Resonant elastic scattering experiments with active and non-active targets

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20th Russbach School on Nuclear Astrophysics
March 18th, 2025

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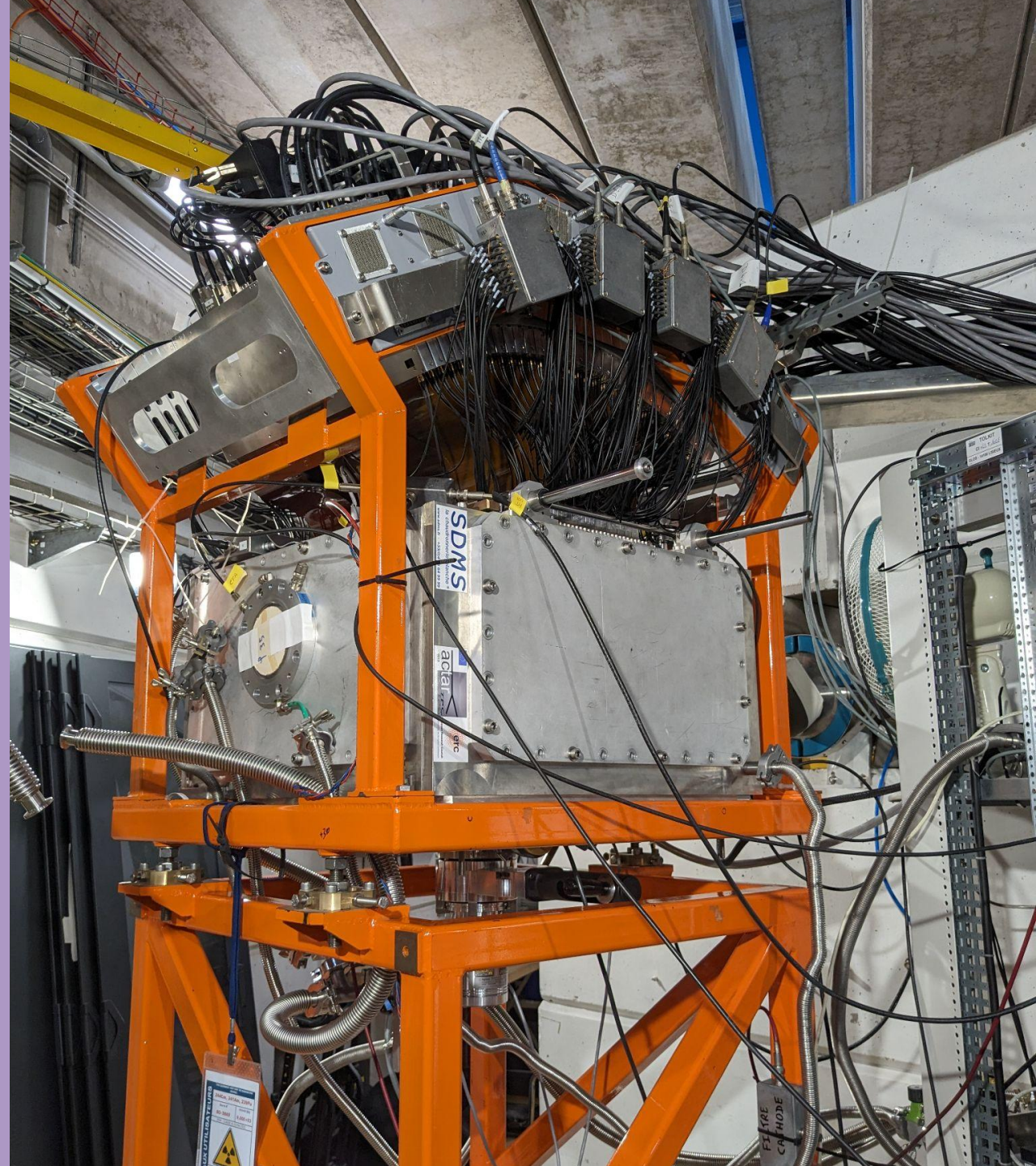
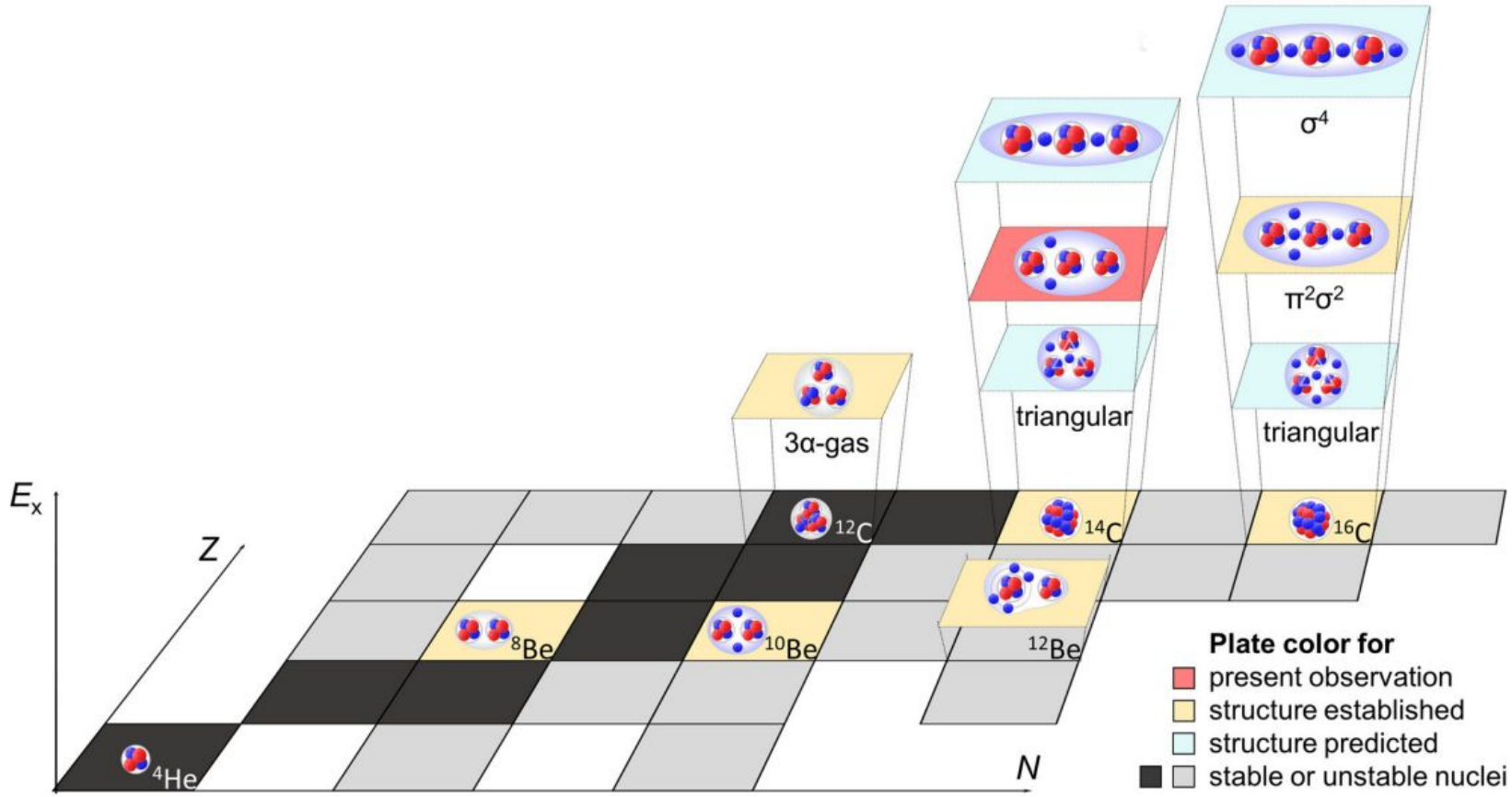
GANIL

Experiment with active target (ACTAR TPC) : ^{12}Be structure in multi-threshold vicinity

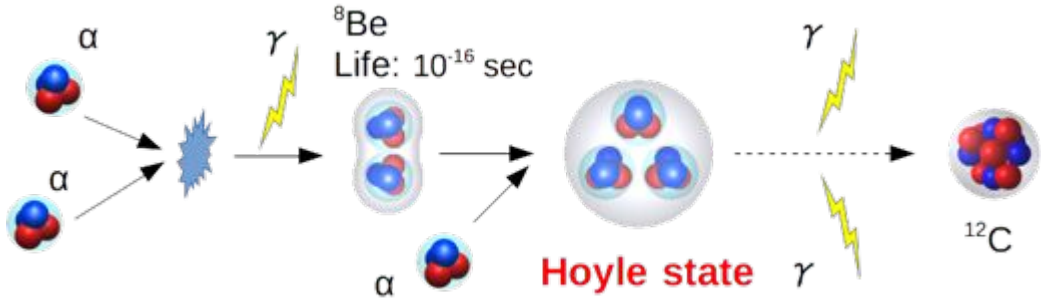


Physics motivation : Clusters

- Light nuclei -> cluster configuration where nucleons are grouped in clusters



Physics motivation : ^{12}Be states



0^+ — 7.65

– – – – – – – – – – 7.37

^{8}Be + α

2^+ — 4.44

0^+ — ground

^{12}C

4^+ — 13.3

2^+ – – – – – – – – – – ? ^{4}He(g.s) + ^{8}He(2+)

? – – – – – – – – – – 12.23 ^{5}He + ^{7}He

0^+ – – – – – – – – – – 12.15 ^{8}Be + 4n

(2^+) — 12.1

0^+ – – – – – – – – – – 12.07 2α + 4n

2^+ – – – – – – – – – – 11.90 ^{6}He (g.s) + ^{6}He(2+)

0^+ — 10.1

– – – – – – – – – – 10.1

^{6}He + ^{6}He

– – – – – – – – – – 8.96

^{4}He + ^{8}He

⋮

– – – – – – – – – – 3.17

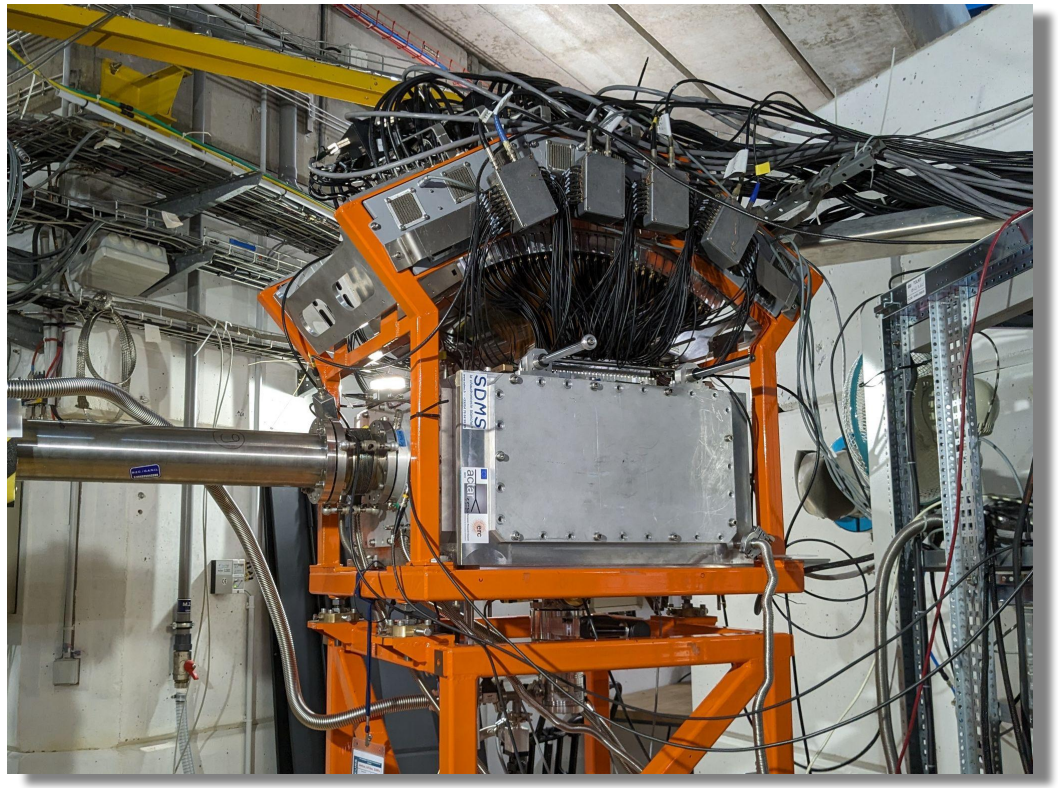
^{11}Be + n

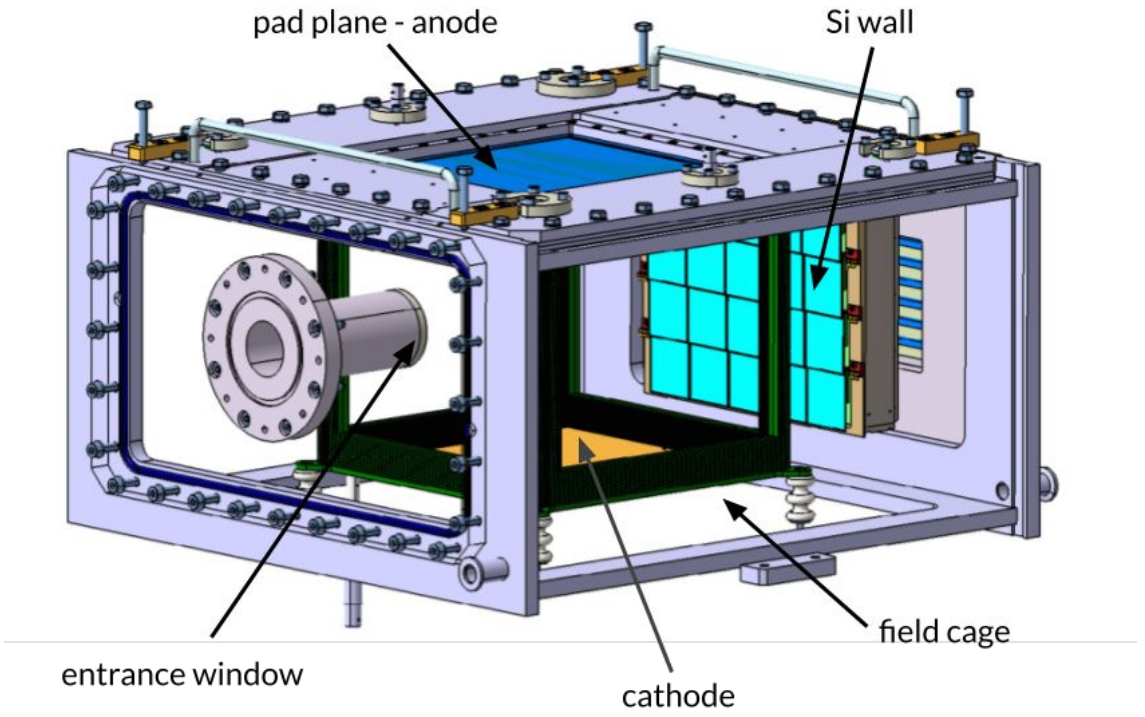
Yang et al. (2014)

^{12}Be

Experiment method : ACTAR TPC

- Resonant elastic scattering reaction α(^{8}He, ^{8}He)α -> population of ^{12}Be states
- ^{8}He beam at 1.8 MeV/u , and ACTAR TPC filled with ^{4}He gas





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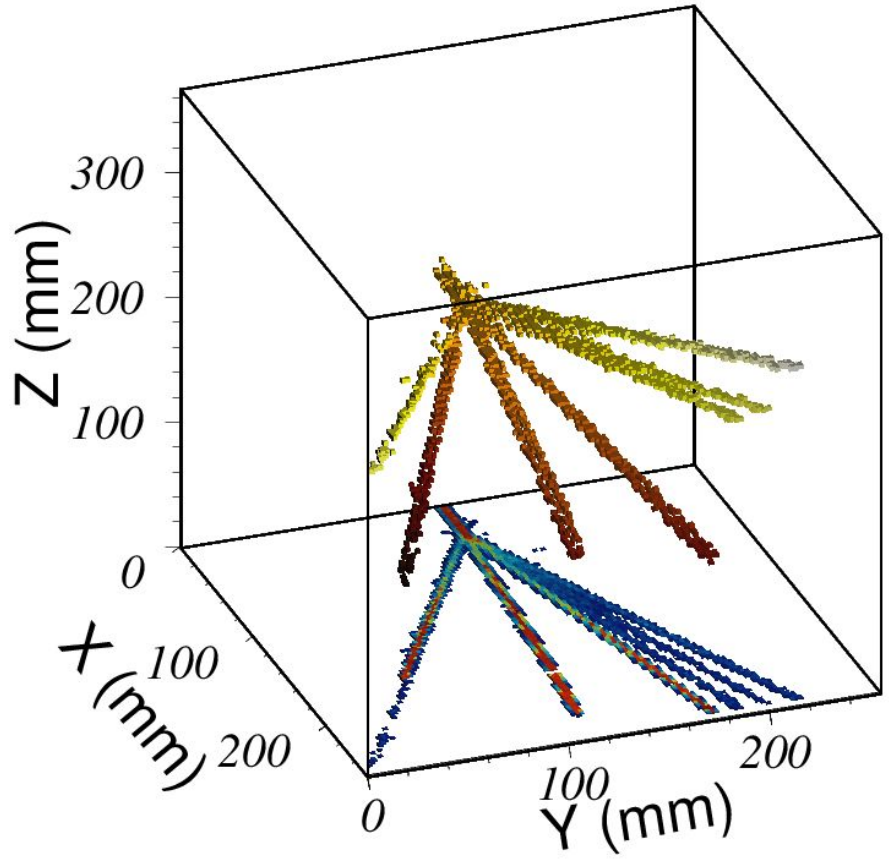
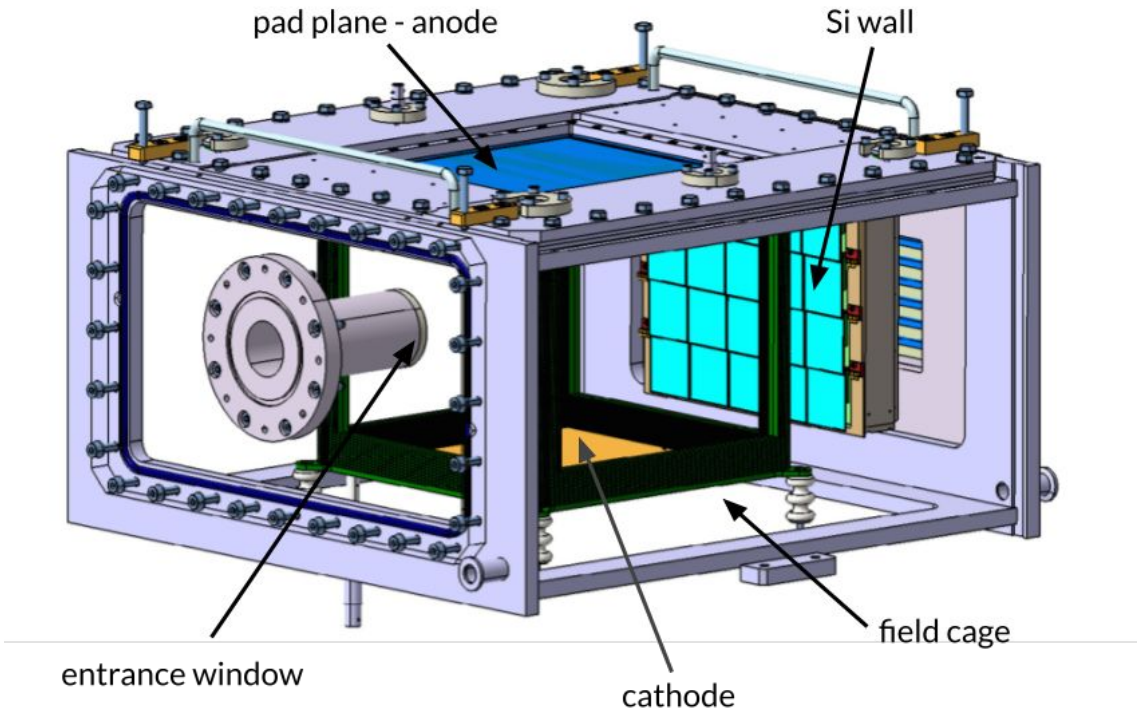
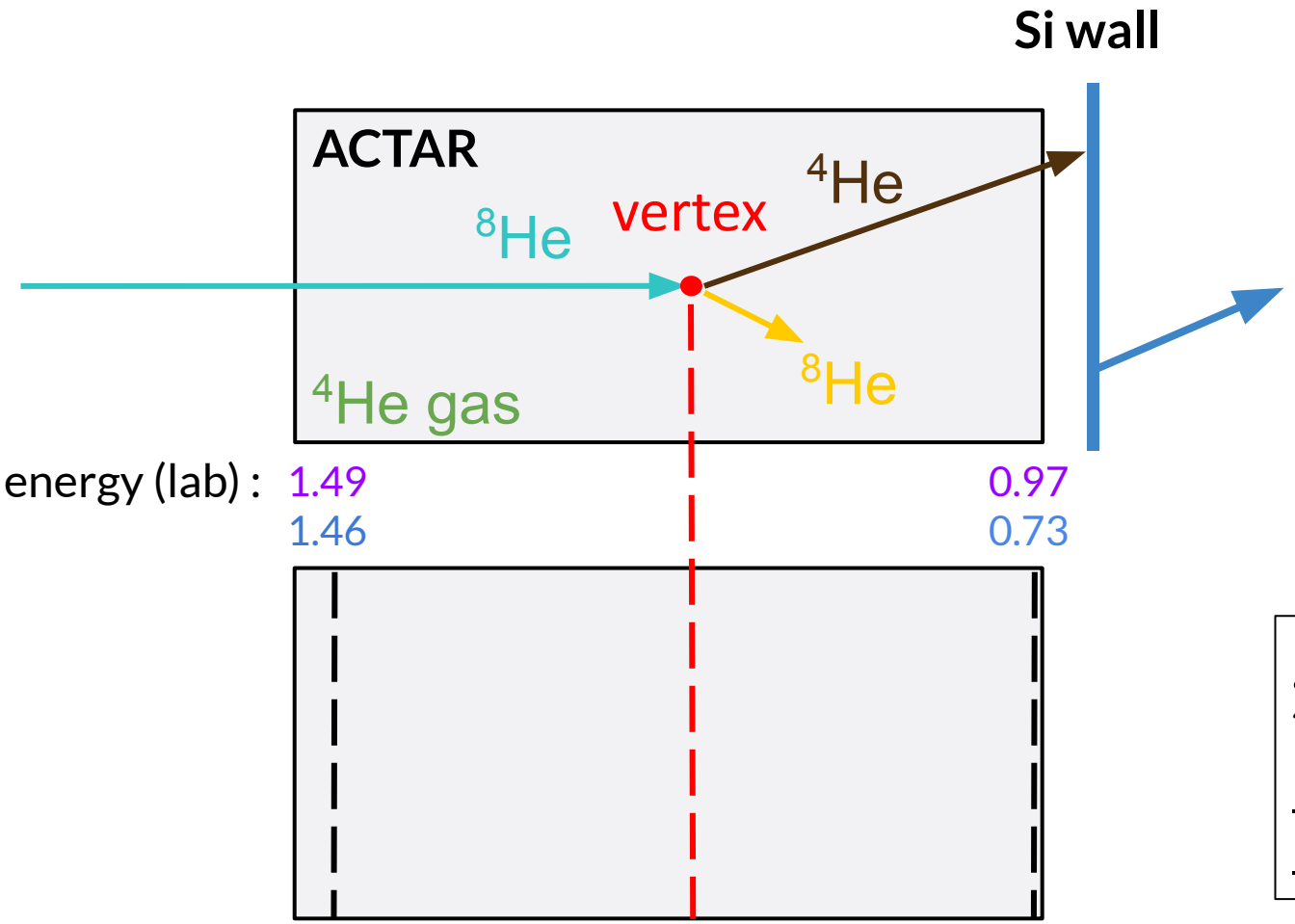
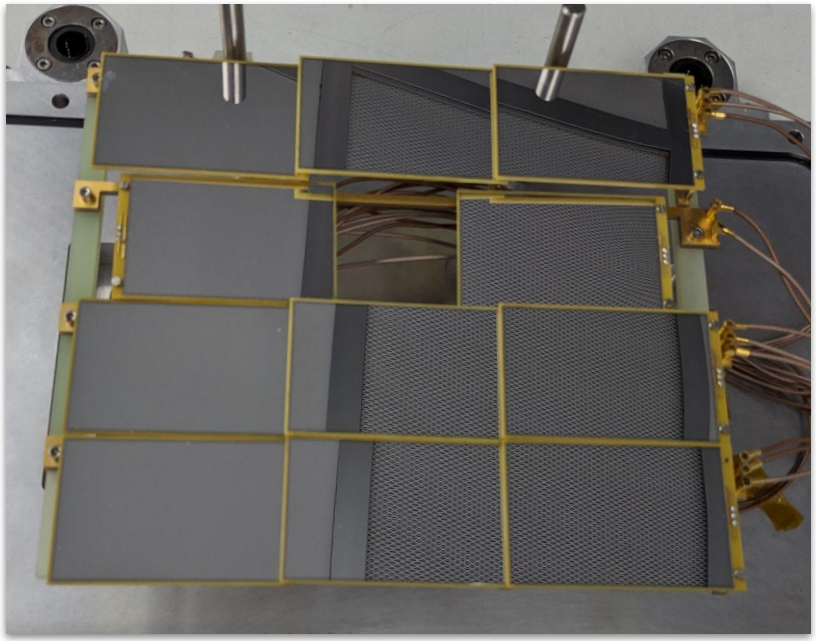




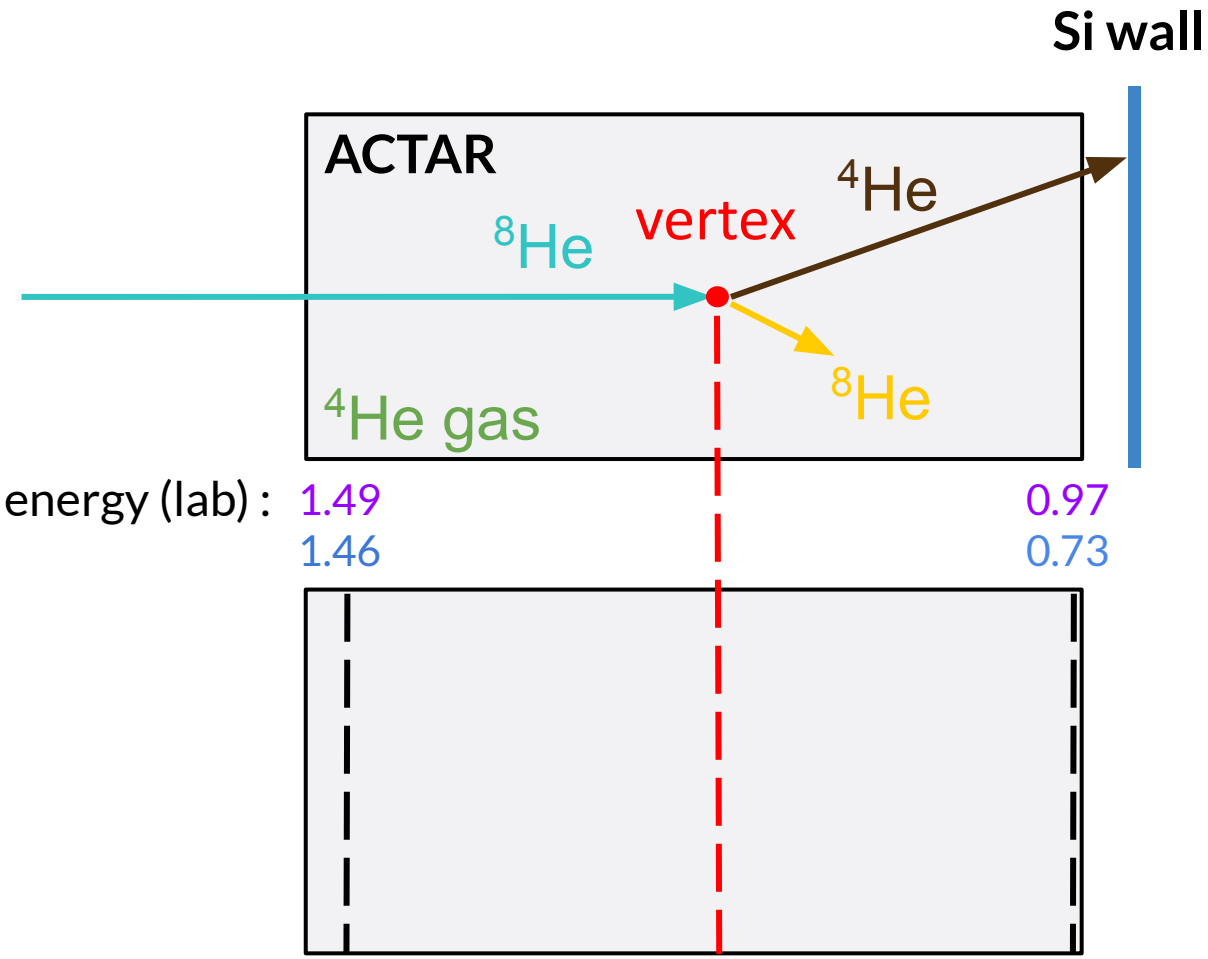
Experiment method : α(^{8}He,^{8}He)α





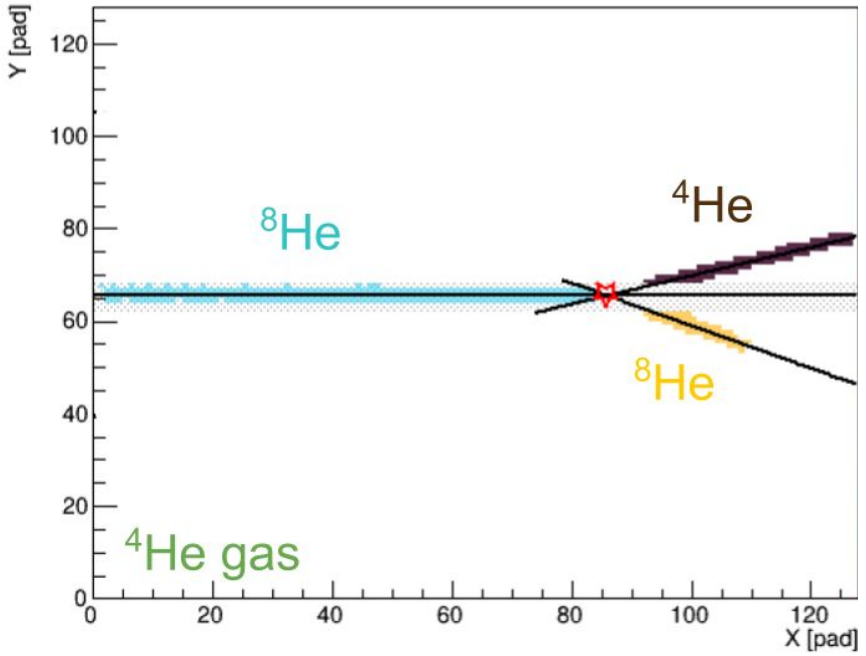
gas :
^{4}He (97%) + iC_4H_{10} (3%)
_ 900 mbar
_ 700 mbar

Experiment method : α(^{8}He,^{8}He)α



^{8}He energy (lab) : 1.49 1.46 | 0.97 0.73

Corresponding E*(^{12}Be) : 13.0 12.9 | 11.1 10.5



gas :
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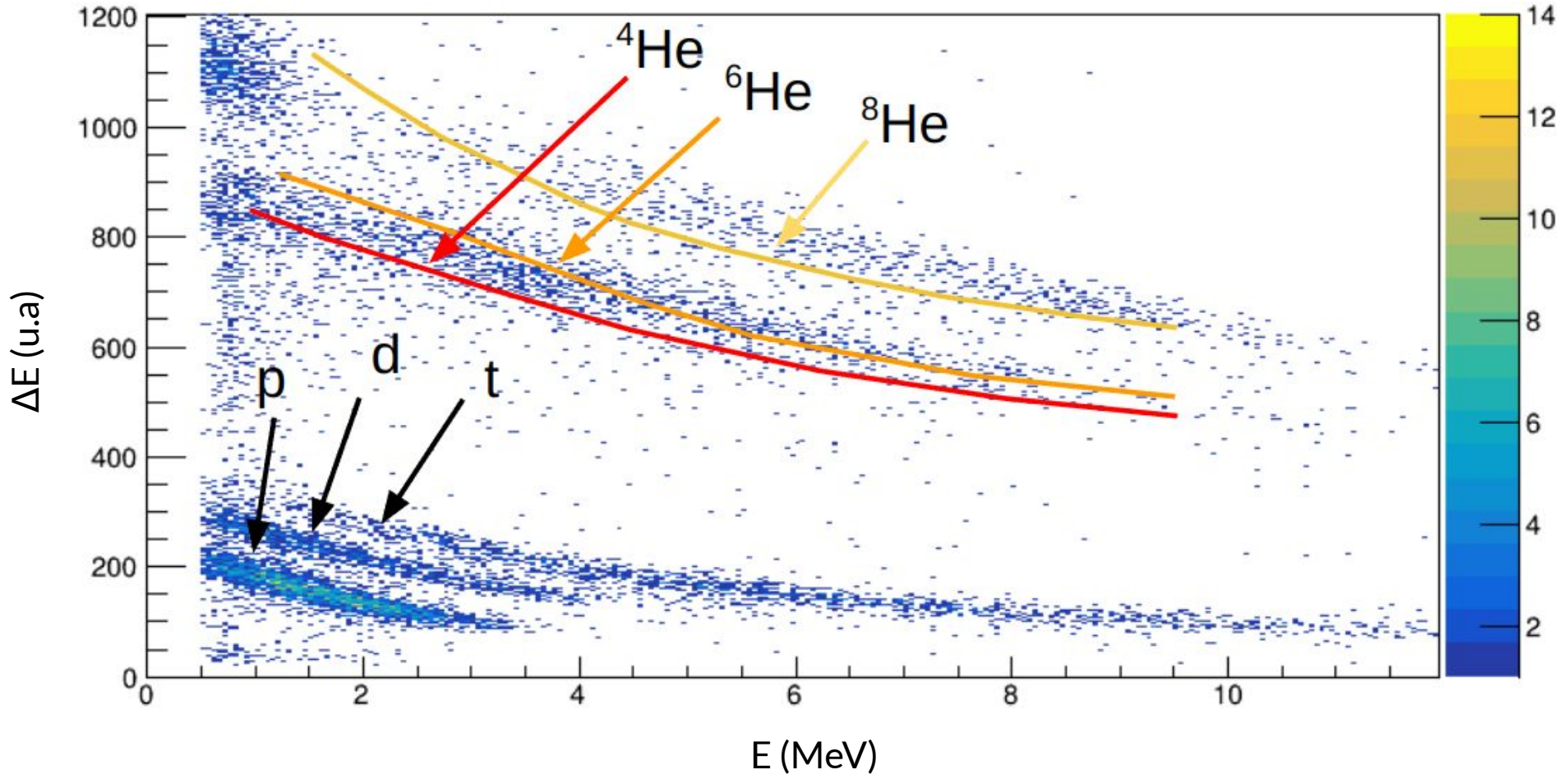
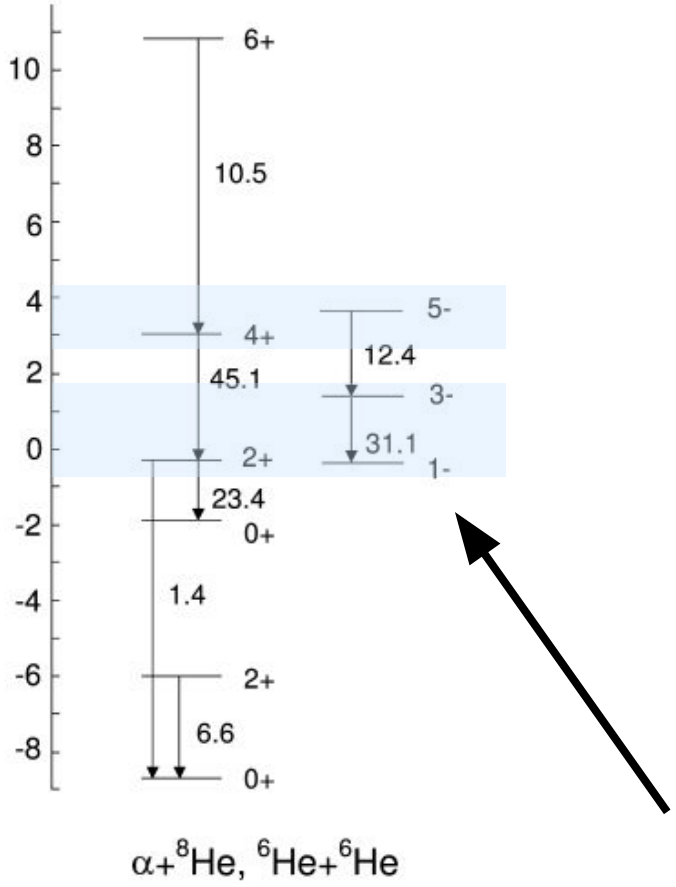
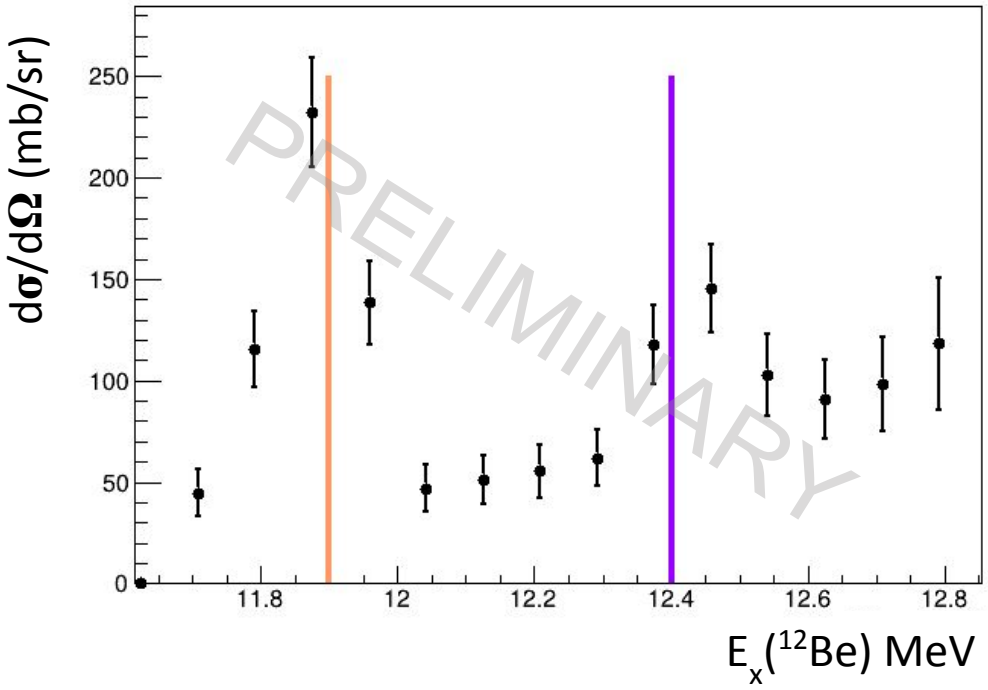
Particle identification



Hypothesis on states measured



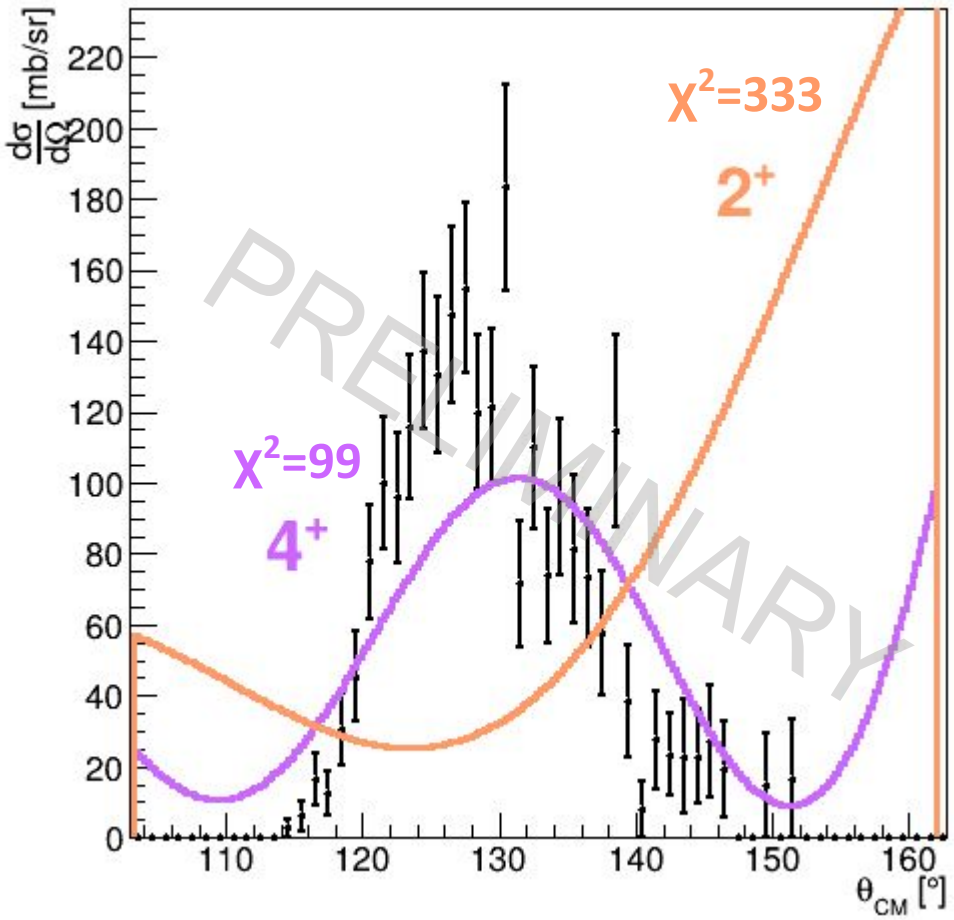


- Two states measured at 11.9 and 12.4 MeV
- Compatible with 12.1 MeV (2^+) by *Yang et al.*
- Two pairs ($2^+/3^-$) and ($4^+/5^-$) predicted by *Descouvemont et al.*
- Hypothesis : 11.9 (2^+ or 4^+), 12.4 (3^- or 5^-)

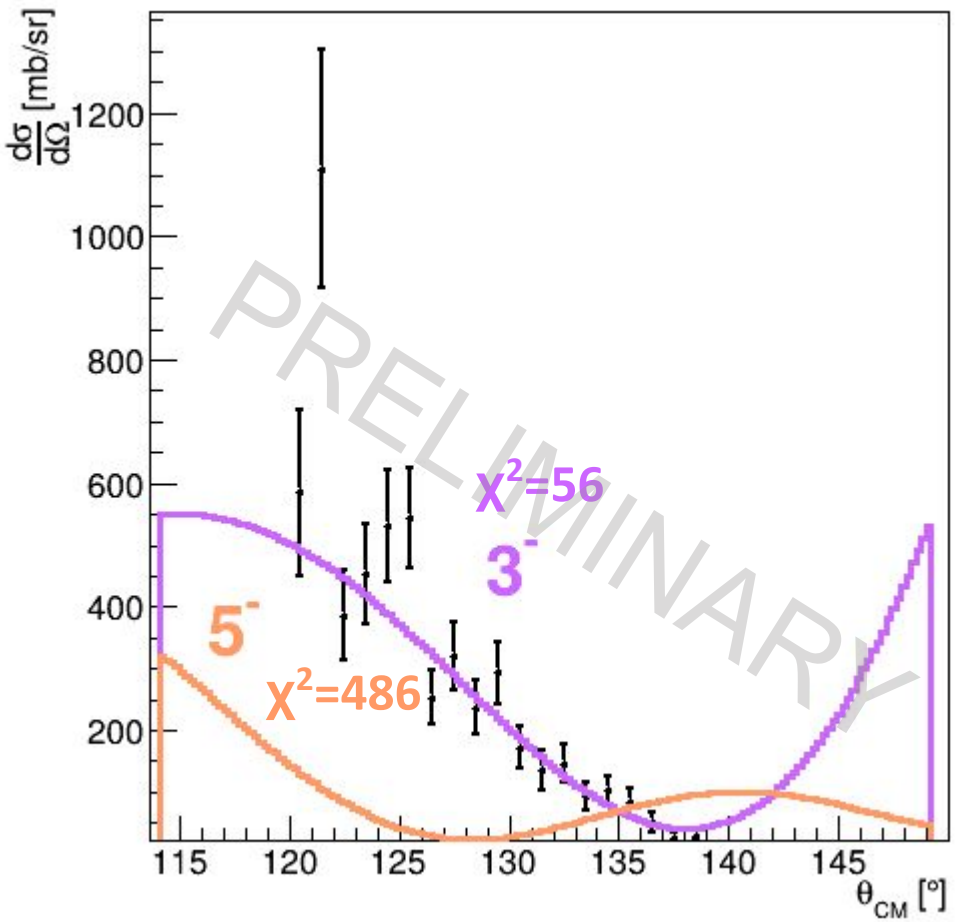
P. Decouvement, D.Baye / Physics Letters B (2001)

Angular distribution

11.9 MeV resonance



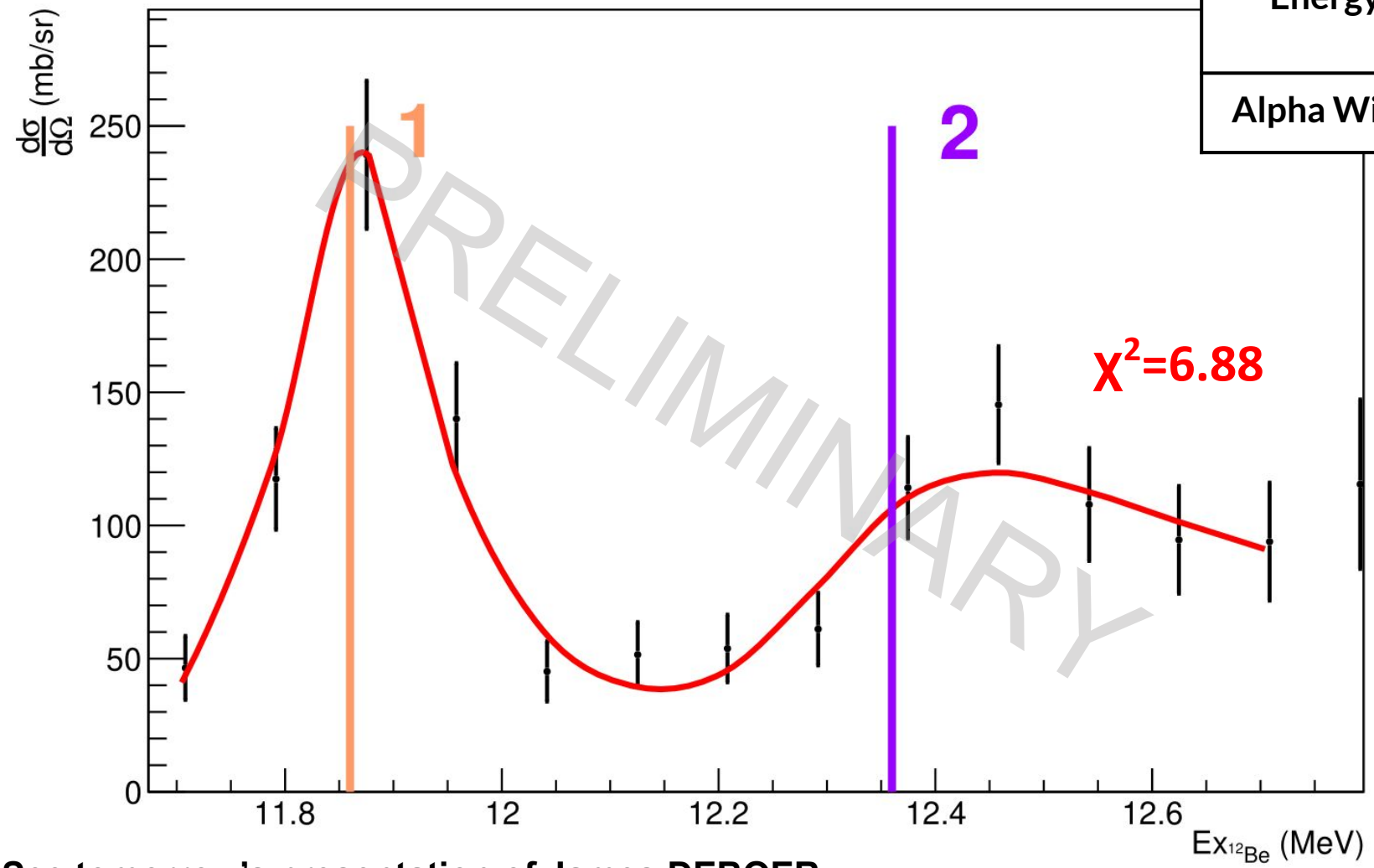
12.4 MeV resonance

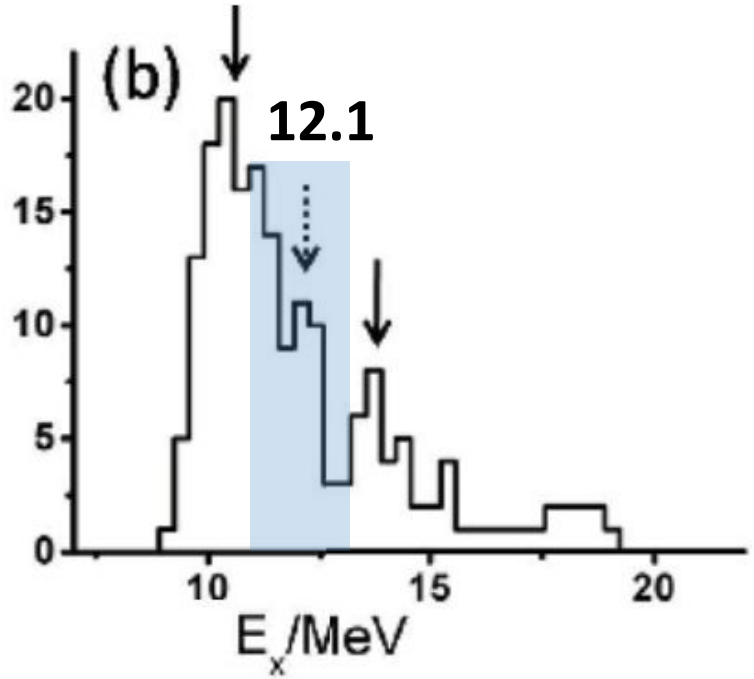


R-Matrix fit with AZURE2

preliminary parameters

Spin	4^+	3^-
Energy (MeV)	11.86	12.36
Alpha Width (keV)	132.51	286



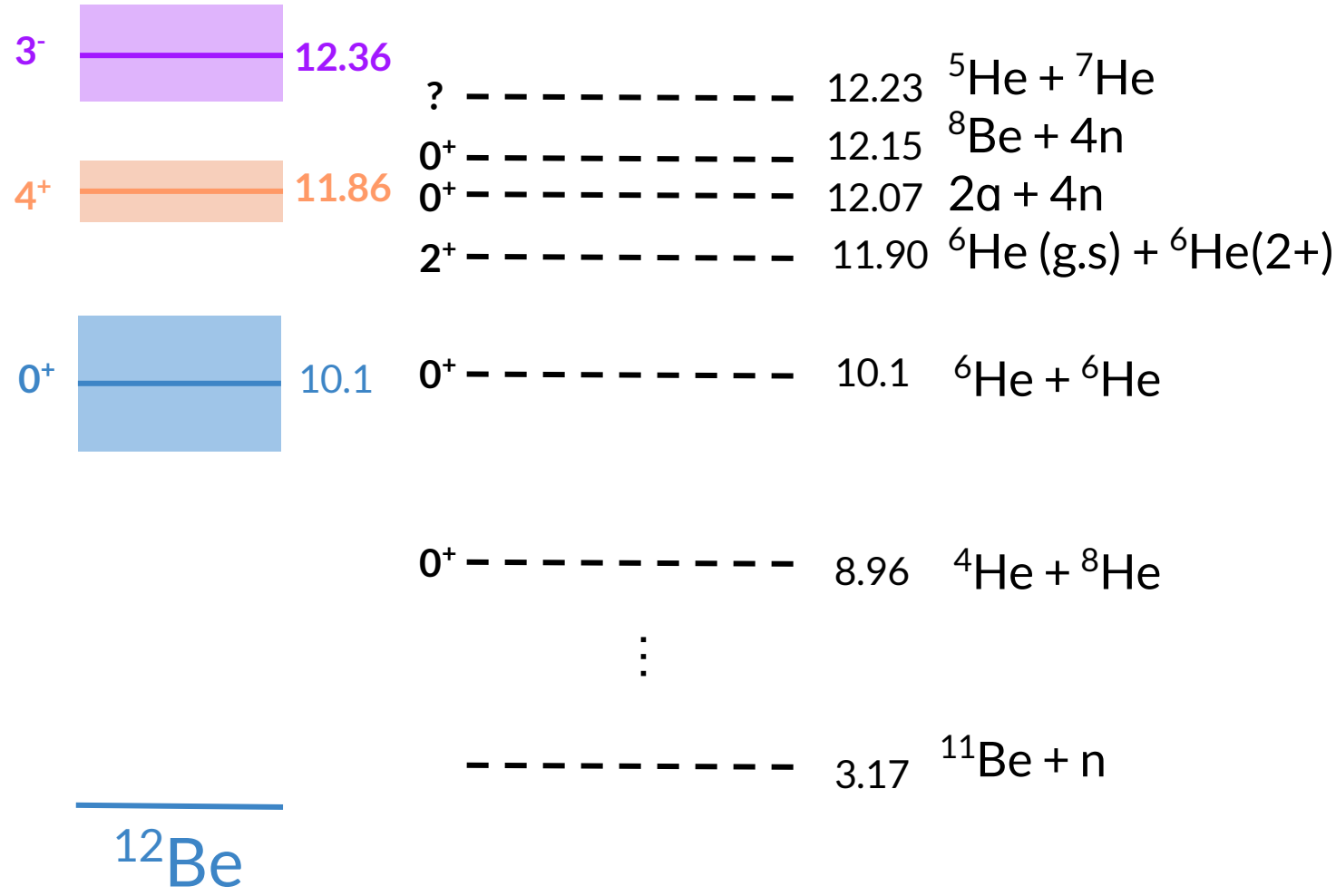


Yang et al. (2014)

See tomorrow's presentation of James DEBOER

Conclusion

- **Two alpha cluster states measured**
- 11.86 MeV - 4^+ :
  - Compatible with 12.1 MeV (2^+) by *Yang et al.* but ≠ spin assignment
  - Compatible with states predicted by *Descouvemont et al.* and *Kanada-En'yo et al.*
- 12.36 MeV - 3^- :
  - Not yet measured, predicted at lower energy



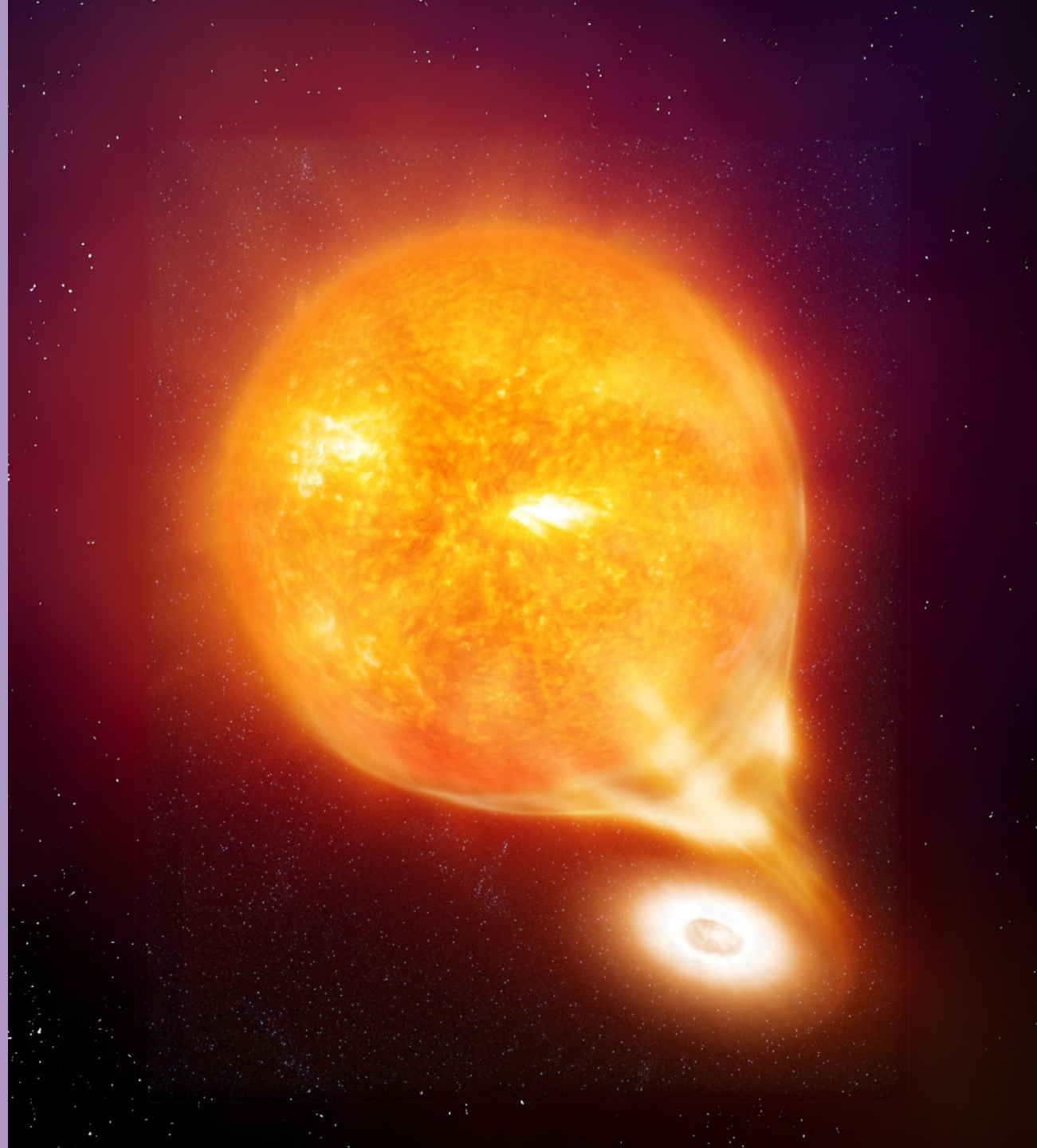
Collaboration

Spokespersons:

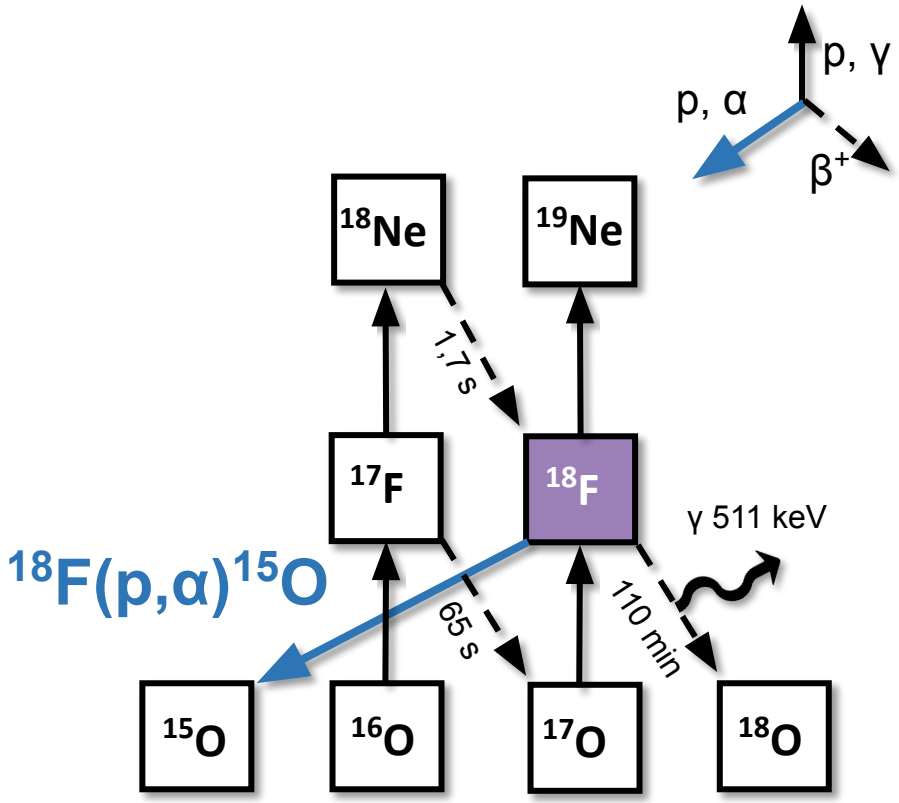
- Valdir Guimarães - University of São Paulo - Brazil
- Thomas Roger - GANIL - France

GANIL, France : F. de Oliveira, T. Roger, J. Pancin, C. Nicolle, M. Fisichella, L. Dienis, A. Cassisa, I. Wakudyanaye, M. Le Joubioux, J. C. Thomas, B. Jacquot, A. Navin
USC, Spain : B. Fernandez-Dominguez, M. Lozano González, B. Errandonea Félix
CEA, France : C. Fougères, M. Vandebrouck
INFN-Sezione di Catania, Italy : M. Grazia Pellegriti
University of Huelva, Spain : A. Miguel Sánchez Benitez
VINCA, Yugoslavia : T. Milanovic, I. Celikovic
IFIN-HH, Bucharest, Romania : M. Stanoiu
NPI ASCR Rez, Czech Republic : J. Mrazek
Michigan State University, USA : J. C. Zamora
NSCL-MSU, USA : Y. Ayyad
IBS (CENS), South Korea : X. Pereira Lopes

Experiment with non-active target :
High resolution spectroscopy of ^{19}Ne to determine the production of ^{18}F in novae

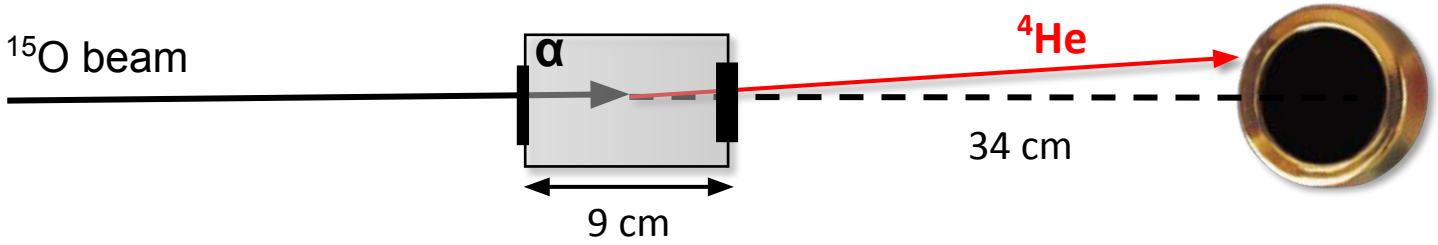


High resolution spectroscopy of ^{19}Ne



Classical novae (CO and ONe)

α(15O,15O)α



- Experiment planned in 22nd April-5th May 2025 at GANIL

See tomorrow's presentation of François DE OLIVEIRA

Collaboration

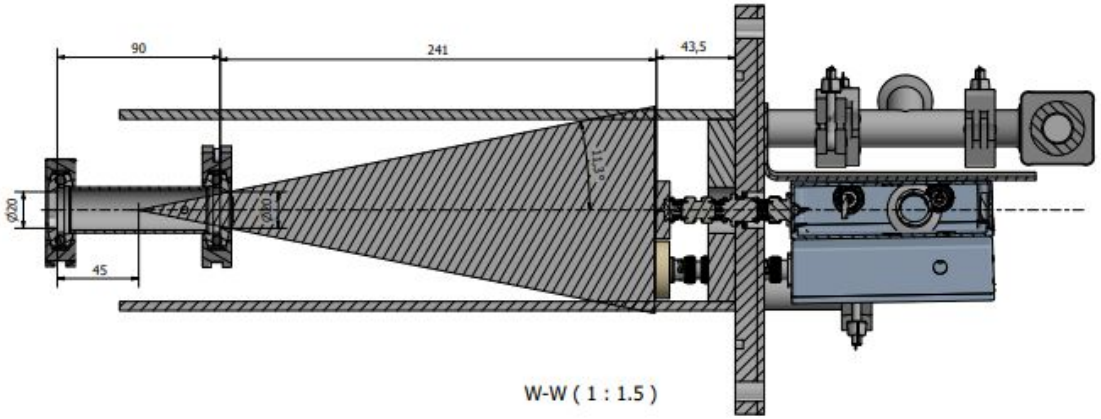
Spokespersons:

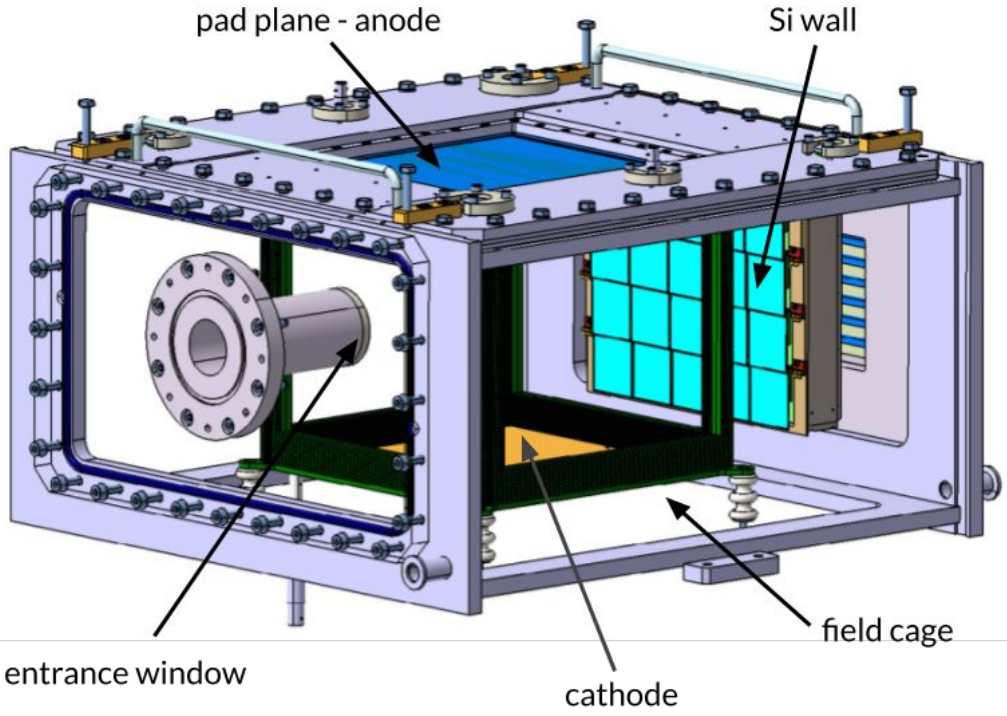
- Chloé Fougères - CEA, DAM - France
- Nicolas De Séréville - IJCLab - France
- Angel Miguel Sánchez Benitez - University of Huela - Spain

Argonne National Laboratory, USA : M. Avila, S. Giraud, D. H. Jayatissa, M. L. Cognata, A. Santiago-Gonzalez, I. Tolstukhin
FRIB, USA : L. Balliet, J. C. Zamora Cardona
GANIL, France : A. Bahini, L. Begue, L. Dienis, A. Francheteau, F. de Oliveira, T. Roger, O. Sorlin
IJCLab, France : F. Hammache, N. Giha, V. Girard Alcindor
INFN, Italy : A. Di Pietro, P. Figuera, R. G. Pizzone, S. Palmerini, S. Romano
IPHC, France : G. Harmant, M. Heine
Universitat Politècnica de Catalunya, Spain : J. José
University of York, UK : A. Laird

Contact : laurie.dienis@ganil.fr

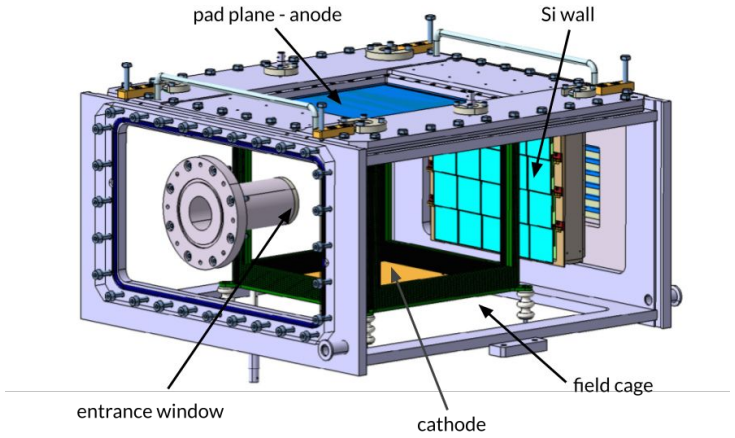
Comparison of the two experiments methods

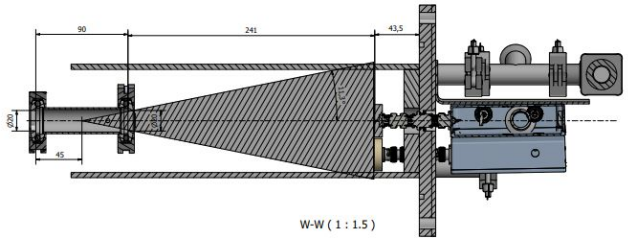




Conclusion

	Active target	Non-active target
Energy Resolution	High	High
Angular Coverage	High	Limited to conserve the energy resolution
Electronic Noise	Higher	Lower
Contaminations	Lower	Higher
Beam Intensity Requirement	Lower	Higher
Angular Distribution Analysis	Feasible due to full angular coverage	Limited, may require additional detectors





Conclusion

Thank you for your attention !

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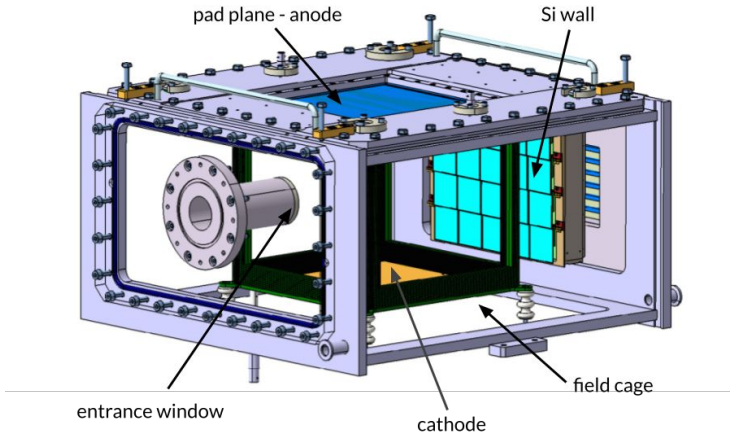
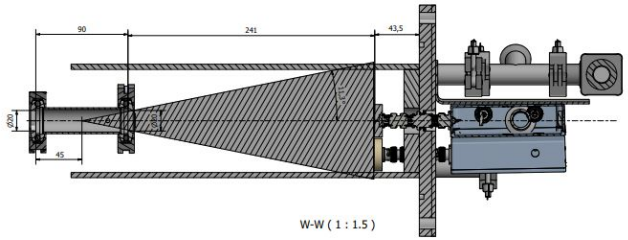
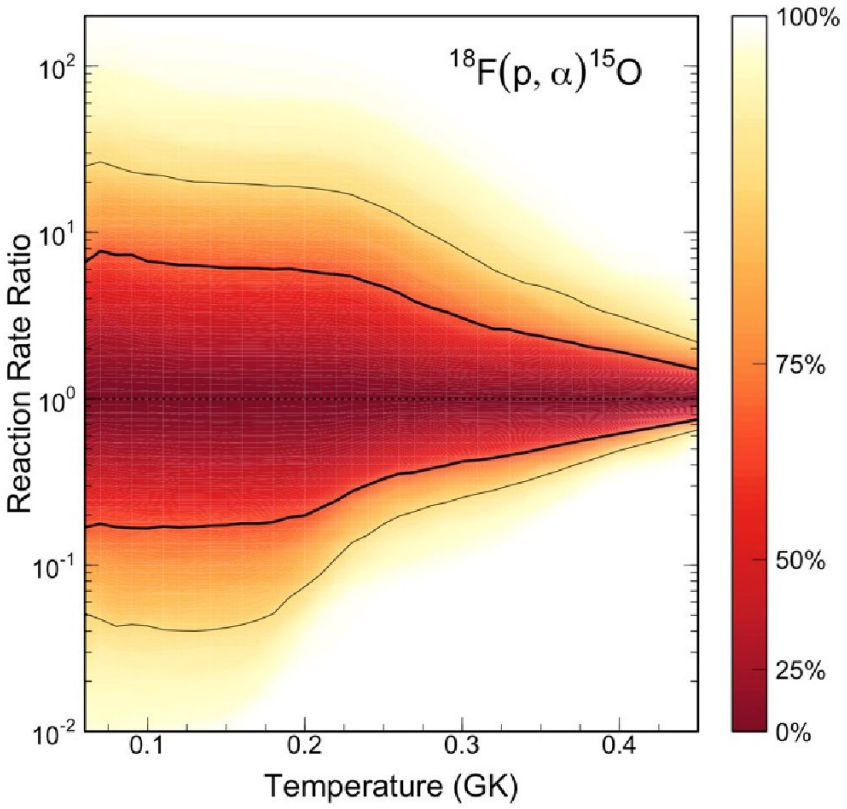


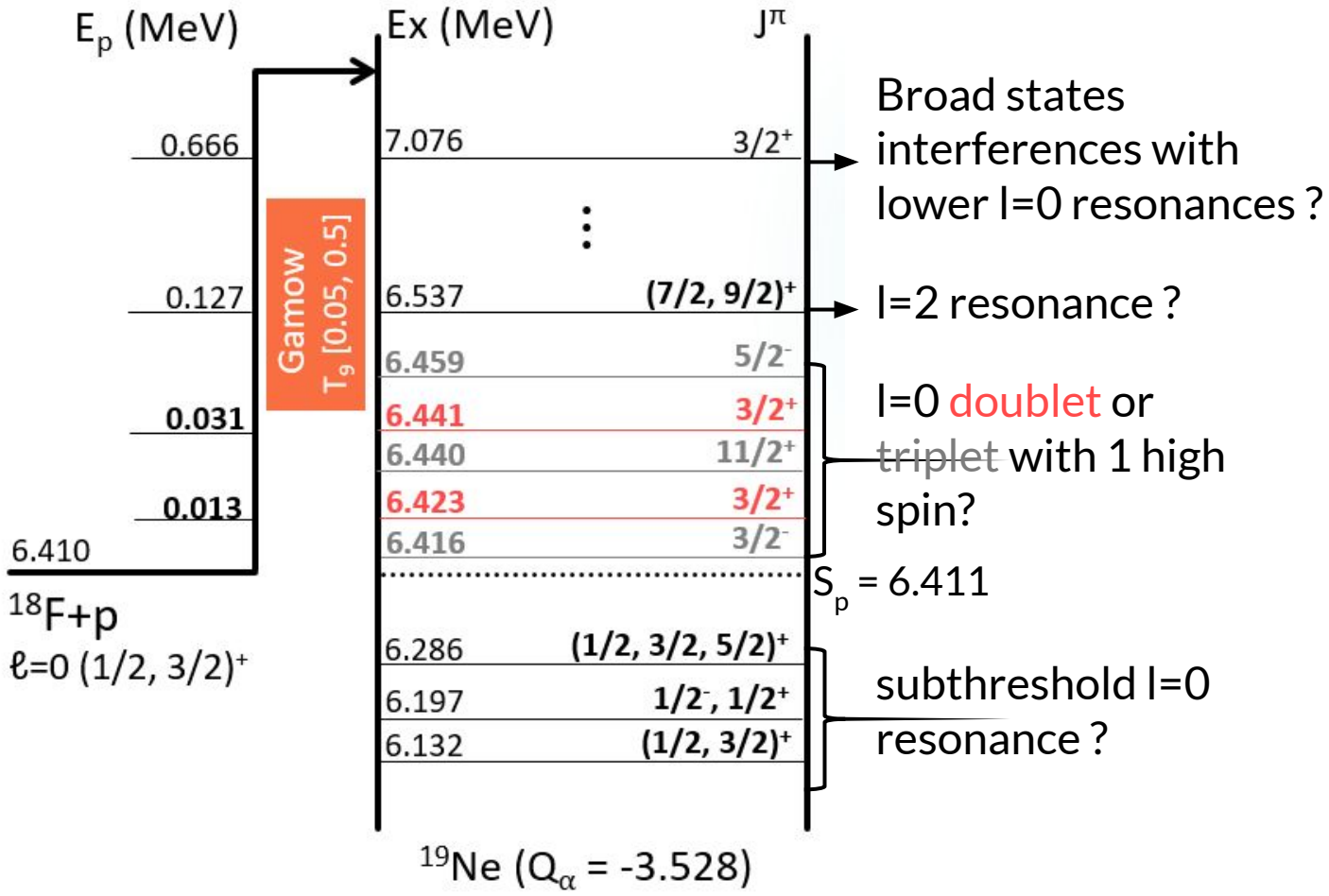


Backup slides

Current status in $^{18}F(p,\alpha)^{15}O$



Rate uncertainties > x10
^{18}F > x3, det. distance > x2



Broad states interferences with lower l=0 resonances ?

l=2 resonance ?

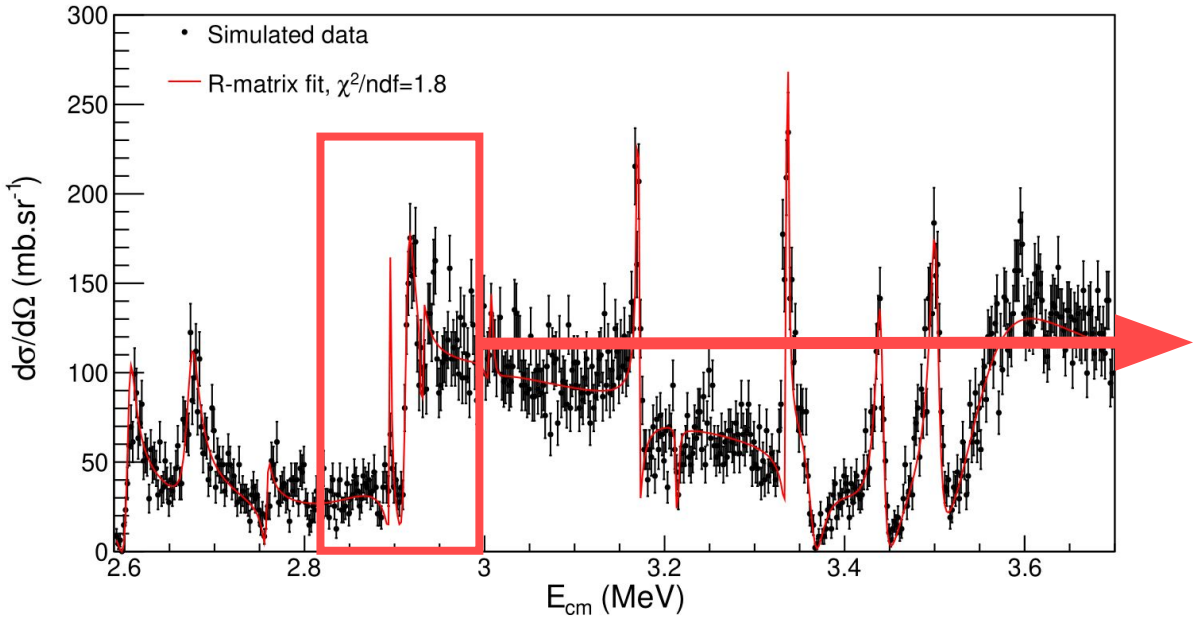
l=0 doublet or ~~triplet~~ with 1 high spin?

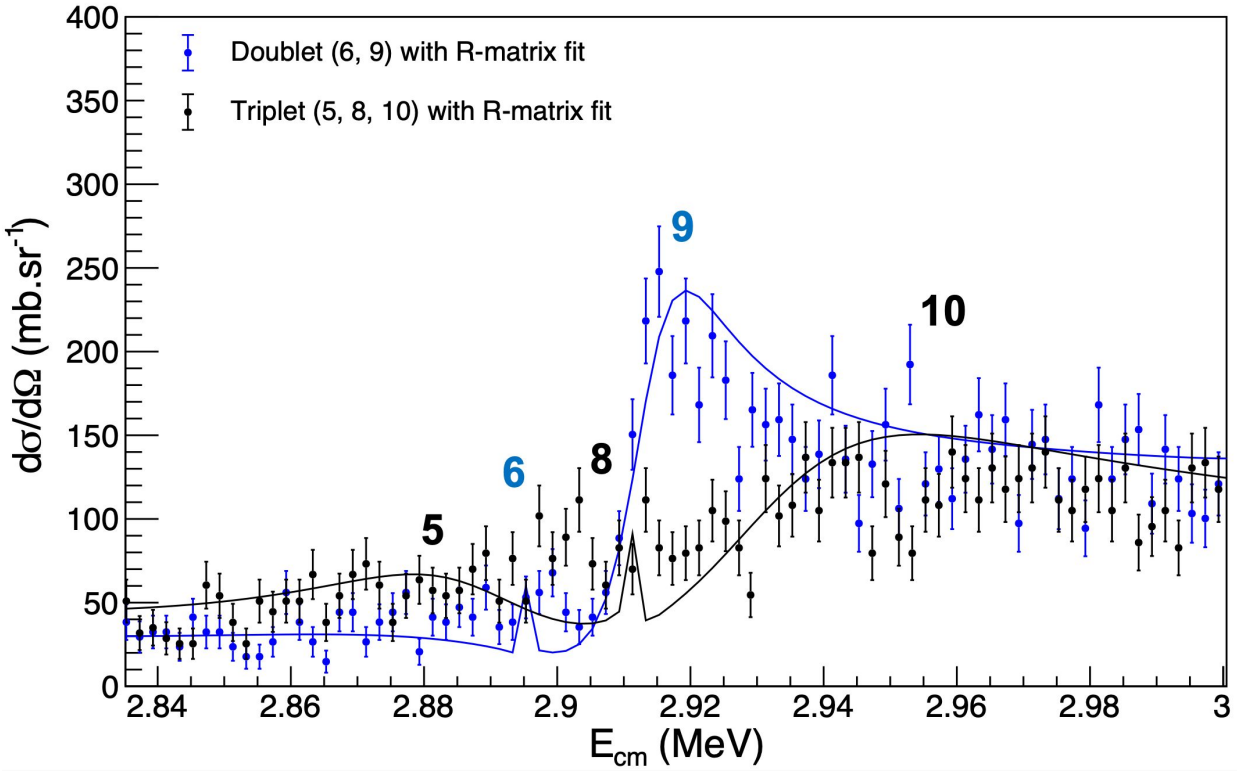
subthreshold l=0 resonance ?

Compound nucleus

Simulated results for the spectroscopy of ^{19}Ne

- Identification of l=0 states near S_p



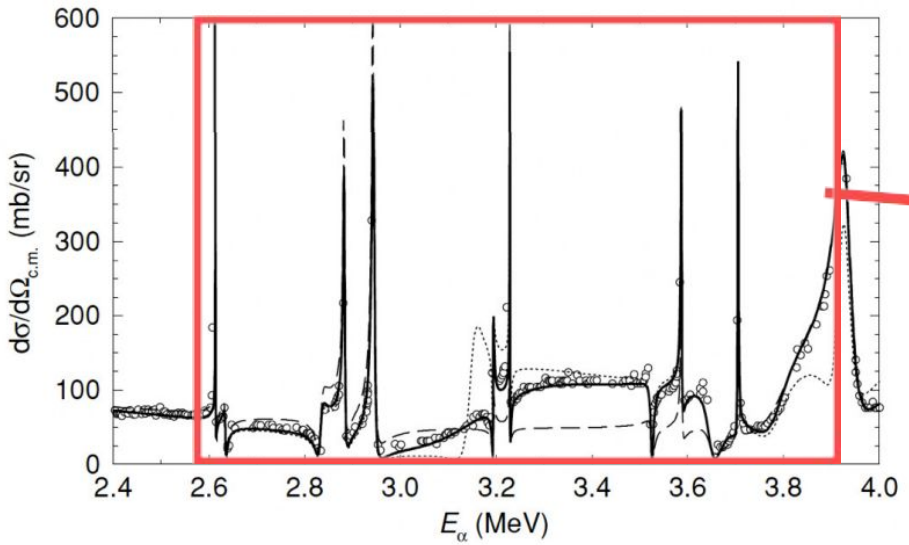


- State spectroscopy : Γ_α resolution down to 2 keV, E_x resolution < 5 keV

Simulated results for the spectroscopy of ^{19}Ne

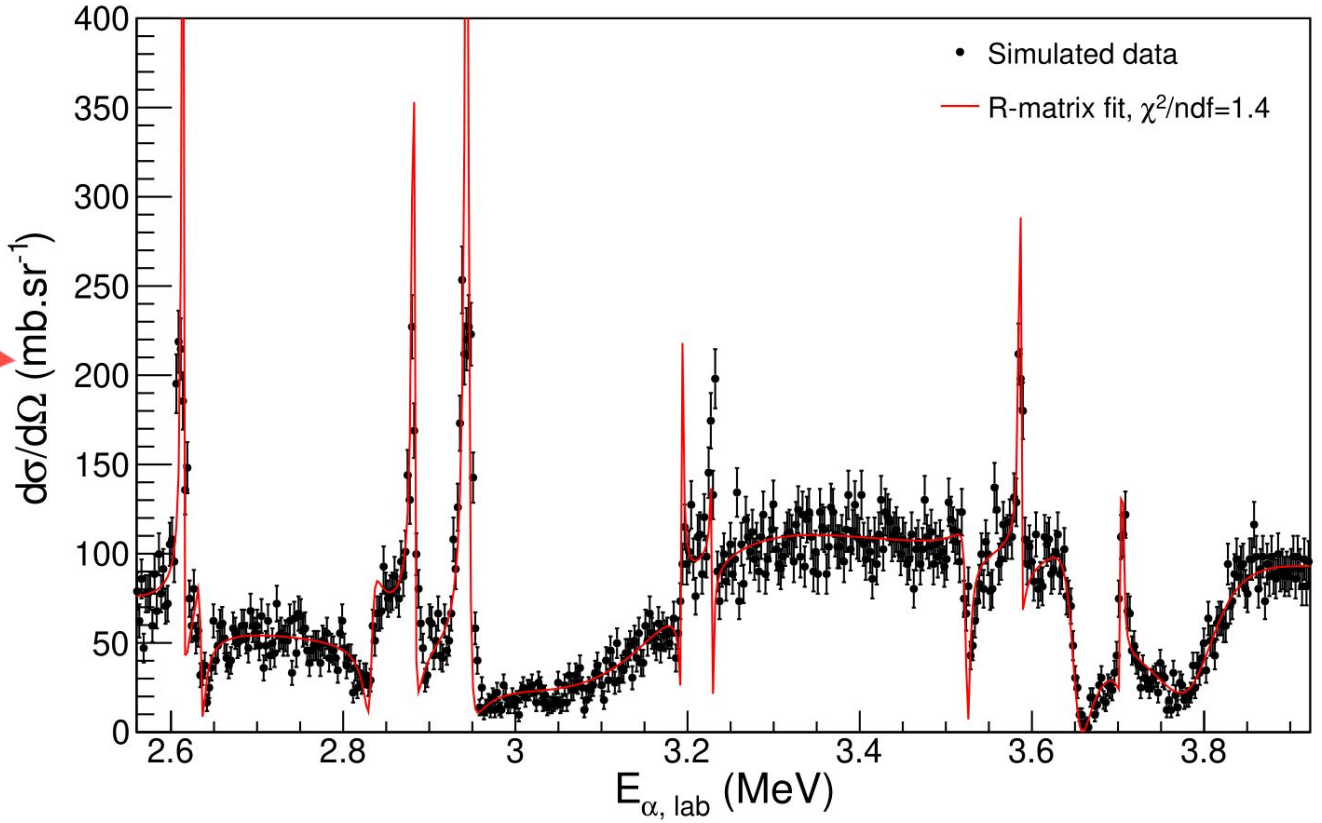
Calibration via elastic α(^{15}N, ^{15}N)α reaction probing analog levels in ^{19}F

Levels in ^{19}F at Ex ∈ [6, 7] MeV
Measurement Smotrich (1961) and reanalysis Bardayan (2005)



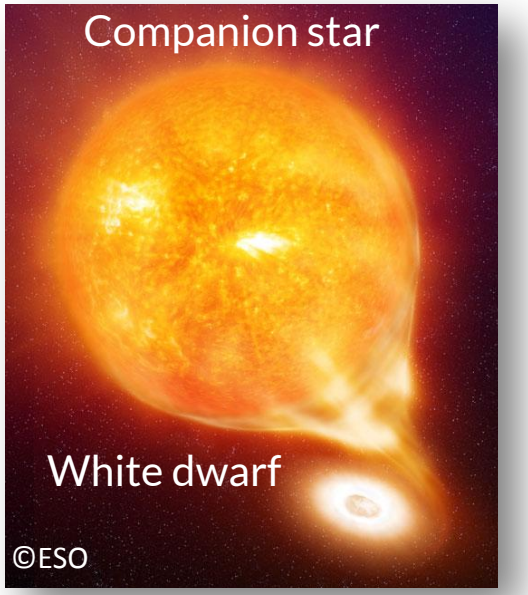
Bardayan (2005)

Present experiment



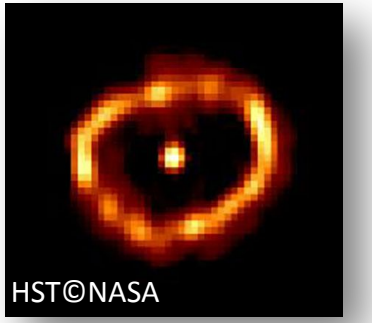
Astrophysical interest : Nova outburst

Matter accretion
-> explosive hydrogen burning



10^4 – 10^5 L_{sun}

Nova Centauri (2013)



Nova Cygni (1992)

Impact

Abundances of elements (^{13}C, ^{15}N, ^{17}O)
Composition of presolar grains

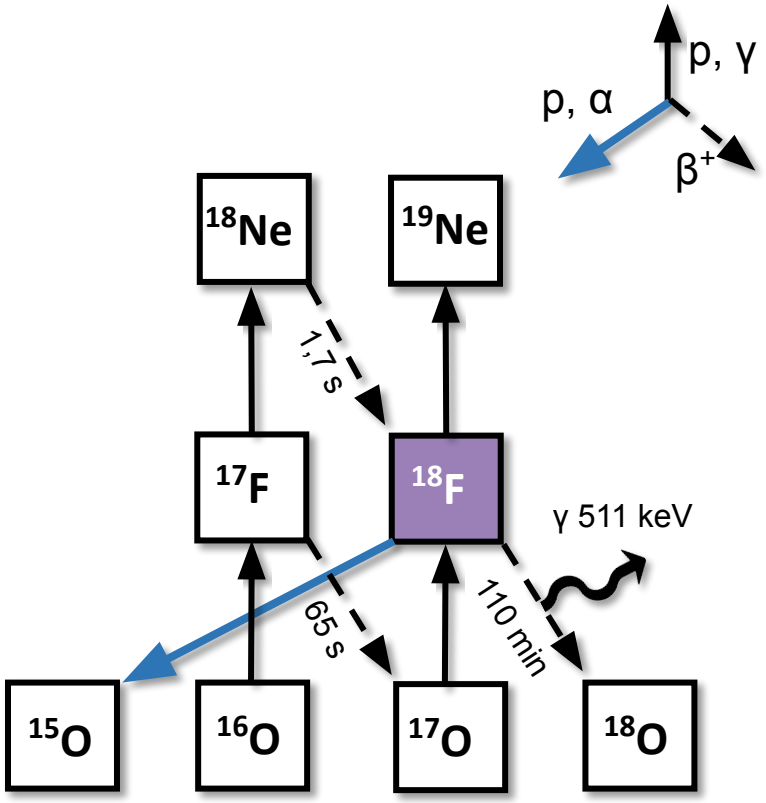
Uncertainties

White dwarf mass
Admixed matters
Accreta metallicity
Dynamics of accretion and ejecta
Other parameters

} Ejected ^{18}F mass

Direct novae observations

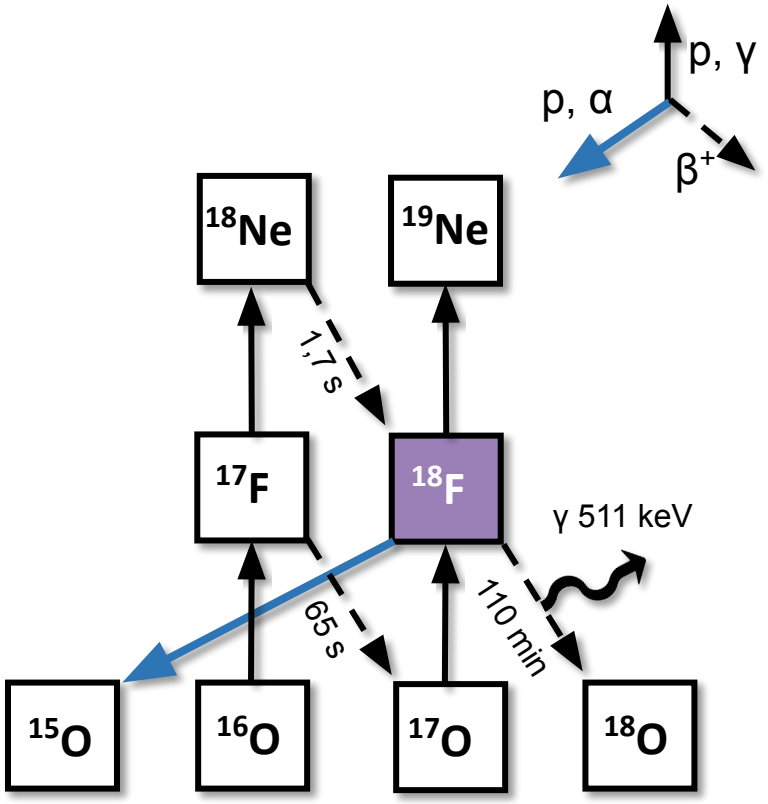
Observed in all wavelengths, not yet with low MeV γ rays



Classical novae (CO and ONe)

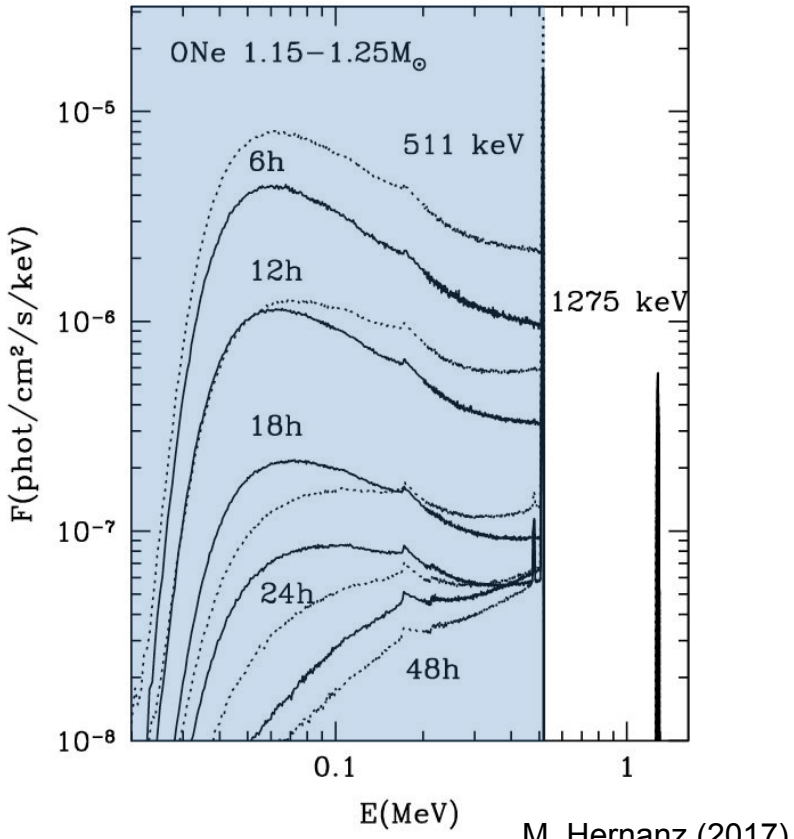
Direct novae observations

Observed in all wavelengths, not yet with low MeV γ rays



Classical novae (CO and ONe)

Emissions from ^{18}F



M. Hernanz (2017)

Direct novae observations

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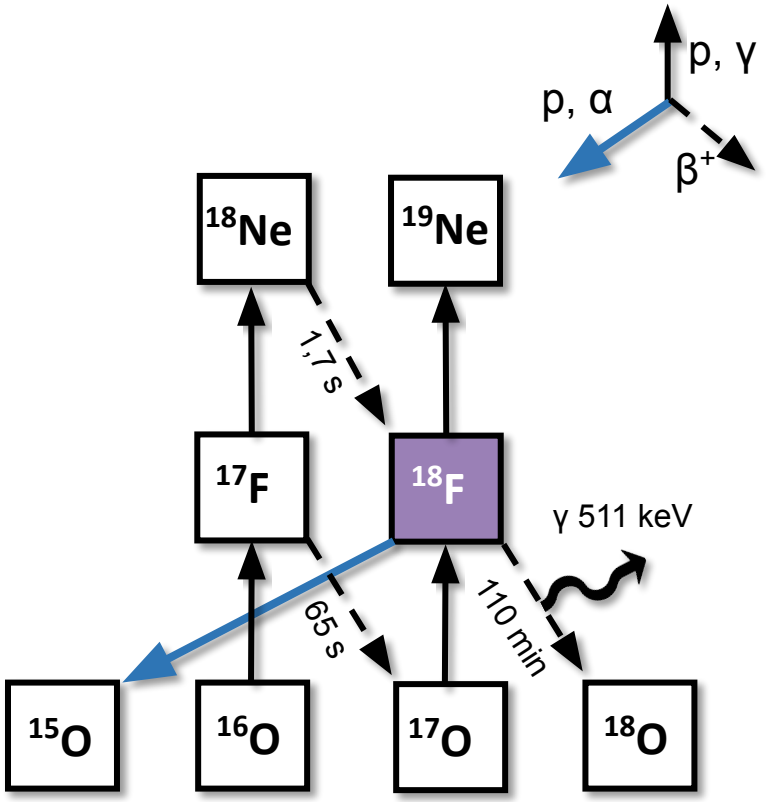
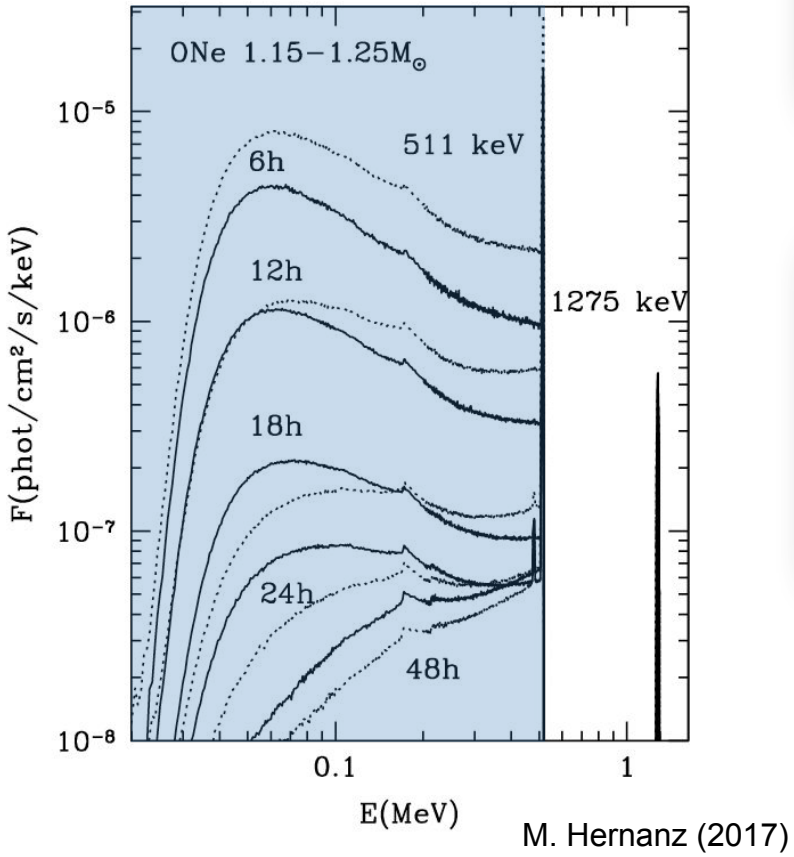


Classical novae (CO and ONe)

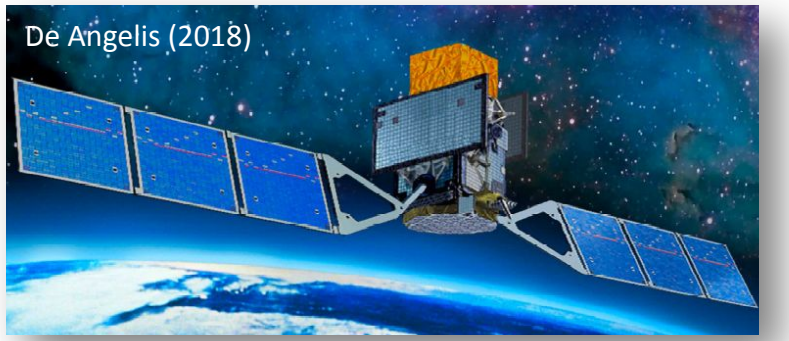
Emissions from ^{18}F



M. Hernanz (2017)

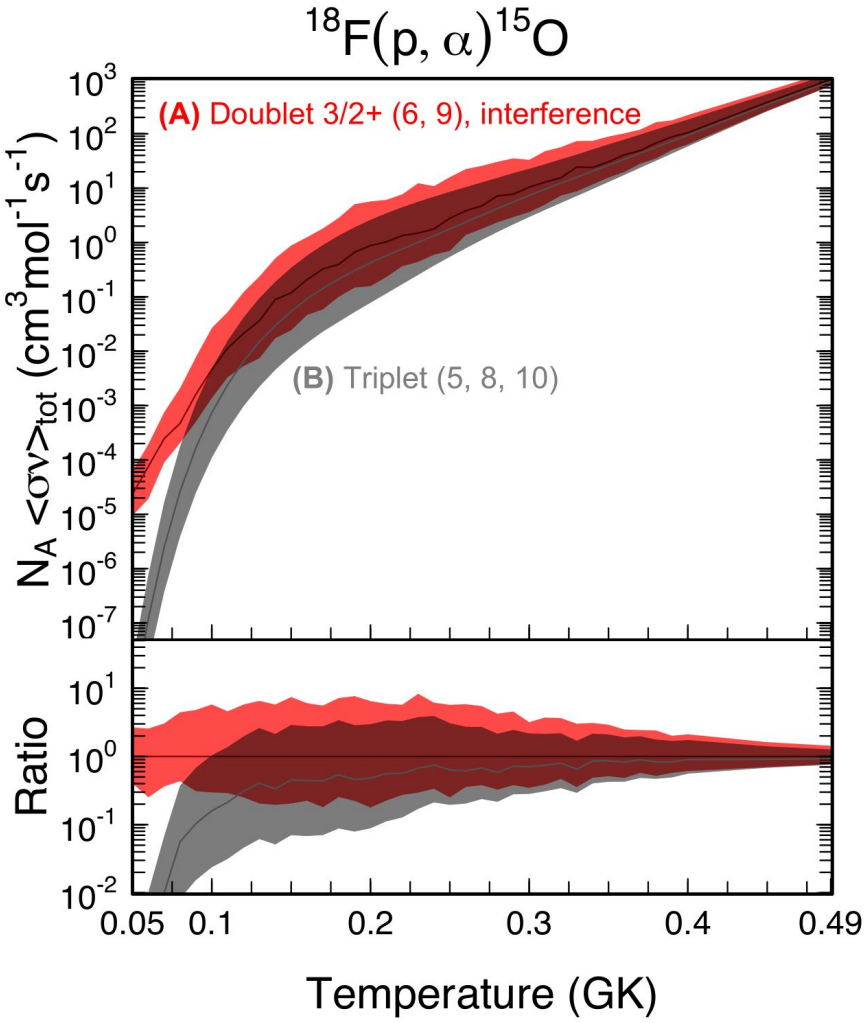
COSI – launch : 2027

e-ASTROGAM – launch : 2029 ?



- Abundance of ^{18}F
- Maximum detectability distance

Impact on the reaction rate $^{18}F(p,a)^{15}O$



	M_{ejec} (10^{-6} $M_\odot$)			
	^{16}O	^{18}O	^{18}F	^{19}F
Rate (A)	1.1	8.5×10^{-6}	1.1×10^{-5}	6.3×10^{-7}
Rate (B)	1.1	1.7×10^{-5}	3.9×10^{-5}	1.1×10^{-6}

Factor 3.5 between the ejected mass calculated with the two rates

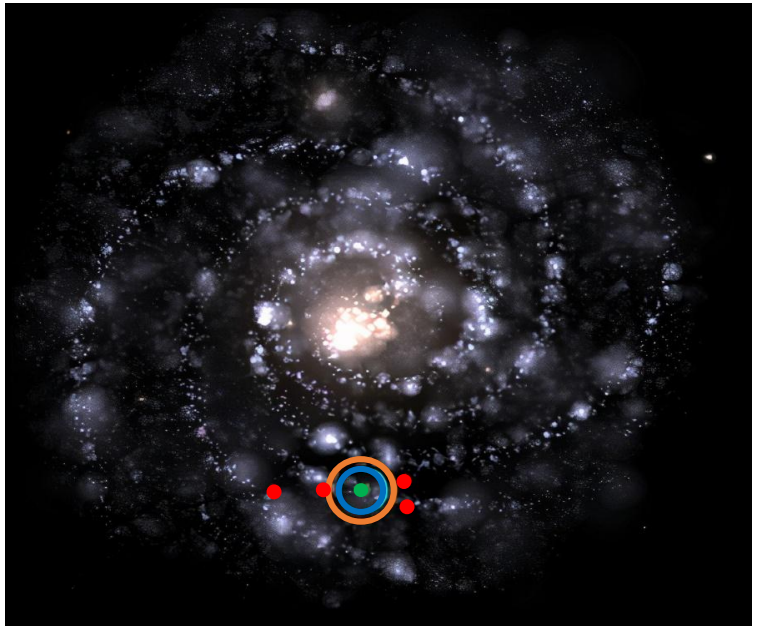
Maximum detectability distance impacted by a factor 1.9

Astrophysical impact

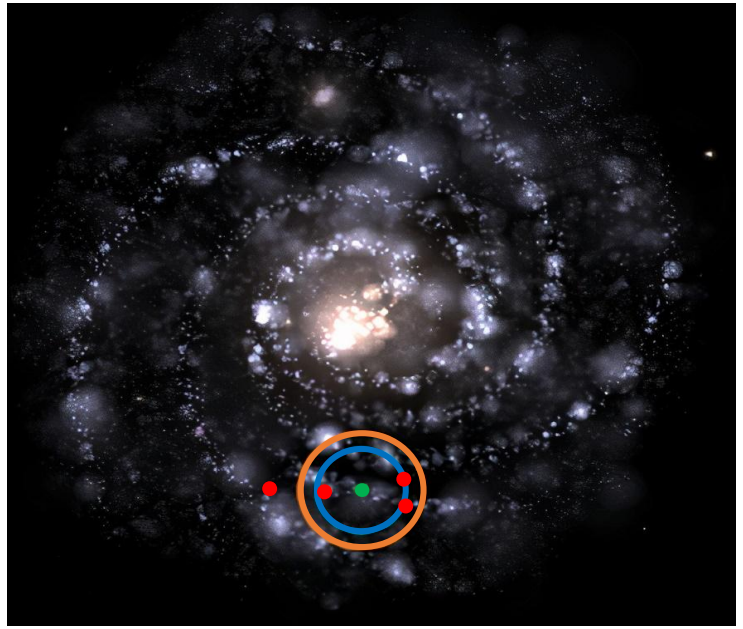
High resolution spectroscopy of ^{19}Ne (σ_{cm} < 5 keV) at GANIL to constrain :

- ^{18}F(p,α)^{15}O rate
- ^{18}F production in nova outbursts
- detection of ^{18}F γ rays in novae for future space telescopes

Rate A



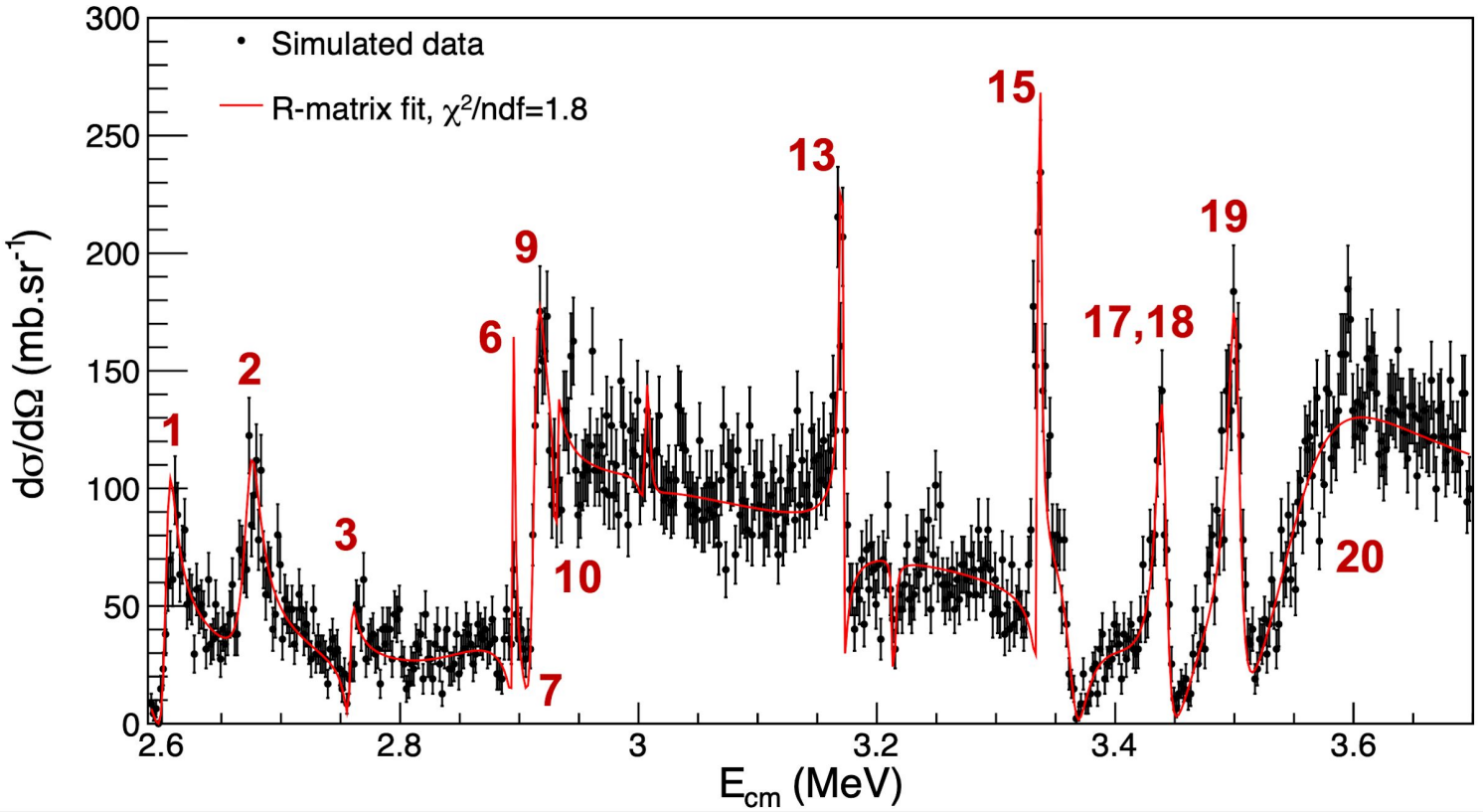
Rate B



Flux in ^{18}F from ONe novae
Sun
COSI
e-ASTROGAM

-> Frequency ~ 1 event / 6 yr

Simulated results for the spectroscopy of ^{19}Ne



E_{cm} resolution < 5 keV