Early Stage Researcher 9: October 2014 – June 2015

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ARDENT
Advanced Radiation Dosimetry European Network Training

I E A P

ERLANGEN CENTRE FOR ASTROPARTICLE PHYSICS

Experimental activities: Overview

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- Los Alamos Neutron Science Center (Dec. 4 - 7, 2014)
  - Broad neutron spectrum from few hundrets of keV up to 600 MeV
  - Timepix (1 mm) and Timepix3 (300 µm)
- SPS at CERN (Feb. 20 – 25, 2015 and March 31 – April 9, 2015)
  - Argon ions (75 GeV/A, 15 GeV/A, 150 GeV/A)
  - Timepix and Timepix3 (different thicknesses)
- Nuclotron of JINR, Dubna (March 10 – 15, 2015)
  - Carbon ions 1 GeV/A
  - Timepix (1 mm), Timepix telescope and Timepix3 (different thicknesses)
- Van-de-Graaff in Montreal (May 16 – 24, 2015)
  - Protons up to 11.4 MeV
  - Timepix (CdTe, GaAs, Si) and Timepix3 (500µm)

Reminder:

Pattern recognition – definition of different cluster types

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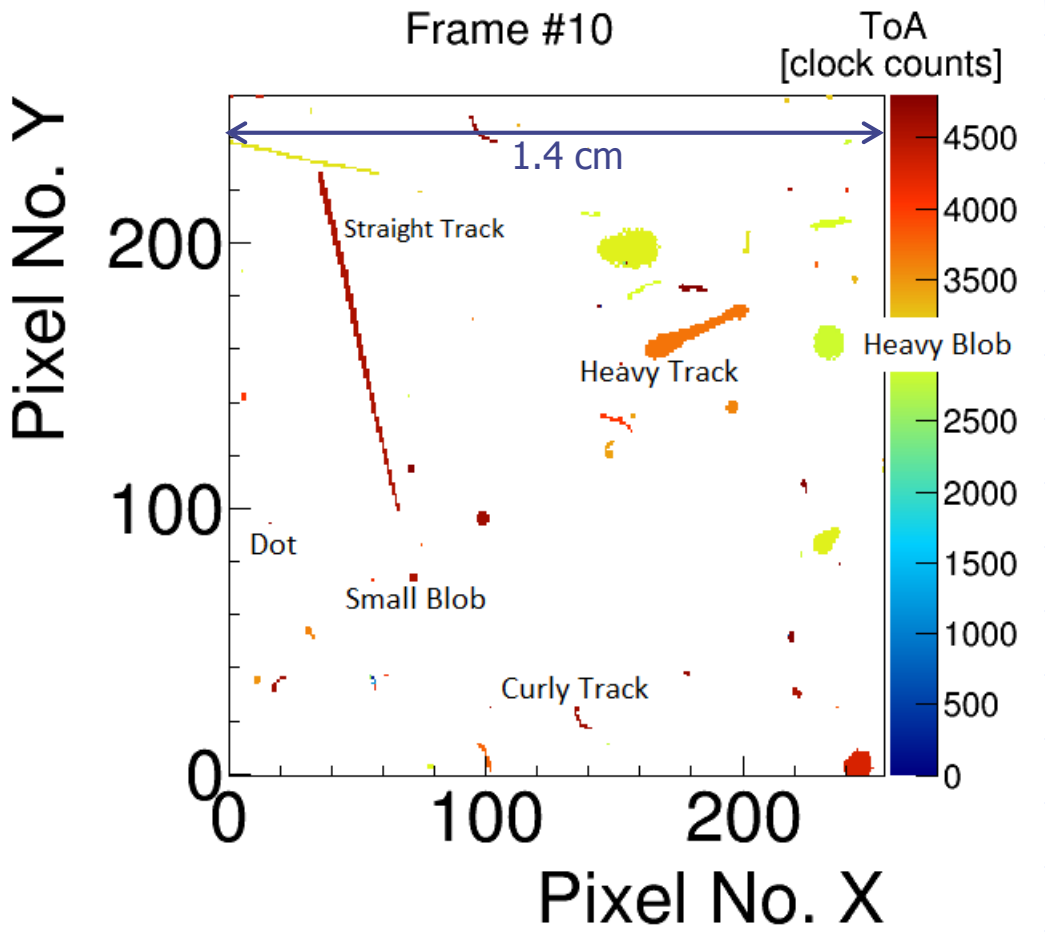

Frame taken with a Timepix (1 mm, 400V, $t_{Acq.}$ = 100µs) in the LANSCE neutron beam.

Low Energy Transfer Events (LETE):

- Dots (photons and electrons ~ 10 keV)
- Small Blobs (photons and electrons)
- Curly Tracks (electrons MeV range)
- Straight Tracks (MIPs, Muons, ...)

High Energy Transfer Events (HETE):

- Heavy Tracks, Heavy blobs (Heavy ionizing particles, e.g. Alpha particles, protons)

TIMEPIX at LANSCE:
Cluster shapes (detector responses) as a function of neutron kinetic energy

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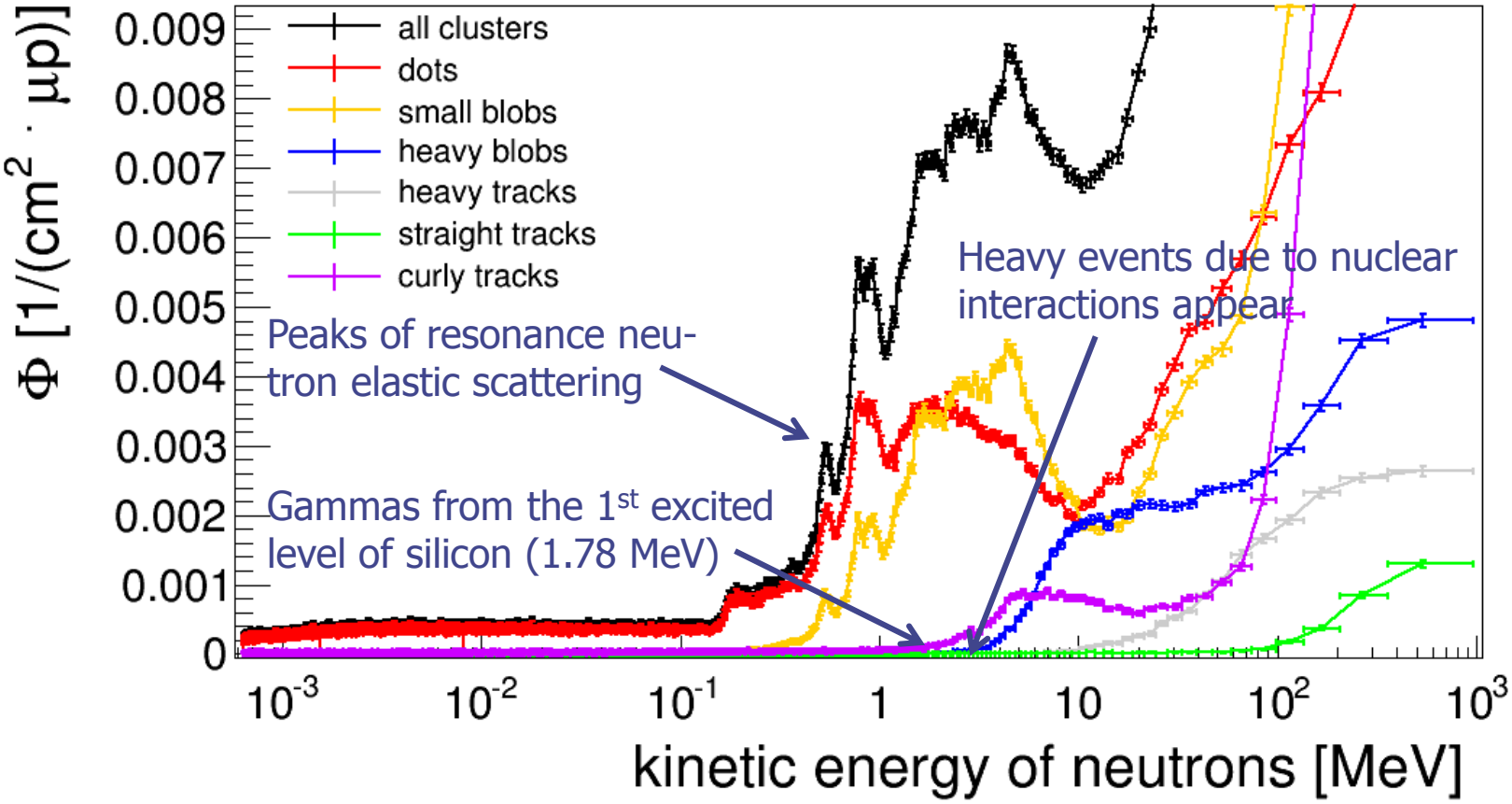
The ToF technique*) was used to assign the detector responses to the corresponding neutron energies (track by track).



*) see: B Bergmann *et al* 2014 *JINST* **9** C05048

Interpretation of the signatures by means of radiation damage

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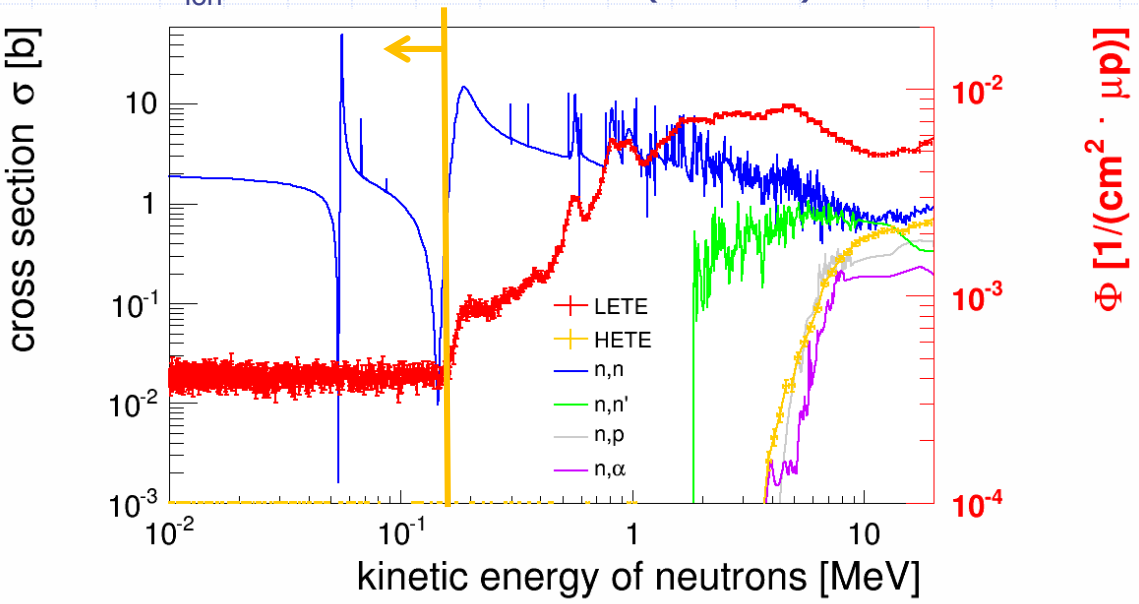
E_{ion} < Detector threshold (4.5 keV)



Category 1 - Low energy deposition by pure ionization:

- Curly tracks, straight tracks
- No damage

Category 2 – Low energy deposited by the recoil silicon of scattering reactions (small angle):

- Dots, small blobs (LETE)
- Displacement damage

Category 3 - High local charge deposition, e.g. in Si(n,X)-reactions:

- Heavy tracks and heavy blobs (HETE)
- Single Event Upsets (SEU) and Multiple Bit Upsets (MBU), permanent damage

TIMEPIX3 at LANSCE:
Cluster shapes (detector responses) as a function of neutron kinetic energies

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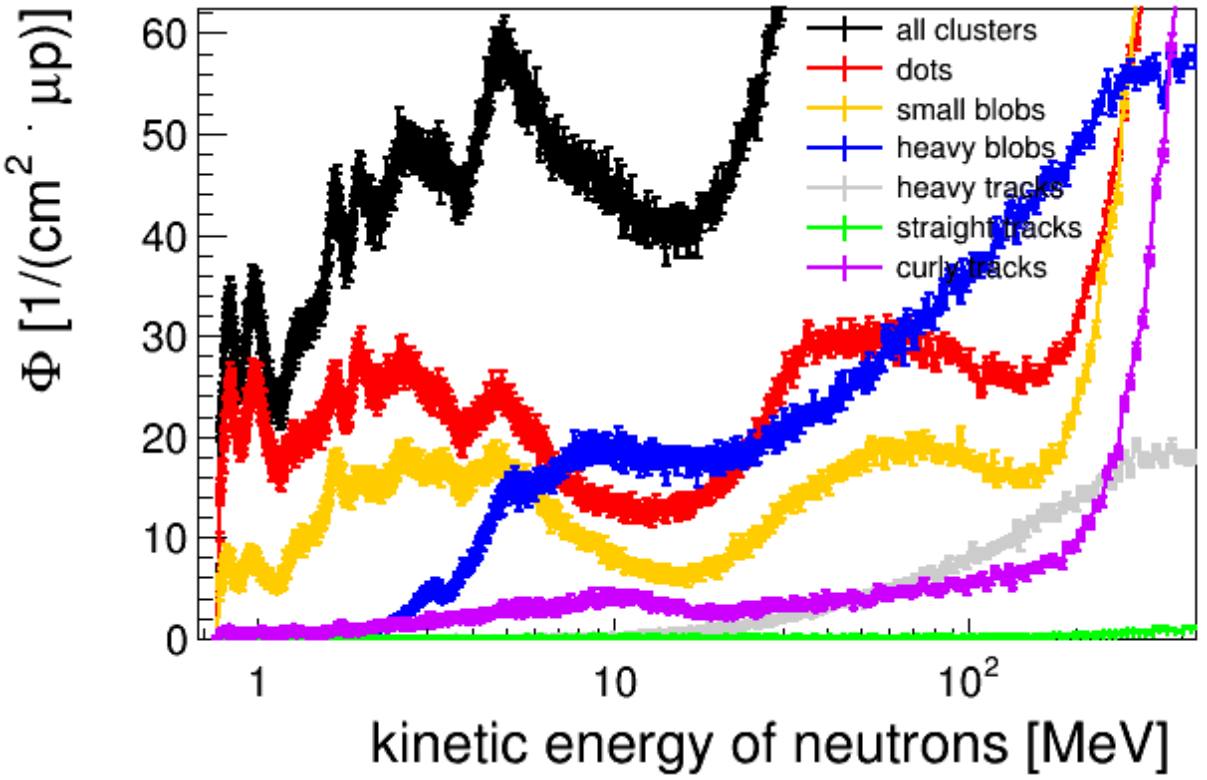
- Same behaviour as for Timepix
- Better time resolution leads to better selection of neutron kinetic energies



Examples of energy spectra for selected neutron energy intervals

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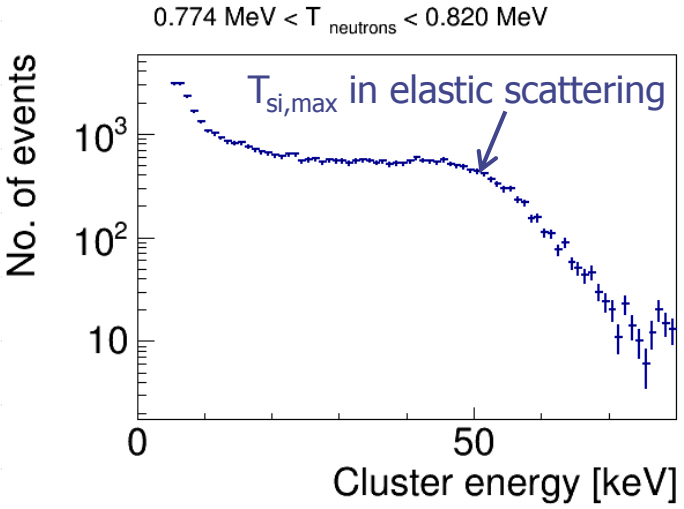

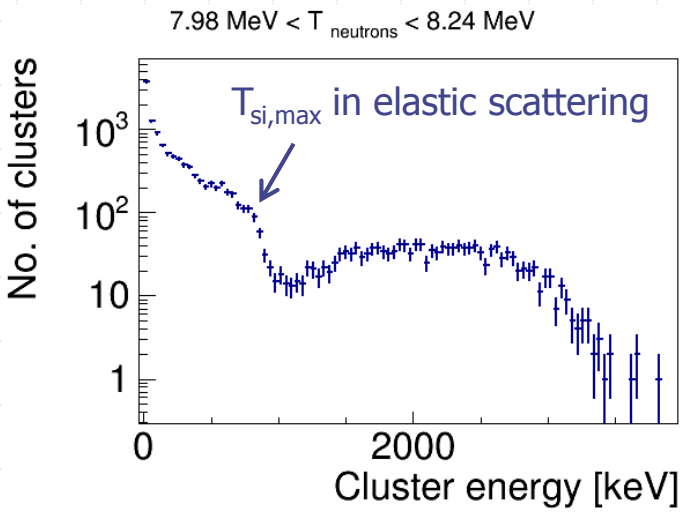

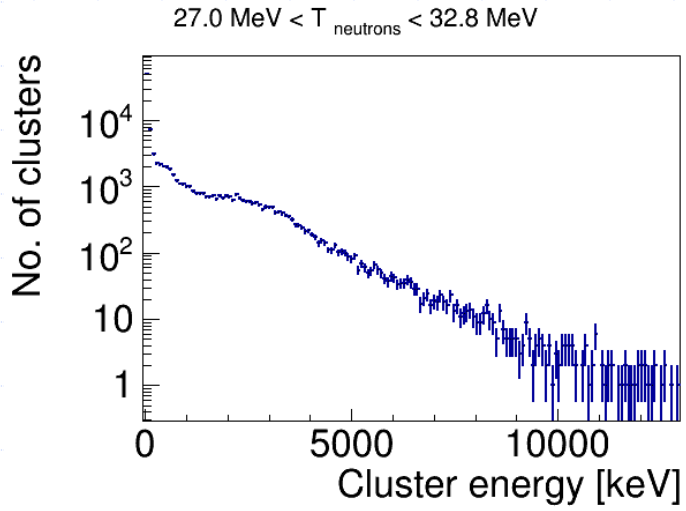

- Time-of-Flight technique used to select quasi-monoenergetic neutrons:
  - $\Delta T_n/T_n$ up to ~ 1% (T_n < 10 MeV)
  - $\Delta T_n/T_n$ ~ 7% (T_n ~ 30 MeV)
- Investigate the spectrum of deposited energies by means of a pulse shape analysis

Interpretation of the measured energy spectra

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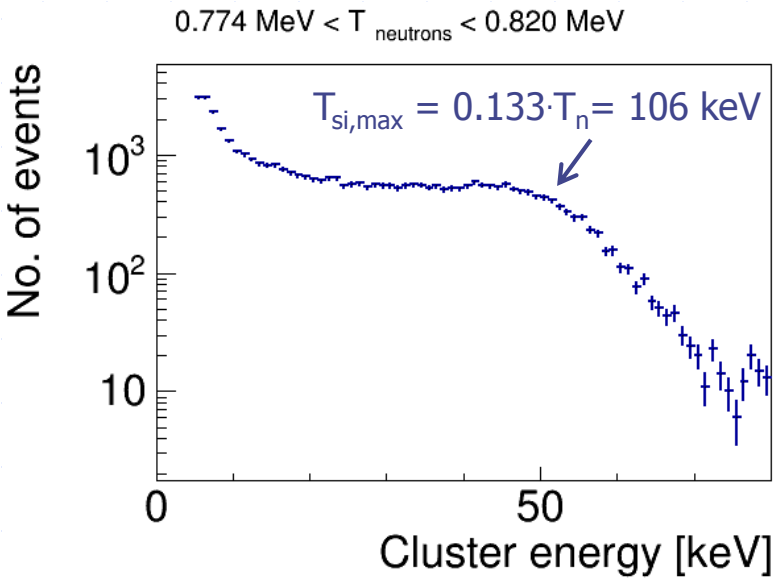
Energy transfer to the silicon nucleus:

$$T_{Si,max} = \frac{4 M_{Si} m_n}{(M_{Si} + m_n)^2} T_n = 0.133 \cdot T_n$$

→ Energy goes partly into displacement (NIEL) and ionization

Signal creation:
The detector measures the charge deposited by the ionization of the recoil silicon nucleus:

- $E_{\text{meas.}} = E_{\text{ion.}}$
- $E_{\text{NIEL}} = T_{Si} - E_{\text{meas.}}$



Neutron scattering - Losses by ionization vs losses due to displacement

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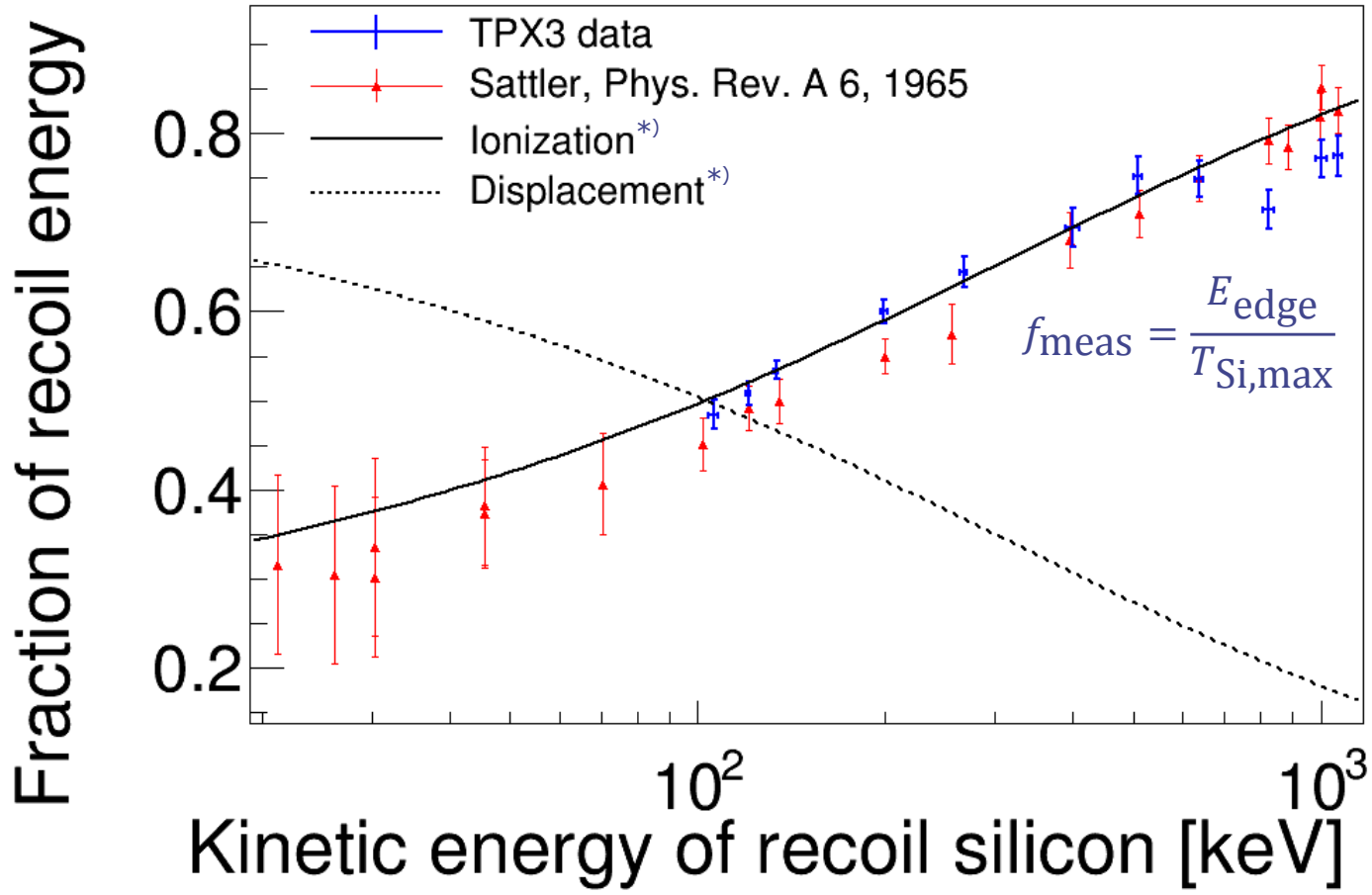
*) The formulae for the calculation can be found in: C. Leroy and P.-G. Rancoita, Rep. Prog. Phys. **70** (2007) 493–625



Detector responses in the form of tracks from different ion species

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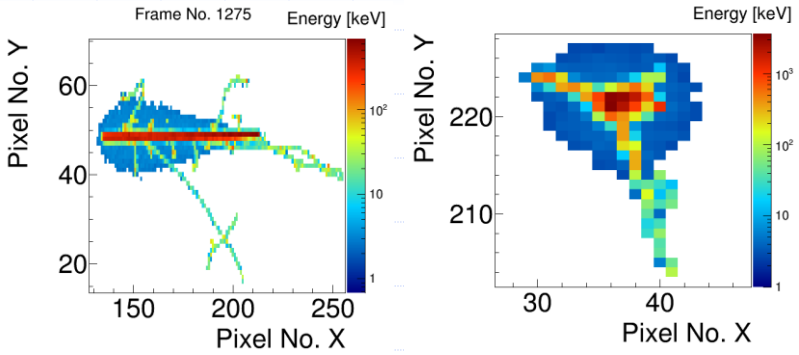
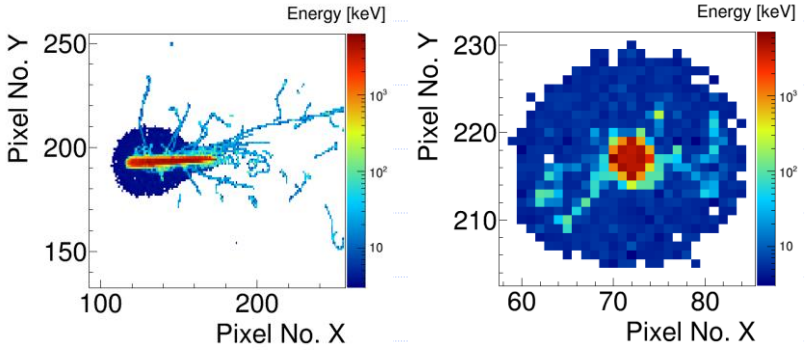
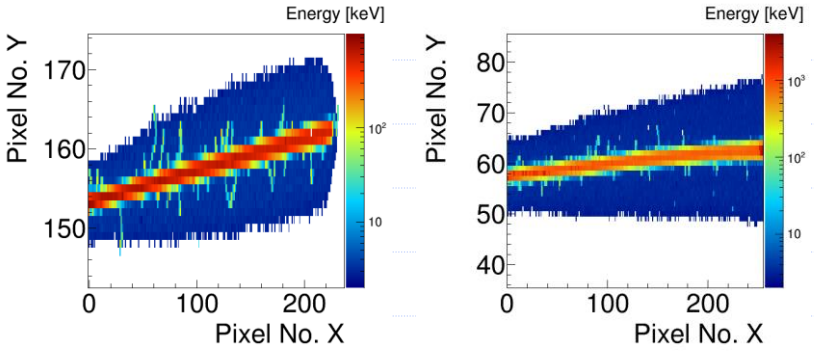


C-12 ions of 1 GeV/A as measured at the nuclotron at JINR in Dubna (Moscow Region): Irradiation at 75° to the sensor normal (left) and perpedicular irradiation (right).

Argon ions of 75 GeV/A measured at the SPS H8 beam line at CERN. The detector was irradiated at 70° to the sensor normal (left) and perpendicular (right)





Measurements at HIT in Heidelberg:
Oxygen ion of 250 MeV/A (left) and **Carbon ion of 200 MeV/A** passing through the sensor parallel to the surface.

Event-by-event evaluation of a Carbon ion 300 MeV/A event

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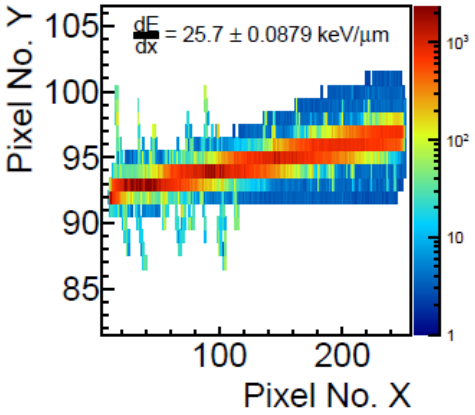
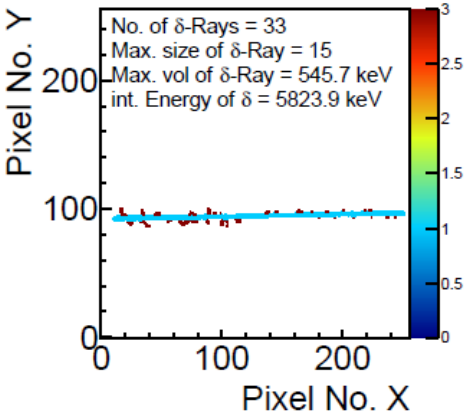
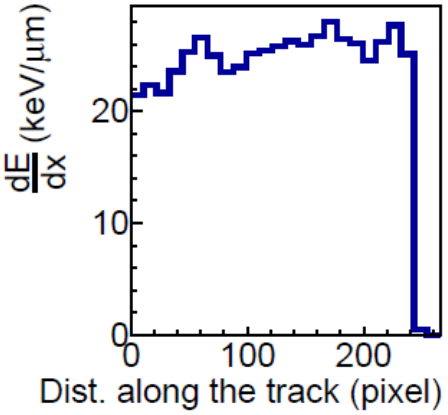
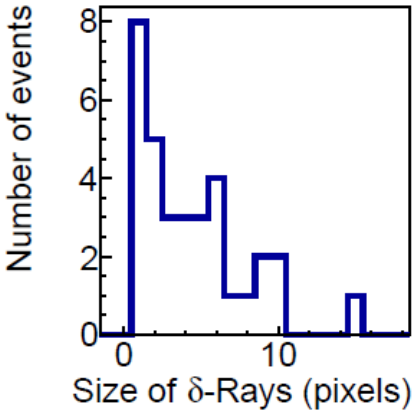


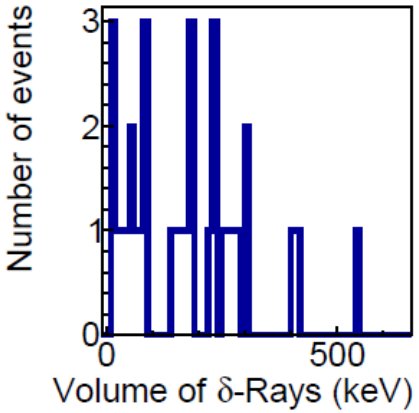




Tracks will be evaluated and interpreted by means of:

- Energy (dE/dx measurements) of the track
- Geometry (width, roundness)
- Characterization of the delta electrons (energy, angle)





First measurements with the TIMEPIX 3

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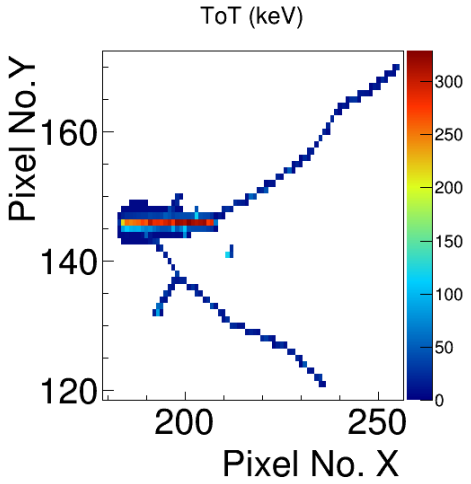
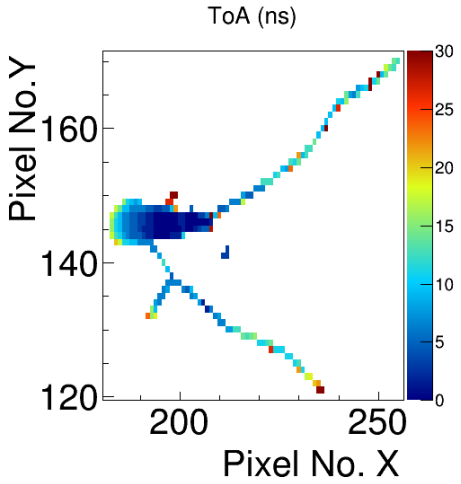
Carbon ion 1 GeV/A:

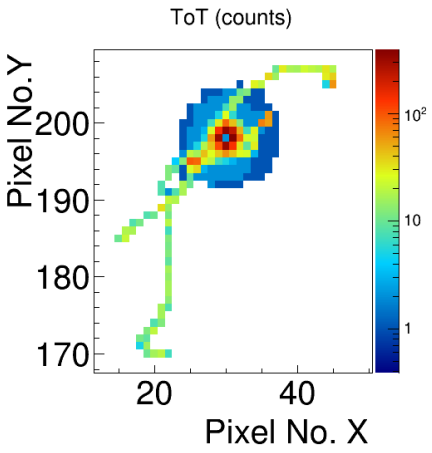
- 300µm thick device
- Bias 90 V
- 75 degree

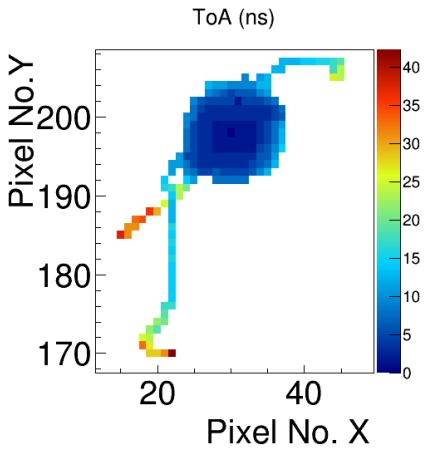
Argon ion 150 GeV/A

- 675 µm thick
- Bias 400V
- 0 degree









Time resolution of 1.56 ns allows to resolve the drift time of the charge carriers.

→ Information about the interaction depth (3D tracking of particles within the sensitive volume)

Conferences

- **IEEE**, Seattle, Nov. 8 – 15, 2015
- **MMND** (Micro-, Mini & Nanodosimetry), Port Douglas, Oct. 20 – 23, 2014
- **IM 2015** (International Confrence on Individual Monitoring of Ionising Radiation), Bruges, April 19 – 24, 2015
- **RAD 2015**, Budva, June 8 – 13, 2015

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Workshops, Training and other Activities

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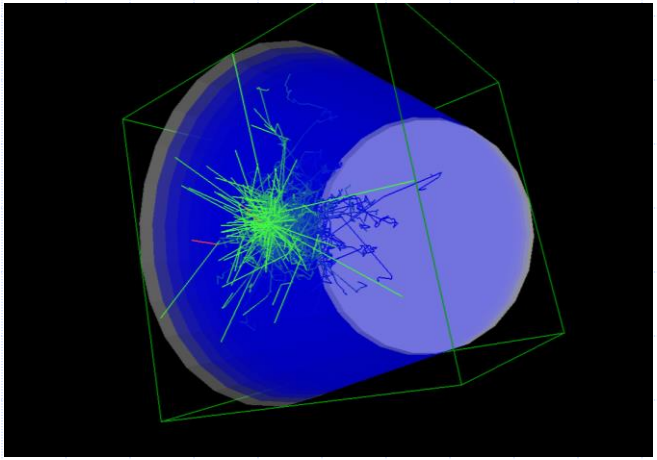
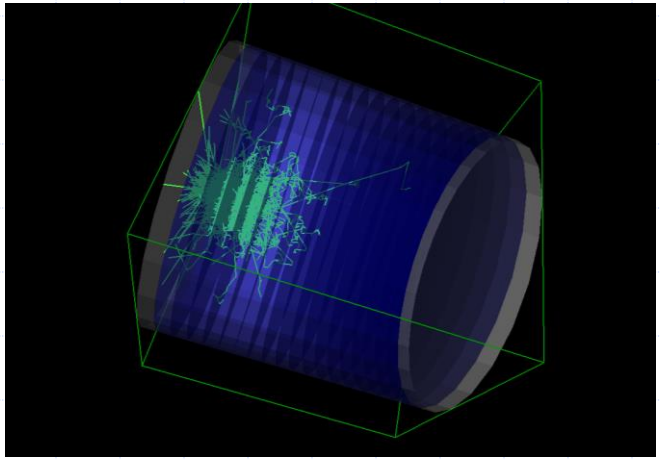
- **Workshops**
  - 3rd Annual ARDENT workshop in Schwarzenbruck (Sept. 29 – Oct. 3, 2015)
  - MPX meeting at CERN (Feb. 18, 2015)
  - SWG 2015 (Spring Workshop on Geant 4), Casta-Papiernicka, SVK (April 26 – May 1, 2015)

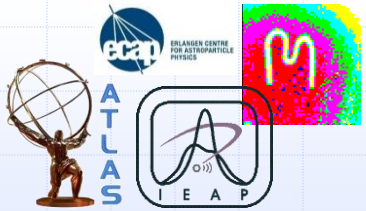




- **Training**
  - Czech language training (ongoing)

Future Activities:

Experiments, Secondment and planned Training



- **Secondment**
  - Erlangen, September 2015
  - Business and administration secondment (?) – IBA (?)

- **Other Training**
  - Czech language courses – ongoing

Thank you for your attention!