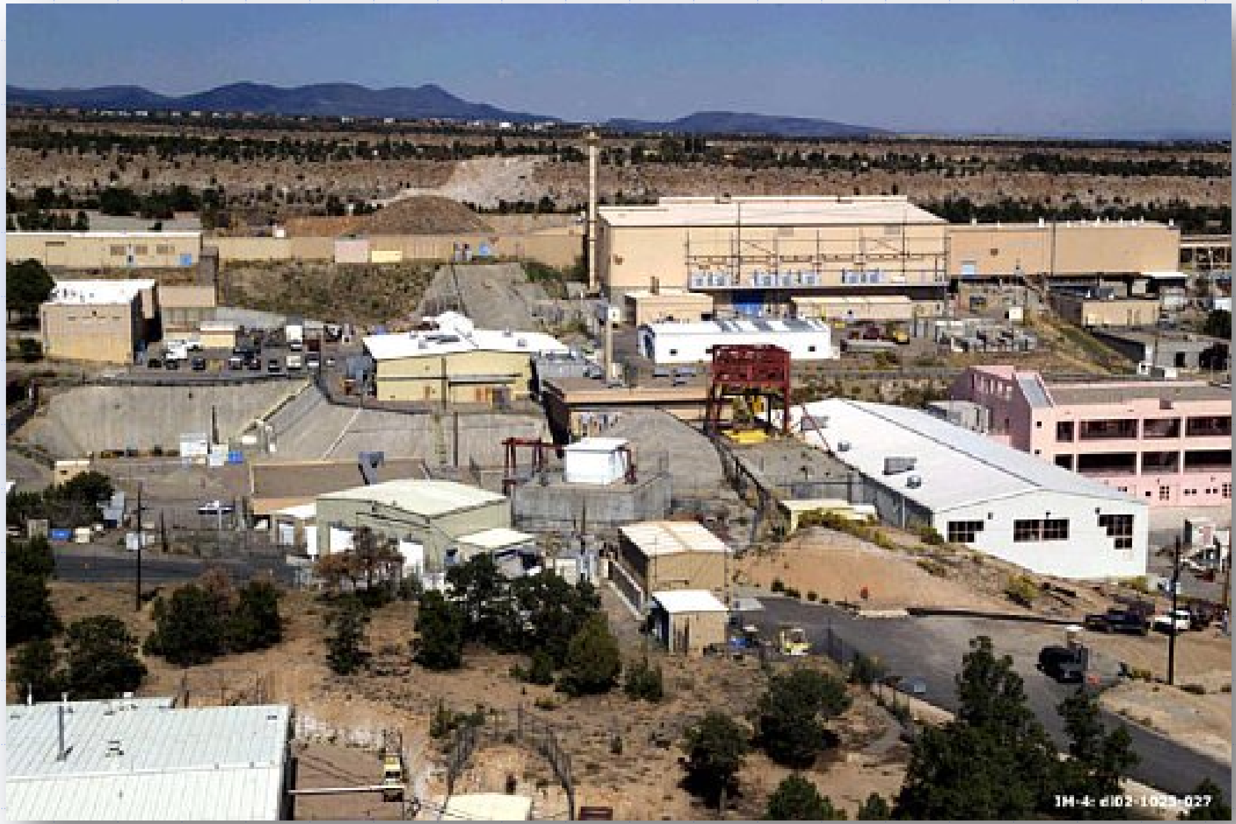
Neutron Time-of-Flight, Proton and Heavy Ion Measurements with a Timepix Detector

B. Bergmann[a)], S. Brons[e)], I. Caicedo[a)], M. Holik[a)], V. Kraus[a)], J. Kirstead[c)], S. Pospisil[a)], M. Silari[d)], H. Takai[c)], D. Turecek[a)], Z. Vykydal[a)] and S. Wender[b)]

a) Institute for 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) Heidelberger Ionenstrahl-Therapiezentrum (HIT)



Time of Flight measurement with neutrons

BEAM TIME AT LOS ALAMOS NEUTRON SCIENCE CENTER

Los Alamos Neutron Science CEnter (LANSCE)

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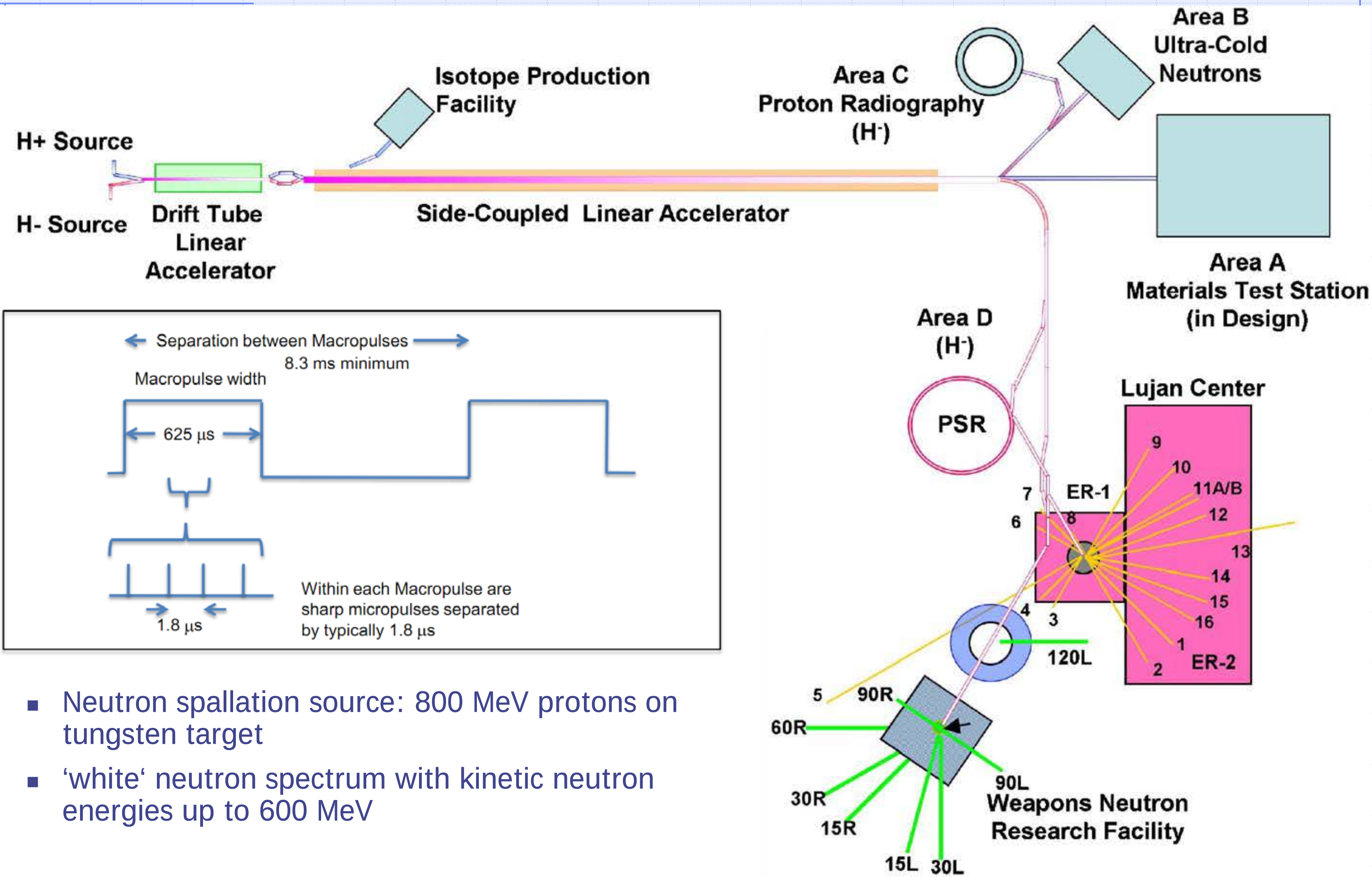

- Neutron spallation source: 800 MeV protons on tungsten target
- ‘white‘ neutron spectrum with kinetic neutron energies up to 600 MeV

Energy spectrum of the neutrons

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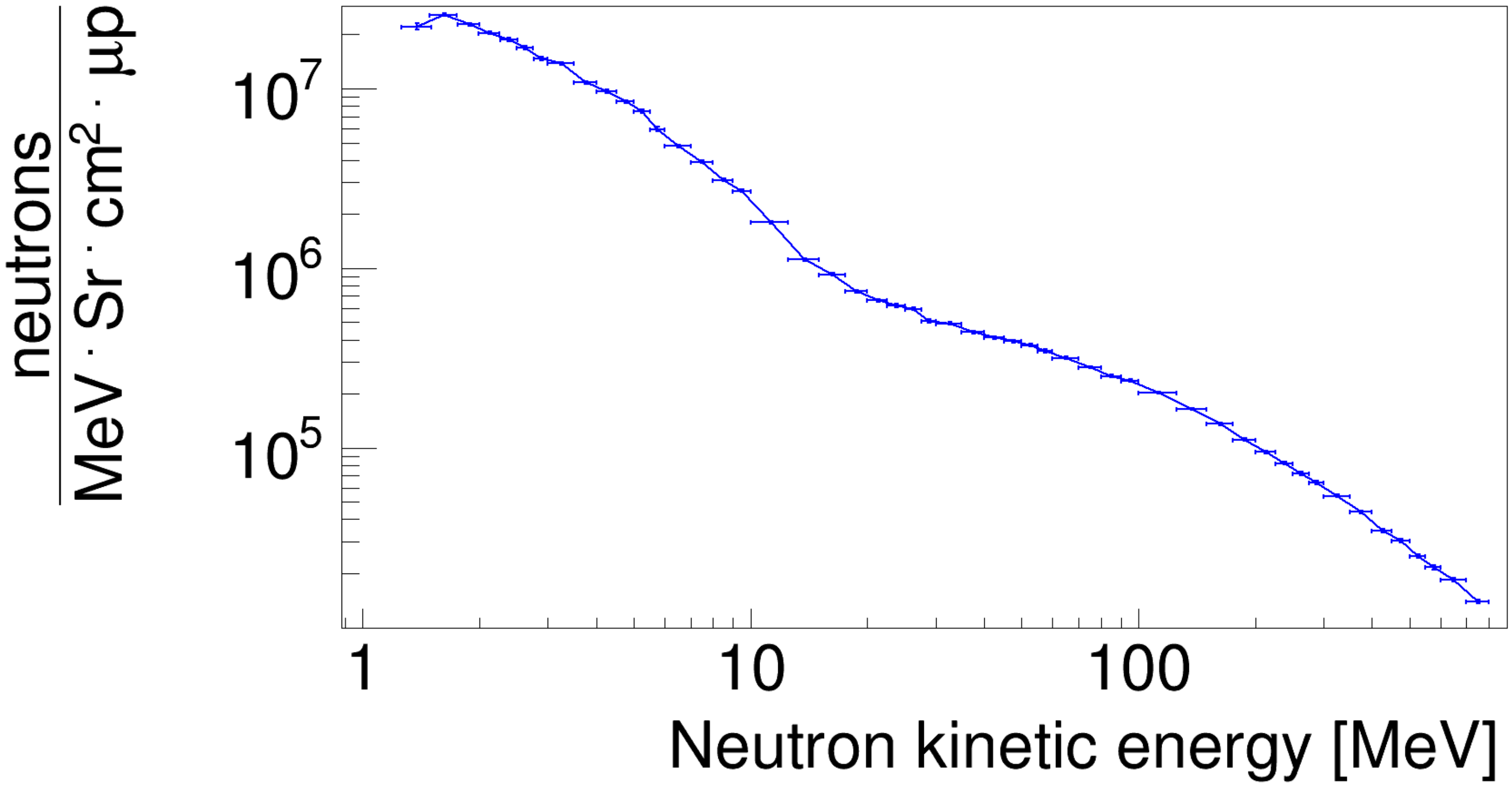

Energy spectrum of the neutrons measured by a ^{238}U fission chamber

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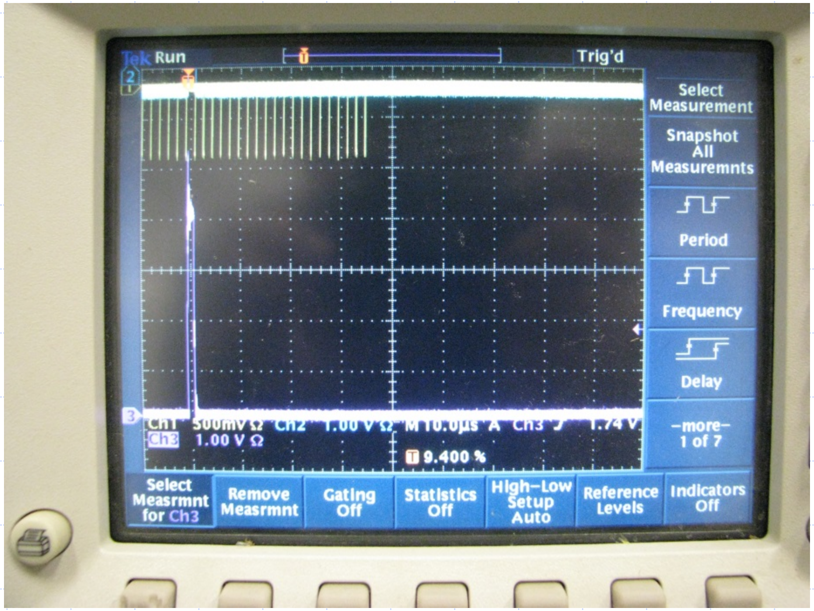
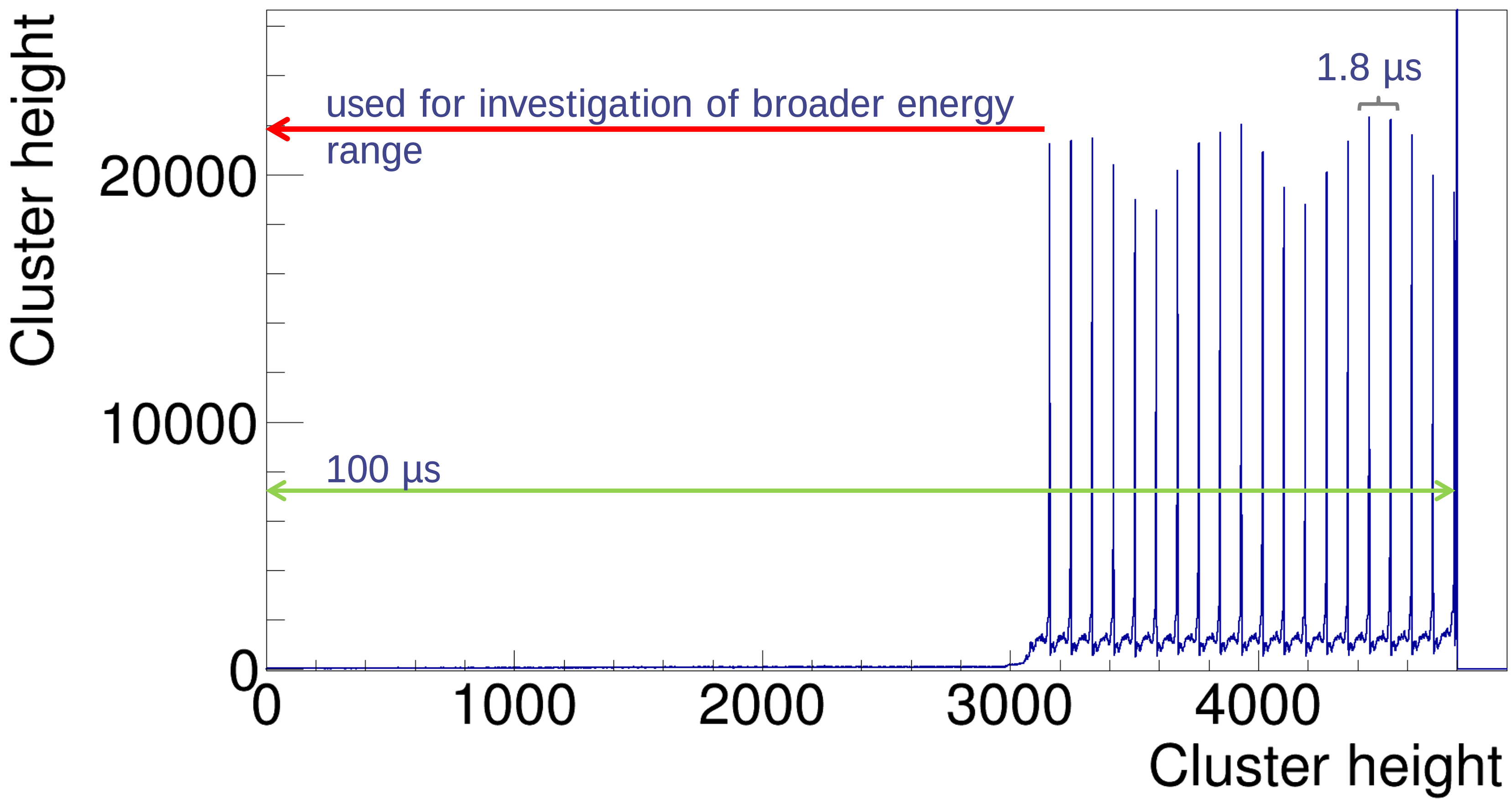
Setup at FP 30 L and trigger signal

- Detector:
  - 1 mm thick silicon sensor layer
  - TOA mode (f_{clock} = 48 MHz)
  - Bias voltage = 400 V
  - t_{acq} = 100 µs
  - 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

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- 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:

$$\mathbf{t_{Flight} = [\underbrace{(ToA_{max} - ToA) \; / \; f_{clock}}_{\text{Time-difference to the gamma flash}} + d/c]}$$

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

- Calculation of the kinetic neutron energy:

$$\mathbf{T = E - M = (\gamma - 1)\, M;}$$

$\gamma = (1 - \beta^2)^{-0.5}$; $\beta = v / c = d / (c \cdot t_{Flight})$;
$M = 957.59$ MeV; $c = 2.9997 \cdot 10^8$ m/s; $d = 20.411$ m

Pattern recognition – definition of different cluster types

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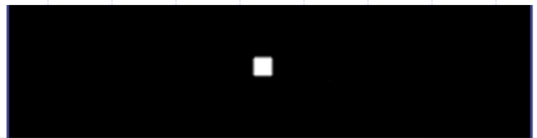
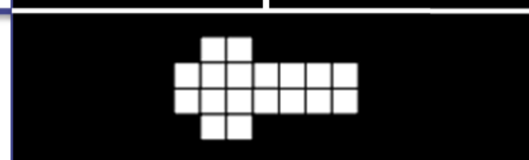
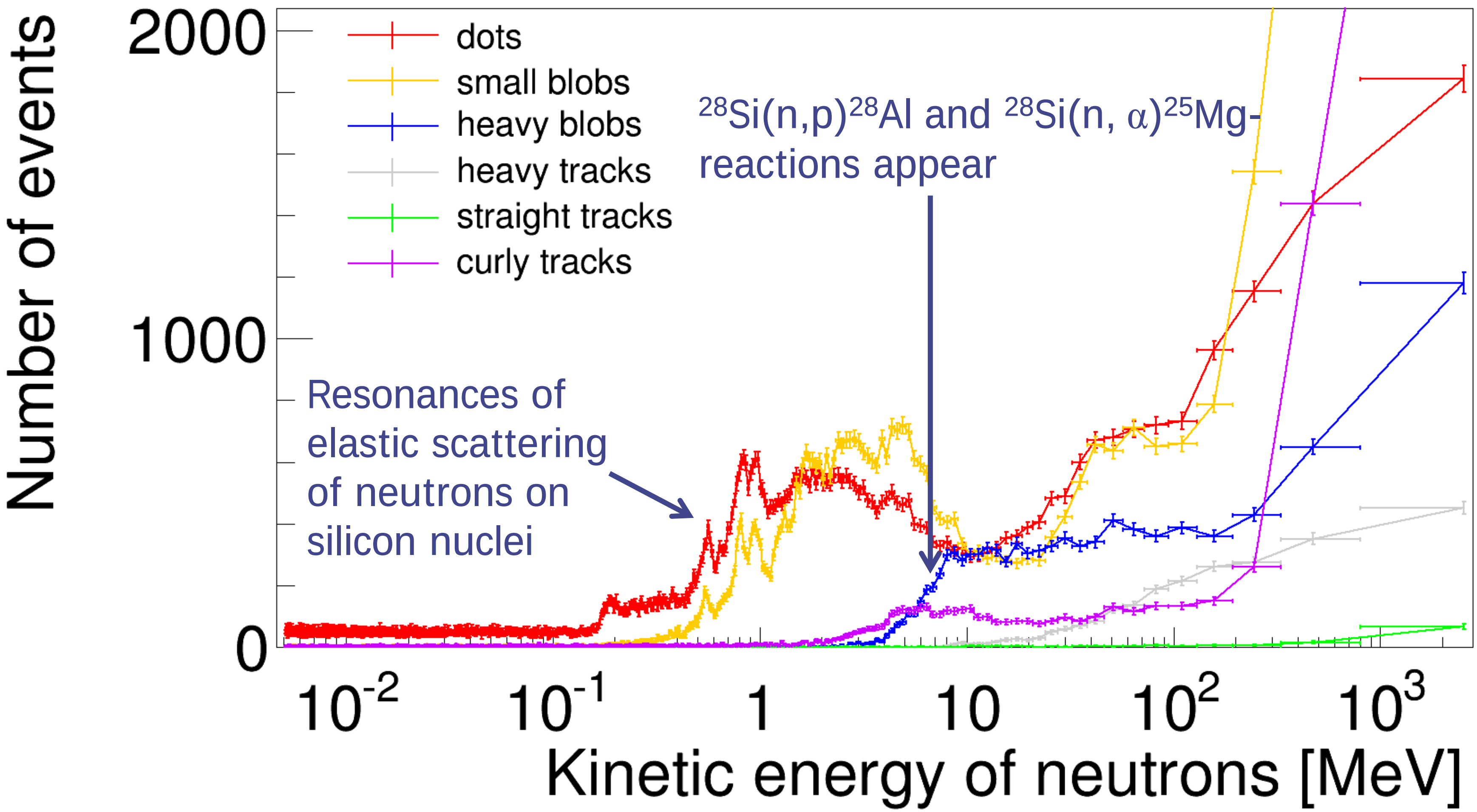
Dot		Photons and electrons (10keV)
Small Blob		Photons and electrons
Curly Track		Electrons (MeV range)
Heavy Blob		Heavy ionizing particles with low range (alpha particles,...)
Heavy Track		Heavy ionizing particles (protons,...)
Straight Track		Energetic light charged particles (MIP, Muons,...)

Cluster shapes as a function of neutron kinetic energy



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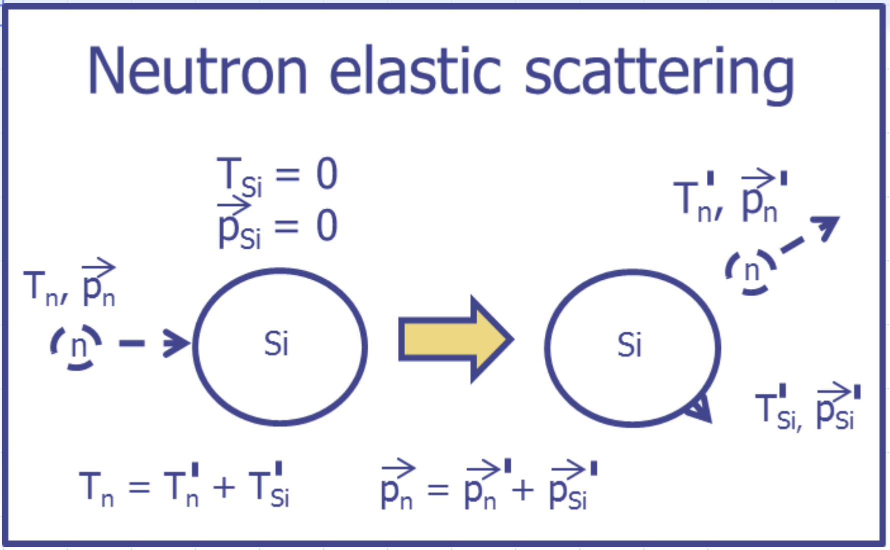
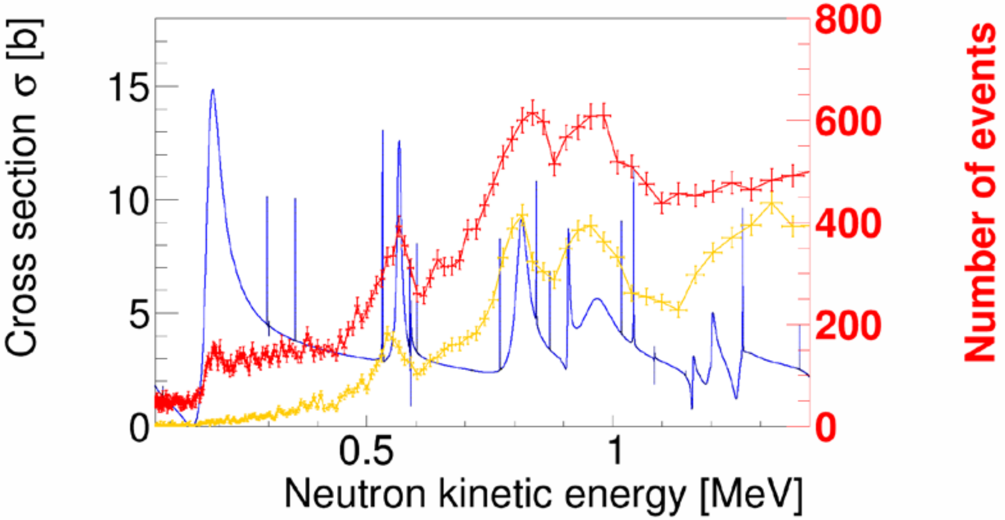
Neutron elastic scattering



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} ~ 70 keV for T_n = 1 MeV).

-> Dots and small blobs



Nuclear reactions on silicon

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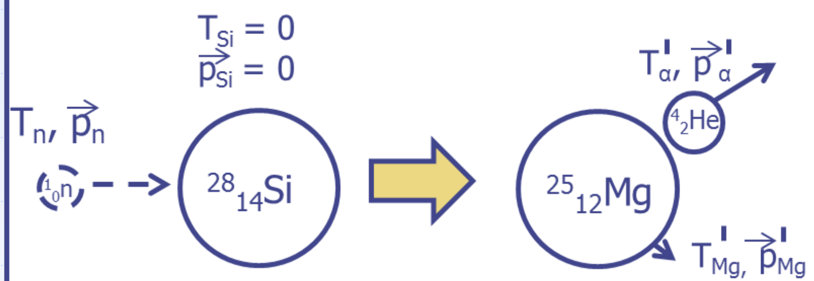
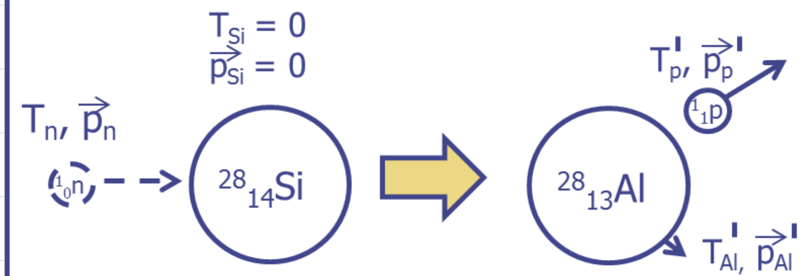
Nuclear reaction: Si (n,α) Mg

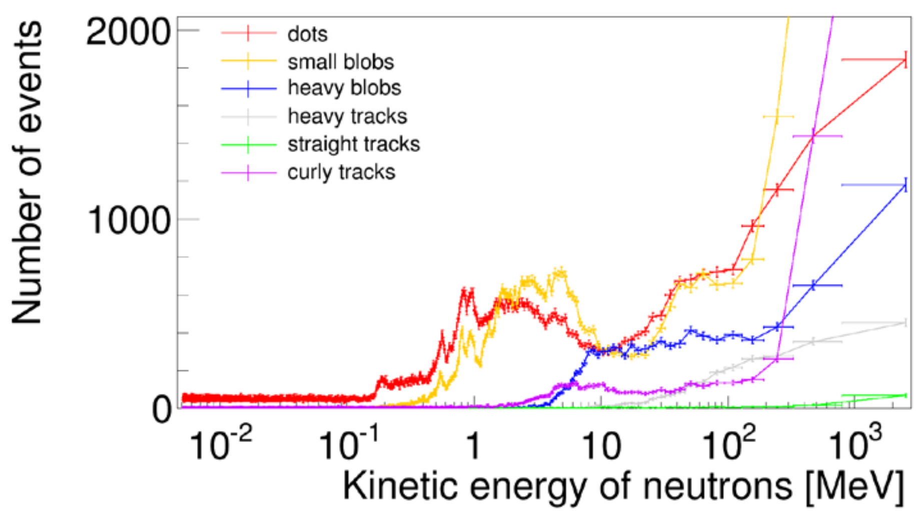


$T_n = T'_p + T'_{Al} + |Q|$

Nuclear reaction: Si (n,p) Al



$T_n = T'_p + T'_{Al} + |Q|$



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

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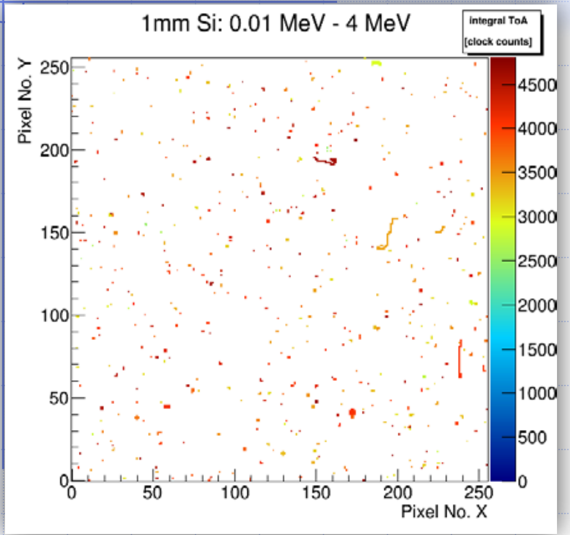
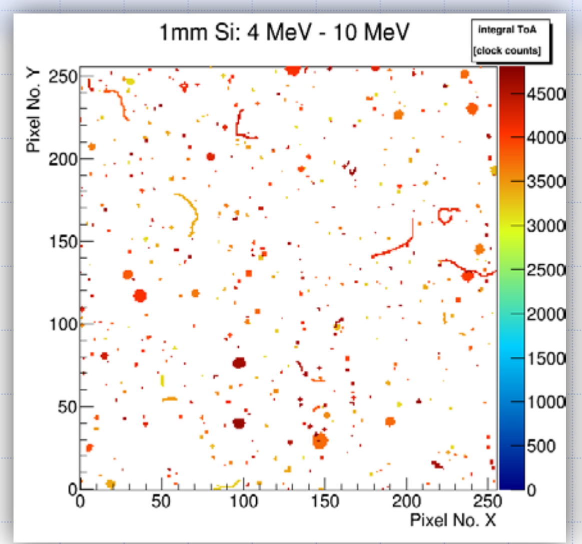
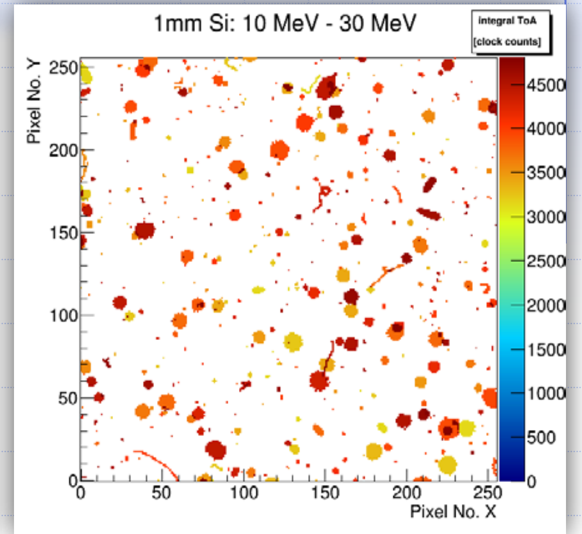
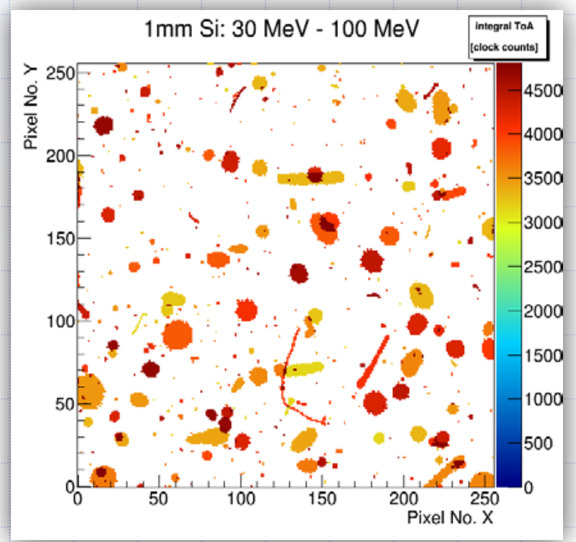
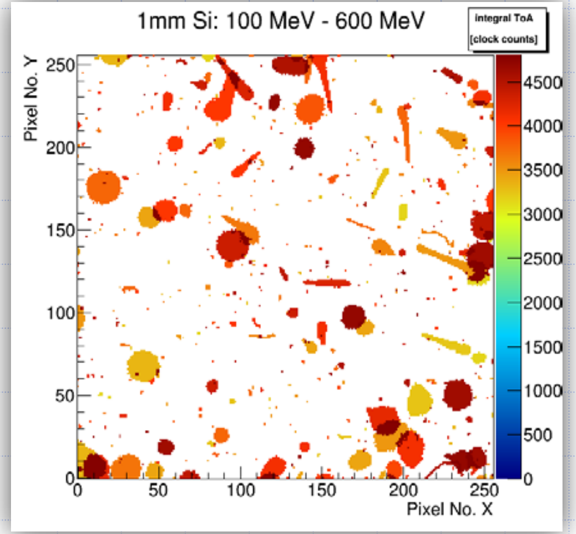


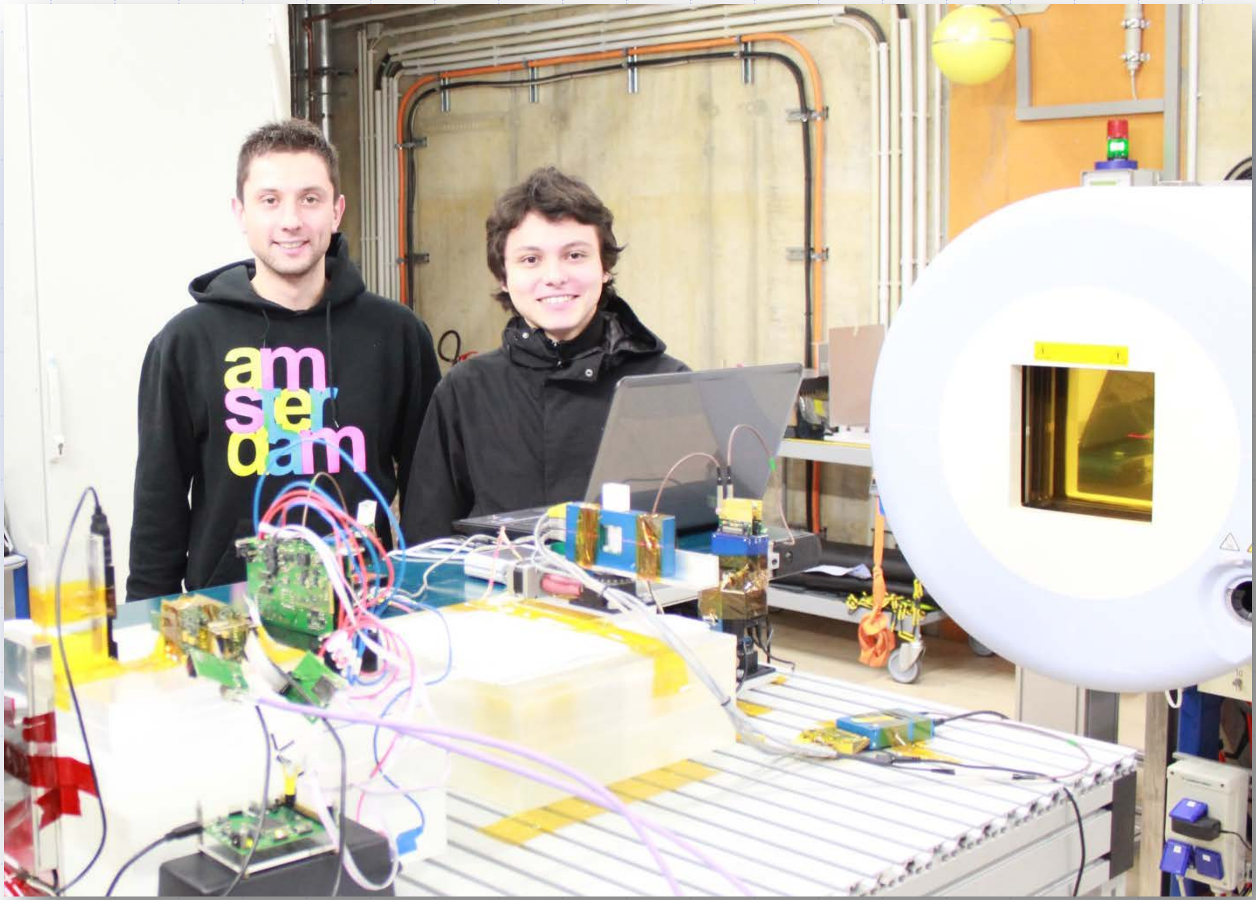


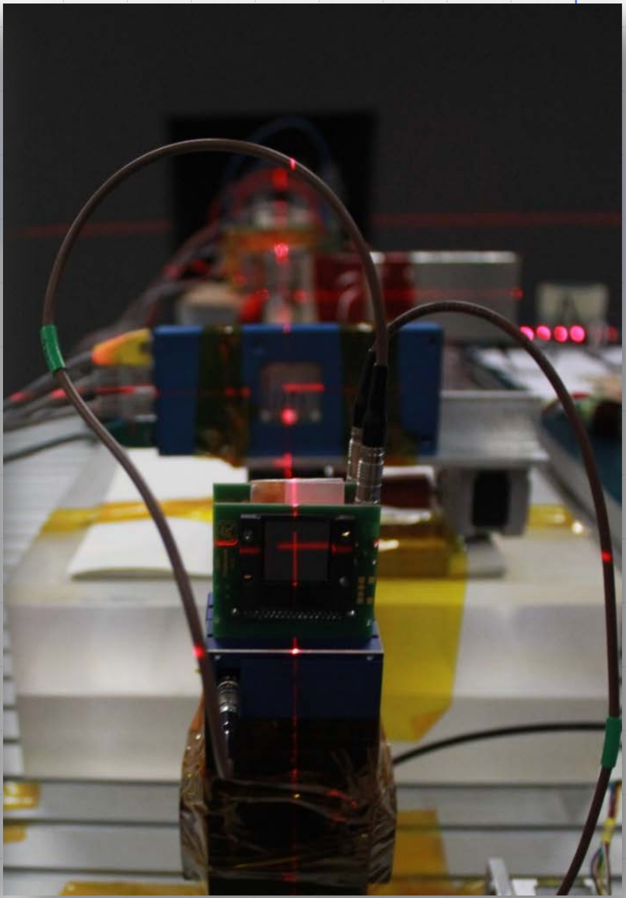






- Above **4 MeV**: nuclear interaction appear
- Above **30 MeV**: HETP are getting more and more asymmetric and bigger with increasing energy
- Above **10 MeV**: tracks with delta electrons are detected





Protons, Carbon, Oxygen and Helium – First look …

BEAM TIME AT HIT IN HEIDELBERG

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Investigated ions species and detector settings

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- Detector
  - 1 mm thick silicon sensor
  - Bias voltage 400 V
  - Clock frequency: f_{clock} = 48 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

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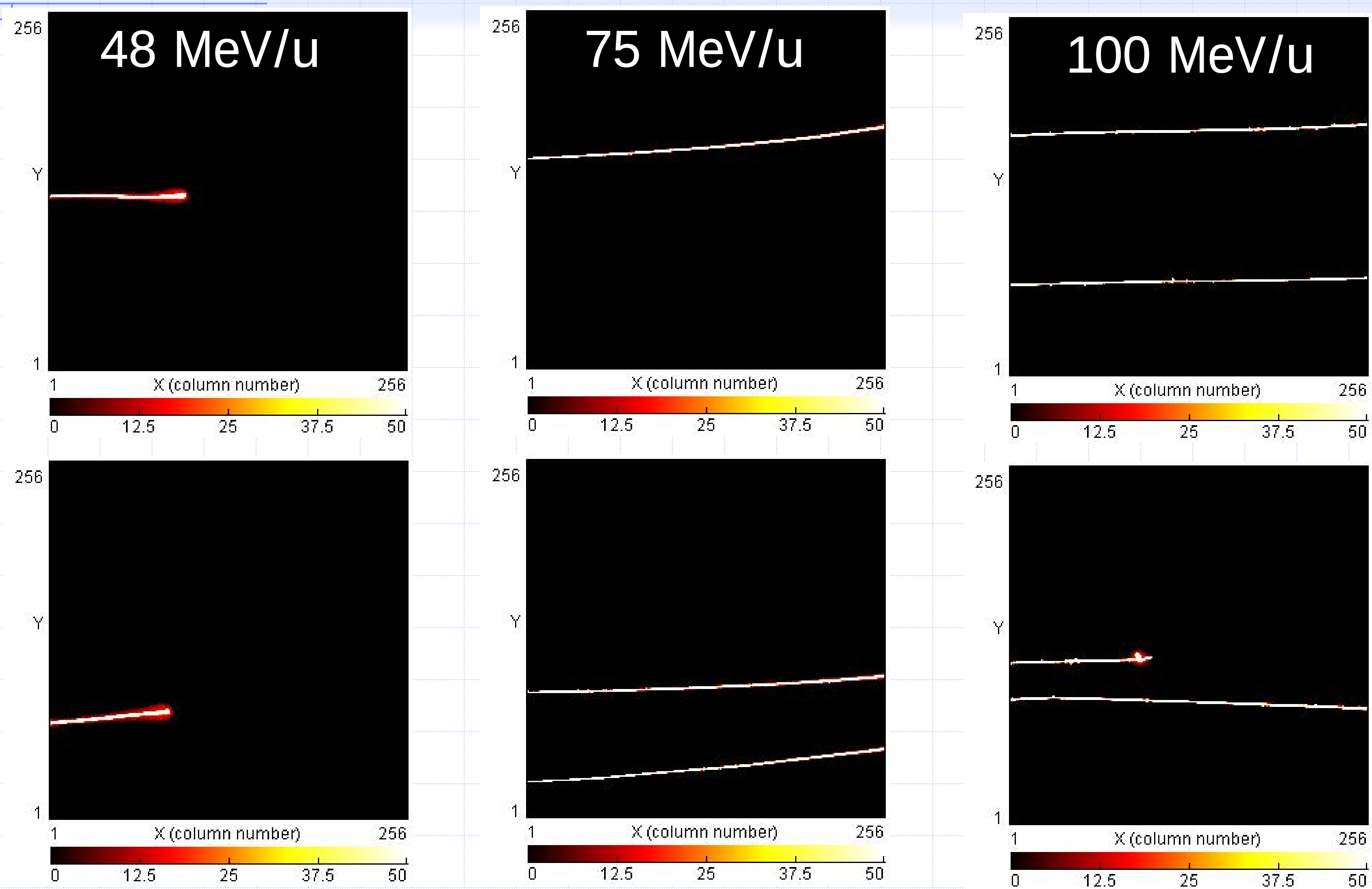
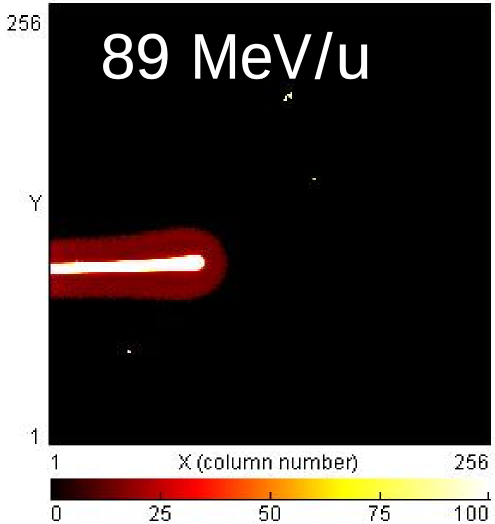
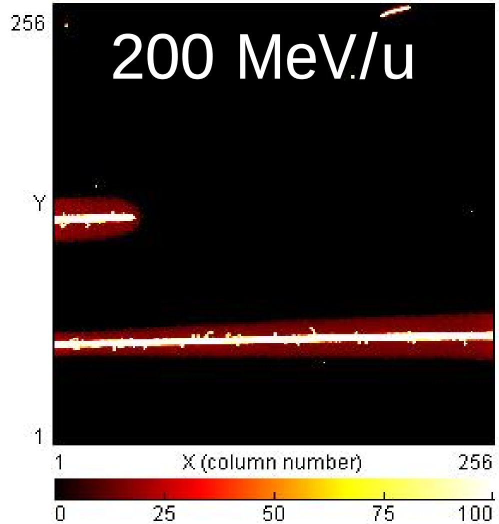
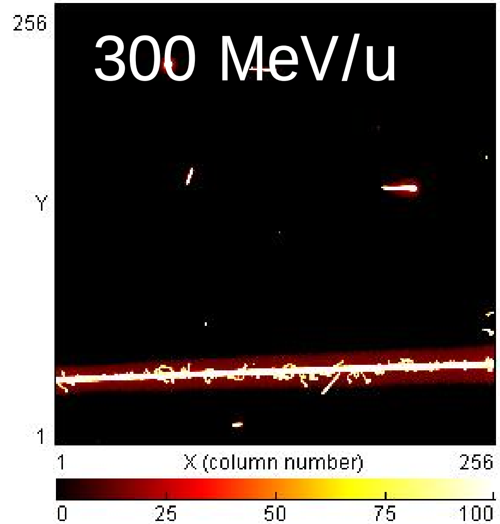


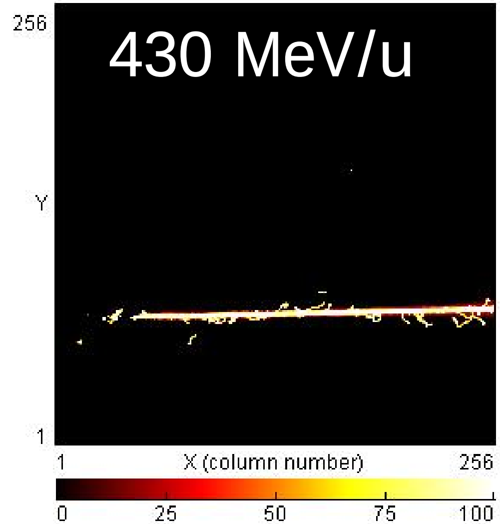
Carbon ions with different energies: 90 degrees



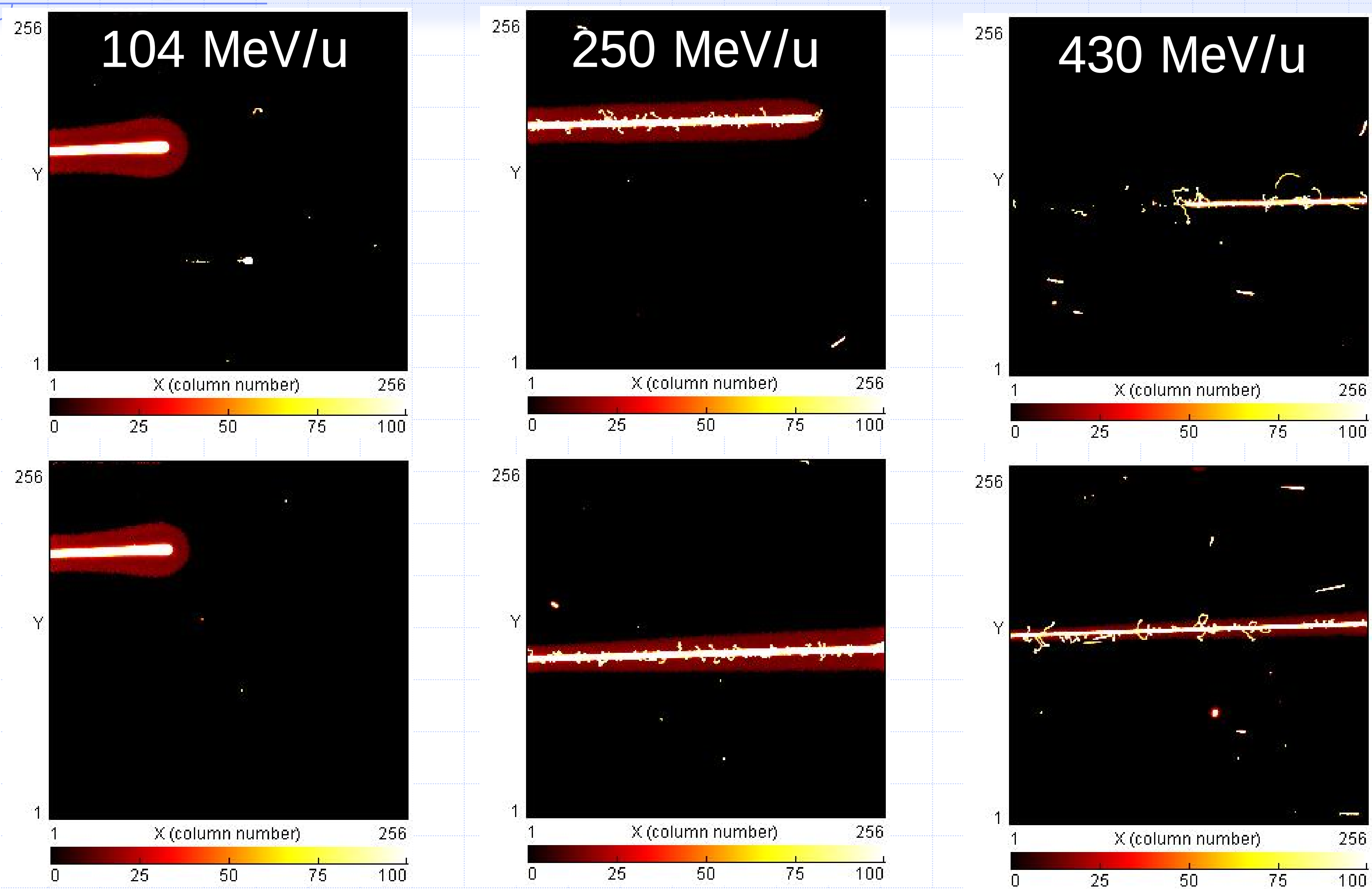




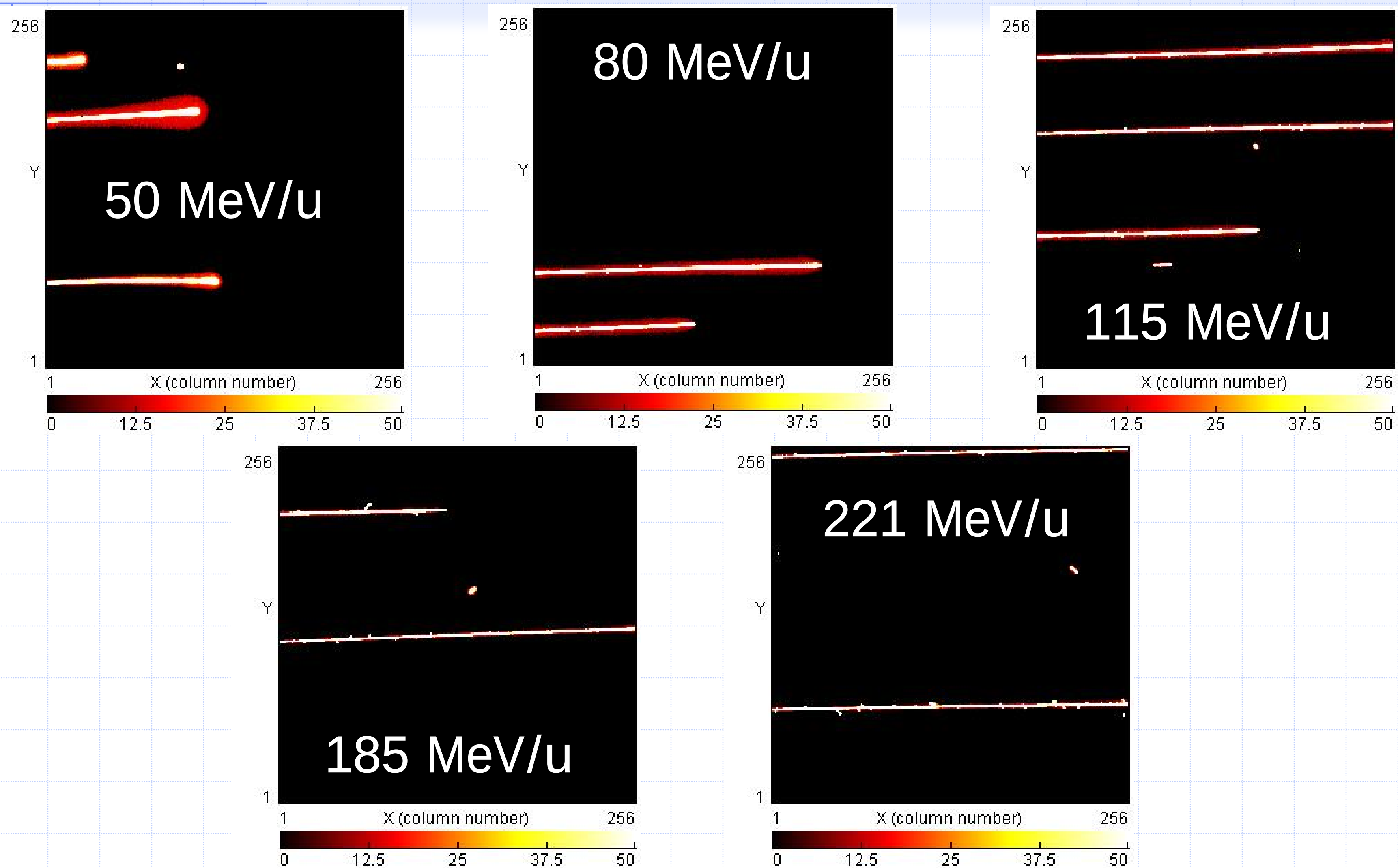
- Halo of pixel with low energy deposition around track - less pronounced for higher energies.
- Number of delta rays increases with increasing energy.



Oxygen ions with different energies: 90 degrees



Alphas with different energies: 90 degrees



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Volcano effect for carbon and oxygen ions – 0 degree

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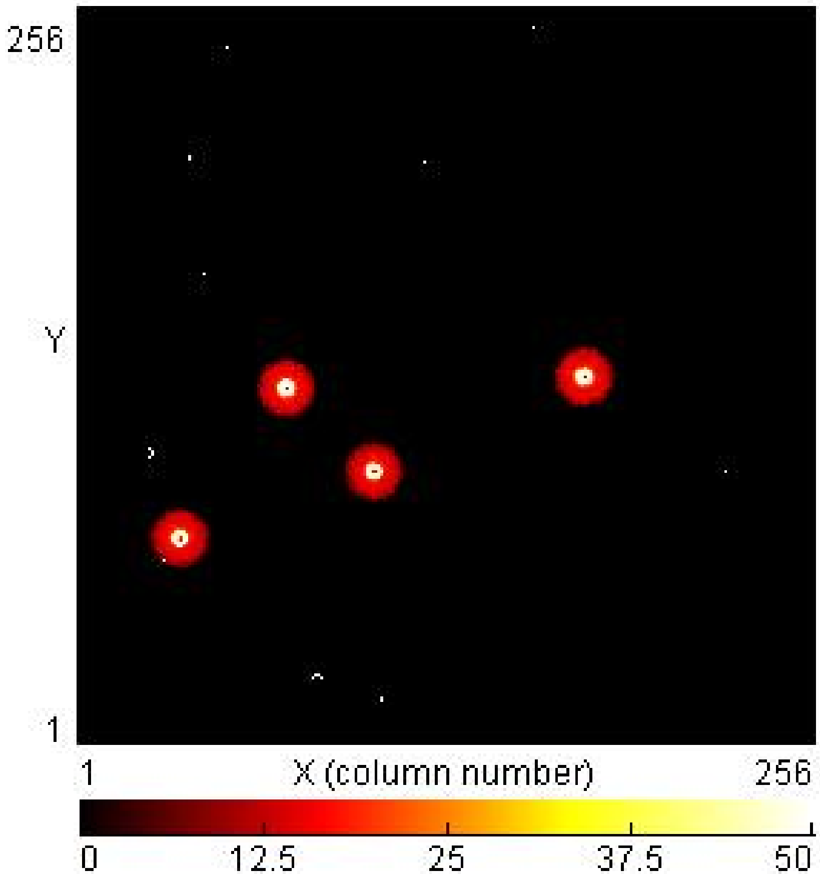
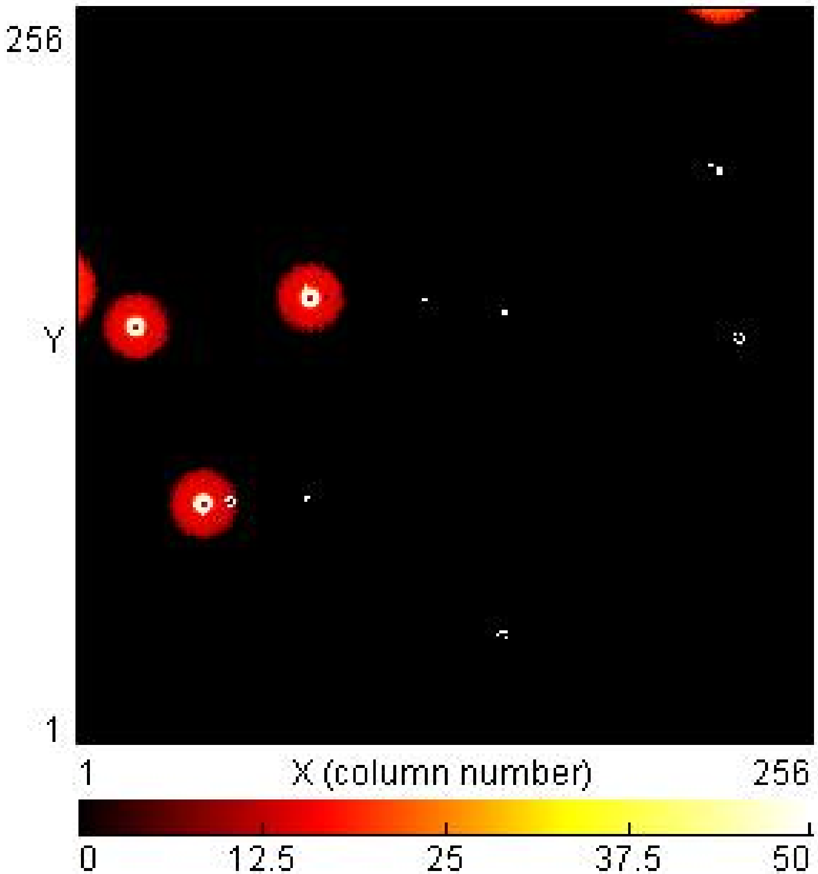
Carbons: 89 MeV/u



Oxygen: 104 MeV/u



Strategy, plan – Categorization and particle identification

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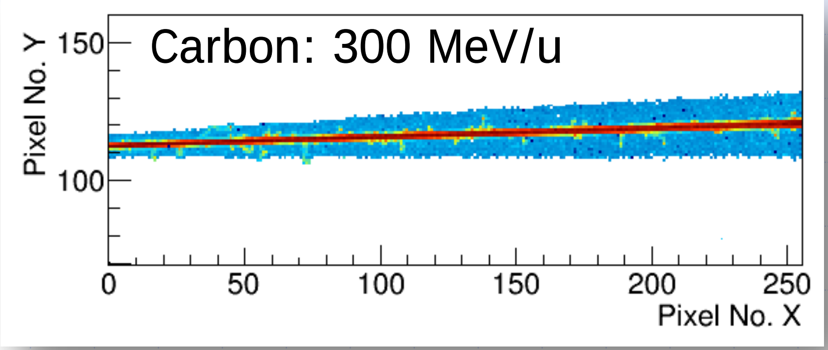
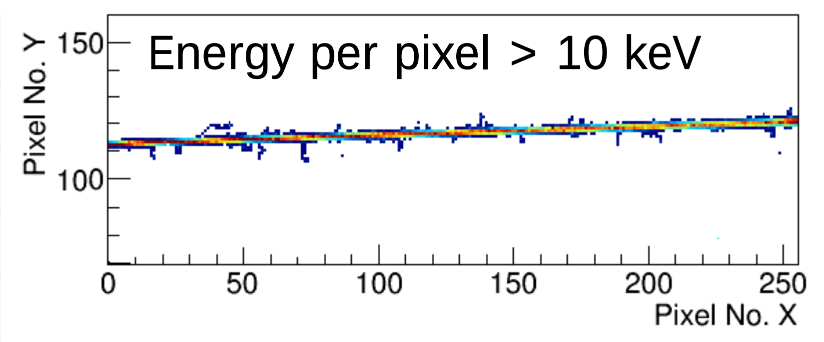
1. Look at track as a whole with low energy halo i.e. characterize size, shape.
2. Strip off halo (cut on energy per pixel).
3. Count number of delta-rays and measure their length.
4. Fit the track to obtain dE/dx information.





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!

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