Outline: From Ge(Li) to Germanium detector array

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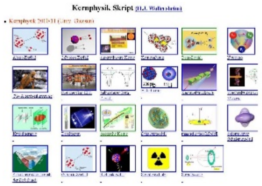
web-page: https://web-docs.gsi.de/~wolle/ and click on 

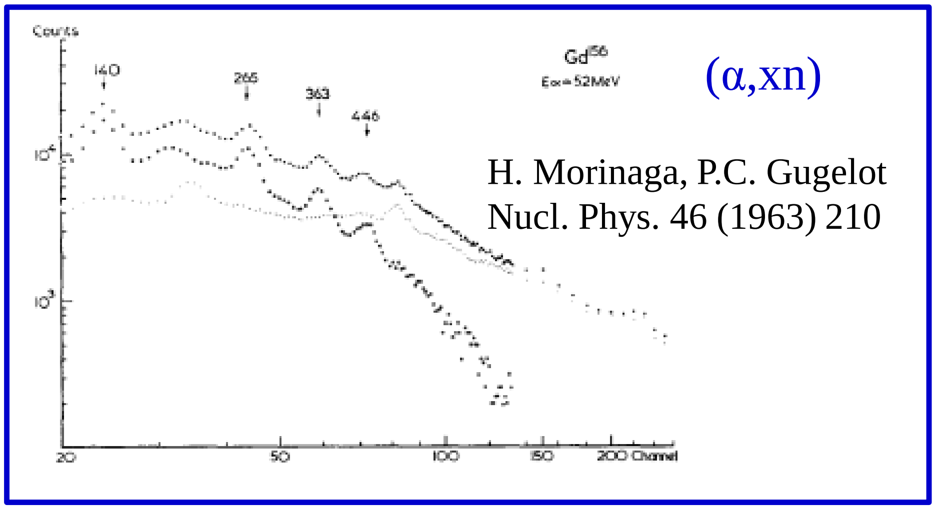
1. 1960ties and 70ties: Ge(Li) detectors
2. 1980ties: national HPGe detector arrays OSIRIS, HERA, TESSA
3. 1990ties: EUROBALL and GAMMASPHERE
4. 2000ties: position-sensitive Ge-arrays MINIBALL, EXOGAM, SEGA
5. under development: 4π γ-ray tracking arrays AGATA, GRETA

Alkali Halide Scintillation Counters

ROBERT HOFSTADTER
Princeton University, Princeton, New Jersey
May 20, 1948

Phys. Rev. 74 (1948) 100

Invention of the NaI(Tl) detector 1948



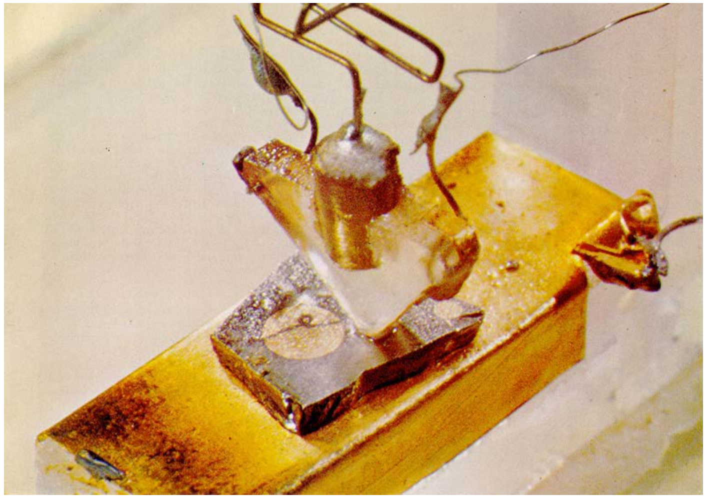
Robert Hofstadter, after hearing about Callmann's work, started testing Tl activated alkali halide crystals. Na(Tl) was found to have the largest output

Germanium transistor

1947

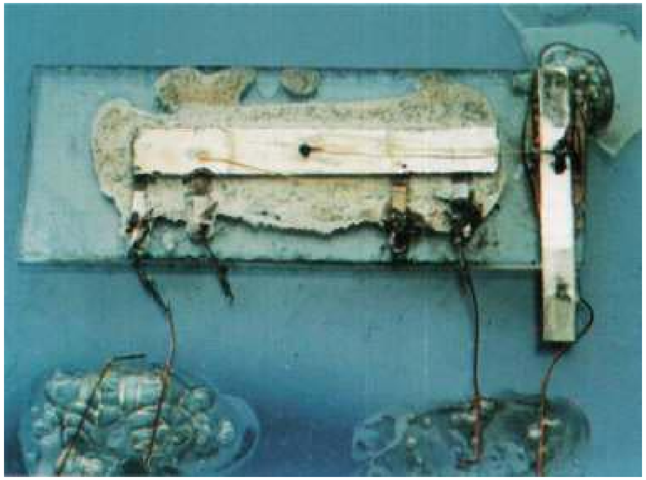
by
William Shockley,
John Bardeen and
Walter Brattain
(left to right)

Early semiconductor devices



first transistor (Bell 1947)

hybrid circuits (1960)



first integrated circuit (1959)

Fairchild IC (1962)

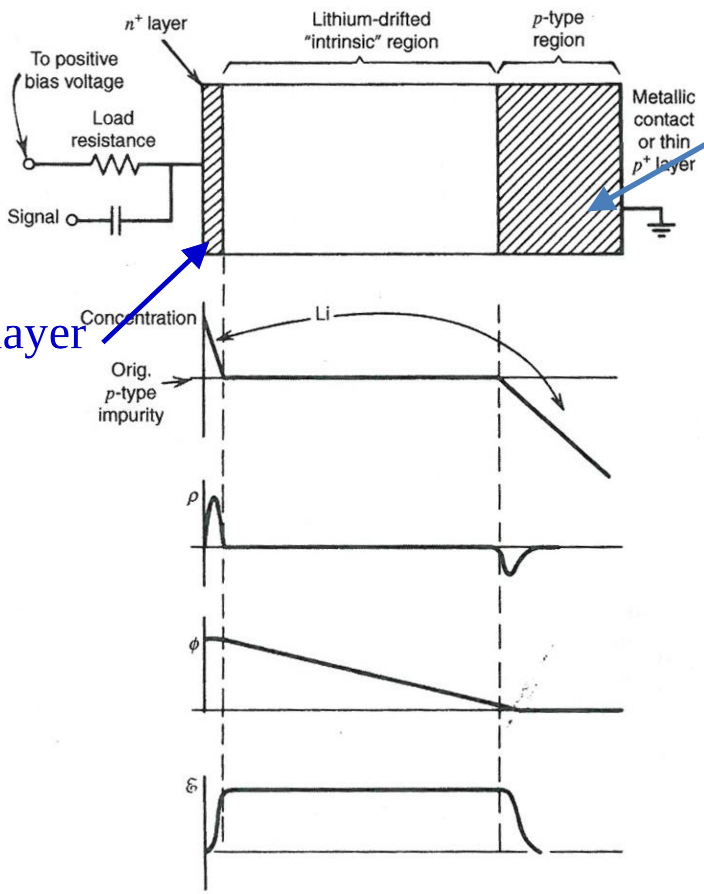
JOURNAL OF APPLIED PHYSICS VOLUME 31, NUMBER 2 FEBRUARY, 1960

Ion Drift in an *n-p* Junction*

E. M. Pell
General Electric Research Laboratory, Schenectady, New York

(Received August 19, 1959)

E. M. Pell 1960

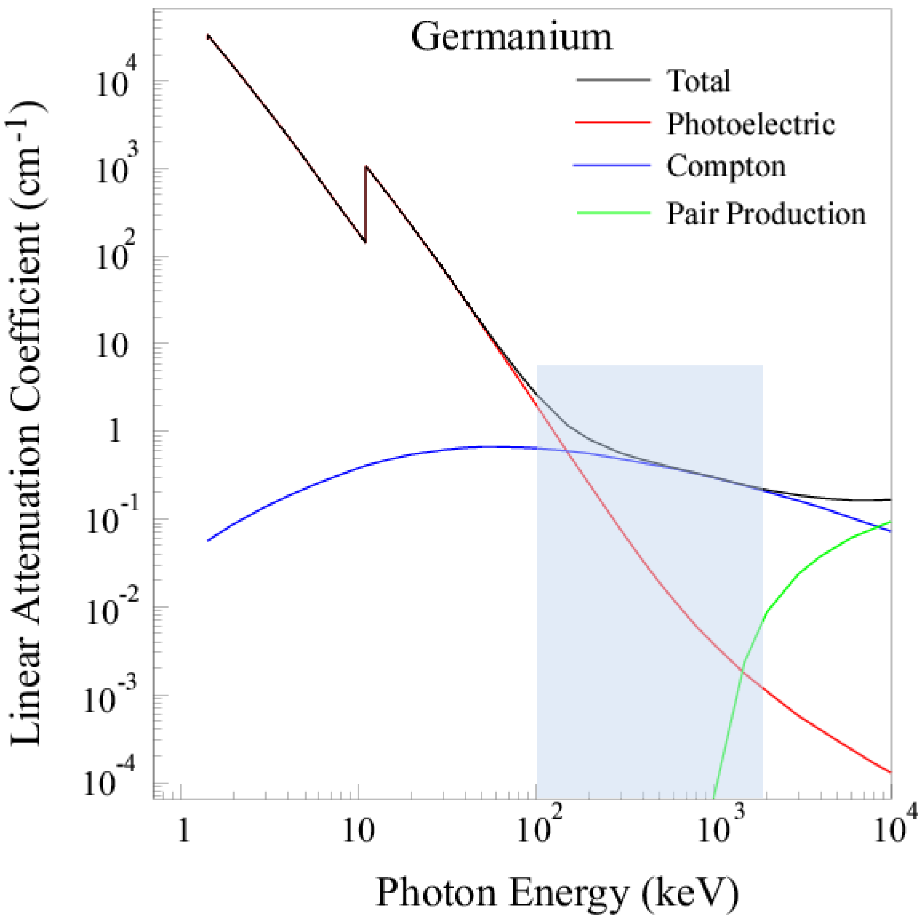


p-type bulk material layer

Li-drifted n^+ layer

Li-drift in p-type Si

Gamma-ray interaction cross section



100 keV – 2 MeV
is **typical γ-ray energy range in nuclear science.**
Compton scattering is dominant (in Ge)!

Photo effect: ~$Z^{4\text{-}5}$, $E_\gamma^{-3.5}$
Compton: ~Z, E_γ^{-1}
Pair: ~Z^2, increases with E_γ

First Ge(Li) detector: D.V. Freck and J. Wakefield

Nature 193, 669 (1962)

Milestone 1

Ge(Li) detector, active volume: 0.2 cm^3

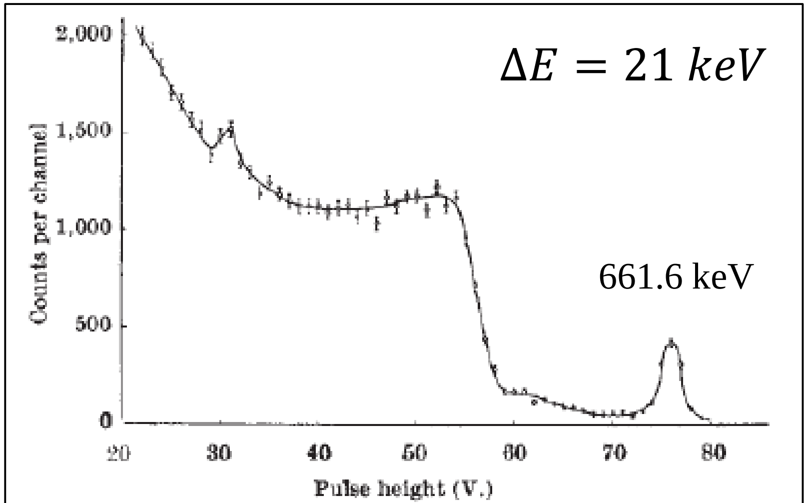


Fig. 1. Pulse-height spectrum from a p-i-n junction in germanium due to 663 keV. γ-rays from cæsium-137

NUCLEAR INSTRUMENTS AND METHODS 25 (1963) 185–187; © NORTH-HOLLAND PUBLISHING CO.

A HIGH RESOLUTION LITHIUM-DRIFT GERMANIUM GAMMA-RAY SPECTROMETER

A. J. TAVENDALE* and G. T. EWAN

Chalk River Nuclear Laboratories, Atomic Energy of Canada Limited

Received 14 October 1963

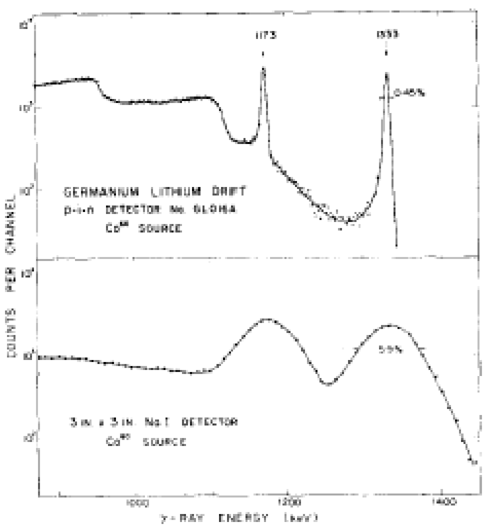


Fig. 1. High energy region of gamma-ray spectrum of Co^{60} observed with the lithium-drift germanium detector. The detector was 18 mm in diameter and had a depletion of 8 mm. It was operated at 77° K with a bias of 450 V across the detector. The intrinsic full energy peak efficiency was 0.2 %. The spectrum shown above was obtained in 10 min using a 20 μC Co^{60} source. For comparison we show the same region of the spectrum observed with a good 3" × 3" NaI scintillation spectrometer. This spectrometer had a resolution of 8.0 % on the 661 keV γ-ray in Ba^{137}.

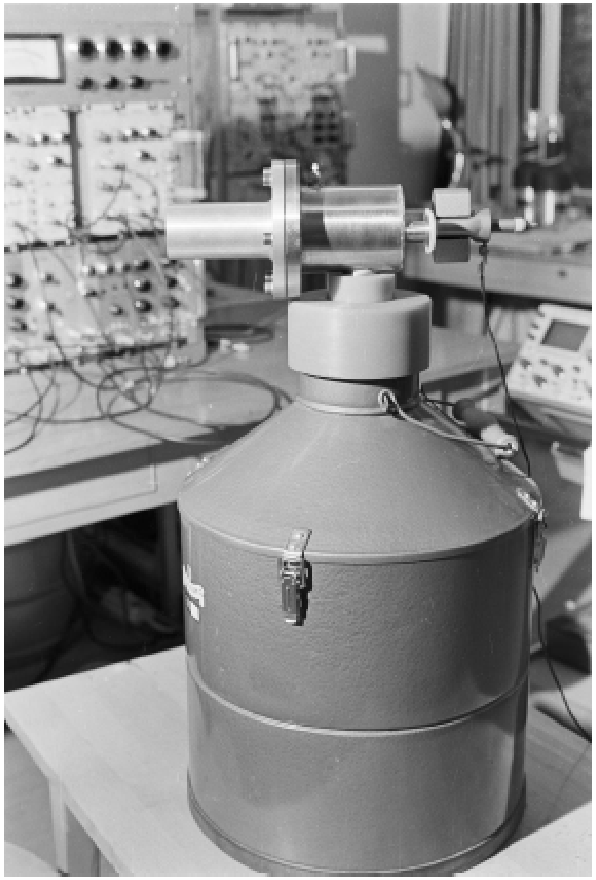
1963 Tavendale and Ewan (Chalk River)

Ge(Li) detector, planar: 2 cm^3

ΔE = 6 keV at 1.3 MeV

use of a cooled FET reduced input noise to 0.7 eV (1965)

Li-drift apparatus
at IKP Cologne



First coaxial detector 1968
ΔE = 3.5 keV at 1.3 MeV
5.5 cm^3

The "five-in-one" Compton polarimeter (1974)

two concentric coaxial Ge(Li) detectors, outer detector 4-fold segmented

energy resolution 3.5 – 5 keV at 1.3 MeV

Ge crystal: 65mm diam., 46mm length

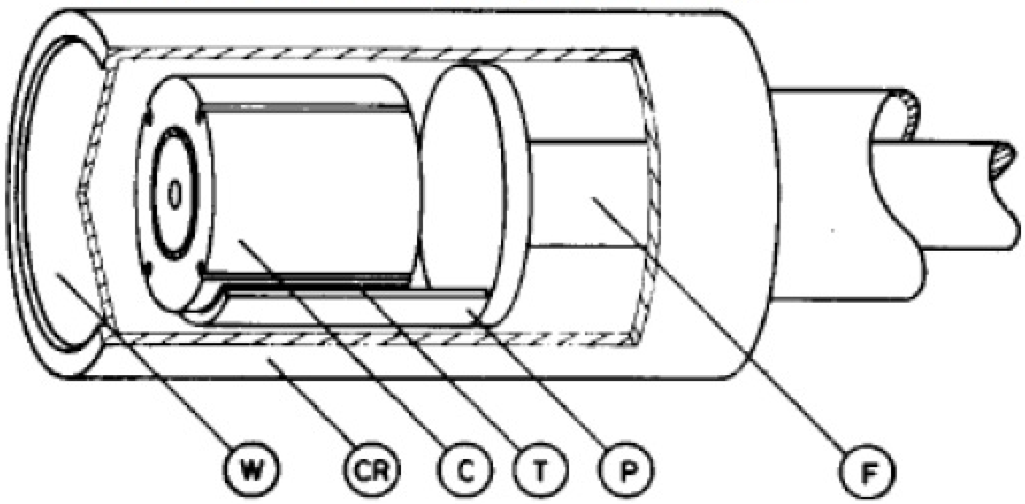


Fig. 1. Cross section of the polarimeter. W = thin window, CR = cryostat, C = crystal, T = Teflon insulation, P = crystal holder, F = cold finger.

Composite Ge-detectors

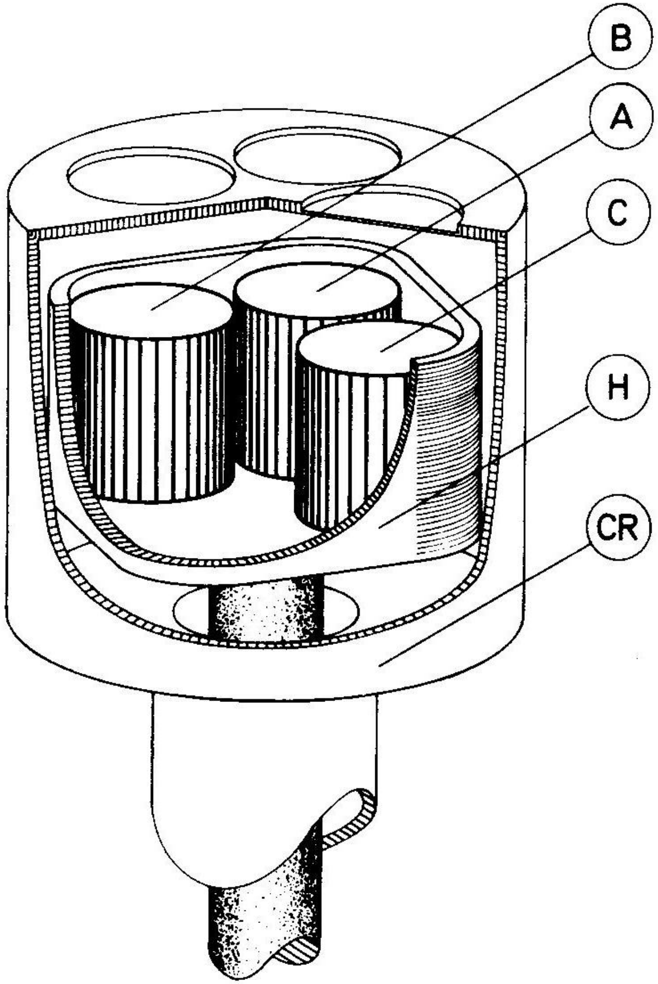


FIG. 4. Three-crystal Compton polarimeter, Detector A acts as scatterer, the absorbers B and C are shielded from direct radiation by a 4 cm collimator of Densimed (see text). CR = cryostat, H = heat shielding.

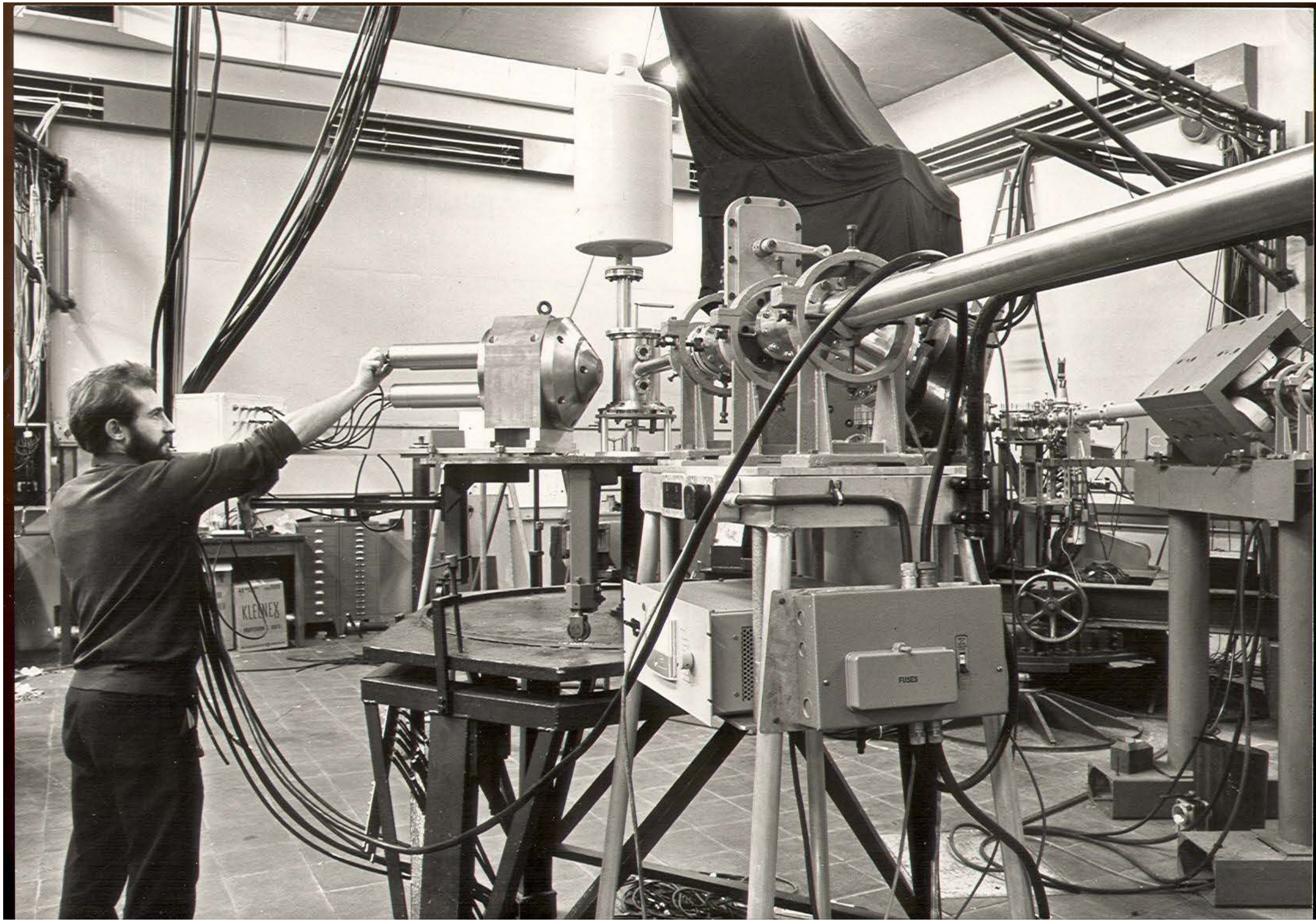
3(4) Ge(Li) detectors
in a common cryostat

1976

resolution 2.1 keV at 1.3 MeV

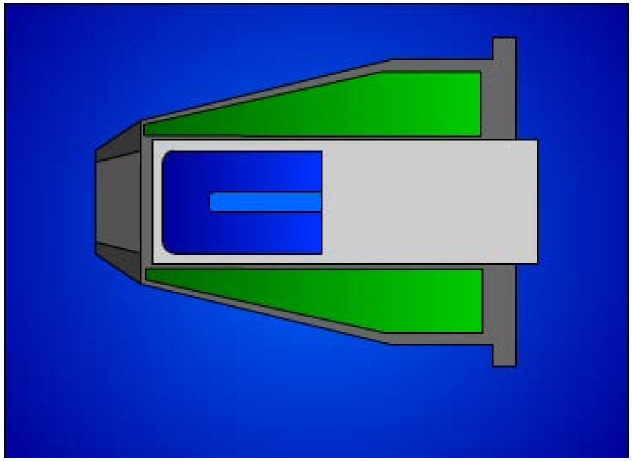
for 3 but not for 4 detectors

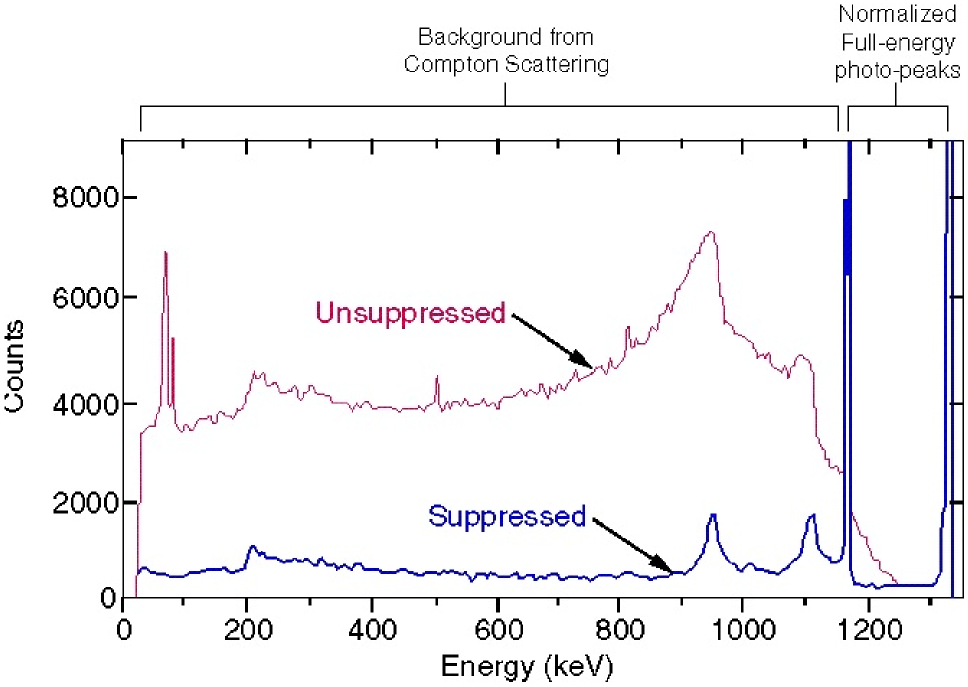
First escape suppression spectrometer at Liverpool



John Francis Sharpey-Schafer

The scattering problem





High background hence suppression shield

High efficiency hence arrays of **E**scape **S**uppressed **S**pectrometer

Arrays of Escape Suppressed Spectrometers

TESSA0 the Escape Suppressed Spectrometer Array

The first one TESSA

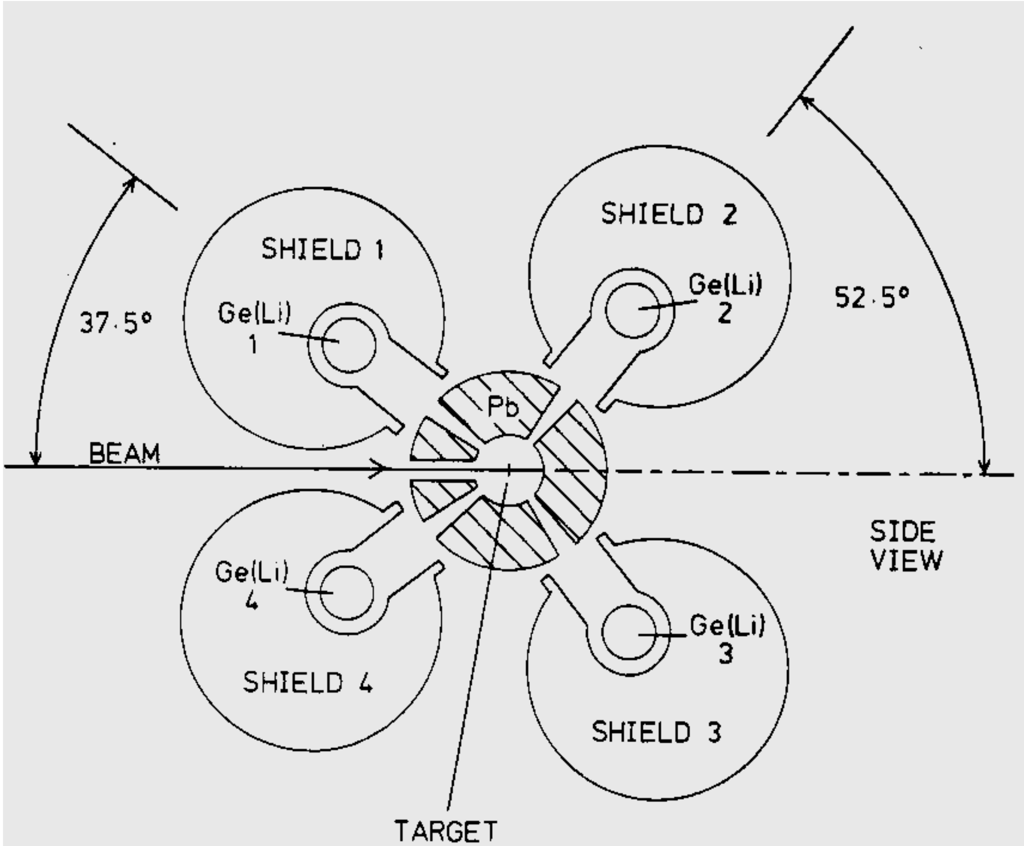
Daresbury study weekend 1979
nuclei far from stability

UK Denmark collaboration
Niels Bohr Institute 1980-1982
FN tandem

5 Ge(Li), 5 NaI(Tl) suppression shields

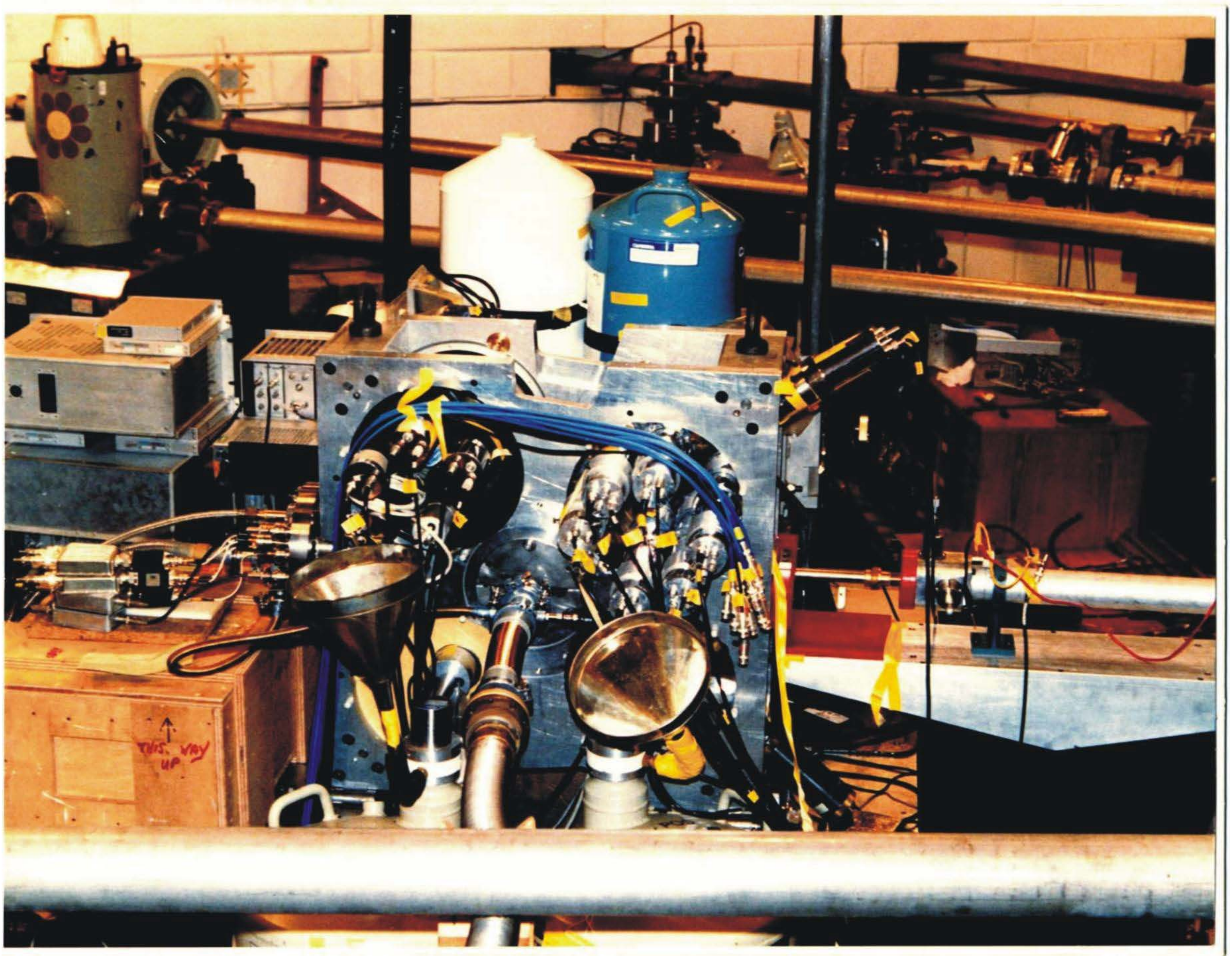
γ^2 factor of 8 improvement in ph. ph. coincidences

no channel selection

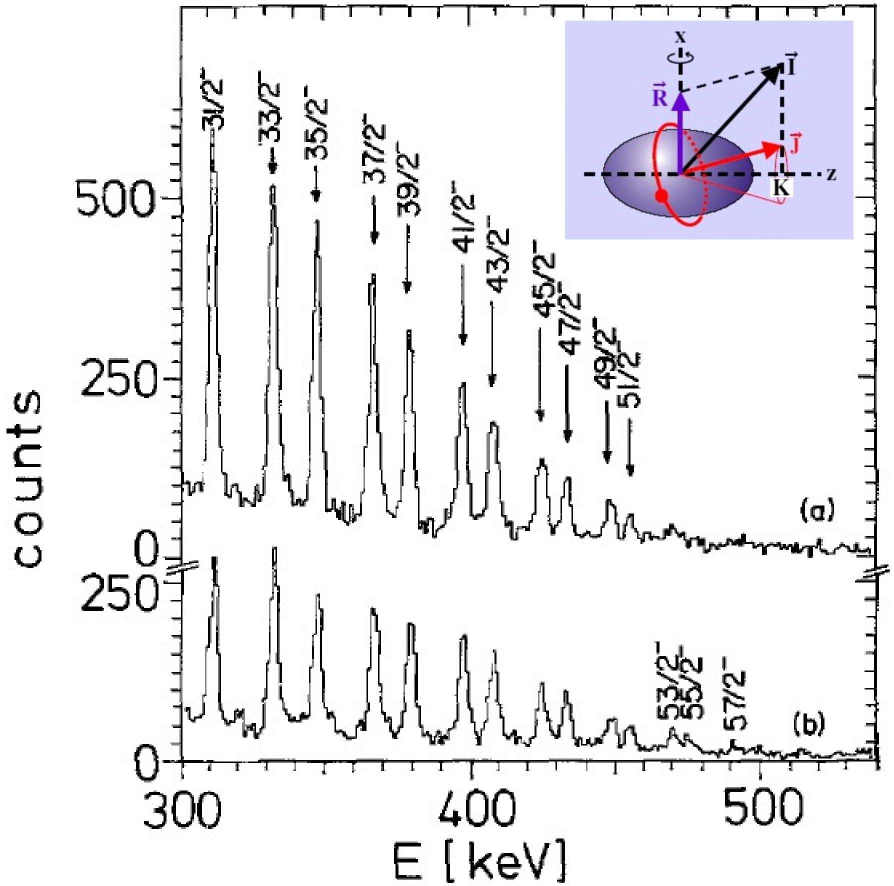


TESSA1 14 element multiplicity filter

TESSA0 the Escape Suppressed Spectrometer Array

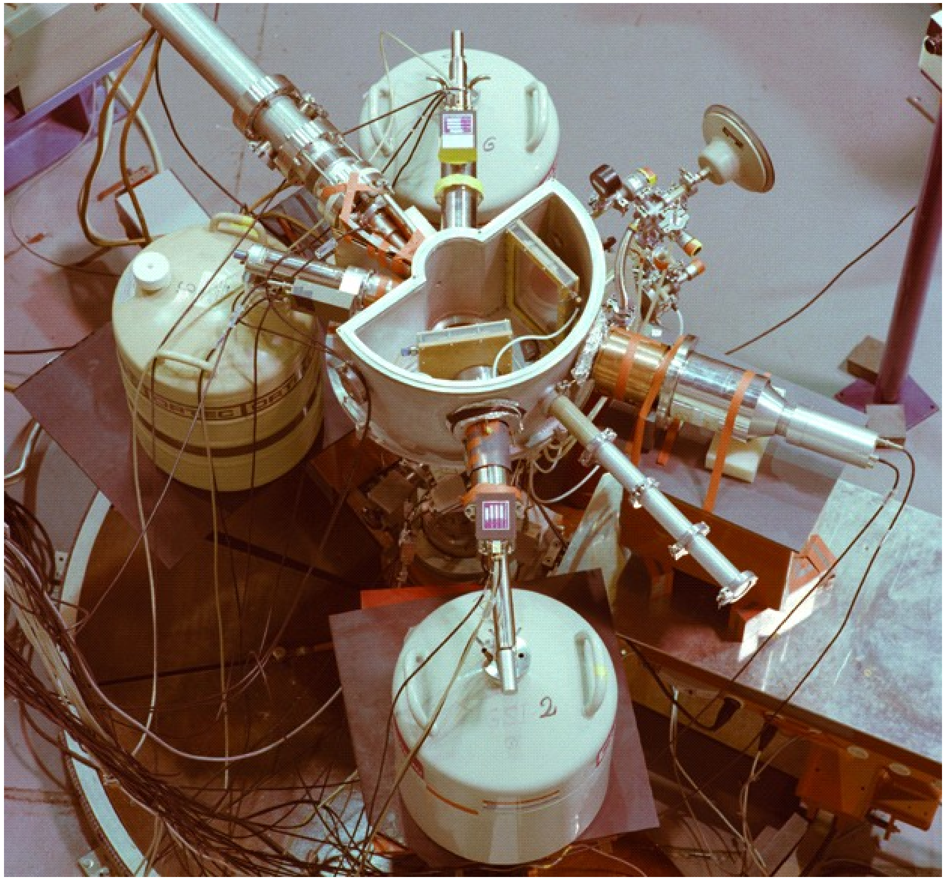


First Coulomb excitation experiments at UNILAC (1980)



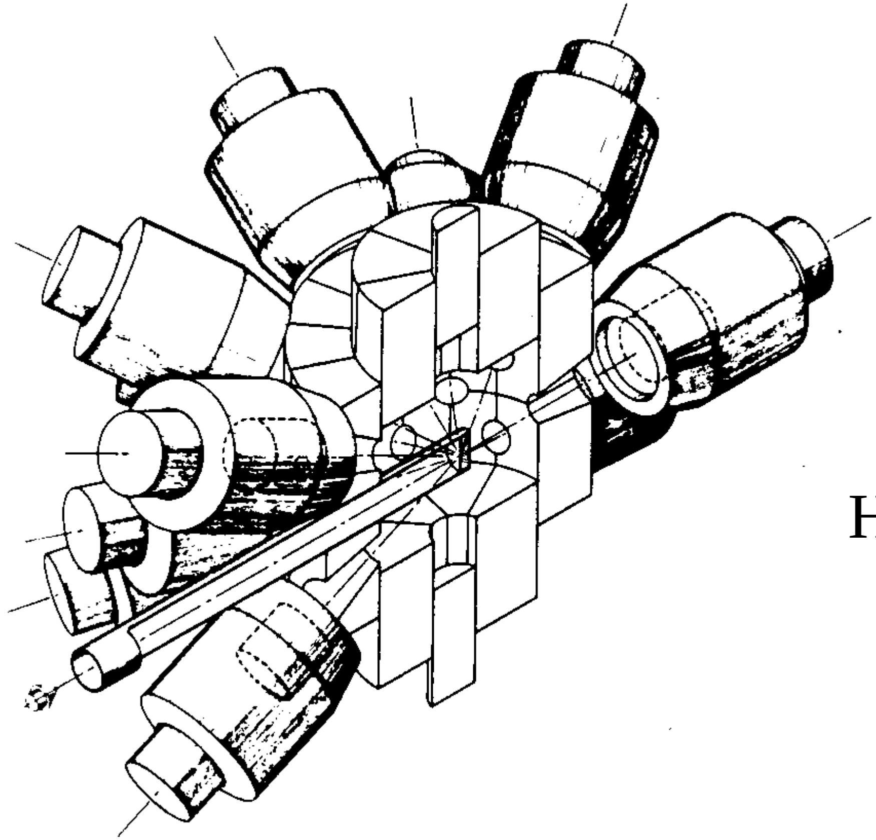
Doppler-corrected γ-ray spectrum for ^{235}U

^{208}Pb (5.3MeV/u) ⟶ ^{235}U



$i_{13/2}$ proton and $j_{15/2}$ neutron alignment in ^{235}U and ^{237}Np

TESSA3, NORDBALL, 8π Spectrometer



~ 1987

HERA at LBNL

BGO replaces NaI(Tl)
1 cm ≈ 1 inch
HERA (LBNL)
21 ESS (25% eff.) + BGO ball
γ-γ-γ coincidences

Development of high-purity Ge at LBNL, Ortec, Umicore …

ERDA NEWS September 19, 1977

Milestone 2

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Review at

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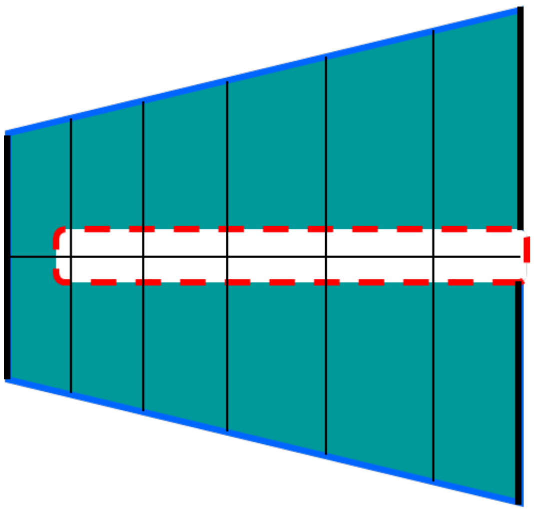
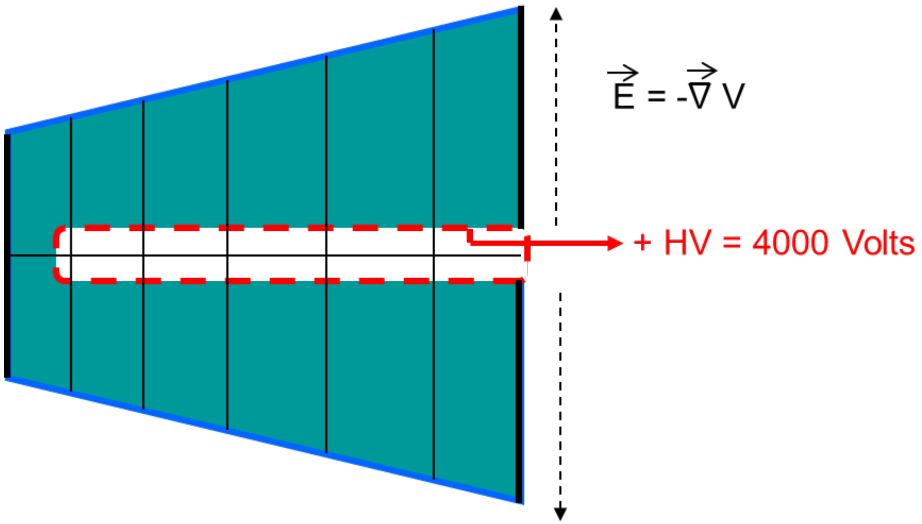
PURE AND COSTLY—Lawrence Berkeley Lab scientists (l-r) William Hansen, Eugene Haller and Scott Hubbard gaze at a germanium crystal worth about $15,000. Purified germanium has scientific applications in archeological dating, geological and chemical analysis, nuclear chemistry, physics and medicine. (LBL Photo)

Production of Ge(li) detectors was abandoned after 1978 when high-purity Ge (HPGe) detectors became commercially available

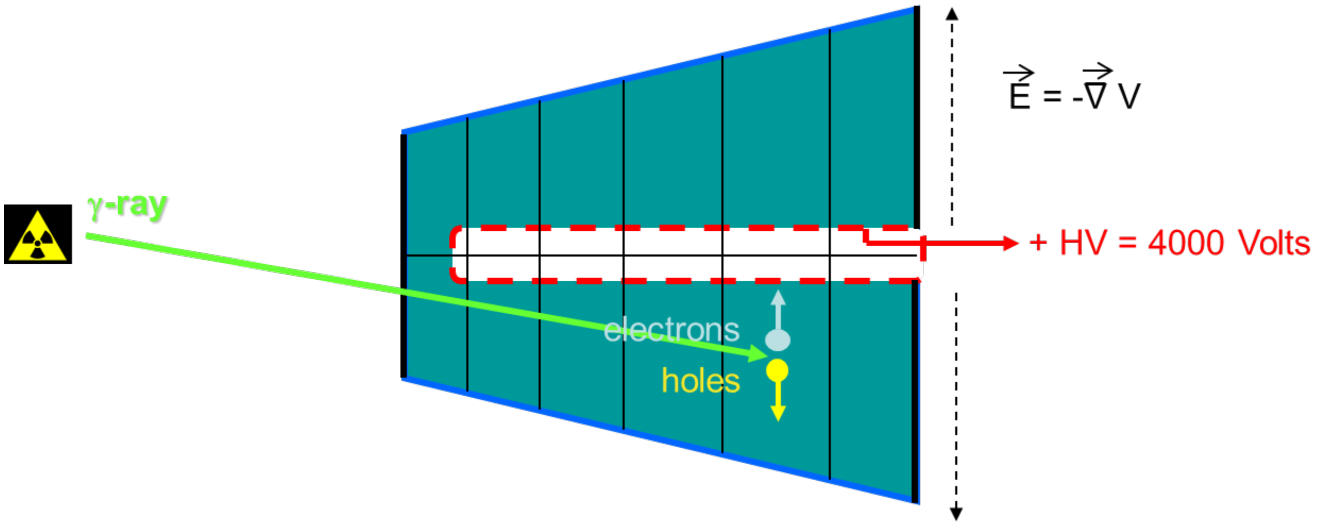
High Purity Germanium detector



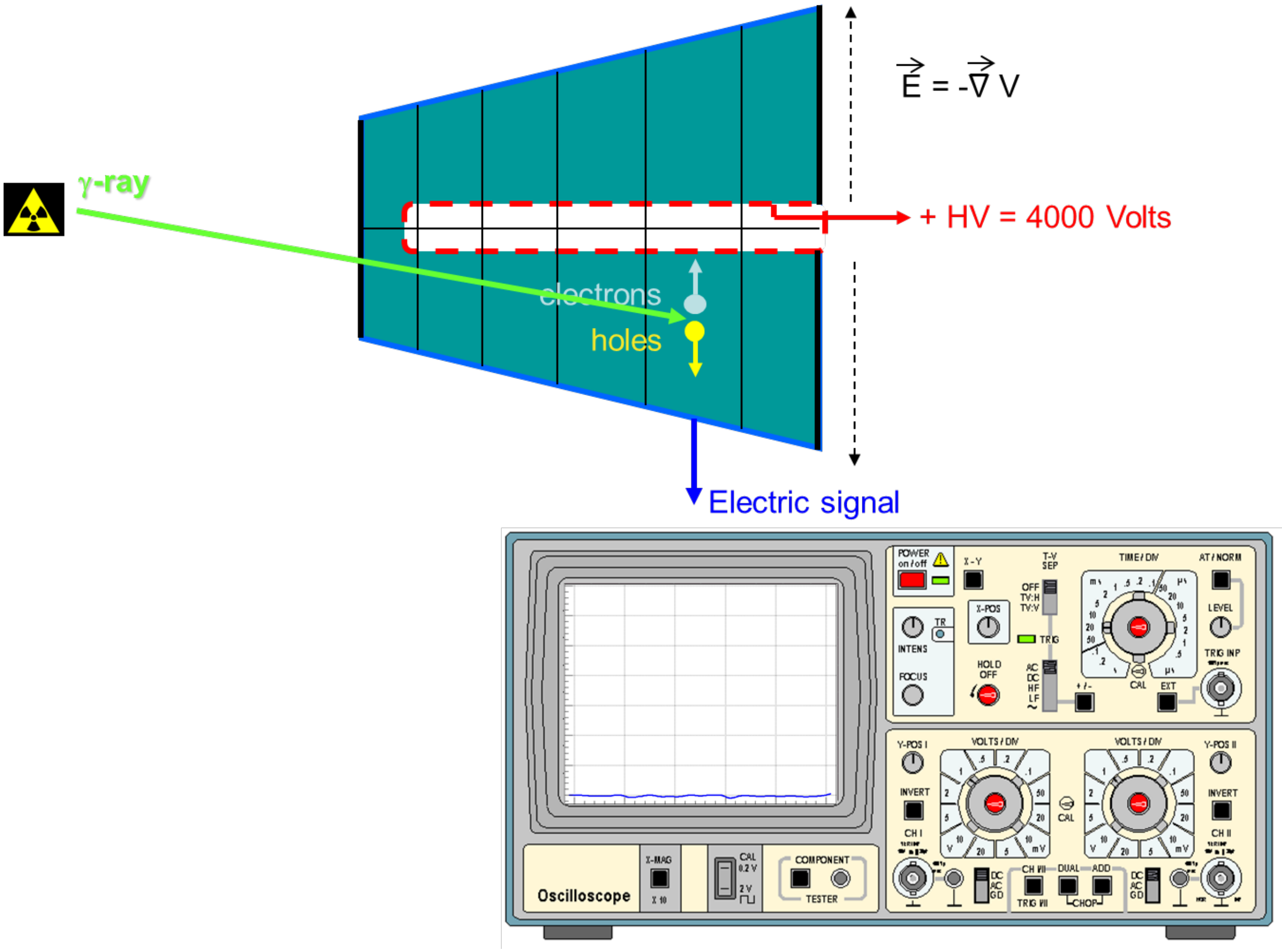
HPGe detector – working principle



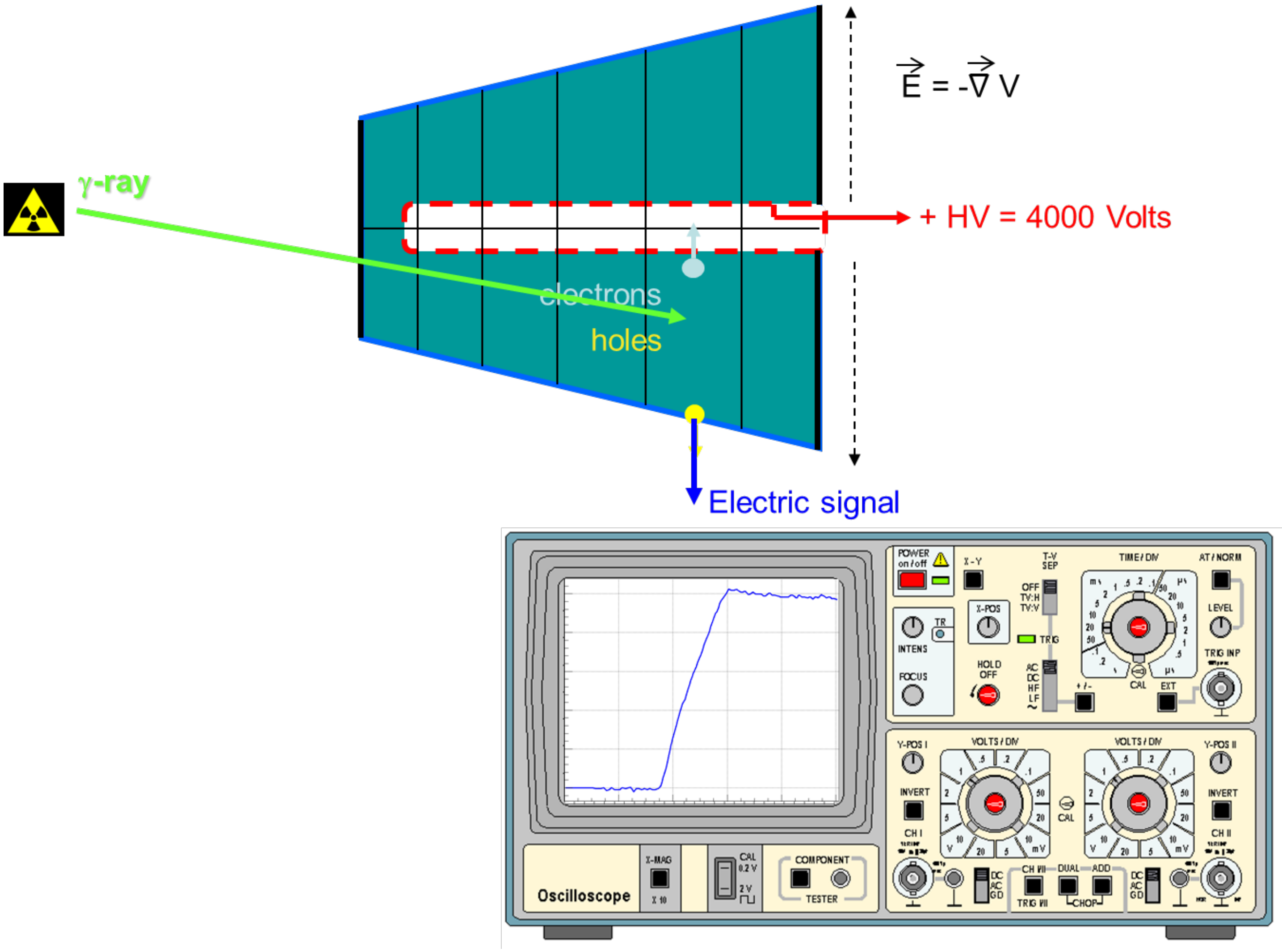
HPGe detector – working principle



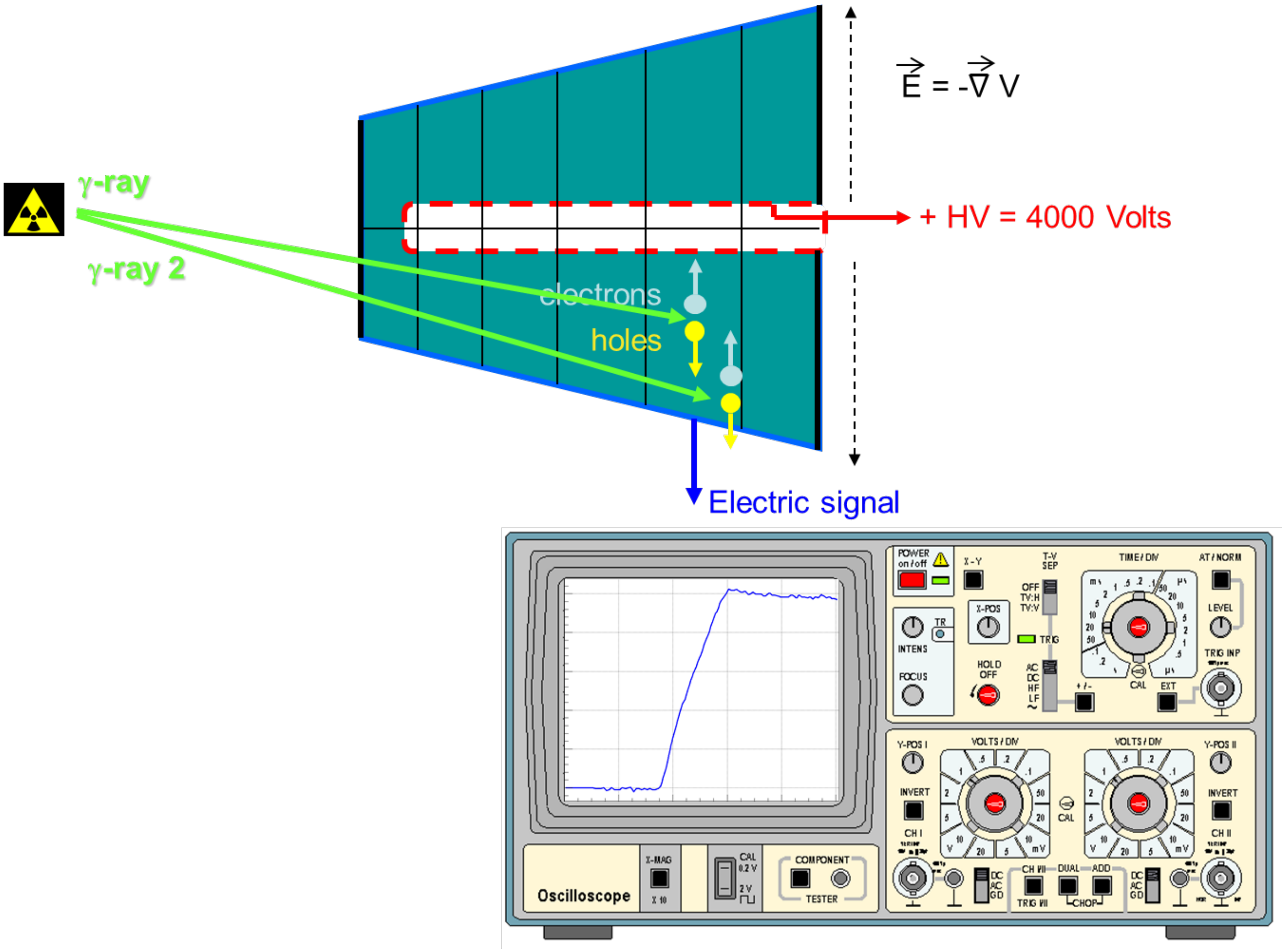
HPGe detector – working principle



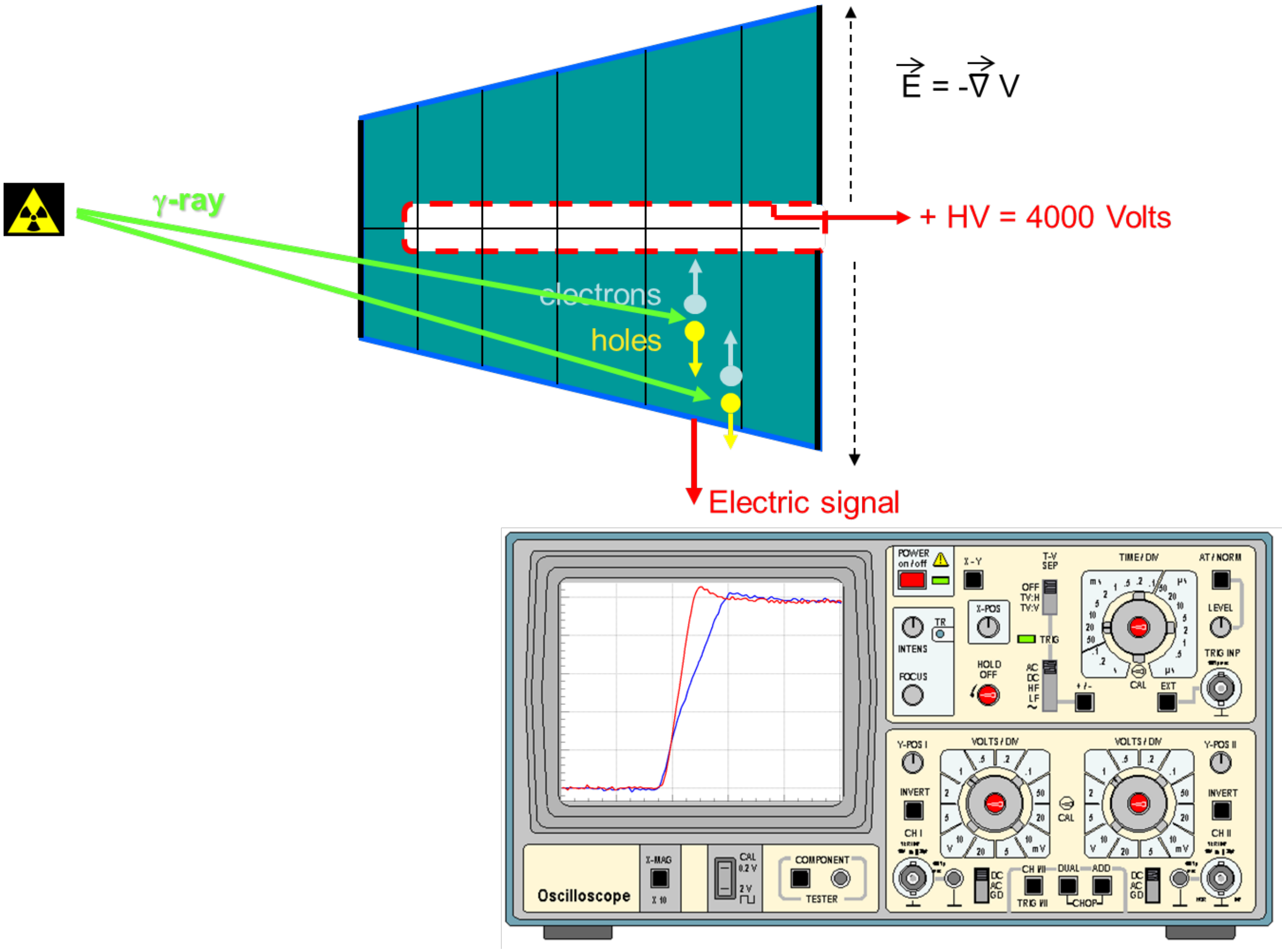
HPGe detector – working principle



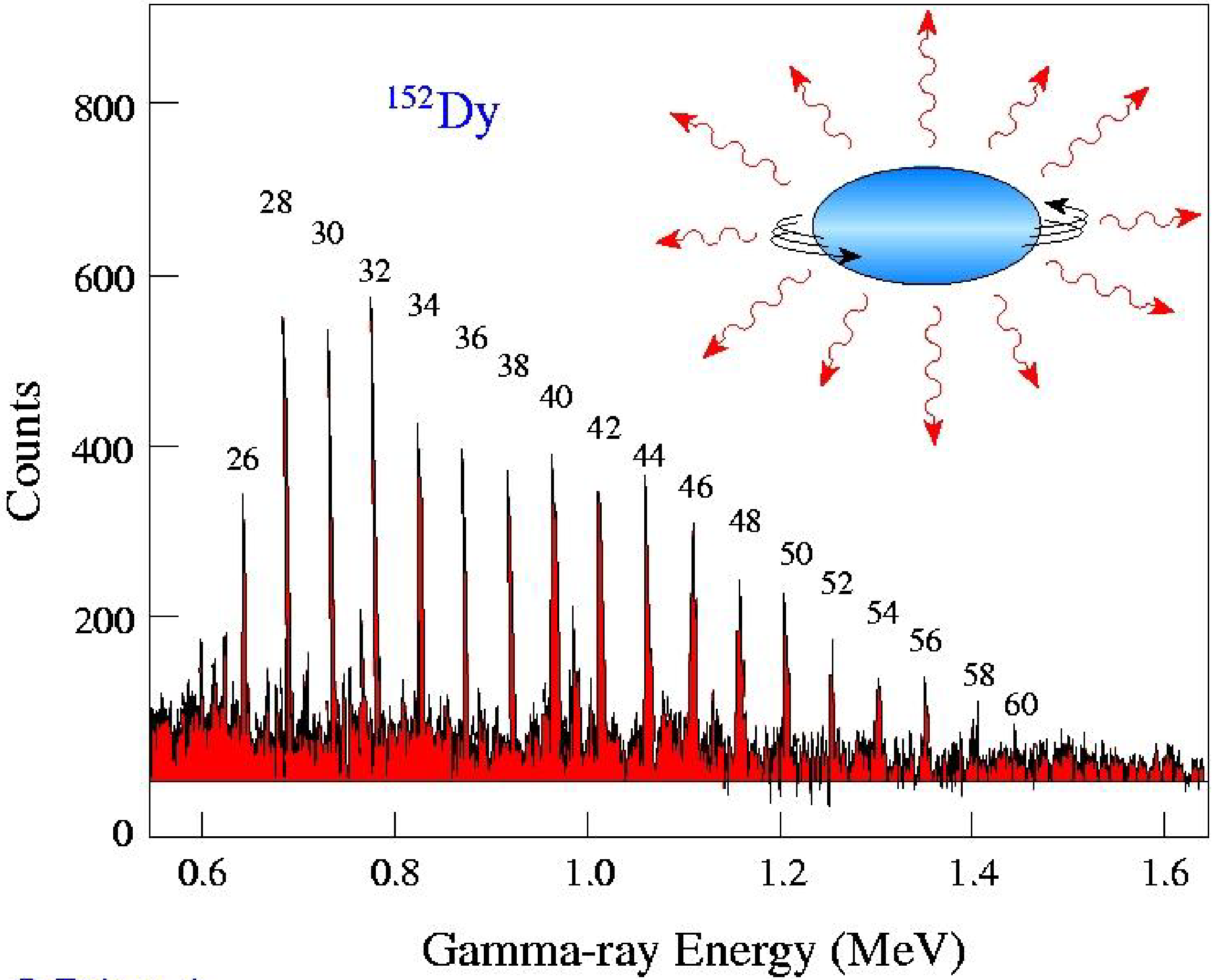
HPGe detector – position sensitivity



HPGe detector – position sensitivity

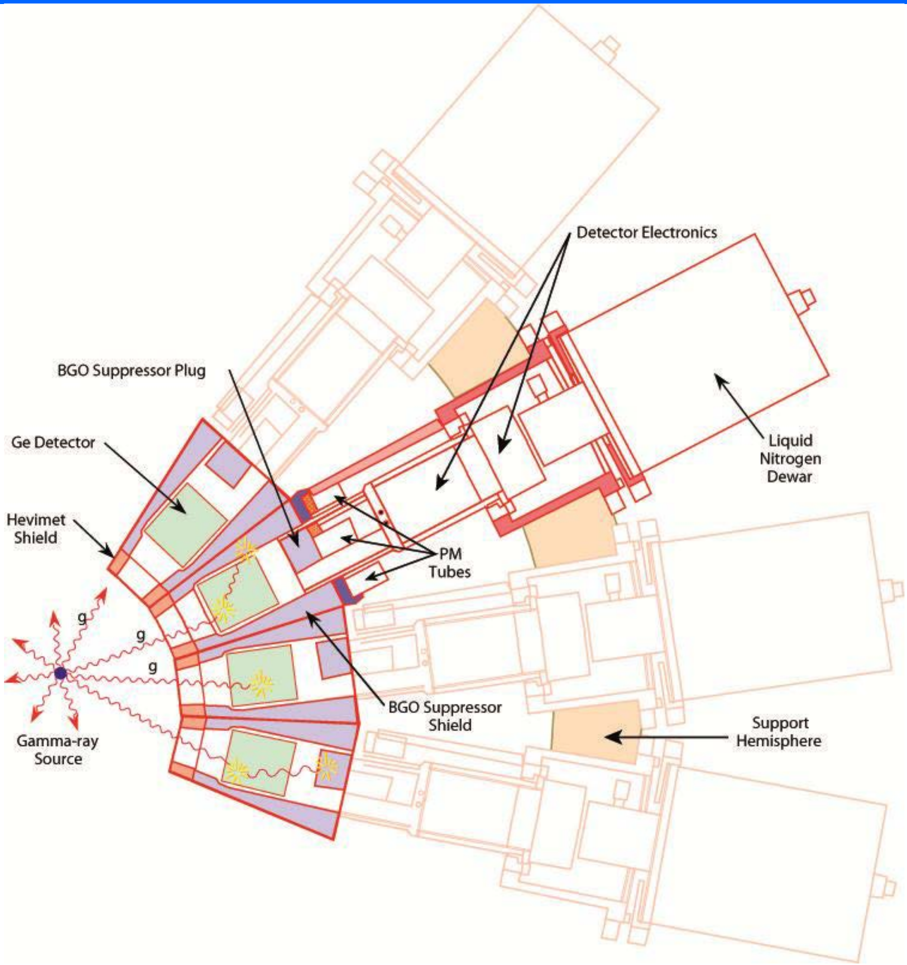


The first case of a high spin superdeformed band

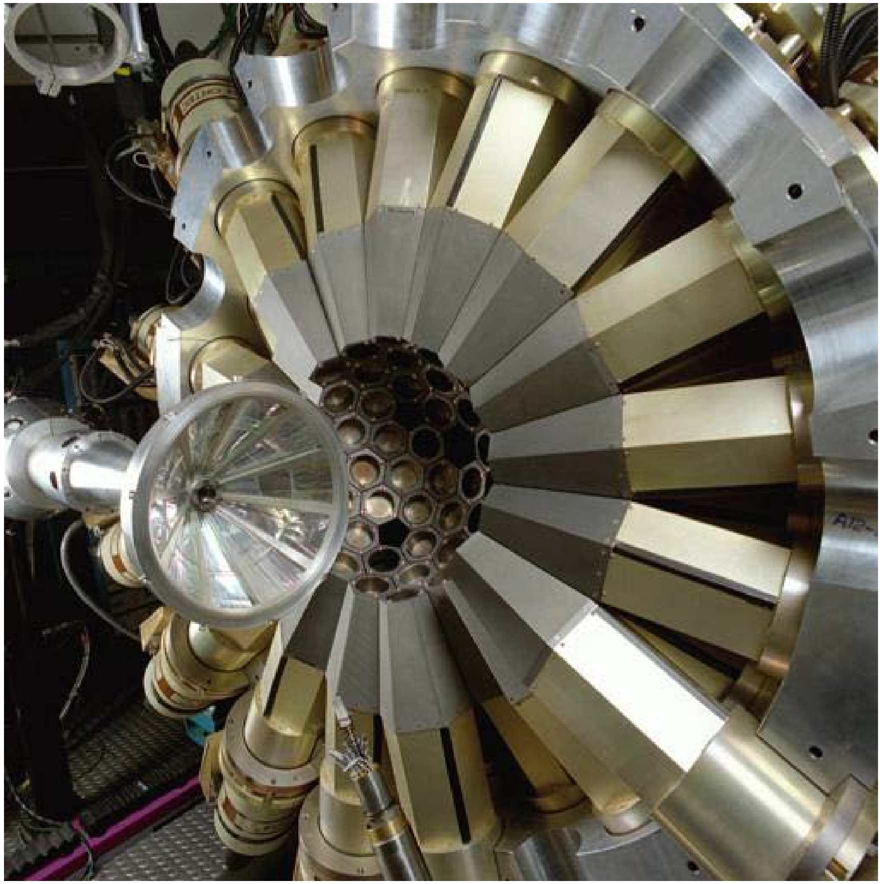


P. Twin et. al
Phys. Rev. Lett. 57 (1986)

GAMMASPERE 1993 Berkeley



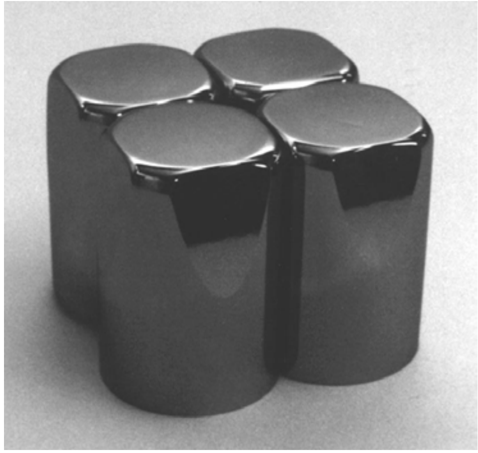
110 Ge detectors (70% eff.)
escape suppression shields



70 detectors segmented into two halves
to reduce the Doppler broadening

M.A. Deleplanque, R.M. Diamond eds Gammasphere proposal 1987

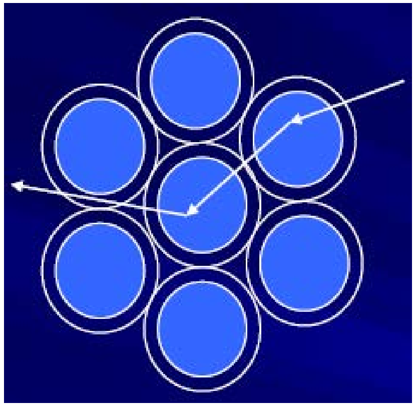
EUROGAM II



24 CLOVER detectors with increased efficiency (130%) and improved granularity

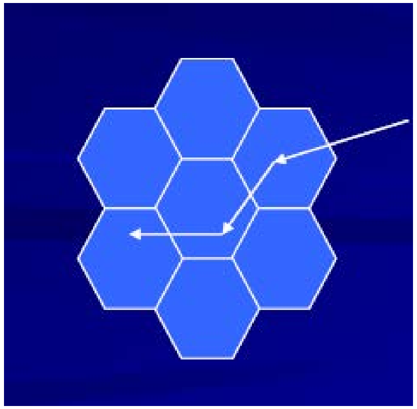
F. A. Beck et al. Conf. Proc. 1994

From EUROGAM to EUROBALL



Late 1980's:

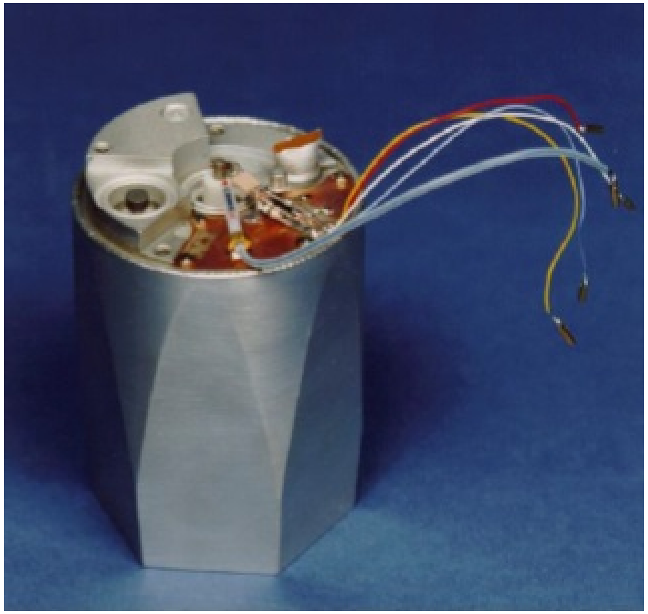
Discussion of a cluster of seven detectors with large efficiency in add-back mode

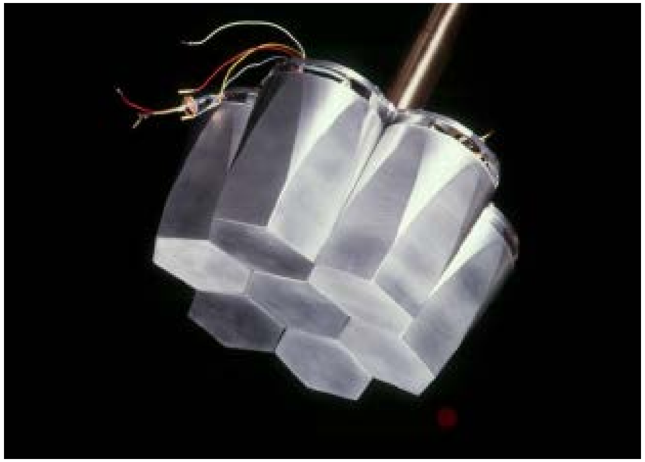


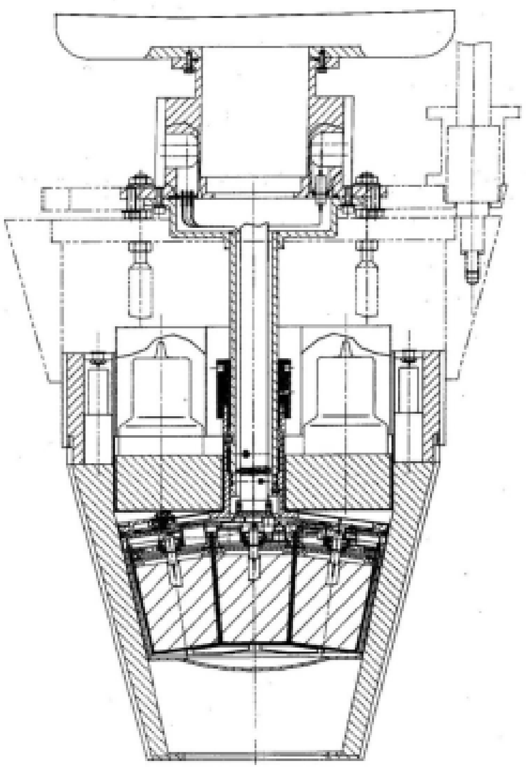
Conclusion:
seven hexagonal detectors in a common cryostat

Encapsulated!

The EUROBALL cluster detector

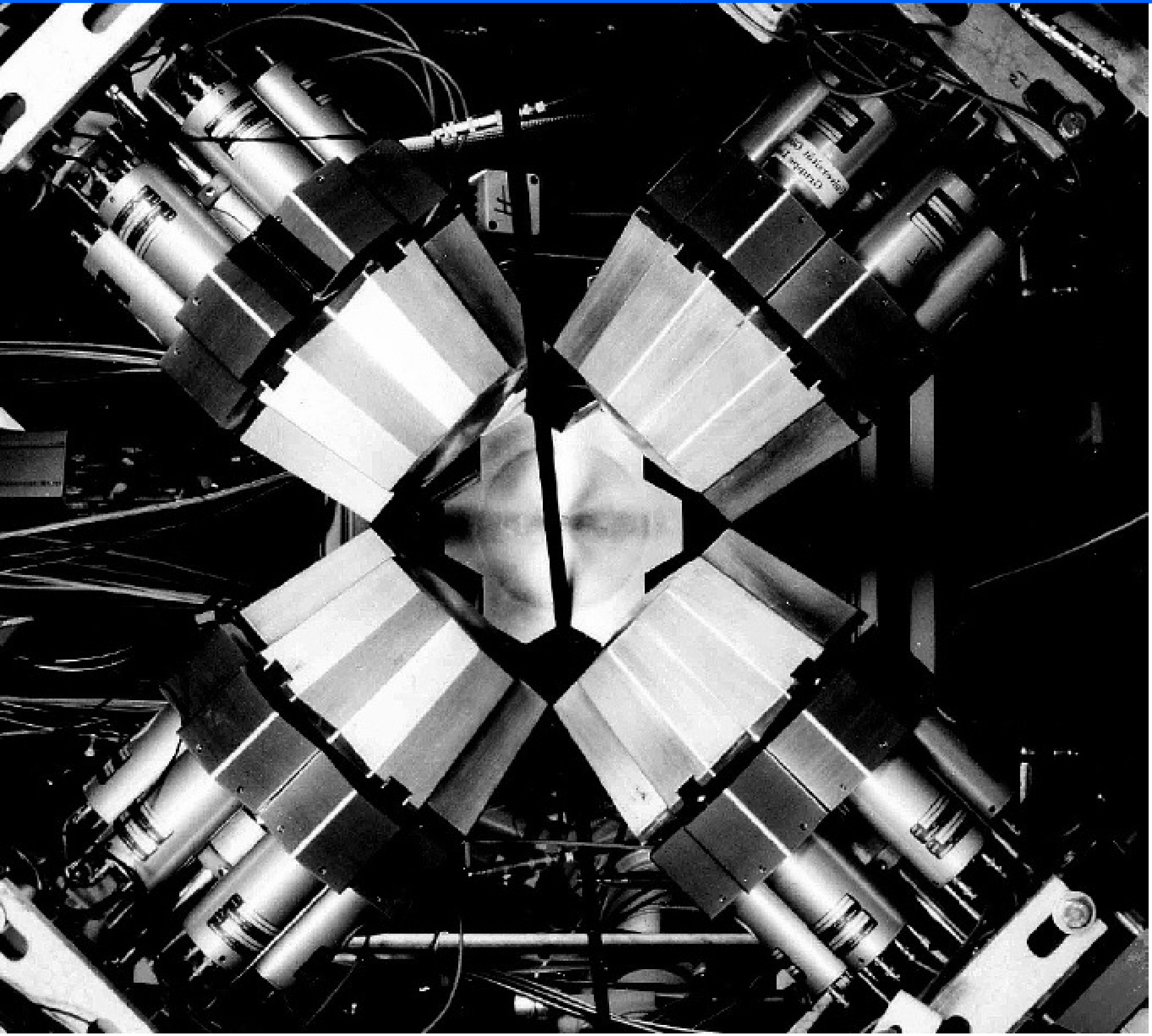






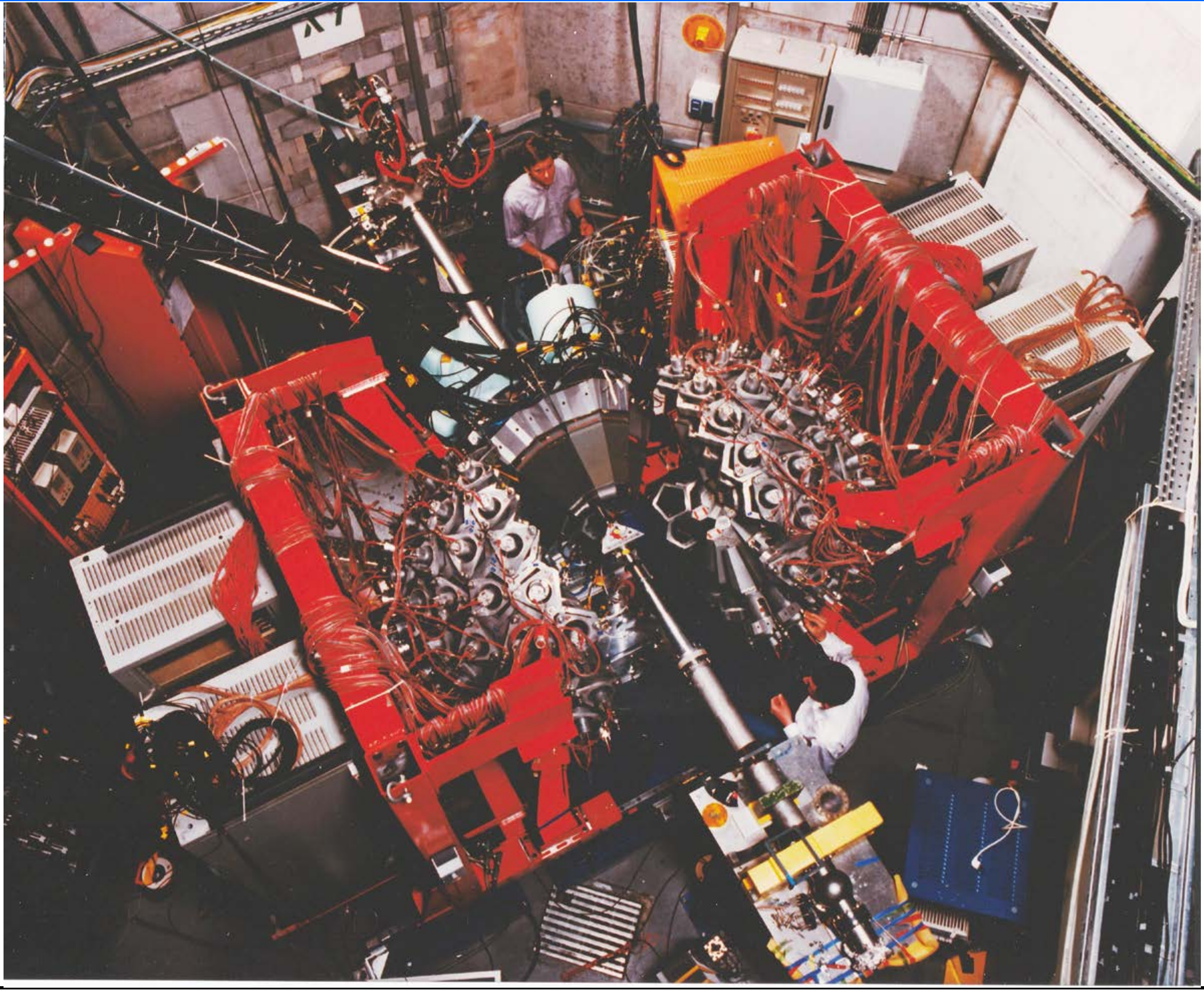
10 kg HPGE
rel. efficiency 600%

EUROBALL-3 demonstrator at GSI 1993

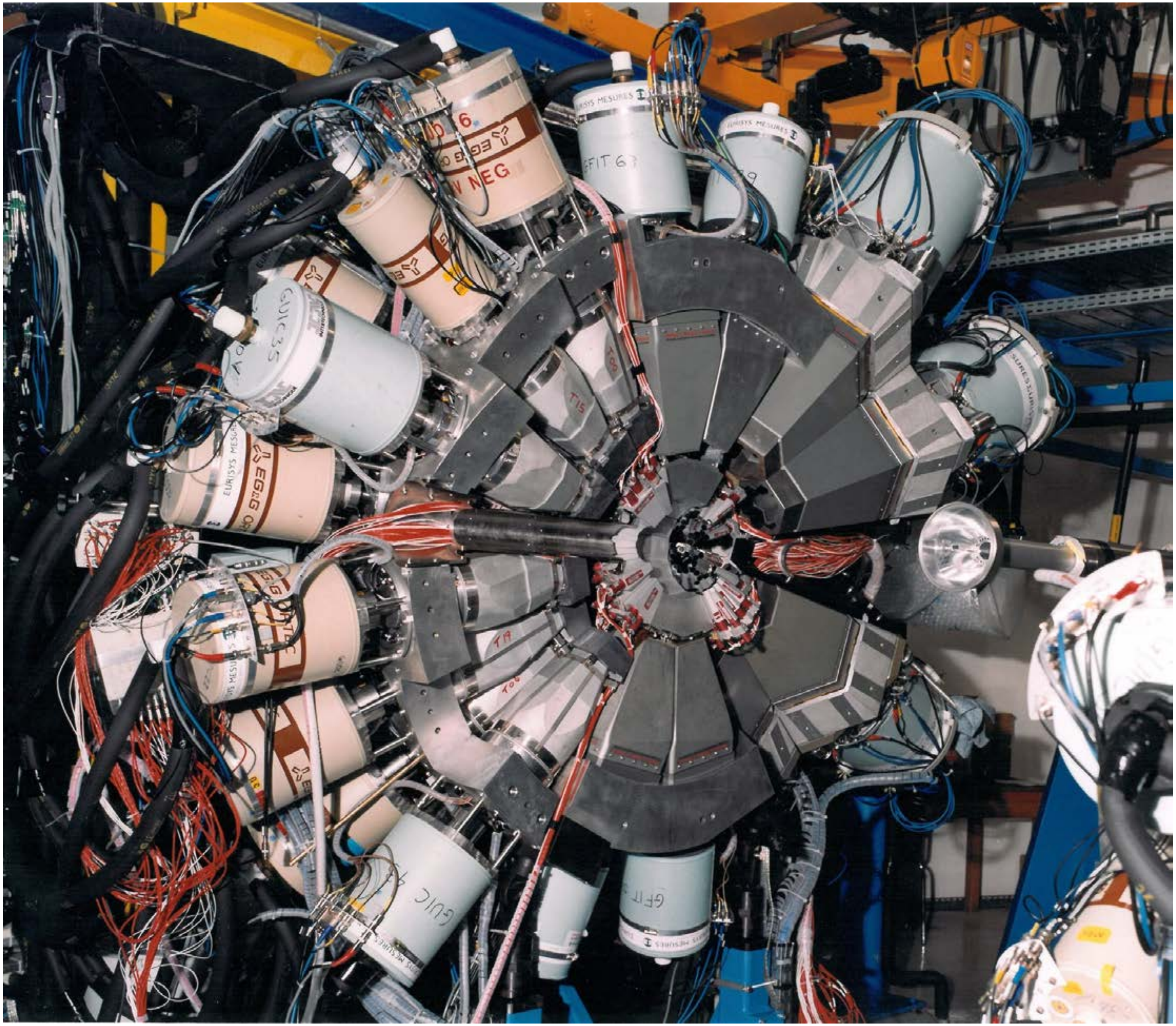


GSI mass separator
efficiency: 19%

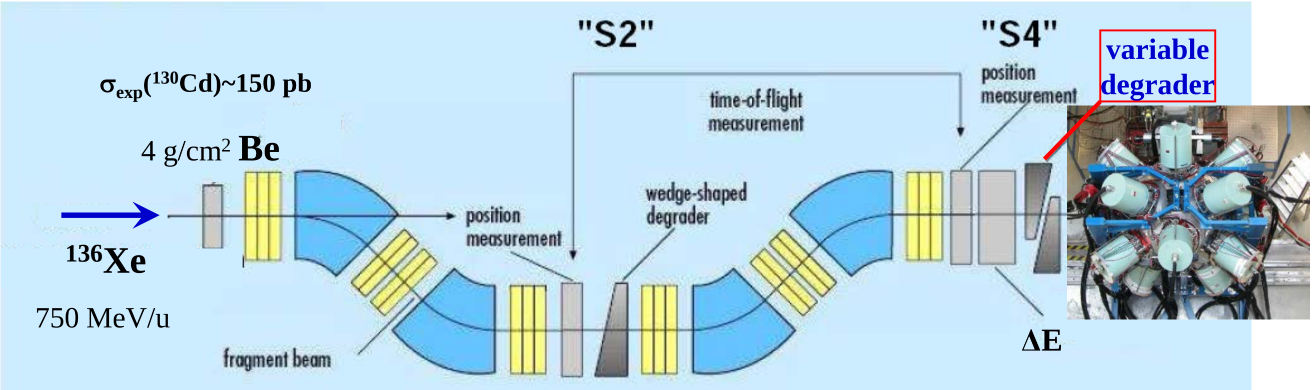
Darmstadt-Heidelberg Crystal Ball and EUROBALL-3 demonstrator 1993

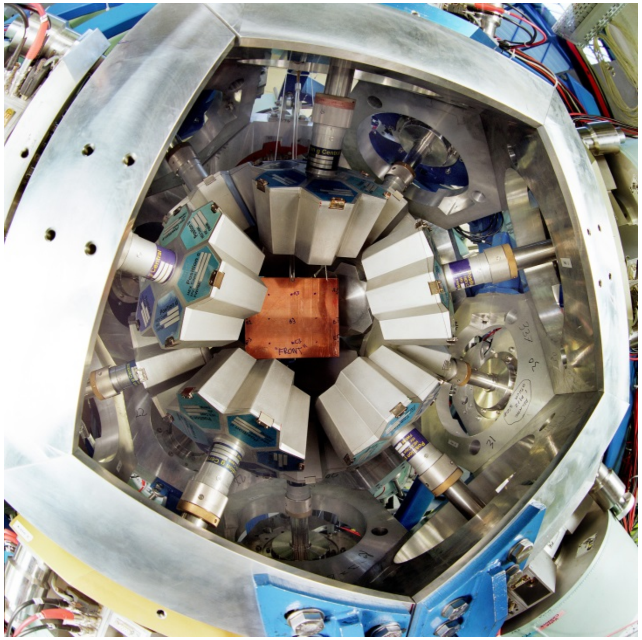


EUROBALL 1997 - 2003



EUROBALL (2003-2009) at RISING Rare ISotope INvestigation at GSI

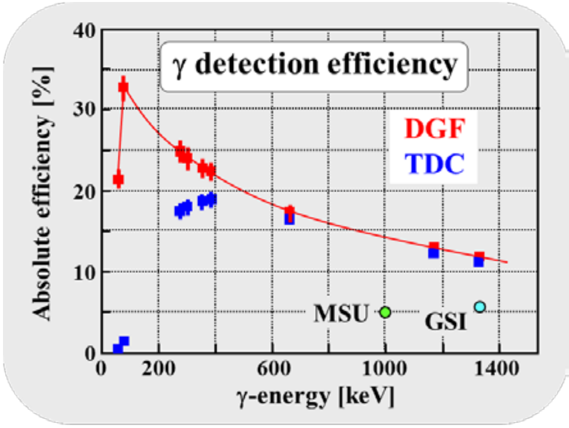




implantation in Cu-plate or in 9 DSSSD

15 Cluster detectors with 105 Ge crystals

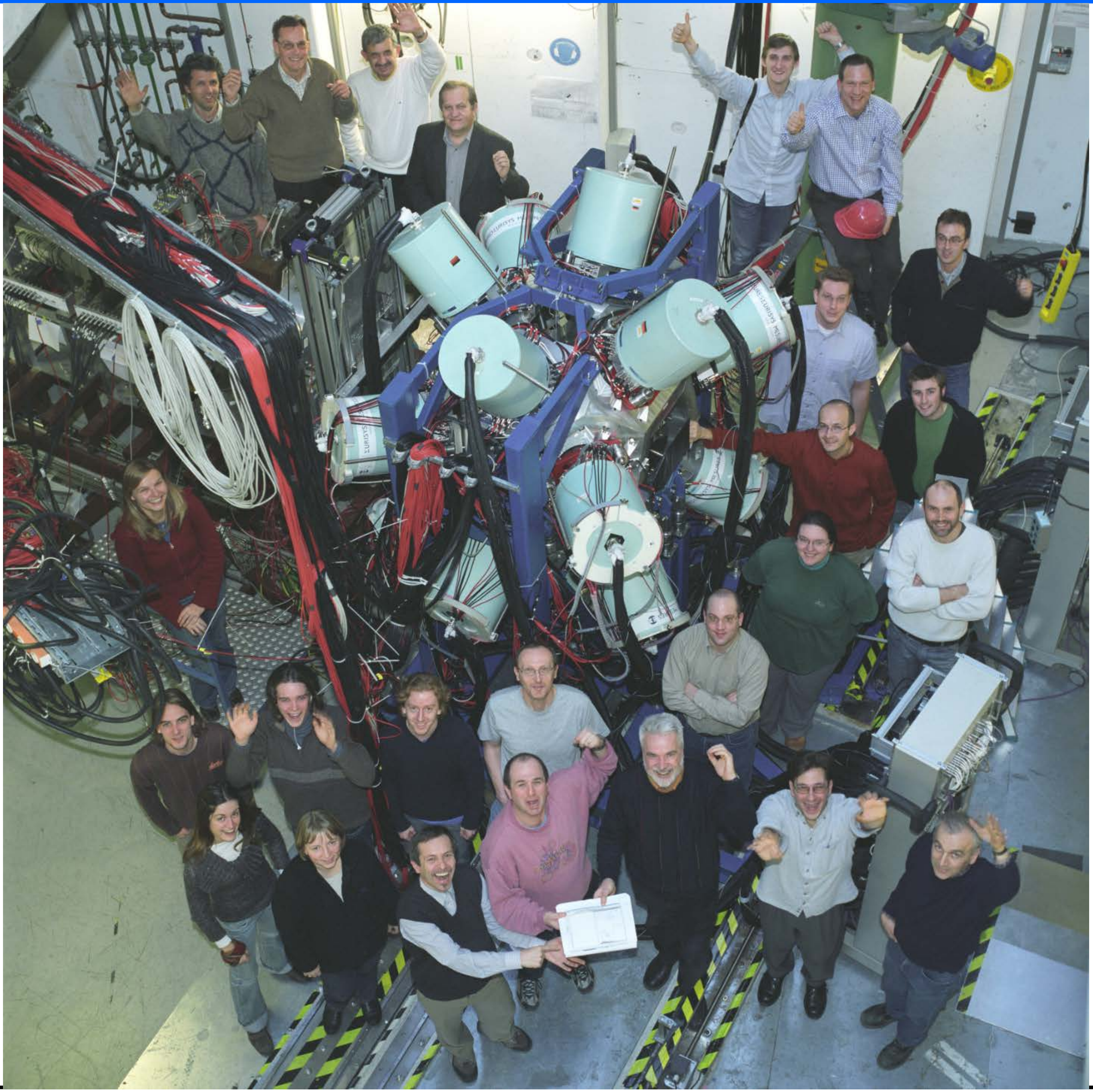
ε_γ = 11% at 1.3 MeV, 20% at 550 keV, 35% at 100 keV



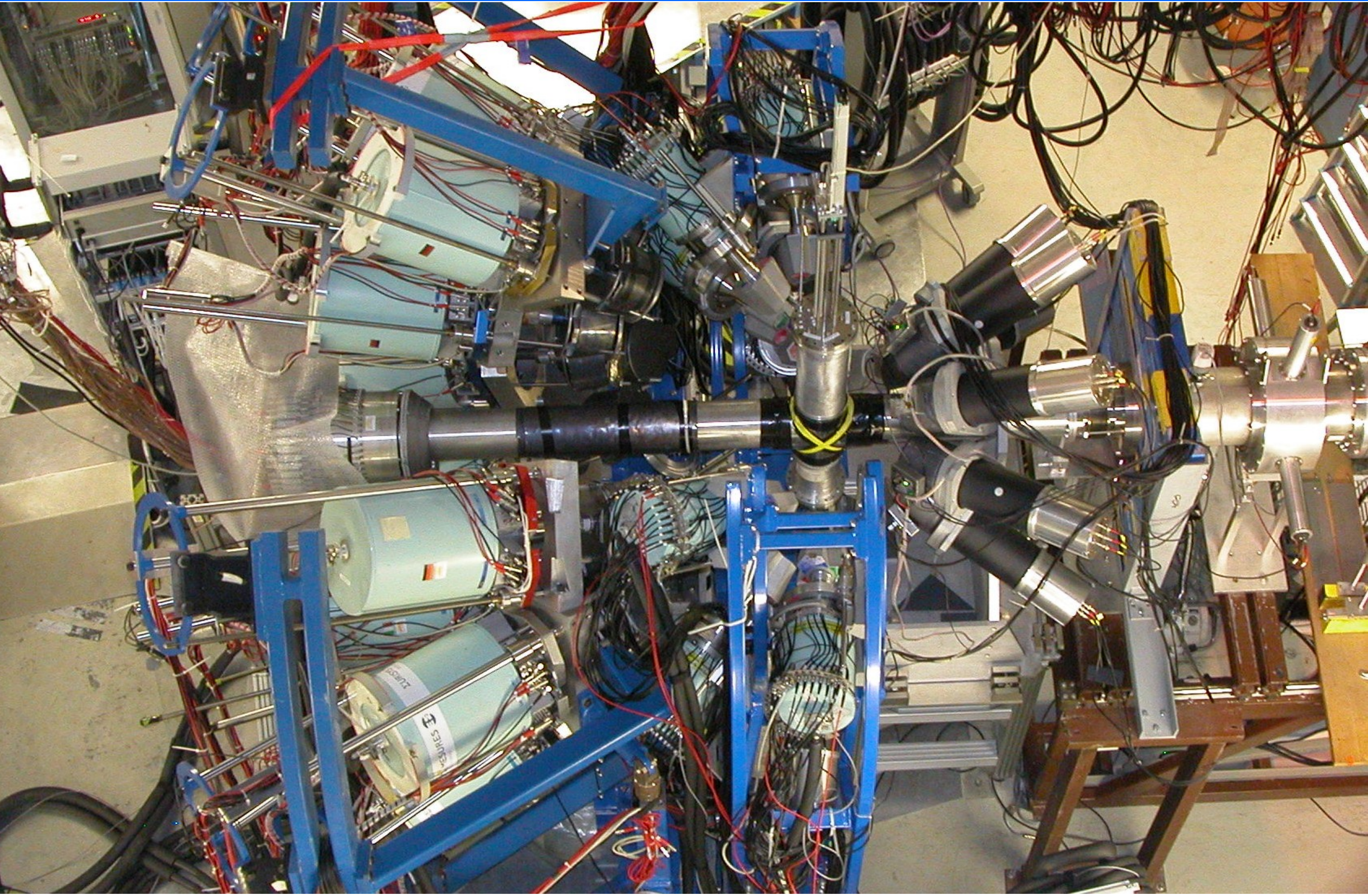
- very high γ-ray efficiency
- high granularity (prompt flash problem)

S. Pietri et al., NIM B261 (2007), 1079

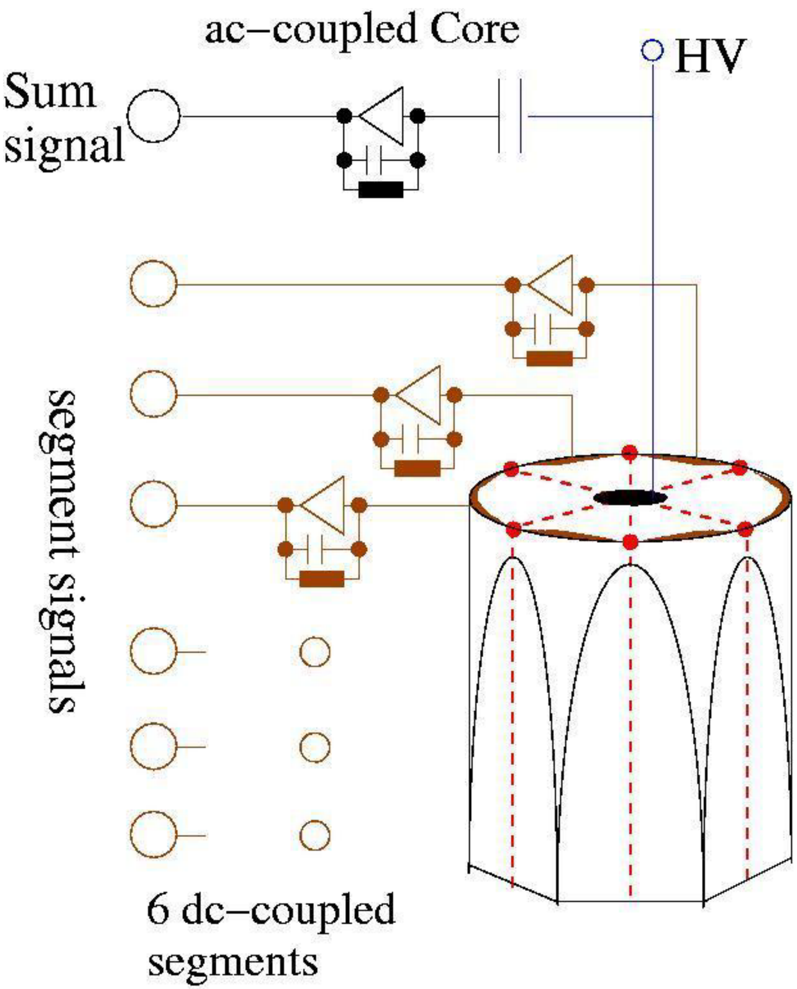
EUROBALL at RISING stopped beam set-up (2006-2009)

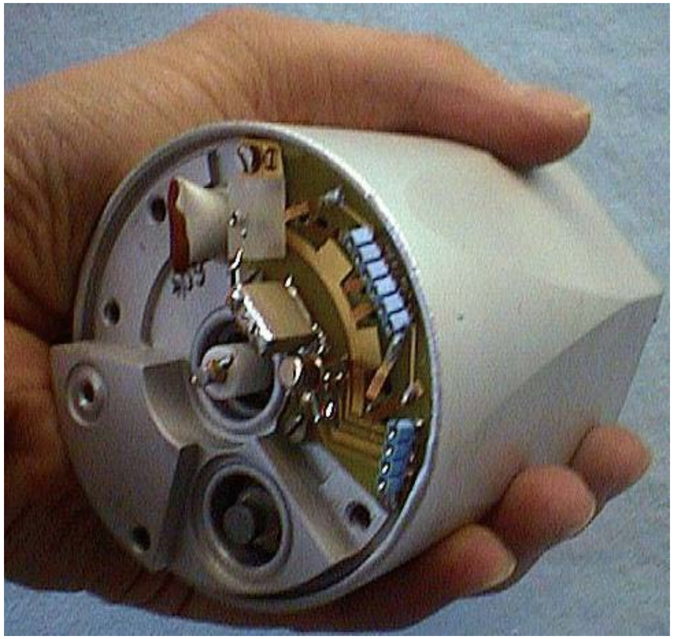


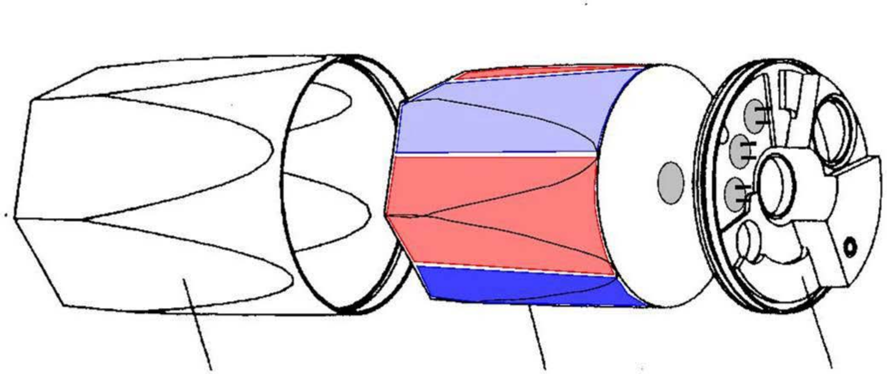
EUROBALL at RISING scattering experiment (2003-2005)



6-fold segmented, encapsulated MINIBALL detector

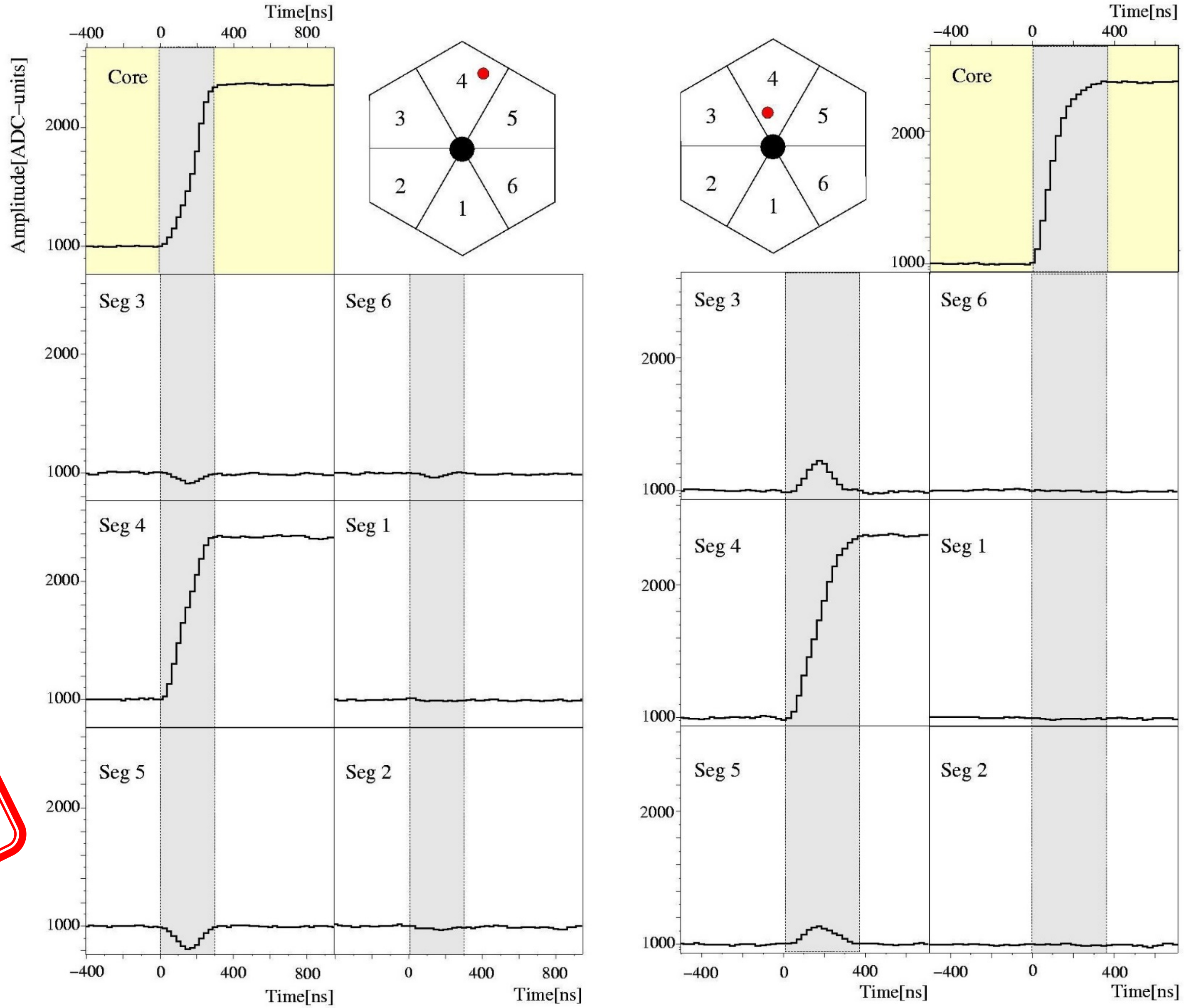






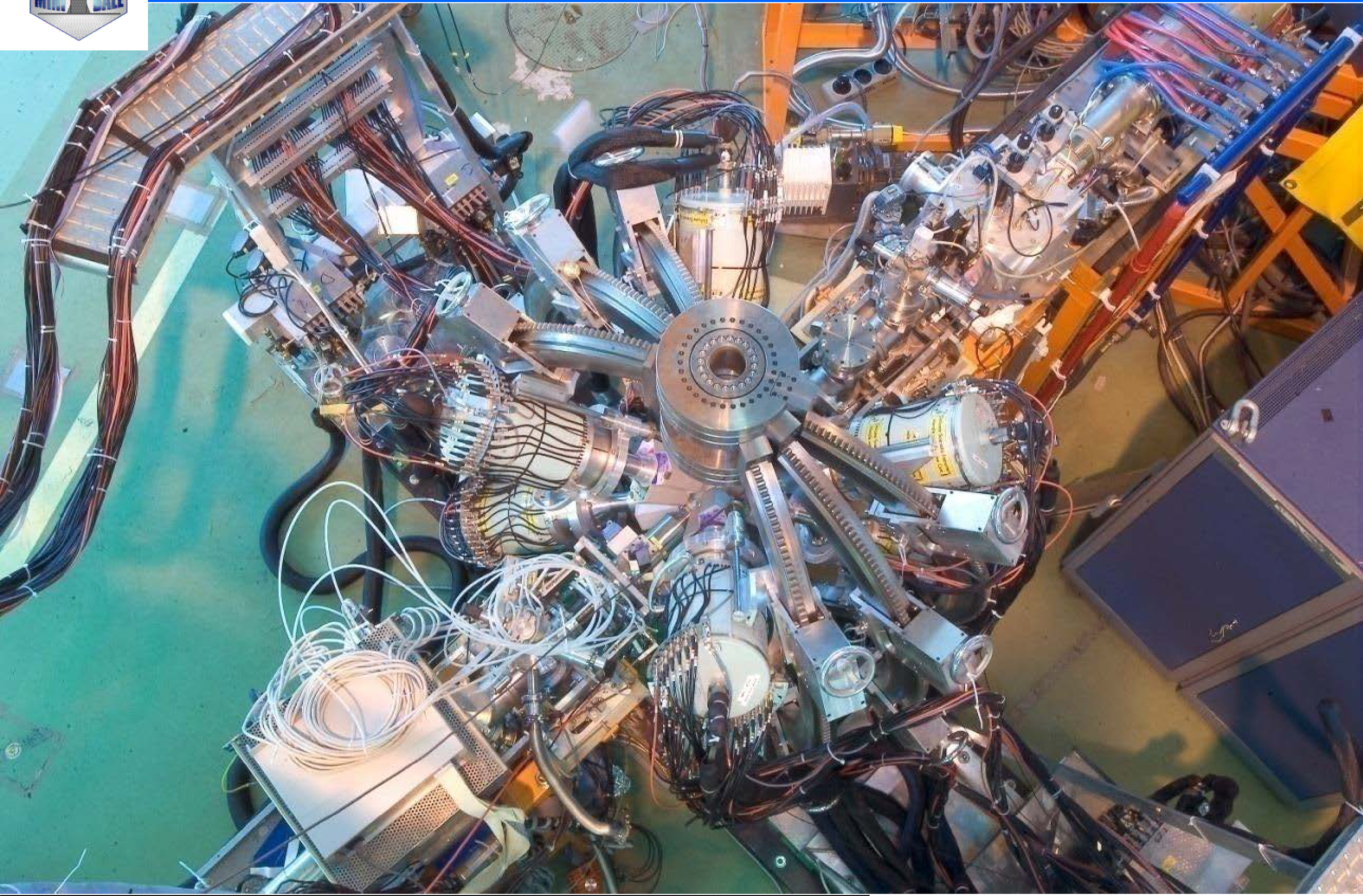
collaboration: Cologne,Heidelberg,Munich, Leuven

Position-sensitive Ge-detectors (pulse shape analysis)

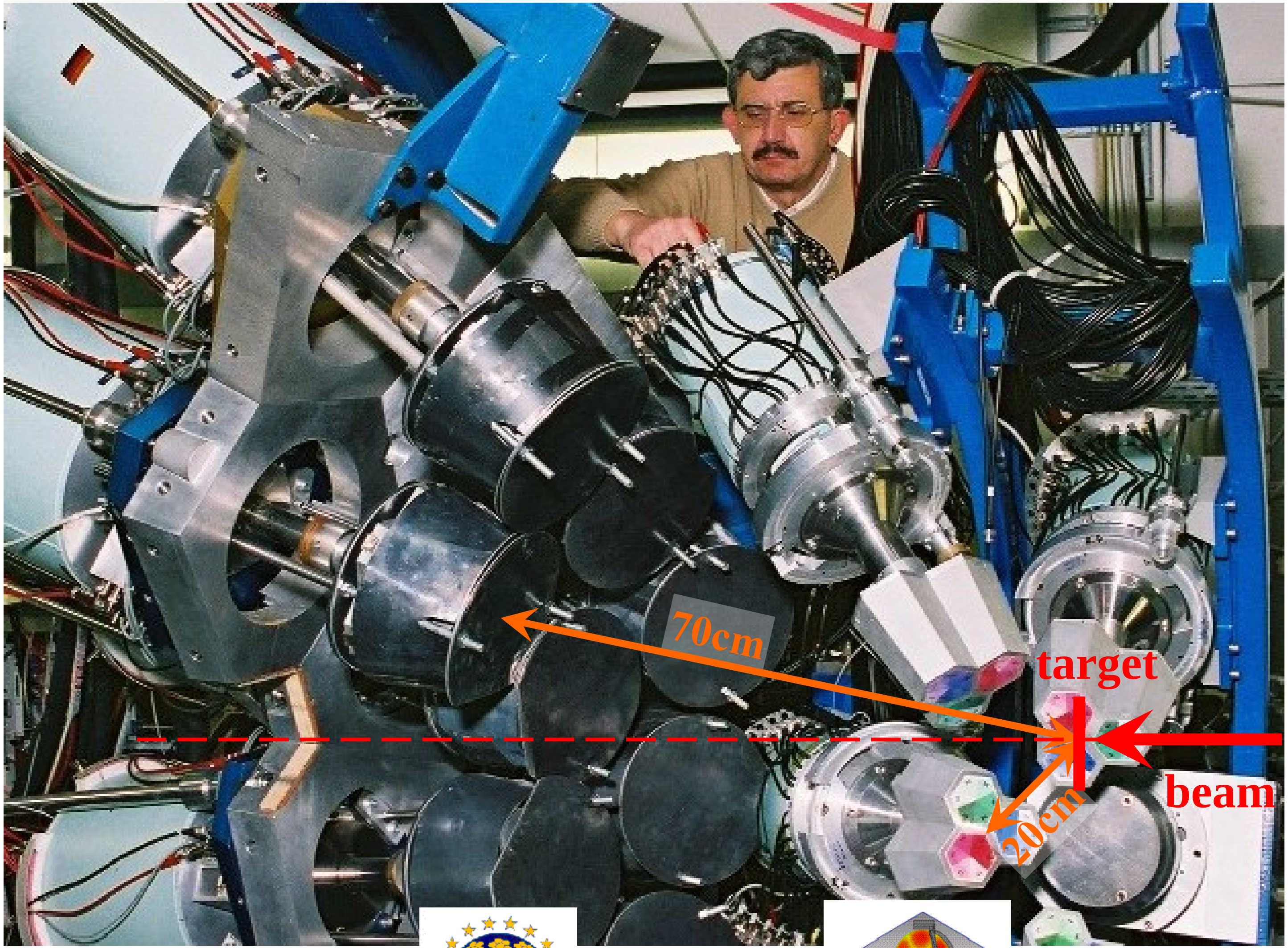


Milestone 3

MINIBALL at REX-ISOLDE



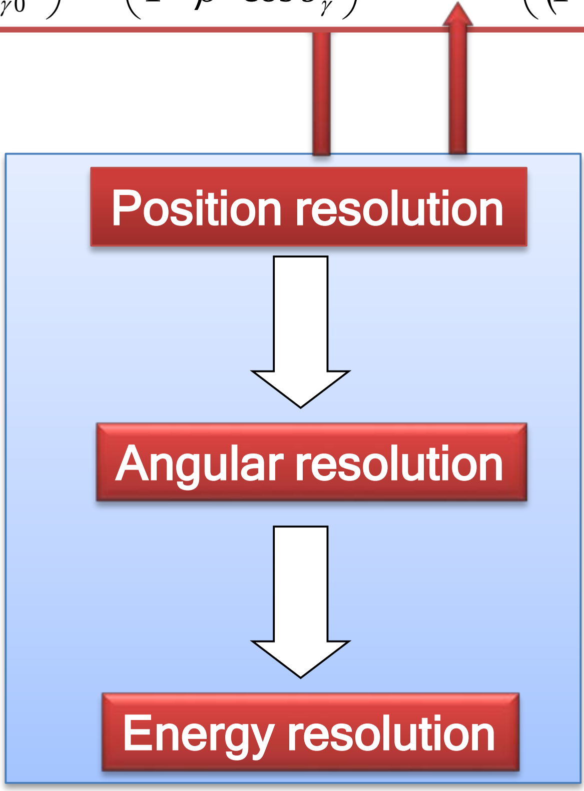
Cluster and MINIBALL detectors at RISING 2005

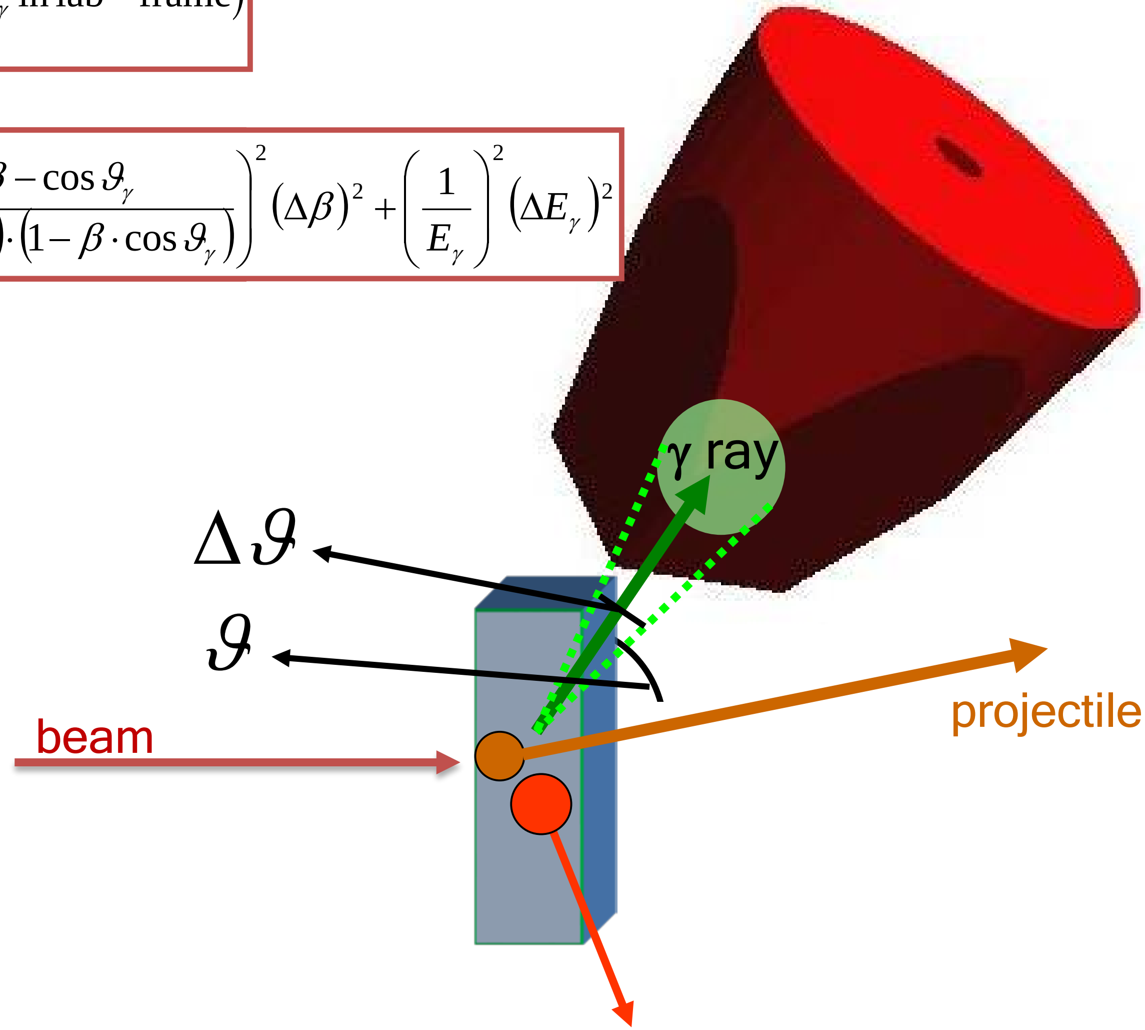


Doppler broadening and position resolution

$$E_{\gamma 0} = E_\gamma \frac{1-\beta\cdot\cos\vartheta_\gamma}{\sqrt{1-\beta^2}} \qquad \left(\beta, \vartheta_p = 0^0, \vartheta_\gamma \text{ and } E_\gamma \text{ in lab} - \text{frame}\right)$$

$$\left(\frac{\Delta E_{\gamma 0}}{E_{\gamma 0}}\right)^2 = \left(\frac{\beta\cdot\sin\vartheta_\gamma}{1-\beta\cdot\cos\vartheta_\gamma}\right)^2 (\Delta\vartheta_\gamma)^2 + \left(\frac{\beta-\cos\vartheta_\gamma}{(1-\beta^2)\cdot(1-\beta\cdot\cos\vartheta_\gamma)}\right)^2 (\Delta\beta)^2 + \left(\frac{1}{E_\gamma}\right)^2 (\Delta E_\gamma)^2$$





The idea of γ–ray tracking

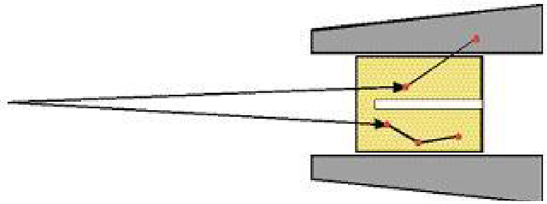
Compton shielded Ge

$\varepsilon_{ph} \sim 10\%$

$N_{det} \sim 100$

$\Omega \sim 40\%$

$\theta \sim 8^0$



large opening angle means poor energy resolution at high recoil velocity

Previously scattered γ-rays were wasted
Technology is available to track them

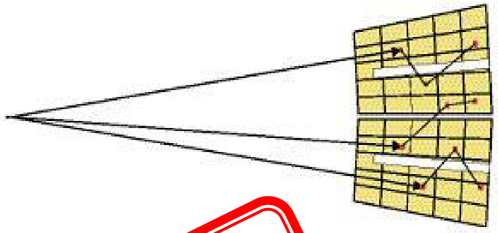
Ge tracking array

$\varepsilon_{ph} \sim 50\%$

$N_{det} \sim 100$

$\Omega \sim 80\%$

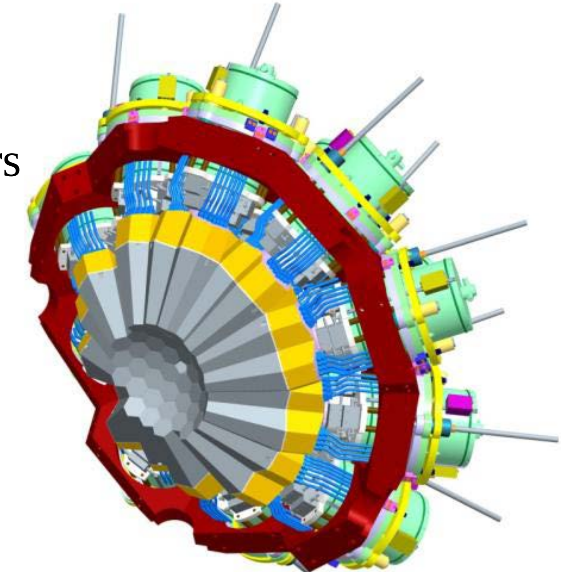
$\theta \sim 1^0$



Milestone 4

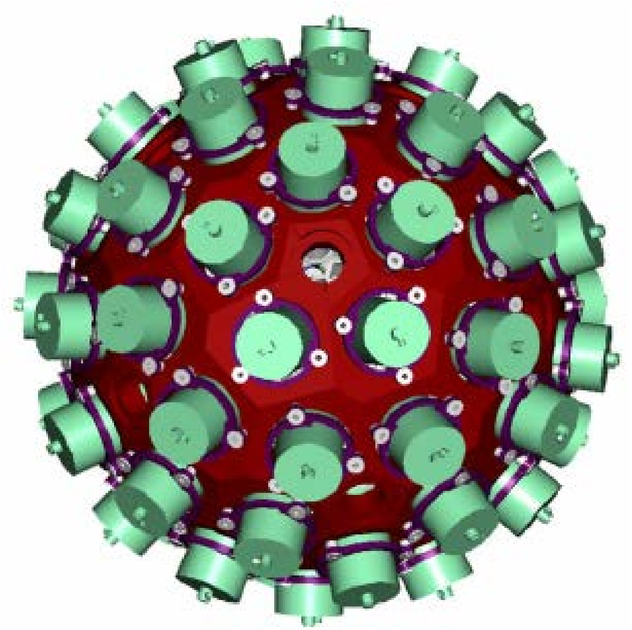
combination of:

- segmented detectors
- digital electronics
- pulse processing
- tracking the -rays



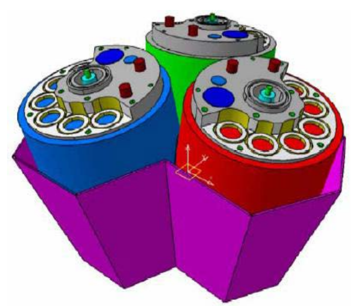
AGATA/GRETA

AGATA: Advanced GAmma Tracking Array



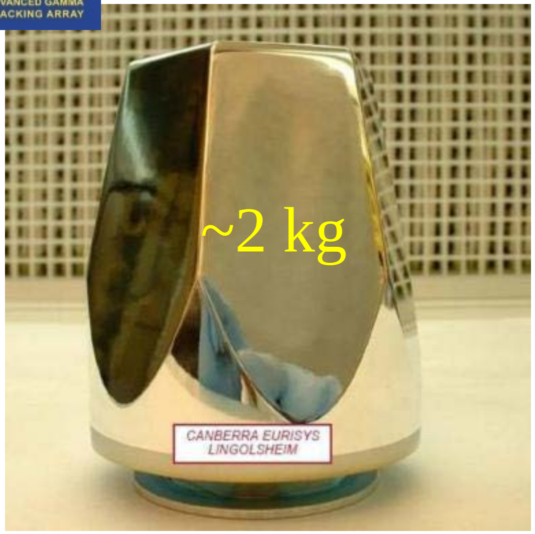
180 hexagonal crystals	3 shapes
60 triple-clusters	all equal
Inner radius (Ge)	23.5 cm
Amount of germanium	362 kg
Solid angle coverage	82 %
36-fold segmentation	6480 segments
Singles rate	~50 kHz

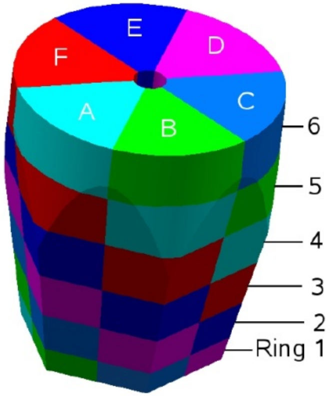
Efficiency:	43% (M_γ=1)	28% (M_γ=30)
Peak/Total:	58% (M_γ=1)	49% (M_γ=30)



6660 high-resolution digital electronics channels
Pulse Shape Analysis → position sensitive operation mode
γ-ray tracking algorithms to achieve maximum efficiency.
Coupling to ancillary detectors for added selectivity

AGATA detectors and AGATA triple-cluster



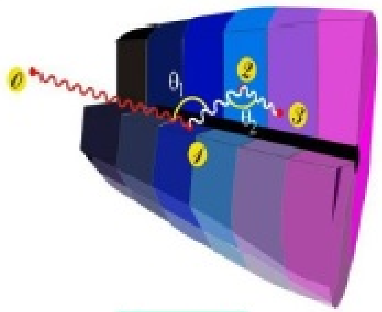


Signals from 36 segments + core
are measured as a function of time
(γ-ray interaction point)

Ingredients of gamma-ray tracking

1

Highly segmented HPGe detectors



2

Digital electronics to record and process segment signals

3

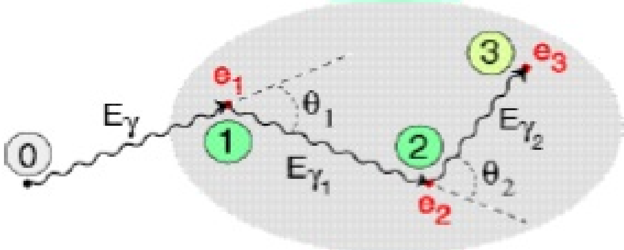
Pulse Shape Analysis to decompose recorded waves

Identified interaction points

$(x,y,z,E,t)_i$

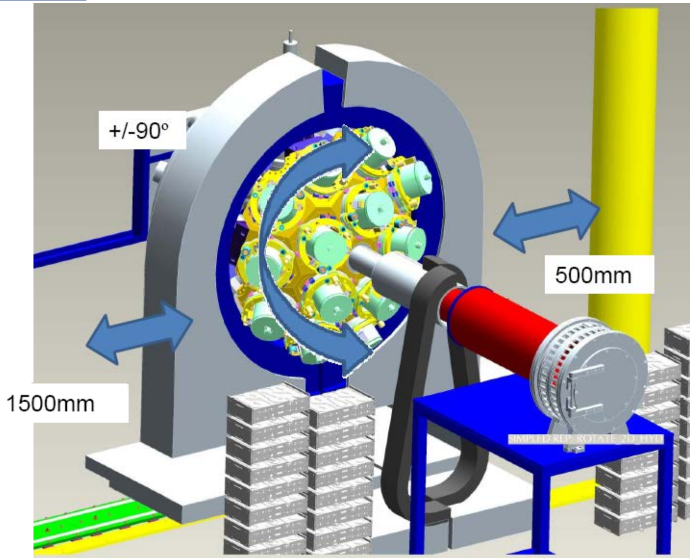
4

Reconstruction of tracks evaluating permutations of interaction points

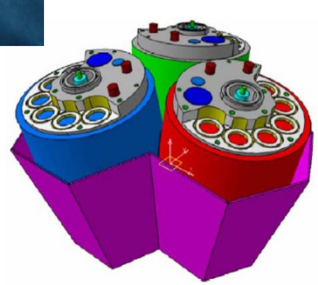


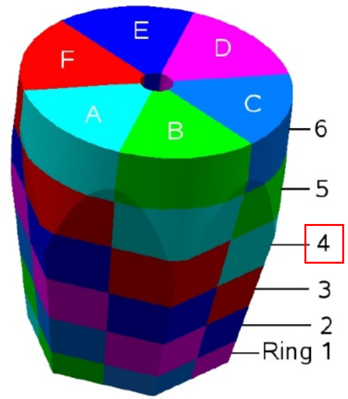
Reconstructed gamma-rays

AGATA: pulse shape analysis

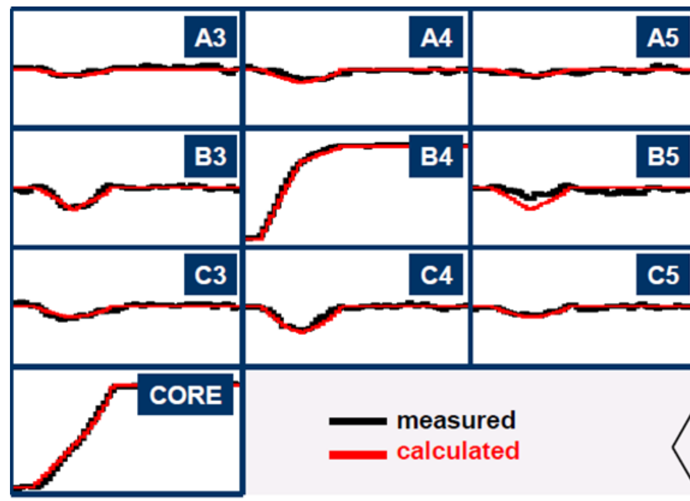


John Strachan

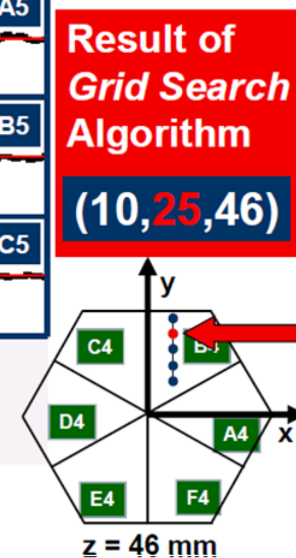




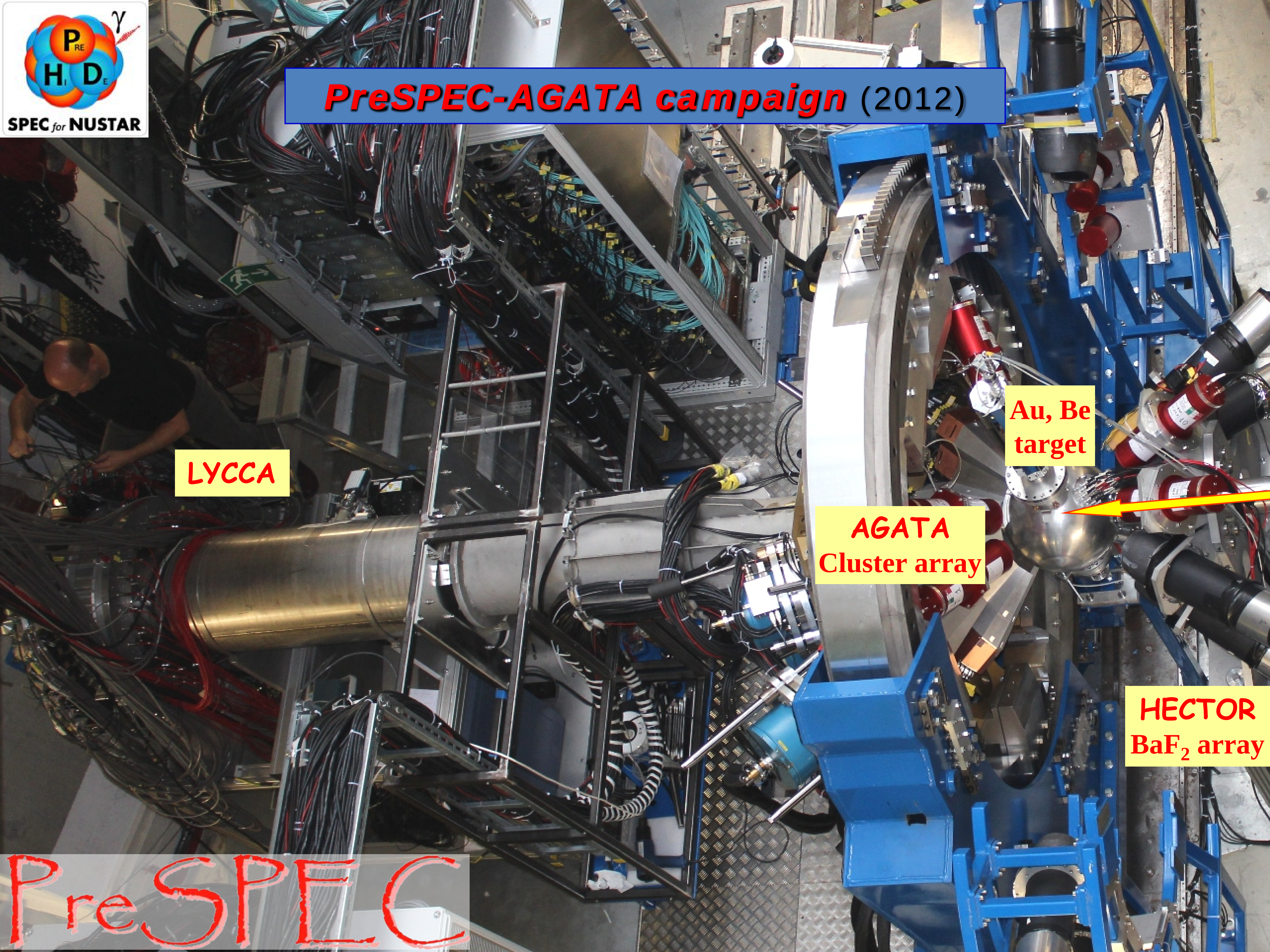
Signals from 36 segments + core are measured as a function of time (γ-ray interaction point)



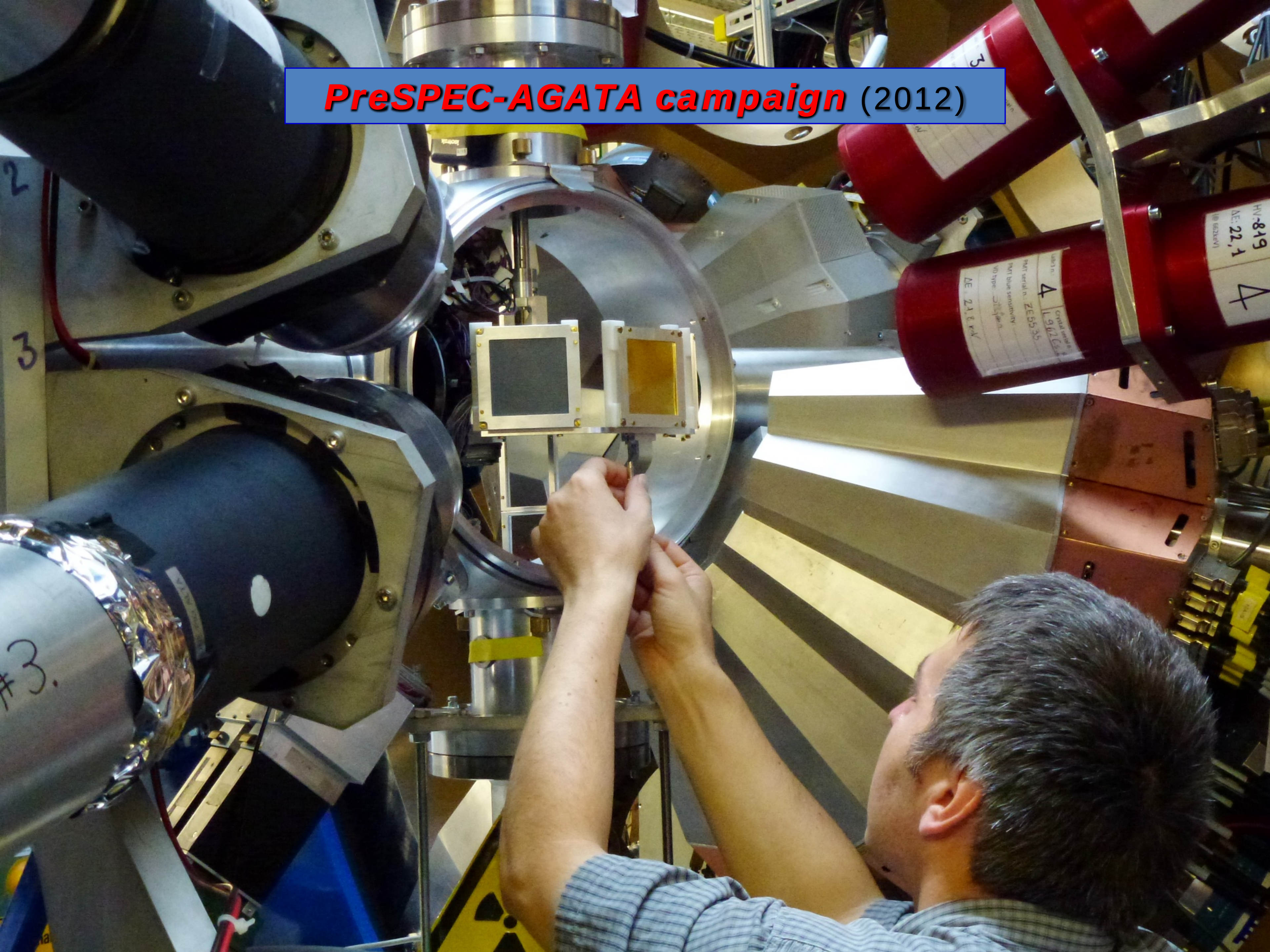
791 keV deposited in segment B4



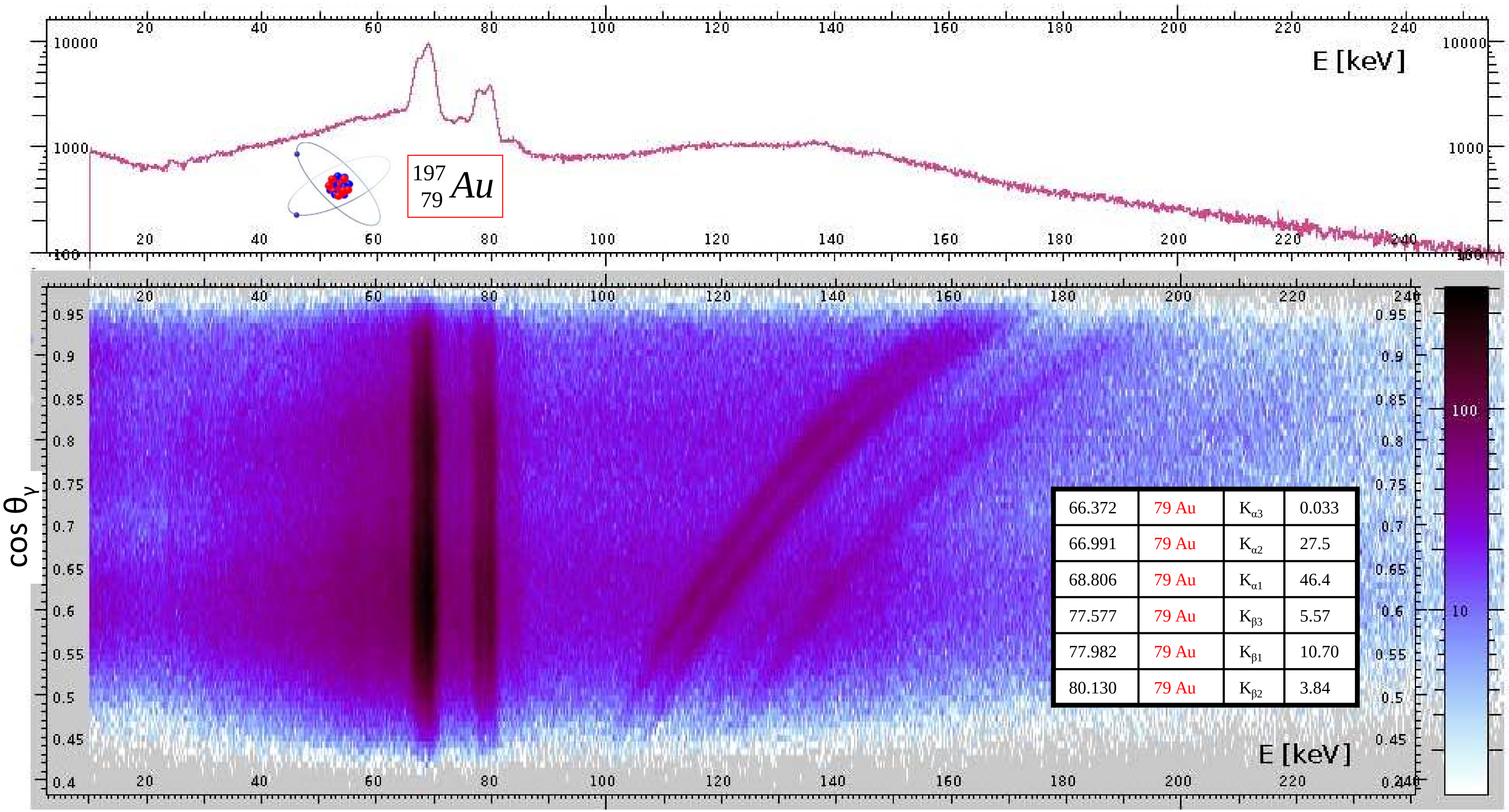
PreSPEC-AGATA campaign (2012)



PreSPEC-AGATA campaign (2012)



Doppler-shift correction – ^{238}U on ^{197}Au (386 mg/cm^2) at 183 AMeV

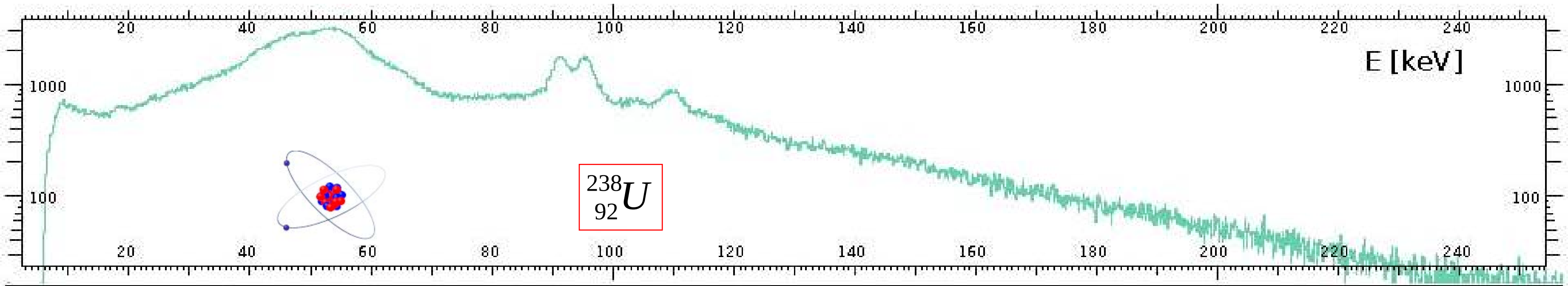


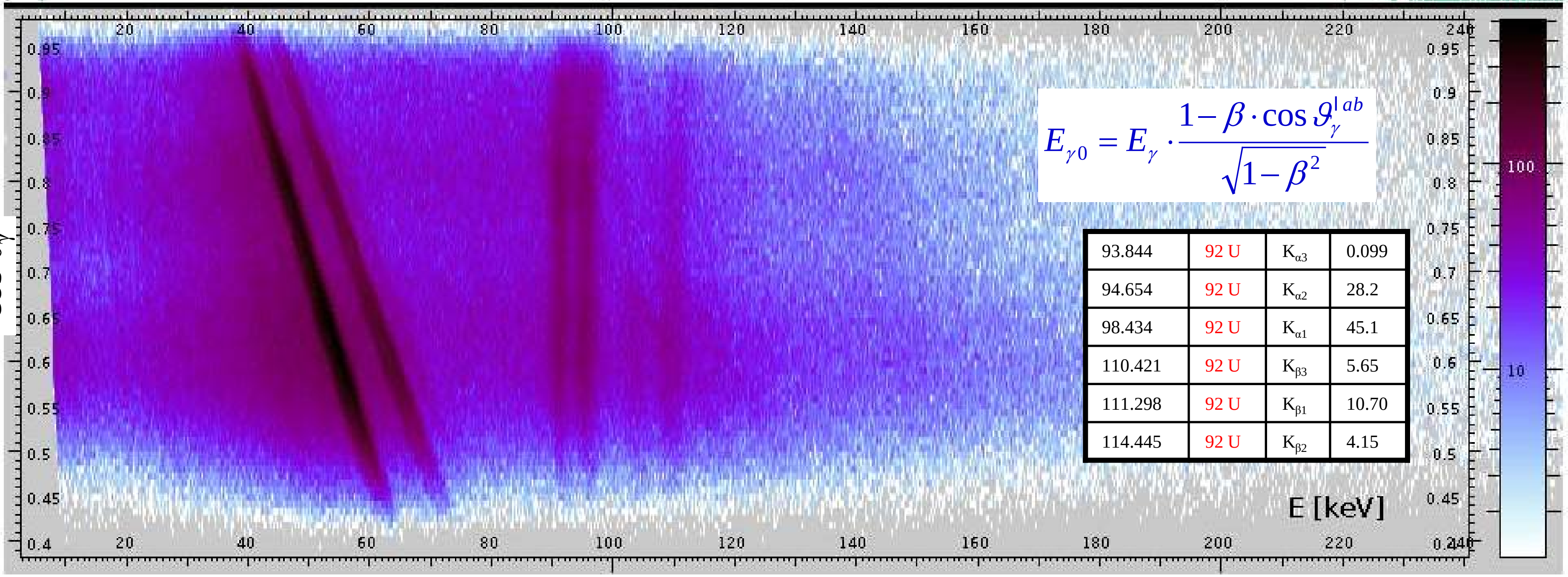
66.372	79 Au	$K_{\alpha3}$	0.033
66.991	79 Au	$K_{\alpha2}$	27.5
68.806	79 Au	$K_{\alpha1}$	46.4
77.577	79 Au	$K_{\beta3}$	5.57
77.982	79 Au	$K_{\beta1}$	10.70
80.130	79 Au	$K_{\beta2}$	3.84

http://ie.lbl.gov/atomic/x2.pdf

Michael Reese

Doppler-shift correction – ^{238}U on ^{197}Au (386 mg/cm^2) at 183 AMeV





$$E_{\gamma 0} = E_{\gamma} \cdot \frac{1-\beta \cdot \cos\vartheta_{\gamma}^{lab}}{\sqrt{1-\beta^2}}$$

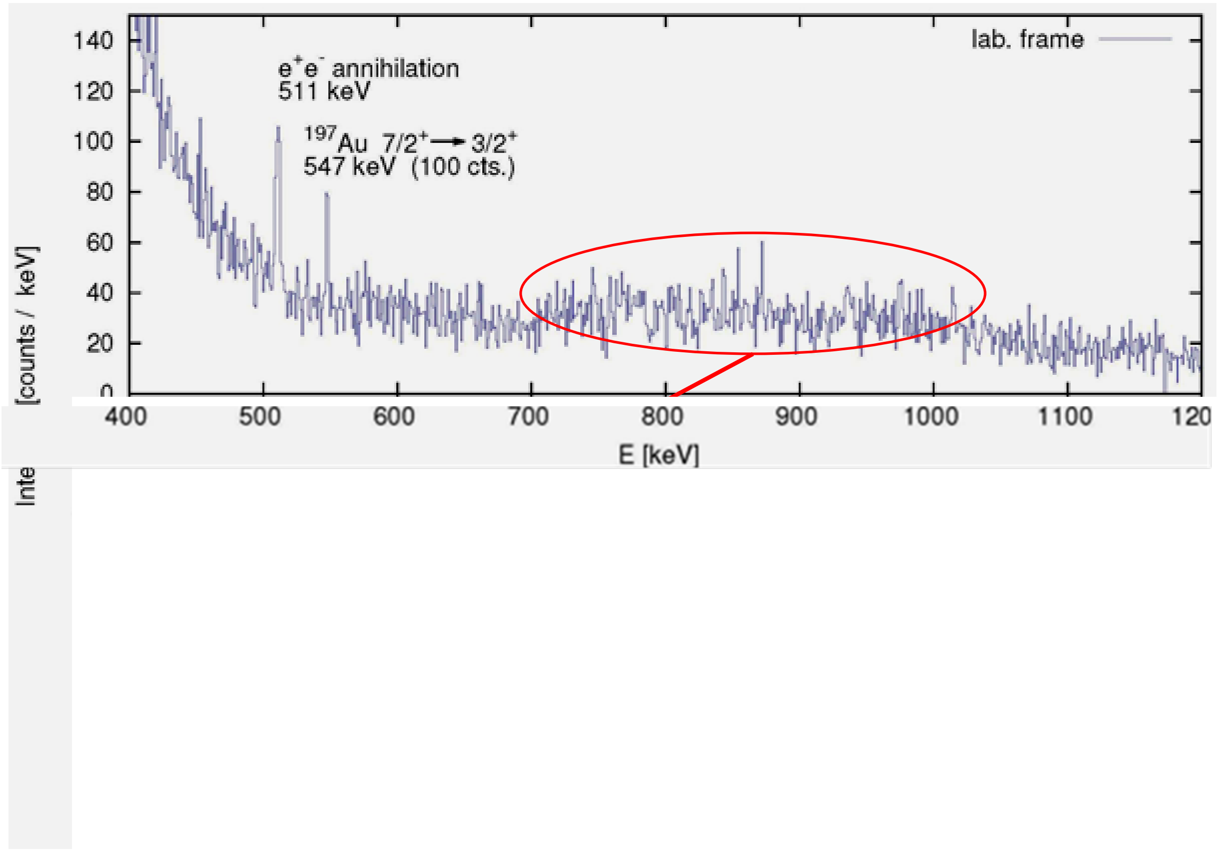
93.844	92 U	$K_{\alpha 3}$	0.099
94.654	92 U	$K_{\alpha 2}$	28.2
98.434	92 U	$K_{\alpha 1}$	45.1
110.421	92 U	$K_{\beta 3}$	5.65
111.298	92 U	$K_{\beta 1}$	10.70
114.445	92 U	$K_{\beta 2}$	4.15

http://ie.lbl.gov/atomic/x2.pdf

Michael Reese

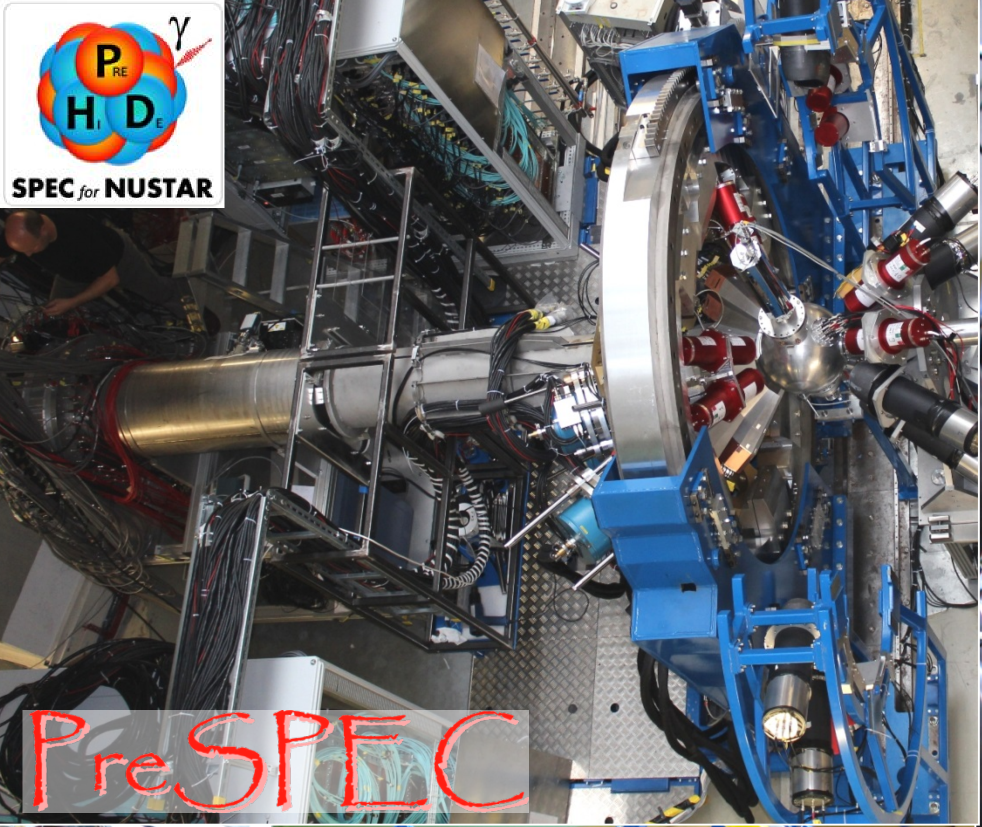
Scattering experiment at relativistic energies

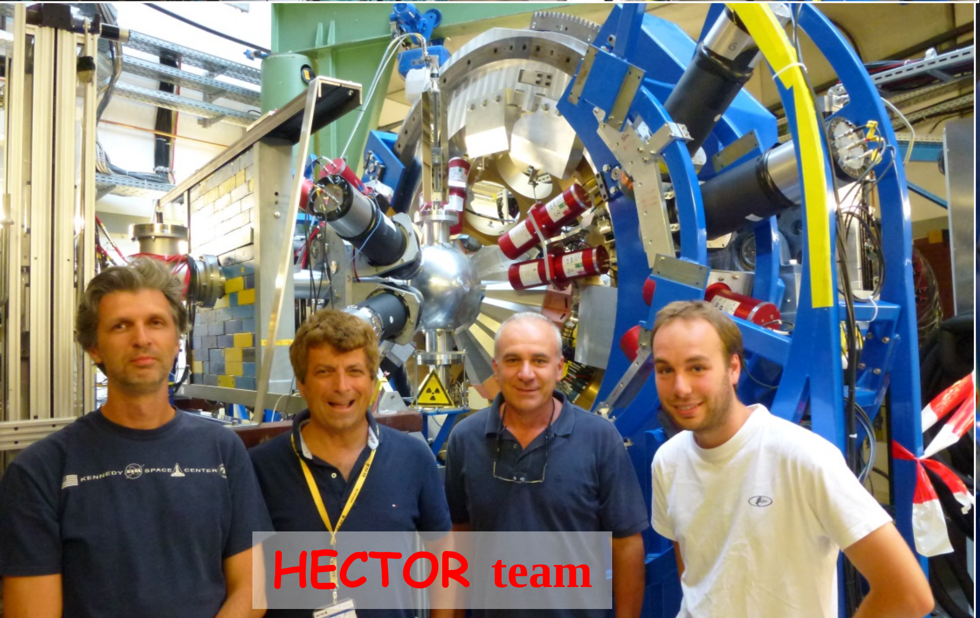
$^{80}Kr \rightarrow {}^{197}Au$, 150 AMeV

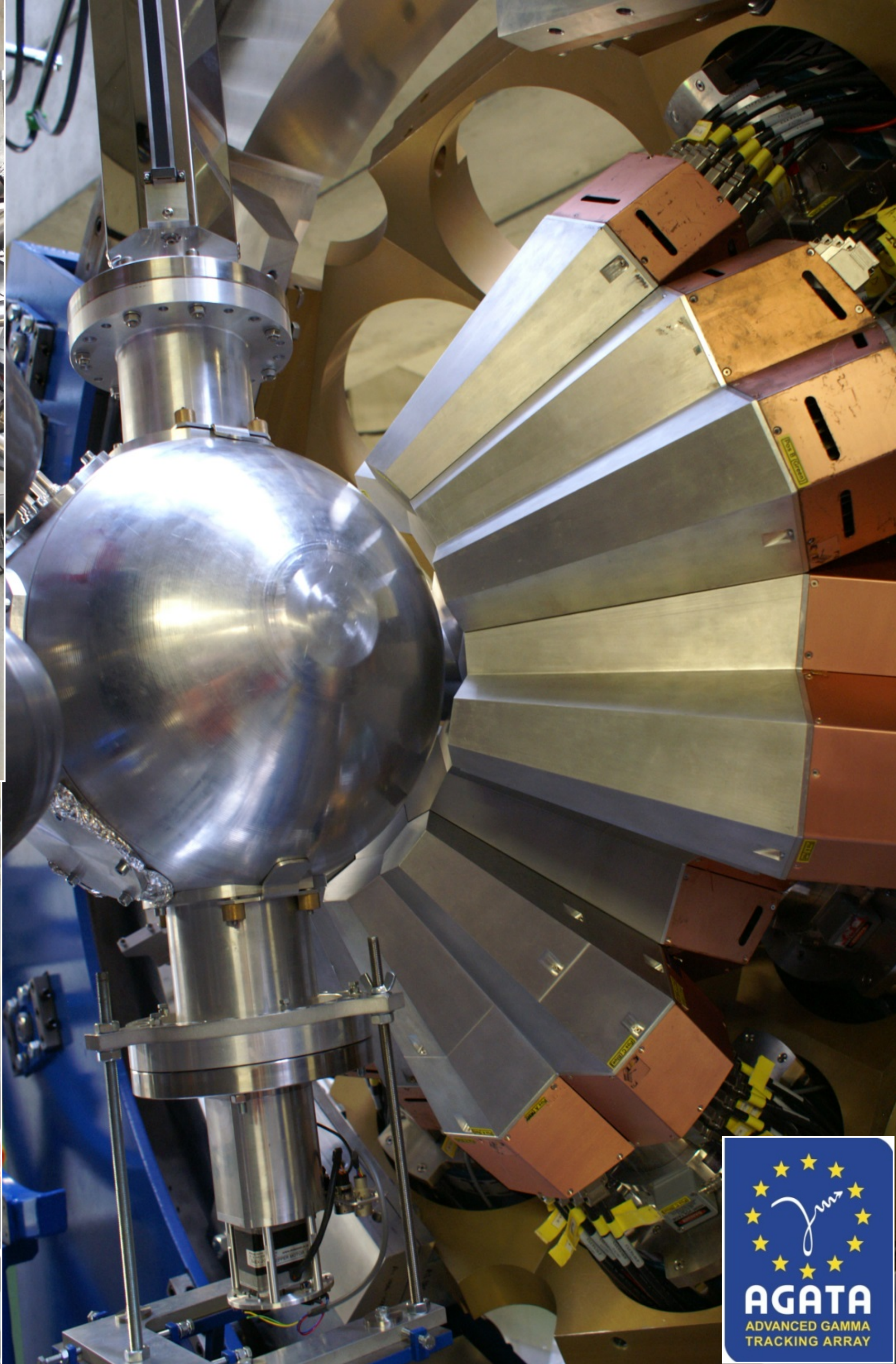


Doppler effect

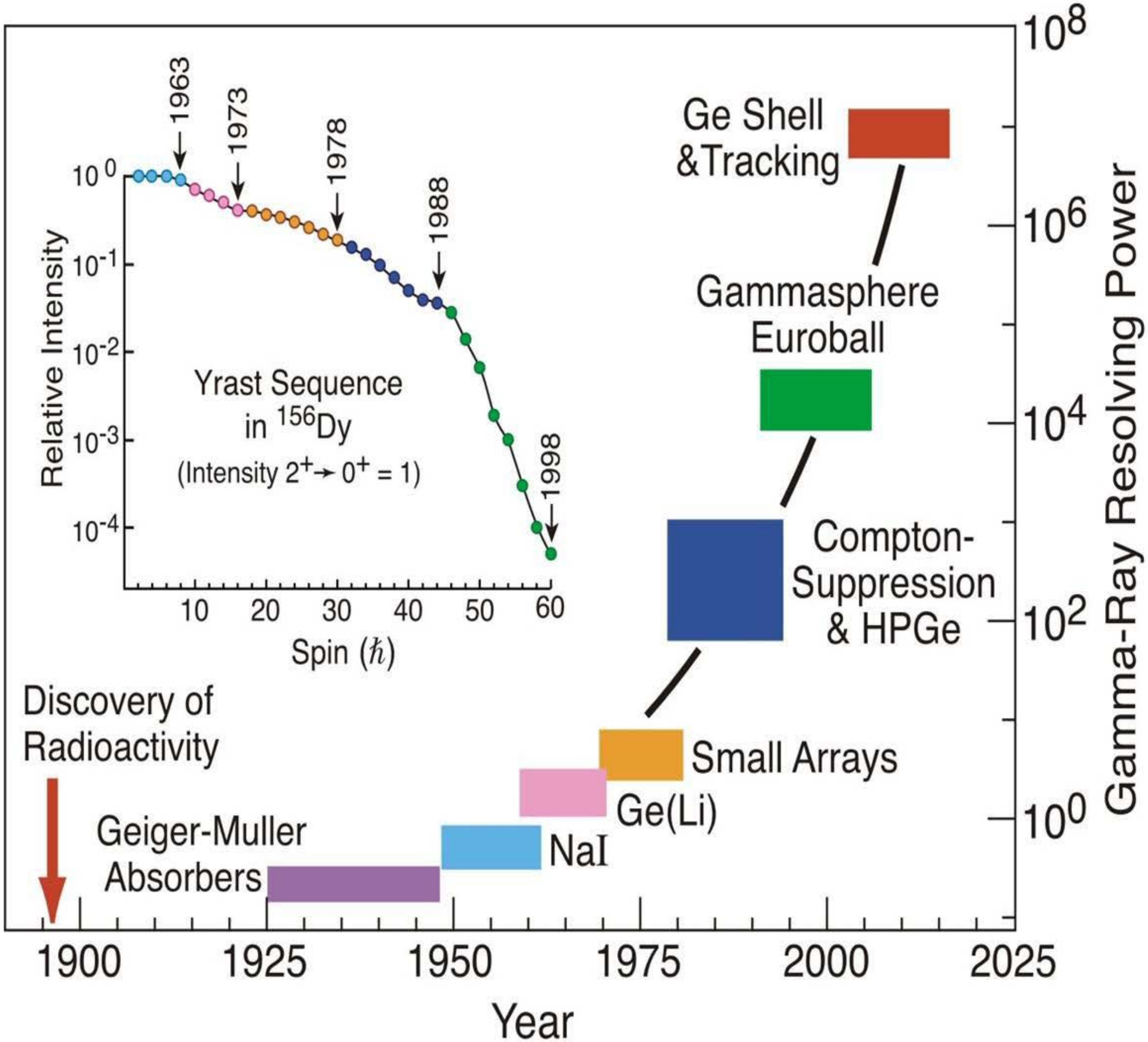
$$\frac{E_{\gamma 0}}{E_{\gamma}} = \frac{1-\beta \cdot \cos \vartheta_{\gamma}^{lab}}{\sqrt{1-\beta^2}}$$


SPEC for NUSTAR
PreSPEC


HECTOR team


AGATA
ADVANCED GAMMA
TRACKING ARRAY

Summary



1963
1973
1978
1988
1998
Relative Intensity
10 0
10-1
10-2
10-3
10-4
Yrast Sequence
in 156Dy
(Intensity 2+→ 0+ = 1)
10
20
30
40
50
60
Spin (ħ)
Ge Shell
&Tracking
Gammasphere
Euroball
Compton-
Suppression
& HPGe
Small Arrays
Ge(Li)
NaI
Discovery of
Radioactivity
Geiger-Muller
Absorbers
10^8
10^6
10^4
10^2
10^0
Gamma-Ray Resolving Power
1900
1925
1950
1975
2000
2025
Year