Experimental Techniques I

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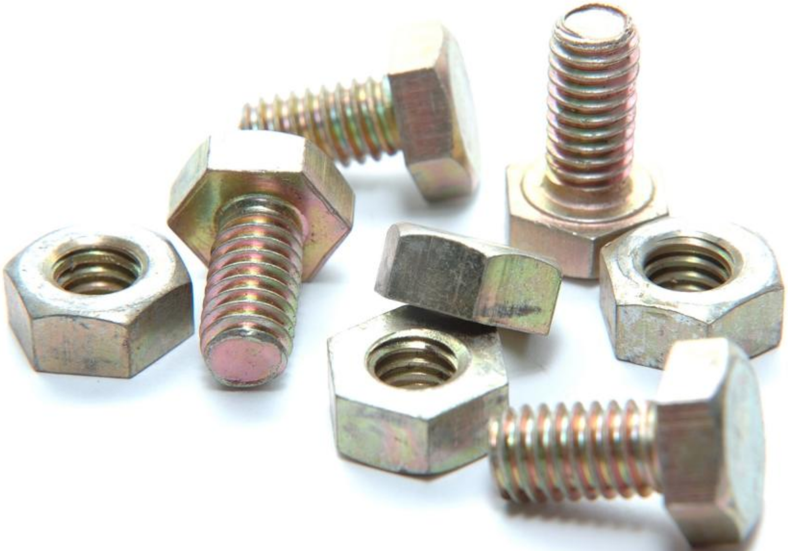
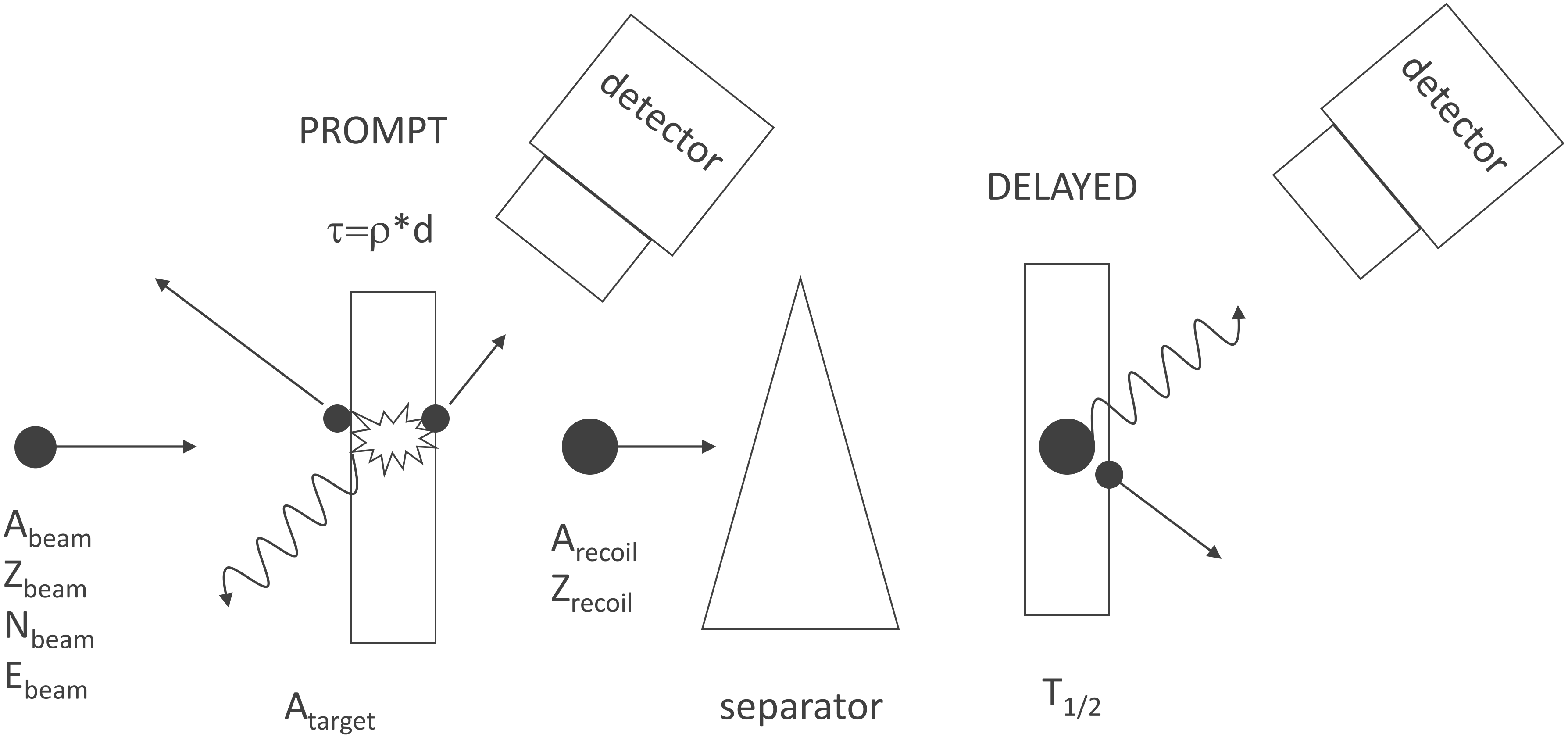


Content

- Nuclear Physics Experiment
- Interaction of Particles with Matter
- Particle Detectors
- Signal Processing

Nuclear Physics Experiment



PROMPT

$\tau=\rho*d$

DELAYED

A_{beam}
Z_{beam}
N_{beam}
E_{beam}

A_{recoil}
Z_{recoil}

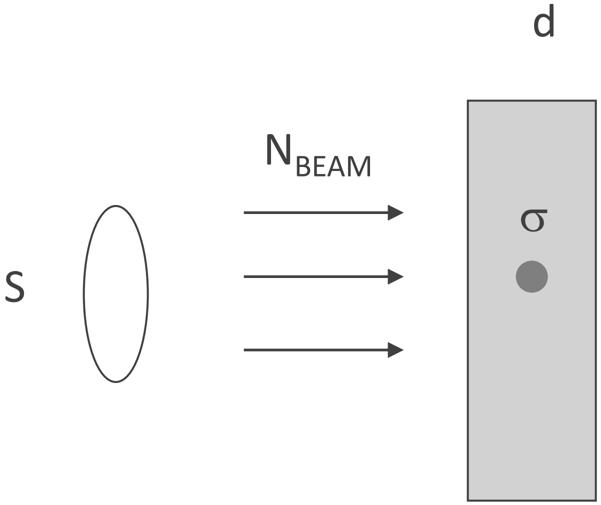
separator

$T_{1/2}$

A_{target}
Z_{target}
d - thickness
ρ - density
τ - surface density

Secondary beam or target!

Cross section/Interaction length



$$n_{TARGET} = \frac{N_{TARGET}}{V}$$

$$n_{TARGET} = \frac{N_A}{A}\rho$$

$$N_{REACTION} = N_{BEAM}\frac{n_{TARGET}Sd\sigma}{S}$$

$$[\sigma] = barn = 10^{-24}cm^2 = (10\,fm)^2$$

cross section

$$outhouse = 1\mu b$$

$$shed = 10^{-24}b$$

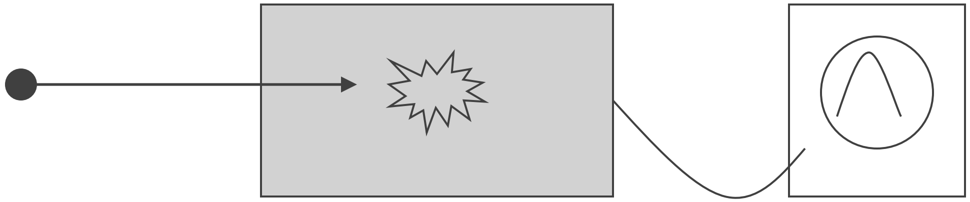
$$P(x) = e^{-n_{TARGET}\sigma x}$$

survival probability

$$\lambda = \frac{1}{n_{TARGET}\sigma}$$

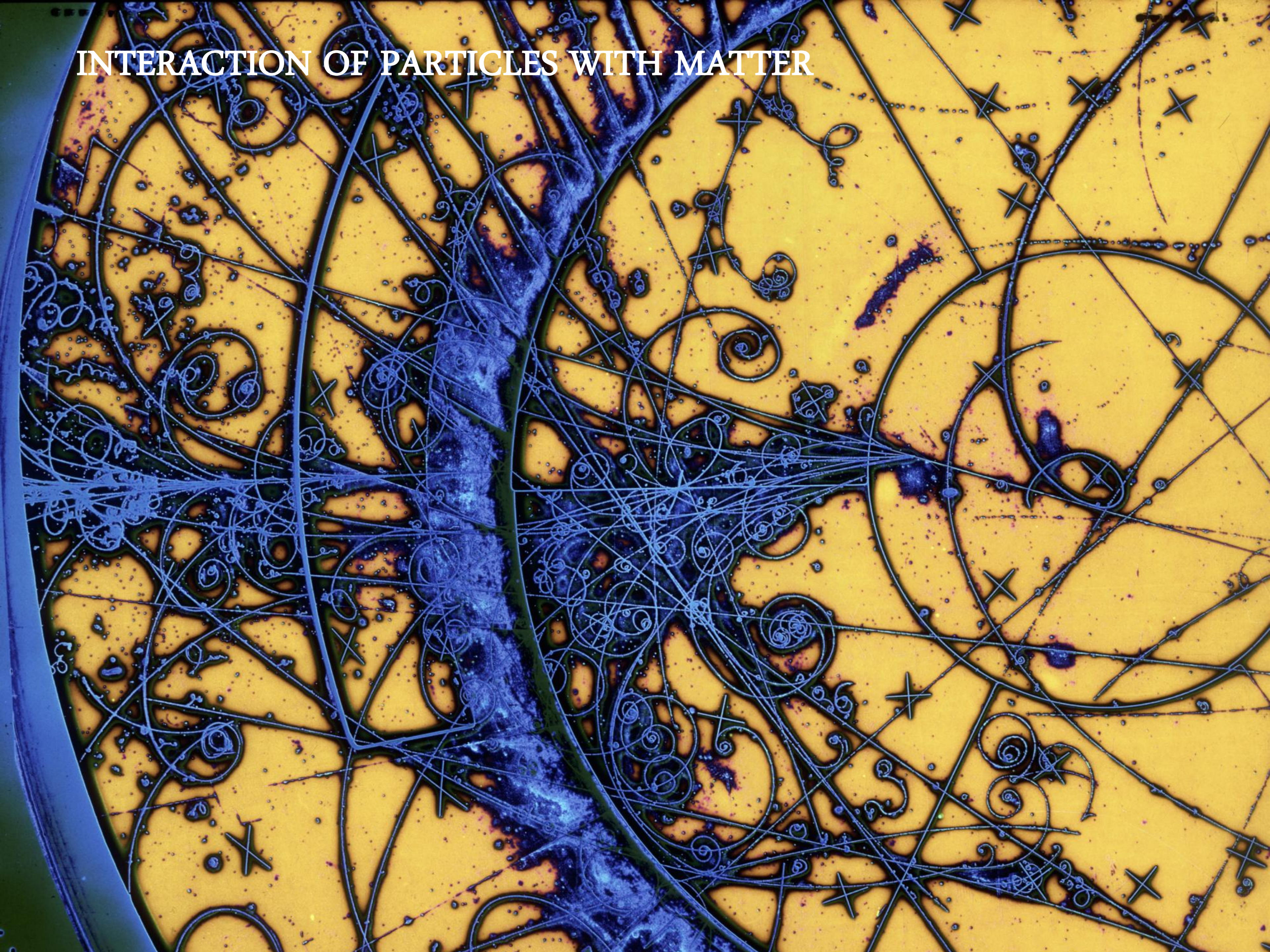
interaction length

Particle detection



- Energy
- Time
- Position
- ID
- Direction
- Velocity
- Momentum
- Mass
- …

- Energy resolution
- Time resolution
- Position resolution
- Efficiency
  - Intrinsic
  - Solid angle
- Count rates
- Radiation damage
- …



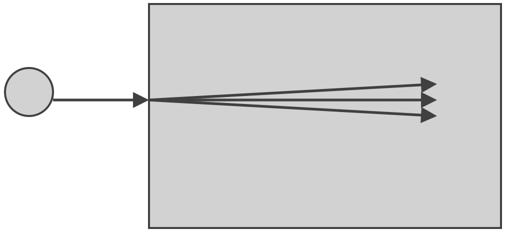
INTERACTION OF PARTICLES WITH MATTER

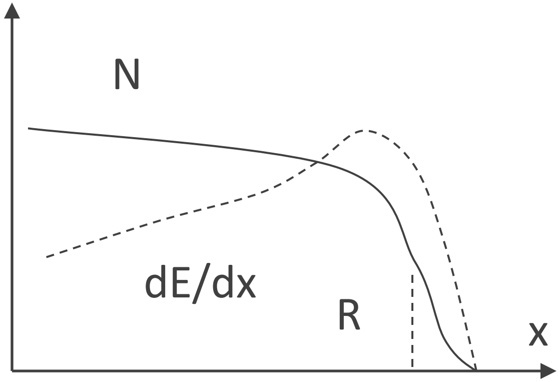
Interaction of particles with matter

- Heavy charged particles : p, d, t, ^{3}He, α, heavier nuclei
- Electrons/positrons: conversion electrons, β^- /β^+ decay, pair production
- Gamma rays
- neutrons

Heavy charged particles

Inelastic interactions
with electrons





$$-\frac{dE}{dx} = \frac{4\pi e^4 z^2}{m_0 v^2} nZ \left[\ln \frac{2m_0 v^2}{I} - \ln\left(1 - \frac{v^2}{c^2}\right) - \frac{v^2}{c^2} \right]$$

Bethe-Block formula

z – projectile atomic number
v – projectile velocity
m_0 - electron mass
e – electron charge

n – target number density
Z – target atomic number
nZ – target electron density
I – average excitation and ionization potential

Stopping Power and Range in Si and Ge

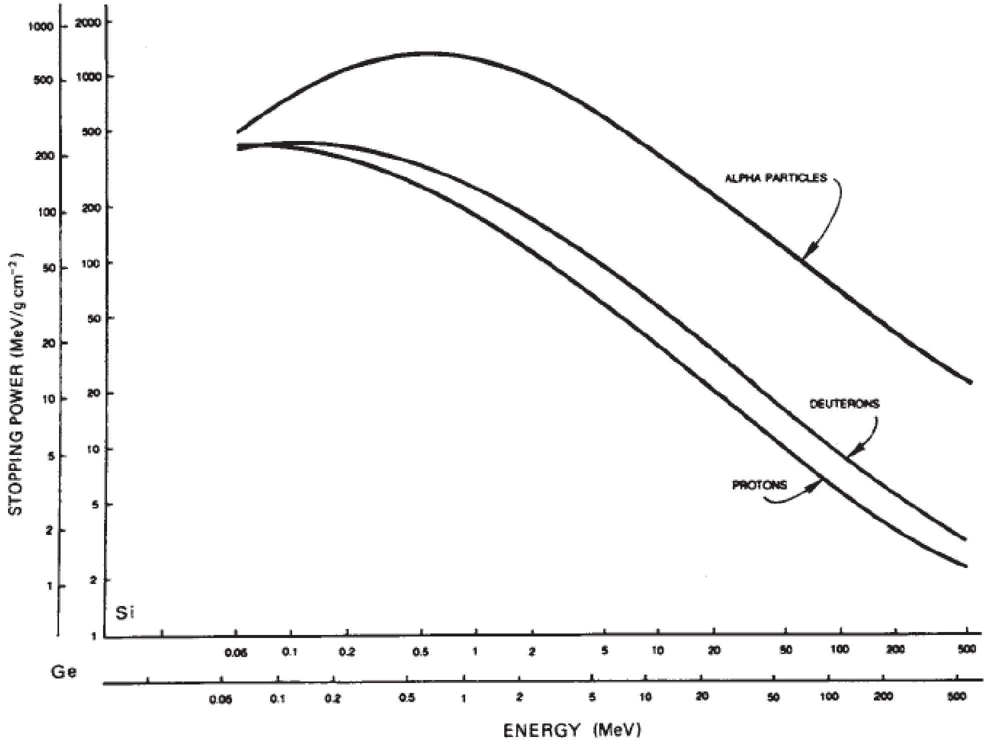


Fig. 1. Stopping Power vs. Energy for Protons, Deuterons, and Alpha Particles in Si and Ge.

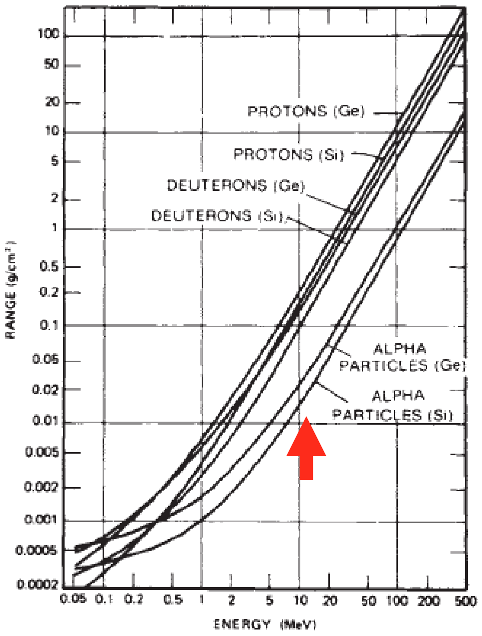
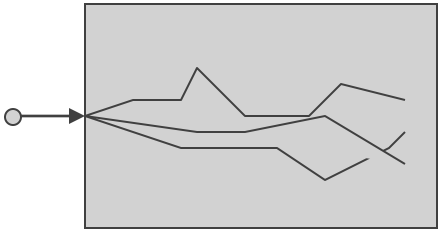


Fig. 2. Proton, Deuteron, and Alpha Particle Ranges in Si and Ge.

ORTEC detector catalog

Electrons (positrons)

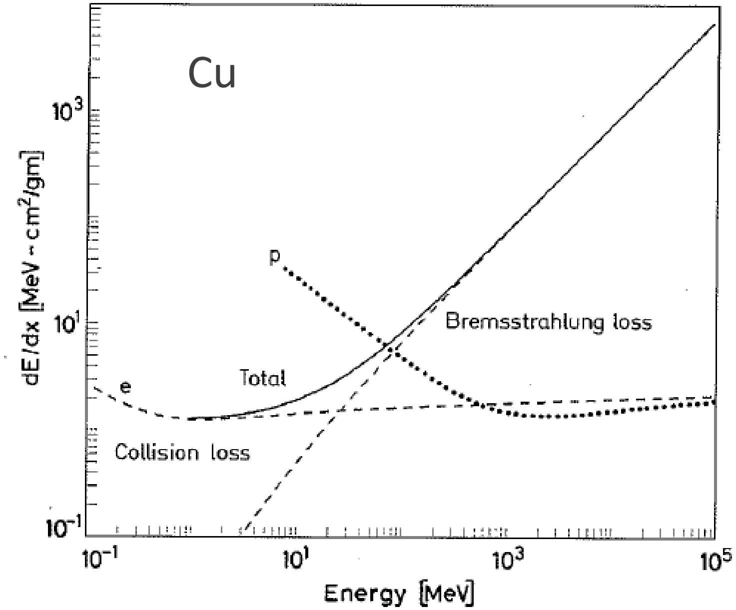
- Same interaction as for ions BUT lower mass
- Radiative energy loss – bremsstrahlung
- Backscattering



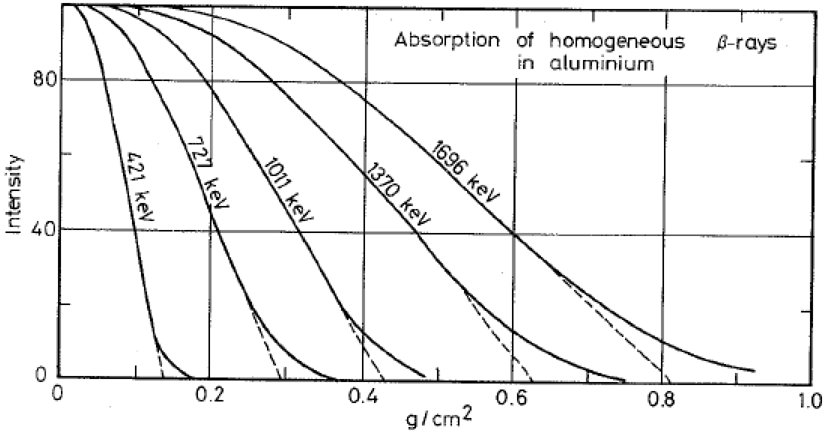
$$-\left(\frac{dE}{dx}\right)_c = \frac{4\pi e^4 z^2}{m_0 v^2} nZ\left[\ln \frac{m_0 v^2 E}{2I^2\left(1-\beta^2\right)} - \ldots\right]$$

$$-\left(\frac{dE}{dx}\right)_r = \frac{E(Z+1)e^4}{137 m_0{}^2 c^4} nZ\left[4\ln \frac{2E}{m_0 c^2} - \frac{4}{3}\right]$$

$$\frac{\left(\frac{dE}{dx}\right)_r}{\left(\frac{dE}{dx}\right)_c} \cong \frac{E[MeV]Z}{700}$$



Electron energy loss



Range not defined well

100 keV -10 MeV – 0.5 keV/μm in Si

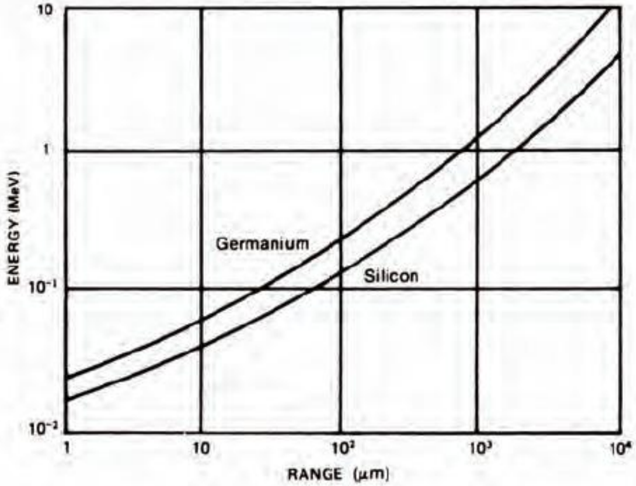
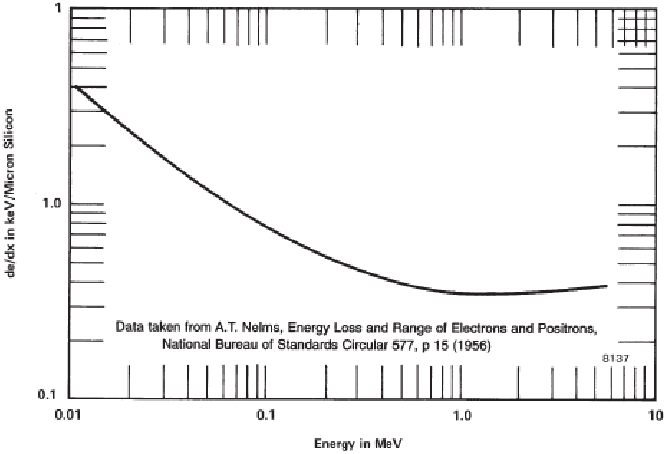


Fig. 3. Zero Transmission Range vs. Energy for Electrons in Si and Ge.

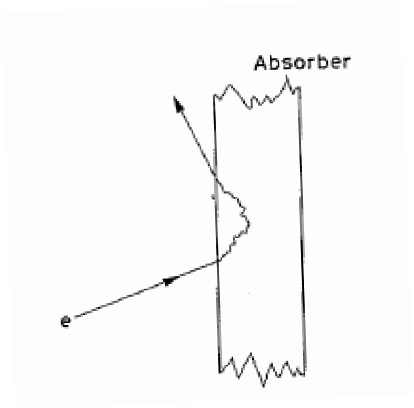


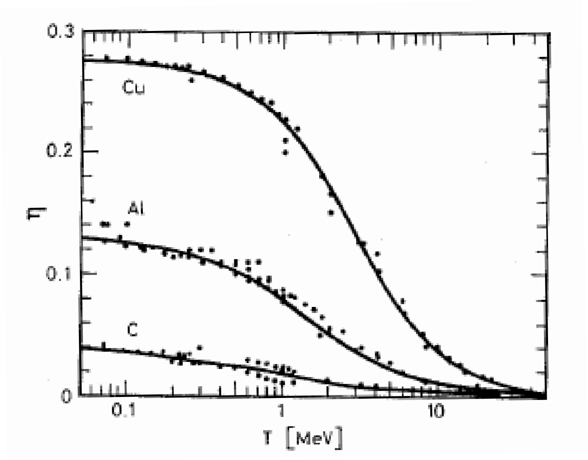
Data taken from A.T. Nelms, Energy Loss and Range of Electrons and Positrons, National Bureau of Standards Circular 577, p 15 (1956)

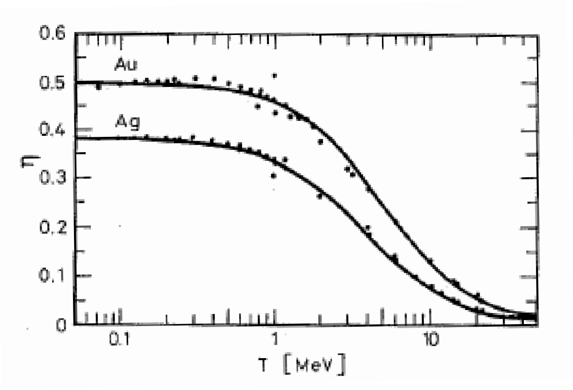
Fig. 7. Specific Energy Loss for Electrons in Silicon.
NOTE: Channeling of ions between crystal planes can result in significant variations from the data shown here.

From ORTEC detector catalog

Electron backscattering



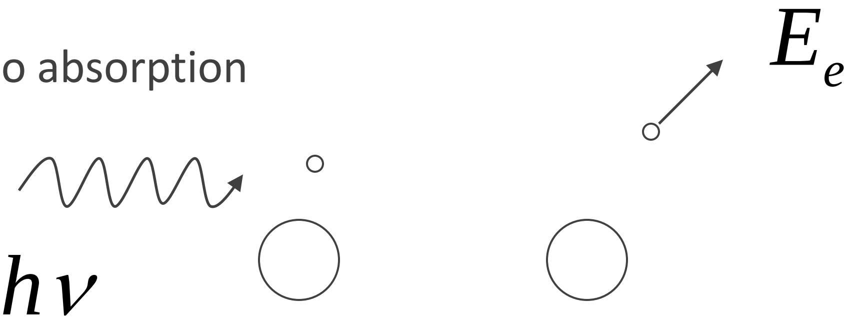




Backscattered fraction

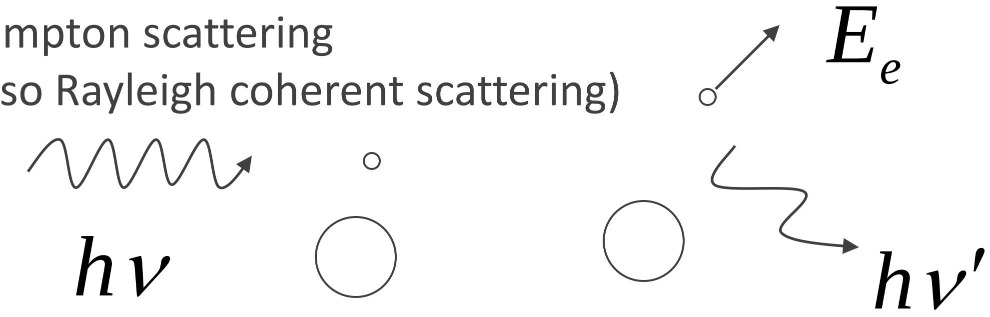
Gamma rays

Photo absorption



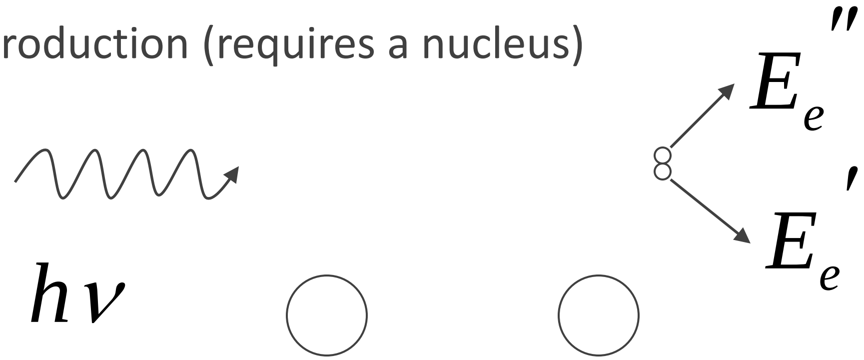
$$h\nu = E_e + B_e$$

Compton scattering
(also Rayleigh coherent scattering)



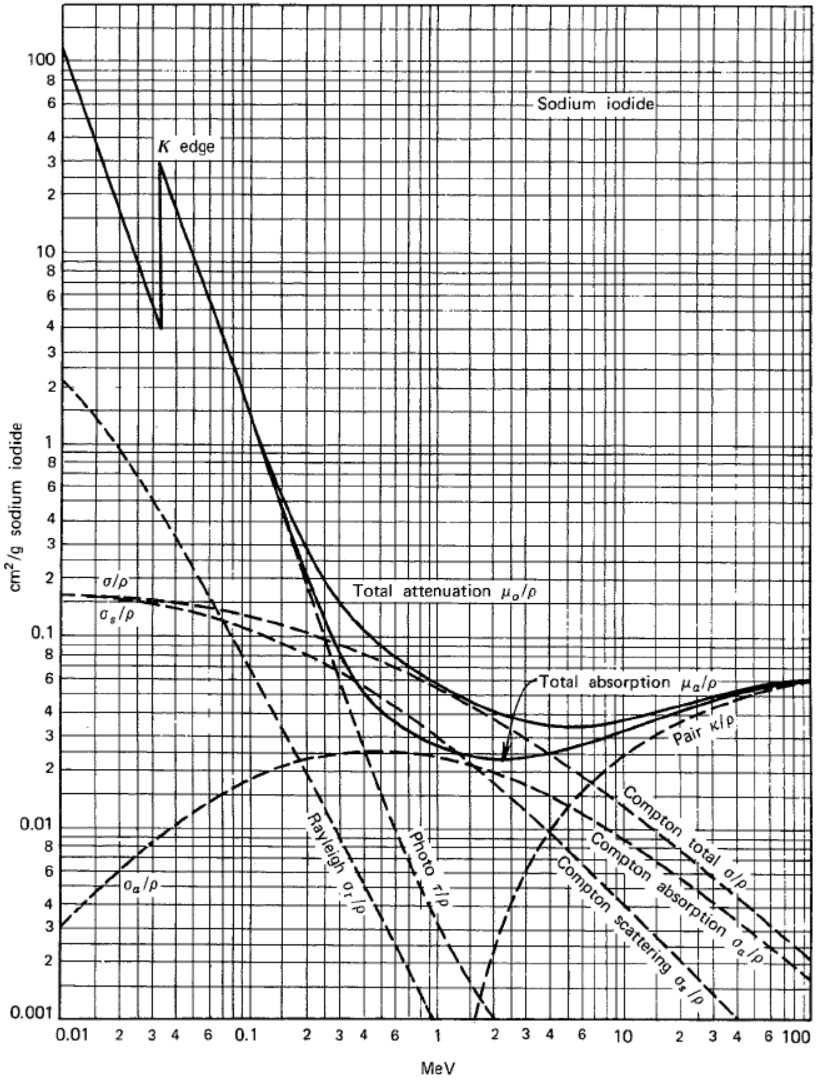
$$h\nu = E_e + B_e + h\nu'$$

Pair production (requires a nucleus)



$$h\nu = E_e'' + E_e' + 2m_0c^2$$

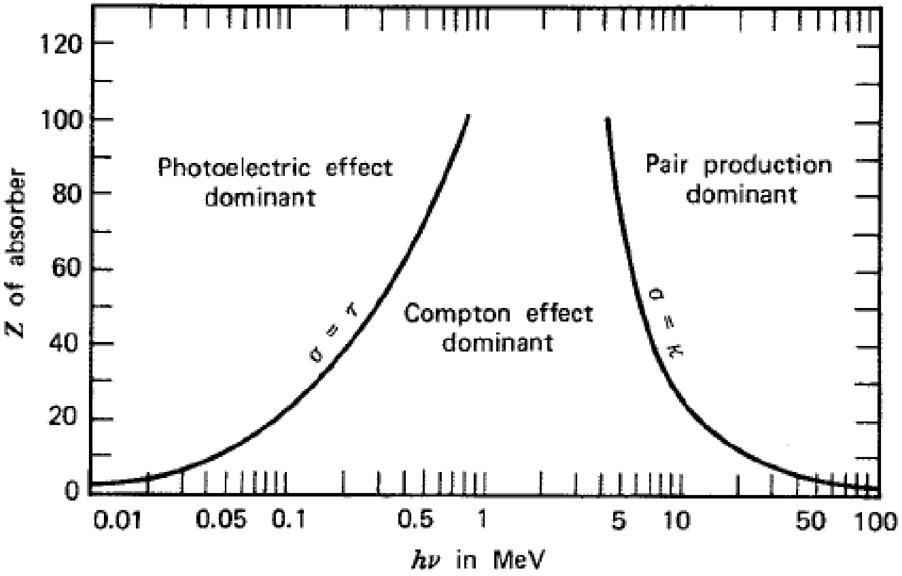
Gamma-ray attenuation



$$\sigma = \sigma_{COMPT} + \tau_{PE} + \kappa_{PAIR} + \sigma_R$$

$$I = I_0 e^{-\frac{\mu_0}{\rho}\tau} = I_0 e^{-\frac{N_A}{A}\frac{\sigma}{\rho}\tau}$$

γ-ray attenuation



Gamma-ray linear absorption coefficient

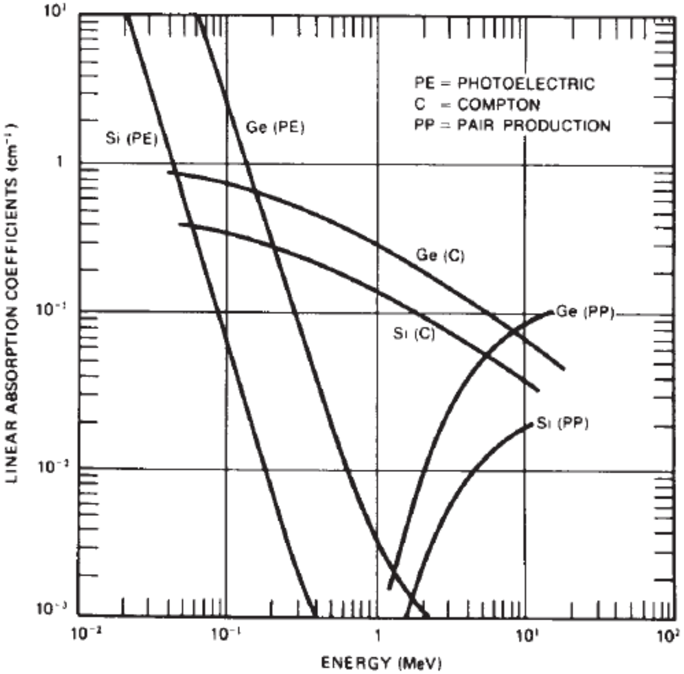
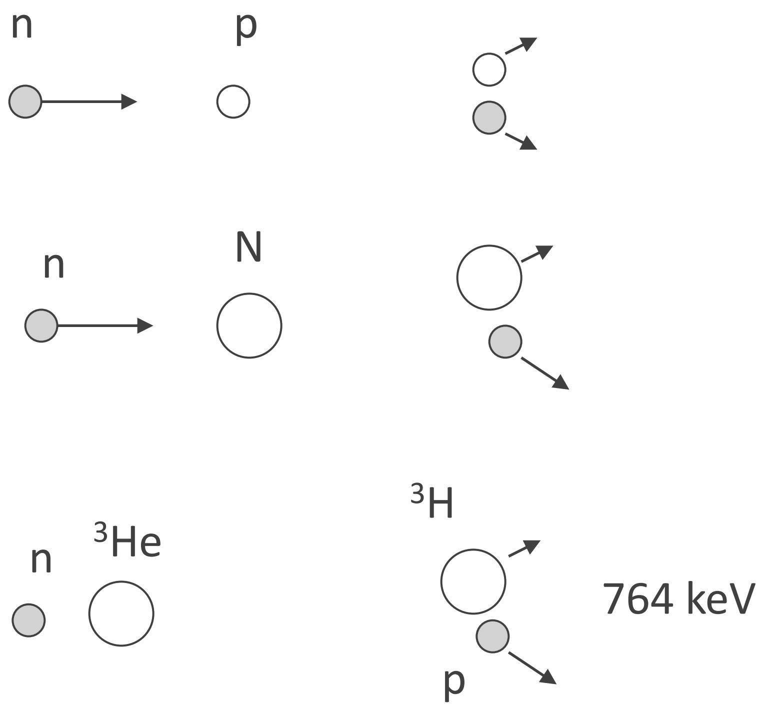


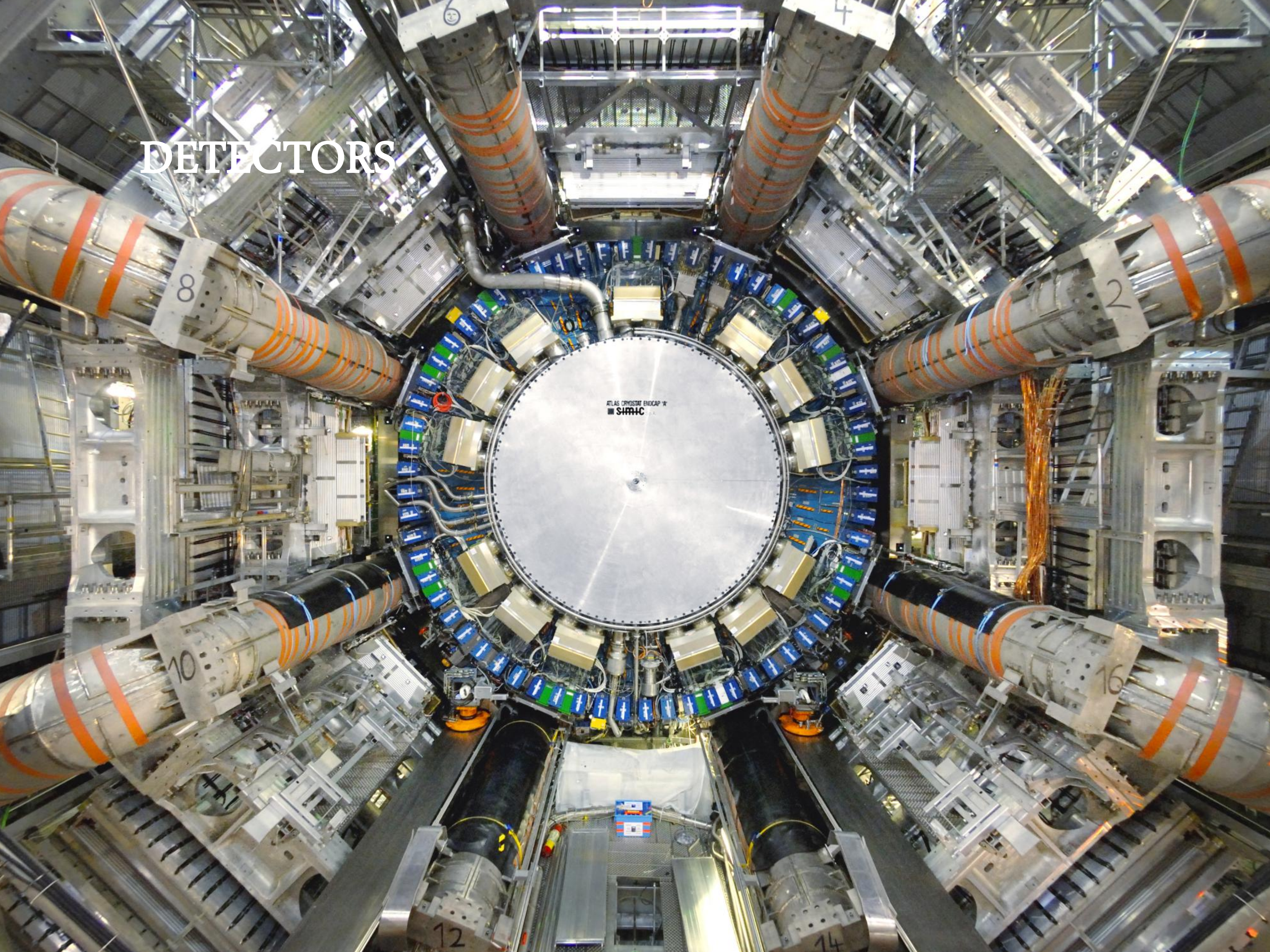
Fig. 4. Linear Absorption Coefficients vs. Gamma-Ray Energy for Si and Ge.

Neutrons

- Fast neutrons
  - Scattering
  - Hydrogen most efficient
- Slow neutrons <0.5 eV
  - Scattering leads to thermalization (0.025 eV)
  - Nuclear reactions with positive Q value
    - (n,γ)
    - (n,α)
    - (n,p)
    - (n,f)



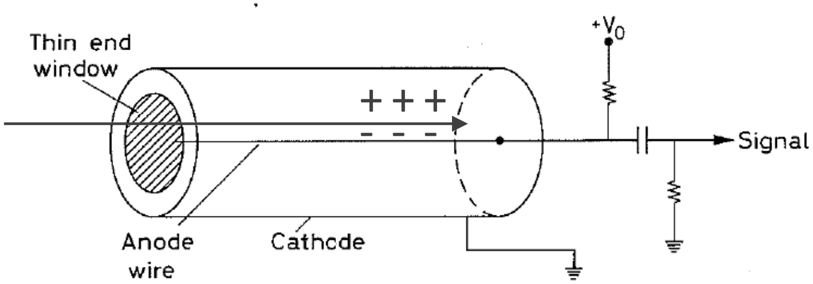
DETECTORS

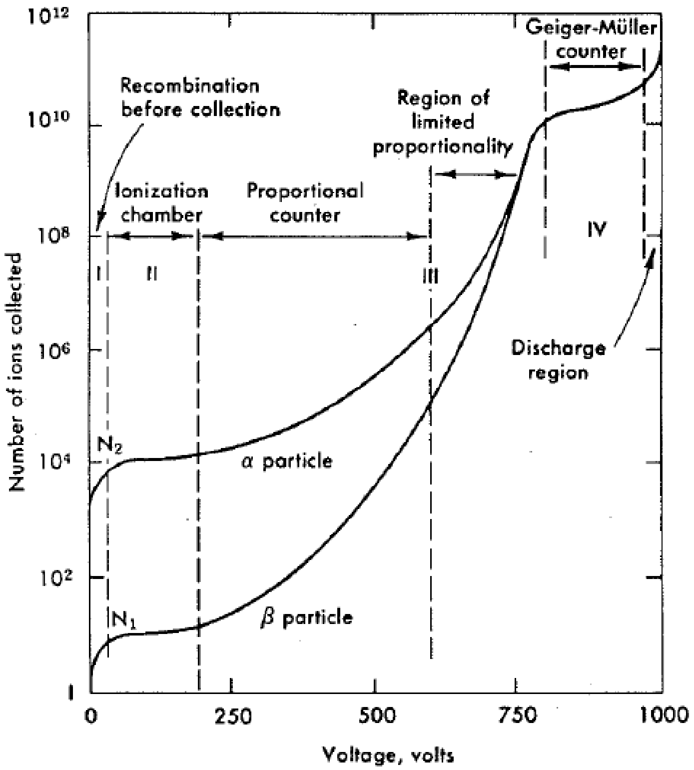


Detectors

- Gas detectors
  - Ionization chamber
  - Multiwire proportional counter
  - Time projection chamber
- Scintillators
  - Organic
  - Non-organic
  - photomultipliers
- Semiconductor detectors
  - Si
  - Ge

Modes of operation of a gas detector





~30 eV mean energy for creating electron-ion pair

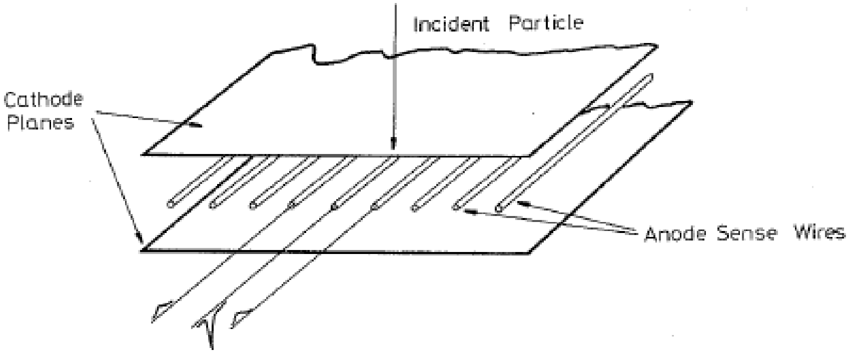
Ar

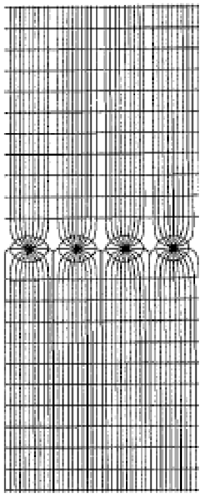
Ar90%+methane10%=P10

Isobutane

…

Multiwire proportional counter



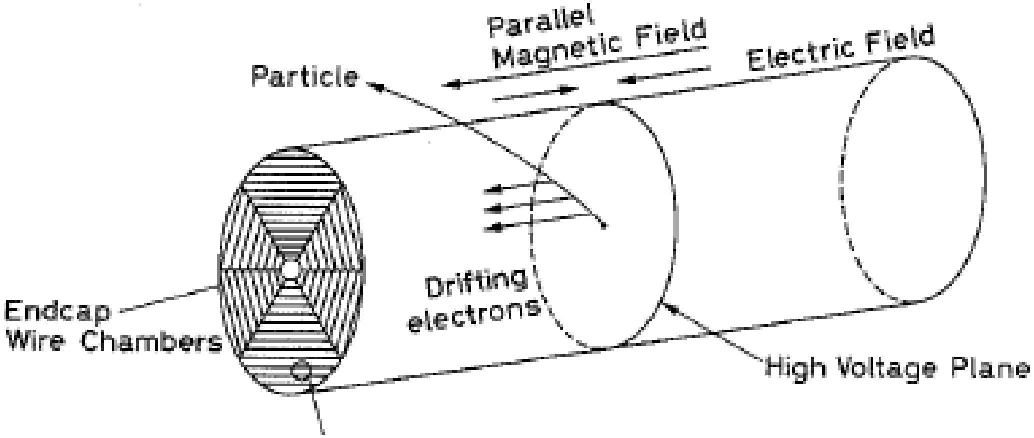


Electrons accelerated in very high electric field close to thin wires ionize more molecules leading to avalanche formation

The Nobel Prize in Physics 1992 was awarded to Georges Charpak *"for his invention and development of particle detectors, in particular the multiwire proportional chamber"*

Time-projection chamber

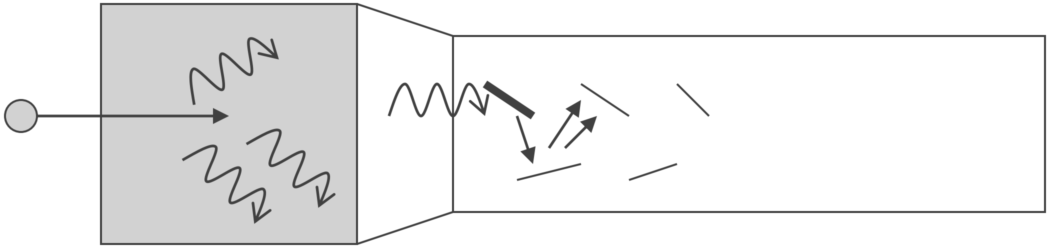
- x,y coordinates
- Drift time along magnetic field provides z-coordinate
- 3-dimensional imaging



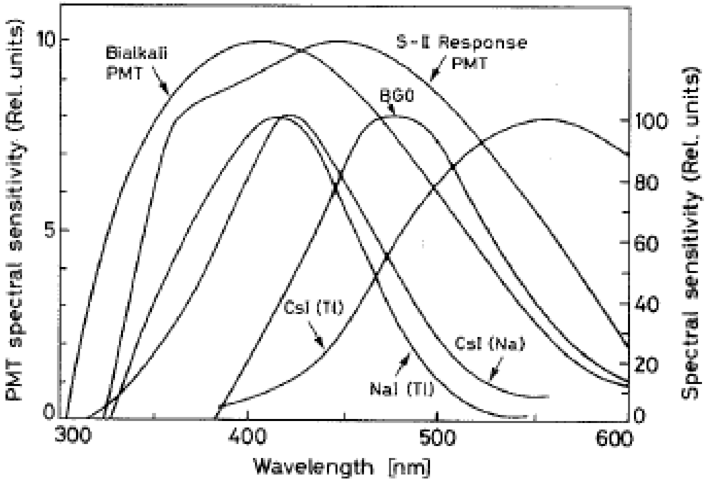
Scintillator detectors

Charged particles excite molecules which deexcite by emitting light

- Organic
  - Plastics
  - Liquid
  - Crystals
- Non-organic
  - Crystals
- Light guides
  - Plastics

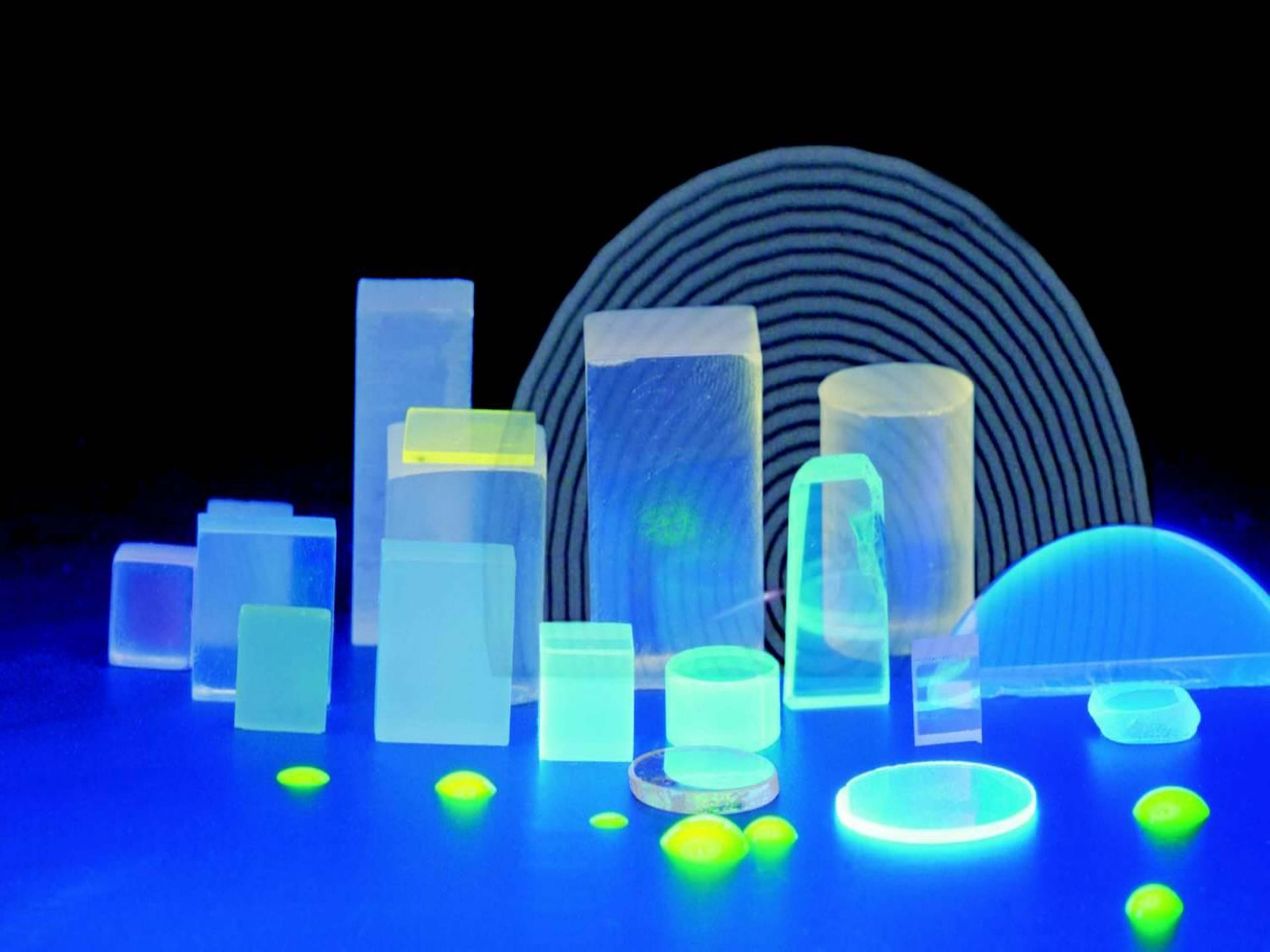


scintillator light guide photomutiplier



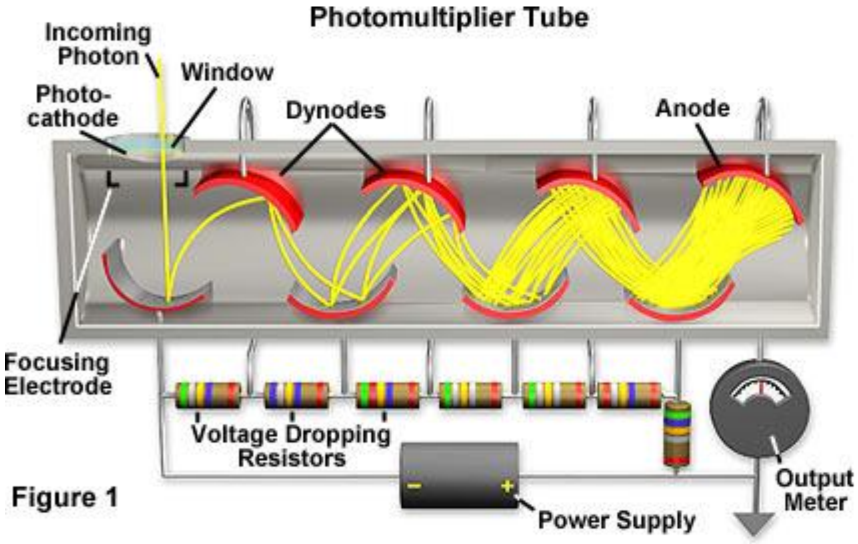
Scintillators - comparison

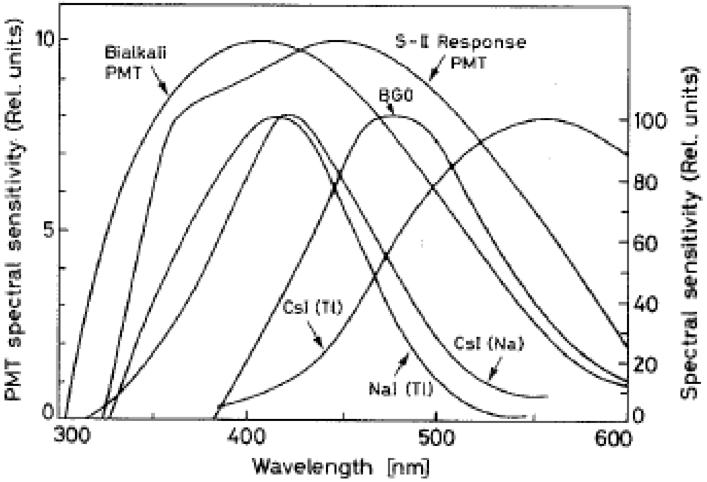
NE102A	plastic	1.03 g/cm3	10 ph/keV	2.4 ns	fast/inexpensive
NE213	liquid	0.87 g/cm3	13 ph/keV	3.7 ns	nγ discrimination
NaI(Tl)	crystal	3.67 g/cm3	38 ph/keV	250 ns	dense Bright common
BaF2	crystal	4.88 g/cm3	10/1.8ph/keV	630/0.7 ns	fast
BGO	crystal	7.13 g/cm3	9 ph/keV	300 ns	dense
LaBr3	crystal	5.08 g/cm3	63 ph/keV	16 ns	dense bright fast

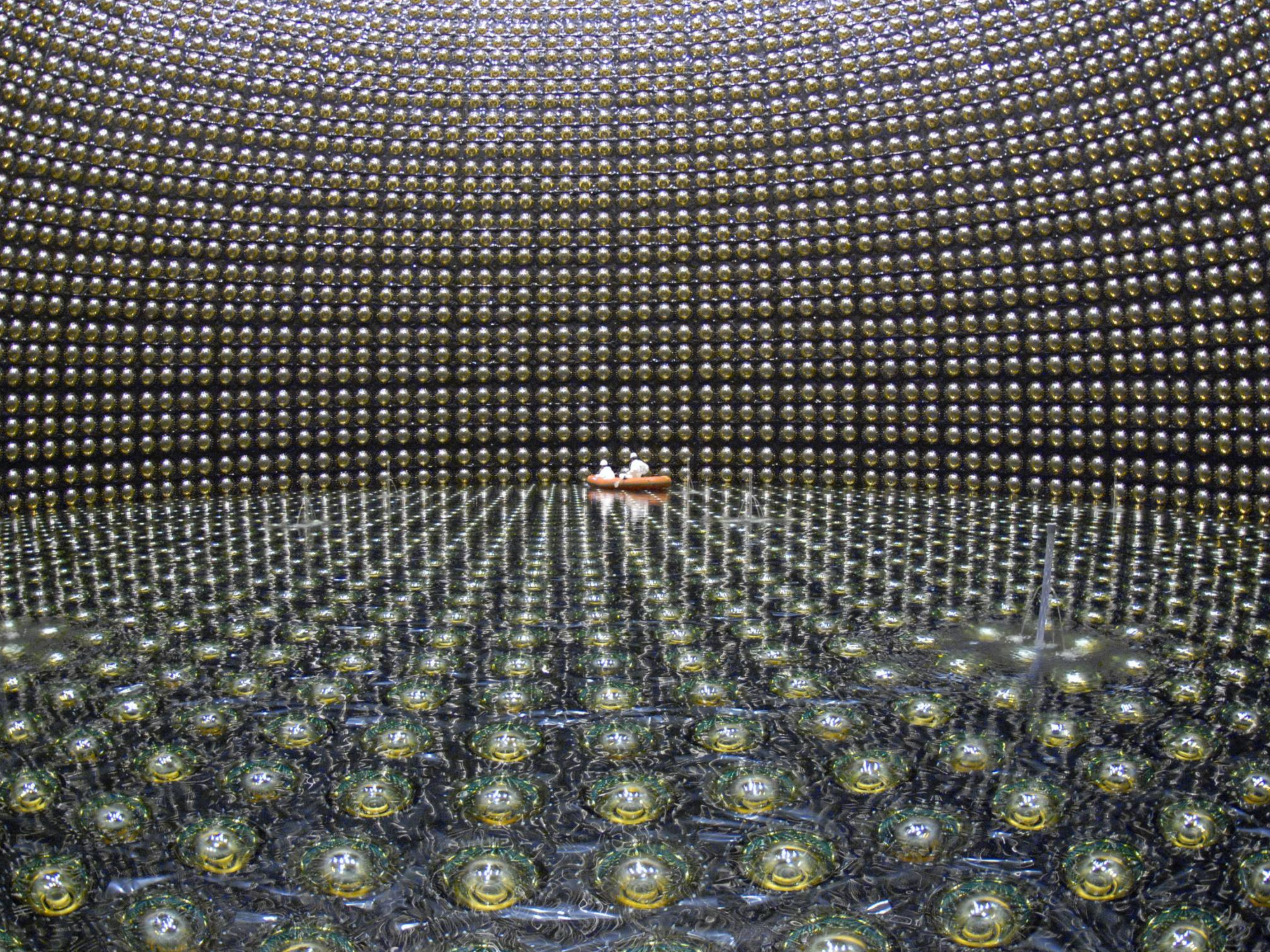


Photomultiplier

- Photomultipliers
- Channel plates
- Photodiodes
- Avalanche photodiodes



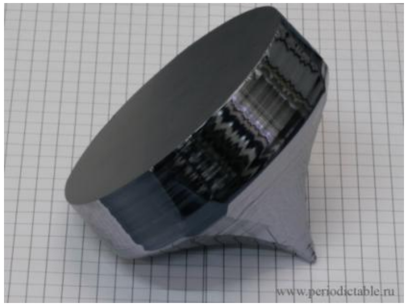




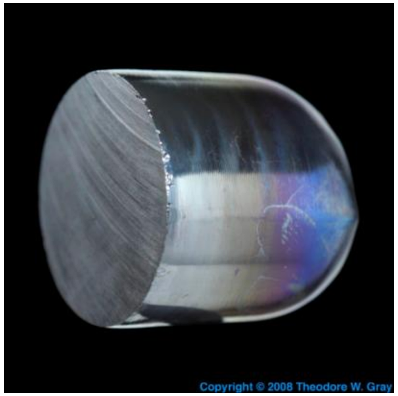
Semiconductor detectors

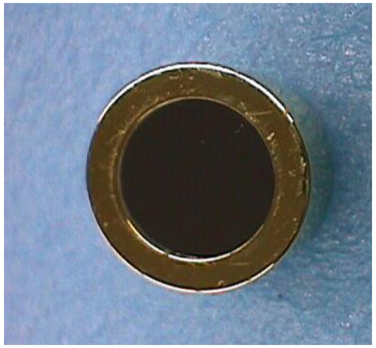
- Dense
- Excellent energy resolution

Germanium

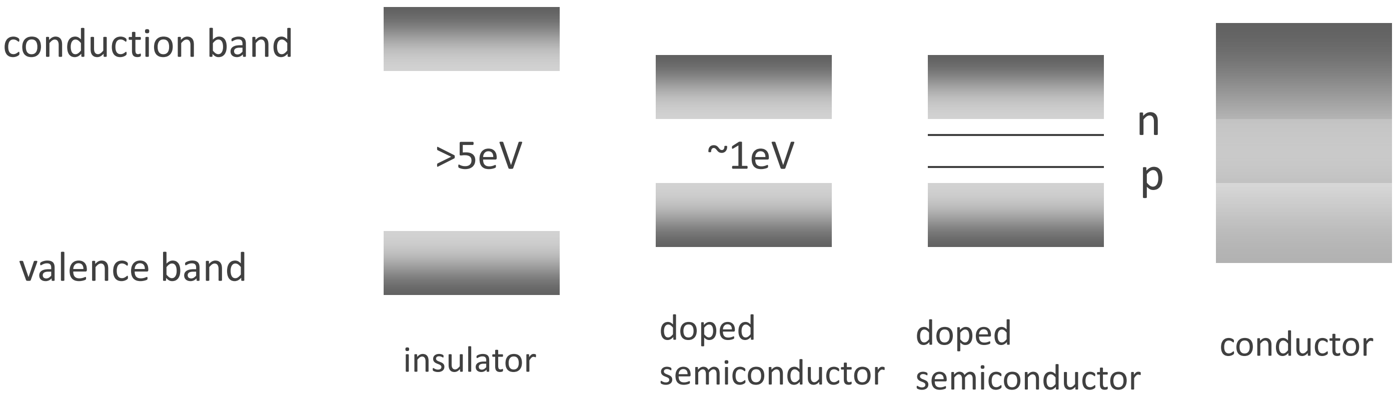


Silicon





Band structure



conduction band

valence band

>5eV

~1eV

n

p

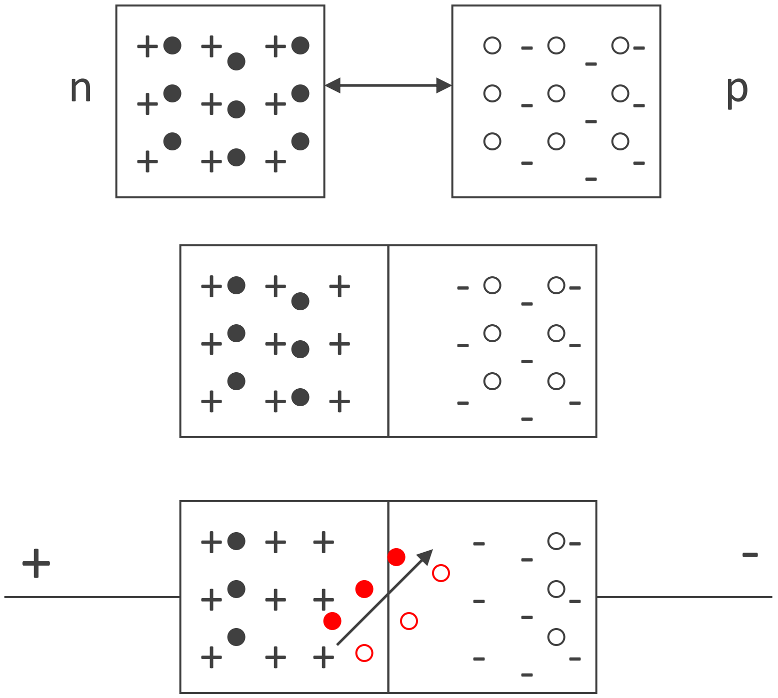
insulator

doped semiconductor

doped semiconductor

conductor

p-n junction



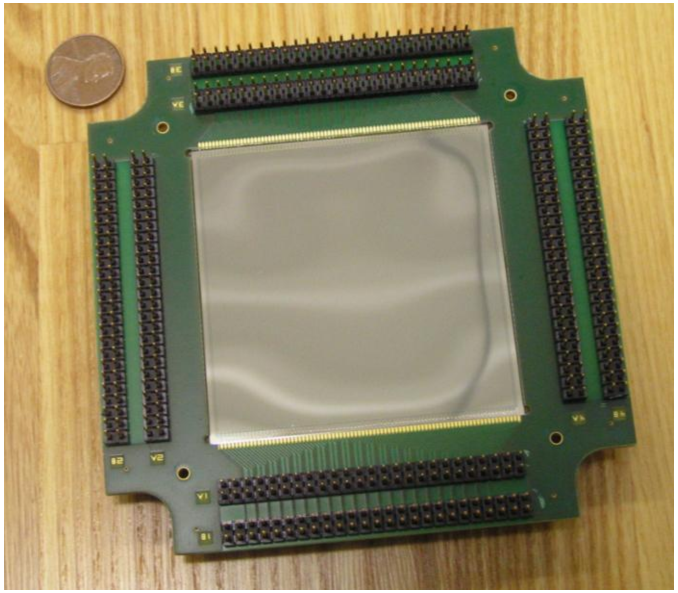
p-n junction

Reversely biased diode

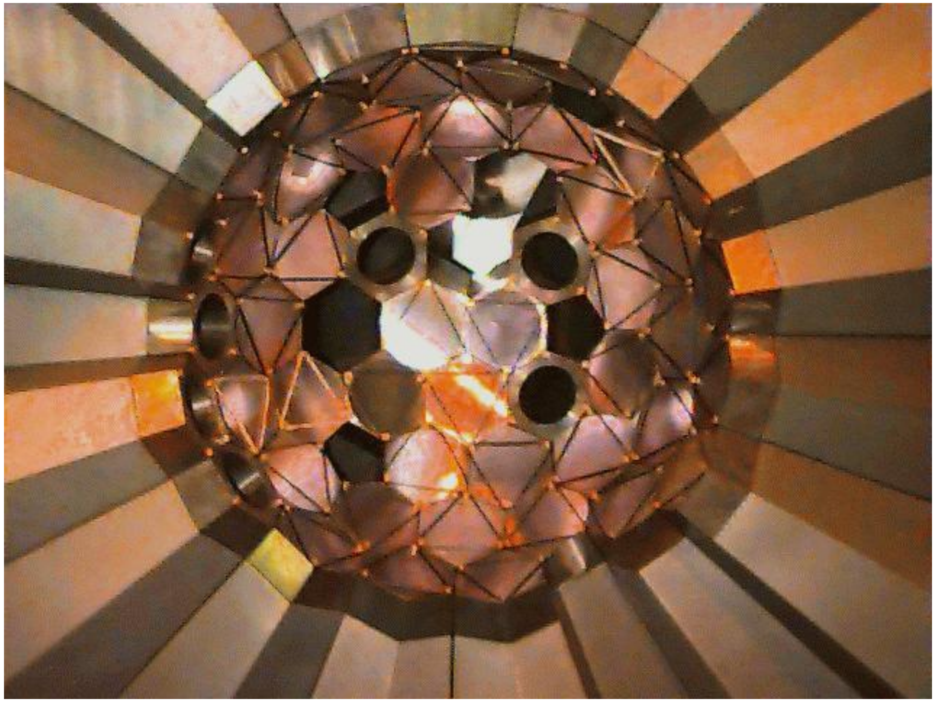
- \+ acceptor atom
- \- Donor atom
- ● Electron
- ○ Hole

Semiconductor detector comparison

material	Atomic number	density	gap	Energy per e-h pair	Temp	Comments
Si	14	2.33 g/cm3	1.1 keV	3.62 keV	300 K room	thin
Ge	32	5.32 g/cm3	0.7 keV	2.96 keV	77 K LN2	Excellent E large Expensive
CdTe	48/52		1.45 keV		300 K room	Small



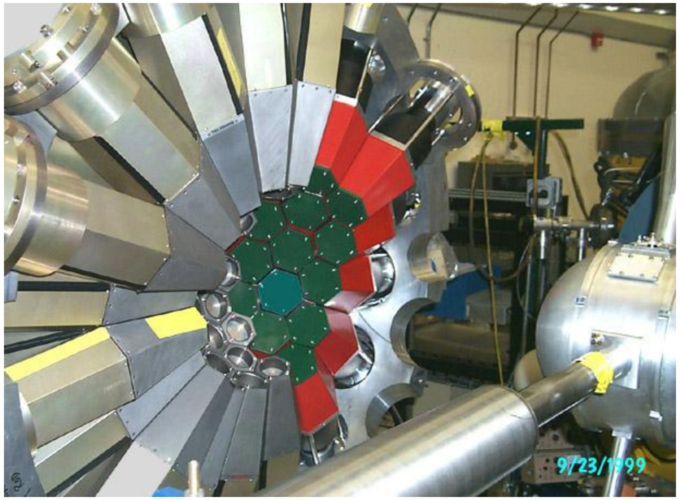
Double sided Si strip Detector



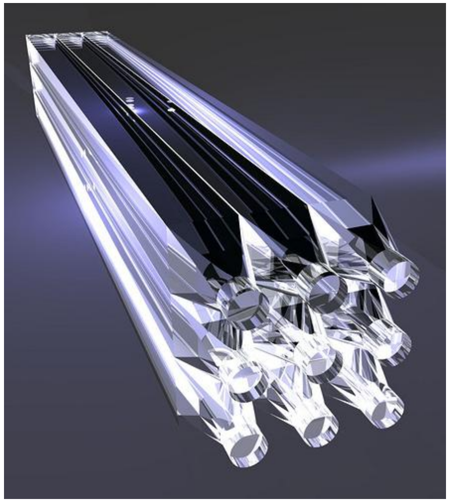
Ge detector arrays

Neutron detectors

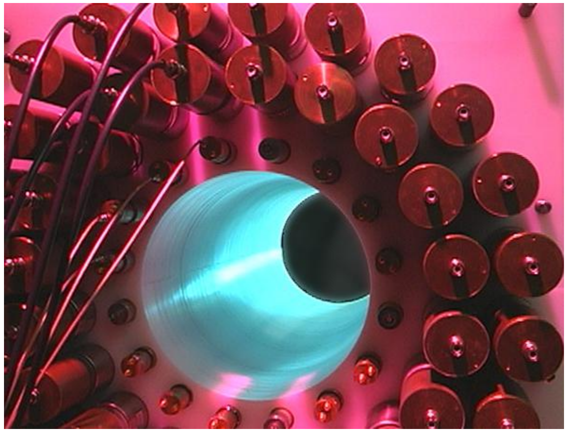
- Liquid scintillators
  - nγ discrimination
  - no energy information
- Plastic detectors
  - Fast
  - TOF measurements
- ^{3}He detectors
  - Moderator
  - proportional ^{3}He counter



Neutron Wall



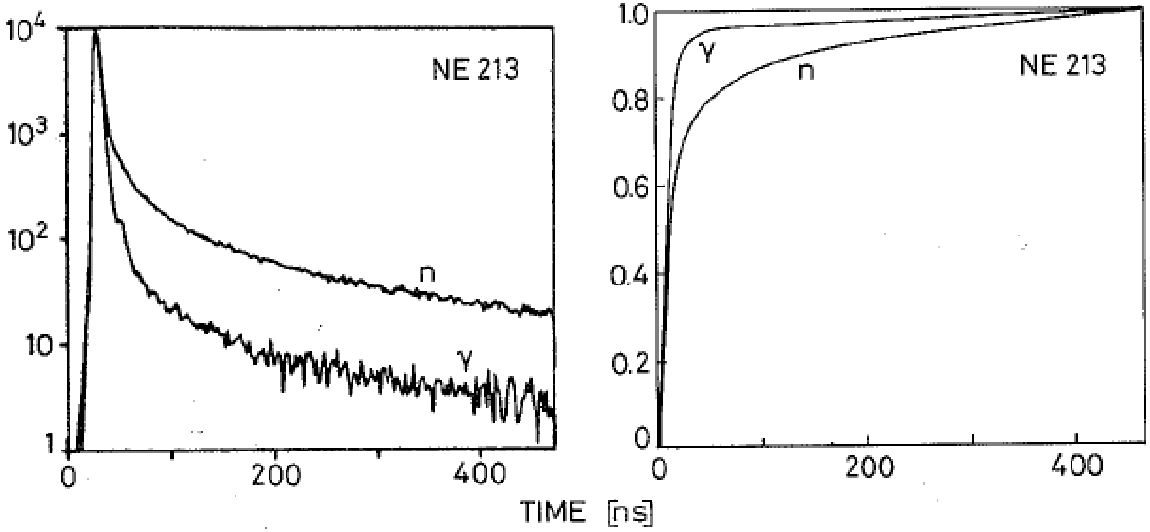
Mona



Nero

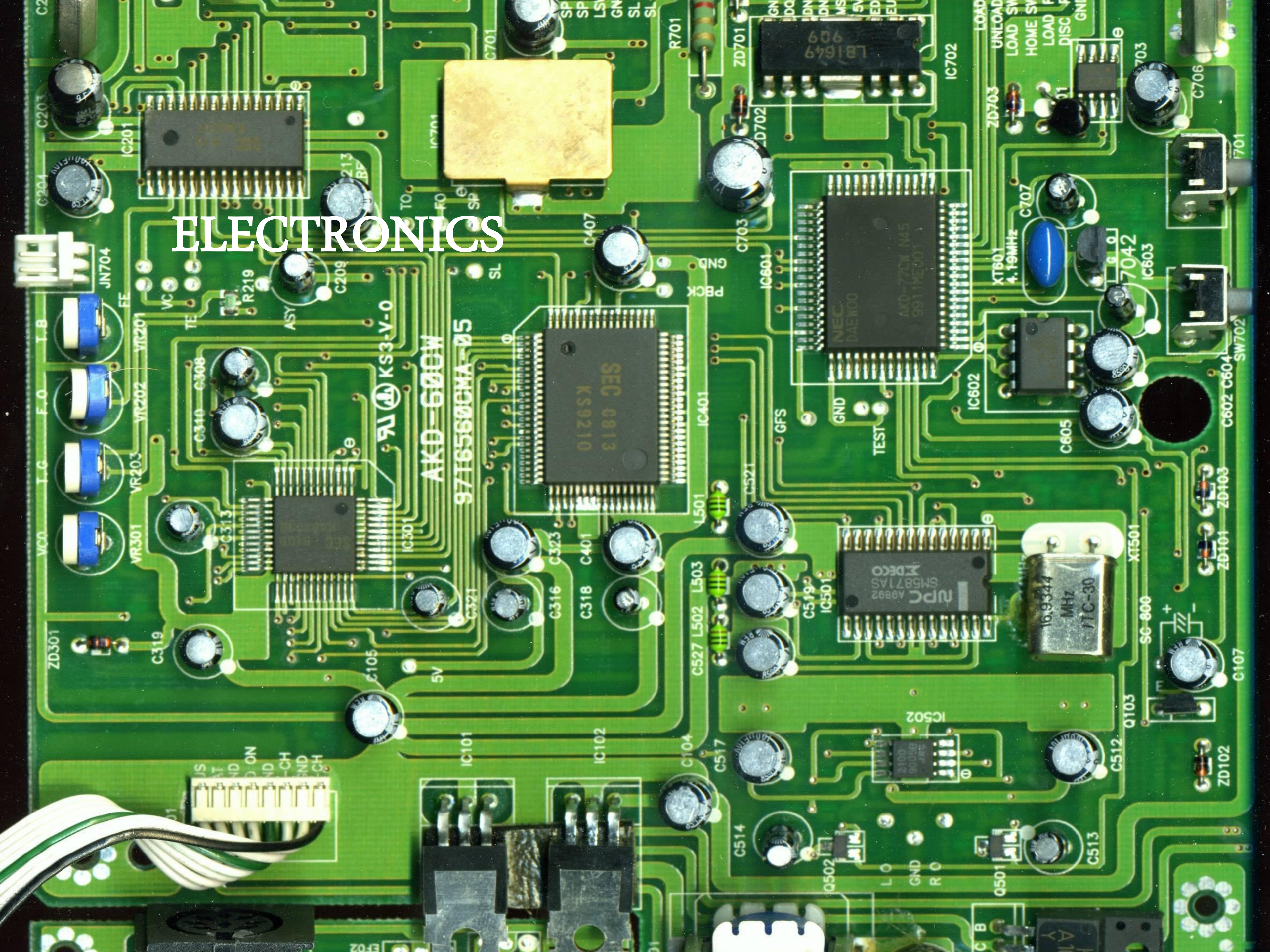
Neutron-gamma discrimination

NE213, BC-529 – fast and slow light component
Electrons and protons excite the 2 components differently

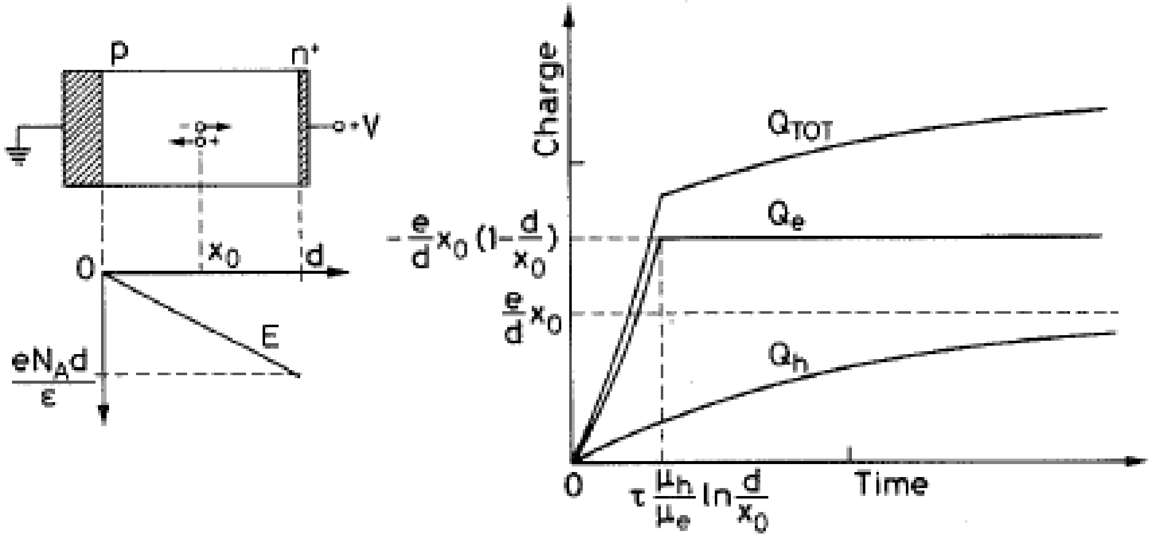


Neutrons are converted into protons
Gamma rays are converted into electrons

ELECTRONICS

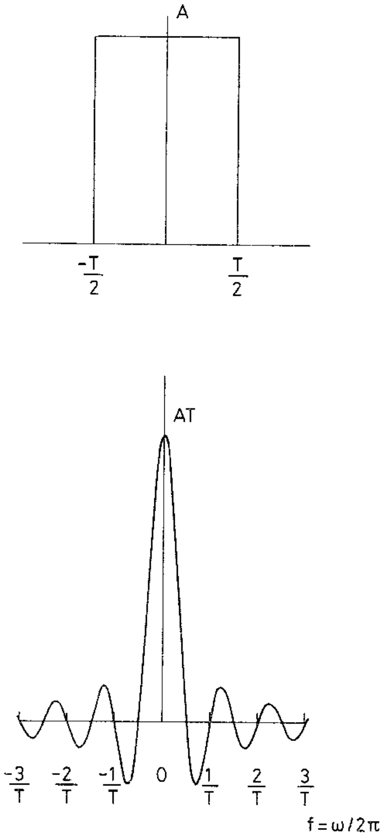


Signal formation

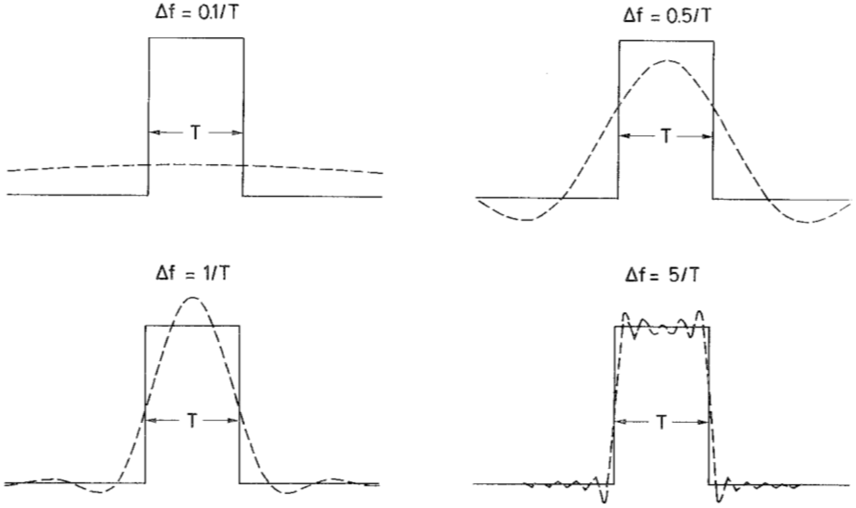


Signal starts the moment the electrons and holes start moving apart.
The risetime depends on the carrier mobility, material resistivity and interaction point.

Frequency domain



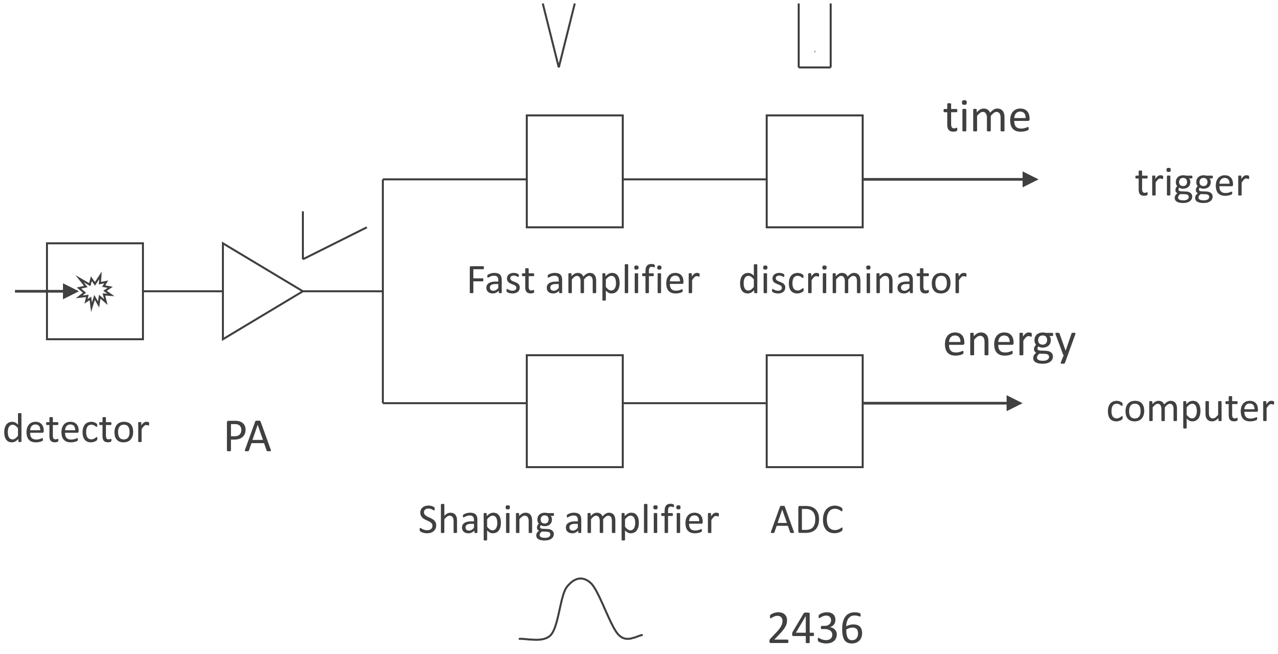
Fourier transform



High frequency cut-off

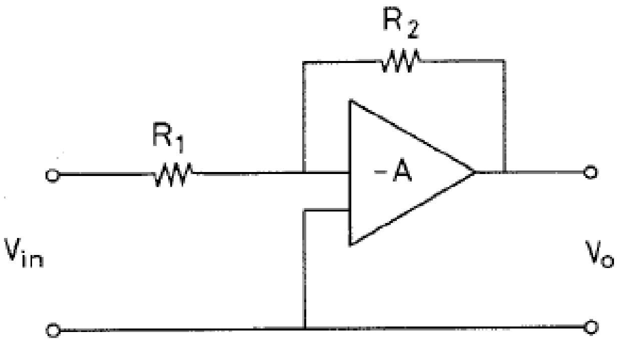
Signal processing

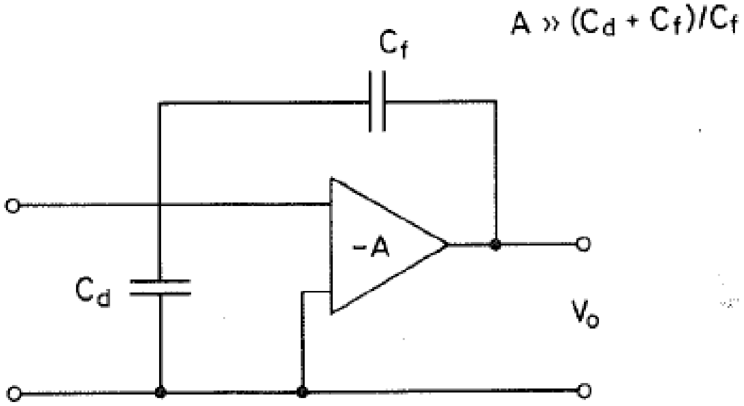
- Preamplifiers
- Amplifiers
- Discriminators
- Analog-to-Digital converters
- Digital electronics



Preamplifiers

- 1st amplification stage
  - Low noise





$$V_0 = \frac{Q}{C_{tot}}$$

$$V_0 = -\frac{Q}{C_f}$$

Voltage sensitive

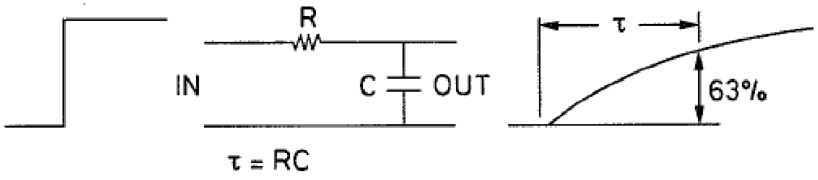
Depends on detector capacitance!

Charge sensitive

resistor parallel to C_f results in exponential tail

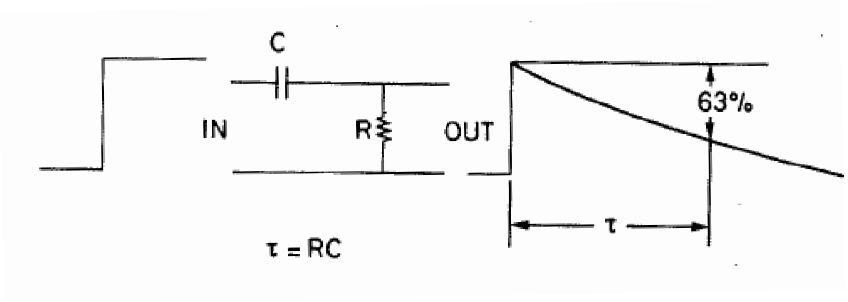
Amplifiers

- 2^{nd} amplification stage
  - Amplification
  - Shaping
  - Filtering



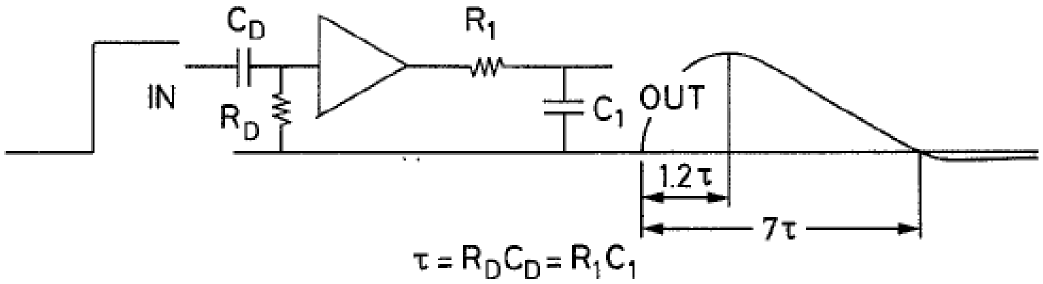
$$f < \frac{1}{2\pi RC}$$

Low pass filter, integrating circuit



$$f > \frac{1}{2\pi RC}$$

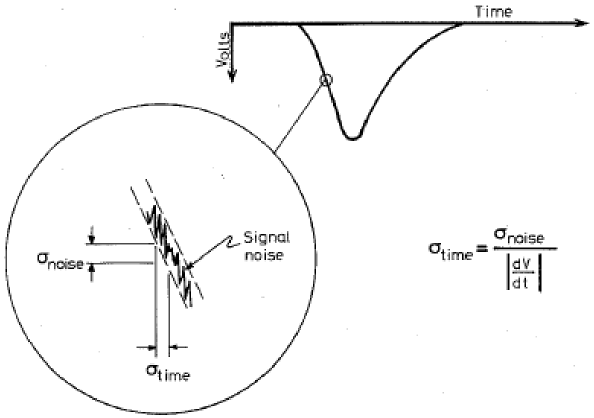
High pass filter, differentiating circuit



CR-RC pulse shaping

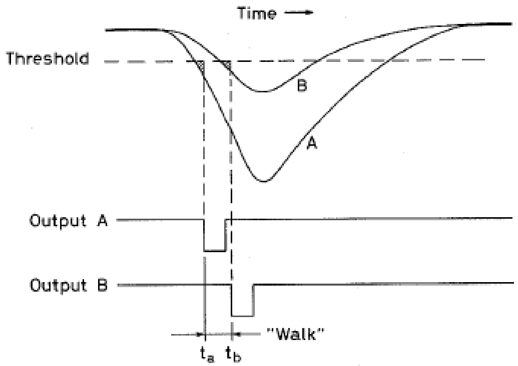
Discriminators

- Time measurement
- Discriminators
  - Leading edge
  - Constant fraction
  - Rise time compensation

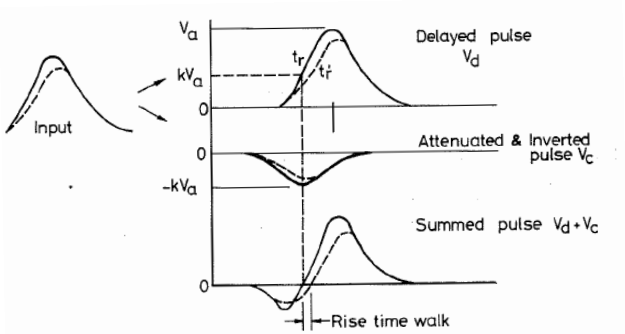


$$\sigma_{time} = \frac{\sigma_{noise}}{\left|\frac{dV}{dt}\right|}$$

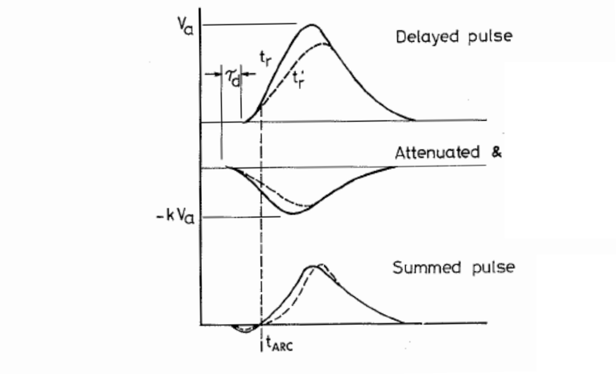
LE



CF

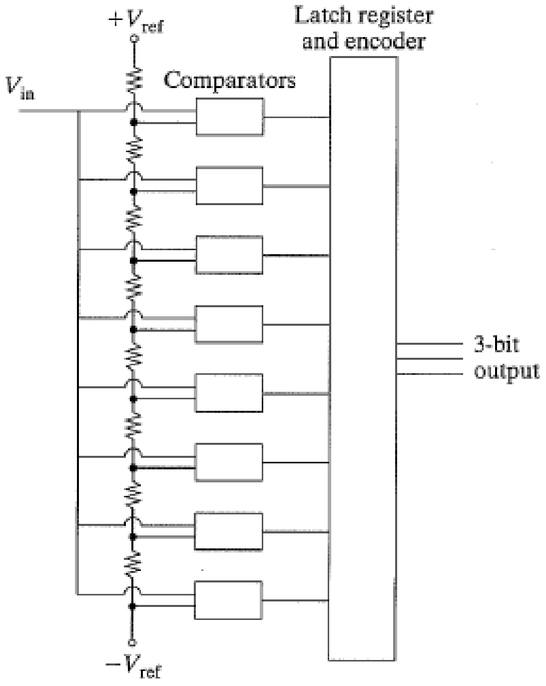


ARC



Analog-to-digital converters

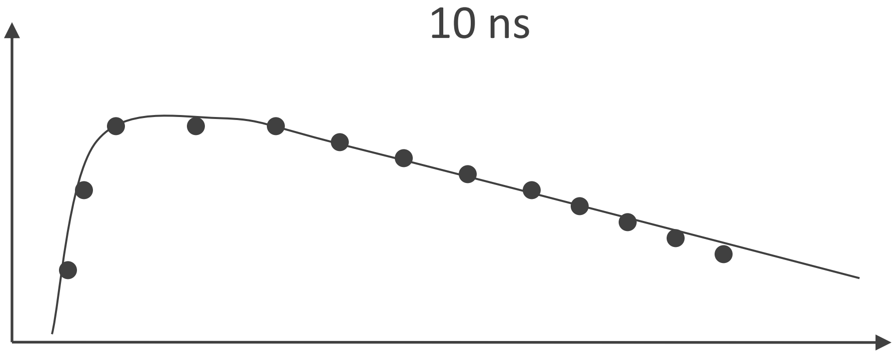
- ADC - amplitude
- QDC - charge
- TDC - time
- Different methods
  - Wilkinson method - accurate
  - Successive approximation - fast
  - Flash ADC – very fast

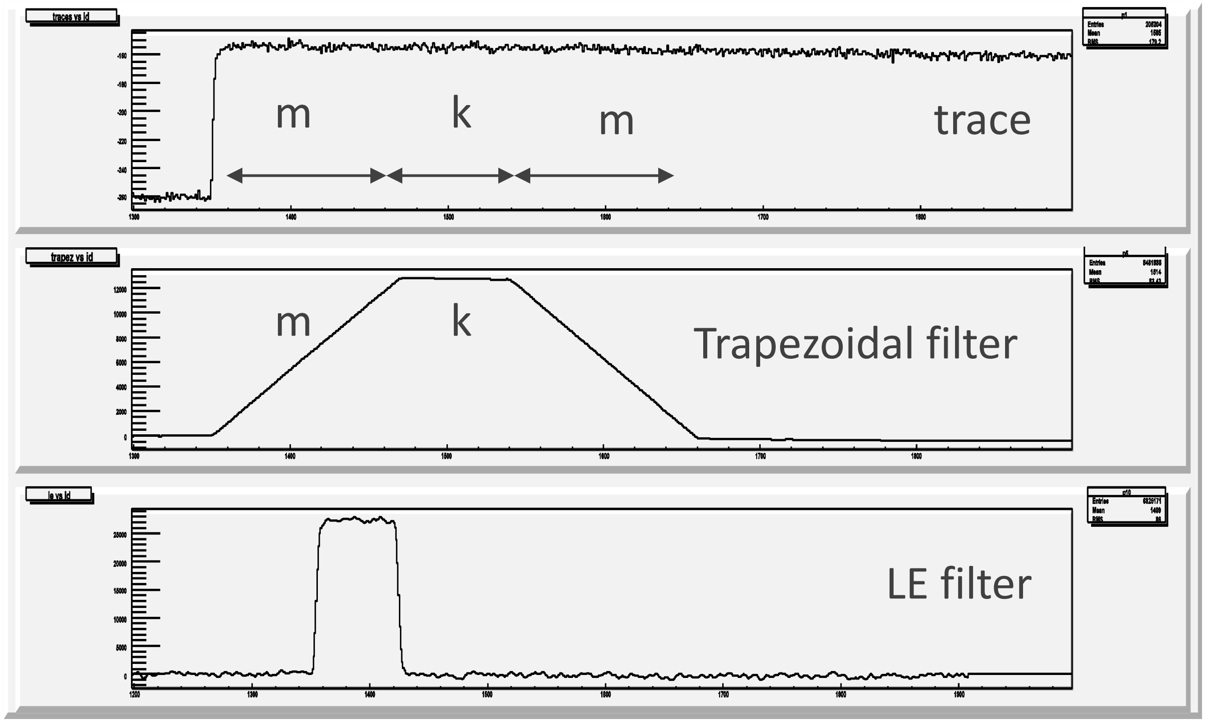


Flash ADC

Digital electronics

- PA signal is digitized every ~10ns
- Trapezoidal filter - energy
- LE filter - time





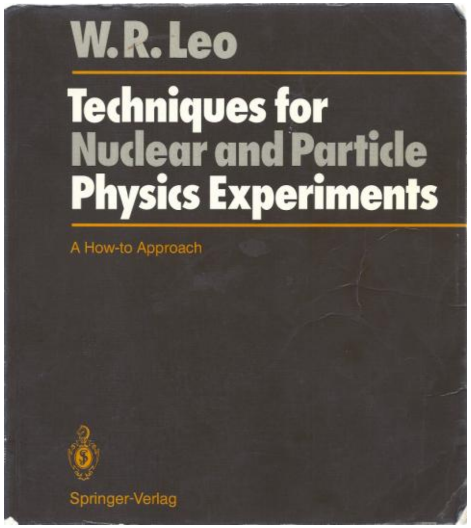
$$x(n)$$

$$y(n) = y(n-1) + x(n) - x(n-m) - (x(n-m-k) - x(n-2m-k))$$

$$y(n) = x(n) - x(n-k)$$

Jordanov&Knoll NIM A345(94)337

Textbooks

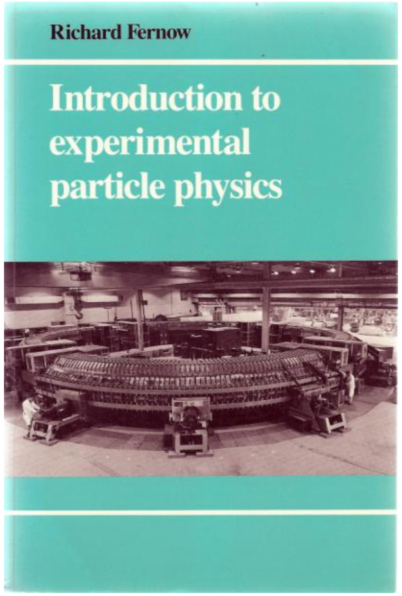


W.R. Leo

Techniques for Nuclear and Particle Physics Experiments

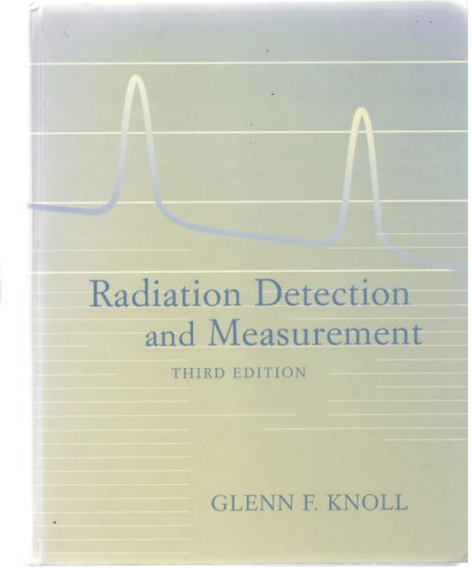
A How-to Approach

Springer-Verlag



Richard Fernow

Introduction to experimental particle physics



Radiation Detection and Measurement

THIRD EDITION

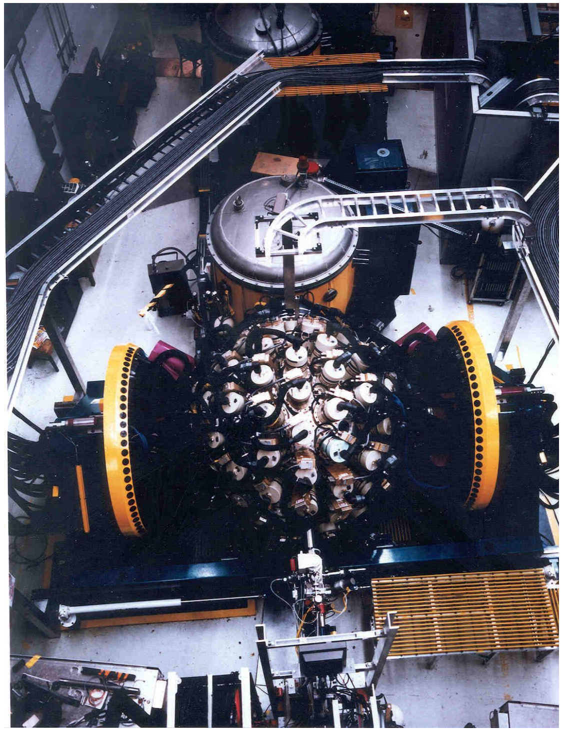
GLENN F. KNOLL

Thank you!

Experimental Techniques II

Darek Seweryniak

Argonne National Laboratory

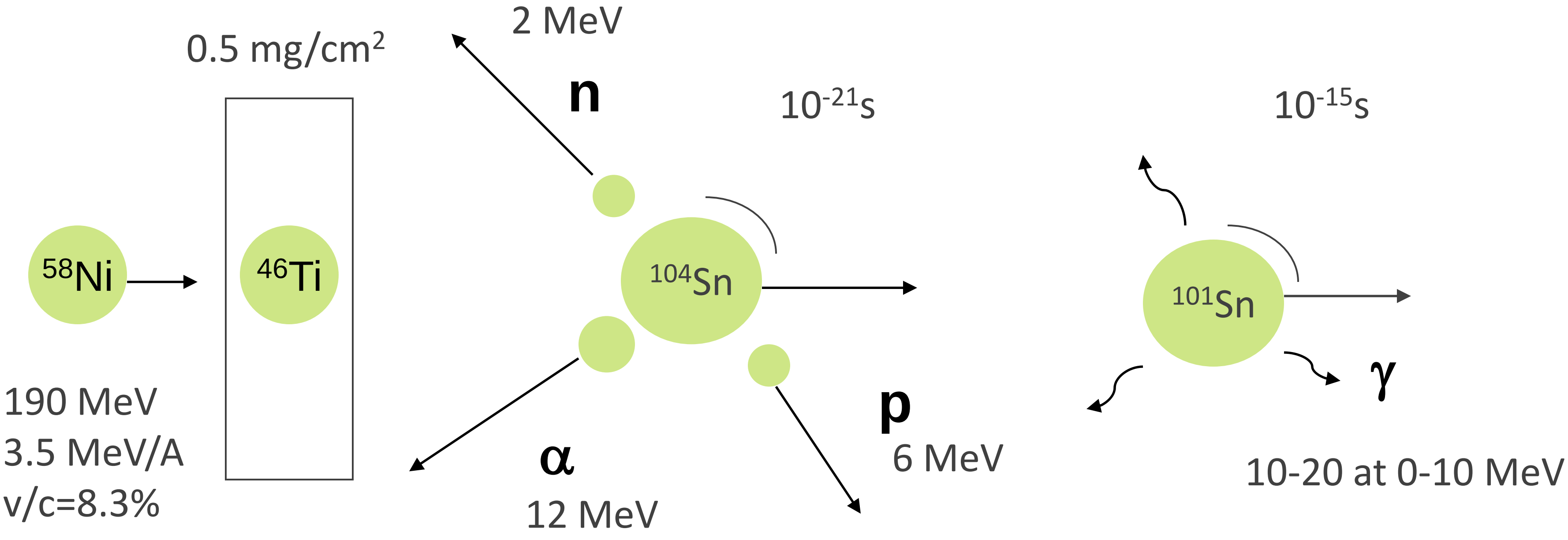


Outline

- In-beam spectroscopy of exotic proton rich nuclei
  - Gammasphere
  - Microball and Neutron Shll
  - Fragment Mass Analyzer
    - Ionization chamber
    - Double-Sided Silicon Strip Detector (DSSD)
- Three great ideas
  - In-trap neutrino-beta correlations
  - Optical time projection chamber
  - Superheated active chamber

Heavy-ion fusion evaporation reactions

^{58}Ni+^{46}Ti->^{101}Sn+3n (50 nb out of 500 mb)



2 MeV

0.5 mg/cm^2

n

10^{-21}s

10^{-15}s

^{58}Ni

^{46}Ti

^{104}Sn

^{101}Sn

γ

p

6 MeV

α

12 MeV

190 MeV
3.5 MeV/A
v/c=8.3%

10-20 at 0-10 MeV

REACTION

E_{CM}=84 MeV
$E_{BARRIER}$=82 MeV
E_{CN}=51 MeV

PARTICLE EVAPORATION

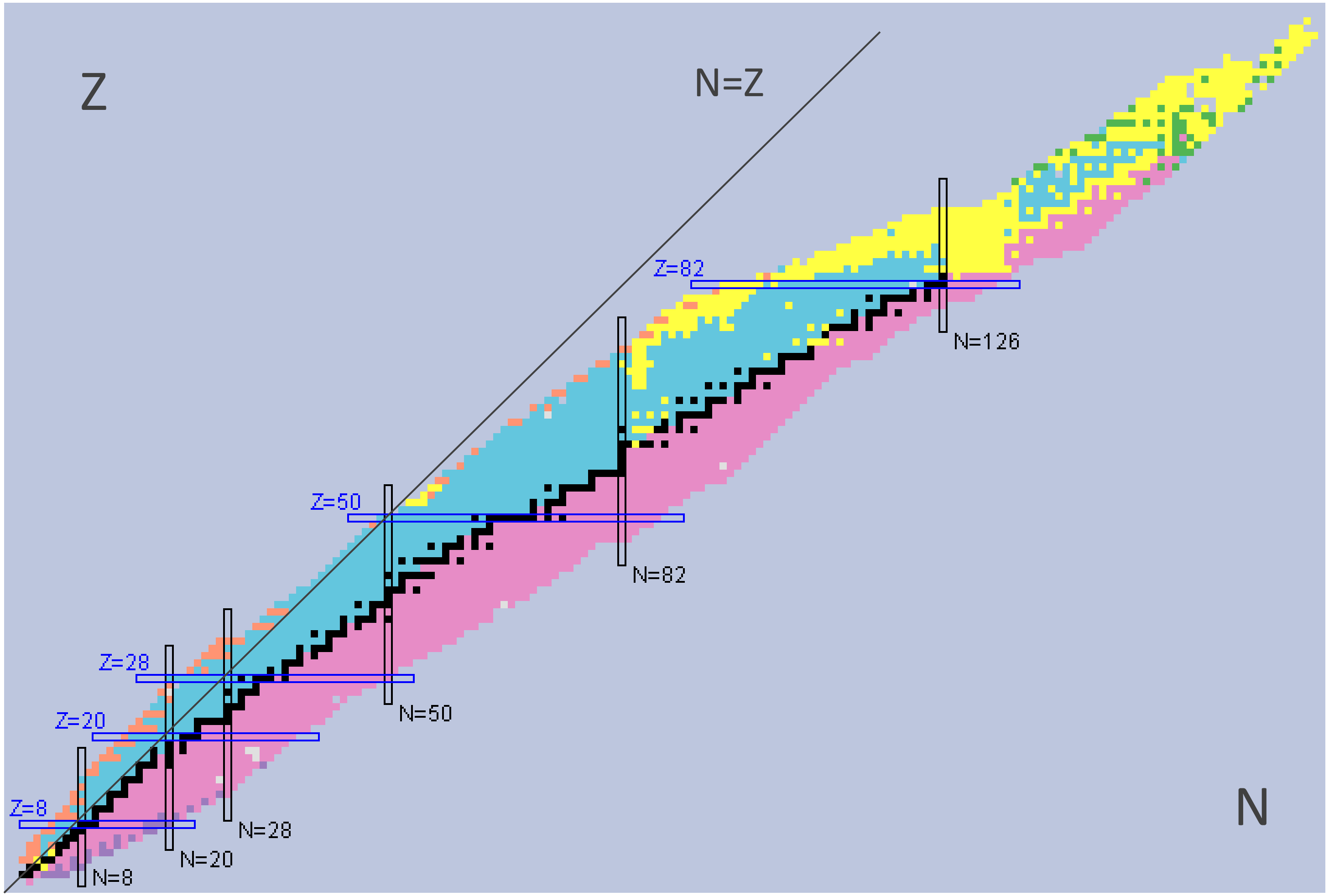
Thermal particle spectra,
average energies in centre of mass,
p, α must overcome Coulomb barrier

DEEXCITATION

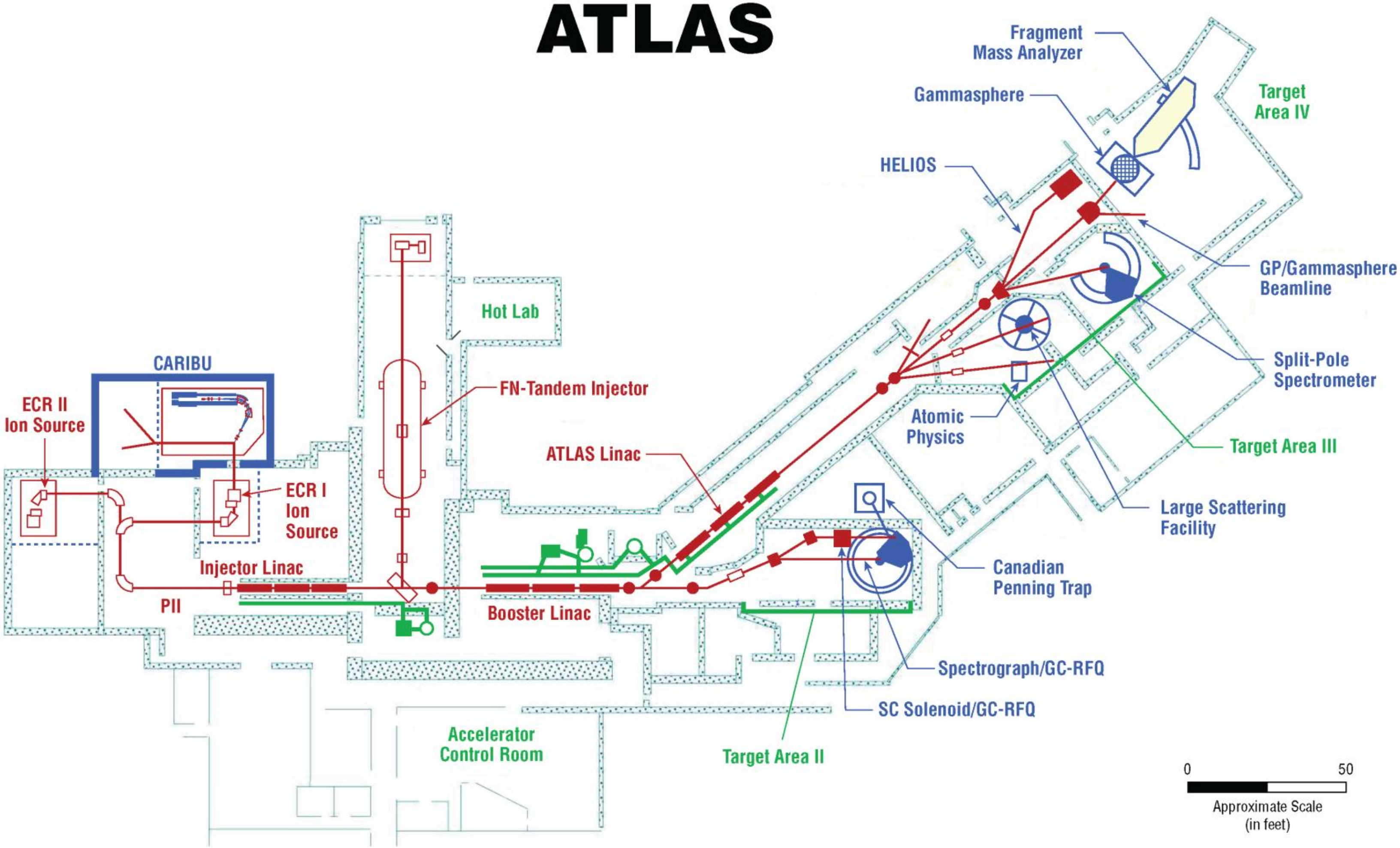
E^*~10 MeV

Many channels open, mostly protons are evaporated, sometimes alpha particles and seldom neutrons!

Why are heavy-ion fusion evaporation good for producing exotic proton rich nuclei?



ATLAS



All stable beams from H to U with energies up to ~10 Me/nucleon

Why bother with fusion-evaporation beams?

Fragmentation

- can produce and identify everything
- prompt spectroscopy impossible

Fusion-evaporation

- higher cross section but thinner targets
- prompt spectroscopy possible
- reaction channel identification difficult

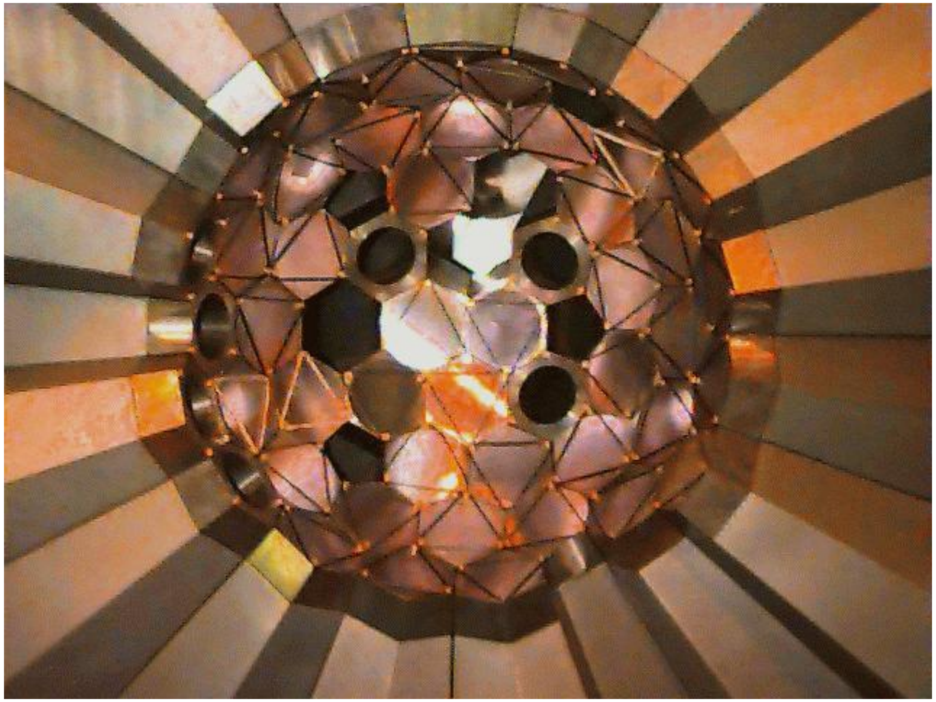
Reaccelerated radioactive beams at up to 12 MeV/nucleon are planned for FRIB!

One could use proton rich radioactive beams to produce and study more exotic nuclei!

Challenge

How to assign prompt gamma rays to exotic nuclei produced with tiny cross sections in the presence of a large background due to strong channels?

GAMMASPHERE
4π array of Compton suppressed γ-ray



Up to 110 HPGe detectors in BGO shields

γ-ray detection efficiency at 1.3MeV ~10%

The world's largest

Originally stationed at LBNL, moved to ANL in 1997 and again in 2003

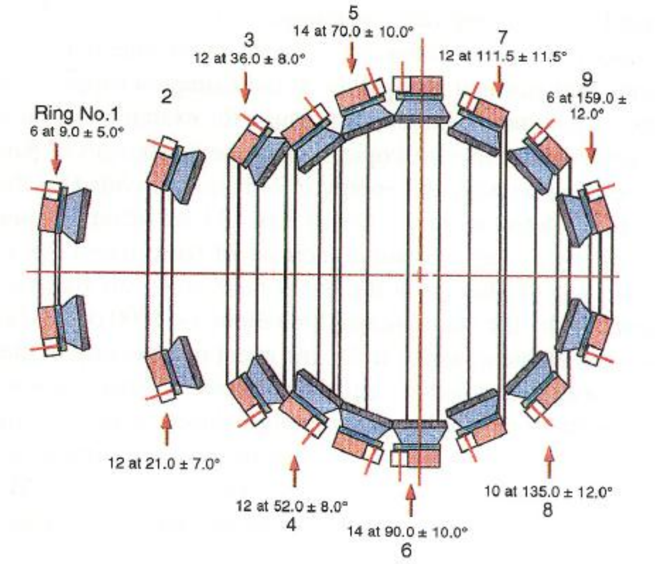
GAMMASPHERE detectors

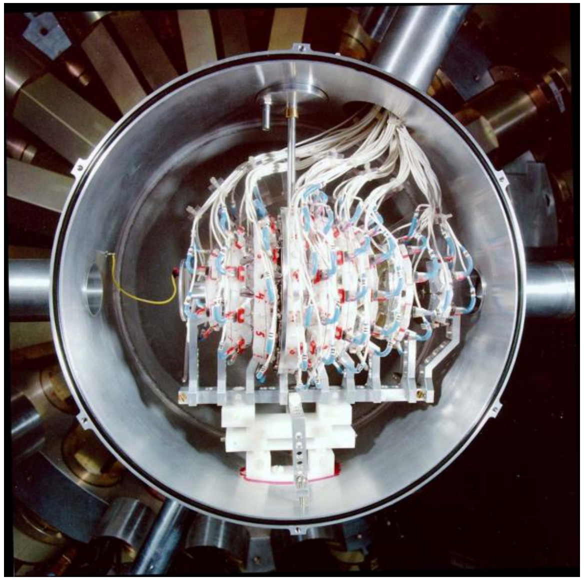
Idea

Detect evaporated particles in coincidence with gamma rays!

Microball – charged particle detector

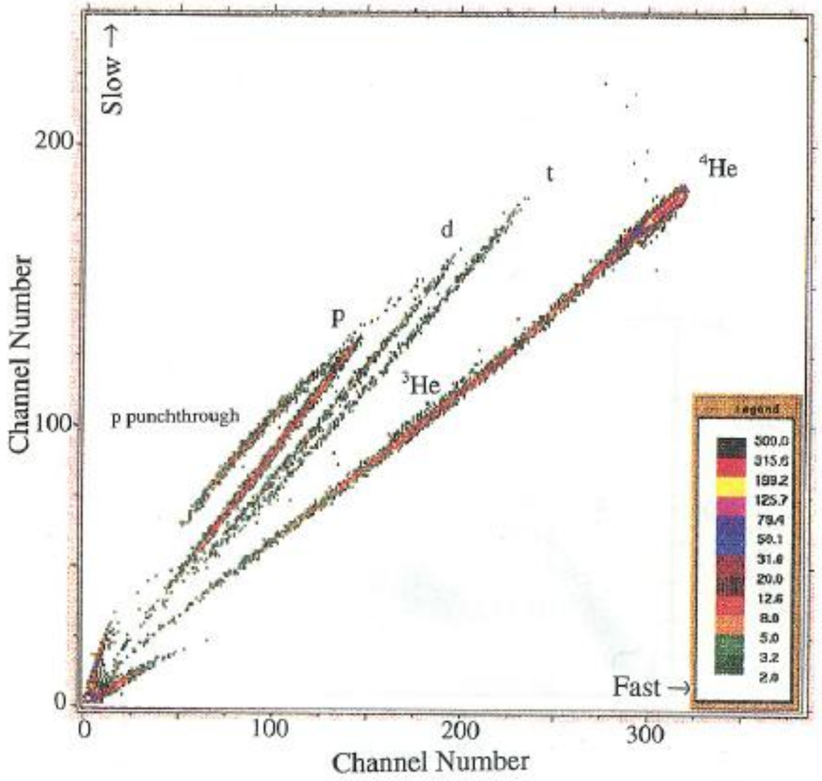
D.G. Sarantites et al., NIM A530, 473 (2004)



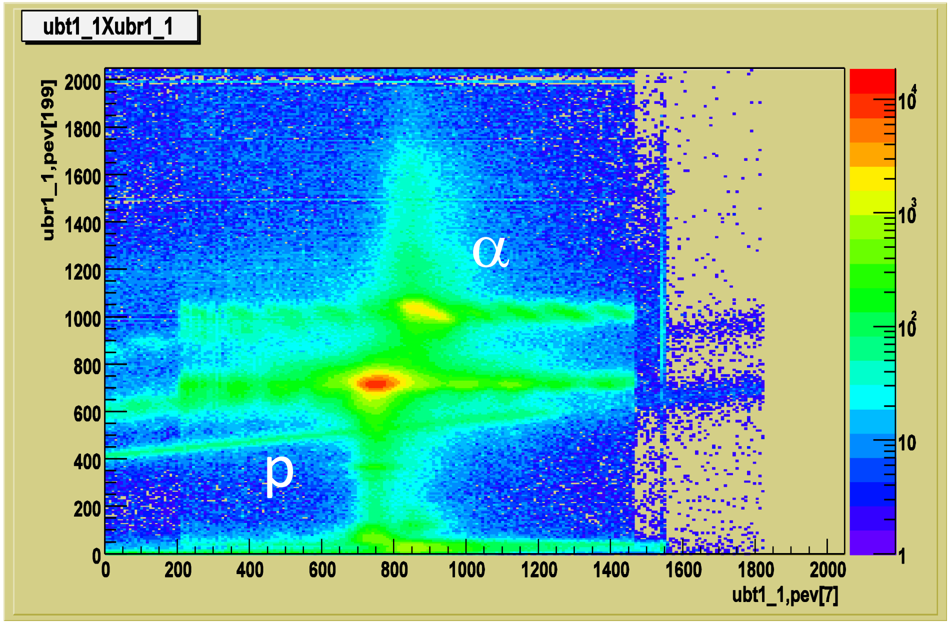


95CsI(Tl) 1-3 mm
0.5-.10, 7μs light components
~4π coverage
In-beam efficiency:
Protons ~ 70%
Alphas ~50%

CsI(Tl) pulse shape discrimination



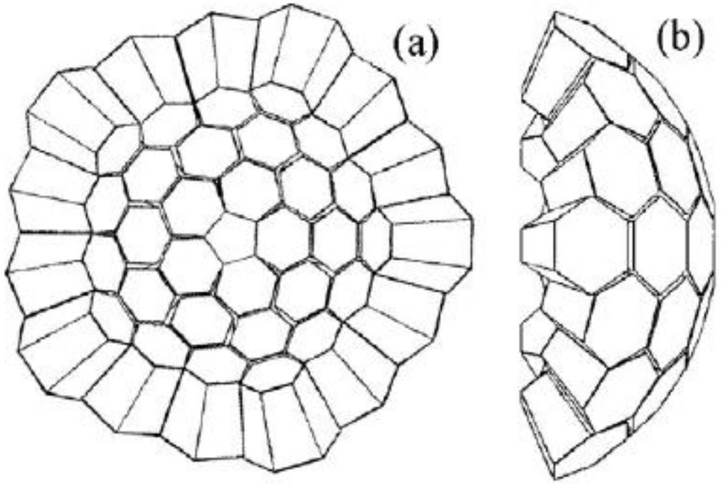
FAST/SLOW



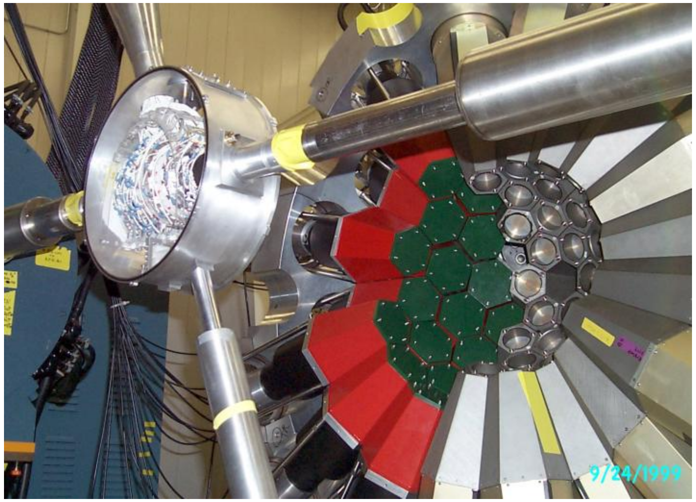
TOF

Neutron Shell

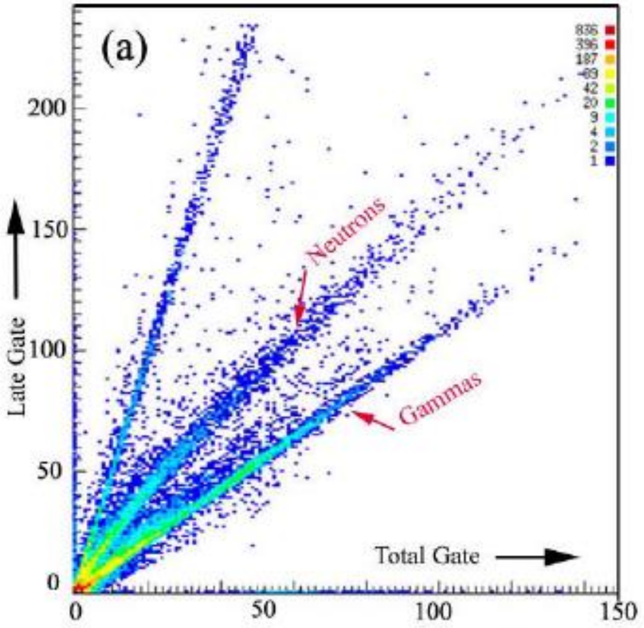
D.G. Sarantites et al., NIM A530, 473 (2004)

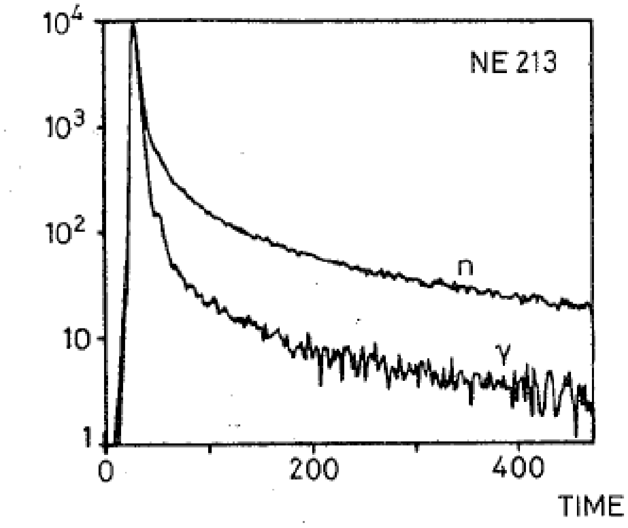


35 BC501A liquid scintillators
~10ns, ~100ns light components
1π array
in-beam Efficiency ~30%



BC501A n-γ discrimination





Channel selection

Problem:
we do not detect all the particles

$$P(k,n)=\binom{n}{k}(1-\varepsilon)^{n-k}\varepsilon^{k}$$

Binomial distribution

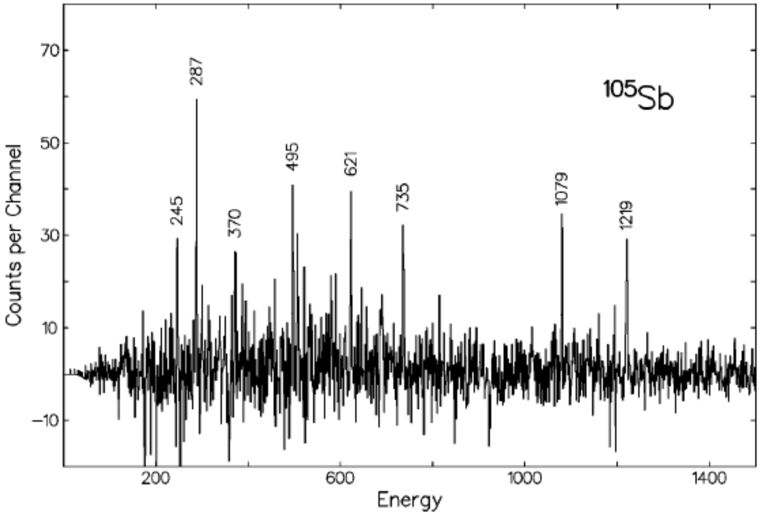
Probability of detecting k particles out of n
ε – detection probability

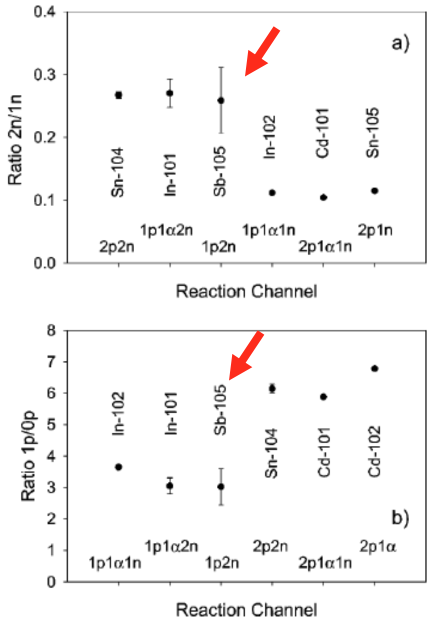
Solution:
use intensity ratios from spectra corresponding to different numbers of detecte particles

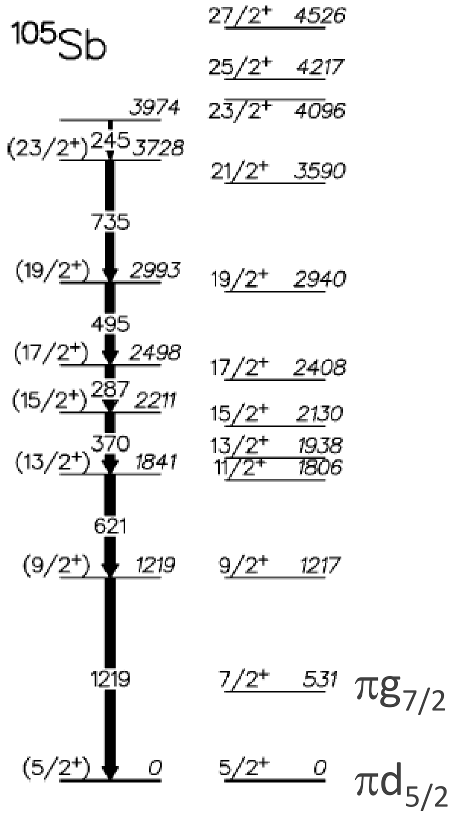
Proton rich nucleus $^{105}\text{Sb}={}^{100}\text{Sn}+\pi+4\nu$

$^{58}\text{Ni}+{}^{50}\text{Cr}\rightarrow{}^{105}\text{Sb}+p2n$

$\sigma \sim 10\ \mu b$







M. Lipoglavsek et al., Phys. Rev. C65, 051307 (2002)

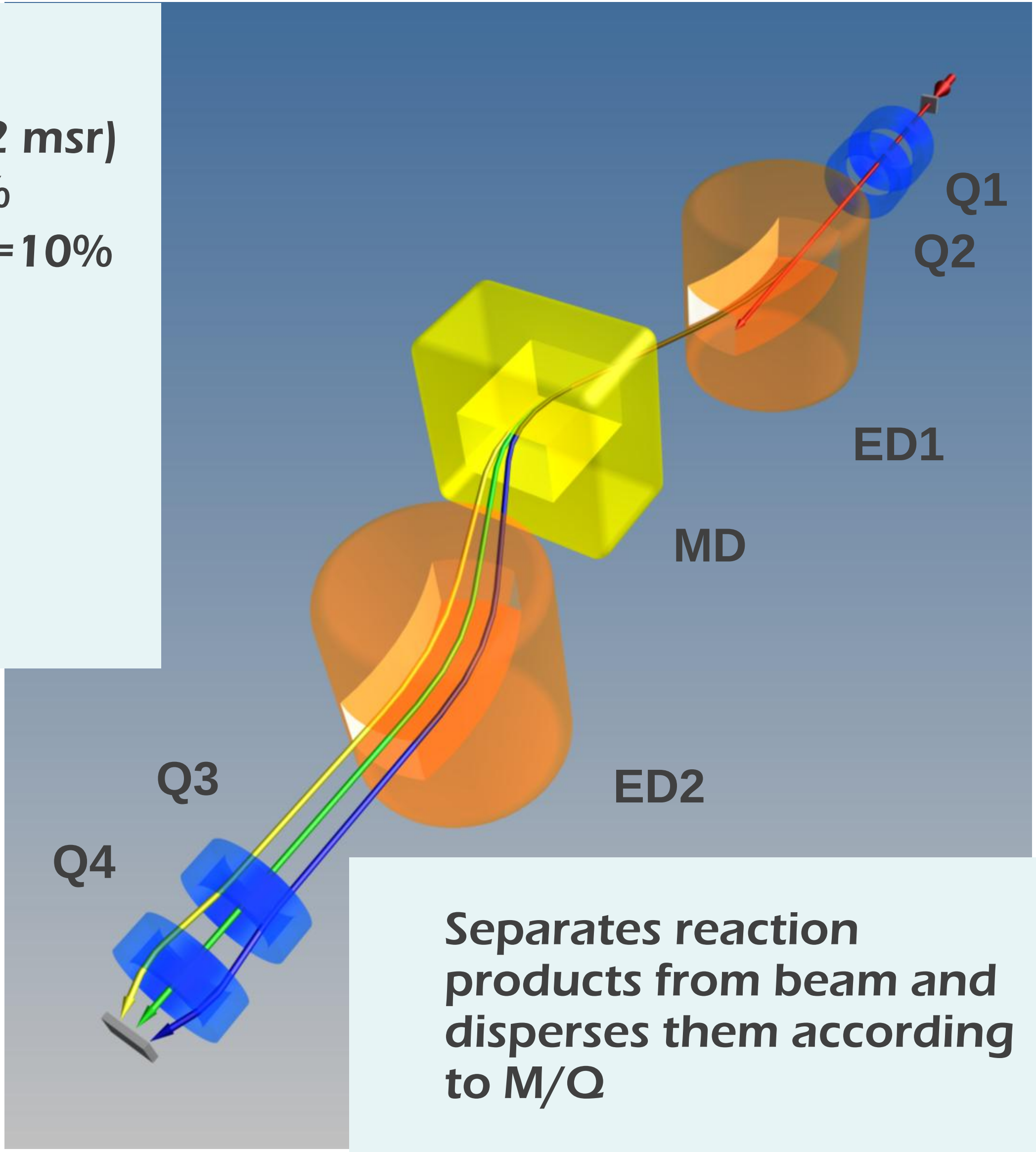
Idea

Measure the mass number and atomic number of reaction products !

Argonne Fragment Mass Analyzer

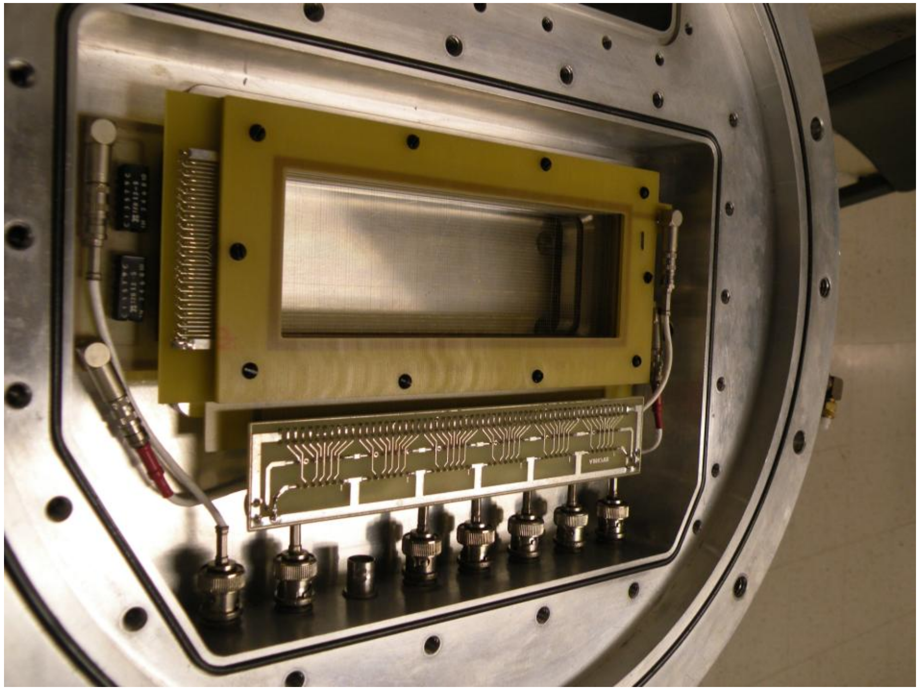
Argonne Fragment Mass Analyzer

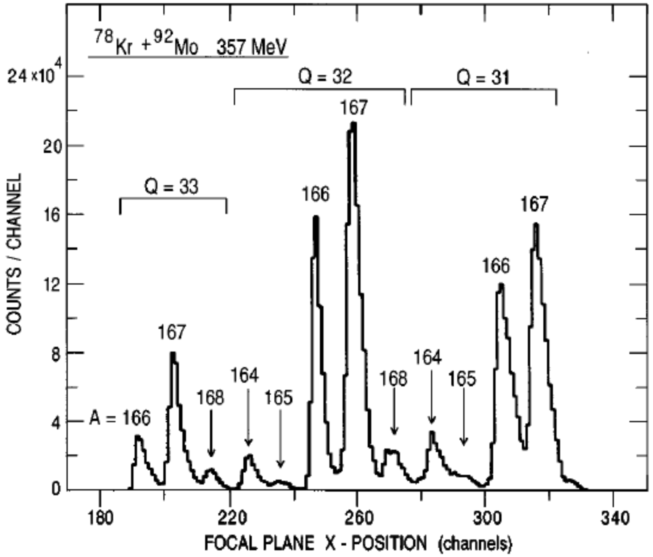
Mass resolution: $\delta M/M \sim 1/350$
Angular acceptance: $\Delta\Omega$=8 msr(2 msr)
Energy acceptance: $\Delta\mathcal{E}/\mathcal{E}$=+/-20%
M/Q acceptance: $\Delta(M/Q)/(M/Q)$=10%
Flight path 8.2m
Max($B\rho$)=1.1Tm
Max($E\rho$)=20MV
Can be rotated off 0 degrees
Can be moved along the axis
Different focusing modes



Separates reaction products from beam and disperses them according to M/Q

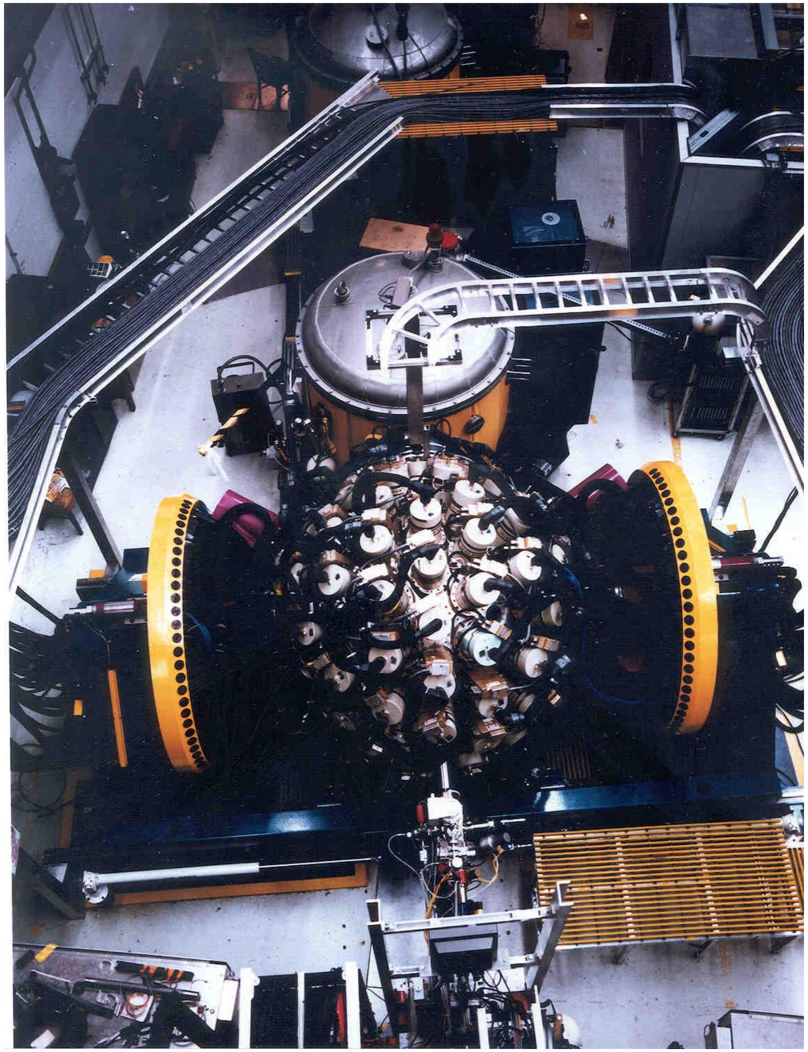
Focal Plane Parallel Grid Avalanche Counter



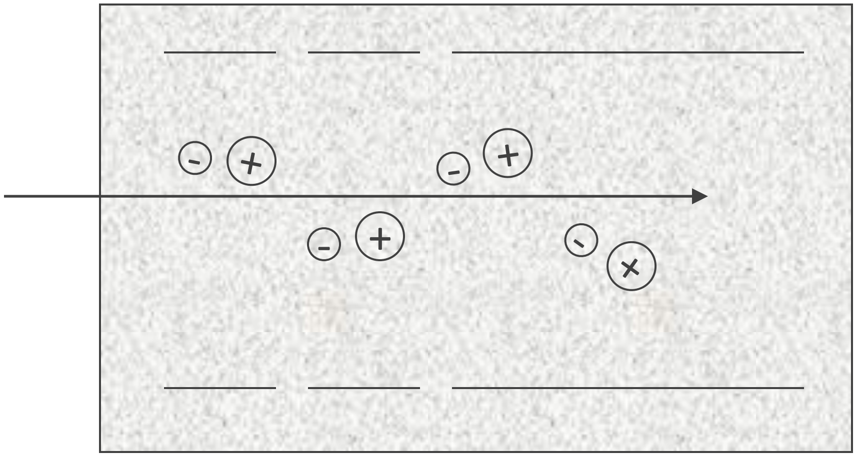


PGAC
Isobutane at 3 Torr
Y and Y wire planes

GAMMASPHERE+FMA

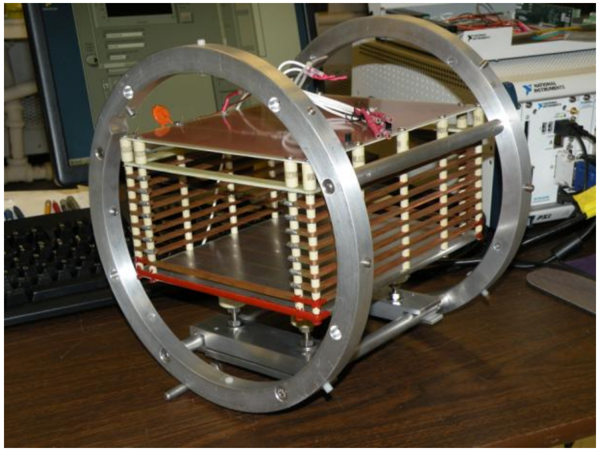


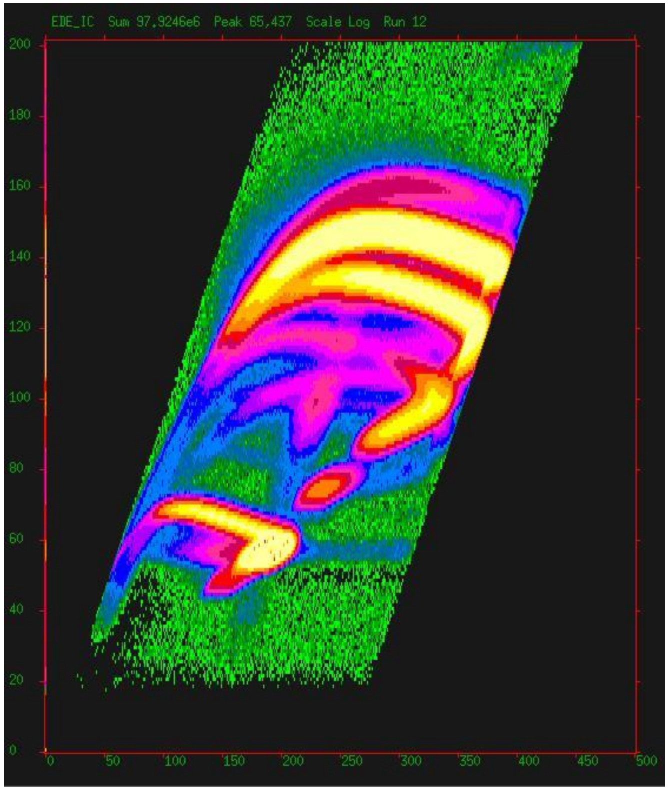
Ionization Chamber



ΔE1 ΔE2 ΔE3

Isobutane ~15 Torr





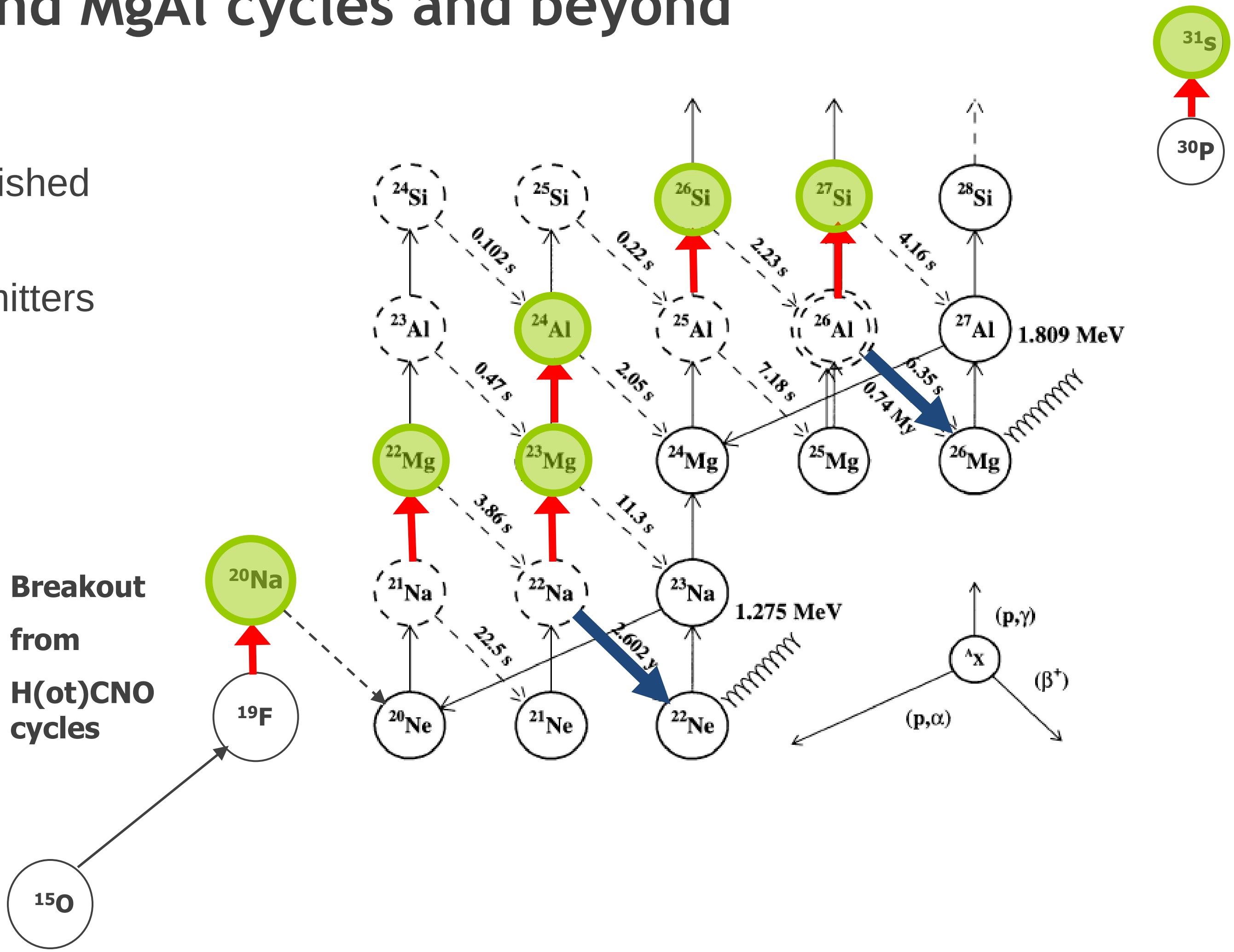
$^{16}O+^{12}C\rightarrow^{26}Si+2n$

This method works well for low Z and fast ions

NeNa and MgAl cycles and beyond

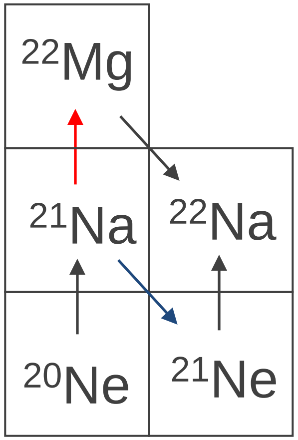
🡅 published

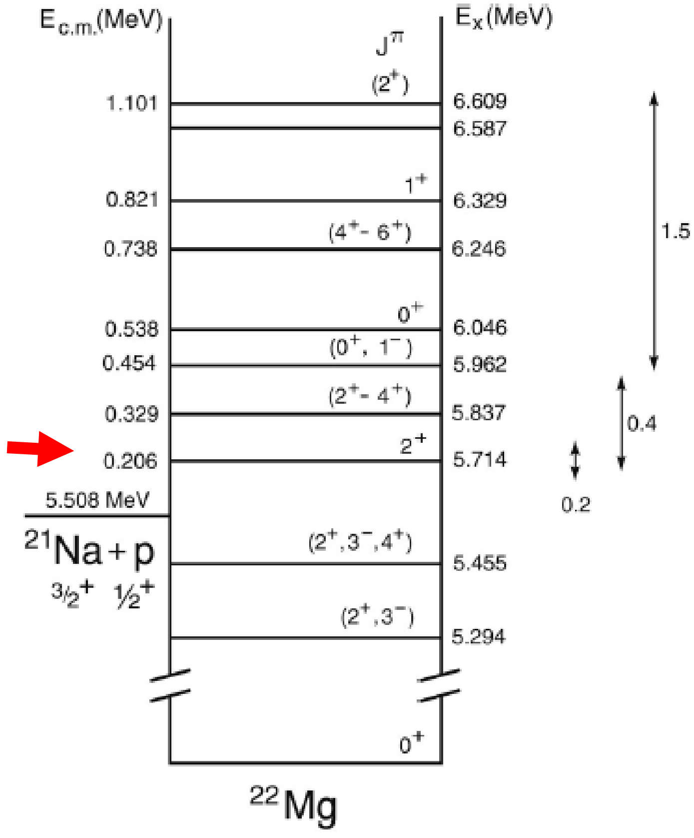
🡖 γ emitters

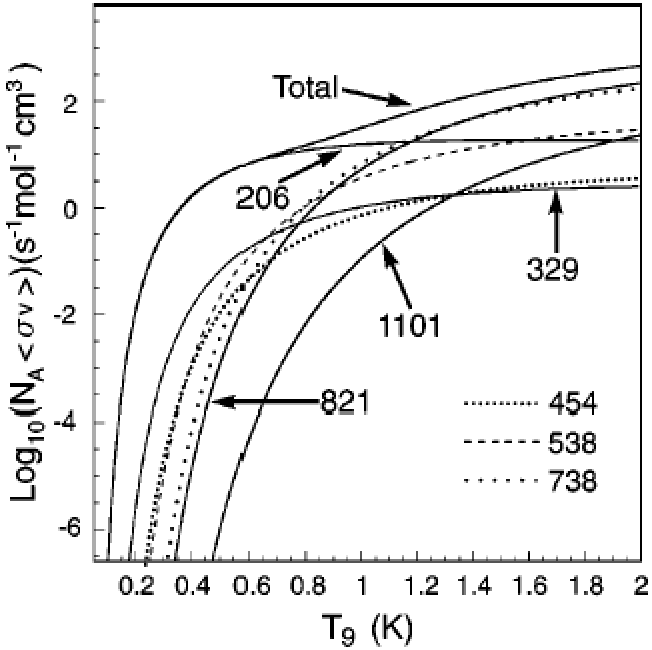


Breakout from H(ot)CNO cycles

The $^{21}Na(p,\gamma)^{22}Mg$ reaction



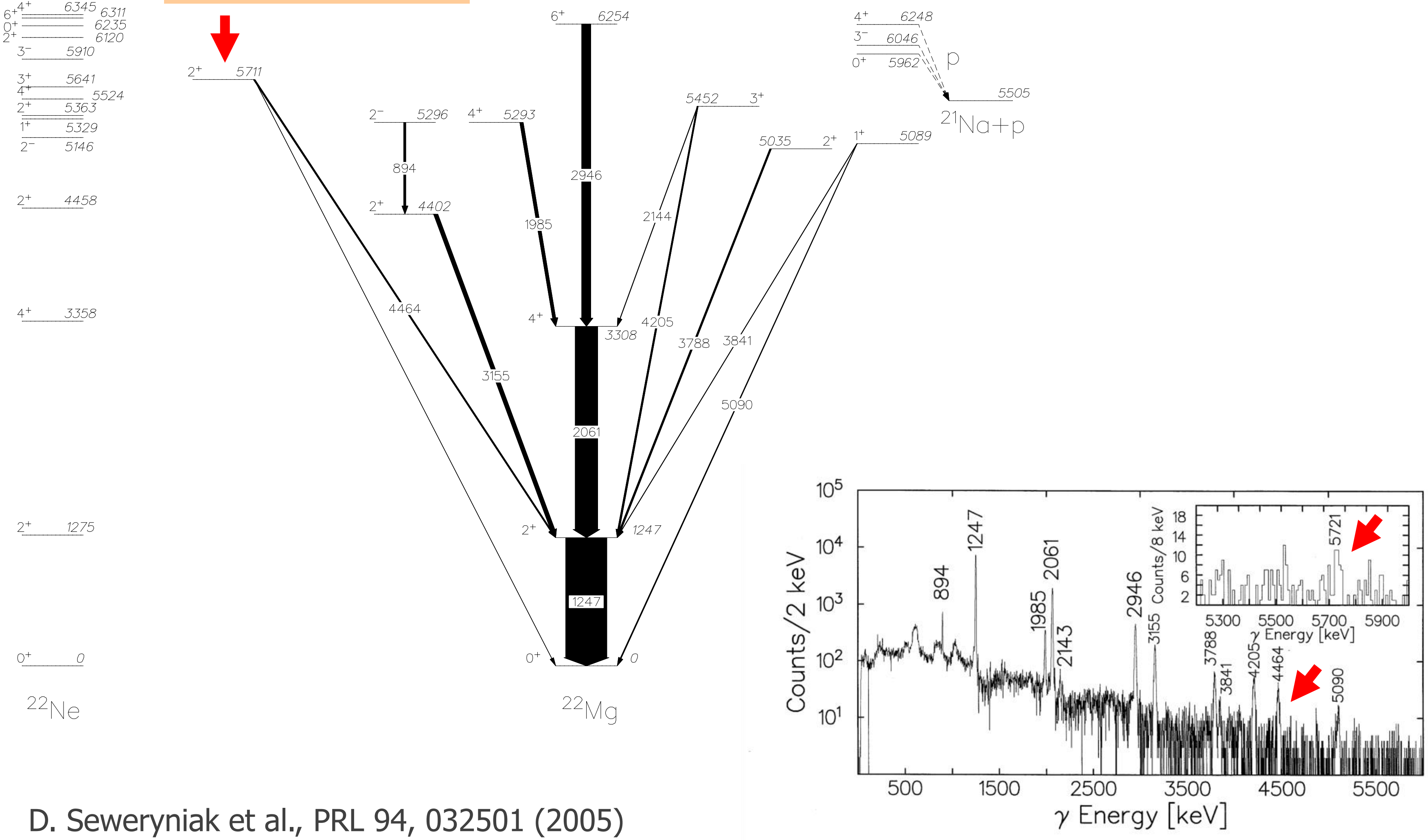




J. D'Auria et al., PRC 69, 065803 (2004)

In-beam spectroscopy of ^{22}Mg

E(2^+)=5711.0(1.0) keV
b($2^+ \rightarrow 0^+$)=14(4)%



D. Seweryniak et al., PRL 94, 032501 (2005)

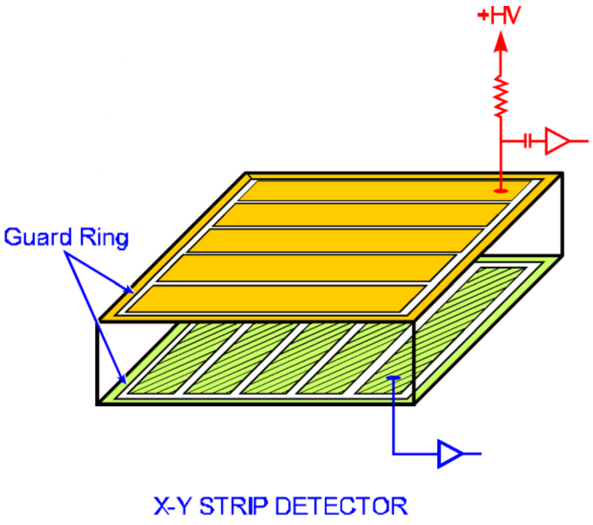
Idea

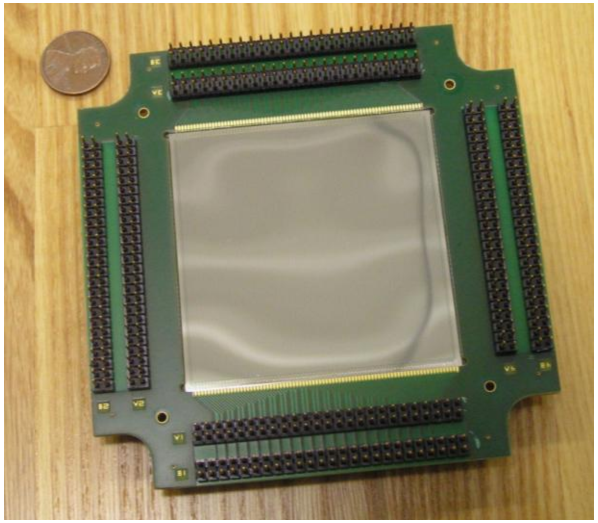
Correlate prompt gamma rays
with characteristic decays
of reaction products!

Problem

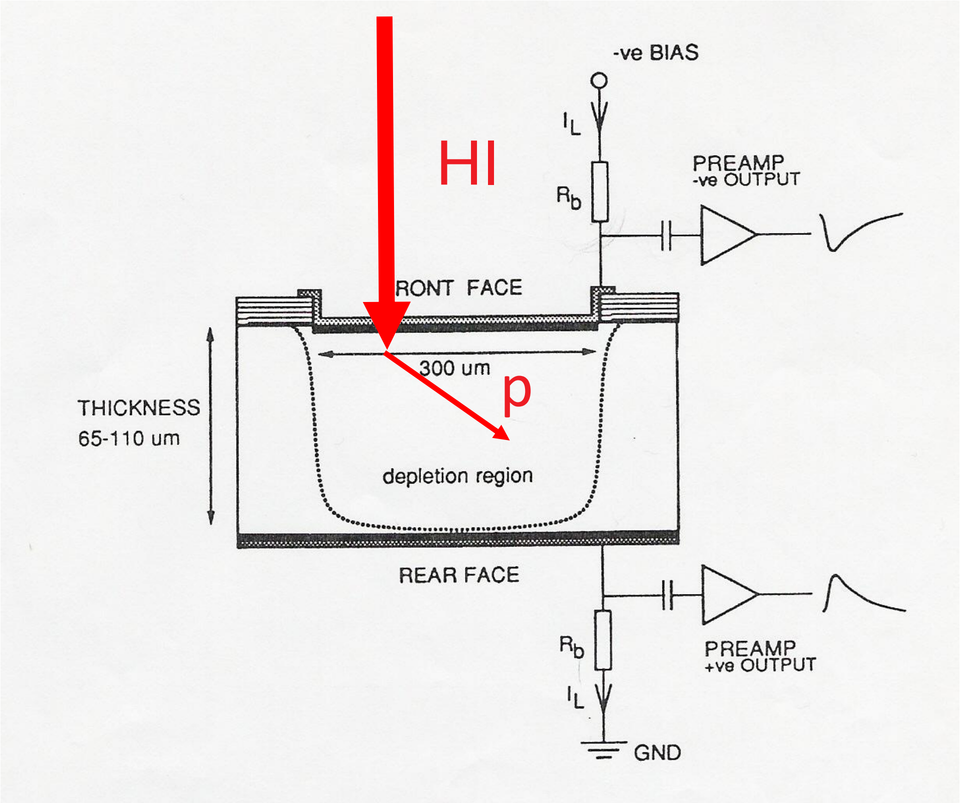
But the decay lifetimes are long?!

Double-Sided Silicon Strip Detector DSSD





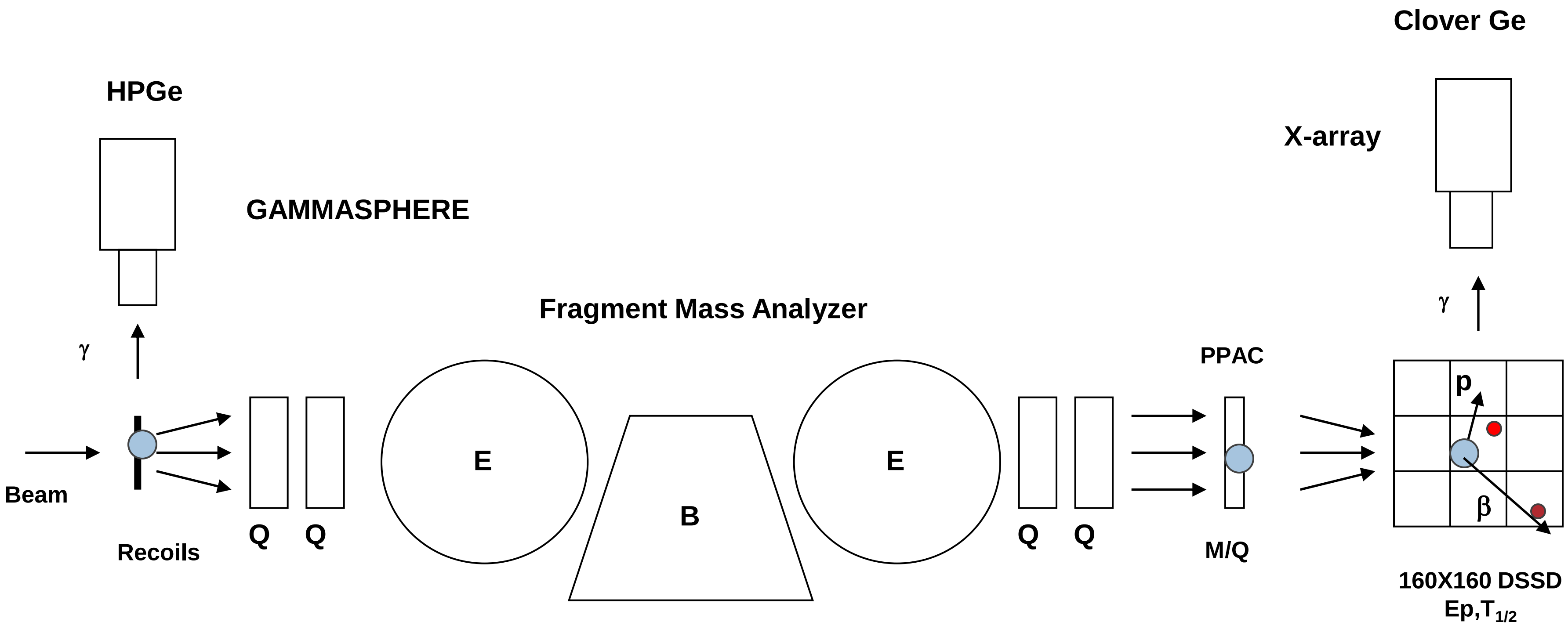
160X160 DSSD



Pixel=300 μmX300μmX100(300)μm

Micron Semiconductor

Recoil-Decay Tagging



Prompt γ rays
Recoils
Implants

⟷

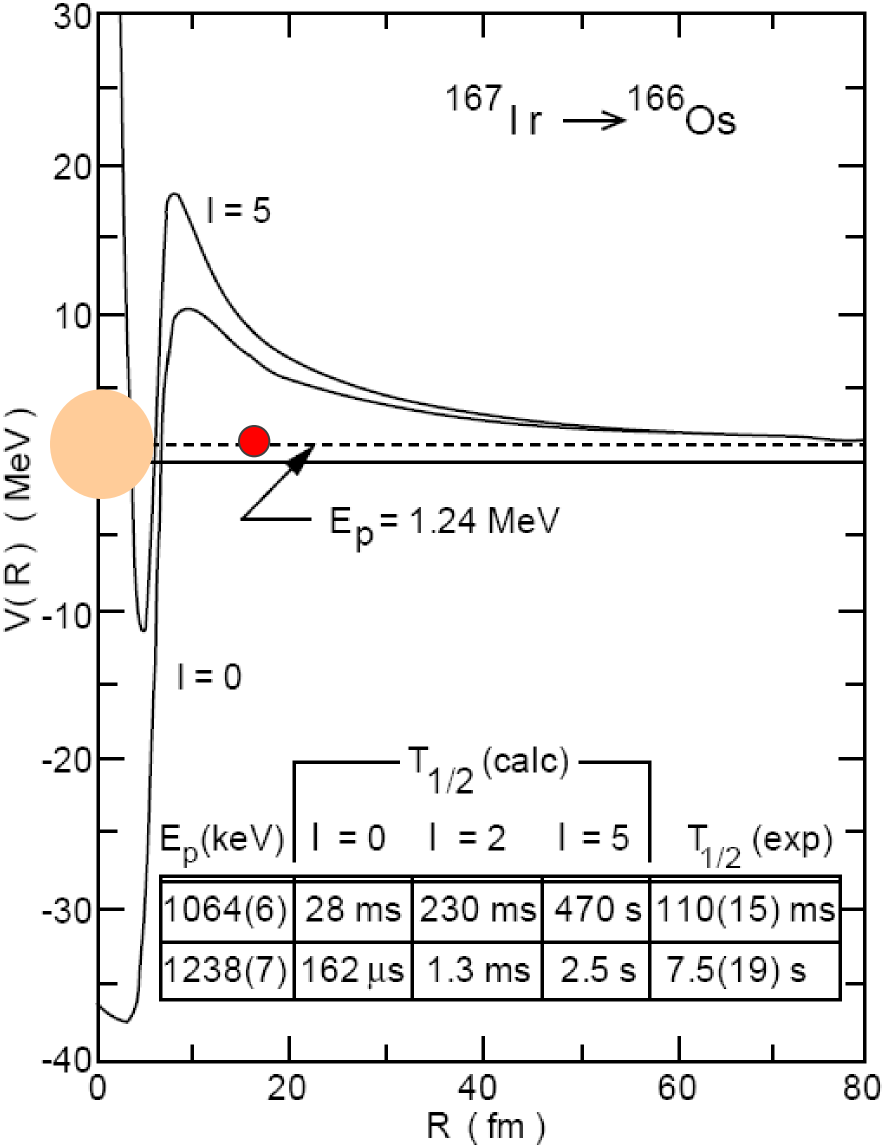
Spatial and time correlations in the DSSD

characteristic decays or chains of decays:

- Protons
- Alphas
- β-delayed particles
- Isomers
- β decay

10nb out of 1b!

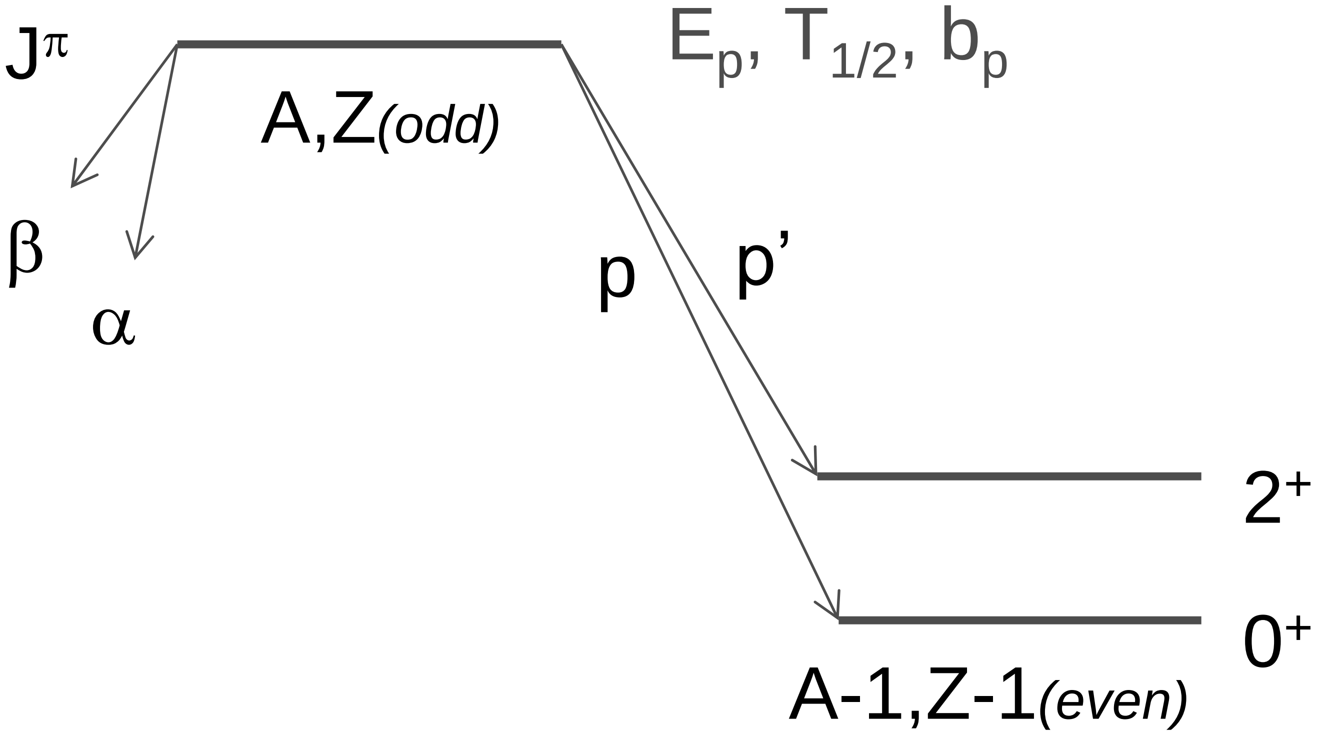
Proton emission



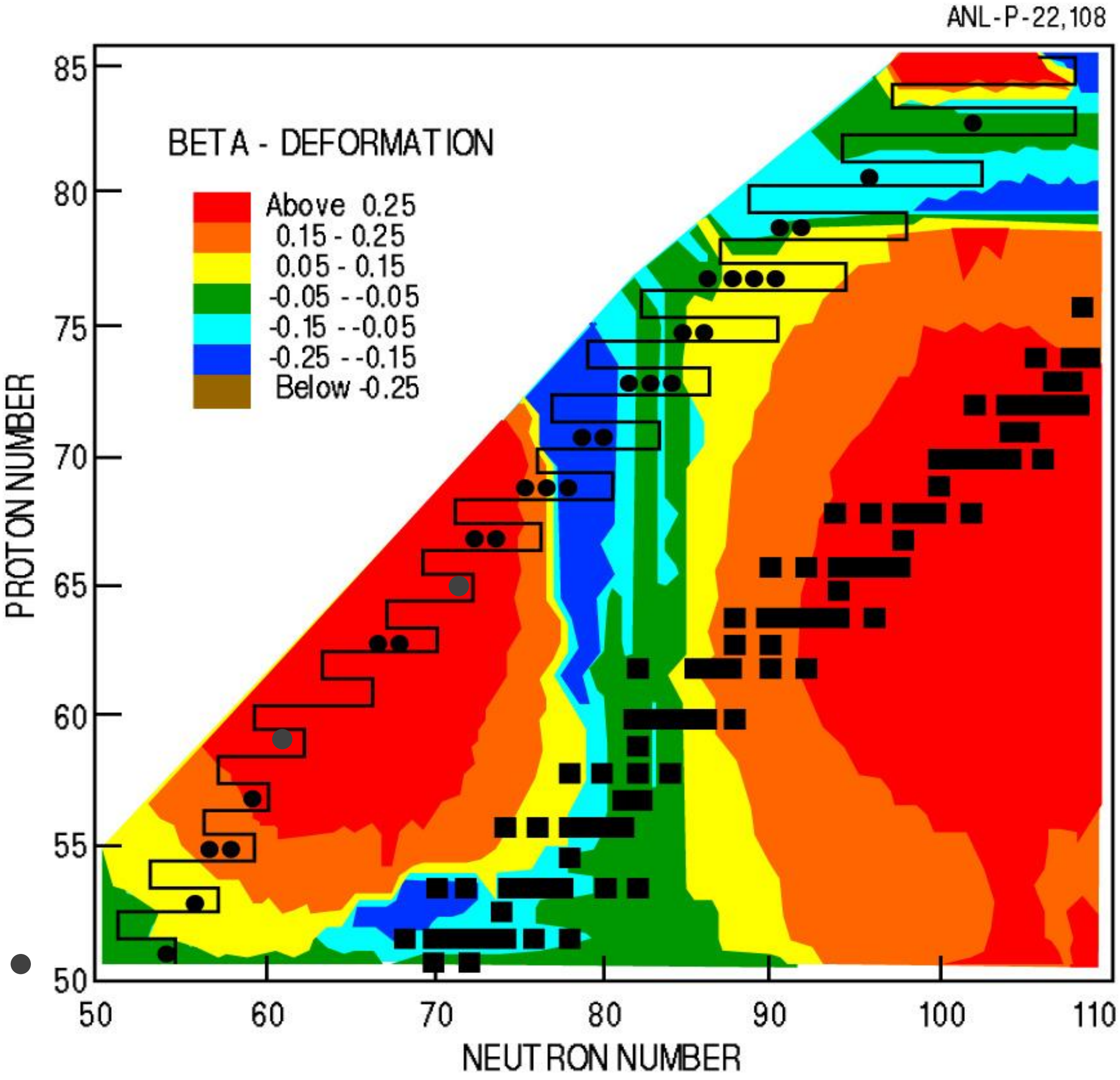
E_p(keV)	$T_{1/2}$(calc) l = 0	$T_{1/2}$(calc) l = 2	$T_{1/2}$(calc) l = 5	$T_{1/2}$ (exp)
1064(6)	28 ms	230 ms	470 s	110(15) ms
1238(7)	162 μs	1.3 ms	2.5 s	7.5(19) s

- ✓ Analogous to α decay
- ✓ No pre-formation factor
- ✓ Decay rates sensitive to E_p and l_p
- ✓ Source of information on nuclear structure and masses far from stability
- ✓ Unique laboratory to study tunneling through a 3D barrier (deformed emitters)

Proton Decay Observables

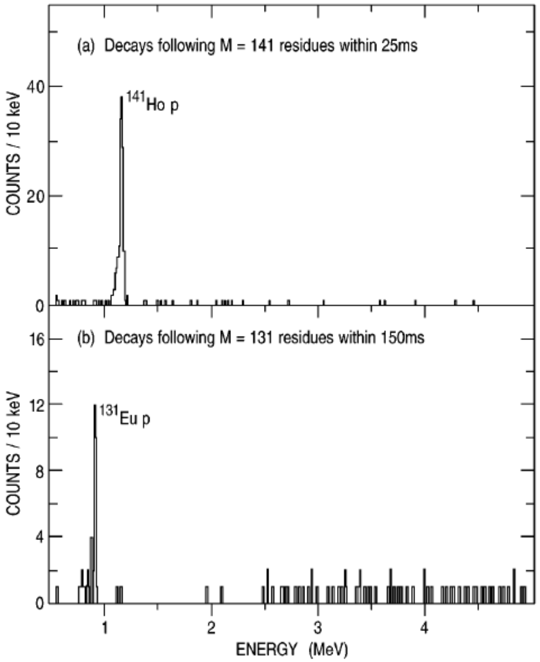


Proton emitter landscape

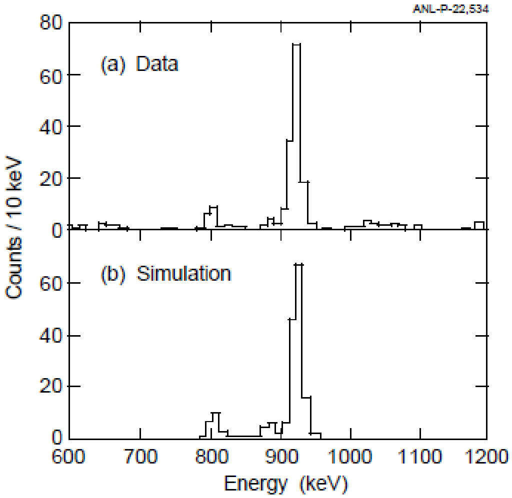


- ✓ Spherical
- ✓ Axially deformed
- ✓ Odd-odd axially deformed
- ✓ Coupling to vibrations
- ✓ Non-axial deformation

Proton emitters



First deformed proton emitters
Anomalous decay rates explained by introducing deformation

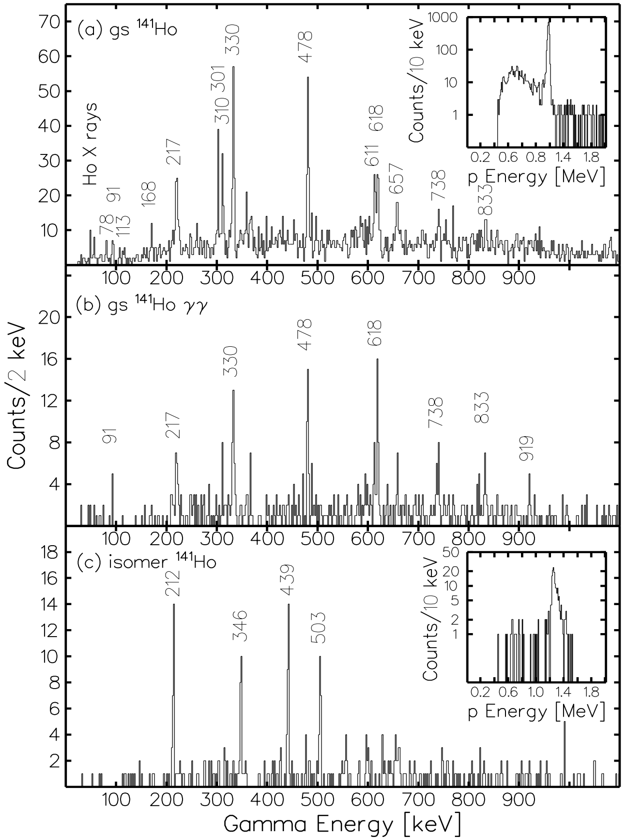


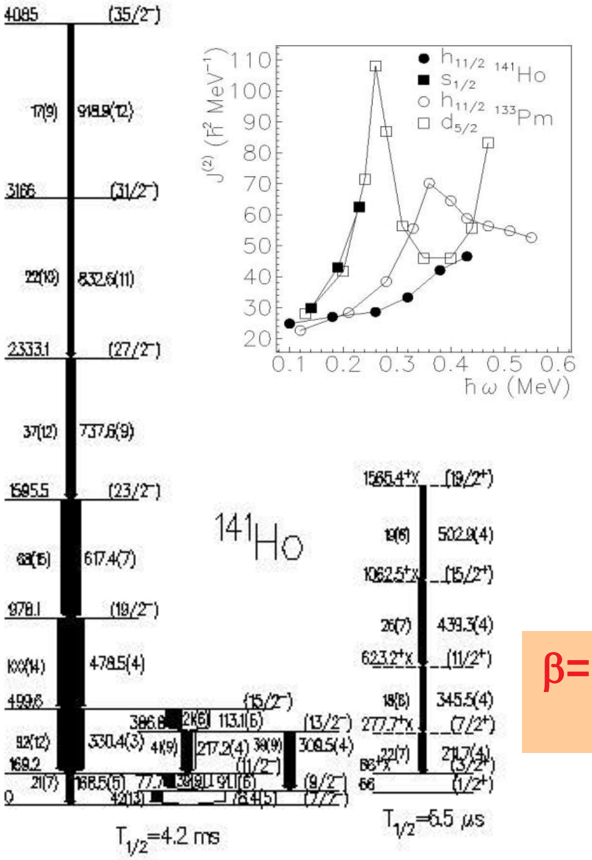
First fine structure

C.N. Davids et al., PRL C55 (1997)2255

A. Sonzogni et al., PRL 83 (1999)1116

Rotational bands in the deformed proton emitter ^{141}Ho





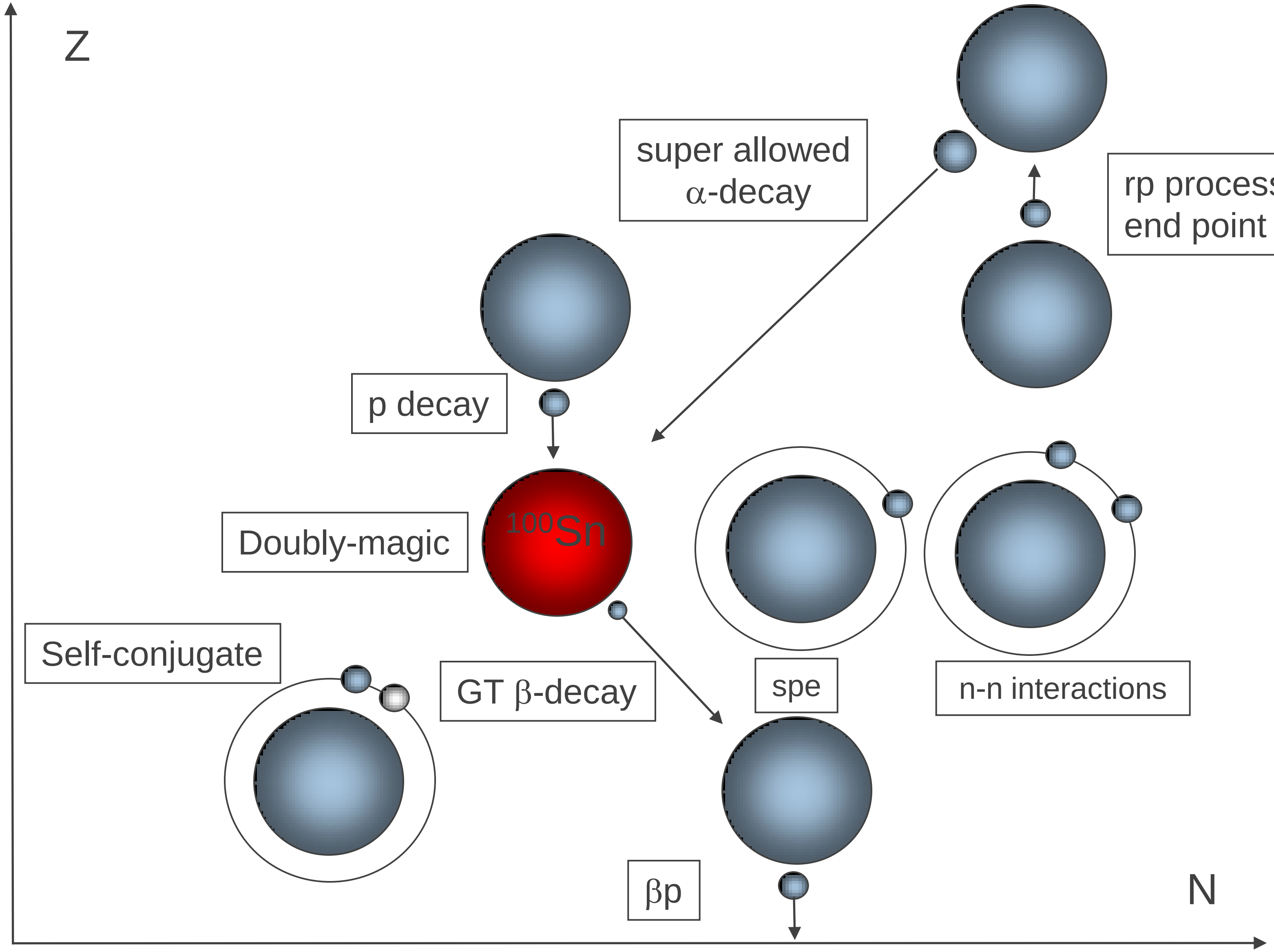
Unexpectedly large signature splitting indicates triaxial shape!

β=0.25(4) from Harris formula

7/2$^-$[523] **½$^+$[411]**

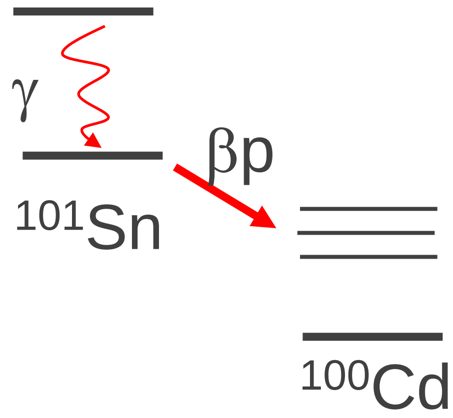
D. Seweryniak et al., PRL C86(2001)1458

^{100}Sn physics



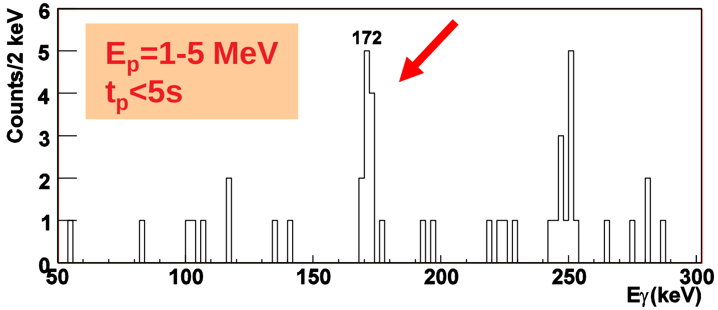
^{101}Sn βp recoil-decay tagging experiment

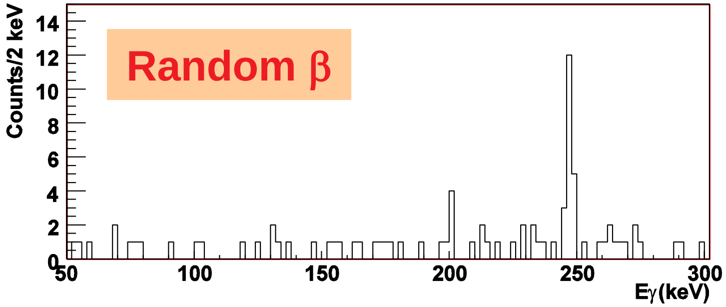
^{101}Sn=^{100}Sn+1n

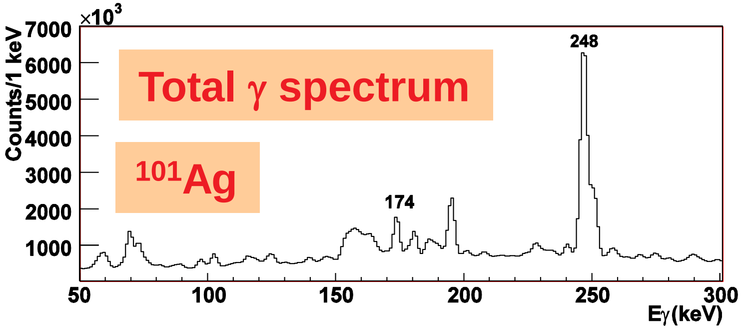


Ep=1.5-5 MeV
$T_{1/2}$=1.9(3)s
$b_{\beta p}$~15%

γ rays

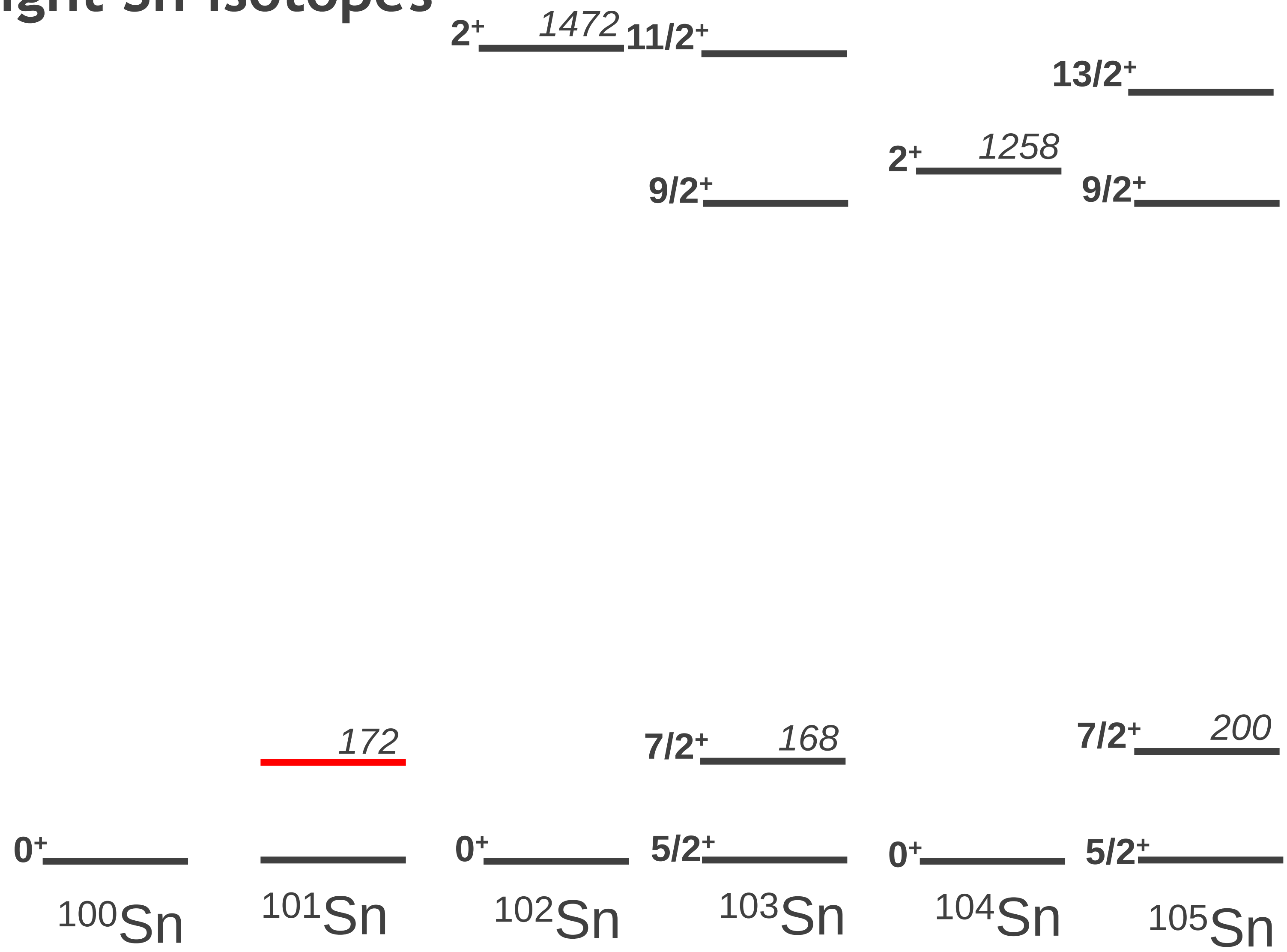




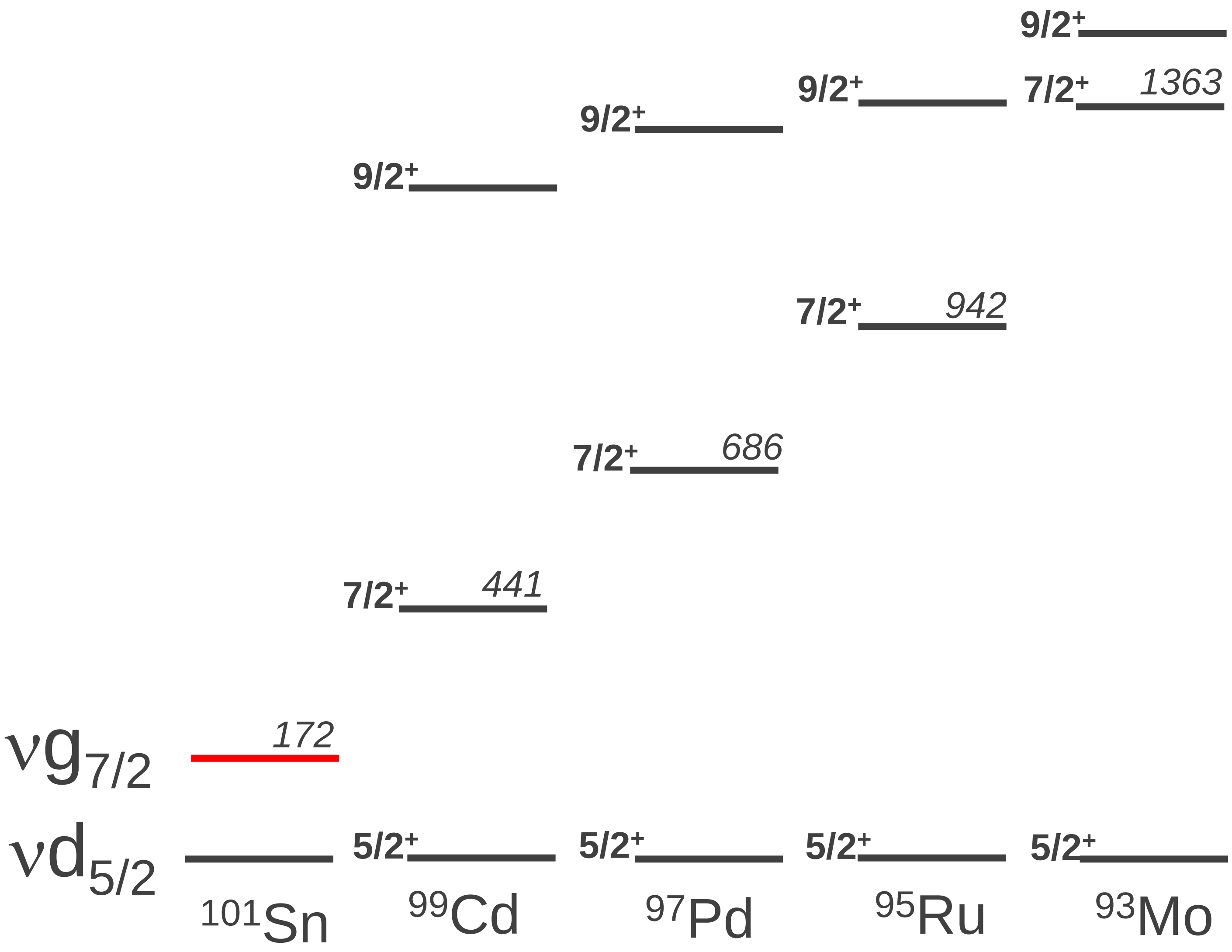


D.Seweryniak et al.,*PRL 99, 022504 (2007)*

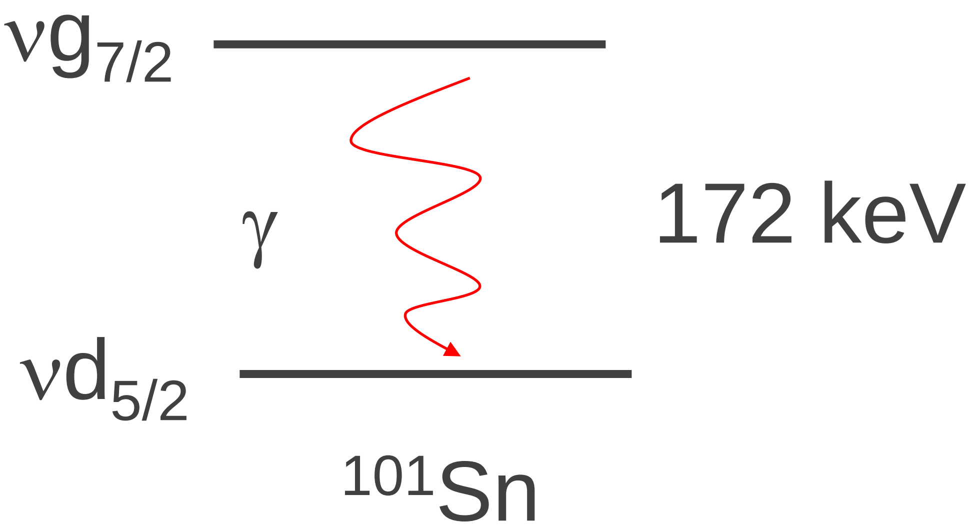
Light Sn isotopes



N=51 isotones

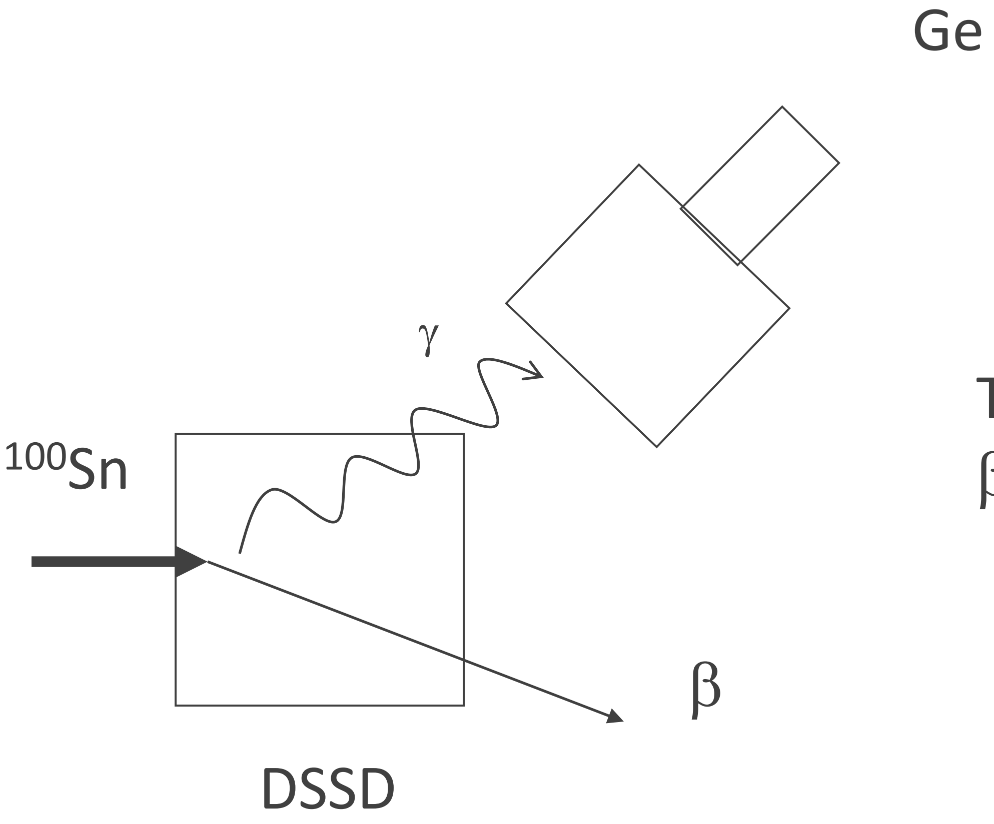


^{101}Sn level scheme



See Douglas diJulio’s poster

^{100}Sn beta delayed gamma tagging?



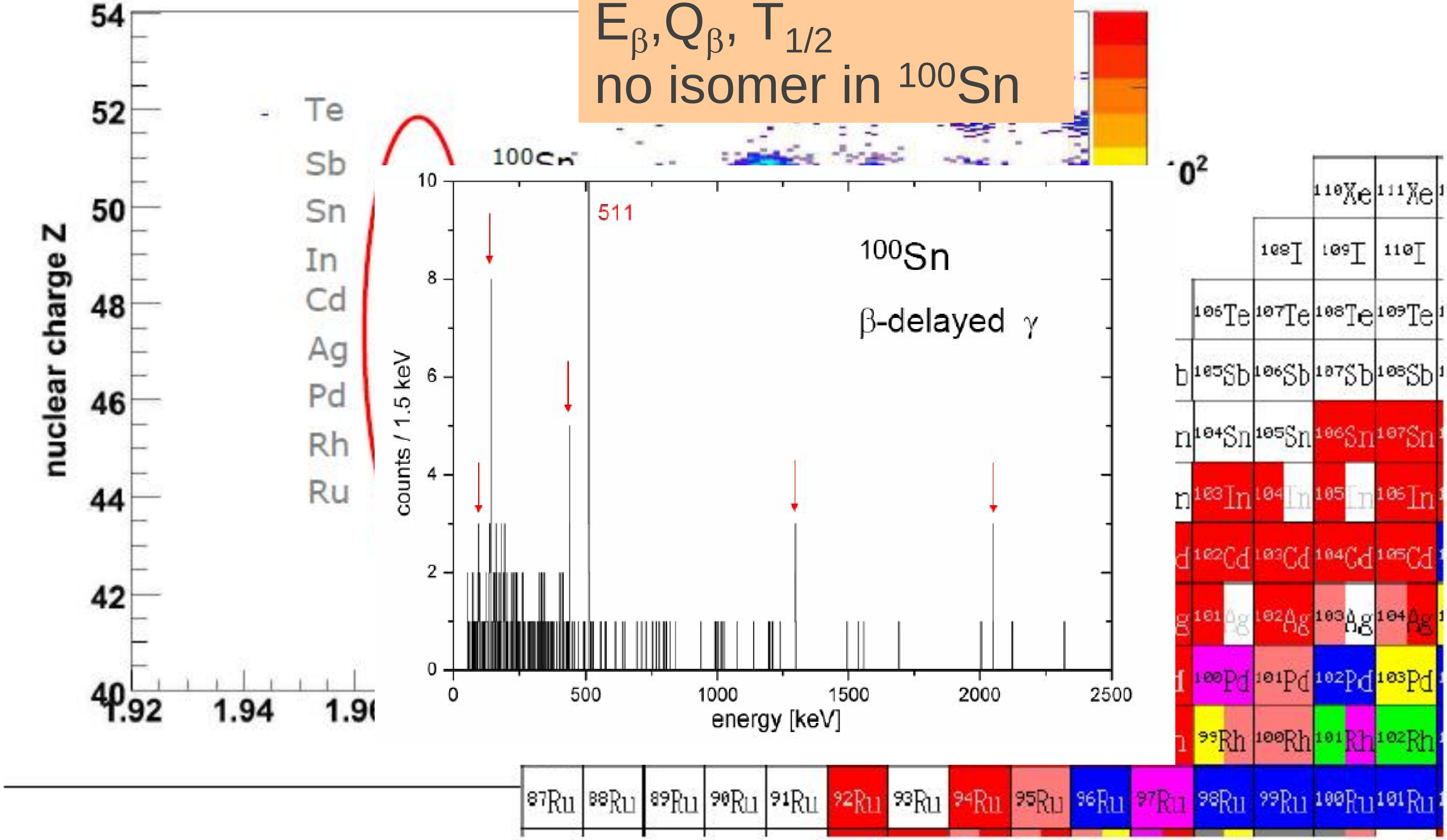
Tagging with characteristic β delayed γ rays

Probing proton dripline

T.Faestermann

analysis: K.Eppinger, C.Hinke

TU München



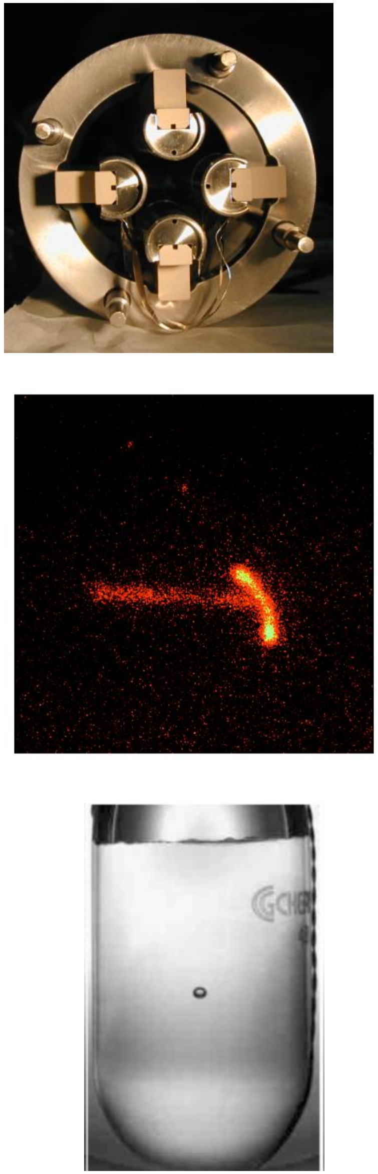
E_β, Q_β, $T_{1/2}$

no isomer in ^{100}Sn

Three great ideas

- In-trap neutrino-beta correlations
- Optical time projection chamber
- Superheated active chamber

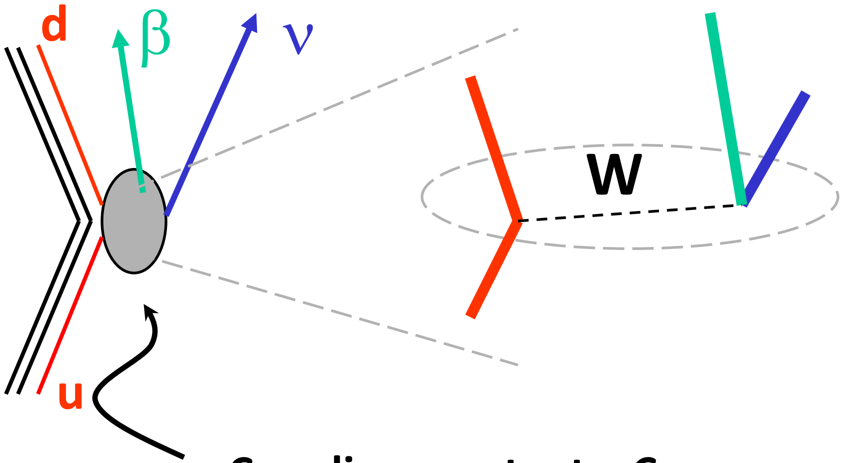
- How to detect a neutrino?
- How to take a photo of a proton?
- Bubble chamber – no need to say more



β – n correlations

slides courtesy of Jason Clark

$$
\begin{aligned}
H_{\text{int}} = {} & (\overline{\psi}_2\psi_1)(C_S\overline{\psi}_e\psi_\nu + C_S'\overline{\psi}_e\gamma_5\psi_\nu) \\
& + (\overline{\psi}_2\gamma_\mu\psi_1)(C_V\overline{\psi}_e\gamma^\mu\psi_\nu + C_V'\overline{\psi}_e\gamma^\mu\gamma_5\psi_\nu) \\
& + \frac{1}{2}(\overline{\psi}_2\sigma_{\lambda\mu}\psi_1)(C_T\overline{\psi}_e\sigma^{\lambda\mu}\psi_\nu + C_T'\overline{\psi}_e\sigma^{\lambda\mu}\gamma_5\psi_\nu) \\
& - (\overline{\psi}_2\gamma_\mu\gamma_5\psi_1)(C_A\overline{\psi}_e\gamma^\mu\gamma_5\psi_\nu + C_A'\overline{\psi}_e\gamma^\mu\psi_\nu) \\
& + (\overline{\psi}_2\gamma_5\psi_1)(C_P\overline{\psi}_e\gamma_5\psi_\nu + C_P'\overline{\psi}_e\psi_\nu)
\end{aligned}
$$



Coupling constants: C_S, C_V, C_A, C_T

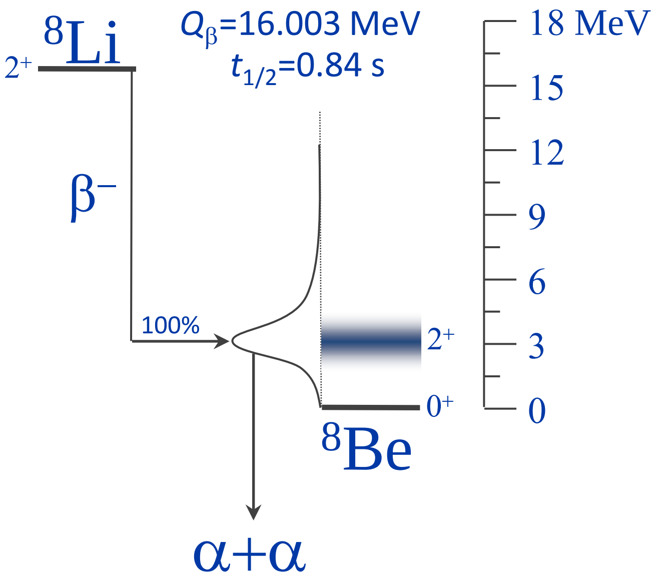
$$
\boxed{dW = dW_o\varepsilon\left[1 + \frac{\vec{p}_e\cdot\vec{p}_\nu}{E_eE_\nu}a + \frac{\Gamma m_e}{E_e}b + \vec{J}\cdot\left(\frac{\vec{p}_e}{E_e}A + \frac{\vec{p}_\nu}{E_\nu}B + \frac{\vec{p}_e\times\vec{p}_\nu}{E_eE_\nu}D\right) + \ldots\right]}
$$

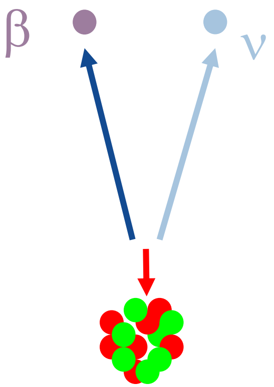
$$
dW_0 = F(Z,E_e)p_eE_e(E_0 - E_e)^2\, dE_e\, d\Omega_e\, d\Omega_\nu
$$

🟦 Compare experimental values to SM predictions

🟧 Put limits on terms “forbidden” by SM

β-ν correlations in ^{8}Li





Neutrino escapes detection!

$$^8\text{Li} \rightarrow {}^8\text{Be}^* + \beta^- + \nu$$

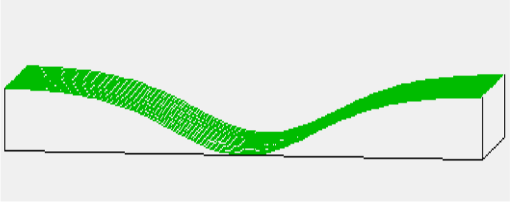
$$\hookrightarrow \alpha + \alpha$$

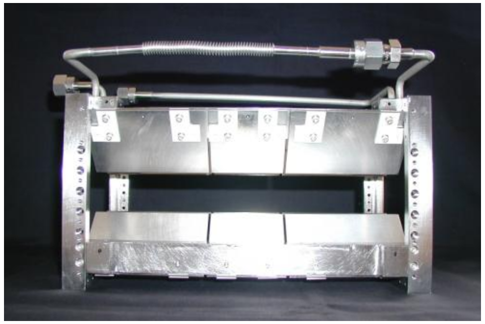
Solution: Detect all particles BUT neutrino and use energy and momentum conservation to characterize the neutrino

Open geometry ion trap for decay studies

A Paul trap is an ion trap which confines ions through the presence of:

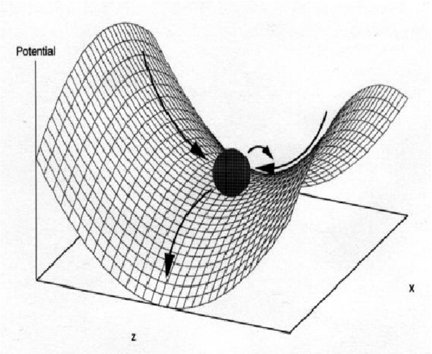
- **constant, electrostatic harmonic potential along beam axis (provides axial confinement)**

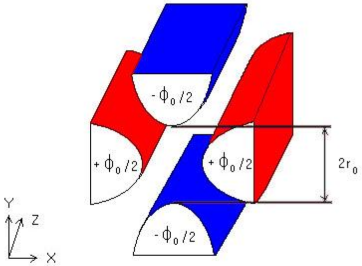


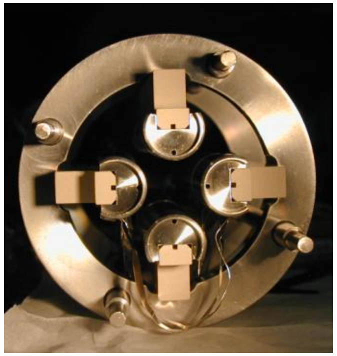


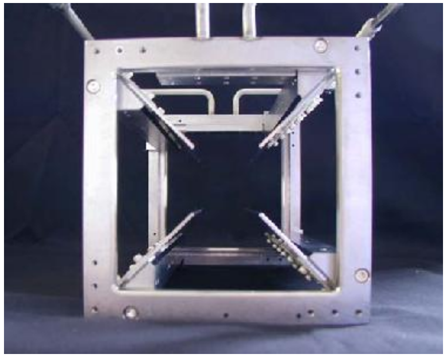
DC (V): 50, -40, 50

- **RF field (provides radial confinement)**



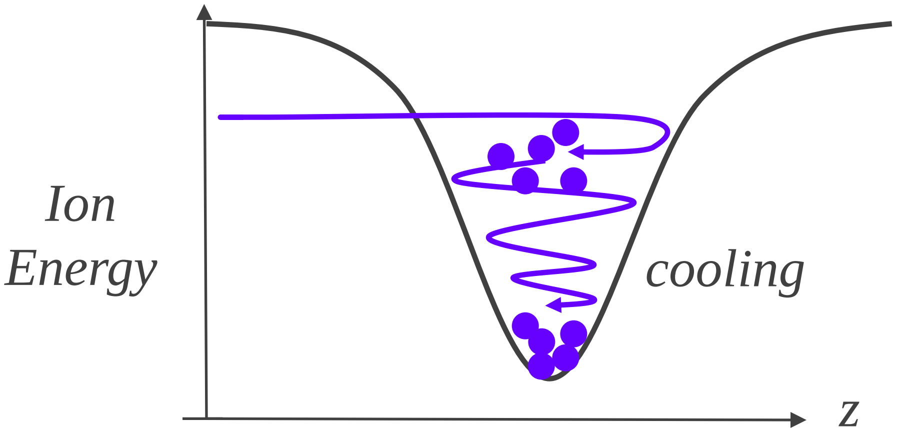




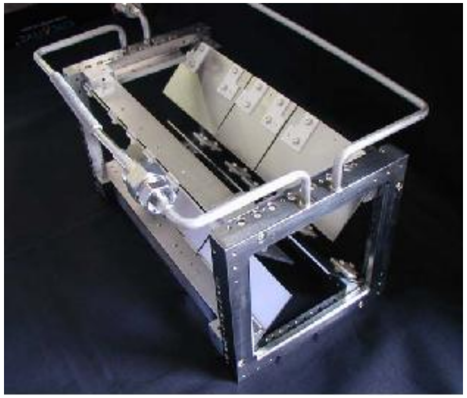


Ion properties in a Paul trap

Buffer gas used to cool ions:



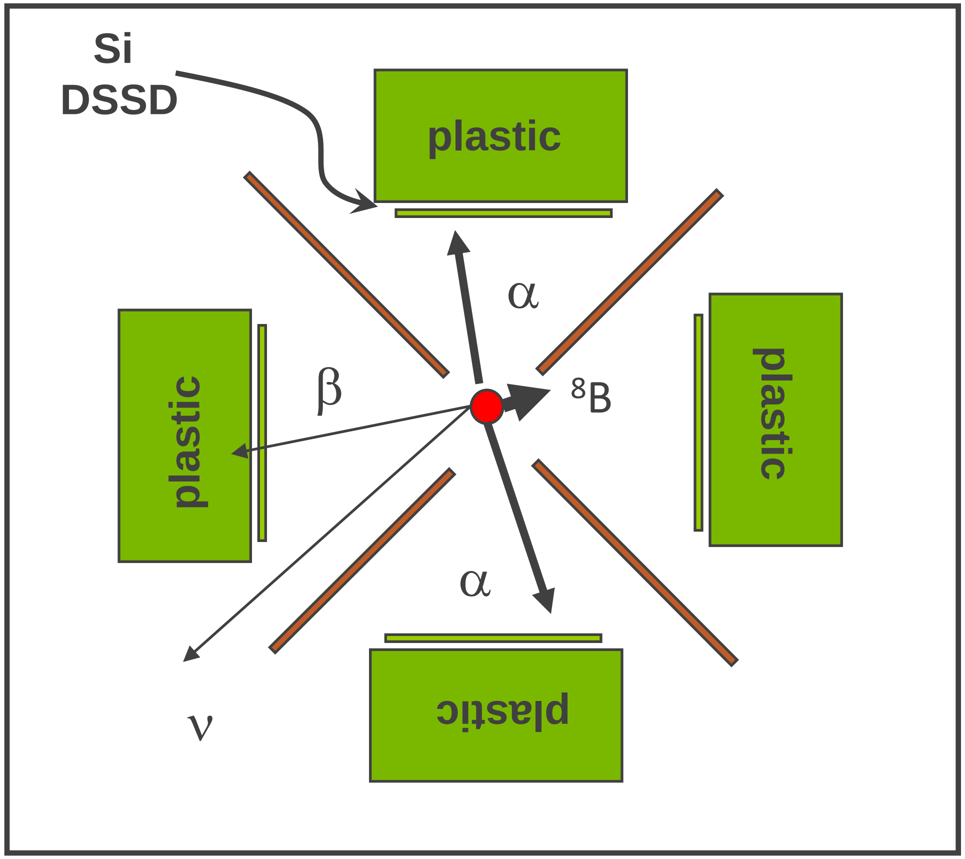
Additional cooling provided by liquid nitrogen cooled trap:

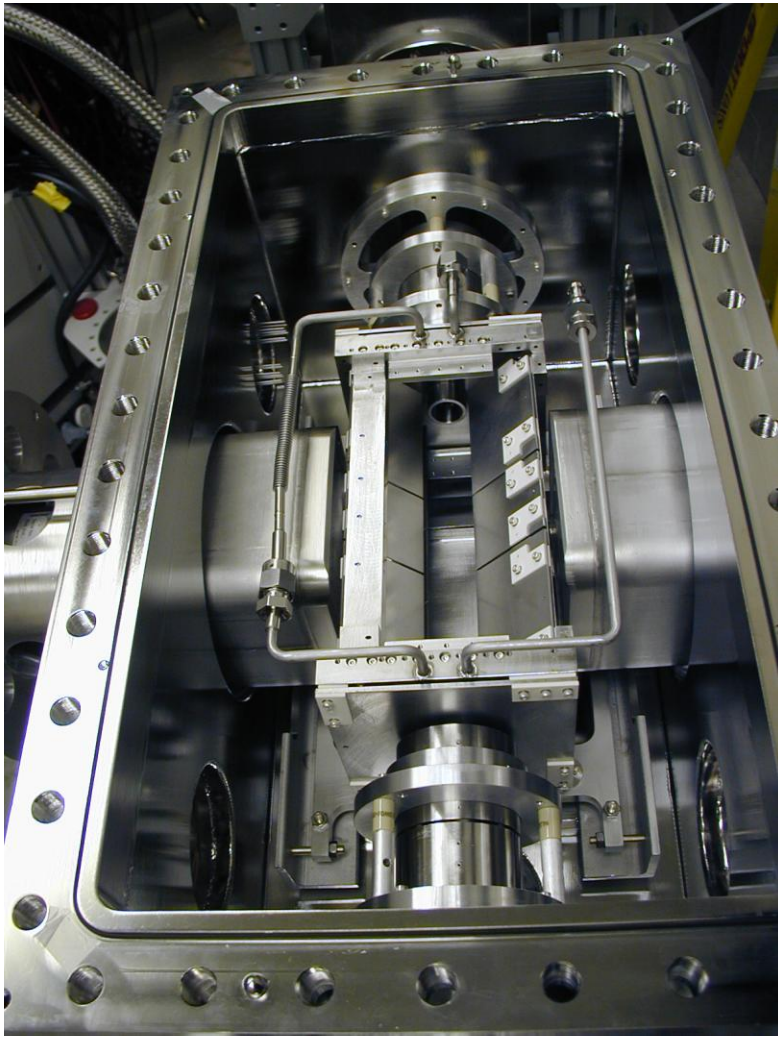


Results:

- **good vacuum properties**
  - **ions have long 'trap lifetime' (> 10 s)**
- **ions are well centered in trap (< 1 mm^3) after cooling (50 ms)**
- **ions almost at rest (< 0.1 eV)**
- **element independent (can use trap for any ion)**
- **good capture efficiency (~ 100%)**

Open geometry Paul trap for decay studies

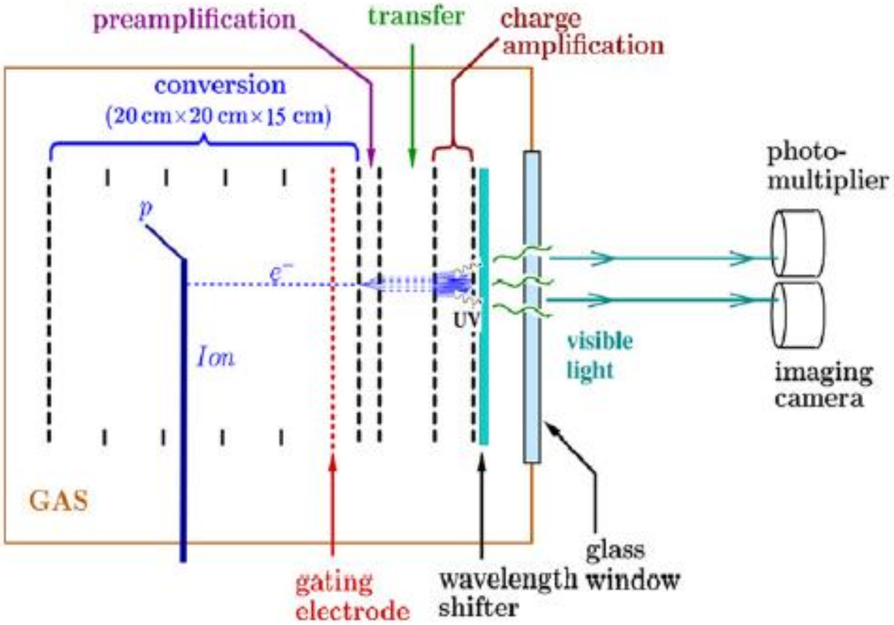




Optical time projection chamber

K.Miernik et al., NIM A581(2007)194

Detection of multi charged particle decay of fragmentation products.



Drift time- Z

CCD camera-X,Y

$Ar(49\%)+He(49\%)+N_2(1\%)+CH_4(1\%)$

$20x20x15cm^3$

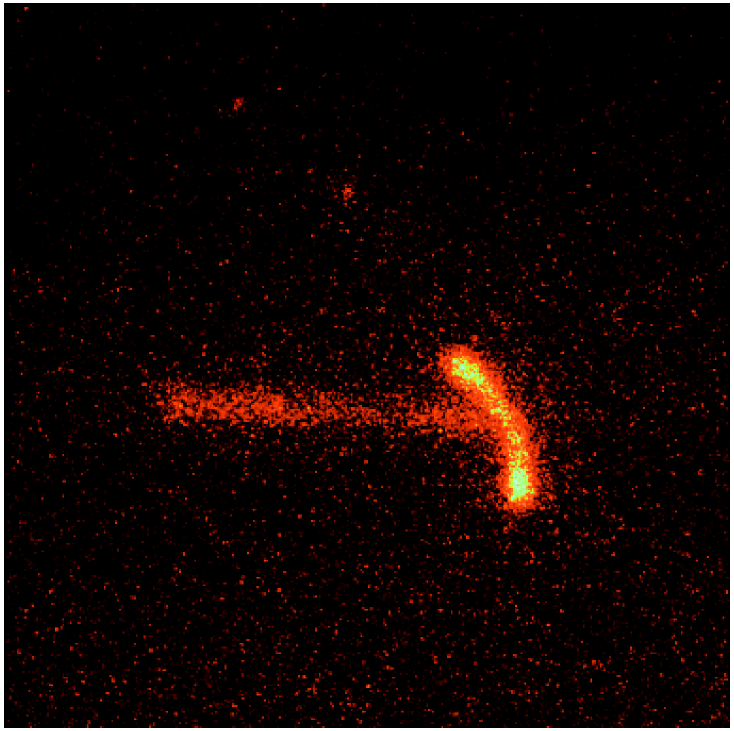
2 gains: HI, decay

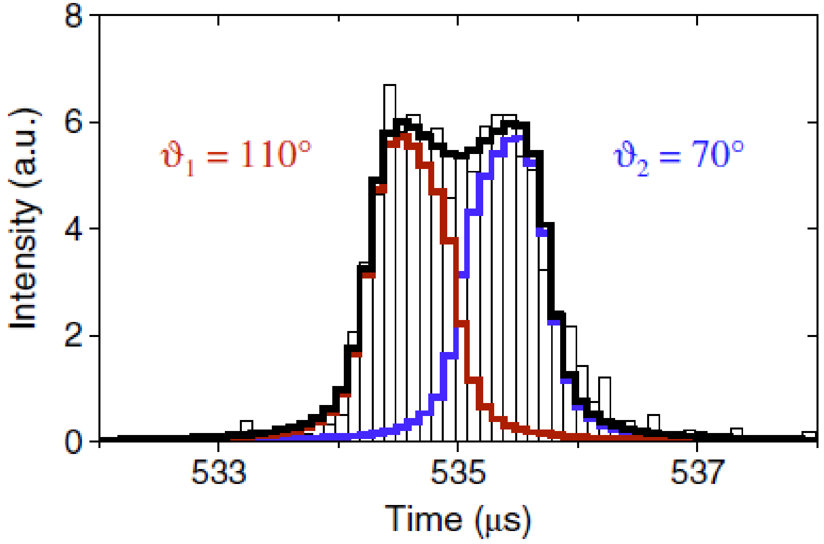
ON-OFF

^{45}Fe 2-proton decay observation

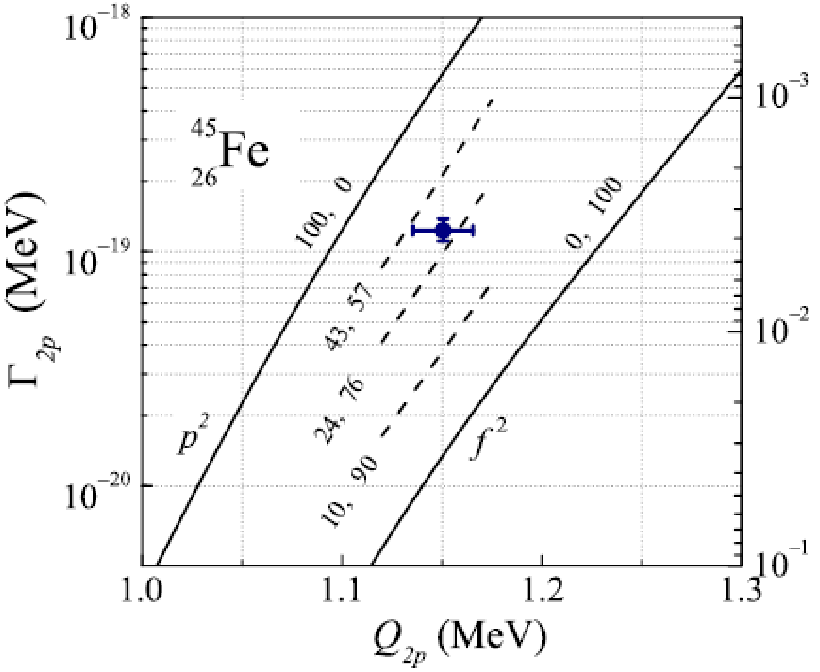
K.Miernik et al., PRL 99, 192501 (2007)

- proton decay energetically impossible
- Proton-proton correlations
  - no correlations
  - ^{2}He emission
  - something in between

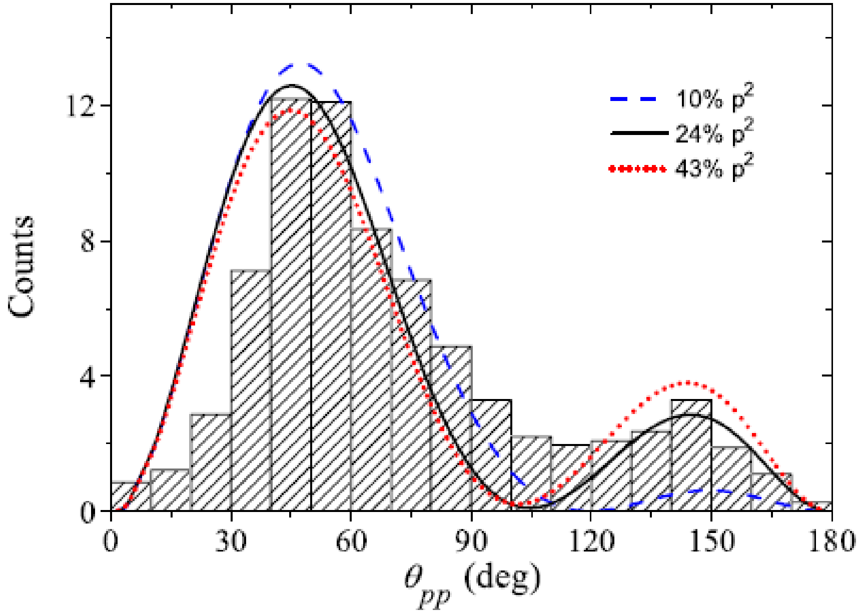




^{45}Fe 2-proton decay results



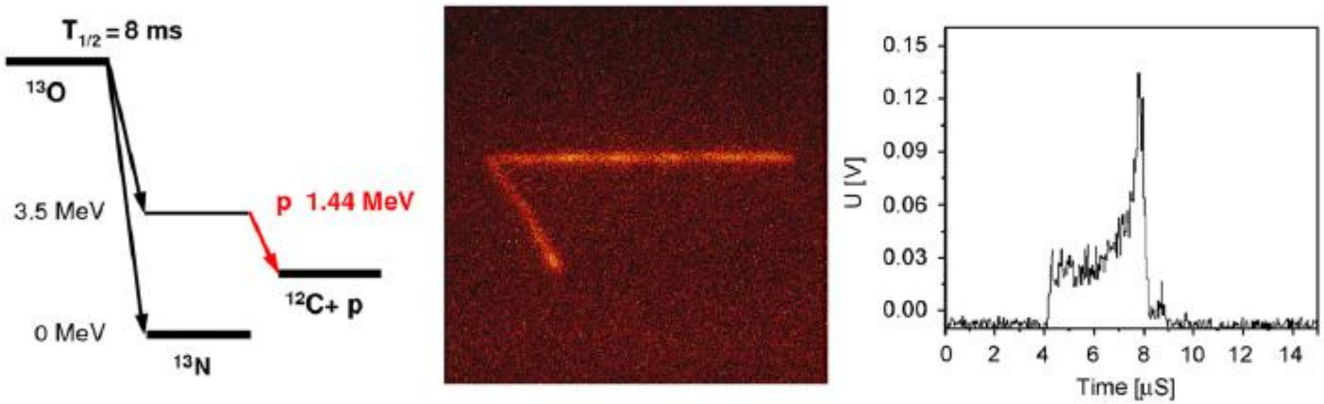
Measured lifetime

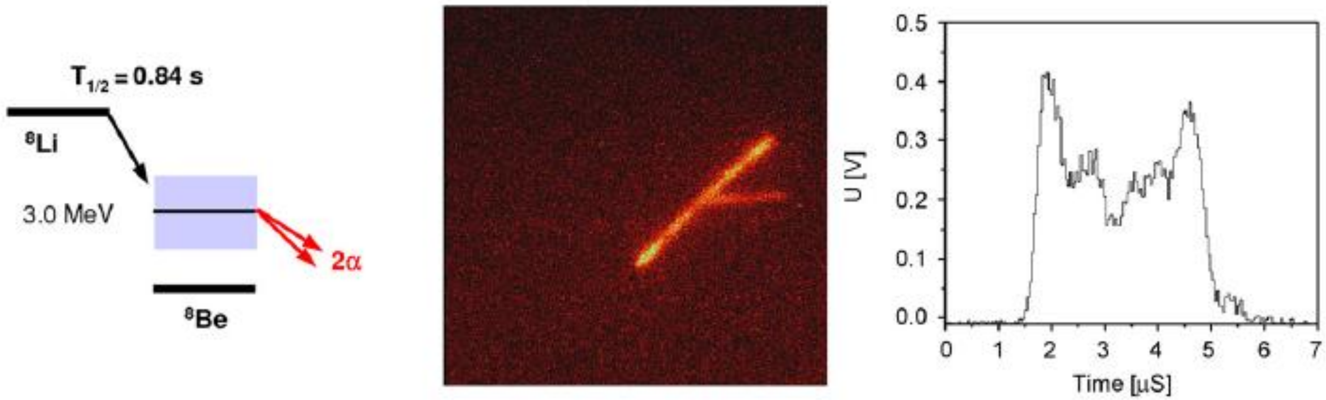


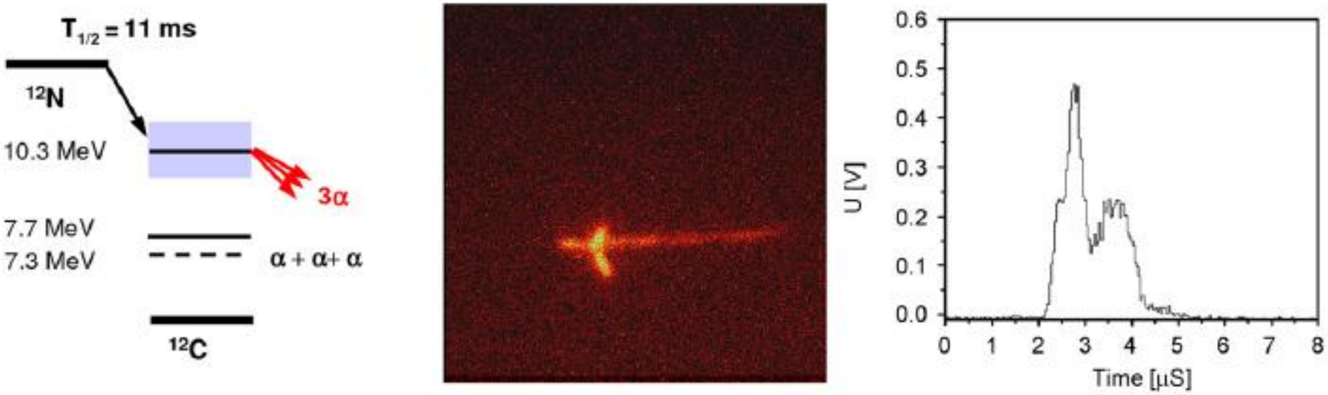
p-p angular correlations

2p decay requires a 3-body model

Recently the 2p decay of the doubly-magic ^{48}Ni was observed at NSCL!


$T_{1/2} = 8$ ms
^{13}O
3.5 MeV
0 MeV
^{13}N
p 1.44 MeV
^{12}C+ p
0.15
0.12
0.09
0.06
0.03
0.00
U [V]
0 2 4 6 8 10 12 14
Time [μS]

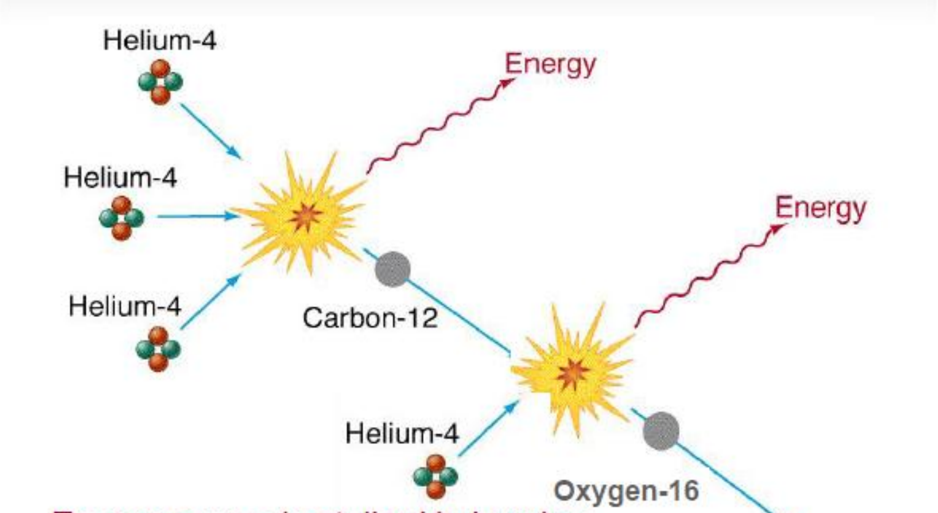

$T_{1/2} = 0.84$ s
^{8}Li
3.0 MeV
2α
^{8}Be
0.5
0.4
0.3
0.2
0.1
0.0
U [V]
0 1 2 3 4 5 6 7
Time [μS]


$T_{1/2} = 11$ ms
^{12}N
10.3 MeV
3α
7.7 MeV
7.3 MeV
α + α+ α
^{12}C
0.6
0.5
0.4
0.3
0.2
0.1
0.0
U [V]
0 1 2 3 4 5 6 7 8
Time [μS]

Superheated active chamber

slides courtesy B. DiGiovine

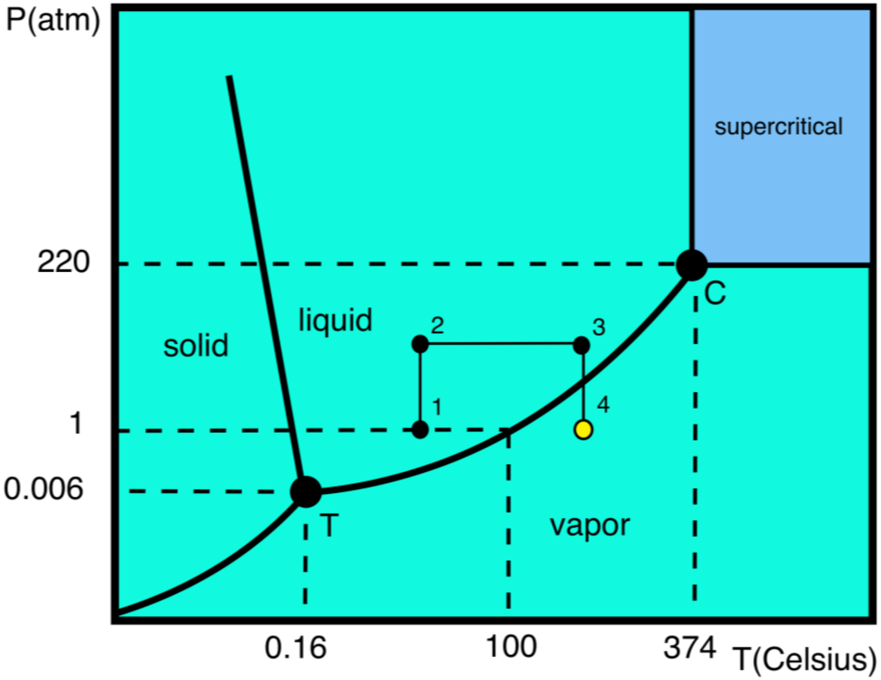
- $^{12}C(^{4}He,\gamma)^{16}O$ reaction important for stellar He burning
- Direct measurements reached their limit
  - Small cross section
  - Background
- Measure inverse reaction $^{16}O(\gamma,\alpha)^{12}C$ using a gamma-ray beam and a superheated active target



Energy source in stellar He burning
Energy release determined by associated reaction rates

Superheated liquid

- Pressure is raised in detector to a value above its vapor pressure at operating temperature (1-2)
- Temperature is then increased to operating temperature (2-3)
- Pressure is then reduced to a value which the active medium should exist in a liquid state (3-4)
- This is called a metastable state, and the liquid is now considered superheated
- Small disturbances in the liquid will cause vaporization
- Recoiling particles from nuclear reactions deposit their energy over a very short distance
- This deposited energy is enough to induce nucleation, which results in a bubble and is our detected event
- The detector system "sees" this event and pressurizes the system causing the bubble to liquefy, resetting the detector (4-3)
- By varying the operating T&P we can vary the amount of superheat, which allows us to adjust the detection threshold of the system

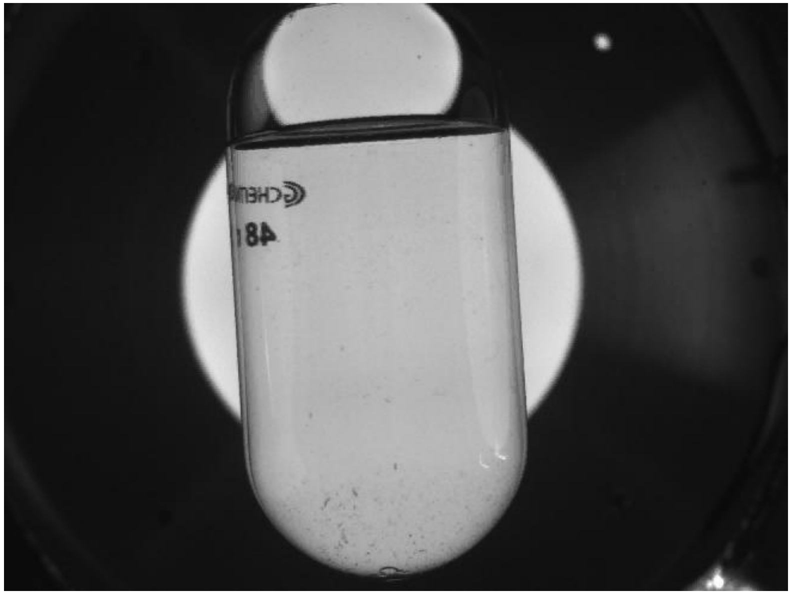


R134-a refrigerant

Later water

Bubble chamber

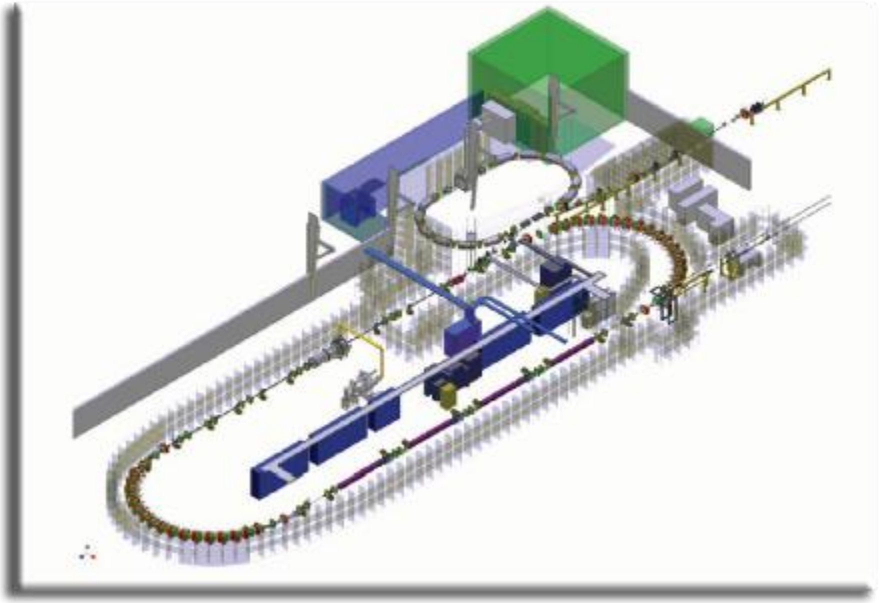
- The detection of the bubble and the subsequent pressurization must be done quickly!
- Utilizing cameras running at 100fps, our software compares to sequential photos, subtracts them, and activates the pressurization cycle within 10ms after the event is detected
- Pressure must begin to increase within ~ 40ms to control the bubble and prevent a run-away boil
- Initial testing of equipment and software at room temperature using a commercial refrigerant R134-a allowed us to troubleshoot and operate the system without the additional complications of high temperatures



HIγS facility

High Intensity Gamma Ray Source

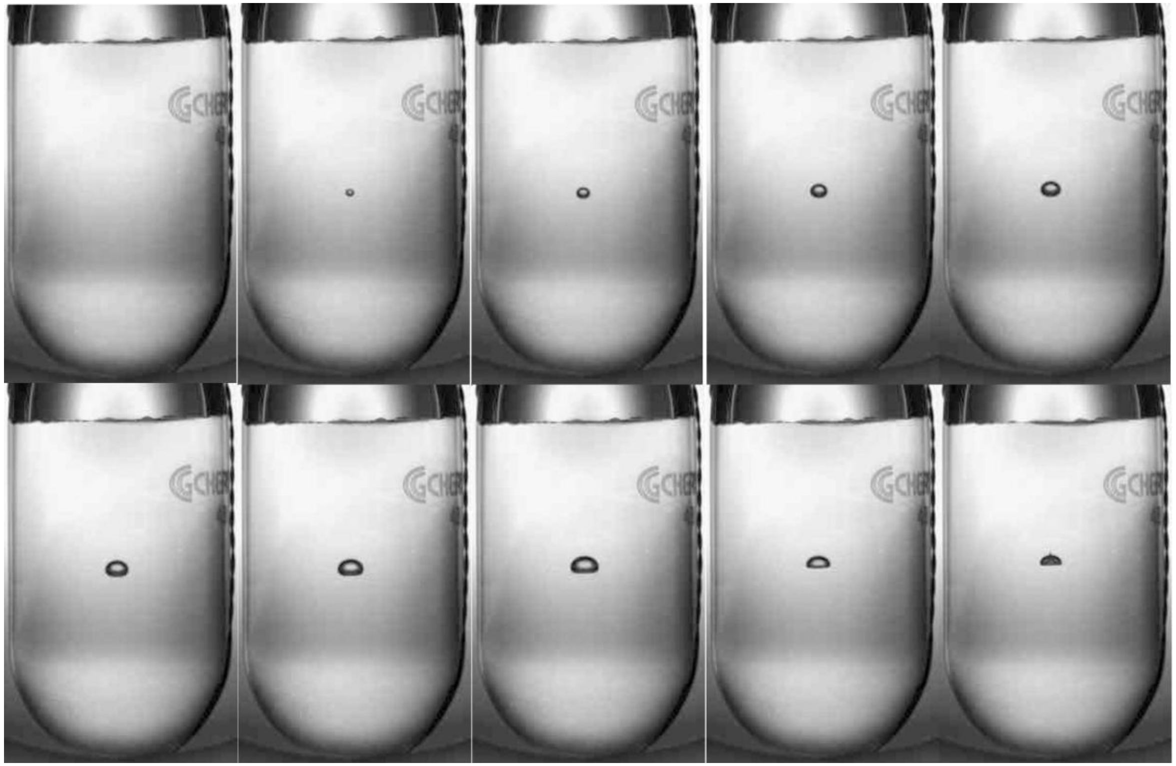
TUNL lab at Duke

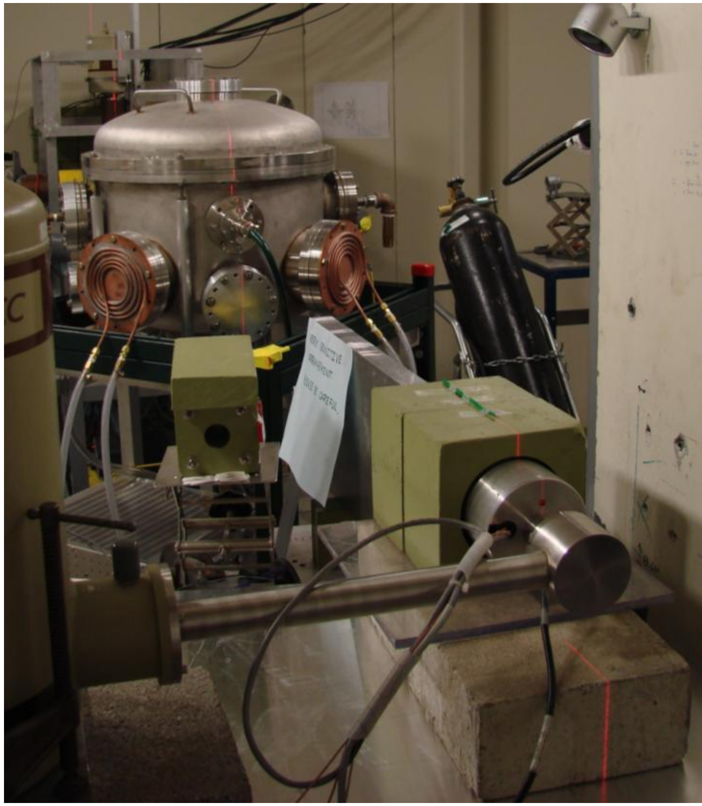


Light compton Backscattered from a high energy electron beam

First experiments at HIγS

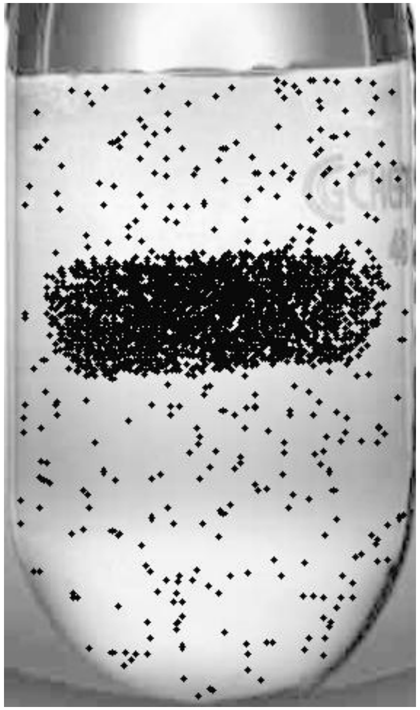
- Proof of principle experiment was conducted at Duke
- Second generation room temperature detector, active medium was R134-a
- Followed excitation function for photodisintegration curve of fluorine





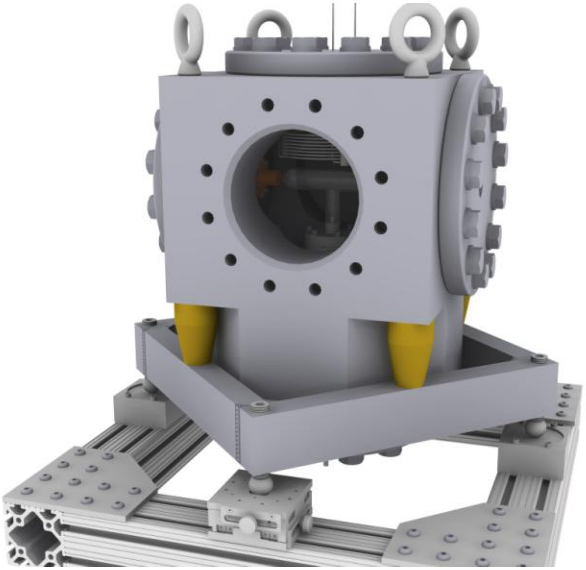
Results from HIγS

- Successfully confirmed excitation function for photodisintegration of fluorine
- Successfully confirmed dN/dt advantage of the technique
- Laid groundwork for future superheated water experiments
- Detector worked so well for preliminary fluorine experiments it will now be dedicated to room temperature experiments, a third detector will be built, realizing lessons learned, for superheated water experiments

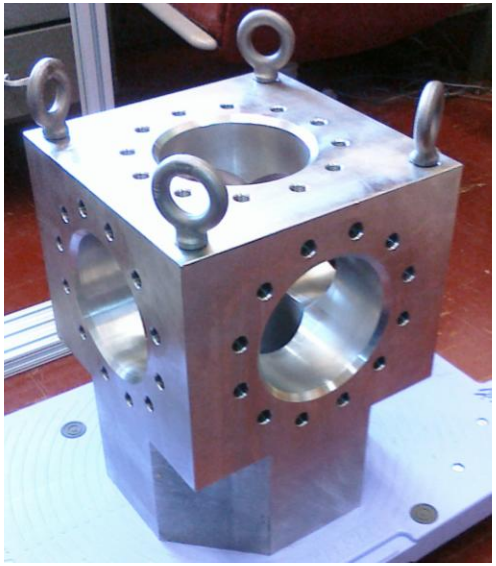


Third generation bubble chamber

- The realization of the high T&P which is necessary to make a viable superheated water bubble chamber spurred a new design direction
- Rather than having a glass vessel support the high pressure differentials an external pressure vessel will support the pressure differential allowing for a thin glass vessel inside connected to a bellows with the active volume, surrounded in a bath of hot oil. This oil is now the fluid that gets acted on directly by the pressurization system
- Components are in the process of manufacture, design work is beginning to finish up, construction should begin by spring



Version 3



Thank you