Why active targets?

What is all the buzz about?

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Drivers of active target development

- **Inverse kinematics**: the use of radioactive beams implies a change from normal kinematics to inverse kinematics

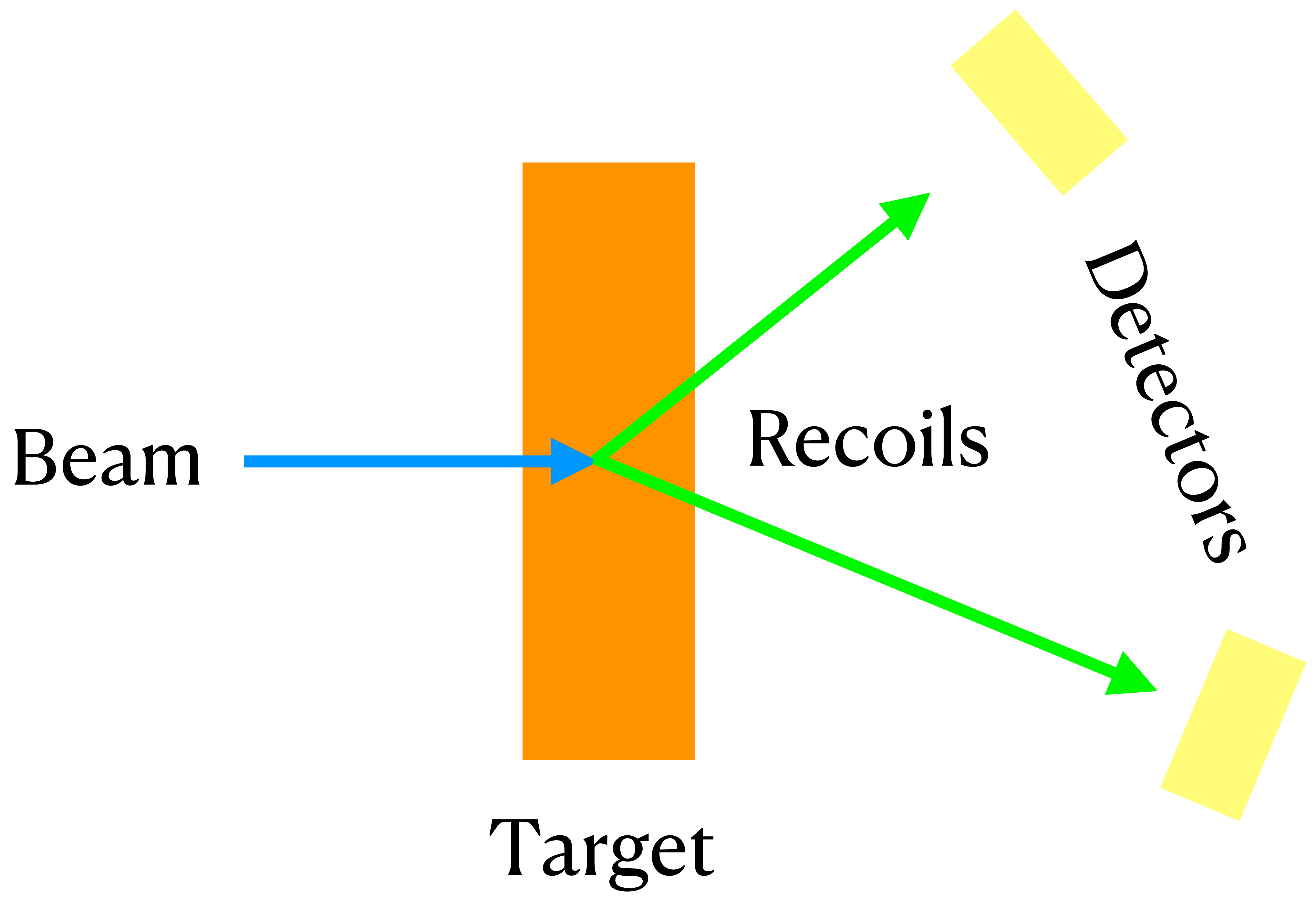
- **Low recoil energies**: in inverse kinematics the recoil particles have very low energies in quasi-elastic reactions such as (d,p) and (α,α')

- **High luminosity**: to compensate the limited intensity of radioactive beams, thick targets and high detection efficiency without loss of resolution are needed

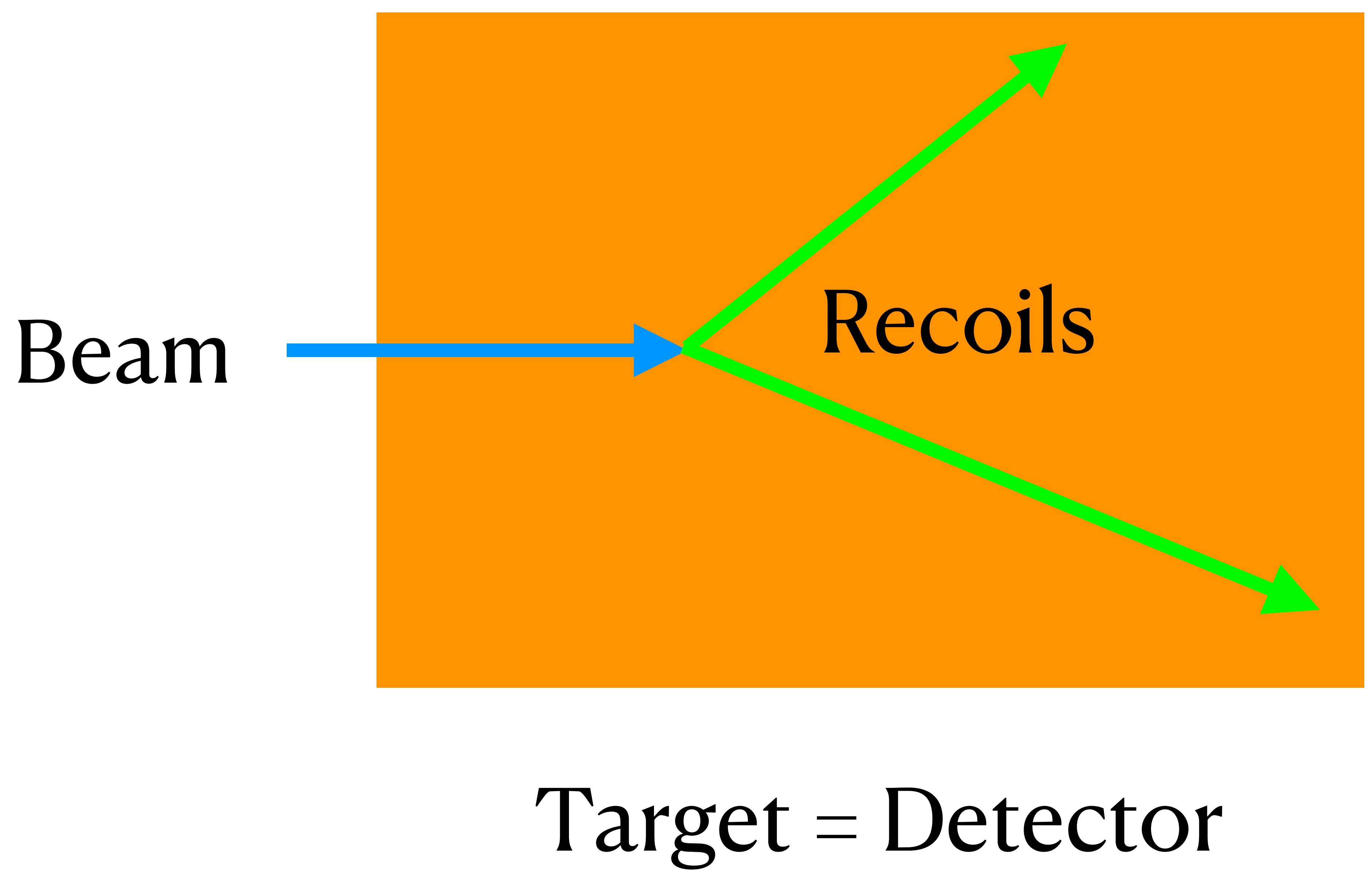
Active targets: the big idea

A simple idea really…

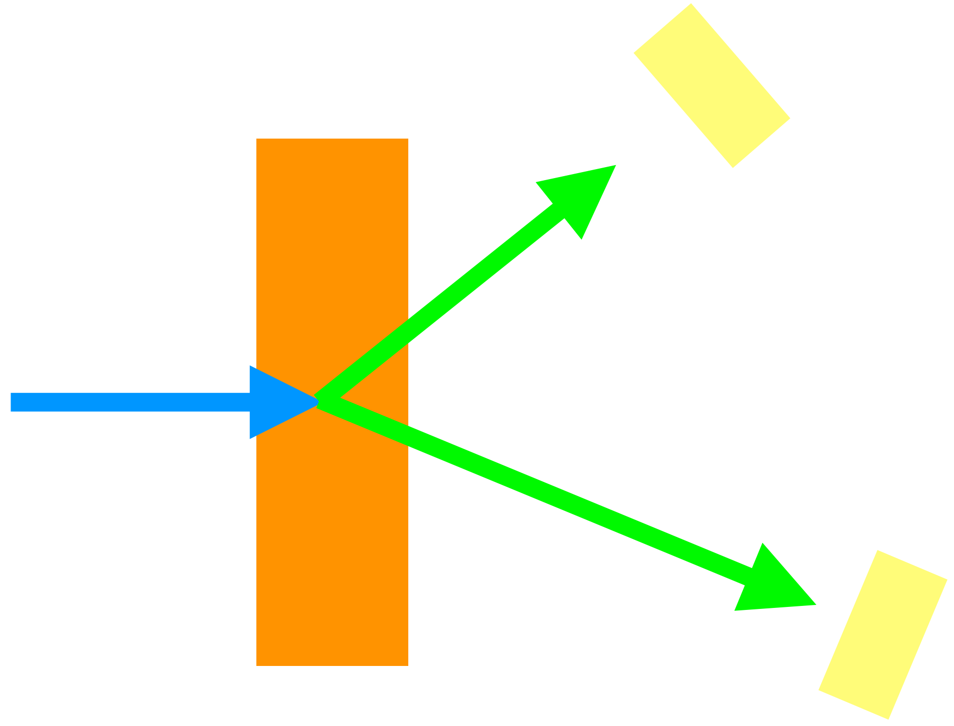
Passive target



Active target



Passive target issues

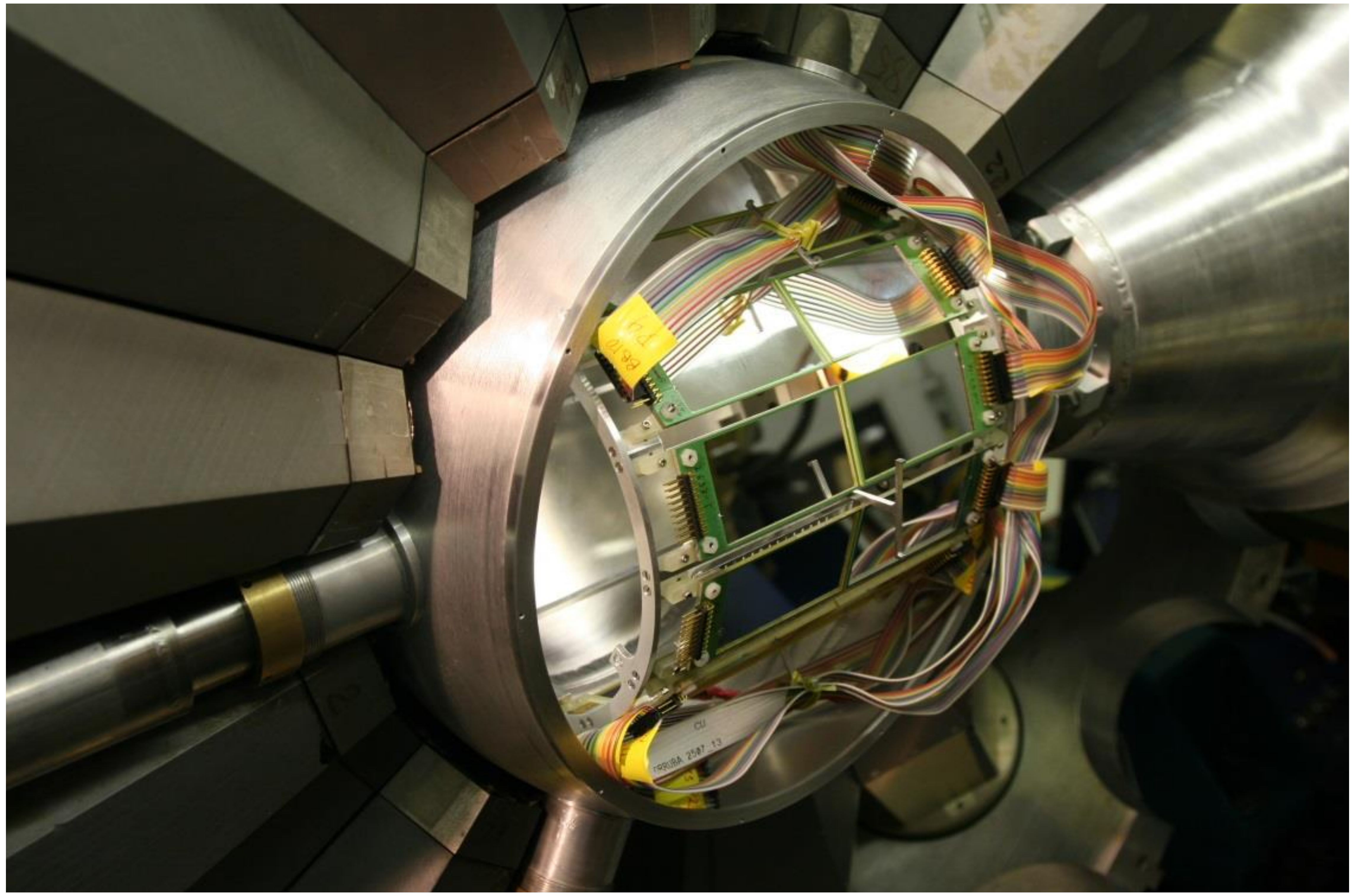


- Compromise between target thickness and resolution
  - The depth at which the reaction takes place is not known
  - Example: 1 MeV proton loses 330 keV in a 1 mg/cm² CH_2 target
- Limited solid angle coverage
  - Compromise between solid angle and angular resolution (and cost!)
- Target contamination
  - Simplest nuclei commonly used in experiments are not available as pure solids
  - Examples: p, d, t, ^{3}He, α are gases at room temperature
  - Use of heavier elements further hurts the thickness/resolution compromise

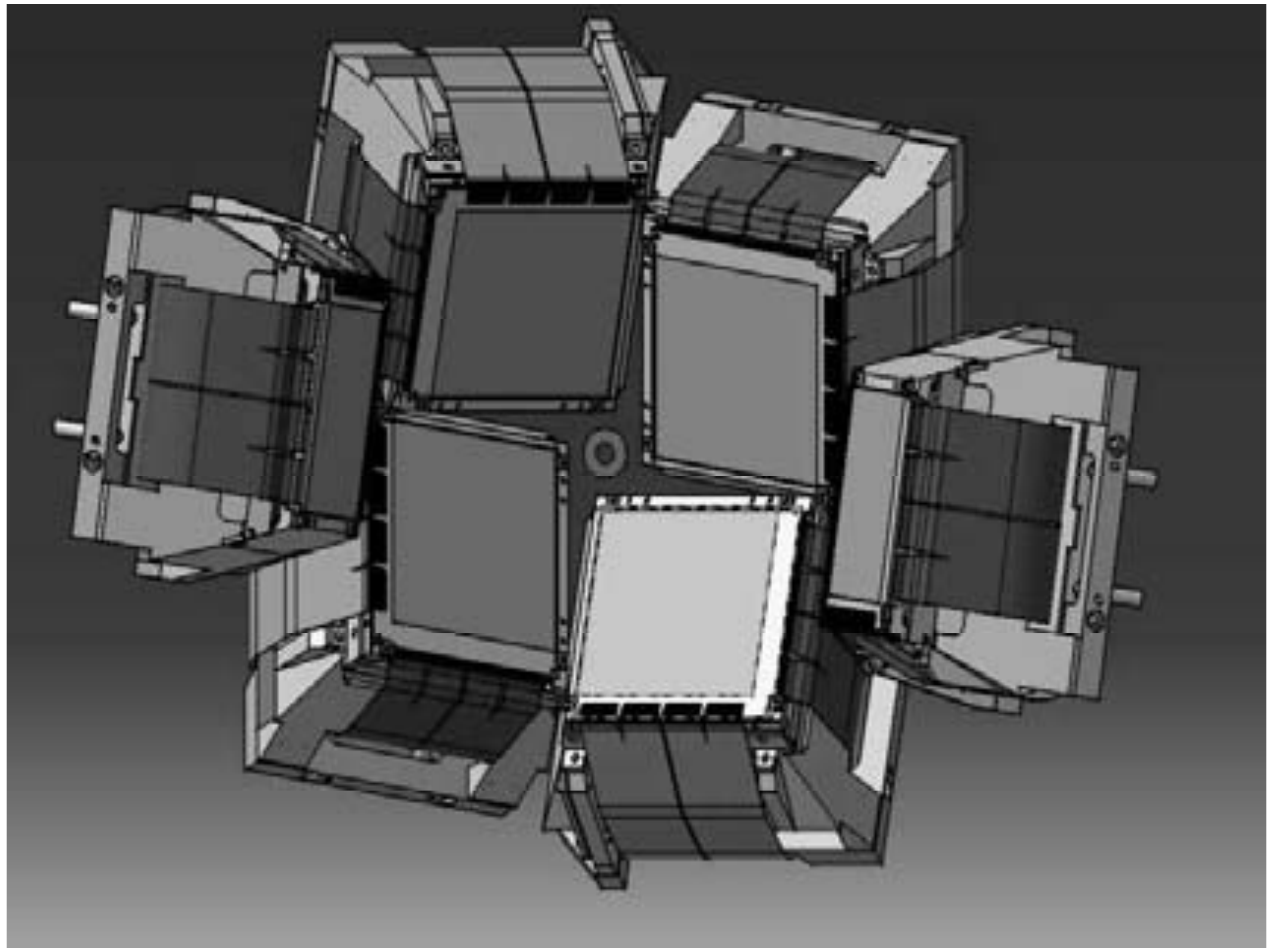
Passive target setups

Two examples

GODDESS

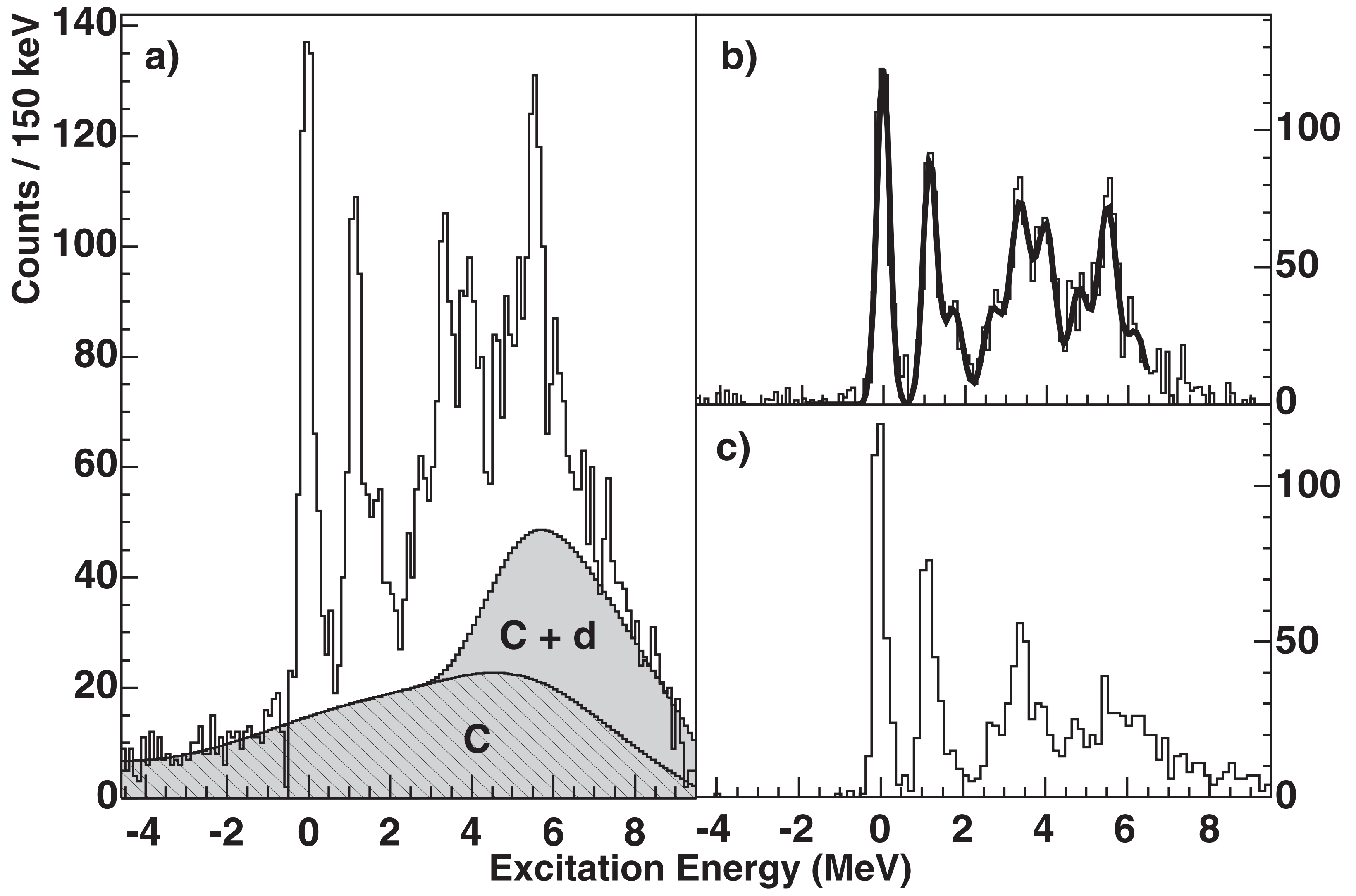


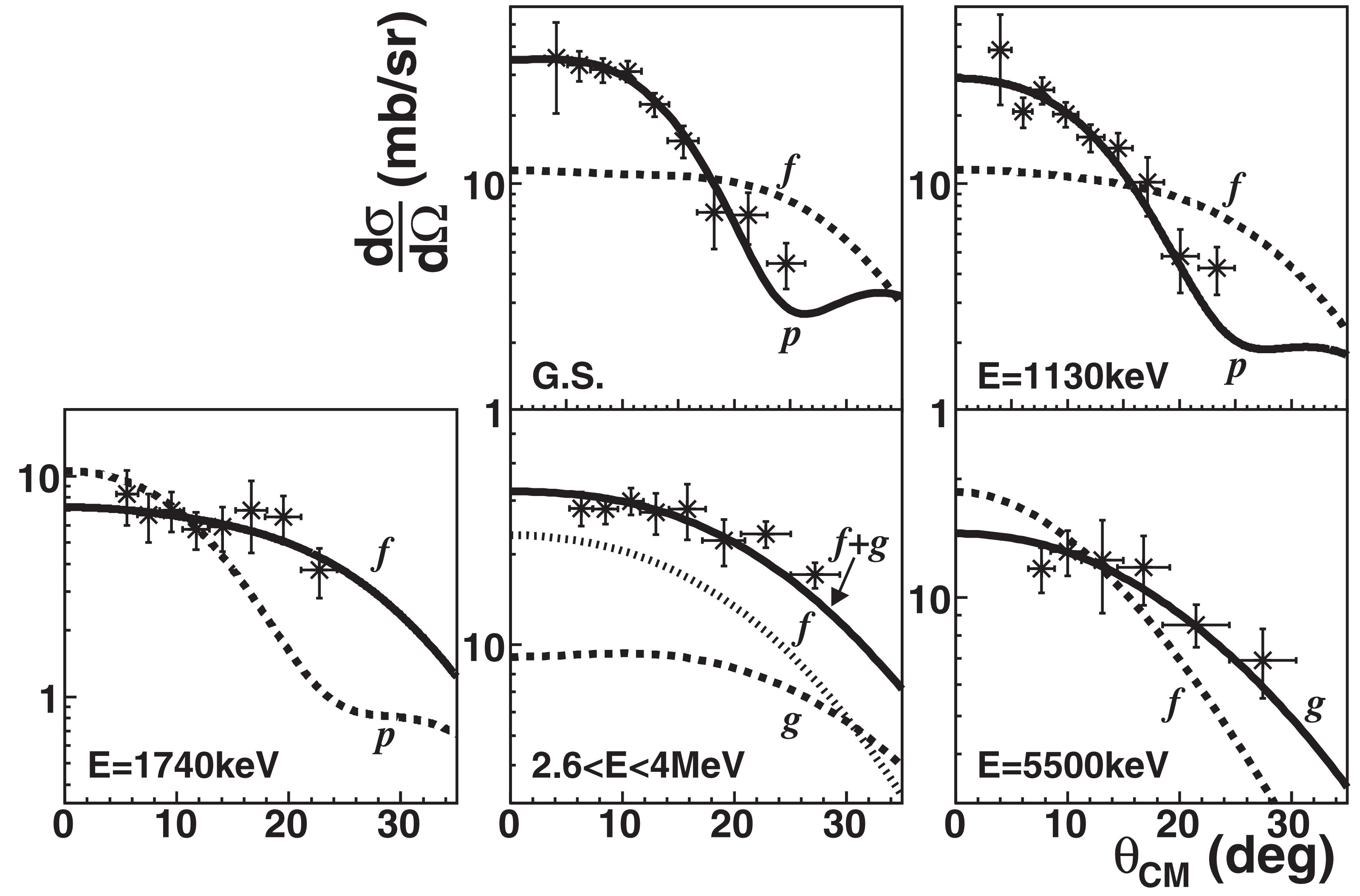
MUST2



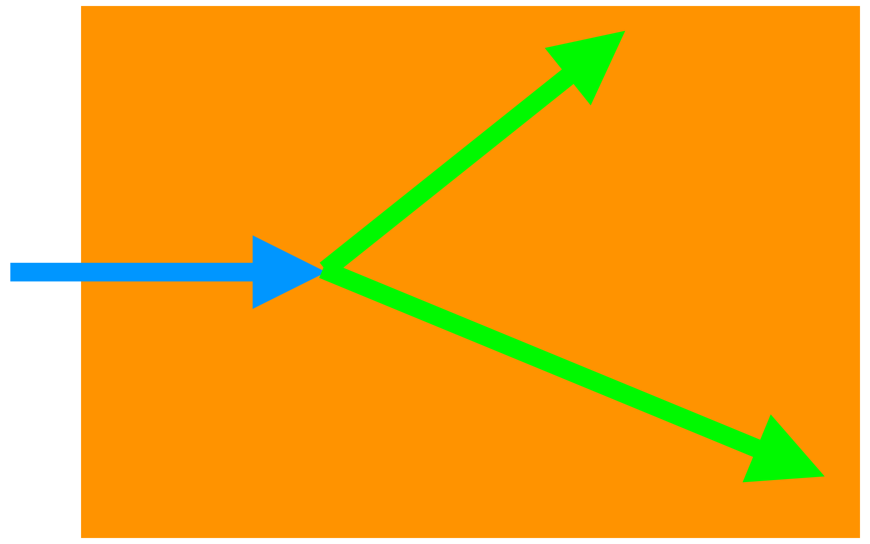
Example of passive target result

- $^{46}Ar(d,p)^{47}Ar$ @ 10 MeV/u
- Target: CD_2 @ 0.38 mg/cm^2
- Beam: ^{46}Ar @ 2 x 10^4 pps
- Apparatus: MUST array + SPEG spectrometer
- Angular range coverage: 110° to 170°
- Energy resolution: 410 keV FWHM
- Angular resolution: 3-5° in CM
- Necessity to subtract ^{12}C background





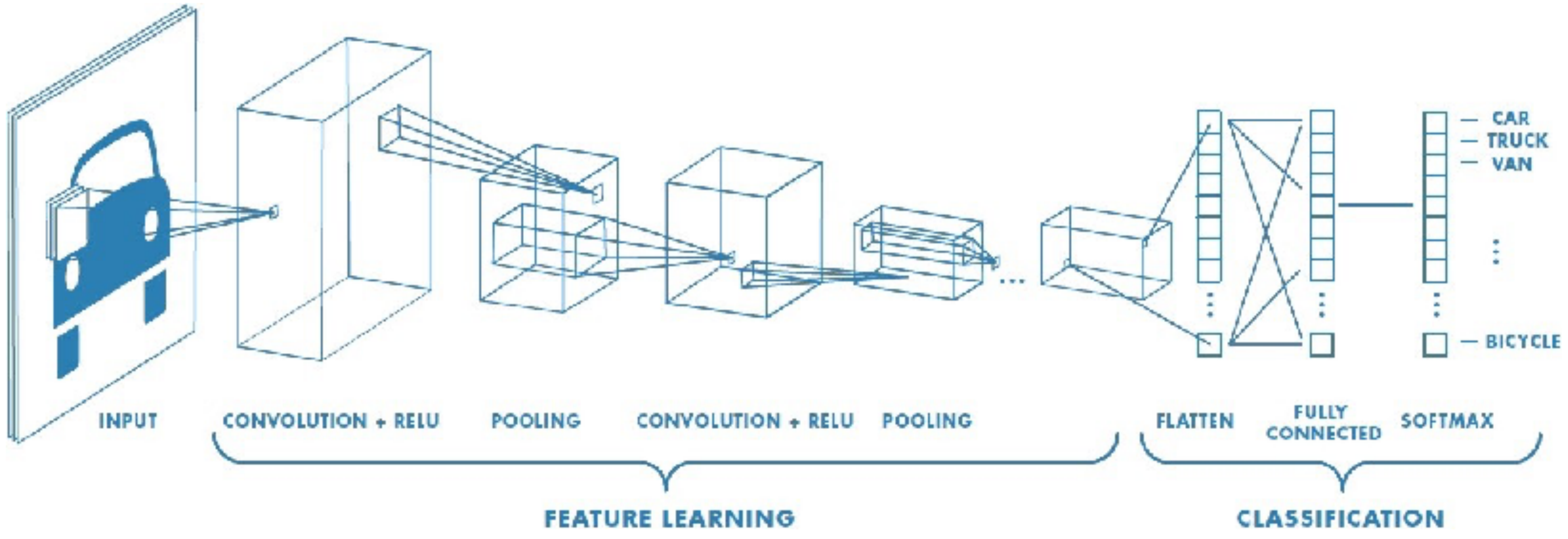
The promises of active targets

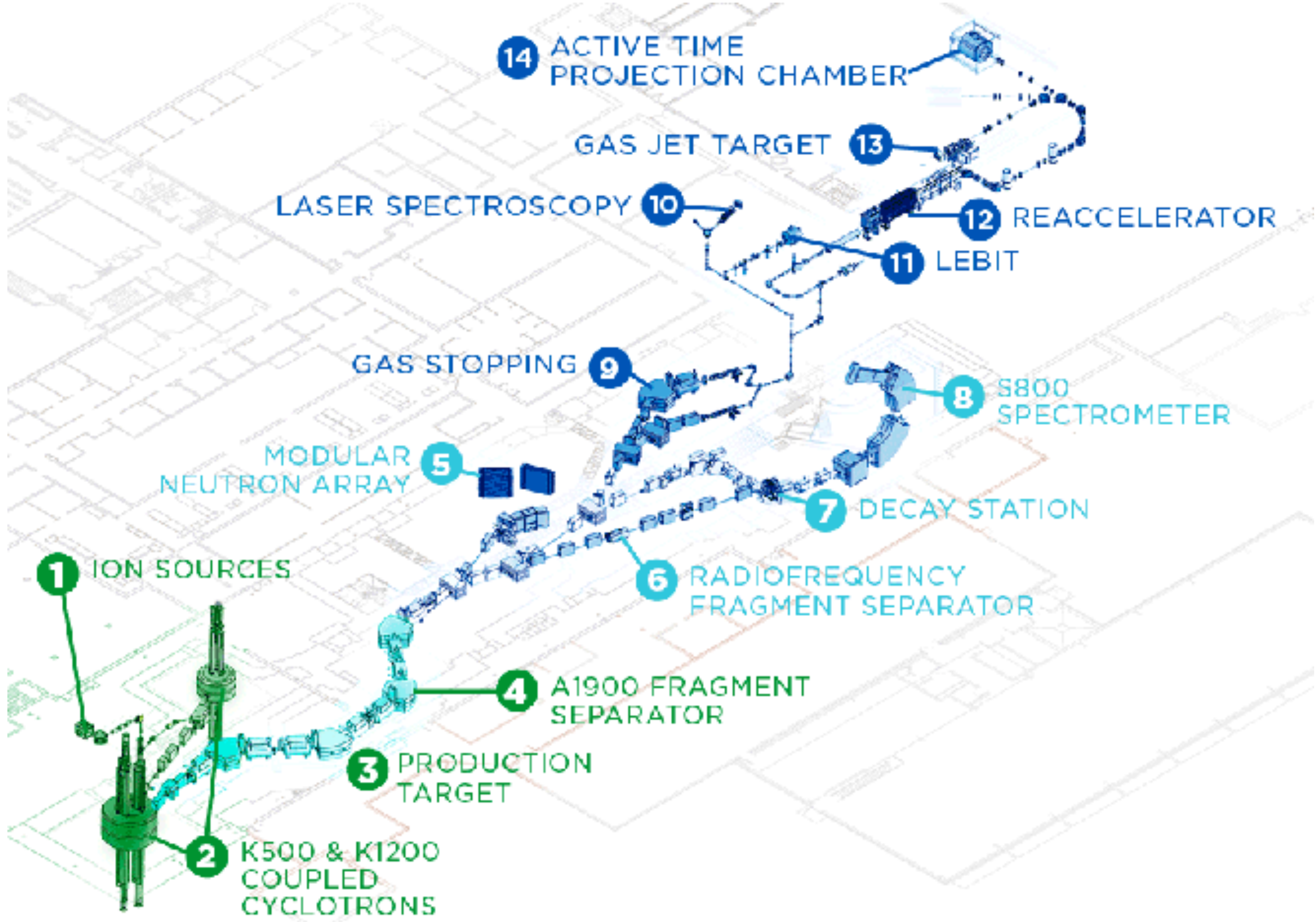


- No more compromise between thickness and resolution
  - Recoil particles can be traced back to the location (vertex) of reaction
  - Energy of reaction measured for each event
- Very large solid angle coverage of recoiling particles
  - Only eventual excluded regions are where the beam is present
- Pure gas targets
  - Very well adapted to the use of light nuclear probes such as p, d, t, ^{3}He, α

Why active targets now?

- Technological advances
  - Electron amplification in pure gases
  - High density and large dynamic range digital electronics
  - New analysis methods of complex data (Machine Learning)
- Radioactive beam advances
  - Wide range of energies available
  - Improved purities and emittance properties





Challenges of active targets

- Generally limited to low intensity beams (< few 10^4 pps)
  - Gas detectors relying on electron drift are relatively slow (cm/μs speeds)
- Choice of gas for detector dictated by physics goals of experiment
  - Target gas is often not the best detector gas
- Trigger generation is tricky
  - Most interesting events are most often not the most frequent
- Data analysis is complex
  - Relationship between raw data and physical properties is very complicated

Applications of active targets

Reactions with low recoil energies

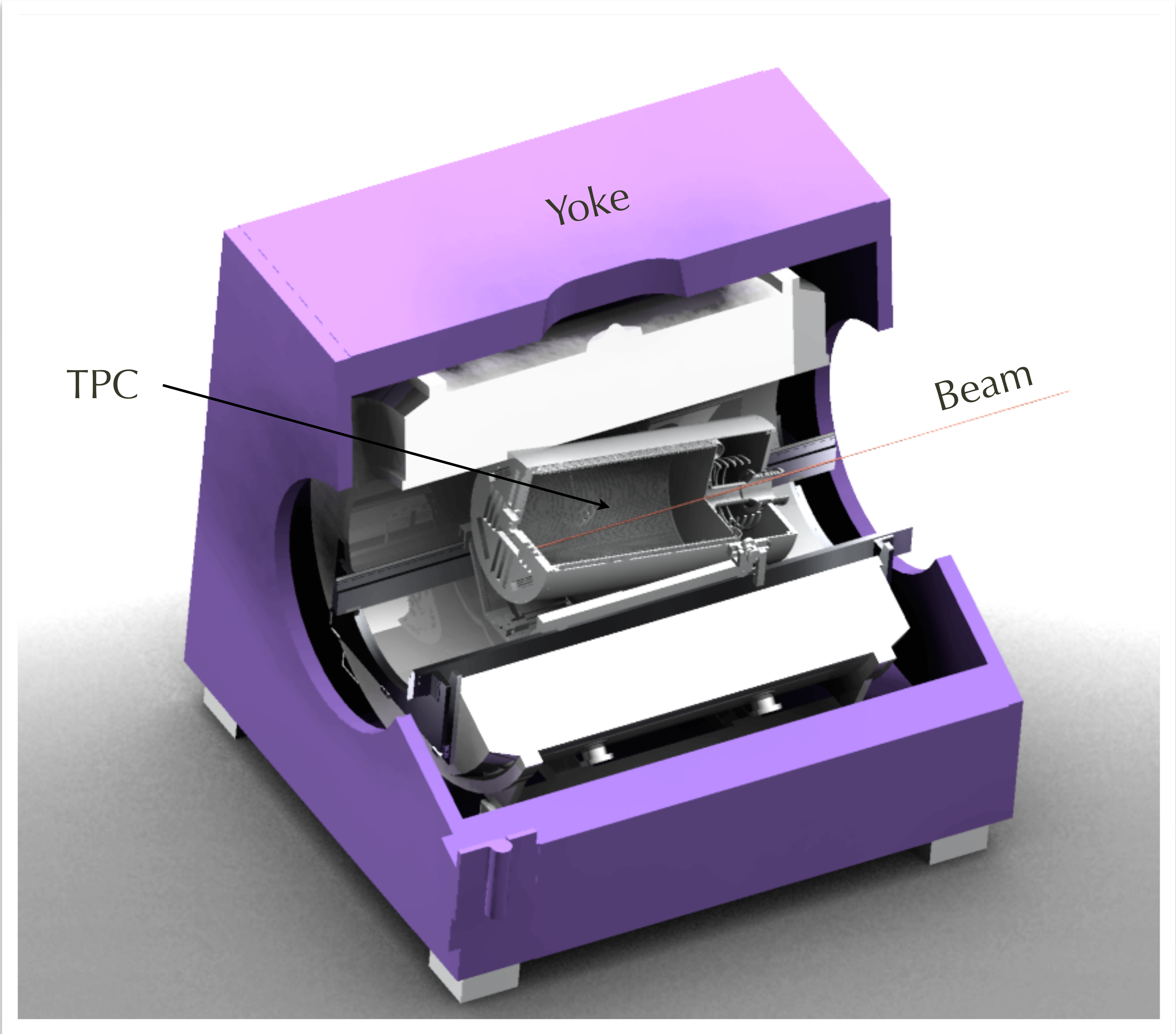
- Low energy radioactive beams (close or above the Coulomb barrier)
  - Spectroscopy with transfer reactions: transfer one or two nucleons to/from the projectile
  - Cluster structure with resonance reactions: elastic and inelastic collisions
  - Fission barrier with fusion/fission reactions: heavy compound nucleus created via fusion
- High energy radioactive beams (around 100 MeV/u and above)
  - Gamow-Teller matrix elements: charge-exchange reactions at low momentum transfer
  - Excitation of collective modes: giant resonances via inelastic scattering
  - Nuclear matter distributions via elastic scattering at high energy

More details in lecture on applications!

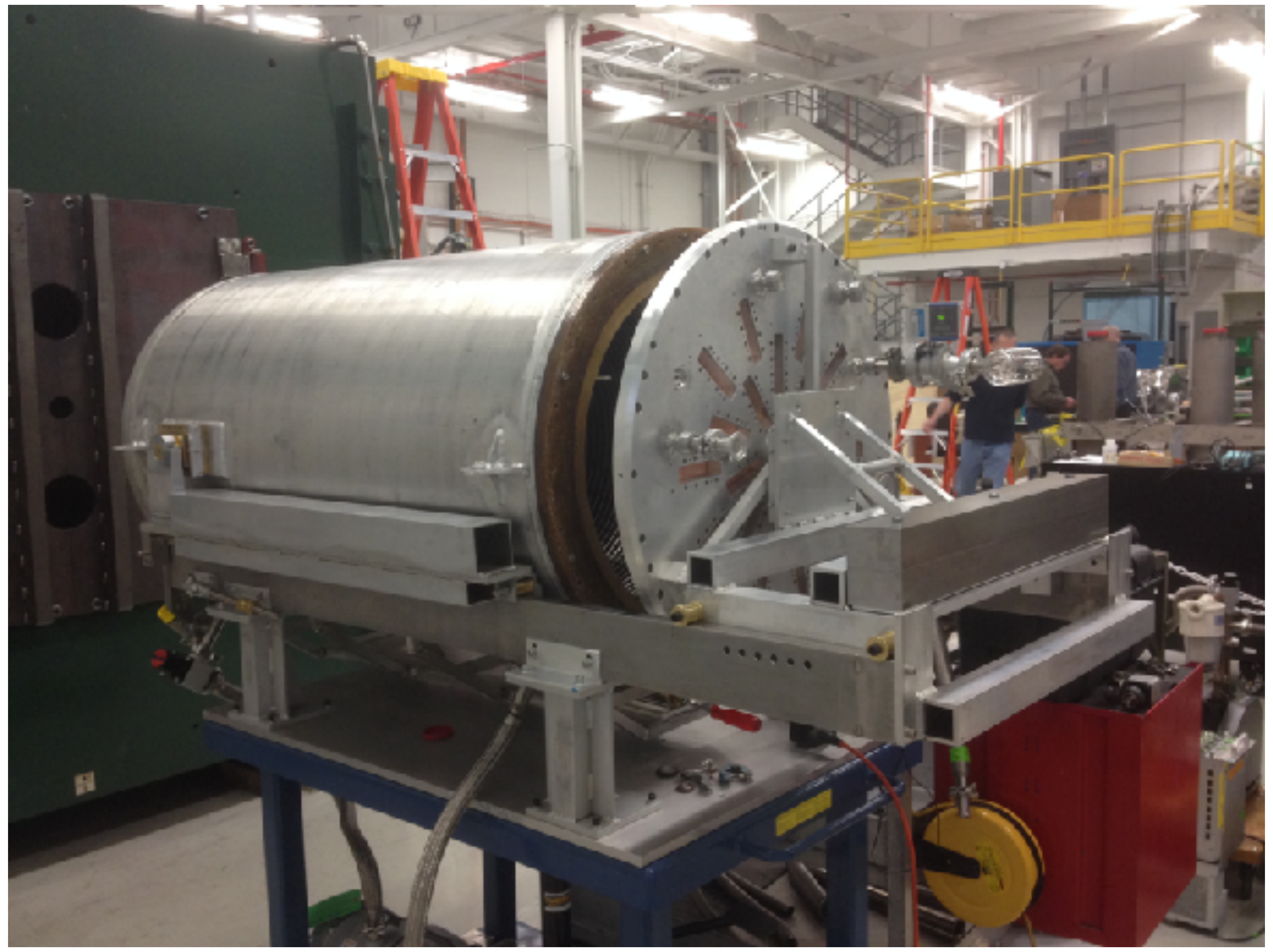
Example: on-axis active targets

Active Target Time Projection Chamber (AT-TPC)

- Beam axis parallel to drift direction of electrons
- Large volume to stop recoil particles
- Can be placed inside a large bore solenoid magnet (MRI)
- Magnetic field parallel to beam axis
- Curved trajectories of recoil particles used to identify them and measure their velocity



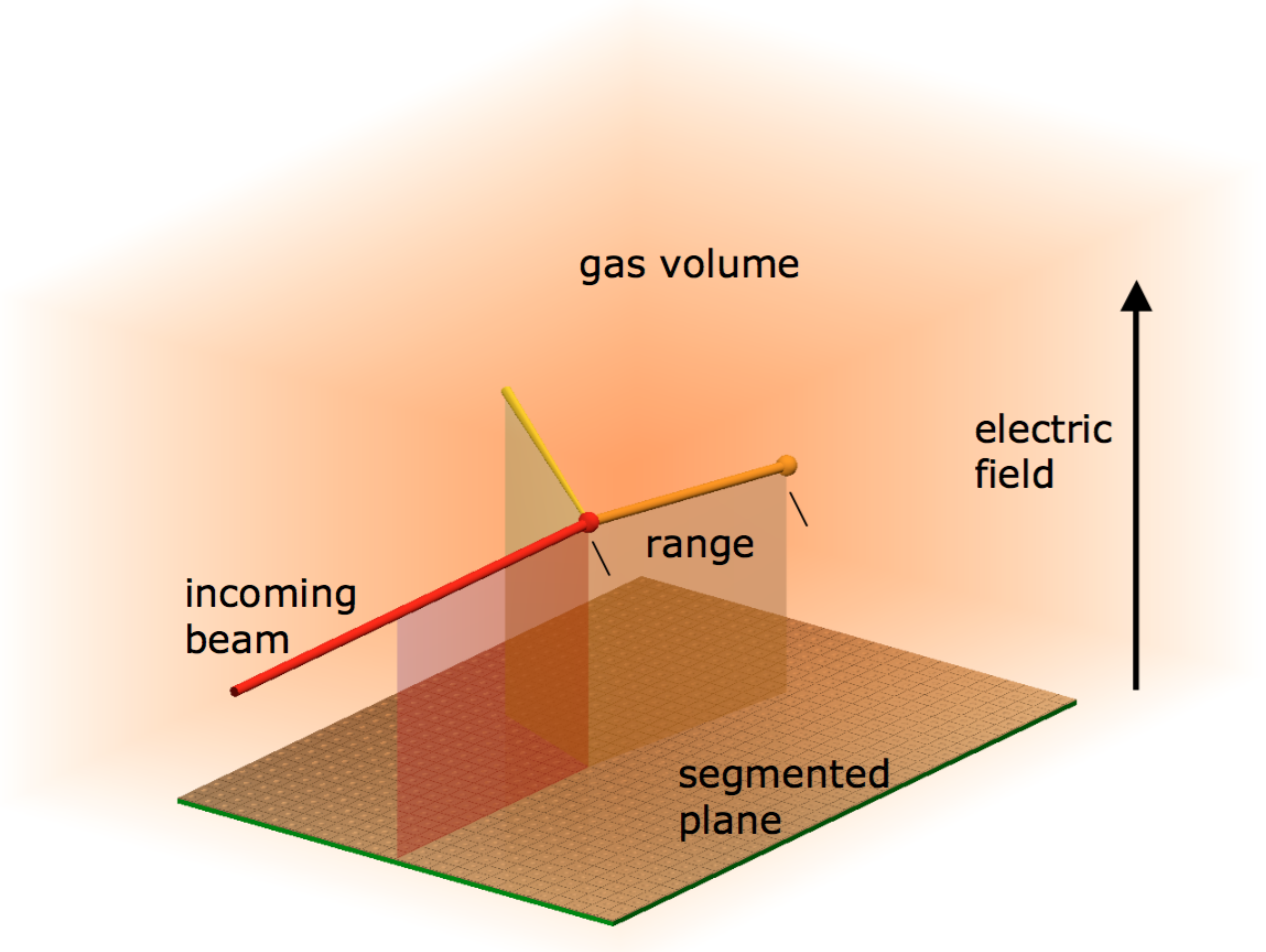
AT-TPC: some pictures



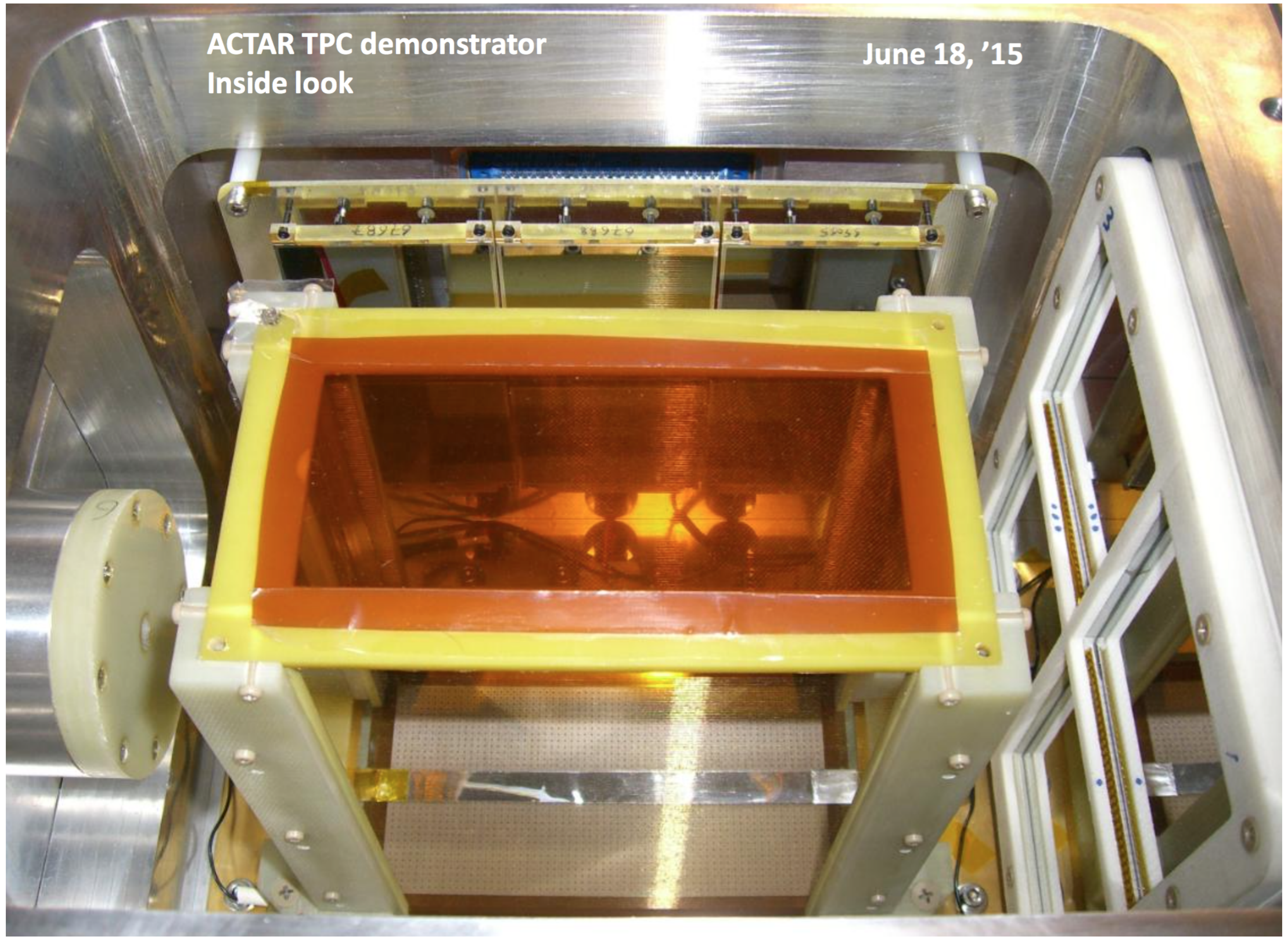
Example: axis-normal active targets

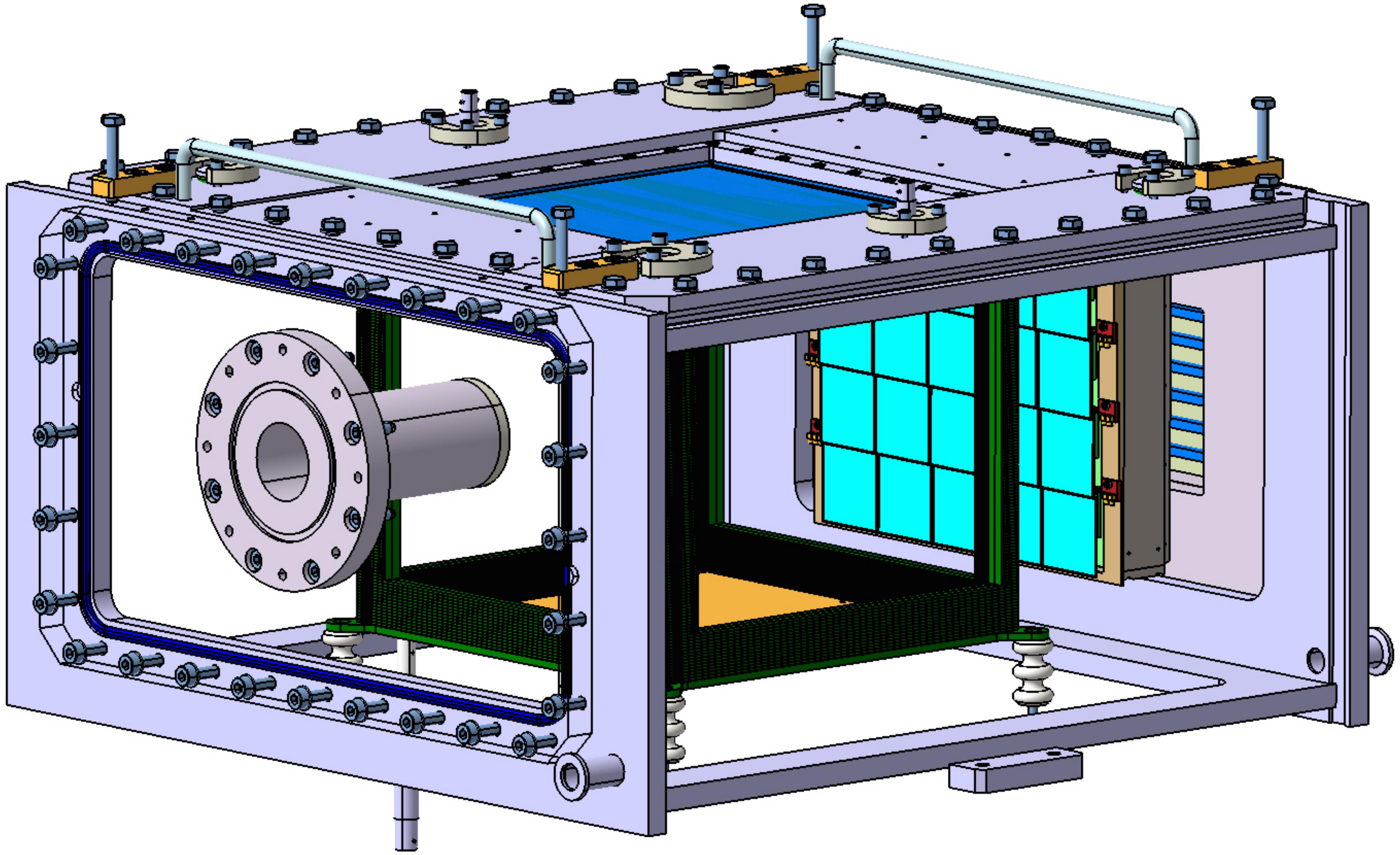
ACTAR Time Projection Chamber

- Beam axis perpendicular to drift direction of electrons
- Smaller volume to place ancillary detectors around it (gamma, neutron)
- Gas volume surrounded by Silicon and CsI scintillators
- Recoil particle identification from energy loss and range



ACTAR: some pictures…





Active targets around the world

Table 1
List of active-target detectors mentioned in this review. The laboratory acronyms are as follows: NSCL (National Superconducting Cyclotron Laboratory, USA), FRIB (Facility for Rare Isotope Beams, USA), Leuven (Katholieke Universiteit Leuven, Belgium), GANIL (Grand accelérateur d'ions lourds, France), Texas A&M (Texas A&M University, USA), RCNP (Research Center for Nuclear Physics, Japan), CENBG (Centre d'Études Nucléaires de Bordeaux-Gradignan, France), Warsaw (University of Warsaw, Poland), GSI (Helmholtzzentrum für Schwerionenforschung, Germany), LLNL (Lawrence Livermore National Laboratory, USA), ANL (Argonne National Laboratory, USA), CNS (Center for Nuclear Studies, Japan).

Name	Location	Main physics theme	Reference	Section(s)
pAT-TPC	NSCL/FRIB	Cluster structure	[3]	5.3.1, 5.3.3, 6.2, 7.2, 8.2.2, 8.3
AT-TPC	NSCL/FRIB	Shell evolution	[4]	2, 3.2.1, 4.3, 4.4, 6.4, 7.1, 7.3, 8.2.2, 9.1
SPECMAT	Leuven	Shell evolution	[5]	2.1, 6.4
MAYA	GANIL	Giant resonances	[6]	2.1, 4.2, 7.3, 9.4
ACTAR	GANIL	Shell evolution	[7]	2.1, 3.2.2, 7.1, 7.3
TexAT	Texas A&M	Shell evolution	[8]	3.2.2, 6.4
MAIKo	RCNP	Cluster structure	[9]	5.3.2
TPC	CENBG	Exotic decays	[10]	6.3
O-TPC	Warsaw	Exotic decays	[11]	6.2, 6.3
MUSIC	GSI	Fusion–fission	[12]	7.1
fissionTPC	LLNL	Fusion–fission	[13]	7.1
MUSIC	ANL	Astrophysics	[14]	8.2
GADGET	NSCL/FRIB	Astrophysics	[15]	6.4
IKAR	GSI	Matter distributions	[16]	9.2
CAT	CNS	Giant resonances	[17]	9.3

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