Neutron Time-of-Flight, Proton and Heavy Ion Measurements with a Timepix Detector

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Time of Flight measurement with neutrons

BEAM TIME AT LOS ALAMOS NEUTRON SCIENCE CENTER

20.2.2014

Benedikt Bergmann - Medipix Meeting
Los Alamos Neutron Science Center (LANSCE)

- Neutron spallation source: 800 MeV protons on tungsten target
- ‘white’ neutron spectrum with kinetic neutron energies up to 600 MeV
Energy spectrum of the neutrons measured by a $^{238}$U fission chamber
Setup at FP 30 L and trigger signal

- Detector:
  - 1 mm thick silicon sensor layer
  - TOA mode \((f_{\text{clock}} = 48 \text{ MHz})\)
  - Bias voltage = 400 V
  - \(t_{\text{acq}} = 100 \mu\text{s}\)
  - Distance to the interaction point 20.411 m
Cluster height spectrum

Acquisition time = 100 µs = 4800 clock counts; Clock frequency = 48 MHz;
Energy assignment by means of the Time-of-Flight technique

- Identify the beginning of the “last” micro-pulse, given by the gamma ray flash from the interaction point ($ToA_{max}$).

- The Time-of-Flight is given as:

$$t_{\text{Flight}} = \left[ \frac{(ToA_{max} - ToA)}{f_{\text{clock}}} + \frac{d}{c} \right]$$

  - Time-difference to the gamma flash
  - time a gamma ray needs to travel from the interaction point to the detector (20.411 m)

- Calculation of the kinetic neutron energy:

$$T = E - M = (\gamma - 1) M;$$

$$\gamma = (1 - \beta^2)^{-0.5}; \quad \beta = \frac{v}{c} = \frac{d}{(c \cdot t_{\text{Flight}})};$$

$$M = 957.59 \text{ MeV}; \quad c = 2.9997 \cdot 10^8 \text{ m/s}; \quad d = 20.411 \text{ m}$$
## Pattern recognition – definition of different cluster types

<table>
<thead>
<tr>
<th>Cluster Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dot</td>
<td>Photons and electrons (10keV)</td>
</tr>
<tr>
<td>Small Blob</td>
<td>Photons and electrons</td>
</tr>
<tr>
<td>Curly Track</td>
<td>Electrons (MeV range)</td>
</tr>
<tr>
<td>Heavy Blob</td>
<td>Heavy ionizing particles with low range (alpha particles, ...)</td>
</tr>
<tr>
<td>Heavy Track</td>
<td>Heavy ionizing particles (protons, ...)</td>
</tr>
<tr>
<td>Straight Track</td>
<td>Energetic light charged particles (MIP, Muons, ...)</td>
</tr>
</tbody>
</table>
Cluster shapes as a function of neutron kinetic energy

Resonances of elastic scattering of neutrons on silicon nuclei

$^{28}\text{Si}(n,p)^{28}\text{Al}$ and $^{28}\text{Si}(n, \alpha)^{25}\text{Mg}$-reactions appear

Number of events

0 1000 2000

Kinetic energy of neutrons [MeV]

$10^{-2}$ $10^{-1}$ 1 $10$ $10^2$ $10^3$
Neutron elastic scattering

Signal creation:
The detector is triggered by the ionization caused by the displacement of the silicon nucleus.

Signatures:
Low energy transfer to the silicon sensor ($T_{Si} \sim 70$ keV for $T_n = 1$ MeV).

-> Dots and small blobs
Nuclear reactions on silicon

**Threshold reactions:**
Q value has to be compensated by energy of the incoming neutron.

**Signature:**
Characterized by high energy deposition in the silicon sensor layer.

-> Heavy tracks and heavy blobs
Detector responses for selected energy intervals

- Above 4 MeV: nuclear interaction appear
- Above 30 MeV: HETP are getting more and more asymmetric and bigger with increasing energy
- Above 10 MeV: tracks with delta electrons are detected
Protons, Carbon, Oxygen and Helium – First look ...

BEAM TIME AT HIT IN HEIDELBERG

20.2.2014

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Investigated ions species and detector settings

- **Detector**
  - 1 mm thick silicon sensor
  - Bias voltage 400 V
  - Clock frequency: \( f_{\text{clock}} = 48 \text{ MHz} \)
  - Time-over-threshold mode

- **Beam time organized by ARDENT framework (~ 17 h)**
  - Protons (48 MeV/u, 75 MeV/u, 100 MeV/u)
  - Carbon ions (89 MeV/u, 200 MeV/u, 300 MeV/u, 430 MeV/u)
  - Oxygen (104 MeV/u, 250 MeV/u, 430 MeV/u)
  - Helium (50 MeV/u, 80 MeV/u, 115 MeV/u, 150 MeV/u, 185 MeV/u, 221 MeV/u)

  - For each particle type the detector has been irradiated under 0°, 60° and 90°
Protons with different energies: 90 degree
Carbon ions with different energies: 90 degrees

- Halo of pixel with low energy deposition around track - less pronounced for higher energies.
- Number of delta rays increases with increasing energy.
Oxygen ions with different energies: 90 degrees
**Alphas with different energies:**

90 degrees:

- 50 MeV/u
- 80 MeV/u
- 115 MeV/u
- 185 MeV/u
- 221 MeV/u

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Volcano effect for carbon and oxygen ions – 0 degree

Carbons: 89 MeV/ u

Oxygen: 104 MeV/ u
Strategy, plan – Categorization and particle identification

1. Look at track as a whole with low energy halo i.e. characterize size, shape.

2. Strip off halo (cut on energy per pixel).

3. Count number of delta-rays and measure their length.

4. Fit the track to obtain dE/dx information.

Identify particle type and particle energy via the size of the halo, the number of delta rays, their length and dE/ dx.
Thank you for your attention!