Measurements of compression modes with radioactive ion beams: techniques and perspectives

Riccardo Raabe

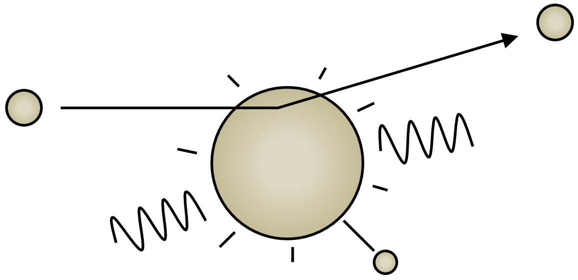
KU Leuven, Instituut voor Kern- en Stralingsfysica

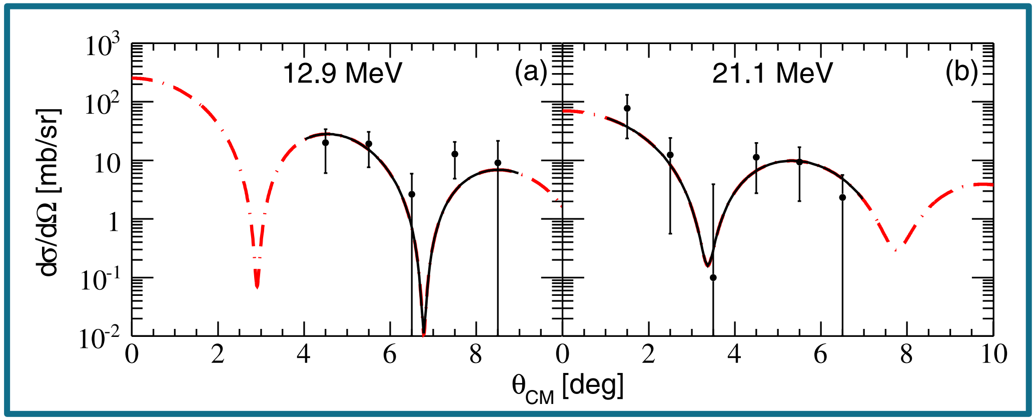
Outline

- Experimental observables in the study of giant resonances
- Direct kinematics
- Methods in inverse kinematics
  - Peculiarity of the kinematics
  - Storage rings
  - Active targets
    Issues and mitigations
- Perspectives
  - Optimised active target and optimised use
  - Detection of de-excitation modes
- Summary

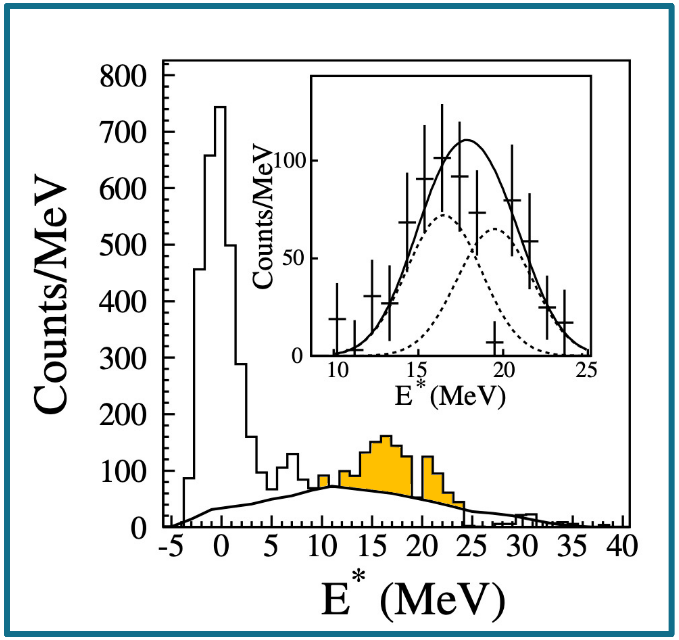
Experimental observables

- Identification of the channel (inelastic scattering)
- Excitation energy through kinematics (missing mass)
- Multipolarity from angular distributions
- De-excitation modes





M. Vandebrouck et al.,
PRL 113 (2014) 032504



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

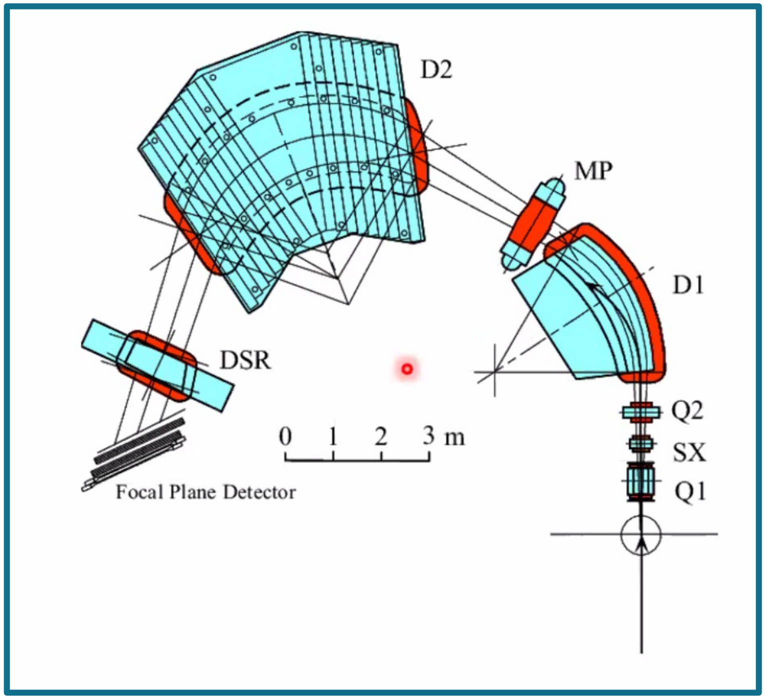
Direct kinematics

- Inelastic scattering:
  maximum cross section
  at very forward c.m. angles
  (ideally 0 degrees)

Stable nuclei

- Direct kinematics
  Large spectrometers to measure
  momentum of scattered particle

Grand Raiden at RCNP Osaka



M. Itoh et al., Phys. Rev. C 68 (2003) 064602

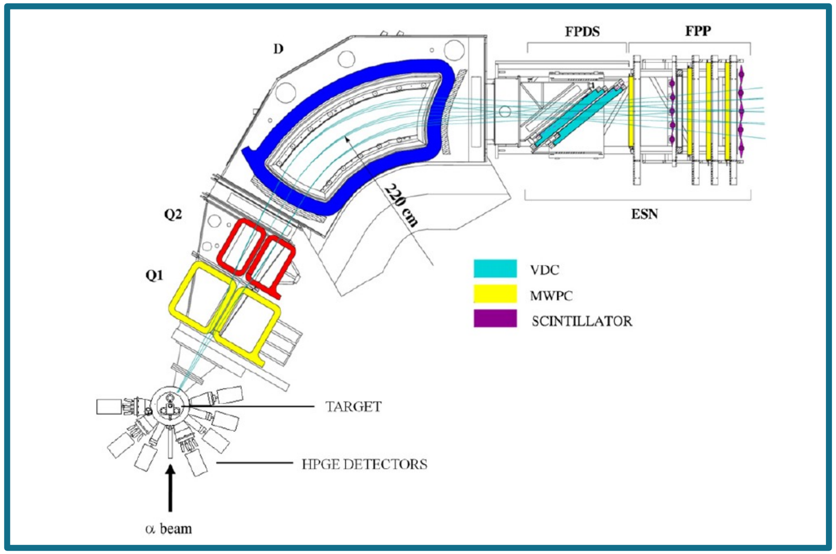
Direct kinematics: de-excitation

- γ-ray coincidence
- Charged-particle coincidence

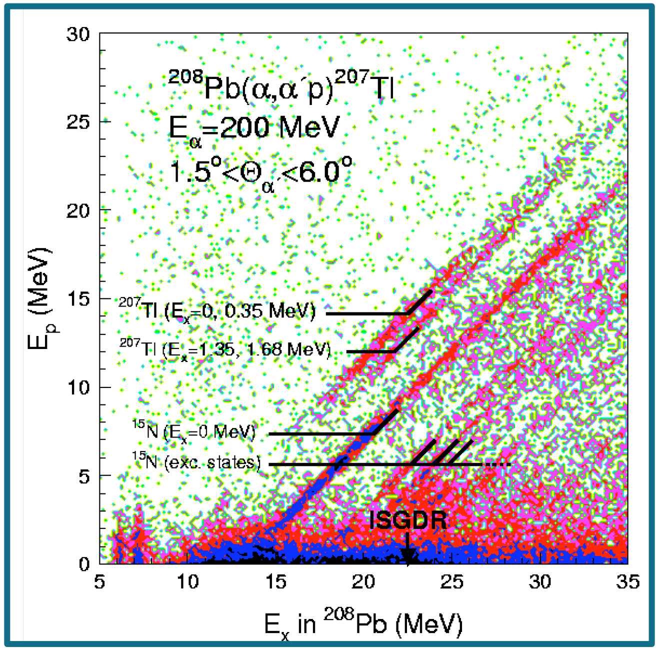
→ background reduction

→ multipolarity of the transition

→ microscopic structure



J. Endres et al., Phys. Rev. C 85 (2012) 064331



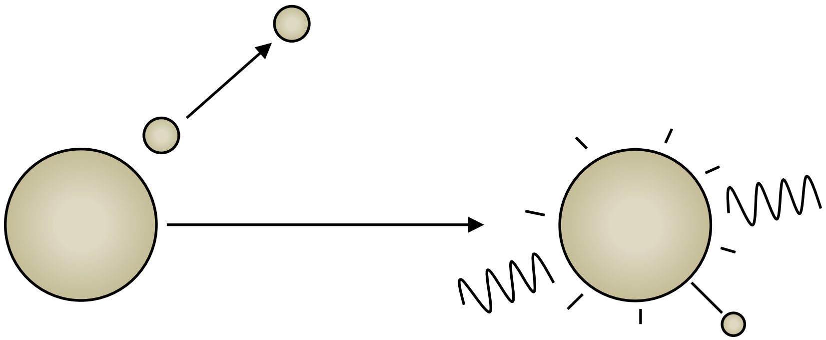
M. Hunyadi et al., PLB 576 (2003) 253

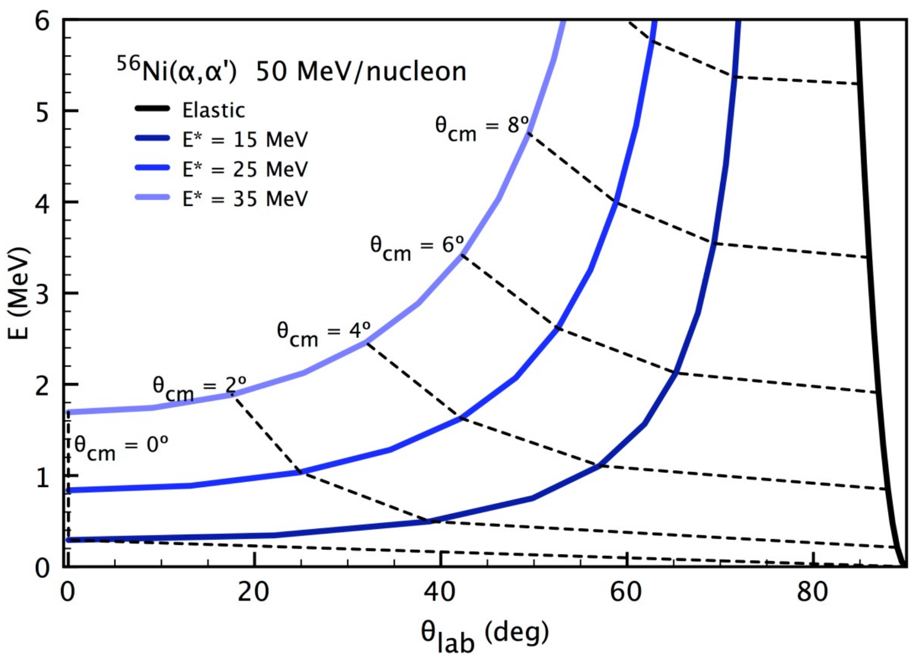
Inverse kinematics

- Heavy particle:
  Change in momentum
  is not measurable
  with sufficient resolution

- Light recoil:
  - forward angles
  - very low energy

→ cannot use a solid target





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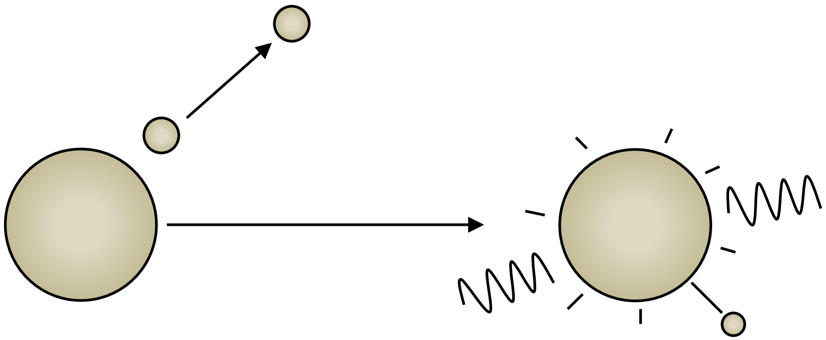
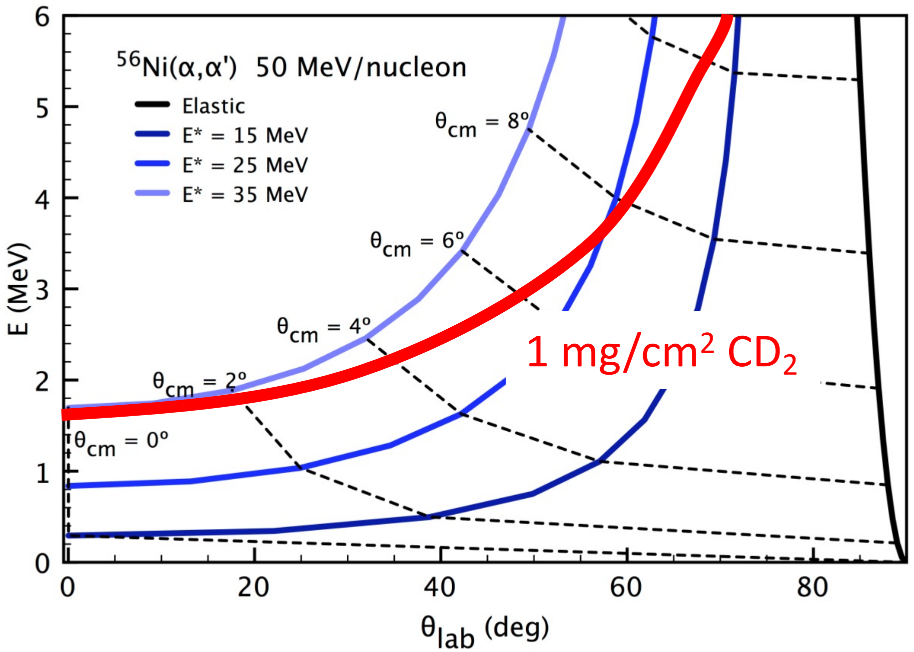
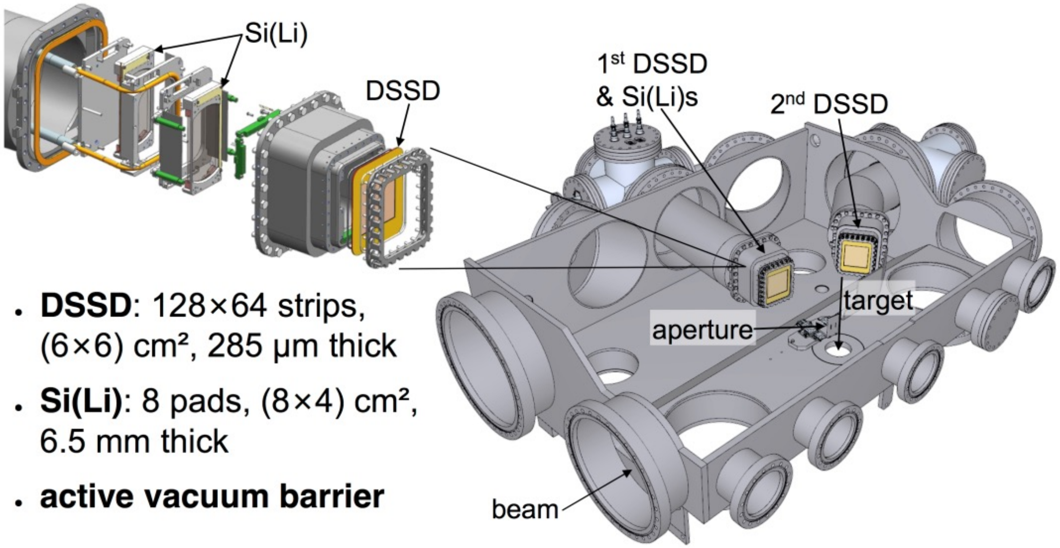




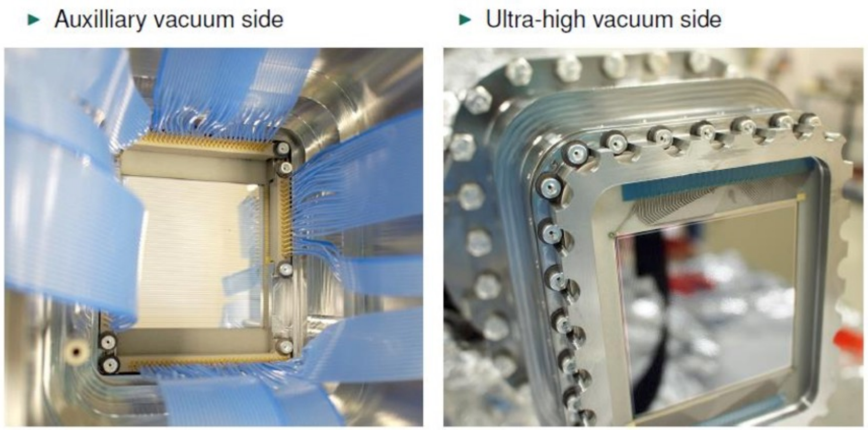
Low momentum-transfer in storage rings

Low energy recoils: detectors as vacuum interfaces

P. Egelhof (GSI), **EXL** Collaboration
H. Moeini et al., NIMA 634 (2011) 77



- **DSSD**: 128×64 strips, (6×6) cm², 285 μm thick
- **Si(Li)**: 8 pads, (8×4) cm², 6.5 mm thick
- **active vacuum barrier**



Low momentum-transfer in storage rings

Physics Letters B 763 (2016) 16–19

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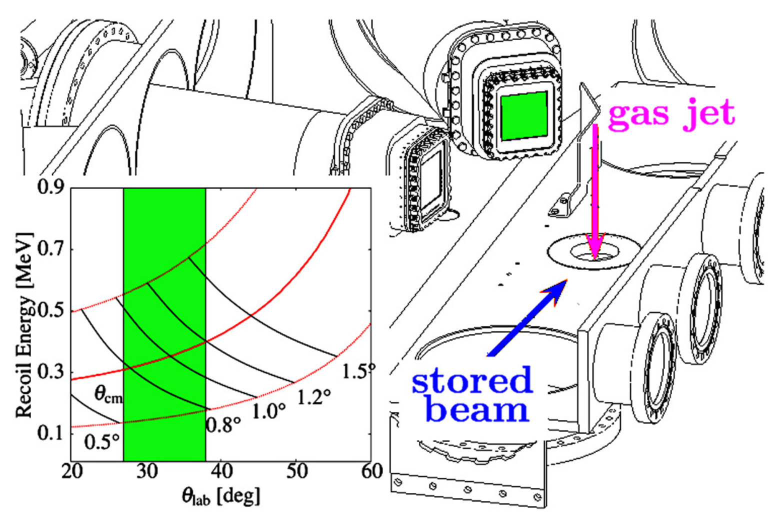
First measurement of isoscalar giant resonances in a stored-beam experiment

J.C. Zamora [a,*], T. Aumann [a,b], S. Bagchi [c,b], S. Bönig [a], M. Csatlós [d], I. Dillmann [b], C. Dimopoulou [b], P. Egelhof [b], V. Eremin [e], T. Furuno [f], H. Geissel [b], R. Gernhäuser [g], M.N. Harakeh [c], A.-L. Hartig [a], S. Ilieva [a], N. Kalantar-Nayestanaki [c], O. Kiselev [b], H. Kollmus [b], C. Kozhuharov [b], A. Krasznahorkay [d], Th. Kröll [a], M. Kuilman [c], S. Litvinov [b], Yu.A. Litvinov [b], M. Mahjour-Shafiei [h,c], M. Mutterer [b], D. Nagae [i], M.A. Najafi [c], C. Nociforo [b], F. Nolden [b], U. Popp [b], C. Rigollet [c], S. Roy [c], C. Scheidenberger [b], M. von Schmid [a], M. Steck [b], B. Streicher [b], L. Stuhl [d], M. Thürauf [a], T. Uesaka [j], H. Weick [b], J.S. Winfield [b], D. Winters [b], P.J. Woods [k], T. Yamaguchi [l], K. Yue [a,b,m], J. Zenihiro [j]

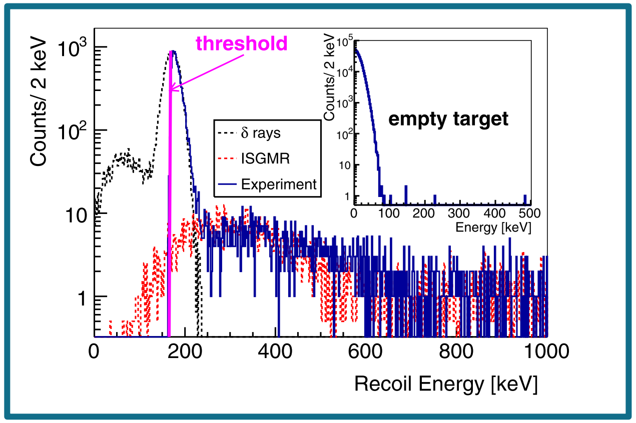
^{58}Ni 100 MeV/A

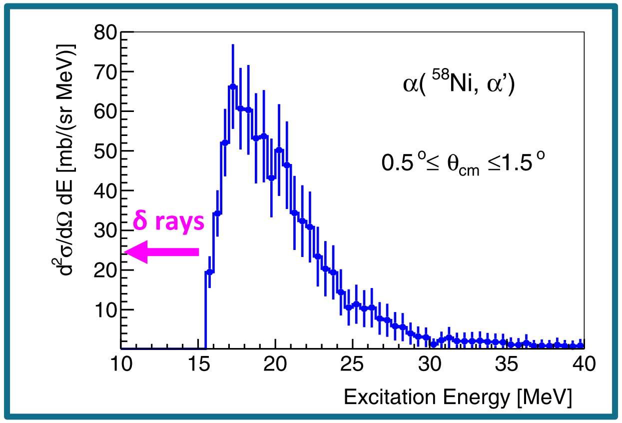


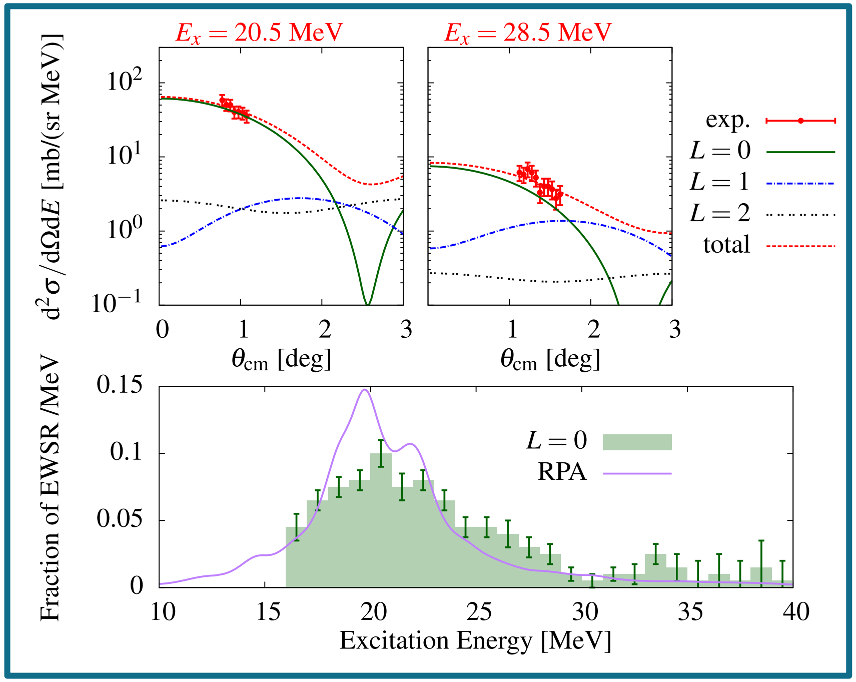
Low momentum-transfer in storage rings

Issues

- Limited solid angle
- Target uniformity
- Background: δ rays







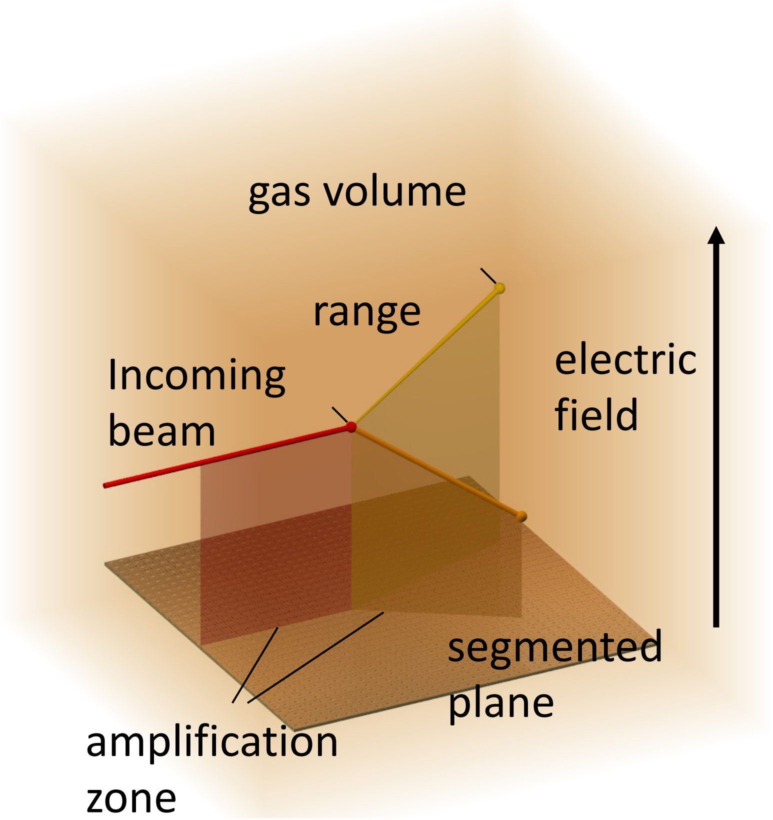
^{58}Ni

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

Active targets

Time-Projection Chamber (TPC)
+ gas is the target

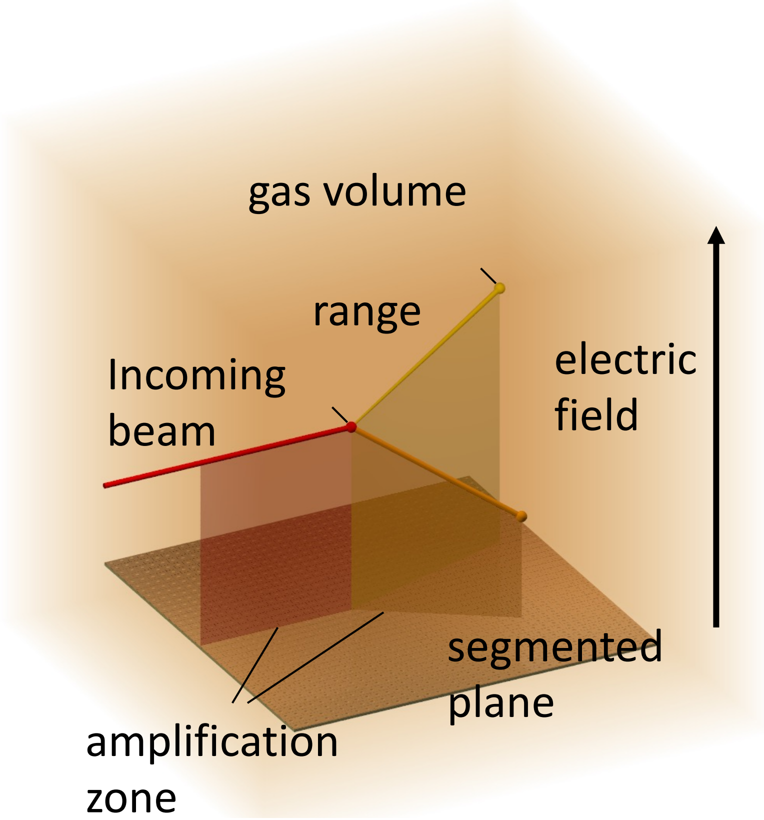
- Electrons produced by ionization drift to an amplification zone
- Signals collected on a segmented "pad" plane ⇒ 2d-image of the track
- 3rd dimension from the drift time of the electrons
- Information:
  - angles
  - energy (from range or charge)
  - particle identification



Active targets

Advantages

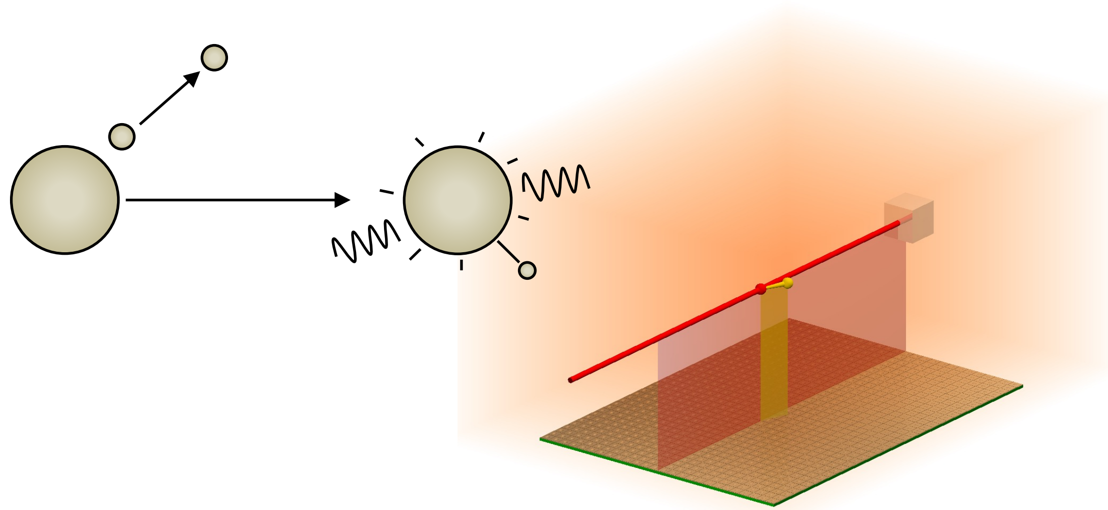
- Large target thickness
  20 cm He @ 1 bar: 3.2 mg/cm^2
  → high luminosity
- Efficient:
  - 4π geometry
  - Low thresholds
- Extremely versatile
  - different gases and pressures
  - variable shape
  - auxiliary detectors

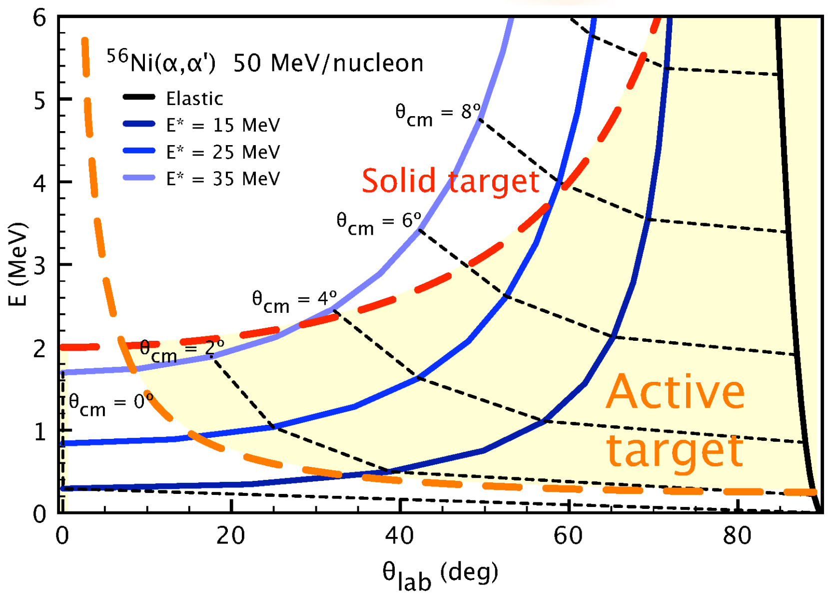


Active targets

Inelastic scattering in active targets

- Scattered particles stopped in the gas
- Low-energy region becomes accessible





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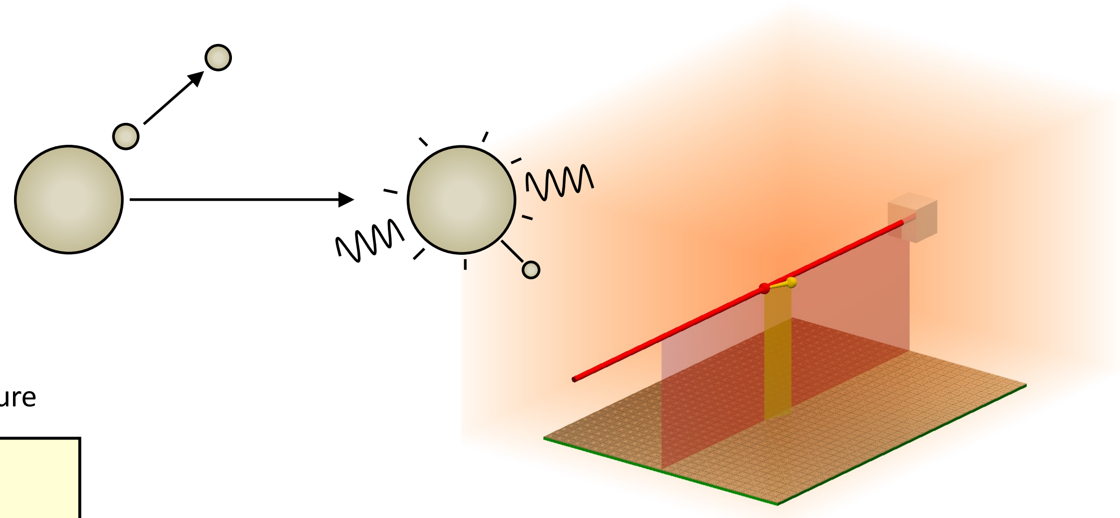
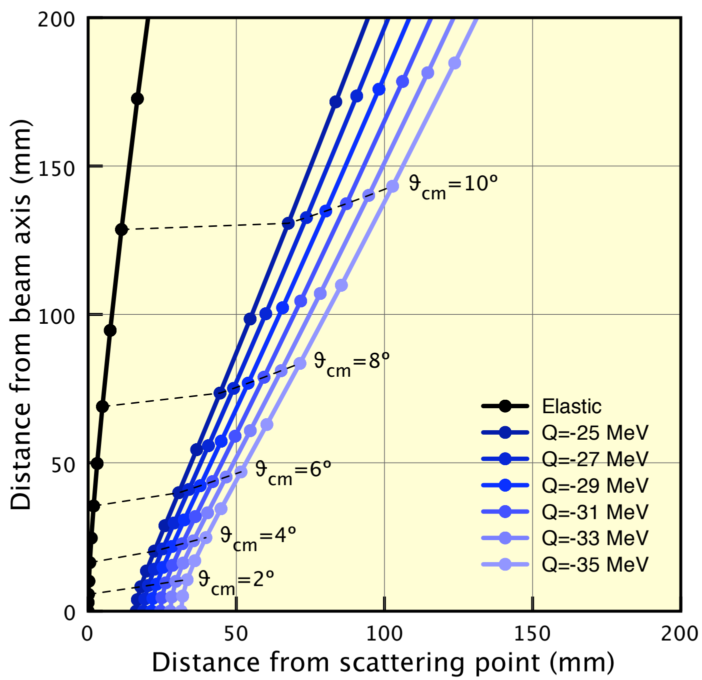
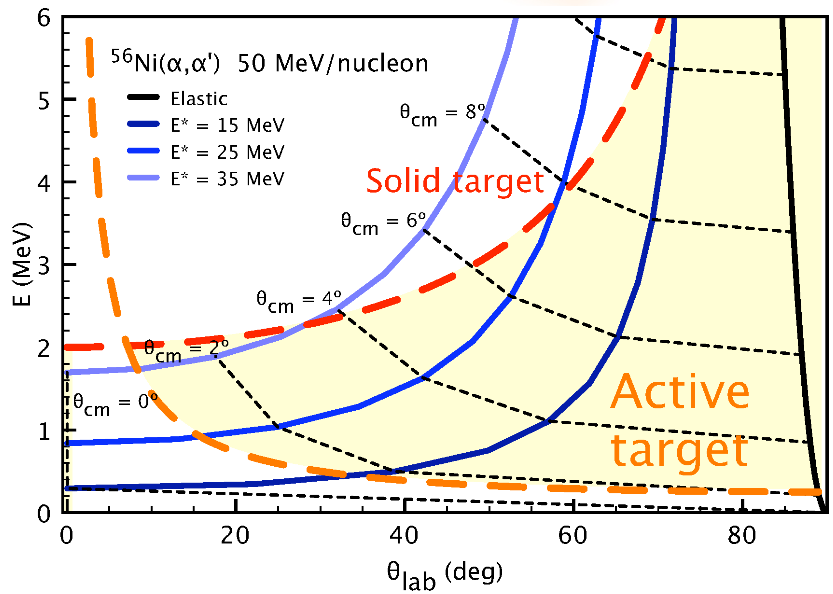
Active targets: dynamic range

- Light recoil:
  - forward angles
    → very low energy
  - energy increases fast
    with angle



^{56}Ni 50 MeV/nucleon, ^{4}He 1 bar pressure





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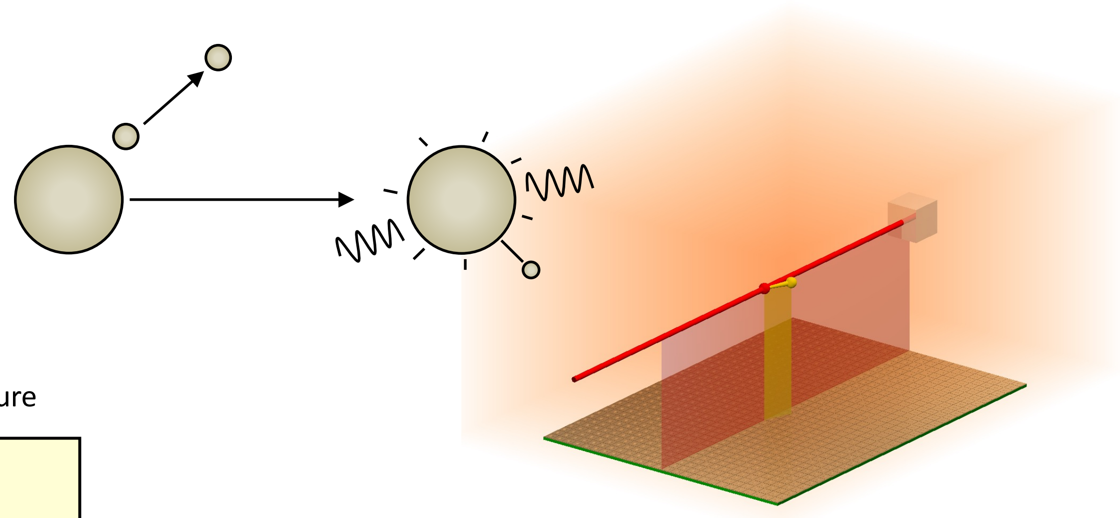
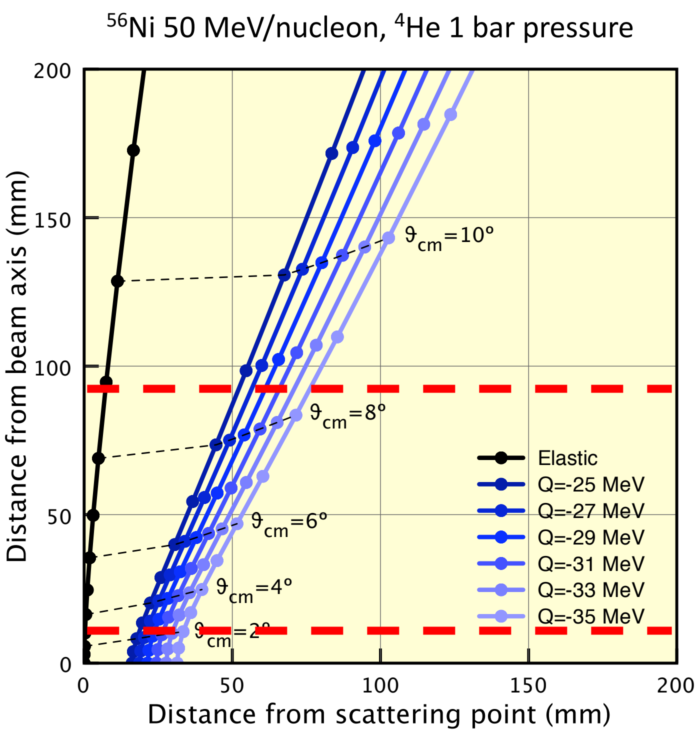
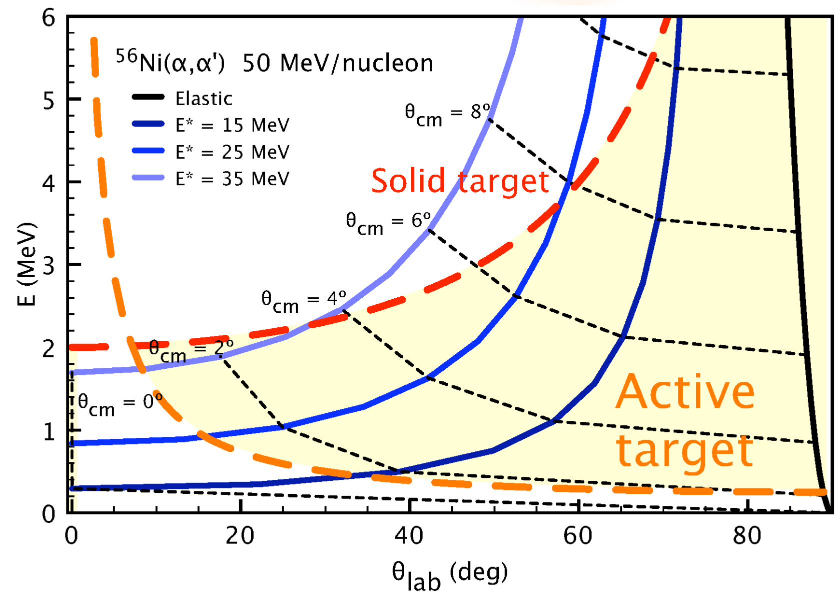




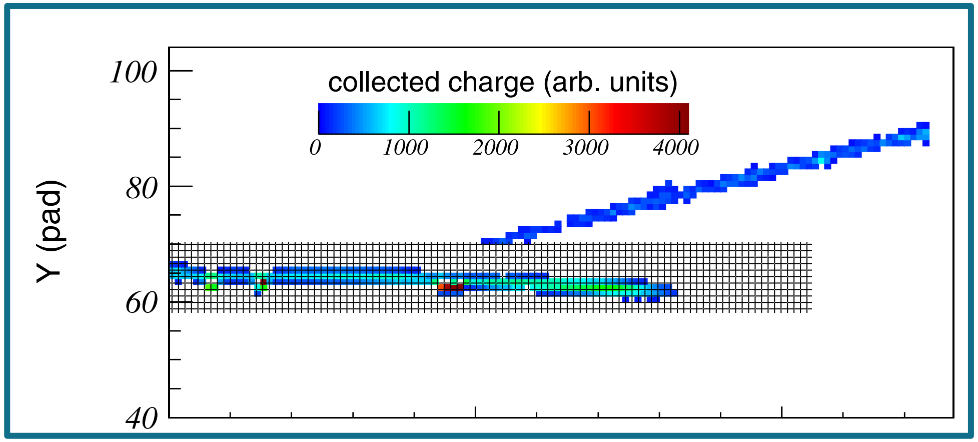


Active targets: beam region

Beam effects

- Signals from beam particles: **saturation**
  → change amplification
  ACTAR TPC: bias on pads
  CAT: T-GEM layers
- Signals from beam particles:
  field distortion
  → use mask

ACTAR TPC, B. Mauss et al., NIM A 940 (2019) 498



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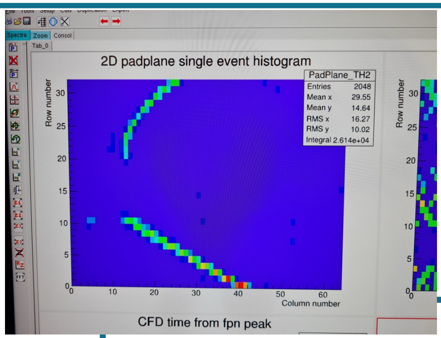
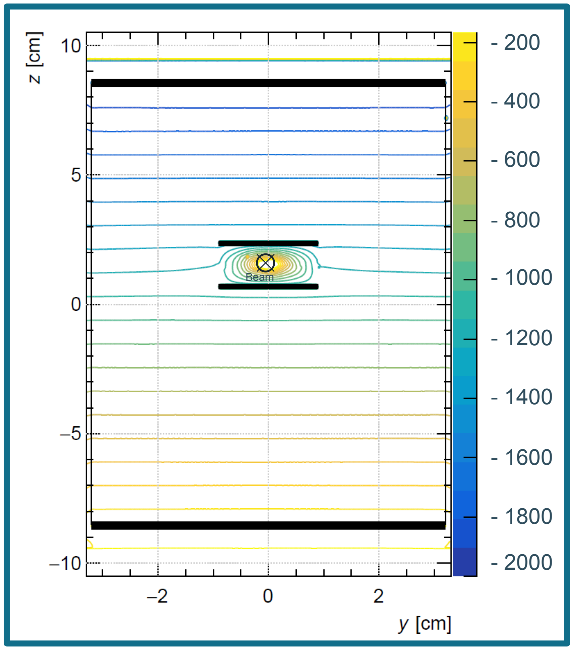
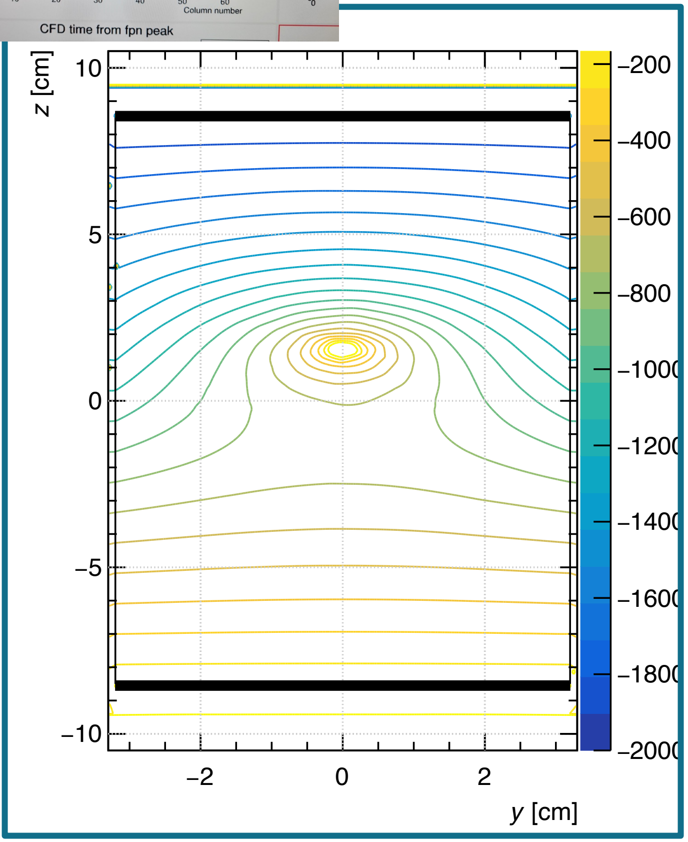




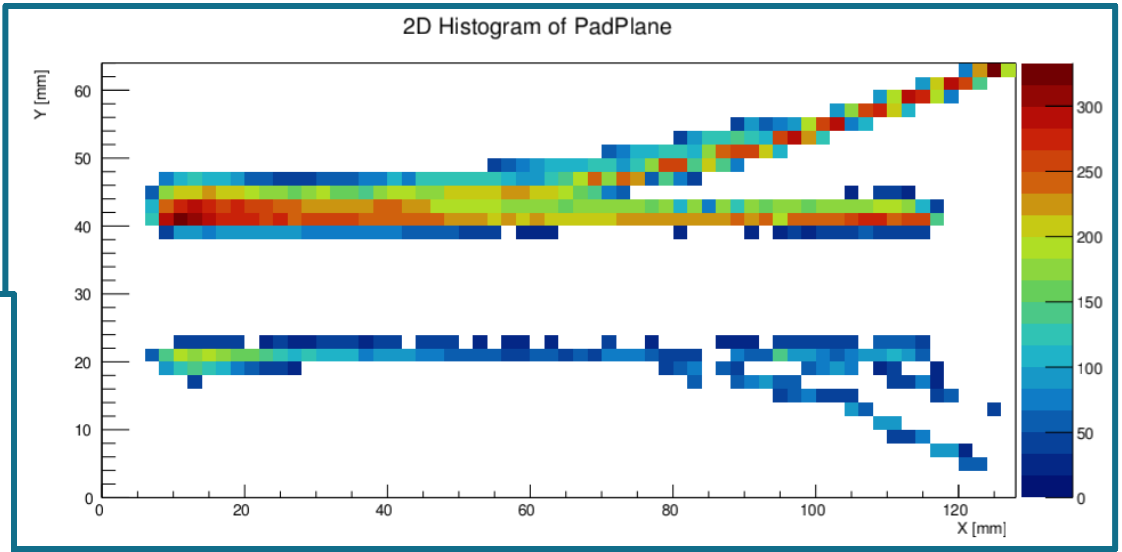


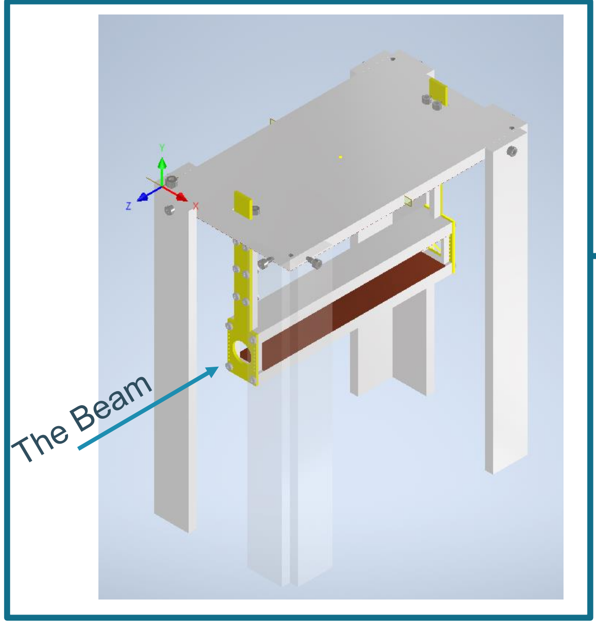
Work of
A. Camaiani, KU Leuven

Active targets: beam region

Beam mask

- Size?
  - Beam divergence
  - Scattered beam
  - δ rays





ACTAR TPC Demonstrator: mask
Work of
A. Camaiani, KU Leuven

KU LEUVEN

Active targets: beam region

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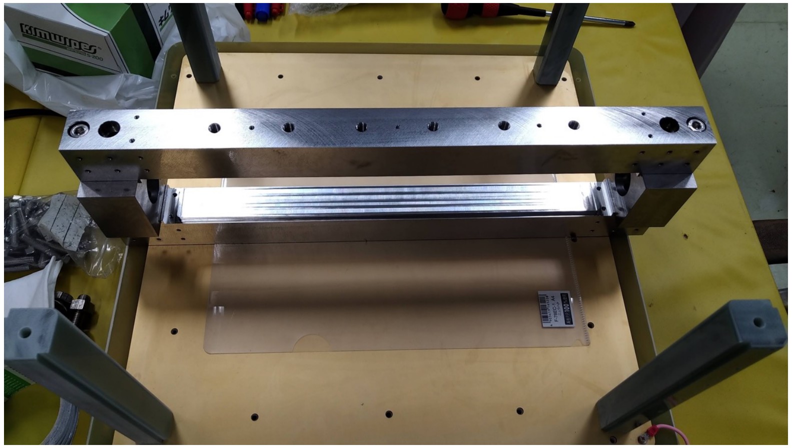
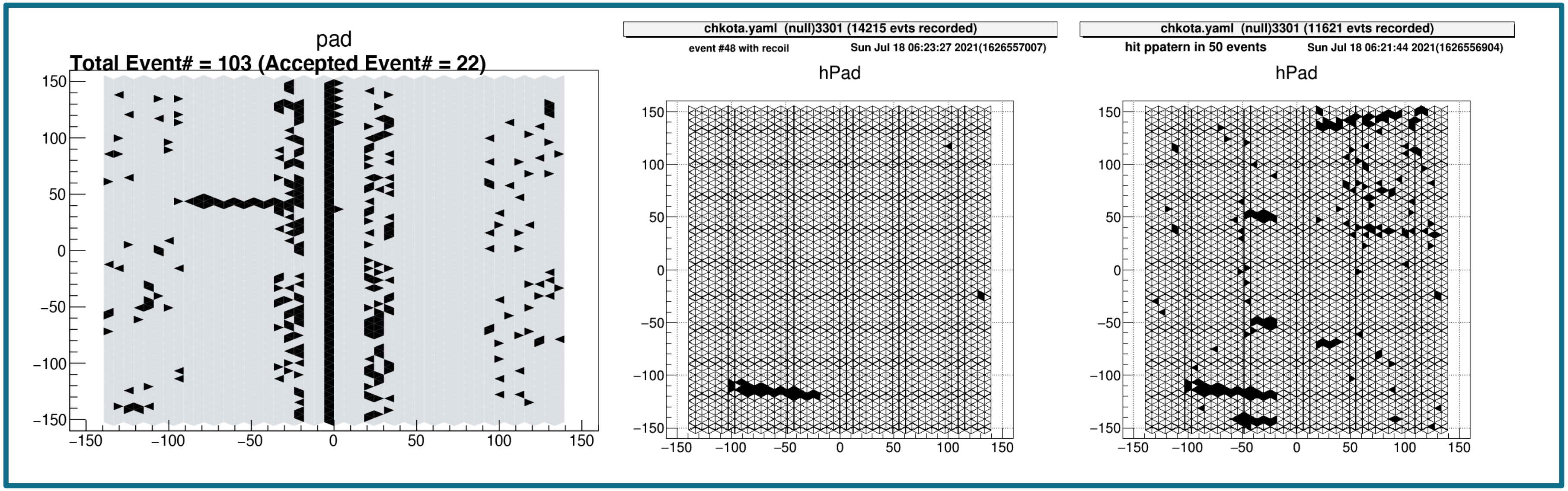


CAT-M: Magnet
S. Ota, RCNP Osaka

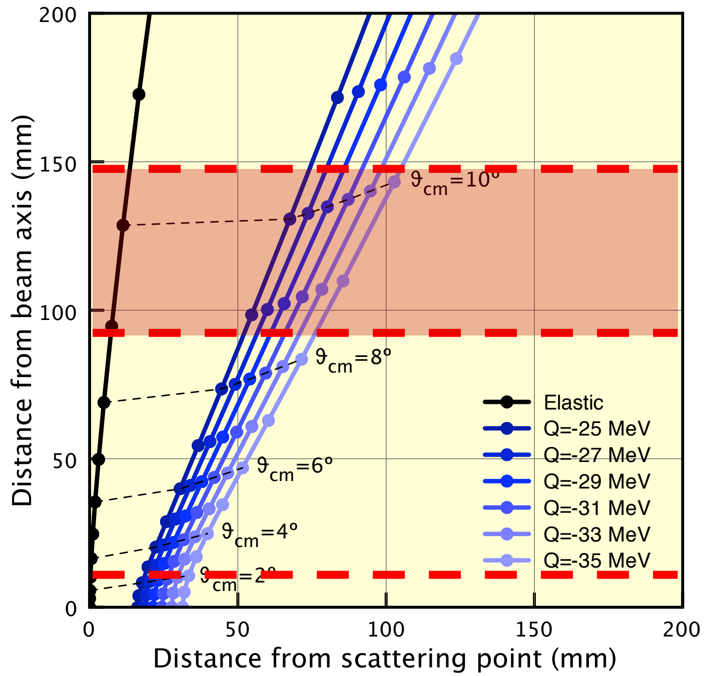


Active targets: auxiliary detectors

Charged-particle detectors

- Where?
  Sides are more important than the front
- Risk of sparks
  → keep a safe distance
  → blind zone
- Use mylar foils to screen electrons
- Adjust pressure for best results

^{56}Ni 50 MeV/nucleon, ^{4}He 1 bar pressure



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Active targets: Auxiliary detectors

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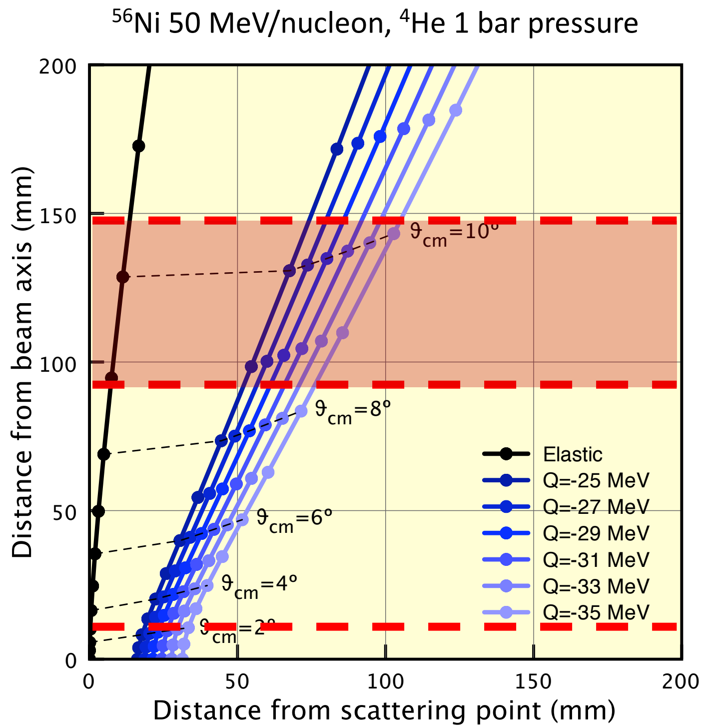
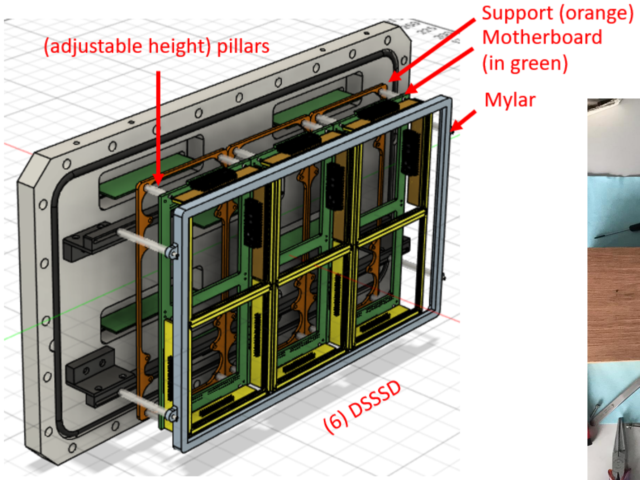
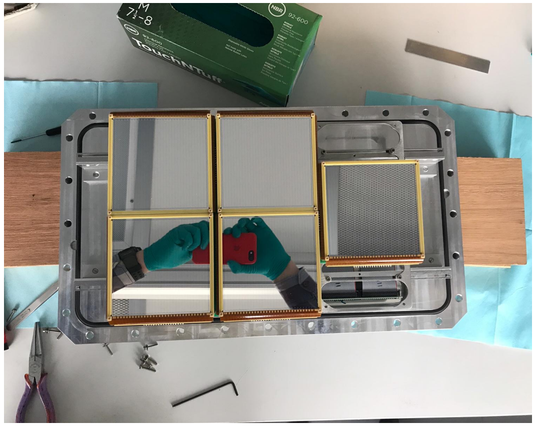




Internal View



@ ACTAR TPC and @ CAT-M: work of S. Ceruti, S. Fracassetti, A. Mentana, O. Poleshchuk, J Refsgaard

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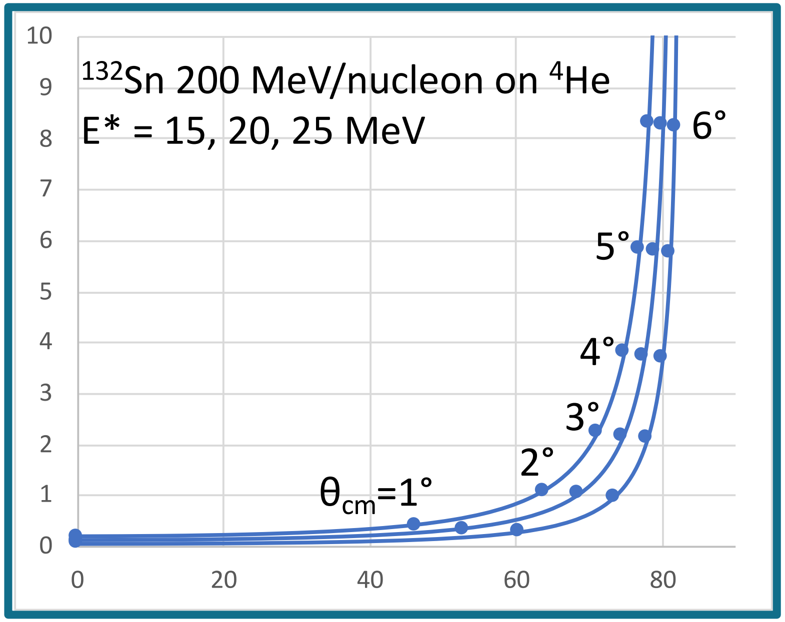
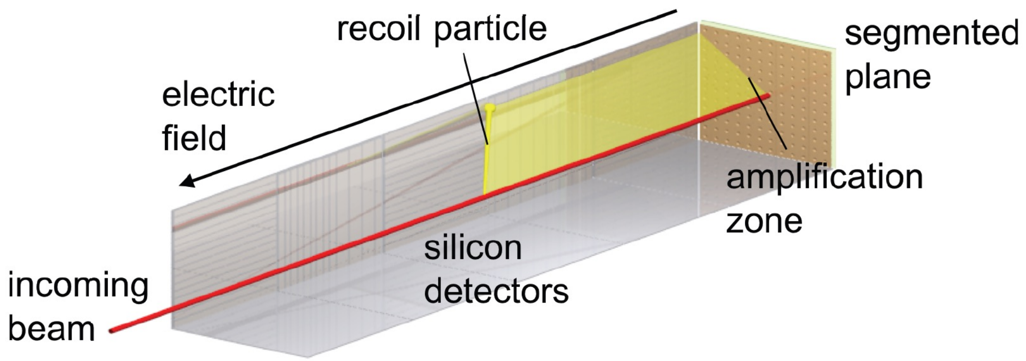
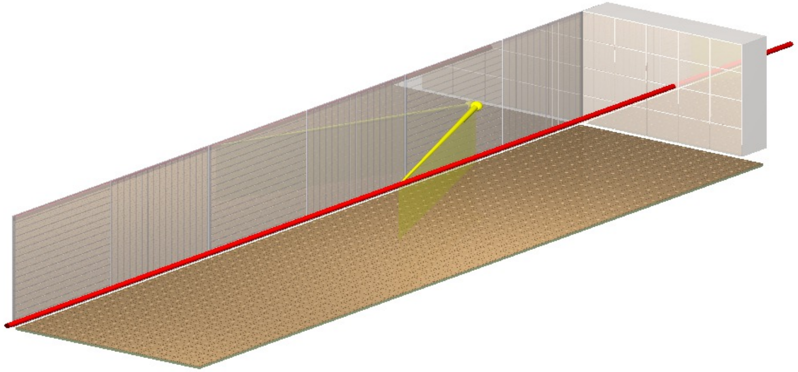
Optimized active target

- Lower pressure
- Elongated geometry (1m?)
- Track reconstruction in gas
- Particle angles from tracks
- Particle energy from ancillary detectors
- Decay particles at forward angles

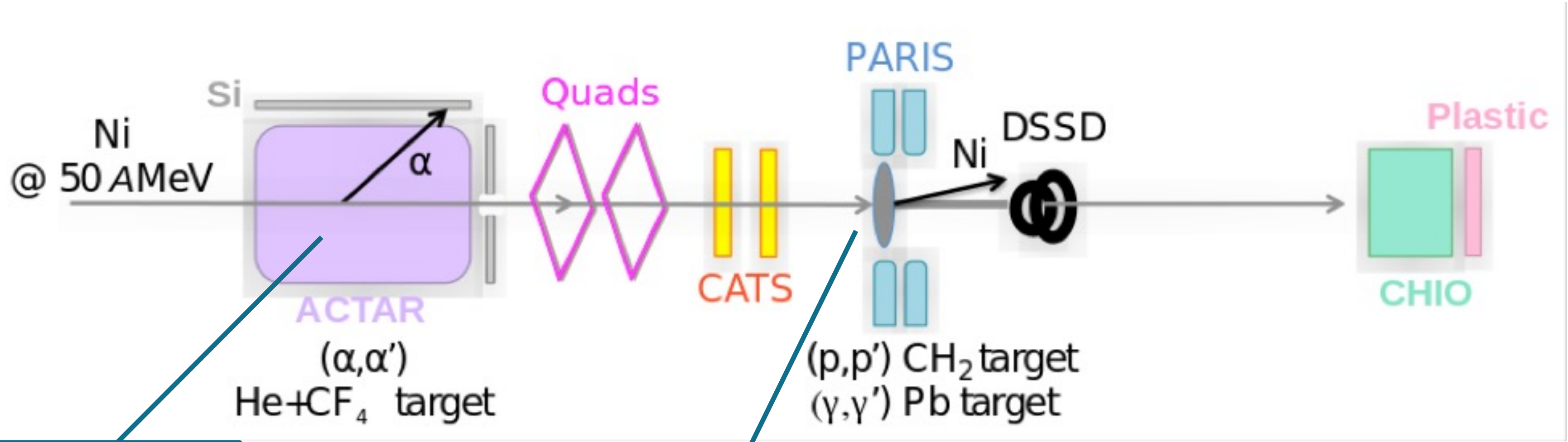






Optimise beam use and opportunities

Yakitori mode



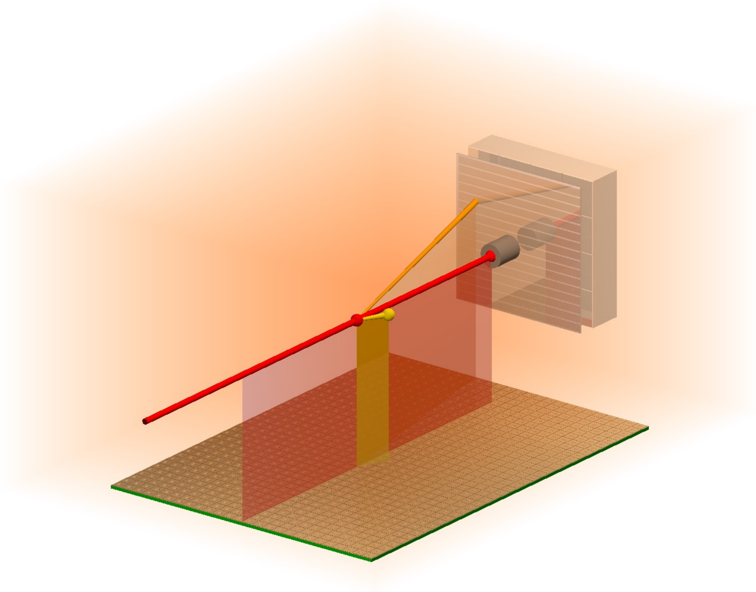
IS GRs
α scattering

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

Measurement of de-excitation modes

Coincident charged-particle detection

- Active target are best suited!
  (with downstream detection)



Measurement of de-excitation modes

Coincident charged-particle detection

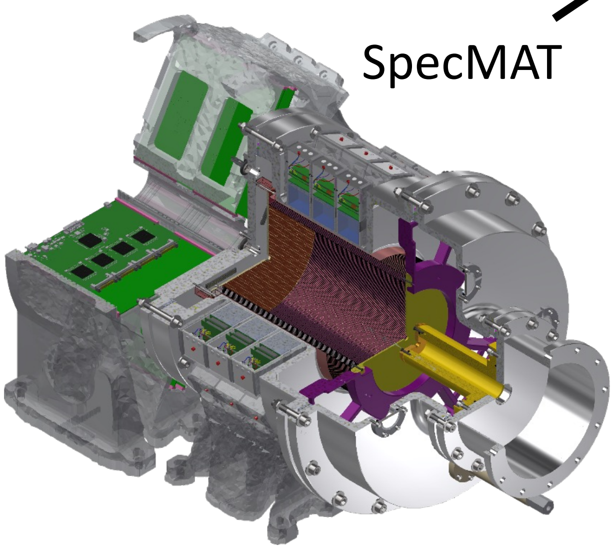
- Active target are best suited!
  (with downstream detection)

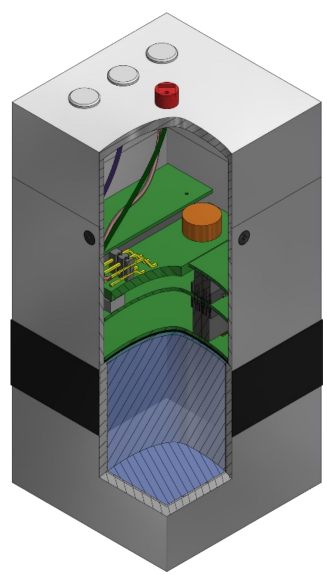
Coincident γ-ray detection

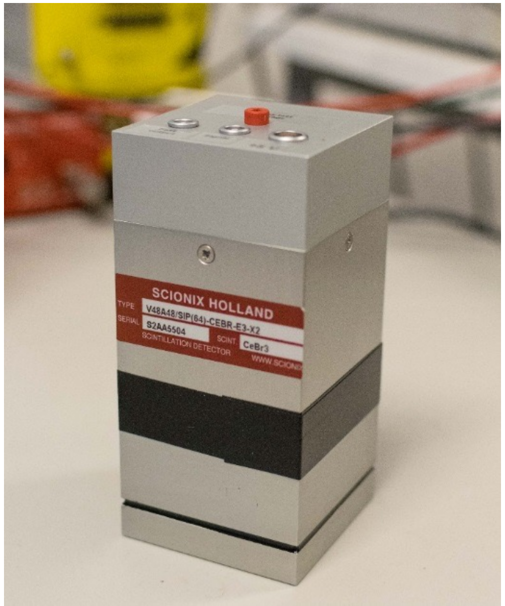
- Coupling to scintillators

45 $CeBr_3$ 48×48×48 mm^3
scintillation detectors

SpecMAT







Summary

- Importance of extending the measurements to unstable nuclei
- Possibilities: storage rings, active targets
  Active targets more "affordable"
- Complex instruments, analysis very involved
  Some intrinsic issues
  but also possibilities to mitigate them

Further thoughts

- Can we go lower in energy?
  Perhaps with light systems (Ne, Mg, Si…)
  Post-accelerated ISOL beams??
- Background subtraction?

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