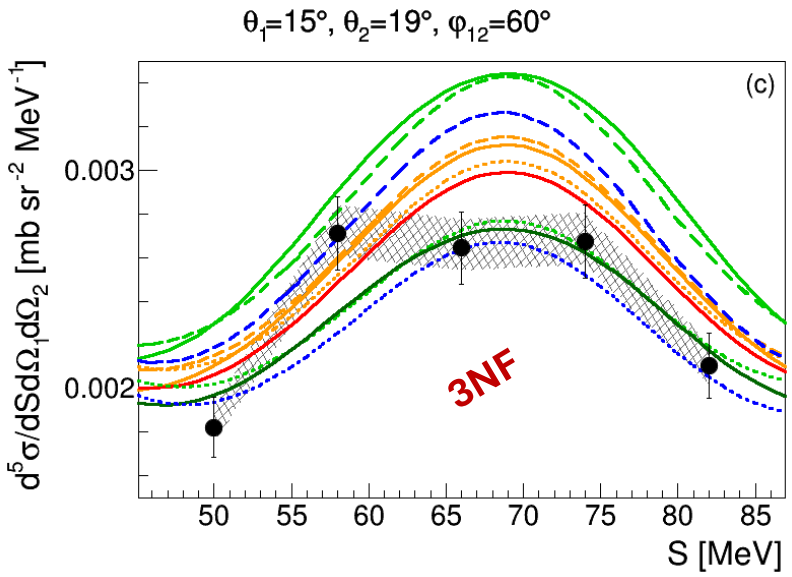


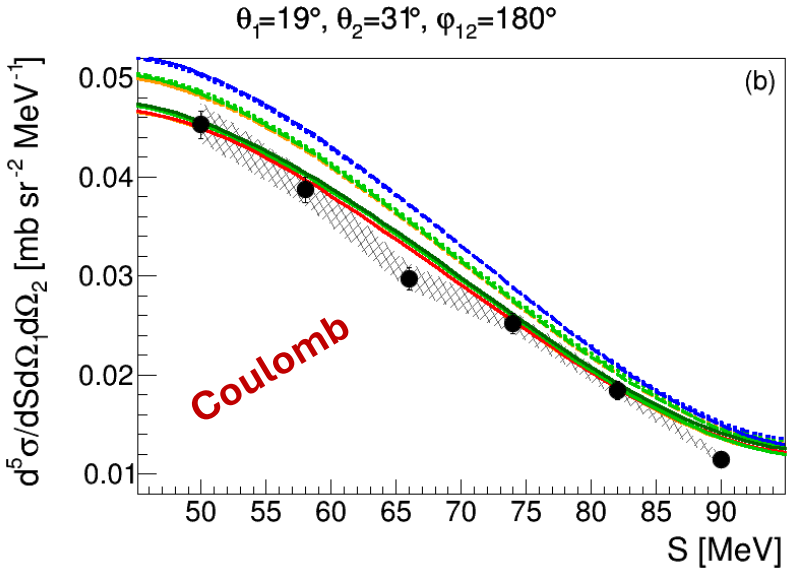


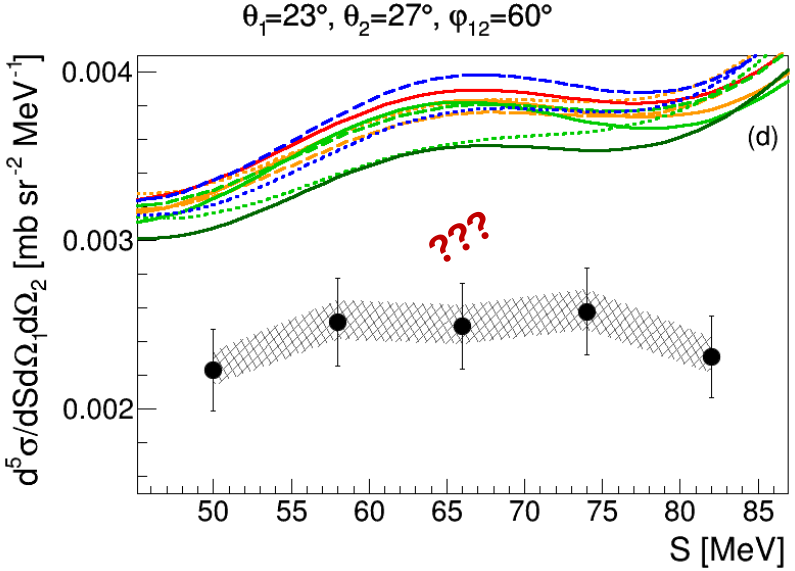


Results and comparison with theory









The differential cross section obtained for:

- a set of **84 angular configurations**;
- polar angles **θ from 13° to 33°**
- azimuthal angle **φ_{12} from 50° to 190°**

- over **500 data points**;

Łobejko A. et al., ***Phys. Rev. C 111***. *54001 (2025)*

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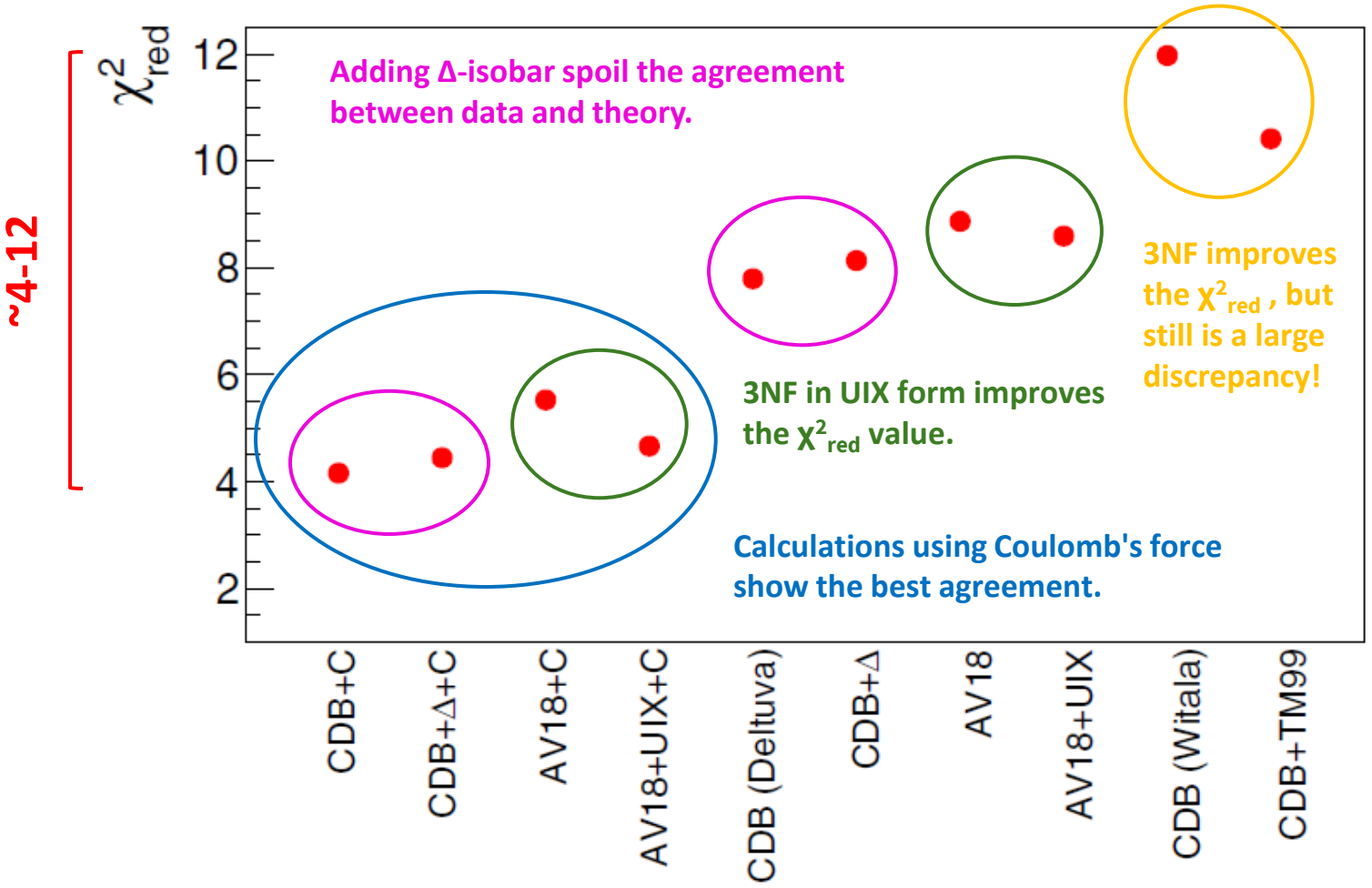
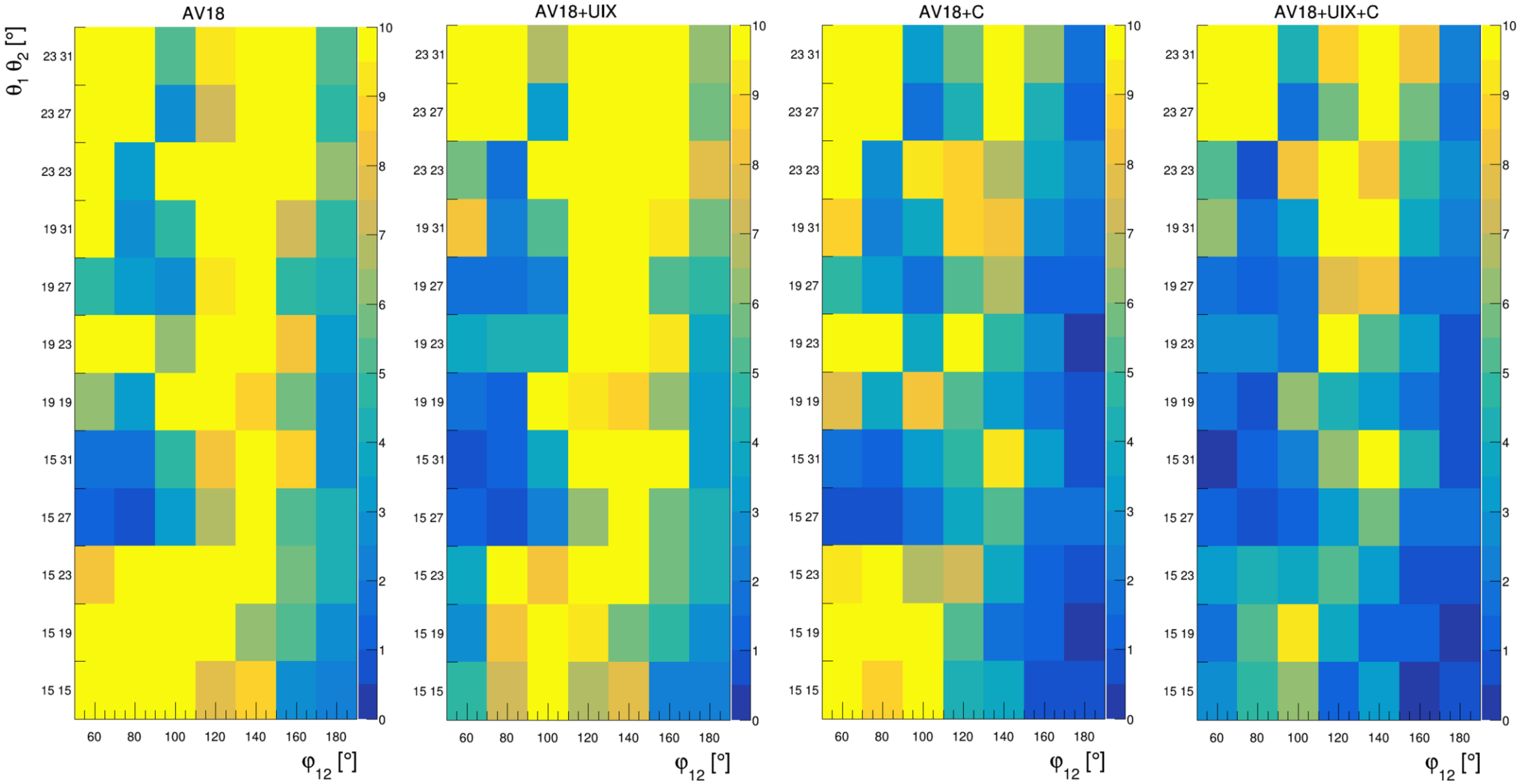


- The **global χ^2_{red}** results strongly **depend** on the **theoretical model;**
- Calculations performed by Witała have **the worst agreement**;
- The impact of the χ^2_{red} by **adding the Δ-isobar is very low and even spoil** the agreement;

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

Results and comparison with theory



The best description is provided by calculations that take into account both 3NF and Coulomb interactions.

Summary and outlook

- The investigated region of the phase space is characterized by significant variation in the differential cross-section values:
  - Regions with the **lower cross-section reveal greater sensitivity to the dynamic effects**.
  - In almost **the entire studied phase space**, the **Coulomb effects** are present.
- The **Coulomb** interaction has to be **necessarily included in the theoretical description** (also, in the context of future comparisons of the data with the intensively developed calculations within the ChEFT).
- **3NF** effects are **moderate** and manifest themselves **locally.**
- For the most **sensitive configurations**, we observe **larger effects of the TM99 and UrbanaIX** forces.
- In the kinematical region where the cross sections are smallest, all the theories significantly overestimate the data.
- **3N forces** (TM99 and UIX) **lower the calculated cross section**, thus **improving** the **description** of the data but by far **not enough** to eliminate the discrepancy.

- In the future, the **results will be extended** by analyzing data from the **subsequent experimental** run covering a **wider angular range**. Configurations close to the so-called **neutron-proton final state interaction** are kinematically similar to the elastic scattering and **can reveal stronger sensitivity to 3NF**.

Thank you for your attention!