The effect of pulse pileup from proton recoils

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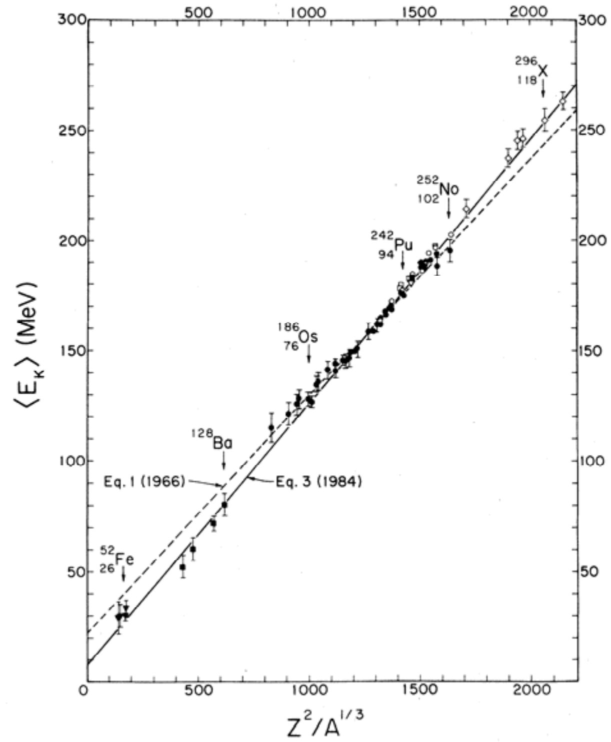
Overview

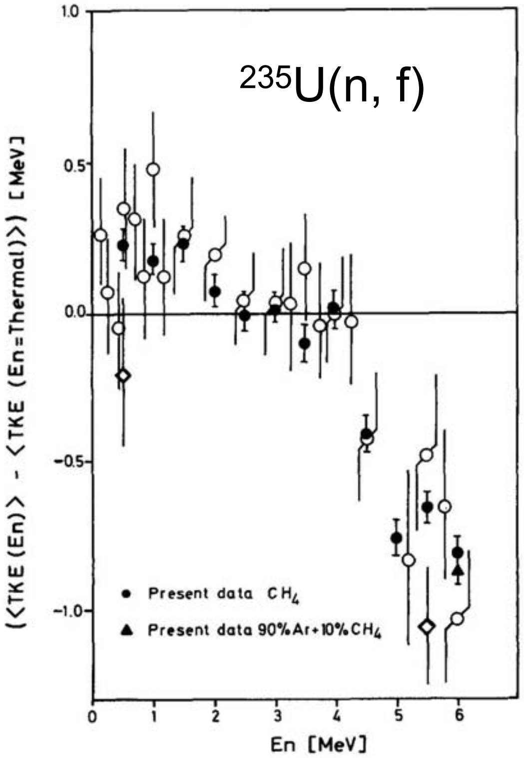
- Fission
- Fission fragment detection techniques
- Pulse pileup
- Calculation of pulse pileup

Total kinetic energy (TKE) in Fission

- $\langle TKE^* \rangle = (0.1189 \pm 0.0011)\, Z^2/A^{1/3} + (7.3 \pm 1.5)$ MeV
- TKE depends mainly on the Coulomb repulsion but also on the excitation of the fissioning system



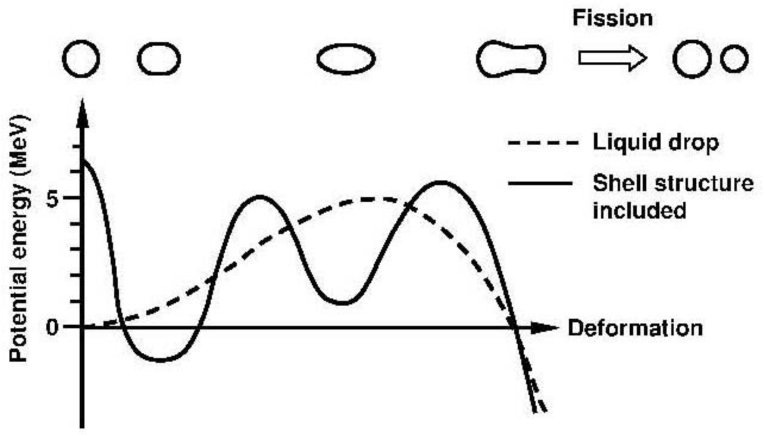
Viola et al. Phys rev. C 31 (1985)



Straede et al. NPA462 (1987) 85-108

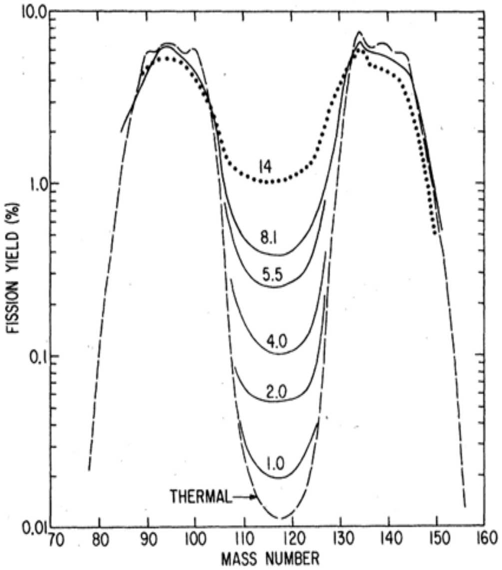
Fission modes

- The actual shape and height of the barrier depends on the deformation. A few pathways in the potential energy landscape leading to fission called fission mode exist.
- Super long (SL) symmetric
- Asymmetric standard 1 and 2 (S1 and S2)
- Probability for symmetric fission increase with excitation. SL increase



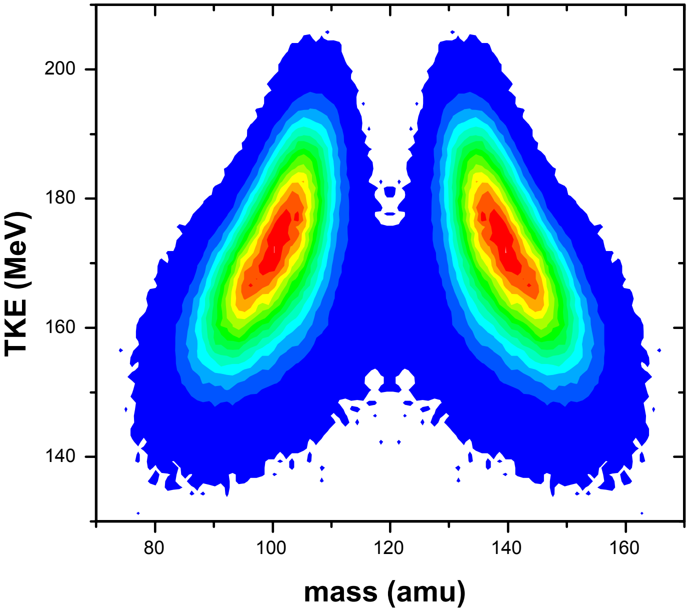
Changes in TKE for ^{235}U(n, f)

- Decrease in TKE for ^{235}U(n, f) as a function of excitation is not because of increased symmetric fission but changed <TKE> for the different mass splits
- The probability that the shape of the fissioning nucleus is more asymmetric and elongated increase as a function of excitation. (higher probability for S2 fission mode)
- Precise knowledge of the TKE is necessary to model the neutron evaporation as a function of excitation of the fission fragments.



^{235}U(n, f)

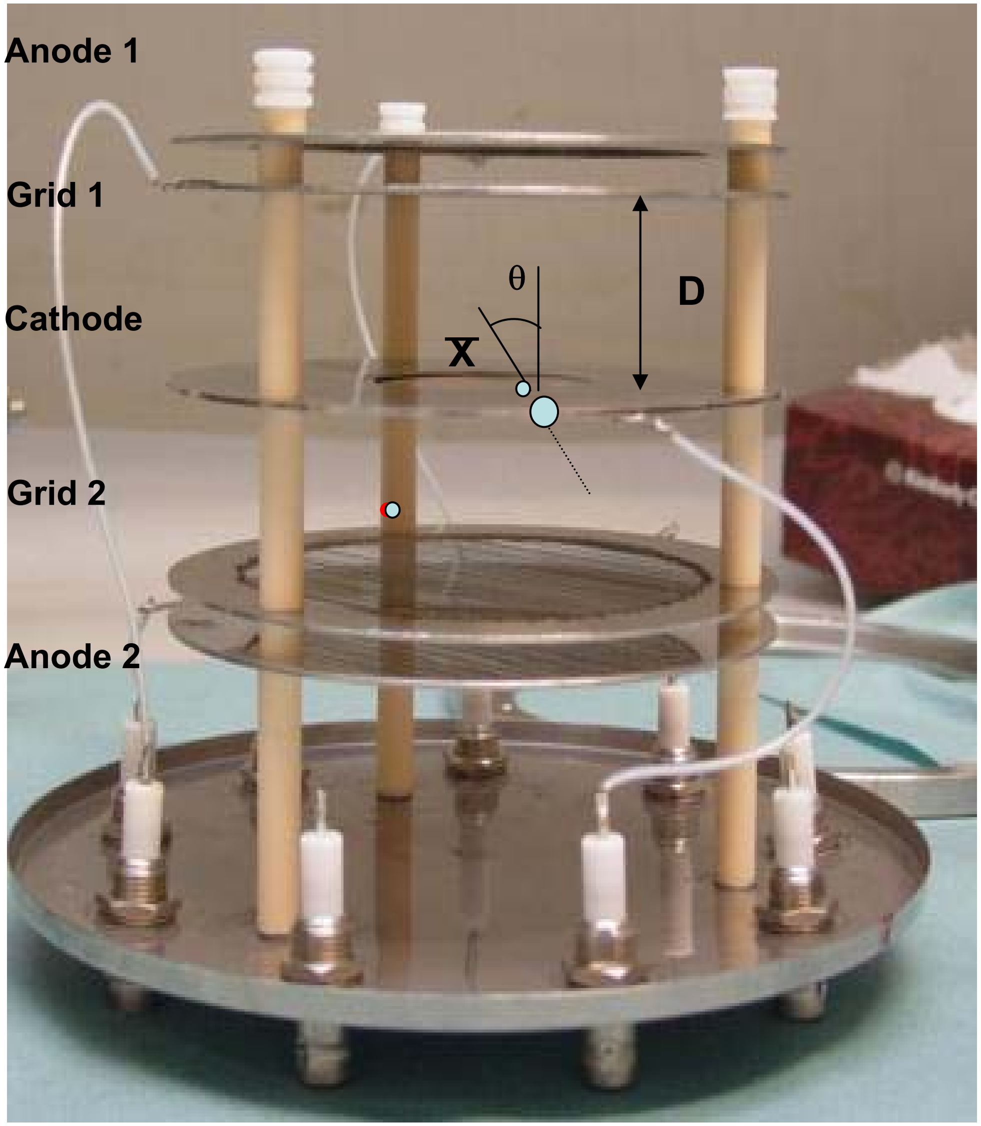
Glendenin et al. Phys rev. C 24 1981

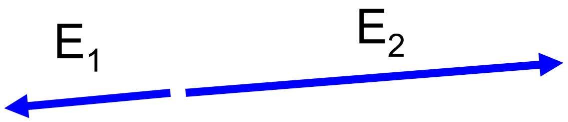


Fission fragment detection techniques

- 2-E method
  - Ionization chamber
  - Solid state ionization chamber
- 2-V method
- Mass spectrometer

Double sided Frisch grid ionization chamber





$$m_1 v_1 = m_2 v_2,$$

$$m_1 + m_2 = m_{CN} \Rightarrow m_1 = \frac{E_2^* m_{CN}}{E_1^* + E_2^*}$$

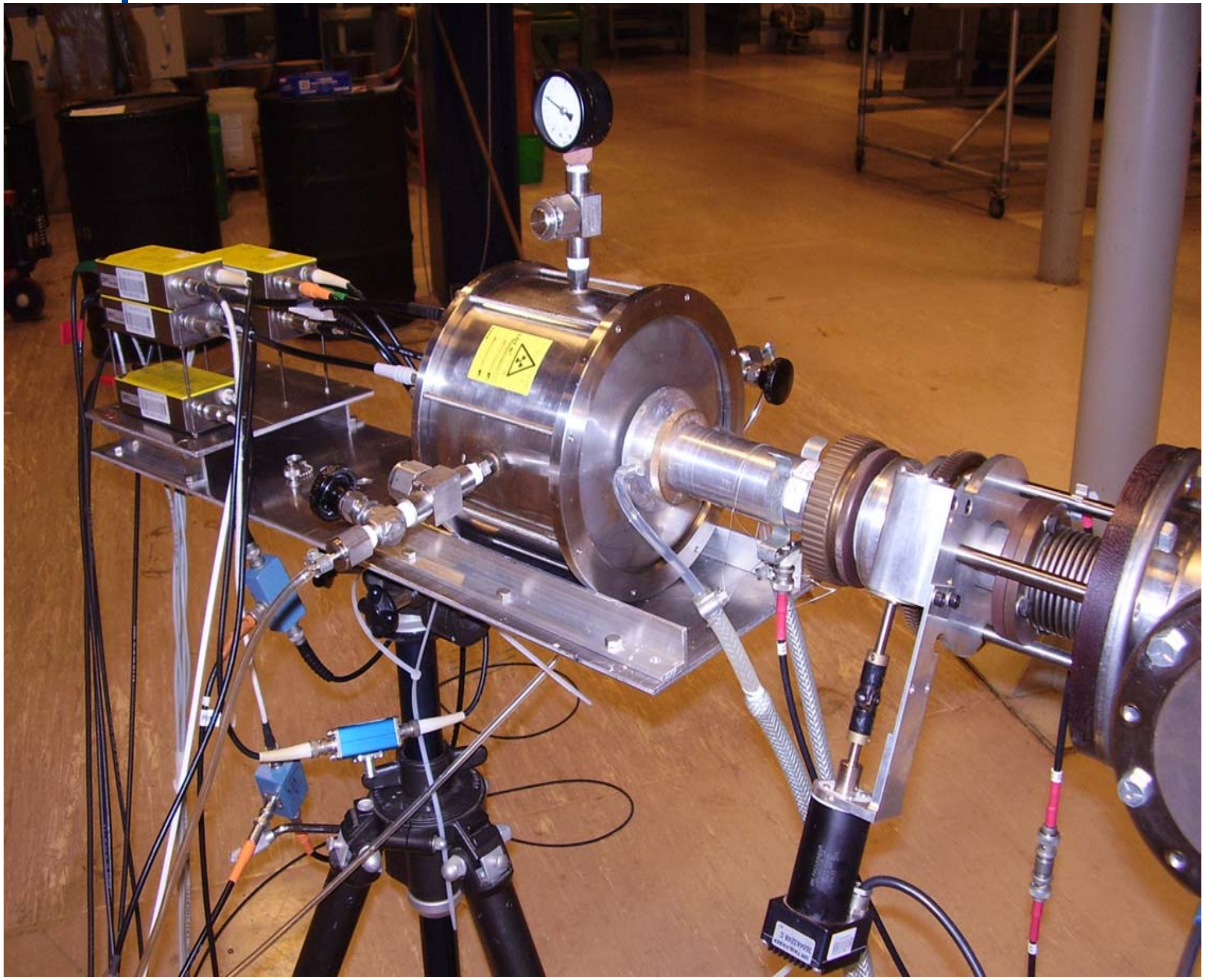
$$TKE^* = E_1^* + E_2^*$$

- P10 gas at atmospheric pressure
- The charge induced on the anode is proportional to the FFs kinetic energy
- A recoiled proton ionizes the gas and adds to the detected signal when they occur in coincidence.

Data corrections:

- Energy calibration
- Energy loss
- Pulse height defect, PHD(A,Z,E)
- Neutron evaporation, “sawtooth” function, ν(A,TKE)
- Iterative analysing technique
- **Proton recoil pileup**

Experiment

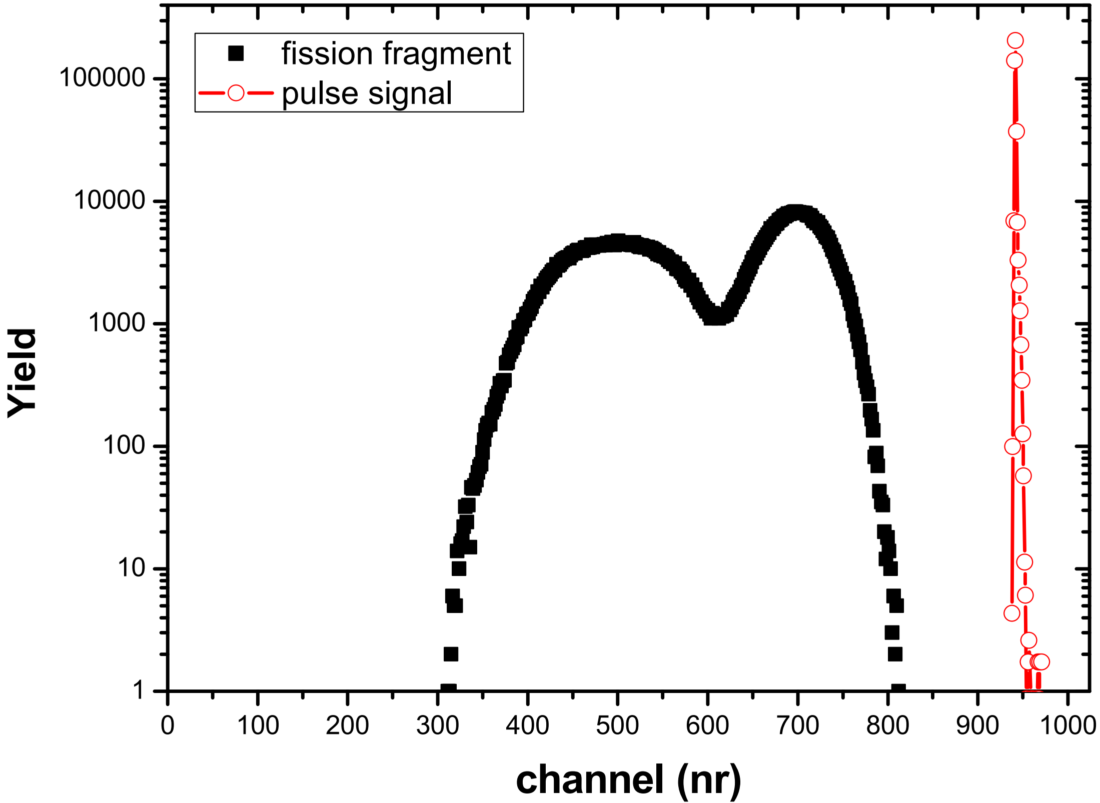


- 7MV Van de Graaff accelerator at IRMM, Geel, Belgium.
- Neutron production:
- $^{7}Li(p, n)^{7}Be$
- $T(p, n)^{3}He$
- Ion current 10-30 μA
- $E_n = 0.9 – 2.0$ MeV
- Pulse signals also put into the pre amplifiers
- Main experiment: $^{238}U(n, f)$

Birgersson et al.
NPA 817 (2009) 1–34

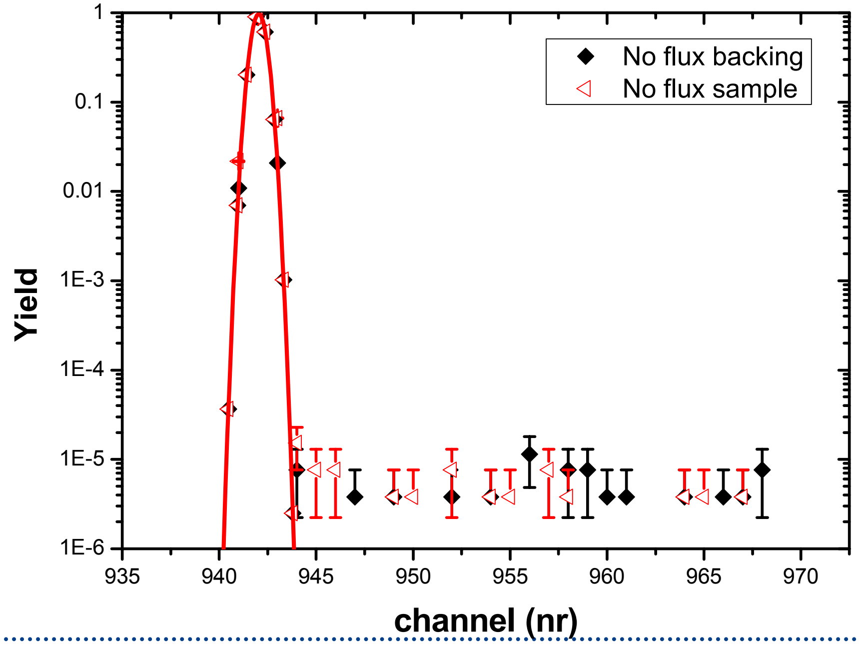
Experimental spectrum

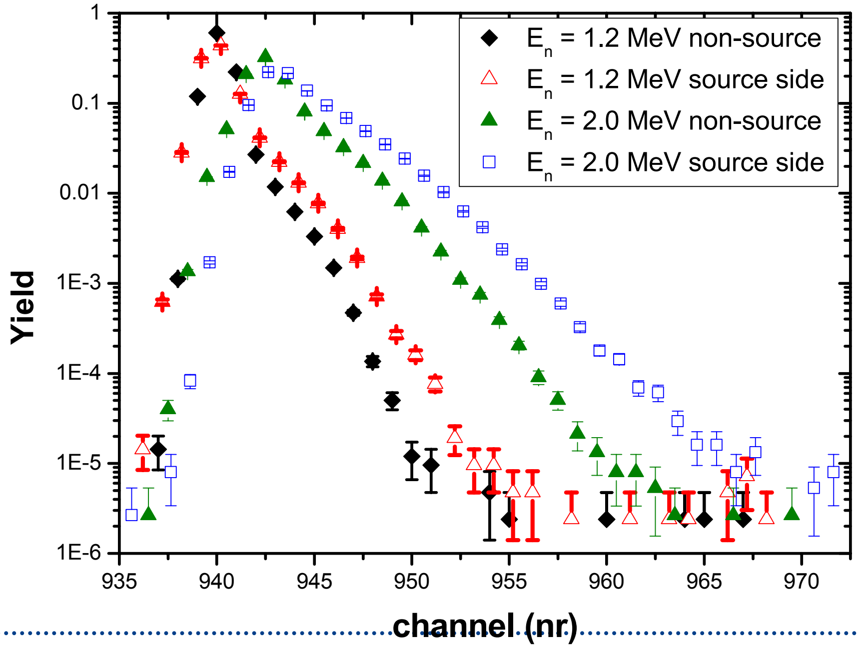
- The pulse signals has approximately the same count rate as the fission fragments and will have the same recoil proton coincidence probability.



Pulse signals in n-fields

- If the pulse pileup comes from recoiled proton pileup, it is clear how to correct the data.
- The increase in measured TKE could then be as large as 0.6 MeV if the n-flux is $2 \cdot 10^5$ n/cm^{2}s at $E_n = 2.0$ MeV using P10 gas.





Overview of the calculation of the pulse pileup spectra

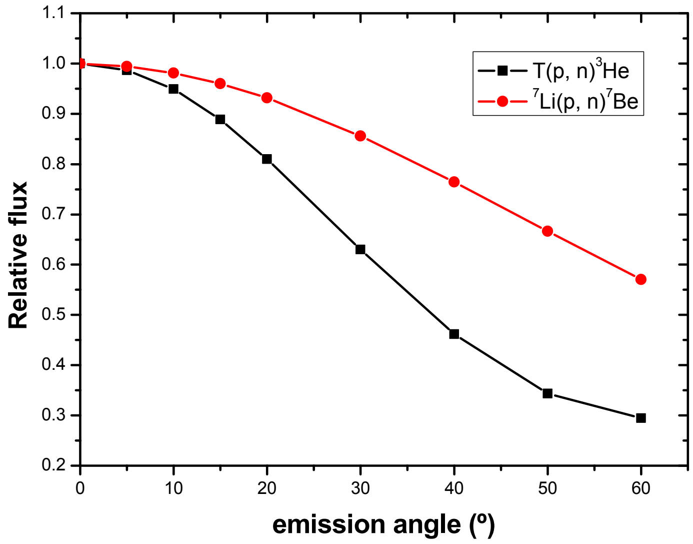
- Calculation of the deposited energy from the recoiled protons in each chamber side

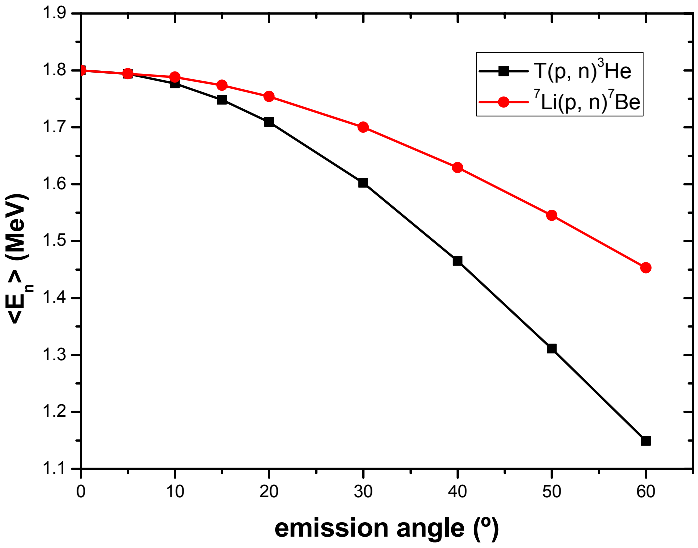
- Estimation of pulse signal shape
  - The probability of r coincidences for a given count rate C_r is given by the Poisson distribution

$$P(r) = \frac{(C_r \Delta T)^r \exp(-C_r \Delta T)}{r!},$$

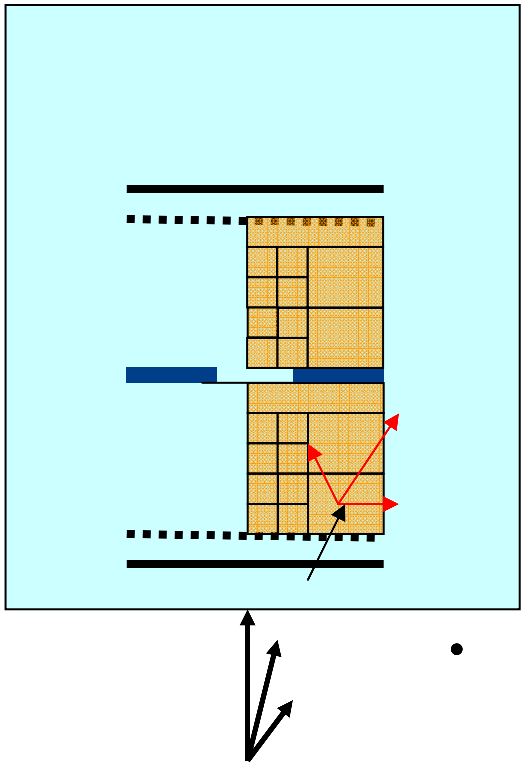
The neutron sources

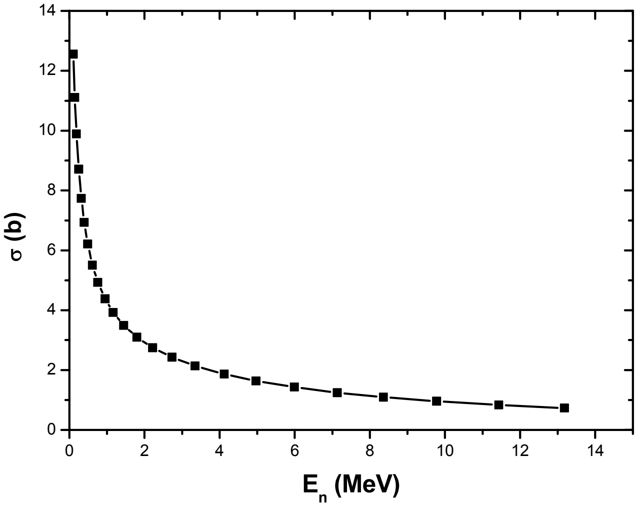
- Neutron flux and energy depends on the neutron emission angle, and reaction



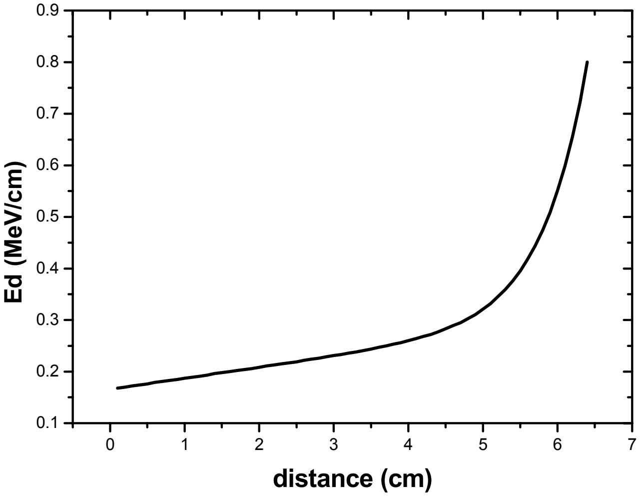


Ionization by proton recoils





Neutron elastic scattering cross section



Ionization by 1.8 MeV Protons in P10 gas

- Proton recoil count rate determined in each segment
  - neutron energy, neutron flux, neutron elastic scattering cross section (isotropic in CM system) and volume of the segment
- $\tan\theta = \sin\theta^{CM}/(1+\cos\theta^{CM})$, $E_p=E_n\cos^2\theta$
- Ionization in sensitive volume (SRIM)
  - Protons might pass the thin uranium layer
- Ionization in region between grid and anode not considered

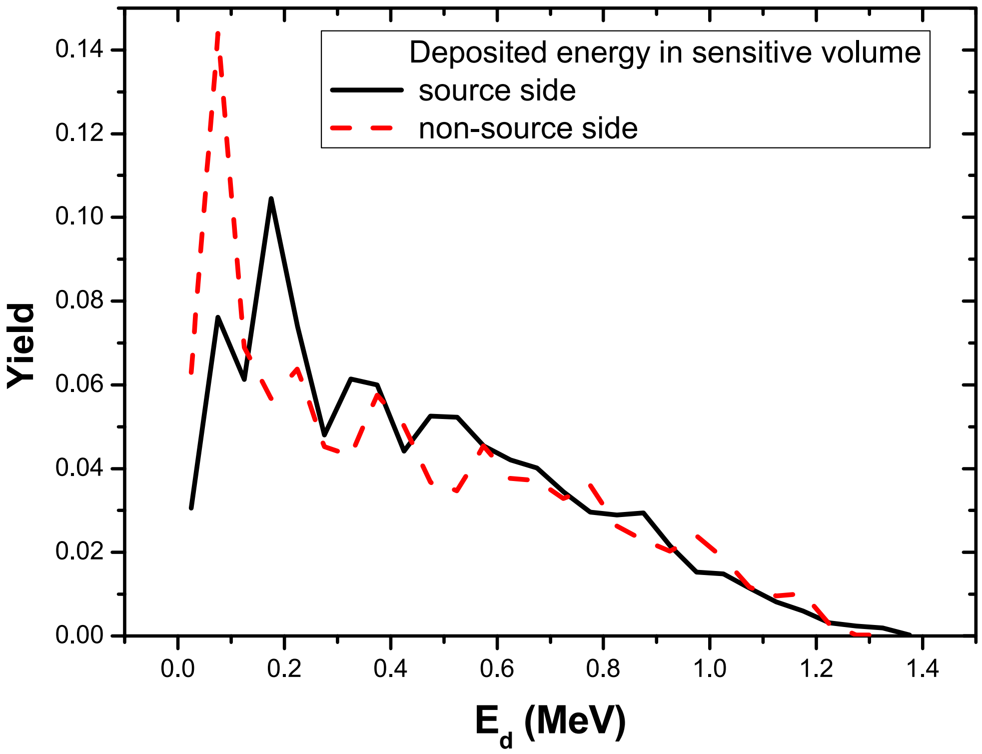
Anode-cathode 3 cm

Anode-grid 0.7 cm

Grid radius 4.5 Cm

Deposited energy spectrum

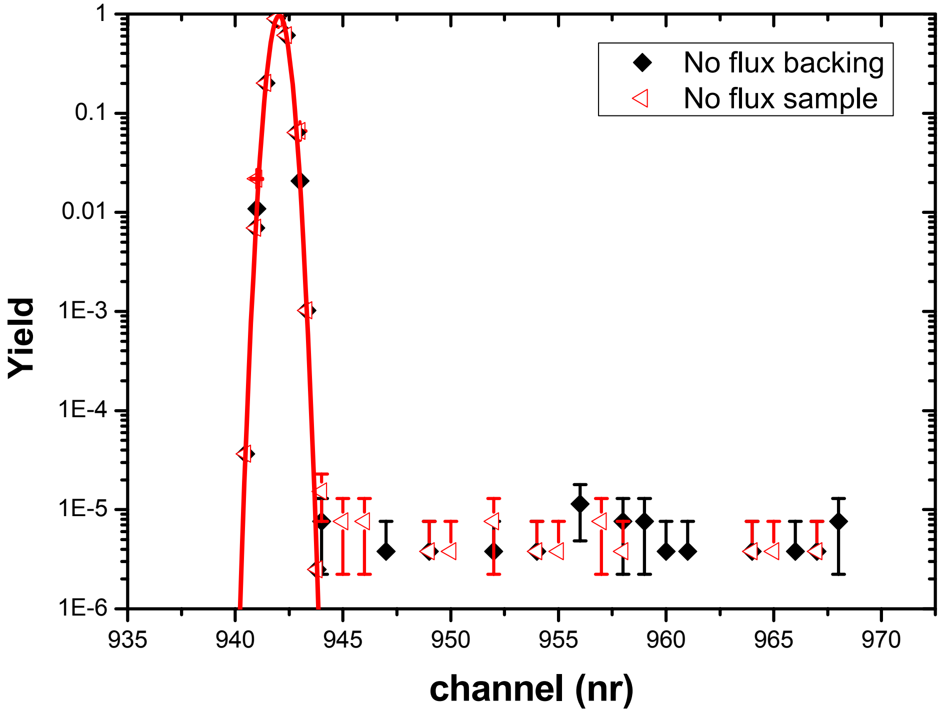
- Based on the n-flux and volume energy spectra from each volume element are scaled and then added to give the deposited energy spectrum for each chamber half

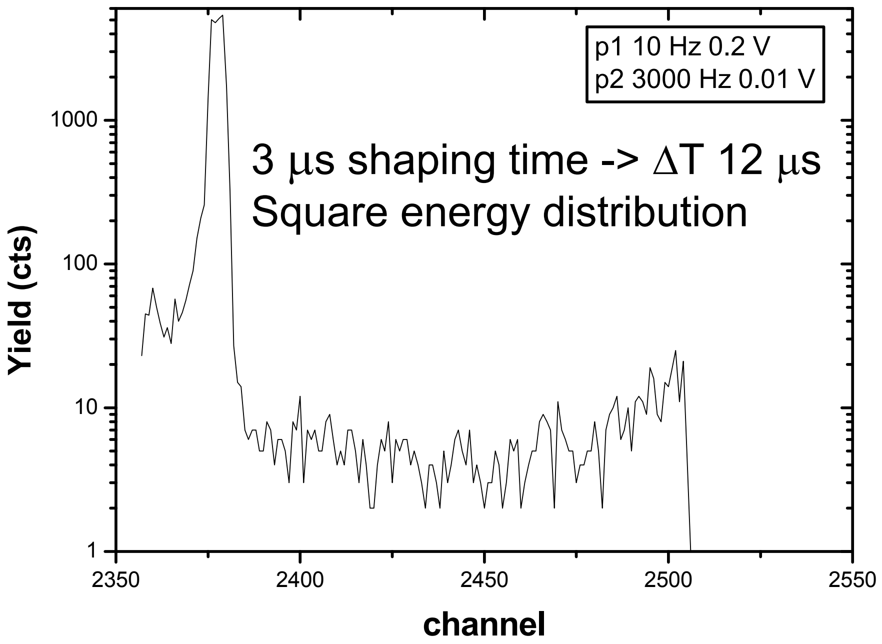


LiF target

E_n = 1.8 MeV

Pulse signal shapes





3 µs shaping time -> ΔT 12 µs
Square energy distribution

Alpha activity 11 Bq

Probability of coincidence in one chamber half 6.6E-5. Above is seen (4.6 ± 1.3)E-5

Channel 969 would correspond to 4.2 MeV, Which is the energy of the alpha from ^{238}U

Alpha pileup not a problem for constant alpha count rates, Demattè et al. NIM A480 (2002) 706

Two pulse signals were added

- 10 Hz 0.2 V signal seen at CH 2375.
- 3000 Hz 0.01 V (below threshold)
- 0.21 signal should be at CH 2375/0.2*0.21=2494
- ΔT = Coincidence Cr/(C1*C2)= 11.3 ± 0.4 µs

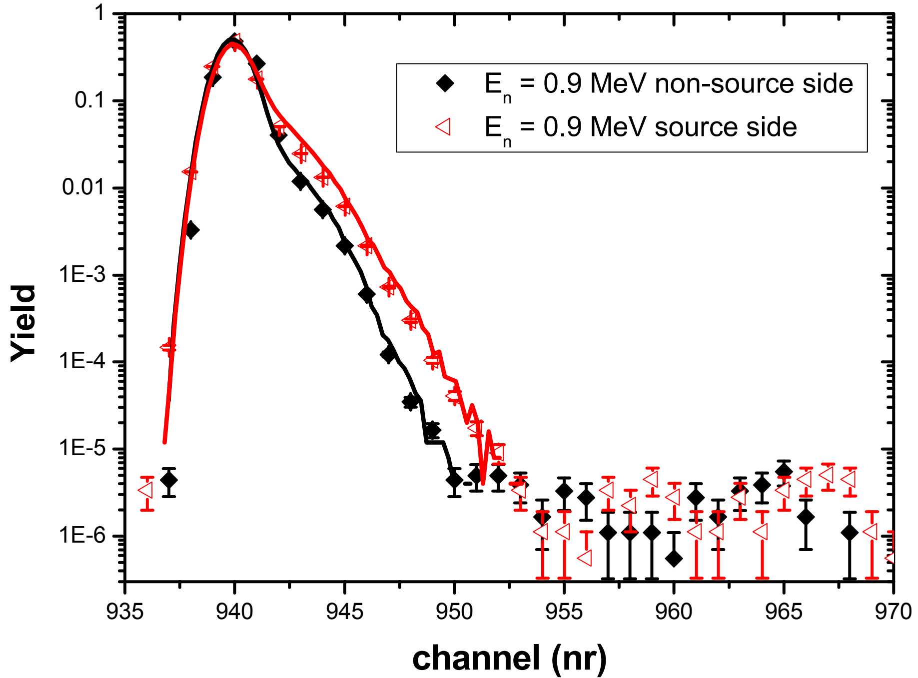
Coincidence spectrum

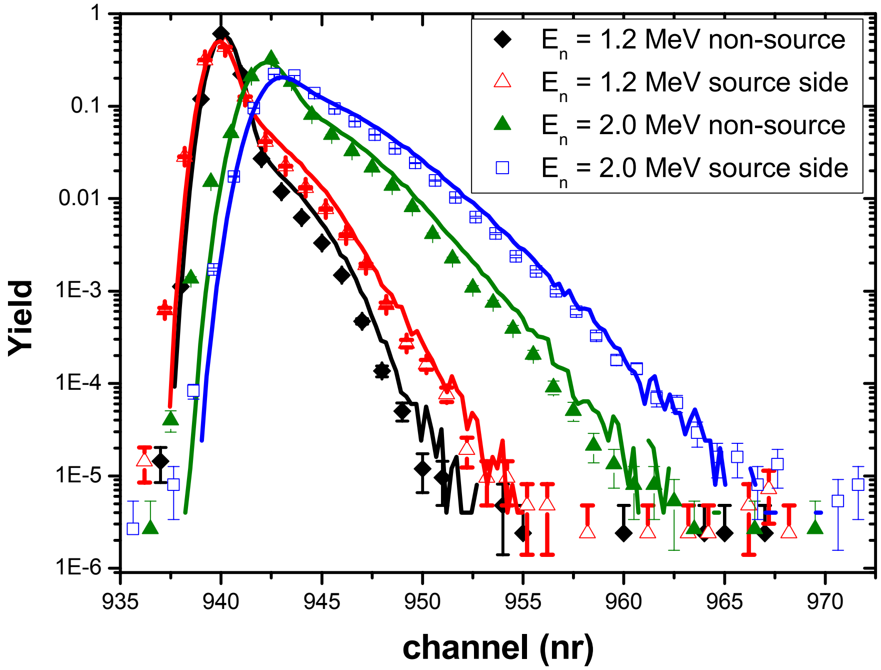
- The count rate from proton recoils in each chamber half is known.
- Gaussian shaped pulse signal (adjusted peak and width)
- Pulse signal spectrum including the pile up determined by Monte Carlo simulation
  - For a fixed number of pulse signals (10^6) the channel number was simulated
  - Based on Poisson statistics the number of signals with 0, 1 ,2 , and so on coincidences. Was determined. The Shaping time of the amplifier was 3 μs and a time window of 12 μs was assumed.
  - One randomized pulse signal is sampled according to

$$Ch = G(s1) + \sum_{x=1}^{n} E_x(s2) \cdot F(s3) \frac{1}{Ch2MeV}$$

  - Number of coincidences is n
  - G(s1) is sampled from a Gaussian distribution
  - E(s2) is sampled from the determined energy spectra
  - F(s2) is sampled from a square distribution

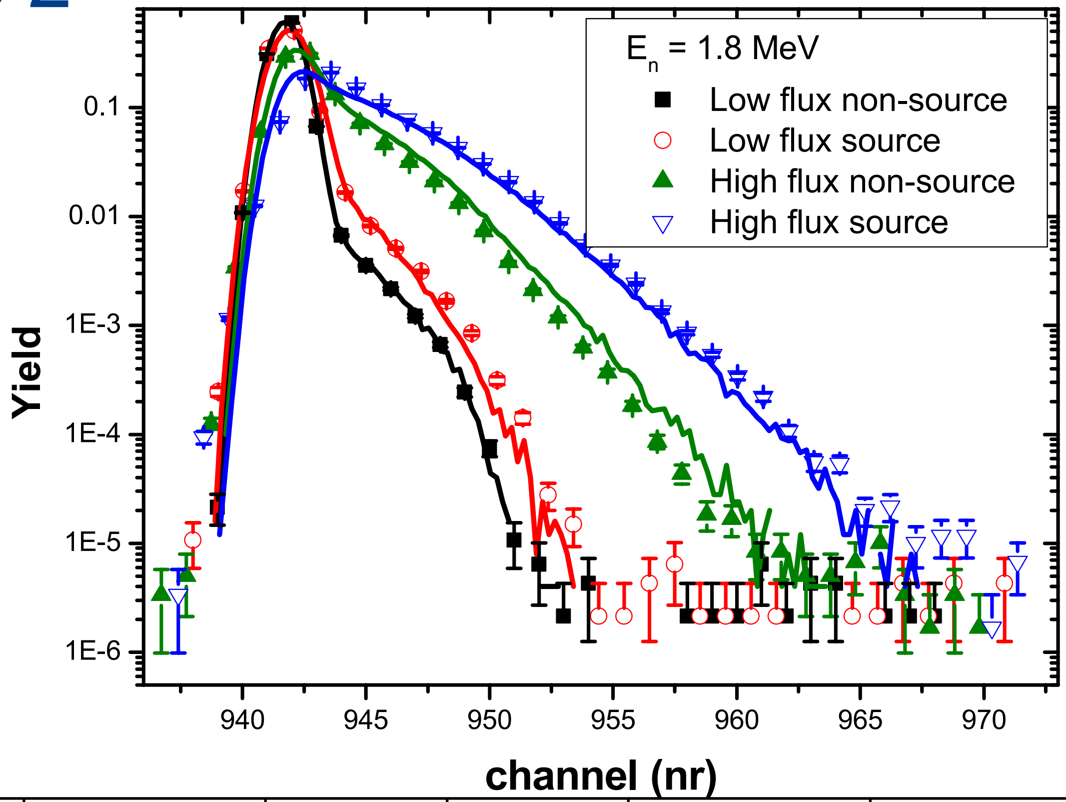
Results 1





E_n centre (MeV)	Target	Target thickness µg/cm²	Ion current (µA)	N-flux at centre (n/cm²s)	non source side (recoils/s)	Source side (recoils/s)	ΔE Non source (MeV)	ΔE Source (MeV)	ΔTKE (MeV)
0.9	LiF	445	45	4.84E4	18300	43200	0.036	0.089	0.13
1.2	LiF	445	36	3.0E4	18300	43000	0.041	0.11	0.15
2	TiT	2083	30	2.05E5	81200	150000	0.22	0.40	0.63

Results 2



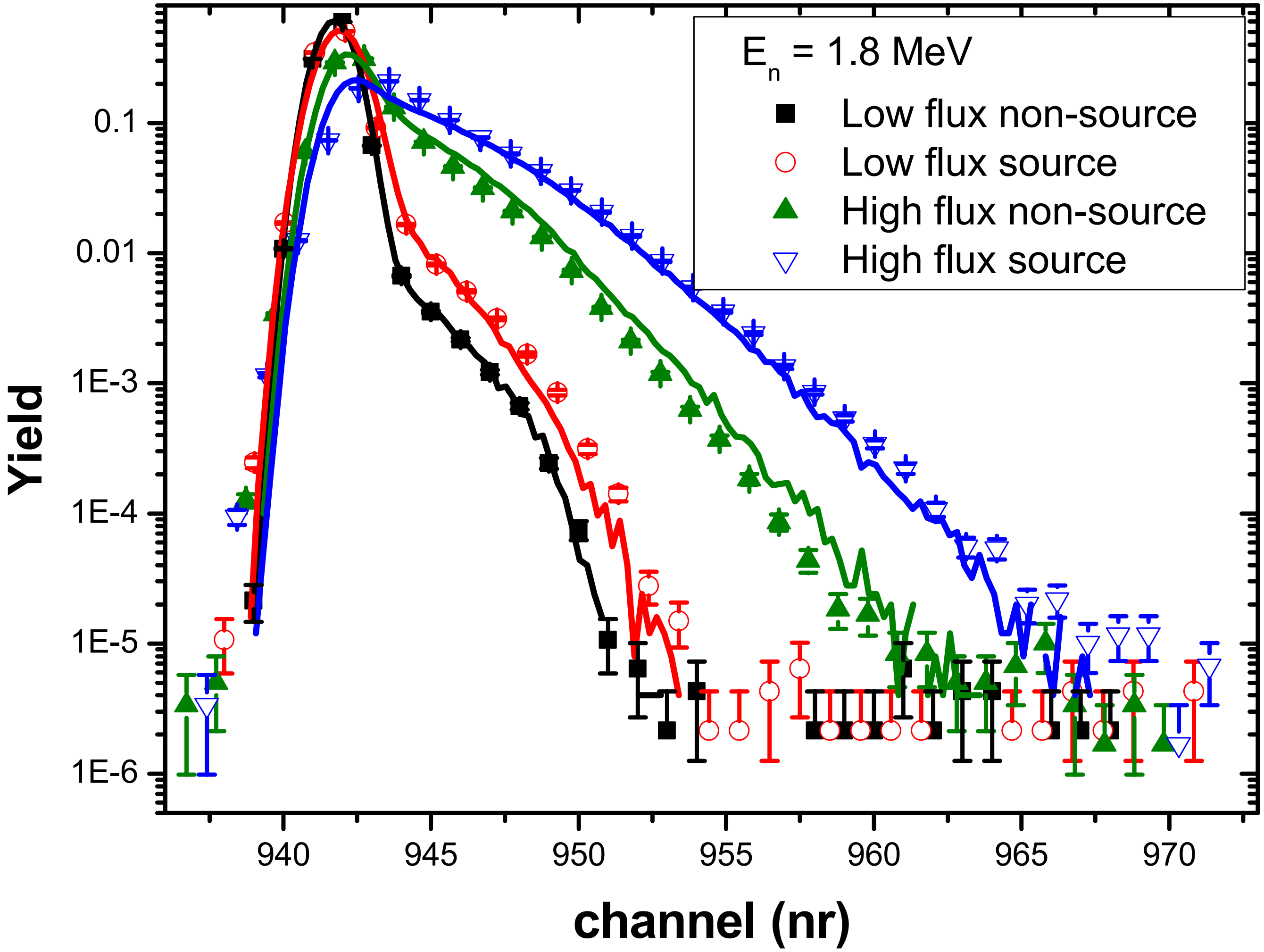
E_n centre (MeV)	Target	Target thickness μg/cm²	ion Current (μA)	N-flux at centre (n/cm²s)	non source side (recoils/s)	Source Side (recoils/s)	ΔE Non source (MeV)	ΔE Source (MeV)	ΔTKE (MeV)
1.8	LiF	445	11	7.71E3	4200	9300	0.011	0.025	0.036
1.8	TiT	2083	33	2.1E5	90400	167300	0.26	0.46	0.72

Coincidence from prompt neutrons?

- The prompt neutrons emitted from the fission fragments will also go through the chamber gas
- It they make elastic scattering on the protons this will also add to the pulse pileup
- However the probability that this happens is only once per every 3000 fissions

Summary

- Pulse pileup from proton recoils in an ionisation chamber can easily be observed using pulse signals
- It is not possible to determined if a single fission fragment event has had any pileup. The fission fragment average energy has the same pulse pileup as the pulse signal
- Correction has to be performed when measuring with different pileup contributions.
- It is possible to calculate very accurately the pulse signal shape



E_n = 1.8 MeV
■ Low flux non-source
○ Low flux source
▲ High flux non-source
▽ High flux source
Yield
0.1
0.01
1E-3
1E-4
1E-5
1E-6
940
945
950
955
960
965
970
channel (nr)