Vinča Institute of Nuclear Sciences,
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Gamma-ray Spectrometry

Instrumentation Part I

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Obligatory slide

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The Ge-detector

The work horse of the radionuclide metrology laboratory

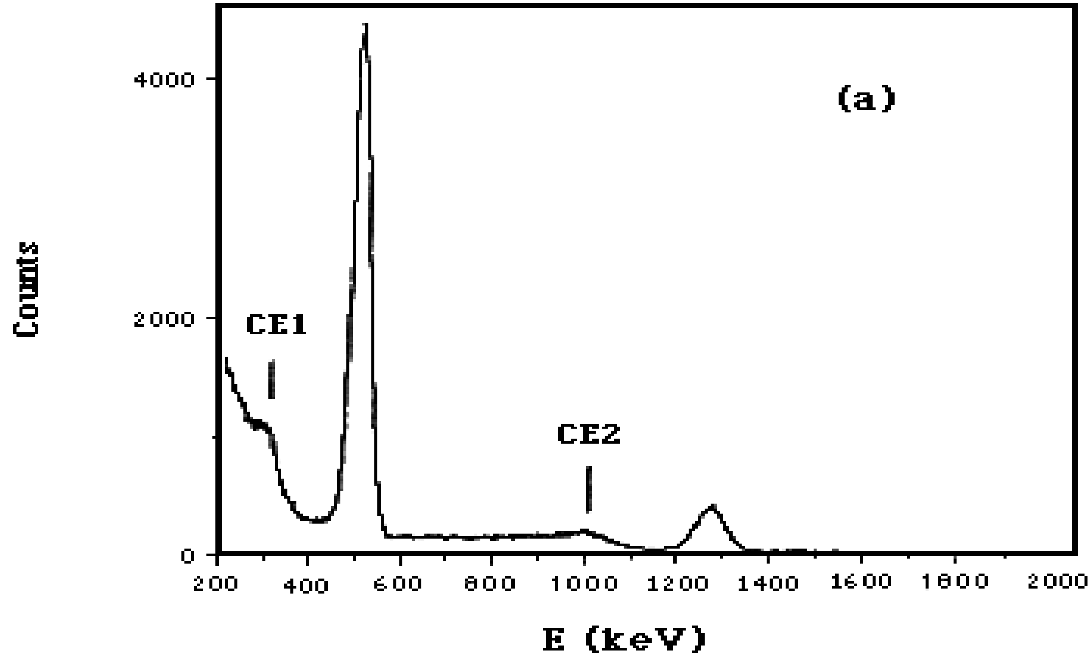
Radiopurity studies, investigate unknown samples, secondary standardisation etc.

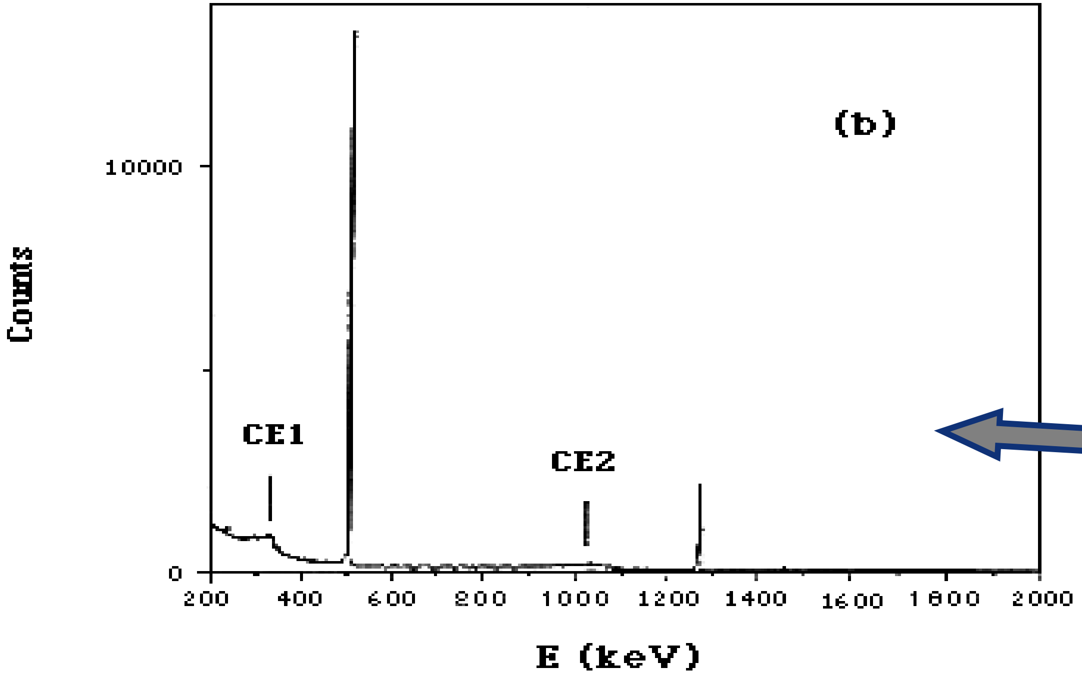
“good” resolution

“good” efficiency

Price…

……





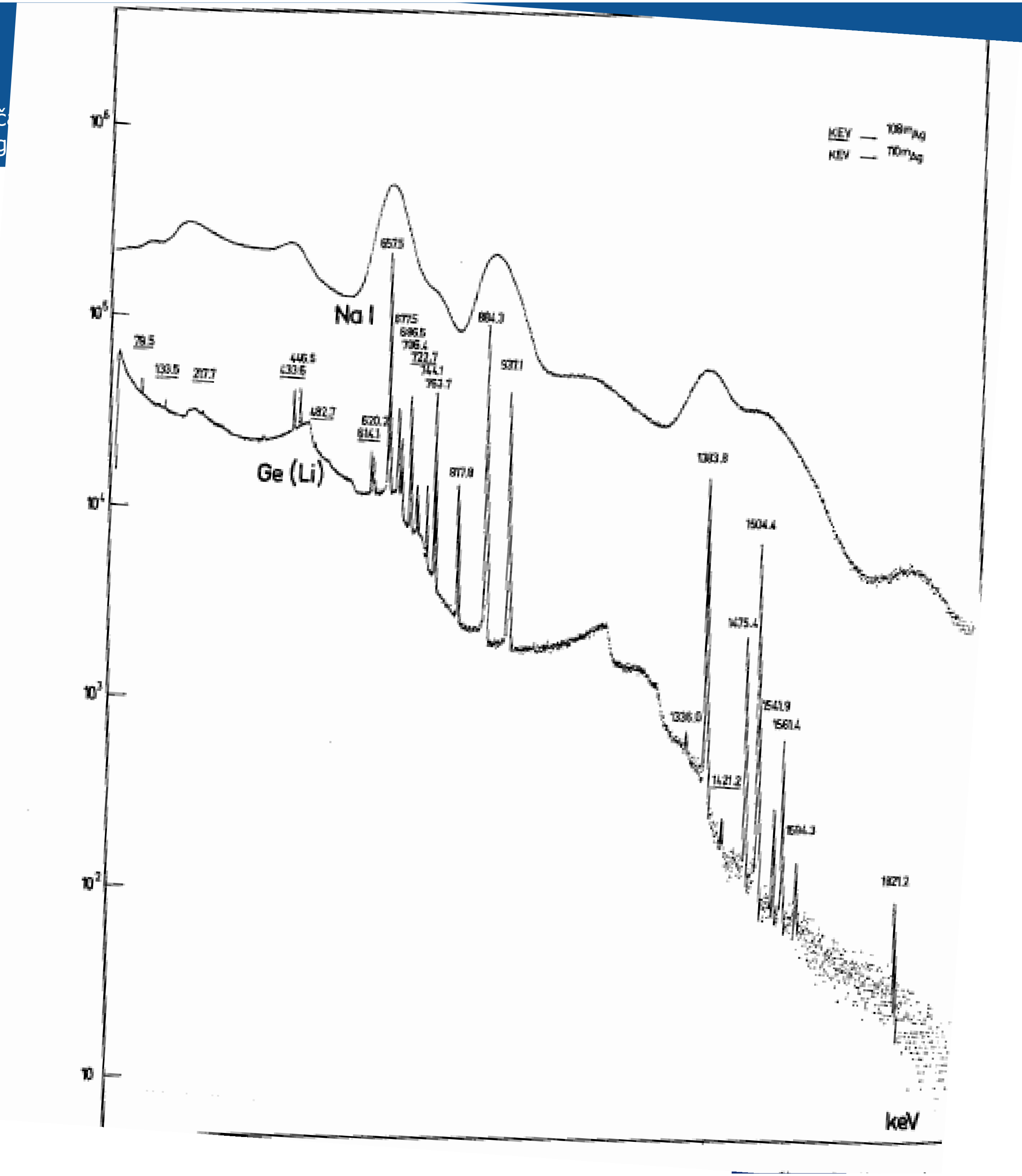
Ge-resolution: ~ 0.18%

NaI resolution: ~ 6%

@ 662 keV

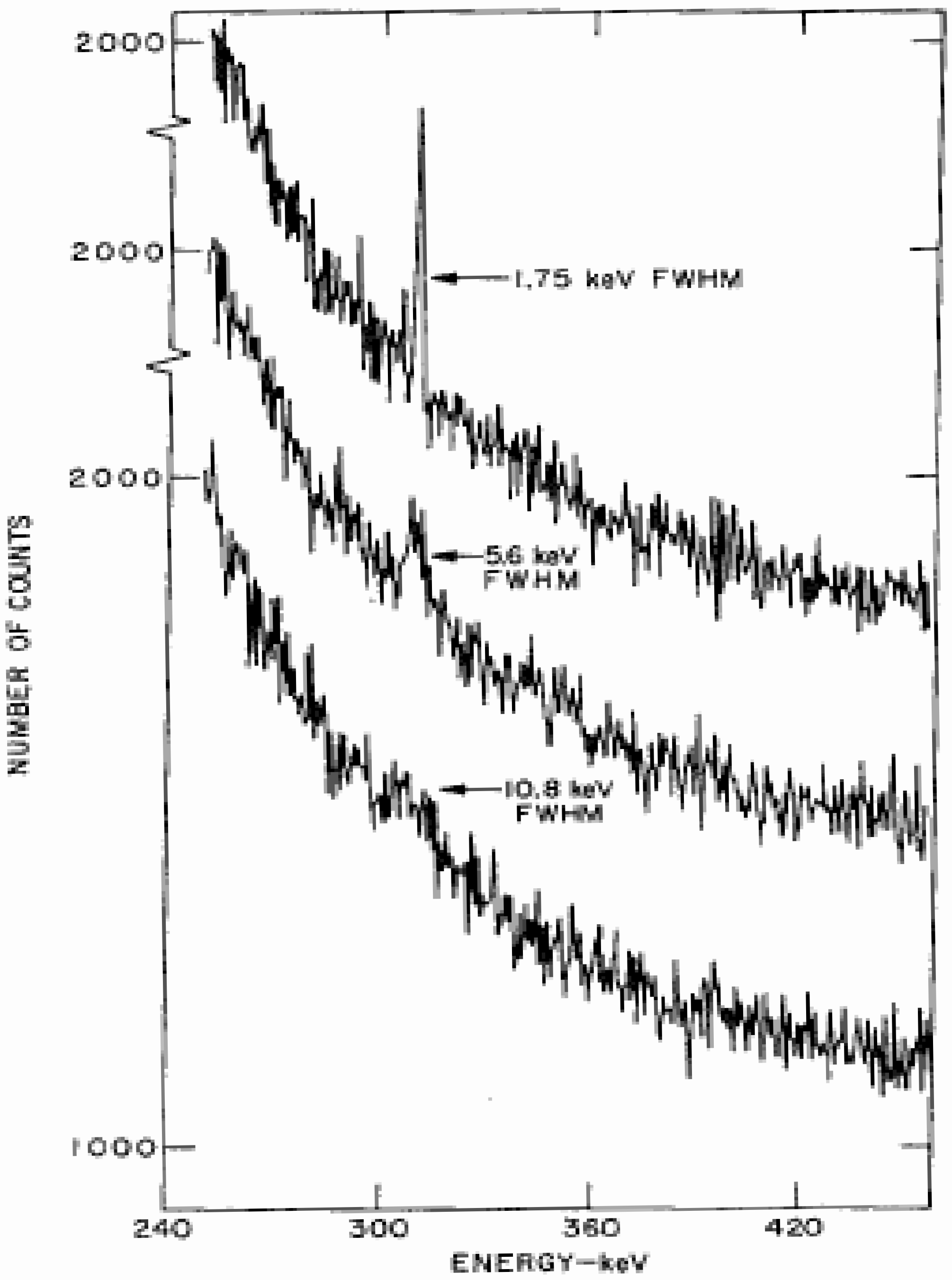
~factor of 35 difference

Which radionuclide?



Extract from Knoll

“Radiation Detection and Measurements”



The effect of detector resolution

Extract from Knoll
"Radiation Detection and Measurements"

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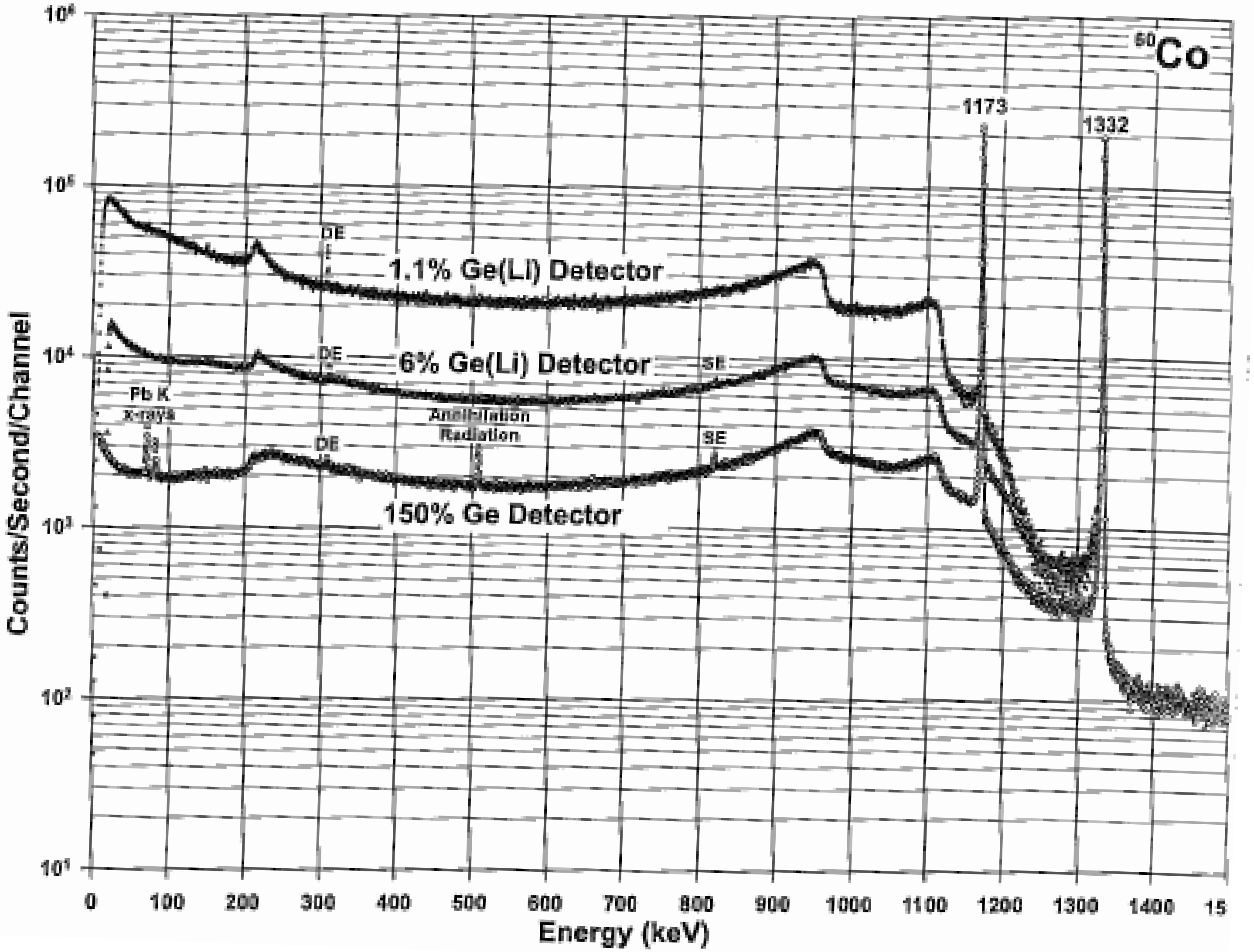

The effect of detector size

Extract from Knoll "Radiation Detection and Measurements"

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Why do we (often) want high efficiency, low FWHM and low background?

Answer:

in order to obtain low <u>detection limits</u>

Detection limit ~ $$\left(\frac{efficiency}{\sqrt{background \cdot resolution}} \right)^{-1}$$

Developments in Ge Detector technology

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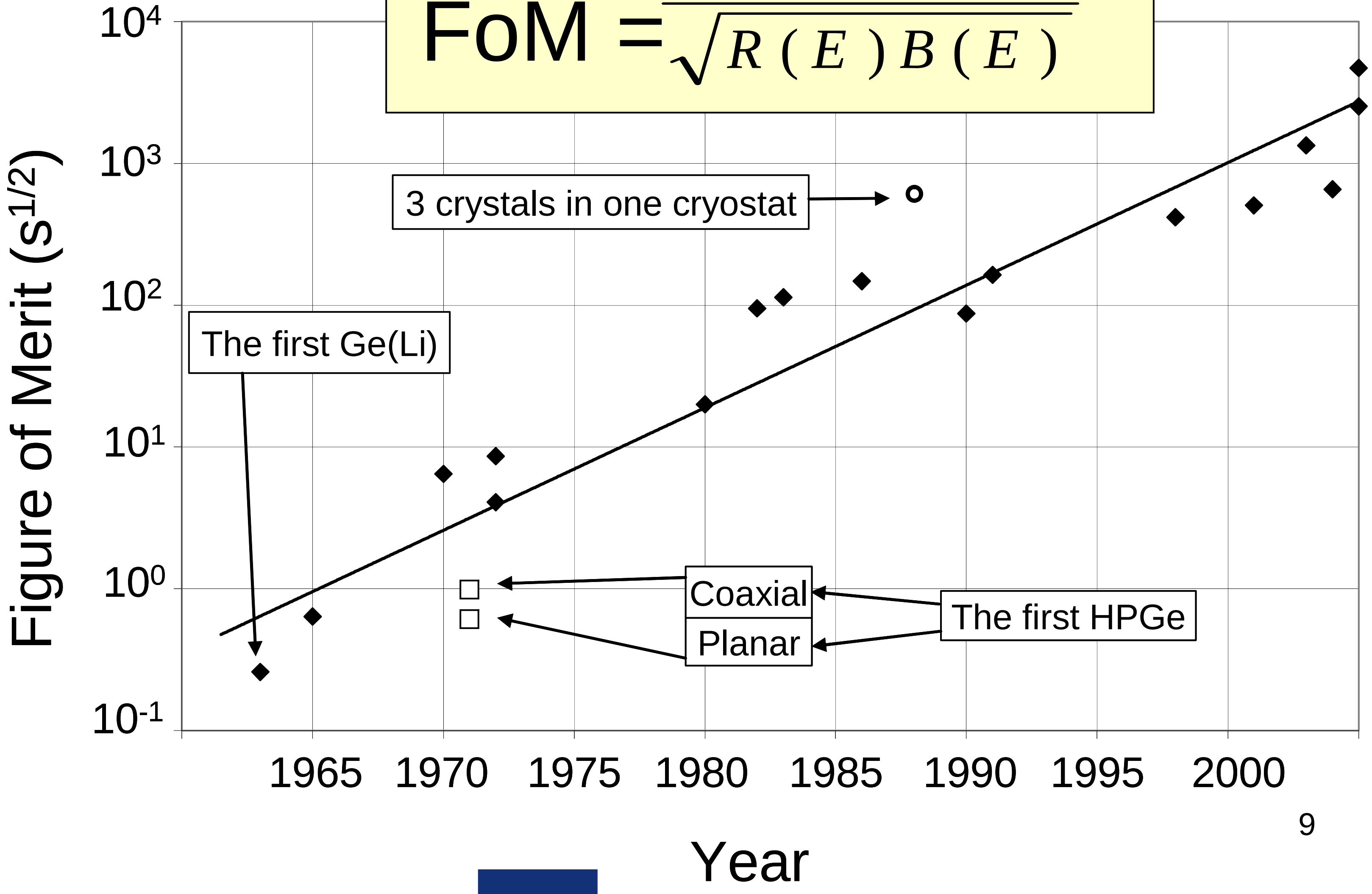
$$\mathrm{FoM} = \frac{\varepsilon(E)}{\sqrt{R(E)\,B(E)}}$$



Inside a Ge-detector

Important to understand how a Ge-detector is constructed in order to be able to:

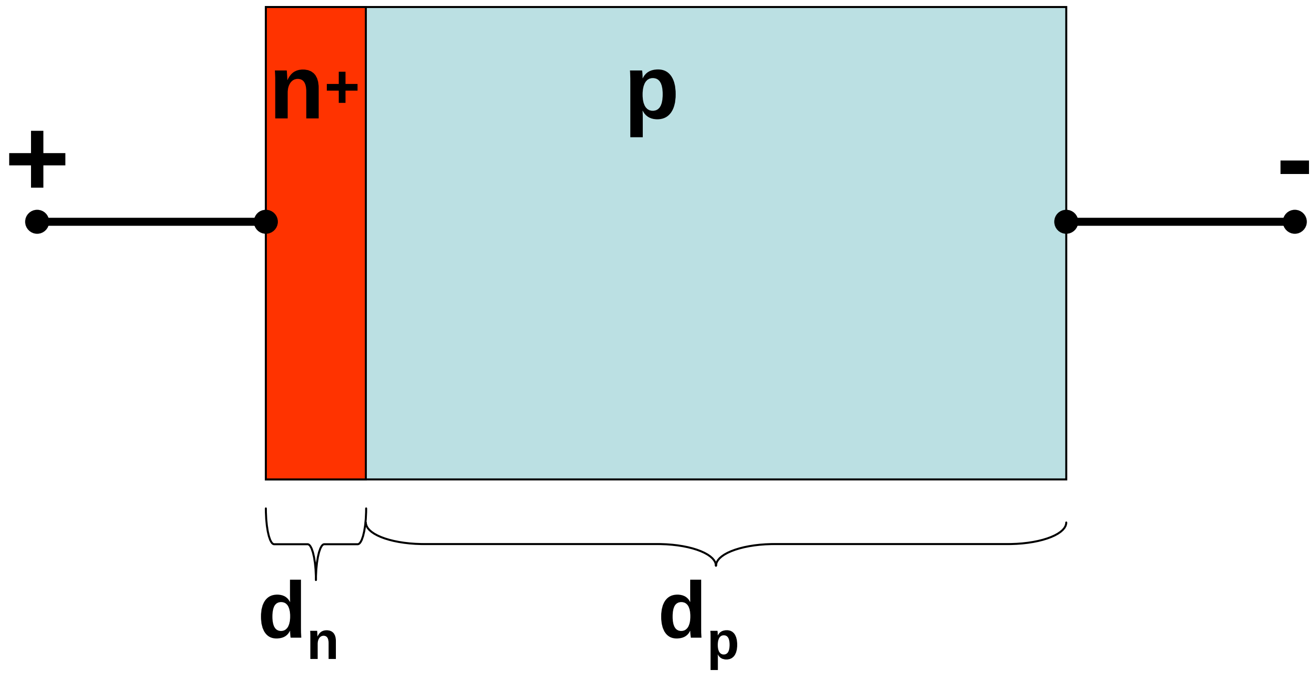
- Make accurate computer models

- Understand possible discrepancies in results

- Understand limitations when designing new systems

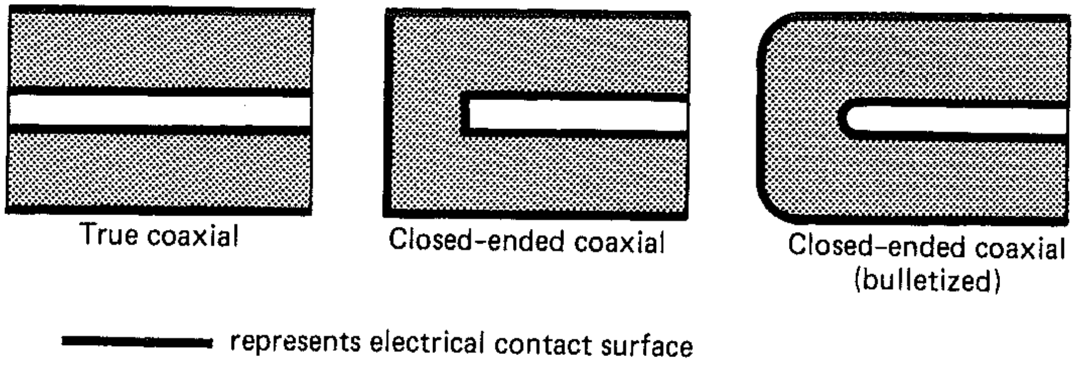
- Understand potential malfunctions or problems with older and newer detectors (long life-time means that old detectors can be available)

A reversed biased p-n junction

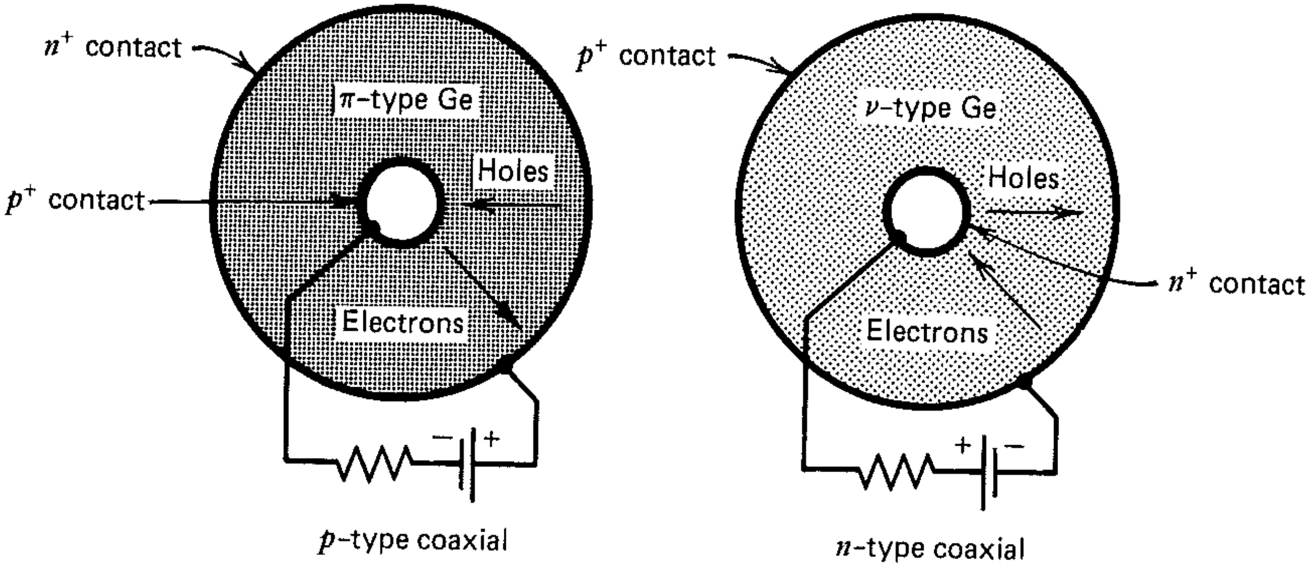


$$N_{electron} \cdot d_{n^+} = N_{holes} \cdot d_p$$

$$d \sim \mathrm{sqrt}(V)$$



Extract from Knoll
"Radiation Detection
and Measurements"



Ge-production (i)

1) Raw material: residue from e.g. Zn-ore with 3-5% Ge or re-cycled electronics

2) Reduction of Ge-oxide

3) Zone-refinement => polycrystal

Resistivity measurement

repeat

4) Czochralski growth => single crystal

Measurements

- Resistivity
- Hall
- DLTS

Ge-production (ii)
Czochralski crucible pulling…

2-3 days

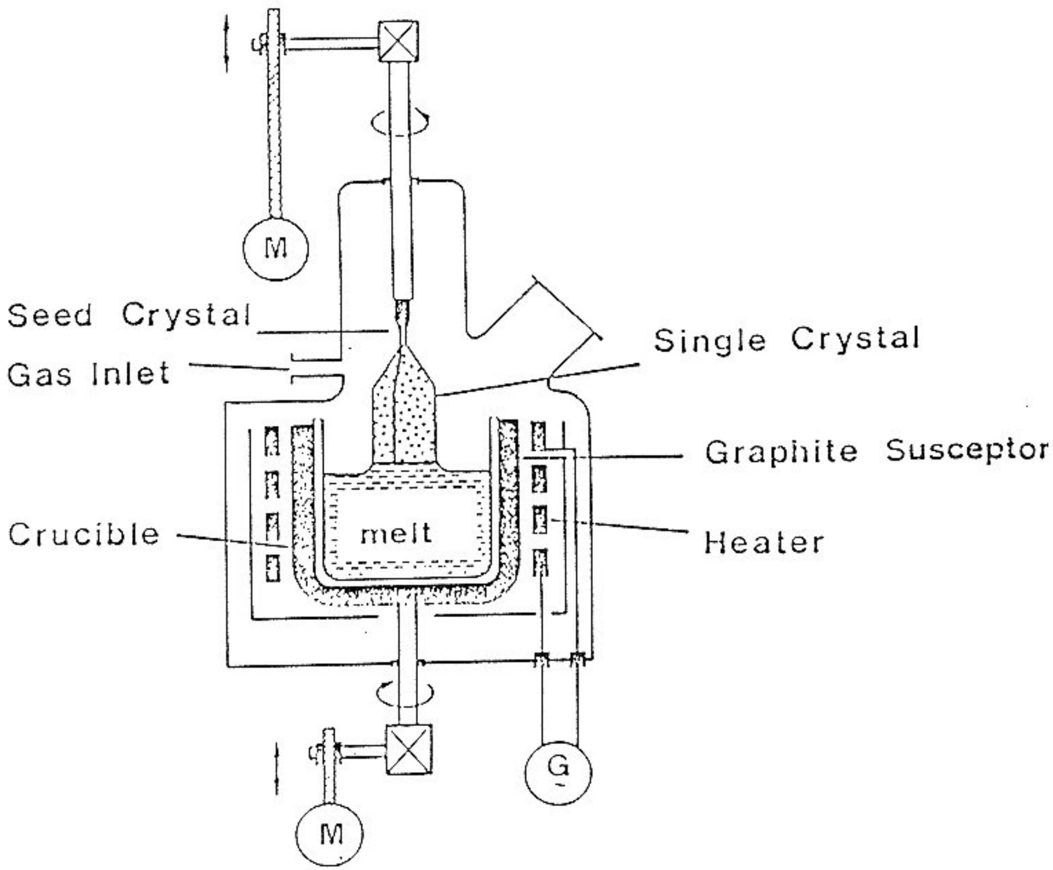
Small "low power", some gas

Needs clean room for large HPGe-detectors

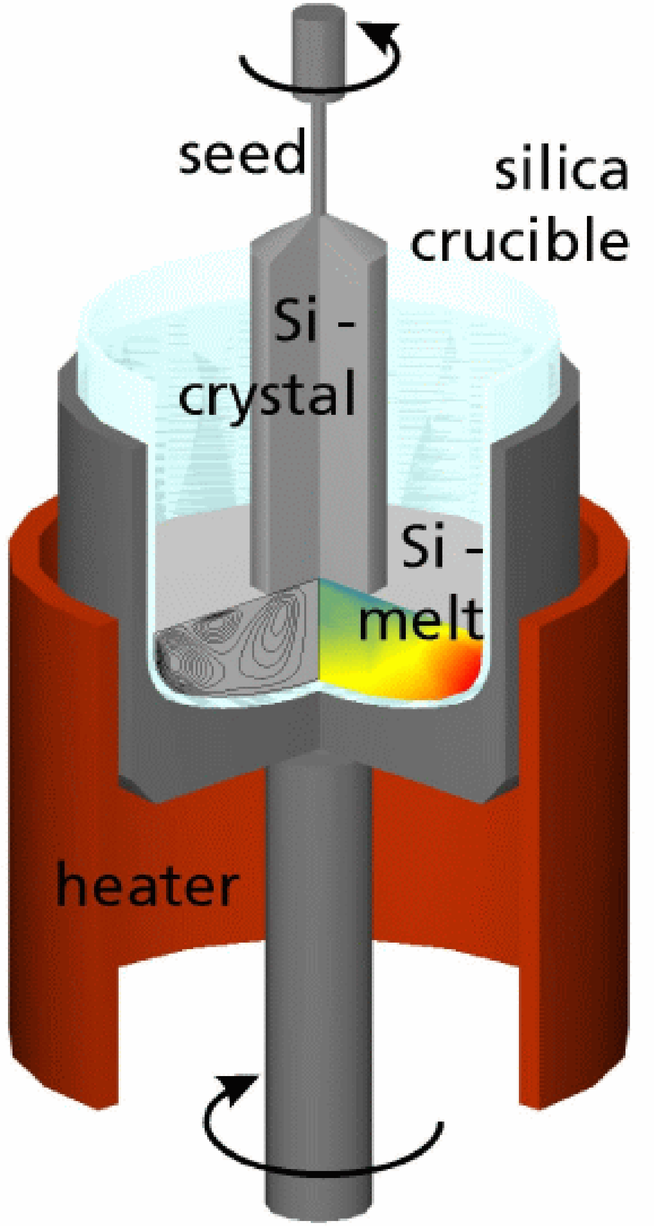
Many secret recipes

Nowadays 4" for HPGe and 6" for other applications

czochraliski cricible pulling



Ge-production (ii)
Czochralski crucible pulling…



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Ge-production (iii)

Only 3 producers (?)

Umicore – Olen, Belgium (mainly n-type)

Tennelec (Canberra) – USA

Ortec - USA

Complex production, few producers => high price

=> Can be worth while to recuperate old (big) crystals

Li-drifting

Early Ge-crystals (Ge(Li) or "jelly") were Li-drifted since not enough purity of crystals could be obtained

Li-atoms are small (=> interstitial), act as n-type (donor) impurity. Ge normally is p-type => cancellation.

Li-drifting was used long for big crystals. Not used anymore as it requires constant cooling of crystal!

- **Contacts made by electrodeposited gold (see example) or using indium-alloys**

Still needed for silicon photon detectors Si(Li) detectors ("silly")

Slower diffusion of Li in Si compared to Ge

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Li-contacts in HPGe

The n+ contacts are made by diffusing Li into the Ge for a short time

(by heating and applying a voltage)

In germanium at room temperature Li diffuses about 0.1 mm in 1 year.

*=> **A detector that was kept at room temperature for long has thicker deadlayers***

Ge-production (iii)
Crystal treatment

(i) Mechanical "shaping"

(ii) Grinding

(iii) Contact structures (etching, diffusion, implantation)

Bulletization

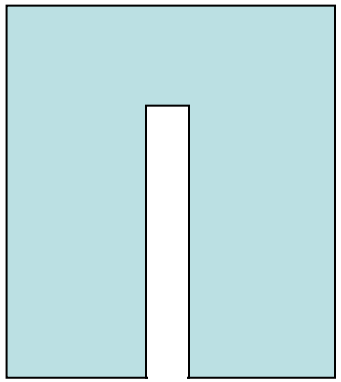
Weak electric field in corners => long rise time => not completely collected within reasonable integration time => rounding of edges =bulletization

Important to include in computer model!!!

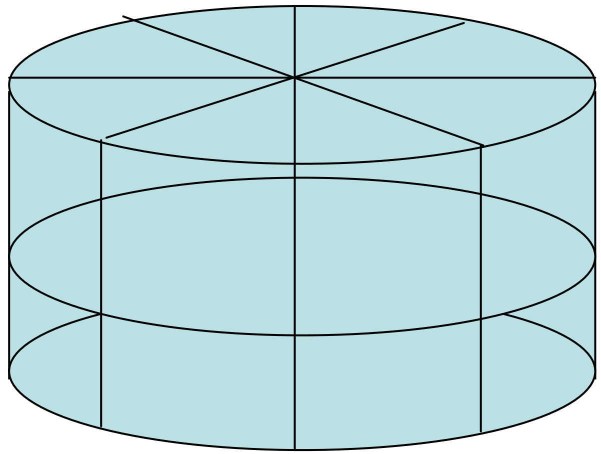
New crystals with sharp edges may have poor charge collection in corners => difficult with Monte Carlo simulations

Different crystal configurations

Coaxial

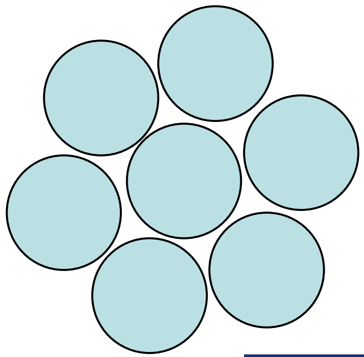


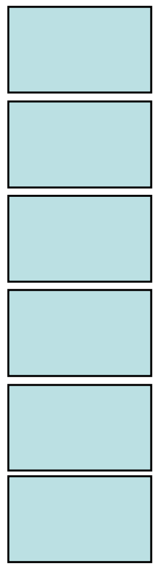
Multi-segmented



Planar

Array detector





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Literature

Product catalogues of manufacturers

- **Ortec**
- **Canberra**
- **(Eurisys)**
- **DSG**
- **(PGT)**
- **(Tennelec)**
- **(Oxford Instr.)**

K. Debertin and R.G. Helmer, "Gamma- and X-ray spectrometry with semiconductor detectors", North-Holland (Elsevier), 1988

G. Gilmore and J. Hemingway, "Practical gamma-ray spectrometry", Wiley, 1995

M.F. Annunziata Ed., Handbook of Radioactivity Analysis, Academic Press, 2003

R. Jenkins, R.W. Gould and D. Gedcke, Quantitative X-ray Spectrometry Dekker Inc., 1995

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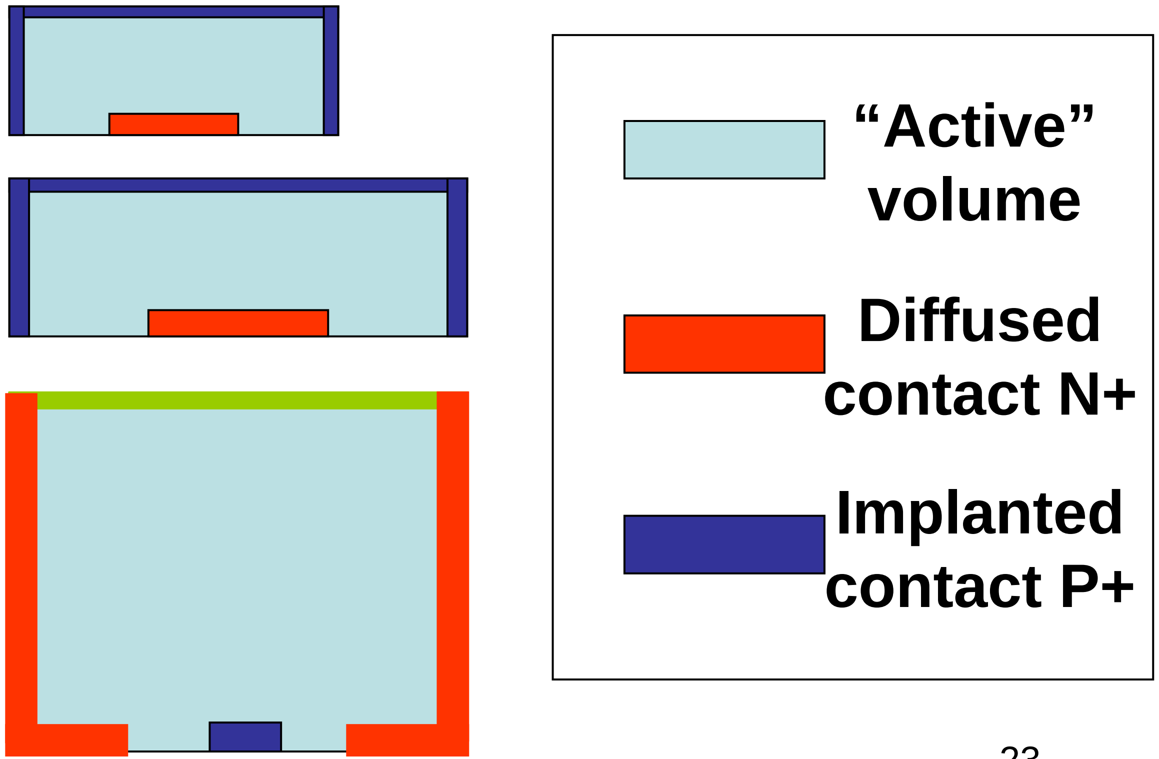
Planar detector (Canberra notation – similar detector available from others)

Ultra LEGe
n-type

LEGe – Low Energy Ge
n-type

BEGe – Broad Energy Ge
p-type (special process)



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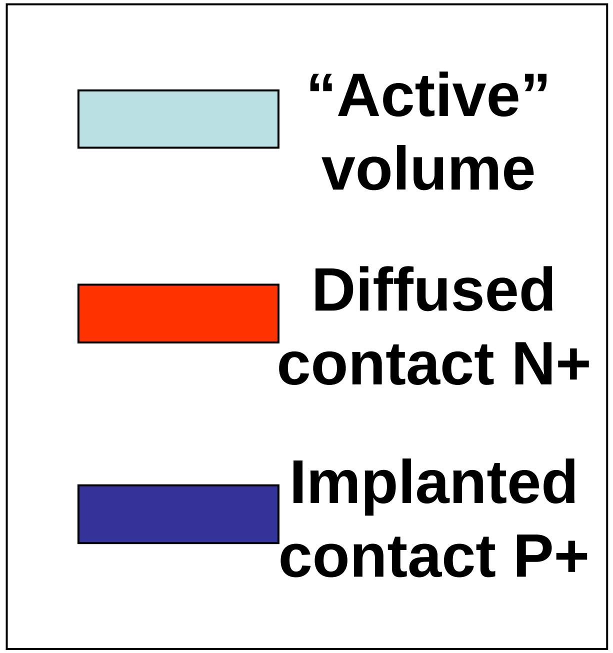
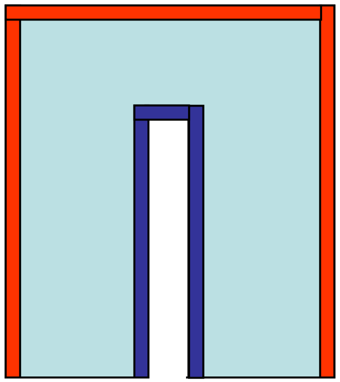
Coaxial detector

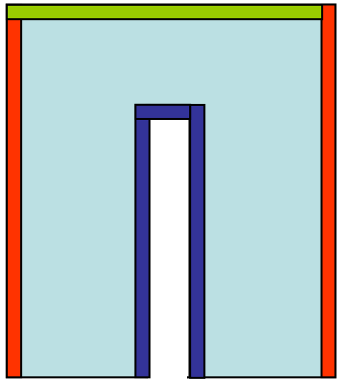
(Canberra notation – similar detector available from others)



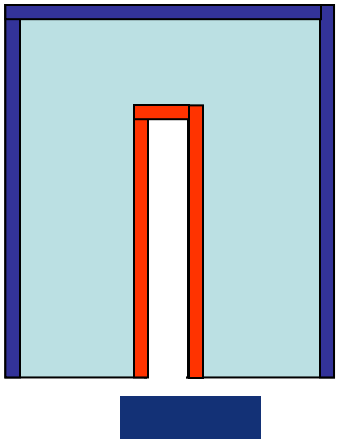
Coaxial
(P-type):



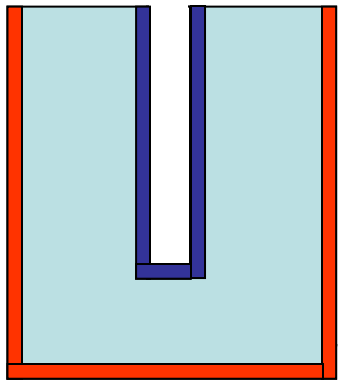
XtRa
(Extended range)
(p-type):



REGe
Reversed Electrode Ge
(n-type):

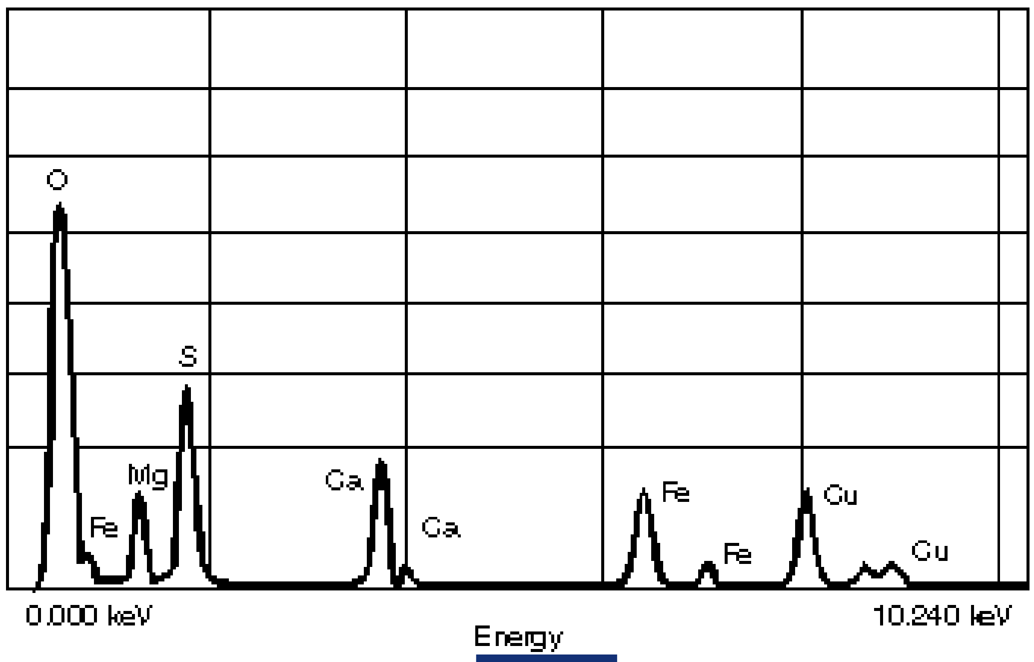


Well-detector:



Which detector shall I buy?

- Ultra LEGe (Low Energy Germanium)
  - To measure the lowest energies with best FWHM and Peak/Background ratio.
  - At synchrotron: in X-ray arrays.



Which detector shall I buy?

- LEGe (Low Energy Germanium) EG&G Ortec: LO-AX
  - Best resolution on the market from 3keV to 300 keV. Safeguards applications.
    - Pu => EURATOM and IAEA interest
- BEGe (Broad Energy Germanium)
  - Large surface, thin window, standardised dimensions.
  - Best resolution vs. efficiency for “real” samples in energy range 5 keV to 1.5 MeV.
  - Whole body counters, low level qualitative and quantitative waste assay, environmental sample counting, ….

Which detector shall I buy?

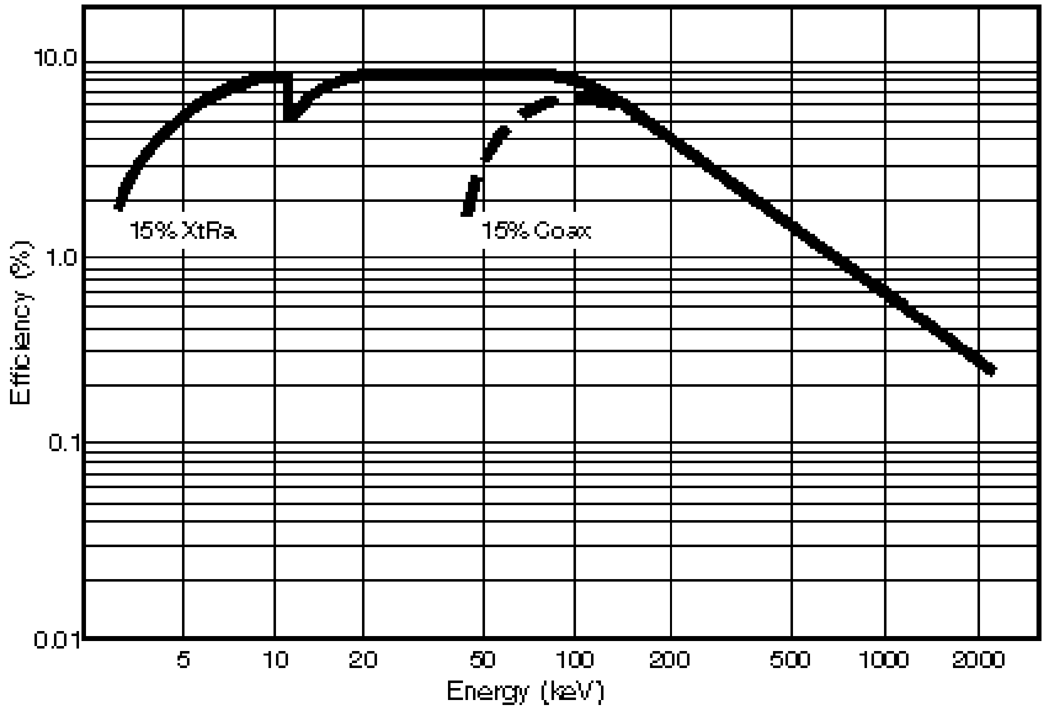
- P-type coaxial detector (SEGe)

  Most common type on the market. => lower price??

- N-type coaxial detector (REGe)
  - Up to 50%.
  - (Nearly) always worse resolution than p-type or XtRa and more expensive.
  - Low sales volume.
  - Only sold for :
    - Applications with fast neutrons.
    - (sometimes) “low” energy Marinelli applications.

Which detector shall I buy?

- XtRa (Extended Range)
  - P-type Coaxial detector with thin (front) window
  - High resolution and good peak shape (better than n-type coax., and cheaper)
  - Rel. Eff. Up to 100% (...and higher)
  - Good as "all purpose"



- Germanium Well Detector
  - Highest (geometrical) efficiency possible for a small sample
  - From 10% rel. eff. (70 cm^3 active vol.) to 100% rel. eff. (450 cm^3) and bigger…
  - Good resolution at high energies (>1 MeV
  - Poor resolution at low energies
  - Important for:
    - Probably the best application for very large HPGe crystals.

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Summary

Unless you have a special purpose in mind a "normal" coaxial with thick deadlayer is recommended

- Thick DL => less problems with Low-E summing
- Can use "thick" window => more robust
- Go for large area (8 cm diameter), but not necessarily so thick

- But BEGe:s are now 50% of the sales.

Windows

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Al (Kryal) – good, but expensive

Al – not radiopure (Th)

Ti – lower Z than Cu not good above ground

Cu – high absorption (not so good above ground)

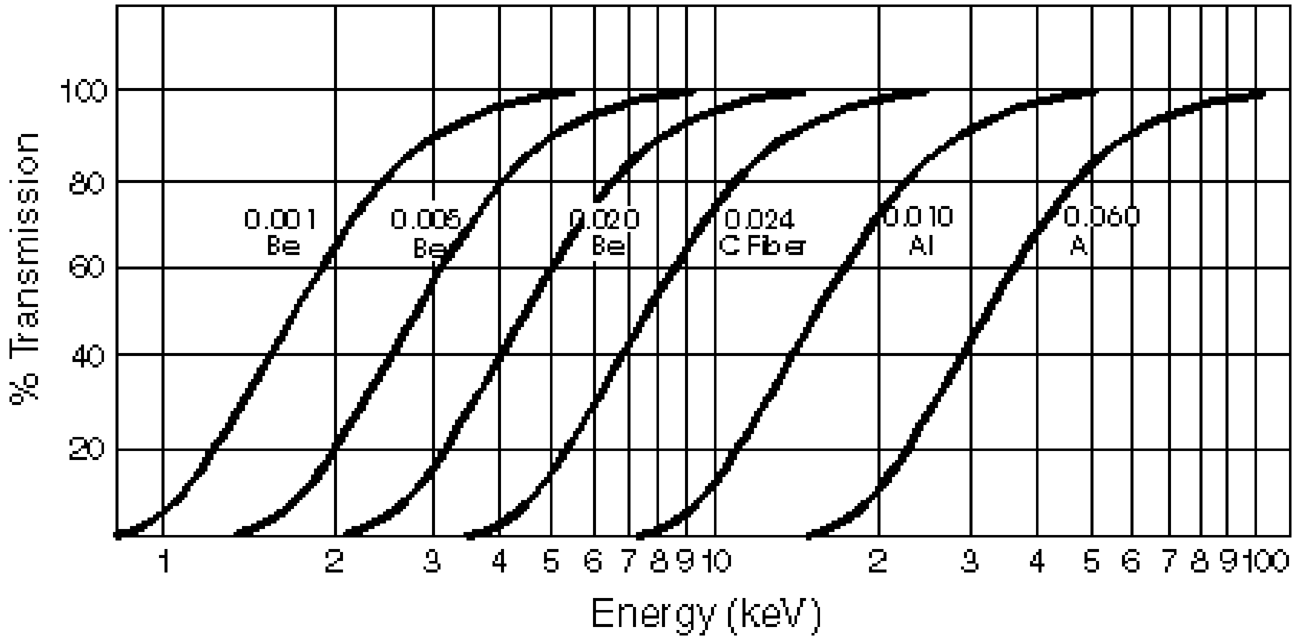
Be –Low absorption, not radiopure

Carbon epoxy – Low absorption, not radiopure

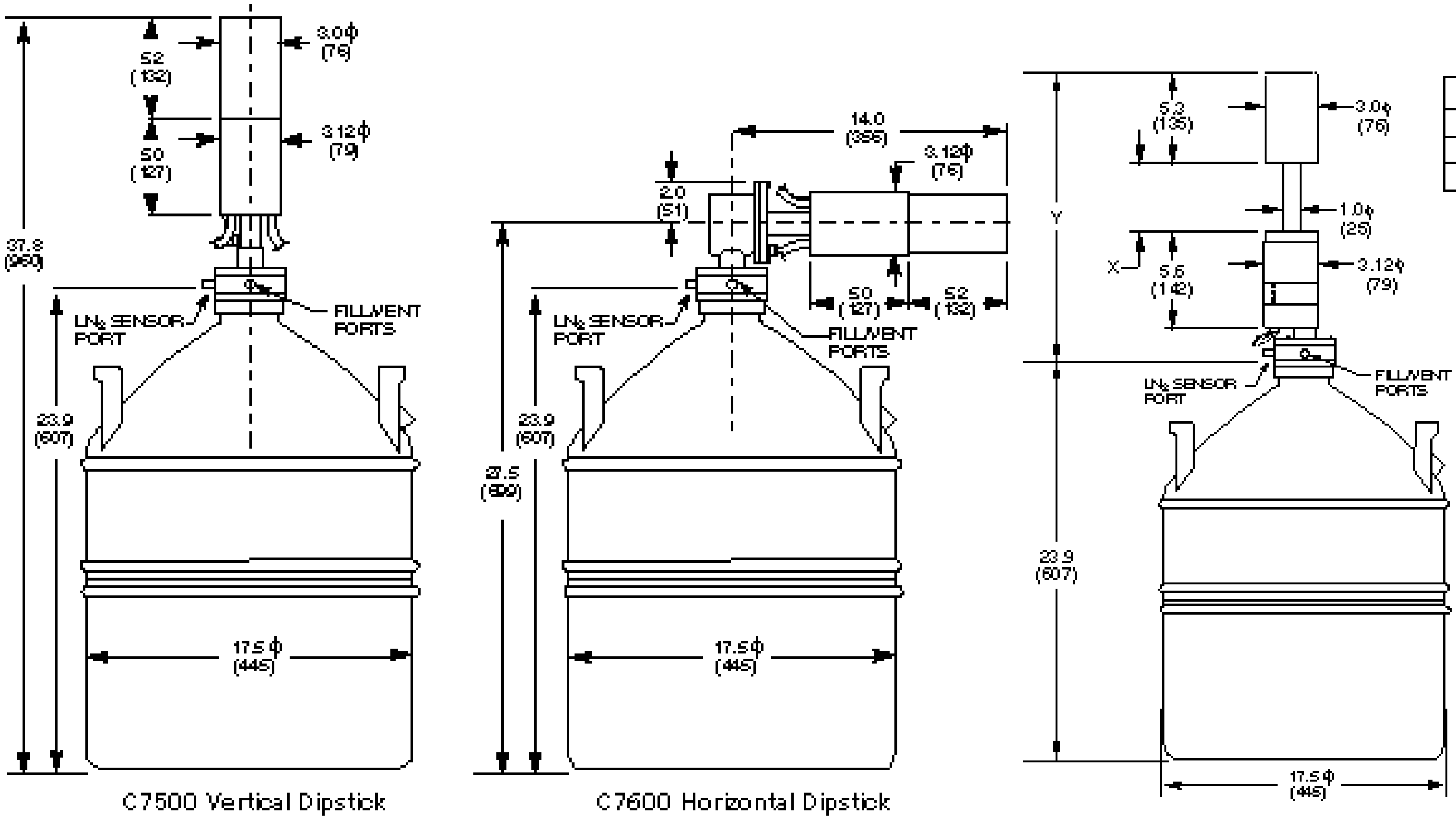
Si – practical problems (light, IR)

Polymers – Low strength, not light-tight

Mg -



Cryostats / Dewar configuration



X	Y
2.0 (51)	14.9 (378)
4.0 (102)	16.9 (429)
6.0 (152)	18.9 (480)

Cryostats / Dewar configuration – Electrical cooling – much development in recent years

“Old” problems that can almost be neglected now

- Moving parts:

Risk for mechanical wear,
More service required,
Reduced life time.
More risk for microphony

- **Reduced cooling power compared to LN_2:**

More demanding for vacuum.
Often start-up problems.
(Not possible with Low background)

Keep your eyes open for new developments

Electrical cooling

Example: Canberra (Ortec also very good and availble from other suppliers as well)

1. **Cryo-Pulse: Electrically Refrigerated Cryostat (Stirling cooler)**
2. **Cryo-Cycle Cryostat: Re-cycling of boil off nitrogen (using Stirling technique) => cooling also during power-loss.**
3. **... ing)**

Major developments in recent years have led to increased use of electrical cooling

Drawbacks:

- **Needs electricity (sometimes a lot)**
- **N_2 for Rn-removal has to be added**
- **(Vibrations)**
- **Cost**
- **(Higher crystal temperature)**

Operation of HPGe

No electrical contact between detector and shield.
(not generally the case as we have examples were the detector work equally well with electrical connection)

Certain detectors can be sensitive to pressure to the detctor arm or window or endcap.

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Low background

Low level Gamma-ray Spectrometry (LGS) = Gamma-ray spectrometry using a detector and shield built from selected radiopure materials and a shield of

Ultra Low level Gamma-ray Spectrometry (ULGS) = LGS with additional measures such as placement in an underground laboratory or use of a muon shield.

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Low background

Advice:

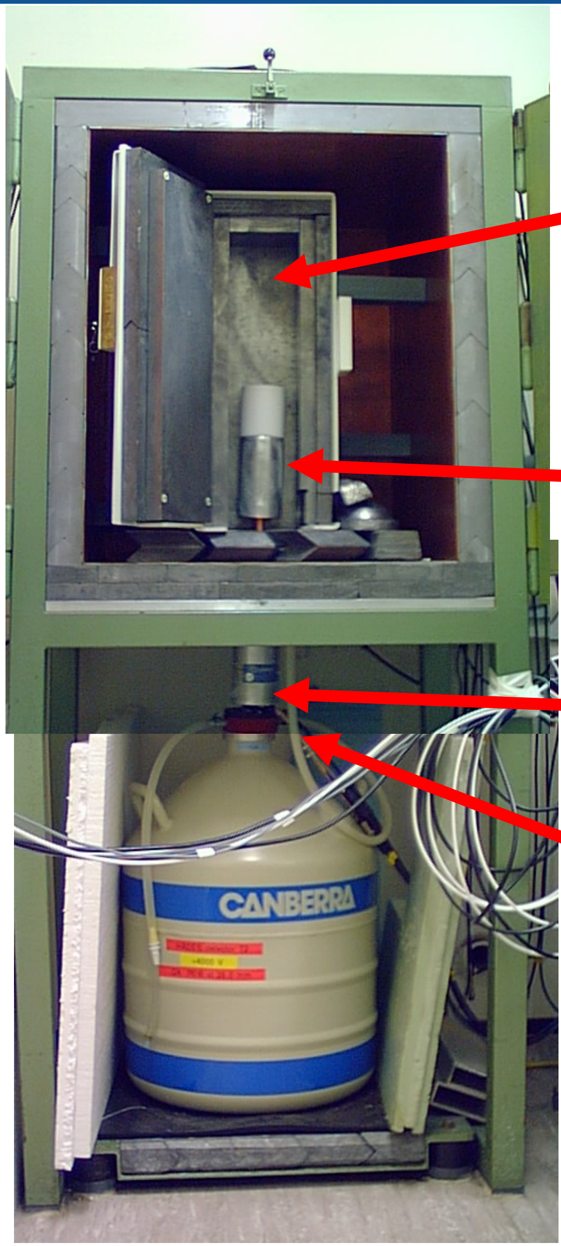
A) Don’t buy a Low background detector unless you really need to!

(i) more fragile (ii) more expensive

B) Don’t place a detector for underground use, above ground

activation of crucial parts

Low Background Detector



Inner 2.5 cm from ULB lead (2 Bq/kg)

Endcap, cryostat and front-end-electronics from selected radiopure materials

Pre-amp outside lead shield

Tube for nitrogen “flushing”

….Other future improvements of "standard" detectors

- Electrical cooling
- Bigger crystals
- Better charge collection
- Better definition of geometry
- Pre-calibrated detectors
- …….