24ème COLLOQUE GANIL

21 au 25 septembre 2026

Bussang, France

CaeSAR
CAEN, STRATÉGIE POUR L'ACCÉLÉRATION EN RECHERCHE

RÉGION NORMANDIE

FRANCE 2030

UNIVERSITÉ CAEN NORMANDIE

Measurement of the $^{19}F(n,\alpha)^{16}N$ cross section with the SCALP detector

The SCALP collaboration (LPC Caen, GANIL, EAMEA, CEA)

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L. Manduci (EAMEA)
X. Ledoux (GANIL)
O. Serot (CEA Cadarache)

LPC CAEN

ENSI CAEN
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GANIL

cnrs

cea

- **Motivations and scientific background**
- **Overview of the experimental setup**
- **E901 Experiment at NFS**
- **Data analysis**
- **Results on the $^{19}F(n,\alpha)^{16}N$ cross section with SCALP**
- **Conclusion and outlook**

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Neutron multiplication factor

$$k_{eff} \equiv \frac{\textit{rate of neutron production}}{\textit{rate of neutron}}$$

loss

THE SCALP PROJECT

- **(n,α) reactions** of interest for nuclear reactors
- **Safety** optimisation: reactor modelling and fuel ageing
- **Cross sections measurements** from threshold up to 20 MeV

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→ ^{19}**F :** Fluoride-based coolants in Molten Salt Reactors (4th Gen)

- $^{19}F(n,\alpha)^{16}N$: **Uncertainties on reactor k_{eff}** (± 40-130 pcm*) *[4]*
- Validation of the experimental setup (large contribution of ^{19}F)

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→ ^{16}**O :** Pressurized Water Reactors & Fast Neutron Reactors (3rd & 4th Gen) fuels/coolants

- NEA : **HPRL (ranked 2nd)**, WPEC 26 (2008) & 40 (2015) *[2] [3]*
- $^{16}O(n,\alpha)^{13}C$: - **Helium formation** in fuel cladding (± 7%) *[1]*
  - **Uncertainties on k_{eff}** (± 100 pcm) *[1]*

pcm = 'per cent mille' = 1e-5

(n,α) CROSS SECTION ON ^{19}F

$$n + {}^{19}\mathrm{F} \rightarrow \alpha + {}^{16}\mathrm{N}$$

→ **Main methods for measuring the ^{19}F(n,α)^{16}N cross section :**

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LPC CAEN

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$T_{1/2} = 7.13s$

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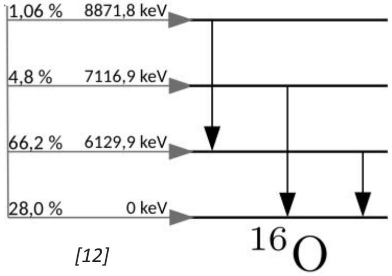
β^-



γ

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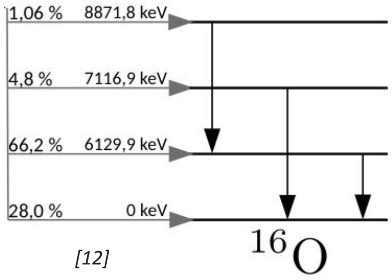

γ

[12]

→ **Main methods for measuring the $^{19}F(n,\alpha)^{16}N$ cross section :**

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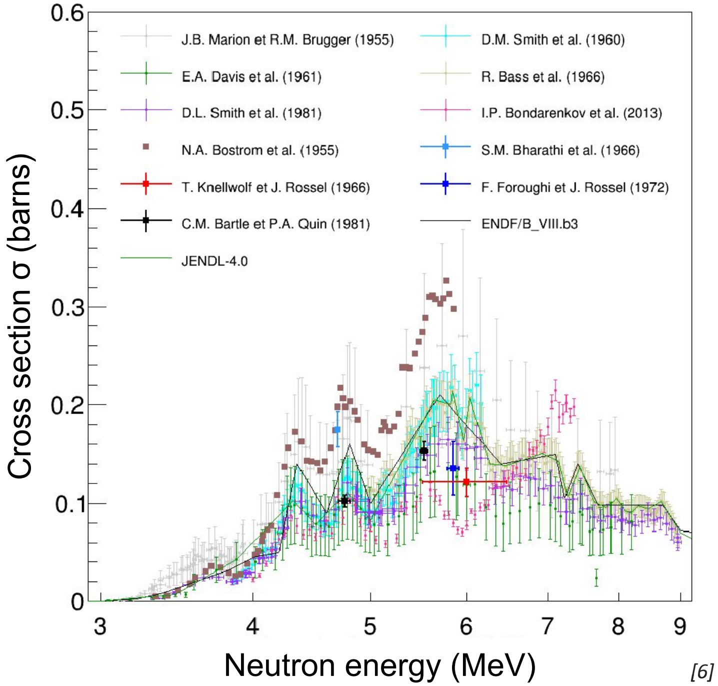
→ **Limits on evaluations**

- Uncertainties from 12% to 40%, discrepancies up to 300% *[7]*
- sparse data above 9 MeV (no data between 9 and 13.5 MeV)



[6]

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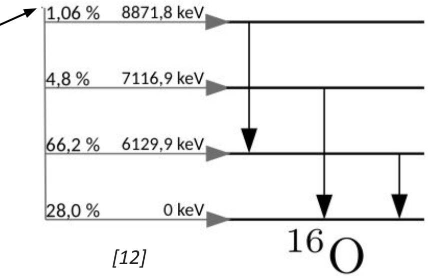

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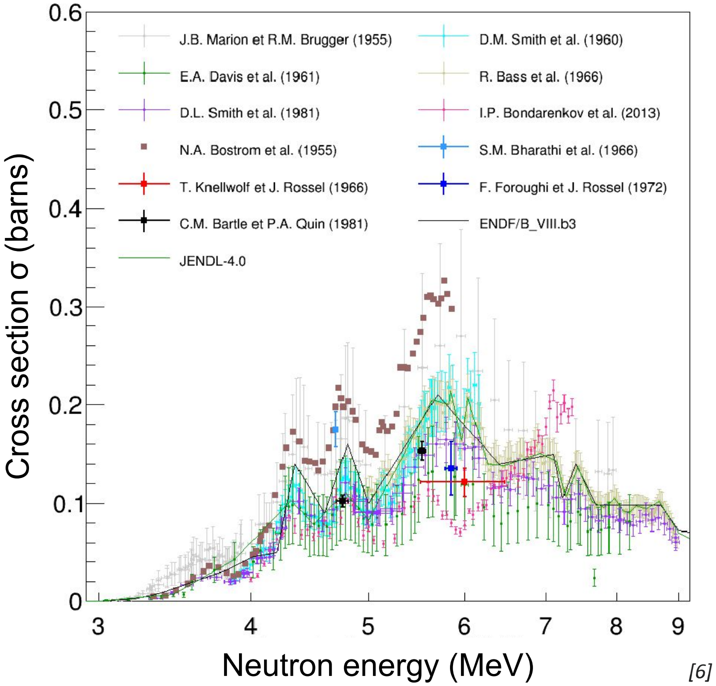
provide new data sets for the evaluation process with SCALP



[6]

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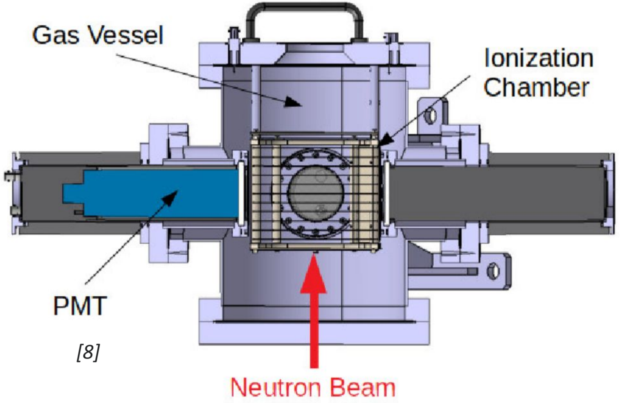
EXPERIMENTAL SETUP

SCALP : Scintillating ionization **C**hamber for **AL**pha **P**article detection in neutron induced reactions



[8]

EXPERIMENTAL SETUP

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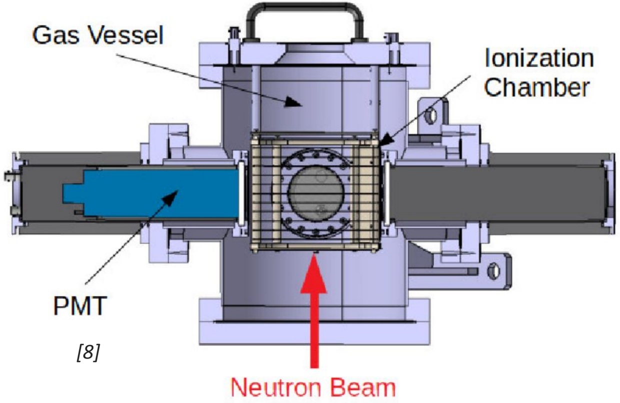
ionization chamber
filled with CF_4

Energy **deposited** by reaction **products**



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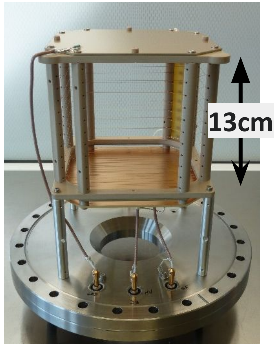

Ionization chamber

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4 **photomultipliers**

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Neutron kinetic energy measured by **time-of-flight**

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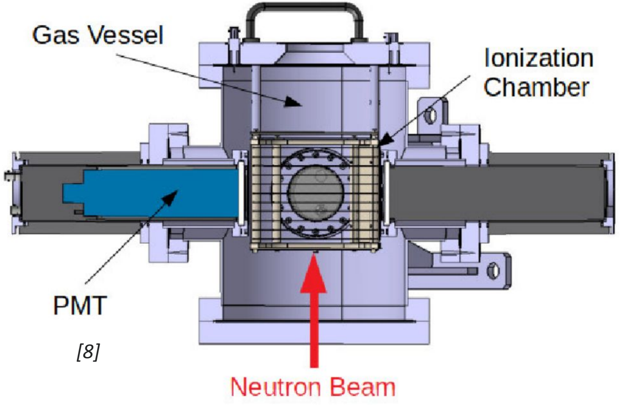

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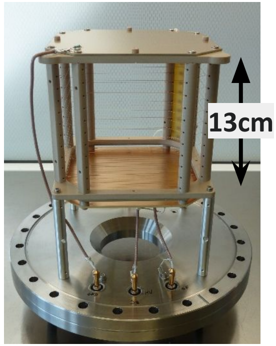

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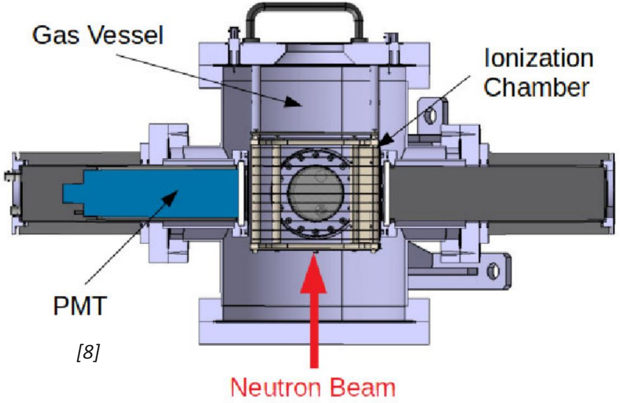

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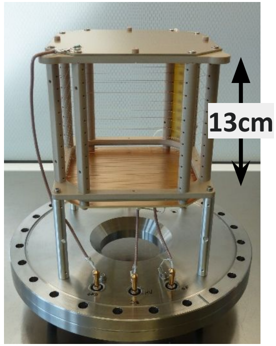

Ionization chamber

gas	IC energy resolution	timing resolution (PMTs)
CF_4	150 keV	600 ps
CF_4 (97%) + CO_2 (3%)	220 keV	> 700 ps

[8]

PREVIOUS SCALP EXPERIMENTS

Facility	NFS (2021)		nELBE (2022)	
Configuration	CF4	CF4 + CO2	CF4	CF4 + CO2
Duration (UT)	15	14	11	16
Data analysis	*A. Chevalier, PhD, 12/2024 [7]*	*not enough stat*	*ongoing*	*not enough stat*

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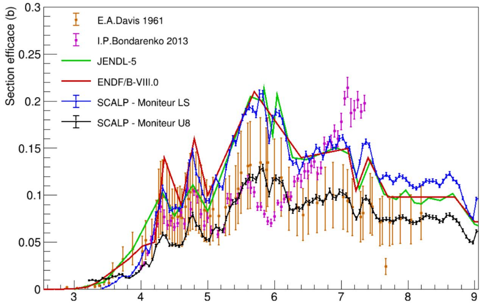

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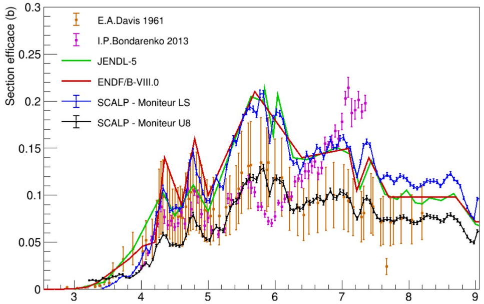

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- **60% of the statistic lost** (prohibitive for $^{16}O(n,\alpha)^{13}C$)

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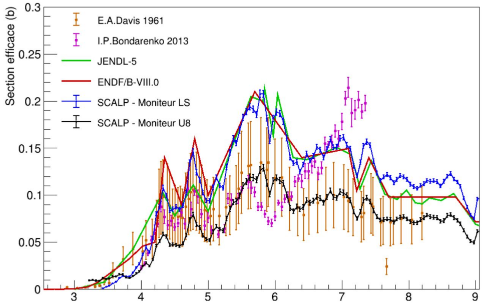

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- different monitors (LS/MM, U8FC) => different results *[10]*

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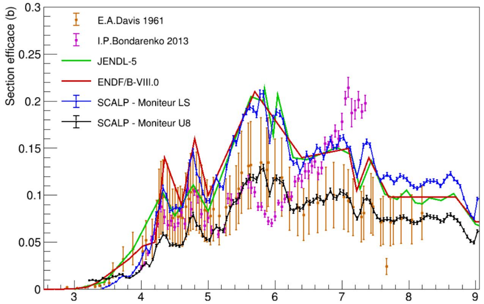

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⟶ **SCALP modifications and improvement of the normalization procedure at NFS (SPIRAL2, GANIL)**

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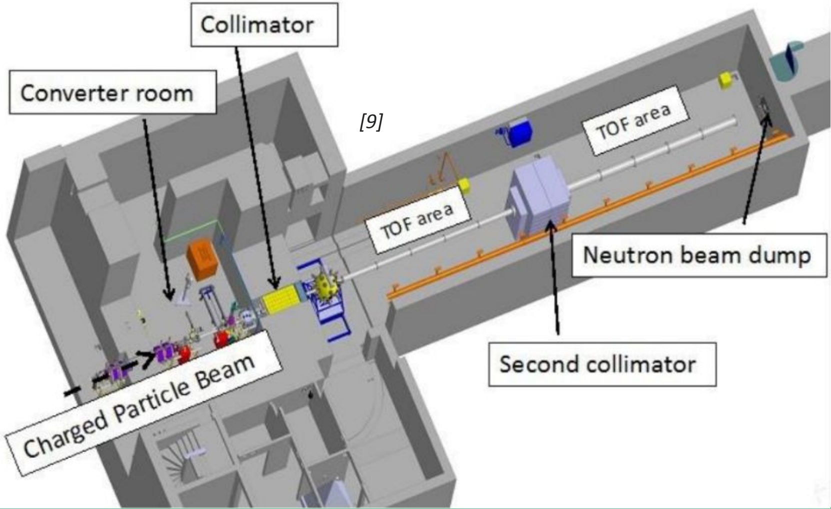
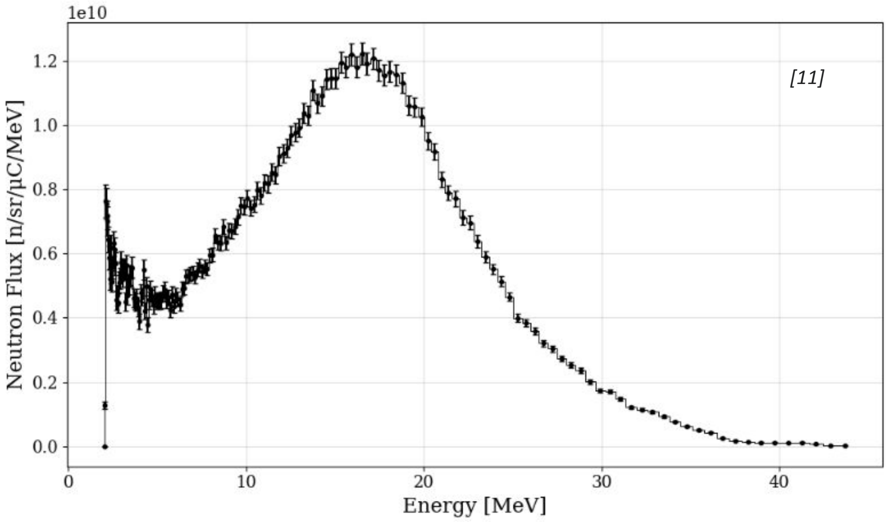


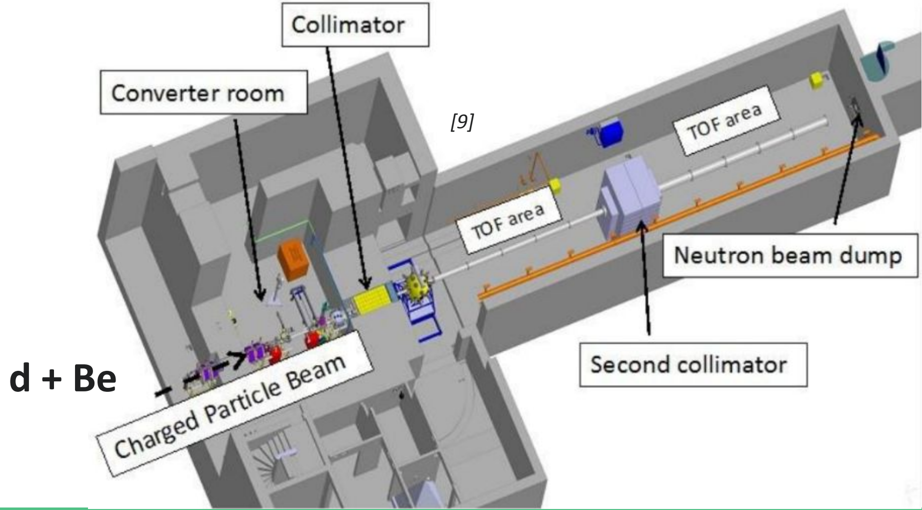
[9]

NEUTRON PRODUCTION @ NFS

NFS = **Neutrons For Science** (SPIRAL2, GANIL) *[9]*

- ^{2}**H beam** (LINAG) @ 38 MeV on **Be target**
- Continuous energy distribution **[1-44] MeV**





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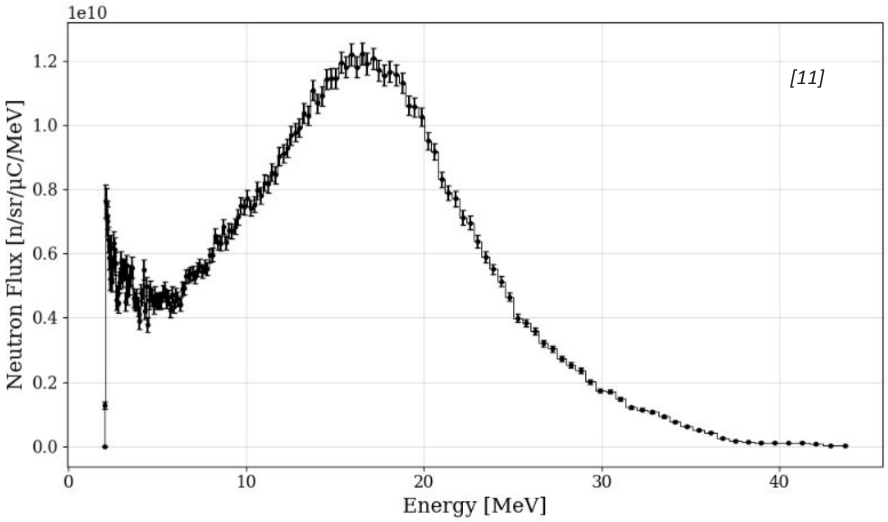
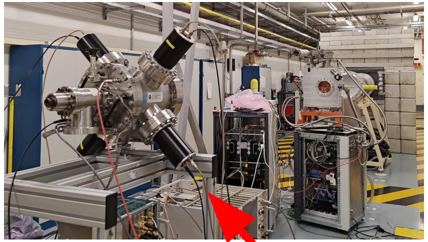


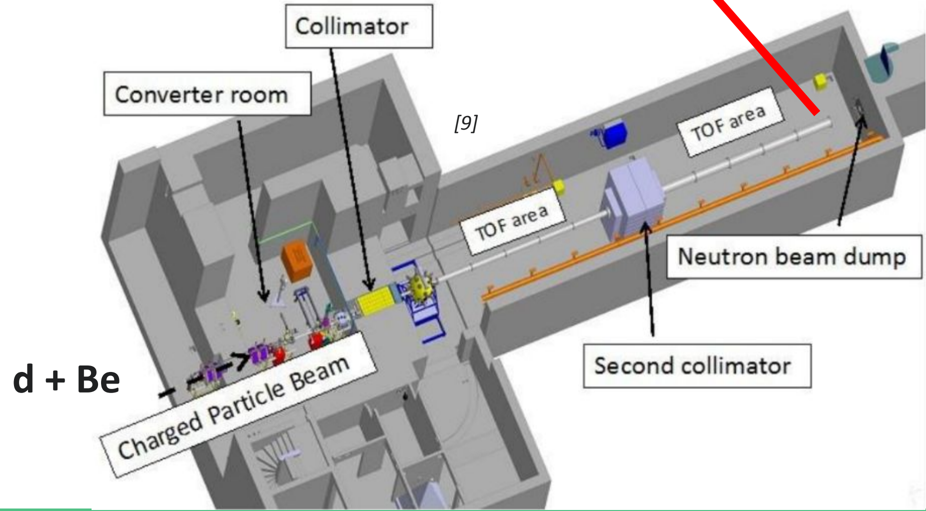
→ SCALP@NFS E901 **(100% CF_4 - 14UT)**

- primary HF 88MHz + beam chopper → T_{HF} = **2.271 μs**
- flight distance : **27.394m**

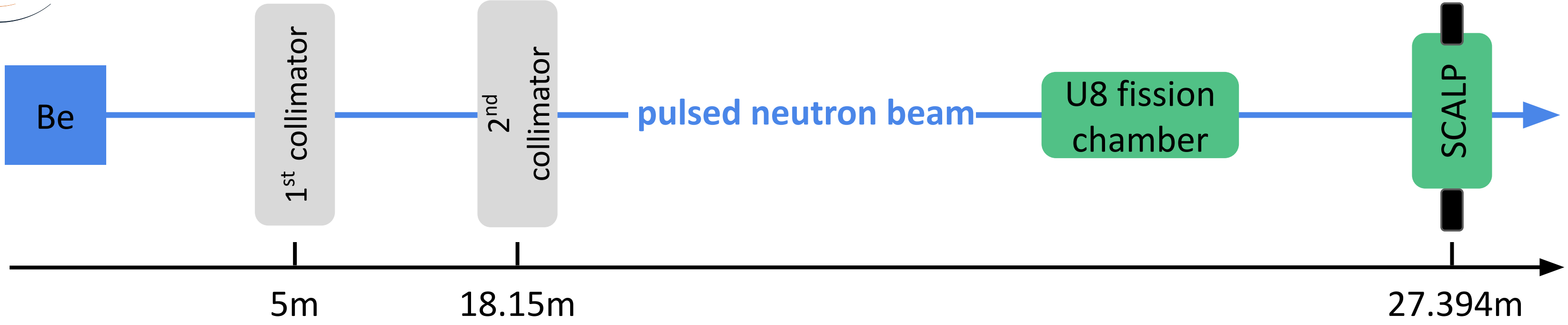
→ *small gamma flash*

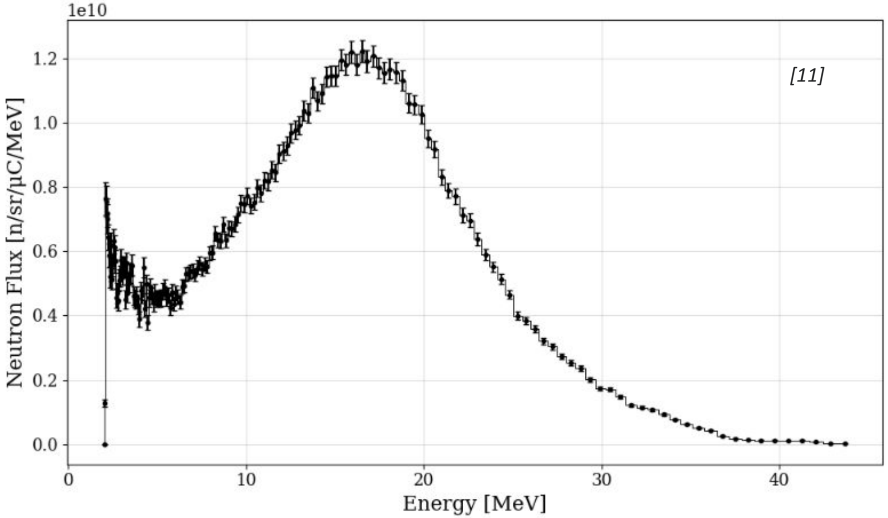
→ *facility suited for the experiment*





MONITORING OF THE NEUTRON FLUX





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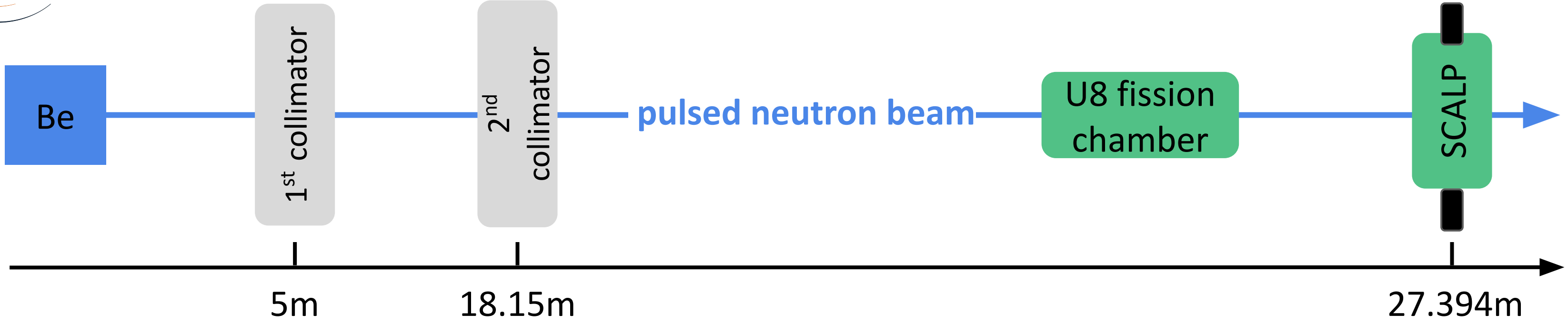
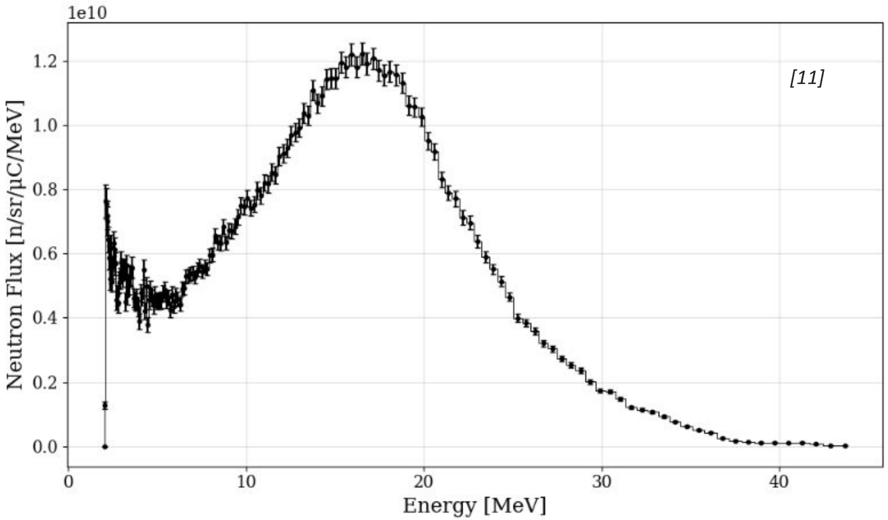
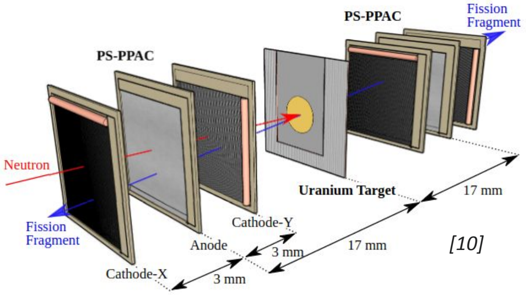




→ **Fission chamber :** detection of ^{238}U(n,f) fragments

- Position Sensitive PPACs for beam profile
- **^{238}U(n,f) cross section for the yield**



→ *non intrusive*

→ *simultaneous operation*

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NEUTRON TIME OF FLIGHT

$$\mathrm{ToF} = (t_{\mathrm{PMT}} - t_{\mathrm{HF}}) \bmod T_{\mathrm{HF}}$$

PMT timestamp

HF timestamp

HF period (2.271 µs)

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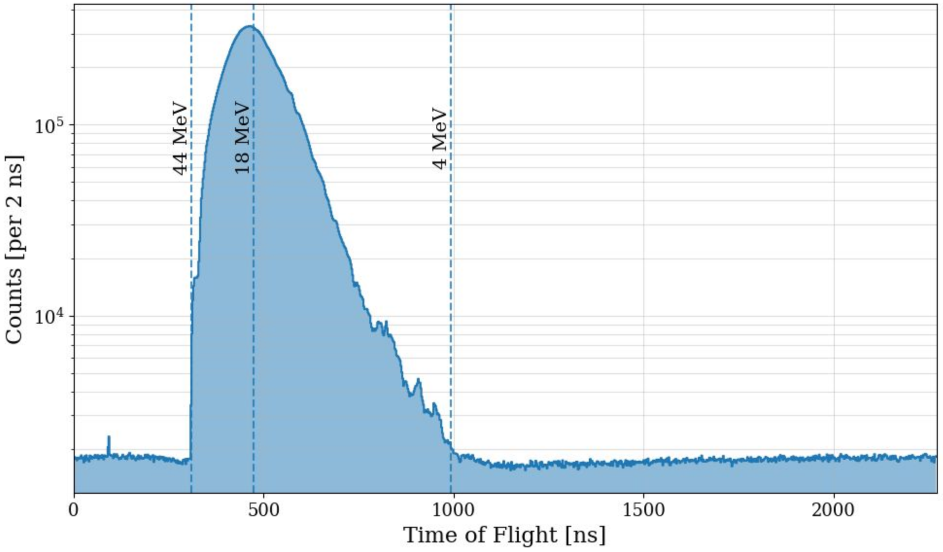

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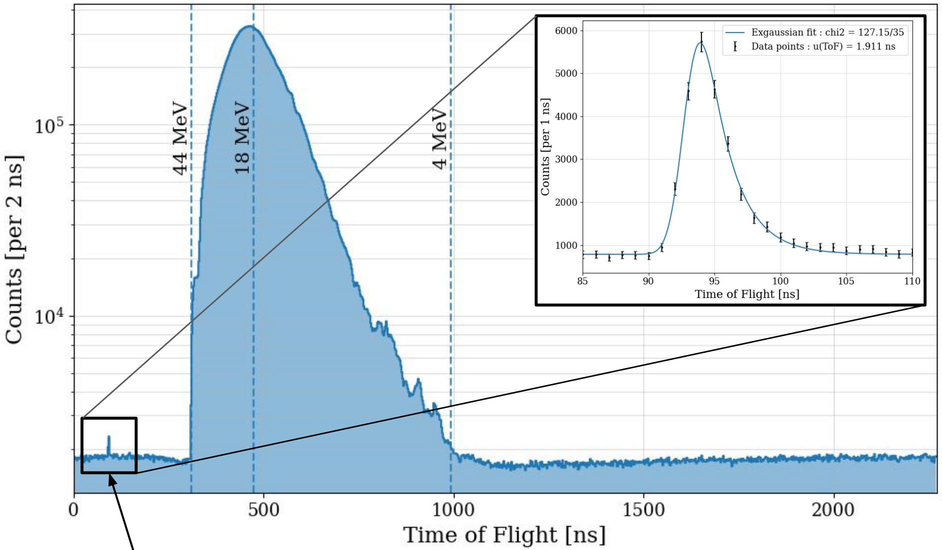

γ flash (ToF reference) ⟶ <u>ToF resolution</u> **< 2ns**

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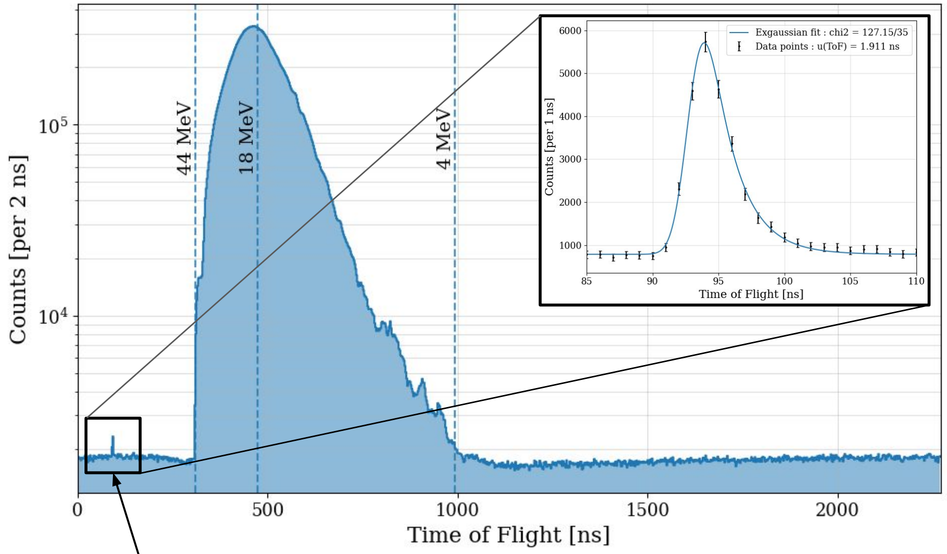

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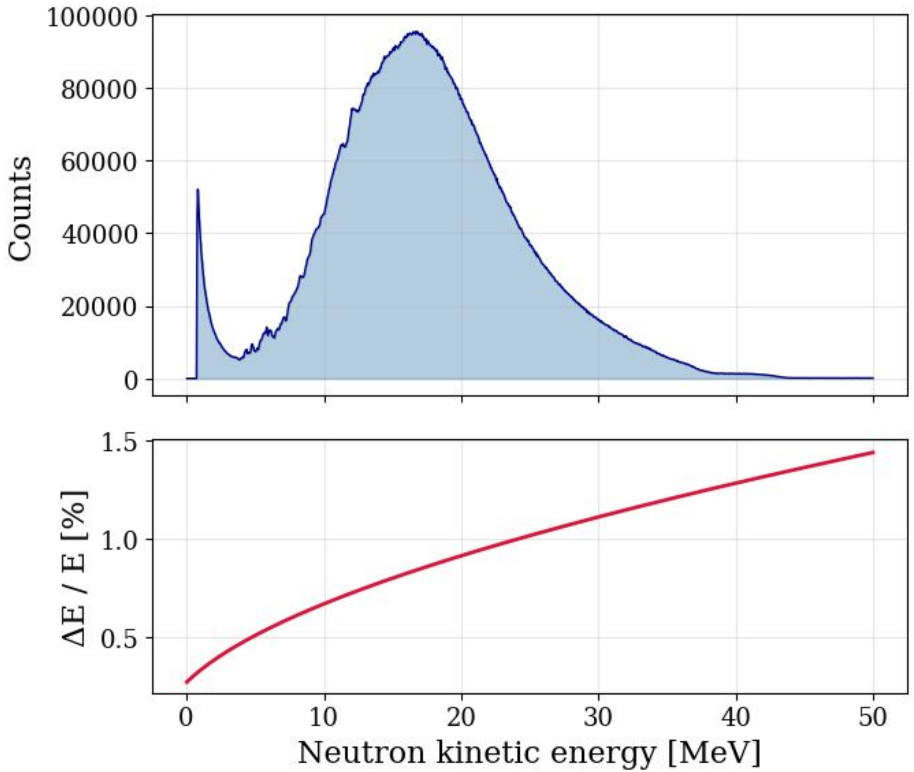
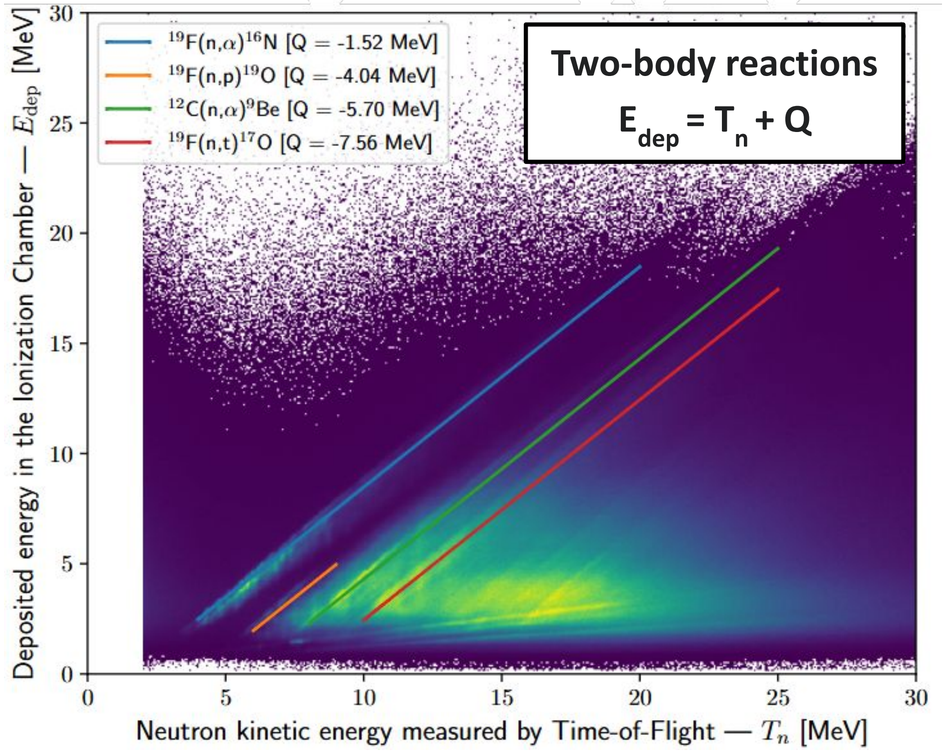
$$T_n = (\gamma - 1) m_n c^2$$



→ <u>Energy resolution</u> **better than 1%** below 20 MeV

IDENTIFICATION OF REACTION CHANNELS



→ $^{19}F(n,\alpha)^{16}N$ is well separated from other reactions

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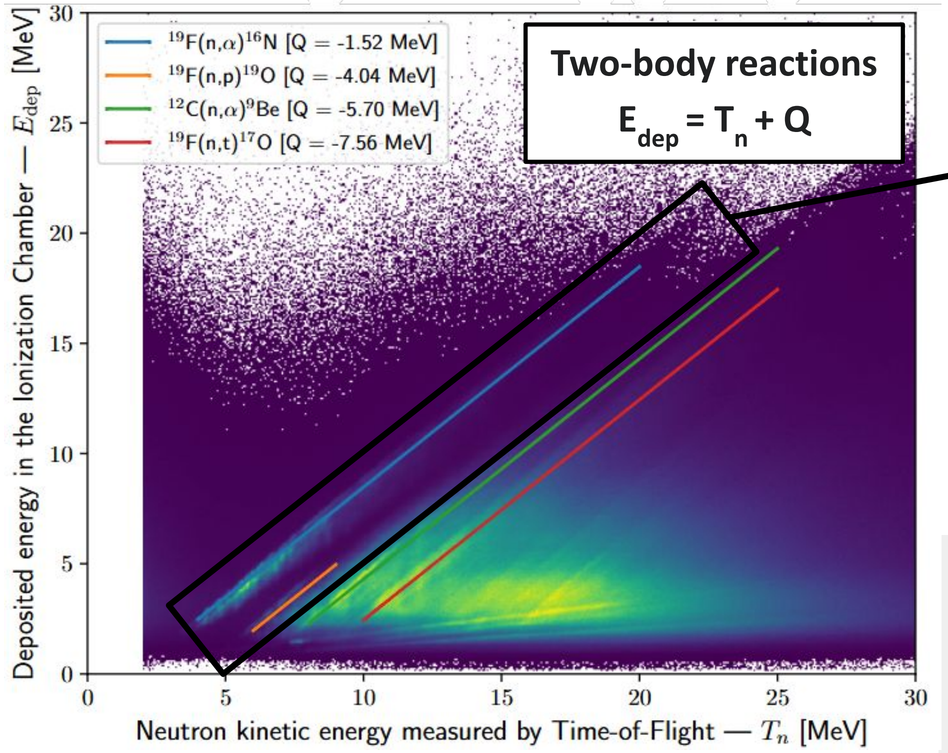

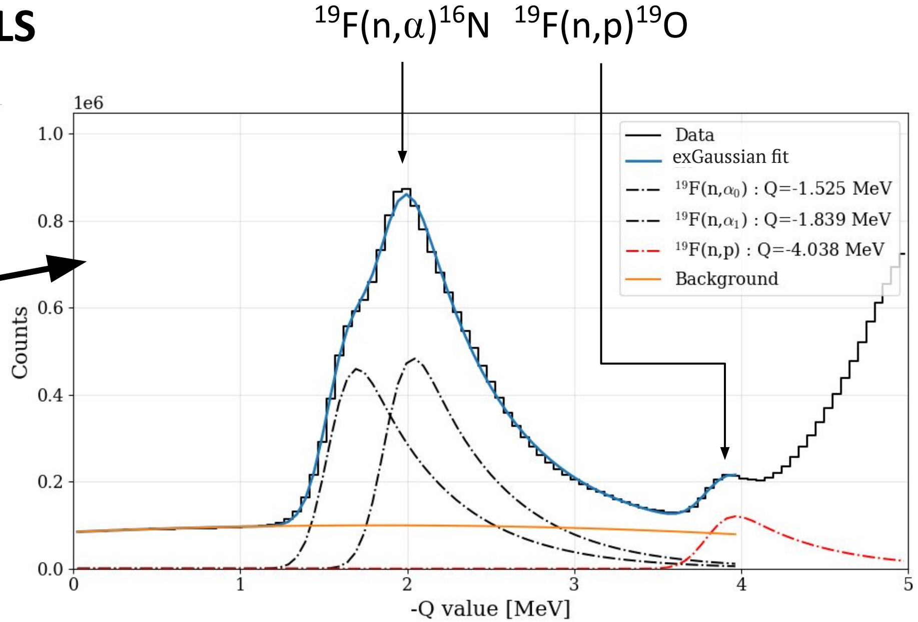

→ **Projection** along the reaction lines : **Q_{val} spectrum**

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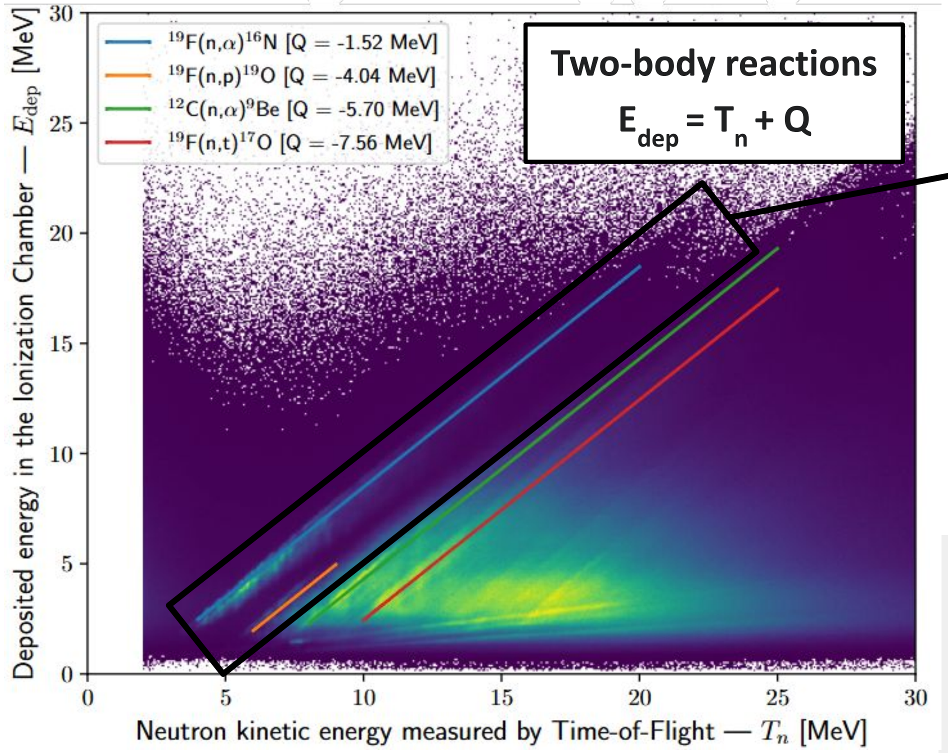

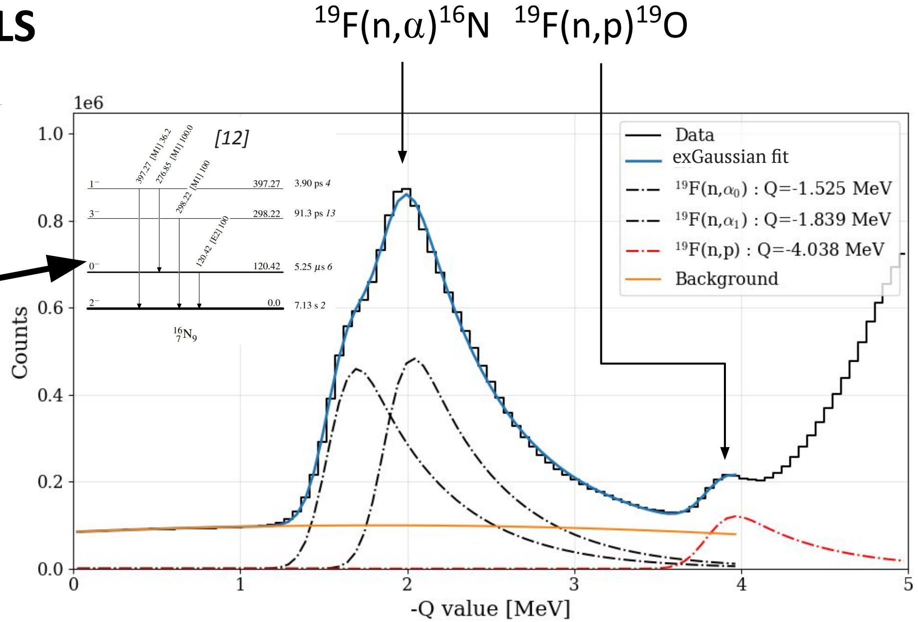

→ ^{19}F(n,α)^{16}N is well separated from other reactions

→ **Projection** along the reaction lines : **Q_{val} spectrum**

→ Residual ^{16}N nucleus :

- 3 **excited states below 400 keV** : Q_{val} shift
- energy resolution : 2 **effective states**
- data matches with TALYS *[13]* calculations

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ESTIMATION OF THE CROSS SECTION

number of $^{19}F(n,\alpha)^{16}N$ events detected with SCALP

cross section [cm²]

$$\sigma(T_n) = \frac{N(T_n)}{\epsilon(T_n)\ \eta_{^{19}F}\ L\ \Psi(T_n)}$$

number of neutrons impinging the detector (beam monitor)

detection efficiency (Geant4 simulation) [%]

length of the detection zone [cm]

target nucleus density [cm^{-3}]

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target nucleus density [cm^{-3}]

with :

$$\Psi(T_n) = \frac{\pi r^2}{d^2} \times Q_{\mathrm{run}} \times \Phi_{FC}(T_n)$$

solid angle spanned by SCALP [sr]

charge on the Be target [µC]

neutron flux measured with the FC [n/sr/µC]

ESTIMATION OF THE CROSS SECTION

$$\sigma(T_\mathrm{n}) = \frac{N(T_\mathrm{n})}{\epsilon(T_\mathrm{n})\ \eta_{^{19}F}\ L\ \Psi(T_\mathrm{n})}$$

- $\sigma(T_\mathrm{n})$: cross section [cm²]
- $N(T_\mathrm{n})$: number of $^{19}F(n,\alpha)^{16}N$ events detected with SCALP
- $\epsilon(T_\mathrm{n})$: detection efficiency (Geant4 simulation) [%]
- $\eta_{^{19}F}$: target nucleus density [cm^{-3}]
- L: length of the detection zone [cm]
- $\Psi(T_\mathrm{n})$: number of neutrons impinging the detector (beam monitor)

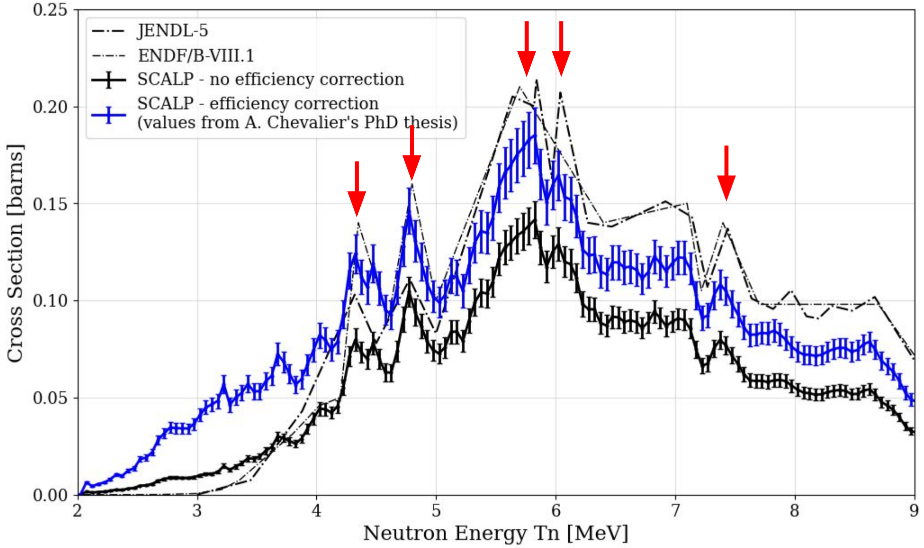
<u>with</u> :

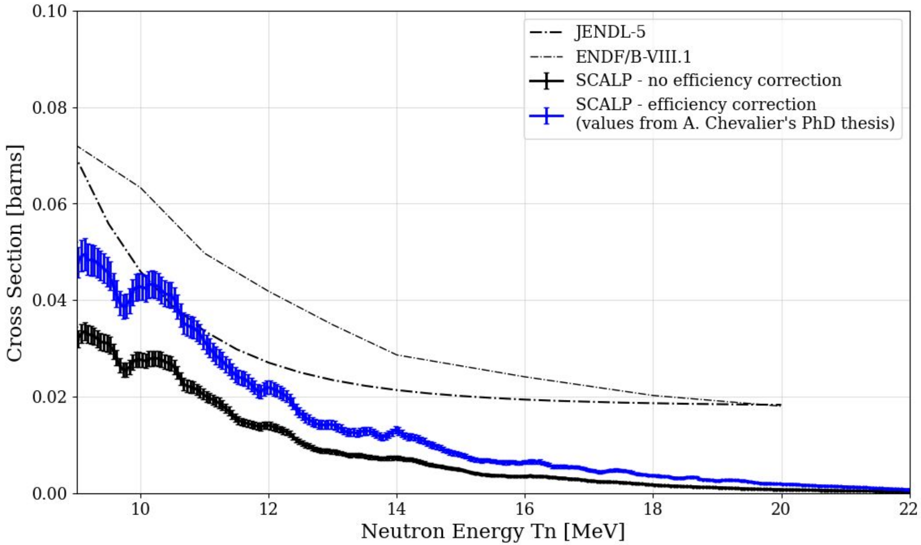
$$\Psi(T_\mathrm{n}) = \frac{\pi r^2}{d^2} \times Q_\mathrm{run} \times \Phi_{FC}(T_\mathrm{n})$$

- $\frac{\pi r^2}{d^2}$: solid angle spanned by SCALP [sr]
- Q_run: charge on the Be target [µC]
- $\Phi_{FC}(T_\mathrm{n})$: neutron flux measured with the FC [n/sr/µC]

Quantity	Relative uncertainty (1σ) (%)
N (Tn)	0.54% - 4.12%
η_{19F}	1.99%
Φ_{FC} (Tn)	2.75% - 6.63%
r	1.60%

ESTIMATED $^{19}F(n,\alpha)^{16}N$ CROSS SECTION - vs evaluations



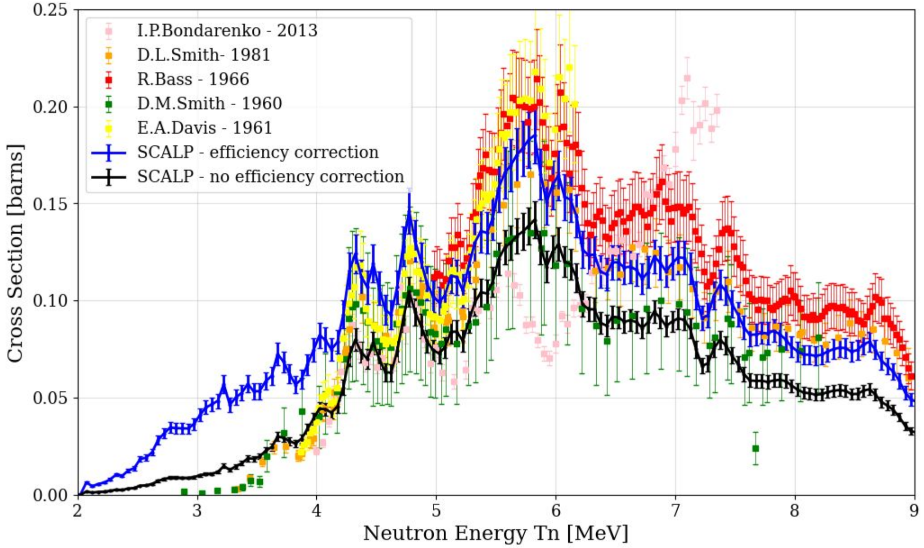


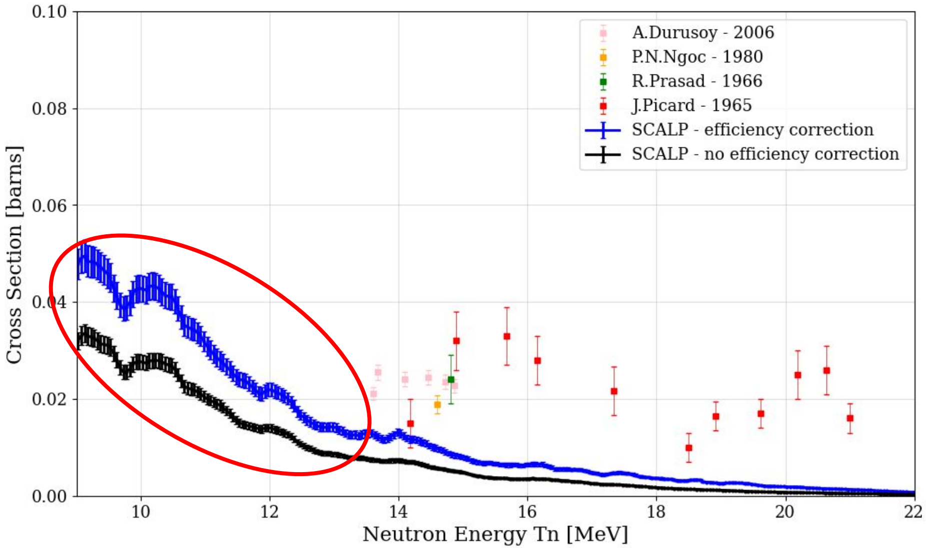
→ **Uncertainty ranges from 5.28% to 7.98%** in the [2, 20] MeV range

→ Reproduction of expected structure at the right energies (validation of energy reconstruction)

→ **Preliminary results** : detection efficiency taken from previous experiment (simulations ongoing)

ESTIMATED $^{19}F(n,\alpha)^{16}N$ CROSS SECTION - vs other measurements





→ **Neutron energy resolution (<1%)** and **u(σ)/σ (<8%)** are competitive, covering [2-20] MeV

→ Confirmation of newly observed structures with SCALP@NFS-2021, new data between 9 MeV and 13.5 MeV

→ **^{16}N excited states > 3 MeV** not accessible (identification matrix) : discrepancies above 10 MeV

- Motivations and scientific background
- Overview of the experimental setup
- E901 Experiment at NFS
- Data analysis
- Results on the $^{19}F(n,\alpha)^{16}N$ cross section with SCALP
    - **Conclusion and outlook**

CONCLUSION AND OUTLOOK

Context

- (n,α) reactions impact nuclear reactor simulations
- new measurements are needed for evaluation

Status

- setup is validated experimentally
- analysis, Geant4 simulations ongoing

++ energy resolution, reaction identification
++ normalization procedure, $u(\sigma)/\sigma < 8\%$ achieved

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$\rightarrow$ **$^{16}O(n,\alpha)^{13}C$:** to be submitted to PAC 2026

++ previous results, preliminary simulations

+ optimizations to improve statistics

CONCLUSION AND OUTLOOK

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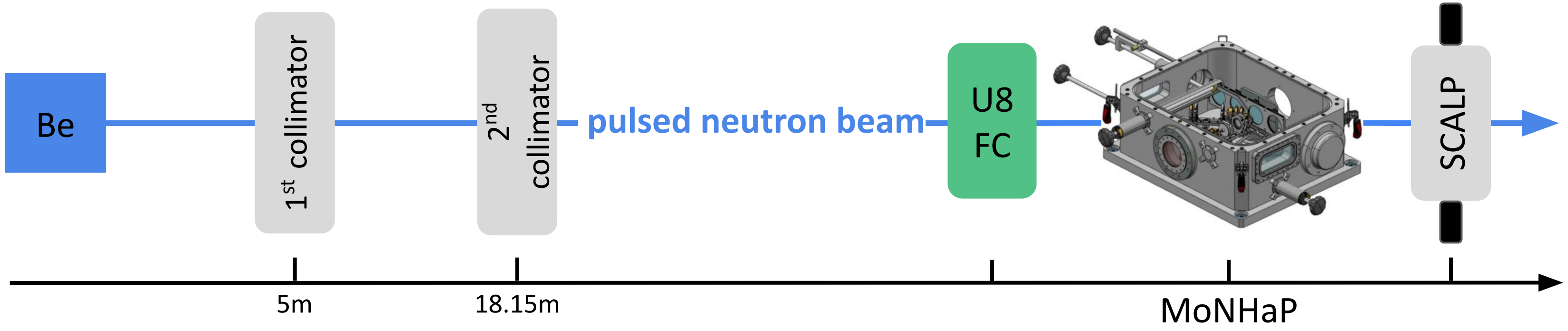
\+ <u>optimizations</u> to improve statistics

→**MoNHaP :** non-intrusive **recoil proton spectrometer**

- normalization with the p(n,n)p cross section
- IAEA primary standard
- in-beam tests : 06/2026 (~33 UTs)
  09/2026 (~XX UTs)



Measurement of the $^{19}F(n,\alpha)^{16}N$ cross section with the SCALP detector

The SCALP collaboration (LPC Caen, GANIL, EAMEA, CEA)

N. Rousseaux, F.R. Lecolley, J.L. Lecouey, G. Lehaut, N. Marie, R. Lafaye, A. Chevalier (LPC CAEN)
L. Manduci (EAMEA)
X. Ledoux (GANIL)
O. Serot (CEA Cadarache)

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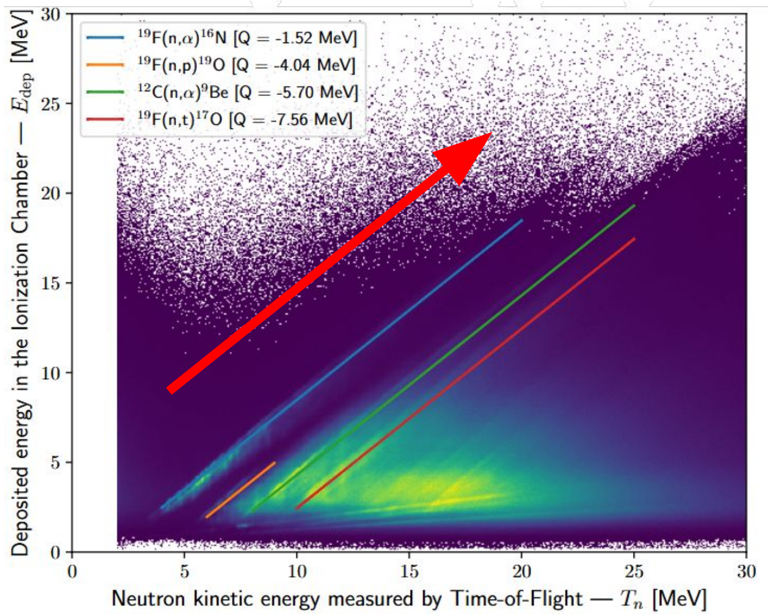
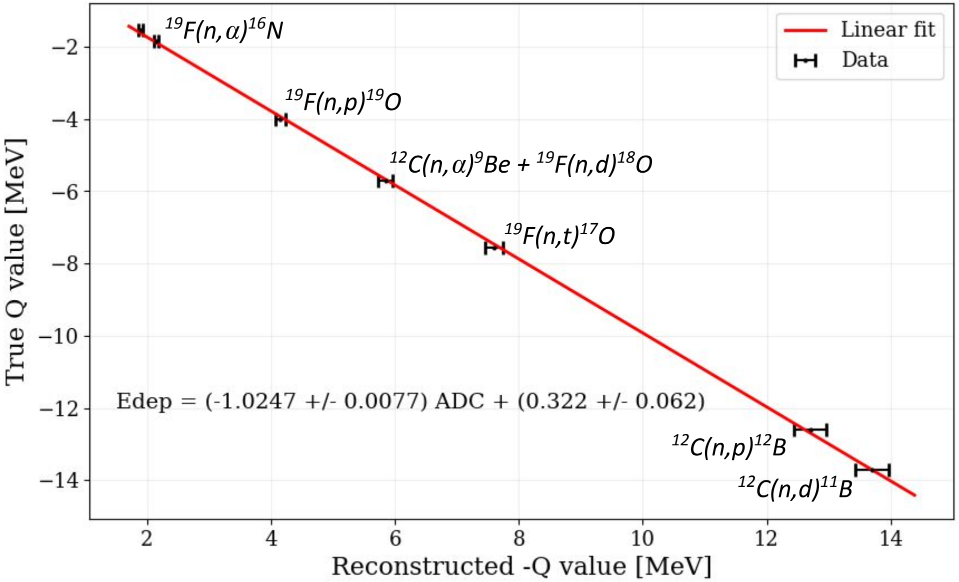
CALIBRATION OF THE IONIZATION CHAMBER

Edep = a * ADC + b -> slope a : PCA on the identification matrix

- diagonalize the covariance matrix
- principal variance direction (reaction lines) = eigenvector

-> offset b : peak indexing on the Qval spectrum



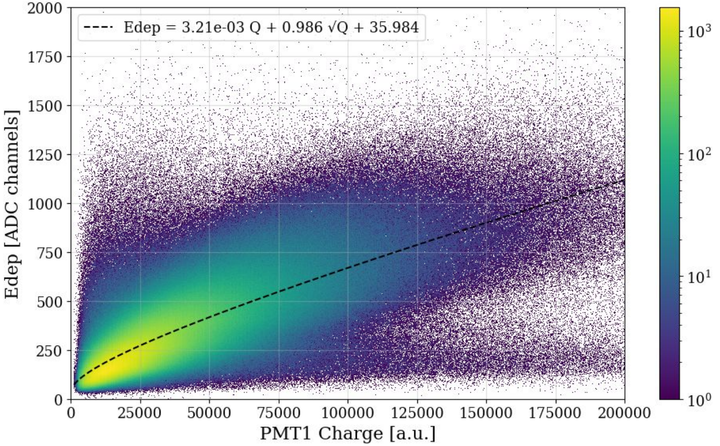


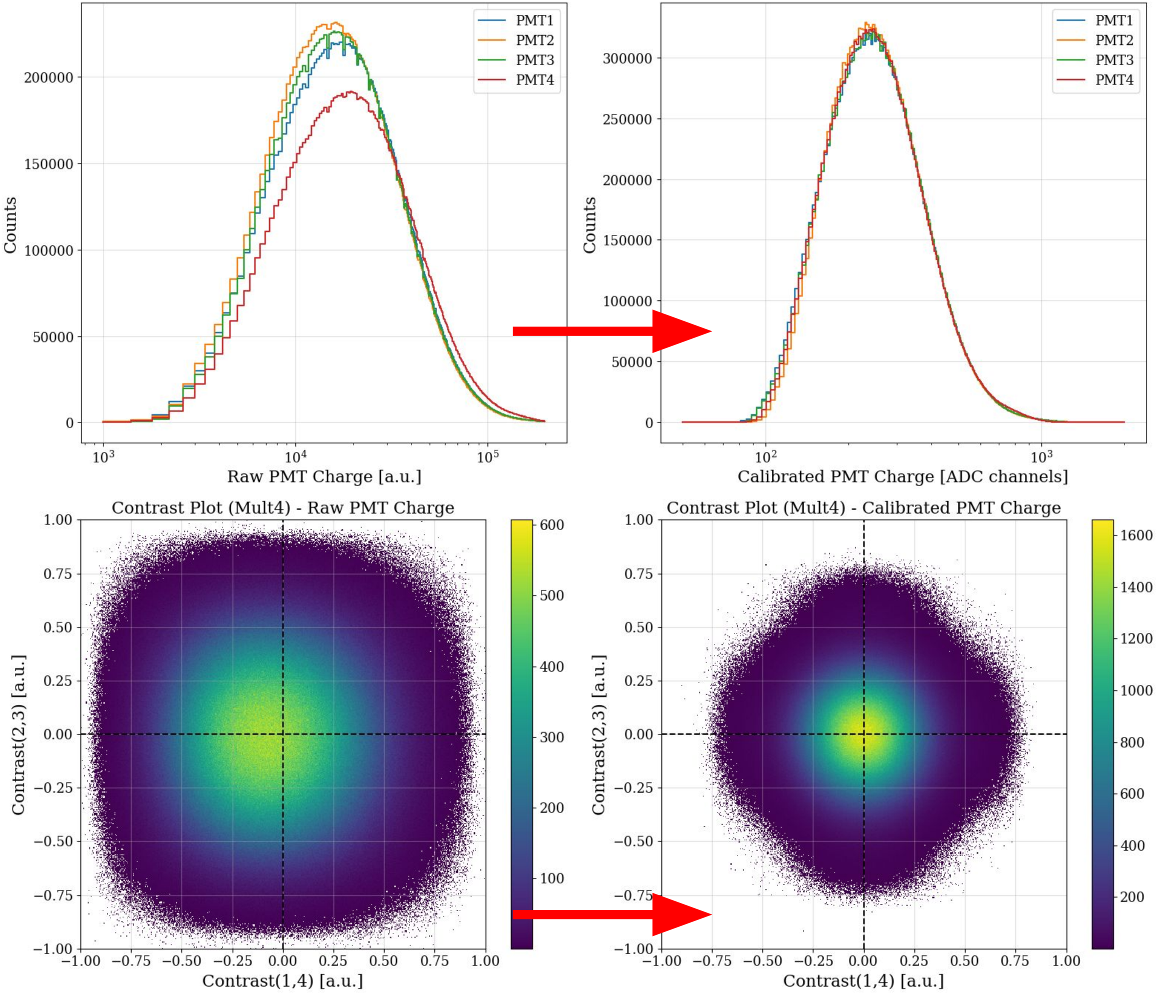
PMT CALIBRATION

-> PMTs are gain-matched on the IC with a polynomial fit

-> Contrast figure : pseudo-position in the transverse axis

$$C_{ij} = \frac{Q_i - Q_j}{Q_i + Q_j}$$

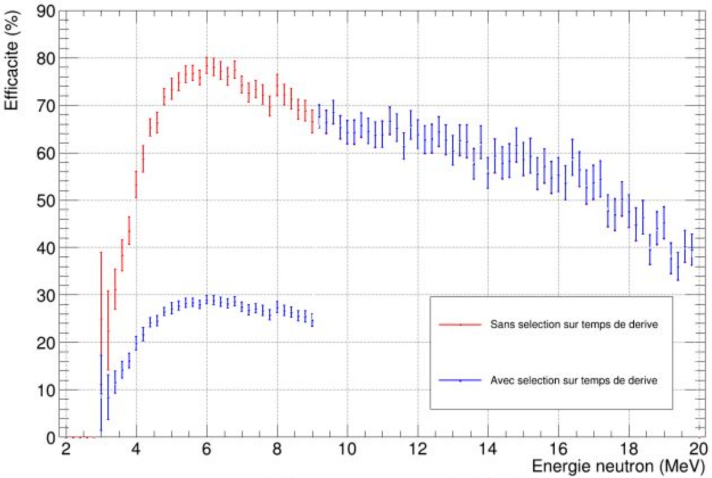




CROSS SECTION COMPARISON

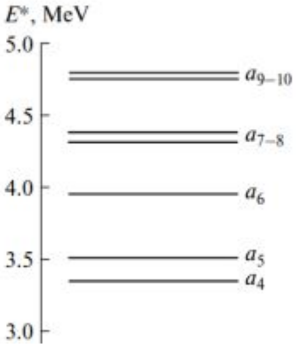
Below 4 MeV :

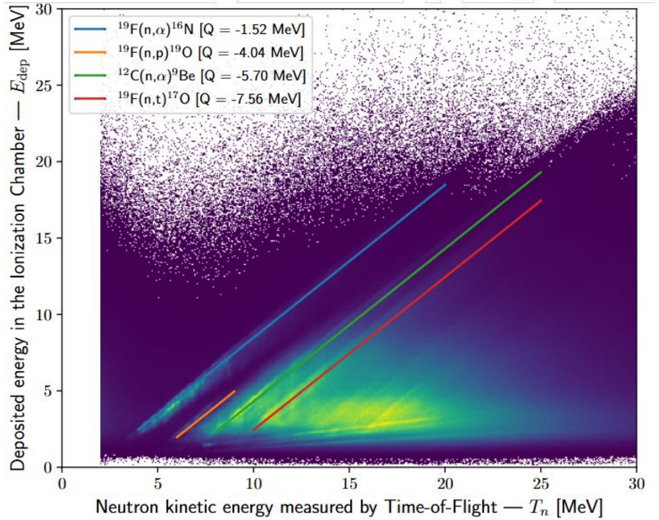
- efficiency values from 2021 : /!\ data contamination
- energy dependent cut : lower eff @ lower Tn
- new event selection : background substraction



Above 10 MeV :

- 16N excited states > 3 MeV
- not accessible with SCALP
- major contribution to the cross section





MEASUREMENT OF THE (n,a) CROSS SECTION ON 16O

- $^{19}F(n,\alpha)$: -1.525 MeV
- $^{16}O(n,\alpha)$: -2.216 MeV

-> delta = 750 keV (400 keV with ES)

-> Neutron energy spectrum deconvolution

-> 1e12 incident neutrons : 2.5% <stat error>