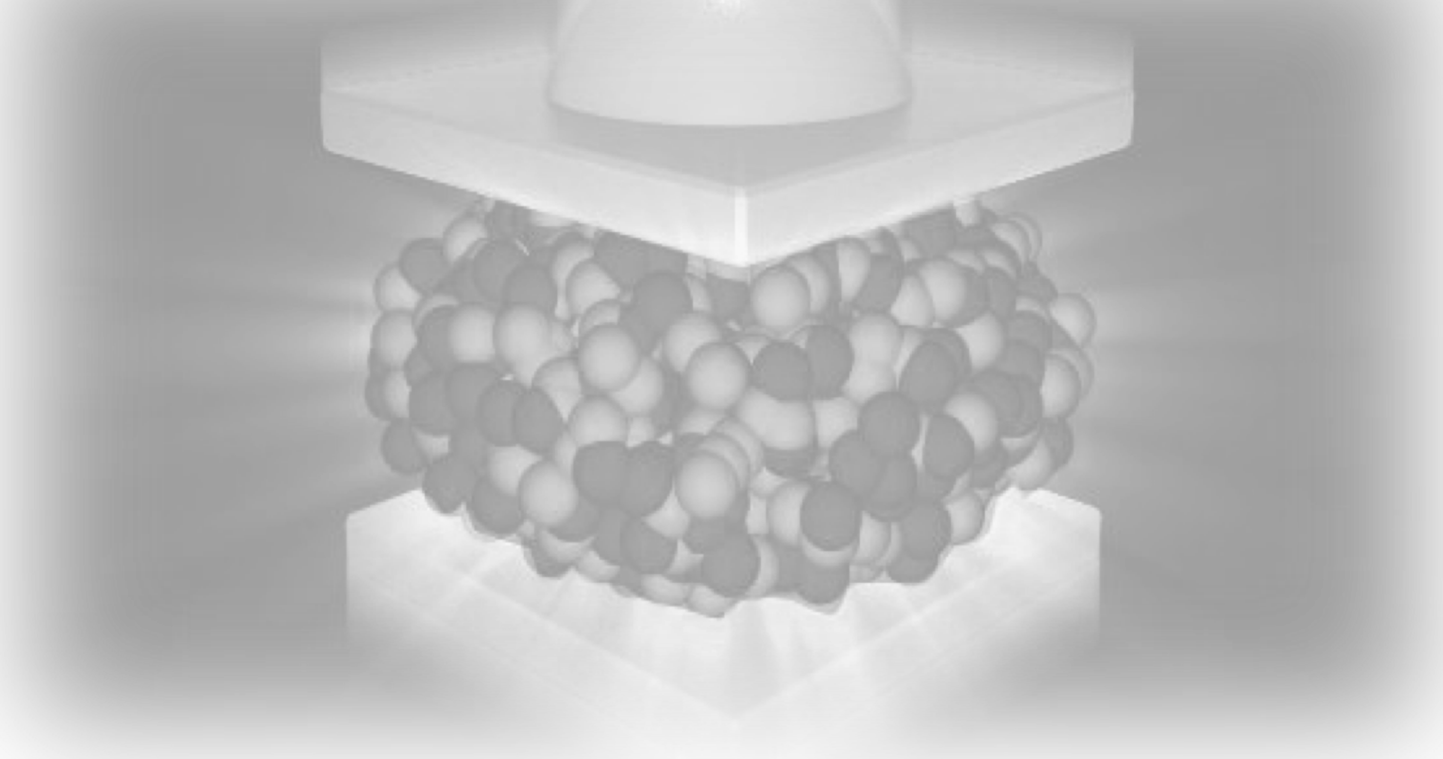
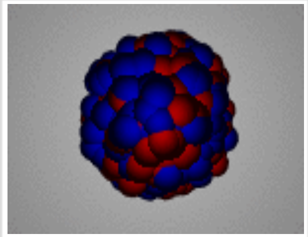
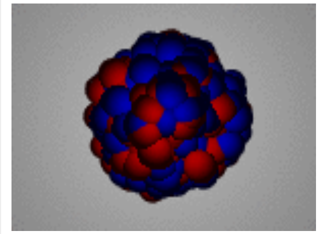
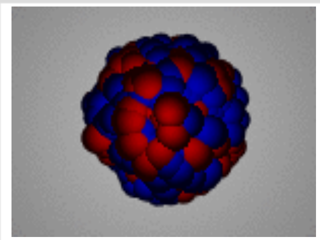
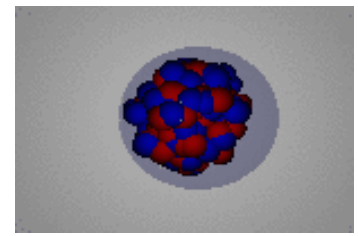
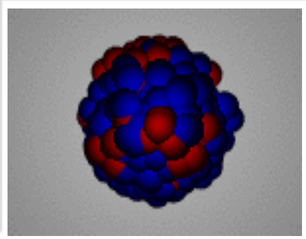
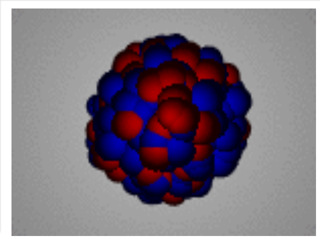
Decrypting collective and single-particle resonances in exotic nuclei

Marine Vandebrouck

Measurement of the Isoscalar Giant Resonances in the neutron-rich nucleus ^{68}Ni



Introduction

Electric GR	$T = 0$ isoscalar	$T = 1$ isovectorial	
$L = 0$ monopole (GMR)			
$L = 1$ dipole (GDR)			
$L = 2$ quadrupole (GQR)			

- Giant resonances are **collective excitation modes**

Incompressibility modulus of infinite nuclear matter K_0
J.P. Blaizot *et al.*, Phys. Rep. 64, 171 (1980)

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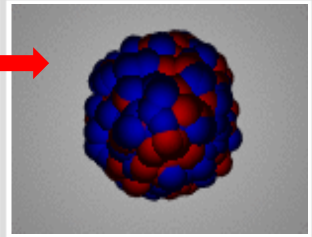
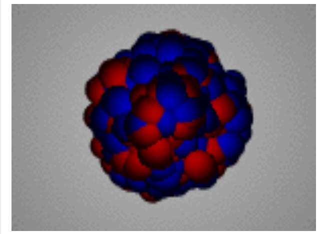
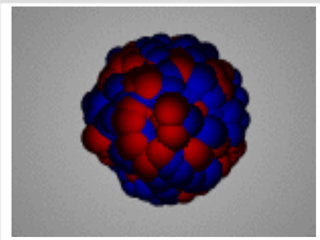
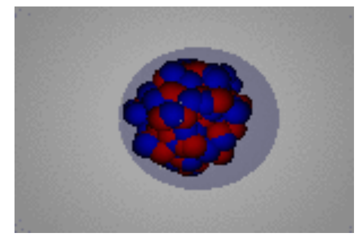
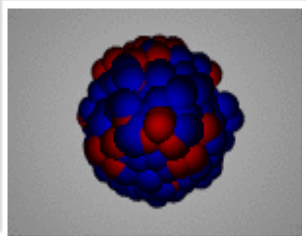
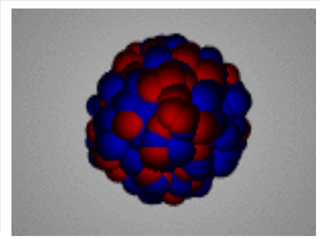
$L = 0$ monopole (GMR)			
$L = 1$ dipole (GDR)			
$L = 2$ quadrupole (GQR)			

- Giant resonances are **collective excitation modes**
- Probing the different facets of the **Equation of State** (EoS)

$$\frac{E}{A} = (E_0 + E_{sym}\delta^2) + L_{sym}x\delta^2 + \frac{1}{2}(K_0 + K_{sym}\delta^2)x^2 + \dots$$

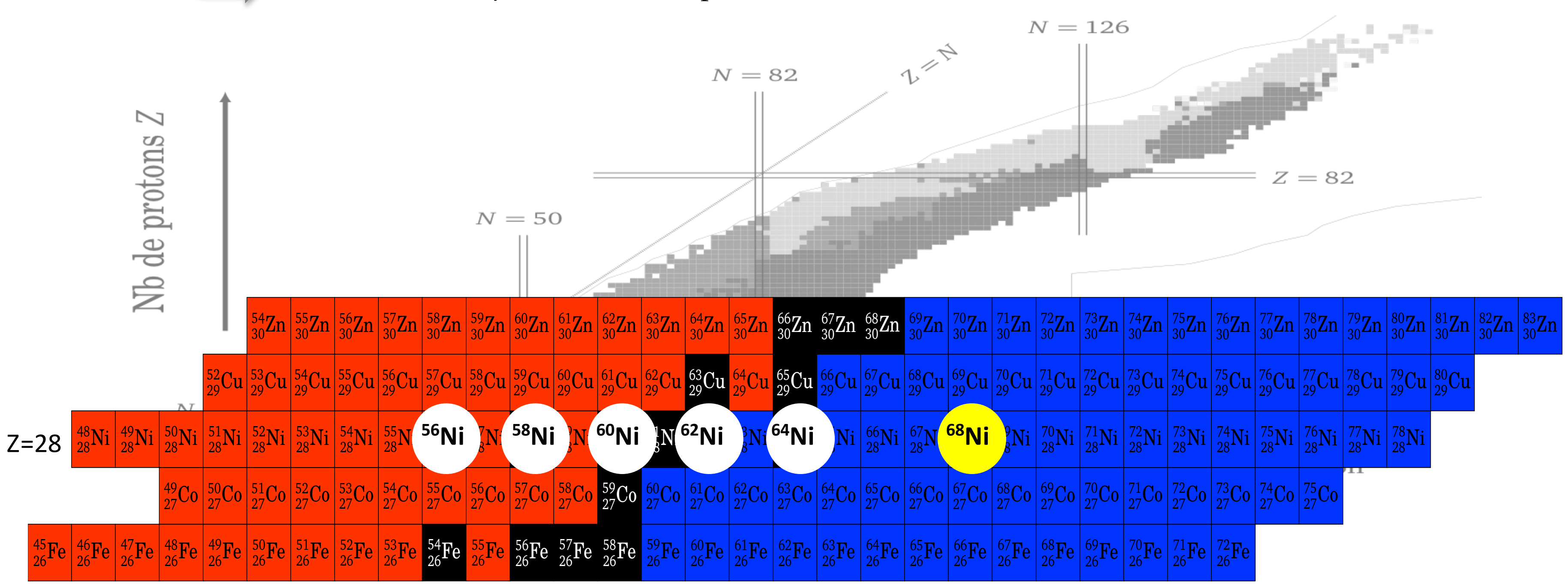
$$x = \frac{\rho - \rho_0}{3\rho_0} \qquad I = \delta = \frac{\rho_n - \rho_p}{\rho_n + \rho_p}$$

- From stable to exotic nuclei : the IVGDR/PDR has been measured in ^{68}Ni, neutron rich Oxygen and Tin isotopes at GSI, in ^{26}Ne at Riken…
- 1st measurement of the ISGMR in unstable nuclei ^{56}Ni : ^{56}Ni(d,d')^{56}Ni*

Monrozeau *et al.*, PRL 100, 042501 (2008)

➡ Study of the ISGMR in a neutron rich Ni : **^{68}Ni**

➡ Continue the study of the Ni isotopic chain



ISGMR in exotic nuclei at GANIL Setup

- How to probe Isoscalar Giant Resonances in exotic nuclei?
  ⇨ Inelastic scattering of isoscalar particles (**(α,α')** or **(d,d')** for example) in inverse kinematics around 50MeV/nucleon
  ⇨ Detection of low energy recoiling α or d

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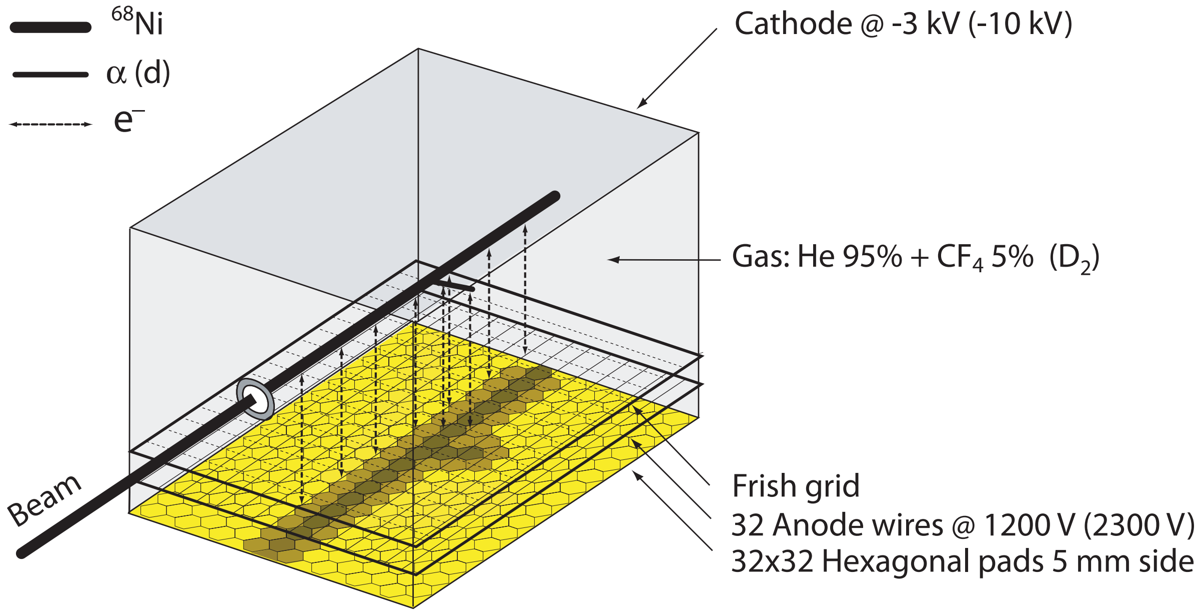
- Use of a pioneering method: **Active target** MAYA



C. E. Demonchy *et al.*, Nucl. Instrum. Meth. 573, 145 (2007)

ISGMR in exotic nuclei at GANIL Setup

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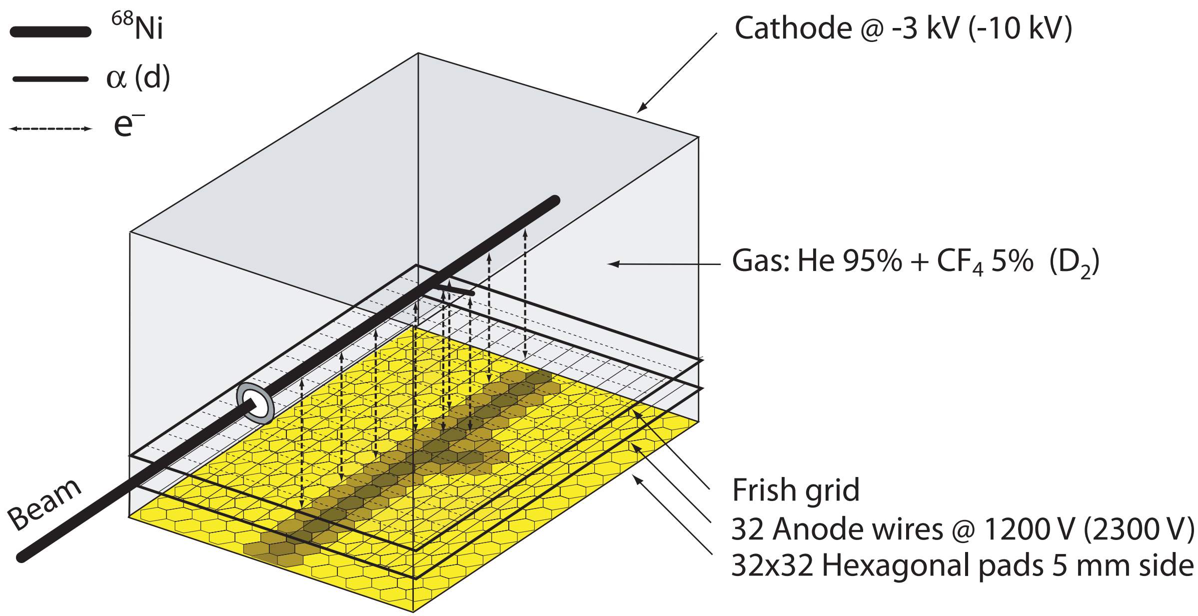
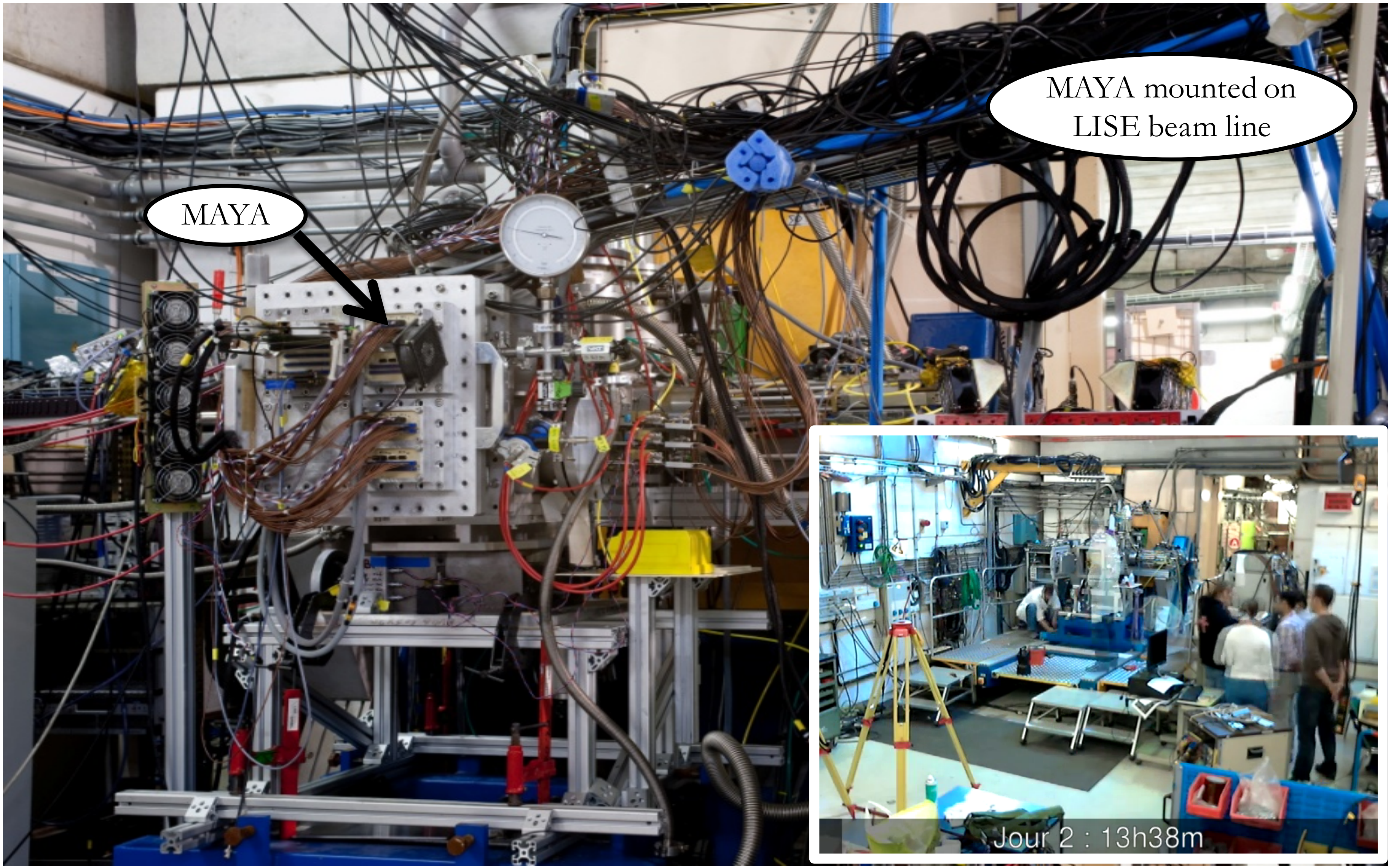


C. E. Demonchy *et al.*, Nucl. Instrum. Meth. 573, 145 (2007)

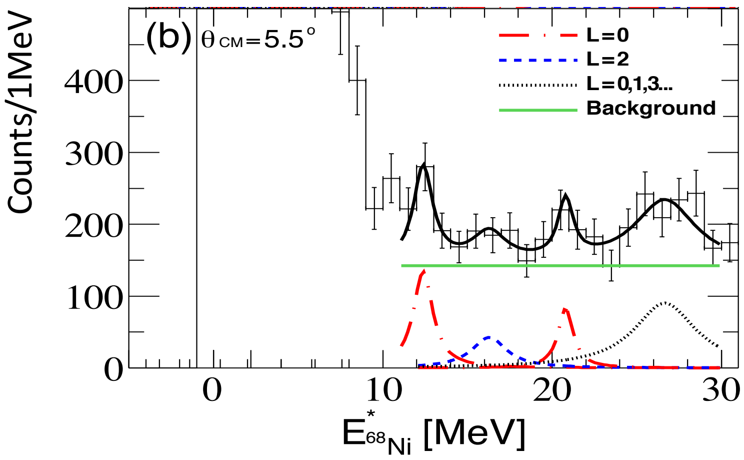
- **Missing mass method**
  ⇨ Reconstruction of excitation energy E*(^{68}Ni) and angular distribution

ISGMR in exotic nuclei at GANIL Setup



Results Measurement of the ISGMR in ^{68}Ni

- **E*(^{68}Ni)** excitation energy spectrum of ^{68}Ni obtained in (α,α')



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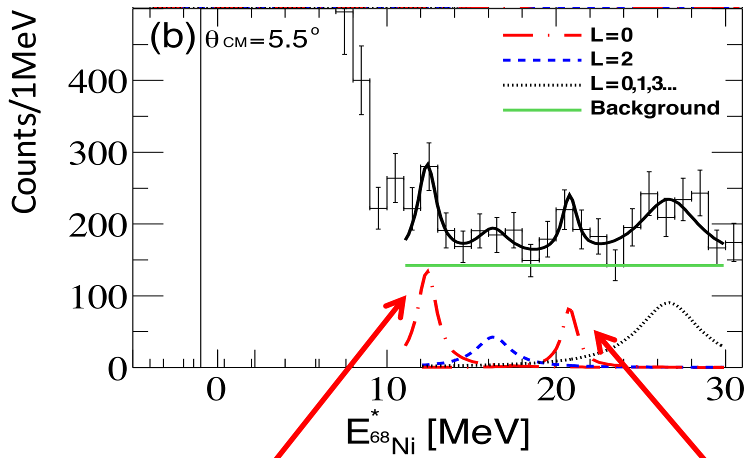
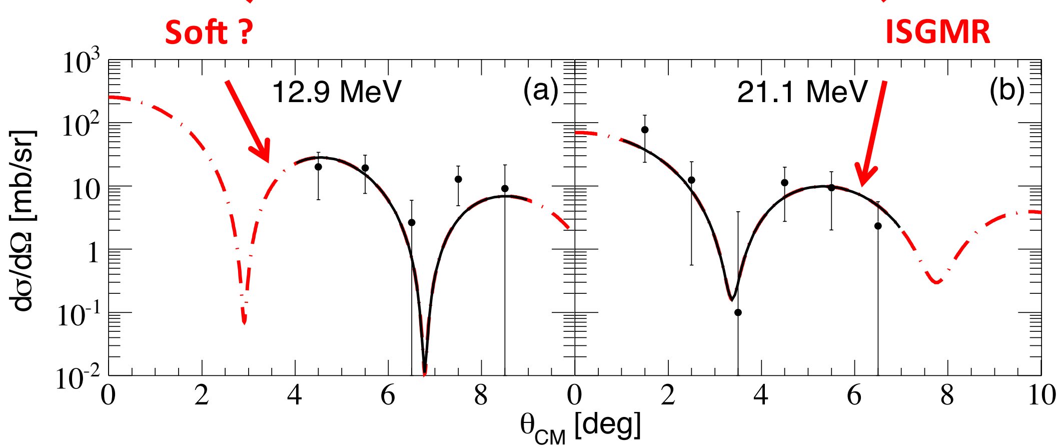


- **Angular distribution** ⇨ L=0 identification

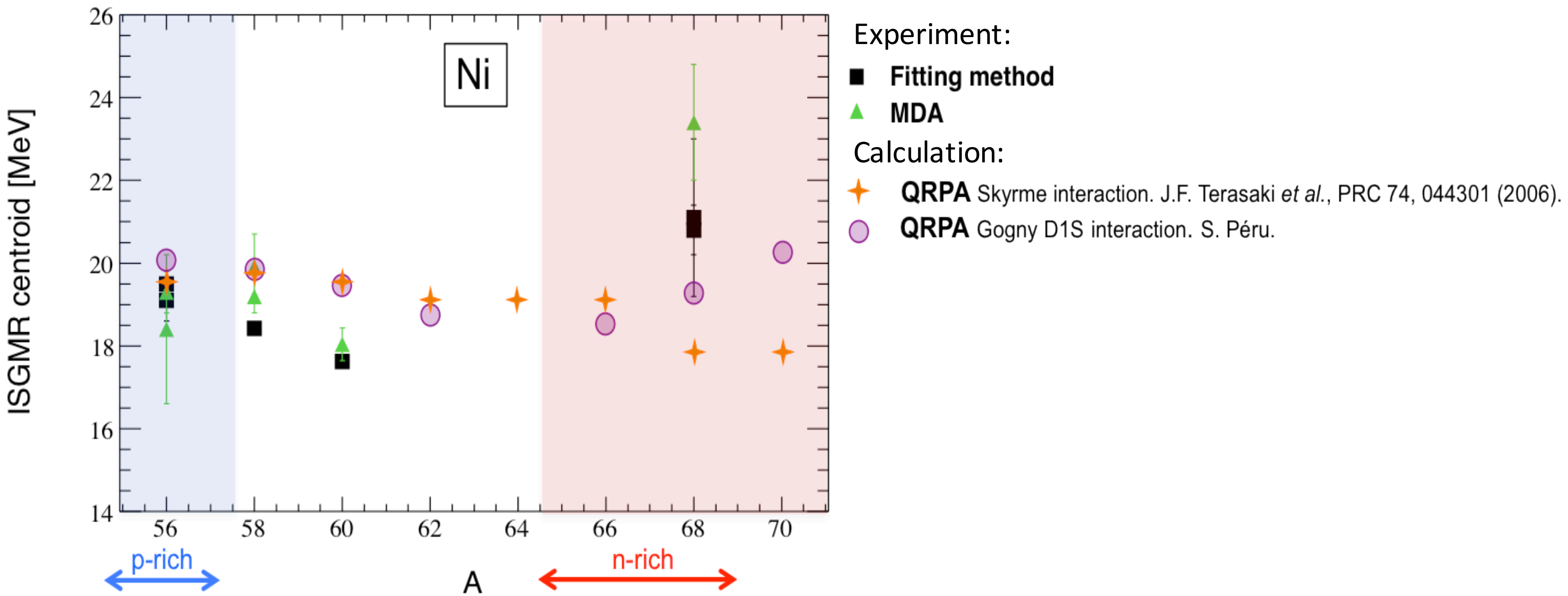


M. Vandebrouck *et al.*, Phys. Rev. Lett. 113, 032504 (2014)
M. Vandebrouck *et al.*, Phys. Rev. C. 92, 024316 (2015)

Conclusion

- Measurement of ISGMR in exotic nuclei ^{68}Ni at GANIL
  ➪ Active targets particularly suited

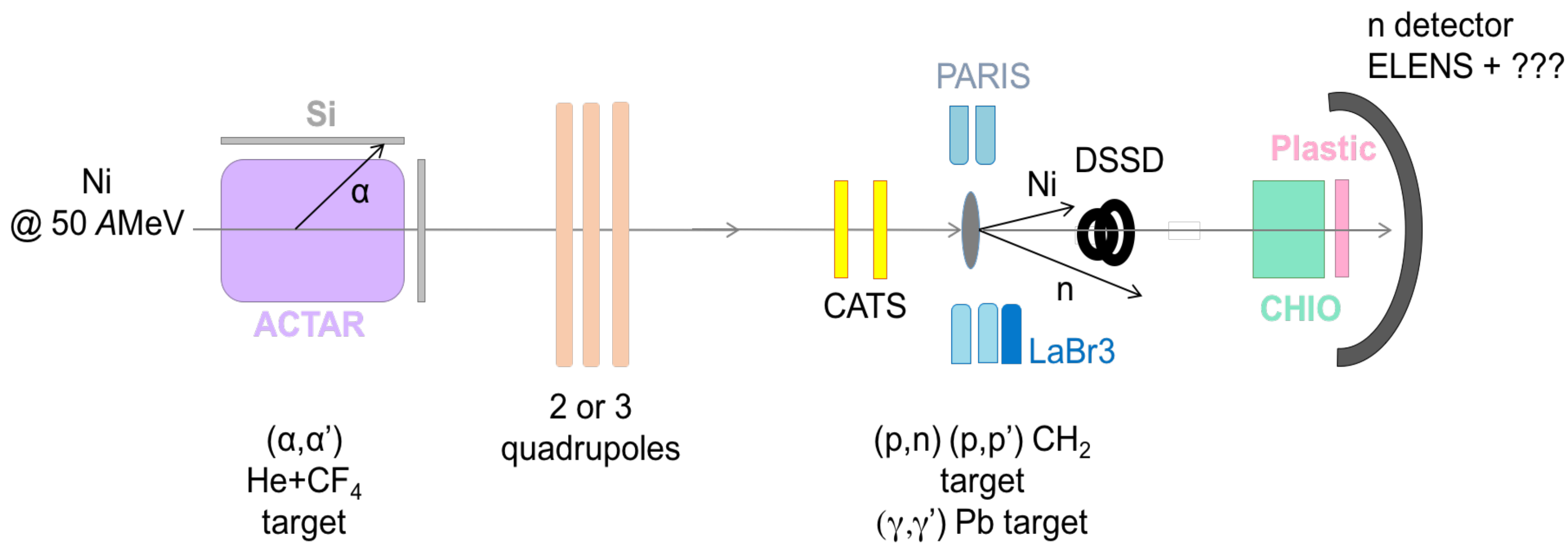
- Some difficulties
  ➪ Limited resolution
  ➪ Measurement along isotopic chains are needed



- Perspectives with ACTAR
  ➪ Increase efficiency and resolution

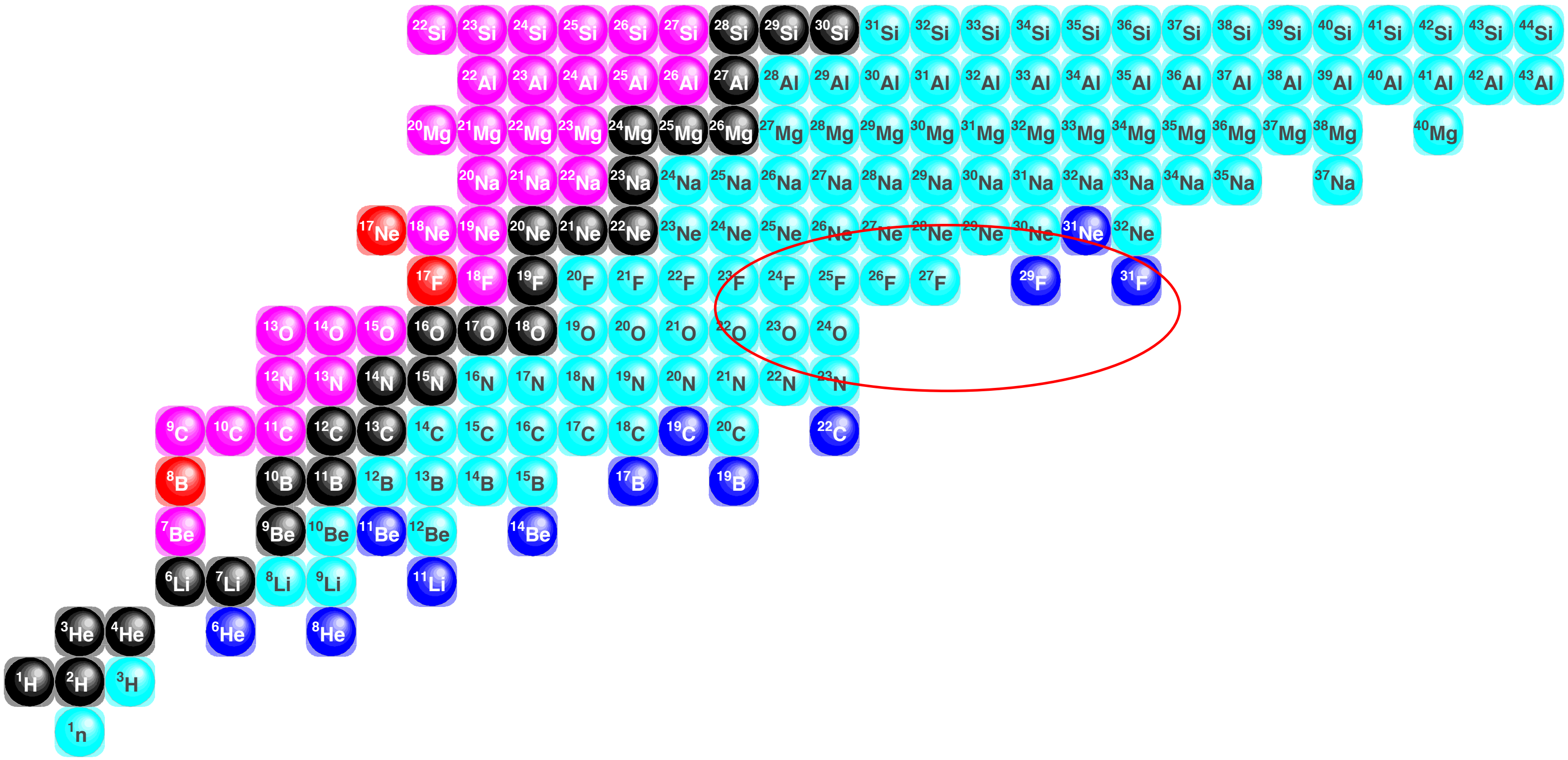
Outlook LOI "Study of giant and pygmy resonances in exotic nuclei at LISE"

- Combined setup at LISE

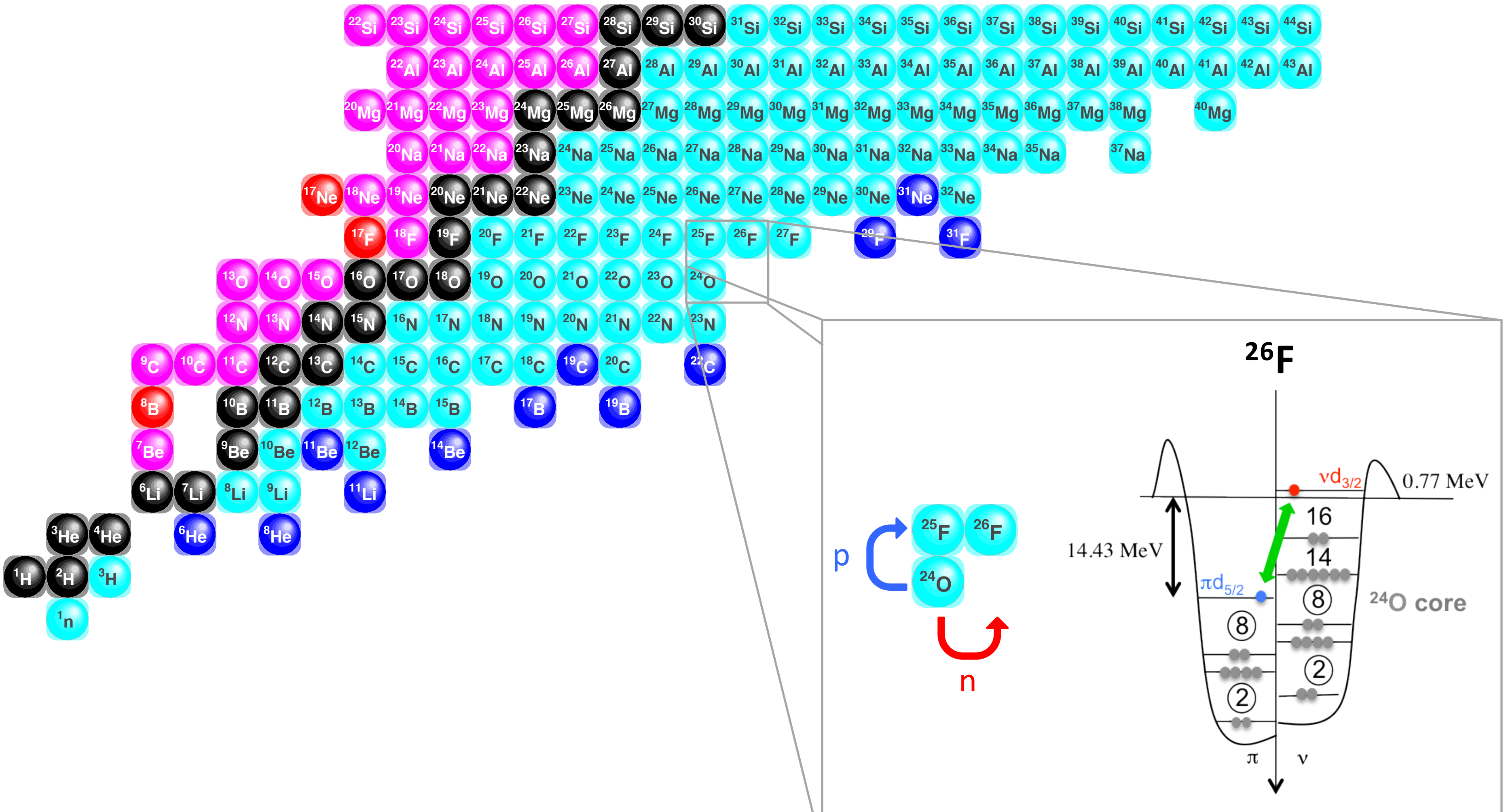


⇨ Measurement of the ISGMR, PDR and AGDR along the Ni isotopic chain from ^{56}Ni to ^{70}Ni
⇨ **Constrain EoS along isotopic chain including exotic nuclei**

Proton-neutron interaction towards the drip line from study of ^{26}F unbound states



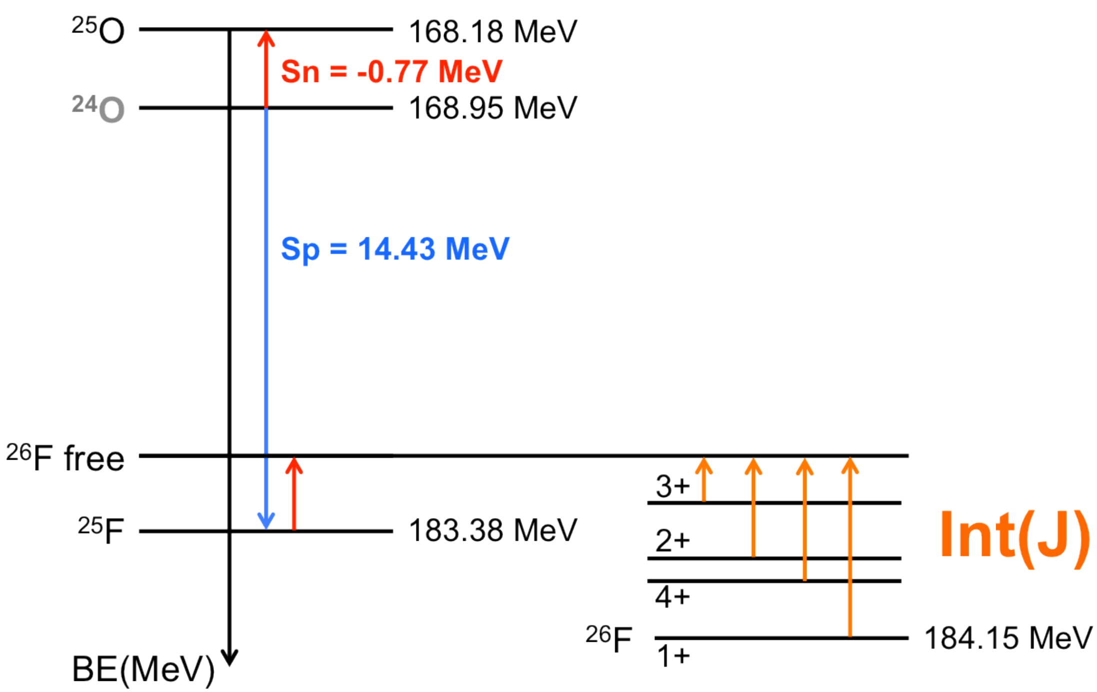
- Extension of the neutron drip line between O and F

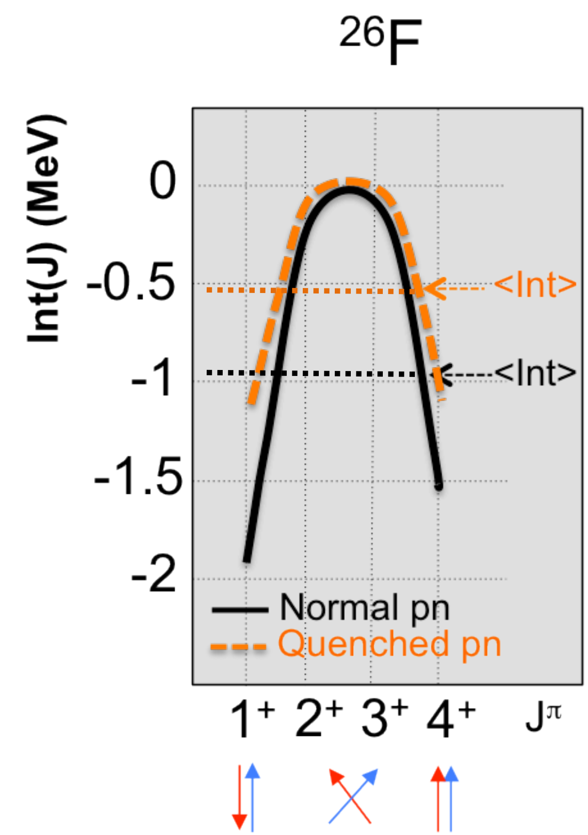


C.R. Hoffmann *et al.*, PRL **100,** 152502(2008) (^{25}O unbound)

- Extension of the neutron drip line between O and F
- ^{24}O doubly magic
- ^{26}**F** ≈ ^{24}O core + 1p + 1n : coupling $(\pi d_{5/2})^1(\nu d_{3/2})^1$ ➡ $J^\pi = 1^+, 2^+, 3^+, 4^+$ multiplet.

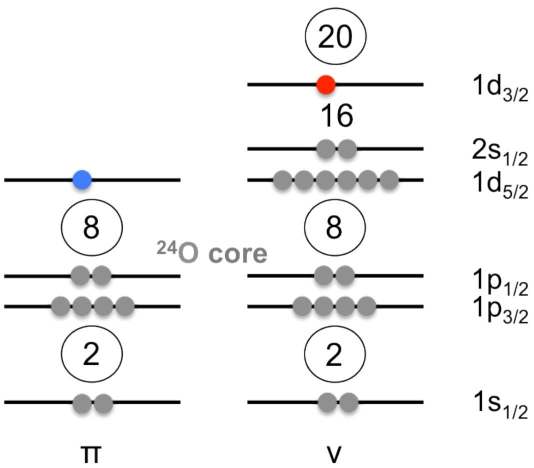
- Comparison between the exp. BE $J^{\pi} = 1^+, 2^+, 3^+, 4^+$ w/ ^{24}O core + 1p + 1n
  ➡ definition of the **interaction energy Int(J)**



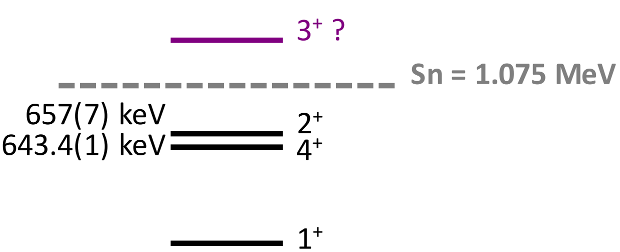


- Representation of the p-n coupling w/ **parabola of interaction energy**
  Mean value gives access to the **average p-n interaction** (monopole term)
  Amplitude depends on the **residual interaction**
- Effect of the continuum ➡ large p-n asymmetry of BE ➡ reduced amplitude and mean value are expected

^{26}F

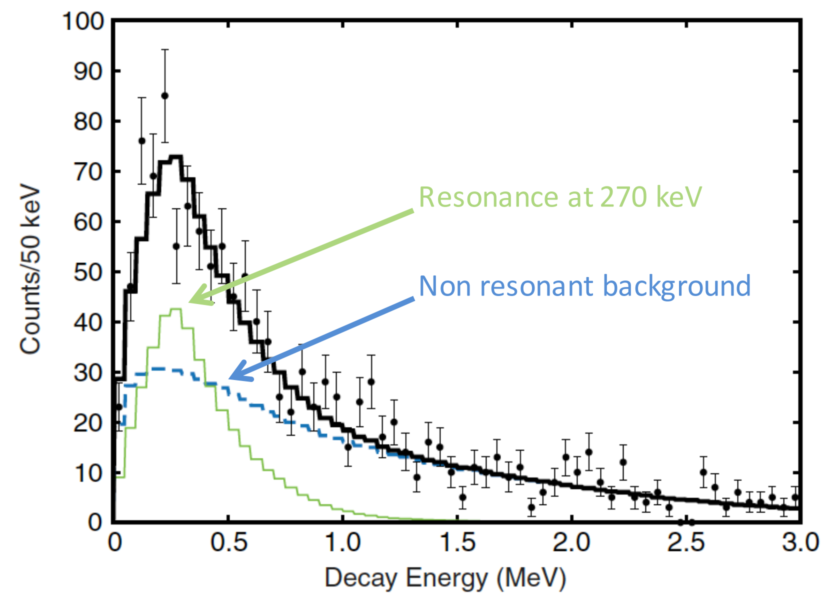


$J^{\pi} = 1^{+}, 2^{+}, 3^{+}, 4^{+}$



Candidate for the 3^{+} unbound state in ^{26}F

- Resonance populated at 270 keV above the neutron threshold in ^{26}F from charge-exchange reaction

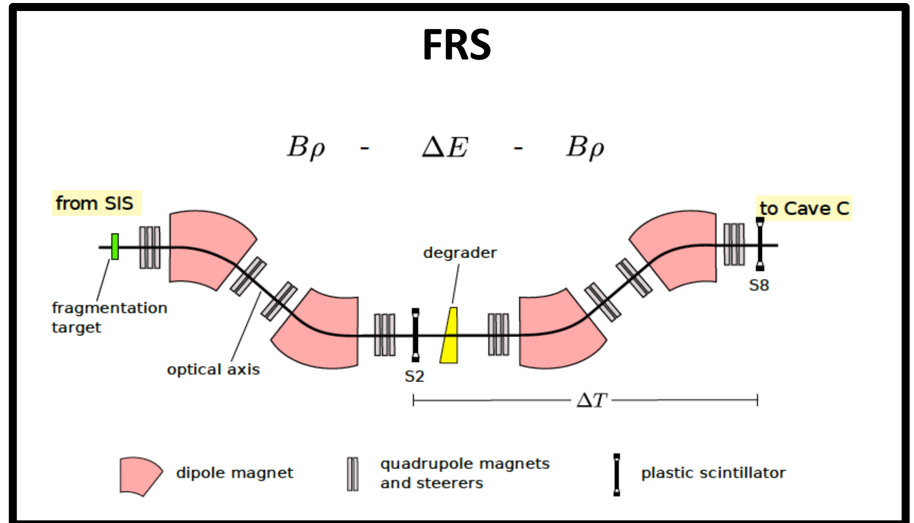


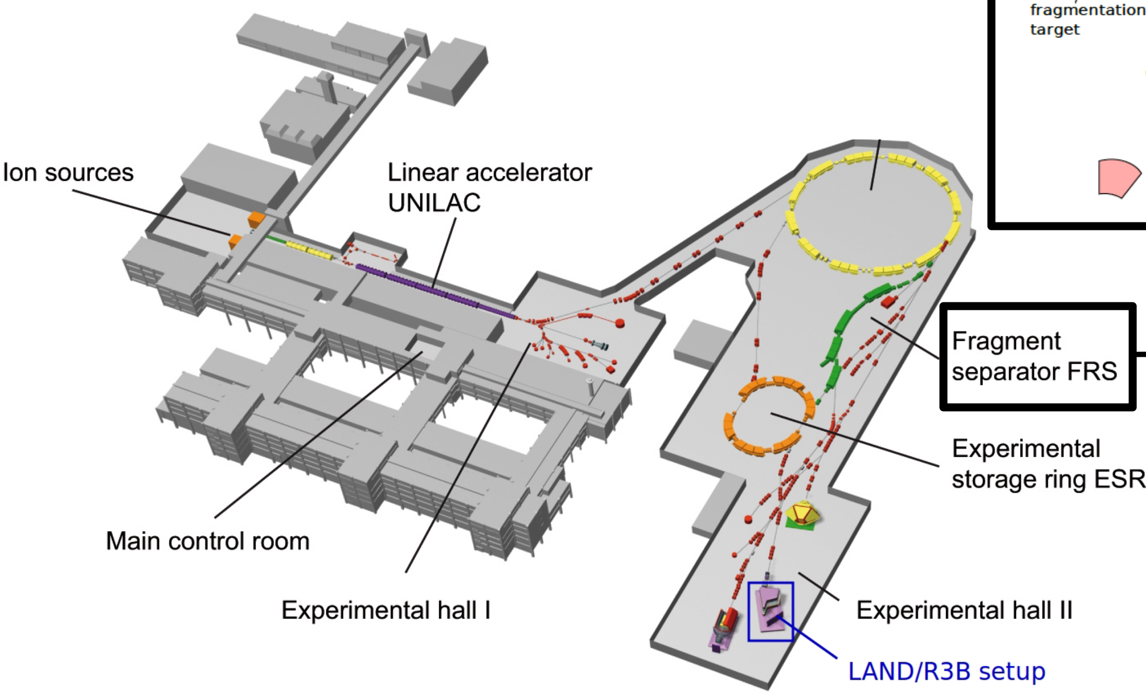
N. Frank *et al.*, PRC **84,** 037302(2011)

→ **Spin assignment ?**

Setup

^{40}Ar
490 MeV/nucleon → fragmentation → ^{27}Ne $\xrightarrow{-1p}$ ^{26}F* → ^{26}F + γ / ^{25}F + n (+γ)

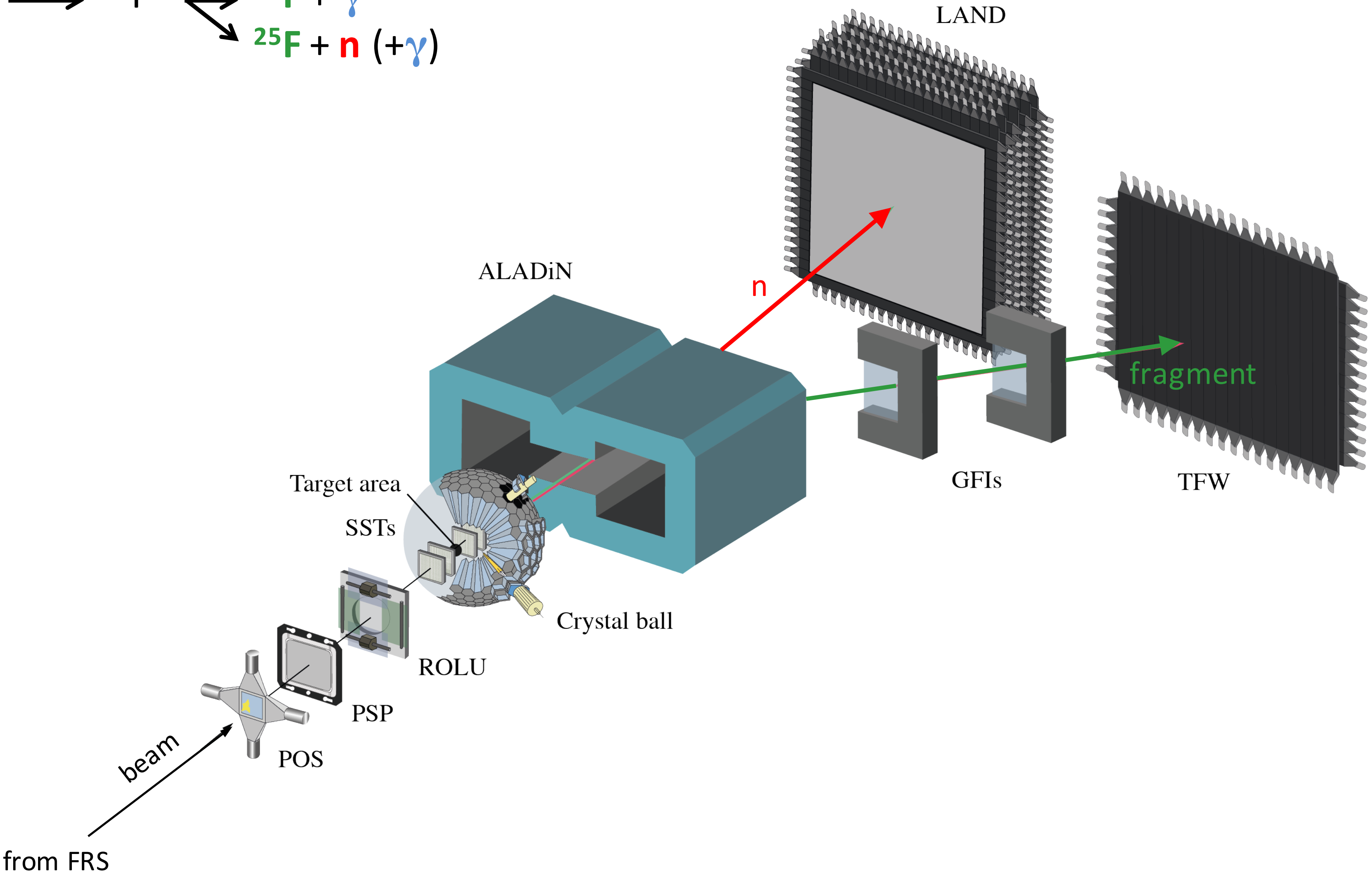




Setup

$^{27}Ne \xrightarrow{-1p} {}^{26}F^* \rightarrow {}^{26}F + \gamma$

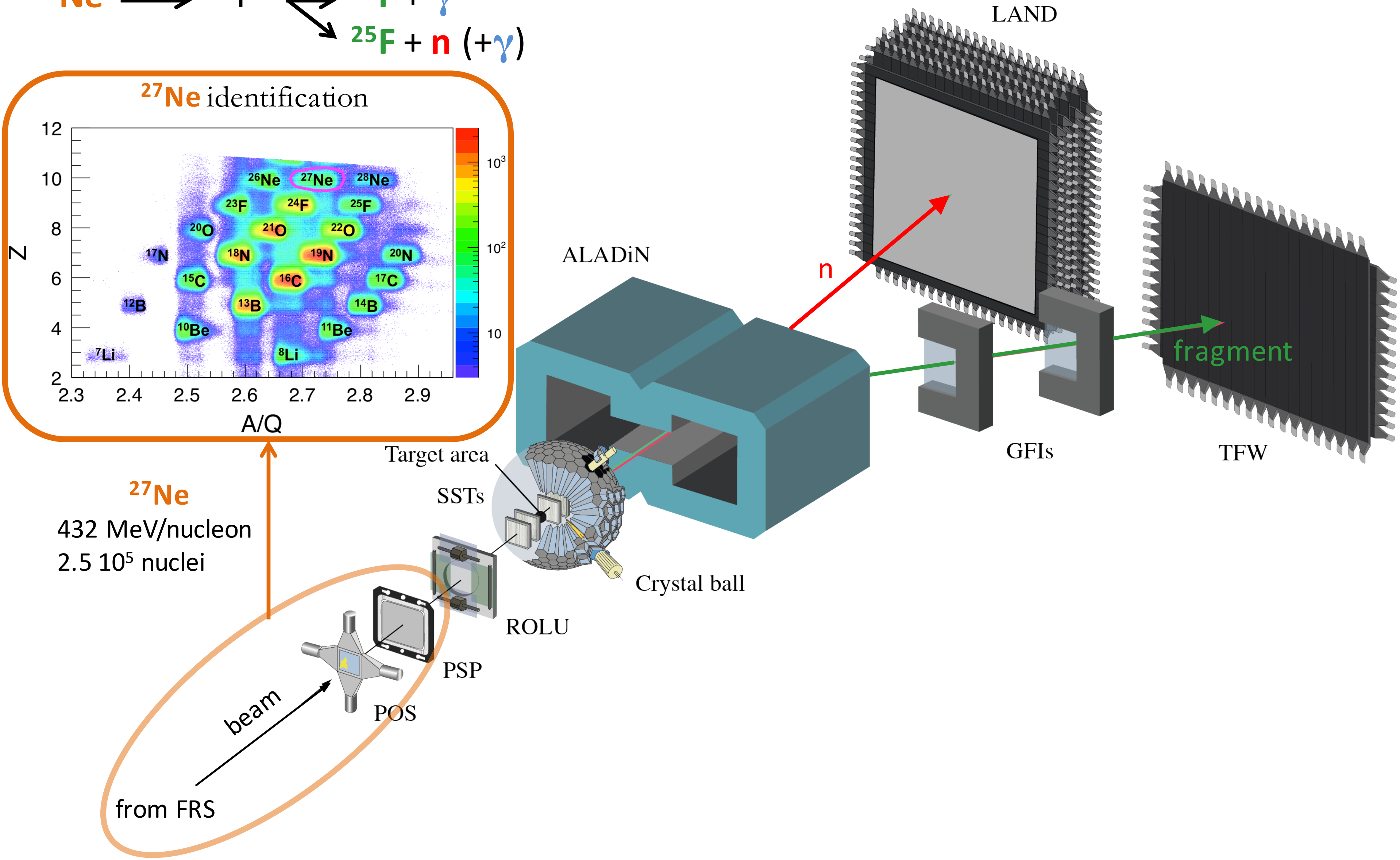
$\phantom{^{27}Ne \xrightarrow{-1p} {}^{26}F^*} \searrow {}^{25}F + n\ (+\gamma)$



Setup

$^{27}Ne \xrightarrow{-1p} {}^{26}F^{*}$ → $^{26}F + \gamma$

→ $^{25}F + n\ (+\gamma)$



Setup

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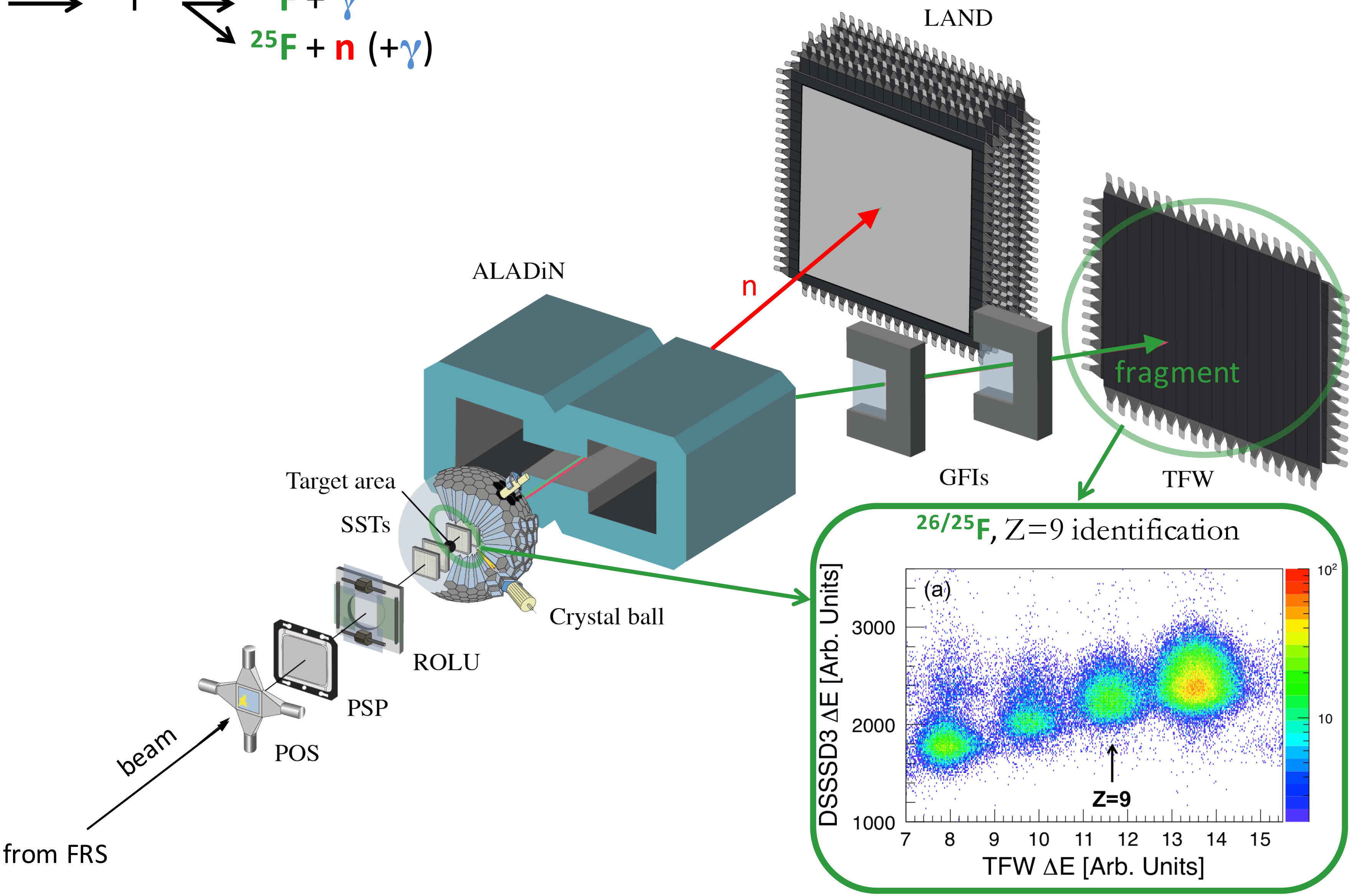
$\qquad\qquad\qquad\quad\;\, \searrow {}^{25}\text{F} + n\ (+\gamma)$



Setup

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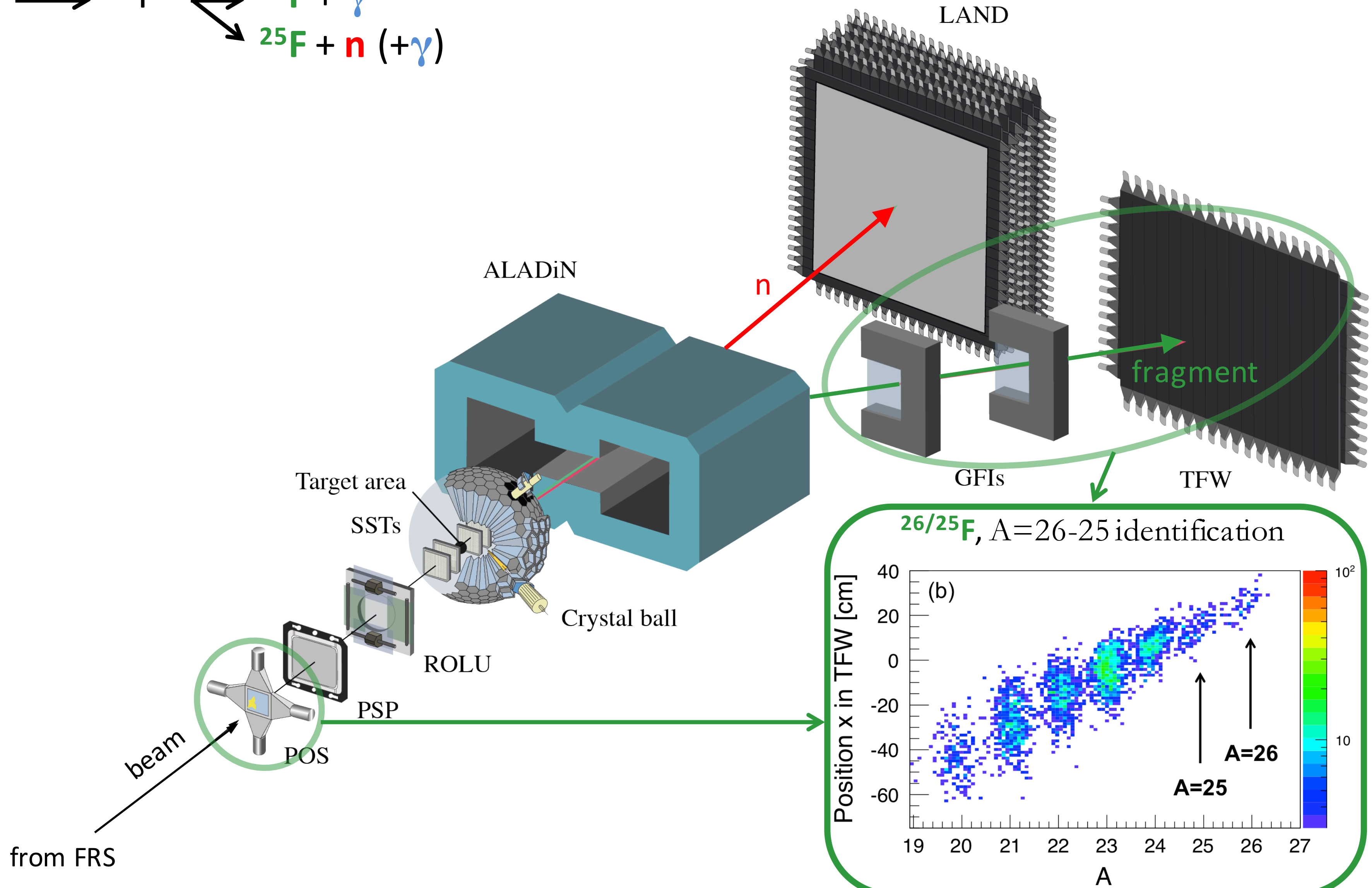

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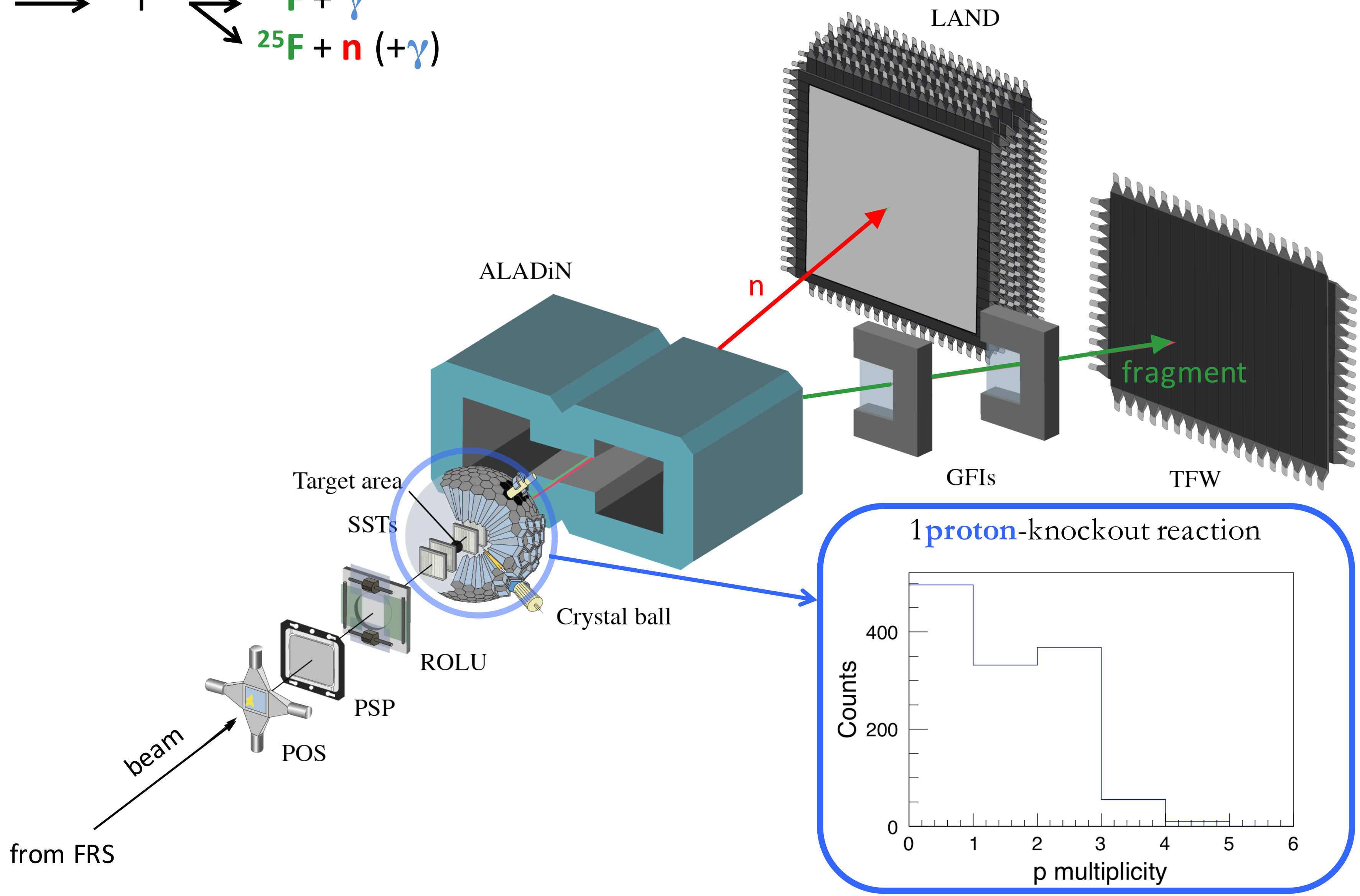

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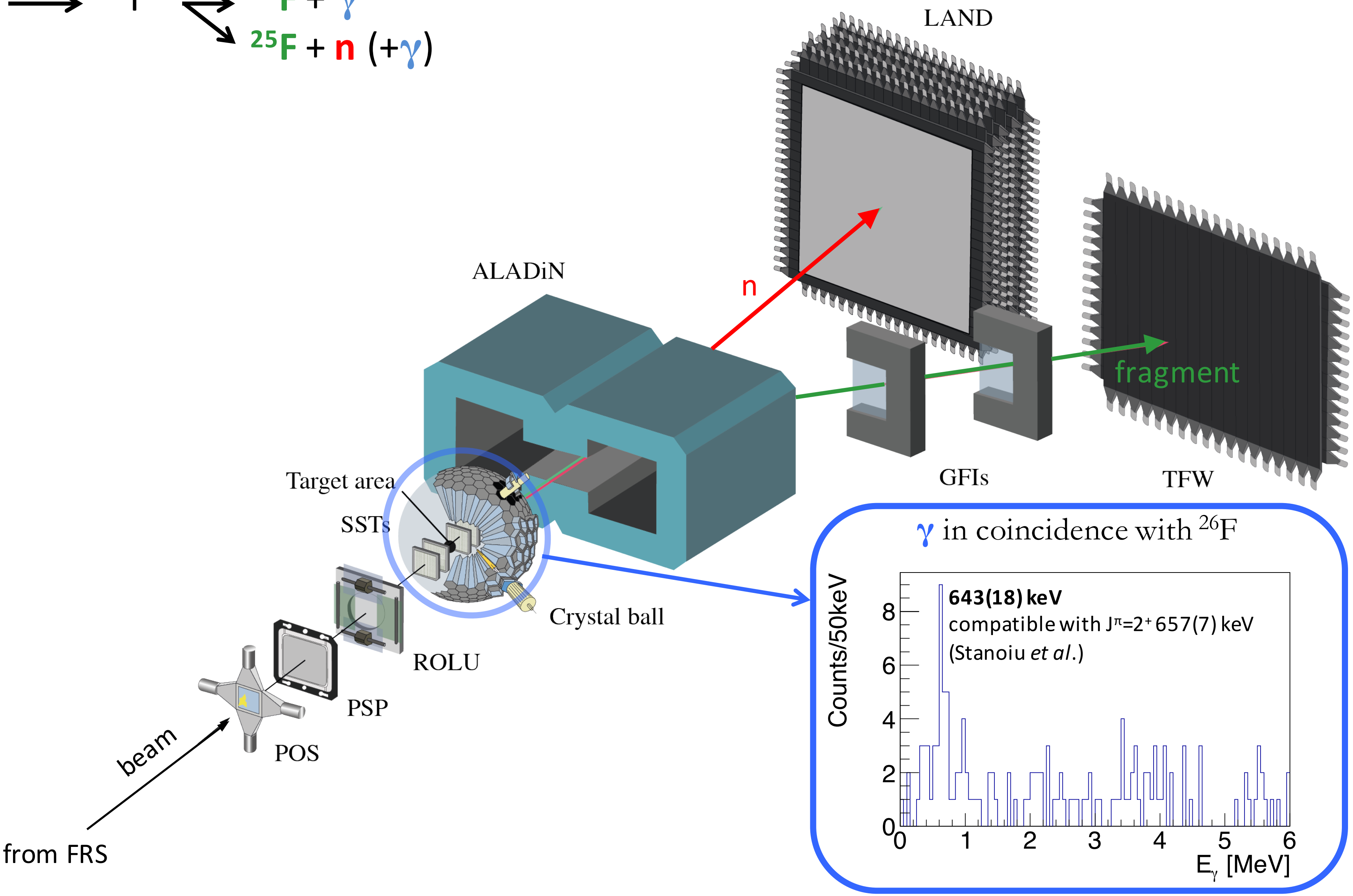
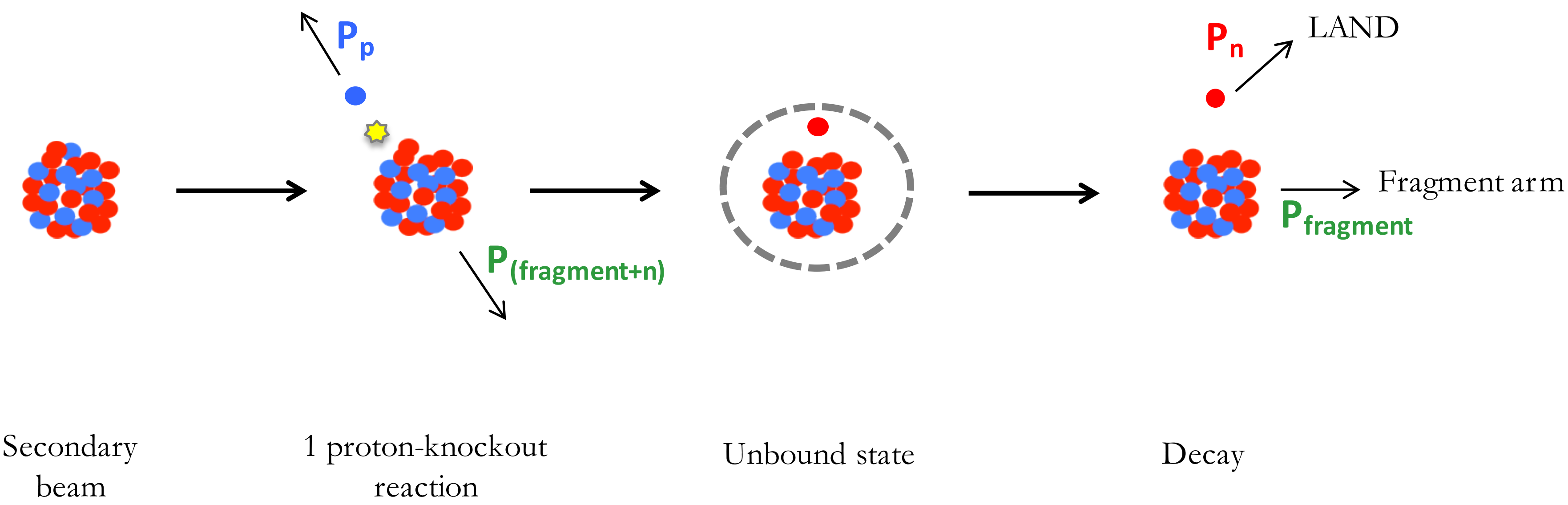


Invariant mass method

- Detection **all** beam like particles + momenta

  ➡ Study ^{26}F unbound states w/ **invariant mass method**



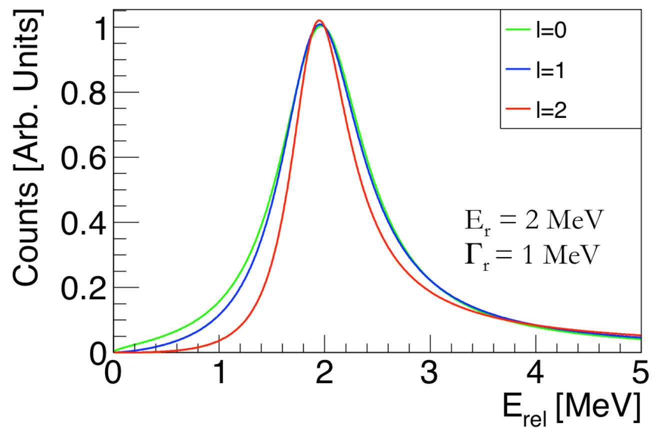
- Relative energy of the system (fragment + n) = (^{25}F+n) : $E_{rel} = \sqrt{m_f^2 + m_n^2 + 2(E_f E_n - p_f p_n \cos\theta)c^2} - m_f c^2 - m_n c^2$

- Width of the resonance ➡ **Neutron configuration**
- Shape of the $P_{(fragment+n)}$ momentum distribution ➡ **Proton configuration**

  ➡ genesis of a resonance from its formation to its decay

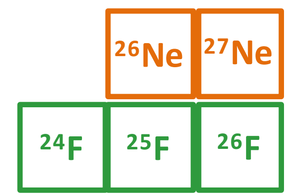
Analysis

- Resonances described by **Breit-Wigner** line shape

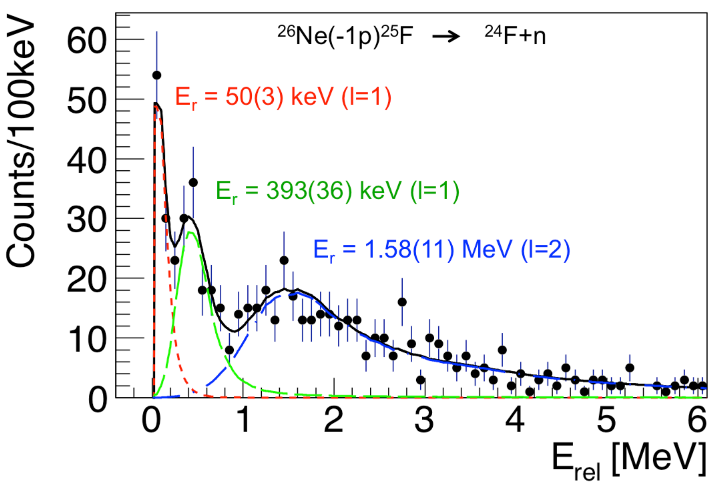


✓ Strong cross-section around Er
✓ Shape depends on l_n = 0,1,2
✓ Characterized by **Er** et **Γr**

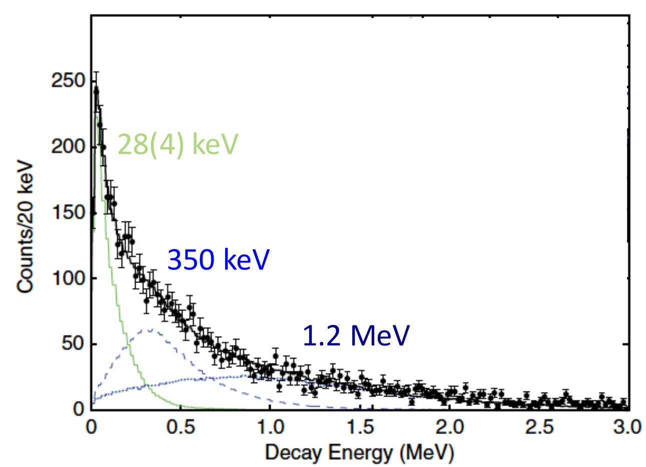
Convoluted by the LAND response matrix
Functions used to fit the relative energy spectra



- Check the analysis procedure on the channel $^{26}Ne \xrightarrow{-1p} {}^{25}F^* \rightarrow {}^{24}F + n\ (+\gamma)$



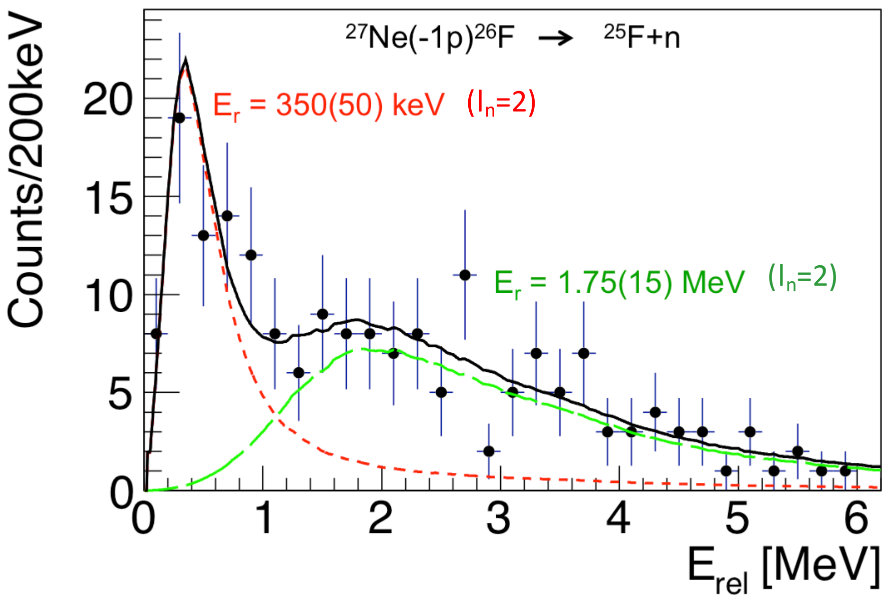
M. Vandebrouck, A. Lepailleur, O. Sorlin *et al.*, to be submitted



N. Frank *et al.*, PRC **84,** 037302(2011)

Results

$$^{27}\mathrm{Ne} \xrightarrow{-1p} {}^{26}\mathrm{F}^{*} \longrightarrow {}^{25}\mathrm{F} + n\ (+\gamma)$$



M. Vandebrouck, A. Lepailleur, O. Sorlin *et al.*, submitted to PRC

- **2 resonances** observed for the system (^{25}F+n)

Results

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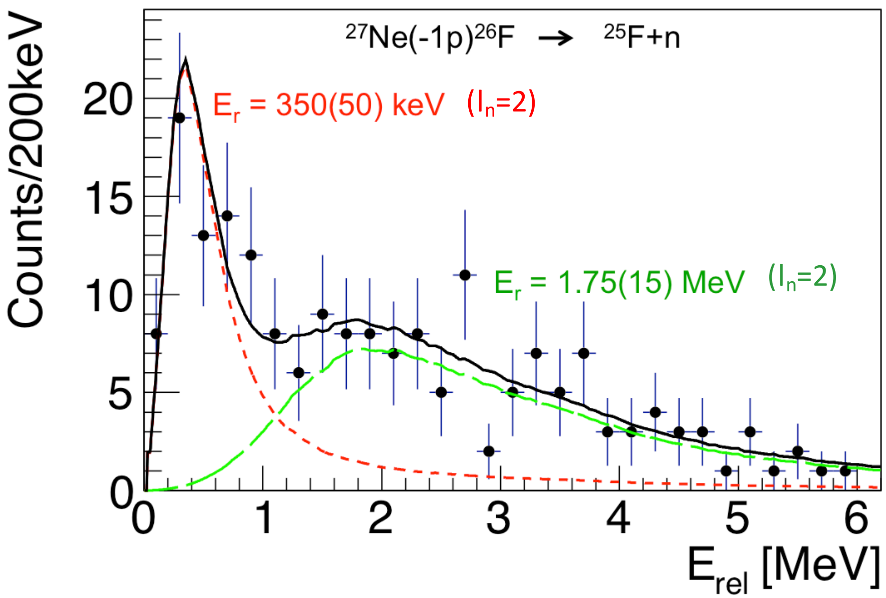
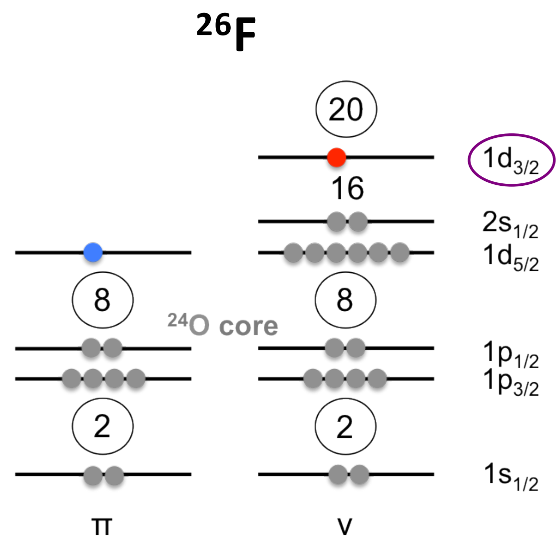


M. Vandebrouck, A. Lepailleur, O. Sorlin *et al.*, submitted to PRC

Resonance 1 at 350keV : $\Gamma_r = 569 \pm 484$ keV
$\Gamma_{sp}(l_n=0)$ =3080 keV
$\Gamma_{sp}(l_n=2)$ =74 keV

Resonance 2 at 1.75MeV : $\Gamma_r = 4.2 \pm 2.5$ MeV

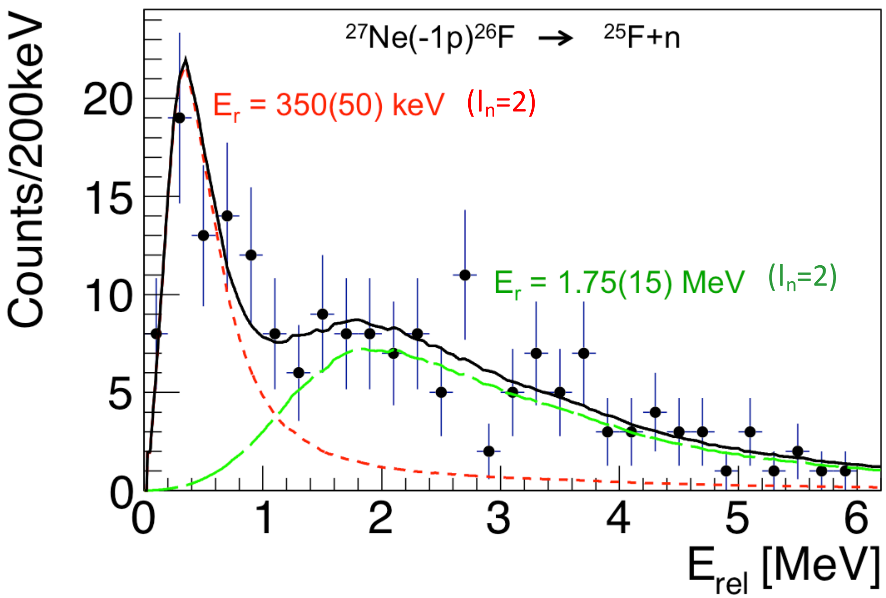


- **2 resonances** observed for the system (^{25}F+n)
- Widths obtained assuming "simple Breit-Wigner"

Comparison to Γ_{sp} : $\Gamma_r(E) = \sum_{l_n} C^2S\, \Gamma_{sp}(l_n, E)$ ➡ Resonance 350 keV mainly $l_n = 2$

Results

$^{27}Ne \xrightarrow{-1p} {}^{26}F^* \longrightarrow {}^{25}F + n\ (+\gamma)$



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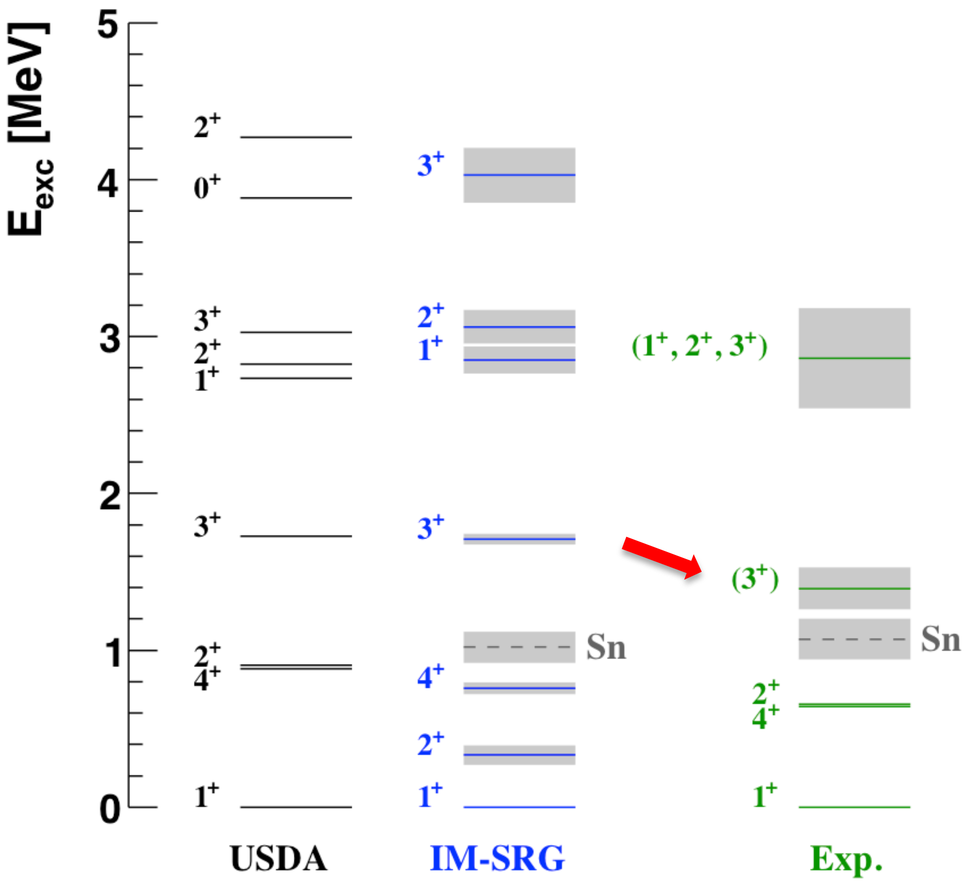
Resonance 2 at 1.75MeV : Γ_r =4.2 ± 2.5 MeV
$\Gamma_{sp}(l_n{=}0)$ =7941 keV
$\Gamma_{sp}(l_n{=}2)$ =2966 keV

- **2 resonances** observed for the system (^{25}F+n)
- Widths obtained assuming "simple Breit-Wigner"

Comparison to Γ_{sp} : $\Gamma_r(E) = \sum_{l_n} C^2S\, \Gamma_{sp}(l_n, E)$

⇒ Resonance 350 keV mainly $l_n = 2$
⇒ Resonance 1.75 MeV mix $l_n = 0$ and $l_n = 2$

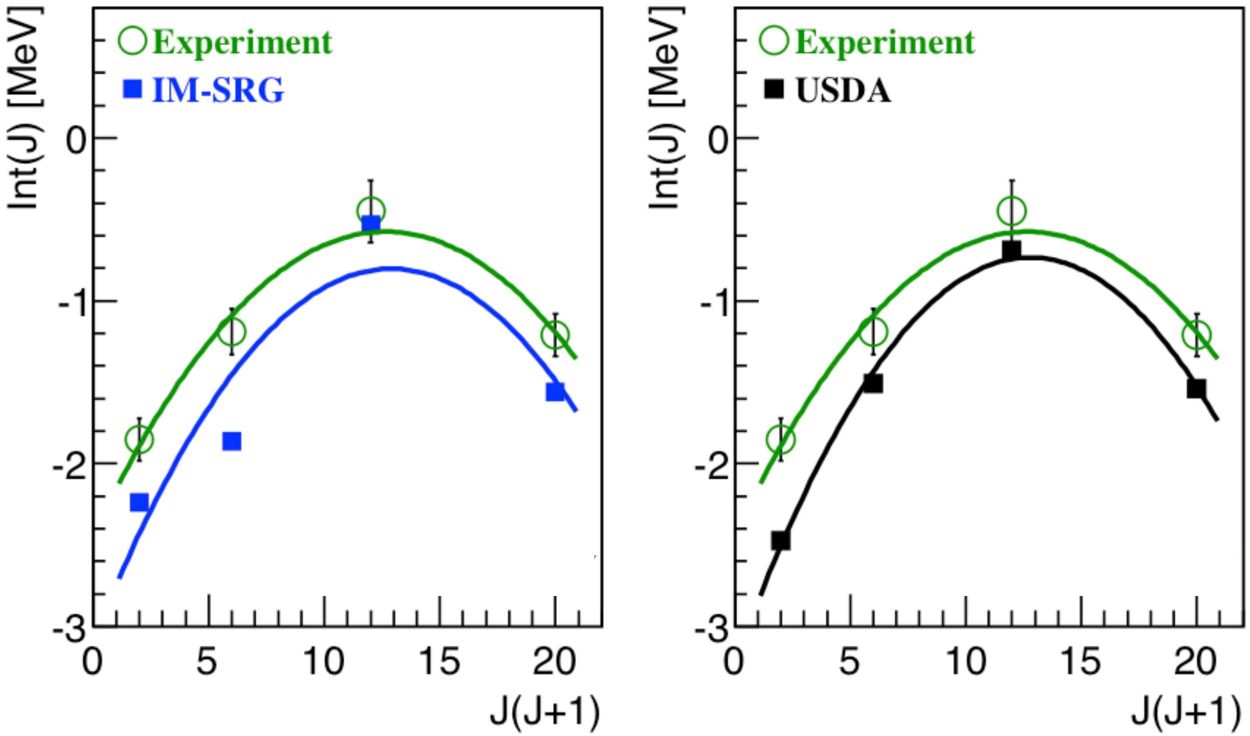
Comparison to the models



M. Vandebrouck, A. Lepailleur, O. Sorlin *et al.*, submitted to PRC

- Comparison to : - USDA phenomenological shell-model
  - ab initio valence space IM-SRG
- Shift in energy ➡ **Due to the lack of treatment of the continuum ?**

Comparison to the models



M. Vandebrouck, A. Lepailleur, O. Sorlin *et al.*, submitted to PRC

- Effective monopole interaction (J-averaged interaction energy) : V^{exp} = - 1.06 MeV
  $V^{IM\text{-}SRG}$ = - 1.41 MeV
  V^{USDA} = -1.40 MeV
- Effective interaction weakened by about 30-40%

Conclusion

- Study of the **unbound states** in ^{26}**F**

- ^{27}**Ne(-1p)**^{26}**F** using the R3B/LAND setup

  ⇨ Identification of the 3^+ state at 1.425 MeV
  ⇨ Several contributions around 2.8 MeV

- Comparison to shell model using **realistic interaction**

  ⇨ Need treatment of the continuum

- Data gives new opportunity to constrain the models

And the future ?

Spectroscopic studies of the heaviest nuclei

- Short term:

  - Cross-section measurement of ^{243}Es (Thesis of Raphaël Briselet)

  - Test SIRIUS (digital electronic, energy measurement without and with pile-up)

- Middle term: commissioning S3