
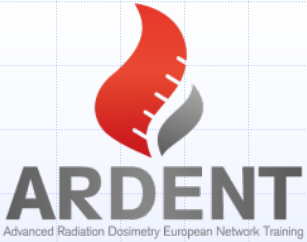


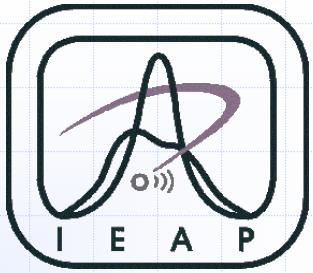


# Study of Fast Neutron Interactions in Silicon by Timepix detectors

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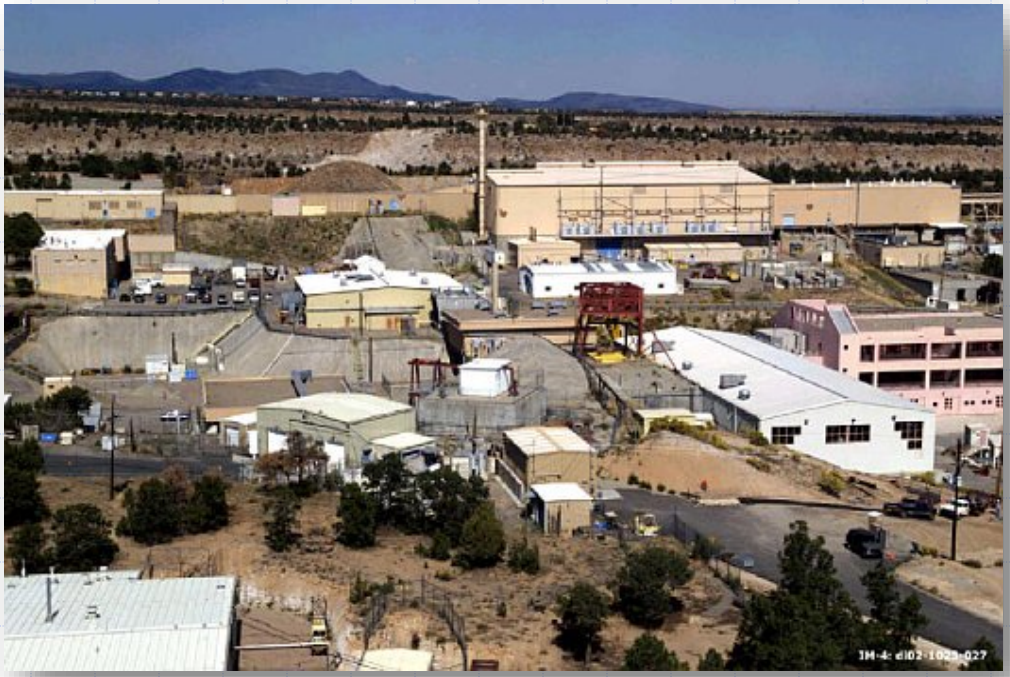
a) Institute of Experimental and Applied Physics, Czech Technical University in Prague
b) Los Alamos Neutron Science Center, Los Alamos National Laboratory
c) Brookhaven National Laboratory
d) CERN
e) Czech Metrology Institute

# INTRODUCTION

Detectors, neutron source, data evaluation techique, ...



# Timepix Detectors

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- Timepix detectors
  - Hybrid pixel detectors
  - Developed at CERN
  - 256 x 256 pixel
  - Pixel pitch: 55µm
  - Silicon sensor layer flip-chip bump bonded to the ASIC

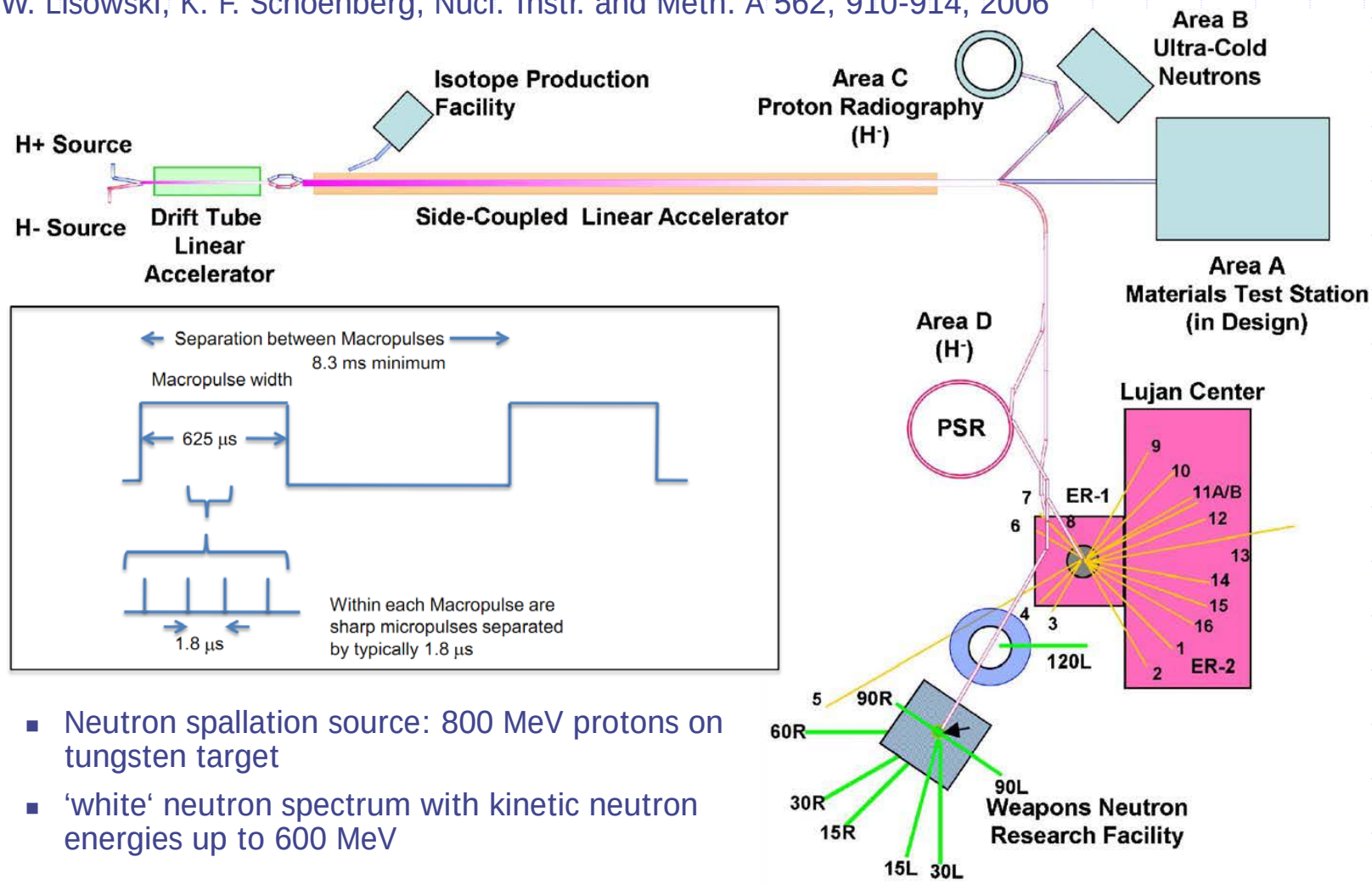

- Timepix:
  - Thickness: 1mm
  - Depletion voltage: 400V
  - Framebased readout (Acq.time 100µs, dead time ~ 11ms)
  - Measurement of either energy **or** time (used in the time mode: resolution 20.6 ns)
  - Threshold set to 4.5 keV

- Timepix 3:
  - Thickness: 300µm
  - Depletion voltage: 90V
  - Data driven readout (Maximal count rate 40 Mpix/s)
  - Measurement of energy **and** time, simultaneously (time resolution 1.56 ns)
  - Threshold set to 5 keV (down to ~2 keV possible)

# Los Alamos Neutron Science CEnter (LANSCE)



P. W. Lisowski, K. F. Schoenberg, Nucl. Instr. and Meth. A 562, 910-914, 2006




- Neutron spallation source: 800 MeV protons on tungsten target
- 'white' neutron spectrum with kinetic neutron energies up to 600 MeV

# LANSCE: Detector setup and neutron energy spectrum

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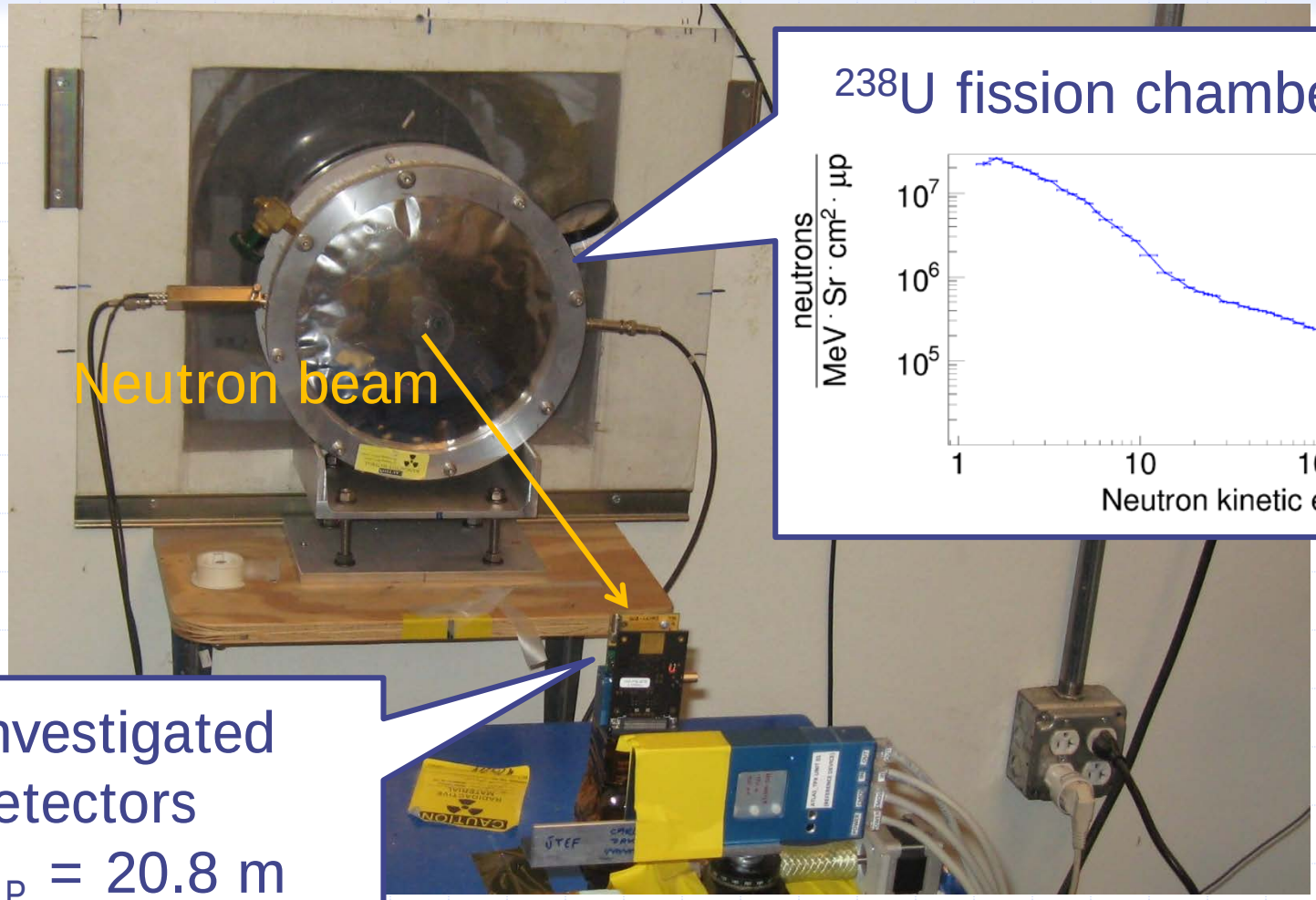


$^{238}$U fission chamber




Investigated detectors
$d_{IP}$ = 20.8 m

# Pattern recognition – definition of different cluster types

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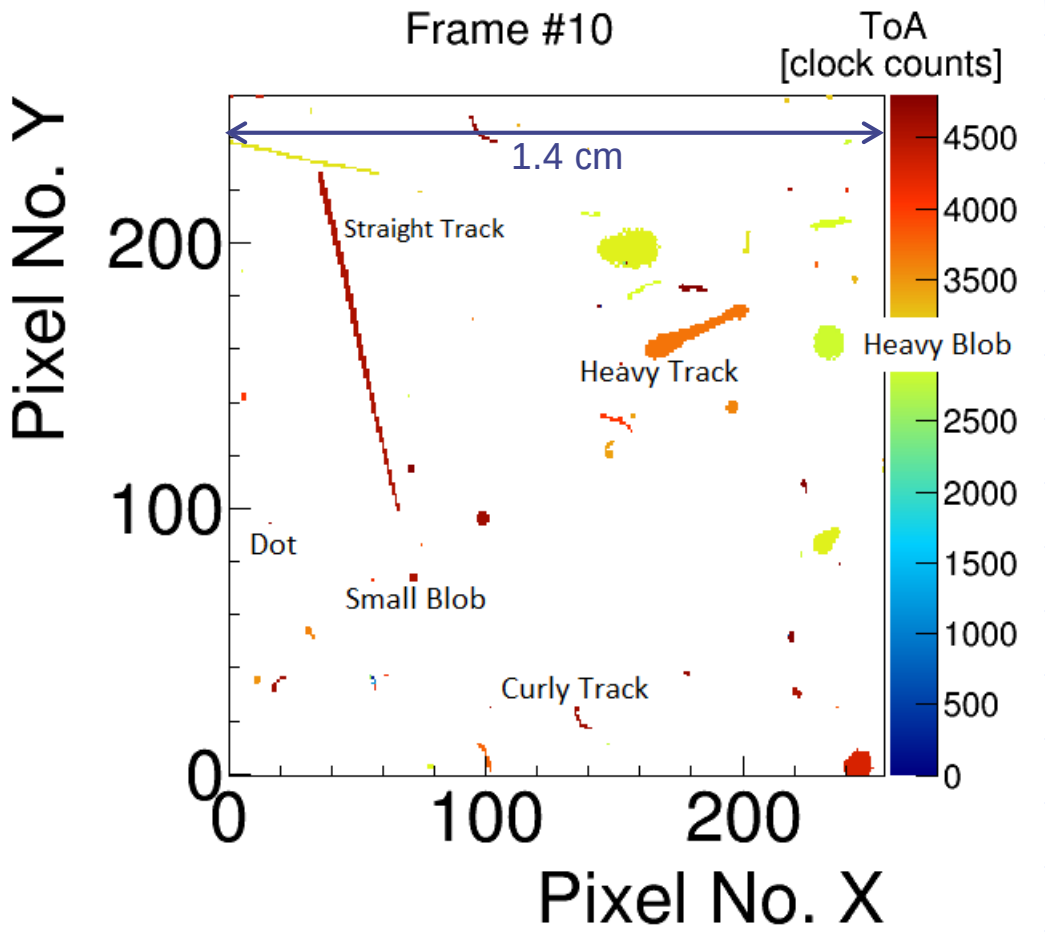



Frame taken with a Timepix (1 mm, 400V, $t_{Acq.}$ = 100µs) in the LANSCE neutron beam.

## Low Energy Transfer Events (LETE):

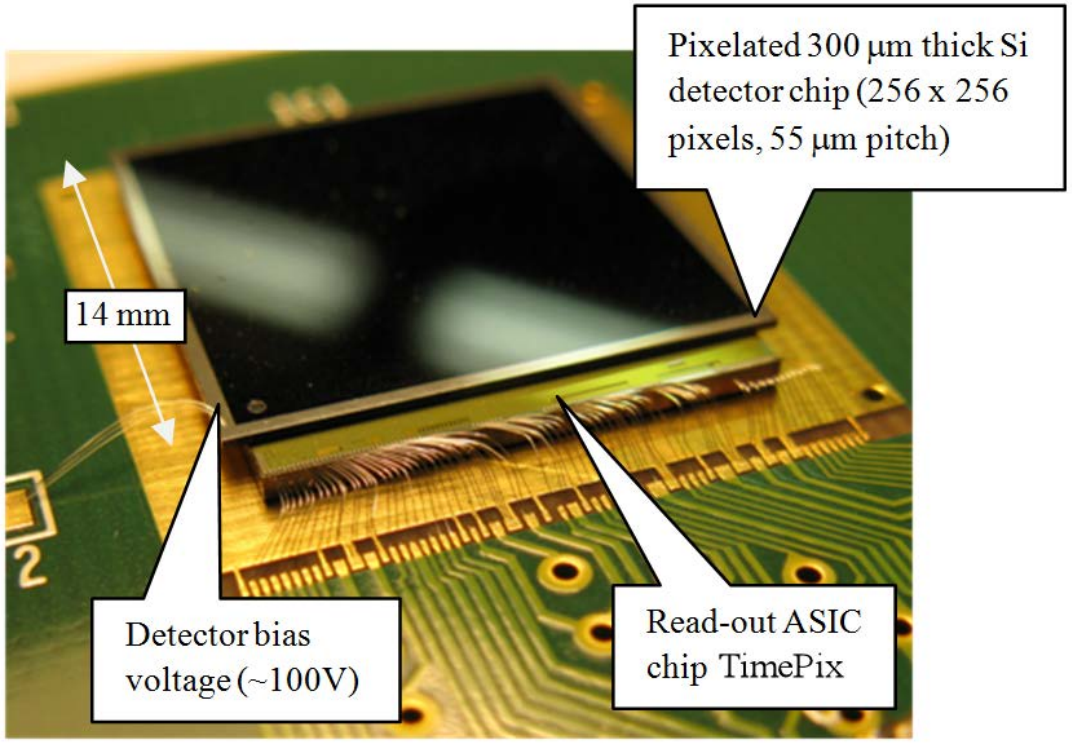
- Dots (photons and electrons ~ 10 keV)
- Small Blobs (photons and electrons)
- Curly Tracks (electrons MeV range)
- Straight Tracks (MIPs, Muons, …)

## High Energy Transfer Events (HETE):

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

# TIMEPIX

Results and discussion by means of radiation damage



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

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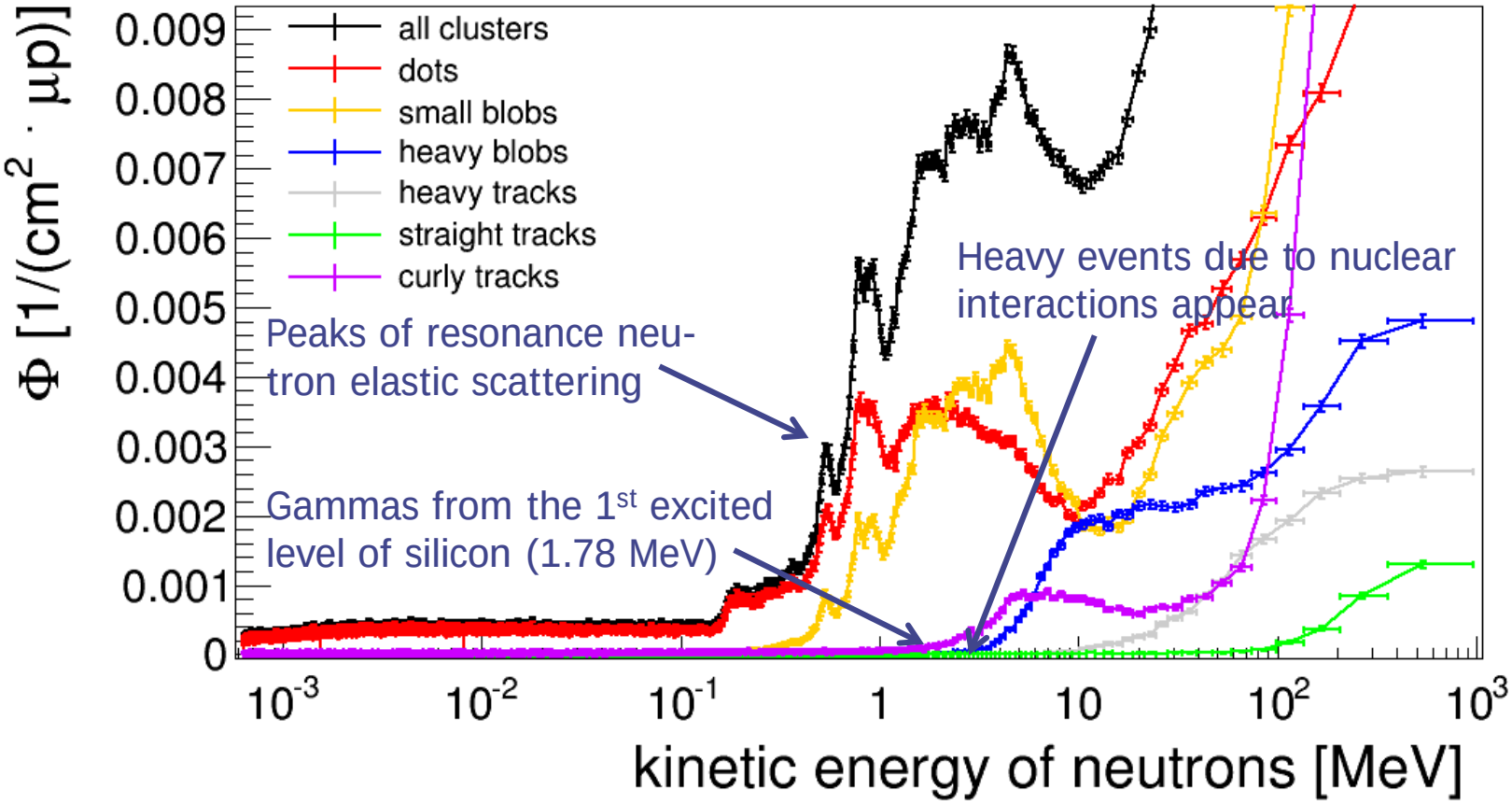
The ToF technique*) was used to assign the detector responses to the corresponding neutron energies (track by track).




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

# TIMEPIX: Detector responses for selected energy intervals

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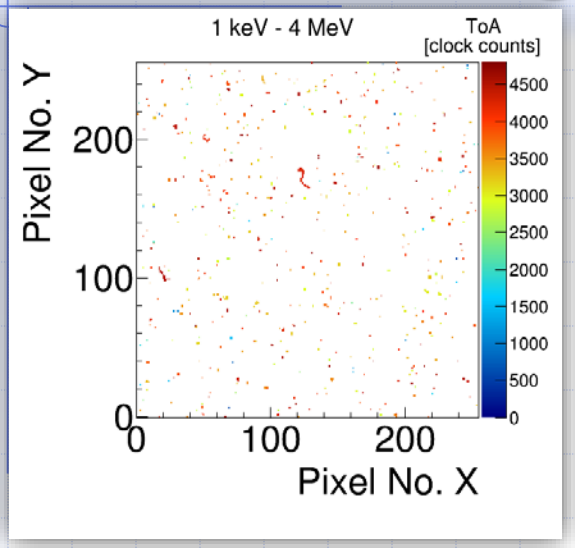


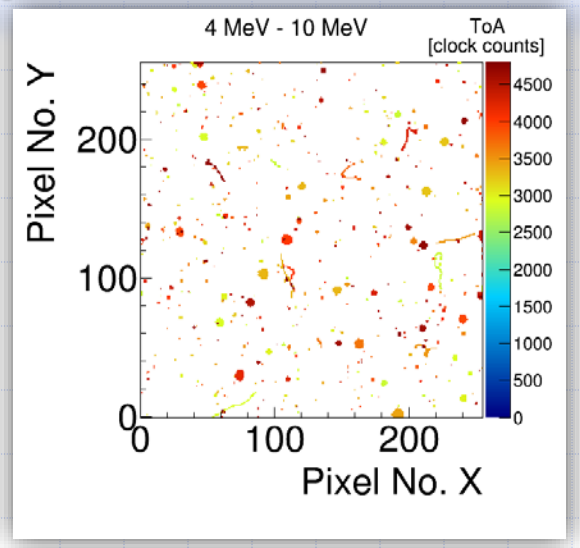


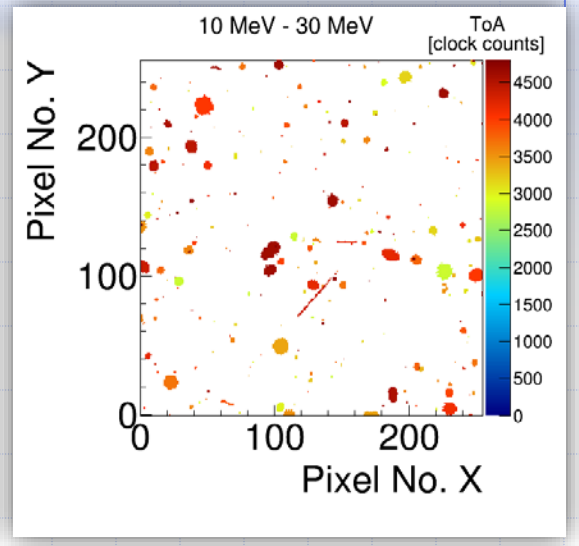


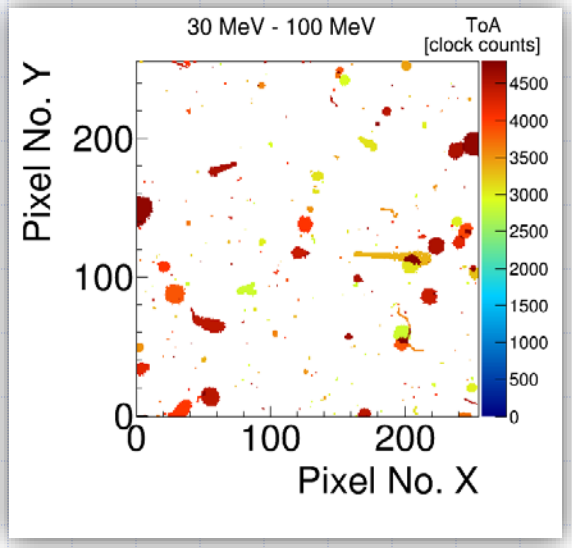


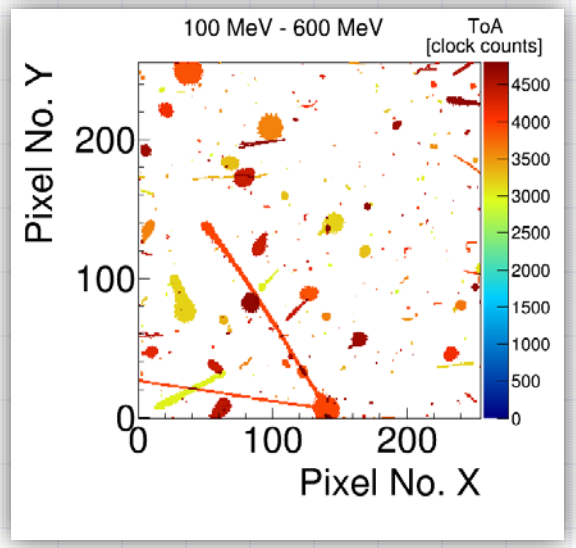


- Above **4 MeV**: HETE appear
- Above **30 MeV**: HETE are getting more and more asymmetric and bigger with increasing energy
- Above **100 MeV**: interactions with long outgoing tracks

# TIMEPIX: Interpretation of the signatures by means of radiation damage

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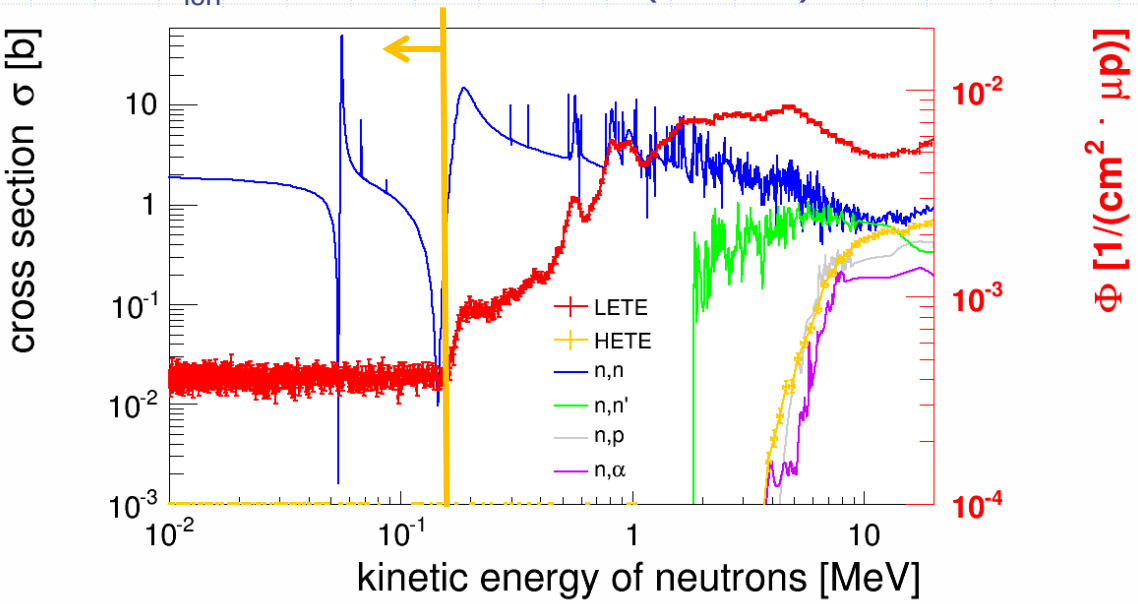
$E_{ion}$ < Detector threshold (4.5 keV)




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

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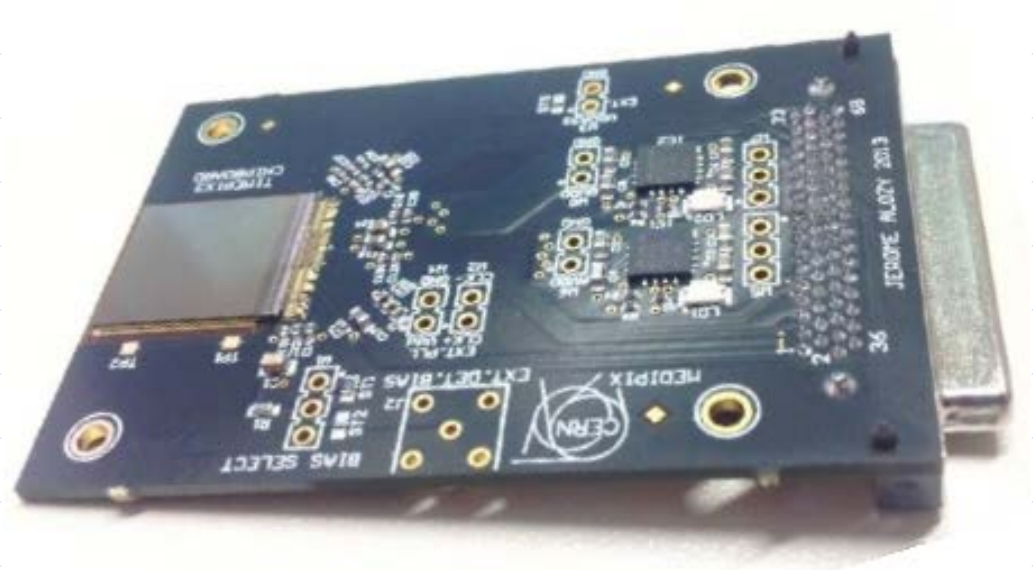
# TIMEPIX3

First look and preliminary results …




Timepix3 CERN chip board

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

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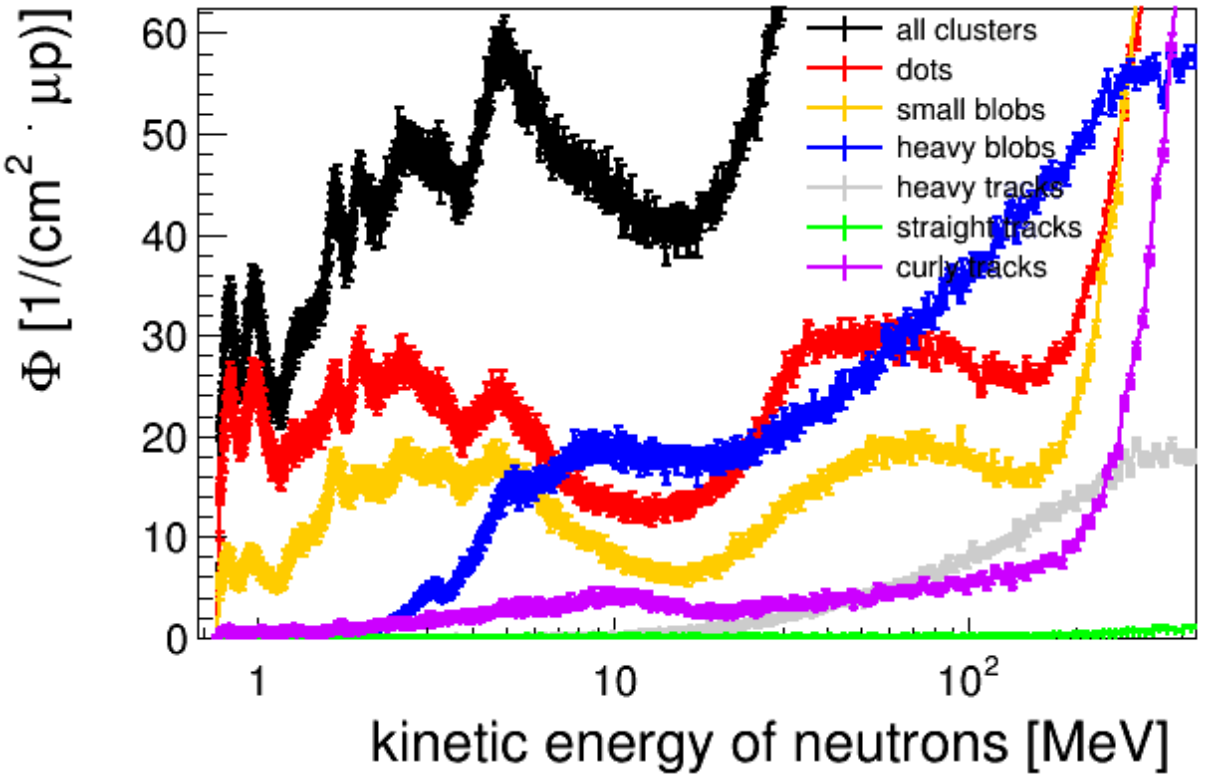
- Same behaviour as for Timepix
- Better time resolution leads to better selection of neutron kinetic energies



# TIMEPIX3: Examples of energy spectra for selected neutron energy intervals

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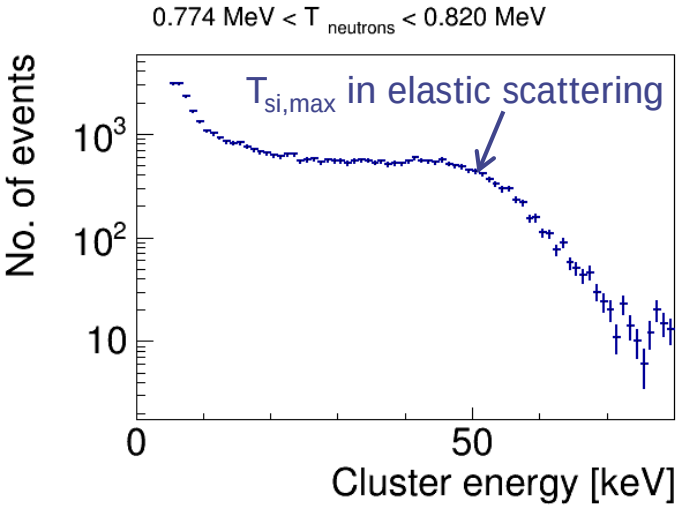


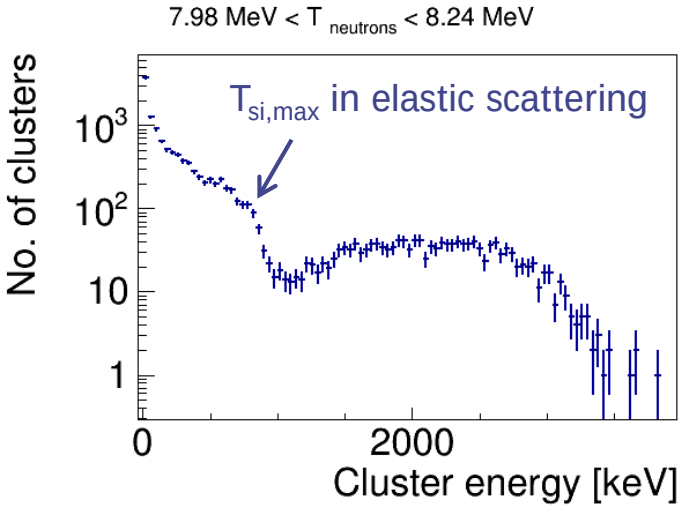


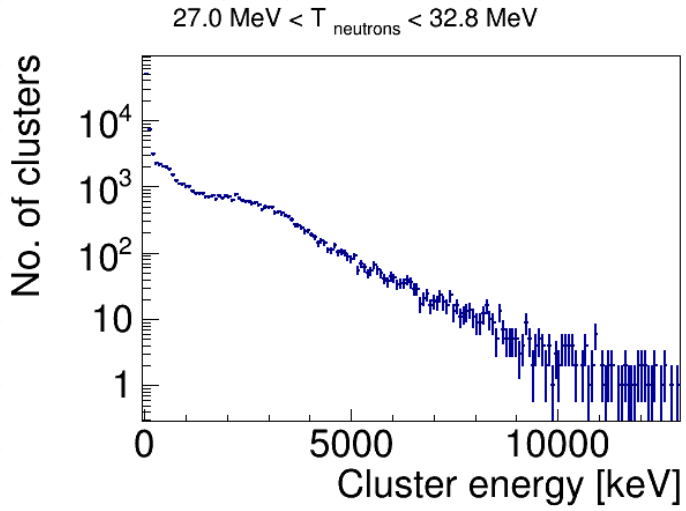


- Time-of-Flight technique used to select quasi-monoenergetic neutrons:
  - $\Delta T_n/T_n$ up to ~ 1% ($T_n$ < 10 MeV)
  - $\Delta T_n/T_n$ ~ 7% ($T_n$ ~ 30 MeV)
- Investigate the spectrum of deposited energies by means of a pulse shape analysis

# Neutron elastic scattering

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Czech Technical University in Prague

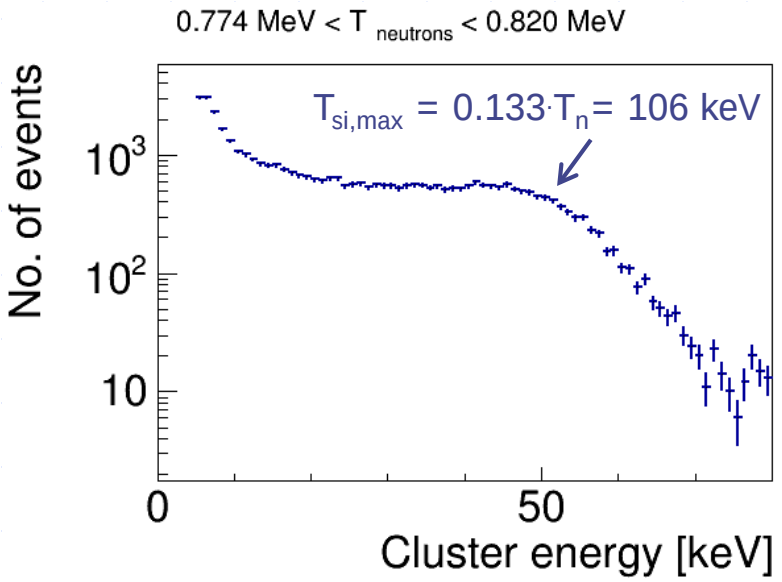
Energy transfer to the silicon nucleus:

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

→ Energy goes partly into displacement (NIEL) and ionization

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

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



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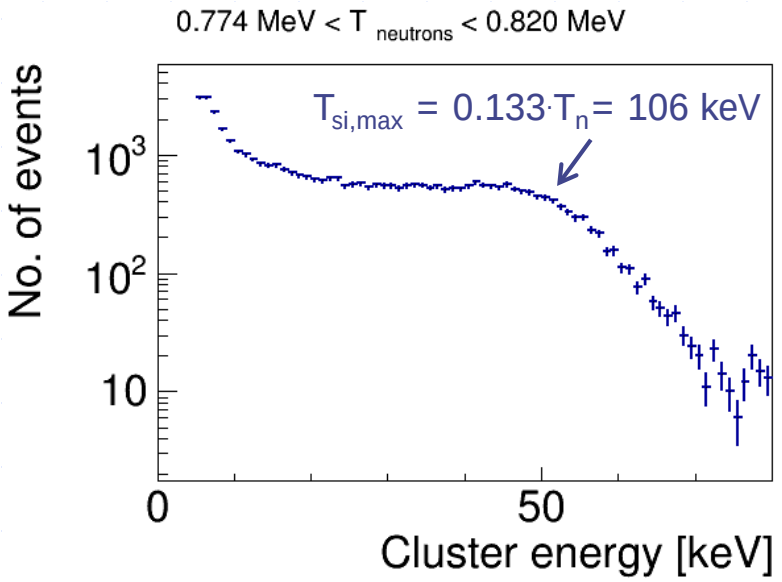

# Neutron scattering: Losses by ionization vs losses due to displacement

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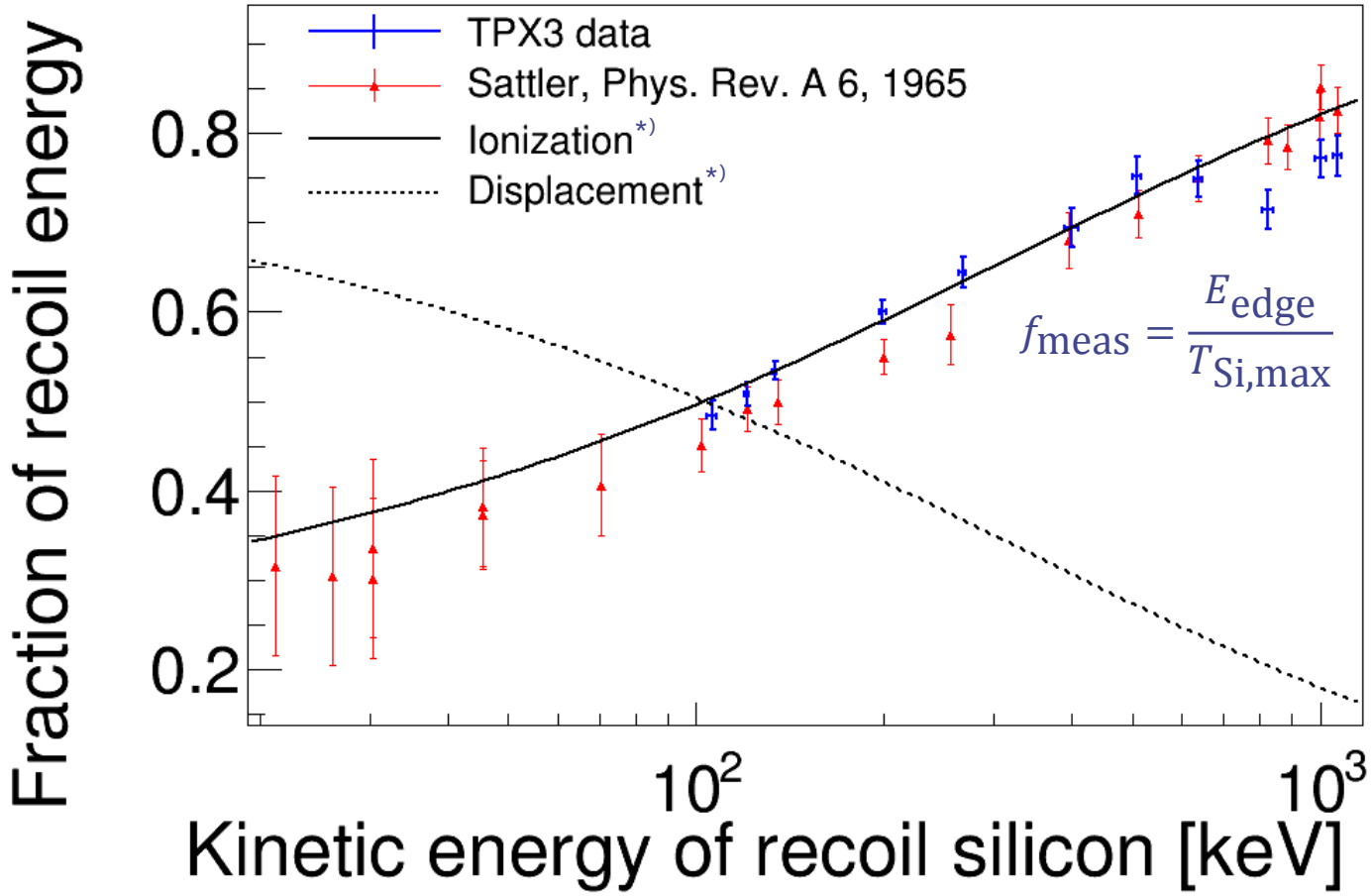
*) The formulae for the calculation can be found in: C. Leroy and P.-G. Rancoita, Rep. Prog. Phys. **70** (2007) 493–625



# SUMMARY AND CONCLUSION

- The response in the form of tracks of a hybrid active pixel detector with silicon sensor layer for different neutron energies was studied by using the ToF technique
  - Different track shapes indicate the different interactions and energy depositions in the sensor layer
  - The detector responses were tried to be interpreted in the context of radiation damage

- A newly developed type of Timepix detectors was tested in the measurement for the first time allowing the simultaneous measurement of energy and time
  - Study the non-ionizing vs. ionizing energy losses (especially for the lower energy region)
  - Deeper insight of the processes leading to the different cluster shapes
  - Understand the nature of SEU and MBU (by coincidence measurement with failures of electronic devices)

## Thank you for your attention!

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