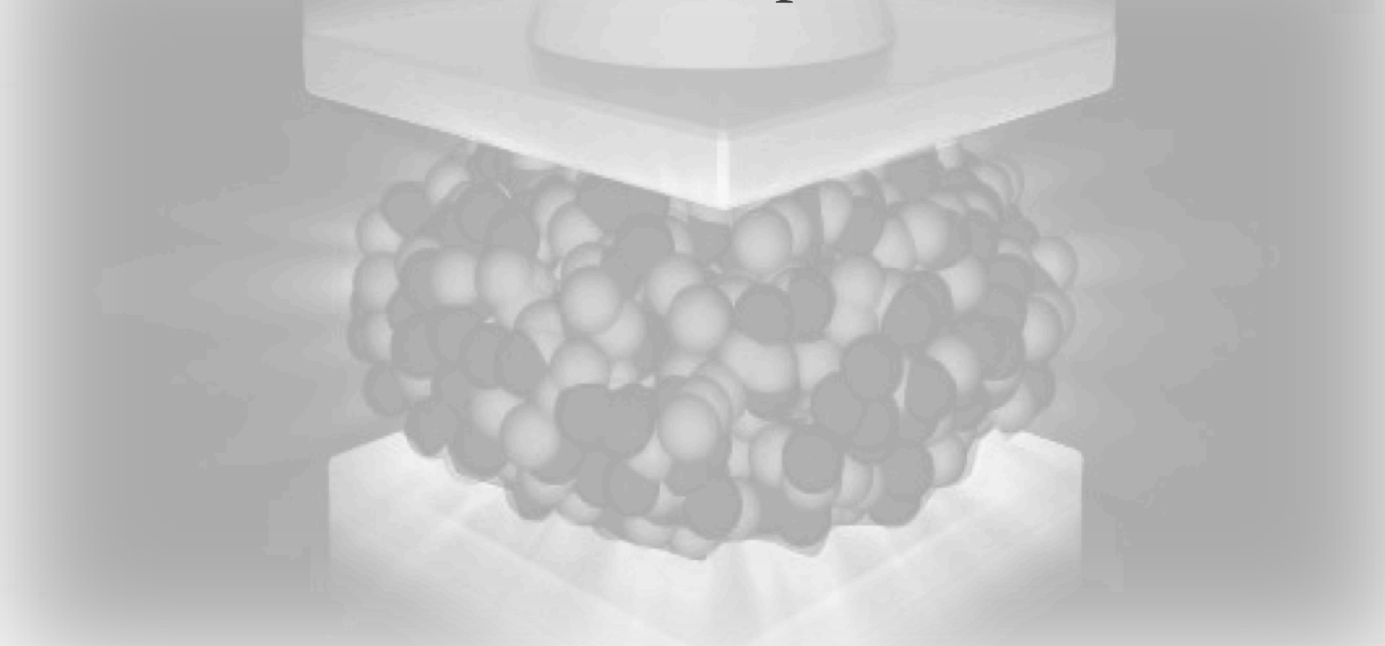
# Isoscalar response of $^{68}$Ni to α-particle & deuteron probes

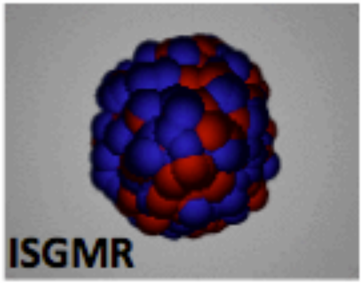
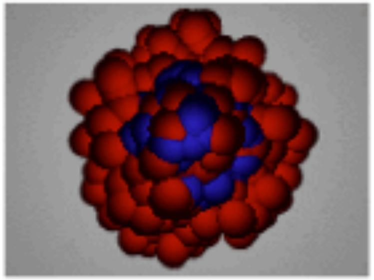
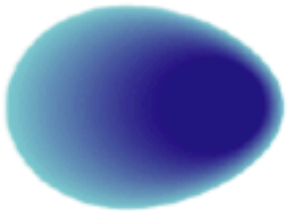
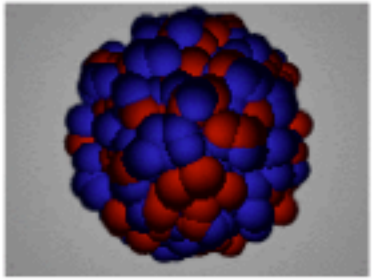
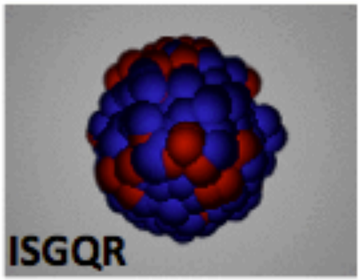
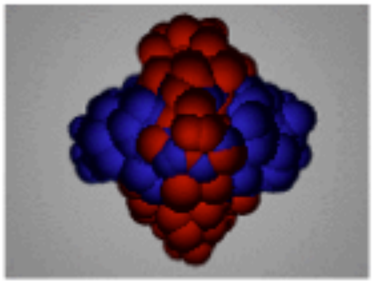



Marine VANDEBROUCK

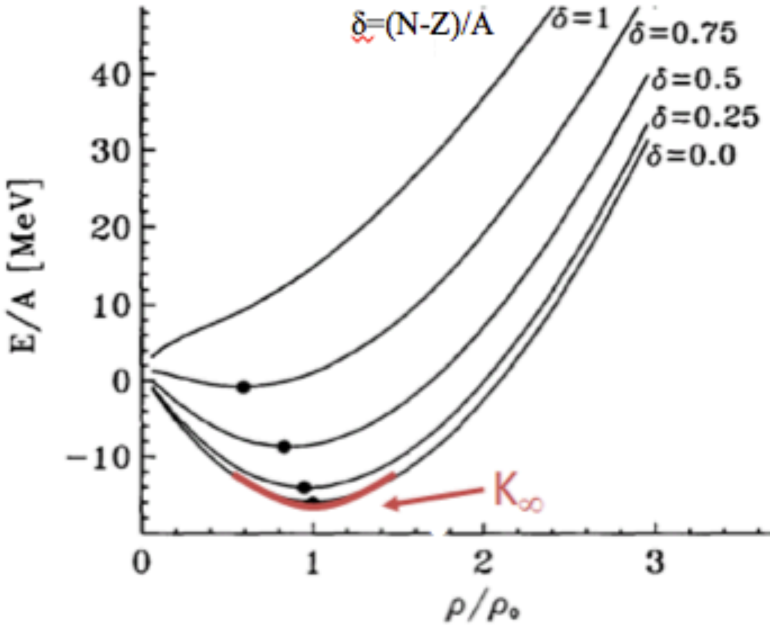
marine.vandebrouck@ganil.fr


DREB2016 – 07/2016

# Introduction What are giant resonances ?

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

# Motivations Nuclear matter incompressibility and ISGMR



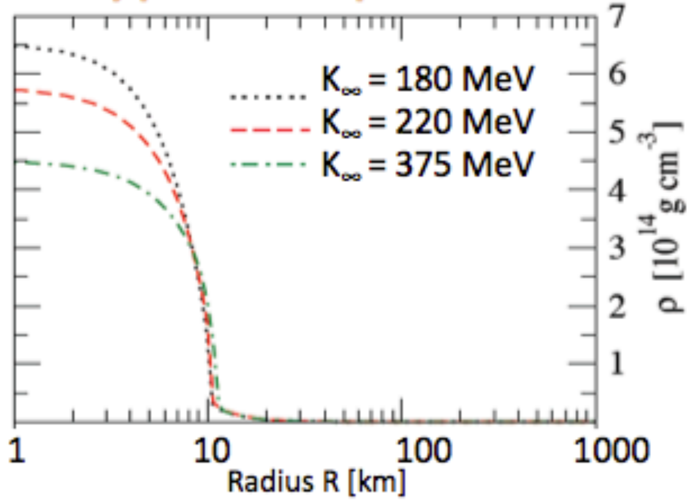

D.T.Khoa *et al.* Nucl. Phys A. **602** (1996)

Microscopic calculation

Centroid of the ISGMR $E_{ISGMR}$

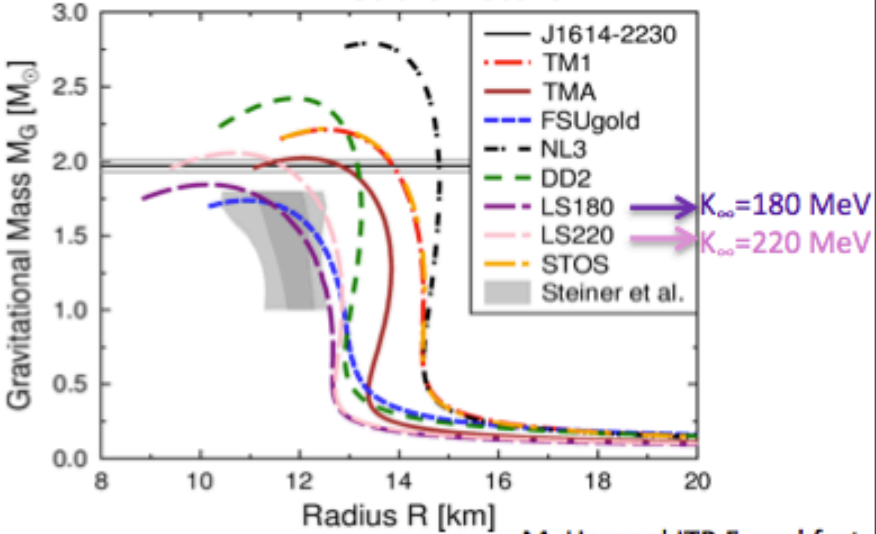
Nuclear matter incompressibility $K_\infty$

**Density profile at supernovae bounce**




A. Fantina PhD (2010) IPNO-IAA

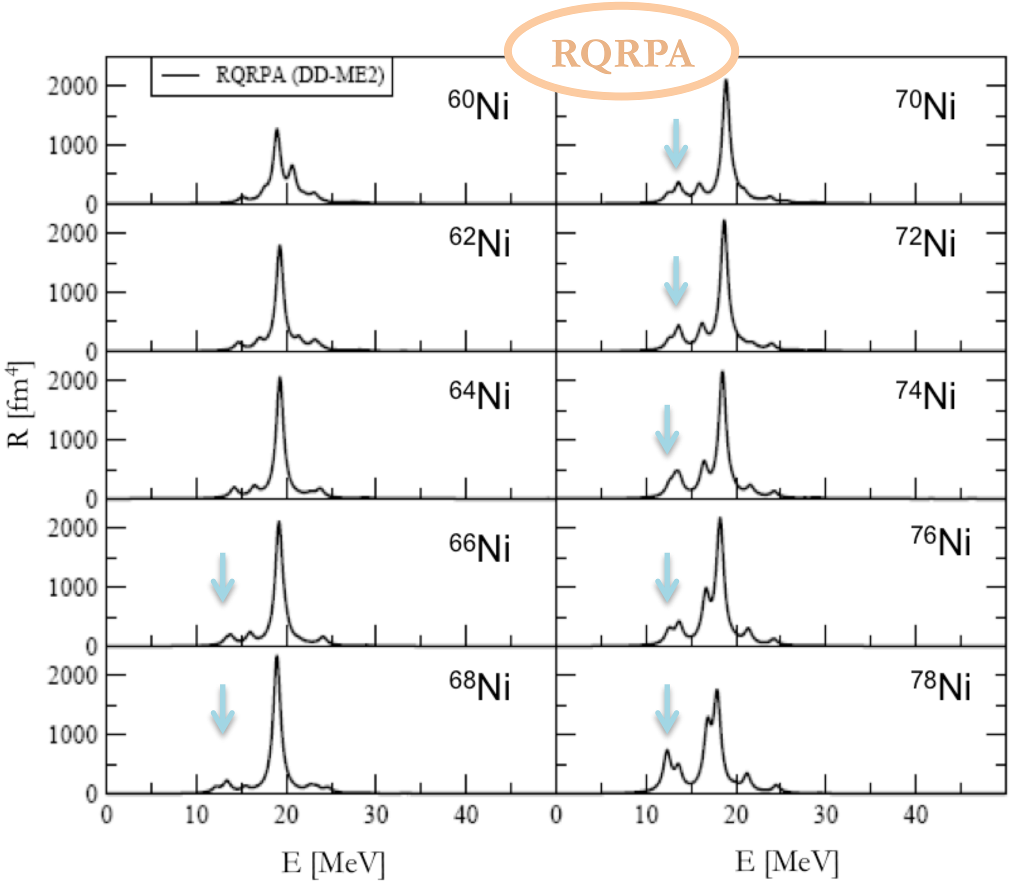
**In neutron stars**



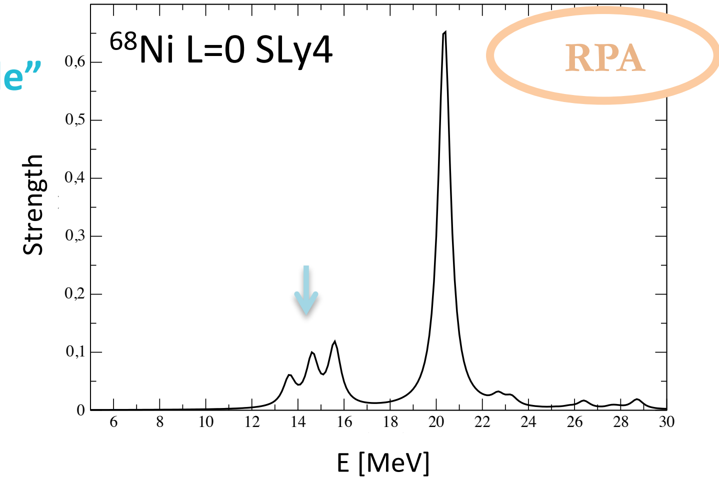

M. Hempel ITP Franckfurt

# Motivations Prediction of a soft monopole mode

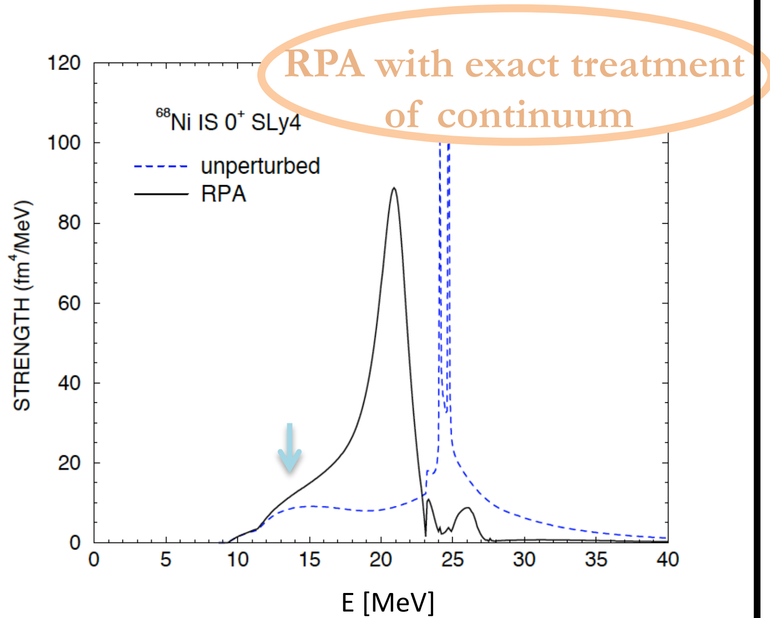
Monopole strength calculation in Ni isotopic
⇨ Prediction of a **low energy mode "Soft monopole mode"**




E. Khan *et al.* Phys. Rev. **C 84**, 051301 (2011)




E. Khan *et al.* Phys. Rev. **C 84**, 051301 (2011)

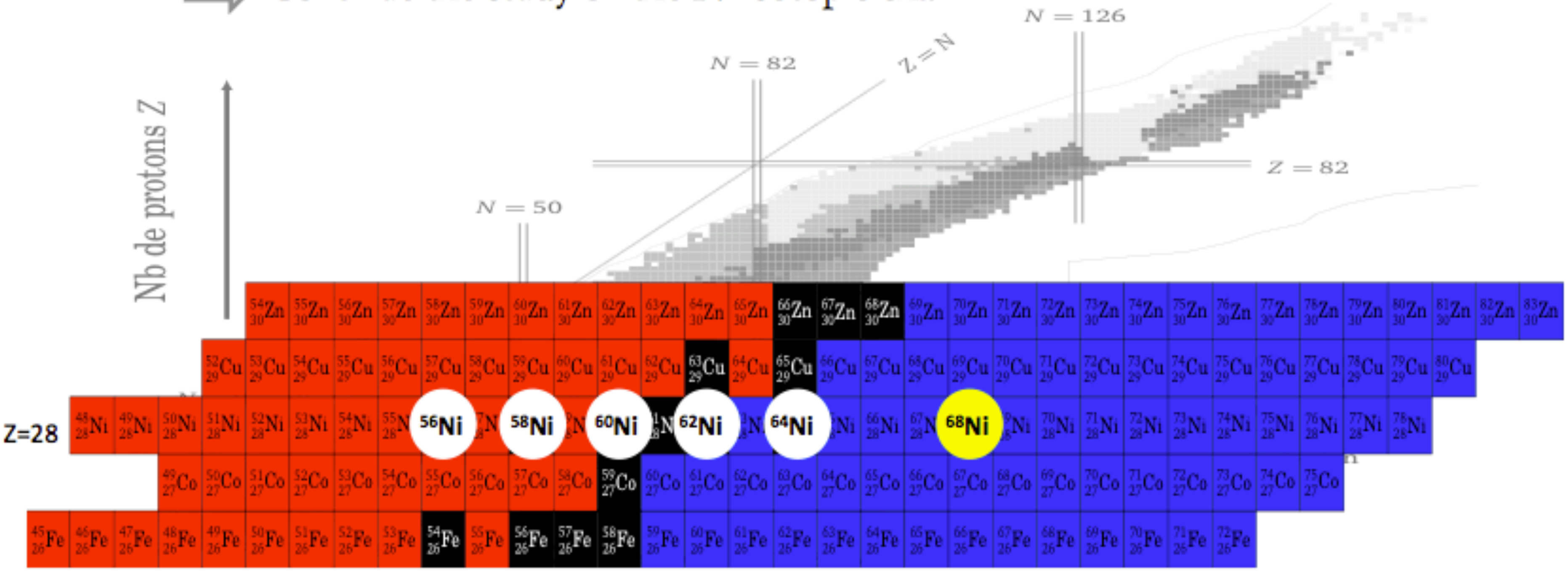



I. Hamamoto *et al.* Phys. Rev. **C 90,** 031302(R) (2014)

# 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)

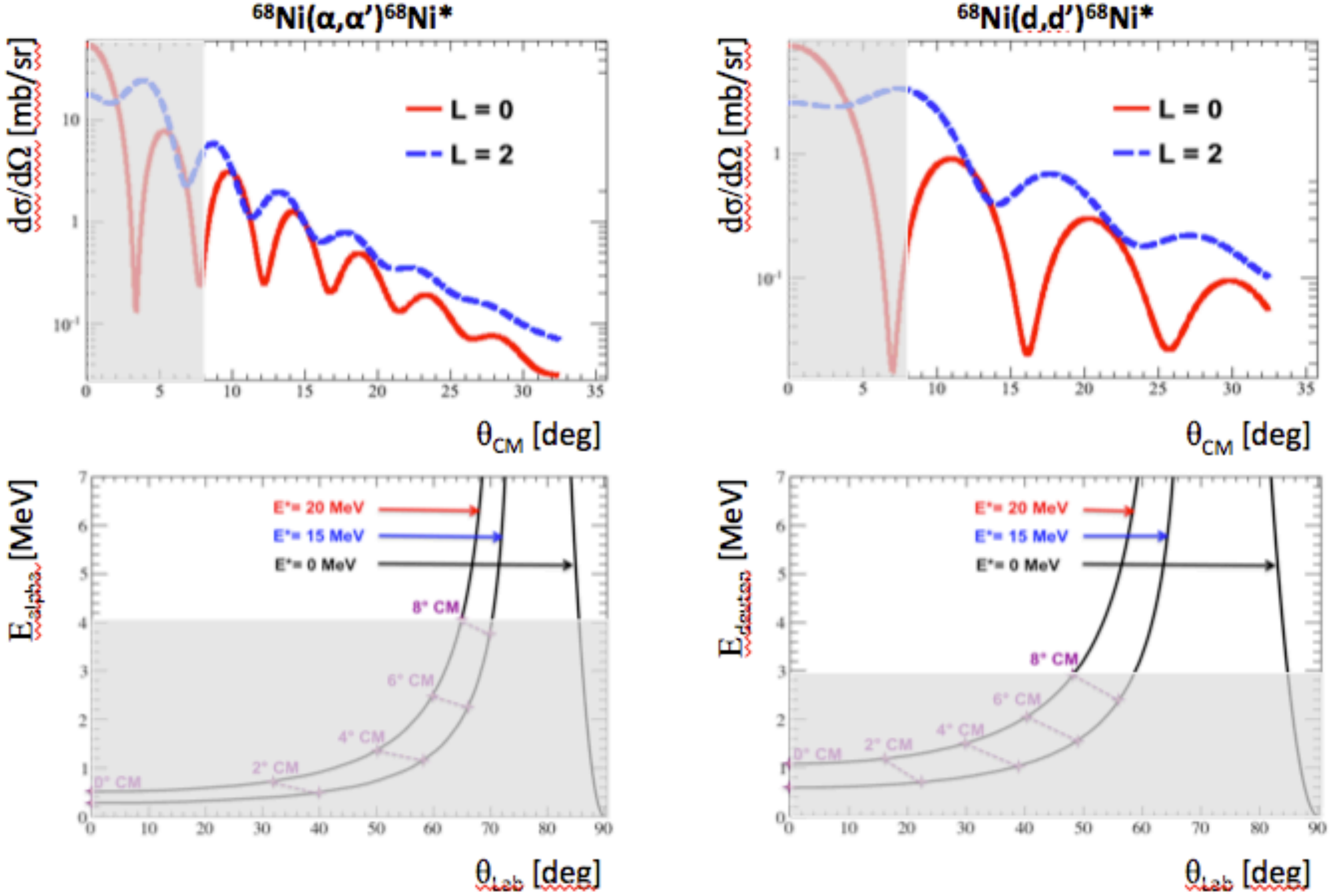
⇨ Study of the ISGMR and ISGQR in a neutron rich Ni : **$^{68}$Ni**
⇨ Continue the study of the Ni isotopic chain




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

# Setup: the active target MAYA why?

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




We have to consider :

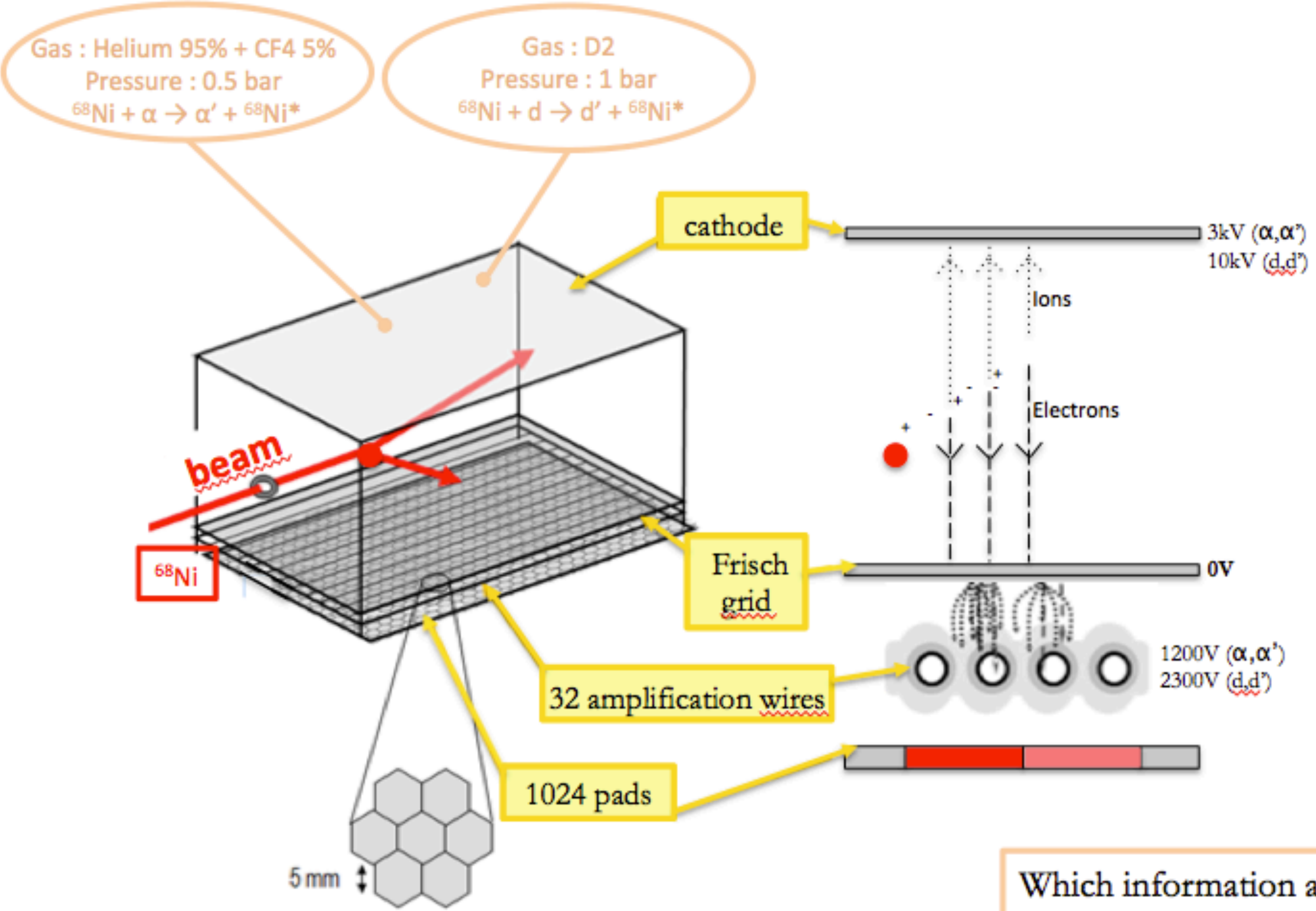
- Inverse kinematics with a low recoiling energy
- Low production rate

Use of an Active Target :

- low detection threshold
- thick target

MAYA

# Setup: the active target MAYA Principle




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

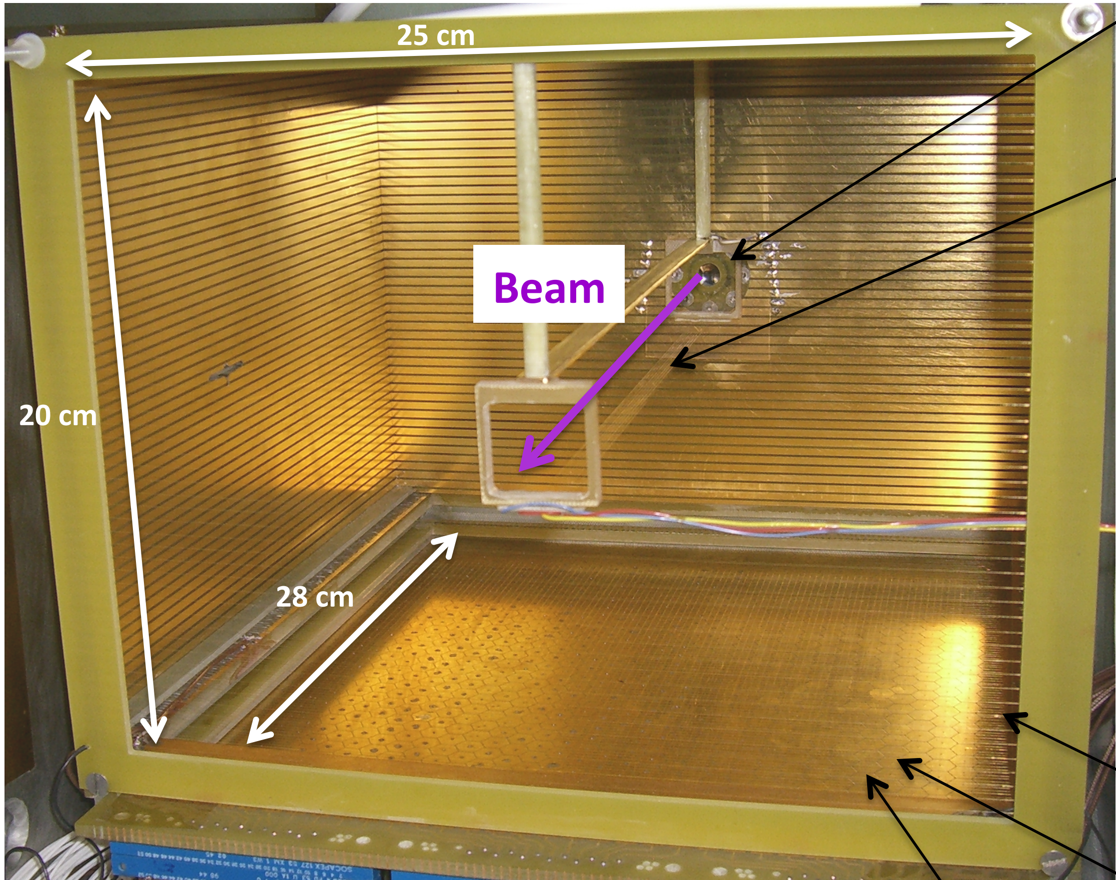
**Time Projection Chamber (TPC) :**

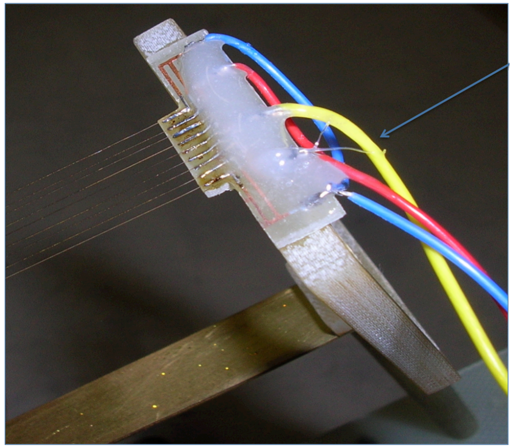
1. The scattered deuteron or α ionizes the gas
2. The electrons drift towards the Frisch grid
3. Amplification on the wires
4. Signal on each pad proportionnal to the amount of electrons collected on the wire above

Which information are stored ?

- Time on each wire
- Charge induced on each pad

# Setup: the active target MAYA MAYA@LISE



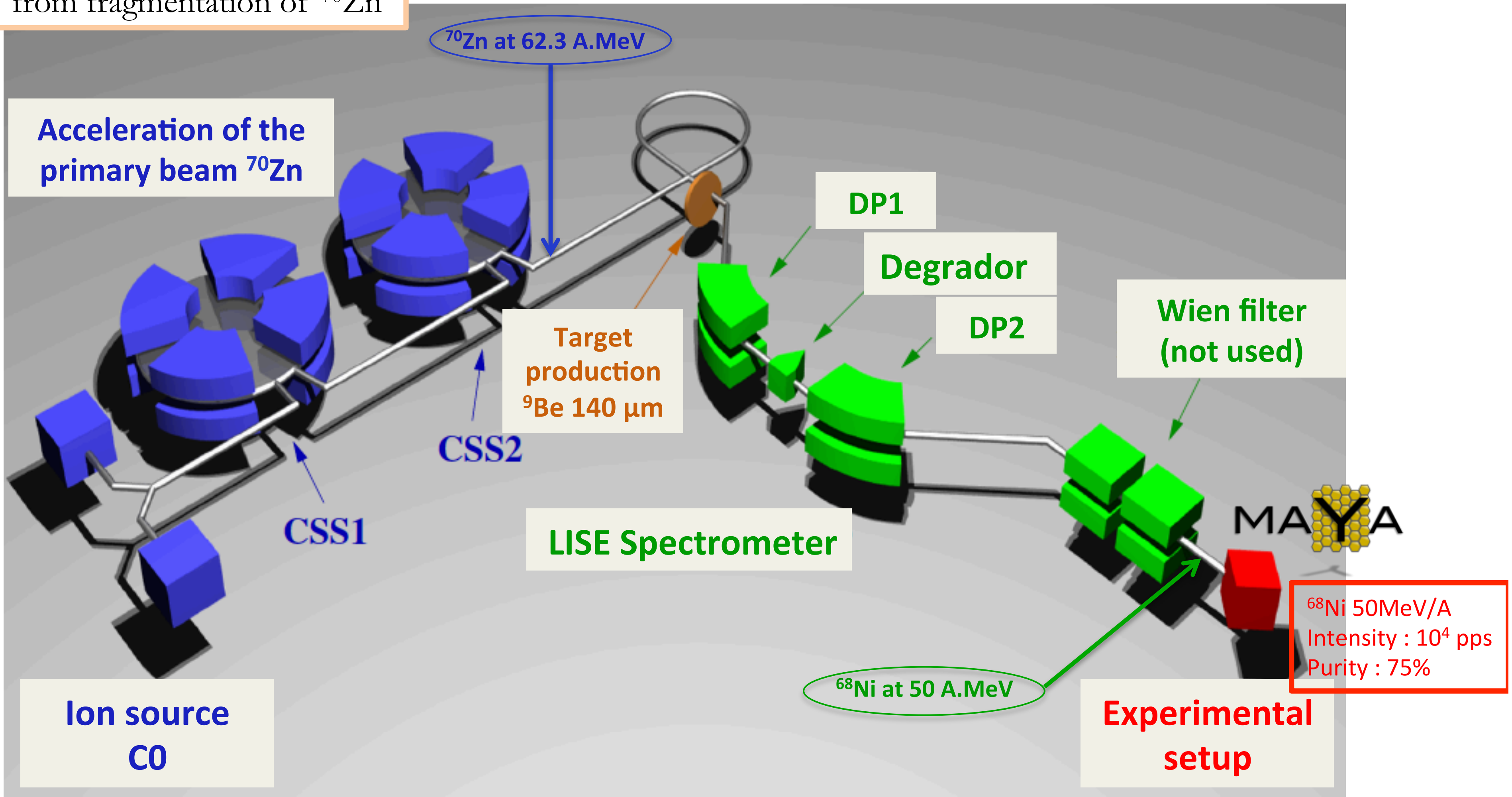



J. Pancin *et al.*, *JINST* **7,** P01006 (2012)

MAYA

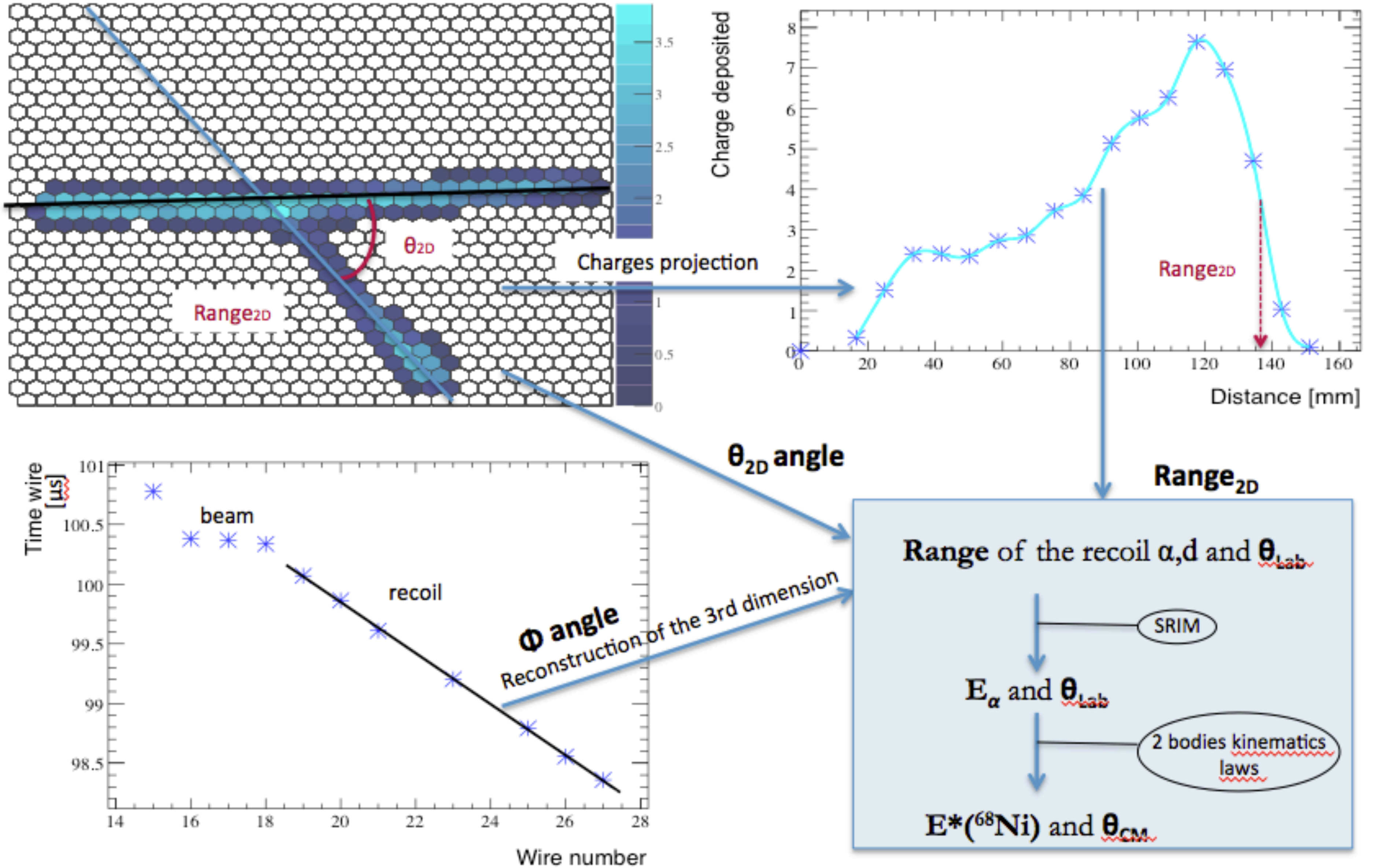
# Setup: the active target MAYA Production of the $^{68}$Ni @GANIL

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



# Results Tracking reconstruction

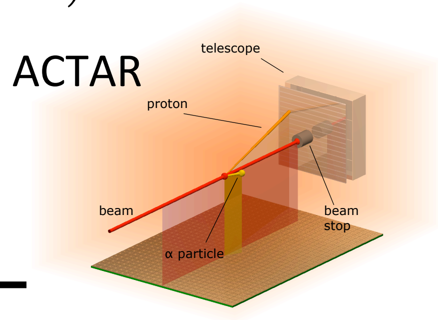
T. Roger *et al.*, Nucl. Instrum. Meth. **638,** 134 (2011)



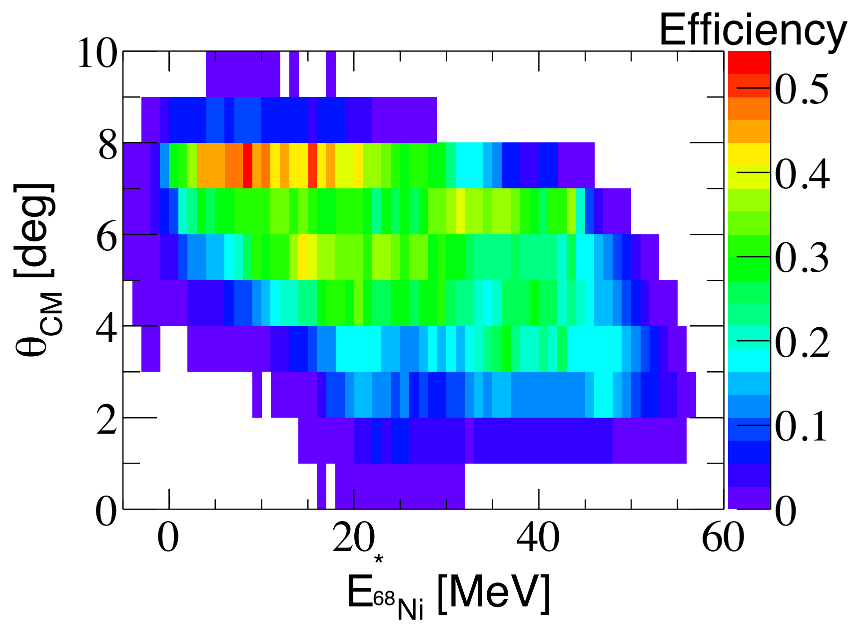
# Results Efficiency

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

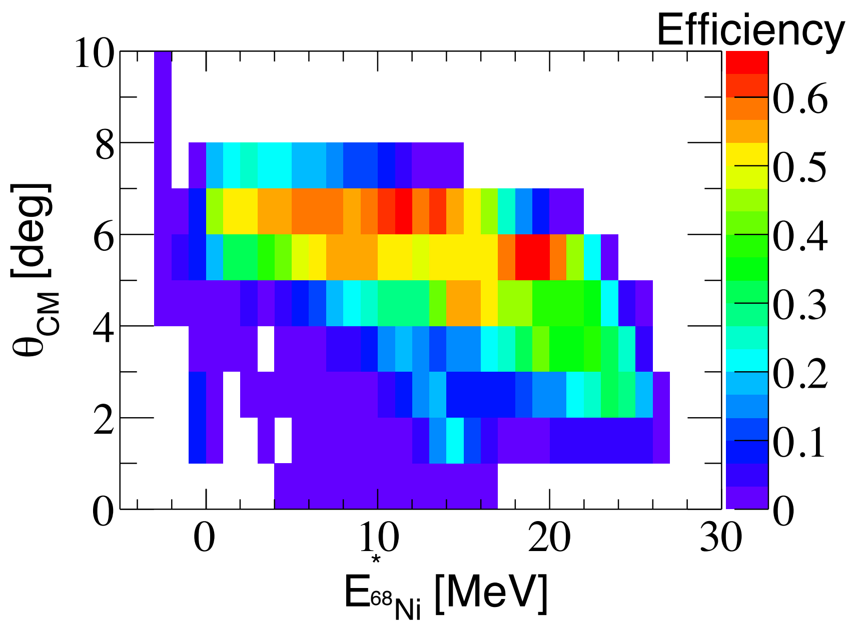
⇨ **Geometric** and **reconstruction** efficiency



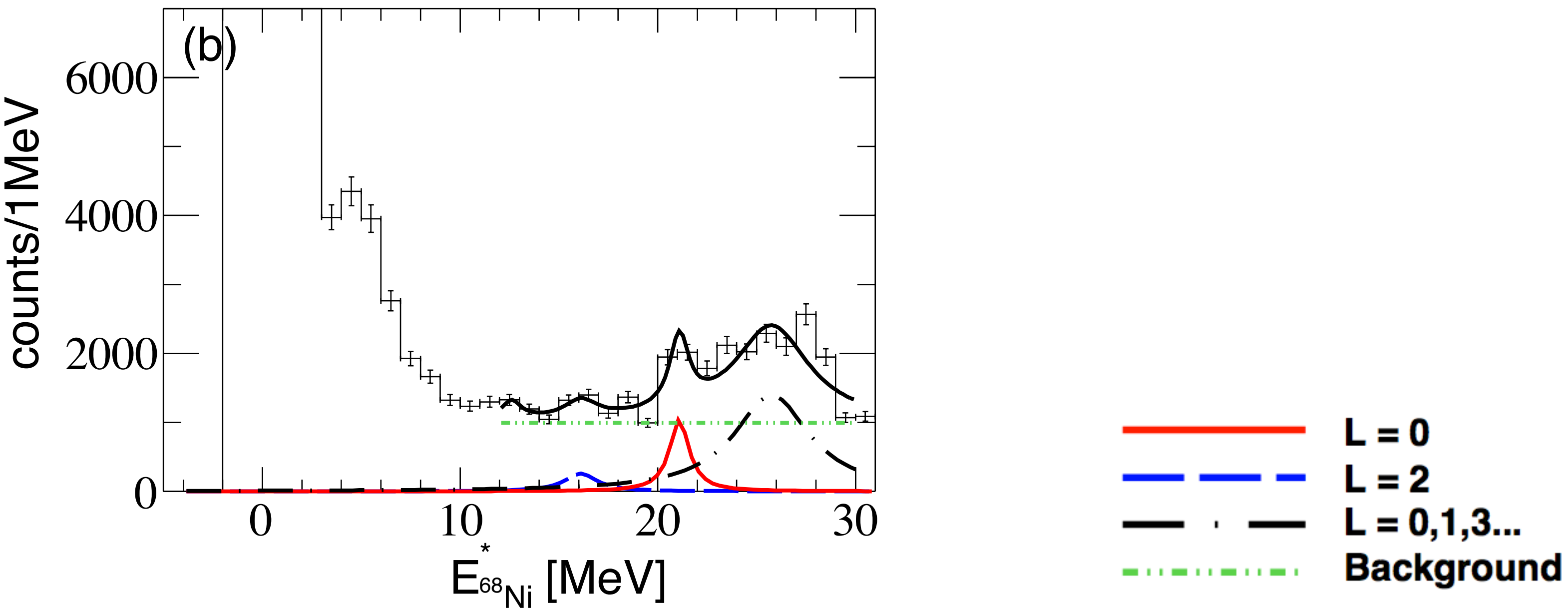

$^{68}Ni(\alpha,\alpha')^{68}Ni^*$




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

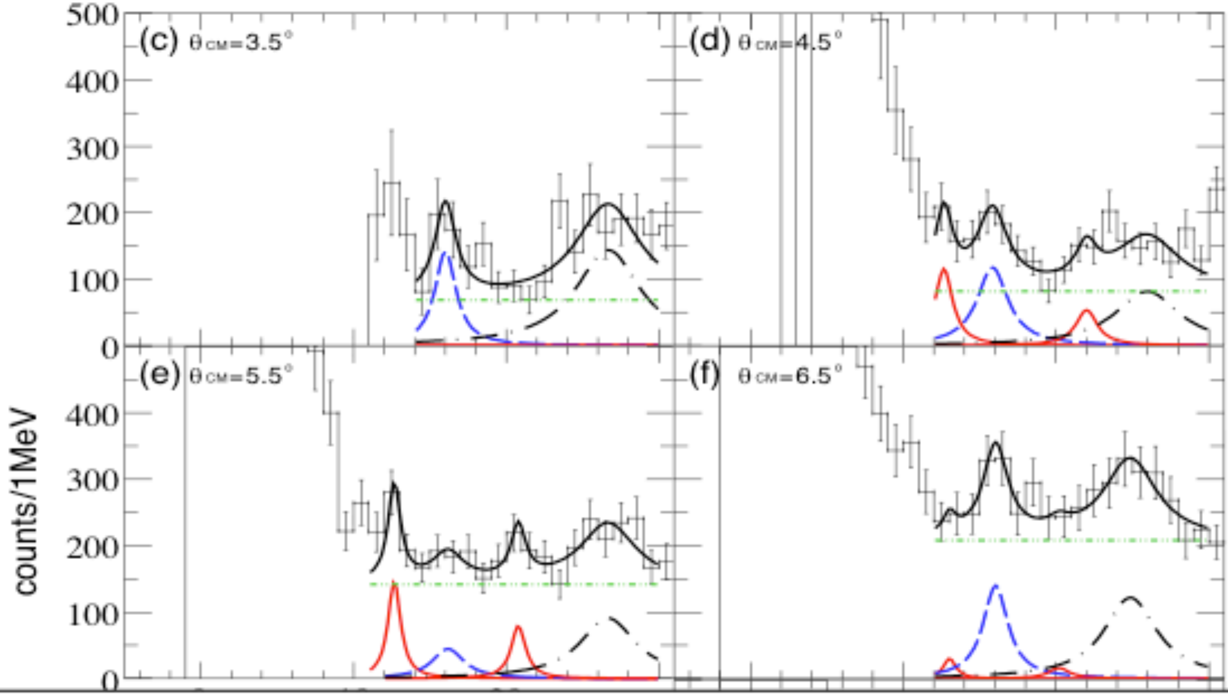


# Results $^{68}Ni(\alpha,\alpha')^{68}Ni^*$ Excitation energy spectra




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

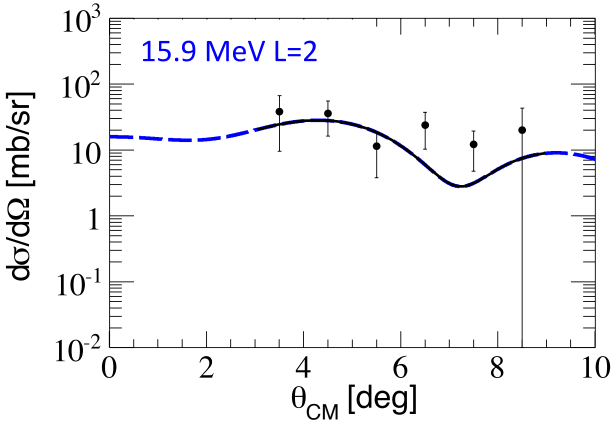
# Results $^{68}Ni(\alpha,\alpha')^{68}Ni^*$ Excitation energy spectra



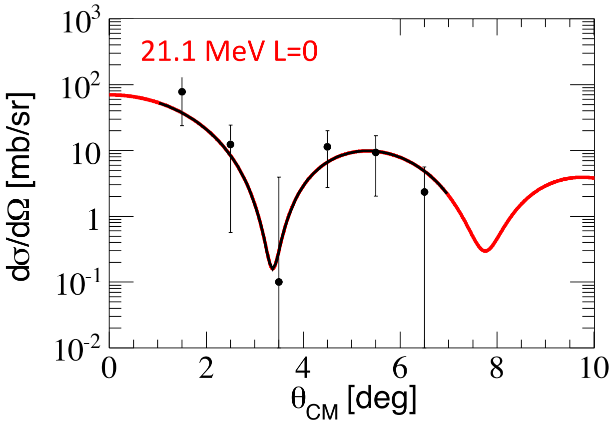

| | Centroid (MeV) | FWHM (MeV) |
|---|---|---|
| Resonance 1 | 12.9±1.0 | 1.2±0.4 |
| Resonance 2 | 15.9±1.3 | 2.3±1.0 |
| Resonance 3 | 21.1±1.9 | 1.3±1.0 |

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

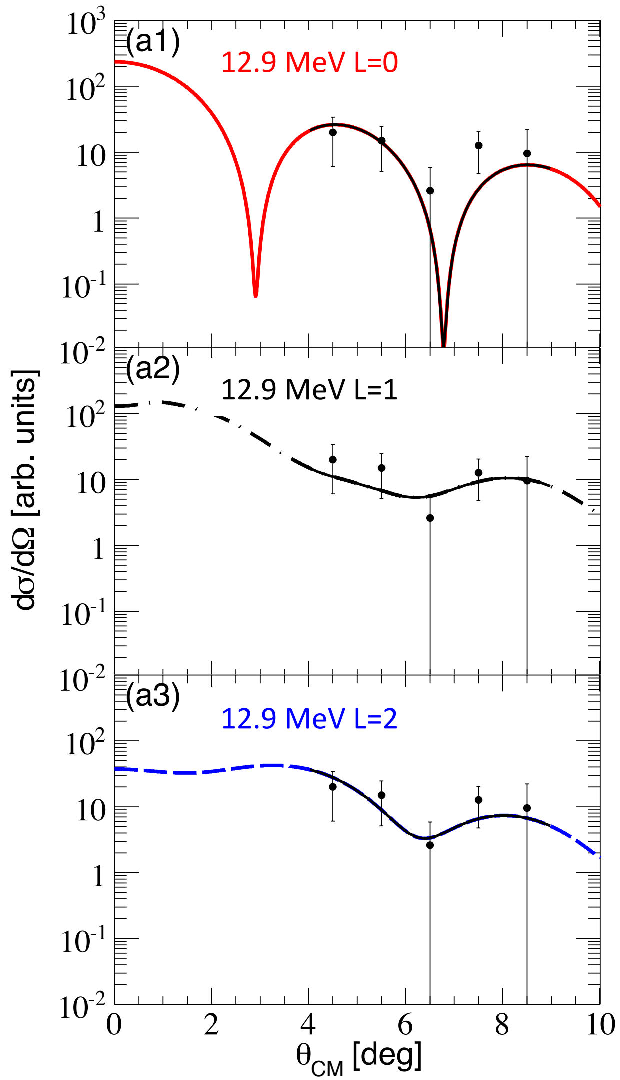
**ISGQR**




**ISGMR**



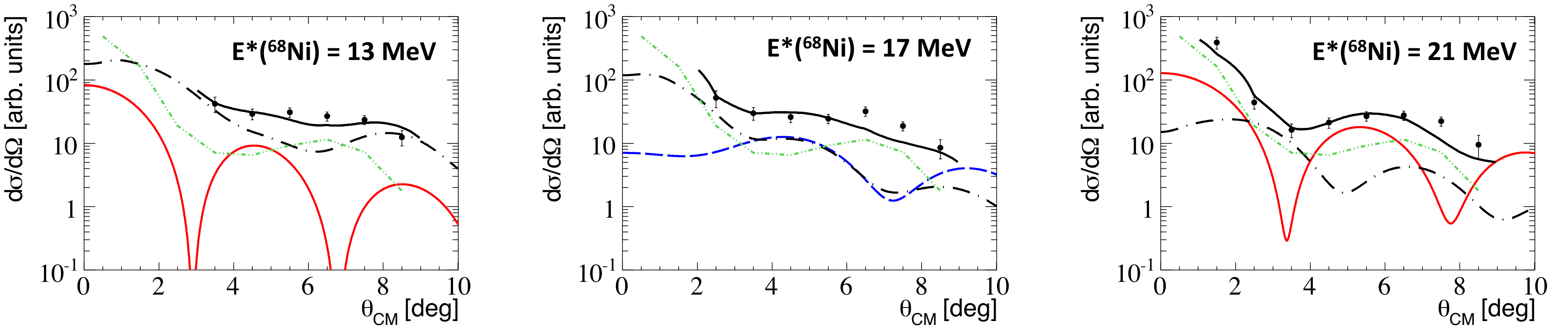

M. Vandebrouck *et al.*, Phys. Rev. **C. 92**, 024316 (2015)

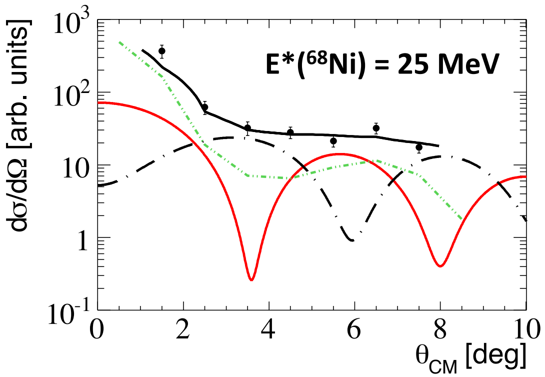



**Soft ISGMR ?**

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

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

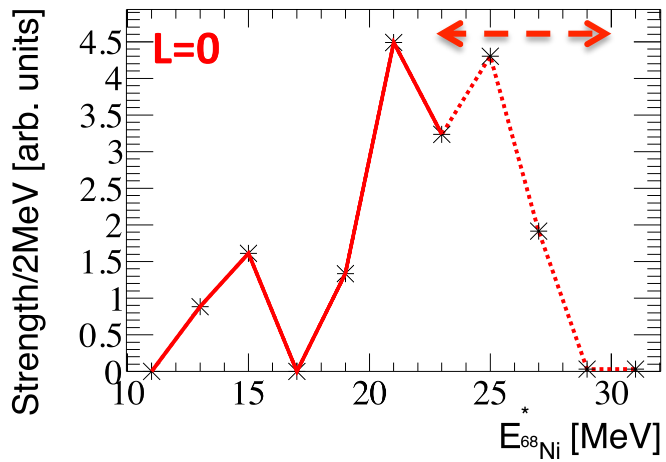


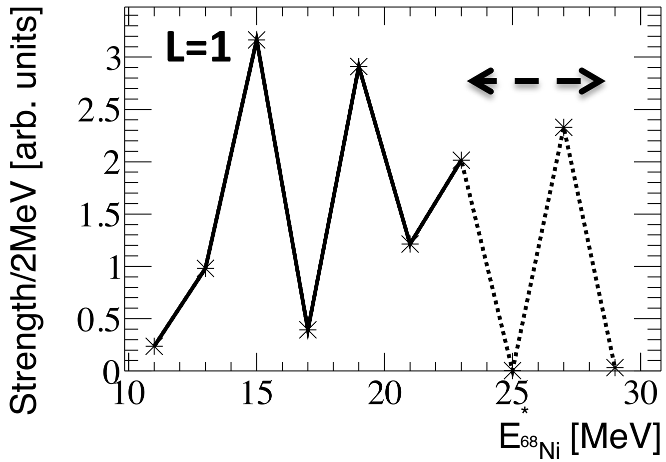




M. Vandebrouck *et al.*, Phys. Rev. **C. 92**, 024316 (2015)

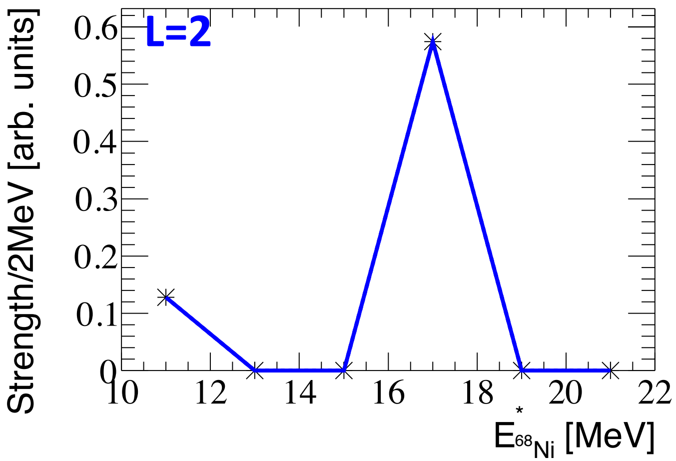
# Results $^{68}Ni(\alpha,\alpha')^{68}Ni^*$ Multipole Decomposition Analysis

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



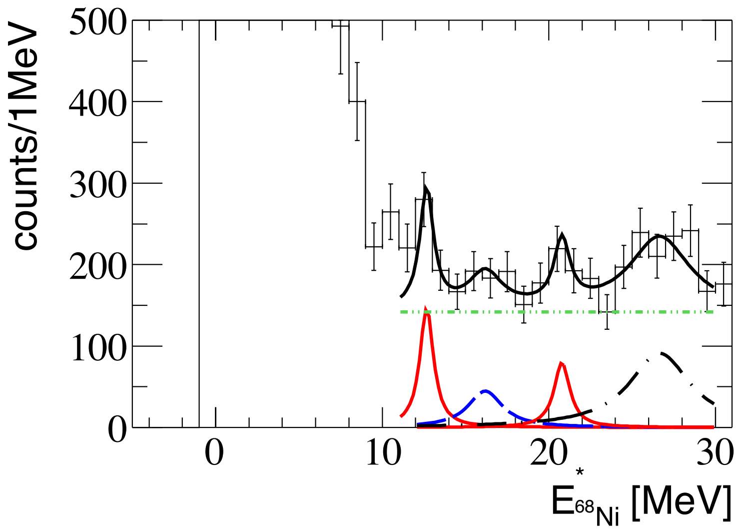

M. Vandebrouck *et al.*, Phys. Rev. **C. 92**, 024316 (2015)




**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 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'*)

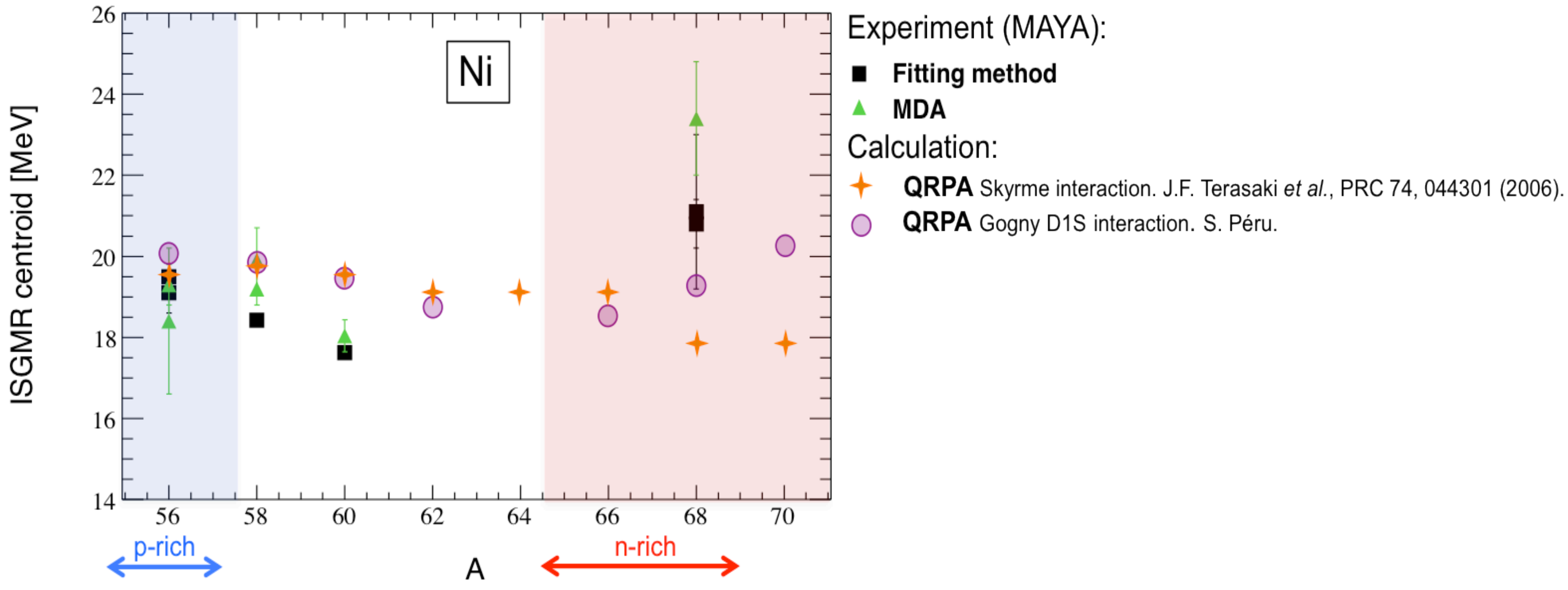
**ISGMR**

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

# Conclusion

- 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
  - → Measurement along isotopic chains are needed



# Study of giant and pygmy resonances in exotic nuclei at LISE (LOI)

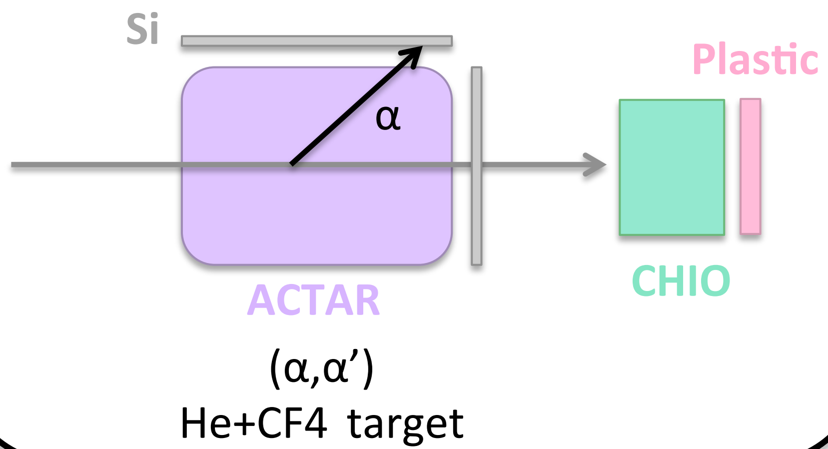
Submitted to GANIL PAC (June 9th/10th 2016)

**M. Vandebrouck, J. Gibelin,** N. L. Achouri**,** M. Assié, D. Beaumel, P. Bednarczyk, Y. Blumenfeld, M. Caamaño, S. Calinescu, S. Ceruti, M. Ciemala, F. Delaunay, Z. Dombradi, A. F. Fantina, B. Fernandez-Dominguez, M. Kmiecik, A. Krasznahorkay, U. Garg, J. Giovinazzo, S. Grévy, M. N. Harakeh, N. Kalantar, E. Khan, E. Litvinova, A. Maj, J. Margueron, F. M. Marqués, I. Matea, S. Péru, R. Raabe, T. Roger, S. Ota, O. Sorlin, J. C. Thomas, the ACTAR TPC collaboration and the PARIS collaboration

# Outlook Probing giant resonances along isotopic chains

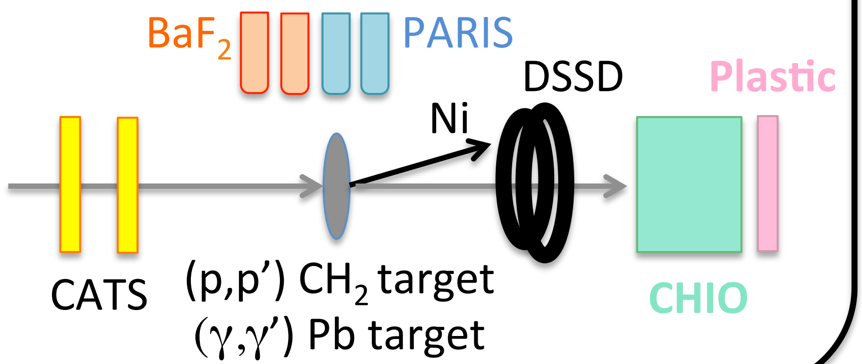
**Compression modes**

(M. Vandebrouck/J. Gibelin/E. Khan et al.)



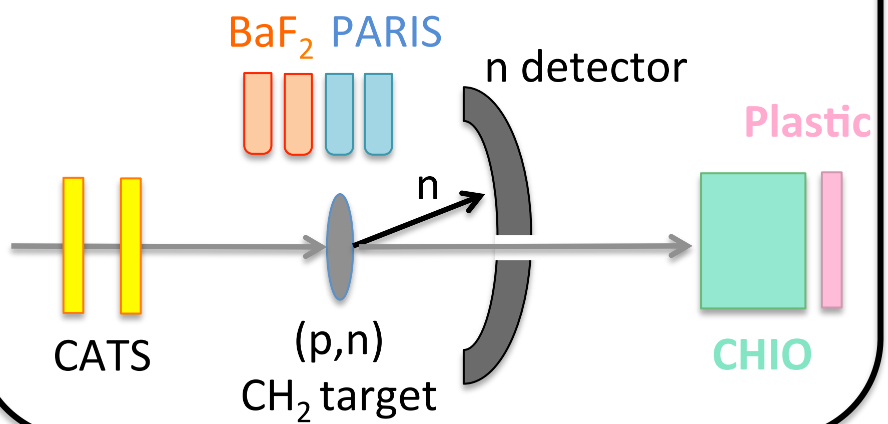

**Isoscalar-Isovector nature of the Pygmy Dipole Resonance**

(S. Calinescu/I. Matea et al.)



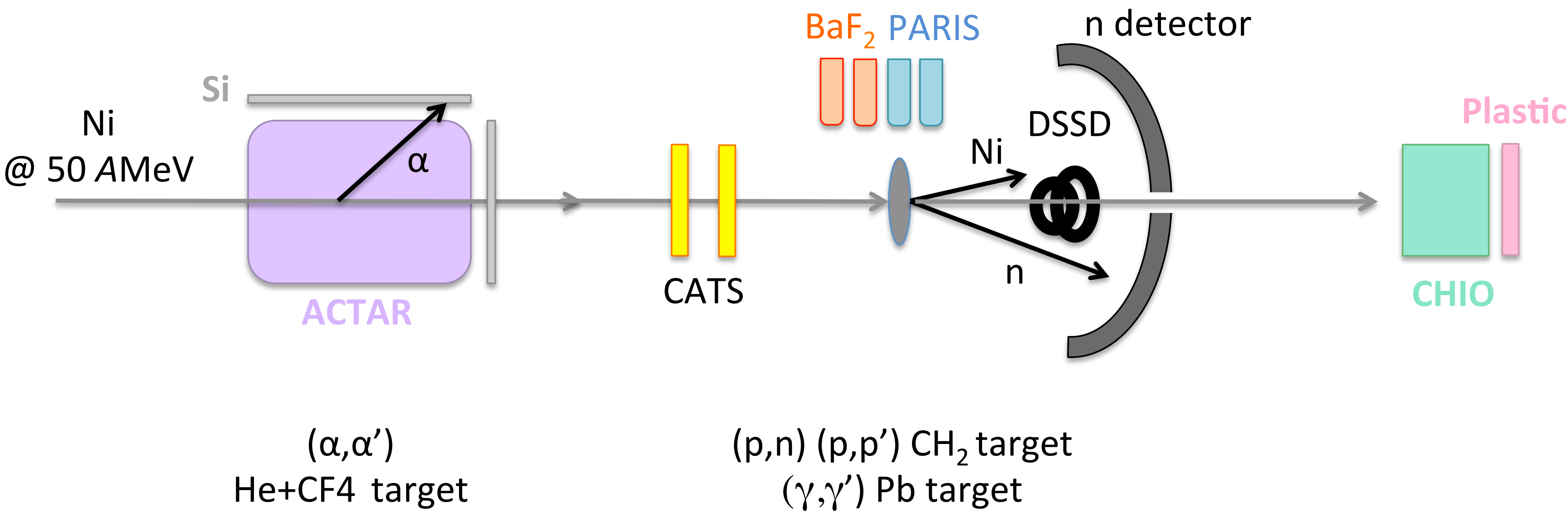

**Anti-Analog Giant Dipole Resonance**

(A. Krasznahorkay et al.)



# Outlook Probing giant resonances along isotopic chains

- Measurements along Ni isotopic chain from $^{56}$Ni to $^{70}$Ni



# 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].

[1] **IPN Orsay**, Université Paris-Sud, IN2P3-CNRS, F-91406 Orsay Cedex, France
[2] **LPC Caen**, ENSICAEN, Université de Caen, CNRS/IN2P3, F-14050 CAEN Cedex, France
[3] **RIKEN Nishina Center**, 2-1 Hirosawa, Wako, Saitama 351-0198, Japan
[4] **Universidade de Santiago de Compostela**, E-15782 Santiago de Compostela, Spain
[5] **GANIL**, CEA/DSM-CNRS/IN2P3, 14076 Caen, France
[6] **Dipartimento de Fisica Università degli Studi di Milano and INFN**, Sezione di Milano, 20133 Milano, Italy
[7] **Physics Department, University of Notre-Dame**, Notre Dame, Indiana 46556, USA
[8] **KVI-CART**, University of Groningen, NL-9747 AA Groningen, The Netherlands
[9] **National Centre for Nuclear Research** ul. Andrzeja Soltana 7, 05-400 Otwock, Poland
[10] **NSCL**, Michigan State University, East Lansing, Michigan 48824-1321, USA
[11] **IKS**, K.U. Leuven, B-3001 Leuven, Belgium
[12] **CEA-Saclay**, DSM, F-91191 Gif sur Yvette Cedex, France