Week 10: Chap. 14 Slow Neutron Detection

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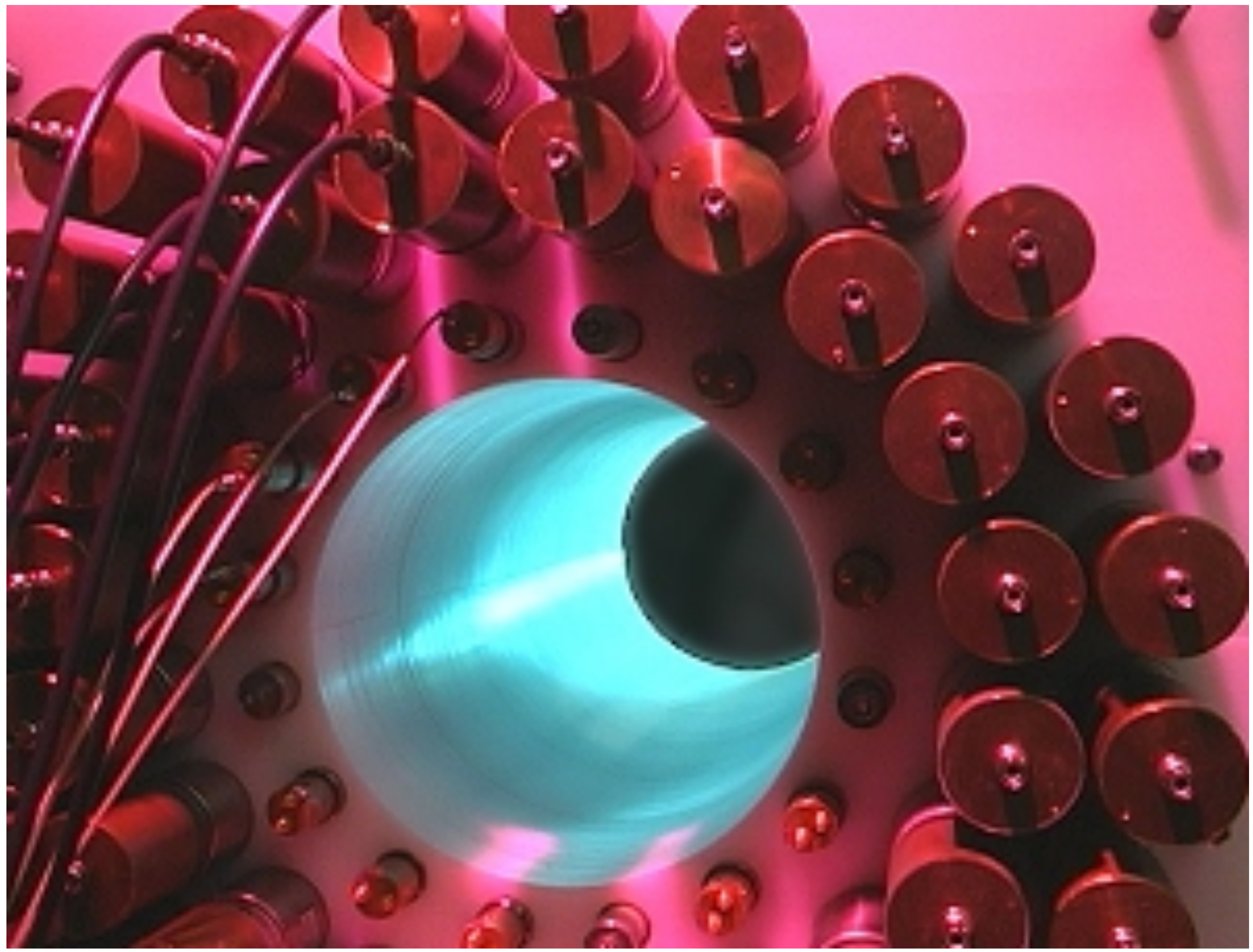
(Gamma ray) Backgrounds

Slow Neutron Detection
-- nuclear reactions
--- spectra properties
-- Proportional Counters
--- fill gas
--- lined detectors

Fast neutron detection



NIM A618 (2o10) 275

All neutron detection relies on observing a neutron-induced nuclear reaction.

The nuclear cross sections have a characteristic variation with energy:

•Charged particle reactions are dominated by the coulomb energy since both reaction partners have a positive charge: $\sigma(E) \sim \pi r^2 (1 - V/E_{CMS})$ where "V" is the coulomb barrier.

•Neutron-induced reactions also have a characteristic shape .. The interaction is always attractive and the cross section for l=0 capture reactions always grows with 1/v at (very) low energies. The form is derived from the Breit-Wigner lineshape:

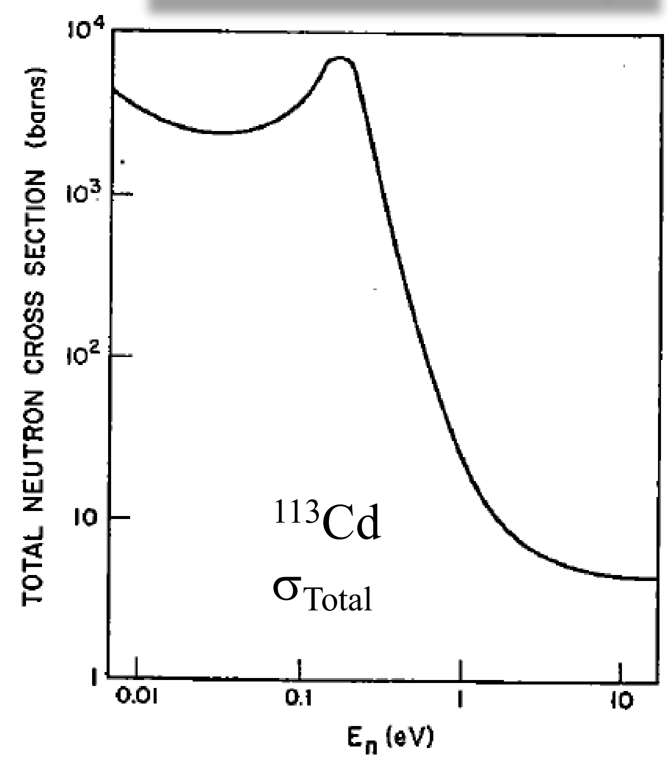
$$\sigma_{Cap} = \pi \lambda\!\!\!^{-2} \frac{\Gamma_n \Gamma_\gamma}{(\mathbf{E} - E_0)^2 + (\Gamma/2)^2}$$

$$\sigma_0 = \pi \lambda\!\!\!^{-2} \frac{4\Gamma_n \Gamma_\gamma}{\Gamma^2} \qquad \mathbf{E} = E_0; \Gamma = \Gamma_n + \Gamma_\gamma + \cdots \cong \Gamma_\gamma$$

$$\sigma_0 = 4\pi \lambda\!\!\!^{-2} \frac{\Gamma_n}{\Gamma_\gamma} \qquad \lambda\!\!\!^- = \frac{\hbar}{mv} \qquad \Gamma_n \sim v$$

$$\sigma_0 \sim \frac{1}{v}$$

$^{113}Cd + n \rightarrow {}^{114}Cd + \gamma$



'Popular' Slow Neutron Reactions

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$n + {}^{3}He \rightarrow ({}^{4}He)^{*} \rightarrow p + {}^{3}H$, Q=0.765 MeV, target abundance = $1.4\text{x}10^{-4}$ % (n,p)

$n + {}^{6}Li \rightarrow ({}^{7}Li)^{*} \rightarrow {}^{4}He + {}^{3}H$, Q=4.78 MeV, target abundance = 7.5% (n,α)

$n + {}^{10}B \rightarrow ({}^{11}B)^{*} \rightarrow {}^{7}Li^{*} + {}^{4}He$, Q=2.31 MeV, Branch=94%, target abundance = 19.9% (n,α)
$\rightarrow {}^{7}Li + {}^{4}He$, Q=2.79 MeV, Branch=6%

$n + {}^{113}Cd \rightarrow ({}^{114}Cd)^{*} \rightarrow {}^{114}Cd + \gamma$, Q~8 MeV , target abundance = 12.2% (21k barns) (n,γ)

$n + {}^{157}Gd \rightarrow ({}^{158}Gd)^{*} \rightarrow {}^{158}Gd + \gamma$, Q~8 MeV , target abundance = 15.6% (255k barns) (n,γ)

$n + {}^{235}U \rightarrow ({}^{236}U)^{*} \rightarrow$ (fission frags) Q~200MeV, TKE~160MeV, abundance = 0.72% (n,f)

Check :

$$y = ax + b$$

$$Log\sigma = \left(\frac{\Delta y}{\Delta x}\right) LogE + b$$

$$\frac{\Delta y}{\Delta x} = -0.485 \quad \rightarrow \quad \sigma = E^{-0.485} \sim 1/\sqrt{E}$$

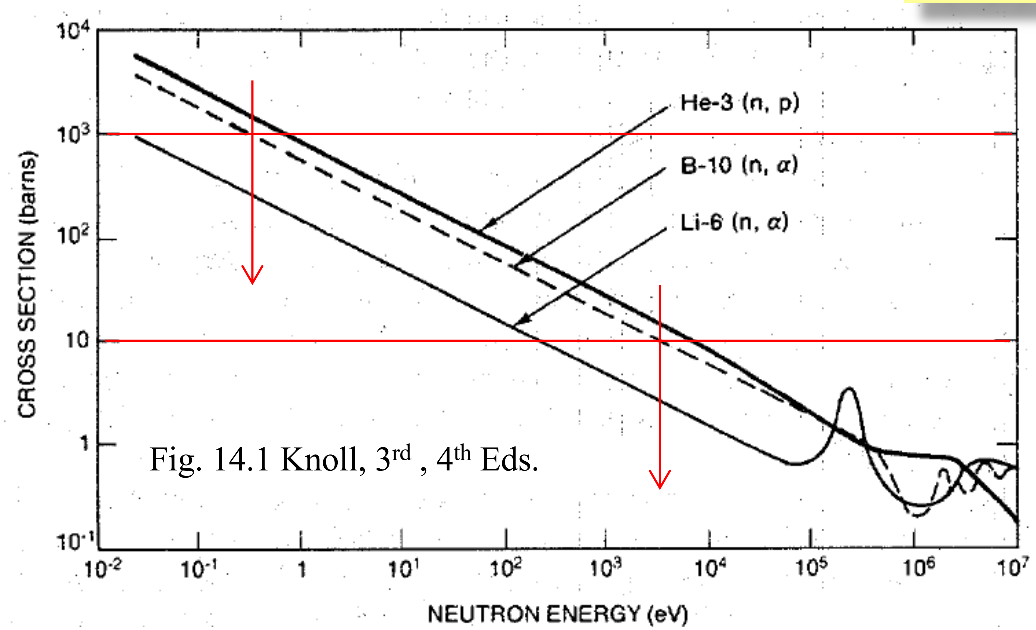

Fig. 14.1 Knoll, 3rd , 4th Eds.

Slow n Detection: Gas-filled counters

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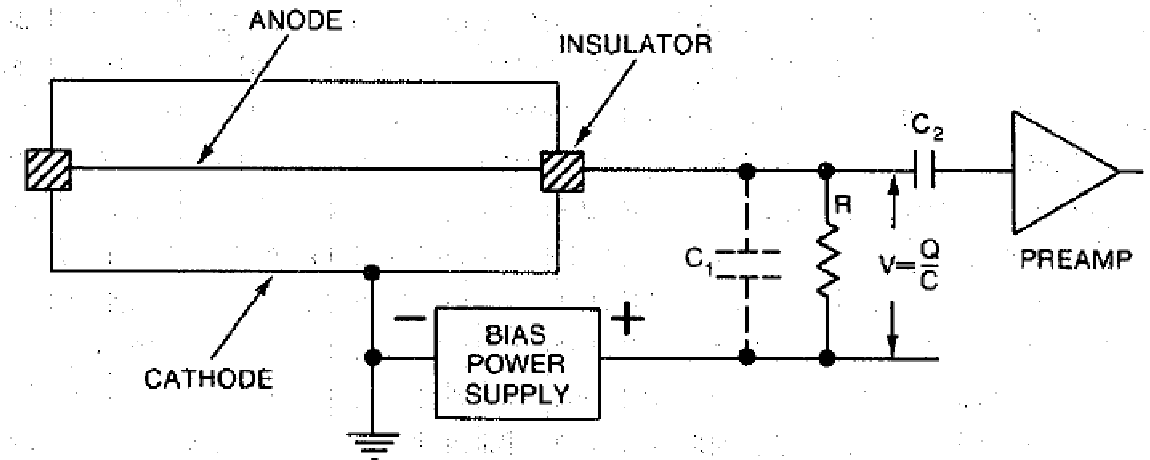
Gas-filled proportional counter .. usual gas-gain amplification on the central anode



$n + {}^3He \rightarrow p + {}^3H$, Q=0.765 MeV σ ~ 5333 λ /1.8 barns

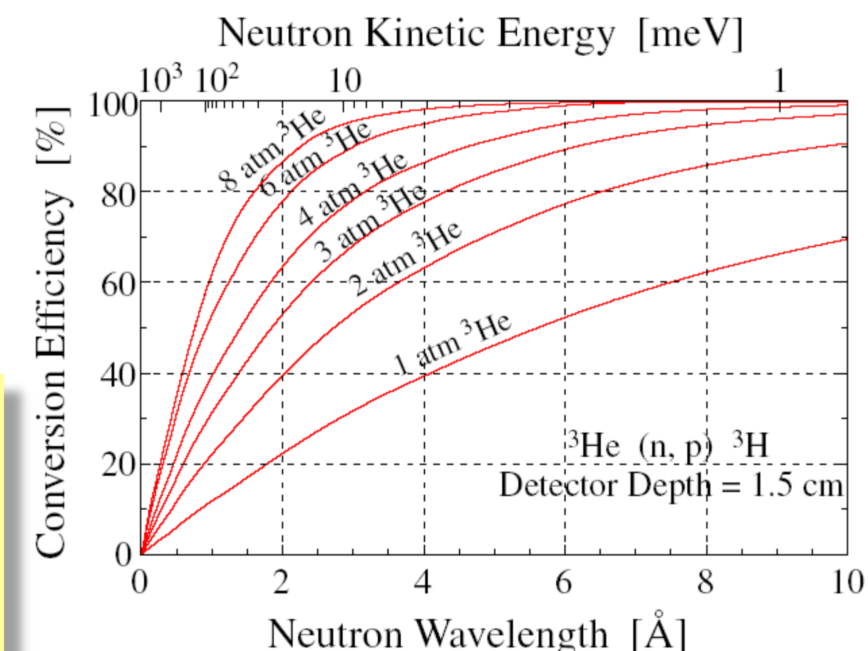
K.E. <eV ~0 → Q3/4 Q/4

0.573 0.191 MeV

Range in Si ~6µm ~5µm

Range in gas ~ 10^3 x Range in solid … few mm's

[N.B. (Rρ) ~ 0.25 mg/cm^2 for these α's in He gas]



What about the pulse-height distribution?

Reaction in gas volume:
→ both products range out -- full energy signal
Reaction elsewhere → ??

Slow n Detection: Gas-filled Pulse Height

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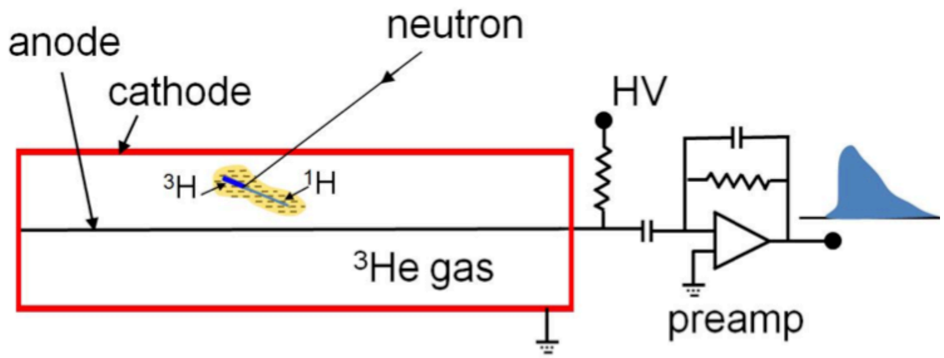
$n + {}^3He \rightarrow p\ (573\ keV) + {}^3H\ (191\ keV)$



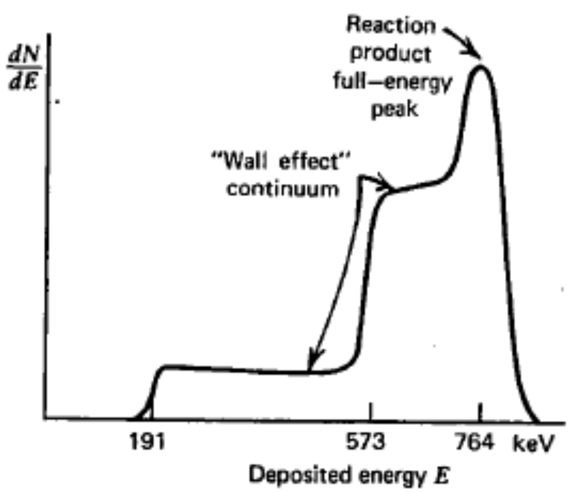
^3He gas W ~ 33 eV

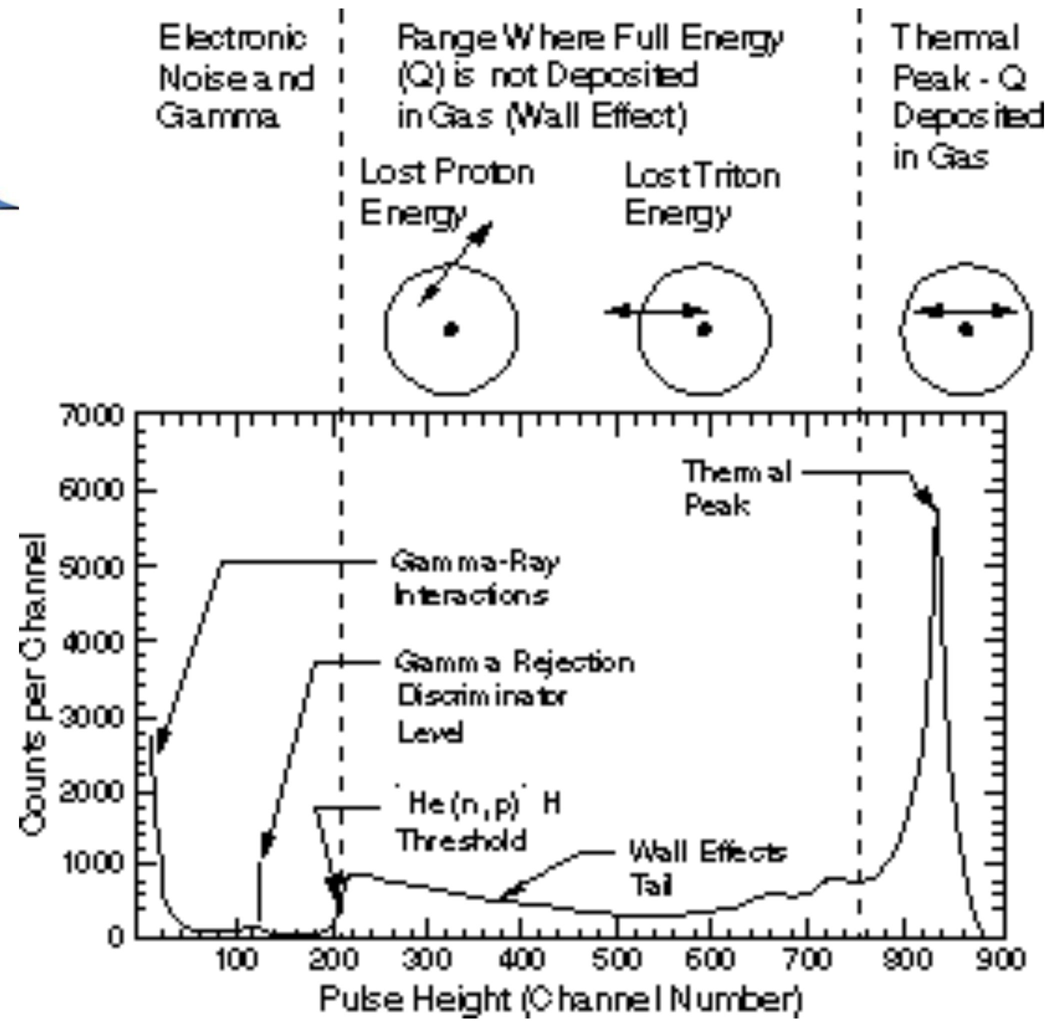
Typical: 25mm diameter, 50μm anode

P = 5-10 bar (!)

V~ 1.5kV .. M ~ 20 .. C ~ 20pF

Ideal



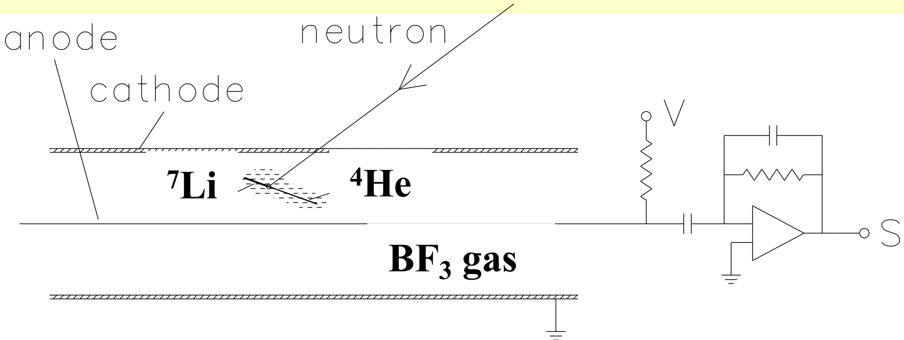


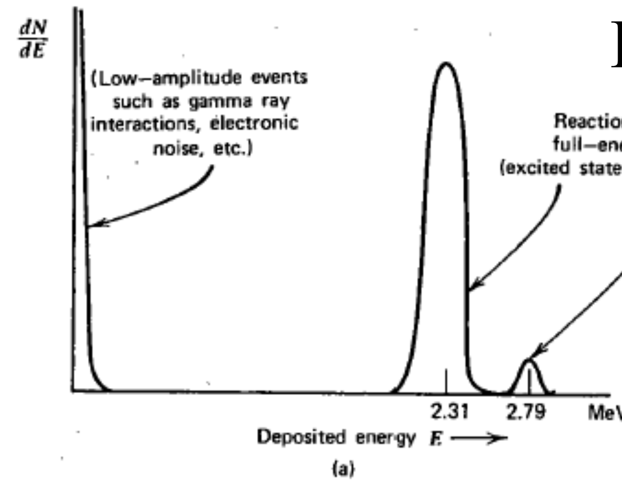
e.g, Rad.Meas. **47** (2012) 577

Adv.Spa.Res. **49** (2012) 1670

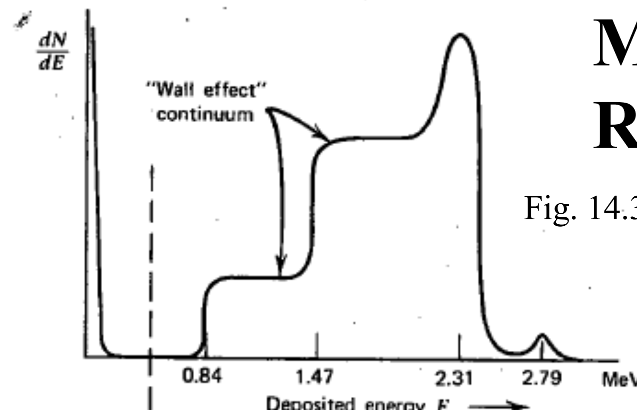
Fig. 14.5 Knoll, 3rd , 14.6 4th Ed.

Slow n Detection: BF_3





Ideal



More Realistic

Fig. 14.3 Knoll, 3rd ,4th Eds.

$n + {}^{10}B \rightarrow {}^{7}Li + {}^{4}He$, Q=2.8 MeV [7%]

$\rightarrow {}^{7}Li^{*} + {}^{4}He$, Q=2.3 MeV [93%]

[K.E. 0.84 1.47 MeV (strong branch)]

(R-air ~ 7.5mm)

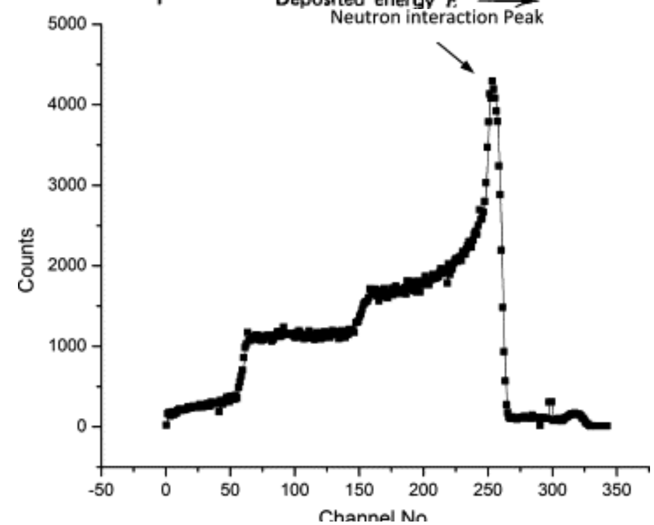
$\rightarrow {}^{7}Li + \gamma$, E_{γ}=0.477 MeV

BF_3 gas W ~ 33 eV, enriched to ~96%

Typical: 25mm diameter, 50µm anode

P = 400 – 700 Torr, (nero 900 Torr)

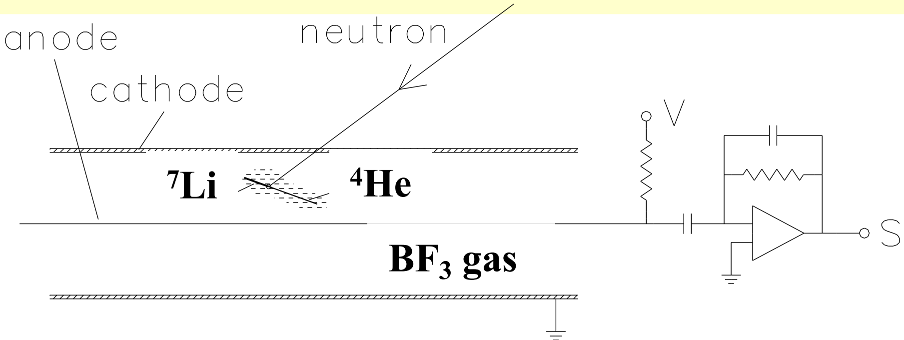
V~ 2.5kV .. M ~ 40



Real

Annl Nucl Energy 62 (2013) 1

Slow n Detection: BF_3



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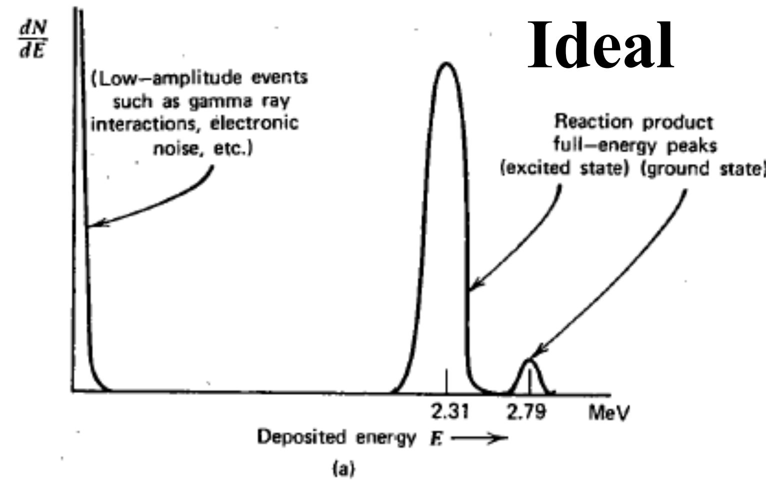
Typical: 25mm diameter, 50μm anode

P = 400 – 700 Torr, (nero 900 Torr)

V~ 2.5kV .. M ~ 40

NIM A 623 (2010) 1035

Ideal



More Realistic

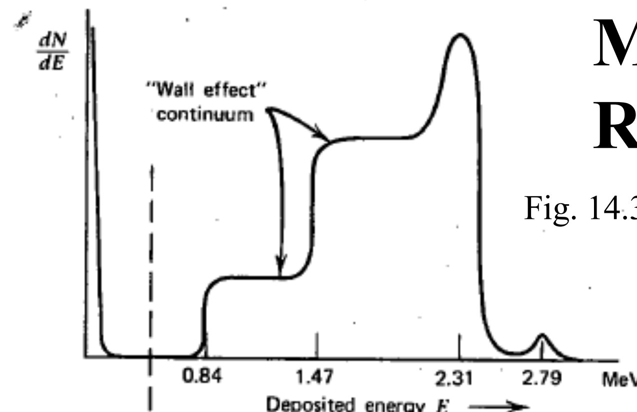
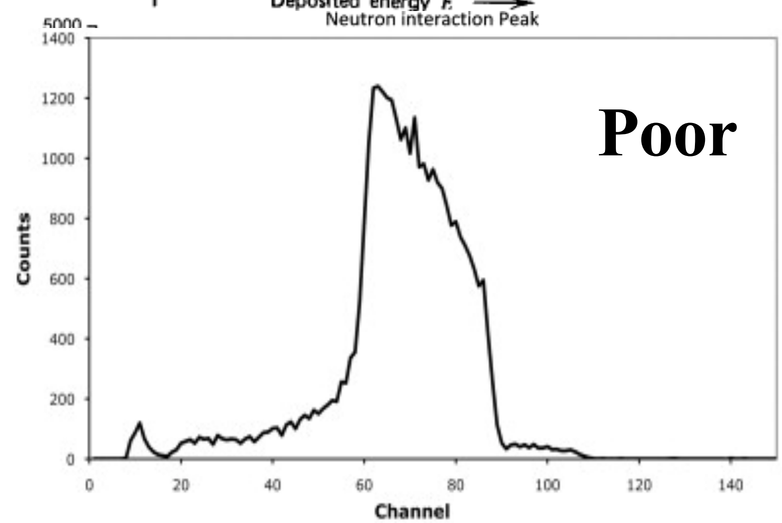
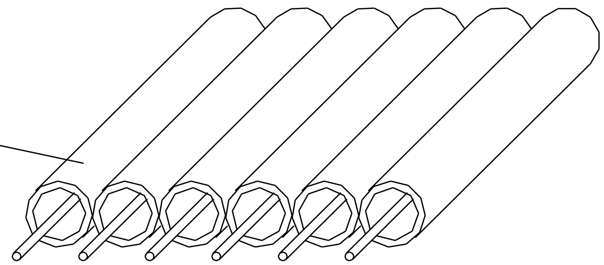


Fig. 14.3 Knoll, 3rd ,4th Eds.

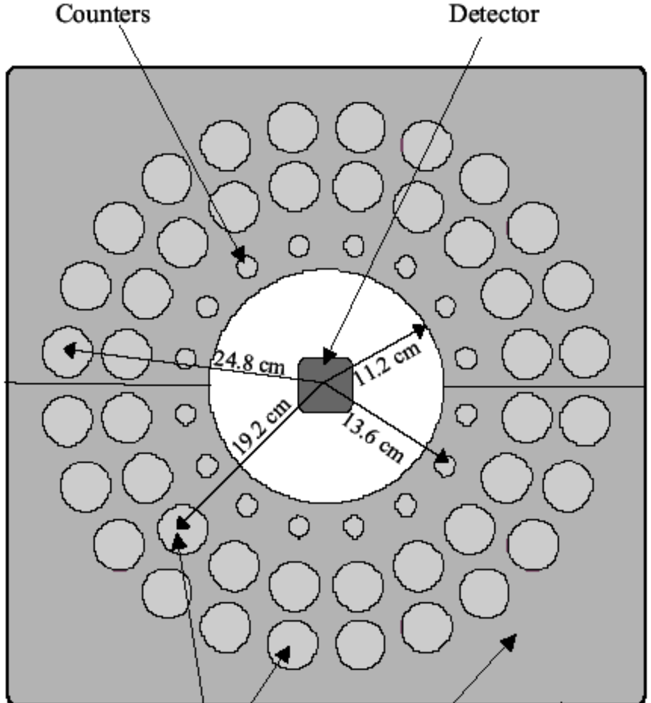
Poor



Multiple Gas Proportional Counters

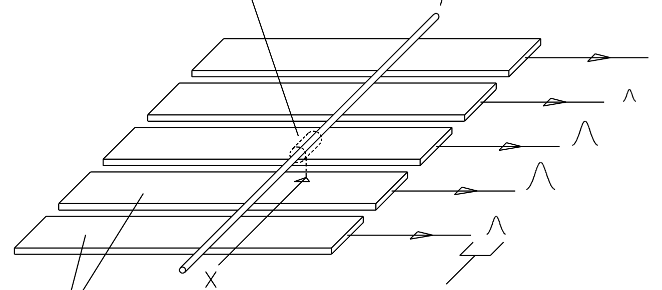


High Efficiency



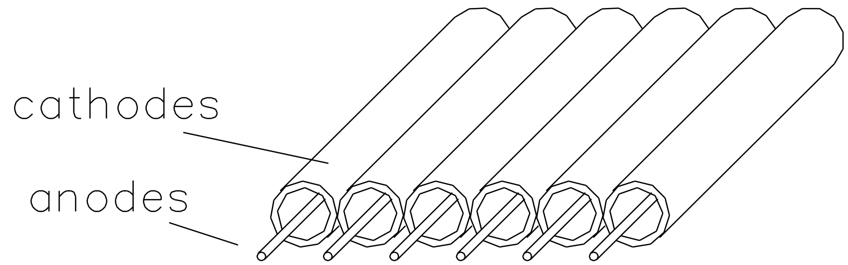
"NERO" @ NSCL
NIM A618 (2010) 275

Position Sensitive

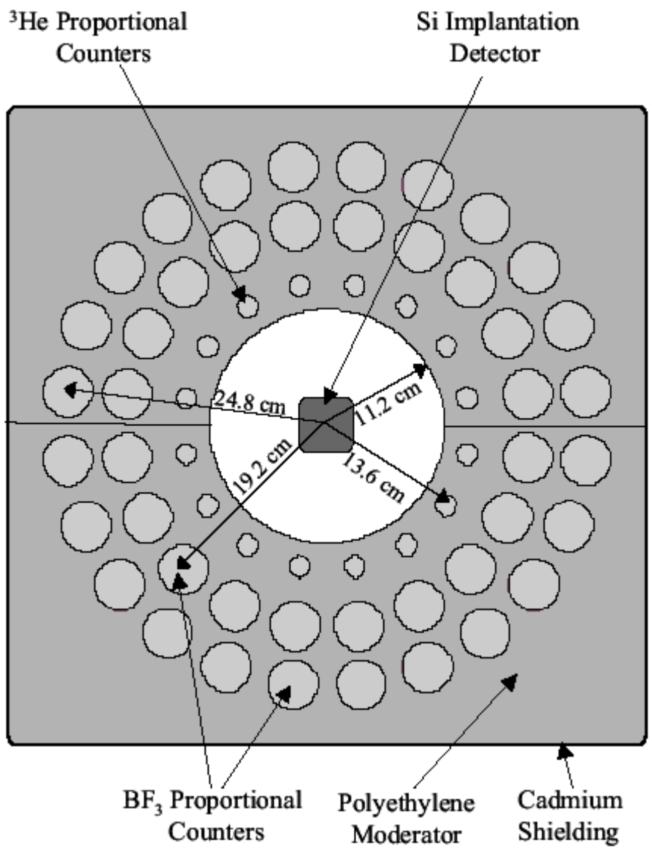


"TOFTOF" @ FRM II
1000 $^3He/CF_4$
9.7/0.3 bar
NIM A580(2007)1414

Multiple Gas Proportional Counters

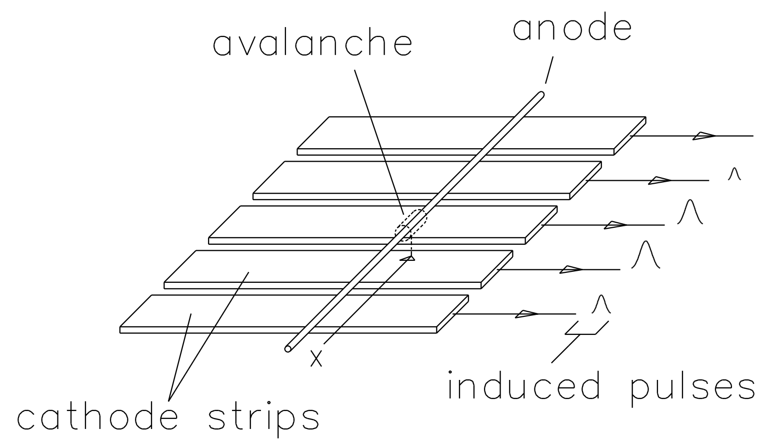


High Efficiency

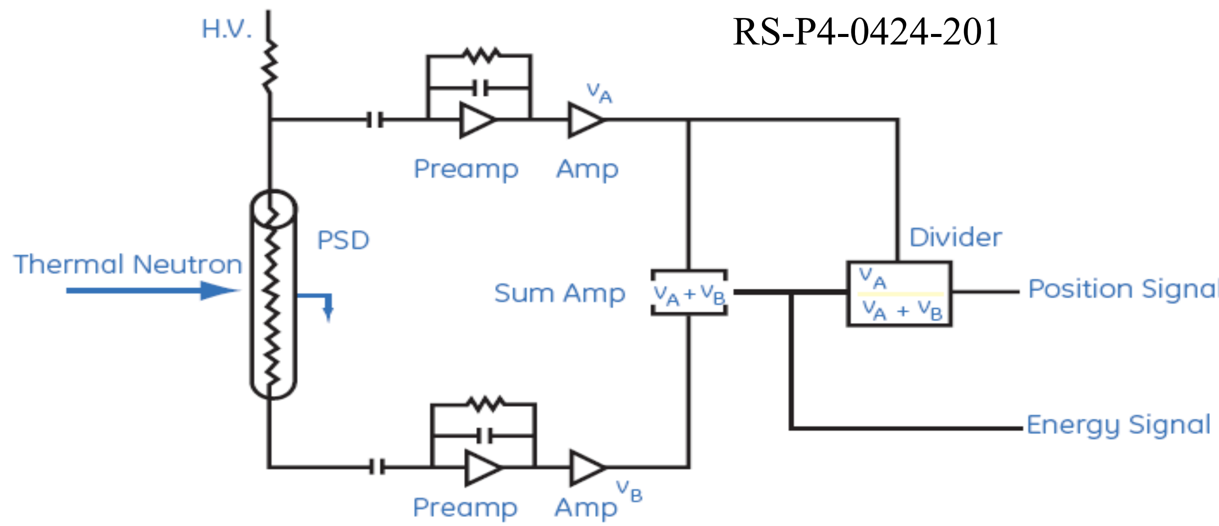


"NERO" @ NSCL
NIM A618 (2o1o) 275

Position Sensitive



General Electric
RS-P4-0424-201



Slow n Detection: Fission Chambers

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n + ^{235}U → (^{236}U)* → (fission frags) Q~200MeV, TKE~160MeV, abundance = 0.72%

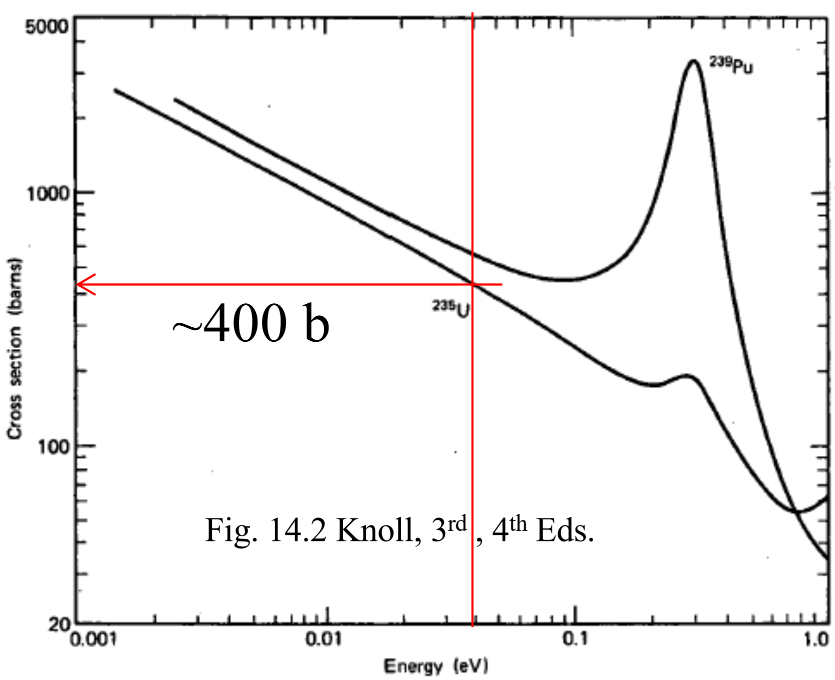
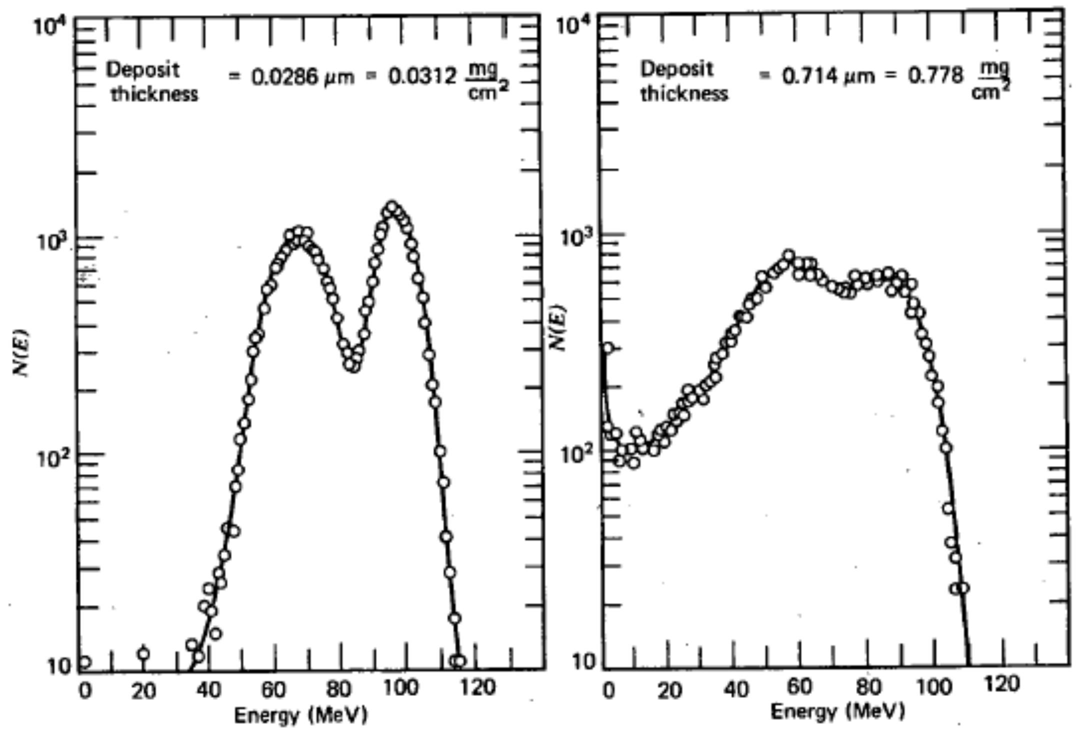


Fig. 14.2 Knoll, 3rd , 4th Eds.



UO_2 deposit on wall Change by ~ 25x

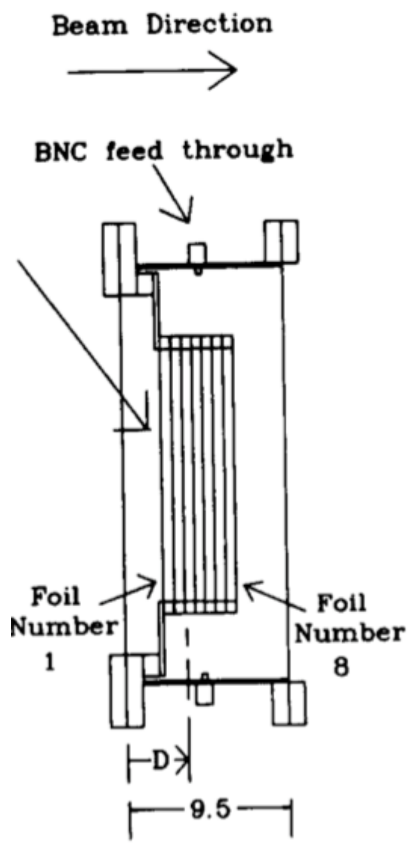
Fig. 14.7 Knoll, 3rd , 14.8 4th Eds.

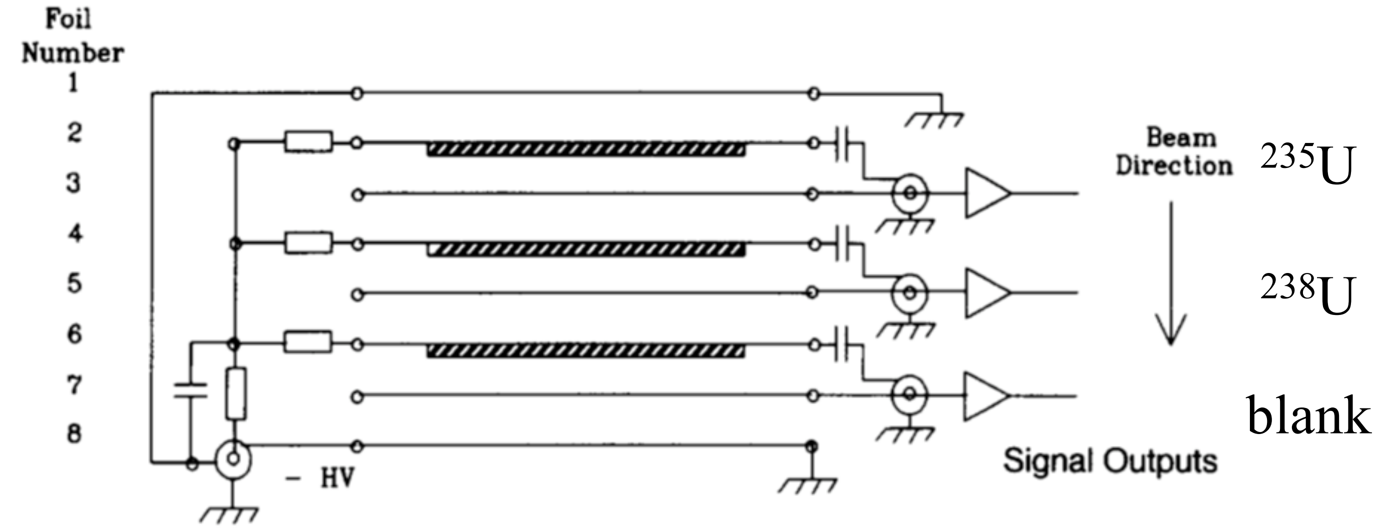
Absorption efficiency of all nuclear reaction-based devices (from text):

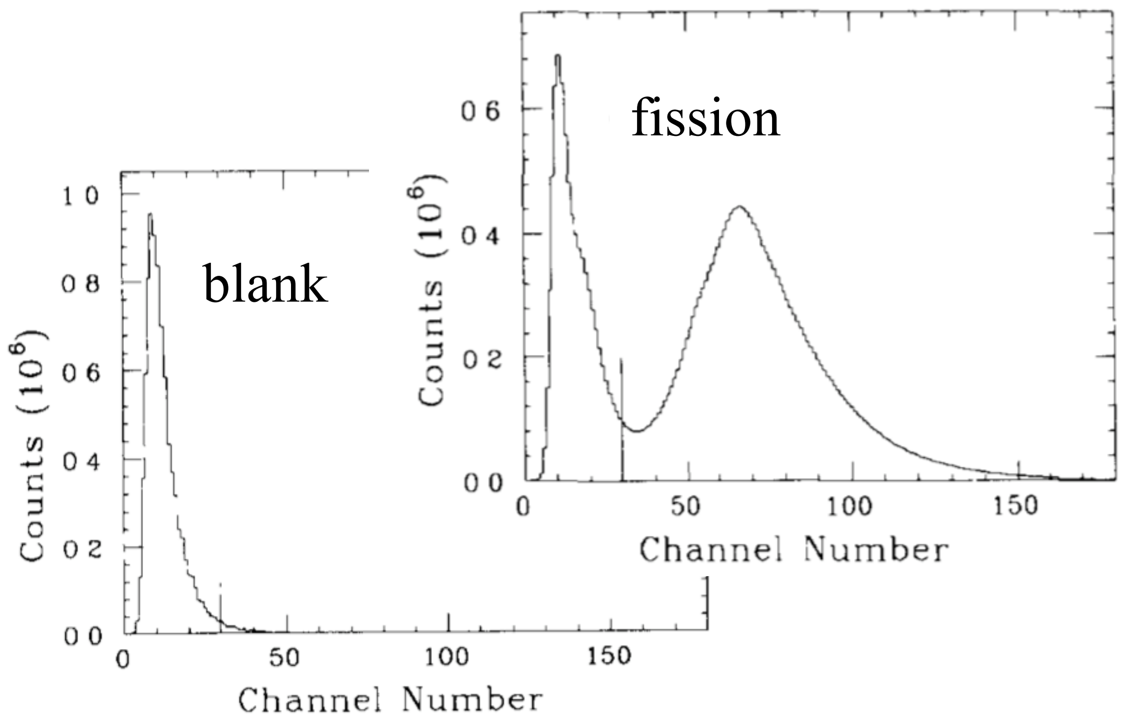
$$\varepsilon(E_n) = 1 - e^{-\Sigma(E)\Delta x} \quad where \; \Sigma(E) = \rho_N \sigma(E)$$

$\varepsilon(E_n) \sim \rho_N \sigma(E) \Delta x$ for small values

Slow n Detection: Fission Chambers







Beam Monitor @ LAMPF
NIM A336 (1993) 226

68 kPa gauge pressure P-10
Parallel plates, 6mm gap, -300 V

Boron-loaded GEM device

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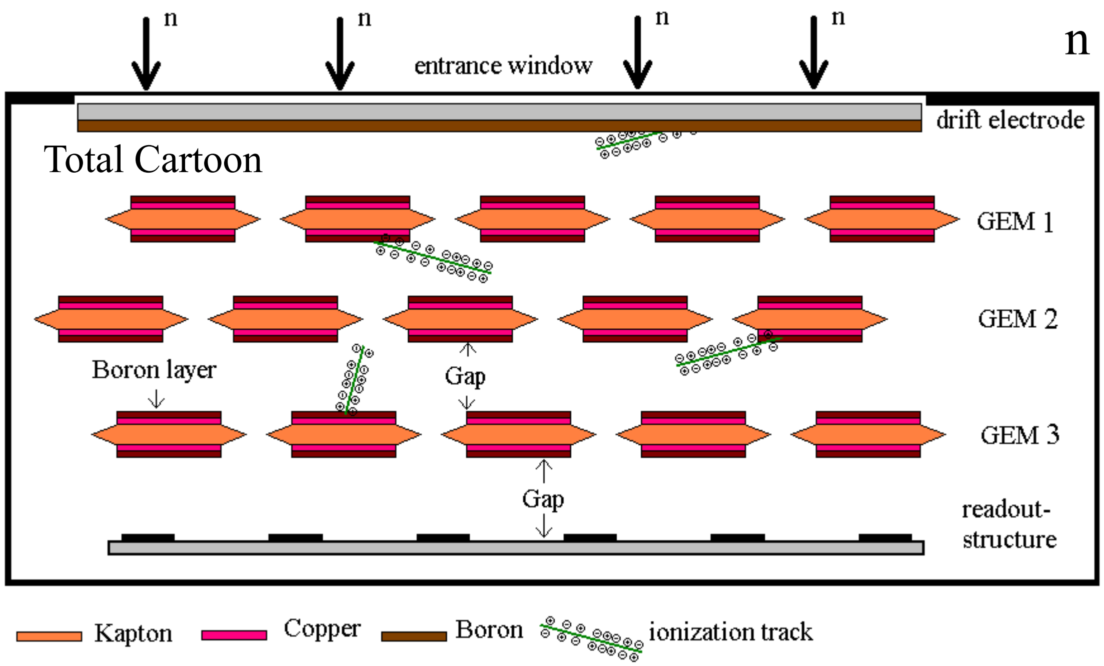
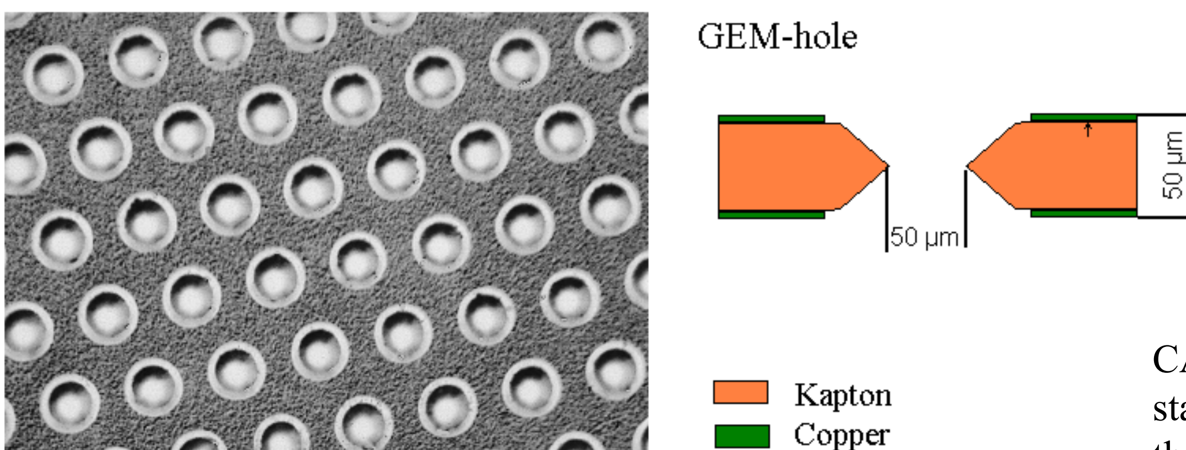
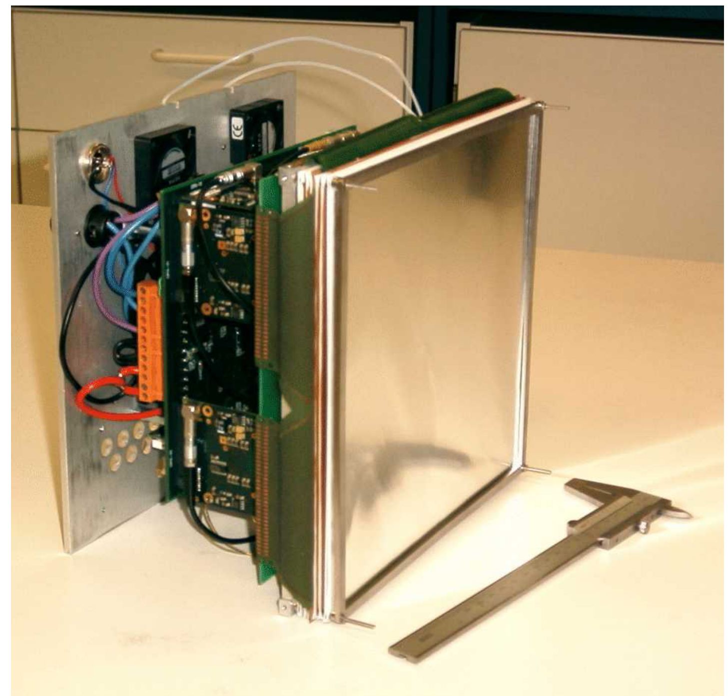
$n + {}^{10}B \rightarrow {}^{7}Li + {}^{4}He$, Q=2.8 MeV [7%]

$\rightarrow {}^{7}Li^{*} + {}^{4}He$, Q=2.3 MeV [93%]







CASCADE Detector, 200 mm x 200 mm, stack of GEM-foils with 2D-readout-structure in the middle, complete readout and histogramming electronics on the backside of the detector

http://www.physi.uni-heidelberg.de/Forschung/ANP/Cascade/

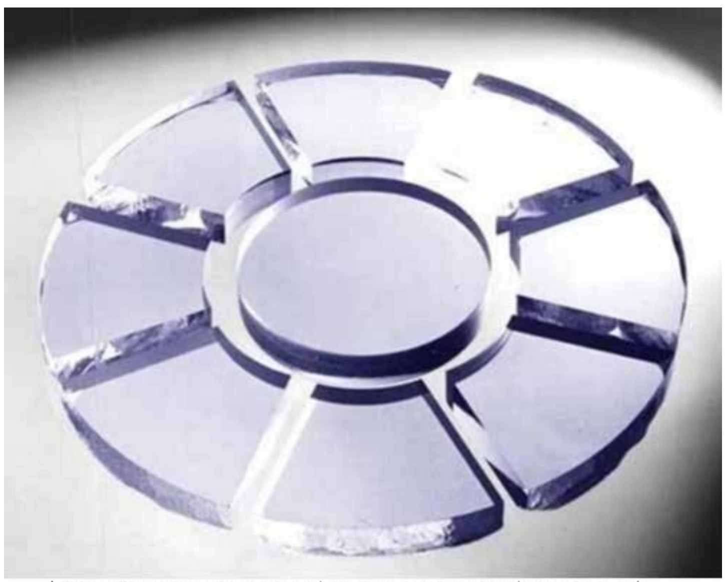
Slow n Detection: lithium scintillators

Lithium loaded materials .. usual scintillation device with PMT for ToF

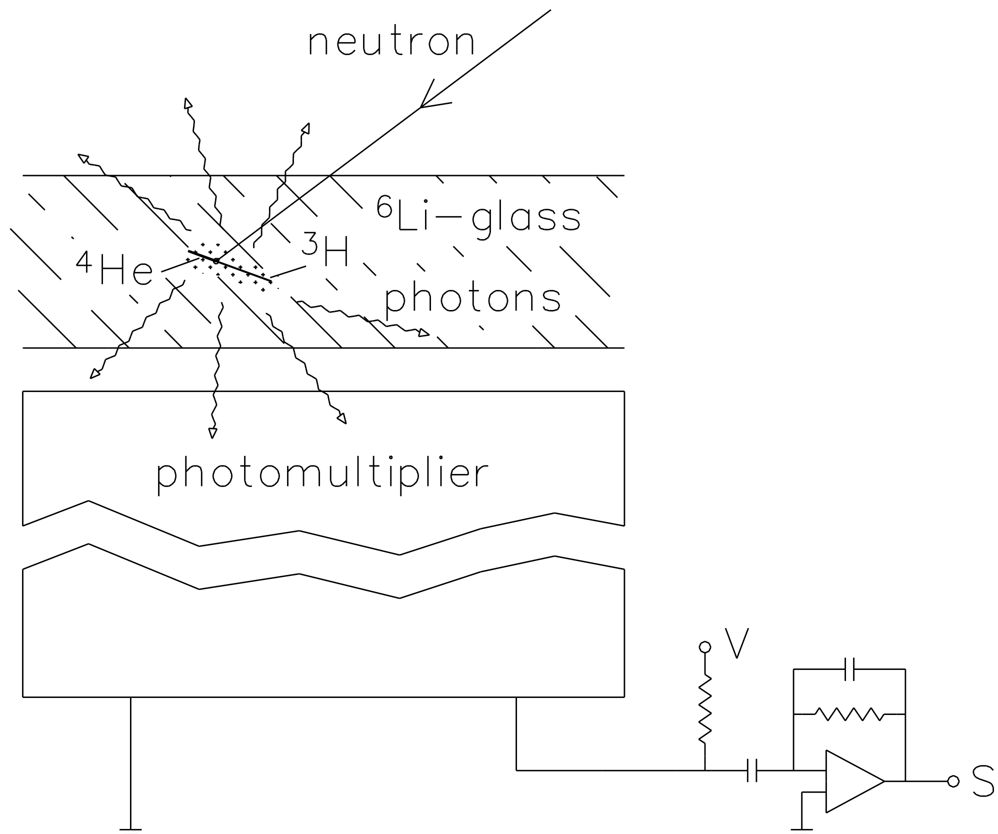
1) Li glass .. Scintillation efficiency ~ 0.45% 395nm, with ~ 7k photons/n
   4% of NaI(Tl), current manufacturers quote 15%

2) LiI (Eu) .. 2.8% 470 nm with ~51k photons/n [~ same as NaI(Tl)]

$n + {}^{6}Li \rightarrow {}^{4}He + {}^{3}H$, Q=4.79 MeV $\sigma \sim 940\ \lambda\ /1.8$ barns



Lithium Glass Array for neutron detection, developed and manufactured by Levy Hill Laboratories for AWRE. Dimensions 8½ "by ½" thick.



Use Wayback Machine to see:
http://www.apace-science.com/ast/g_scint.htm

Chap. 14 – Slow n Detection Question

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Estimate the intrinsic efficiency and signal height from a fission chamber for thermal neutrons made up as follows: a natural uranium metal coating of 1 mg/cm^2 on the inside of a 1cm diameter tube with a 50μm central anode. The tube is filled with Ar/Methane (P-10) at 1 atm pressure and is operated at 1000V and has a (stray) capacitance of 50 pF.

$$\varepsilon(E_n)$$