High Resolution Neutron Detection using GridPix chips

Innovative Neutron Detection

towards a neutron time projection chamber

- using pixel chips
- equipped with InGrid meshes
- for high time and spatial resolution

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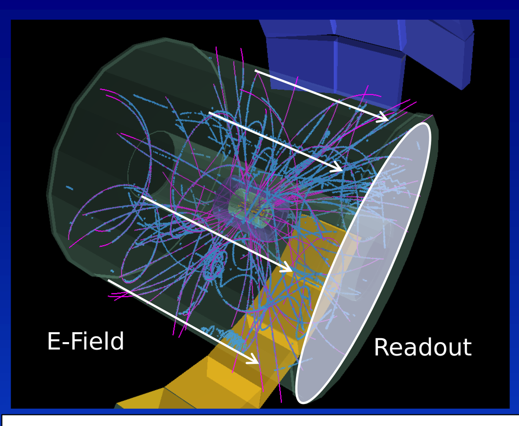
The world of detectors used in thermal neutron scattering instrumentation has changed. By alerts on the future Helium-3 supply, critical to perspectives of the large-scale research infrastructures, the run on substitutional technologies started. Most of the solutions could be adapted from developments of particle physics and are comprised of one or more layers of Boron-10. The Time Projection Method achieves a very high resolution by projecting ionization tracks onto a highly granular readout. The University of Bonn develops a novel system based on reconstructing boron conversion tracks using the Timepix - CMOS based chips with 55 micrometer sized pixels operated at clock speeds up to 80 MHz. Each matrix of 256 x 256 pixels is equipped with an InGrid - microstructured aluminum meshes 50 micrometer ontop of the pixels serving as a charge amplifier.

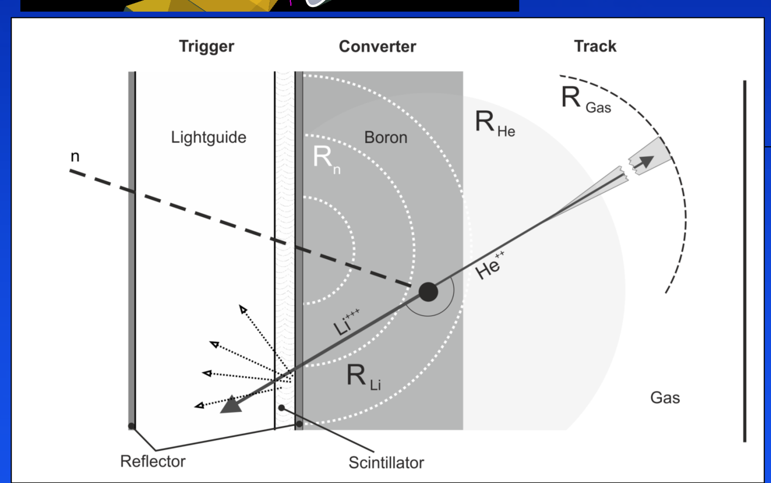
In a first prototype with 8 Timepix chips, which are arranged in parallel to a boron layer, the track topology with this unrivaled high resolution has been studied. By reconstructing the origin of the conversion ions a time resolution of < 50 ns and a spatial resolution of 100 micrometer has been achieved. As this setup now allows the full reconstruction of the conversion tracks down to the electron level the understanding of the track topology can help interpreting the signals in more coarsely resolved systems. The aim of the project is to evaluate the feasibility of realizing a **neutron Time Projection Chamber.**

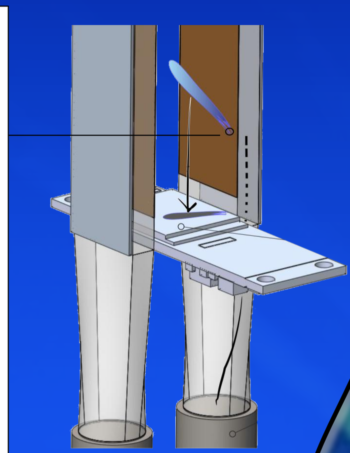
Detection Method



A Time Projection Chamber consists of a large volume filled with gas. Particles leave ionized tracks which are projected onto a readout located outside the beam. This allows for time and spatially resolved measurements.

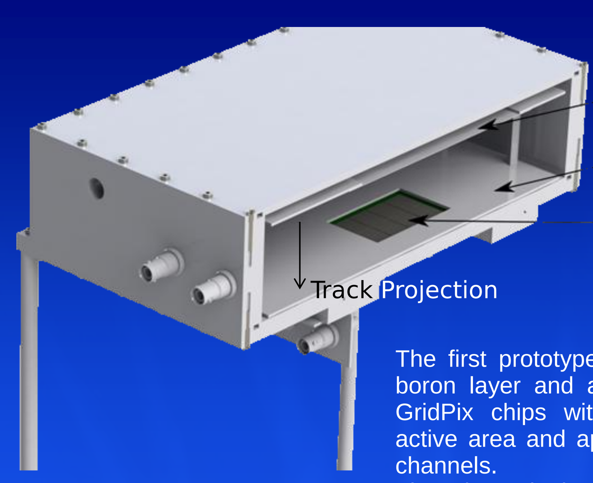
- Trigger & Track Principle for the neutron TPC:
  - Using both conversion products
  - Combination of gaseous tracking detector [Timepix] and a photo sensitive detector [SiPMs]





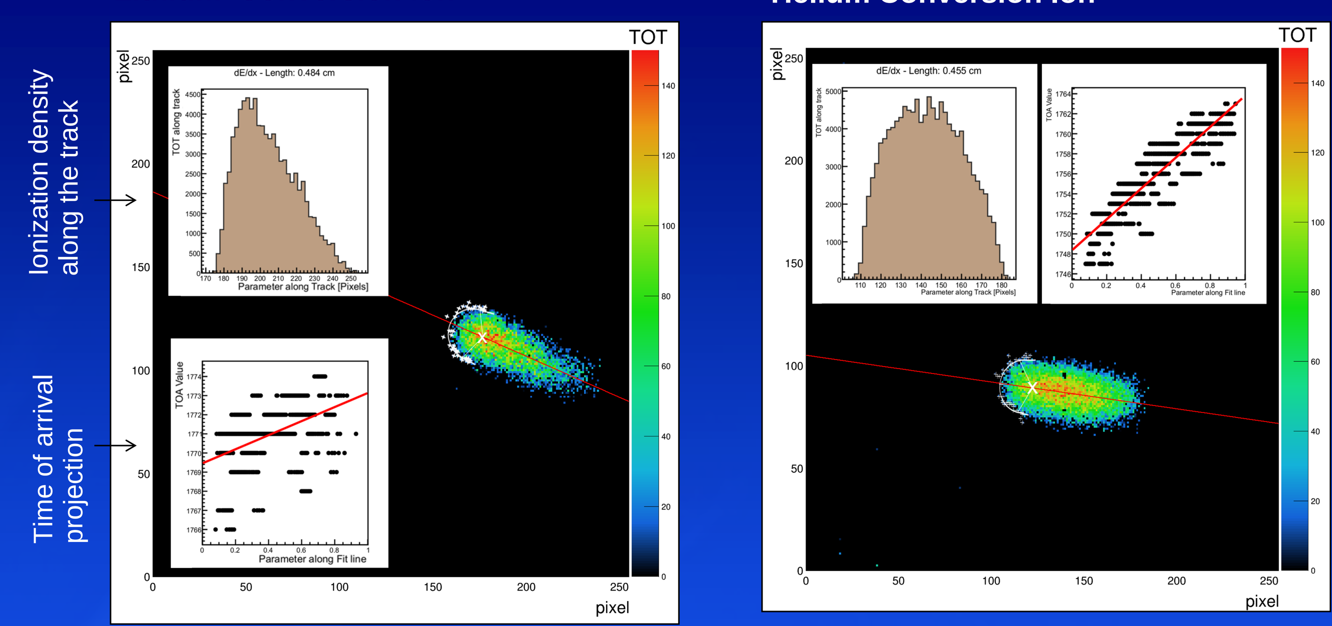
Schematic not-to-scale drawing of the working principle of the n-TPC: One conversion ion from a thin boron layer is used to generate a trigger by a scintillator, the other provides spatial information from leaving a track in a gaseous detector

Test Detector



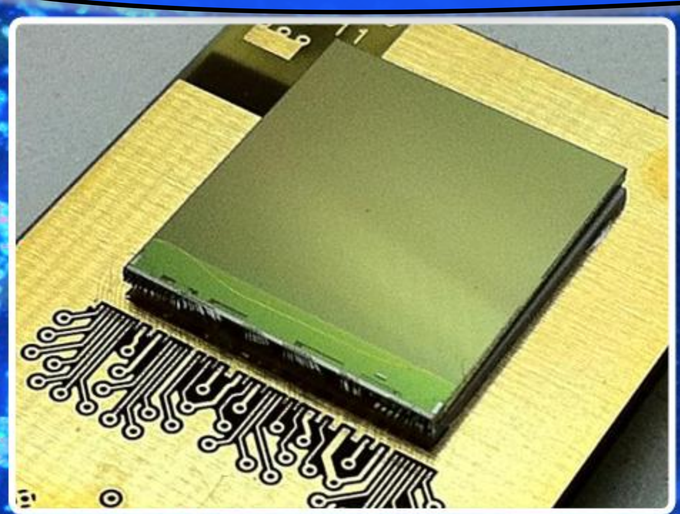
The first prototype consists of a one boron layer and a readout unit of 8 GridPix chips with approx. 15 cm^2 active area and approx. 460000 pixel channels.
The primary ionization charge from the tracks of the conversion ions is projected from the drift cathode to the readout.

Event Reconstruction



Reconstruction steps:
(after cluster identification using DBSCAN)

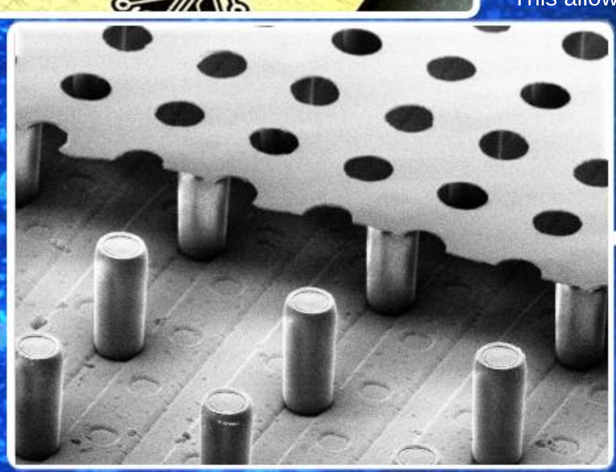
- Fitting a straight line through the TOT values.
- Fitting a straight line through the TOA values. Lower values indicate pixels having detected a signal more early therefore denoting the starting time of the track. The reference to this drift time is given by an external trigger.
- Fitting a circle to the outermost pixels of the side, which was flagged as the origin of the track by the TOA identification.
- Intersecting circle and TOT line and locating the origin by shifting this point inwards along main axis by a distance determined by the track diameter and inclination.

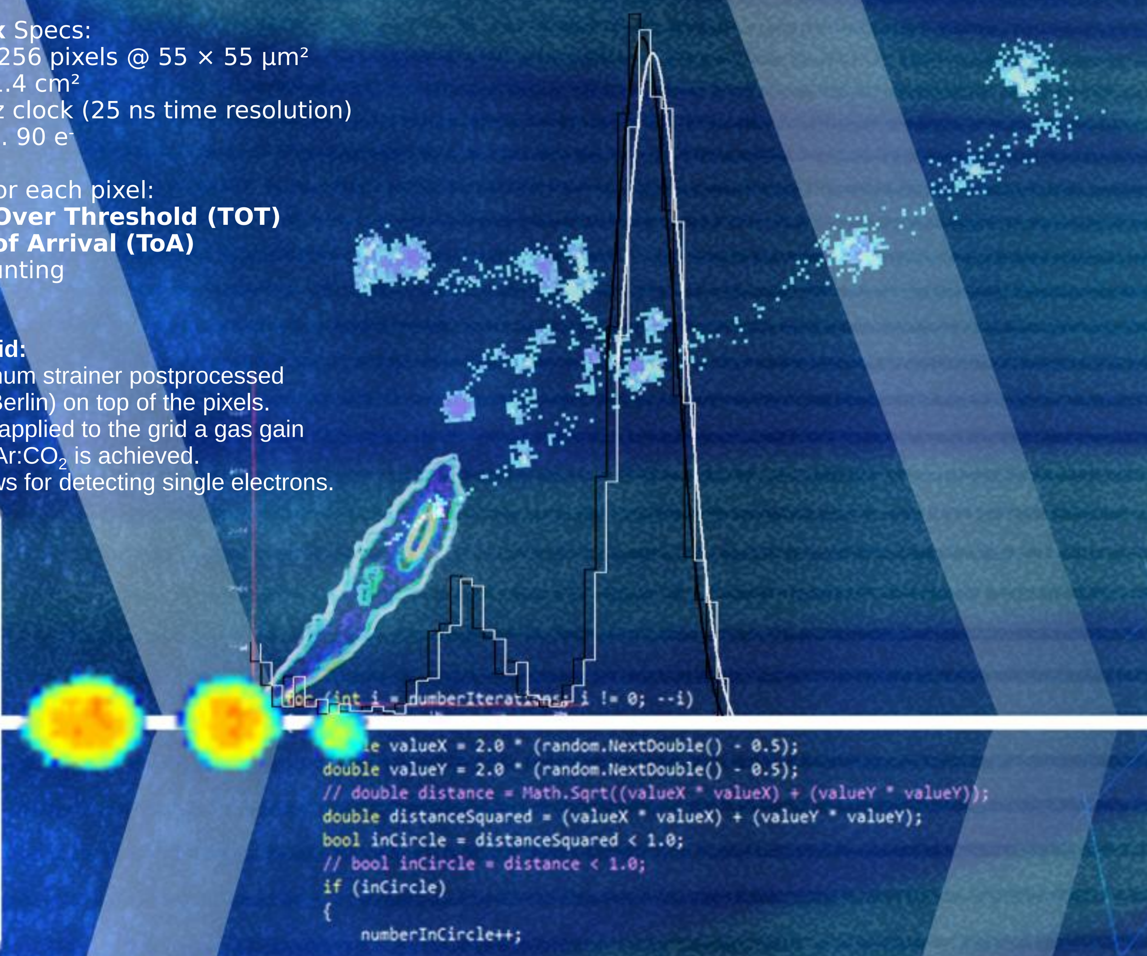


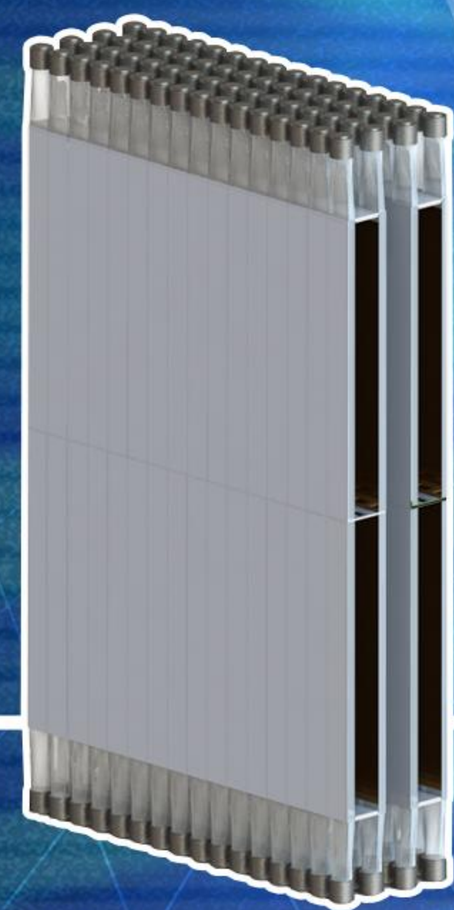
Timepix Specs:
- 256 × 256 pixels @ 55 × 55 μm^2
- 1.4 × 1.4 cm^2
- 40 MHz clock (25 ns time resolution)
- ENC ca. 90 e^-

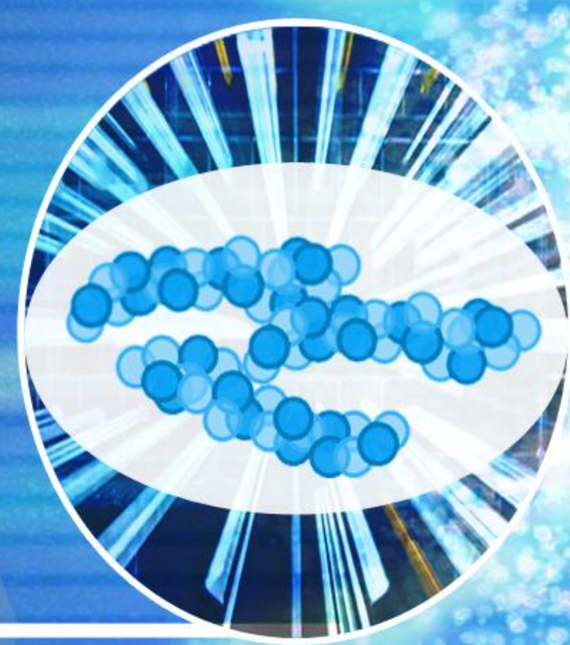
Modes for each pixel:
- **Time Over Threshold (TOT)**
- **Time of Arrival (ToA)**
- Hit Counting

The InGrid:
an aluminum strainer postprocessed (by IZM Berlin) on top of the pixels.
At 420 V applied to the grid a gas gain of 10^3 in Ar:CO_2 is achieved.
This allows for detecting single electrons.



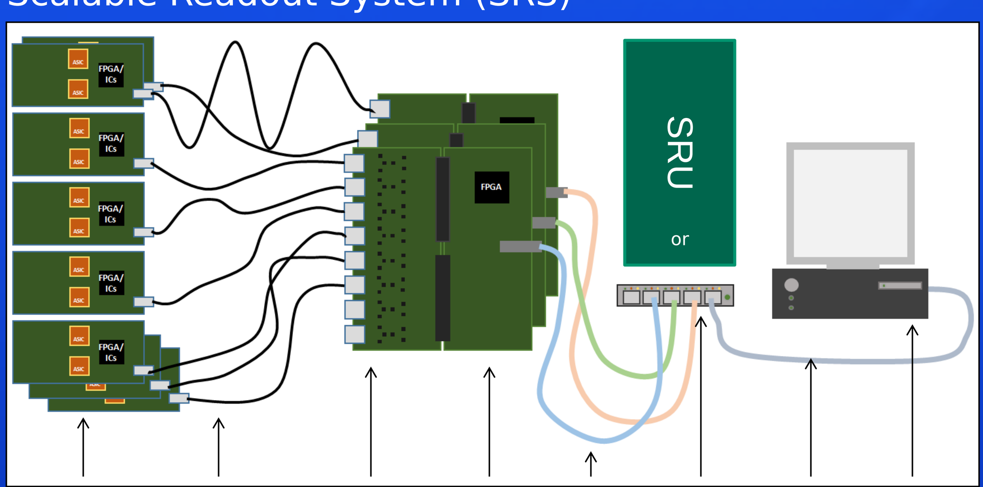






Readout Electronics

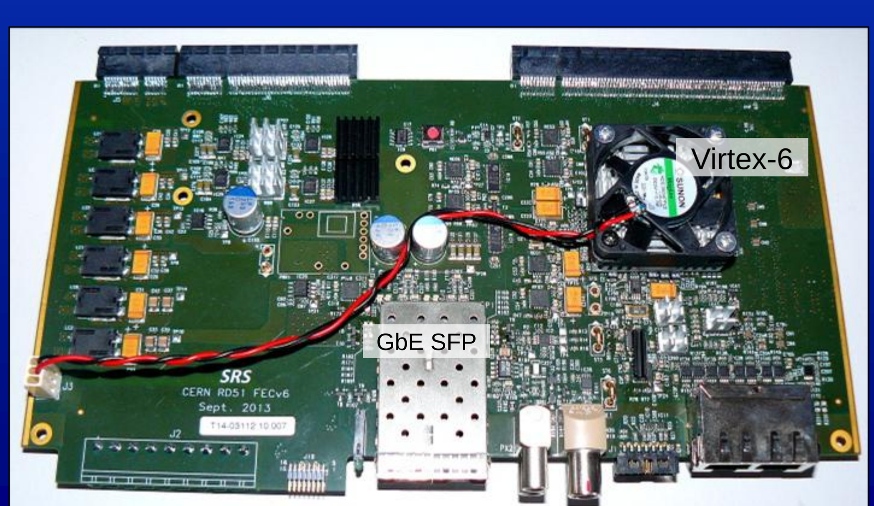
Scalable Readout System (SRS)



ASICs □ HDMI cable □ Adapter card + FEC □ Ethernet □ Switch □Ethernet □ PC

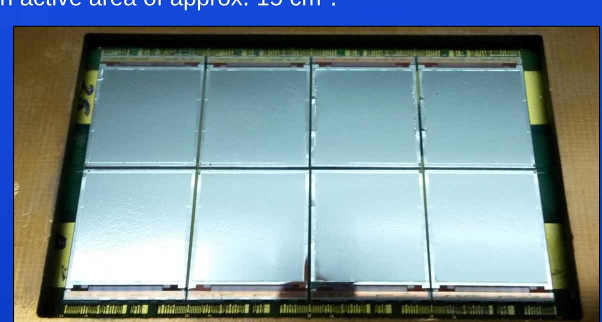
The Octoboard, on which the GridPix chips are mounted, is connected to an intermediate board, which acts as a customizable breakout for our subdetectors. Two HDMI interfaces are used for communication with the readout system - one for the slow control, the other one for data transfer. The slow control contains all state and action instructions that will be given to the chips. The intermediate board is connected to the C-card (adapter), serving as a communication interface for HDMI data transfer to the front end card (FEC) for up to four Octoboards or 32 Timepix chips. The Front End Card features a Virtex-6 FPGA, which hosts the state machine for the slow control and the data acquisition and zero-suppression unit. The system is run by the Timepix Operation Firmware (TOF), which communicates with the computer via GBit Ethernet by the Timepix Operation Software (TOS).

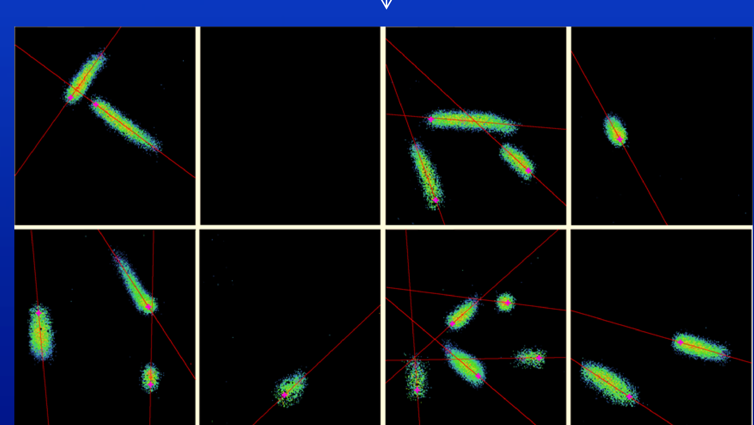
FECv6 (2013)



GridPix 8-chip board

8 Timepix chips are aligned in an array of 2x4 chips of 256x256 pixels, called Octoboard carrier, with approx. 525 000 pixels in total and an active area of approx. 15 cm^2.



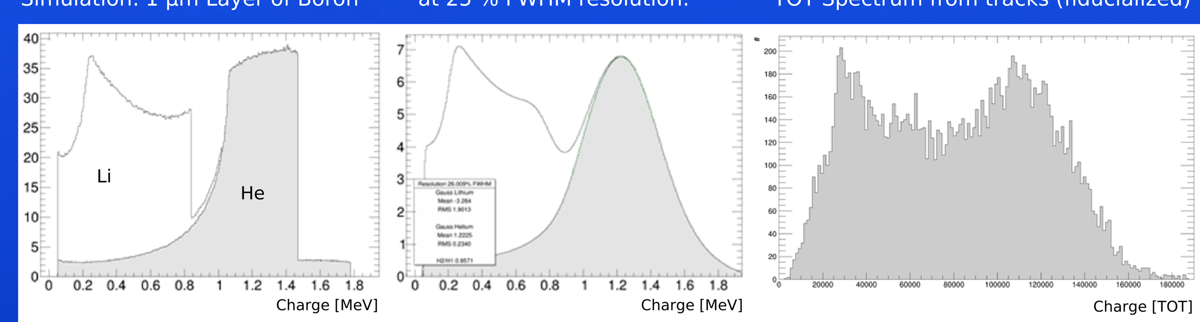


Event display showing exemplarily a collection of neutron conversions on the full Octoboard with Ar:CO2 at 350 V grid voltage. Two of the chips are disabled. The color code indicates the measured charge density in the TOT mode, whereas 5 % of the pixels, which are operated in TOA, are extrapolated by neighboring values.

Results

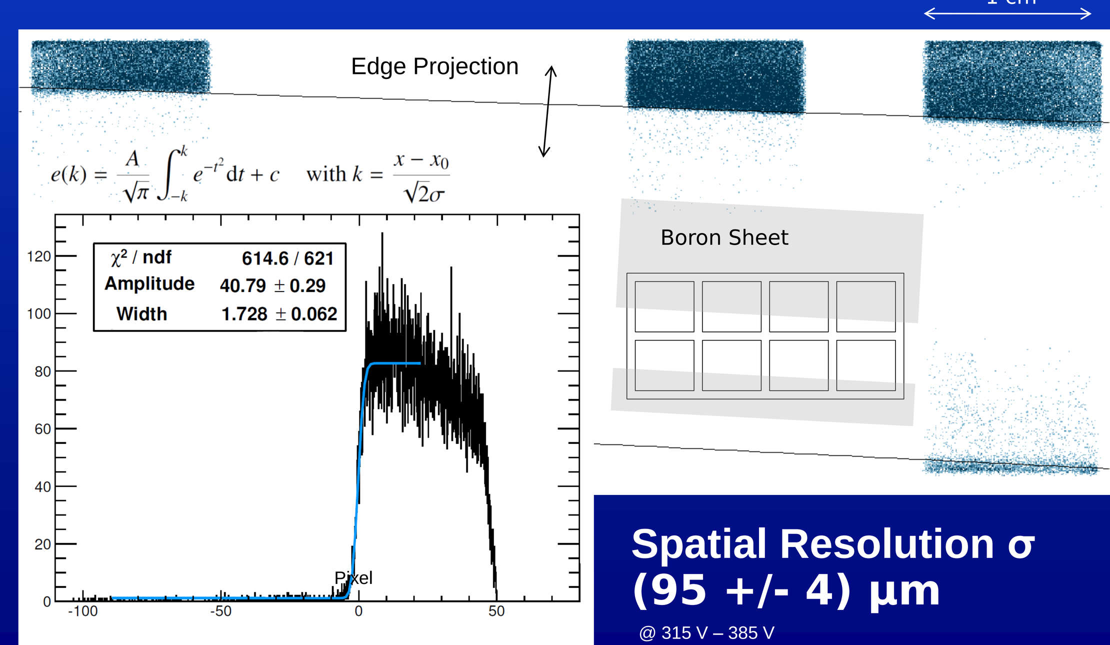
For our analysis the reconstructed starting points were fiducialized to select tracks which were projected fully onto the chip. This provides the typical energy deposition spectrum of a boron lined gaseous detector.

Simulation: 1 µm Layer of Boron — at 25 % FWHM resolution: — TOT Spectrum from tracks (fiducialized)



The spatial distribution was determined by replacing the homogeneously coated cathode by a boron strip with a clearly defined edge. The figure below shows the reconstructed starting points. A straight line was fitted to the data by calculating the residuals to this function and fitting an error function to the histogram of those whereas the parameters for the best line fit were minimized to yield an abscissa shift for the edge function close to zero and a slope minimizing the variance around the edge.

1 cm



Spatial Resolution σ (95 +/- 4) µm
@ 315 V – 385 V

References

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J. Kaminski, et al., *GridPix detectors - introduction and applications*, Nucl. Instrum. Methods A **845** (2017) 233–235. doi: 10.1016/j.nima.2016.05.134
M. Köhli et al., *Novel Neutron Detectors based on the Time Projection Method*, Physica B: Condensed Matter - ICNS Proceedings. doi: 10.1016/j.physb.2018.03.026

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