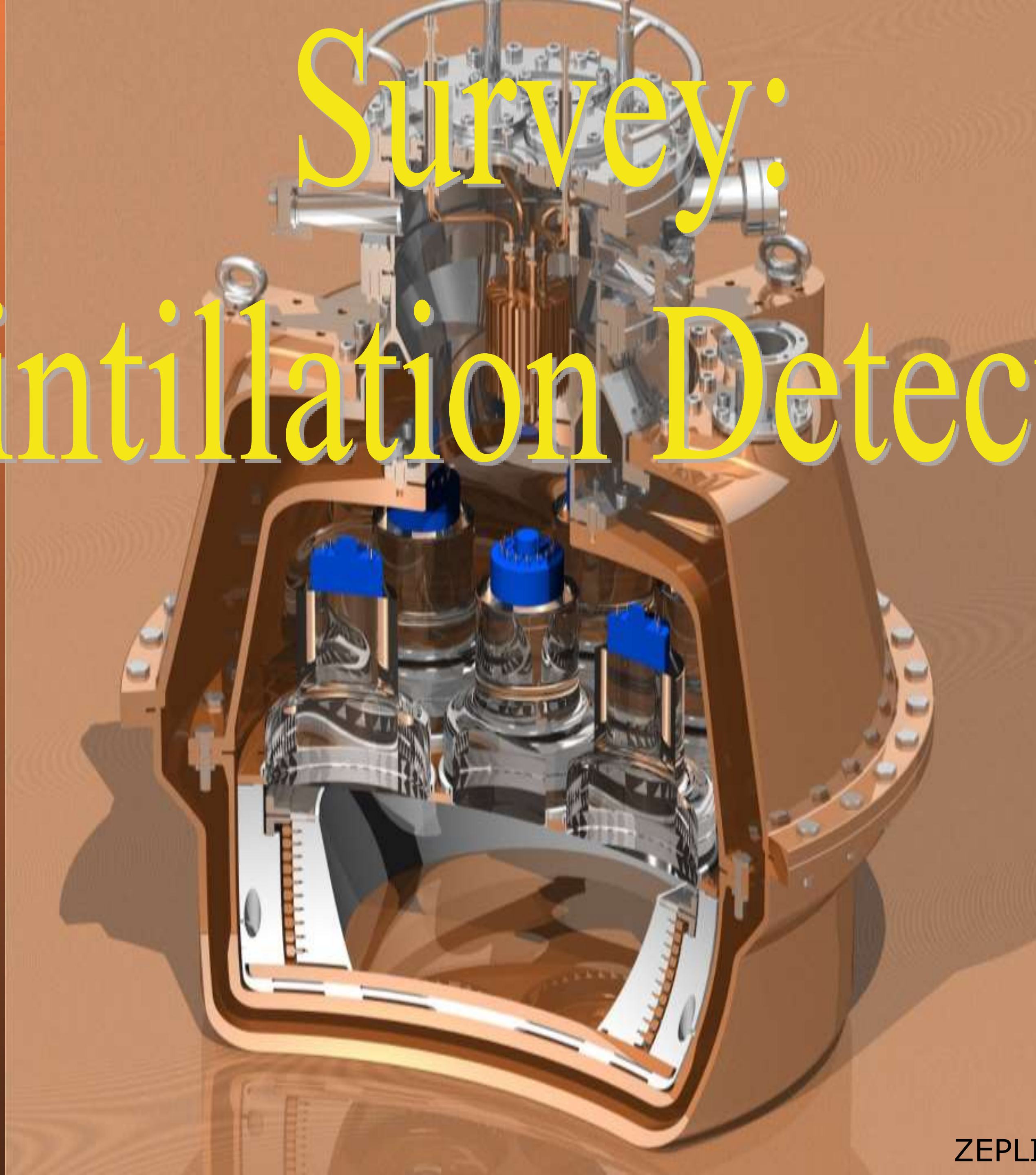
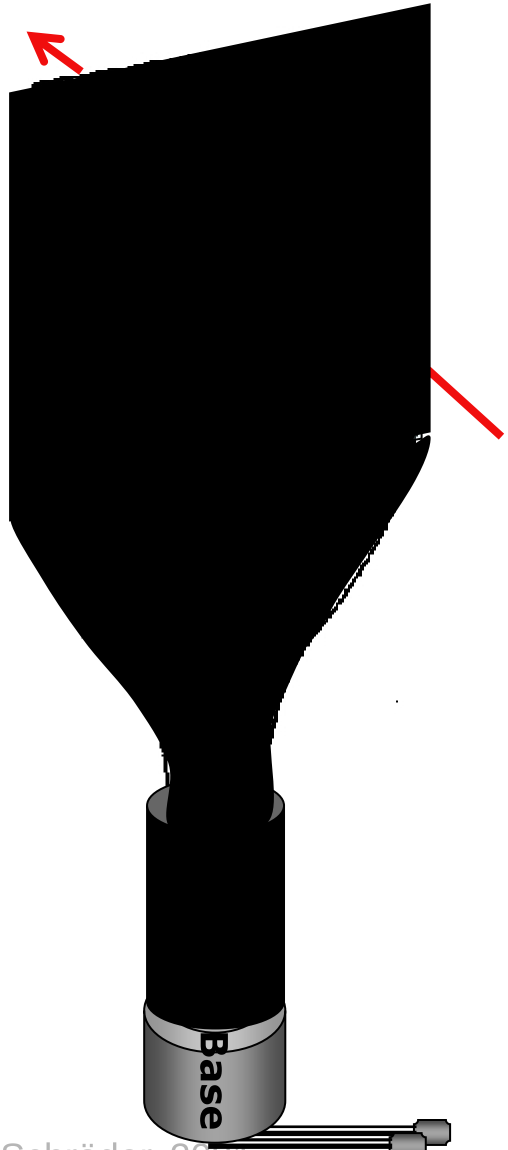
Survey: Scintillation Detectors



ZEPLIN III

Construction of Scintillation Counters



- Scintillator $(q\ (\Delta E) \rightarrow h\nu \rightarrow h\nu^*)$
- Light guide (*collect, average, direct*)
- Photomultiplier $(h\nu^* \rightarrow e^- \rightarrow n\ e^-)$
- Base (*power PM dynode chain, readout*)

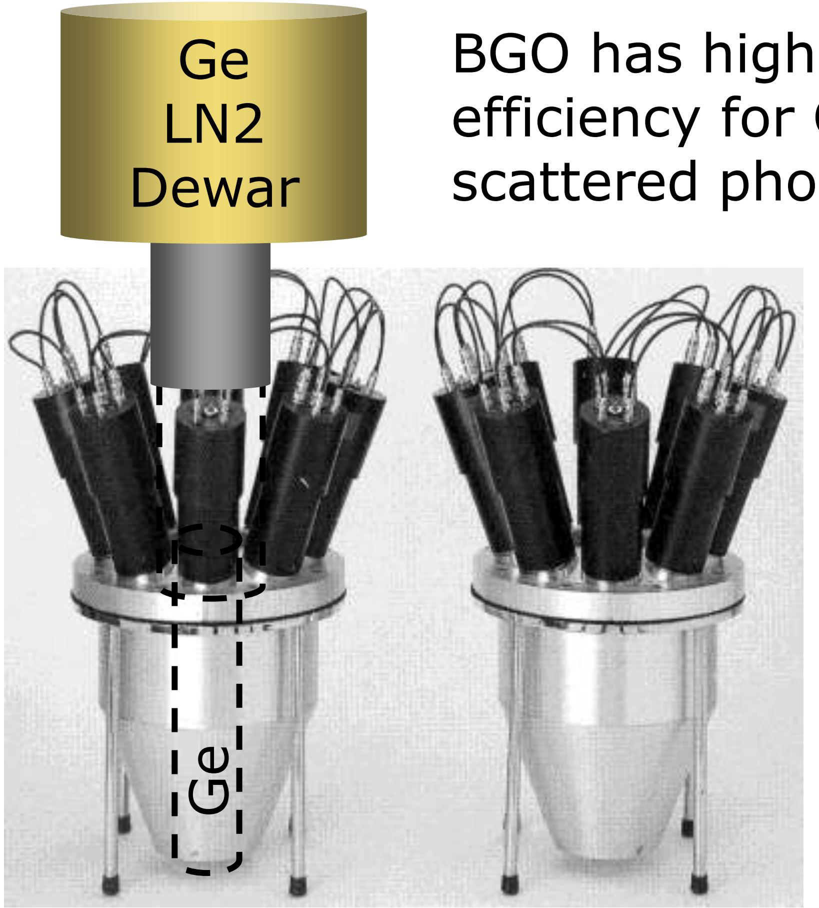
Scintillating Materials

Inorganic
- *gas* (*Ar, Xe,...*)
- *liquid* (*He, Xe,...*)
- *solid* (*NaI, CsI, BGO,* BaF_2..)

Organic
- *liquid* (*xylene, benzene,..*)
- *solid* (*polystyrene,..*)

Protect scintillator + light guide against external light (→ wrap in black tape/plastic)

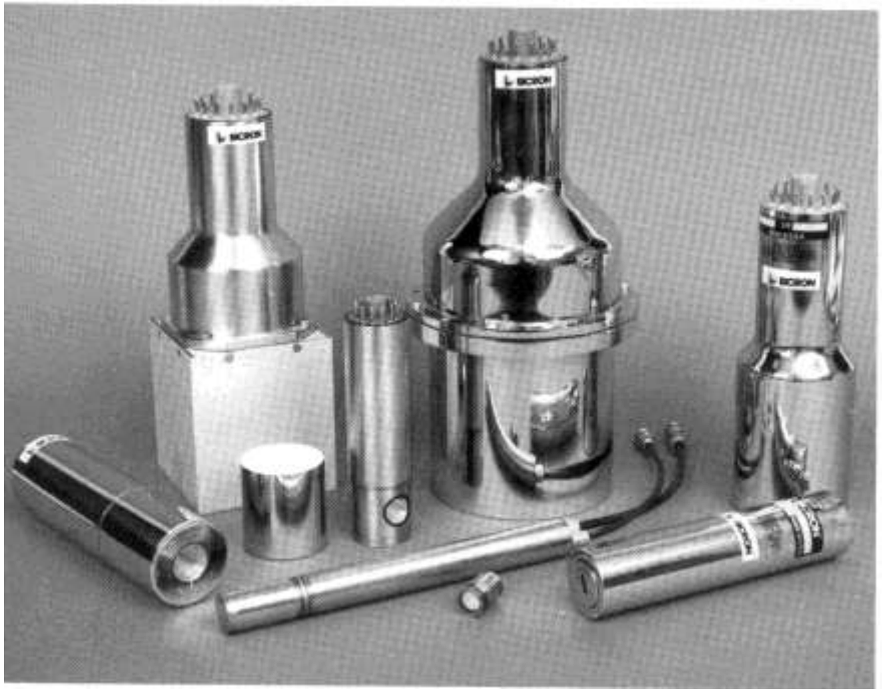
BGO Detectors



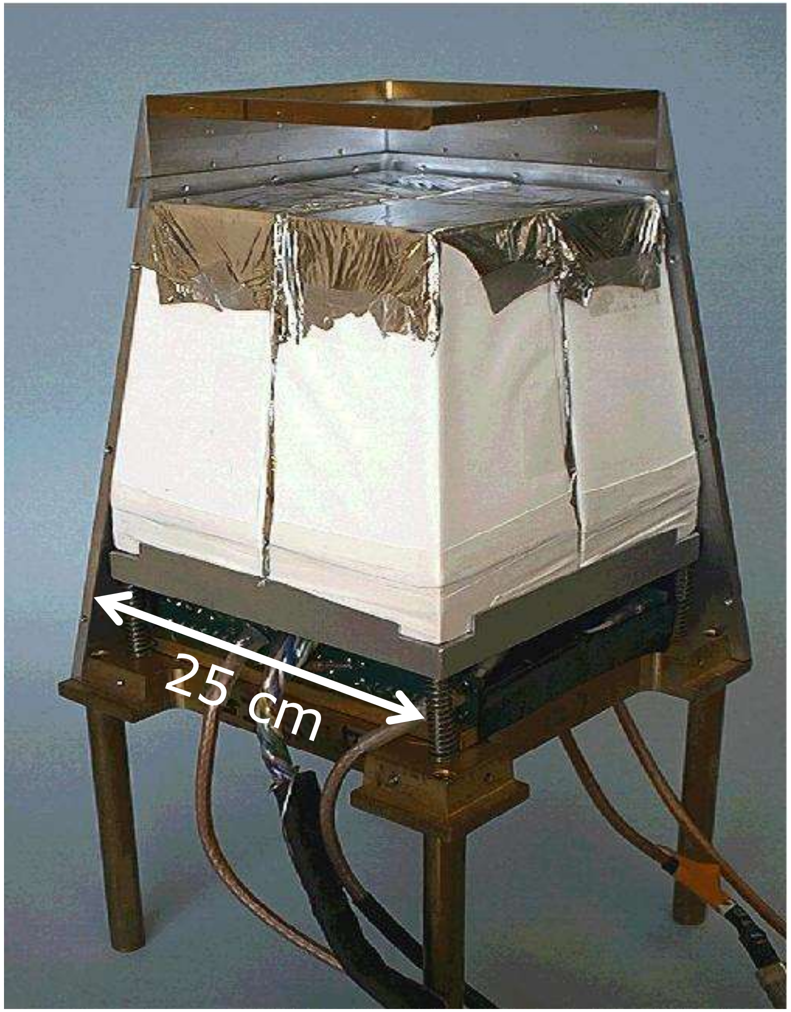
BGO has high density, high efficiency for Compton scattered photons

Anti-Compton Shield detectors for high-resolution γ spectroscopy with LN2 cooled Ge detectors

NaI(Tl) and CsI(Tl) Scintillation Detectors

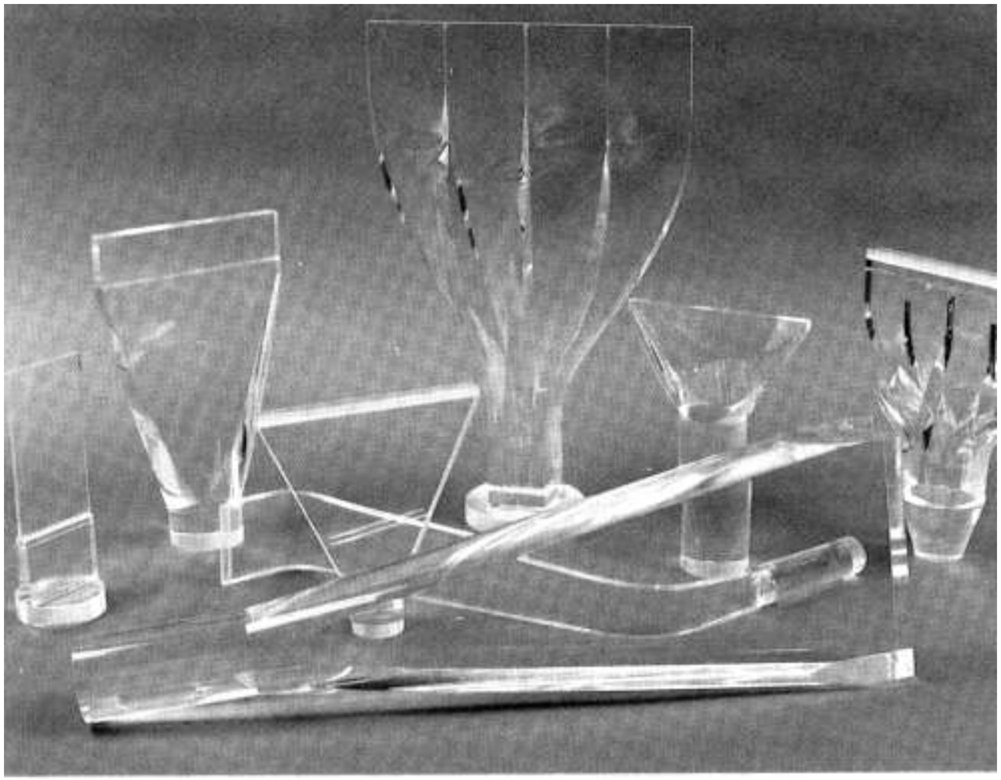


Commercial NaI(Tl) detectors: Integral lines. (Harshaw)



Segmented CsI(Tl) detectors for LASSA array (deSouza)

Light Guides



Liouville Theorem: constant phase space volume (decrease cross section of guide → loss of intensity)

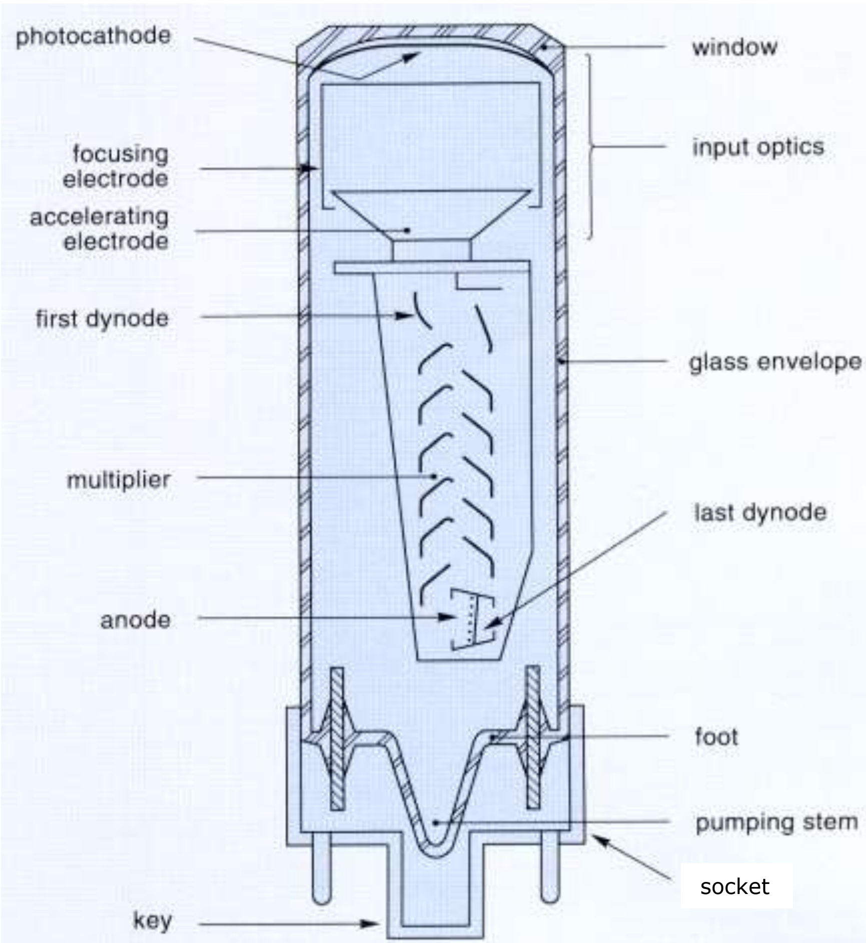
Bending radius r large enough for total internal reflection

$$n^2 - 1 > \left(d/2r + 1\right)^2$$

n=refractive index
d=diameter of guide

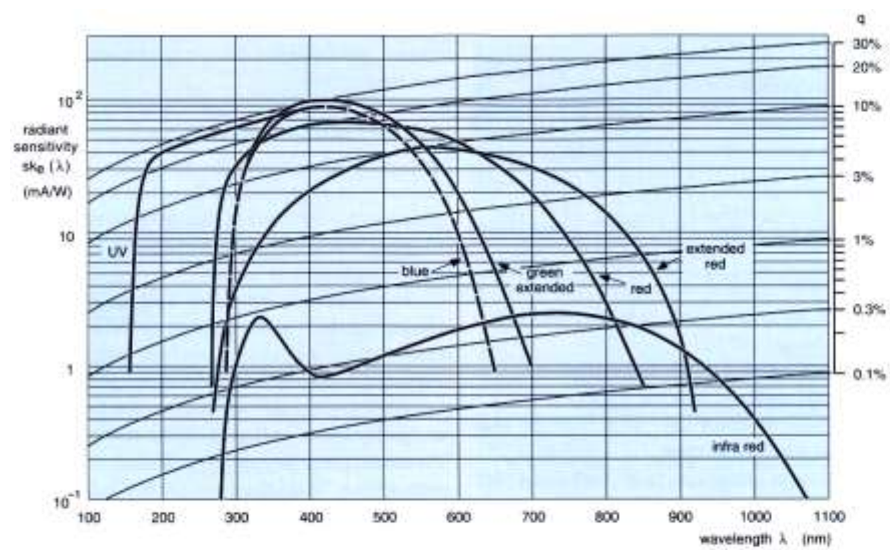
Electronic Photo-Multipliers

Philips 56 AVP



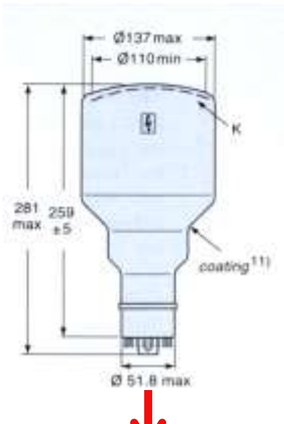
Criteria for choice:

- match photo cathode to scintillator light
- quantum efficiency
- rise time
- entrance window (glass, quartz,..)
- gain factor (1 e^- → n e^-)
- dark current

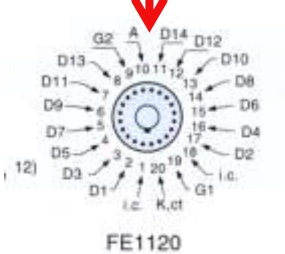


PM Operation

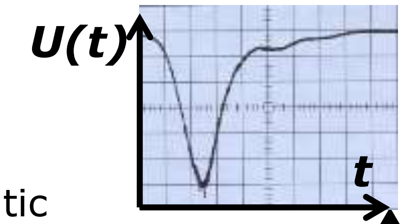
Fast PM: pulse rise time ~2 ns, gain: $3{\cdot}10^7$



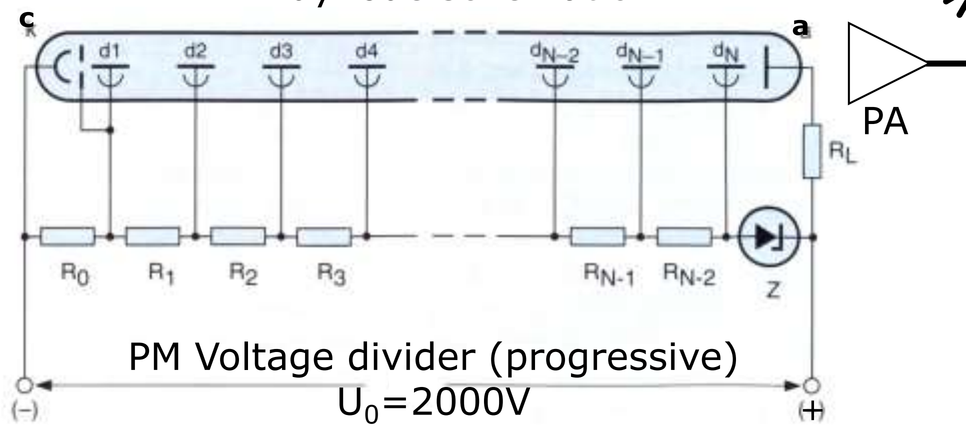
Philips XP 2041
5″ dia cathode
N=14 dynodes
+ focusing electrodes
Needs curvature
adapter cathode/scint.

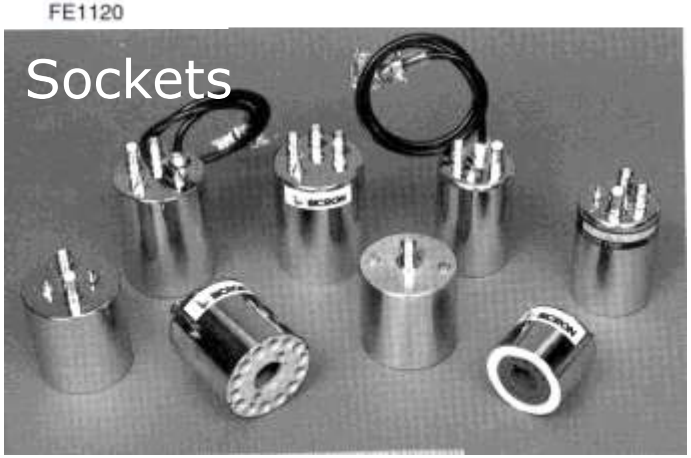


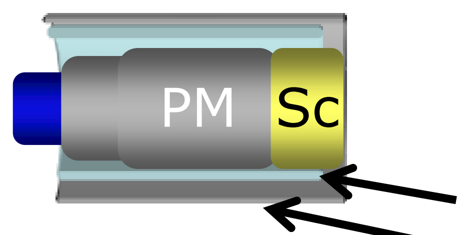
Socket FE1120
pin connections



PM dynode schematic



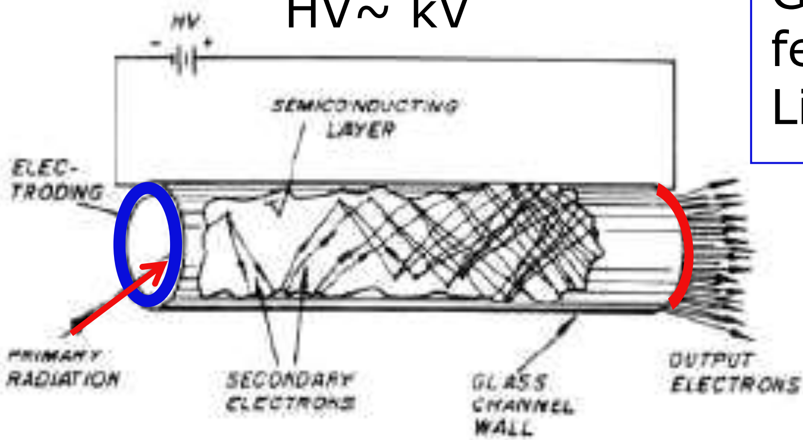




mu-metal shield tube provides protection from external *B* field.

Channel Electron Amplifiers

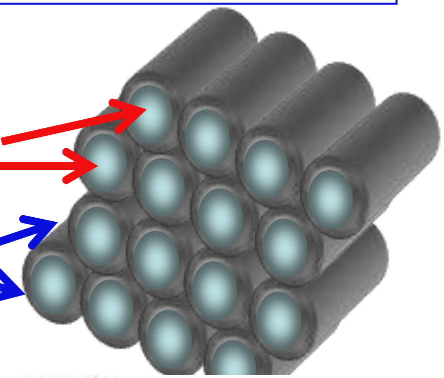
HV~ kV



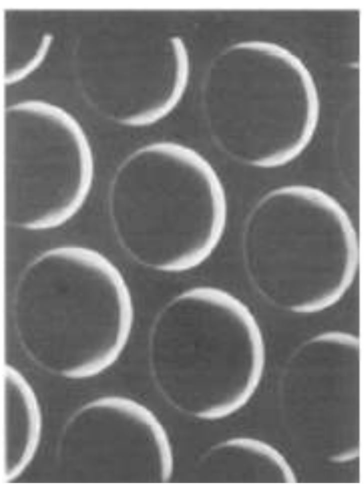
Glass fiber tubes (straight or curved), few 10 μm dia. etched, inside coating LiF, MgF_2, KCl, CsI,..

soft core glass

lead glass cladding

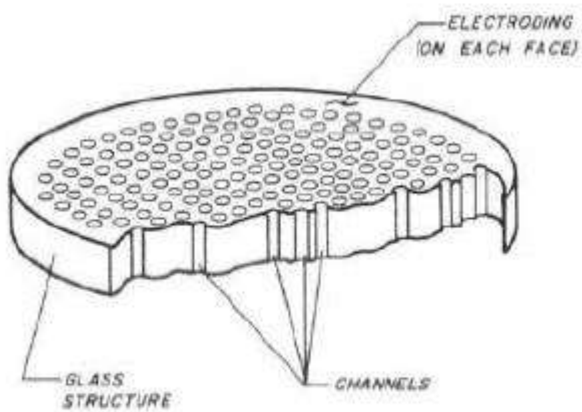


Stacked tubes

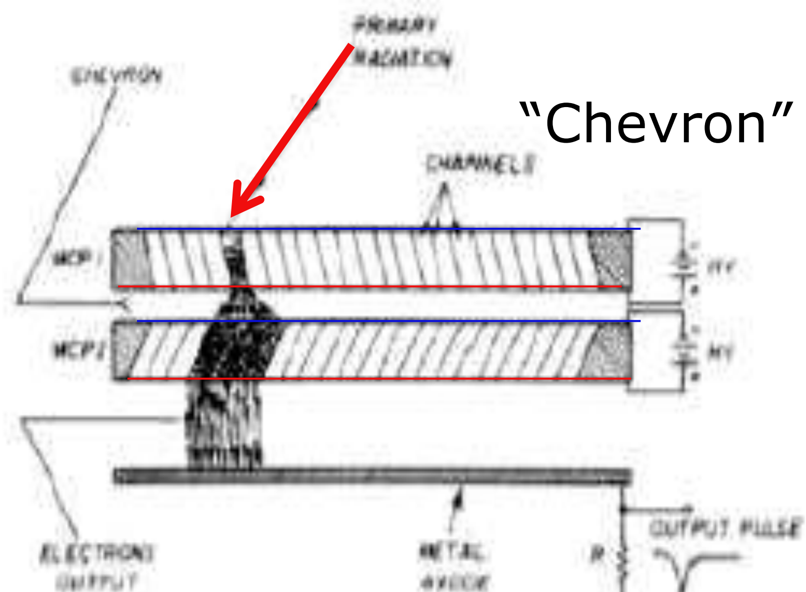


MCP face

Multi-Channel Plate

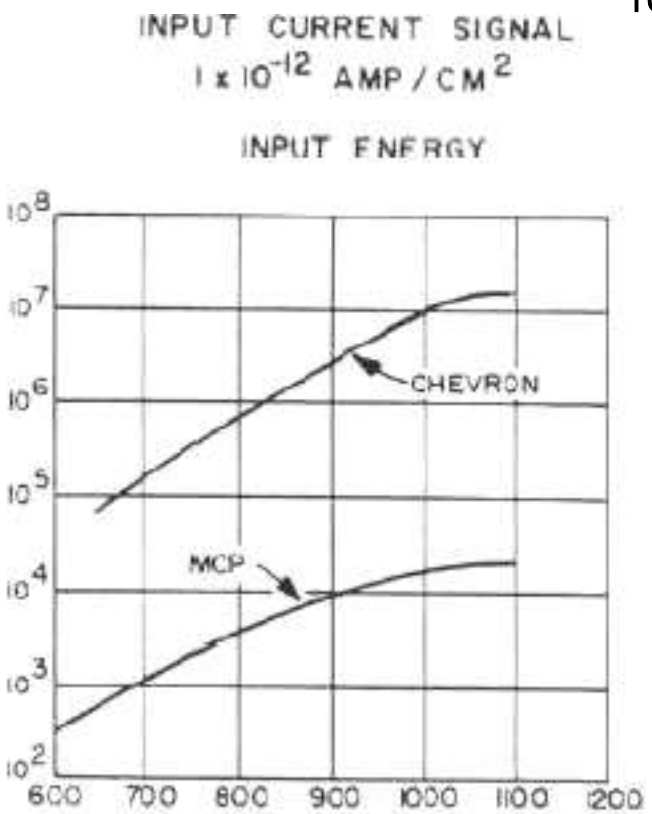


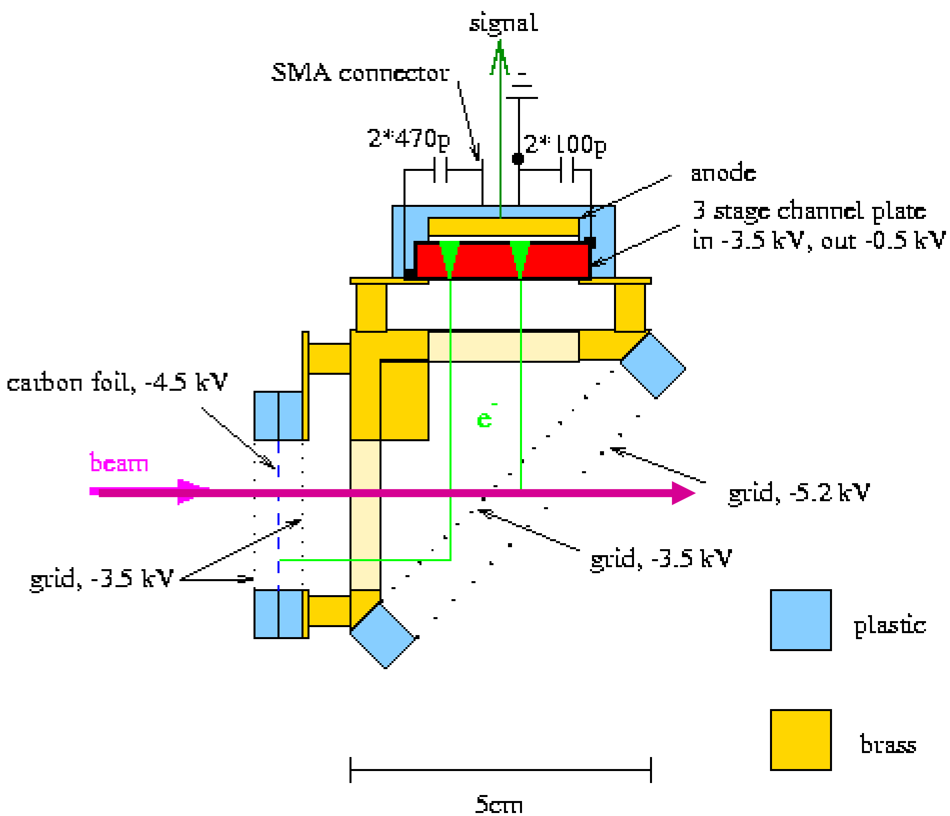
"Chevron"



Applications of Channel Plate Multipliers

high gain=high efficiency, fast response. Use for timing (TOF-Start/Stop)

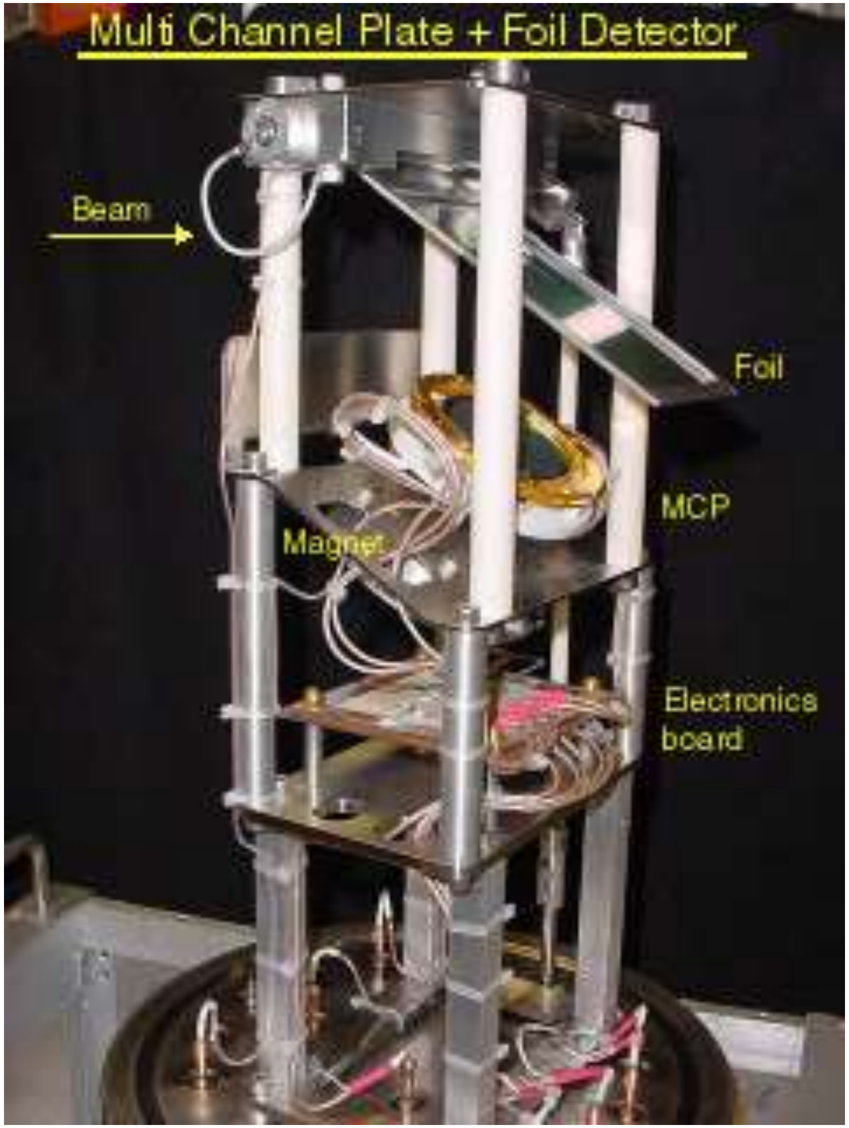




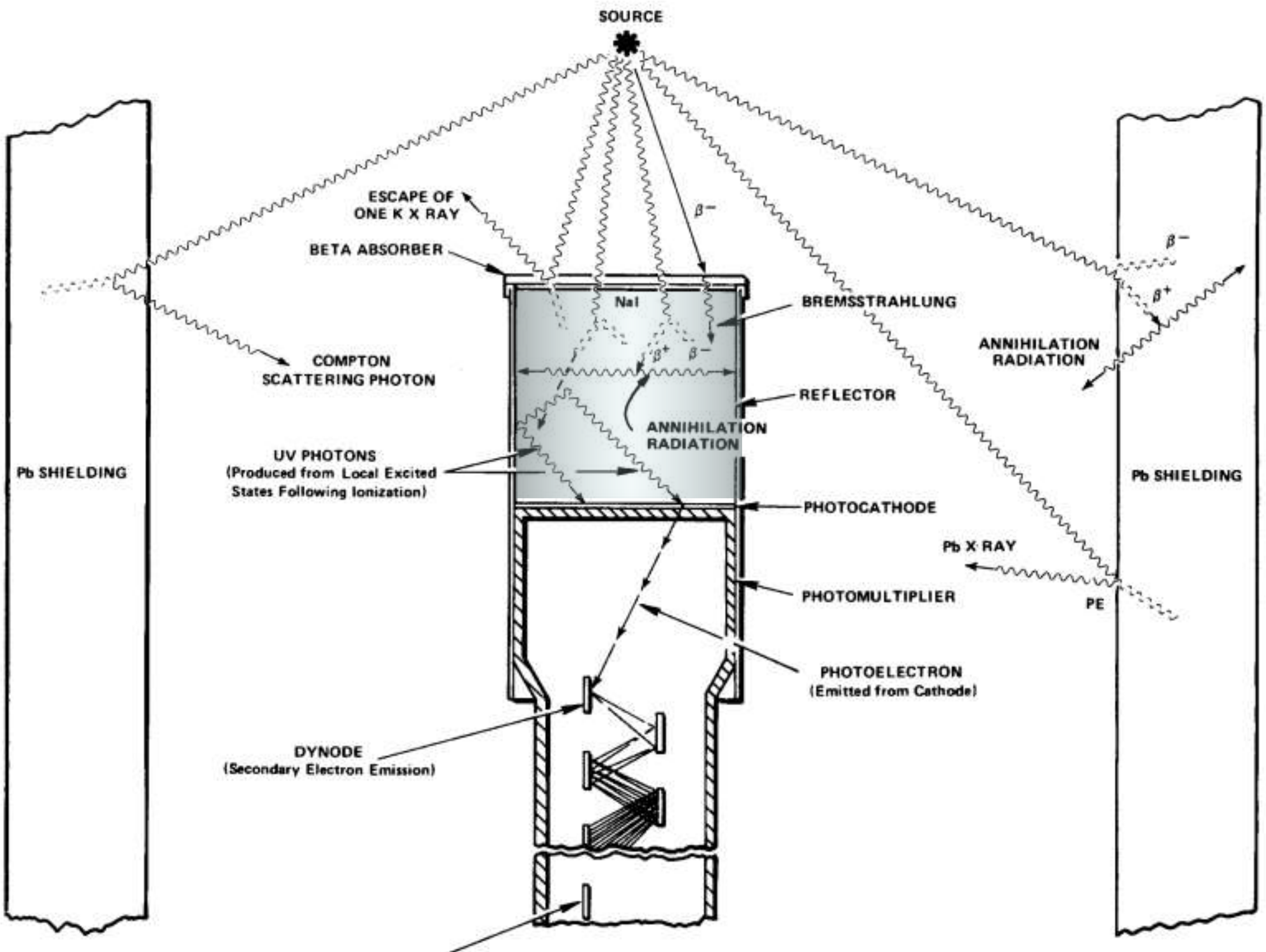
HI beam releases δ electrons in C foil, multiplied with multi-stage chevron

Examples of MCP e-Multipliers

Chevron mounted: El-Mul Technologies Ltd.



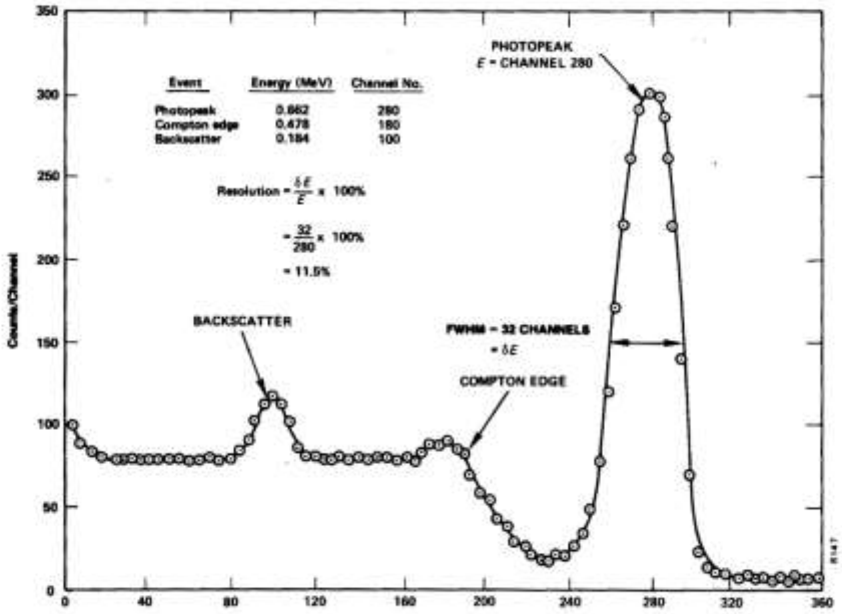
Environment of γ Scintillation Measurement



W. Udo Schröder, 2021

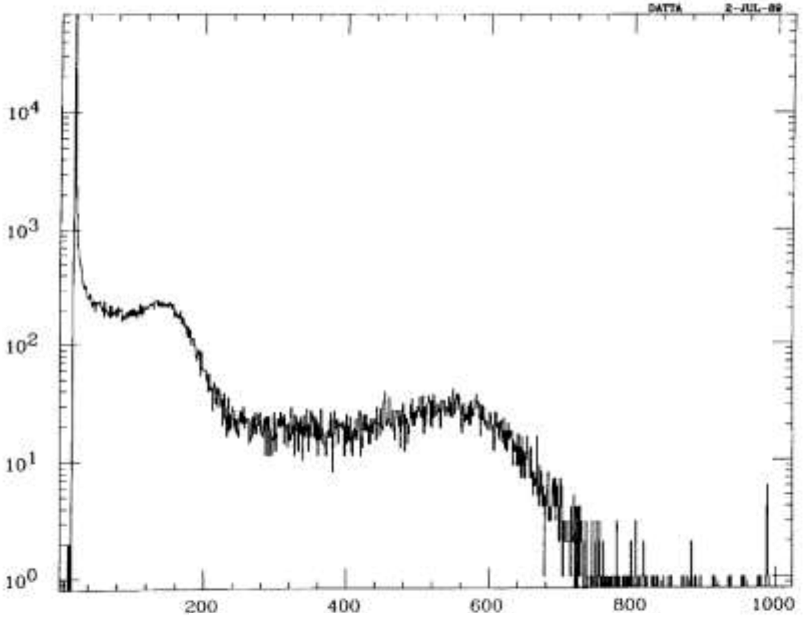
Photon Response

^{137}Cs- γ spectrum with inorganic scintillator (NaI)



Light Output (Energy)

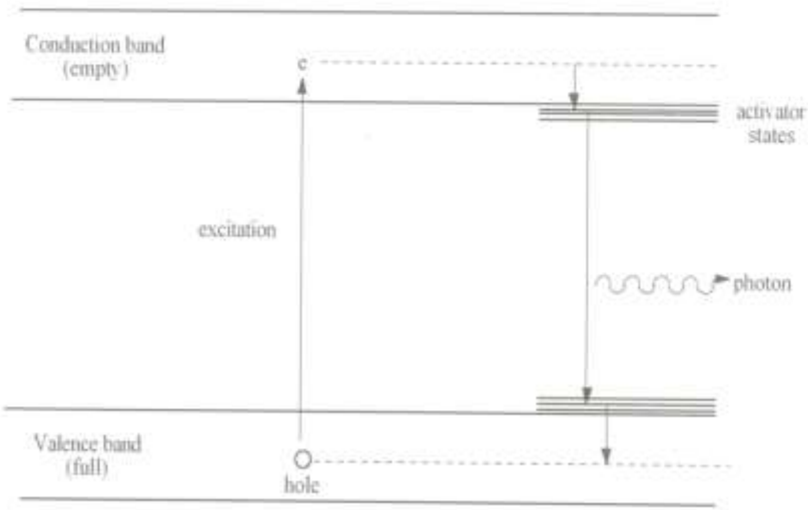
^{22}Na- γ spectrum with organic scintillator (NE213)



Light Output (Energy)

Low-Z detector material → no photo peak

Scintillation Mechanism: Inorganic Scintillators



Excitation electronic:
VB → CB (or below)
Trapping of e- in activator states (Tl) doping material, in gs of activator band e transition emits lower Eγ, not absorbed.

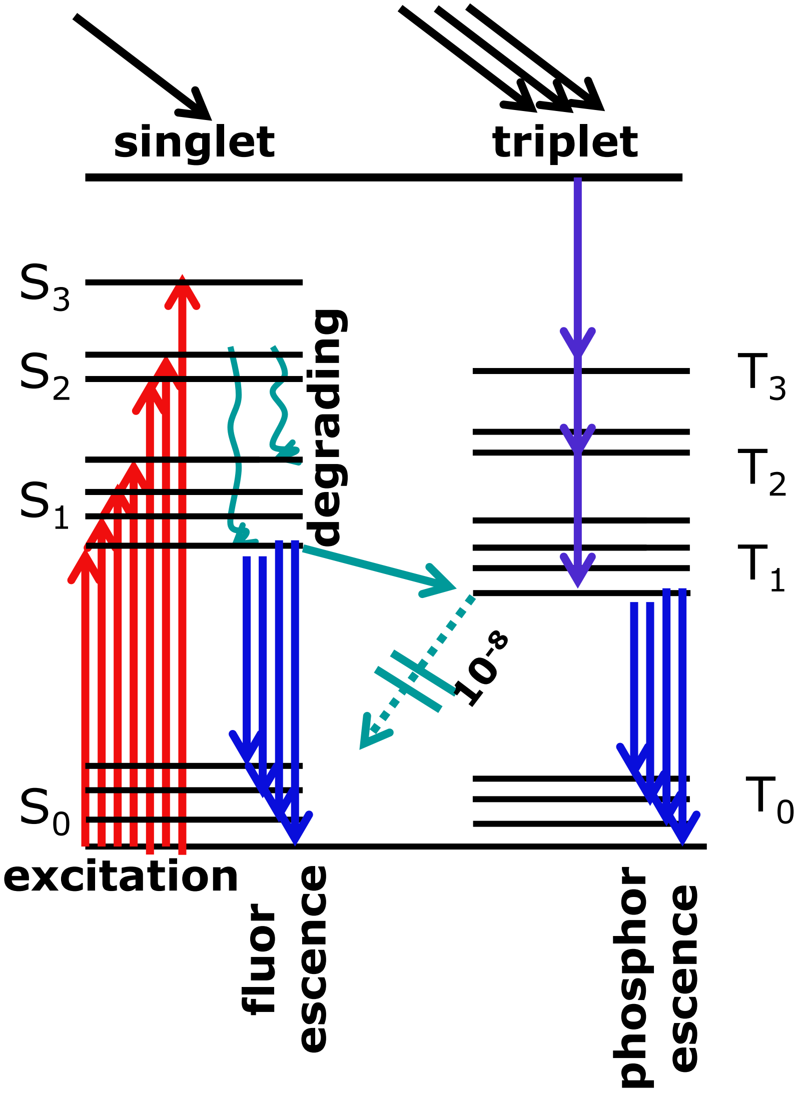
Primary ionization and excitations of e- or excitons (e^-,h^+) → sequential deexcitation with different time constants.

Shifts spectrum to longer wave lengths

Advantage of inorganic scintillators: high density, stopping power → good efficiency

Disadvantage of inorganic scintillators:
slow response – μs decay time, “after glow”,
some are hygroscopic

Scintillation Mechanism: Organic Scintillators



Excitation of molecular states determined by π electrons: singlets (↑↓) and triplets (↑↑). Form vibrational band heads

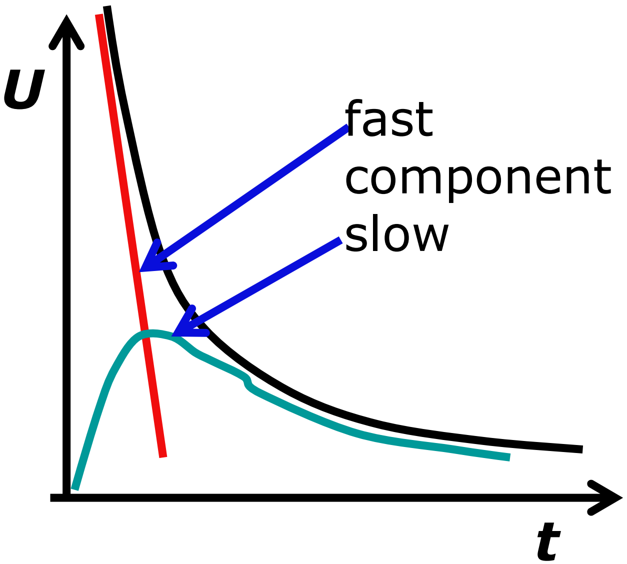
Trapping of e- in triplet states, slow decay to S_0 ground state

Triplet excited (3:1) via ion recombination.

Decay via collisions
TT → SS+phonons (τ~ 300 ns)

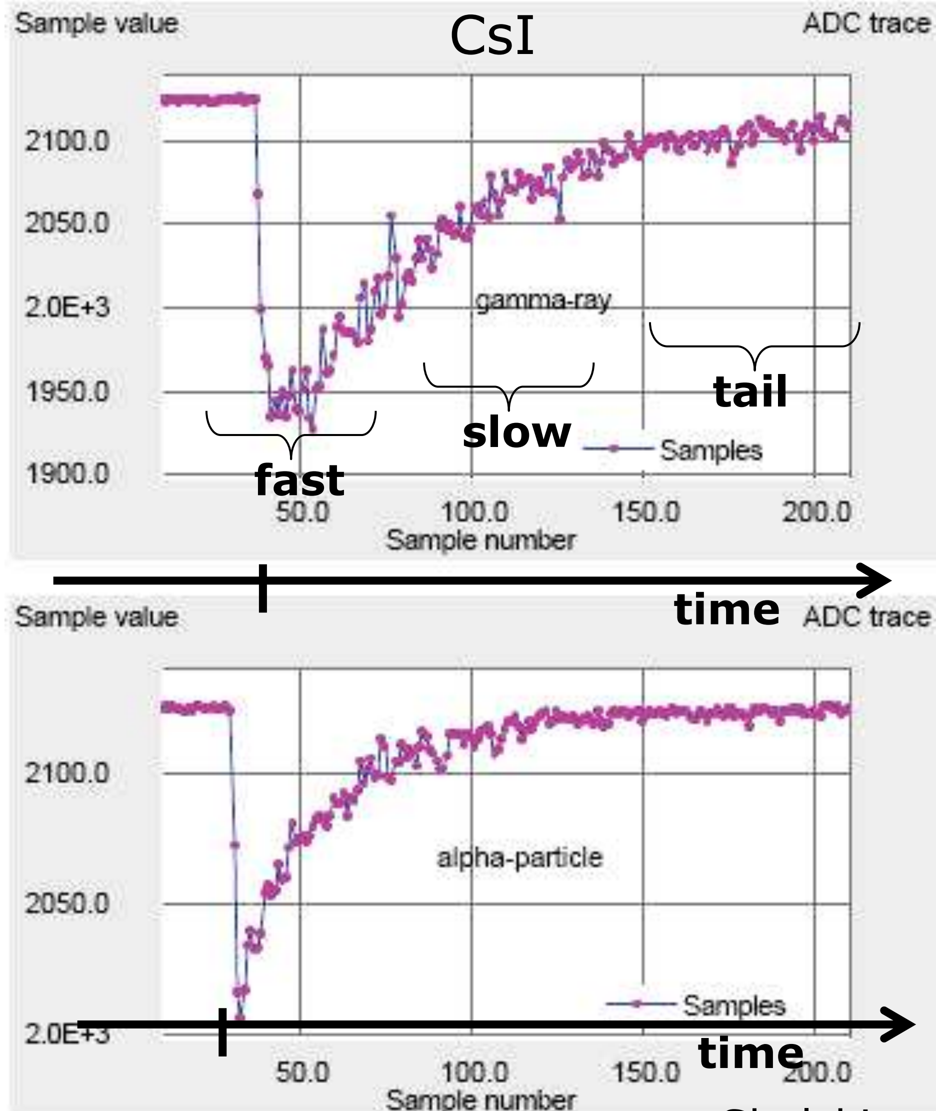
E1 excitation/radiation less transitions depends on ionization density (A,Z,E)

Light Output Response



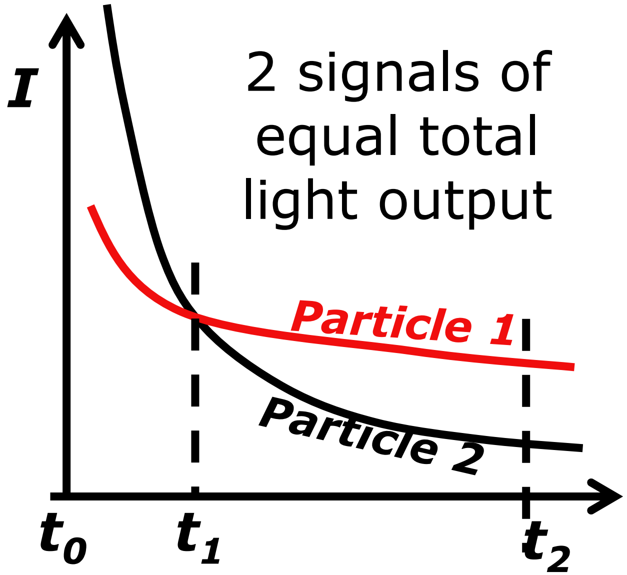
Different radiation leads to different mix of fast and slow → ID

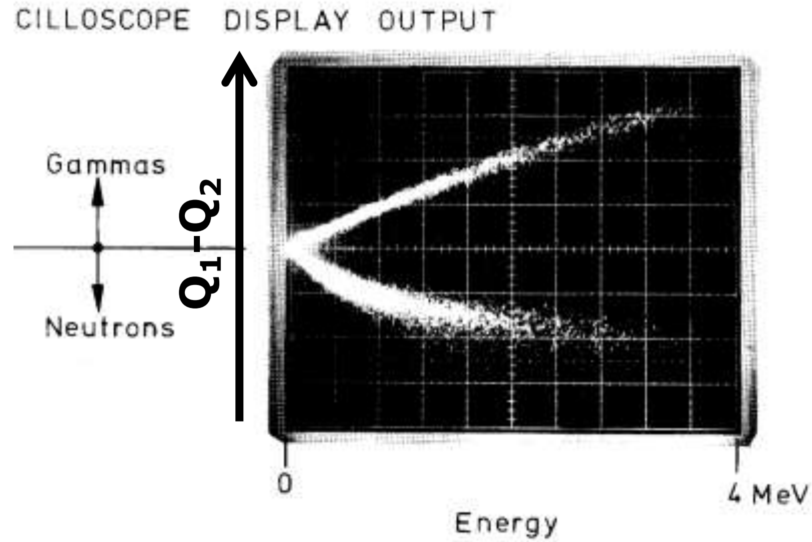
Pulse shape discrimination
retained electronically →



Skulski, pc

Pulse Shape Analysis



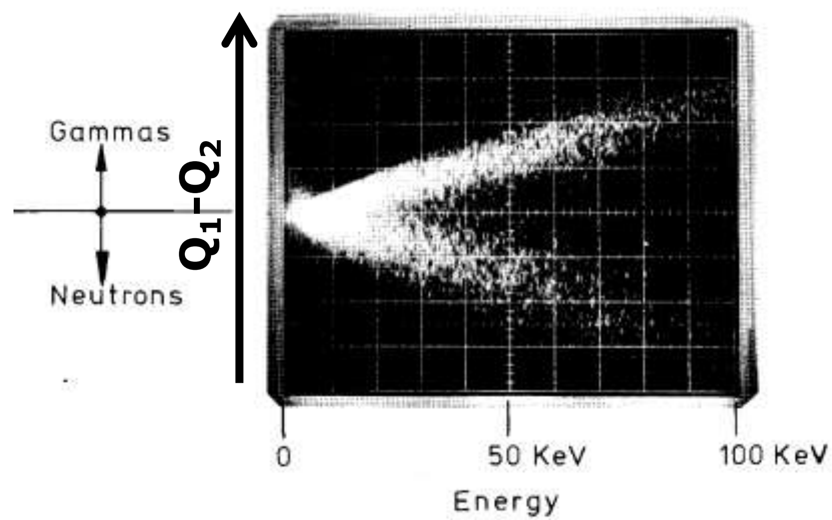


$$Q_1 = \int_{t_0}^{t_1} I(t)dt$$

$$Q_2 = \int_{t_1}^{t_2} I(t)dt$$

fast component
slow

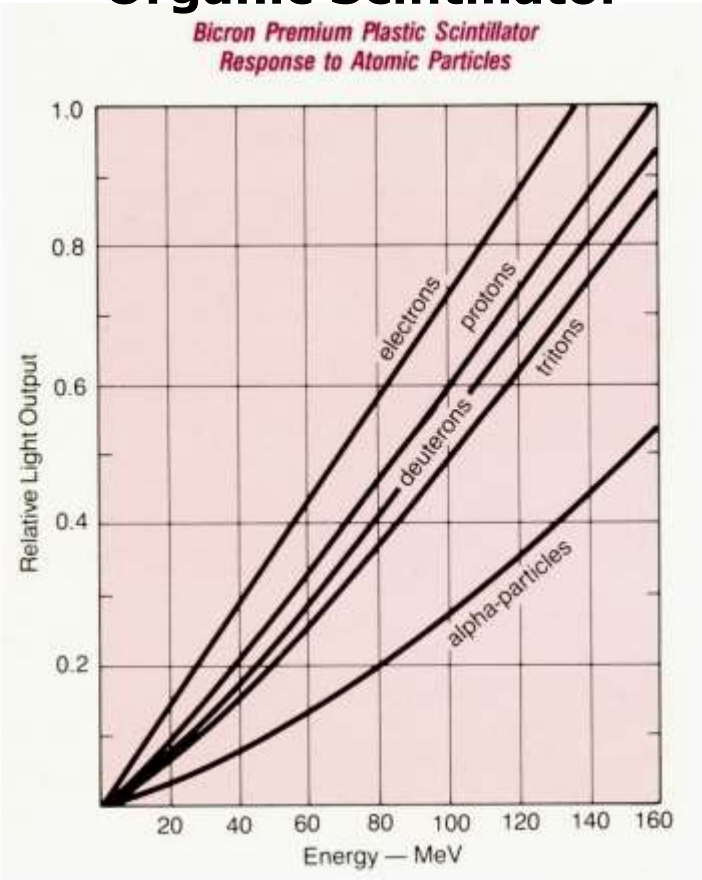
$$Q_1 + Q_2 = Q \propto L(Energy)$$



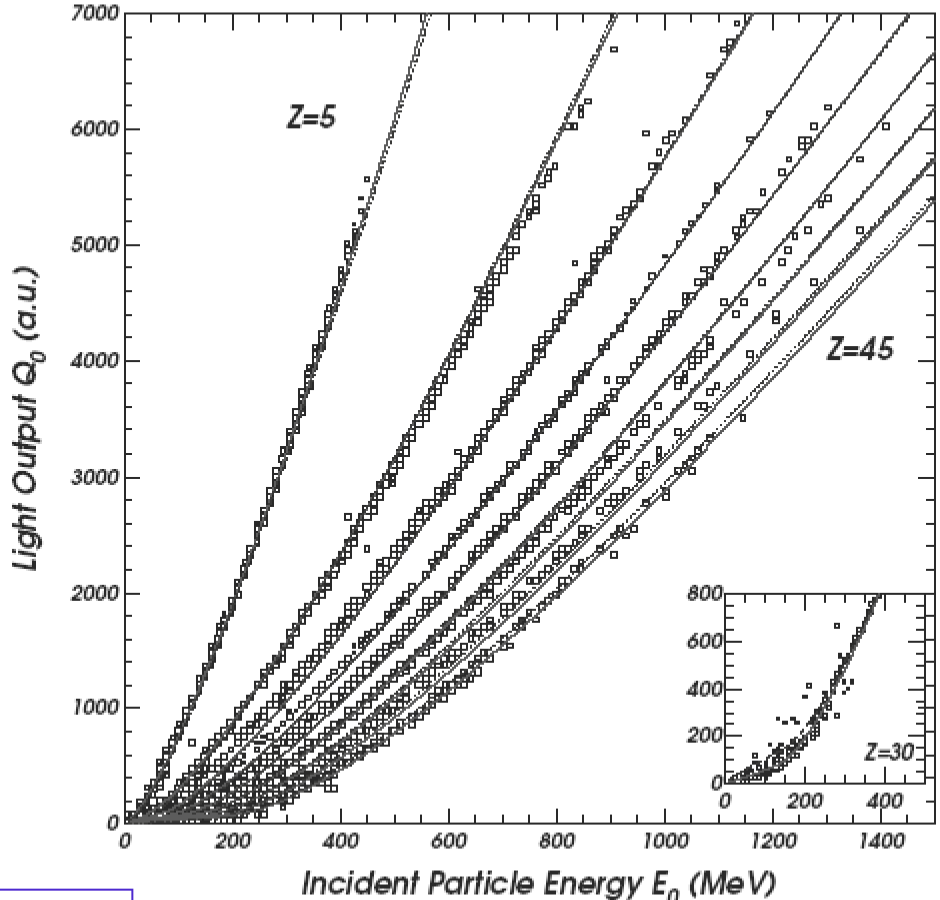
Particle ID via Pulse Shape Analysis

Bicron Corporation

Organic Scintillator



Inorganic Scintillator CsI(Tl)

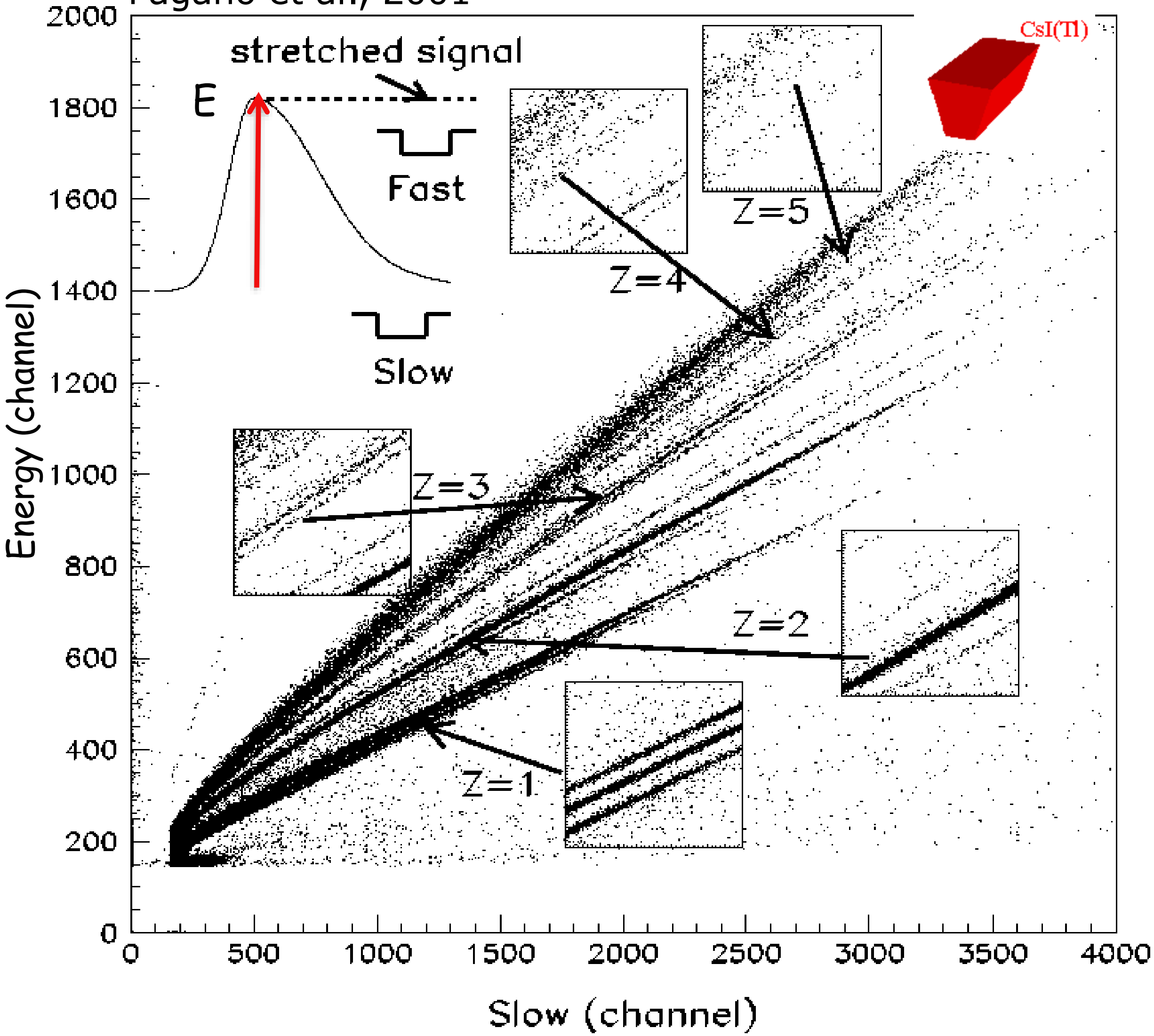


For given energy, heavier particles have less light output (quenching)

INDRA Collaboration

Light Charged Particle Identification: CsI(Tl)

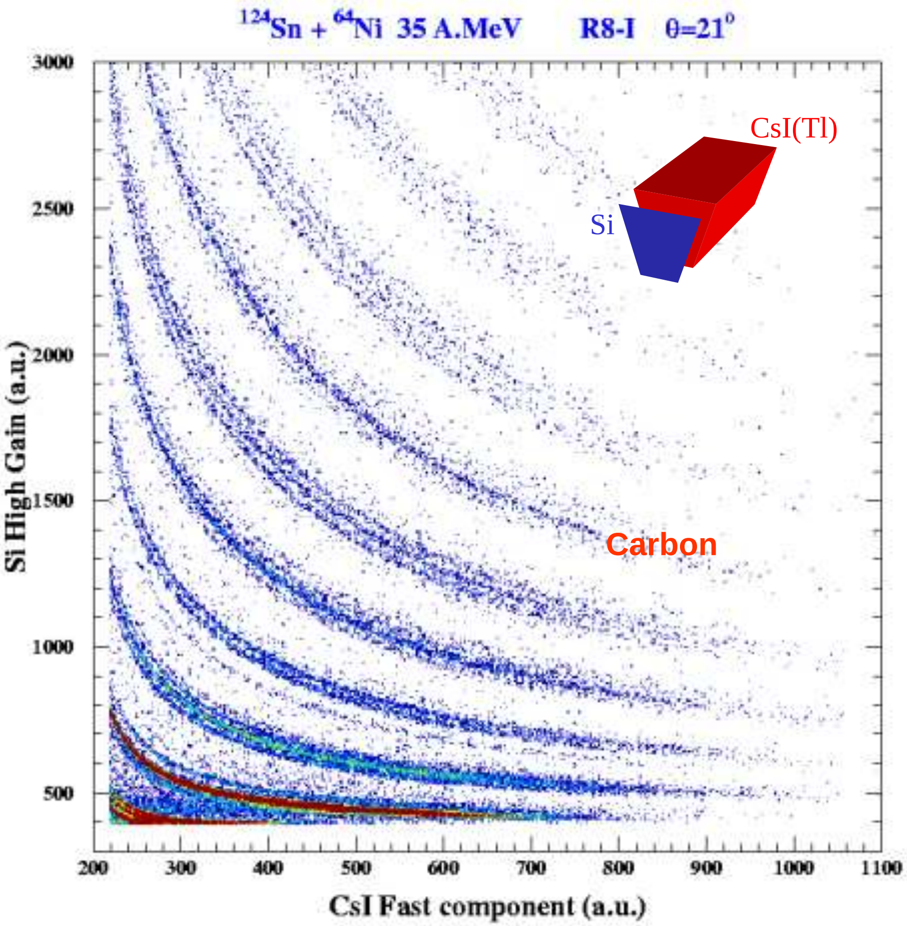
Pagano et al., 2001



A-Z Identification of LCP's:
CsI(Tl)with photodiode read-out and pulse shape discrimination (Chimera 14° (ring 6I)).

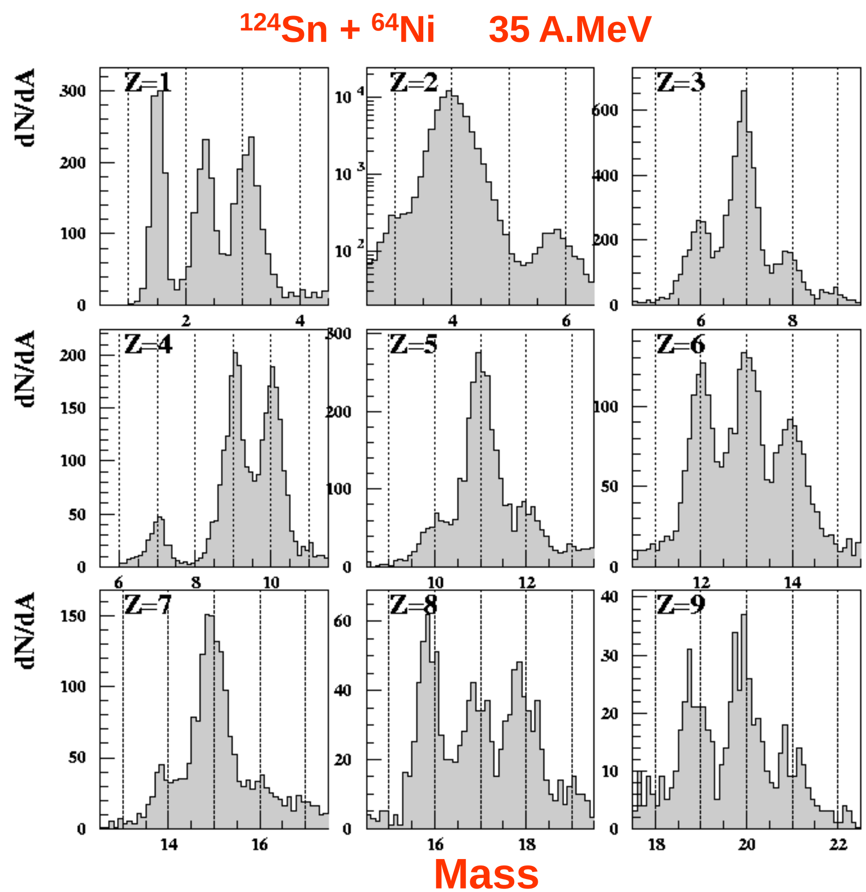
PID threshold for α and protons: 4-5 MeV proton equivalent energy. Good p, d, t discrimination > 20 MeV proton energy.

ΔE-E Isotope Identification



Combine CsI with Si ΔE

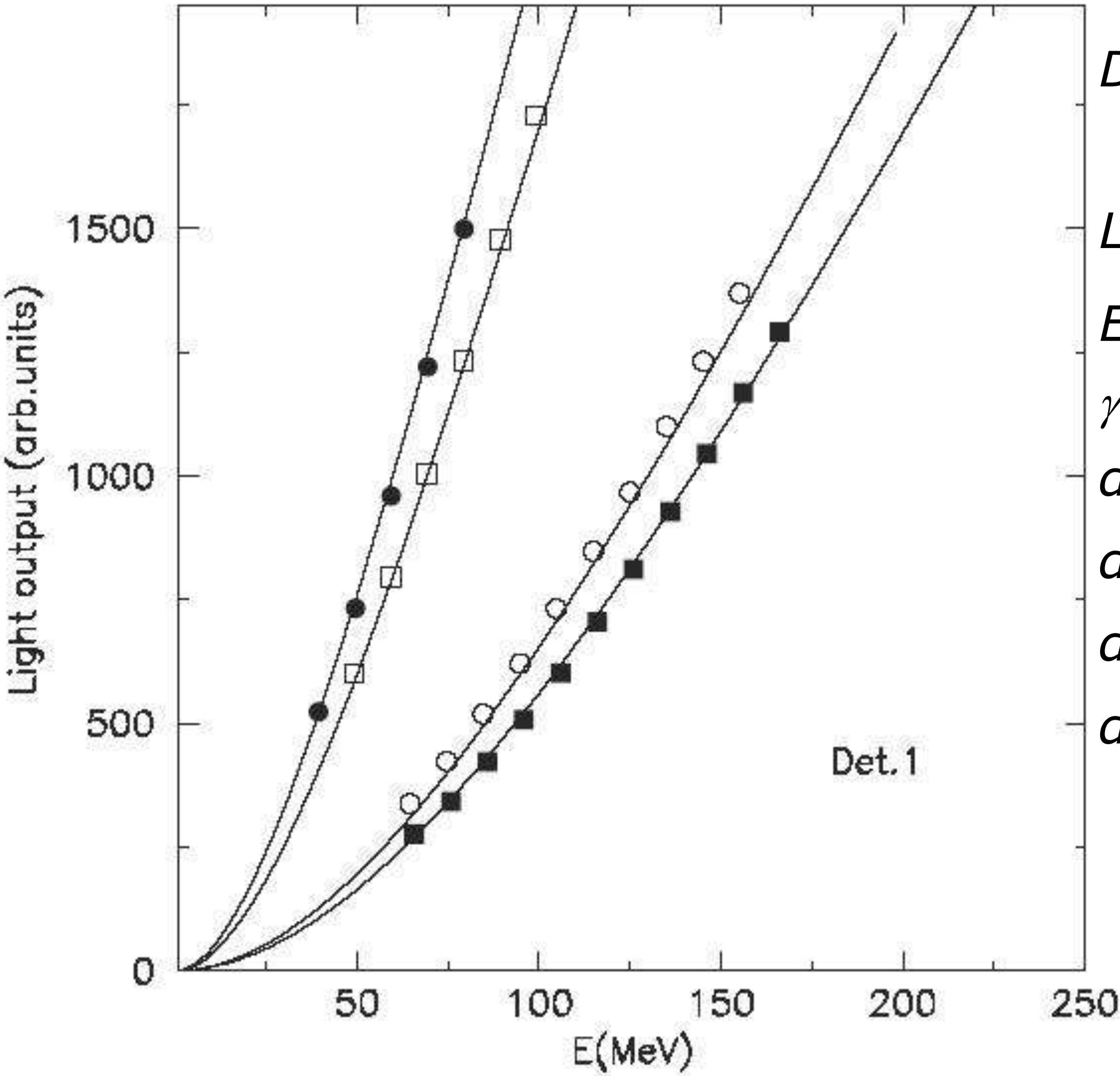
A-Z identification (up to Z=9) based on a Bethe-Bloch formula, no need for energy calibration



1) Reverse collaboration, LNS report (2001).
2) L.. Tassan Got, Preprint IPNO-DR—01-008

CsI(Tl) Light Output Parameterization

Abondanno et al., NIM A488, 604 (2002)



Data fitted $^{7}Li,...,^{48}Ti$

$$L(E) = \gamma\left[E + E_0\left(e^{-E/E_0} - 1\right)\right]$$

$$E_0 = d_1 \cdot Z$$

$$\gamma = d_2/Z + d_3 + d_4 \cdot Z$$

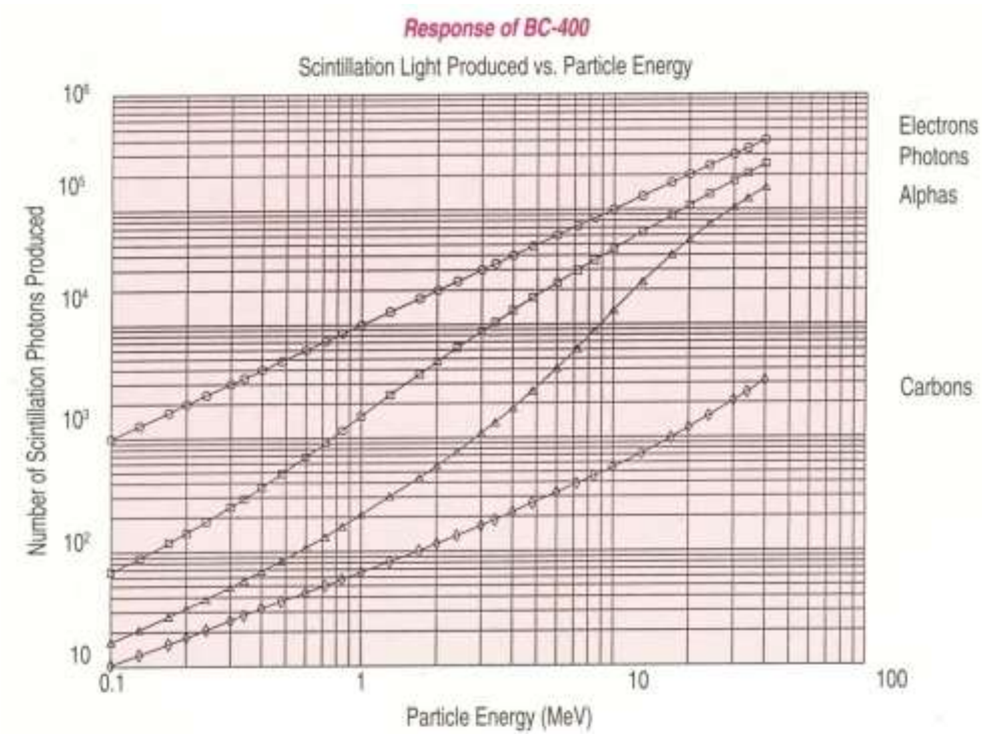
$$d_1 = (5.31 \pm 0.05)MeV$$

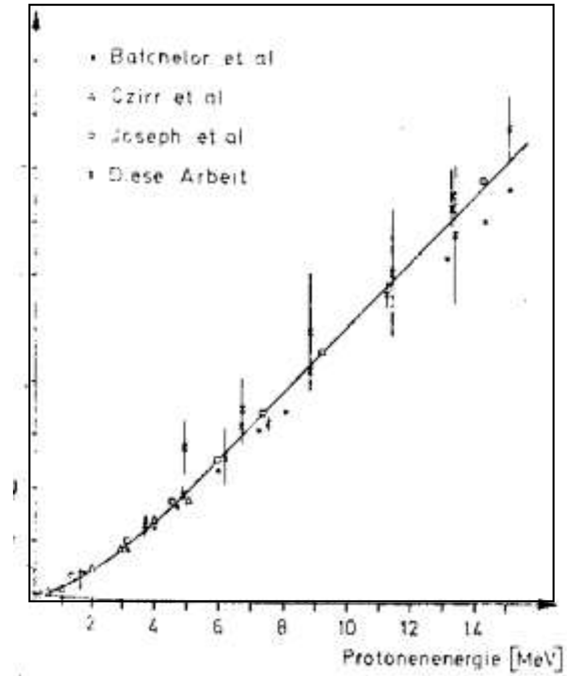
$$d_2 = (101.03 \pm 0.49)MeV^{-1}$$

$$d_3 = (7.60 \pm 0.06)MeV^{-1}$$

$$d_1 = (0.00 \pm 0.22 \cdot 10^{-3})MeV^{-1}$$

Non-Linear Light Output Response





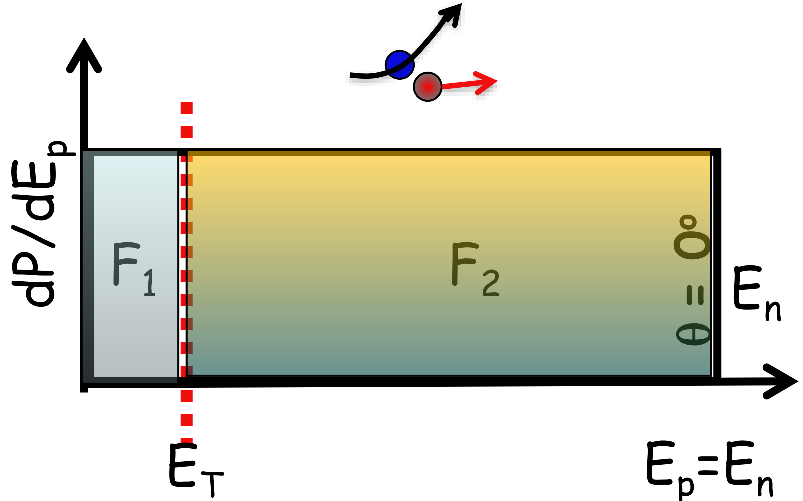
For a given energy, electrons & photons have the highest light output

NE 213 liquid scintillator:
e-equivalent energies $E_e \leftrightarrow E_p$

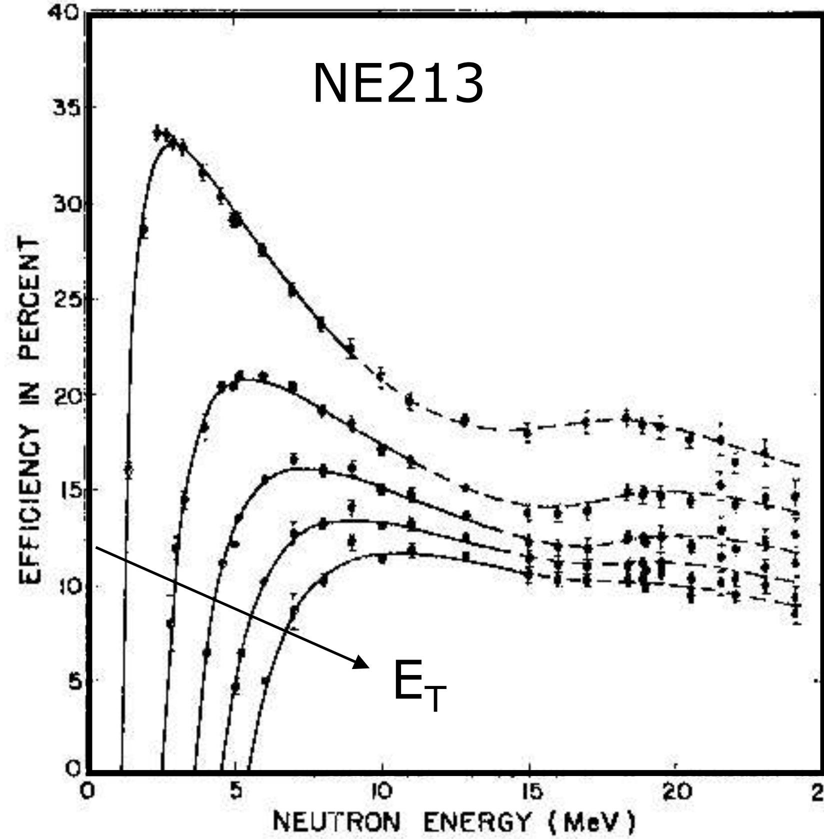
$$E_e(E_p) = \begin{cases} \left(0.18 MeV^{-1/2}\right) E_p^{3/2} & E_p < 5.25 MeV \\ 0.63 E_p - 1.10 MeV & E_p \geq 5.25 MeV \end{cases}$$

Efficiency of *p*-Recoil NeutronDetectors

angle dependent n-p energy transfer → continuous recoil energy spectrum



Electronic detector threshold

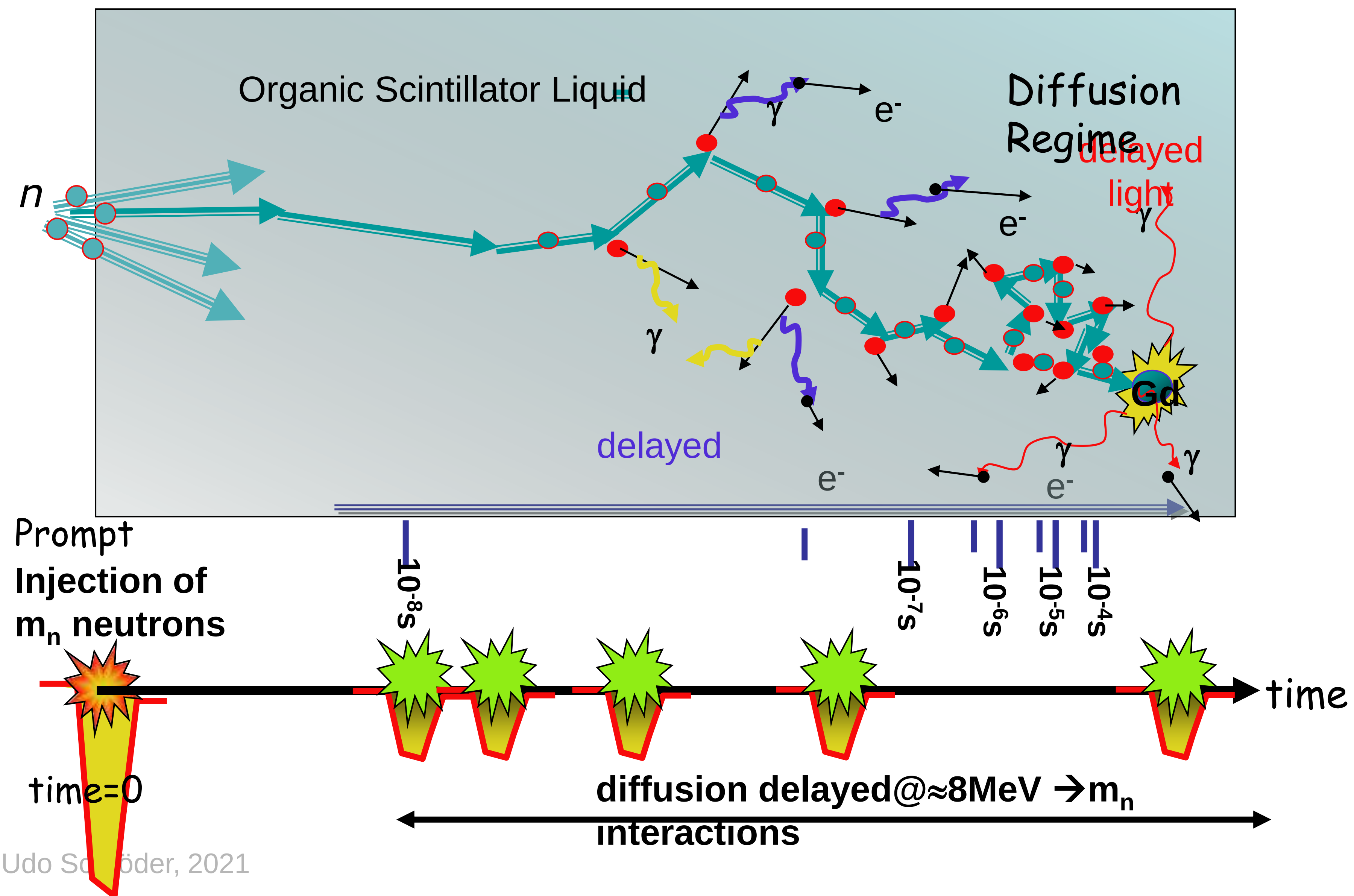


$$\varepsilon(E_n, E_T) = \frac{F_2}{F_1 + F_2}$$

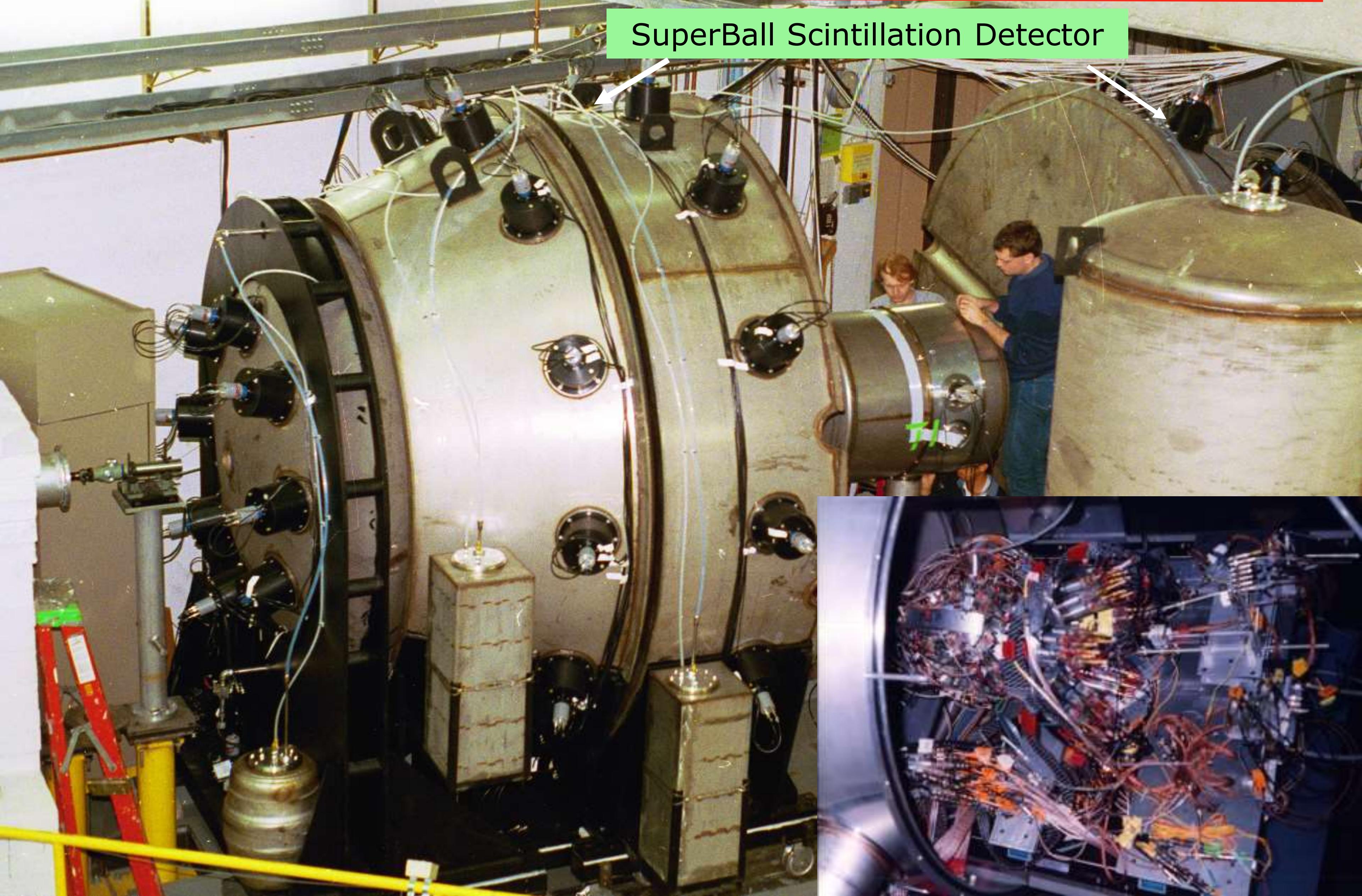
$$\approx \sigma(E_n)\left[1 - \frac{E_T}{E_n}\right]$$

$$\sigma(E_n) = \sum_{X,y} \sigma_{X(n,y)}(E_n) \;\; all \;\; n - induced$$

Activated Scintillation Process



SuperBall-Dwarf Calorimeter



The End