TimePix hybrid pixels detectors for particle identification and dosimetry

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https://indico.cern.ch/event/954194

Outline of the talk

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I. To give an introductory information:

- What does it mean ***hybrid pixel semiconductor detectors***
- And how these detectors are currently used for position sensitive ***detection of photons, charged particles and neutrons***

II. To describe of capabilities of Medipix/Timepix pixel detectors

- for ***high resolution (nearly nanometric) radiography with X-rays and neutrons,***
- and for ***3D particle tracking and dosimetry of mixed radiation fields in physics experiments, medicine and for space research***

III. To bring to you basic information needed for real measurements ***of alpha particles, electrons and photons*** and ***neutrons*** prepared by myself, Vladimír Vícha and Michael Holík, who will present them tomorrow starting at 11:30.

www.cern.ch/medipix

Medipix/Timepix hybrid pixel detector device

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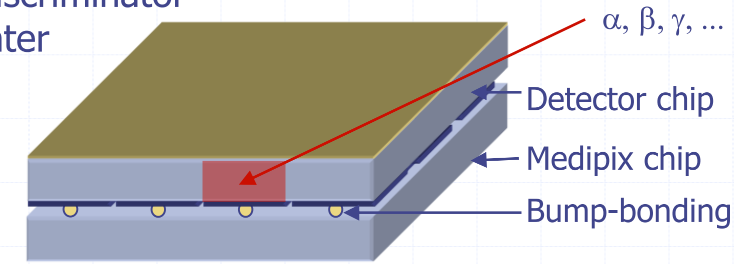
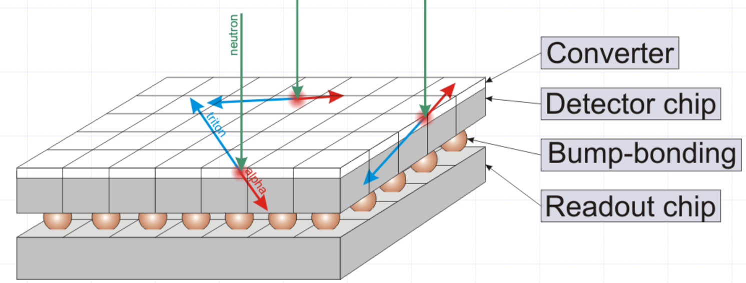
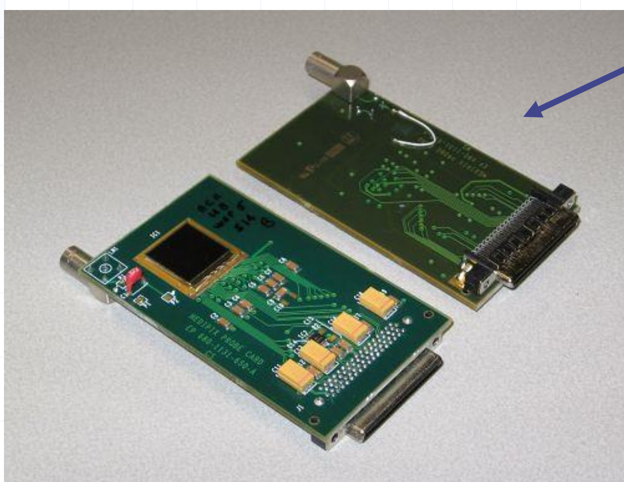
- Planar pixellated detector (Si, GaAs, CdTe, thickness: 300/700/1000μm)
- Bump-bonded to Medipix readout chip containing in each pixel cell:
  - amplifier,
  - double discriminator
  - and counter

- Converter materials to detect
  - thermal neutrons: 6Li(n,α)T, Q=4.78MeV
    10B(n,α)7Li, Q=2.78MeV
  - fast neutrons: recoiled protons from PE-foil

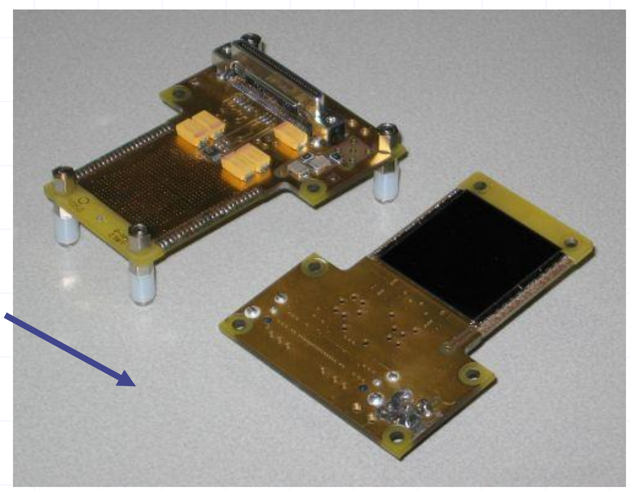






Medipix2/Timepix
Pixels: 256 x 256
Pixel size: 55 x 55 μm^2
Area: 1.5 x 1.5 cm^2

Medipix2/Timepix Quad
Pixels: 512 x 512
Pixel size: 55 x 55 μm^2
Area: 3 x 3 cm^2



Medipix – single quantum counting detector
Timepix - spectroscopic pixel detector with ToT and ToA modes of operation

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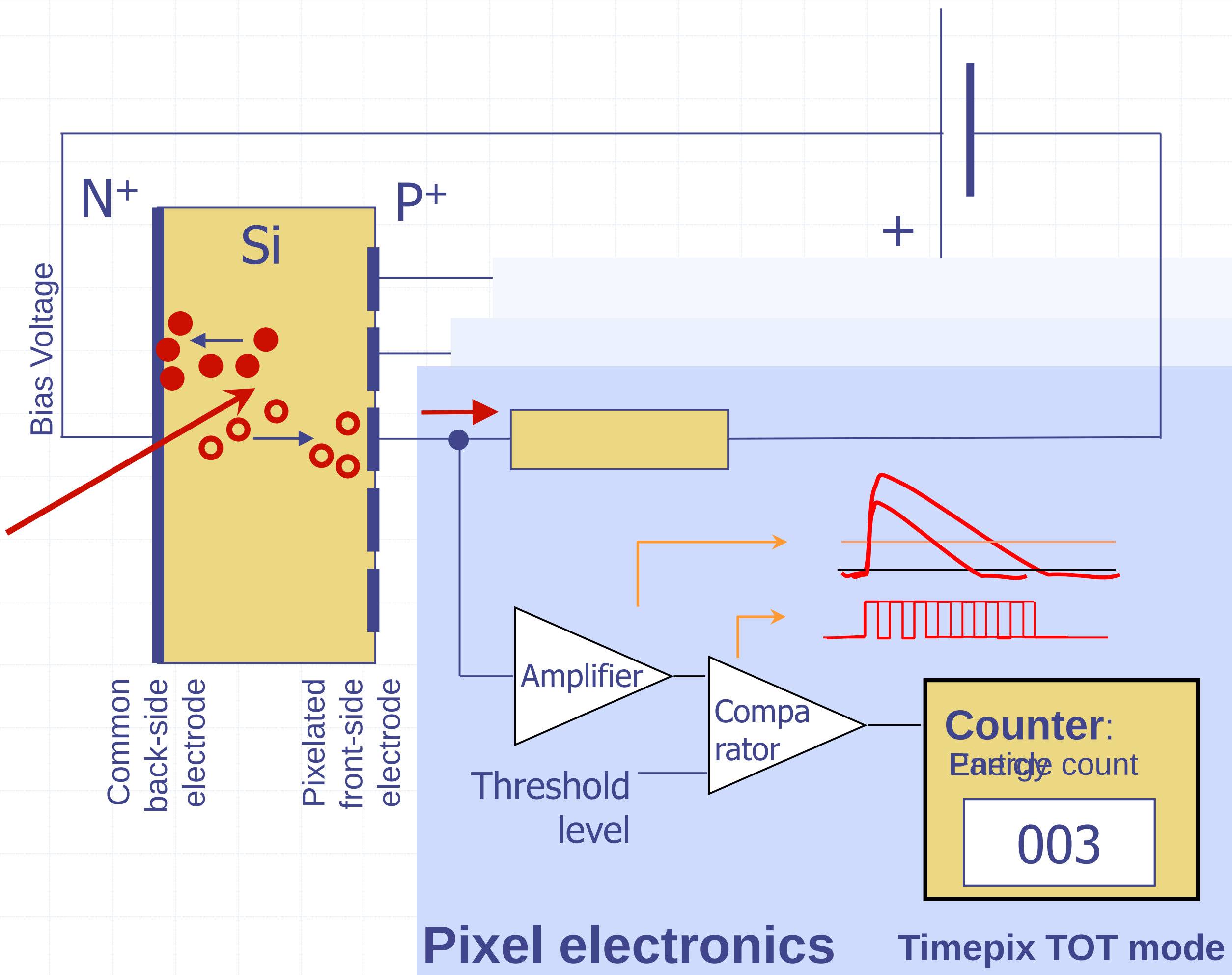

Threshold level above electronic noise
⇒ **No false counting.**

Digital integration (counting)
⇒ **No dark current.**

Unlimited dynamic range and exposure time. Counts obey poissonian distribution.

65k spectroscopic chains:
- SCA in case of Medipix
- MCA in case of Timepix
- MCA+TDC with Timepix3

Energy calibration
(Calibration of 65k MCA! Question: how to deposit defined energy into a volume 55x55x300 μm^3?)

Particle counting pixel detectors

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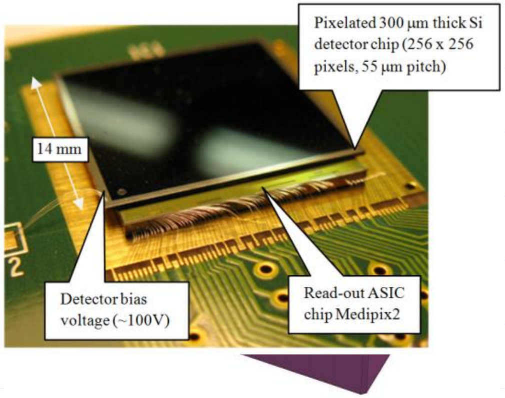
Pilatus - PSI

- 60 x 97 pixels
- Pitch of 172 um
- Counter: 20 bits
- Single threshold
- Module 16 chips
- Large area - tilling

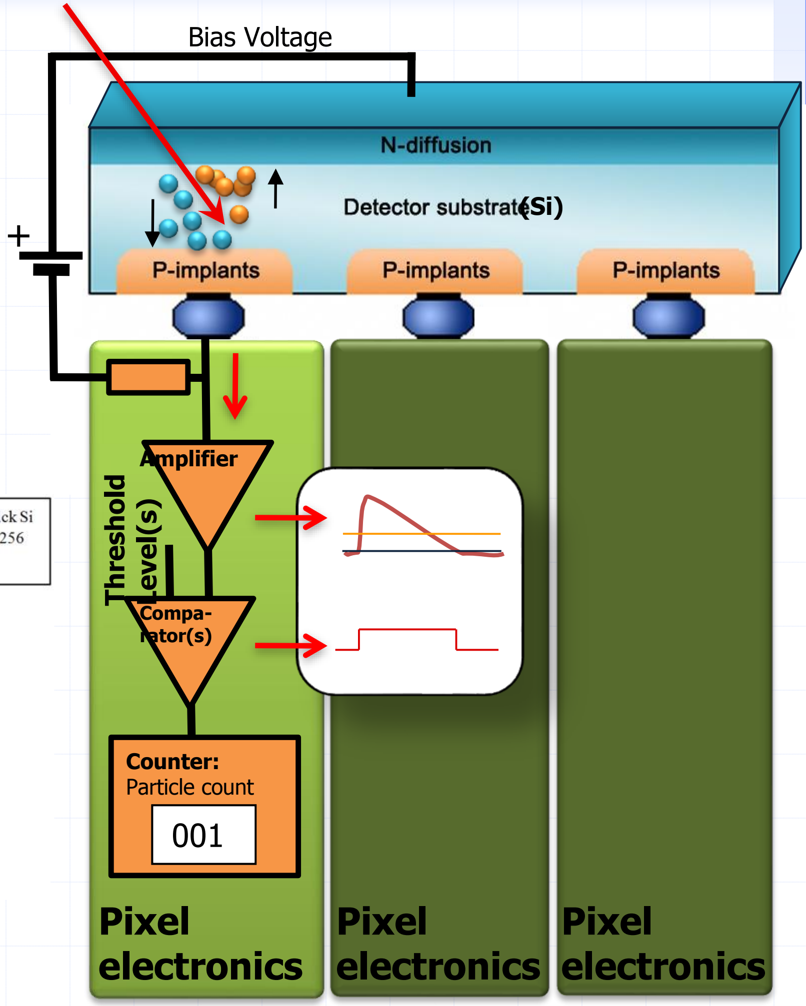
Medipix2 – CERN

- 256 x 256 pixels
- Pitch of 55 um
- Two thresholds
- Module 4 chips
- Large area: under development (RELAXd)



Timepix - CERN

- Time stamp
- ToT or ToA mode
- Timepix3 -ToT and ToA simultaneous



About development of R/O interfaces for Medipix/Timepix devices

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HISTORY 1995-2011:

MAMOGRAPHY

- CAMAC/VME
- MUROS (NIKHEF)
- USB1 (IEAP)
- USB Lite (IEAP)
- RUIN (IEAP)
- MARS (NZ)
- USB2 (IEAP)
- TPX Lite (IEAP)

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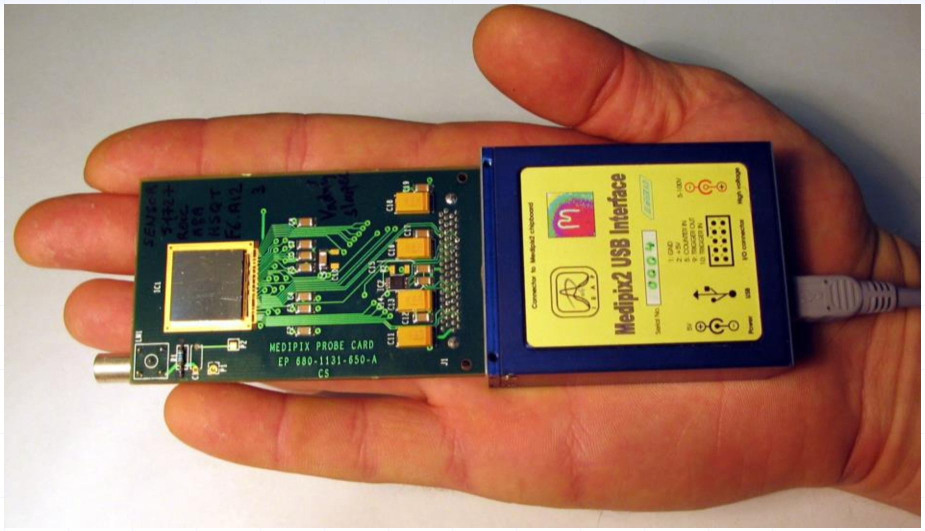
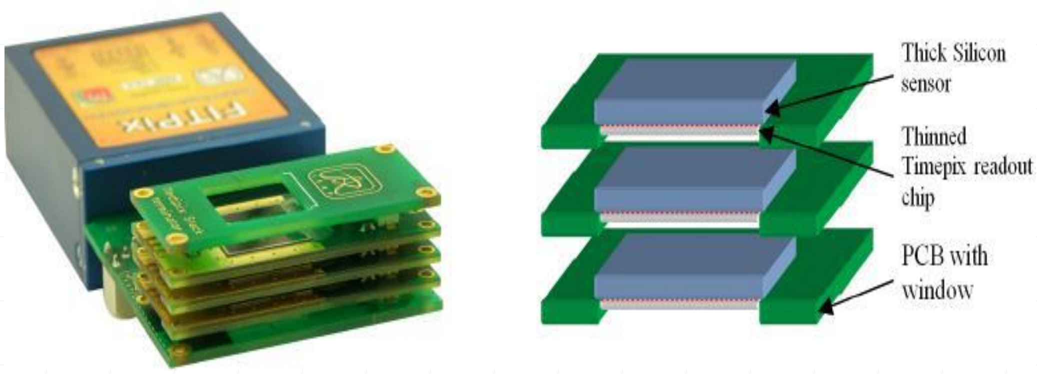
Medipix/Timepix – USB2 controlled portable device



- Medipix/Timepix motherboard (R/O chip developed at CERN in frame of Medipix2 collaboration) assembled to USB2 interface board (developed with Pixelman software package at IEAP CTU in Prague), http://www.utef.cvut.cz/MEDIPIX.
- The MEDIPIX/Timepix-USB device connected to the portable PC. Up to 80 frames per second (USB2 serial connection) or 800 f/s (parallel connection). One PC can effectively run up to 50 devices.
- Light version of the Medipix-USB interface (on the right).

Timepix based devices developed and tested in IEAP CTU



Multilayer particle telescopes

WidePIX 6.5 Megapixel detector

WidePIX camera was designed for imaging of large objects. It consists of array of 10x10 of hybrid single quantum counting detector Timepix developed by Medipix collaboration in CERN. The technology allowing coverage of large area is based on application of edgeless silicon sensors developed in VTT Finland. The whole **WidePIX** device was designed and developed in IEAP CTU in Prague and developed in cooperation with Advacam, Prague.

PIXELMAN SW Package
to control, read and evaluate data from pixel devices

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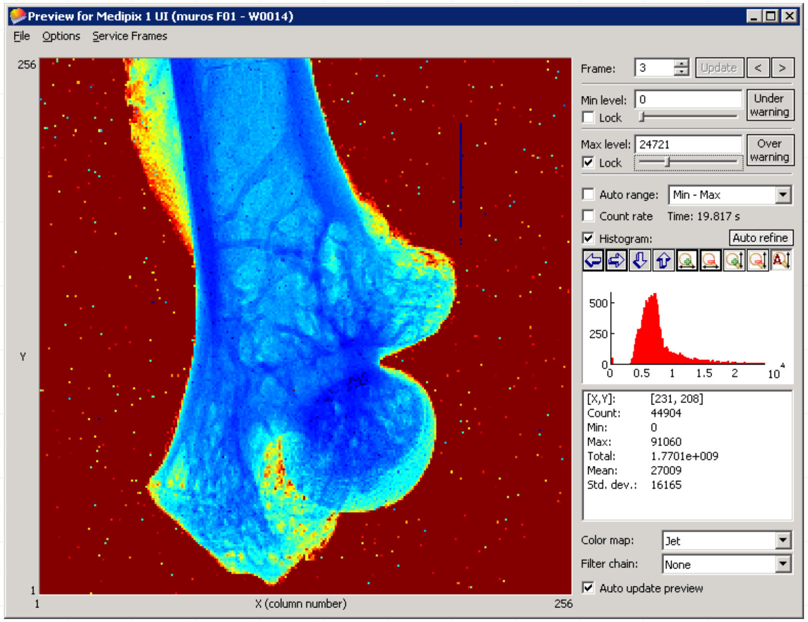
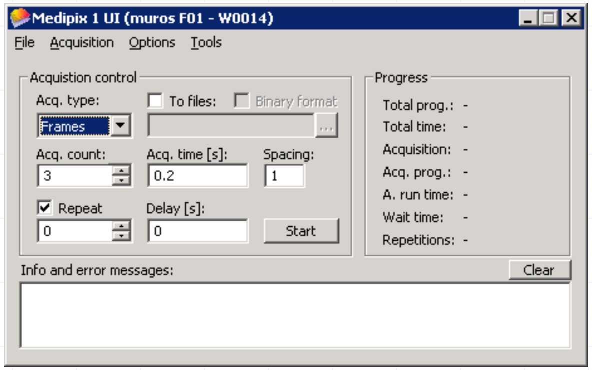
- Software package for Medipix/Timepix acquisition control and data evaluation, equalization procedure and energy per pixel calibration
- Supports all available Medipix/Timepix based detectors
- Supports all commonly used readout interfaces
- It is designed for maximum flexibility and interoperability with other devices (like stepper motor control unit) to control complex experiments.
- This is achieved by modular architecture with support of custom made plugins.





Response of Medipix2 device to natural background radiation

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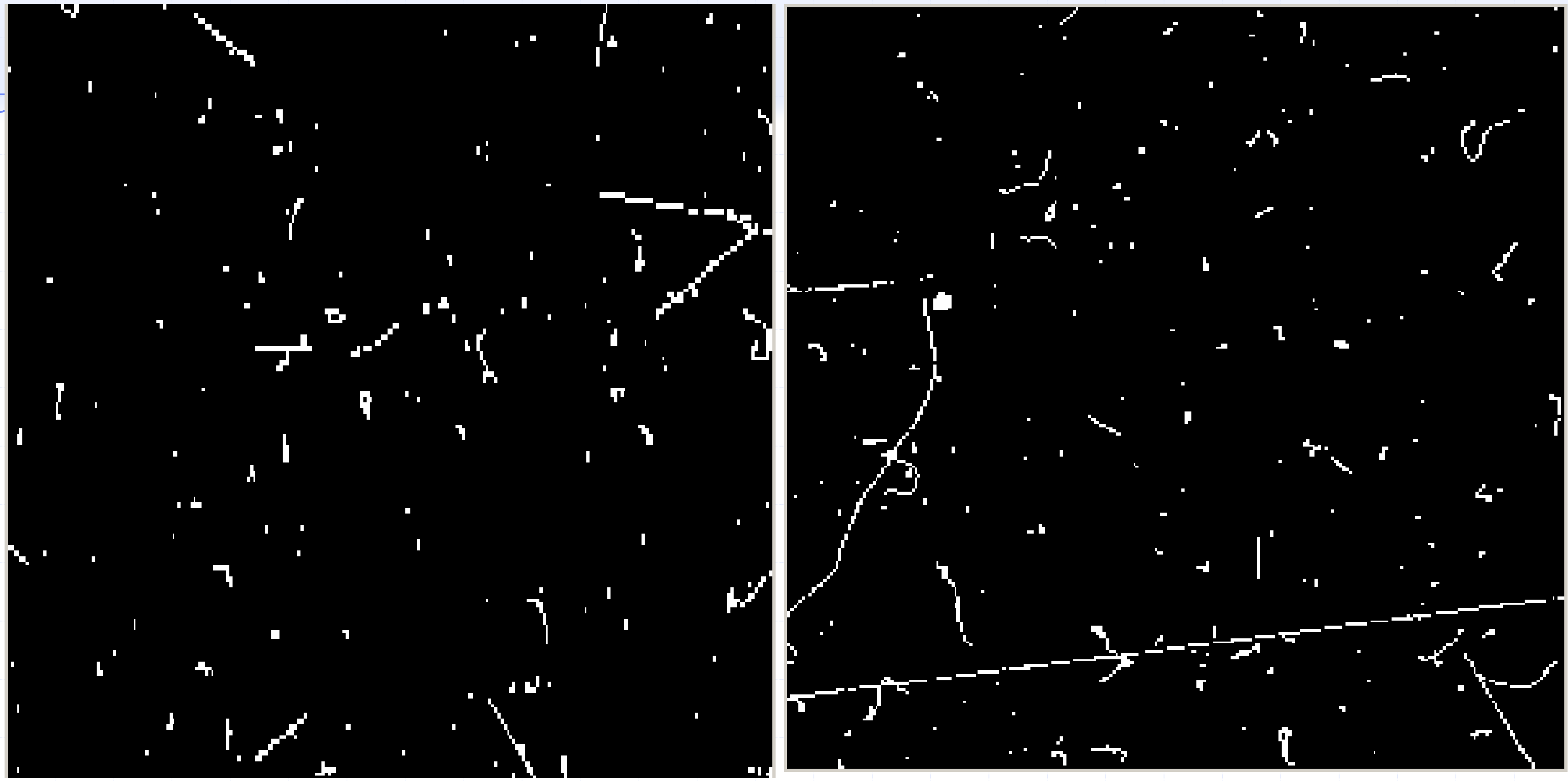

Clearly recognizable **tracks and traces** of

- **electrons** generated mostly by X-rays, gamma rays via photoeffect and compton scattering,
- **electron-positron pair** produced by gamma photon with energy higher than 1022 keV
- **alpha particles** from decay of Radon isotopes and their daughter nuclei,
- linear tracks of **cosmic muons** origin some of them with associated delta electrons

Noiseless particle detection

Tracking mode of pixel detector operation

(on-line imaging of tracks and traces of single radiation quanta)

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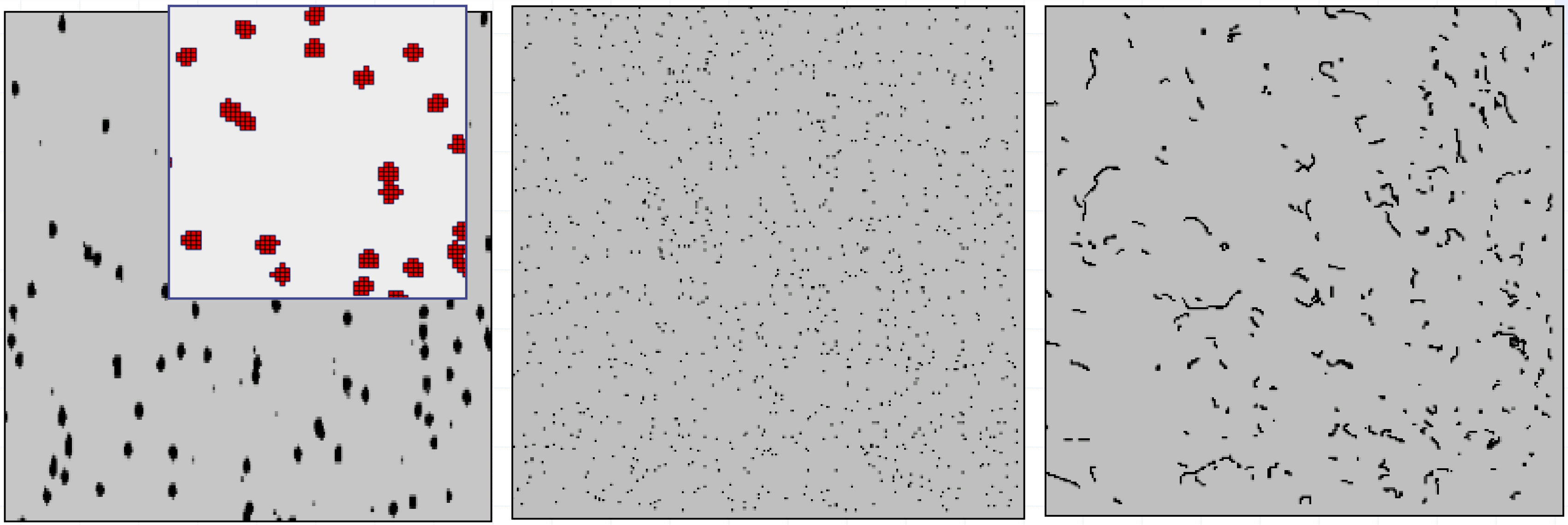

- ^{241}Am alpha source gives clusters of ~5x5 pixels measured with the MEDIPIX-USB device and a 300 μm thick silicon sensor. The clusters are shown in detail in the inlet. The cluster sizes depend on particle energy and threshold setting.
- Signature of X-rays from a ^{55}Fe X-ray source. Photons yield single pixel hits or hits on 2 adjacent pixels due to charge sharing.
- A ^{90}Sr beta source produces curved tracks in the silicon detector.
- A pixel counter is used just to say “YES” if individual quantum of radiation generates in the pixel a charge above the pre-selected treshold.

Experimental setup

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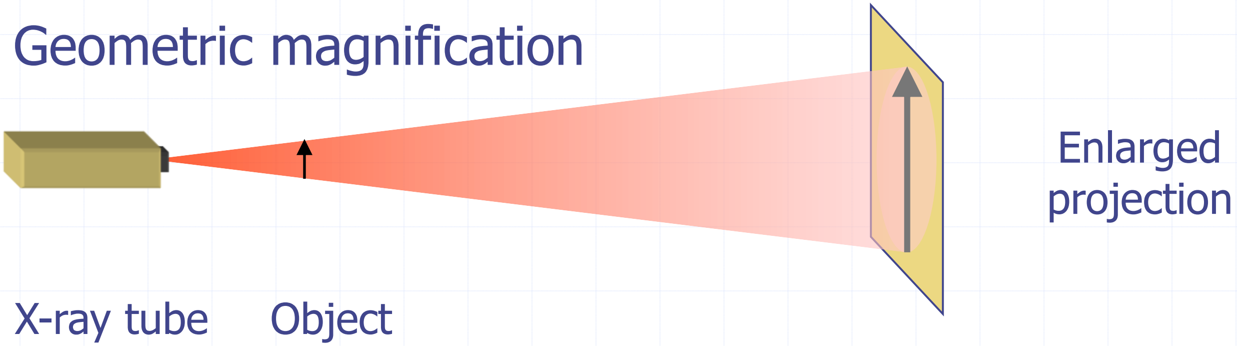
Requirements:

- Microfocus X-ray source to enable geometrical magnification
- Adjustable object holder (three translations + rotation)
- Sample stabilization (temperature, humidity)
- Equipment for automatic calibration of pixel responses
- Detector holder and detector stabilization (temperature, condensing point)

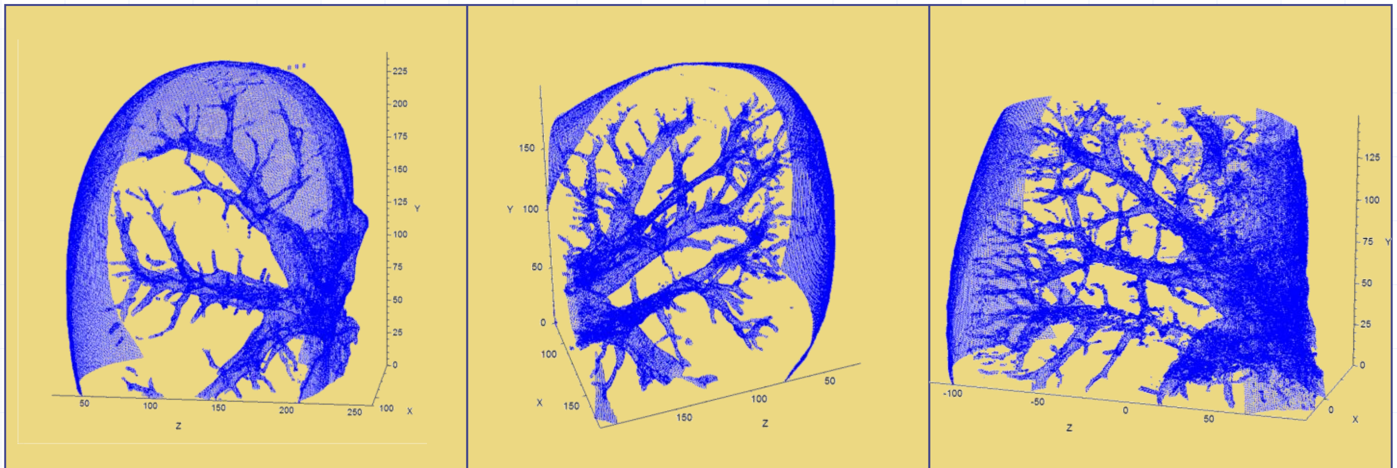
Geometric magnification

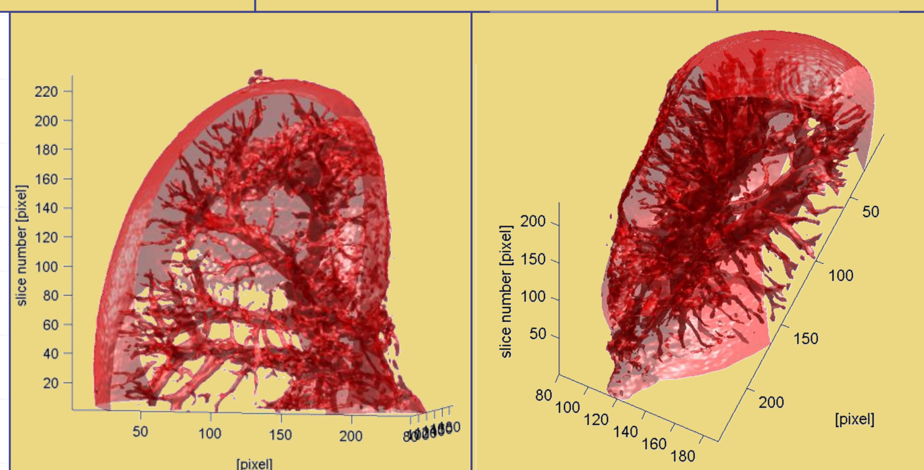


Soft tissue X-ray imaging

Mouse Kidney Tomography

Missing angles => Iterative algorithm instead of Filtered back projection (3 iterations in OSEM 5)





High resolution X-ray radiography:

Example: Leaf Miner story

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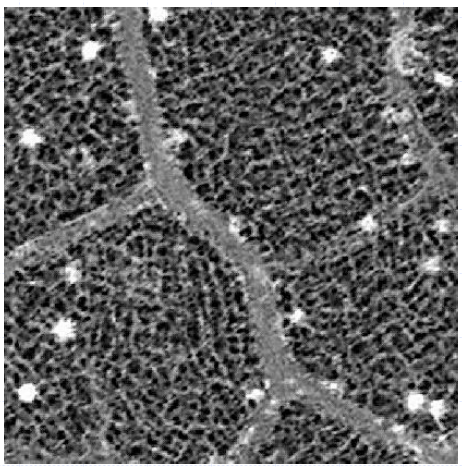
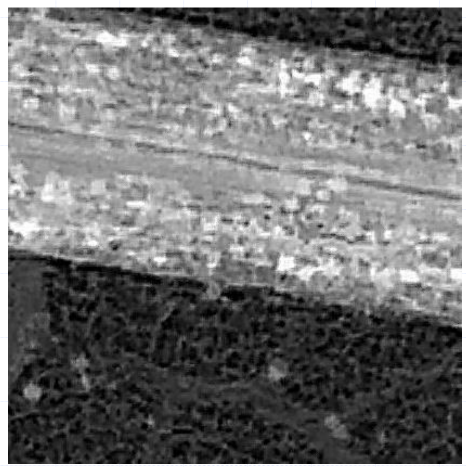
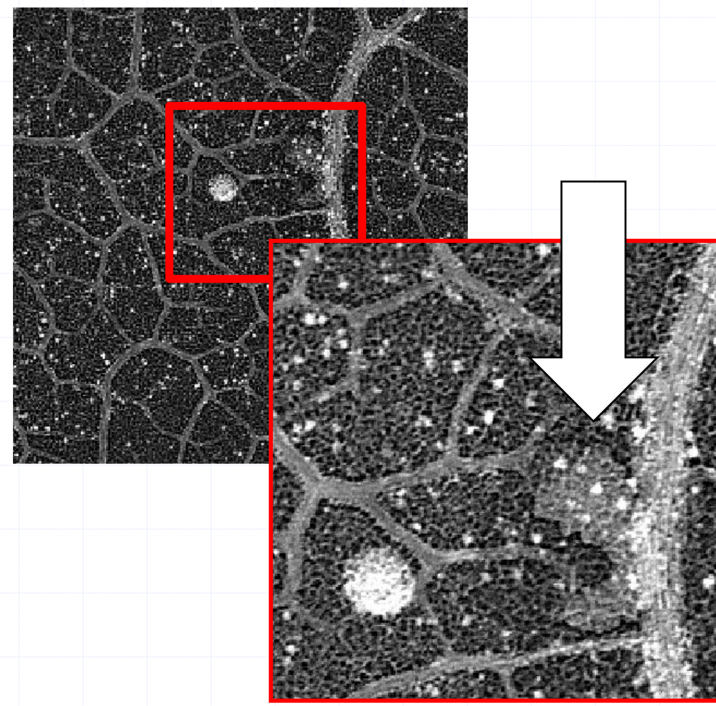
Leaf miner (*Cameraria ohridella*) - small moth. In larvae stadium it lives inside of chestnut tree leafs making "mines" and causing serious problems to the tree. Indication: chestnut leafs get brown, dry and fall down early.

Courtesy of J.Dammer (CTU in Prague), P.M.Frallicciardi (U.of Napoli) and F. Weyda (SBU Ceske Budejovice)







Healthy chestnut tree leaf structure (no parasite) – cellular structure of leaf is nicely observed (resolution below 1 um). The white spots are small drops of resin secreted by the leaf.

Example: Leaf Miner story

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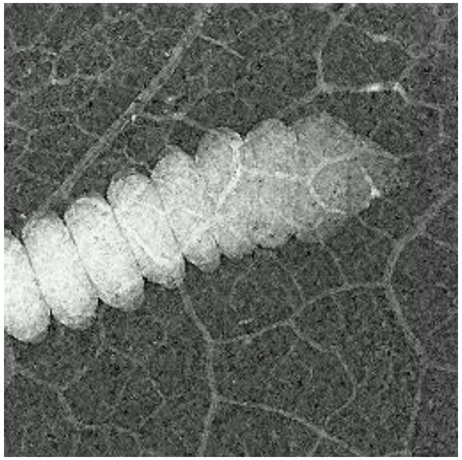
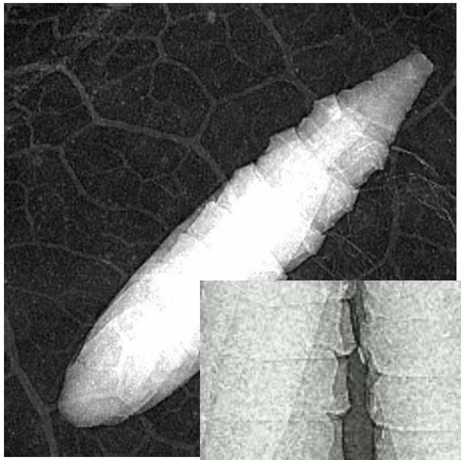
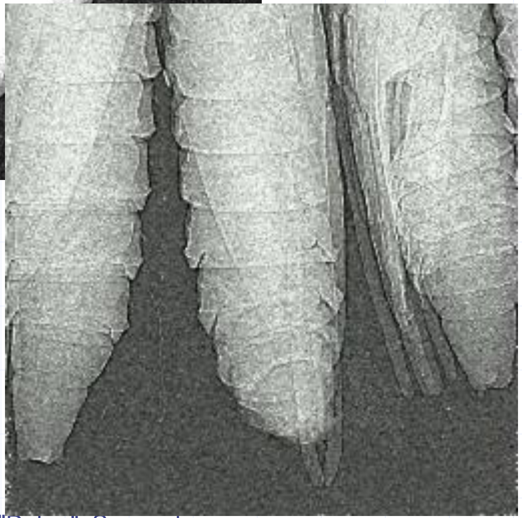
Worms are growing up and after three feeding instars larvae build-up a silken cocoon (pupae)







Several collected pupas

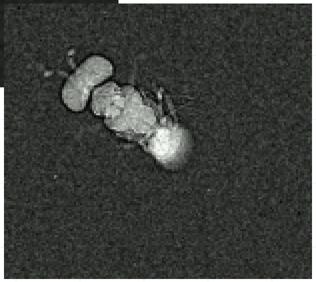
High resolution X-ray radiography:

Example: Leaf Miner story - Cure

The best cure: natural enemy (parasitic wasp)

Certain small wasps can put eggs into leaf miner pupas

Parasite inside of parasite:



Parasite kills the pupa and leaves it as adult wasp

Virtual histology: Micro-CT analysis of soft biology samples

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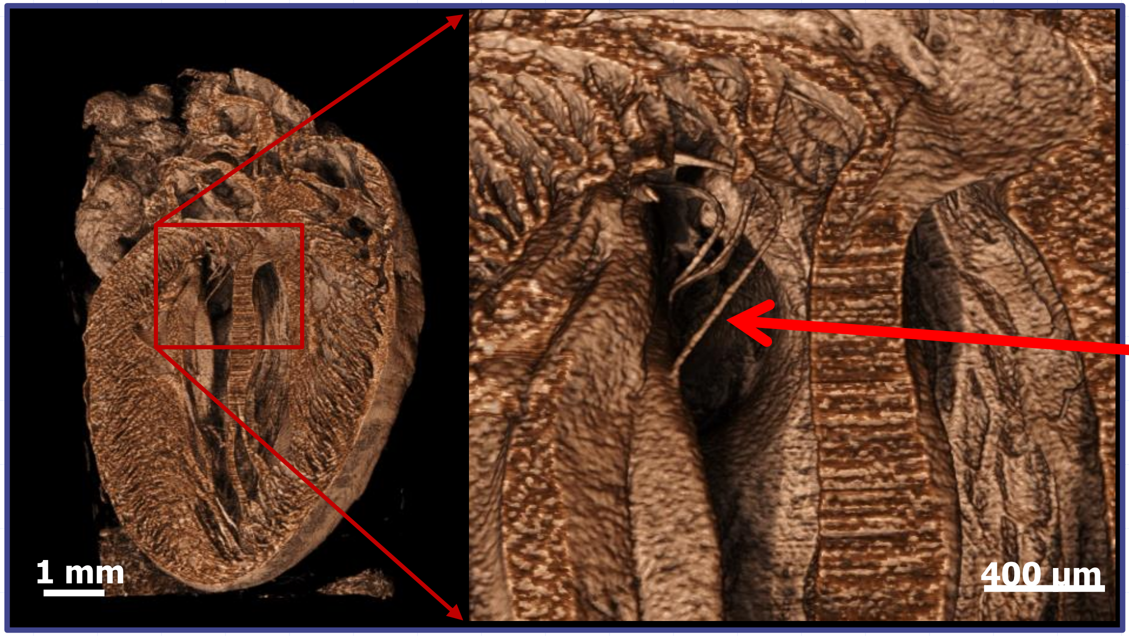
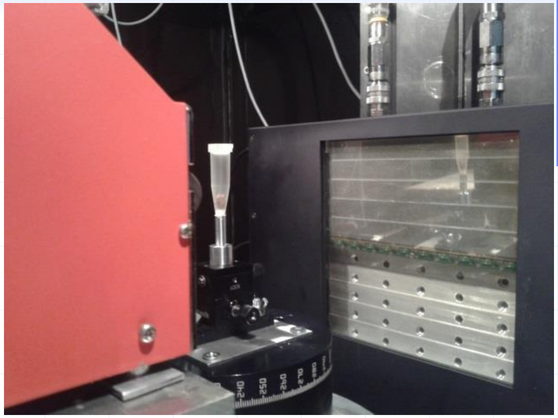
- Micro-CT becomes a non-destructive competitor to tissue histology, as the achievable resolution of micro-CT techniques continuously improves
- Typically, sample staining by high-Z contrast agents is needed
- Timepix technology provides micro-CT data with reasonable contrast without any dedicated X-ray contrast agents



Volume rendering of an **ethanol-preserved mouse heart** scanned using the WidePIX$_{10x5}$ detector with resolution of 7 µm



Micro-CT scanner at laboratory of IEAP is equipped with WidePIX$_{5x10}$ detector

Chondrae tendineae:
Fine tendon fibers keeping tension to heart valves and, therefore, maintaining a proper function of the heart.

Jan Dudák, PhD Thesis
"Energy sensitive X-ray radiography and tomography optimized for small animal imaging", FBMI CTU in Prague, 2020

Noiseless particle detection

Tracking mode of pixel detector operation

(On-line imaging of tracks and traces of single radiation quanta)

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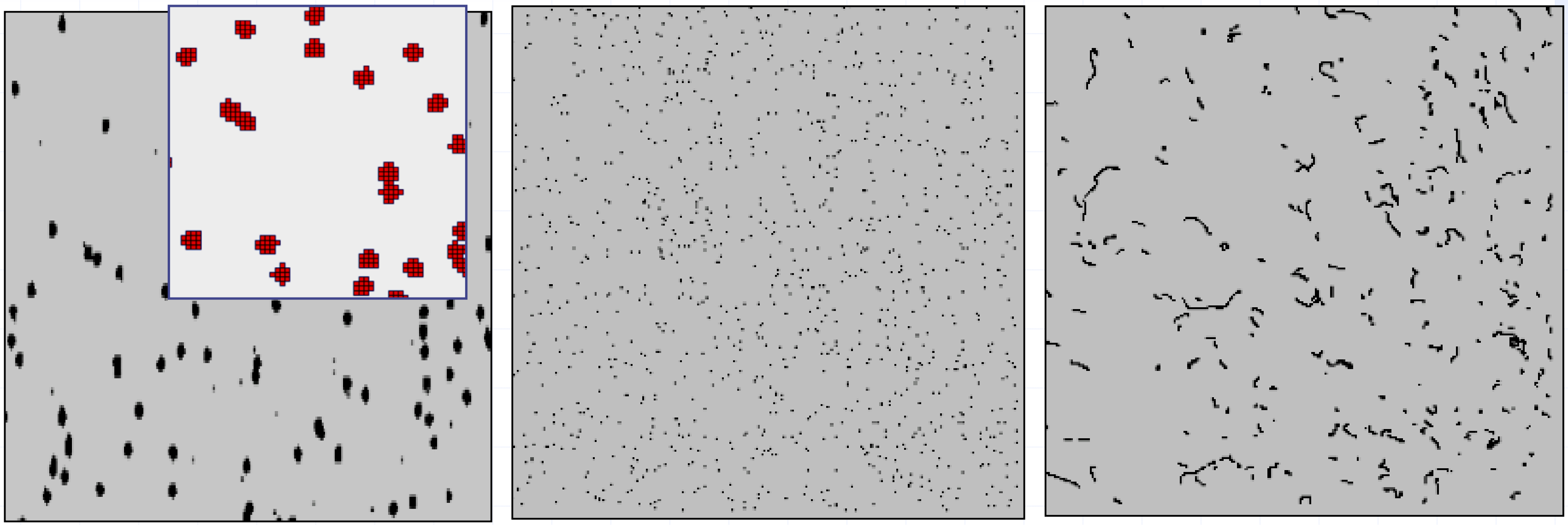

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- A ^{90}Sr beta source produces curved tracks in the silicon detector.
- A pixel counter is used just to say “YES” if individual quantum of radiation generates in the pixel a charge above the pre-selected treshold.

Dependence of cluster size on applied bias (on electric field in semiconductor)

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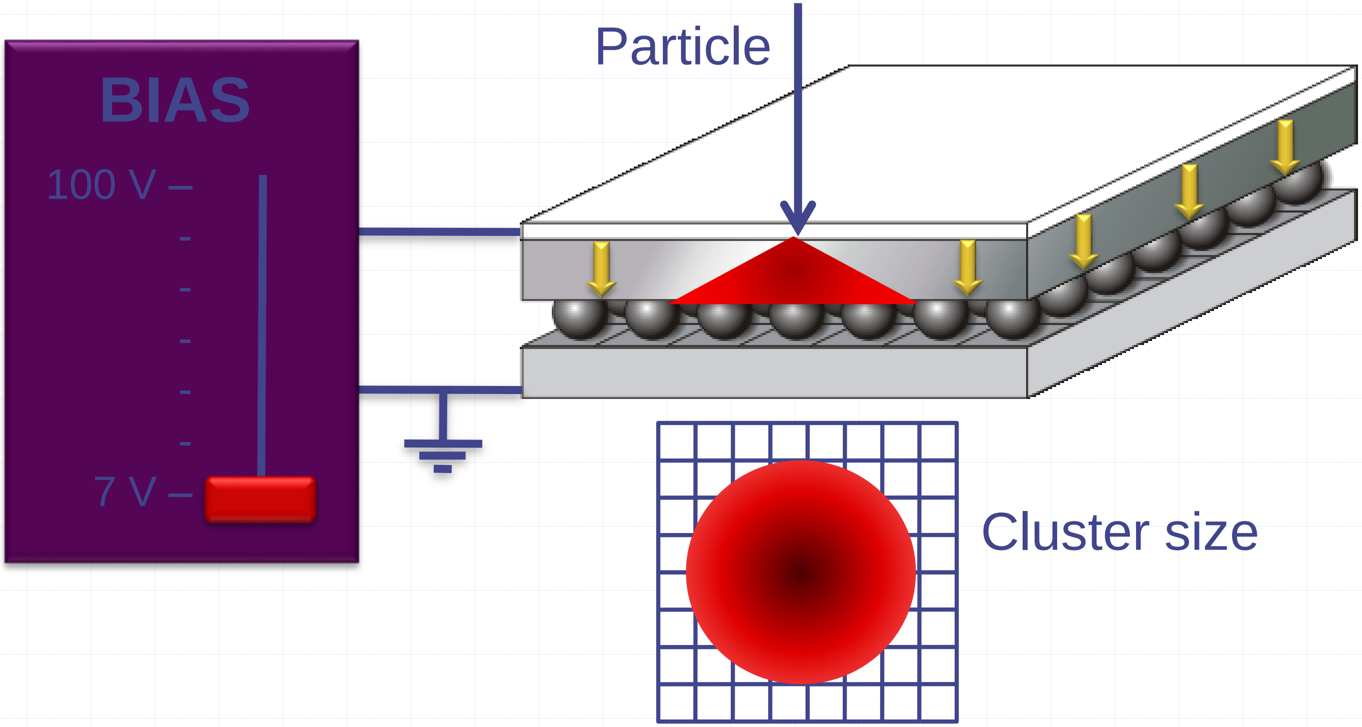

3D-visuallization of proton tracks in silicon pixel detector recorded by Timepix device.

Illumination under different angles (0 and 76 degrees) and different applied detector biases (7.2 V and 30 V)

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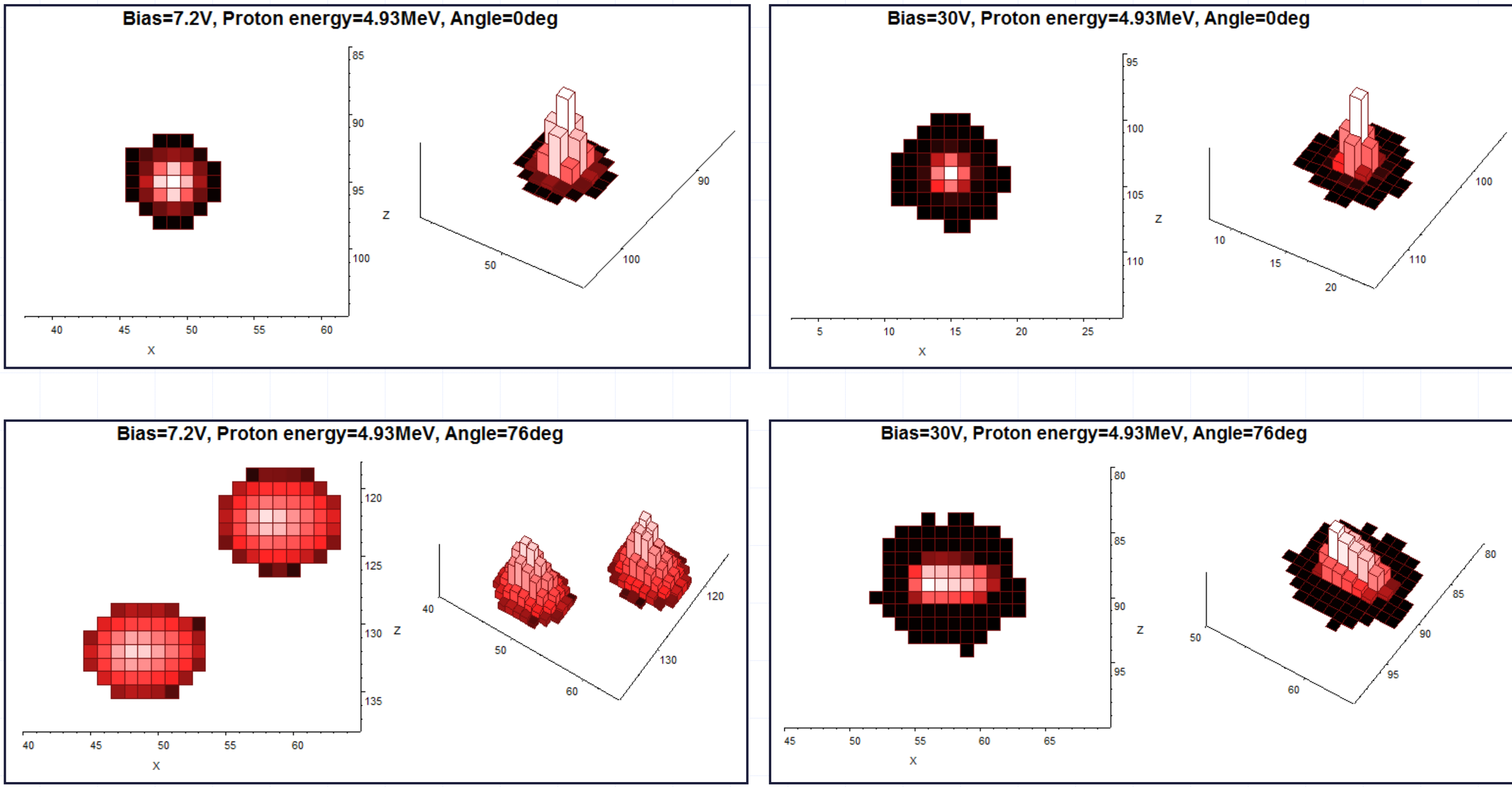
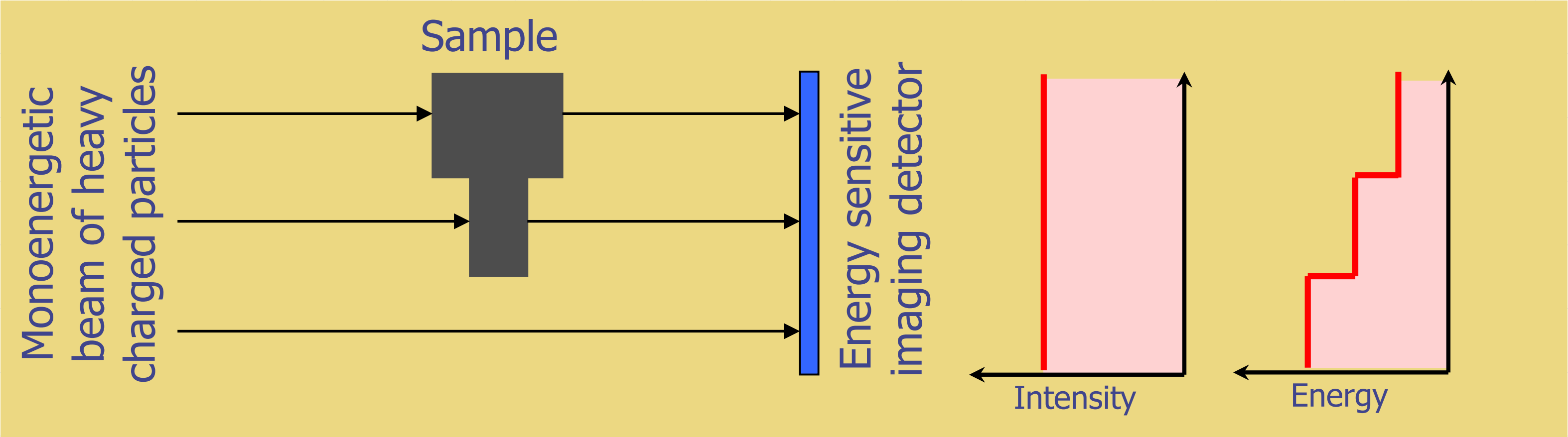


What is the spatial resolution? X- and Y-coordinates are determined with a precision of about 500nm. Determination of angle is with a precision of about 1°. It needs additional experiments.

Application:

Radiography with highly ionizing particles



- **Heavy charged particles** (protons, deuterons, tritons, alphas, ions) can be used (impossible with photons, difficult with electrons due to huge change of direction).
- Instead of transmitted beam intensity the **energy losses** of individual particles are measured.
- Just single particle is needed to measure material "density".
- With common sources of heavy charged particles (isotopes, ion beams) it is feasible to inspect just small (thin) objects (thin layer, foils, cellular structures)
- **Precision of thickness measurement can be in nanometer scale**.

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Radiography with heavy charged particles:

Simple example with Medipix2

By cluster analysis it can be determined:
- **Centroid** to increase spatial resolution (subpixel resolution)
- **Size** as a measure of particle energy

Wing of fly
(less than 20 particles per pixel)

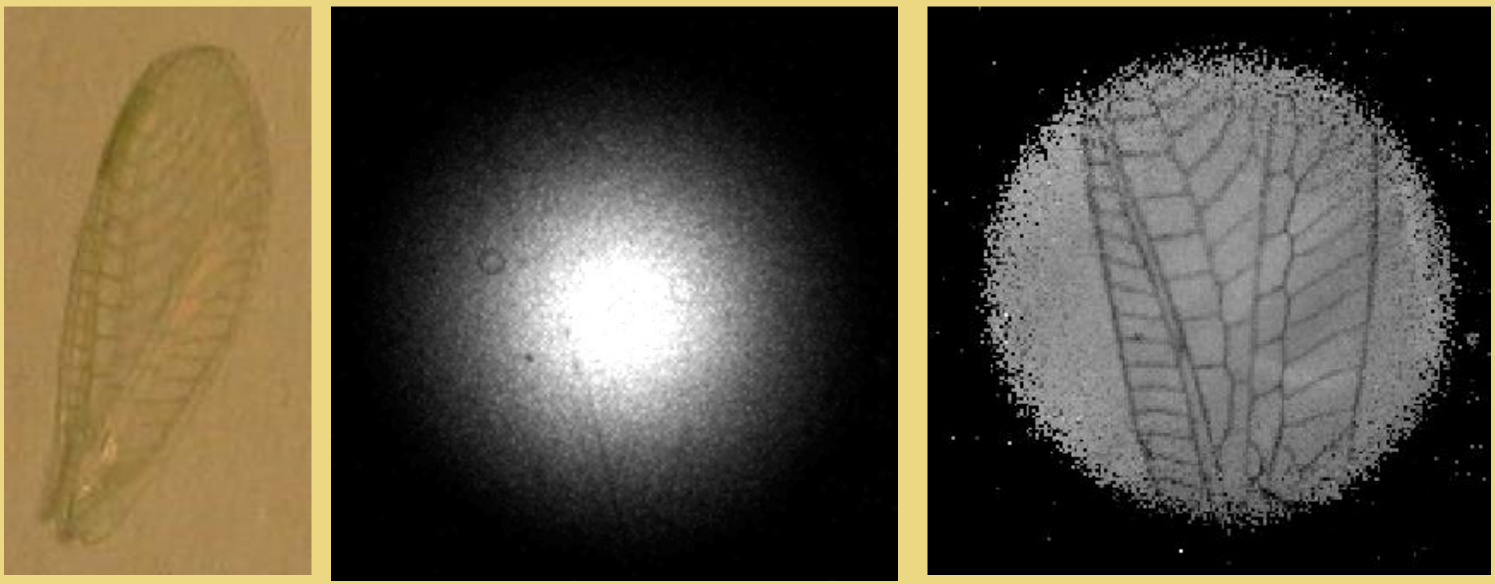

Photo Intensity Energy

Single ^{8}He ion decay sequence recorded by Timepix operating in ToA mode

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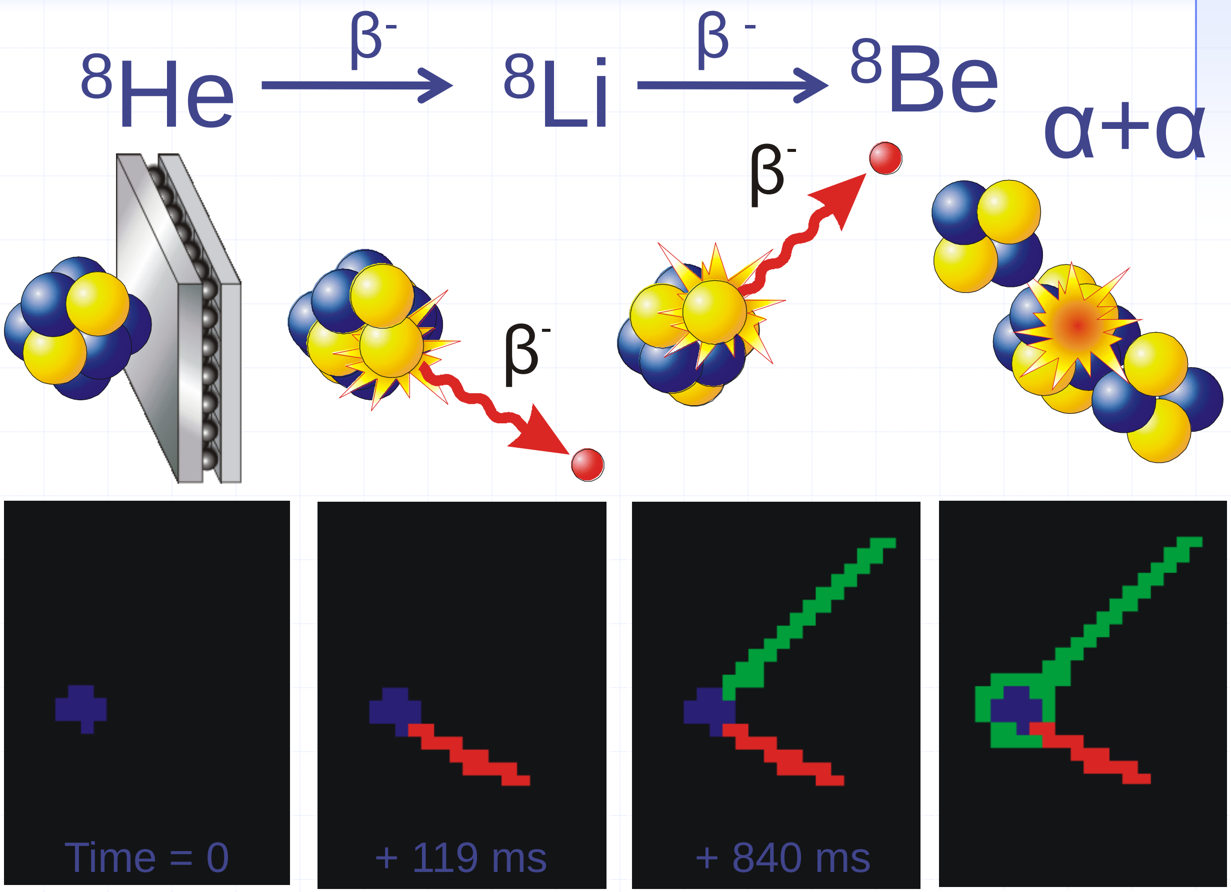
^{8}He ion hits the Timepix sensor where undergoes β-decay

Subsequent decays of the daughter nuclei by emission of one beta and two alpha particles follows



Observation of decays of individual atomic nuclei in short times (≤ milisecond)

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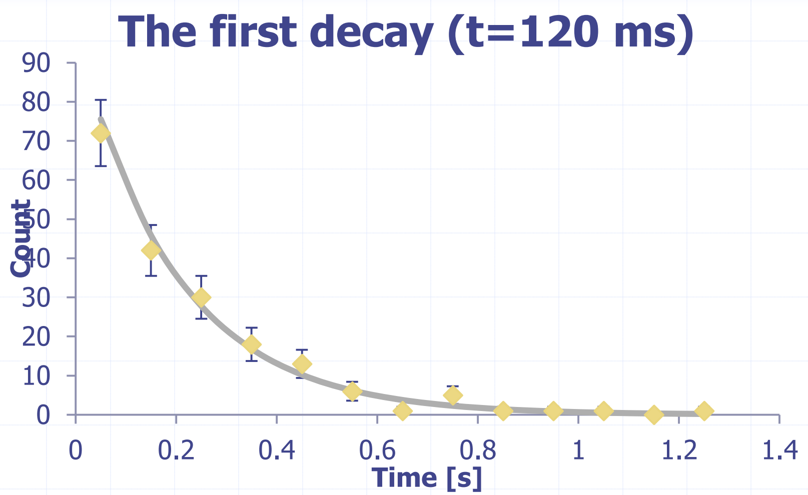

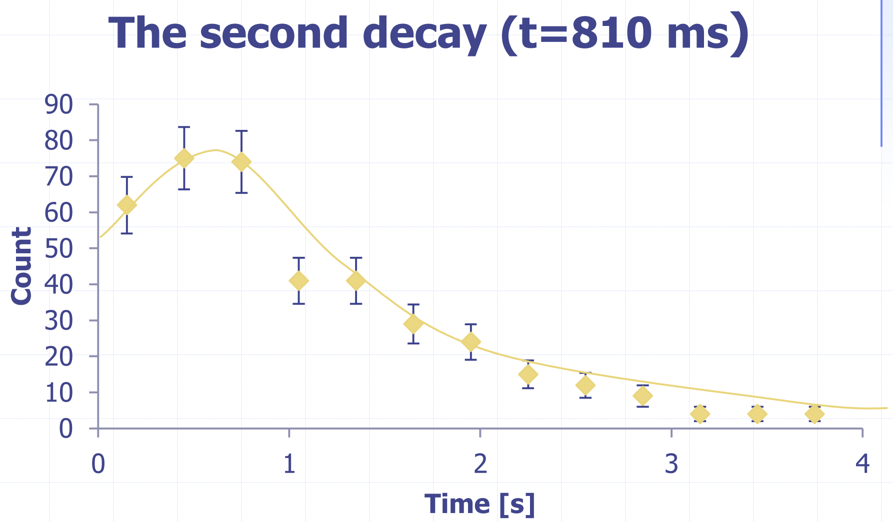

Time and spatial coincidence technique permits:
- observation and measurement of decay of individual nucleus
- in range from microseconds to seconds (and longer).

One can exactly observe what has happened in well known position of semiconductor and when. What about SEE studies?

The world of neutrons is very colorful

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1. **It deals with neutrons of kinetic energies T_n in the range of 15 orders, 10^{-7} eV < T_n < 10^{8} eV,** when we talk about ultra-cold, cold, thermal, resonance, intermediate, fast and relativistic neutrons.

2. In all reactions used to release neutrons from nuclei, **born neutrons are always fast.** Slowing down processes based on neutron scattering with nuclei are responsible for change of their energies in all environment.

3. **The nature of neutron interactions with nuclei depends significantly on T_n:**

- In the case of cold, thermal and resonance neutrons, the neutron wavelengths have to be taken in account and **radiative capture of neutrons (n,γ)** is dominating process.
- In the case of intermediate and fast neutrons, strong interactions with atomic nuclei dominate as **two-particle interactions**, such as elastic scattering and inelastic scattering, and classical (n, alpha) or (n, p) nuclear reactions.
- In the case of neutrons with energies higher than 20 MeV, **more complex reactions and fragmentation** processes are becoming crucial.

About neutron converters, detectors and radiation background

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All of the above mentioned processes can be used to detect neutrons. However, the **choice of the converter depends on what neutrons are to be detected and for what purpose the detectors are to be used.** This applies to all types of detectors, be the gas, scintillation (liquid, solid, hydrogen rich) or semiconductor detectors.

Neutrons from the source are always accompanied by high-energy gamma radiation from inelastic scattering, nuclear reactions and above all from radiation capture of neutrons (with energies up to 11 MeV) on the nuclei of elements from the surrounding environment.

Indeed, one can find everywhere a number of nice publications describing neutron detectors with high neutron detection efficiency, which however suffer from high efficiency also to gamma rays. Then, to get a net neutron-induced signal only, the **undesirable gamma signal** has to be discriminated, what is not an easy task at all. However, this problem can be successfully overcome by using a **thin sensor with the neutron converter to energetic ions.**

Why semiconductor neutron detectors can compete with gas and scintillating detectors?

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a) **Silicon detectors** had become well developed **for high resolution alpha and energetic ions spectroscopy in nuclear physics** and **for many applications** profiting from their **excellent resolution, window less detection, low bias, low power, small dimensions** opening possibility to make **portable devices**.

b) **The adaption of the detectors with small sensitive volume for detection and spectroscopy of neutrons based on their conversion to highly ionizing ions of relatively high energies permits the reliable discrimination of neutrons from gamma rays and electrons**. Such devices were optimized for monitoring of neutrons in mixed n-gamma radiation fields with applications in nuclear reactor experiments and different moisture meters.

c) **In the case of pixel detectors with neutron converters to short-range energetic particles** (like ^{6}LiF, ^{10}B, hydrogen rich material as CH_2, ^{235,238}U), a **thin pixelated sensor allows then discrimination of unwanted signal from gamma photons** according to energy, but also **"noiseless" recognition of a neutron according** to its track observed in the detector.

Response of the silicon diode with CH_2 converter to 4.2 MeV neutrons (recoil proton spectroscopy)

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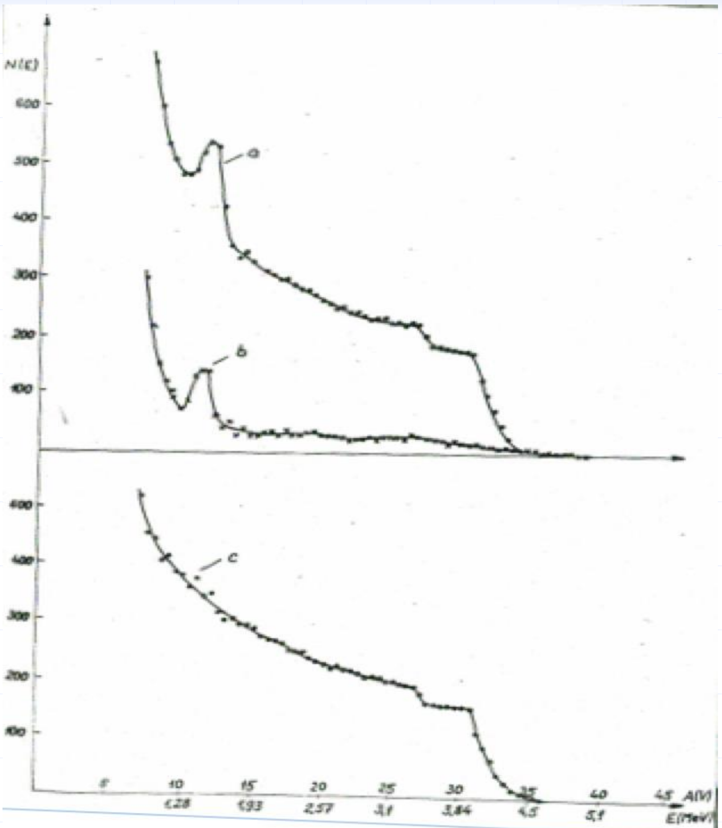
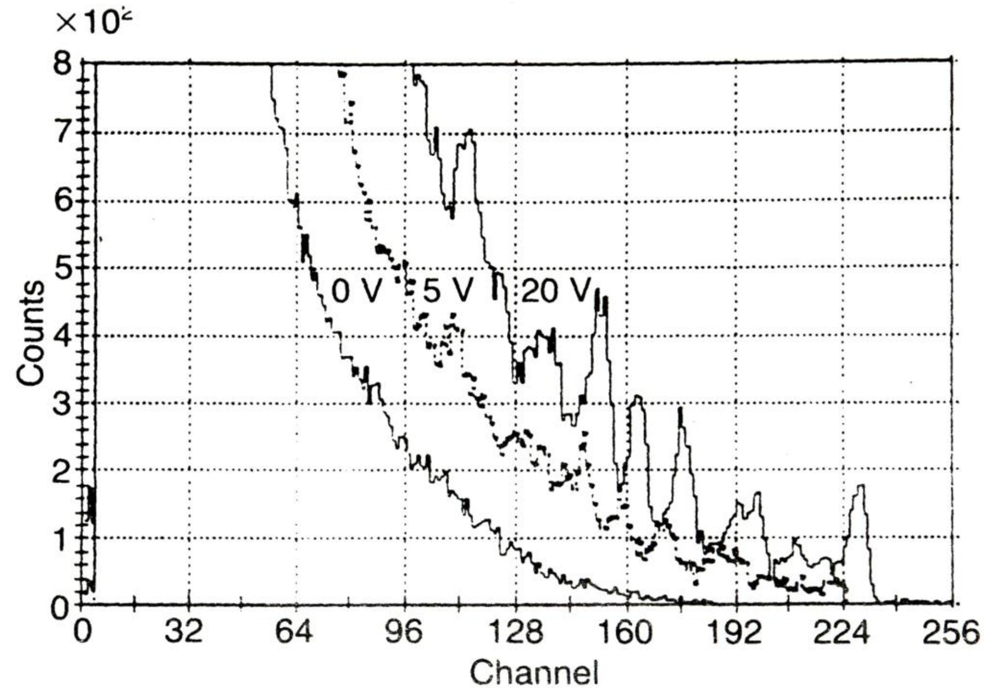


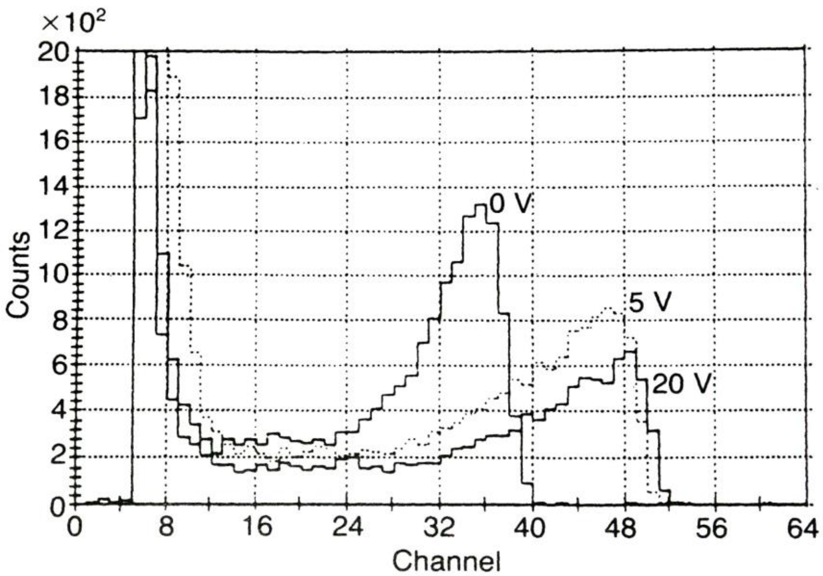
a) Silicon diode with CH2 converter
b) Silicon diode without CH2 (background)
c) Net spectrum of recoiled protons



Pulse height spectrum of Silicon diode when illuminated by fast neutrons (14.8 MeV) at different bias (0, 5, 20 V). Peaks from interaction of fast neutrons with ^{28}Si are clearly seen

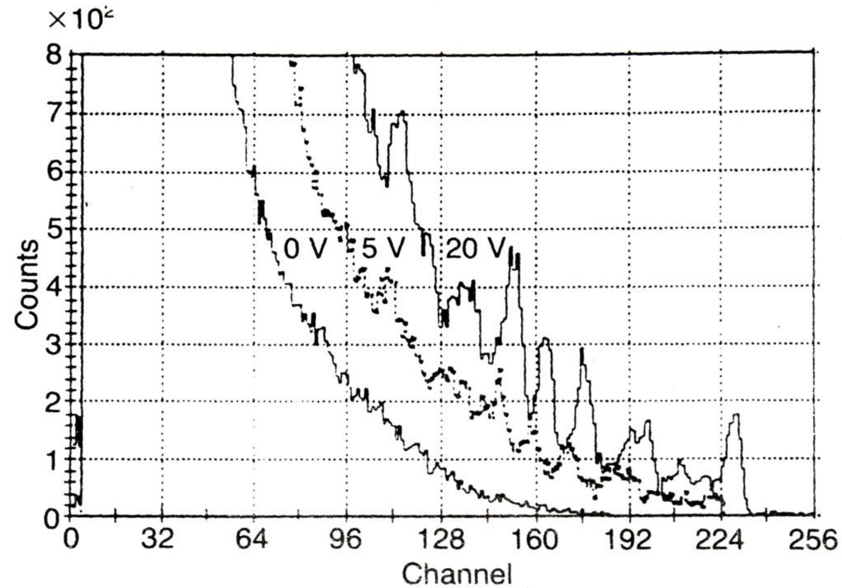
Responses of semiconductor diode with ^{6}LiF converter to thermal and fast neutrons

Silicon diode + ^{6}LiF converter Illuminated by thermal neutrons



Pulse height distributions of neutron detector on thermal neutrons at different bias (0, 5, 20 V). Detector operates well in the self-biased regime.

Silicon diode illuminated by fast neutrons



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Motivation – neutron radiography

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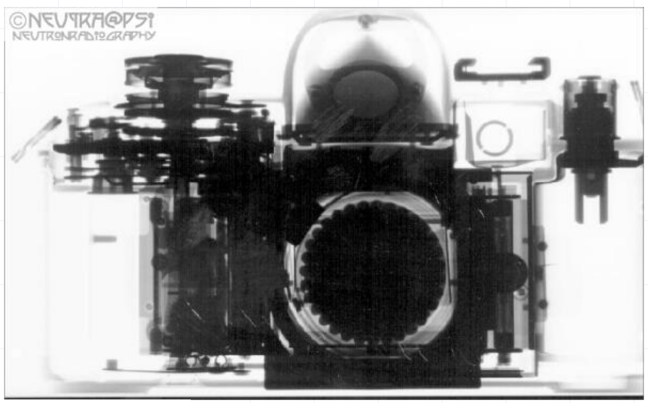
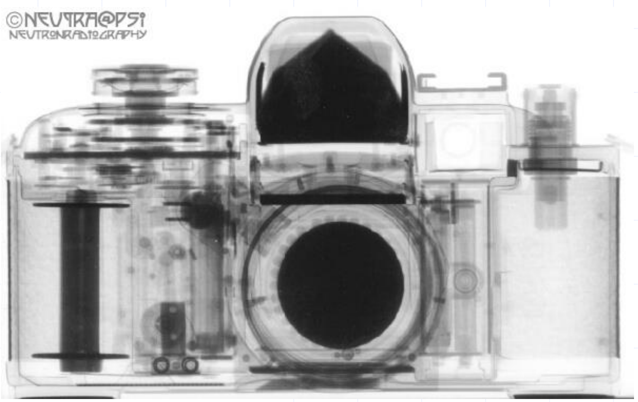
- While X-rays are attenuated more effectively by heavier materials like metals, neutrons allow to image some light materials such as hydrogenous substances with high contrast.
- Neutron radiography can serve as complementary technique to X-ray radiography



X-rays



Neutrons

In the X-ray image, the metal parts of the photo camera are seen clearly, while the neutron radiogram shows details of the plastic parts.

The Neutronography based on

^{6}Li(n,α)T, Q=4.78MeV and ^{10}B(n,α)^{7}Li, Q=2.78MeV

(energetic charged products define interaction with deeply subpixel resolution)

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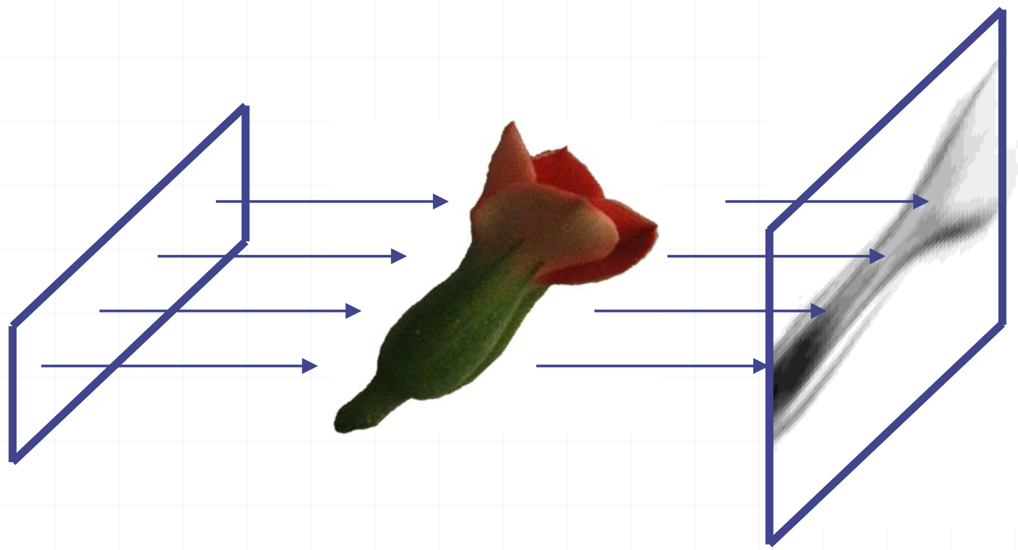
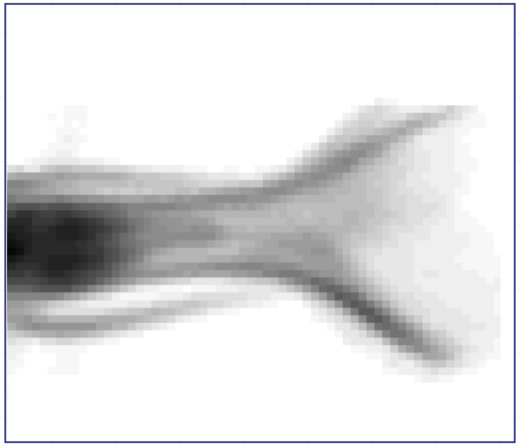


Parallel beam of thermal neutrons

Specimen attenuating the beam

Shadow on detector plane



Neutronogram

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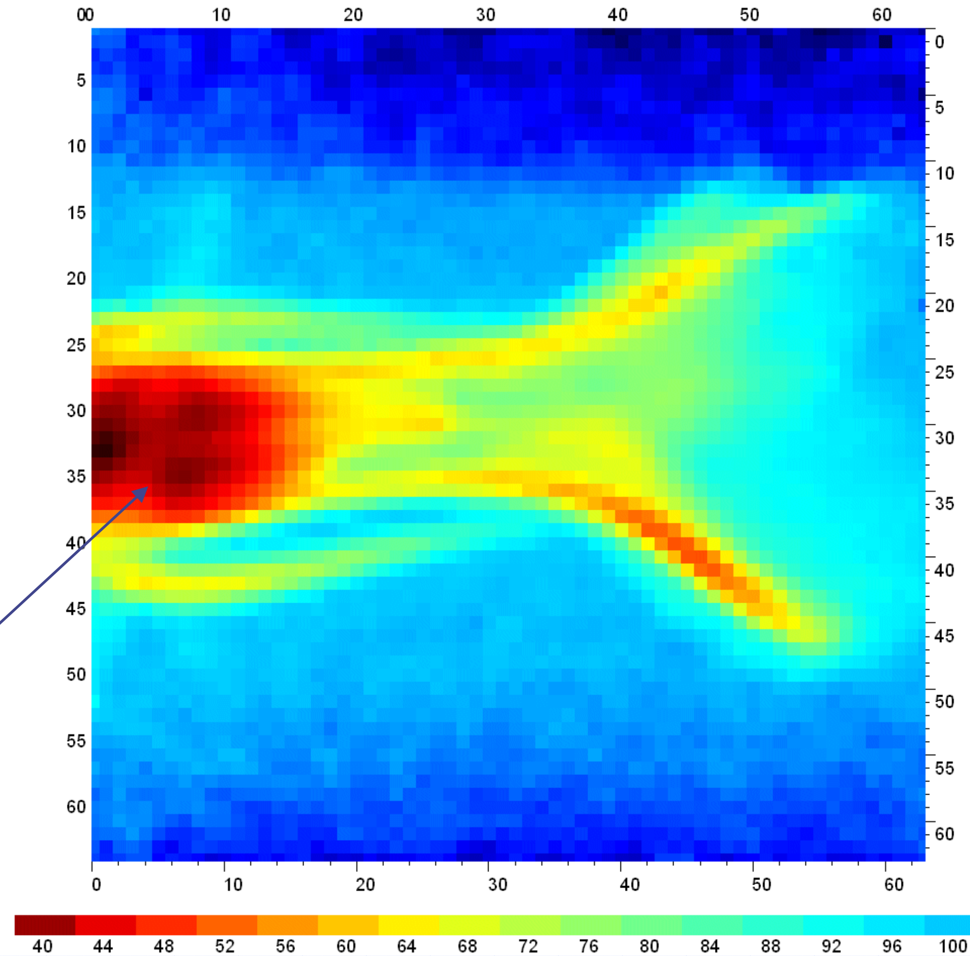
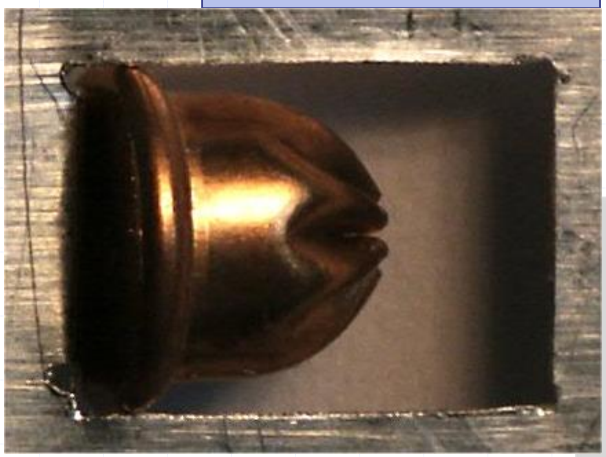
Flower behind Al plate

Look through metal with thermal neutron beam at NPI Rez by means of Medipix detector with ^{6}LiF converter

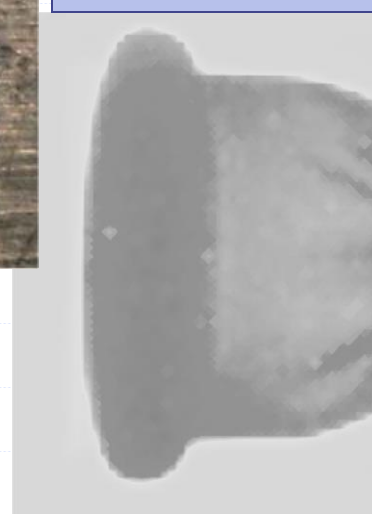


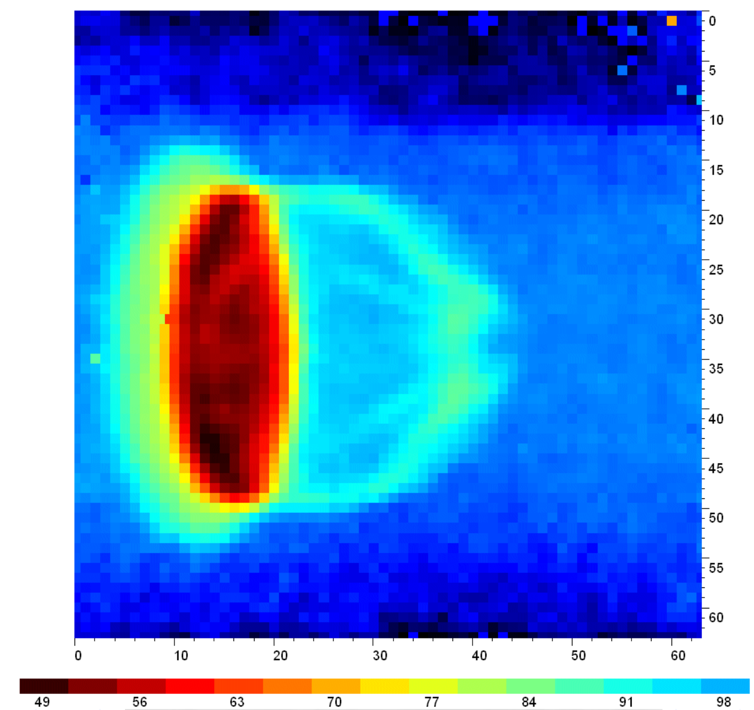
Neutron radiography with Medipix coated by ^{6}LiF: Blank cartridge. Look through metal!

Photography



Roentgenogram





Blank shell
(cartridge)

Explosive filling

Neutron microtomography

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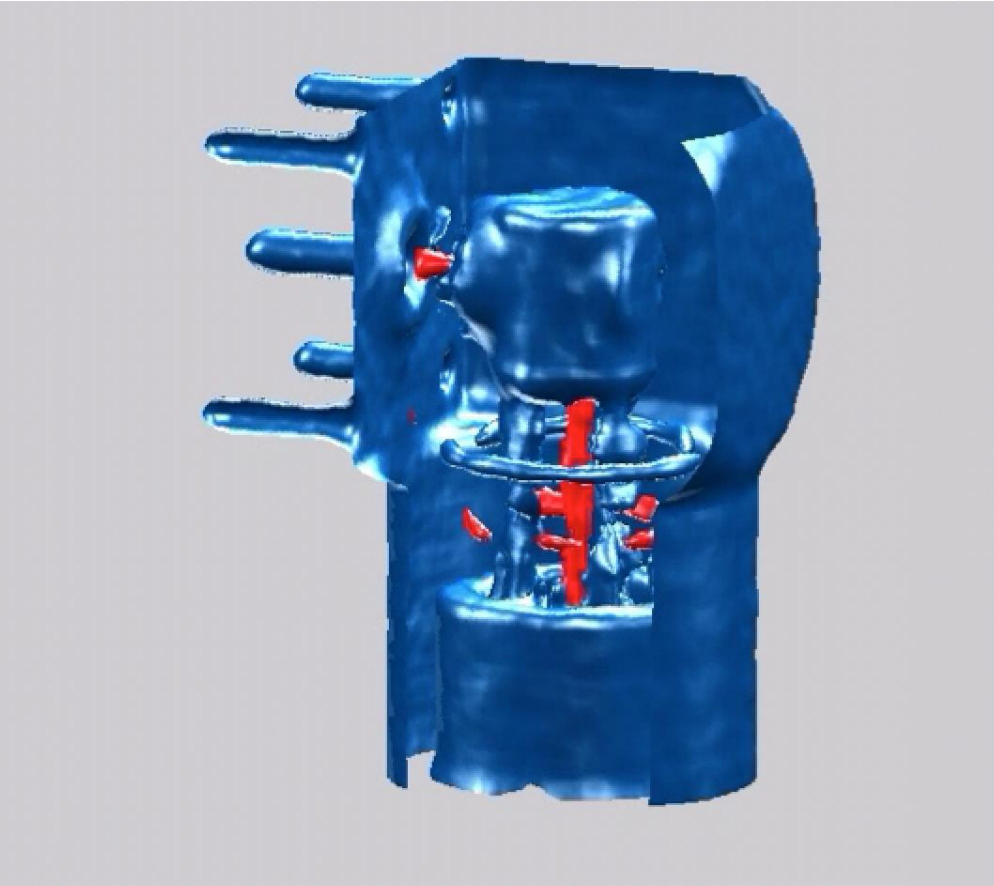
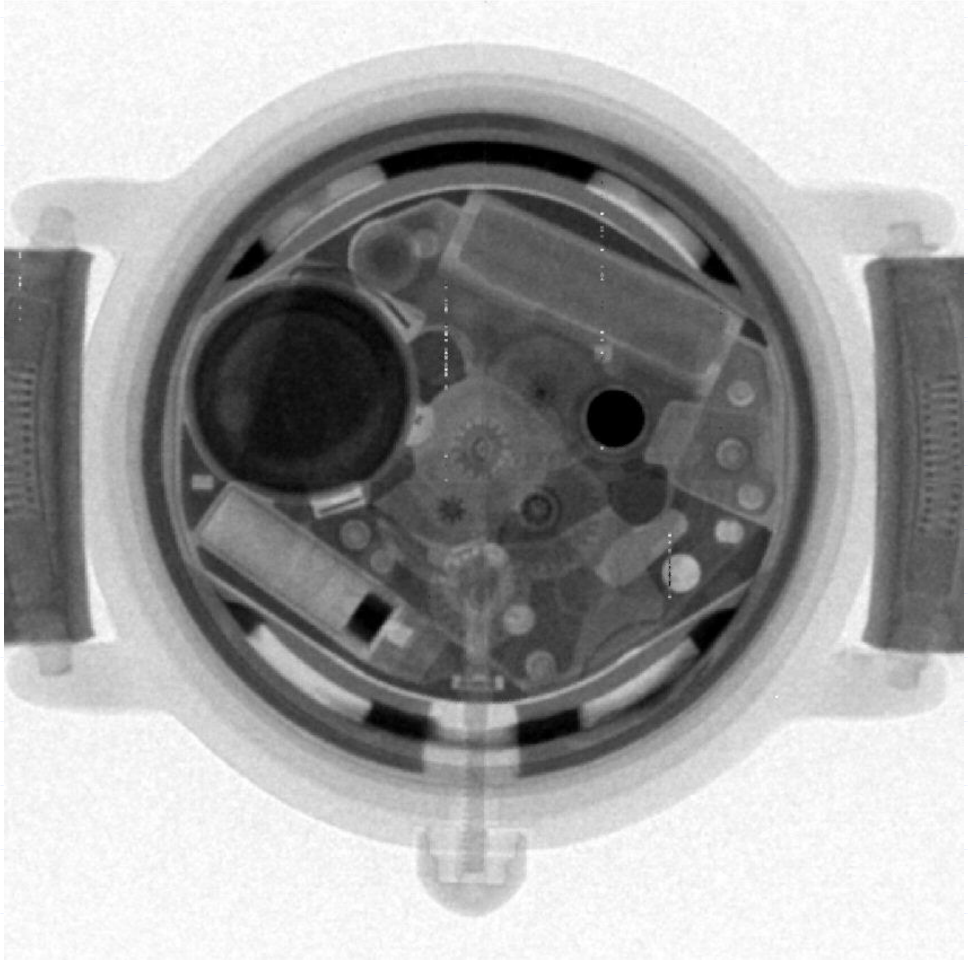
Lemo connector

Golden contacts inside

Taken 100 projections
150 seconds each.
Reconstruction using filtered back-projection algorithm.



Cold neutron radiography performed at PSI
Wrist watch



Test of Spatial Resolution

Medipix2 Quad system coated with 6LiF converter illuminated by cold neutrons

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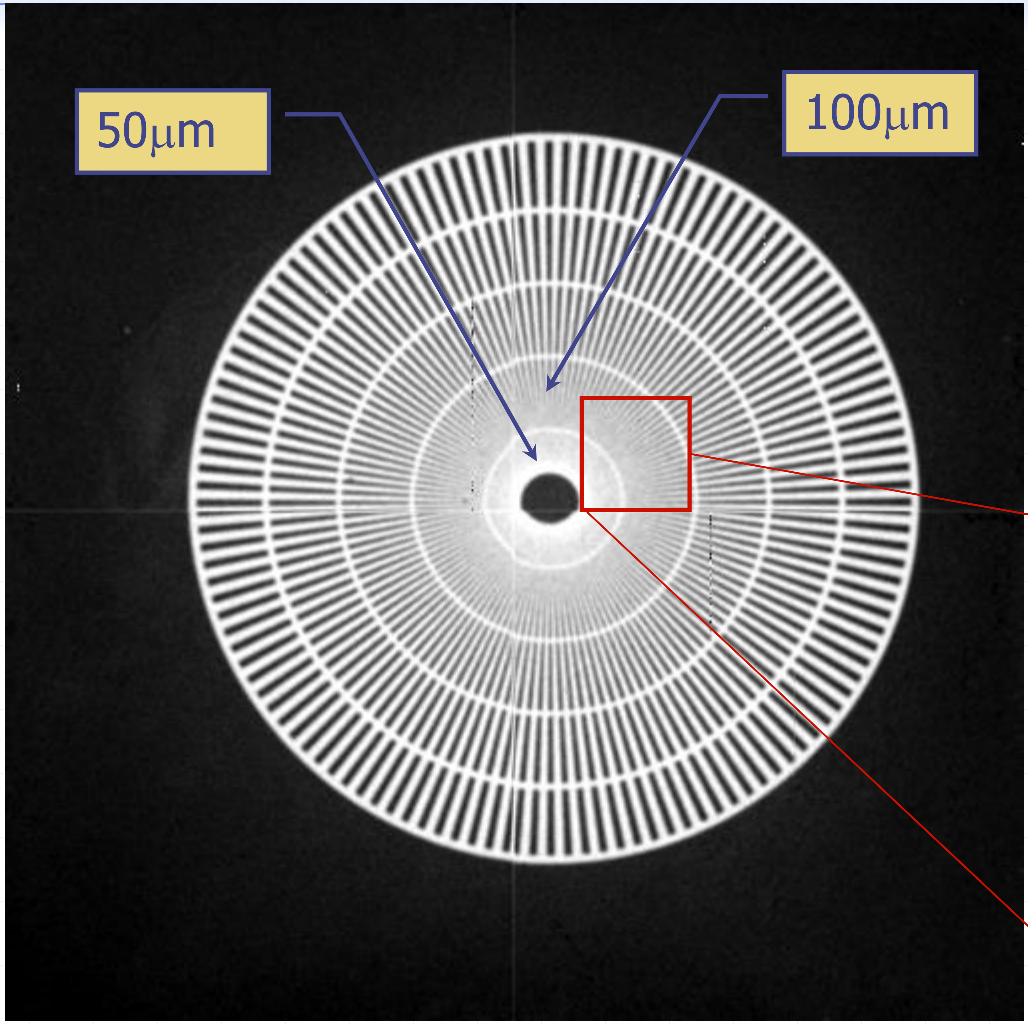

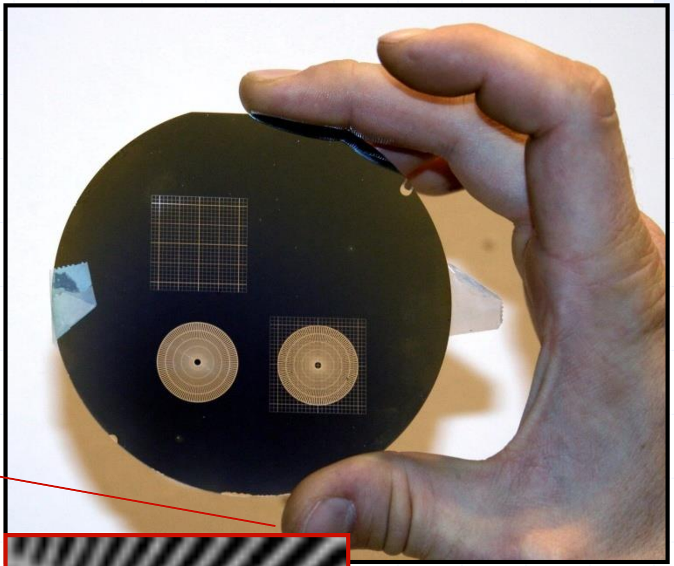

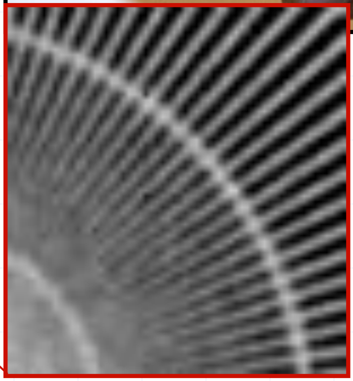

=>Resolution 65μm!

Principle of slow neutron detection using 6LiF converter

About detection efficiency and position resolution

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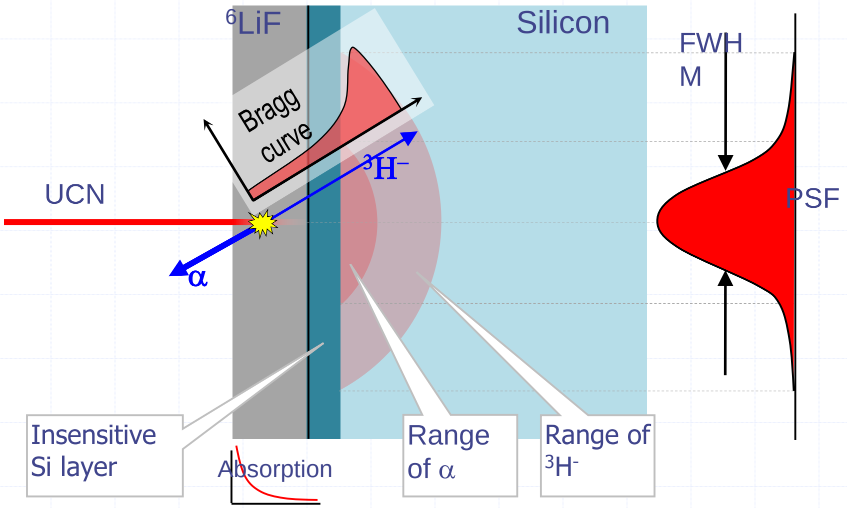
- Simulations performed using MCNP, SRIM and Matlab
- Aim: To estimate detection efficiency and spatial resolution

Geometry used in simulations



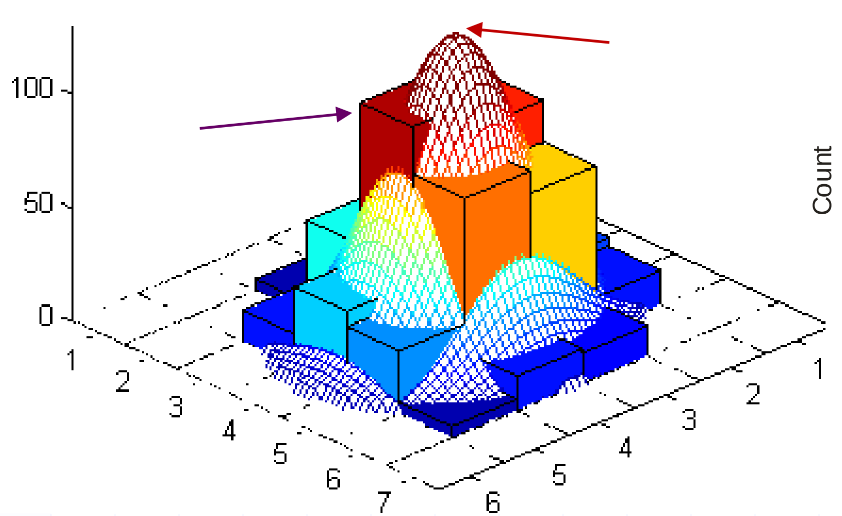
Expected UCNs velocity: 500 cm/s. For such neutrons the cross section of ^{6}Li increases to **0.34 Mbarn**. The cross section of ^{10}B reaches **1.67 Mbarn**.

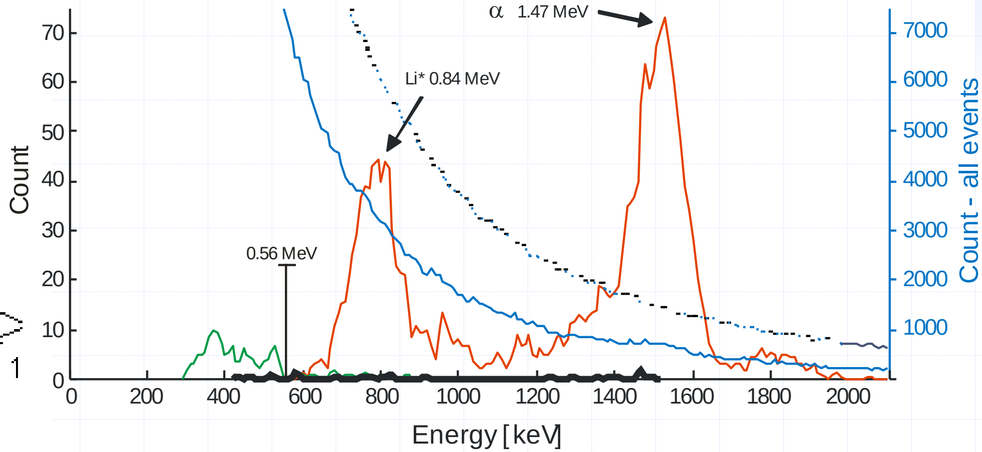
50% of such UCNs are fully absorbed in ^{6}LiF layer of 85 ug/cm^2 (~ 320 nm thickness). For ^{10}B it is layer of 7 ug/cm^2 (~ 30 nm thickness).

Used ^{6}LiF density of 2.65 g/cm^3 and ^{10}B density of 2.35 g/cm^3.

At ^{6}LiF converter thickness of about 5 mg/cm^2, the thermal neutron detection efficiency achieved is about 5%.

High resolution position sensitive neutron detection based on $^{10}B(n, \alpha)^{7}Li$ reaction





Pixel detector response to every charged article (alpha and 7Li) in a form of 3D-cluster with a shape corresponding to convolution of Gaussian and individual pixel responses

Corresponding amplitude spectrum measured by integration of cluster volumes. ^{10}B converter thickness 1.8 ug/cm^2 (~ 36 nm)

The spectroscopy of alpha particles and ^{7}Li and analysis of their clusters recorded by Timepix detector permits to achieve spatial resolution up to 3 micrometers

Neutron images with Timepix detector and resolution calibrated by Siemens star

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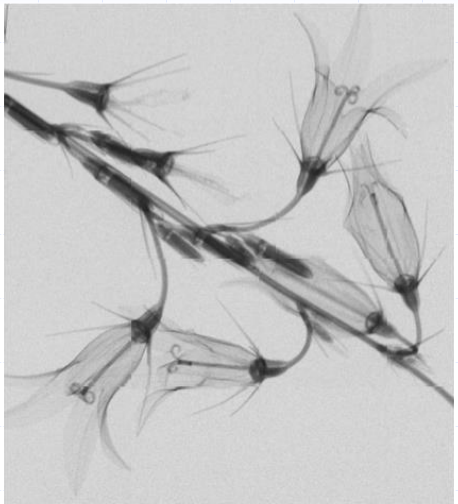

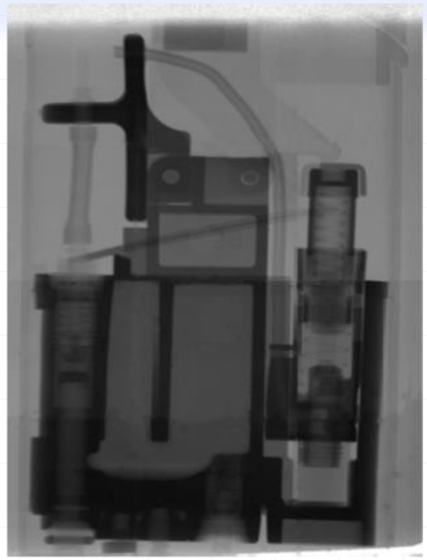

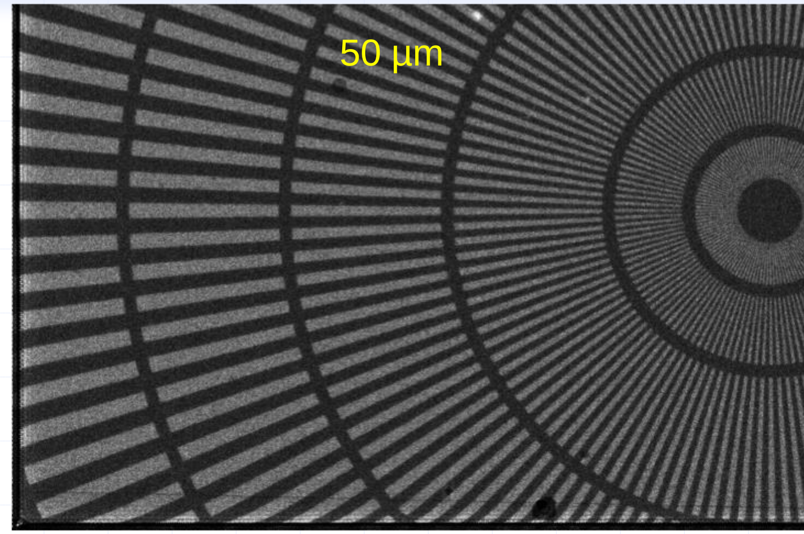

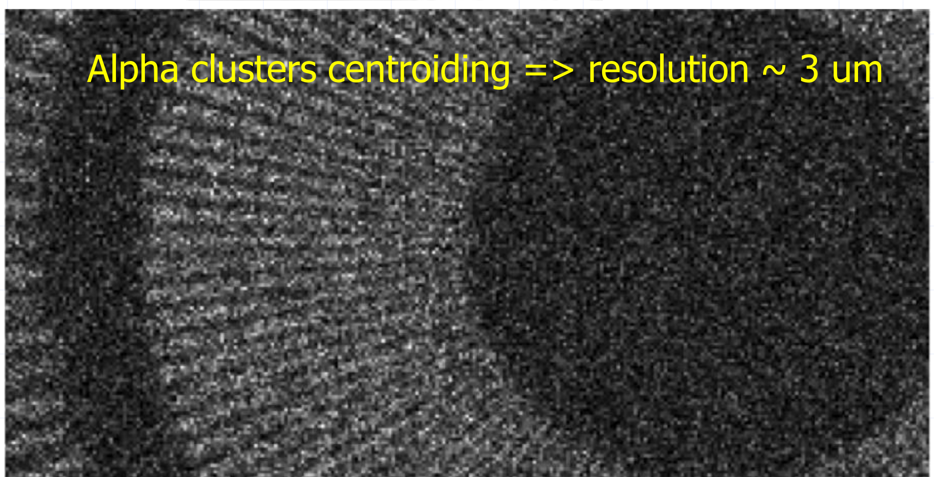

Flock of 11 MeV protons entering the silicon sensor under 85°

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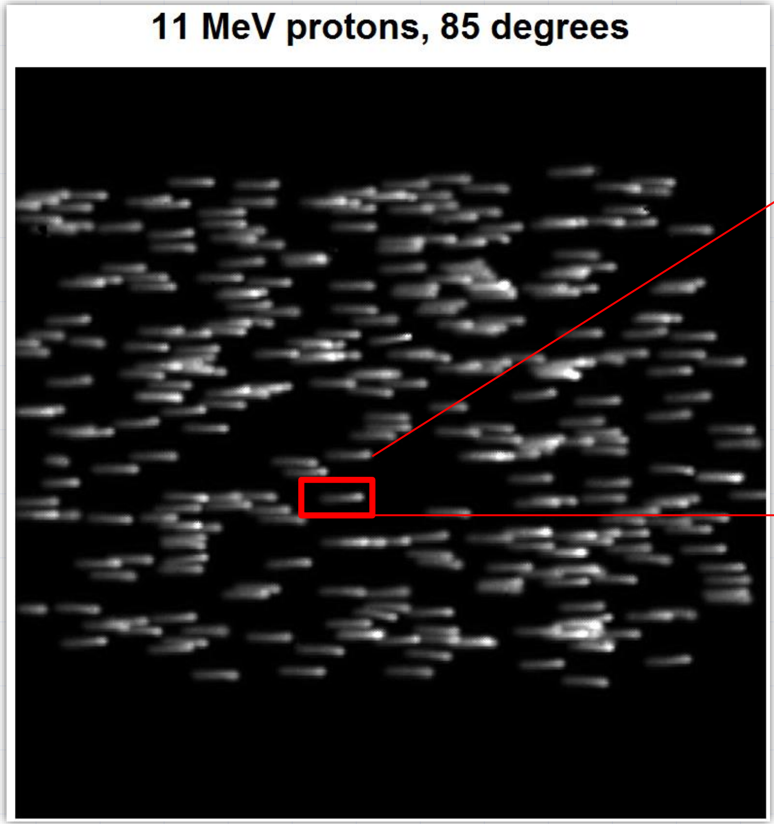
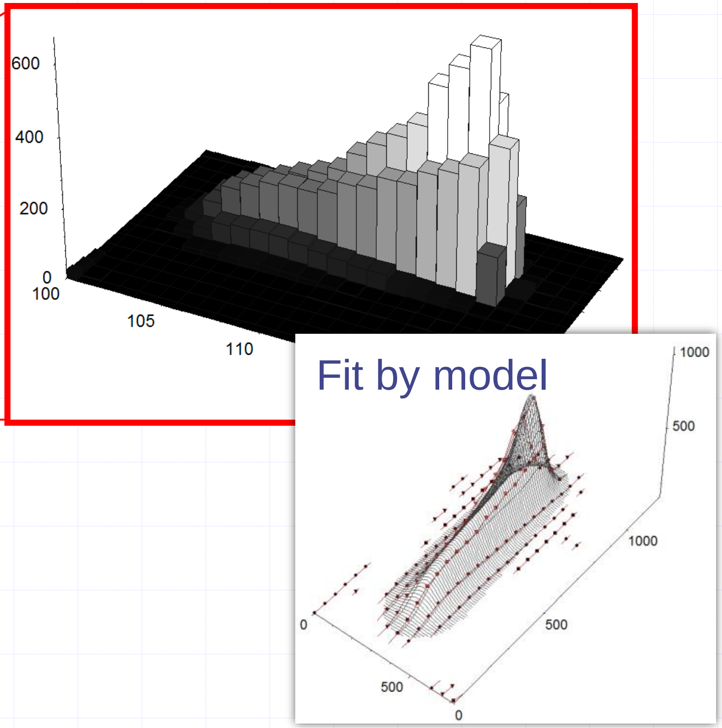


ΔE/Δx Bragg profile nicely pronounced, proton range about 960 µm



Track of MIP particle – cosmic muon

Charge sharing effect helps to determine all three track coordinates with quite high resolution (deeply submicrometric in case of x and y)

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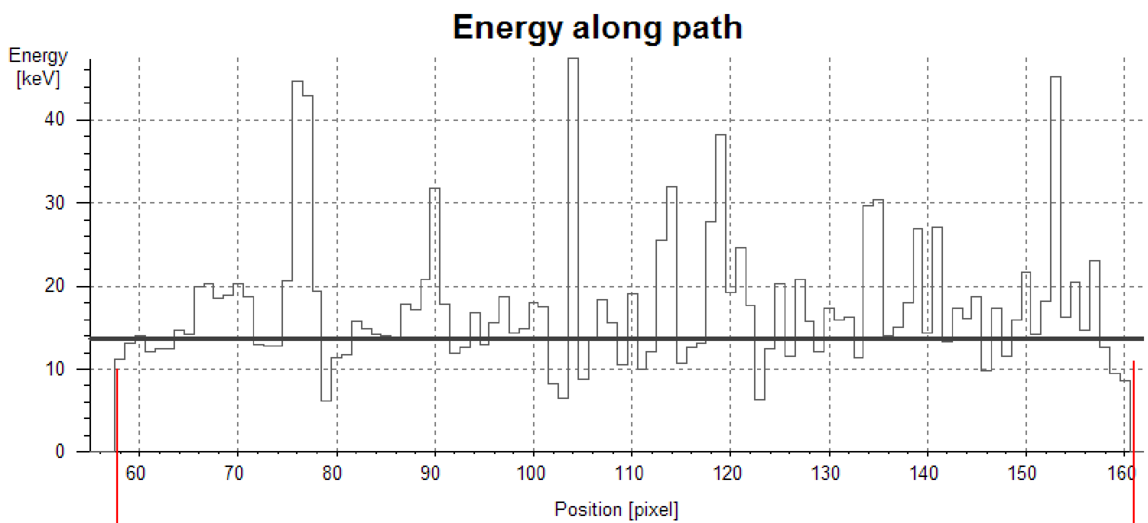
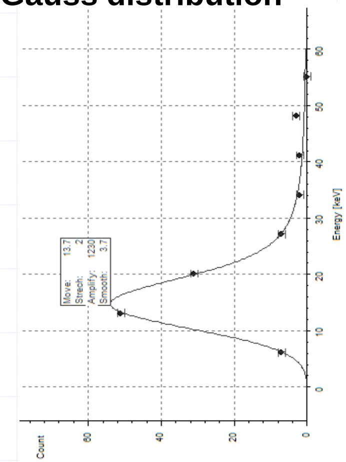
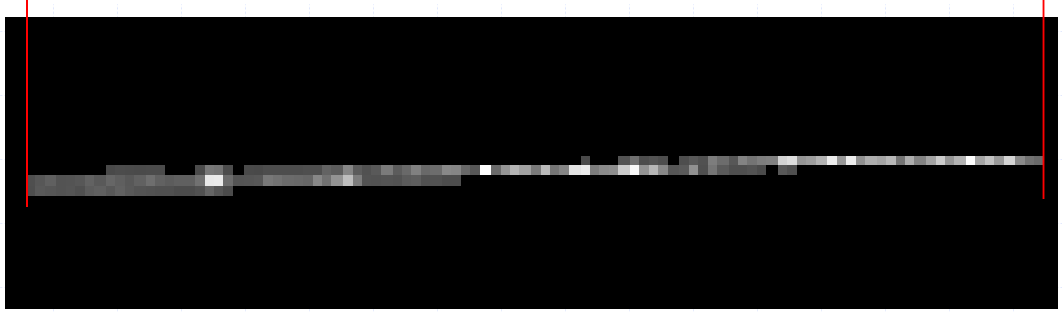
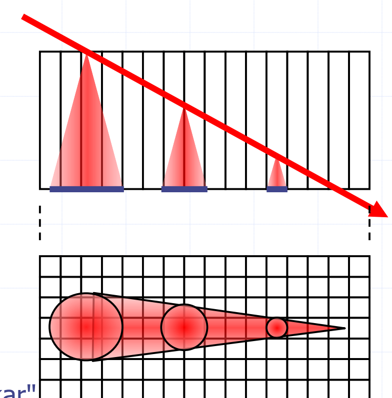


Energy distribution fit by convolution of Landau and Gauss distribution





Track recorded by TimePix device



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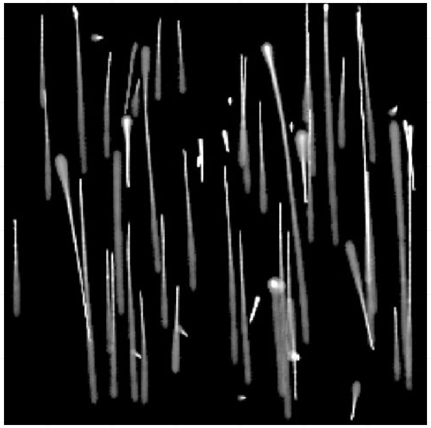
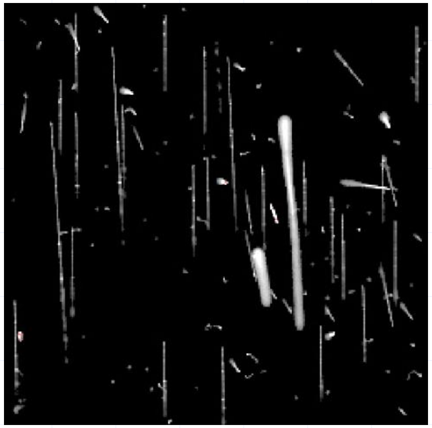
Typical observed tracks of particles used for hadron therapy beam

Protons 48 MeV



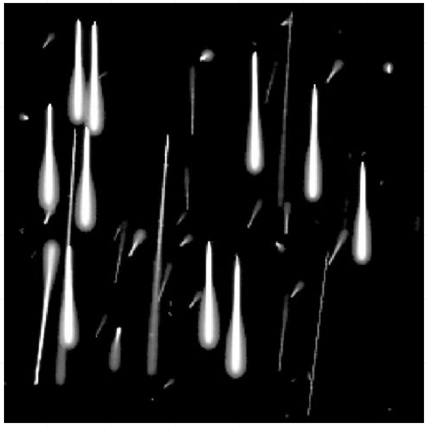
Only protons and their scattering, no secondaries.

Protons 221 MeV



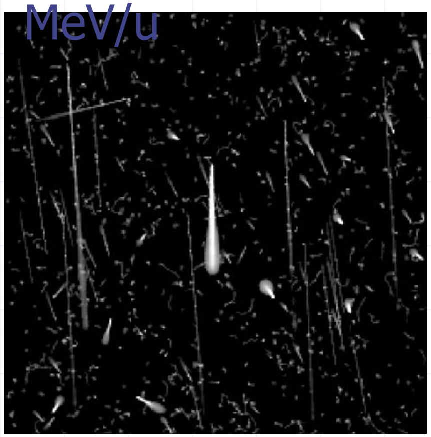
Many secondaries, (delta electrons fragments).

Carbons 89 MeV/u



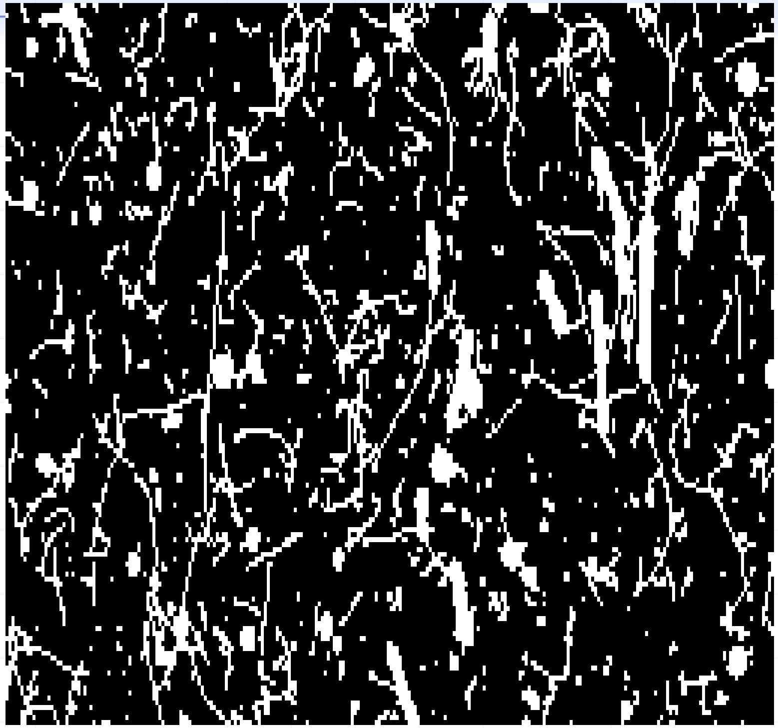
Carbons and protons and their scattering, no secondaries.

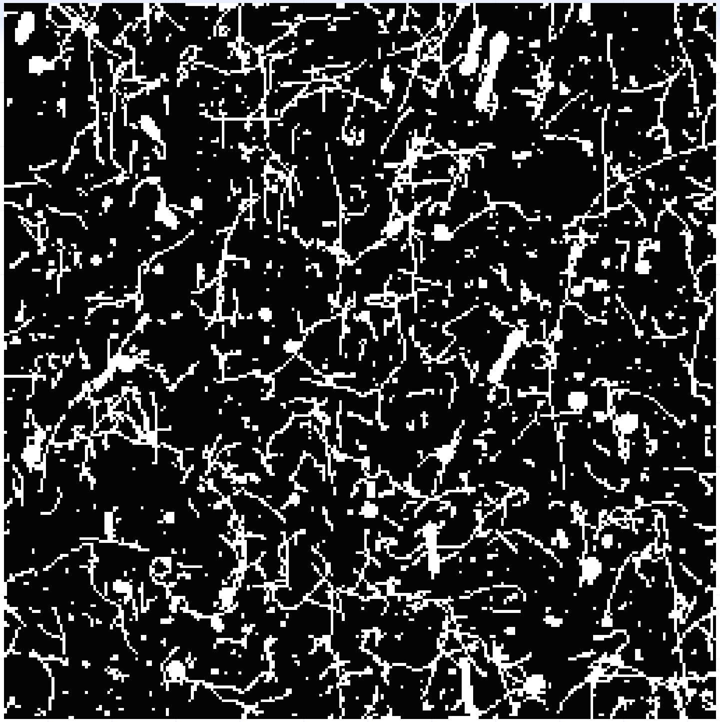
Carbons 430 MeV/u



Carbons and many secondaries.

Response of MEDIPIX2 detector with CH_2 converter to fast neutrons (17MeV)





- The direction of the neutrons with respect to the image was upstream (from bottom to top). The huge background is due to gamma rays which accompany neutrons. Half of the sensor (the right-hand side) was covered with a CH2 foil about 1.3 mm thickness.
- One can clearly recognize long and rather thick tracks of recoiled protons (up to 2 mm, vertically oriented) and big tracks and clusters generated via 28Si(n,α)25Mg, 28Si(n,p)28Al nuclear reactions in the body of the silicon detector. These events are displayed on the dense background caused by tracks and traces of electrons from interactions of gamma rays. One can even recognize that proton tracks shapes follows a Bragg law.

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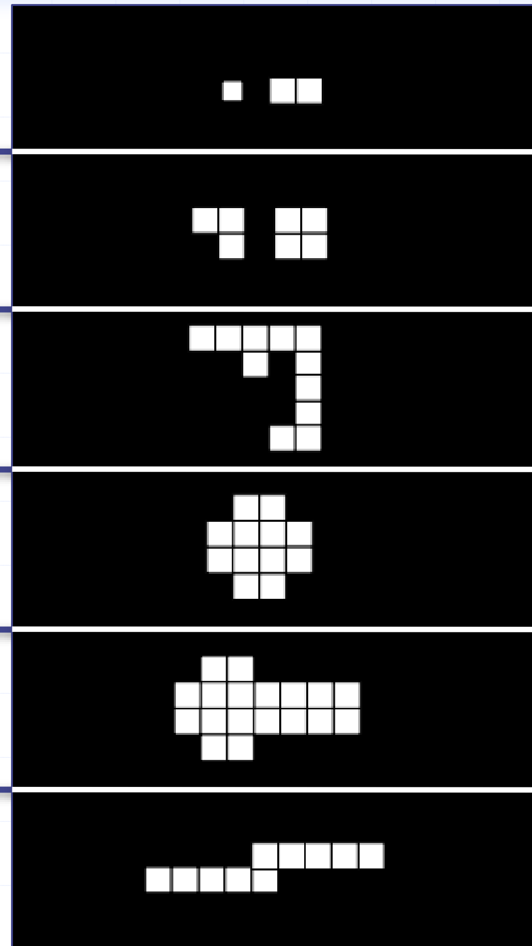
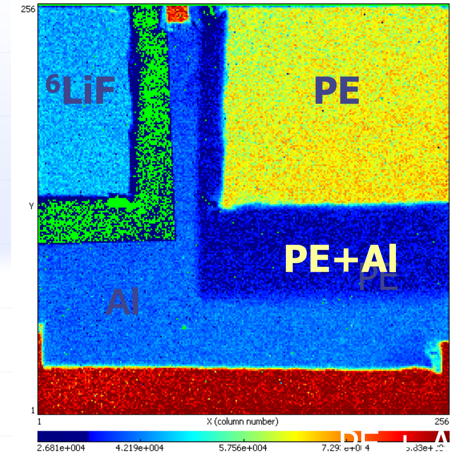
Review of the characteristic patterns
Event by event processing

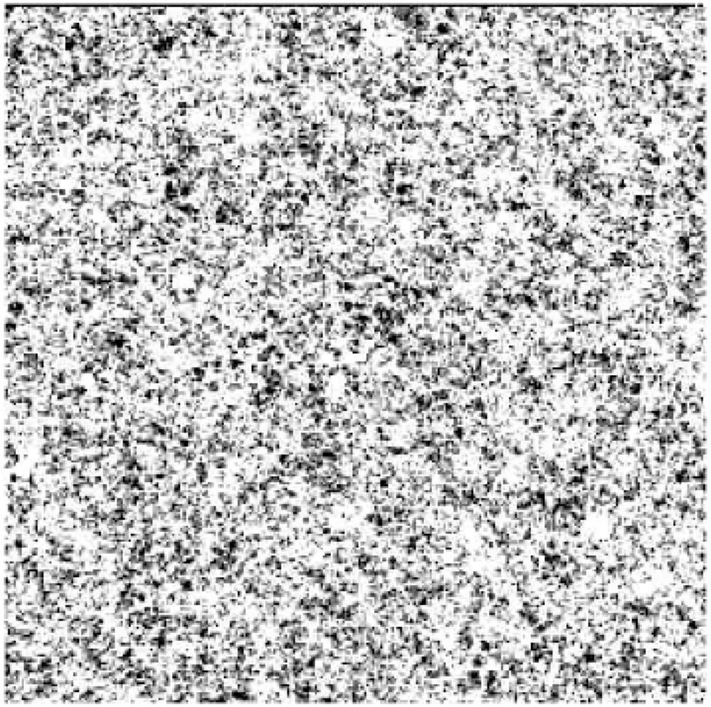


Pattern	Particles
1) Dot	Photons and electrons (10keV)
2) Small blob	Photons and electrons
3) Curly track	Electrons (MeV range)
4) Heavy blob	Heavy ionizing particles with low range (alpha particles,…)
5) Heavy track	Heavy ionizing particles (protons,…)
6) Straight track	Energetic light charged particles (MIP, Muons,…)

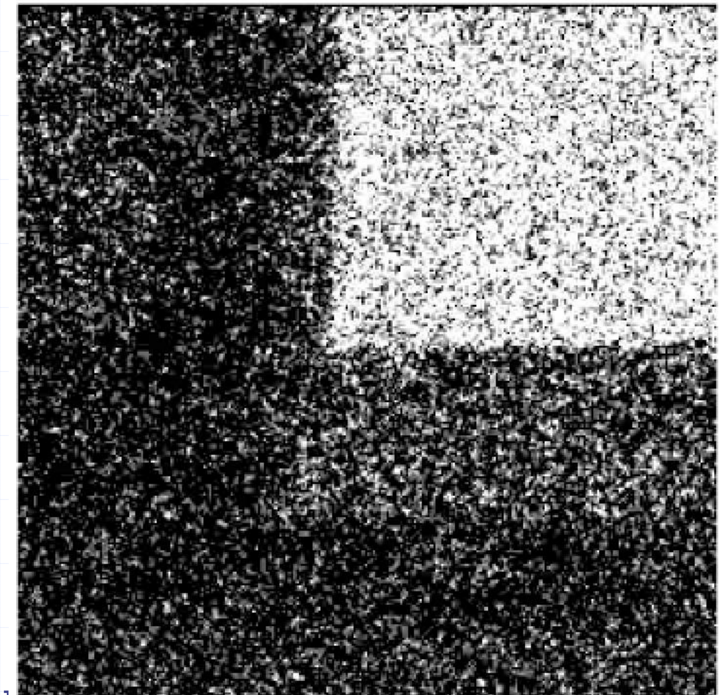
^{252}Cf neutrons measured in counting mode at different thresholds



252Cf, low threshold (8 keV)



252Cf, high threshold (300 keV)



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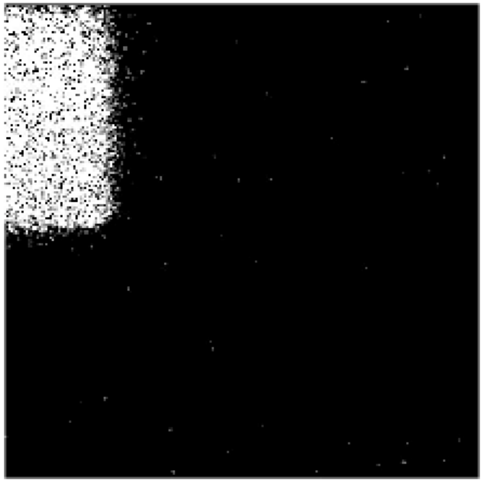
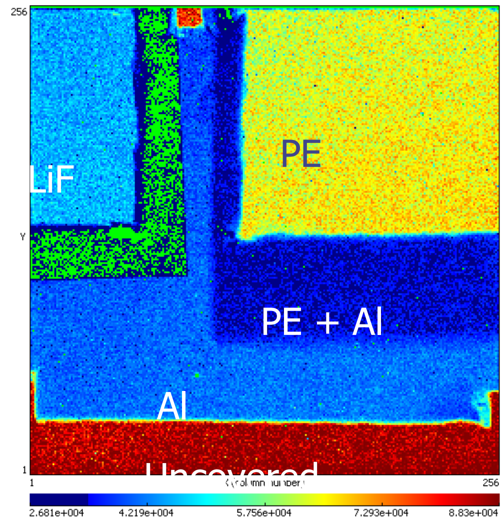
Responses to neutrons of different energies measured at high threshold in counting mode

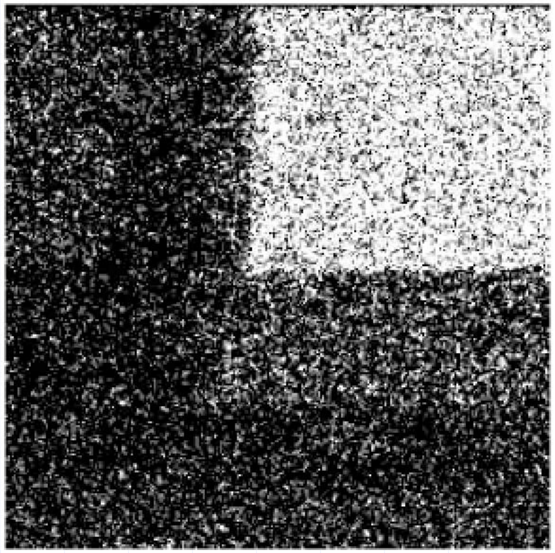
Identification of spectral composition of incoming neutron radiation can be done by comparing responses of different sensitive regions.

Thermal neutrons – 500s

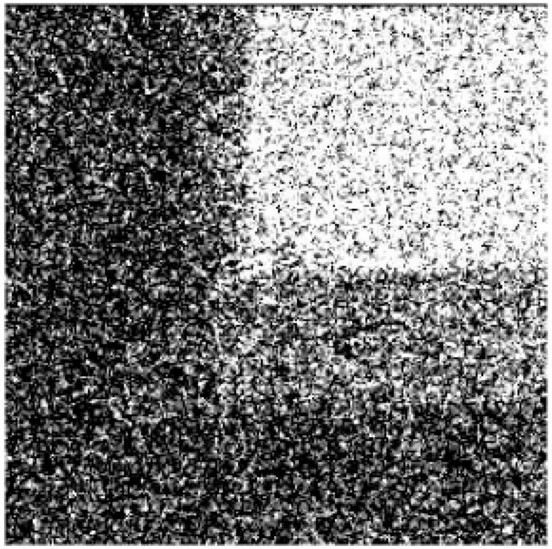




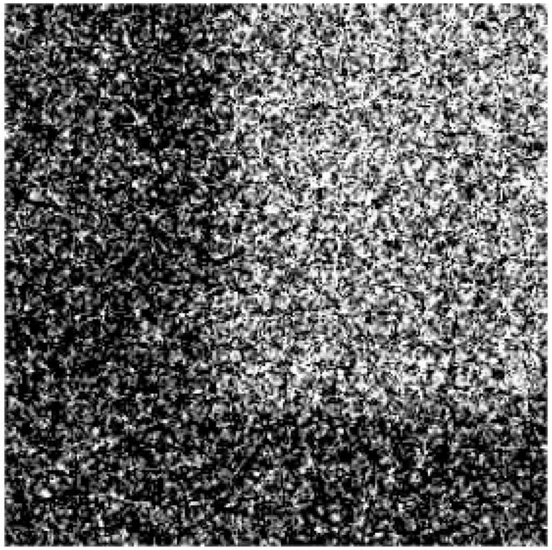
252Cf – 2000s



241AmBe – 2000s



17 MeV neutrons at 0º



On-line radiation monitoring in ATLAS experiment at LHC (16 devices installed within ATLAS)

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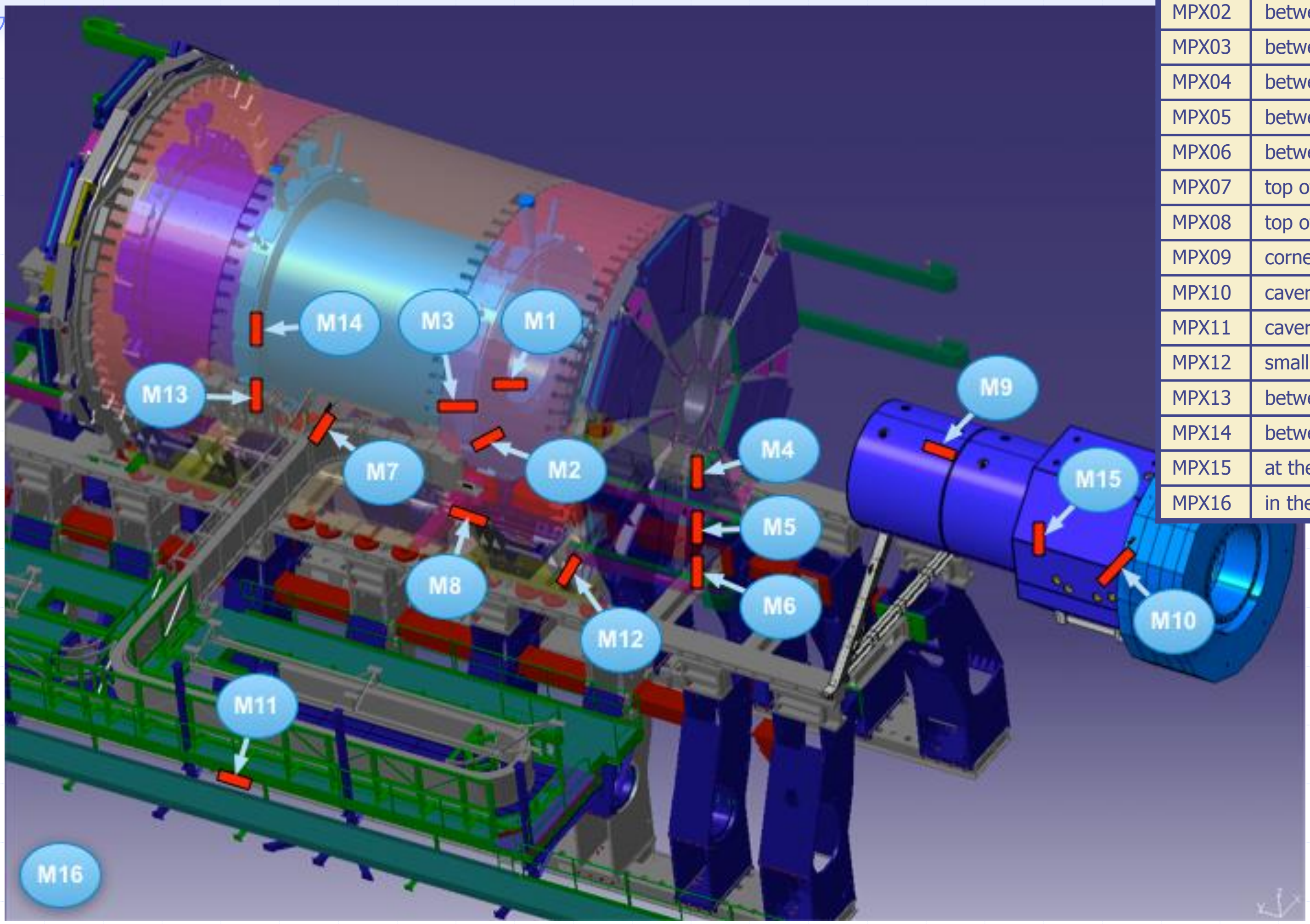
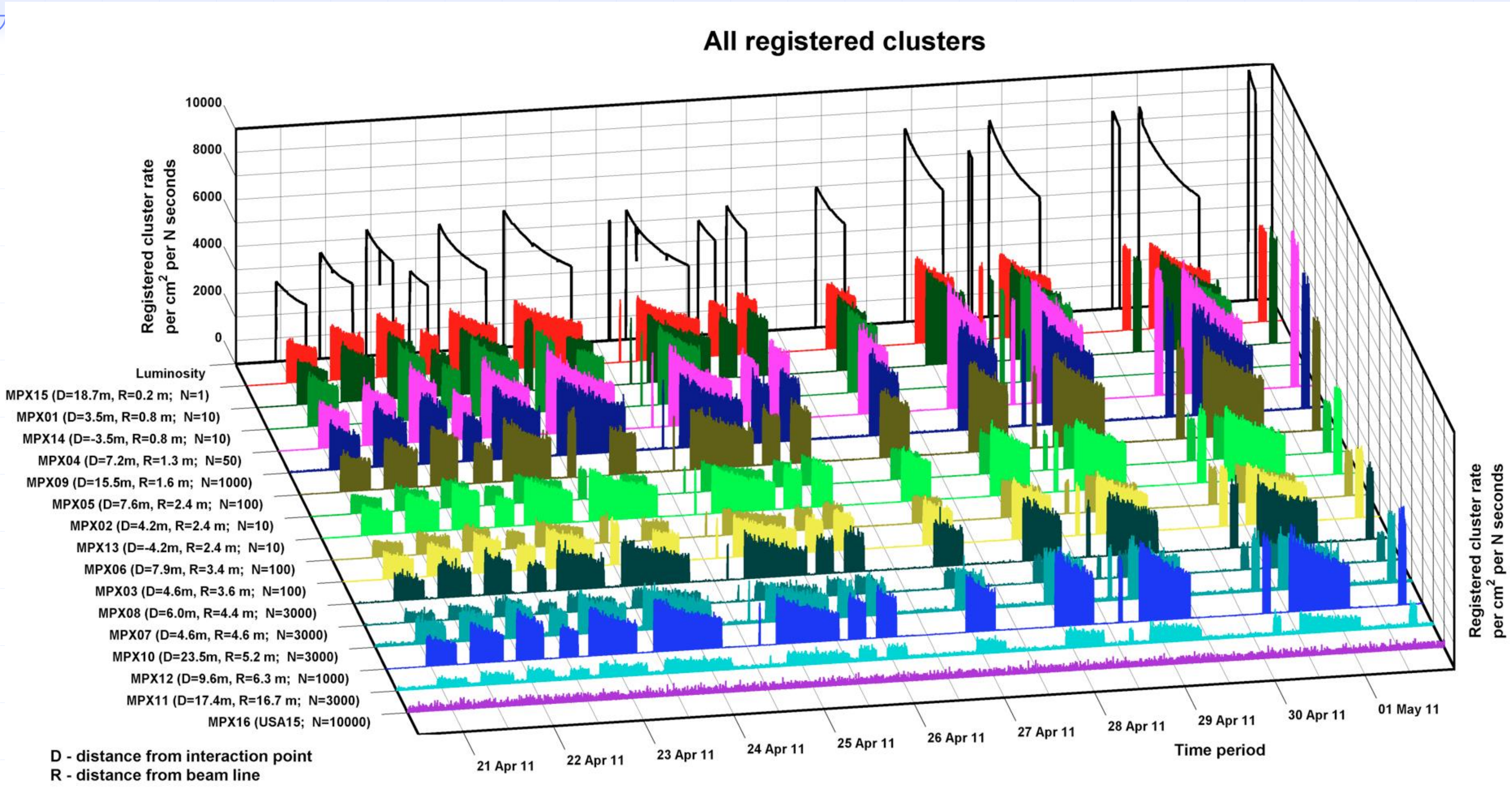


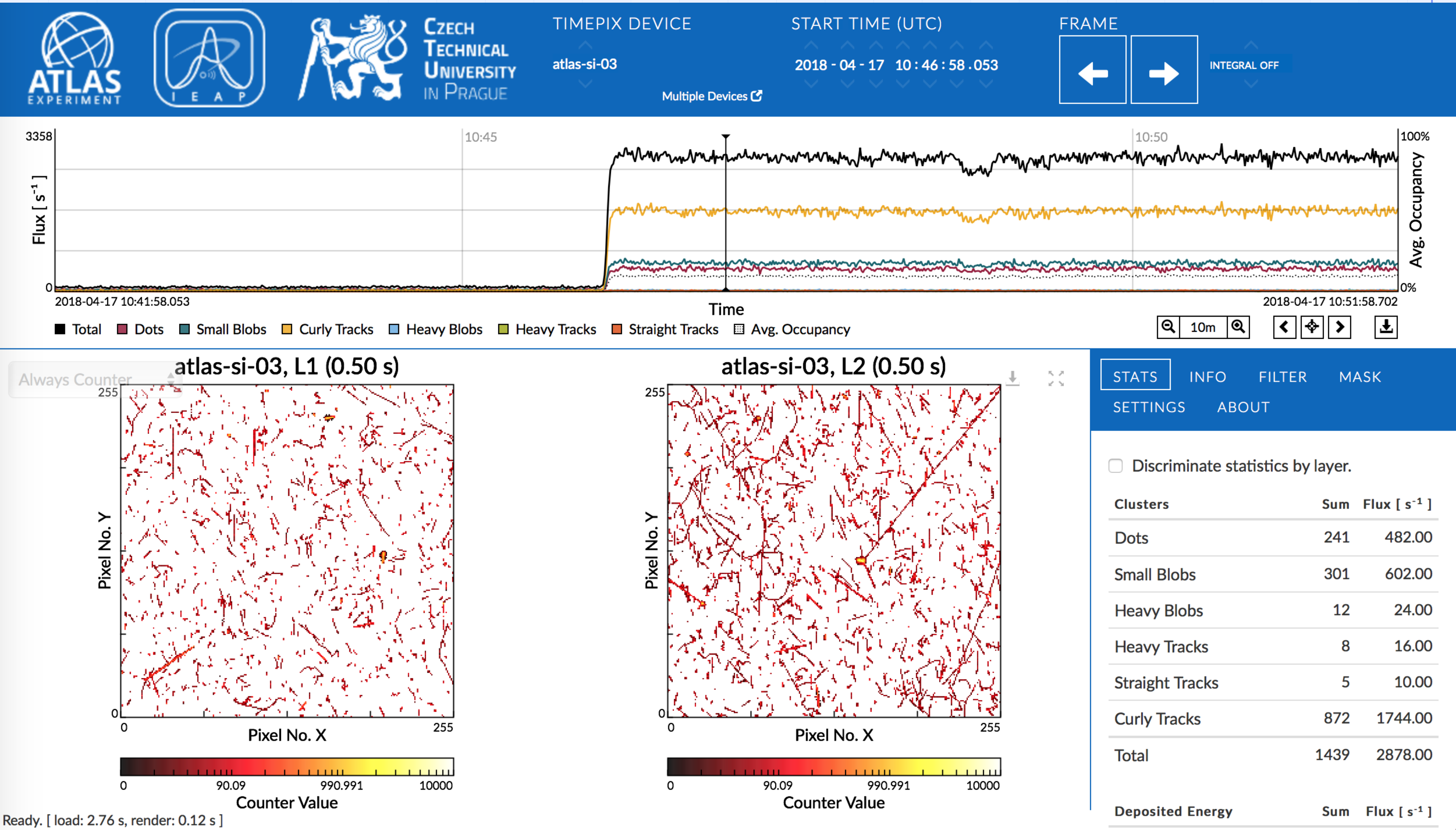
MPX01	between ID and JM plug
MPX02	between ID, LARG and JM
MPX03	between LARG and LARG EC
MPX04	between FCAL and JT
MPX05	between LARG and JT wheel
MPX06	between LARG and JT wheel
MPX07	top of TILECAL barrel
MPX08	top of TILECAL EXT. barrel
MPX09	corner between JF cyl. and hexagon
MPX10	cavern wall A or C side
MPX11	cavern wall USA side
MPX12	small wheel
MPX13	between ID and JM plug
MPX14	between ID, LARG and JM
MPX15	at the back of Lucid detector
MPX16	in the USA15 cavern

Correlation between the responses of the ATLAS-MPX detectors and the LHC luminosity



Period 21 April 2011 – 01 May 2011

Visualization of individual ATLAS-TPX devices in operation



Van der Meer scans (2 horizontal followed by 2 vertical) as observed with the detector MPX15 during p-p Fill 1089 on 9.05.2010.

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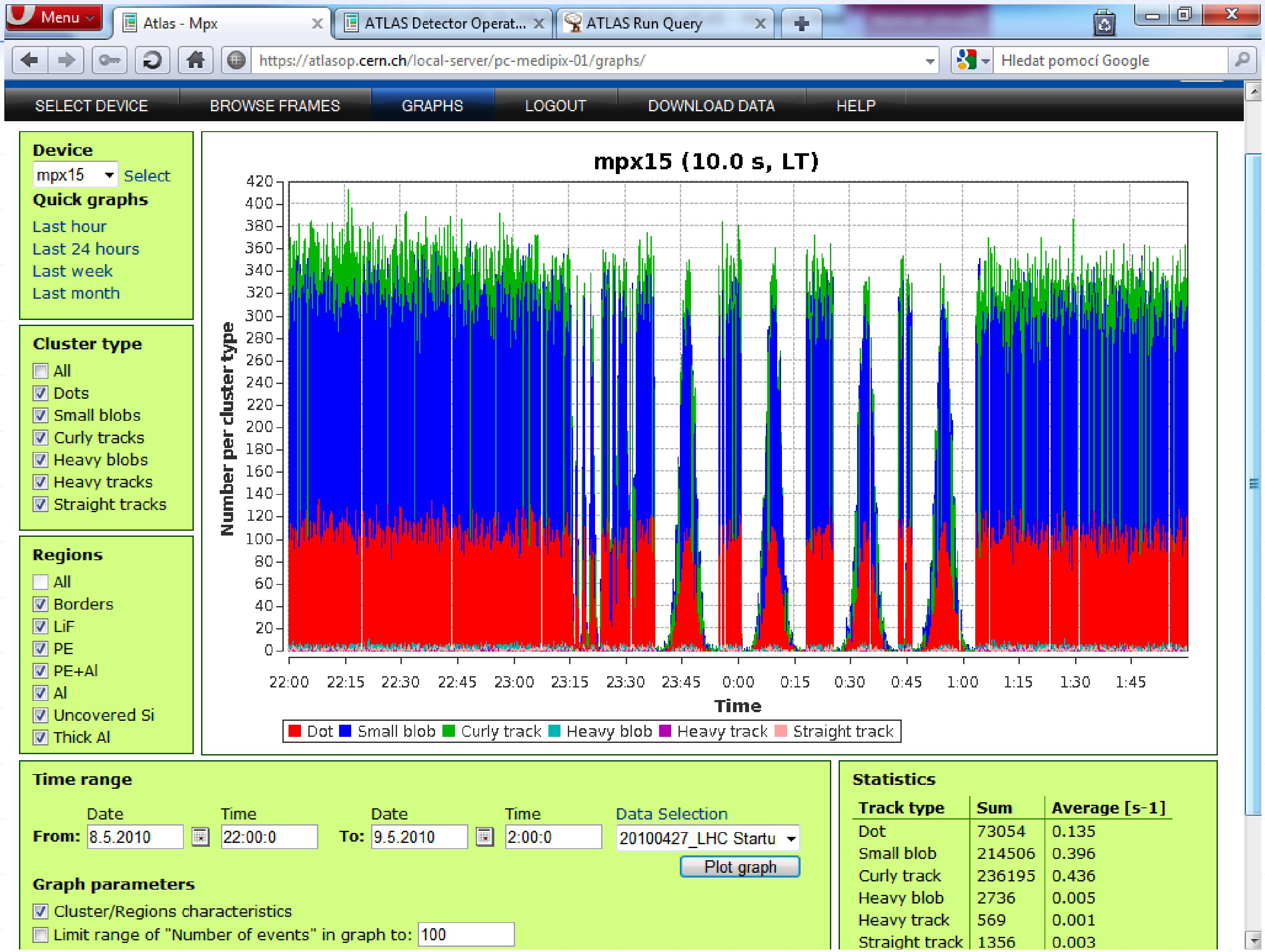
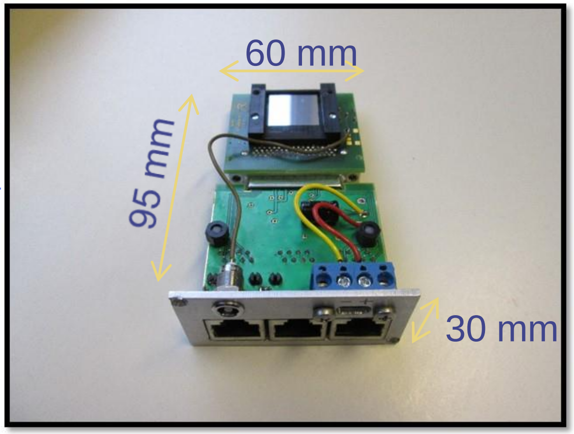
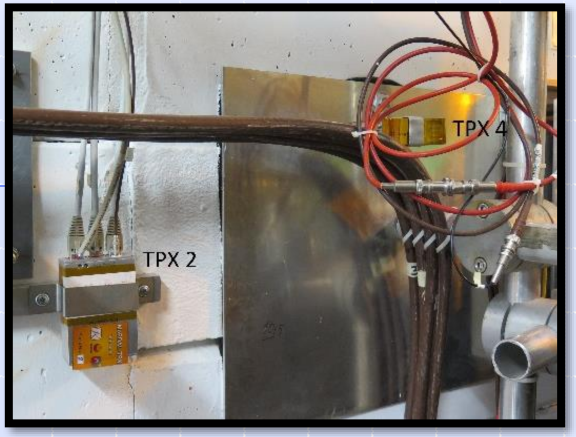
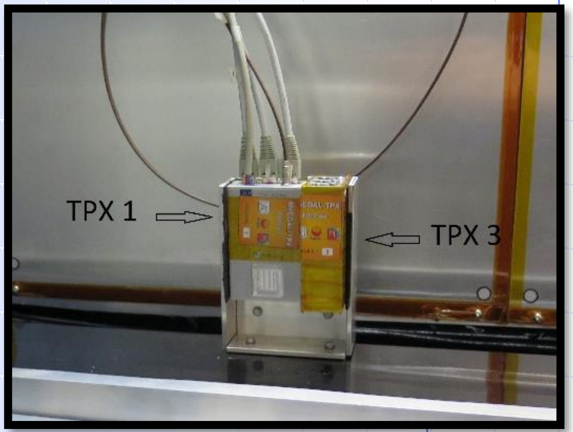


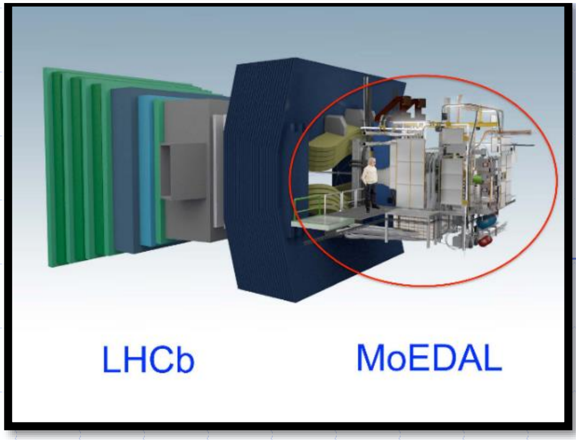
The TPX devices in the MoEDAL network

5 Timepix detectors of different thicknesses (300 µm and 1000 µm, 1 of them equipped with neutron converters) placed in chipboards with radiation tolerant electronics installed in the MoEDAL at LHC









Timepix devices in the MoEDAL experiment

Scheme of TPX detector network in MoEDAL experiment

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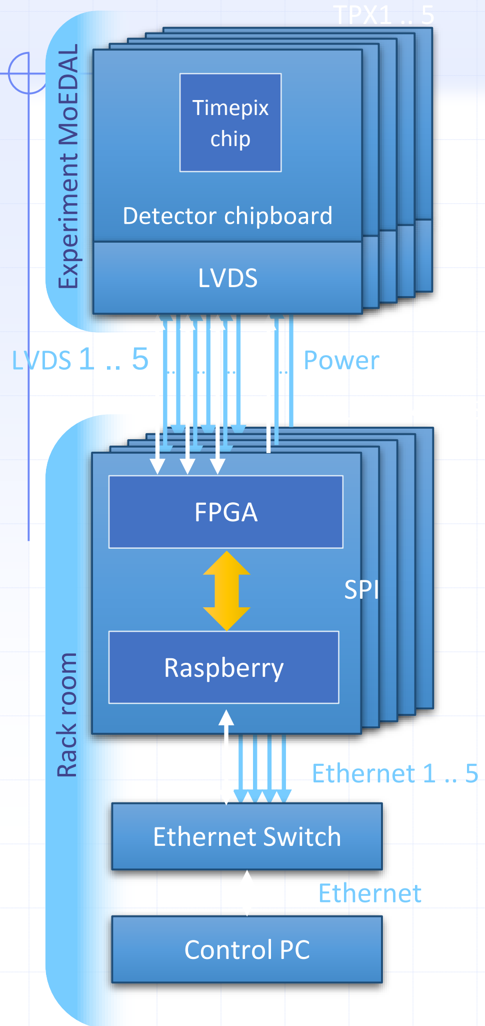
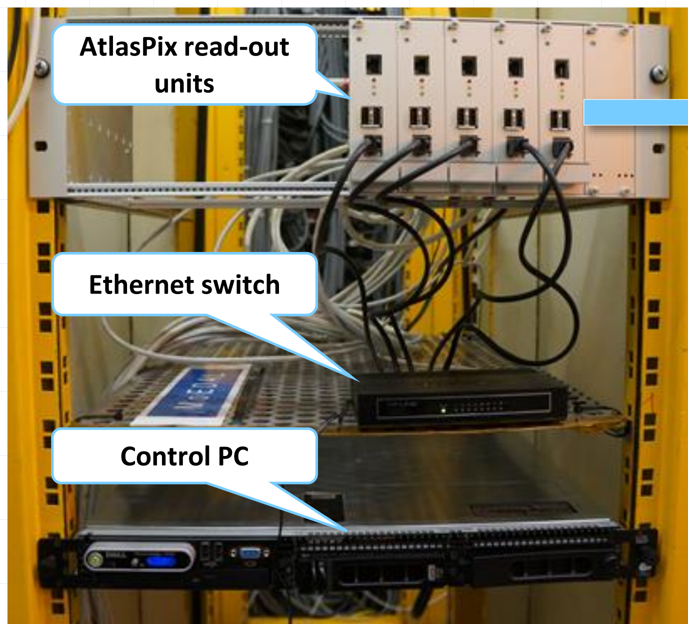
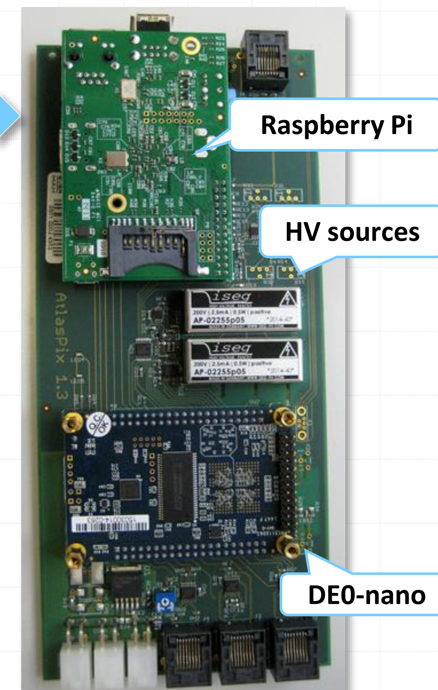
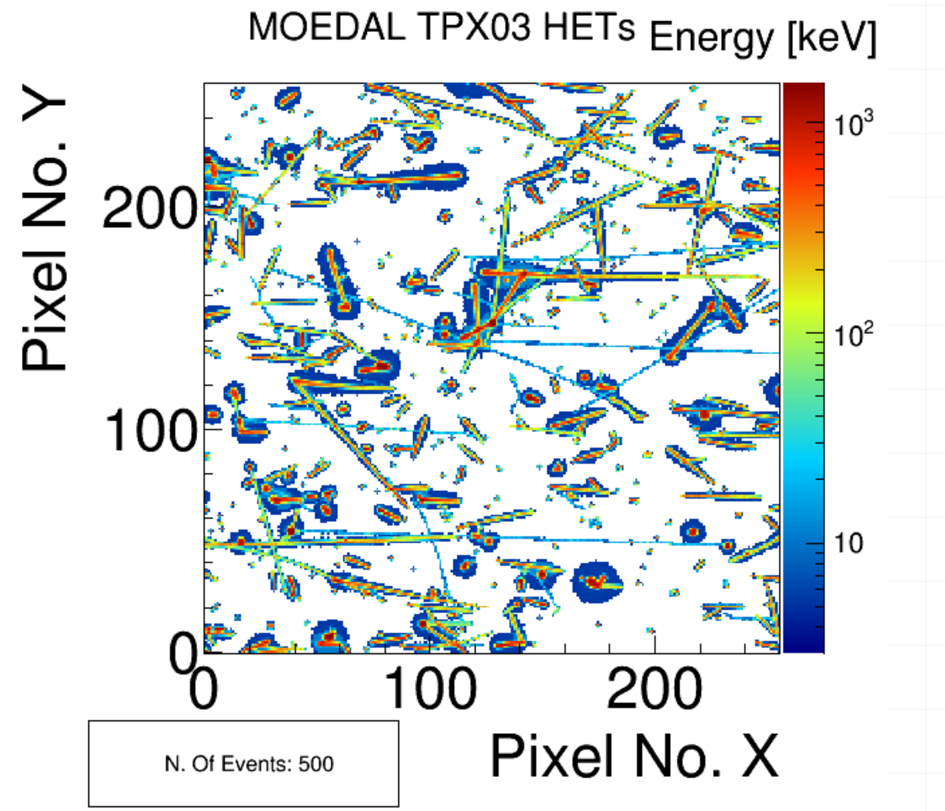




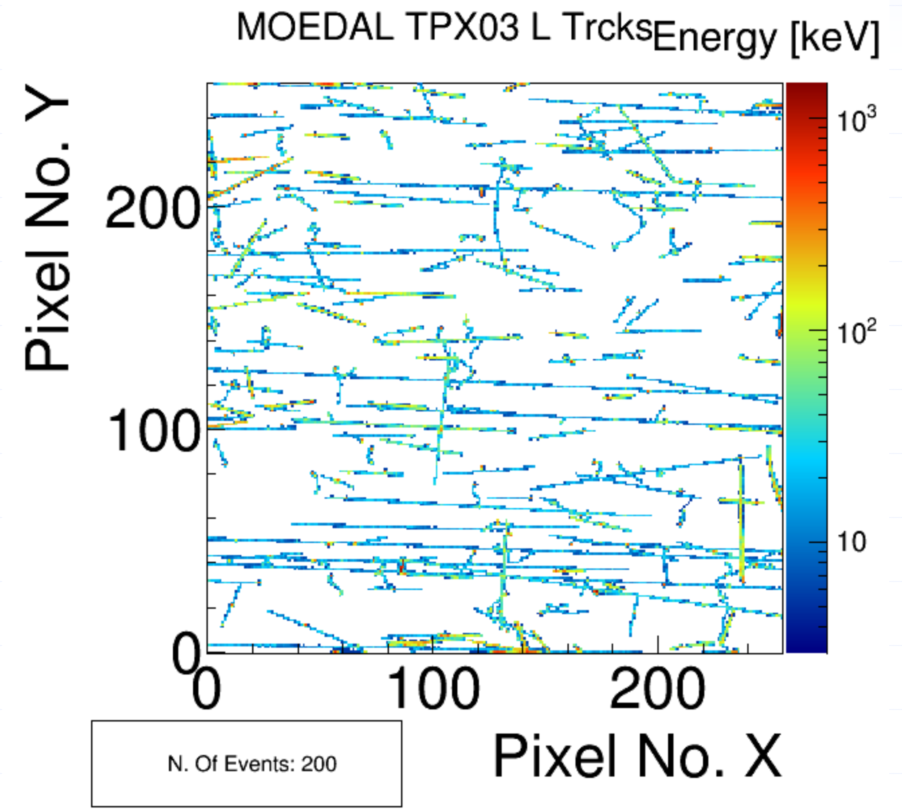


Selected tracks observed with MOEDAL TPX03
12/09/2015

High Energy Transfer Events
(Min Clstr Height: 300 keV)



Long Tracks
(Min Clstr Height: 300 keV)



Palm-top particle telescope concept

Variable setup - number of detectors can be stacked

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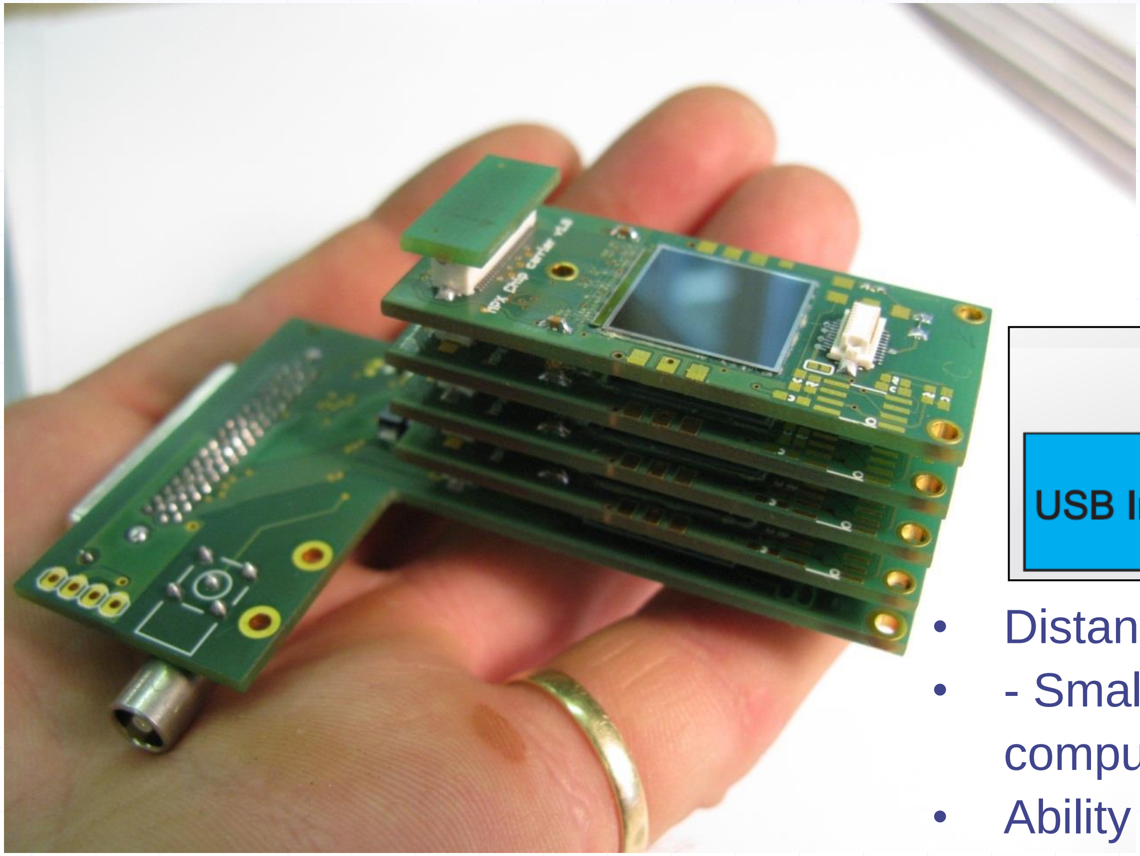
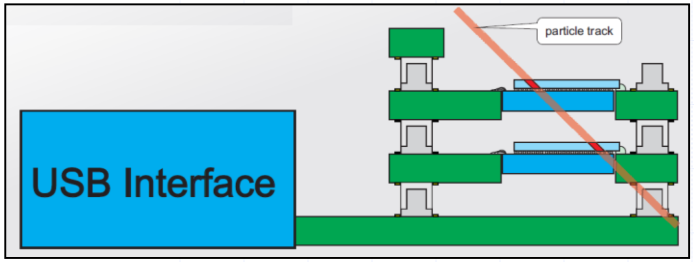
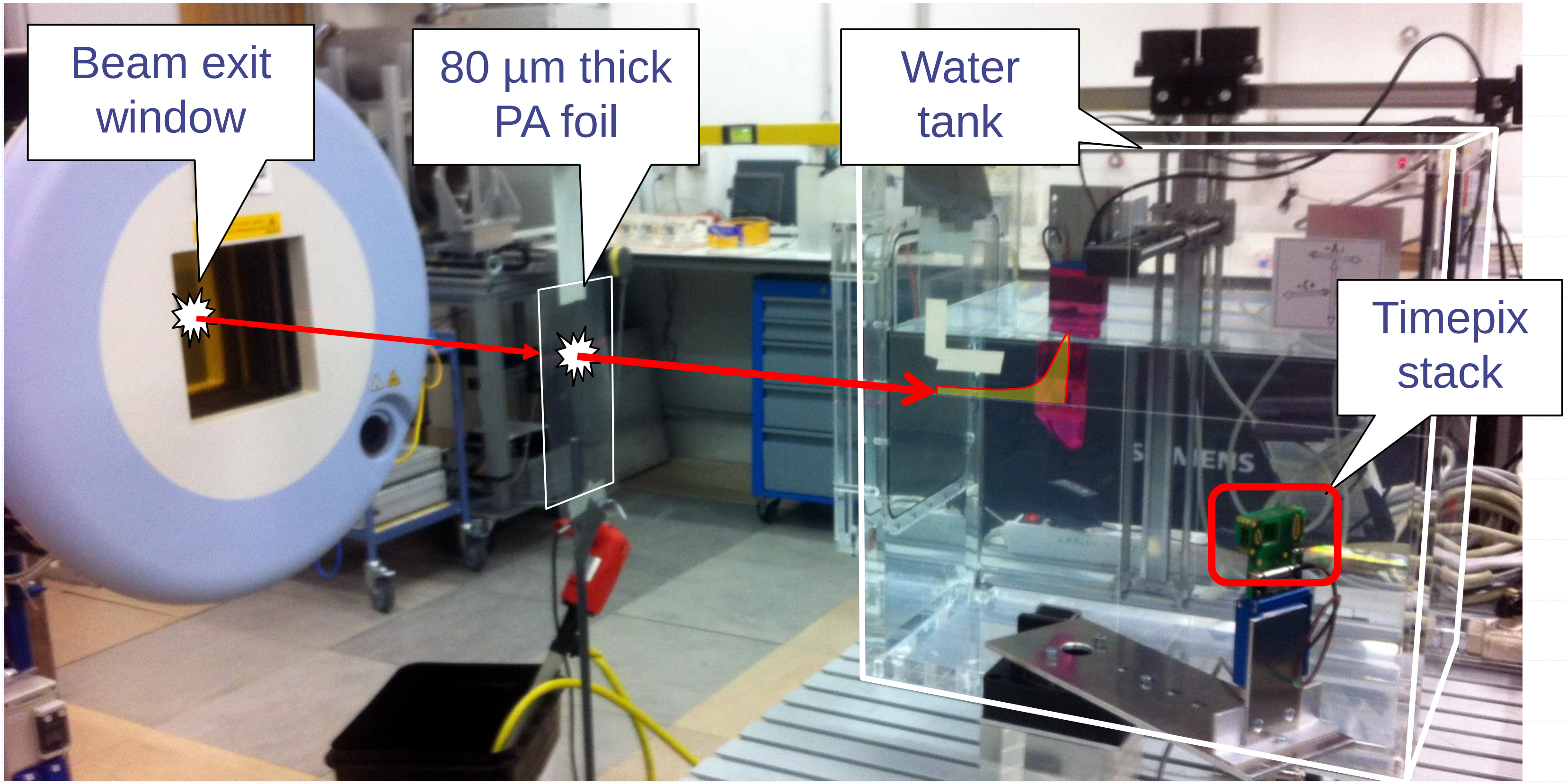




- Distance of layers down to 1.6 mm
- - Small USB interface and laptop computer used for readout
- Ability to distinguish charged and neutral particles by means of coincidence between layers

Medical application:
Hadron therapy - Experimental setup



Visualization of secondary particles produced by the beam

Particle beam vizualization in air and in the phantom

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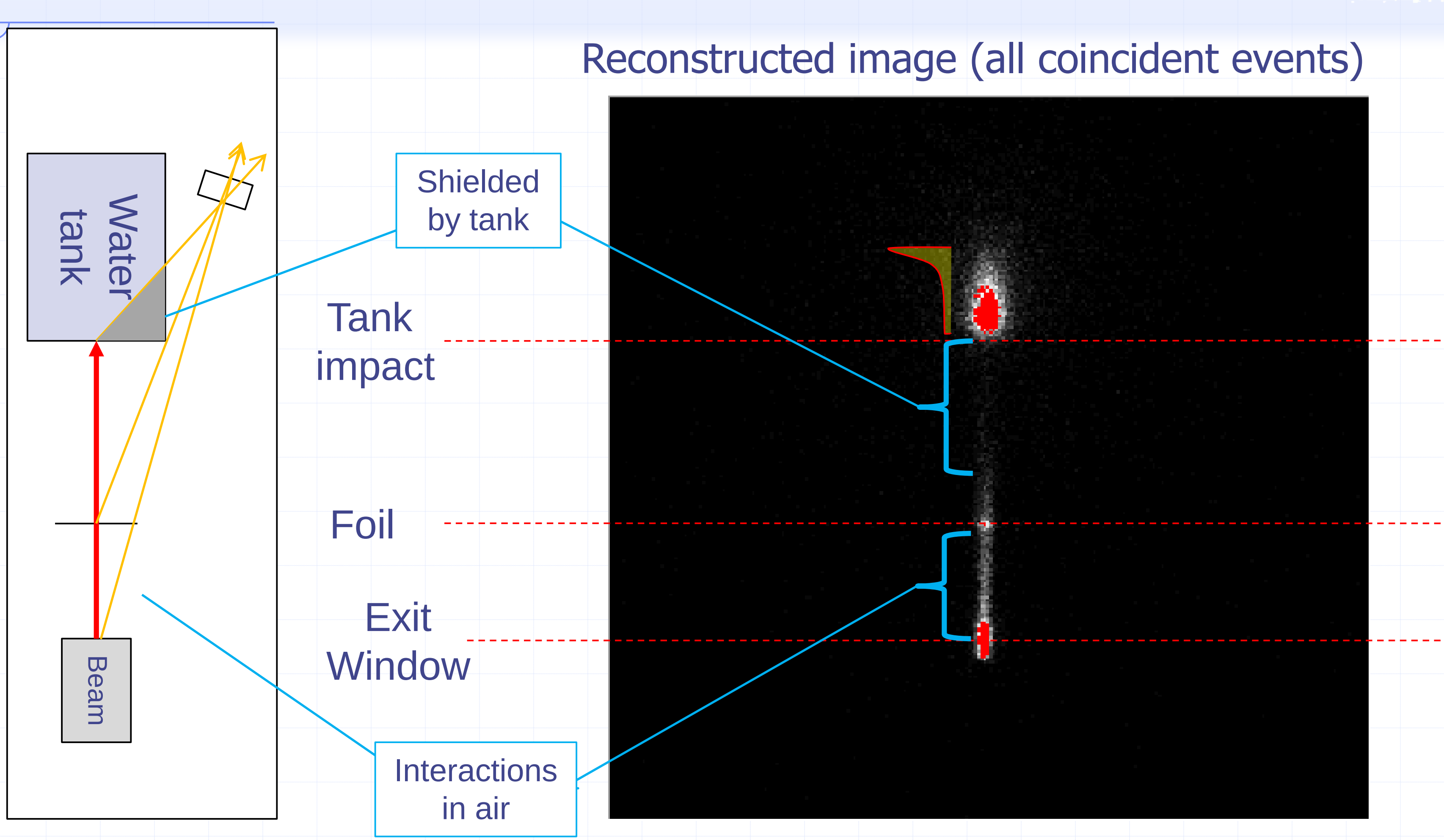
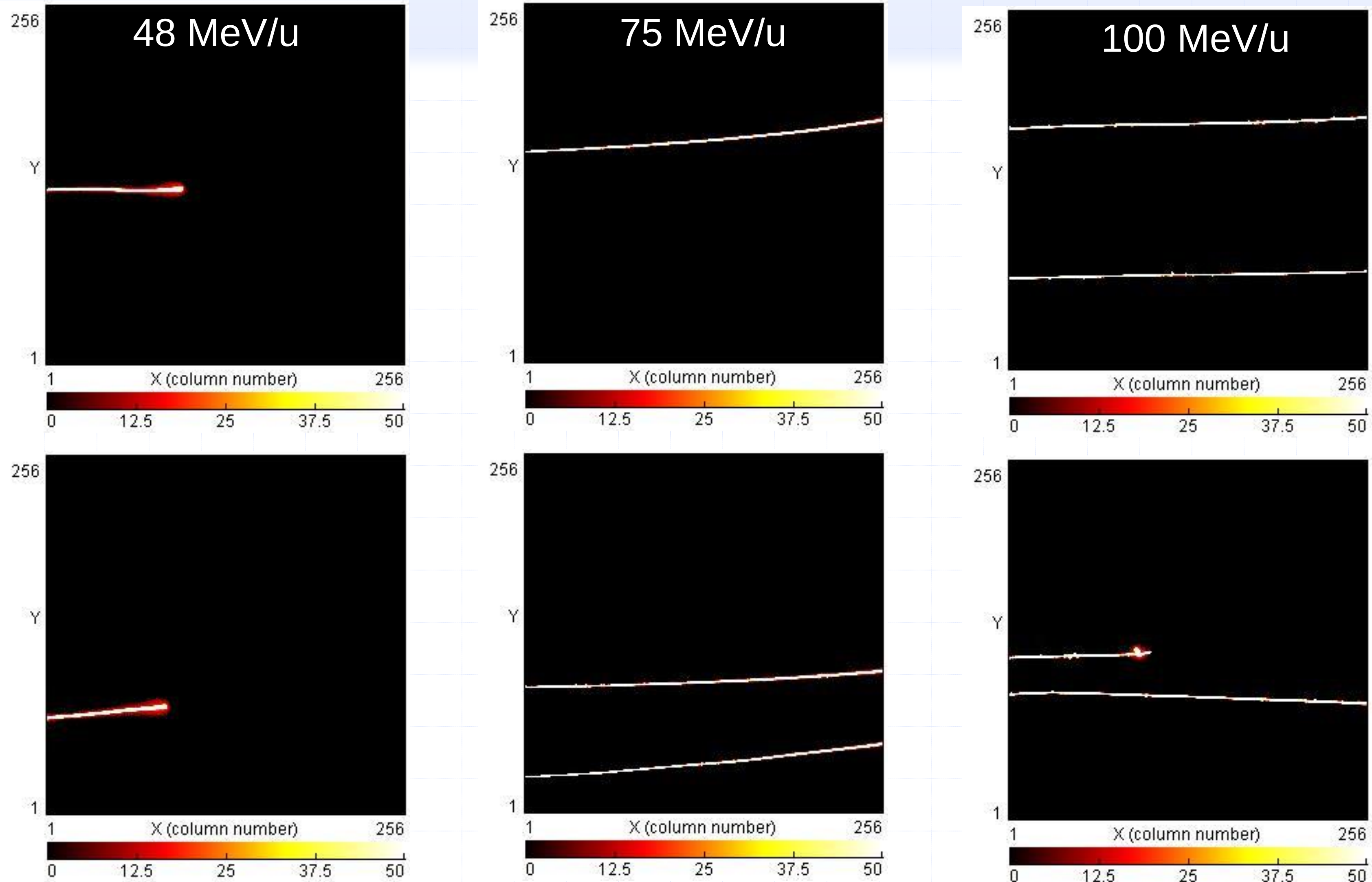
Reconstructed image (all coincident events)



Protons with different energies: 90 degree



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Alphas with different energies: 90 degrees

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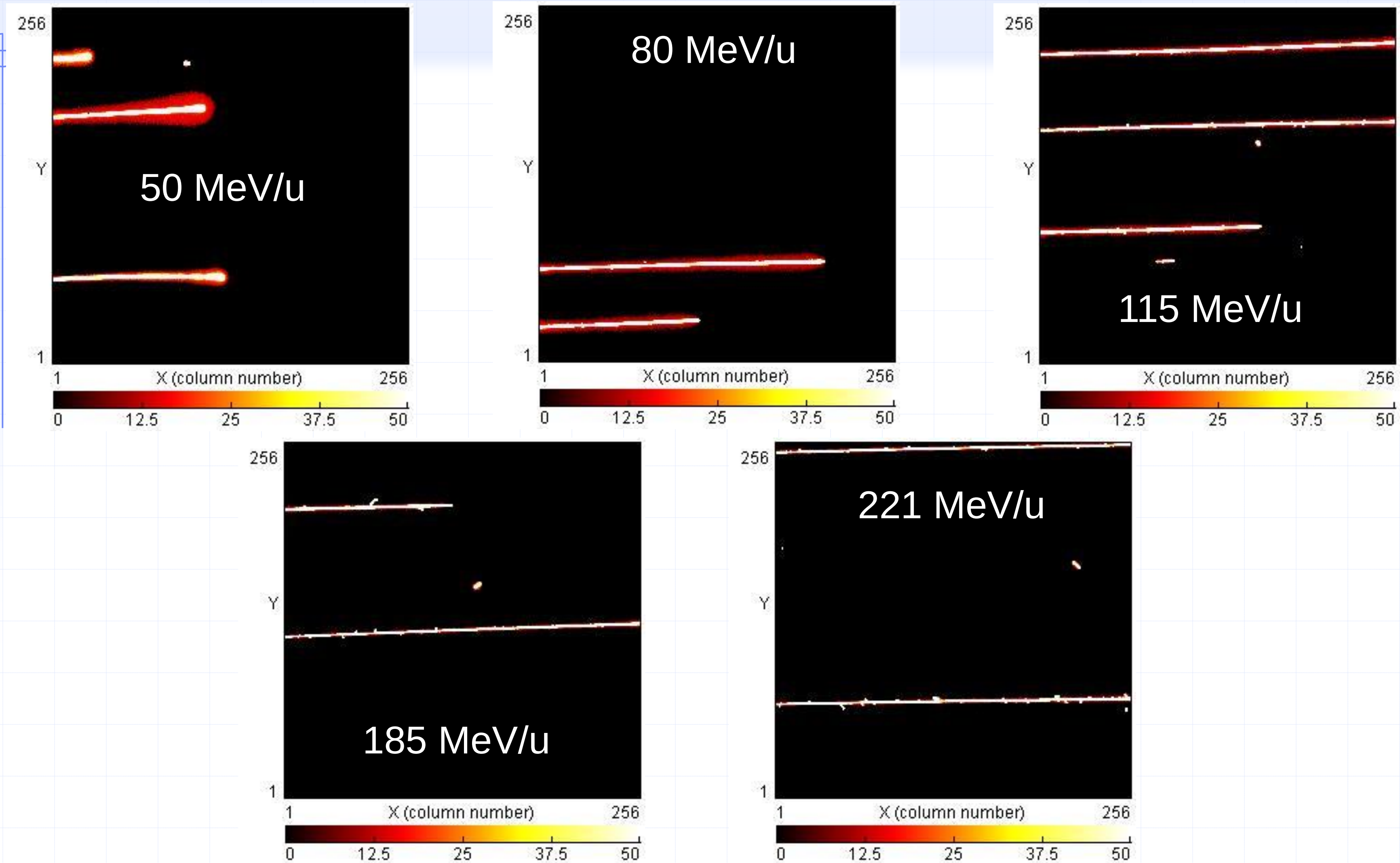

Carbon ions with different energies: 90 degrees

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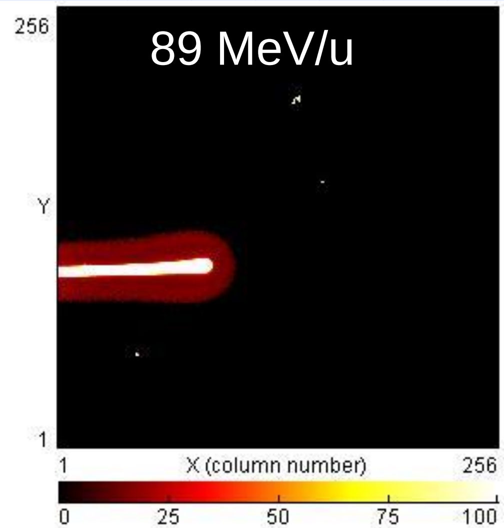
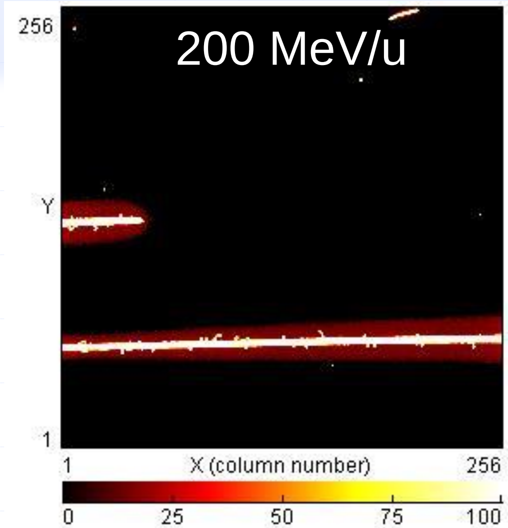
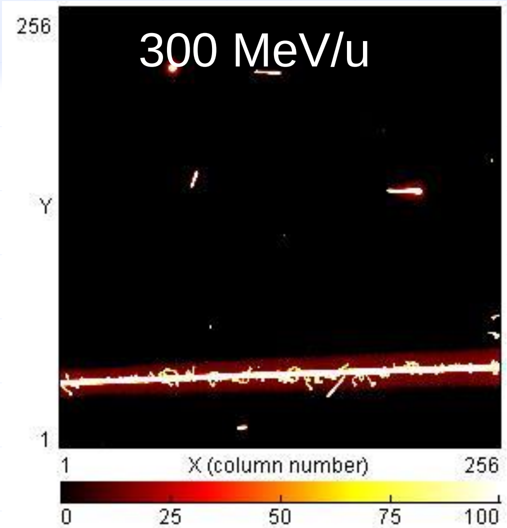
Czech Technical University in Prague

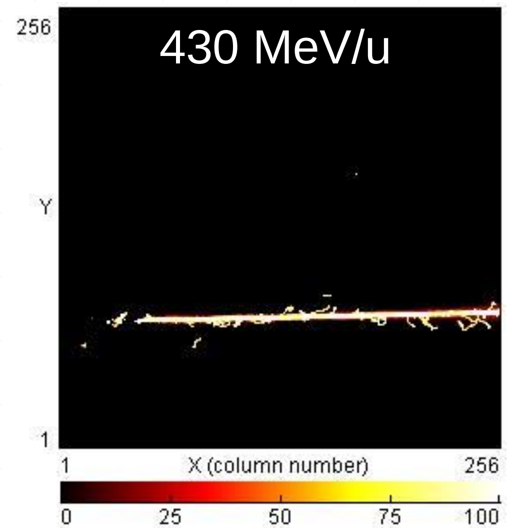






- Halo of pixel with low energy deposition around track - less pronounced for higher energies.

- Number of delta rays increases with increasing energy.



Oxygen ions with different energies: 90 degrees

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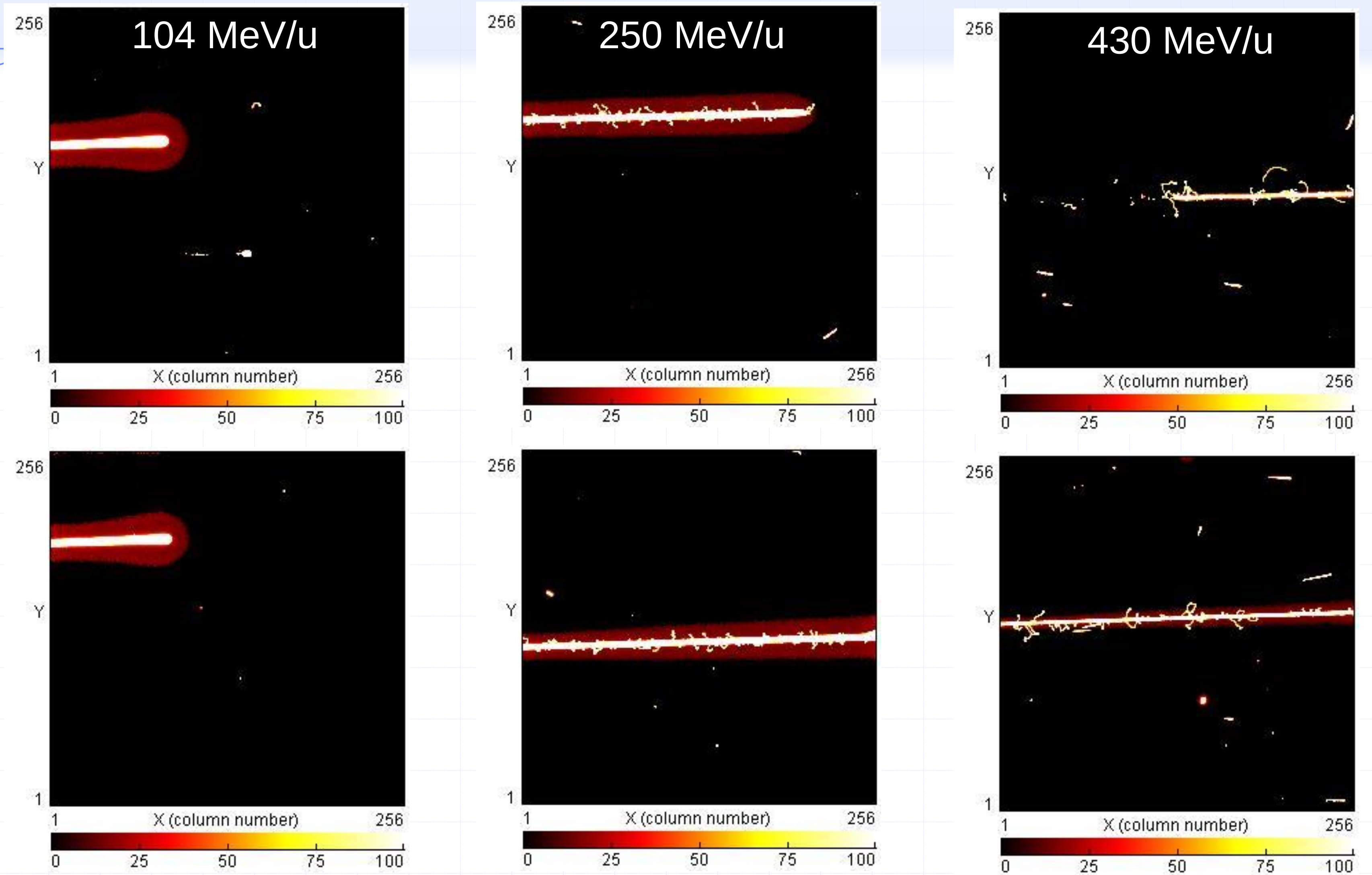

Tracks of Pb ions as measured on SPS beam at CERN (rear-side glancing angular incidence about 4.1 degree)

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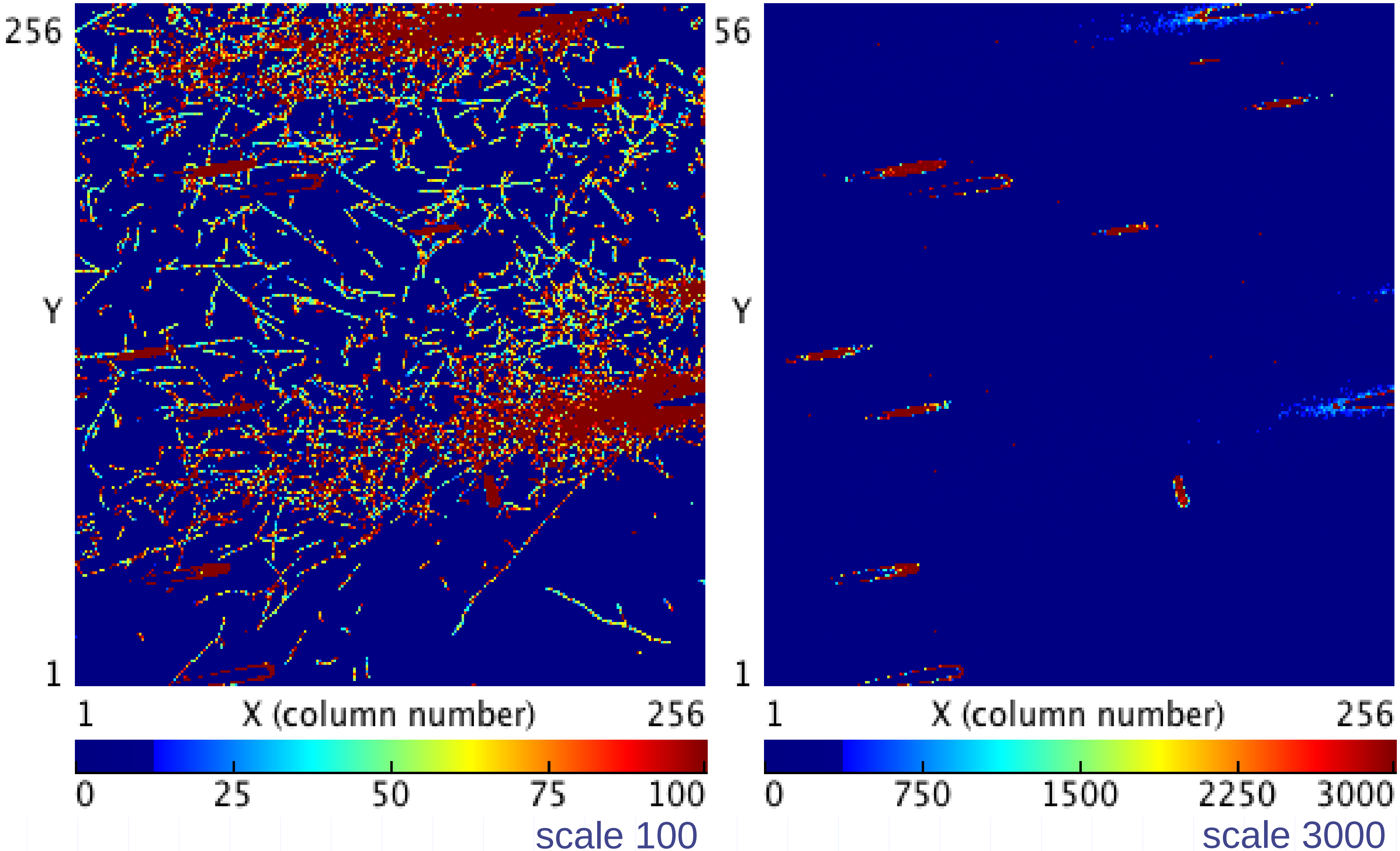
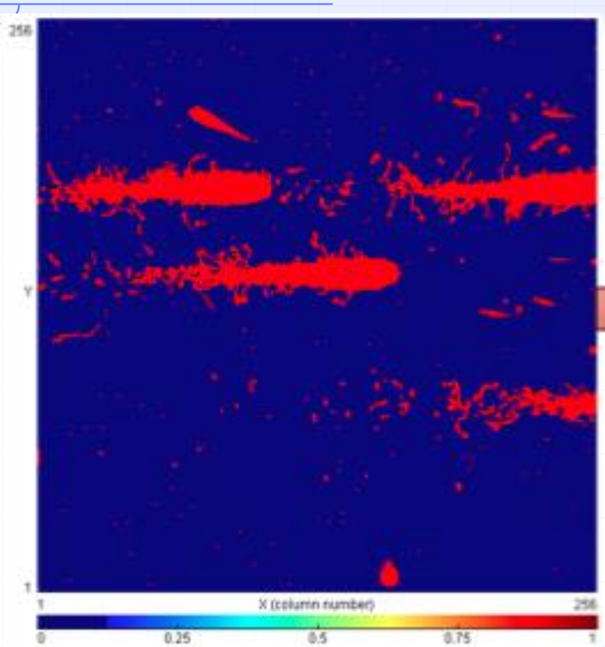


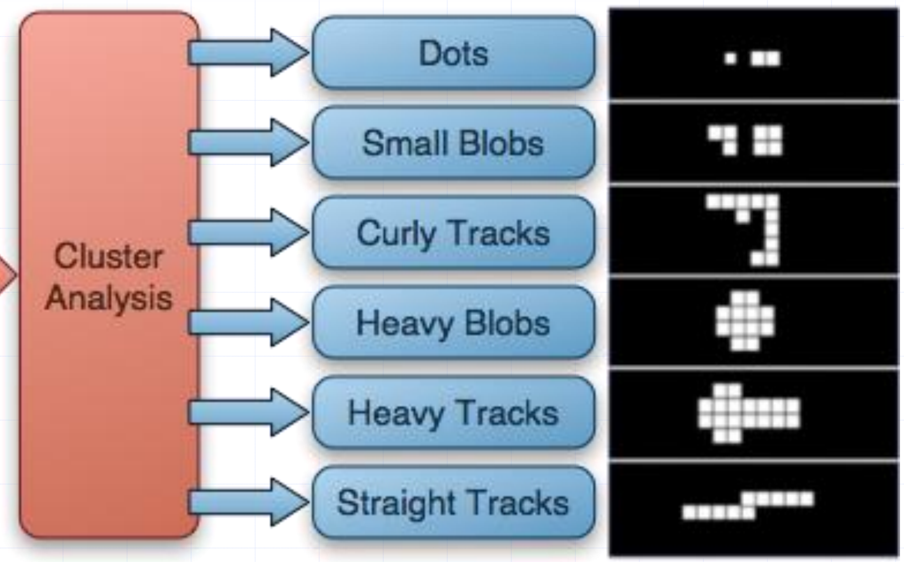
Imaged with low threshold on the left and with high threshold on the right

Online miniaturized Timepix Quantum Dosimeter

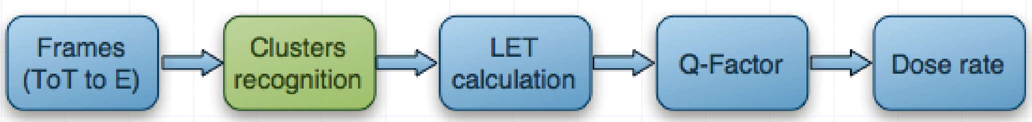
Single particle visualization & tracking



Frame containing 400 MeV 56Fe, 85°, measured at HIMAC, Japan



Cluster analysis algorithm is successfully working in ATLAS-MPX network



TIMEPIX3

The pixel device permitting simultaneous measurement of Time over Threshold (ToT - collected charge) and Time of Arrival (ToA) of the signal in every pixel with resolution 1.6 ns.

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Czech Technical University in Prague

It can be effectively used for simultaneous measurement
- of Time-of-Flight of detected particle,
- Energy of this particle deposited in the sensor and
- a drift time of charge in the sensor

- Thickness: 300µm
- Bias: 90 V
- Triggered
- Data driven mode
- T0 synch when trigger signal was received

Timepix3 CERN chip board

Fast neutron ToF measurement with TIMEPIX

LANSCE neutron sources and nuclear science flight paths

(combined ToA and ToT modes)

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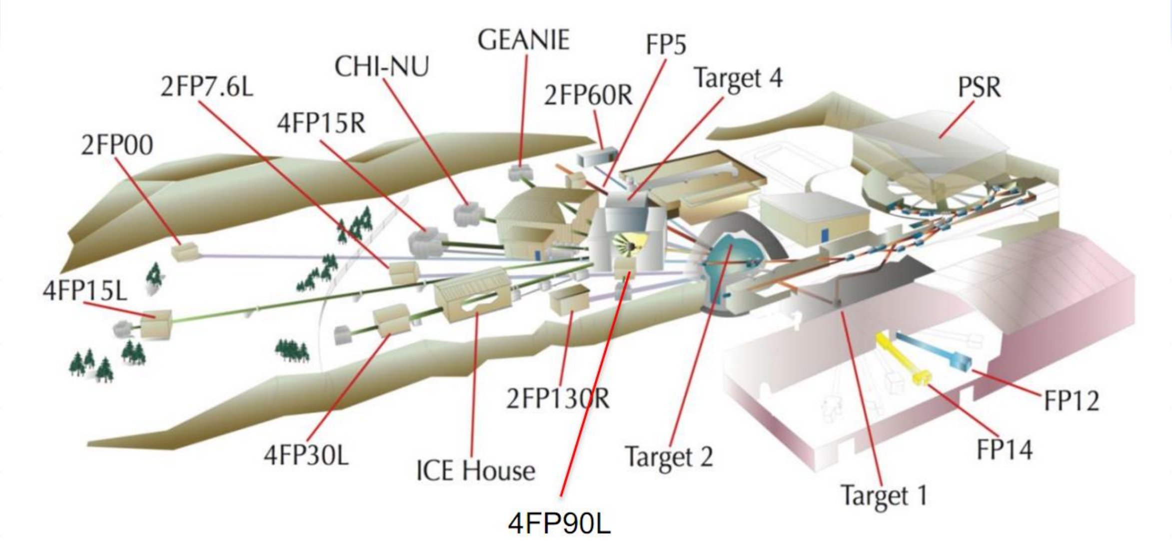
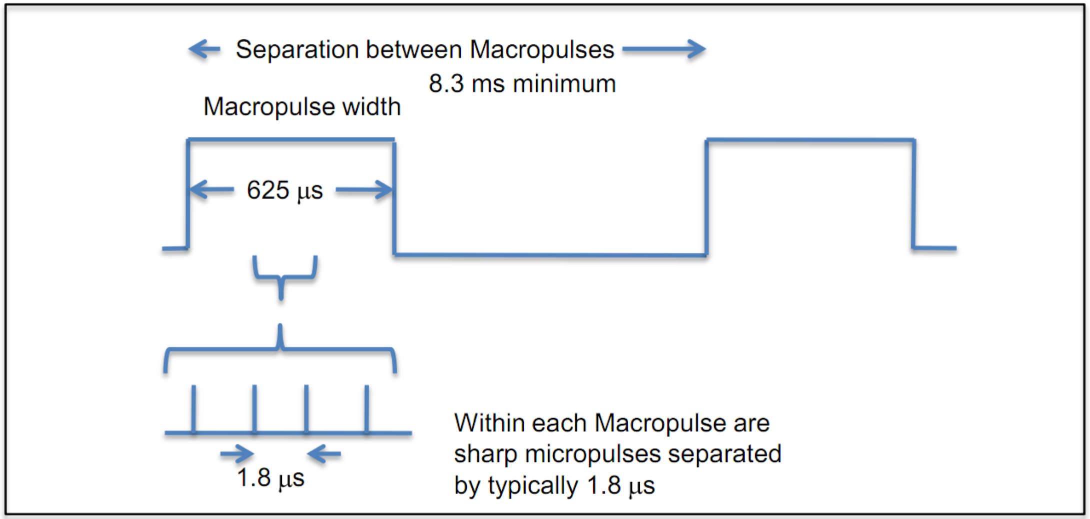
Czech Technical University in Prague

- The layout of the LANSCE neutron sources and Nuclear Science flight paths



- Time structure of the proton beam for typical Target-4 operation



Cluster shapes
Timepix detector responses as a function of neutron kinetic energy

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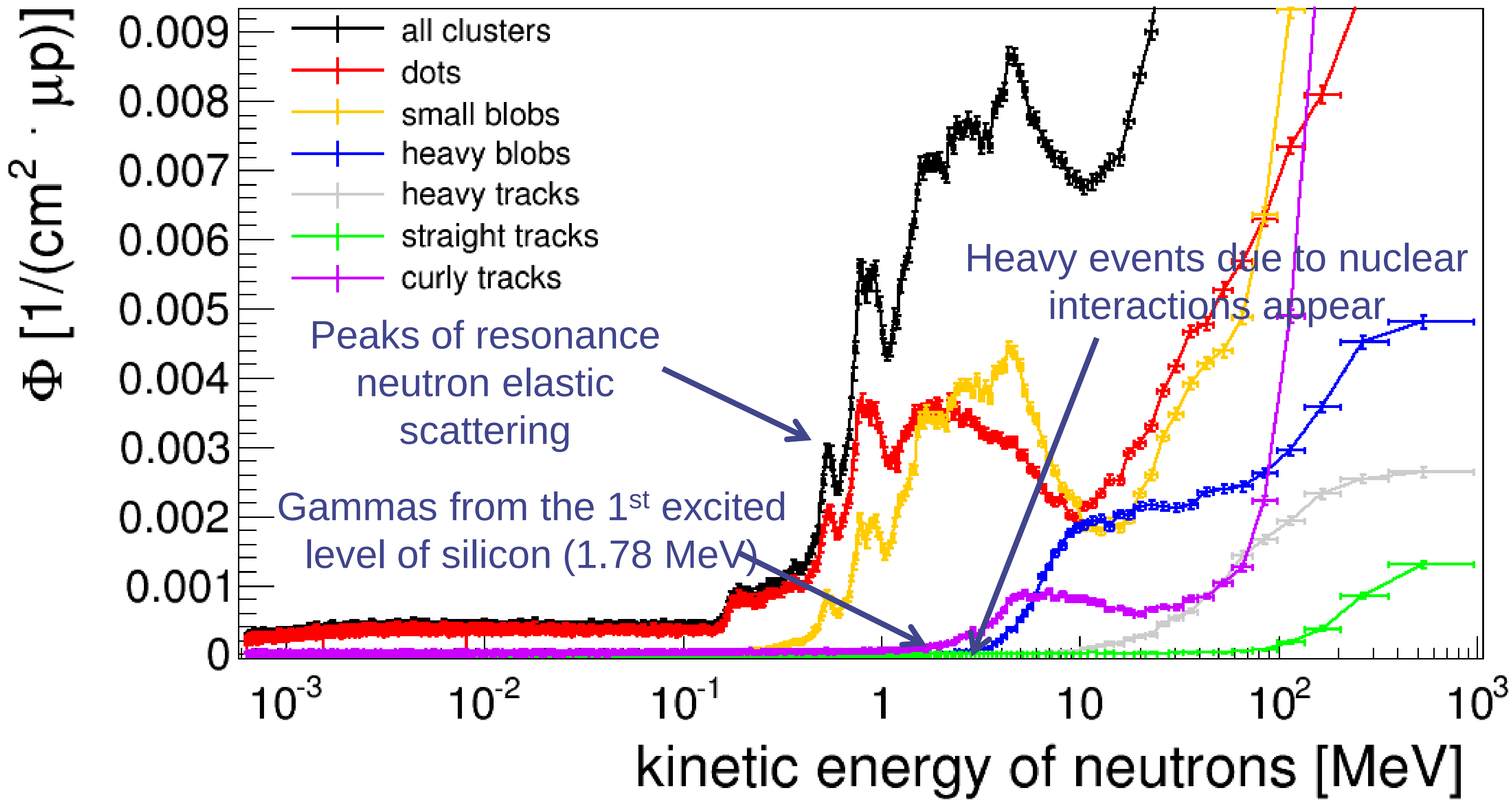
Czech Technical University in Prague

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

Response of Timepix: Energy region 0.4 – 1.2 MeV

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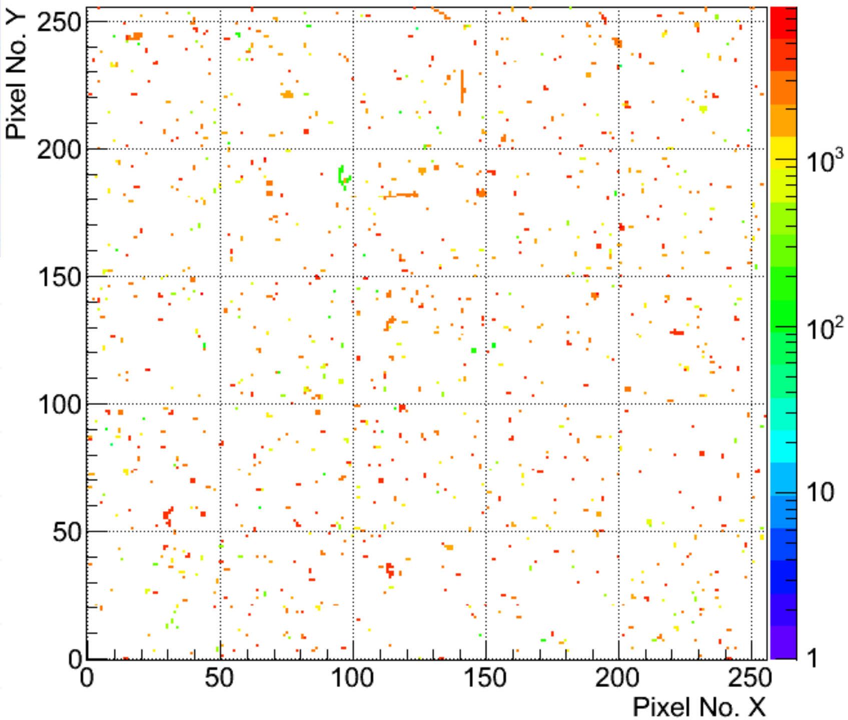
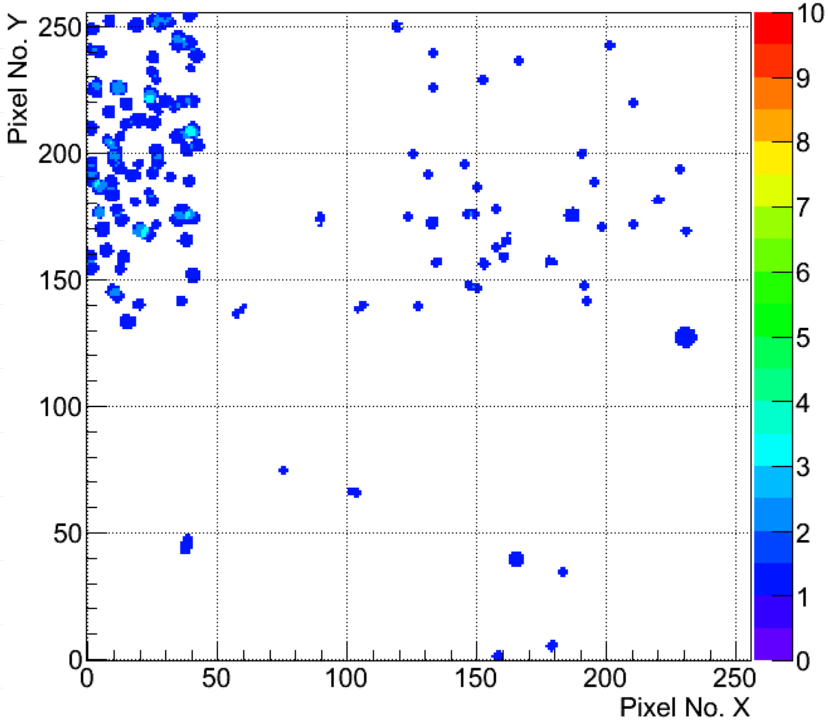
Czech Technical University in Prague

- Mainly dots, curly tracks are found in this energy region
- Heavy blobs below LiF indicate presence of slow/thermal neutrons
- Also PE region shows slightly enhanced count rate



All types of clusters in this energy region integral picture (1000 events were considered)



Heavy tracks and heavy blobs in this energy region (139 events were found)

Response of Timepix: Energy region 1.2 – 3.4 MeV

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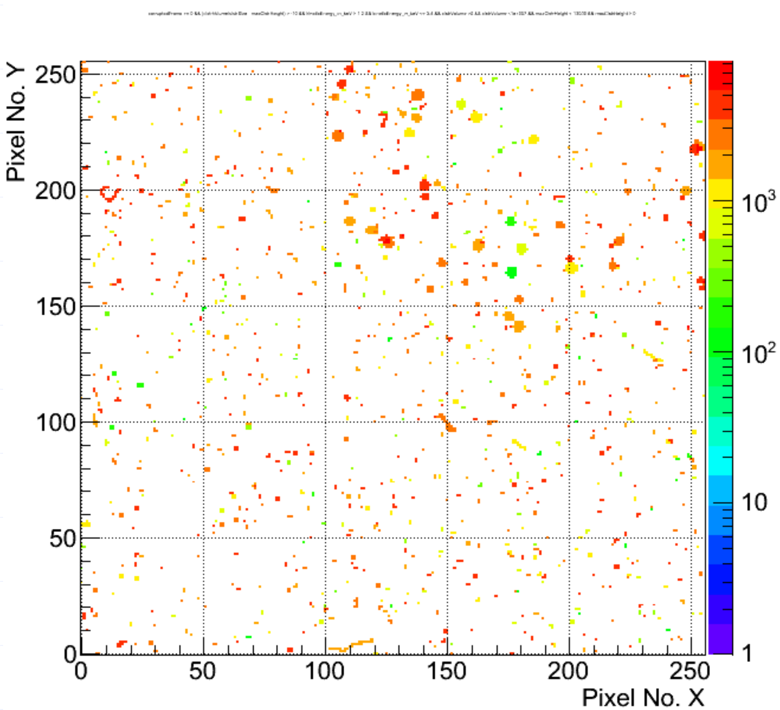
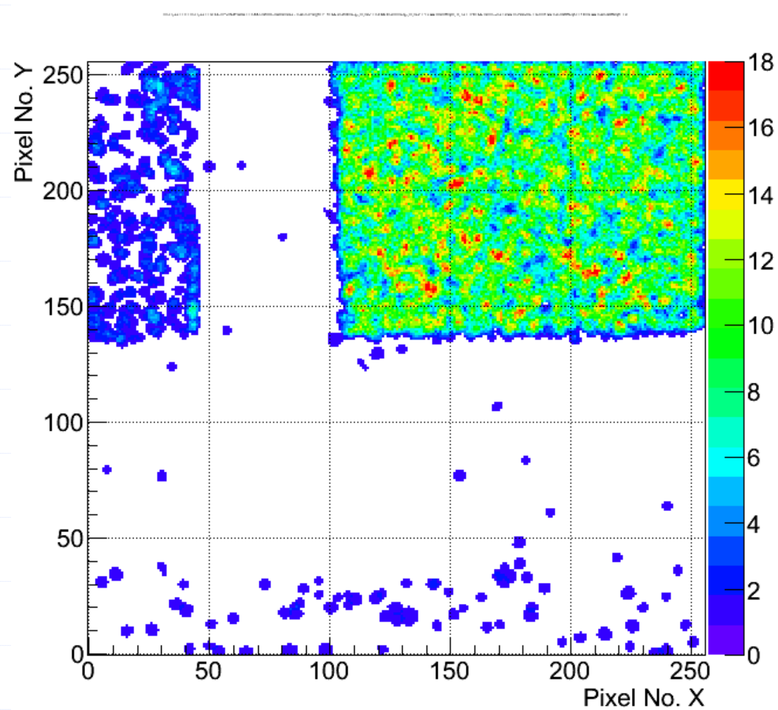
Czech Technical University in Prague

- Heavy blobs below LiF indicate presence of slow/thermal neutrons
- Clear signal of High Energy Transfer Particles (HETP) below PE
- uncovered area shows also a few events



All types of clusters in this energy region integral picture (1000 events were considered)



Heavy tracks and heavy blobs in this energy region (full statistics - 10259 events were found)

Response of Timepix:
Energy region 3.4 – 5.0 MeV

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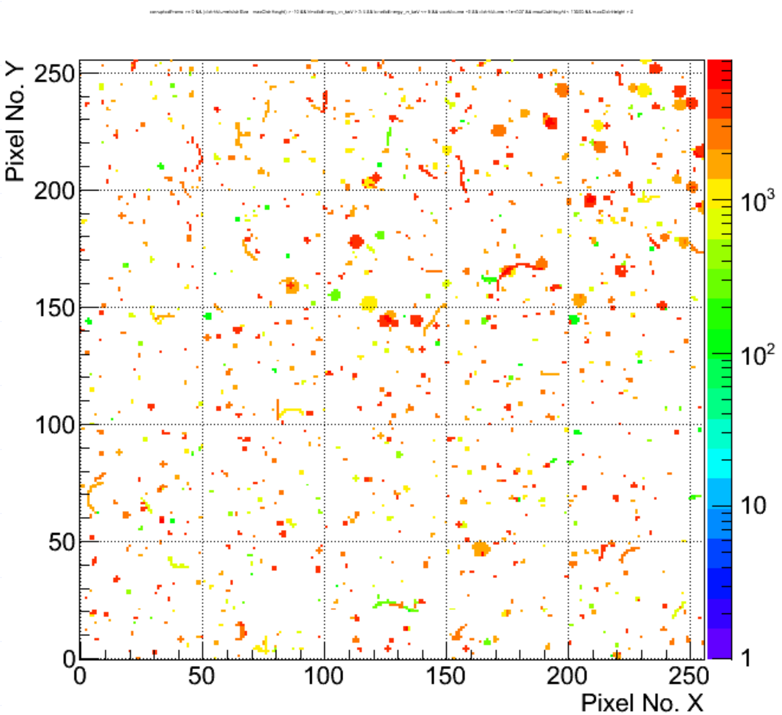
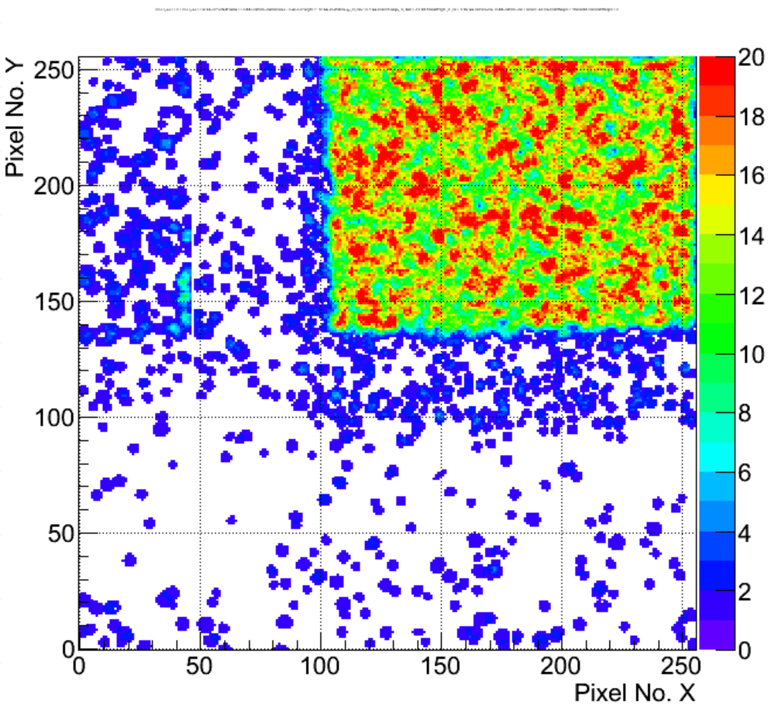
Czech Technical University in Prague

- Clear signal of HETP below PE
- Also in PE+Al region HETP are becoming visible



All types of clusters in this energy region integral picture (1000 events were considered)



Heavy tracks and heavy blobs in this energy region (full statistics – 13406 events were found)

Response of Timepix: Energy region 5.0 – 10 MeV

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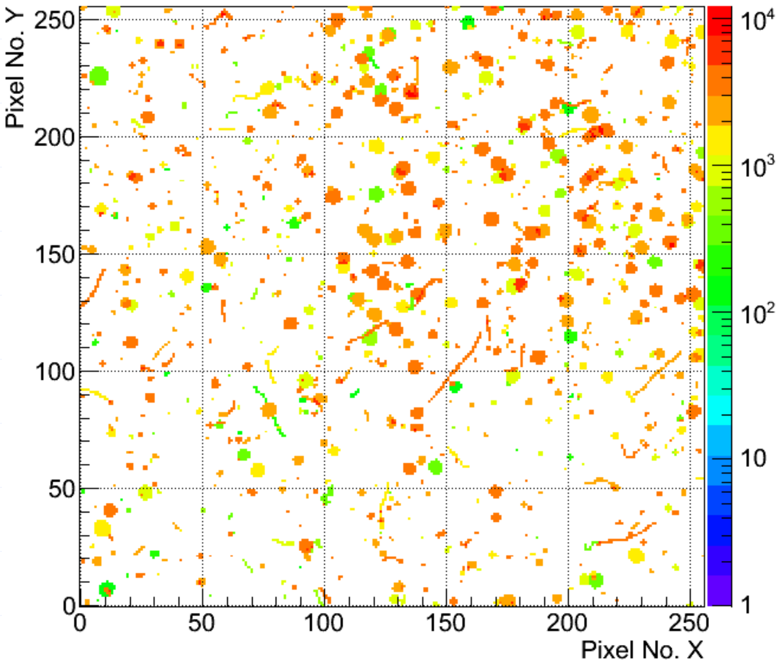
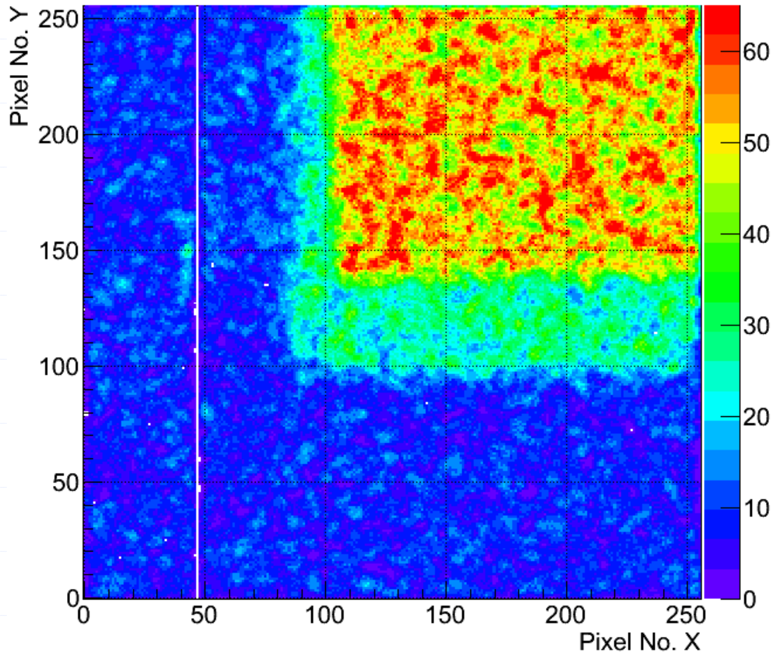
Czech Technical University in Prague

- Higher HETP count rate below PE and PE+Al
- HETP: cluster still look roundly shaped
- Almost no enhancement below LiF



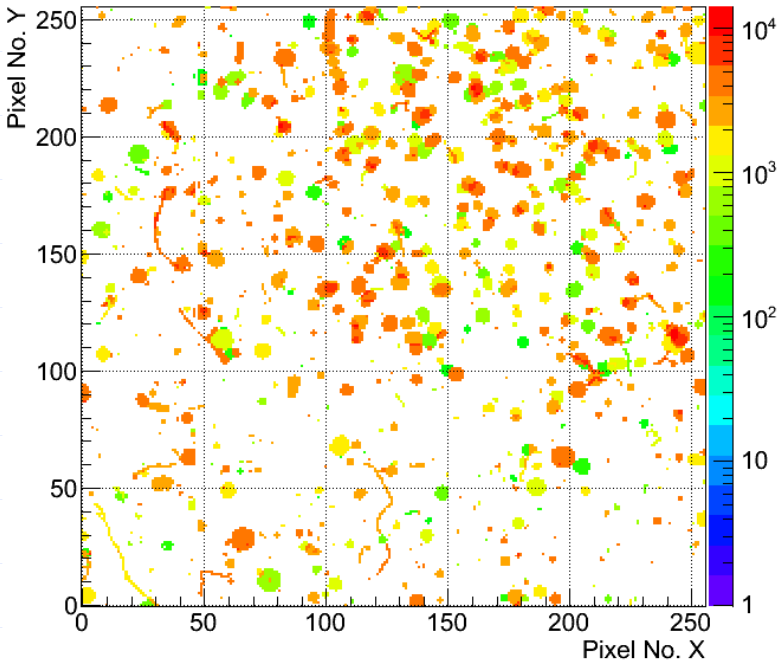
All types of clusters in this energy region integral picture (1000 events were considered)



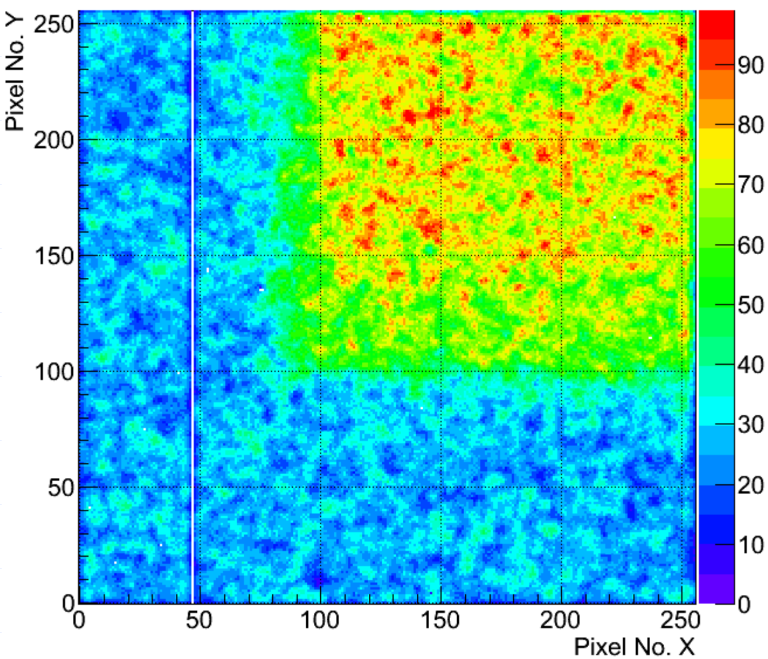
Heavy tracks and heavy blobs in this energy region (full statistics - 61712 events were found)

Response of Timepix:
Energy region 10 – 30 MeV

- Higher HETP count rate below PE and PE+Al (contrast to other regions begins to decrease)
- HETP equally distributed below all other regions
- HETP: Clusters become bigger and asymmetric



All types of clusters in this energy region integral picture (1000 events were considered)



Heavy tracks and heavy blobs in this energy region (full statistics - 111901 events were found)

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Response of Timepix:
Energy region 30 – 100 MeV

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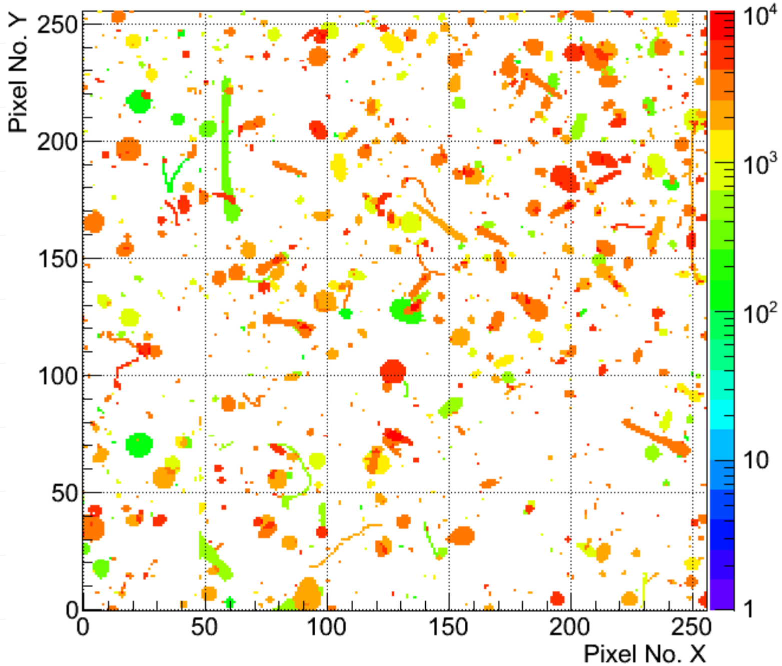
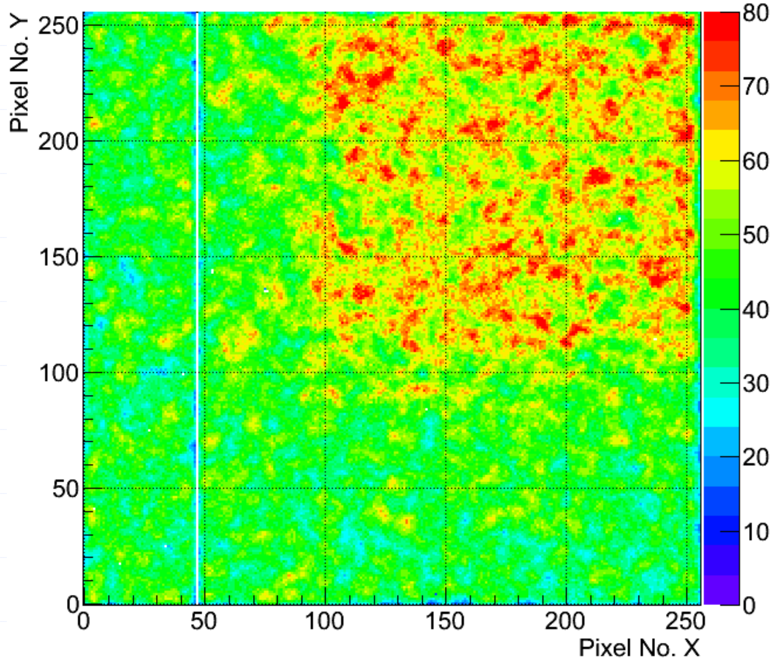
Czech Technical University in Prague

- Still enhanced response below PE and PE+Al
- Contrast to all other region is decreasing
- Cluster are getting bigger and more and more asymmetric



All types of clusters in this energy region integral picture (1000 events were considered)



Heavy tracks and heavy blobs in this energy region (full statistics - 93227 events were found)

Response of Timepix: Energy region 100 – 300 MeV

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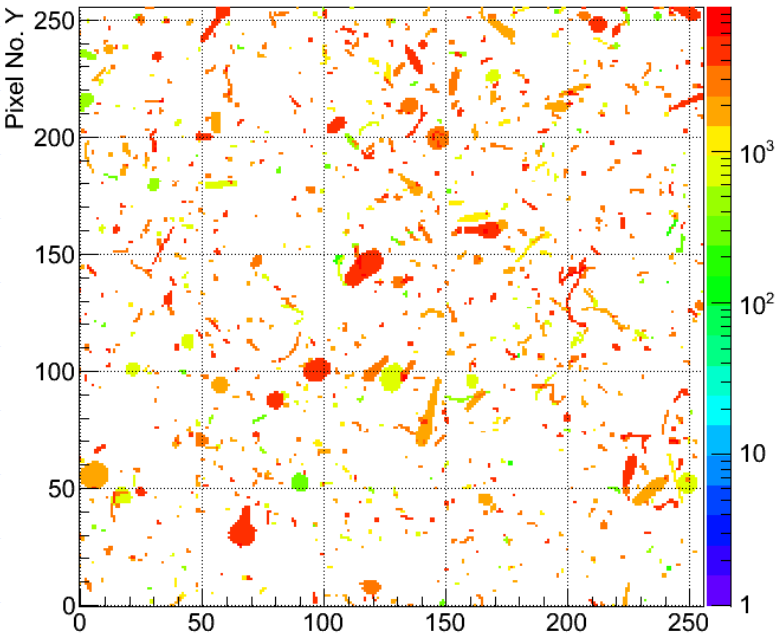
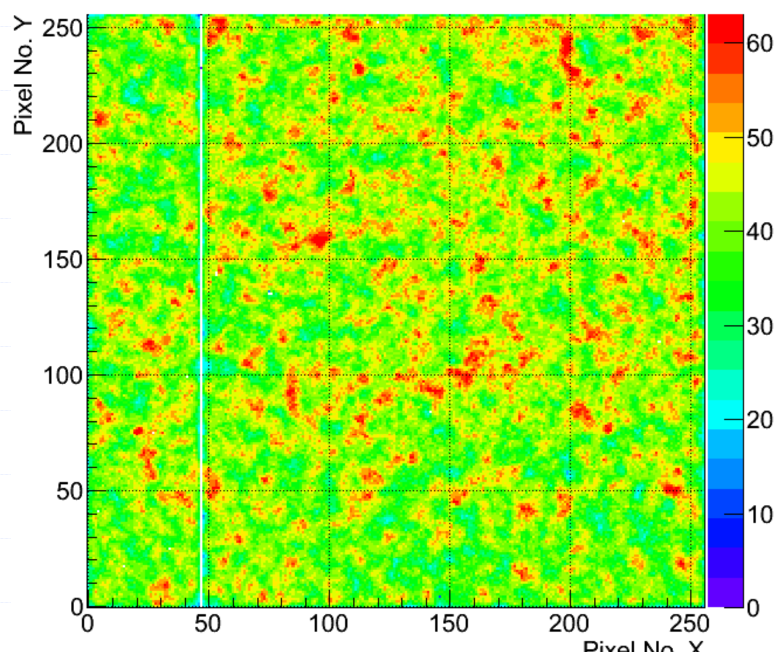
Czech Technical University in Prague

- HETP nearly equally distributed below all regions
- HETP Cluster shapes
  - Are getting bigger and more and more asymmetric
  - Round clusters with outgoing tracks are seen



All types of clusters in this energy region integral picture (1000 events were considered)

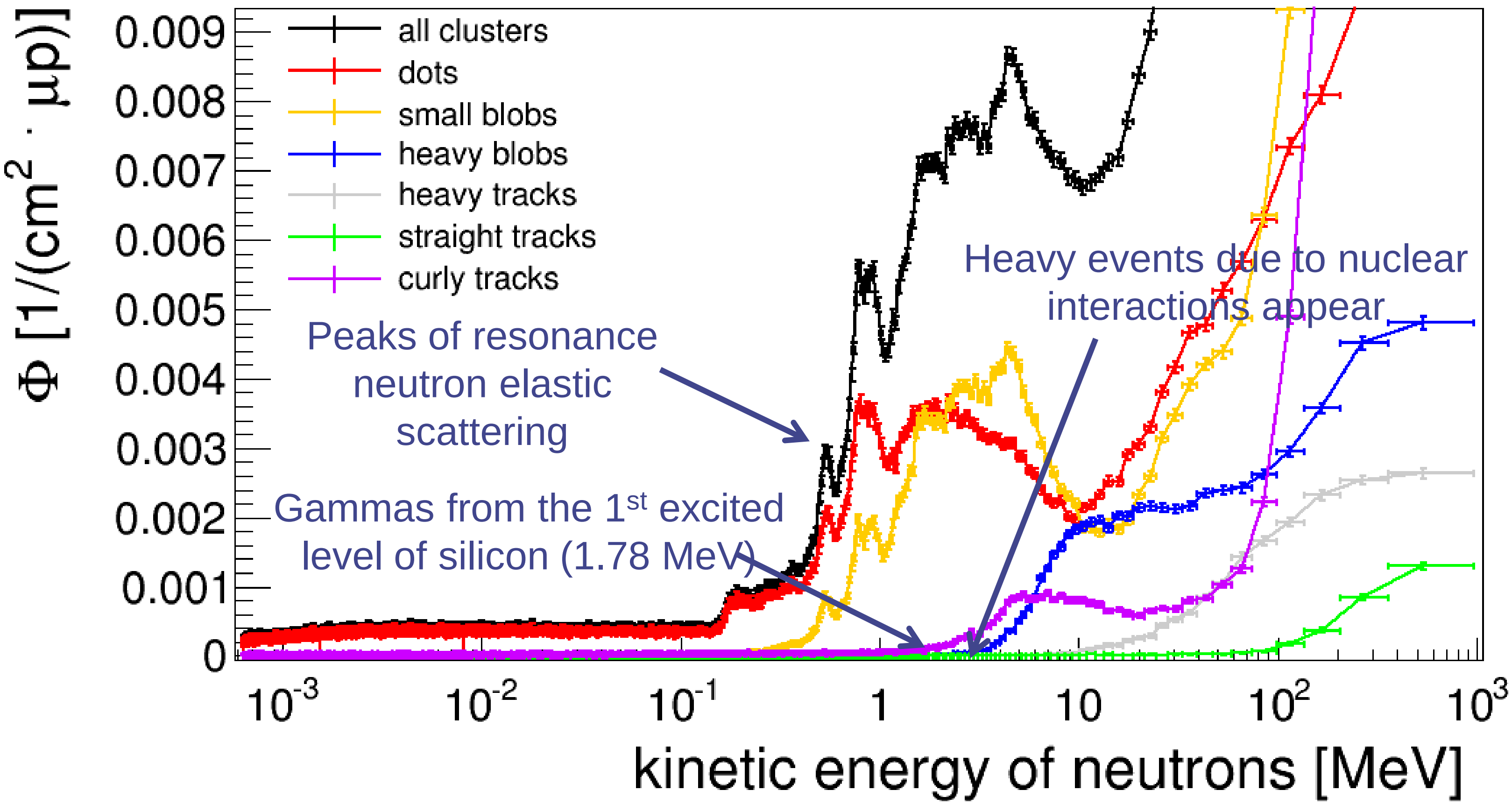


Heavy tracks and heavy blobs in this energy region (full statistics - 64755 events were found)

Cluster shapes
Timepix detector responses as a function of neutron kinetic energy

Institute of Experimental and Applied Physics
Czech Technical University in Prague

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

Number of detected neutron interactions (clusters) in 300 μm thick silicon sensor as a function of neutron kinetic energy.

Up to 4 MeV they mostly corresponds to elastic or inelastic neutrons on silicon nuclei.

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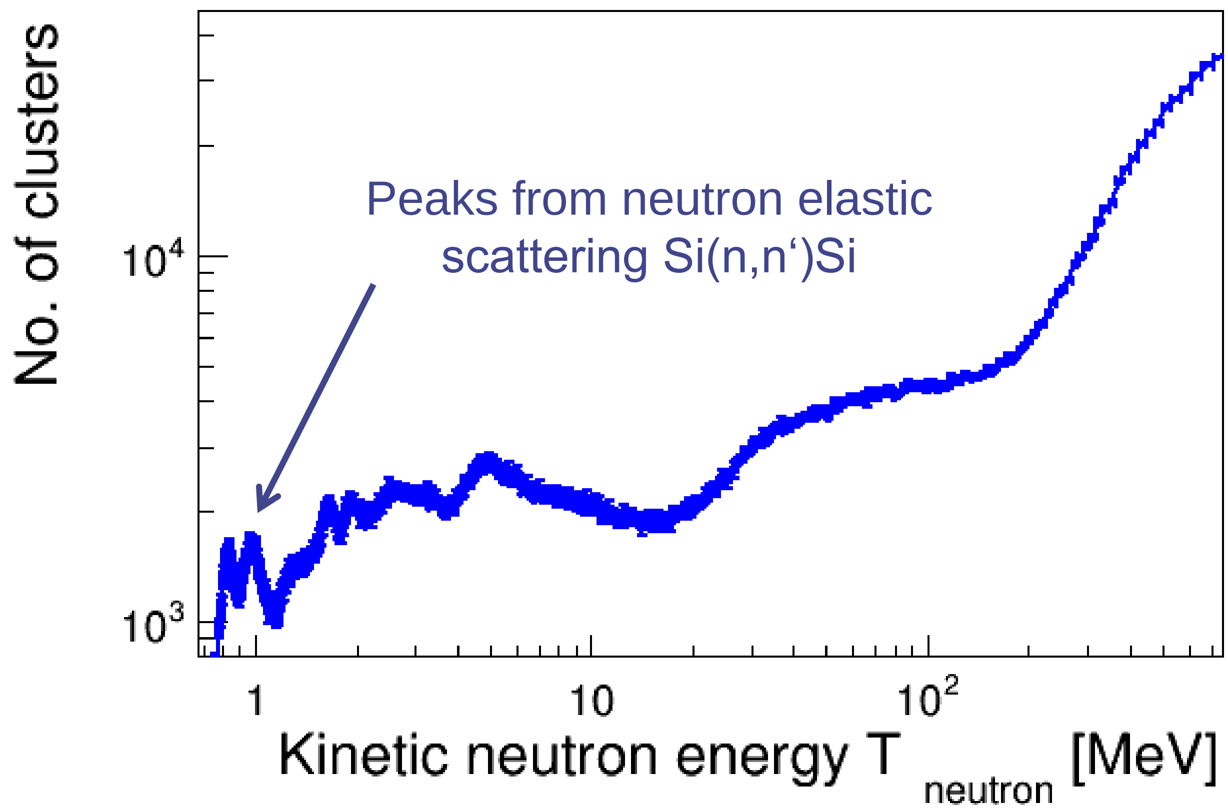
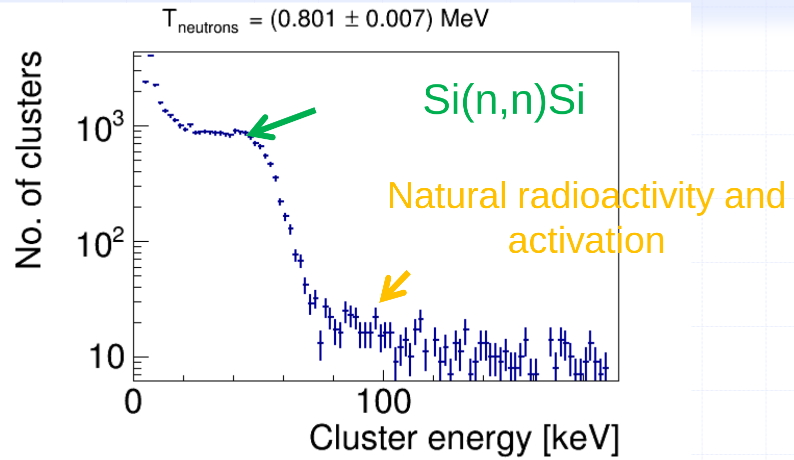
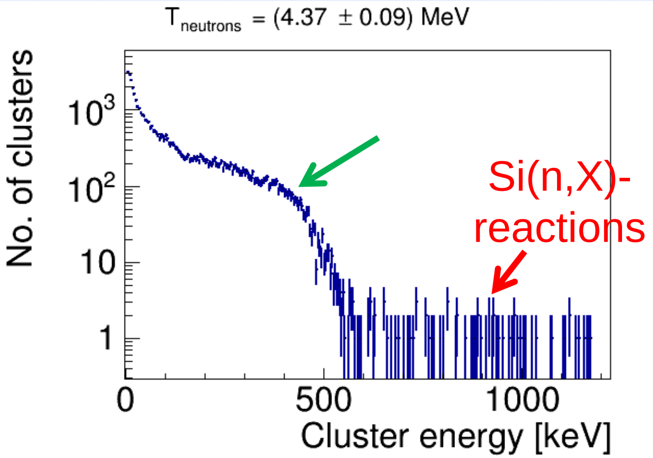
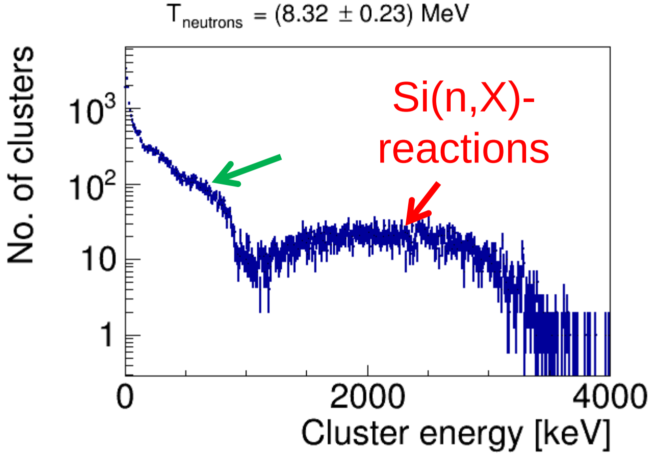


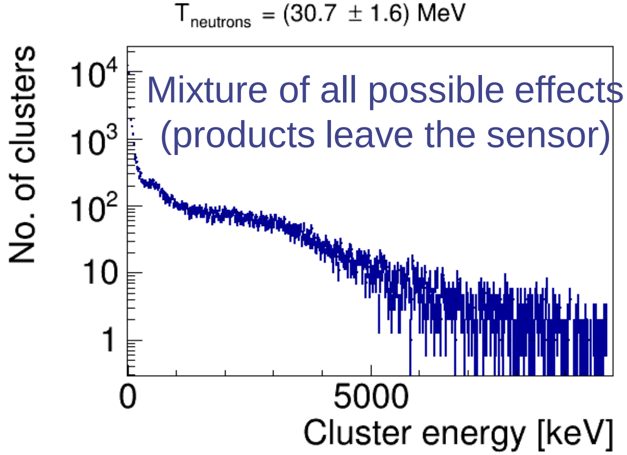
Energy spectra corresponding to elastic and/or inelastic scattering of neutrons on Si nuclei

Institute of Experimental and Applied Physics
Czech Technical University in Prague









Examples of heavy ionizing events induced by neutrons of different energies selected according their cluster sizes

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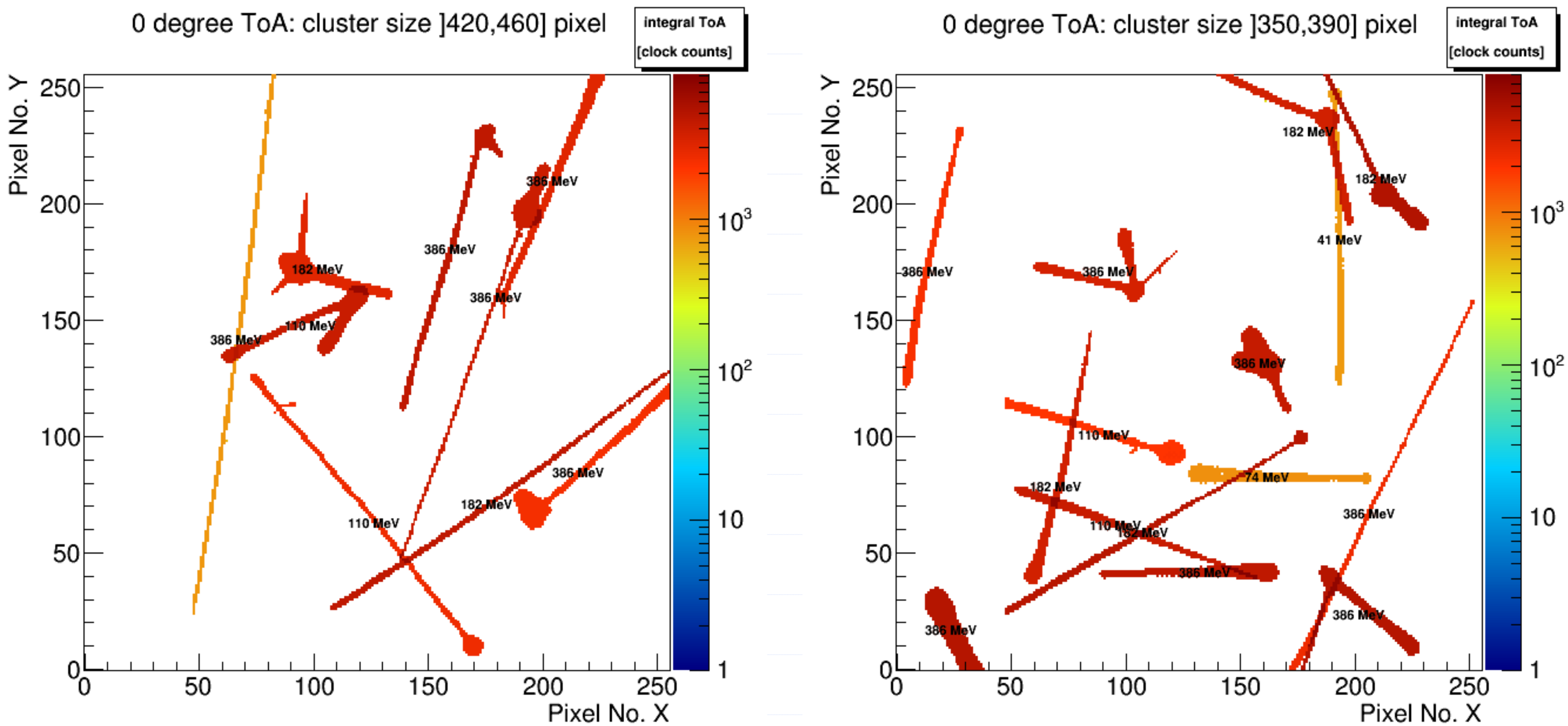

Different colors and black numbers assigned to individual clusters indicate the energy of incoming neutrons as measured by means of the TOF technique

Timepix3 in ATLAS
synchronized with LHC clock

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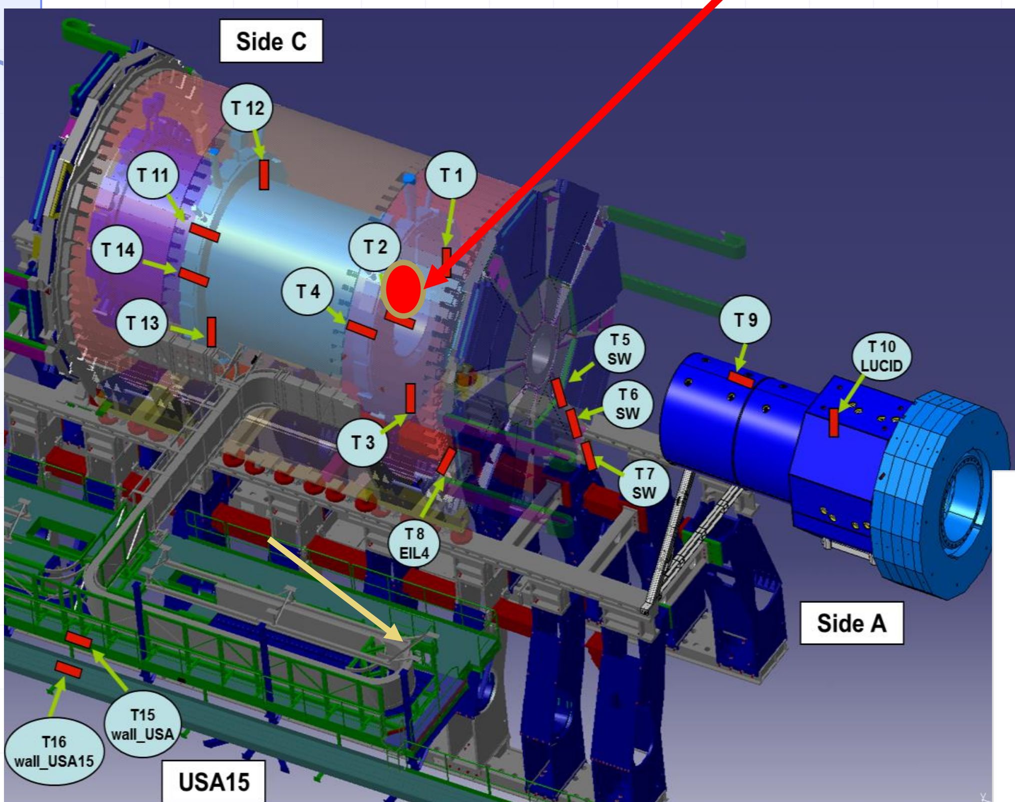
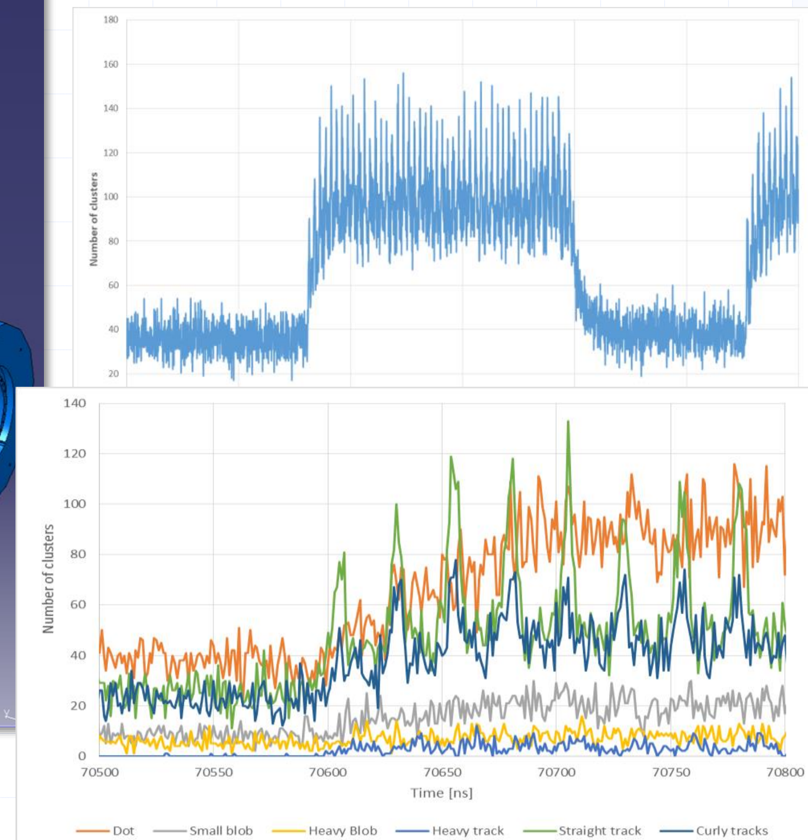
Czech Technical University in Prague



Detail view on bunch-bunch collisions recorded by TPX3



Measurement in ATLAS cavern

500 um Silicon sensor
10 s frame in data driven mode

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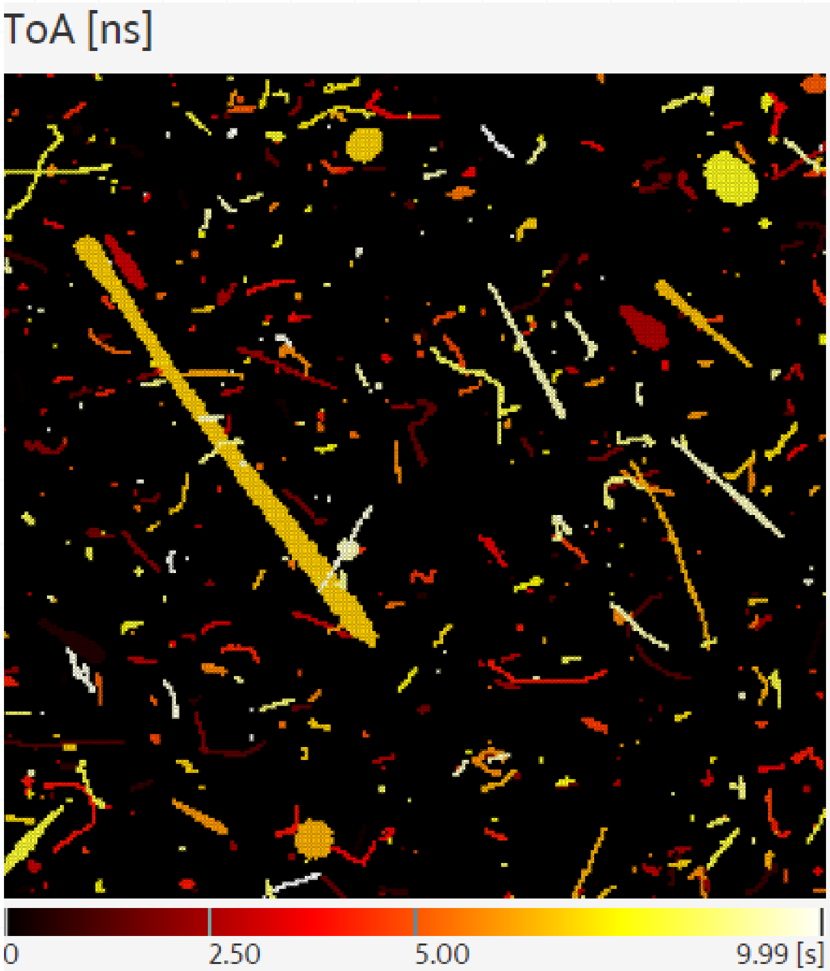
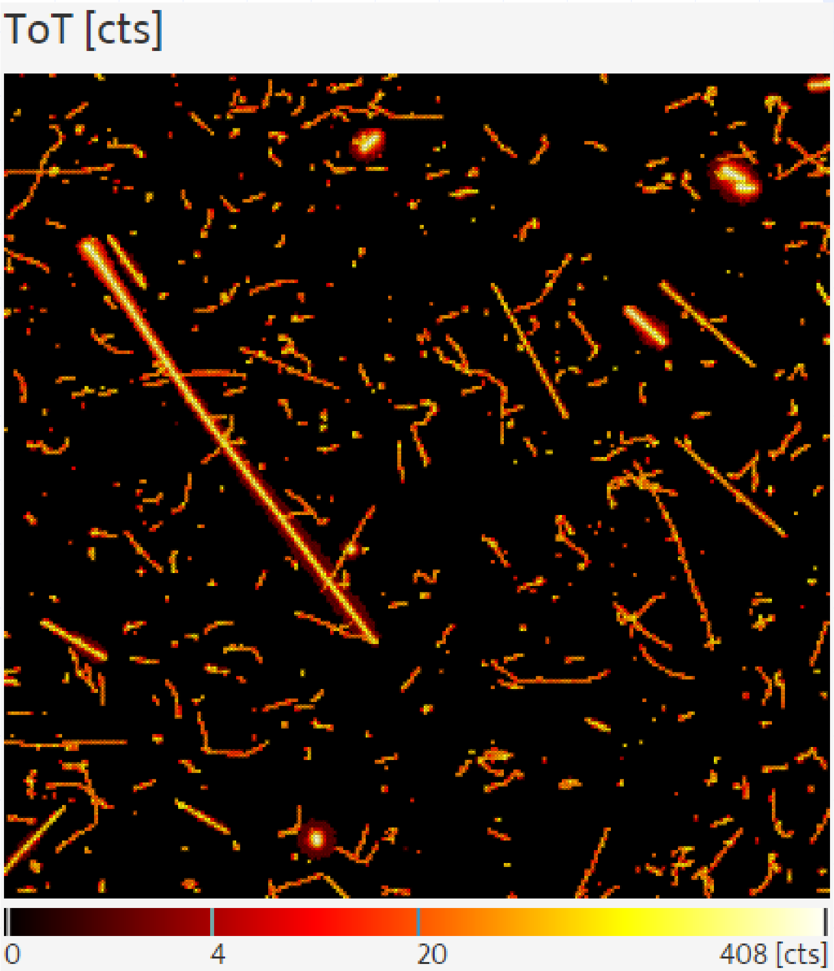
Czech Technical University in Prague





Cluster composition corresponding to registered tracks during proton LHC bunch-bunch collisions

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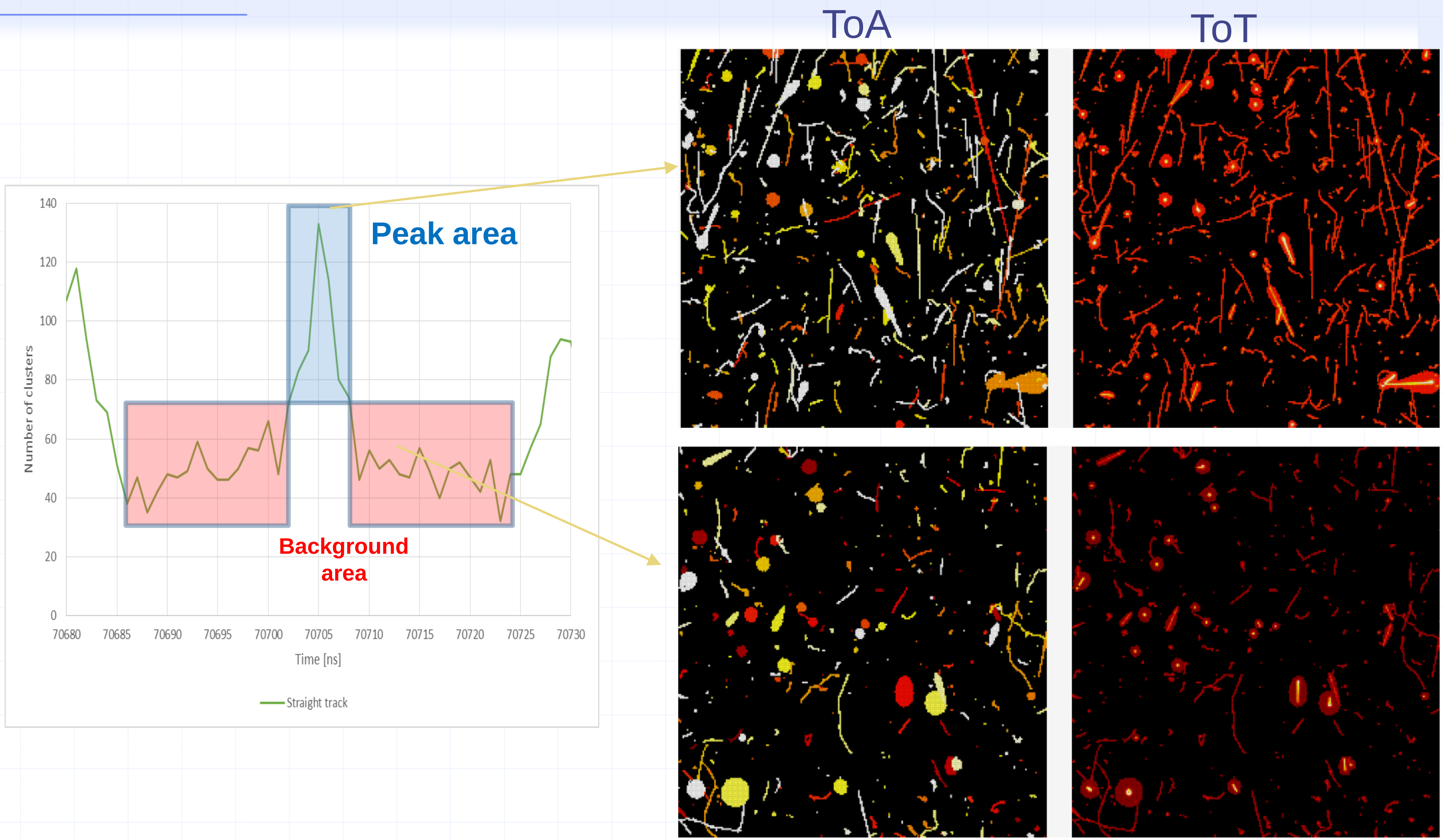

Cluster composition corresponding to registered tracks during proton LHC bunch-bunch collisions

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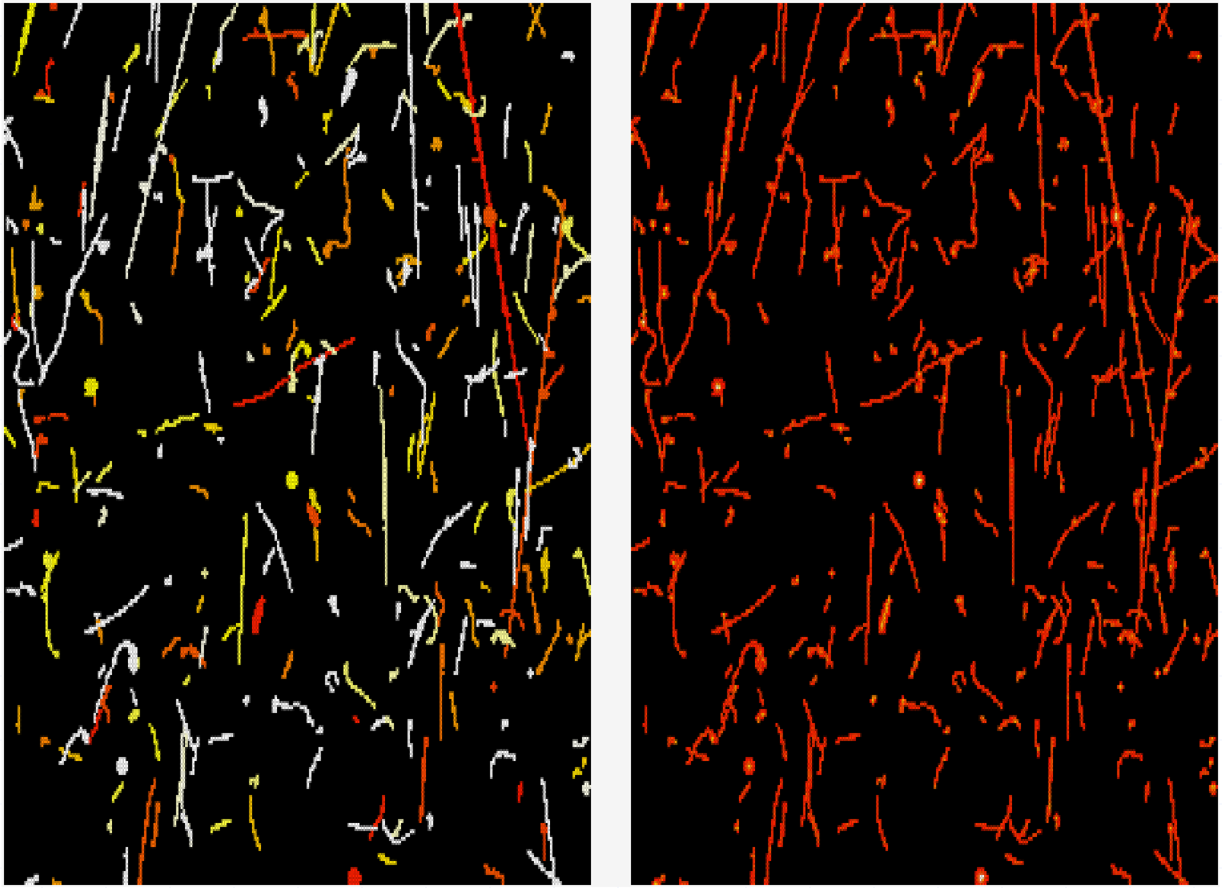
- Example of „frame“ in peak area – straight and curly tracks only



Straight tracks (MIPS) and curly tracks dominating periodically within 2.5 ns bunch-bunch collisions

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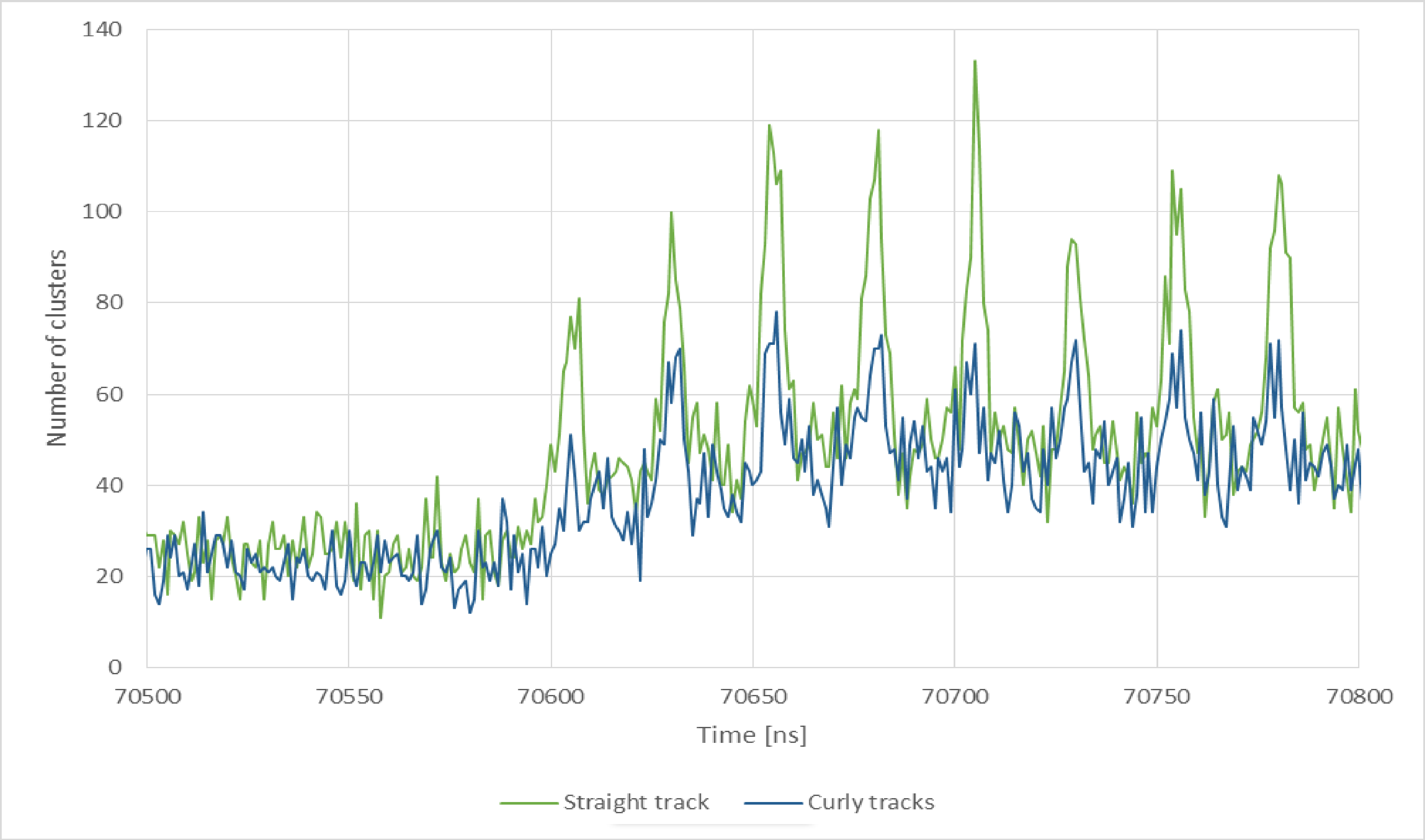

3D reconstructed 120 GeV/c pion tracks with long outgoing delta electron

500 um Si sensor, Timepix3, time resolution 1.56 ns

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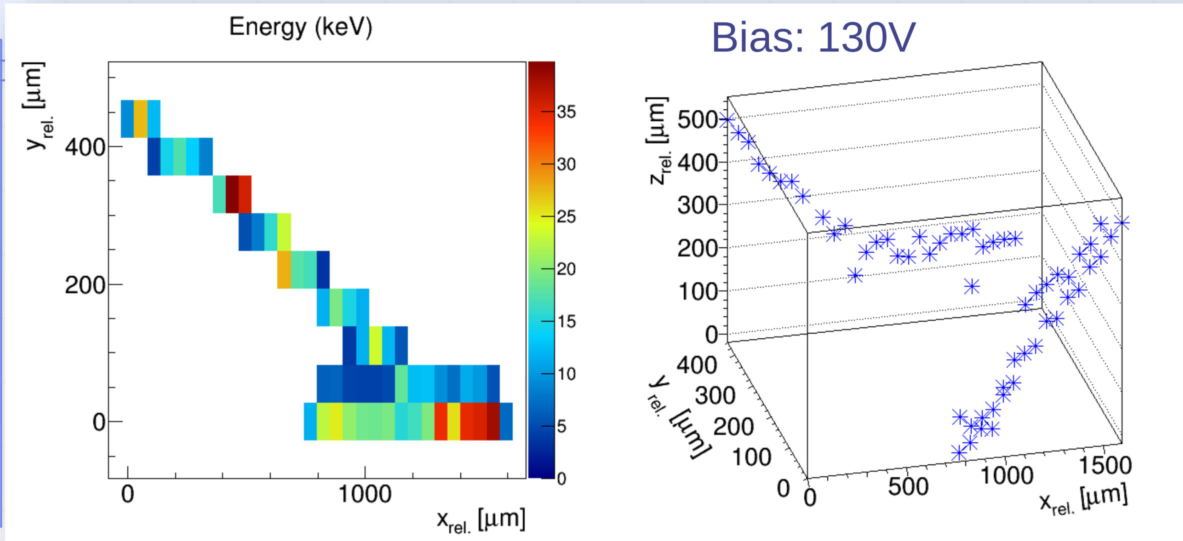
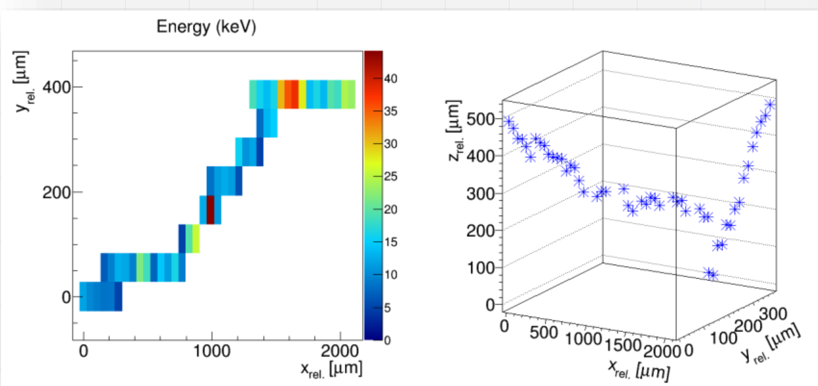
Bias: 130V

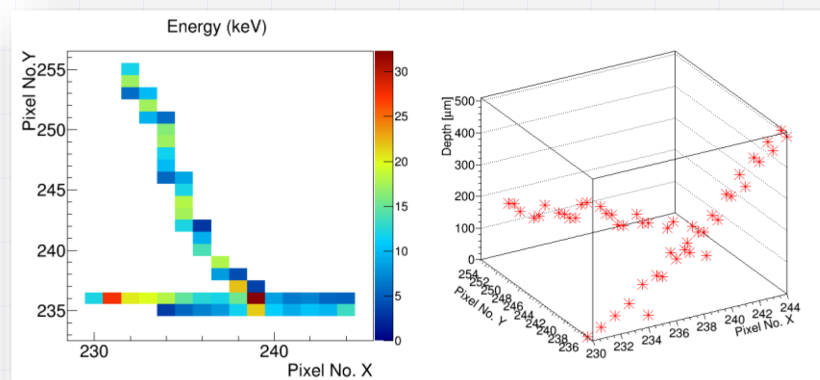


- Tracks selected by requiring a minimal drift time difference $\Delta t_{drift} > 42$ ns (130V) or $\Delta t_{drift} > 22$ ns (230V)
- Time measurement of pixels with $E_i < 4$ keV ignored
- Z-resolution ~ 30 um

Bias: 130V



Bias: 230V



Cosmic muon track (natural background radiation in Prague)

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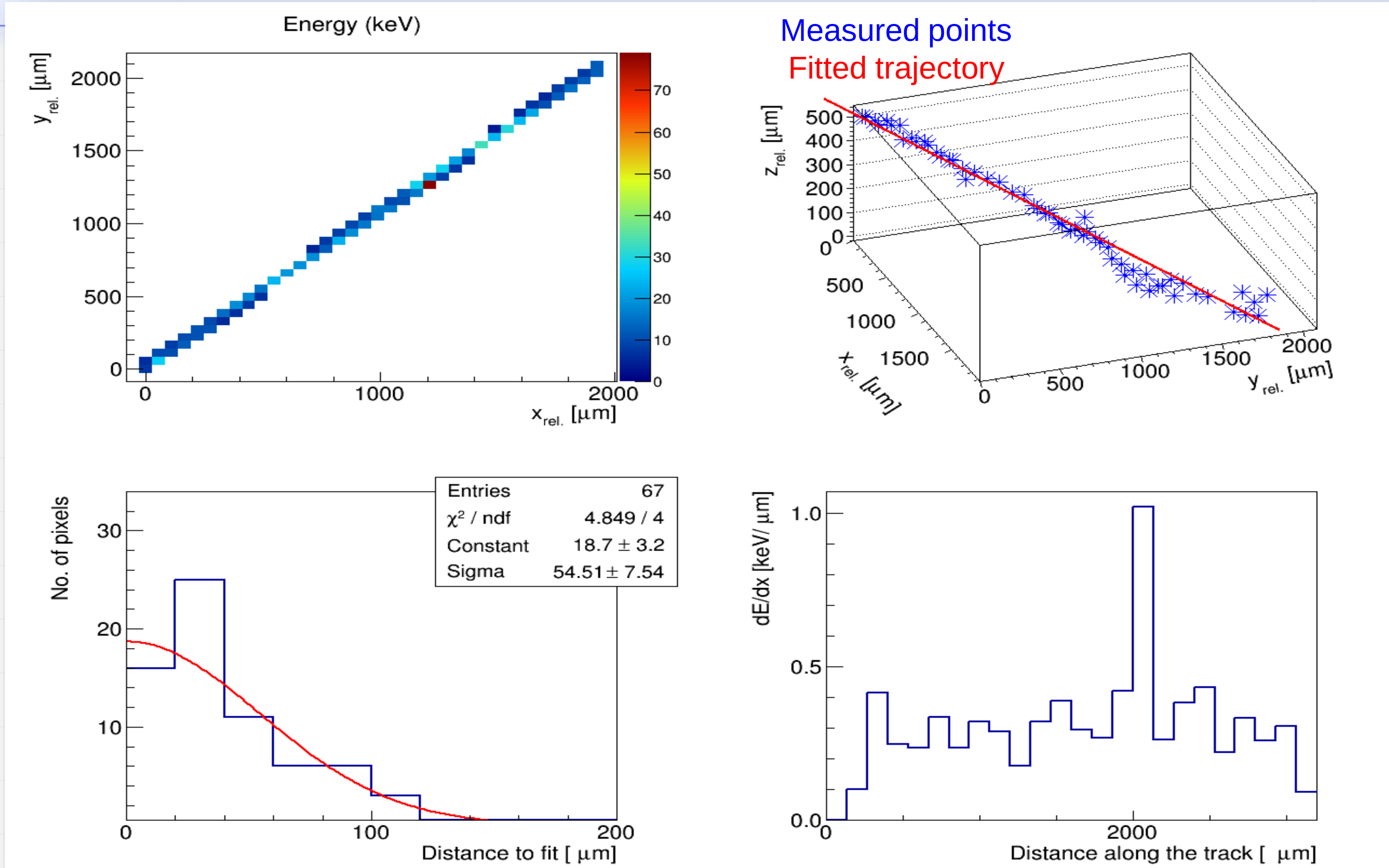

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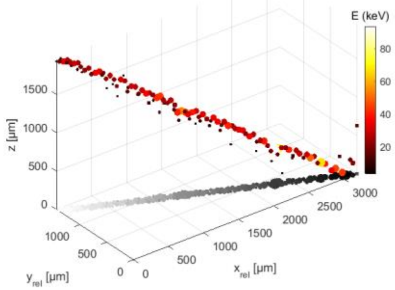
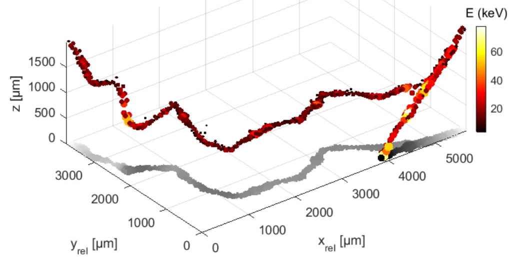
3D-visualisation of particle tracks in CZT measured at SPS

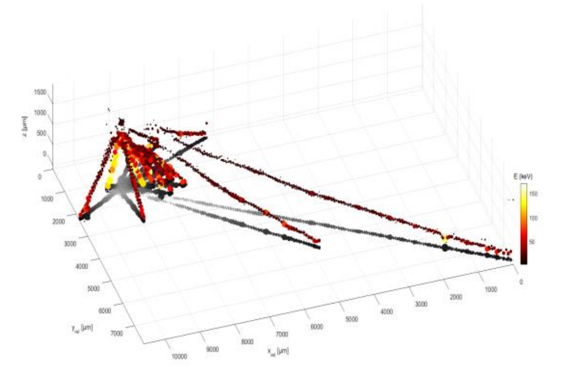
Muon



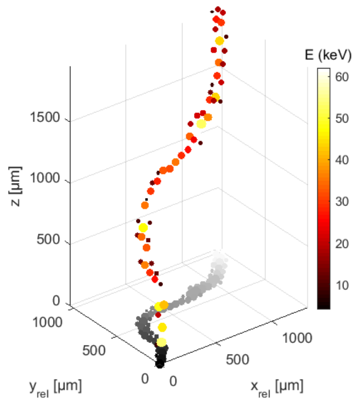
Pion + delta electron



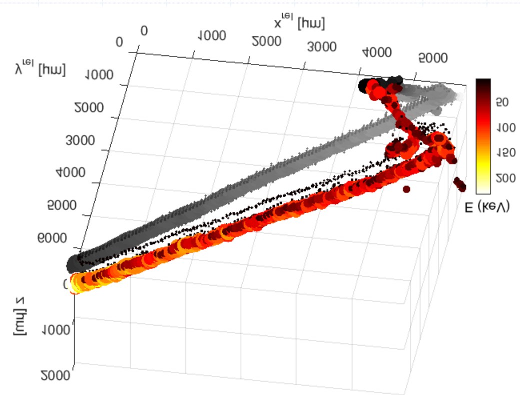
Fragmentation



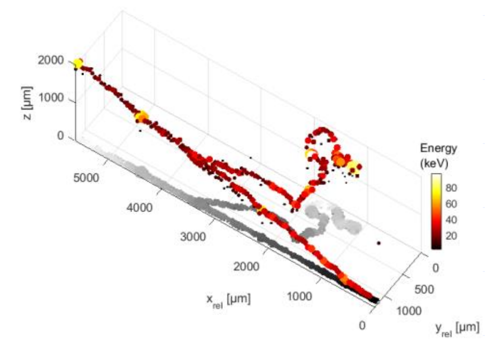
Electron



Heavy track



Pion + delta electron



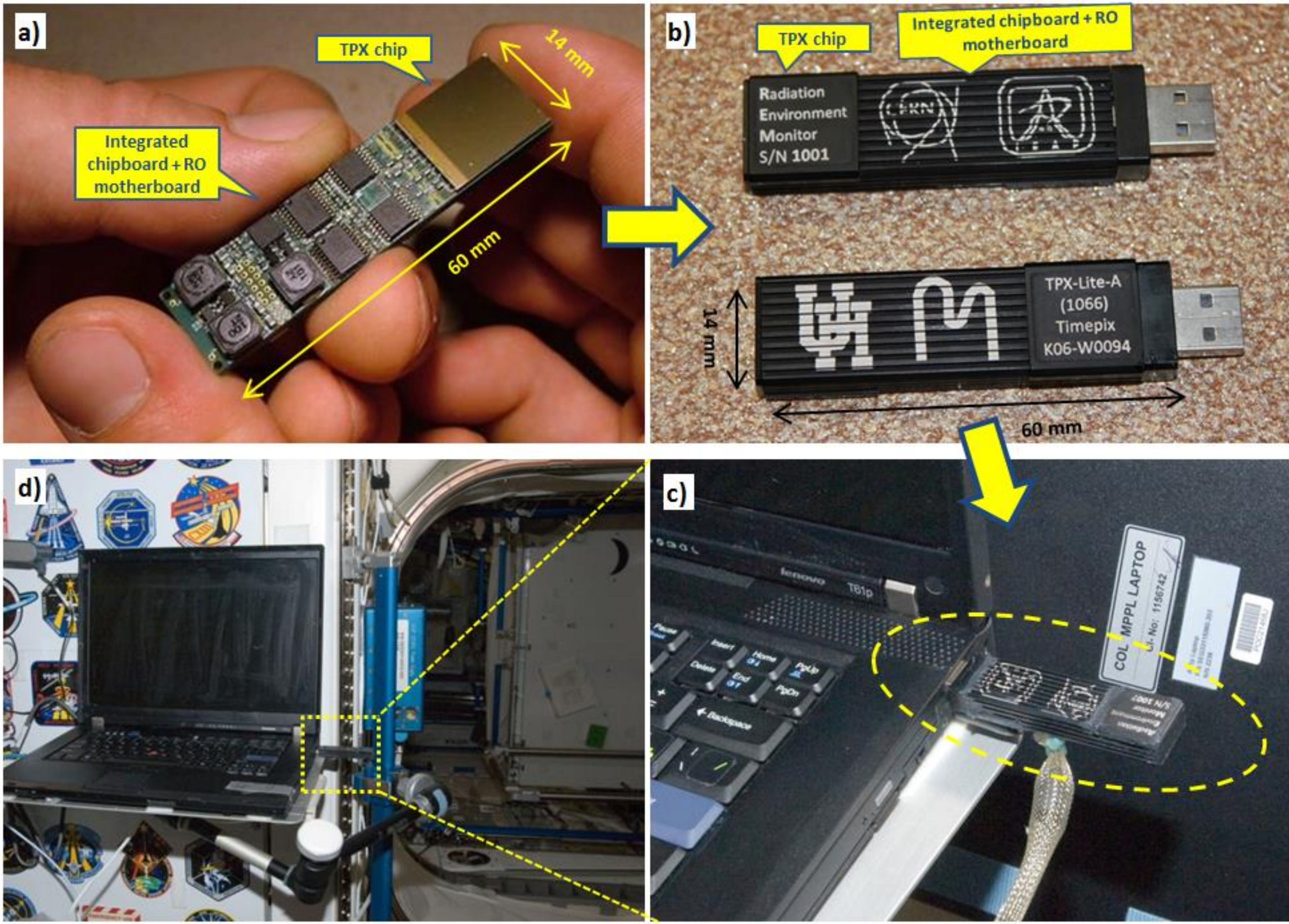
Timepix devices for space applications NASA, ESA

Institute of Experimental and Applied Physics
Czech Technical University in Prague

Timepix as a universal highly miniaturised radiation Monitor for use on ESA spacecraft.

The proposed device is called SATRAM and it is scheduled to fly on PROBA-V in late 2014. Motherboard of control unit for Timepix detector as developed for ESA project at IEAP CTU in Prague.

Miniaturized USB unit with detector Timepix as prepared (in cooperation with University of Houston) and delivered to NASA (10 pcs). Will be used for dosimetric measurements at ISS.



Timepix detector in the highly miniaturized LITE architecture (a) customized for the ISS (b) as deployed with an on-board laptop via USB port (c) in a NASA Module at the ISS (d). Work done in cooperation with NASA and the University of Houston.

The IEAP CTU Timepix based device used by NASA astronauts on ISS (courtesy of L.Pinsky, UoH)

Dosimetry in space on ISS

- Timepix for the first time in the space on the altitude ~400km
- 5 detectors deployed on ISS fromOctober 2012

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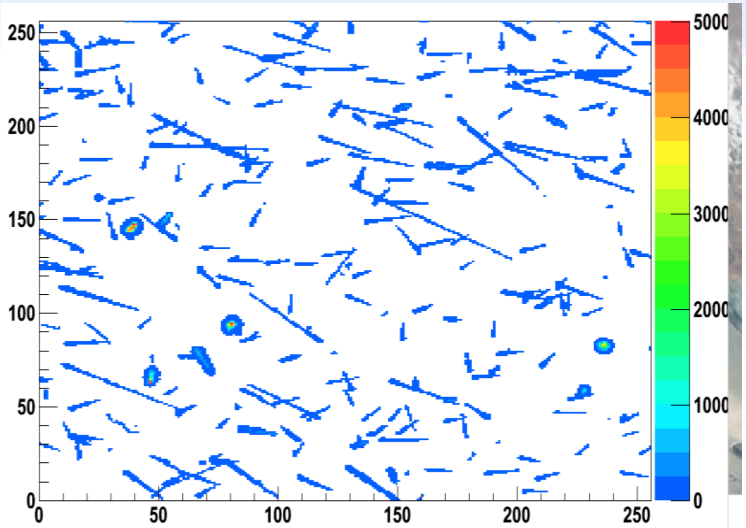
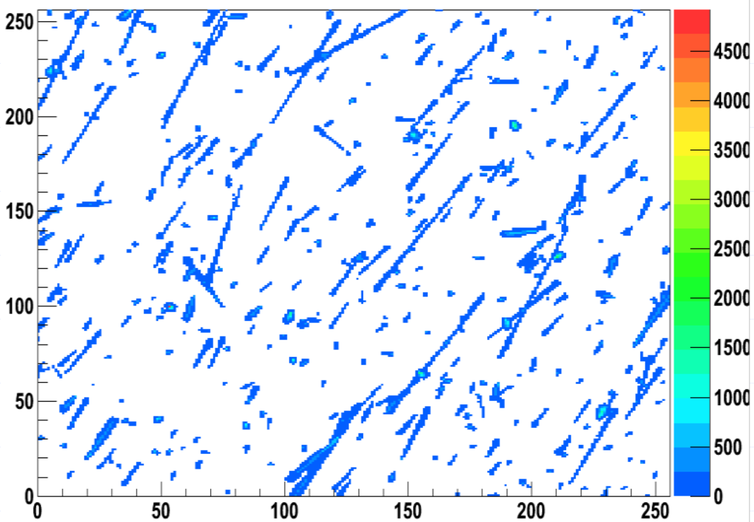
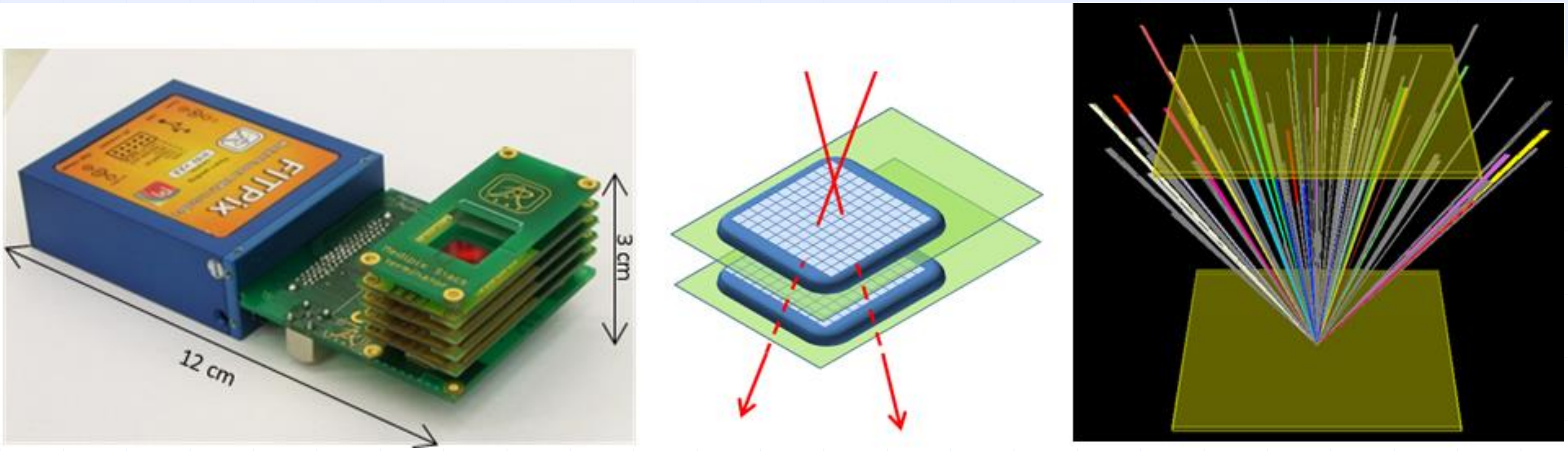
Czech Technical University in Prague



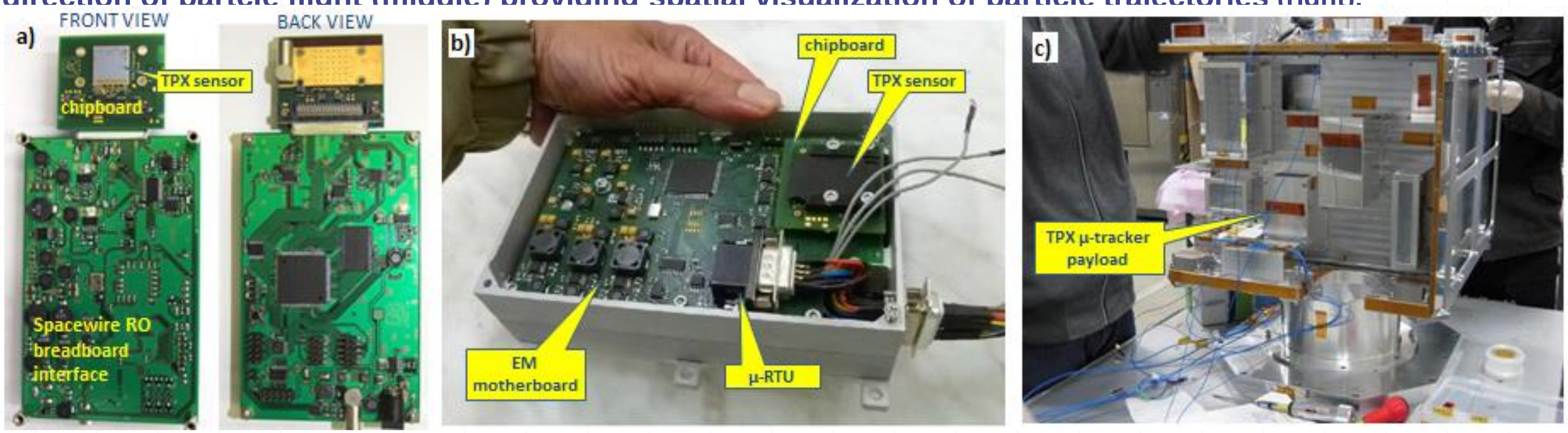


RISESAT

Rapid International Experimental Satellite
Timepix particle μ-tracker particle telescope



Particle micro-tracker of a stack of Timepix detector chipboards with common motherboard and single integrated R/O interface (left). Illustration of particle telescope on two pixelated sensors determining the direction of partcle flight (middle) providing spatial visualization of particle trajectories (right).



Timepix μ-tracker for the RISESAT satellite consisting of two separate devices with synchronized operation. Spacewire interface (a), payload engineering model (b) and its position in the 50 Kg micro-satellite (c).

- SATRAM payload (arrow) onboard ESA Proba-V satellite.
- ESA Vega-2 launcher rocket upper stage

Dosimetry in space: SATRAM – ESA Proba-V satellite

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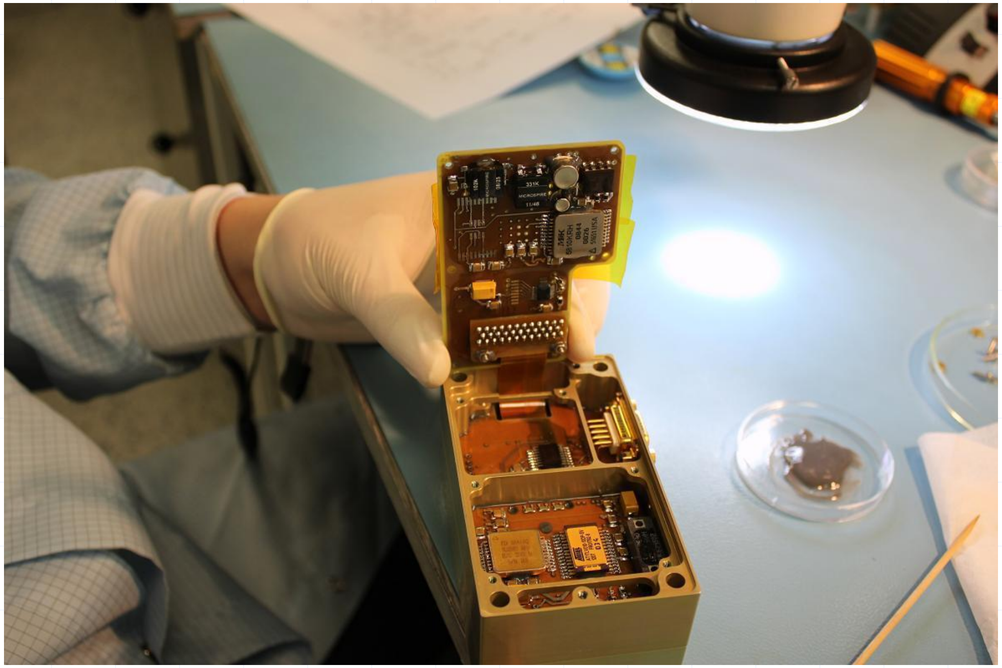
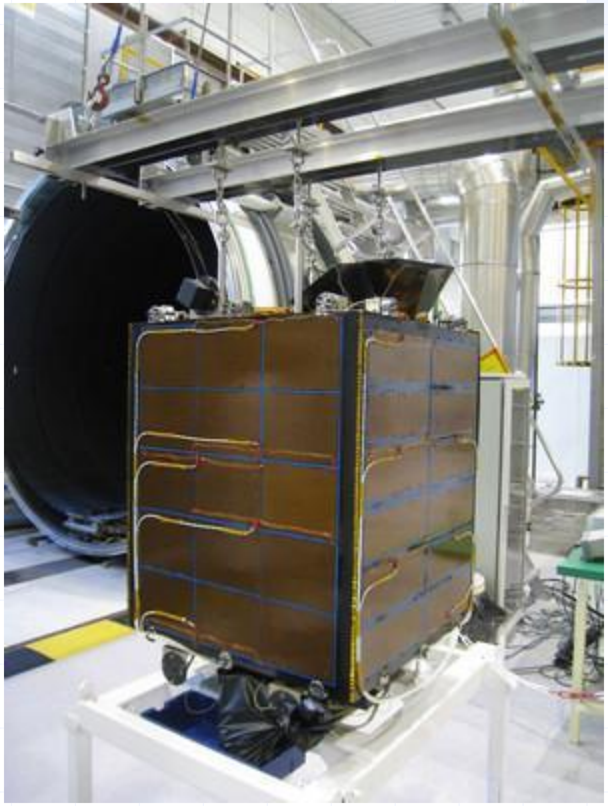
Characterization of mixed radiation field on low orbit of PROBA-V satellite

- Altitude ~ 800 km
- Timepix for the first time outside in the space
- Launched in May 2013





Typical frame with exotic track

Pay attention to the directionality of recorded proton tracks during the flight across the South Atlantic

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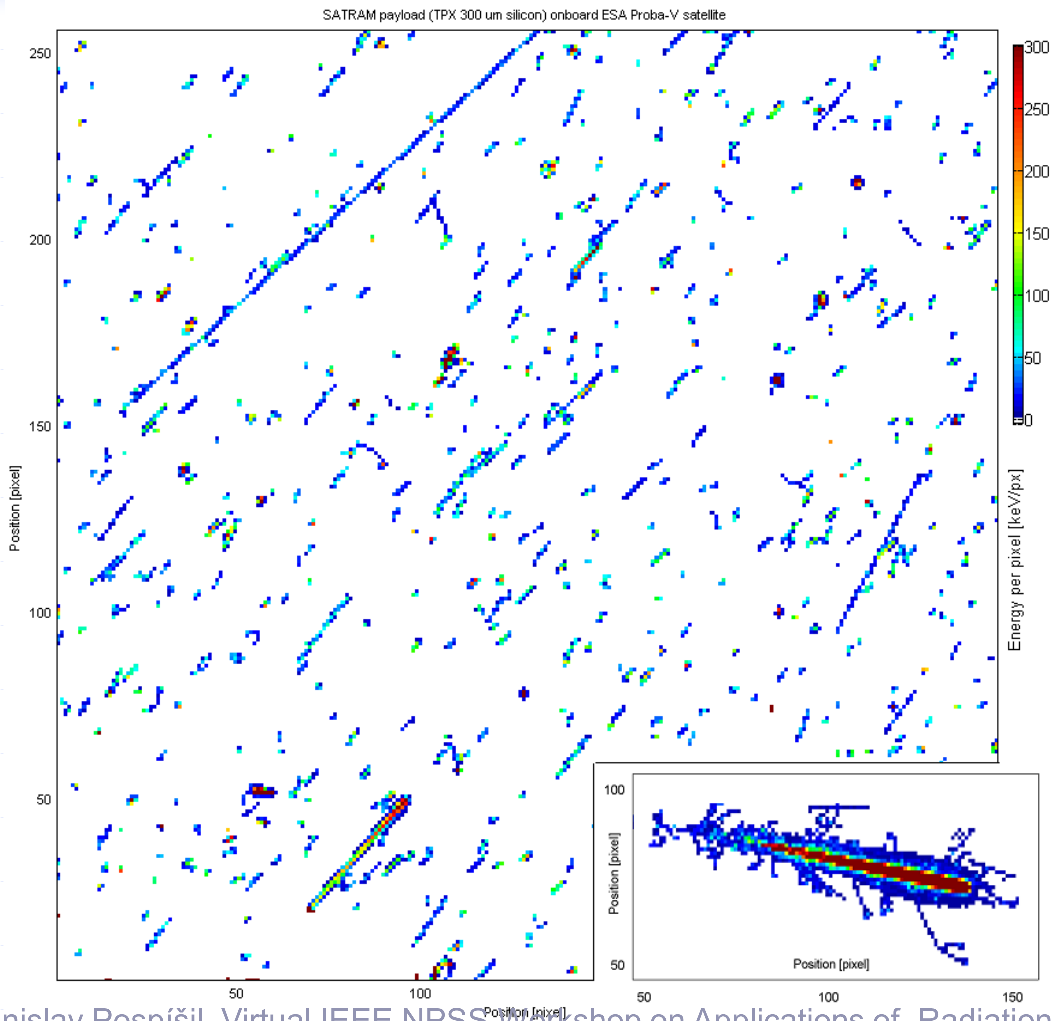
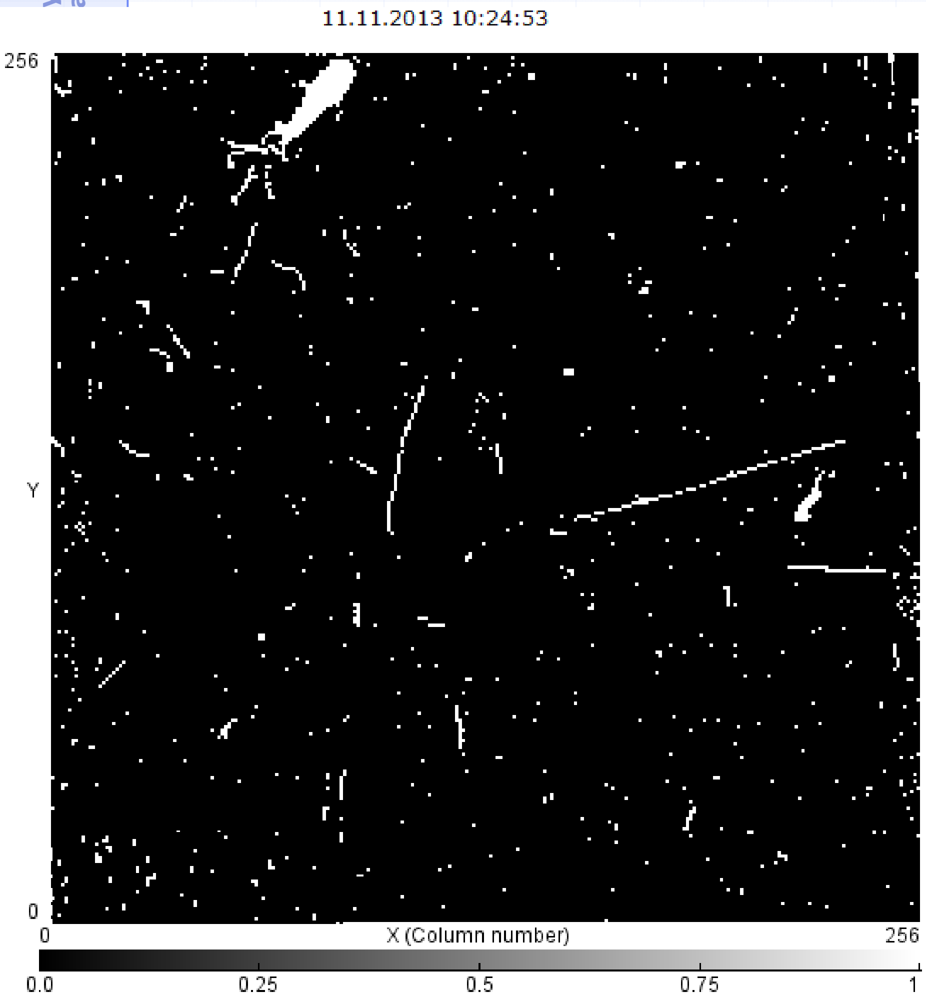
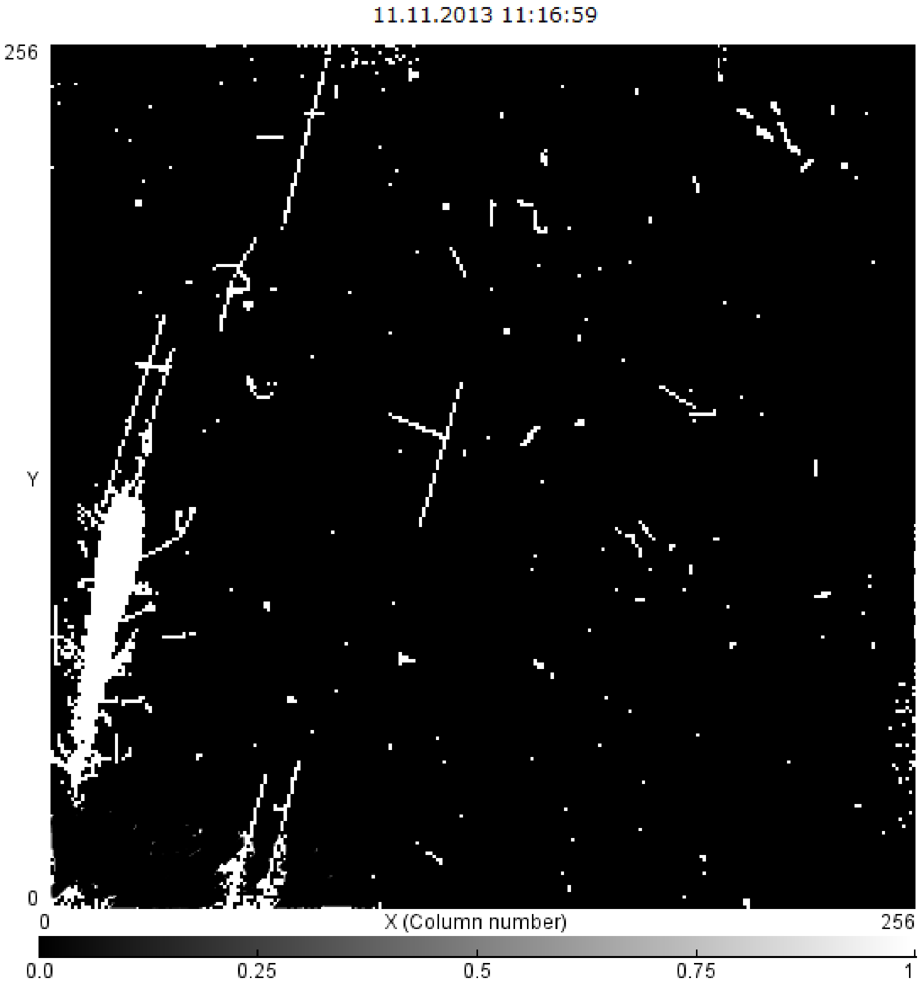


Timepix/ESA Proba-V:
LEO space radiation @ 820 km

Energetic heavy charged particles (ions)





Timepix/ESA Proba-V:

LEO space radiation @ 820 km

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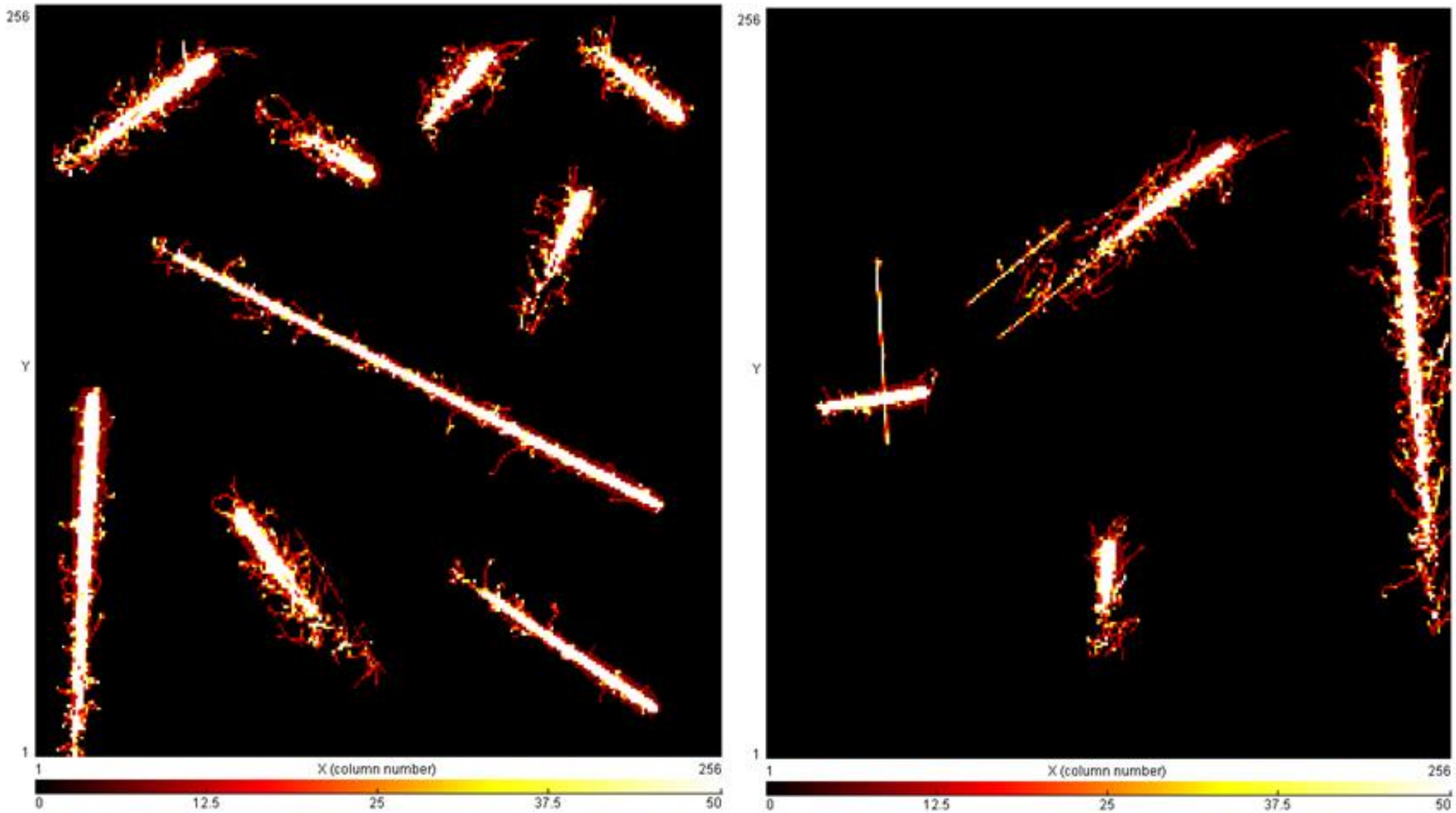
HETPs: Highly energetic heavy charged particles (ions) → HZE's



Timepix/ESA Proba-V:

LEO space radiation @ 820 km

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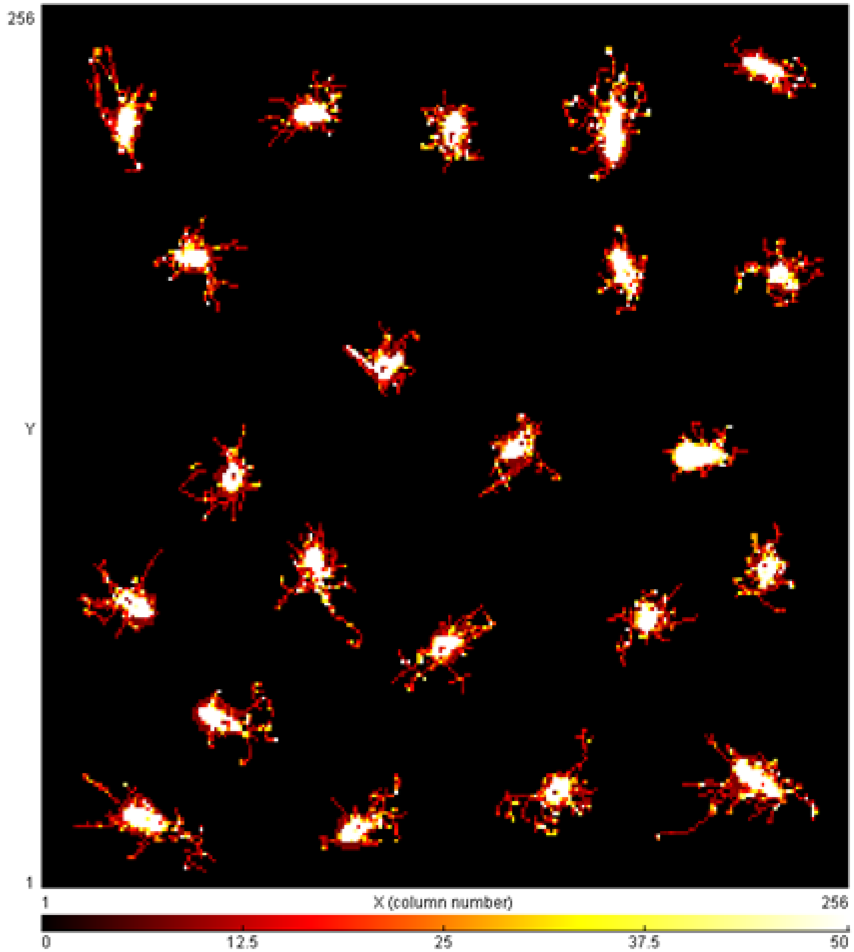
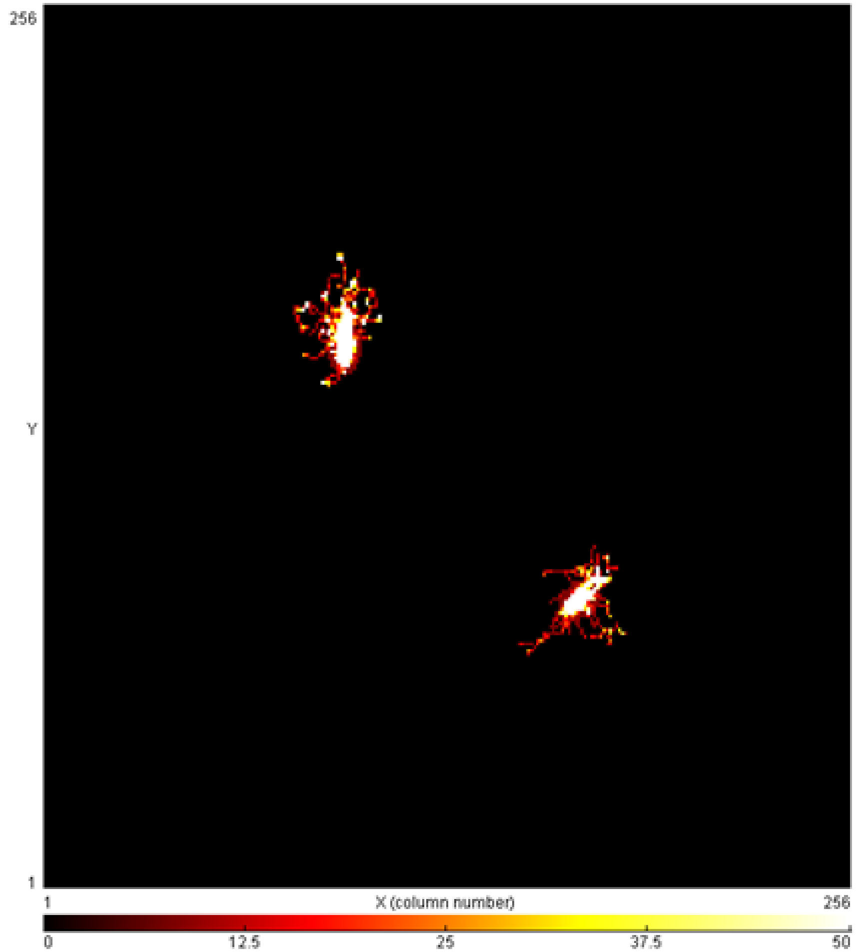
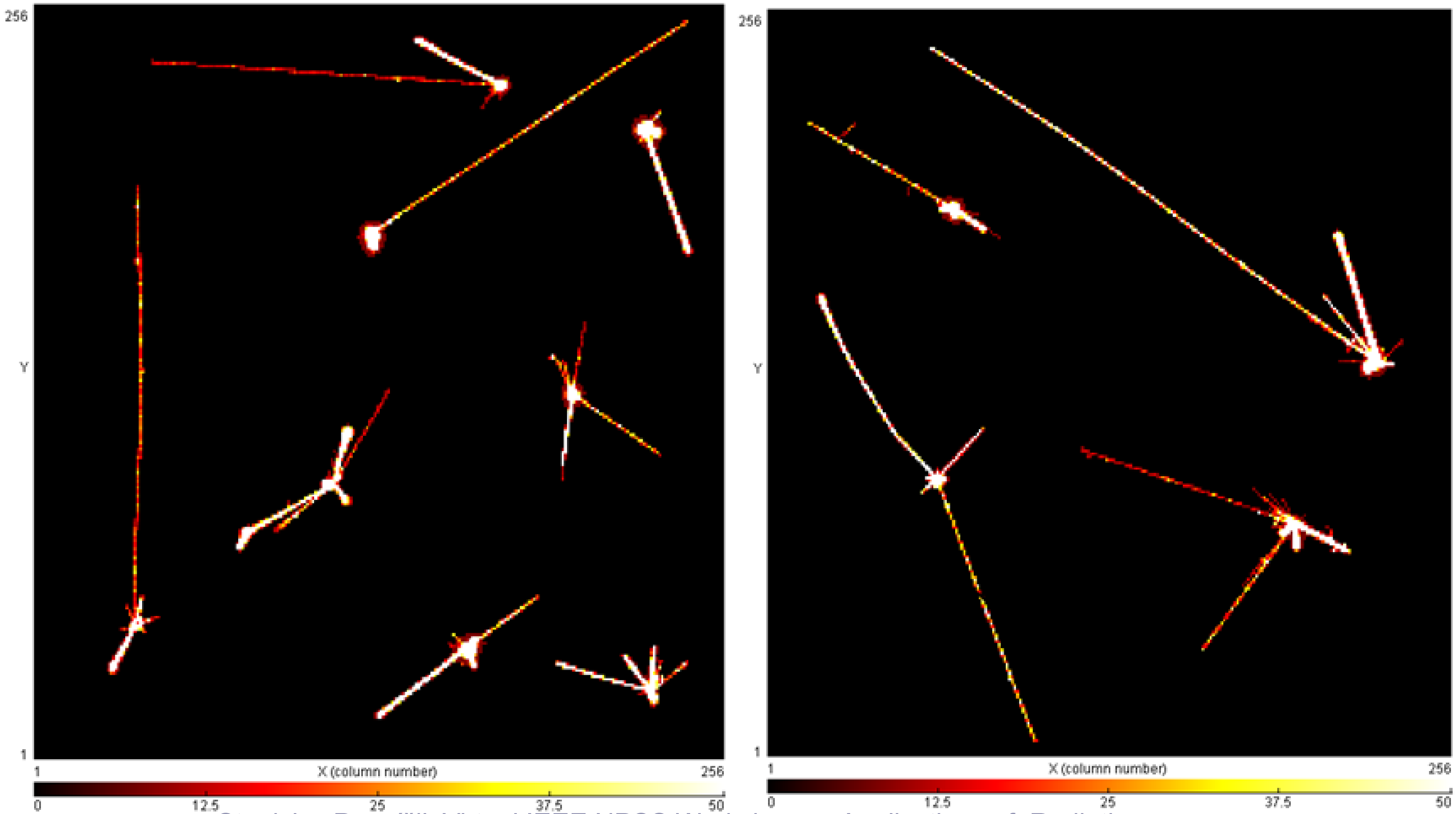




Timepix/ESA Proba-V:
LEO space radiation @ 820 km

LETPs: Energetic light charged particles (I) + nuclear interactions



Measured radiation map by Satram device in orbit

around the Earth at an altitude of 820 km from the earth's surface obtained within 36 days from January 1, 2014 to February 7, 2014 logarithmic scale in μG/hr.

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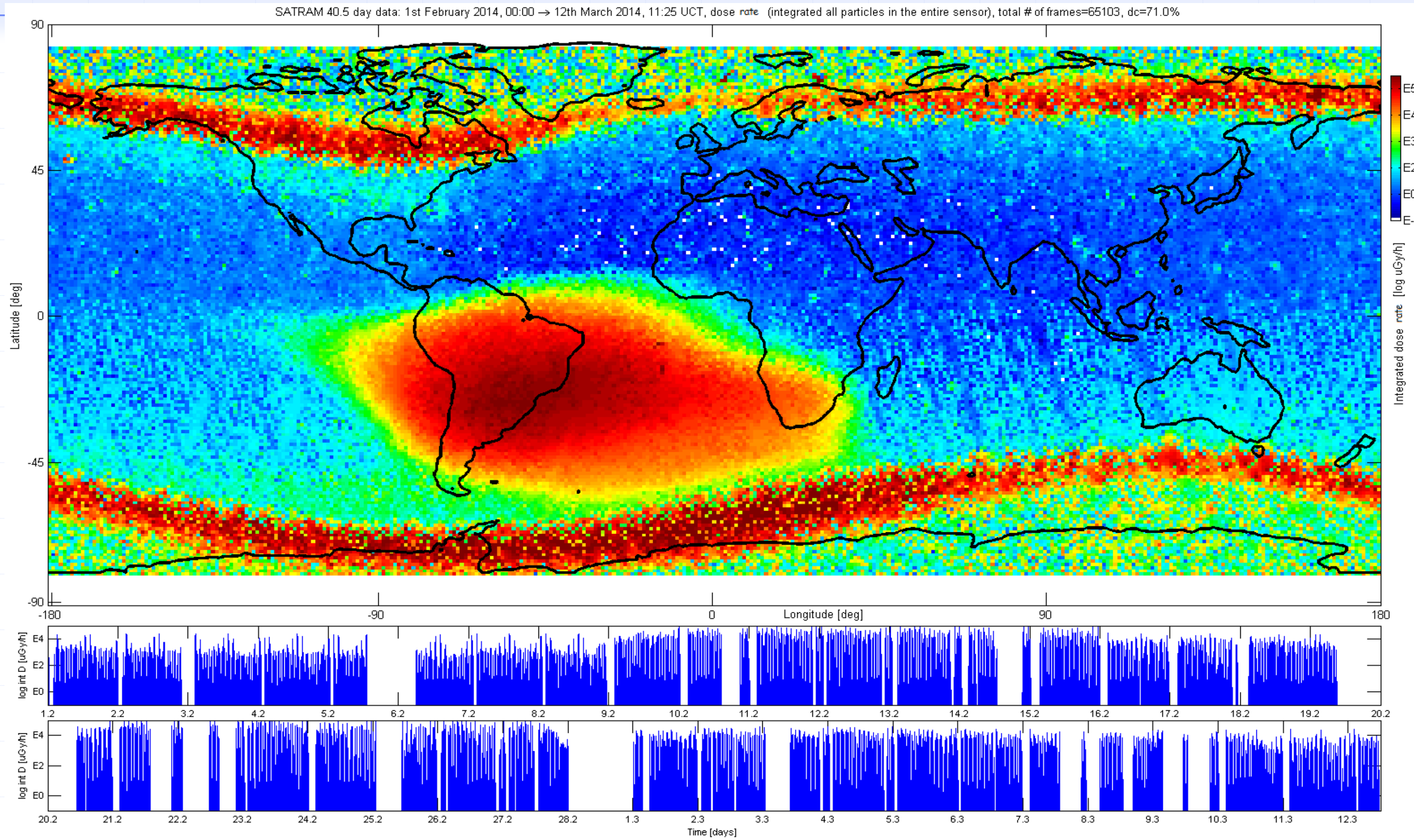
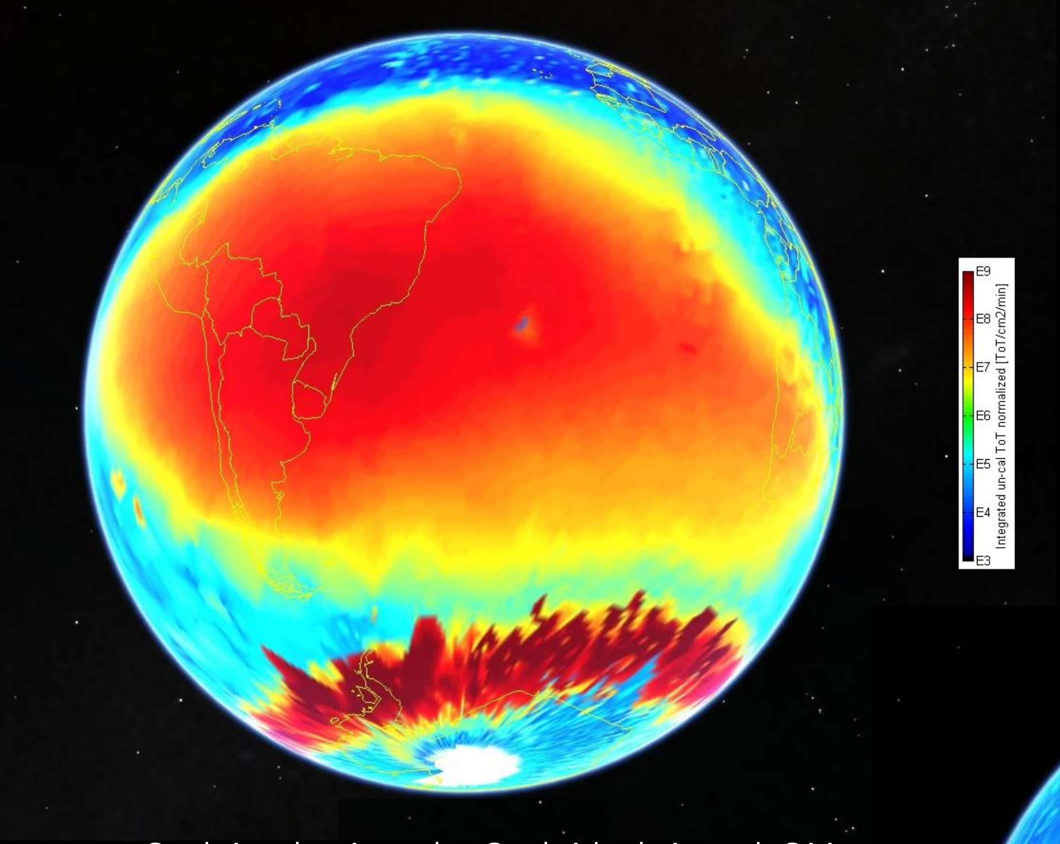
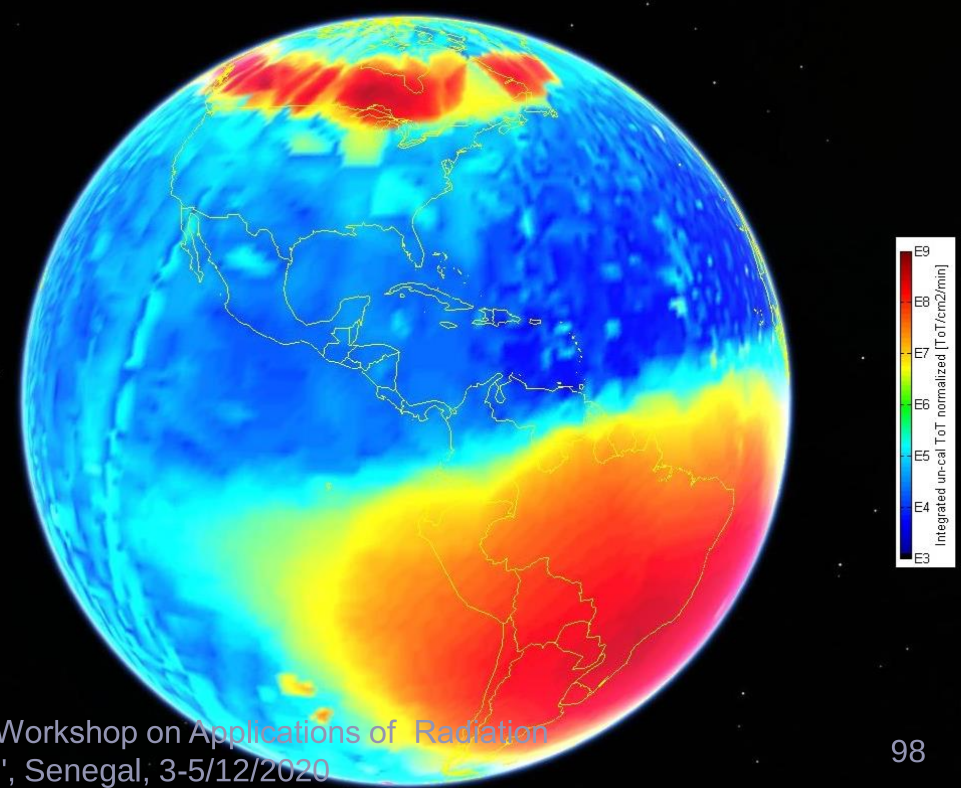


SATRAM – Proba-V



South America, Antarctica, South Atlantic Anomaly SAA

The Americas



Radiation field Earth map spatial distributions measured by Timepix onboard ESA Proba-V satellite LEO orbit 820 km altitude displaying all radiation components integrated over 5.5 months

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Thank you for your attention