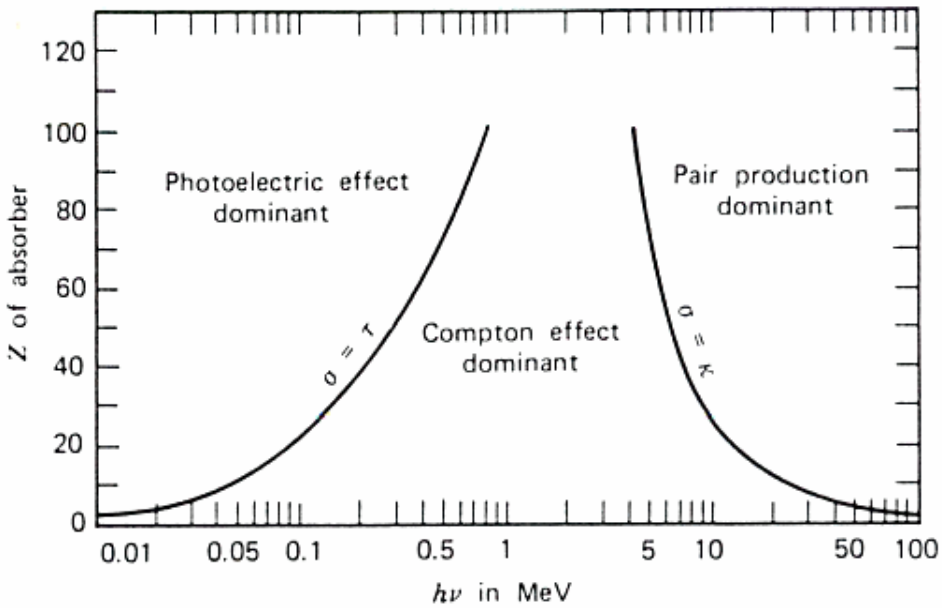
Modern Arrays for γ and particles Detection

- Basic concepts of radiation interaction & detection
- Ge Arrays: EUROBALL & AGATA
- Ancillary Devices

γ-ray interaction

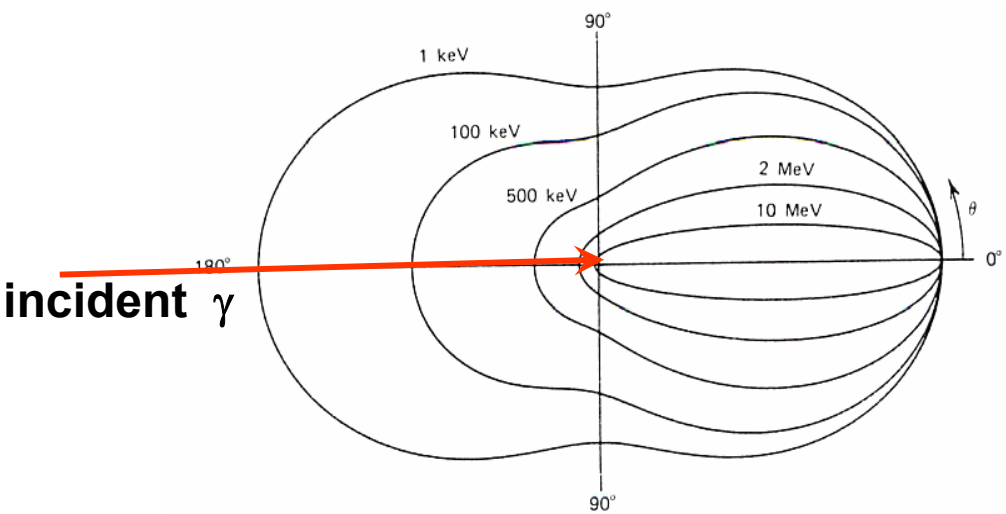


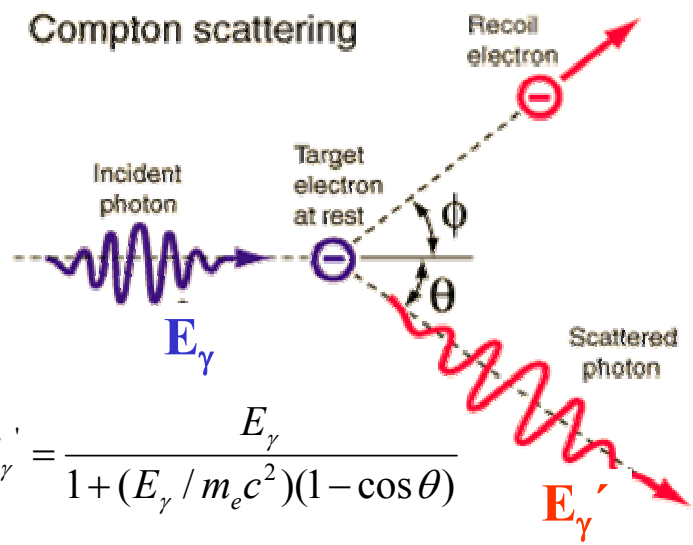
$$\sigma_{ph} \approx \frac{Z^n}{E_\gamma^{3.5}} \qquad n = 4-5$$

$$\sigma_C \approx \frac{Z}{E_\gamma} \ln E_\gamma$$

$$\sigma_{pp} \approx Z^2 \ln E_\gamma$$

Compton scattering angular distribution

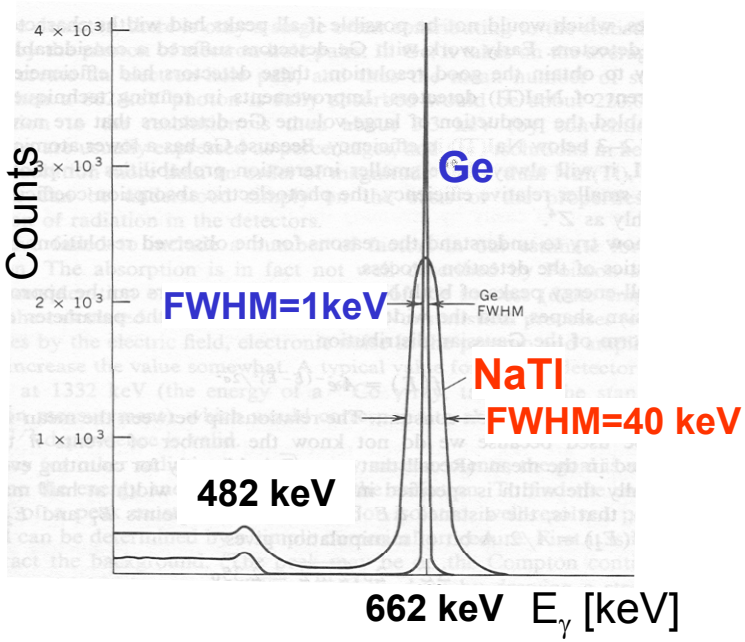


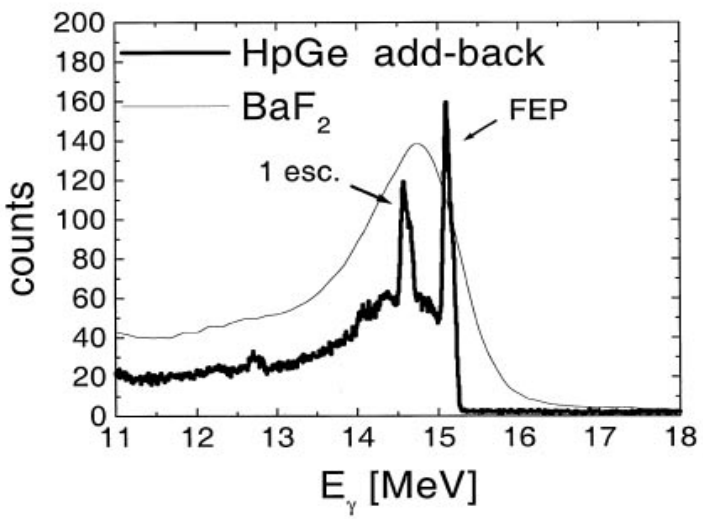


$$E_\gamma' = \frac{E_\gamma}{1 + (E_\gamma / m_e c^2)(1 - \cos\theta)}$$

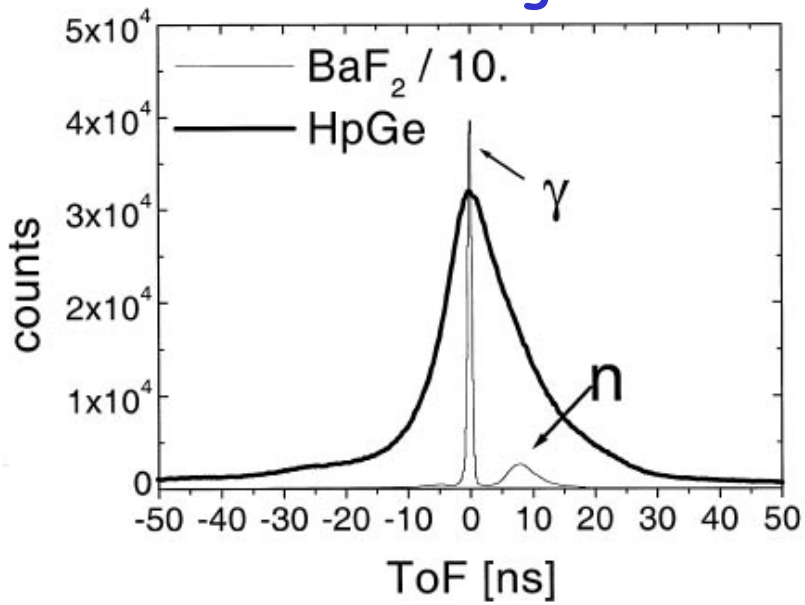
The detector performances depend on the the detector properties

Energy resolution

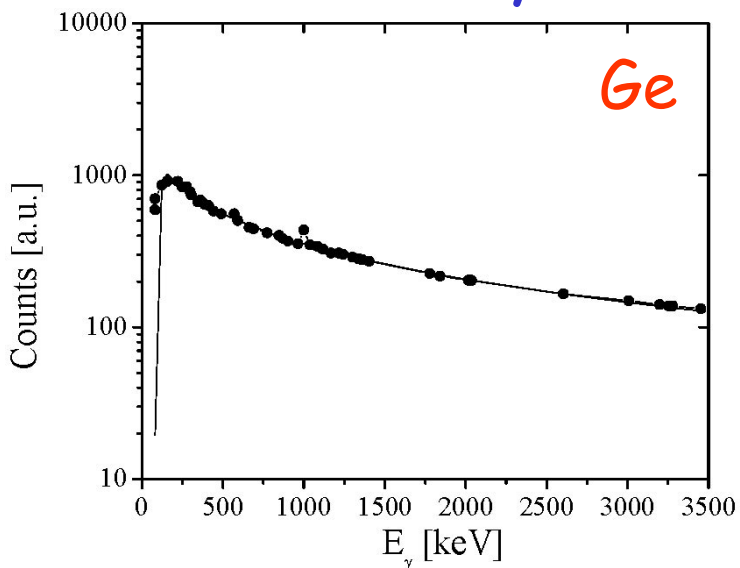




Timing



efficiency



We detect recoil electrons and NOT photons !

Scattered – photon energy

$$E_{\gamma'} = \frac{E_\gamma}{1+\left(E_\gamma/m_e c^2\right)\left(1-\cos\theta\right)}$$

Scattered recoil – electron energy :

$$E_{kin} = E_\gamma - E_{\gamma'} = \frac{E_\gamma\left(E_\gamma/m_e c^2\right)\left(1-\cos\theta\right)}{1+\left(E_\gamma/m_e c^2\right)\left(1-\cos\theta\right)}$$

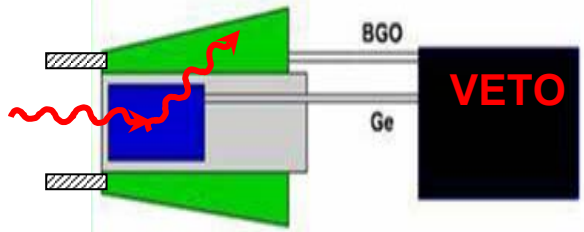
Minimum photon energy : $\theta = 180^0$

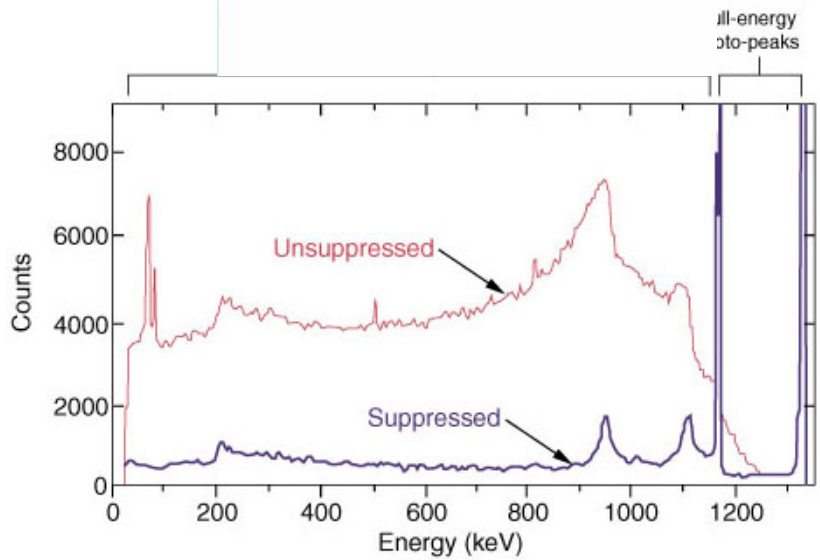
$$E_{\gamma'} = \frac{E_\gamma}{1+2E_\gamma/m_e c^2}$$

Maximum electron energy (Compton Edge)

$$E_{kin} \le E_{CE} = E_\gamma \frac{2\left(E_\gamma/m_e c^2\right)}{1+2\left(E_\gamma/m_e c^2\right)}$$

Ge detector + anti-Compton (BGO)

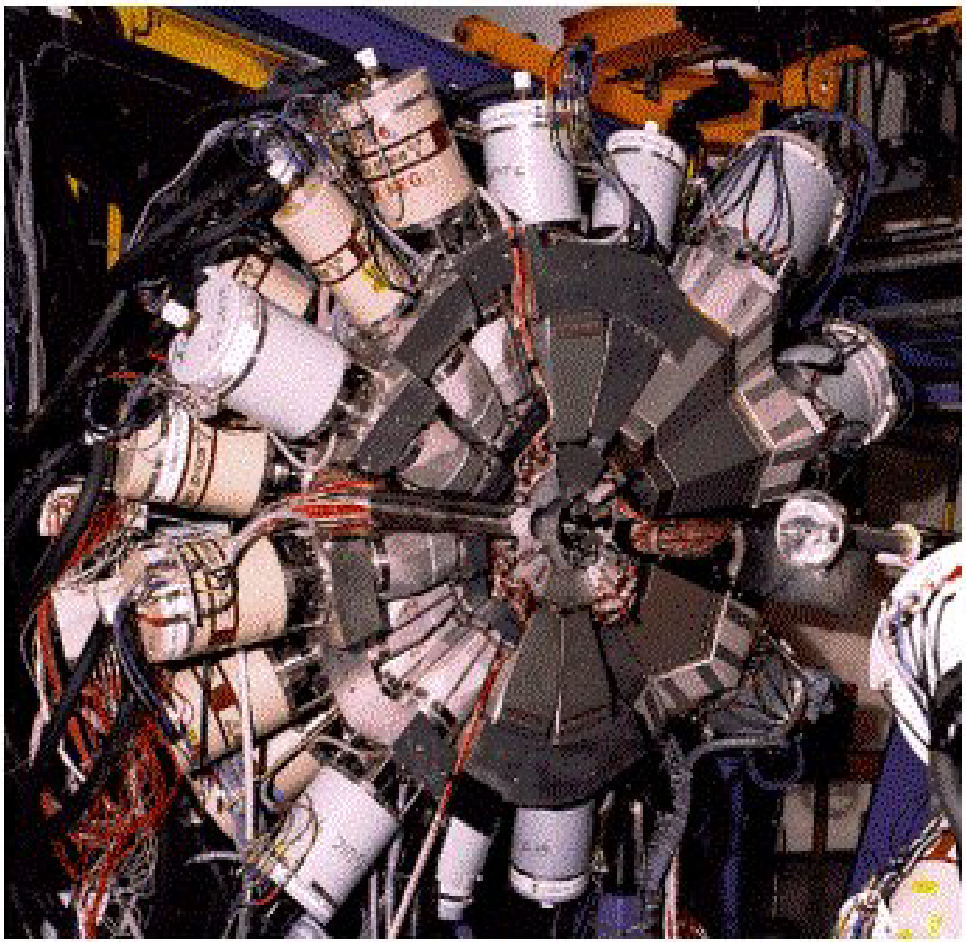


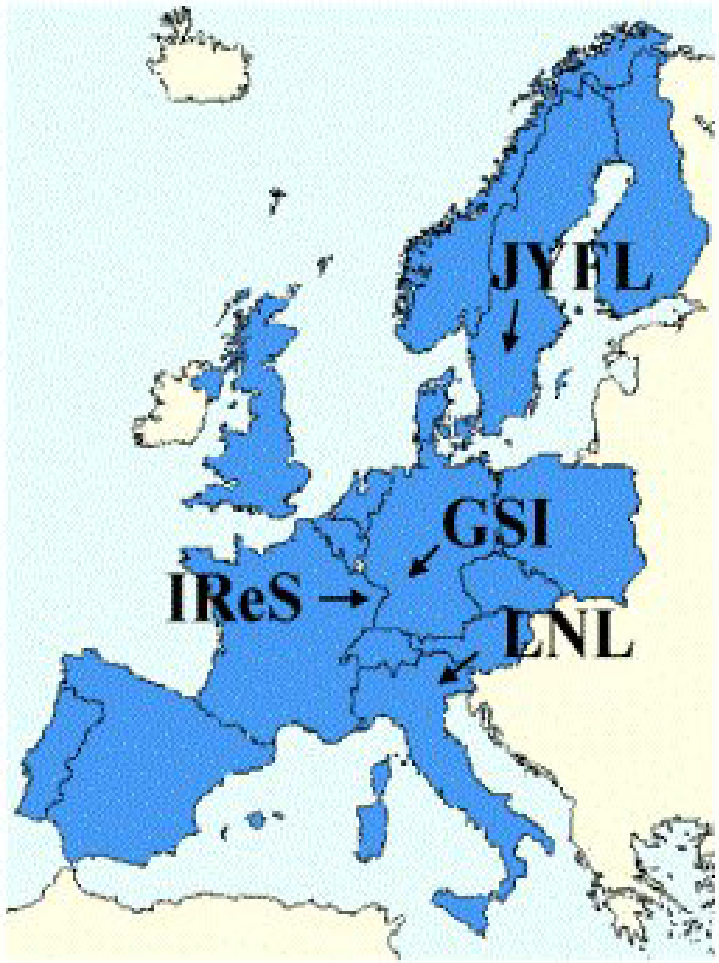


GAMMA -DETECTOR Systems

- Ge detector + BGO shields
- Multiplicity filter (BGO or BaF2)
- Si detectors for particles (p, α, d)
- RMS, PPAC (for recoil detection)

EUROBALL



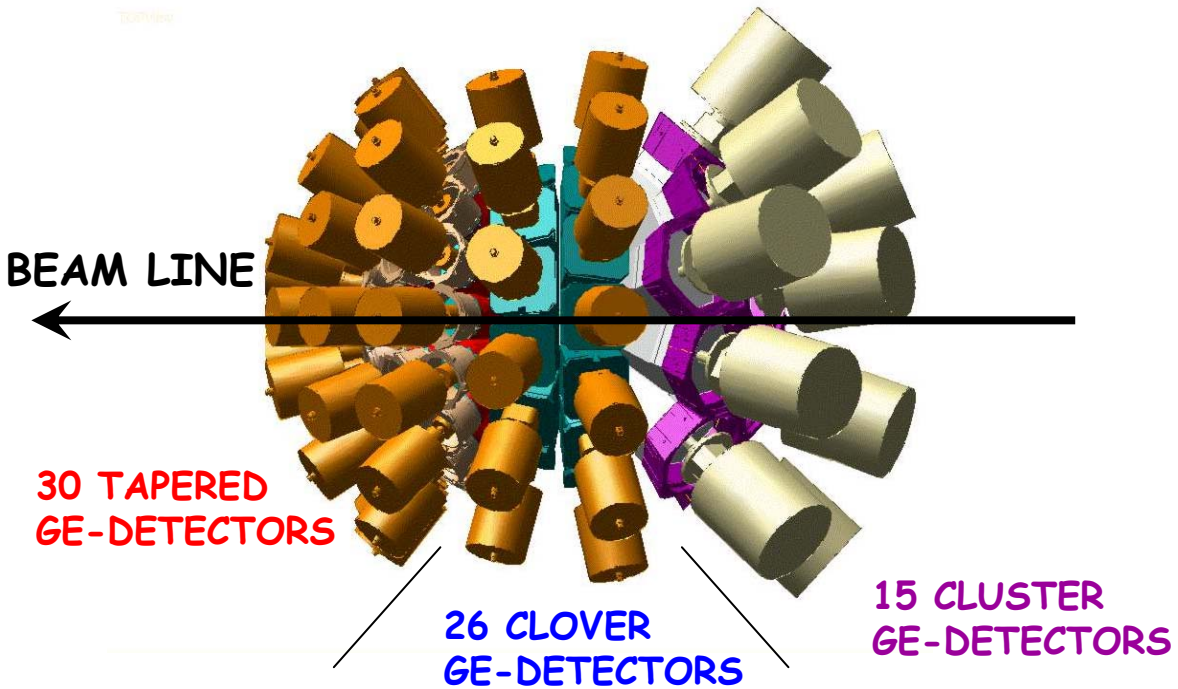


4π Ge detector Array


EUROBALL @ IRES (Strasbourg)

EUROBALL

(239 Ge Crystals)

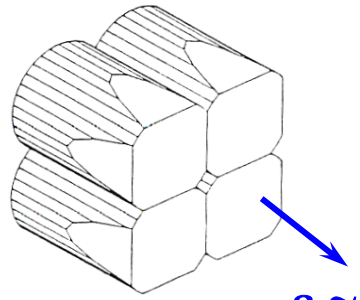


	30 Tapered	26 Clovers	15 Clusters	71(239)
Angle	5 at 18° 10 at 35° 15 at 52°	13 at 77° 13 at 103°	5 at 130° 5 at 137° 5 at 157°	
Distance	37.5 cm	~26.9 cm	44.5 cm	
ε_{ph}(%) effective*	1.3 1.1	3.7 2.6	4.4 3.3	9.4 7.0
R effective*	9.3 7.9	8.3 6.8	10.5 8.9	9.5 7.9

E_γ=1.3 MeV, SE_γ = 70 keV, M_γ = 30, v/c=2%

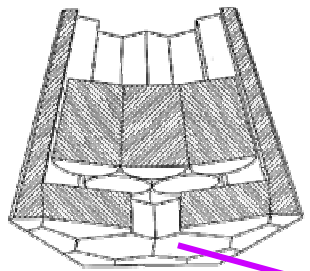
Composite Ge detectors

HPGE CLOVER



$\varepsilon \approx 35\%$

HPGE CLUSTER



$\varepsilon \approx 60\%$

EUROBALL

M_γ=30, v/c=2%

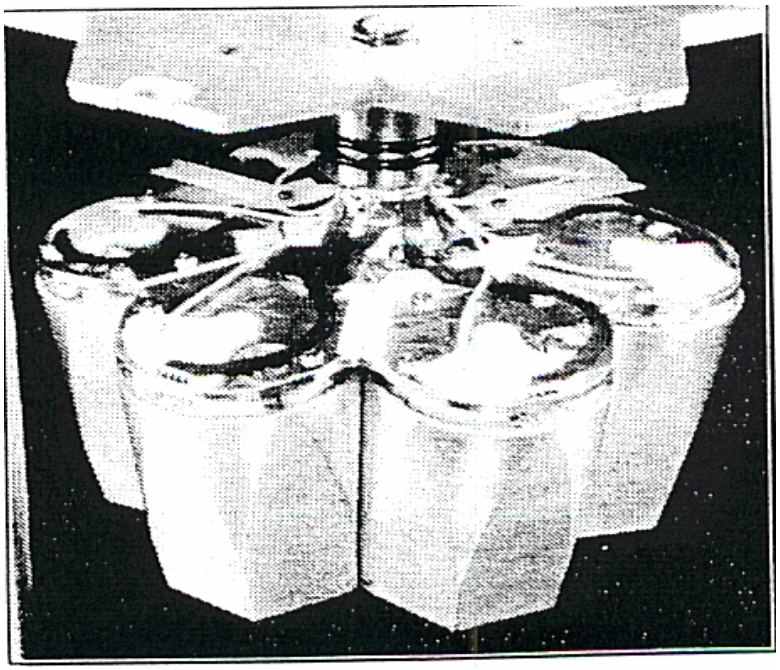
$\varepsilon_\gamma \approx 6.5$ %

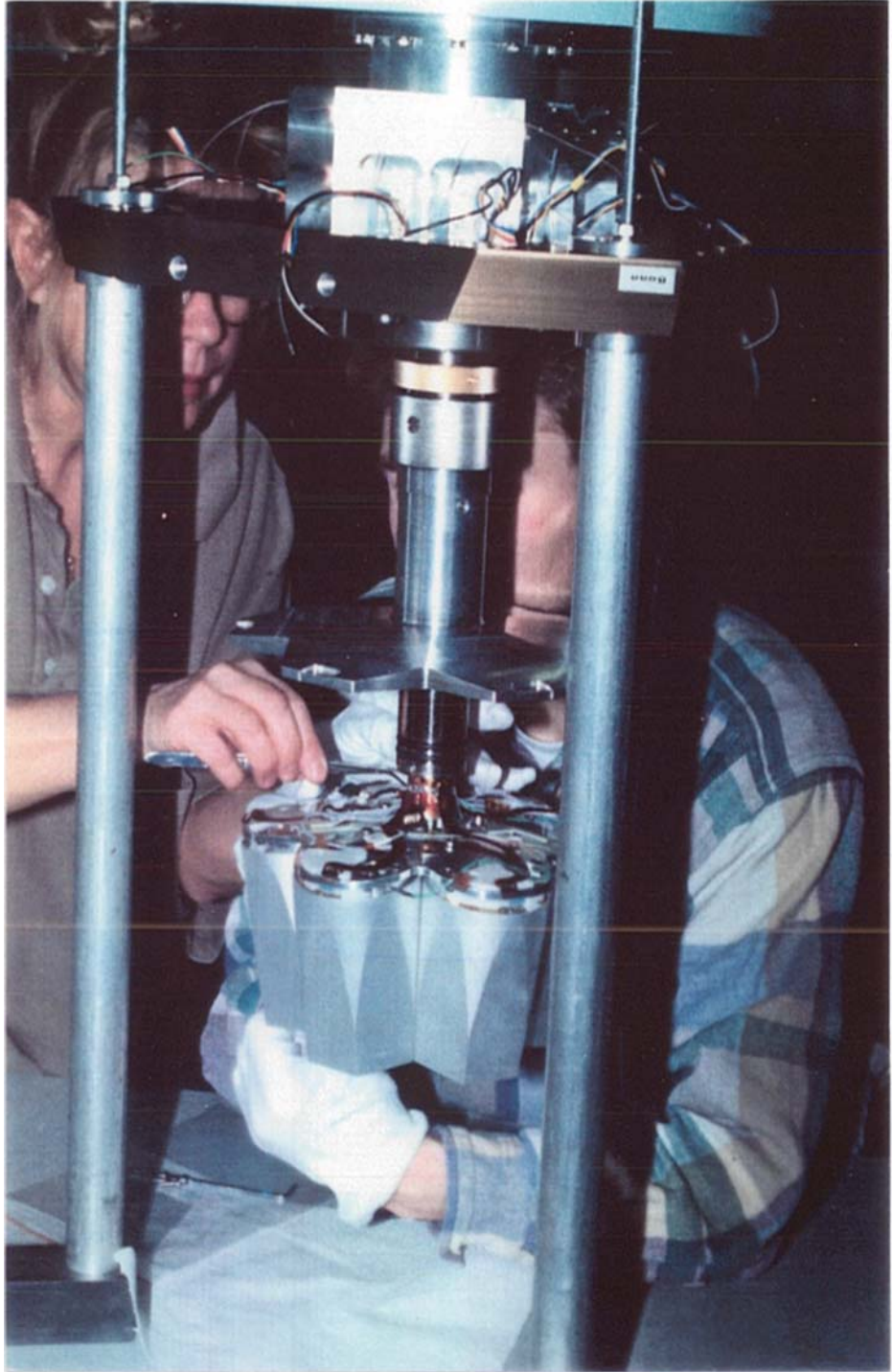
P/T ≈ 40 %

$\Omega \approx 40\%$

Full Ball: Ge+BGO ≈ 4π

Cluster Ge detector



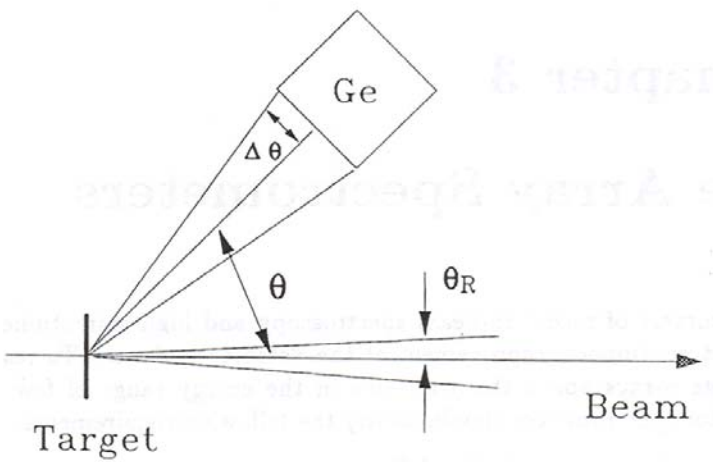


Effetto Doppler

$$E_\gamma = E_{\gamma 0}(1 + \frac{v}{c}\sin\theta_\gamma)$$

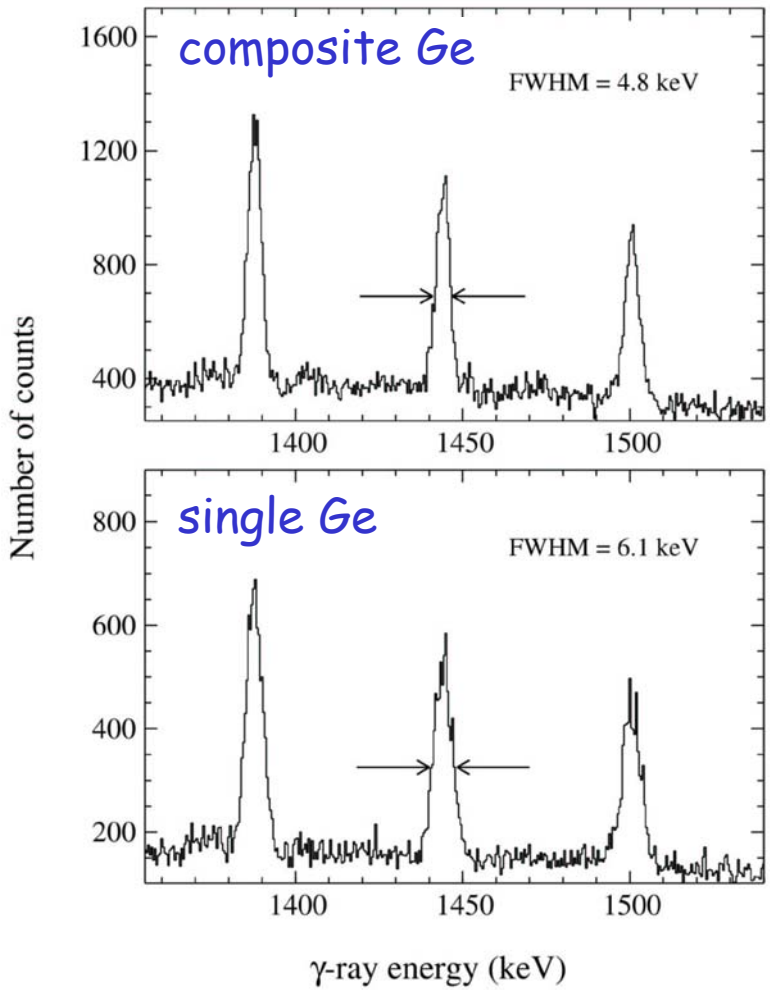
Doppler broadening

$$\Delta E_\gamma = 2E_{\gamma 0}\frac{v}{c}\sin\theta_\gamma \sin\Delta\theta$$



Ge detectors with
large opening angle
suffer of a considerable
energy deterioration

Solution:
composite Ge detectors



$^{30}Si + ^{124}Sb \rightarrow ^{149}Gd$

E_{beam}=158MeV

v/c=2.1%

Resolving power

$$R_F = \left(\frac{SE_\gamma}{\Delta E_\gamma} \times \frac{P}{T} \right)^F$$

array capability of identifying weak γ cascades

SE_γ = γ-ray energy spacing

ΔE_γ = γ-ray energy resolution

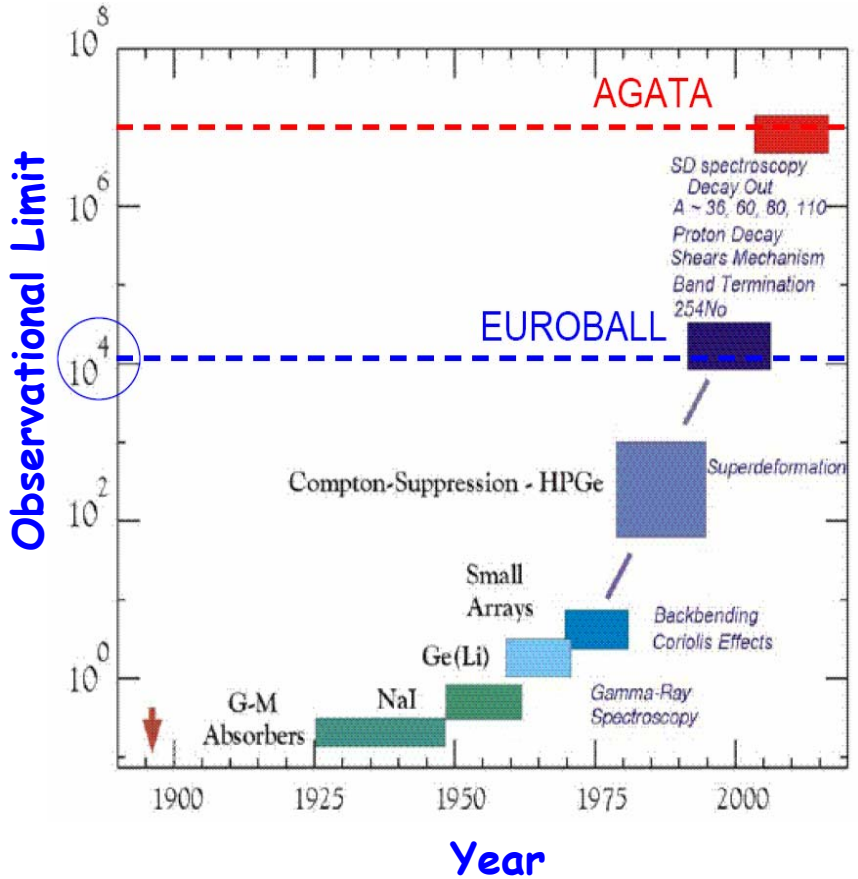
$\frac{P}{T}$ = Peak-to-total (Compton)

F = Measured fold

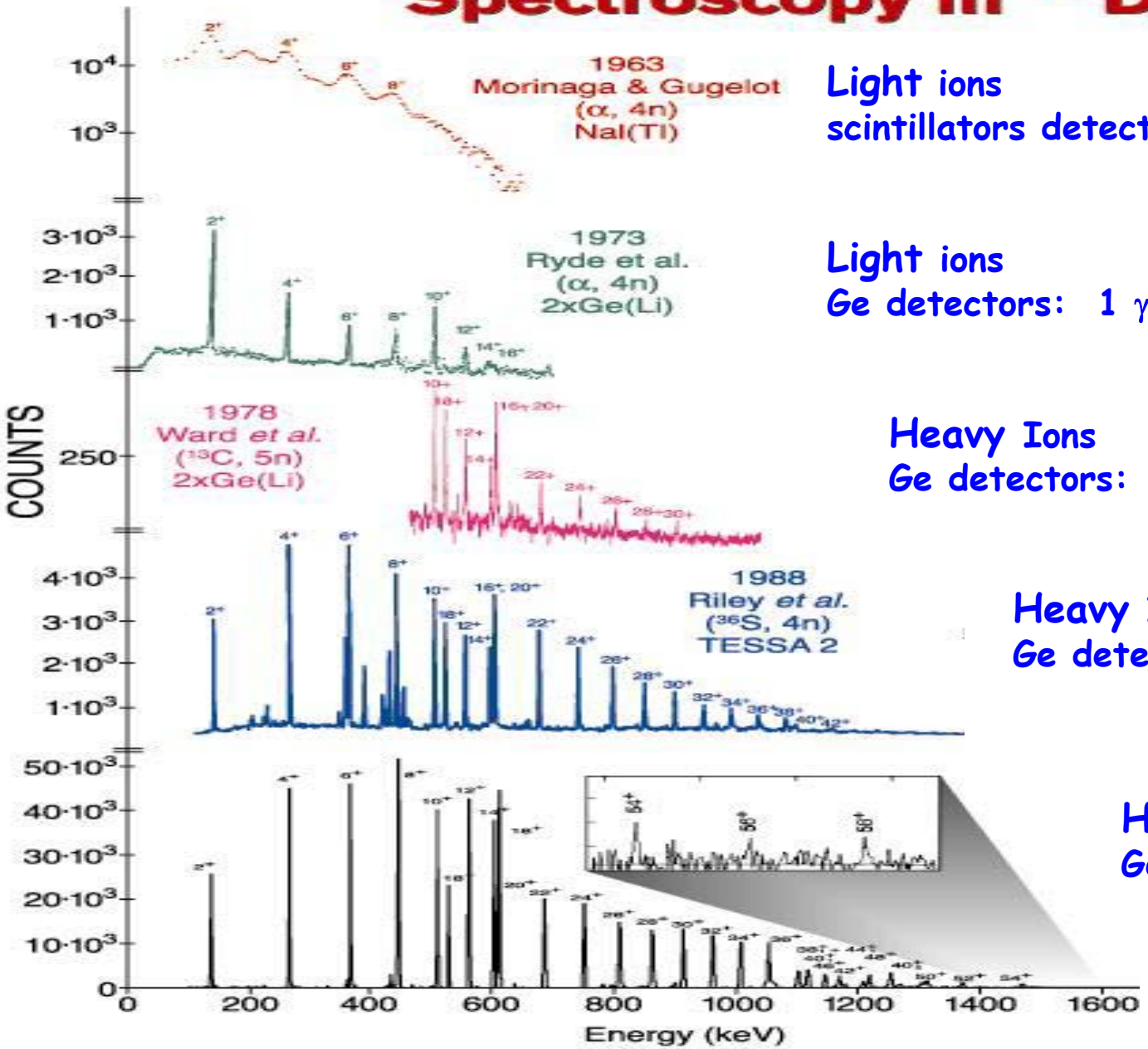
$$< F >= P_{ph} M_\gamma$$

$N_{Ge} \Omega \varepsilon_{ph} P_i$ = Total photopeak efficiency

Observation Limit



Evolution of High-Spin γ-ray Spectroscopy in ^{156}Dy



Light ions
scintillators detectors

Light ions
Ge detectors: 1 γ

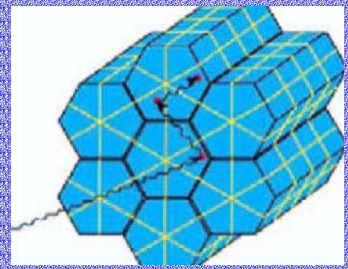
Heavy Ions
Ge detectors: 1 γ

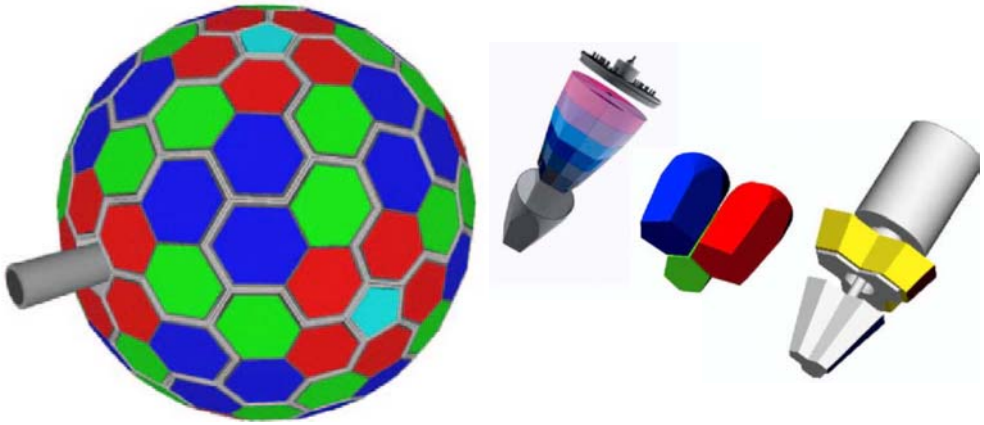
Heavy Ions
Ge detectors: ≥ 2 γ

Heavy Ions
Ge detectors: ≥ 3 γ

AGATA
Advanced Gamma Tracking Array

based on position sensitive Ge





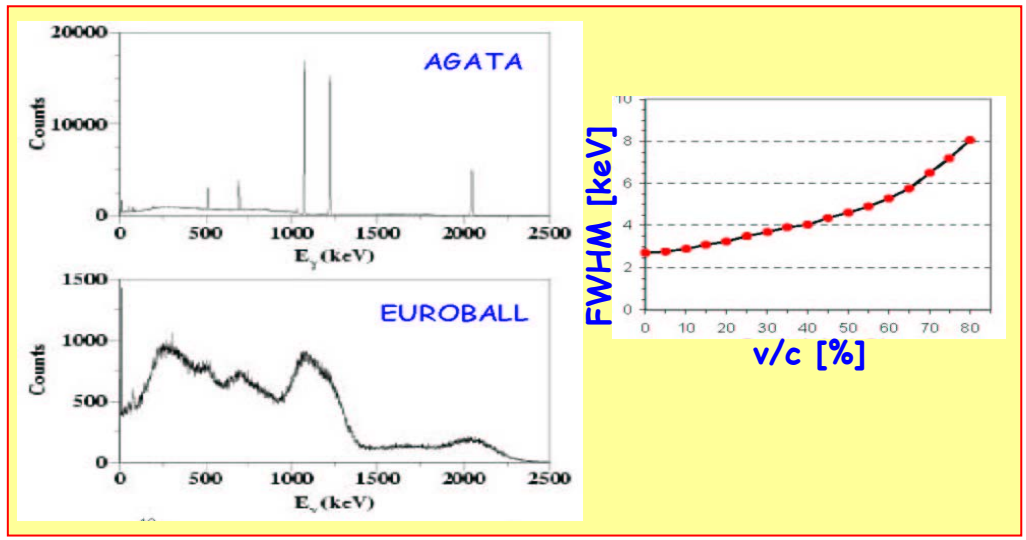
192 segmented Ge detectors
(36 segments each) ⇒ 6780 segments

180 hexagonal Ge in 60 triple clusters
12 pentagonal Ge

2.5 tons

R_{inner} = 17 cm, R_{outer} = 26 cm
$\Omega \approx 77\%$

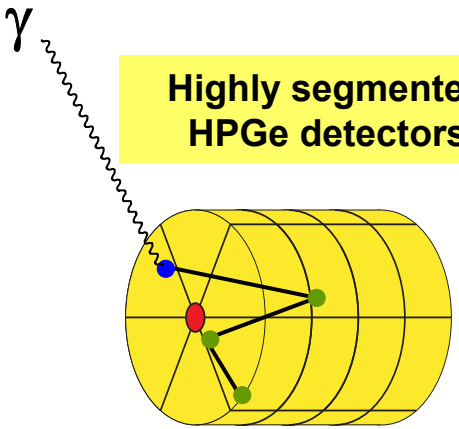
$\varepsilon \approx 40\%$ ($M\gamma$=1), 20% ($M\gamma$=30)
P/T ≈ 65% ($M\gamma$=1), 50% ($M\gamma$=30)
FWHM ≈ 1 keV (1 MeV, source)
≈ 6 keV (1 MeV, v/c ≈50%)
instead of 40 keV at present !!



- **Digital electronics** (to record and process segments signals)
- **Pulse Shape Analysis** (to extract position and energy of interaction)
- **Tracking Analysis** (to reconstruct γ-rays tracks from interaction points)

Construction ≈ 8 y, Cost ≈ 40 M€

AGATA: Advanced Gamma Tracking Array

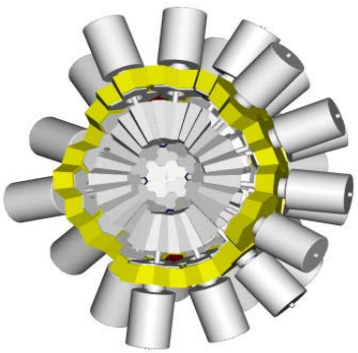


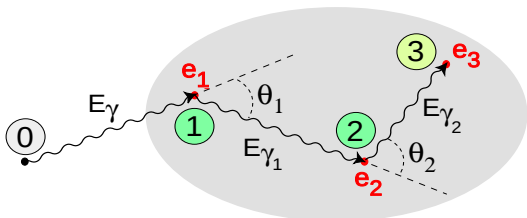
Highly segmented HPGe detectors

Pulse shape analysis to identify interaction points

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

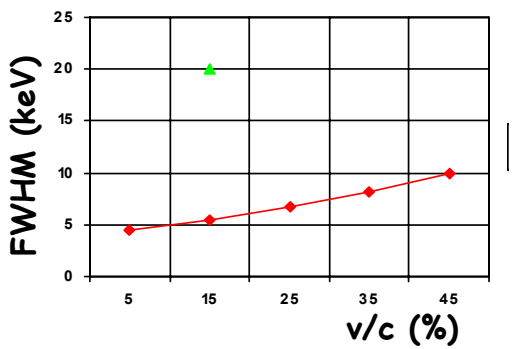
reconstruction of tracks via Compton scattering analysis





180 crystals configuration

Irregular hexagonal crystals	3 shapes
60 triple-clusters	identical
Radius	23,5 cm
Solide angle Ge	82%
Nb of segments	6480
Nb of channels	6660



ε~ 40 - 20 % (M_γ=1 — M_γ=30)
(10 – 5%)
Count rate ~ 3 MHz - 300 kHz
(1 MHz - 20 kHz)

Köln September 2005:
1⁰Triple-cluster test

Demonstrator
6 Triple-clusters :
ε~ 5 - 3 %
Ready by 2007
(LNL-GANIL)

Ancillary Detectors

- Innerball: calorimeter
- Hector: high - energy γ-rays
- Diamant: charged particles
- Neutron wall: n identification
- Recoil filter: evaporation residua

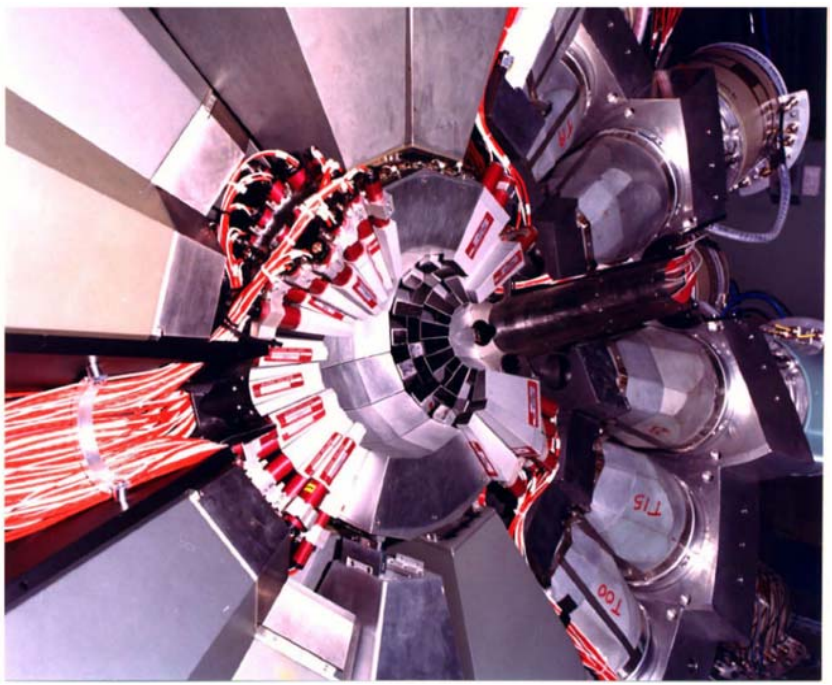
Inner Ball

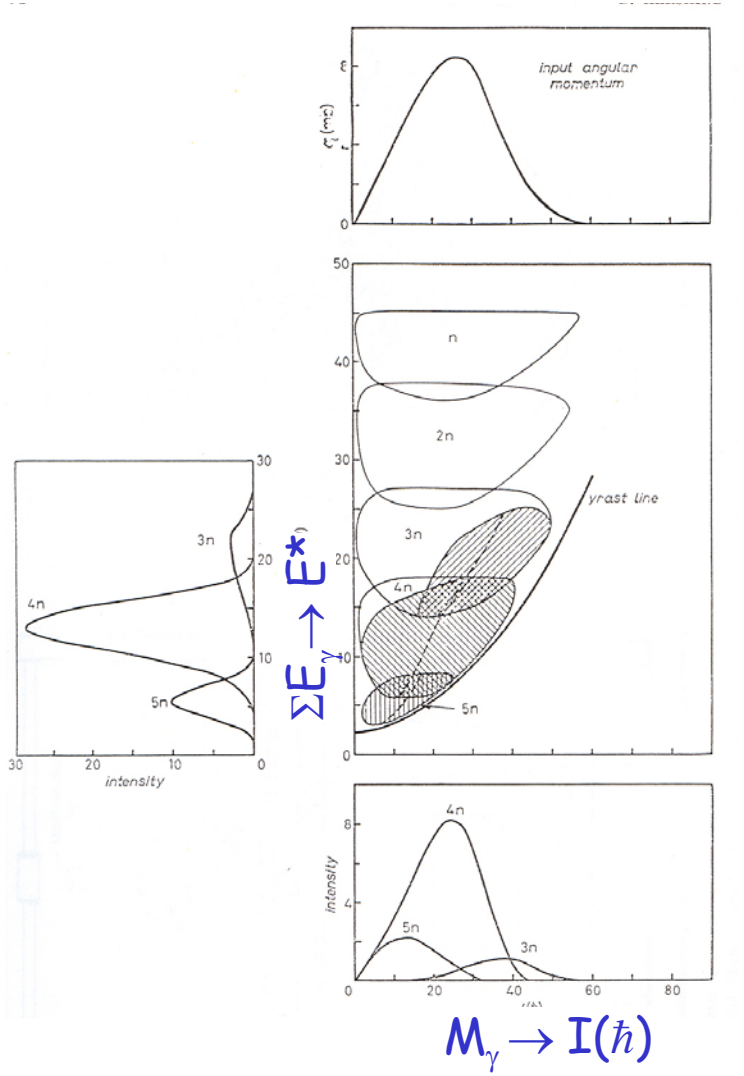
(143 BGO detectors)

Filtro del canale di reazione

γ-multiplicity $M_\gamma \rightarrow I$

γ-sum energy $\Sigma E_\gamma \rightarrow E^*$



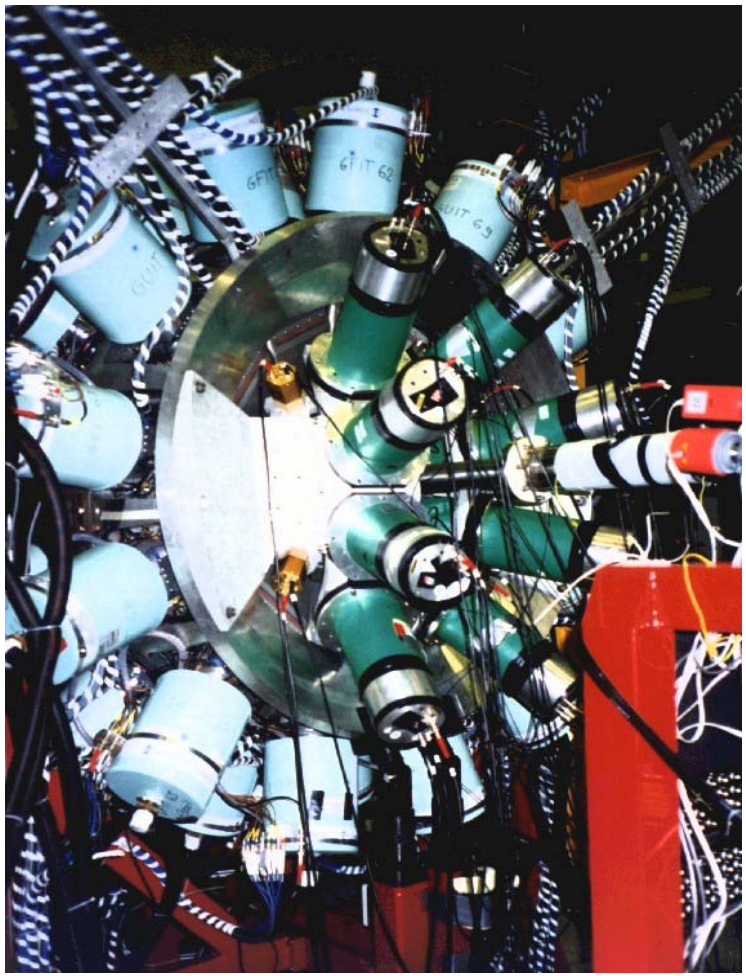


Full Ball: Ge + InnerBall $\approx 4\pi$

40% 60%

Hector

(8 BaF_2 detectors)



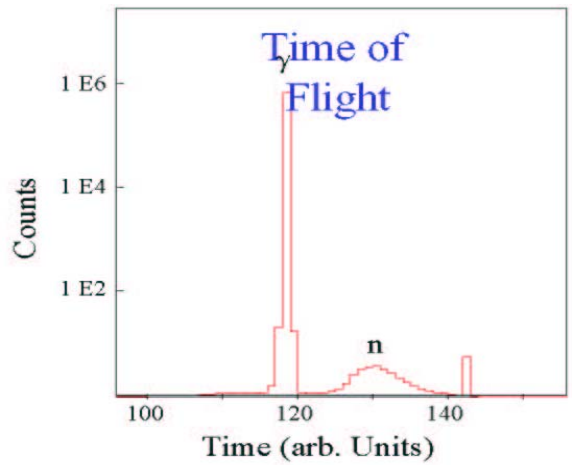
$\Delta E\gamma/E\gamma$ (^{60}Co) ≈ 11%

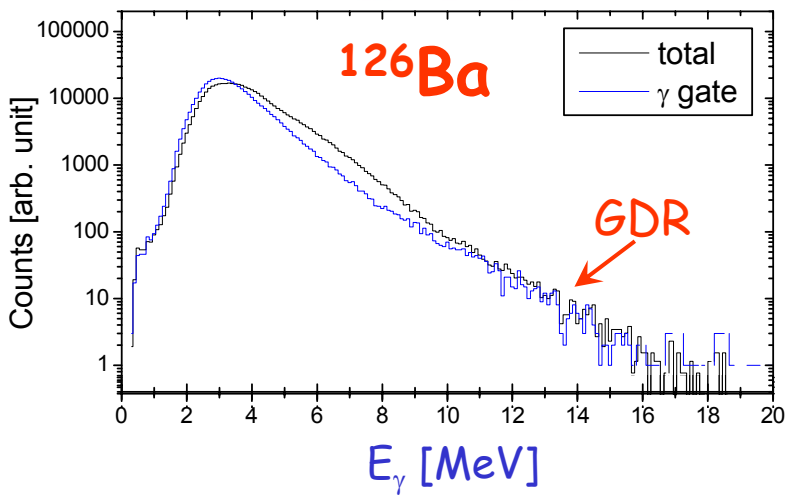
$\Delta T \approx 1$ ns

ε_{ph} (15 MeV) ≈ 10%

LED gain monitor

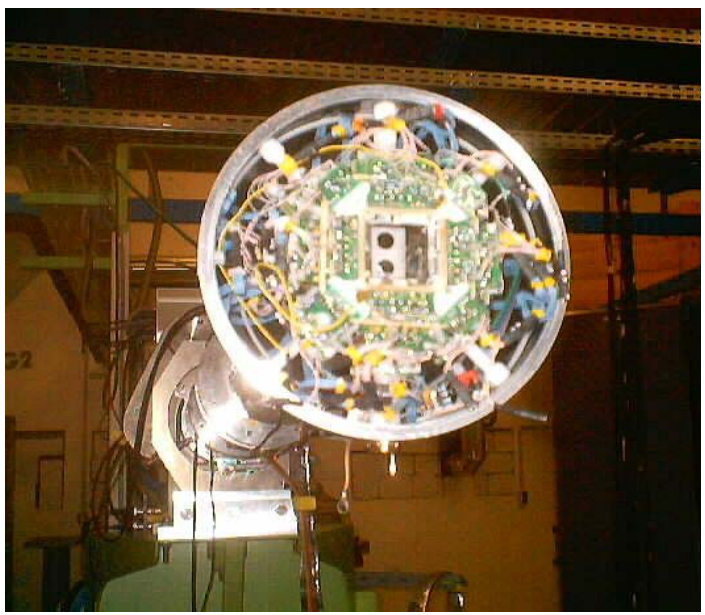
14cm × 18 cm



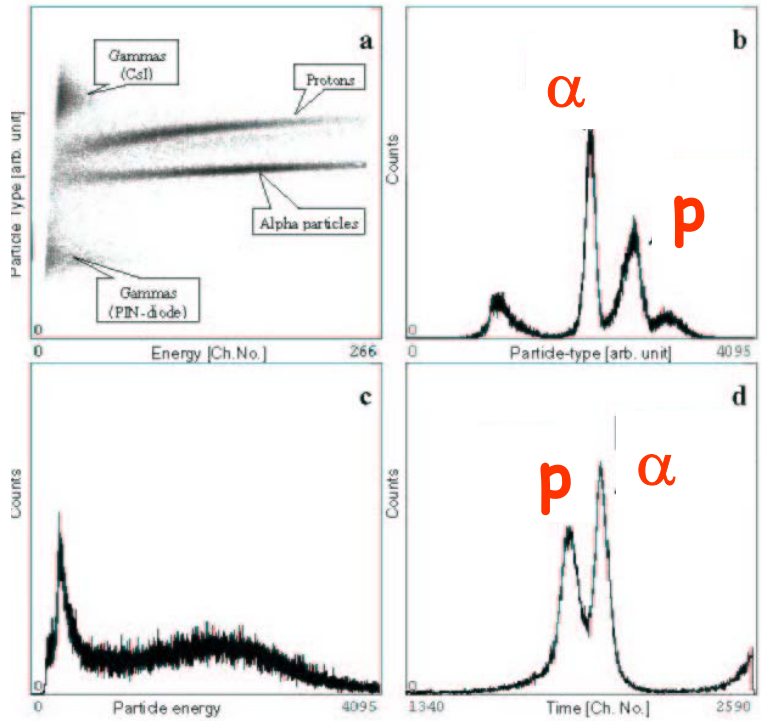


Diamant

(84 CsI(Tl) detectors)



light charged particle detector array



$\varepsilon_{proton} \approx 70\%$, $\varepsilon_{\alpha} \approx 50\%$

Operating mode:

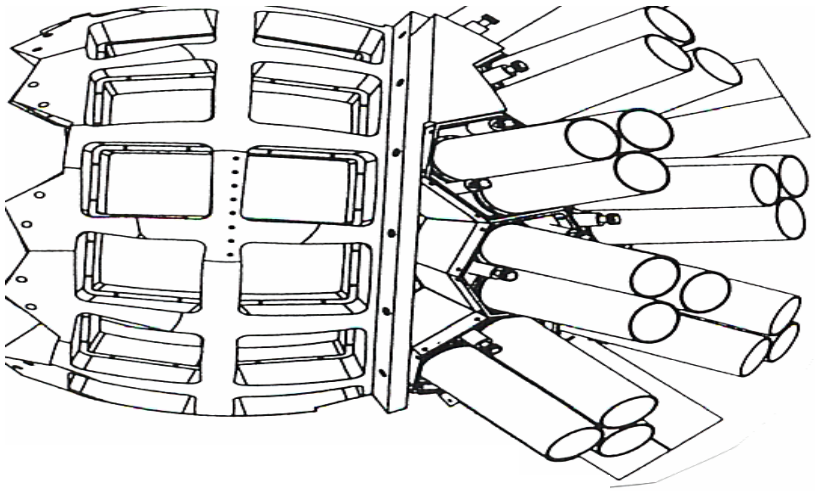
DIAMANT alone: particle-xn channels

DIAMANT + Ge : particle-xn + xn channels

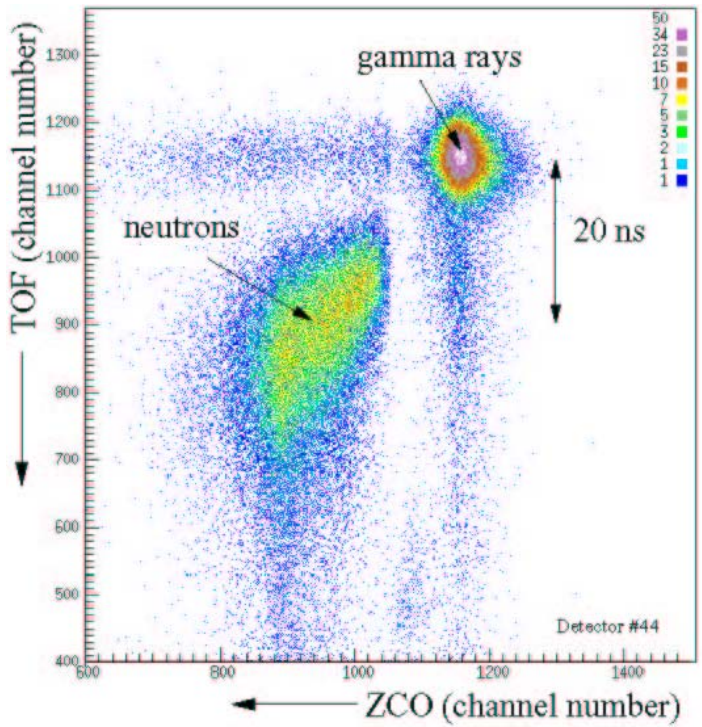
Neutron Wall

(50 detectors ~ 1π)

Important in the study
of **neutron deficient nuclei**
(one looks for the evaporation of 1-2 n)



Liquid Scintillators BC501A
Total Volume ~ 151 litri



Basic Principle:

- elastic scattering n – p (of the liquid scintillator)
- separation between n and γ with TOF + pulse shape (ZCO time)

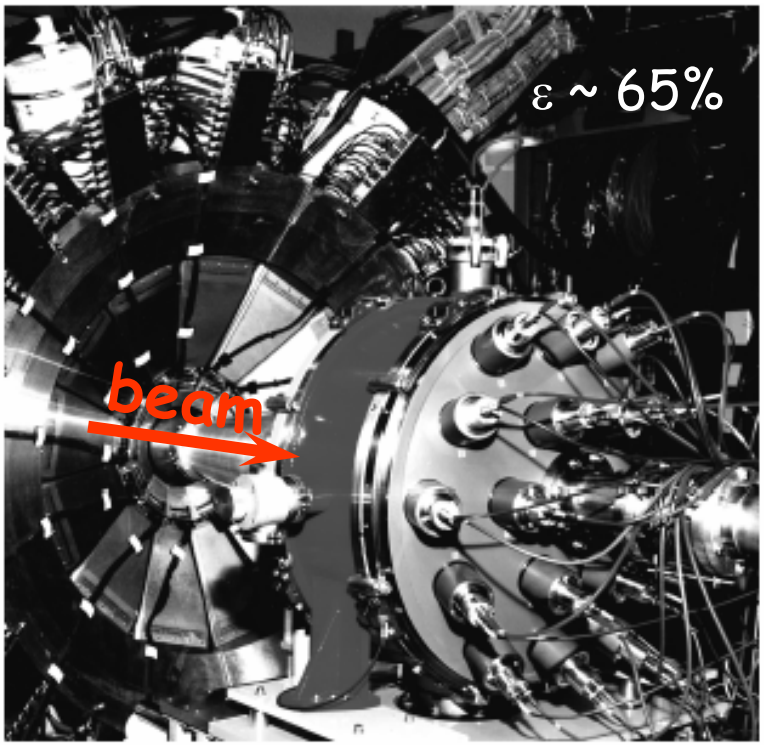
Recoil Filter Detector

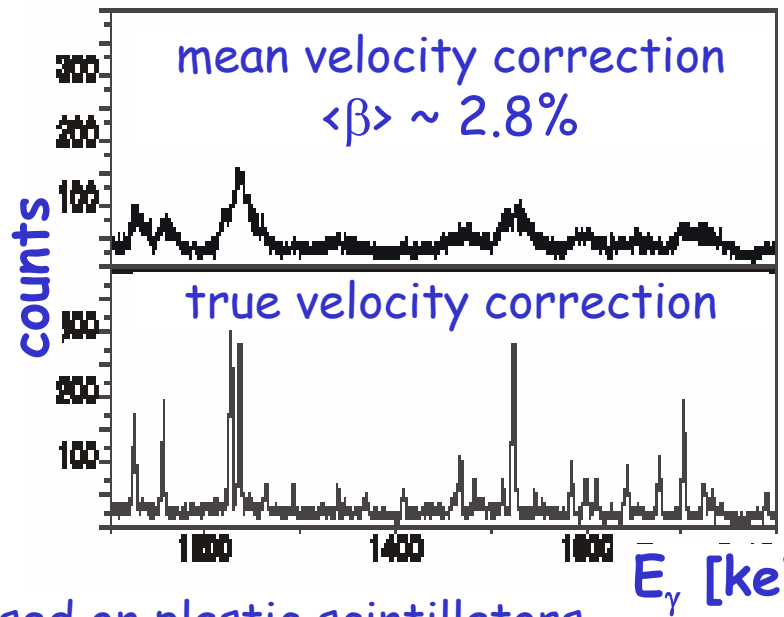
(50 detectors ~ 1π)

Importante in the study
of **heavy nuclei** where one has

1. **Only few evaporation** residua
2. Large fraction of fission
3. Large amount of particle emission

Residues identification & v/c determination





18 elements of mylar foils (0.5 -2 μm):

Recoiling ions produce from the mylar
electrons accelerated from 20 kV and focused on plastic scintillators

elettrons ∝ energy released by the ion

The Angular Momentum World of the Nucleus