Measurements of the isoscalar monopole response in the neutron-rich nucleus ^{68}Ni

Introduction
Motivations
Setup : the active target MAYA
Results
Conclusion and outlook

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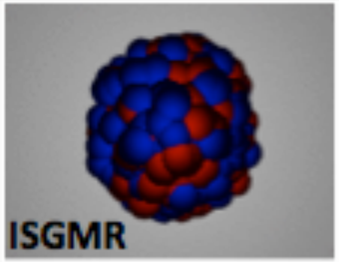
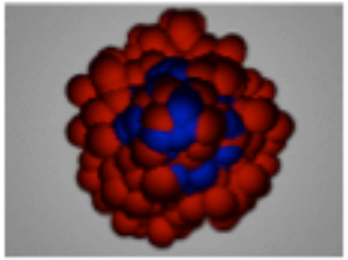
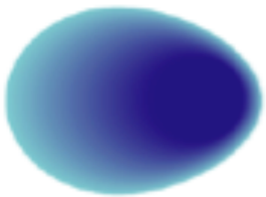
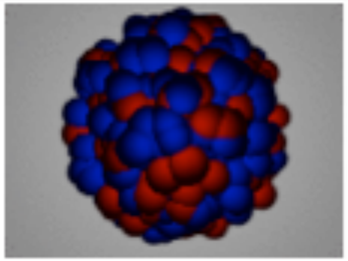
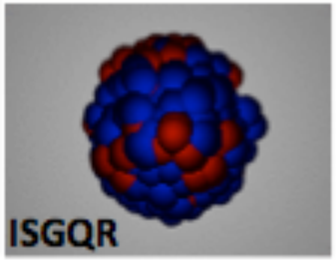
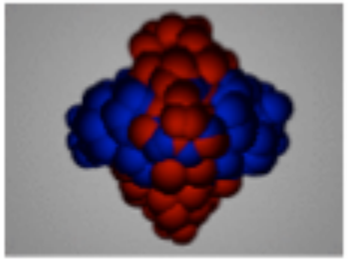
What are giant resonances ?

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

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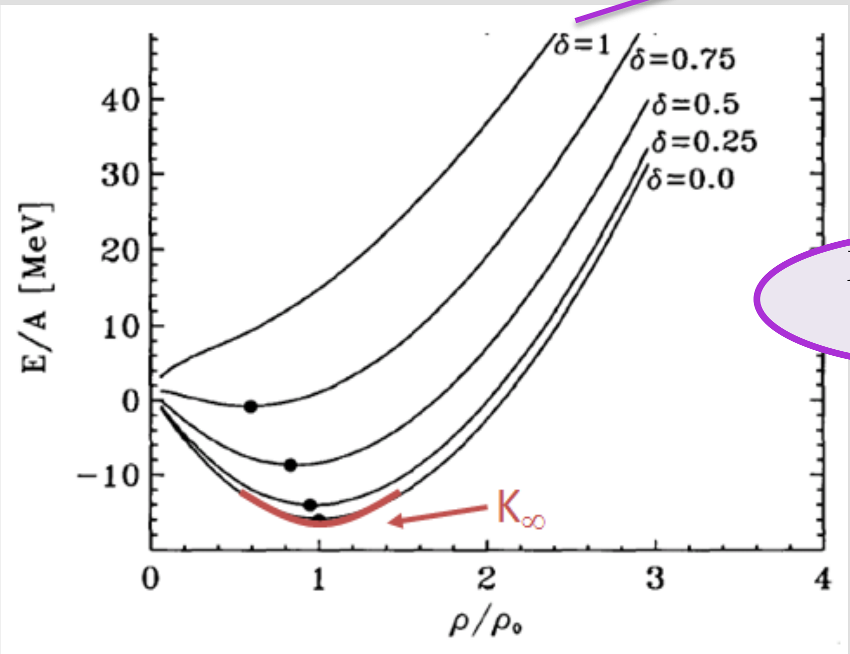
Motivations Nuclear matter incompressibility and ISGMR

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

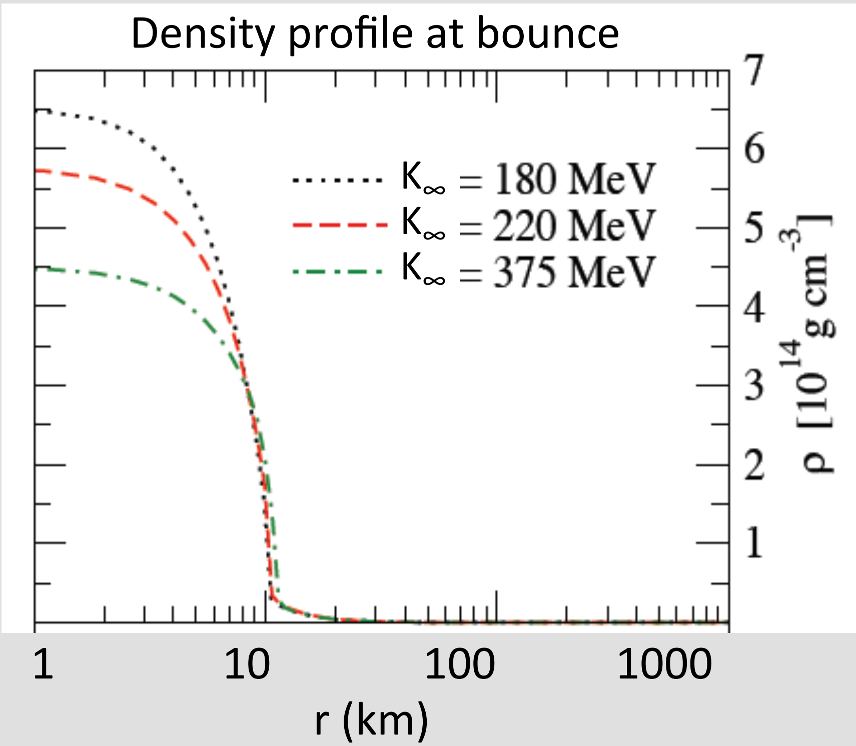
Determination of the nuclear matter incompressibility $\mathbf{K_\infty}$

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.

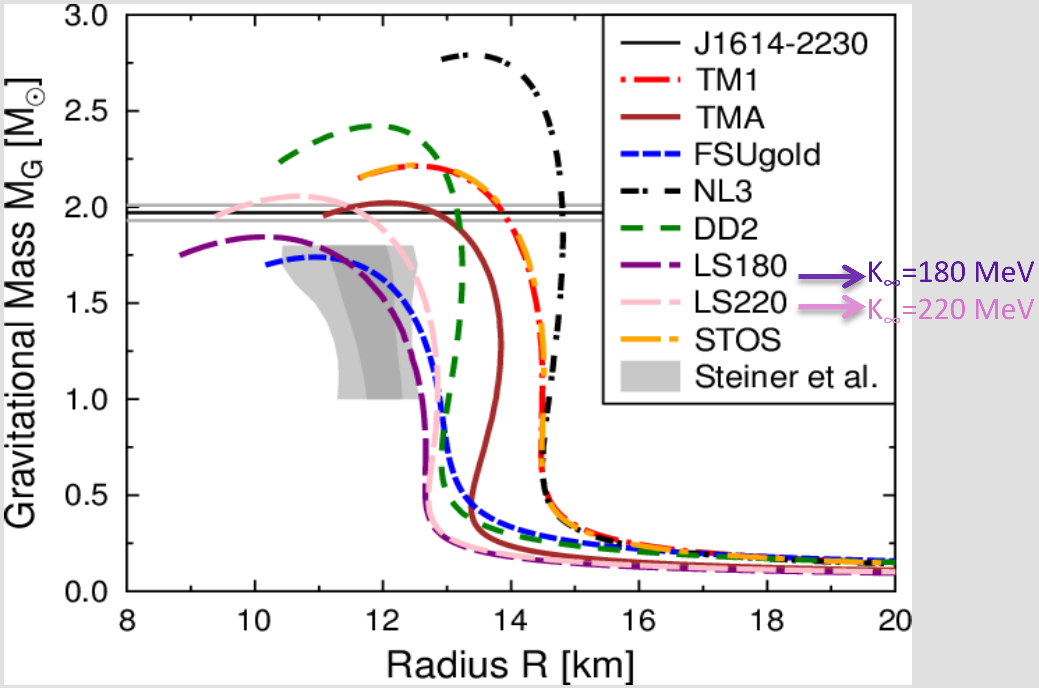
Motivations Nuclear matter incompressibility and ISGMR

In supernovae bounce



A. Fantina PhD (2010) IPNO-IAA

In neutron stars

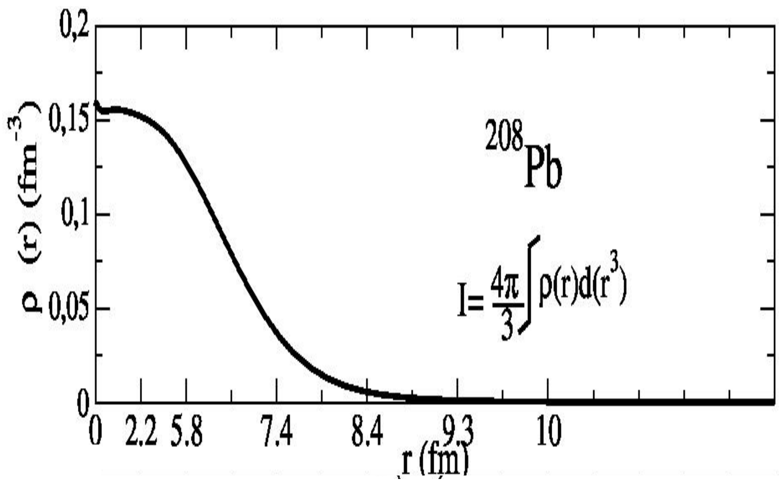


M. Hempel ITP Franckfurt

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_∞

⇩

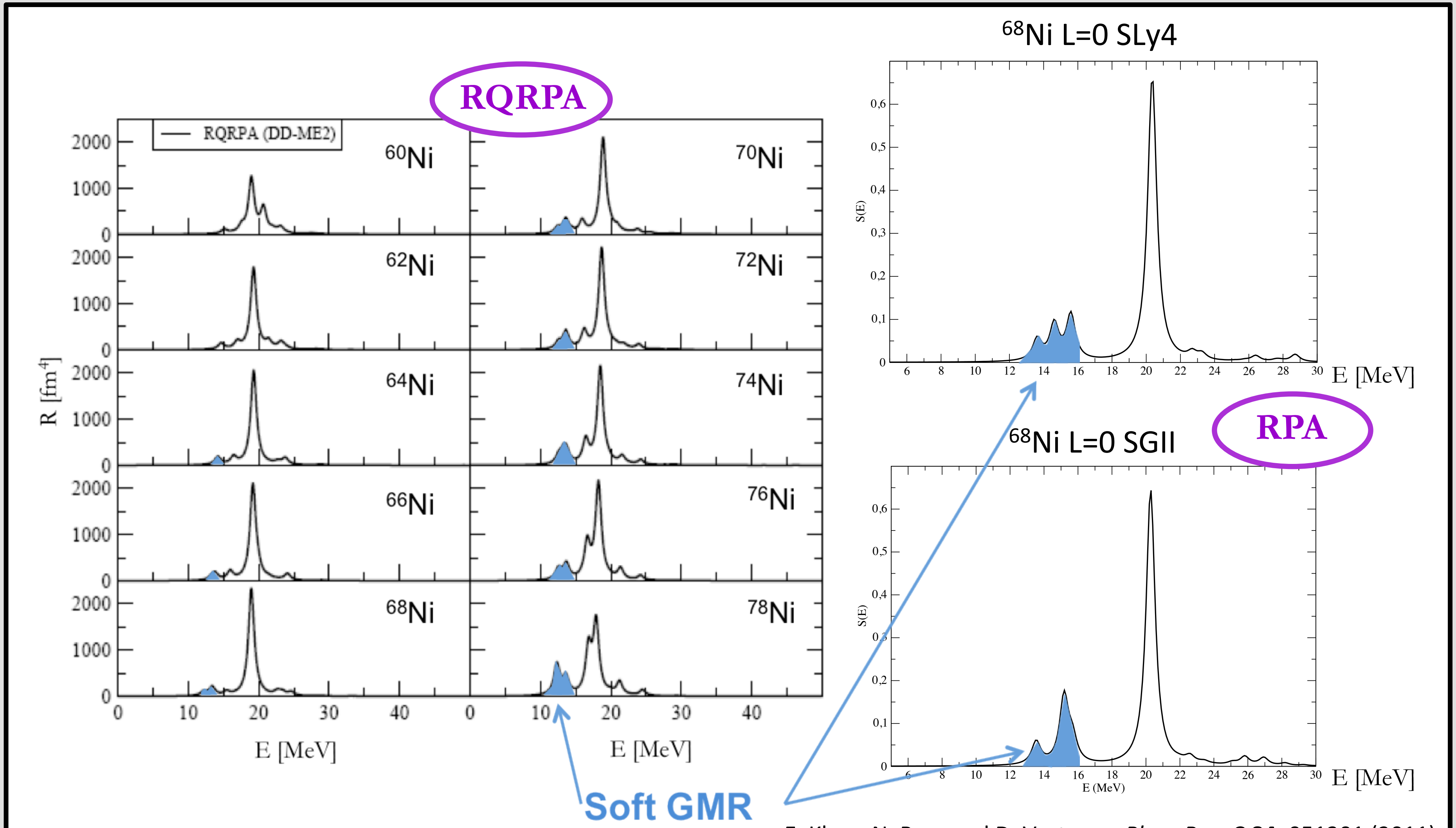
Need measurement of E^*_{GMR} along isotopic

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



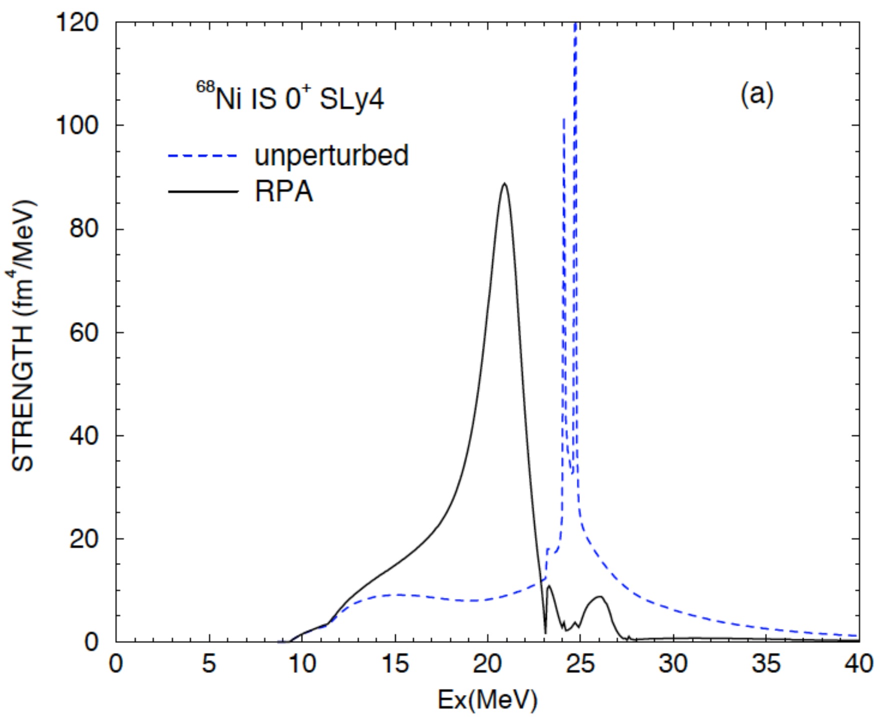
E. Khan, N. Paar and D. Vretenar, *Phys. Rev.* **C 84**, 051301 (2011)

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

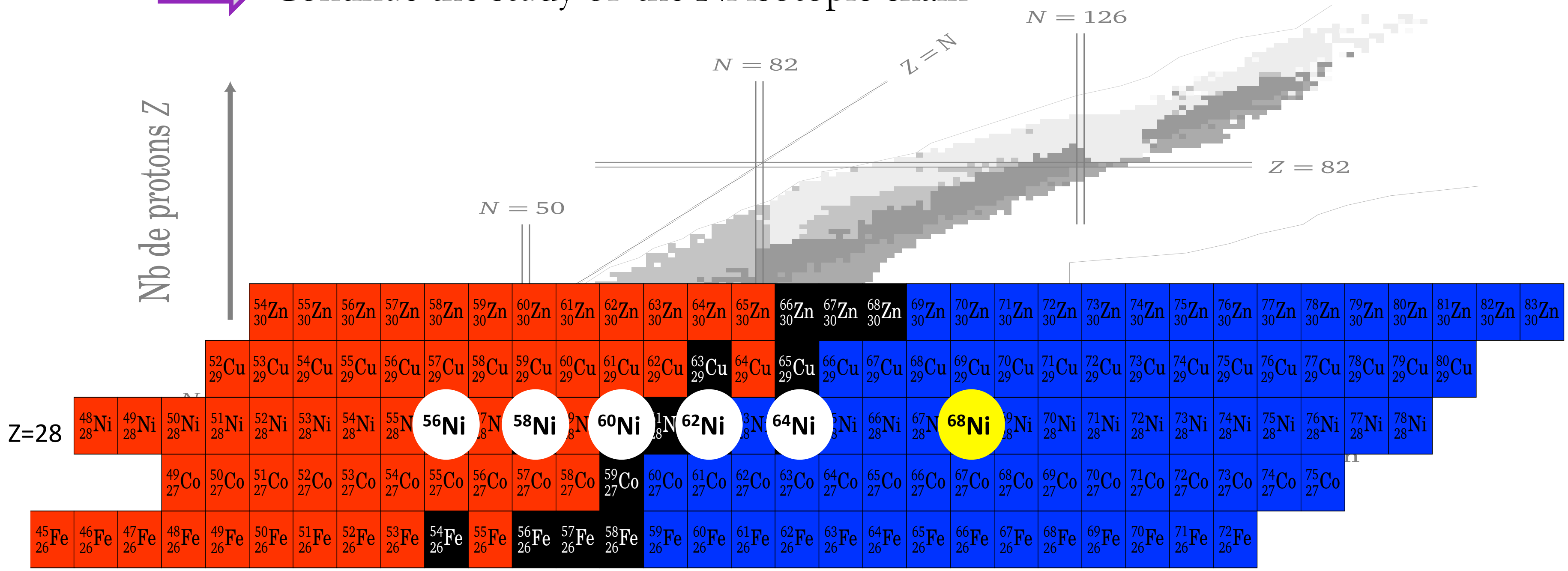


I. Hamamoto and H. Sagawa, Phys. Rev. **C 90,** 031302(R) (2014)

- 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

Measurements of the isoscalar monopole response in the neutron-rich nucleus ^{68}Ni

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- **Setup : the active target MAYA**
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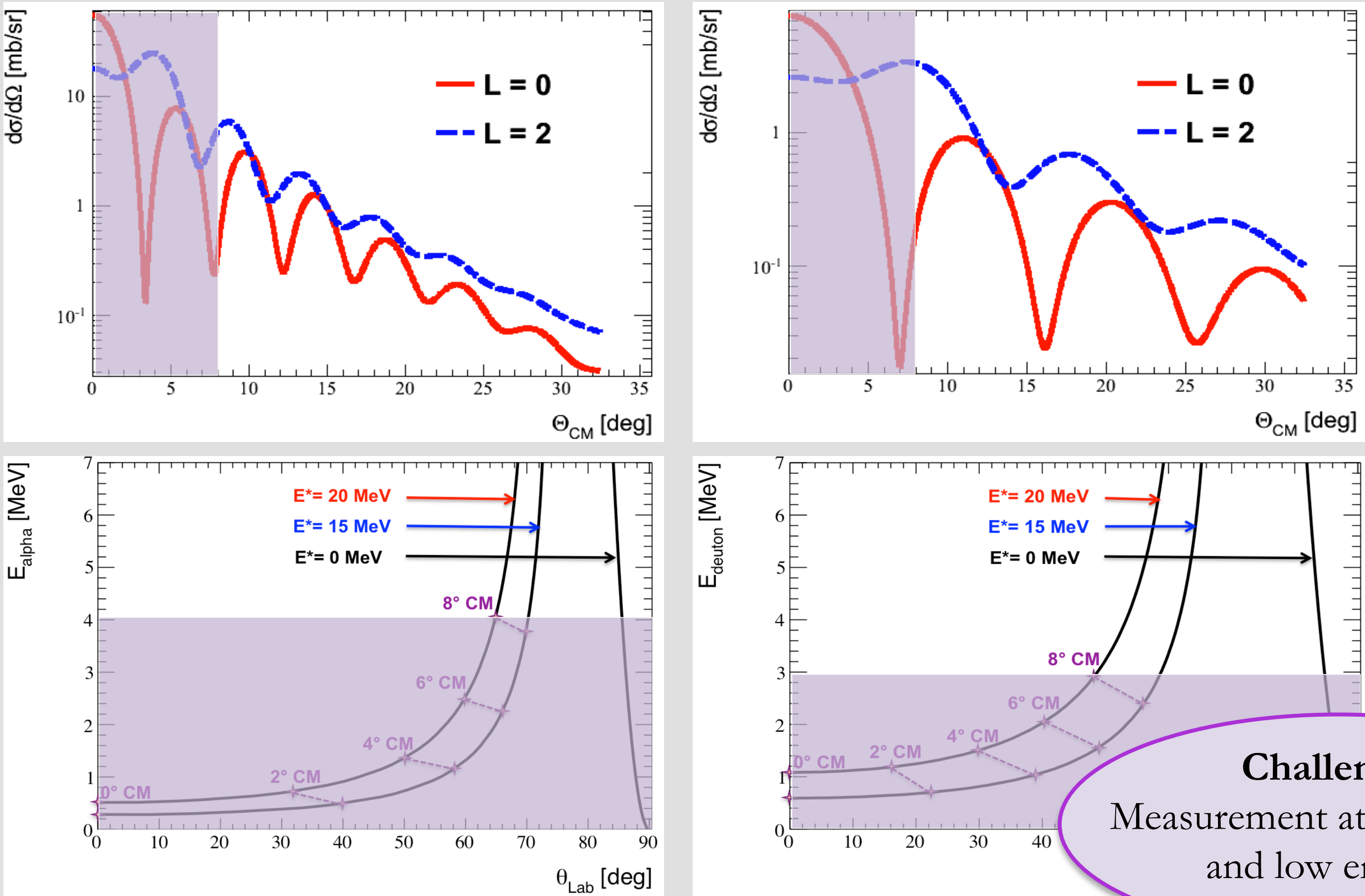
Setup: the active target MAYA why?

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

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



Challenge :
Measurement at small angles and low energies

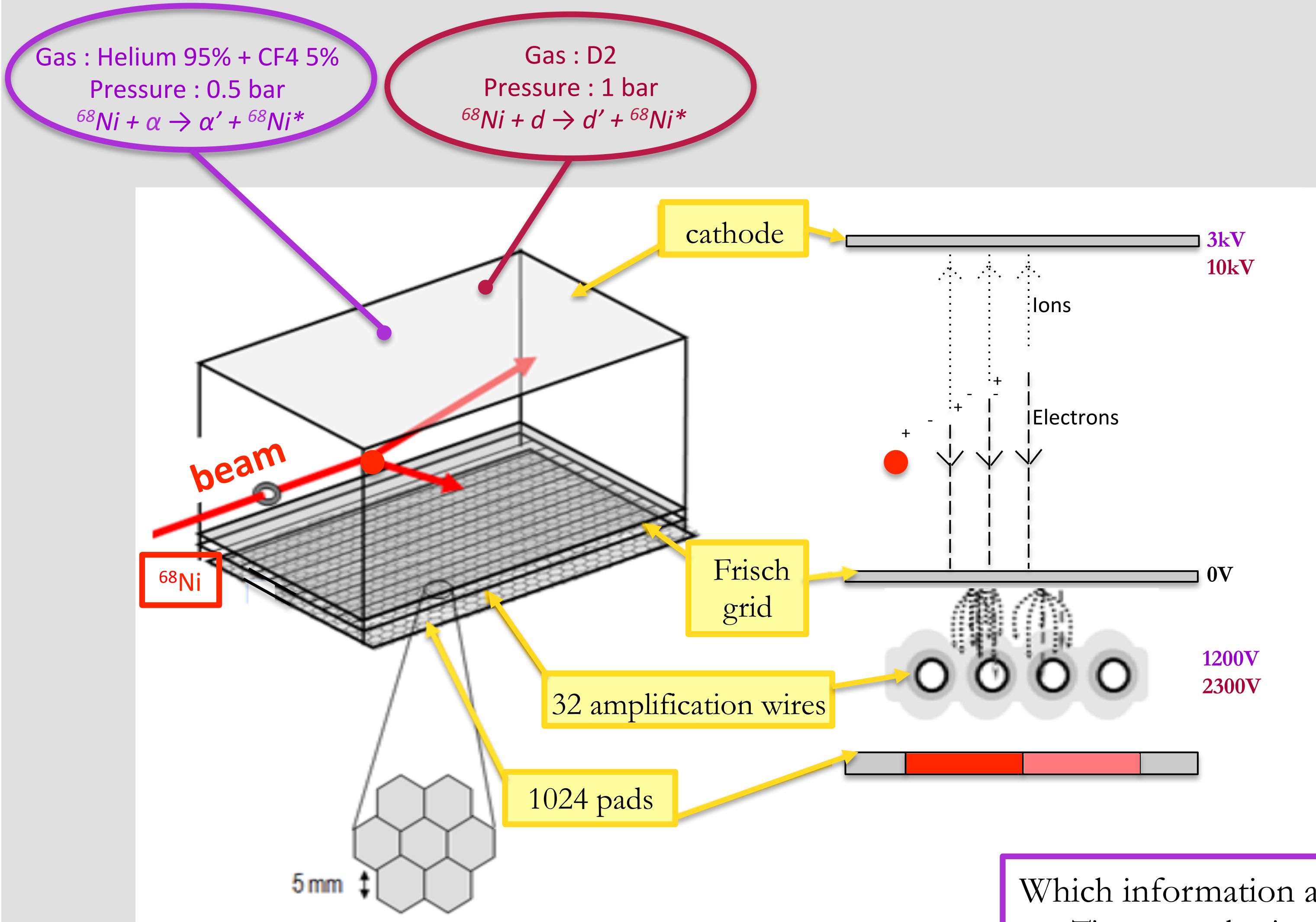
We have to consider :
- Inverse kinematics with a low recoiling energy
- Low production rate

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

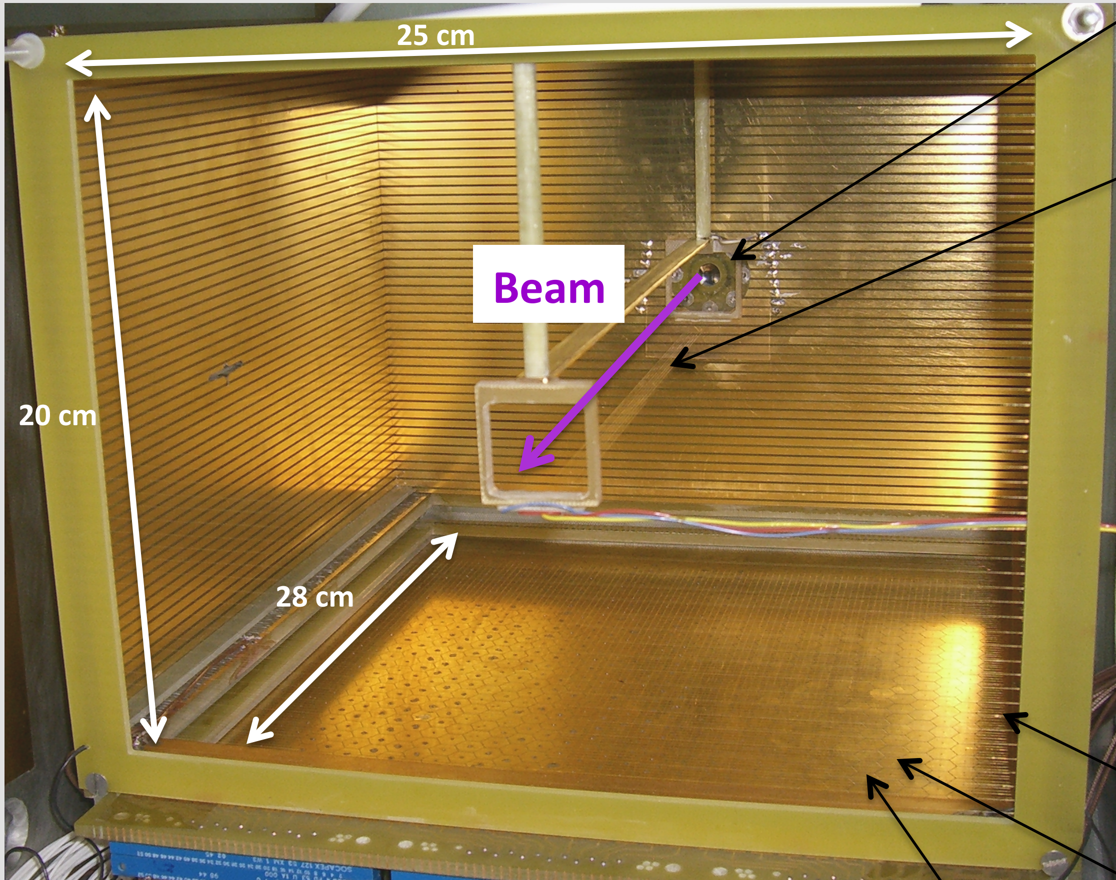
2. The electrons drift towards the Frisch grid

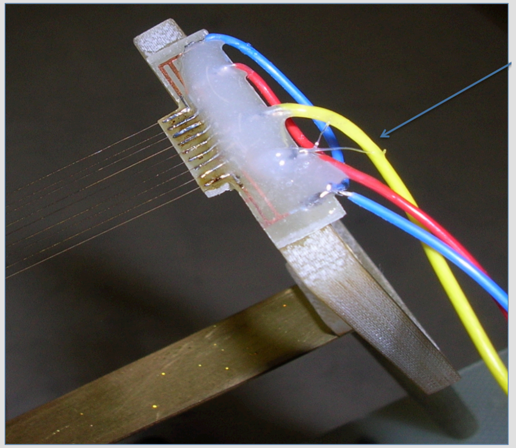
3. Amplification on the wires

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

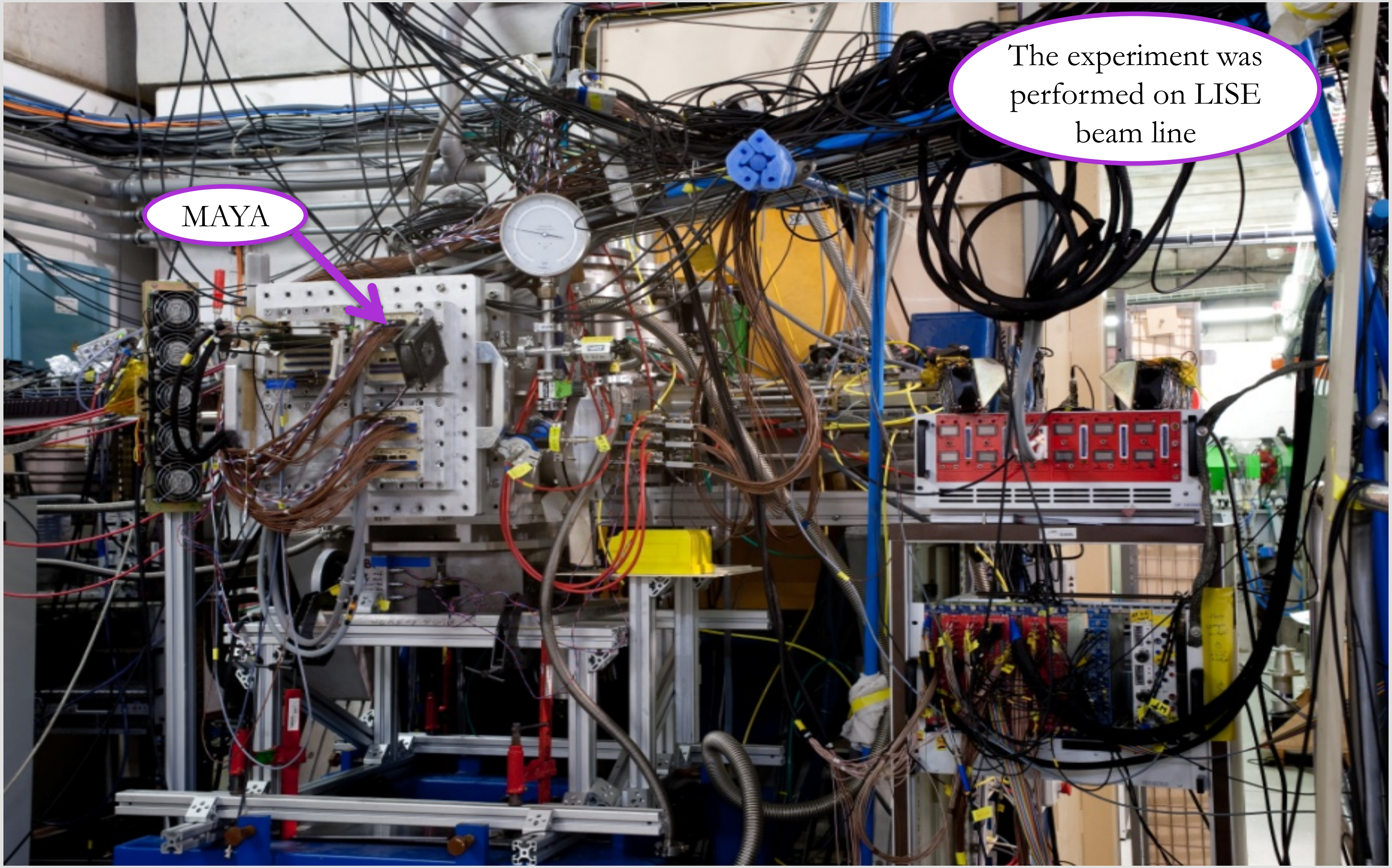
Setup: the active target MAYA MAYA@LISE





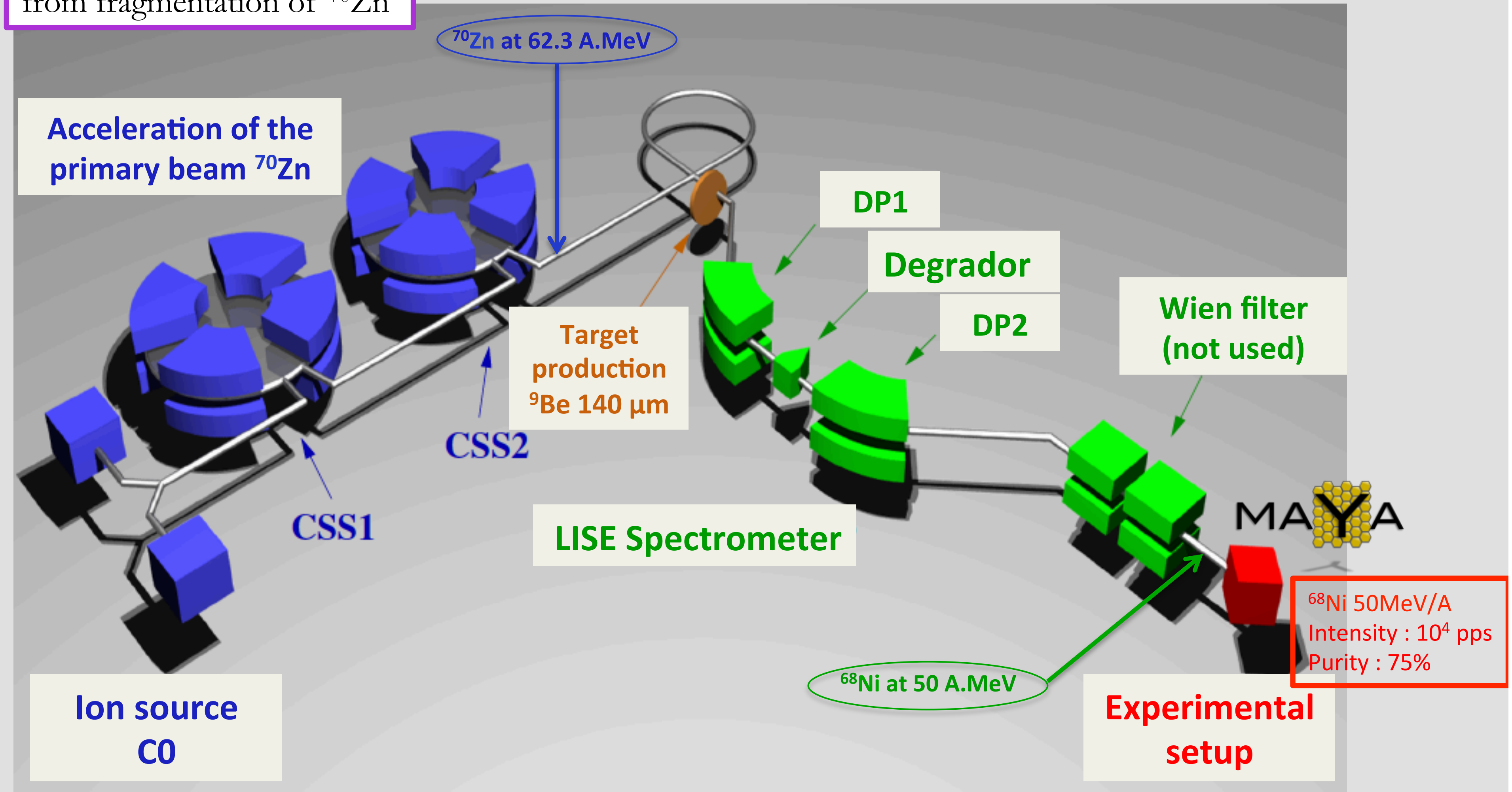
J. Pancin *et al., JINST* **7,** P01006 (2012)

Setup: the active target MAYA MAYA@LISE



Setup: the active target MAYA Production of the ^{68}Ni @GANIL

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



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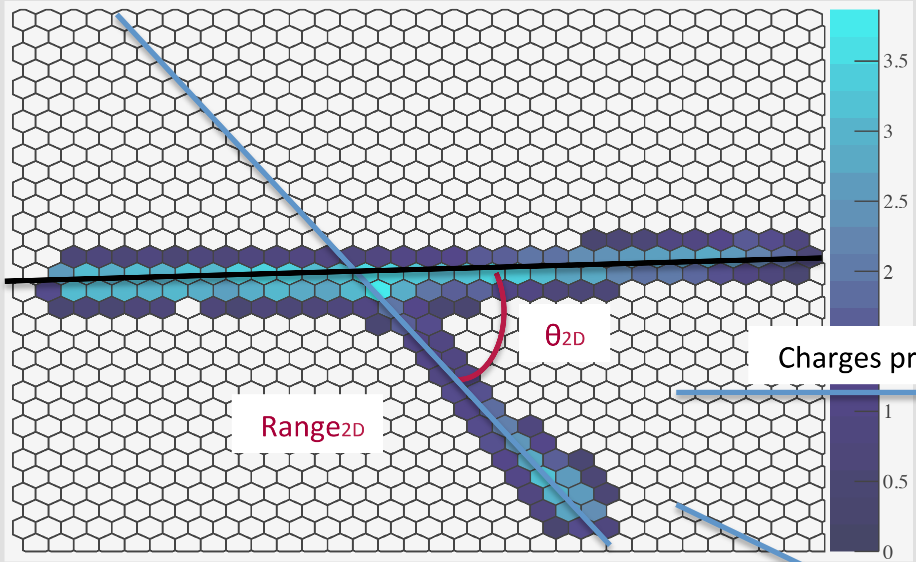
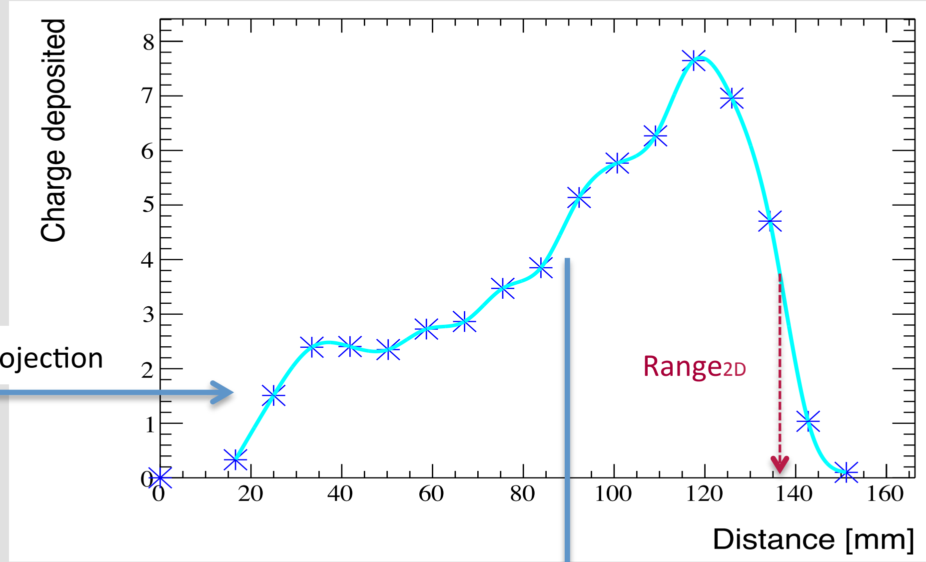
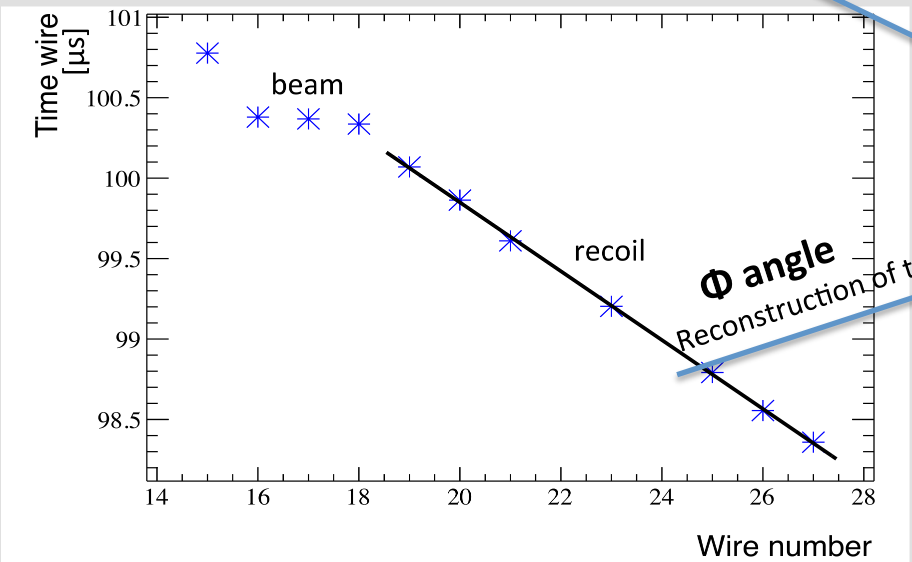
Results Tracking reconstruction

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







Φ angle

Reconstruction of the 3rd dimension

θ_{2D} angle

$Range_{2D}$

Range of the recoil α,d
and **θ**

↓ SRIM

E_α and **θ**

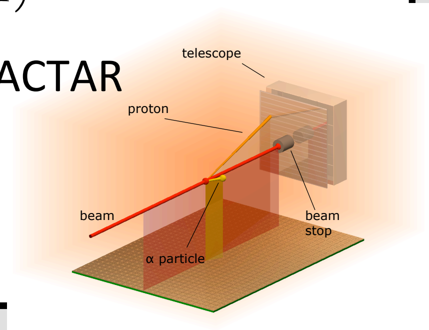
↓ 2 bodies kinematics laws

E*(^{68}Ni) and **θ_{CM}**

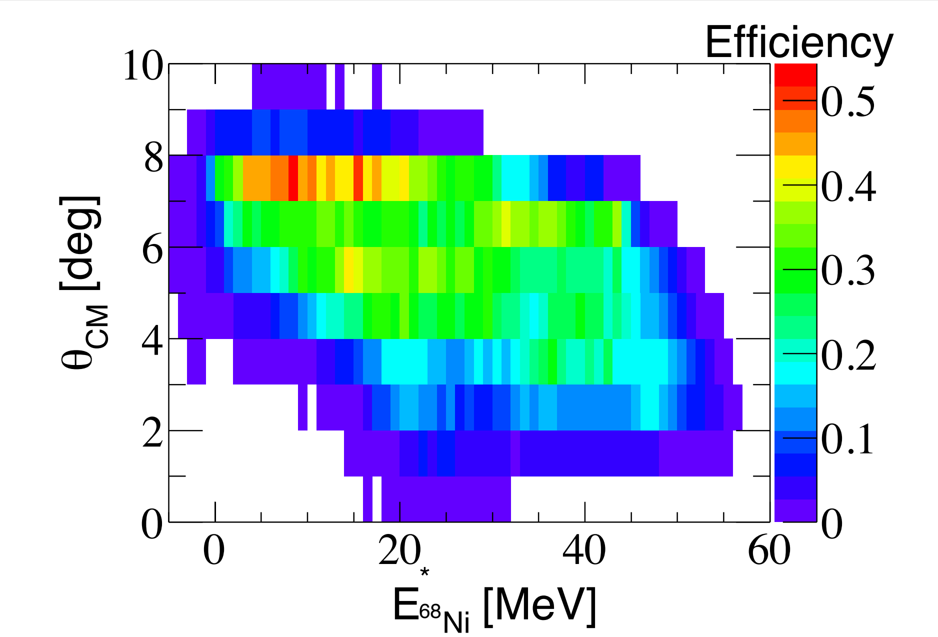
Results Efficiency

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

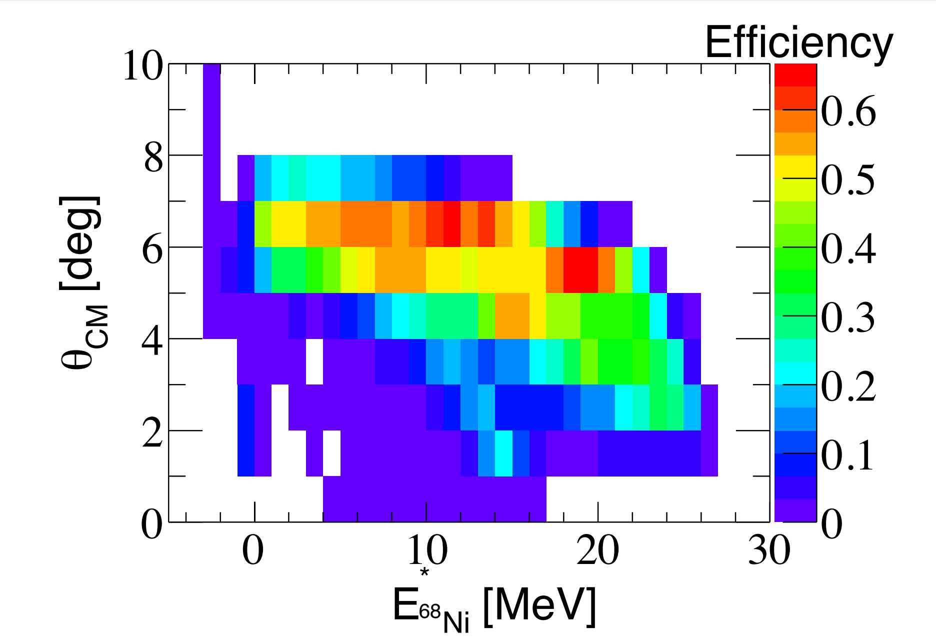
⇨ **Geometric** and **reconstruction** efficiency



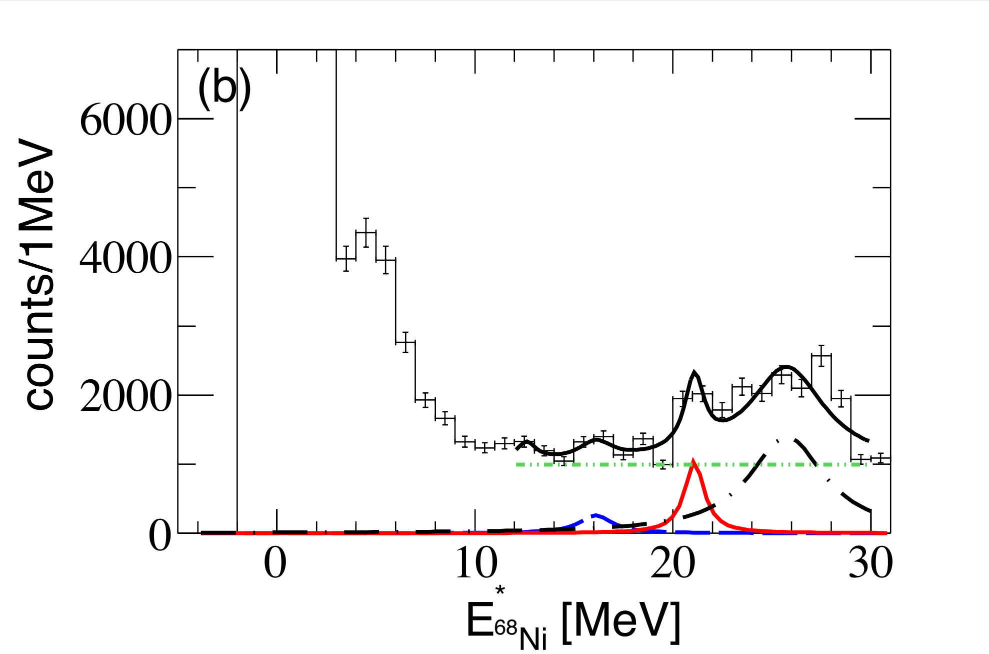
$^{68}Ni(\alpha,\alpha')^{68}Ni^*$

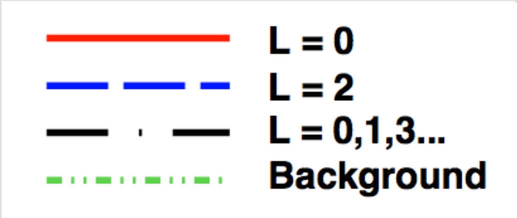


$^{68}Ni(d,d')^{68}Ni^*$



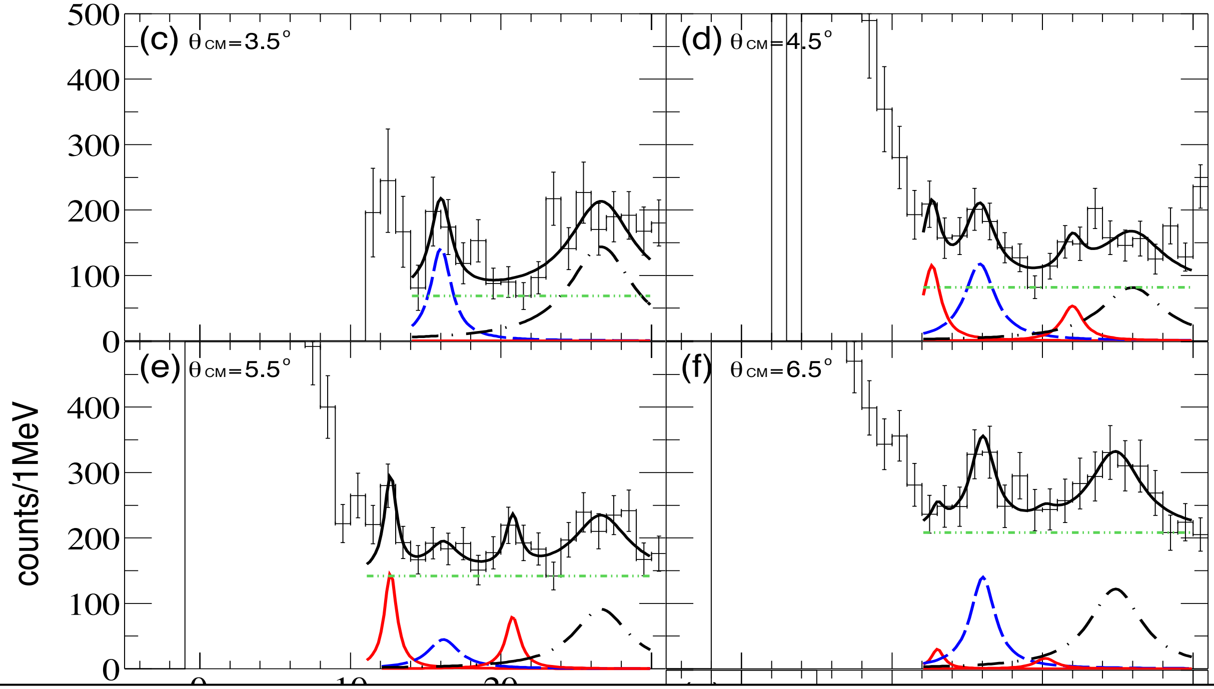
Results $^{68}Ni(\alpha,\alpha')^{68}Ni^*$ Excitation energy spectra





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

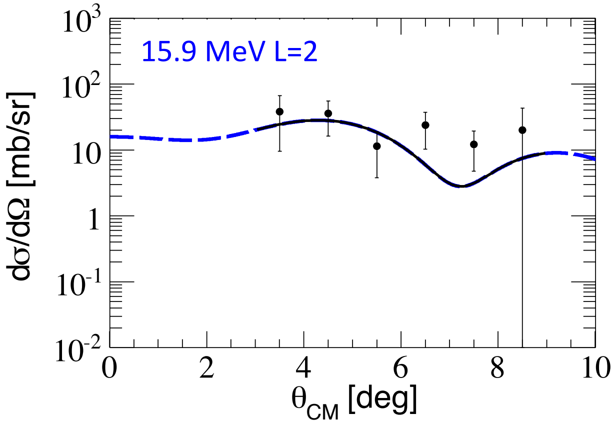
Results $^{68}Ni(\alpha,\alpha')^{68}Ni^*$ Excitation energy spectra



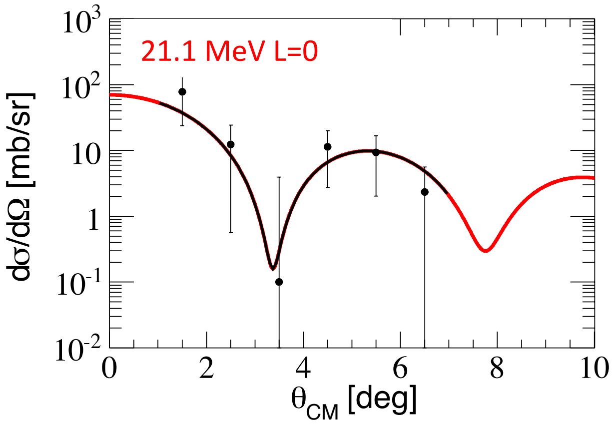
	Centroid (MeV)	FWHM (MeV)
Resonance 1	12.9±1.0	1.2±0.4
Resonance 2	15.9±1.3	2.3±1.0
Resonance 3	21.1±1.9	1.3±1.0

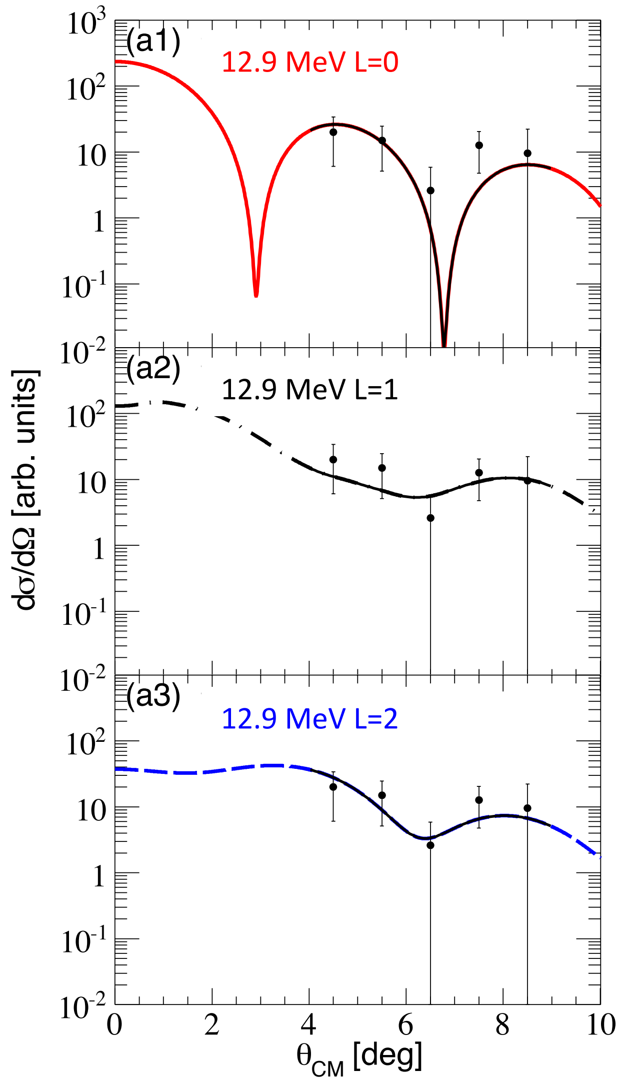
Results $^{68}Ni(\alpha,\alpha')^{68}Ni^{*}$ Angular distribution

ISGQR



ISGMR



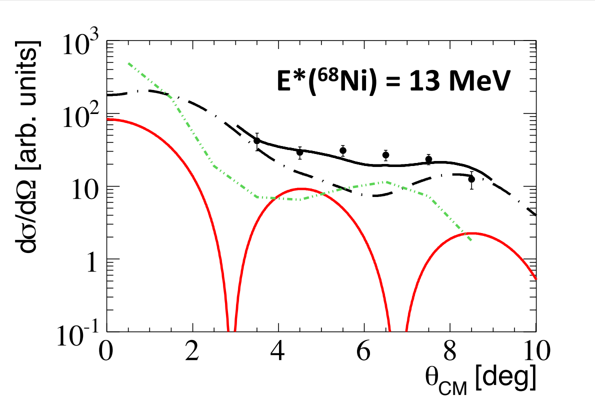


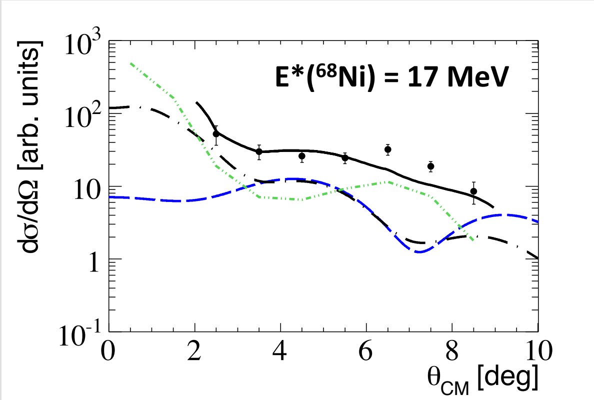
Soft ISGMR ?

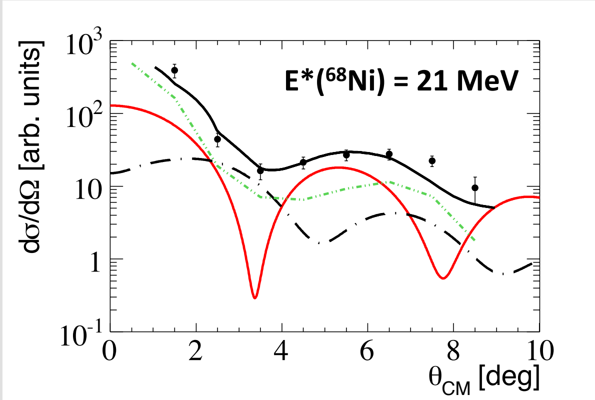
M. Vandebrouck *et al.*, Phys. Rev. C. 92, 024316 (2015)

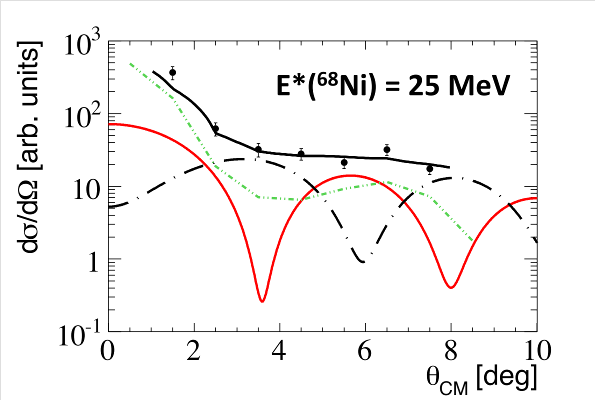
Results ^{68}Ni(α,α')^{68}Ni* Multipole Decomposition Analysis

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

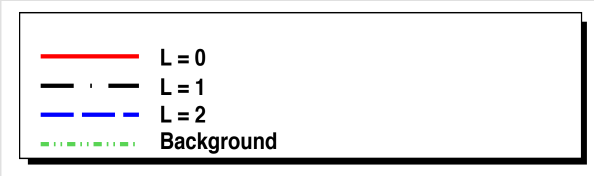






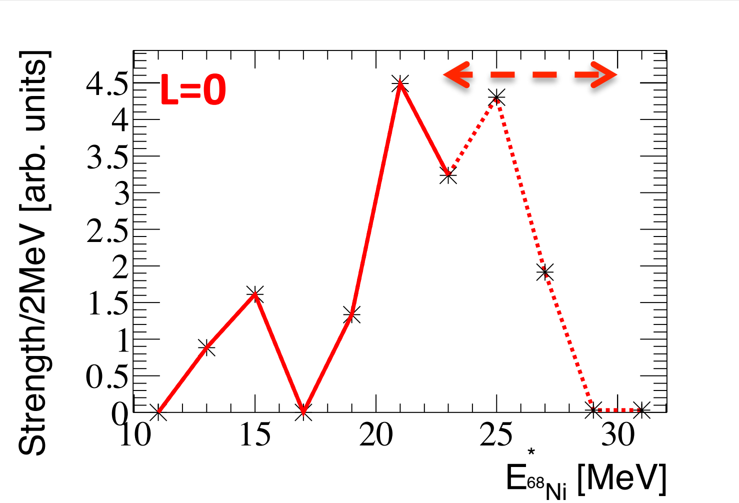


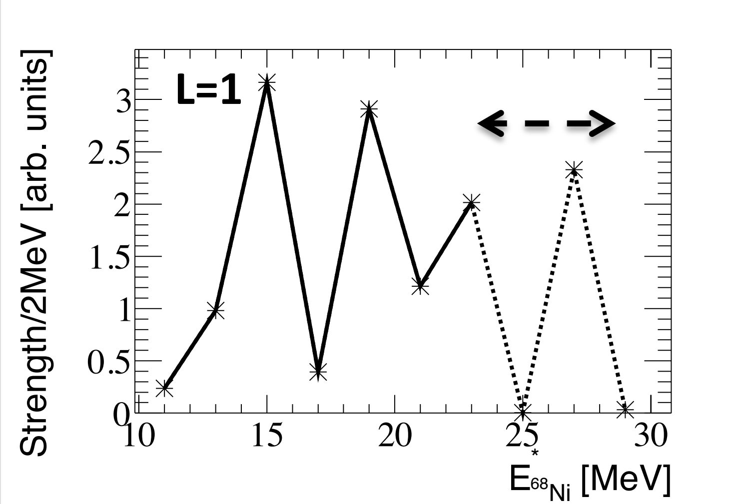
M. Vandebrouck *et al.*, Phys. Rev. C. 92, 024316 (2015)

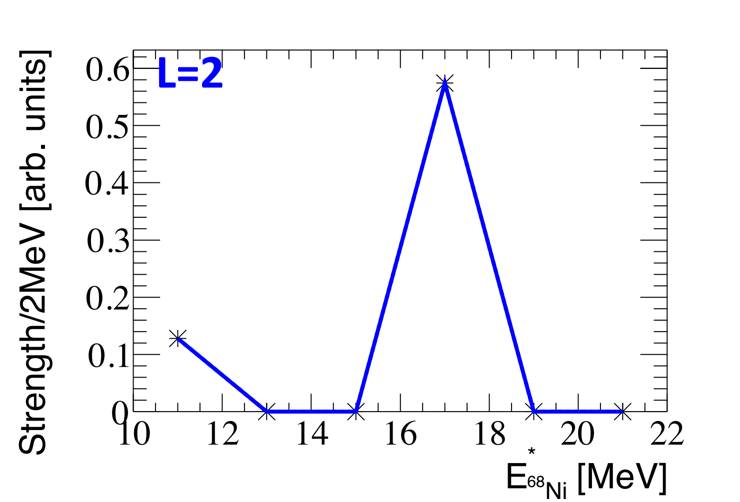


Results $^{68}Ni(\alpha,\alpha')^{68}Ni^*$ Multipole Decomposition Analysis

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







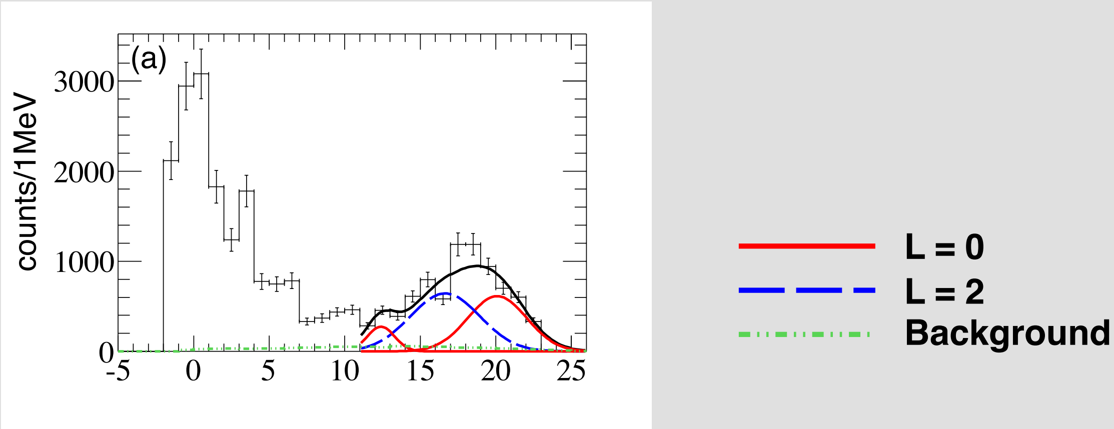
M. Vandebrouck *et al.*, Phys. Rev. C. 92, 024316 (2015)

Résultats

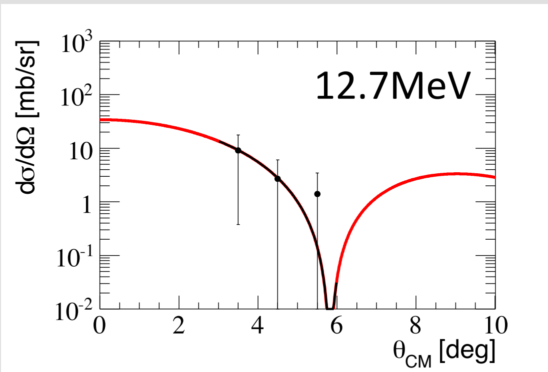
- **L = 0 :** - fragmentation of the ISGMR with a shoulder at 21 MeV
  - increase of the strenght at 13 MeV
- **L = 1 :** - increase of the strenght at 21MeV and below 15MeV
- **L = 2 :** - concentration of the strenght around 16 MeV
- From 23 MeV other multipolarities…

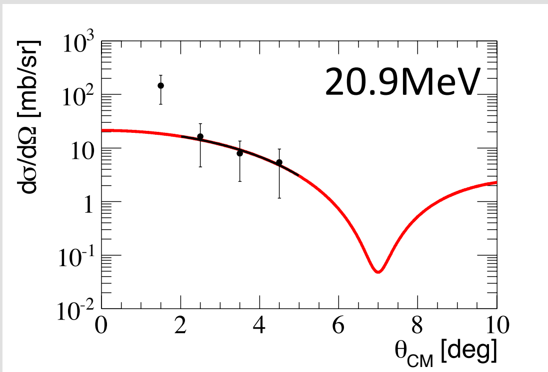
Results $^{68}Ni(d,d')^{68}Ni^*$

Fitting method

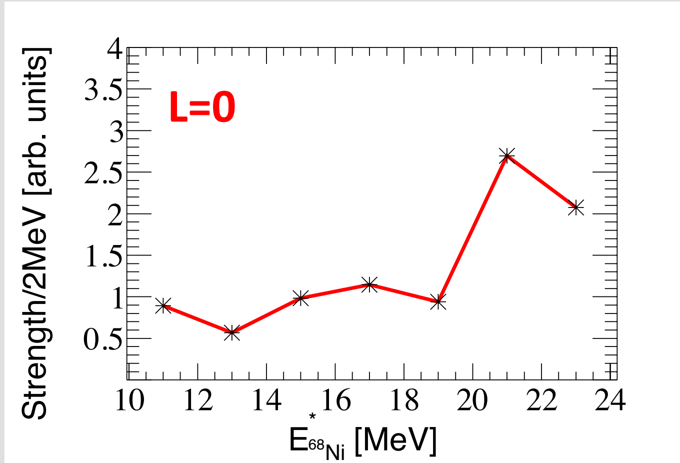


	Centroid (MeV)	FWHM (MeV)
Resonance 1	12.7±0.3	2.2±0.5
Resonance 2	16.5±2.0	4.3±2.6
Resonance 3	20.9±1.0	4.4±0.5



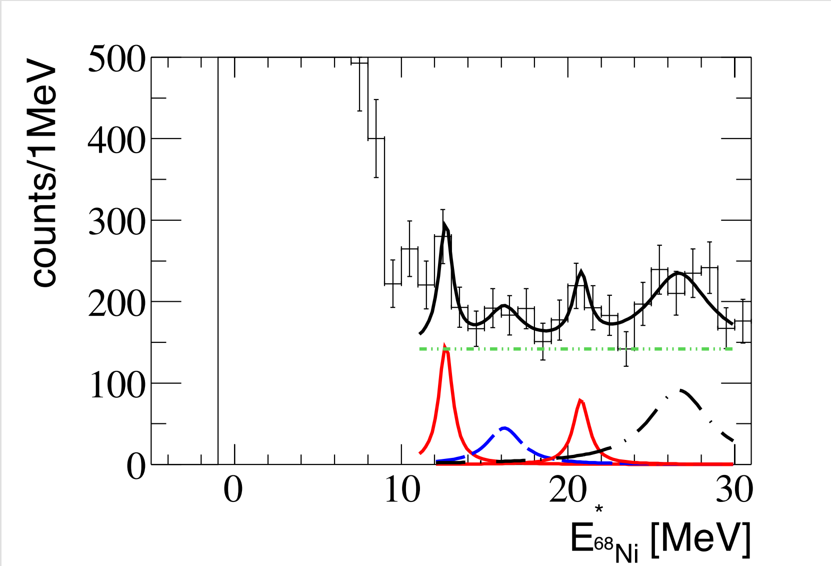


Multipole Decomposition Analysis (MDA)



M. Vandebrouck *et al.*, Phys. Rev. C. 92, 024316 (2015)

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'*)

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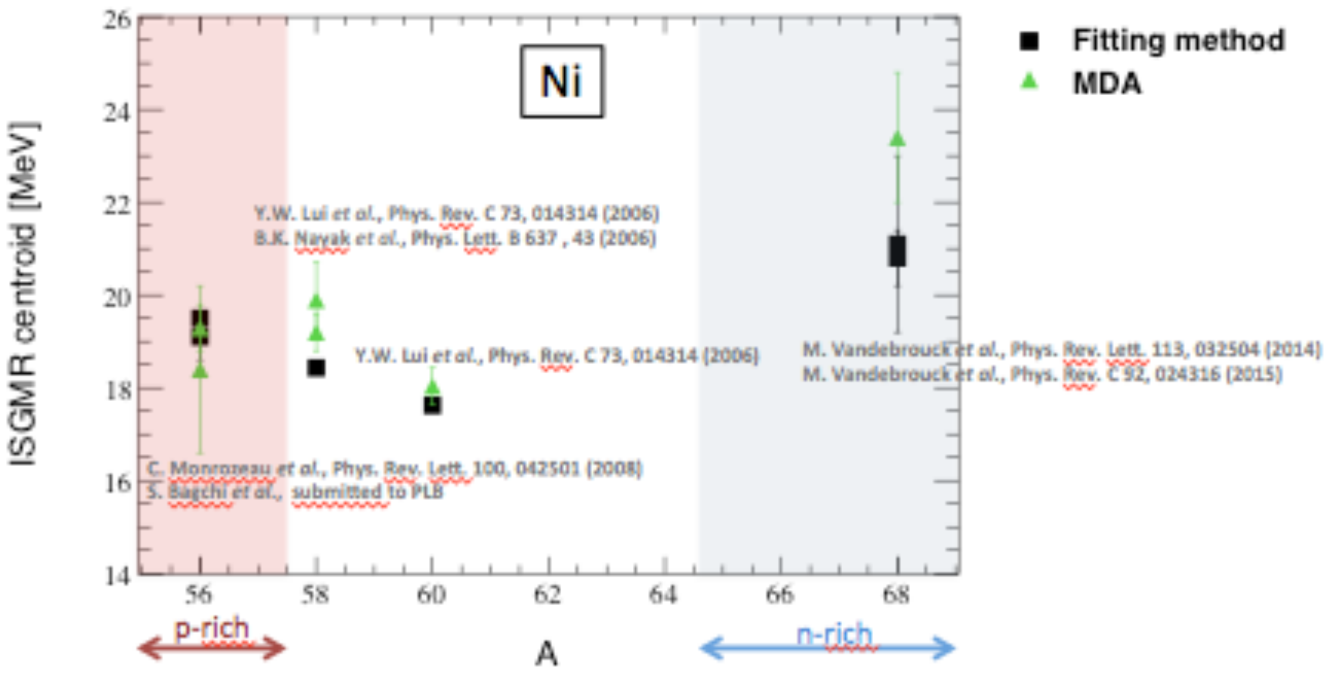
Conclusion and outlook

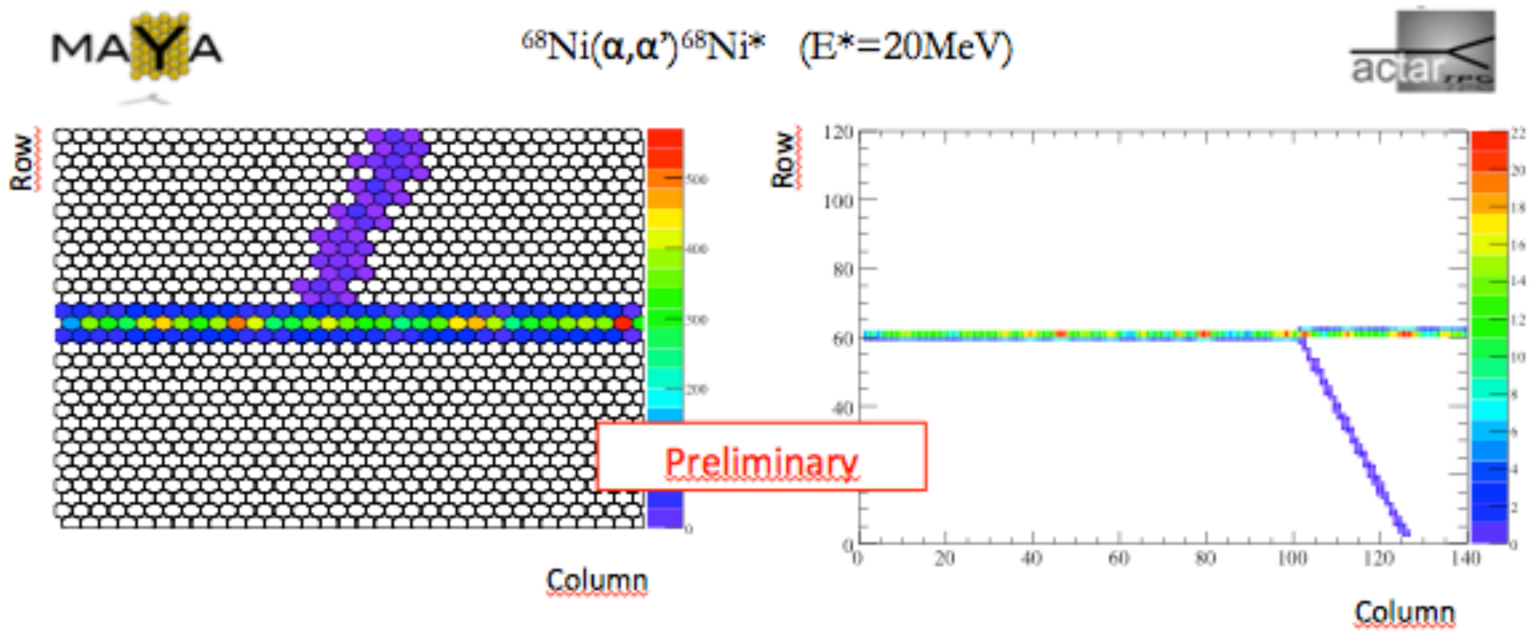
- First measurement of the isoscalar giant resonances in neutron-rich nucleus (^{68}Ni)
  ^{68}Ni(α,α')^{68}Ni* and ^{68}Ni(d,d')^{68}Ni
  - ➔ Indication new modes
  - ➔ Active targets suited for ISGR studies



- Some difficulties…
  - ➔ Limited Resolution
  - ➔ Analysis considering fragmentation of the strength

Conclusion and outlook

- New detection systems
  - ➔ Next generation of active target like ACTAR (T. Roger talk)



  - ➔ storage ring + gas-jet target + detector telescopes (N. Kalantar talk)

- Isoscalar monopole strength in heavier exotic nuclei (S. Ota talk)

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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