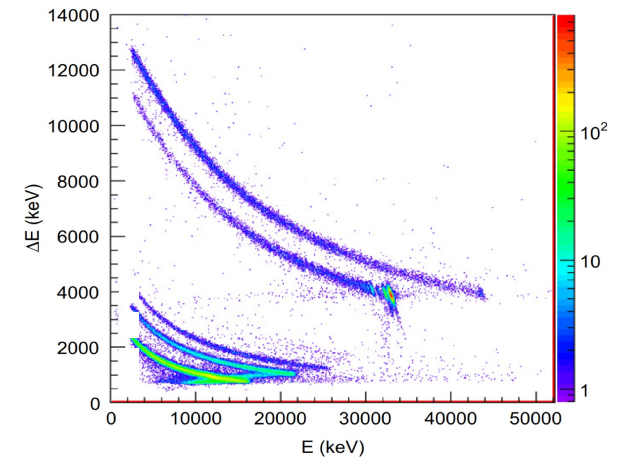


Particle, Gamma, Electron spectroscopy

1. Particle identification E-DE technique
2. Gamma spectroscopy
3. Electron spectroscopy

Particle, Gamma, Electron spectroscopy

1. Particle identification E-DE technique
2. Gamma spectroscopy
3. Electron spectroscopy



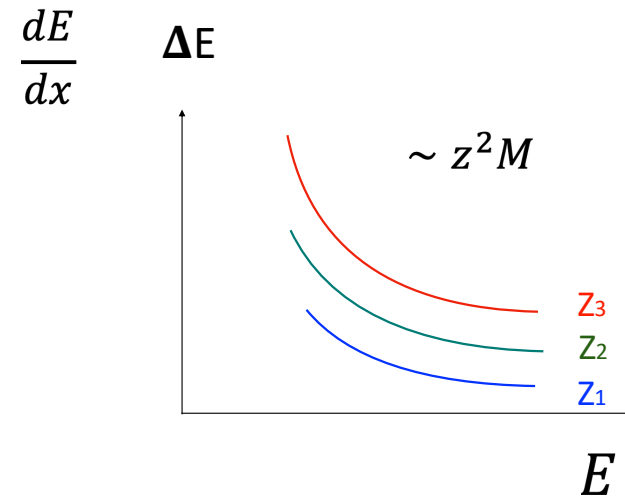
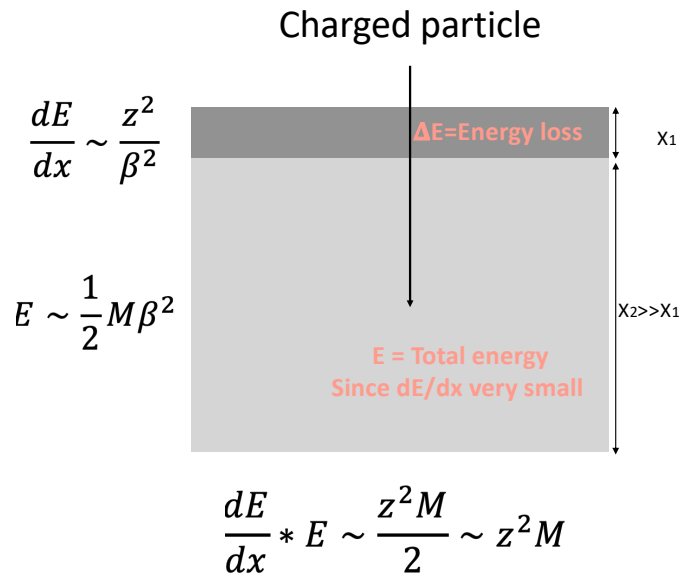
Particle identification via E-DE technique.

$$-\frac{dE}{dx} = 2\pi N_a r_e^2 m_e c^2 \rho \frac{Z}{A} \left(\frac{z^2}{\beta^2} \right) \left[\ln \left(\frac{2m_e \gamma^2 v^2 W_{\max}}{I^2} \right) - 2\beta^2 - \delta - 2 \frac{C}{Z} \right] \longrightarrow -\frac{dE}{dx} = C \frac{z^2}{\beta^2} f(\beta, I)$$

Detectors:

Silicon

Ionization chambers



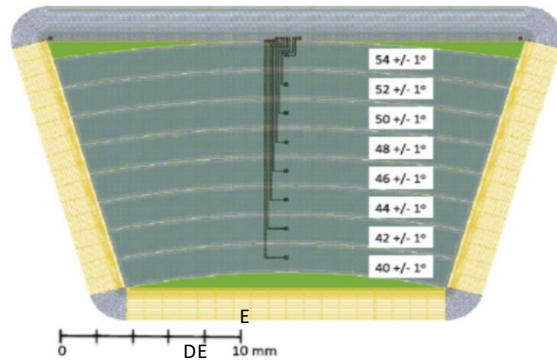
1- Particles with the different z :

Larger Z , larger energy loss $Z_3 > Z_2 > Z_1$

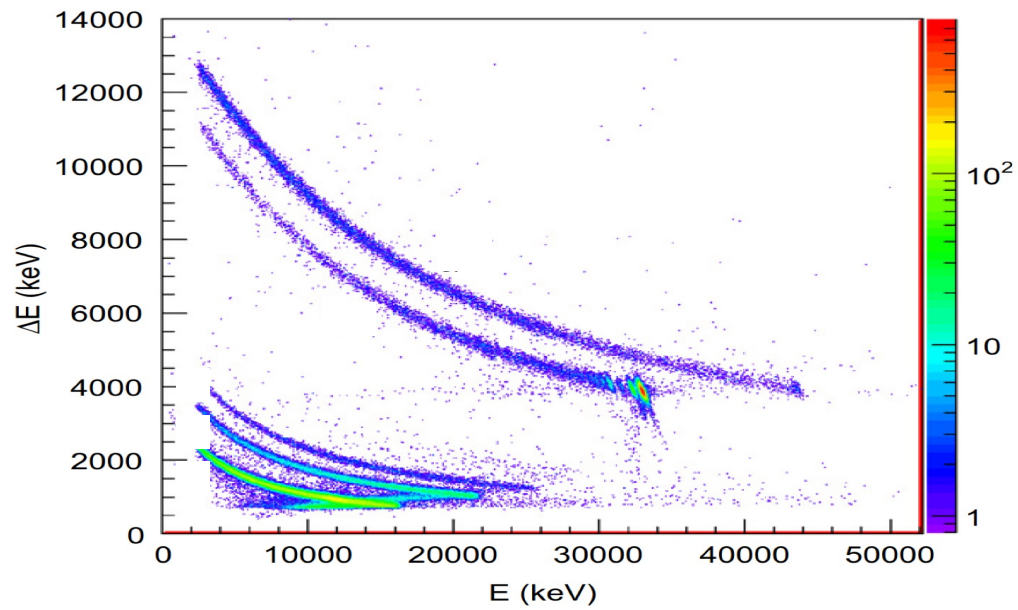
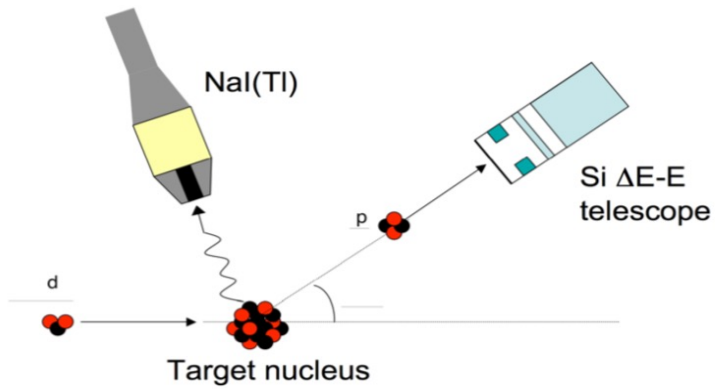
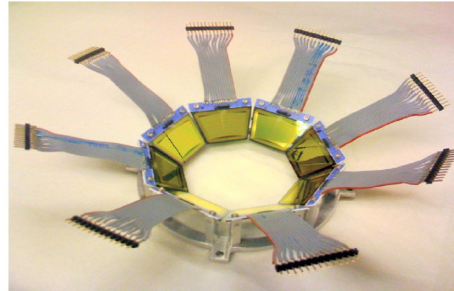
2- Particles with the same z : (isotopes)

Larger Mass (M), larger energy loss between the particles with the same Z

SiRi detector at OCL



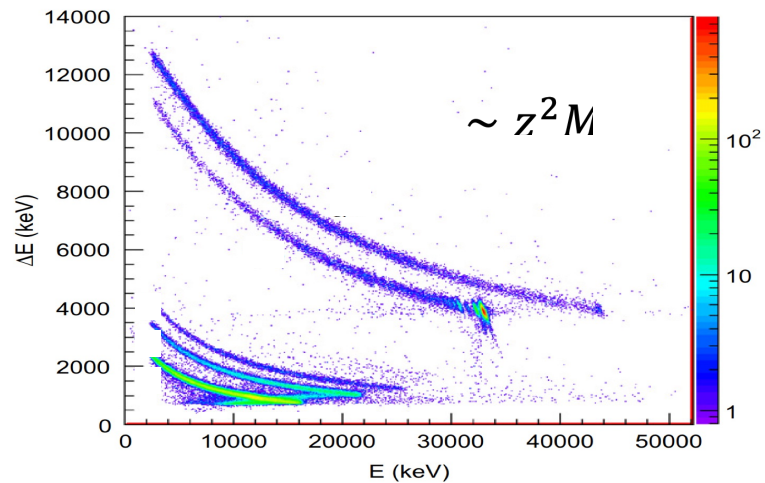
Front detector (for DE) 130 μm thick
Back detector (for E) 1550 μm thick



5 bananas to 5 particles

Can you assign each banana to a one particle?

Proton, deuteron, triton, ^3He , alpha (^4He)



1-Particles with the different z :

Larger Z , larger energy loss $Z_3 > Z_2 > Z_1$

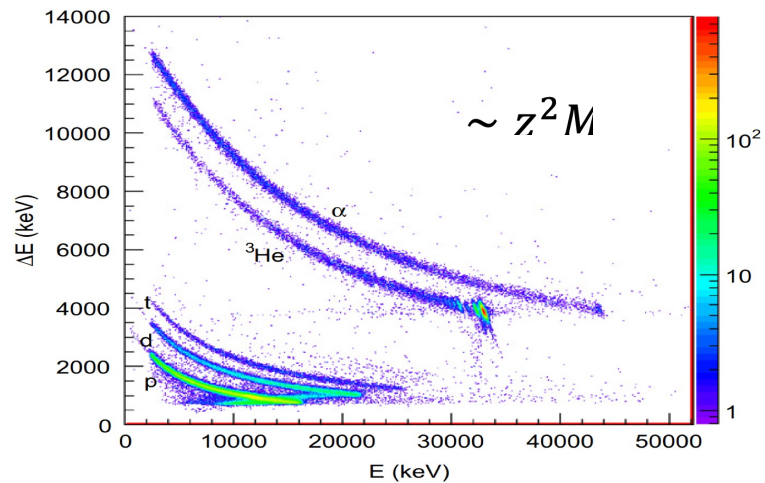
2- Particles with the same z : (isotopes)

Larger Mass, larger energy loss between the particles with the same Z

5 bananas to 5 particles

Can you assign each banana to a one particle?

Proton, deuteron, triton, ^3He , alpha (^4He)



1-Particles with the different z :

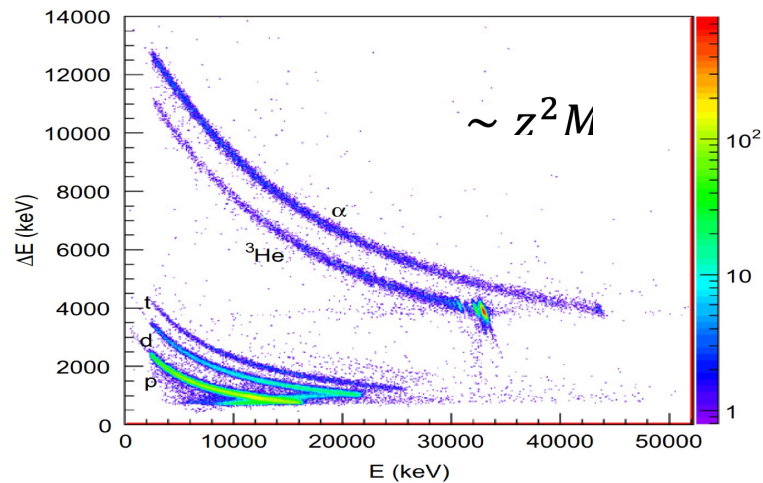
Larger Z , larger energy loss $Z_3 > Z_2 > Z_1$

2- Particles with the same z : (isotopes)

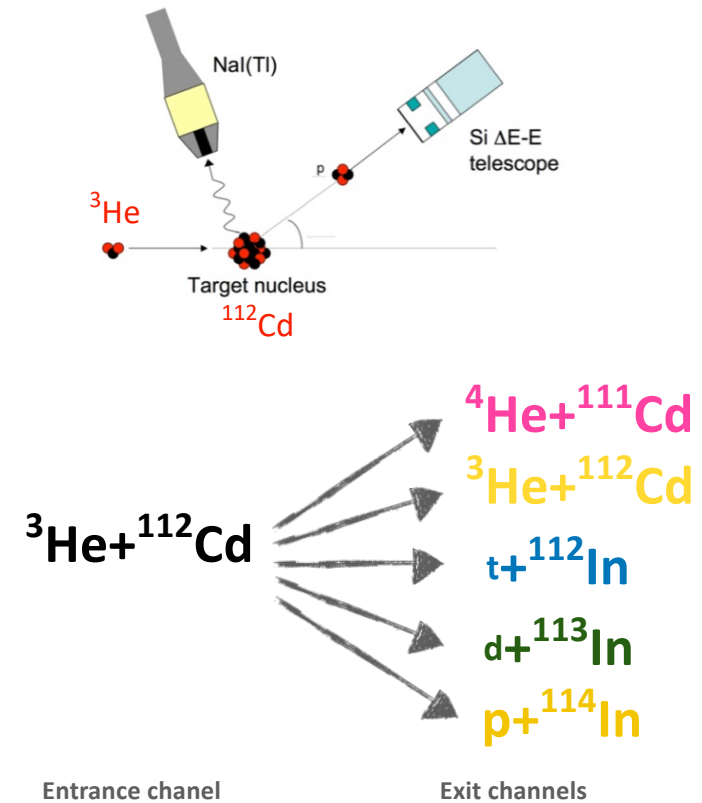
Larger Mass, larger energy loss between the particles with the same Z

5 bananas to 5 particles

Can you assign each banana to a one particle?
Proton, deuteron, triton, ^3He , alpha (^4He)



Why do we need this particle identification at the end?

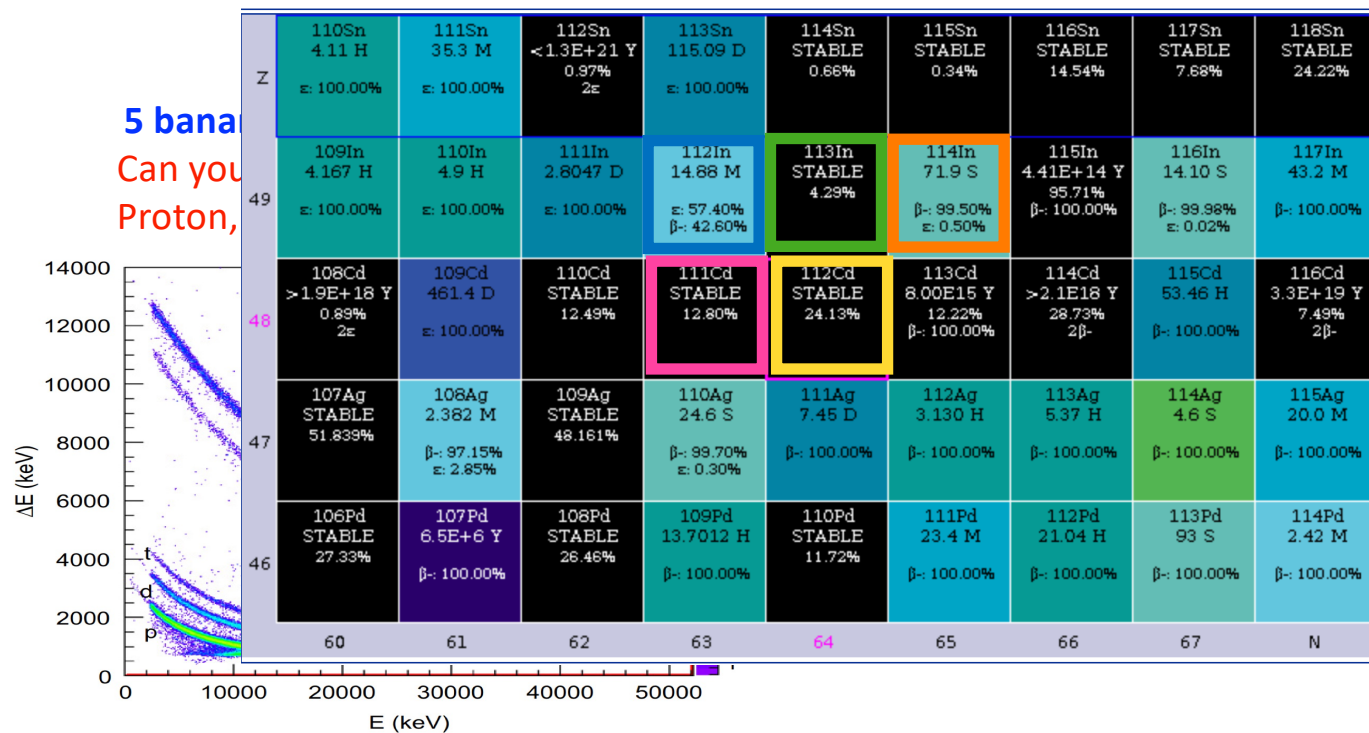


1-Particles with the different z :

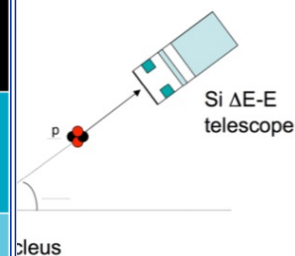
Larger Z , larger energy loss $Z_3 > Z_2 > Z_1$

2- Particles with the same z : (isotopes)

Larger Mass, larger energy loss between the particles with the same Z



particle identification at the end?

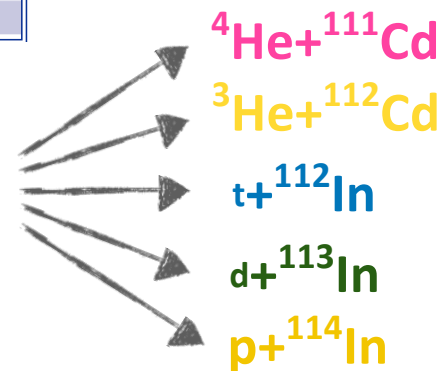
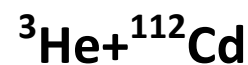


1-Particles with the different z:

Larger Z, larger energy loss $Z_3 > Z_2 > Z_1$

2- Particles with the same z: (isotopes)

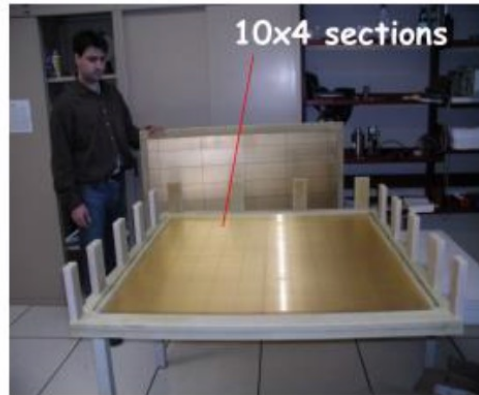
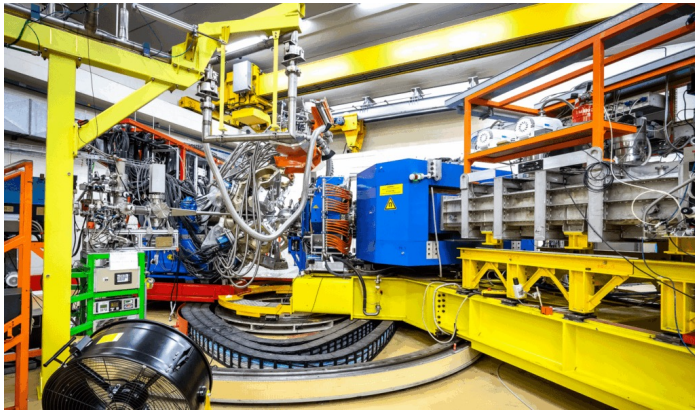
Larger Mass, larger energy loss between the particles with the same Z



Entrance channel

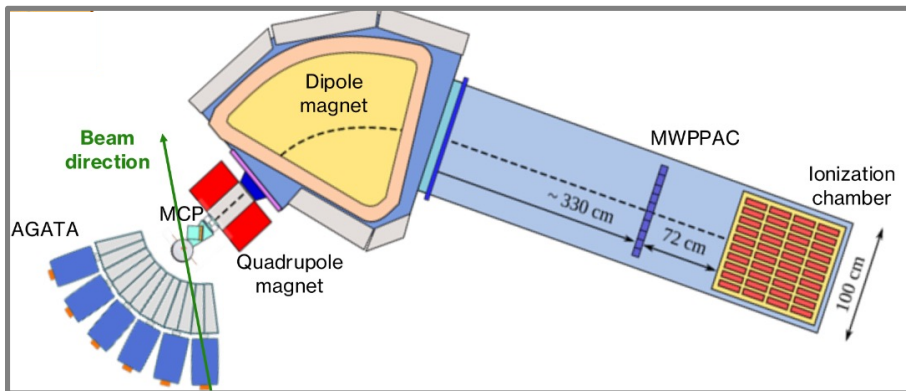
Exit channels

Stable Ion Beam facility, Laboratori Nazionali di Legnaro, Italy
(Soon will host Radioactive ion beam facility!)

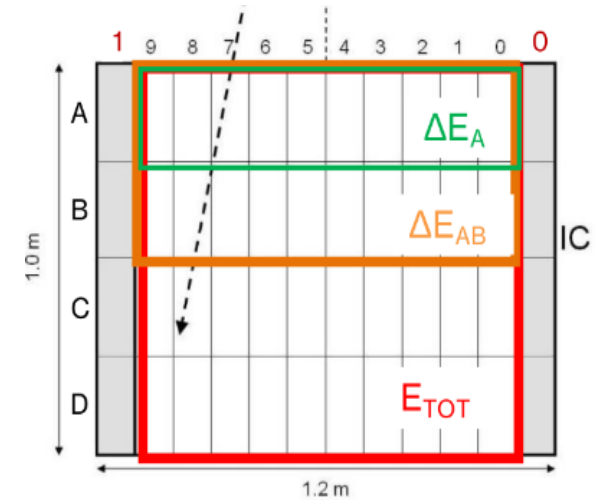
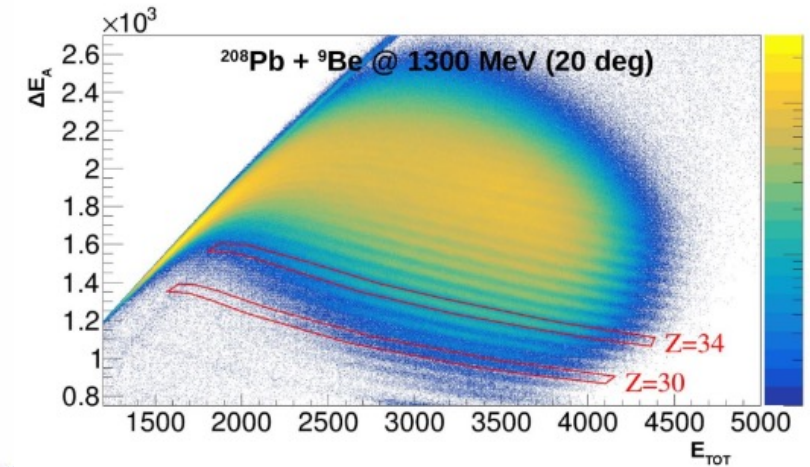


Filling gas: CH_4 , 99% purity
(CF_4 for energetic heavy-ions)
Filling pressure: 20-100 mbar

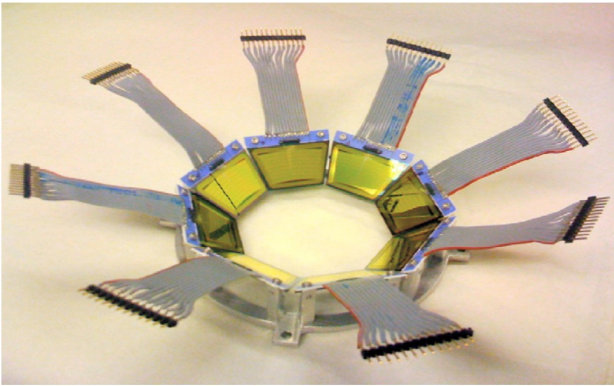
Ionization chamber



$$\Delta E \propto Z^2 f(\beta)$$



SiRi Silicon detector, Oslo

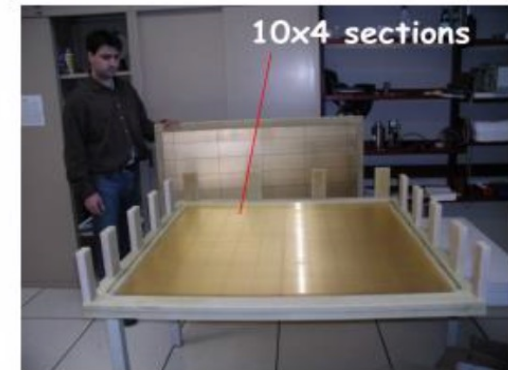


Which detector type has better energy resolution?
What do you need to know for that?

$$R = 2.35 \sqrt{\frac{F}{J}} = 2.35 \sqrt{\frac{Fw}{E}}$$

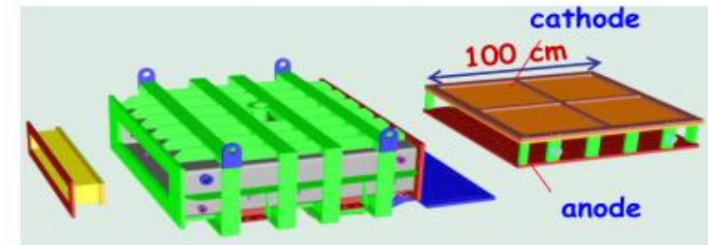
$$N_{\text{quanta}} = \frac{E}{w}$$

Ionization Chamber, Italy



Filling gas: CH₄, 99% purity
(CF₄ for energetic heavy-ions)

Filling pressure: 20-100 mbar



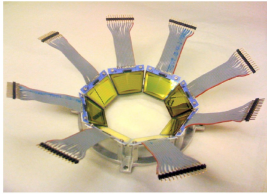


Table 10.2. Average energy for electron-hole creation in silicon and germanium

	Si	Ge
300 K	3.62 eV	—
77 K	3.81 eV	2.96 eV

10.4.3 The Fano Factor and Intrinsic Energy Resolution

The intrinsic energy resolution, as we saw in Chap. 5, is dependent on the number of charge carriers and the Fano Factor. Despite numerous experiments, the Fano factor for both silicon and germanium is still not well determined. However, it is clear that F is small and on the order of 0.12. This, of course, contributes greatly to enhancing the resolution of semiconductors which already profit greatly from the small average energy required to create an electron hole pair.



Table 6.1. Excitation and ionization characteristics of various gases

	Excitation potential [eV]	Ionization potential [eV]	Mean energy for ion-electron pair creation [eV]
H ₂	10.8	15.4	37
He	19.8	24.6	41
N ₂	8.1	15.5	35
O ₂	7.9	12.2	31
Ne	16.6	21.6	36
Ar	11.6	15.8	26
Kr	10.0	14.0	24
Xe	8.4	12.1	22
CO ₂	10.0	13.7	33
CH ₄		13.1	28
C ₄ H ₁₀		10.8	23

Table 6.2. Measured Fano factors for various gas mixtures

Gas	F	Ref.
Ar 100%	$0.2^{+0.01}_{-0.02}$	[6.4]
	$<0.40 \pm 0.03$	[6.5]
Ar + 80% Xe	$<0.21 \pm 0.03$	[6.5]
Ar + 24% Xe	$<0.23 \pm 0.02$	[6.5]
Ar + 20% Xe	$<0.16 \pm 0.02$	[6.5]
Ar + 5% Xe	$<0.14 \pm 0.03$	[6.5]
Ar + 5% Kr	$<0.37 \pm 0.06$	[6.5]
Ar + 20% Kr	$<0.12 \pm 0.02$	[6.5]
Ar + 79% Kr	$<0.13 \pm 0.02$	[6.5]
Xe 100%	$<0.15 \pm 0.01$	[6.6]
	$<0.15 \pm 0.03$	[6.5]
Kr 100%	$<0.23 \pm 0.01$	[6.6]
	$<0.19 \pm 0.02$	[6.5]
Kr + 1.3% Xe	$<0.19 \pm 0.01$	[6.6]
Kr + 20% Xe	$<0.21 \pm 0.02$	[6.6]
Kr + 40% Xe	$<0.22 \pm 0.01$	[6.6]
Kr + 60% Xe	$<0.21 \pm 0.01$	[6.6]
Kr + 95% Xe	$<0.21 \pm 0.01$	[6.6]

$$N_{\text{quanta}} = \frac{E}{w}$$

$N_{e-\text{ionpairs}}$

Gas detectors

Ionization chambers
Proportional counters
PPAC detectors
Drift chambers
TPC (Time Projection Chamber)

$N_{e-\text{holepairs}}$

Semiconductor
detectors

HPGe, Ge(Li)
Si, Si(Li)

N_{photons}

Scintillation
detectors

Organic scintillators
Plastic
Liquid
Inorganic scintillators
NaI(Tl)
CsI(Tl)
LaBr₃(Ce)
BGO

Ionization chambers (Energy $\rightarrow$ heavy charged particles)
Proportional counters (Energy $\rightarrow$ heavy charged particles)
PPAC detectors (Position x,y $\rightarrow$ heavy charged particles)
Drift chambers (Position x,y $\rightarrow$ heavy charged particles)
TPC (Time Projection Chamber) (Position x,y,z $\rightarrow$ heavy charged particles)

HPGe, Ge(Li) (Energy $\rightarrow$ gamma rays)
Si (Position, Energy $\rightarrow$ heavy charged particles, electrons)
Si(Li) (Position, Energy $\rightarrow$ electrons)

Organic scintillators

Plastic (Time, energy, position if segmented $\rightarrow$ heavy charged particles, electrons, neutrons) (pulse shape discrimination $\rightarrow$ neutron-gamma discrimination)
Liquid (pulse shape discrimination $\rightarrow$ neutron-gamma discrimination) (neutrons)

Inorganic scintillators

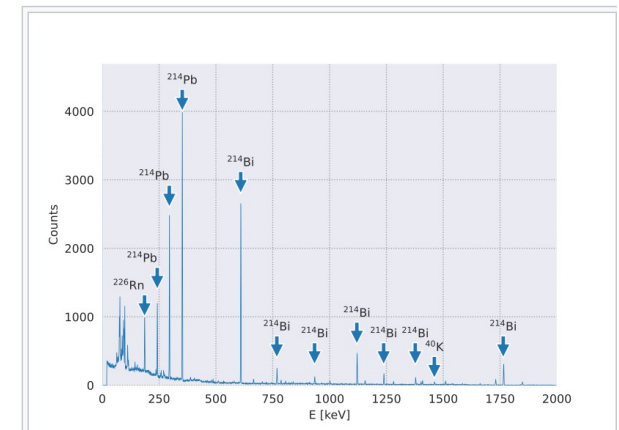
Nal(Tl) (Energy $\rightarrow$ gamma rays)
CsI(Tl) (Energy $\rightarrow$ gamma rays)
LaBr₃(Ce) (Energy, time $\rightarrow$ gamma rays) (pulse shape discrimination $\rightarrow$ neutron-gamma discrimination)
BGO (veto $\rightarrow$ gamma rays)

Particle, Gamma, Electron spectroscopy

1. Particle identification E-DE technique
2. **Gamma spectroscopy**
3. Electron spectroscopy

Gamma-ray spectroscopy is the *qualitative* study of the **energy spectra** of **gamma-ray sources**, such as in the nuclear industry, geochemical investigation, and astrophysics.^[1]

Gamma-ray spectrometry, on the other hand, is the method used to acquire a *quantitative* spectrum measurement.^[2]

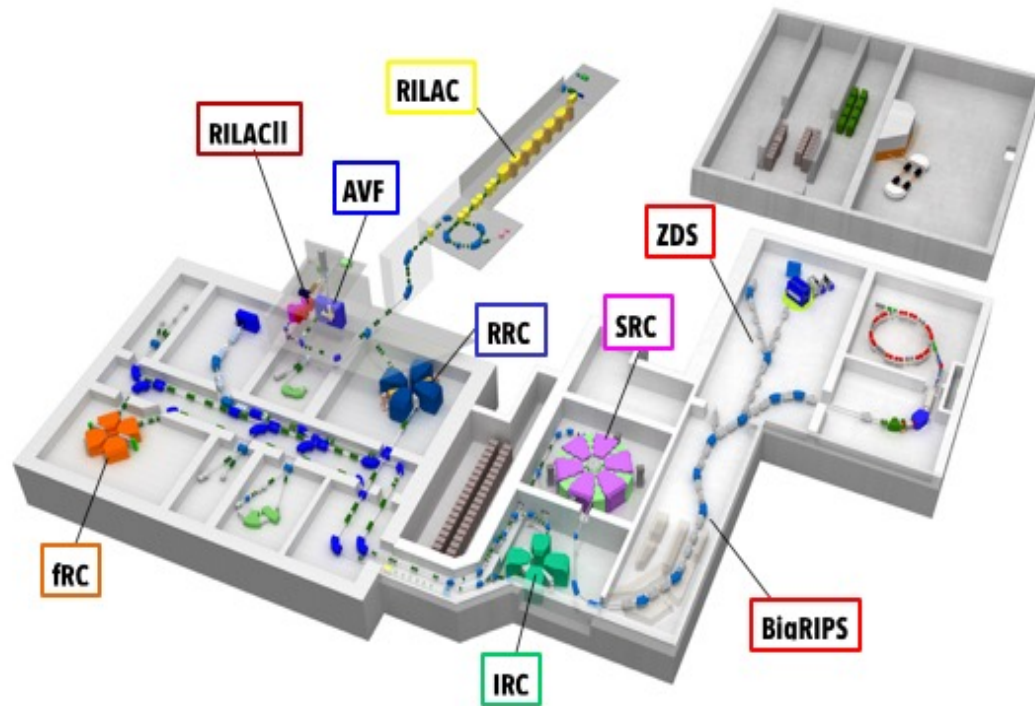


The gamma-ray spectrum of natural **uranium**, showing about a dozen discrete lines superimposed on a smooth continuum, allows one to identify the **nuclides** ^{226}Ra , ^{214}Pb , and ^{214}Bi of the uranium **decay chain**. This spectrum was taken from a Uranium ore sample from **Moab, Utah**.

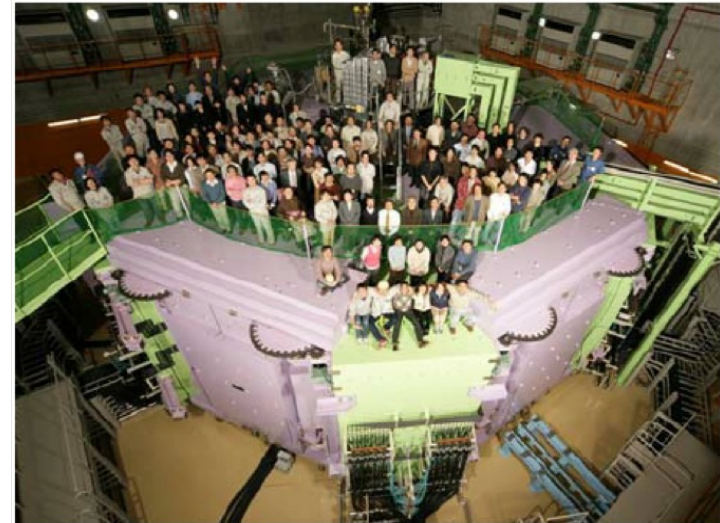


Radioactive Ion Beam Facilities are necessary to produce Exotic nuclei/beams and to study their unknown structure

Radioactive Ion-Beam Facility at RIKEN, Japan



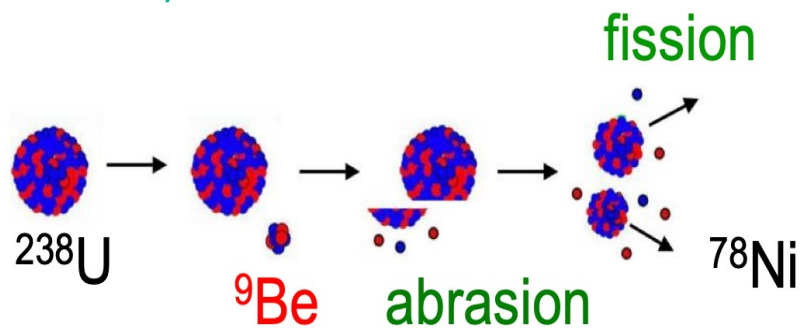
SRC: World Largest (Heaviest) Cyclotron



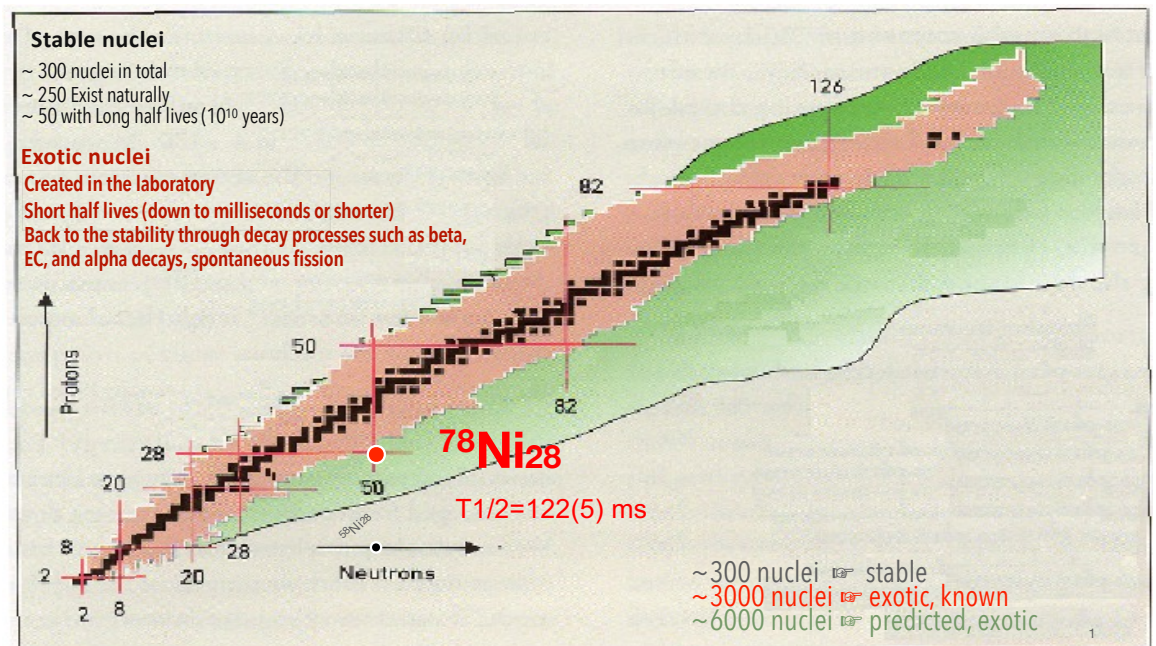
The SRC is the world's first superconducting ring cyclotron with the ever largest K-value of 2600 MeV, which expresses the maximum bending power of extracted beam from the cyclotron

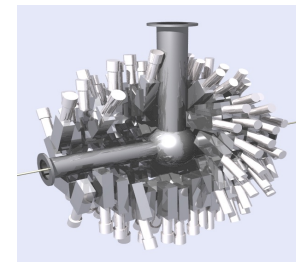
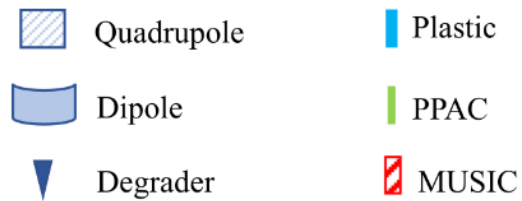
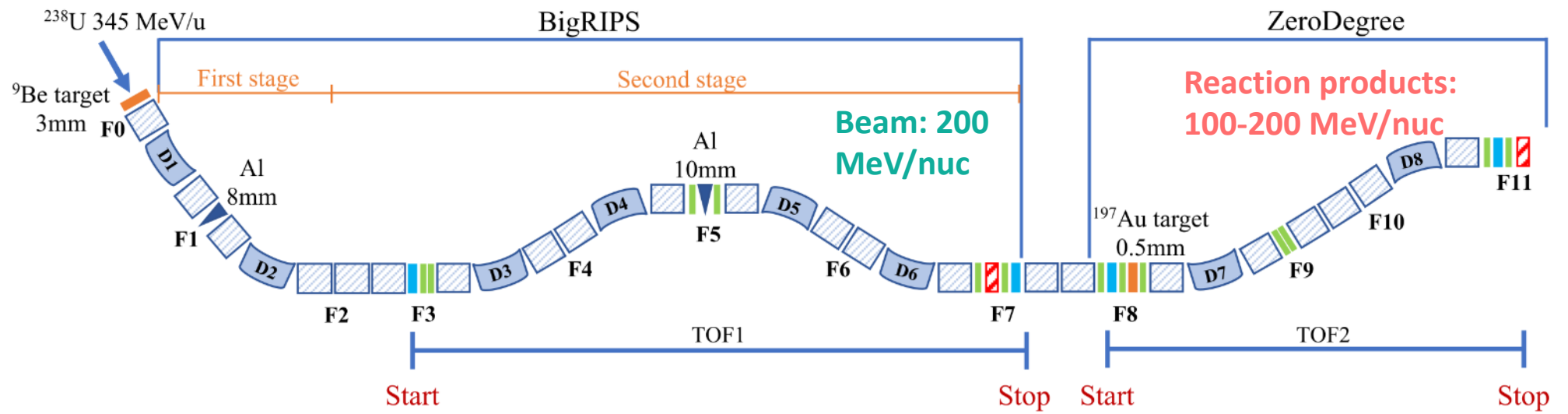
Most intense uranium beam - ^{238}U

345 MeV/nuc=82000 MeV

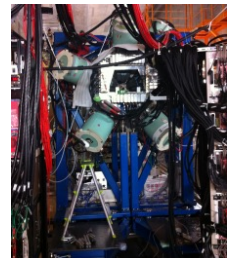


200 MeV/nuc=15600 MeV





★ **DALI**
186 NaI (TI)
detectors

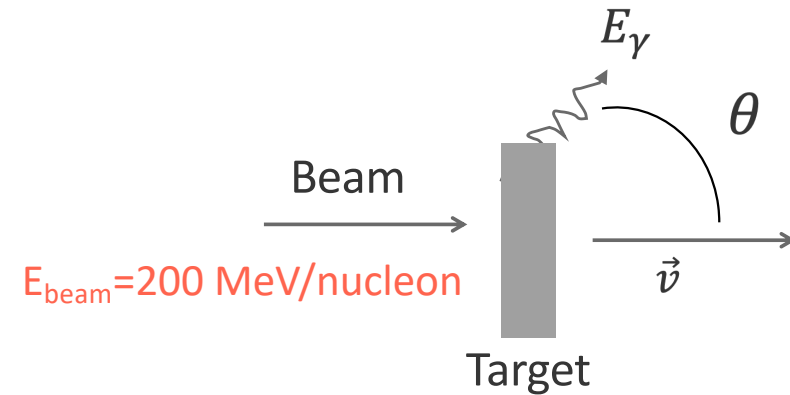
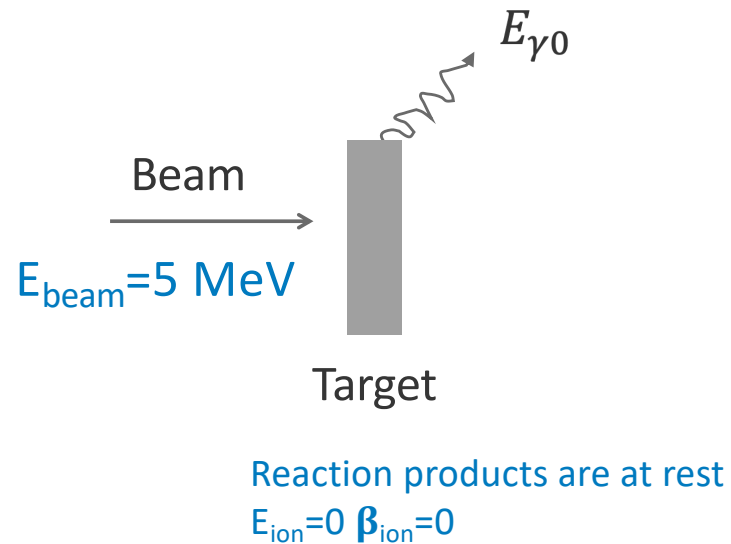


Germanium
detectors

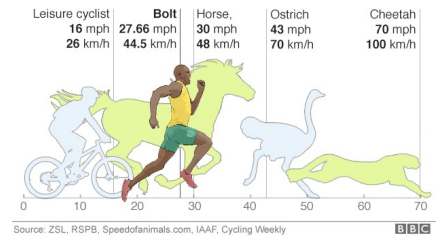
- i. Doppler effect and Doppler correction
- ii. Energy resolution due to moving ions and detector angular opening

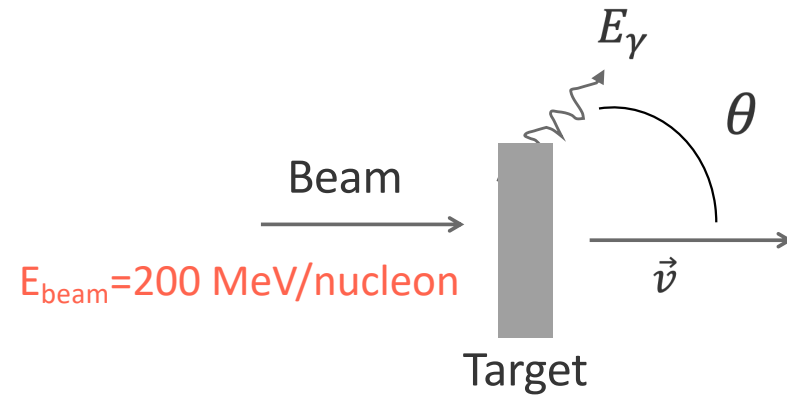
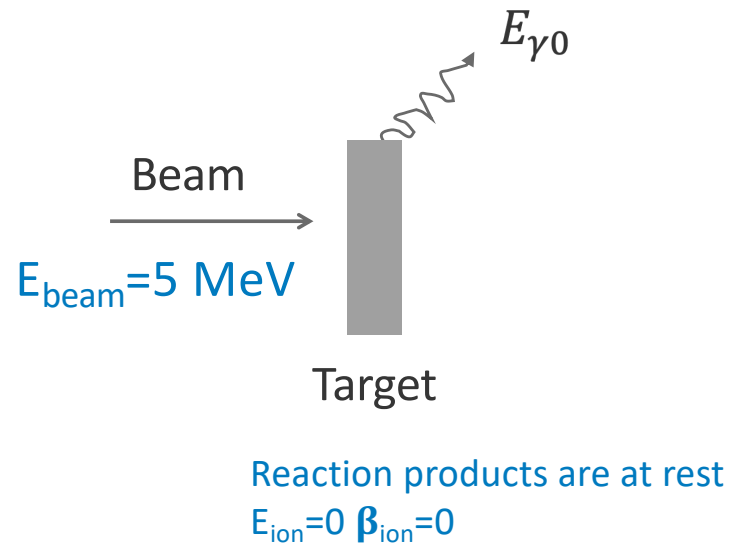
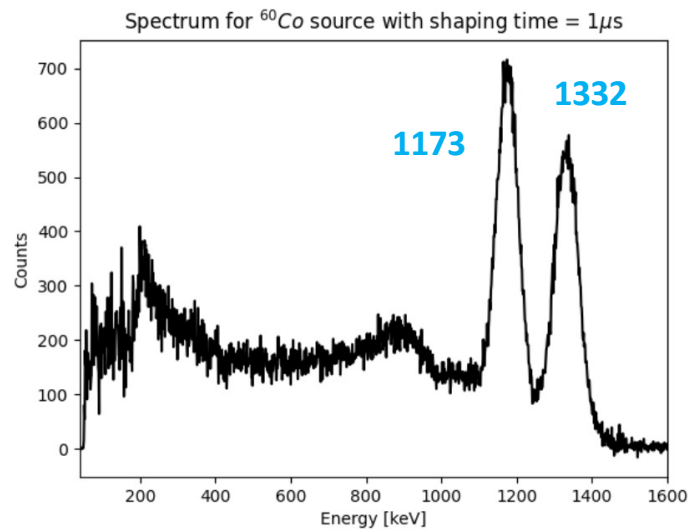
- i. Doppler effect and Doppler correction
- ii. Energy resolution due to moving ions and detector angular opening

- Gamma-ray emitted from a ^{60}Co source will not change its energy.
- Or in a nuclear reaction where all the reaction products are stopped inside the target.

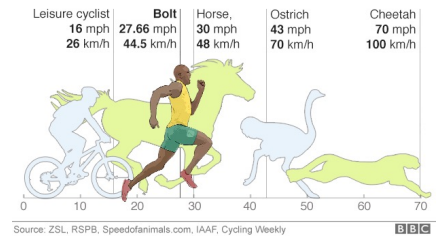


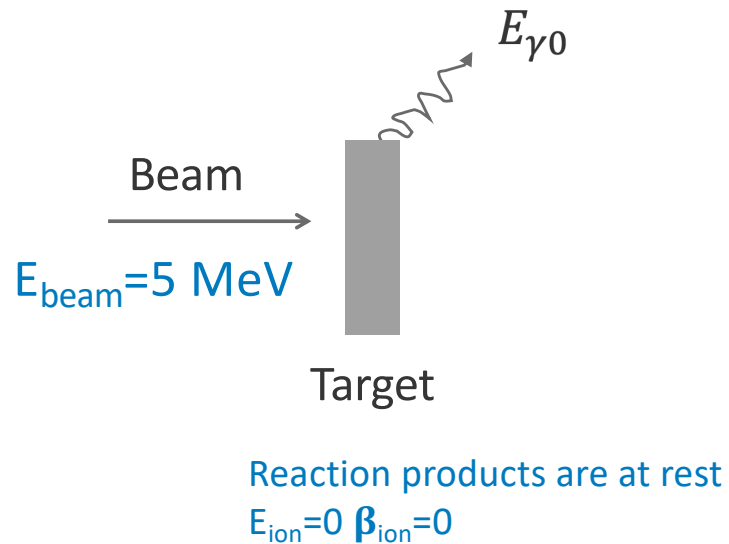
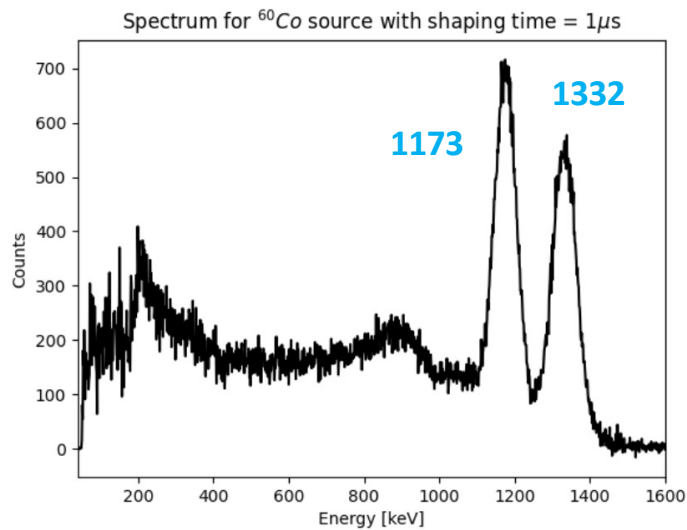
Reaction products exit the target with high velocity.
 $E_{\text{ion}} = 100\text{-}200 \text{ MeV/nucleon}$
 $\beta_{\text{ion}} = v/c = 0.5 \rightarrow 50\%$



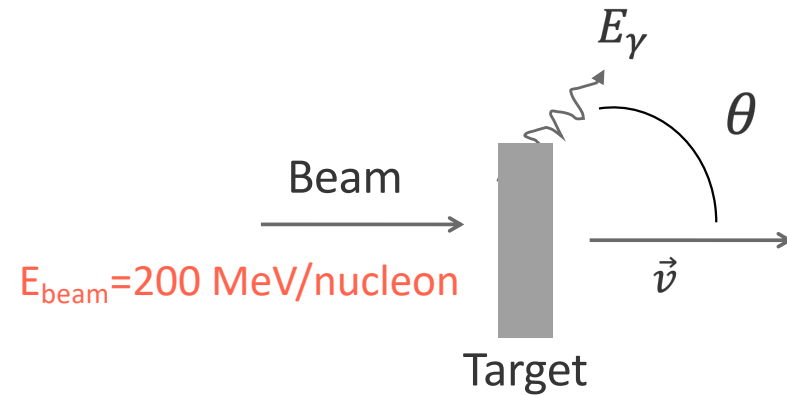
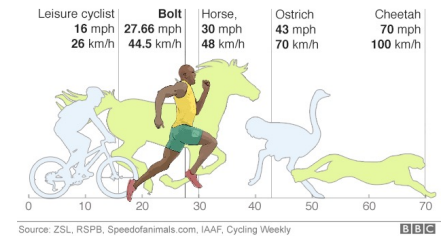


Reaction products exit the target with high velocity.
 $E_{\text{ion}} = 100\text{-}200 \text{ MeV/nucleon}$
 $\beta_{\text{ion}} = v/c = 0.5 \rightarrow 50\%$

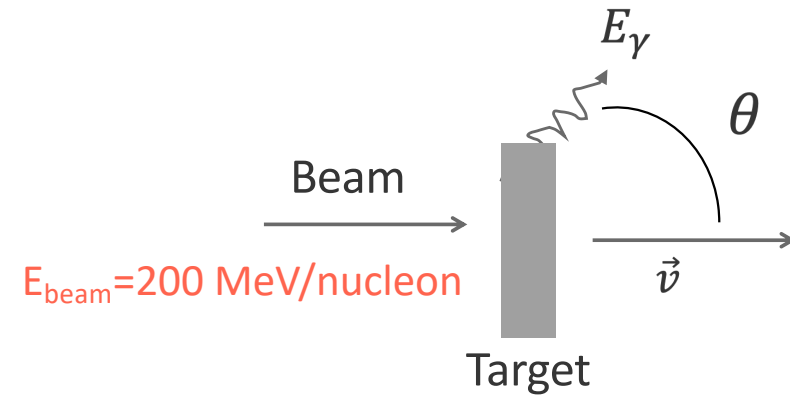
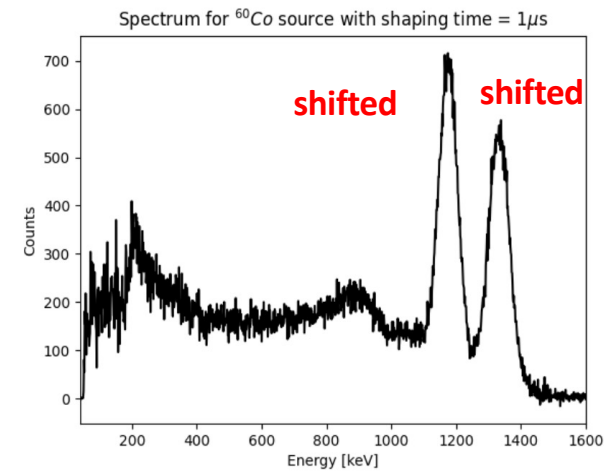
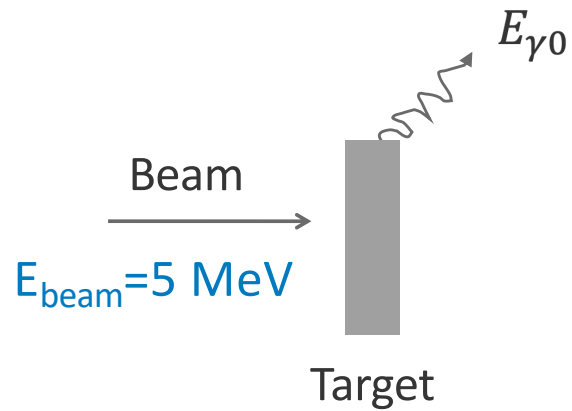
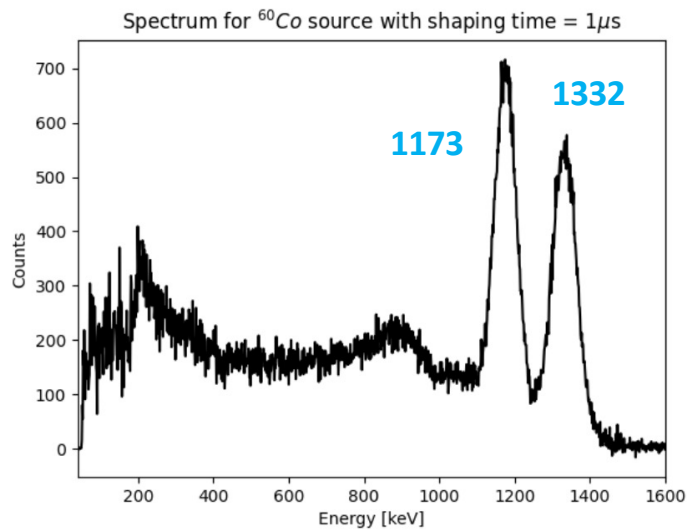




- Gamma ray emitted from a moving nucleus will experience a Doppler shift.
- Think about accelerating a ^{60}Co nucleus at a high energy and sending it to a target. Like holding the ^{60}Co source in hand and run like crazy :)



Reaction products exit the target with high velocity.
 $E_{\text{ion}} = 100\text{-}200 \text{ MeV/nucleon}$
 $\beta_{\text{ion}} = v/c = 0.5 \rightarrow 50\%$



Doppler (shift) formula

$$E_{\gamma 0} = \gamma(1 - \beta \cos \theta) E_{\gamma}$$

What does each symbol mean?

$E_{\gamma 0}$ **Rest-frame gamma-ray energy**
The original transition energy we want to recover

E_{γ} **Measured gamma-ray energy**
The energy measured by the detector

γ **Lorentz factor**
Accounts for relativistic effects

β **Speed ratio, v/c**
The nucleus's speed as a fraction of the speed of light

v **Nuclear velocity**
How fast the emitting nucleus is moving

c **Speed of light**
Approximately 3.00×10^8 m/s

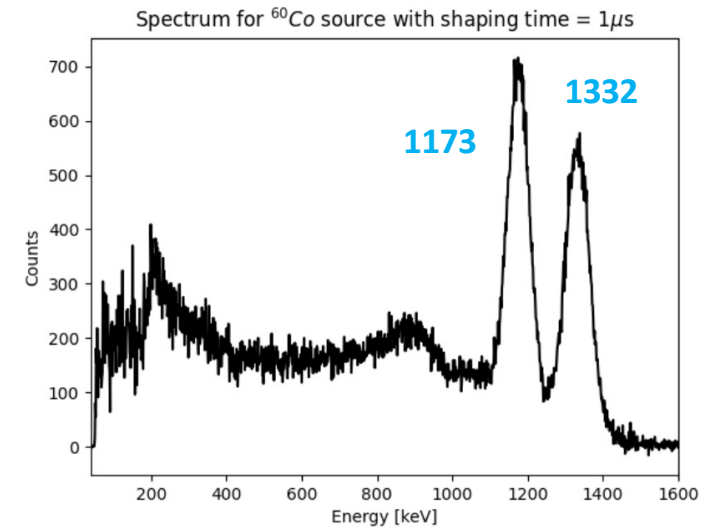
θ **Emission angle**
Angle between the nucleus's velocity and the emitted gamma-ray direction in the laboratory

$\cos \theta$ **Cosine of the angle**
Determines how motion affects the measured energy

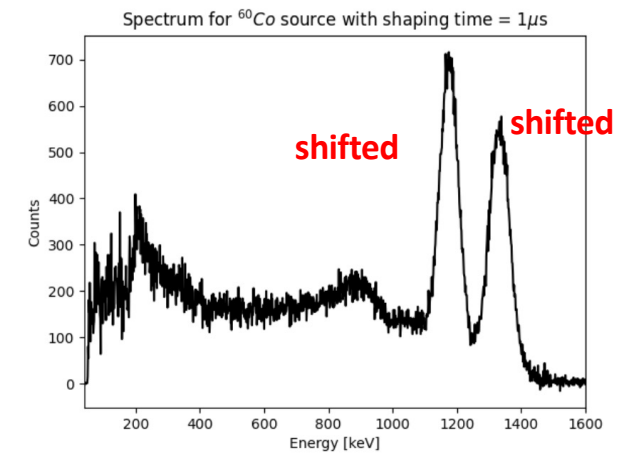
$$\beta = \frac{v}{c}$$

$$\gamma = \frac{1}{\sqrt{1 - \beta^2}}$$

$E_{\gamma 0}$

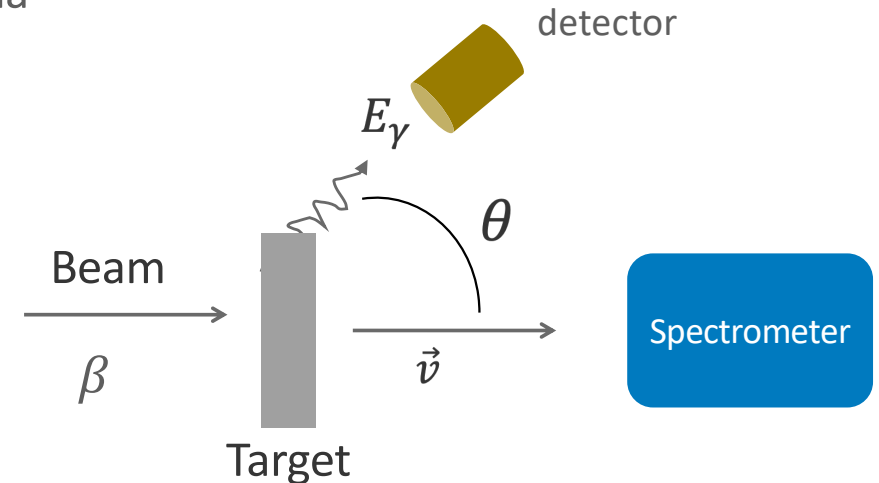


E_{γ}



Doppler correction

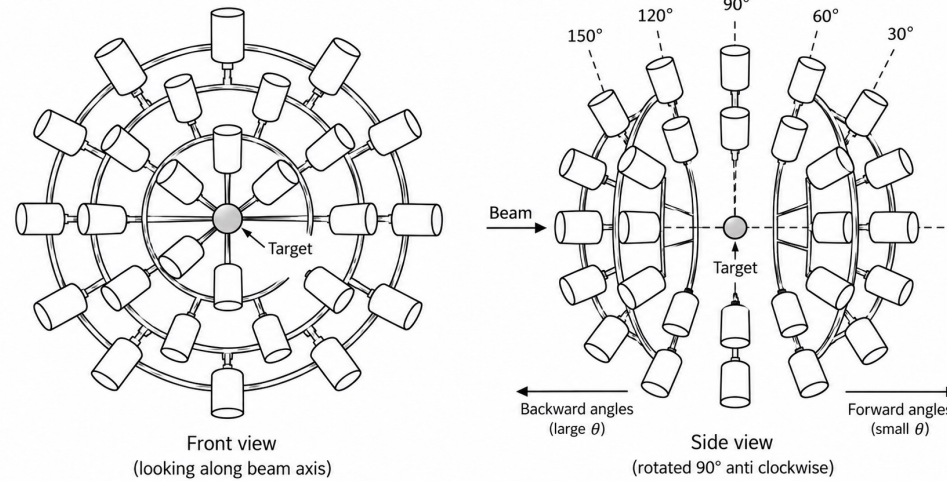
- If we know the velocity (β) of the ion exiting the target, we can apply Doppler correction to correct the shifted gamma ray energy to its original value.
- We also need to know the θ angle. This is given by the position of the detector.



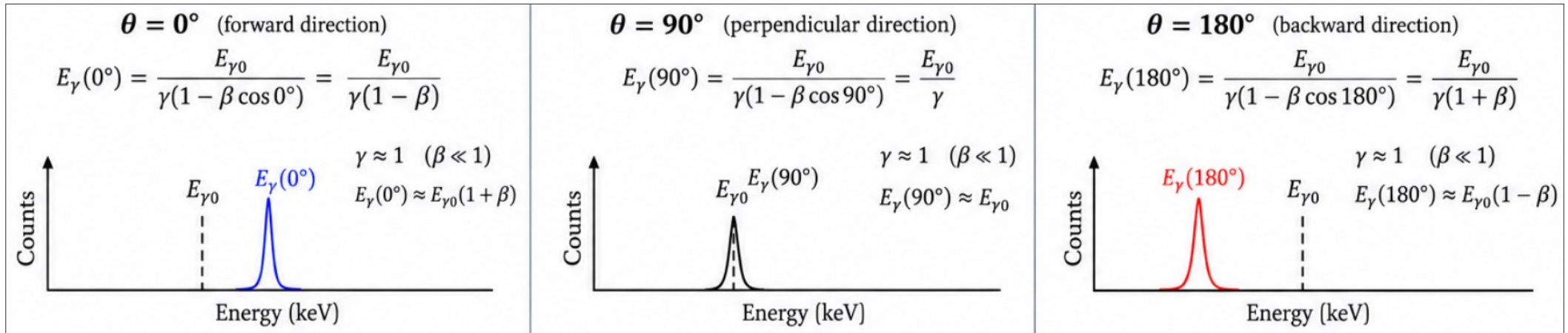
Doppler shift formula

$$E_{\gamma 0} = \gamma(1 - \beta \cos \theta) E_\gamma$$

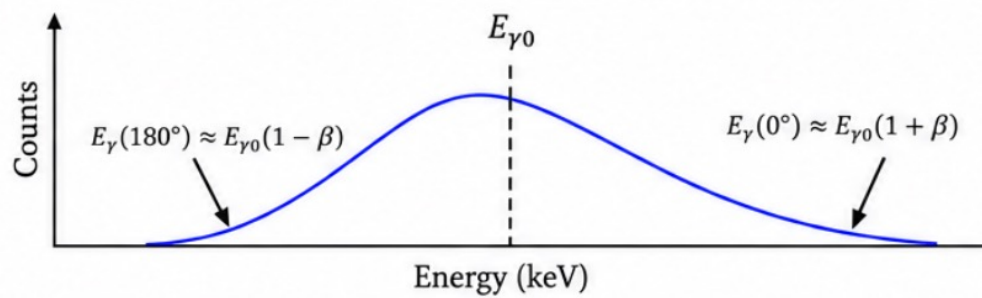
$$E_\gamma = \frac{E_{\gamma 0}}{\gamma(1 - \beta \cos \theta)}$$



$$E_{\gamma} = \frac{E_{\gamma 0}}{\gamma(1 - \beta \cos \theta)}$$



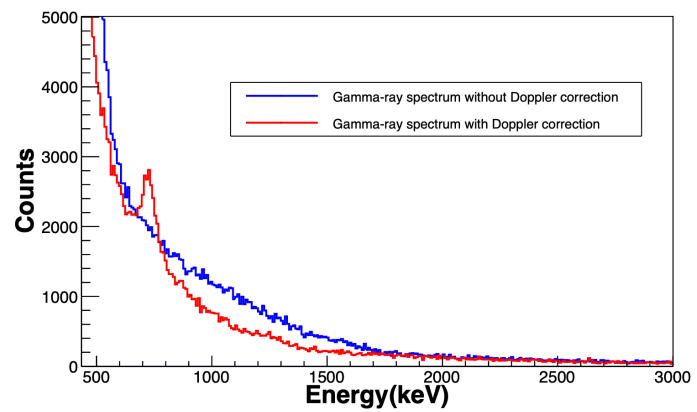
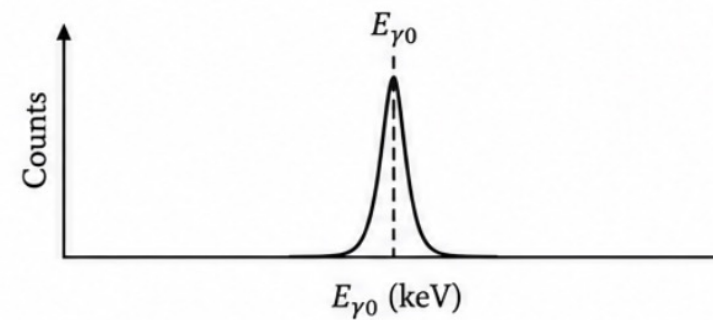
Uncorrected spectrum (whole array)



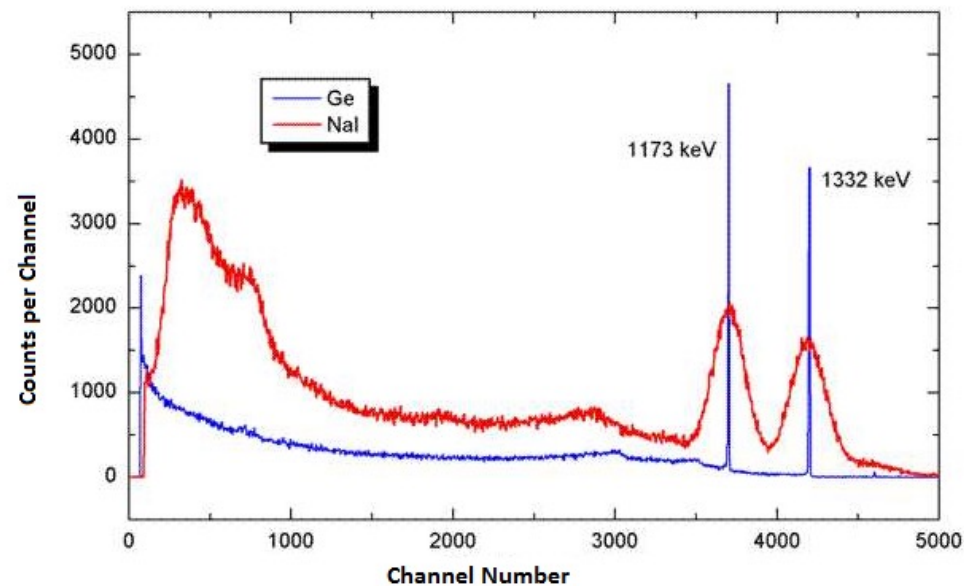
Doppler
correction



Doppler-corrected spectrum



- i. Doppler effect and Doppler correction
- ii. Energy resolution due to moving ions and detector angular opening



$$(\text{FWHM})_{\text{overall}}^2 = (\text{FWHM})_{\text{statistical}}^2 + (\text{FWHM})_{\text{noise}}^2 + (\text{FWHM})_{\text{drift}}^2 + \dots$$

- FWHM in the energy spectrum corresponds to $(\text{FWHM})_{\text{overall}}$
- It is dominated by the **statistical fluctuations**, i.e. by the discrete nature of the measured signal
- Noise component, very important too for having an optimal energy resolution.
- What about the last component?

$$E_{\gamma 0} = \gamma(1 - \beta \cos \theta) E_{\gamma}$$

$$\beta = v/c$$

$$\gamma = \frac{1}{\sqrt{1 - \beta^2}}$$

$$\frac{\Delta E_{\gamma 0}}{E_{\gamma 0}} = \frac{\beta - \cos \theta}{(1 - \beta^2)(1 - \beta \cos \theta)} \Delta \beta$$

Derivative of $E_{\gamma 0}$ for β gives the resolution contribution due to the beam velocity

$$\frac{\Delta E_{\gamma 0}}{E_{\gamma 0}} = \frac{\beta \sin \theta}{(1 - \beta \cos \theta)} \Delta \theta$$

Derivative of $E_{\gamma 0}$ for θ gives the resolution contribution because of the angular opening (called angular resolution)

$$(\text{FWHM})_{\text{overall}}^2 = (\text{FWHM})_{\text{statistical}}^2 + (\text{FWHM})_{\text{noise}}^2 + (\text{FWHM})_{\text{beam}}^2 + (\text{FWHM})_{\text{angular}}^2$$

- These factors are because of the fact that the gamma ray is emitted from the moving nucleus!
- Can be reduced with reducing target thickness ($\Delta \beta$) and detectors in farther distance ($\Delta \theta$)!

4 π -Ge Arrays: Single crystals with BGO suppression

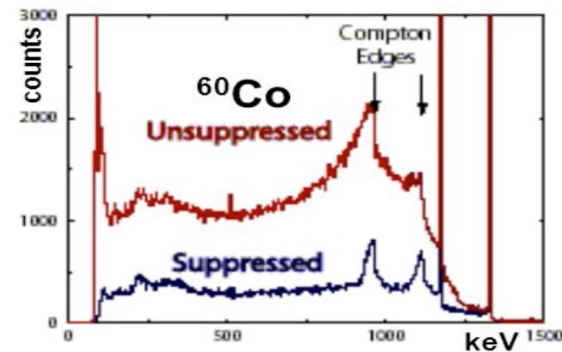
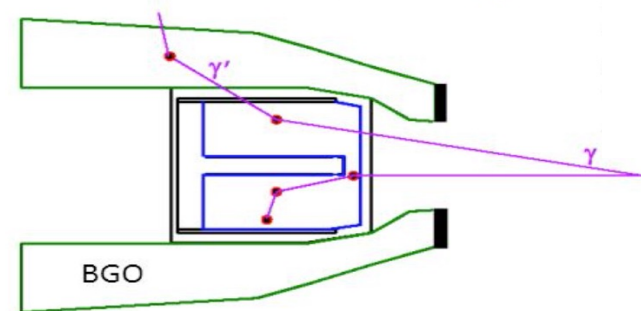


ROSPHERE at Bucharest, Romania

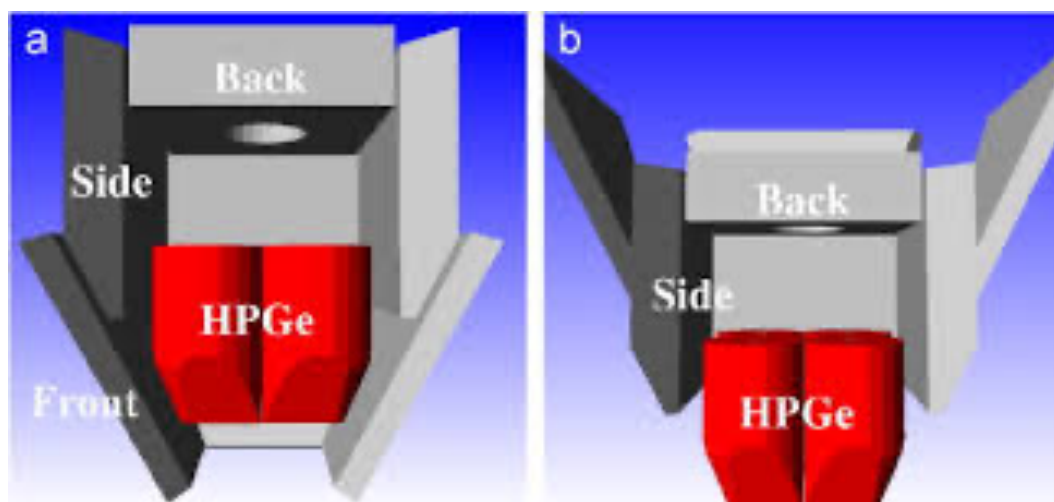
Table 7.3. Average energy loss per scintillator photon for electrons

Material	ϵ [eV/photon]
Anthracene	60
NaI	25
Plastic	100
BGO	300

BGO Compton suppression



For large Ge arrays: **P/T (Peak to Total) Ratio** improves from 20% to 60%



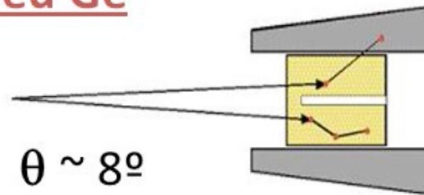
Compton Shielded Ge

ϵ_{ph} ~ 10%
 N_{det} ~ 100

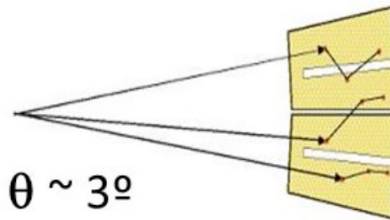
Ω ~ 40%

Ge Sphere

ϵ_{ph} ~ 50%
 N_{det} ~ 1000



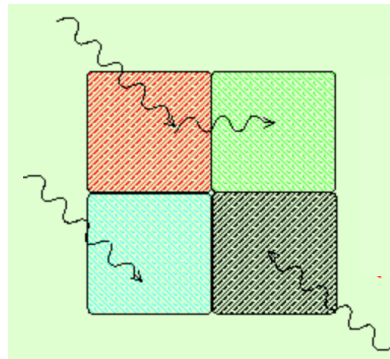
large opening angle
means poor energy
resolution at high
recoil velocity



too many detectors
are needed to avoid
summing effects

Compton
suppression

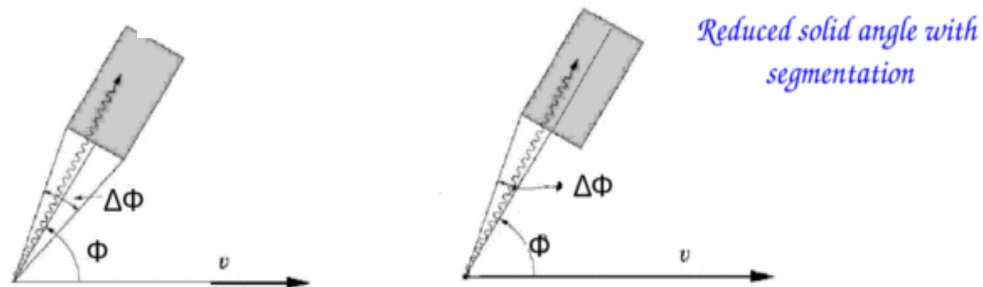
ADDBACK



4π -Ge Arrays:

Segmented crystals

Clover (4-fold segmentation)



1- Segmentation reduces the solid angle, thus improves energy resolution

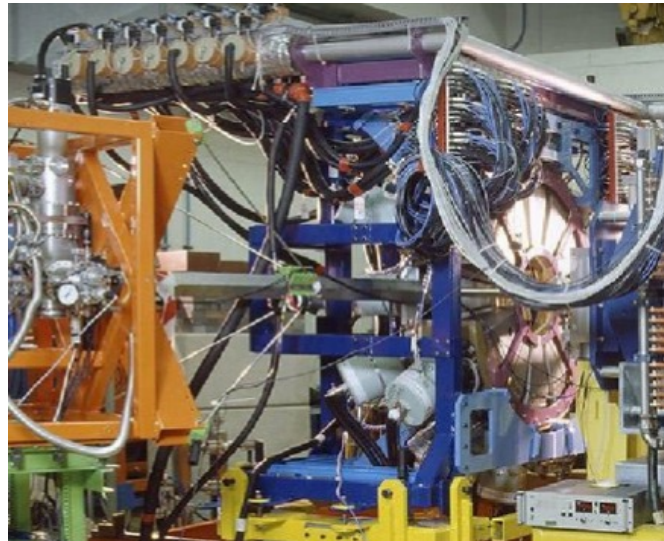
2- Segmentation allows for recovering the scattered event instead of rejecting it. This has a direct effect on the reconstruction of the Compton scattered gammas into the full-energy peak, increased efficiency!

4π -Ge Arrays: Segmented crystals

Clover (4-fold segmentation)

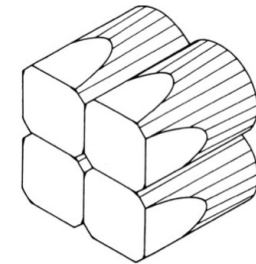


CLARA array at LNL-Italy
Now in Finland.



CLARA array:

- 25 detectors
- Each detector is segmented – 4 fold
- $25 \times 4 = 100$ detectors
- Calibration of 100 detectors :)



1- Segmentation reduces the solid angle, thus improves energy resolution

2- Segmentation allows for recovering the scattered event instead of rejecting it. This has a direct effect on the reconstruction of the Compton scattered gammas into the full-energy peak, increased efficiency!

MINIBALL at CERN/ISOLDE

6-fold segmentation

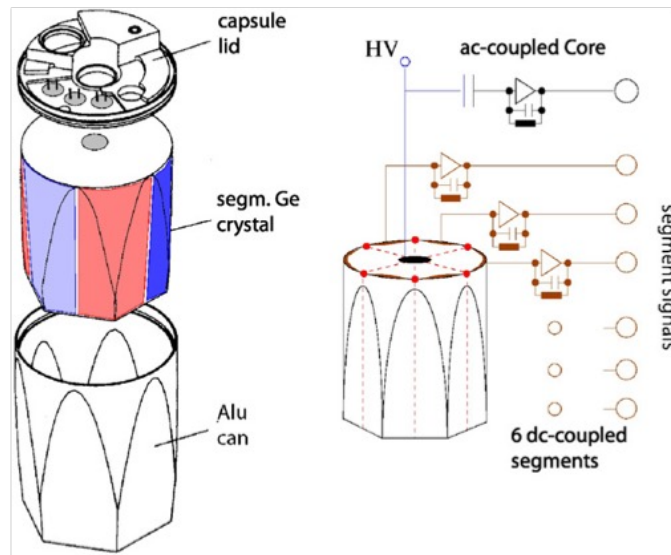
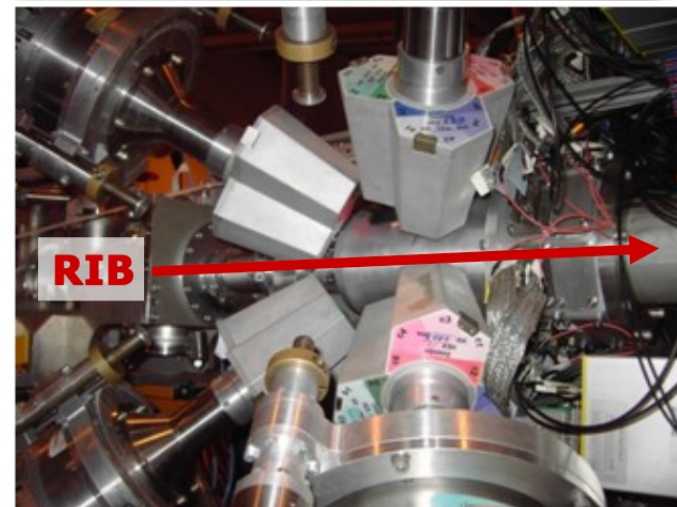
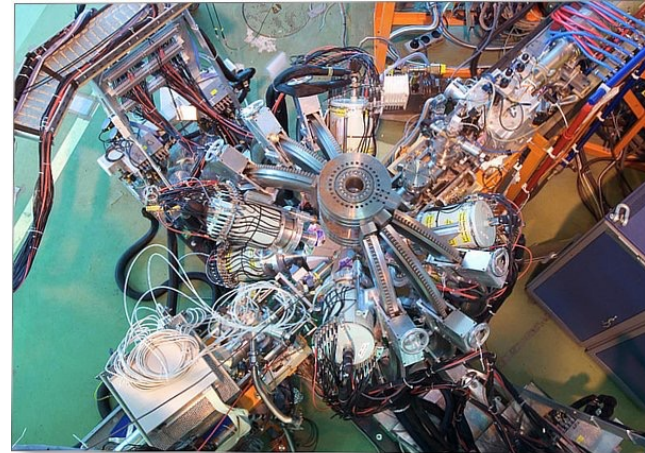


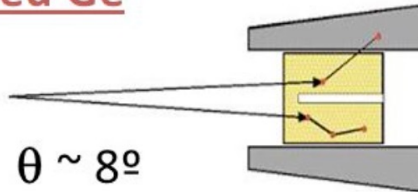
Fig. 23. The segmented MINIBALL detector.



Compton Shielded Ge

ϵ_{ph} ~ 10%
 N_{det} ~ 100

Ω ~ 40%



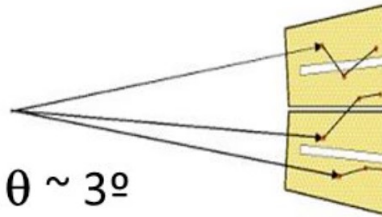
$\theta \sim 8^\circ$

large opening angle
means poor energy
resolution at high
recoil velocity

Compton
suppression

Ge Sphere

ϵ_{ph} ~ 50%
 N_{det} ~ 1000



$\theta \sim 3^\circ$

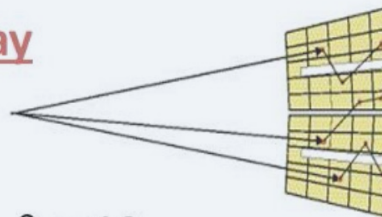
too many detectors
are needed to avoid
summing effects

ADDBACK

Ge Tracking Array

ϵ_{ph} ~ 50%
 N_{det} ~ 100

Ω ~ 80%



$\theta \sim 1^\circ$

Combination of:

- segmented detectors
- digital electronics
- pulse processing
- tracking the γ -rays

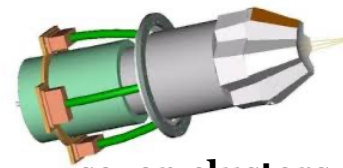
TRACKING

3- Higher segmentation allows for gamma-ray tracking. This has a direct effect on even better resolution and efficiency. In this way, we create a high-resolution, high-efficient Germanium array!

4π -Ge Arrays: Highly segmented *HPGe* arrays



triple clusters



seven clusters

36-fold segmentation

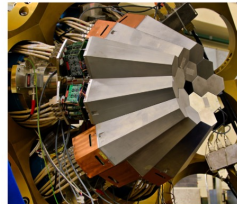
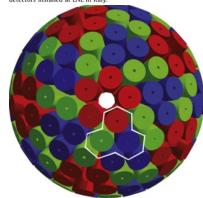
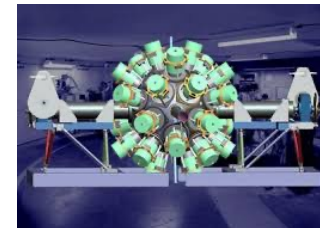
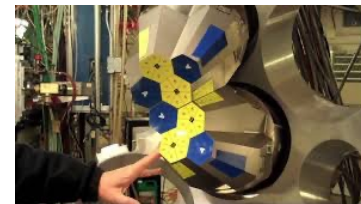


Fig. 6. (Colour online) Photograph of the setup with five AGATA triple cluster detectors installed at JINR, Ufa.

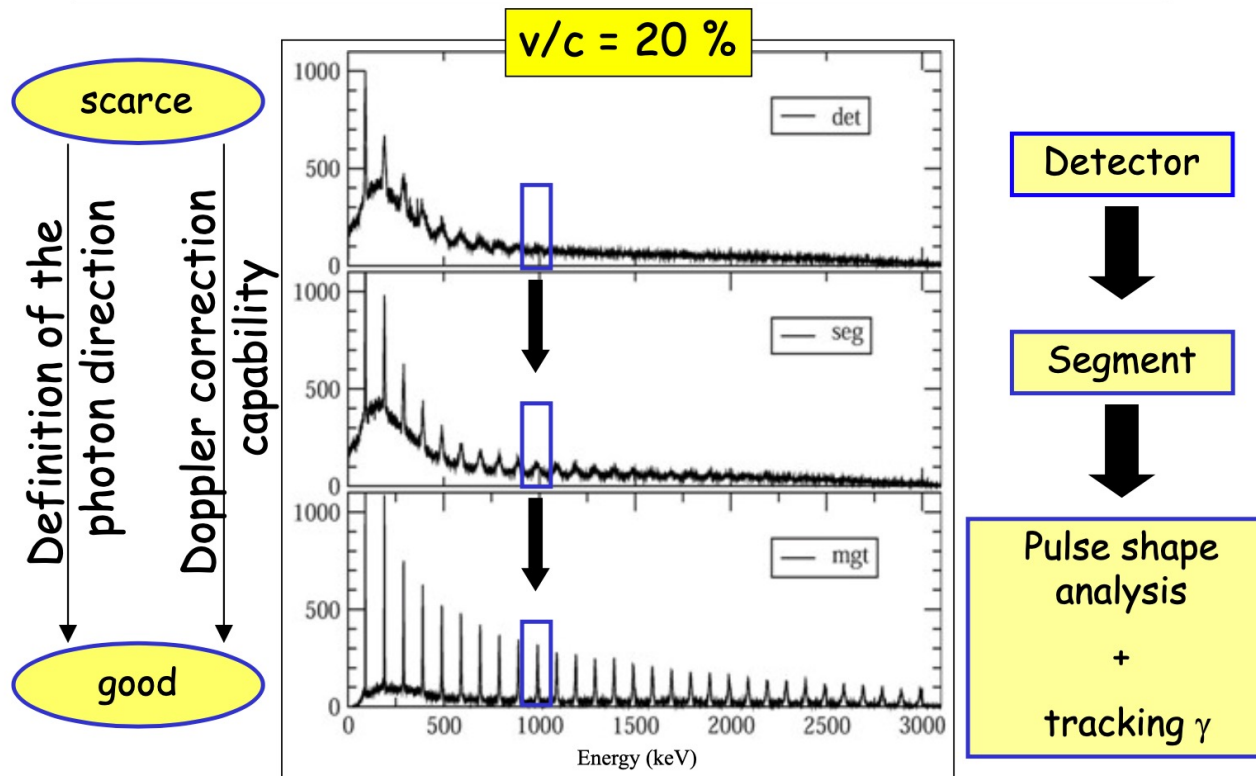


AGATA, Europe



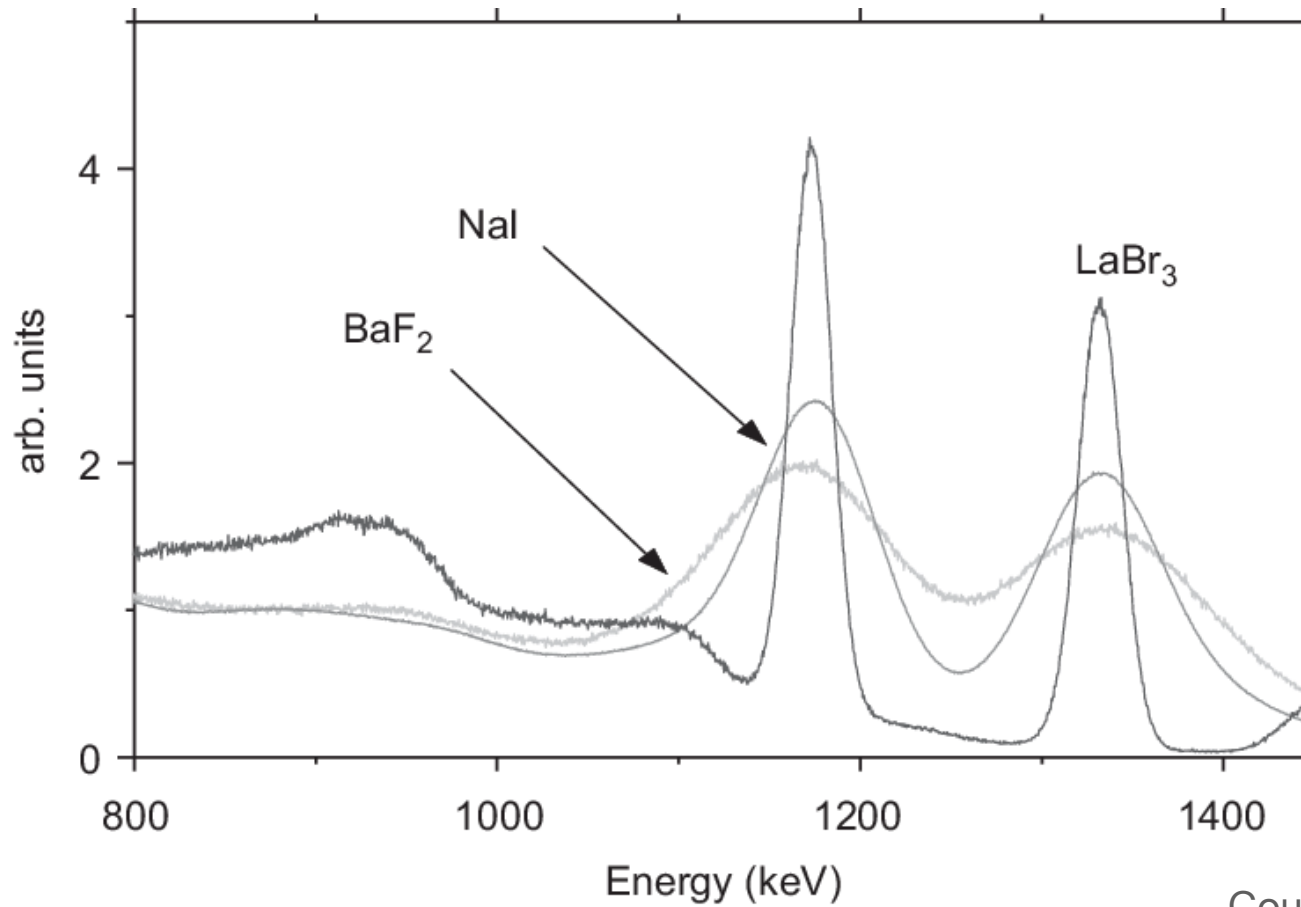
GRETA, USA

Benefits of the γ -ray tracking



Courtesy of Enrico Farnea,
LNL, INFN, Padova, Italy

Resolution comparison of some inorganic scintillators.



Courtesy of F. Crespy,
University of Milan, Italy.

DALI2 NaI(Tl) array at RIKEN, Japan: 186 crystals organised into 11 layers + a forward wall, covering 20°-150°

A gamma ray of 2.5 MeV is emitted when the nucleus is at rest, $\beta=0$

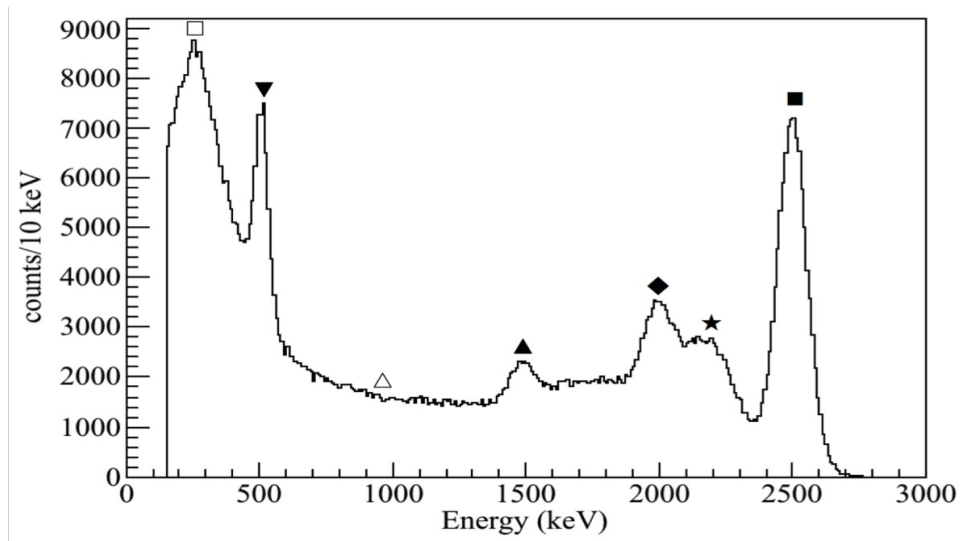
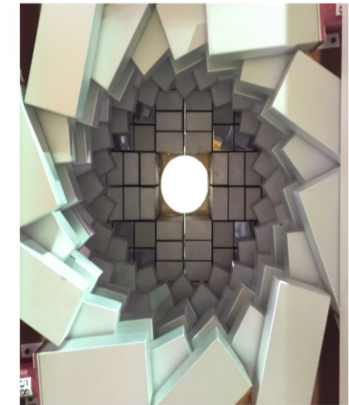
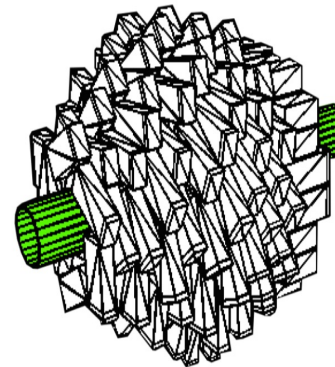


Figure 3.11: Simulated DALI2 response function for a γ ray with an energy of 2.5 MeV emitted by a source at rest ($\beta = 0$). The symbols on the spectrum indicate the most important parts of the spectrum and are explained in the text.

Geant4 simulations



Courtesy of V. Vaquero, PhD thesis, Madrid Univ.



?? The Case of the Missing 2.5 MeV Gamma Ray!

A detective activity on the DALI2 spectrum

One gamma ray.
Many clues.
What happened?



Mission briefing

A nucleus at rest emits a single gamma ray with an energy of **2.5 MeV**. Our DALI2 NaI(Tl) detector array at RIKEN records the event.



DALI2 NaI(Tl) array at RIKEN, Japan: 186 crystals organised into 11 layers + a forward wall, covering 20°–150°



Your mission

Identify the physical process responsible for each symbol in the spectrum.

You have 3 minutes to discuss in pairs and solve the case!

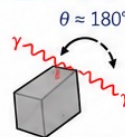


Clues

- The spectrum is a simulation for a 2.5 MeV γ ray emitted at rest ($\beta = 0$) and detected with DALI2.
- Each symbol ($\square$, $\star$, $\triangle$, $\diamond$, ∇ , $\blacksquare$) marks an important feature in the spectrum.
- Each feature has a different physical origin.
- Use what you know about gamma-ray interactions in matter!

1. $\square$

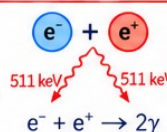
This gamma ray scatters in the surrounding material (detector housing, support structure, etc.) at a large angle (close to 180°) and is then detected with reduced energy.



Process name: _____
Peak: _____

2. $\star$

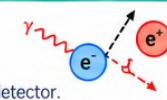
After pair production, the electron and positron annihilate, producing two 511 keV gamma rays. One of these 511 keV photons is detected in the detector.



Process name: _____
Peak: _____

3. $\diamond$

The 2.5 MeV gamma ray undergoes pair production. Both 511 keV annihilation photons escape from the detector.



Process name: _____
Peak: _____

A gamma ray of 2.5 MeV is emitted when the nucleus is at rest, $\beta = 0$

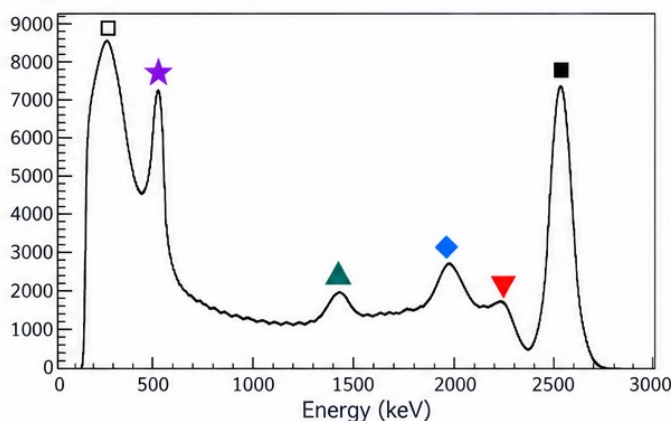
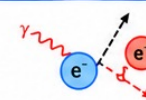


Figure: Simulated DALI2 response function for a γ ray with an energy of 2.5 MeV emitted by a source at rest ($\beta = 0$). The symbols on the spectrum indicate the most important parts of the spectrum and are explained in the text.

Courtesy of V. Vaquero, PhD thesis, Madrid Univ.

4. $\triangle$

The 2.5 MeV gamma ray undergoes pair production. One of the 511 keV annihilation photons escapes from the detector.



Process name: _____
Peak: _____

5. ∇

This is the end point of the Compton continuum. The gamma ray scatters in the detector, transfers part of its energy to an electron, and escapes.



Process name: _____
Peak: _____

6. $\blacksquare$

This gamma ray is completely absorbed in the detector, depositing all its energy (2.5 MeV). No energy escapes!



Process name: _____
Peak: _____



Final challenge: NaI(Tl) vs HPGe – will all these features disappear?

Question:

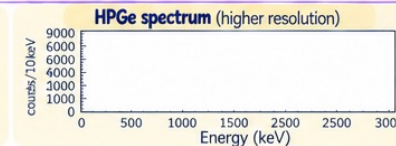
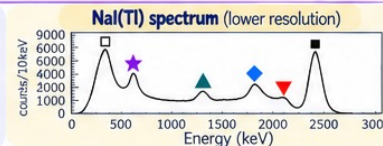
If we replace the NaI(Tl) array with an HPGe detector, will all these features disappear?

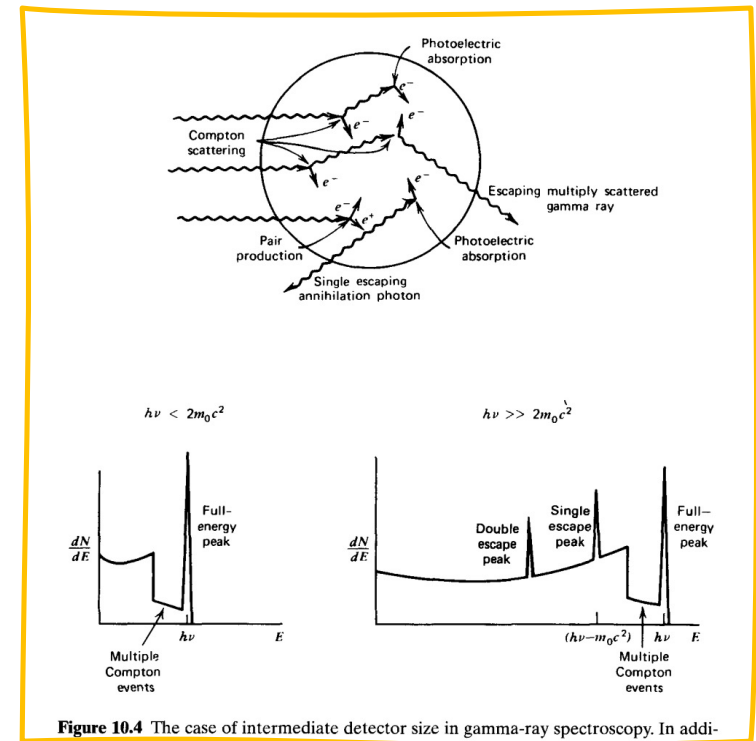
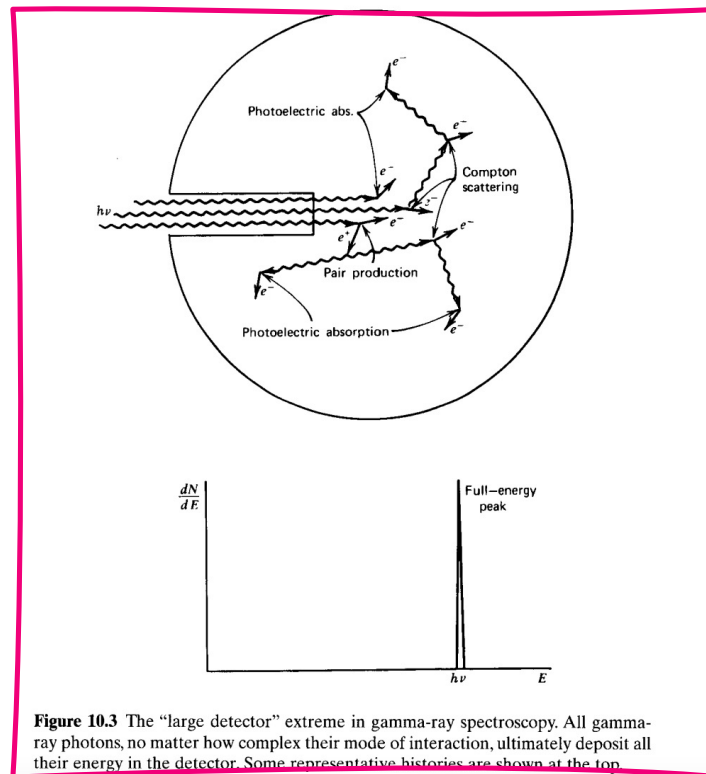
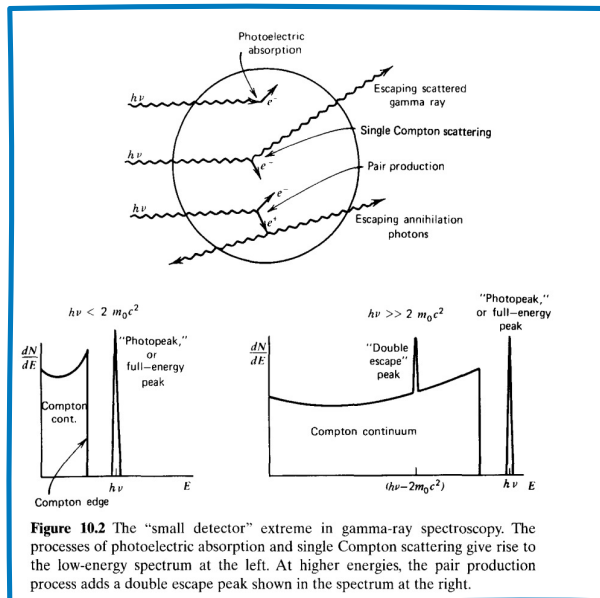


NaI(Tl) HPGe

Hint:

The same interaction processes still occur (Compton scattering, pair production, etc.), so the same features are present. However, the peak widths and the ability to resolve the features are much better with HPGe due to its superior energy resolution.





Which size of detector did we use in the NaI experiment?

Particle, Gamma, Electron spectroscopy

1. Particle identification E-DE technique
2. Gamma spectroscopy
3. **Electron spectroscopy**

Internal conversion electron spectroscopy

internal conversion:

- The excitation energy is transferred directly to electrons near the nucleus and these electrons fly away from the atom.
- The process is called “internal conversion” and the emitted electrons are called (internal) “conversion electrons”.
- It is an electromagnetic process and compete with the emission of gamma rays.

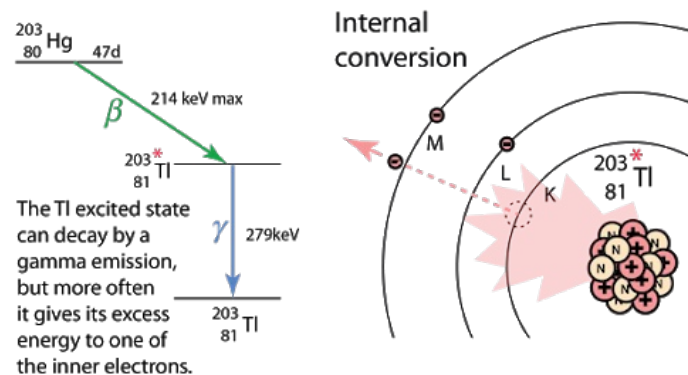
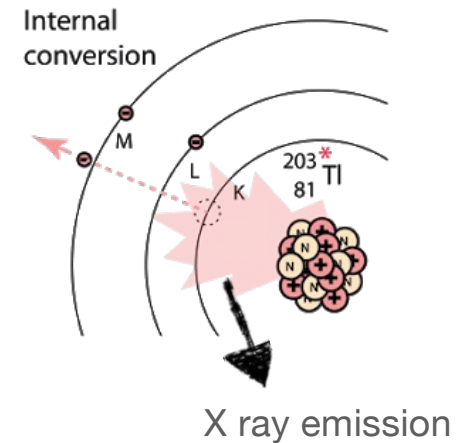
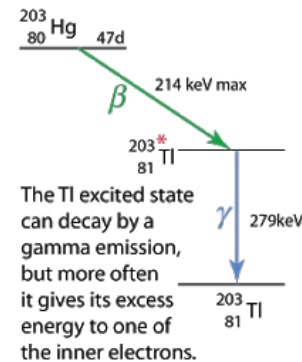
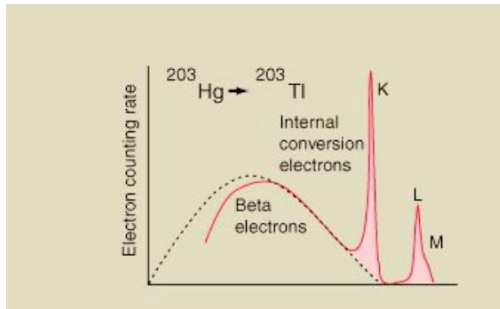


Figure: <http://hyperphysics.phy-astr.gsu.edu/hbase/Nuclear/radact2.html>

Example of ^{203}Hg decay:



Internal conversion

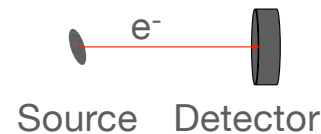
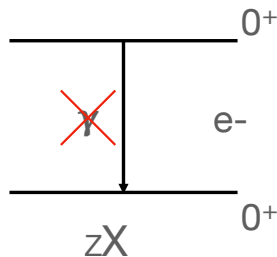
- a) different than beta decay (In IC, electron already exists in an atomic orbit and is therefore not created)
- b) Not a two-step process (i.e., first a photon is emitted by the nucleus and then interacts with an orbiting electron via PA)

$0^+ \rightarrow 0^+$ Transition

The internal conversion is the only mode for the $0^+ \rightarrow 0^+$ transition in nuclei (E0)

Higher-energy internal conversion can be observed

Very important for understanding structure of nuclei such as sudden deformation and shape changes so-called shape coexistence



- Large backgrounds from decays and reaction products cover electron conversion peaks
- The aim is to separate conversion electrons and suppress the unwanted background

How do we detect internal conversion electrons?

NUCLEAR INSTRUMENTS AND METHODS 98 (1972) 1-8; © NORTH-HOLLAND PUBLISHING CO.

CONVERSION ELECTRONS SEPARATED FROM HIGH BACKGROUND

J. VAN KLINKEN* and K. WISSHAK

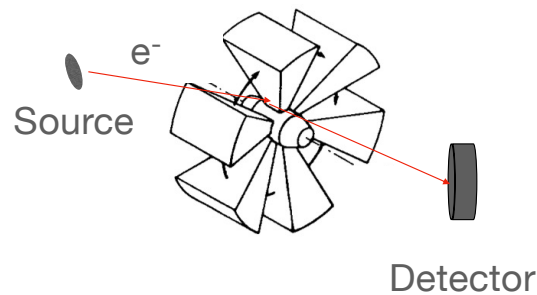
Kernforschungszentrum Karlsruhe, Zyklotronlaboratorium, Karlsruhe, Germany

II. Physikalisches Institut der Universität Heidelberg, Heidelberg, Germany

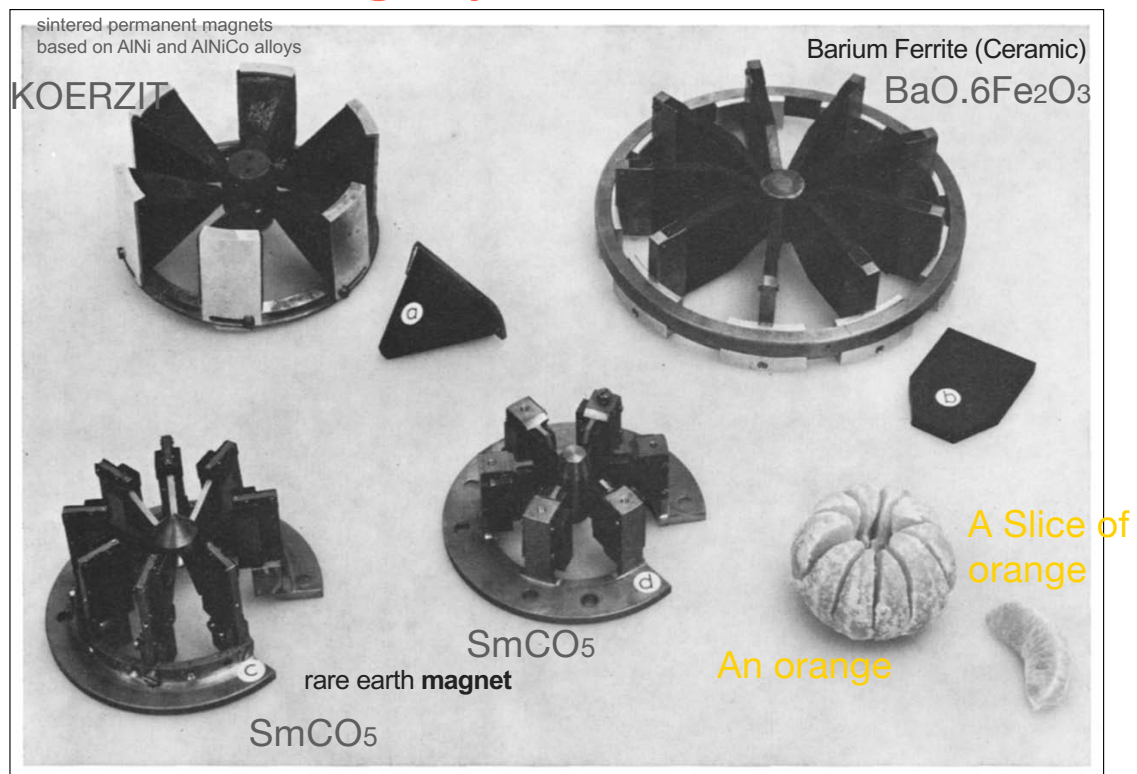
Received 20 September 1971

A mini-orange-type combination of permanent magnets can separate electrons from positrons. Used as a filter in front of a Si(Li) detector, the magnet system enhances the detection efficiency of conversion electrons and suppresses the influence of β^+ -, α -, p- and γ -radiation. It improves peak-to-background

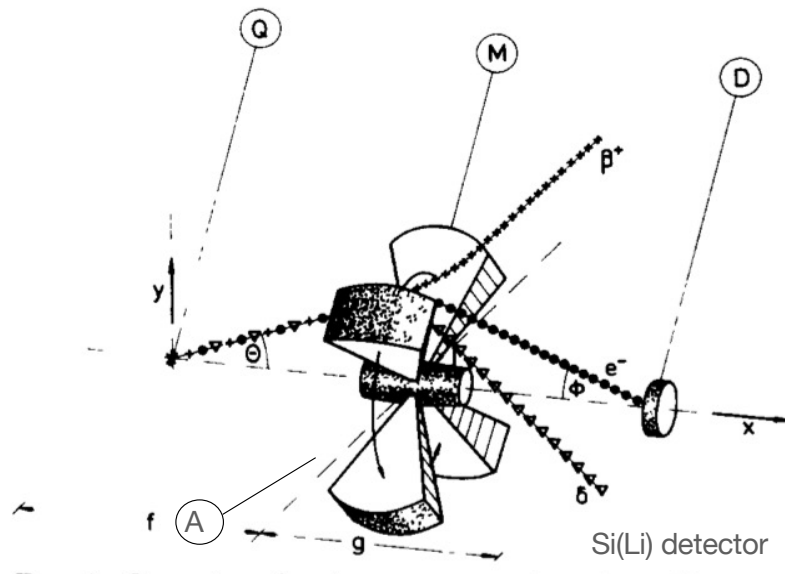
ratios by a factor of up to 80. The system has been applied for energies between 0.03 and 1 MeV, using different magnet configurations. The corresponding transmission curves have full widths at half maximum between 0.15 and 0.4 MeV.



Mini-Orange Spectrometers, MOSs



J. Van Klinken et al., NUCLEAR INSTRUMENTS
AND METHODS 130 (1975) 427



W.NEUMANN et al.,NUCLEAR INSTRUMENTS AND METHODS 164 (1979) 539-545

The setup consists of
a **Si(Li) detector (D)**
a filter of permanent magnets (M)
a central absorber of lead or tungsten (A)
a source (Q)

Permanent magnets are materials where the magnetic field is generated by the internal structure of the material itself. "hard" ferromagnetic materials such as alnico and ferrite

Si(Li) detector (2-3cm² area)
Larger detectors have poorer energy resolution

2,3, and 5 mm of thickness

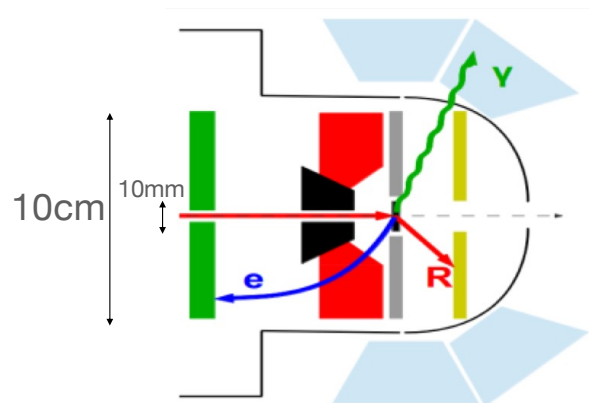
The central absorber suppresses γ -rays and stops X-rays, α -rays and high-energy β^- rays.

Filter provides a toroidal magnetic field

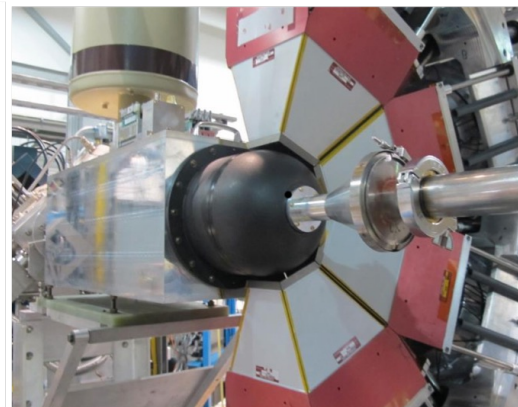
The field is designed to bend the electrons in a toroidal path around the central absorber and towards the detector.

Needs cooling because of Lithium with high mobility.

SPICE array at TRIUMF, CANADA



R: Recoiling heavy ions



SPICE consists of an **electron detector**, **photon shield** and a **magnetic lens**.

Si(Li) detector (6.1 mm thick)
Detector is **segmented** into 12 segments
and 10 rings: 120 pixels
Cooling via liquid nitrogen
FWHM < 5 keV resolution

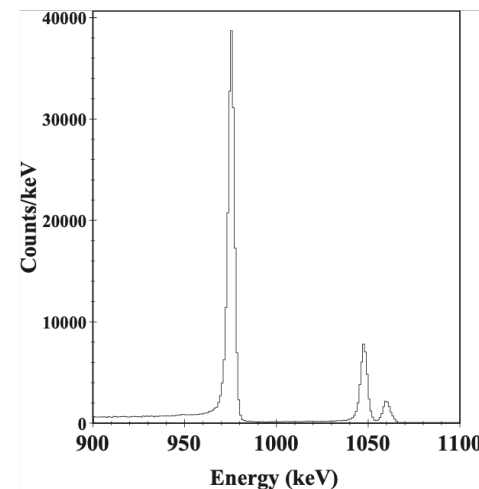


Figure 2. Raw electron spectrum in SPICE from a ^{207}Bi source, showing three distinct peaks of the K, L and M electrons associated with the 1063.7-keV γ ray. This clearly demonstrates the impressive optimum experimental resolution SPICE can achieve with FWHM = 4.5 keV at 1 MeV.

Questions to you

- Can we use the Bethe-Bloch formula for the ΔE -E technique for particle identification in nuclear physics experiments? ? Give an example.
- Can we use this technique in High-energy Physics? Give an example.
- What are the main reasons of choosing silicon or ionization chamber for charged-particles for a given experiment?
- What is “gamma ray spectroscopy”? How do we typically calibrate gamma ray detectors? Why should we use gamma ray sources with energy transitions in the full energy range we are interested in?
- Compare a typical gamma-ray pulse-height spectrum in organic and inorganic scintillator detector. Which one would you choose?
- Does the volume of the detector matter? Can you draw a pulse height spectrum for 662-keV gamma-ray energy for NaI(Tl) detector in “small” and “large” dimensions?
- Imagine a gamma ray source that emits only 2 MeV photons. Compare the measured pulse-height spectrum for a typical Germanium detector and NaI(Tl).
- What are the sources of 511 keV peak in the gamma-ray spectra?
- What type of detection system is used for internal-conversion spectroscopy? What is done in modern detection systems to improve the resolution?