Measurement of the neutron detection efficiency of the KLOE calorimeter

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Why neutrons at KLOE ?

- Detection of **neutrons of 10^1-10^2 MeV traditionally performed with organic scintillators**: **efficiency** scales with thickness ⇒ **1%/cm**
- Use of **high-Z material improves neutron efficiency**

(C.Birattari et al., NIM A297 (1990) and NIM A338 (1994)

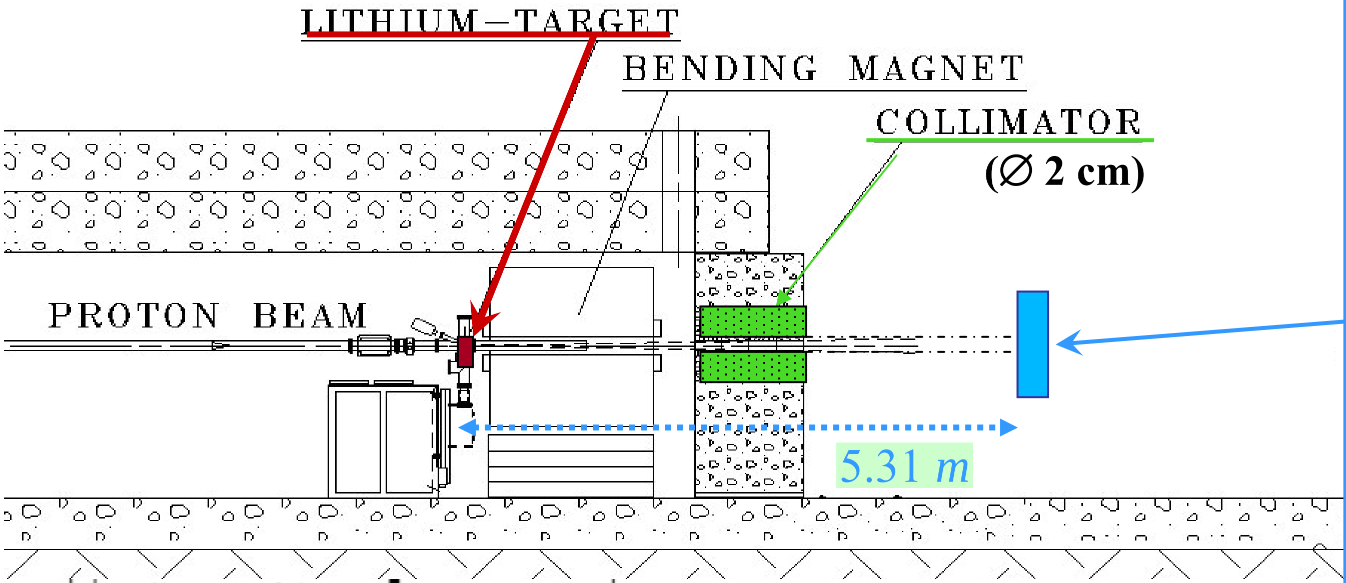
T.Baumann et al., NIM B192 (2002))

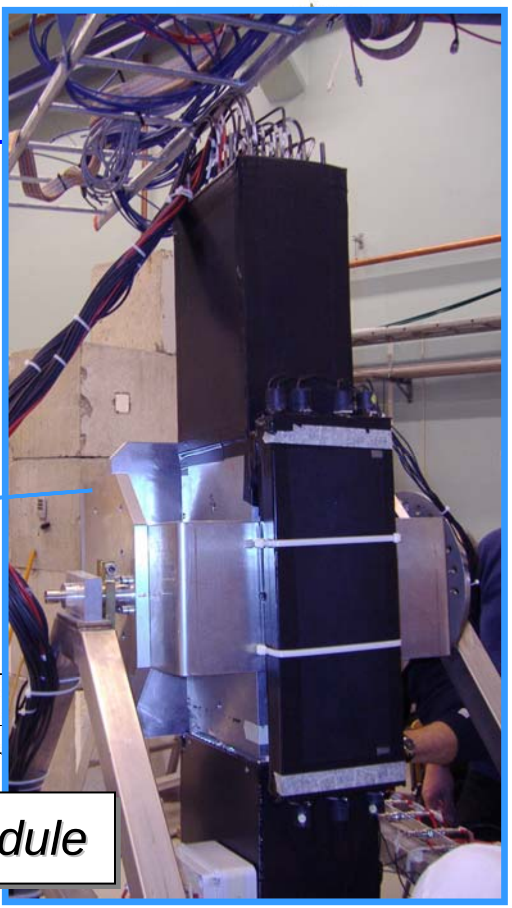
- Preliminary estimate with **KLOE data** (*n* produced by K^- interactions in the apparatus) shown **high efficiency (~40%)** for neutrons with $E_n < 20$ MeV, **confirmed by the KLOE MC**
- *n* detection is relevant for the **DAΦNE-2 program at LNF**; two proposals:
  - search for deeply bounded kaonic nuclei (AMADEUS)
  - measurement of the neutron time-like form factors (DANTE)

Tests have been performed with the neutron beam of the The Svedberg Laboratory in Uppsala

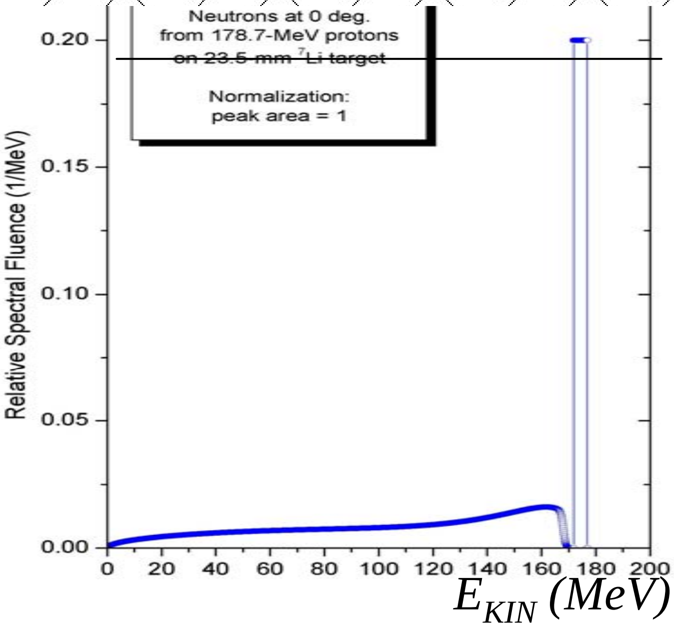
(October 2006 and June 2007)

The neutron beam @ TSL





KLOE calorimeter module



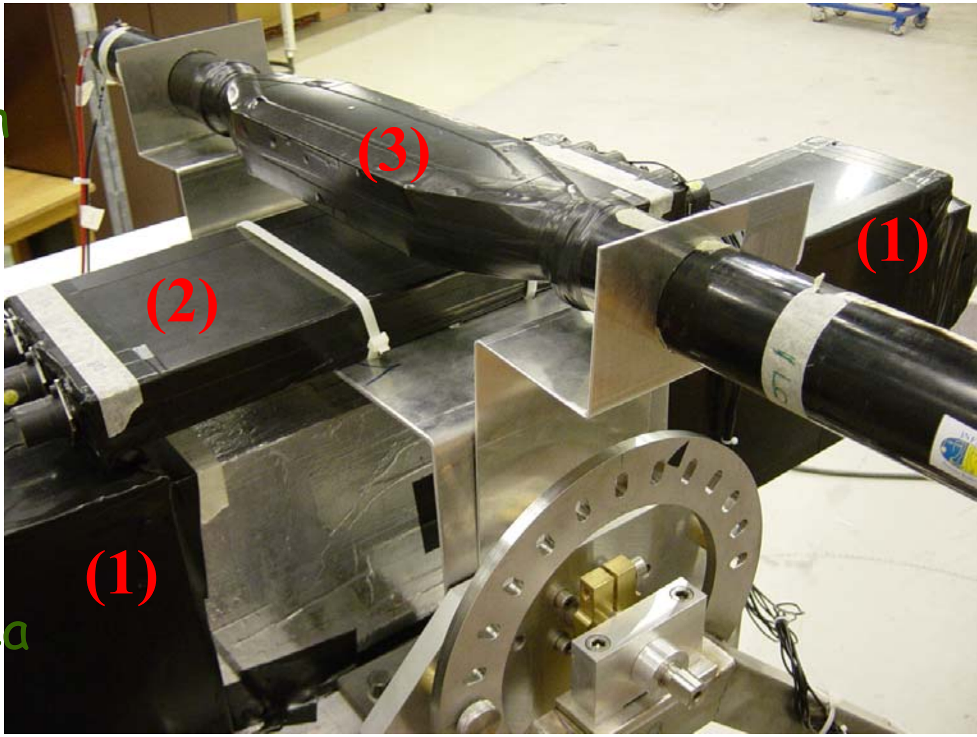
- Neutrons produced in the reaction 7Li(p,n)^{7}Be
- Proton beam energy from 180 MeV to ~20 MeV
- Neutron energy spectrum peaked at max energy (at 180 MeV ⇒ f_p=42% of n in the peak)
- Tail down to thermal neutrons

Experimental setup

1. **KLOE EMC prototype**:
   total length ~60 cm, 3×5 cells (4.2 cm × 4.2 cm) read out at both ends by Hamamatsu/Burle PMT's

2. Beam Position Monitor:
   array of 7 scintillating counters 1 cm thick (removed in June '07)

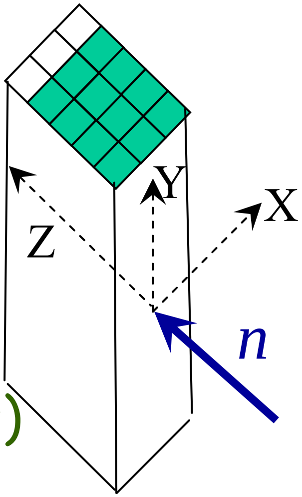
3. Reference counter :
   NE110; 5 cm thick; 10×20 cm^2 area (June 2007 ⇒ two other NE110 counters 2.5 cm thick)



Everything is mounted on a rotating frame allowing for vertical (data taking with *n* beam) and horizontal (for calibration with cosmic rays) positions

Trigger & DAQ

KLOnE
KLOe Neutron Efficiency



Trigger:

- **No neutron tagging available: self-triggering required**
- **Scintillator trigger**: Side 1 – Side 2 overlap coincidence
- **Calorimeter trigger**: **analog sum of the signals of the cells** (4 or 5 planes out of 5) $\Rightarrow$ $\Sigma_A \cdot \Sigma_B$ **overlap coincidence**
- **Trigger** signal is **phase-locked with the RF** signal (45 - 54 ns)

Acquired Data:

- For each configuration/energy: **scans with different trigger thresholds**
- Three data-sets:
  - **E_{peak} = 174 MeV** -- October 2006 - two weeks
  - **E_{peak} = 46.5 MeV** -- June 2007
  - **E_{peak} = 21.8 MeV** -- "

  } **4 days h24**
- Typical run: 10^6 events - Max DAQ rate : 1.7 kHz (Simplified version of the KLOE experiment DAQ system (VME standard))

Efficiency measurement

Global efficiency measurement: integrated over all the energy spectrum

$$\varepsilon = \frac{\text{Rate(trigger)}}{\text{Rate}(n)\cdot f_{\text{live}}\cdot\alpha}$$

flive = fraction of DAQ live time

α = acceptance (assuming beam fully contained in the calorimeter surface ⇒ $\alpha \approx 1$*)

*At low energies: presence of Beam halo!
Evaluated through TSL off-beam counters

Absolute flux of neutrons measured after the collimator

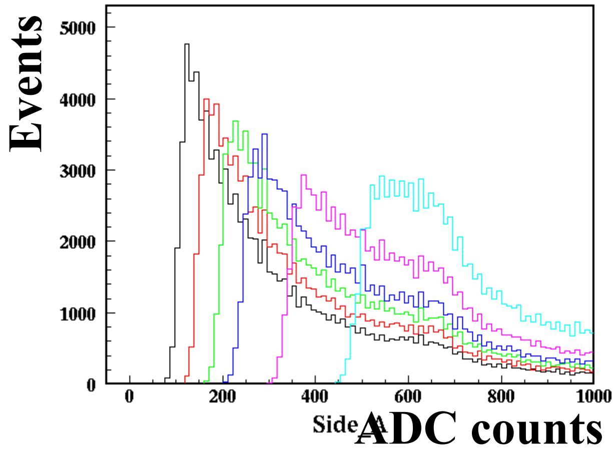
- **2 monitors of beam intensity** (A.Prokofiev et al.,PoS (FNDA2006)016):
  - Ionization Chamber Monitor (7 cm ∅): online monitor, not position sensitive
  - Thin-Film Breakdown Counter (1 cm ∅): offline monitor; used to calibrate the ICM by measuring the neutron flux at the collimator exit
- $\text{Rate}(n) = \text{Rate(ICM)} \cdot K \cdot \pi r^2 / f_p$

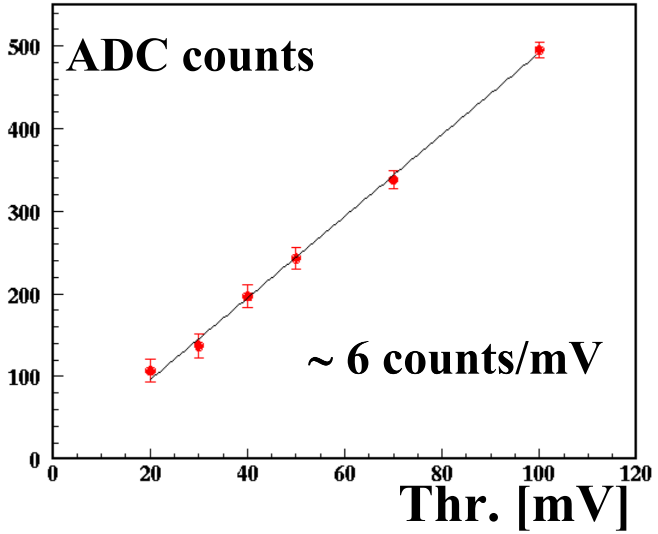
r = collimator radius (1 cm)
K = calibration factor (TFBC to ICM)
fp = fraction of neutrons in the peak

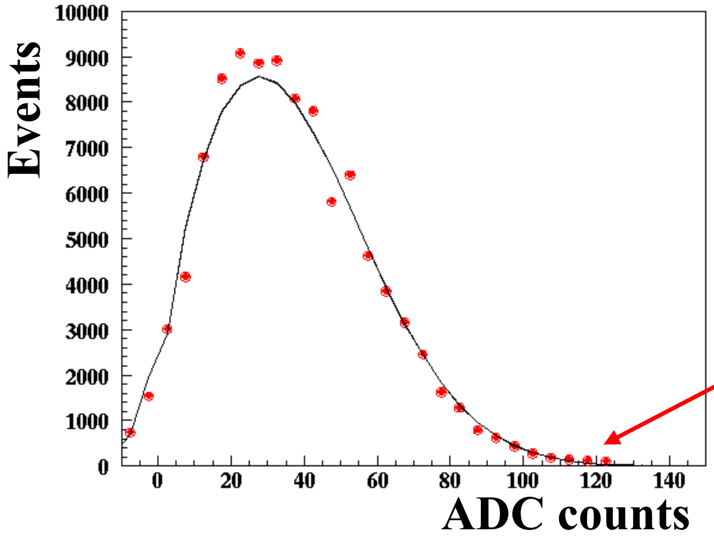
⇒ accuracy: 10% at higher peak energy (174 MeV)
20% at lower peak energy (22 – 46 MeV)

Scintillator calibration

- Trigger threshold calibration in equivalent electron energy (MeV):







β source to set the energy scale in MeV:

^{90}Sr β^- endpoint = 0.56 MeV

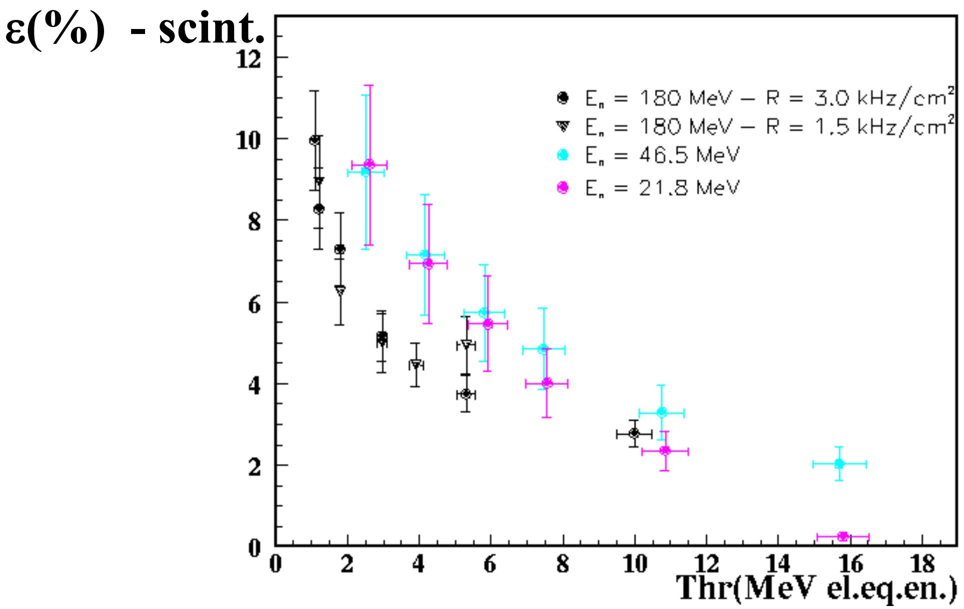
^{90}Y β^- endpoint = 2.28 MeV

25 keV/ADC count

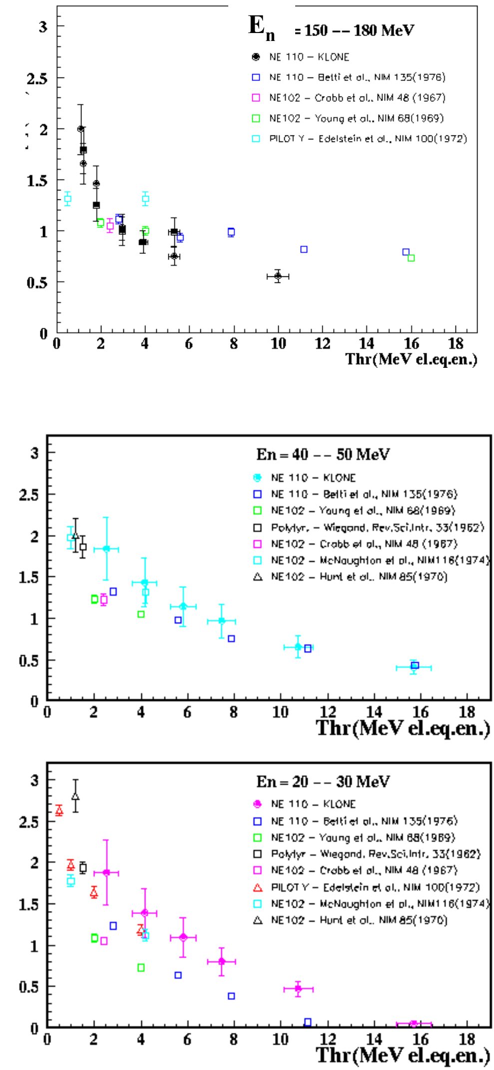
Thr. [mV]	20→100
Thr. [MeV]	2.5→15

Scintillator efficiency

- **Agrees with the "thumb rule" (1%/cm) at thresholds above 2.5 MeV el.eq.en.**



ε(%)/ cm of scintillator



- **Agrees with previous measurements in the same energy range after rescaling for the thickness**

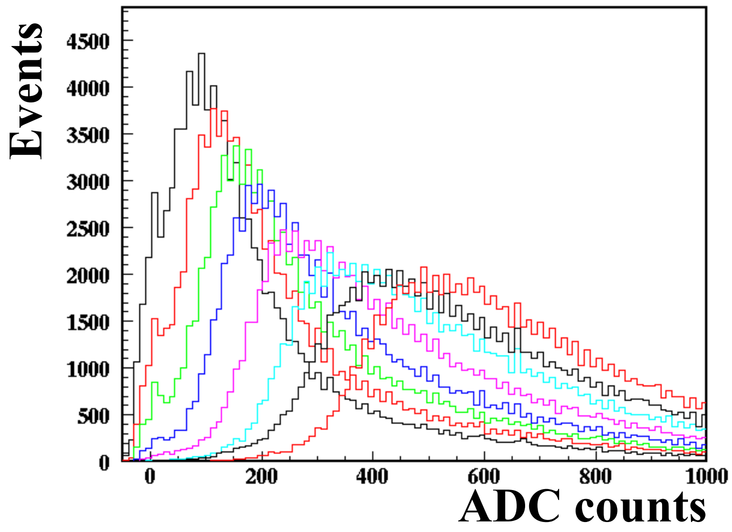
Larger errors at low energies due to:

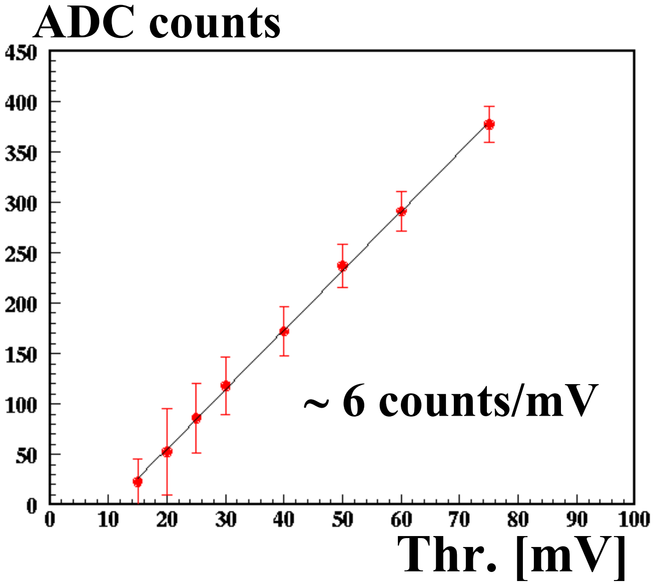
- big uncertainty in the beam halo evaluation
- worse accuracy of the beam monitors

Correction factor for beam halo ≈ 0.9 ± 0.1

Calorimeter calibration

- **Cell response equalization: MIP peak at ~ 550 ADC counts**
- Trigger threshold calibration





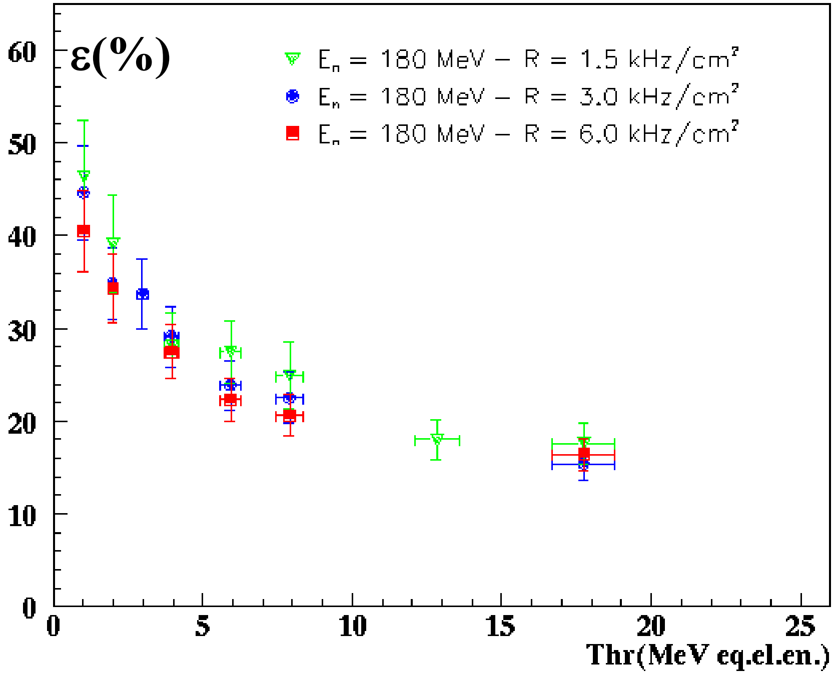
Energy scale calibration with the MIP/MeV conversion factor from KLOE (1 MIP in one calorimeter cell ≈ 35 MeV eq. en.)
(KLOE Collaboration, NIM A354 (1995),352)

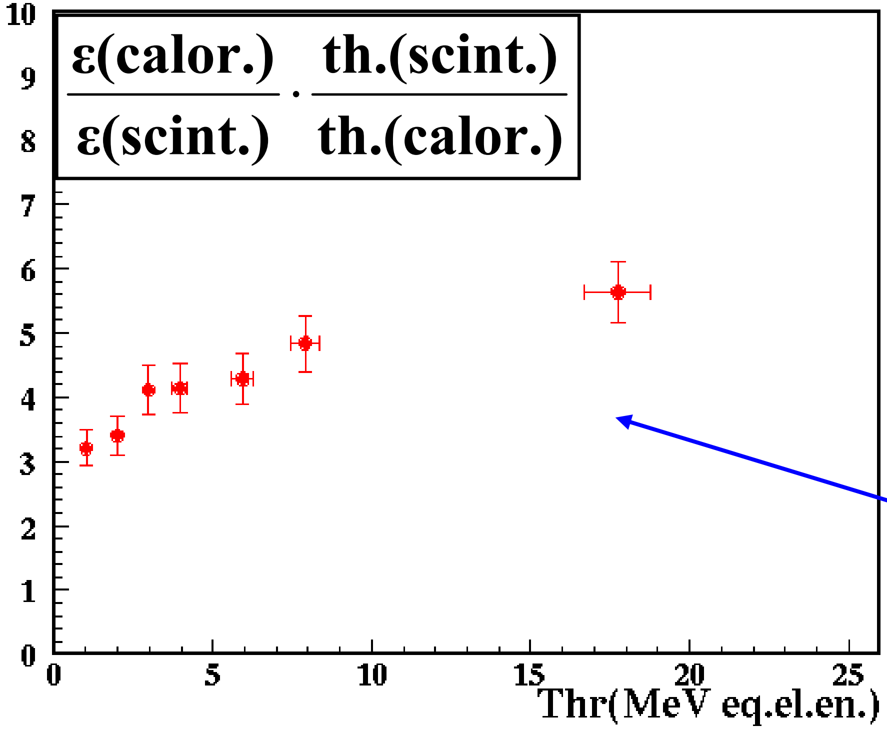
Thr. [mV]	15→75
Thr. [MeV]	1.5→23

Calorimeter efficiency (174 MeV)

- **Very high efficiency**
  w.r.t. the naive expectation
  (~ 10% @ 2 MeV thr.)

- Stable for different run conditions



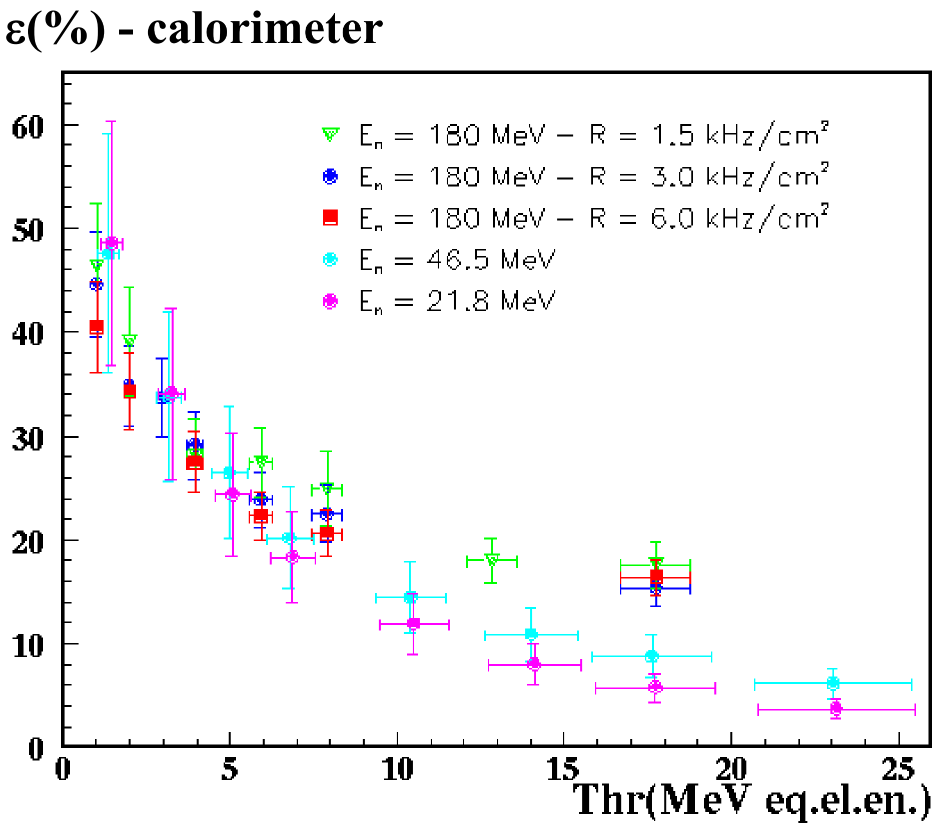


$$\frac{\varepsilon(\text{calor.})}{\varepsilon(\text{scint.})} \cdot \frac{\text{th.(scint.)}}{\text{th.(calor.)}}$$

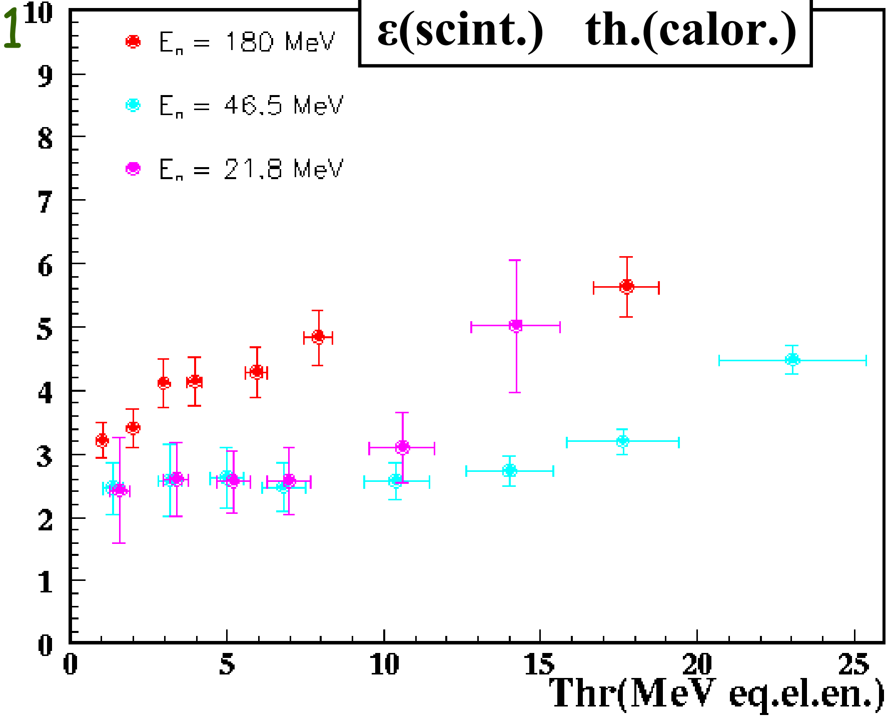
Comparison with our scintillator normalized to the same active material thickness

Calorimeter efficiency (21-46 MeV)

- **Very high efficiency**
- Agreement with the high energy measurements
- Correct. factor for beam halo ≈ 0.8 ±0.1



$$\frac{\varepsilon(\text{calor.})}{\varepsilon(\text{scint.})} \cdot \frac{\text{th.(scint.)}}{\text{th.(calor.)}}$$

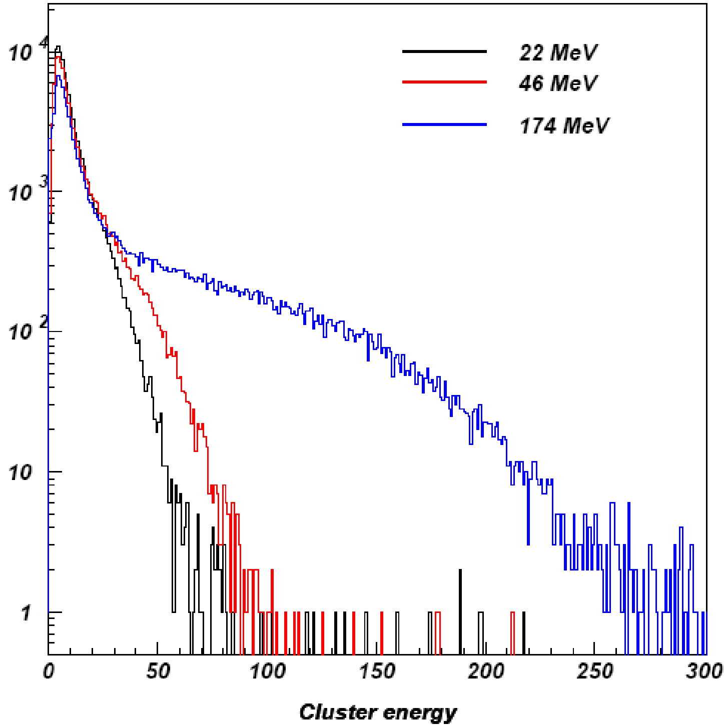


The ratio is almost independent from the halo

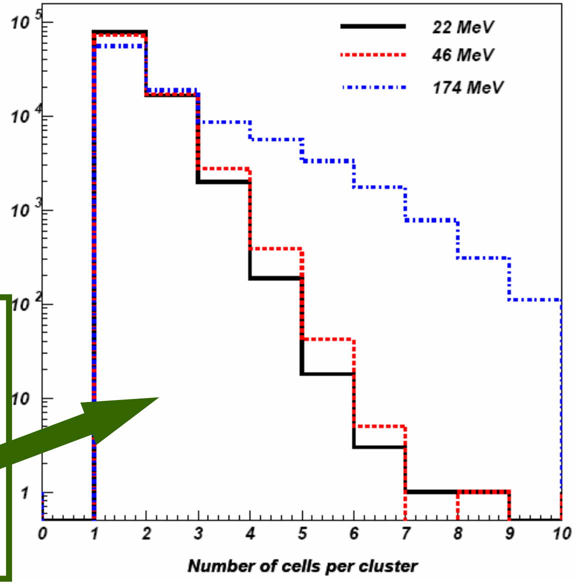
(Ratio normalized to the same active material thickness)

Events' anatomy

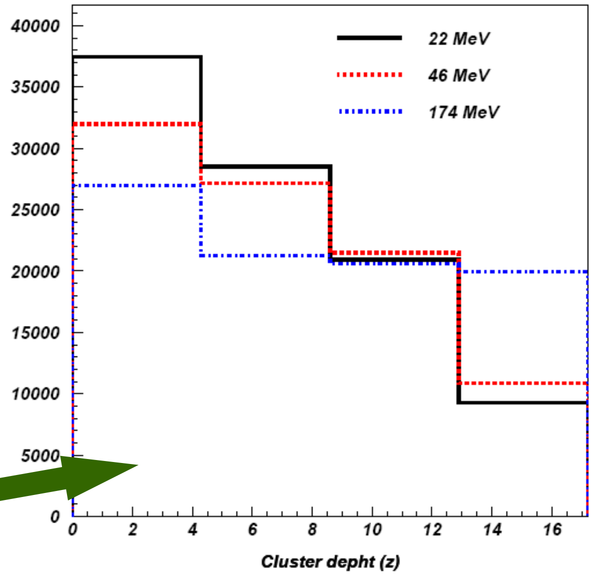
Energy deposited by neutrons for the three beam energies



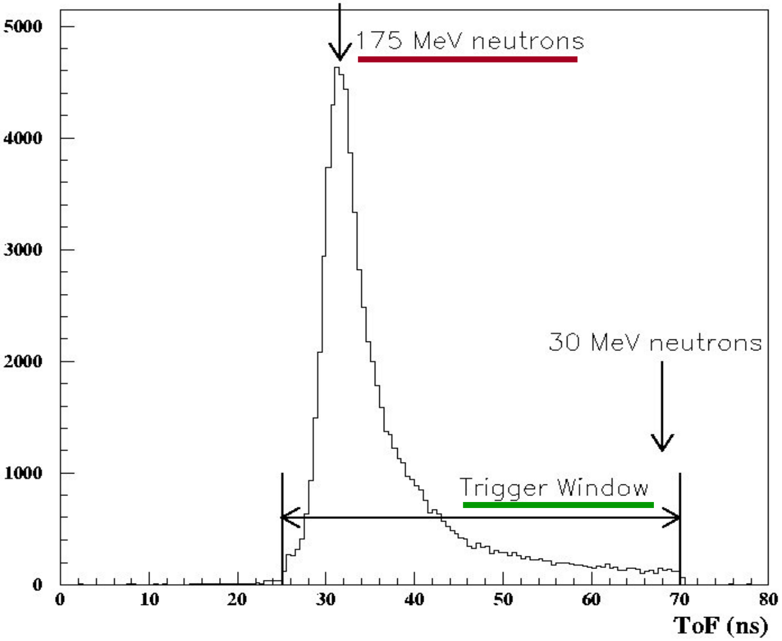
Number of cells per neutron cluster increases with beam energy



Position of neutron clusters in the calorimeter along the forward direction

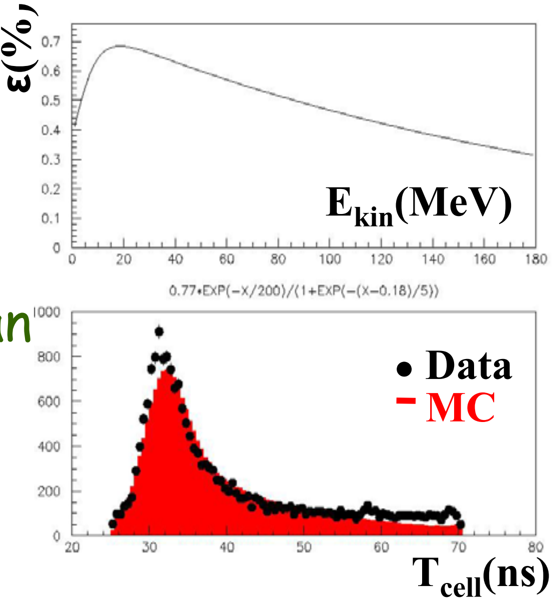


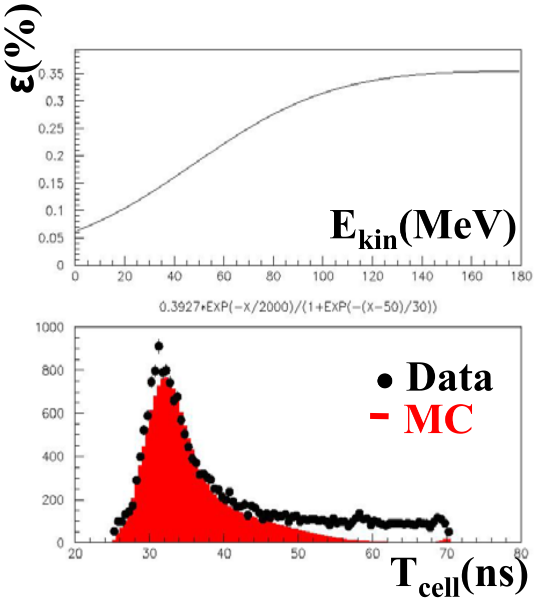
Efficiency vs energy



Energy spectrum can be related to Time Of Flight

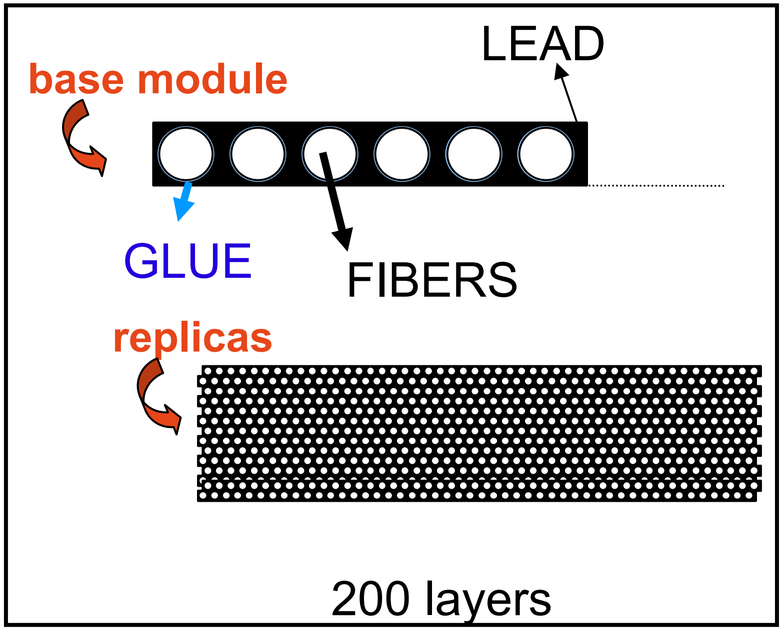
Fast MC to test the sensitivity of the time distribution to the shape of the efficiency curve shows better agreement with an efficiency decreasing with energy



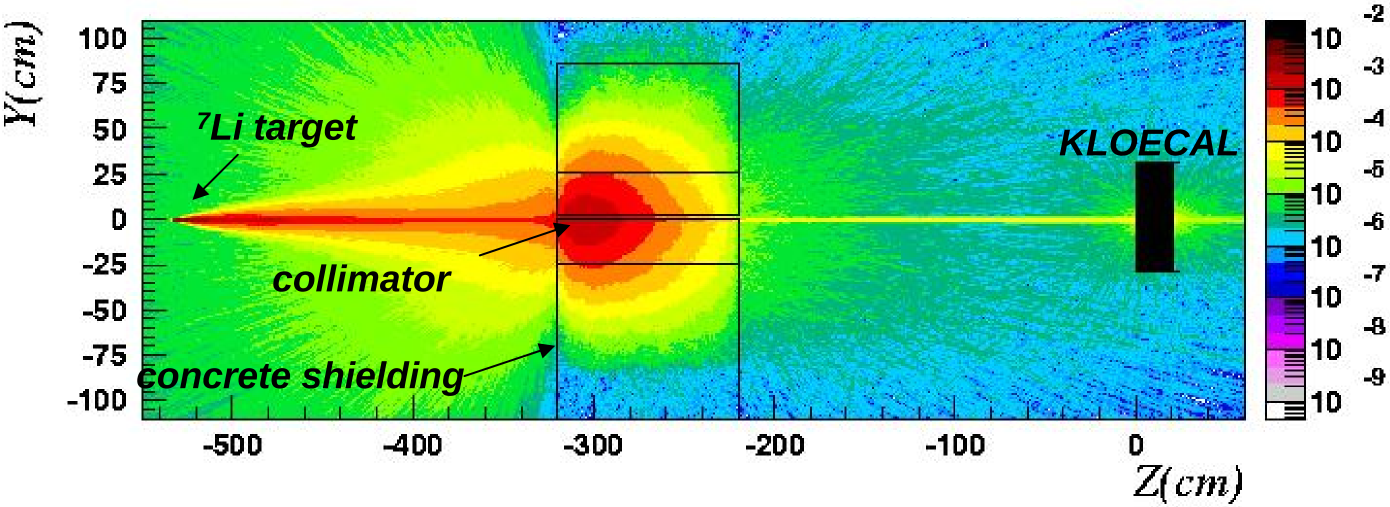


MC simulation

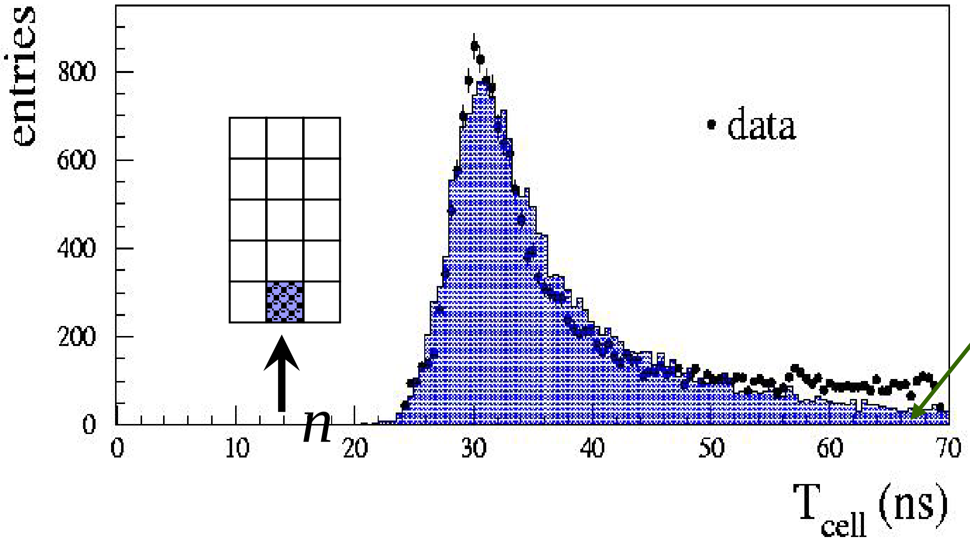
A **detailed simulation** of the **calorimeter structure** and of the **beamline** (source, collimator and concrete shielding) has been carried out with the **FLUKA Code**



Neutron fluence along the beamline (n/cm^2/29000n)



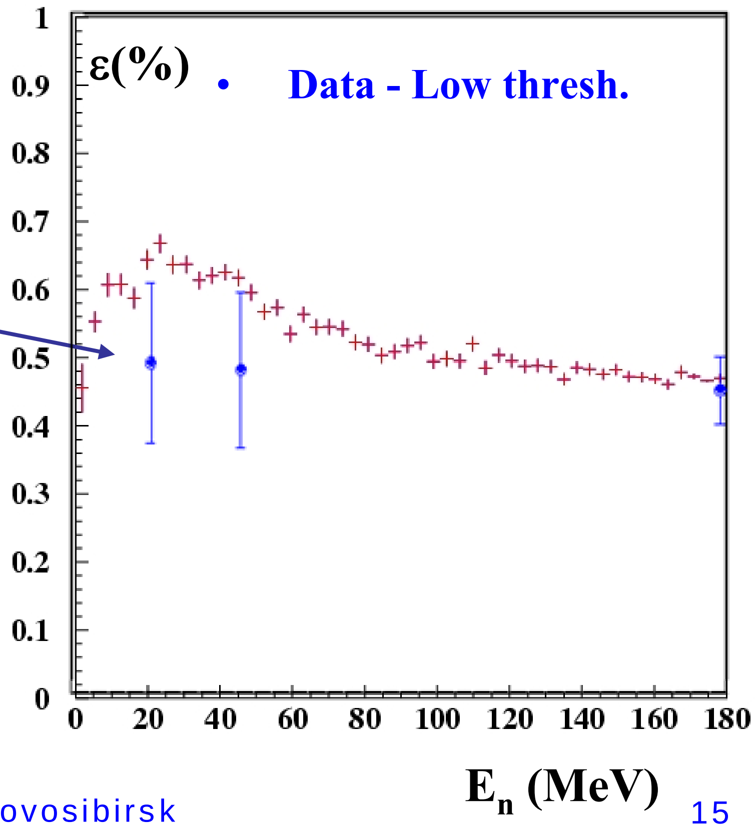
Preliminary results of MC



Some discrepancy in the low energy part of the spectrum

- No cut in released energy
- No trigger simulation

  ⇒ Upper limit on ε



Efficiency enhancement appears to be due to the large inelastic production of secondary neutrons in Pb.

Conclusions

- **The first measurement of the detection efficiency for neutrons of 20 - 180 MeV of a high sampling Pb-sci.fi**. calorimeter has been performed at the The Svedberg Laboratory in Uppsala.
- Measurement of the ***n* efficiency of a NE110 scintillator agrees with published results** in the same energy range.
- **The KLOE calorimeter efficiency, integrated over the whole neutron energy spectrum, ranges between 30-50 % at the lowest trigger threshold.**
- Estimate of beam halo, the main source of uncertainty at low energies, is being carried on, also with further tests at TSL which are foreseen to better understand the halo.