LABORATÓRIO DE INSTRUMENTAÇÃO
E FÍSICA EXPERIMENTAL DE PARTÍCULAS
partículas e tecnologia

Participation in the development of a new neutron detection technology based on ^{10}B-RPCs

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Supervisors

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Motivation

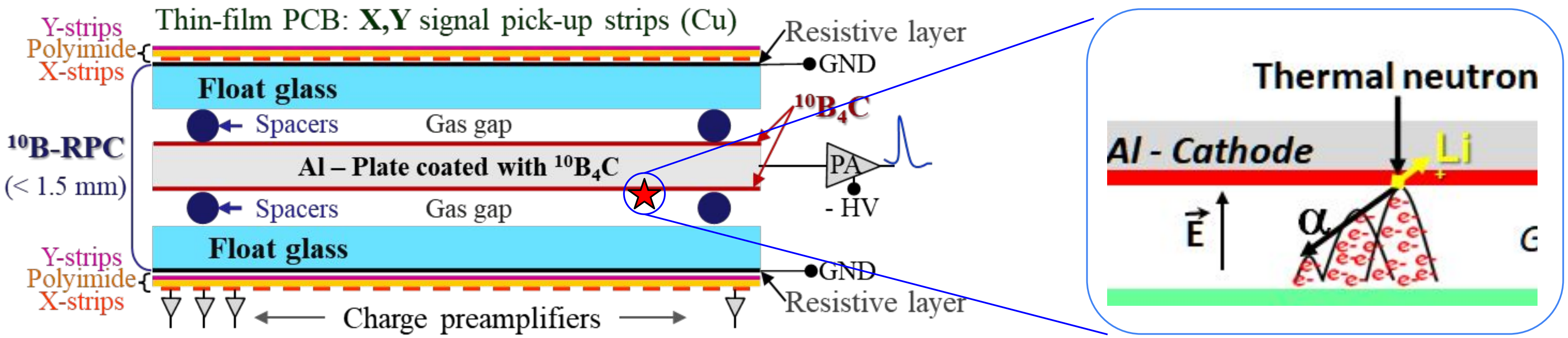
- ➢ Need for alternatives of ^{3}He-based detectors → ^{10}B-based
- ➢ RPCs are widely used in large area detectors, e.g., in High Energy Physics (HEP) and Astroparticle Physics experiments

Advantages of ^{10}B-RPC detectors:

- Very high timing resolution (sub-ns)
- Good spatial (down to ~100 μm) resolution
- Modularity and scalability
- Large detection areas at affordable cost

nRPC-4D: Detector concept (Simple)

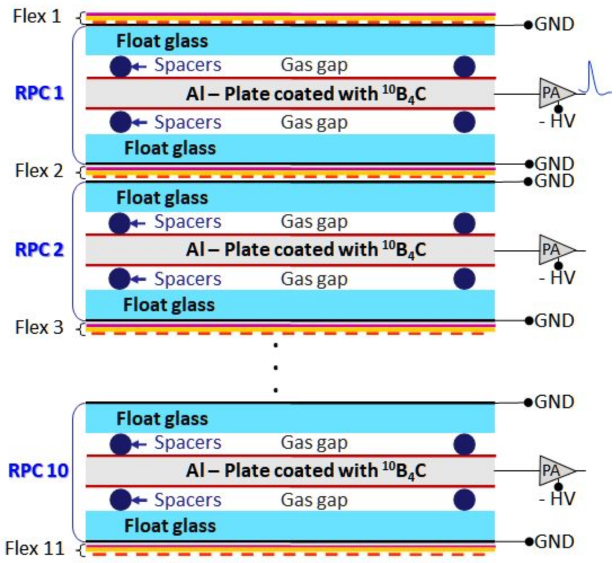
Combines RPCs with $^{10}B_4C$ thin films to get sensitivity to thermal neutrons
Provide data on 2D position of every detected neutron

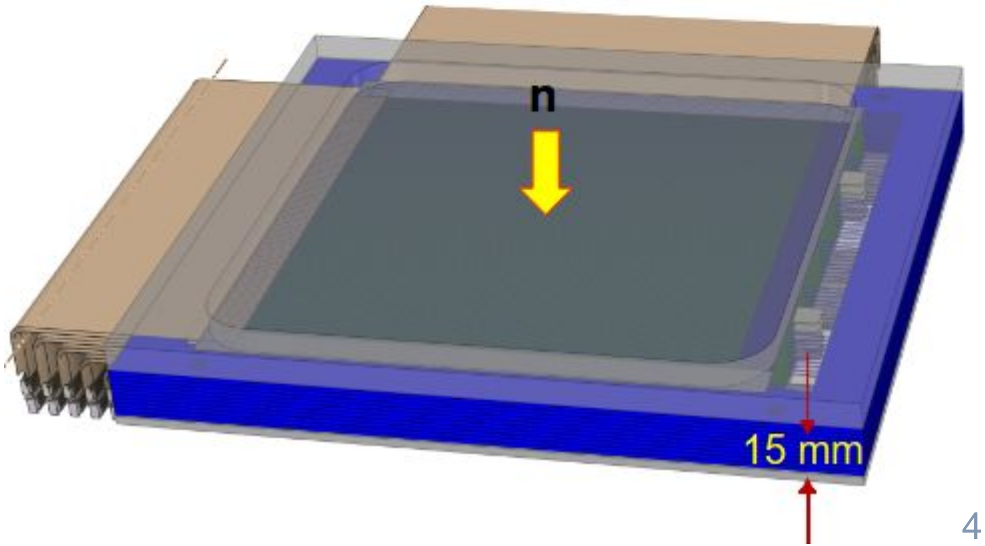


$$n + {}^{10}B \rightarrow \begin{cases} {}^{7}\mathrm{Li}(0.84\ \mathrm{MeV}) + {}^{4}\mathrm{He}(1.47\ \mathrm{MeV}) + \gamma(0.47\ \mathrm{MeV}), & 94\% \\ {}^{7}\mathrm{Li}(1.01\ \mathrm{MeV}) + {}^{4}\mathrm{He}(1.78\ \mathrm{MeV}), & 6\%. \end{cases}$$

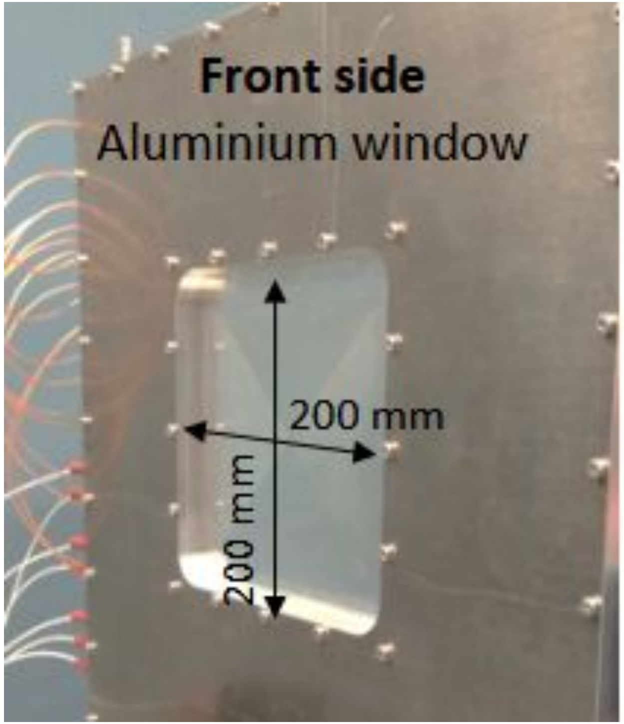
nRPC-4D: Detector concept (Multiple Layers)

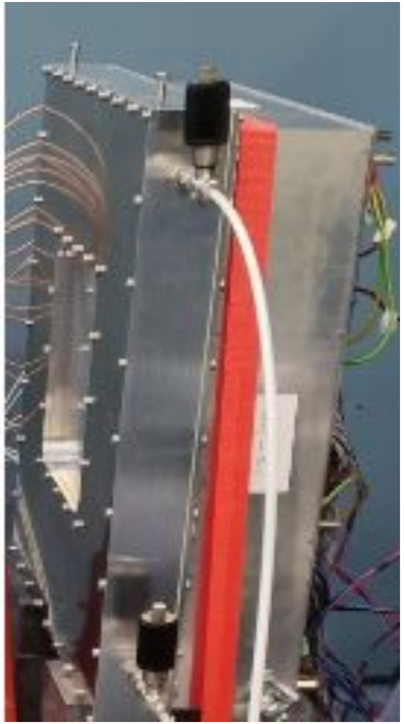
- Offers XYZt (4D) readout capability
- High neutron detection efficiency (>50%)

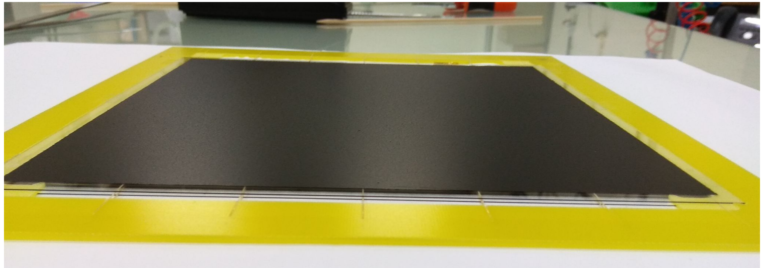


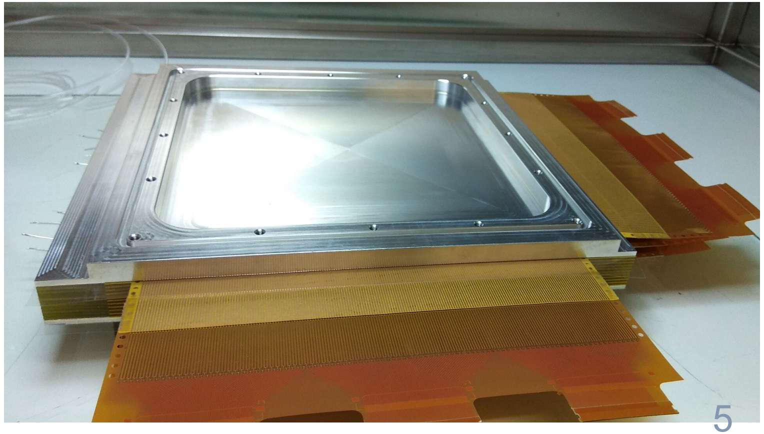


Close-ups and Components Overview



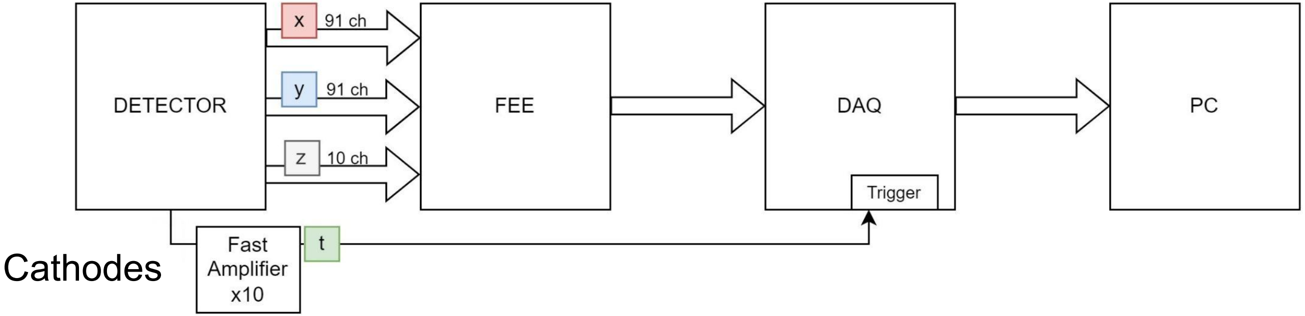


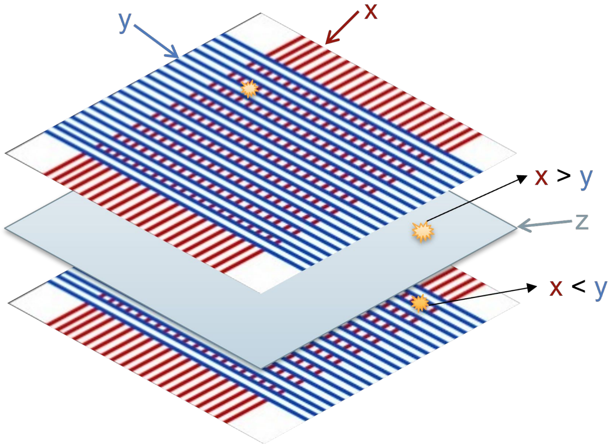


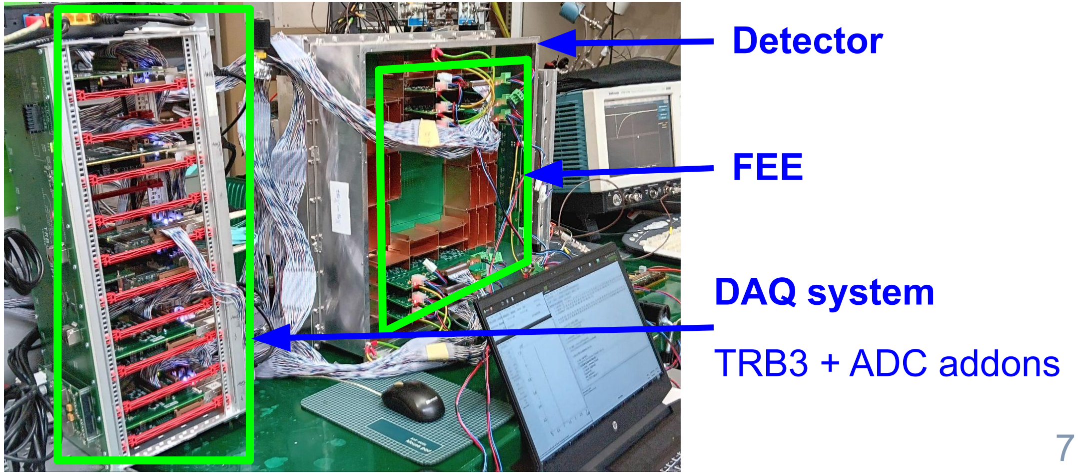


Detector Readout

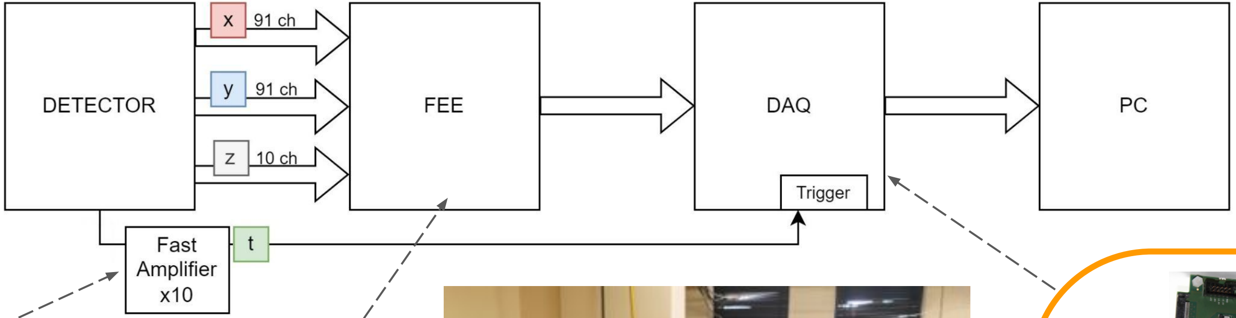
Detection System



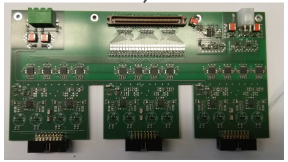




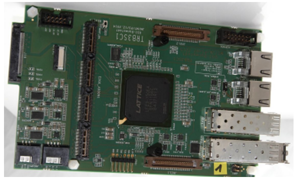
Detection System



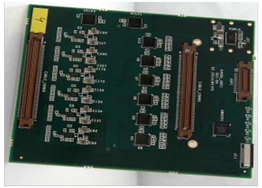
Timing amplifiers
(Bipolar polarity, gain ~60 @ 1GHz and LVDS outputs)



Front End Electronics Board
(24 charge PAs with 50 mV/pC sensitivity)



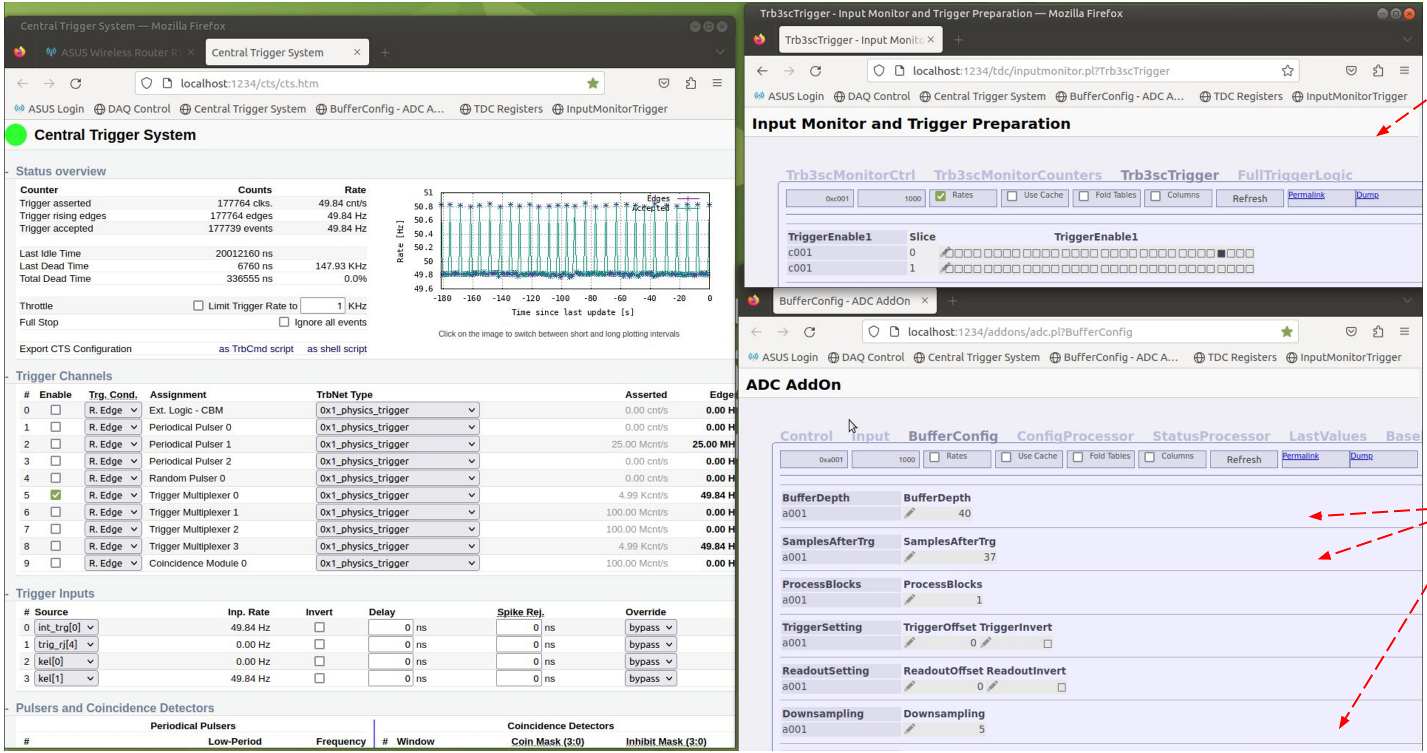
DAQ - TRB3 (trb.gsi.de)
(48 ch 10 ps TDC)



ADC addon
(48ch 40 MHz streaming ADCs)

DAQ control and configuration

3. Select the Trigger Mode



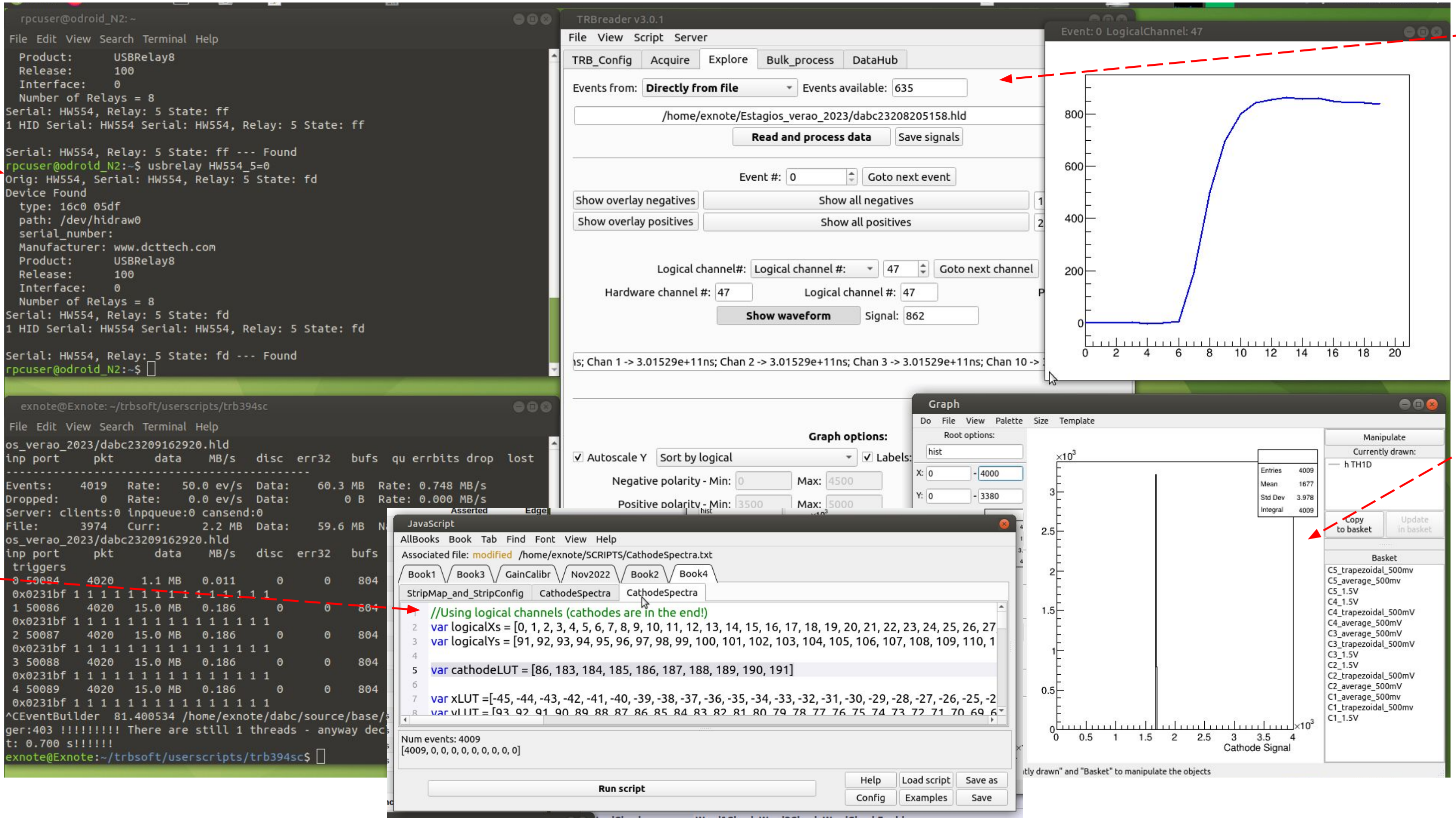
1. Start up the system

2. Adjust DAQ's parameters

Data acquisition and signal processing

4.
Acquire the data

6.
In ANTS2, modify the Javascript file

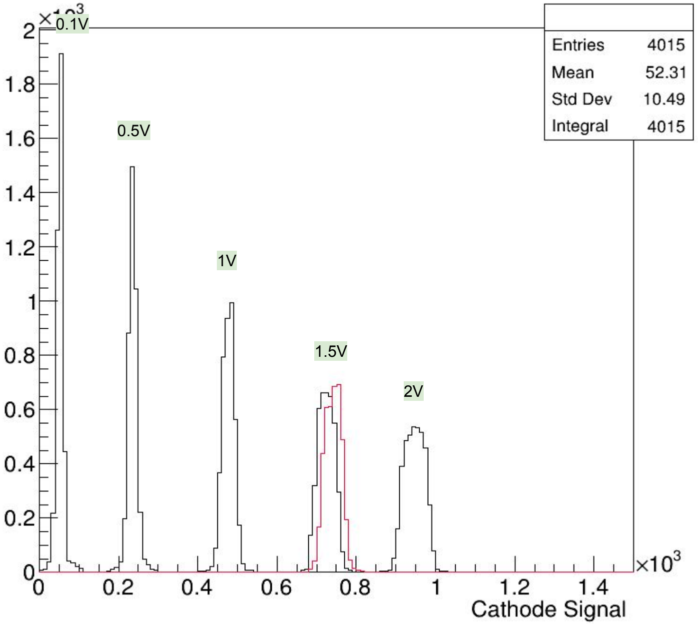


5.
Visualize the waveforms using TRBreader

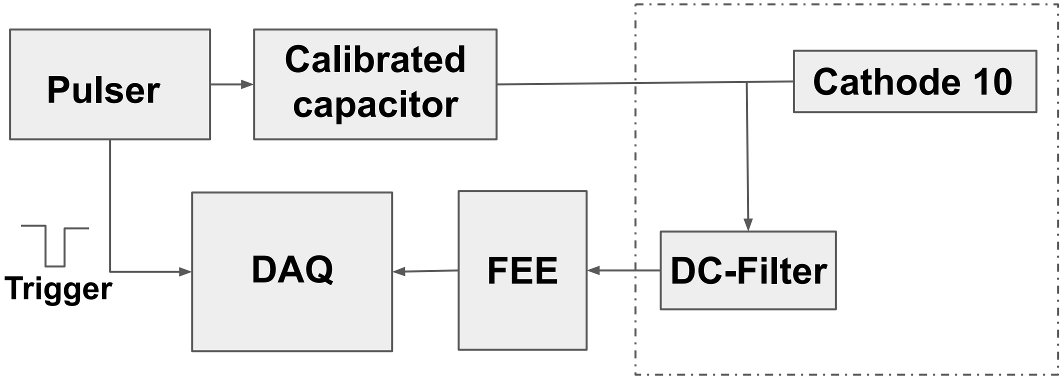
7.
Obtain the charge spectrum

Calibration of the cathodes channels

Example of the charge calibration for the cathode no. 10



Distribution of the cathode signal amplitudes for increasing values of the applied voltage (V_{in}), showed in black for cathode no. 10. The red curve represents the signal amplitude for cathode no. 7 and displays a similar sensitivity when applying a tension of 1.5V.

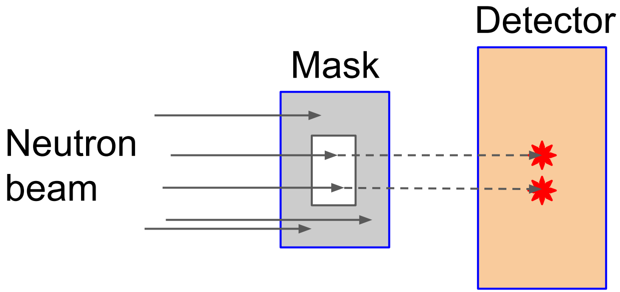


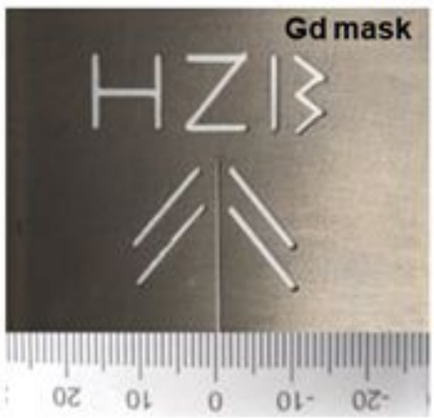
Optimal Values:

Buffer Depth = 40
Samples After Trigger = 37
Down Sampling = 4

XY Position Reconstruction

XY Position reconstruction

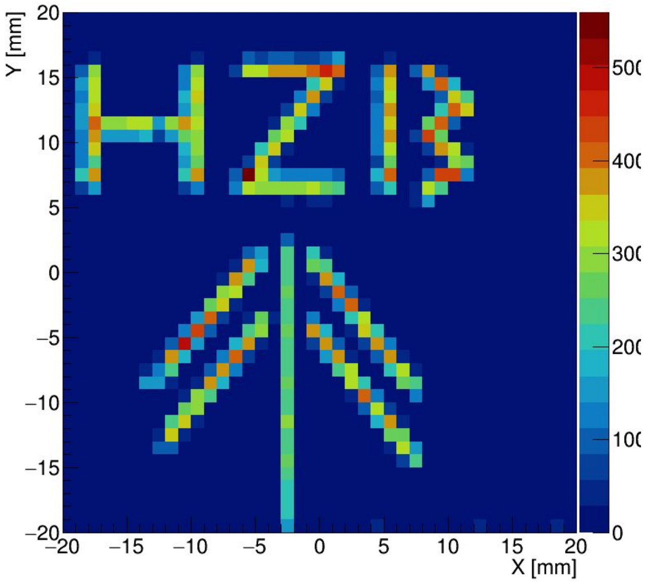




0.25 mm thick gadolinium mask forming the letters “HZB” and a pictogram of a tree

- **Objective**: to evaluate the performance of the detector in terms of spatial resolution and degree of distortion.
- Three methods to perform the reconstruction were studied, tested and then compared to each other.
- Used experimental data recorded at the V17 neutron beam line at Helmholtz-Zentrum Berlin (HZB).
- The “HZB” mask was irradiated with a neutron beam with very low divergence.

Position reconstruction: strongest strip method

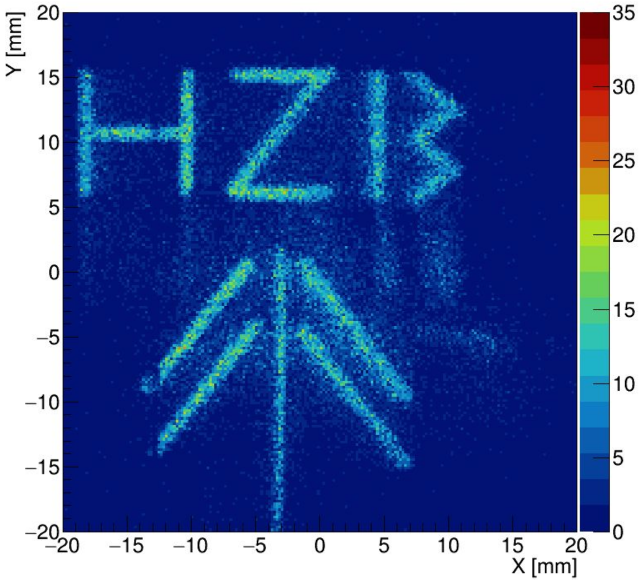


Reconstruction image obtained using the strongest strip approach
(40 x 40 bins)

➔ Every reconstruction method operates independently for *X* and *Y* directions for each event.

- The event position is set on the centre coordinate of the strip in which the strongest signal is detected.
- Due to the spatial resolution and step between the strips of the detector, this method is not the best approach.

Position reconstruction: Centroid method



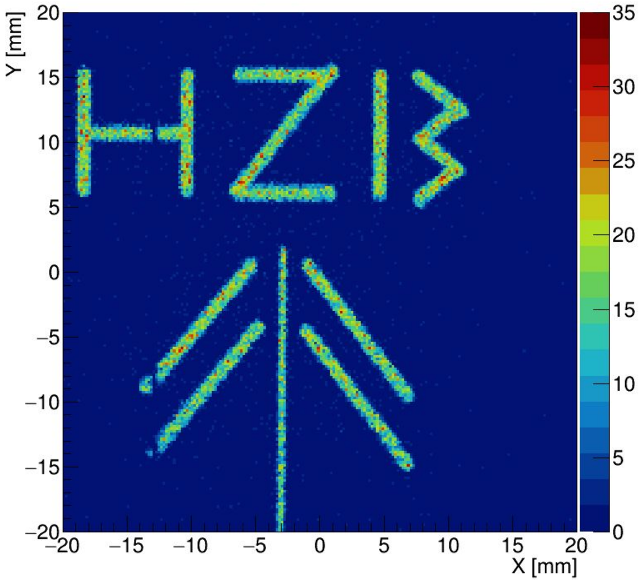
Reconstruction image obtained using a simplistic Centroid approach (200 x 200 bins)

- Similar to the calculation of the centre of mass of an object.
- The position *X* (same for *Y*) is given by the sum of the strip positions X_i weighted by the strip signals S_i over the sum of the strip signals:

$$X = \frac{\sum_i X_i S_i}{\sum_i S_i}$$

- The sums are performed over every strip of the set, resulting in many “ghost” events (the event is pushed to a wrong position by the weight of other signals).

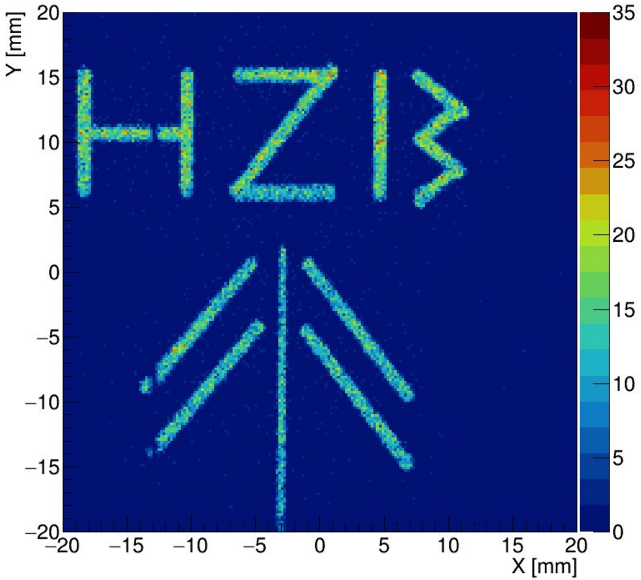
Position reconstruction: Centroid method



Reconstruction image obtained using an optimized Centroid approach (N = 4; 200 x 200 bins)

- Find the strip with the maximum signal.
- Consider *N* strips left and right the one with the maximum signal:
  - *2N+1* signals (or less) are taken into account.
- Perform the centroid calculation from the previous slide.
- Filtering based on discarding events in which:
  - The number of selected strips is less than 2.
  - The cathode signal is below or above certain thresholds.
  - The ratios $\frac{\sum_i S_{X,i}}{\sum_j S_{Y,j}}$ and $\frac{\sum_i S_{X,i} + \sum_j S_{Y,j}}{Cathode\ Signal}$ are below or above certain values.

Position reconstruction: Statistical method



Reconstruction image obtained using the Statistical approach (200 x 200 bins)

- *Strip Response Function* (SRF): describes the dependence of the strip signal on the lateral distance:

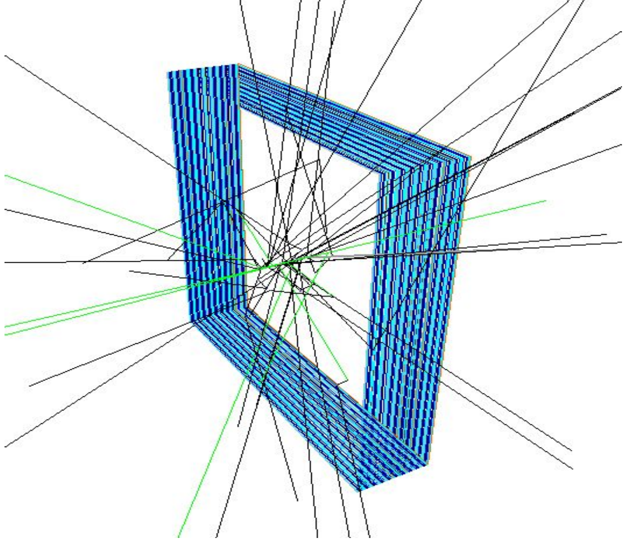
$$SRF_i(x) = \frac{A}{cosh(W(x - x_i))}$$

- 7 signals (or less) are taken into account (maximum + 6).
- Fitting according to the SRF above.
- The obtained *x* value gives the event position.
- Find the best possible match between observed strip signals and the corresponding signals predicted using SRF's. Achieved by evaluating:
  - Chi-square of the fit and value of W.

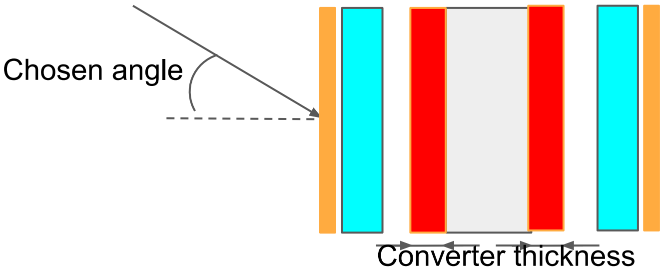
Simulations

Simulation: Motivation

- Simulations are needed to build a detector optimized in terms of detection efficiency and counting rate.
- We performed simulations considering the effect of the converter thickness and neutron angle of incidence on the detection efficiency.
- To perform the simulations we used the software package ANTS3.
- ANTS3 makes use of GEANT4 which is a toolkit for Monte-Carlo simulation of passage of particles through matter.
- Throughout simulations we have chosen neutron energy to be 25 meV.

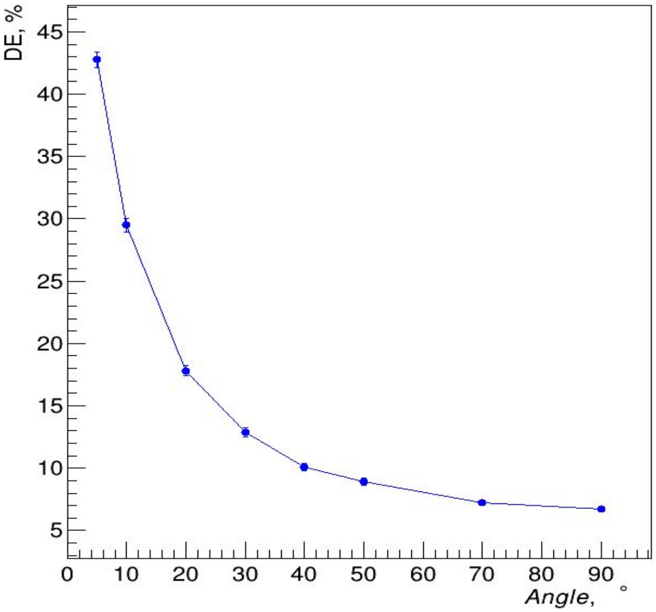


Simulation of 50 neutrons passing through the 10 Double-Gap RPC detector. Neutron tracks in green. Gamma-ray tracks in black.

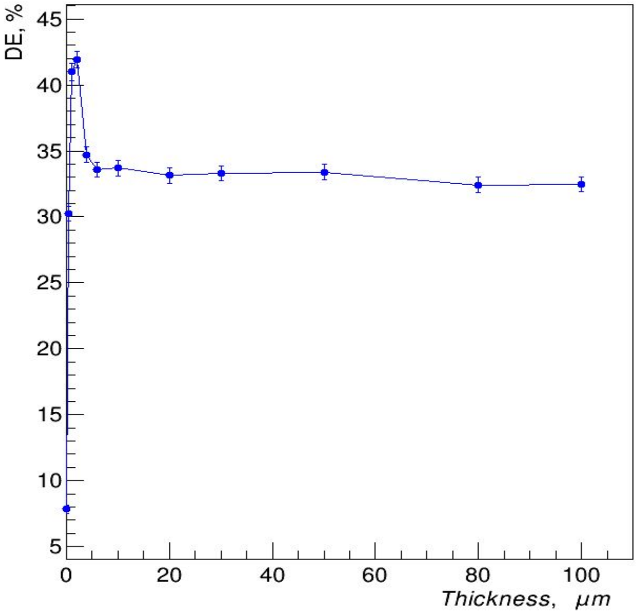


Schematic image on orientation of the neutron beam and converter thickness.

Effect of the angle of incidence and converter thickness

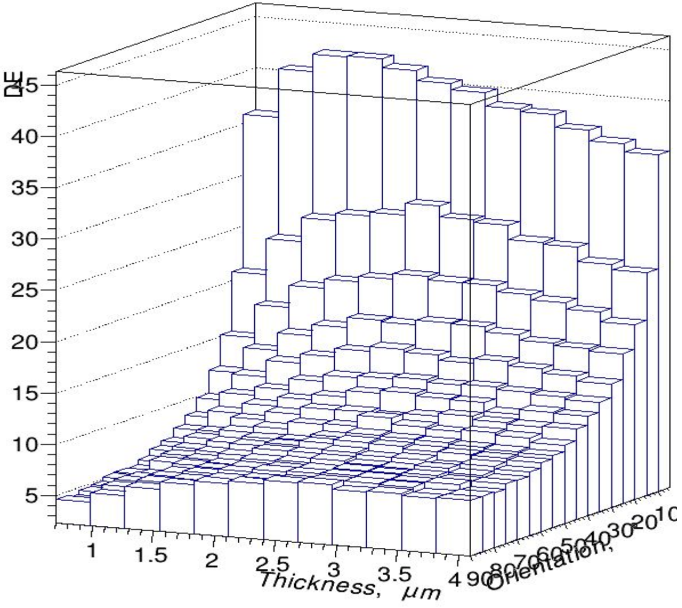


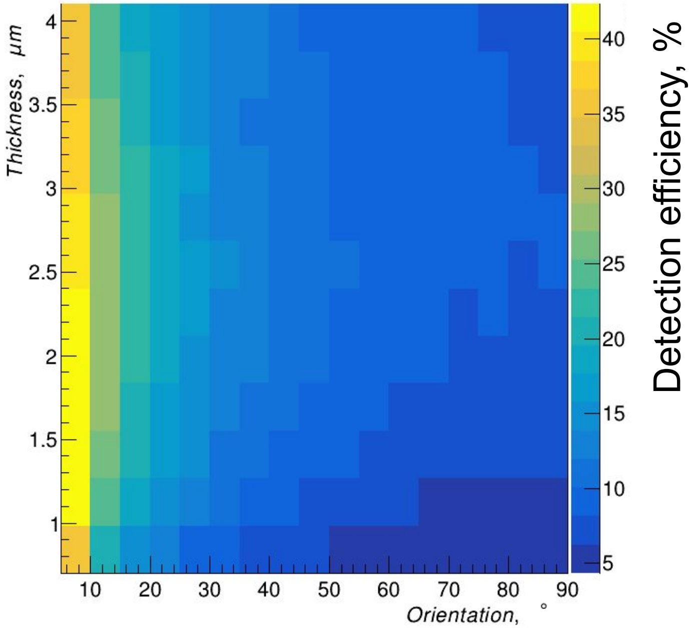
Detection Efficiency as a function of neutron beam angle of incidence. Zero degrees is the normal incidence. Converter thickness was maintained at 1.15 μm.



Detection Efficiency as a function of converter thickness. Orientation was maintained at 5º.

Effect of the angle of incidence and converter thickness





Detection efficiency as a function of the angle of incidence of neutrons and the converter thickness.

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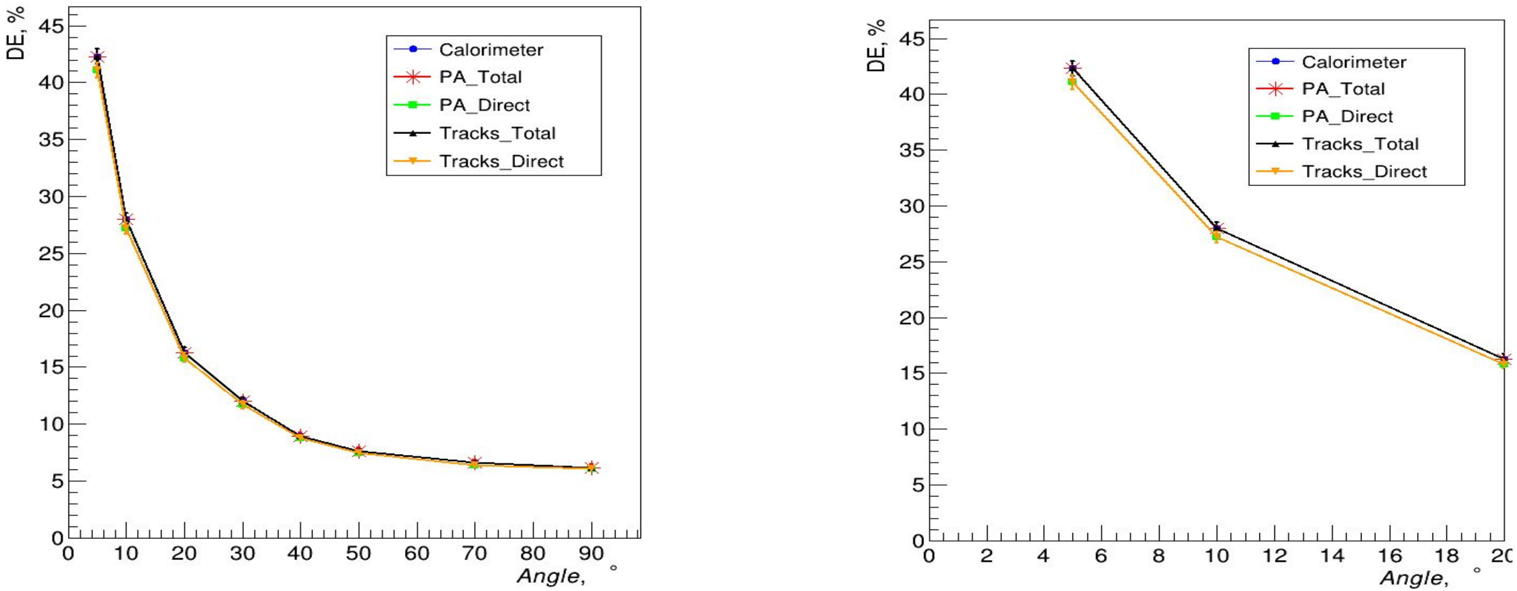
Detection efficiency: total and only for non-scattered neutrons



Detection efficiency as a function of neutron angle of incidence. **On the left:** Variation across all studied angles. **On the right:** Zoom in for angles between 0º and 20º.

- The expected contribution from elastically scattered neutrons to the background is weak.

Conclusions

- Learnt how the 10 Double-Gap RPC neutron detector at LIP was built.
- Helped installing the Front-End Electronics in the detector.
- Learnt how the DAQ System was used to retrieve the signal data arising from the detection of neutrons.
- Learnt how to perform a X and Y position reconstruction of the neutrons.
- Performed simulations in order to determine the optimal thickness of the neutron converter and the optimal neutron angle of incidence.
- Learnt that when building a prototype detector it is important to have done simulations before in order to be able to use optimal materials/sizes in it.