Developments in in-beam conversion electron spectroscopy

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Reflections on the atomic nucleus conference

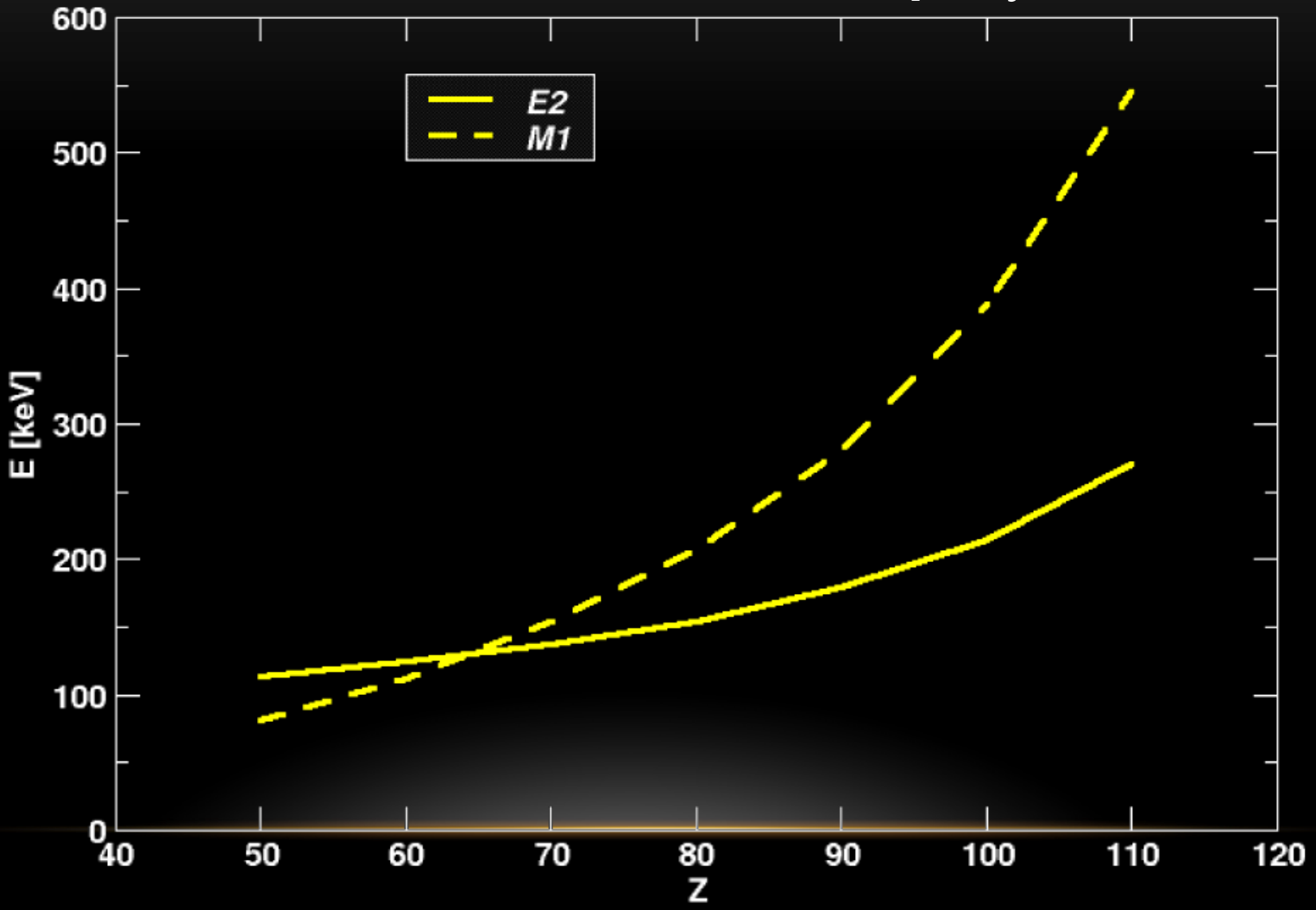
28-30 July 2015

Liverpool, UK

OUTLINE

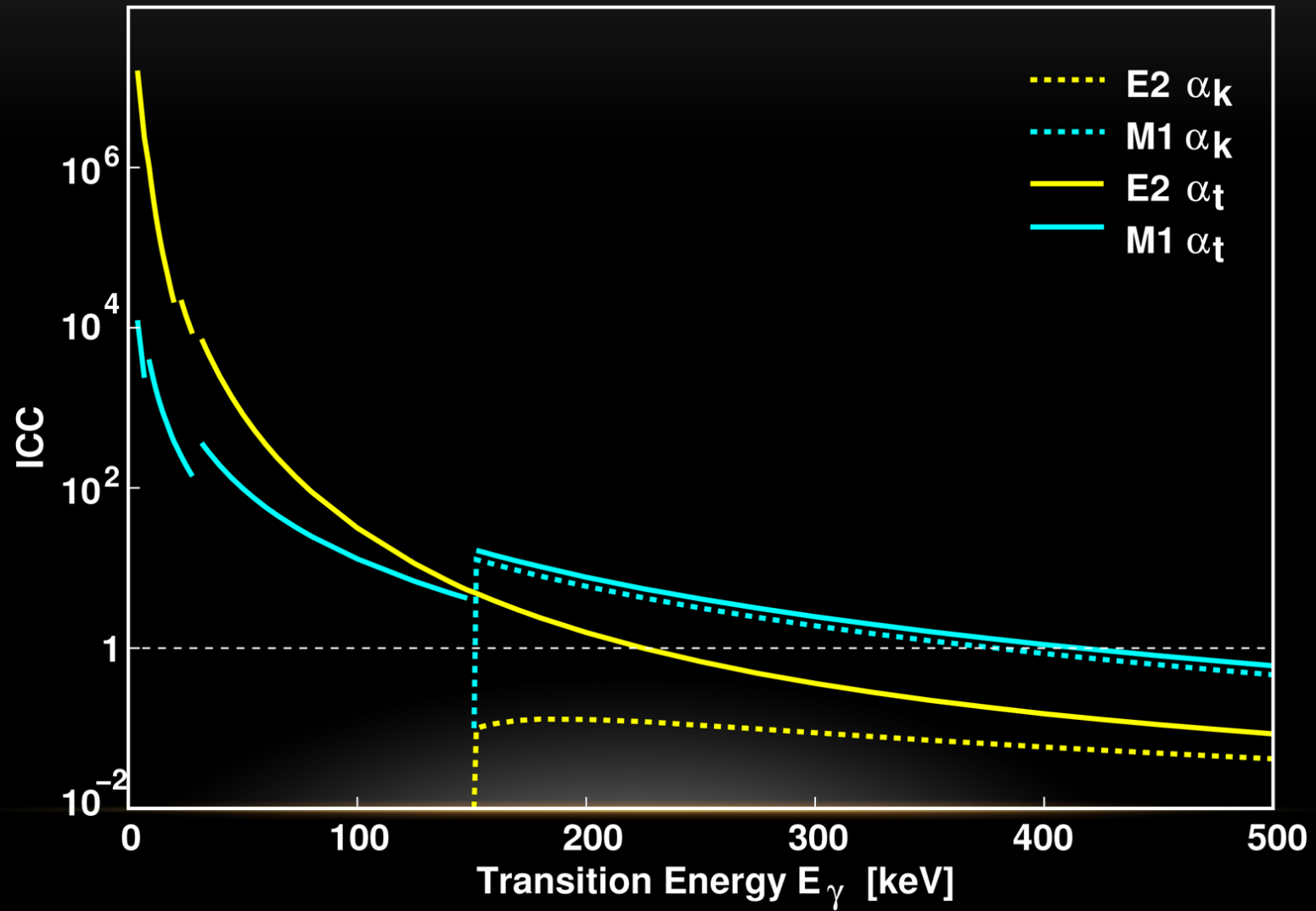
- ✓ Front matter – motivation
- ✓ SACRED – innovative apparatus
- ✓ SAGE – simultaneous $e^{-}\gamma$ spectroscopy
- ✓ SPEDE – $e^{-}\gamma$ spectroscopy with radioactive beams
- ✓ Backmatter

Internal conversion dominance over γ-ray emission



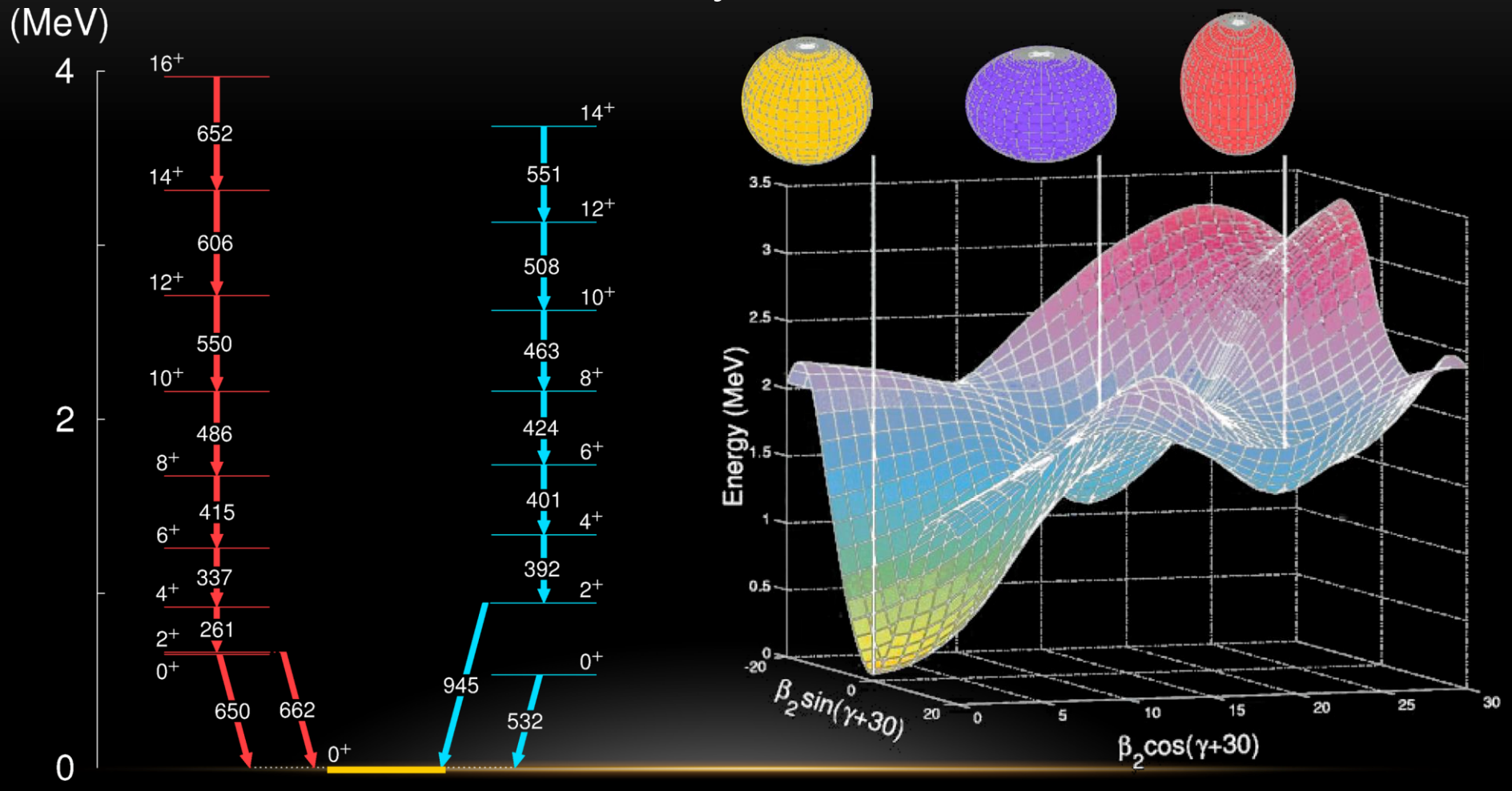
D. M. Cox *el al*., Eur. Phys. J. A (2015) 51: 64

Internal conversion coefficients for ^{254}No



P. Papadakis *et al.*, AIP Conf. Proc. 1090, 14 (2009)

The E0 transitions – solely via internal conversion



A. N. Andreyev *et al.*, Nature 405, 430 (2000)

J. Pakarinen *et al.*, Phys. Rev. C 72 011304(R) (2005)

Electron spectroscopy challenge

- Electron detection within the same chamber as the target
- δ-electrons production cross section of the order of megabarns
- Intensity distributed to electrons originating from different atomic shells

δ-electron suppression | High resolution and efficiency | Channel selection

Further motivation and key players

Jyväskylä monopole group* that has, since 1975, concentrated its efforts to reach the following goals:

(i) To develop new methods necessary for systematic studies of 0^+ states via their electromagnetic decay (or population), with special reference to E0 transitions.

(ii) To carry out systematic measurements in certain regions of interest; as the first step, near closed proton cores.

(iii) To obtain nuclear-structure information on features especially probed by electric monopole transitions. For example, E0 matrix elements may imply the presence of proton particle-hole excitations or pairing vibrations, deformation, neutron excitations, state dependence of effective monopole charges, etc.

(iv) To stimulate theoretical work by providing reliable systematic data.

J. Kantele, XIV Masurian summer school on nuclear physics, 1981

R. Julin

Further motivation and key players

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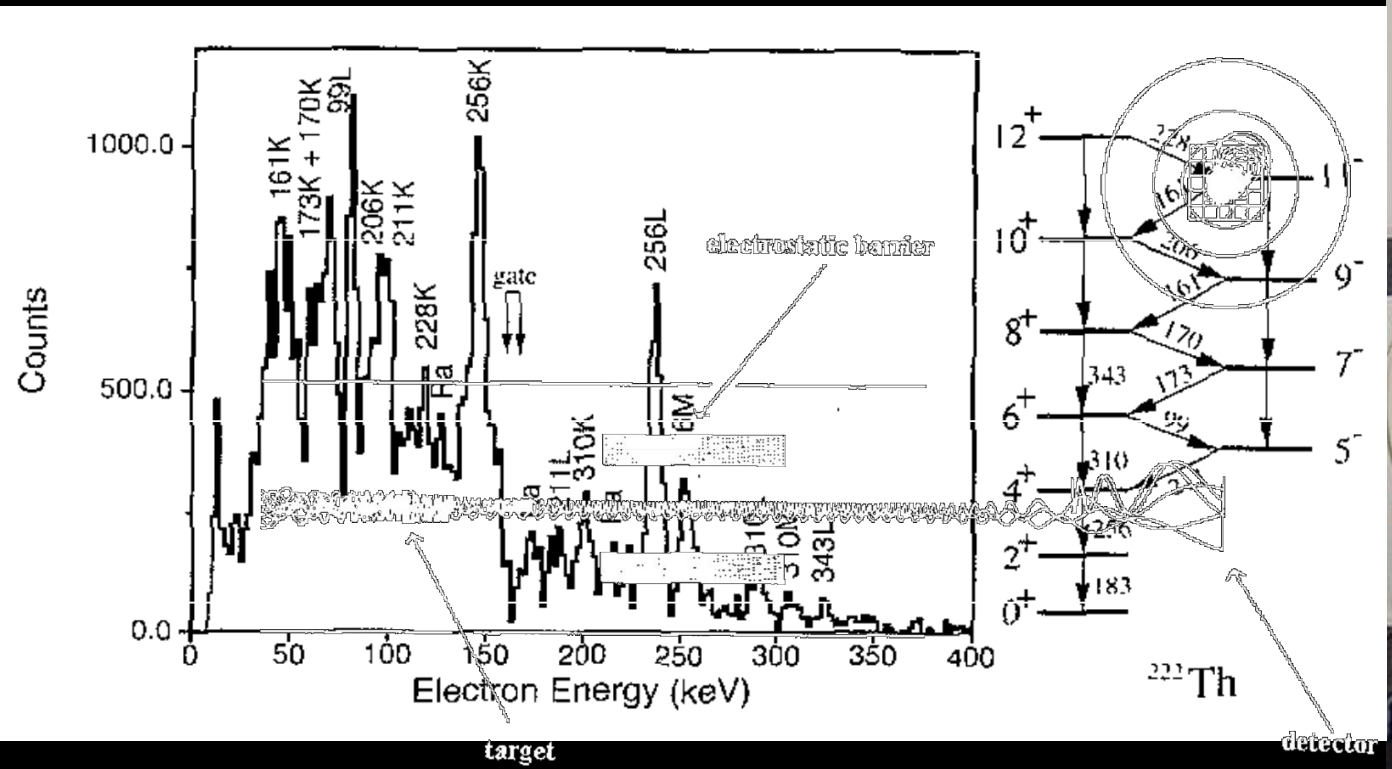
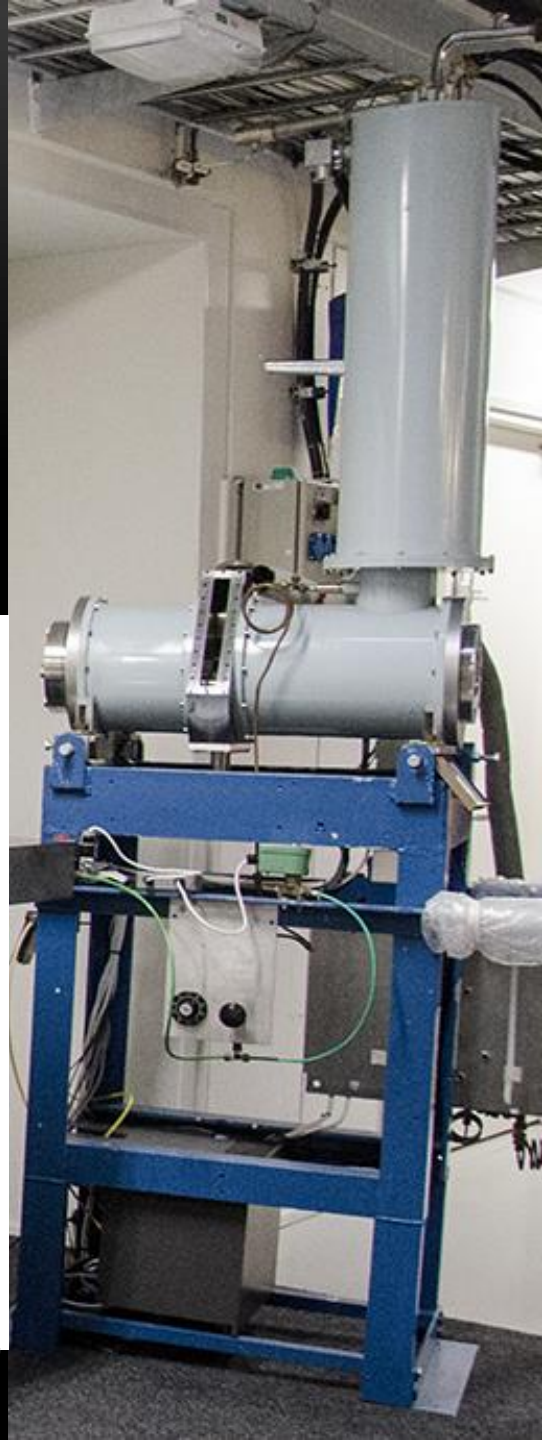
SACRED – first incarnation

$^{208}Pb(^{18}0,4n)^{222}Th$ – 1% channel

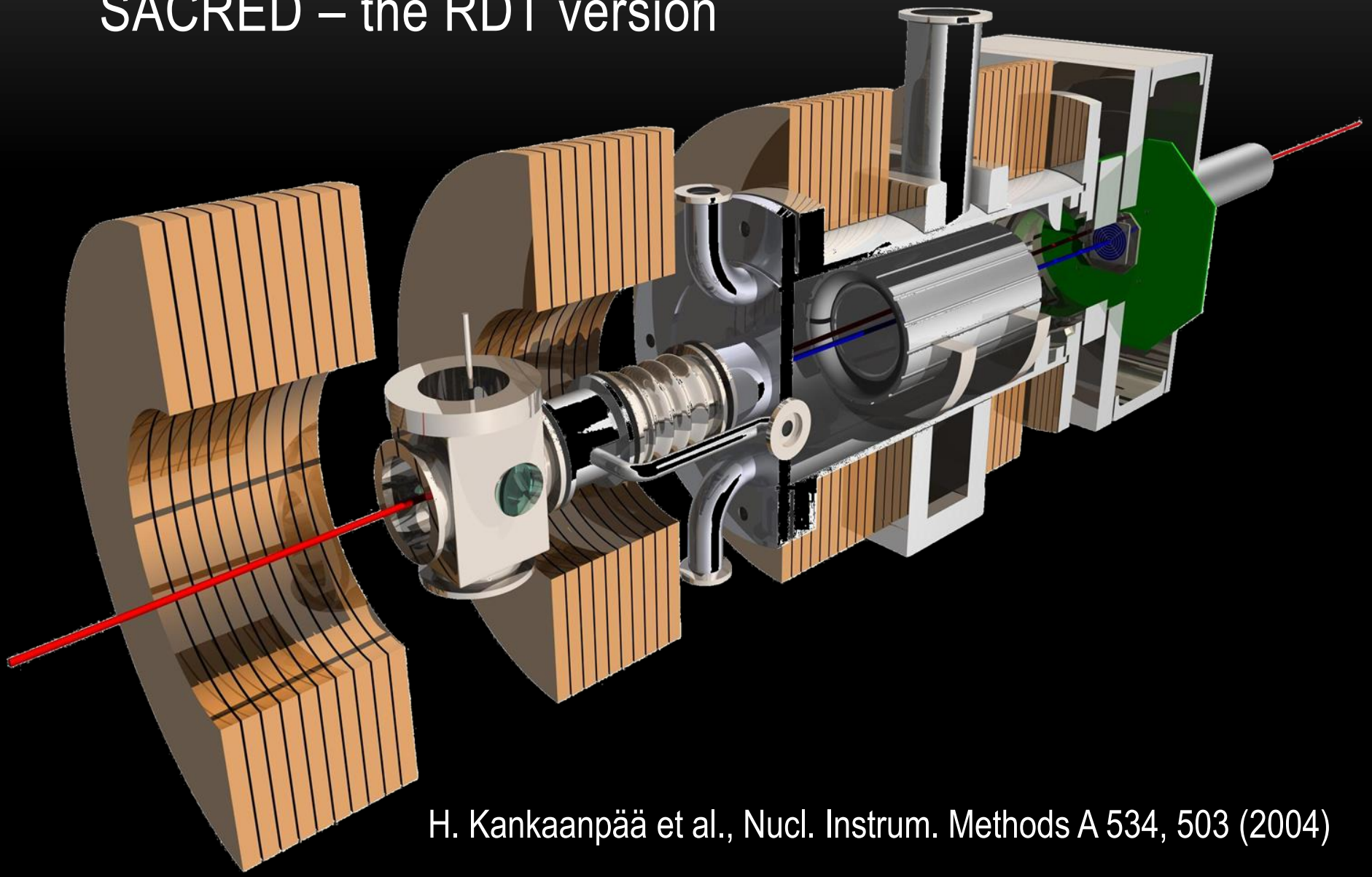
E_{beam} = 95 MeV





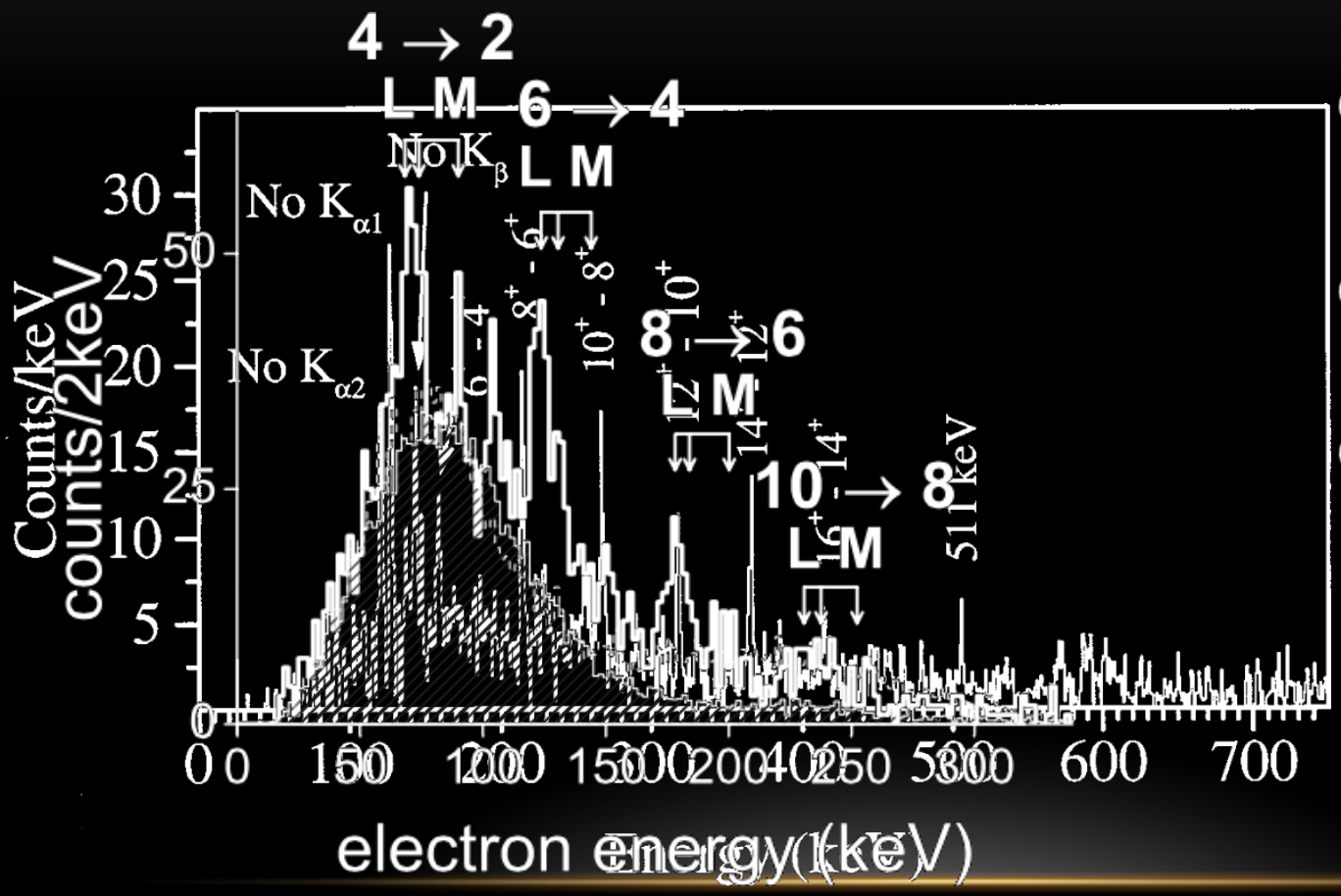
P. A. Butler et al., Nucl. Instrum. Methods A 381, 433 (1996)

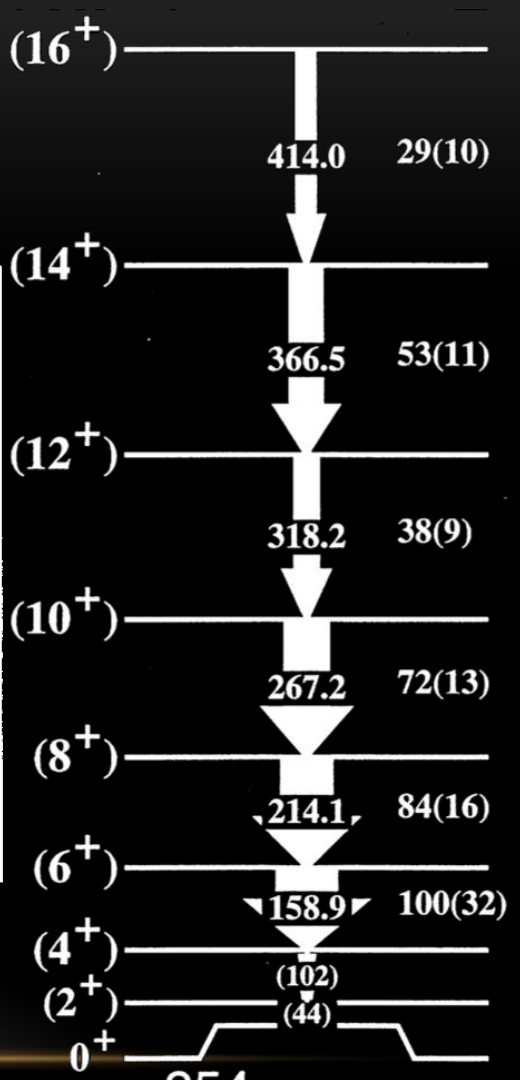
SACRED – the RDT version



H. Kankaanpää et al., Nucl. Instrum. Methods A 534, 503 (2004)

^{254}No – prompt γ-ray energy spectrum





M. Leino *et al*., Eur. Phys. J. A 6, 63–69 (1999)

P.A. Butler *et al*., Phys. Rev. Lett. **89**, 202501 (2002)

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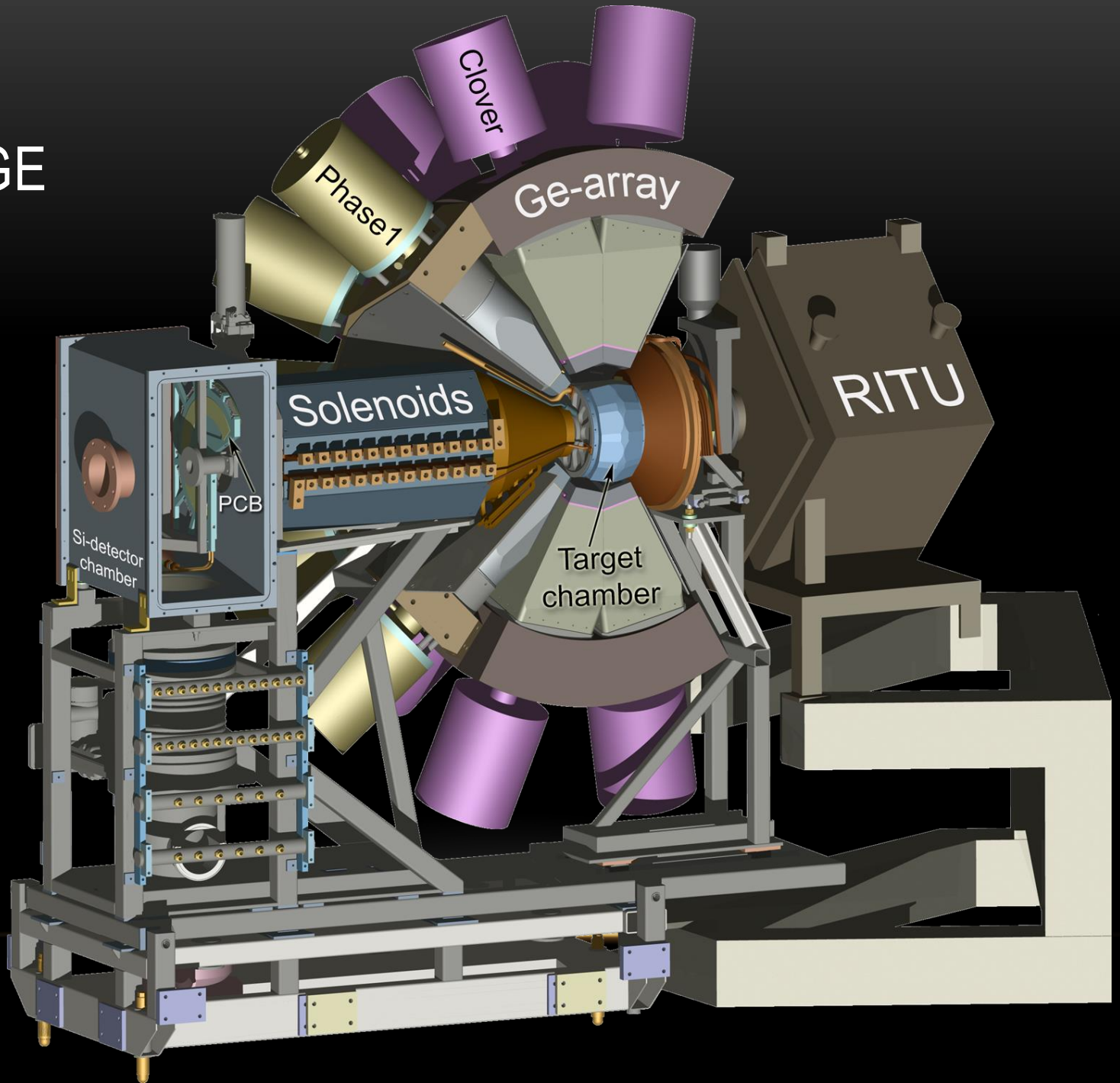
- ✓ SPEDE – electron spectroscopy with RIBs
- ✓ Backmatter

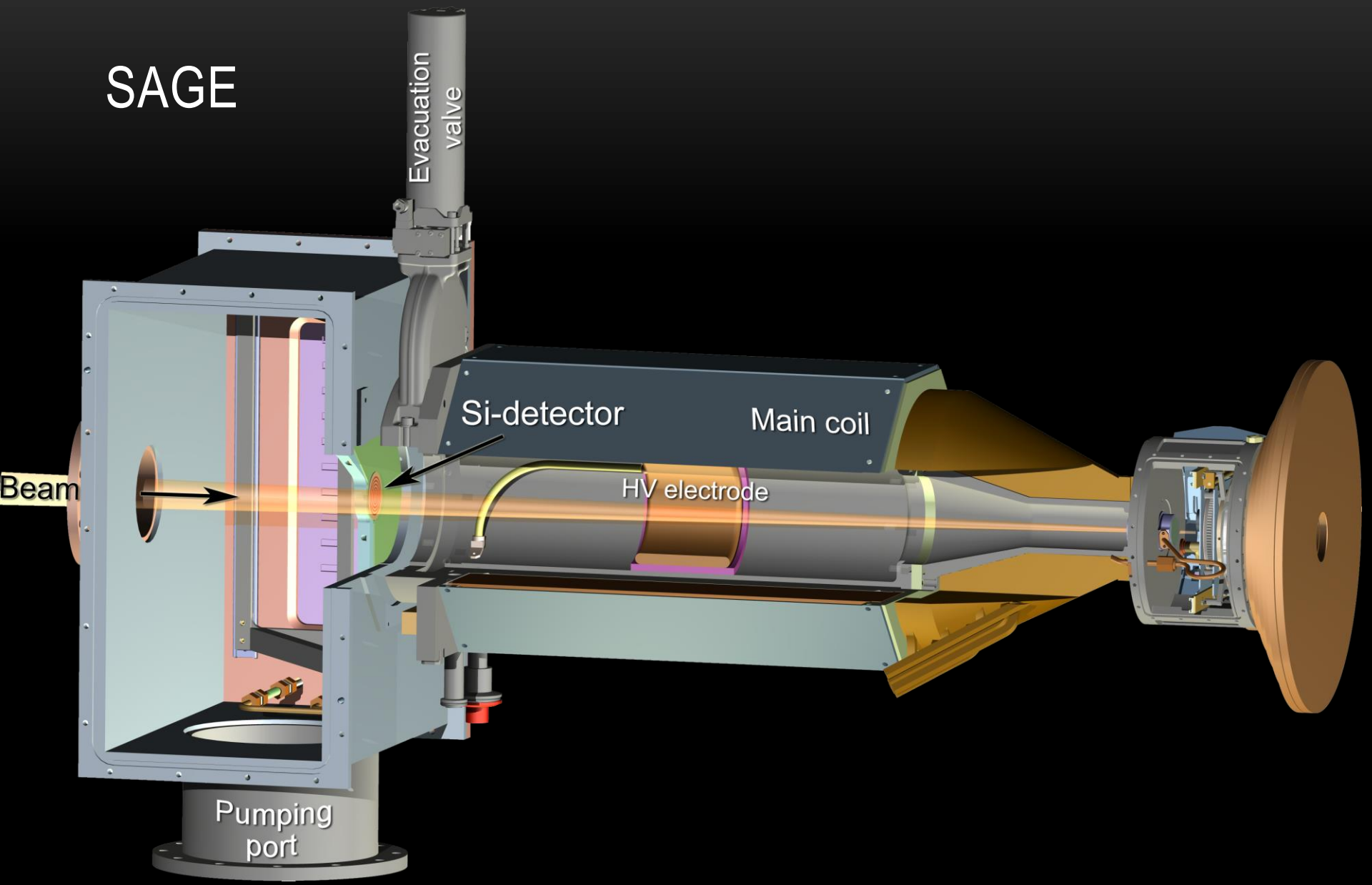
SAGE

J. Pakarinen, P. Papadakis, J. Sorri, R.-D. Herzberg *el al.*, EPJ A 50, 53 (2014)

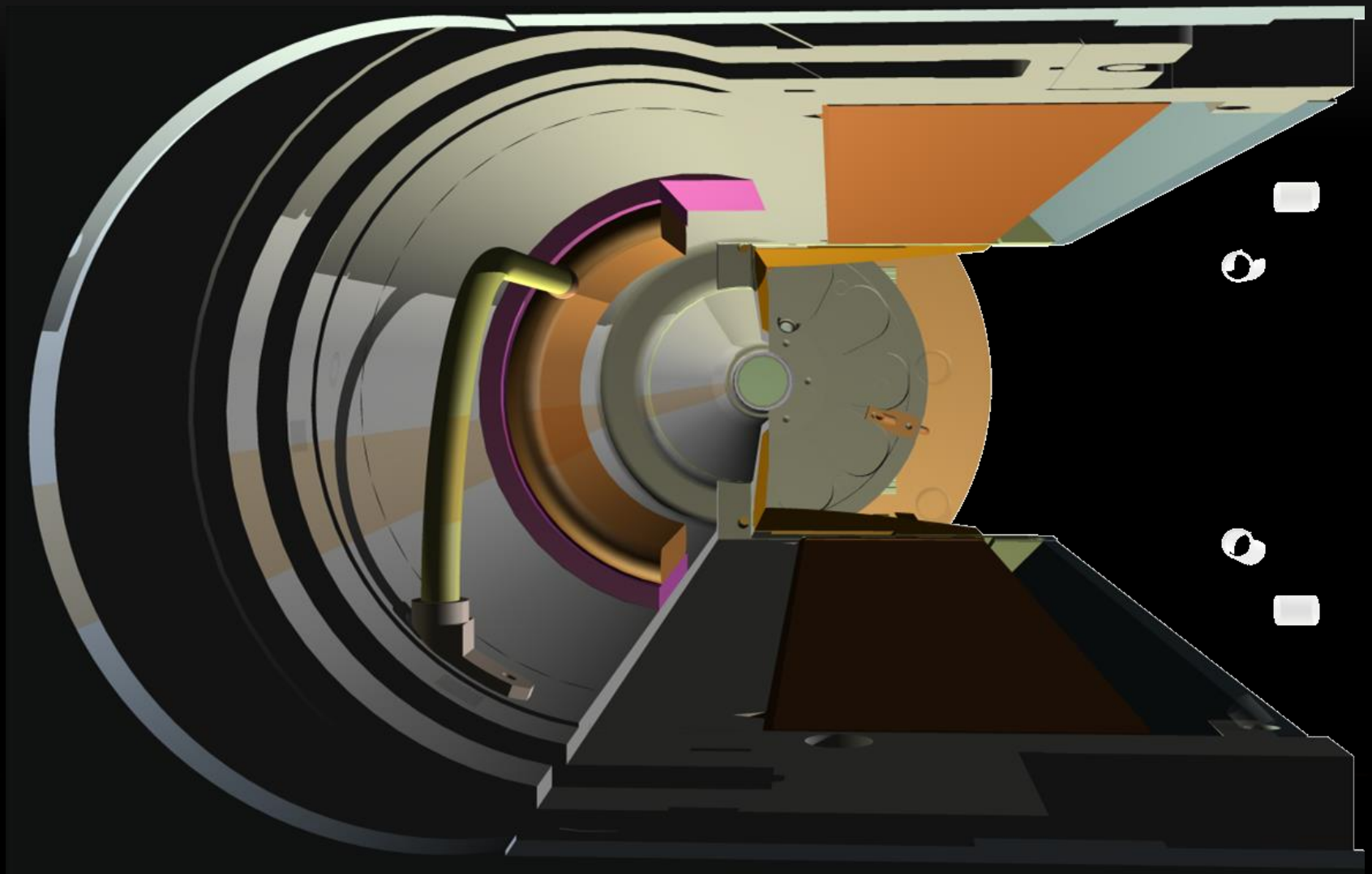
SAGE


Clover
Phase1
Ge-array
RITU
Solenoids
PCB
Si-detector chamber
Target chamber

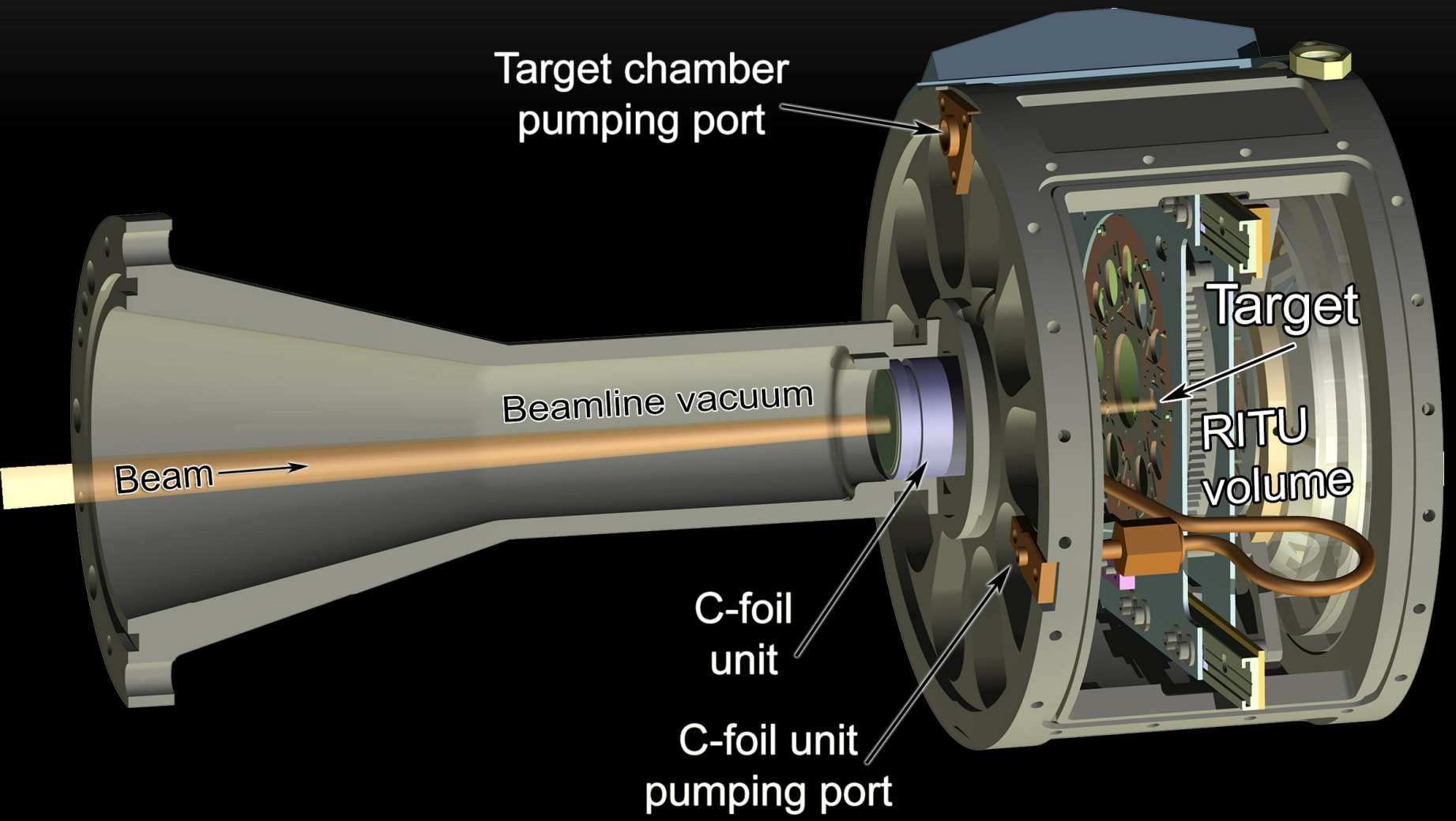
SAGE

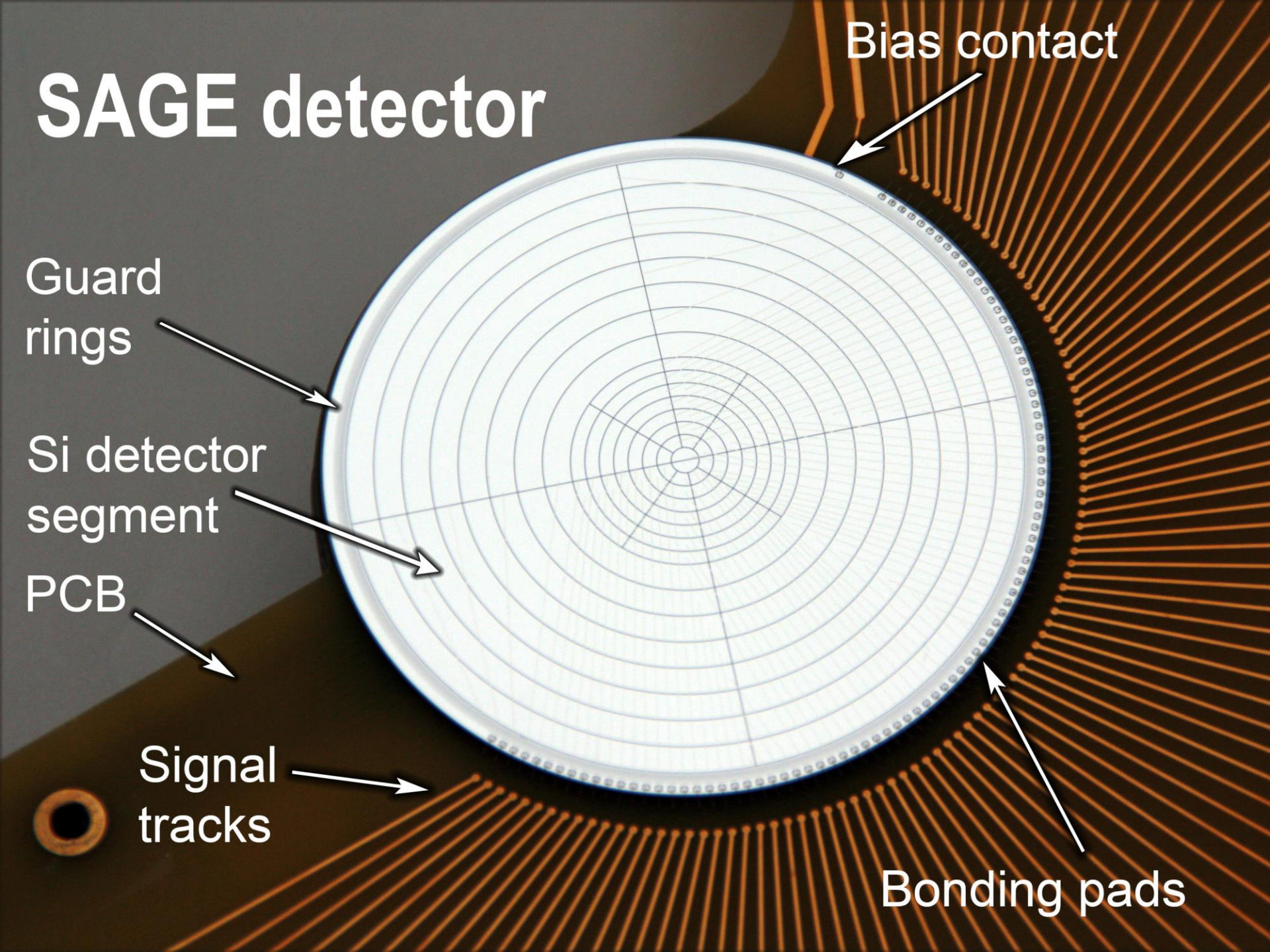

Evacuation valve
Si-detector
Main coil
Beam
HV electrode
Pumping port

SAGE entrance as seen by a beam particle

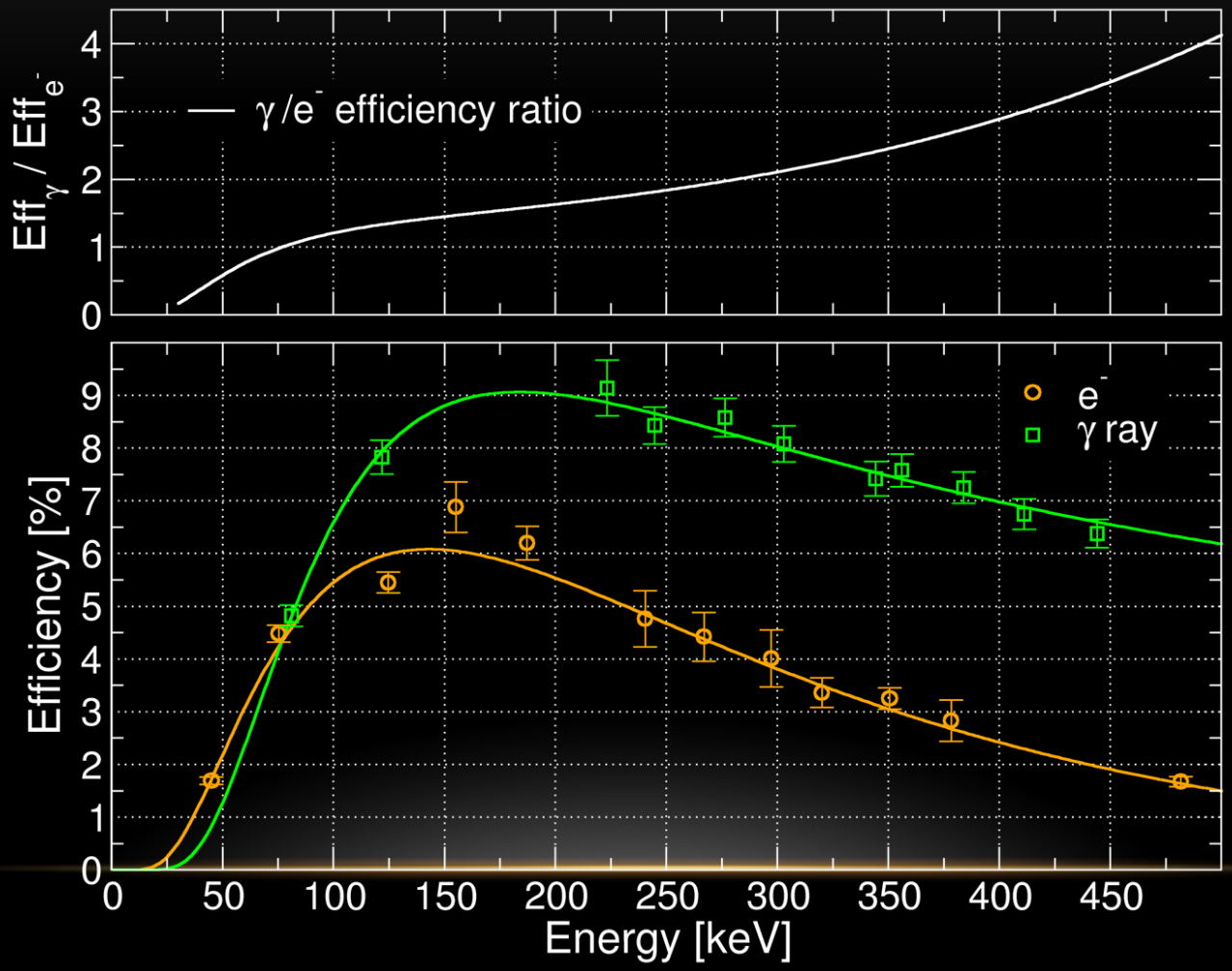


SAGE

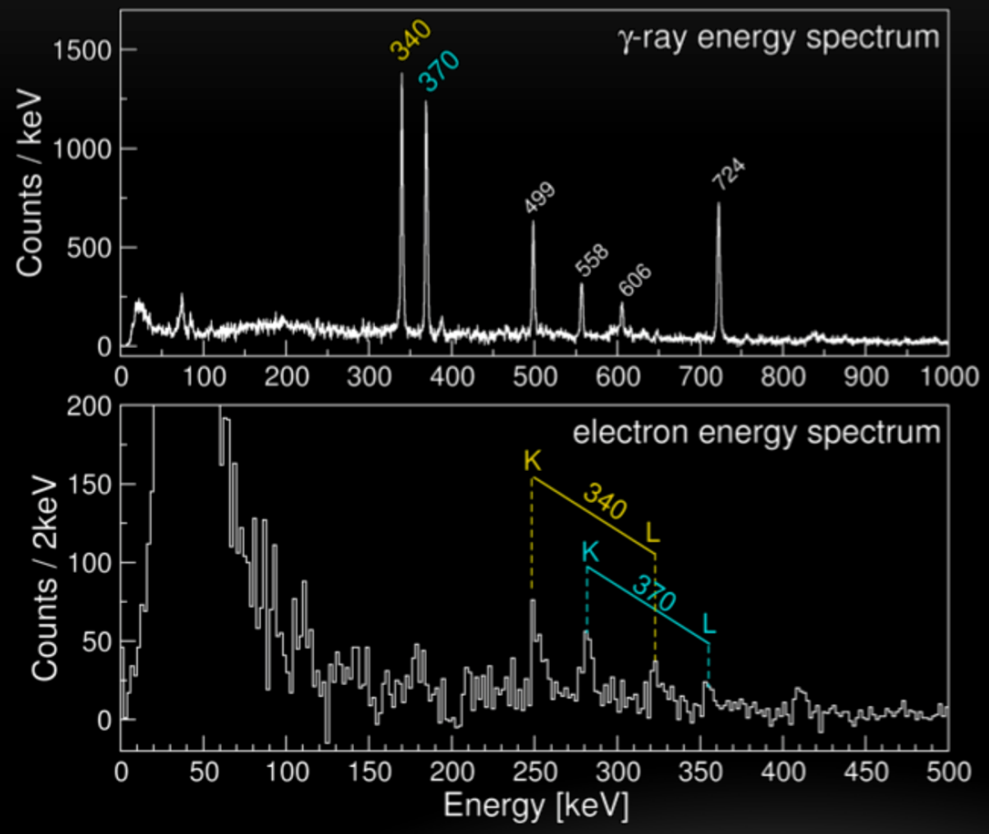

Target chamber
pumping port
Target
Beamline vacuum
RITU
volume
Beam
C-foil
unit
C-foil unit
pumping port

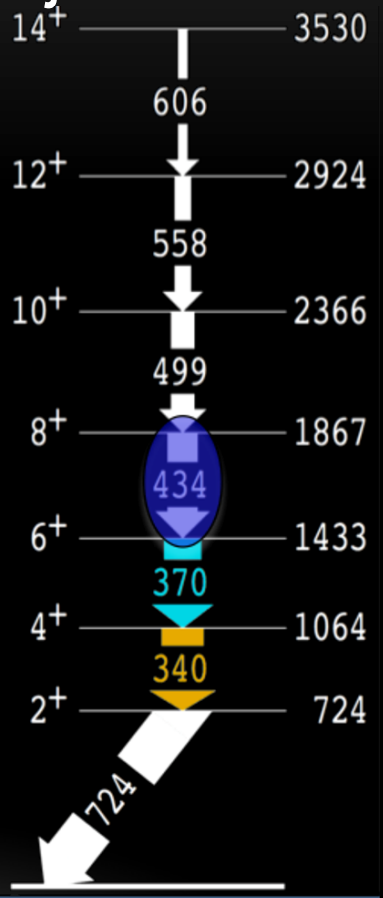

SAGE detector
Bias contact
Guard rings
Si detector segment
PCB
Signal tracks
Bonding pads

SAGE efficiency



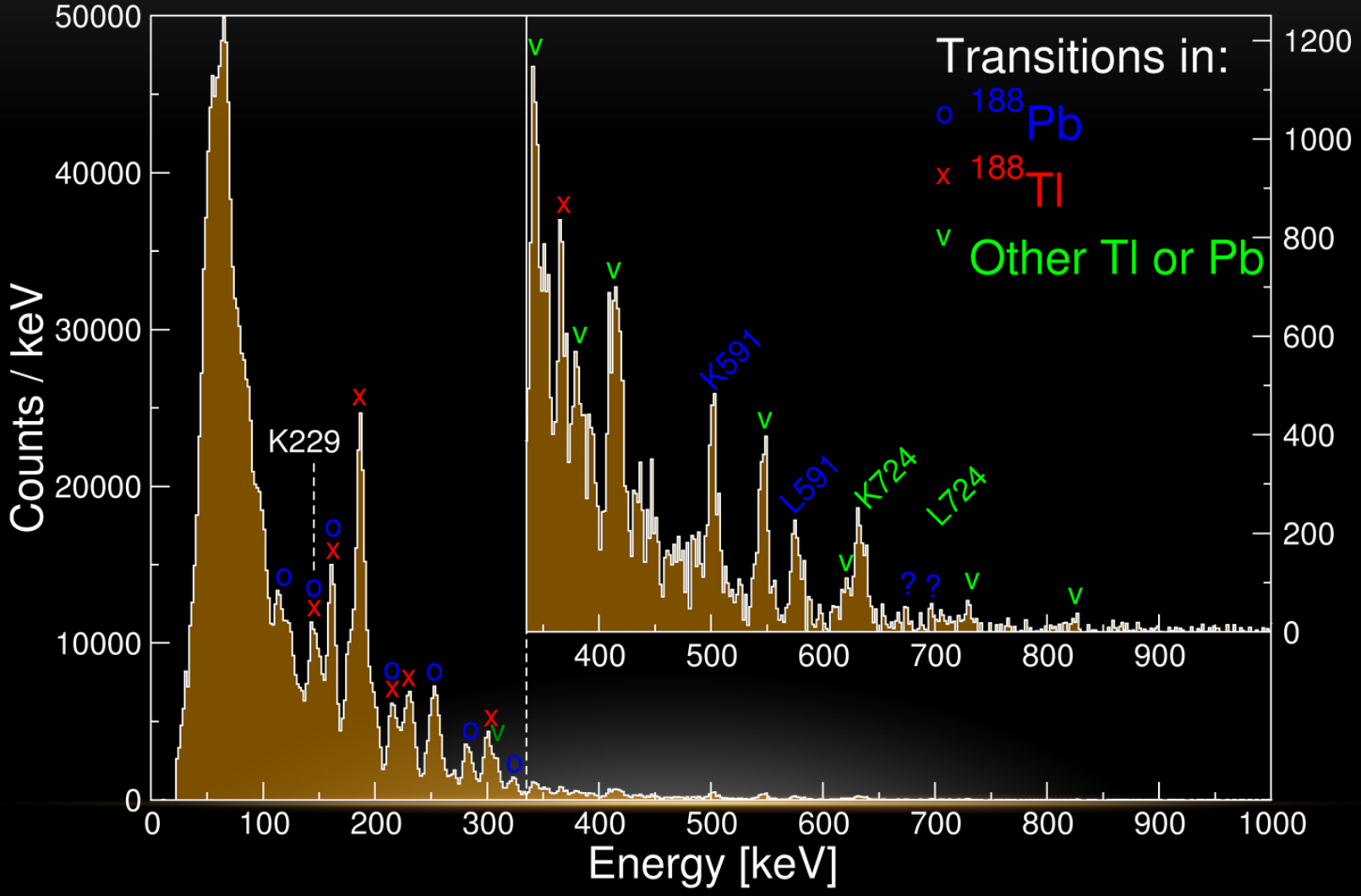
^{188}Pb – RDT electron and γ-ray projections





Transition energy	α_{K340}	α_{L340}	α_{K370}	α_{L370}
M1 (BrIcc)	0.248(4)	0.0422(6)	0.198(3)	0.0336(5)
E2 (BrIcc)	0.0486(7)	0.0238(4)	0.0401(6)	0.0176(3)
SAGE	0.044(4)	0.026(4)	0.042(5)	0.021(4)

Recoil gated electron singles in the ^{188}Pb experiment



SAGE experiments

	135 total Days	Notes
Simultaneous conversion-electron and gamma-ray spectroscopy using SAGE; An in-beam study of ^{253}No	10	Paper in preparation Thesis
Exploring shape co-existence in ^{202,204}Rn	7	Analysis on-going
Shape co-existence in $^{182\text{-}188}$Hg	7	PRC 83, 037303 (2011)
Exploring nuclear shapes in the transitional region of N~90: Coulomb excitation of ^{152,154}Sm to study E0 transitions with SAGE	4	PLB 732, 161 (2014) Thesis
Probing E0 transitions in ^{188}Pb using the SAGE spectrometer	9	Analysis on-going
Complete Spectroscopy of the Transfermium Nucleus ^{255}Lr	30	Paper in preparation Thesis
Spectroscopy of the odd-proton ^{249,251}Md	12	Analysis on-going
Probing E0 transitions in ^{186}Pb using the SAGE spectrometer	10	Analysis on-going
Study of high-K states in ^{254}No using the SAGE spectrometer	11	Analysis finished
Simultaneous in-beam gamma-ray conversion electron spectroscopy of ^{194}Po employing the SAGE spectrometer	7	Analysis on-going
Spectroscopy of the odd-proton nucleus ^{249}Md and feasibility study for ^{243}Es	7	No electrons
Characterization of a new structure in octupole-deformed ^{222}Th using gamma-ray and conversion-electron spectroscopy	7	Analysis on-going
Shape Coexistence in Odd-Au Isotopes: In-beam Gamma-ray and Conversion Electron Coincidence Spectroscopy	14	Analysis on-going

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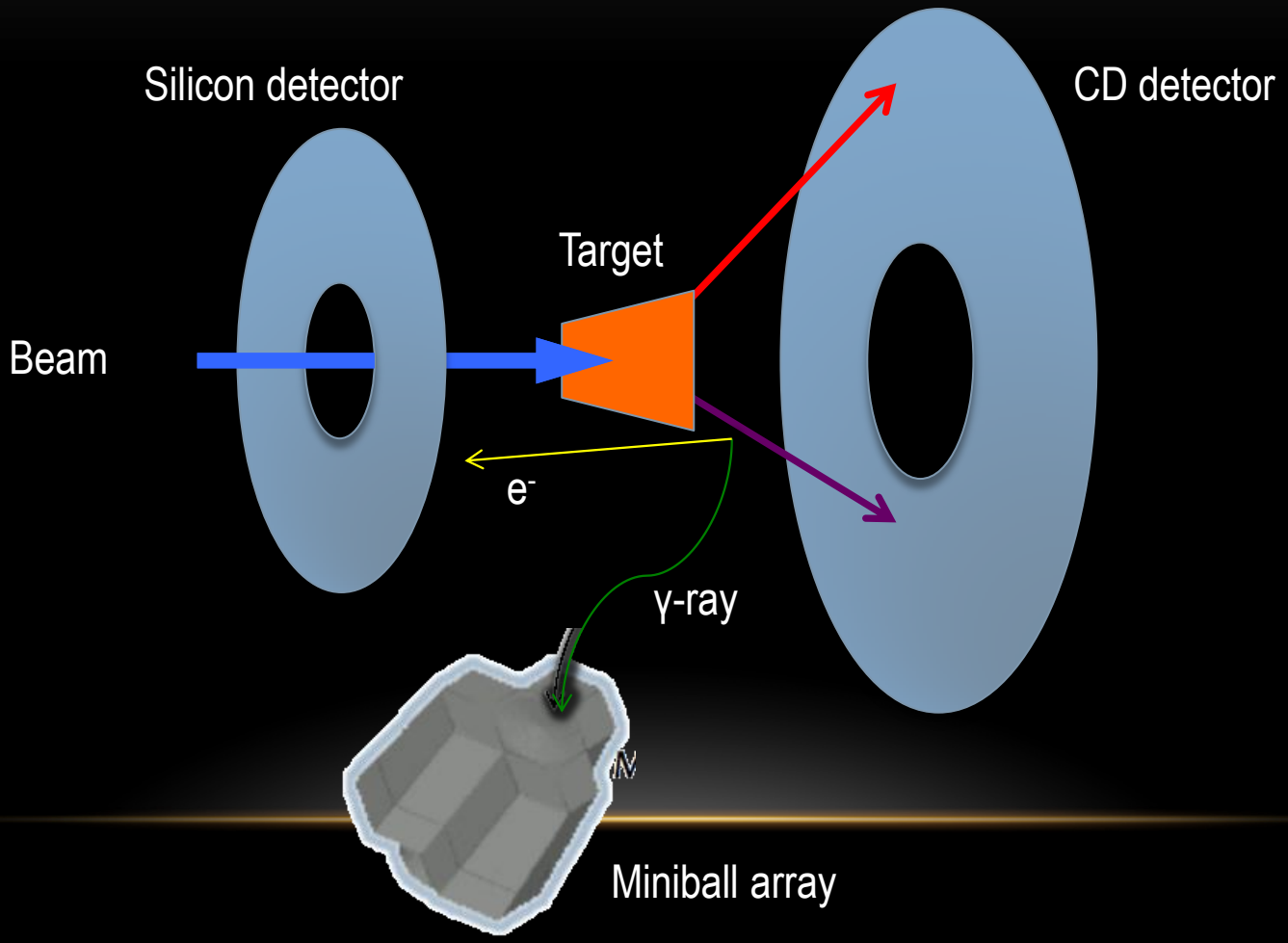
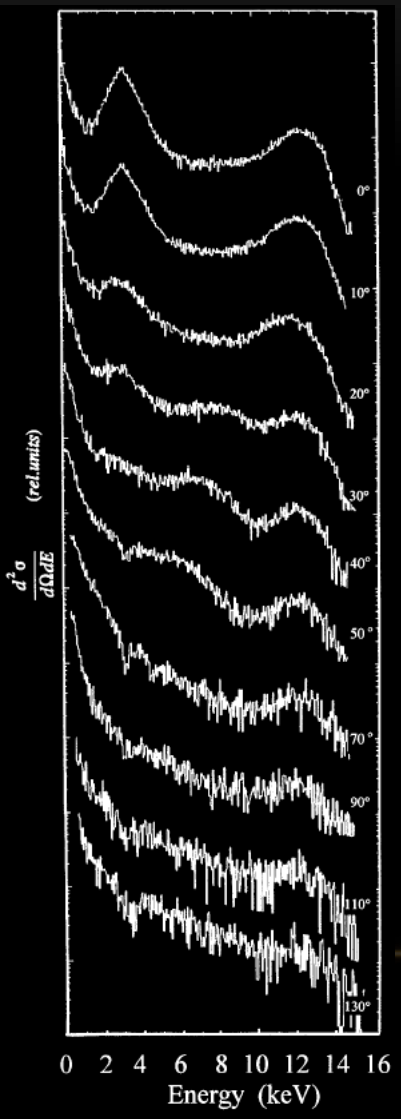
SPEDE – γe^- spectroscopy with radioactive beams

- Completely new concept
- Essential information for analysis of Coulomb excitation data
- To be combined with MINIBALL at HIE-ISOLDE, CERN

SPEDE concept



δ-electron challenge

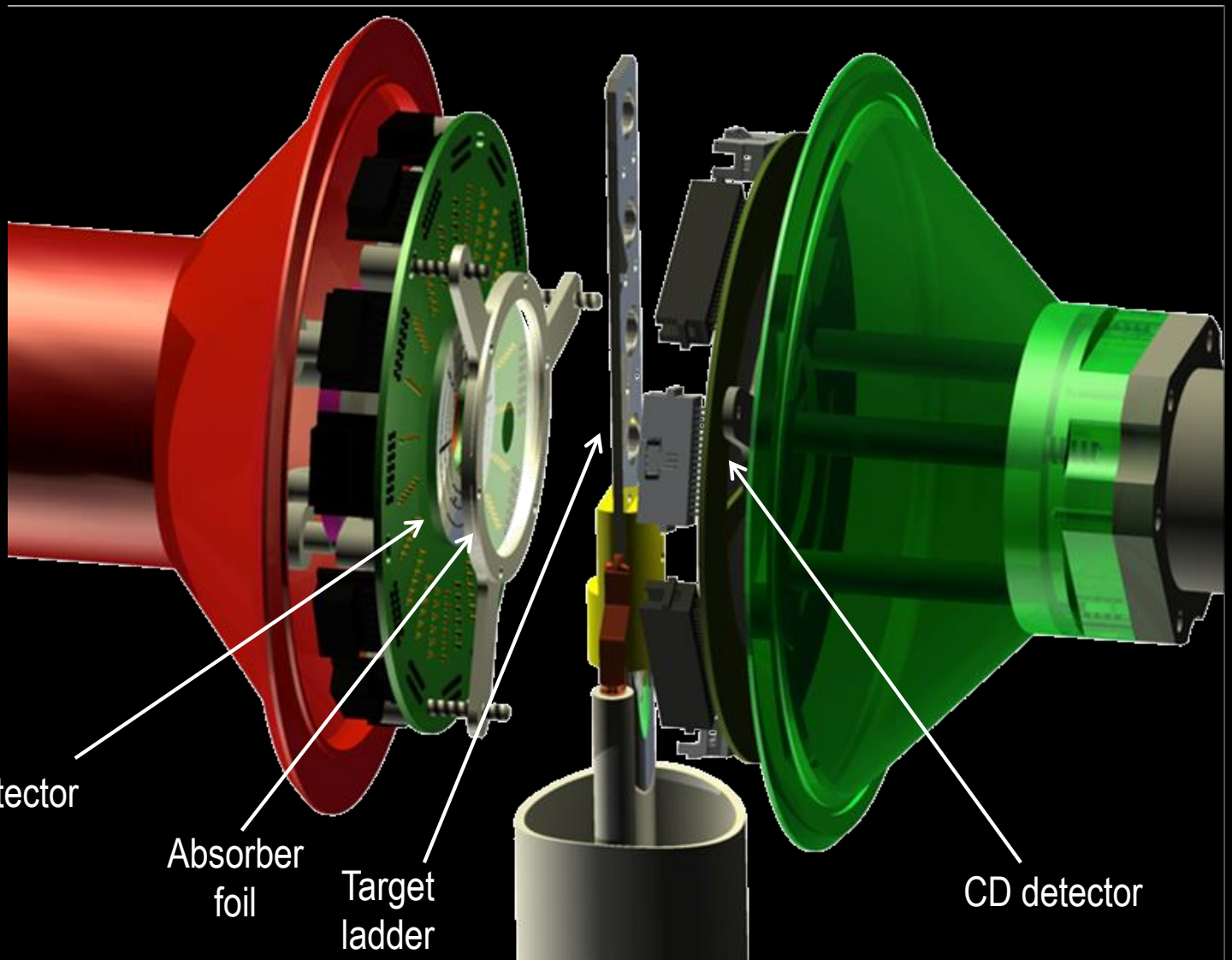


- δ electrons produced in beam and target collisions
- Detector at backwards angle
- HV on target
- Absorber foil between target and detector
- RIBs - lower beam intensity

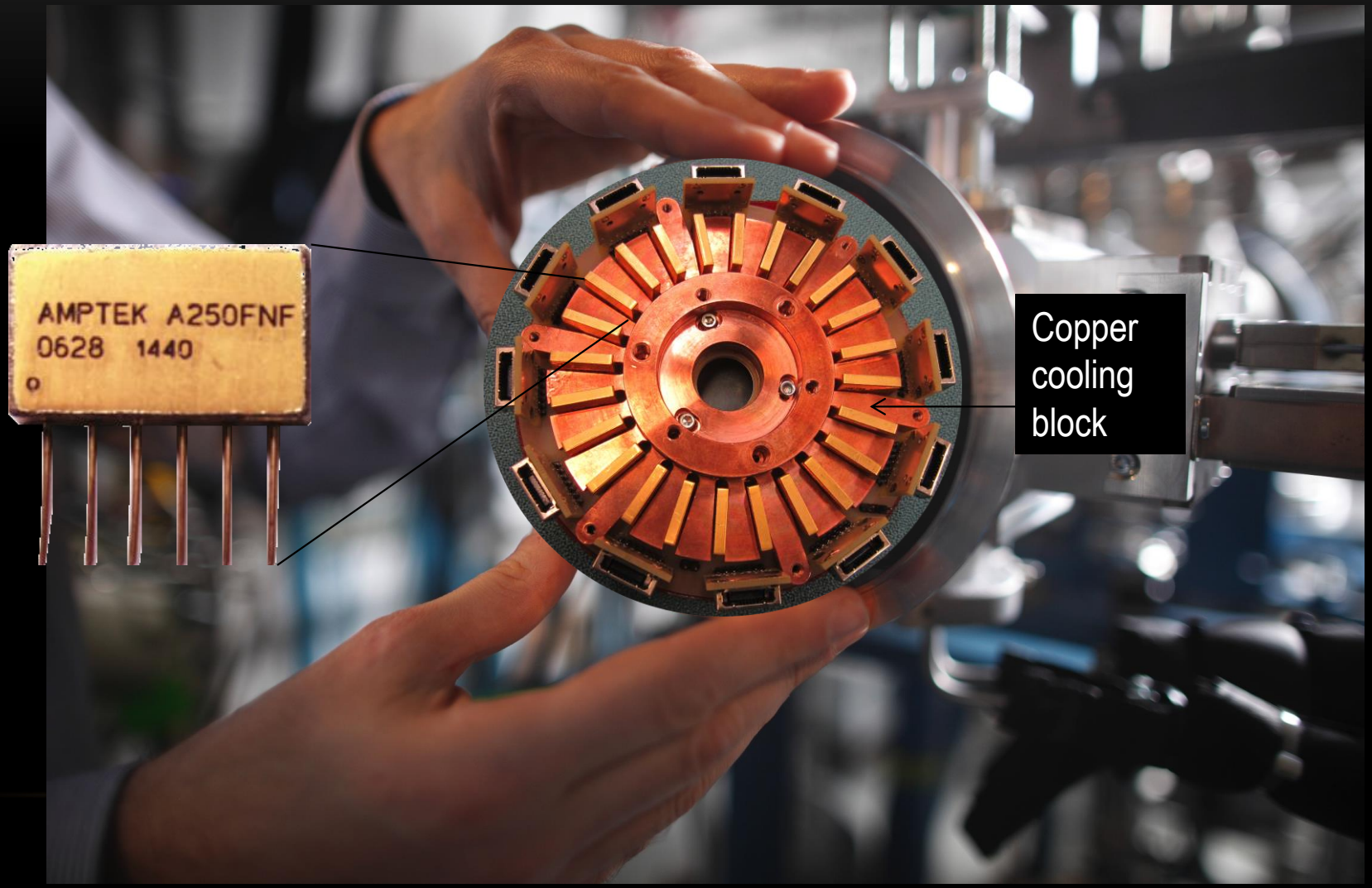
- β-decay background supressed through coincidences with scattered particles

U. Bechthold *et al.*, Phys. Rev. Lett **79**, 2034 (1997)

From concept to design



Si detector and front-end electronics

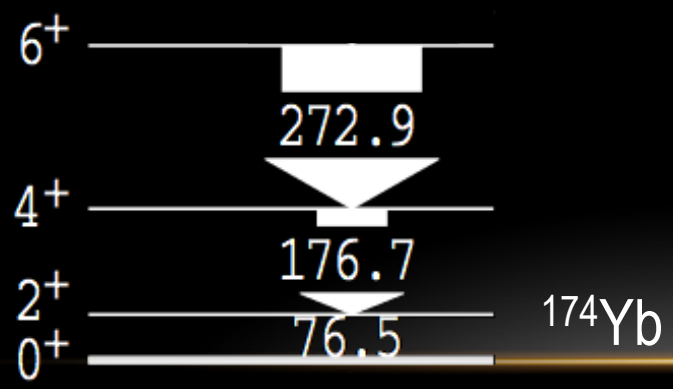


24 segments, 500μm thick.

Cooled to -15C

^{174}Yb Coulex test

- ^{40}Ar on ^{174}Yb
- E_{beam} 4.1MeV/u
- I_{beam} ~40E6pps
- Aluminised Mylar foil
- Tests with no high-voltage and 5kV on target

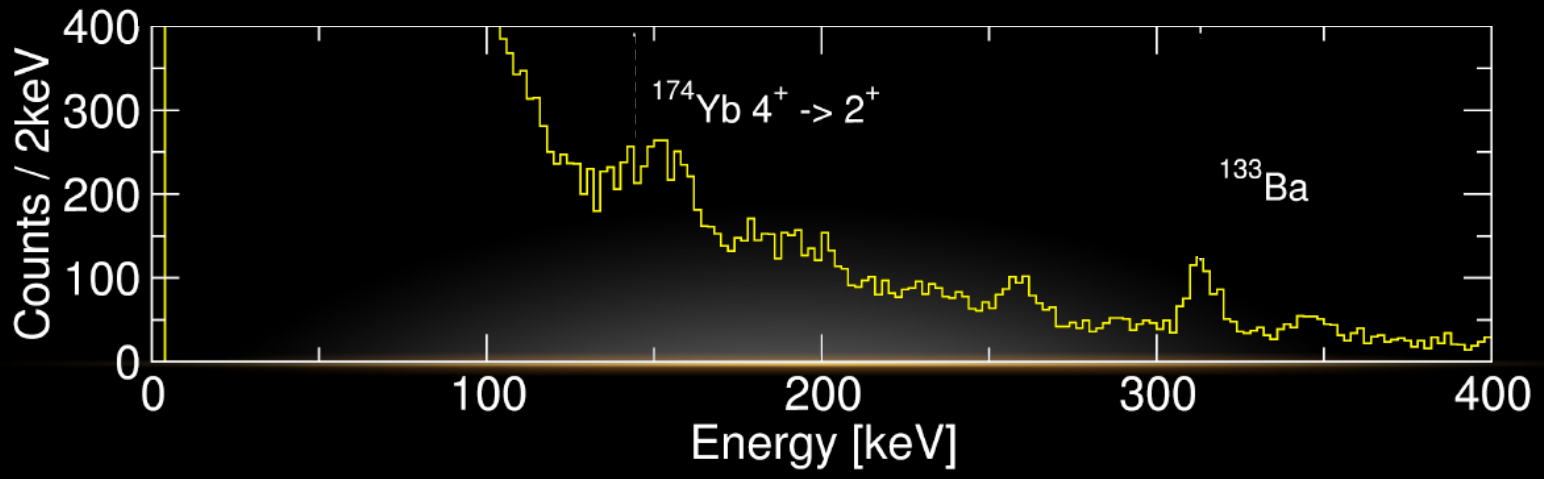


Conversion electrons for the 176.7keV transition:

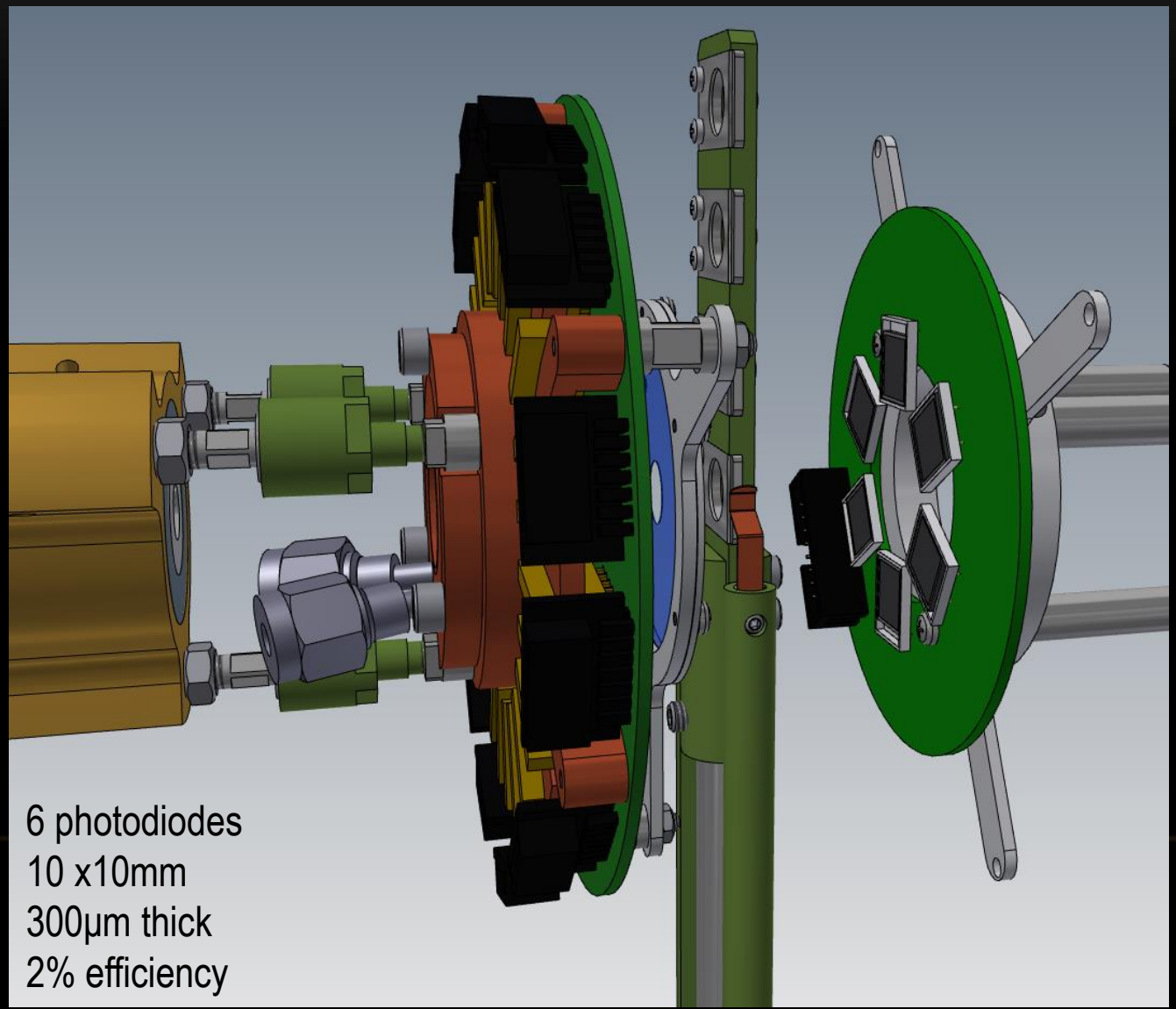
K: 115.3keV

L: 166.1keV

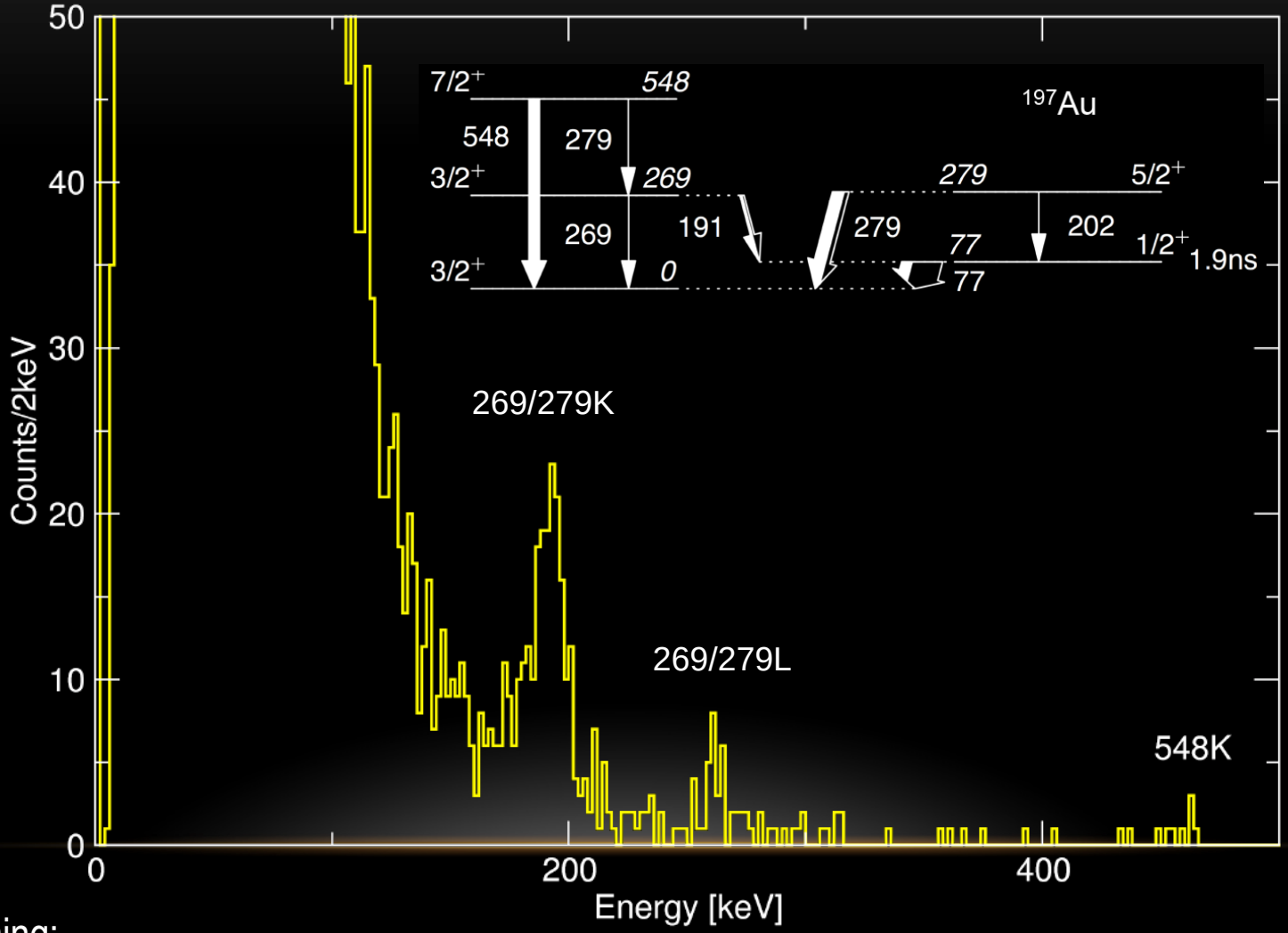
High-voltage on/off



Particle detector array



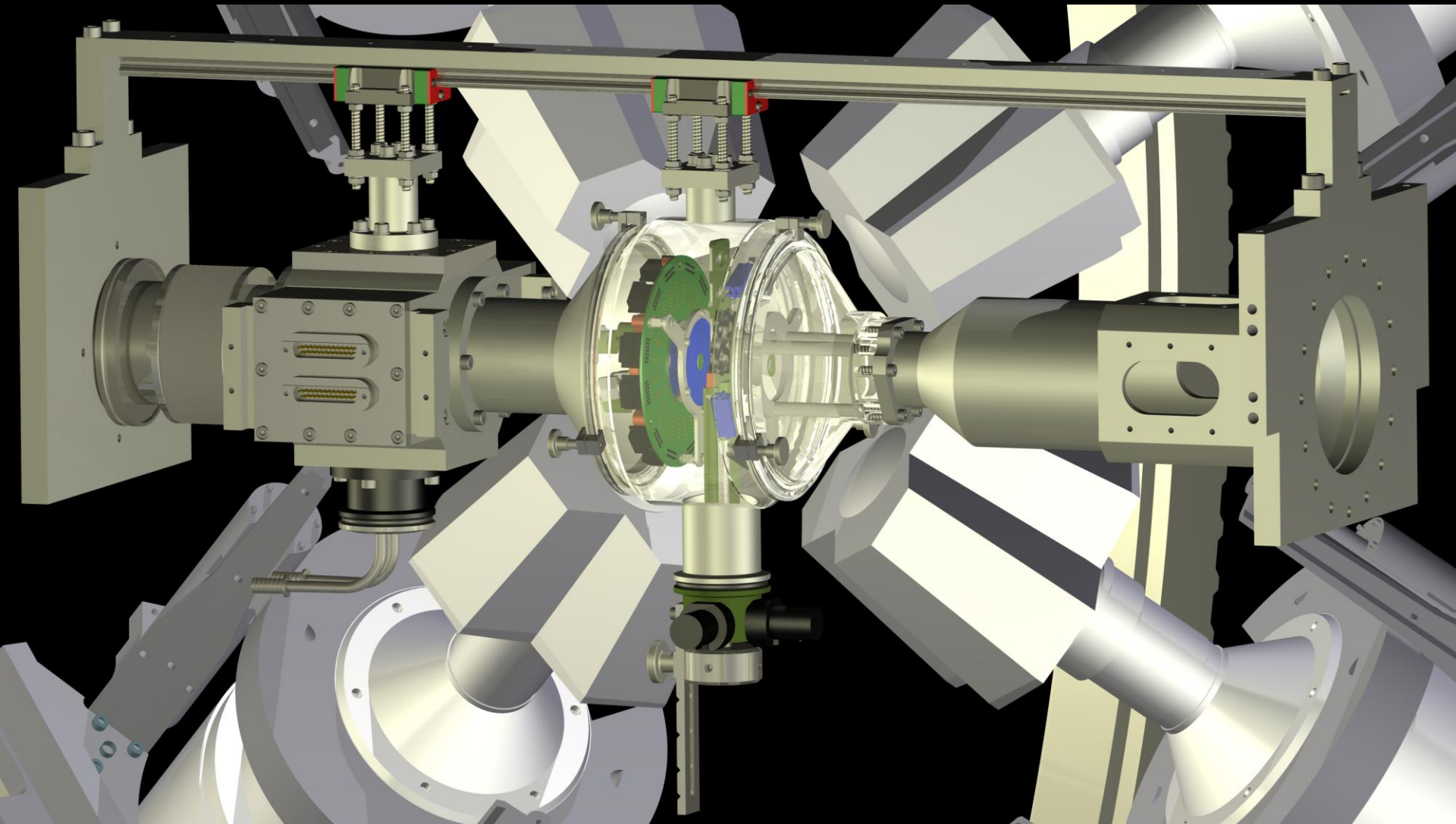
Particle gated electron singles



Commissioning:

^{197}Au on ^{197}Au, I_{beam} = 4.1 MeV/u

SPEDE at MINIBALL

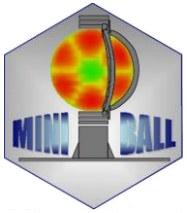


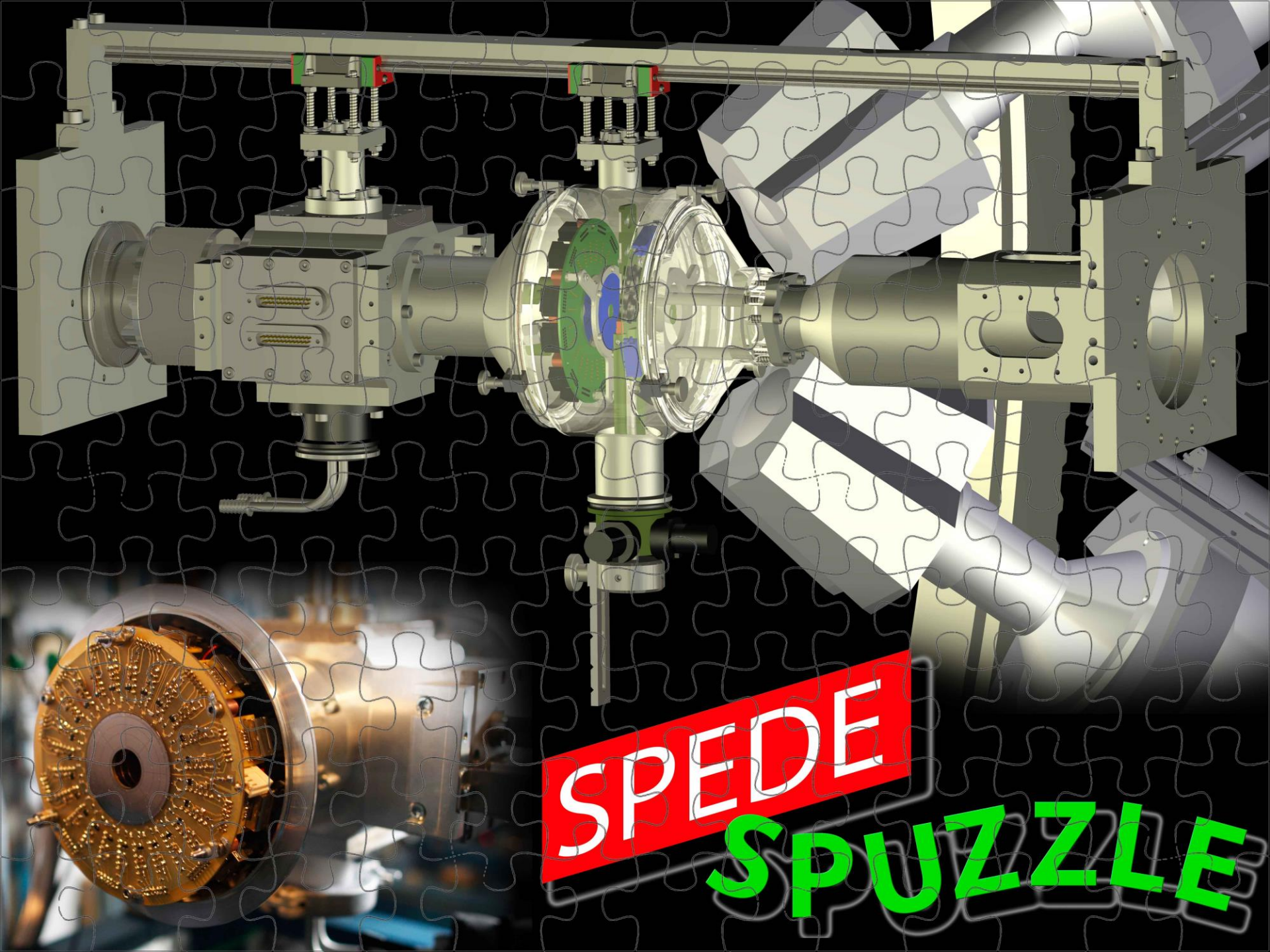
Future prospects

- Number of arrays developed
  (also mini-Oranges, SPICE, ULESE…)
- Experimental programme will continue
- Experiments with radioactive beams
  (SPICE, SPEDE)
- Recoil shadow method
  (lifetimes)

- Lenghty beam times

Acknowledgements




SPEDE
SPUZZLE