First measurement of the isoscalar giant resonances in a neutron-rich nucleus: ^{68}Ni with the active target MAYA

Isoscalar Giant Resonances
Motivations
Setup : the active target MAYA
Results

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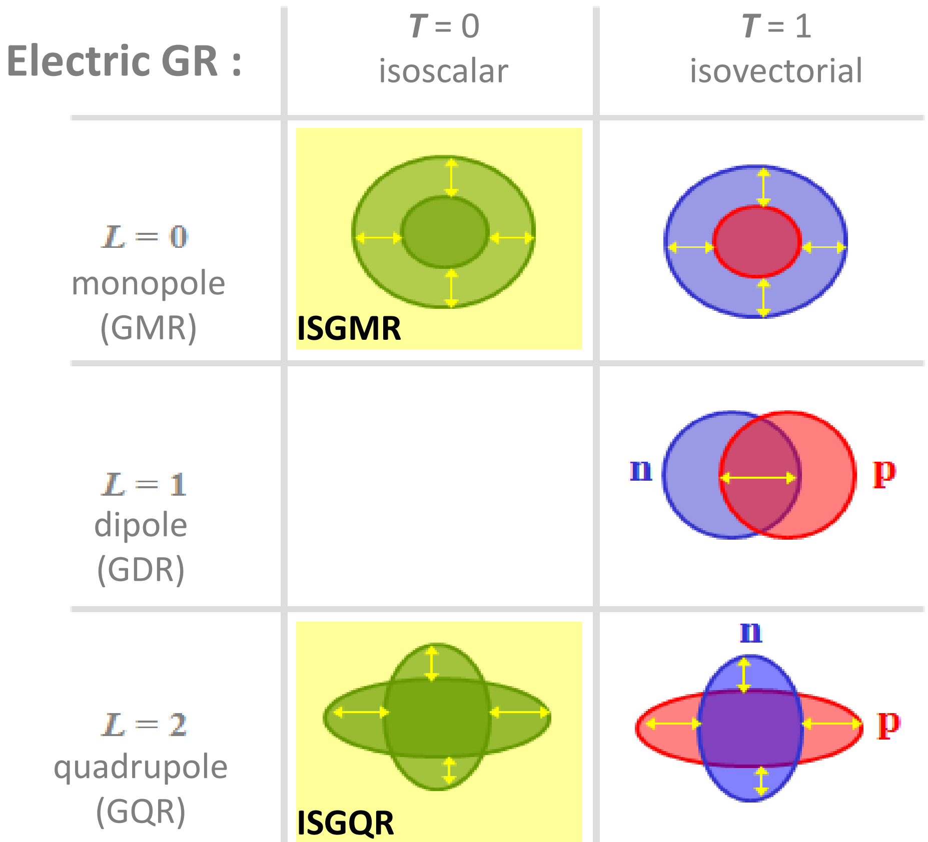
Giant Resonances

What are giant resonances ?

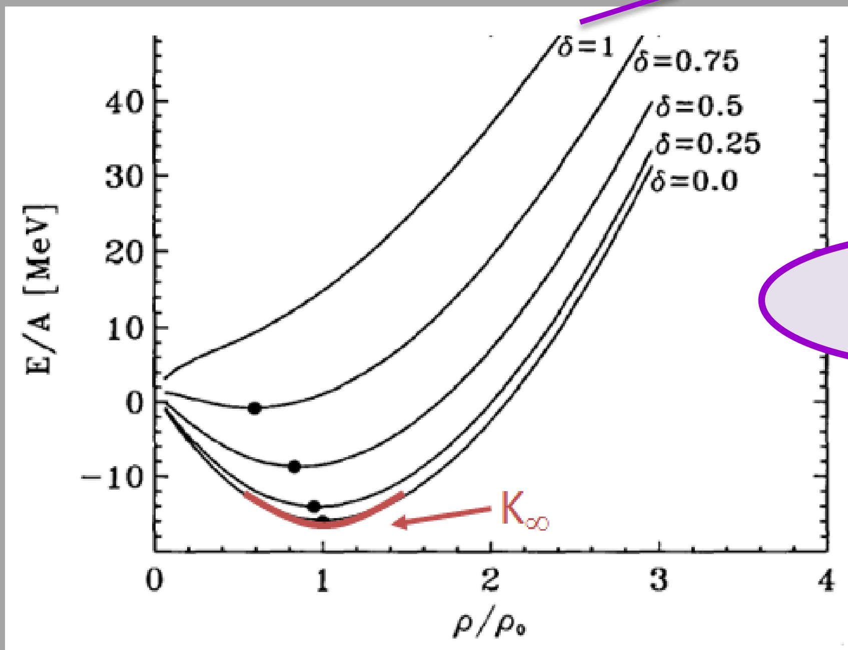
- **Collective excitation mode**
- Feature :
  - Important cross section (100 mb)
  - Exhaust a large part of the EWSR
  - Properties change smoothly with the number of nucleons
- Quantum number of the excitation :
  - Spin ***S***
  - Isospin ***T***
  - Multipolarity ***L***



Motivations

Nuclear matter incompressibility and ISGMR

Asymetry
δ=(N-Z)/A



D.T.Khoa *et al*. Nucl. Phys A. **602** (1996)

Microscopic calculation

- Centroid of the ISGMR $\mathbf{E_{ISGMR}}$

$$E_{ISGMR} = \sqrt{\frac{\hbar^2 K_A}{m < r^2 >}}$$

Determination of the compression modulus of the nucleus $\mathbf{K_A}$

- Compression modulus of the nucleus $\mathbf{K_A}$

Liquid drop development

Determination of the nuclear matter incompressibility $\mathbf{K_\infty}$

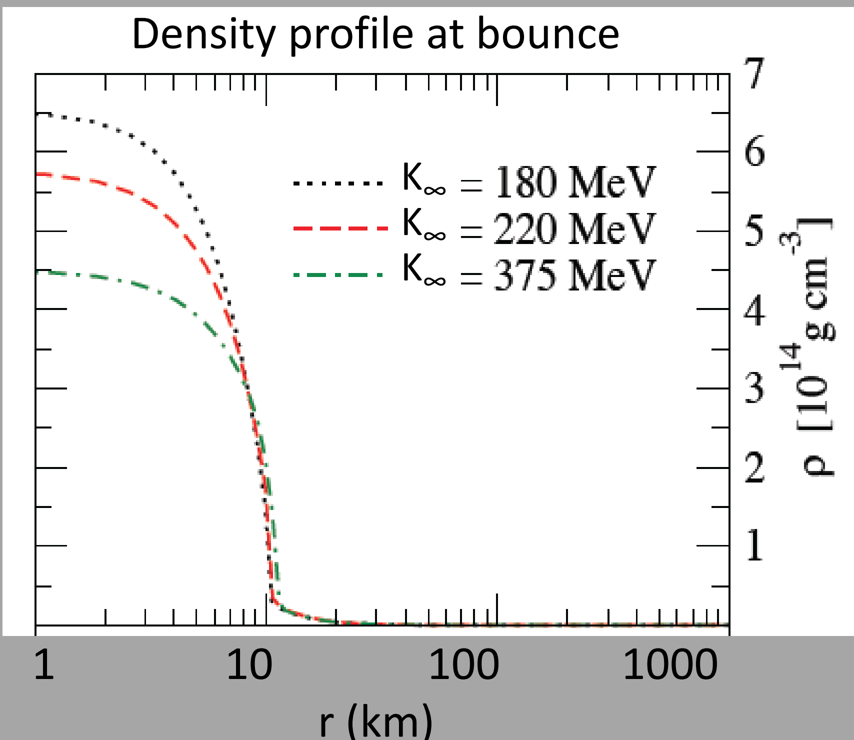
Status

$\mathbf{K_\infty}$ has been constrained for symmetric and asymmetric matter**.** To gain a better knowledge of $\mathbf{K_\infty}$, we need studies along isotopic chains, including exotic nuclei.

Motivations

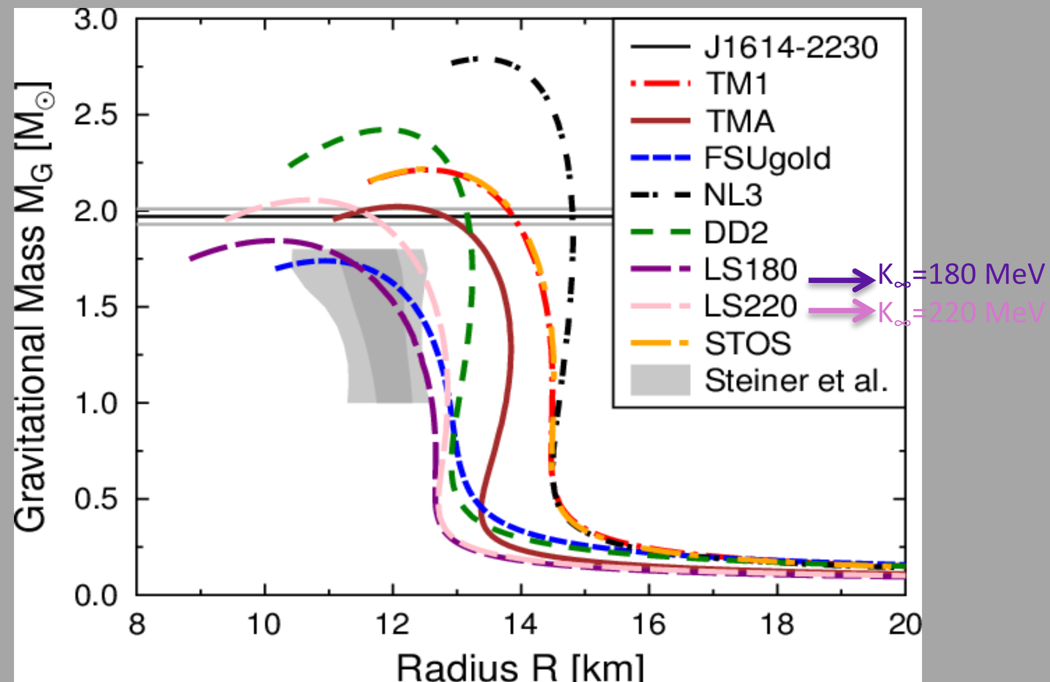
Nuclear matter incompressibility and ISGMR

In supernovae bounce



A. Fantina PhD (2010) IPNO-IAA

In neutron stars



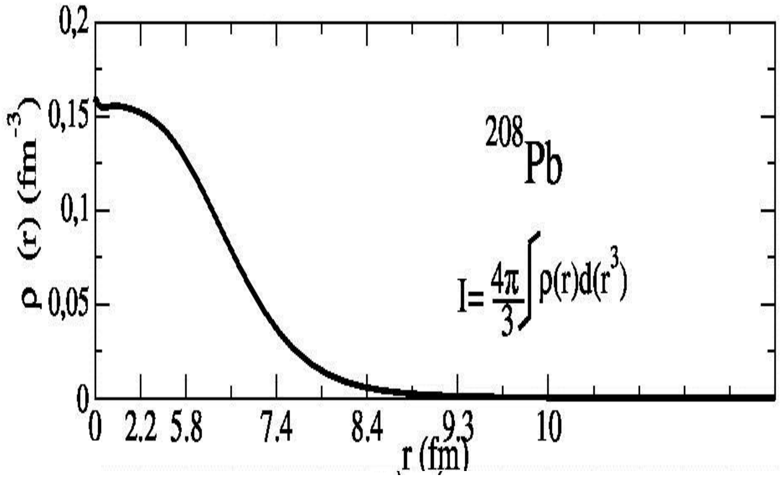
M. Hempel ITP Franckfurt

Motivations

Nuclear matter incompressibility and ISGMR

Does ISGMR really related to K_∞ ?

- K_∞ = 220 MeV ± 30 MeV
- No single functional to reproduce K_∞ calcuated from E^*_{GMR}(Pb) and K_∞ calcuated from E^*_{GMR}(Sn)
- K_∞ ↔ asymetry $\delta = (N-Z)/A$



- Surface : 2/3 of nucleons in ^{208}Pb
- Saturation density area may not be the most probed

E^*_{GMR} provides $K(\rho)$ and not K_∞

⇩

Need measurement of E^*_{GMR} along isotopic

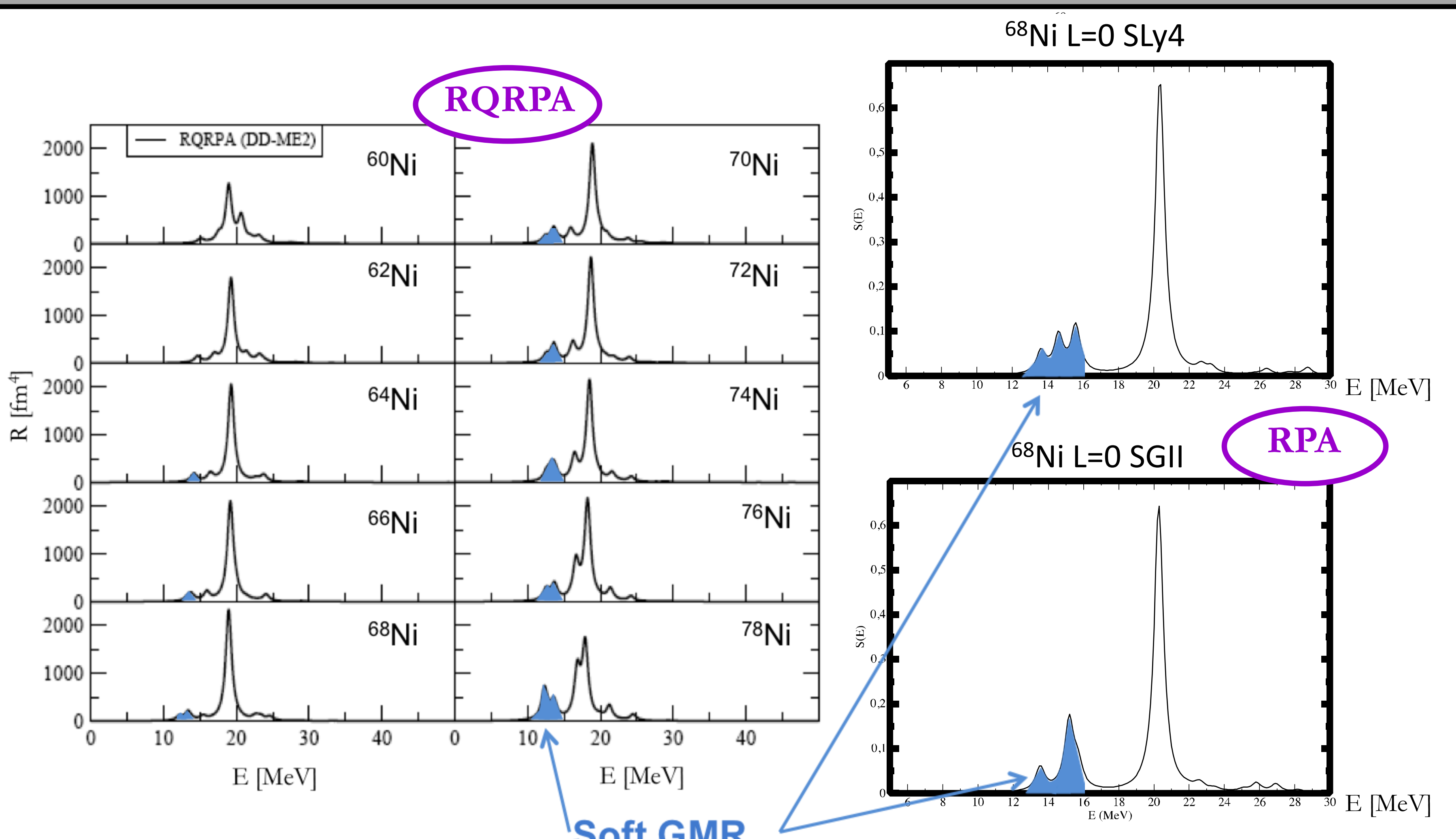
E. Khan, *et al.*, *Phys. Rev. Lett.* **109**, 092501 (2012)

Motivations

Prediction of a soft monopole mode

Prediction of the monopole strenght in Ni isotopic

⇒ Prediction of a low energy mode



E. Khan, N. Paar and D. Vretenar, *Phys. Rev.* **C. 84**, 051301 (2011)

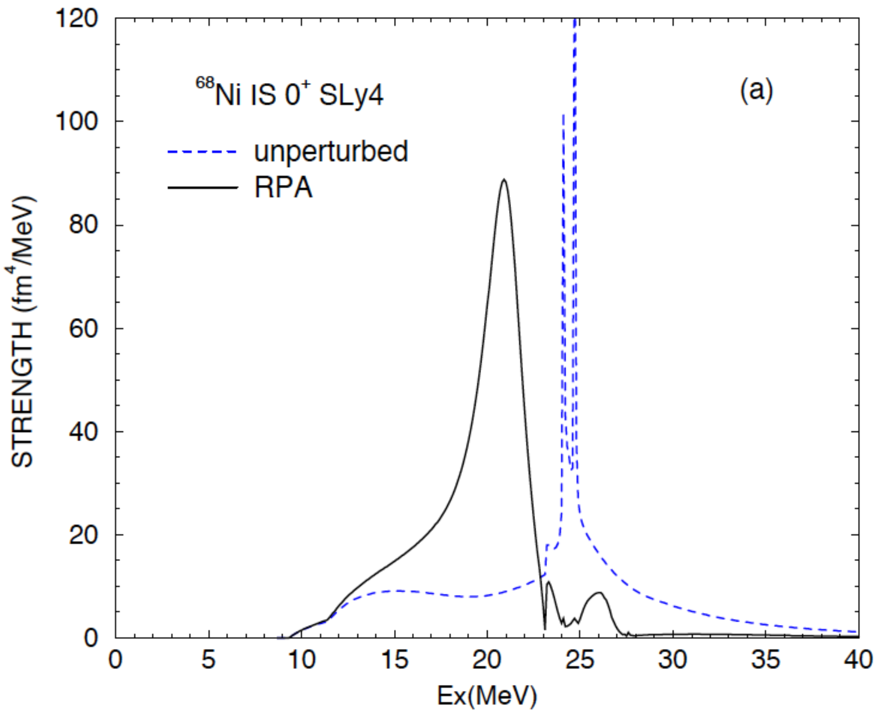
Motivations

Prediction of a soft monopole mode

Prediction of the monopole strenght in Ni isotopic

⇒ Prediction of a low energy mode

RPA with exact treatment of continuum



I. Hamamoto and H. Sagawa, Phys. Rev. **C. 90,** 031302(R) (2014)

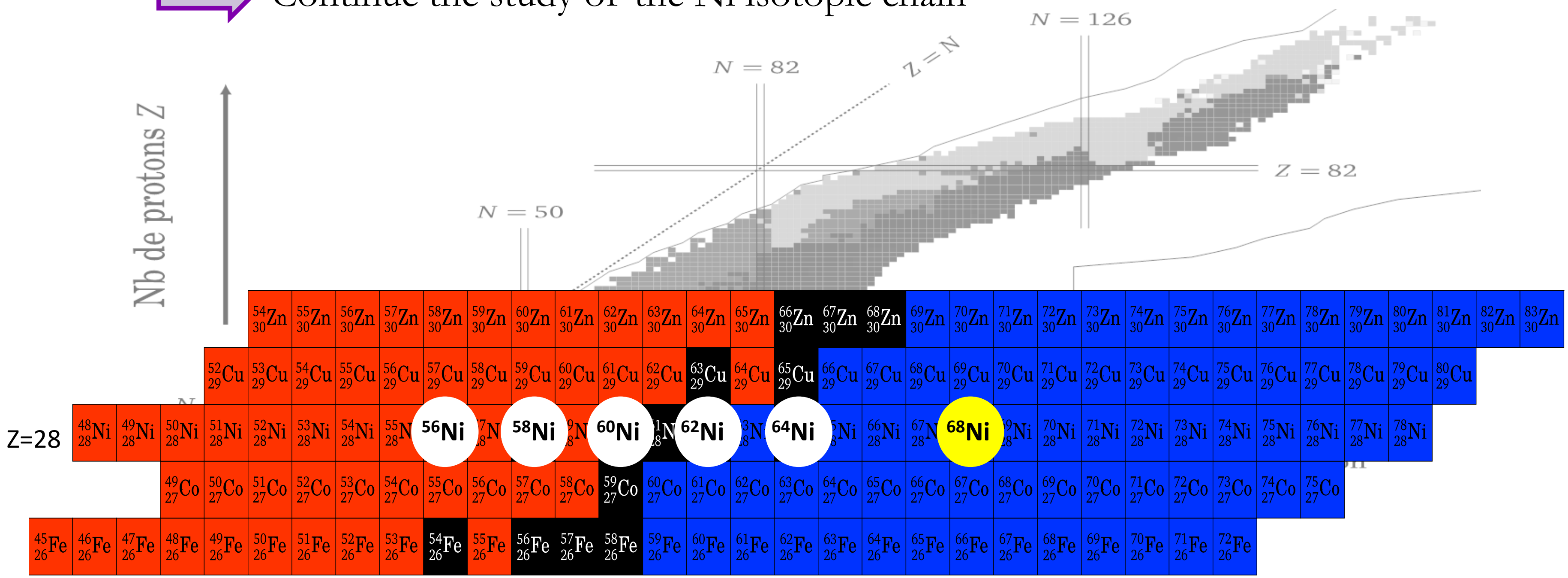
Motivations

Status of the GR measurement in unstable nuclei

- Understand these excitation modes 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 and ISGQR in unstable nuclei ^{56}Ni : *^{56}Ni(d,d')^{56}Ni**
  Monrozeau *et al., Phys. Rev. Lett.* **100,** 042501 (2008)

⇨ Study of the ISGMR and ISGQR in a neutron rich Ni : **^{68}Ni**

⇨ Continue the study of the Ni isotopic chain



Study of the ISGMR and ISGQR using inelastic scattering *^{68}Ni(α,α')^{68}Ni** and *^{68}Ni(d,d')^{68}Ni**

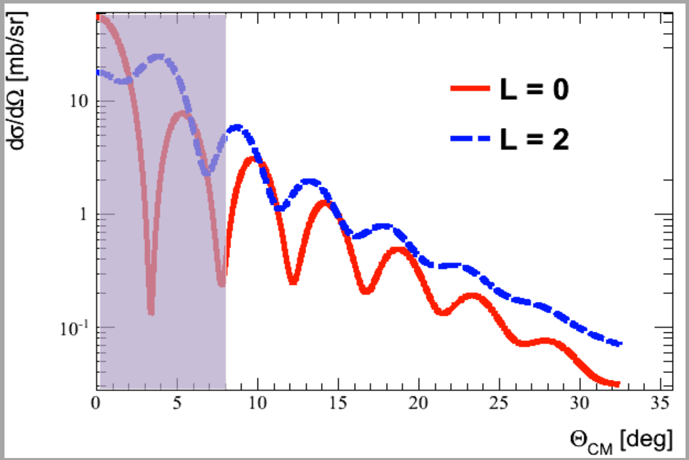
Experiment at GANIL

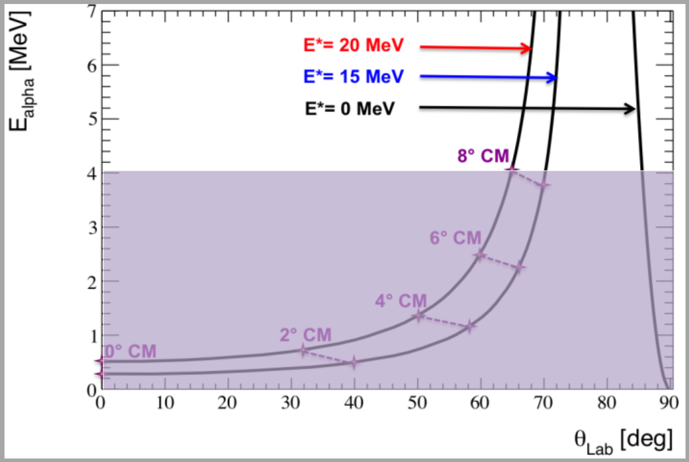
Setup : the active target MAYA

Need an active target

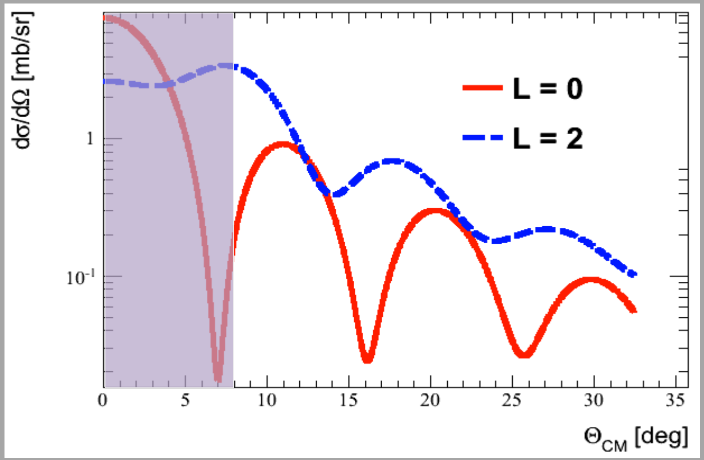
Study of the ISGMR and in ISGQR using inelastic scattering *^{68}Ni(α,α')^{68}Ni** and *^{68}Ni(d,d')^{68}Ni**

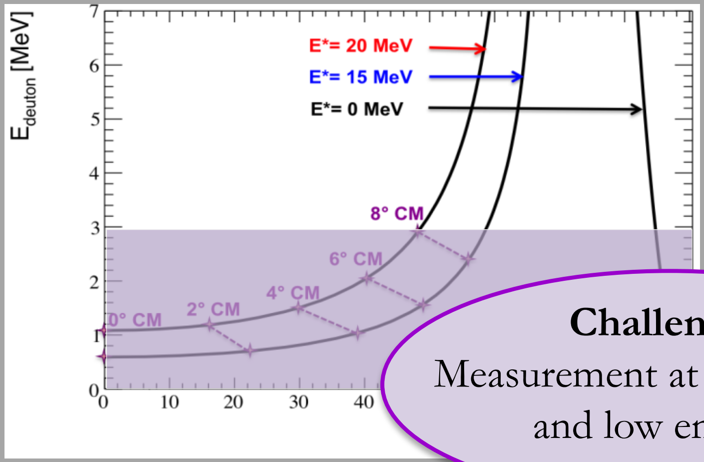
*^{68}Ni(α,α')^{68}Ni**





*^{68}Ni(d,d')^{68}Ni**





Challenge :
Measurement at small angles and low energies

We have to consider :

- Inverse kinematics with a low recoiling energy
- Low production rate

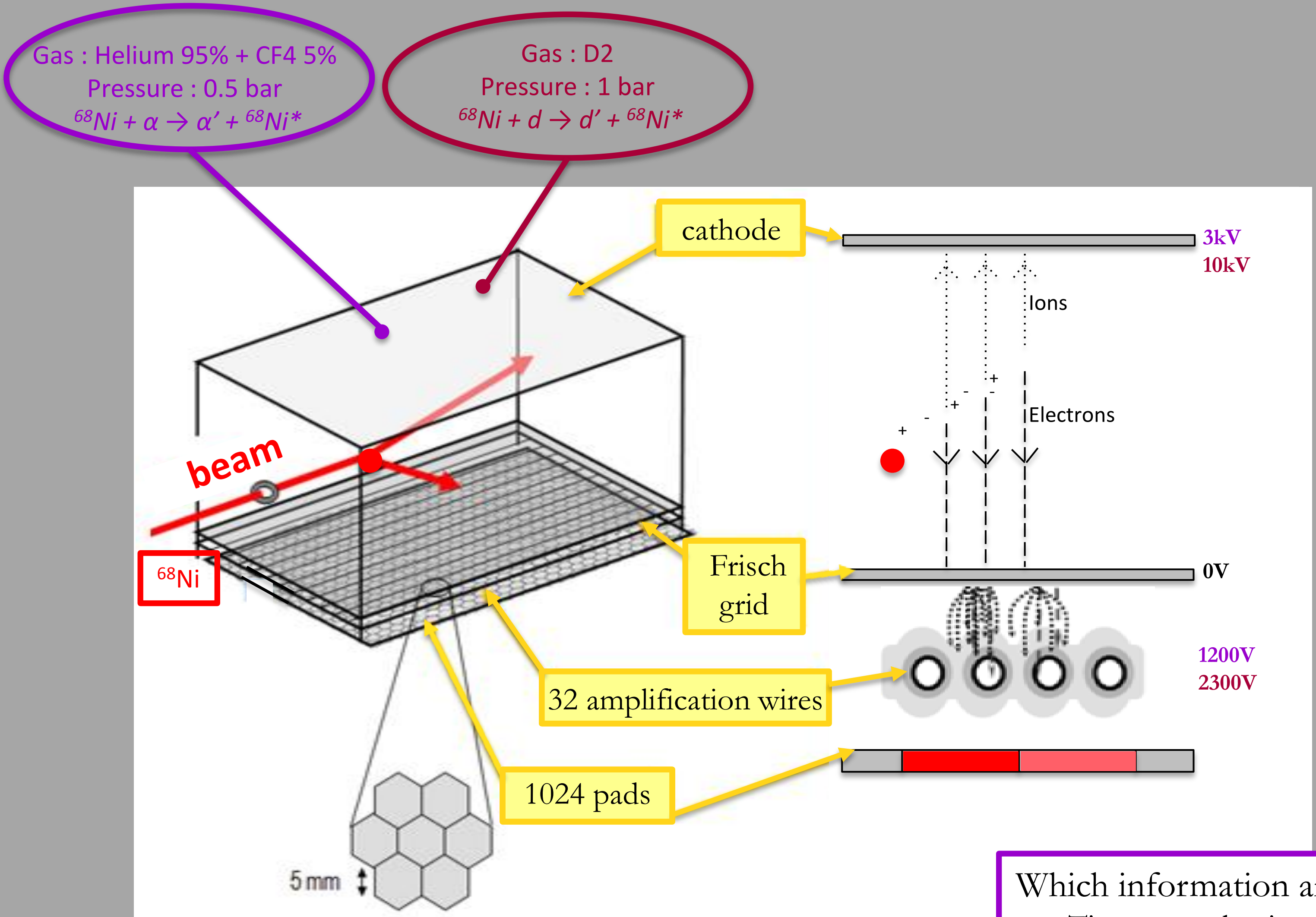
Use of an Active Target :

- low detection threshold
- thick target

MAYA

Setup : the active target MAYA
Principle

The active target MAYA



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

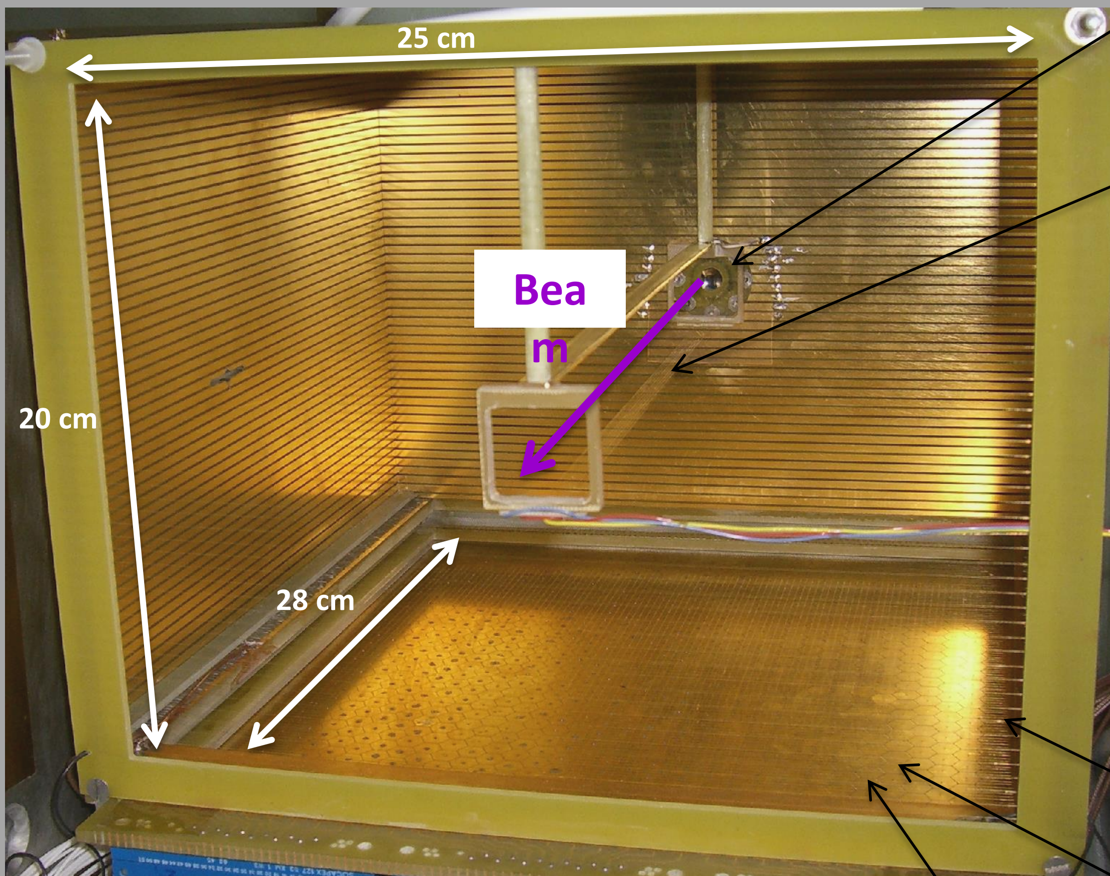
Time Projection Chamber (TPC) :

1. The scattered deuteron or α ionizes the gas
2. The electrons drift towards the Frisch grid
3. Amplification on the wires
4. Signal on each pad proportionnal to the amount of electrons collected on the wire above

Which information are stored ?
- Time on each wire
- Charge induced on each pad

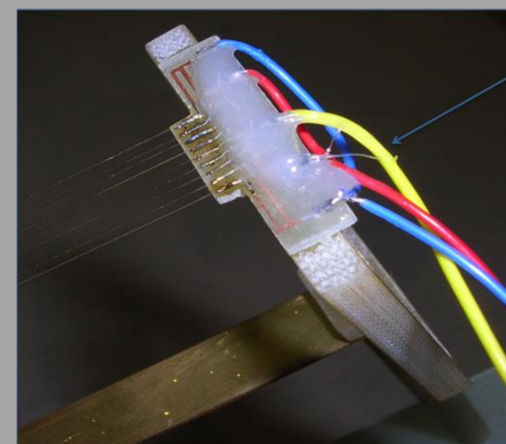
Setup : the active target MAYA

MAYA@LISE



Entrance window

Electrostatic mask



J. Pancin *et al.*, *JINST* **7,** P01006 (2012)

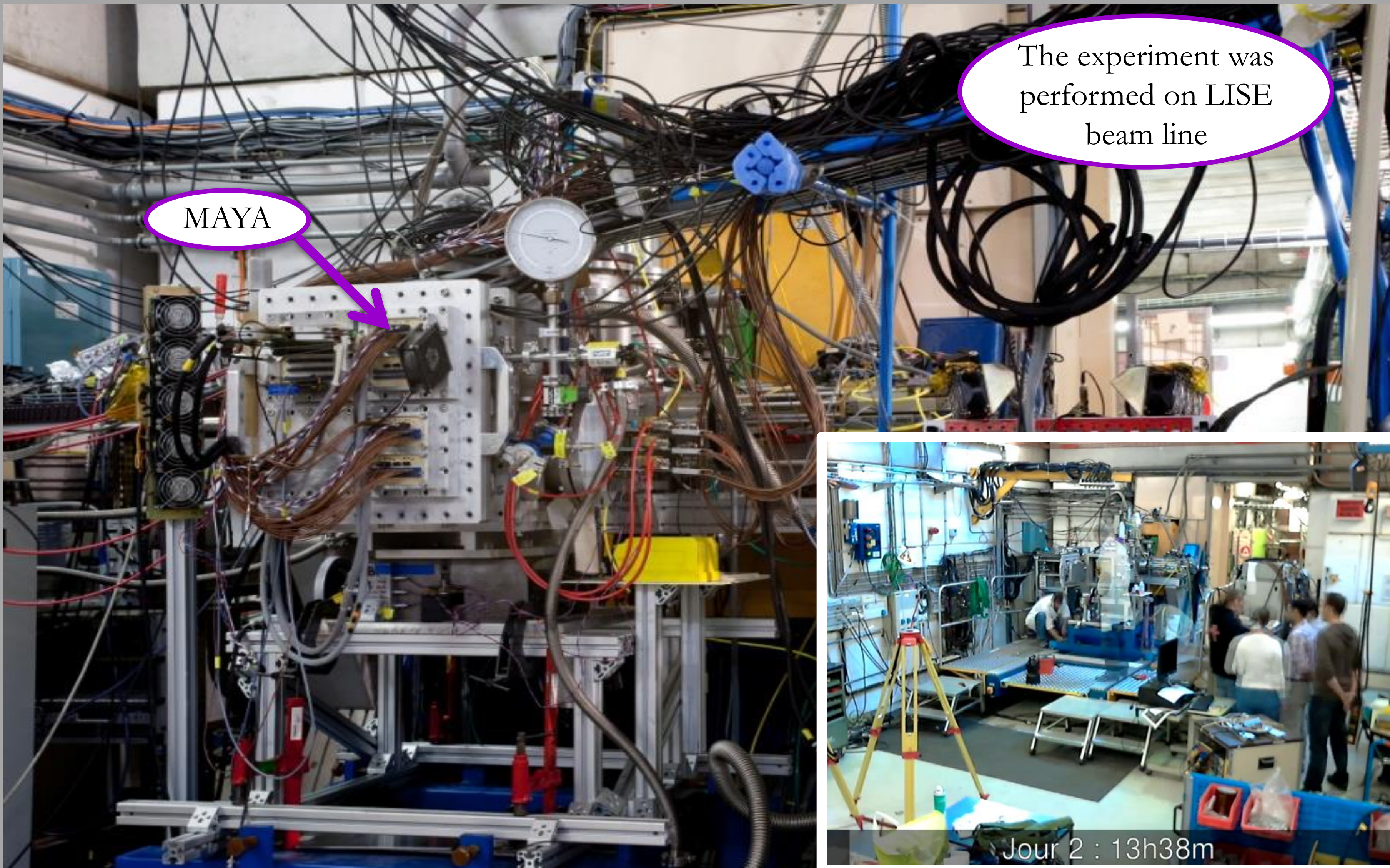
Wires of the field degrador

Wire plane

Pad plane

Setup : the active target MAYA

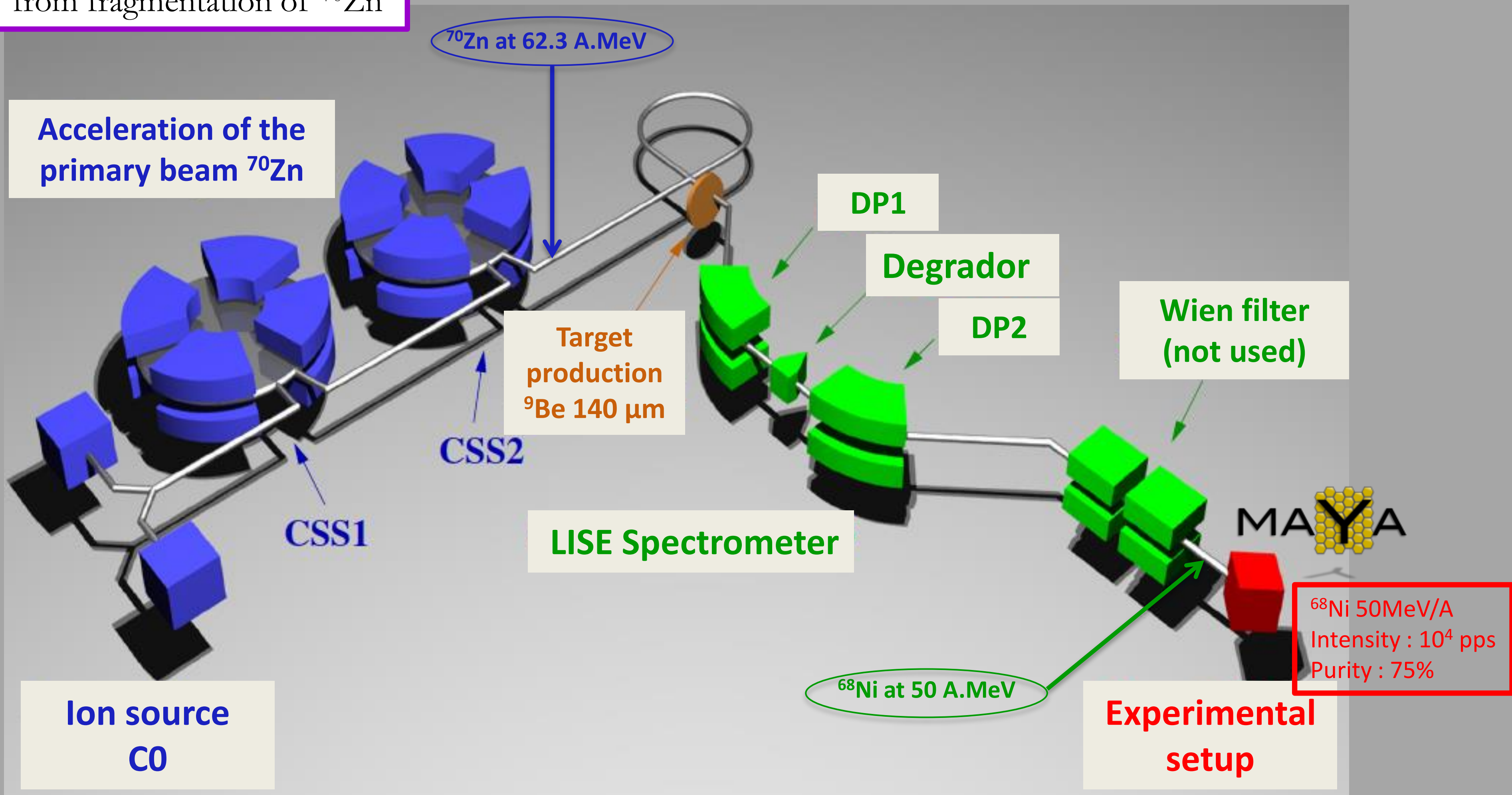
MAYA@LISE



Setup : the active target MAYA

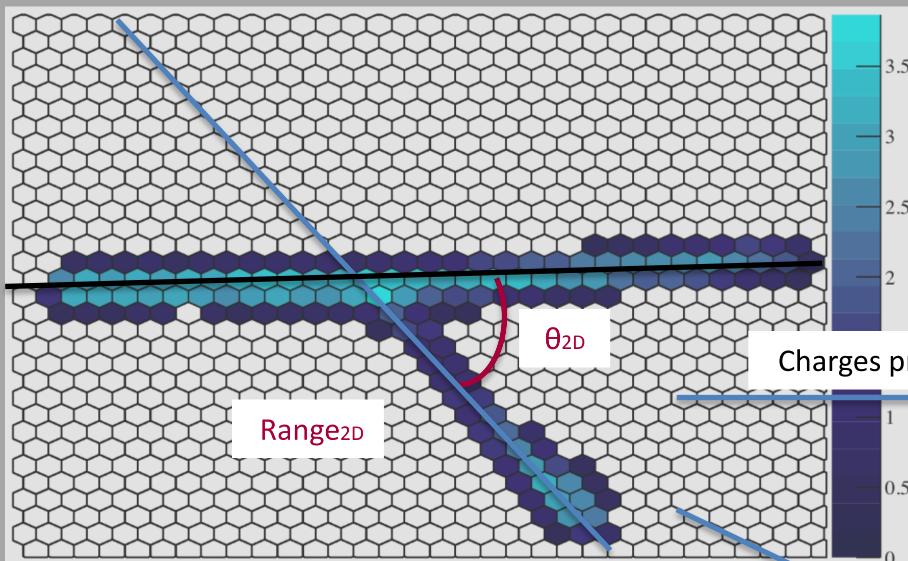
Production of the ^{68}Ni at GANIL

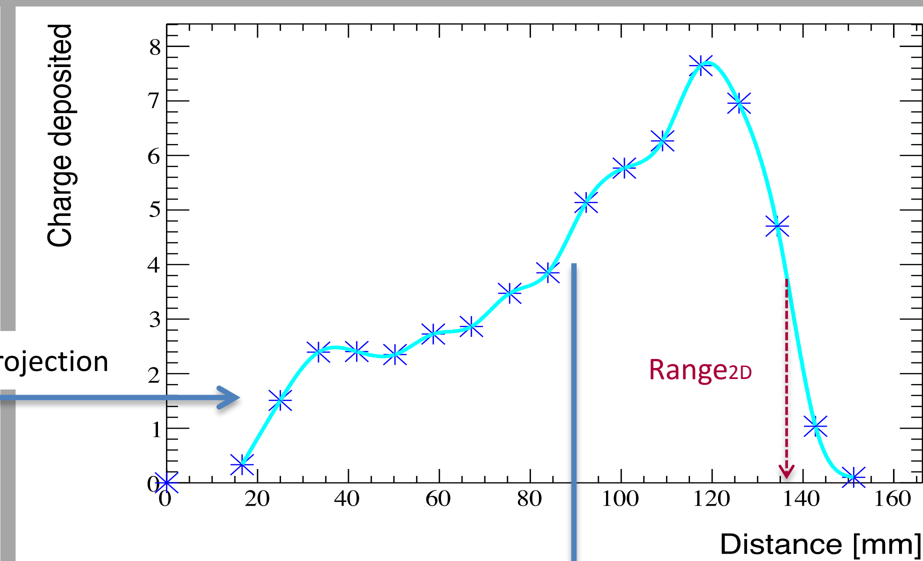
Production of ^{68}Ni beam from fragmentation of ^{70}Zn

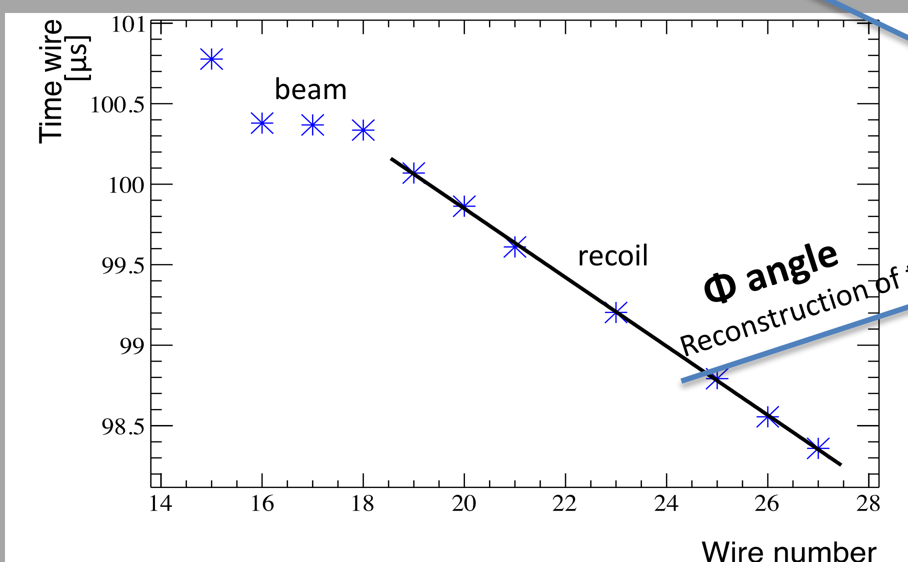


Results
Tracking reconstruction

T. Roger *et al.*, Nucl. Instrum. Meth. **638,** 134 (2011)







θ_{2D} angle

$Range_{2D}$

Φ angle

Reconstruction of the 3rd dimension

Range of the recoil α
and **θ**

SRIM

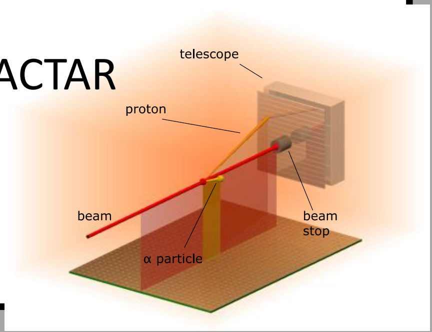
E_α and **θ**

2 bodies kinematics laws

E*(^{68}Ni) and θ_{CM}

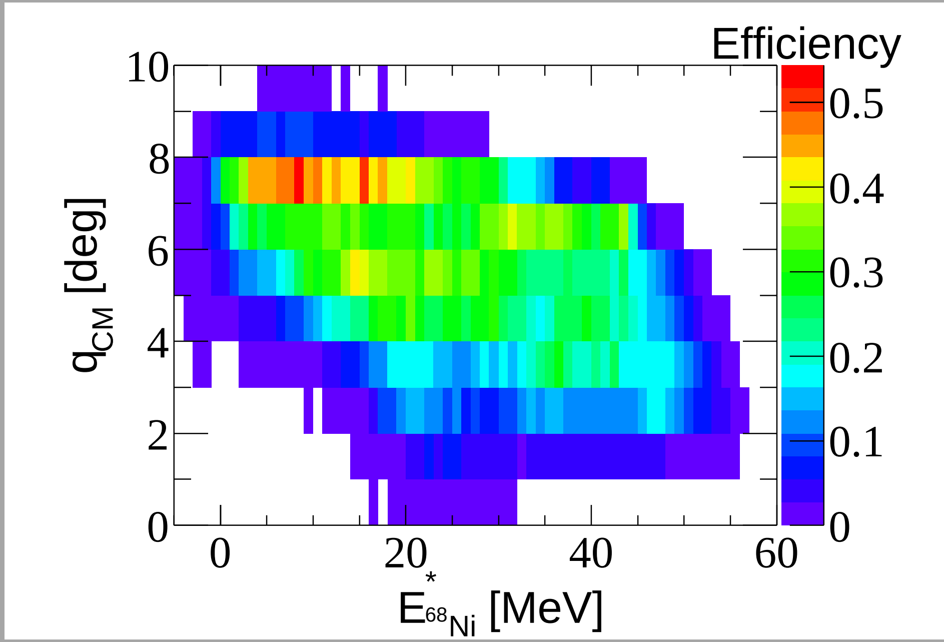
Results
Efficiency

- Geometric efficiency using ActarSim code (based on Geant4 and ROOT)
- Each simulated event is reconstructed with the code for physical events

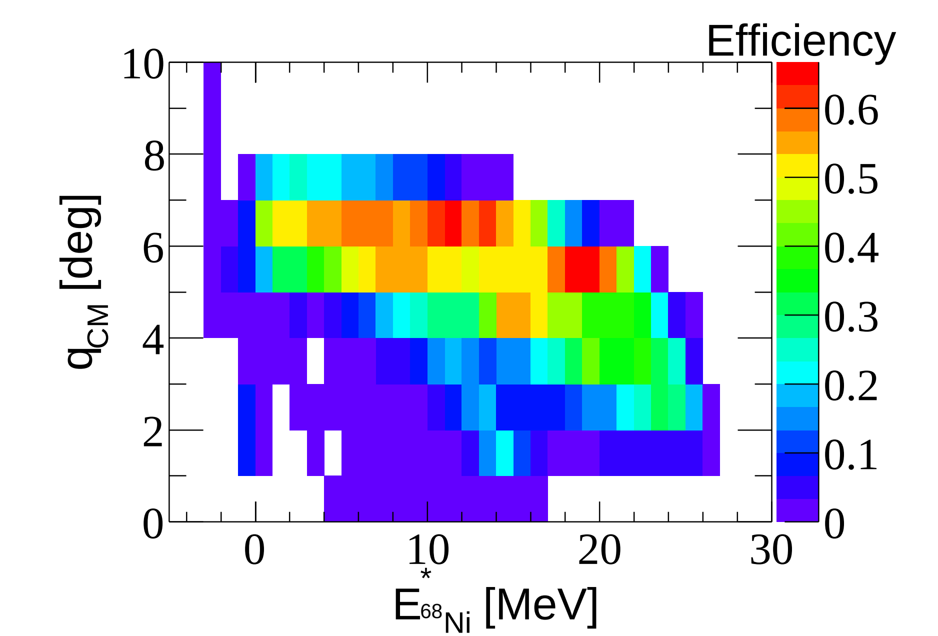


⇨ **Geometric** and **reconstruction** efficiency

$^{68}Ni(\alpha,\alpha')^{68}Ni^*$

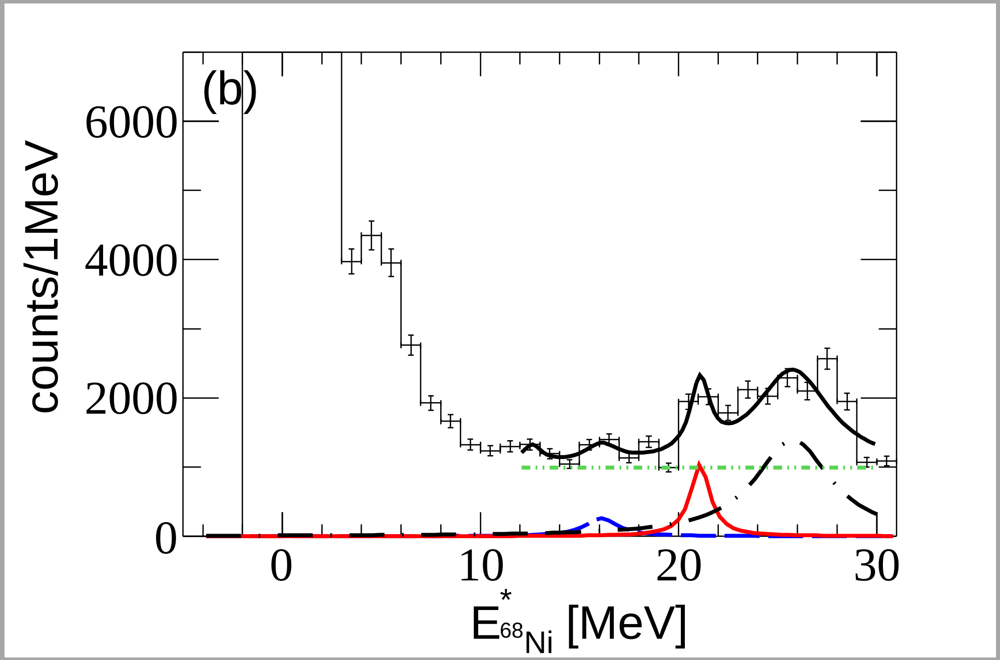


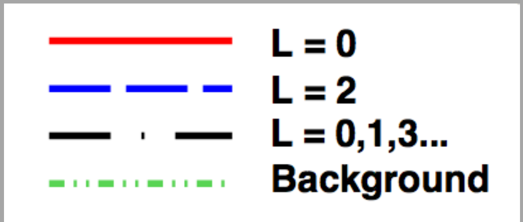
$^{68}Ni(d,d')^{68}Ni^*$



Results $^{68}Ni(\alpha,\alpha')^{68}Ni^*$

Excitation energy spectra

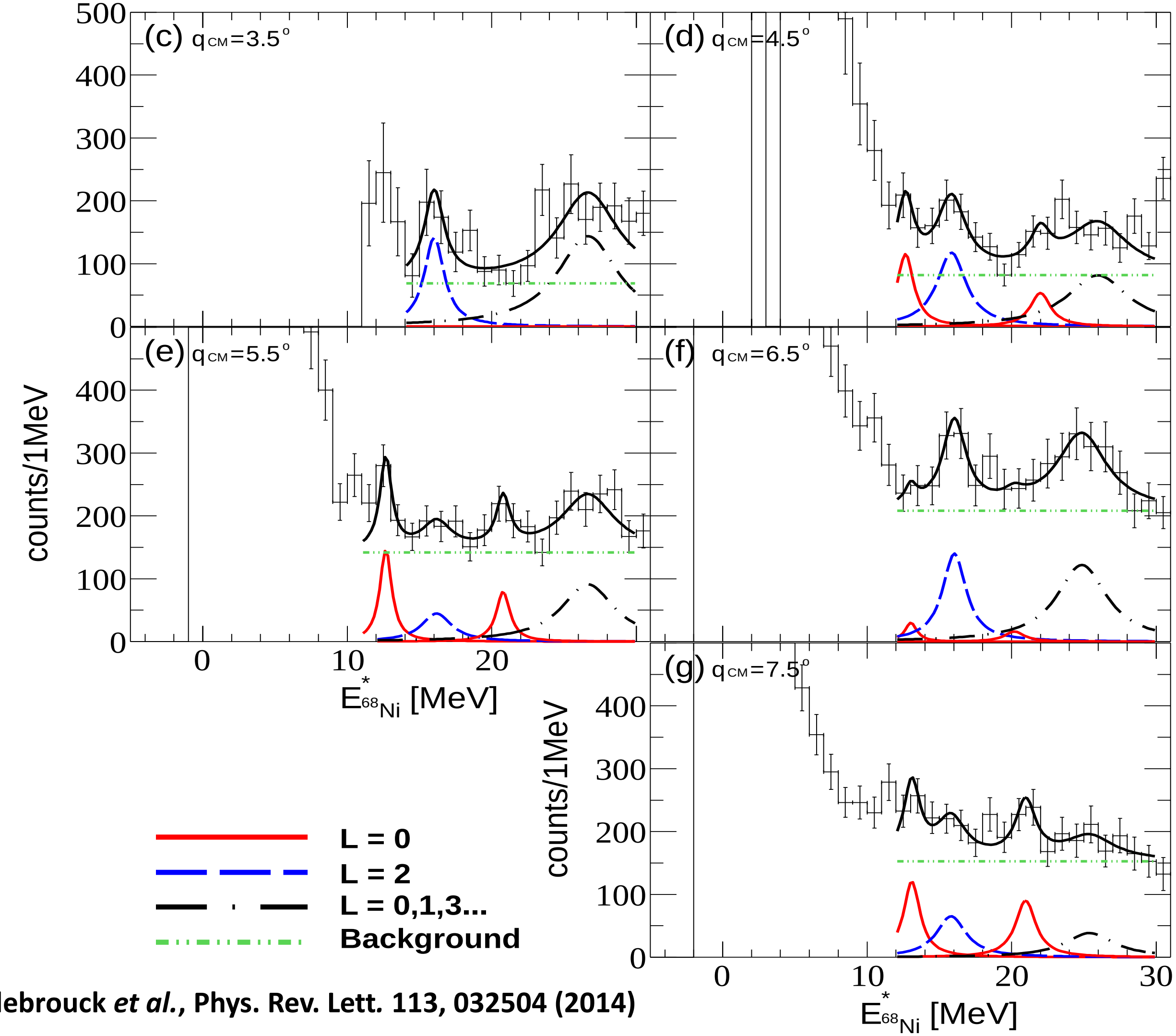




M. Vandebrouck *et al.*, Phys. Rev. Lett. 113, 032504 (2014)

Results $^{68}Ni(\alpha,\alpha')^{68}Ni^{*}$

Excitation energy spectra



M. Vandebrouck *et al.*, Phys. Rev. Lett. 113, 032504 (2014)

Results $^{68}Ni(\alpha,\alpha')^{68}Ni^*$

Excitation energy spectra

	Centroid (MeV)	FWHM (MeV)
Resonance 1	12.9±1.0	1.2±0.4
Resonance 2	15.9±1.3	2.3±1.0
Resonance 3	21.1±1.9	1.3±1.0

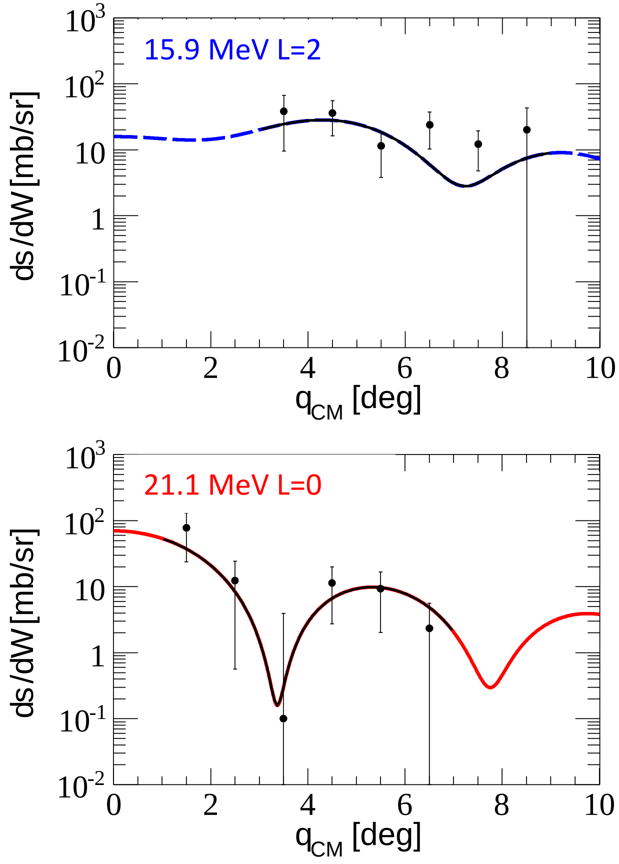
M. Vandebrouck *et al.*, Phys. Rev. Lett. 113, 032504 (2014)

Results $^{68}Ni(\alpha,\alpha')^{68}Ni*$

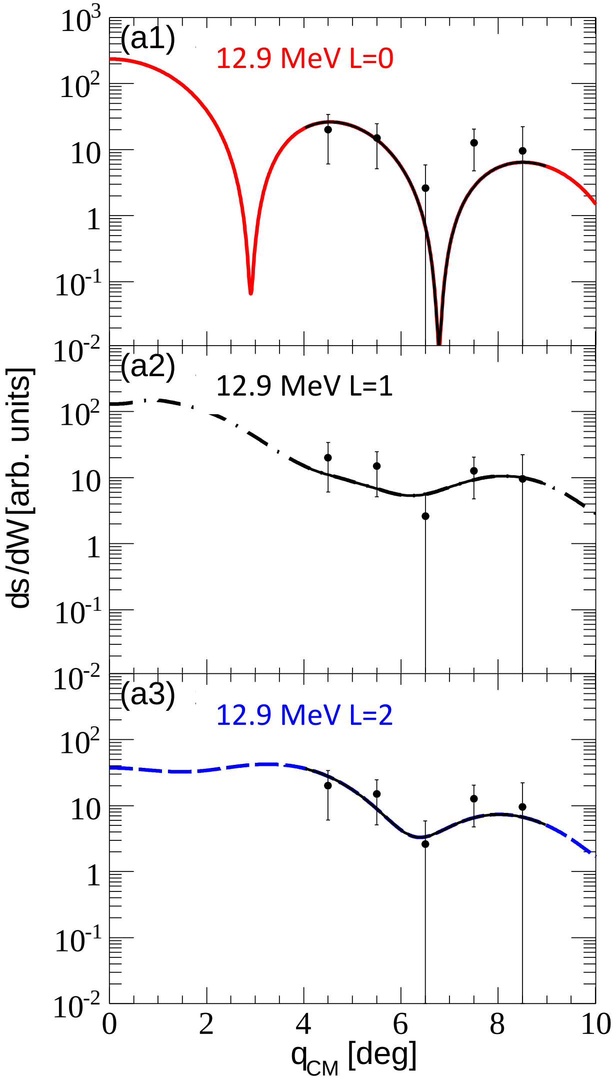
Angular distribution

ISGQR

ISGMR



M. Vandebrouck *et al.*, to be submitted

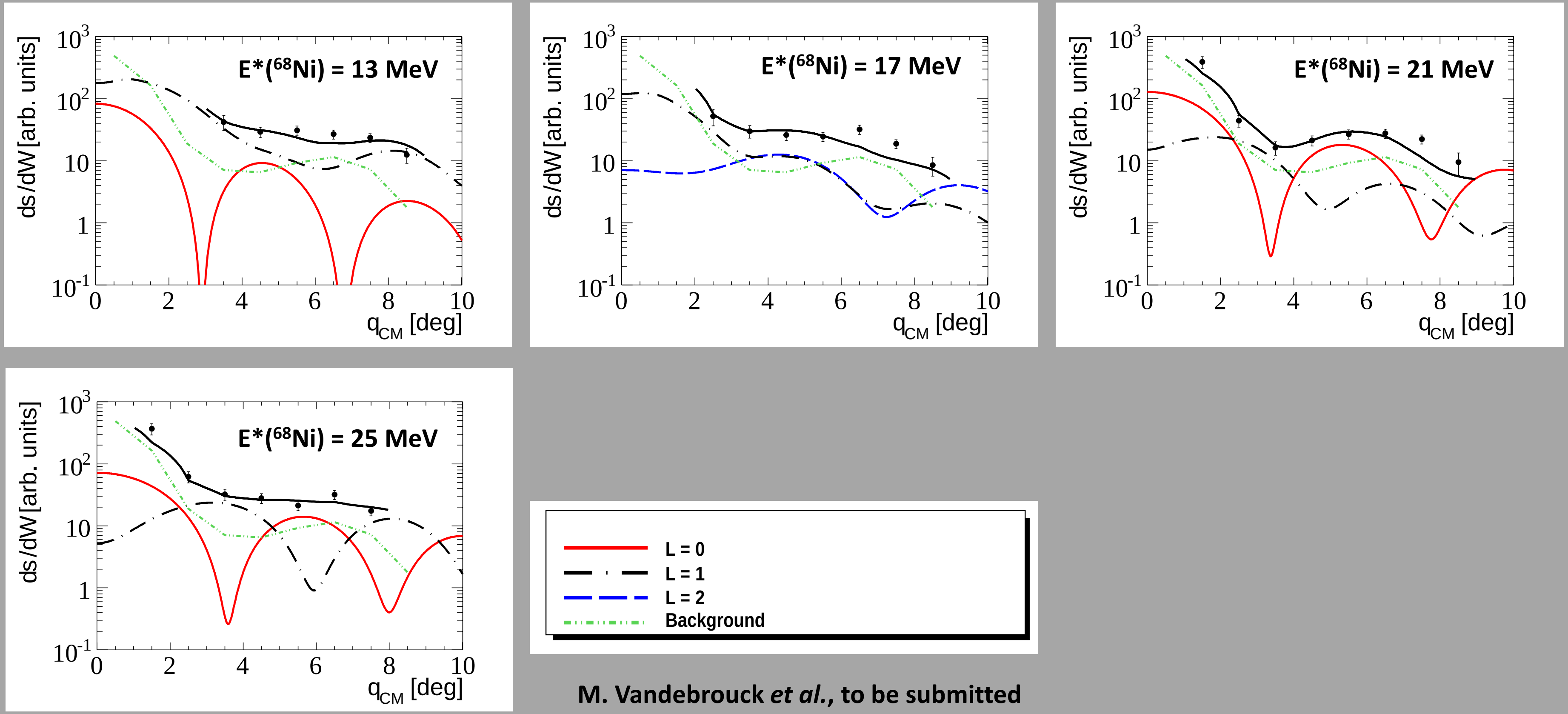


Soft ISGMR ?

Results $^{68}Ni(\alpha,\alpha')^{68}Ni^*$

Multipole Decomposition Analysis

$$\left.\frac{d\sigma}{d\Omega}\right|_{exp}(\theta_{CM},E^*) = \sum_{L=0}^{2} S_L(E^*)\left.\frac{d\sigma_L}{d\Omega}\right|_{theo}(\theta_{CM}) + \frac{d\sigma_{fond}}{d\Omega}(\theta_{CM})$$

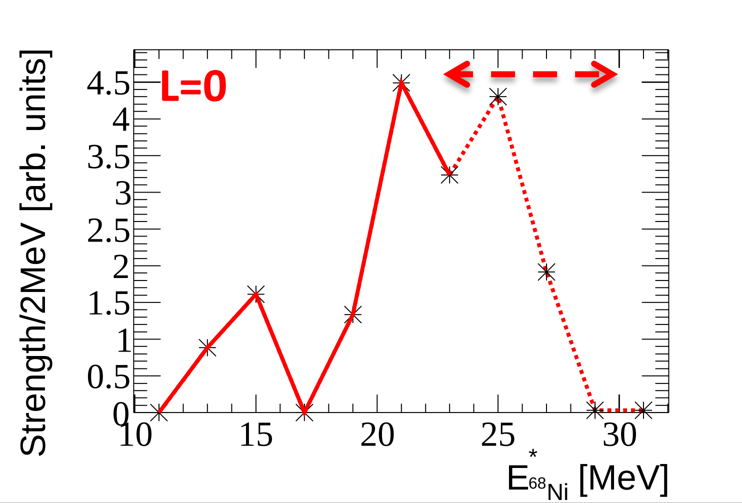


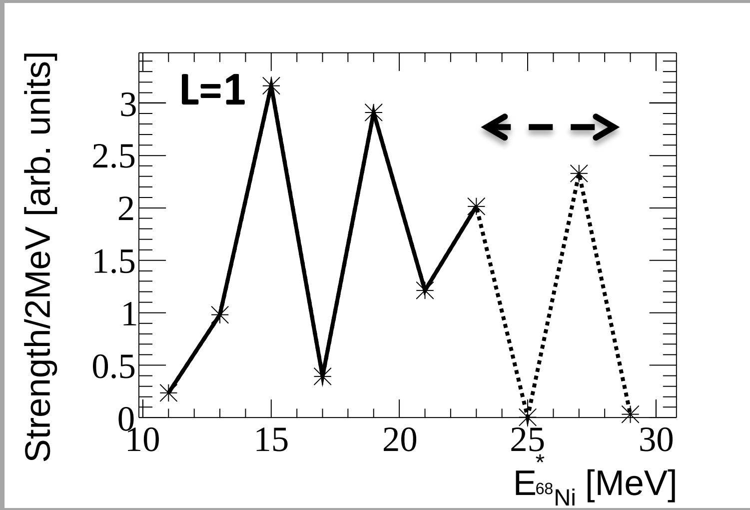
M. Vandebrouck *et al.*, to be submitted

Results $^{68}Ni(\alpha,\alpha')^{68}Ni^*$

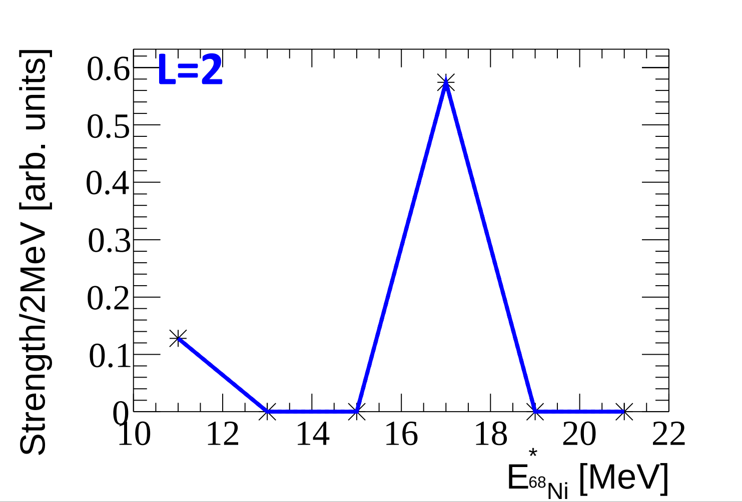
Multipole Decomposition Analysis

$$\left.\frac{d\sigma}{d\Omega}\right|_{exp}(\theta_{CM},E^*) = \sum_{L=0}^{2} S_L(E^*) \left.\frac{d\sigma_L}{d\Omega}\right|_{theo}(\theta_{CM}) + \frac{d\sigma_{fond}}{d\Omega}(\theta_{CM})$$





M. Vandebrouck *et al.*, to be submitted

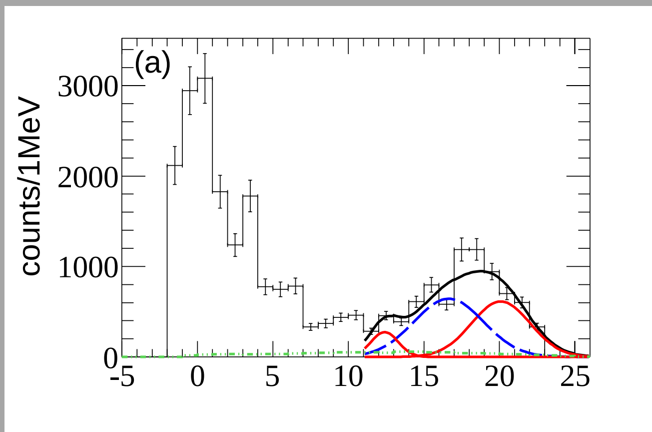


Résultats

- **L = 0** : - fragmentation of the ISGMR with a shoulder at 21 MeV
  - increase of the strenght at 13 MeV
- **L = 1** : - increase of the strenght at 21MeV and below 15MeV
- **L = 2** : - concentration of the strenght around 16 MeV
- From 23 MeV other multipolarities…

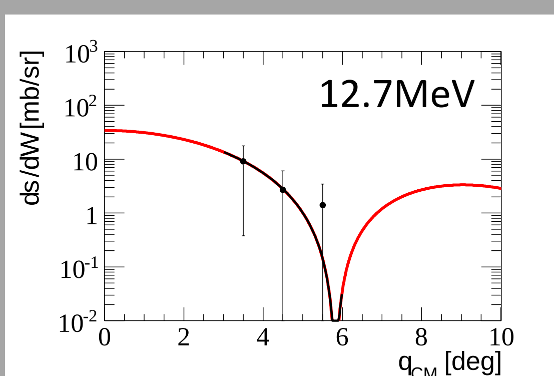
Results $^{68}Ni(d,d')^{68}Ni^*$

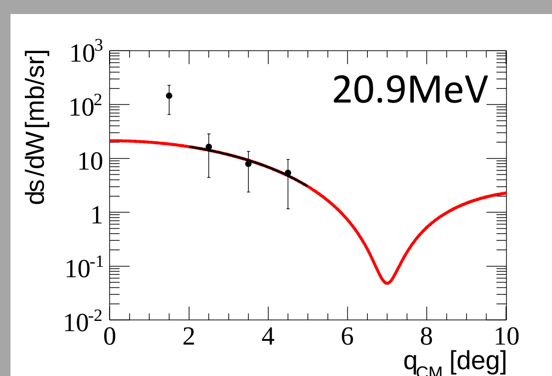
Fitting method



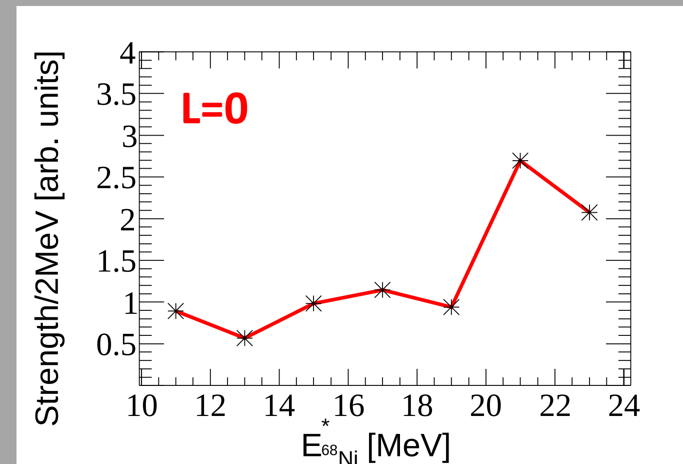
L = 0
L = 2
Background

	Centroid (MeV)	FWHM (MeV)
Resonance 1	12.7±0.3	2.2±0.5
Resonance 2	16.5±2.0	4.3±2.6
Resonance 3	20.9±1.0	4.4±0.5





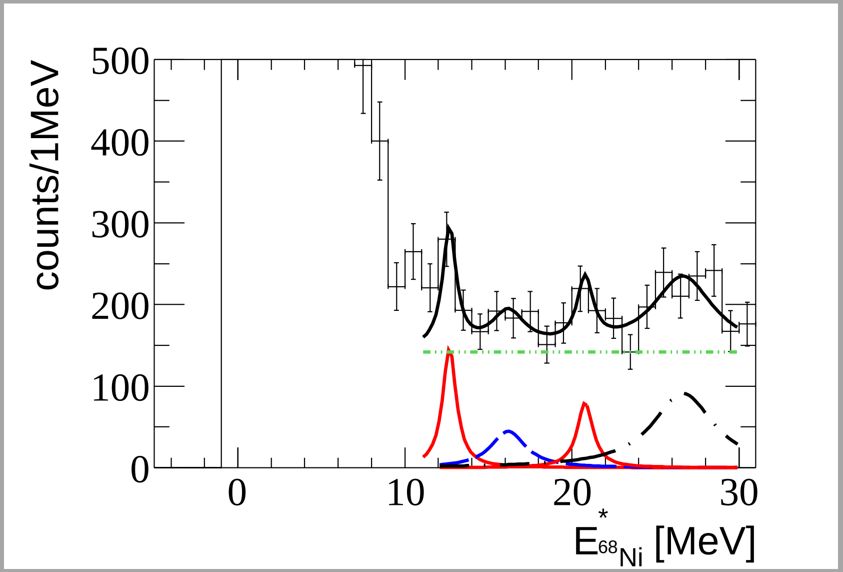
Multipole Decomposition Analysis (MDA)



M. Vandebrouck *et al.*, to be submitted

Results

Synthesis



Soft ISGMR

Mixed with **ISGDR**
12.9 ± 1.0 MeV in (α,α')
12.7 ± 0.3 MeV in (*d,d'*)

ISGQR
15.7 ± 1.0 MeV in (α,α')
16.5 ± 2.0 MeV in (*d,d'*)

ISGMR

Fragmented strength with a shoulder at :
21.1 ± 1.9 MeV in (α,α')
20.9 ± 1.0 MeV in (*d,d'*)

Conclusion and outlook

Conclusion

- Measurement of the isoscalar strength in ^{68}Ni
- Study of inelastic scattering ***^{68}Ni(α,α')^{68}Ni**** and ***^{68}Ni(d,d')^{68}Ni**** with MAYA active target

  ↳ First use of MAYA with the mixture (He + CF_4)

  Better statistics in ***(α,α')***

- 2nd measurement of ISGR in an exotic nuclei : - Study of isotopic chain including exotic nuclei
  - GR with active target

Outlook

Active target development

- Active target adapted for GR studies
- ACTAR + GET development

Isoscalar monopole strength in exotic nuclei

- Study in heavier nuclei

Collaboration

J. Gibelin[2], E. Khan[1], N.L. Achouri[2], H. Baba[3], D. Beaumel[1], Y. Blumenfeld[1], M. Caamaño[4], L. Càceres[5], G. Colò[6], F. Delaunay[2], B. Fernandez-Dominguez[4], U. Garg[7], G.F. Grinyer[5], M.N. Harakeh[8], N. Kalantar-Nayestanaki[8], N. Keeley[9], W. Mittig[10], J. Pancin[5], R. Raabe[11], T. Roger[11,5], P. Roussel-Chomaz[12], H. Savajols[5], O. Sorlin[5], C. Stodel[5], D. Suzuki[10,1], J.C. Thomas[5].

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