Modern high pulse height resolution fast neutron spectrometer

Dzhonrid Abdurashitov

Institute for Nuclear Research
Russian Academy of Sciences
Moscow, Russia

For the INR-NIST collaboration

HEND Workshop, ISR, Moscow
June 3, 2010

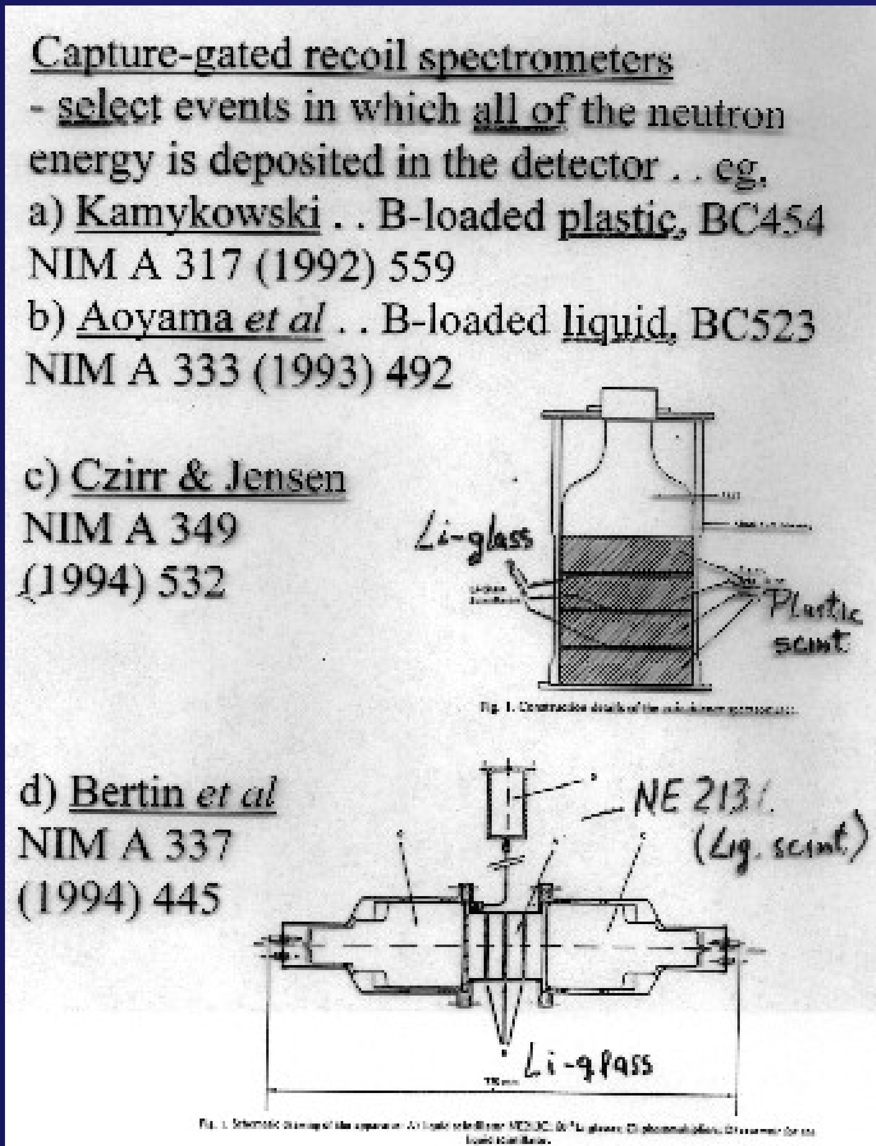
Neutron spectrometry methods

+ Capture Gated (with ^{6}Li, ^{10}B,…)

- Recoil nuclei techniques (H or He proportional counter, organic and nonorganic scintillator, etc.)
- Charged products of n-induced reactions ($^{28}Si(n,\alpha)^{25}Mg_{gs}$ at silicon semiconductor)
- Threshold reactions (neutron activation techniques)
- Time-of-flight measurement
- Bonner spheres (thermal neutron detector inside spherical moderator)

Most of them do not produce an adequate Pulse Height distribution requiring thus a response function to unfold

Capture gated recoil spectrometers


Capture-gated recoil spectrometers
- select events in which all of the neutron energy is deposited in the detector . . eg.

a) Kamykowski . . B-loaded plastic, BC454
NIM A 317 (1992) 559

b) Aoyama *et al* . . B-loaded liquid, BC523
NIM A 333 (1993) 492

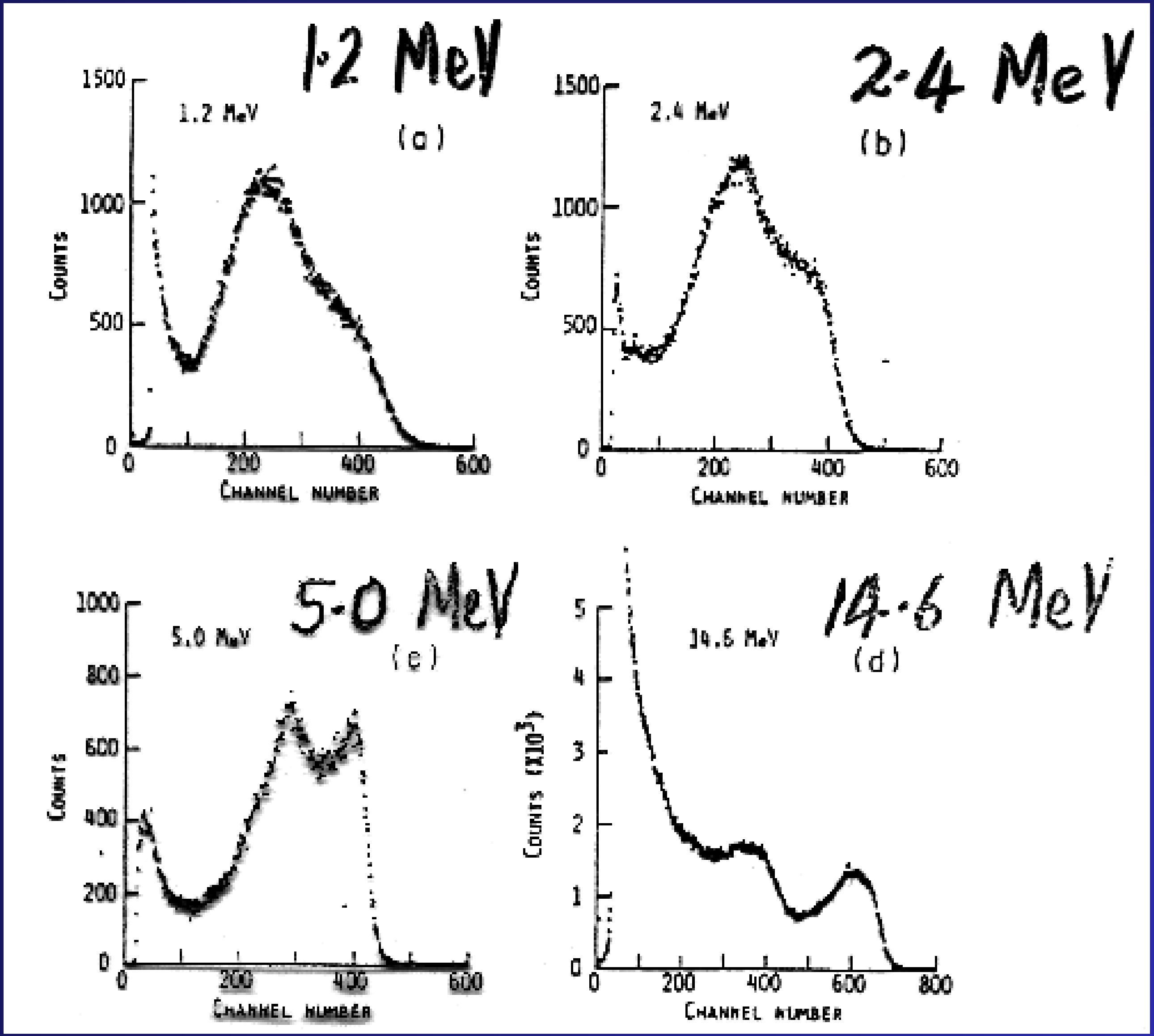
c) Czirr & Jensen
NIM A 349
(1994) 532

d) Bertin *et al*
NIM A 337
(1994) 445

Plastics or liquid doped with B or Li

“Capture gated” means that only those neutrons which deposited all initial energy in the detector are used for the spectrometry

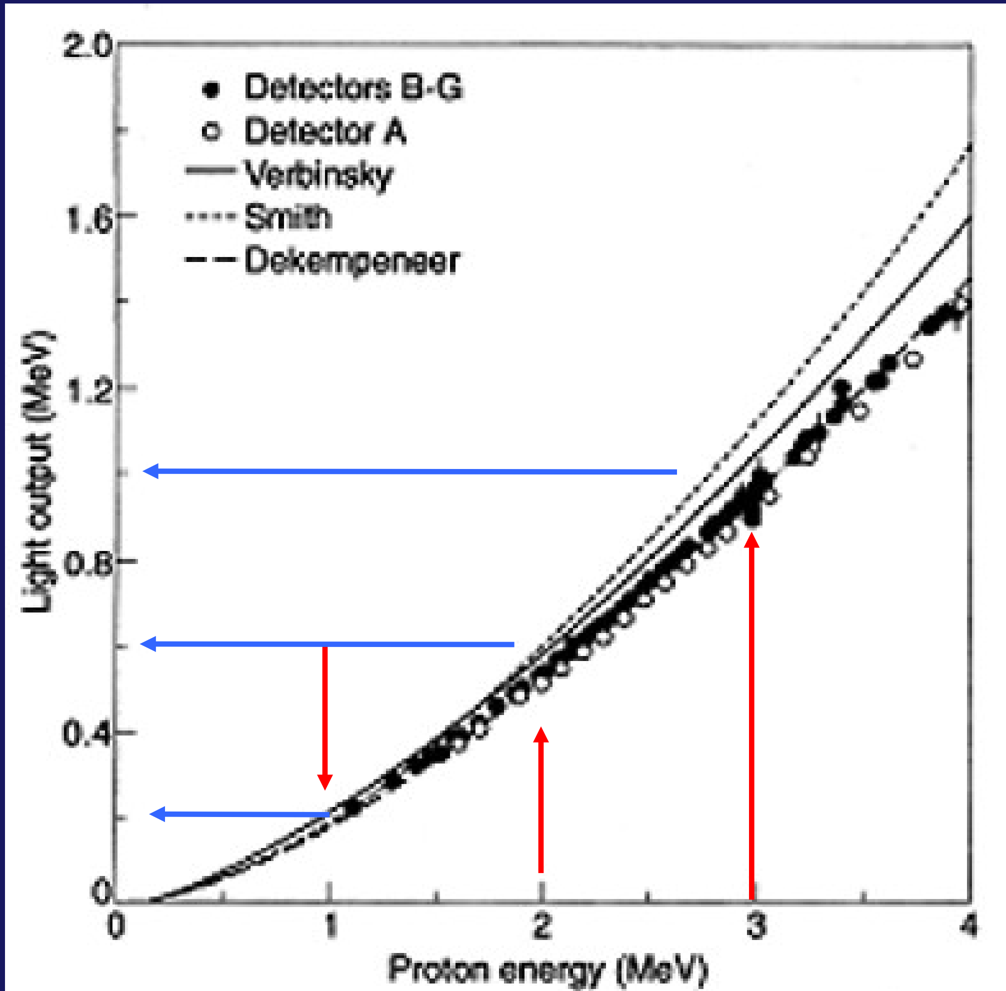
Response function of capture gated spectrometer



<u>Specific features</u>

- Double peak
- Dynamics

What is a reason?



Assume $E_n = 3$ MeV

1 Recoil (3 MeV) :

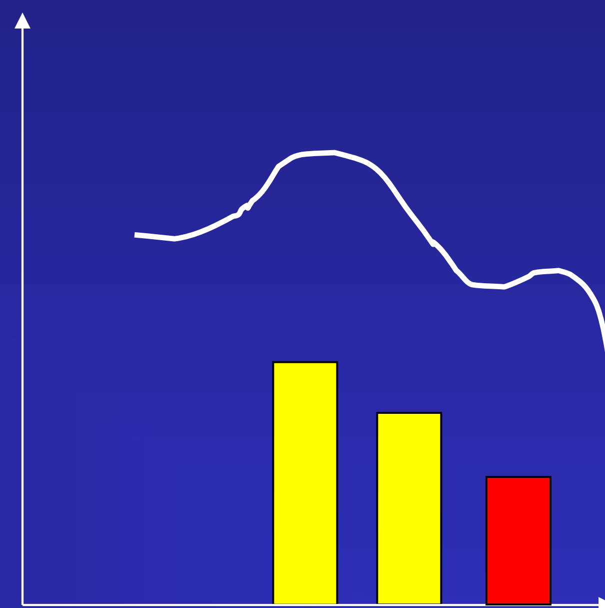
1 MeV escale

2 Recoils (1+2 MeV) :

0.2 + 0.6 = 0.8 MeV escale

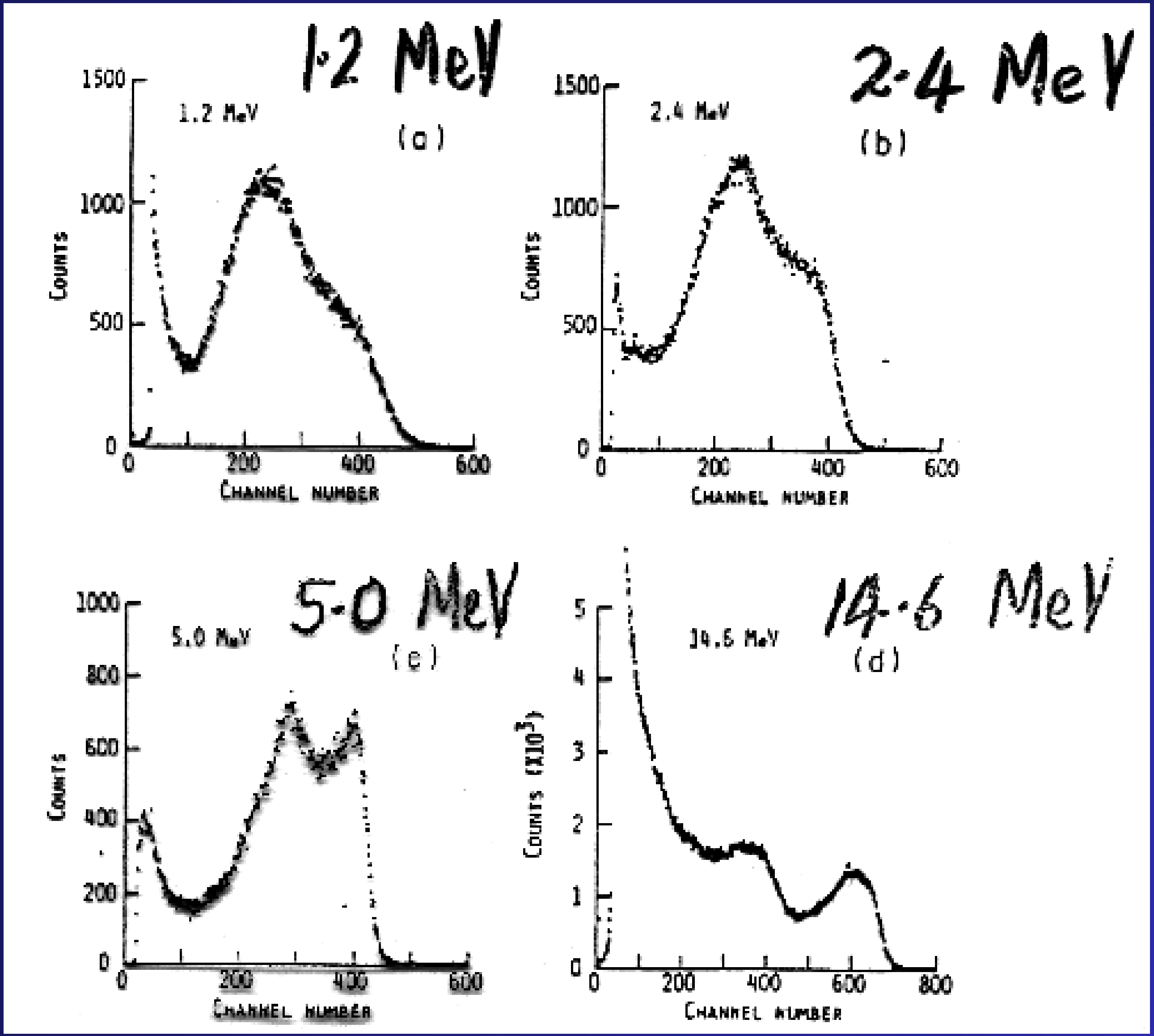
3 Recoils (1+1+1 MeV) :

0.2 + 0.2 + 0.2 = 0.6 MeV escale



Energy, MeV electron scale

Response function of capture gated spectrometer



<u>Summary</u>

Double peak is from multiplicity of recoil protons combining with nonlinear light yielding obviously

How to obtain high Pulse Height Resolution?

- If neutron is captured,

$$E_n \approx \Sigma\, E_{pi}$$

- Due to non-linear light yield,

$$\Sigma\, I(E_{pi}) \neq I(\Sigma\, E_{pi})$$

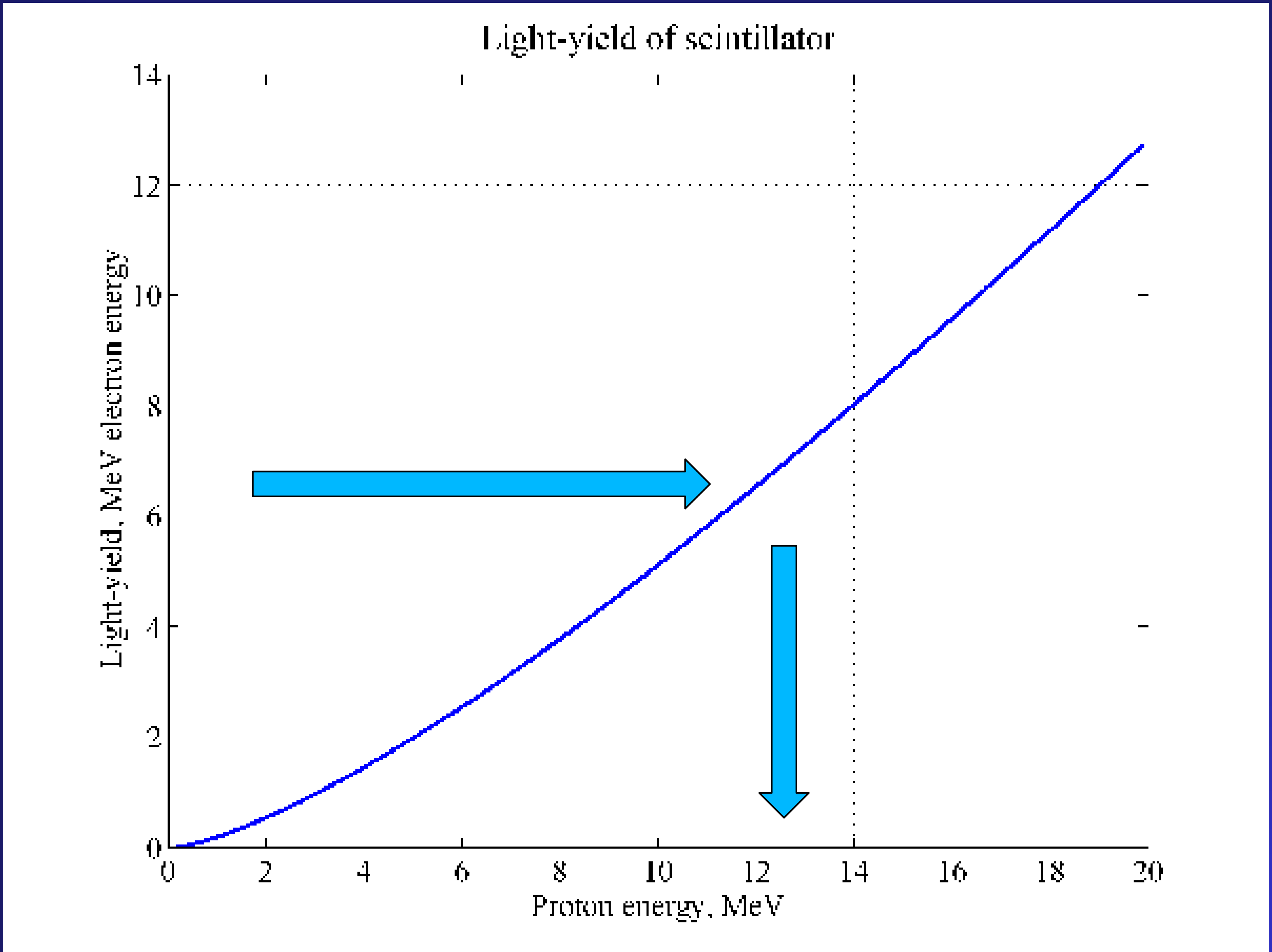
- If one detects recoils separately and light yield function is known,

$$E_n \approx \Sigma\, E_p(I_i)$$

Main idea:

ISOLATED SEGMENTS!

Nonlinearity of light-yield of scintillator for recoil protons (NE-213)



The high pulse height resolution fast neutron detector: crucial points

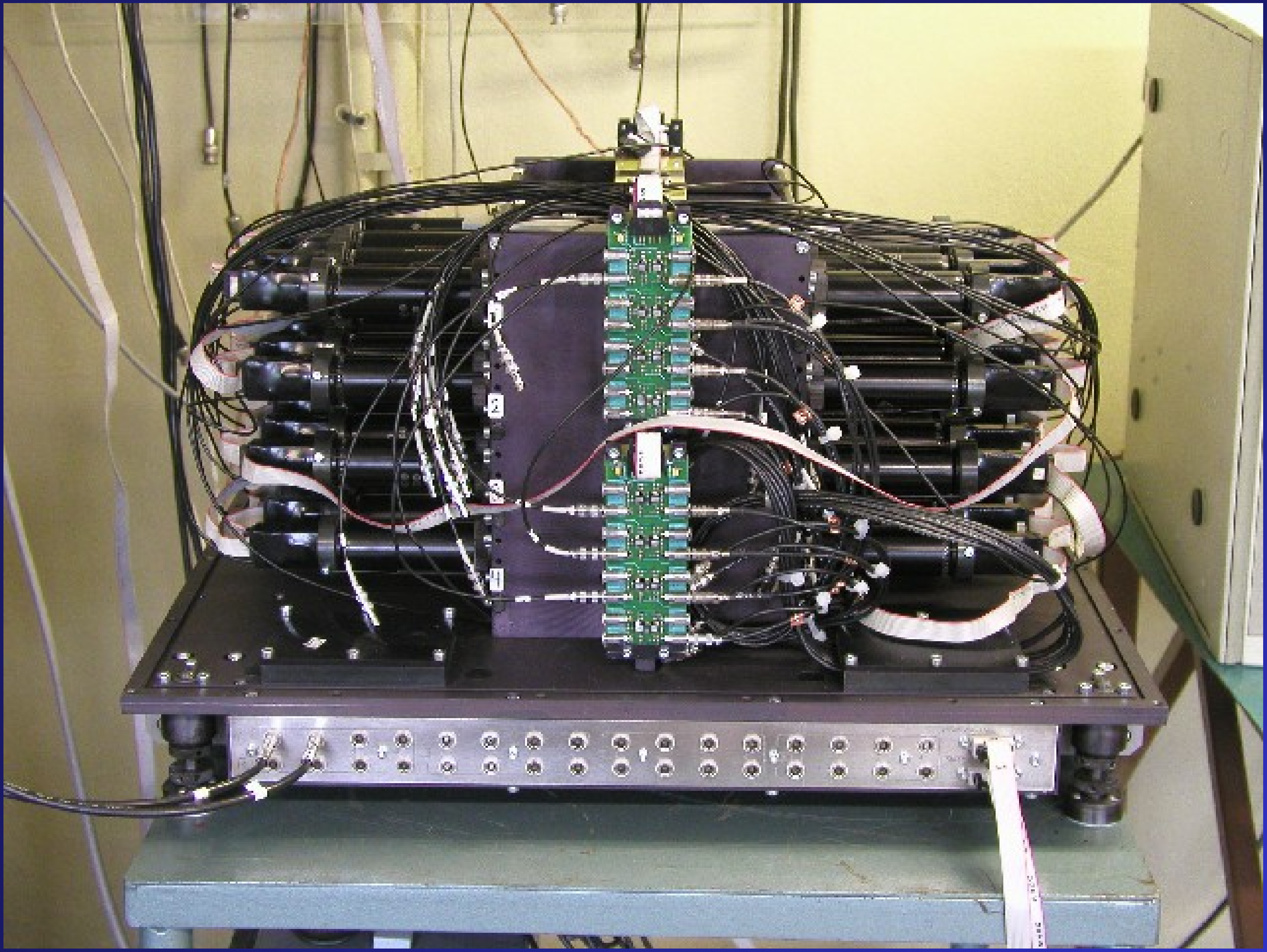
- The ratio H/C as high as possible (~1.1 for plastics, 1.5-1.8 for liquids)
- 1 recoil proton in each section (>90%)
- Light yield as much as possible (1000-5000 photons/MeV)
- Light collection as uniform as possible (<10%) – internal reflection
- $^{6}Li(n,\alpha)^{3}H$+4.8 MeV – the highest energy for massive products
- Pulse shape discrimination
- Fast triggering (≥2 coincident sections in less than 50 ns)

Characteristics of the pilot version

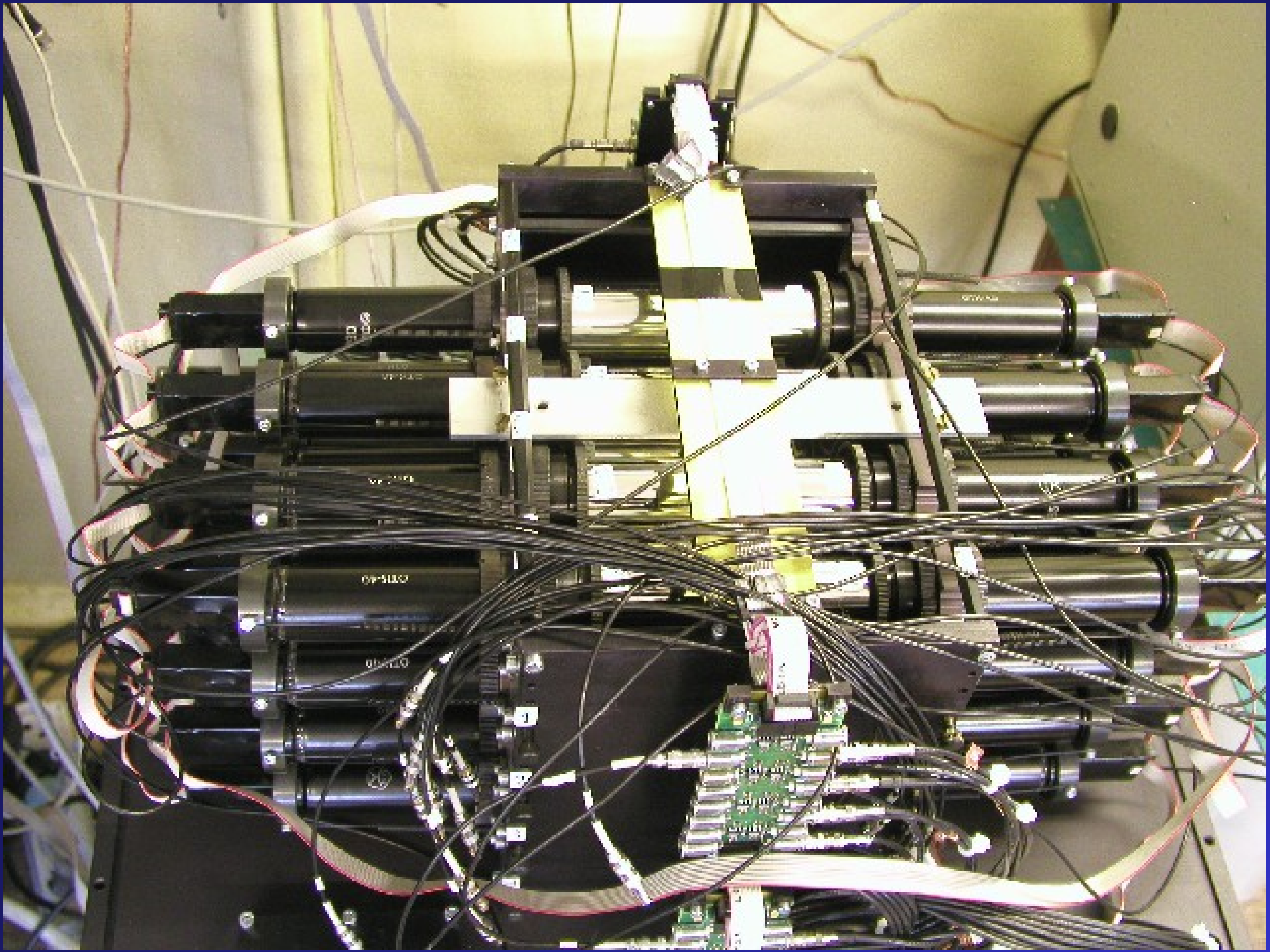
- Type of the detector: segmented capture gated
- Detector volume: ≈1.2 l of liquid
- Total number of segments: 16
- Total number of PMT: 32
- Energy range: 3 – 30 MeV
- Energy resolution (E_n=14 MeV): 20 – 25%
- Detector efficiency (E_n=3 MeV): 0.2 – 0.5%
- Total dimensions : 550×430×340 mm^3
- Total mass of the detector: 34.7 kg

The detector – external view

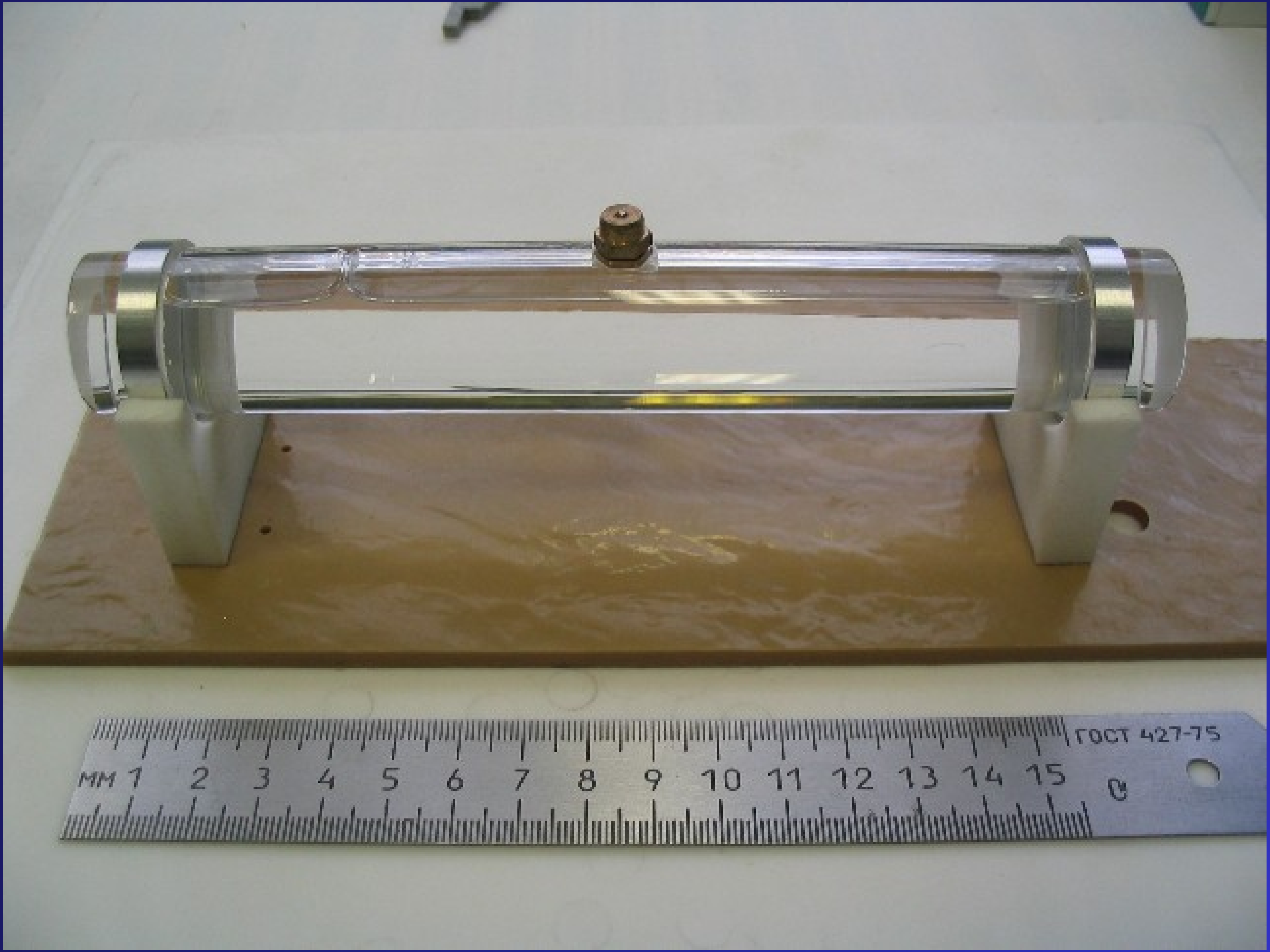
The detector – internal view



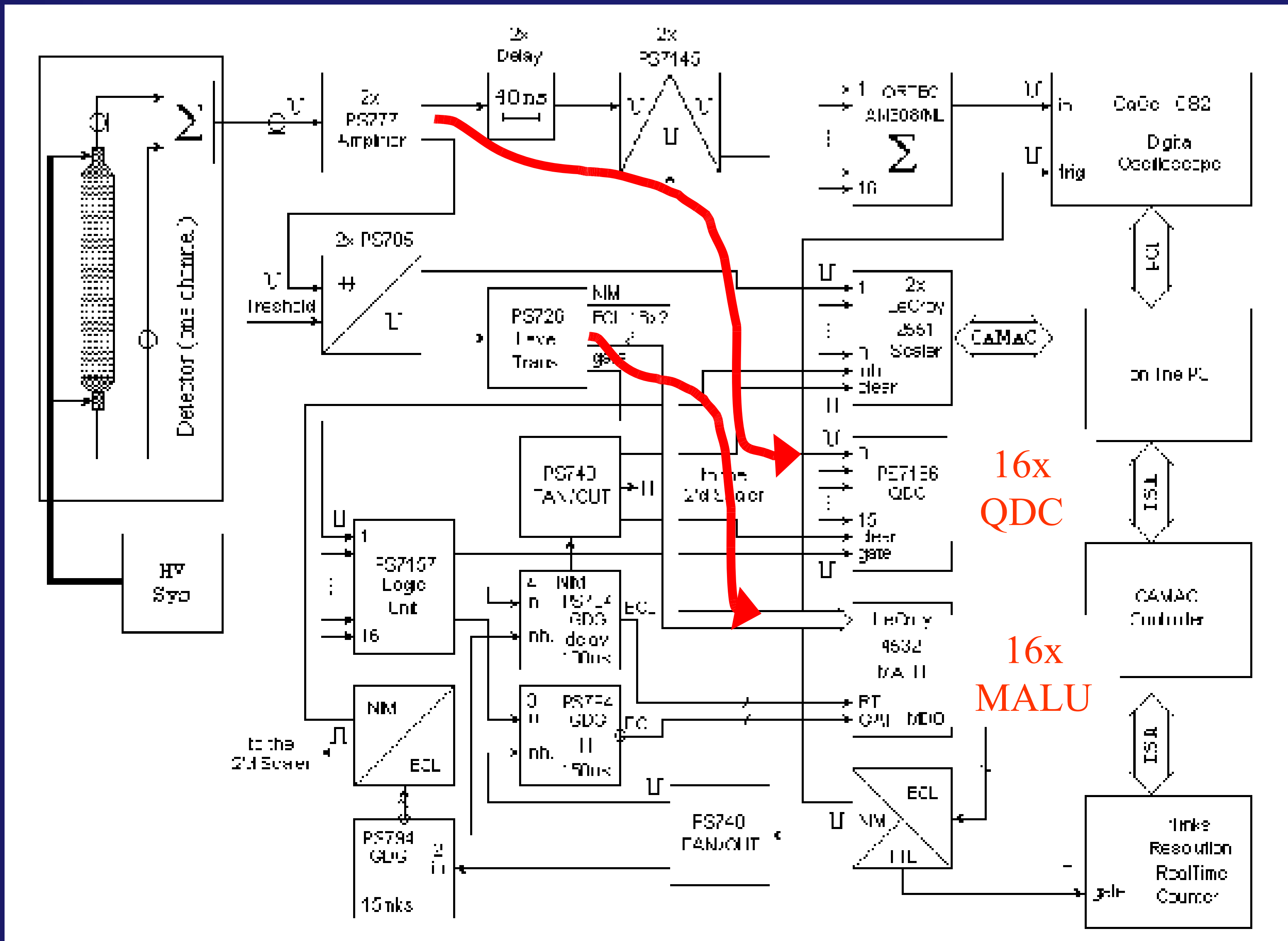
The detector inside



Design of segment

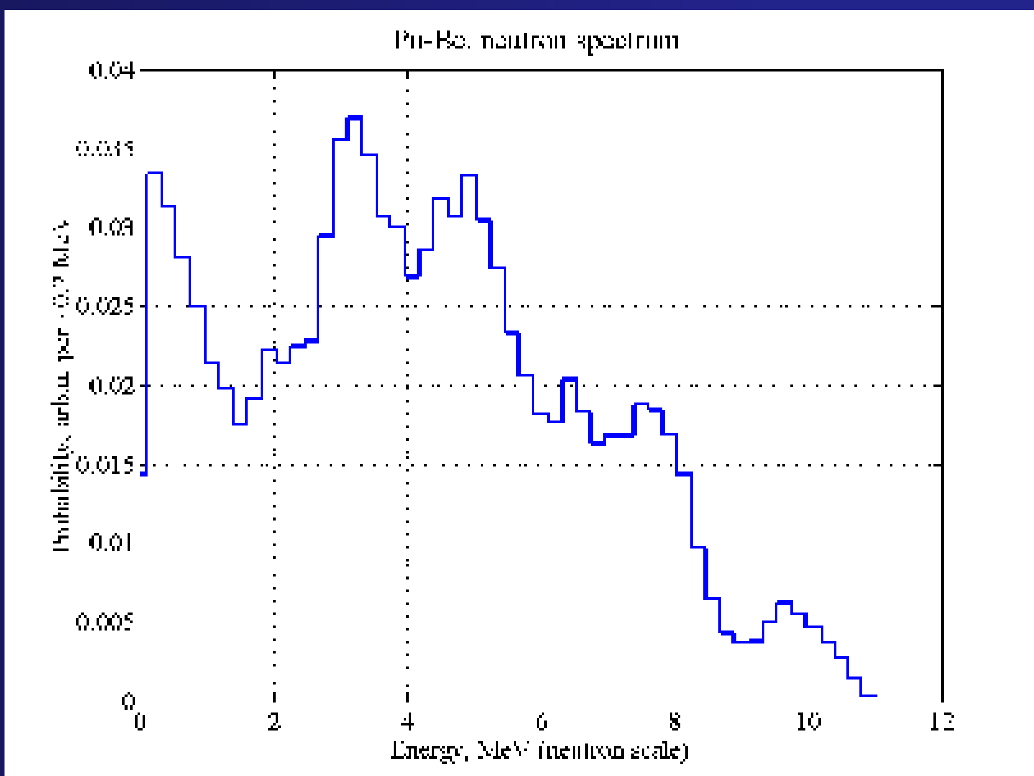


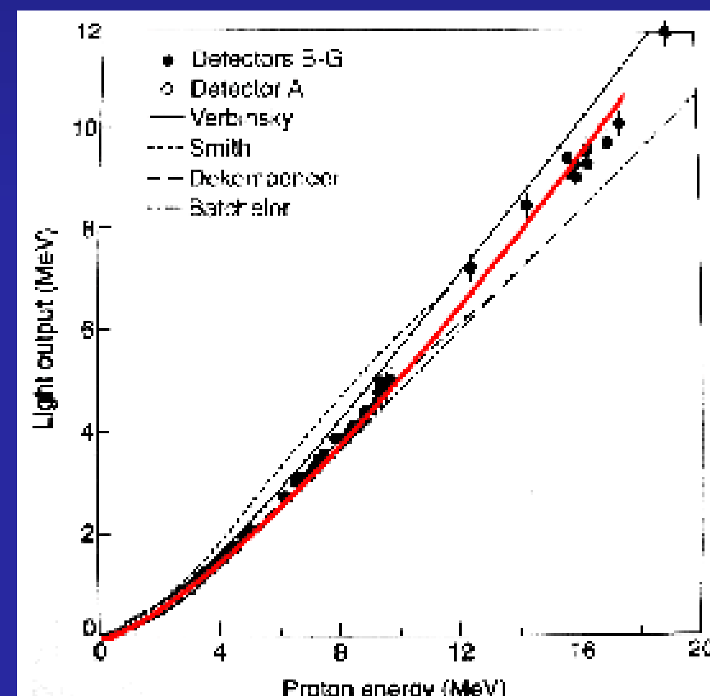
DAQ system. Quasi-capture mode



Sources and shielding

1. ^{40}K – γ-source, 1.46 MeV (C.E. 1.24 MeV), intensity ~10^3 s^{-1}, distance=10 cm
2. Pu-α-Be – n+γ, E_γ=4.44 MeV (C.E. 4.2 MeV), intensity ~10^7 s^{-1}, yield 0.6, d=80 cm,
3. D-T – neutrons, E=14.1 MeV, intensity ~10^3 s^{-1}, distance 20 cm,
4. Shield - 3 cm W, linear attenuation on 4 MeV gamma - 0.05





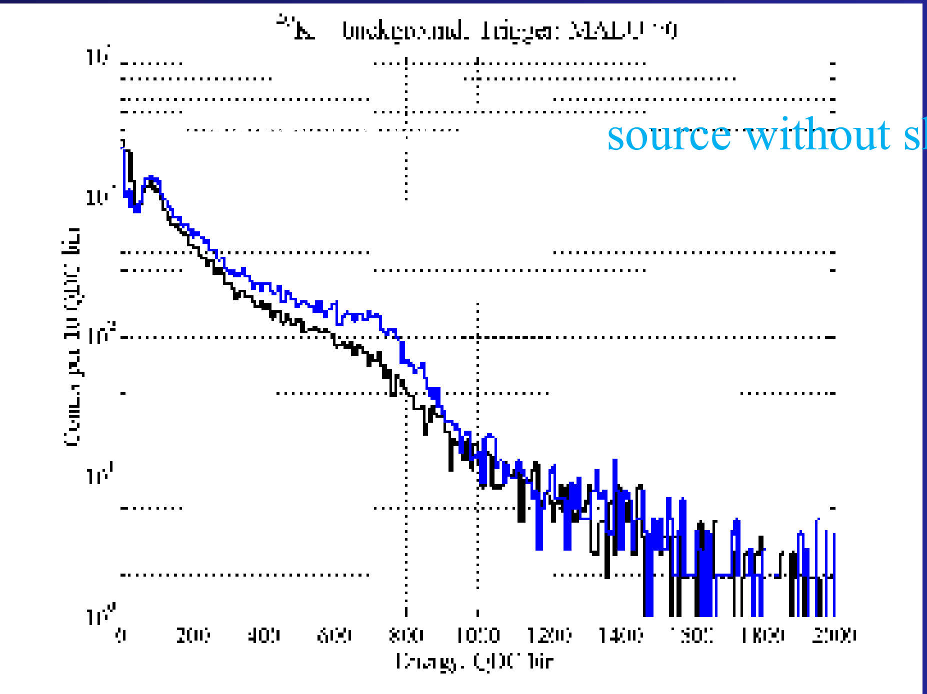
Trigger: >0 hit segments, electron scale

Calibration: Compton edge ^{40}K 1.24 MeV – 700 chn QDC = 1.8 keV/chn

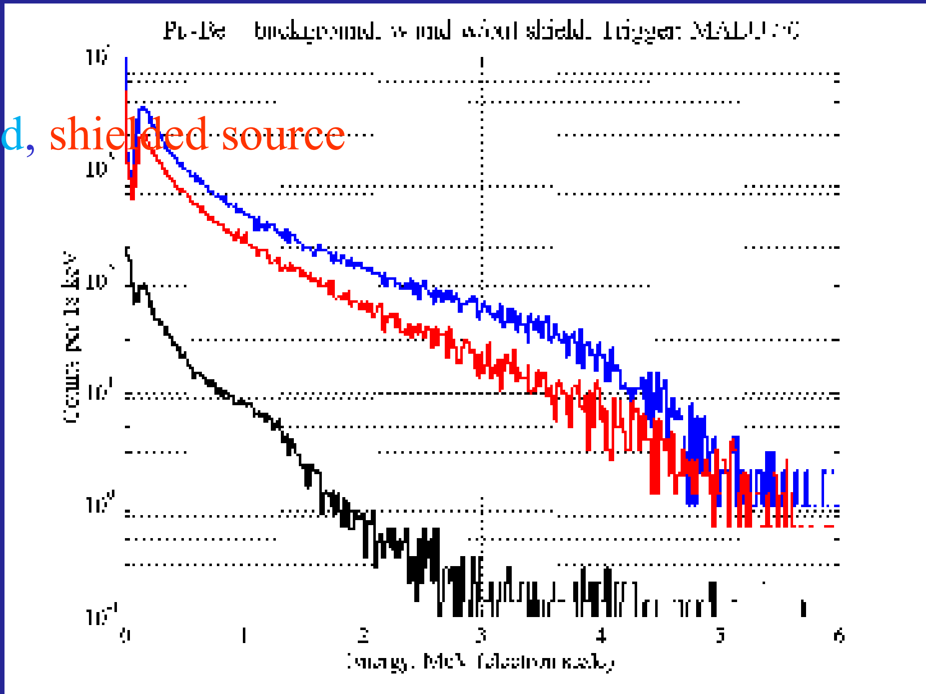
Threshold: [50 chn QDC] = [90 keV, electron scale] = [630 keV, proton scale]

Compton edge of 4.44 MeV located at 4.2 MeV – in good agreement with ^{40}K calibration

The edge of recoil pulse height spectrum is ~5 MeV ee, or ~10 MeV proton scale



source without shield, shielded source

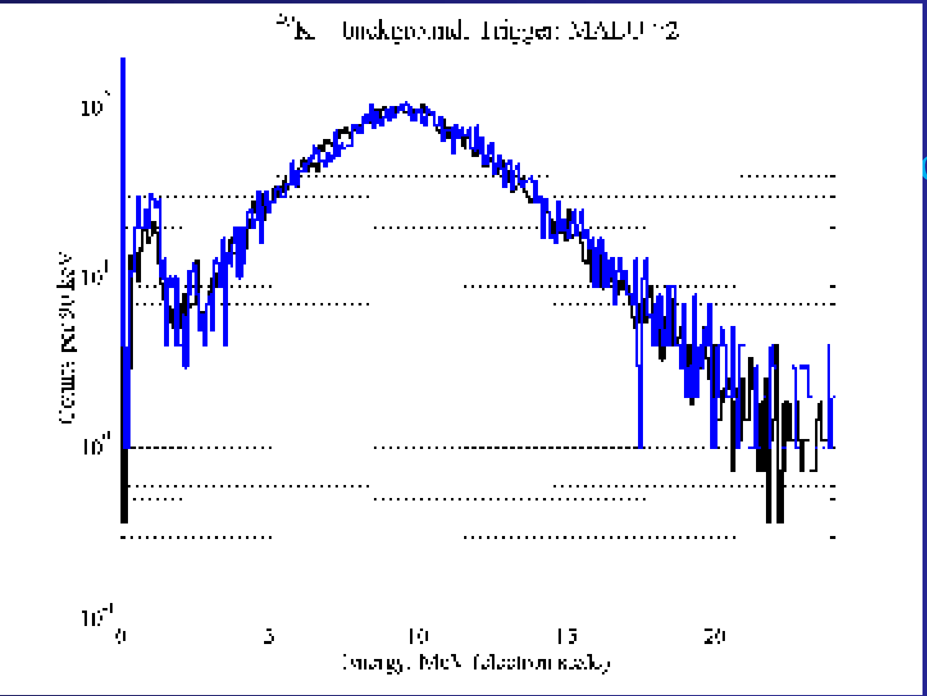


Trigger: >2 hit segments, electron scale

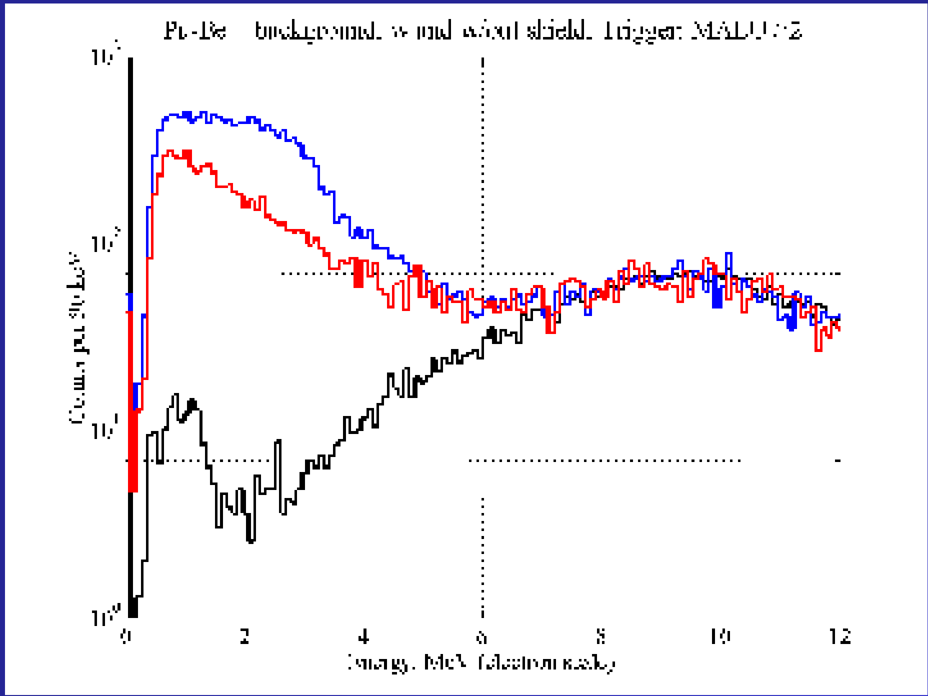
Segment threshold: [90 keV, electron scale] = [630 keV, neutron scale]

Threshold of sum pulse height spectrum: 270 keV, electron scale

Effective threshold, neutron scale: ~3.0 MeV



out

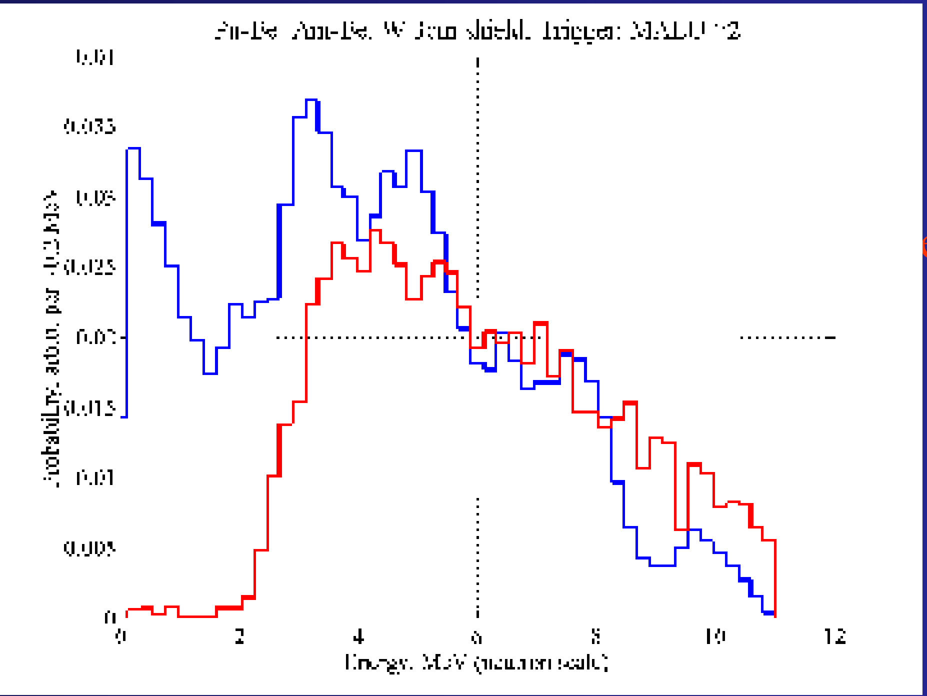


Trigger: >2 hit segments, neutron scale

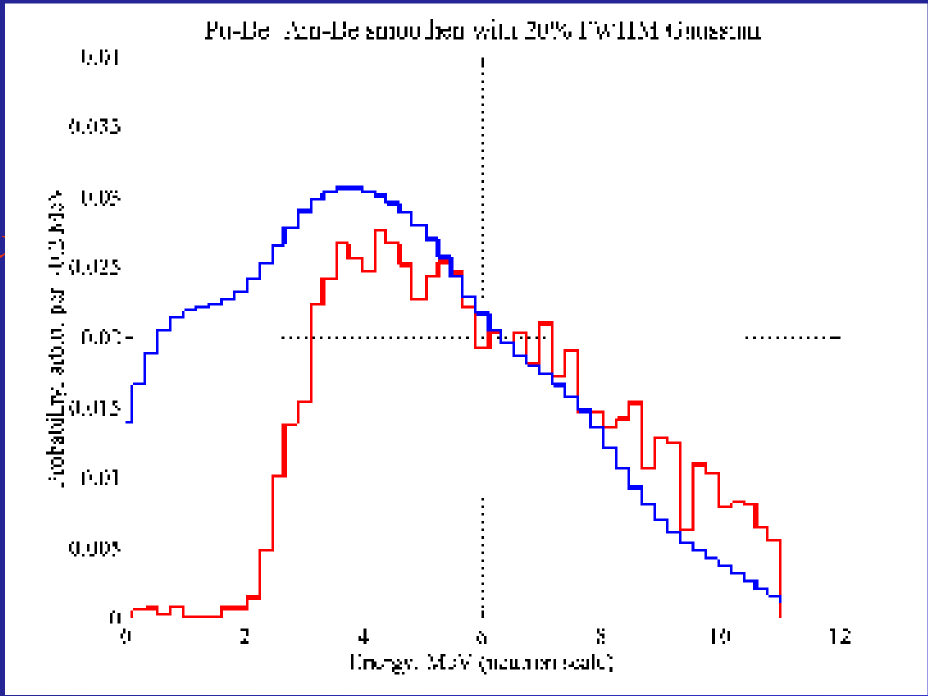
Restore technique: measure individual flashes – calculate individual recoil energies – obtain neutron energy as a sum of recoils

Smooth: Gaussian with FWHM=20% at 8 MeV

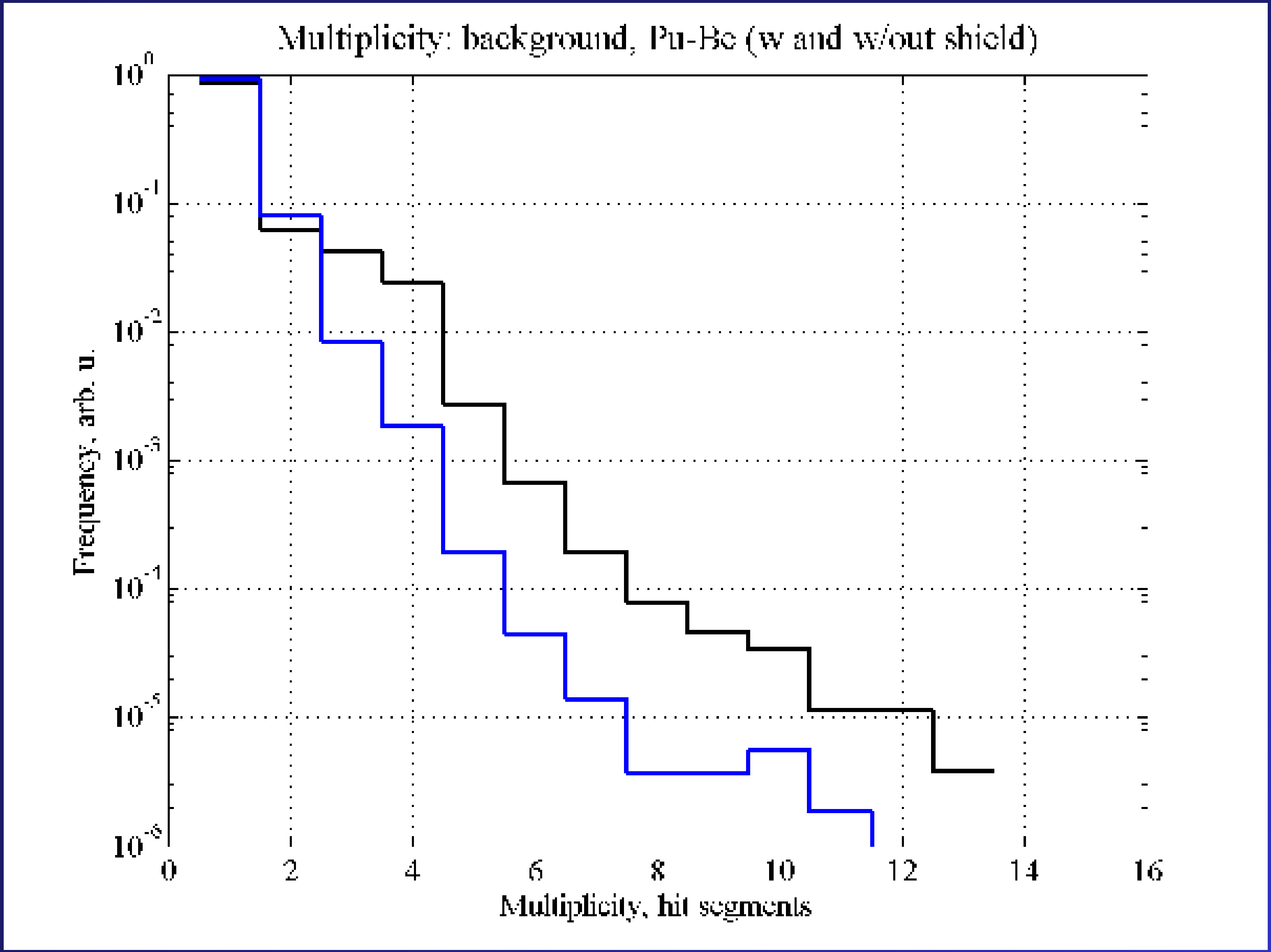
Effective threshold, neutron scale: ~3.0 MeV



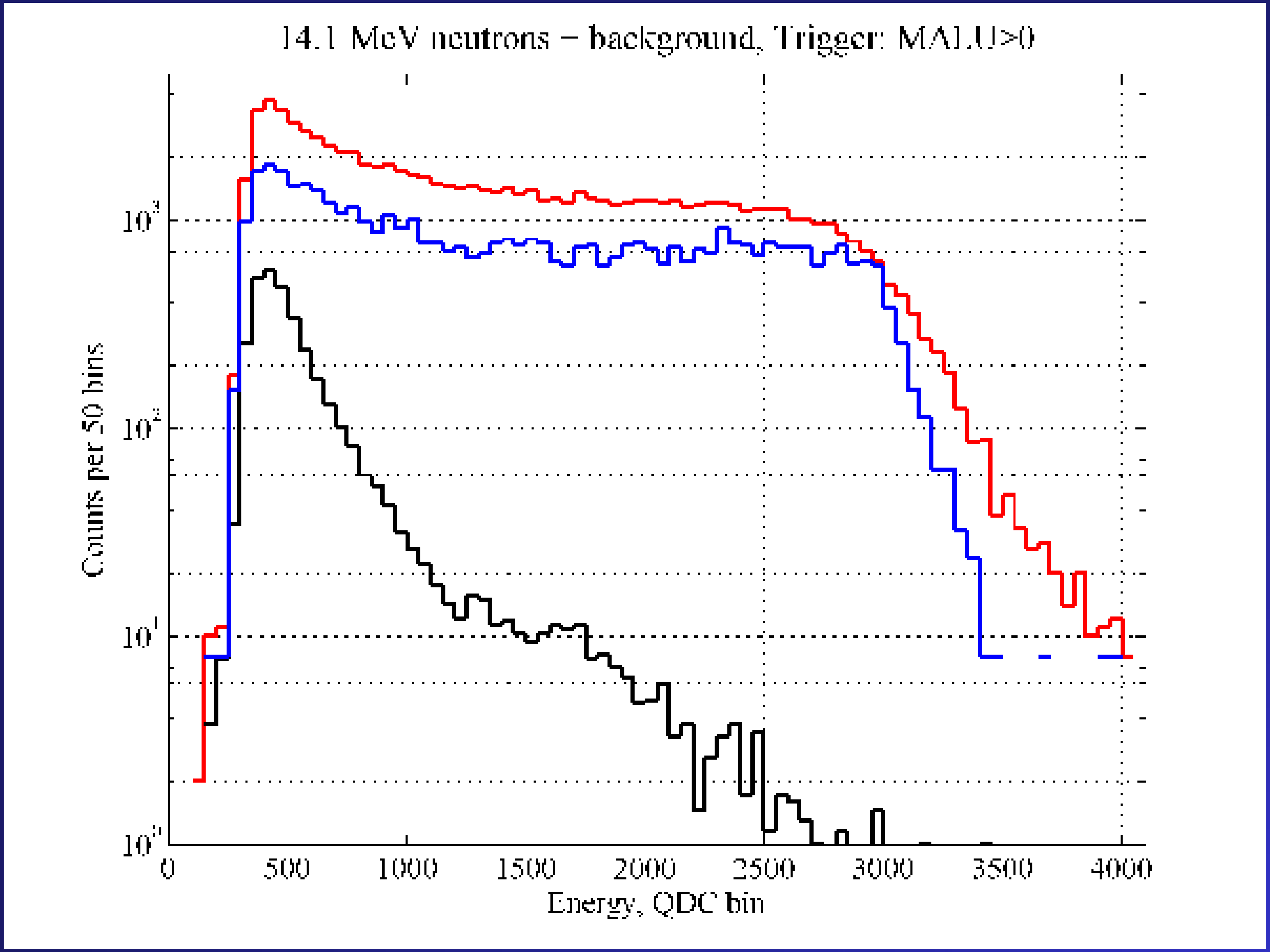
easu



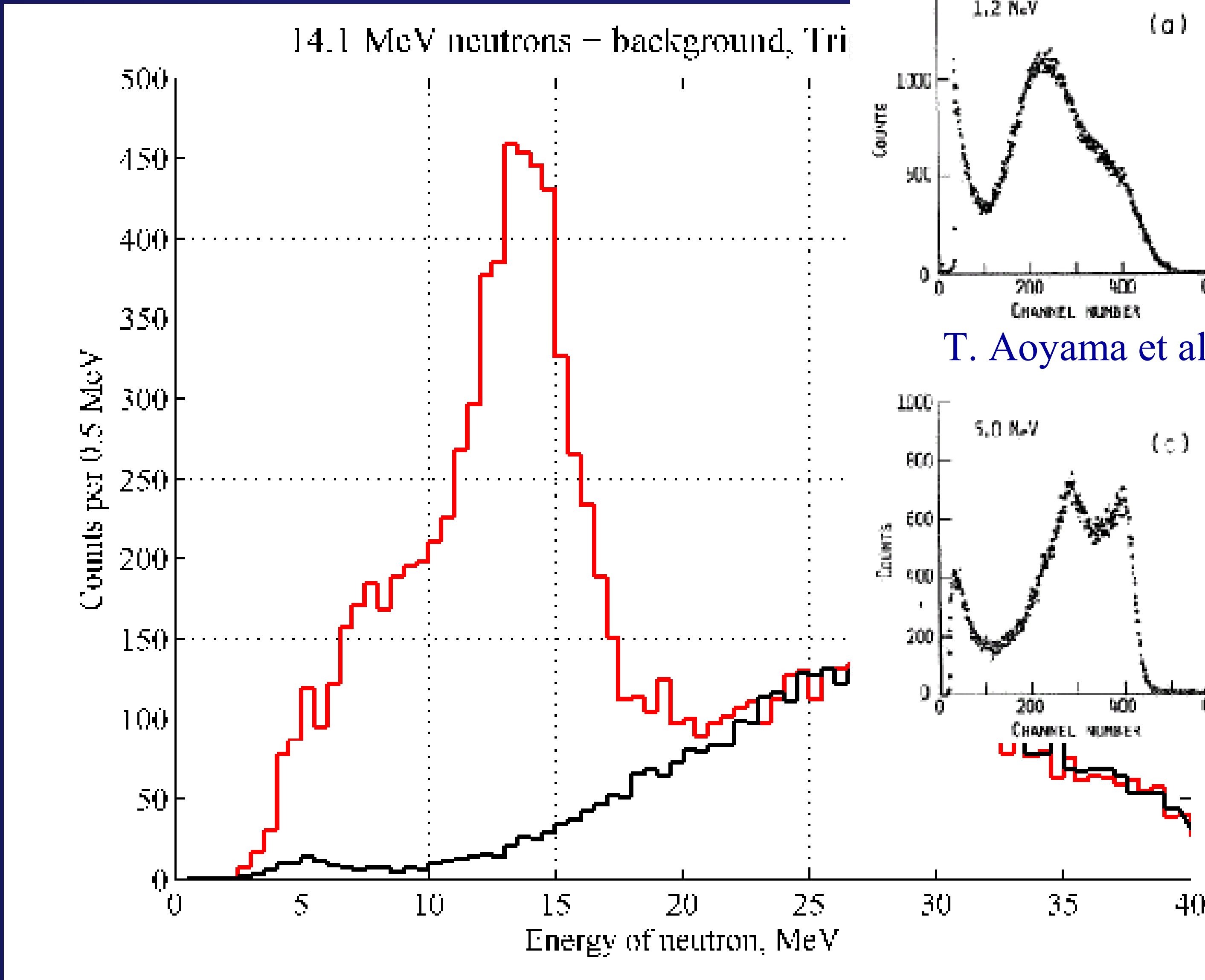
Multiplicity distribution: neutrons (b) & bkg (k)

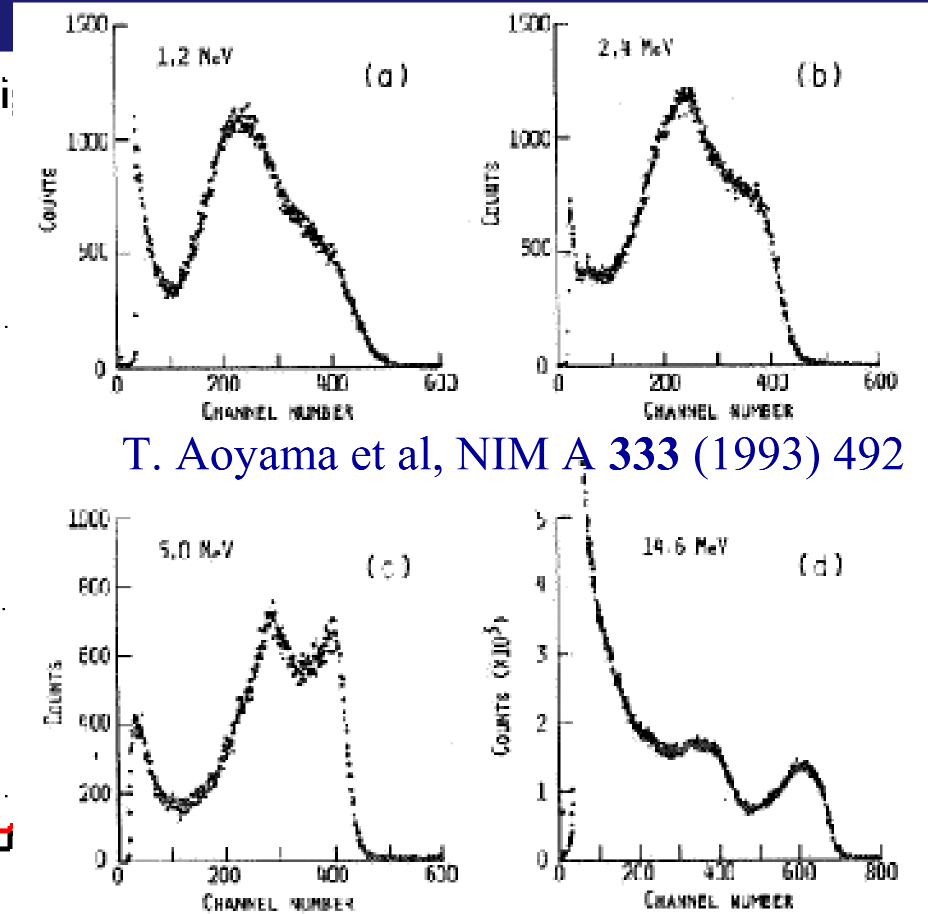


Step response of the detector on 14.1 MeV neutrons



14.1 MeV neutrons energy distribution on cosmic muons background (neutron energy scale)





T. Aoyama et al, NIM A **333** (1993) 492

SUMMARY

- The principle of separate recoils detection is demonstrated
- If applied – fast neutron spectrometry online
- Wide field to improve (PSD, capture gating)
- Pulse height resolution ~15-20% at 14 MeV is expected
- Efficiency – 0.1-1% in 1-20 MeV