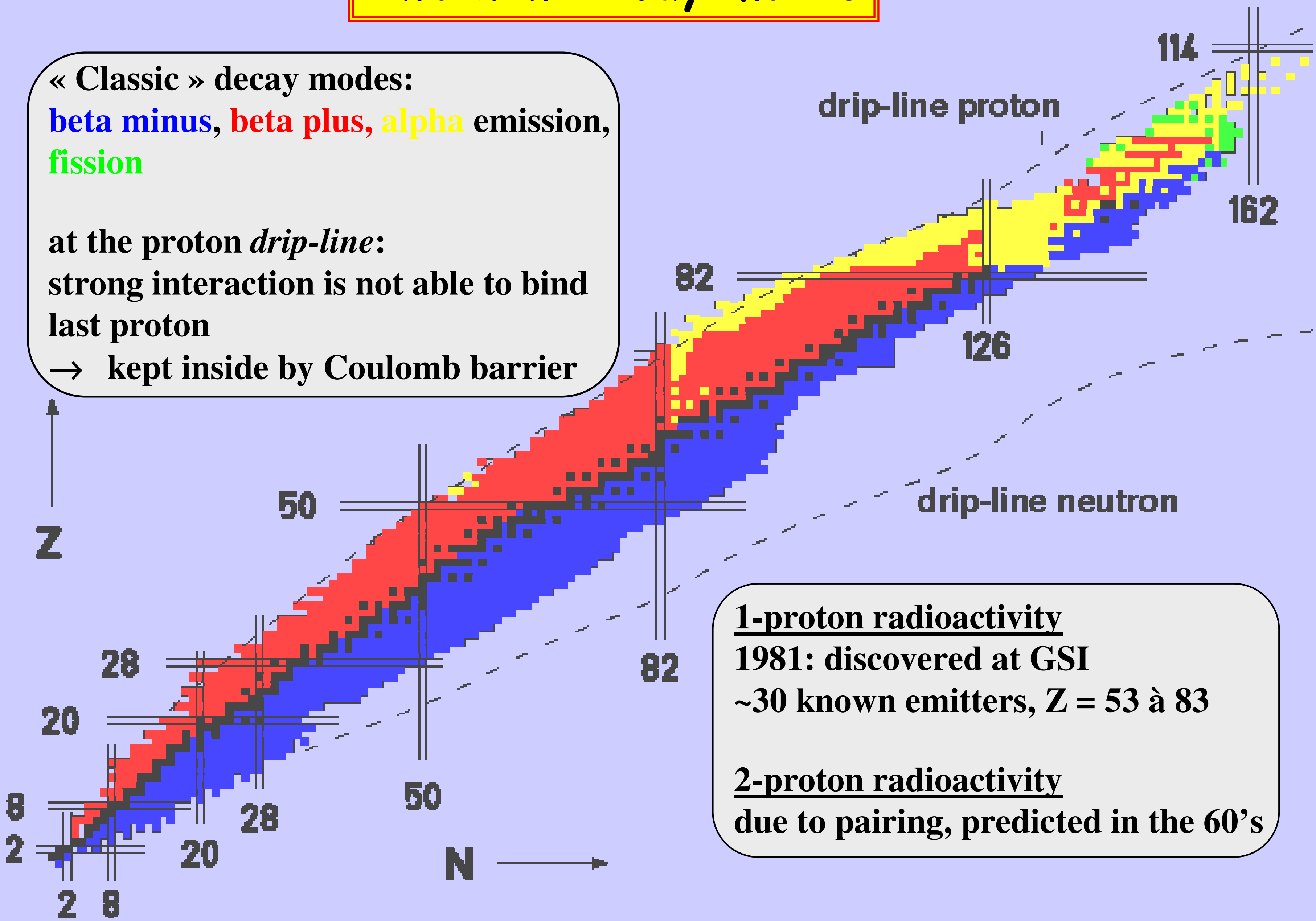
Some recent examples …

- Prompt particle decay from deformed excited states
- Superdeformed bands all over the chart of nuclides
- Spectroscopy of transfermium nuclei: Towards the SHE's …
- Ground state proton decay: spectroscopy beyond the dripline

Two new decay modes

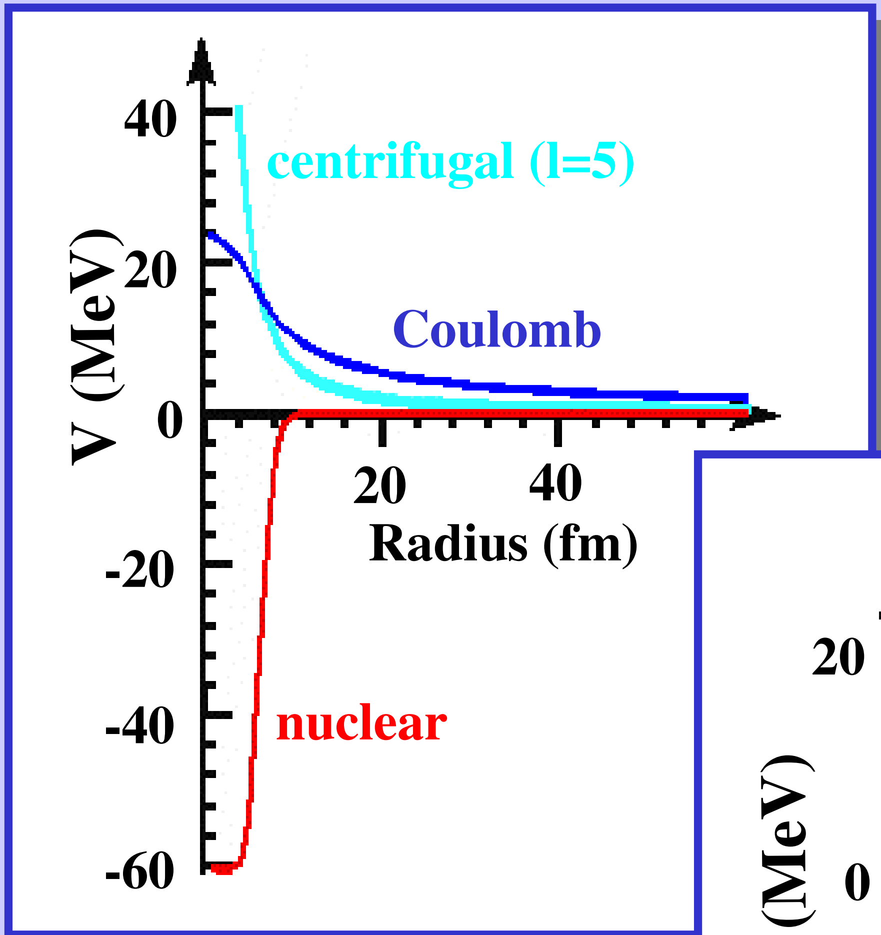
« Classic » decay modes:
beta minus, beta plus, alpha emission, fission

at the proton *drip-line*:
strong interaction is not able to bind last proton
→ kept inside by Coulomb barrier

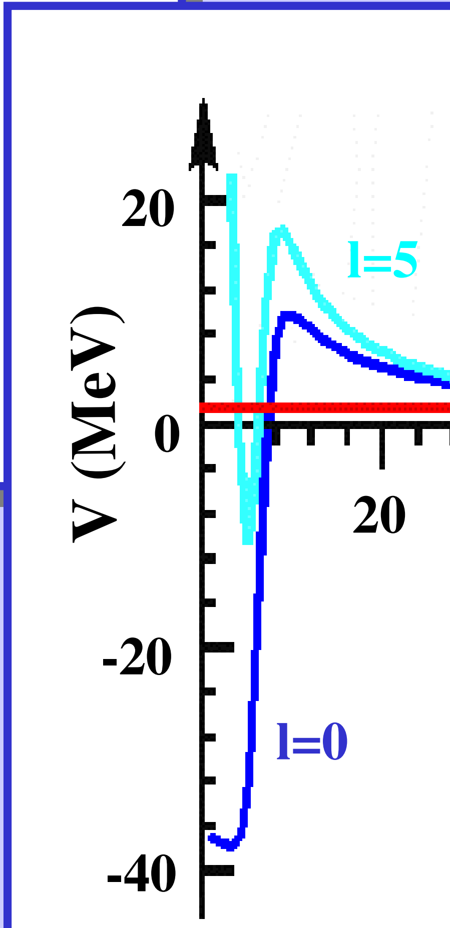


<u>1-proton radioactivity</u>
1981: discovered at GSI
~30 known emitters, Z = 53 à 83

<u>2-proton radioactivity</u>
due to pairing, predicted in the 60's



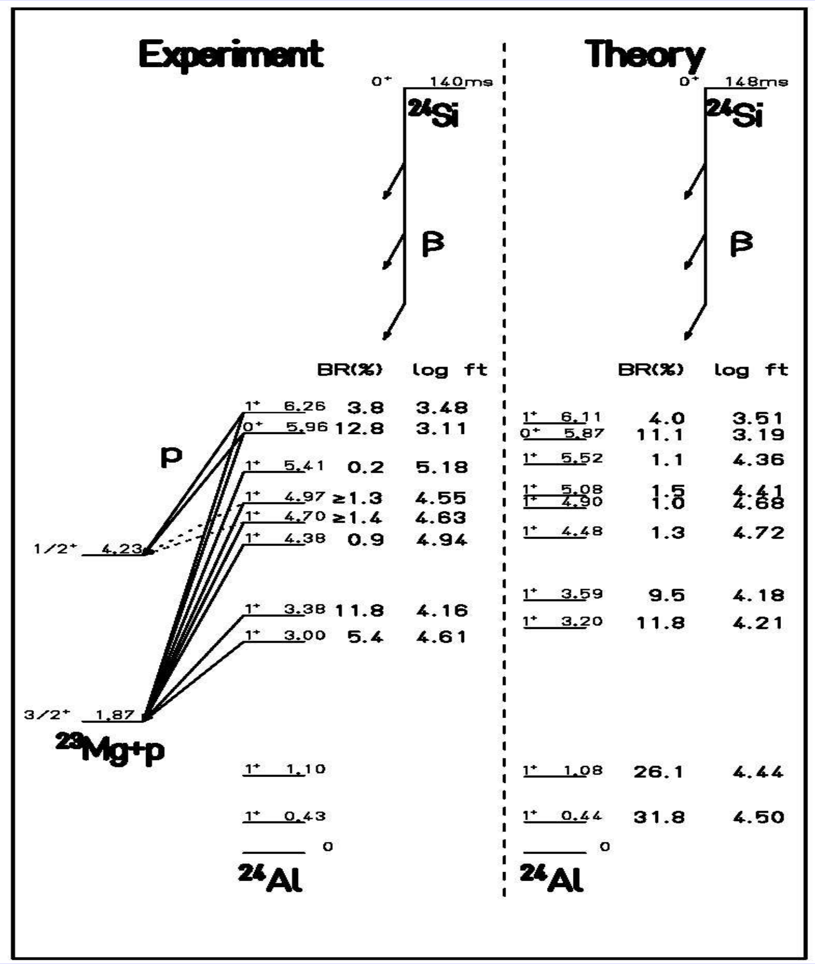
Strong influence of angular momentum !



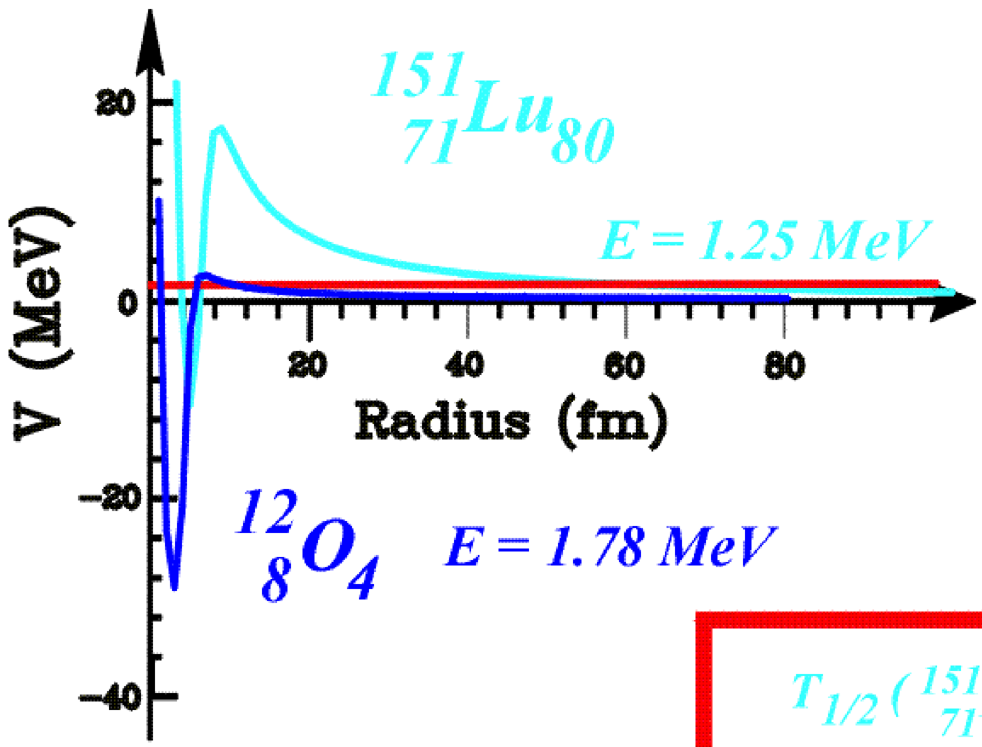
$T_{1/2}(l=0) = 3\mu s$

$T_{1/2}(l=5) = 81ms$

We are not talking about β-delayed proton decay …



… but ground state proton decay of nuclei beyond the proton dripline !



$T_{1/2}(^{151}_{71}Lu_{80}) = 81ms$

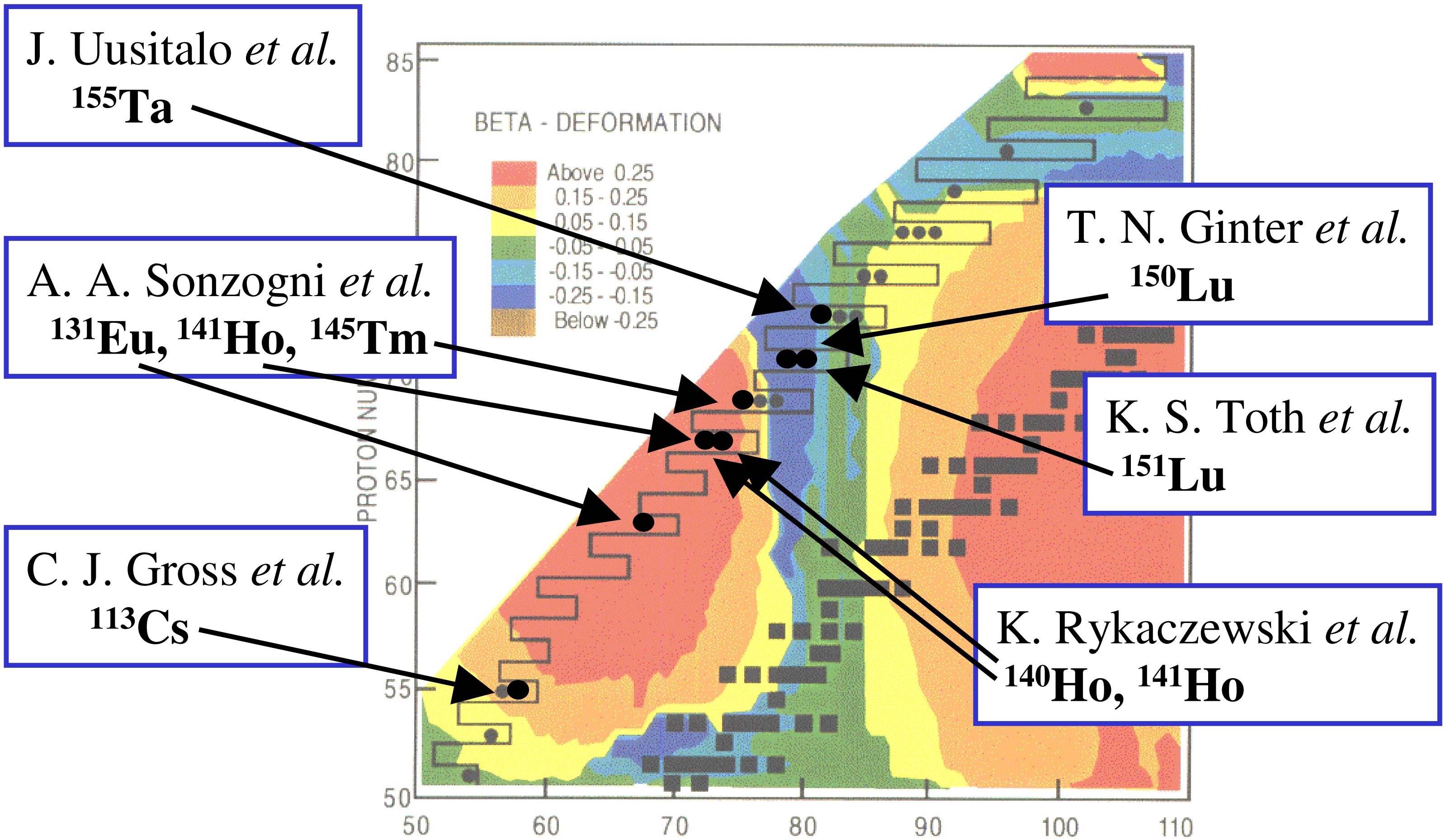
$T_{1/2}(^{12}_{8}O_{4}) \sim 10^{-21} s$

"Long" (observable) lifetimes in heavy nuclei due to Coulomb and angular momentum barrier !

How to study proton radioactivity ?

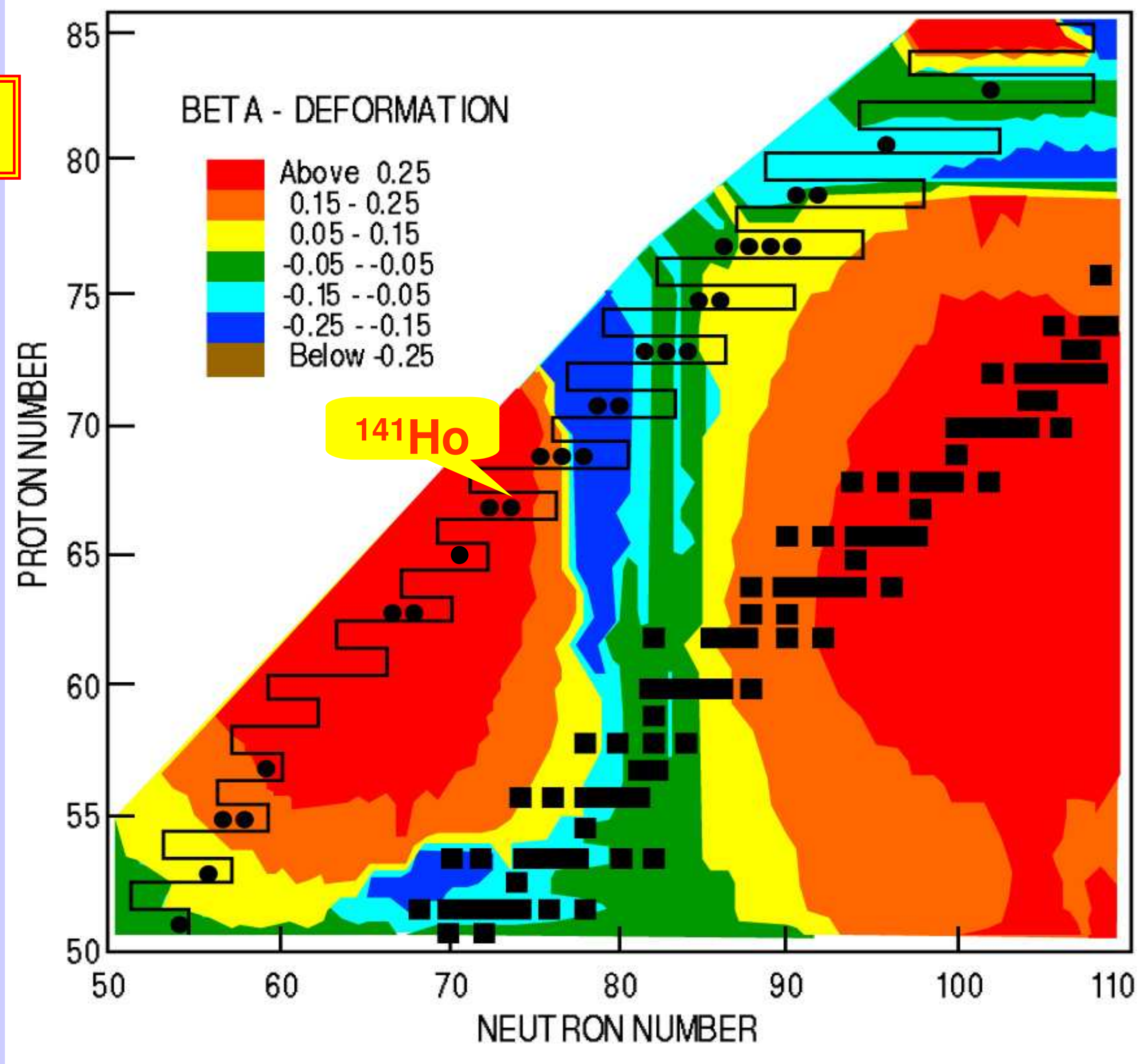
- choose heavy nuclei: Longer lifetimes due to Coulomb and angular momentum barrier
- produce in fusion evaporation reactions
- separate and subsequently stop in a detector for identification
- use segmented silicon strip detectors to observe delayed decay (recoil decay tagging)

Some of the recently observed proton emitters



P. J. Woods and C. N. Davids, Annu. Rev. Nucl. Part. Sci. **47** (1997) 541

One example: ^{141}Ho



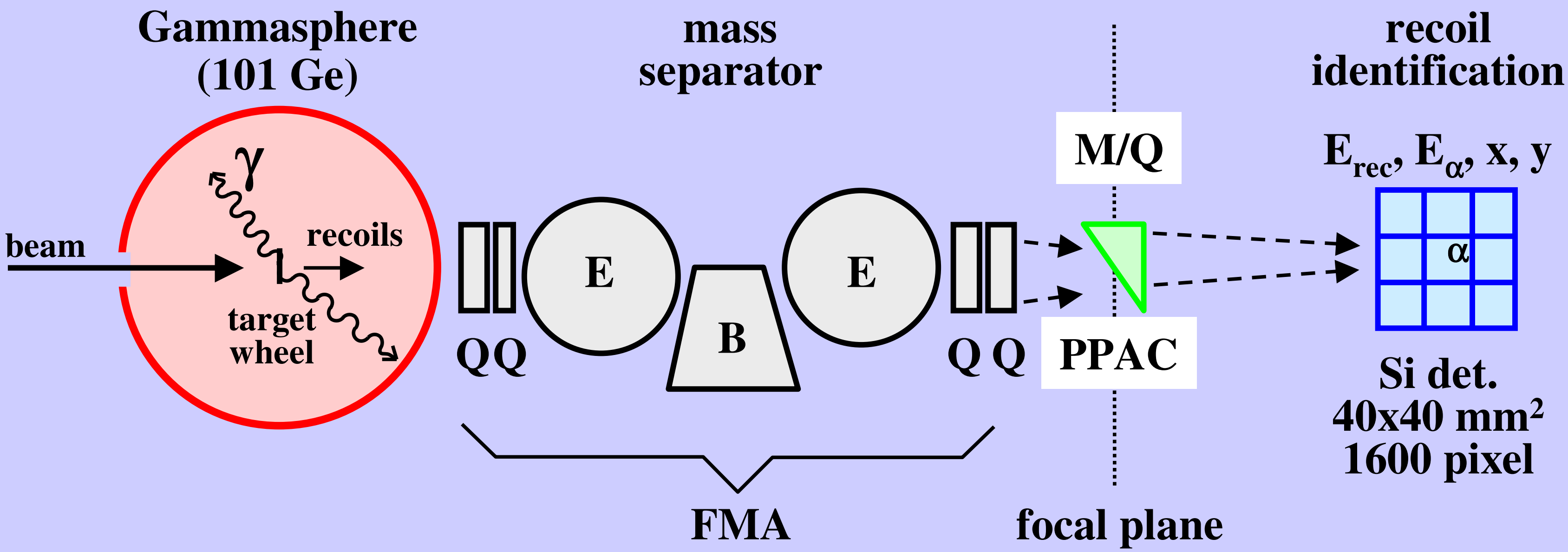
Reactions:

^{92}Mo + ^{54}Fe à ^{141}Ho + p4n @ 292 MeV

^{54}Fe + ^{92}Mo à ^{141}Ho + p4n @ 502 MeV

σ~100 nbarn

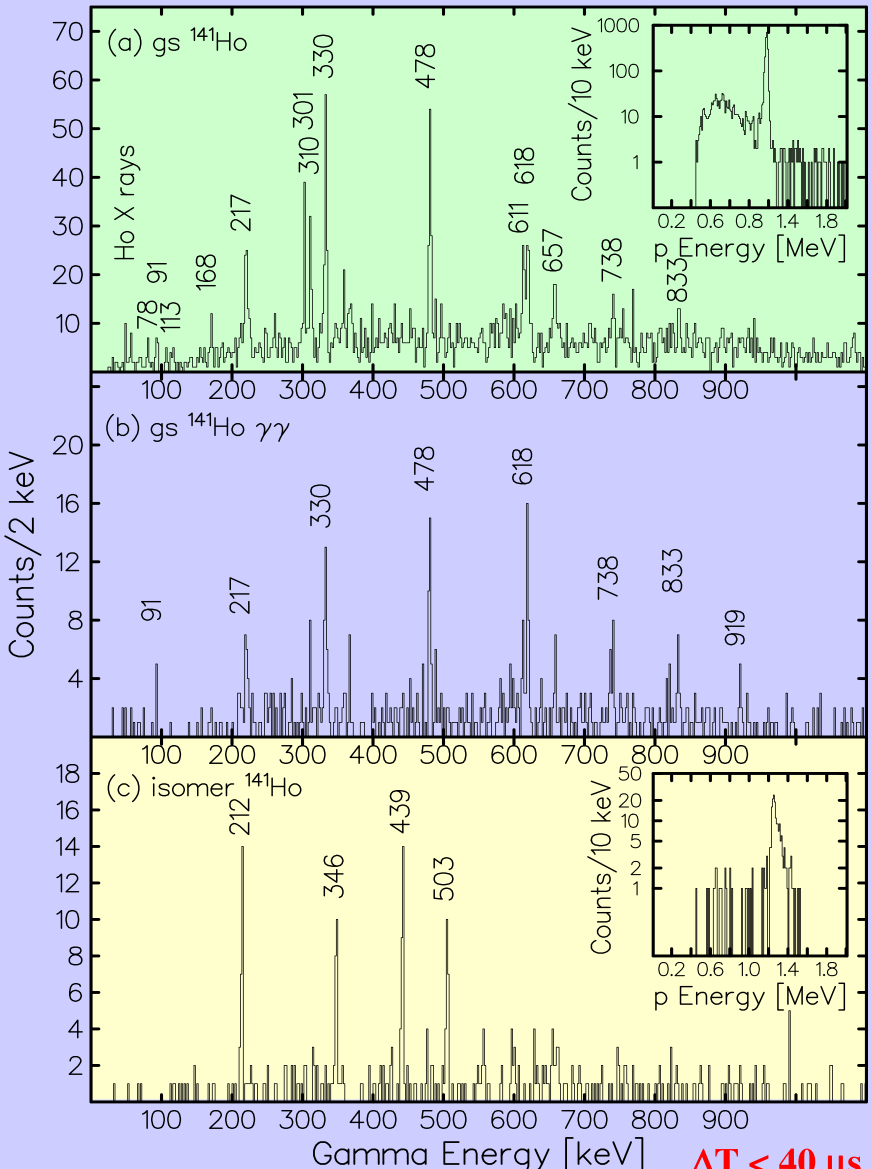
Recoil decay tagging with Gammasphere+FMA



- same setup than in No experiment
- now proton instead of α decay

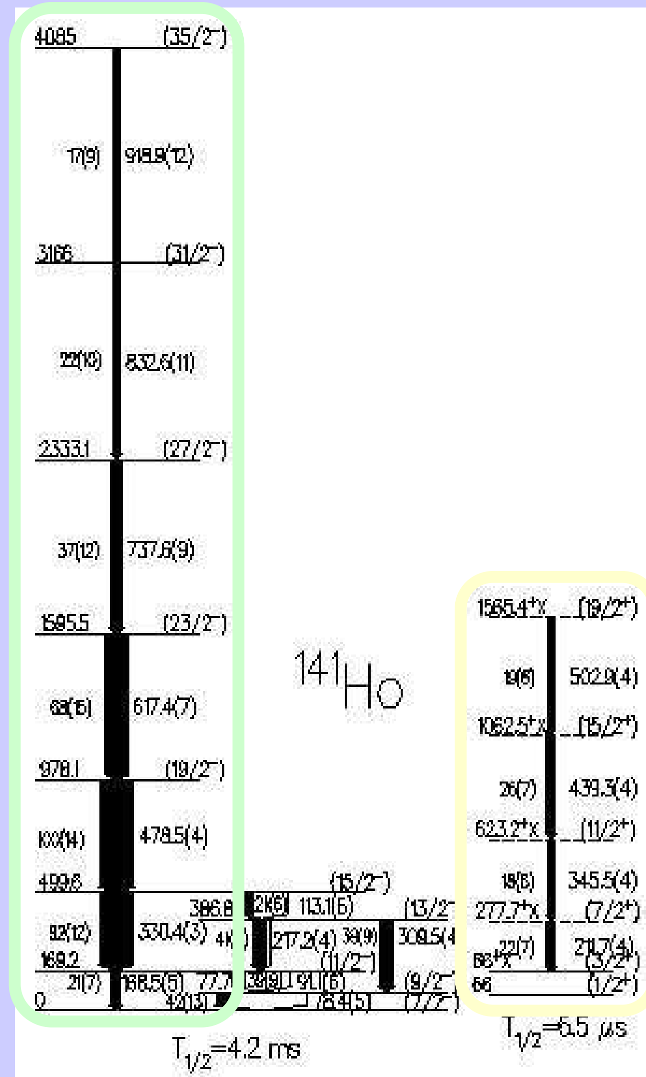
Proton-gated γ-spectra

50 µs < ΔT < 25 ms



ΔT < 40 µs

Level scheme of ^{141}Ho



γ-ray spectroscopy beyond the proton dripline !

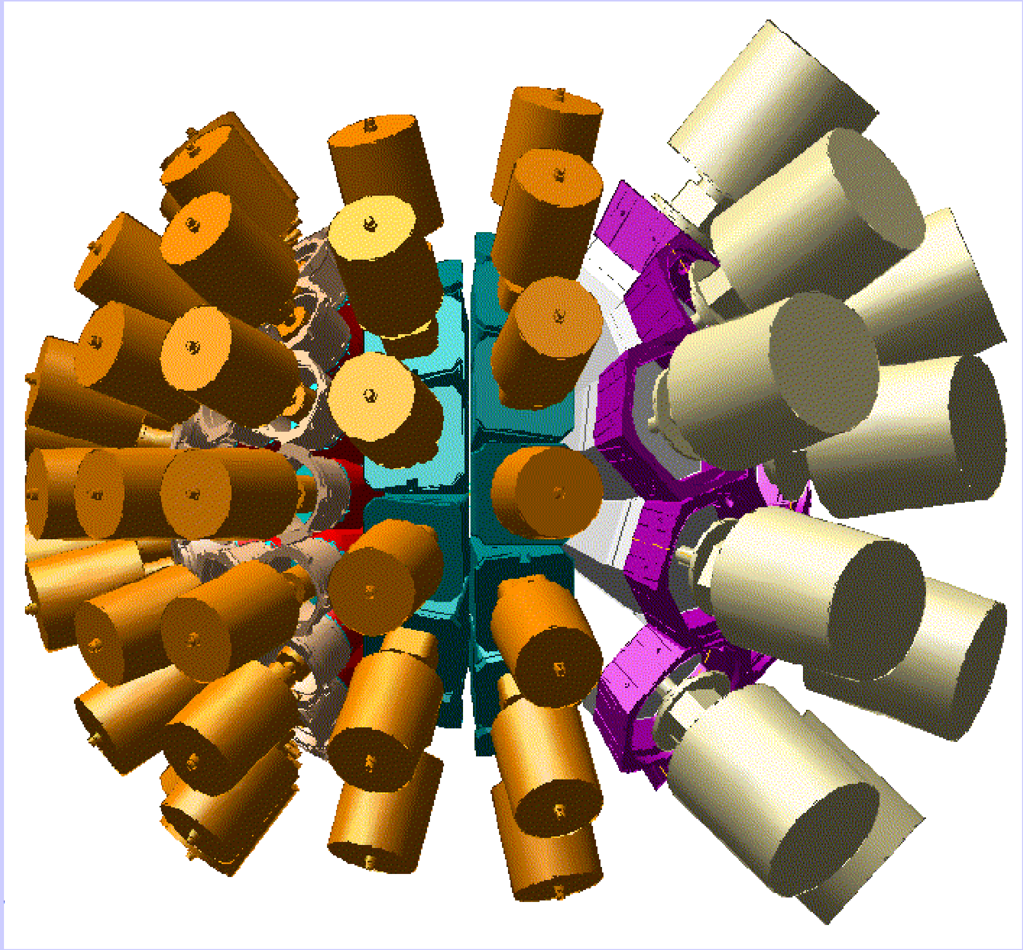
High spin physics: Instrumentation, experimental techniques and examples

Andrea Jungclaus

Universidad Autónoma de Madrid

- **introduction**
- **γ-ray spectrometer**
- **ancillary detectors**
- **examples:**
  - **prompt particle decay from deformed excited states**
  - **superdeformed bands**
  - **spectroscopy of transfermium nuclei**
  - **ground state proton decay**
- **next generation γ-ray spectrometer**

And what comes next after EB and Gammasphere: The next generation of γ-ray spectrometer …



old:
e.g. EUROBALL

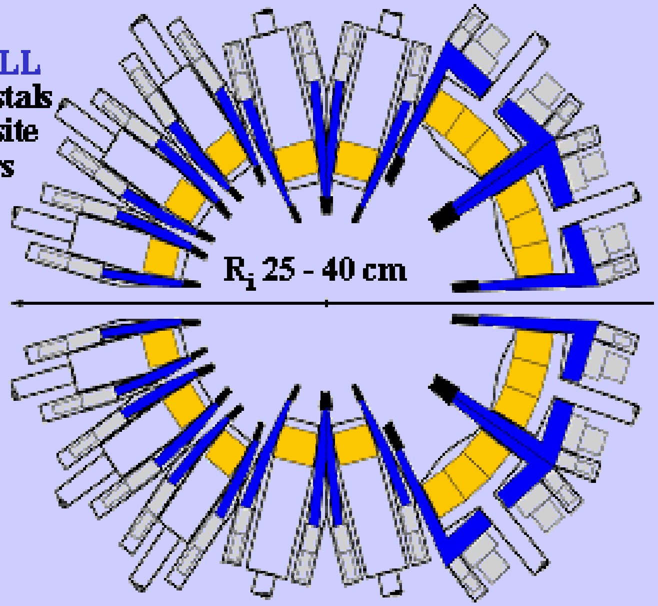
View into the collimators of EUROBALL

Large fraction of dead solid angle !

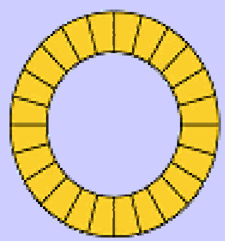
⇓

Try to get rid of Compton suppression shields !

Why don't we use a Ge shell ?



"High-spin" spectrometer

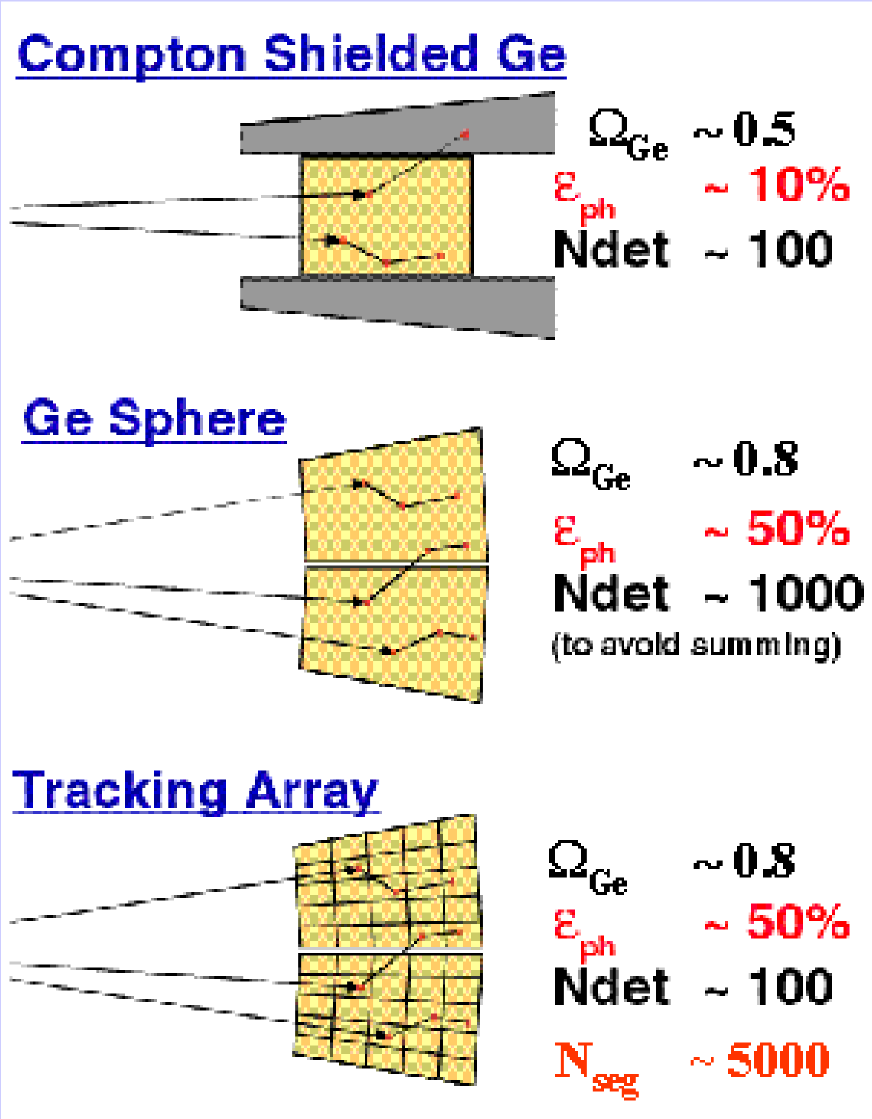


Another problem:
small R → large Ω →
large Doppler broadening !

M=1	P_{ph} : ≈9%	≈65%	
	P/T: ≈60%	≈85%	
M=30	P_{ph} : ≈6.5%	≈6.5%	!
	P/T: ≈40%	≈13%	

summing

The possible solution of these problems

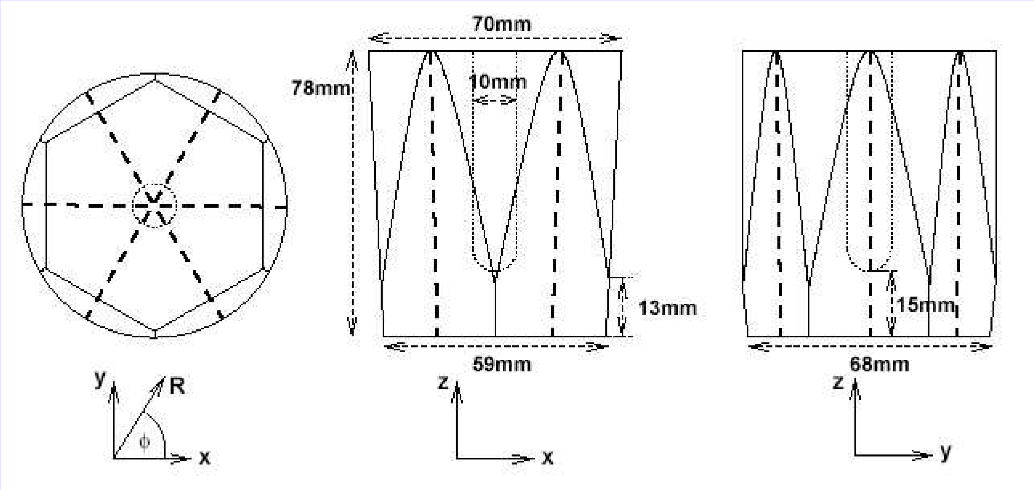


like **EUROBALL, Gammasphere** etc. for high-spin spectroscopy after fusion-evaporation reactions

for low-rate experiments: e.g. **MINIBALL** at REX-ISOLDE

The future: **AGATA** in Europe and **GRETA** in the US

The MINIBALL Ge module

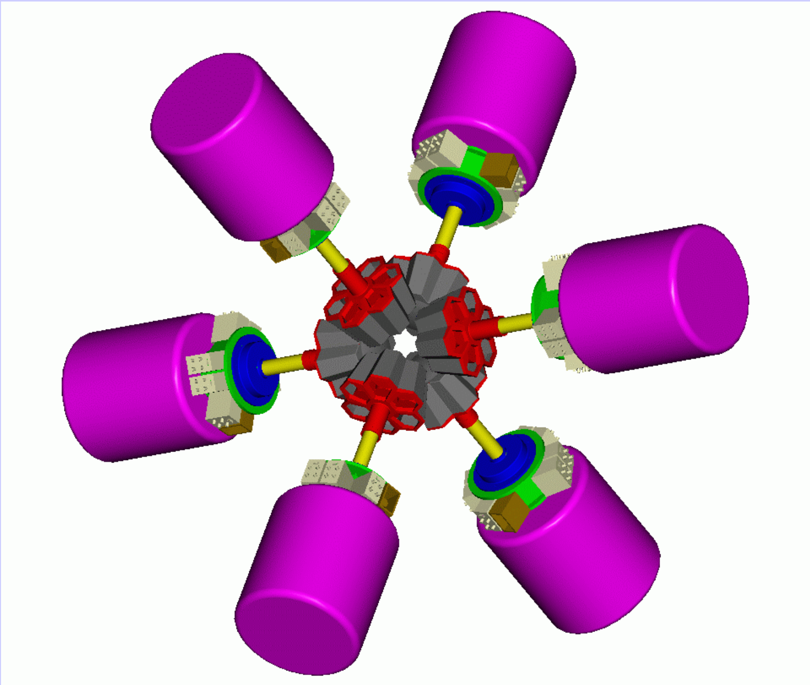


length: 78mm
diameter: 68 mm

(same shape as Ge crystals in EUROBALL Cluster detectors)

asymmetric triple cryostats

The MINIBALL array for low-rate experiments

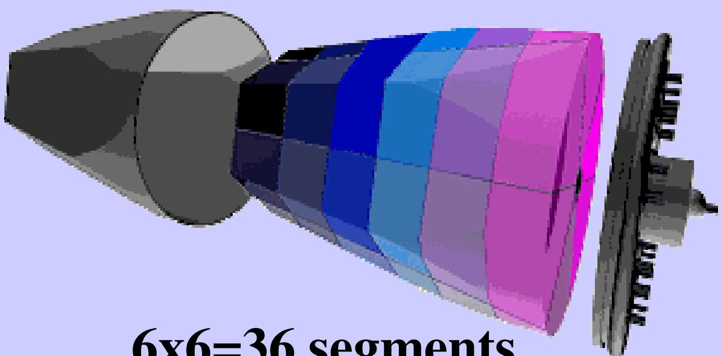


42 6-fold segmented Ge crystals in cryostats with 3 (4) crystals

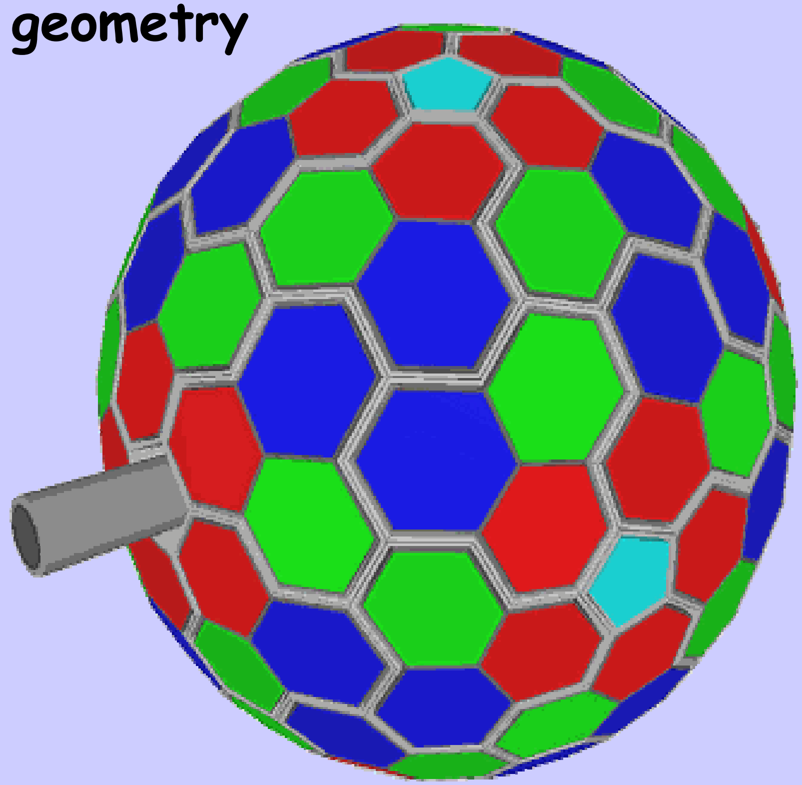
AGATA – Advanced GAmma Tracking Array

AGATA
geometry

AGATA
module



6x6=36 segments

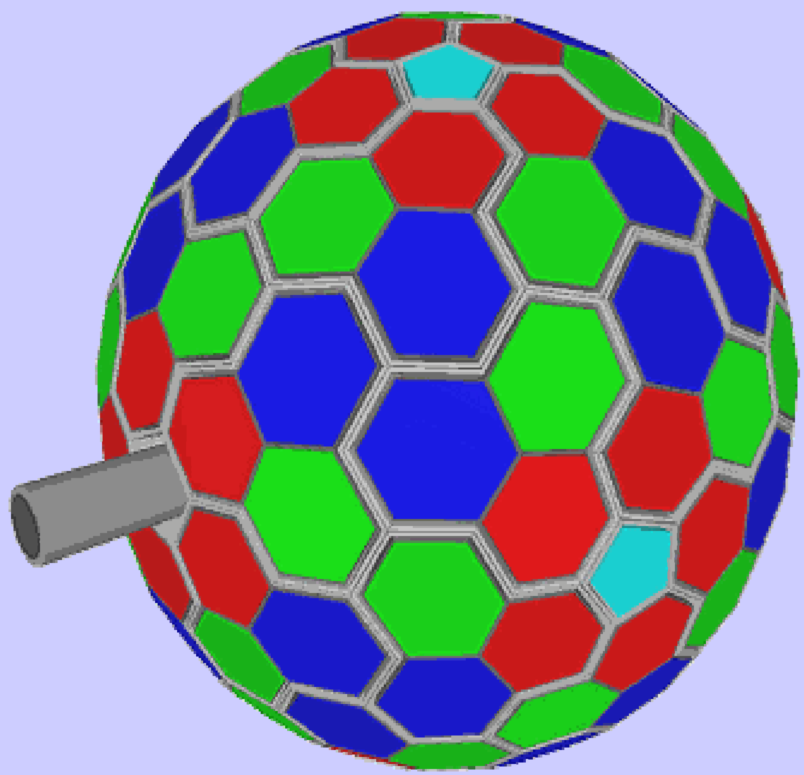


50% photopeak efficiency !

AGATA design elements

(Advanced Gamma Tracking Array)

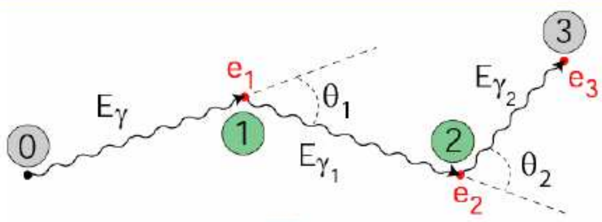
4π γ-array design based on 190 highly segmented germanium detectors



- 180 hexagonal crystals
  in 3 different, asymmetric shapes
  grouped in 60 triple-cluster cryostats
- 10 pentagonal crystals
  individually canned
- 230 kg of germanium
  crystals of ∅ 8 cm; L : 9 cm
- full sphere with
  solid angle coverage ~78 %
  inner-outer radius of 17-26 cm
  total of 6780 segments

γ-ray tracking

Photons do not deposit their energy in a continuous track, rather they lose it in discrete steps

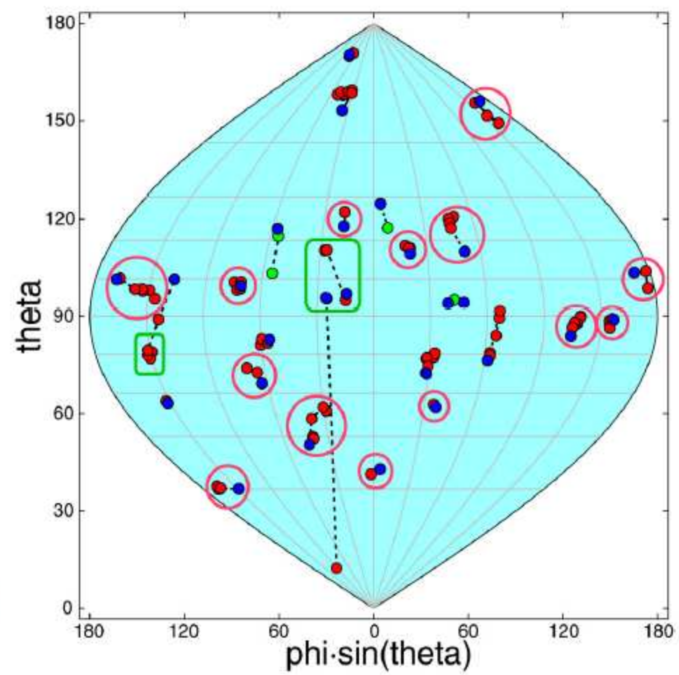


One should identify the sequence of interaction points belonging to each individual photon

Tough problem! Especially in case of high-multiplicity events

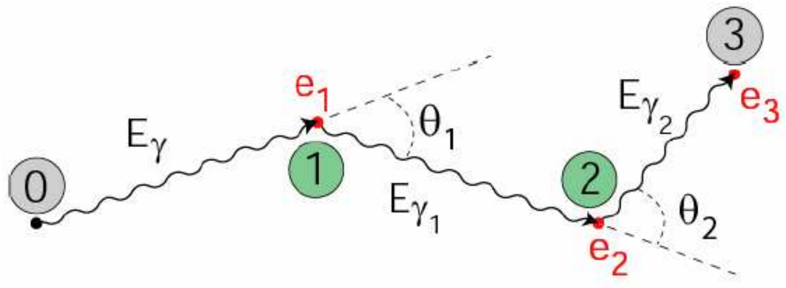
A high multiplicity event

$E\gamma$=1.33MeV, $M\gamma$=30



Tracking algorithms

Basic ingredient: Compton scattering formula

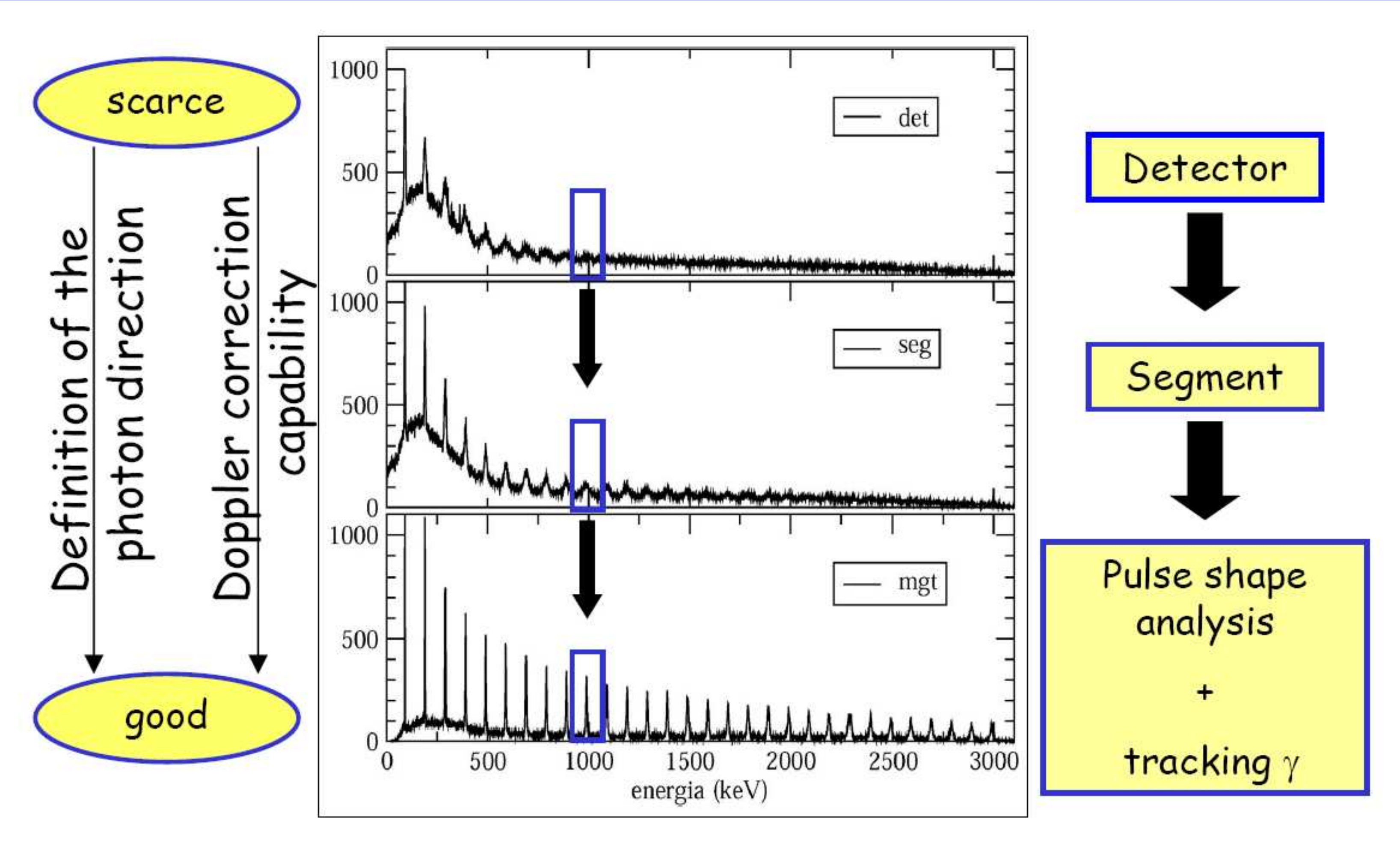


$$E_{\gamma i} = \frac{E_{\gamma i-1}}{1+\frac{E_{\gamma i-1}}{m_0 c^2}(1-\cos\theta_i)} \qquad e_i = E_{\gamma i-1} - E_{\gamma i}$$

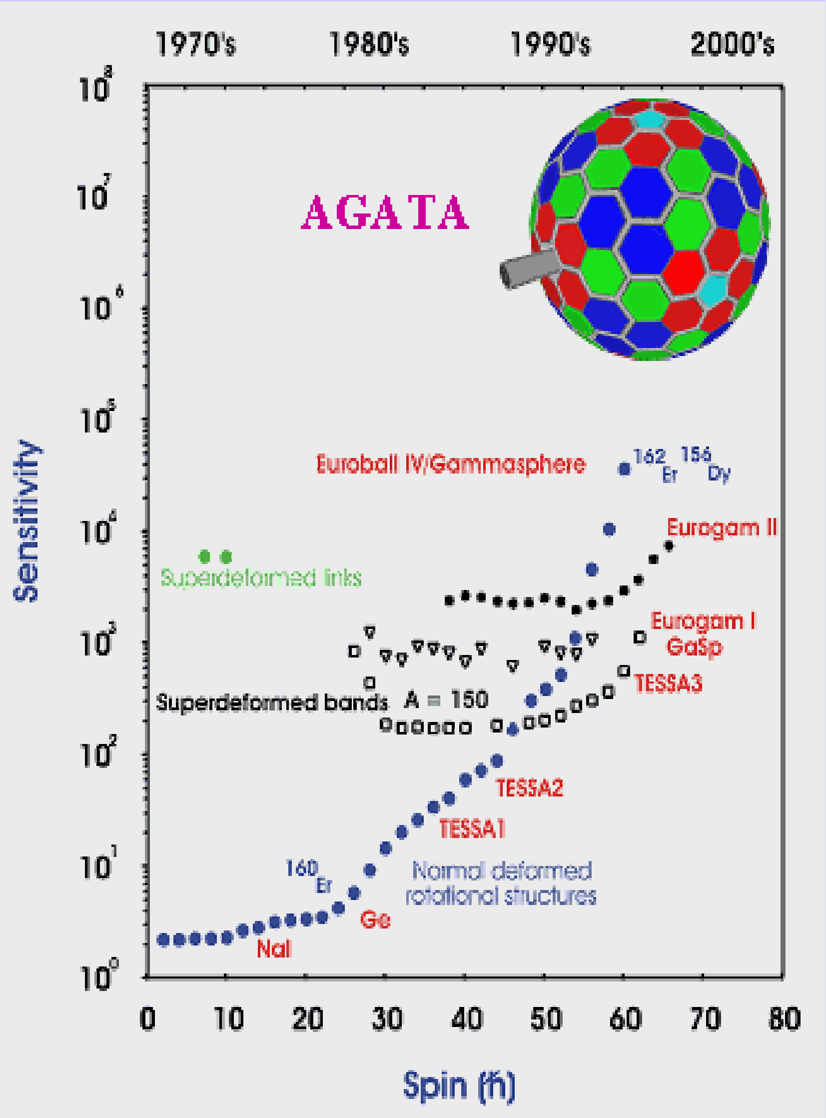
Several algorithms are available:

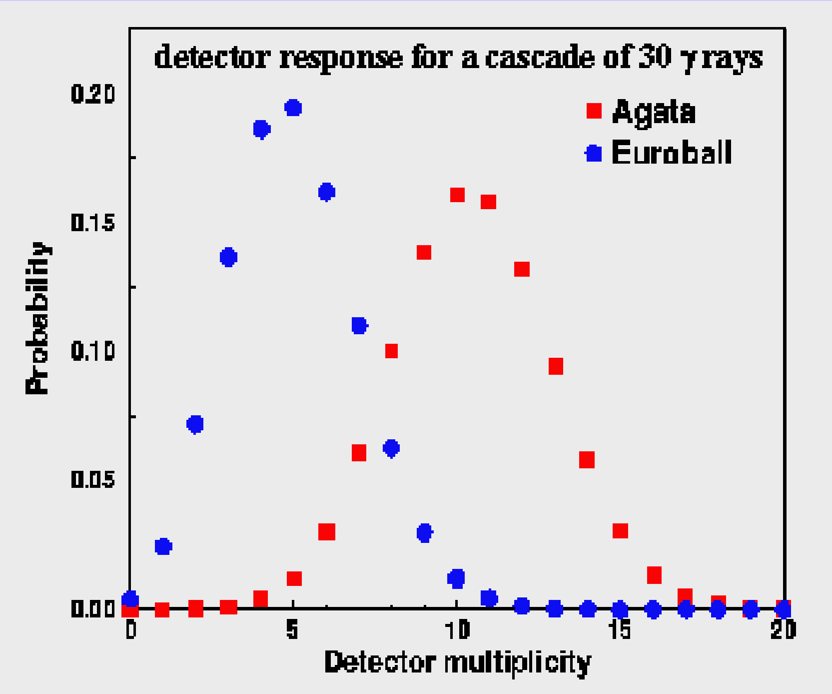
- Clustering
- Clustering + forward tracking
- Backtracking
- Probabilistic tracking
- Fuzzy tracking

Benefits of the γ-ray tracking



From EUROBALL/Gammasphere to AGATA ...



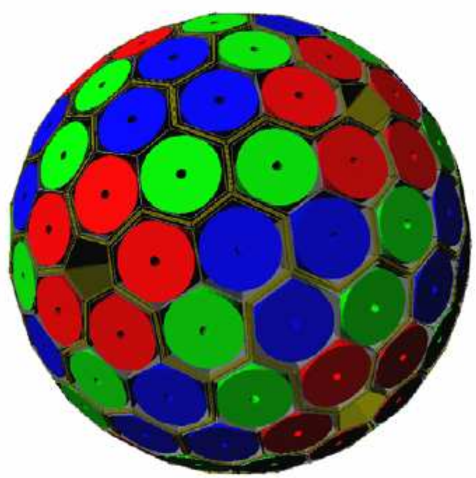


fold distribution for M_{γ}=30

AGATA

(Advanced GAmma Tracking Array)

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



Main features of AGATA

Efficiency: 39% (M_γ=1) 25% (M_γ=30)
today's arrays ~10% (gain ~4) 5% (gain ~1000)

Peak/Total: 53% (M_γ=1) 46% (M_γ=30)
today ~55% 40%

Angular Resolution: ~1° →
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 packed in 60 triple-clusters
- Digital electronics and sophisticated Pulse Shape Analysis algorithms allow
- Operation of Ge detectors in position sensitive mode → γ-ray tracking
- Demonstrator ready by 2007; Construction of full array from 2008