Neutron detection efficiency of the KLOE calorimeter

KLOE
KLOe Neutron Efficiency

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for the KLONE Group
Motivations

• Detection of n of few to few hundreds of MeV is traditionally performed with organic scintillators (elastic scattering of n on H atoms produces protons detected by the scintillator itself)
  ⇒ efficiency scales with thickness ⇒ 1%/cm
• Preliminary estimate with KLOE data (n are produced by kaon interactions with the beam-pipe and DCH walls) + KLOE MC showed ε ~ 40%, larger that the expected ~ 10%
• Interesting “per se”: KLOE calorimeter has very good time resolution, good energy resolution, and high efficiency for photons;
  ⇒ could be the first of a new kind of neutron detectors
• Relevant for the future experiments at LNF (see AMADEUS and DANTE LOIs): study of deeply bound kaonic nuclei and measurement of the nucleon time-like form factors require good efficiency for neutrons

A test has been performed with the neutron beam of the The Svedberg Laboratory of Uppsala during last October
KLONE group

LNF: S.Bertolucci, C.Curceanu, S.Giovannella, M.Iliescu, M.Martini, S.Miscetti, B.Sciascia, F.Sirghi

ROMA1: C.Bini, A.DiDomenico, P.Gauzzi, G.DeZorzi

ROMA3: P.Branchini, B.DiMicco, F.Nguyen, A.Passeri

CNAO: A.Ferrari

A lot of help from: Mechanic shop (G.Bisogni, U.Martini et al.), electronics group (A.Balla et al.) and detector support group (M.Anelli, A.DiVirgilio et al.) + Transports (M.Rossi, P.Caponera)

A lot of help also from TSL group
KLONE group pictures ..
Experimental setup

1. Old KLOE prototype:
   total length \( \sim 60 \) cm
   \( 3 \times 5 \) cells \((4.2 \text{ cm} \times 4.2 \text{ cm})\)
   read out at both ends by Hamamatsu/Burle PMTs

2. Beam Position Monitor:
   array of 7 scintillating counters
   1 cm thickness

3. Reference counter:
   NE110; 5 cm thick; 10×20 cm\(^2\) area

All mounted on a rotating frame allowing for vertical (data taking with n beam) and horizontal (for calibration with cosmic rays) positions
BLUE Hall @ TSL

178 MeV protons on $^7$Li target

Circular collimator of 2 cm diameter, collimator exit: 3 m from the target

Calorimeter @ 5 m from target

KLONE setup
Neutron source

- Neutron beam from 178.7 MeV protons on $^7$Li target

- 42% of neutron at max energy

- Absolute flux of neutrons in the peak measured after the last collimator:

  3 beam intensity monitors; for normalization we used the Ionization Chamber Monitor (ICM) the most accurate (10%)
Time structure

Tek Run: 50.0ks/s  Sample

\[ \Delta : 2.42 \text{ms} \]
\[ \circ : 0 \text{s} \]

\[ \sim 5 \text{ ns FWHM} \]

\[ 4.2 \text{ ms} \]

\[ 2.4 \text{ ms} \]

\[ 41 \text{ ns} \]

\[ \sim 5 \text{ ns FWHM} \]
Trigger

- No beam extraction signal available
- **Scintillator trigger:** Side 1 – Side 2 coincidence \((T1 = S_1 \cdot S_2)\)
- **Calorimeter trigger** based on the analog sum of the signals of the first 12 cells (4 planes out of 5) \(\Rightarrow T1 = \Sigma_A \cdot \Sigma_B\)
- Trigger signal is phase locked with the RF signal \((T1_{\text{free}})\)
- Vetoed from retriggering by a 5 – 35 \(\mu\)s busy signal and by the DAQ busy \(\Rightarrow T2\) is the final trigger signal

- \(T1_{\text{free}}, T2\) and the ICM monitor signal are acquired by a scaler asynchronous from DAQ

\[
\text{Rate}(n) = I_0 \cdot \pi r^2 \cdot \text{Rate}(\text{ICM})/(0.33 \text{ Hz}) / 42\%
\]

ICM calibration: \(I_0 = 3 \text{ kHz/cm}^2 \Leftrightarrow \text{Rate}(\text{ICM}) = 0.33 \text{ Hz}\)

\(T2/T1_{\text{free}} = \text{fraction of Live Time} \Rightarrow \text{essential for the efficiency evaluation}\)
Collected data

- Beam time allocated by TSL: 8 shifts of 8 hours in October 2006

- 3 large data sets with different beam intensity
  - Low intensity = 1.5 kHz/cm²
  - Medium intensity = 3 kHz/cm²
  - High intensity = 6 kHz/cm²

- DAQ rate = 1.7 kHz

- For each configuration: several runs of 15 – 30 min, with different trigger thresholds

  - Typical run ⇒ 0.5 – 1.5 Mevents

- With beam off: cosmics rays for calibration with MIPs

- Some runs with β source (⁹⁰Sr) for the scintillator calibration
Scintillator calibration

- Trigger threshold calibration: mV to ADC counts
- $\beta$ source to set the energy scale in MeV
- $^{90}\text{Sr} \ \beta^- \ \text{endpoint} = 0.564 \ \text{MeV}$
  $\rightarrow ^{90}\text{Y} \ \beta^- \ \text{endpoint} = 2.283 \ \text{MeV}$
- Fit of the $\beta$ spectrum:
  ADC counts to MeV factor as a free parameter

![Graphs showing calibration results]
Scintillator efficiency

- Agrees with the rule of thumb: \( \sim 1\%/\text{cm} \)
- Compare with previous measurements in the same energy range by scaling them to our thickness
- Good check of the method

\[ \varepsilon = \frac{\text{Rate(trigger)}}{\text{Rate(n)}} \text{ corrected for the dead time} \]
Calorimeter calibration

- Cell response equalized: MIP peak at $\sim 600$ ADC counts

- Trigger threshold calibration
  (HP attenuators used for $\Sigma_A$ and $\Sigma_B$ not to exceed the dynamic range of the ADC; different attenuation factors $\Rightarrow f_A=2.0$, $f_B=1.7$)

- Energy scale set with MIPs using the conversion factor from KLOE: a MIP in a calorimeter cell corresponds to an electron of 35 MeV

![Graph showing calibration results](attachment:graph.png)
Trigger rates

• Different run conditions

• Dead time increases with beam intensity

• Very important for the efficiency evaluation
Calorimeter efficiency

$$\varepsilon = \frac{\text{Rate(trigger)}}{\text{Rate(n)}}$$
corrected for the dead time

- $\sim 10\%$ uncertainty on both horizontal and vertical scales
- Very high efficiency w.r.t. the naive expectation (8 cm of sci.fi. $\Rightarrow \sim 8 - 10\% @ 2$ MeV thr.)
- Stability vs different run conditions
- Small decrease of the efficiency with the beam intensity $\Rightarrow$ pile-up?

$\varepsilon(\text{scint.})$ scaled by $8/5$
Some events

![KLOE DISPLAY V. 1.0](image1)

n beam

Two cluster event
Making cluster

- Signal is localized in ~ 1 cell

Cluster (Side A only)

<table>
<thead>
<tr>
<th>Ncell/Clus</th>
<th>Nev x 10</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-1</td>
<td>2500</td>
</tr>
<tr>
<td>1-2</td>
<td>7500</td>
</tr>
<tr>
<td>2-3</td>
<td>10000</td>
</tr>
<tr>
<td>3-4</td>
<td>7500</td>
</tr>
<tr>
<td>4-5</td>
<td>10000</td>
</tr>
</tbody>
</table>

4 cell cluster - very rare event
n energy spectrum

- TOF spectra
- Correct TOF for wrong association of clock
- From TOF we get $\beta$ of the neutron
- Assuming the n mass we obtain the energy spectrum
n energy spectrum

- Efficiency vs energy of neutrons can be studied

- Comparison data – fast MC (only first plane of calorimeter)
n energy spectrum

- Comparison data – fast MC
- Worse agreement if we assume an efficiency increasing with energy
MC simulation

- To make a deep comparison data – MC a detailed description of the calorimeter and all the main elements of the beamline (source, collimator and concrete shielding) have been simulated with the FLUKA Code

Neutron fluence along the beamline (n/cm²/29000n)
Preliminary results of MC

- Simulated neutron beam: $E_{\text{kin}} = 180$ MeV
- Each primary neutron has a high probability to have elastic/inelastic scattering in Pb

In average 5.4 secondaries per primary neutron are generated, counting only neutrons above 19.6 MeV.

<table>
<thead>
<tr>
<th>target</th>
<th>$P_{el}(%)$</th>
<th>$P_{inel}(%)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pb</td>
<td>32.6</td>
<td>31.4</td>
</tr>
<tr>
<td>fibers</td>
<td>10.4</td>
<td>7.0</td>
</tr>
<tr>
<td>glue</td>
<td>2.3</td>
<td>2.2</td>
</tr>
</tbody>
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<table>
<thead>
<tr>
<th>neutrons above 19.6 MeV</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>neutrons</td>
<td>62.2%</td>
</tr>
<tr>
<td>photons</td>
<td>26.9%</td>
</tr>
<tr>
<td>protons</td>
<td>6.8%</td>
</tr>
<tr>
<td>He-4</td>
<td>3.2%</td>
</tr>
<tr>
<td>deuteron</td>
<td>0.4%</td>
</tr>
<tr>
<td>triton</td>
<td>0.2%</td>
</tr>
<tr>
<td>He-3</td>
<td>0.2%</td>
</tr>
</tbody>
</table>
In addition, secondaries created in interactions of low energy neutron (below 19.6 MeV) are - in average - **97.7 particles per primary neutron**.

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>neutrons</td>
<td>94.2%</td>
</tr>
<tr>
<td>protons</td>
<td>4.7%</td>
</tr>
<tr>
<td>photons</td>
<td>1.1%</td>
</tr>
</tbody>
</table>

The enhancement of the efficiency appears to be due to the huge inelastic production of neutrons on Pb. These secondary neutrons:
- are produced isotropically;
- are associated with a sizeable amount of photons and protons, which can be detected in the nearby fibers;
- have a lower energy and then a larger probability to do new interactions in the calorimeter with neutron/proton/\(\gamma\) production.
Conclusions

• A successful two weeks long data-taking at the TSL “n” beam has been carried out by the KLONE group
• Reference measurement of “n” efficiency for a NE110 scint. agrees with published results in the same energy range.
• The measured “global” “n” efficiency for the KLOE calorimeter with 1 – 4 MeV el.eq.en. thresholds, ranges between 30-50 % (exp. ∼8-15 % if response proportional to sci.fi. equivalent thickness)
• Study of the efficiency as a function of n-energy is in progress
• Full simulation with FLUKA is in progress to understand the reason of such a large efficiency
• Request for another test in 2007 in Louvain is in preparation (E = 10 – 70 MeV; larger interbunch time)
Spares
Media pesata sull’energia delle celle:

\[
Z_{\text{CLU}} = \frac{\sum_{\text{celle}} Z_{\text{cella}} \times E_{\text{cella}}}{\sum_{\text{celle}} E_{\text{cella}}}
\]
Media pesata sull’energia delle celle:

\[ X_{\text{CLU}} = \frac{\sum_{\text{cella}} X_{\text{cella}} \times E_{\text{cella}}}{\sum_{\text{cella}} E_{\text{cella}}} \]

P. Gauzzi
Scintillator calibration

- Trigger threshold calibration: ratio of ADC spectrum when the corresponding TDC is fired (not overflow) to the total ADC spectrum
- Threshold = $\frac{1}{2}$ of the plateau

<table>
<thead>
<tr>
<th></th>
<th>$P_1$ (counts)</th>
<th>$P_2$ (counts/mV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$S_1$</td>
<td>5.9</td>
<td>1.146</td>
</tr>
<tr>
<td>$S_2$</td>
<td>27</td>
<td>1.018</td>
</tr>
</tbody>
</table>
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- **Calorimeter trigger** based on the analog sum of the signals of the first 12 cells (4 planes out of 5) \( \Rightarrow T_1 = \Sigma_A \cdot \Sigma_B \)

- \( T_{1\text{free}} = T_1 \) strobed with the RF signal

- \( T_{1\text{free}} \) is vetoed from retriggering by a 5 – 35 \( \mu \)s busy signal and by the DAQ busy

- \( T_2 \) is the final trigger signal

- \( T_{1\text{free}}, T_2 \) and the ICM monitor signal are acquired by a scaler asynchronous from DAQ

\[
\text{Rate}(n) = I_0 \cdot \pi r^2 \cdot \frac{\text{Rate}(\text{ICM})/(0.33 \text{ Hz})}{42\%}
\]

ICM calibration: \( I_0 = 3 \text{ kHz/cm}^2 \Leftrightarrow \text{Rate}(\text{ICM}) = 0.33 \text{ Hz} \)

\[
\frac{T_2}{T_{1\text{free}}} = \text{fraction of Live Time} \Rightarrow \text{essential for the efficiency evaluation}
\]