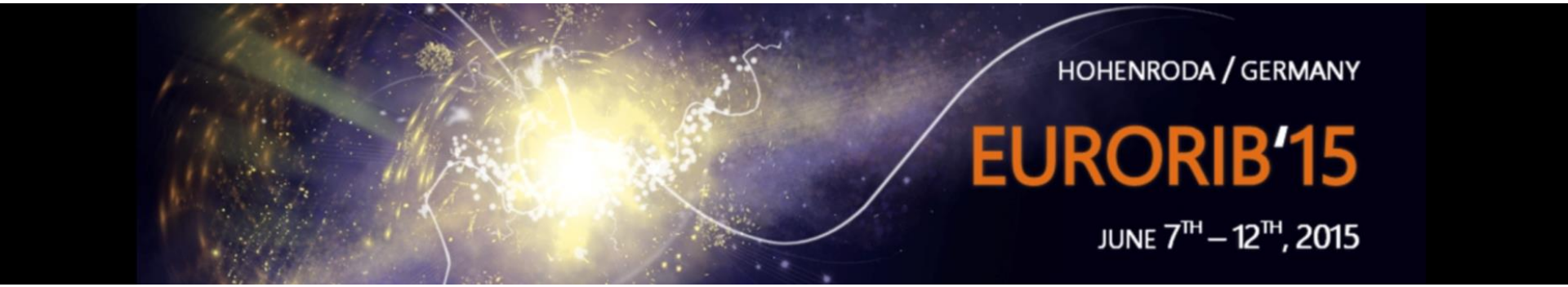
Active targets for research on exotic nuclei

Riccardo Raabe

KU Leuven, Instituut voor Kern- en Stralingsfysica



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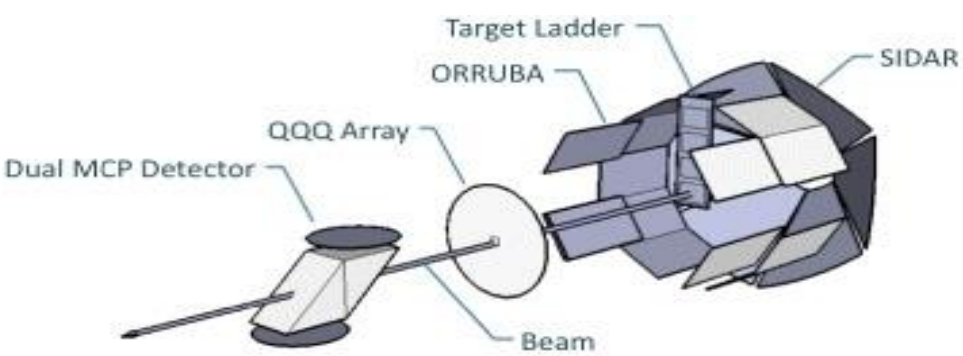
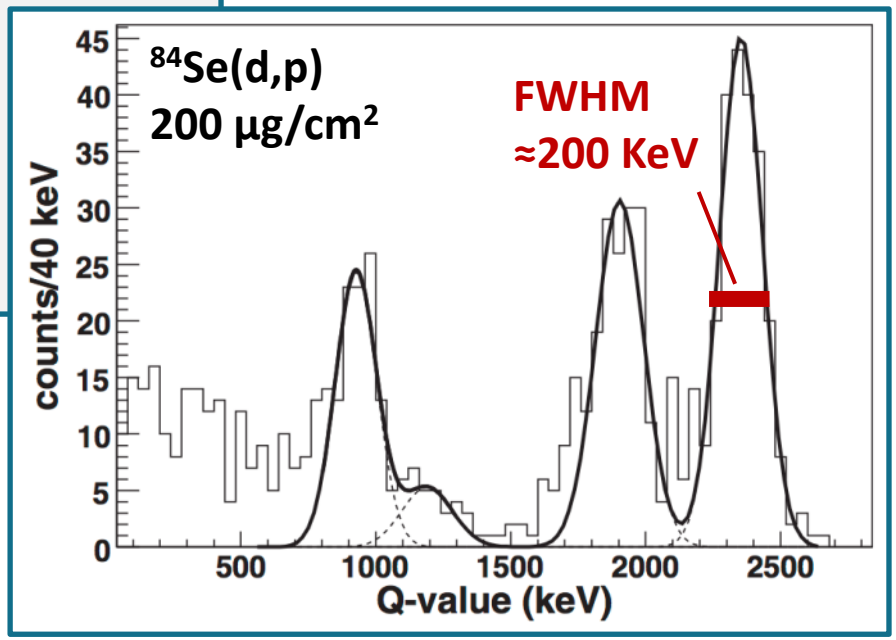
Why active targets

- Increase luminosity without compromising resolution
- Light ion probes in inverse kinematics → gaseous targets
- Reactions with low momentum transfer → low thresholds





J.S. Thomas et al., PRC 76 (2007) 044302

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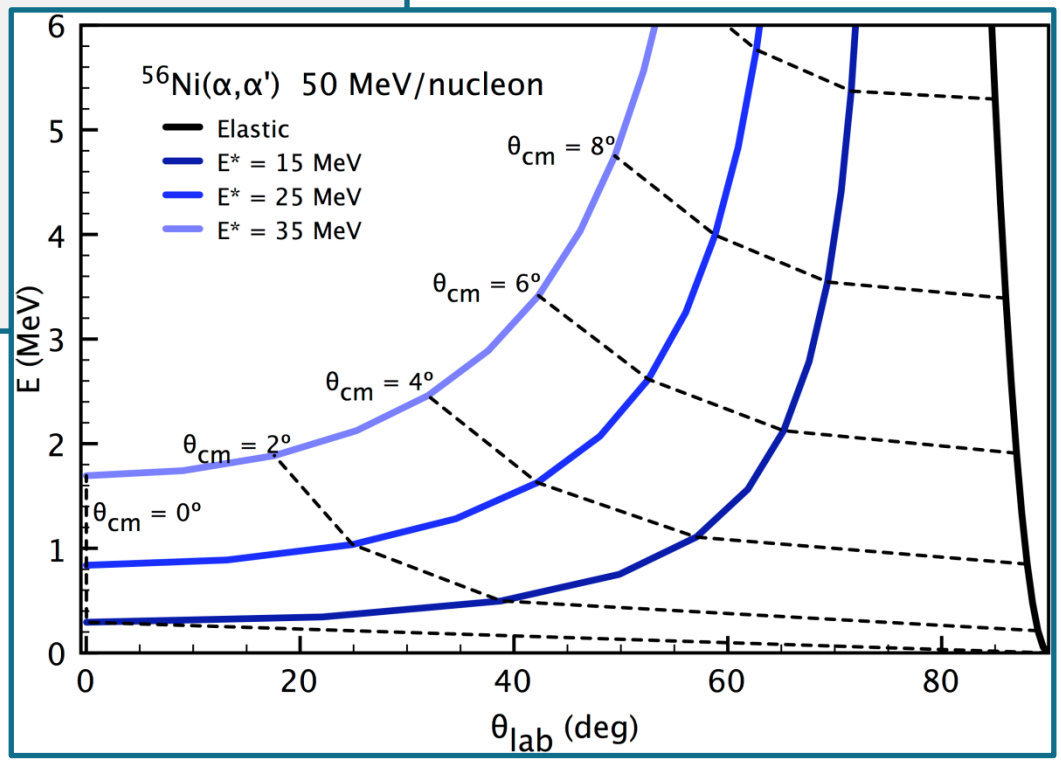
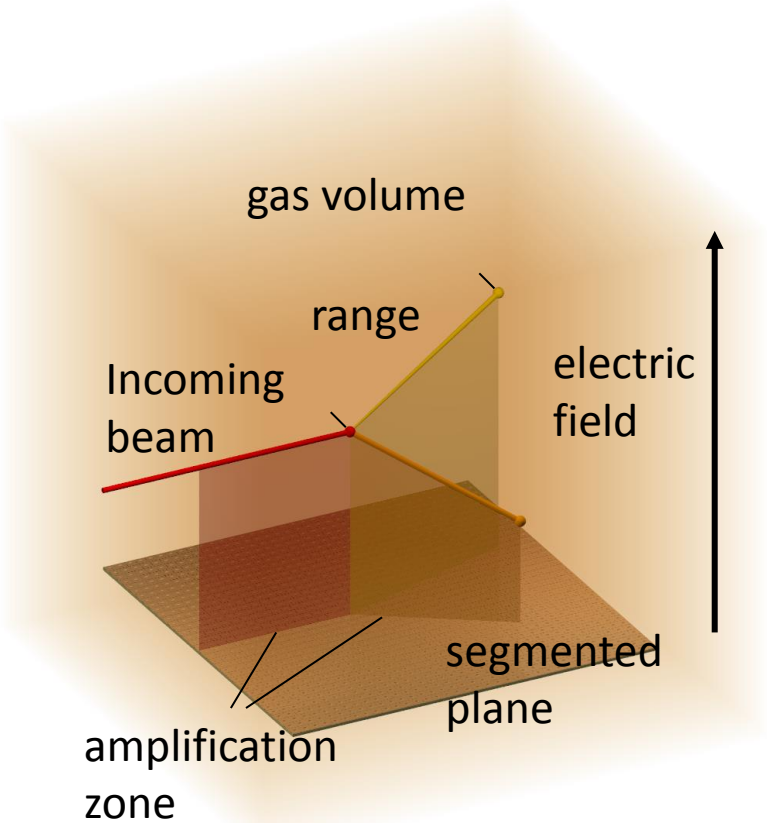


Concept

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



- Efficient
- Versatile

Comparison with high-energy devices

High-energy physics	Nuclear structure
Minimum ionising particles	Very high dynamic range
Trigger from ancillary detectors	Internal trigger
Complex reaction High occupancy Through-tracks	Low occupancy Stopped tracks
Resolution ≈50 µm	Resolution ≈1 mm

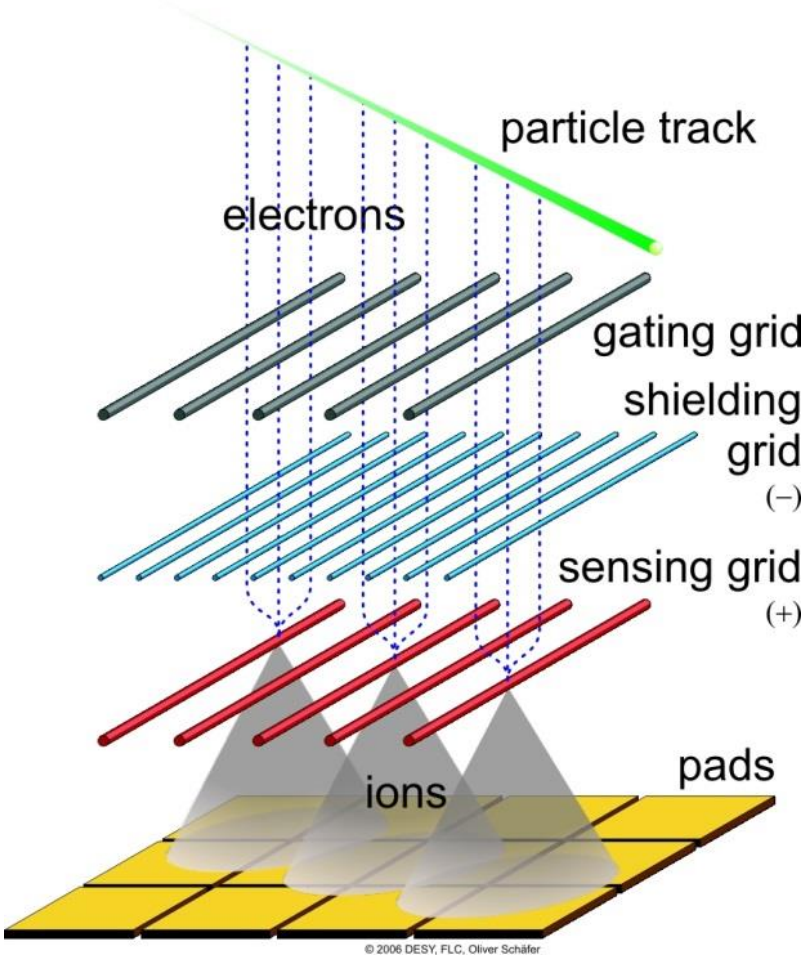
Amplification technology

From wires…

- Broad signals (induction)
- Mechanically complex, fragile

…to Micro-Pattern Gas Detectors

- Robust
- Reduced ion feedback



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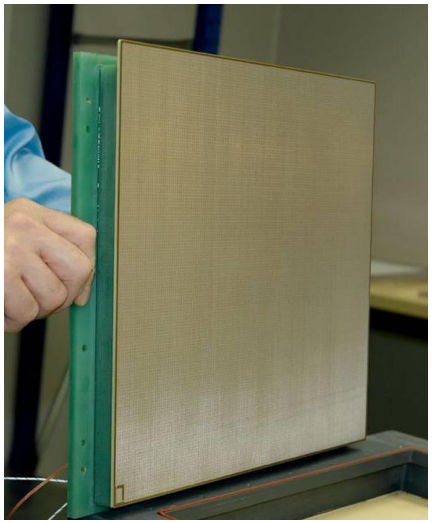
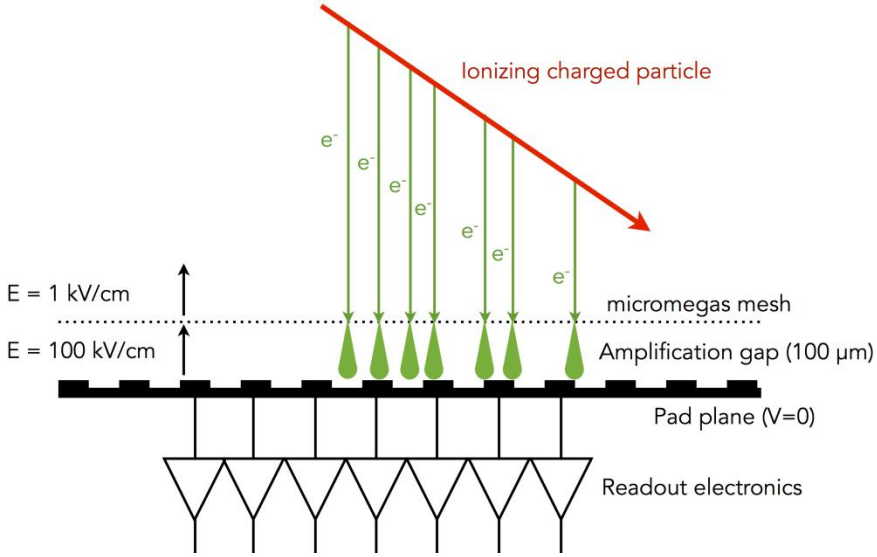


Micromegas

Y. Giomataris et al. NIMA 376 (1996) 29



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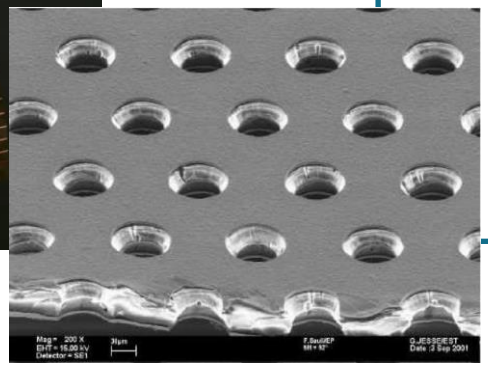
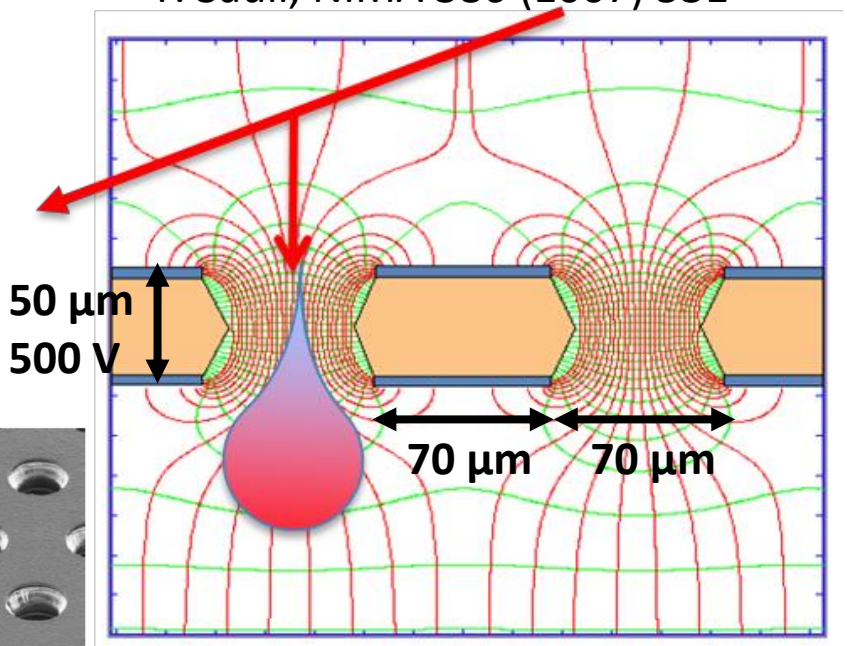


Gas-electron multipliers (GEM)

F. Sauli, NIMA 386 (1007) 531

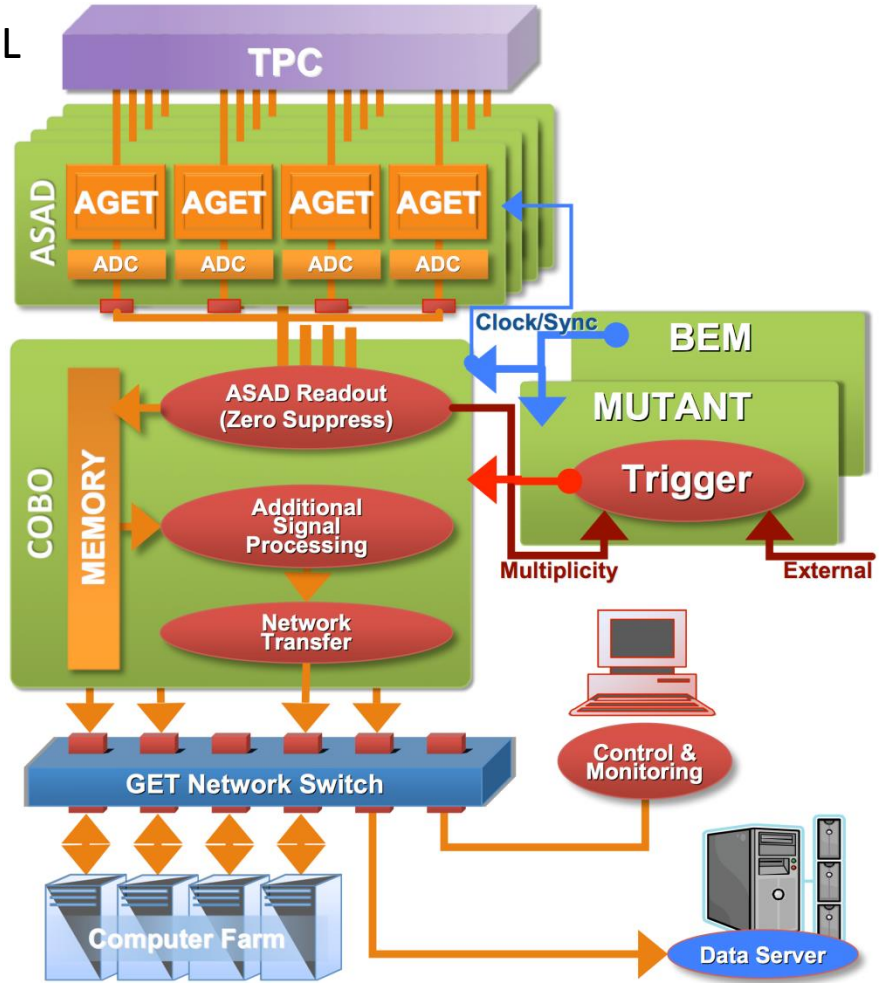


Electronics

GET – General Electronics for TPCs

CEA-Saclay, CENBG- Bordeaux, GANIL-Caen, NSCL

- High front-end density (up to 30 000 channels)
- High-rate throughput (selective readout, zero suppression)
- High dynamic range
- Versatile (amp factor, sampling)
- **Intelligent trigger**
  L0 external
  L1 multiplicity
  L2 topology



Present active targets

Detector	Home	Technology	Vertex	Physics
IKAR	GSI	---	No	Elastic (ρ)
Maya	GANIL	Wires	Yes/No	Various
ACTAR TPC	Various (EU)	Micromegas	Yes/No	Various
MSTPC	Various (Jap)	Wires/GEM	Yes	Resonant (AP)
CAT	CNS	GEM	Yes	Inelastic (GR)
MAIKo	RNCP	MicroPIXEL	Yes	Inelastic (CLU)
pAT-TPC	MSU	Micromegas	Yes	Resonant (CLU)
AT-TPC	MSU-FRIB	Micromegas	Yes	Various
TACTIC	TRIUMF	GEM	No	$^{8}Li(\alpha,n)^{11}Be$
ANASEN	FSU/LSU	Wires	Yes	Res, elastic
MINOS	IRFU	Micromegas	No	Direct (p,xp)
O-TPC	TUNL	Grid	Yes	γ-dissociation

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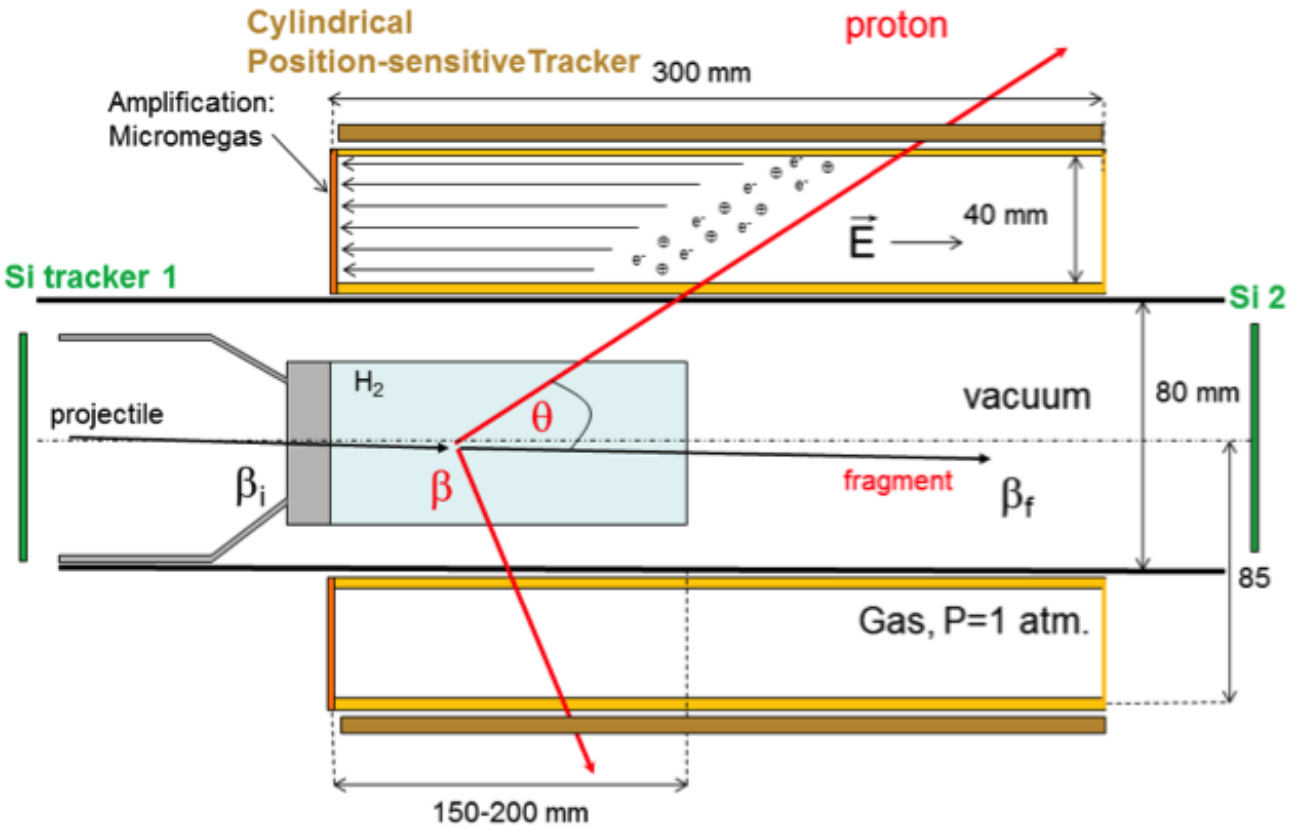
Vertex trackers

- Hunting rare events
- Intense beams masked or outside
- IKAR, TACTIC, CAT, Maya (masked), MINOS

MINOS

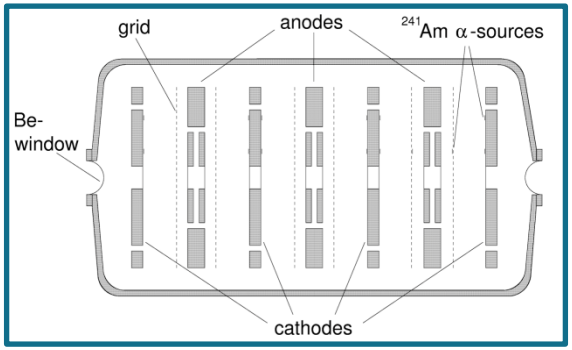
European Research Council
Established by the European Commission

A. Obertelli et al., EPJA 50, 8 (2014)

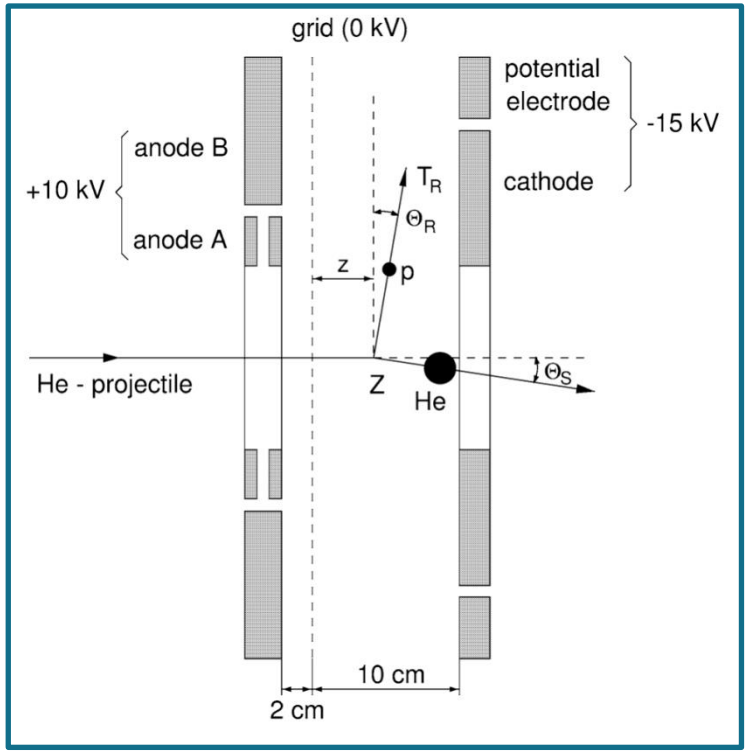


IKAR

- 10 bar H_2
- 6 chamber elements
- Information: vertex, energy, angle
- Elastic scattering → matter distribution $^{4,6,8}He$, $^{12,14}Be$



S. R. Neumaier et al., NPA 712, 247 (2002)



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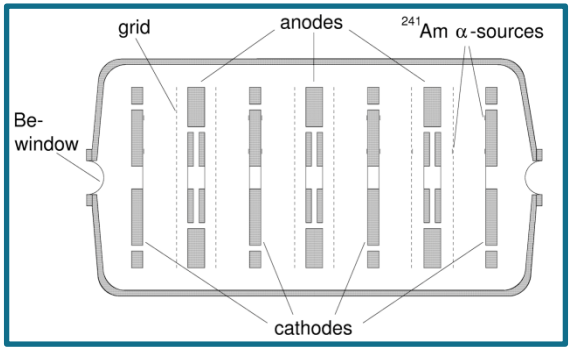

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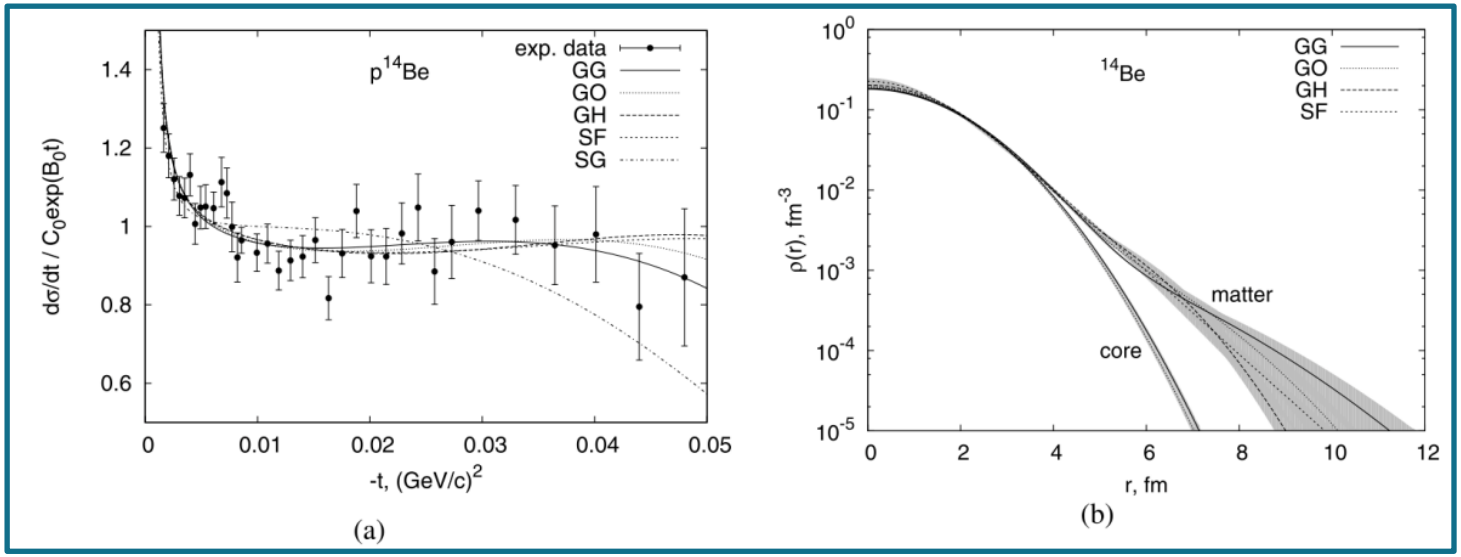
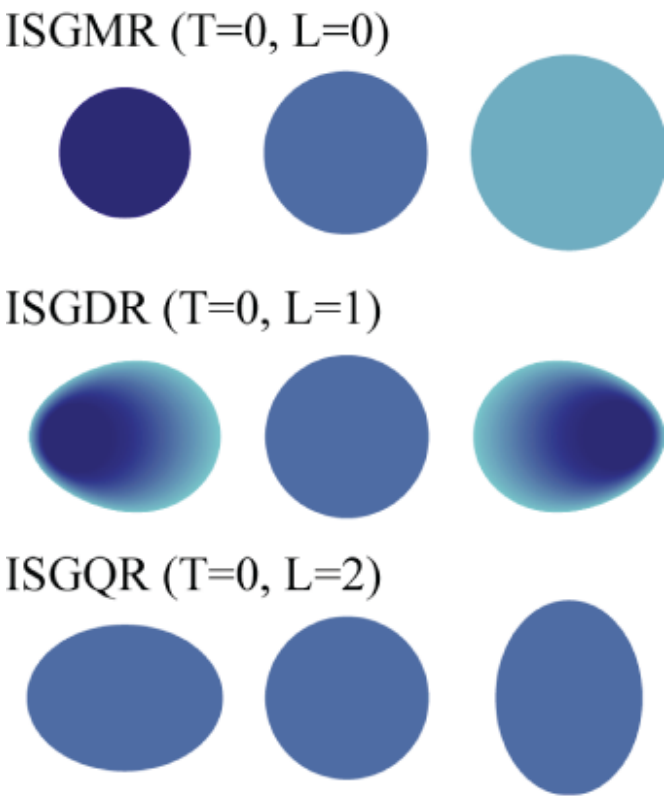


S. Ilieva et al., NPA 875, 8 (2012)

Maya with the mask

Investigations of collective modes: isoscalar resonances

- ^{56}Ni(d,d') GMR and GQR
  C. Monrozeau et al., PRL 100 (2008) 042501
- ^{68}Ni(d,d') and (α,α')
  GMR, GQR and soft monopole
  M. Vandebrouck, PRL 113 (2014) 032504
  M. Vandebrouck, submitted to PRC
- ^{56}Ni(α,α') GMR and GDR
  S. Bagchi, submitted to PLB



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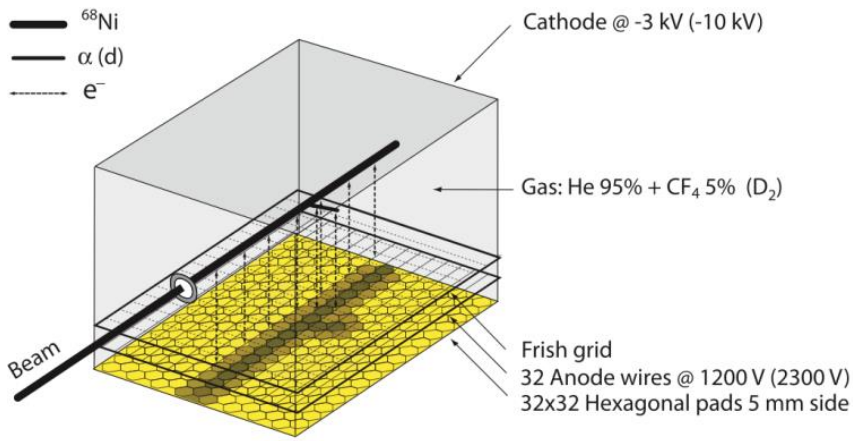

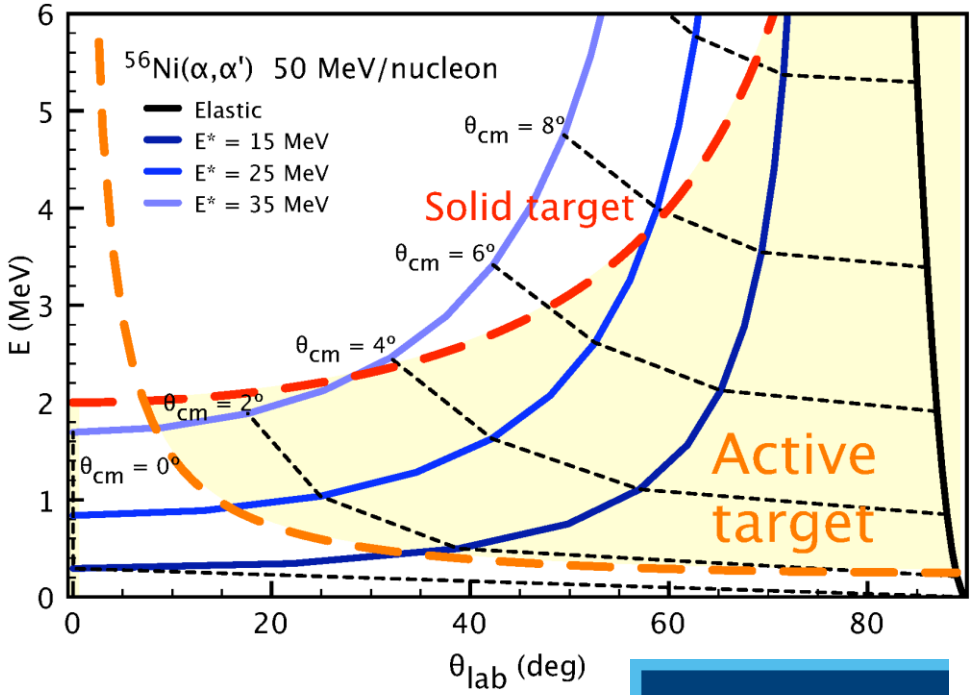

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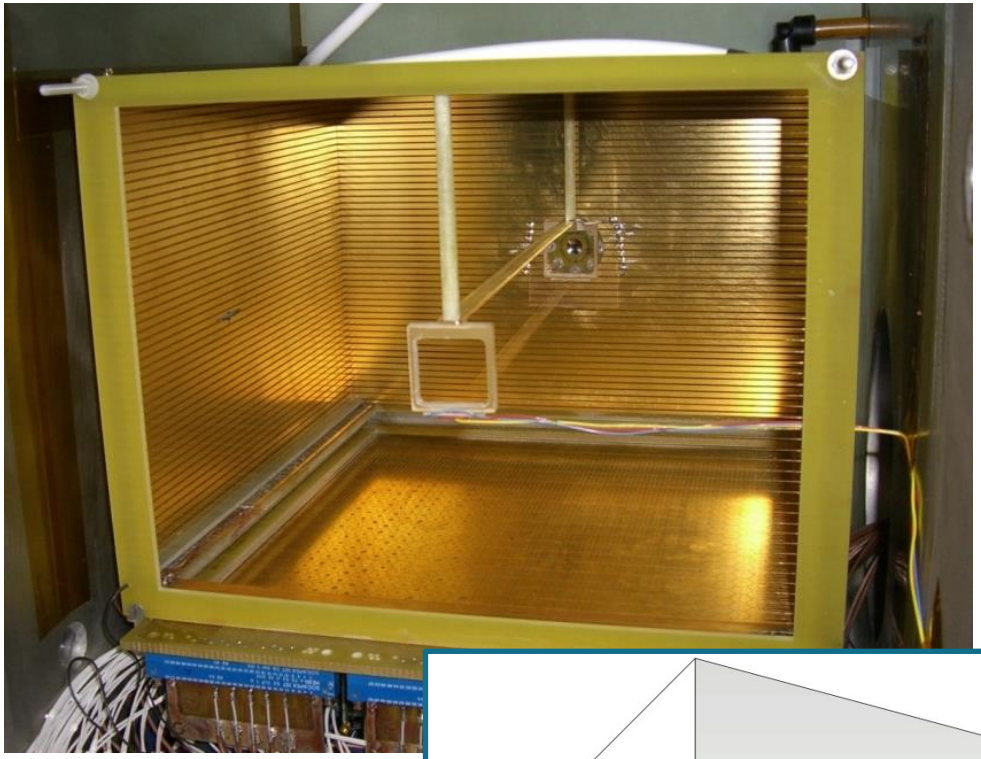
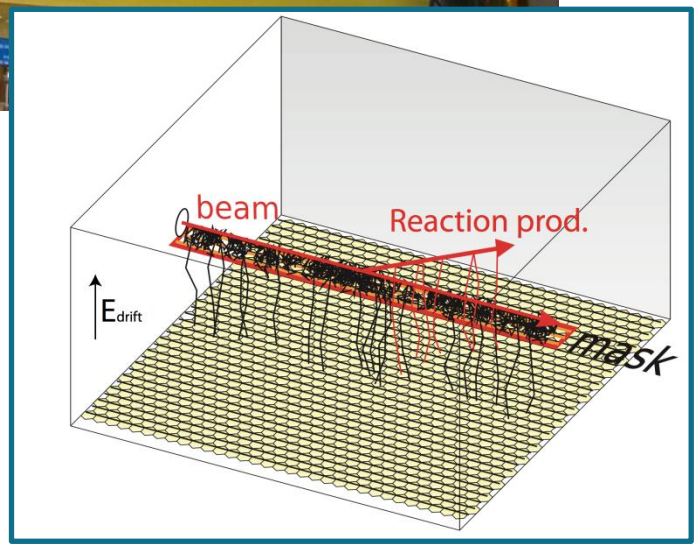
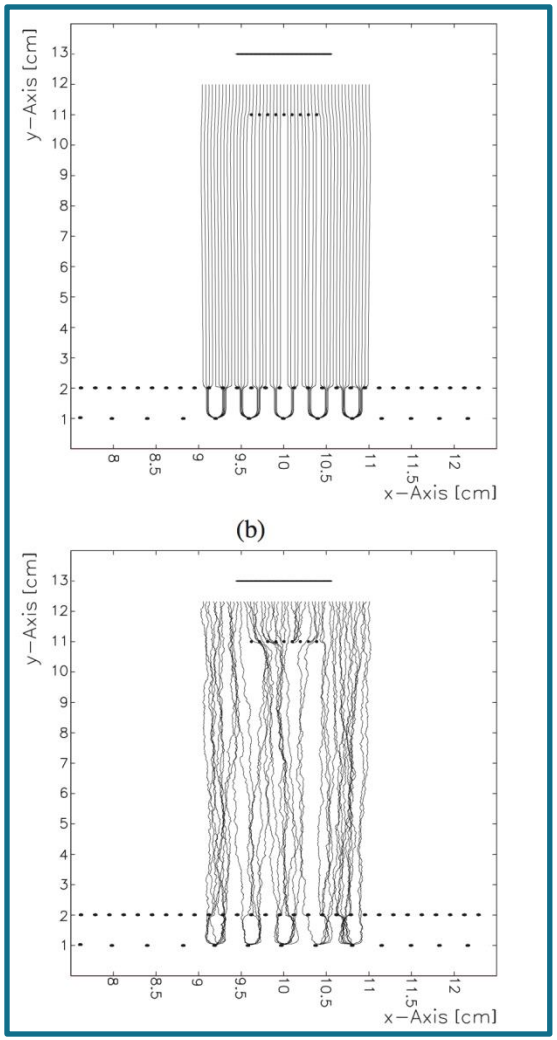
Maya with the mask





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



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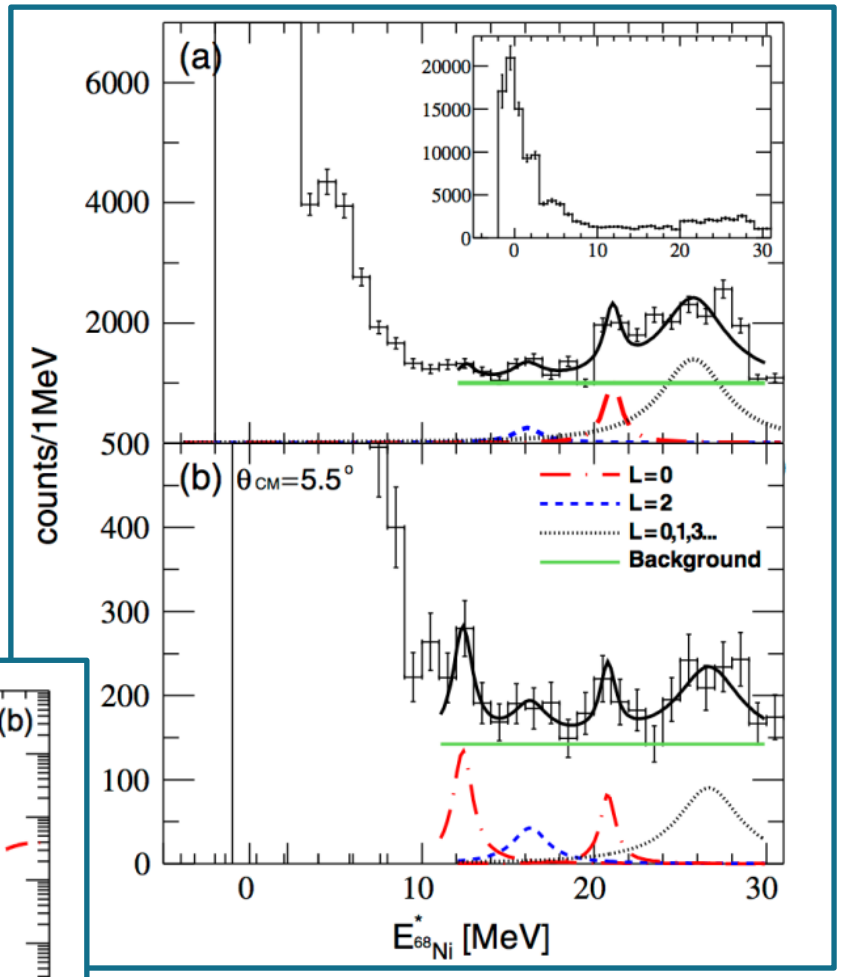
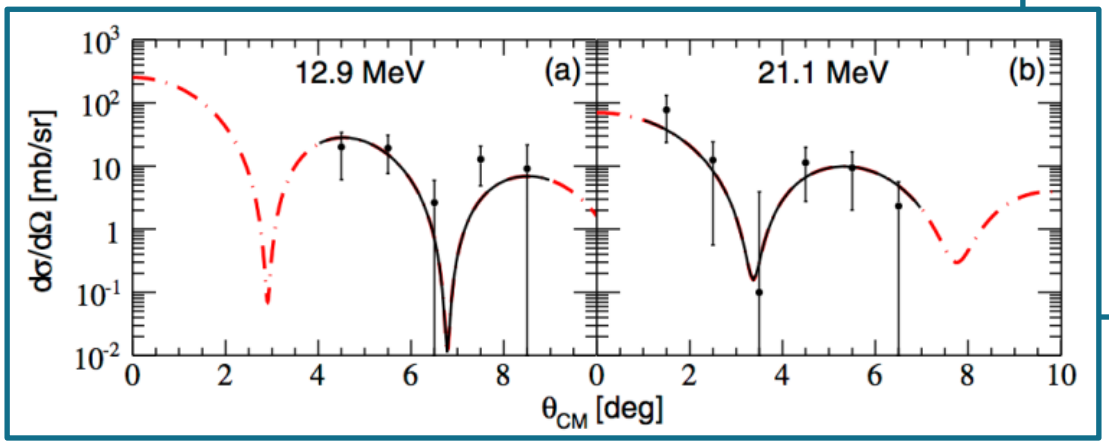




ACTAR TPC for Giant Resonances

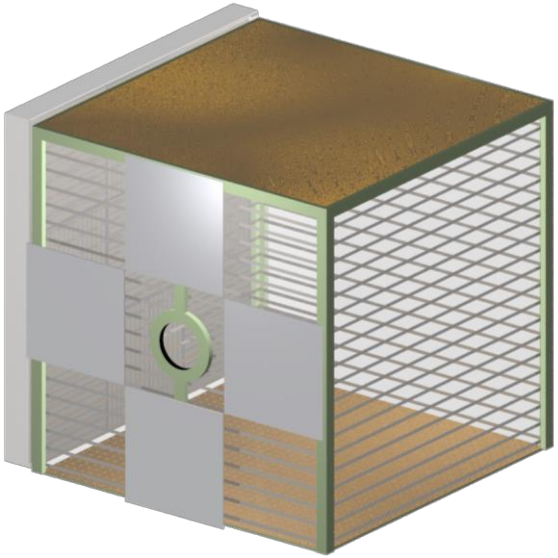
ACTAR TPC

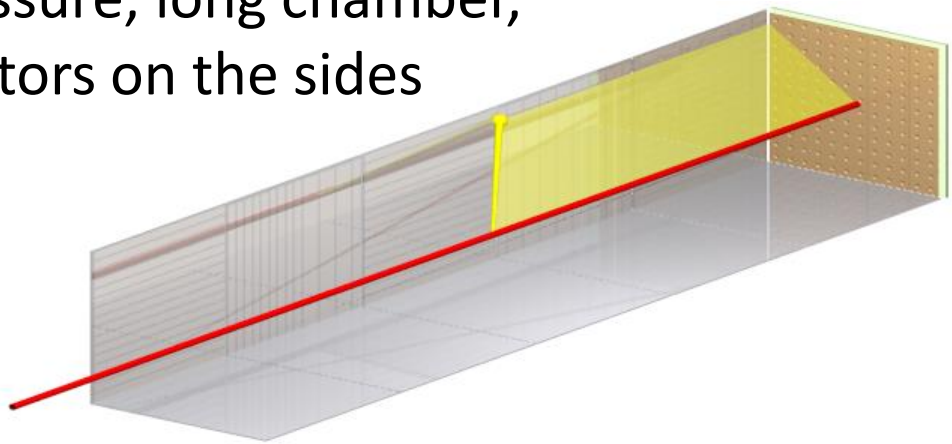
GANIL, CEA Saclay, CENBG, IPNO,
KU Leuven, Santiago de Compostela

European Research Council
Established by the European Commission

G.F. Grinyer, GANIL

- Basic configuration:
  cubic, ≈16000 channels
  Amplification with micromegas
- Auxiliary charged-particle detectors
- Configuration for inelastic scattering:
  low pressure, long chamber,
  Si detectors on the sides





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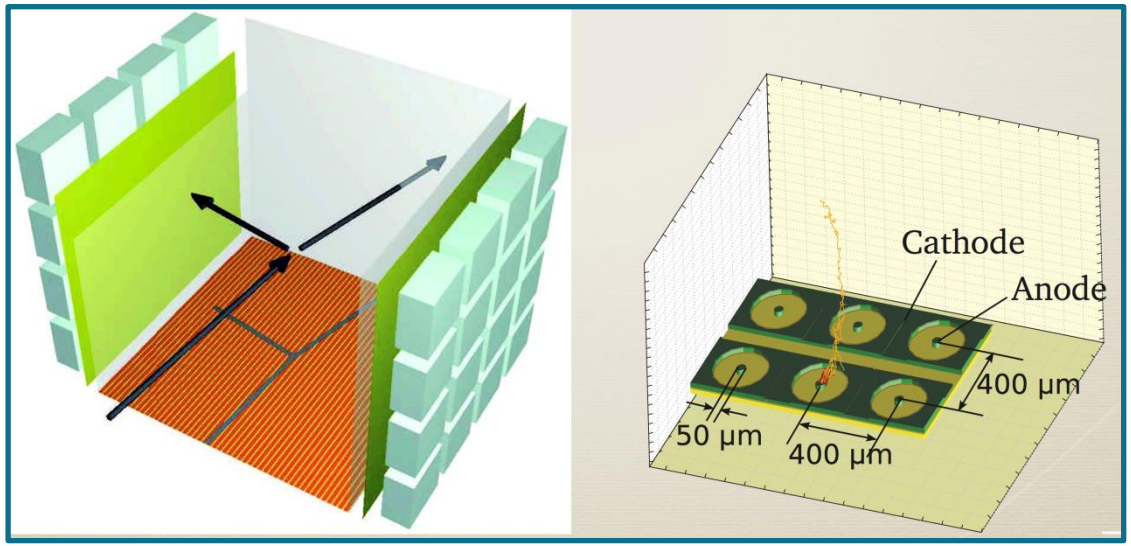
3D cameras

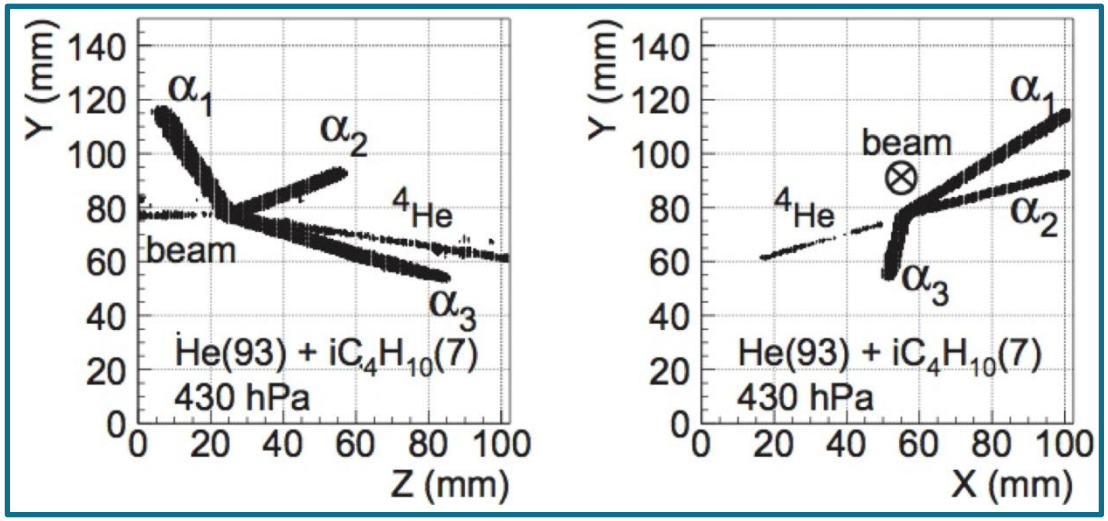
- Exploit the weakest beams ("normal" cross sections)
- All incoming particles generate a signal → selective trigger is essential
- MAIKo, MSTPC, OTPCs, ANASEN, (p-)AT-TPC, ACTAR TPC…

MAIKo

T. Furuno et al., J. of Phys. Conf. Series 569 (2014) 012042

- Cluster states in ^{12}C via $^{12}C(\alpha,\alpha')^{12}C^*$
- 14x14x14 cm^3
- He+CO_2 430 mbar
- GEM+µPIXEL 256+256 channels

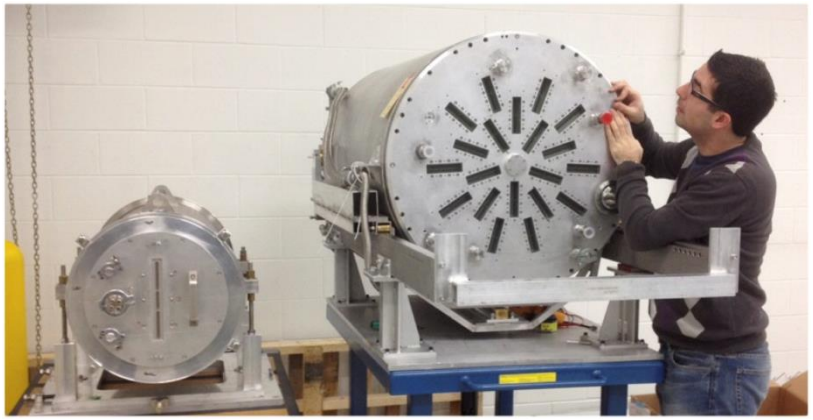


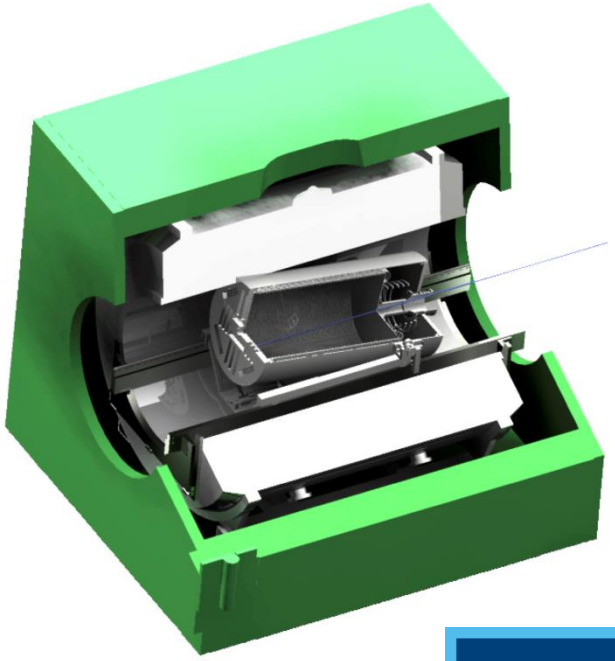


AT-TPC at NSCL (FRIB)

D. Bazin, W. Mittig, S. Beceiro Novo

- Placed inside 2 Tesla solenoid (increase range and measure Bρ)
- 250 liters (1 m by 55 cm) active volume
- Physics cases:
  resonant reactions,
  transfer reactions,
  inelastic to GRs,
  heavy ion reaction to EoS

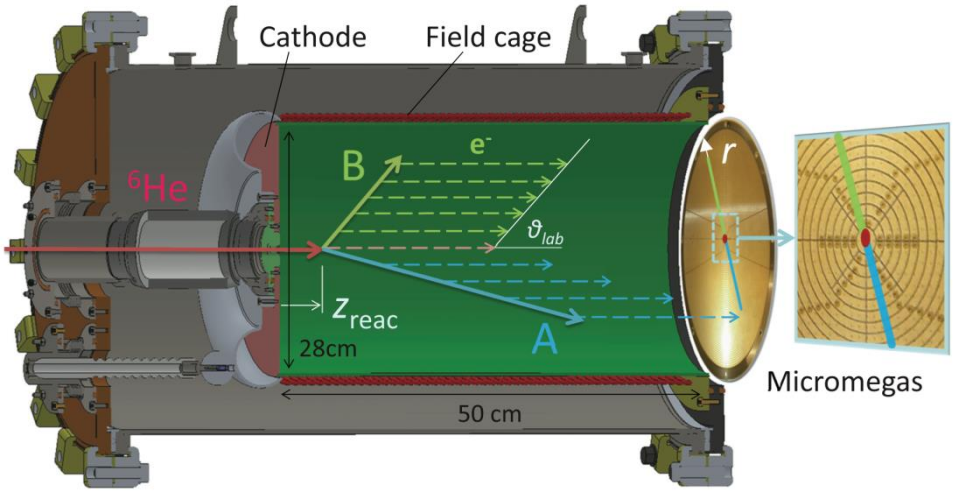


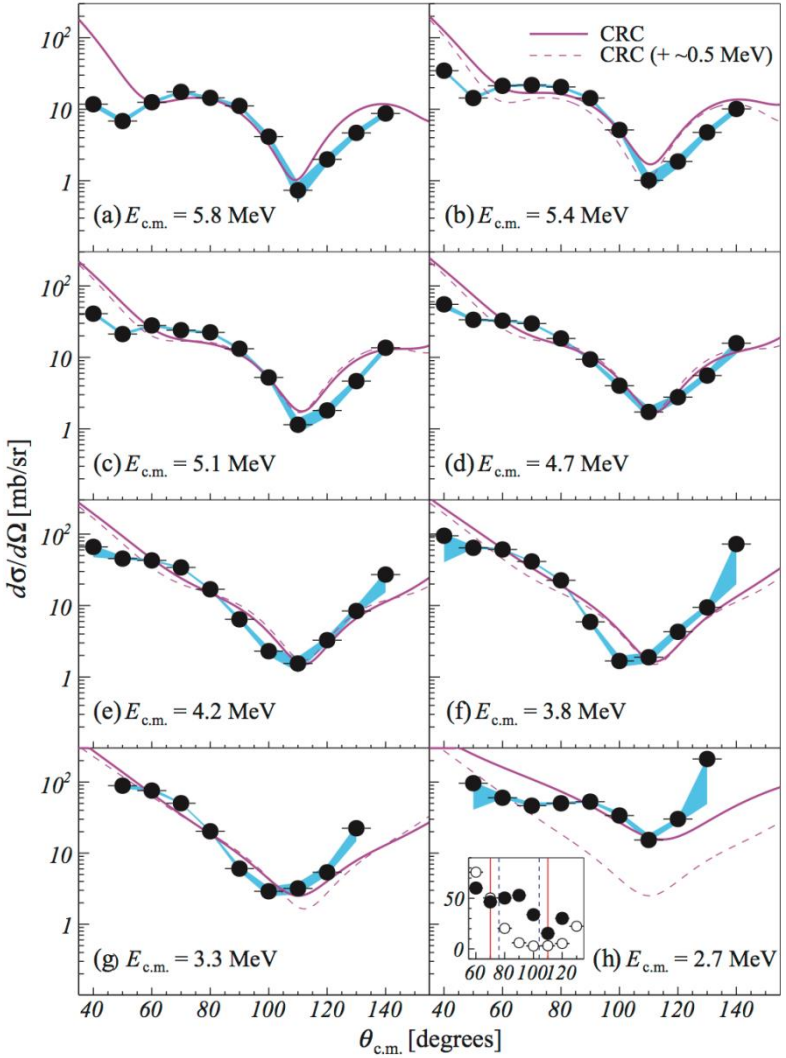


Prototype AT-TPC

D. Suzuki et al., PRC 87 (2013) 54301

- Half size of AT-TPC (linear)
  253 pads
- $^{6}He+^{4}He$
  Resonance at 9.98 MeV (4^{+})
  (10.15 MeV previously observed)





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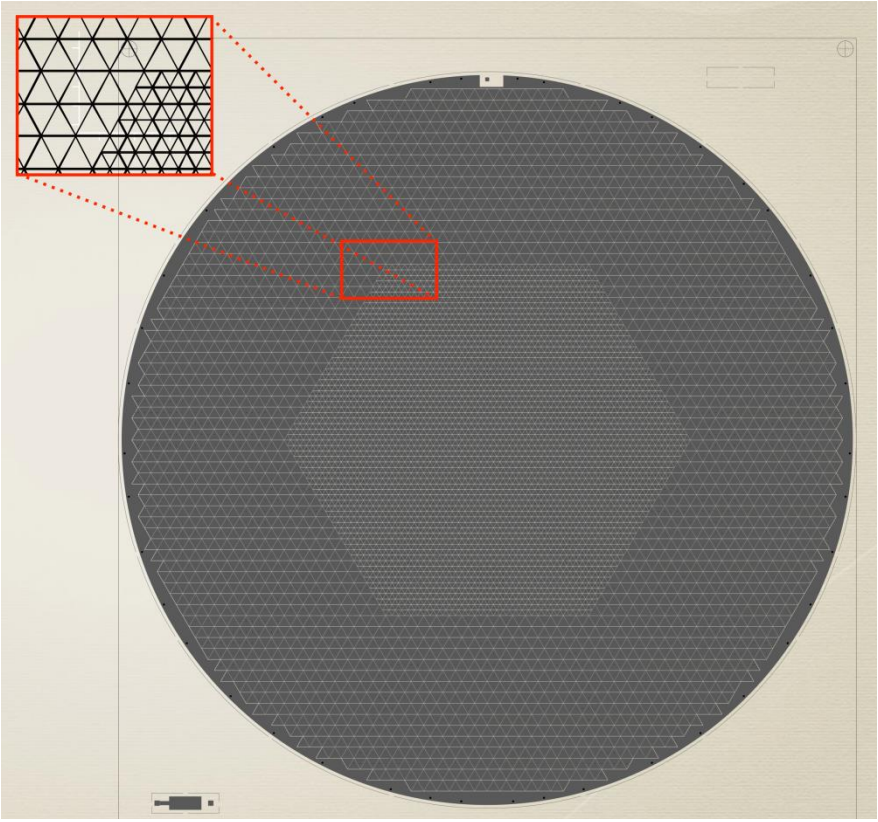
AT-TPC at NSCL (FRIB)

D. Bazin, W. Mittig, S. Beceiro Novo

- 10 240 pads, 55 cm diameter
  small triangles 4.7 mm side



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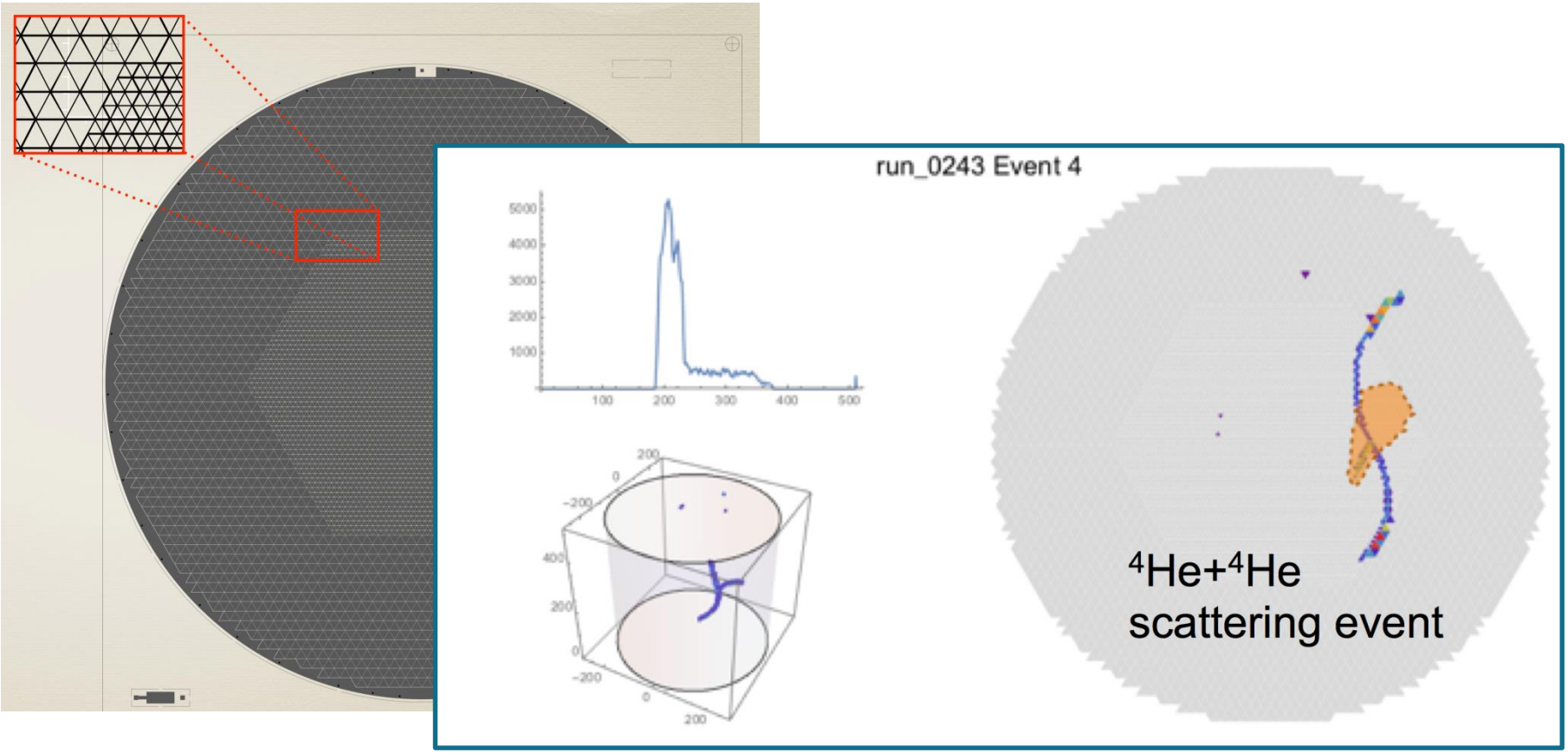
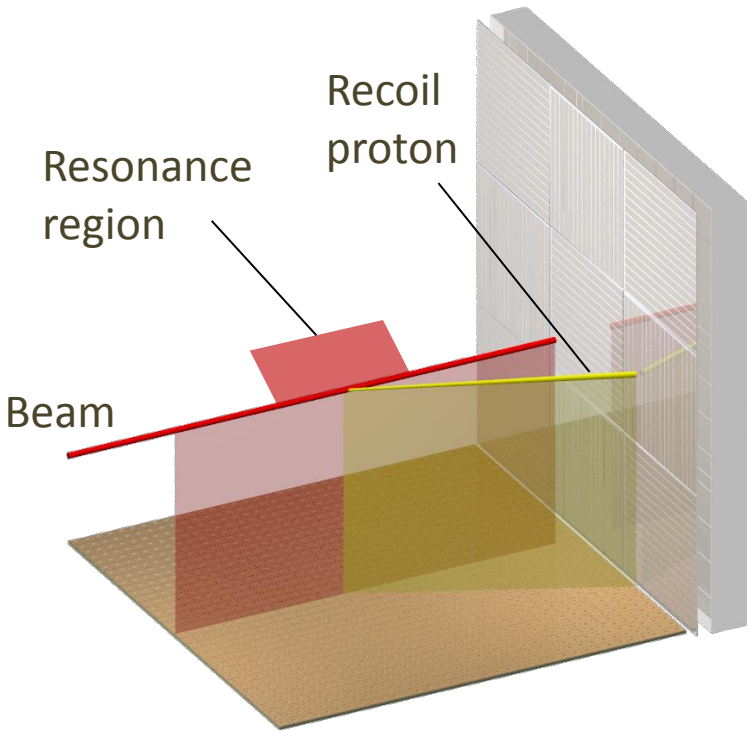


Resonant elastic with Maya

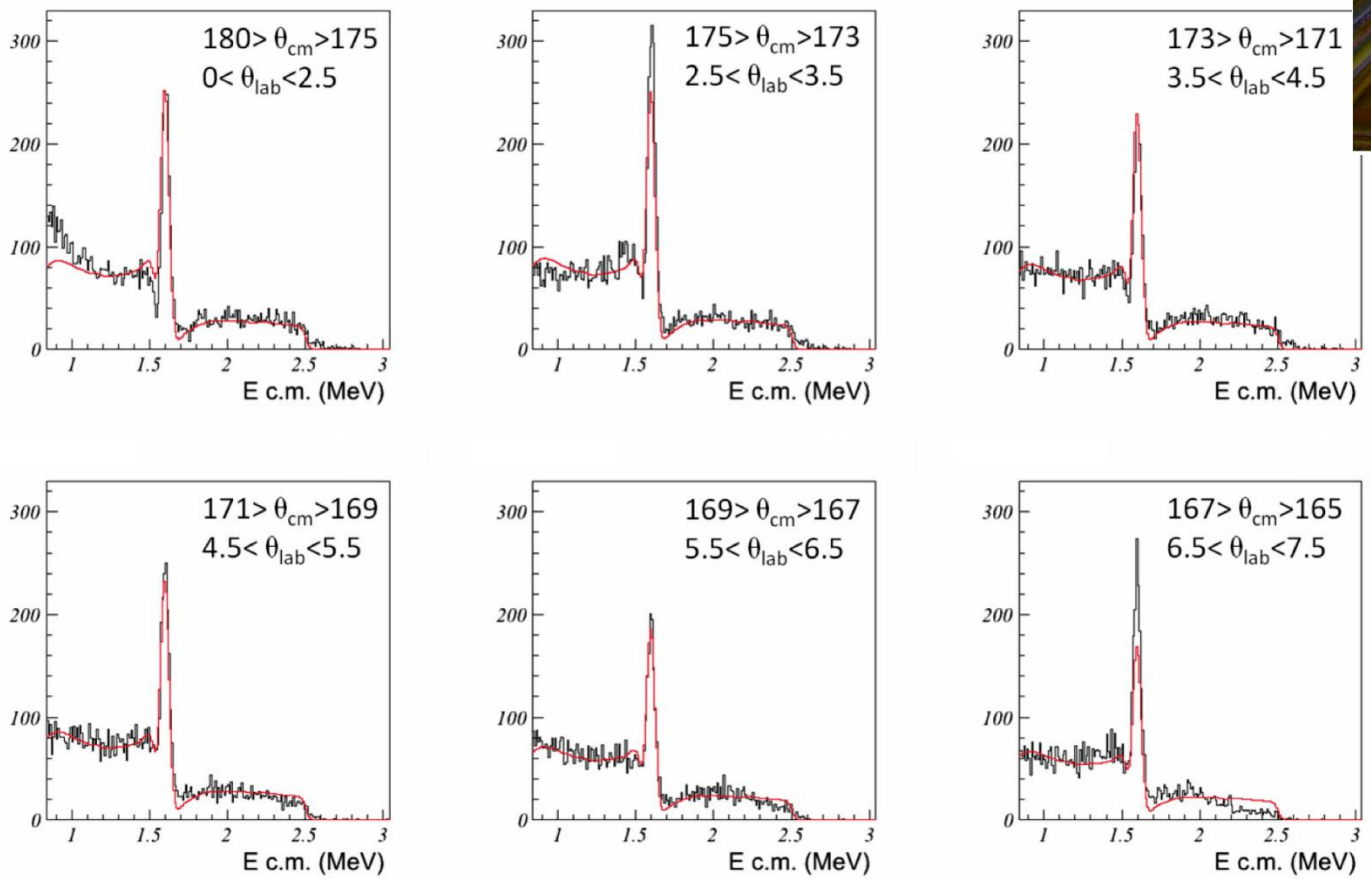
- Thick target method
- Measure: interaction point
  identification recoil
  E, angle recoil particle
- Redundant information:
  - separation elastic
    from other channels
  - detection in a large solid angle
    without loss in resolution



Resonant elastic with Maya

S. Sambi et al., EPJA 51 (2015) 25

- ^{12}Be(p,p') and ^{12}C(p,p') at REX-ISOLDE

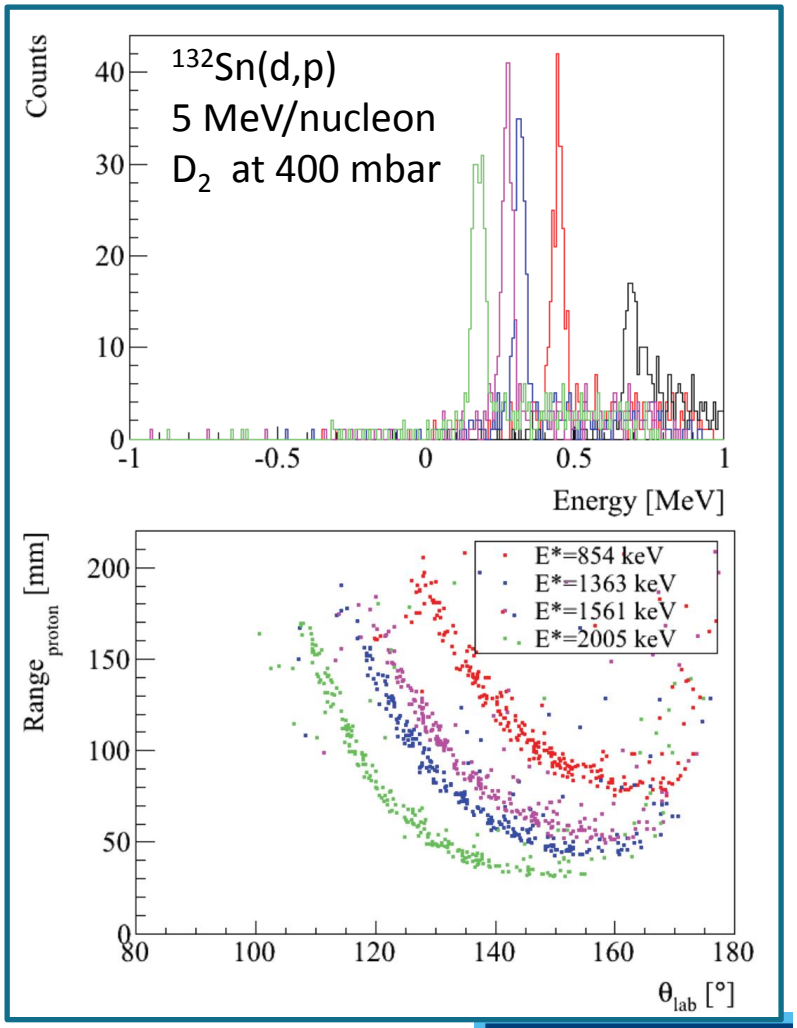


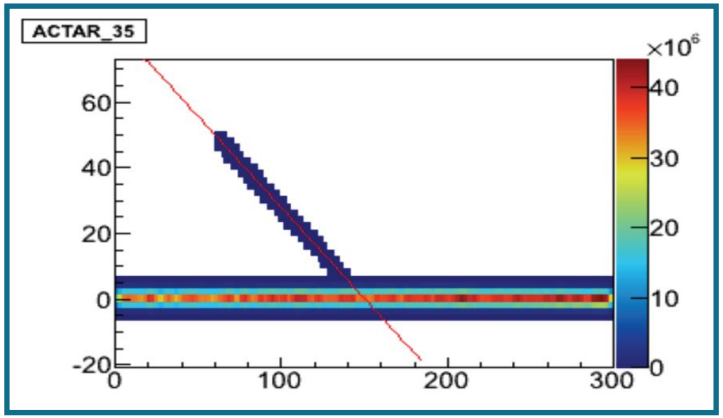
ACTAR TPC: transfer reactions

Source: ACTARSim Report,
D. Perez-Loureiro & G. Grinyer

Characteristics of transfer reactions

- 1 mm vertex resolution
  → equivalent to 15 μg/cm^2 CD_2
- Total thickness ≈25 times larger
- Particles are stopped in gas or escape laterally
- Resolution ≈110 keV for particles stopped in gas

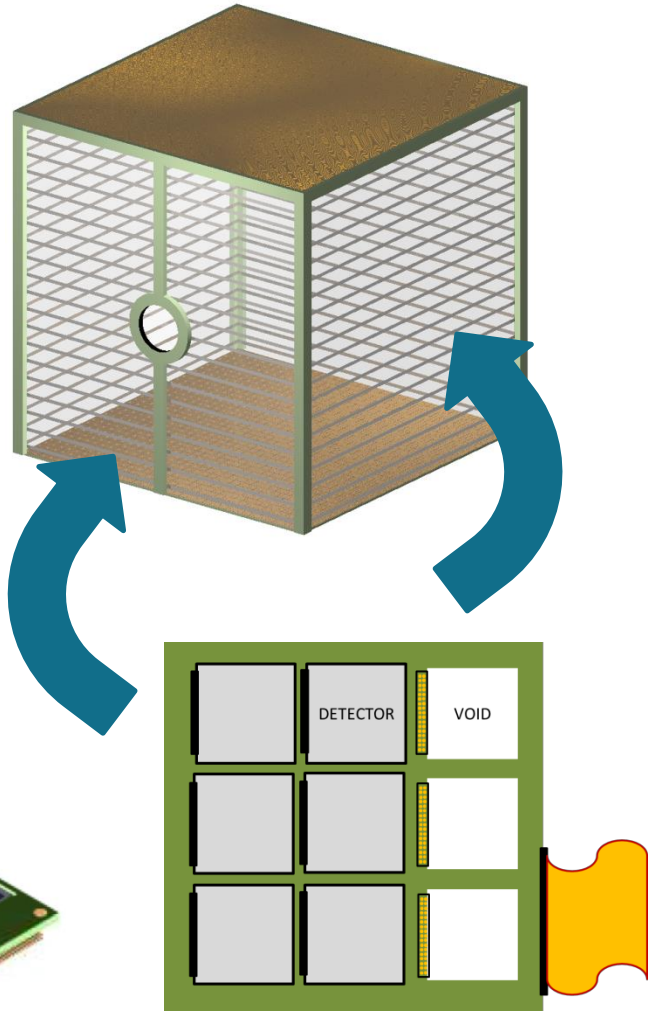


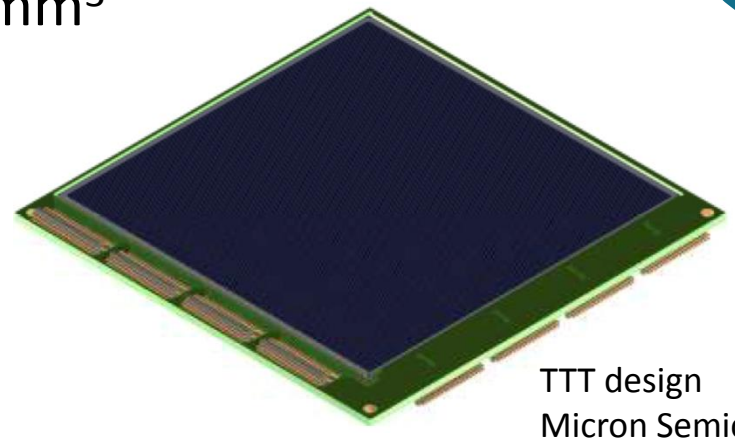


ACTAR TPC

Si Detectors: modular design

- Mother boards with connectors and signal routing
- Detectors on daughter boards (frames) plug onto mother board
- Mother board mechanically fixed on flanges
- 100 x 100 x 1 mm^3
  32 + 32 strips



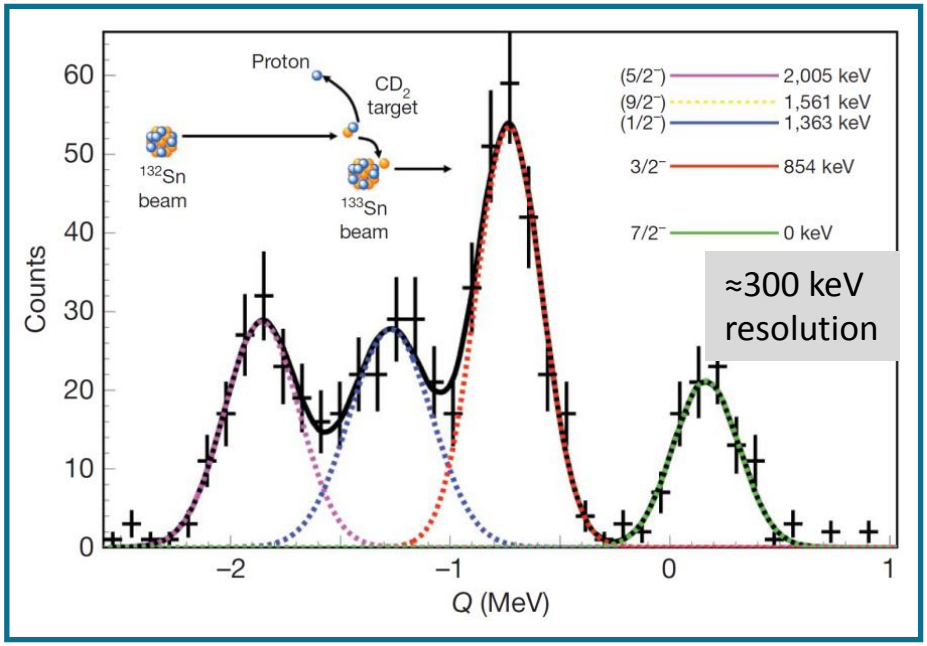


TTT design
Micron Semiconductors

Is particle detection sufficient?

- Main uncertainties:
  - vertex position for small-angle tracks
  - straggling (3%-4%)
  → total resolution ≈10% (compare simulations)

- γ-ray detection interesting
  - if sufficient efficiency (≈10% or better)
  - if better resolution



K.L. Jones et al., Nature 465 (2010) 454

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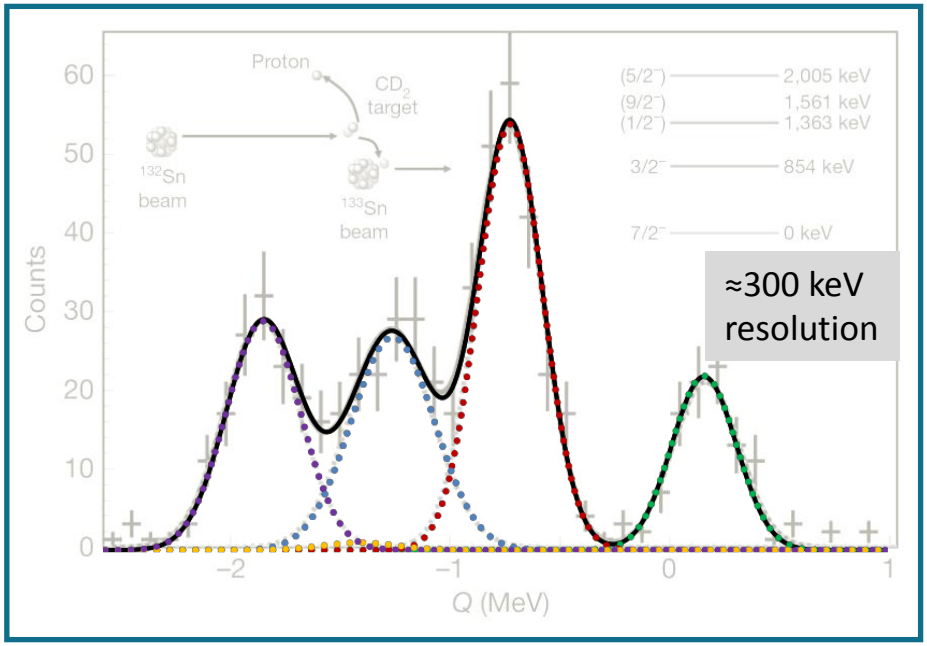

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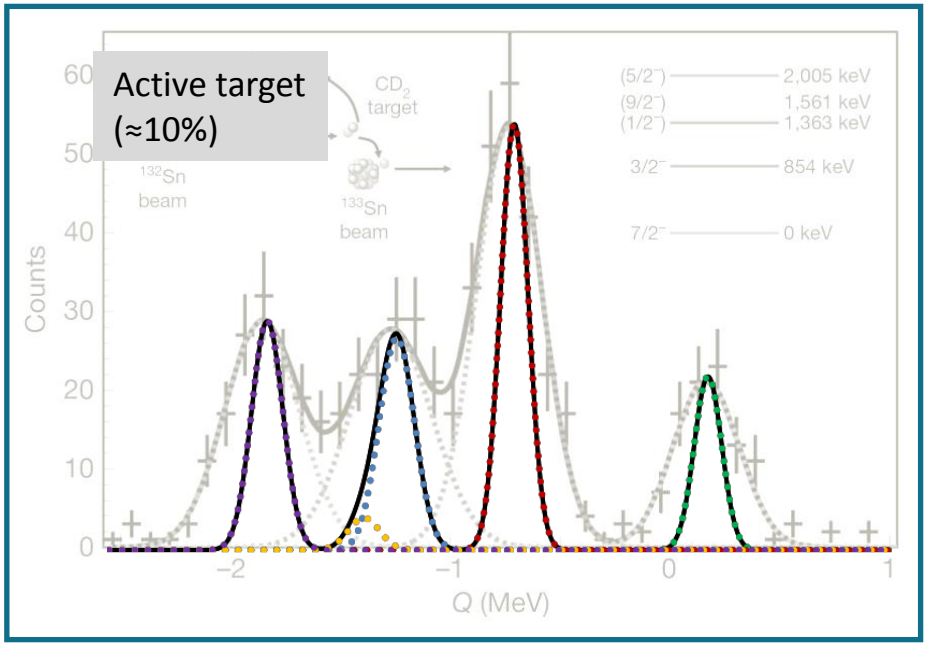
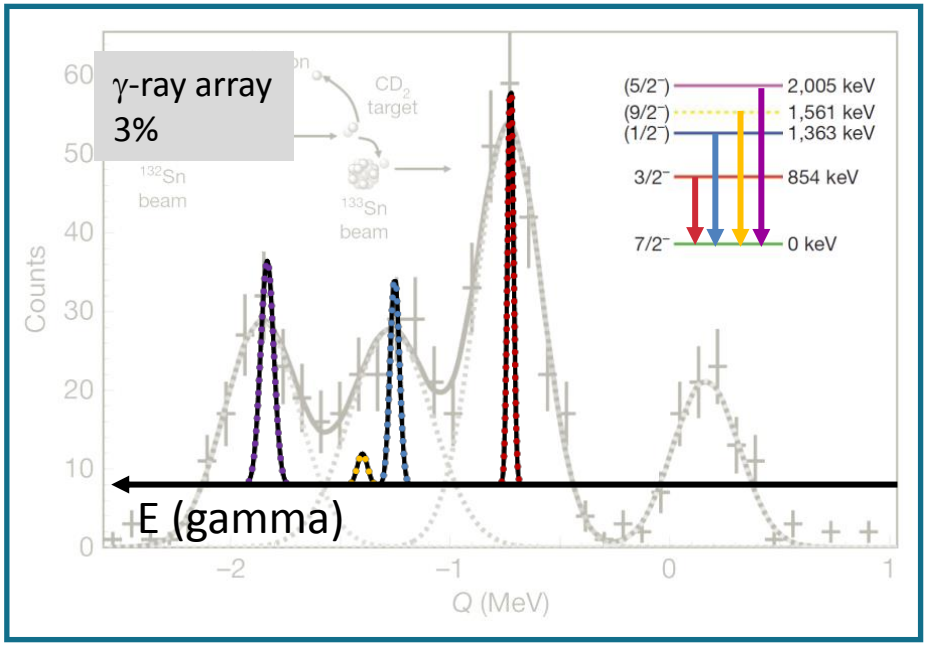


K.L. Jones et al., Nature 465 (2010) 454

Is particle detection sufficient?

- Main uncertainties:
  - vertex position for small-angle tracks
  - straggling (3%-4%)
  → total resolution ≈10% (compare simulations)

- γ-ray detection interesting
  - if sufficient efficiency (≈10% or better)
  - if better resolution



K.L. Jones et al., Nature 465 (2010) 454

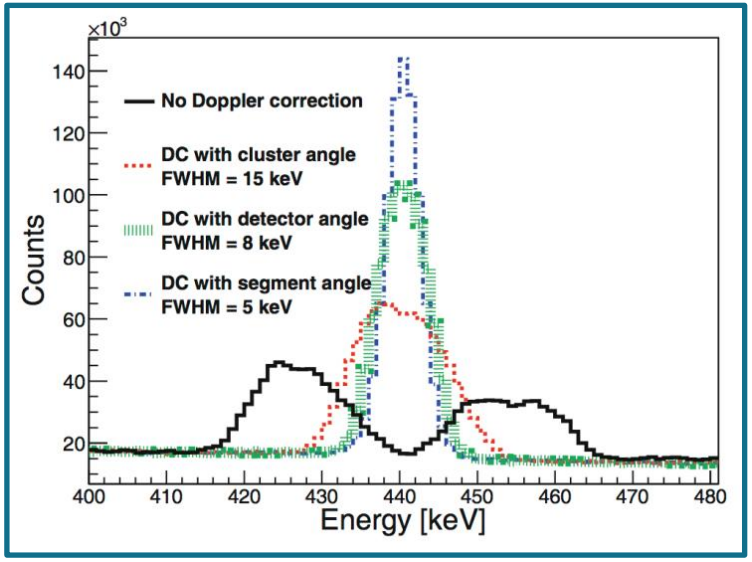
γ-ray detection

Issues

- Efficiency
  - (new) scintillators preferred over Ge
  - good angular coverage
  - interested in low energy (up to ≈2 MeV)
    → little material
    between source and detectors

- Resolution
  - Intrinsic resolution
  - Doppler broadening
    → good position resolution
  - Compare Miniball:
    ≈30 mm diameter elements
    at ≈120 mm

N. Warr et al., EPJA 49 (2013) 40



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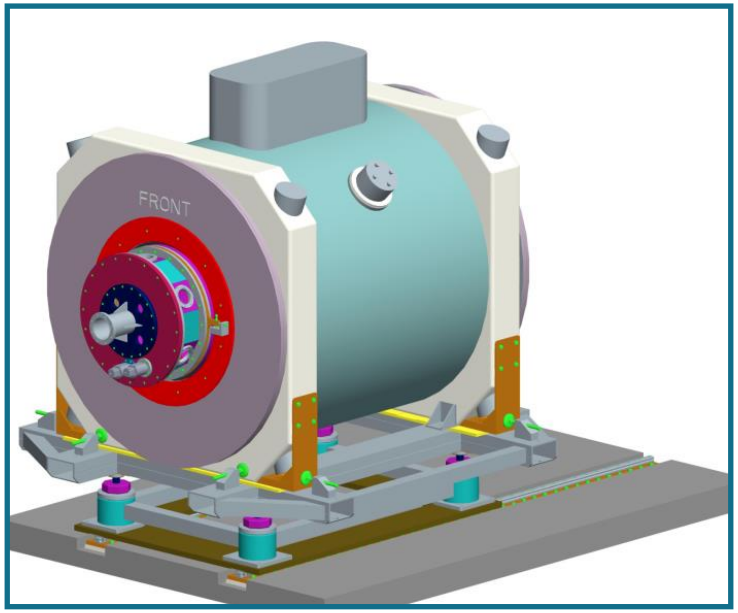
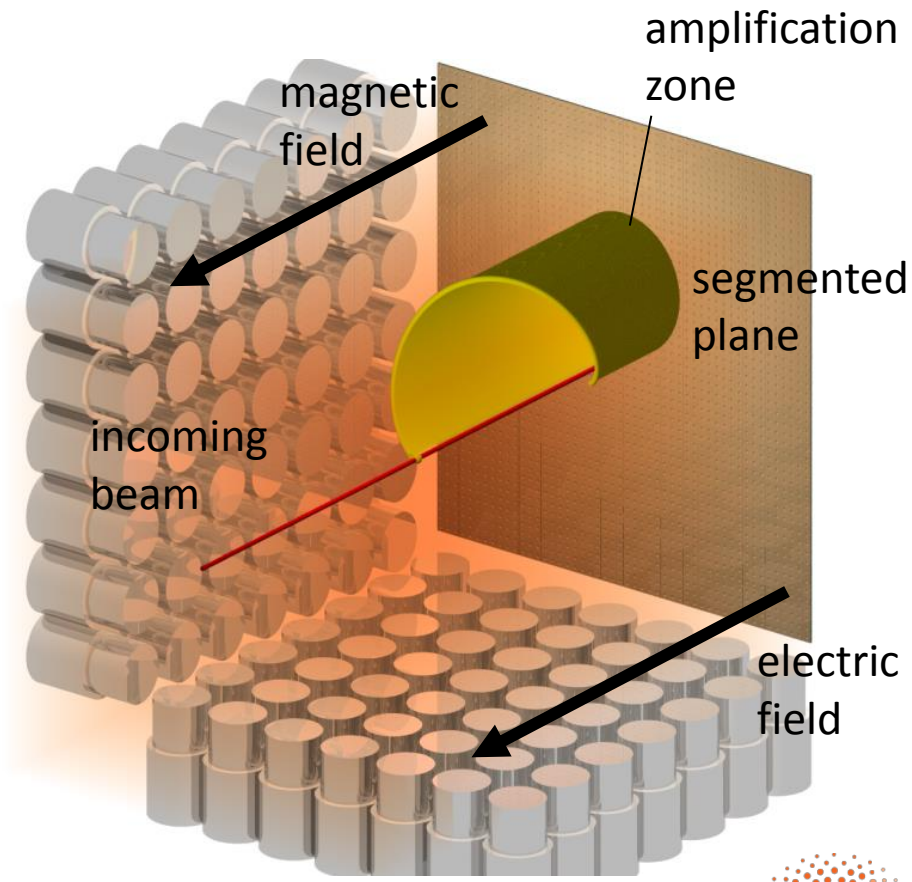
SpecMAT configuration

- With solenoid: cylindrical configuration SiPM for amplification
- Tests with prototypes are in progress





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Summary

Active target detectors provide unique opportunities in low-energy Nuclear Physics

- Radioactive beams:
  low intensity and inverse kinematics
  → Active target detectors:
  high luminosity and high resolution
- Versatile: use of different reaction tools for low-energy nuclear physics
- New instruments:
  - higher counting rates
  - higher dynamic range
  - higher resolution
  - combine with various auxiliary detectors

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