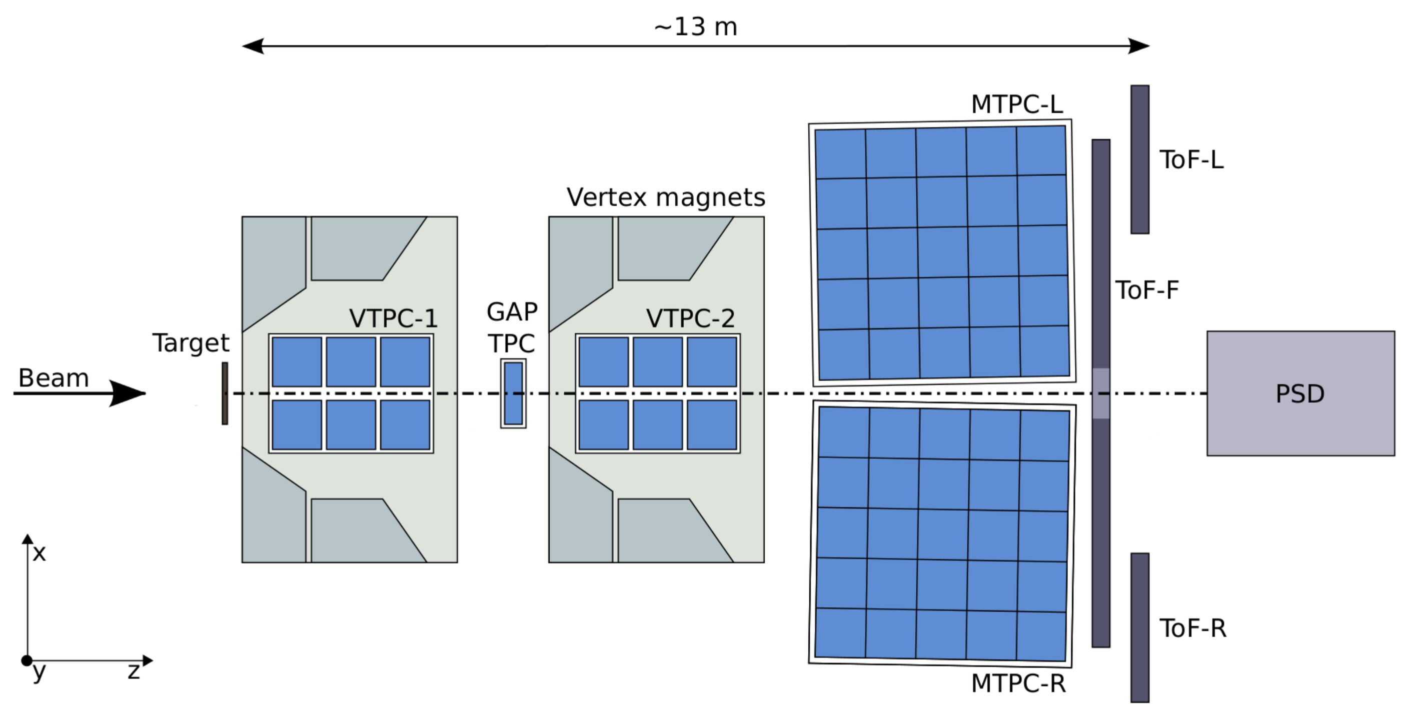
Time Projection Chambers

of the NA61/SHINE experiment

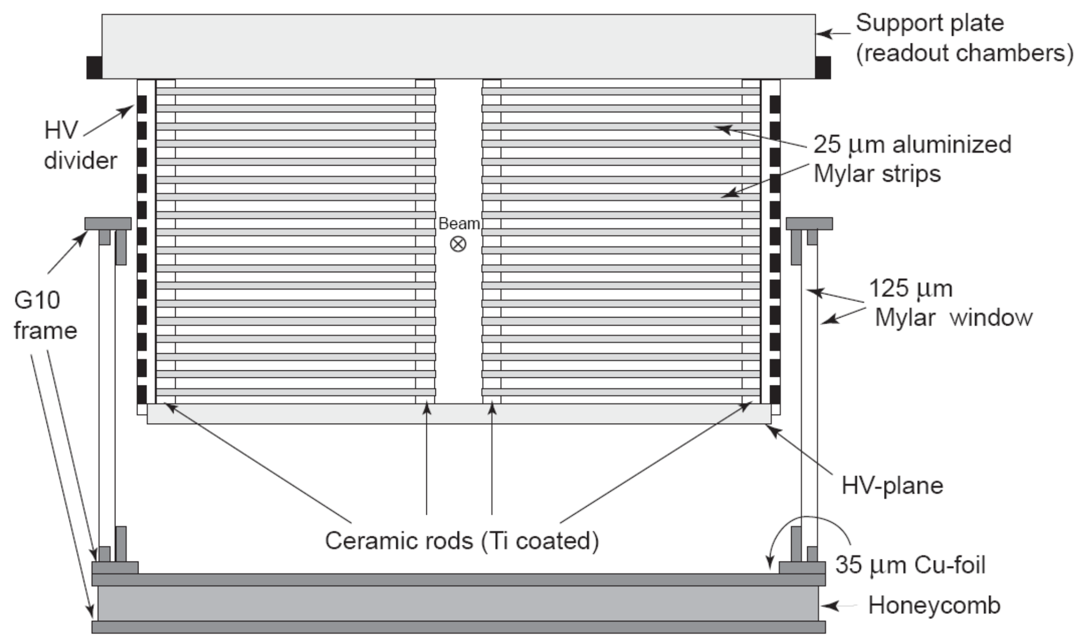
Detectors setup



The main tracking devices of the *NA61/SHINE* experiment are four Time Projection Chambers (TPC). Two of them (Vertex TPCs: *VTPC-1* and *VTPC-2*) are located in the magnetic field, two others (Main TPCs: *MTPC-L* and *MTPC-R*) are positioned downstream of the magnets. In addition a smaller TPC (*GAP-TPC*) is mounted between the two *VTPCs*. It is centered on the beamline for measuring particles with the smallest production angles. There is also the Low Momentum Particle Detector (*LMPD*), which consists of two small TPC chambers around the target.

Construction of the TPC

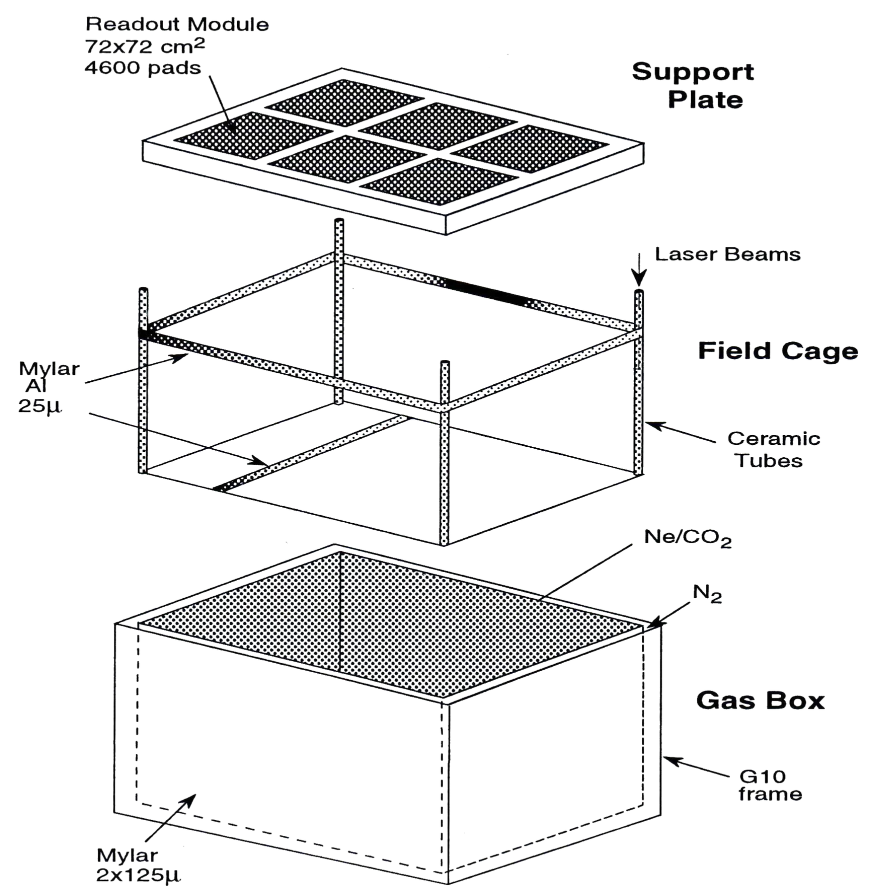
The TPCs consist of a large gas volume in which particles leave a trail of ionization electrons. A uniform vertical electric field is established by a surrounding field cage made of aluminized Mylar strips that are kept at the appropriate electric potential by a voltage divider chain. The electrons drift with constant velocity under the influence of the field towards the top plate where their position, arrival time, and total number are measured with proportional wire chambers. In order to achieve high spatial resolution the chamber top plates are subdivided into pads of about one square centimeter area, a total of about 180 000 for all TPCs. From the recorded arrival times of the track signals and the known pixel positions one gets a sequence of 3-dimensional measured points along the particle trajectories.



Construction of the TPC

Each Main TPC has a readout surface at the top of $3.9\times3.9\text{m}^2$ and a height of the field cage of about 1.1m. It is filled with a gas mixture of Ar/CO_2 in the proportion 95/5. The track signals are read out by 25 proportional chambers providing up to 90 measured points and ionization samples on each particle trajectory. The accuracy of the measurement of the average ionization energy loss for a particle is about 4%.

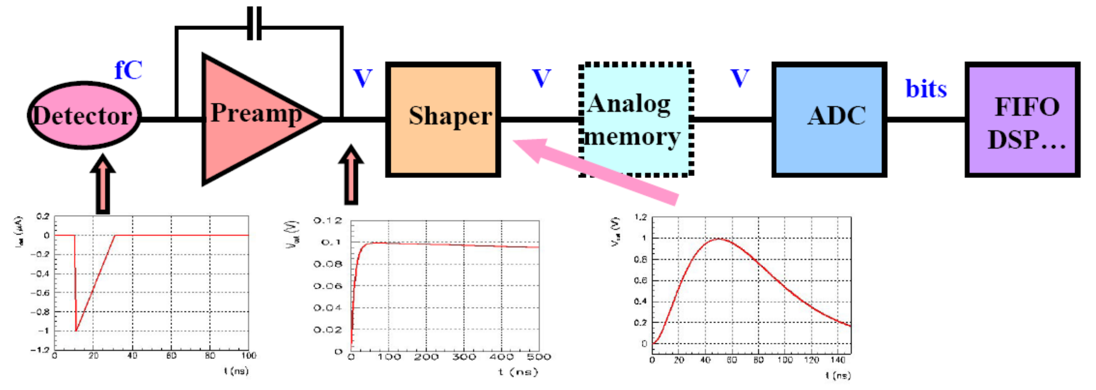
Each Vertex TPC consists of a gas box with $2.0\times2.5\text{m}^2$ top surface area and 0.67m depth. The inserted field-cage structures exclude the region of 0.12 m on either side of the beamline in which the particle density in Pb+Pb reactions is so high that trajectories cannot be resolved. A gas mixture of Ar/CO_2 in the proportion 90/10 is employed. The readout is performed by 6 proportional chambers on the top which provide up to 72 measurements and ionization samples on the particle trajectories.



Front-end electronics

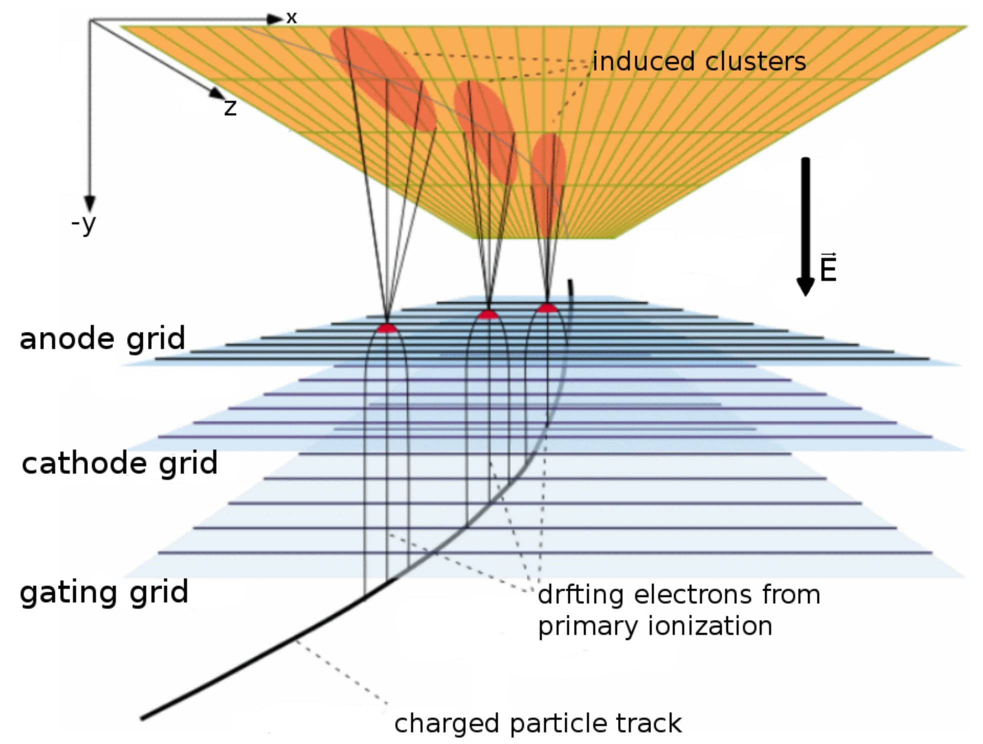
Readout of the charge signal of the pads in consecutive short time intervals provides *3 dimensional* information on the particle trajectories traversing the the TPCs. The electronic readout of the pads is performed by the *TPC Front End Electronics (FEE)*.

One FEE channel is dedicated to each readout pad, pre-amplifies the signal and stores the analog charge of a given time sample in a capacitor array. After the analog charges are stored in the capacitor arrays their digitization is performed via a *Wilkinson ADC* on the card, and the digitized charge values are forwarded to the readout electronics.



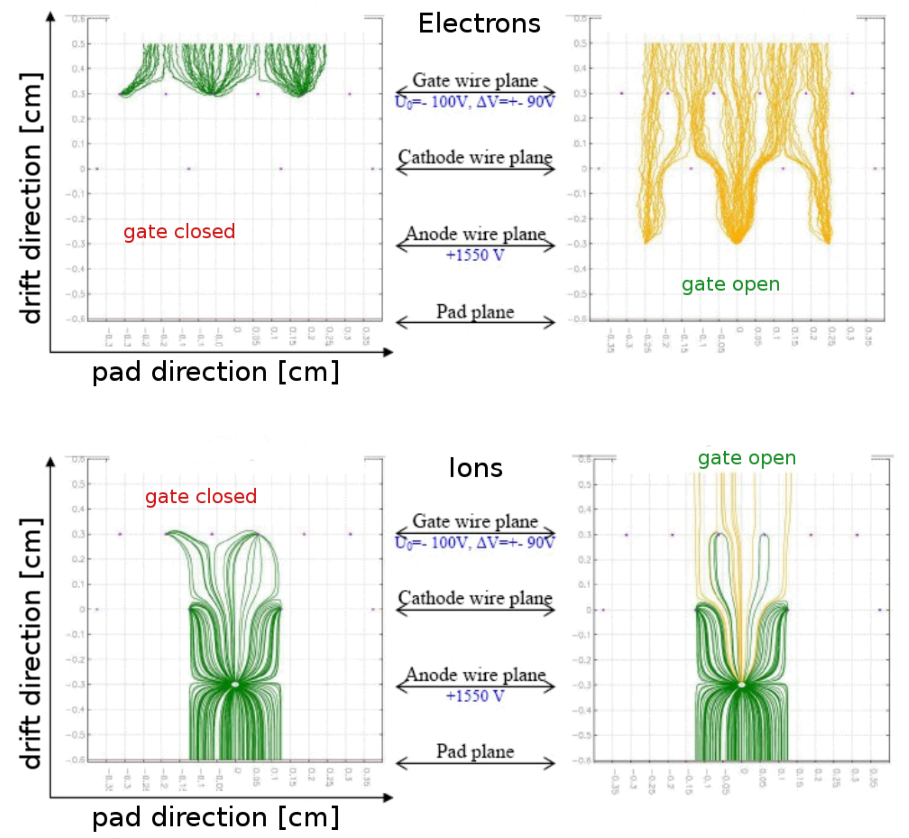
Working principle

As a high energetic charged particle bursts through the TPC, it leaves the track of ionized gas. In the homogeneous electric field the electrons from primary ionization are drifted in y direction. Close to the pad plane they are accelerated by the cathode and then attracted to anode wires causing the particle shower, which later hits the pads inducing electronic signals.



Amplifying grid

In the pictures below there are shown simulated tracks of electrons coming from the chamber volume. With the gating grid in an open mode they are reaching anode wires, causing the ion shower. Ions are pushed away from anodes and they reach the pad plane. When the gate is closed all the electrons land on gate wires and there is no signal induced.



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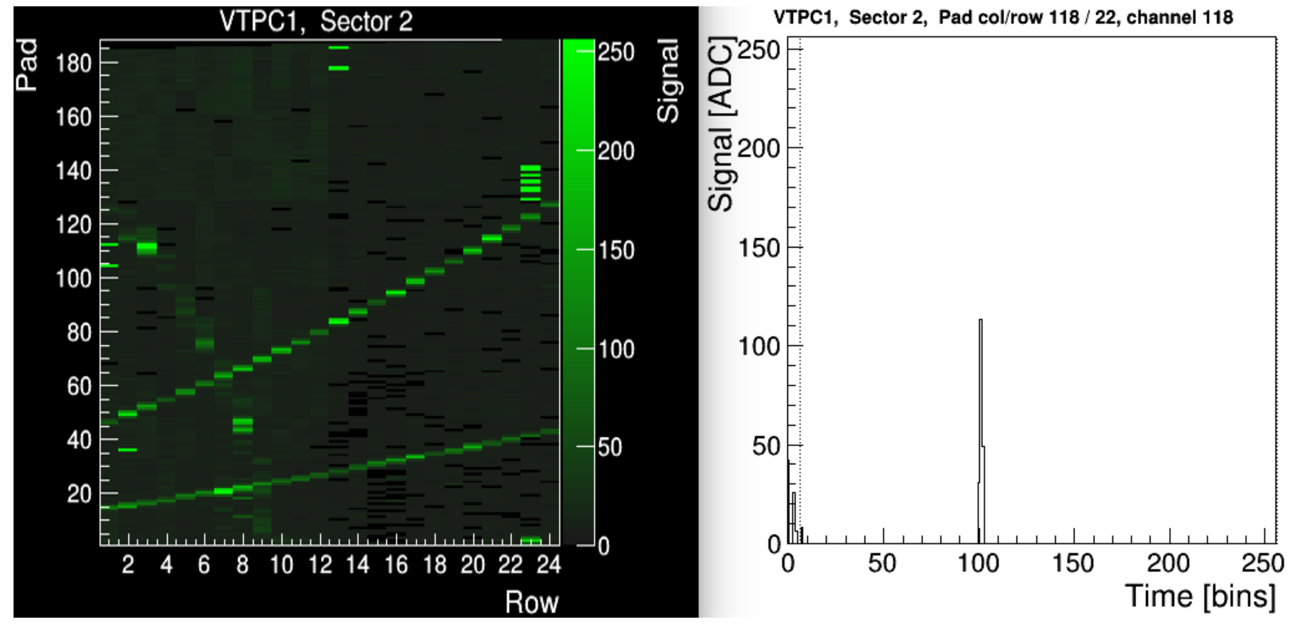
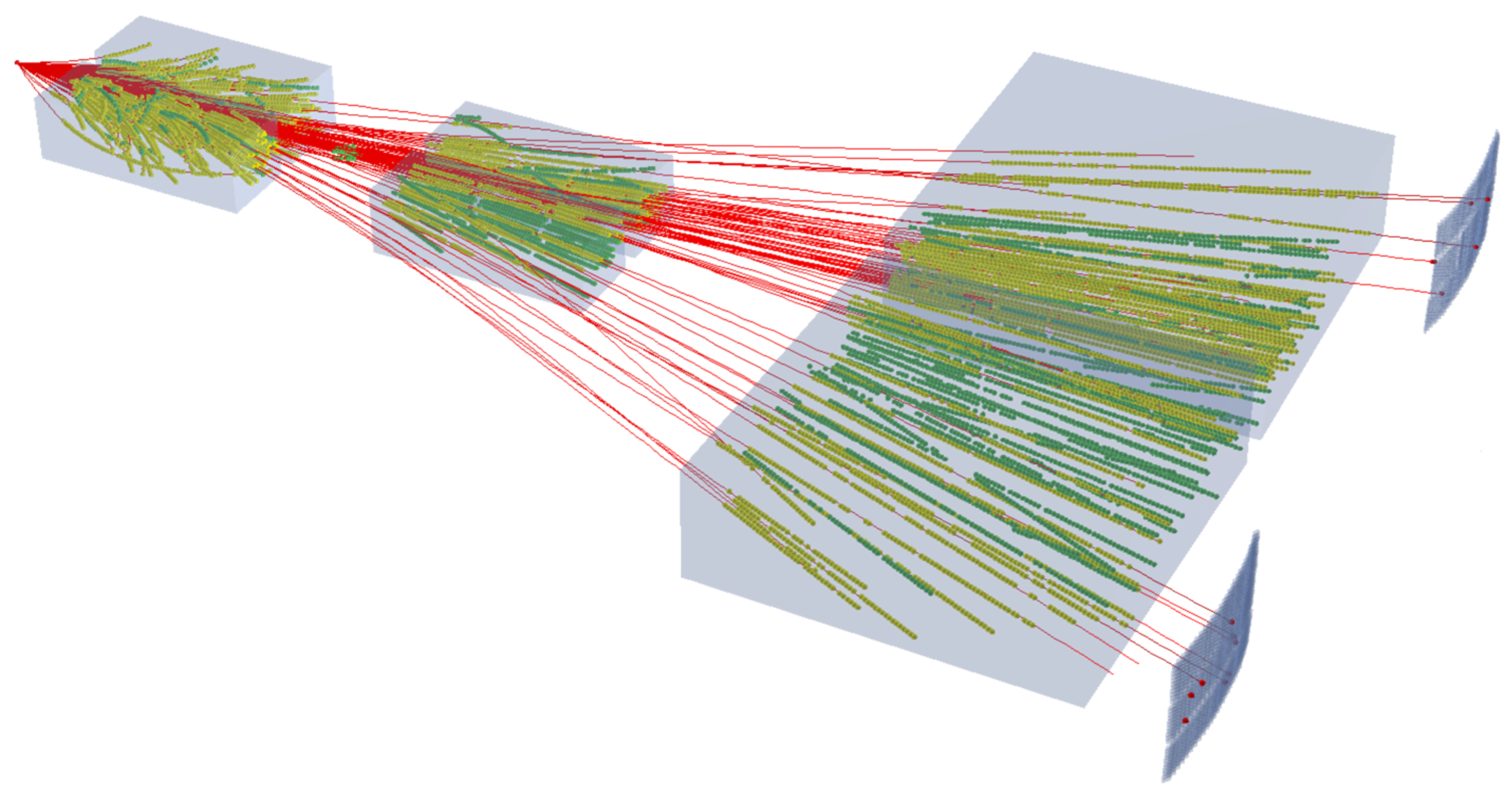
Read-out signals and signal clusters



Each pad reads a signal in a time-frame of 50 μs. Peaks of the histograms are then composed into clusters – both position-wise and time-wise.

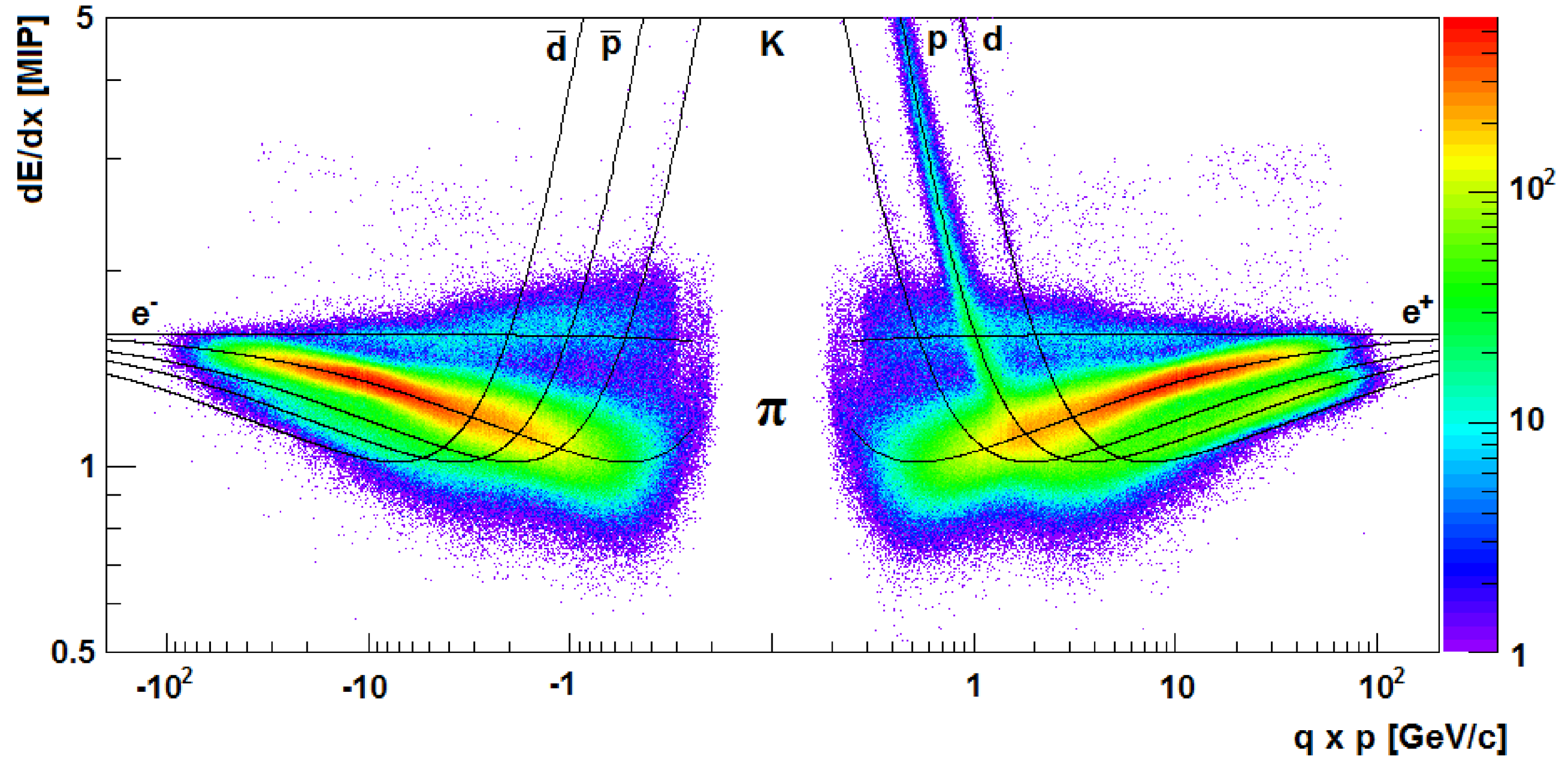
Track identification



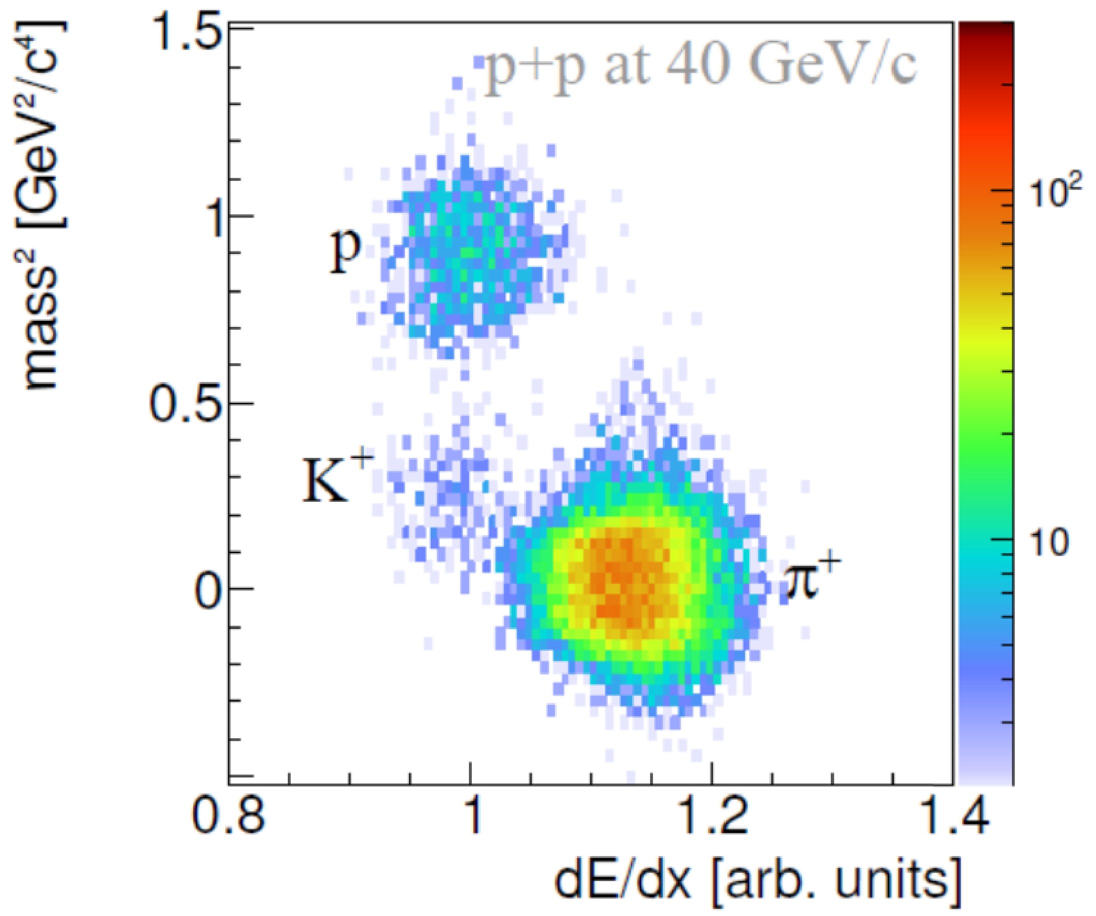
The TPCs allow reconstruction of over 1000 tracks in a single Pb+Pb interaction. Up to 234 clusters and samples of energy loss per particle trajectory provide high statistics for precise measurements.

Particle identification

Knowing the precise $\frac{dE}{dx}$ ratio we can identify particles, which flew through the TPC:

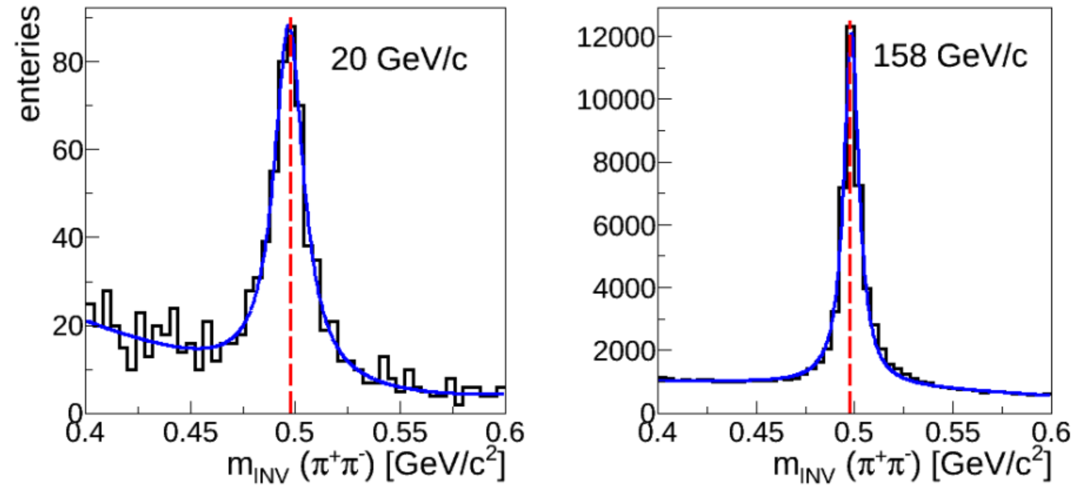


The precision of $\frac{dE}{dx}$ measurement is limited due to energy loss fluctuations. Repeated measurements are in fact samples from an energy loss distribution, which shows large fluctuations towards high losses, so called **Landau tails**. However for a thick enough material the number of collisions grows and the distribution resembles Gaussian function (central limit theorem).
High energy charged particles undergo an additional energy loss (in addition to ionization energy loss) due to **bremsstrahlung**, i.e. radiation of photons, in the Coulomb field of the atomic nuclei.

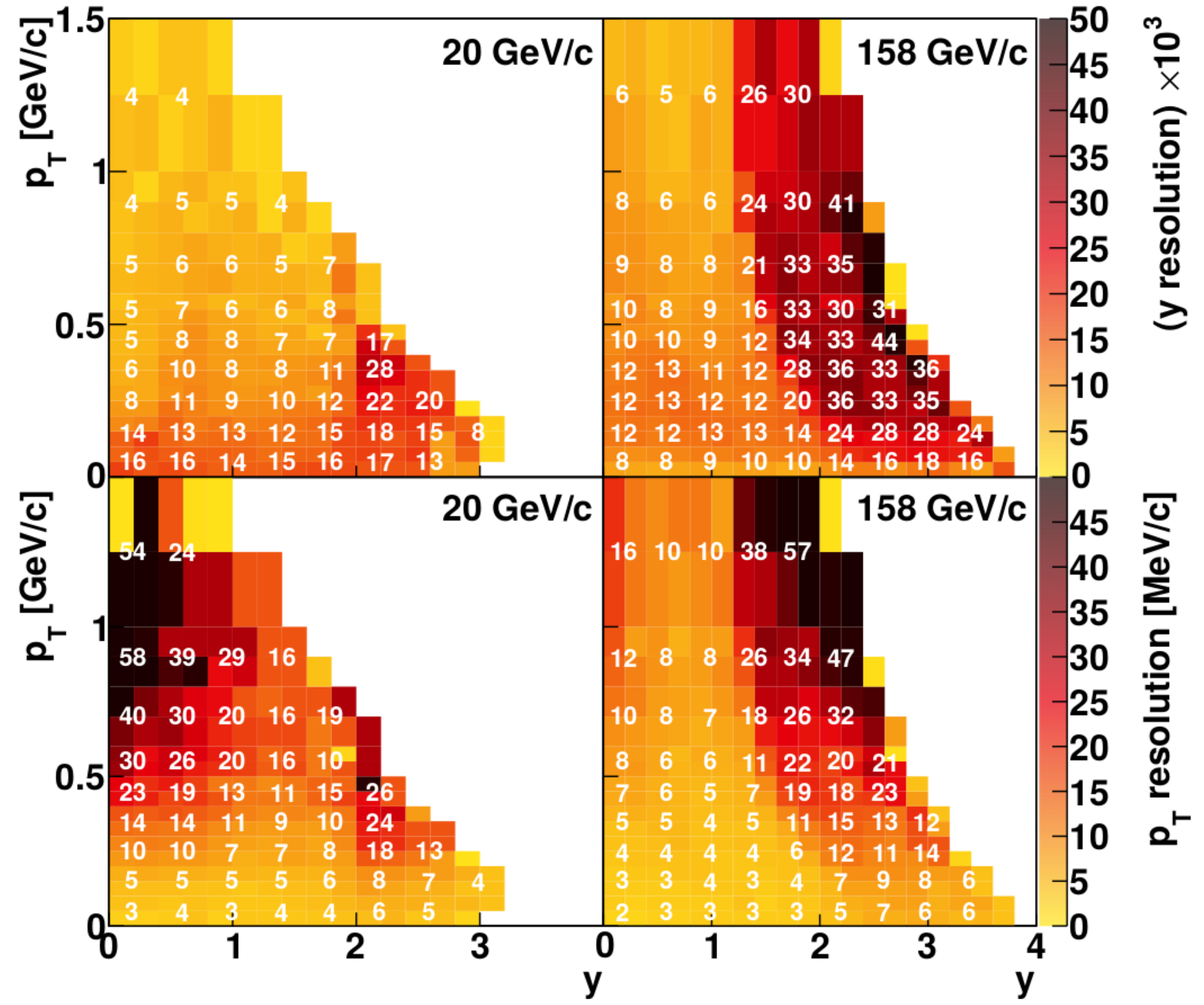


Physics performance

The quality of measurements was studied by reconstructing masses of K^0_S particles from their V^0 decay topology. As an example the invariant mass distributions of K^0_S candidates found in p+p interactions at 20 and 158 GeV/c are plotted in the figure below. The measured peak positions 496.8±0.6 and 498.3±0.1 MeV/c² are in reasonable agreement with the PDG value $m_{K^0_S}$ = 497.6 MeV/c².



The track reconstruction efficiency and resolution of kinematic quantities were studied using a simulation of the detector. Estimates were obtained by matching of generated tracks to their reconstructed partners. As examples, the reconstruction efficiency as a function of rapidity y and transverse momentum p_T for negatively charged pions produced in p+p interactions at 20 and 158 GeV/c is shown in the figure below.
The resolution was calculated as the FWHM of the distribution of the difference between the generated and reconstructed y and p_T. Presented results were obtained for negatively charged pions passing the event and track selection criteria used in the data analysis, including rejection of the azimuthal angle regions where the reconstruction efficiency drops below 90%.



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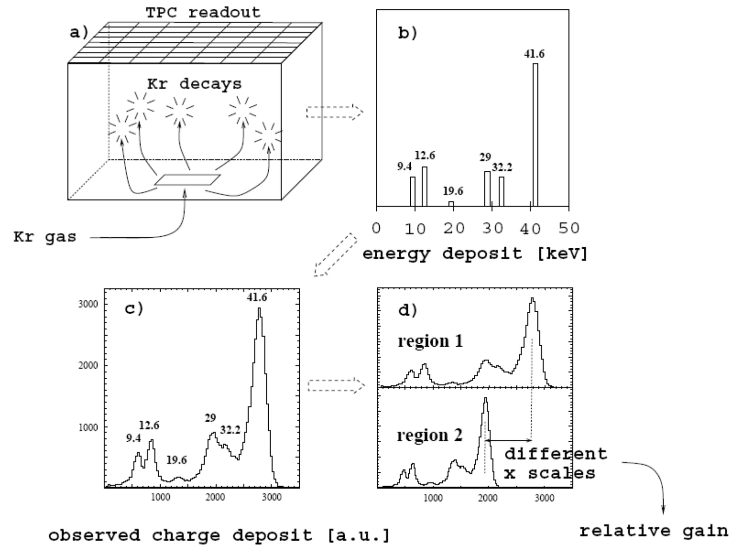
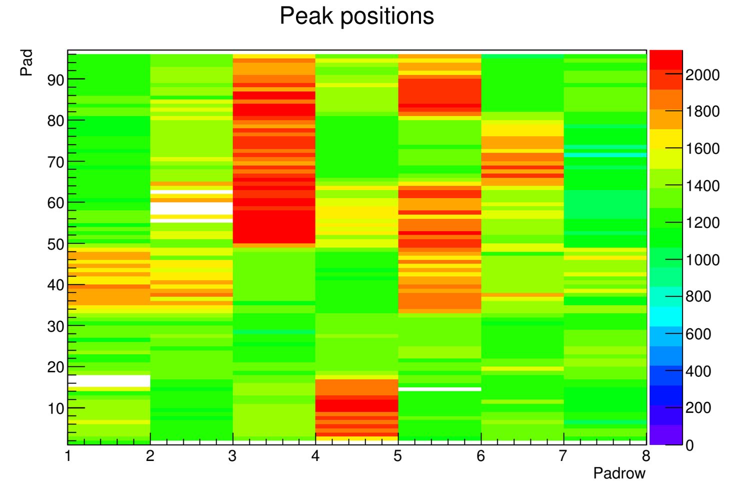
Gain calibration

Krypton calibration is a crucial process to increase resolution of time projection chamber pads. First, we inject radioactive krypton $^{83}_{36}Kr$ gas to the time projection chambers and wait for decays. As the $^{83}_{36}Kr$ has short half life, we can quickly obtain signal on pads.

Having large enough statistic from pad readout, we can compare obtained data with *Monte Carlo simulation* for krypton decay. Taking the main krypton peak position from MC simulation and comparing it with main peak in pad data, we obtain a *factor* that can be used to increase resolution of time projection chambers. Pads that have overflow in data readout can be silenced and pads with underflow can be strengthen. This also allows us to determine malfunctioning pads.

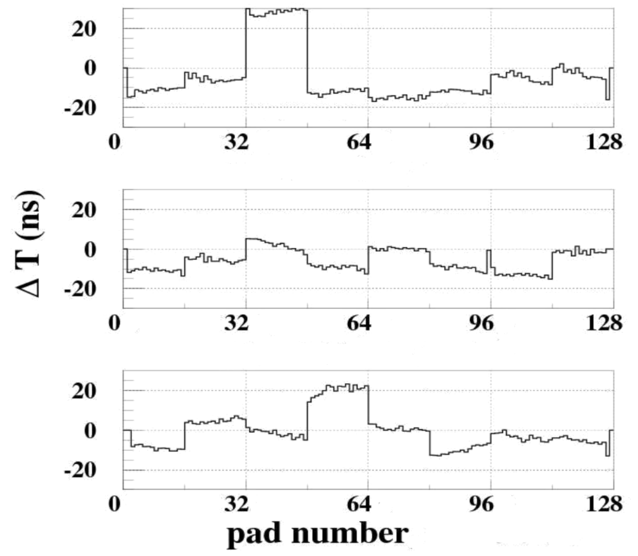


Scheme of *krypton calibration*

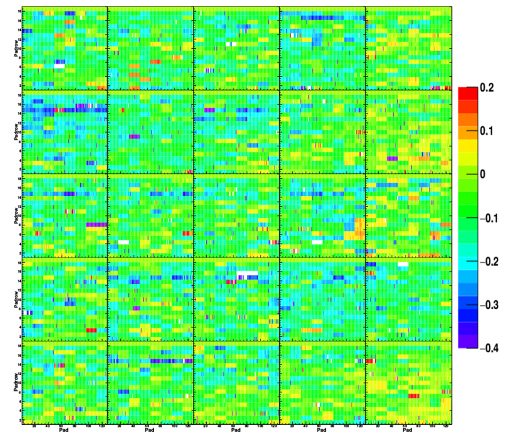


Krypton *peak position* in Gap TPC

Time calibration



Time delays pictured for *MTPCL*. The scale is in time bin units (1 time bin = 100 ns).

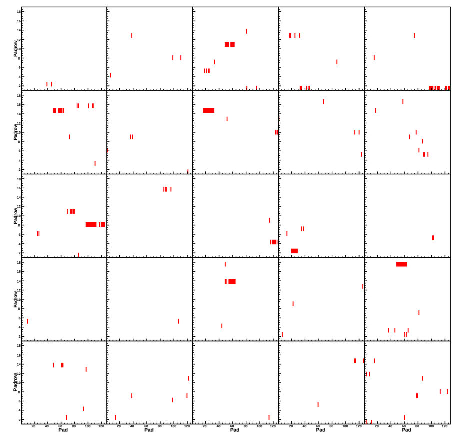


Due to differences in fabrication and electronics' properties there are time delays observed, specific for each pad. The resolution of the detector is estimated for 100 ns and the delays may even exceed this value. Time shifts between pads are distinguished into two categories:

- Chip to chip – trigger cable length variations (large).
- Pad to pad – shaping time variations (small).

There are 16 pads under one chip, therefore the larger step every 16 pads is clearly visible. Such a calibration is also able to determine malfunctioning pads.

A map of malfunctioning pads for *MTPCL*. The number of faulty pads equals ≈1% of total number of pads.



Ageing

Pictures presenting possible ageing effects of wires in gating grids.