Week 8: Ch. 12 Germanium diodes

Semiconductor Diodes

Germanium-based Diodes

-- basics of germanium

--- Ge(Li), Si(Li), intrinsic material

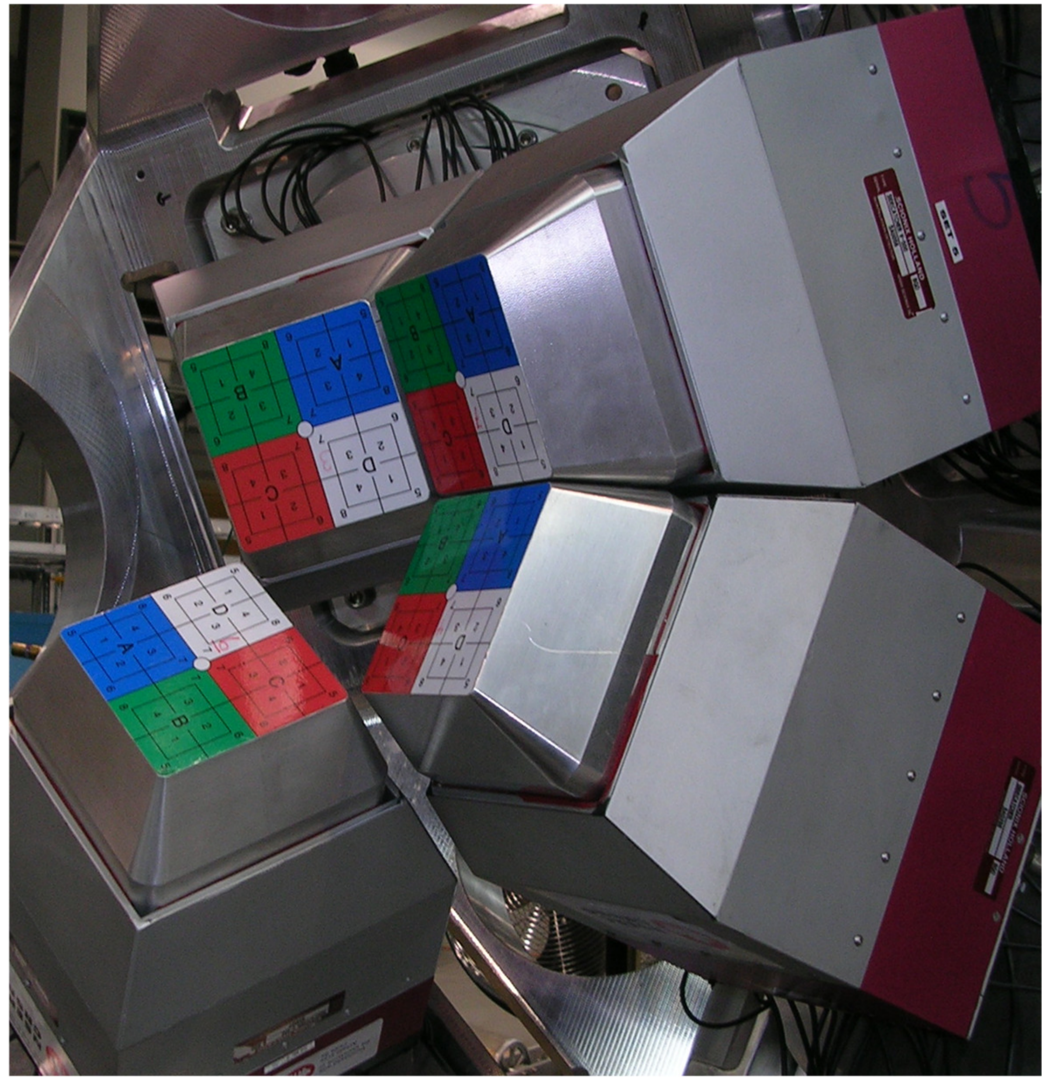
--- Contacts

--- Pulse shapes

-- Compton Suppression

--Tracking

Other Semiconductors



Four TIGRESS detectors at TRIUMF

Chap. 12 – Germanium Based Detectors

The semiconductors provide the lowest value of "w" and thus the highest resolution for energy deposited, Silicon has become widely available in thin disks but the low atomic number (14) limits its use for photon detection – a higher Z is needed.

13	14	15
5 B 10.811	6 C 12.011	7 N 14.007
13 Al 26.982	14 Si 28.086	15 P 30.974
31 Ga 69.72	32 Ge 72.59	33 As 74.922
49 In 114.82	50 Sn 118.69	51 Sb 121.75
81 Tl 204.37	82 Pb 207.19	83 Bi 208.98

- Sn & Pb are "metallic"
- Ge is only elemental option
- GaAs, InSb are used somewhat
- CdZnTe is a "new" material

Germanium is more metallic than silicon – band gap is lower, higher signals, higher thermal noise, easier to purify, donor/acceptor dopant level is lower

Large volumes are available (~1 L) from zone refining
n-type usually has Oxygen in the matrix
p-type usually has Aluminum in the matrix
"hyperpure" material is readily available .. Intrinsic.

Diode Detectors – lithium compensation

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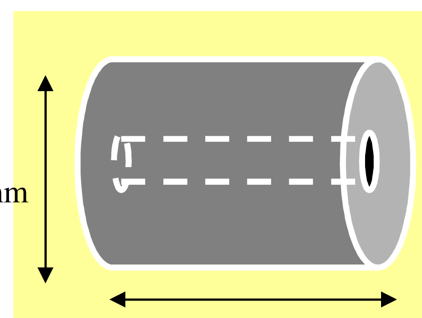
A technique we discussed that can control the resistivity/conductivity of semiconductor diodes was adding dopants. Another important use of dopants is to cancel or compensate for trapping sites in the material due to impurities, crystal defects, etc. Lithium metal (Group 1, a good donor) can be applied to the surface with some interesting results:

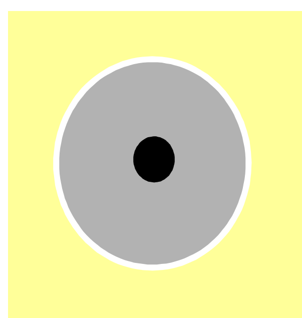
Electron → existing hole site

Li^{+} (under bias & heat) → existing donor site

- The ions will remain in place with constant bias (Si) or with cooling (Ge).
- These devices are labeled as Si(Li) or Ge(Li) …
- Si(Li) are generally planar; Ge(Li) cylindrical called "coaxial" and "coax"
- The Ge(Li) devices have mostly been retired from active service because they must ALWAYS be kept at liquid nitrogen temperatures. The Si(Li) devices remain important due to the inability to produce large volume ultrapure silicon at at present.

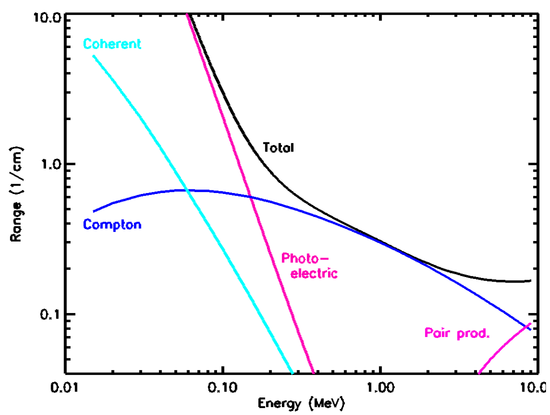
Typical:
40 mm x 150 mm

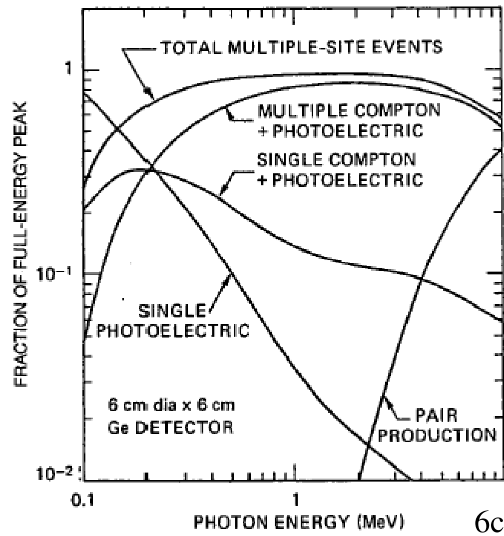




Li (donor) on outside is n-type
and creates the rectifying contact
Crystal then is p-type
Inner contact can be ohmic or p-type
Electric field is radial in a "true coax"

Germanium Based Detectors – Geometry





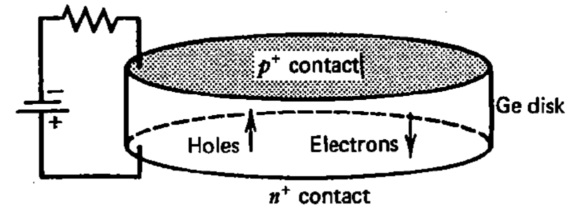
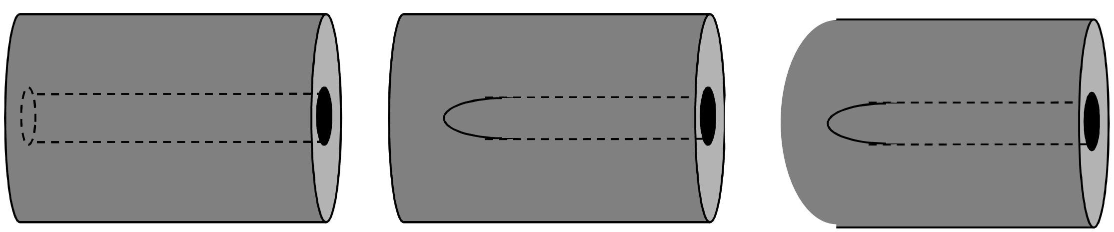


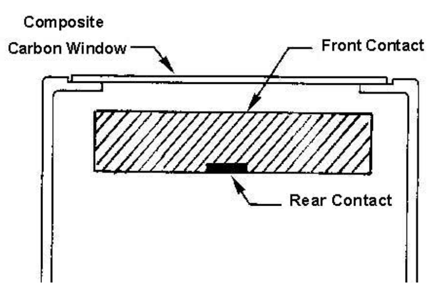
Fig. 12.2 Knoll, 3rd , 4th Ed.

Multiple Compton Scattering is most likely process in "nuclear regime"
Planar devices: low energy photons.

6cm x 6cm Fig. 12.16 Knoll, 3rd , 12.17 4th Ed.

Intrinsic or high purity germanium can be formed into coaxial shapes with radial electric fields, end-caps are often left on and further they can be "bulletized"





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Extremely low capacitance device with unusual electrode design but funky electric field

Shape, material and contacts are separate variables.

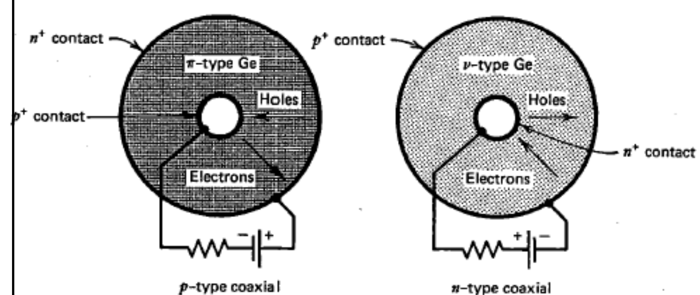

Fig. 12.3 Knoll, 3rd , 12.4 4th Ed.

Germanium Based Detectors – damage

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The devices can be n-type or p-type …
p-type is easier to produce but n-type is more resistant to neutron damage ..
(cf. H.W. Kramer, IEEE NS-27 (1980) 218)

^{A}Ge (n,n') ^{A}Ge E_n ~ 2-5 MeV the E_{recoil} ~ 40 keV Range ~ 40 nm
σ ~ 3-4 b (r_{Ge} ~ 0.122 nm)

^{74}Ge (n,γ) ^{75}Ge → β^{-}+ν-bar+ ^{75}As $T_{1/2}$ = 83 m
σ ~ 1 b for thermal neutrons

Mean free path: $\lambda = 1 / \sigma N_0$

$$\lambda_{Fast} = \frac{1}{4x10^{-24}\,cm^2\left(5.35g/cm^3 N_A/72.6g\right)}$$

$$\lambda_{Fast} = 6\;cm$$

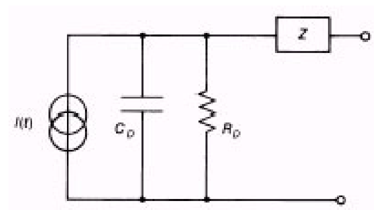
$$\lambda_{Thermal} \sim 24\;cm$$

Lattice defects are more likely to trap holes than electrons – minimize hole travel:
Therefore, implant boron (p type) to make outside contact on n-type germanium

Germanium Based Detectors – Signal Shape

Position-dependence of the signal shapes from planar Ge detectors similar to that for gas filled parallel plate ion chambers but with a slow rise. (no Frisch grid !)

$$t \sim \frac{3.8cm}{4x10^{6}\,cm/s} \sim 10^{-6}\,s$$



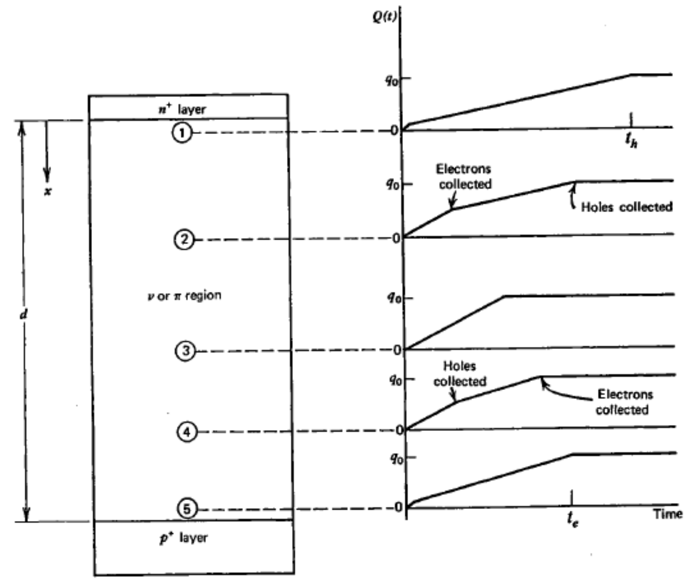
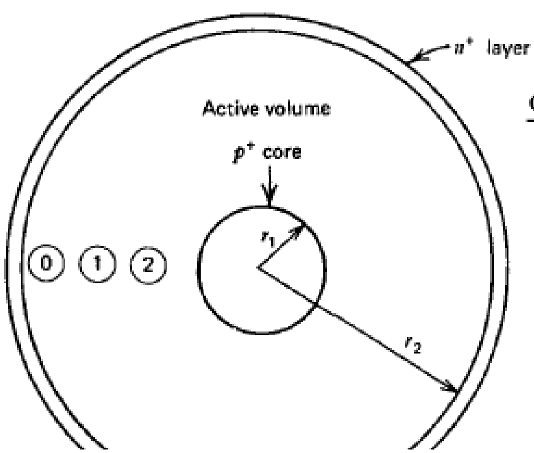


Fig. 12.11 Knoll, 3rd , 12.12 4th Ed.

Pulse shapes from coaxial and end-cap devices are more complicated due to electric field shapes.



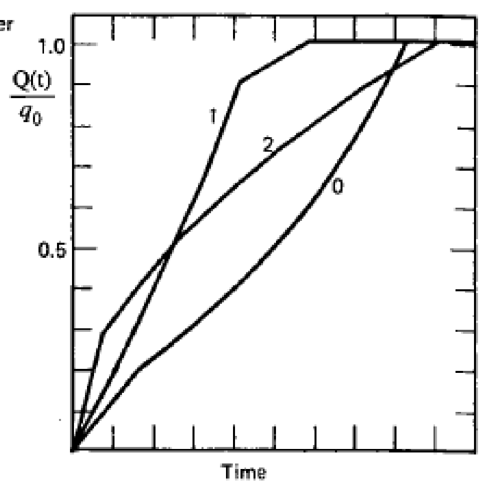


Fig. 12.12 Knoll, 3rd , 12.13 4th Ed.

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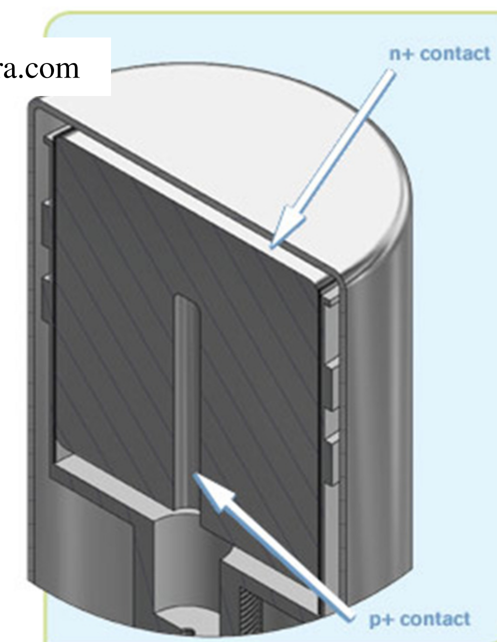

Germanium Based Detectors – SeGA

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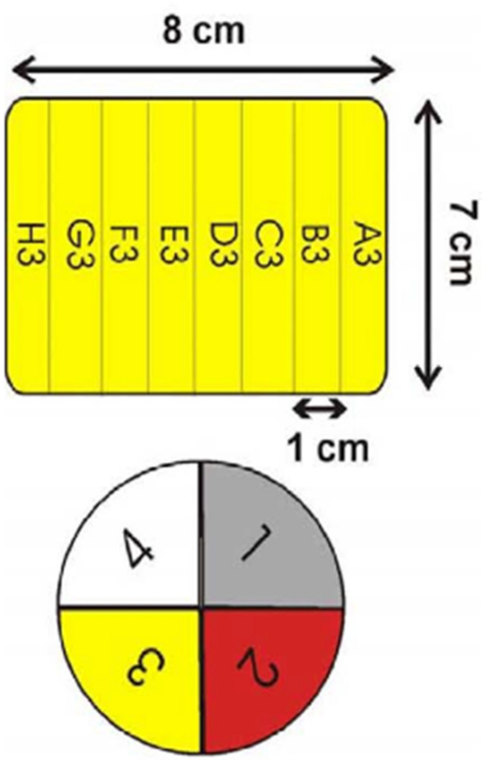
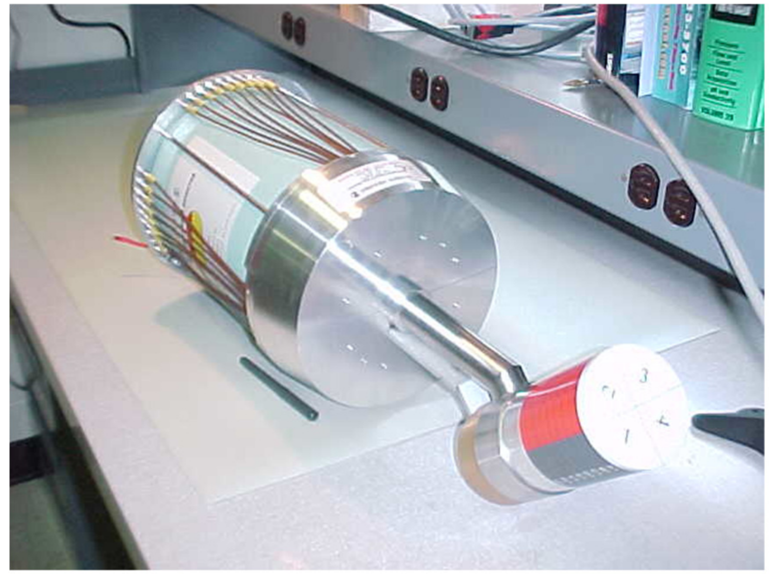
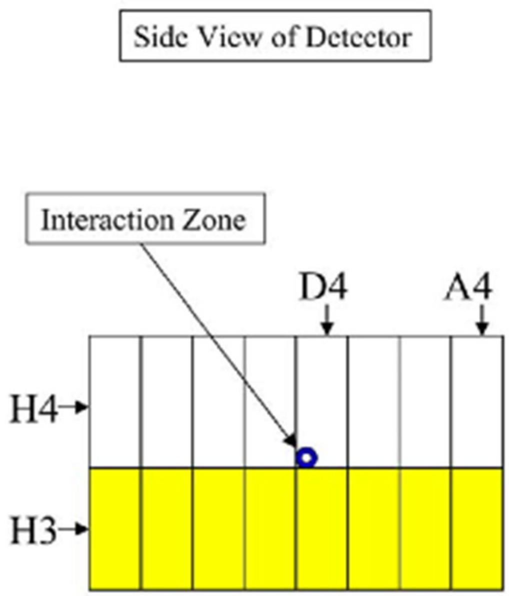
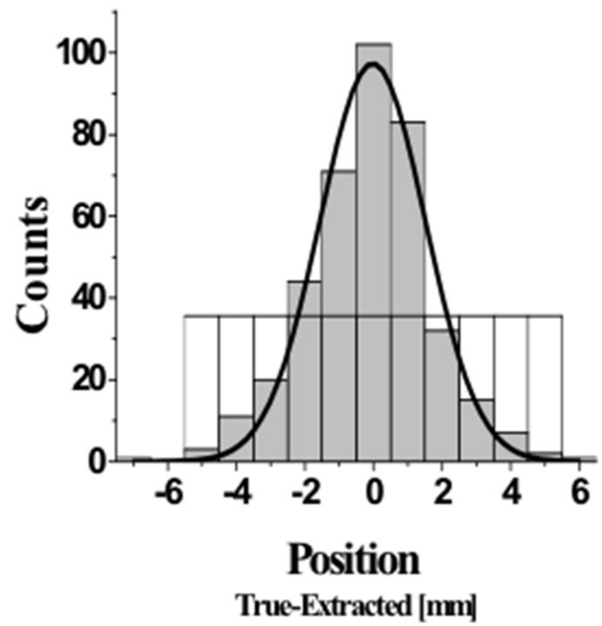




1.37 kg , ~256 cm^3
closed-end
n-type, p+ contact 0.3μm





AGATA Signal Shapes – 37 signals / detector

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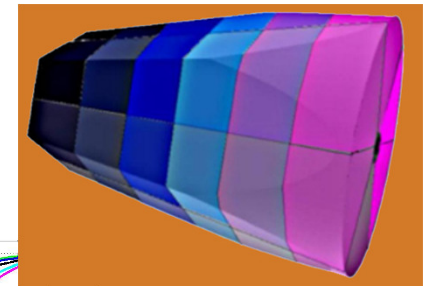
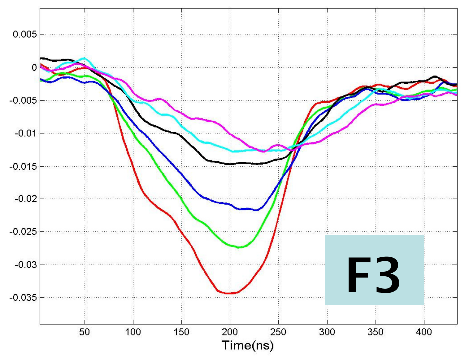
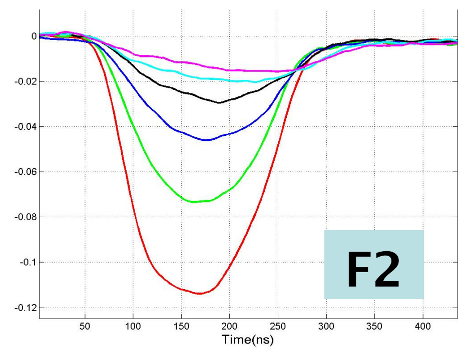
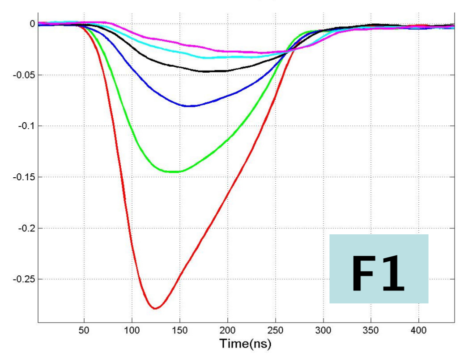
Advanced Tracking Array – European Next-generation device
Shaped crystal segmented into 6 azimuthal cuts x 6 longitudinal slices
(Goal: three close-packed crystals x 60 units = 180 detectors)

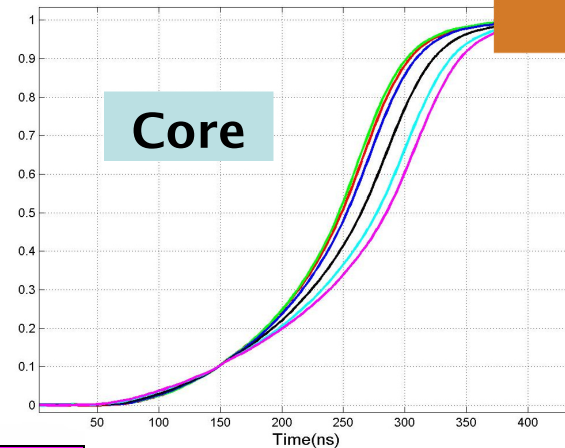


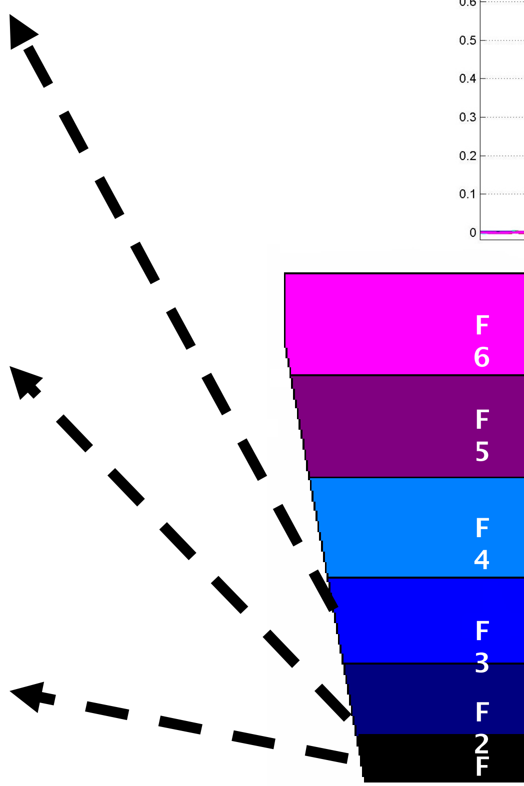
90 mm long
80 mm base ϕ

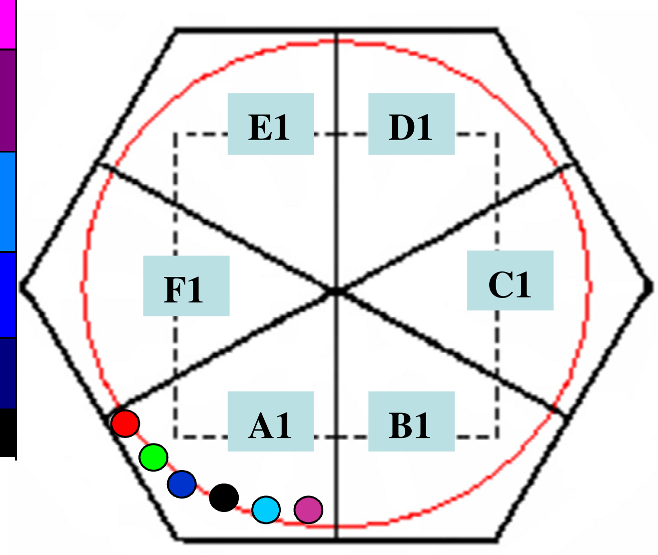






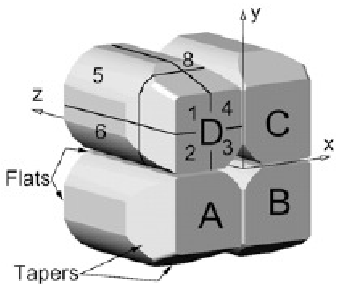






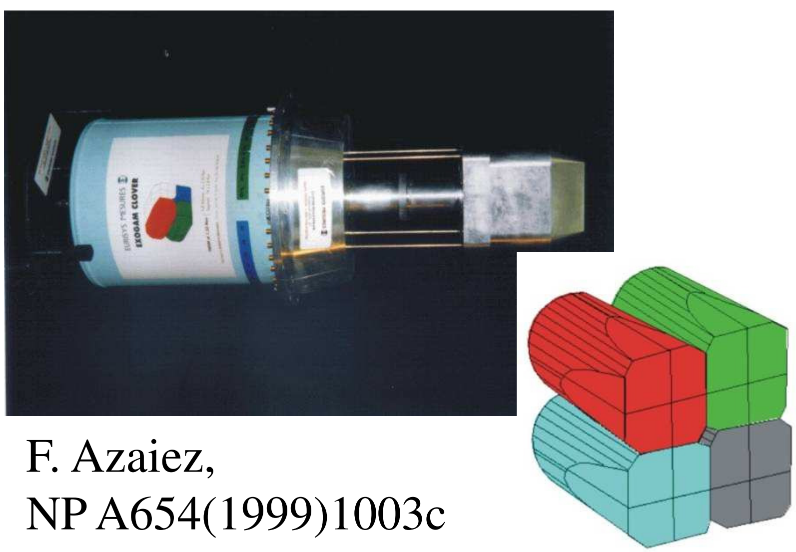
Germanium Based Detectors – Clovers

TIGRESS (TRIUMF)



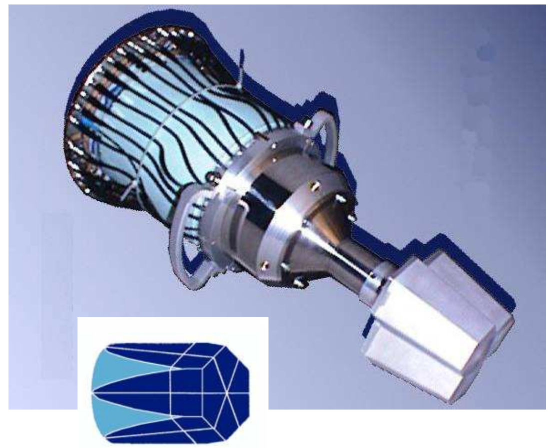
C.Svenson, et al.,
NIM A250(2oo5)348

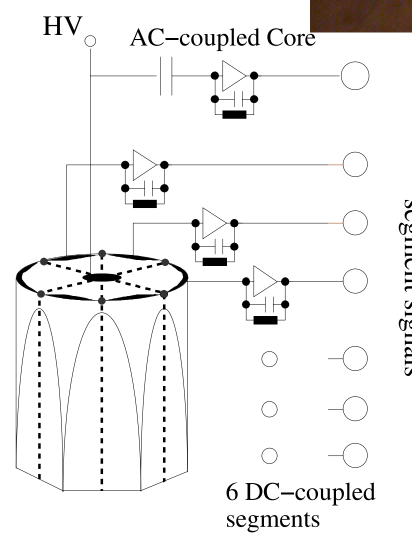
EXOGAM (GANIL)



F. Azaiez,
NP A654(1999)1003c

MINIBALL (CERN)





J. Eberth, et al., AIP Conf. 656(2oo3)349

Germanium Based Detectors – "Peak" Efficiency

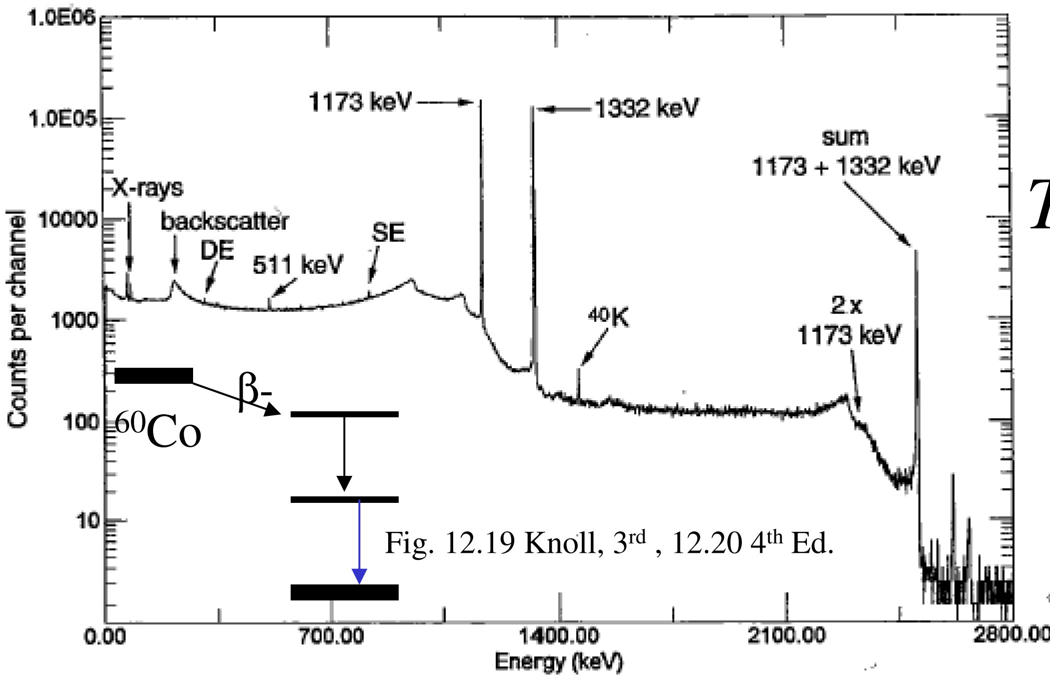
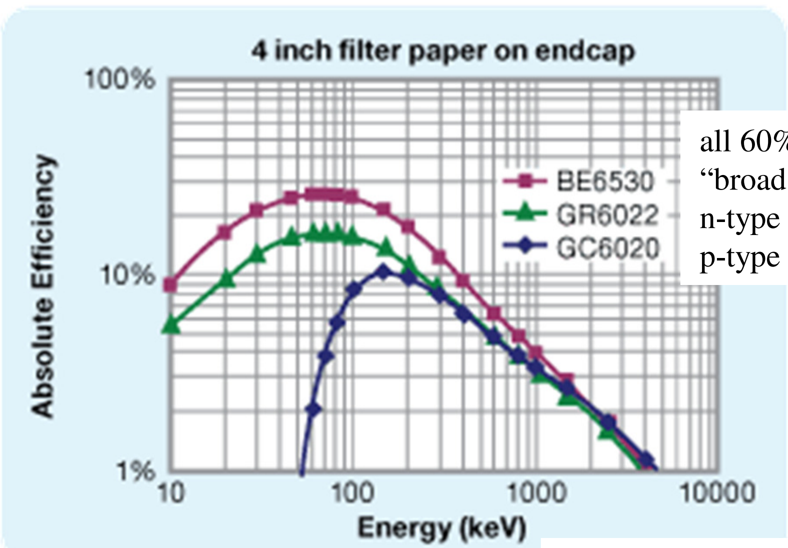


Fig. 12.19 Knoll, 3rd , 12.20 4th Ed.

That should be: Photo-Peak



all 60% det's
"broad range"
n-type coax
p-type coax

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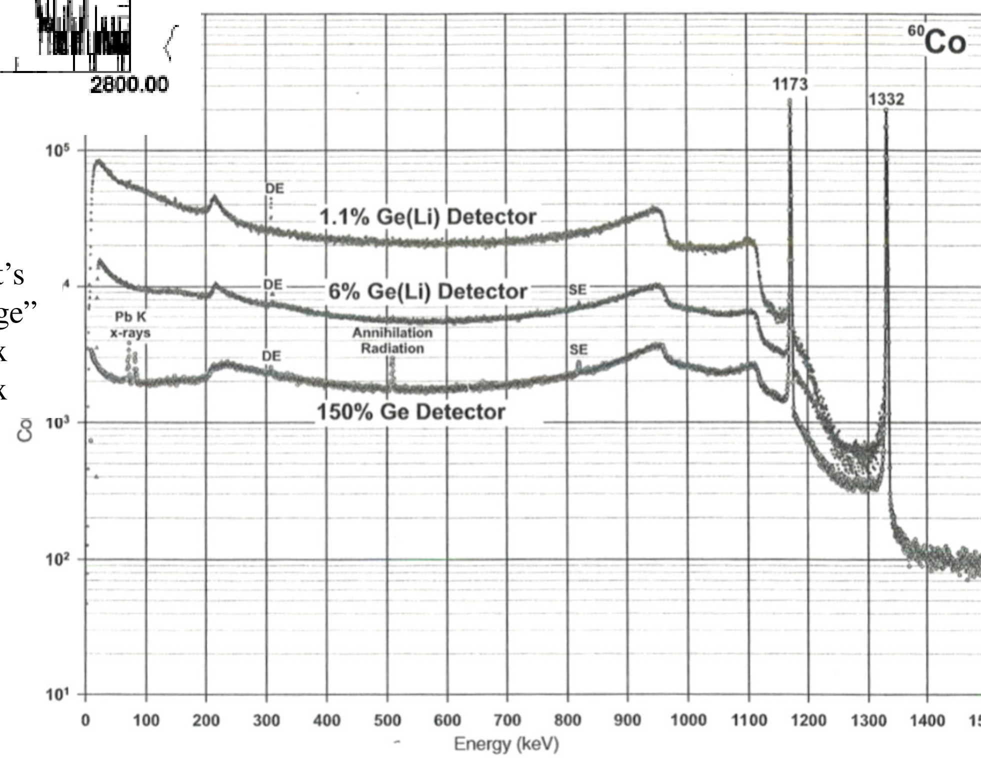

Germanium Based Detectors –"200% Efficiency"

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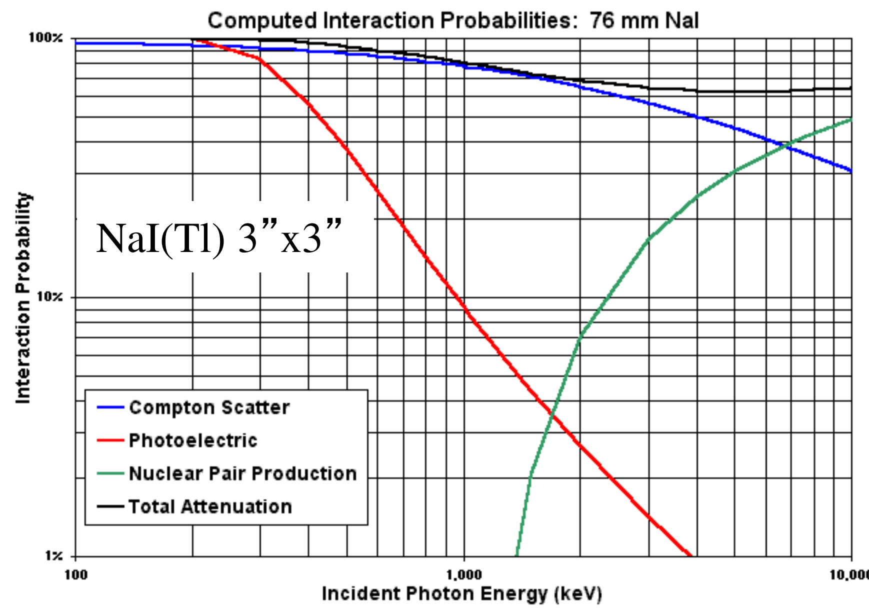
Detector efficiency for a germanium detector is often quoted in percent of that for a 3"x3" NaI(Tl) detector at a distance of 25 cm (for historical reasons) and generally for the 1332.5 keV line from ^{60}Co.
The reference photopeak efficiency for the 3"x3" detector is $1.2 x 10^{-3}$ (cf. p.459 in text).

$$\varepsilon_{geo} = \frac{1}{2}\left(1 - \frac{d}{\sqrt{d^2 + a^2}}\right) \qquad d = 25cm,\ a = 1.5''$$

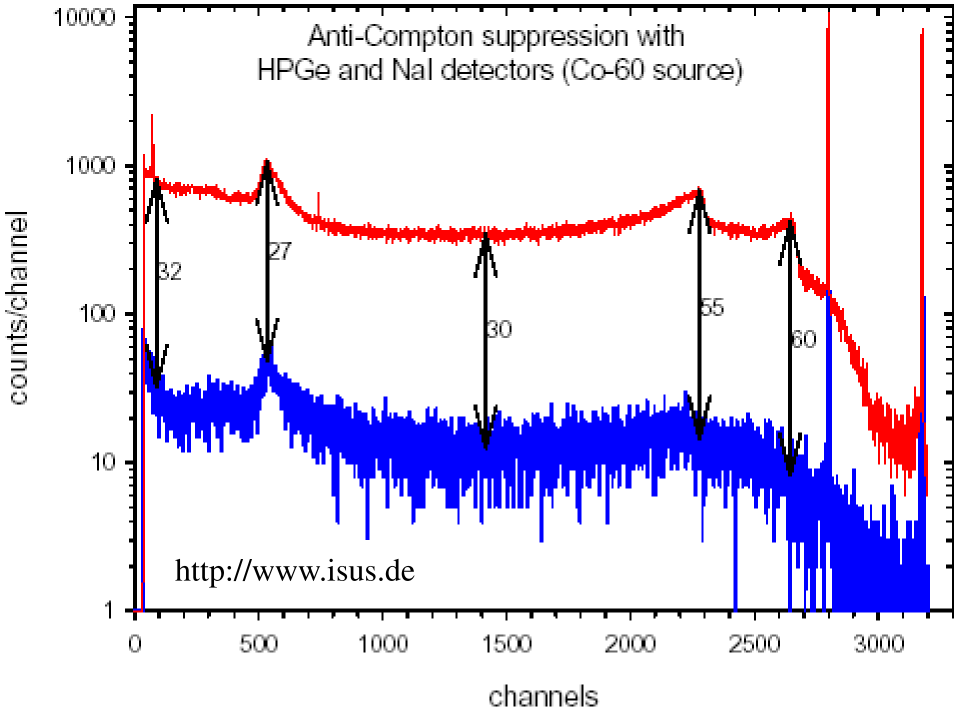
$$\varepsilon_{geo} = 5.707x10^{-3}$$

$$\varepsilon_{\text{total photopeak}}(NaI) = 1.2x10^{-3} \rightarrow \varepsilon_{\text{intrisic photopeak}}(NaI) = 0.210$$



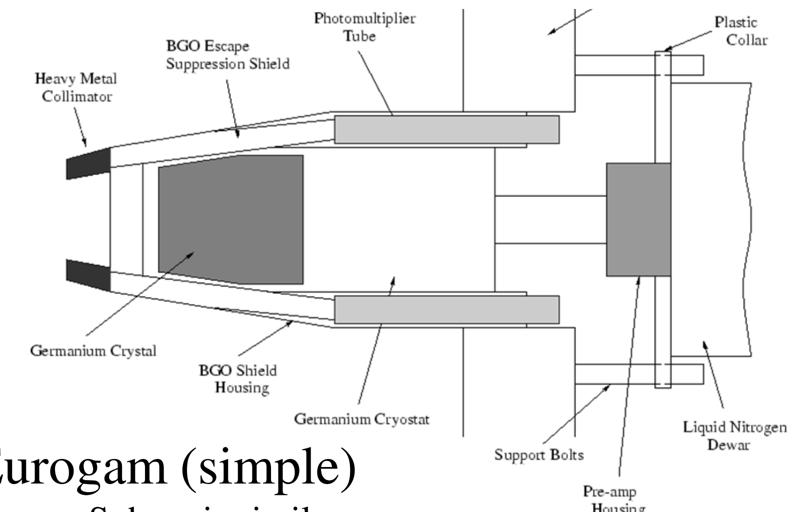
Note that the "total efficiency" for the 3"x3" detector is ~ 0.7 at this energy (any interaction).

Germanium Based Detectors – Anticompton



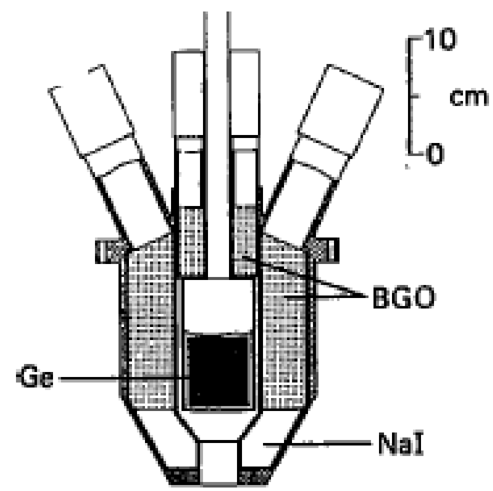
Anticompton shields: Improve the <u>quality</u> of the signal by rejecting events when (Compton-scattered) photons leave the Ge crystal.

Figure similar to 12.26 in 4th Ed.



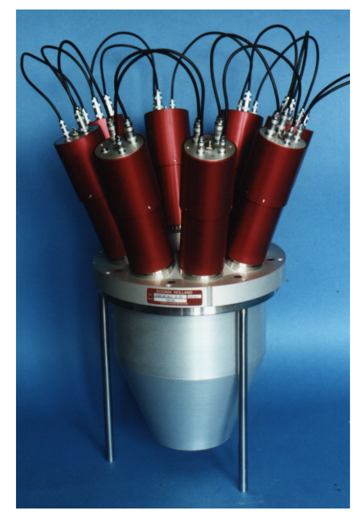
Eurogam (simple)

GammaSphere is similar



“Tessa” mixed shield

Fig. 12.25 Knoll, 3rd , 12.26 4th Eds.



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“4π” detectors, Compton-supressed

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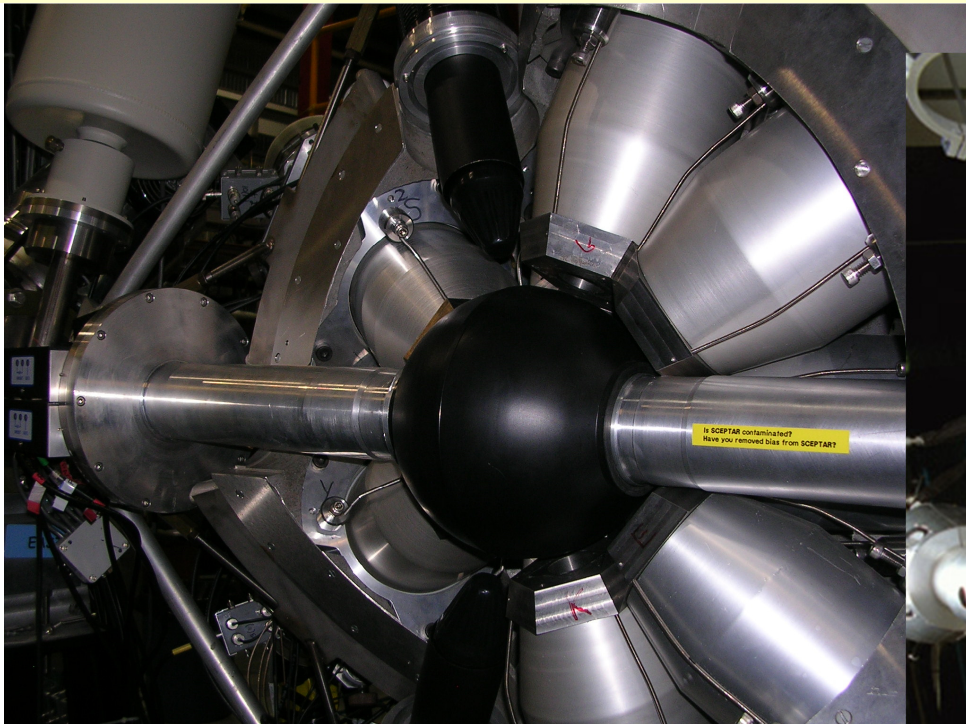
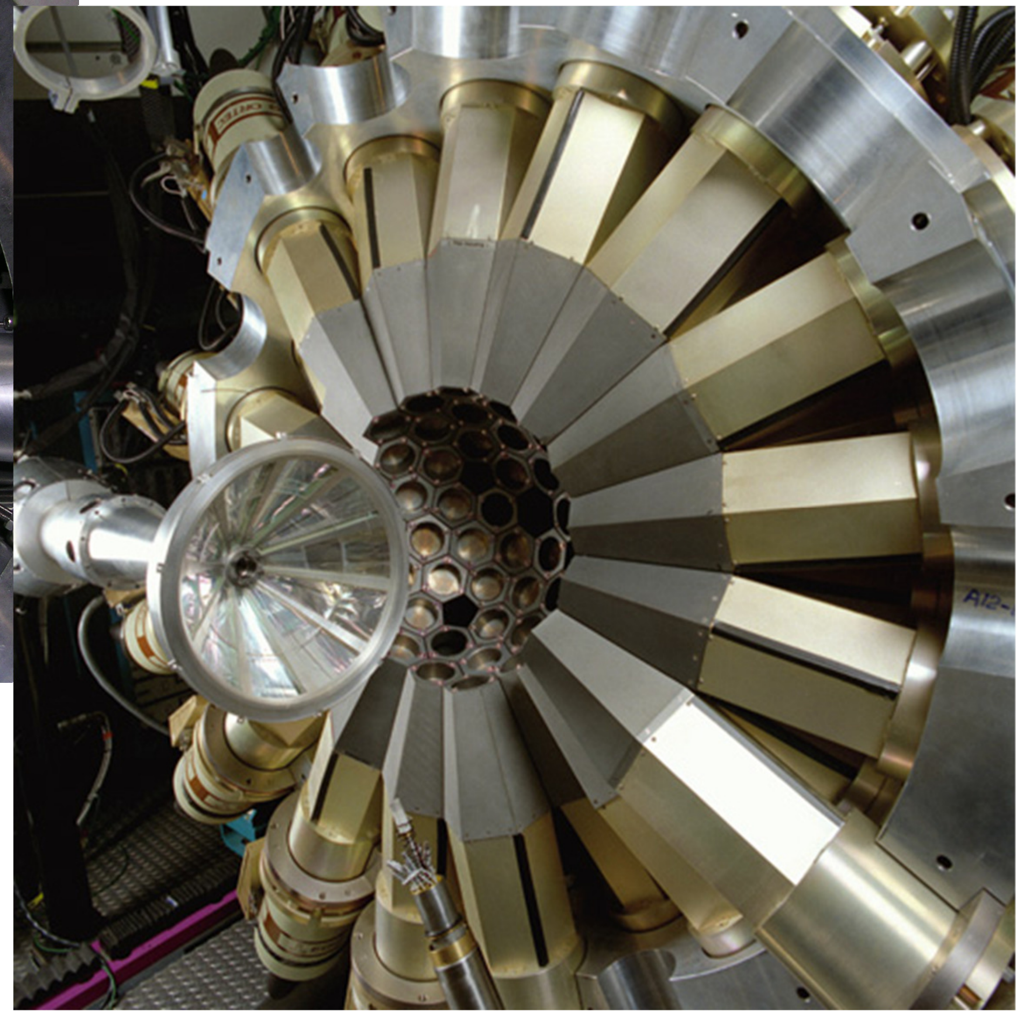


“8π” detector at TRIUMF, 20 HpGe with anticompton shields, 10 BaF_2 or $LaBr_3(Ce)$ scintillators, early 1990’s



Gammasphere now at ANL, 110 HpGe with BGO anticompton shields, full-energy peak efficiency ~9% (1.33MeV) late 1990’s

Note: a large fraction of solid angle is taken by suppressors – interactions in these materials are generally lost.

Next generation - Tracking

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3D position sensitive Ge Detector

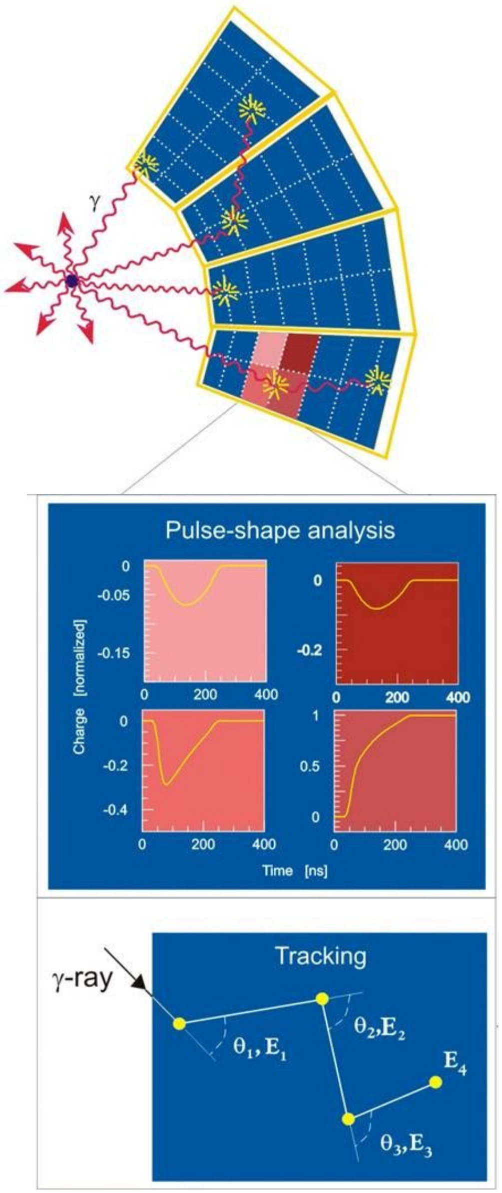
Close-pack segmented Ge crystals and work to unravel the series of interactions

Resolve position and energy of interaction points

Digital signal processing to extract energy of each interaction and sub-segment position resolution $\sigma \sim 2$mm

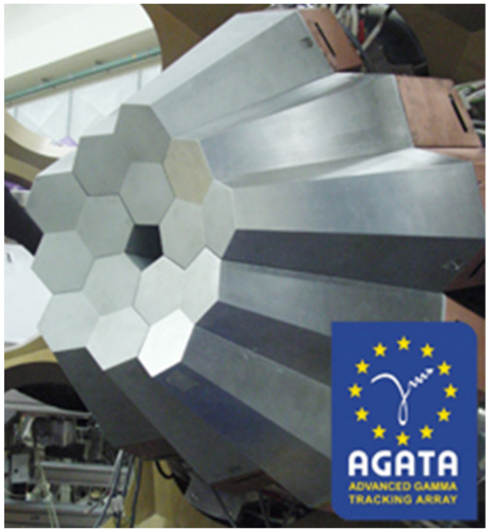
Determine scattering sequence

Sophisticated data analysis to group events and follow tracks using Compton Scattering relationships.

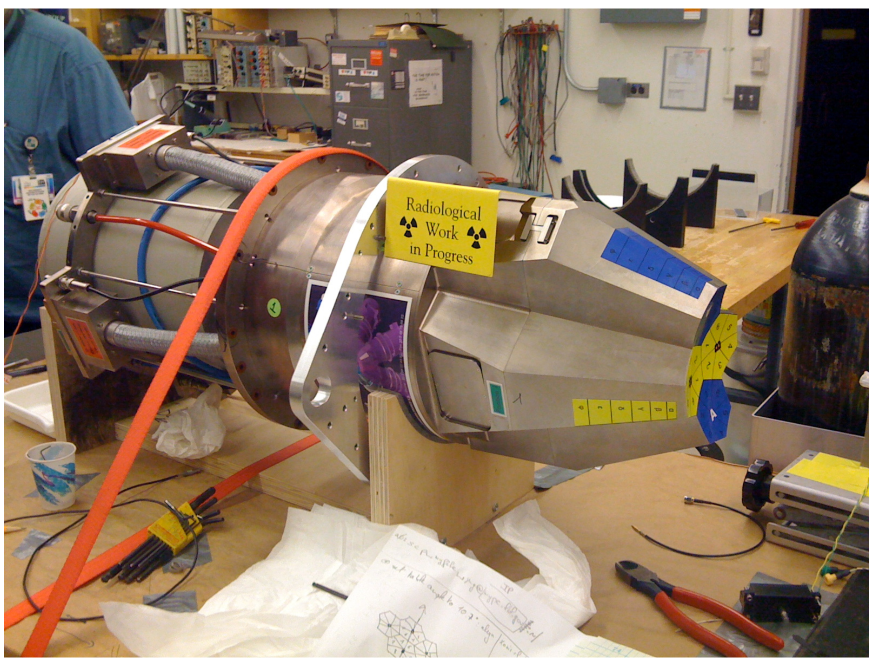


From D. Radford, ORNL

Next Generation – Packed Arrays



Advanced Tracking Array – European Goal: three close-packed crystals x 60 units = 180 detectors)



GRETINA detector (LBL),
1st NSCL campaign 7-quads
28 crystals, 6x6 segments, 1π
2nd NSCL campaign 10-quads