Week 10: Chap. 15 Fast Neutron Detection

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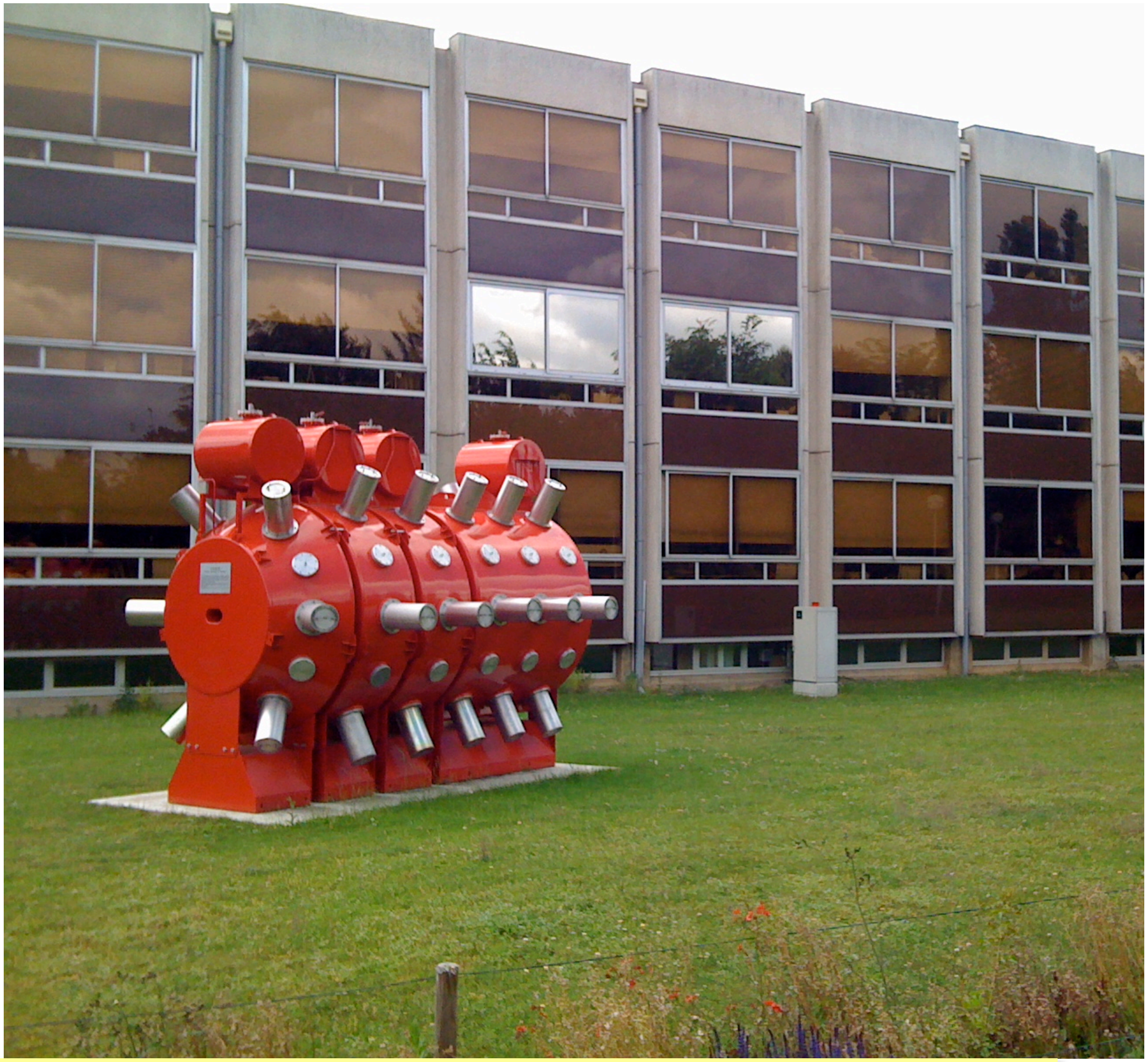
Slow Neutron Detection

Fast Neutron Detection
-- nuclear reactions reprise
-- Thermalize neutrons, counters
--- “Long” counters
--- Liquid scintillator counters
-- Scatter neutrons
--- Kinematics
--- Solid scintillators
--- Neutron arrays

Pulse Processing



Final resting place of ORION detector, Caen, FR

Chap. 15 – Fast Neutron Detection

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

The capture cross sections for fast-neutron induced reactions are small compared to those at low energies (in the limit: geometric cross sections with occasional resonances).

Two approaches to detect fast neutrons:
– thermalized & capture which only provides a “count” (al la NERO)

– Elastic scatter from protons at high energy – observe recoils for ToF techniques.

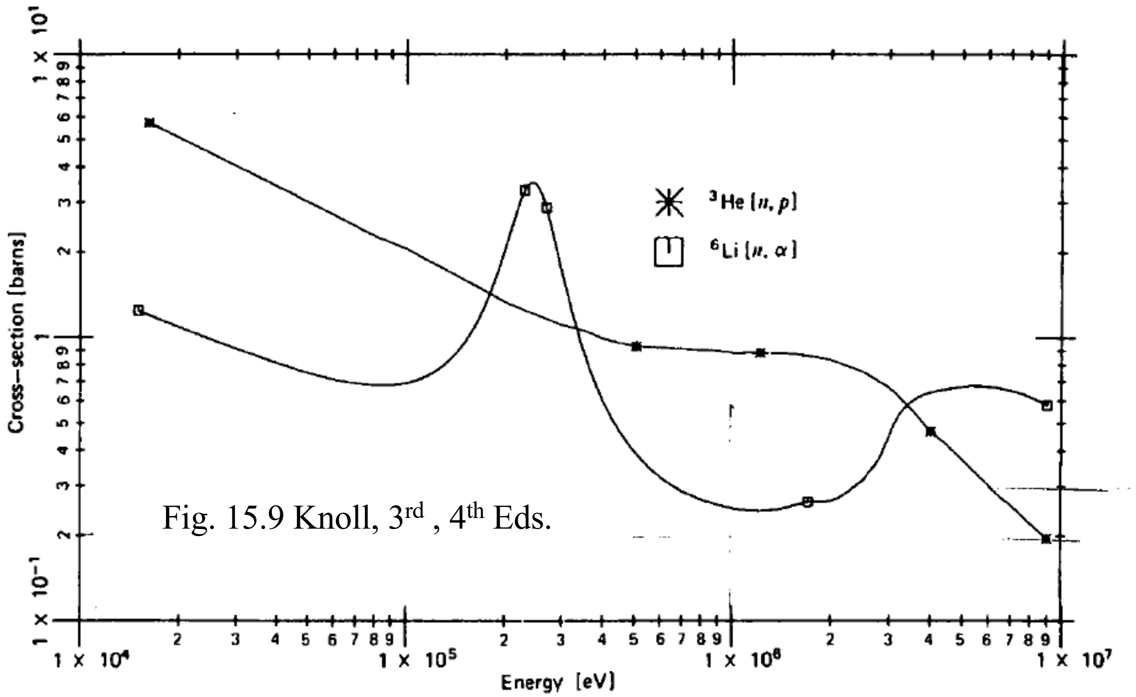
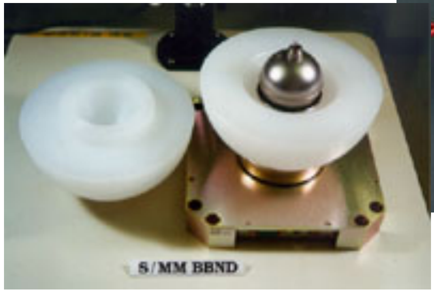


Fig. 15.9 Knoll, 3rd , 4th Eds.

Bonner Spheres – “Counter”

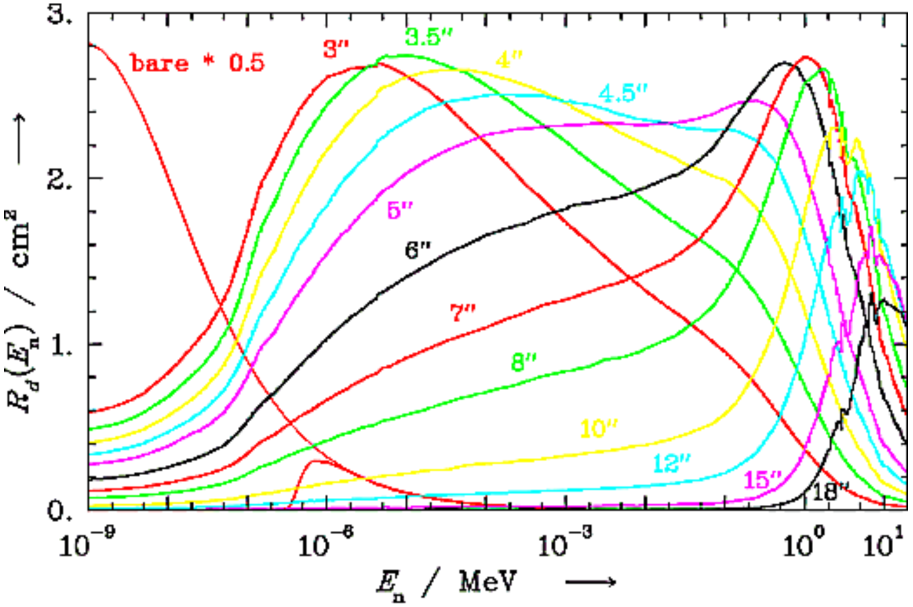
$n + {}^{3}He \rightarrow ({}^{4}He)^{*} \rightarrow p + {}^{3}H$, Q=0.765 MeV

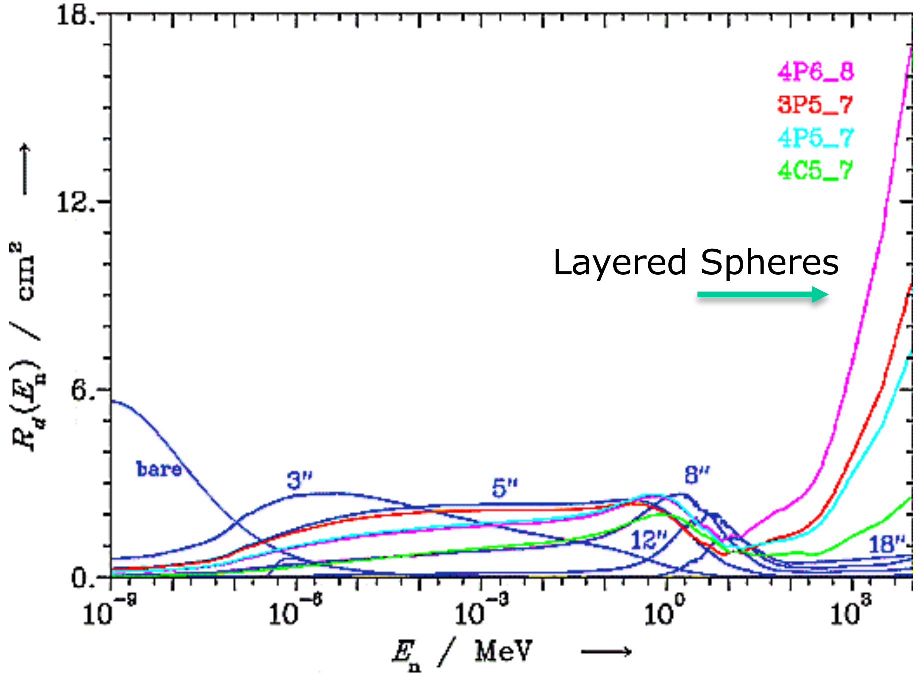
Moderate neutrons in spheres of different sizes and then detect the neutrons in a proportional counter in the center. Add metal for highest energy neutrons … unfold response to get distribution.



STS-102 Space Shuttle, six spheres, 3He, 6atm

JRadMeas 42 (2007) 1510 Neut ISS
ZMedPhys 18 (2008) 265 Rad. Monitor ISS





Layered Spheres

See also NIM A620 (2010) 260 -269

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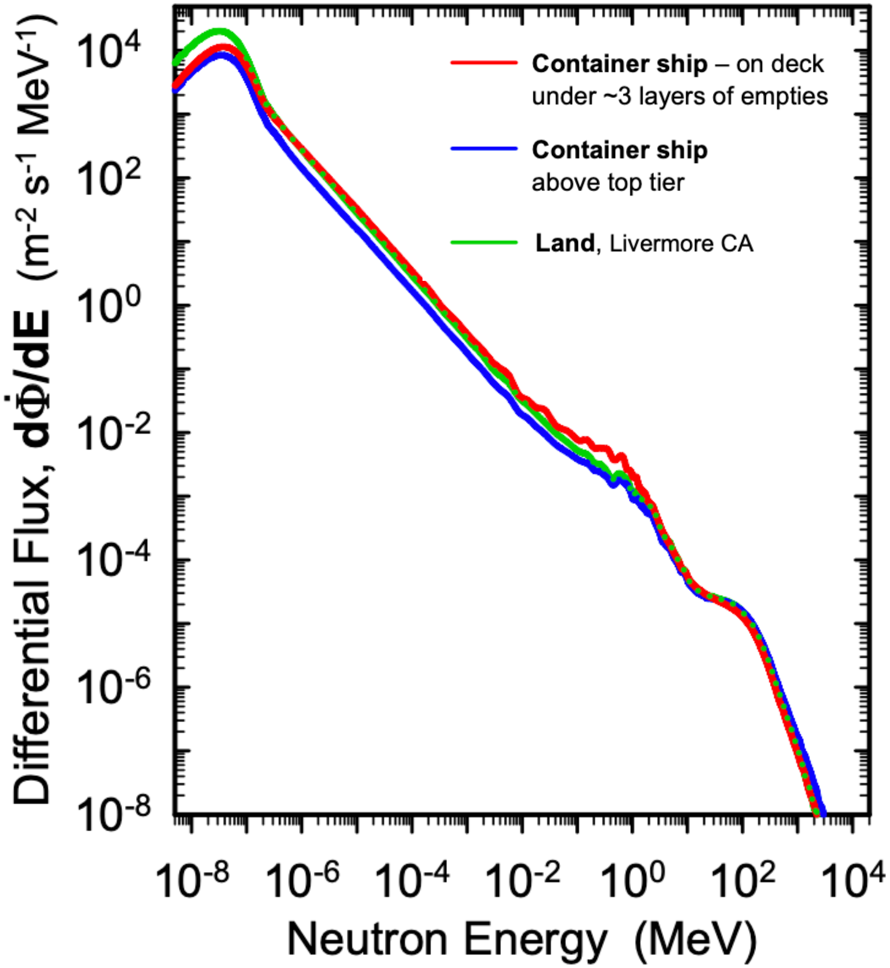
Neutrons in the Environment

National Urban Security Technology Laboratory, NYC

MICHIGAN STATE UNIVERSITY

Components of NUSTL's new neutron spectrometer

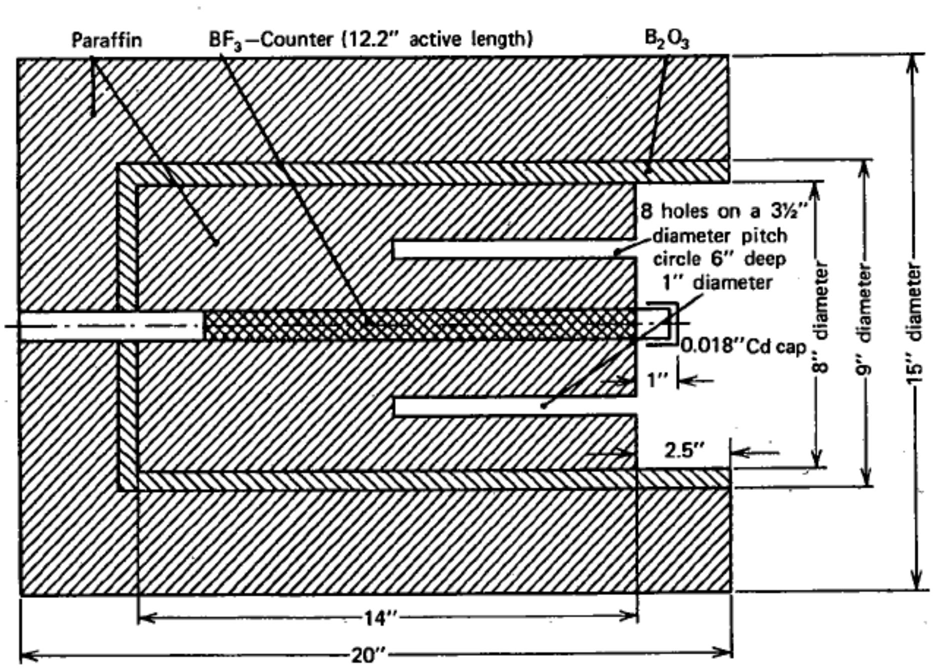


NMworkshop/2015 Goldhagen_nuclear_detection.pdf

Fast neutron detection: Long Counter

n + ^{10}B → (^{11}B)* → ^{7}Li* + ^{4}He , Q=2.31 MeV, Branch=94%, target abundance = 19.9%

→ ^{7}Li + ^{4}He , Q=2.79 MeV, Branch=6%



*

NSCL Bucket neutron detectors use BF$_3$ (1" diameter, 4" long, 400Torr) in a paraffin filled container.
Paraffin: C_nH_{2n+2} n= 20 to 40
Cadmium metal cover

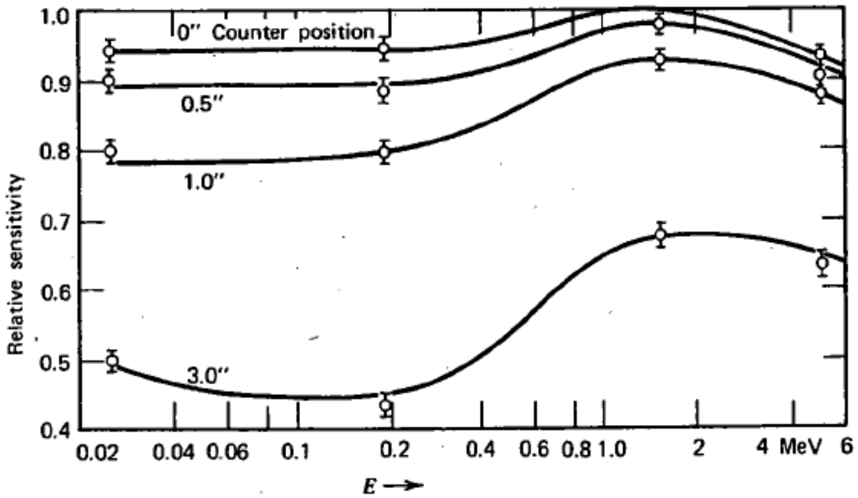
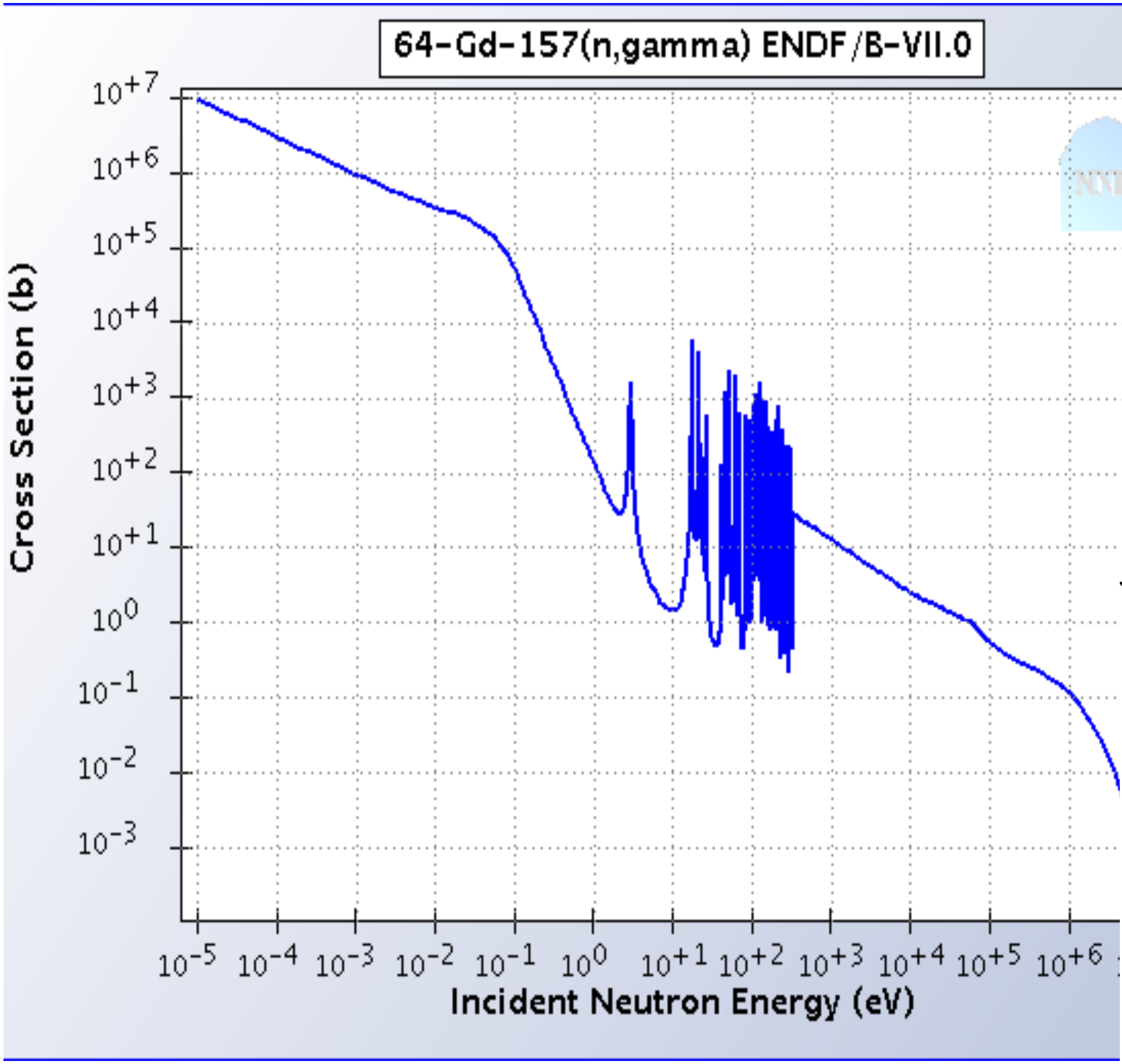
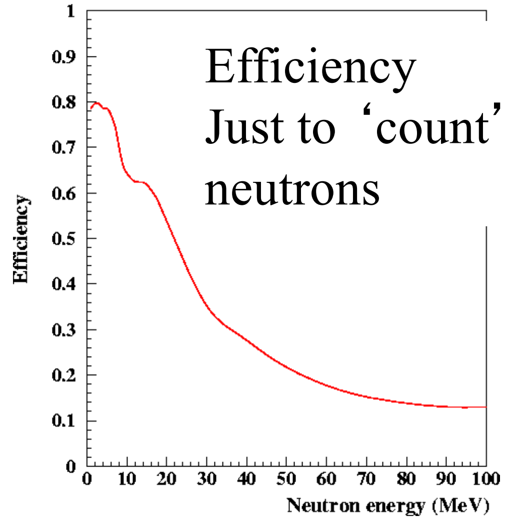


Fig. 15.6 Knoll, 3rd , 4th Eds.

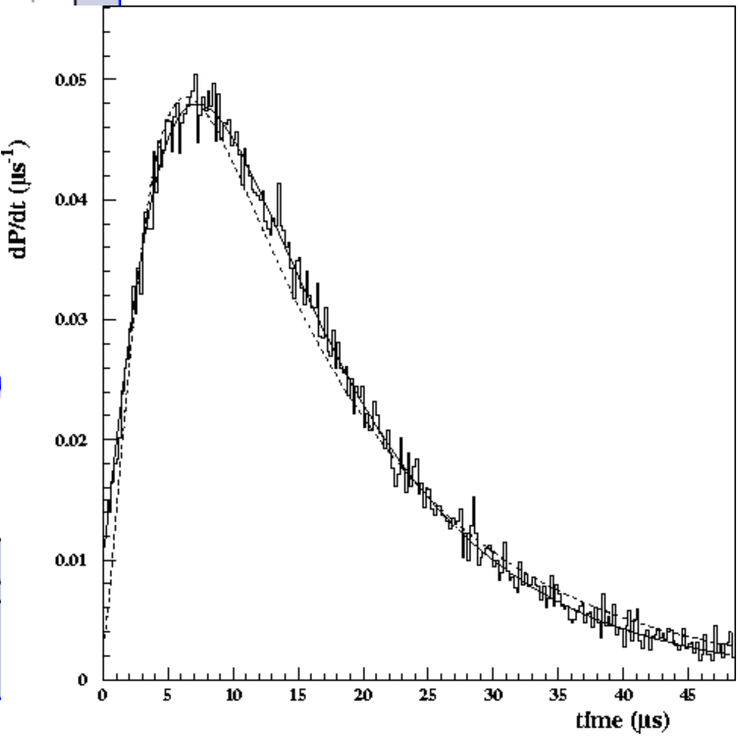
Gd-loaded Liquid Scintillator – “Counter”

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





Efficiency
Just to ‘count’
neutrons



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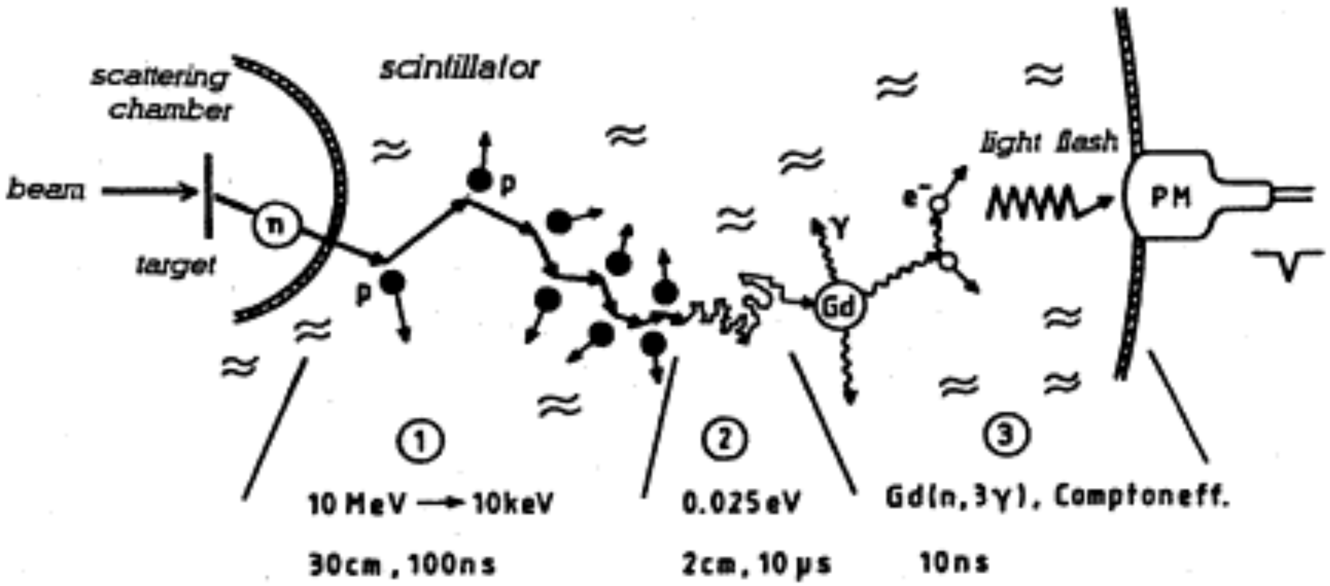

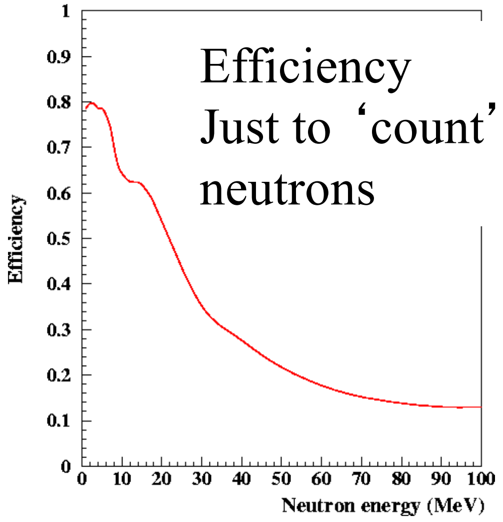
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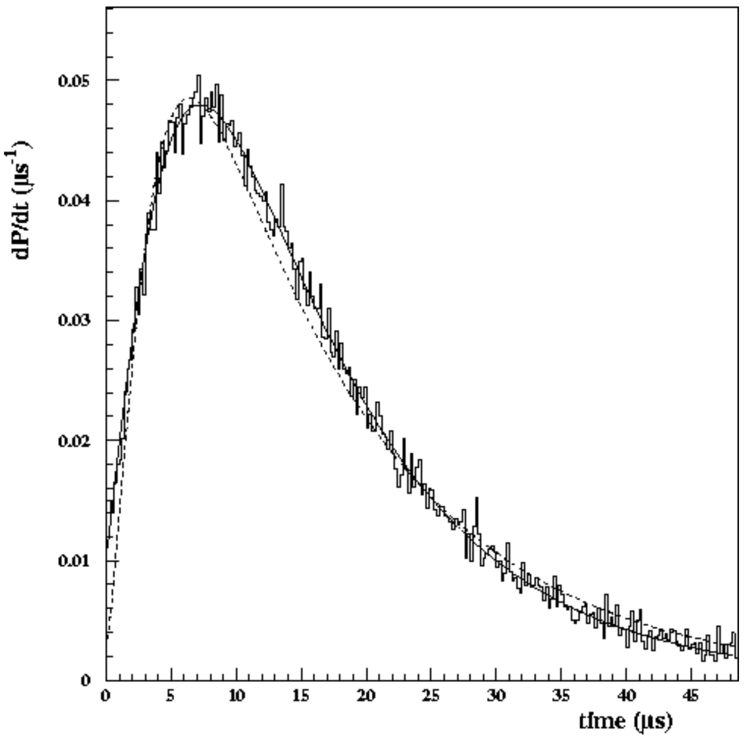
Just to ‘count’ neutrons

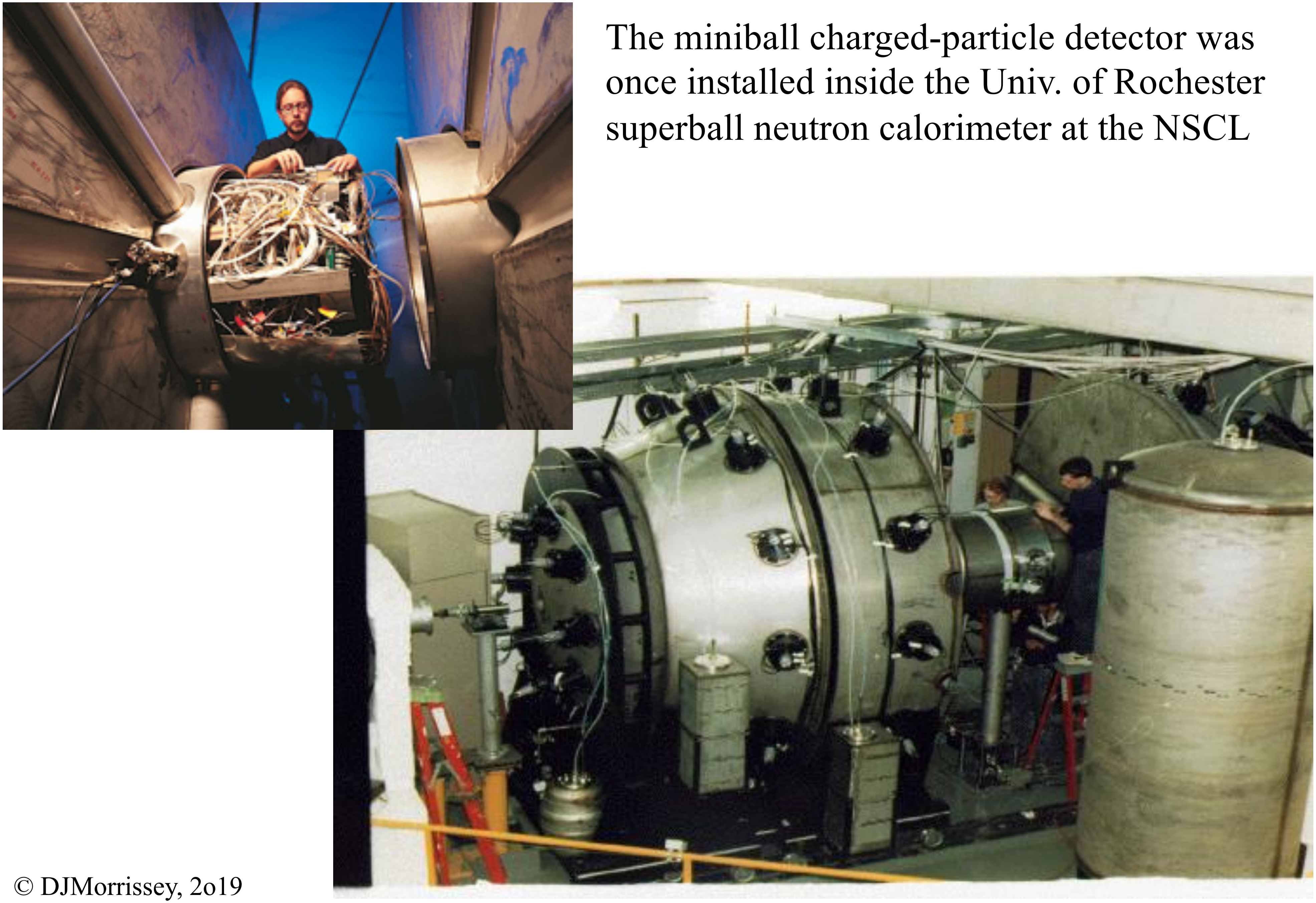


Cf. NIM A508 (2003) 295, Jahnke et al.

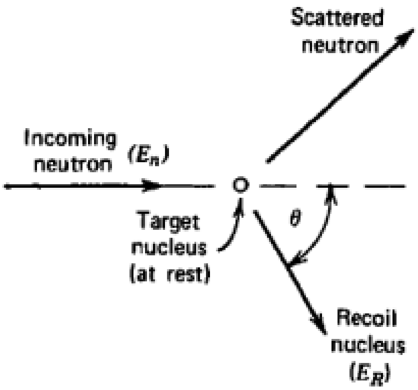
Neutron “multiplicity filter” originally used for neutron multiplicity in fission, then used in nuclear reaction dynamics “ORION” detector at GANIL , similar to “superBall” at NSCL (both decommissioned)

Gd-loaded Liquid Scintillator – “SuperBall”

The miniball charged-particle detector was once installed inside the Univ. of Rochester superball neutron calorimeter at the NSCL



Fast Neutron Detection: Scattering



$$\frac{E_R}{E_n} = \frac{4A}{(1+A)^2} Cos^2\theta_{lab}$$

E_R max at $\theta_{lab} = 0^o$ (neutron goes back, 180^o)

Tgt	A	$4A/(1+A)^2$
^{1}H	1	1
^{2}H	2	8/9=0.889
^{4}He	4	16/25=0.64
^{12}C	12	48/169=0.284

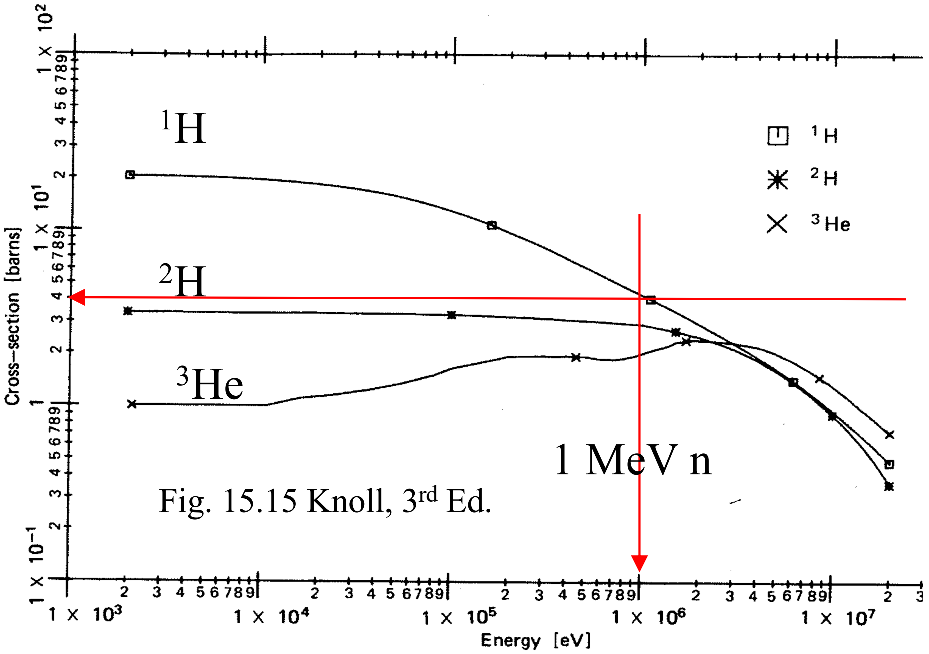
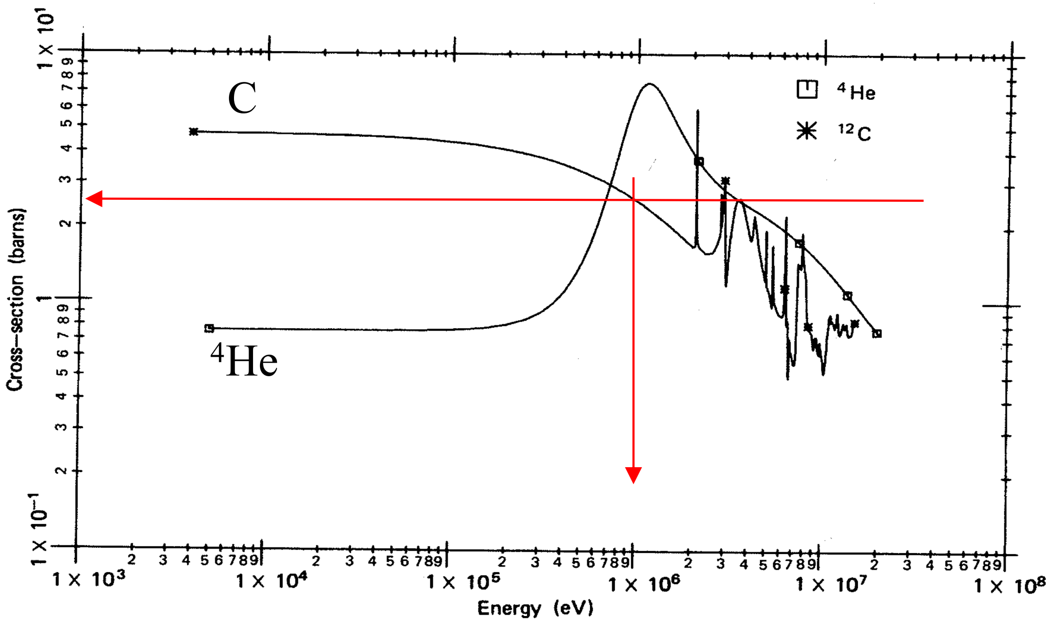
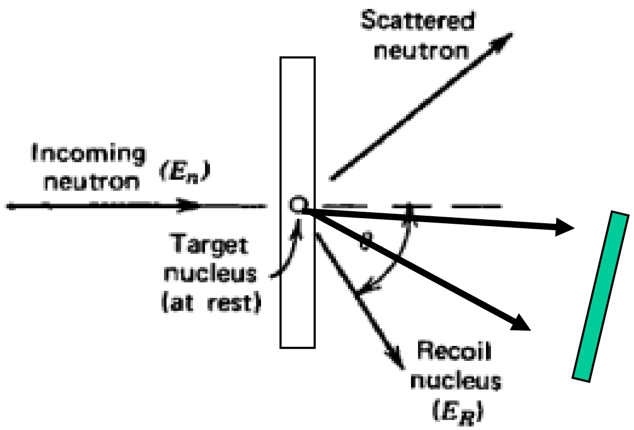


Fig. 15.15 Knoll, 3rd Ed.



Fast Neutron Detection: Absorption



Proton-radiator telescope: Target allows protons to escape. Target thickness has to be consistent with the $\Delta E/\Delta\Theta$ of the recoil angular distribution.

20 MeV n .. Scatters and gives protons
10 MeV p in CH_2 .. dE/dx ~30MeV/ g/cm^2

$$E_p = E_n \cos^2\theta \qquad \Delta E_p = E_p(\theta) - E_p(0)$$
$$\Delta E_p = E_n[1-\cos^2\theta]$$
$$\Delta E_p = E_n \sin^2\theta \quad (\sim 3\% \text{ for } 0\text{-}10^{\circ})$$

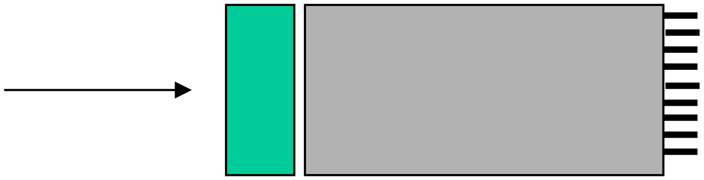
Energy loss must be less than change with angle

$$\Delta x \sim \Delta E_p / (dE/dx) = 0.03 * 20\text{MeV} / 30 \text{ MeV/ g/cm}^2$$
$$\Delta x \sim 0.02 \text{ g/cm}^2$$

Efficiency is set by thickness

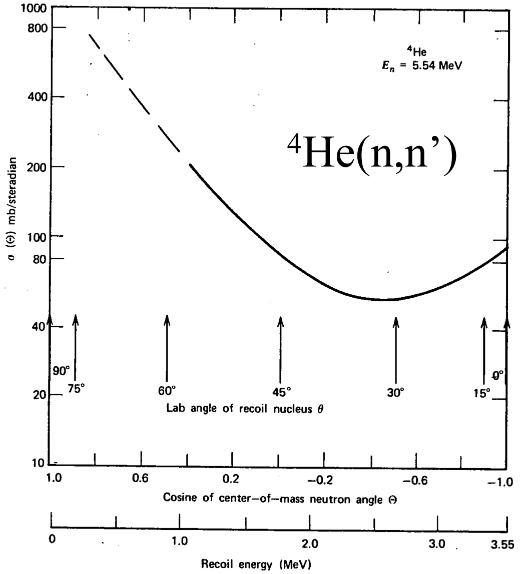
$$\rho_n\,\Delta x \sim (2*6\text{x}10^{23} / 14)\ 0.02 = 1.7\text{x}10^{21}\ /\text{cm}^2$$
$$\sigma(E{=}20\text{ MeV}) = 0.4\text{ b}$$
$$\varepsilon = 1 - e \wedge(-\rho_n\,\Delta x\,\sigma) = 7\text{x}10^{-4}$$

Give up! Use a thick plastic scintillator .. 10 cm ε~0.2

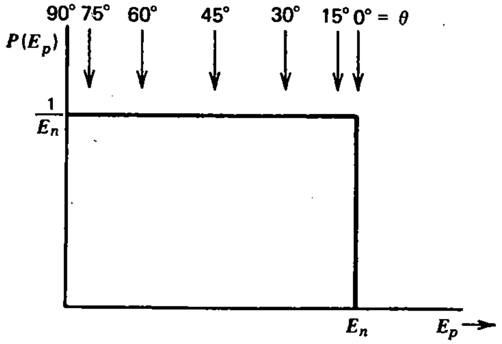


N.B. modern variant of this is a gas-filled ‘active target’

Fast Neutron Detection: Scattering Pulse Height



^{4}He(n,n')



Recoil Energy

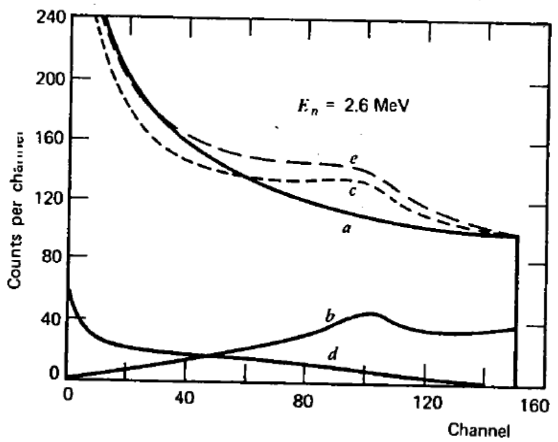
^{4}He(n,n') angular distribution is shown

^{12}C(n,n') cross section has a modest angular distribution .. Small energy dependence on recoil angle. Note that the carbon recoil energy usually falls below the detector threshold but the scattered neutron can go on to interact.

The ^{1}H(n,n') distribution is flat.

Combine and fold with scintillator light output
(a) ^{1}H(n,n') single scattering
(b) ^{1}H(n',n'') double scattering
(d) ^{12}C(n,n') scattering

2.6 MeV neutron
1"x1" stilbene



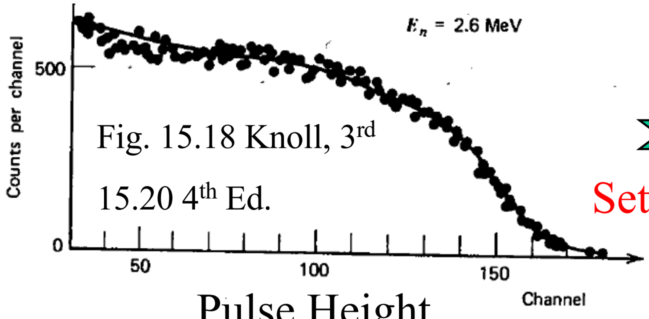
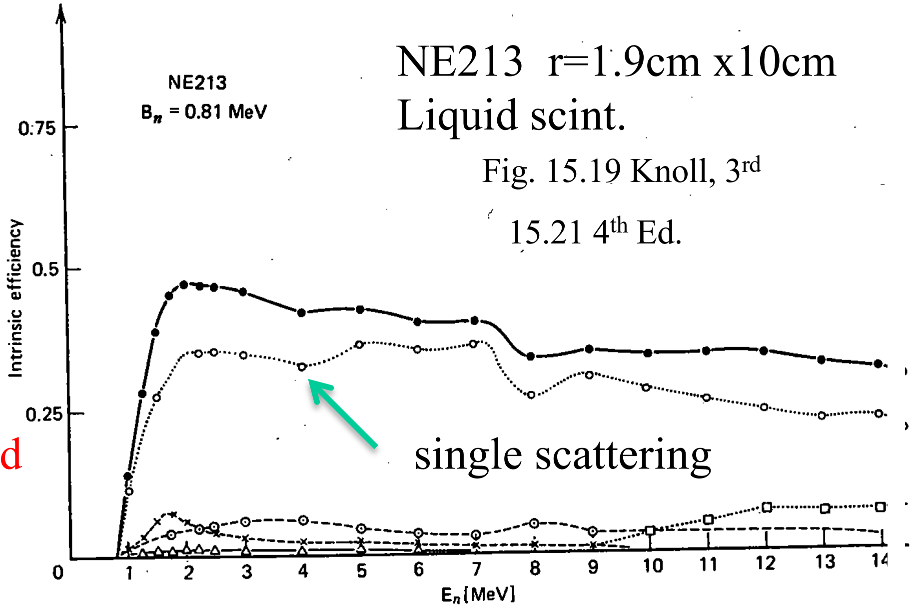


Fig. 15.18 Knoll, 3rd

15.20 4th Ed.

Pulse Height

Set threshold



NE213 r=1.9cm x10cm
Liquid scint.

Fig. 15.19 Knoll, 3rd

15.21 4th Ed.

single scattering

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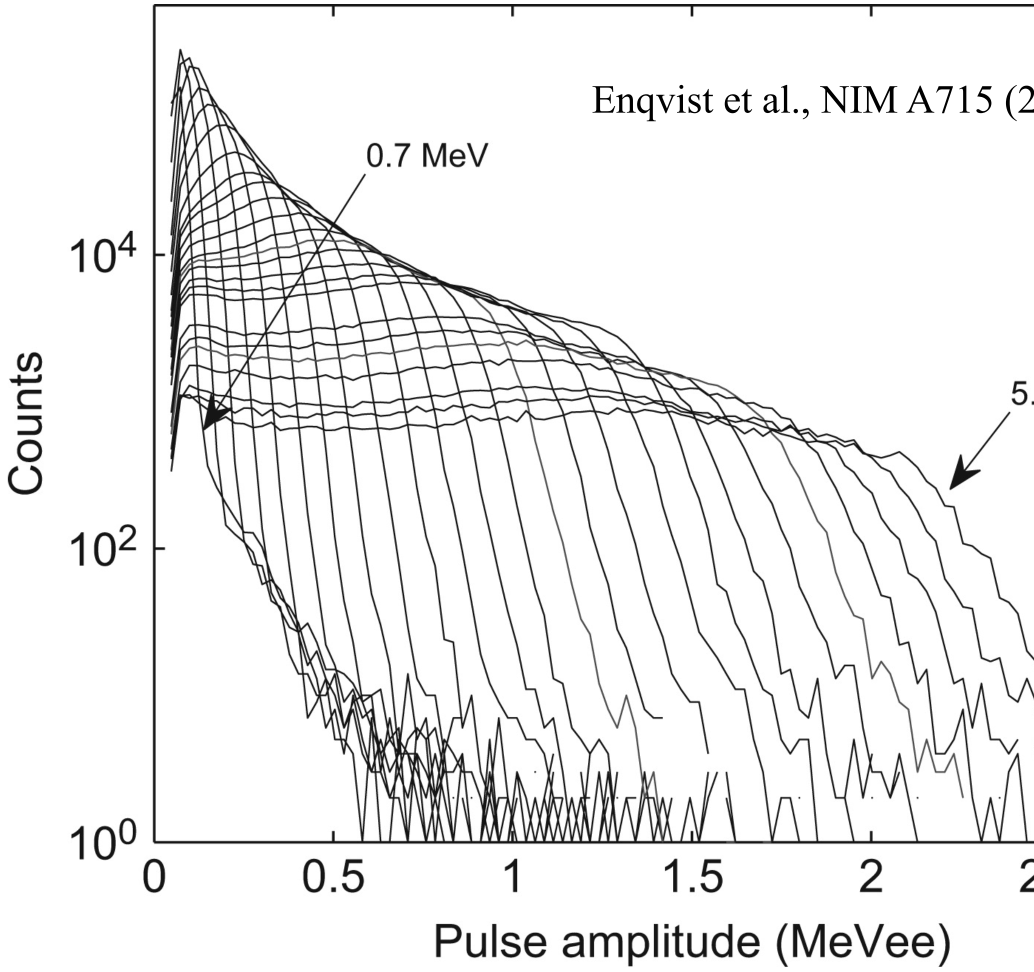
Fast Neutron Detection: Expt. Pulse Height



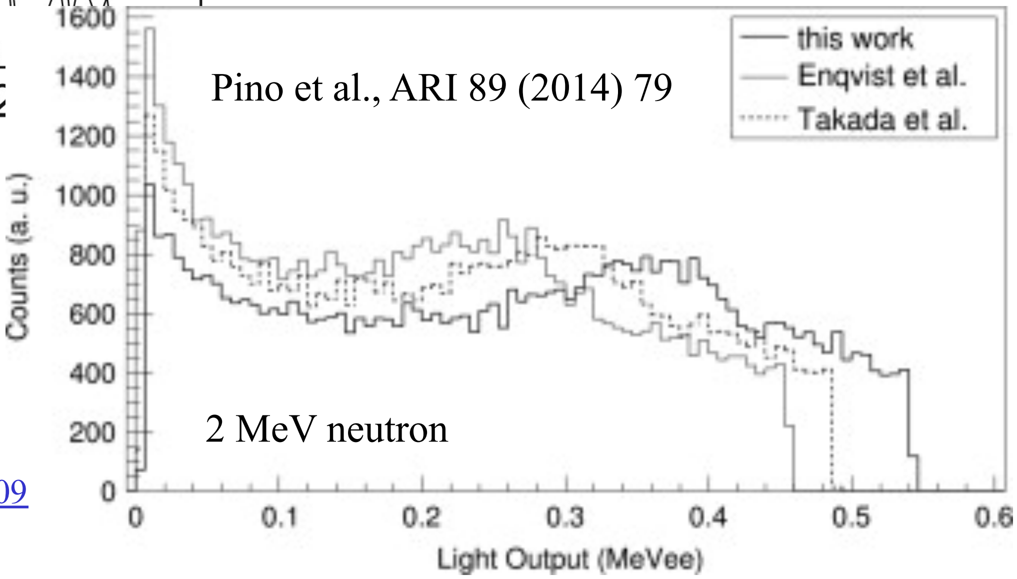
Enqvist et al., NIM A715 (2013) 79

EJ-309

MeVee : MeV electron-equivalent

Calibrate system with fast electrons

Observe neutron signals on that scale



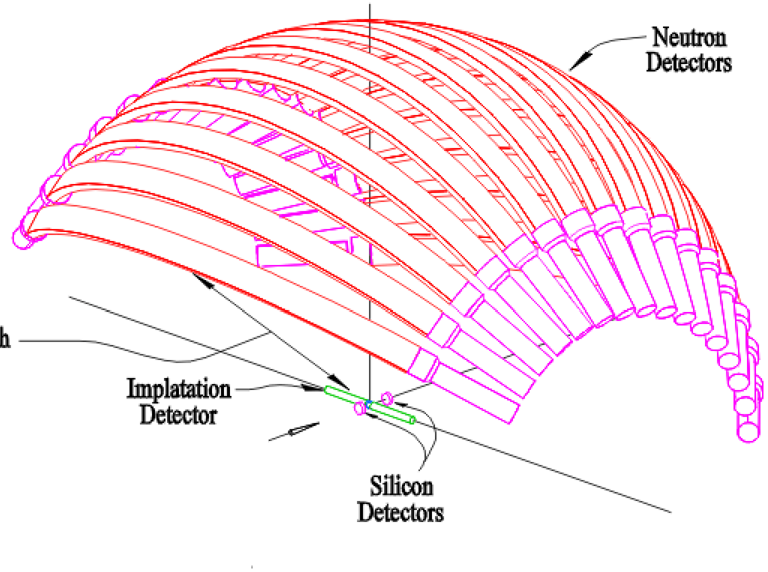
Pino et al., ARI 89 (2014) 79

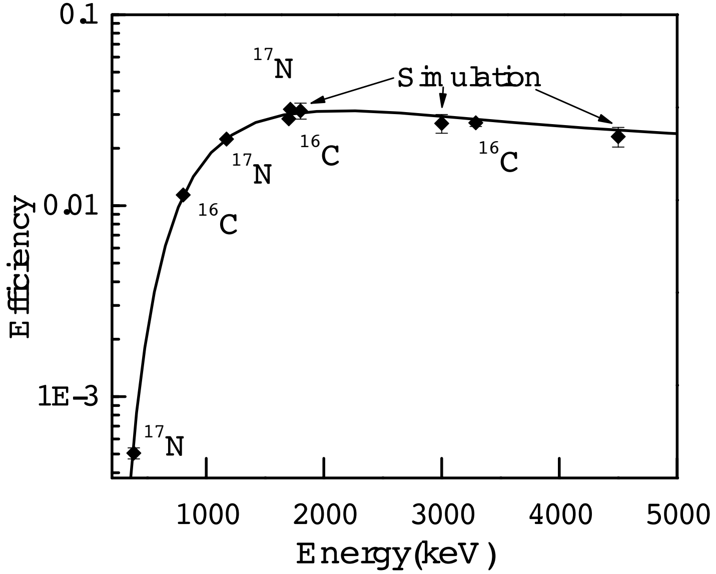
2 MeV neutron

http://www.eljentechnology.com/products/liquid-scintillators/ej-301-ej-309

Fast Neutron Detection: Arrays – Intrinsic Effic.

DNArray
1m radius
90° x3”x1”

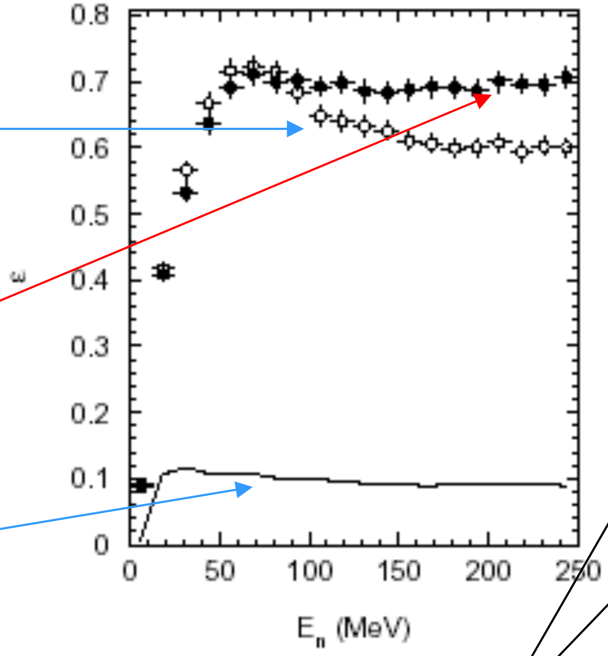


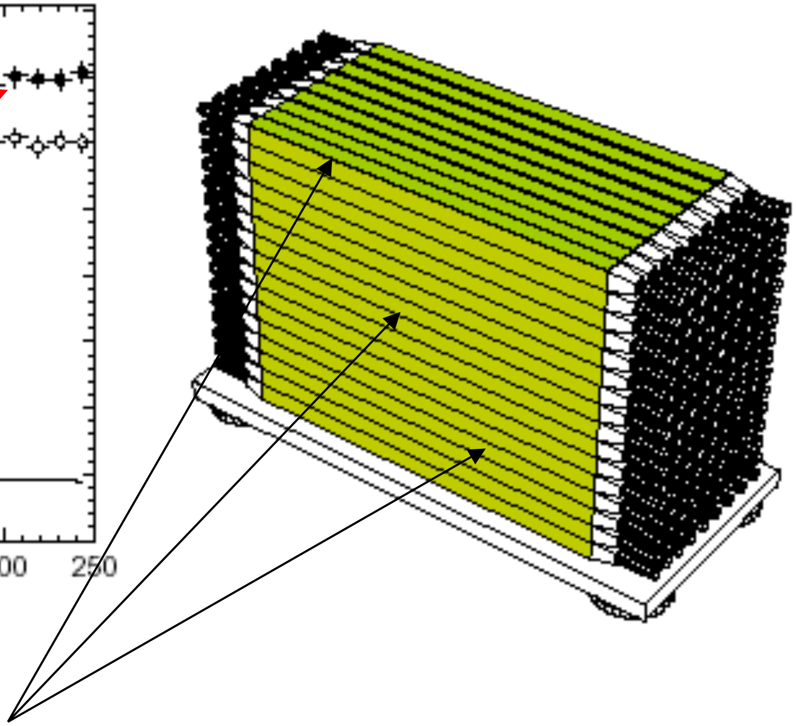


MoNA plastic scintillator
Ten layers – plastic scint.
2m x 10x10cm^2

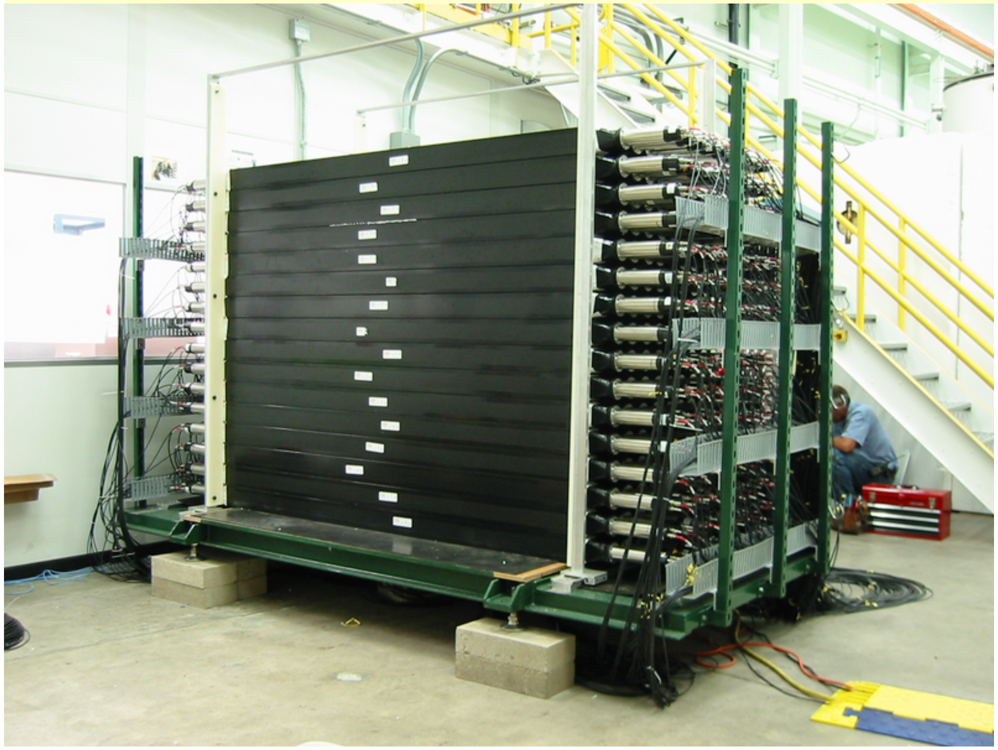
Add Iron converter layers

NSCL “neutron wall”
One layer of liquid scint.





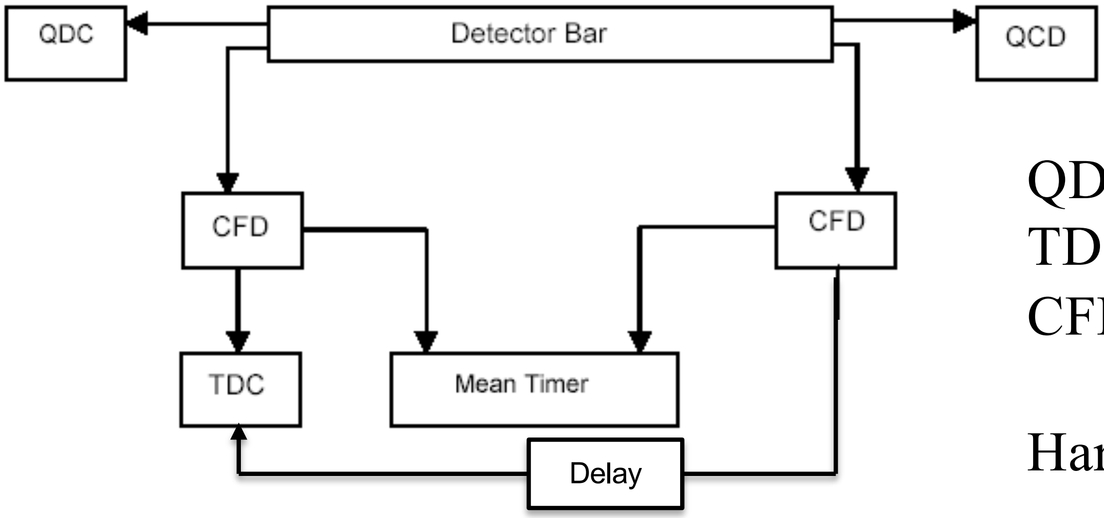
Fast Neutron Detection: Arrays - ToF



$E_n << m_o c^2$

$$E = \frac{m}{2}v^2 = \frac{m}{2}\left(\frac{L}{t}\right)^2$$

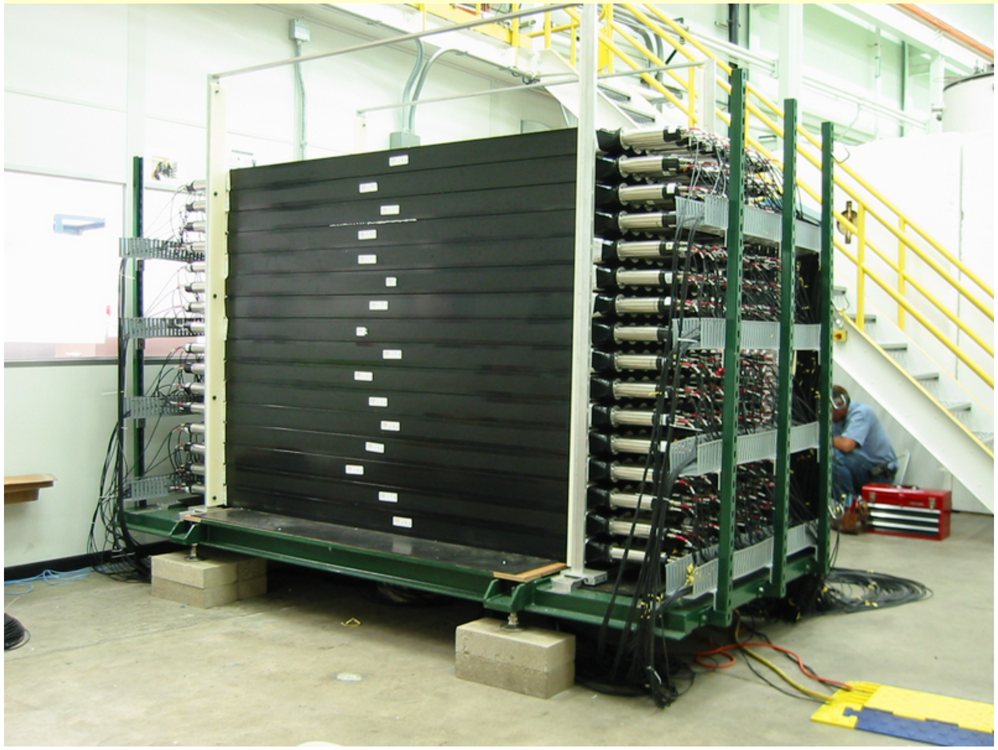
$$\frac{dE}{dt} = \frac{-mL^2}{t^3} \rightarrow \frac{dE}{dt} = \frac{-2E}{t} \rightarrow \frac{dE}{E} = \frac{-2dt}{t}$$



QDC – charge to digital convertor
TDC – time to digital convertor
CFD – constant fraction discriminator

Hardware construction of position/ToF

Fast Neutron Detection: Arrays - ToF



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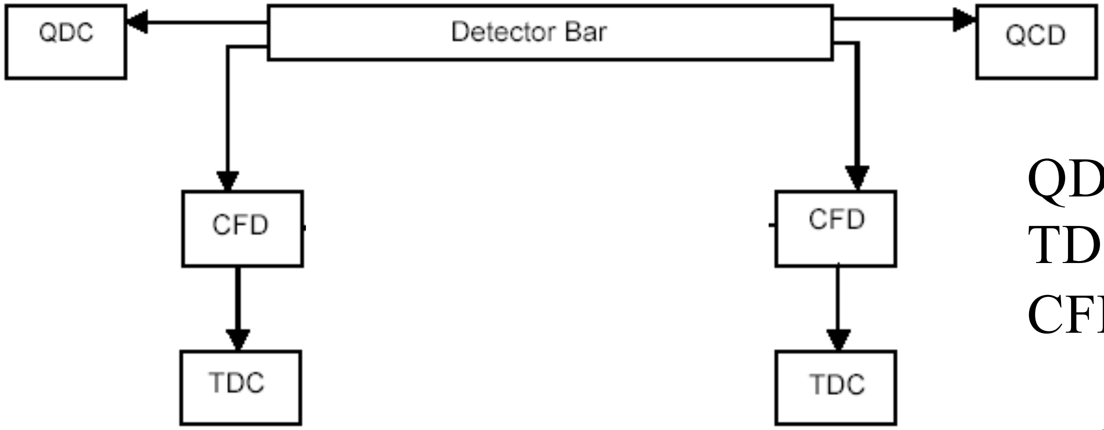

QDC – charge to digital convertor
TDC – time to digital convertor
CFD – constant fraction discriminator

Software construction of position/ToF

Chap. 15 – Fast n Detection: Question

Estimate the number of photons reaching the end of a fast-neutron detection bar from the interaction of a cosmic ray muon passing horizontally through the midpoint of the bar along the thinnest direction. The attenuation length of the bars was found to be 4.2m, the bars are each 300x45x30 mm^3, are made from BC-408 scintillator and are readout on the long ends. The position uncertainty was found to be 6.2 cm using the time-difference technique. Estimate the time resolution in ns that would be consistent with this position resolution.