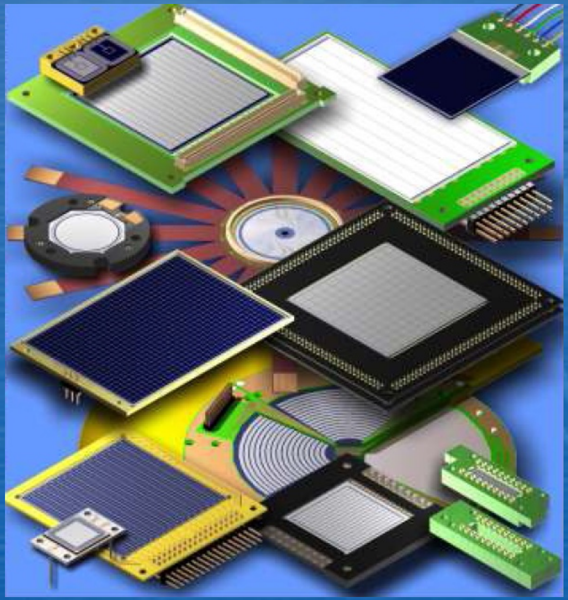
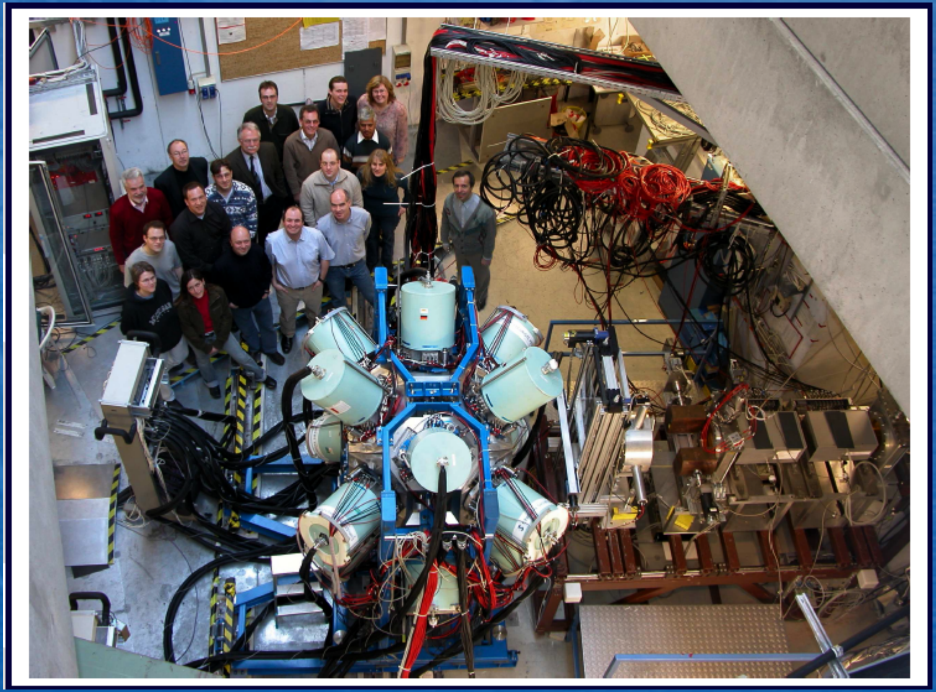
Semiconductor Detectors

Takashi Kishida



Silicon Detector



RISING in Germany → RIKEN RIBF
Germanium Detector (EURICA)

Using Semiconductor Detectors at RIBF (2011,Feb.)

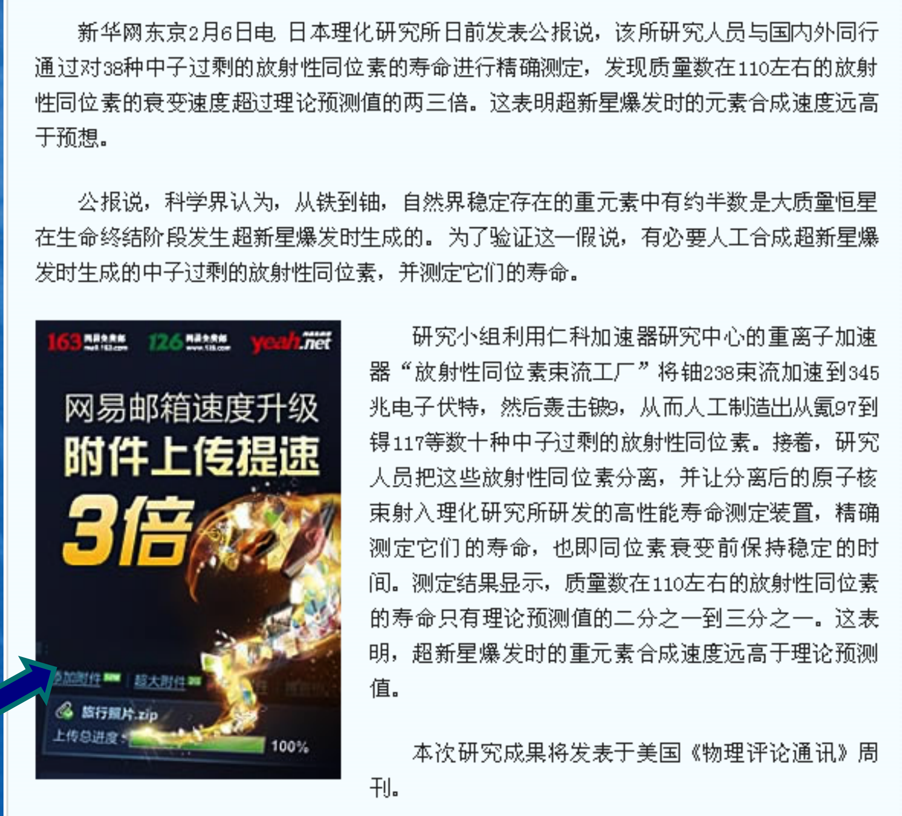
日本研究称超新星爆发时元素合成速度比预测快

2011-02-07 09:10:15 来源：新华网(广州) 跟贴 22 条 手机看新闻

核心提示：日本对38种中子过剩的放射性同位素的寿命进行精确测定，发现质量数在110左右的放射性同位素的衰变速度超过理论预测值的两三倍。这表明超新星爆发时的元素合成速度远高于预想。

新华网东京2月6日电 日本理化研究所日前发表公报说，该所研究人员与国内外同行通过对38种中子过剩的放射性同位素的寿命进行精确测定，发现质量数在110左右的放射性同位素的衰变速度超过理论预测值的两三倍。这表明超新星爆发时的元素合成速度远高于预想。

公报说，科学界认为，从铁到铀，自然界稳定存在的重元素中有约半数是大质量恒星在生命终结阶段发生超新星爆发时生成的。为了验证这一假说，有必要人工合成超新星爆发时生成的中子过剩的放射性同位素，并测定它们的寿命。



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研究小组利用仁科加速器研究中心的重离子加速器“放射性同位素束流工厂”将铀238束流加速到345兆电子伏特，然后轰击铍9，从而人工制造出从氪97到锝117等数十种中子过剩的放射性同位素。接着，研究人员把这些放射性同位素分离，并让分离后的原子核束射入理化研究所研发的高性能寿命测定装置，精确测定它们的寿命，也即同位素衰变前保持稳定的时间。测定结果显示，质量数在110左右的放射性同位素的寿命只有理论预测值的二分之一到三分之一。这表明，超新星爆发时的重元素合成速度远高于理论预测值。

本次研究成果将发表于美国《物理评论通讯》周刊。

More results coming at RIBF

Outline of this Lecture

- Introduction
  - Detectors General Requirements
  - Why use semiconductor detectors?

- Basic Principles
  - P-type, N-type
  - Depletion zone
  - Type of detectors

- Performance
  - Energy Measurement
  - Position Measurement

- Electronics

- Operation : How to use?

Requirements for detectors

- **Energy measurement**
  - Energy loss (dE)
  - Total energy (E)
  - Pulse shape
- **Position measurement**
  - (X, Y, Z) → Tracking
  - Bρ → Momentum (p)

- **Timing measurement**
  - Timing (velocity β)
  - High counting rate (dN/dt)
- **Count measurement**
  - Sensitivity to particle (ε)
  - Insensitive to background (S/N)
  - Radiation hardness

There are many types of detectors.

- Scintillation detector (Tamagawa-san)
- Gas detector
- ⇨ Semiconductor detector

→ Is there a perfect detector ?!

What is the advantage of semiconductor detector?

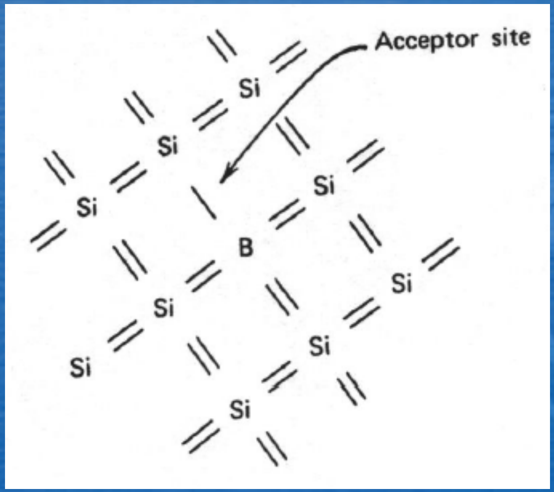
Characteristics of Semiconductor

- Low ionization energy
  - good signal
- Long mean free path
  - good charge collection efficiency
- High mobility
  - fast charge collection
- Si ... Lower Z = 14
  - low multiple scattering
  - Little cooling
- Ge .. Higher Z = 32
  - higher stopping power
  - Cooling is required.

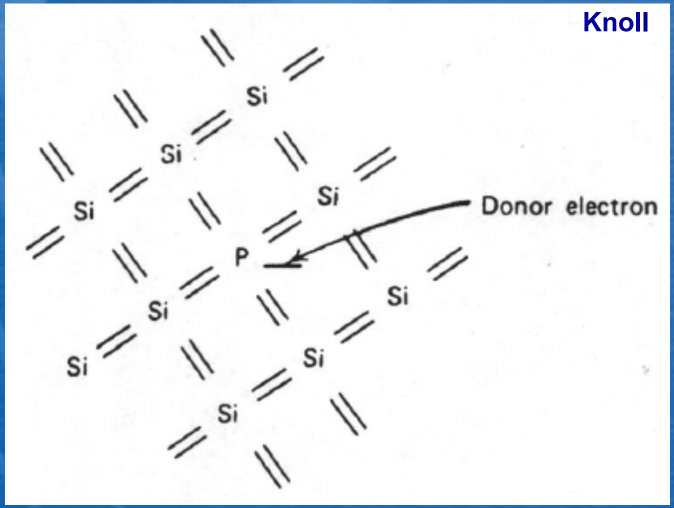
Detector	Ionization energy I (eV)	Energy resolution @ 5MeV $2.35/\sqrt{(5x10^{6}/I)}$
Scintillation	100 ~ 500	1.1 ~ 2.4 %
Gas	30	0.6 %
Semiconductor	3	0.2%

Basic Principles
[To dope the silicon with impurities]

Boron doping (p-type)
holes are majority carriers

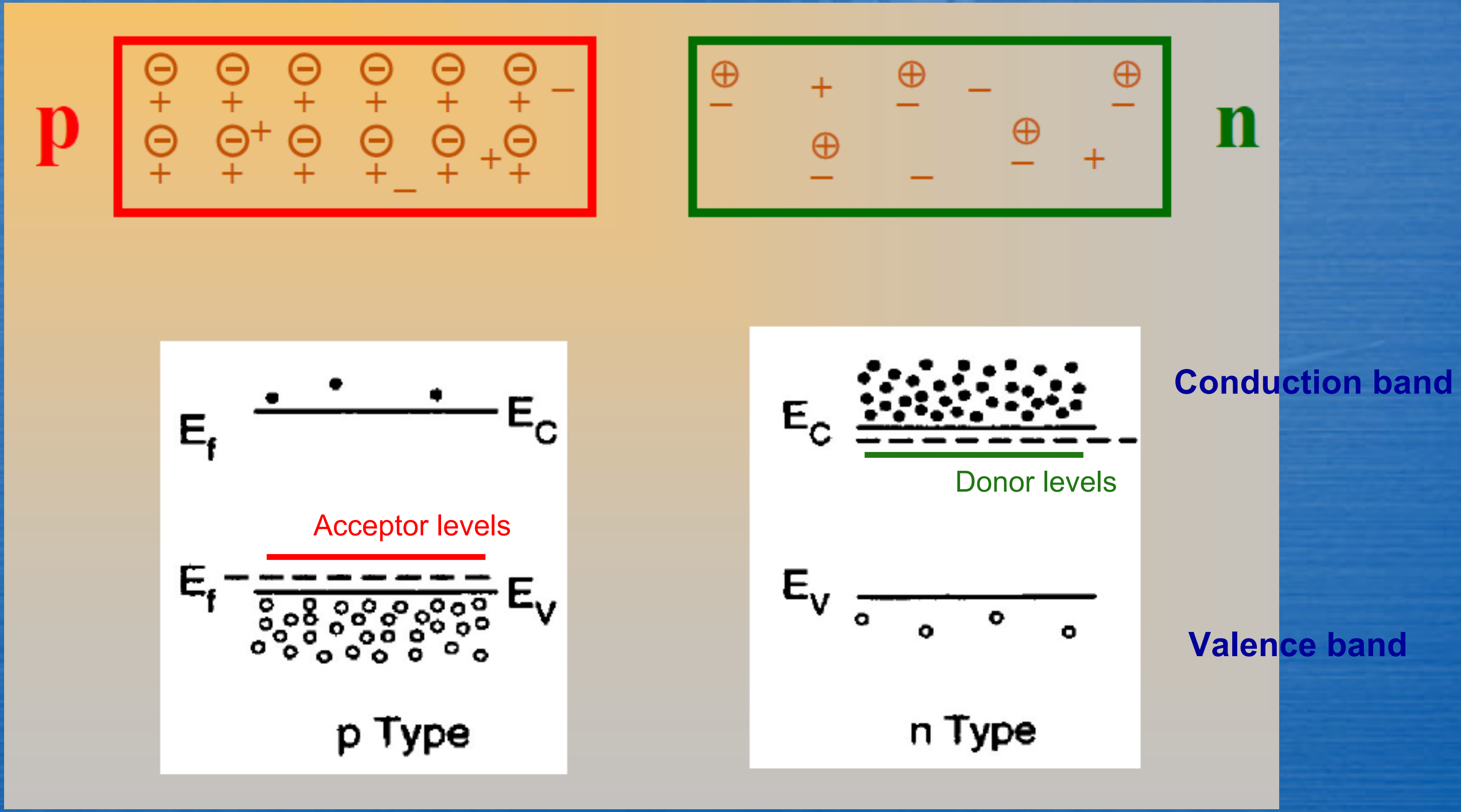


Phosphorus doping (n-type)
electrons are majority carriers

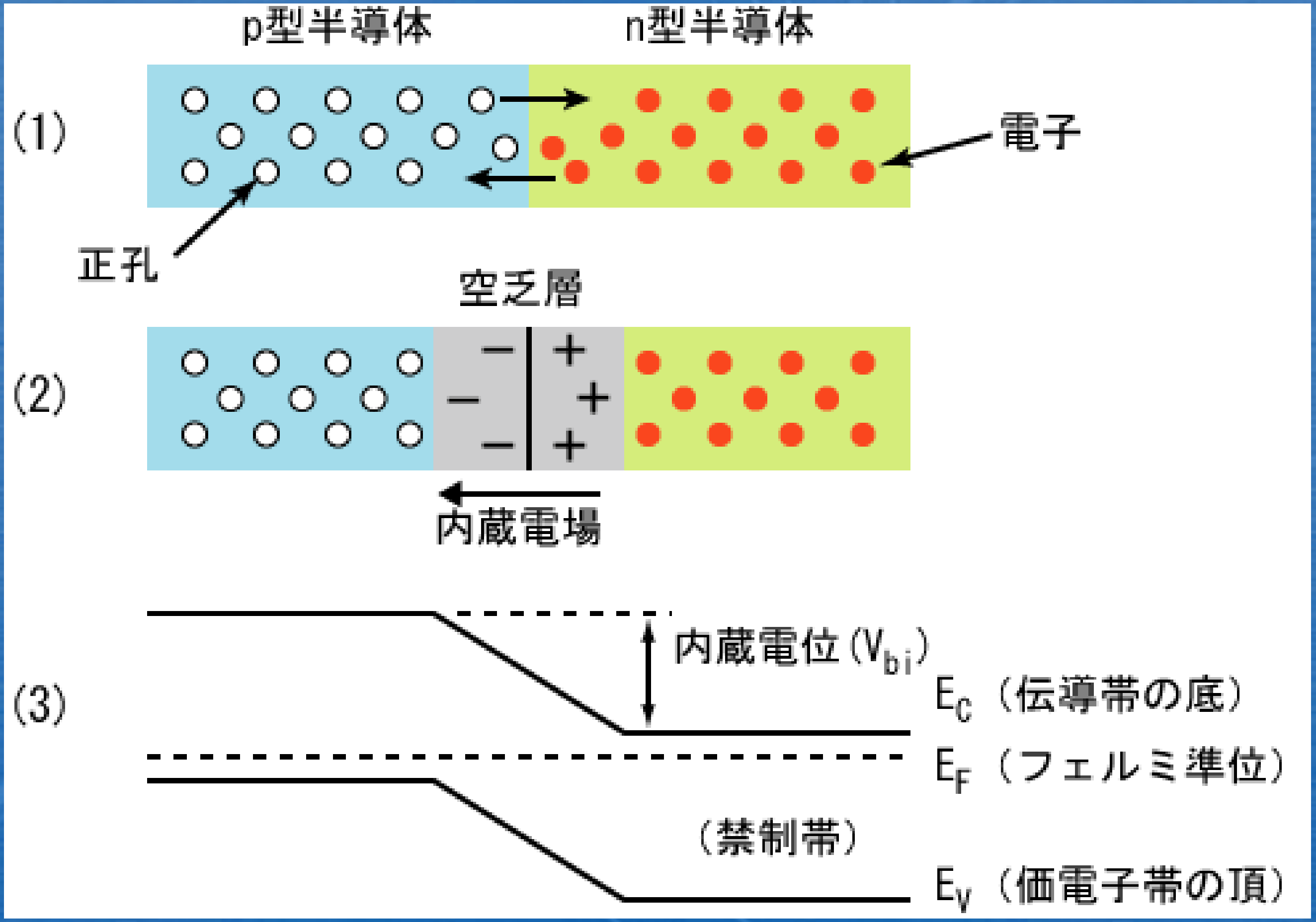


Knoll

Basic Principles

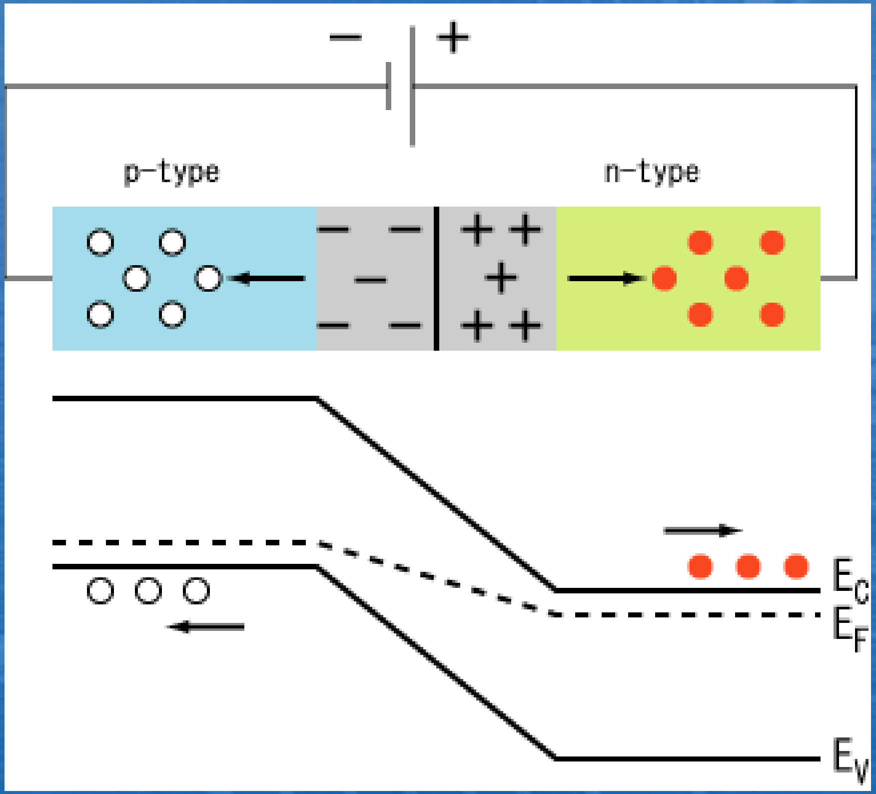


Basic Principles



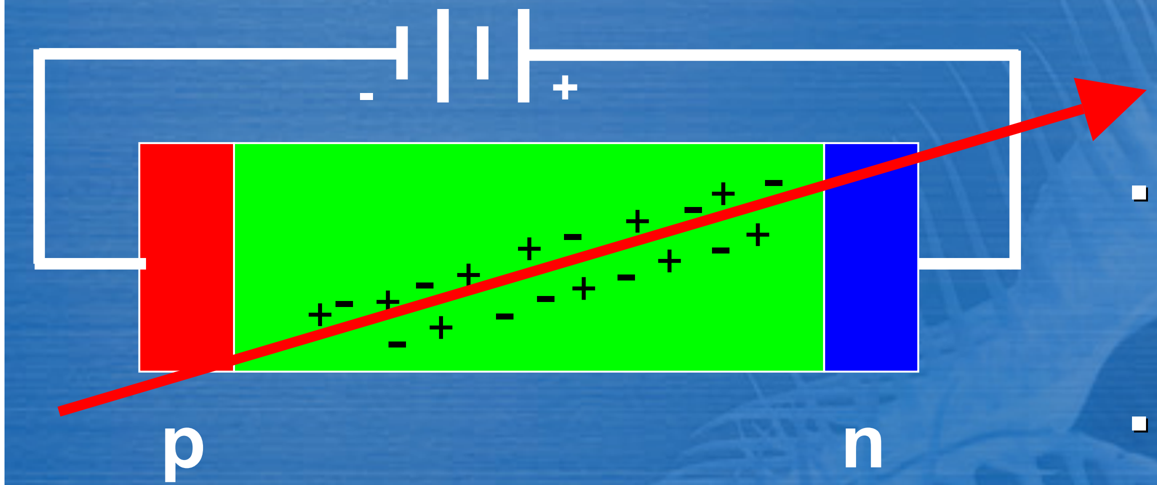
Depletion Zone

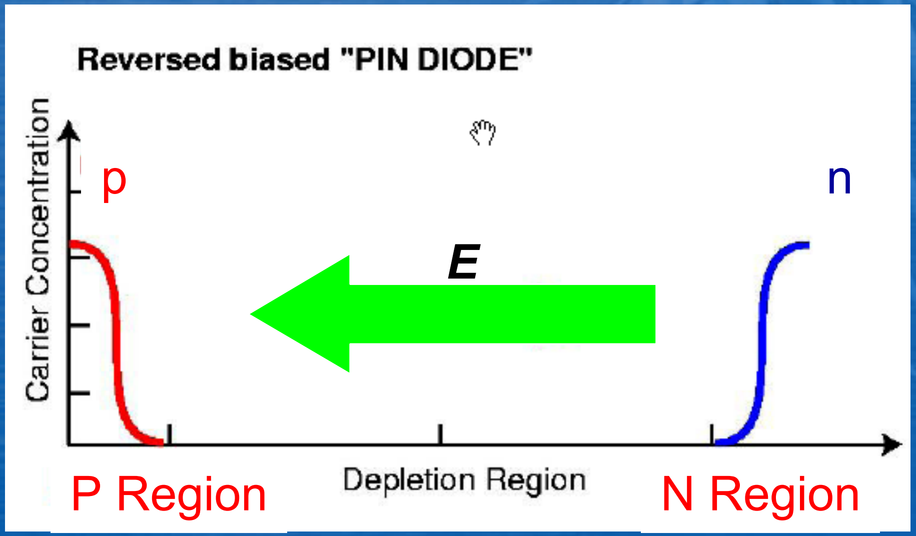
Basic Principles



Depletion Zone becomes larger

Basic Principles

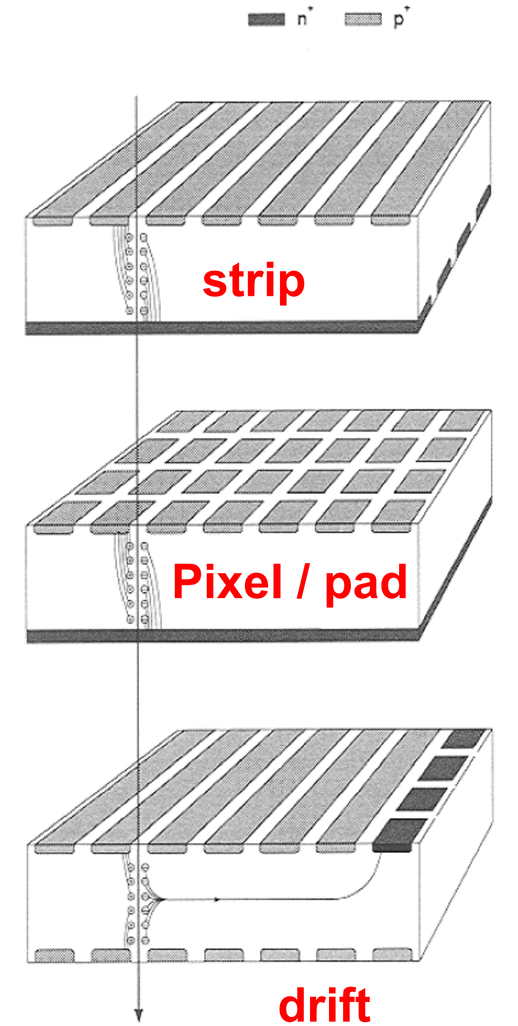




- Use ionization signal left behind by charged particle passage.
- Ionization produces electron(e)-hole(h) pairs, use electric field to drift the e and h to the oppositely charged electrodes.
- Si needs 3.6 eV to produce one e-h pair.
- Ge needs 2.98 eV to produce one e-h pair.

Types of Silicon detectors

- Strip devices
  - High precision
  - Large active area
  - Single-sided or Double-sided
- Pixel devices
  - True 2-D measurement
  - Small areas, but high track density
- Drift devices



Types of Ge-detectors

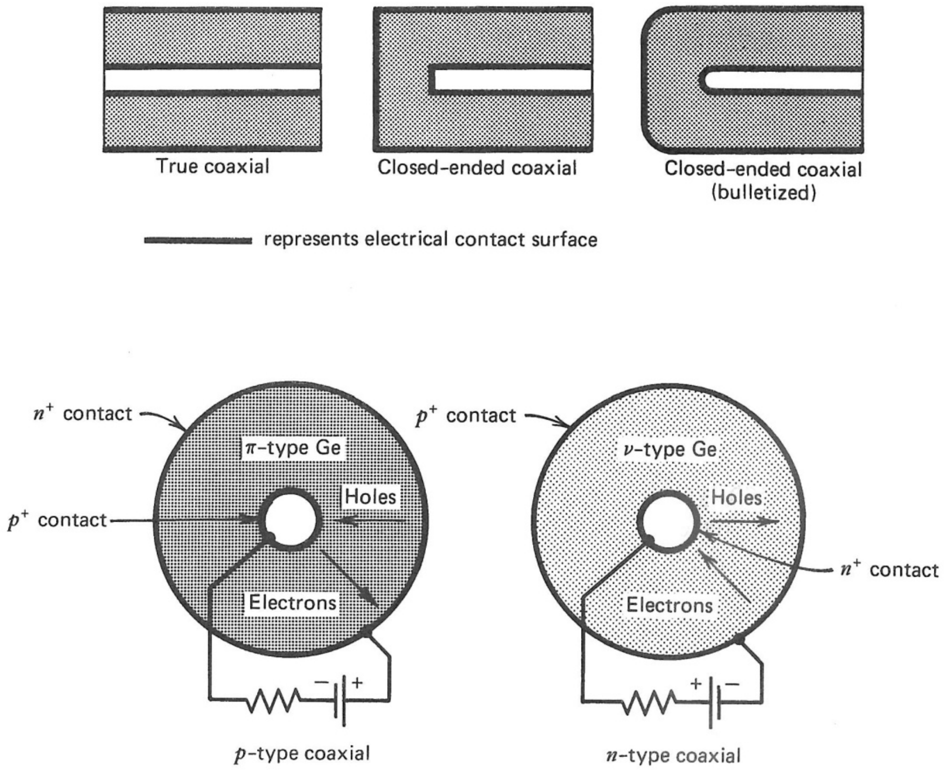
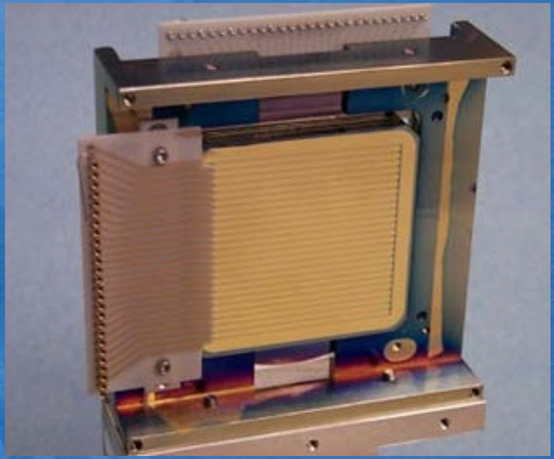


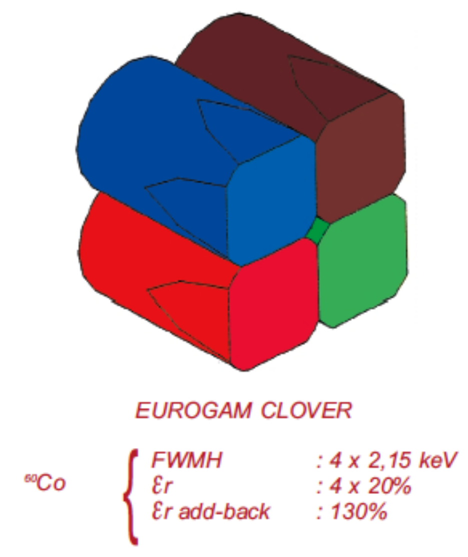
Figure 12.3 At the top are shown the three common shapes of large-volume coaxial detectors. Each represents a cross-sectional view through the axis of a cylindrical crystal. The outer electrode is extended over the flat front (left) surface in both closed-ended cases. Cross sections perpendicular to the cylindrical axis of the crystal are shown at the bottom. The HPGe material may be either high-purity p or n type. The corresponding electrode configurations are shown for each type.



Strip Ge detector

Clover Detector

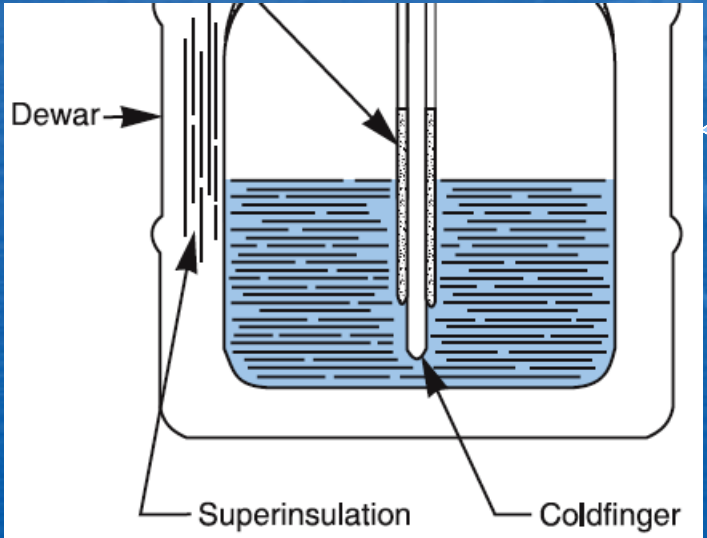
4 crystals



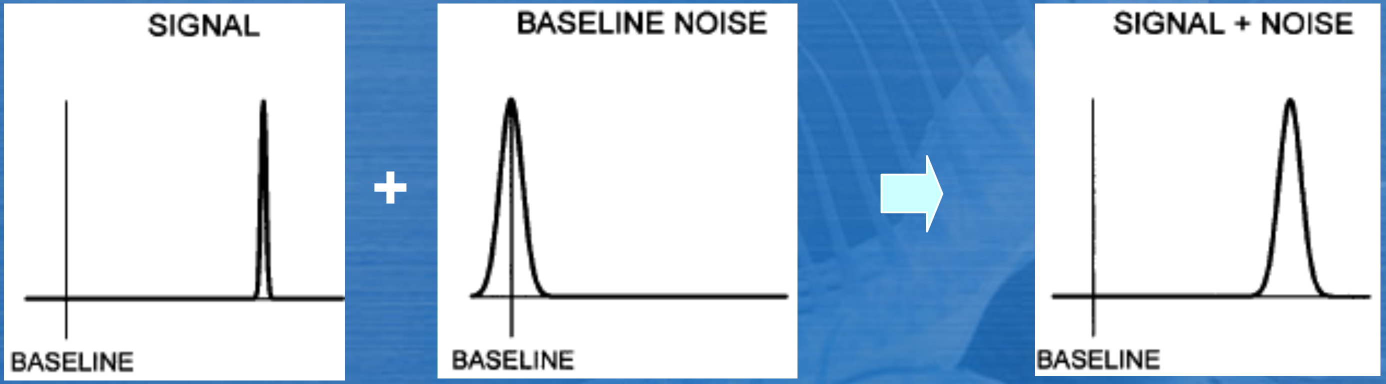
EUROGAM CLOVER

^{60}Co
- FWMH : 4 x 2,15 keV
- ε_r : 4 x 20%
- ε_r add-back : 130%

Liquid Nitrogen for cooling



Energy Resolution



If Signal Variance << Baseline Variance
→ Electronics (baseline) noise
critical for resolution

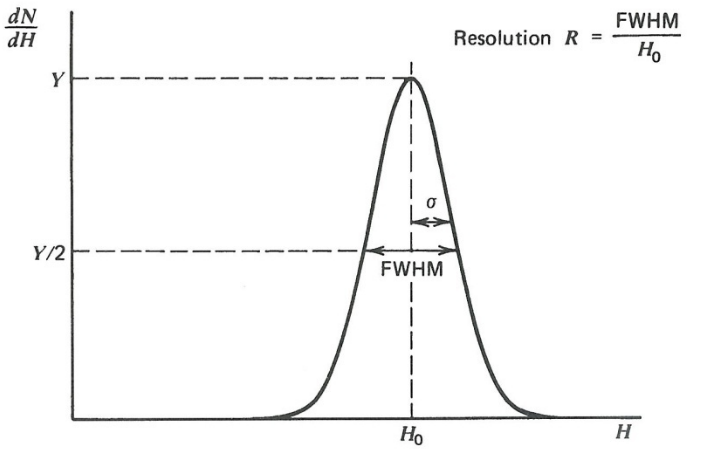


Figure 4.5 Definition of detector resolution. For peaks whose shape is Gaussian with standard deviation σ, the FWHM is given by 2.35σ.

Energy Resolution : NaI(Tl) vs Ge

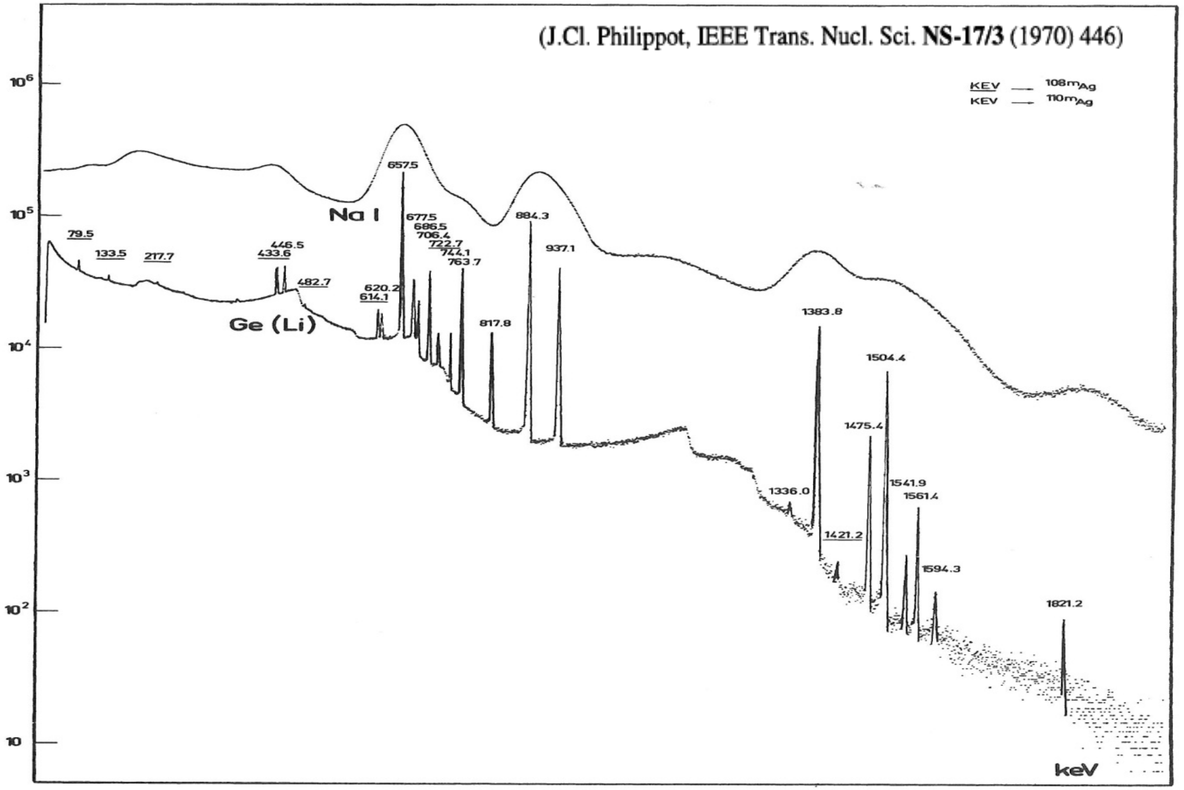


Figure 12.7 Comparative pulse height spectra recorded using a sodium iodide scintillator and a Ge(Li) detector. The source was gamma radiation from the decay of ^{108m}Ag and ^{110m}Ag. Energies of peaks are labeled in keV. (From Philippot.[13])

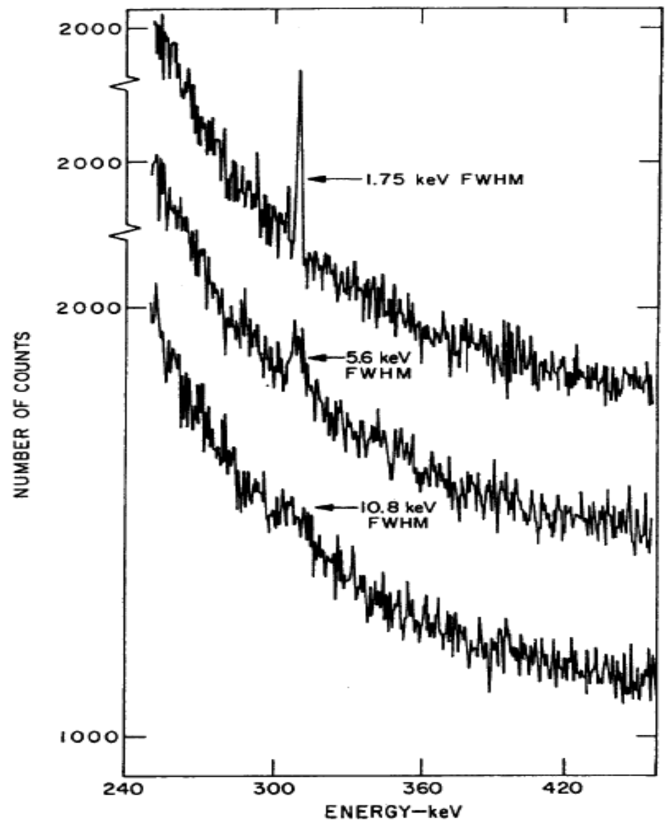
Semiconductor detector

➔ Excellent detector for energy measurement !!

Energy Resolution

[Signal to Background Ratio (S/N)]

Signal to background ratio improves with better resolution
(signal counts in fewer bins compete with fewer
background counts)



G.A. Armantrout, *et al.*, IEEE Trans. Nucl. Sci. **NS-19/1** (1972) 107

→ Good Energy Resolution
→ Higher Statistics

We can extract
- **precise peak position,**
- **and find NEW Peaks!!**

Position Measurement

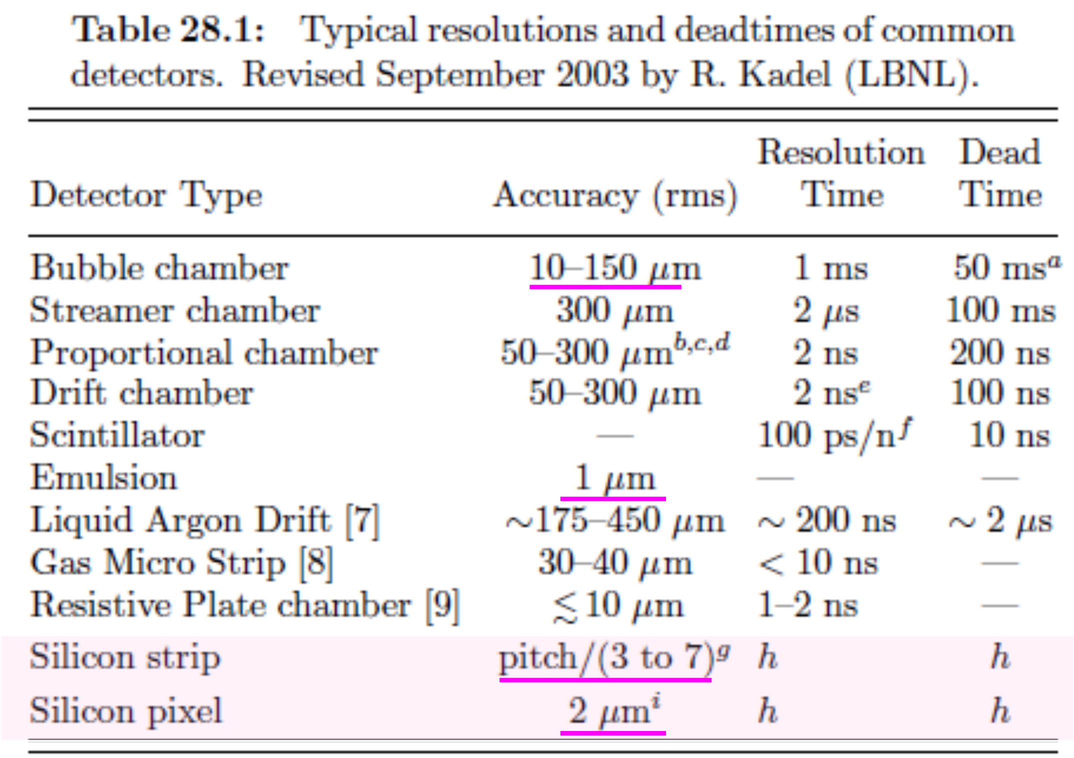
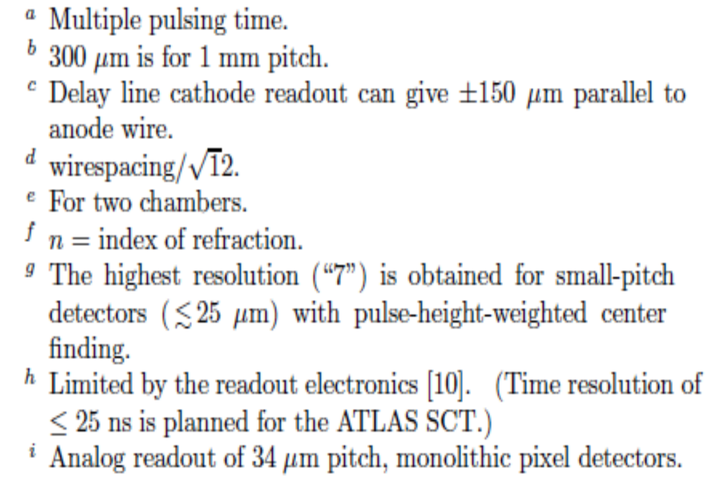


Table 28.1: Typical resolutions and deadtimes of common detectors. Revised September 2003 by R. Kadel (LBNL).

Detector Type	Accuracy (rms)	Resolution Time	Dead Time
Bubble chamber	10–150 μm	1 ms	50 ms[a]
Streamer chamber	300 μm	2 μs	100 ms
Proportional chamber	50–300 μm[b,c,d]	2 ns	200 ns
Drift chamber	50–300 μm	2 ns[e]	100 ns
Scintillator	—	100 ps/n[f]	10 ns
Emulsion	1 μm	—	—
Liquid Argon Drift [7]	$\sim$175–450 μm	$\sim$ 200 ns	$\sim$ 2 μs
Gas Micro Strip [8]	30–40 μm	$<$ 10 ns	—
Resistive Plate chamber [9]	$\lesssim$ 10 μm	1–2 ns	—
Silicon strip	pitch/(3 to 7)[g]	[h]	[h]
Silicon pixel	2 μm[i]	[h]	[h]



[a] Multiple pulsing time.

[b] 300 μm is for 1 mm pitch.

[c] Delay line cathode readout can give ±150 μm parallel to anode wire.

[d] wirespacing/$\sqrt{12}$.

[e] For two chambers.

[f] n = index of refraction.

[g] The highest resolution ("7") is obtained for small-pitch detectors ($\lesssim$ 25 μm) with pulse-height-weighted center finding.

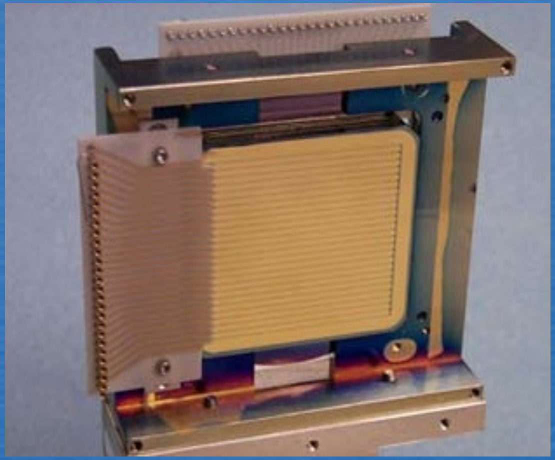
[h] Limited by the readout electronics [10]. (Time resolution of $\lesssim$ 25 ns is planned for the ATLAS SCT.)

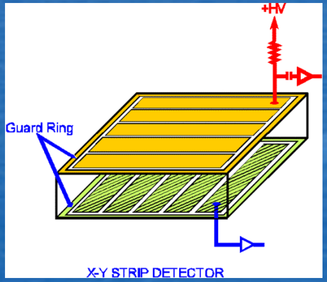
[i] Analog readout of 34 μm pitch, monolithic pixel detectors.

Silicon Detectors

- very good position resolution.
- works under high magnetic field.
- high rates and triggering.

Position Sensitive Ge detectors

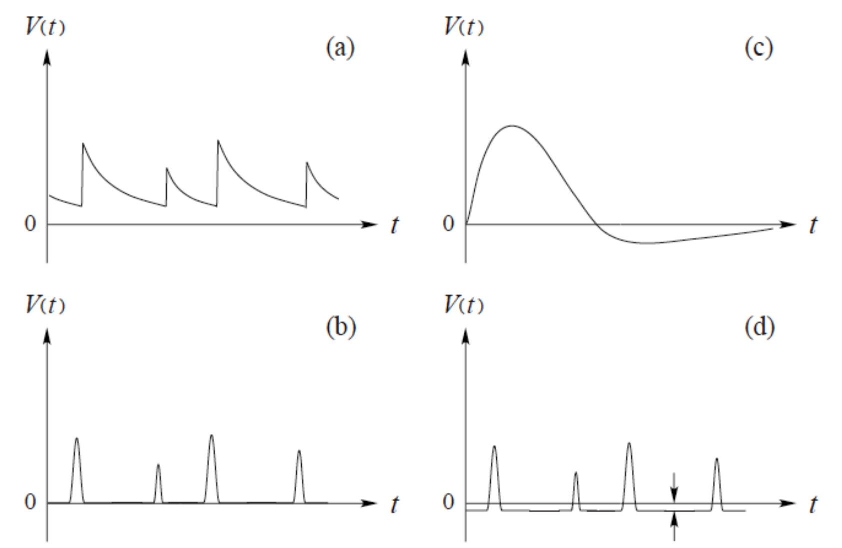




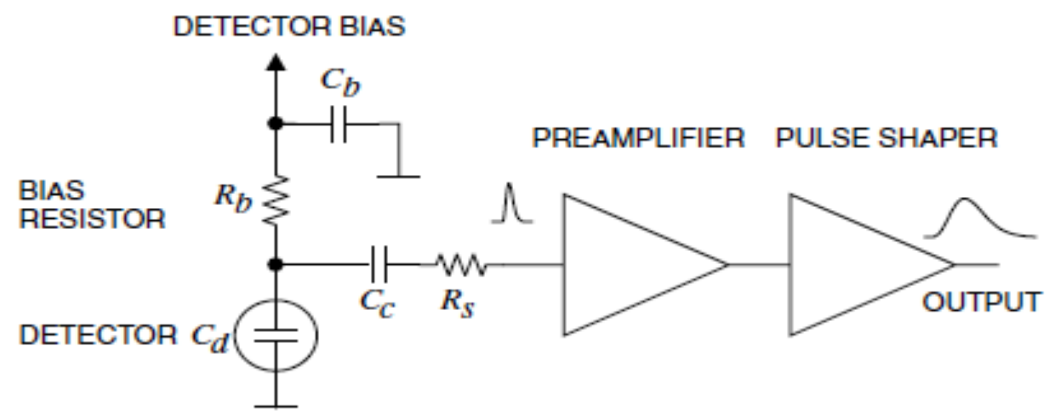
Ge detector array (GRAPE)
CNS, Univ. of Tokyo

Signals

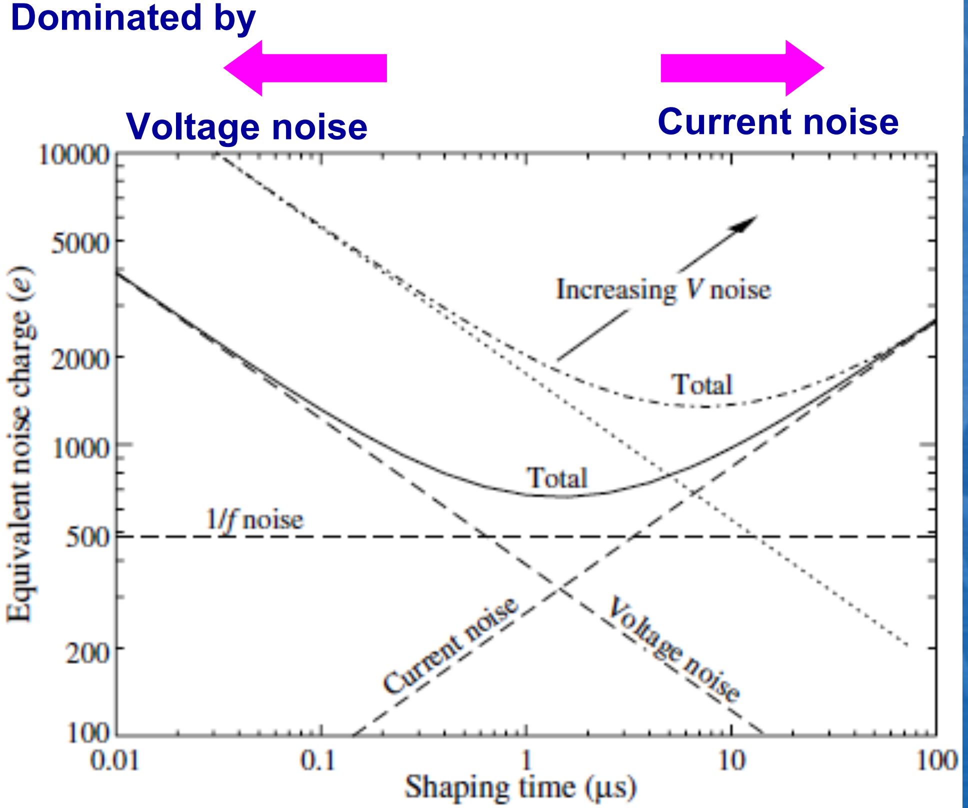
(a) Output of preamp
(b) Output of shaping amp
(c) Undershoot
(d) Base-line shift



The output of preamplifier : rapidly rising step, followed by a slow exponential decay.
Amplitude of the step = energy of the detected radiation
Exponential decay time = feedback resistor in parallel with the feedback capacitor.



Shaping Time



Dominated by

Voltage noise

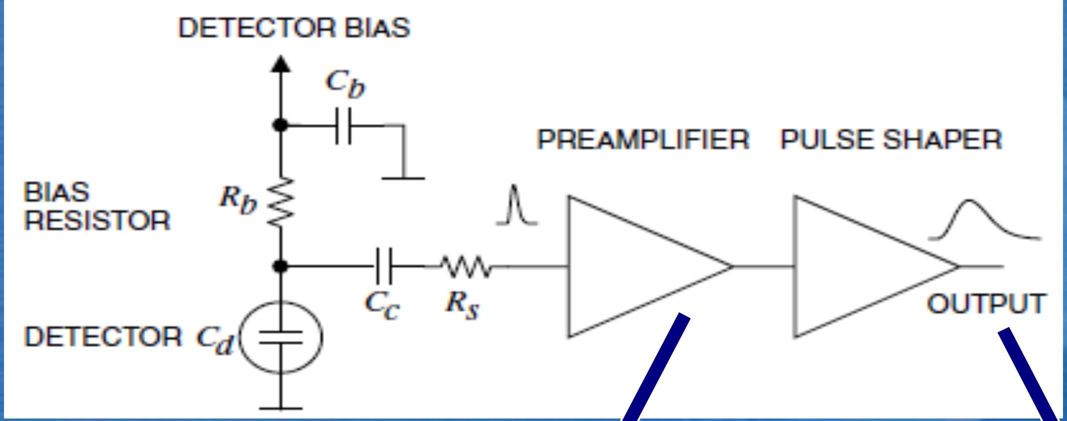
Current noise

Figure 28.20: Equivalent noise charge *vs* shaping time. Changing the voltage or current noise contribution shifts the noise minimum. Increased voltage noise is shown as an example.

PRL667

Optimization is required in shaping time, ~ 1 μs

Electronics : Pile-up



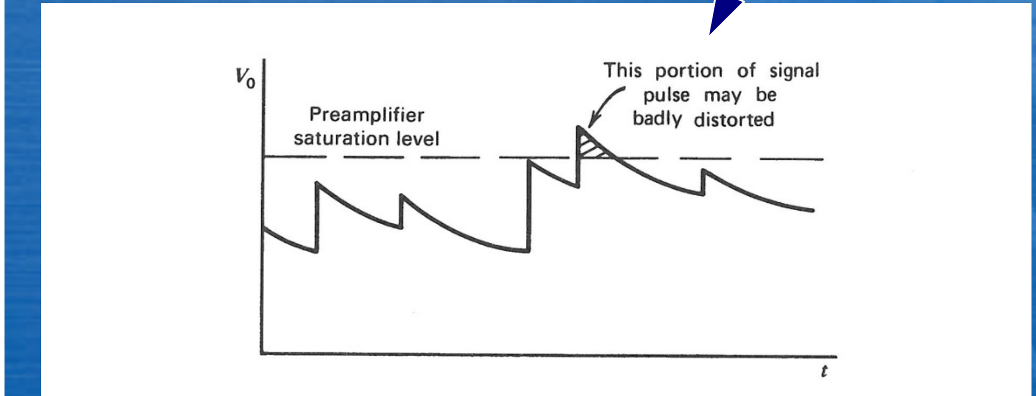
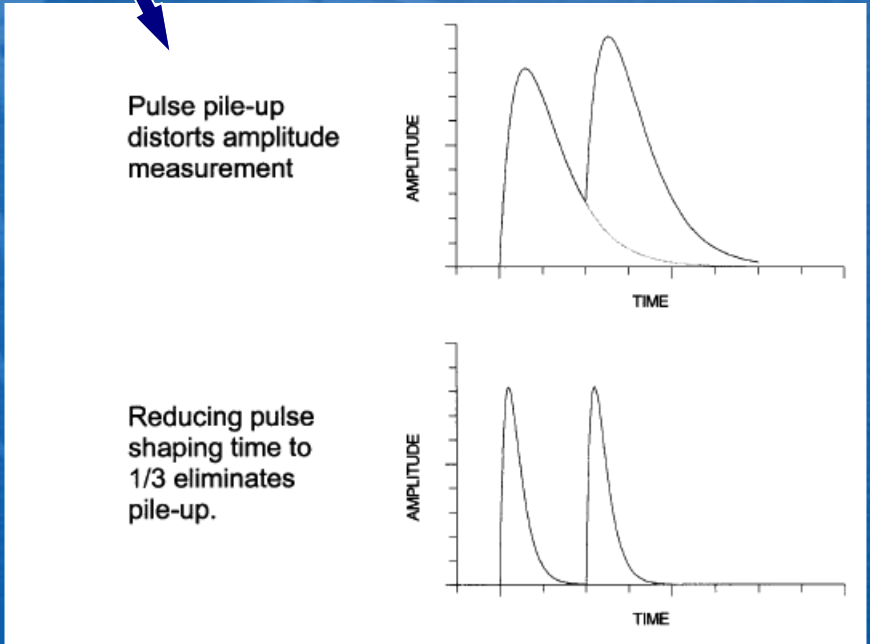


Figure 17.3 The pile-up of pulses within the preamplifier at high rates. If the saturation level of the preamplifier is exceeded, some pulses can be seriously distorted.



Pulse pile-up distorts amplitude measurement

Reducing pulse shaping time to 1/3 eliminates pile-up.

Operation

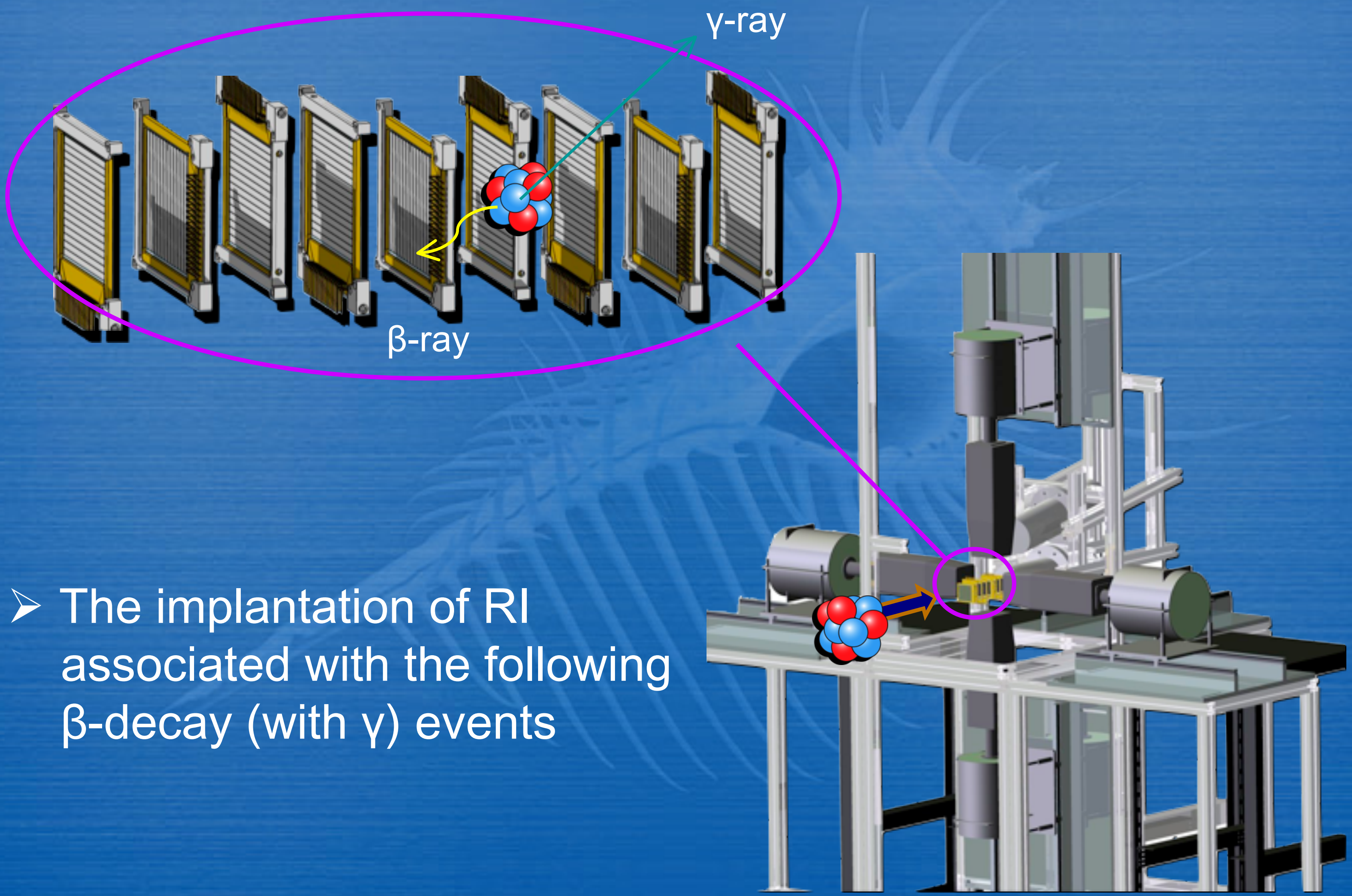
DELICATE Devices

- HV should be increased SLOWLY..
  - Check its maximum HV value and Polarity (+/-)
  - Check the current in HV module and its signal carefully.
  - If something is wrong, stop the operation and investigate the reason.

- Shock / vibration may destroy the detector.
  - Careful handling.

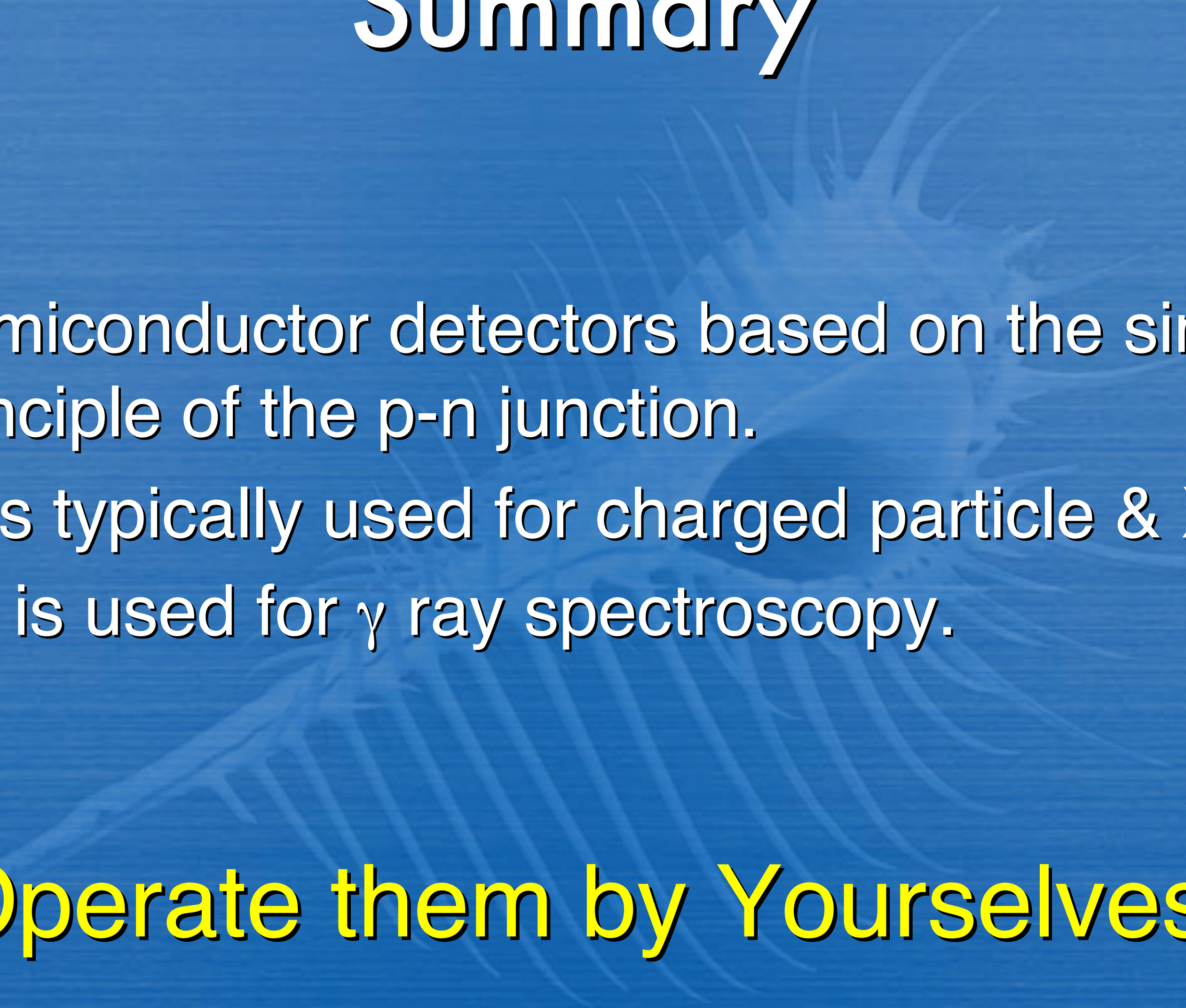
- Silicon detectors
  - Only the support frame can be touched.
  - Silicon detector hates moisture.
  - Sensitive to photons (light) … Operate in dark place.

- Ge-detector
  - Liquid nitrogen is required to cool the detector down.



- The implantation of RI associated with the following β-decay (with γ) events

Summary



- Semiconductor detectors based on the simple principle of the p-n junction.
- Si is typically used for charged particle & X-ray
- Ge is used for γ ray spectroscopy.

Operate them by Yourselves !