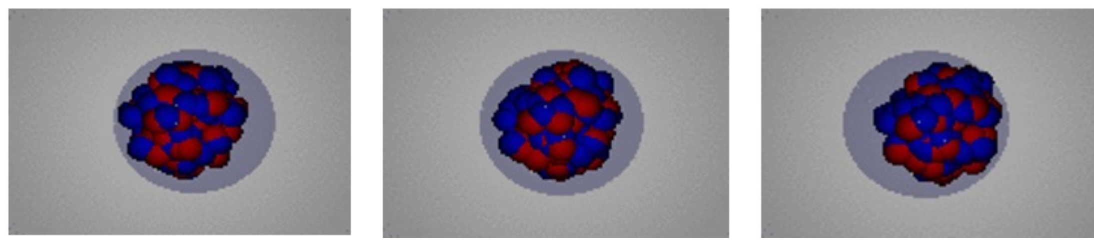
DE LA RECHERCHE À L'INDUSTRIE

Nuclear structure studies using inelastic scattering reactions: example of the pygmy resonance in ^{140}Ce



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GCM2022 Workshop
October 2022

Introduction: How protons and neutrons contribute to the pygmy resonance?

1. Goal of the study of the PDR in ^{140}Ce using the neutron inelastic scattering reaction

2. Experimental setup at NFS

3. Online results from the experiment performed in September 2022

4. Perspectives

Nature of a nuclear excitation

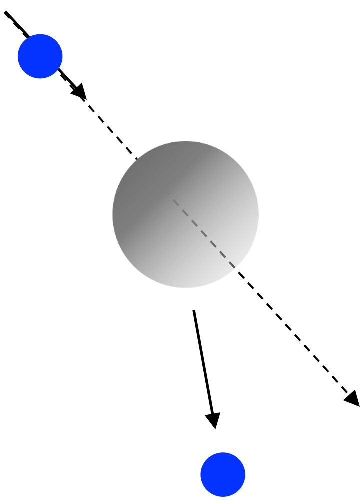
What is the nature of a nuclear excitation ?

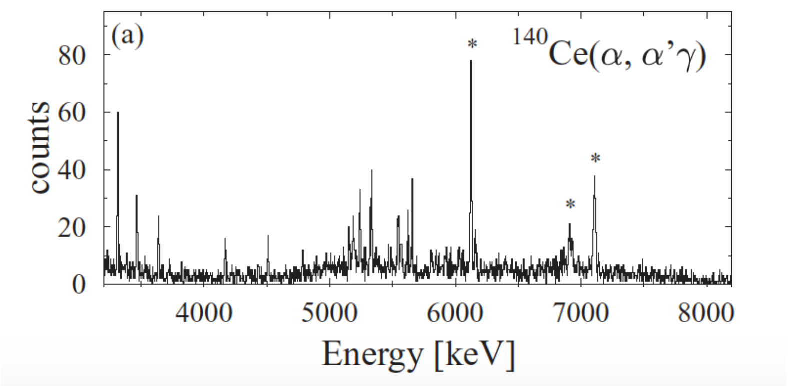
Contributions of the protons and neutrons to the excitation strength ?

Tool
scattering reaction

Observables
Excitation energy, E_γ and cross section

Interpretation
Comparison to microscopic calculations





D. Savran *et al*. Phys. Lett. B 786 (2018)

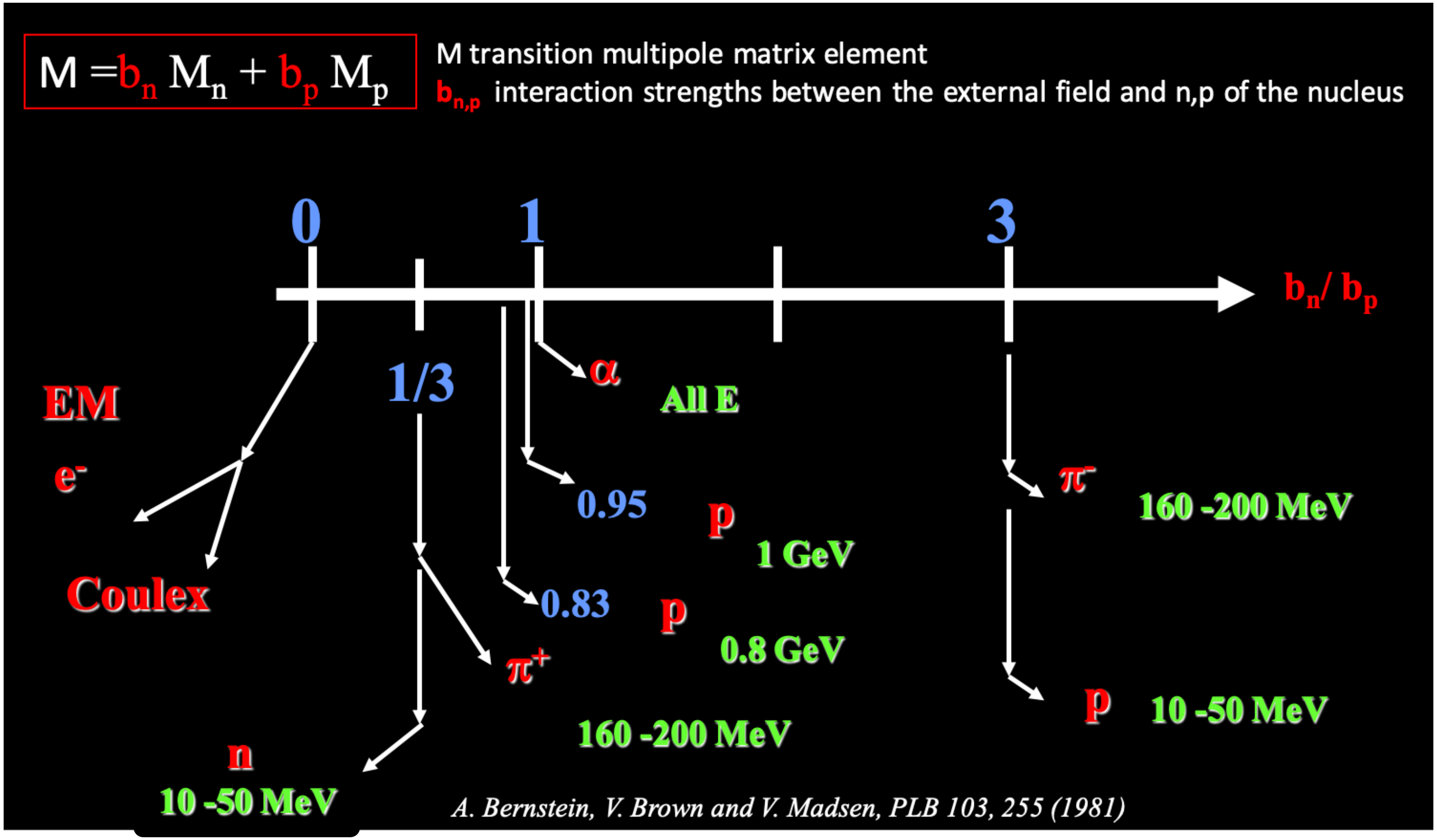
Transition density

$$M_{p(n)} = \int \rho_{fi}^{p(n)}(r) r^{L+2} dr$$

Multipole moment

Multipolarity of the transition

Complementarity of the scattering experiments



The pygmy dipole resonance (PDR)

PDR
(Pygmy Dipole Resonance)

- oscillation of a neutron skin against a symmetric proton/neutron core
- additionnal E1 strength at lower energy

GDR
(Giant Dipole Resonance)

- oscillation of neutrons against protons
- exhausts ~ 100% E1 strength

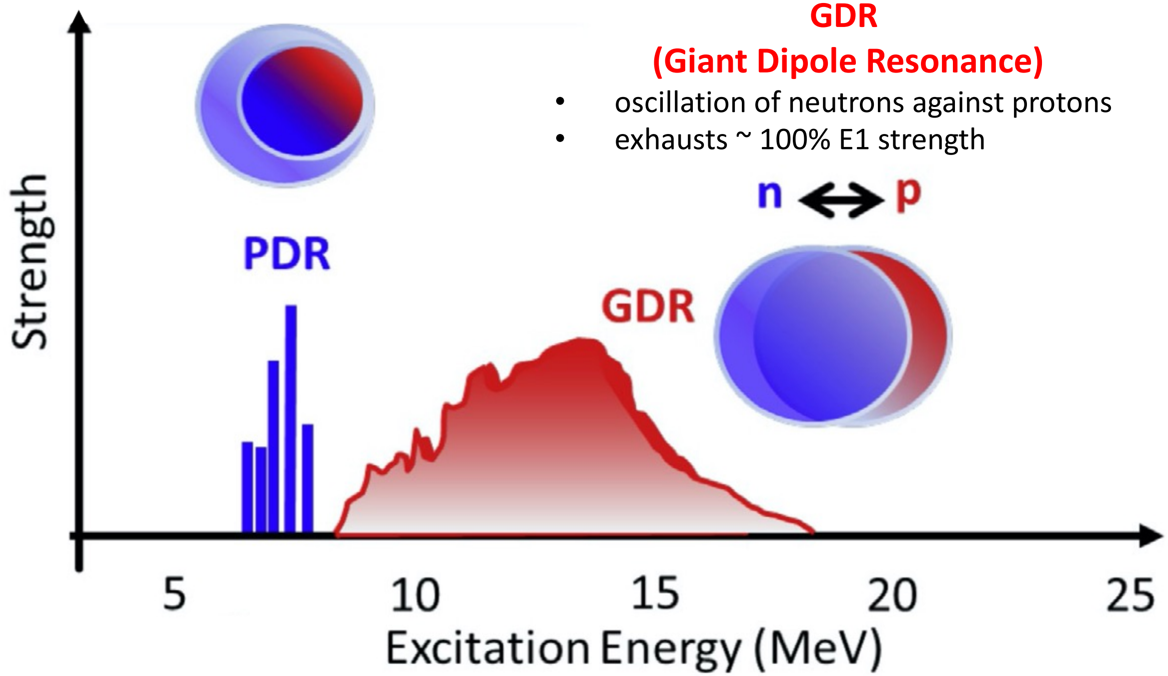


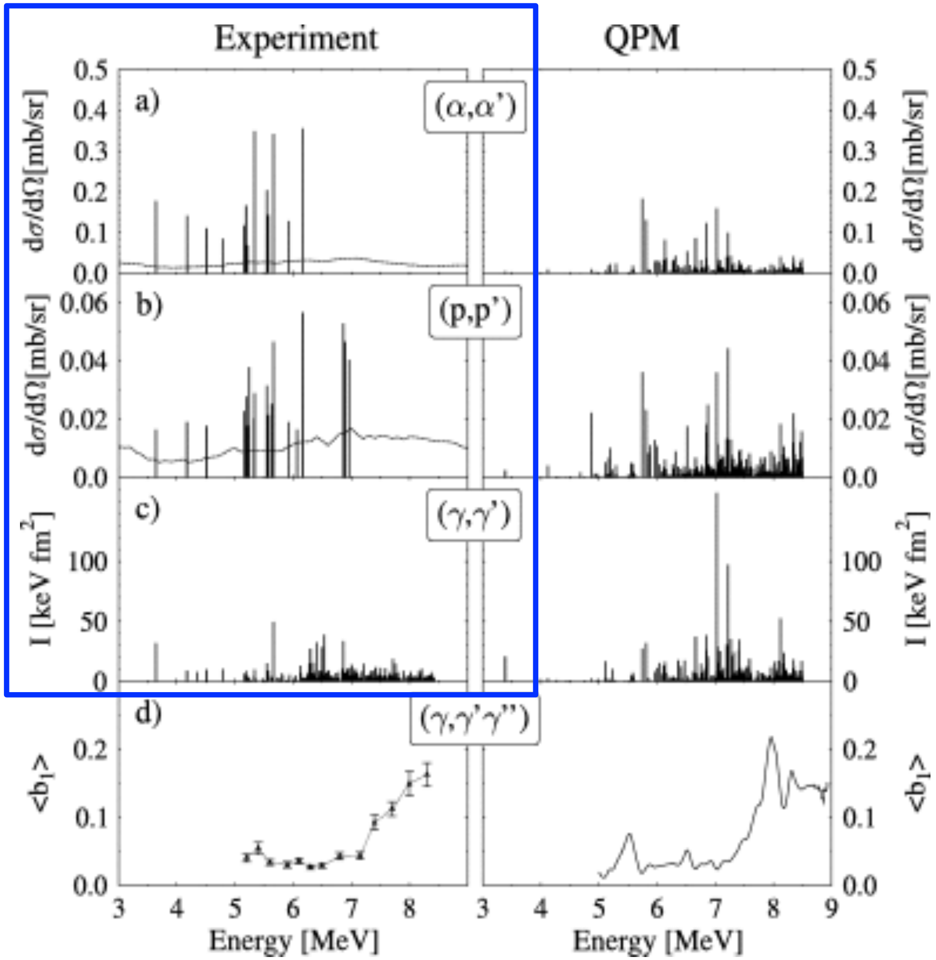
Figure extracted from A. Bracco *et al*. Prog. Part. Nucl. Phys. 106 (2019)

PDR plays important role:

- as a constraint of the Equation of State
- for the nucleosynthesis r process

Microscopic structure of the PDR

^{140}Ce



D. Savran *et al*. Phys. Lett. B 786 (2018)

Isoscalar probes ➡ 4-6 MeV

Proton probe ➡ selected states

Electromagnetic probe ➡ 4-8 MeV

If several models are able to reproduce E1 strength at lower energy than the GDR, they do not agree on the fine structure

New probes are necessary to resolve the complexity of the isospin character of the PDR

➡ study **PDR in ^{140}Ce using (n,n')**

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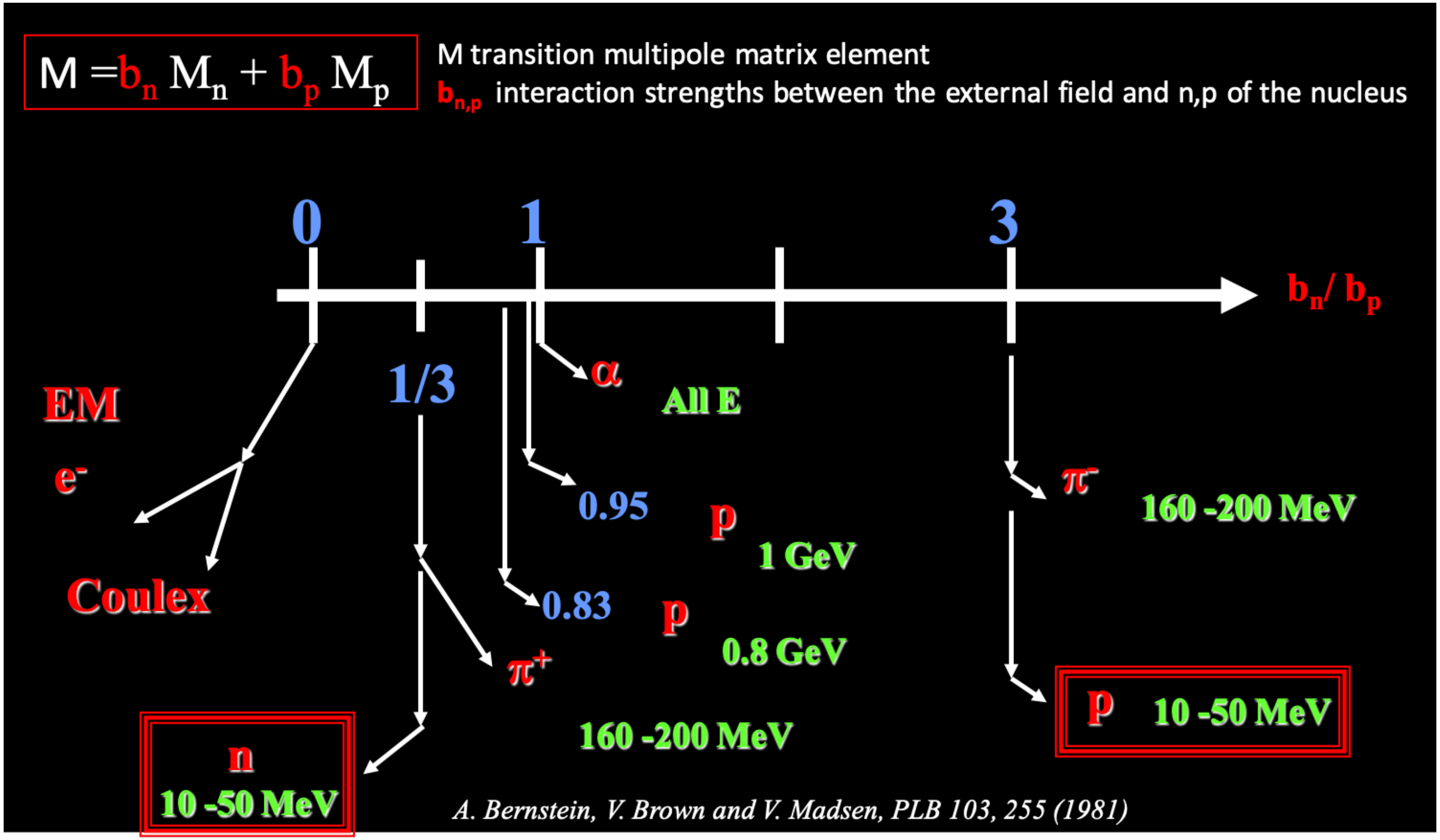
Motivation of the proposed experiment

WHY ?

(n,n’) is an elementary probe:

- which does not require Coulomb correction
- complementary to (p,p’) and to other reactions



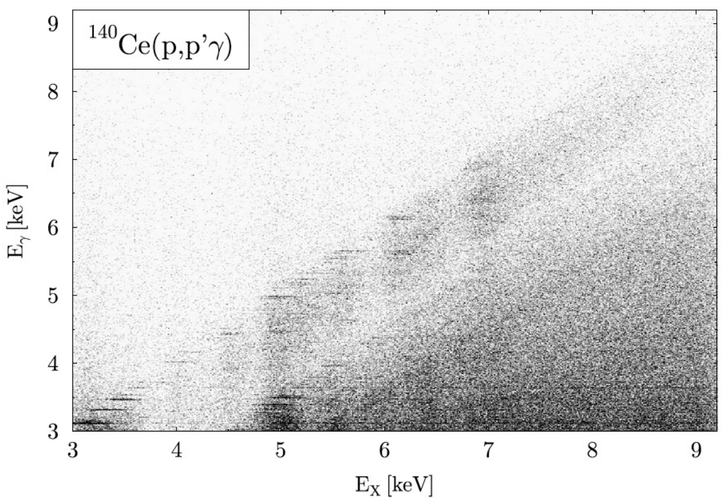
Goal of the experiment

HOW ?

EXPERIMENT

$^{140}Ce(n,n')^{140}Ce^*(\gamma)^{140}Ce \leftrightarrow {}^{140}Ce(n,n'\gamma)^{140}Ce$

1. Detect n' and γ in coincidence

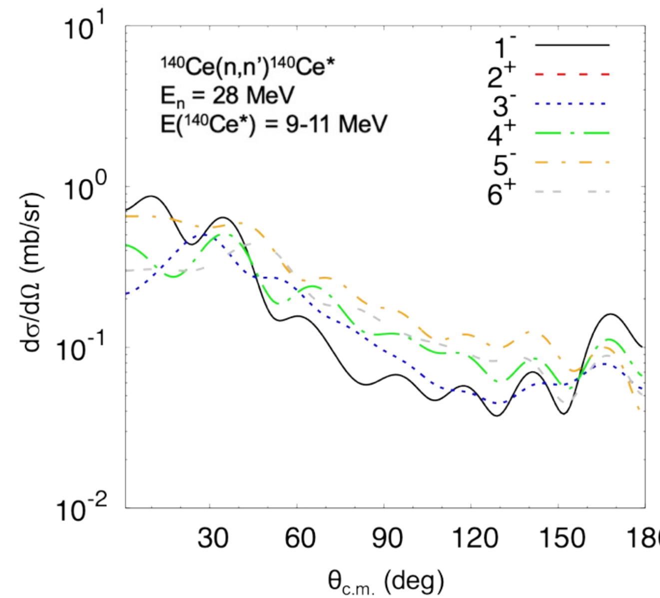


D. Savran *et al.* Phys. Lett. B 786 (2018)

BUT :
- Ex = E*(^{140}Ce) reconstructed using the n' TOF. Few MeV energy resolution
- PARIS scintillators instead Ge detector. 2-3% energy resolution in the PDR energy region

More difficult !

2. Measure the n' and γ angular distributions of a given excitation energy range to assess the 1^- strength.



3. For each 1^- excited state/energy range: extract the (n,n') cross section

Goal of the experiment

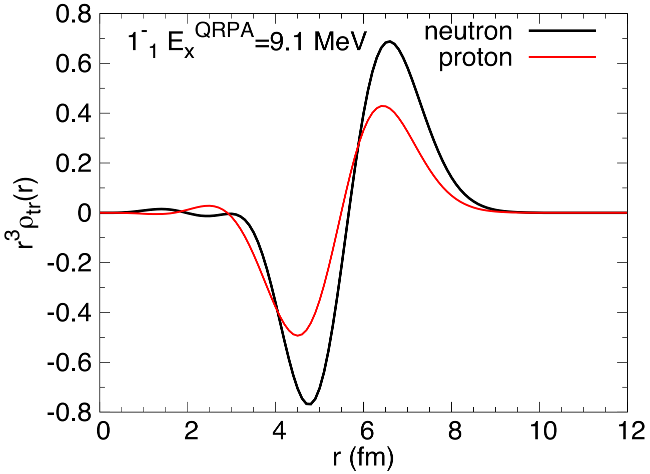
HOW ?

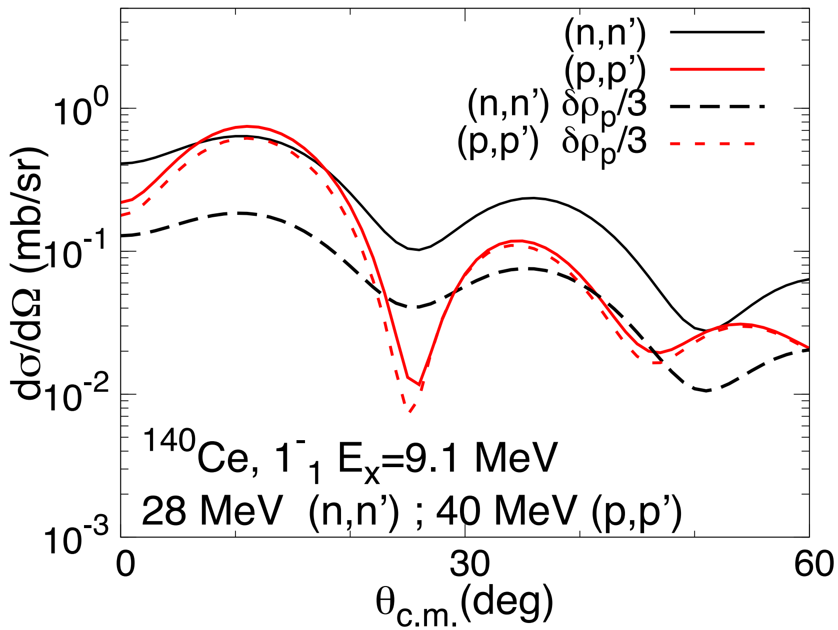
ANALYSIS of the cross sections for E1 states and INTERPRETATION

1. Compare the measured (n,n') to theoretical cross sections
2. Compare the (p,p') data of the literature to the calculations

The comparison exp. vs theory for (n,n') and for (p,p') will **pin down the role of protons and neutrons in the PDR**

Example of calculations: QRPA transition densities (Gogny D1M interaction) + DWBA calculations using a microscopic density-dependent potential model approach





QRPA (S. Péru) + DWBA-JLM (M. Dupuis)
QRPA S. Péru *et al.*, CEA DAM EPJA 55:232 (2009)
DWBA with JLM M. Dupuis *et al.*, PRC100, 044607 (2019)

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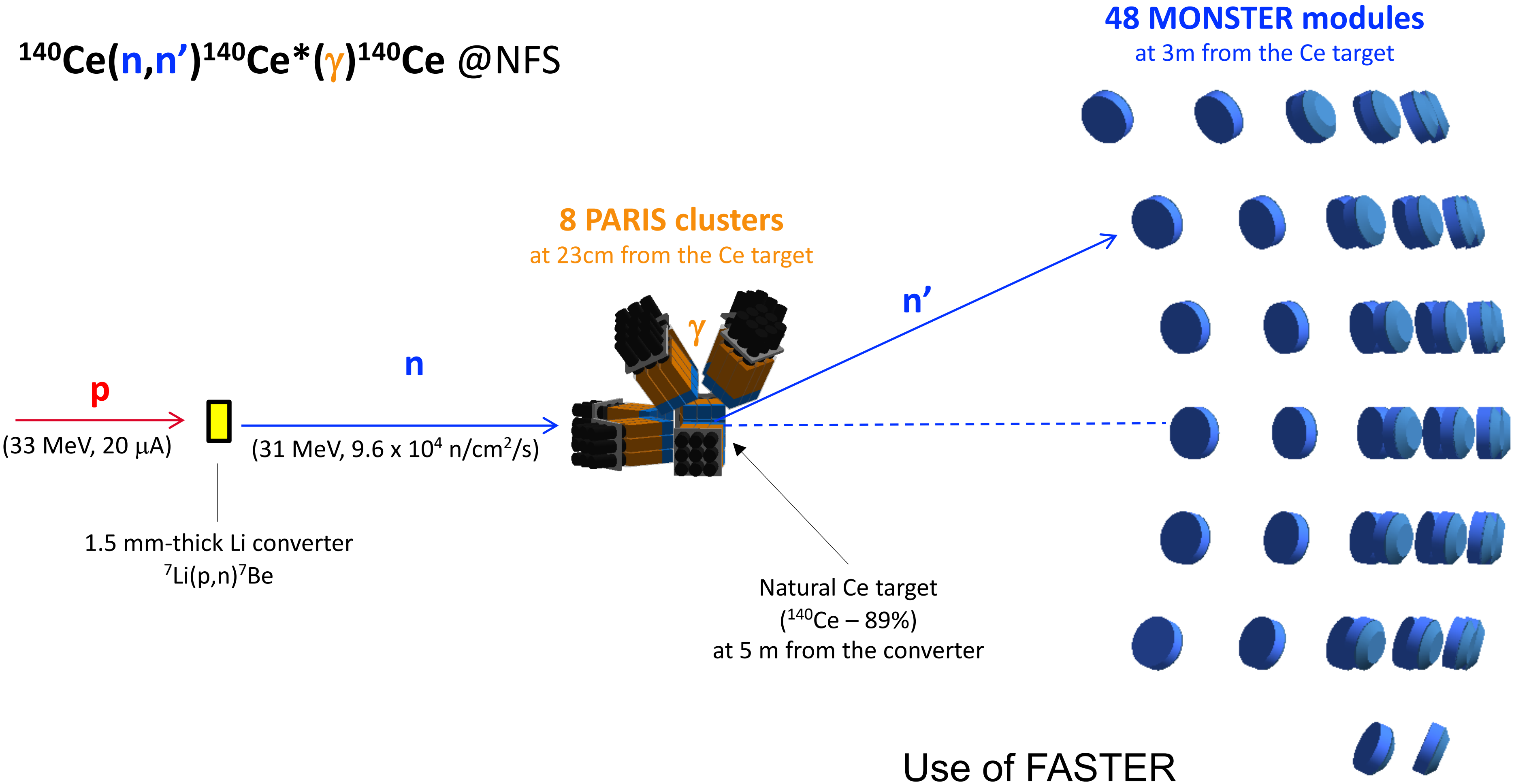
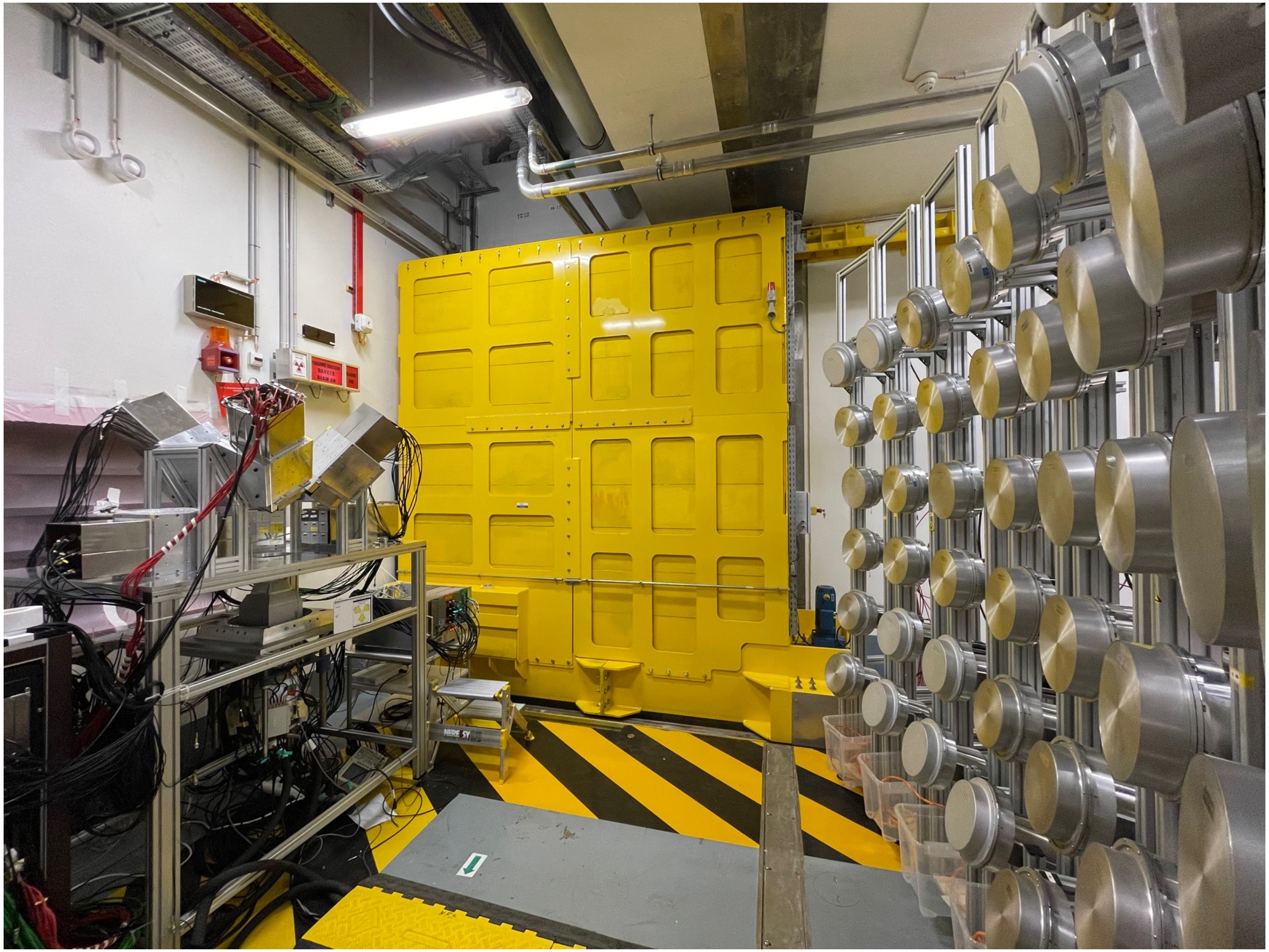
Experimental setup

$^{140}Ce(n,n')^{140}Ce^*(\gamma)^{140}Ce$ @NFS



Use of FASTER acquisition for PARIS and MONSTER

Experimental setup



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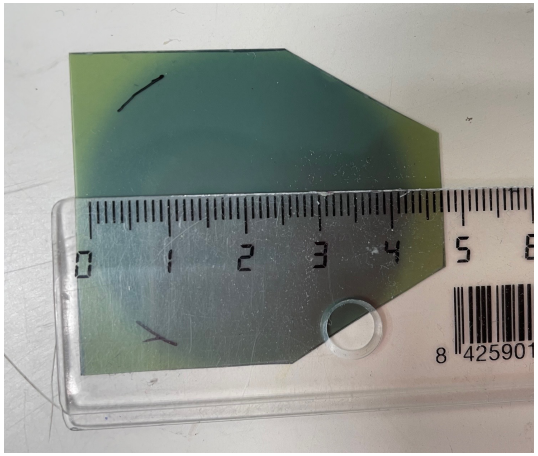
Neutron beam 1/2

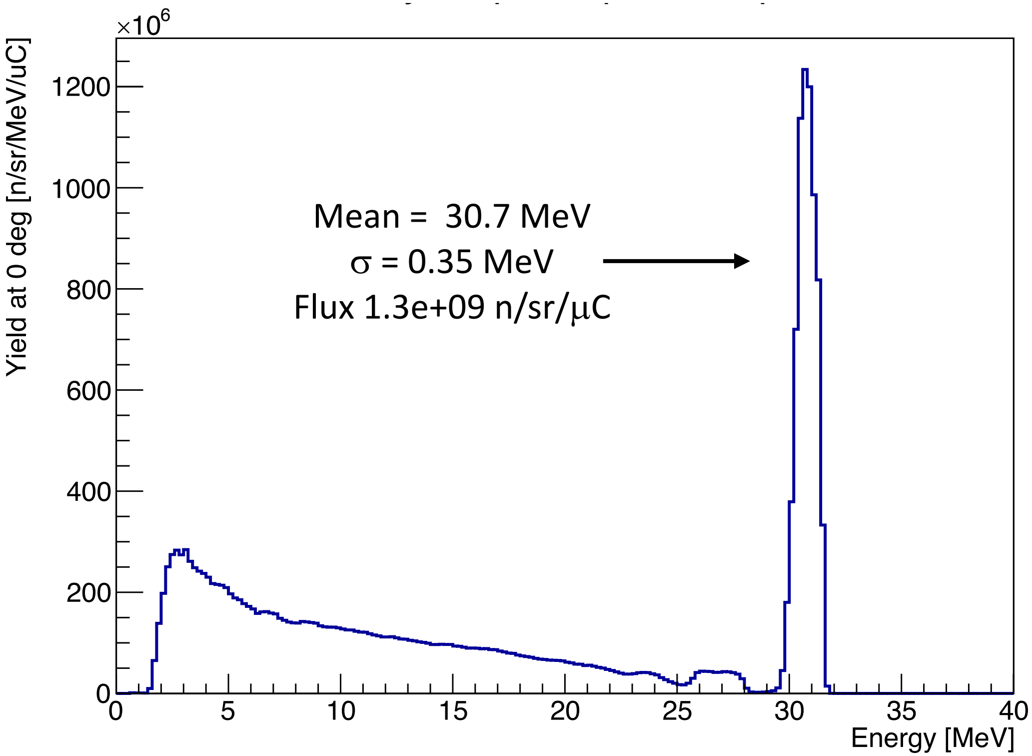
Beam size on target

To check the neutron beam size at the Ce target position, a photographic plate has been placed at the entrance



Neutron beam spot at the target place
(∅ = 4 cm)

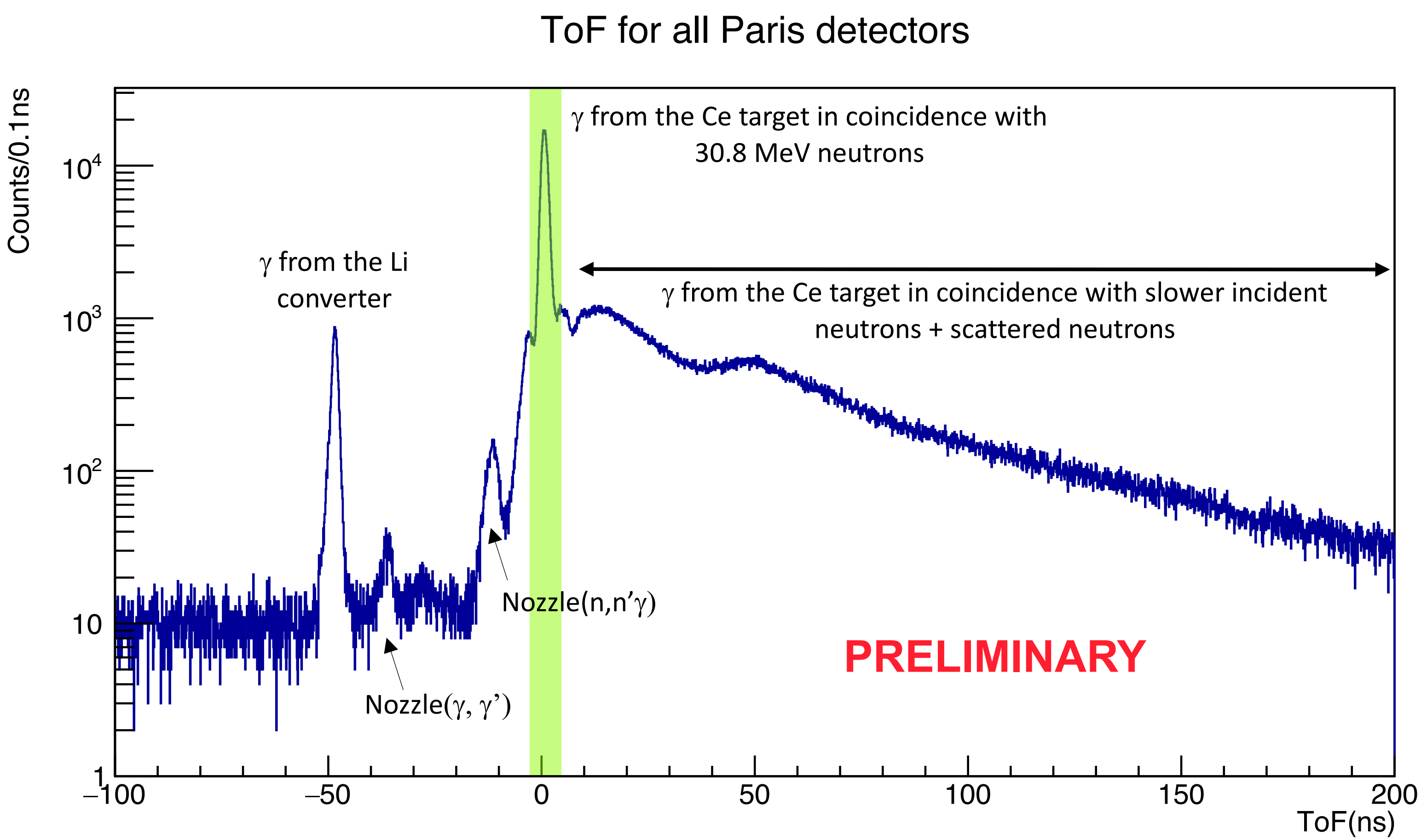
Intensity



- Intensity extracted with uncertainty < 5%
- How clean the tail ?

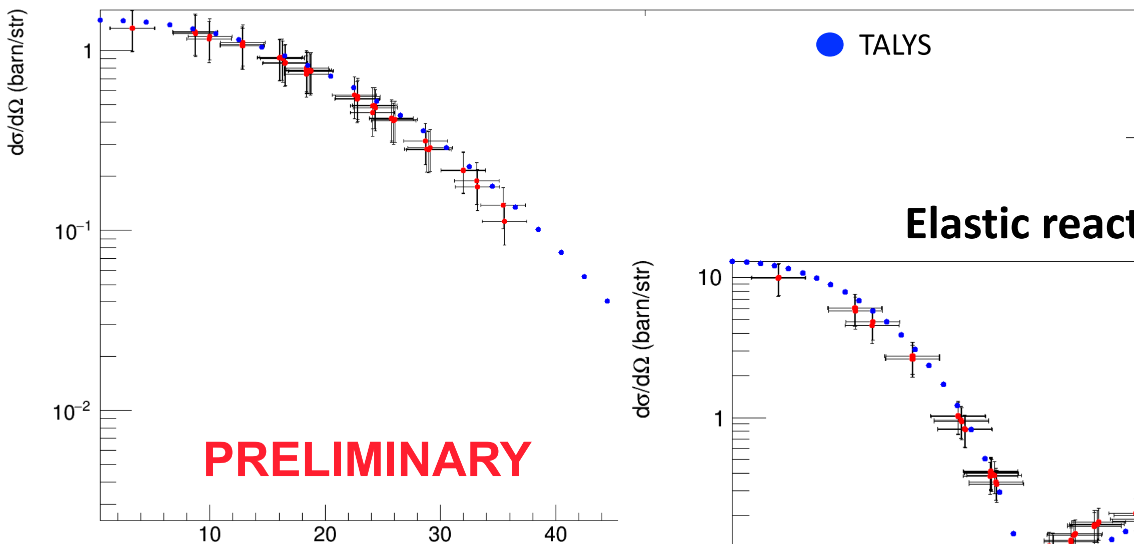
Neutron beam 2/2

Use Time of Flight between PARIS and HF to select gammas coming from 30.7 MeV neutron interaction on the Ce target



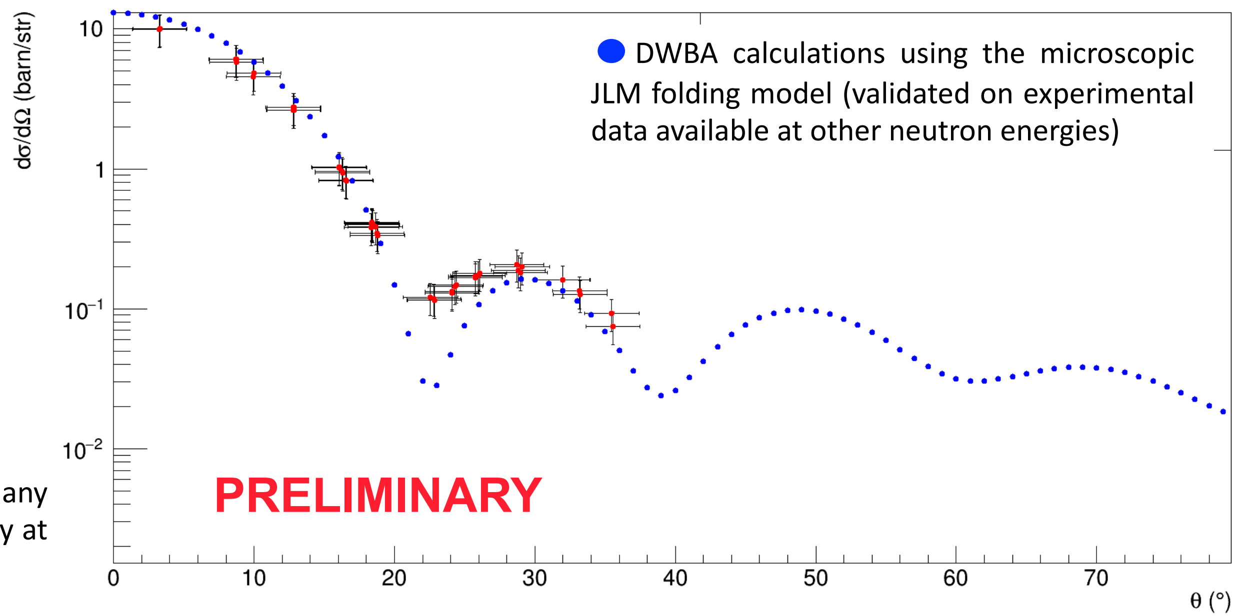
Reconstruction validation of the scattered neutron with MONSTER

Elastic reaction channel $^{12}C(n,n)^{12}C$



Experimental points
Extracted differential cross-section without any normalization, assuming 8% intrinsic efficiency at 30.7 MeV for each

Elastic reaction channel $^{140}Ce(n,n)^{140}Ce$



Theoretical calculations follow well the experimental angular distribution

Collaboration

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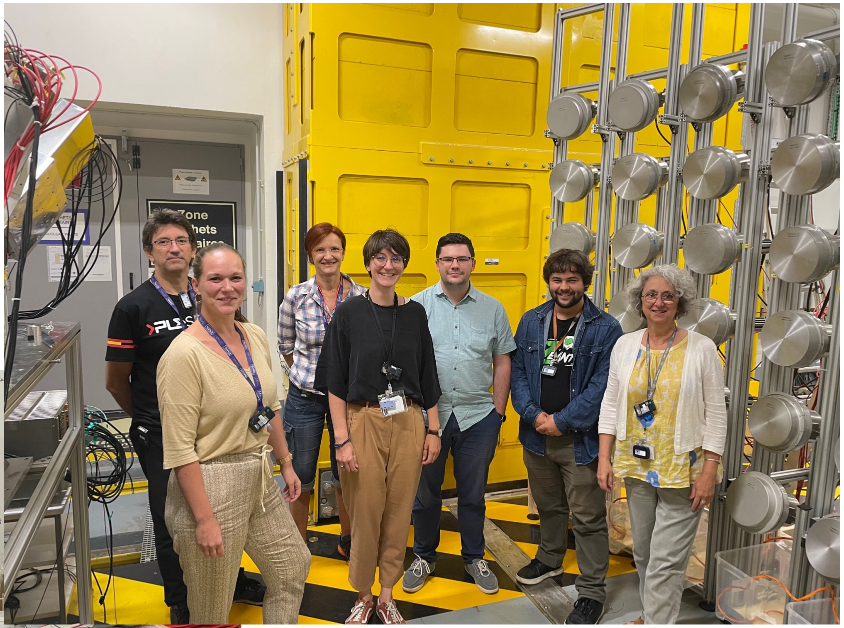
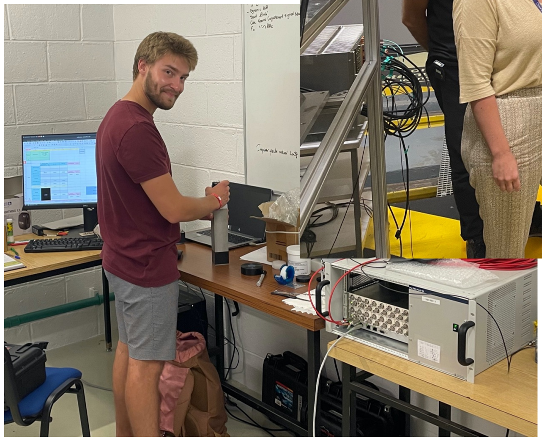
6. CIEMAT (Spain)
7. Institut of Nuclear Physics PAN Krakow (Poland)
8. Université de Strasbourg, Institut Pluridisciplinaire Hubert Curien
9. KVI-CART (The Netherlands)
10. IP2I Lyon (France)
11. IFIN-HH, Bucharest (Romania)
12. Milano University and INFN (Italy)





Thank you for your attention !