

Testing three-body forces in light nuclei

Lifetime measurements in ^{20}O in the range of femtoseconds

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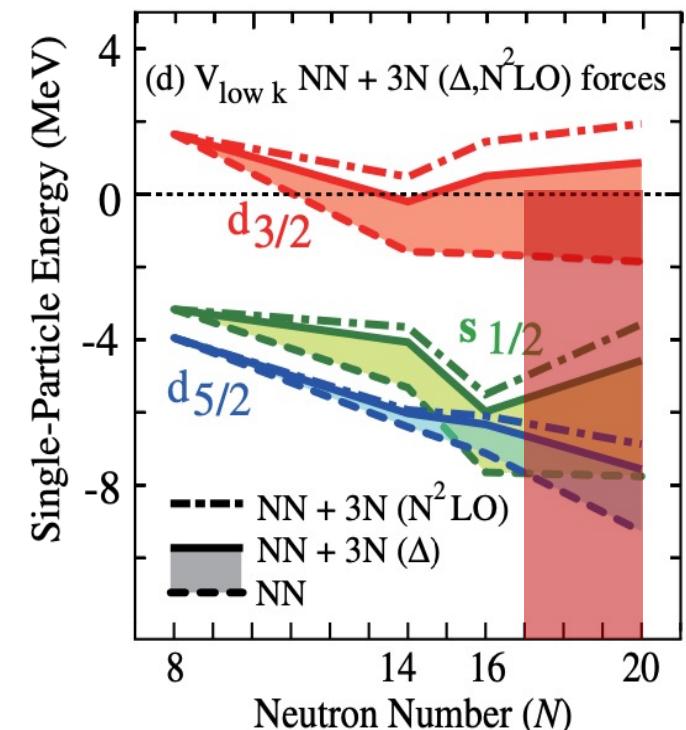
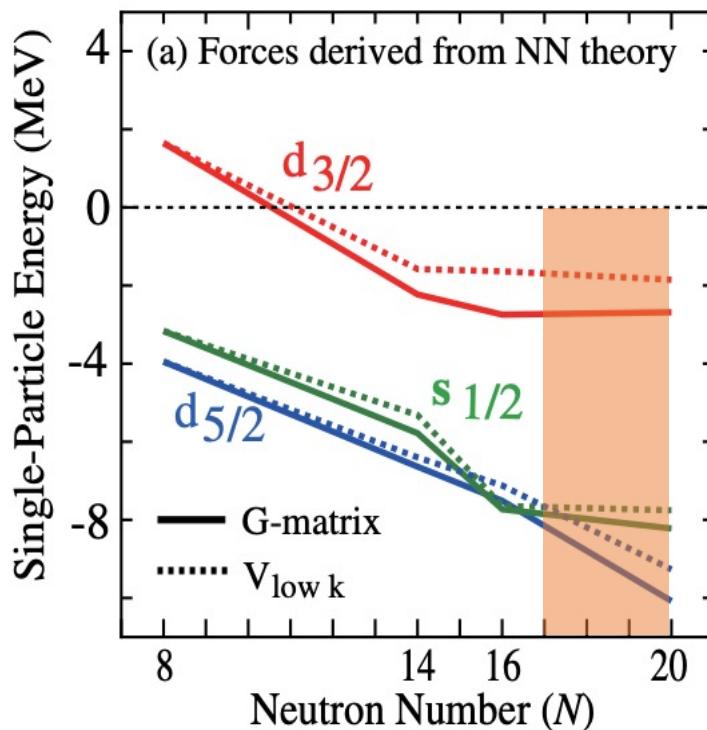
Istituto Nazionale di Fisica Nucleare
Laboratori Nazionali di Legnaro



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di Ferrara**

Scientific motivations

- The position of the drip line of the oxygen isotopic chain is reproduced by introducing the **3N forces**.
- The location of the drip line changes from the $d_{3/2}$ orbital ($N=20$, ^{28}O) to the $s_{1/2}$ ($N=16$, ^{24}O).
- Additional information on the relative position of **$s_{1/2}$ and $d_{3/2}$ orbitals** is need.



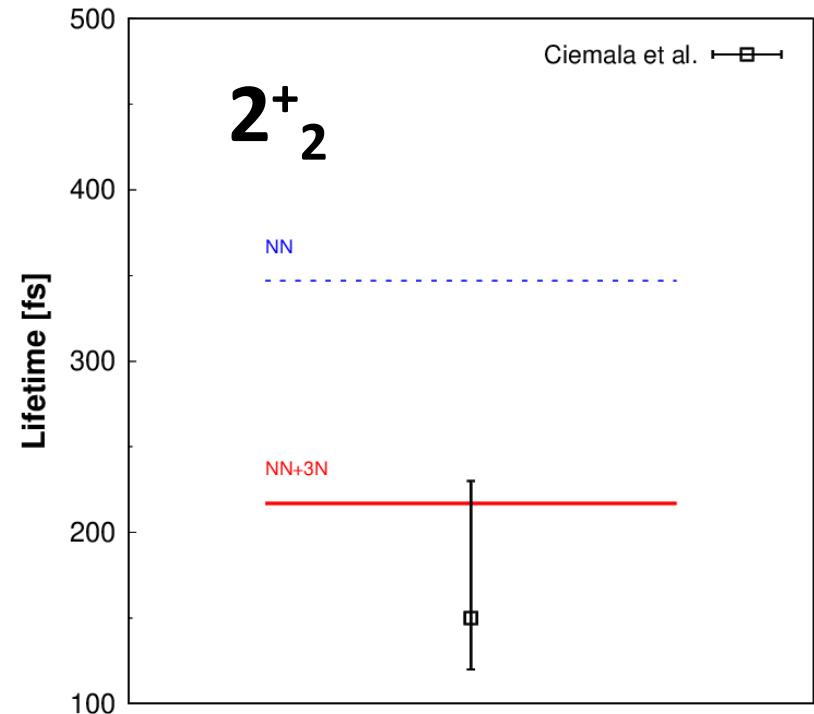
T. Otsuka et al., PRL **104**, 012501 (2010)

Scientific motivations

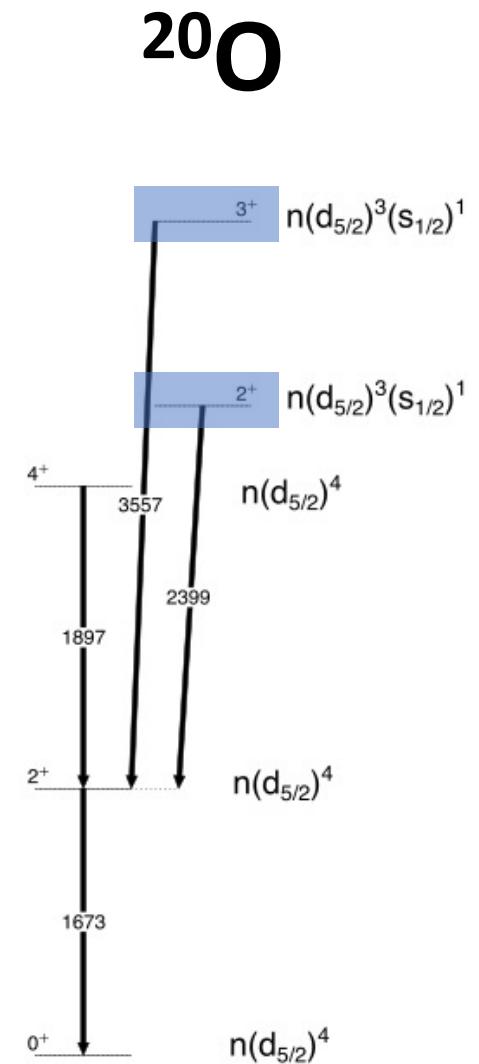
- In ^{20}O , the 2^+_2 and 3^+_1 states are based on a mixed configuration of $d_{5/2}$ and $s_{1/2}$;
- The positions of the the orbitals influences the lifetime of the 2^+_2 and 3^+_1 states of ^{20}O .

Motivations:

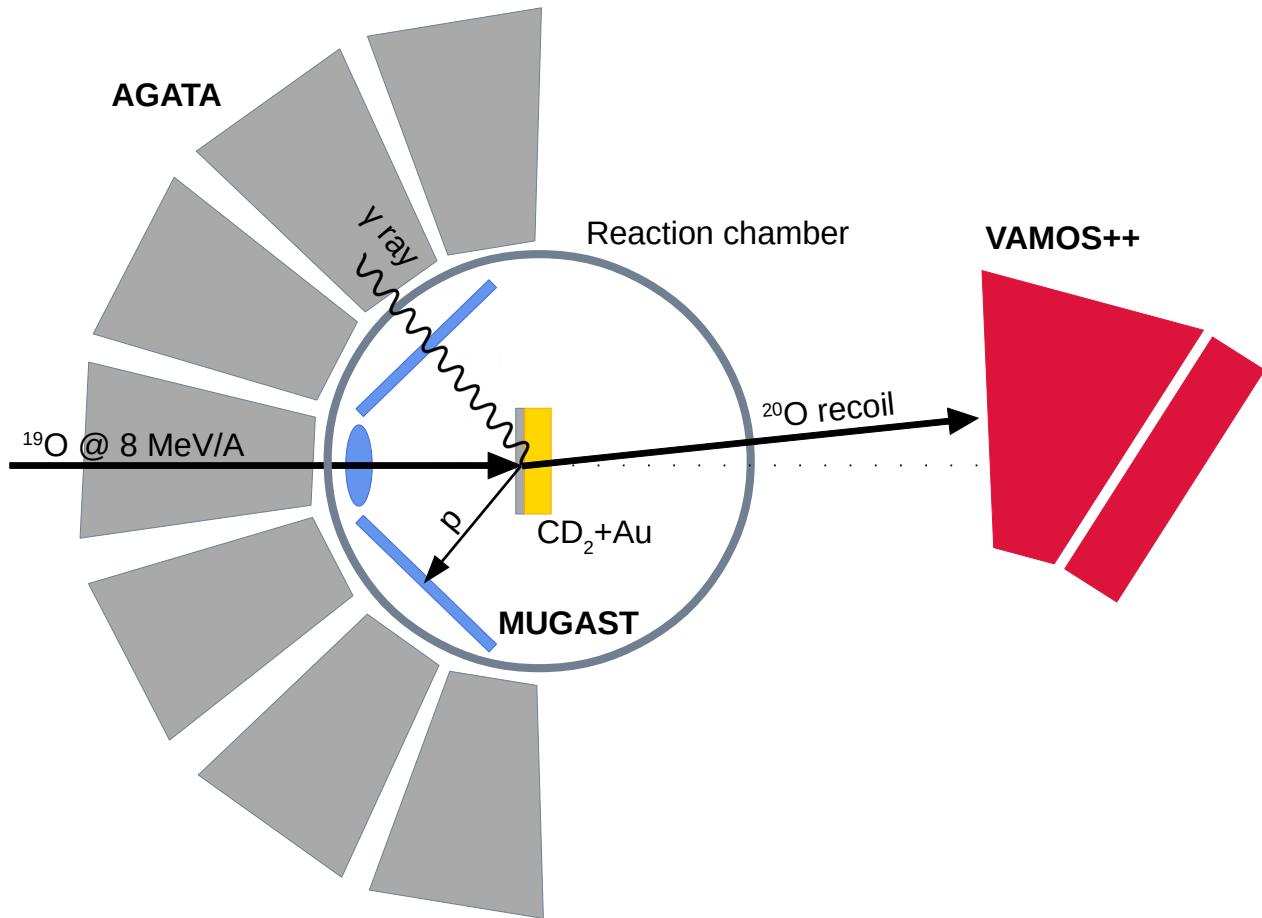
- Control on the feeders;
- Reducing the errors;
- Measure the 3^+ state.



M. Ciemala et al, PRC **101** 021303 (2020)

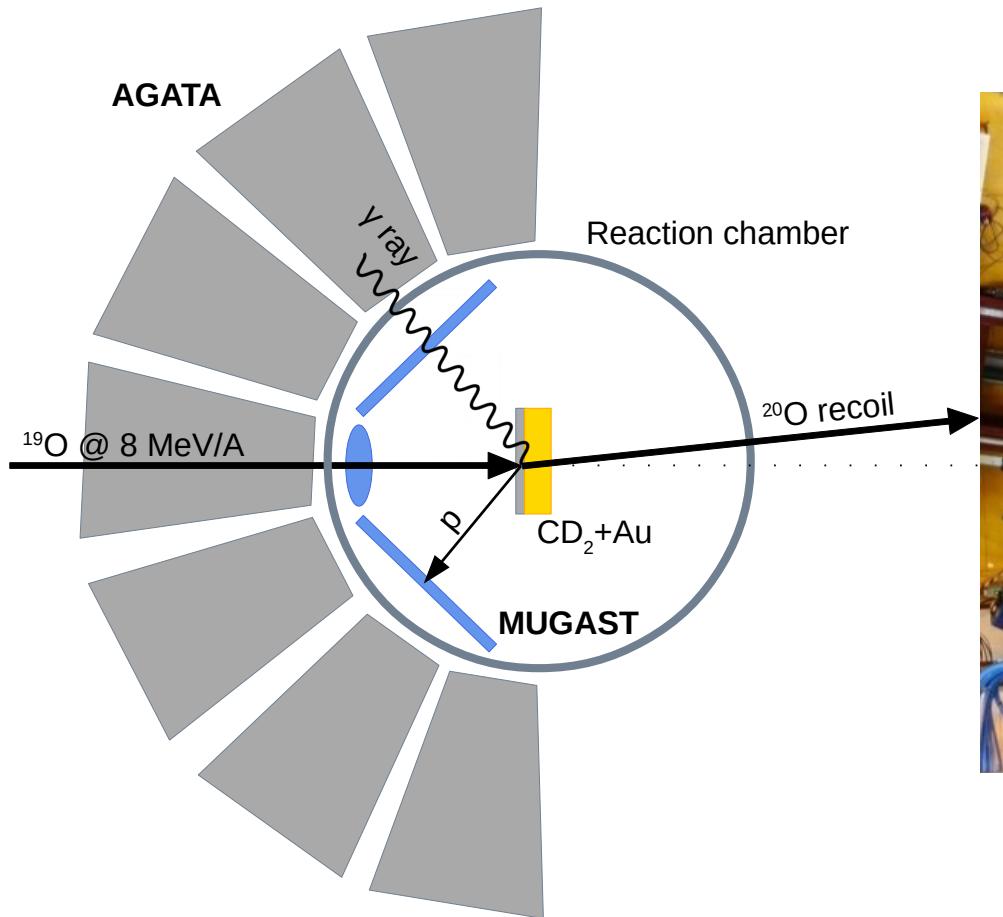


The experiment



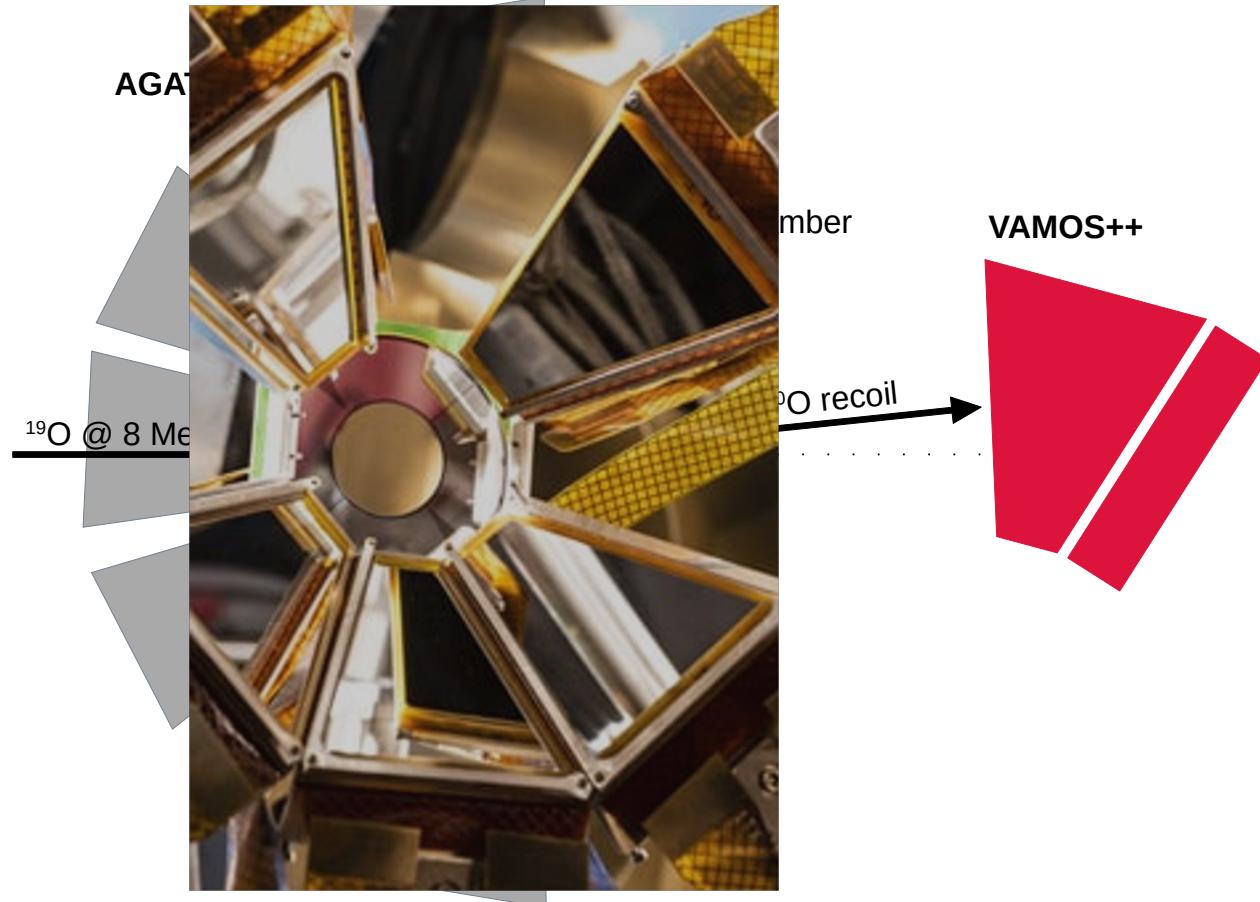
- Performed in GANIL (France)
- Spokespersons: E. Clément, A. Goasduff;
- $^{19}\text{O}(\text{d},\text{p})^{20}\text{O}$ reaction;
- RIB of ^{19}O @8 MeV/A i: 4×10^5 pps, purity > 99%;
- Target CD_2 0.3 mg/cm² + $^{\text{nat}}\text{Au}$ 20 mg/cm²;
- AGATA array + MUGAST + VAMOS.

The experiment: VAMOS++



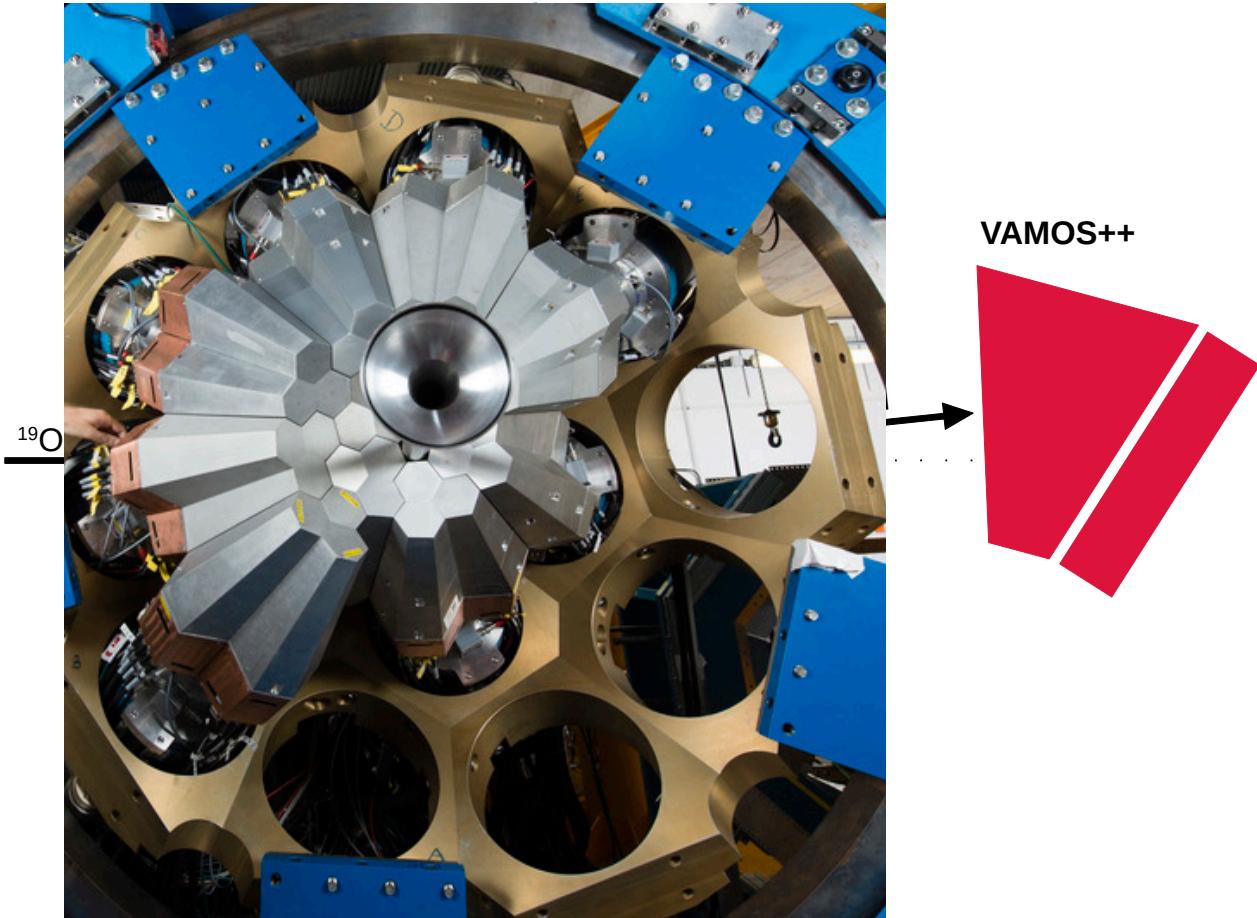
- Magnetic spectrometer;
- Identification of the channel of interest.

The experiment: MUGAST



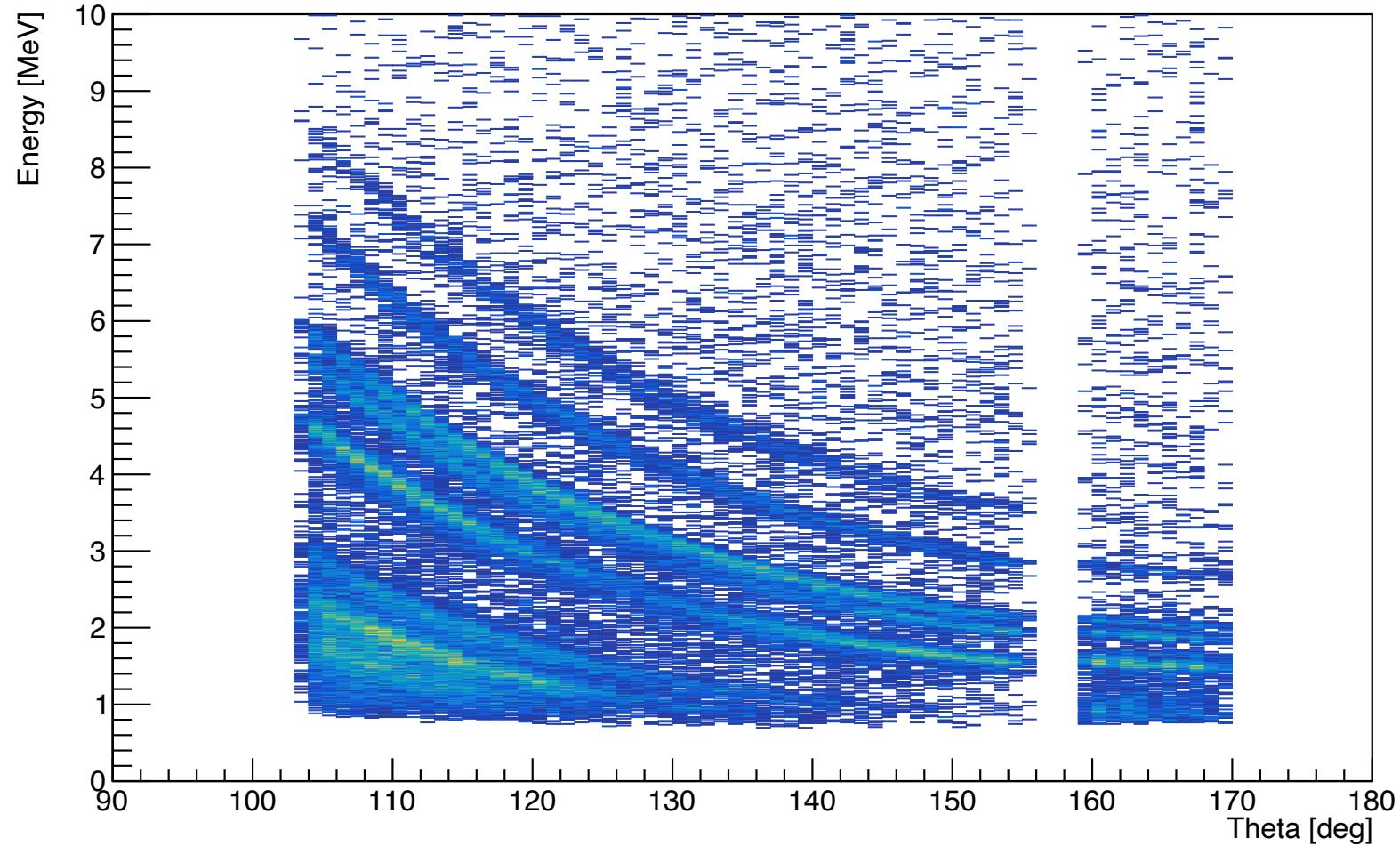
- Array of silicon detectors;
- Detection of light charged particles;
- 7 trapezoids + 1 annular;
- Designed to be coupled to AGATA;
- Segmentation of the silicons;
- Good energy and angular resolution.

The experiment: AGATA

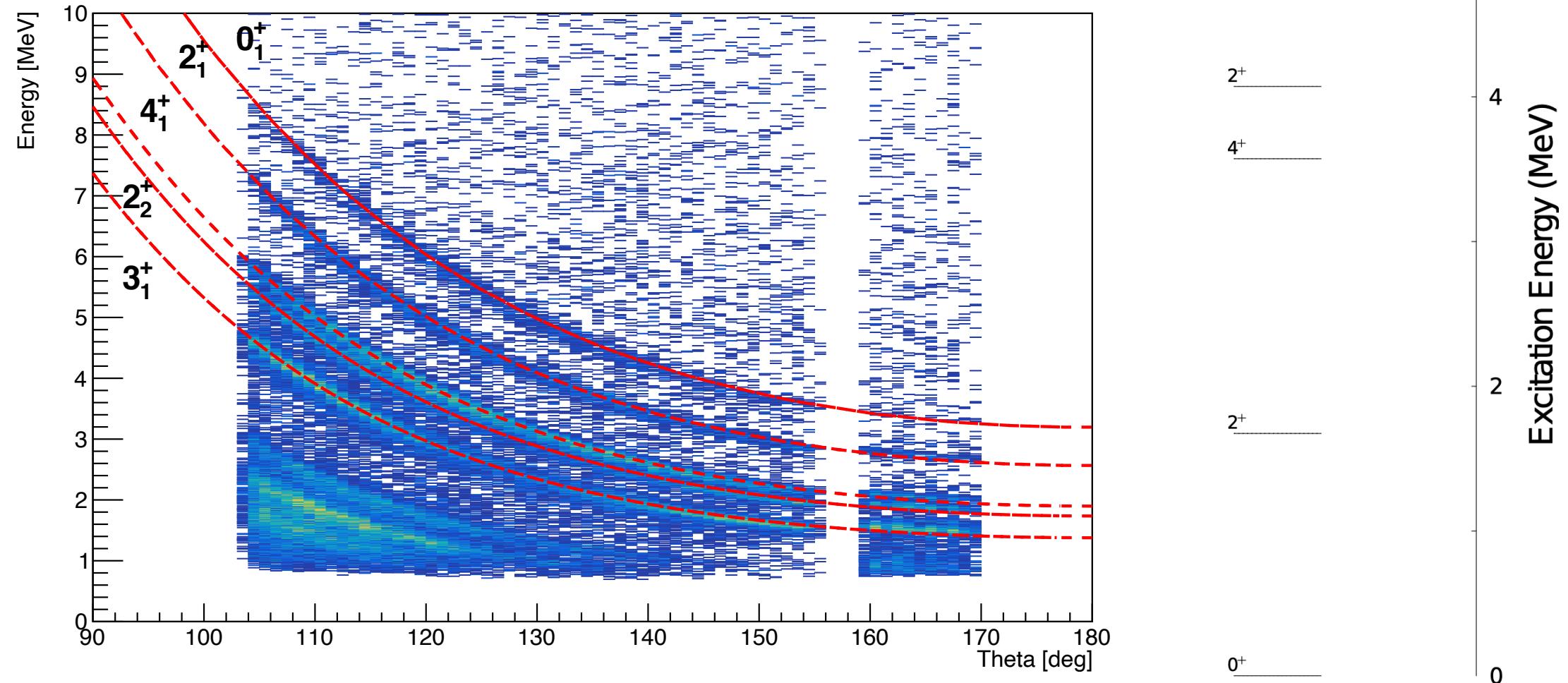


- State-of-the-art of gamma-ray array.
- 36 HPGe crystals;
- 36 segments per crystal + 1 core;
- Combination of PSA and tracking;

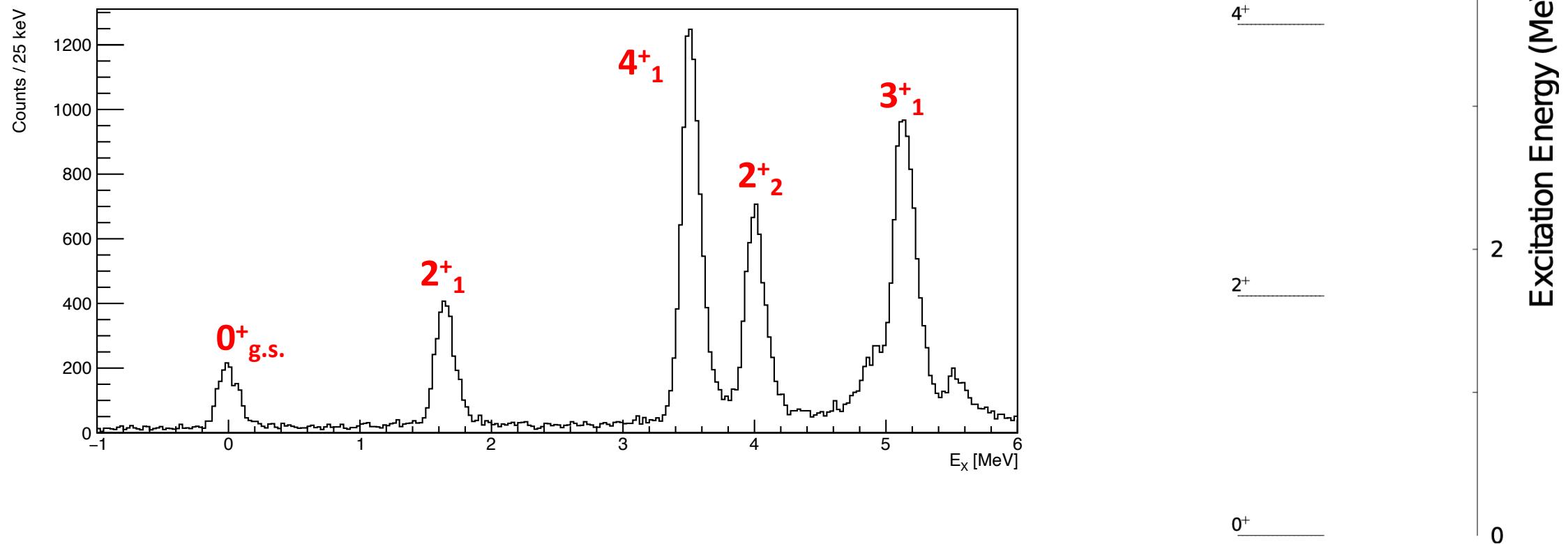
Kinematic lines



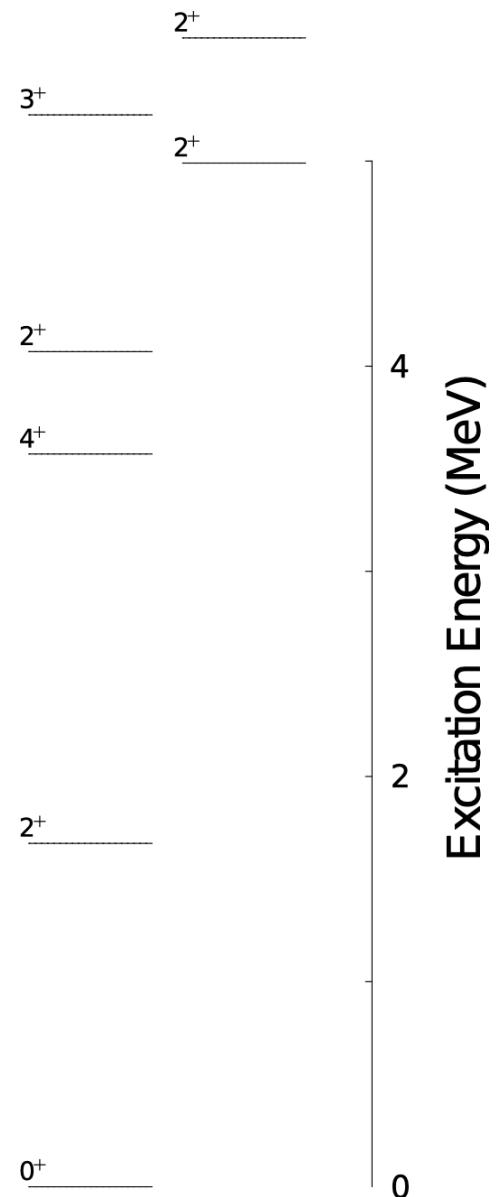
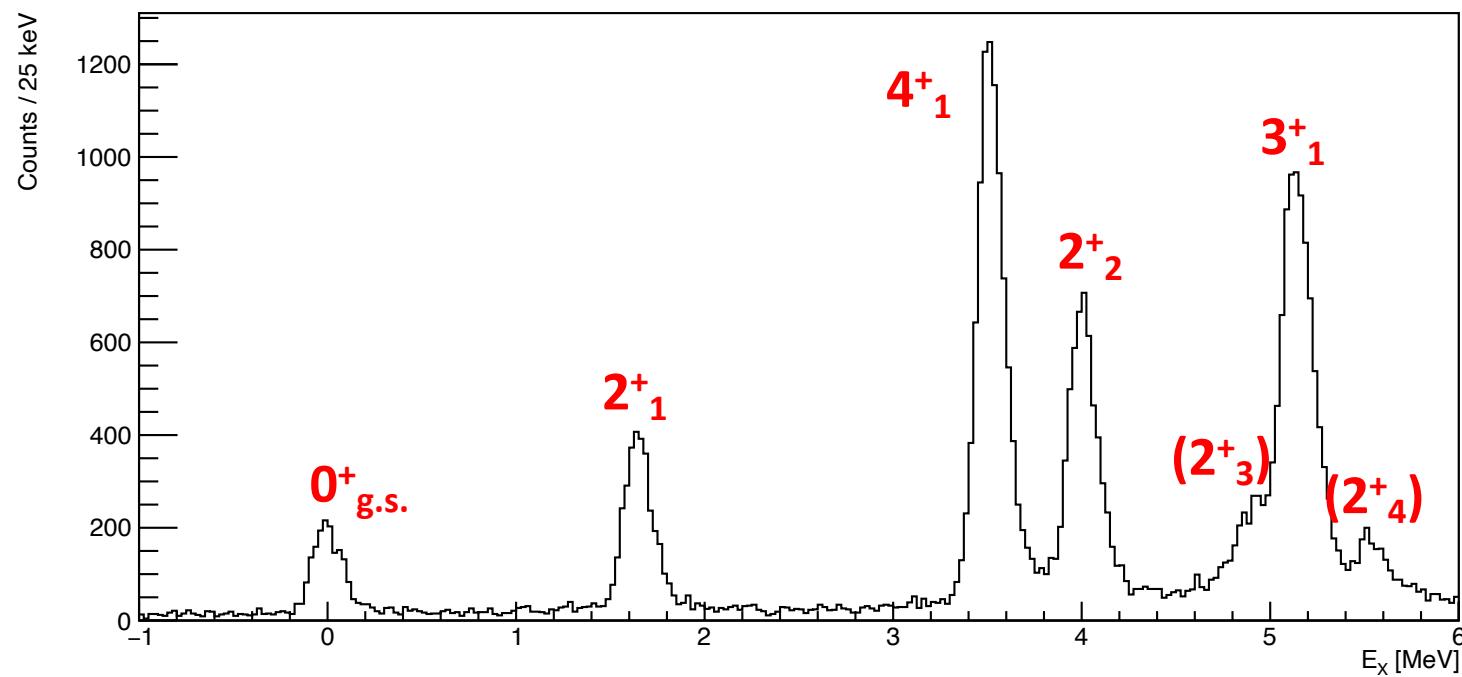
Kinematic lines



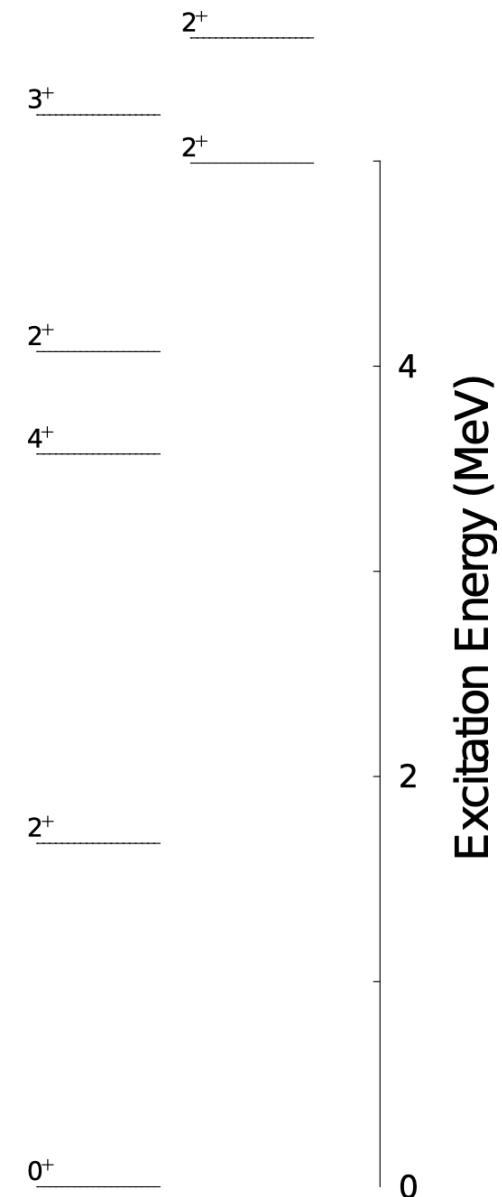
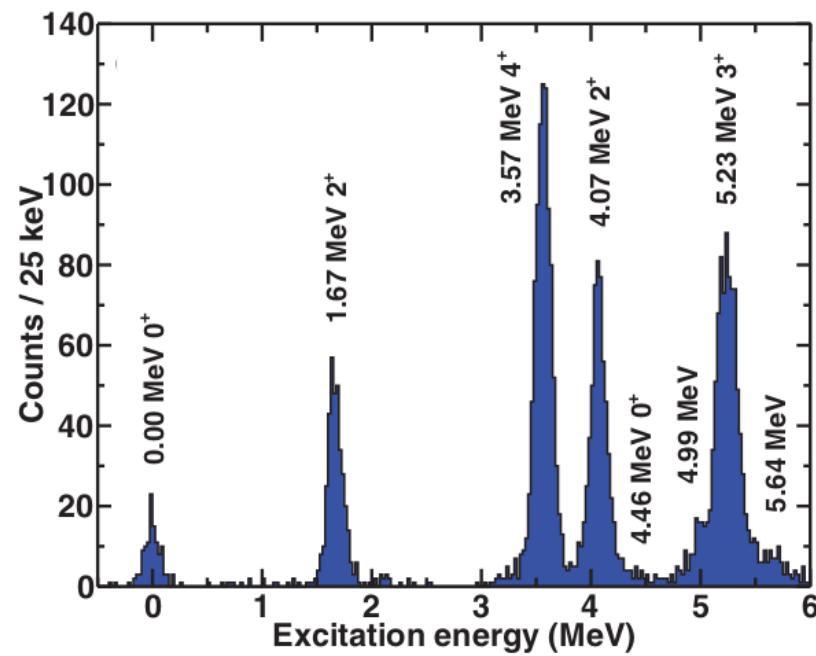
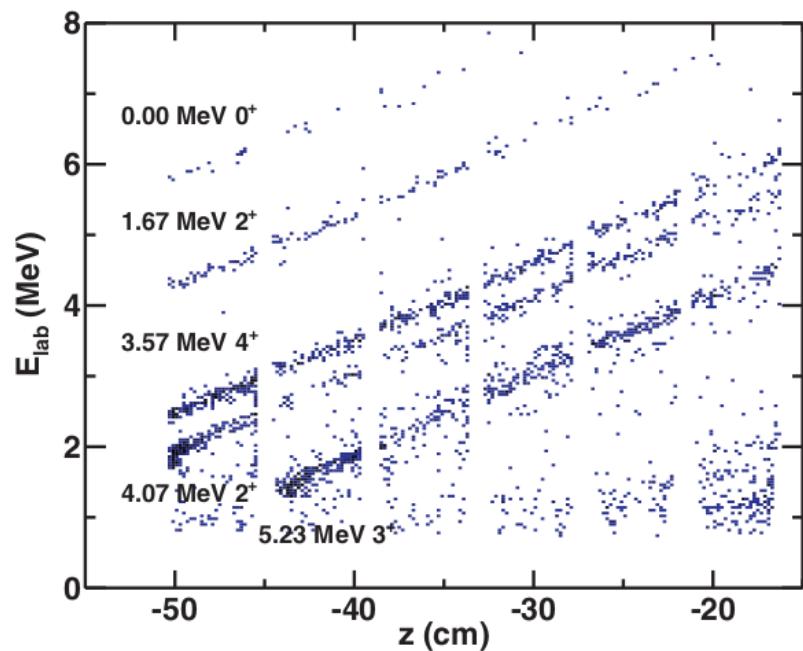
Excited states of ^{20}O



Excited states of ^{20}O

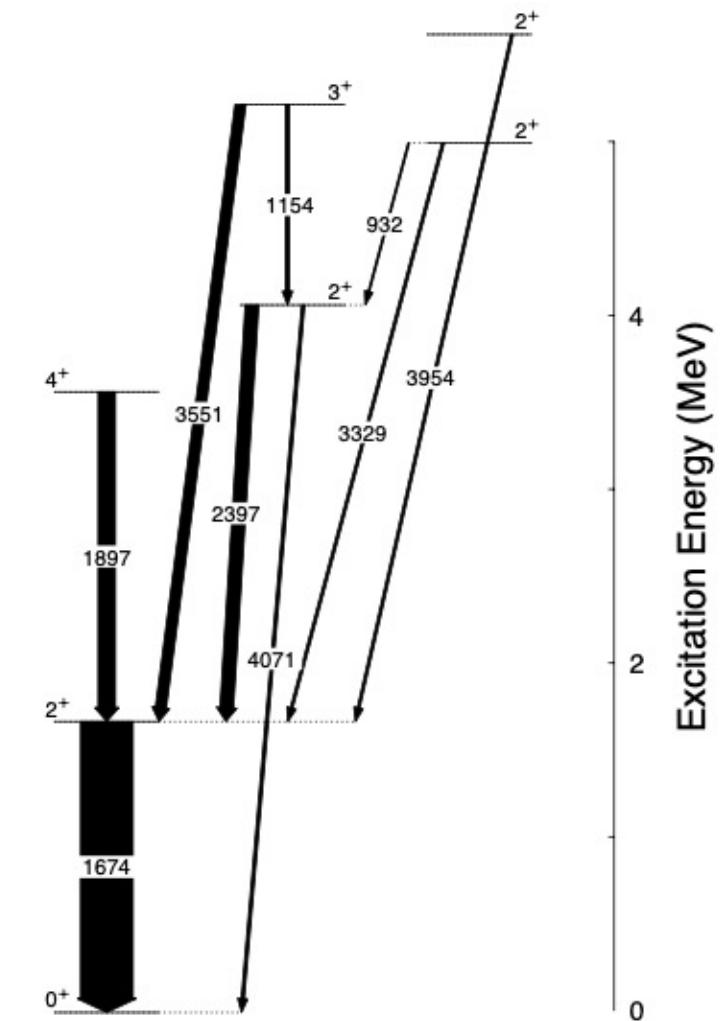
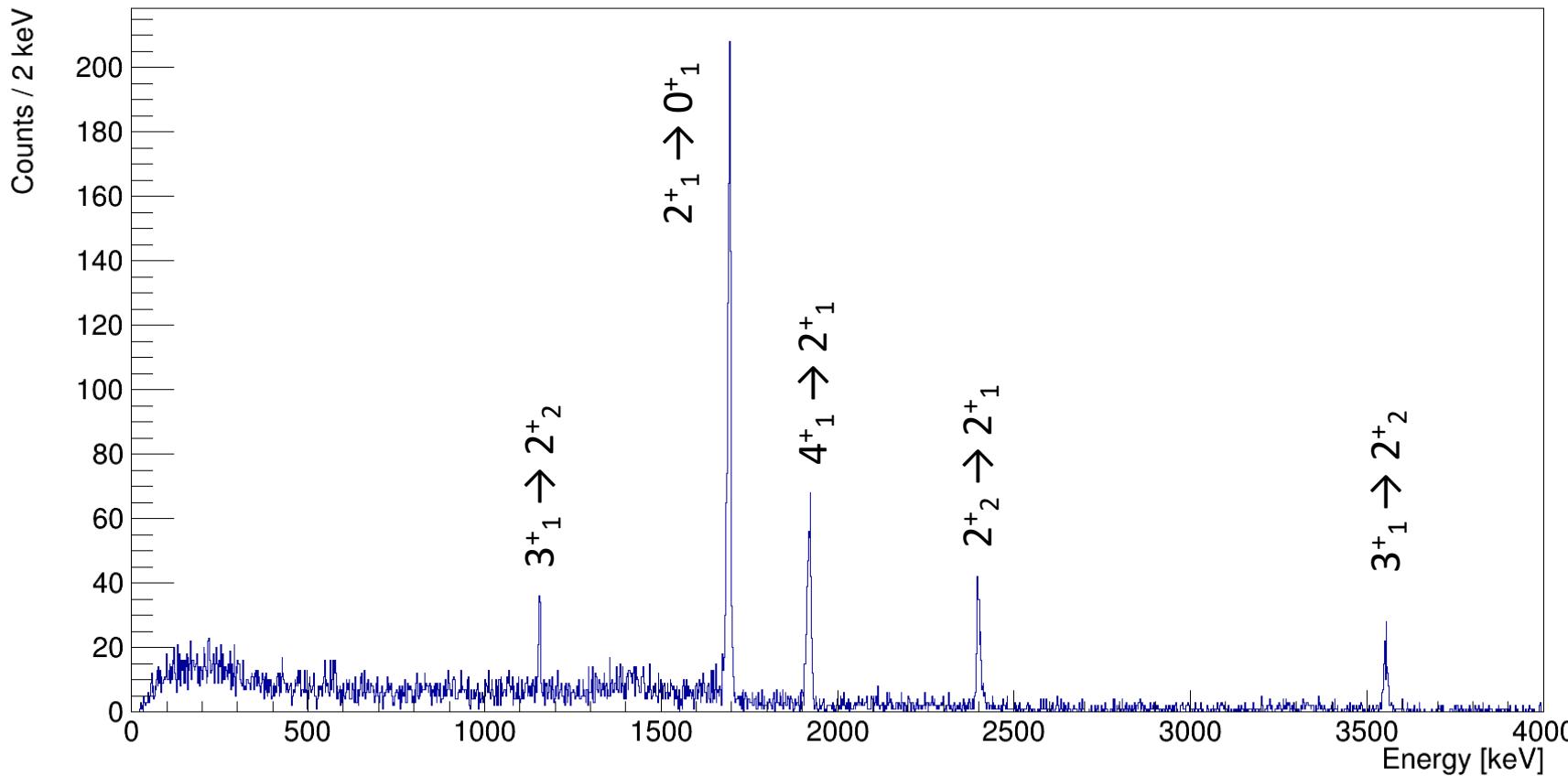


Excited states of ^{20}O



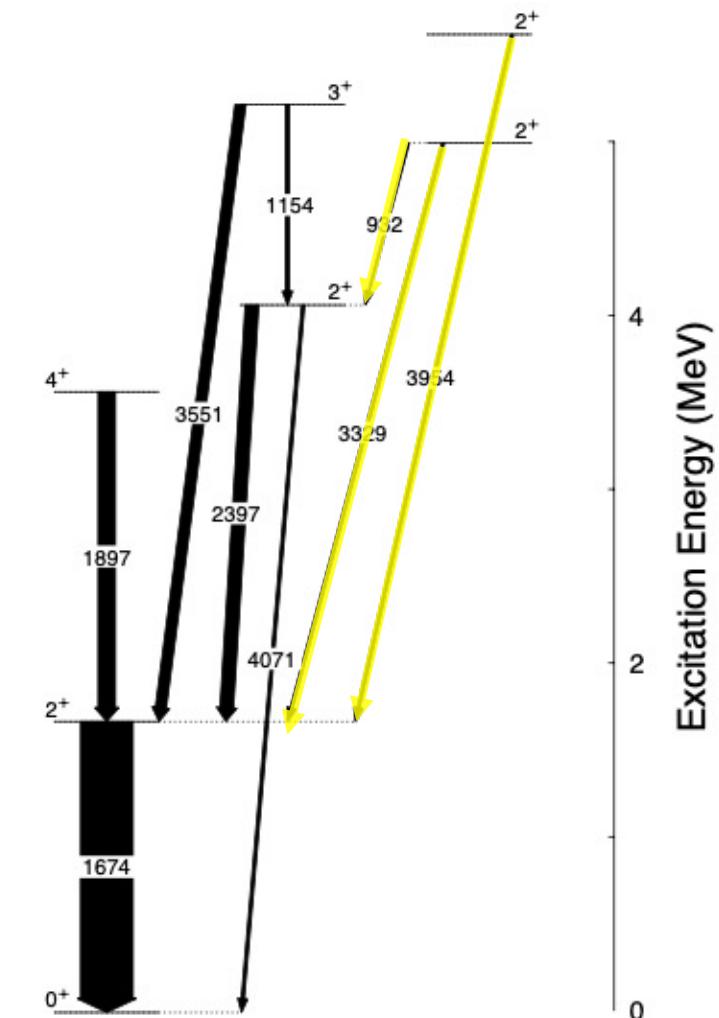
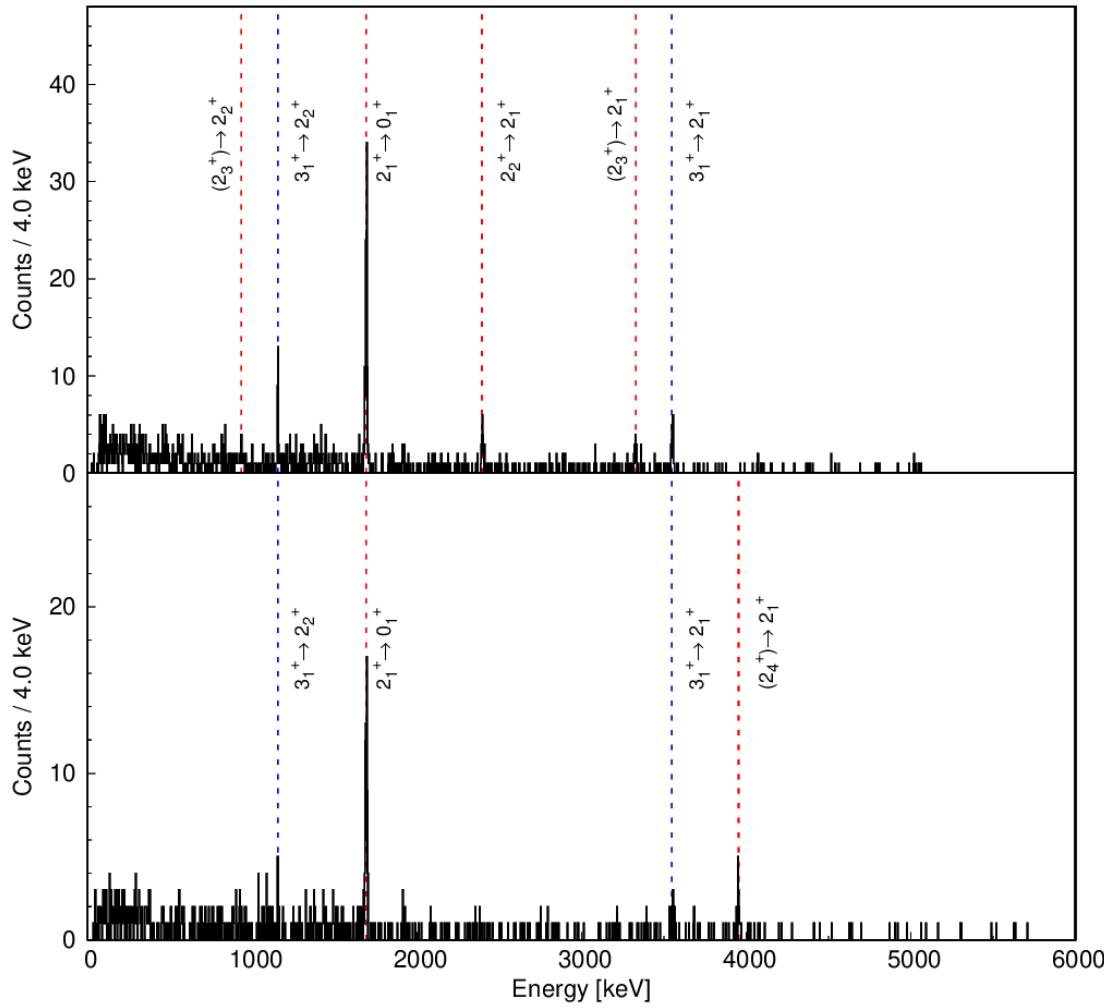
C. Hoffman et al., PRC **85**, 054318 (2012)

Particle- γ spectroscopy of ^{20}O

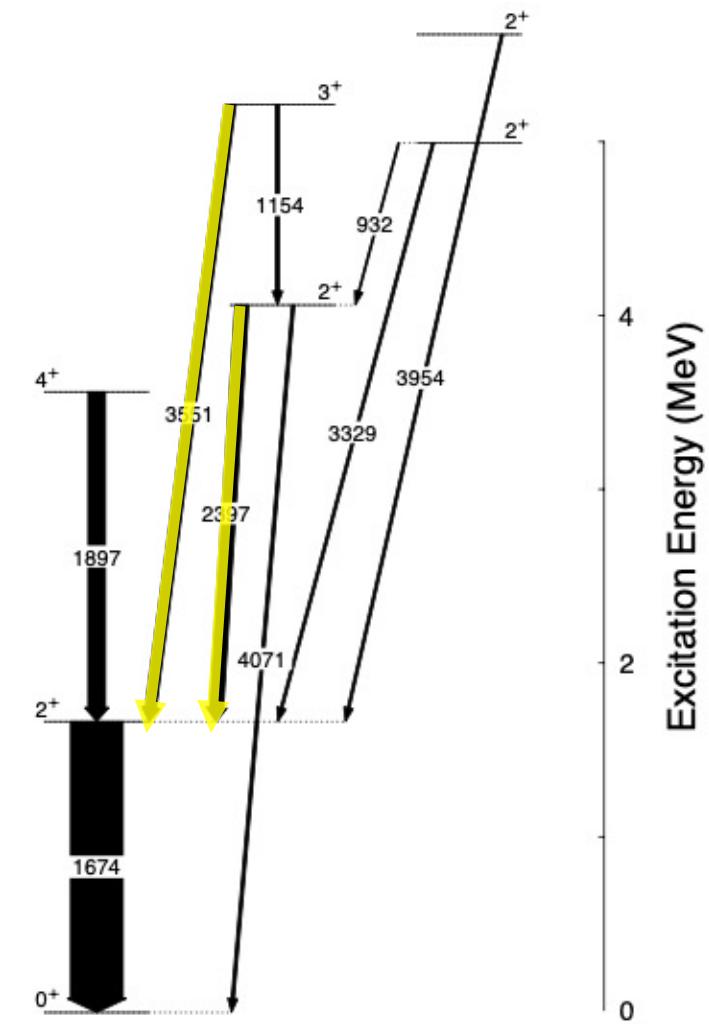
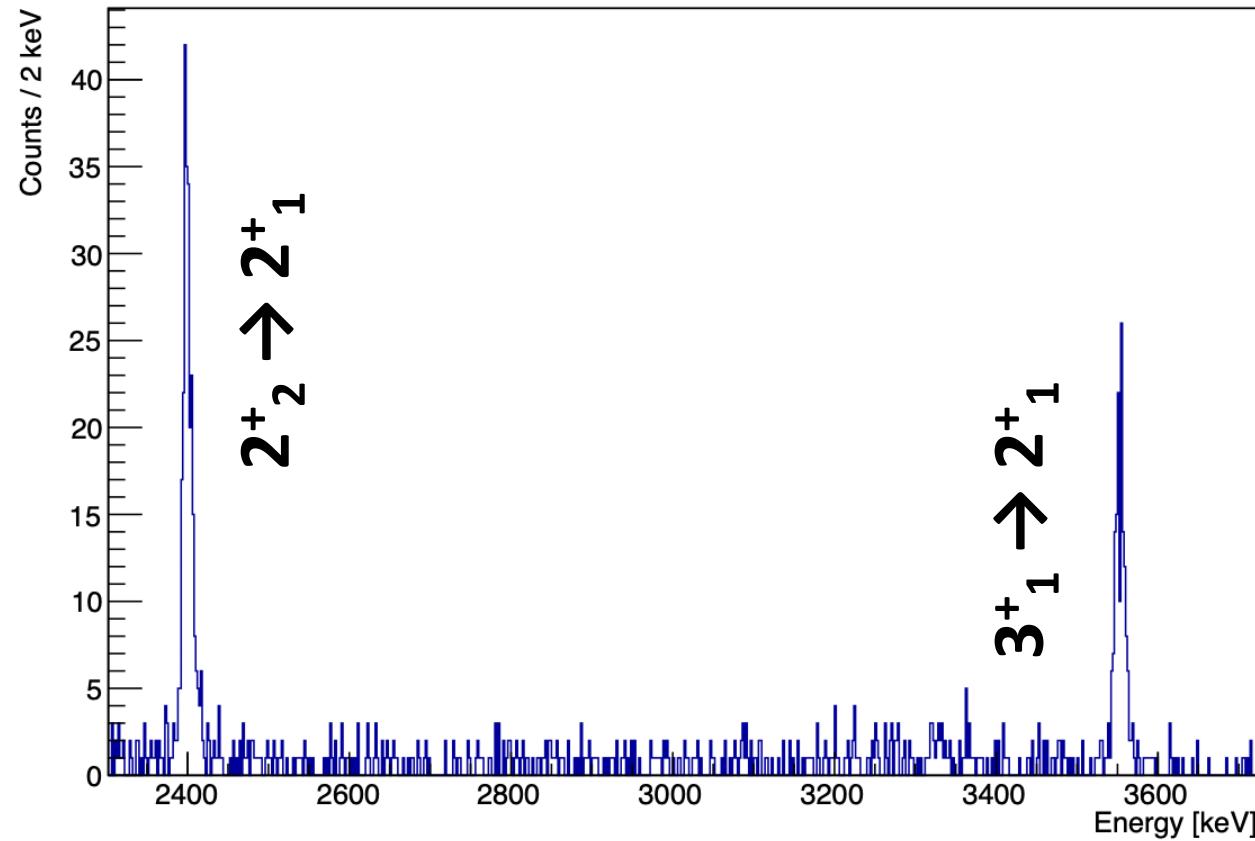


Particle- γ spectroscopy of ^{20}O

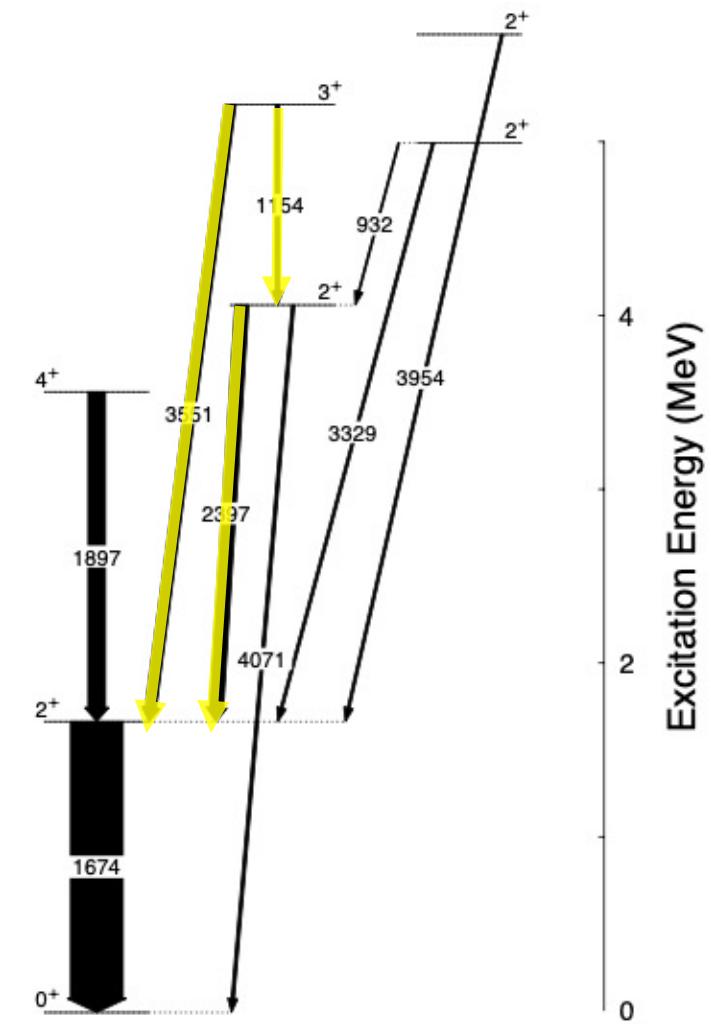
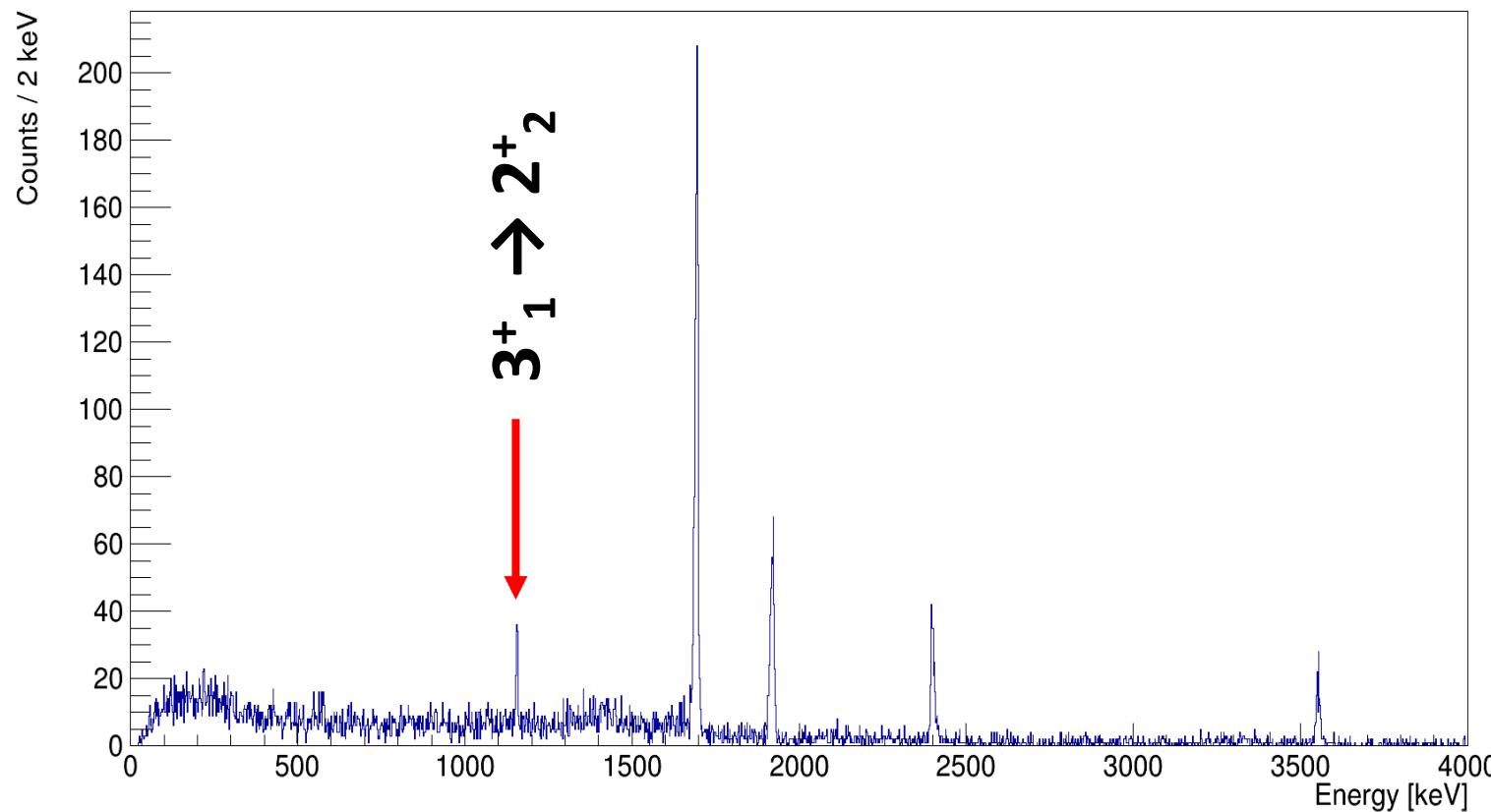
Gate 4.9 MeV
Gate 5.6 MeV



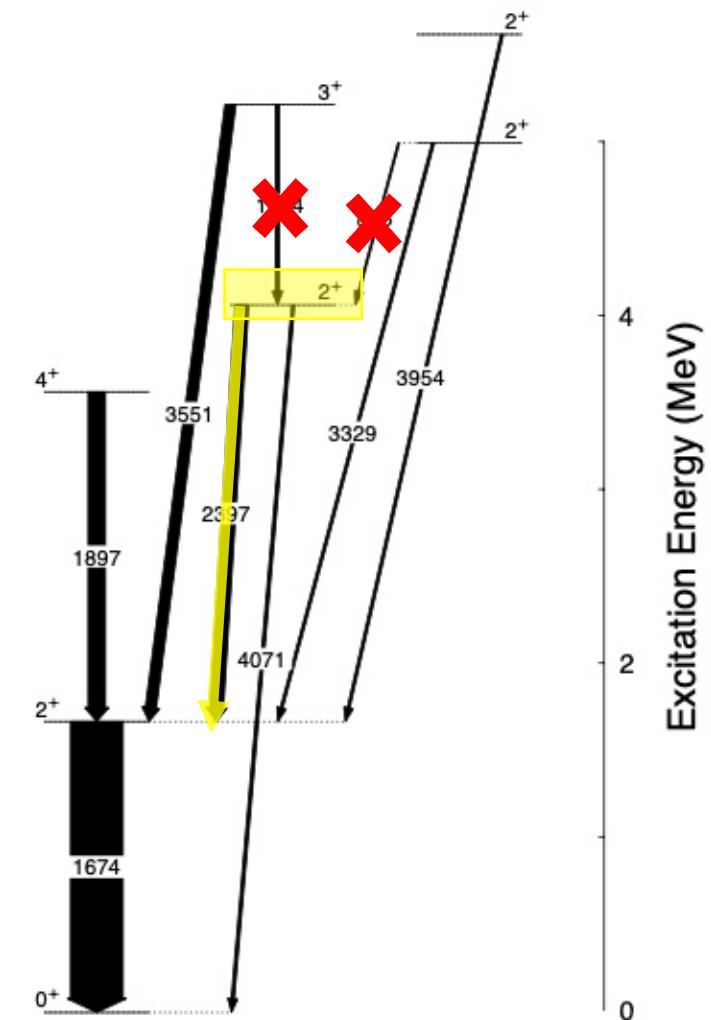
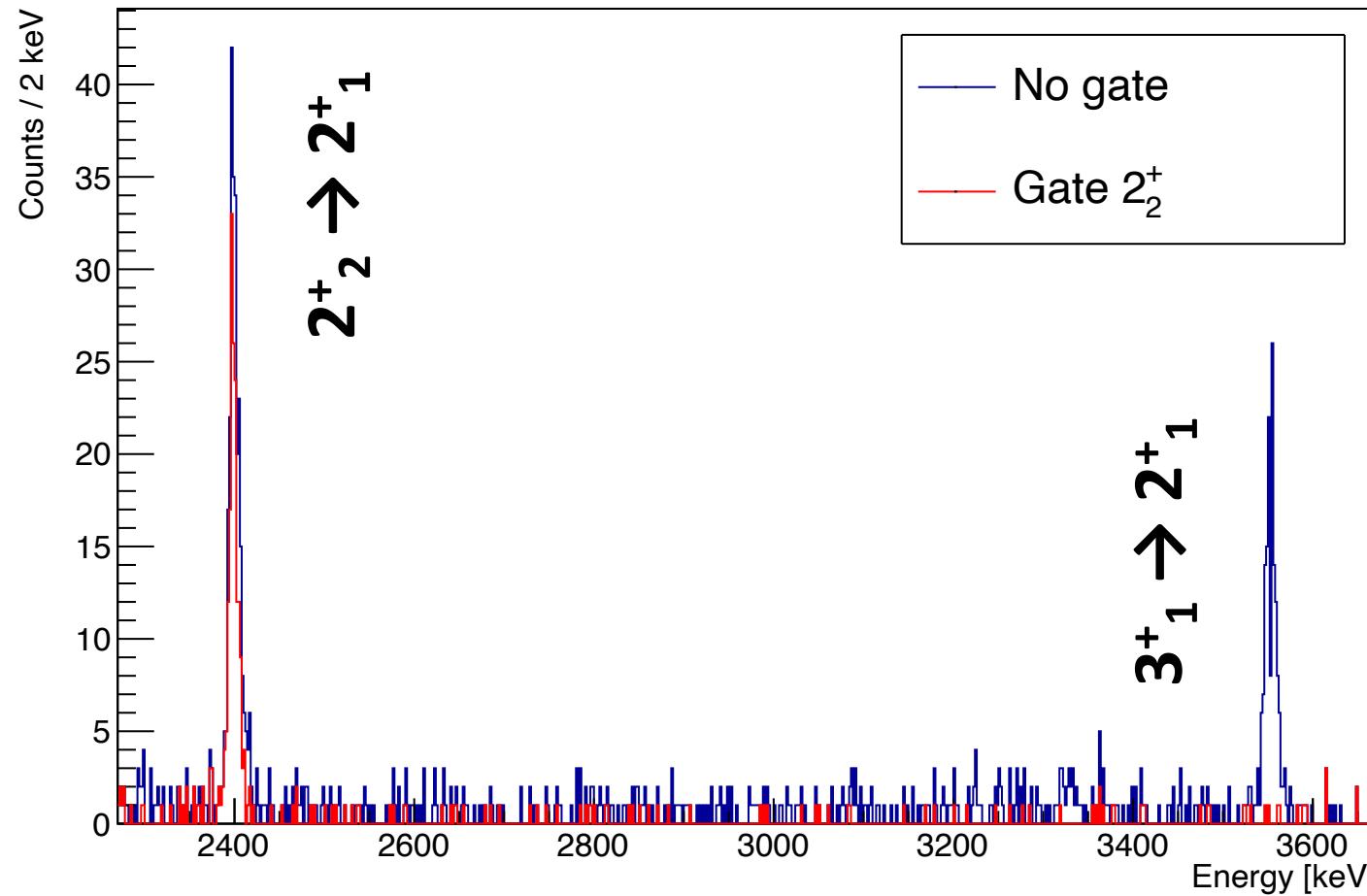
Particle- γ spectroscopy of ^{20}O



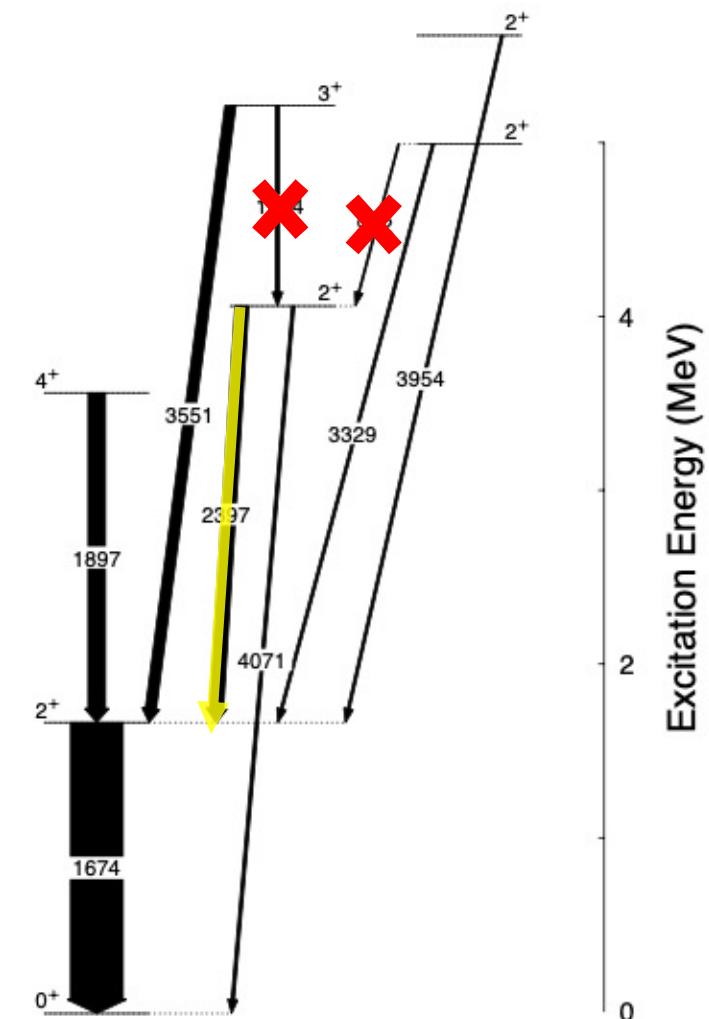
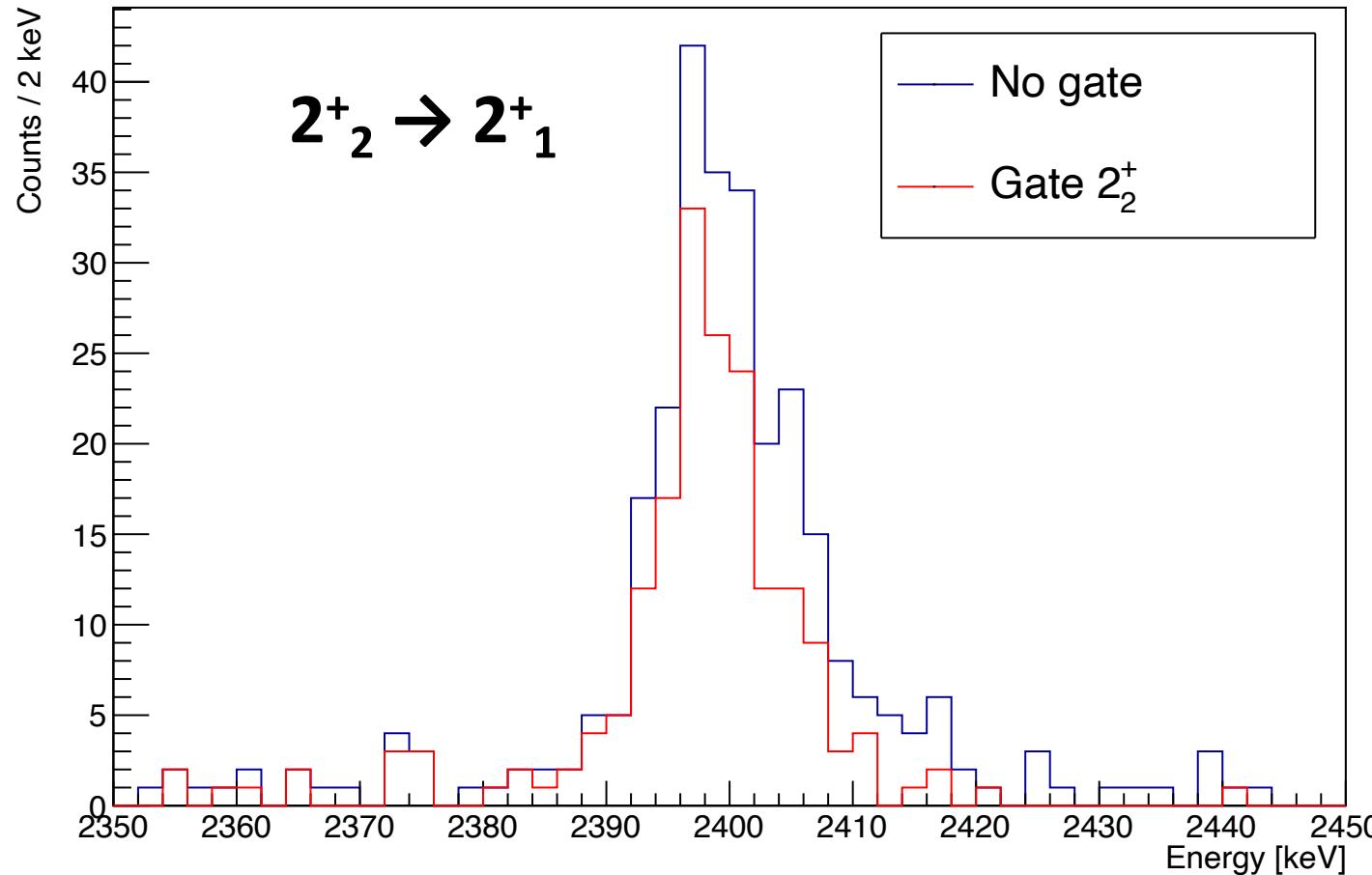
Particle- γ spectroscopy of ^{20}O



Particle- γ spectroscopy of ^{20}O



Particle- γ spectroscopy of ^{20}O



Monte Carlo simulation

Experimental lineshape of the transitions of interest compared to simulated one.

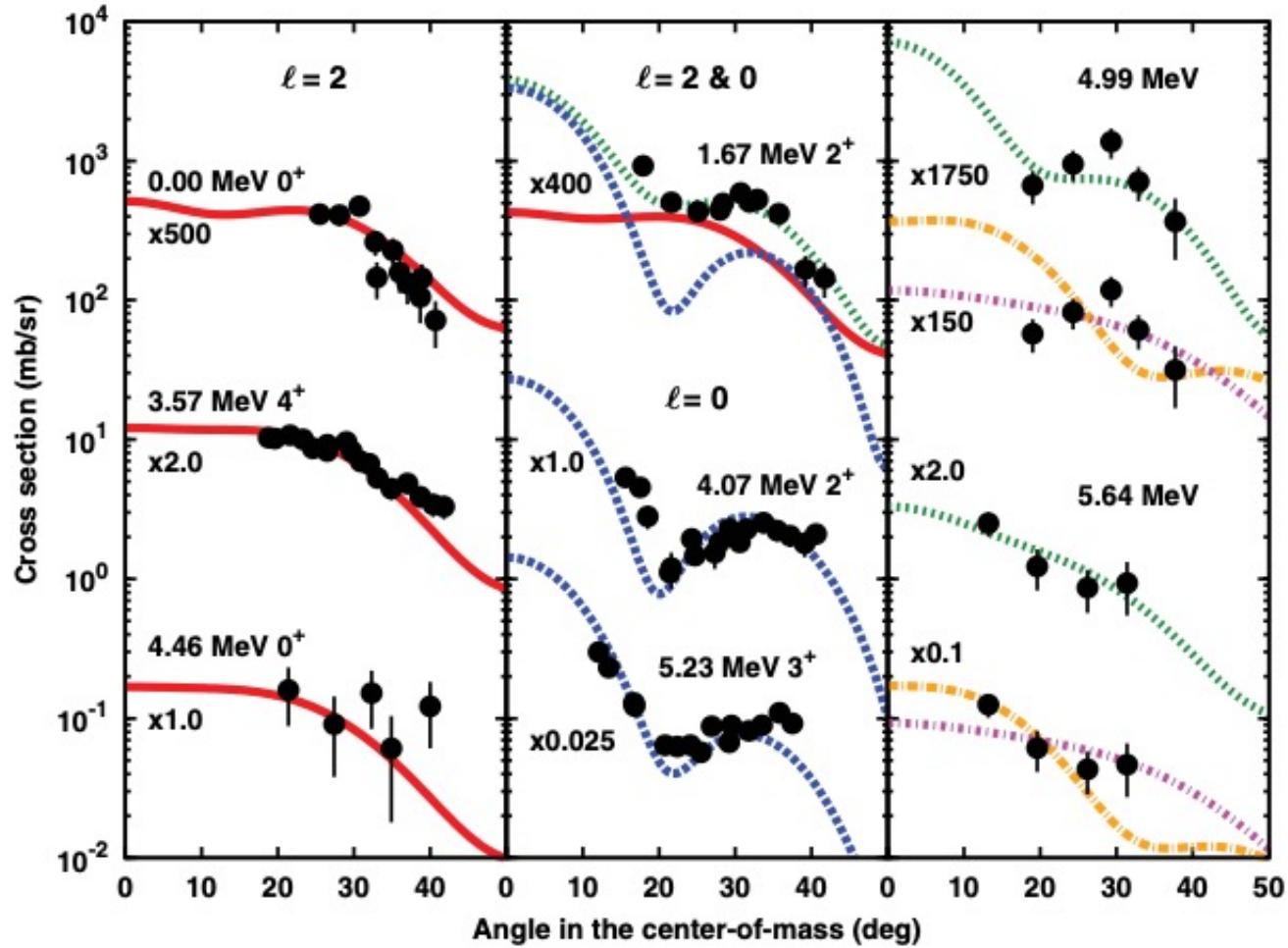
Complete geometry and performance of the setup reproduced in the AGATA Geant4 code.

Realistic parameters included:

- Measured energy and position resolution of the detectors;
- Disabilitation of missing strips of MUGAST;
- **Particle angular distribution;**
- Energy Loss;

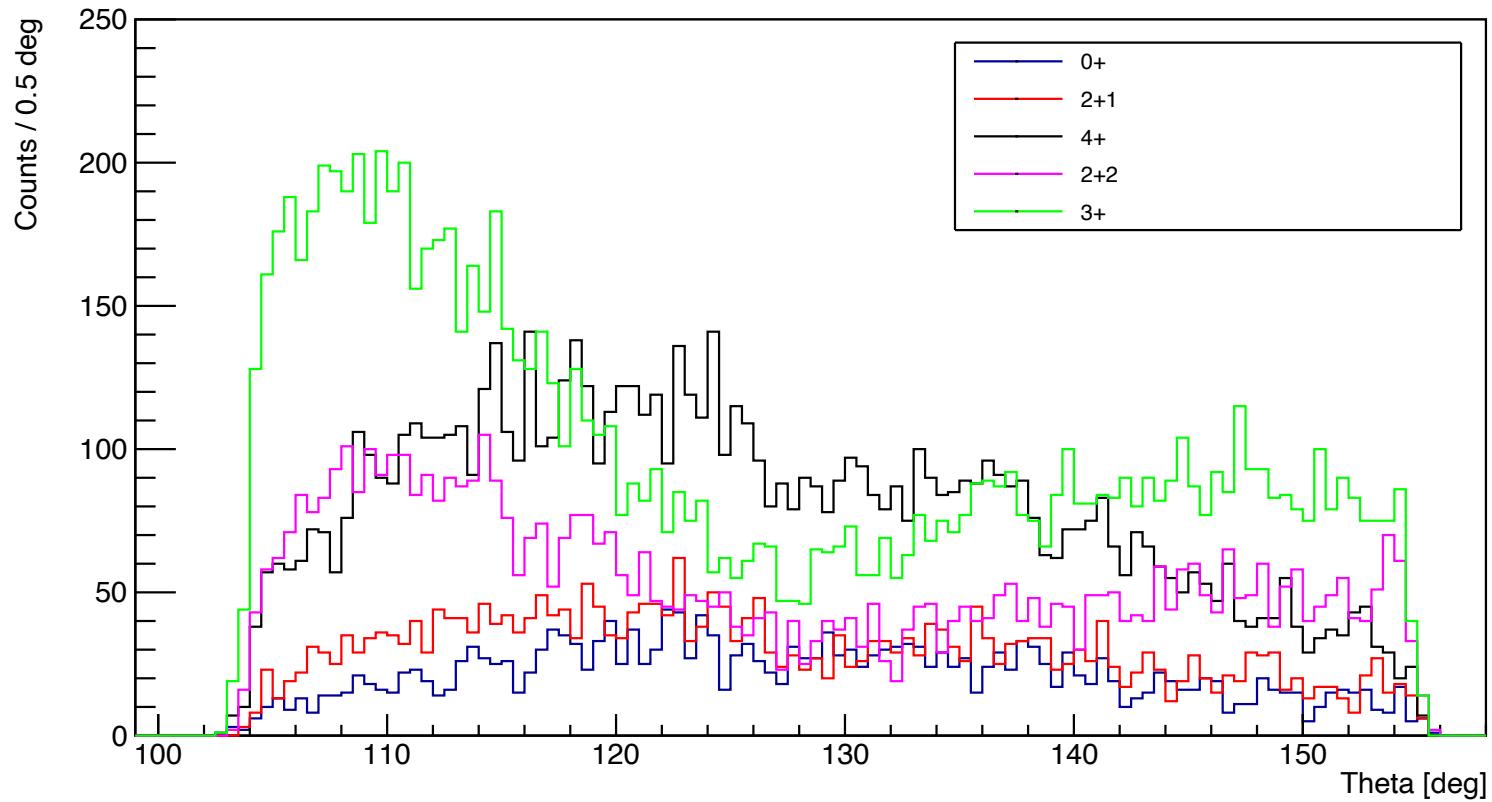
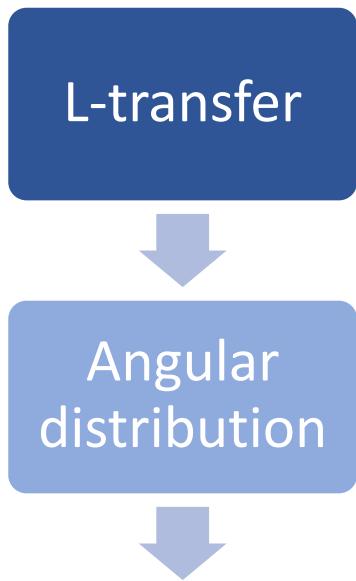
Angular distribution

L-transfer

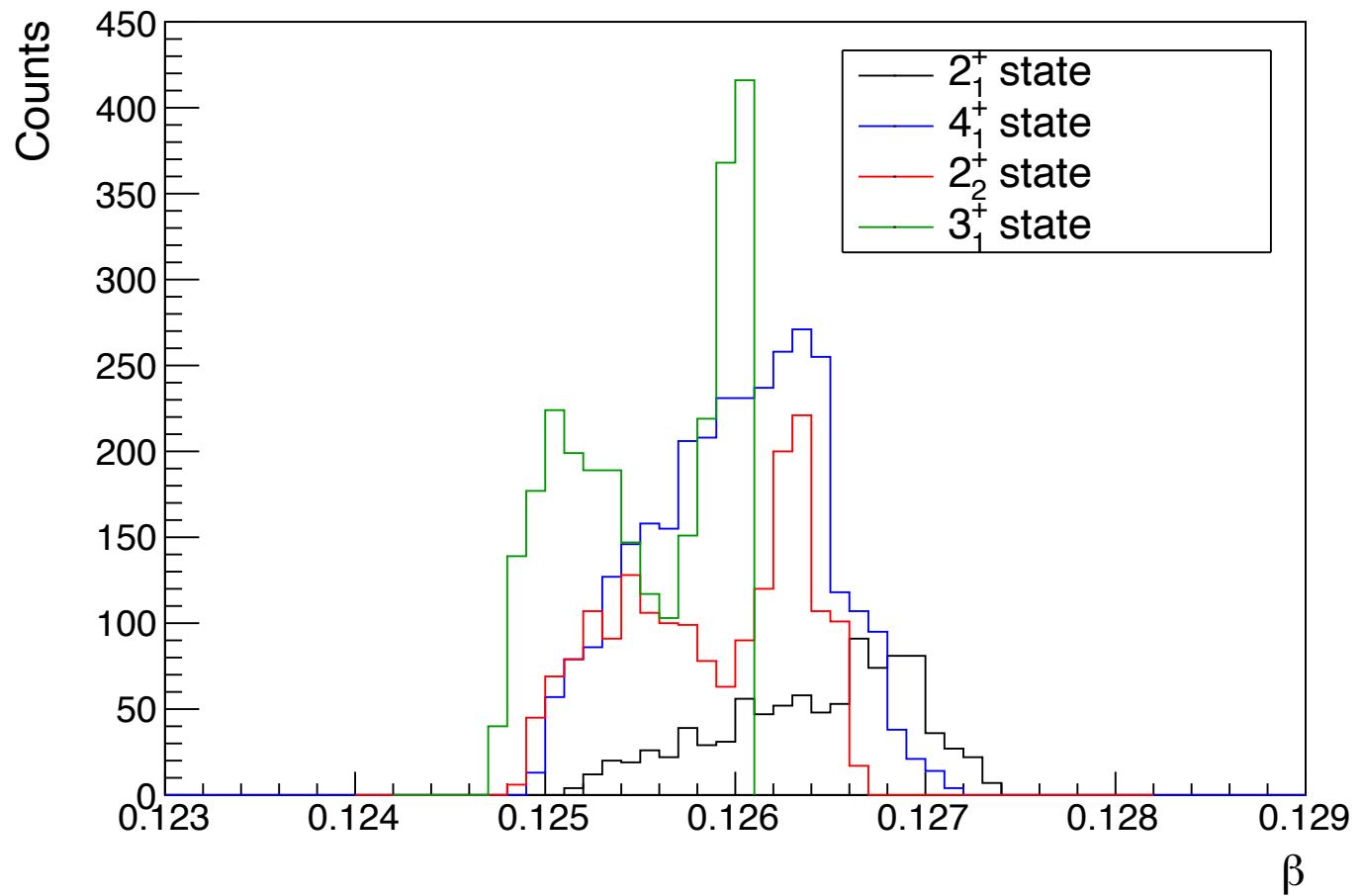
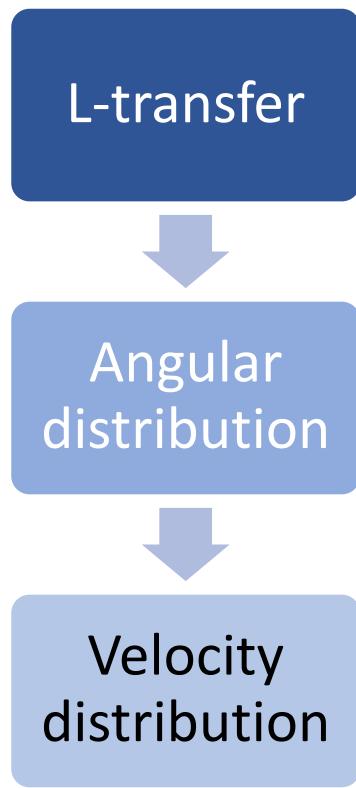


C. Hoffman et al., PRC 85, 054318 (2012)

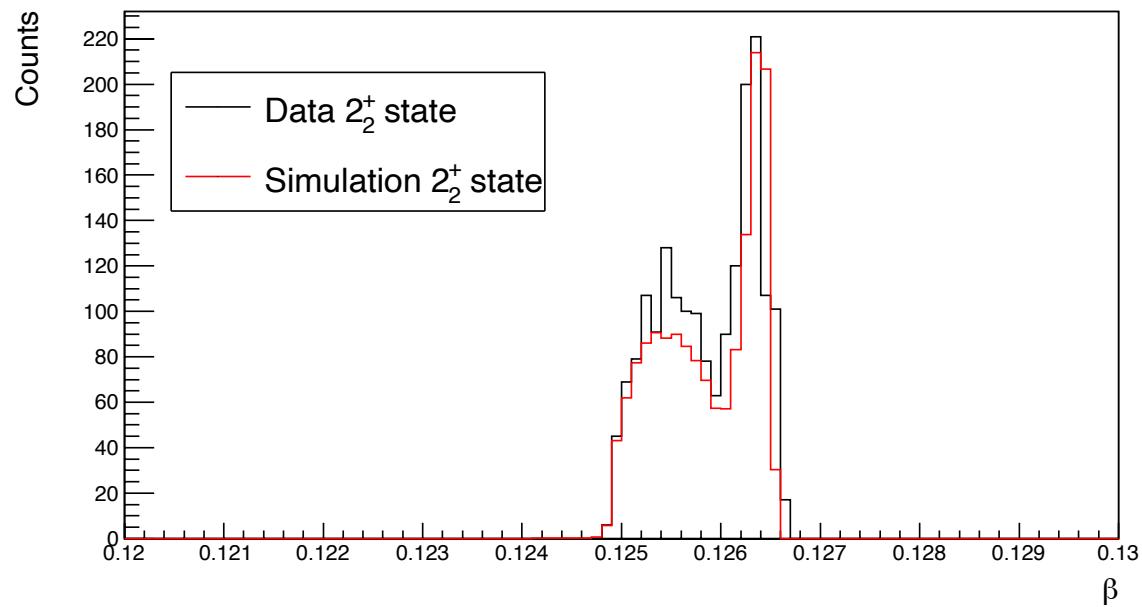
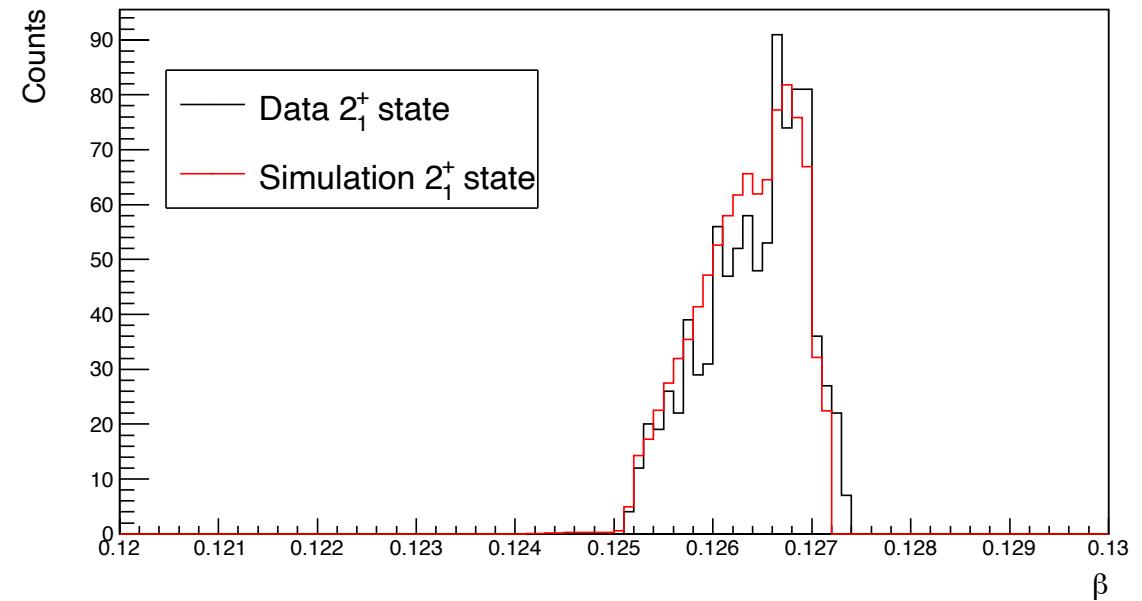
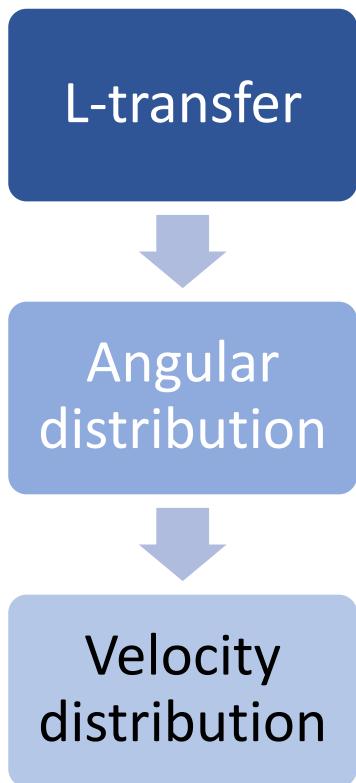
Angular distribution



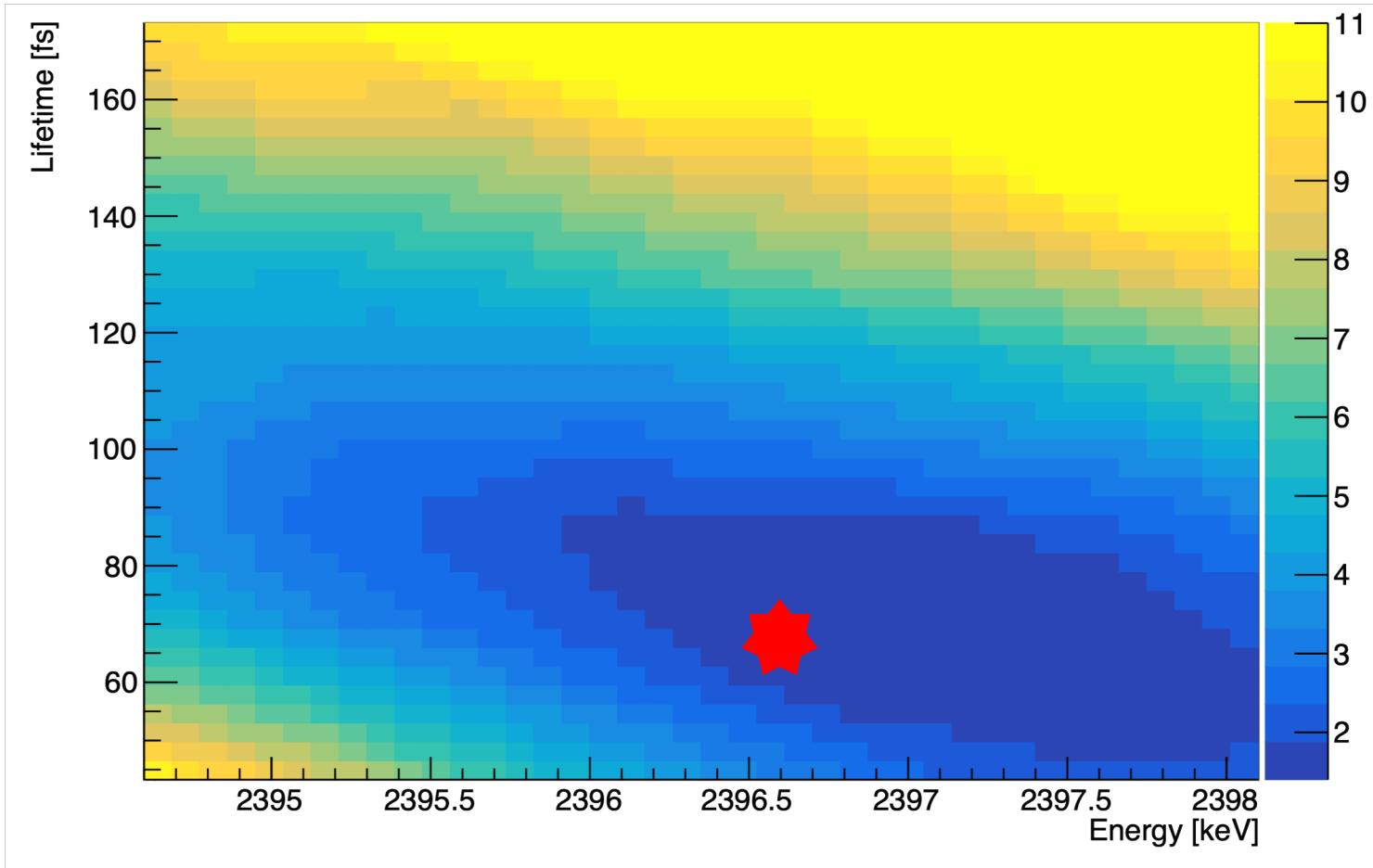
Angular distribution



Angular distribution

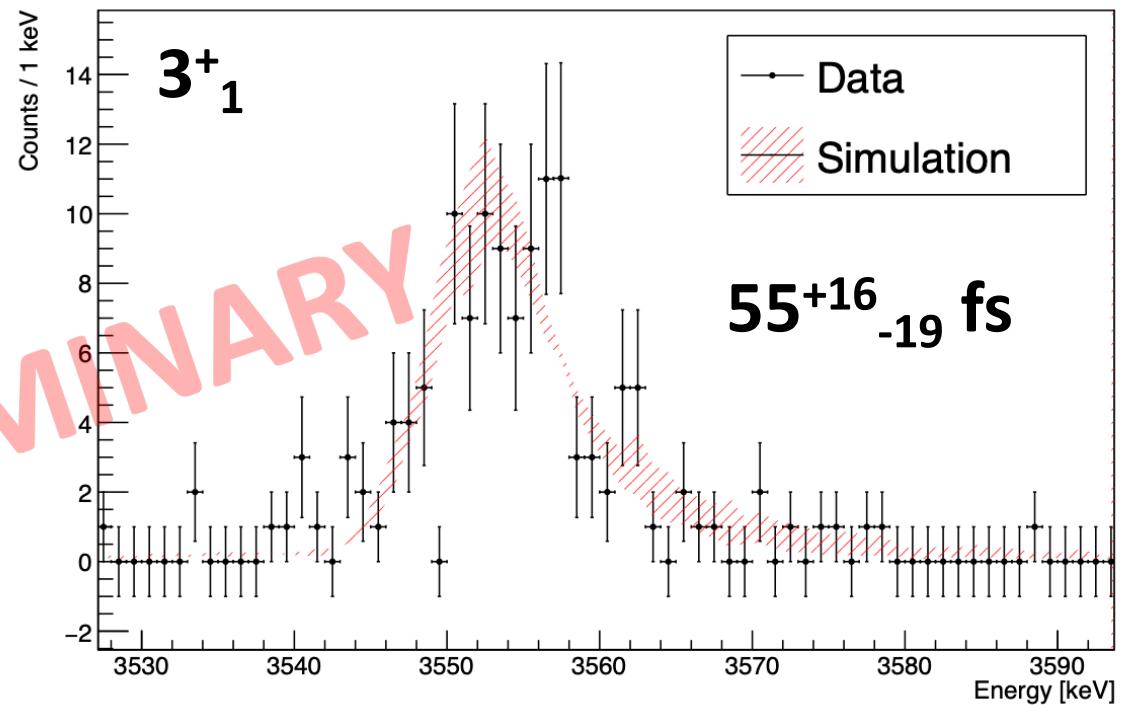
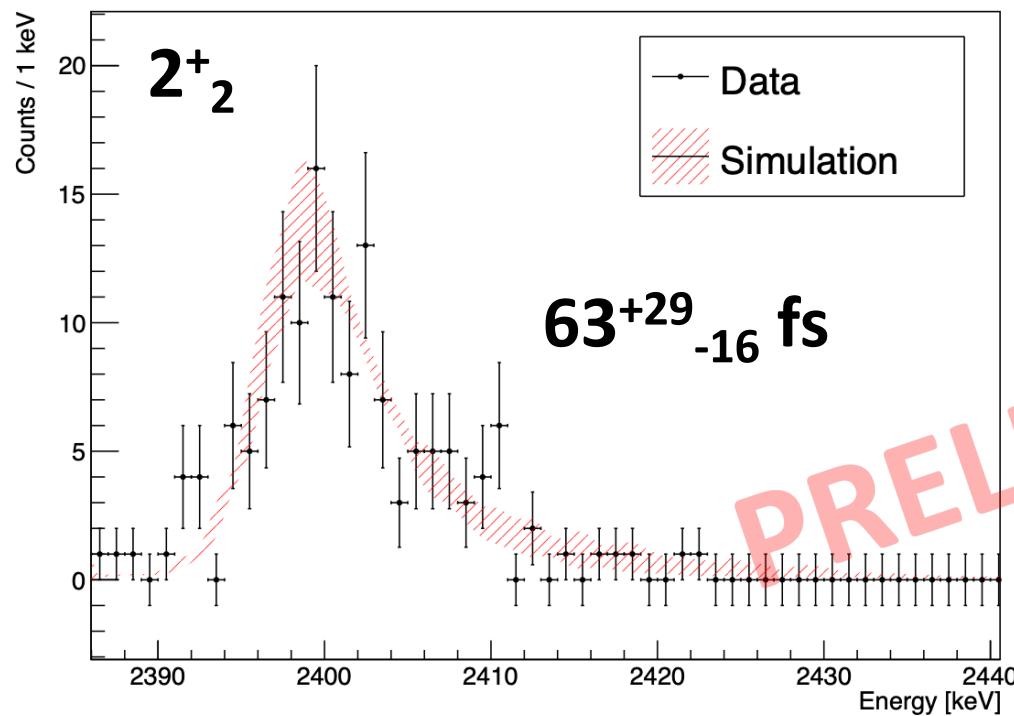


Lifetime measurements



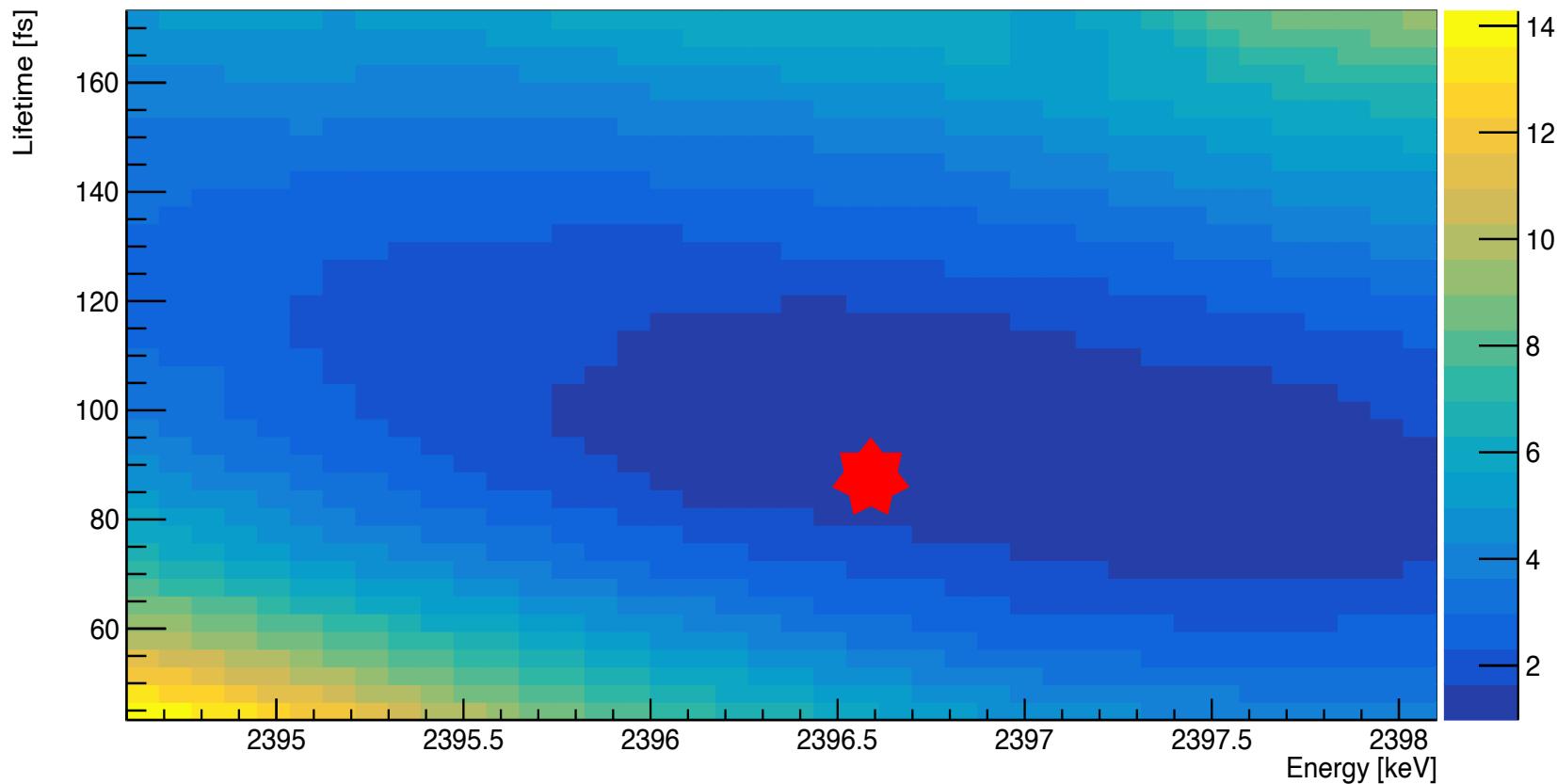
- Gate on the E_x of 2^+_2
- Best energy for 2396.6 keV;
- Best lifetime value 63 fs;
- Least- χ^2 value below 2;
- Statistical errors evaluated using the $\Delta\chi^2$ method.

Lifetime measurements



Systematic errors around 5%

Influence of higher-lying states

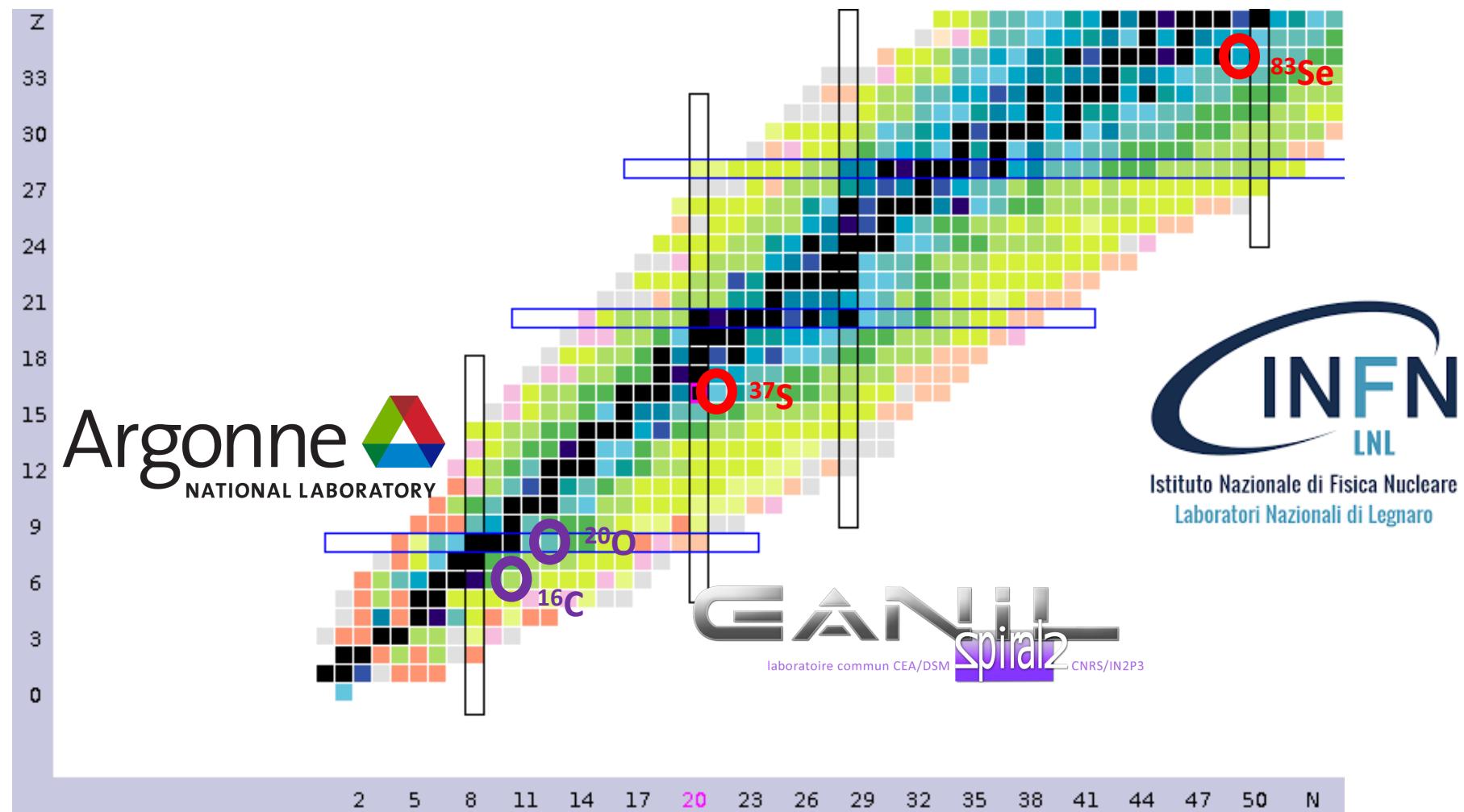


No E_X gate 2^+_2

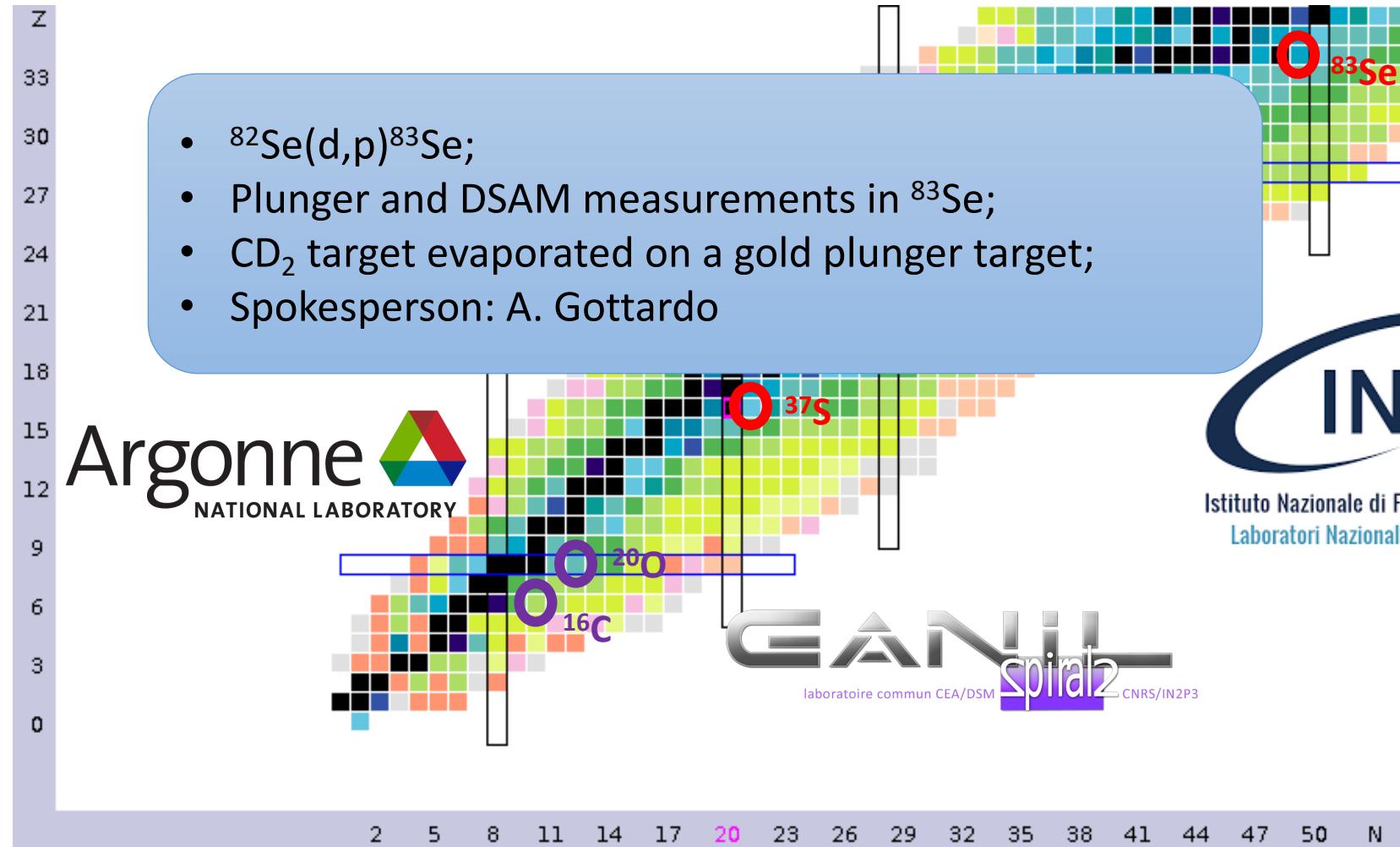


$\tau = 87^{+27}_{-14}$ fs
30% longer

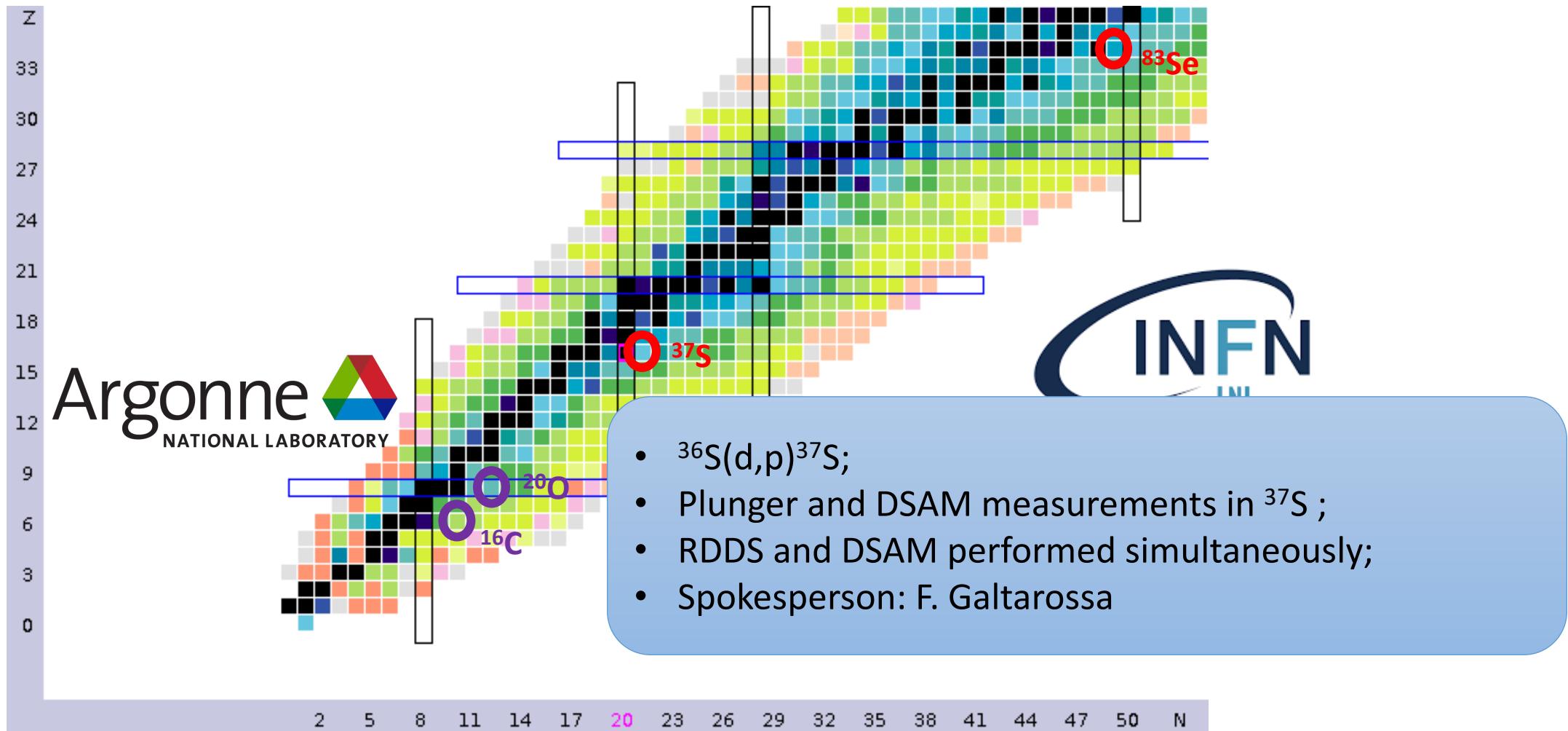
Direct reactions and lifetime measurements



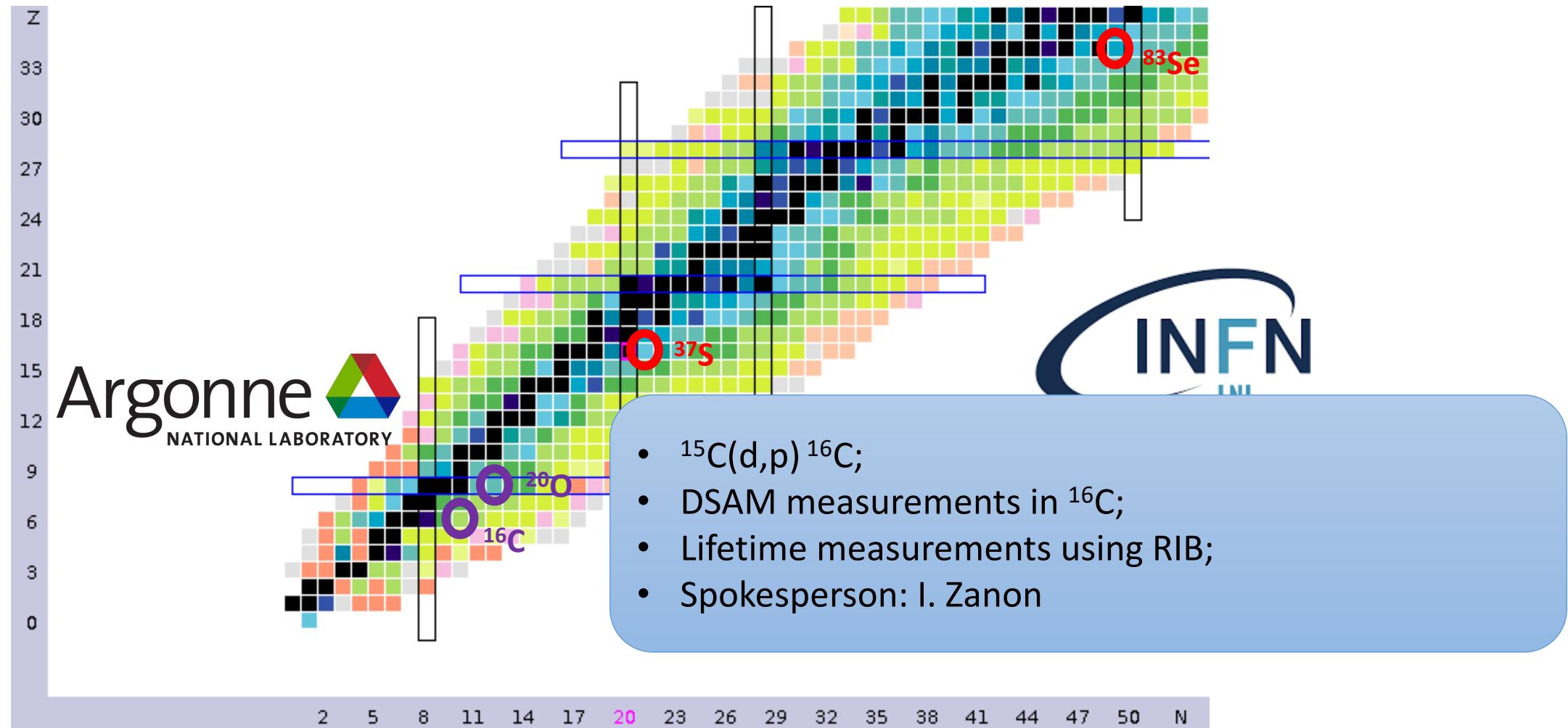
Direct reactions and lifetime measurements



Direct reactions and lifetime measurements

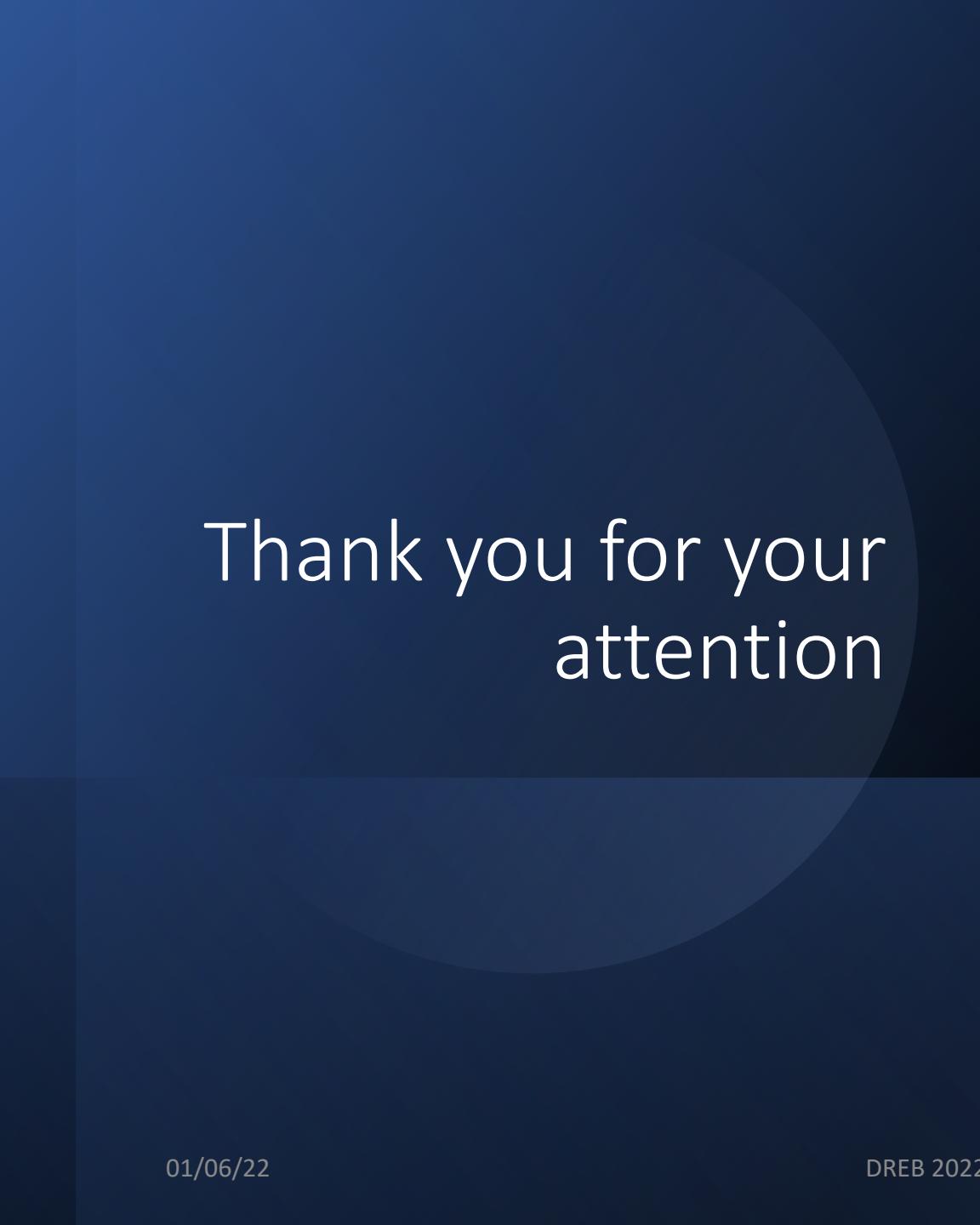


Direct reactions and lifetime measurements



Conclusions

- Challenging experiment with state-of-the art particle detection and γ -ray tracking;
- Precise control on the population of the states using of (d,p) reaction to populate ^{20}O ;
- Lifetime measurement of the 2^+_2 and 3^+_1 states;
- Further investigation for theoretical interpretation.



Thank you for your
attention

The collaboration

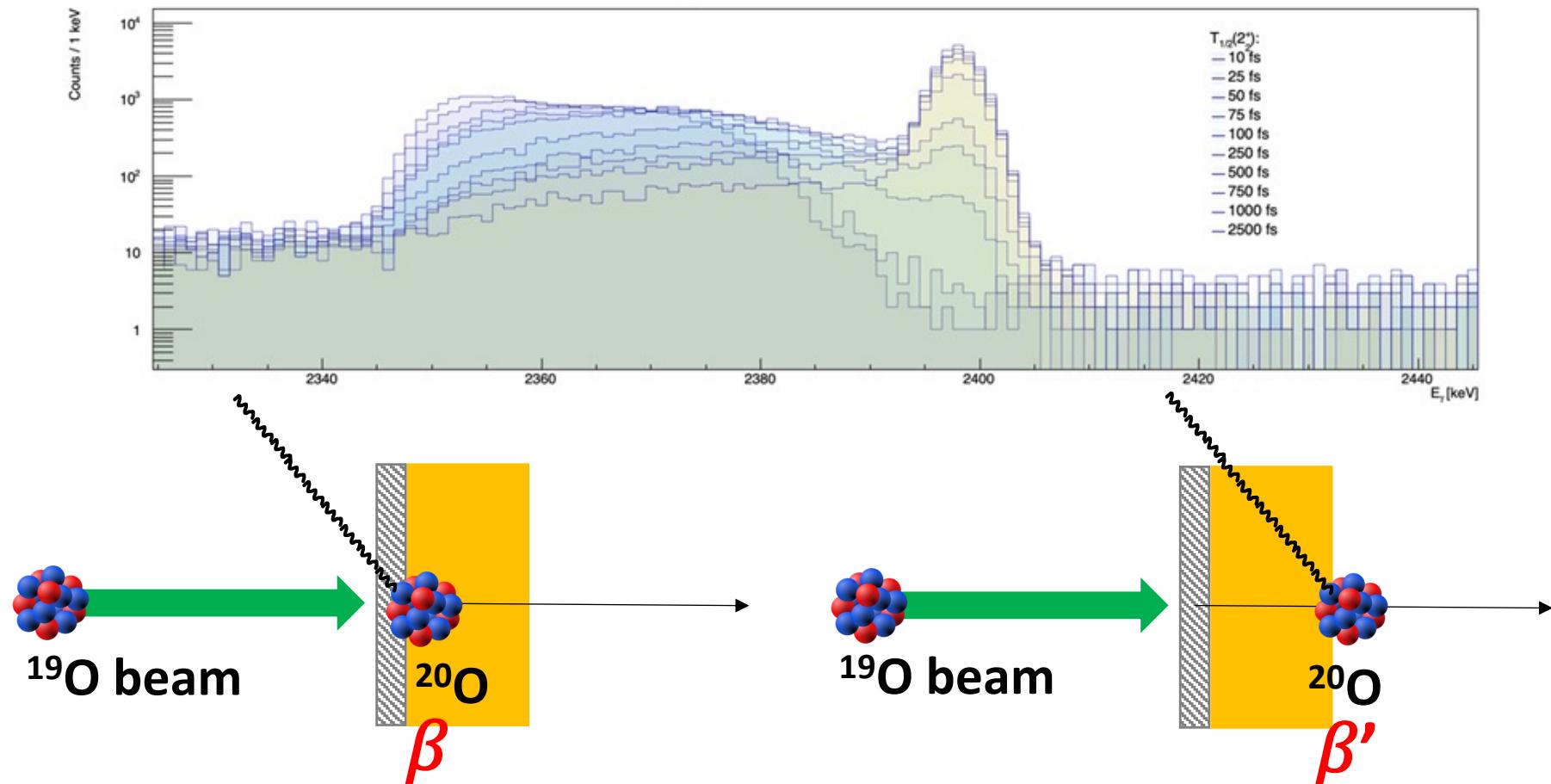
I.Zanon, E. Clément, A. Goasduff, M. Ciemała,
M. Assié, F. Flavigny, C. Fougeres, S. Leblond,
A. Lemasson, A. Matta, D. Ramos, K. Rezynkina,
M. Rejmund, M. Siciliano, D. Ackermann, D. Beaumel,
S. Bottoni, D. Brugnara, N. de Sereville, F. Delauney,
F. Didierjean, G. De France, P. Delahaye, J. Dudouet,
D. Fernández Fernández, J.L. Fuentes,
A.F. Gadea Raga, F. Galtarossa,
V. Girard-Alcindor, F. Hammache, A. Kosoglu,
C. Lenain, J. Ljungvall, A. Lopez-Martens,
G. Pasqualato, D. Ragueira Castro, J.S. Rojo,
A. Utepov, Y.H. Kim, M. Zielinska

On behalf of the AGATA, VAMOS and MUGAST
collaborations

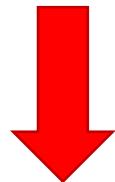
Back-up



The Doppler Shift Attenuation Method

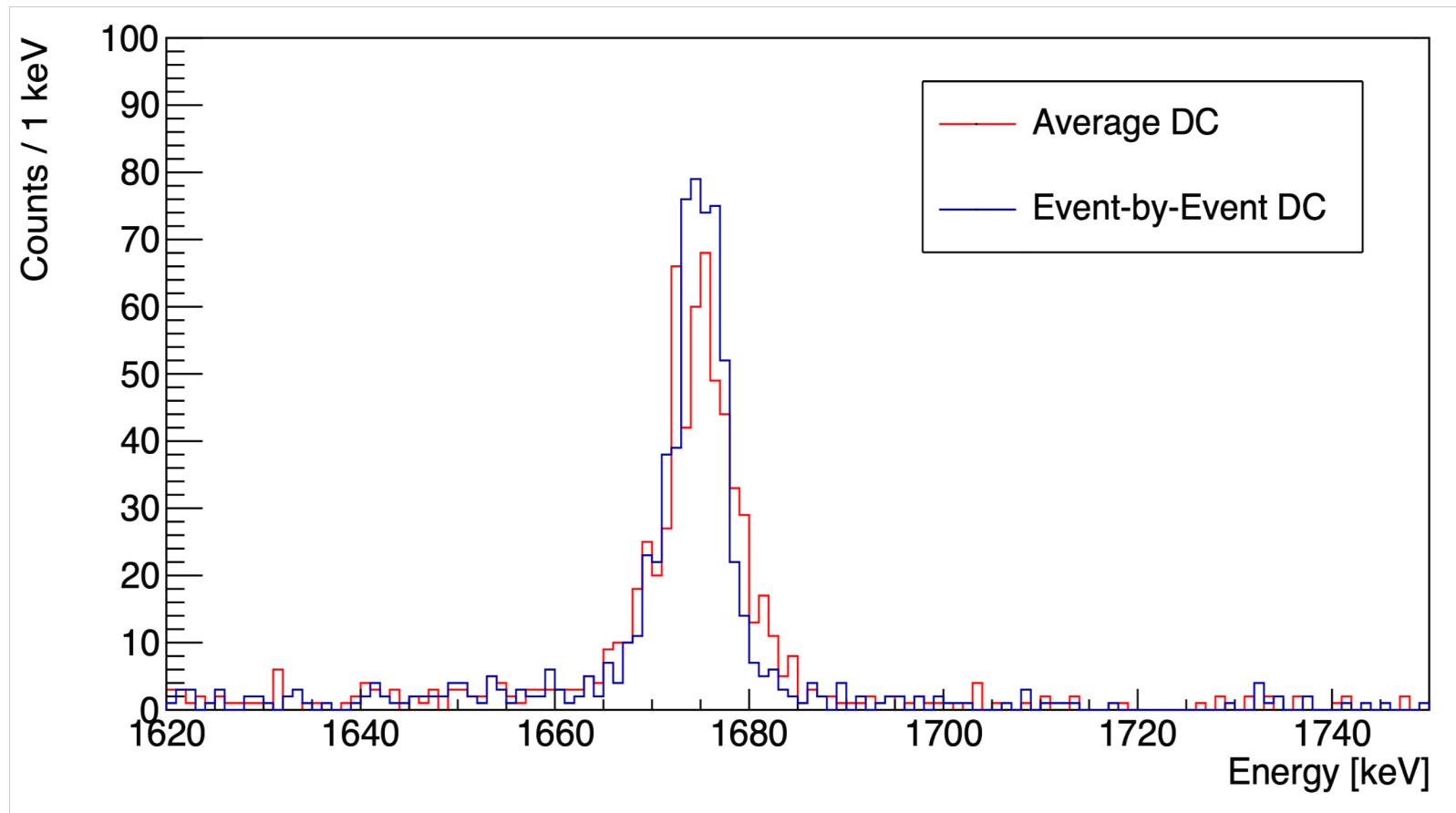


- Optimization of the degrader;
- Resolution of AGATA and MUGAST;



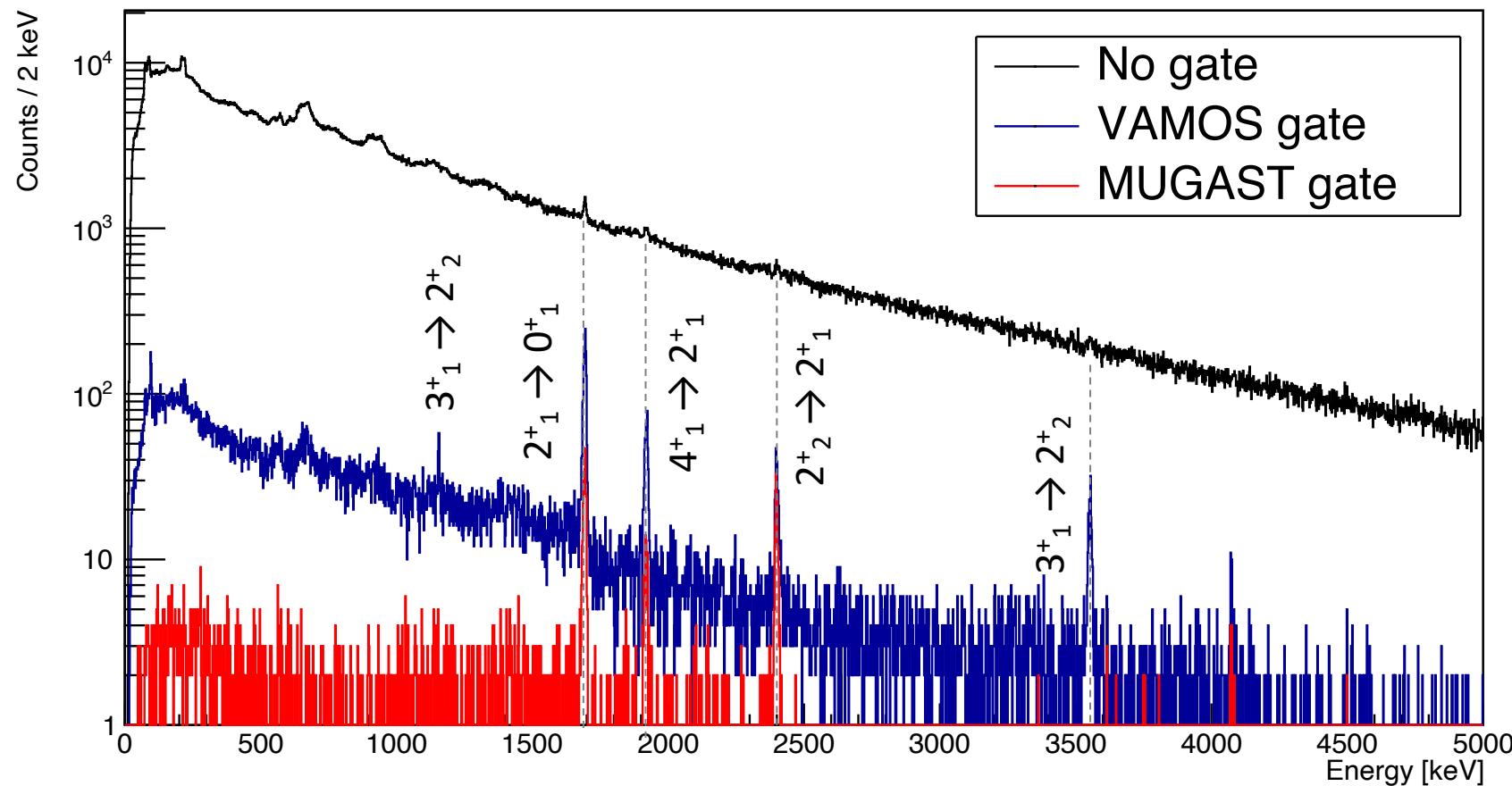
Range of
femtoseconds

Event-by-event Doppler correction



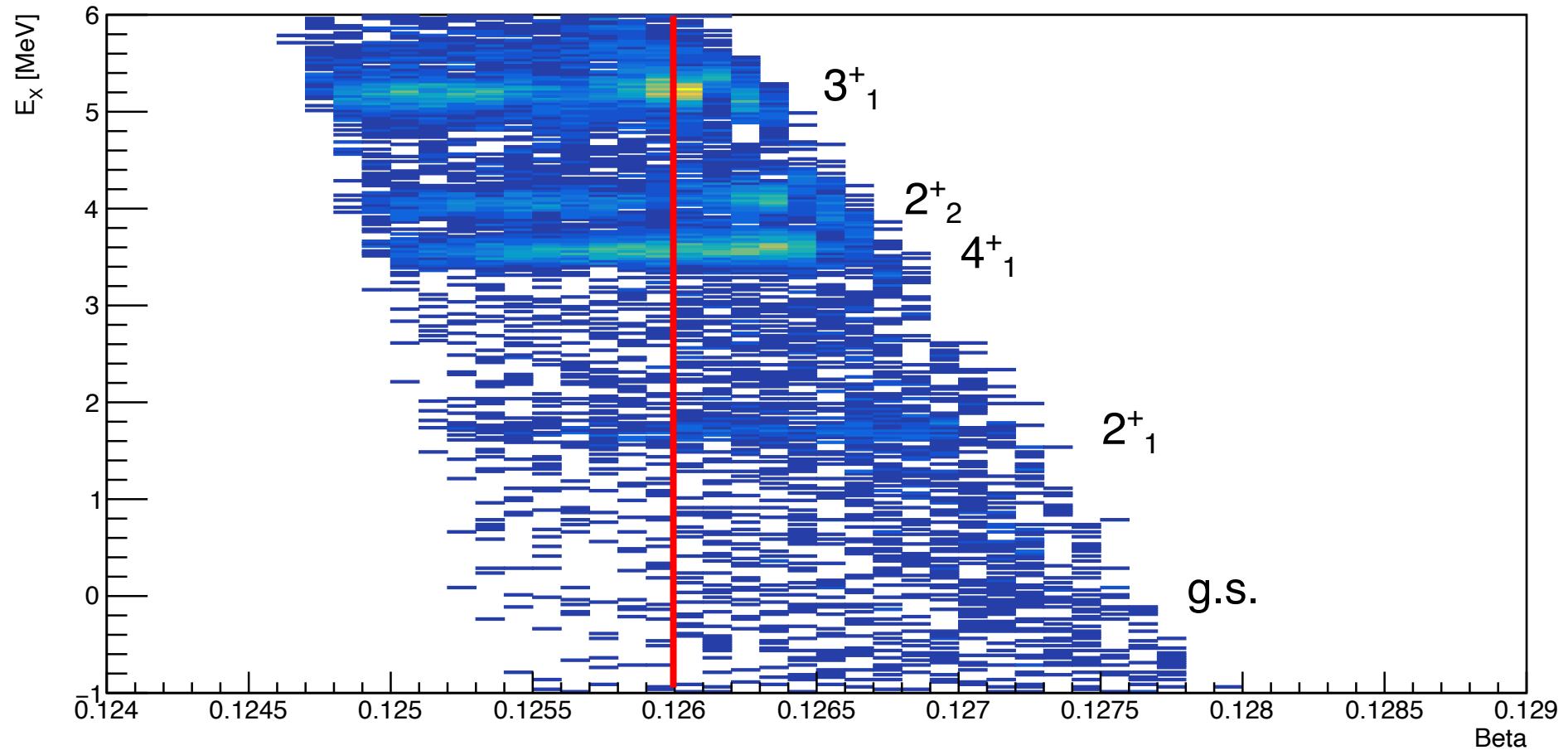
- Detection of the proton;
- Kinematic reconstruction;
- Improved the resolution of 25% with respect to the one using the average $\beta=12.6\%$

Selectivity of the setup



- Low beam intensity;
- AGATA triggerless;
- Different gates to reduce the background.

Velocity- E_x dependence



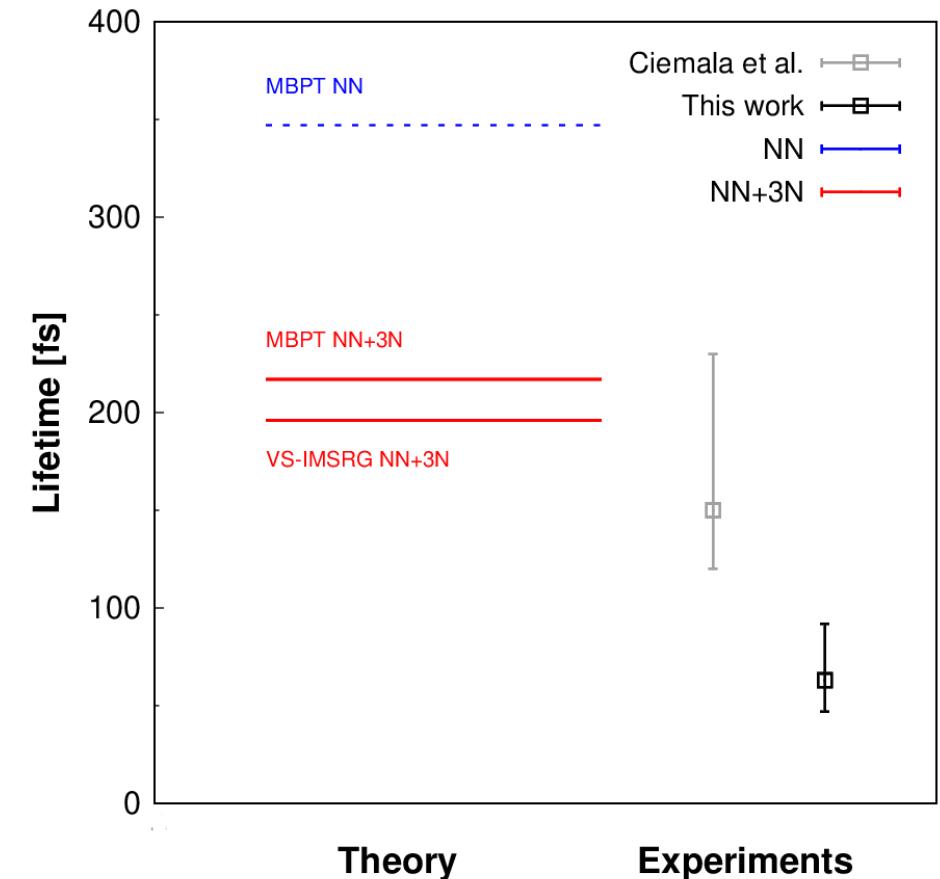
Ab-initio interpretation

The new experimental value of the 2^+_2 confirms the influence of 3N forces in this region.

Discrepancy with previous data within 2σ :

- Target-degrader thickness;
- Possible unobserved feeders.

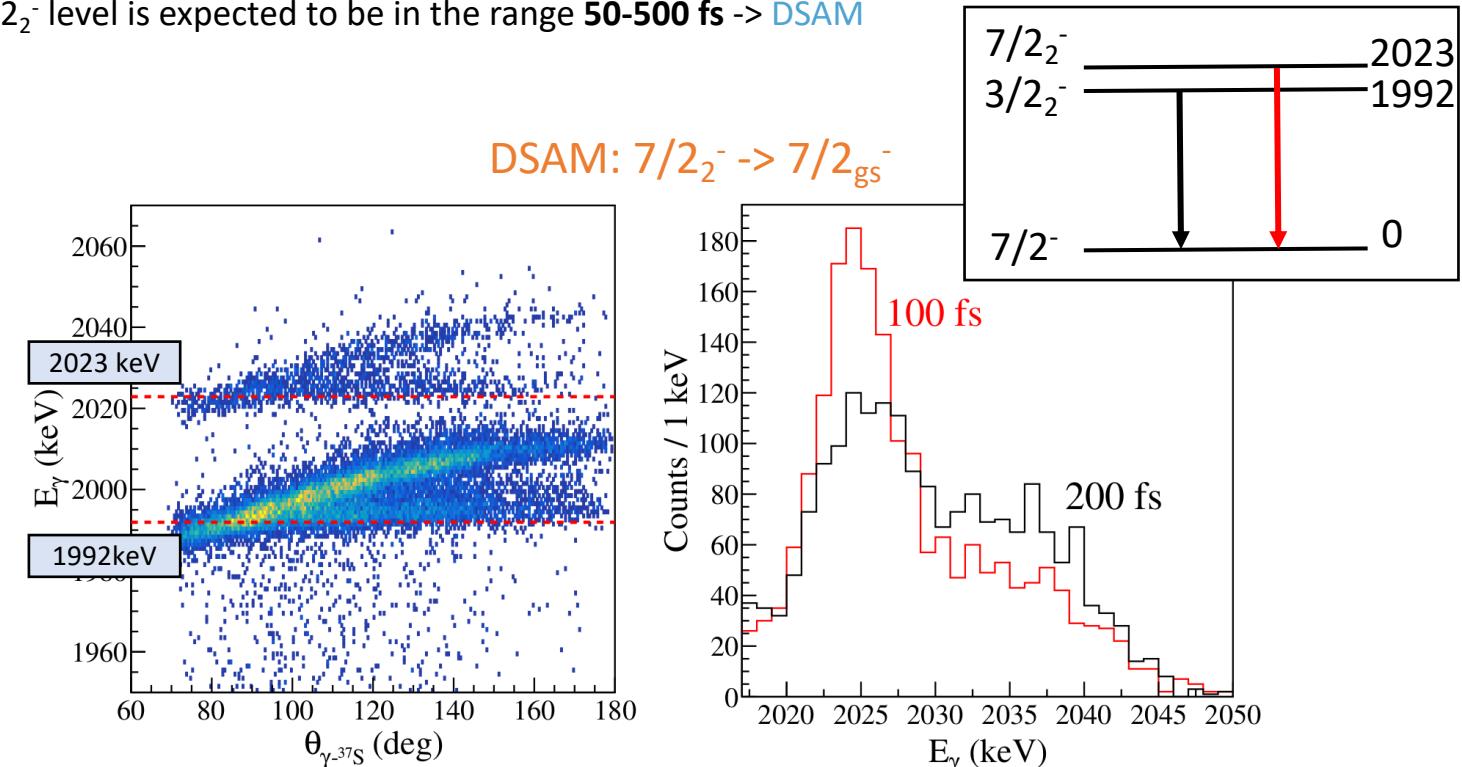
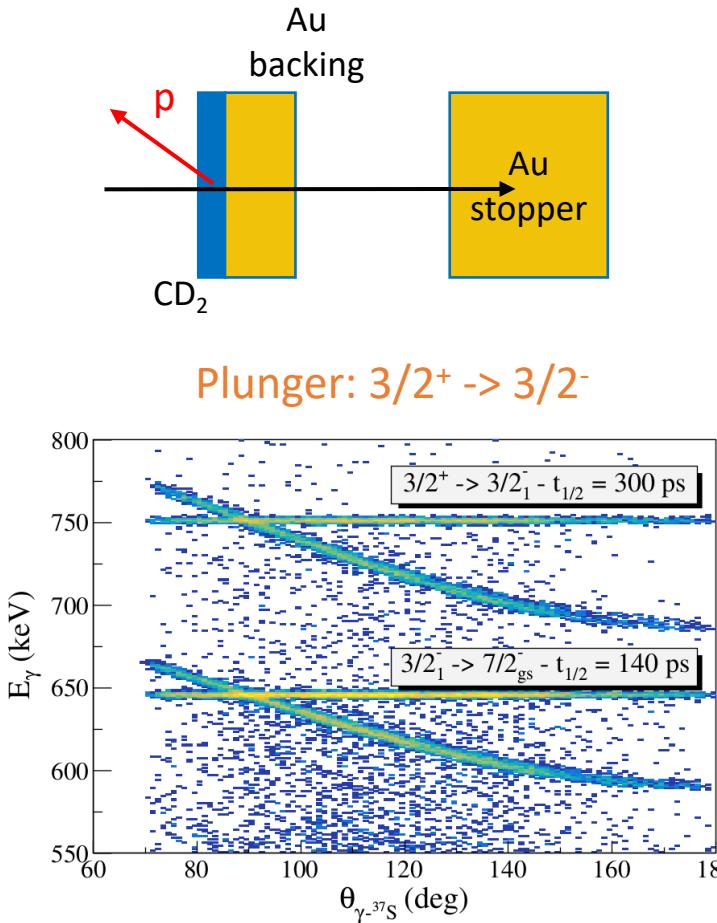
Discrepancy with theory still to be investigated.



*M. Ciemała et al, PRC **101** 021303 (2020)*

Simulations for lifetime determination

- The lifetime of the $3/2^+$ level is expected to be in the range **10-500 ps** -> **PLUNGER**
- The lifetime of the $7/2^-$ level is expected to be in the range **50-500 fs** -> **DSAM**



The DSAM and plunger measurement can be performed **at the same time**.