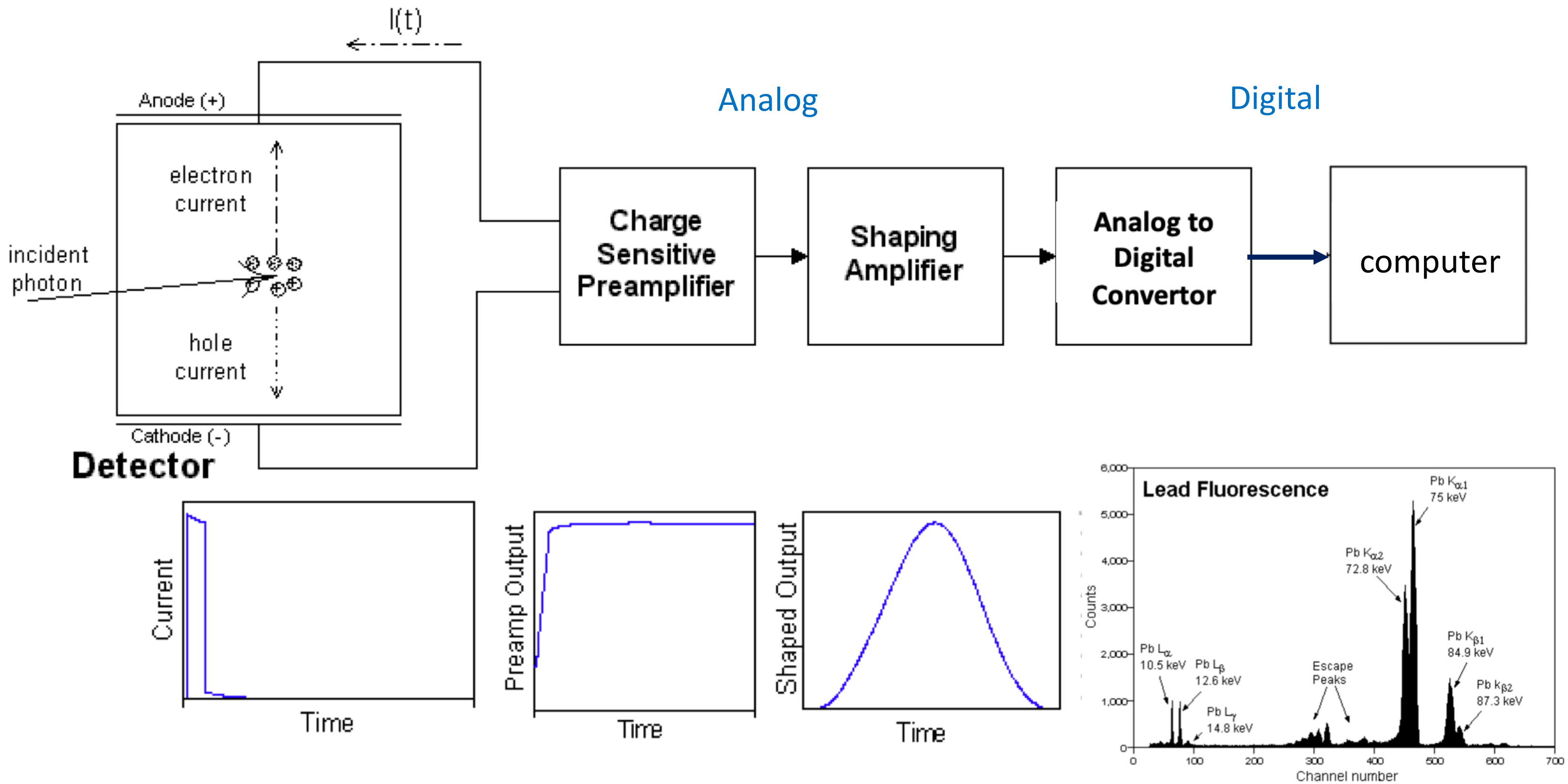
Major Detector Principle



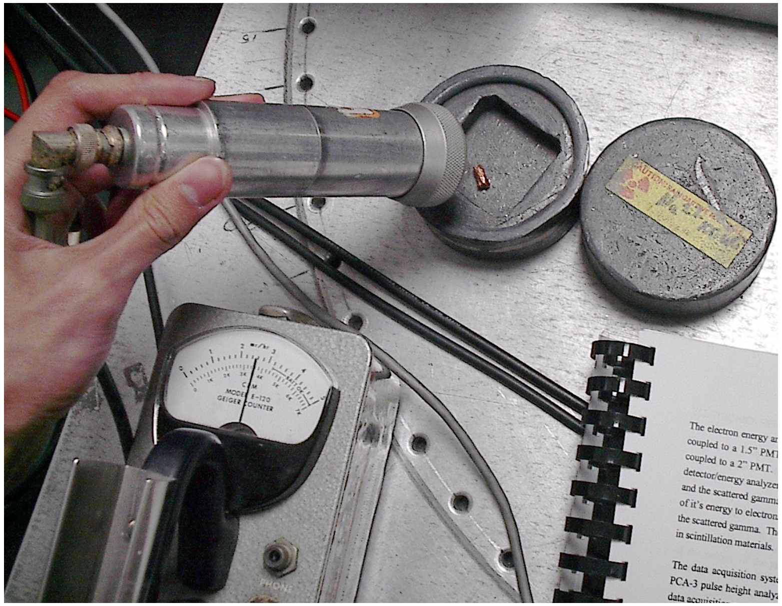
1. Particle interacts with material of detector, generate some signal
2. Amplification
3. Analog to Digital conversion
4. Getting into computer
5. Analyze at digital data ->physics

What do we mean by particle detection?

- Counting 计数

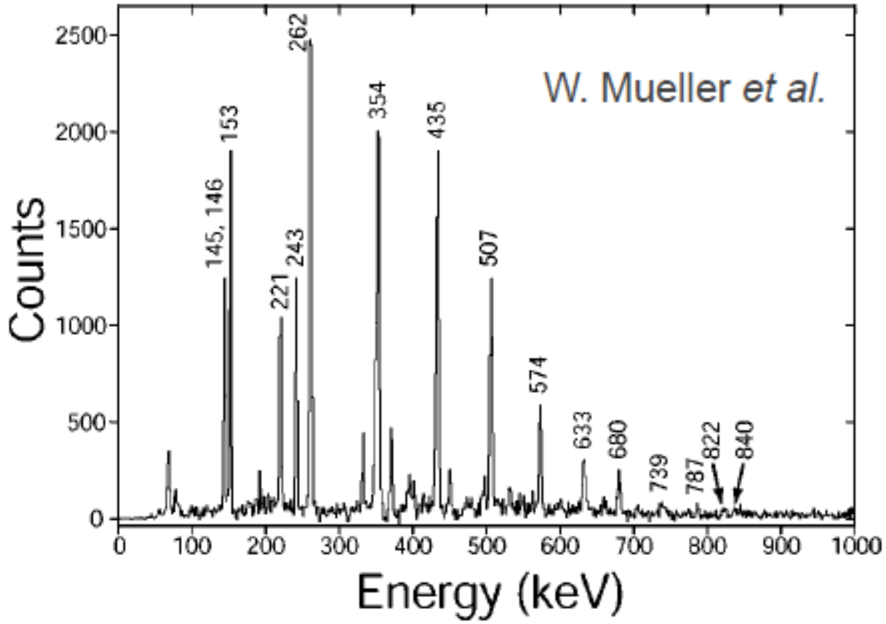
- Spectroscopy
  - Gamma-ray spectroscopy
  - Charged-particle spectroscopy
  - Decay spectroscopy

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



What do we mean by particle detection?

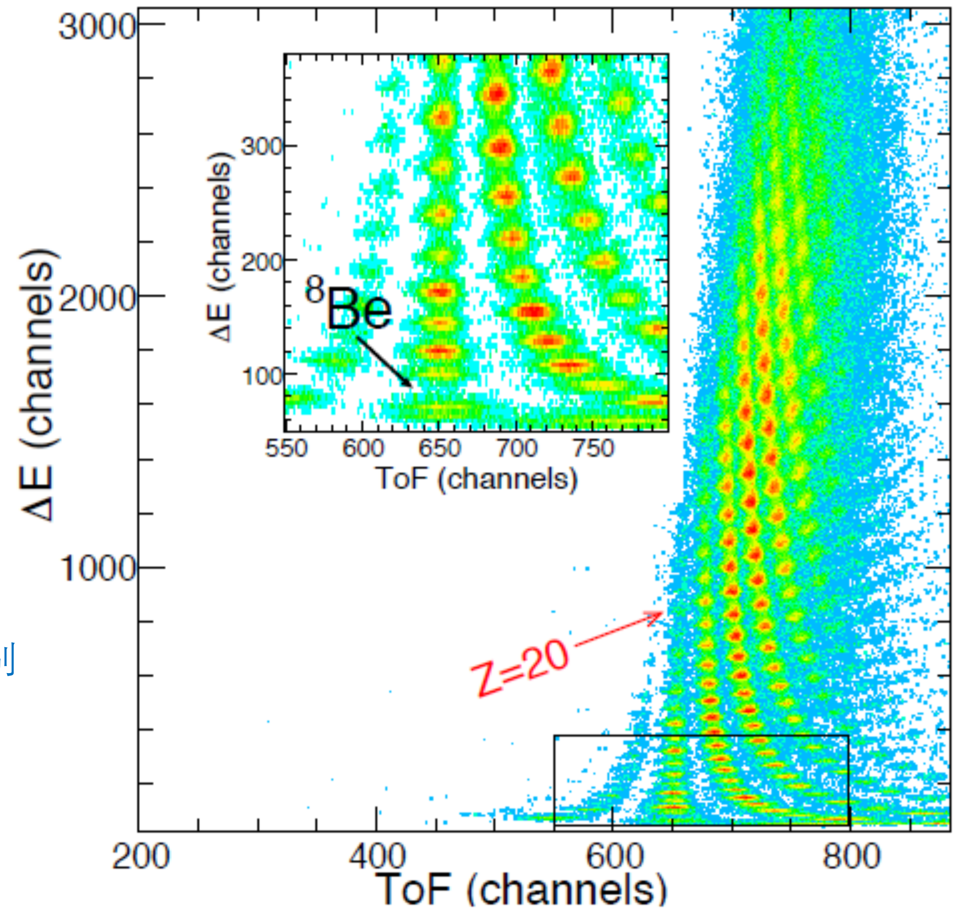
- Counting
- Spectroscopy 谱学
  - Gamma-ray spectroscopy
  - Charged-particle spectroscopy
  - Decay spectroscopy



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

What do we mean by particle detection?

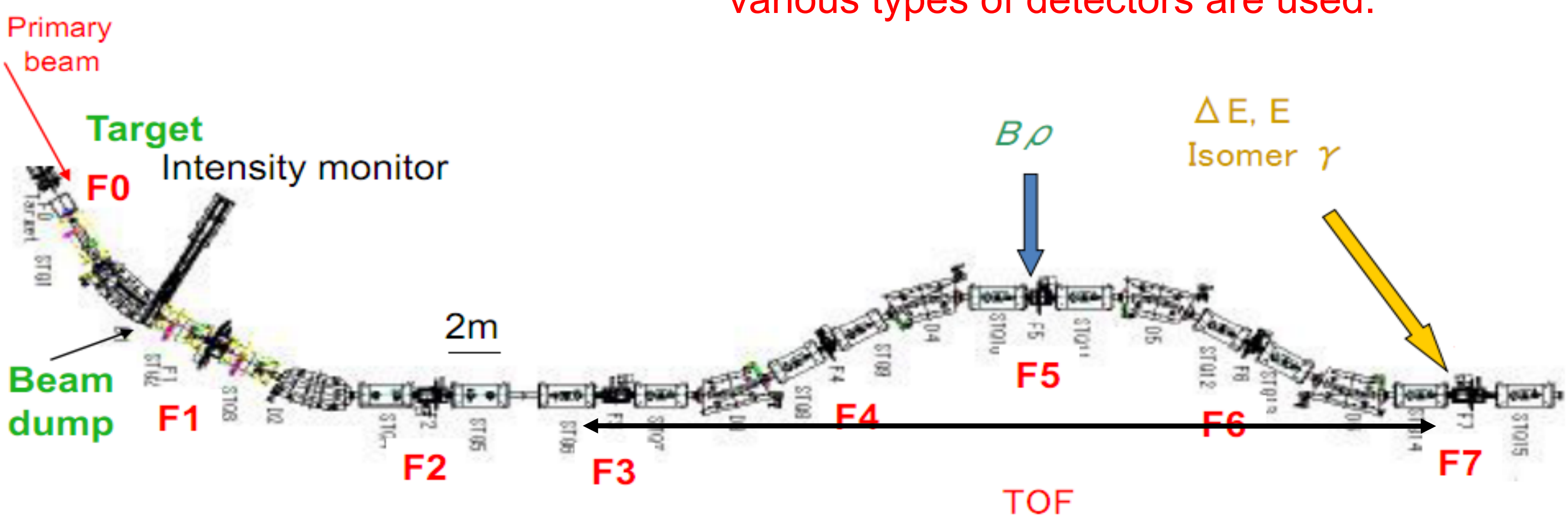
- Counting
- Spectroscopy
  - Gamma-ray spectroscopy
  - Charged-particle spectroscopy
  - Decay spectroscopy
- Particle Identification 粒子鉴别
  - Nuclei: *Z, A*
  - Neutron, gamma??

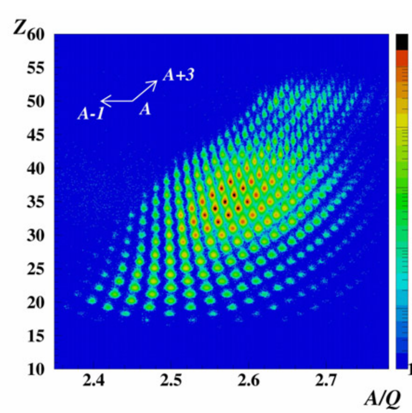


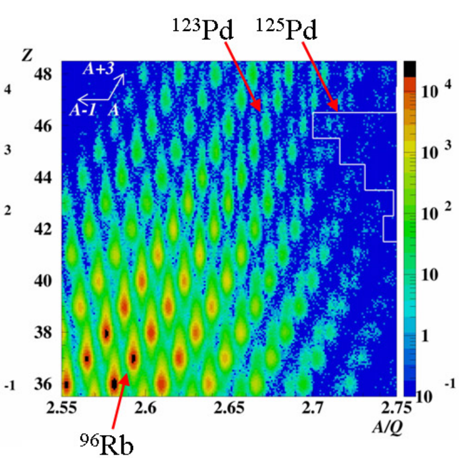
Detectors - in Accelerator Line

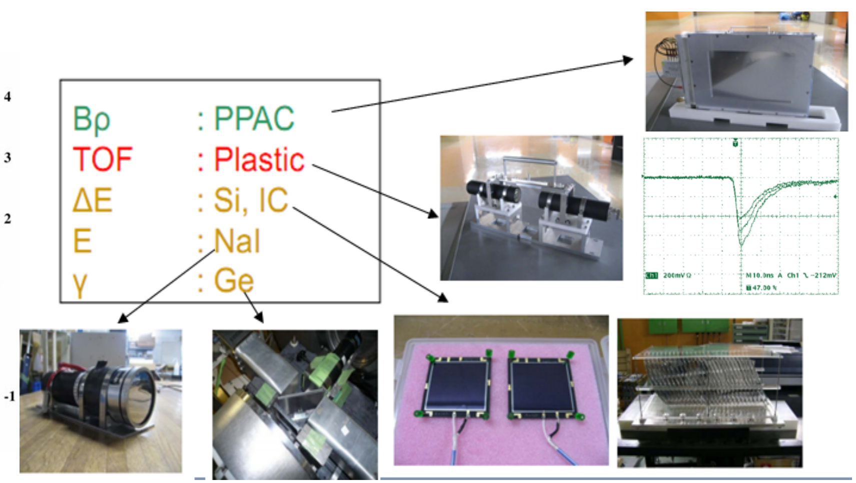
BigRIPS RIKEN, Japan

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



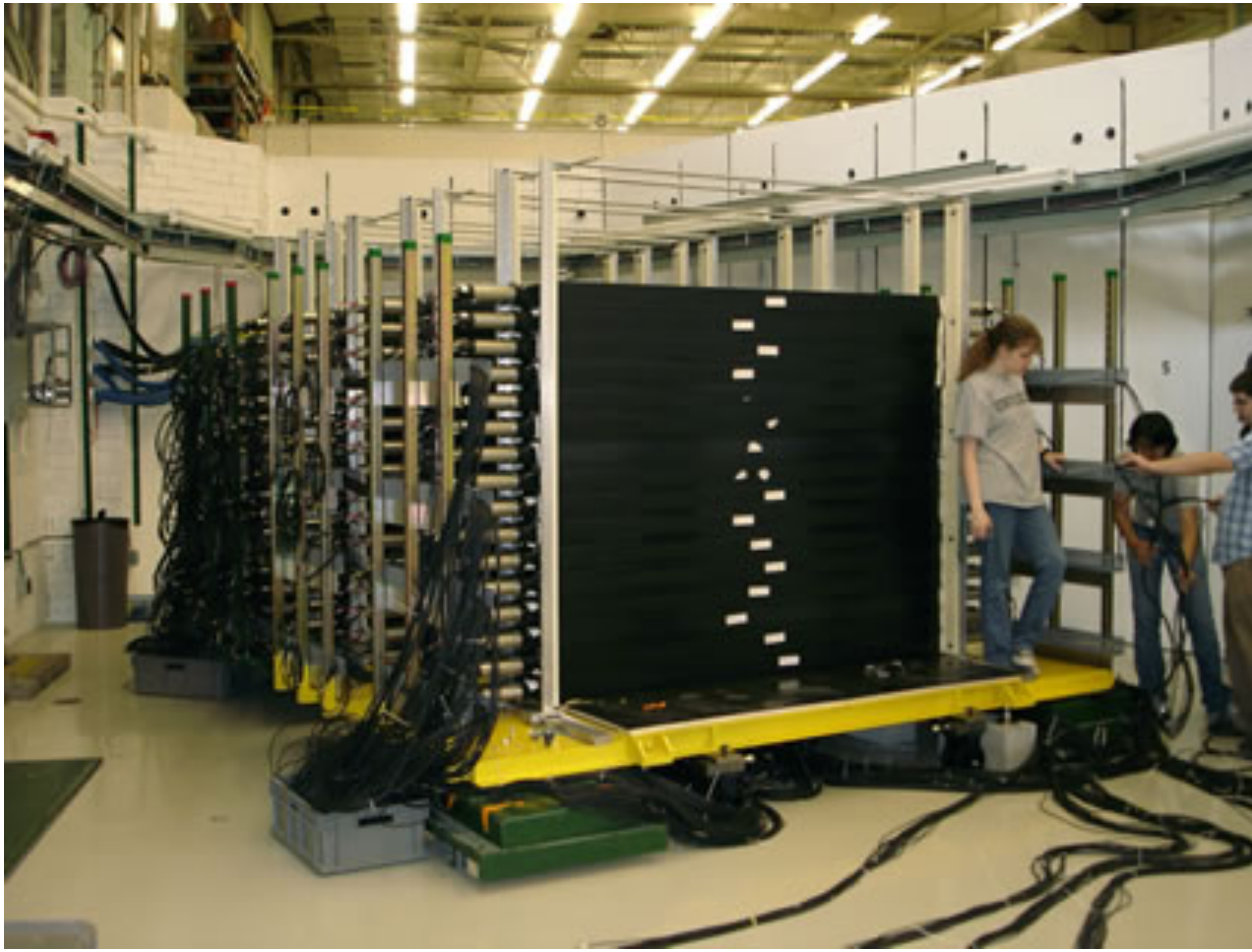


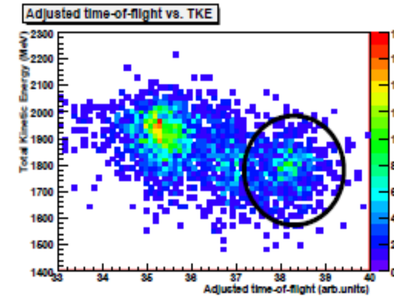


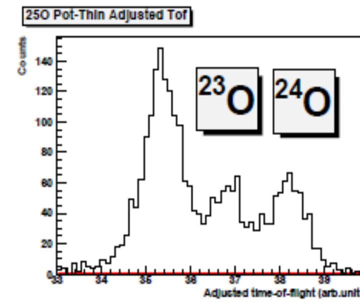


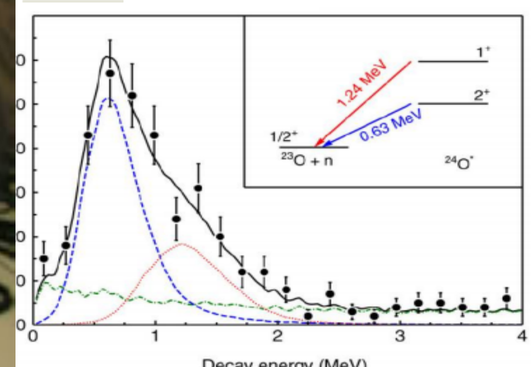
Detection System – Nuclear Physics

Spectroscopy of neutron-unbound systems NSCL,MSU





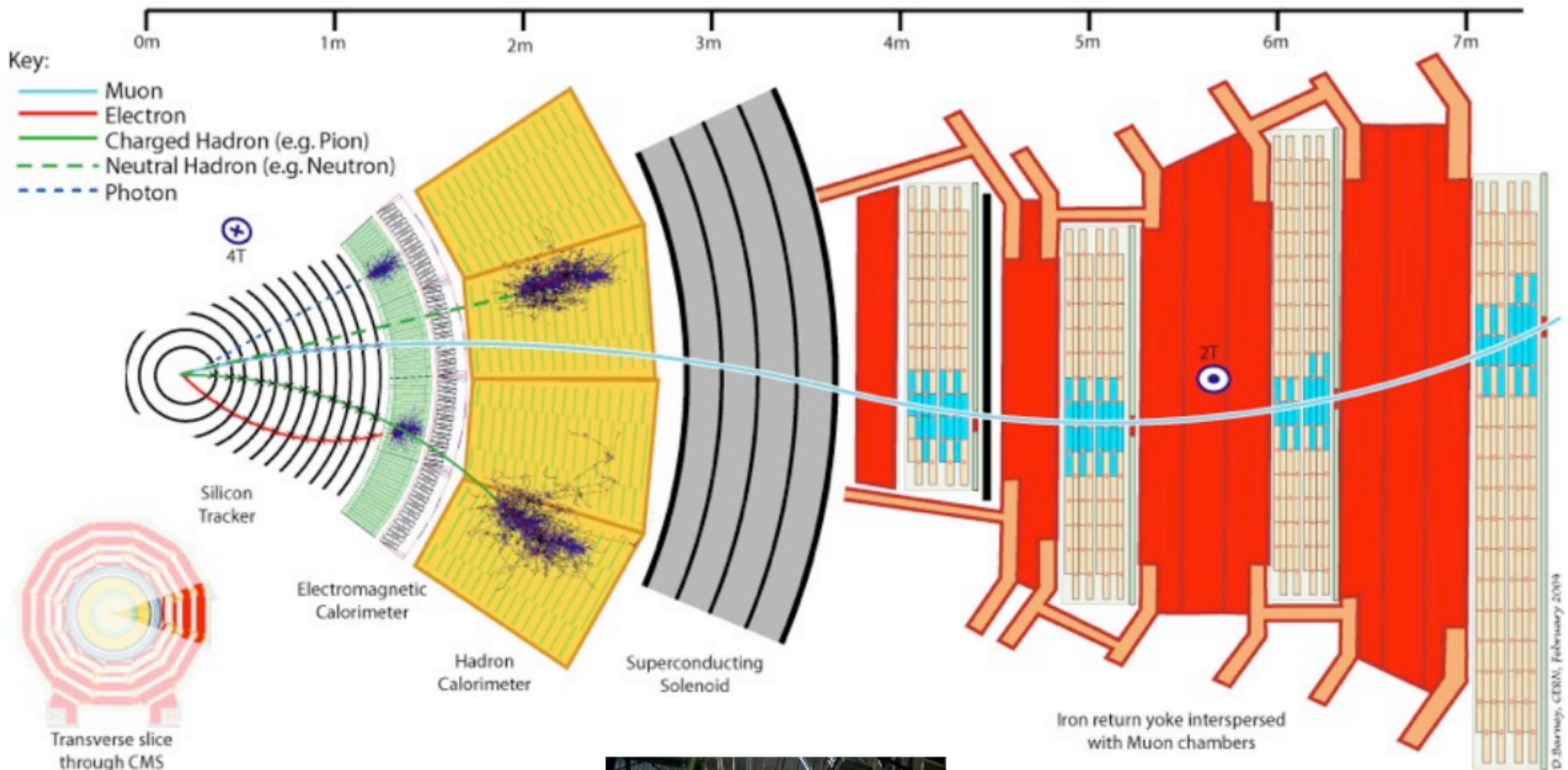


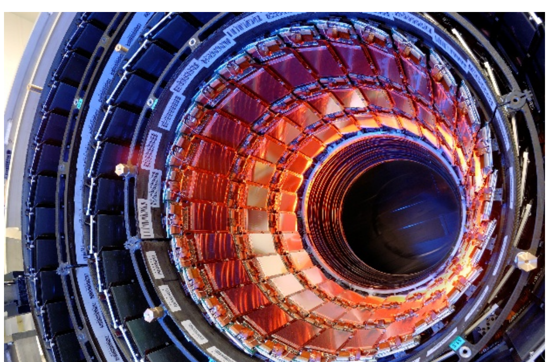


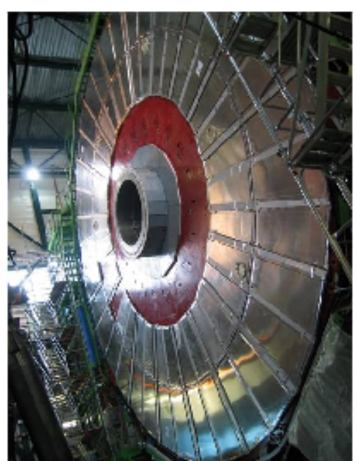
C.R. Hoffman* *et al.*, PLB 672, 17 (2009)

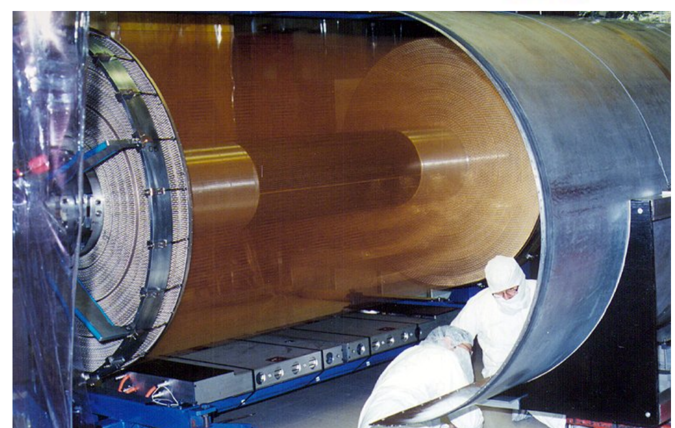
^{24}O

Detection System – Particle Physics

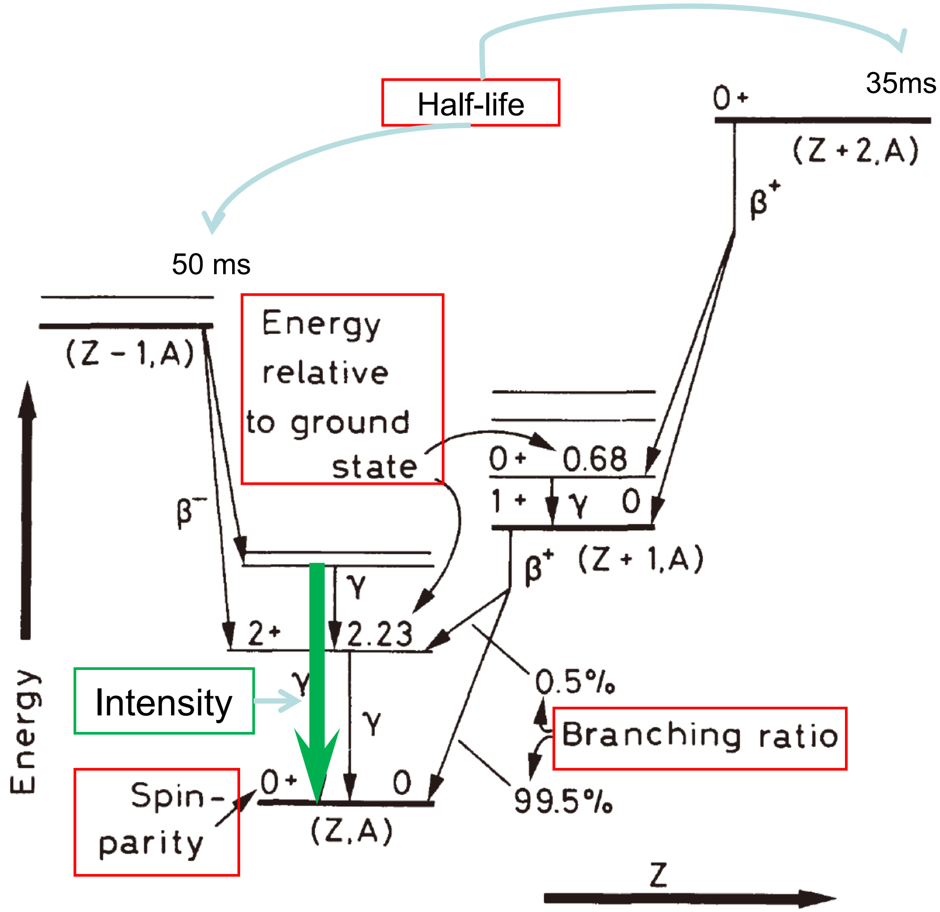


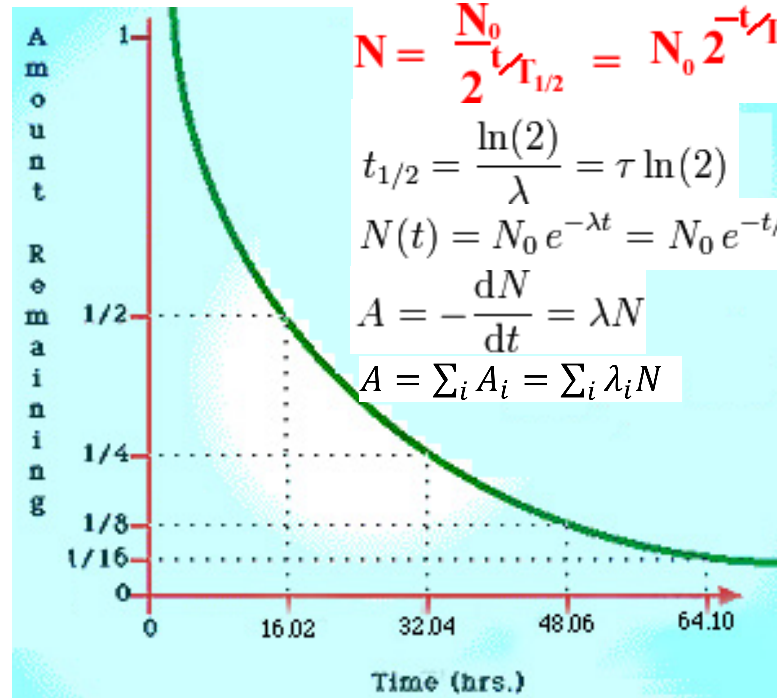






Nuclear Level Diagrams 能级纲图





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

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

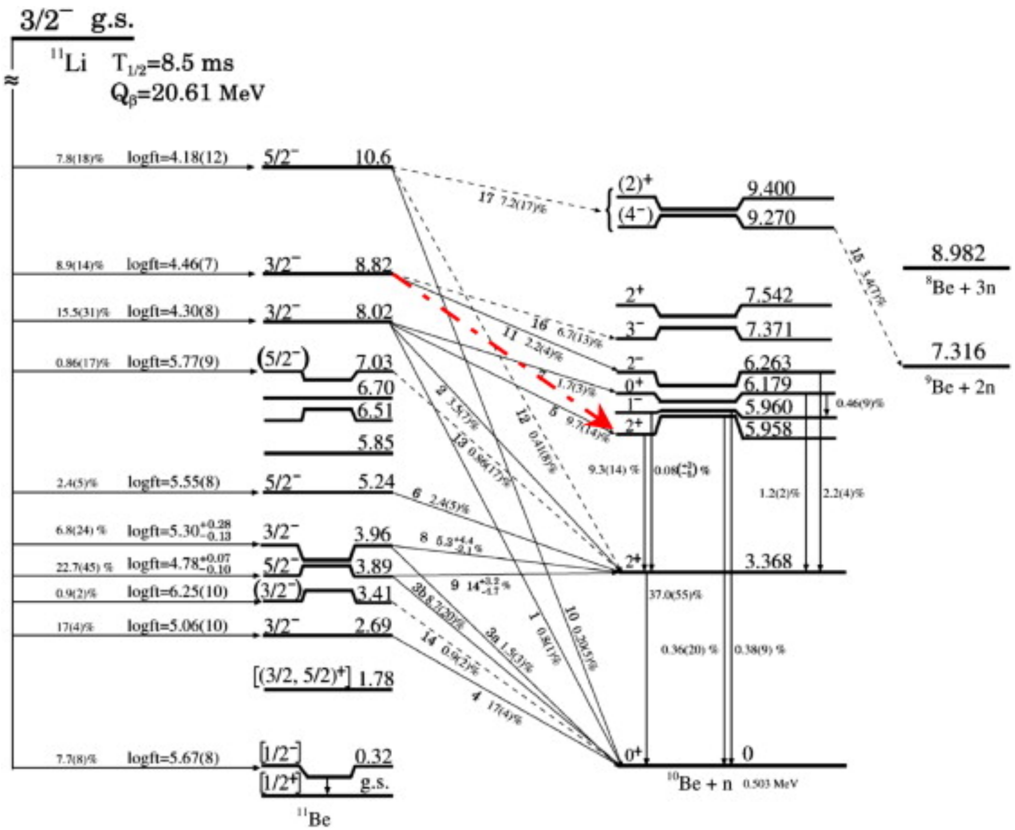
$$N(t) = N_0 e^{-\lambda t} = N_0 e^{-t/\tau}$$

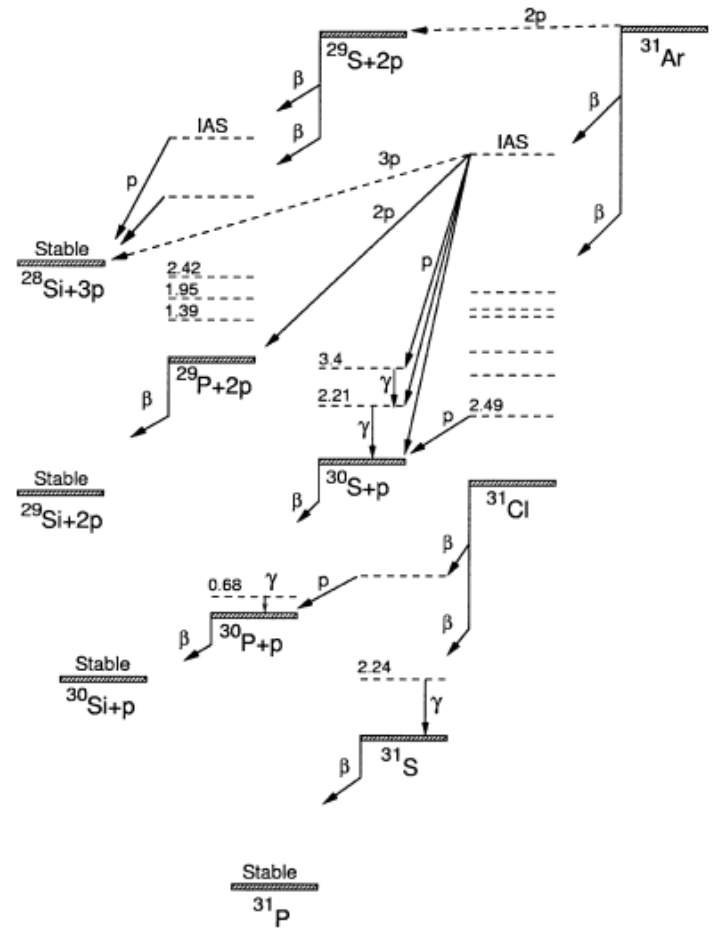
$$A = -\frac{dN}{dt} = \lambda N$$

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

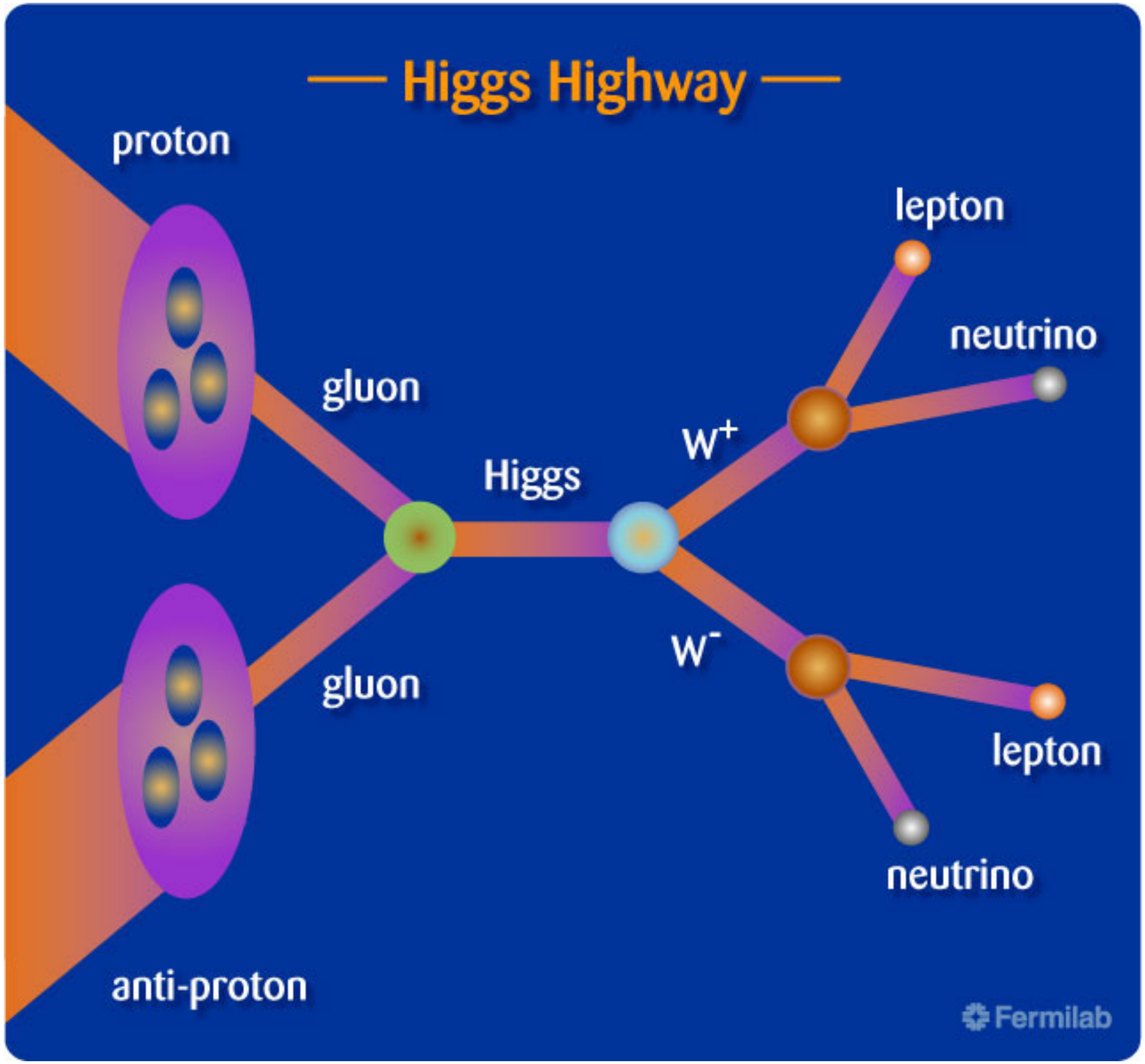
- Excitation energy， Spin/Parity
- Decay mode(α,β,EC..)
- Branching ratio: $BR = A_i/A = \lambda_i/\lambda$
- Half-life/lifetime :
  partial half-life: $T_{1/2,i} = ln2/\lambda_i$
- Relative/absolute Intensity

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

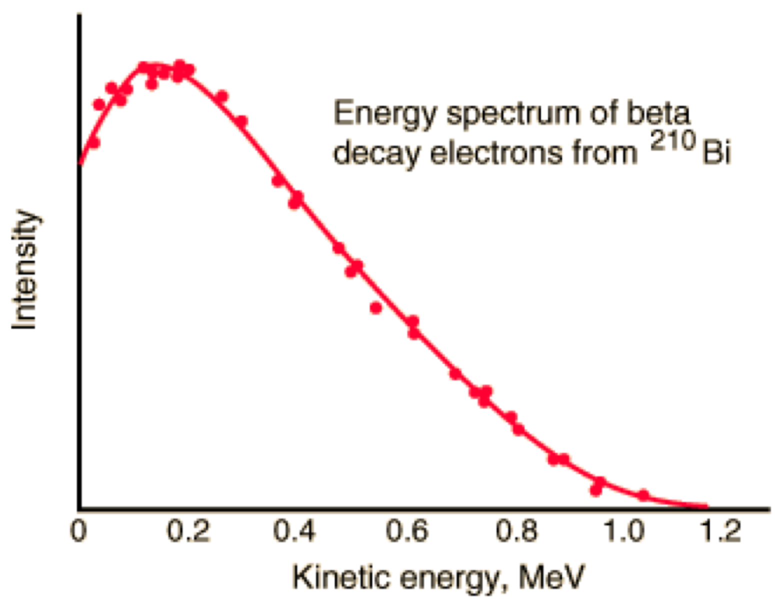


Table 1.1 Some "Pure" Beta-Minus Sources

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

■	stable nuclei	~300 nuclei
□	unstable nuclei observed so far	~2700 nuclei
—	drip-lines (limit of existence) (theoretical predictions)	~6000 nuclei
=	magic numbers	

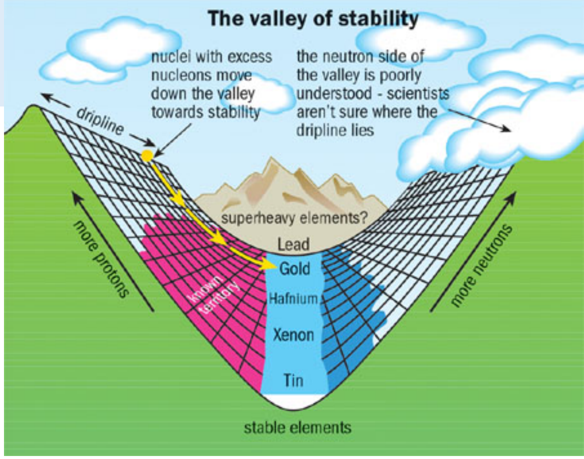
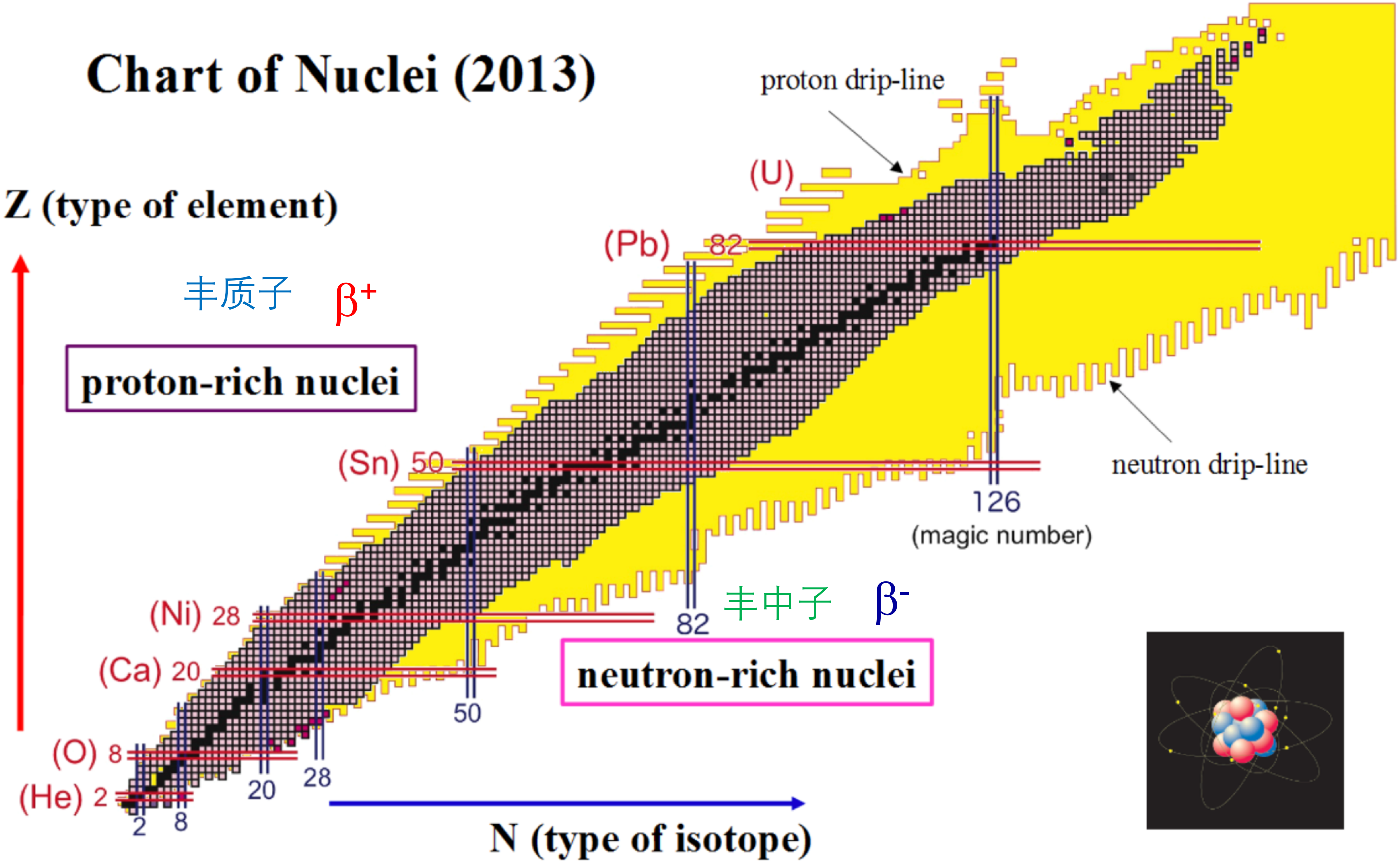
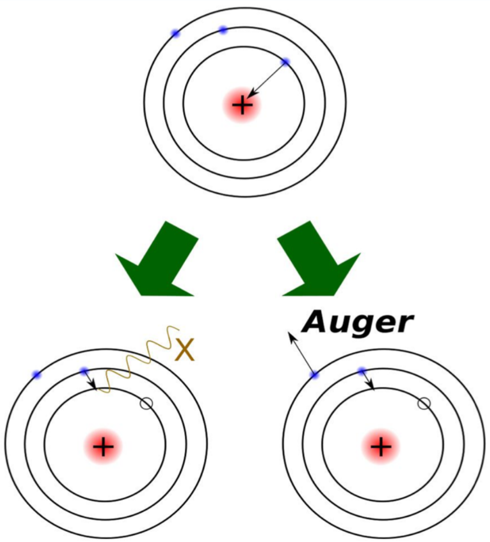


Chart of Nuclei (2013)



Electron Capture(EC) 电子俘获

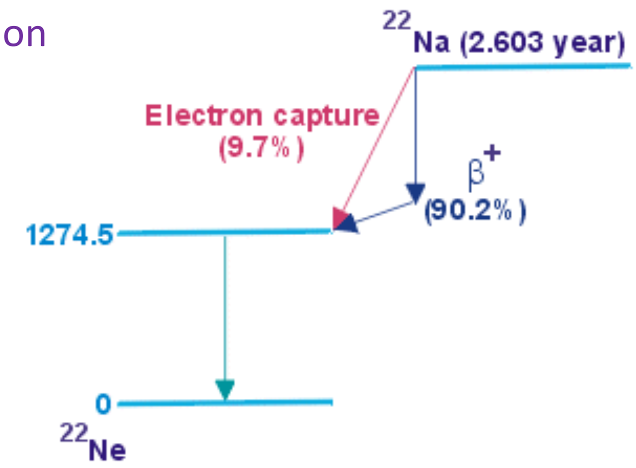


$$e^- + p \rightarrow n + v$$

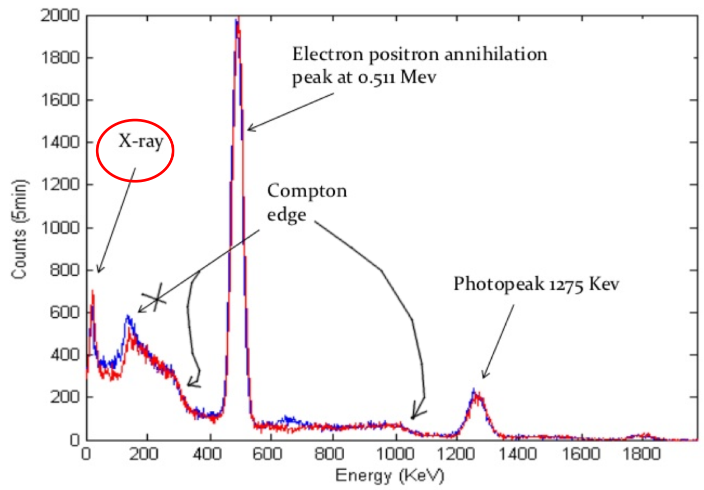
$$e^- + {}^{207}_{83}\text{Bi} \rightarrow {}^{207}_{82}\text{Pb} + v_e$$

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

In 10% there is no positron emission because of EC



Nai(Tl) spectrum for Na-22



Alpha-decay

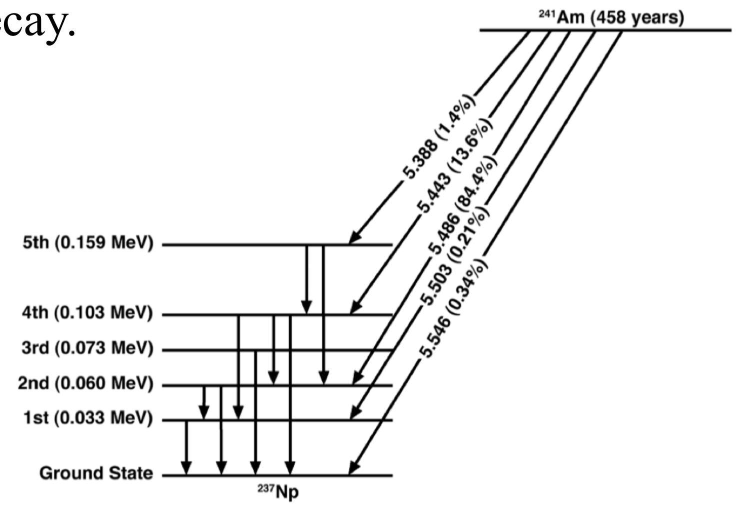
- Nuclides with A>150 are unstable against alpha decay.

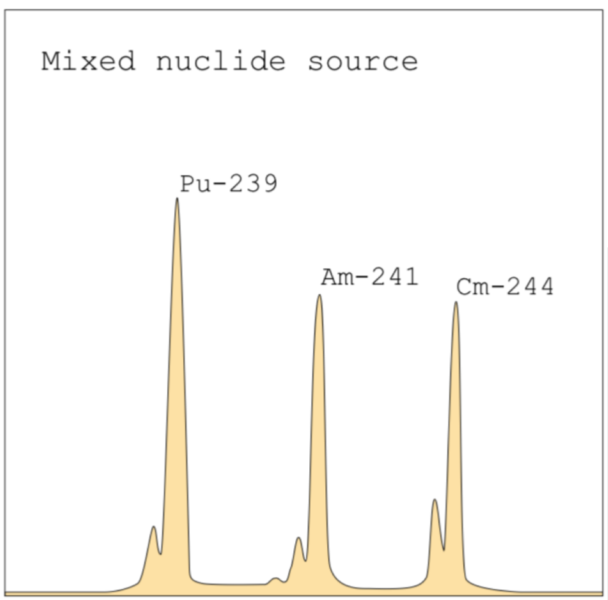
$$^{A}_{Z}X \rightarrow {}^{A-2}_{Z-2}Y + {}^{4}_{2}\alpha$$

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

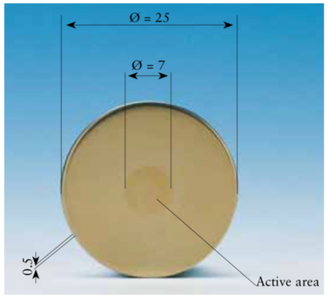
- Decay alpha particles are monoenergetic.

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



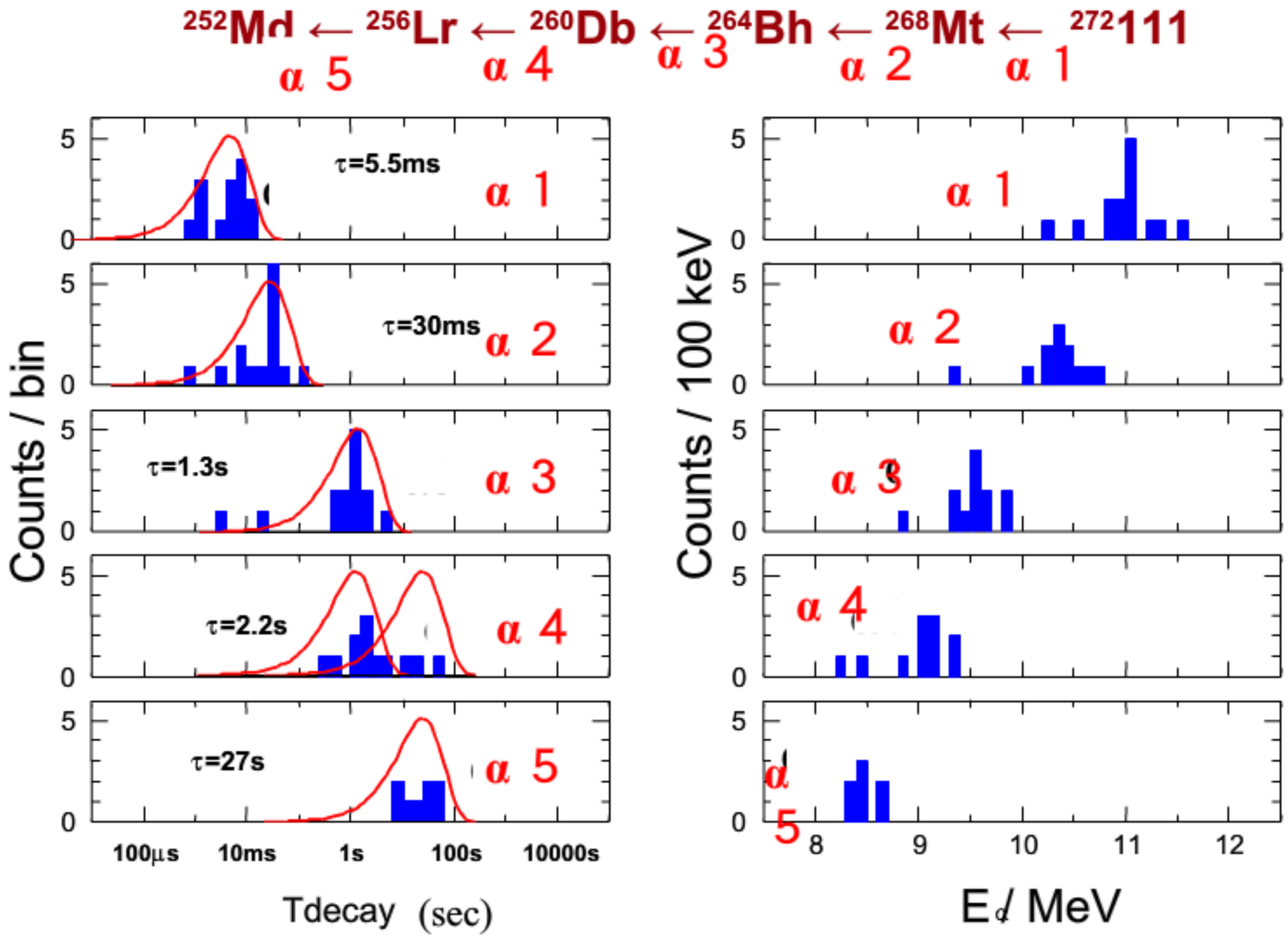


Since dE/dx is so large for alpha particles the sources are prepared in thin layers



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



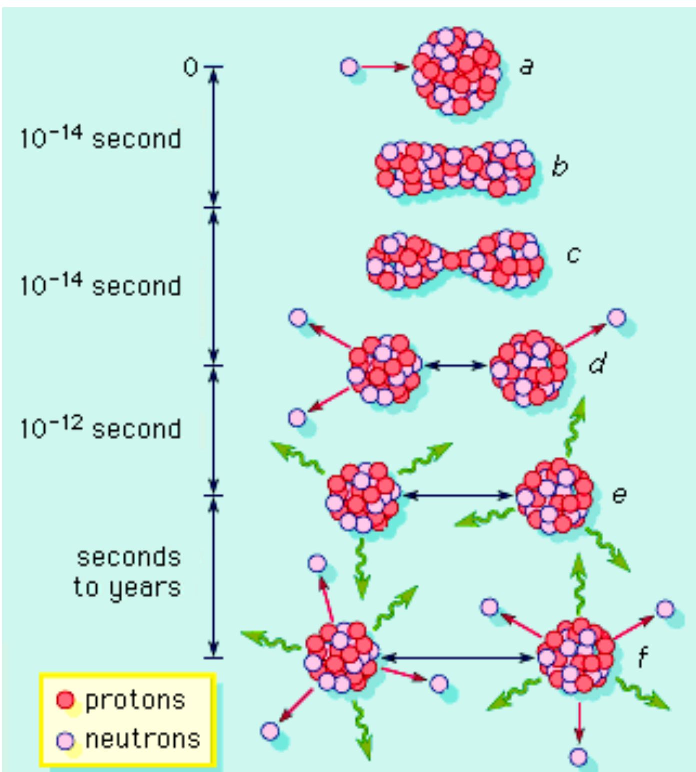
Alpha decay of Super-heavy elements

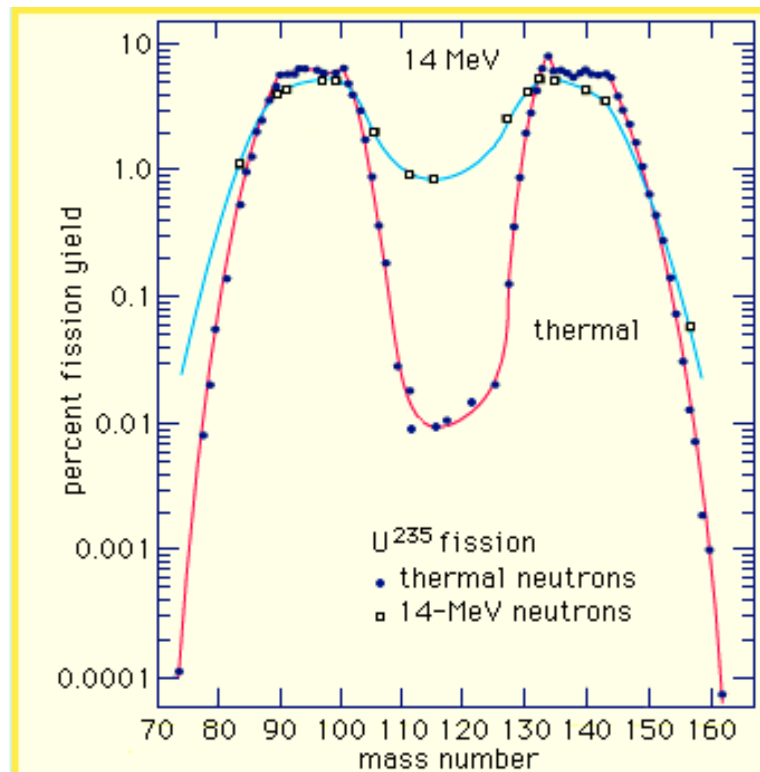
Spontaneous Fission 瞬发裂变

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.

$$^{252}\mathrm{Cf}(\sim 3\%\ \mathrm{SF}), \mathrm{TKE} \sim 185\mathrm{MeV}$$





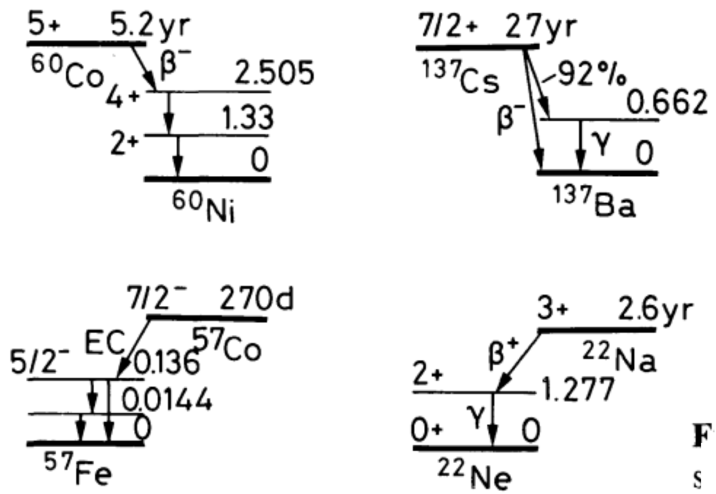
γ-decay

缓发/延发

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

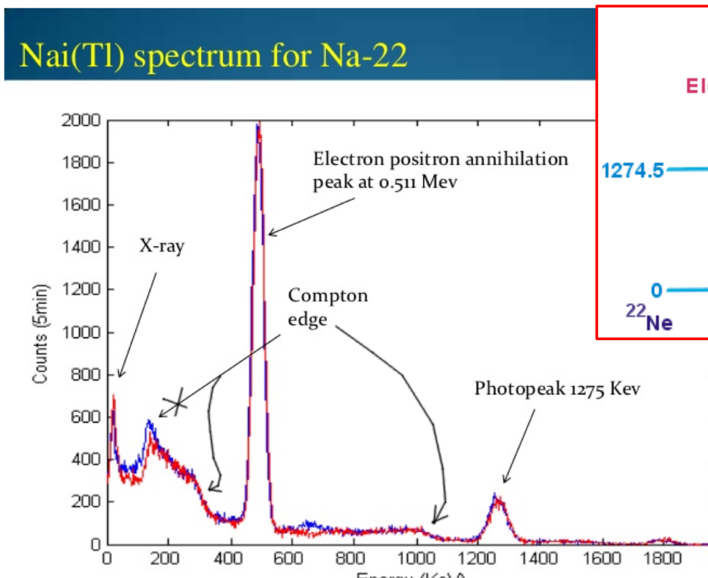
Through the β-decay process, the daughter nuclide is formed in an excited state which is unstable against gamma emission.

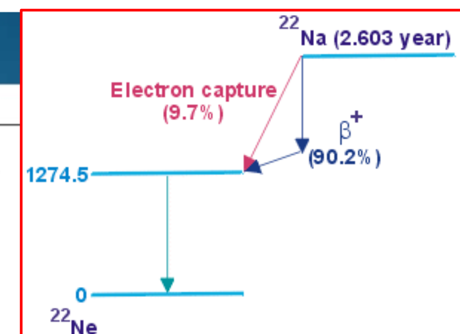
Encapsulation of the source absorbs the electron. Typical gamma energies are ~1 MeV



Annihilation: 湮灭

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





Internal conversion 内转换

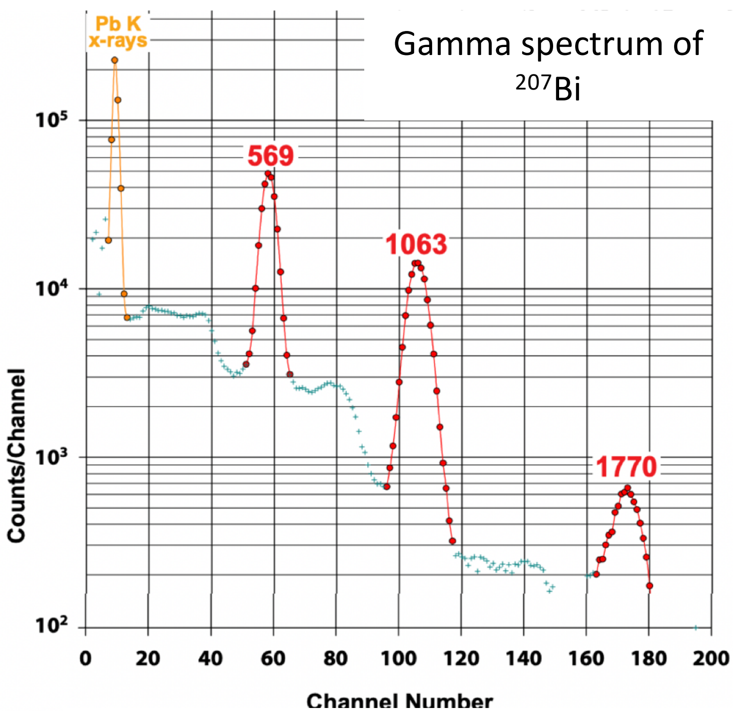
In IC, the excitation energy of a nucleus is transferred to one of the electrons in the K, L, or M shells that are subsequently ejected

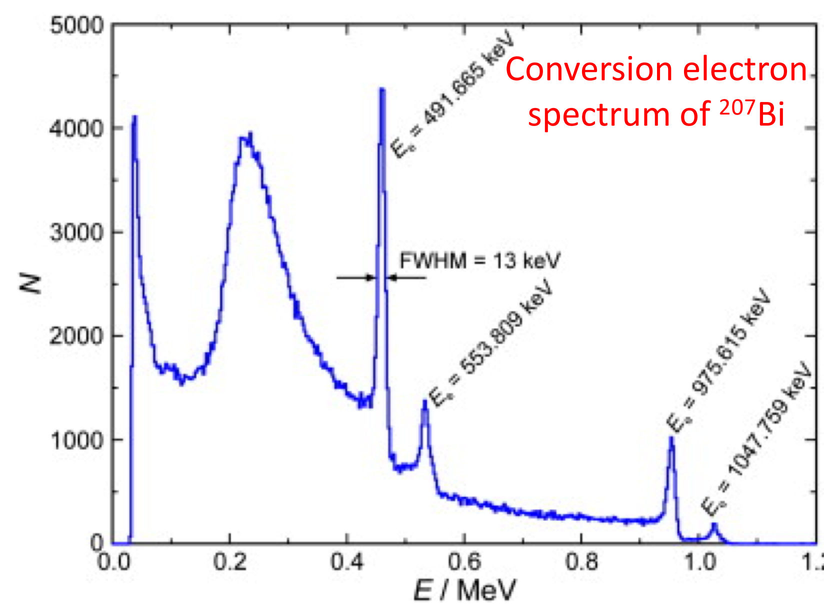
$$E_e = h\nu - EB$$

in atom Pb: E_{KB} = 88.0keV E_{LB} ~ 14.3keV

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

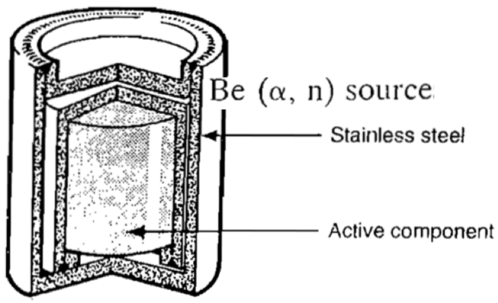
Spontaneous Fission: ^{252}Cf the neutrons are primarily emitted with a thermal energy spectrum in the rest frame of the moving fragments (KE ~ 1MeV/u). $I \propto E^{1/2}e^{-E/T}$

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

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

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

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



Photonuclear Reactions:

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

Accelerator Reactions:

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

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

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

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

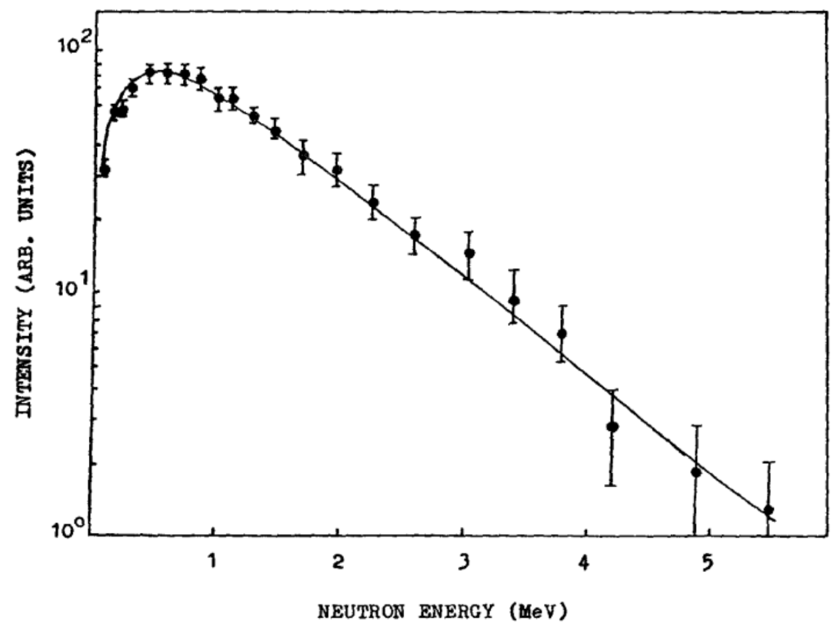
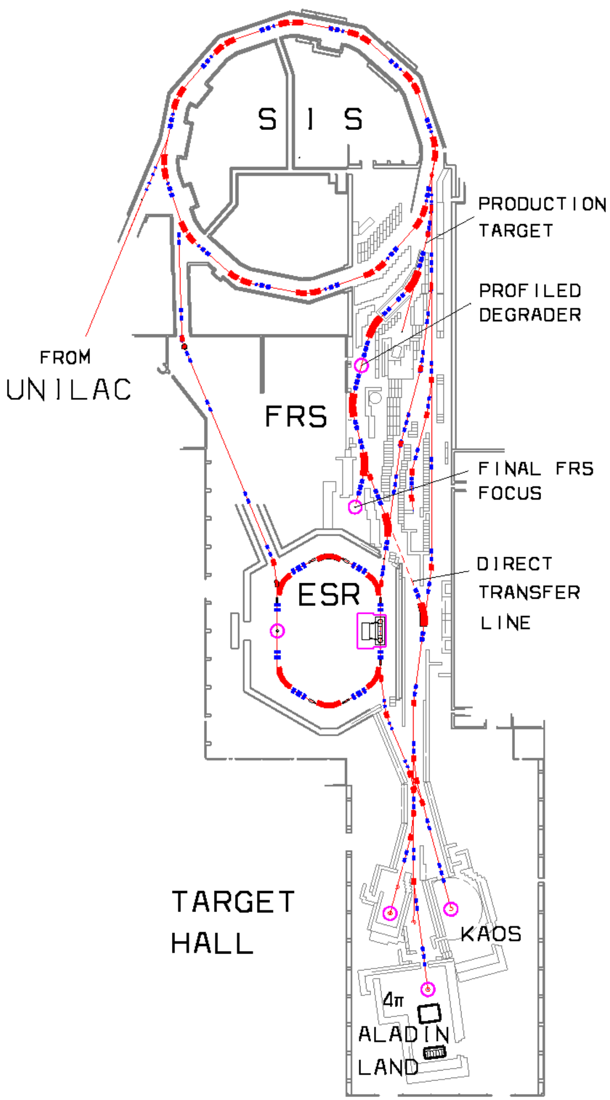


Figure 1.10 Measured neutron energy spectrum from the spontaneous fission of ^{252}Cf. (From Batenkov et al.[18])

Heavy ions from accelerator



GSI accelerator facility