Agata Collaboration Council Meeting 2024

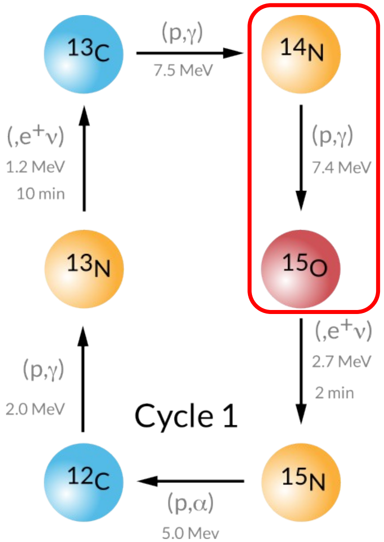
Lifetime measurement of 6.79 MeV state in ^{15}O for nuclear astrophysics

Speaker: Elia Pilotto

September 2024

Introduction

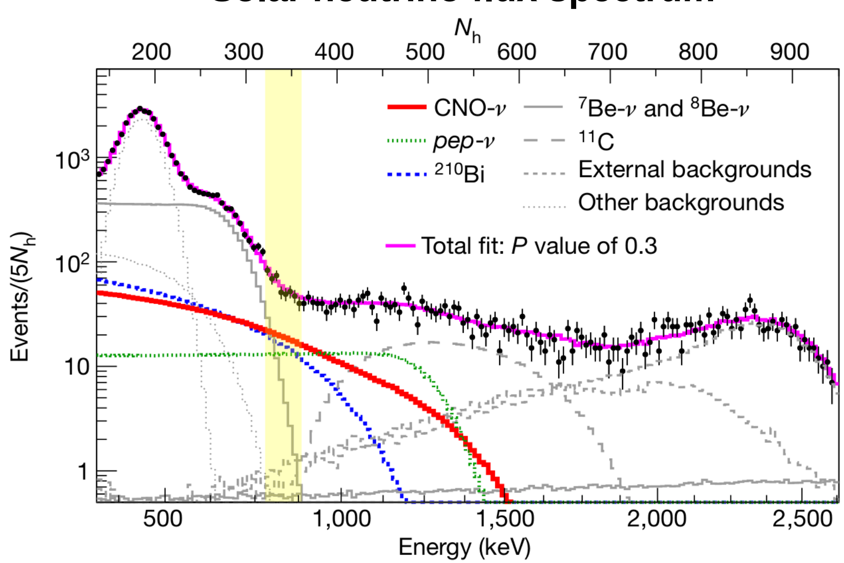
CNO-cycle I



- Main energy production mechanism in stars larger than our Sun
- Equilibrium governed by the **$^{14}N(p,\gamma)^{15}O$** reaction, the slowest of the cycle
- Gamow peak is at 10 – 30 keV, direct measurement stop at 90 keV
- **Sub-threshold resonance** dominates at astrophysically relevant energies and heavily impacts extrapolation
- **Resonance width** is directly correlated to **lifetime** of the state

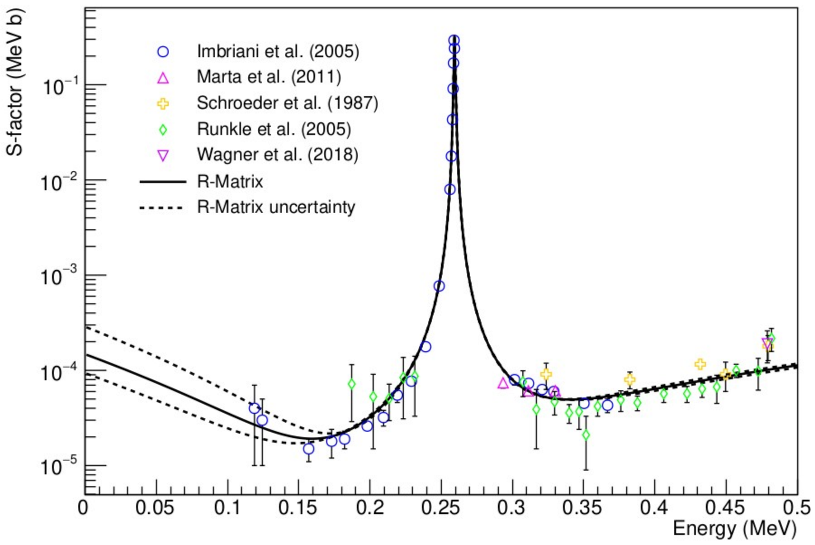
Reaction cross section → **Solar metallicity measurement** ← **Neutrino flux measurement**

Solar neutrino flux spectrum

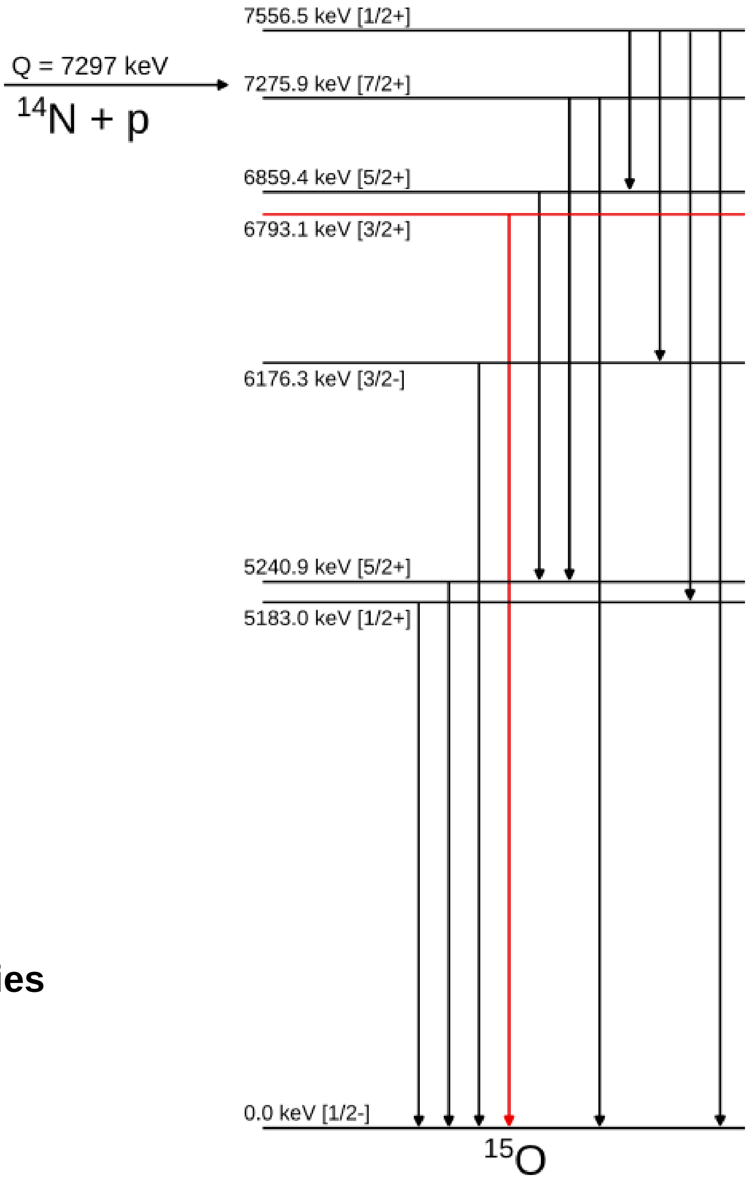


Borexino collaboration, Nature 587 (2020)

State of the art of the reaction



R-Matrix fit parameters according to Frentz et al, PRC (2021)



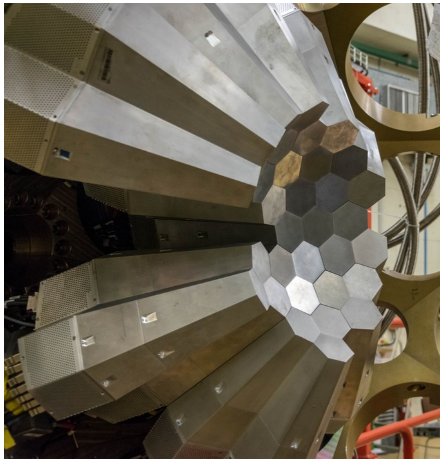
6.79 MeV state lifetime estimates

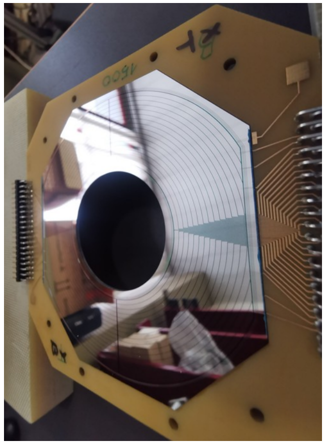
Dataset	τ_{obs} (fs)
Frentz et al. (2021)	0.6 ± 0.4
Bertone et al. (2001)	1.6 ± 0.75
Schurmann et al. (2008)	< 0.77
Galinski et al. (2014)	< 1.8
Sharma et al. (2020)	< 1.18

- **Sub-fs lifetime**
- **Large uncertainties**

The Experiment

- Performed in November 2023
- Reaction: **$^3He(^{16}O,^{15}O)^4He$ @ 50 MeV**
- Setup: **Agata + Sauron DSSSD**
- **D**oppler **S**hift **A**ttenuation **M**ethod (**DSAM**)





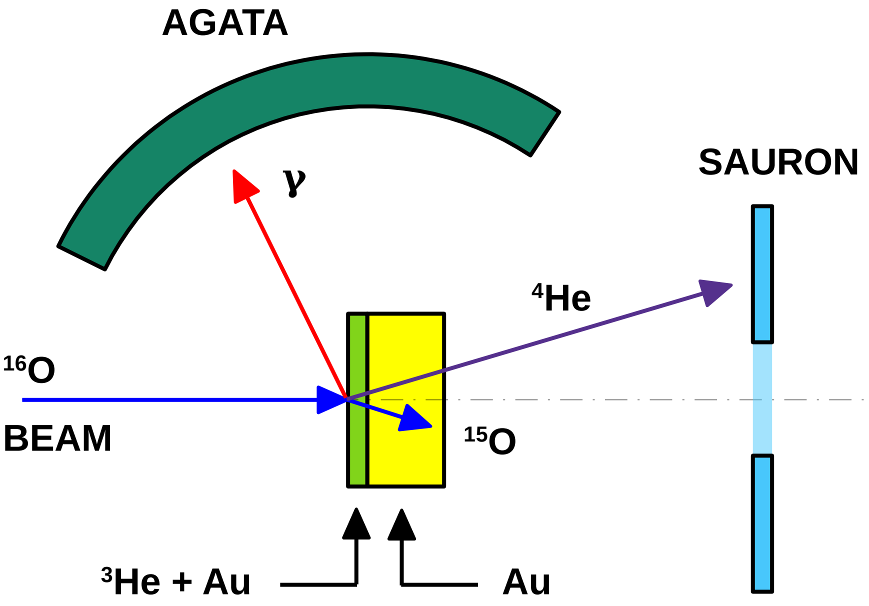
Targets used

1st set of targets

- Produced at HZDR (Dresden) by ^{3}He **implantation**
- 13 um Au substrate
- 0.1 um ^{3}He + Au implantation layer

2nd set of targets

- Produced at ICMS (Seville) by **magnetron sputtering***
- 13.6 um Au substrate
- 0.4 um ^{3}He + Au growth layer

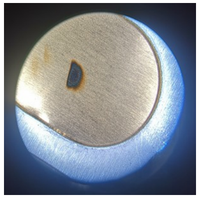


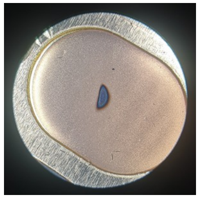
**A. Fernandez et al, Materials and Design 186 (2020)*

Target characterization

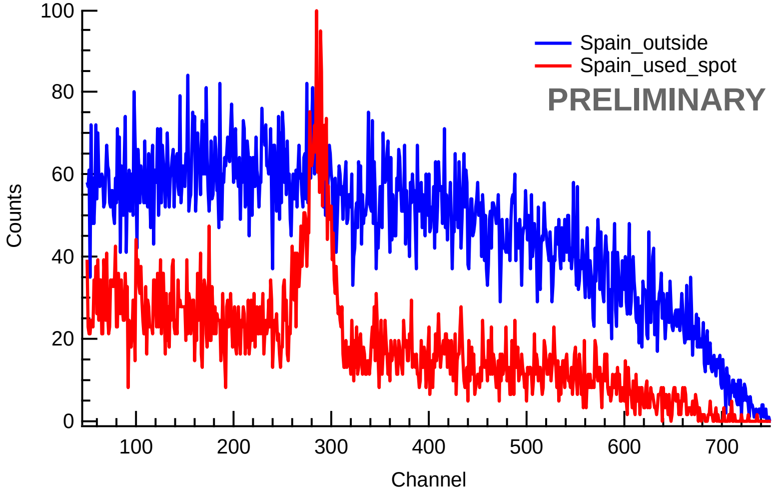
Objectives
- Contaminants
- ^{3}He depth profile

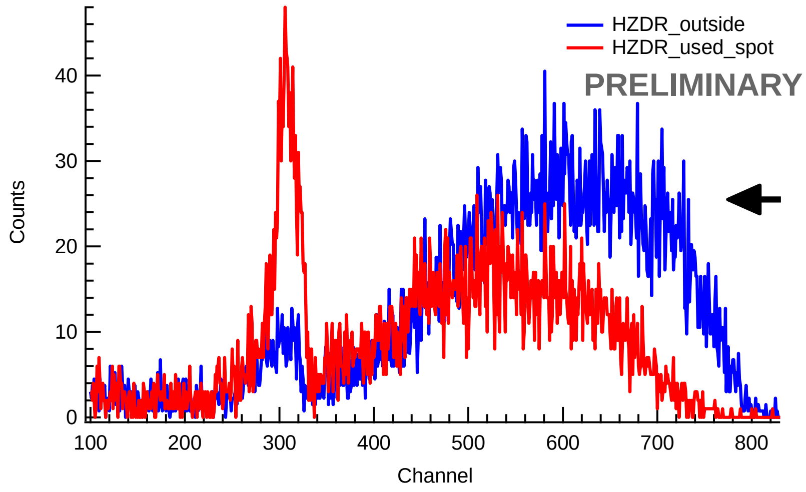
In Beam Analysis (IBA)
- **N**uclear **R**eaction **A**nalysis (**NRA**) performed at CNA in Seville
- **E**lastic **R**ecoil **D**etection **A**nalysis (**ERDA**) performed at HZDR in Dresden





ERDA measurement at HZDR – Dresden





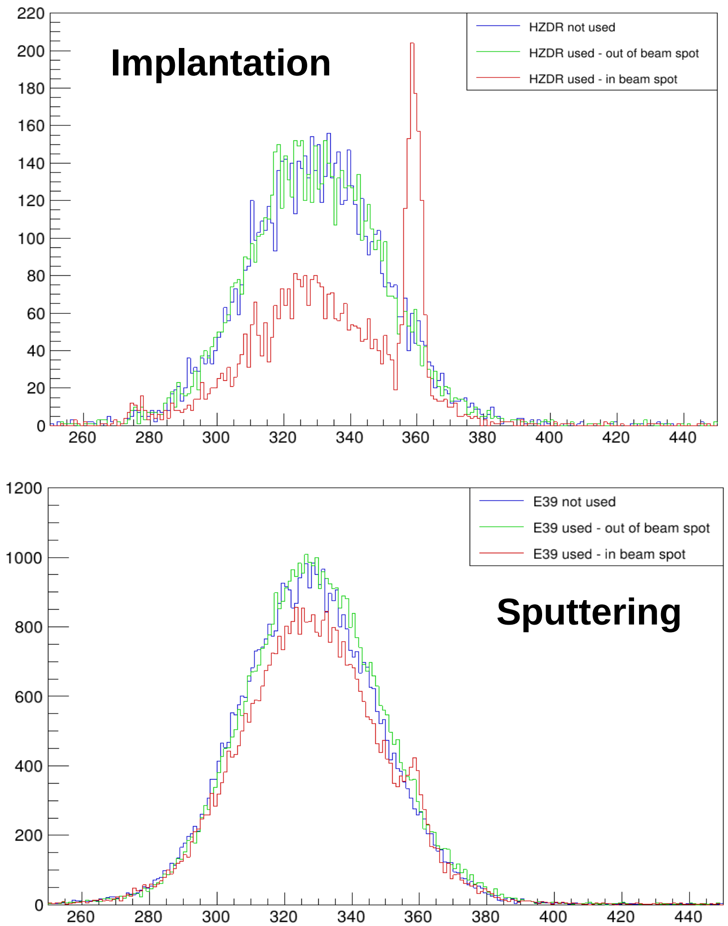
^{3}He loss concentrated in the surface

ERDA performed by F. Munnik (HZDR)

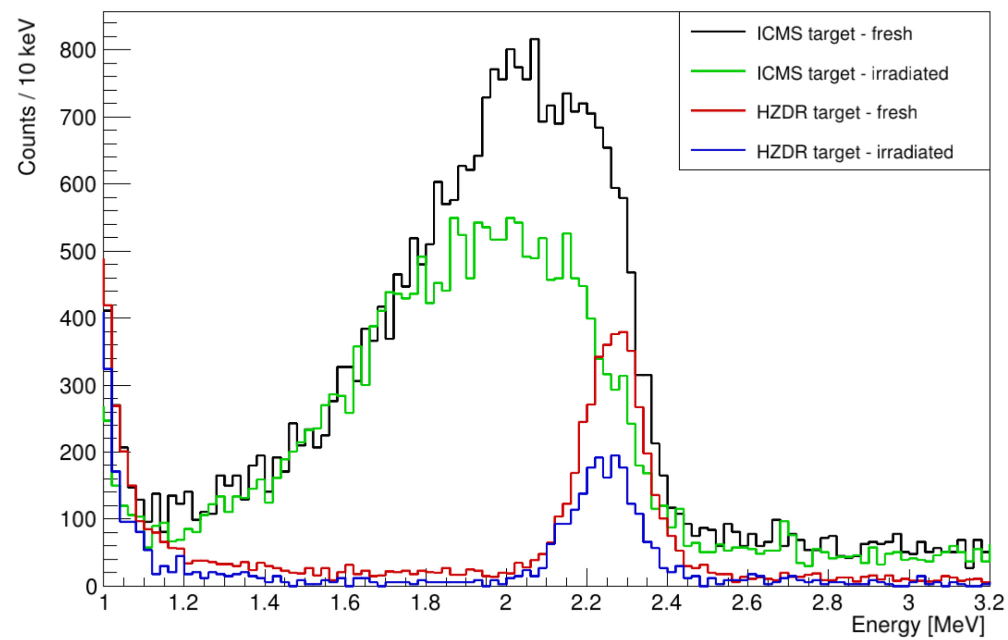
Target characterization

NRA measurement at CNA – Seville

April 2024 measurement



July 2024 measurement



- C, O contaminants only in the beam spot
- ICMS targets show higher initial ^{3}He content → factor 7
- ICMS targets retain ^{3}He content better → factor 14
- ICMS targets have a thicker ^{3}He layer → factor 4

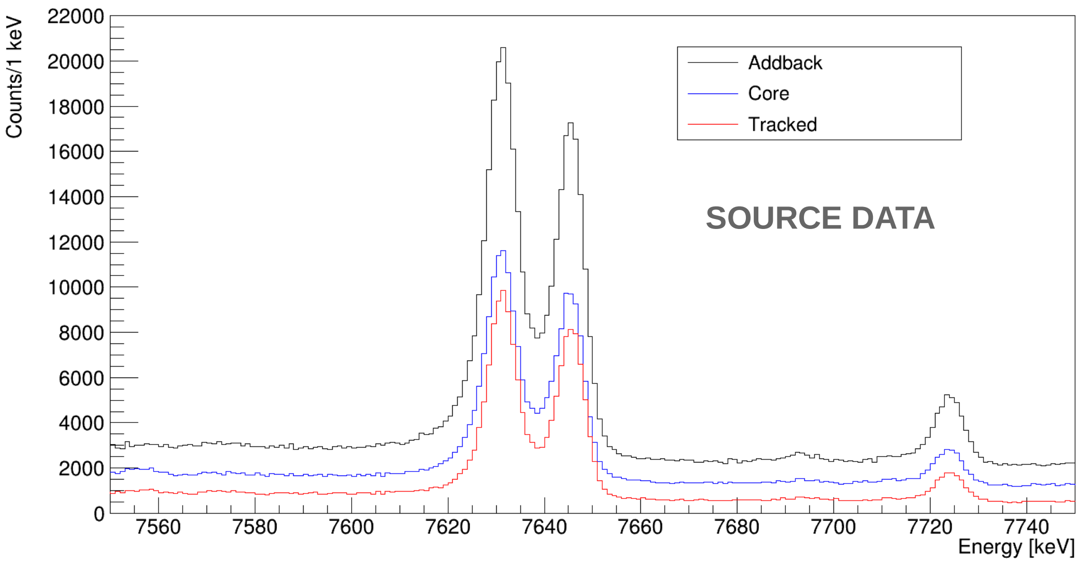
NRA performed by J. Ferrer (CNA)

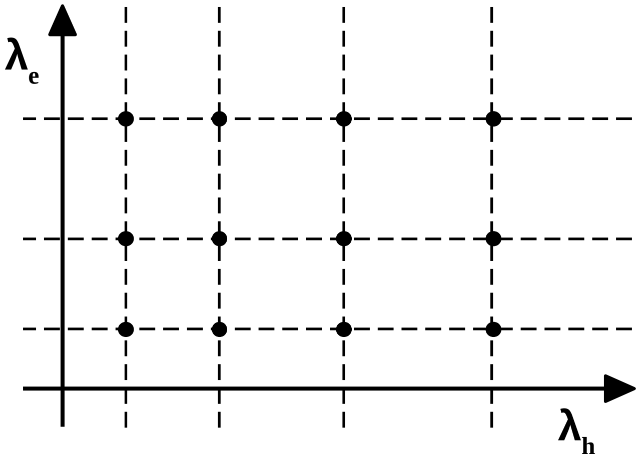
Presorting – Post PSA improvements

sub-fs lifetime → high precision required → presorting improvements were deemed necessary

Neutron damage correction

- **Addback** was deemed advantageous **over tracking** at the energies of interest, so **core energy (CC)** optimization only
- Implementation of **Adaptive Grid – Search** algorithm
- *Fine tuning by hand*





Adaptive Grid-Search

$$\frac{E_{meas}(x)}{E_{corr}(x)} = 1 + \frac{t_e(x)}{\lambda_e} + \frac{t_h(x)}{\lambda_h}$$

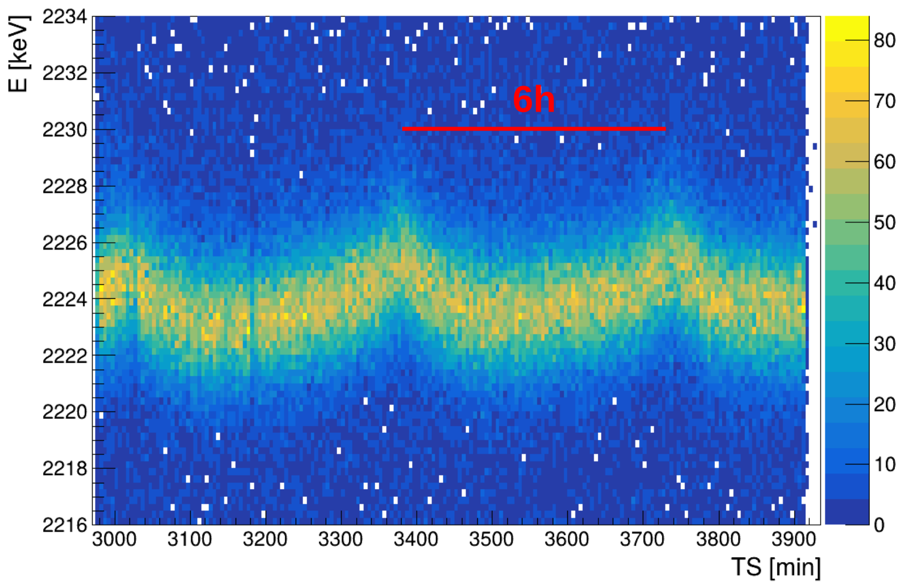
λ_e: inverse eletron – trap density
λ_h: inverse hole – trap density

Presorting – Post PSA improvements

Time dependent gain correction

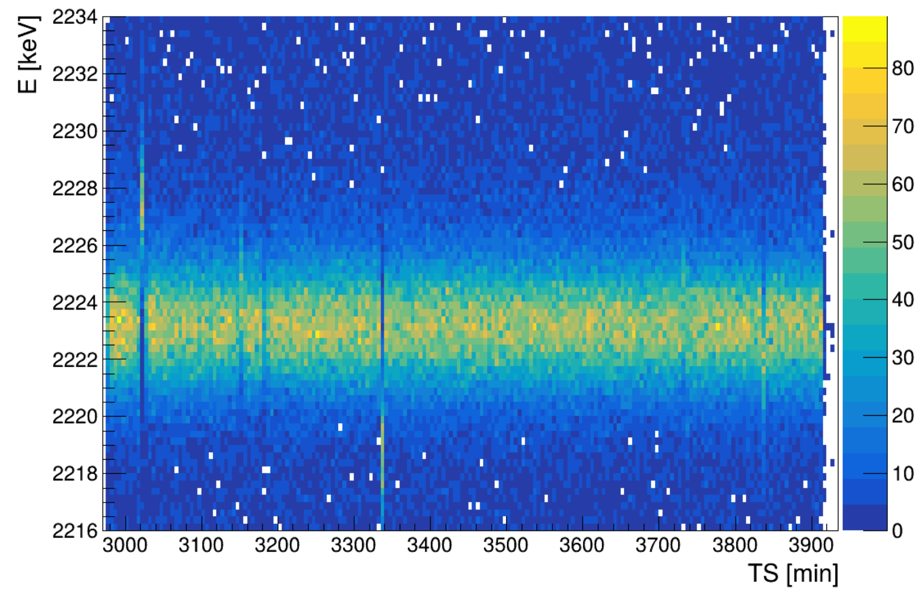
- Core energy **gain oscillations** were observed, attributed to temperature effects
- Implementation of a **time – dependent gain correction** directly in the femul code
- Correction parameters were estimated using **Cross Correlation Method* (CCM)**

BEFORE



fwhm = 3.807(15) keV @ 2223 keV

AFTER



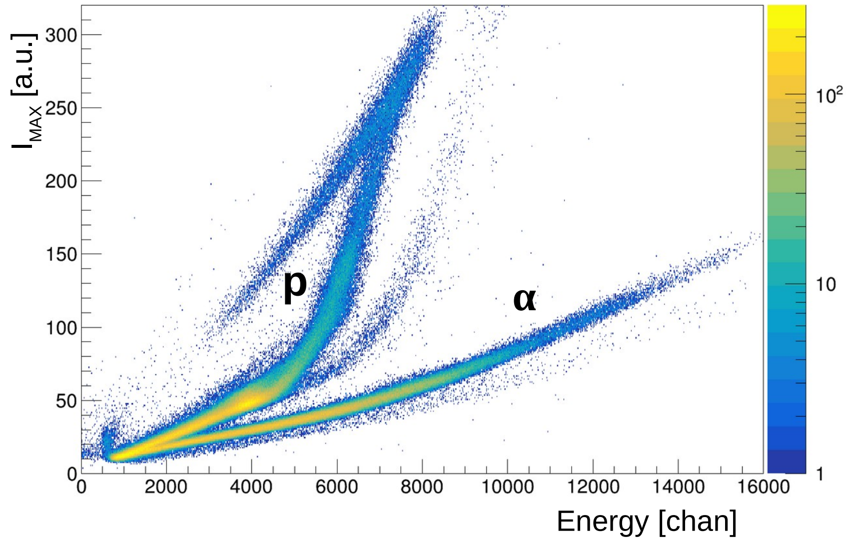
fwhm = 3.525(17) keV @ 2223 keV

**NIM paper: https://doi.org/10.1016/j.nima.2021.165368*

Further analysis

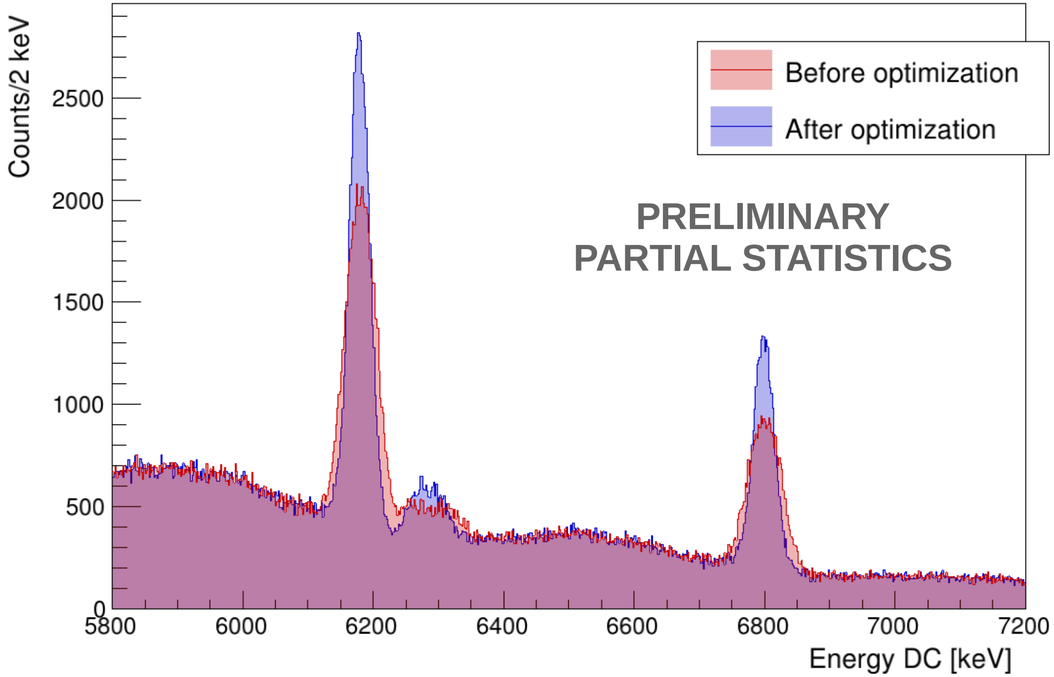
Sauron presorting

- Sauron DSSSD detector at forward angles
- **P**ulse **S**hape **D**iscrimitation (**PSD**) was used for **particle identification**
- Calibration with triple – α source



Optimization

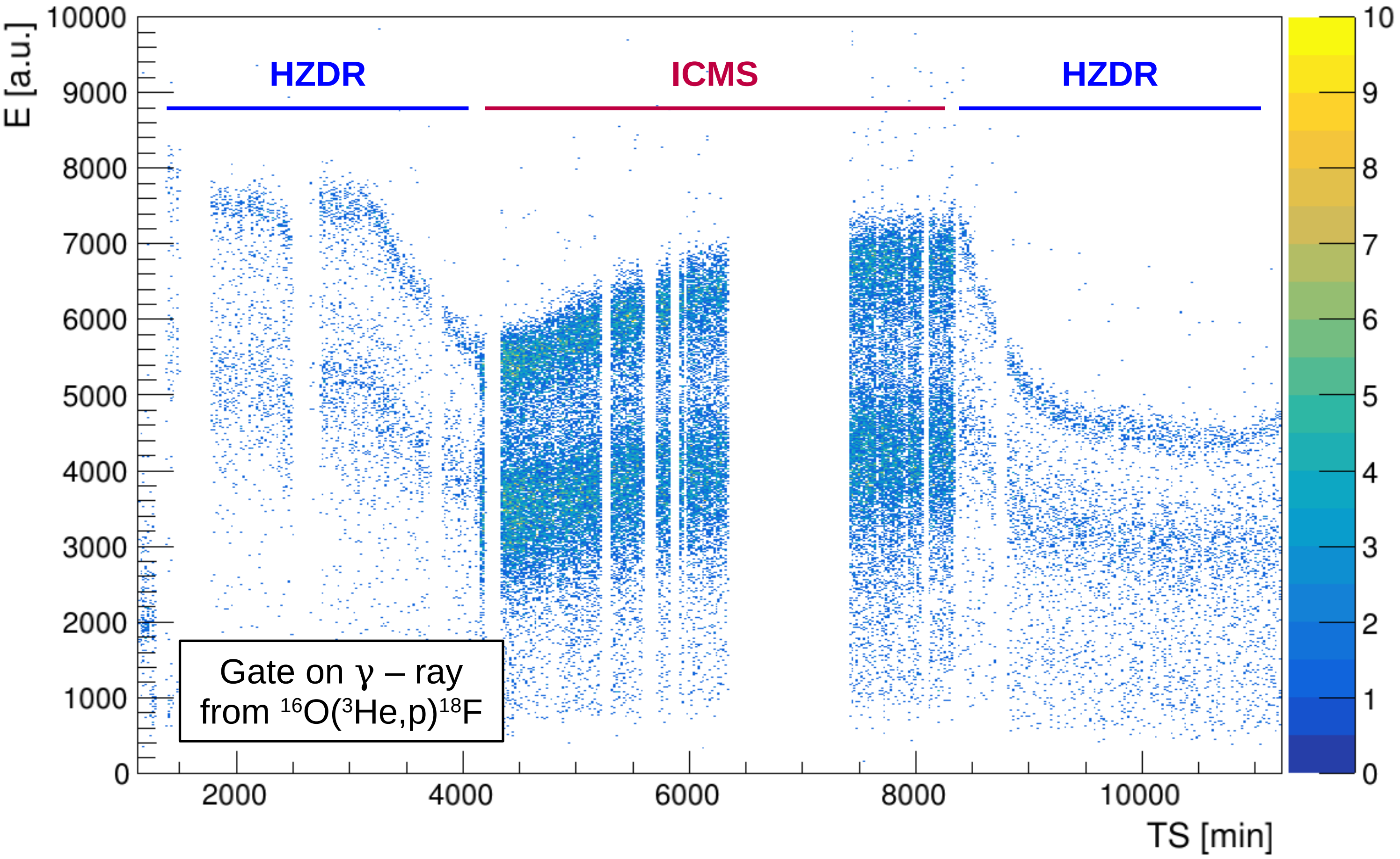
Doppler corrected γ – ray spectrum



fwhm 55 → 33 keV [26 keV in simulations]

Future prospects

- Sauron stability



- Simulations and lifetime analysis

Agata Collaboration Council Meeting 2024

Thank you for your attention

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