Study of collective excitations with active targets

PARIS User meeting, LNL-INFN, 28-29/11/2019

Alice Mentana

KU Leuven, Instituut voor Kern- en Stralingsfysica

Outline

1. **Physics background:**
   - Giant Resonances
   - IsoScalar modes: ISGMR
   - Equation of State
   - Open questions

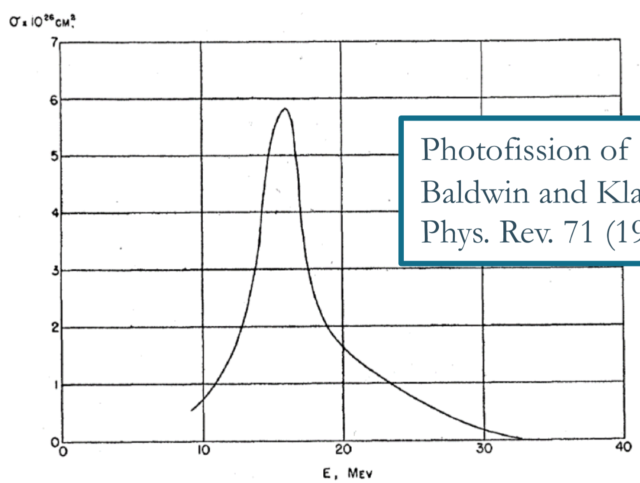
2. **The experiment:**
   - ISGMR in ^{68}Ni
   - Experimental technique
   - Previous result
   - The experiment
   - Preliminary analysis & ongoing work

3. **Future perspective**

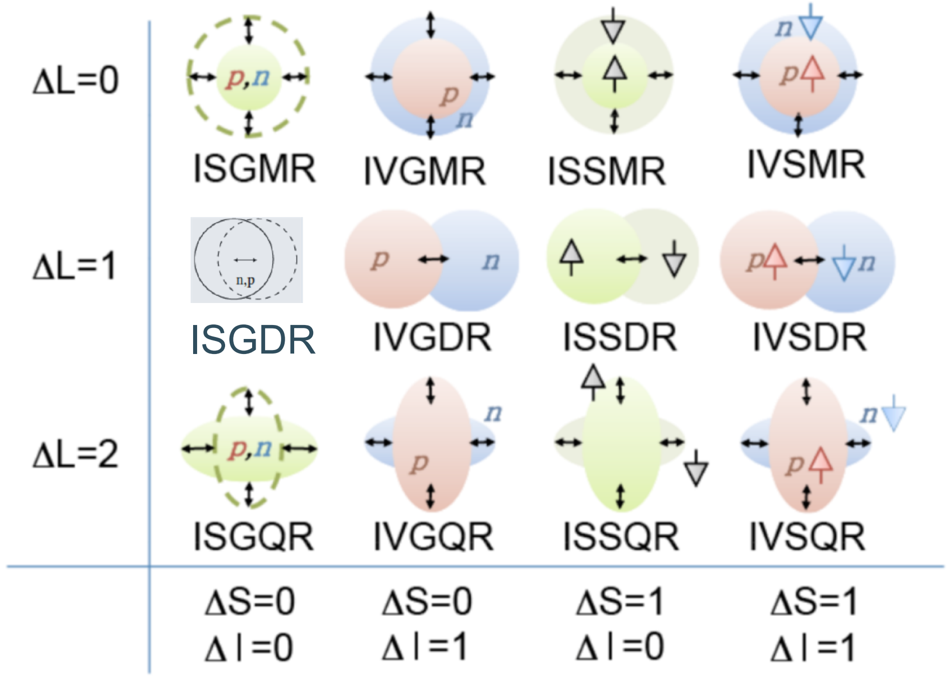
1. Physics background

Giant Resonances

- Coherent motion of nucleons
- Spin (S), isospin (I) and angular momentum (L) involved
- IVGDR (since 1947): Oscillation of protons against neutrons
- **ISGMR**: Compression motion of nucleons together.



Photofission of 238U
Baldwin and Klaiber
Phys. Rev. 71 (1947) 3



M. N. Harakeh and A. van der Woude,
Giant Resonances: Fundamental High-Frequency Modes of Nuclear Excitation
Oxford University Press

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Giant Resonances

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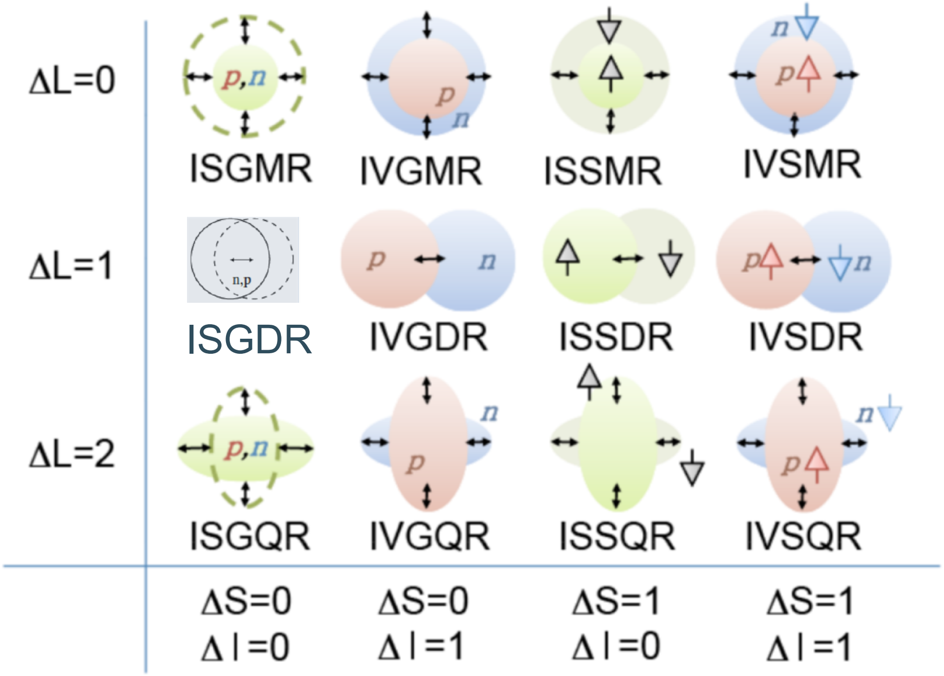

Provide information on **features of finite nuclei and nuclear matter** (incompressibility, symmetry energy, neutron skin).

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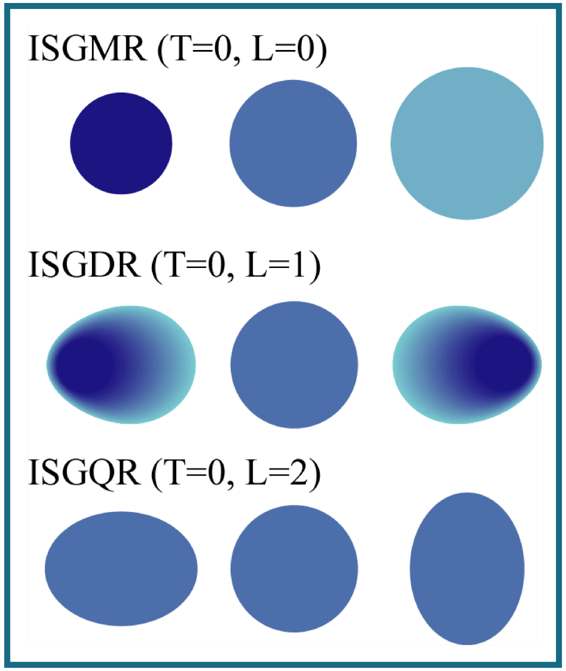
Isoscalar modes: ISGMR



- Isoscalar modes are compression modes
  $\rightarrow$ tool to study incompressibility of nuclear matter K_∞
  through the nuclear incompressibility K_A

$$E_{ISGMR} = \hbar\sqrt{\frac{K_A}{m\langle r^2\rangle}}$$

K_∞ can be extracted from:

- an expansion of K_A:
  $$K_A = K_{vol} + K_{surf}A^{-1/3} + K_{sym}\left(\frac{N-Z}{A}\right) + K_{Coul}\frac{Z^2}{A^{4/3}}$$
  by fitting data and assuming $K_{vol} = \lim_{A\to\infty} K_A = K_\infty$

- RPA calculations that provide K_∞ and E_{ISGMR}
  $K_\infty = 230 \pm 40$ MeV (Kahn et al, Phys. Rev. Lett. 109 (2012) 092501)

Equation of State

- K_∞ is an ingredient of the nuclear Equation of State (EoS)
- EoS is used to describe

  - heavy-ion collision

  - core-collapse supernovas

  - neutron star

→ the study of the **effect of the isospin asymmetry on the K_∞** is crucial for the knowledge of the EoS of the asymmetric nuclear matter E/A(ρ, $\alpha=\frac{N-Z}{A}$)

Open questions

- Can we improve our estimate of $\mathbf{K}_{\infty}$?
- Why open-shell nuclei seem to be softer? (Case of Sn and Cd)
- Can we constrain better the EoS density dependence?
- What happen in exotic nuclei? Do Soft modes exist?

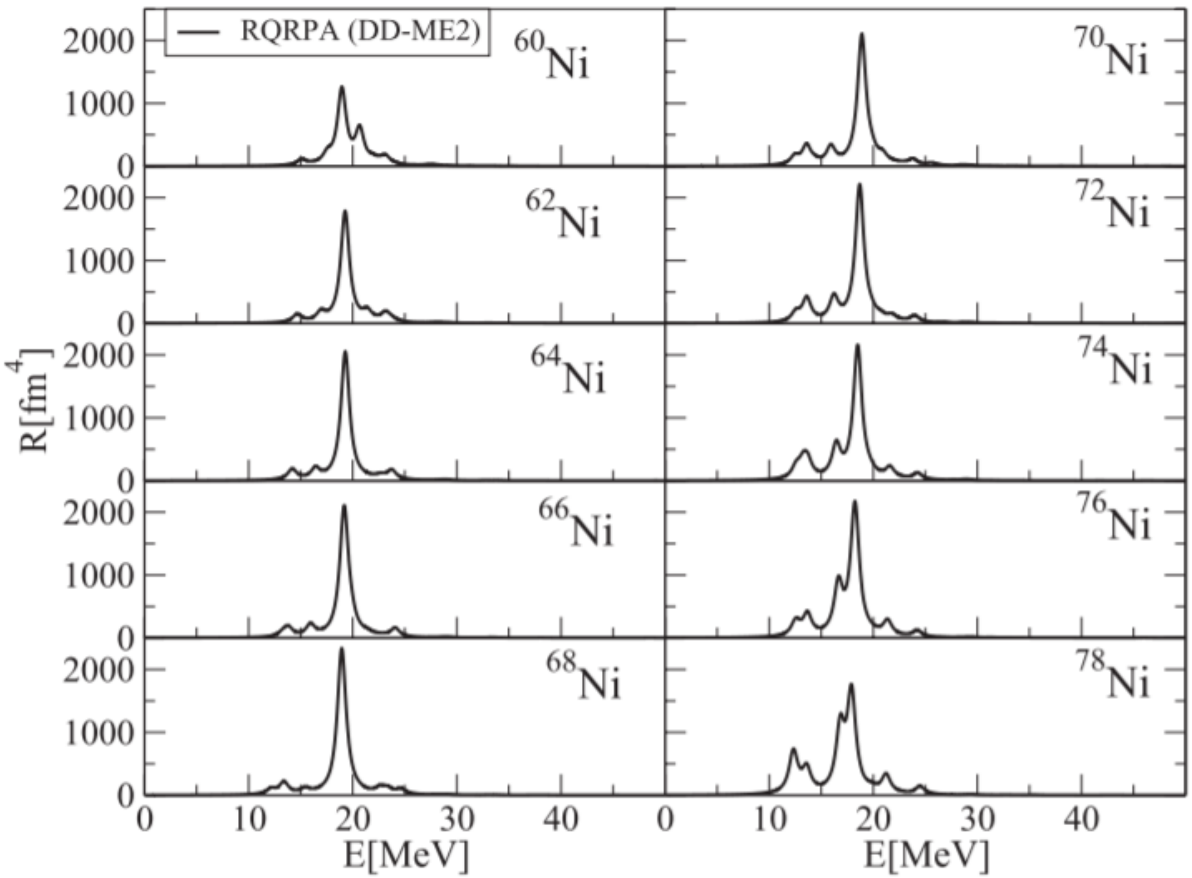
Ni isotopic chain

possibility to measure isoscalar monopole strength from neutron-deficient to neutron-rich nuclei:

- **^{58}Ni and ^{60}Ni (stable isotopes) (α,α')**
  - Y.-W. Lui PRC 73, 014314 (2006)
  - J.C. Zamora PLB 763 (2016)16
- **^{56}Ni(d,d')**
  - C. Monrozeau et al., PRL 100 (2008) 042501
- **^{68}Ni(d,d') and (α,α')**
  - M. Vandebrouck, PRL 113 (2014) 032504
  - M. Vandebrouck, PRC 92 (2015) 024316
- **^{56}Ni(α,α')**
  - S. Bagchi, PLB 751 (2015) 371

Ni isotopic chain

→ development of strength with neutrons enrichment: **Soft Monopole** mode!



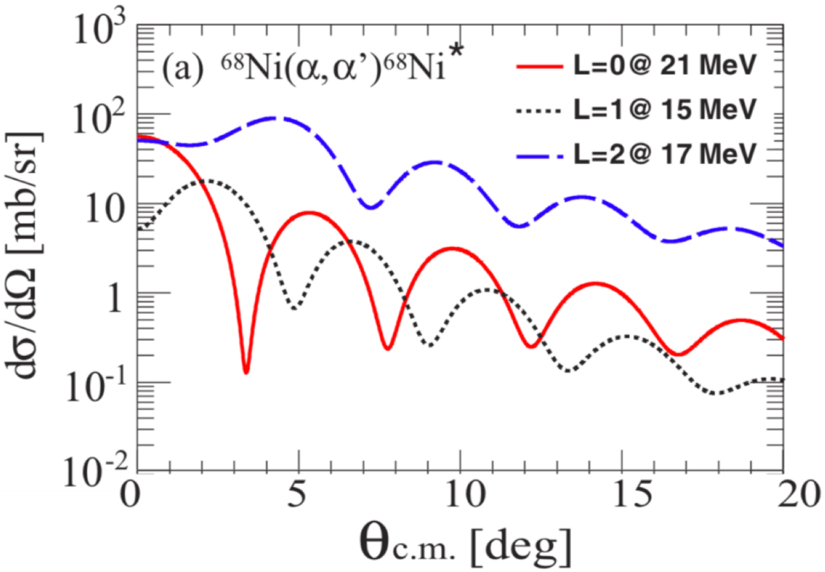
E. Kahn et al., Phys. Rev. C **84**, 051301(R) (2011)

2. The experiment

ISGMR in ^{68}Ni

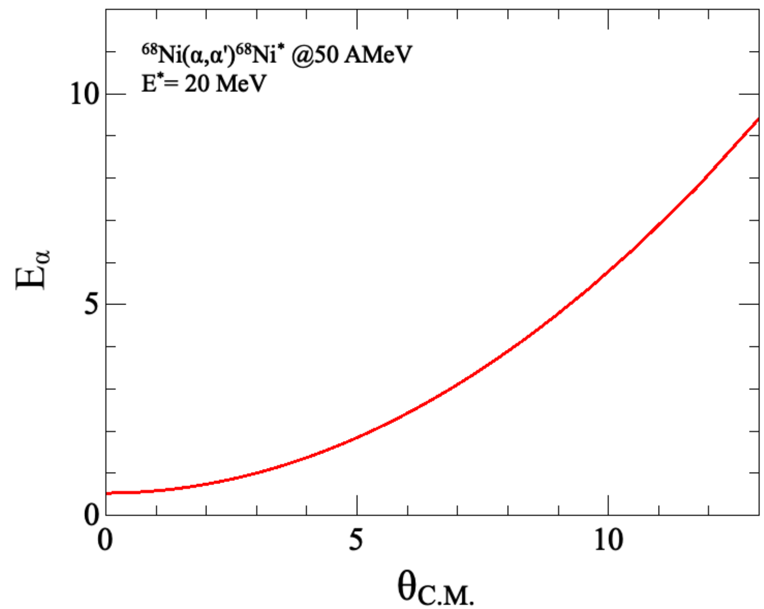
Inelastic scattering of α particle in **inverse kinematics: ^{68}Ni(α, α′)^{68}Ni***

→ $E^{*}_{ISGMR}(^{68}Ni) \sim 20$ MeV



M. Vandebrouck, PRC 92 (2015) 024316

maximum at low angles:
detection region $0° < \theta_{CM} < 6°$

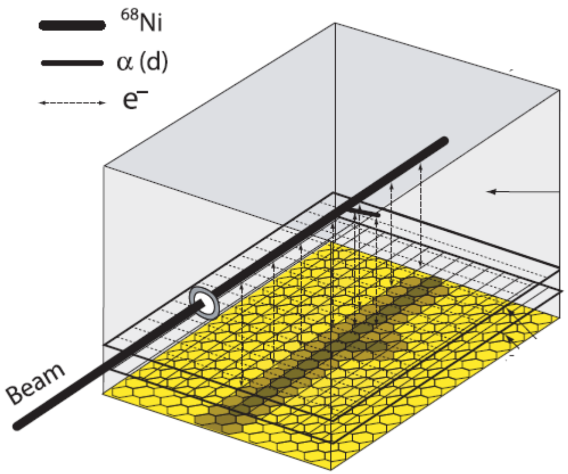


low energy of the recoil particles:
$0.5 < E_\alpha < 2.5$ MeV

Experimental technique

- inverse kinematics
- maximum cross section at forward angle
- low momentum transfer (small energy of recoil particles)

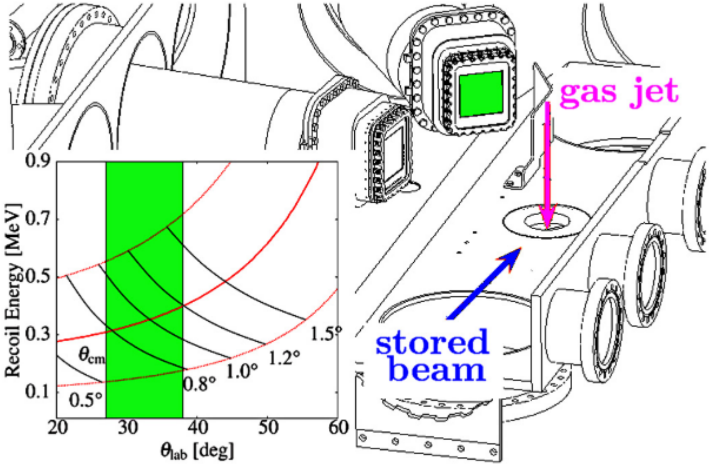
ACTIVE TARGET



C.E. Demonchy et al., NIM A573, 145 (2007)

T. Roger et al., NIM A895, 126 (2018)

STORAGE RING



J.C. Zamora et al., PLB 763, 16-19 (2016)

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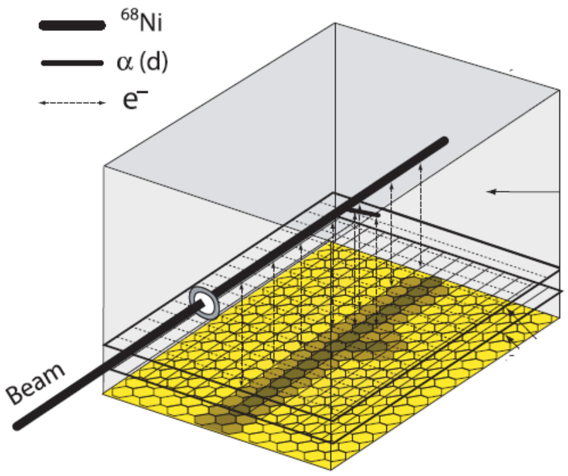

C.E. Demonchy et al., NIM A573, 145 (2007)

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GRs with the previous active target (MAYA):

- ^{56}Ni(d,d') GMR and GQR
  C. Monrozeau et al., PRL 100 (2008) 042501
- ^{56}Ni(α,α') GMR and GDR
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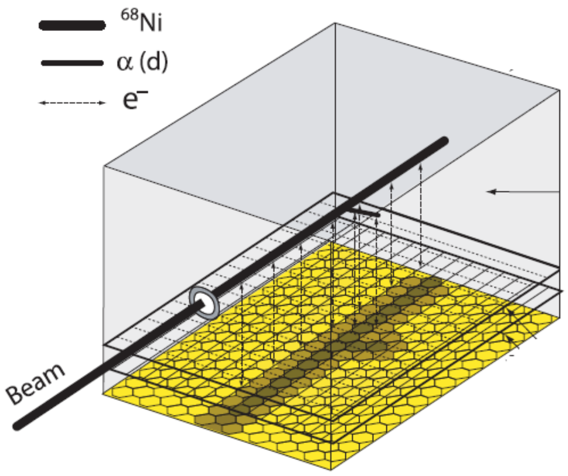

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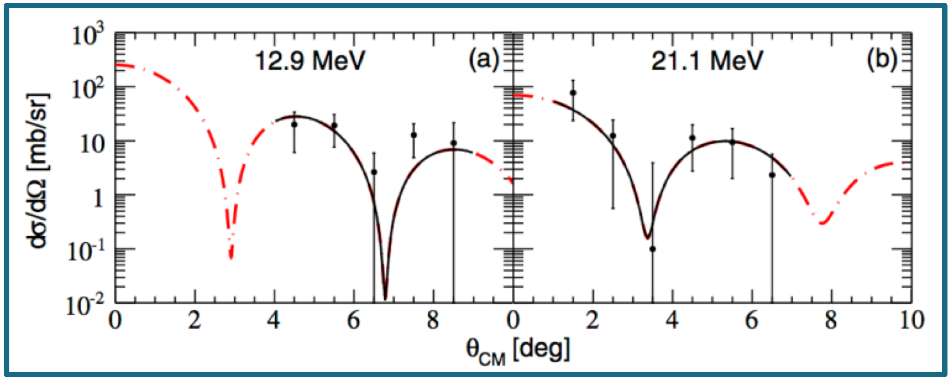
ISGMR in ^{68}Ni: previous result

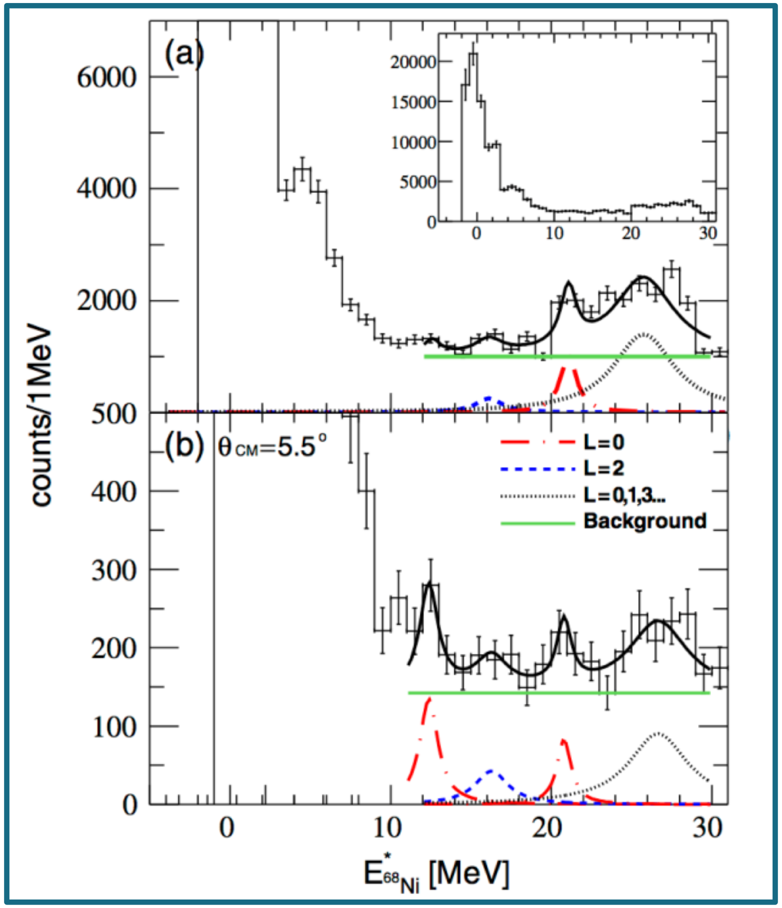
with the active target **MAYA**:

M. Vandebrouck, PRL 113 (2014) 032504
M. Vandebrouck, PRC 92 (2015) 024316

^{68}Ni (α,α') @ 50 AMeV

- beam intensity 4×10^4 pps, purity 75%
- He + 5% CF4 pressure 500 mb
- recoil threshold 600 keV
- large background
- limit in angular distribution





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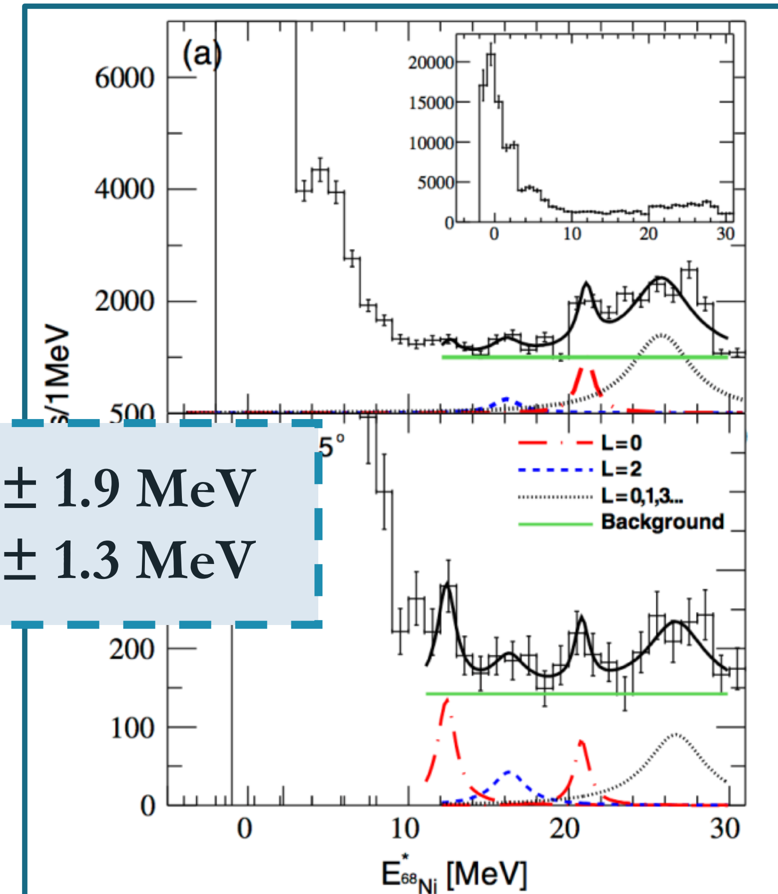
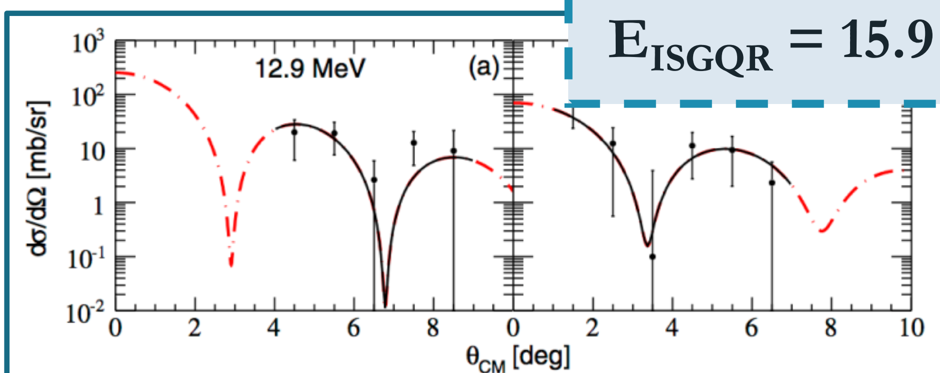


E_{ISGMR} = 21.1 ± 1.9 MeV
E_{ISGQR} = 15.9 ± 1.3 MeV



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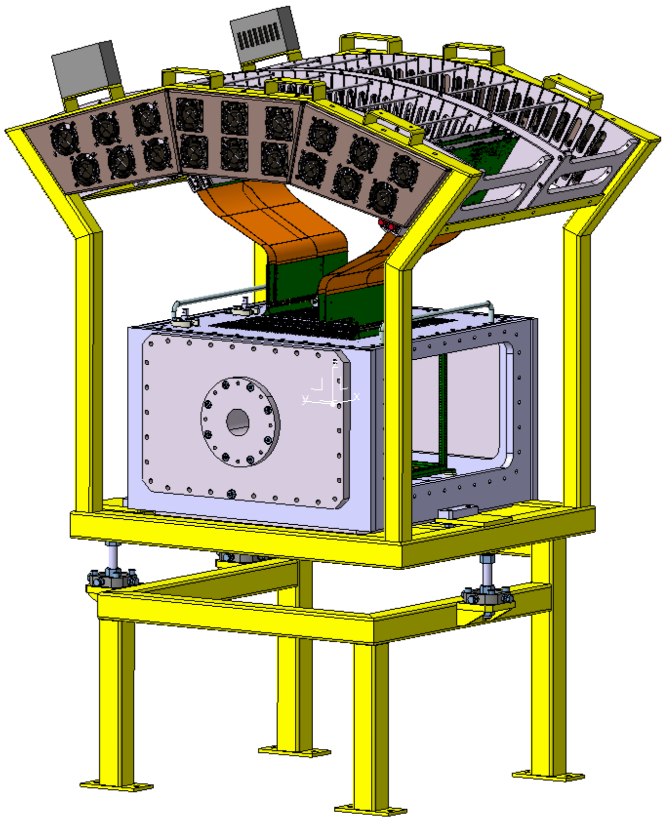
Setup upgrade

Beyond MAYA: ACTAR-TPC

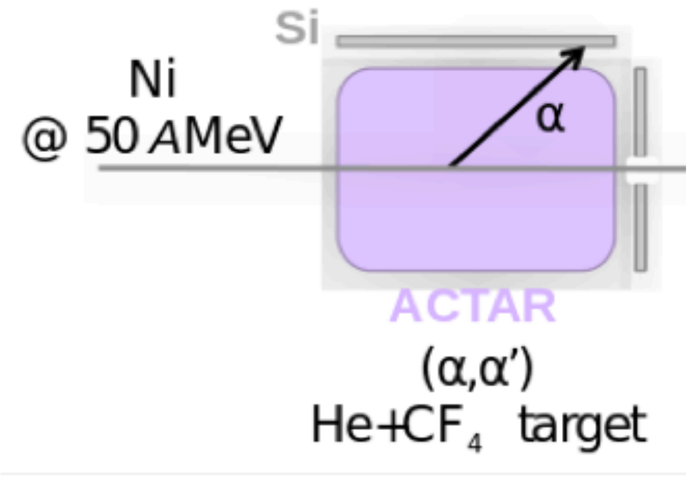
- Multi-particle detection
- Higher segmentation
- Lower energy threshold
- Higher resolution
- Higher reconstruction efficiency
- New electronics (16k channels)



The experiment

New experiment with ACTAR-TPC : April-July 2019 @GANIL

- Benchmark with ^{58}Ni
- Repeat (improve!) ^{68}Ni(α,α'): measure the **monopole strength of ^{68}Ni**, with emphasis on the existence of the **soft** component



→ PhD project of A. Arokiaraj, KU Leuven

The experiment

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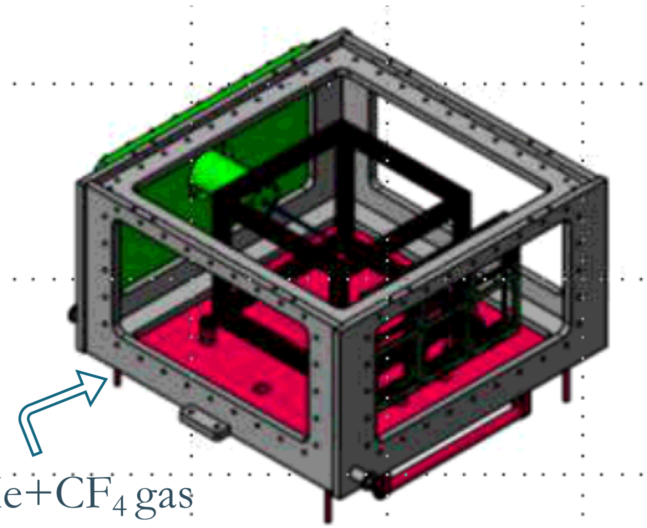
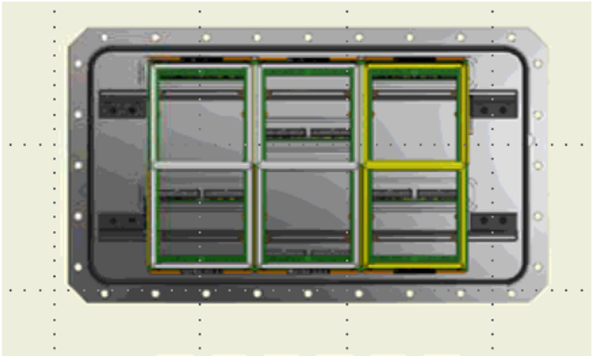
→ setup: **ACTAR-TPC + 10** Silicon detectors (**DSSSDs**) on the lateral flanges



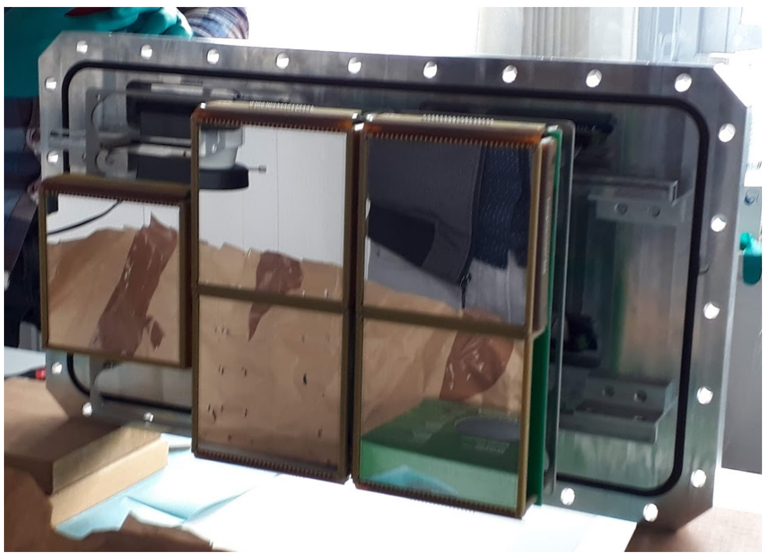
He+CF_4 gas

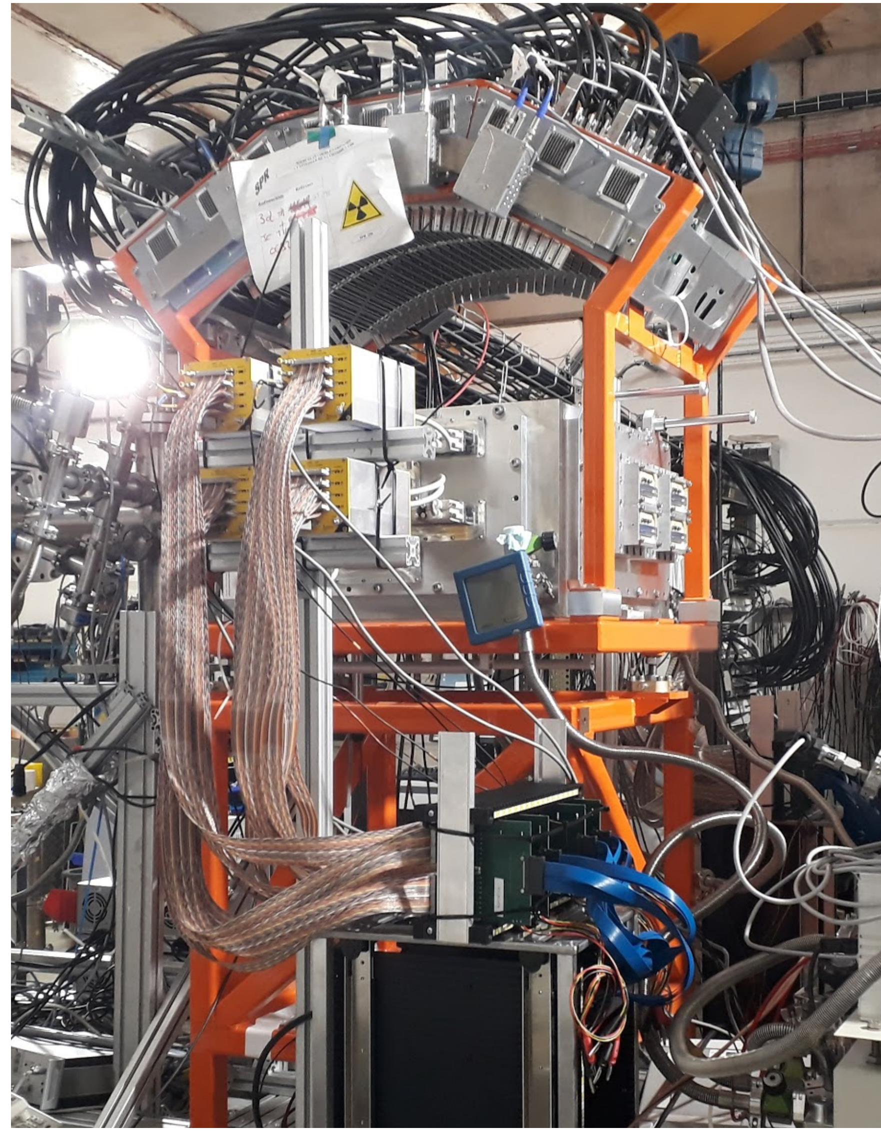


designed by O.Poleshchuk, KU Leuven

The experiment

…the experimental setup…
(April 2019)





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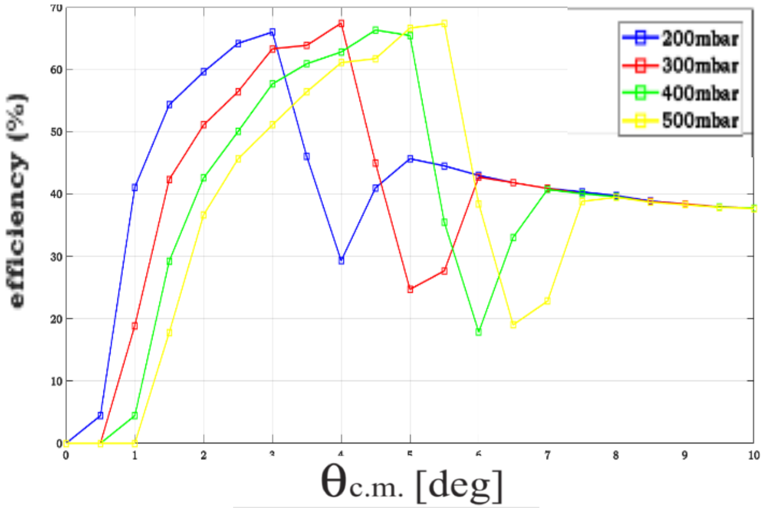
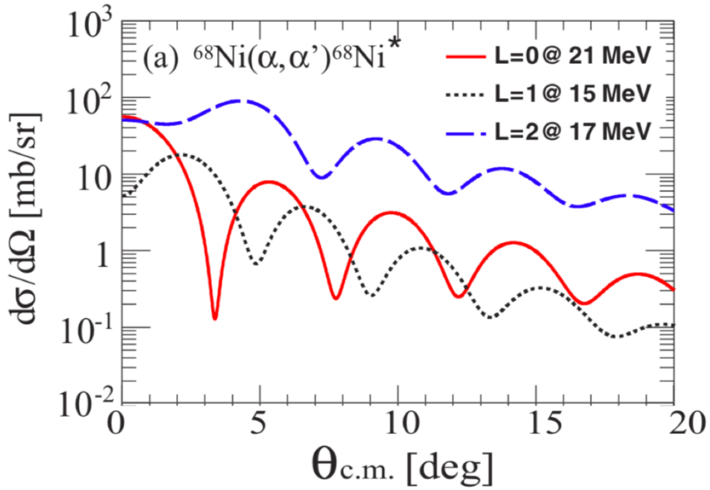
Experimental conditions





- gas: He(98%)+CF_4(2%)
- gas pressure: 400 mbar

^{58}Ni(α,α′) @ 49 AMeV

- beam intensity: 3 10^4 pps
- 13 BTU

^{68}Ni(α,α′) @ 49 AMeV

- beam intensity: 3 10^4 pps
- 10 BTU

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Preliminary analysis: ^{58}Ni

1. Identification of the scattered particles

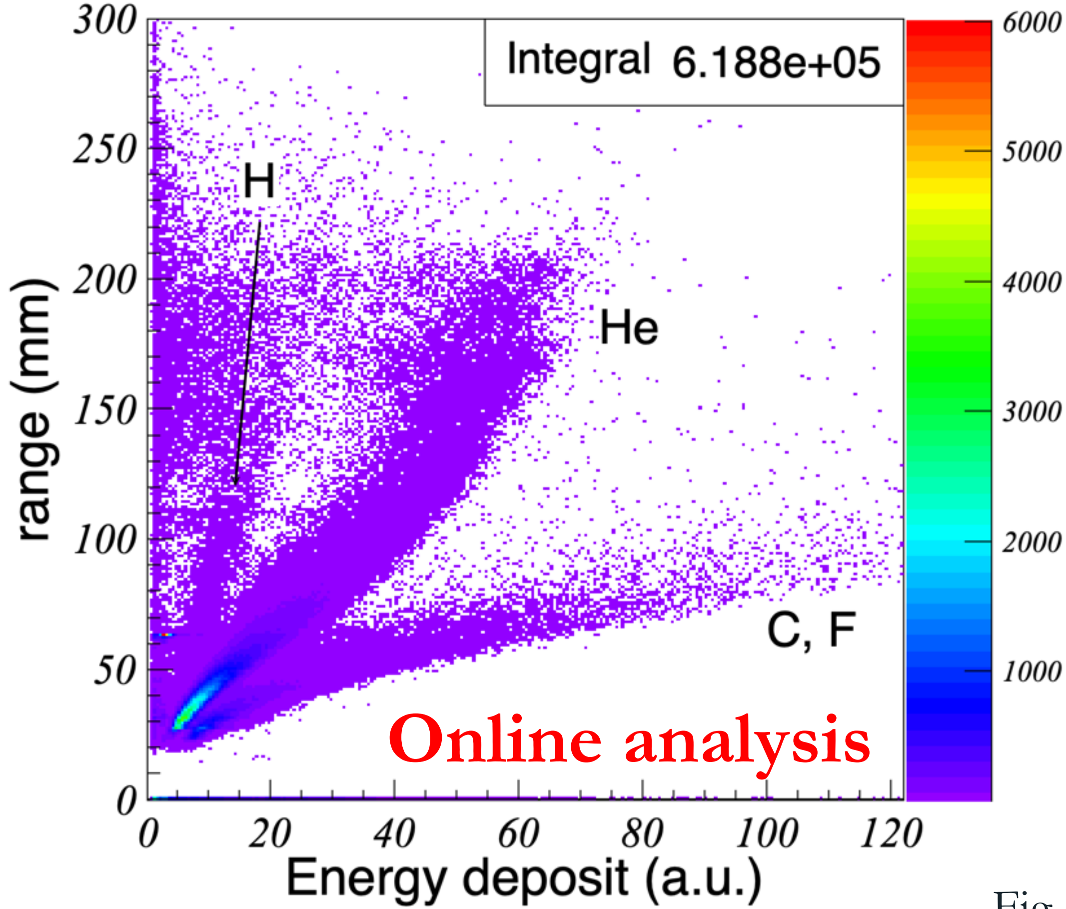


Fig credits: B.Mauss

Preliminary analysis: ^{58}Ni

2. Kinematic curve

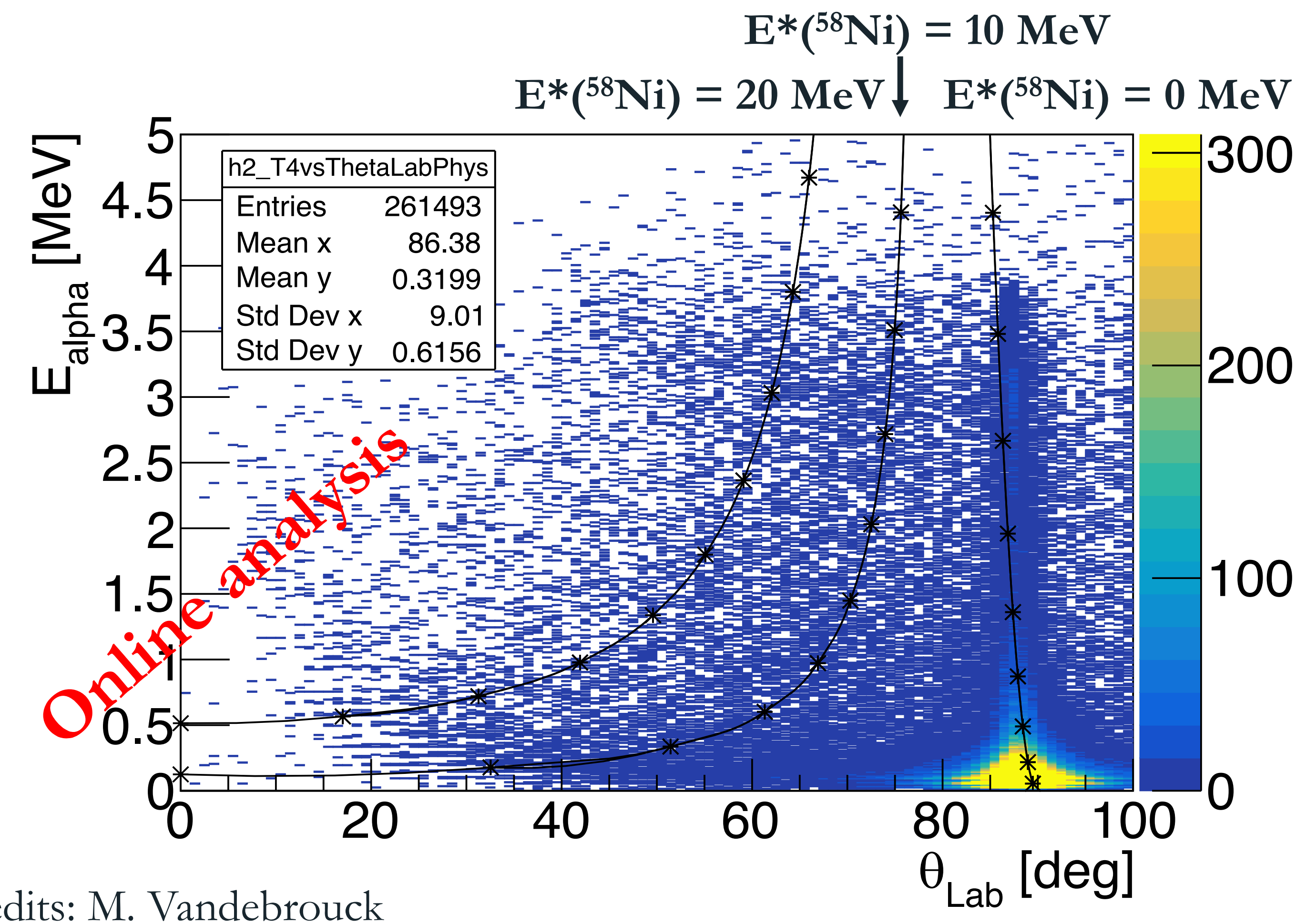


Fig. credits: M. Vandebrouck

Preliminary analysis: ^{58}Ni

3. ^{58}Ni excitation energy spectrum

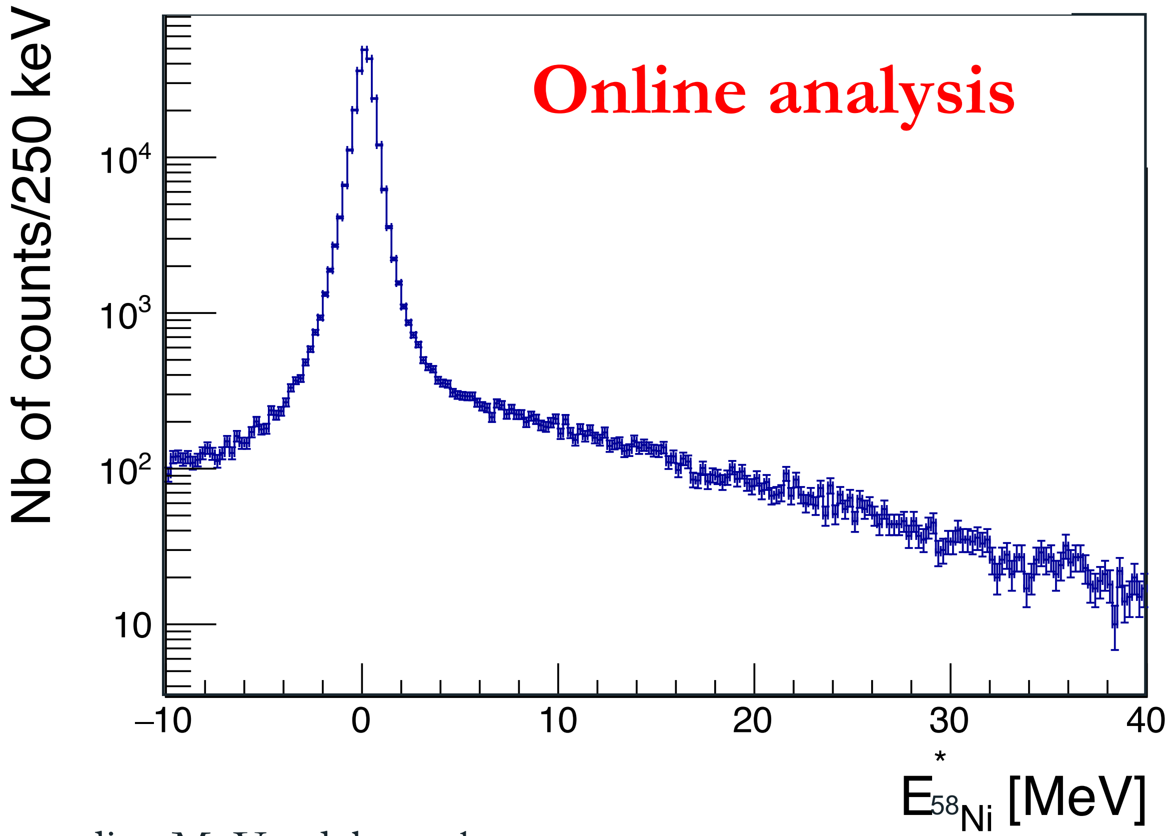


Fig. credits: M. Vandebrouck

Resolution

R_{elast}: ~ 420 keV

⬇

3-4 times better than MAYA

Preliminary analysis: ^{68}Ni

1. Identification of the scattered particles
2. Kinematic curve

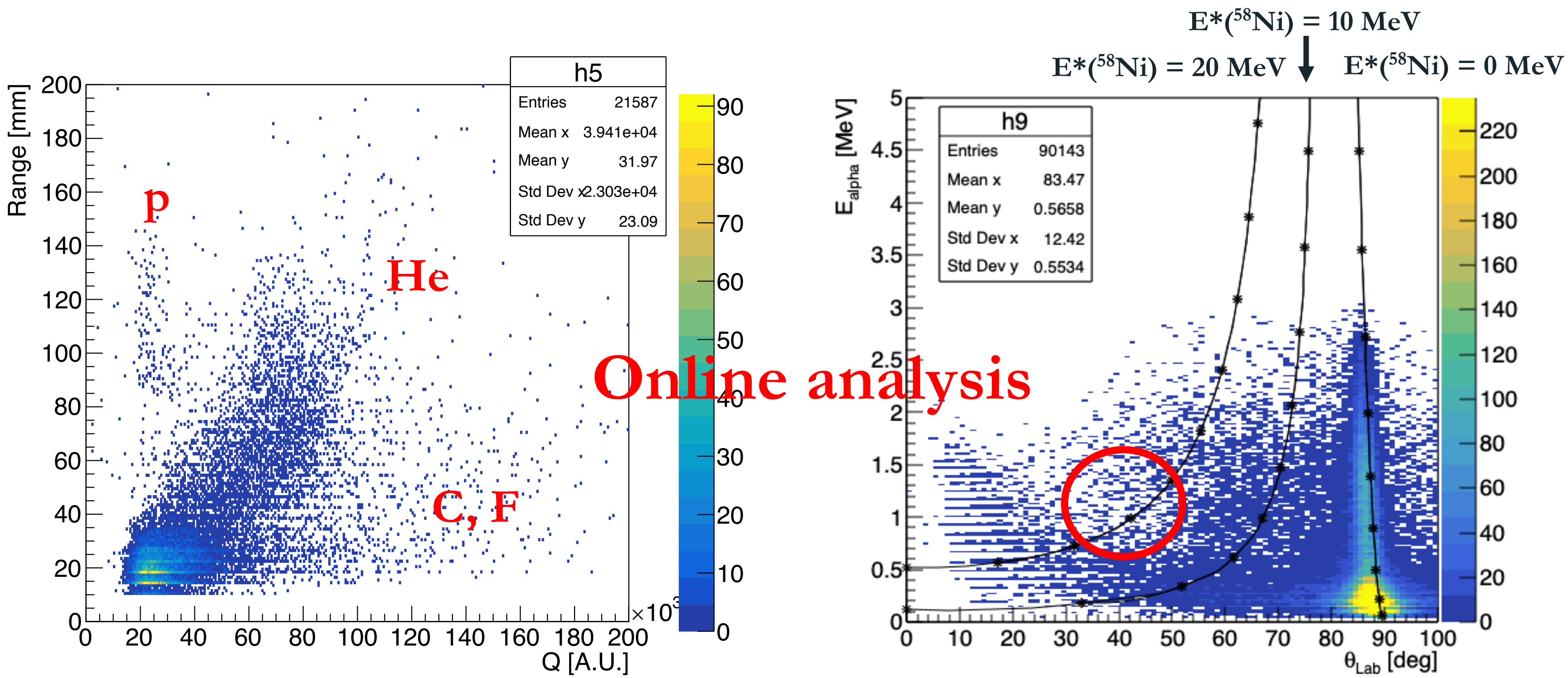
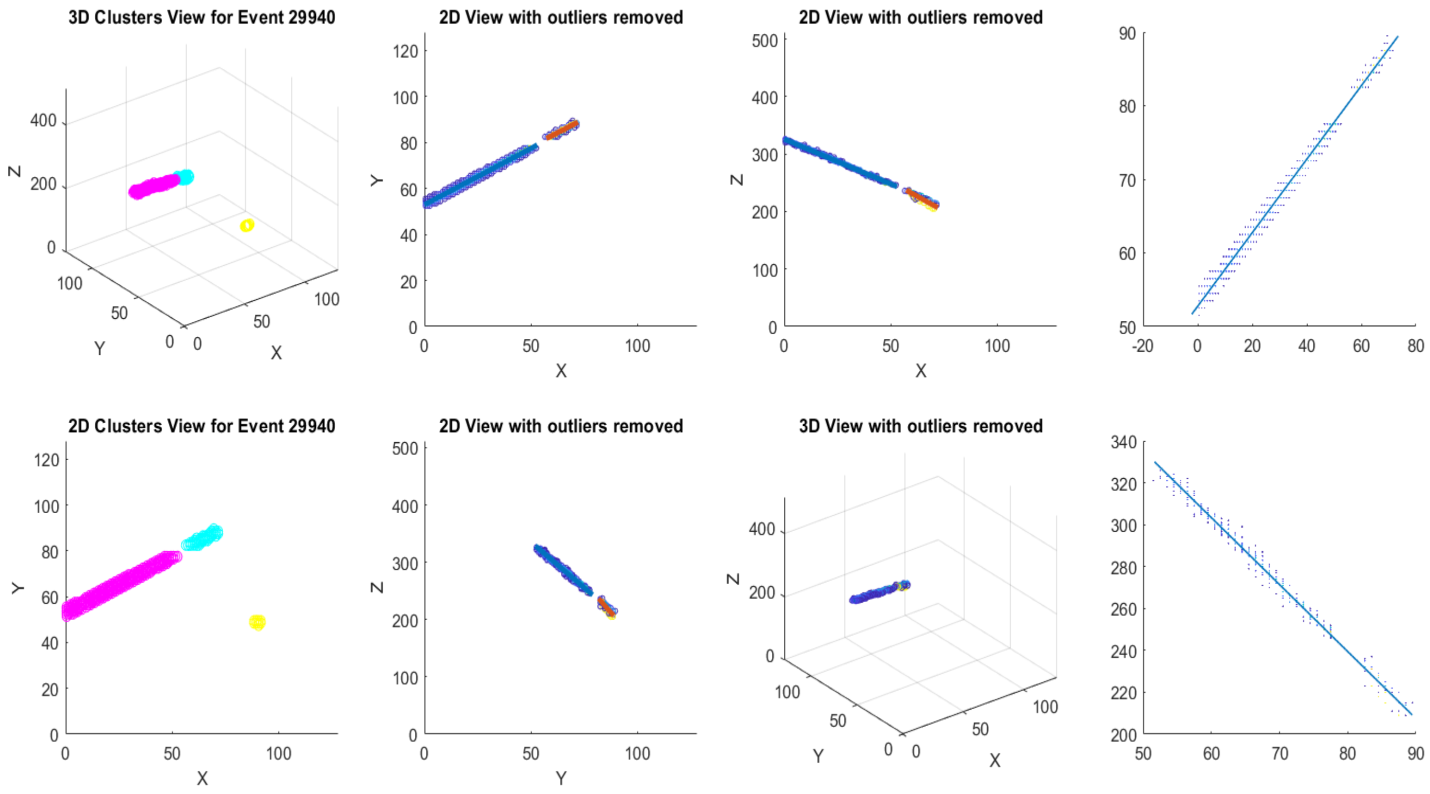


Fig. credits: M. Vandebrouck

Ongoing work

→ Track reconstruction algorithm: identification of clusters, track orientation, cluster merging for tracks with holes



A. Arokiaraj, KU Leuven

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3. Future perspective

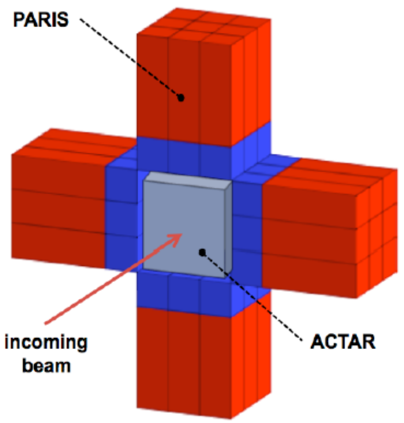
Future perspective

collective modes investigation with active targets:

→ first measurement of isoscalar GRs with ACTAR-TPC in Ni region

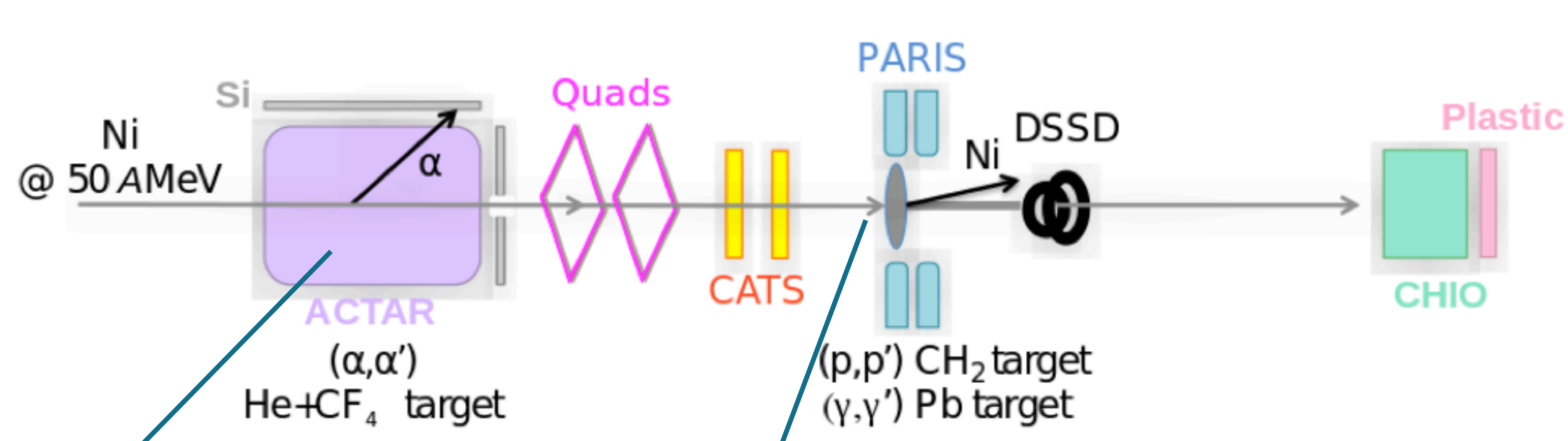
→ improvement in the detection setup:

- optimise the resolution for GRs studies
- couple to **γ**-ray detectors, the PARIS array: study the PDR



Future perspective

1. Yakitori mode:



IS GRs
α scattering

PDR
- Coulomb excitation (Pb target)
- p scattering (CH_2 target)

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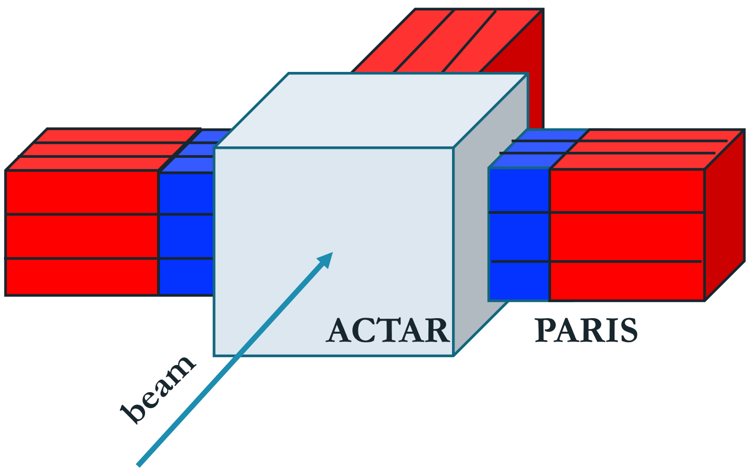
Future perspective

2. **ACTAR "surrounded" by 3/4 PARIS clusters**

   → **PDR:** inelastic scattering in inverse kinematics



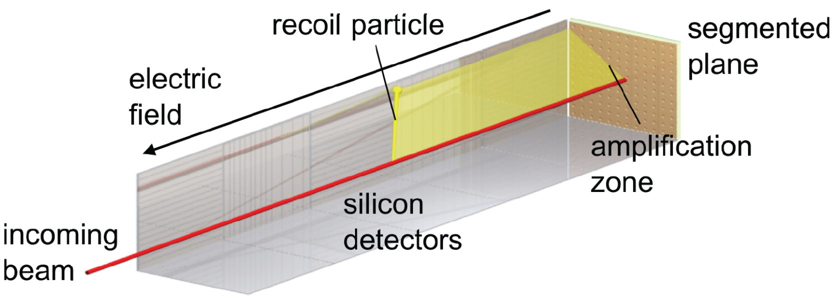
- PARIS on the lateral flanges: thinner flanges? (to go closer)
- electronics: integrate the scintillators part into ACTAR part

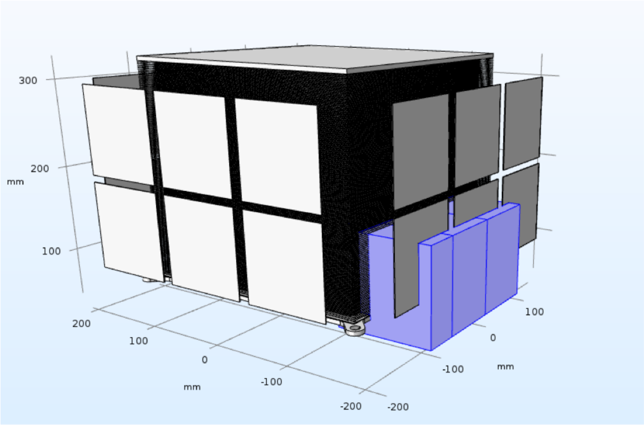
gas: He and H → investigation of both IS-IV part!

Future perspective

New GR-dedicated active target (KU Leuven):

- (much?) lower pressure
- Longer target (1m?) to compensate for pressure
- Particle energy: DSSSDs (18)
- Particle angles: tracks





…now under design…

→ key point: electic field simulation

Work of S. Fracassetti, KU Leuven

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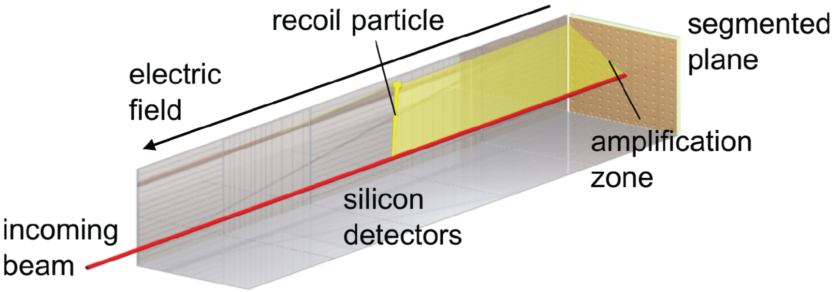
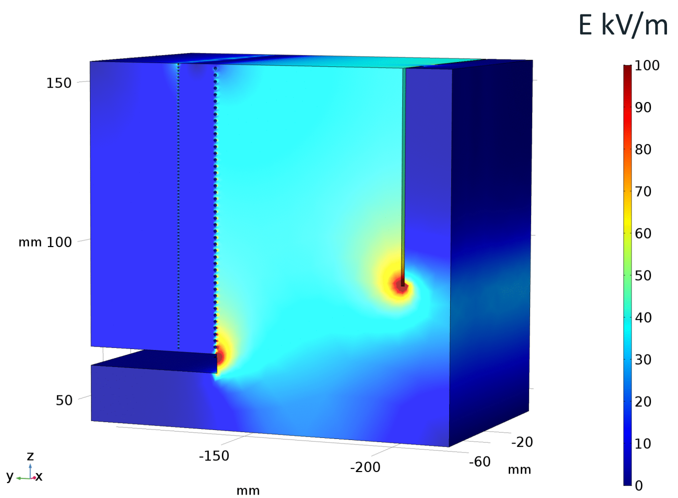




…now under design…

→ key point: electic field simulation

Work of S. Fracassetti, KU Leuven

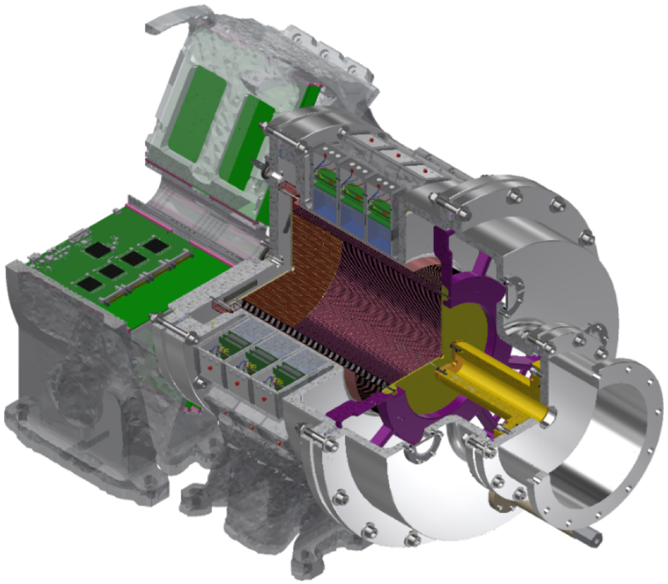
Future perspective

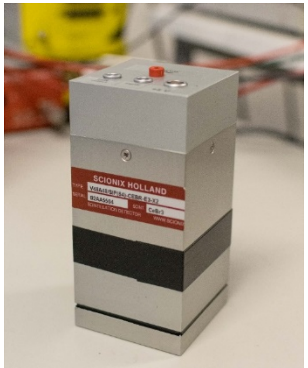
SpecMat

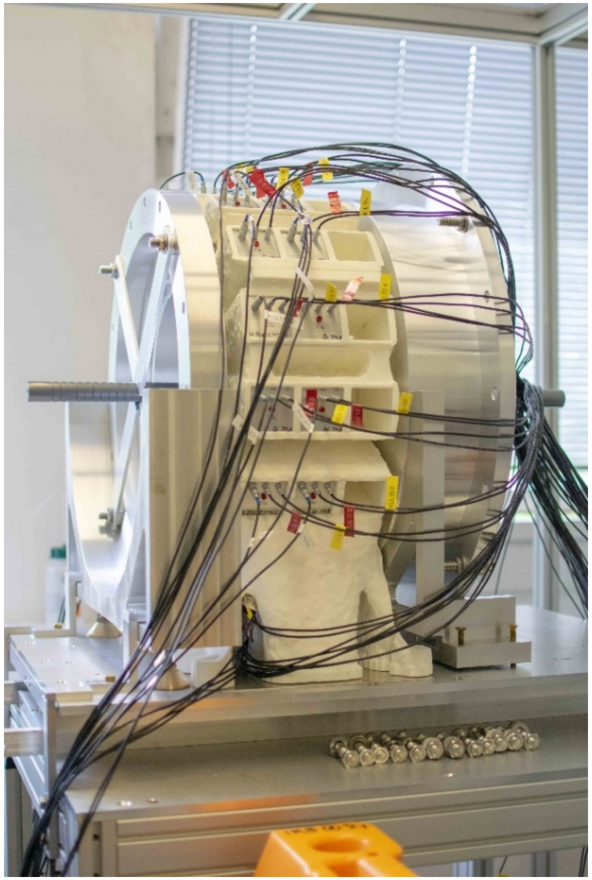
→ Active target in magnetic field

+

→ scintillators: 45 $CeBr_3$ ($48\times48\times48$ mm^3)







Work of O. Poleshchuk, KU Leuven

Summary

Collective modes very important for nuclear research and beyond:

- IS-GRs (compression modes): related to incompressibility and Equation of State of nuclear matter
  $\longrightarrow$ nuclear physics, astrophysics implications
- Measurements on chain of isotopes:
  radioactive beams in inverse kinematics, active targets
- $(^{58})\ ^{68}$Ni measured at LISE-GANIL with ACTAR-TPC:
  $\longrightarrow$ successful beam time, (promising) ongoing analysis

Future perspective:

- Optimised target
- Coupling with **γ**-array PARIS: PDR

N. L. Achouri[3], M. Assié[4], S. Barlini[21], D. Beaumel[4], P. Bednarczyk[5], G. Benzoni[1], N. Blasi[1], Y. Blumenfeld[4], S. Bottoni[1](PDF), A. Bracco[1], A. Buccola[21], M. Caamaño[6], S. Calinescu[7], A. Camaiani[21], F. Camera[1], G. Casini[21], M. Cicerchia[19](S), M. Ciemala[5], M. Cinausero[19], F. Crespi[1], F. Delaunay[3], Z. Dombradi[9], D. Fabris[22], B. Fernandez-Dominguez[6], F. Flavigny[4], C. Frosin[21], S. Galès[4], U. Garg[10], J. Gibelin[3], J. Giovinazzo[11], G. Gosta[1](S), F. Gramegna[19], S. Grévy[11], M. N. Harakeh[12], C. Iwamoto[17], N. Kalantar[12], E. Khan[4], M. Kmiecik[5], A. Krasznahorkay[8], S. Leoni[1], E. Litvinova[13,14], A. Maj[5], T. Marchi[19], A. Mentana[8](PDF), G. Mantovani[19](S), J. Margueron[15], F. M. Marqués[3], I. Matea[4], B. Mauss[2] (S), B. Million[1], P. Morfouace[2] (PDF), P. Ottanelli[21], L. Pellegri[20], S. Péru[16], S. Piantelli[21], O. Poleshchuk[8],R. Raabe[8], A.A. Raj[8](S), M. Renaud[8](S), J. Refsgaard[5], X. Roca Maza[1], T. Roger[2], S. Ota[17], O. Sorlin[2], J. C. Thomas[2], H. Tokieda[17], S. Valdré[21], M. Vandebrouck[18], O. Wieland[1], J. Yang[7](S) the ACTAR TPC collaboration and the PARIS collaboration

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