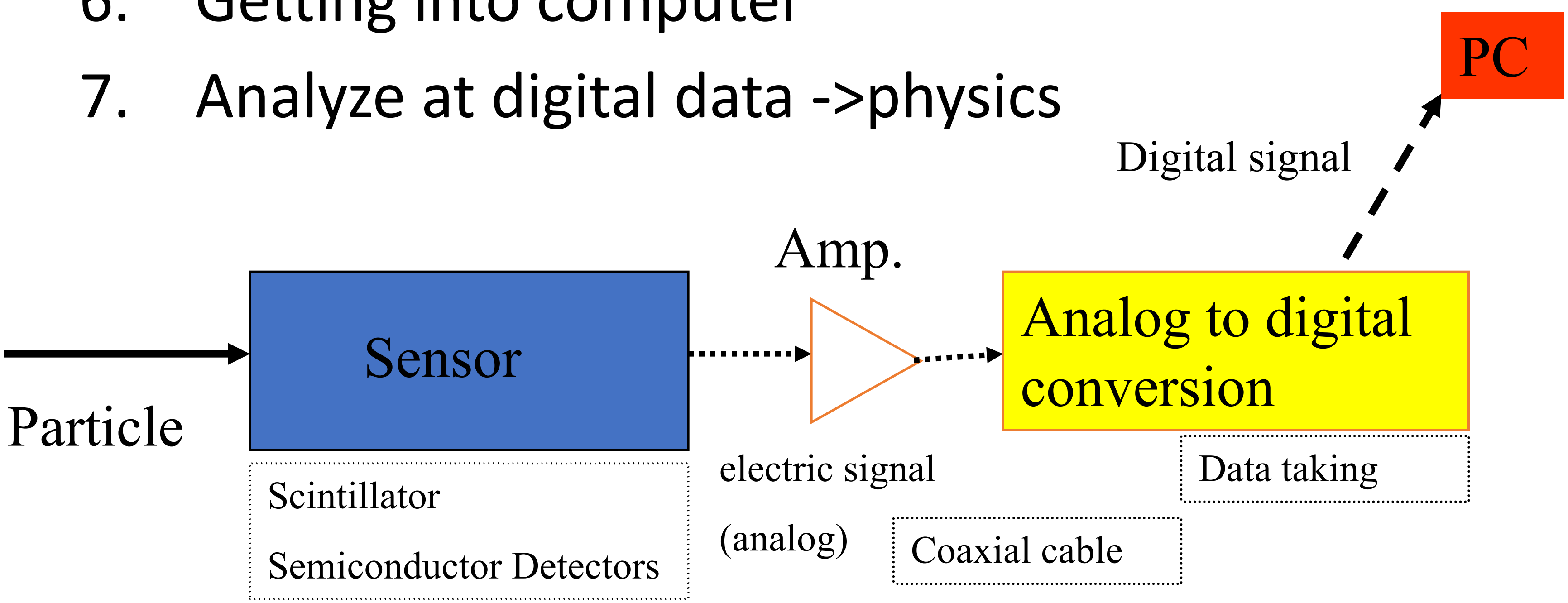
Major Detector Principle

1. Particle penetrates or stops at detector
2. Particle interacts with material of detector
3. Generating some signal
4. Amplification mechanism
5. Analog to Digital conversion
6. Getting into computer
7. Analyze at digital data ->physics



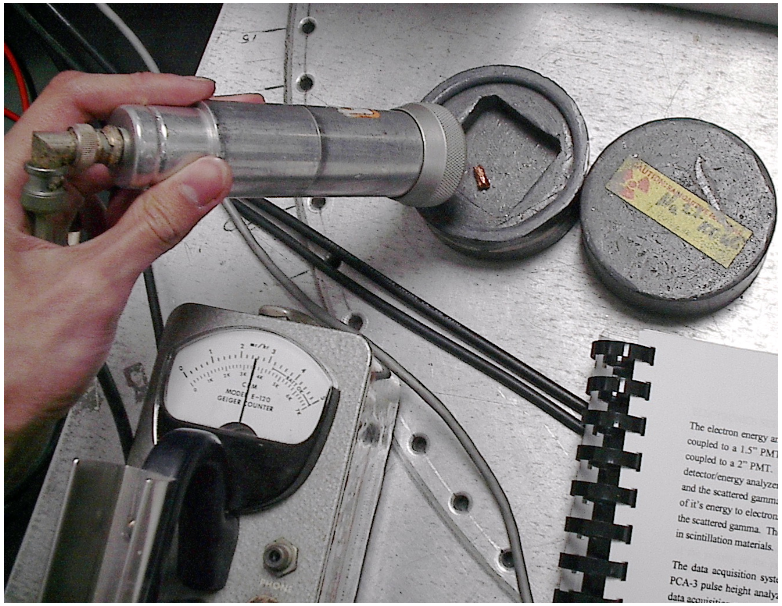
Introduction

What do we mean by particle detection?

- Counting

- Spectroscopy
  - Gamma-ray spectroscopy
  - Charged-particle spectroscopy
  - Decay spectroscopy

- Particle Identification
  - Nuclei: *Z, A*
  - Neutron, gamma??



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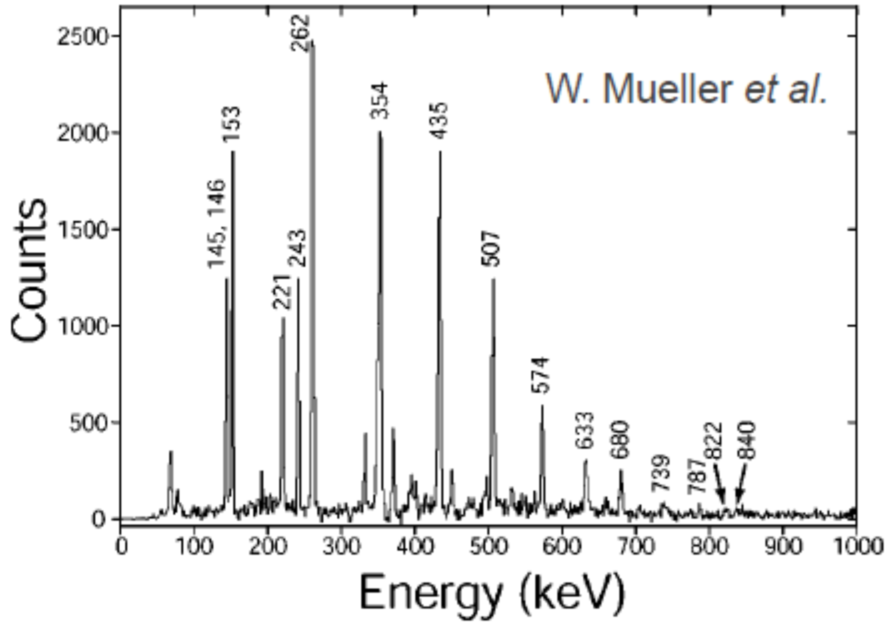

- Particle Identification
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Introduction

What do we mean by particle detection?

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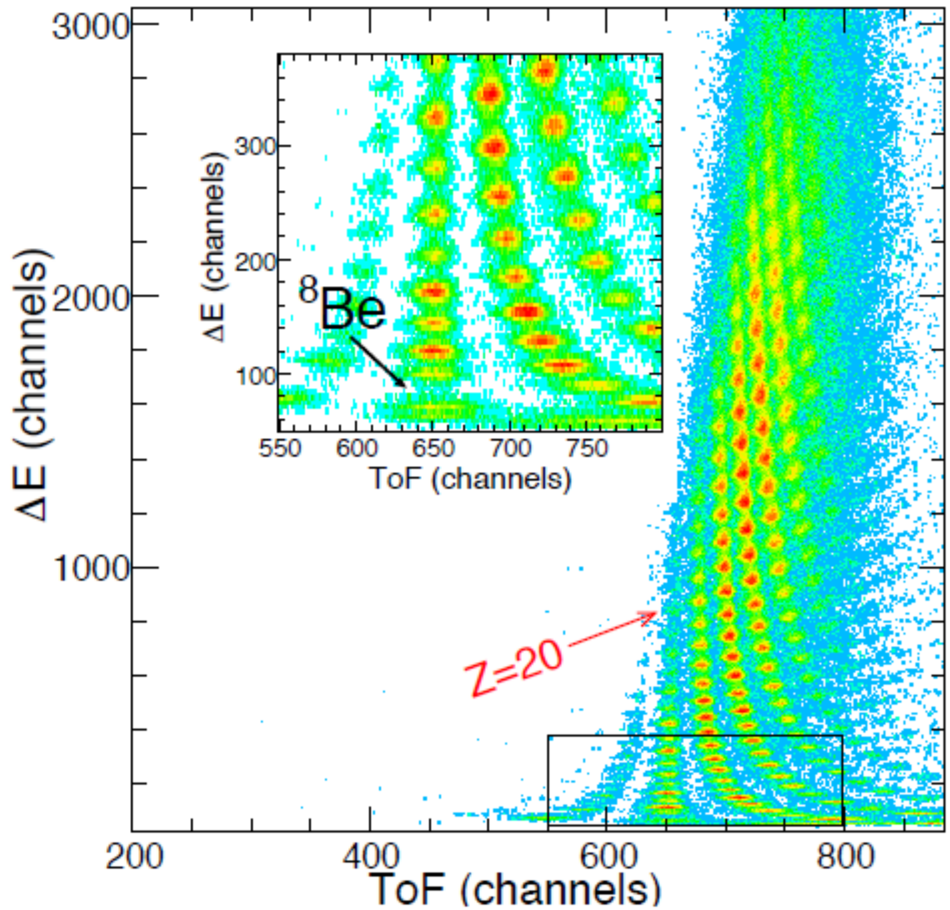
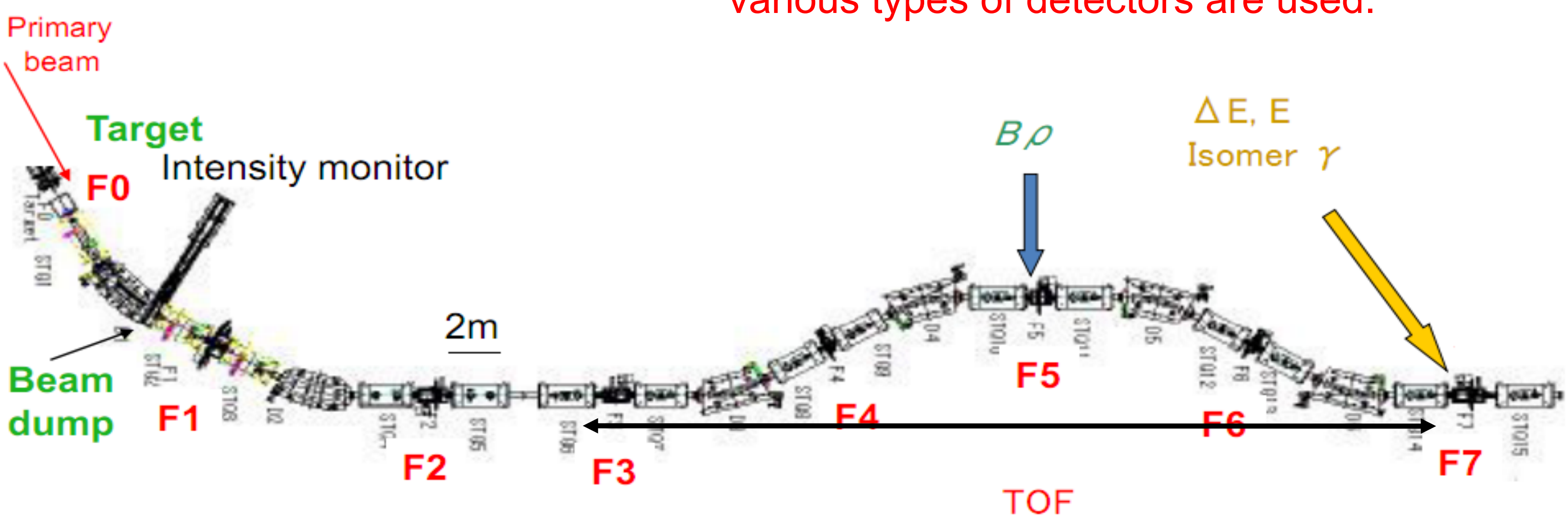
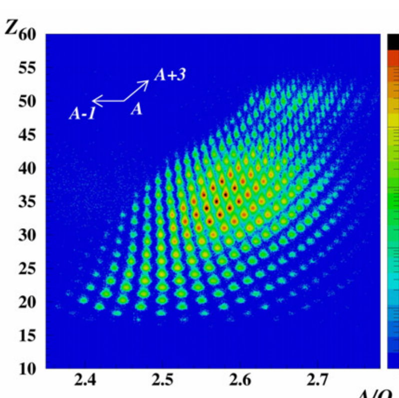


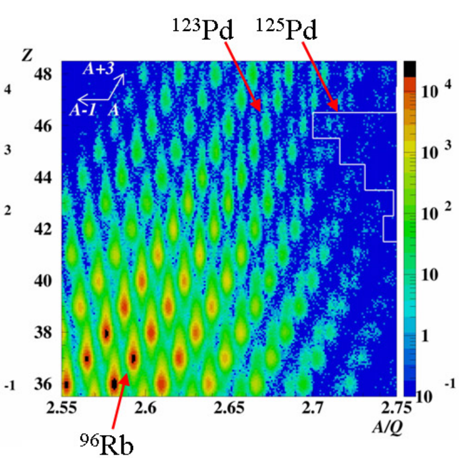
Detectors in Accelerator Line

BigRIPS RIKEN, Japan

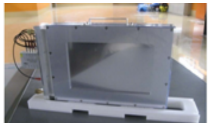
Depending on the type of particle and its energy various types of detectors are used.

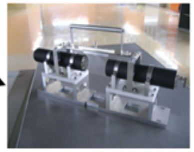


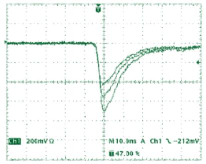


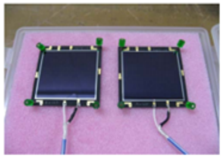


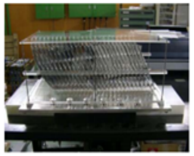
Bρ	: PPAC
TOF	: Plastic
ΔE	: Si, IC
E	: NaI
γ	: Ge





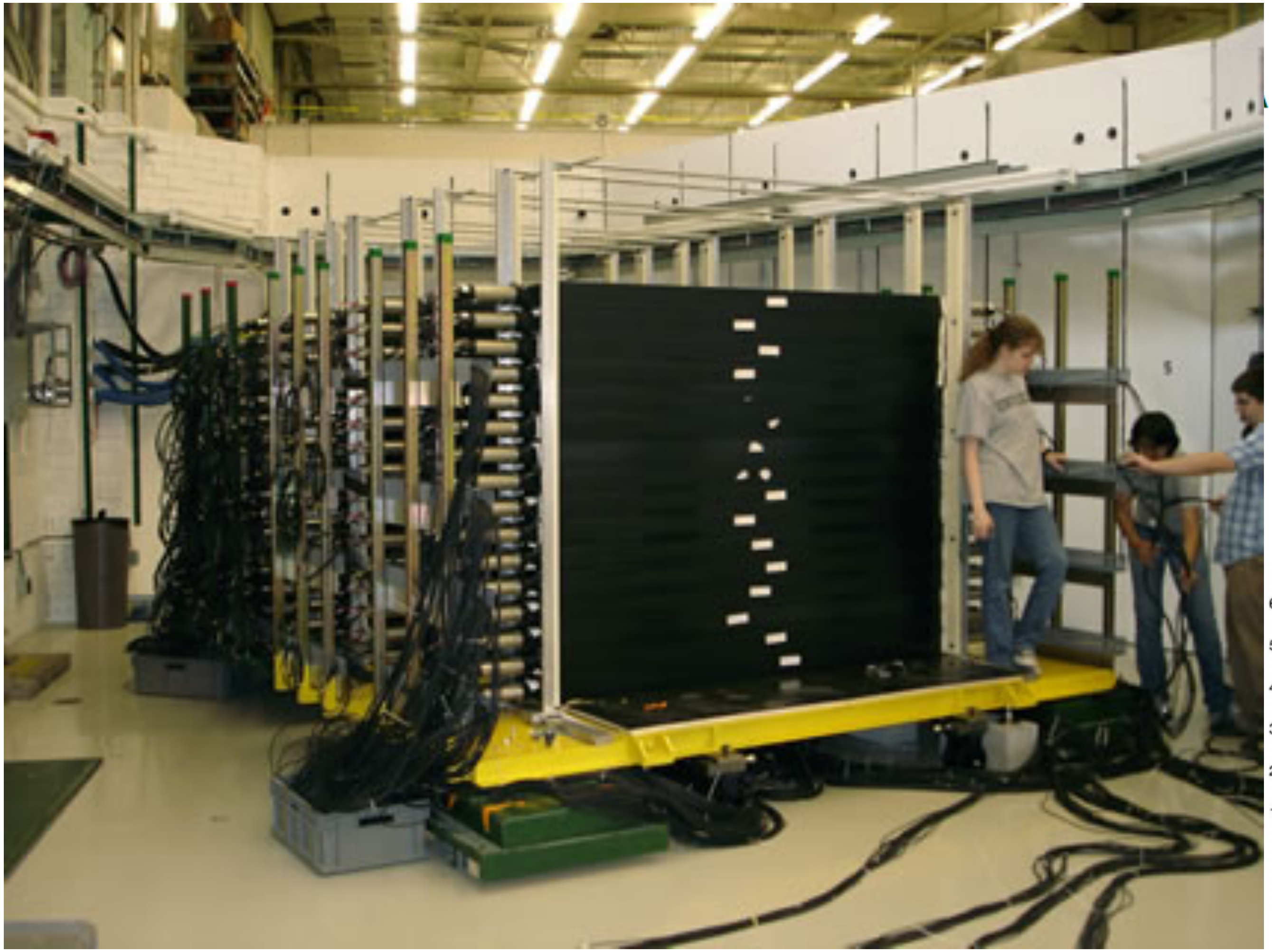


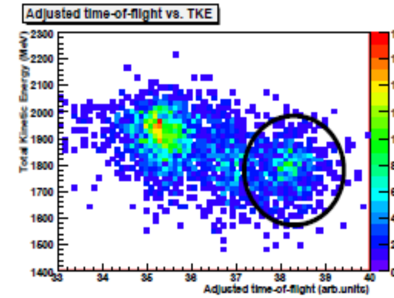


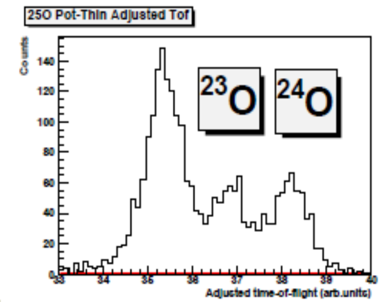


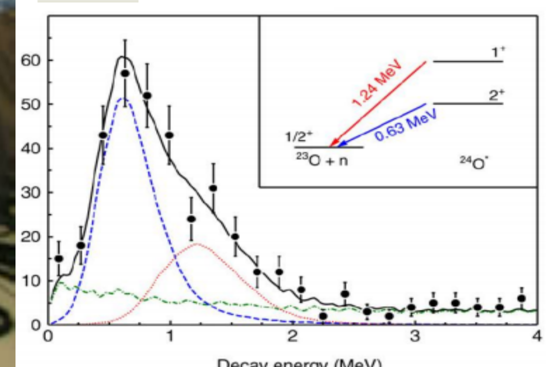
Detection System – Nuclear Physics

Spectroscopy of neutron-unbound systems NSCL,MSU





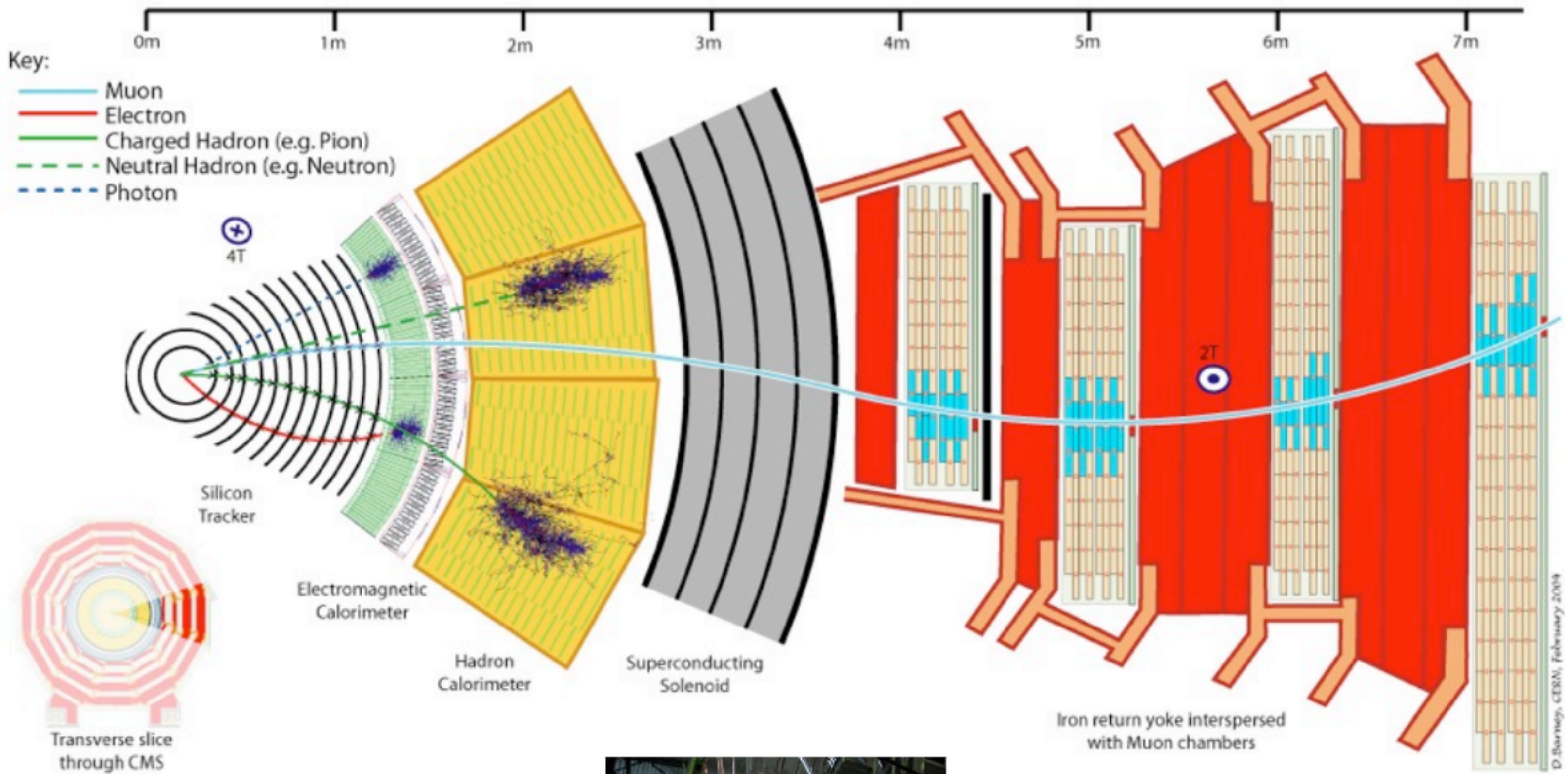


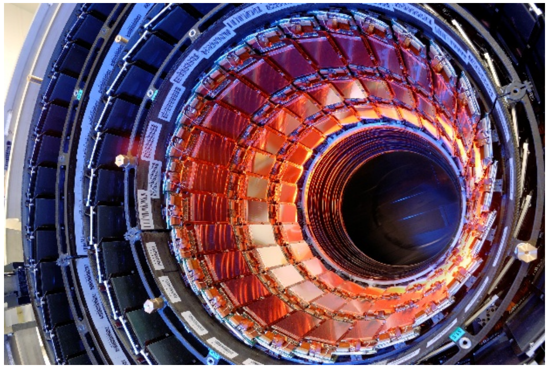


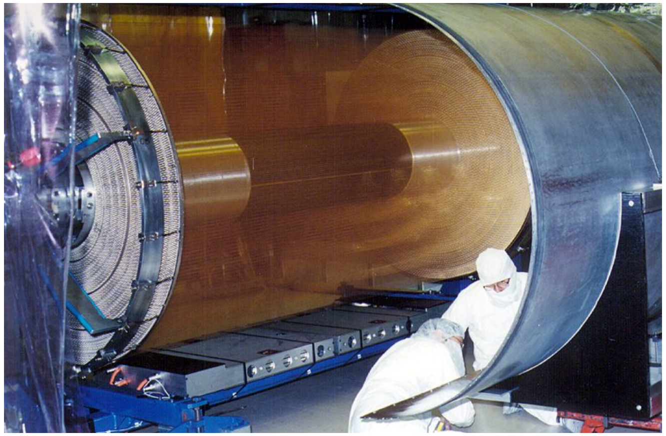
C.R. Hoffman* *et al.*, PLB 672, 17 (2009)

^{24}O

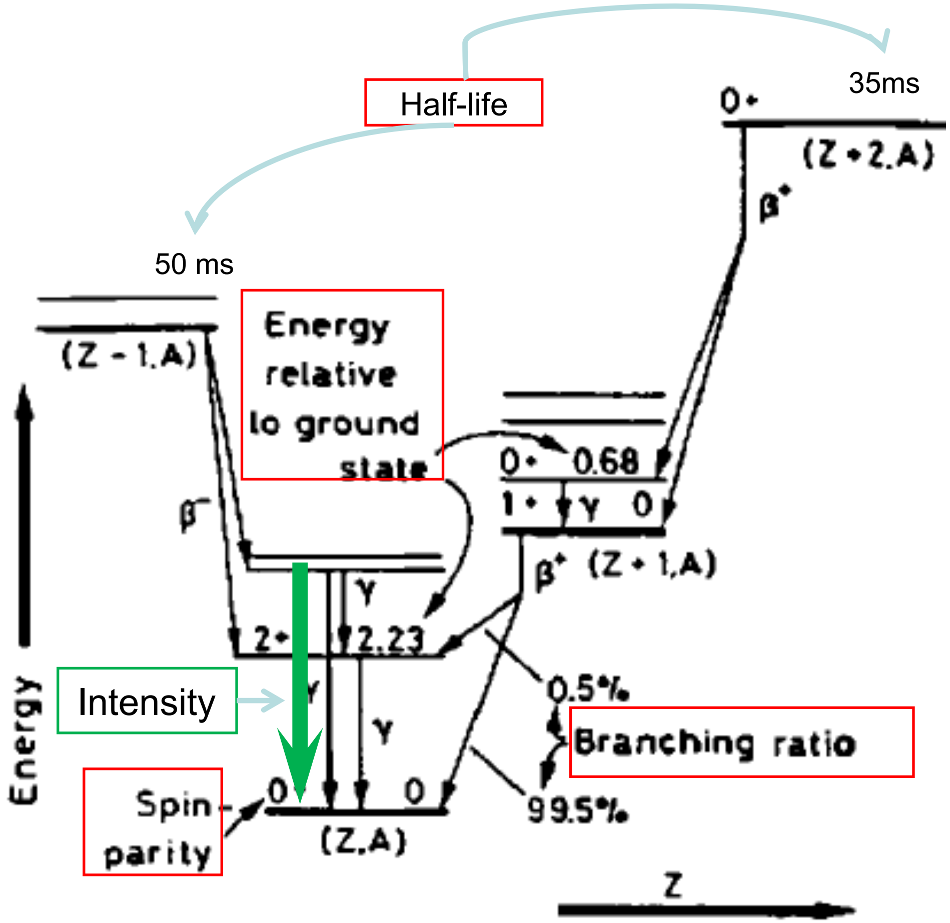
Detection System – Particle Physics

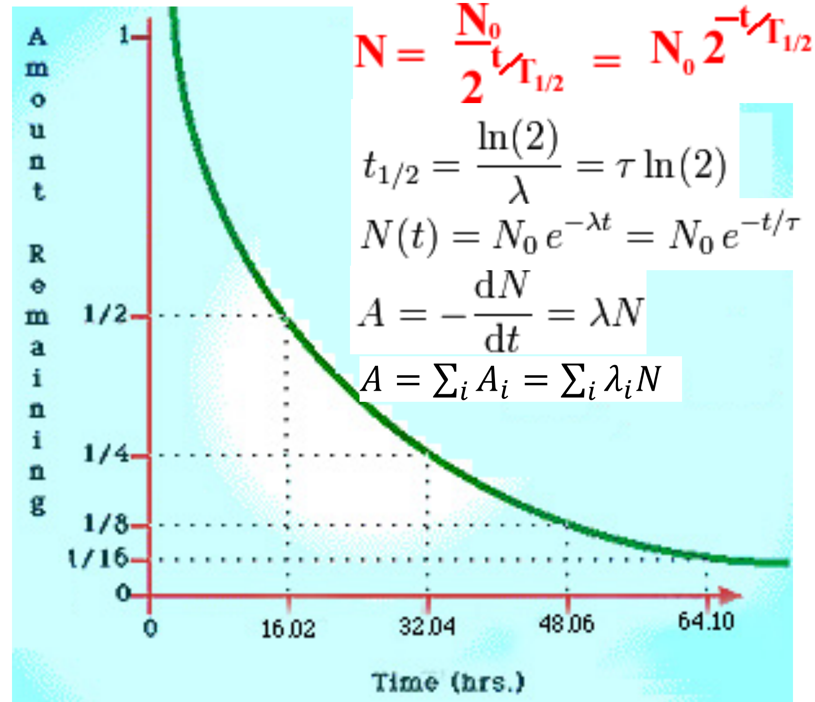






Nuclear Level Diagrams





$$N = \frac{N_0}{2^{t/T_{1/2}}} = N_0 2^{-t/T_{1/2}}$$

$$t_{1/2} = \frac{\ln(2)}{\lambda} = \tau \ln(2)$$

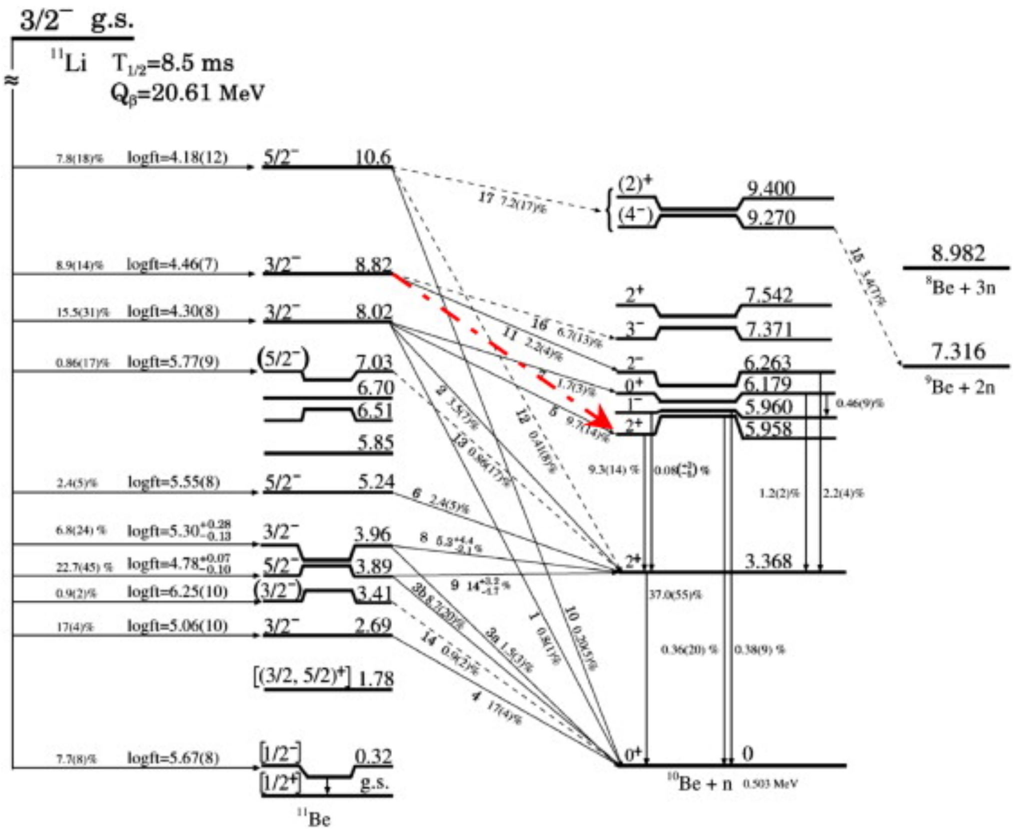
$$N(t) = N_0 e^{-\lambda t} = N_0 e^{-t/\tau}$$

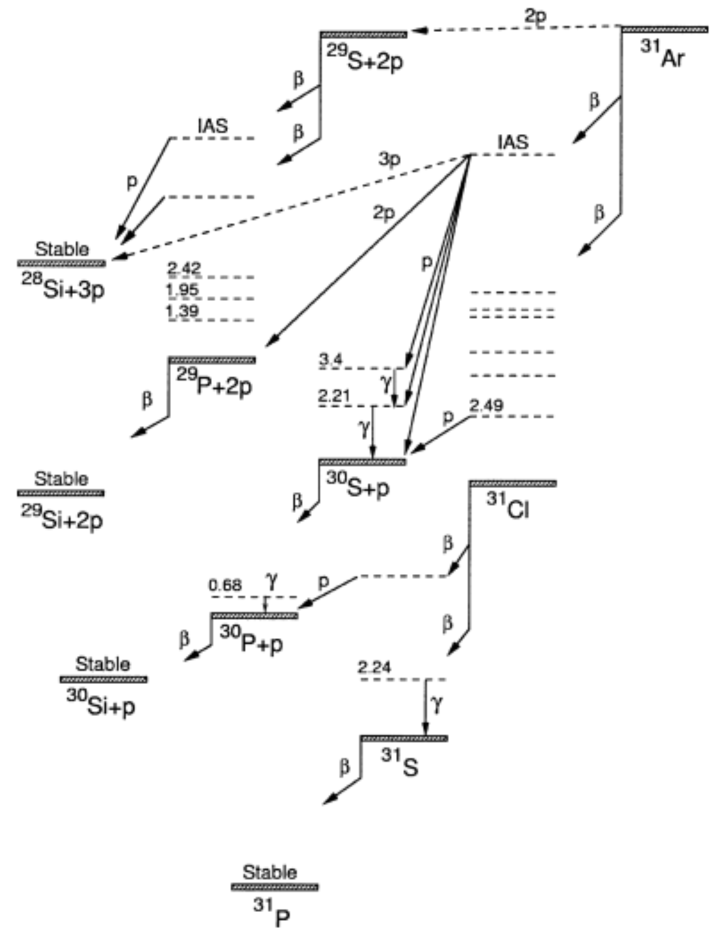
$$A = -\frac{dN}{dt} = \lambda N$$

$$A = \sum_i A_i = \sum_i \lambda_i N$$

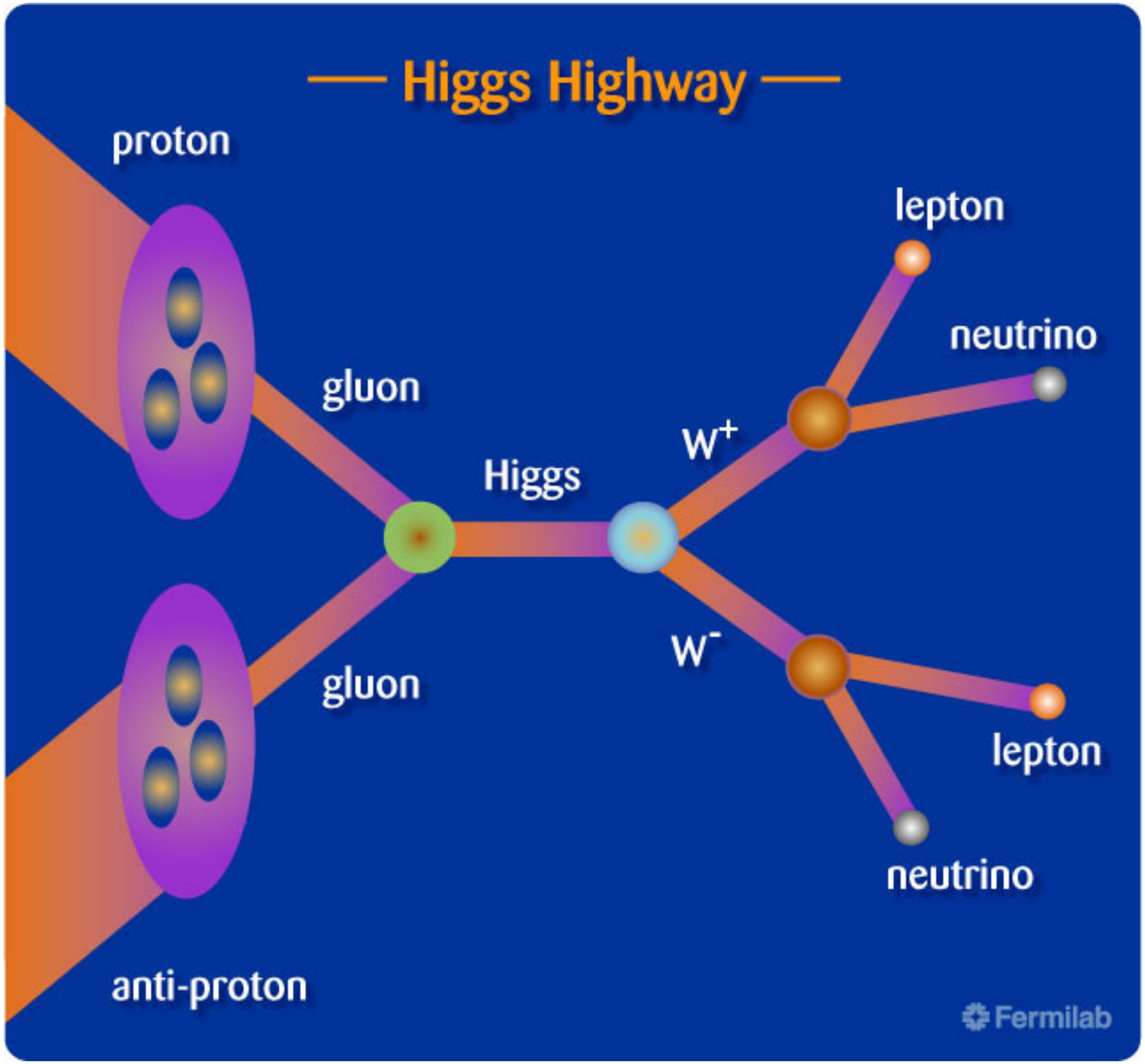
- Excitation energy， Spin/Parity
- Decay mode(α,β,EC..)
- Branching ratio: $BR = A_i/A = \lambda_i/\lambda$
- Half-life/lifetime :
  partial half-life: $T_{1/2,i} = ln2/\lambda_i$
- Relative/absolute Intensity

β-decay of ^{11}Li and ^{31}Ar





Higgs Highway



Beta-decay

β^- $n \rightarrow p + e^- + \bar{\nu}$ $^{14}C \rightarrow {}^{14}N + e^- + \bar{\nu}$ $Q_{\beta^-} = M(A,Z) - M(A,Z+1)$ $Q_{\beta^-} = (T_e)_{max} = (T_\nu)_{max}$

β^+ $p \rightarrow n + e^+ + \nu$ $^{13}N \rightarrow {}^{13}C + e^+ + \nu$ $Q_{\beta^+} = M(A,Z) - M(A,Z-1) - 2m_e c^2$

Because beta decay is a three body decay, the electron energy spectrum is a continuum

Continuous energy spectrum

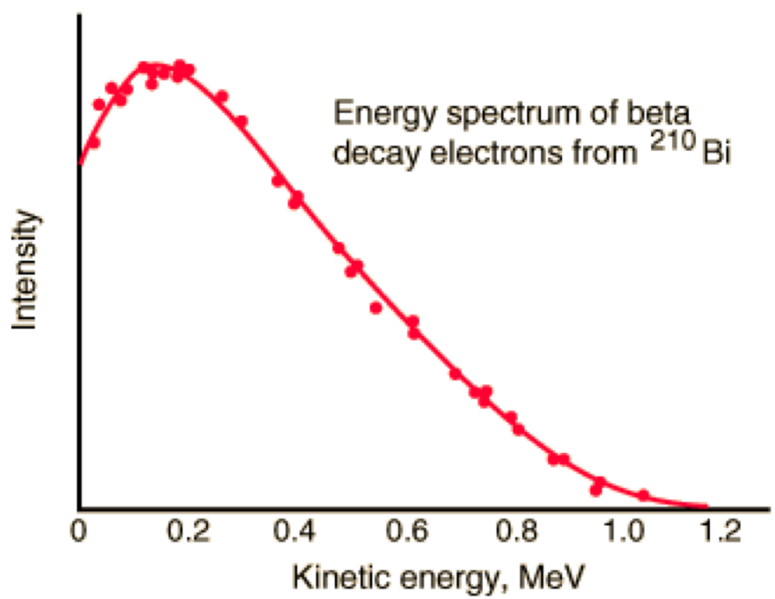
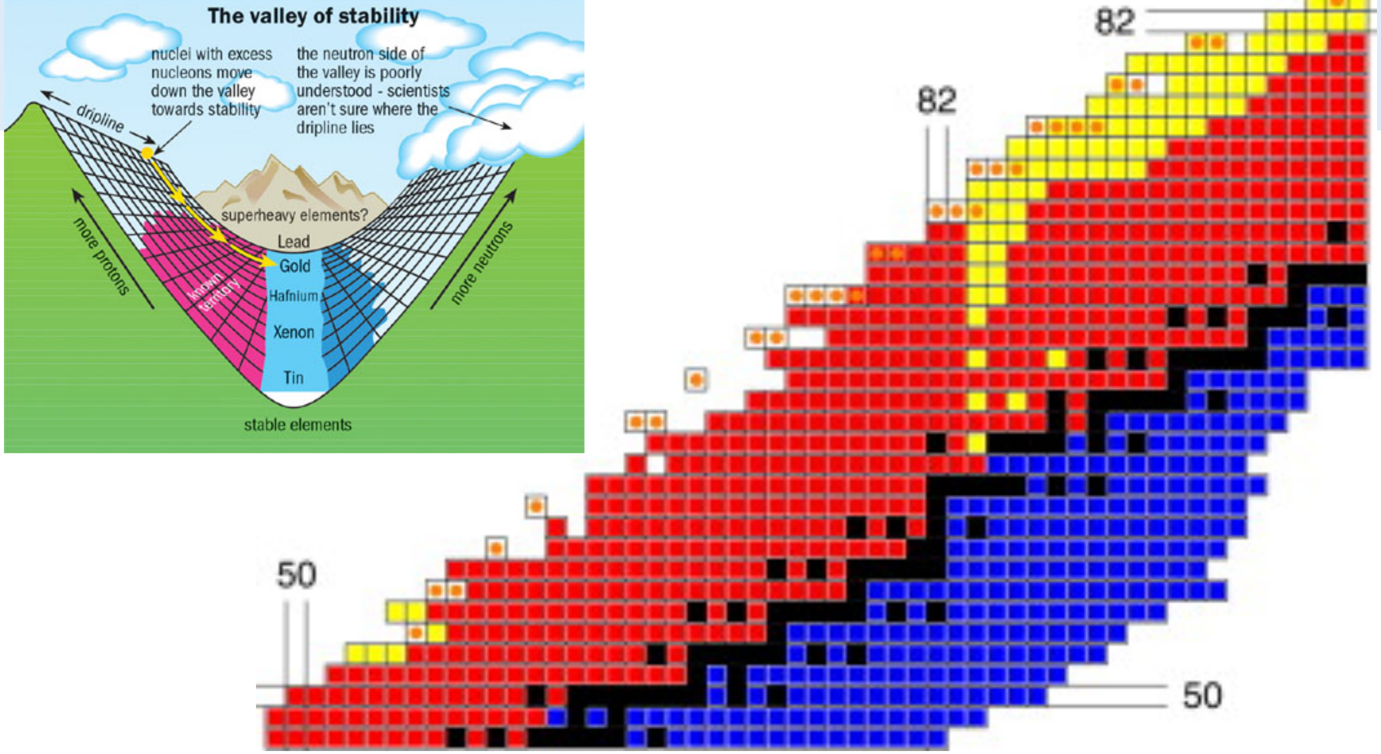


Table 1.1 Some "Pure" Beta-Minus Sources

Nuclide	Half-Life	Endpoint Energy (MeV)
^{3}H	12.26 y	0.0186
^{14}C	5730 y	0.156
^{32}P	14.28 d	1.710
^{33}P	24.4 d	0.248
^{35}S	87.9 d	0.167
^{36}Cl	3.08×10^5 y	0.714
^{45}Ca	165 d	0.252
^{63}Ni	92 y	0.067
$^{90}Sr/^{90}Y$	27.7 y/64 h	0.546/2.27
^{99}Tc	2.12×10^5 y	0.292
^{147}Pm	2.62 y	0.224
^{204}Tl	3.81 y	0.766

Like alpha sources, beta sources must be thin because of dE/dx losses



Proton-rich β^+

Stable

Neutron-rich β^-

Electron Capture(EC)

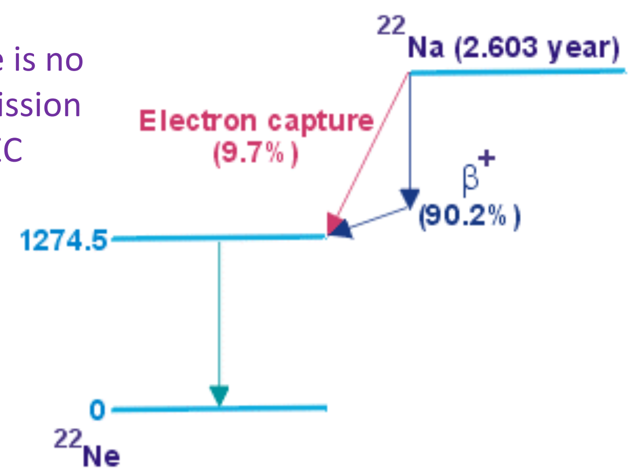
$$e^- + p \rightarrow n + v$$

$$e^- + {}^{207}_{83}\mathrm{Bi} \rightarrow {}^{207}_{82}\mathrm{Pb} + v_e$$

EC follows by the emission of a characterisitic x-ray or Auger electrons

EC can occur for mass differences < $2m_ec^2$

In 10% there is no positron emission because of EC



Alpha-decay

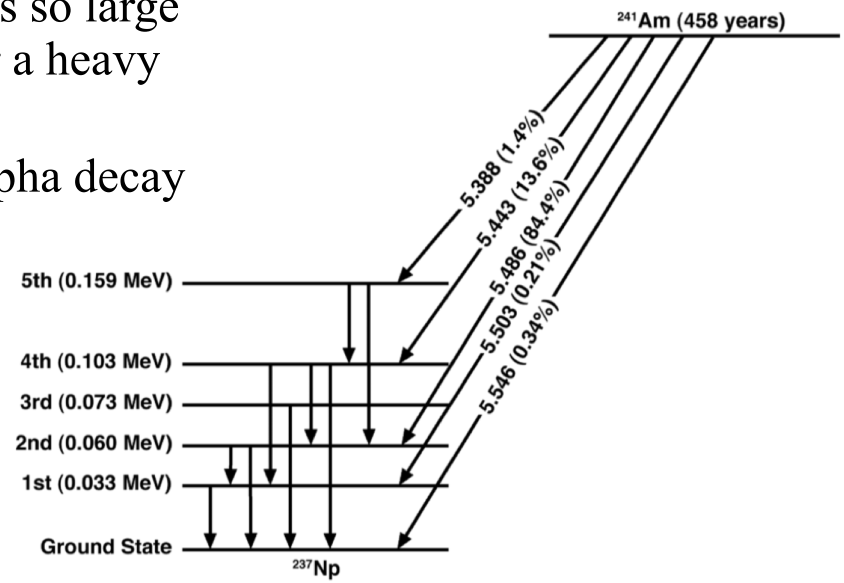
- Because the binding energy of the alpha particle is so large (28.3 MeV), it is often energetically favorable for a heavy nucleus to emit an alpha particle
    - Nuclides with A>150 are unstable against alpha decay

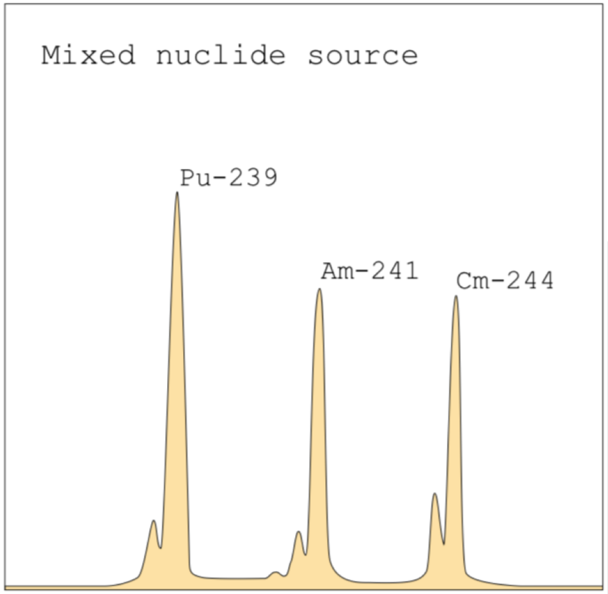
$$^{A}_{Z}X \rightarrow ^{A-2}_{Z-2}Y + ^{4}_{2}\alpha$$

$$^{241}_{95}Am \rightarrow ^{237}_{93}Np + ^{4}_{2}\alpha$$

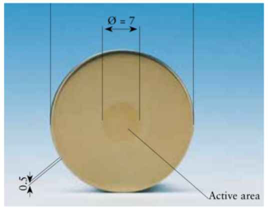
- Decay alpha particles are monoenergetic

Typical alpha energies are $4 < E_{\alpha} < 8$ MeV



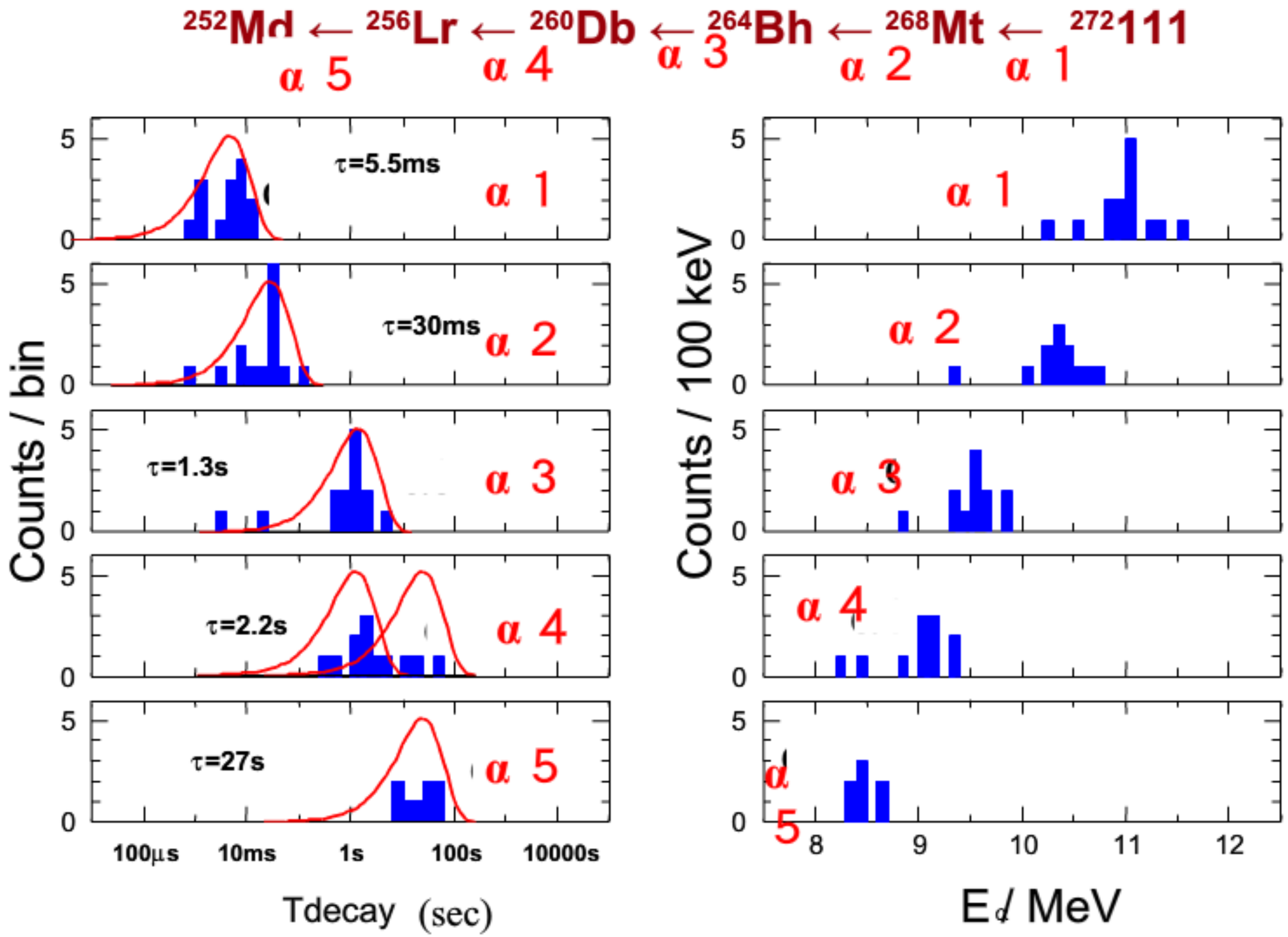


Since dE/dx is so large for alpha particles the sources are prepared in thin layers



Radionuclide	Alpha particle energy [MeV]	Intensity [%]
Pu-239	5.105	11.5
	5.143	15.1
	5.155	73.4
Am-241	5.388	1.4
	5.443	12.8
	5.486	85.2
Cm-244	5.763	23.3
	5.805	76.7

Discovery of super-heavy elements



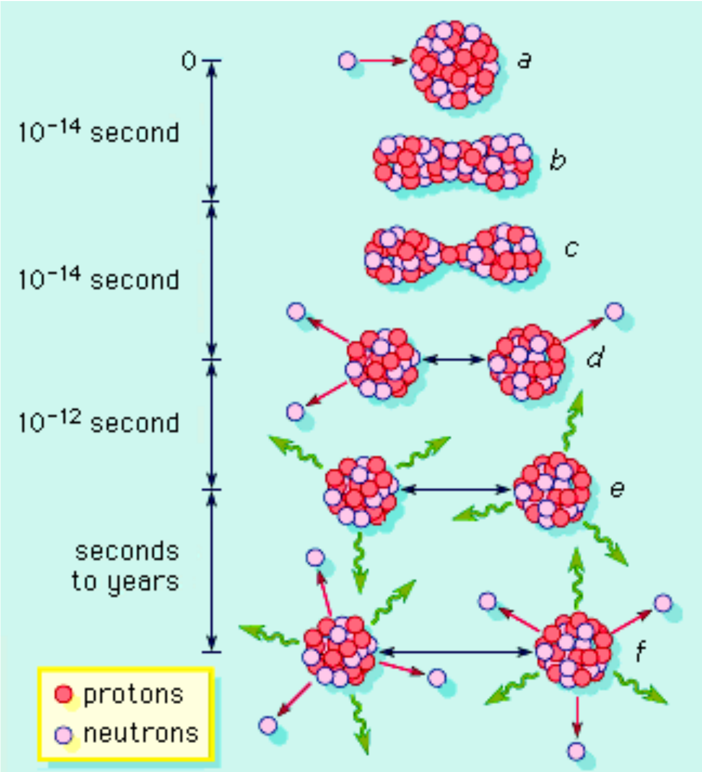
Alpha decay of Super-heavy elements

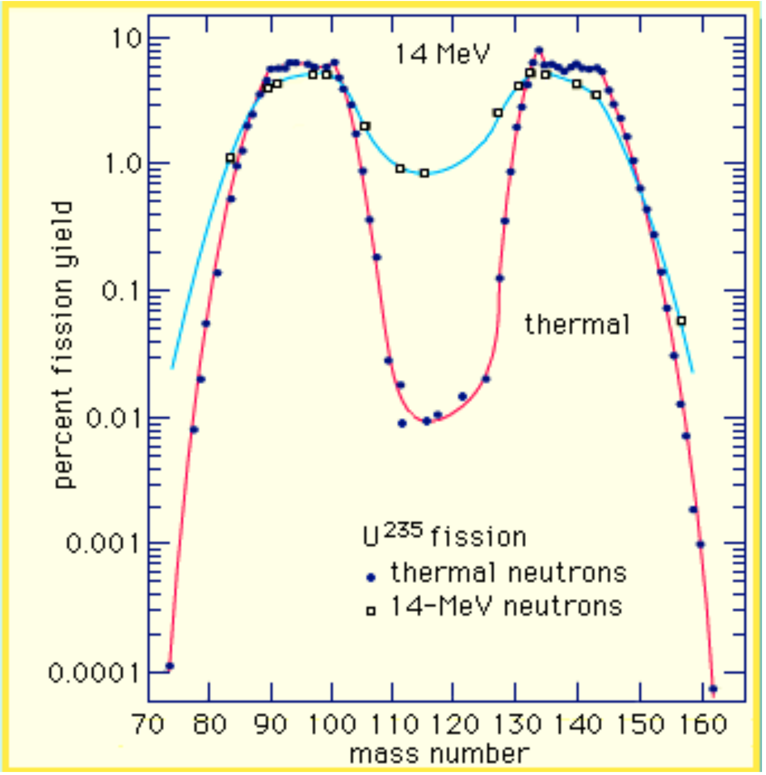
Spontaneous Fission

$^{A}Z \rightarrow {}^{A-Z}(Z-y)^{*} + {}^{X}y^{*} + Qf \qquad e.g.\ ^{252}\mathrm{Cf}(\sim 3\%\ \mathrm{SF})\mathrm{TKE} \sim 185\mathrm{MeV}$

Spontaneous fission is another quantum mechanical tunneling process similar to alpha-decay that is rare in the light actinide nuclei and increases in importance with Z and limits the stability of nuclei with Z>98.

All fission processes produce a statistical distribution of radioactive products, fast neutrons and γ's.

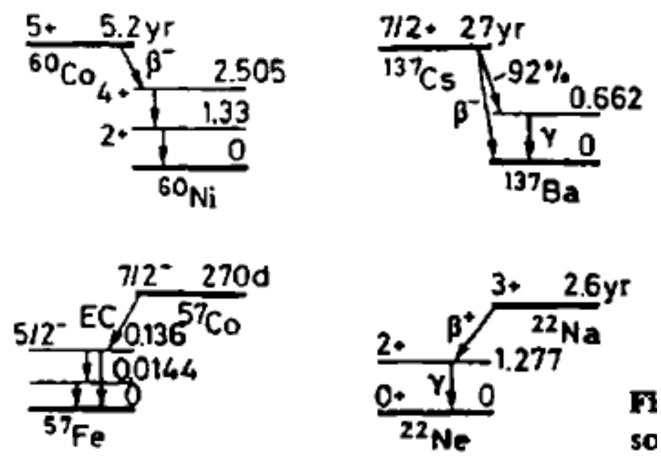




γ-decay

Gamma rays are emitted by nuclear excited states, their lifetimes are generally too short to provide useful sources (except for some special cases called "isomeric" states).

Beta-delayed γ **:** $^{A}(Z \pm 1) \rightarrow {}^{A}Z^{*} \rightarrow {}^{A}Z + \gamma$

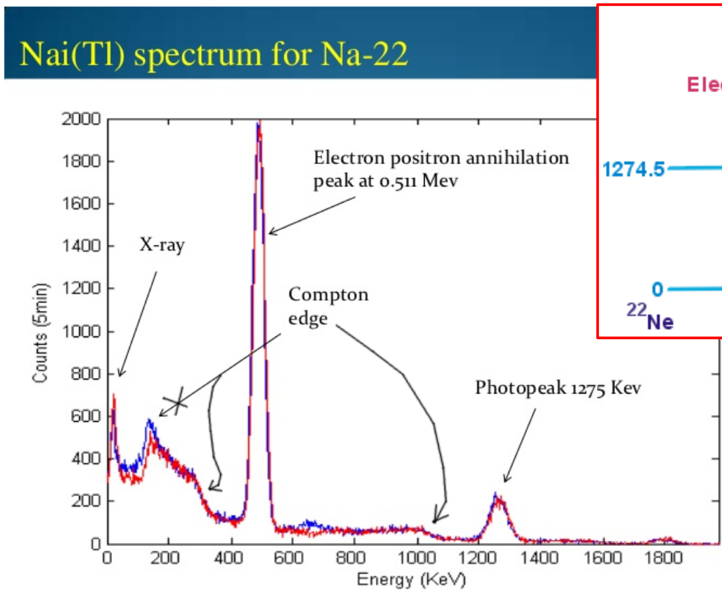


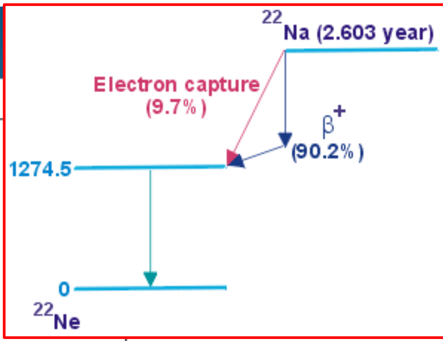
Through the β-decay process, the daughter nuclide is formed in an excited state which is unstable against gamma emission. The characteristic timescale of this particle emission process is that of the β-decay of the parent.

Encapsulation of the source absorbs the electron.
Typical gamma energies are ~1 MeV

Annihilation:

In β^+ decay(e.g ^{22}Na) the emitted positron will usually stop and annihilate producing two 0.511 MeV gammas





Internal conversion

In IC, the excitation energy of a nucleus is transferred to one of the electrons in the K, L, or M shells that are subsequently ejected

$E_e = h\nu - EB$ in atom Pb: E_{KB} = 88.0keV E_{LB} ~ 14.3keV

the only practical way to produce monoenergetic electrons in the keV-MeV range in the laboratory

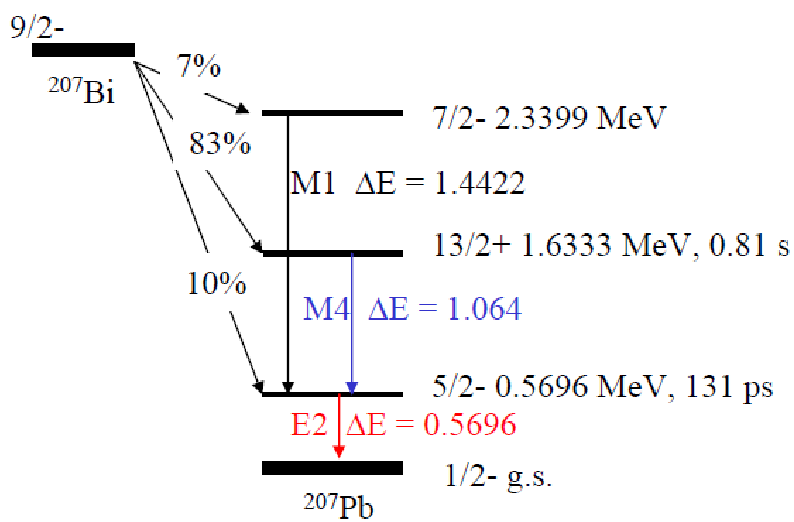
Gamma emission and IC compet
$\lambda_{total} = \lambda_{gamma} + \lambda_{IC}$

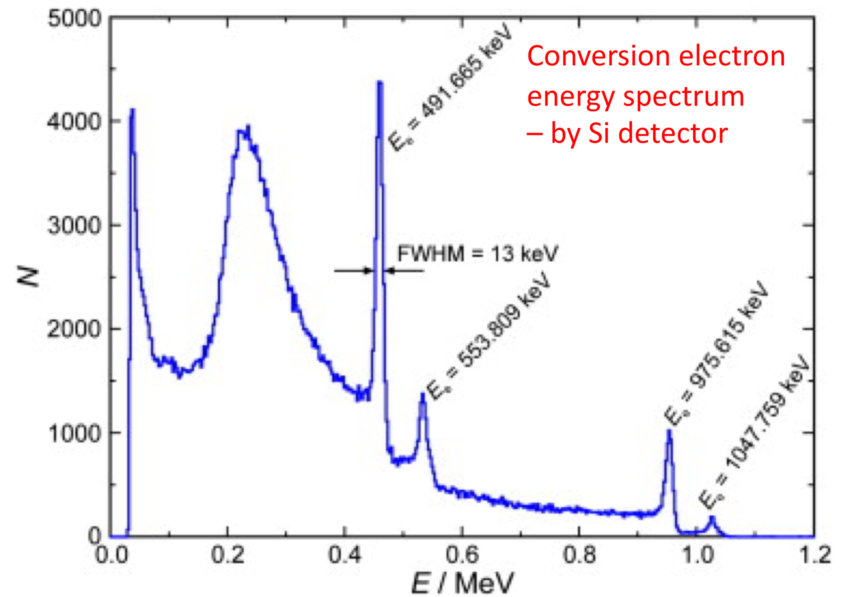
Conversion coefficient $\alpha == \lambda_{IC}/\lambda_{gamma}$

IC is more important for heavy nuclei where the EM fields are large and the orbits of inner shell electrons are close to the nucleus

Table 1.4. Some internal conversion sources

Source	Energies [keV]
^{207}Bi	480, 967, 1047
^{137}Cs	624
^{113}Sn	365
^{133}Ba	266, 319





neutrons

Neutrons have to be produced in nuclear reactions, the energy spectrum will depend on the reaction.

Spontaneous Fission: ^{252}Cf the neutrons are primarily emitted with a thermal energy spectrum in the rest frame of the moving fragments (KE ~ 1MeV/u). $I \propto E^{1/2} e^{-E/T}$

PuBe & AmBe(α, n): intimately mixed metals

$$^{238}\mathrm{Pu} \to {}^{234}\mathrm{U}^{2-} + {}^{4}\mathrm{He}^{2+} + Q_\alpha = 5.7012\ \mathrm{MeV}, KE_\alpha < 5.14\ \mathrm{MeV}$$

$$^{4}\mathrm{He}^{2+} + {}^{9}\mathrm{Be} \to {}^{13}\mathrm{C}^{2+*} \to {}^{12}\mathrm{C}^{2+} + n \quad Q = \cdots\ \mathrm{MeV}$$

$$\to 12\mathrm{C}^{2+*} + n' + Q'$$

Photonuclear Reactions:

$$\gamma + {}^{9}\mathrm{Be} \to {}^{8}\mathrm{Be} + n, \qquad Q = -1.666\ \mathrm{MeV}$$

Accelerator Reactions:

$$p + 7\mathrm{Li} \to {}^{7}\mathrm{Be} + n \qquad Q = -1.64\ \mathrm{MeV}$$

$$d + 9\mathrm{Be} \to {}^{10}\mathrm{Be} + n \quad Q = 4.36\ \mathrm{MeV}$$

$$d + d \to 3\mathrm{He} + n \qquad Q = 3.26\ \mathrm{MeV}$$

$$d + t \to 4\mathrm{He} + n \qquad Q = 17.6\ \mathrm{MeV}$$

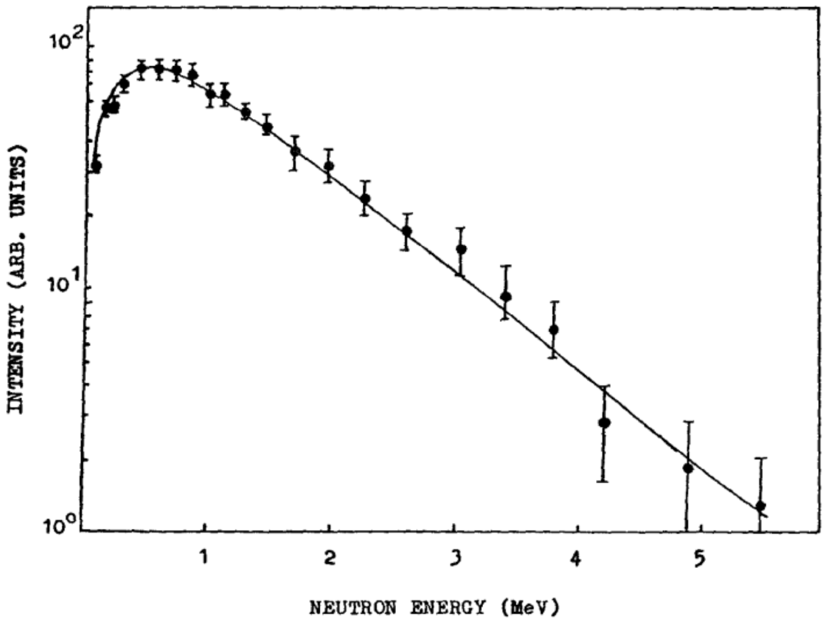
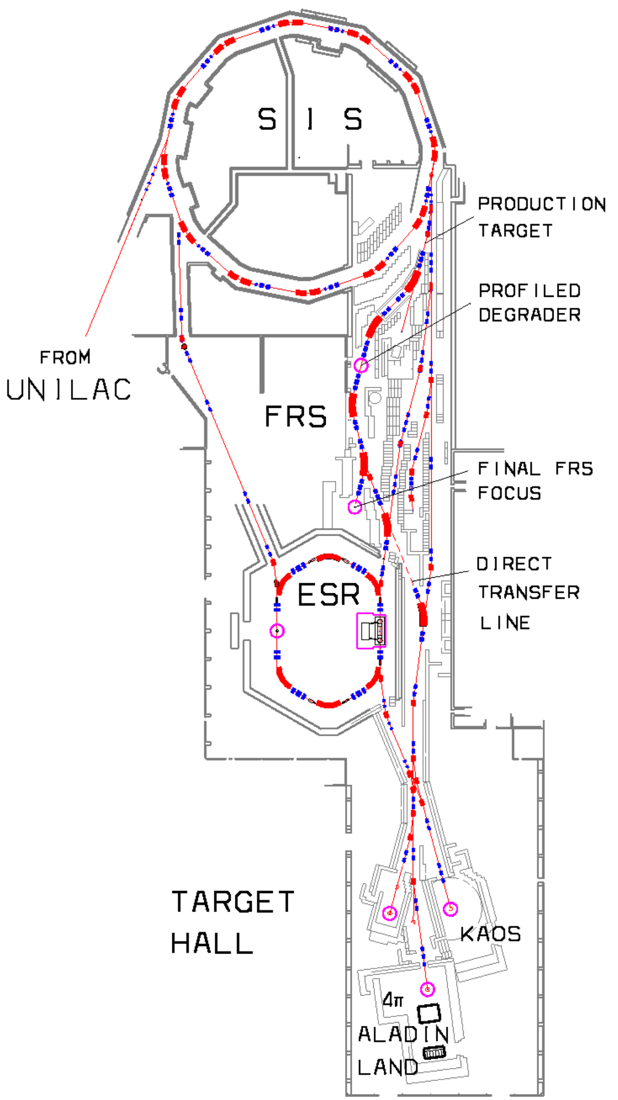


Figure 1.10 Measured neutron energy spectrum from the spontaneous fission of ^{252}Cf. (From Batenkov et al.[18])

Heavy ions from accelerator



GSI accelerator facility