LABORATÓRIO DE INSTRUMENTAÇÃO
E FÍSICA EXPERIMENTAL DE PARTÍCULAS
partículas e tecnologia

A four-dimensional timing RPC neutron detector concept

Luís Margato[1], A. Morozov[1], G. Canezin[1], A. Blanco[1], J. Saraiva[1], L. Lopes[1], P. Fonte[1,2], Chung Chuan Lai[3], Per-Olof Svensson[3], Linda Robinson[3,4], Richard Hall-Wilton[3,5], Florian M. Piegsa[6]

1. Laboratory of Instrumentation and Experimental Particles Physics, University of Coimbra, Portugal
2. Coimbra Polytechnic – ISEC, Portugal
3. Detector Group, European Spallation Source ERIC (ESS), Sweden
4. Ynvisible Production AB, Sweden
5. Sensors and Devices Centre, Fondazione Bruno Kessler (FBK), Italy
6. Laboratory for High Energy Physics, Albert Einstein Center for Fundamental Physics, University of Bern, Switzerland

Fundação para a Ciência e a Tecnologia

REPÚBLICA PORTUGUESA | CIÊNCIA, TECNOLOGIA E ENSINO SUPERIOR

EXPL/FIS-NUC/0538/2021

Outline

- Motivation
- Timing RPC for neutrons
- nRPC-4D concept
- First results on BOA beamline at PSI
- Conclusions

Motivation

Resistive Plate Chamber (RPC)

A type of gaseous detector developed in the 80s for large detection areas at low-cost - *Santonico, R. Cardarelli (1981)*

Widely used in HEP and Astroparticle Physics

New application are emerging, e.g., in muon tomography and RPC-PET scanners

This work

A neutron detector combining timing RPCs with $^{10}B_4C$ thin films

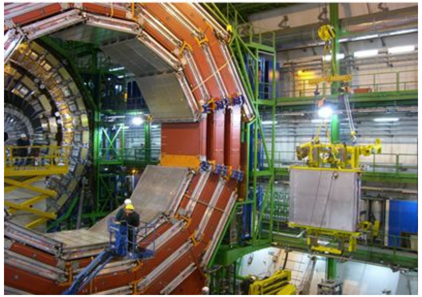
RPCs can offer:

- Accurate timing (sub-ns) and good spatial (100 μm) resolution
- Modularity and scalability
- Large detection areas at affordable cost

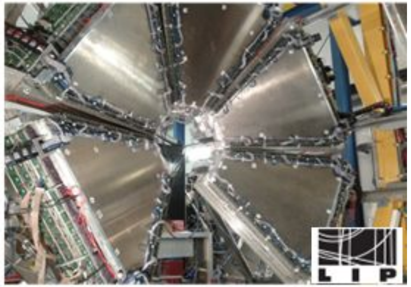
Argo Tibet 6700 m^2

ATLAS@CERN
CMS@CERN
HARP@CERN (TOF)
ALICE@CERN (TOF)
HADES@GSI (TOF)
FOPI@GSI (TOF)
STAR@RHIC (TOF)
BELLE@KEK
OPERA@LNF
ARGO@Tibet
Etc.

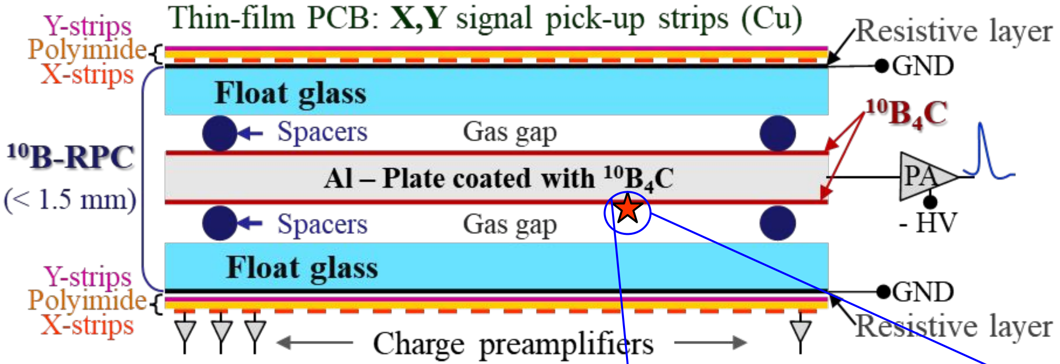
CMS Trigger 2953 m^2

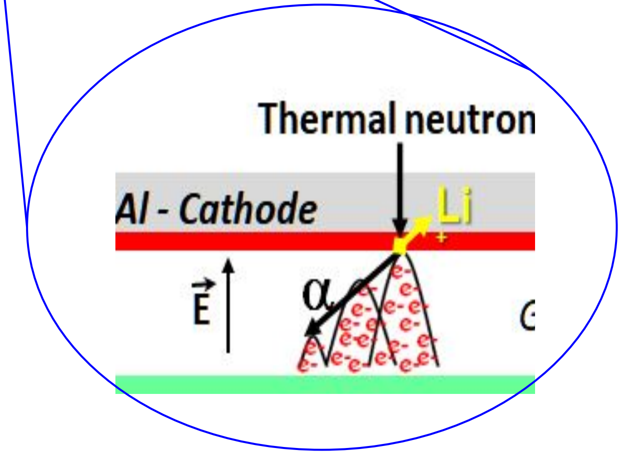


HADES@GSI TOF Wall ~8 m^2



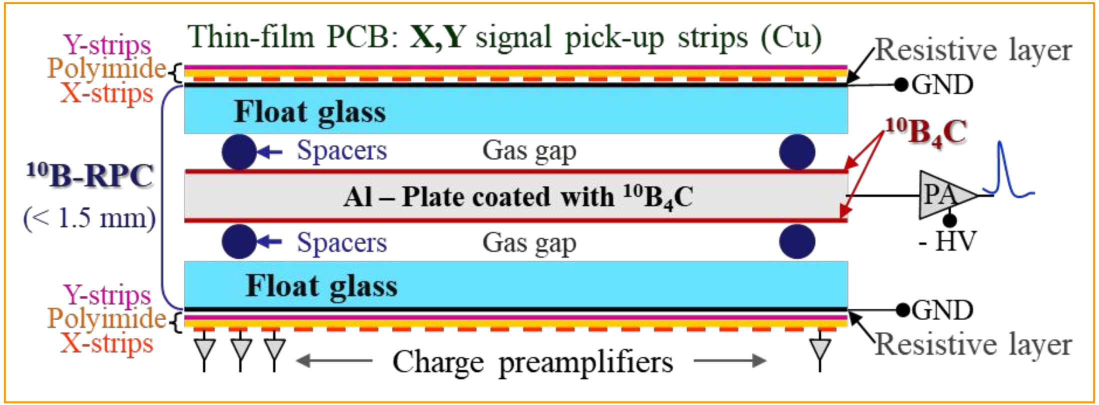
Timing RPC detection unit (double gap)



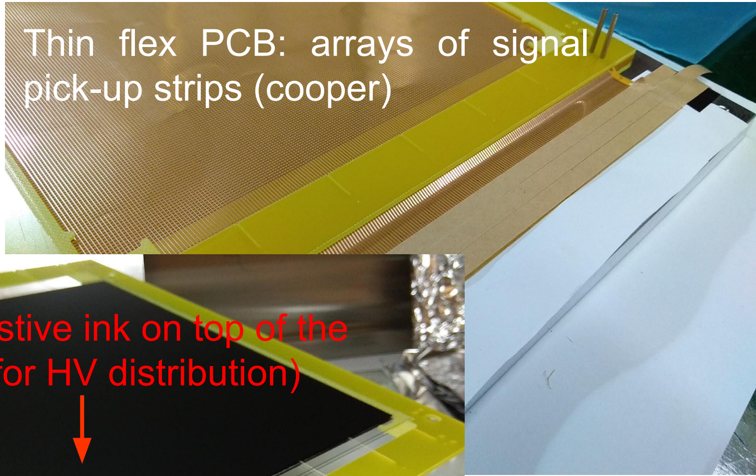


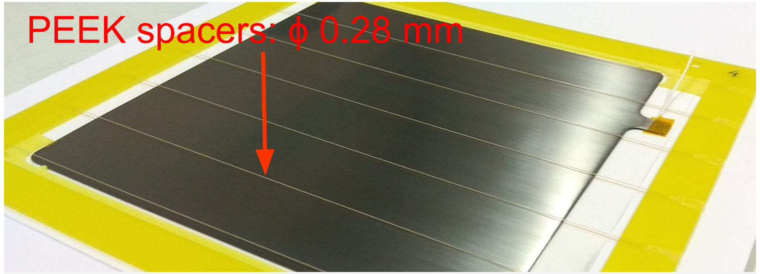
$$n + {}^{10}B \rightarrow \begin{cases} {}^{7}\mathrm{Li}(0.84\ \mathrm{MeV}) + {}^{4}\mathrm{He}(1.47\ \mathrm{MeV}) + \gamma(0.47\ \mathrm{MeV}), & 94\% \\ {}^{7}\mathrm{Li}(1.01\ \mathrm{MeV}) + {}^{4}\mathrm{He}(1.78\ \mathrm{MeV}), & 6\%. \end{cases}$$

Timing RPC detection unit (double gap)

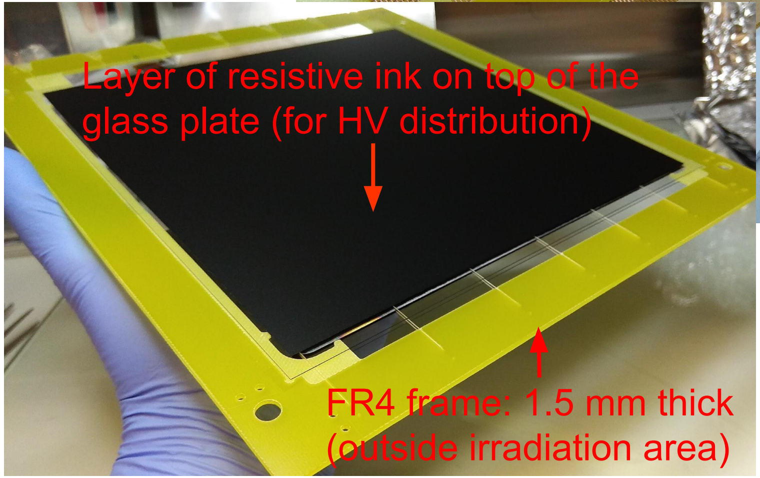


Standalone and versatile unit





Al-plates (0.3 mm thick) coated with $^{10}B_4C$ (^{10}B enrichment > 97%) at the **ESS Detector coatings workshop**



EUROPEAN SPALLATION SOURCE

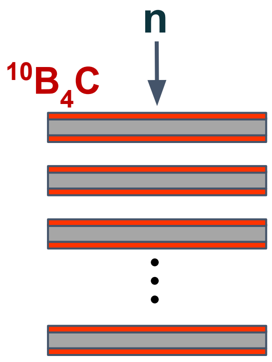
LIP

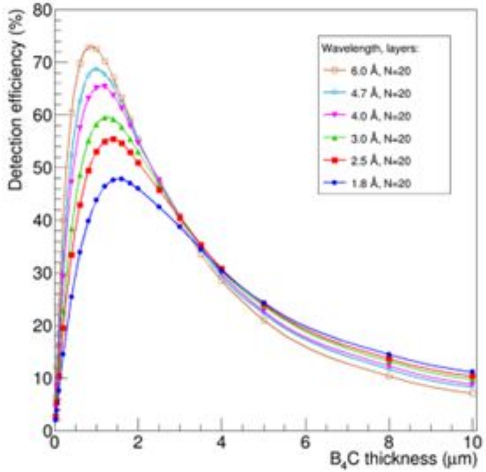
Only ~ 5% (λ_n=1.8 Å) detection efficiency for a single $^{10}B_4C$ layer at normal neutron incidence

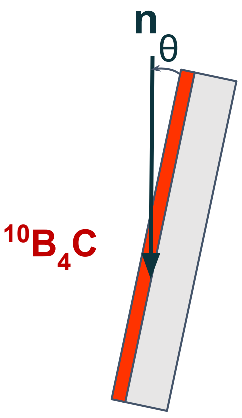
Two approaches have been adopted so far to improve it:

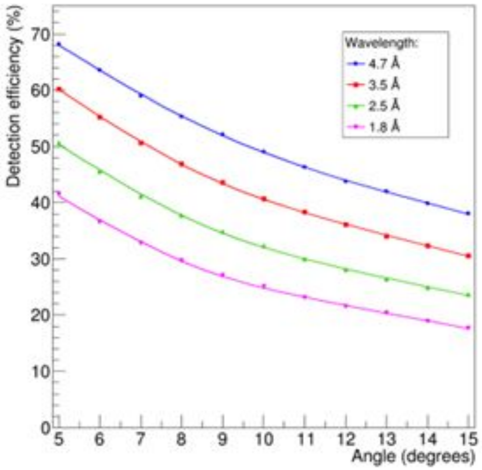
- **Multilayers (neutron at normal incidence)**
  similar to, e.g., Cascade [1] and Multigrid [2] neutron detectors

- **Inclined geometries (neutron grazing angle incidence)**, like in, e.g., the Multiblade detector [3,4]







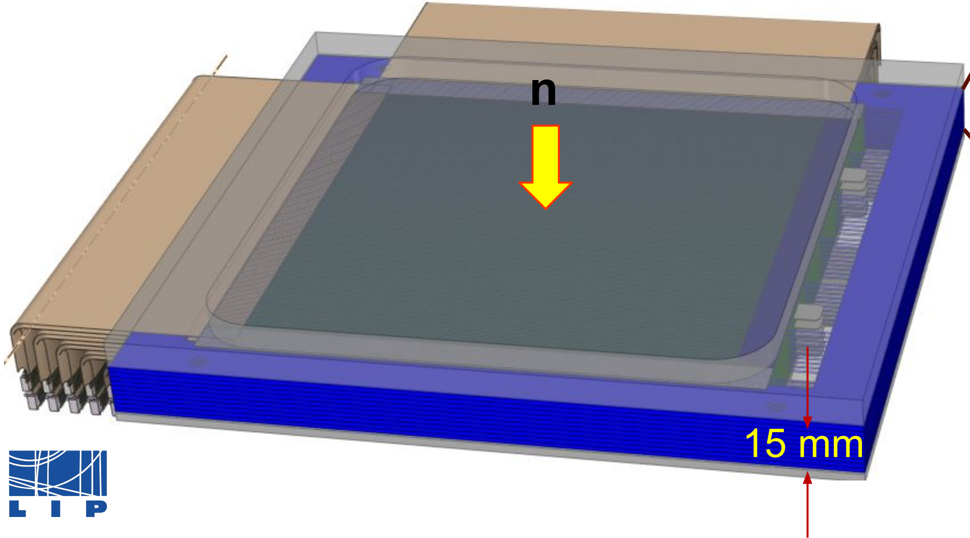


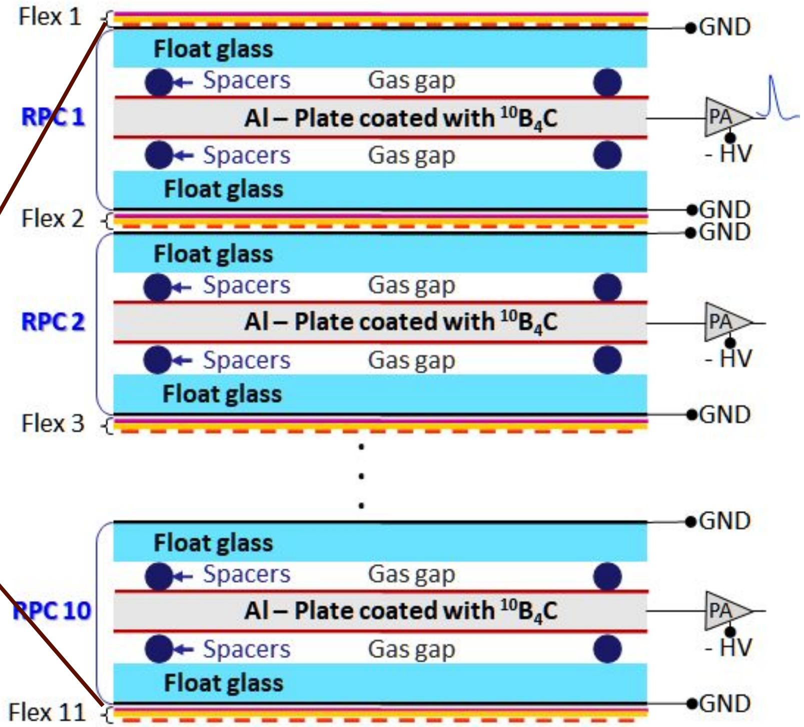
L.M.S. Margato and A. Morozov 2018 JINST 13 P08007

[1] B. Guérard et al.,NIM A 720 (2013) 116
[2] M Köhli et al 2016 J. Phys.: Conf. Ser. 746 012003
[3] B. Guérard et al. NIM A 554(2005)392
[4] F. Piscitelli et al., 2014 JINST 9 P03007

The nRPC-4D concept

- **Multilayer configuration**
  - **Stack of 10 timing RPCs units**
- **XYZ position and timing**
  - **Sub-millimeter spatial resolution**
  - **Timing in the ns range**





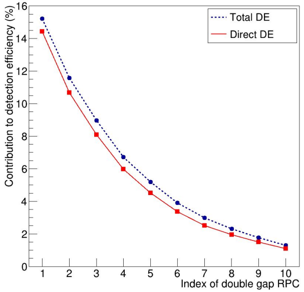
The nRPC-4D concept

- **Detection efficiency > 50 % (4.7 Å)**

RPC components:

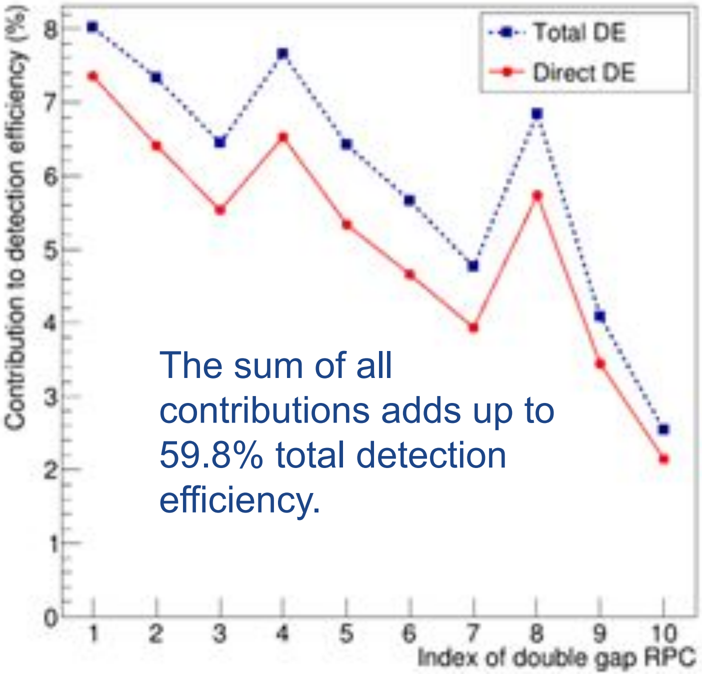
- 0.33 mm thick glass anodes (soda lime glass)
- 0.30 mm thick cathodes (Al alloy 5754)
- 0.28 mm wide gas gaps filled with R134a (1 atm)
- **$^{10}B_4C$ layers (^{10}B enrichment level of ~97%) of various thickness:**
  - 0.4 µm for RPC 1 to 3
  - 0.6 µm for RPC 4 to 7
  - 2.2 µm for RPC 8 to 10

All $^{10}B_4C$ layers with the same thicness



Detection Efficiency

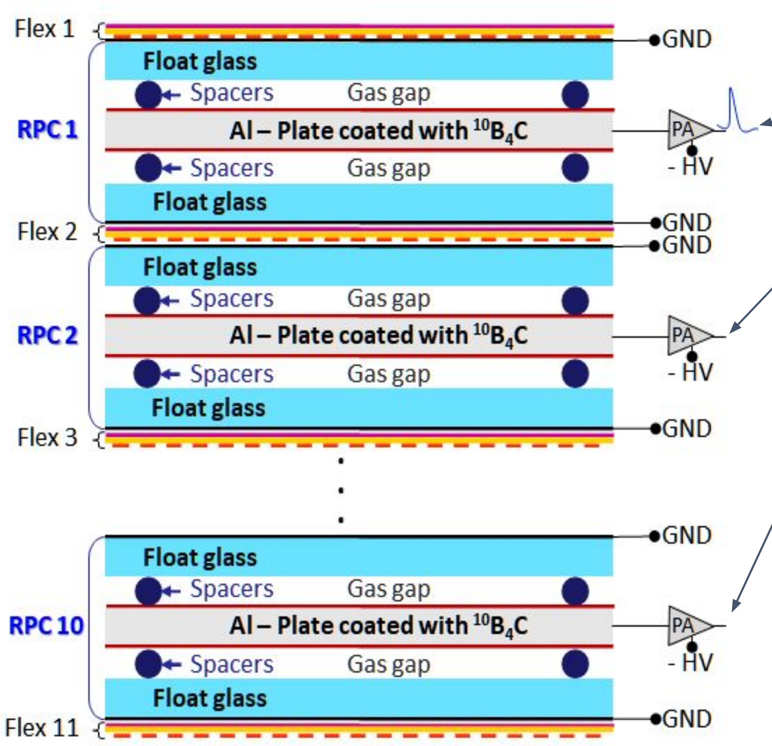
Simulations in Geant4 (v10.7.2)



The sum of all contributions adds up to 59.8% total detection efficiency.

Primary neutrons (4.7 Å) generated as a pencil beam with normal incidence at the center of the detector.

Readout of the Z- coordinate and timing

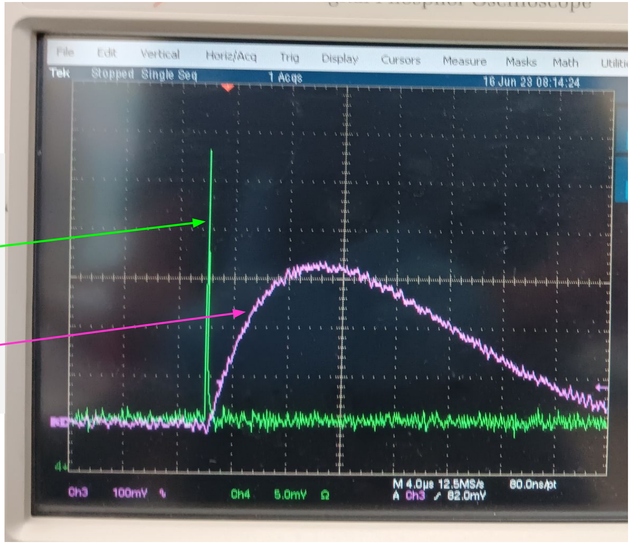


Cathode signal

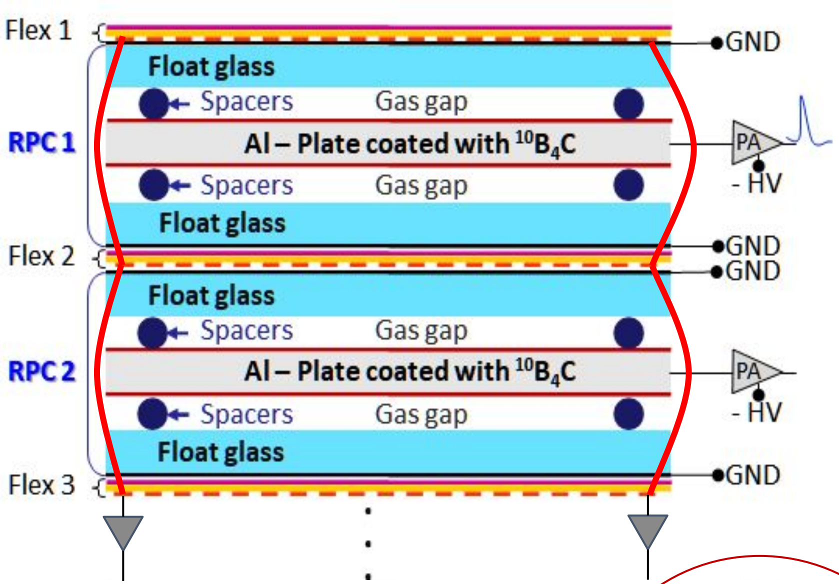
- Identification of the double gap timing RPC where a neutron is captured
- Event timing information

Signal components

- Electronic (very sharp)
- Ionic



Readout of the XY- coordinates



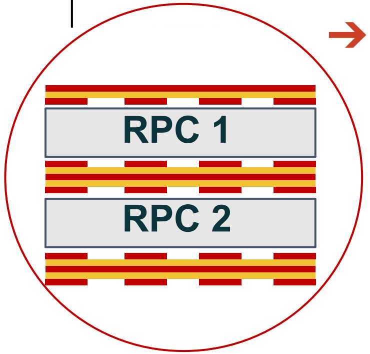
XY strip arrays, normal to each other, facing the anode glass plates

10 x RPCs: 11 x 2 x 200 strips (4400)

X (Y) strips, of each array, with the same index interconnected and read by the same electronic channel

➔ 400 elect. channels

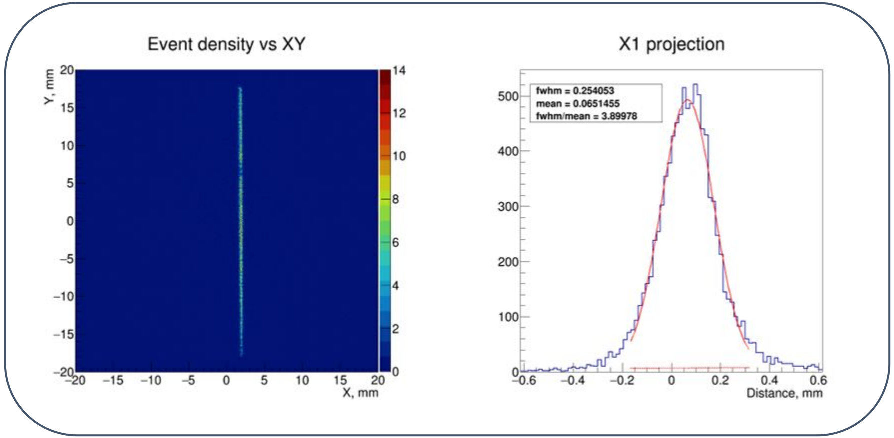
➔ **Consequence**: ambiguity in the $^{10}B_4C$ layer where the neutron is captured for a previous XY strip arrays geometry we've used



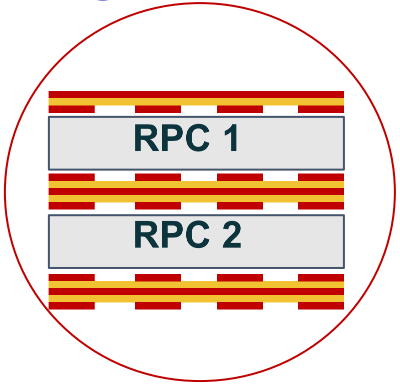
Readout of the XY- coordinates

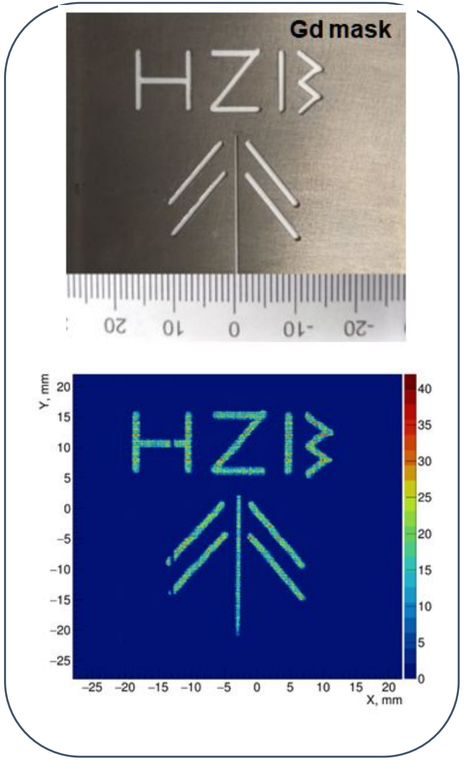
➢ Arrays of strips in the previous design

Spatial resolution ~ 0.25 mm FWHM (X-coord.)



Beam collimated by a vertical Cd slit





A. Morozov *et al* 2021 JINST **16** P08032

Position reconstruction: COG algorithm

(x,y) - reconstructed event position

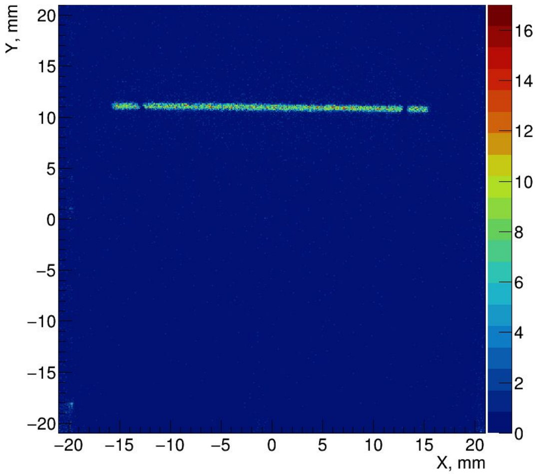
S_i - signals from the strips;

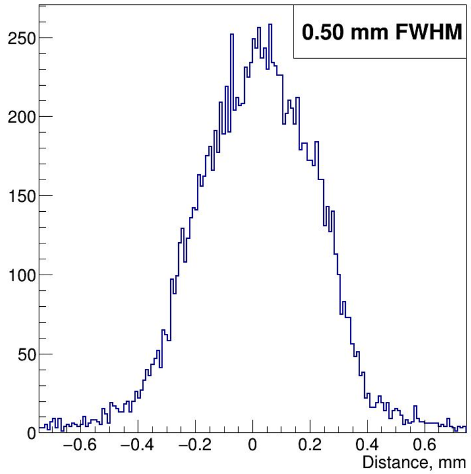
X_i, Y_i - positions of the strips

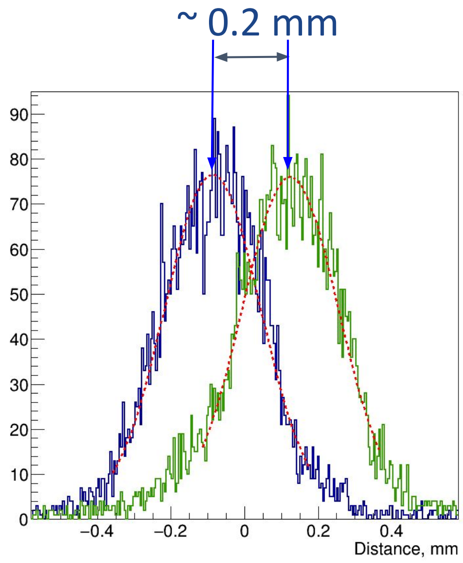
$$x = \frac{\sum X_i S_i}{\sum S_i} \qquad y = \frac{\sum Y_i S_i}{\sum S_i}$$

Readout of the XY- coordinates

➢ **Arrays of strips in the previous design**







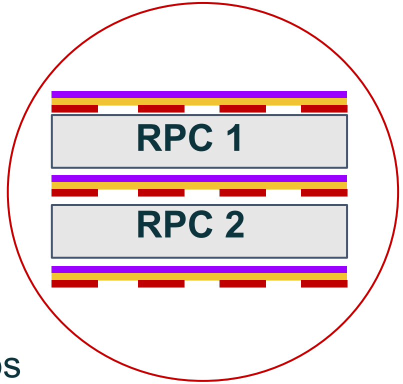
A. Morozov *et al* 2021 *JINST* **16** P08032

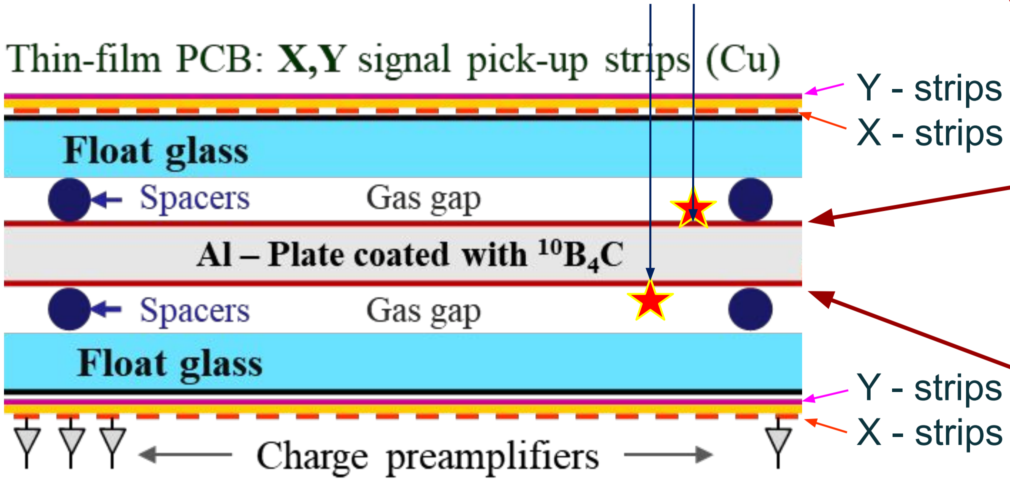
Spotted misalignment between the strip arrays for the Y coordinate

To perform misalignments corrections between the XY arrays of strips is crucial to identify the $^{10}B_4C$ layer where the neutron is captured

Identification of the $^{10}B_4C$ layer where the neutron is detected

- **New geometry for the strip arrays**





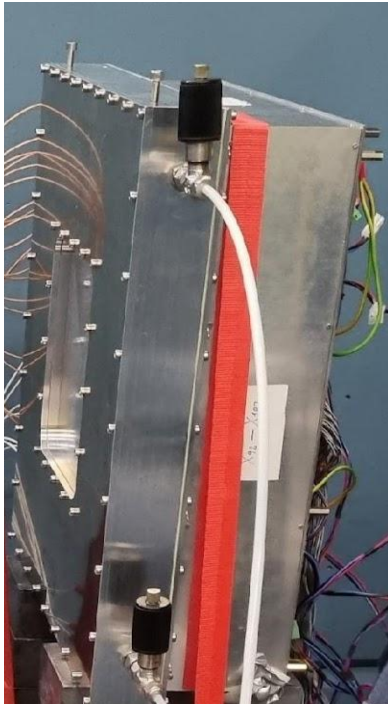
Neutron capture in the top $^{10}B_4C$ layer

X- Sum signal > **Y**- Sum signal

Neutron capture in the bottom $^{10}B_4C$ layer

X- Sum signal < **Y**- Sum signal

Detector prototype



Front: Aluminium entrance window (0.2 mm thicK)

Back: Front End Electronics and triggering boards (custom)

Front End Electronics

- Boards with 24 charge PAs (50 mV/pC)

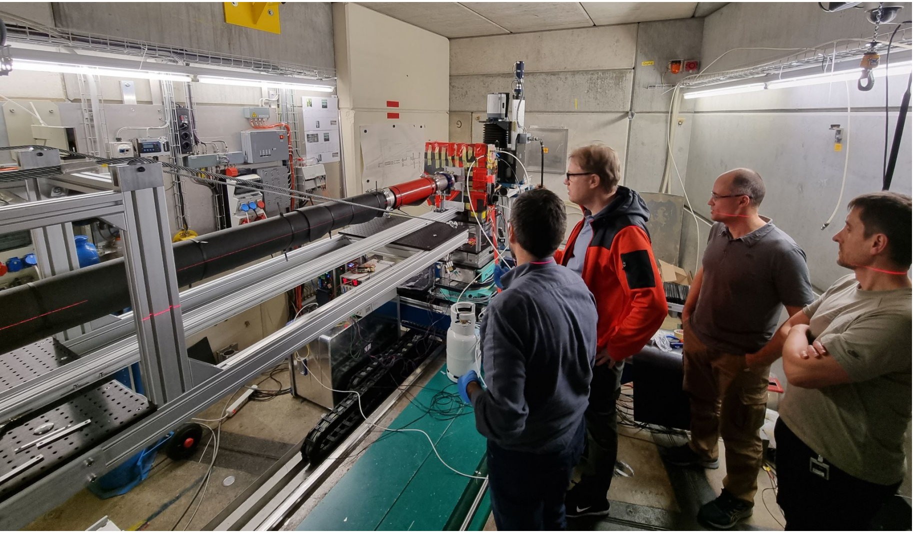
Timing amplifier

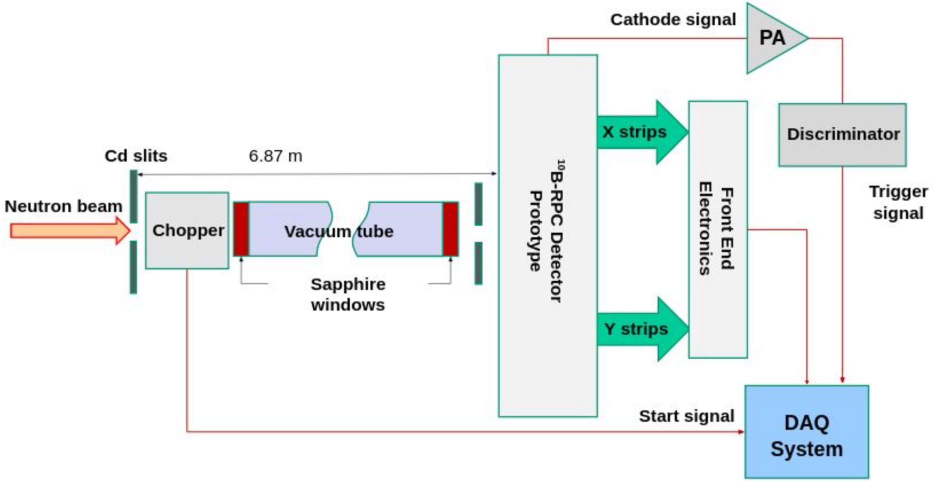
- Polarity (bipolar)
- Wideband amplification (gain 60 @ 1GHz)
- LVDS output

DAQ - TRB3 (trb.gsi.de)

- 48 ch 10 ps TDC
- ADC addon (48 ch 40 MHz streaming ADCs)

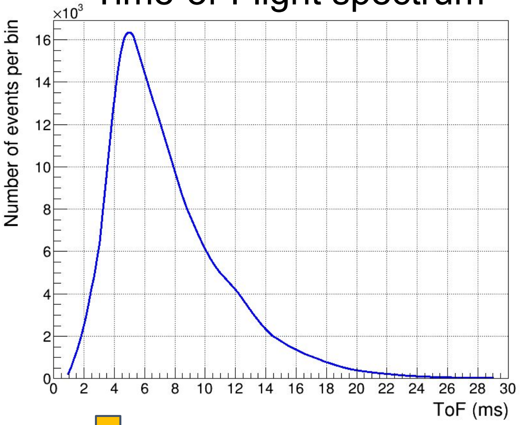
Detector 1st tests at BOA beamline at PSI



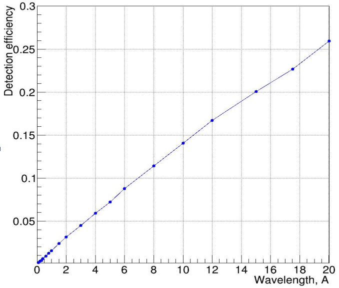


Measurement of the neutrons ToF

Time-of-Flight spectrum



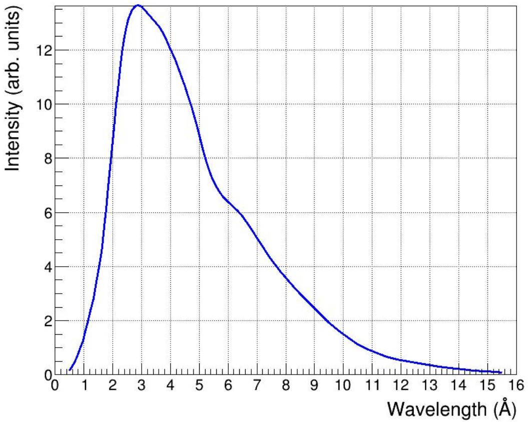
$\lambda = h/p$

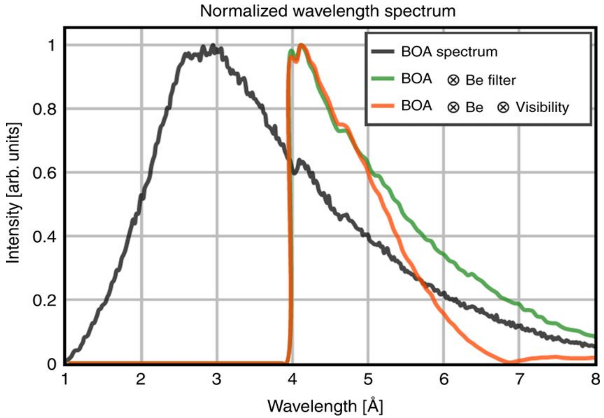


Correction accounting to the DE dependence on neutron wavelength

The determined spectrum shows to be in good agreement with data from literature

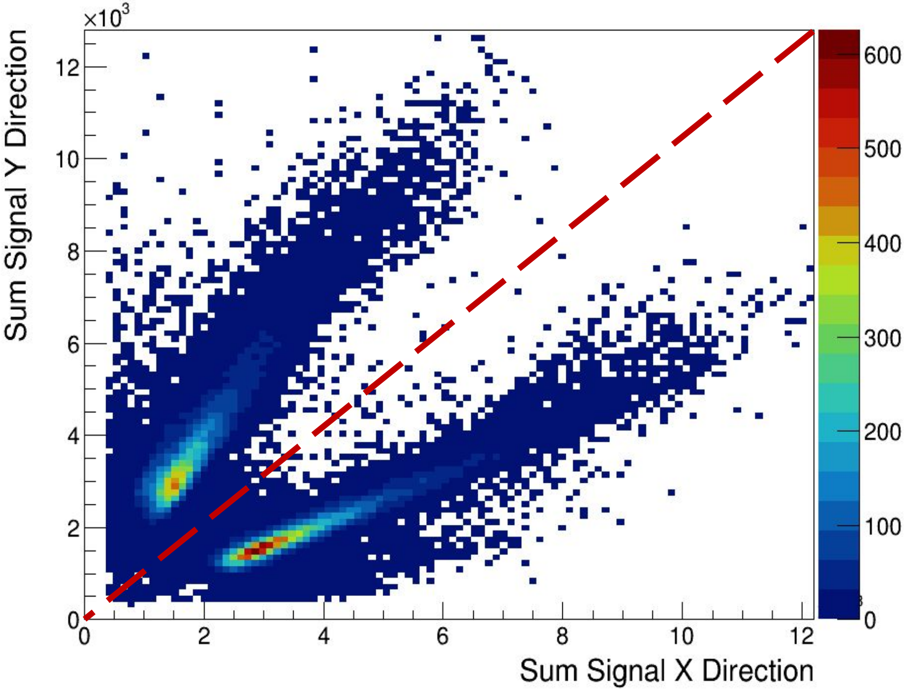
Wavelength spectrum

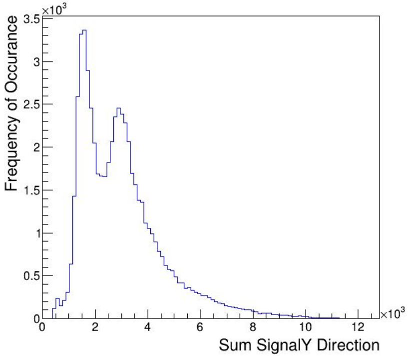


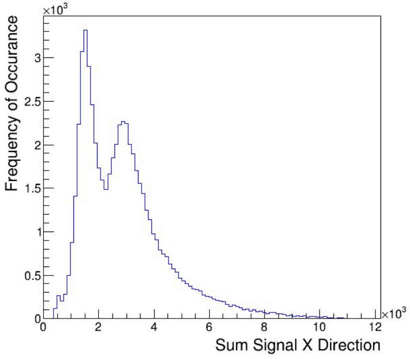


Jacopo Valsecchi et. Al.,
NATURE COMMUNICATIONS
https://doi.org/10.1038/s41467-019-11590-2

Identification of the $^{10}B_4C$ layer where the neutron is detected







- ➔ Allows for misalignment correction between XY arrays of strips
- ➔ Avoids the uncertainty (e.g., ~ 400 ns for λn = 5 Å) due neutron ToF through the cathode (0.3 mm thick)

Conclusions

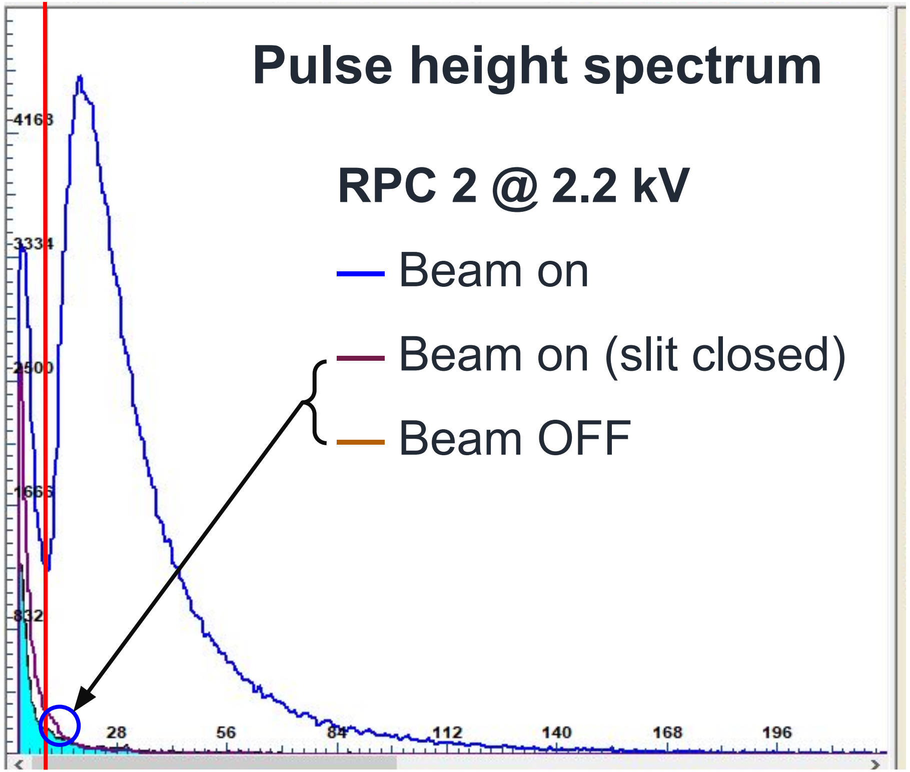
- **A timing RPC based neutron detector with XYZ and timing readout capability was described**
- **Capability to measure neutron ToF is demonstrated**
- **A new approach to readout the XY coordinates was implemented:**
    - Ability to identify the $^{10}B_4C$ layer where the neutron is captured was shown,
        - **Improved ToF determination capability** and **XY spatial resolution**

Ongoing

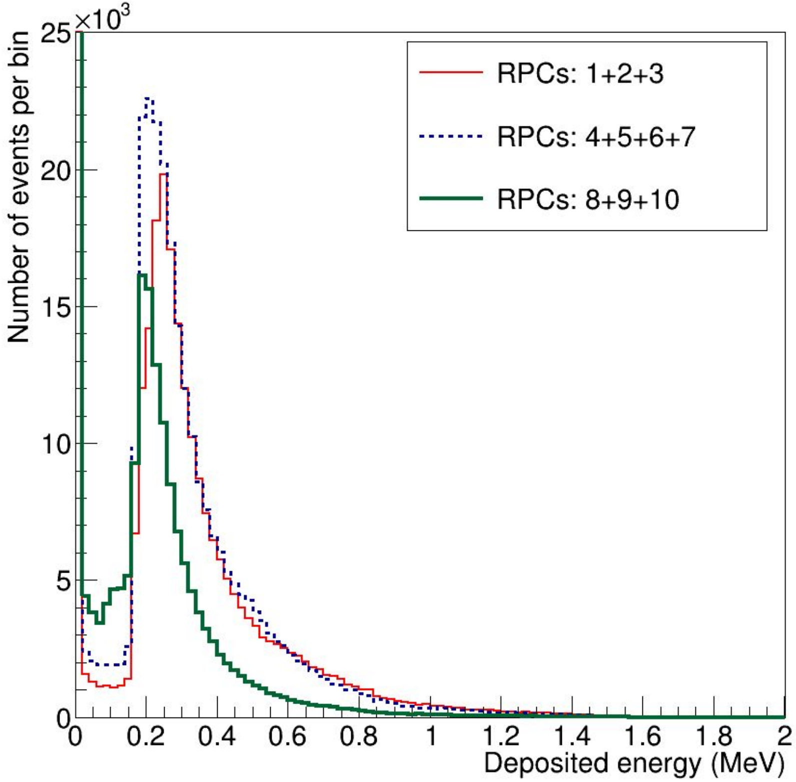
A full-scale **nRPC-4D** prototype with 10 double gap RPCs is being assembled. The detector characterization is to be performed on a neutron beam at ILL

Thank you for your attention

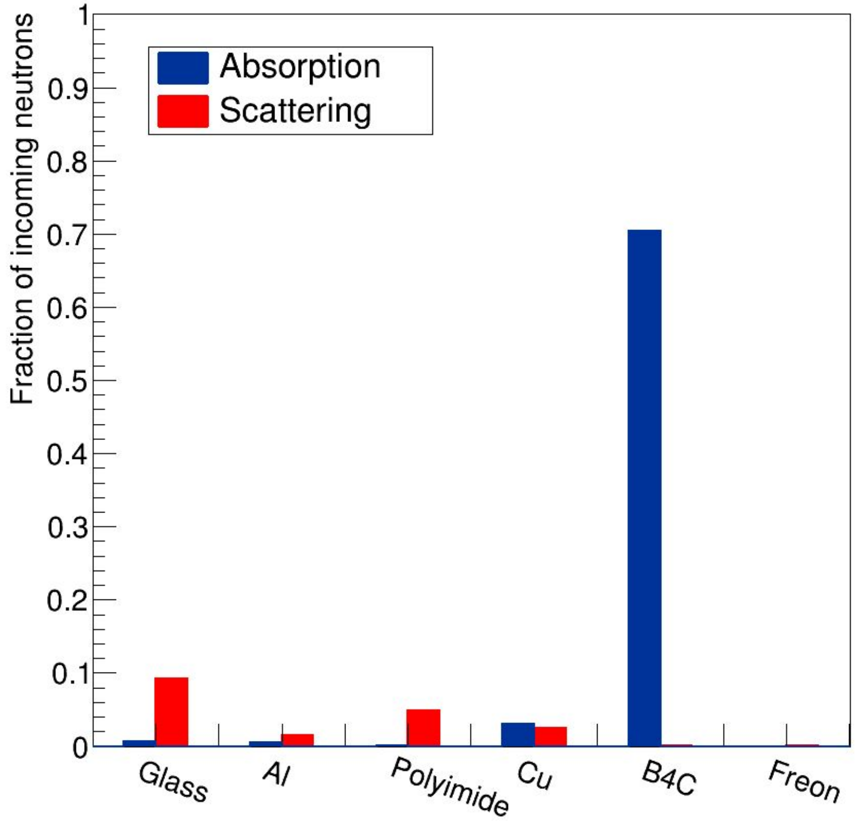
Extra Slides



Energy deposition in the gas gap

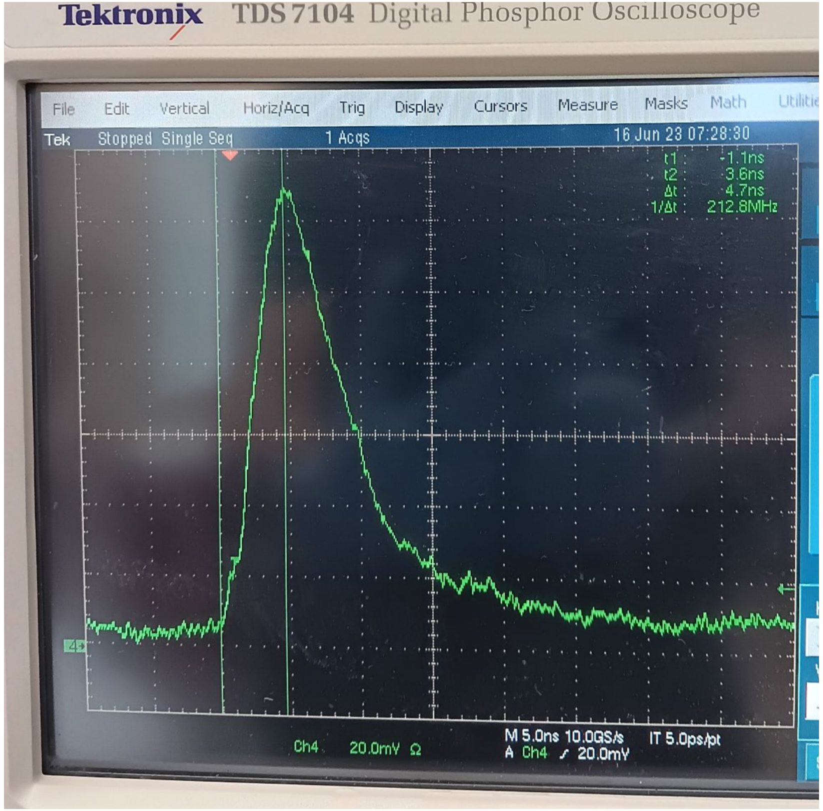


Extra Slides



Extra Slides

Cathode signal (electronic component)

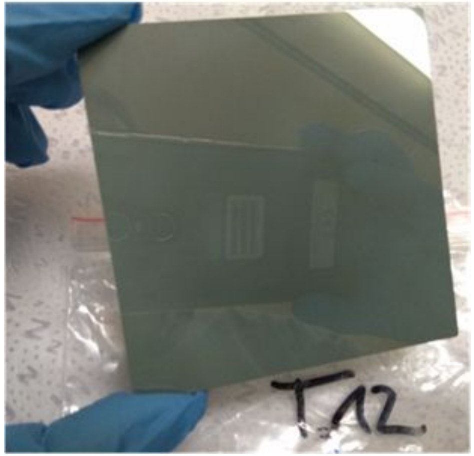


Extra Slides

High rate: ^{10}B-RPCs with low resistivity electrodes

Low-resistive glass [1]
Bulk resistivity: ~10^{10} Ω.cm)

Ceramics composite [2]
Bulk resistivity: 10^{8} - 10^{10} Ω.cm



$$V_{eff} = V_{ap} - IR = V_{ap} - \left(\frac{I}{A}\right)\rho l$$

V_{ap}: Applied voltage

V_{eff}: Effective voltage applied across the gap

I: Counting current drawn by the detector in area A

R: Electrical resistance seen by this current

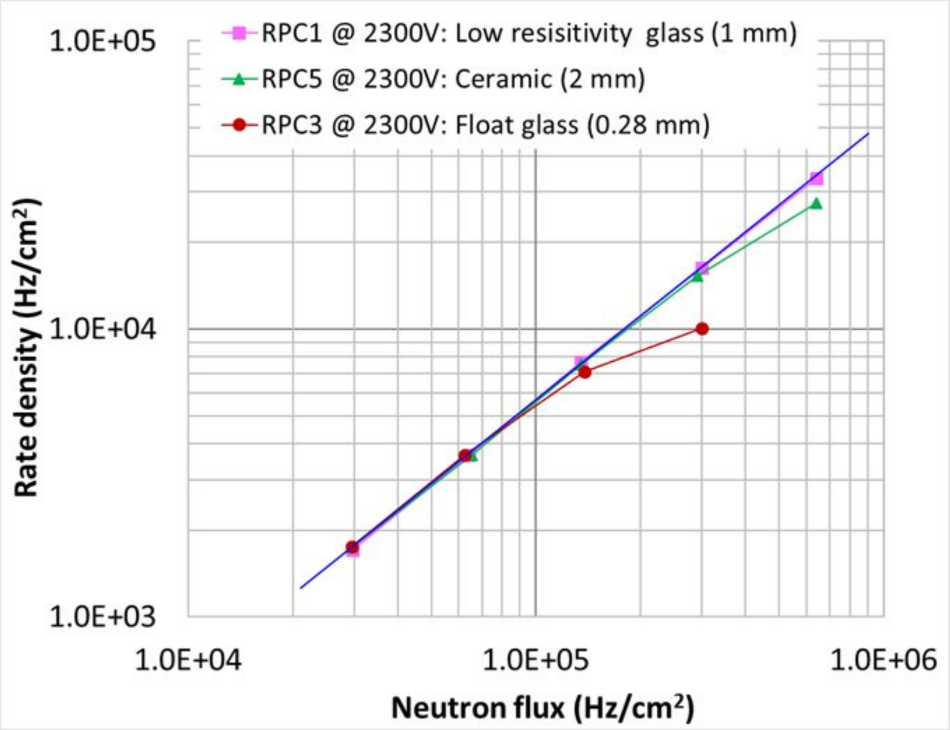
P: DC bulk resistivity of the electrode resistive material

[1] J. Wang et al., Nucl. Instrum. Meth. A 713 (2012) 40

[2] A. Laso Garcia et al., Nucl. Instrum. Meth. A 818 (2016) 45

Extra Slides

High rate: ^{10}B-RPC with low resistivity electrodes



L.M.S. Margato *et al* 2021 *JINST* **16** P07009

Rate vs neutron flux (beam test at HZB)