Event-by-Event Track Analysis by Means of a Timepix Device

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Heavy Ion Measurements at HIT

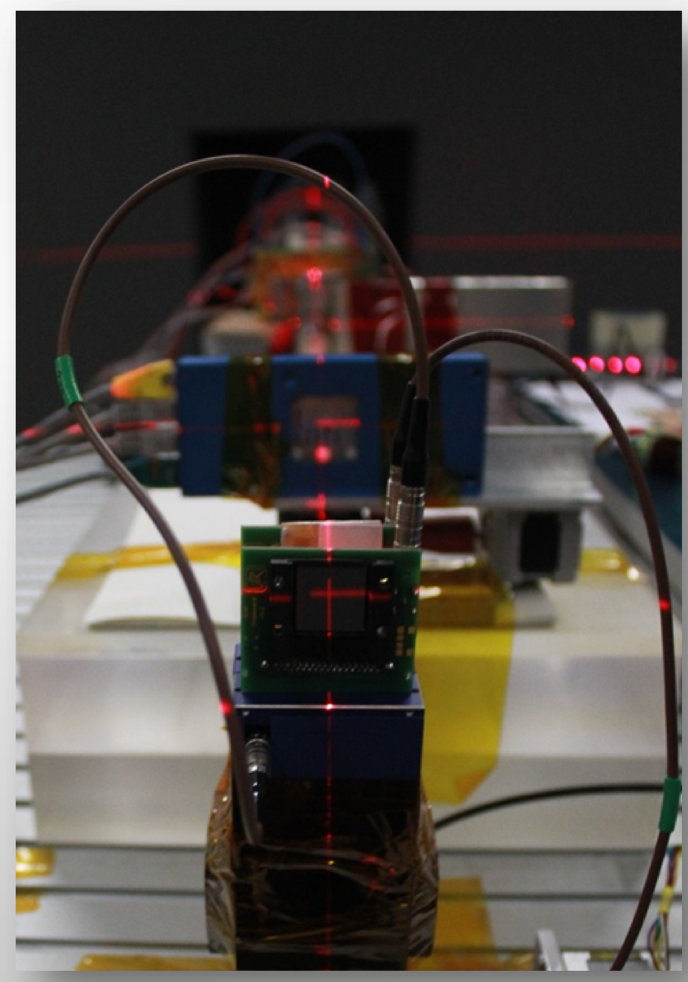
Detector

- 300 µm thick silicon sensor layer
- Bias voltage 50 V
- 48 MHz clock frequency
- Time-over-Threshold mode

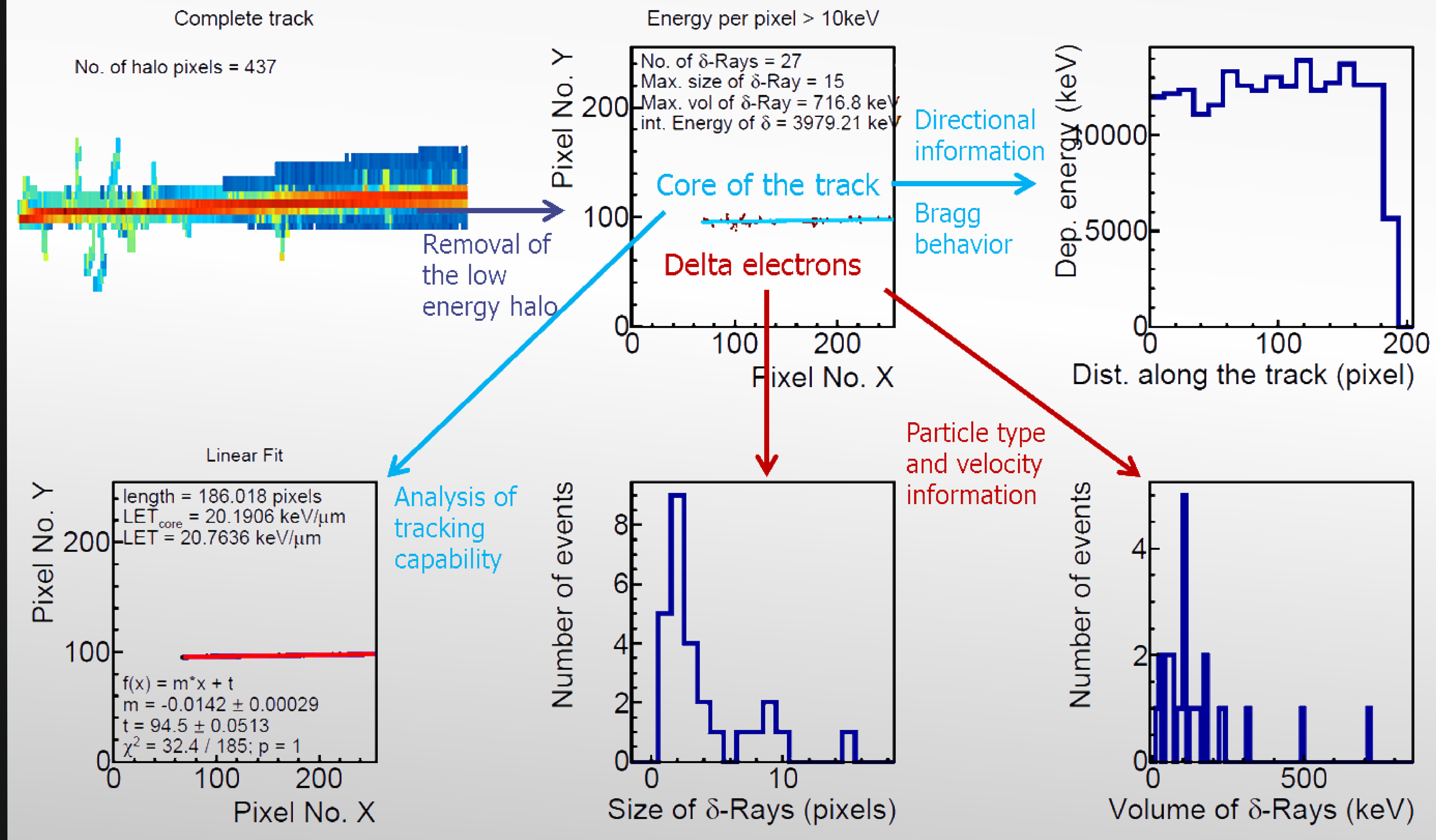
Particle types

- Protons (48 MeV, 75 MeV, 100 MeV)
- Helium ions (50 MeV/A, 80 MeV/A, 115 Me V / A , 150 MeV/A, 185 MeV/A, 221 MeV/A)
- Carbon ions (89 MeV/A, 200 MeV/A, 300 MeV/A, 430 MeV/A)
- Oxygen ions (104 MeV/A, 250 MeV/A, 430 MeV/A)

For each particle type the detector has been irradiated through 0°, 60° and 90°.



Event-by-Event Analysis

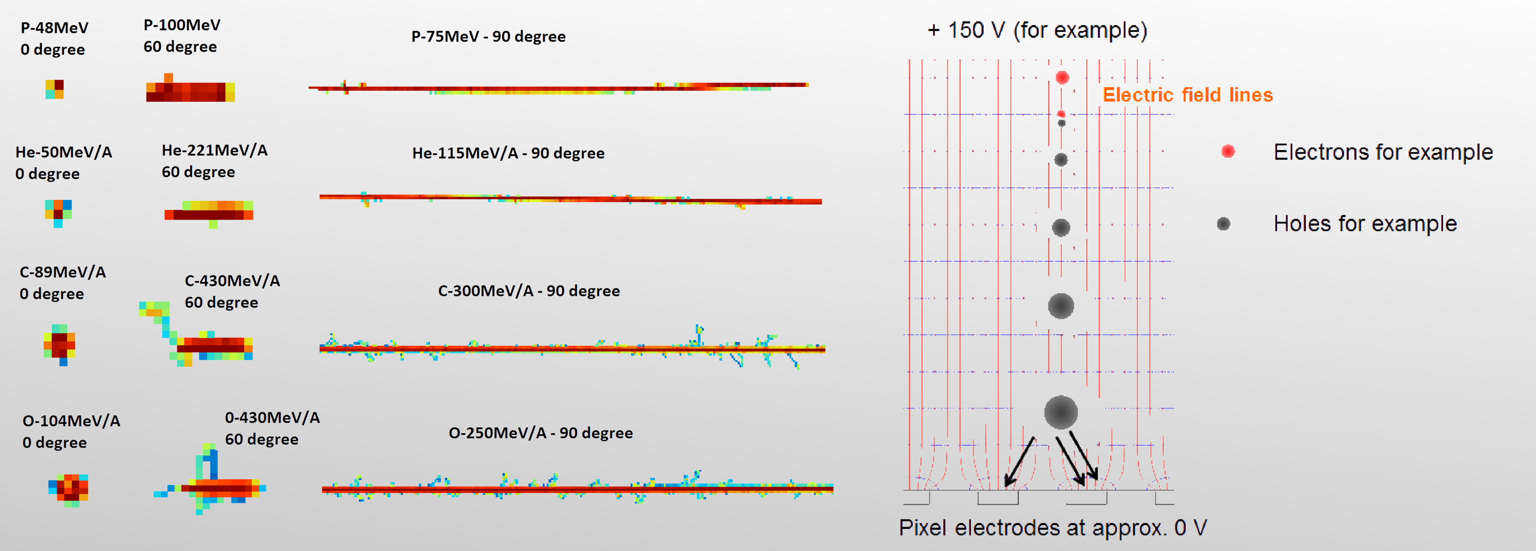


Simulations in GRAS/GEANT4

GRAS (GEANT4 Radiation Analysis for Space Appications)

- Implementation of a module describing the response of a pixelated detector
- Diffusion and repulsion of the charges during their drift through the silicon sensor were modeled
- Above the saturation level of 1800 keV per pixel the response of each pixel was randomized

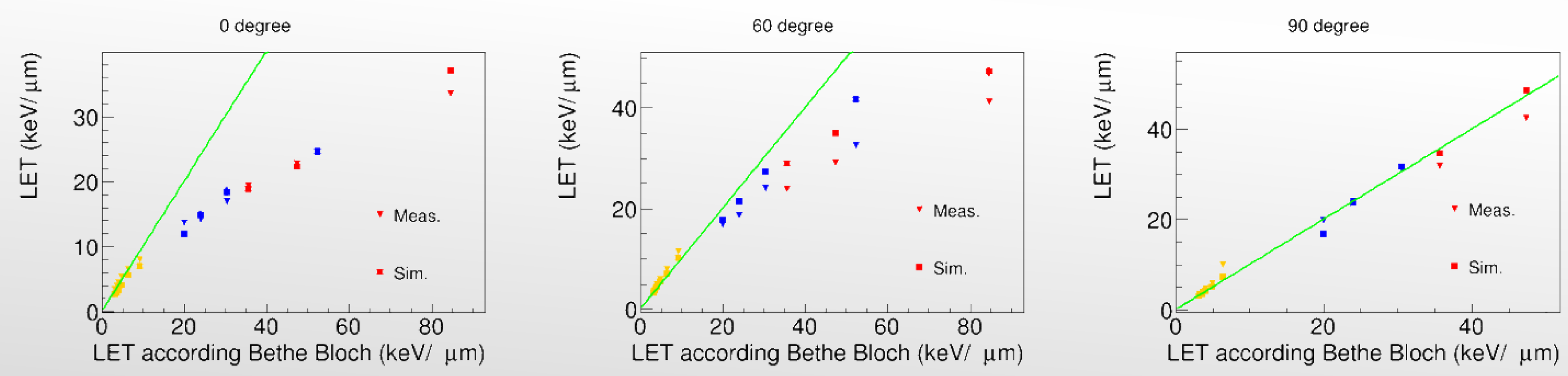
Examples of simulated tracks:



Measured and Simulated LET-Responses

Stopping power according Bethe-Bloch Formula:

$$-\left\langle \frac{dE}{dx} \right\rangle = Kz^2 \frac{Z}{A} \frac{1}{\beta^2} \cdot \left[\frac{1}{2} \ln \frac{2m_e c^2 \beta^2 \gamma^2 T_{max}}{I^2} - \beta^2 - \frac{\delta(\beta\gamma)}{2} \right]$$



In the measurements at the angles 0° and 60° the predicted values by the Bethe-Bloch formula are only reached in the lower LET range. It is the range, where the per pixel energy deposition is below the saturation level for each pixel. For the measurement at 90° hardly any pixel exceeds the saturation level. Thus the measured LET resembles the theoretically calculated one.

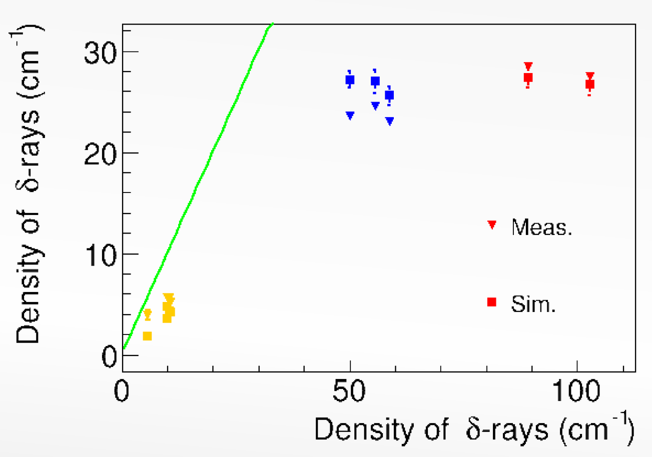
Delta Electron Properties

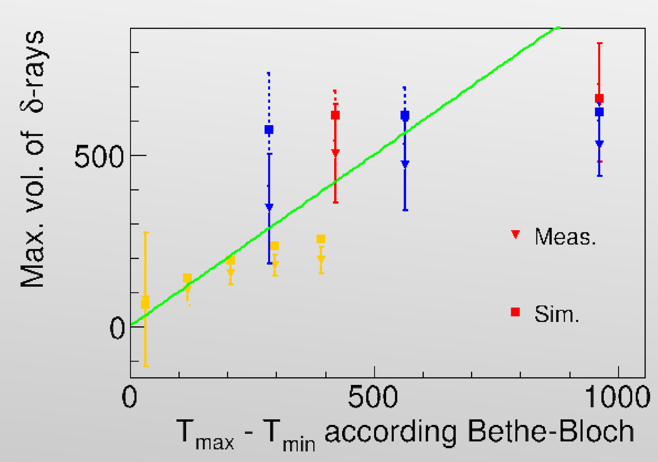
Linear delta electron density

$$\frac{d^2N}{dTdx} = \frac{1}{2} K z^2 \frac{Z}{A} \frac{1}{\beta^2} \frac{F(T)}{T^2}$$

Integration from T_{min} to T_{max} gives

$$\frac{dN}{dx} = 179 \cdot 10^{-3} \cdot \frac{\text{MeV}}{\text{cm}} \cdot \left(\frac{1}{T_{min}} - \frac{1}{T_{max}} \right)$$





Maximum energy of delta electrons

$$T_{max} = \frac{2m_e c^2 \beta^2 \gamma^2}{1 + \frac{2\gamma m_e}{M} + \left(\frac{m_e}{M} \right)^2}$$

Different T_{min} were chosen empirically, depending on the track widths:

- T_{min} (protons) = 120 keV
- T_{min} (helium) = 150 keV
- T_{min} (carbons,oxygen) = 200 keV

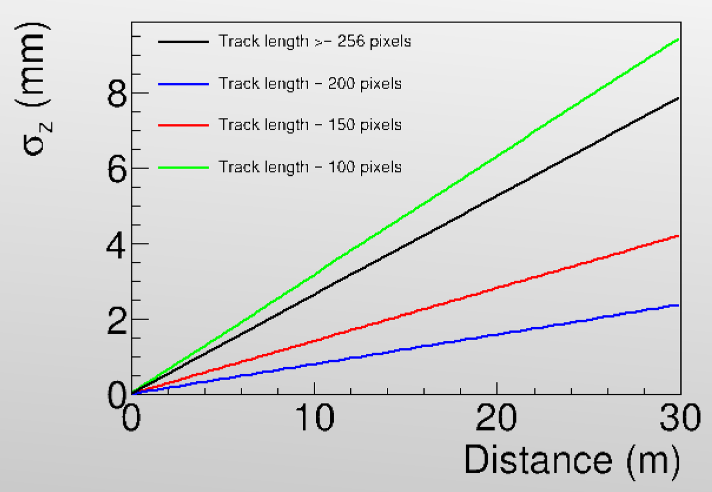
Tracking Capability of TPX Devices

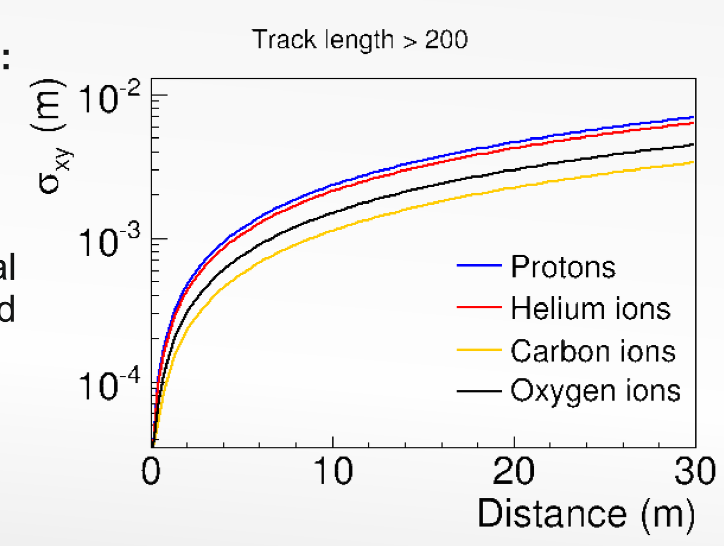
Energy weighting of the xy-pixel coordinates:

$$y_{mean}(x_i) = \frac{\sum_{j=y_{min}}^{y_{max}} E_j \cdot y_j}{\sum_{j=y_{min}}^{y_{max}} E_j} \qquad \Delta y_{mean}(x_i) = \sqrt{\frac{\sum_{j=y_{min}}^{y_{max}} E_j}{12}}$$

After applying a linear fit f(x) = mx + t the spatial resolution in the xy-detector plane is calculated according:

$$\sigma_{xy}(x) = \sqrt{(\Delta m \cdot x)^2 + \Delta t^2}$$





Spatial resoution in the z-coordinate:

$$z(r) = \frac{300\ \mu m}{l_{track}} \cdot r \rightarrow \Delta z(r) = \frac{300 \mu m \cdot r}{l_{track}^2} \Delta l_{track}$$

For tracks with defined start and endpoint

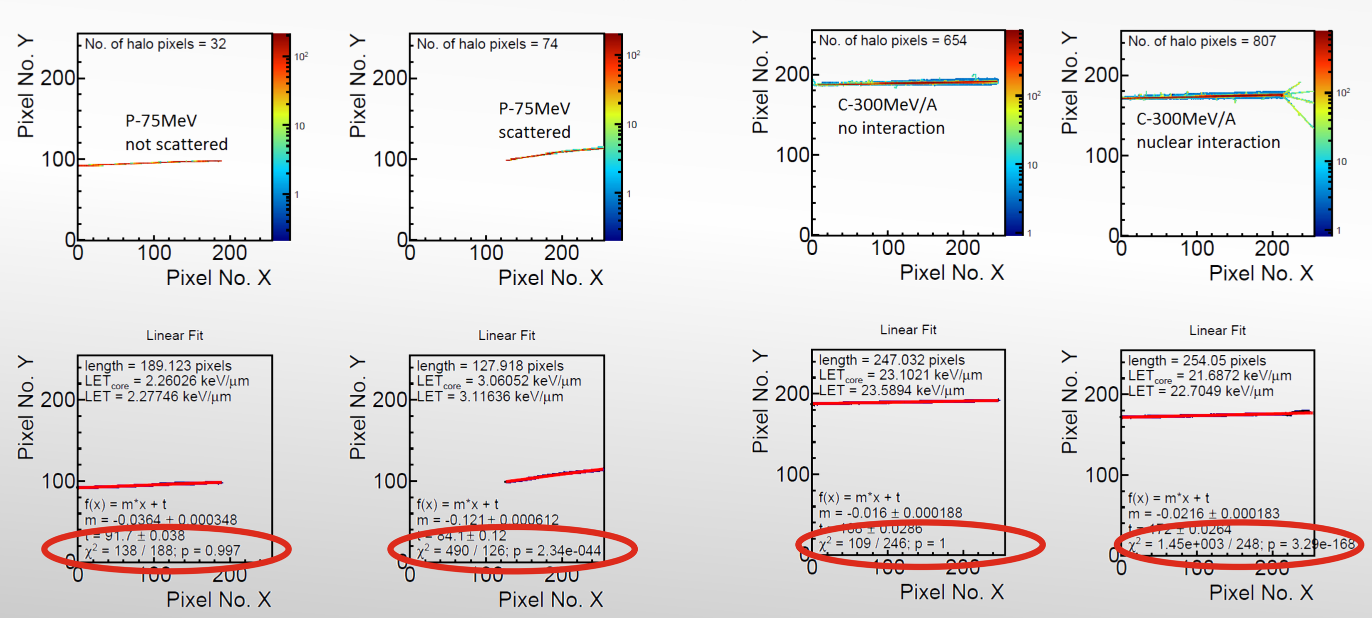
$$\Delta l_{track} = \frac{110 \mu m}{\sqrt{12}} = 31.75\ \mu m$$

else

$$\Delta l_{track} = \frac{600 \mu m}{\sqrt{12}} = 173.21\ \mu m$$

Scattered Tracks and Nuclear Reactions

Can the goodness of fit parameters (reduced chi square, kolmogorov-smirnoff probability) be used to identify scattered tracks and/or nuclear reactions? - **Study in progress!**



Summary and Outlook

An event-by-event track analysis was presented. The TPX detector response was modeled with the GRAS simulation package. Reasonable agreement of simulation and measurement was found. The described evaluation technique can now be used for different particle and astroparticle physics applications.

Applications of the analysis technique:

- **Space applications:** The SATRAM device is mounted on the PROBA-V satellite and measures the radiation in open space. Several USB-Lite devices are measuring the composition of the radiation in the ISS.
- **MOEDAL** experiment in the LHC in CERN: two TPX devices were installed in the MOEDAL experiment as radiation monitors
- **ATLAS**: A network of 16 MPX devices was installed in the ATLAS detector. With MPX no information about the LET is available. However, for devices in the tracking mode the delta electron analysis might be used for particle identification.