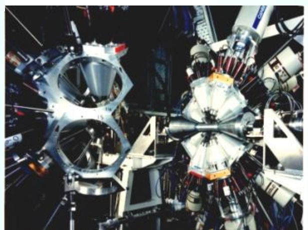
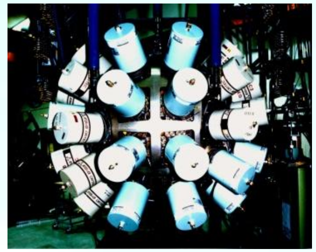
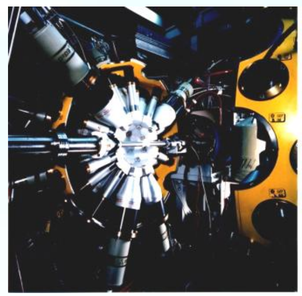
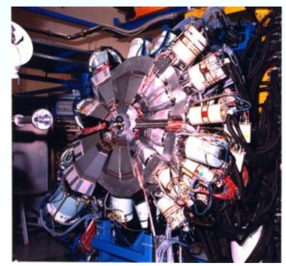
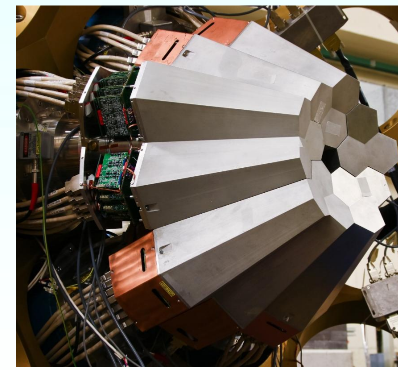
Gamma spectroscopy from Liverpool to Europe

We’ve won (done) it five times

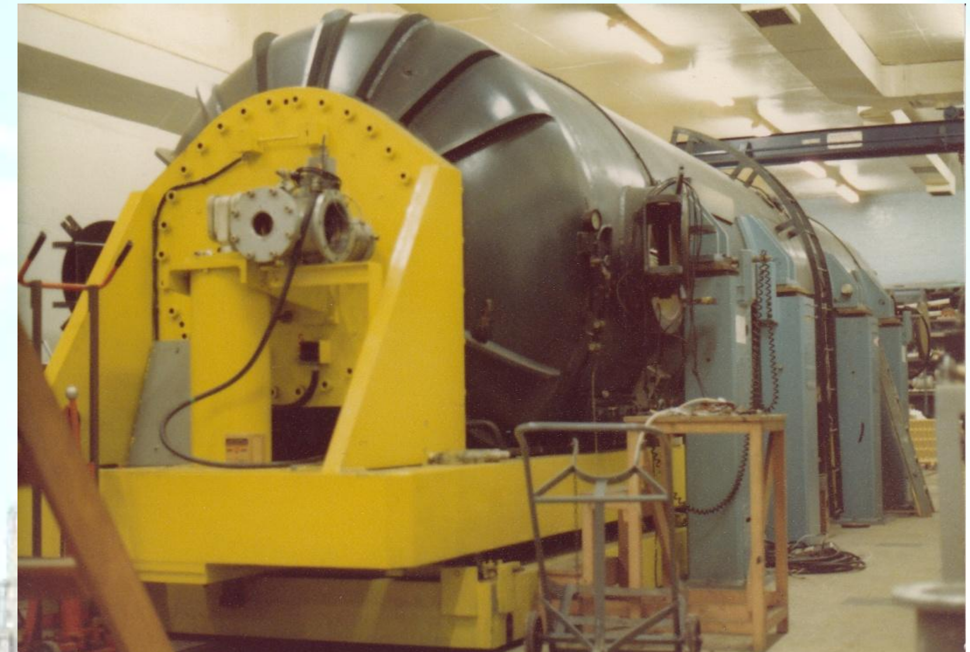



John Simpson
Nuclear Physics Group
STFC Daresbury Laboratory

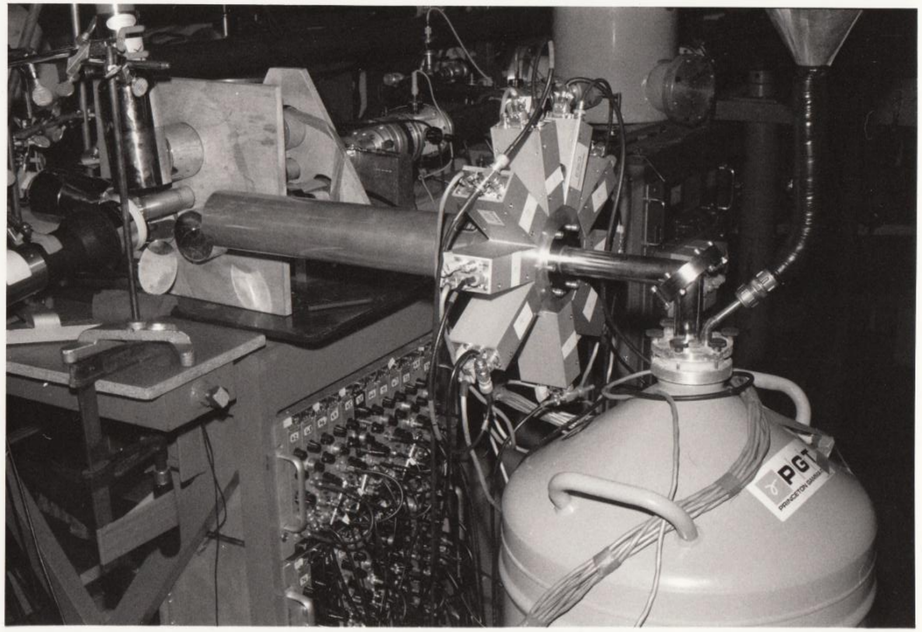
EGAN Workshop, Liverpool, December 2011

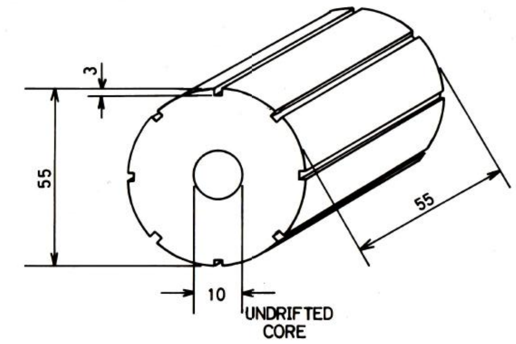
Visiting Professor at
The University of Liverpool

The Liverpool Tandem



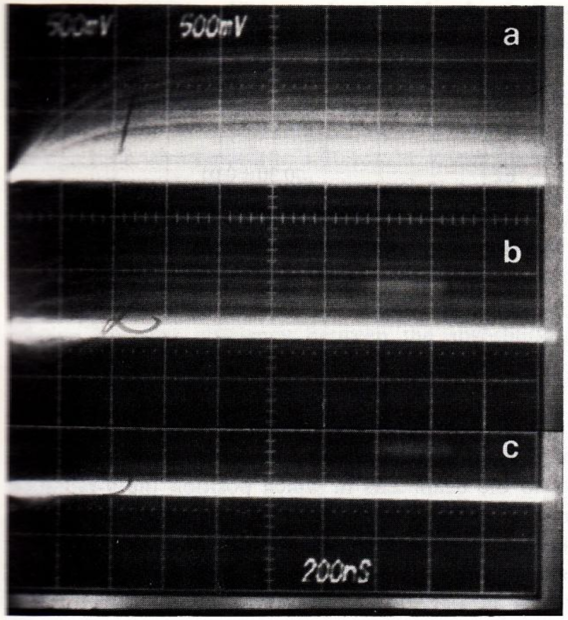
•*Application of a Sectored Ge(Li) Detector as a Compton Polarimeter*
J.Simpson, P.A.Butler and L.P.Ekström
Nucl.Instr.Meth. **204** (1983) 463-469.

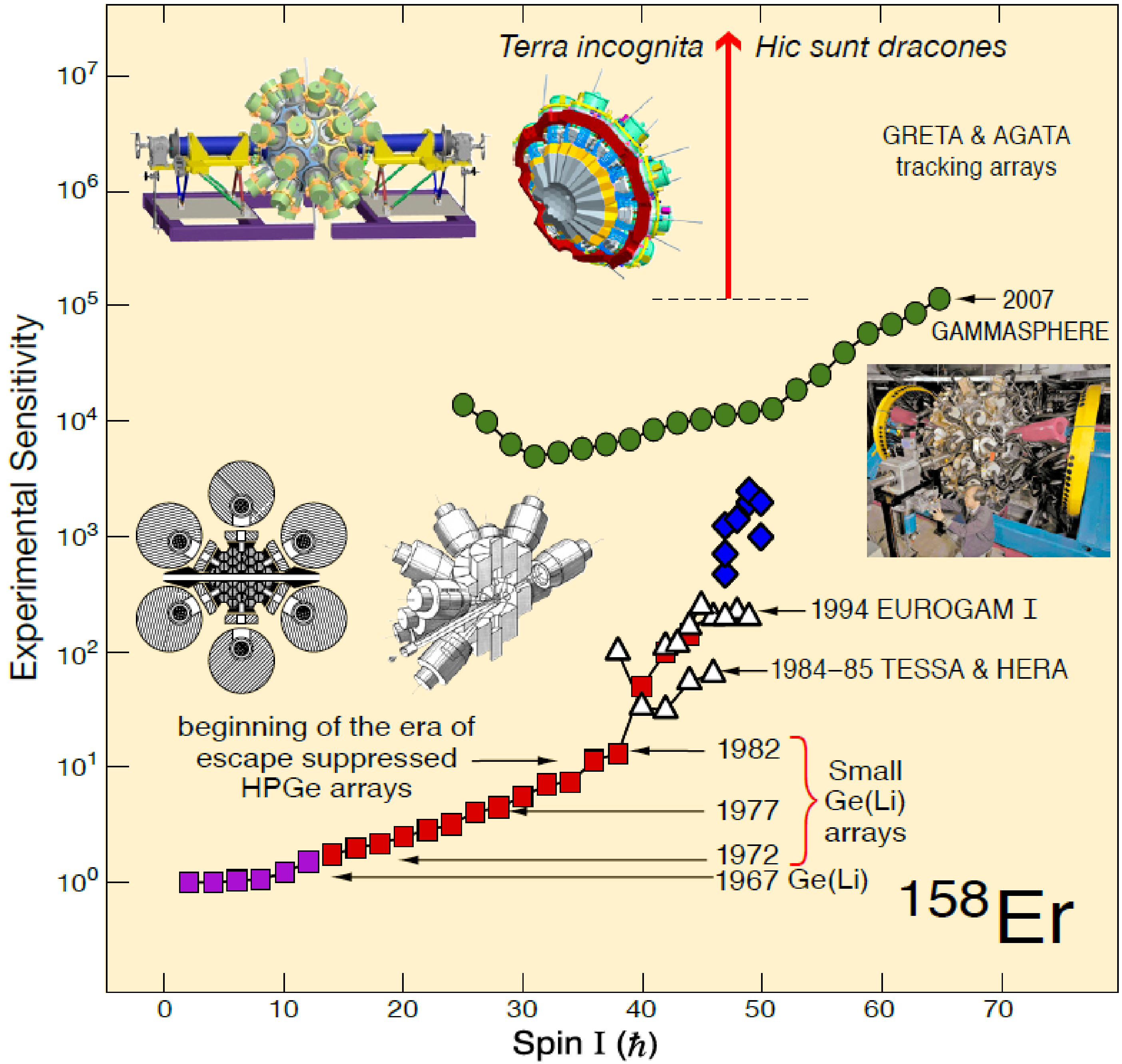




SECTORED GERMANIUM CRYSTAL

Image pulses




Terra incognita
Hic sunt dracones
GRETA & AGATA
tracking arrays
2007
GAMMASPHERE
1994 EUROGAM I
1984–85 TESSA & HERA
beginning of the era of
escape suppressed
HPGe arrays
1982
1977
1972
1967 Ge(Li)
Small
Ge(Li)
arrays
158Er
Experimental Sensitivity
Spin I (ħ)
10^0
10^1
10^2
10^3
10^4
10^5
10^6
10^7
0
10
20
30
40
50
60
70

The nucleus is always full of surprises

Instrumentation advances ⇔ New Science

Gamma-ray spectroscopy before Escape Suppressed Spectrometer Arrays

NaI detectors ~1950-   resolution ~6% @ 1MeV

Ge detectors ~1960   resolution ~0.2% @ 1MeV

NaI arrays

Ge arrays   few Ge(Li)

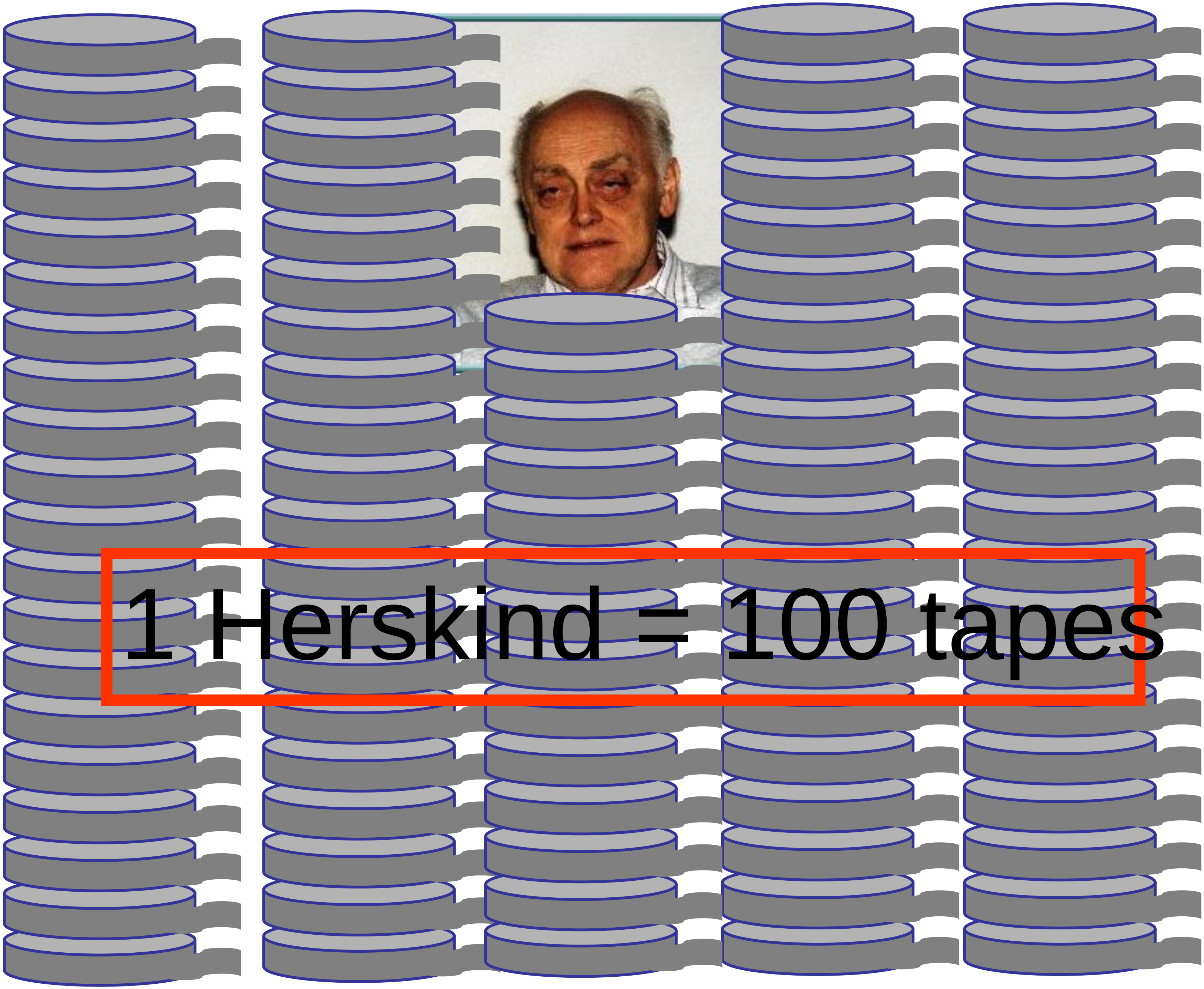
Few ESS's

Sum energy detectors, multiplicity filters

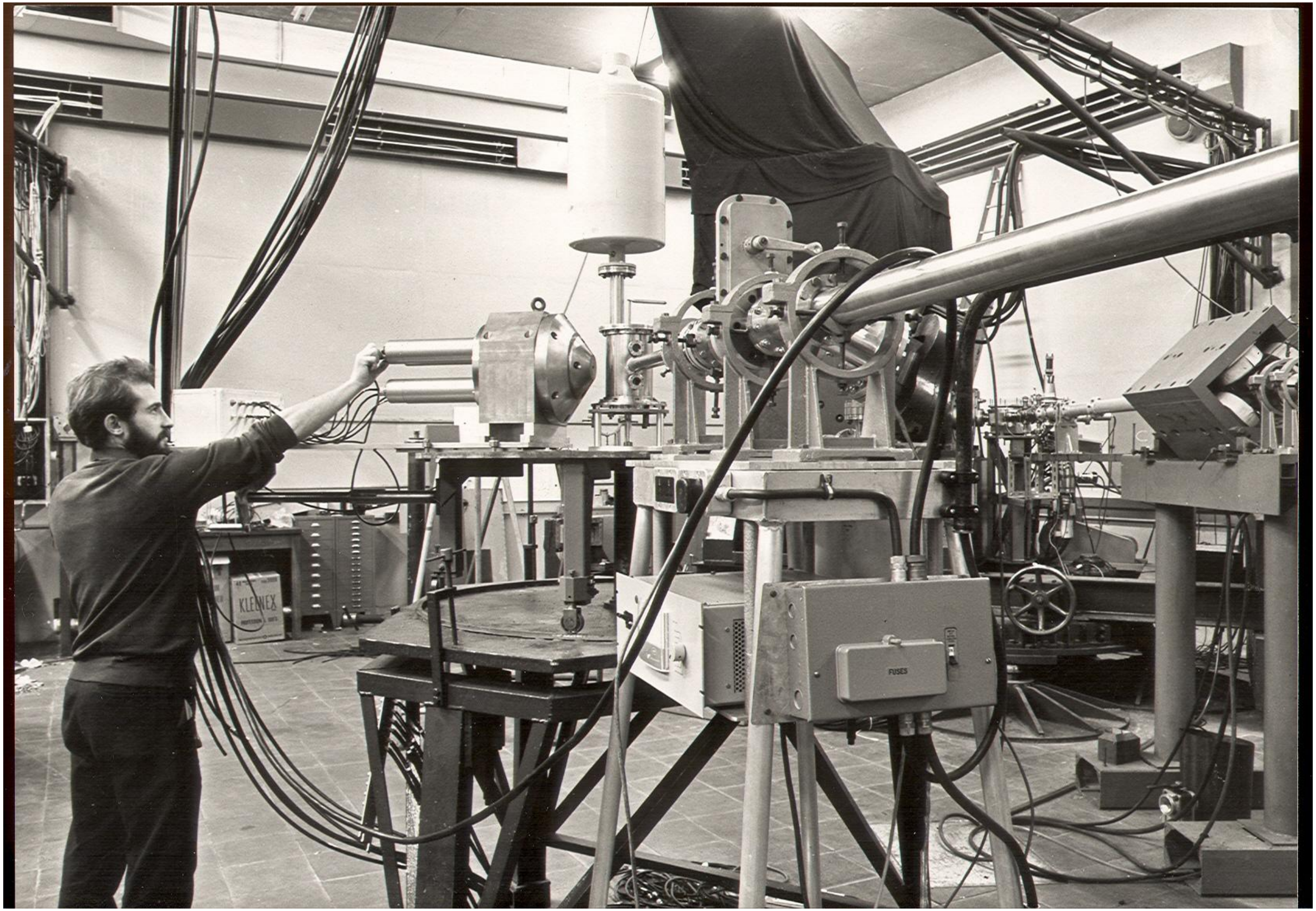
Spin spectrometer Oak Ridge

Crystal ball Heidelberg

Storage problem

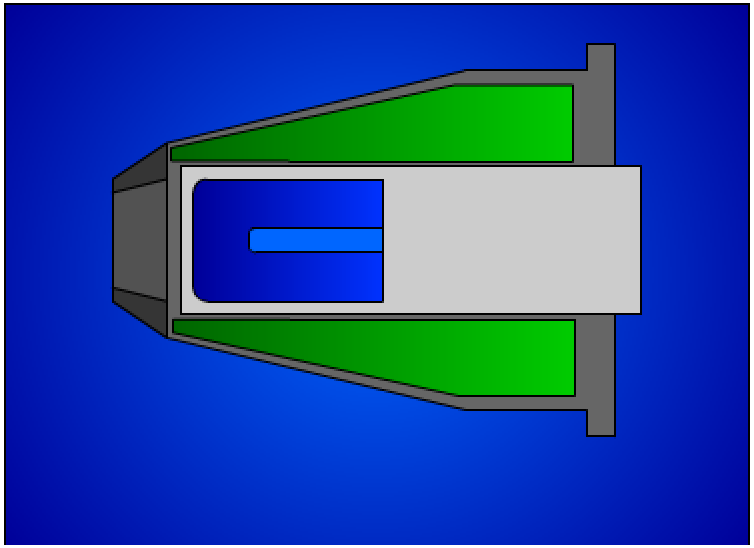

1 Herskind = 100 tapes

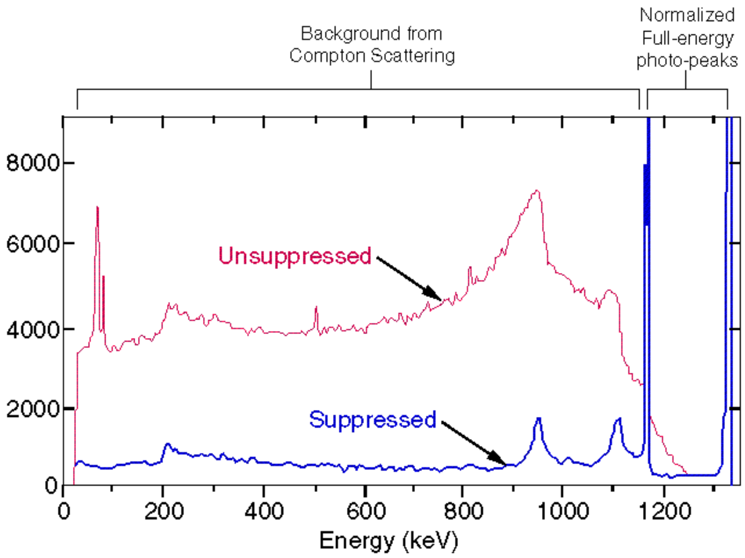
The First Escape Suppressed Spectrometer at Liverpool



John Francis Sharpey-Schafer 1968

The scattering problem...





High background hence suppression shields

High efficiency hence arrays of ESS

Arrays of Escape Suppressed Spectrometers

TESSA0 The Escape Suppressed Spectrometer Array

The first one TESSA

Daresbury Study Weekend 1979
Nuclei Far from Stability

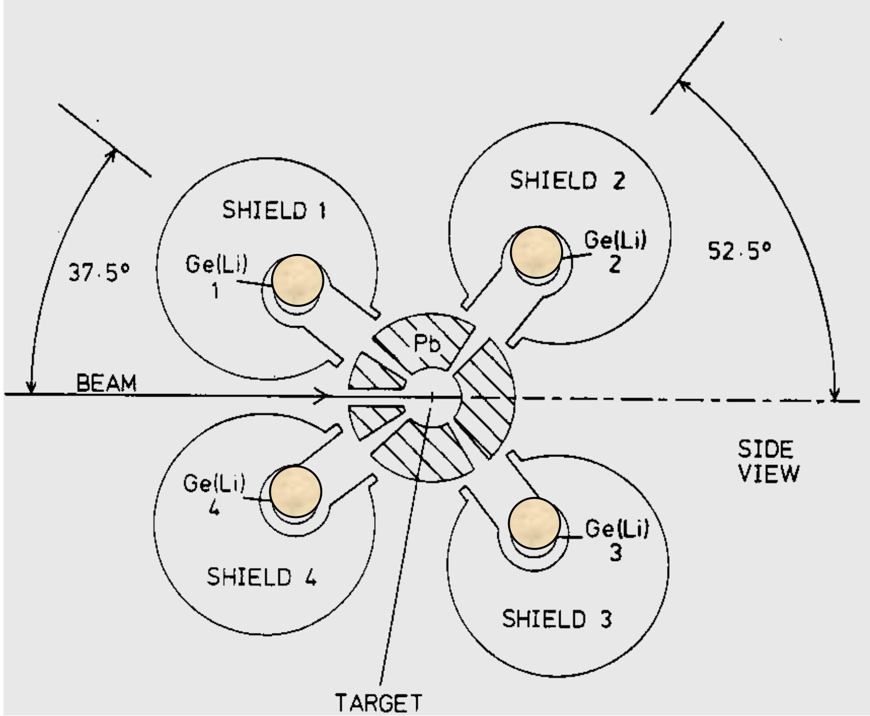
UK Denmark collaboration
Niels Bohr Institute 1980-1982
FN tandem

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

γ^2 Factor of 8 improvement in ph. ph. Coincidences

No channel selection

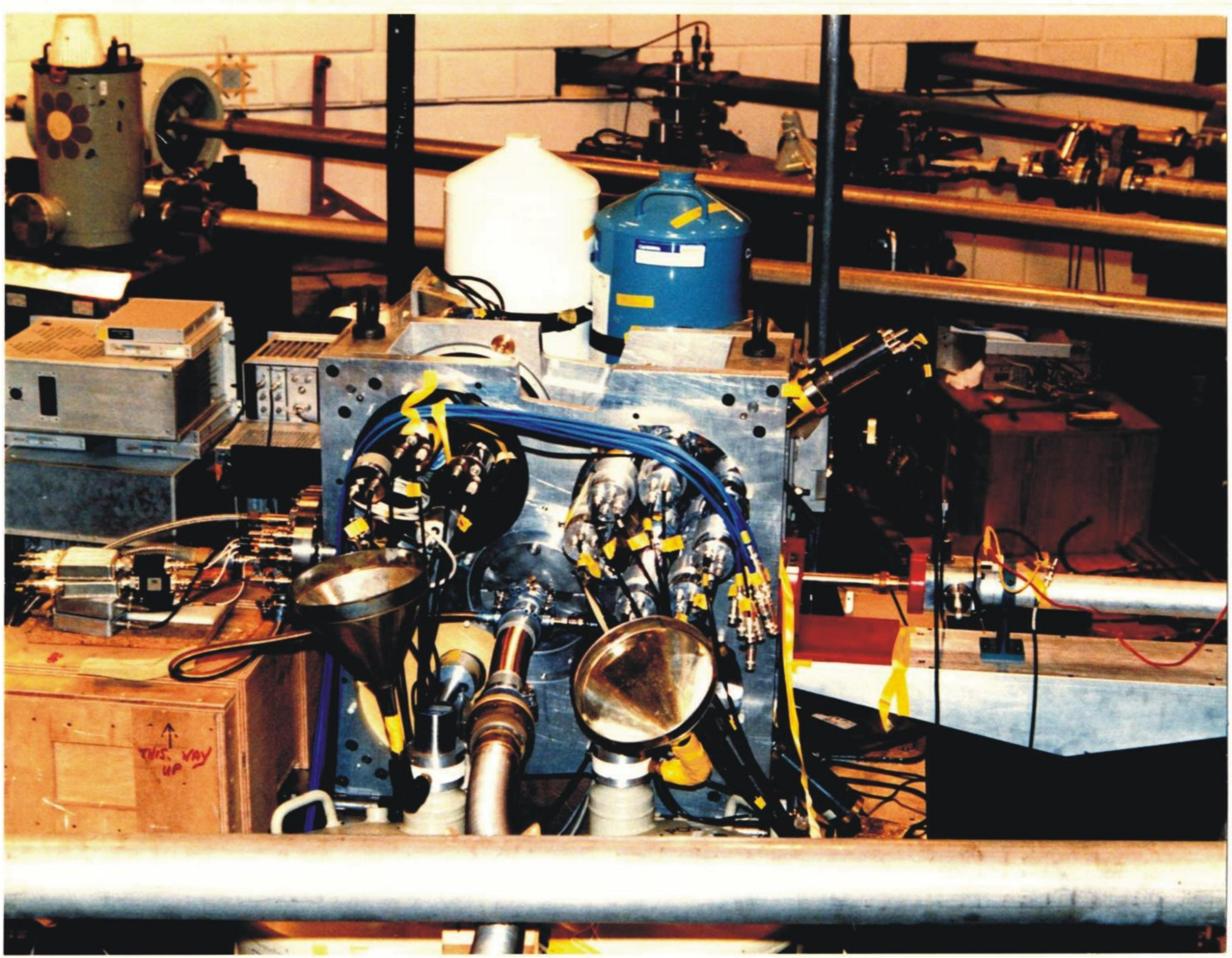
γ^2 Factor of 8 improvement in ph. ph. Coincidences



TESSA1

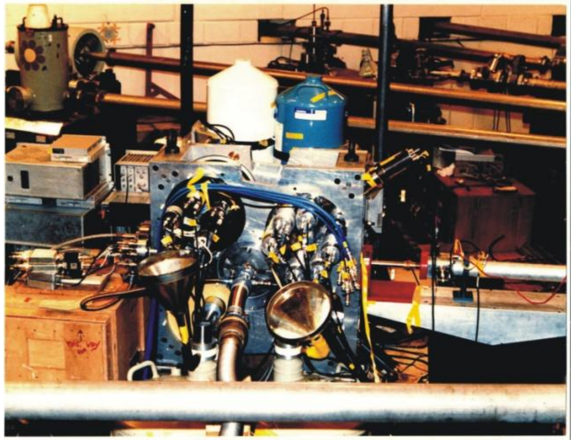
14 element multiplicity filter

TESSA0 The Escape Suppressed Spectrometer Array



Spectroscopy of nuclei near ^{158}Er (since 1980)

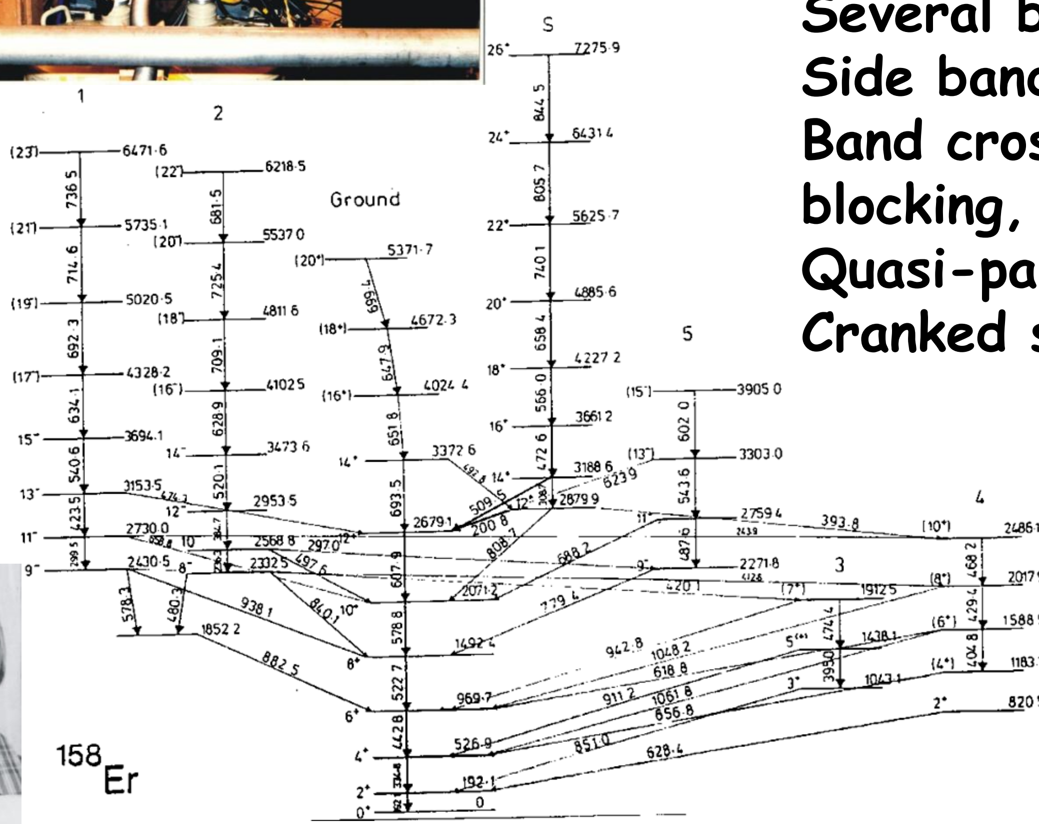
~1980 yrast states to spin ~30, naked Ge arrays



~1980-1982 TESSA

Escape suppressed array at NBI

Several bands
Side bands to spins in mid 20's
Band crossing systematics,
blocking, pairing reduction
Quasi-particle configurations
Cranked shell model

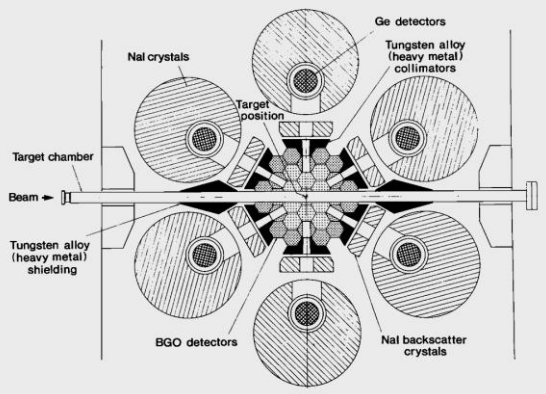


J.Simpson et al., J.Phys. G10 (1984) 383

1983 TESSA to Daresbury

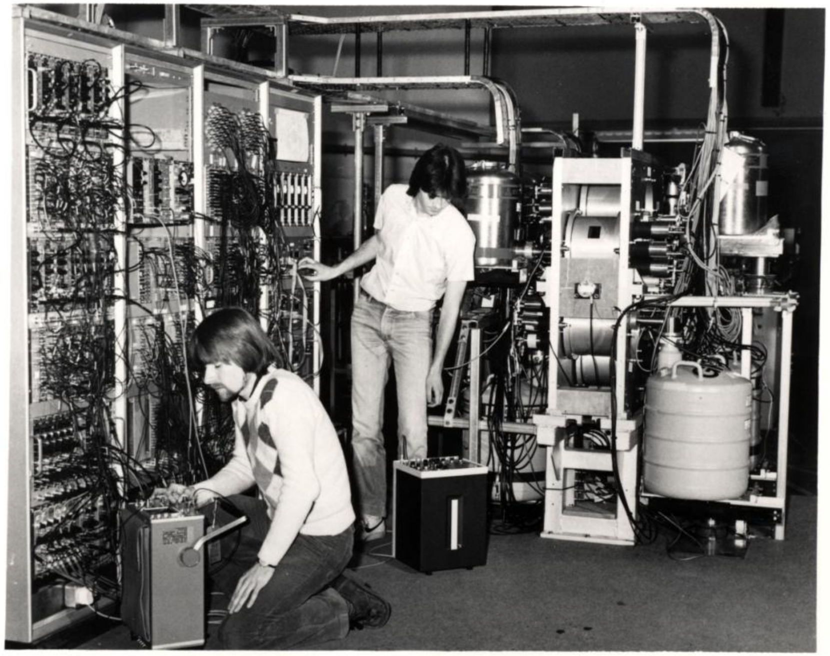
Heavier Ion beams

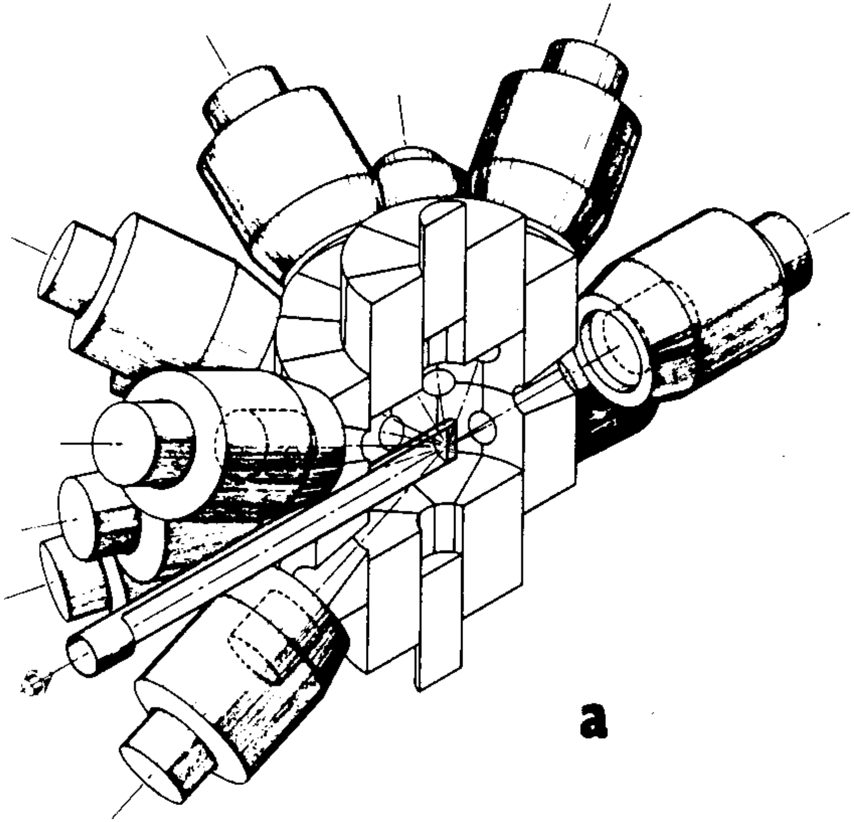
6 ESS, 50 element inner BGO ball



Multiple bands to spin I~40
Prolate to oblate transition
Systematics of second ($\pi h_{11/2}$) alignments
Evidence for superdeformation in ^{152}Dy, $E_{\gamma 1}$ vs. $E_{\gamma 2}$ plots

TESSA2





~1987

BGO replaces NaI(Tl)

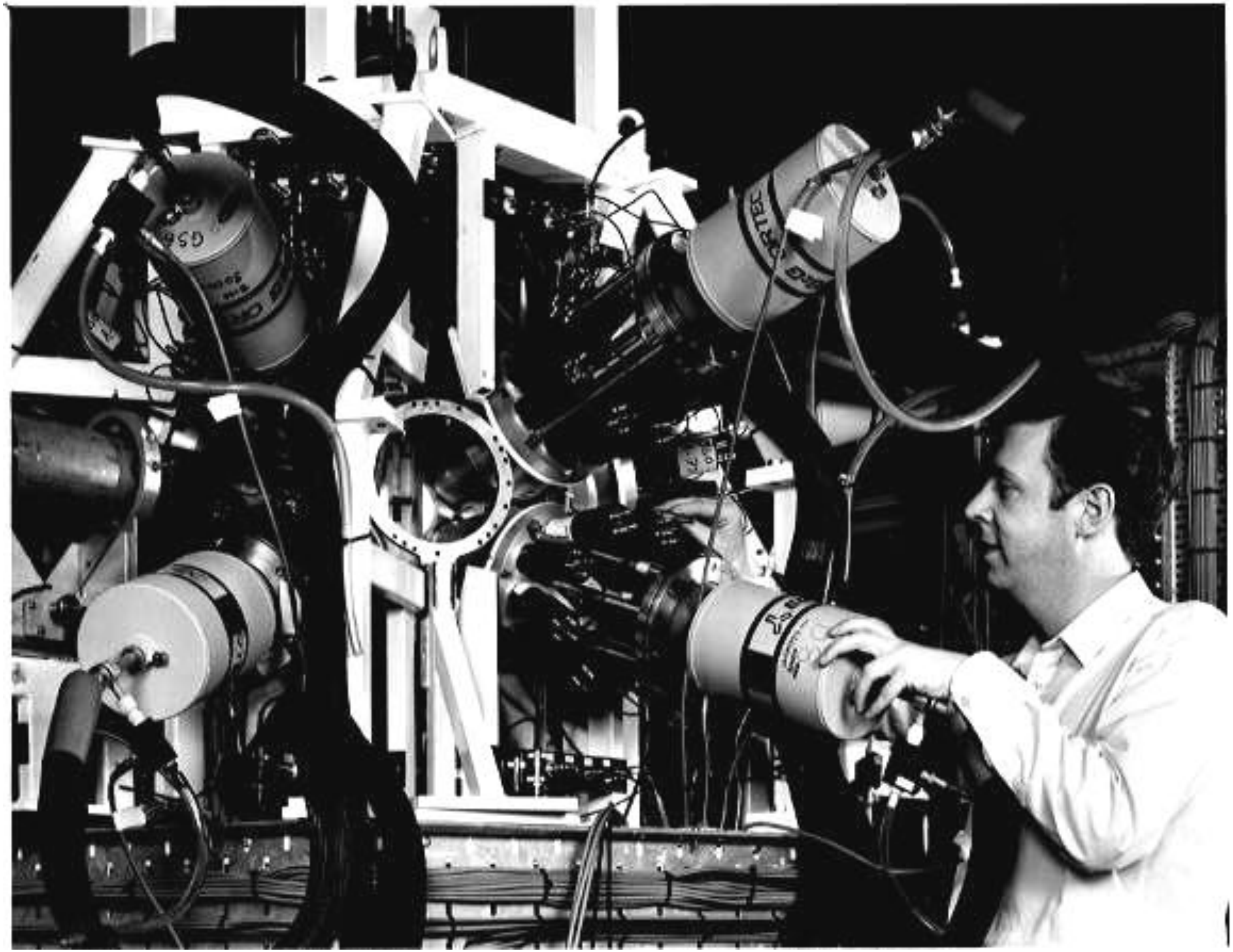
1cm ≅ 1 inch

HERA (LBNL)

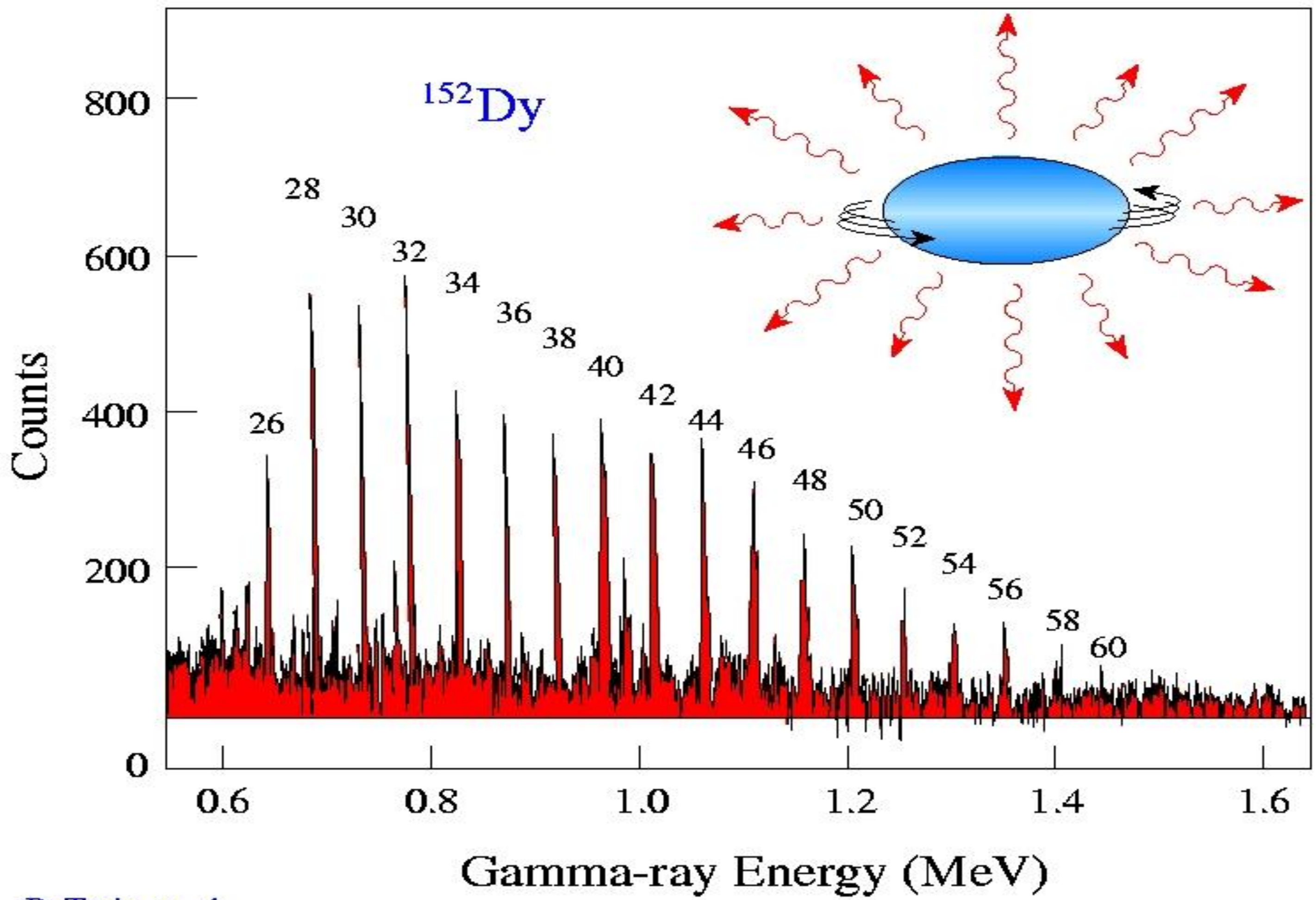
21 ESS + BGO ball

γ-γ-γ

TESSA3



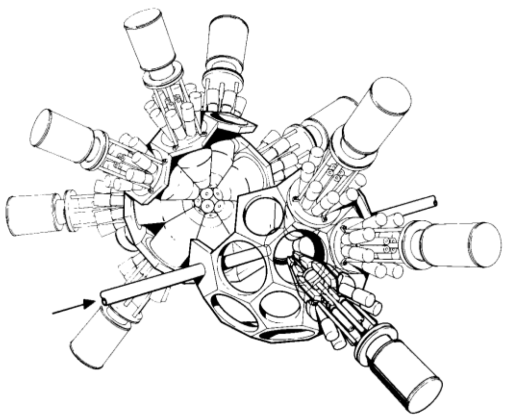
The first case of a high spin superdeformed band



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

ESSA30

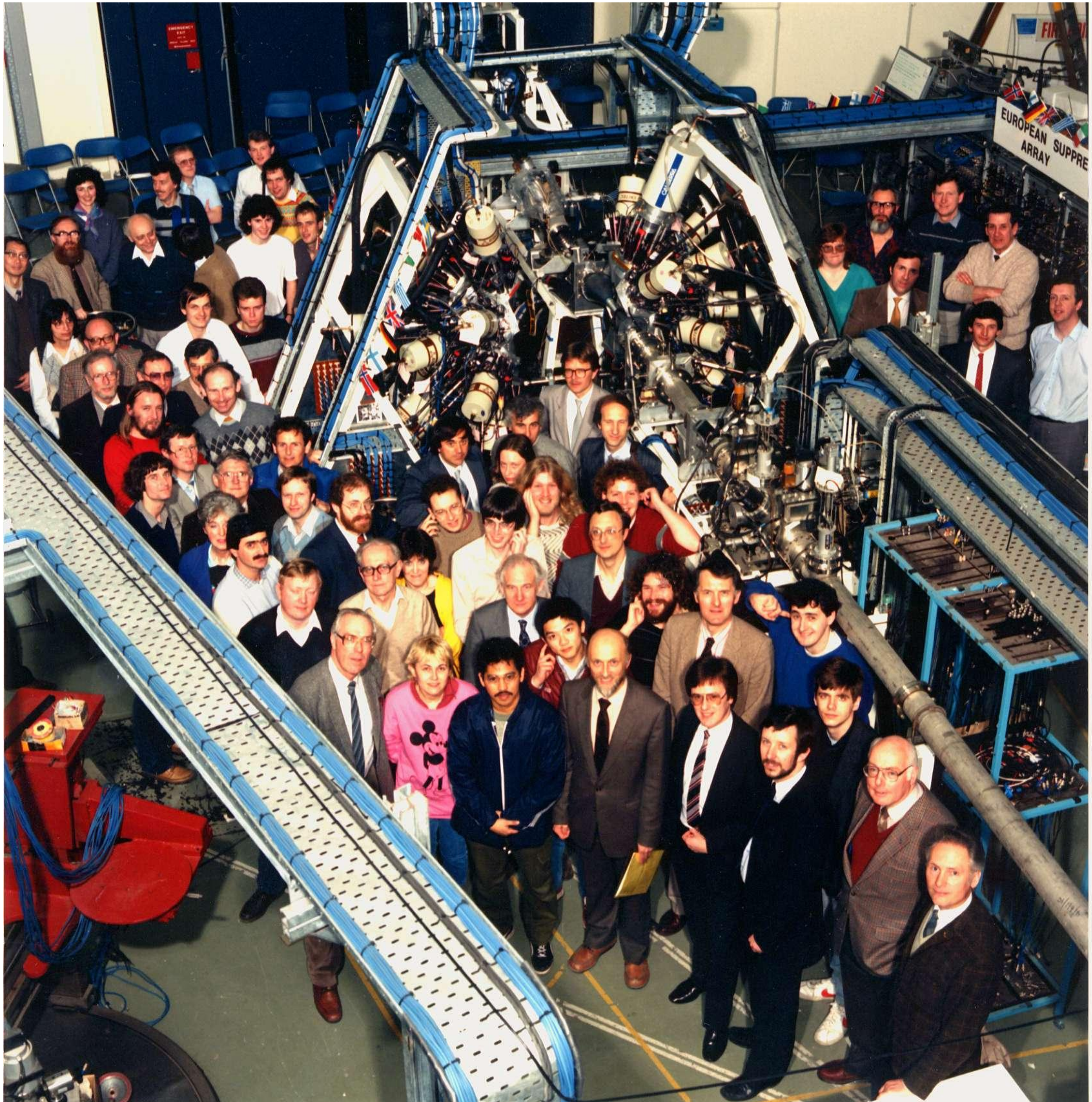
European collaboration
UK, Denmark, Germany, Italy, Greece



30 ESS (British, German, Italian, Scandinavian)
Daresbury
April 1987 for 8 months

Spokespersons:
Ryde, Lisle, Lieder, Sletten, Butler, Nolan, Sharpey-Schafer,
Kirwan, Wadsworth, Hubel, Durell, Lieb, Jones

Euroball Koln, Simonskall, Strasbourg, Bad Honnef


EUROPEAN SUPPRE
ARRAY

Large array of escape-suppressed spectrometers led to a revolution in gamma-ray spectroscopy

~1990

Many array world wide
10-20 ESS
TESSA, Nordball, Chateau de Cristal, HERA, ORIRIS, MIPAD, 8π, ANL,….

Efficiency ~ 0.5% - 1.5%

Structure features ~1% of total nuclear intensity

- Superdeformation
- Shape Changes
- Alignments
- N=Z nuclei to Mo
- Damping
- Fission fragment spectroscopy
- Pairing collapse
- Octupole shapes

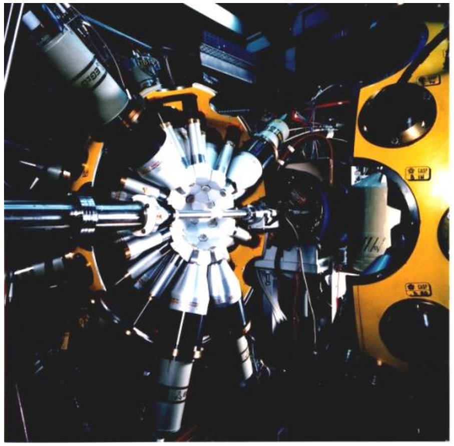
Physics programme required a much more efficiency array with high resolving power to lower the intensity limit by orders of magnitude

1991

Increase the detection efficiency

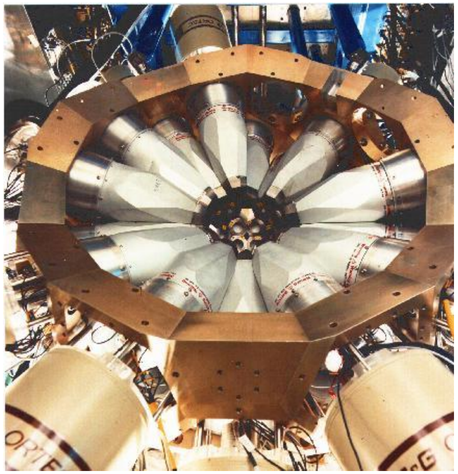
Use more Ge detectors

Use large Ge detectors 70% - 80%



Composite Ge detectors (Clovers, Clusters)

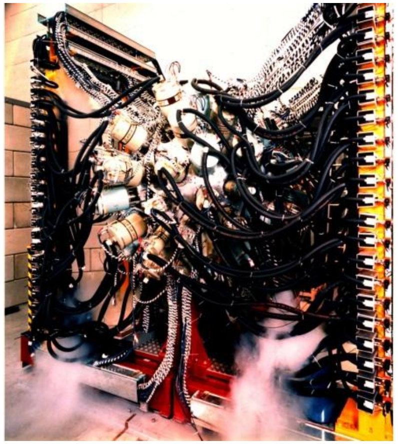
GaSp, Legnaro, Italy 40 detectors



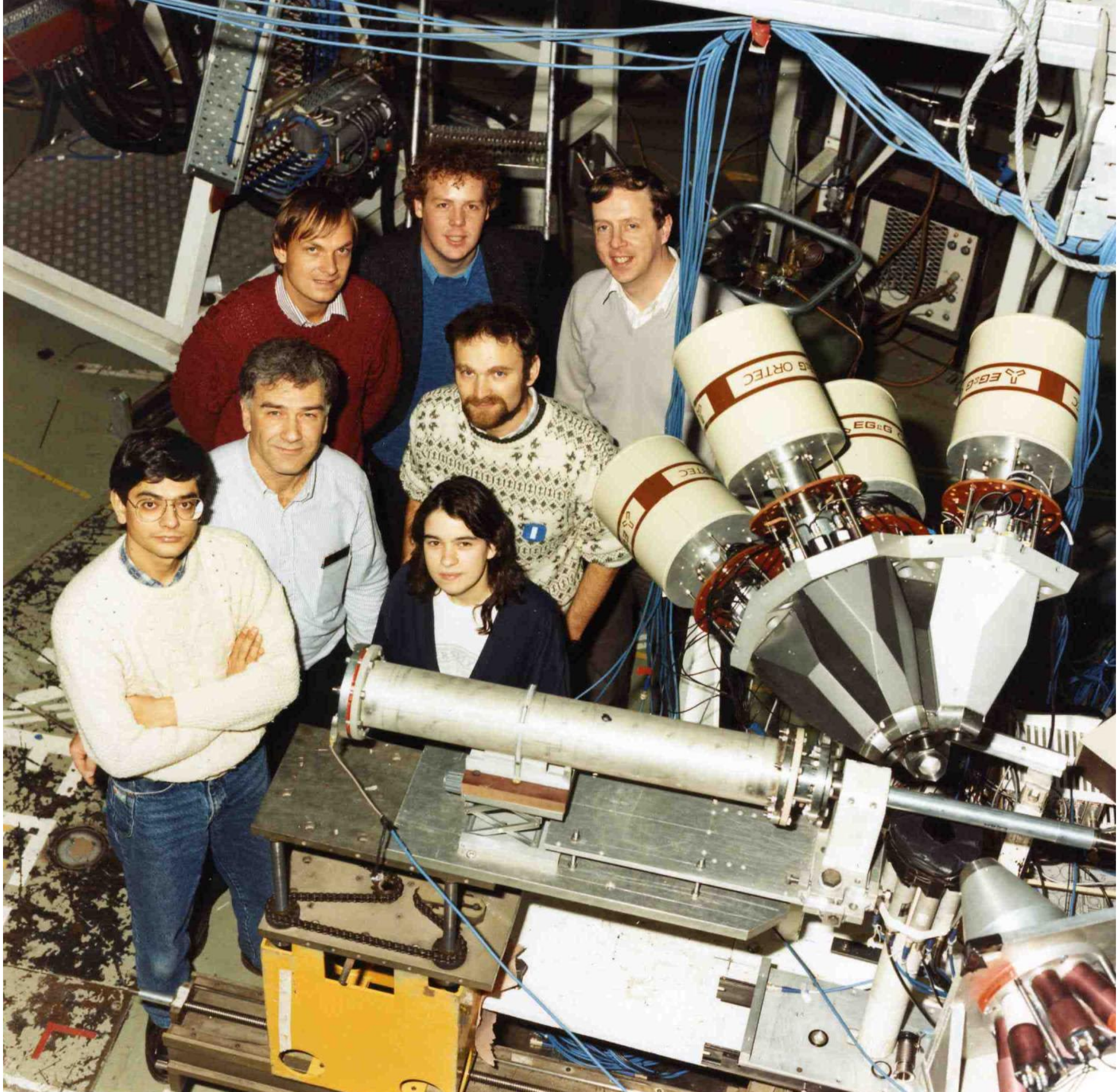
Eurogam 1 Daresbury UK/France 45 detectors

Euroball Strasbourg, Legnaro

Gammasphere E.I. 30-100 detectors. LBNL ANL

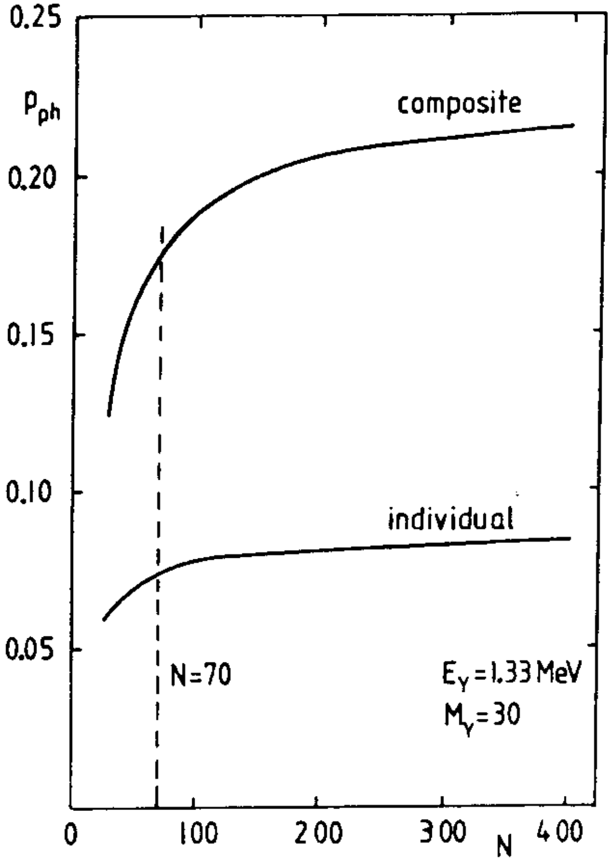



28

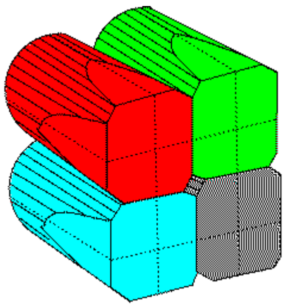

EG&G
ORTEC

DETECTOR DEVELOPMENTS

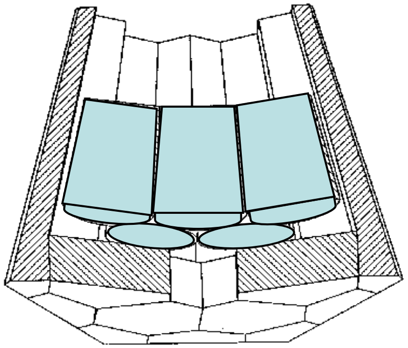
Increase photopeak efficiency from 5% to ~10%
Increase granularity, increase resolving power
Use composite Ge detectors
Detector with more than 1 Ge crystal in the same cryostat



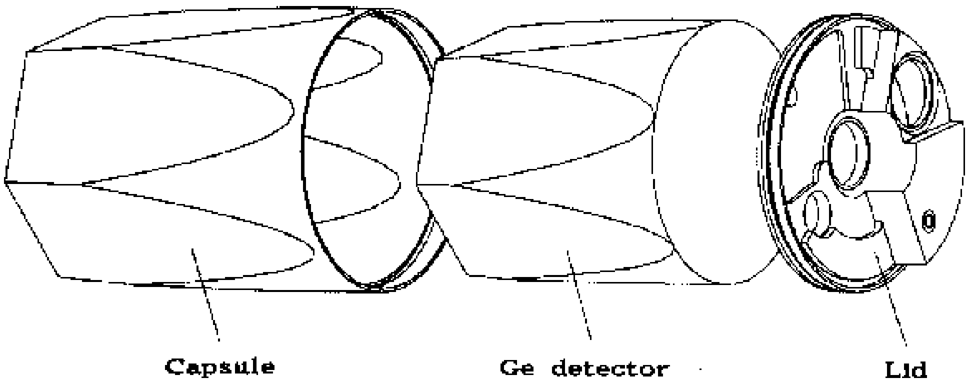
Clover detector
4 crystals per detector
Eurogam II, Euroball



Cluster detector
7 crystals per detector
encapsulated detectors



Cluster detector



Encapsulated Ge detector

Hexagonal tapered crystals ~60 mm dia, ~ 70mm length

Crystal sealed in an Al capsule

Vacuum of crystal and cryostat decoupled

Close packing

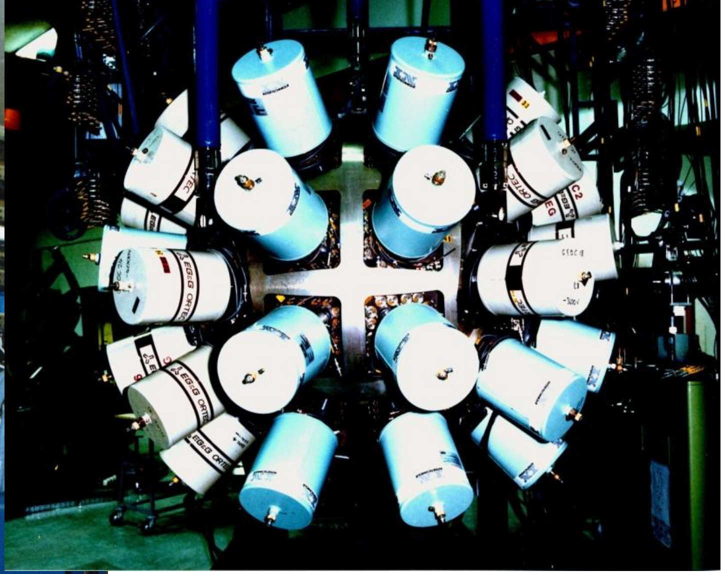
Crystal never exposed

Easy handling and repairs, annealing

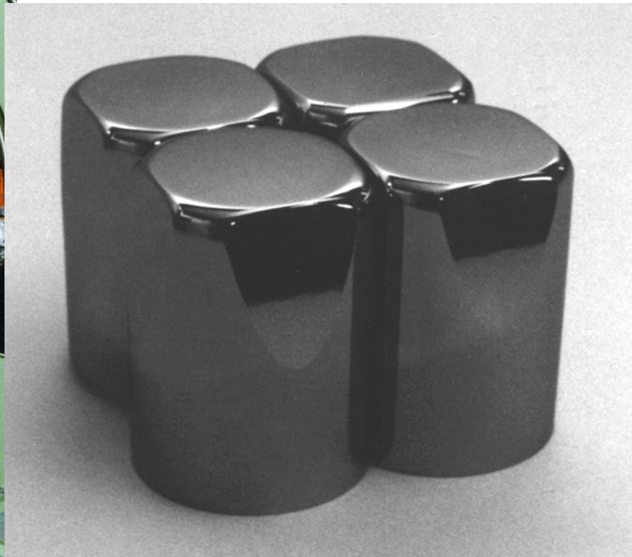
Intertechnique (EM), Univ Koln, KFA Julich

J.Eberth et al., Prog. Part. Nucl. Phys 28 (1992) 49

Eurogam2 at Strasbourg

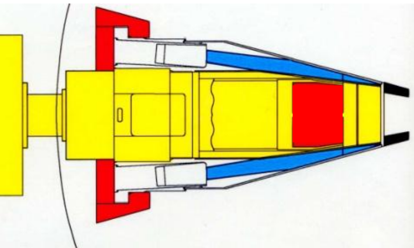


Clovers at ~90^0

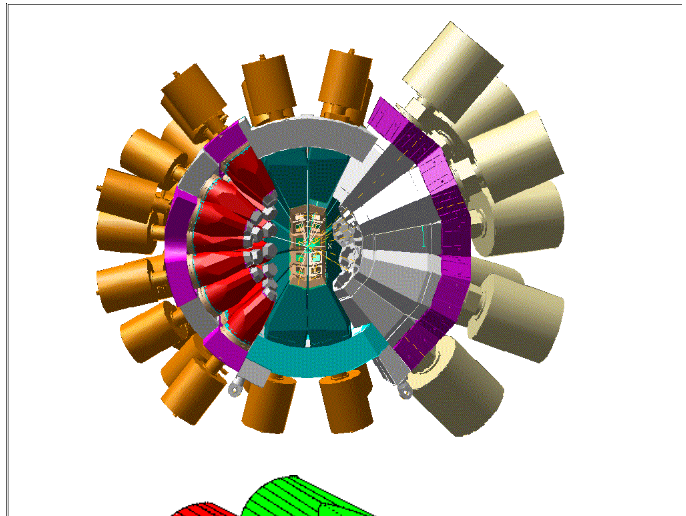


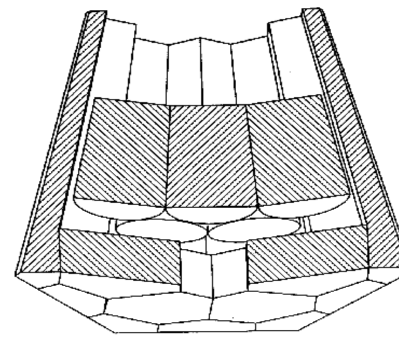
Euroball

European collaboration
France, Denmark, Germany, Italy, Sweden and the UK

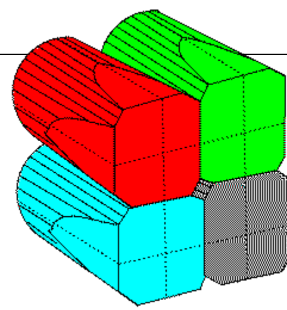


30 Large single crystal
Ge detectors





15 Cluster Ge detectors
7 encapsulated Ge crystals per cluster



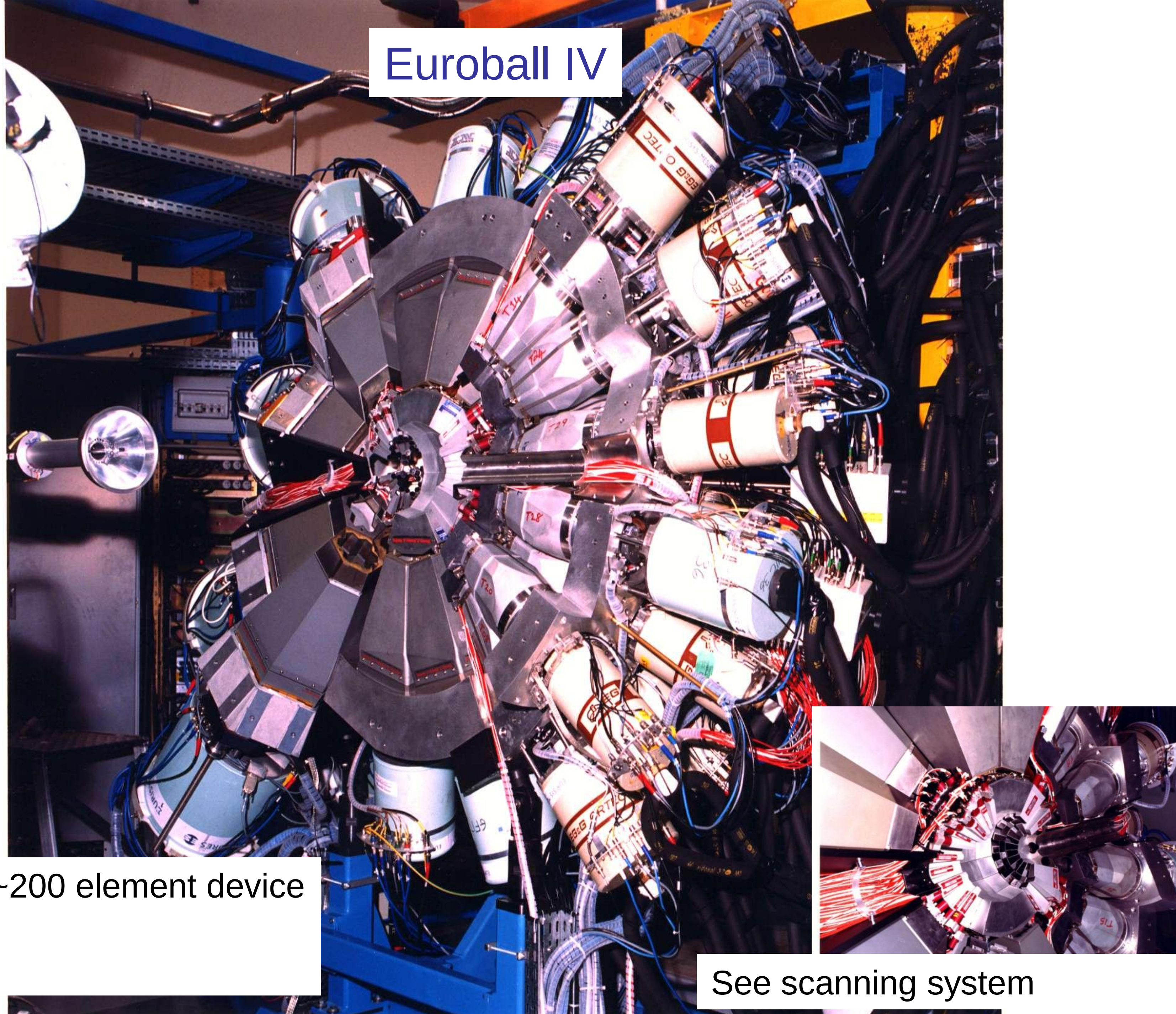
26 Clover Ge detectors
4 crystals per cryostat

239 Ge crystals
Suppression shields
Total peak efficiency calculated to be 9.4%
Intensity limit ~ 10^{-5}

INFN Legnaro Euroball III
IReS Strasbourg Euroball IV
Inner ball

Euroball III at Legnaro

Euroball IV



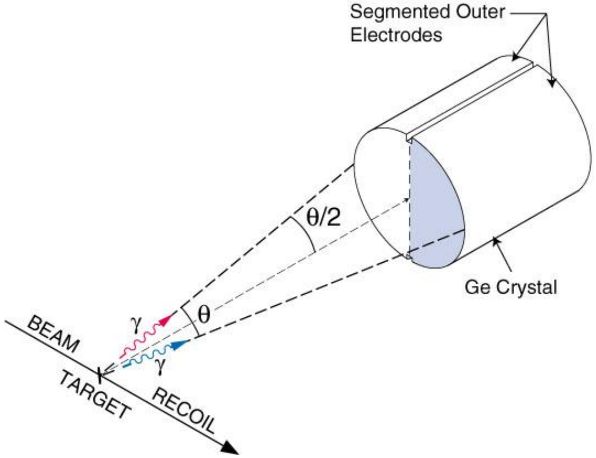
Inner ball ~200 element device
BGO + Ge
$\Omega > 90\%$

See scanning system

Segmentation of detectors

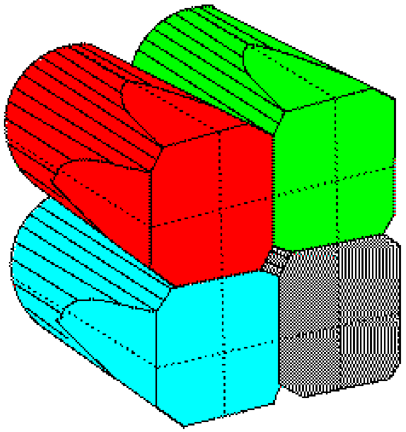
Improve granularity (reduce Doppler broadening)

Gammasphere



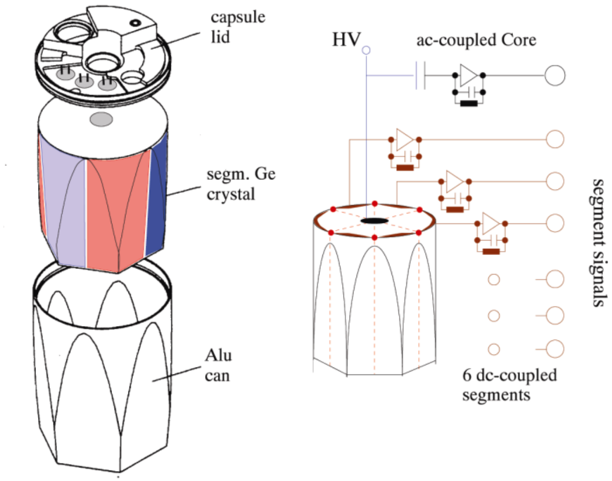
2-fold segmentation
Single crystal Ge detector

Exogam



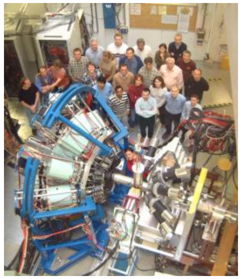
4-fold segmentation
Clover Ge detector

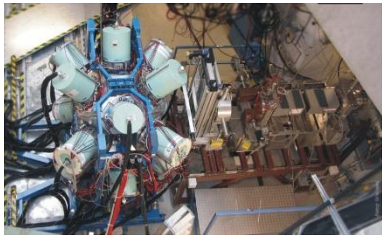
Miniball

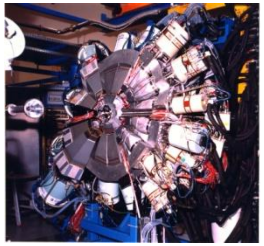


6-fold segmentation
Encapsulated Ge detector

Instrumentation in Europe



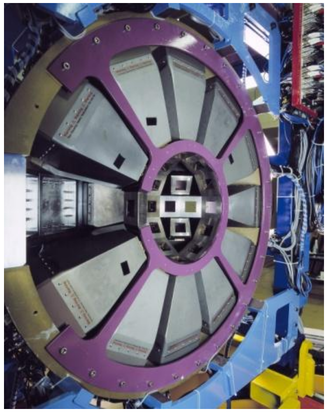




Euroball

RISING, GSI

JUROGAM, GREAT,
SaGe, LISA, MARA, JYFL

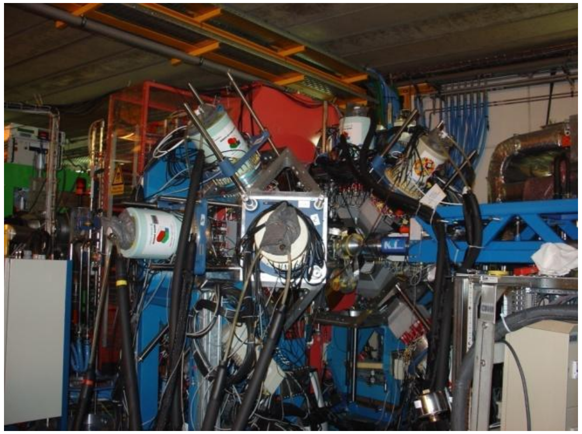


CLARA, LNL

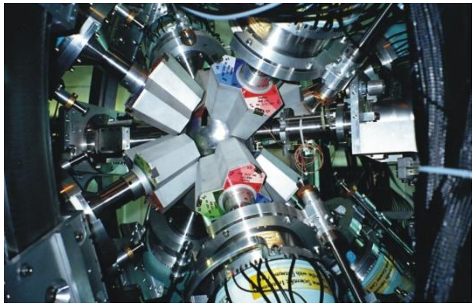
Radioactive beam spectroscopy

EXOGAM, SPIRAL, Ganil

MINIBALL, RexIsolde, HIE-ISOLDE



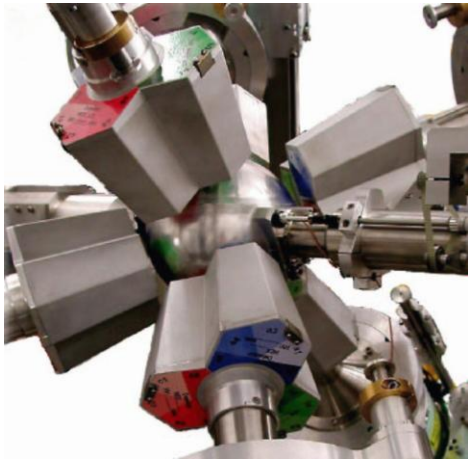
Segmentation
Encapsulation
Position
determination from
pulse shape analysis



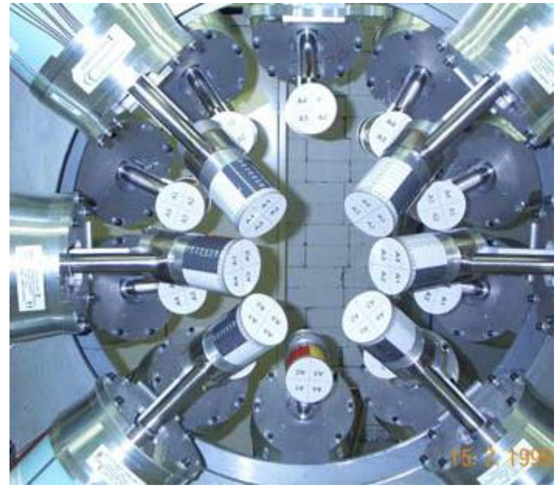
EGAN
GAMMAPOOL
Loan Pool IN2P3/STFC

Gamma-ray tracking projects
MARS
TMR EU collaboration

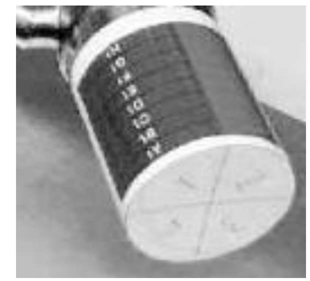
Arrays for the present generation of RIBs

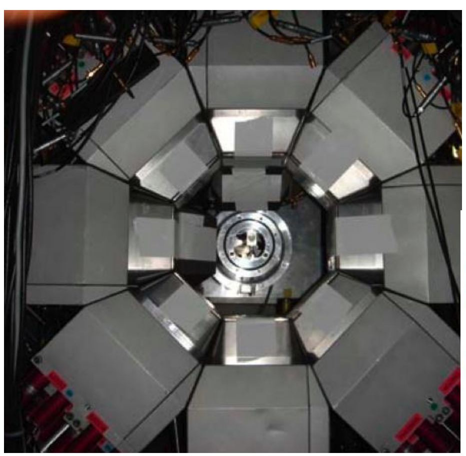


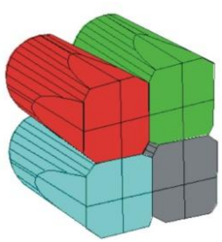
MINIBALL triple-clusters
with 6 and 12 fold segmentation



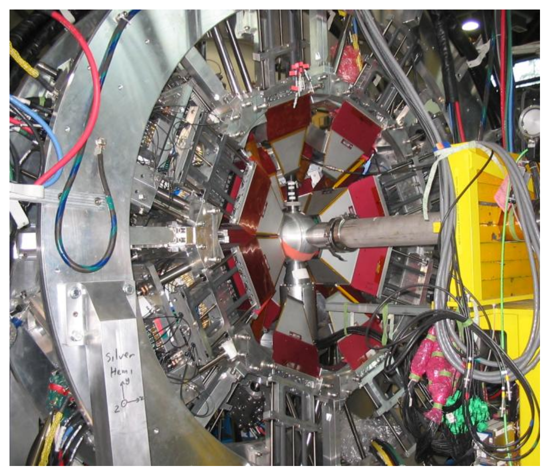
SeGA (Segmented Germanium Array at NSCL)
with 32-fold segmentation



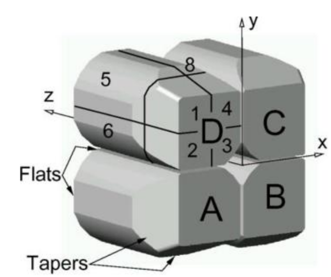




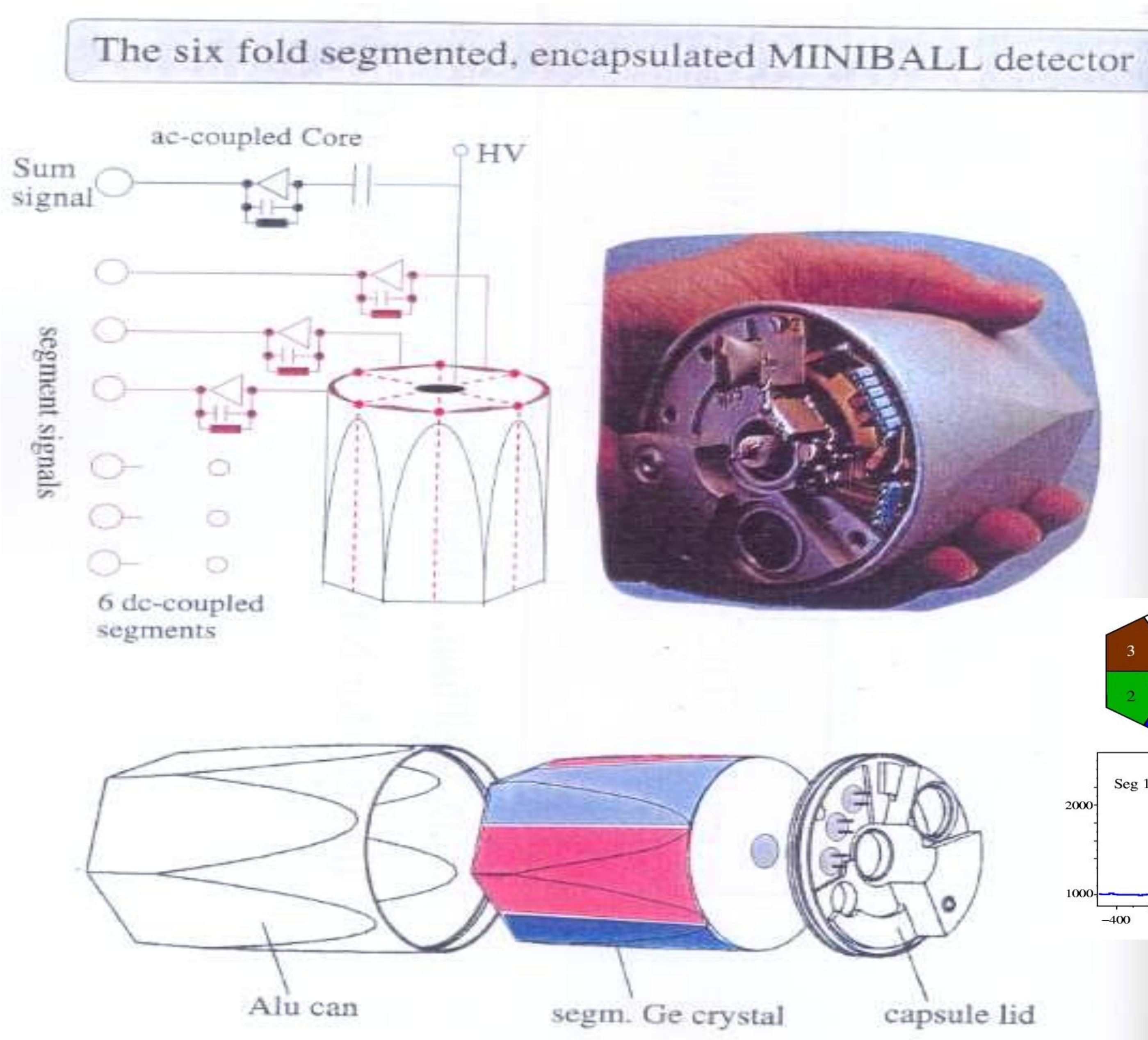
EXOGAM at GANIL
with 4-fold segmented clovers



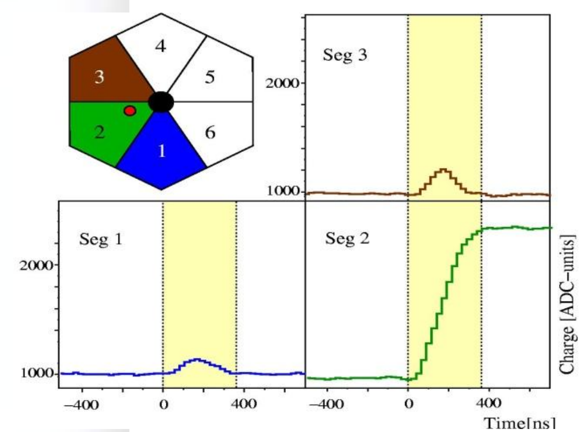
TIGRESS (TRIUMF-ISAC Gamma-Ray Escape Suppressed Spectrometer)
with 32 fold segmentation
(8-fold segmented clovers)



Position from segmentation AND pulse shape analysis

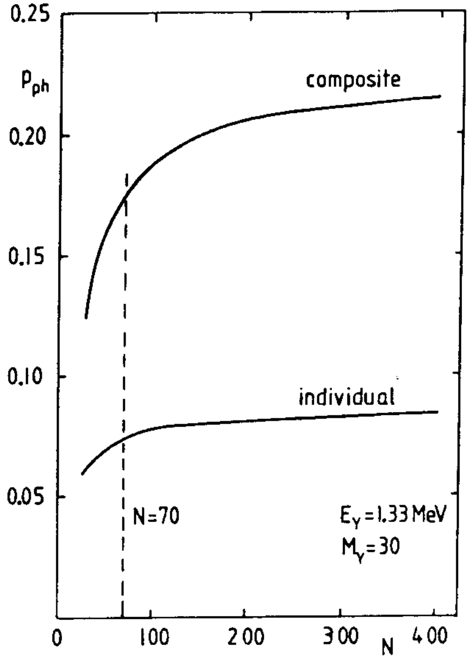


Miniball,
MARS,
UK etc.



How to make progress?

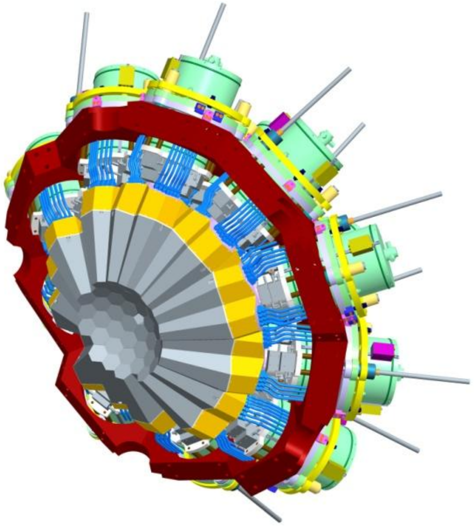
- Gamma ray tracking
- Electronically segmented detectors
- Pulse shape analysis (energy, time and position)



M.A. Deleplanque et al., Nucl. Instr. and Meth. A430 (1999) 292.

What next?

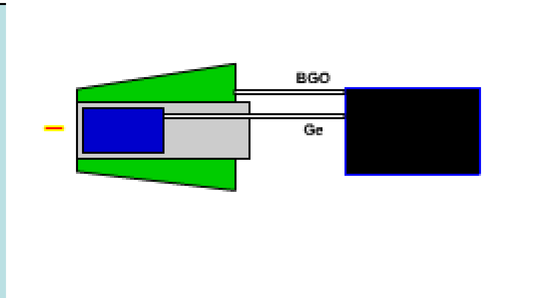
AGATA: Advanced Gamma Tracking Array

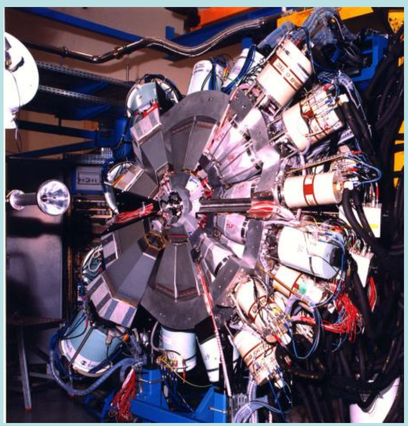


Concept of gamma-ray tracking in Ge semiconductor detectors
Huge increase in efficiency and sensitivity

Idea of γ-ray tracking

Large Gamma Arrays based on Compton Suppressed Spectrometers



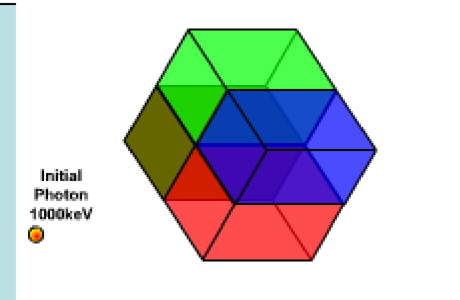


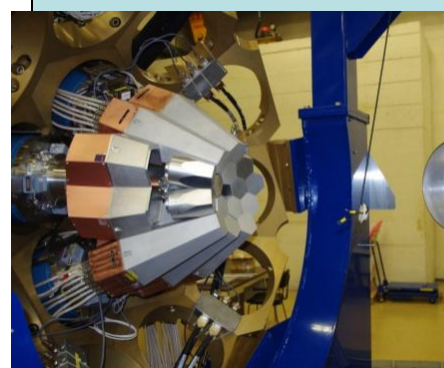
EUROBALL

GAMMASPHERE

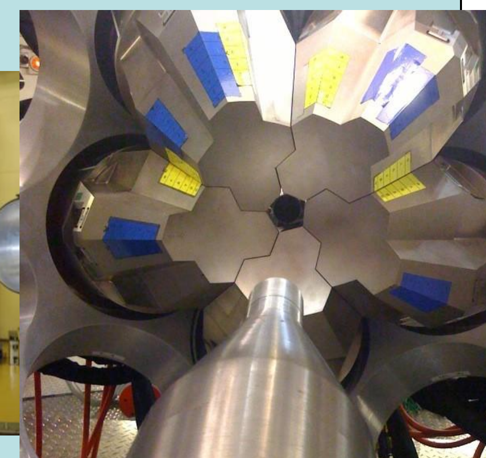
$\varepsilon \sim$ 10 — 5 %
(M_γ=1 — M_γ=30)

Tracking Arrays based on Position Sensitive Ge Detectors





AGATA



GRETINA/GRETA

$\varepsilon \sim$ 40 — 20 %
(M_γ=1 — M_γ=30)

Huge increase in sensitivity

Why do we need AGATA?

FAIR
SPIRAL2
SPES
REX-ISOLDE
MAFF
EURISOL
HI-Stable

- Low intensity
- High background
- Large Doppler broadening
- High counting rates
- High γ-ray multiplicities

Harsh conditions!
Need instrumentation with

High efficiency
High sensitivity
High throughput
Ancillary detectors

Conventional arrays will not suffice!

New challenges in Nuclear Structure

<u>Shell structure in nuclei</u>

- Structure of doubly magic nuclei
- Changes in the (effective) interactions

<u>Proton drip line and N=Z nuclei</u>

- Spectroscopy beyond the drip line
- Proton-neutron pairing
- Isospin symmetry

<u>Nuclear shapes</u>

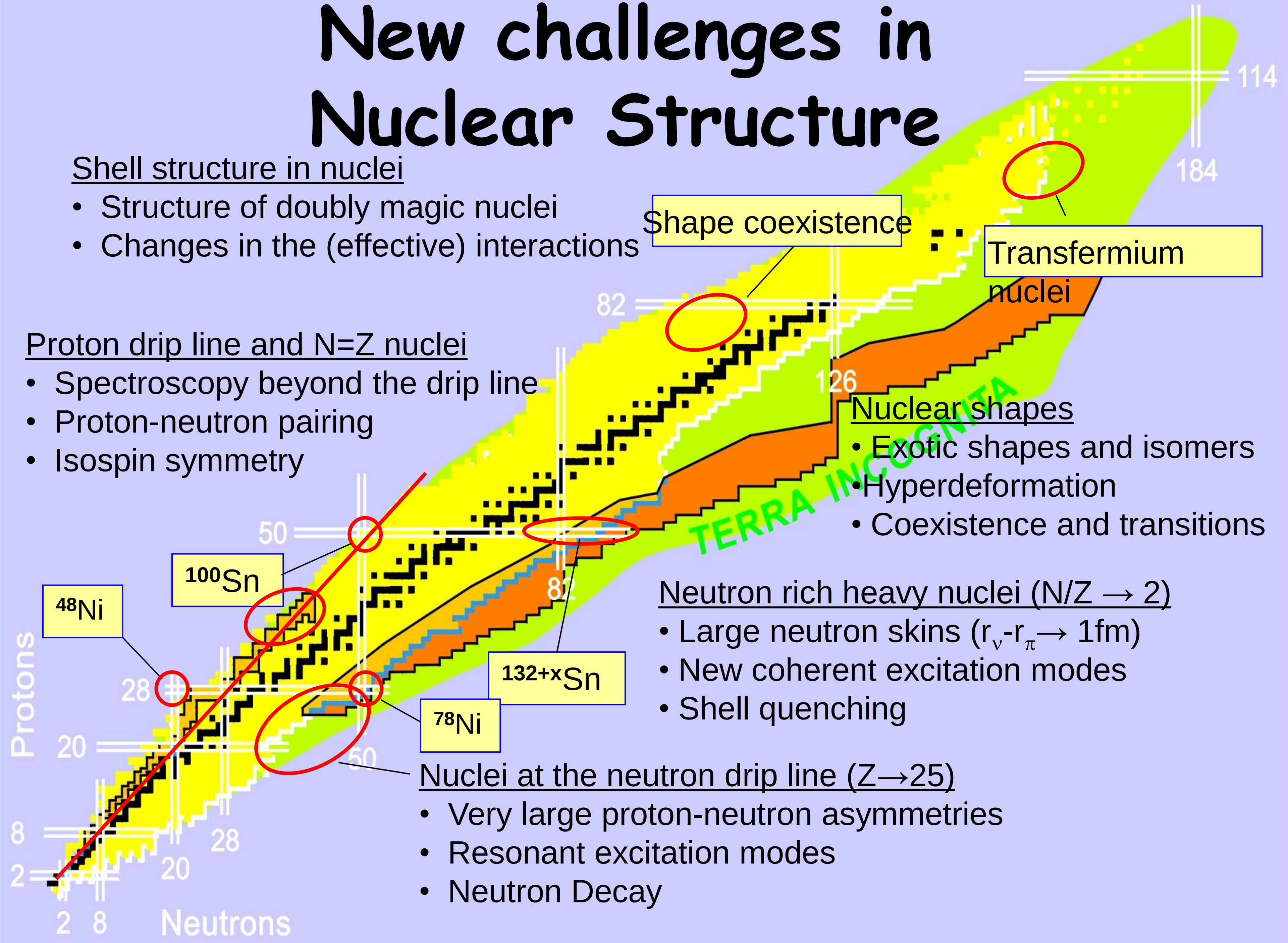
- Exotic shapes and isomers
- Hyperdeformation
- Coexistence and transitions

<u>Neutron rich heavy nuclei (N/Z → 2)</u>

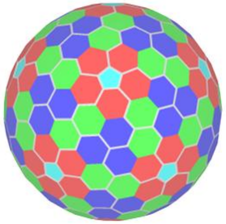
- Large neutron skins (r_ν-$r_\pi \rightarrow$ 1fm)
- New coherent excitation modes
- Shell quenching

<u>Nuclei at the neutron drip line (Z→25)</u>

- Very large proton-neutron asymmetries
- Resonant excitation modes
- Neutron Decay



The AGATA Collaboration

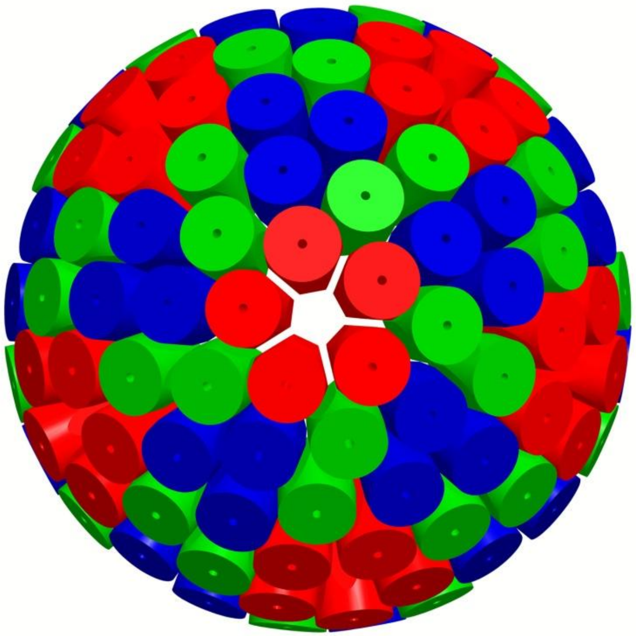


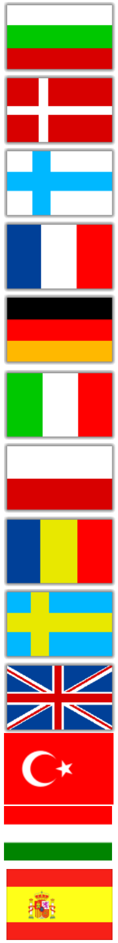
13 Countries
>40 Institutions

Bulgaria:	**Univ. Sofia**
Denmark:	**NBI Copenhagen**
Finland:	**Univ. Jyväskylä**
France:	**GANIL Caen, IPN Lyon, CSNSM Orsay, IPN Orsay, CEA-DSM-DAPNIA Saclay, IPHC Strasbourg, LPSC Grenoble**
Germany:	**GSI Darmstadt, TU Darmstadt, Univ. zu Köln, TU München**
Hungary:	**ATOMKI Debrecen**
Italy:	**INFN-LNL, INFN and Univ. Padova, Milano, Firenze, Genova, Napoli,**
Poland:	**NINP and IFJ Krakow, SINS Swierk, HIL & IEP Warsaw**
Romania:	**NIPNE & PU Bucharest**
Sweden:	**Univ. Göteborg, Lund Univ., KTH Stockholm, Uppsala Univ.**
Turkey:	**Univ. Ankara, Univ. Istanbul, Technical Univ. Istanbul**
UK:	**Univ. Brighton, STFC Daresbury, Univ. Edinburgh, Univ. Liverpool, Univ. Manchester, Univ. West of Scotland, Univ. Surrey, Univ. York**
Spain:	**IFIC Valencia, IEM-CSIC Madrid, LRI Univ. Salamanca**

AGATA
(Design and characteristics)

4π γ-array for Nuclear Physics Experiments at European accelerators providing radioactive and stable beams





Main features of AGATA

Efficiency: 43% (M_γ =1) 28% (M_γ =30)
today's arrays ~10% (gain ~4) 5% (gain ~1000)

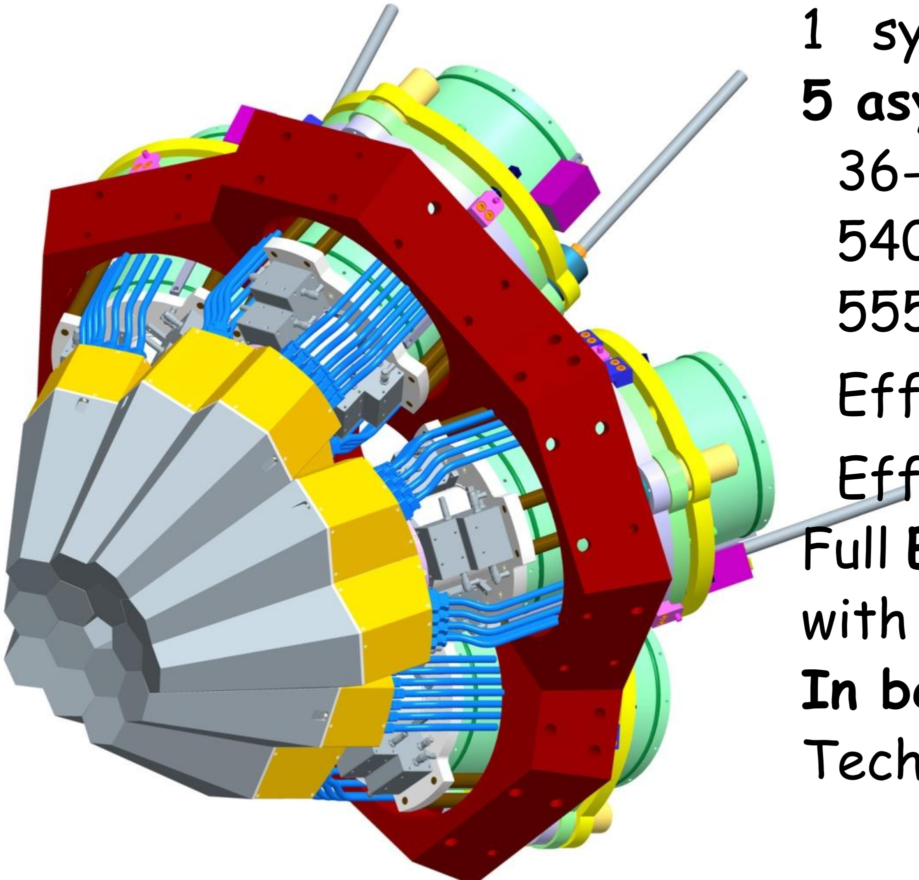
Peak/Total: 58% (M_γ=1) 49% (M_γ=30)
today ~55% 40%

Angular Resolution: ~1º →
FWHM (1 MeV, v/c=50%) ~ 6 keV !!!
today ~40 keV

Rates: 3 MHz (M_γ=1) 300 kHz (M_γ =30)
today 1 MHz 20 kHz

- 180 large volume 36-fold segmented Ge crystals in 60 triple-clusters
- Digital electronics and sophisticated Pulse Shape Analysis algorithms allow
- Operation of Ge detectors in position sensitive mode → γ-ray tracking

The First Step:
The AGATA Demonstrator



1 symmetric triple-cluster

5 asymmetric triple-clusters

36-fold segmented crystals

540 segments

555 digital-channels

Eff. 3 – 8 % @ M_γ = 1

Eff. 2 – 4 % @ M_γ = 30

Full **EDAQ**

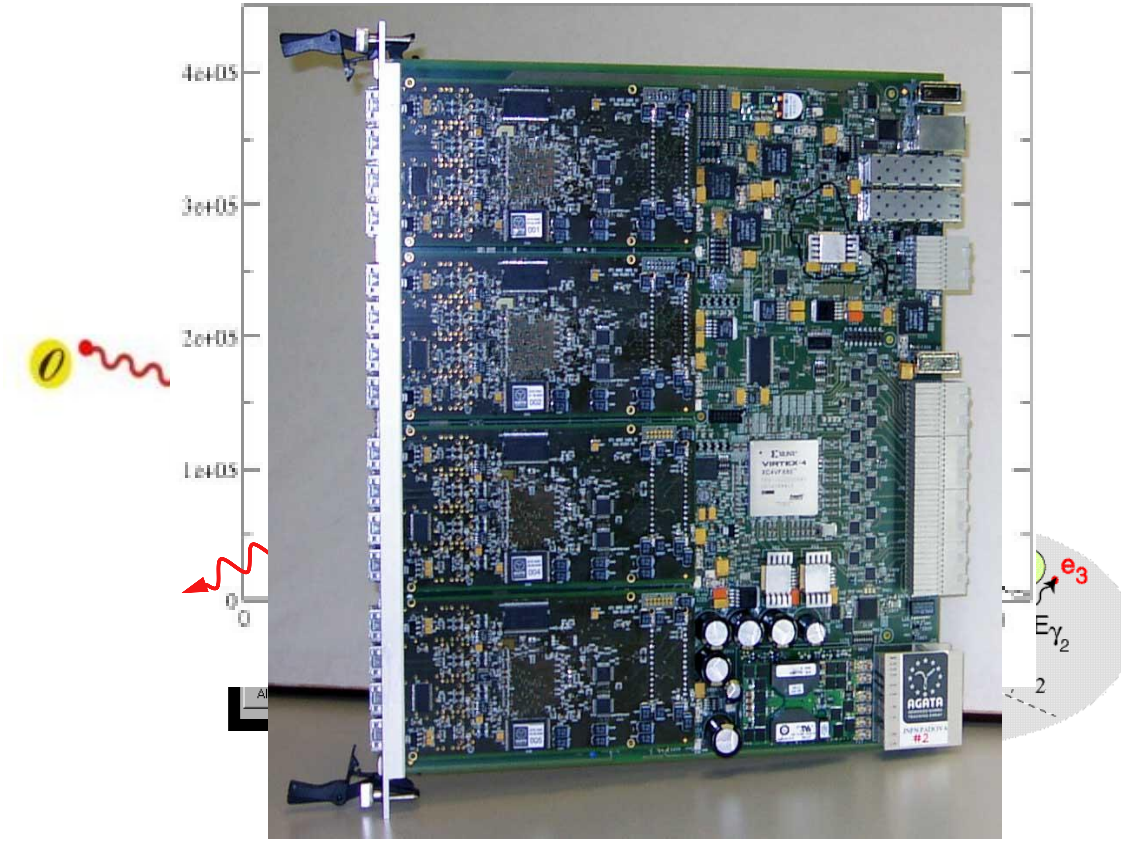
with on line PSA and γ-ray tracking

In beam Commissioning

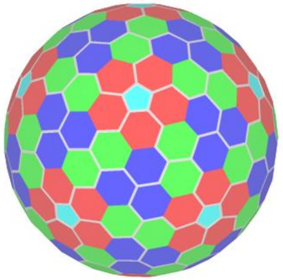
Technical proposal for full array

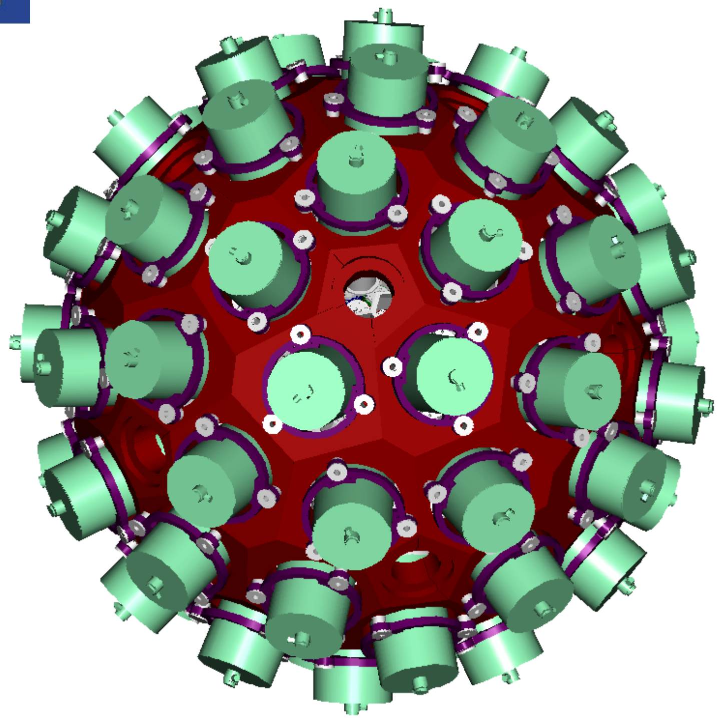
Cost 6.7 M€ Capital

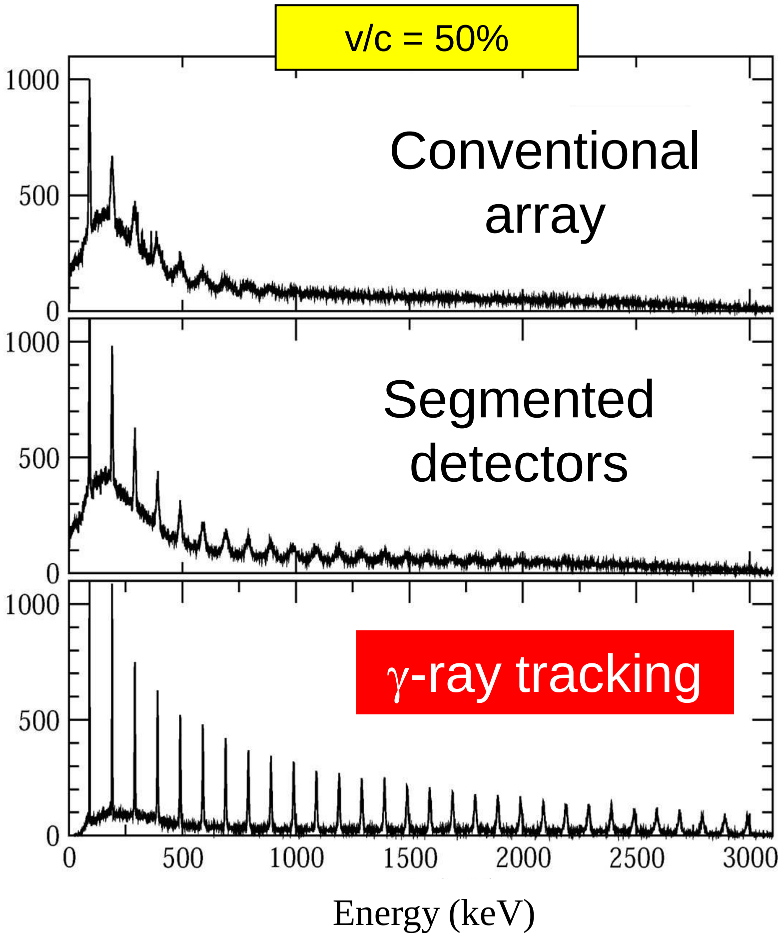
Gamma-ray tracking - how it works



AGATA
(Advanced GAmma Tracking Array)

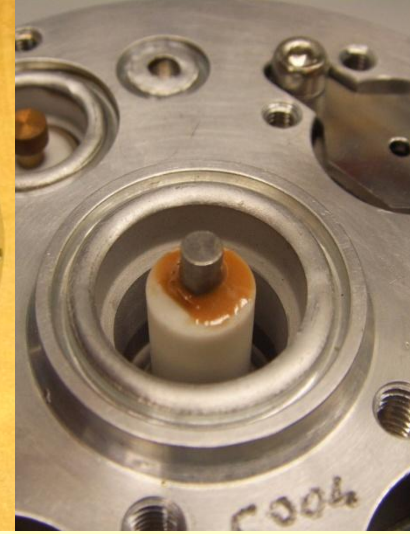


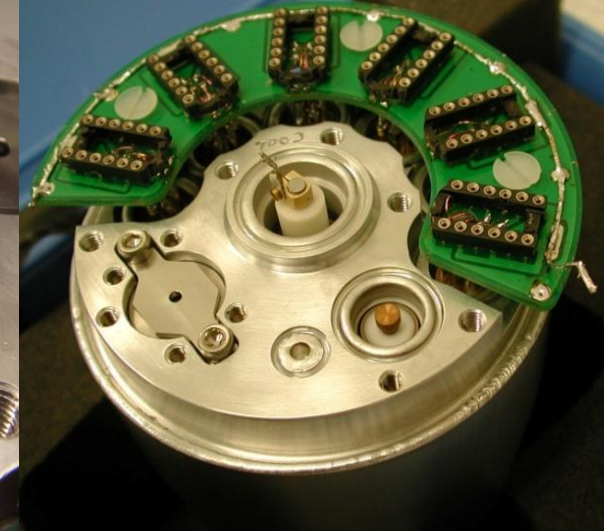




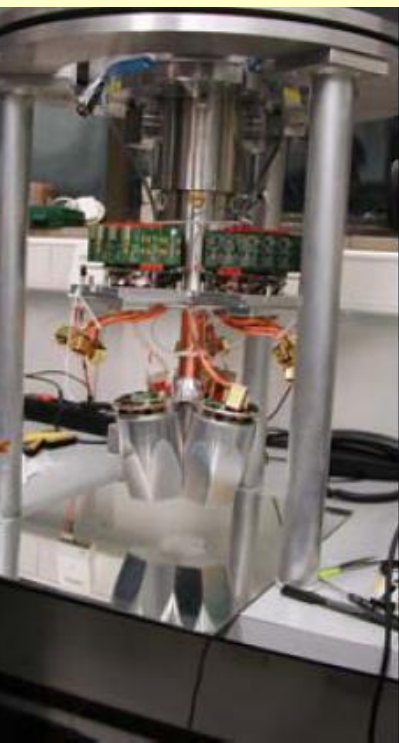
The innovative use of detectors (pulse shape analysis, γ-ray tracking, digital DAQ) will result in high efficiency (~40%) and excellent energy resolution, making AGATA the ideal instrument for spectroscopic studies of weak channels.

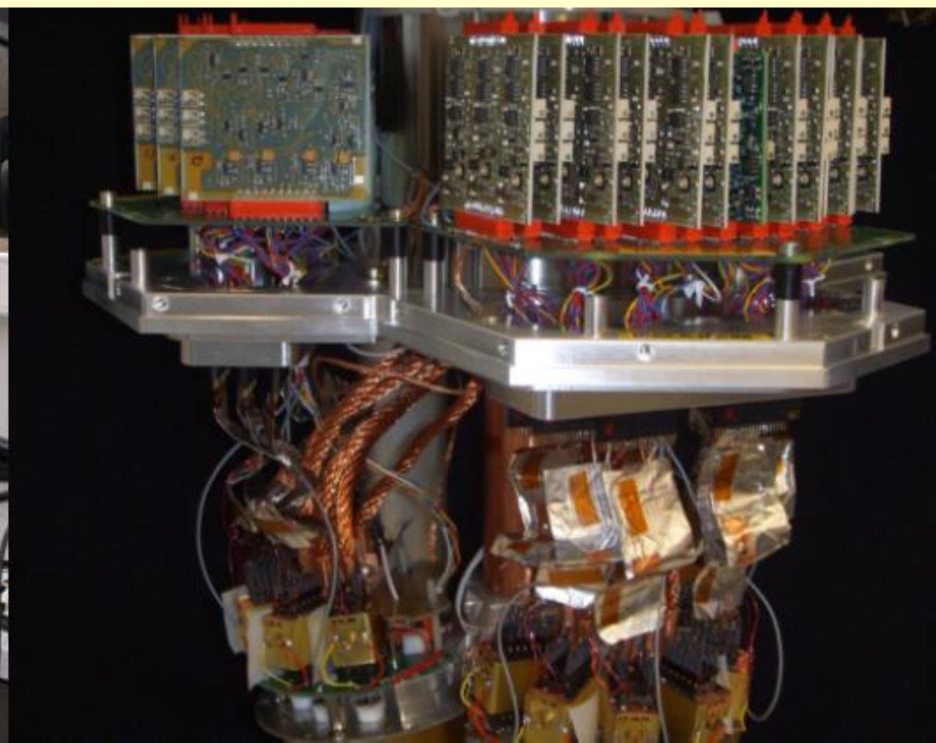
The effective energy resolution is maintained also at “extreme” v/c values

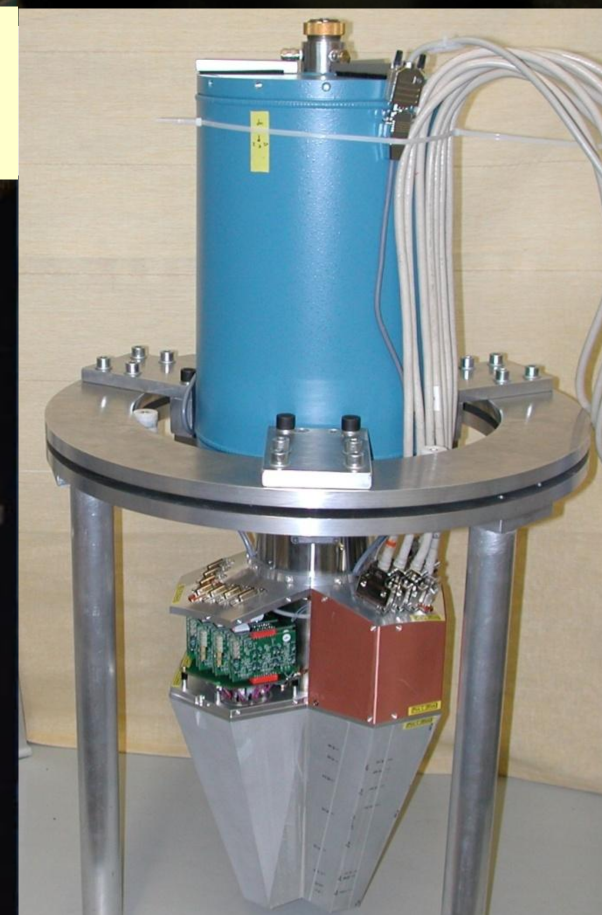


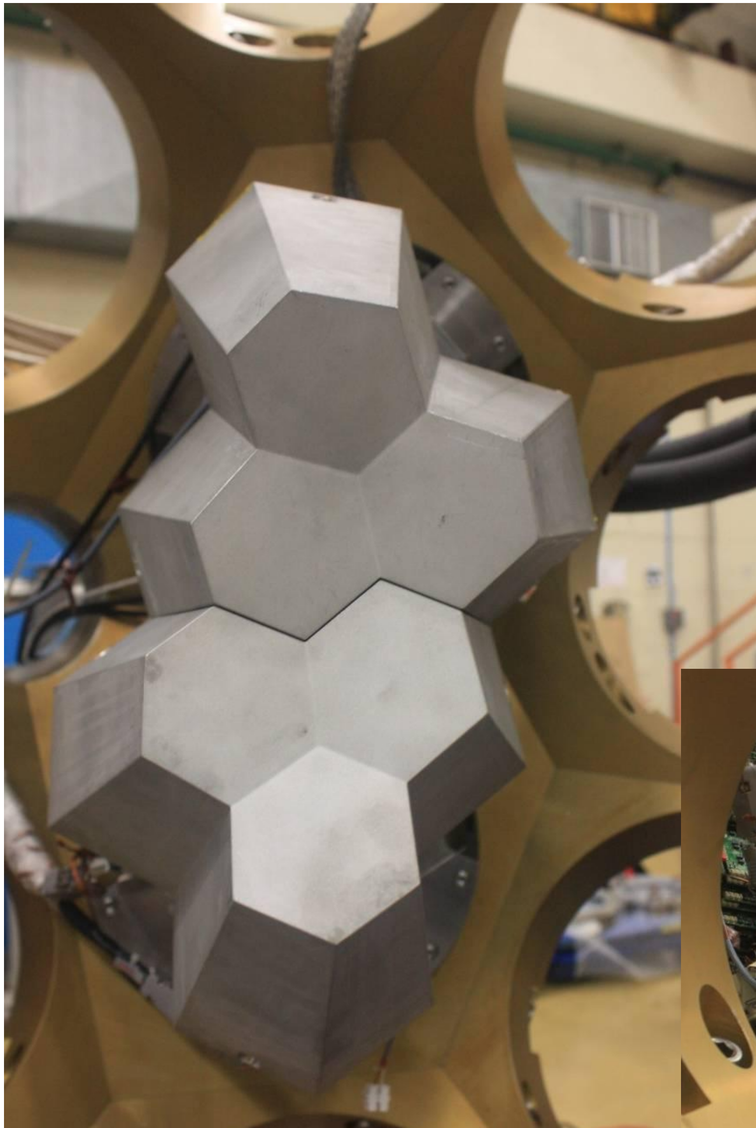


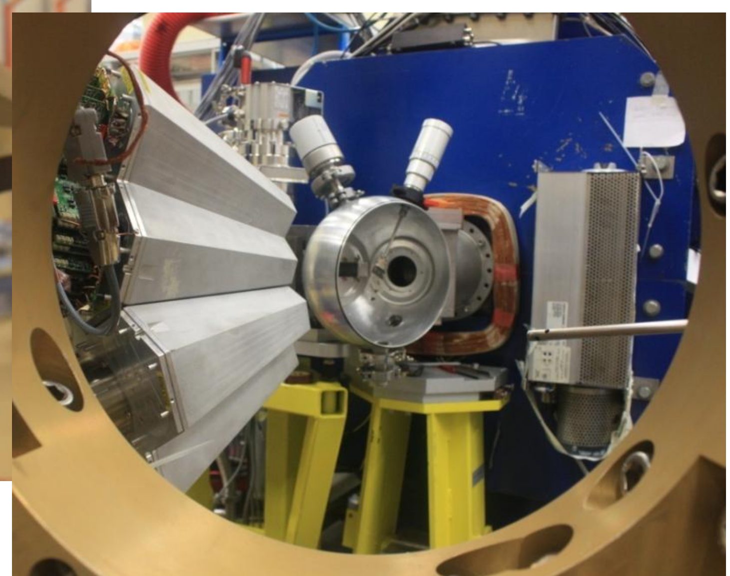
First AGATA triple-detector @ IKP Cologne







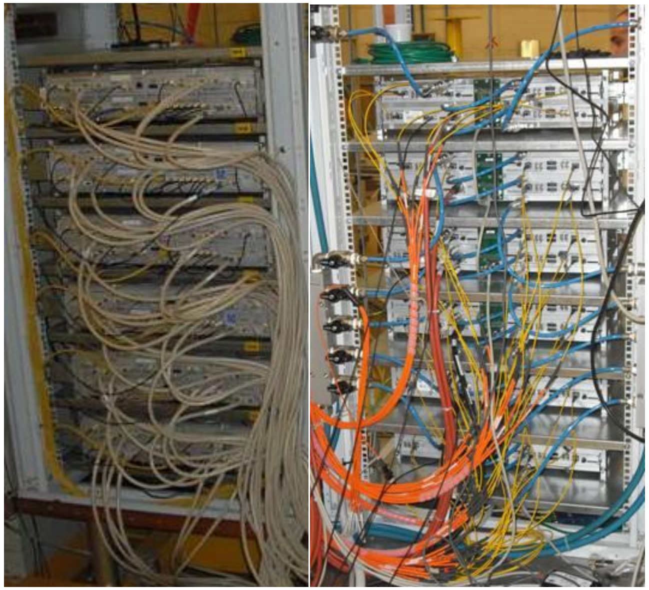





AGATA: Digital Electronics

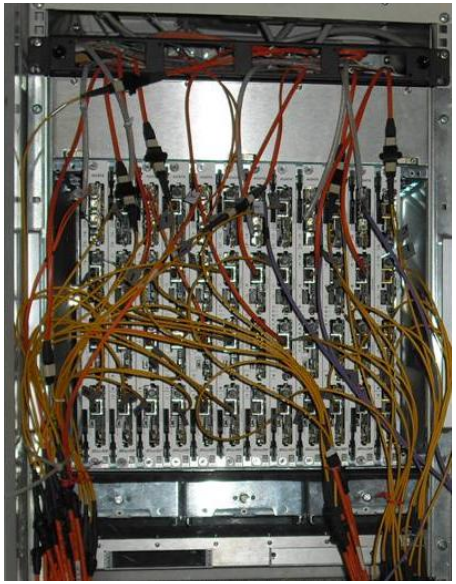
Digitisers
in the experimental hall

10 m long MDR cables



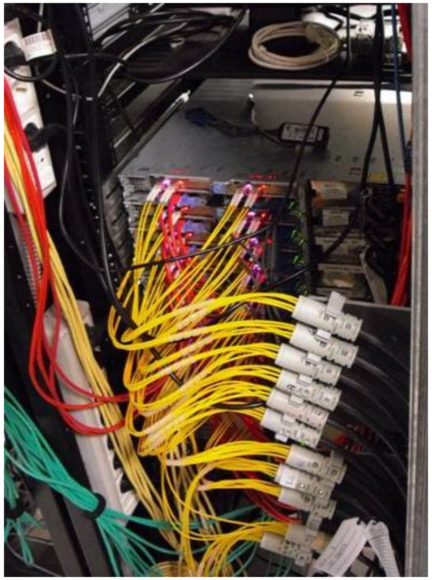
80 m long optical fibers

Digital proc. electronics
in the users area



20 m long optical fibers

Computer farm
in the computing room



LAN to the disk servers

100Mhz, 14 bit
Synchronous &
continuous

(7.6GB/s/crystal)

Triggering
Energy
Trace capture

(10 kB/evt/crystal)

Preprocessing
PSA
Tracking

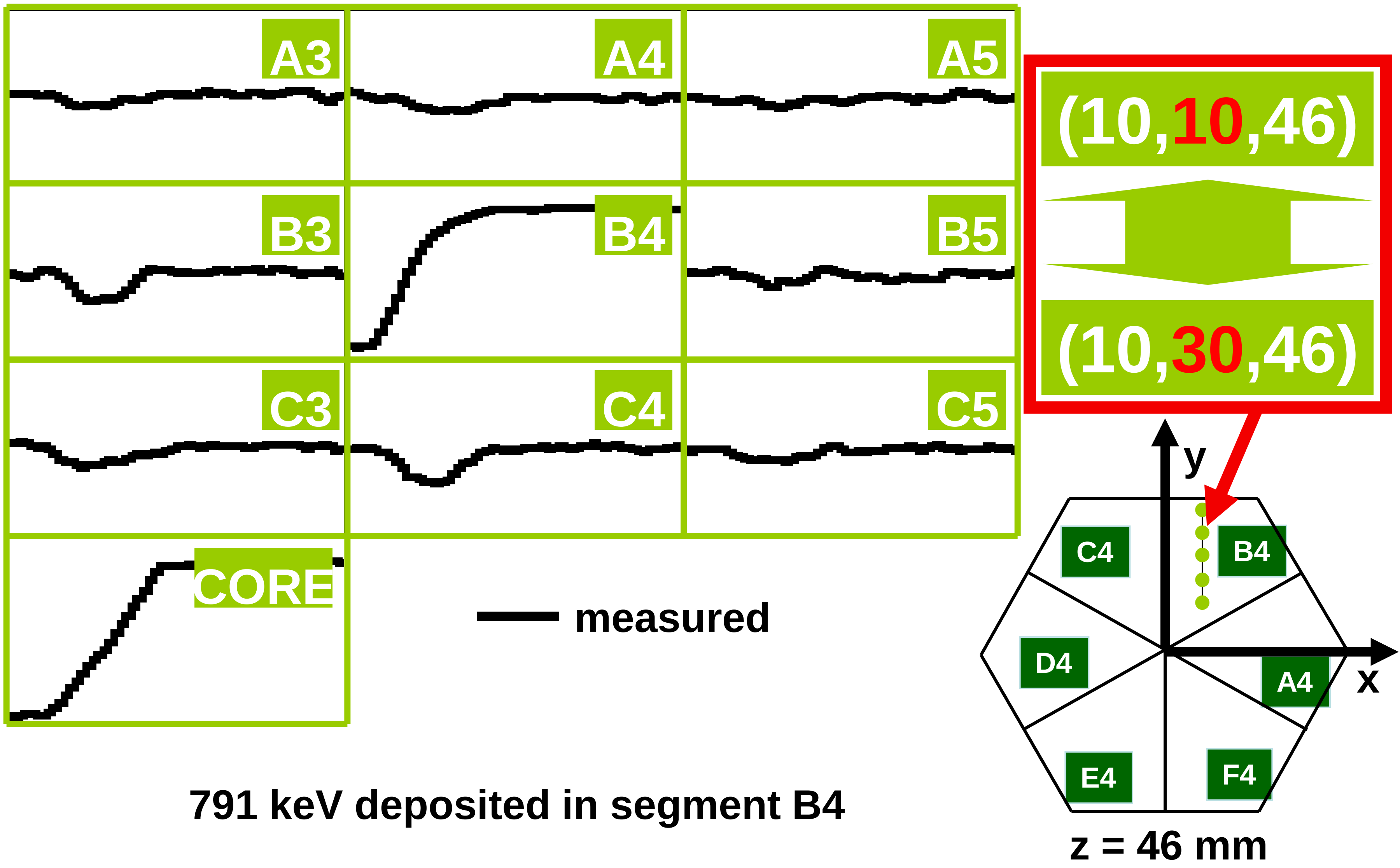
Global
Triggering
System

GTS

Clock &
Trigger validation

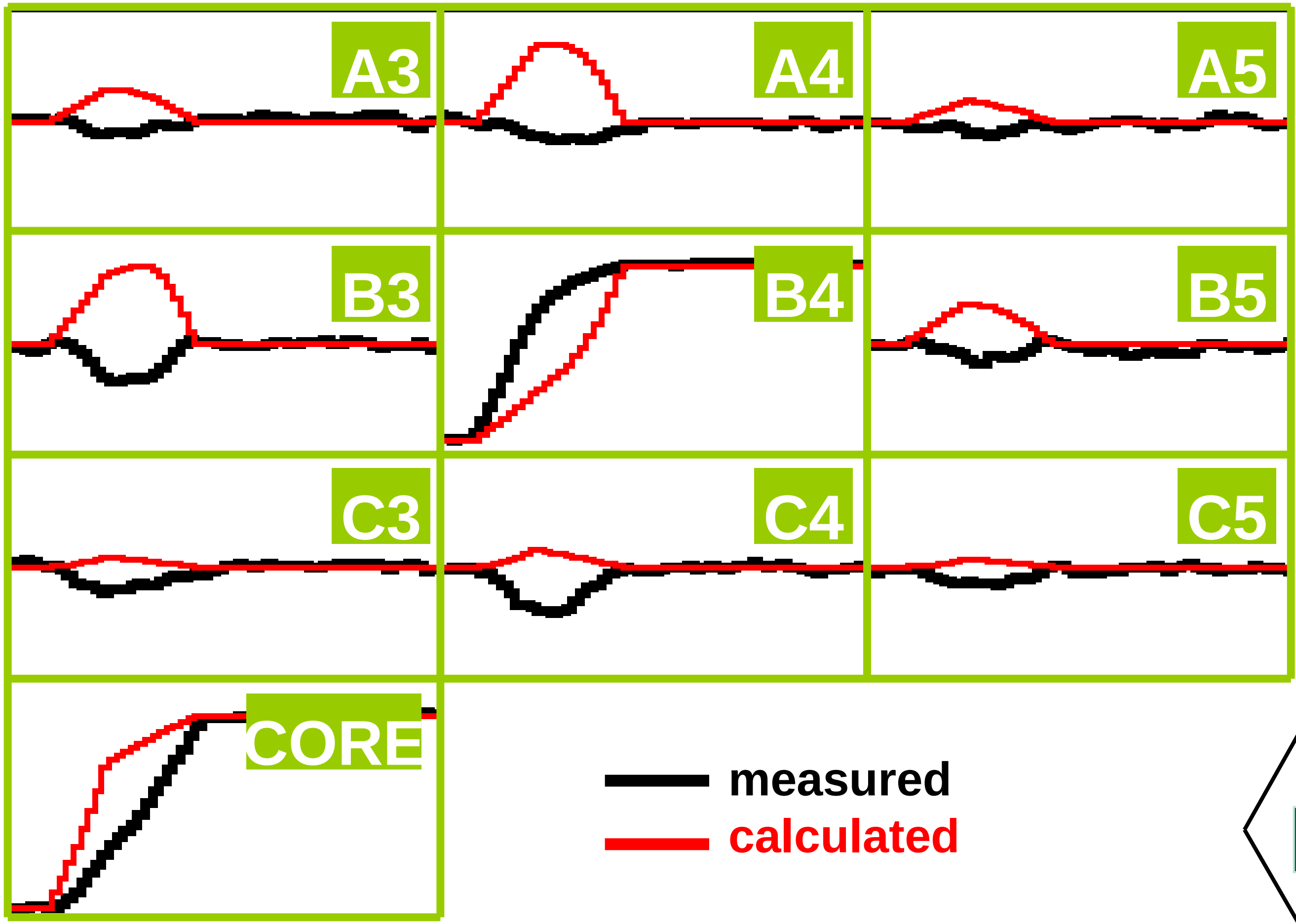
Science & Technology Facilities Council
Nuclear Physics Group

Pulse Shape Analysis concept

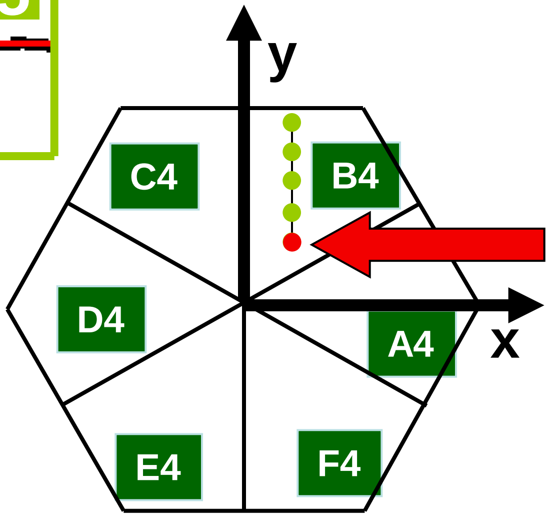


791 keV deposited in segment B4

Pulse Shape Analysis concept



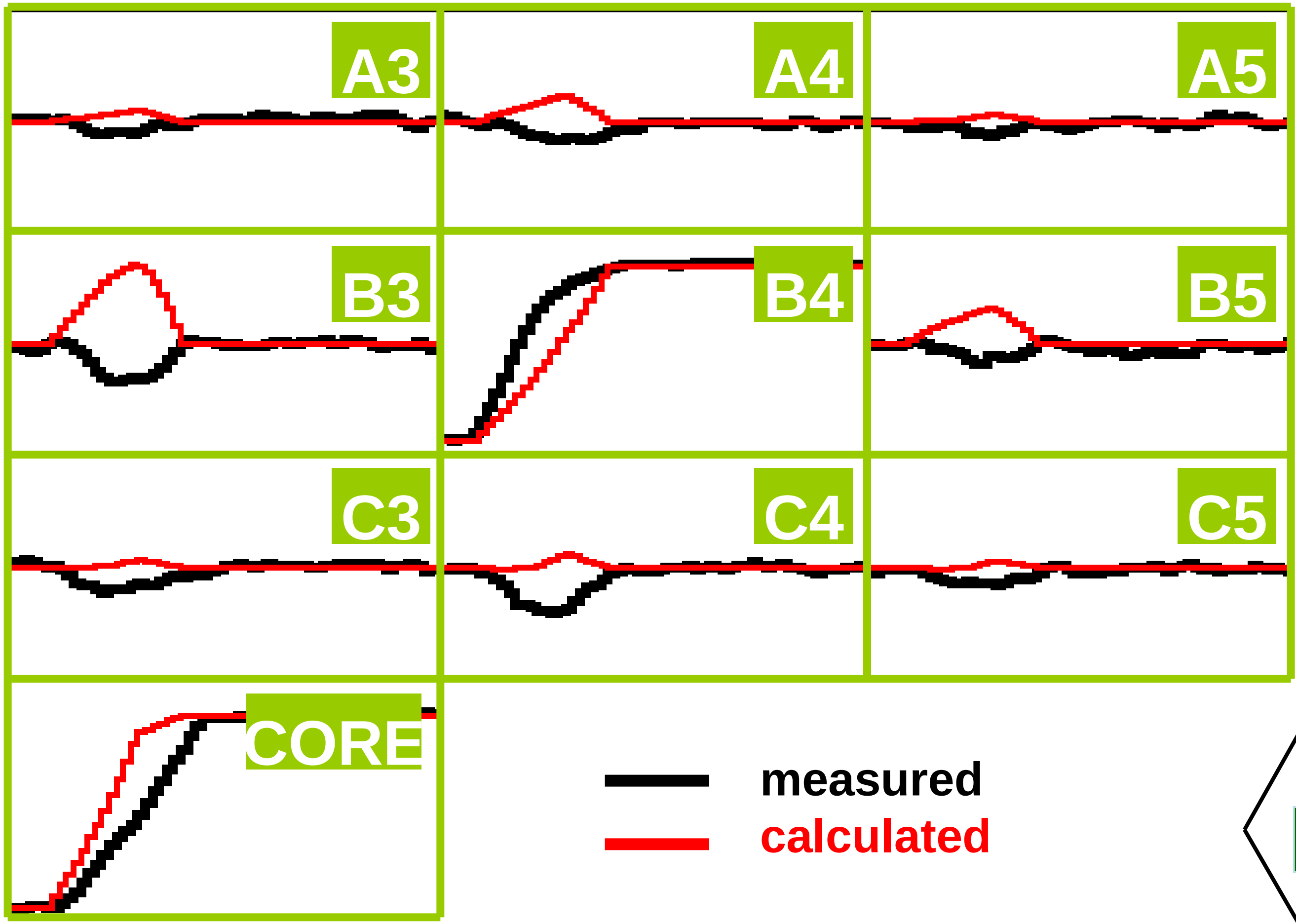
(10,10,46)



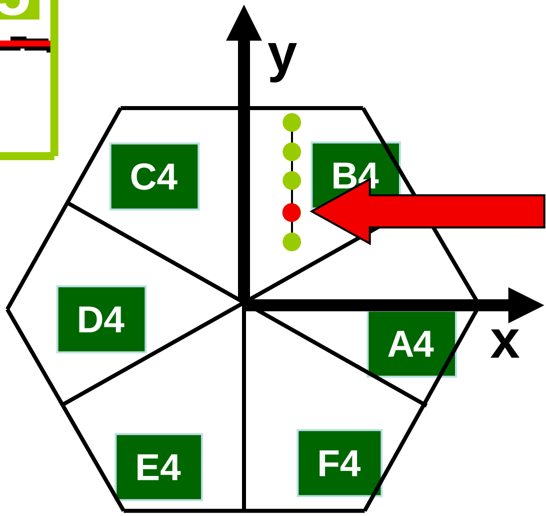
z = 46 mm

791 keV deposited in segment B4

Pulse Shape Analysis concept



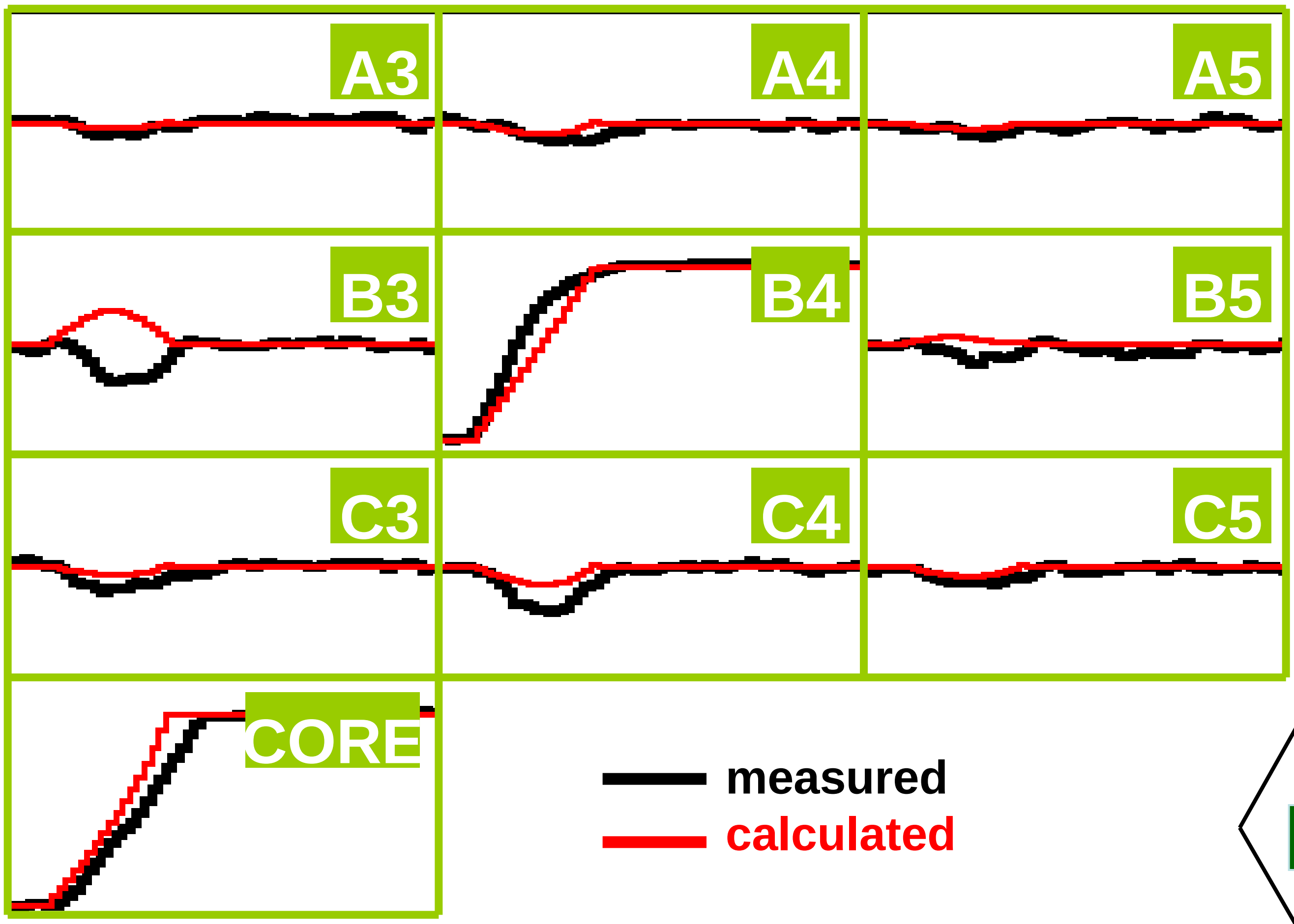
(10,15,46)

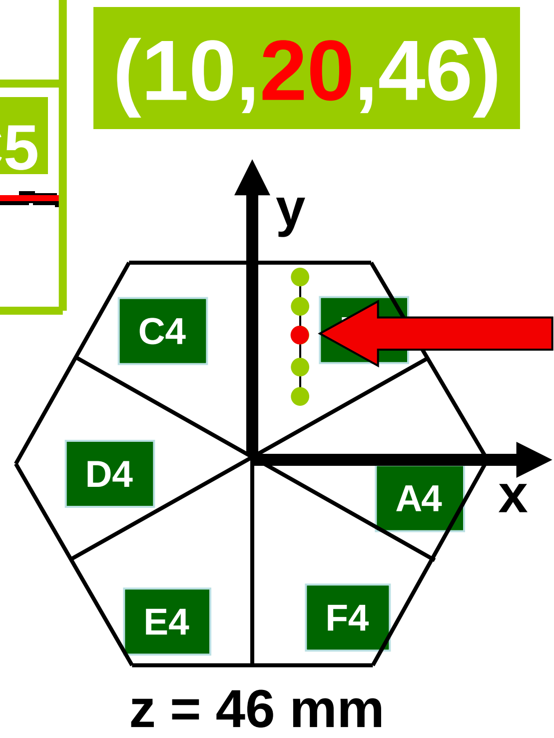


791 keV deposited in segment B4

z = 46 mm

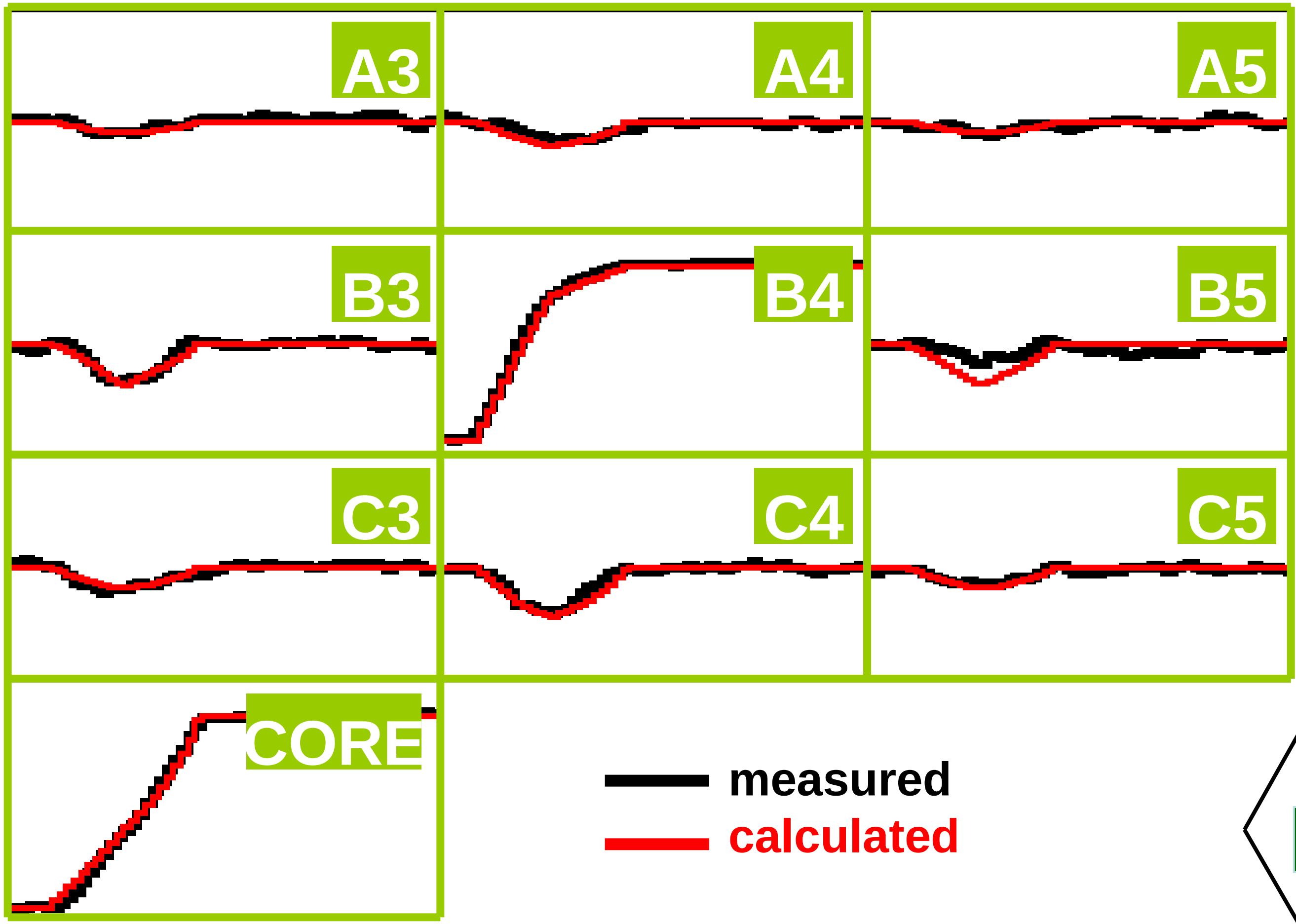
Pulse Shape Analysis concept



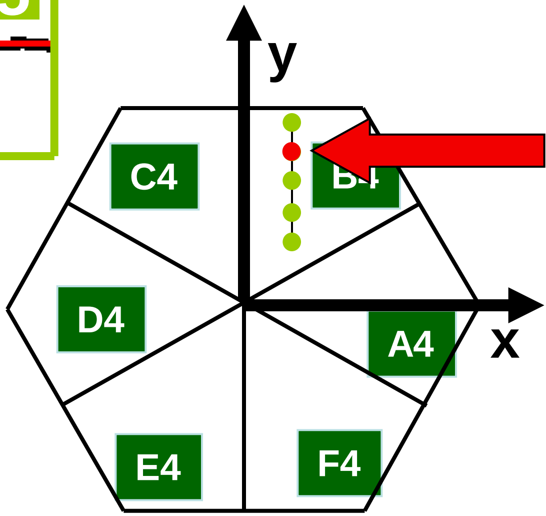


791 keV deposited in segment B4

Pulse Shape Analysis concept



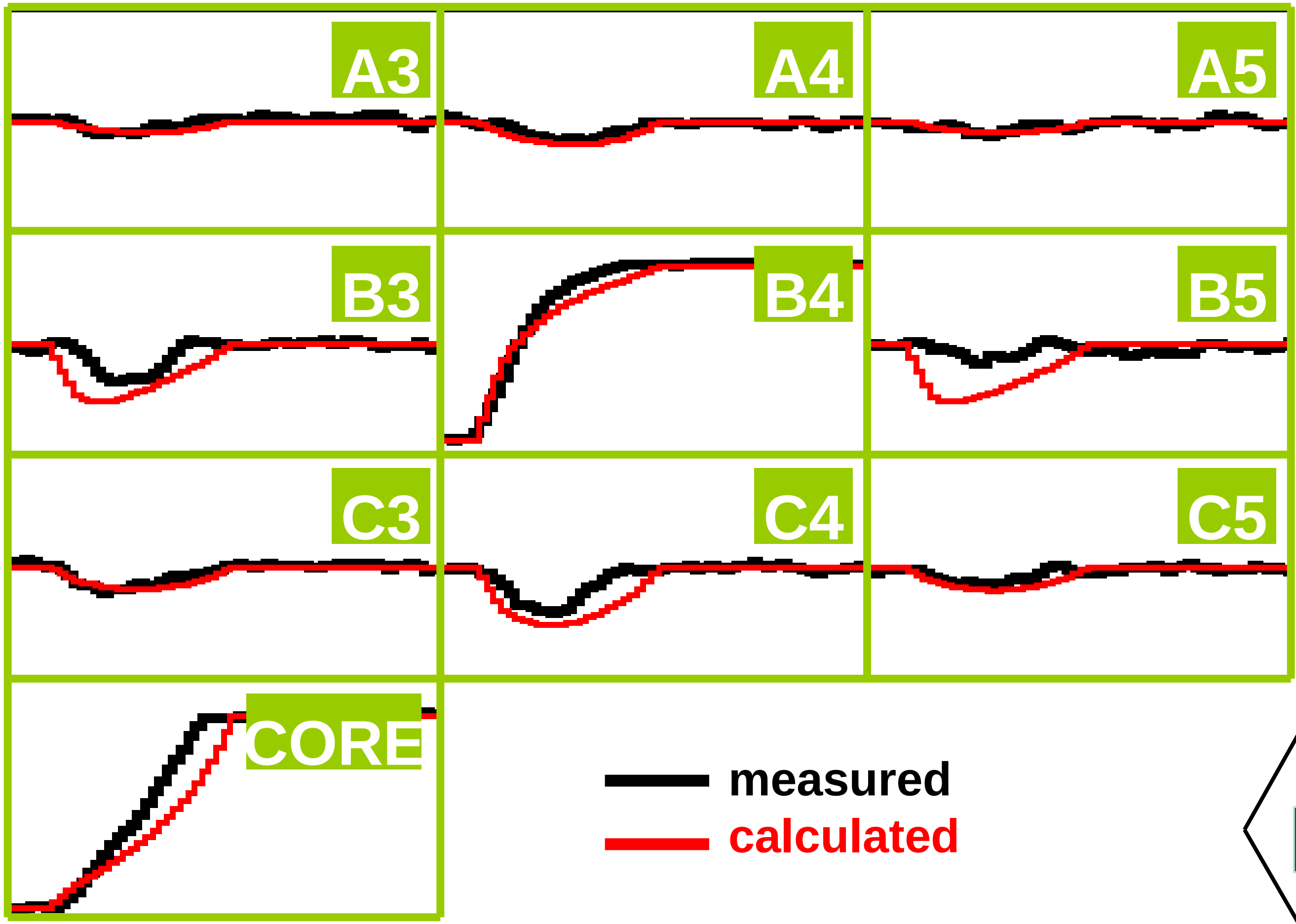
(10,25,46)

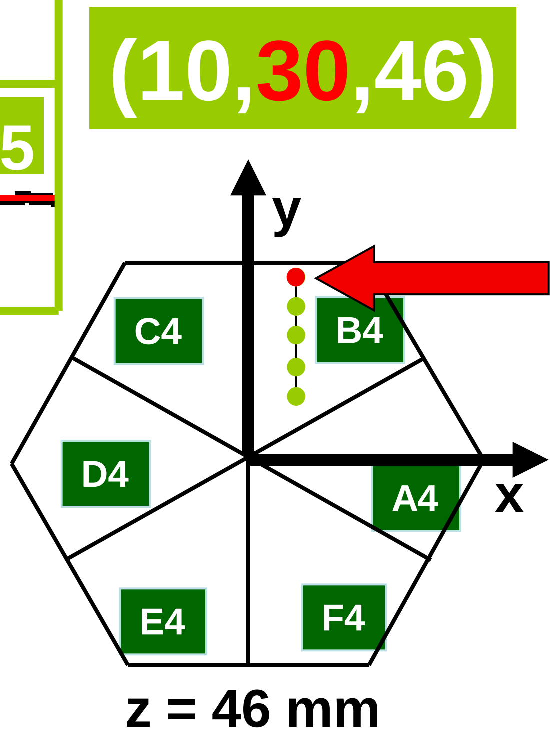


z = 46 mm

791 keV deposited in segment B4

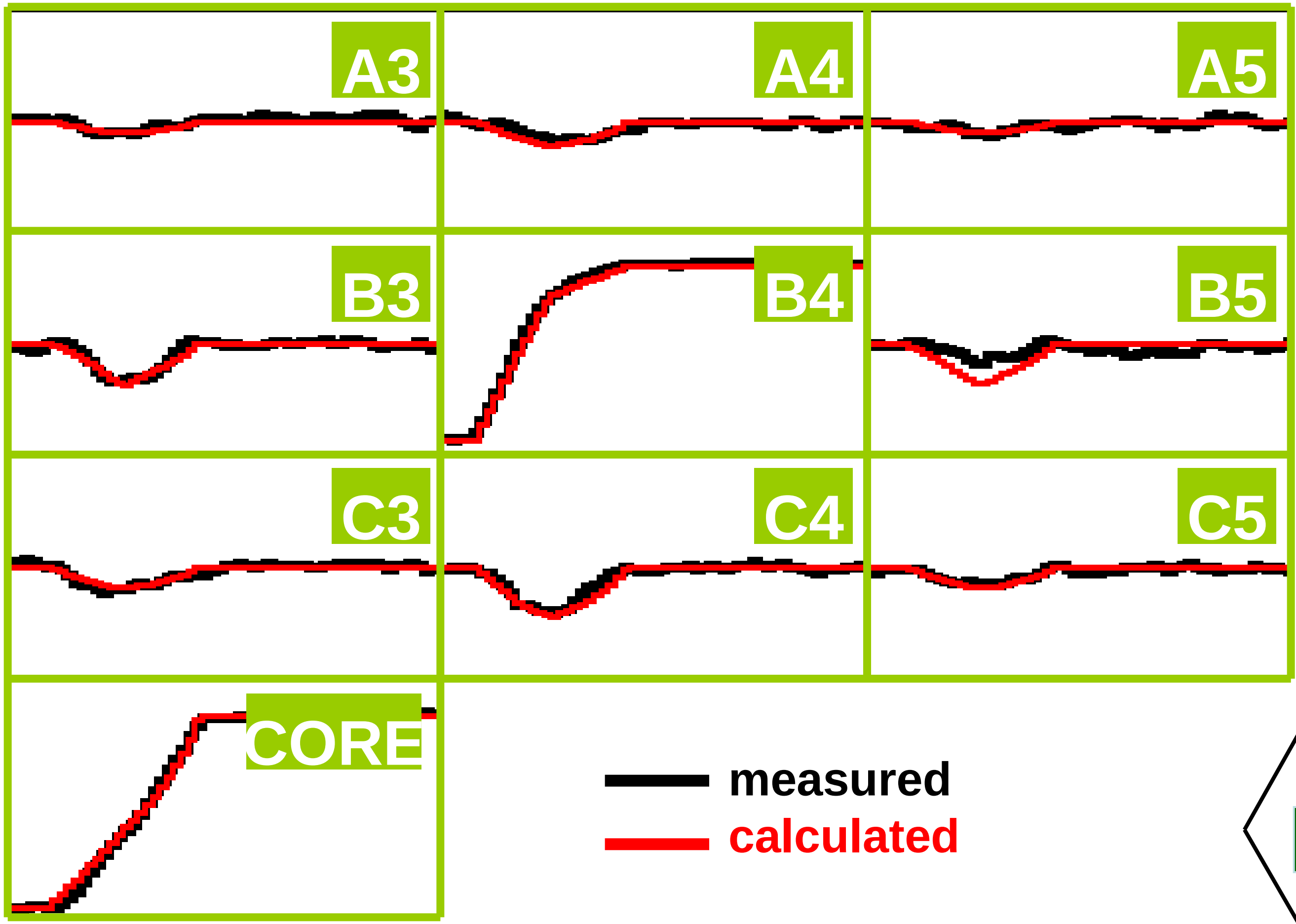
Pulse Shape Analysis concept





791 keV deposited in segment B4

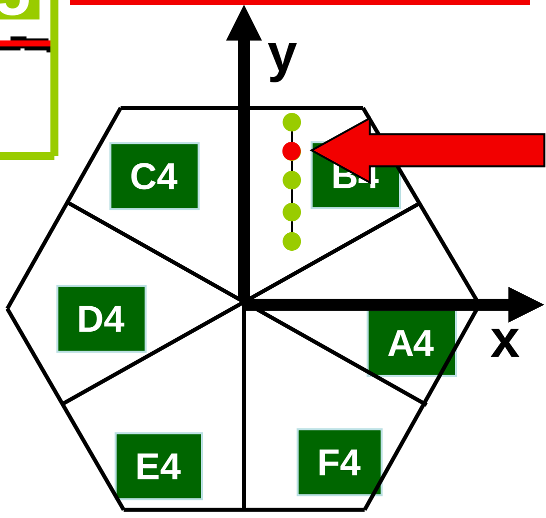
Pulse Shape Analysis concept



791 keV deposited in segment B4

Result of *Grid Search* algorithm

(10,25,46)



z = 46 mm

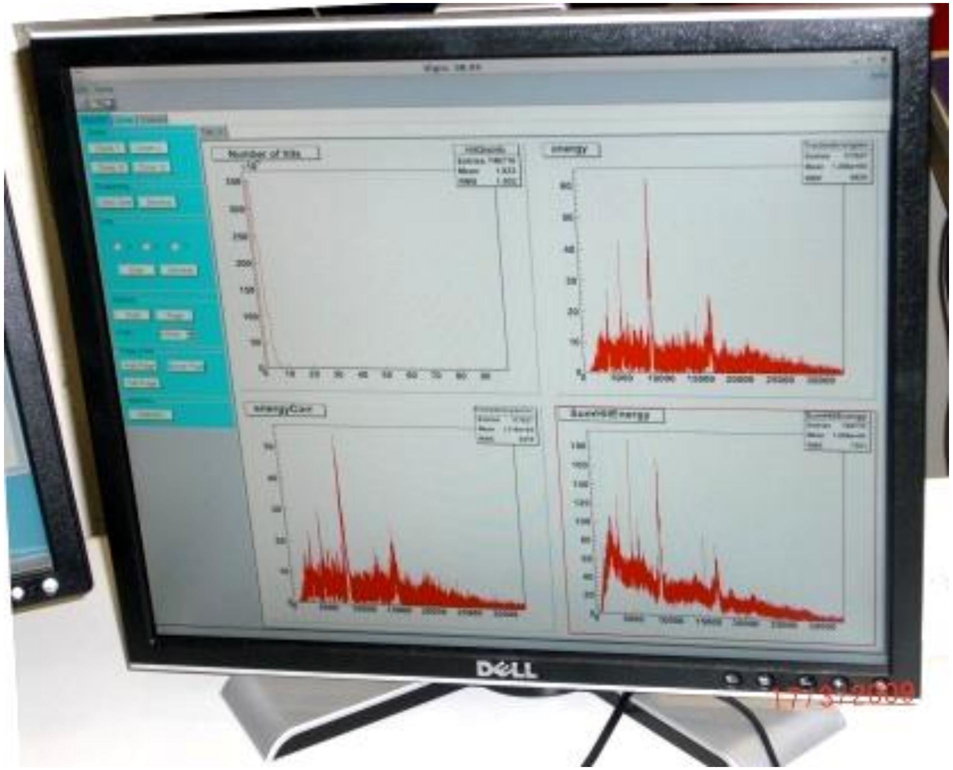
AGATA Scan Setup

- Two symmetric crystals scanned at U. Liverpool
- Scans of asymmetric crystals ongoing at Liverpool
- Scanning systems, CSNSM Orsay, Strasbourg, GSI
- Annealing

RUNNING!

- $^{30}Si@70MeV + ^{12}C$

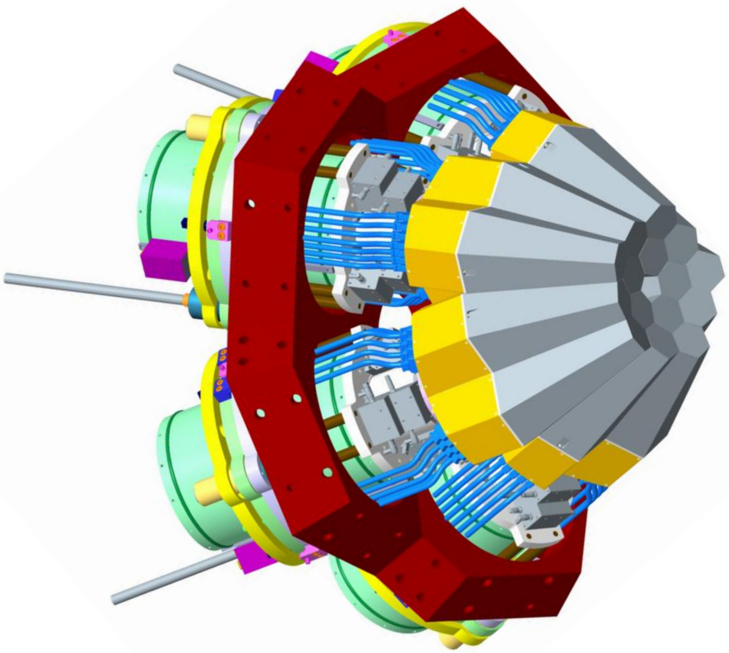
11:42
17/03/2009

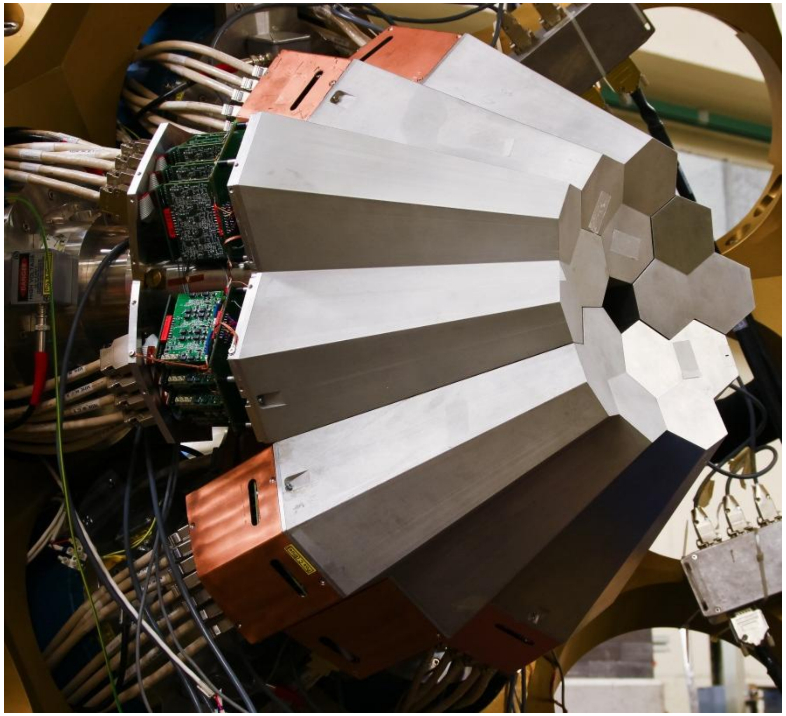


- Pre-processing
- PSA
- Tracking

The AGATA Demonstrator

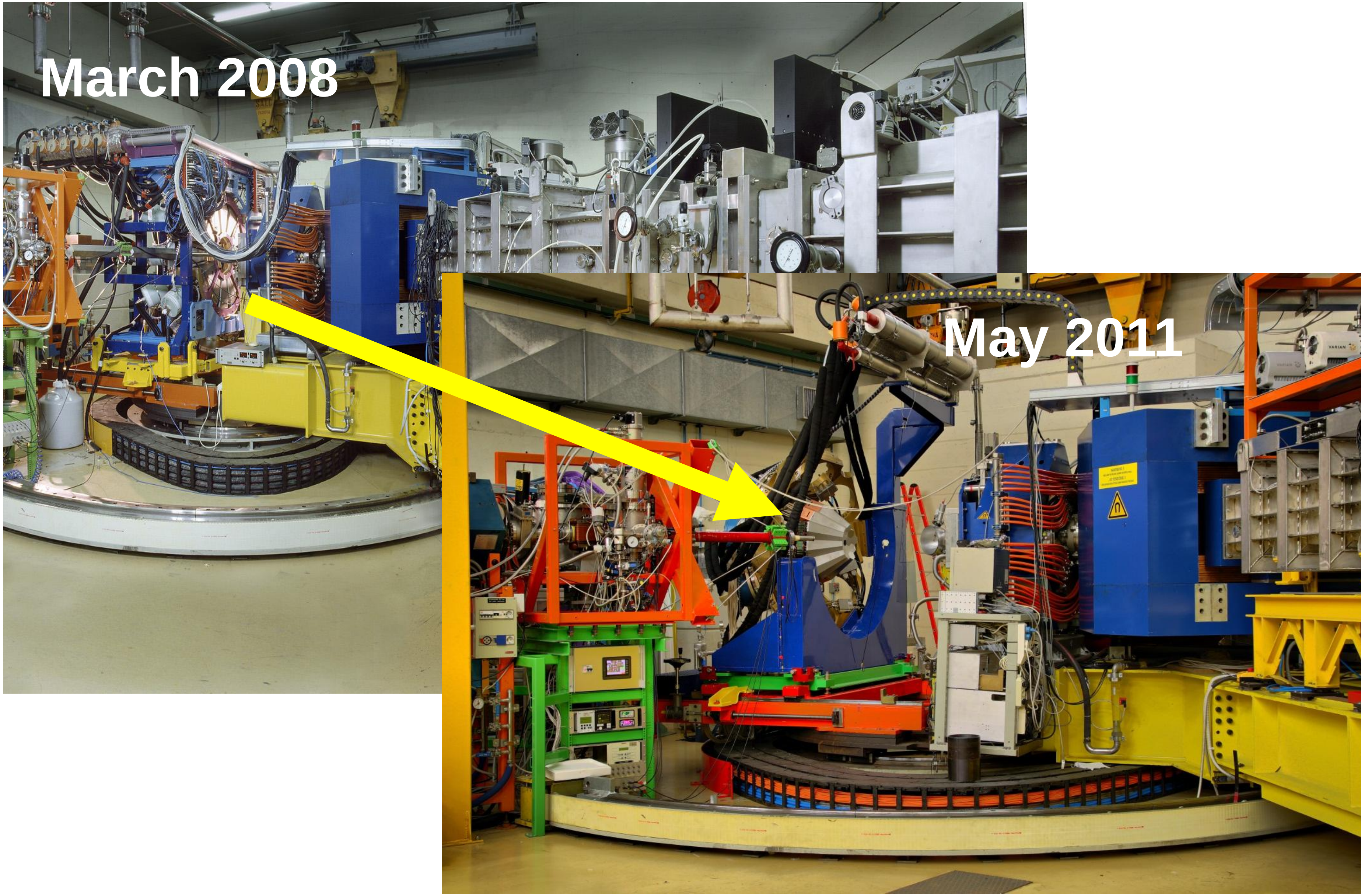
Objective of the final R&D phase 2003-2008





From Design to Reality

From CLARA to AGATA

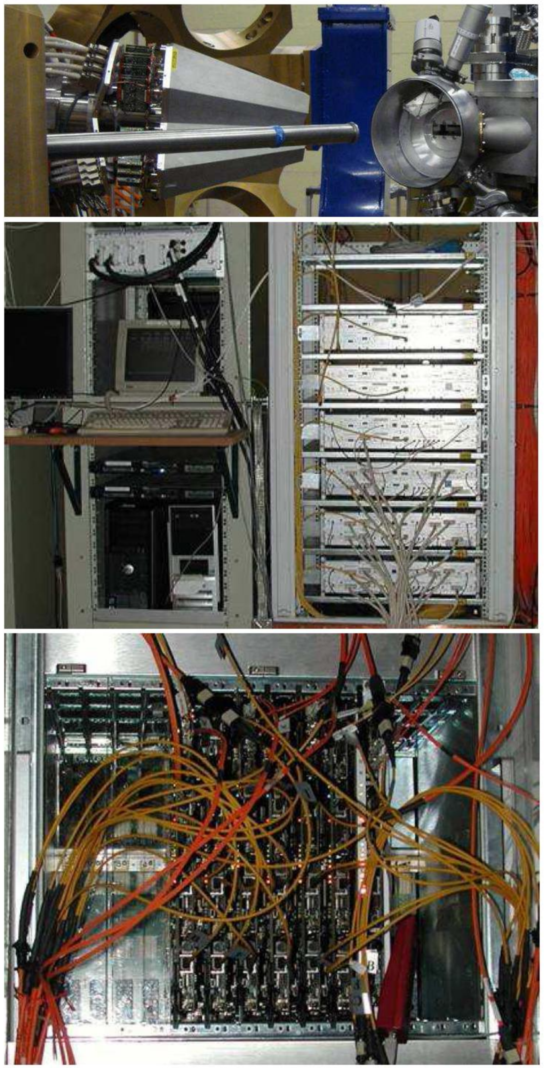


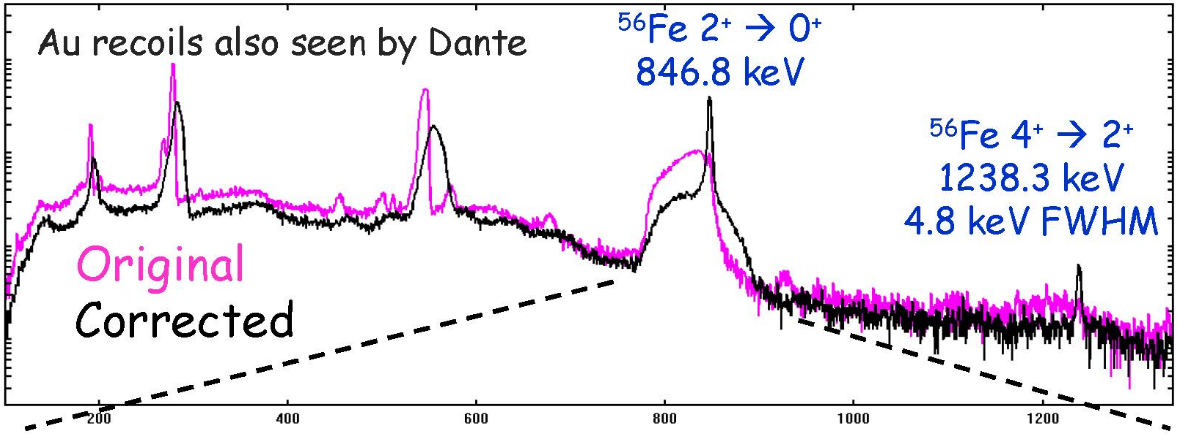
AGATA Inauguration

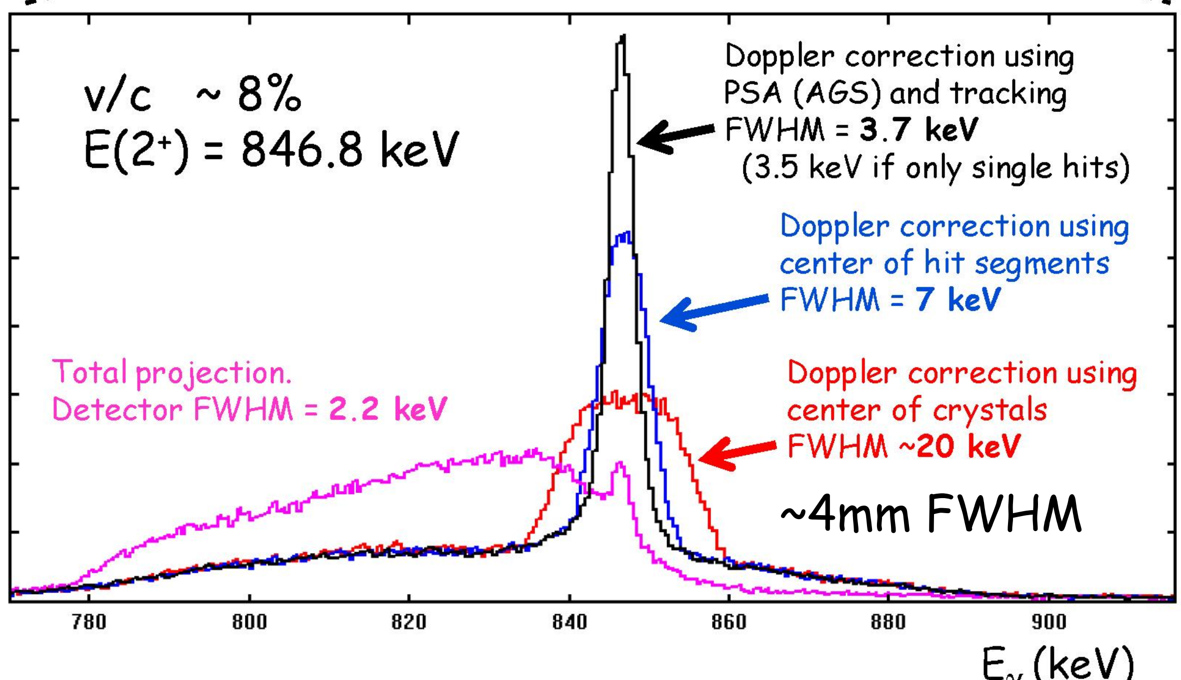
April 2010

220 MeV $^{56}Fe \rightarrow {}^{197}Au$

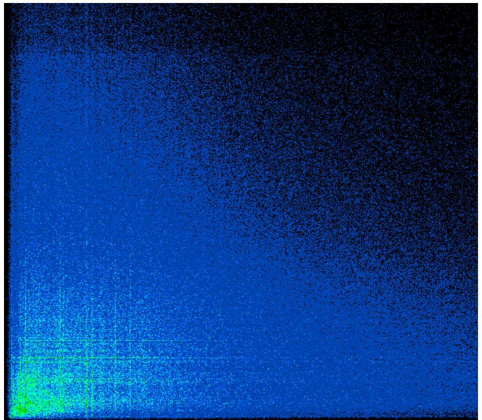
ATC1 + DANTE





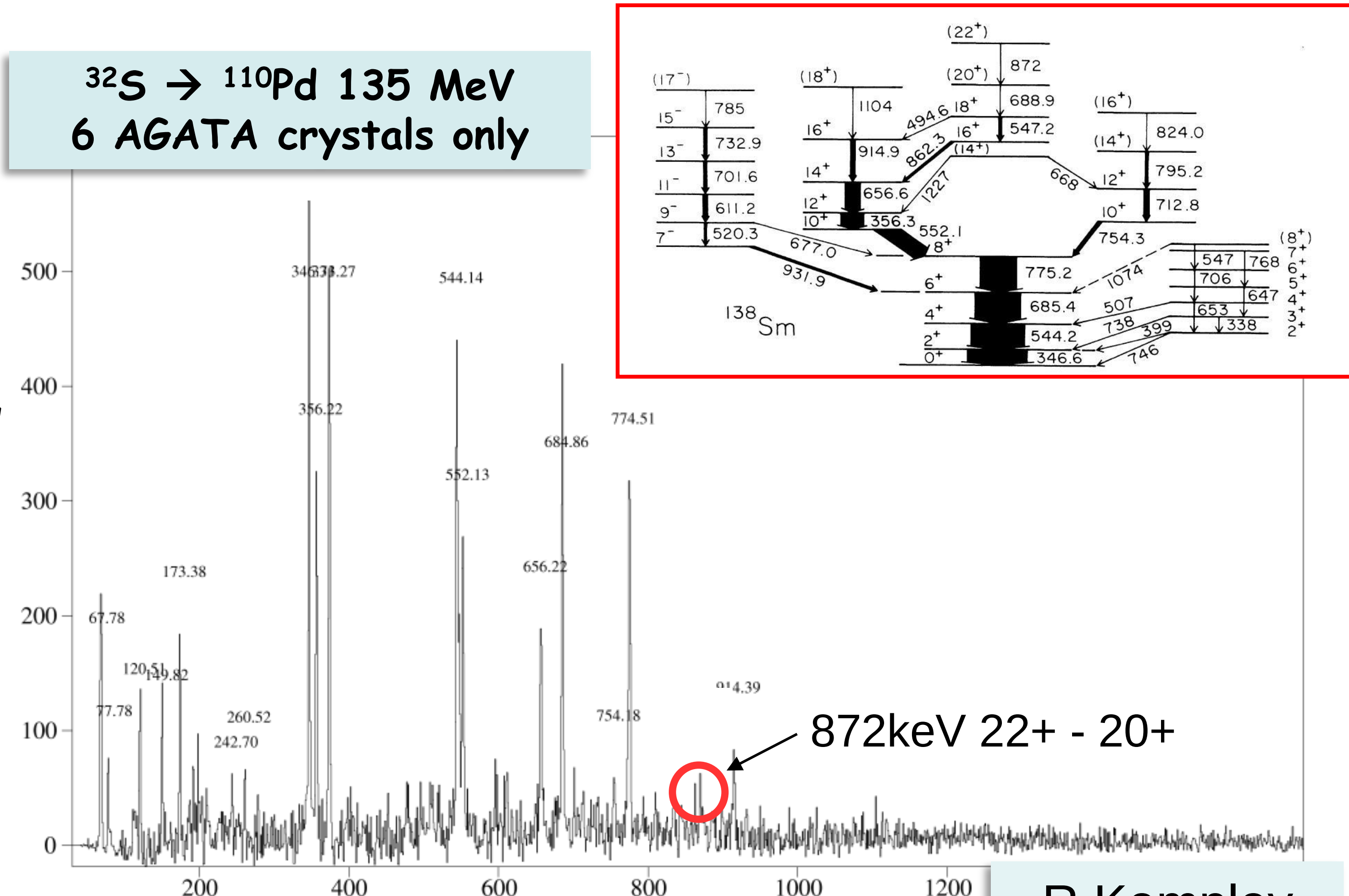


γγ capabilities



The performance of AGATA using γ-ray tracking is comparable with conventional arrays with a much larger number of crystals (possible issues with counting rates …)

$^{32}S \rightarrow {}^{110}Pd$ 135 MeV
6 AGATA crystals only



^{138}Sm
6 gates on:
347keV,545keV,
686keV,775keV,
552keV,357keV

R.Kempley

AGATA experiments LNL

AGATA proposals (~19 runs + 4 test experiments)

- Collectivity at maximum nucleon valency: Investigation of ground-state rotation in the neutron-rich Dy, Er and Yb nuclei J.Ollier, P.-A.Soderstrom, P.H.Regan, J.Simpson, J. Nyberg et al., +PRISMA+DANTE
- Spectroscopy of neutron rich Th and U nuclei after multi-nucleon reactions, P.Reiter et. Al., +PRISMA+DANTE
- Delayed shape transition in ^{196}Os, V. Modamio, Zs. Podolyak, C. Wheldon, W. Korten et al., + PRISMA
- Characterization of new structures in octupole-deformed radium and thorium nuclei, J.F.Smith et al.,
- Near and sub-barrier transfer reactions in 60Ni+118Sn, Montanari et al., PRISMA
- Isospin mixing in N=Z nucleus ^{80}Zr at medium temperature, A Giaz, F. Camera et al., +HECTOR
- Structure beyond the N=50 shell closure in neutron-rich nuclei in the vicinity of 78Ni: The case of N=51 nuclei, Verney, Duchene,de Angelis et al., +PRISMA+PLUNGER
- Lifetimes of intruder states in N ~ 20 sd-pf-shell neutron-rich nuclei Chapman, Haas et al., +PRISMA+PLUNGER
- RDDS lifetime measurement in the region of the neutron-rich doubly magic 132Sn: Lifetime of the 6+ state in 136Te. A. Gadea et al., +PRISMA+PLUNGER
- Development of the nuclear structure of neutron–rich isotopes in the Z»38 region populated by heavy–ion induced fission Merchan Ur, Marginean et al., +PRISMA+LaBr3
- Confirmation of the molecular structure of excited bands in 21Ne, C.Wheldon et al., +TRACE
- Order-to-chaos transition in warm rotating 174W nuclei, Valeria Vandone, **Silvia Leoni** et al., +HELENA
- Lifetime measurements of the neutron-rich Cr isotopes, Valiente-Dobon et al., +PRISMA+PLUNGER
- Neutron-rich nuclei in the vicinity of ^{208}Pb, Z.Podolyak et al., +PRISMA+DANTE
- Lifetime measurement in neutron-rich Ni, Cu, and Zn isotopes, Eda Sahin, Maria Doncel, Andreas Goergen et al., + PRISMA+PLUNGER
- Lifetime measurement of the 6.792 MeV state in 15O, Roberto Menegazzo – Calin Ur et al., + PRISMA+PLUNGER
- Coulomb excitation of the presumably superdeformed band in 42Ca, Adam Maj, Pawel Napiorkowski, Faisal Azaiez et al., +DANTE
- Precision lifetime study in the neutron-rich N=84 isotone ^{140}Ba from DSAM measurements following Coulomb-barrier alpha-transfer reactions on a ^{136}Xe, Leske Joerg et al., Si detector
- Inelastic scattering as a tool to search for highly excited states up to the region of the Giant Quadrupole Resonance Roberto Nicolini, **Angela Bracco** +HELENA+TRACE

Test Experiments (tandem beams only)

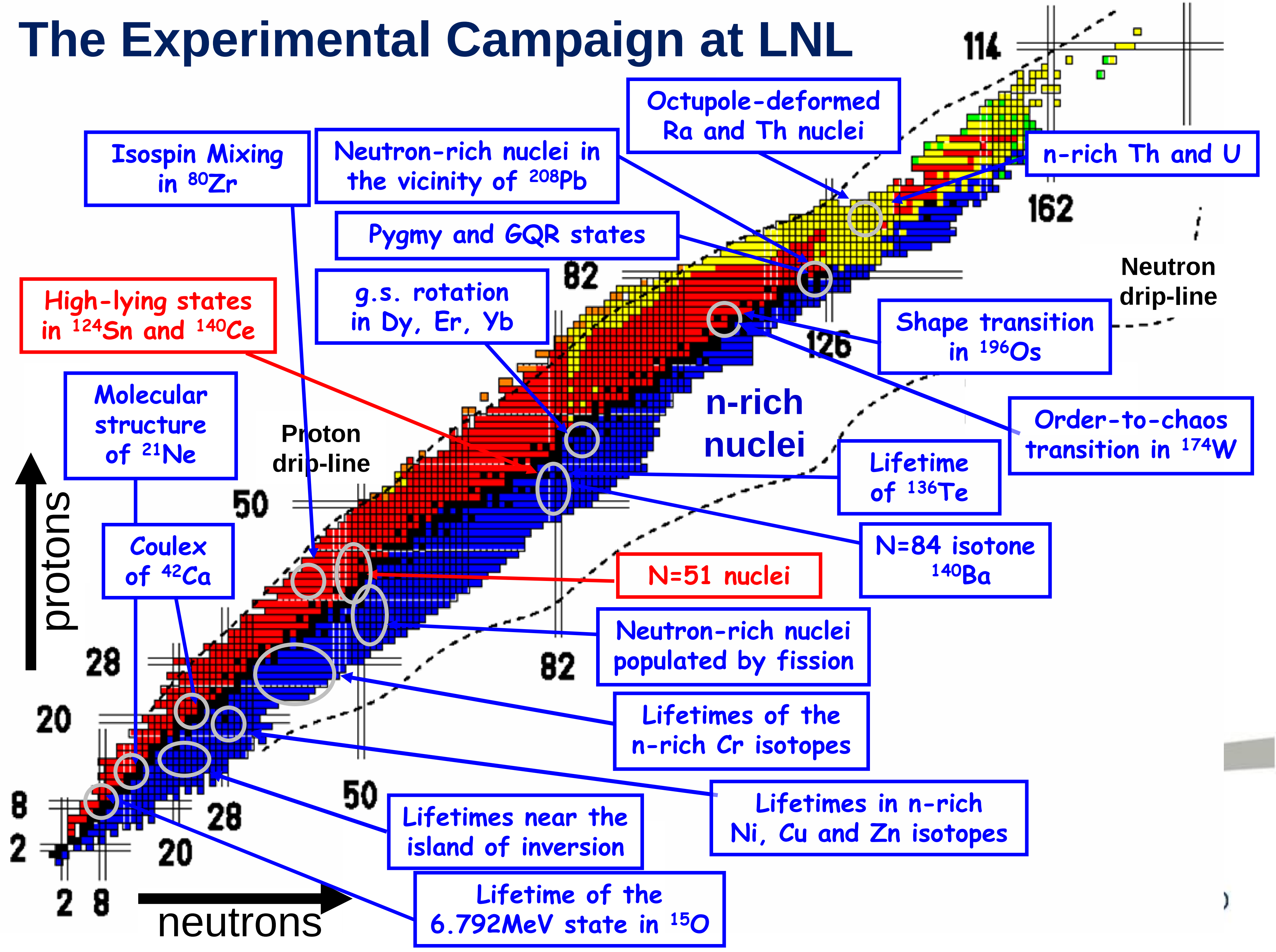
F.Haas et al, Lifetime measurements with the AGATA Demonstrator at LNL

F.Crespi, Response of AGATA to high-energy gamma rays (

P.G.Bizzeti, Polarization capabilities of AGATA

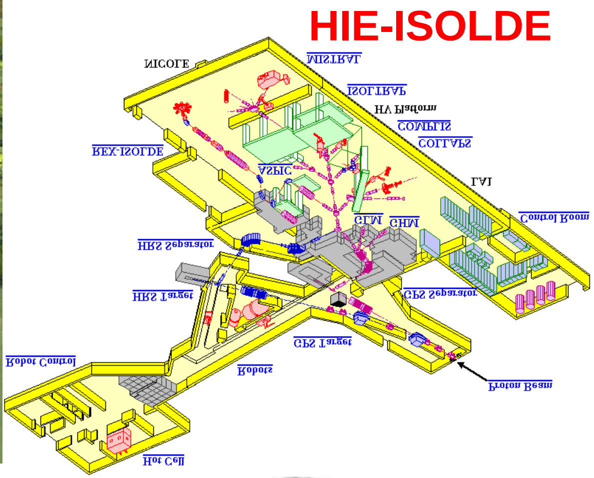
A. Atac, ^{252}Cf source measurement.

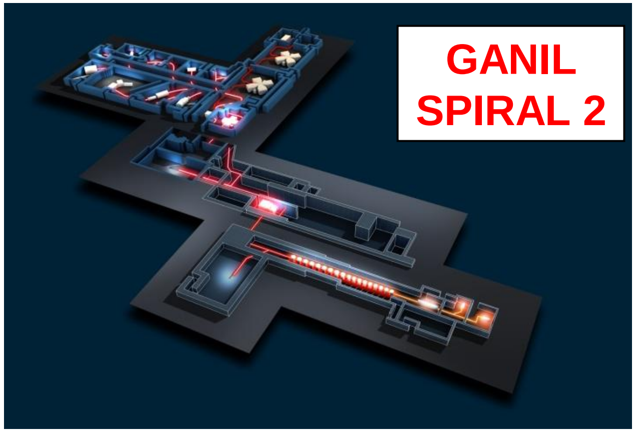
The Experimental Campaign at LNL



AGATA : 4π γ-array for Nuclear Physics Experiments

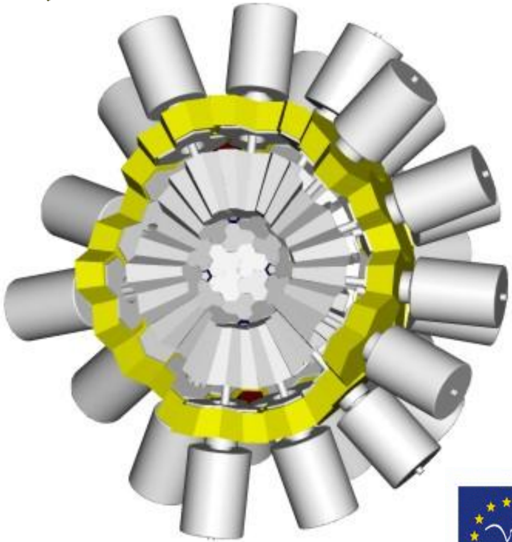
at major European accelerators providing radioactive and stable beams



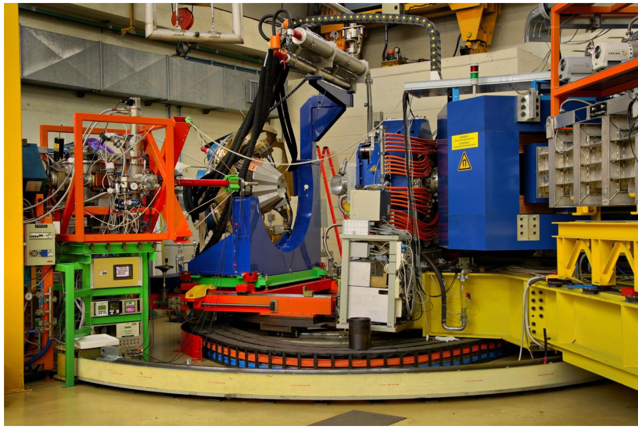


EURISOL

European Separator On-Line
Radioactive Nuclear Beam Facility

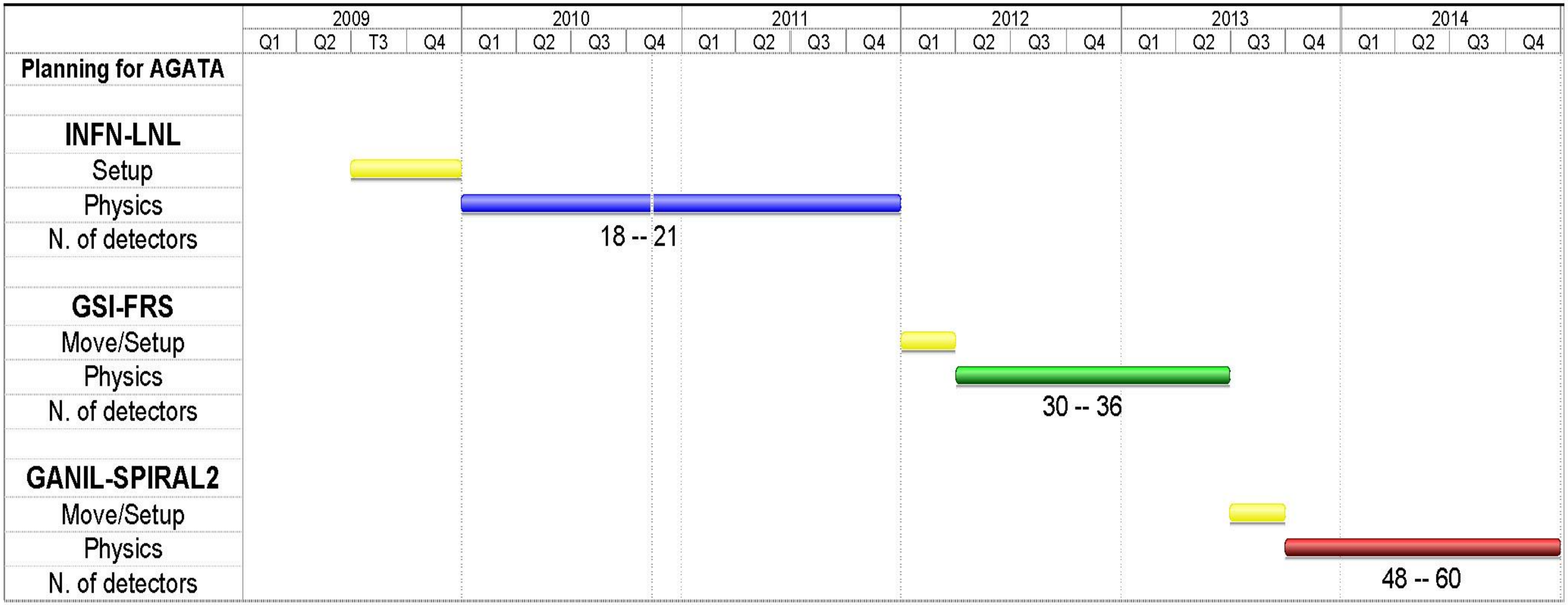


AGATA



LEGNARO

Current planning



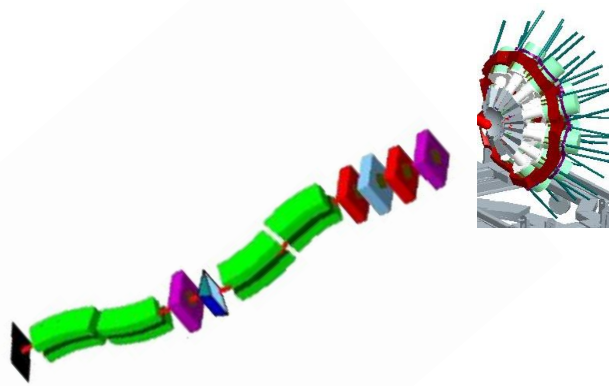
Proposed deployment of AGATA for the experimental campaigns at the three AGATA host Laboratories

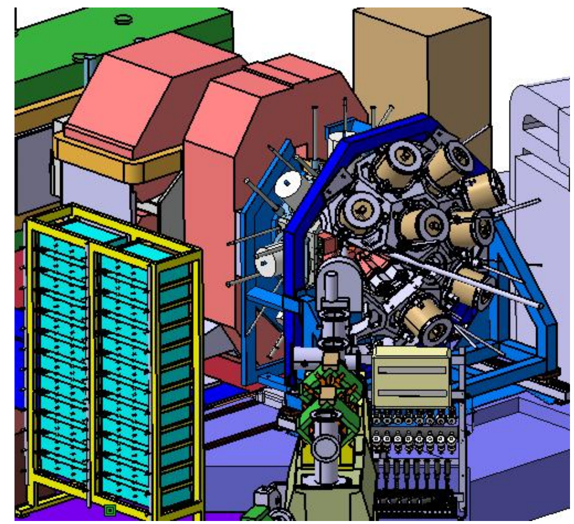
AGATA's Movements

2010 → LNL
5TC

2012 → GSI/FRS
5TC+5DC

2014 → GANIL/SPIRAL2
~15TC





AGATA +PRISMA

Total Eff. ~6%

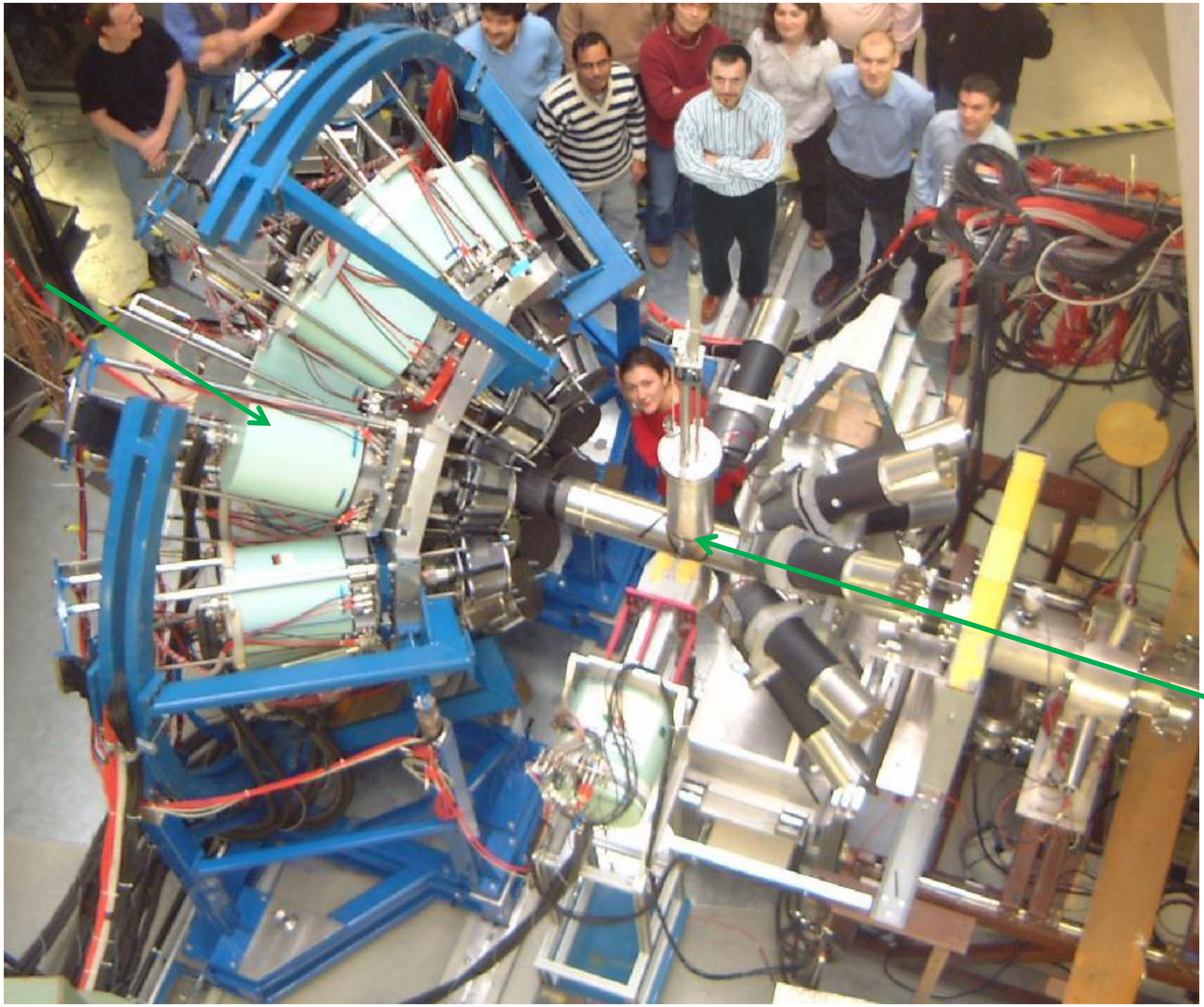
AGATA @ FRS

Total Eff. > 10%

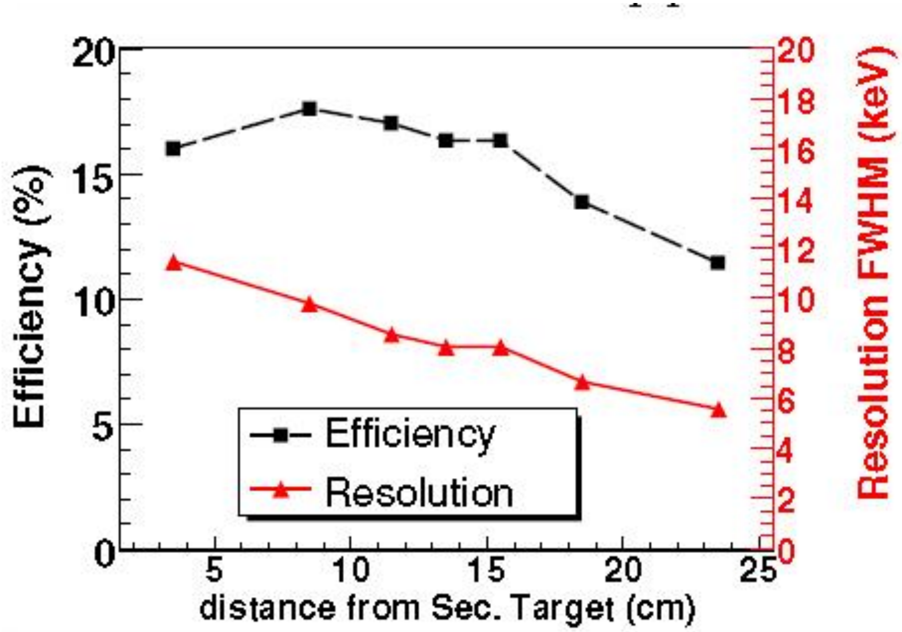
AGATA + VAMOS
+ EXOGAM+

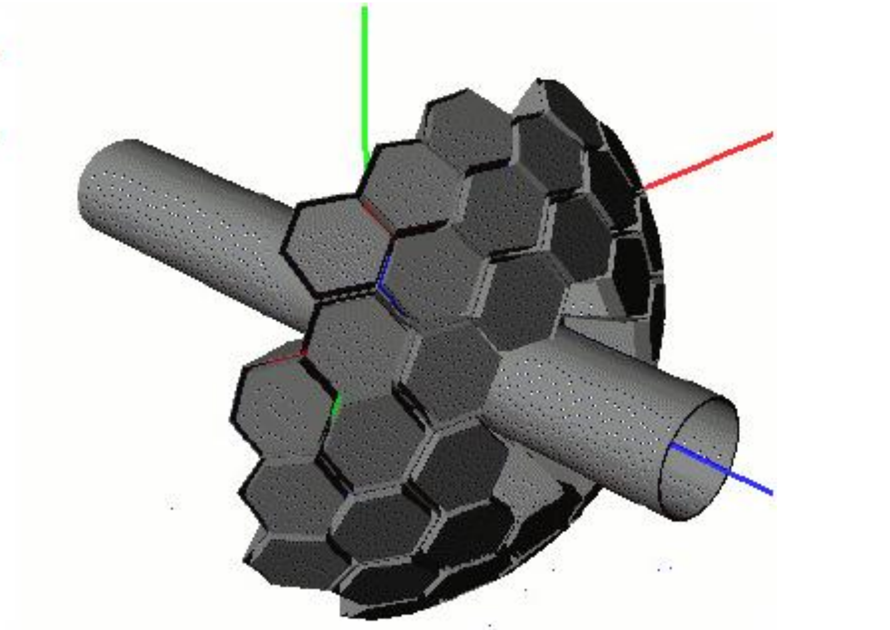
Total Eff. > 20%

AGATA replaces RISING at GSI

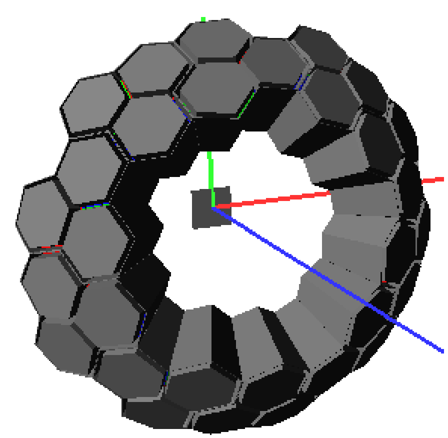


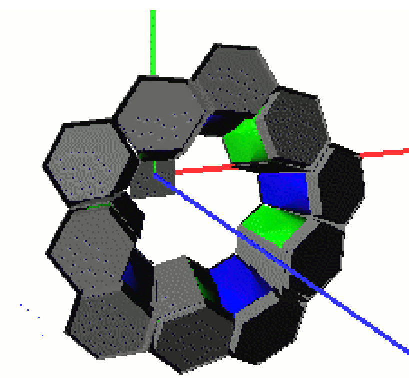
AGATA performance



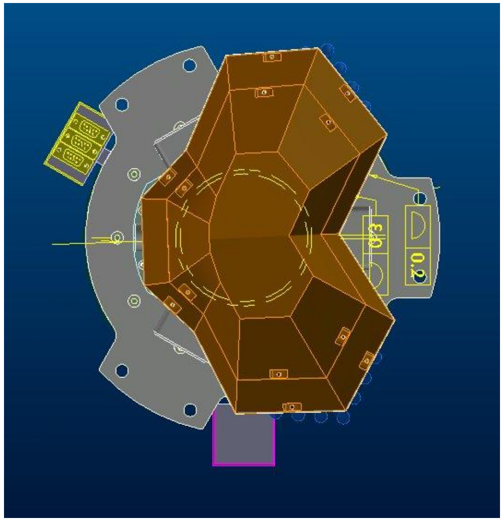


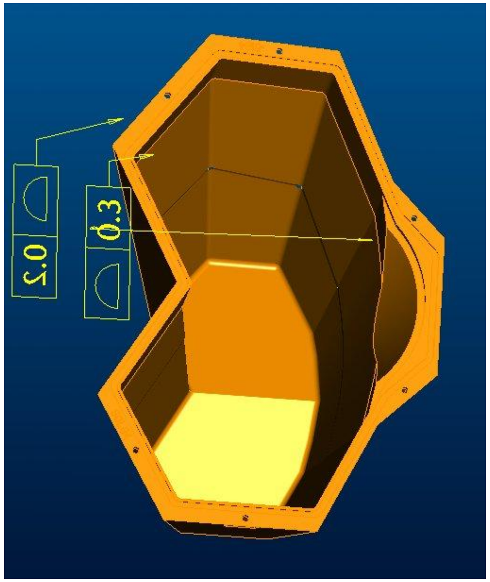
Complete models for experimen
simulation available

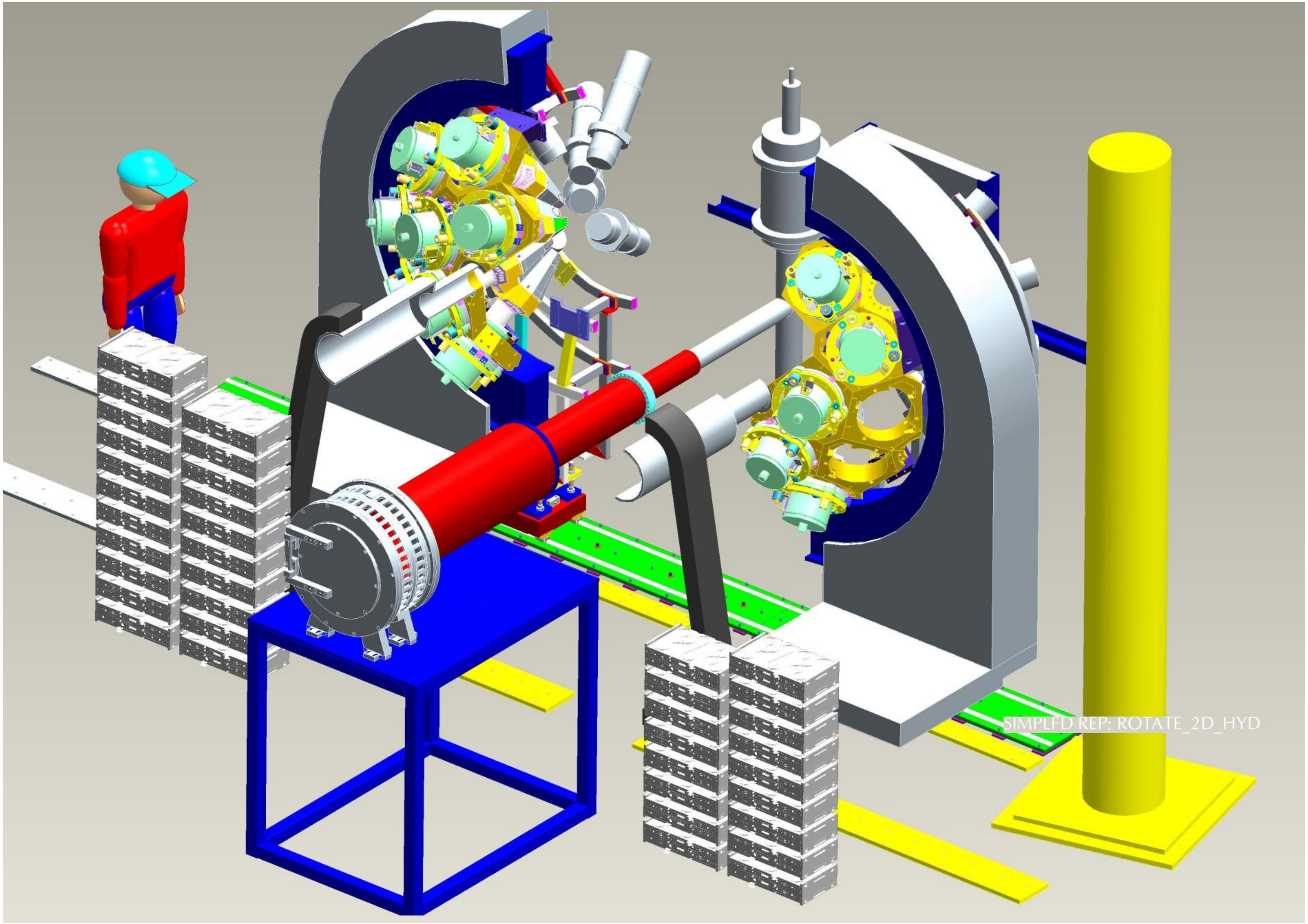




10 triple 5 Doubles
5 Doubles provide almost
50% of the efficiency!







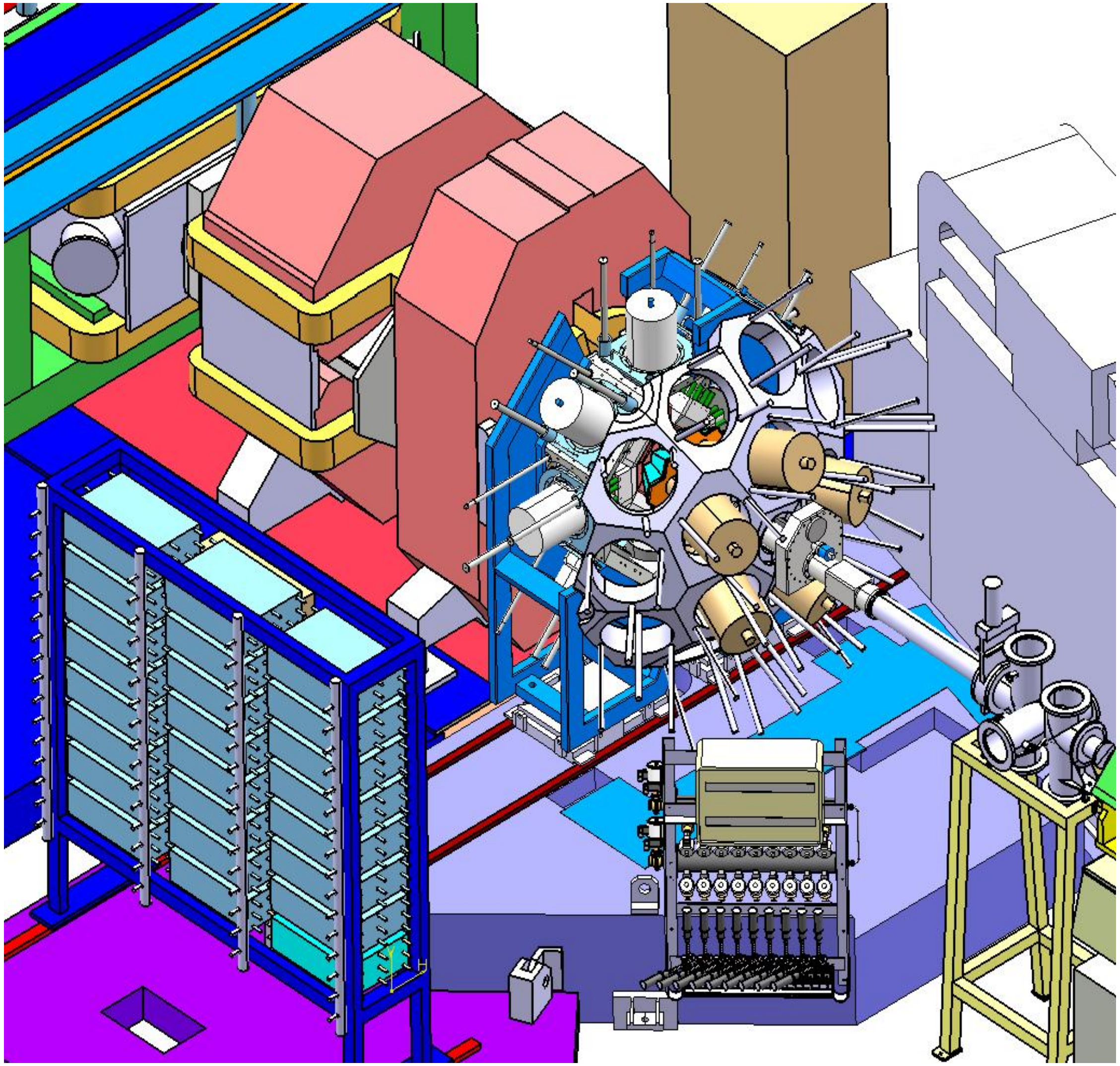
Ready and Operating by April 2012!

Assembly at GSI

Assembly at Daresbury

Ready and Operating by April 2012!

AGATA at GANIL



2014:

up to 15 triple clusters at VAMOS

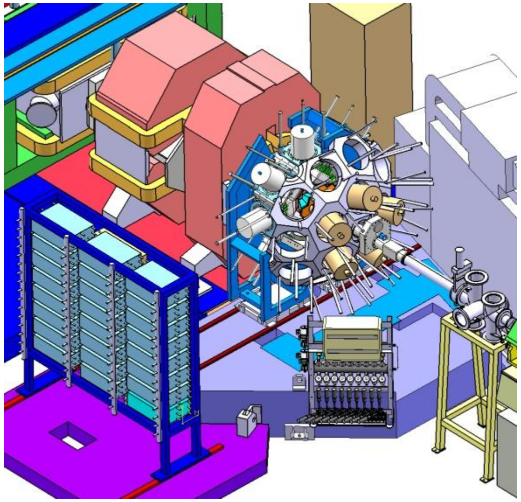
Stable ions (C-U) @ 5-100A.MeV

- ➢ **Deep-inelastic & fission products**

Radioactive beams @ 3-20A.MeV

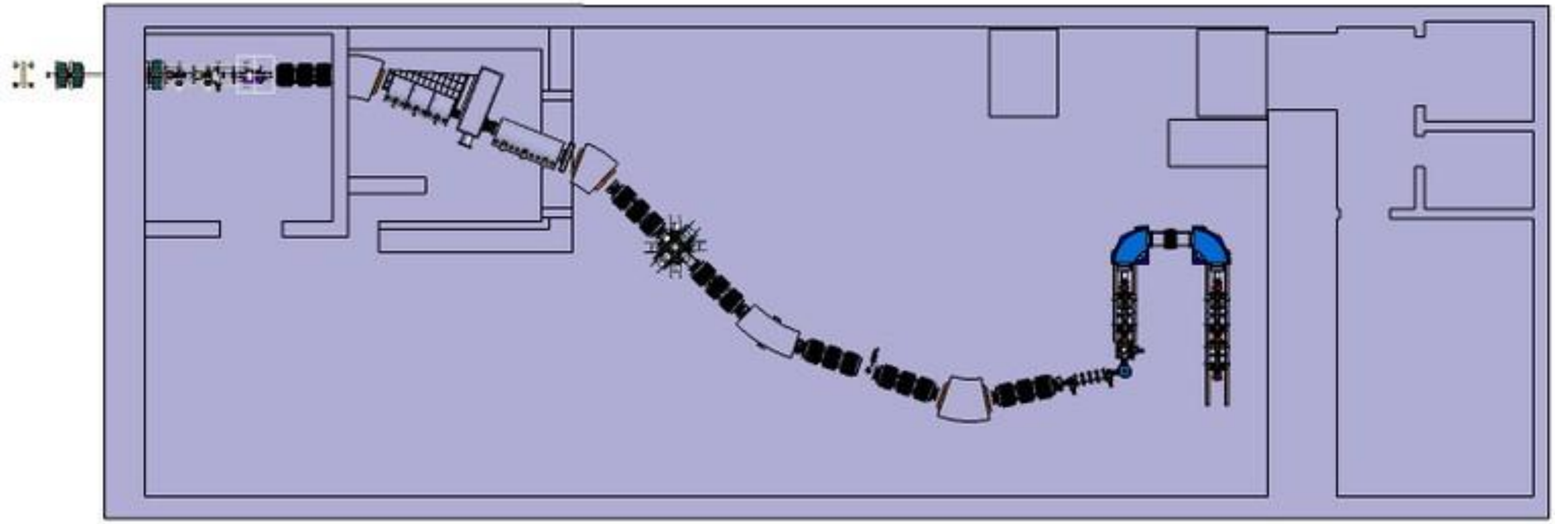
- ➢ **Coulomb & inelastic excitation, transfer reactions**

AGATA 1π at GANIL : possible locations



In G1 coupled to VAMOS (and EXOGAM2 if needed): SIBs, RIBs

At the intermediate focal plane of S3: SIBs



Acknowledgements

- Huge technical achievement
- Many people and laboratories
- Ongoing
- Physics

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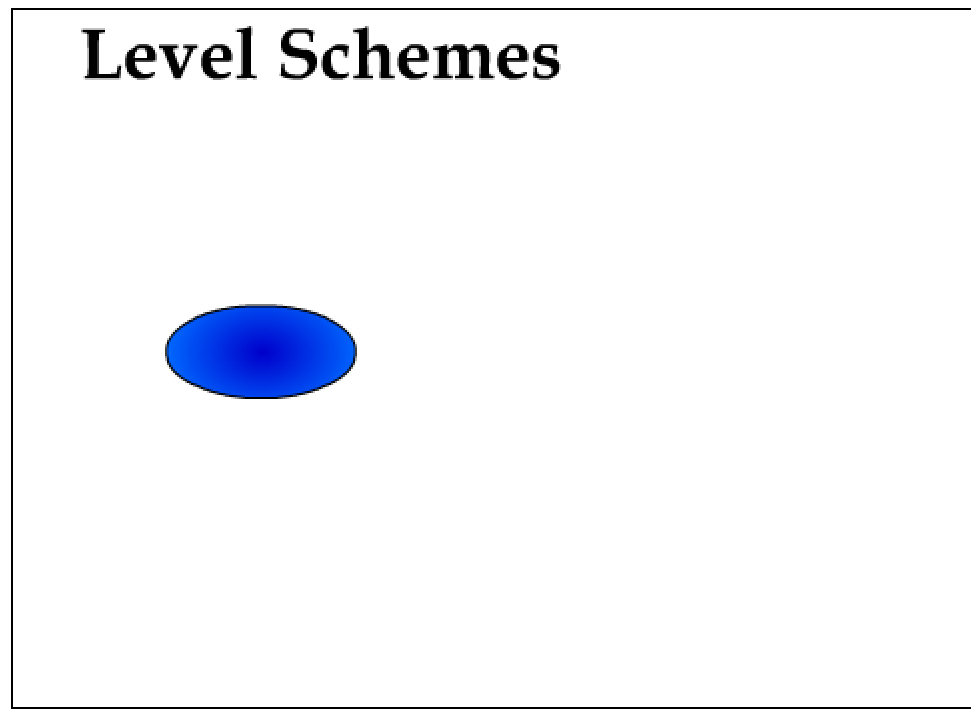
EGAN Workshop

Segmented detectors

PSA

DATA analysis

Skills--- Output



Acknowledgements

AGATA – Advanced Gamma Tracking Array
Nuclear Instruments and methods, Accepted

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