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Neutron Detectors

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Ongoing Project: SINE2020

Science & Innovation with Neutrons in Europe in 2020

SINE2020 is a consortium of **18 partner** institutions from **12 countries**.
Funded by the European Union through the **H2020** programme

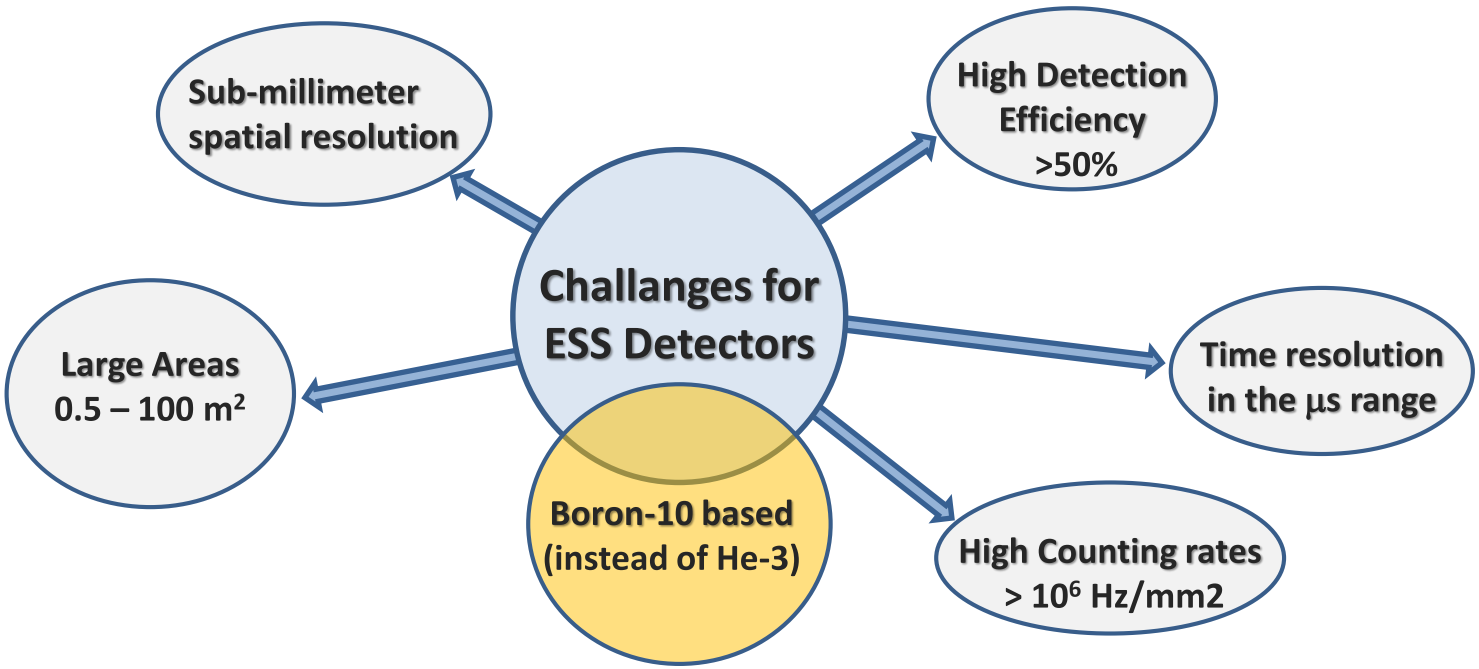
SINE2020 objectives:

- Preparing Europe for the unique opportunities at the European Spallation Source (ESS)
- Developing the innovation potential of neutron Large Scale Facilities

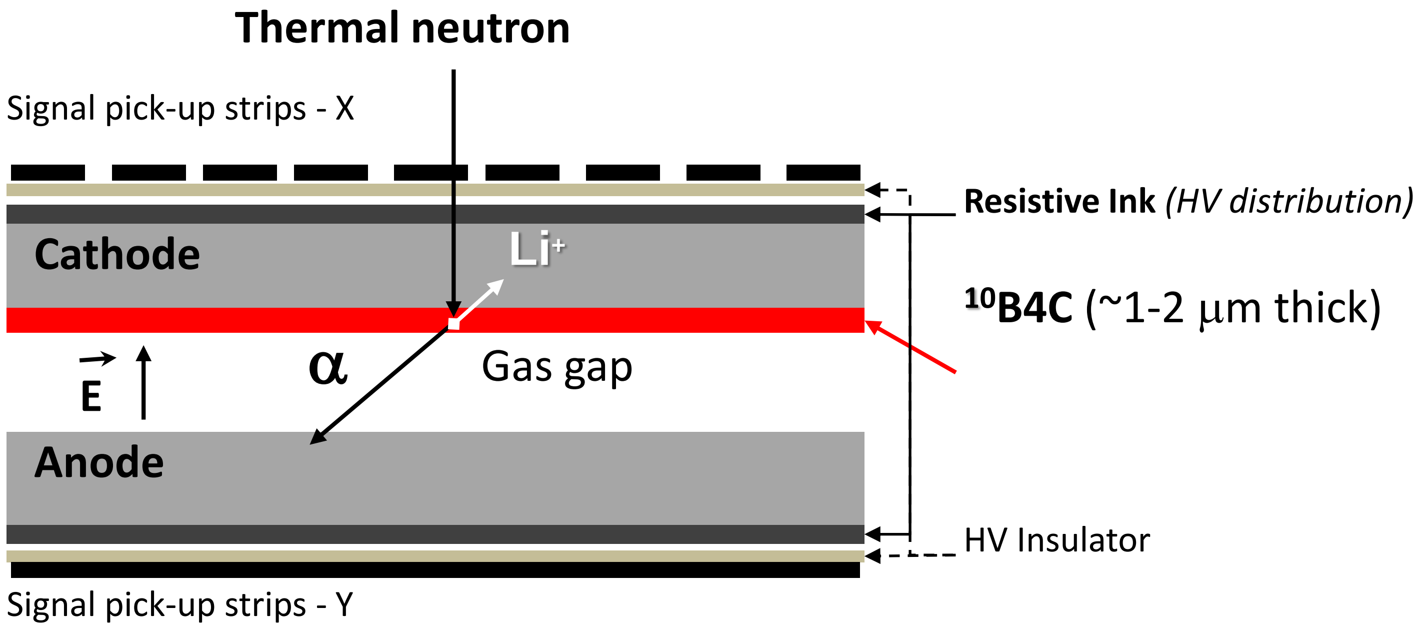
Ongoing Project: SINE2020

Main objectives of LIP:

Evaluate the potencial of B-10 RPCs for thermal neutron detectors



Working principle



$$n + {}^{10}B \rightarrow ({}^{11}B)^* \begin{cases} {}^{7}Li^* \ (\mathbf{0{,}84\ MeV}) + {}^{4}He\ (\mathbf{1{,}47\ MeV}) + \gamma\ (\mathbf{0.47\ MeV}), \quad \mathbf{Q = 2{,}31\ MeV} \quad \mathbf{(94\ \%)} \\ {}^{7}Li\ (\mathbf{1{,}02\ MeV}) + {}^{4}He\ (\mathbf{1{,}78\ MeV}), \quad \mathbf{Q = 2{,}79\ MeV} \quad \mathbf{(6\ \%)} \end{cases}$$

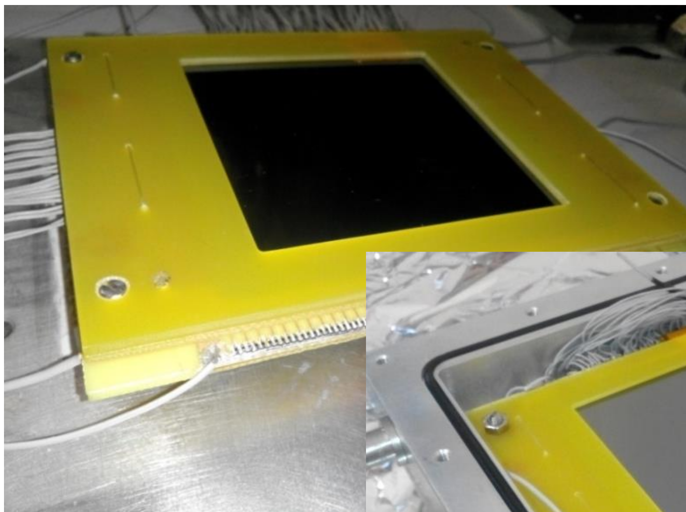
$\sigma_{capture}$ = 3840 barns at 1.8Å

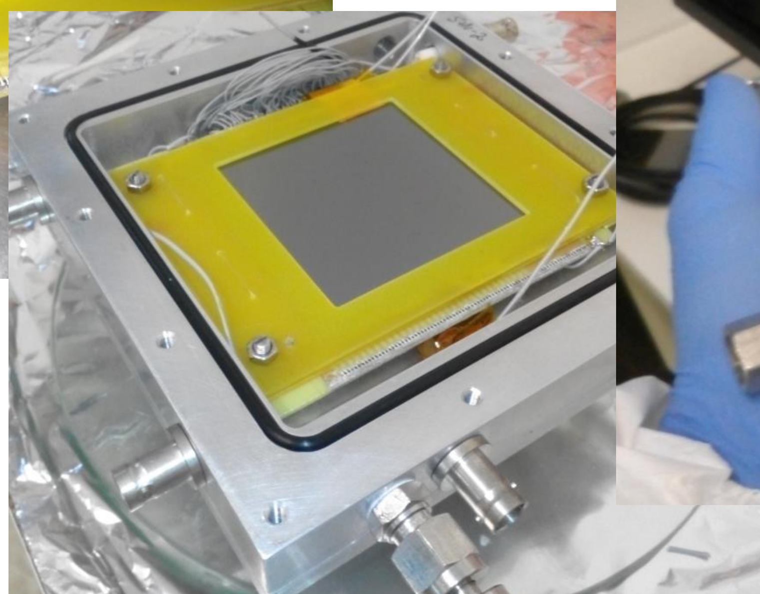
Firts Tests with neutrons at TUM-FRMII

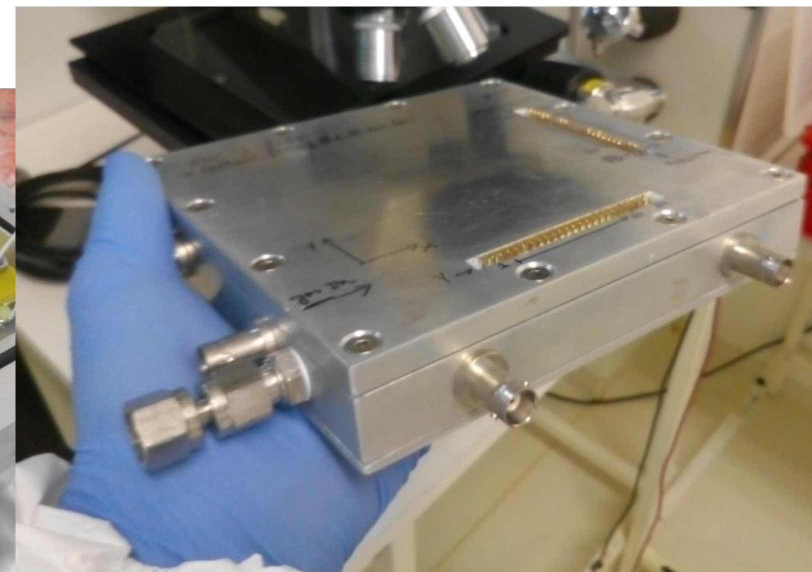
Two $^{10}B_4C$ coated RPCs were tested:

- **RPC-1**: *gas-gap width* of **1 mm**
- **RPC-2**: *gas-gap width* of **0.35 mm**

Aluminum electrode coated with $^{10}B_4C$ of 2 μm thick





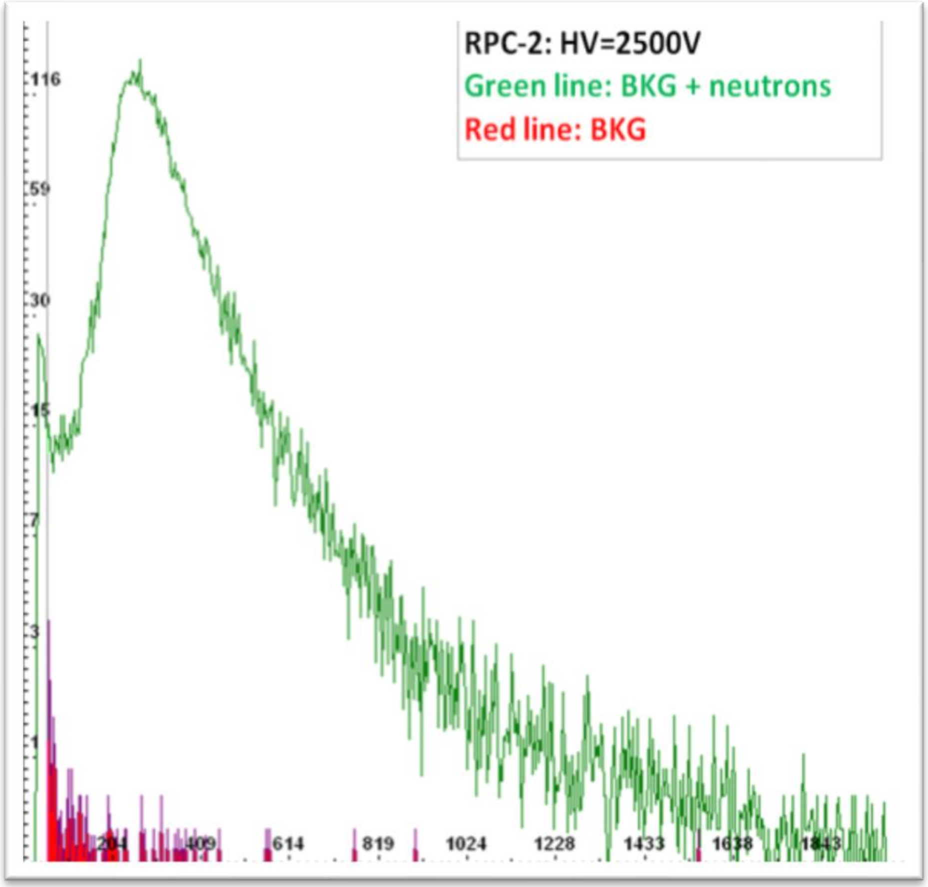


Gas tight box

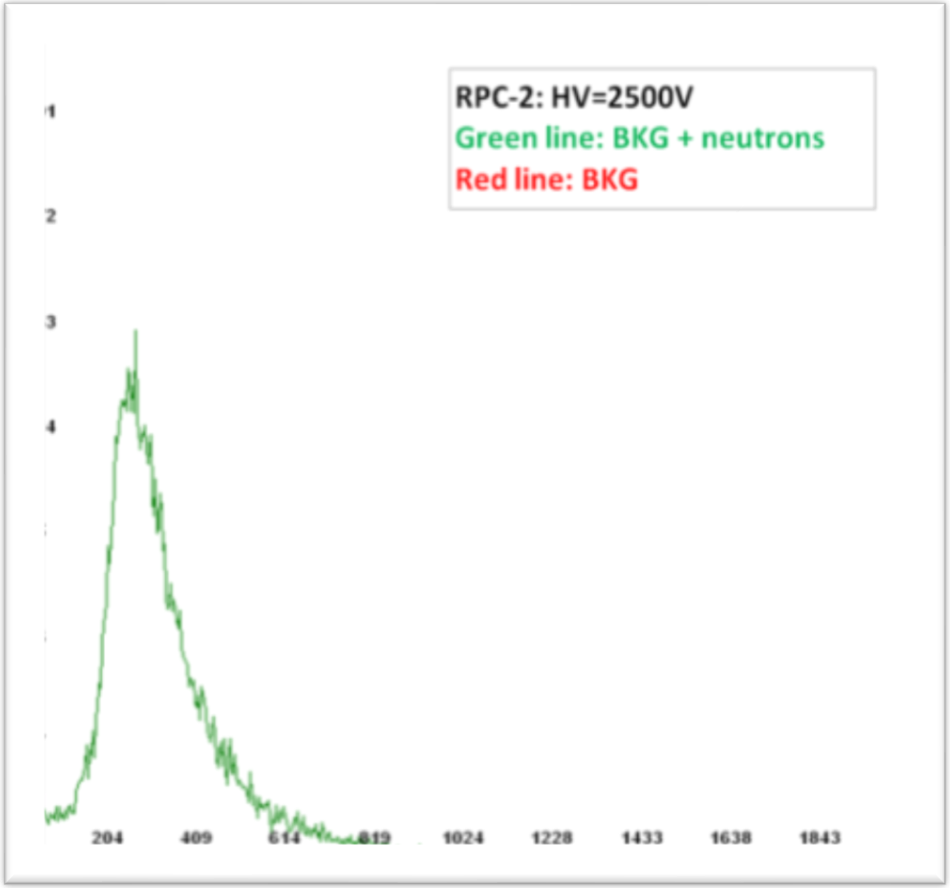
Firts Tests with neutrons at TUM-FRMII

Results: PHS

Log-scale



Linear-scale

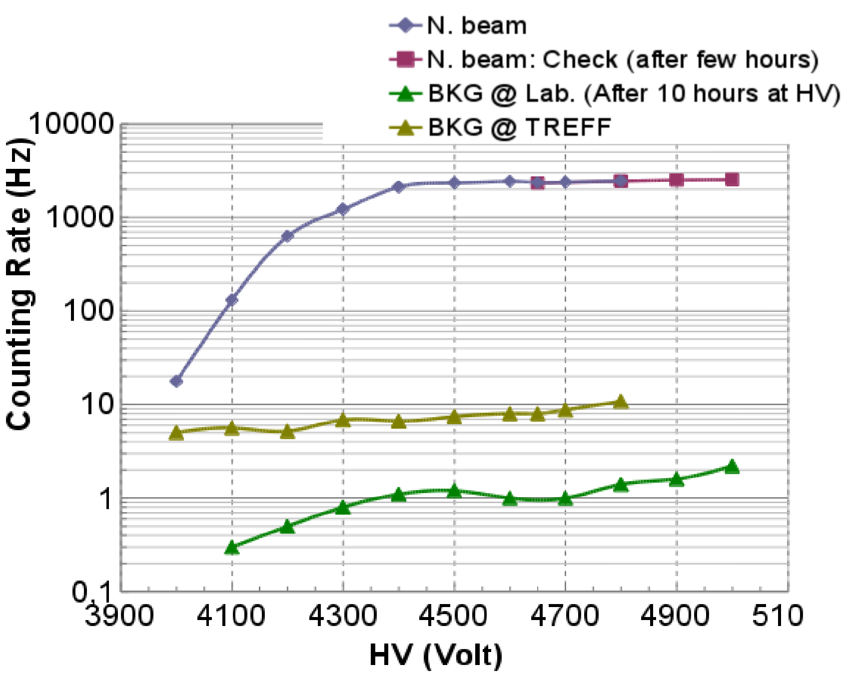


Firts Tests with neutrons at TUM-FRMII

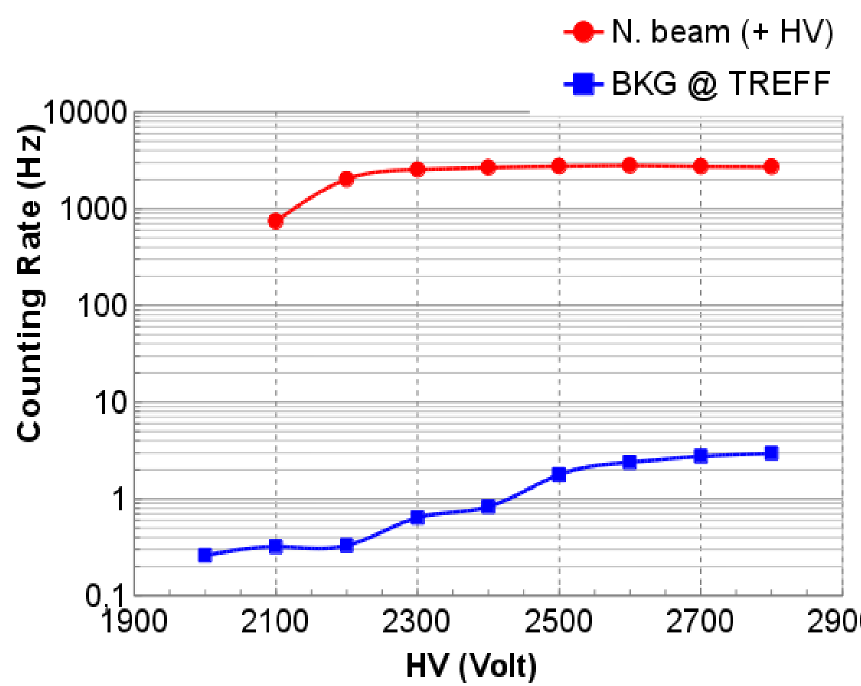
Results: Plateau

Wide HV plateau > 500 V for both RPCs

RPC-1 (1.0 mm gas-gap)

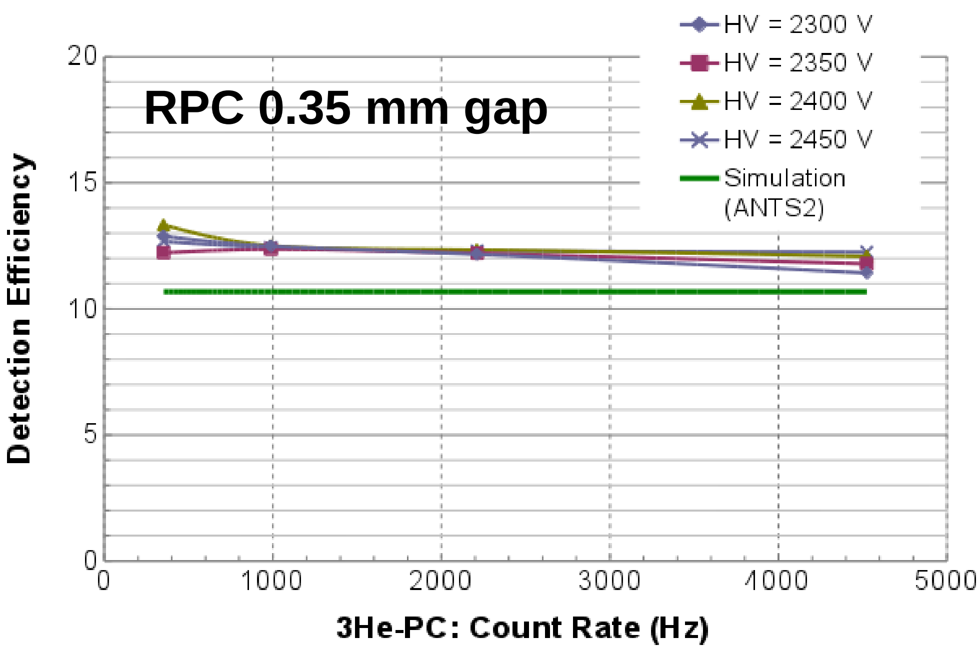


RPC-2 (0.35 mm gas-gap)



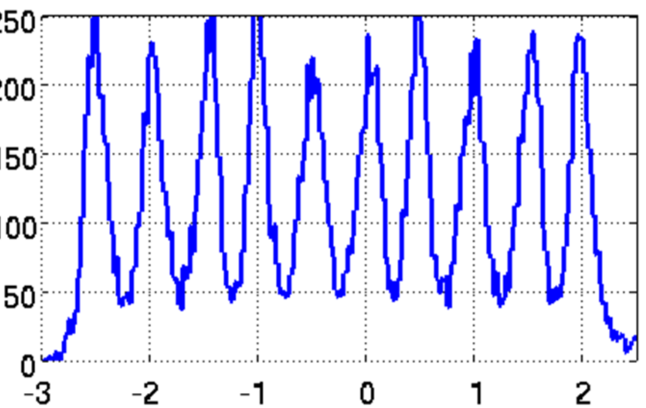
Firts Tests with neutrons at TUM-FRMII

Results: Efficiency and Spatial Resolution



[3]He-Proportonal Counter was used as the reference detector
(efficiency of 97 % at 4.7 Å)

Spatial resolution better than 0.24 mm FWHM for both X and Y

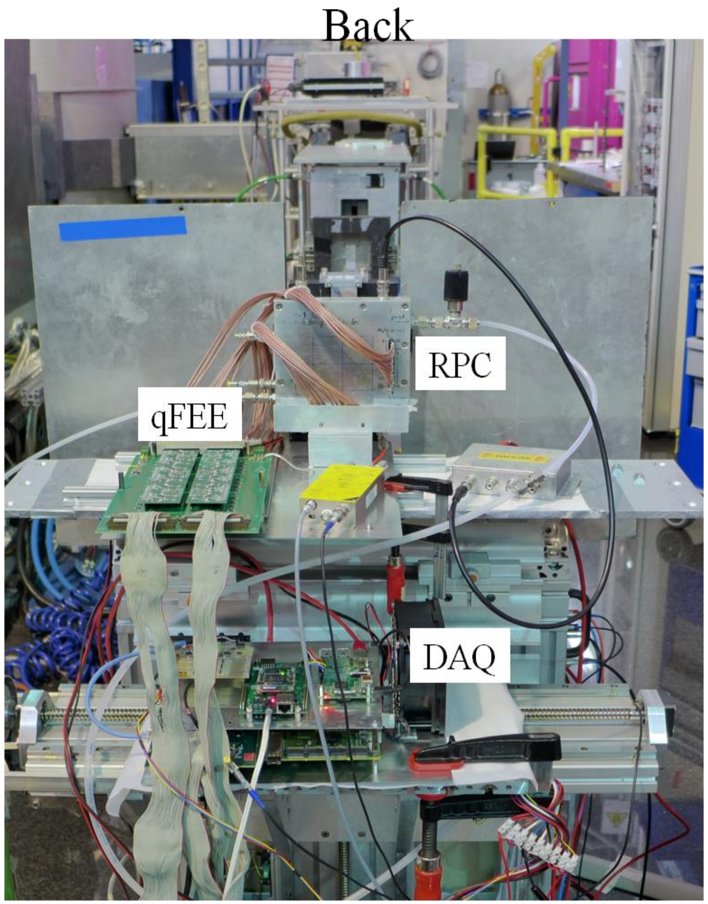


– Cadmium slit of 0.2 mm

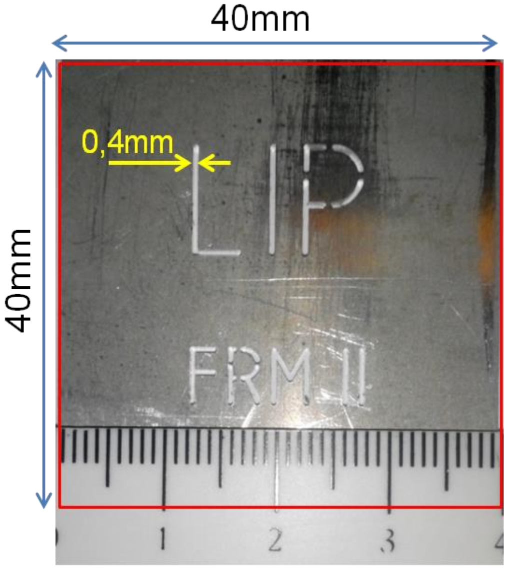
– Pitch of 0.5 mm

Firts Tests with neutrons at TUM-FRMII

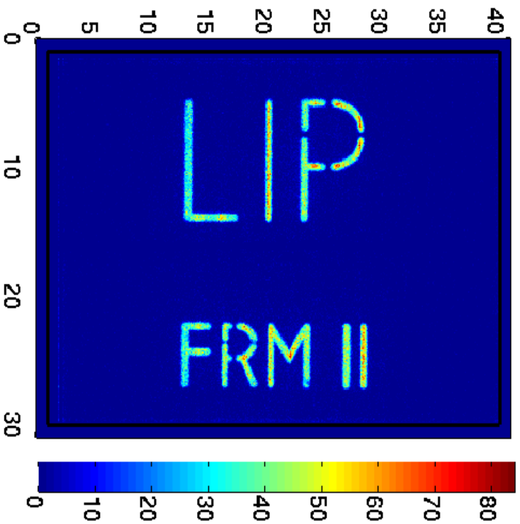
TREF neutron beam line (λ= 4.7 Å)



RPC-2 : 2D Spatial Resolution



Cd Mask (1mm thick)



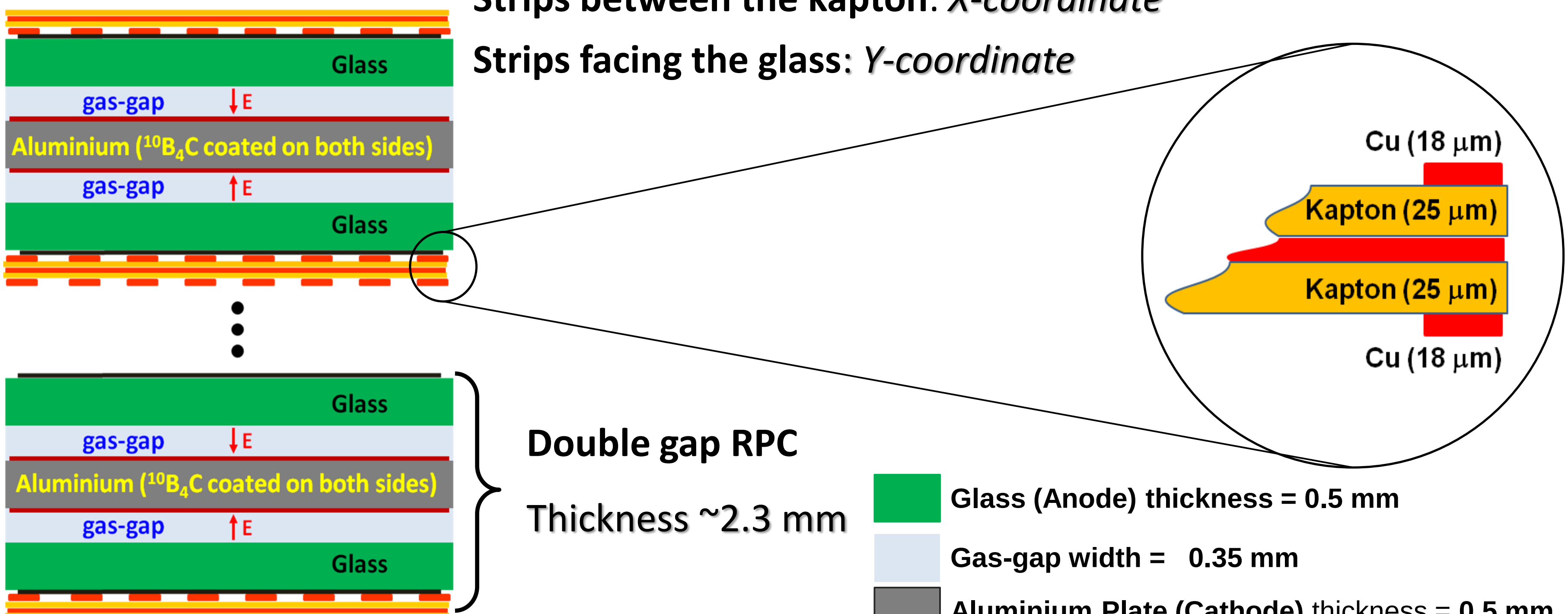
Multilayer Architecture

Stack of 10 Double-Gap RPCs (20 layers of $^{10}B_4C$)

x 20 Layers of $^{10}B_4C$

Strips between the kapton: ***X-coordinate***

Strips facing the glass: ***Y-coordinate***

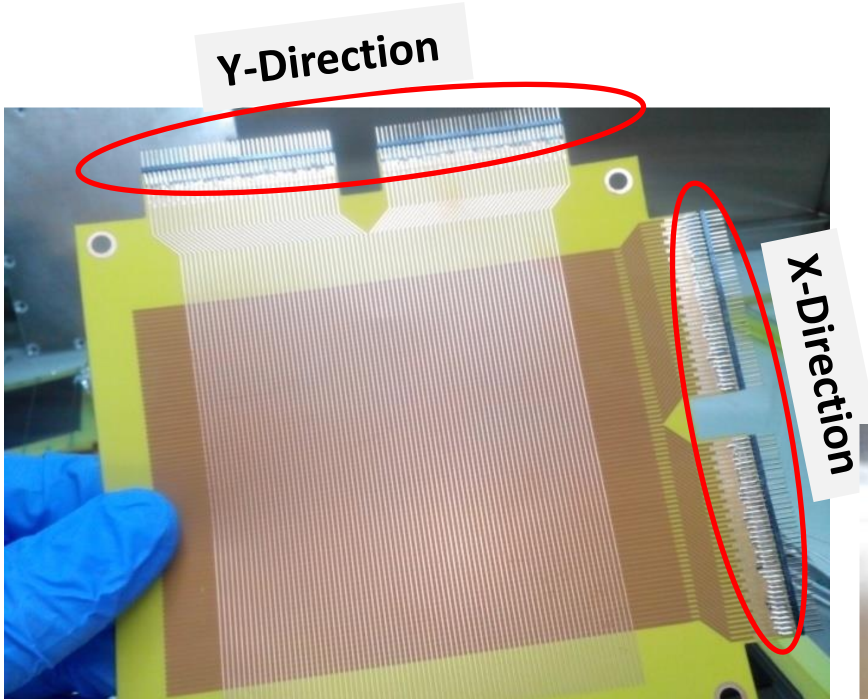


Double gap RPC

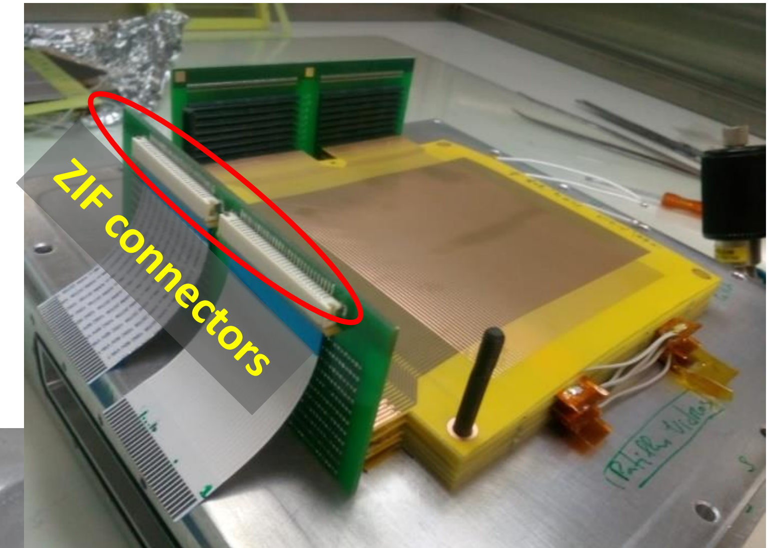
Thickness ~2.3 mm

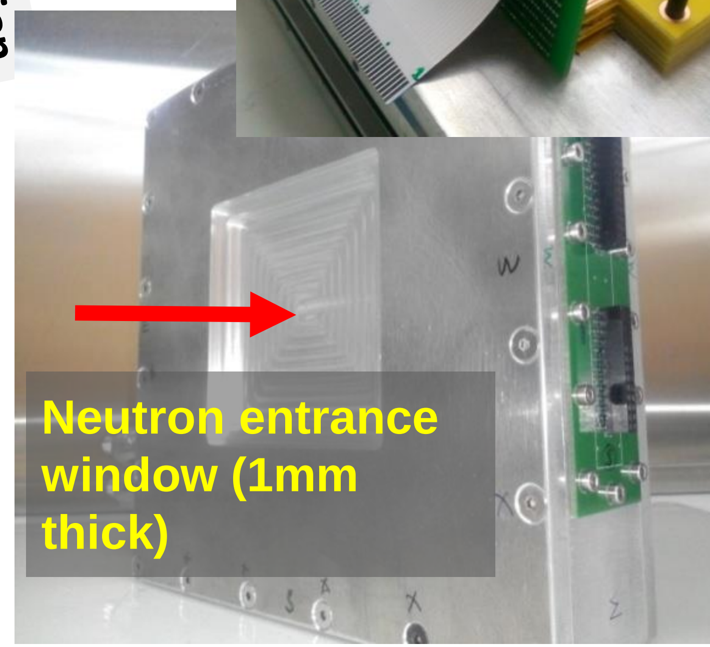
- **Glass (Anode) thickness = 0.5 mm**
- **Gas-gap width = 0.35 mm**
- **Aluminium Plate (Cathode)** thickness = **0.5 mm**
- **$^{10}B_4C$ layer: Thickness** ~ 1 **μm**
- **Resistive Ink:** thickness = **0.04 mm**

Multilayer Architecture
Stack of 10 Double-Gap RPCs (20 layers of $^{10}B_4C$)



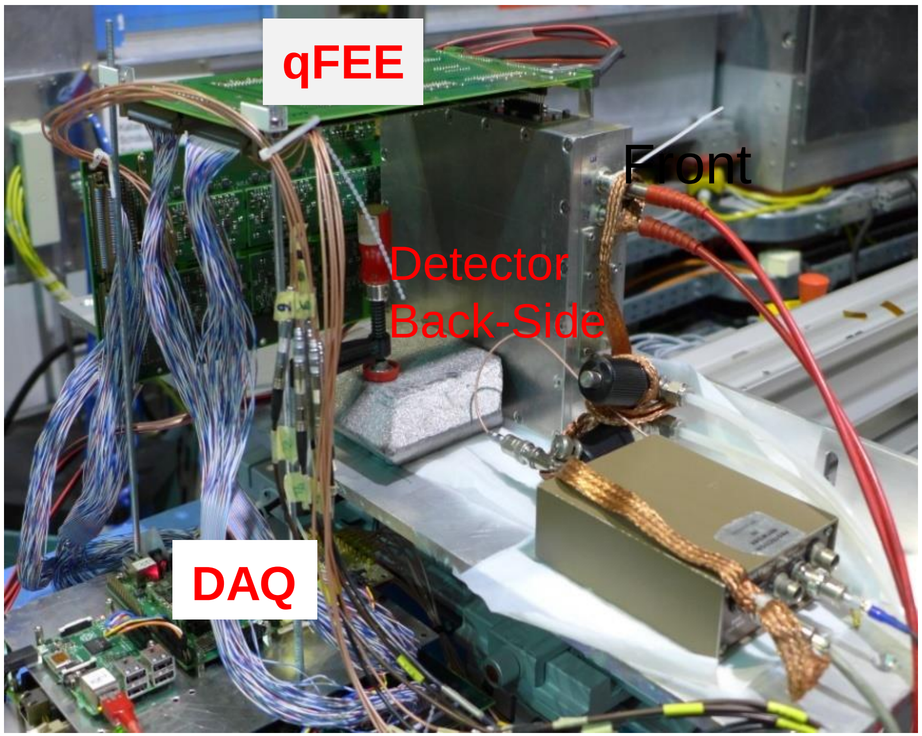
Thin PCB with signal pickup strips
2D readout

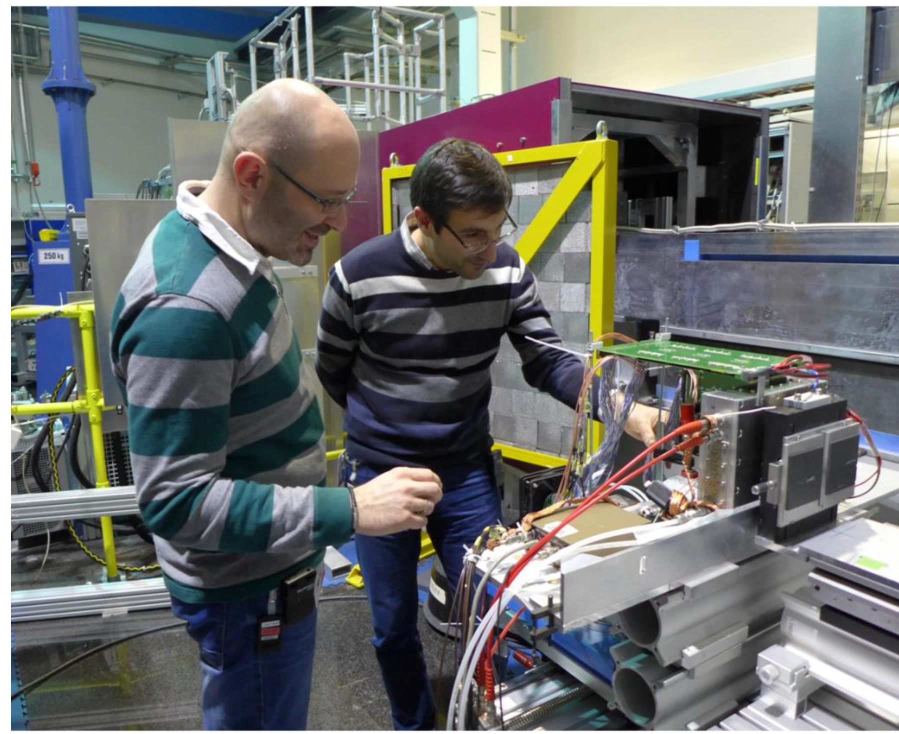




Multilayer Architecture
Stack of 10 Double-Gap RPCs (20 layers of $^{10}B_4C$)

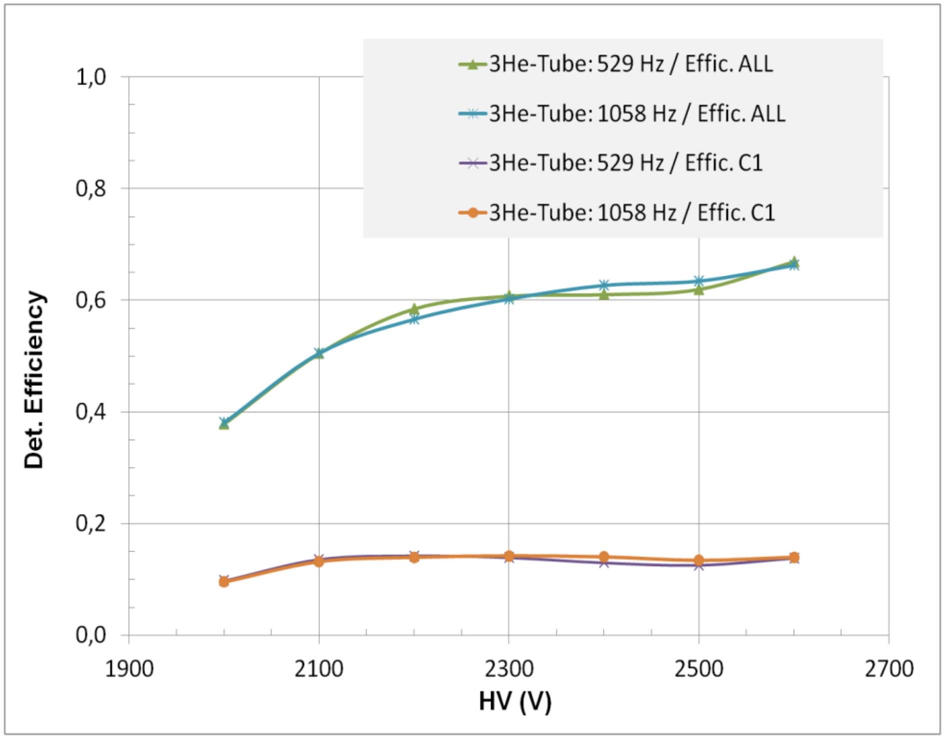
Detector at FRMII/ TREFF - neutron beamline





Multilayer Architecture
Stack of 10 Double-Gap RPCs (20 layers of $^{10}B_4C$)

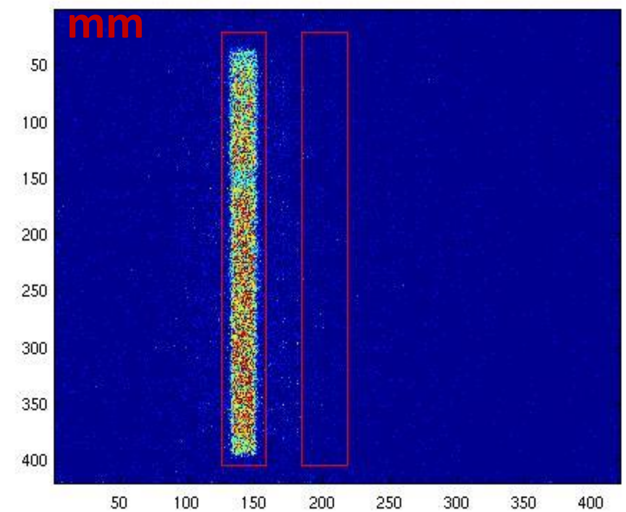
Detection efficiency



A correction factor was applied using a Signal to BKG ratio extracted from the reconstructed events

^{3}He-Proportonal Counter was used as the reference (efficiency of 97 % at 4.73 Å)

Cadmium Slit: 2 mm x 35 mm



The counting rate was given by the trigger of each individual cathode: **C1, C2, C3, …, C10**

Cathode area = 90 x 90 mm

Readout area: 43 x 43 mm

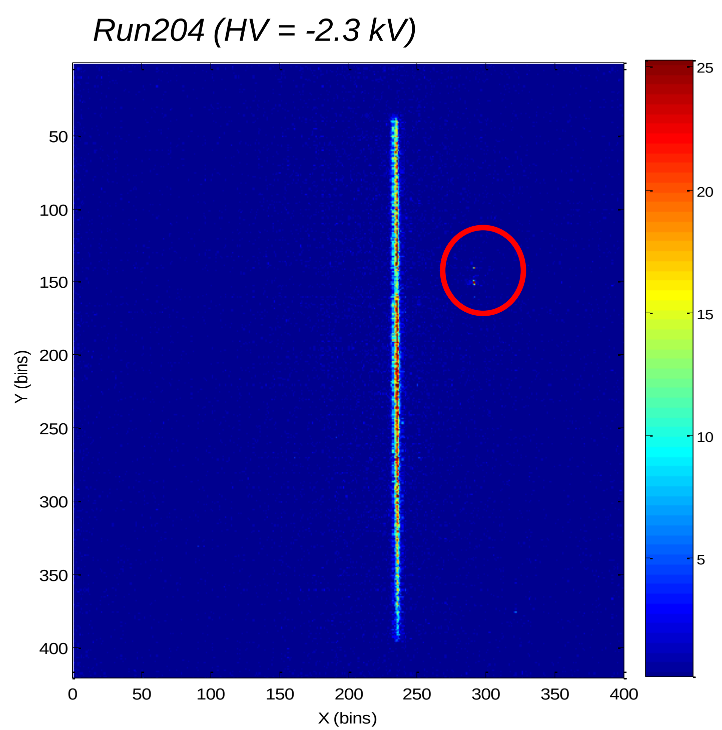
Multilayer Architecture

Stack of 10 Double-Gap RPCs (20 layers of $^{10}B_4C$)

Spatial resolution

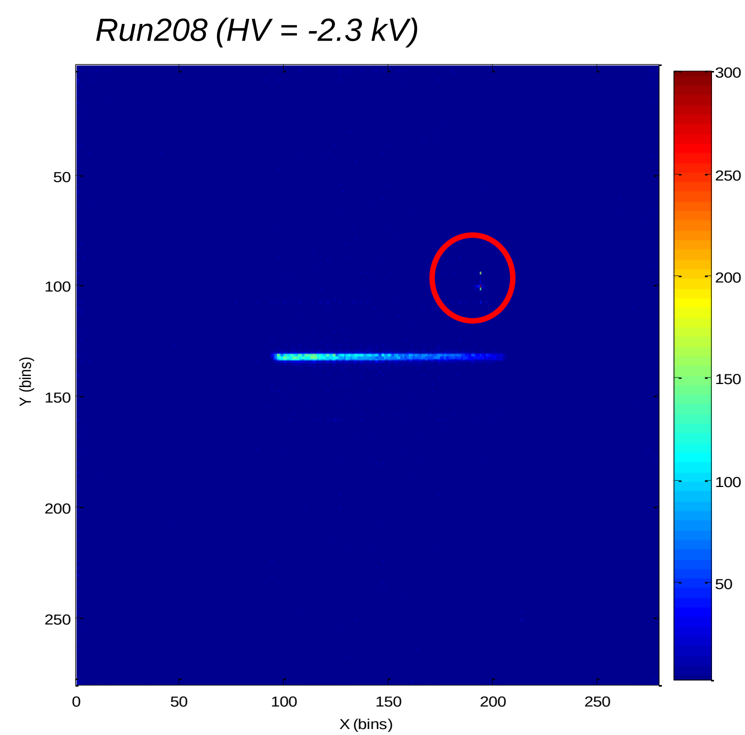
Vertical Slit: 0.075 mm x 35 mm

FWHM (X - direction) ~ 0.25 mm



Horizontal Slit: 0.075 mm x 16 mm

FWHM (Y - direction) ~ 0.35 mm

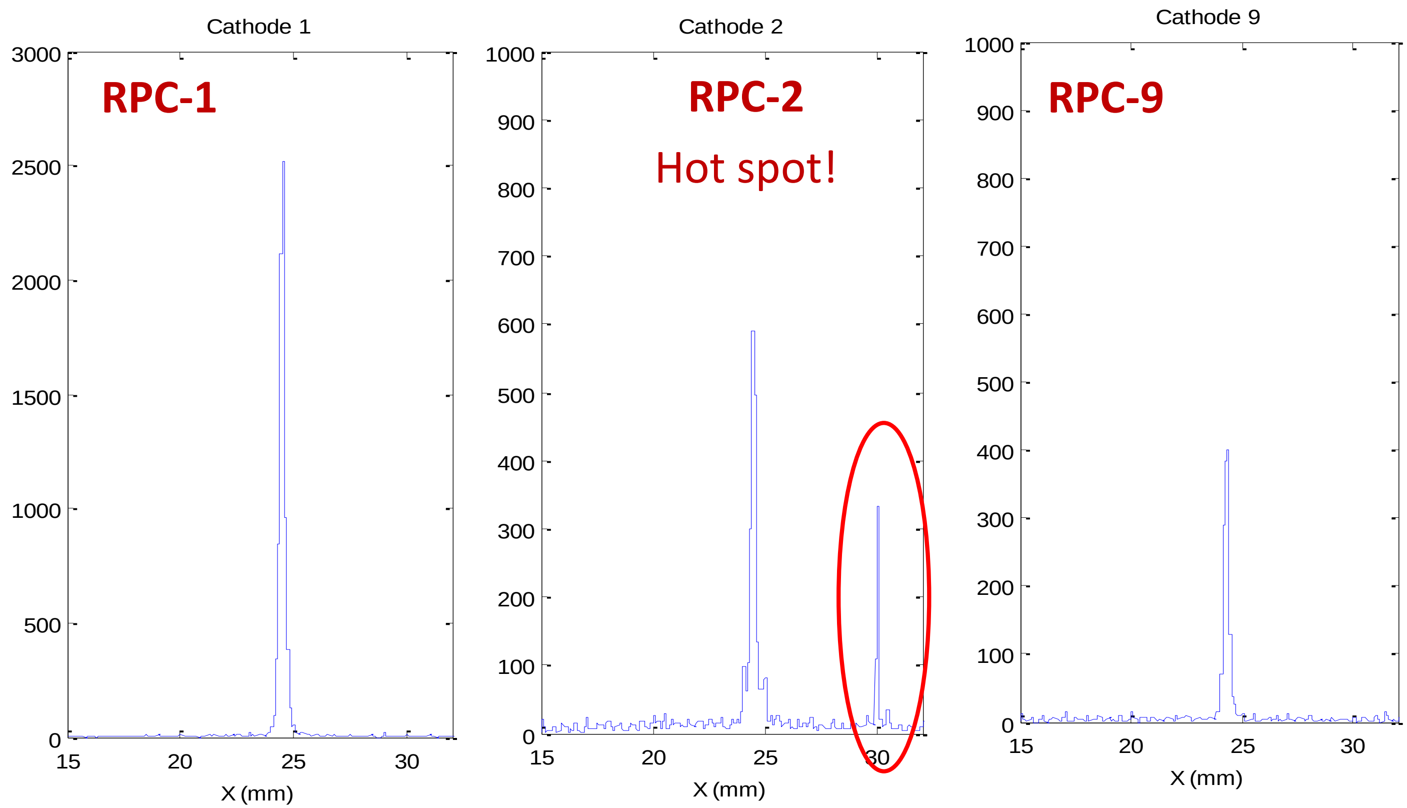


Obs.: Beam divergence ~30 μm

Multilayer Architecture
Stack of 10 Double-Gap RPCs (20 layers of $^{10}B_4C$)

Spatial resolution

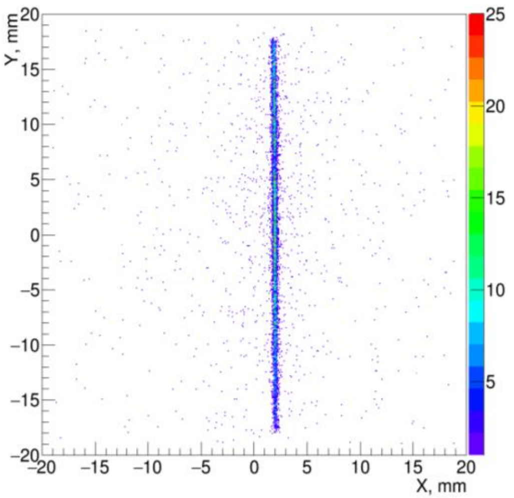
Vertical Slit



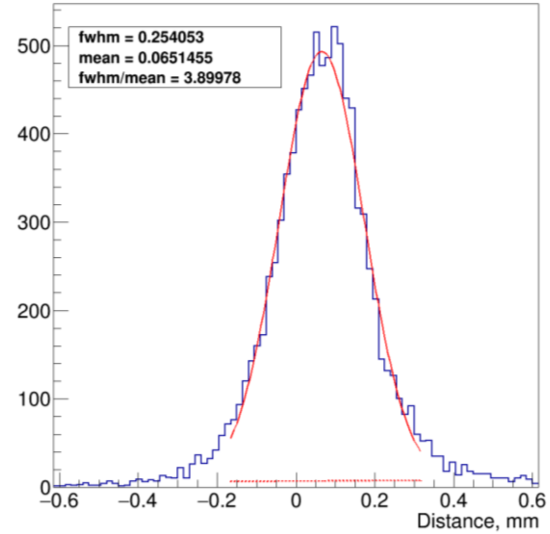
Spatial resolution – Data processing with ANTS2

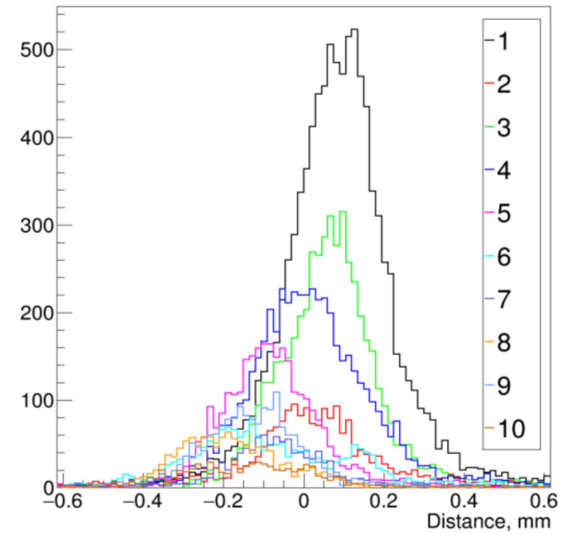
Centroid reconstruction: strongest signal strip and 4 neighbouring strips

Vertical Slit



Projection *vs* X-direction (ALL 10 RPCs): FWHM ~ 0.25 mm





There are both a **systematic shift** and **random fluctuations** in the profile positions.

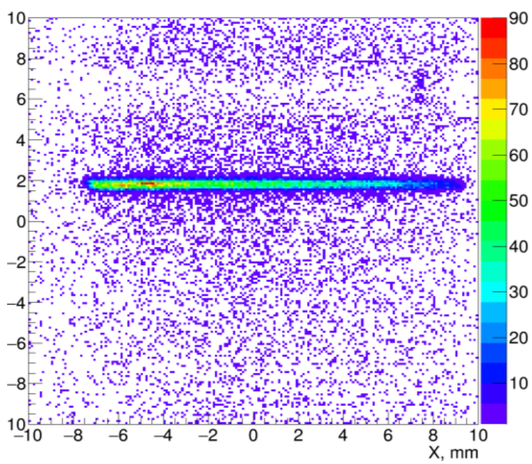
Multilayer Architecture

Stack of 10 Double-Gap RPCs (20 layers of $^{10}B_4C$)

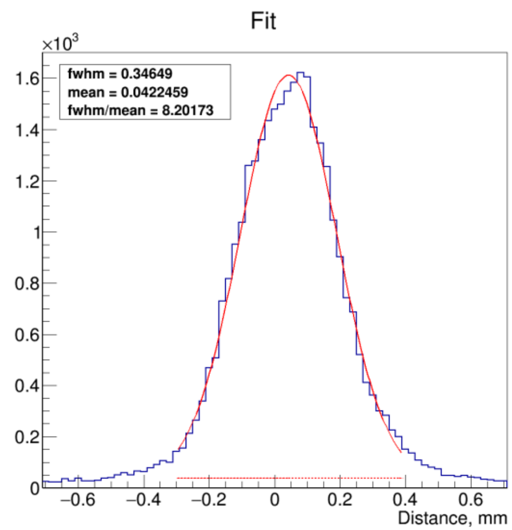
Spatial resolution – Data processing with ANTS2

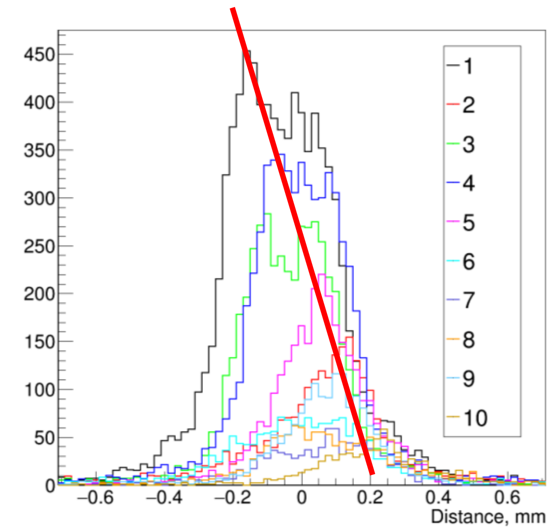
Centroid reconstruction: strongest signal strip and 4 neighbouring strips on each side

Horizontal Slit



Projection *vs* Y-direction (ALL 10 RPCs): FWHM ~ 0.35 mm



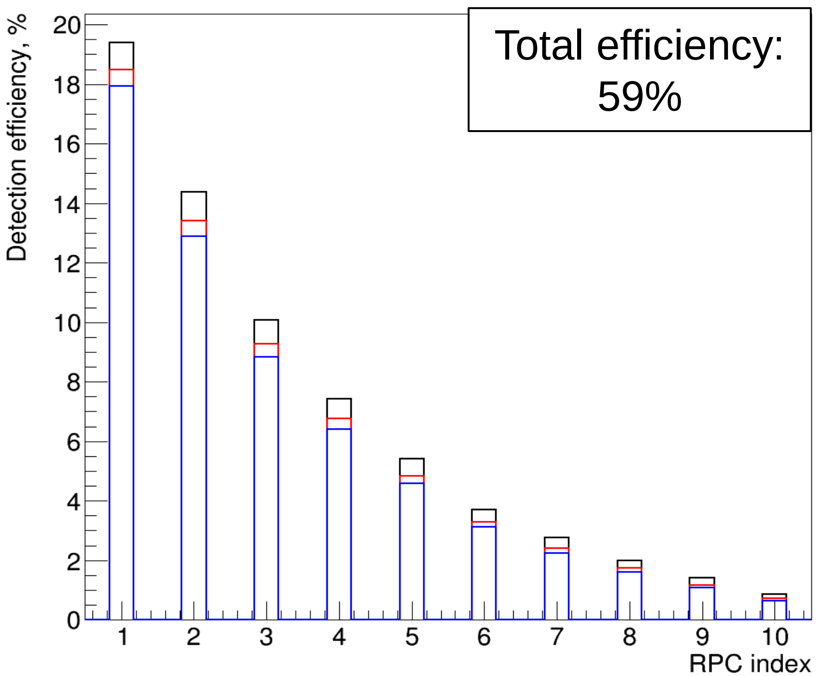


The **systematic shift** suggests **non-normality** of the beam to the RPCs of ≈0.4º (0.2 mm over 30 mm)
The **misalignments** of the RPCs in the stack are about 0.05 mm.

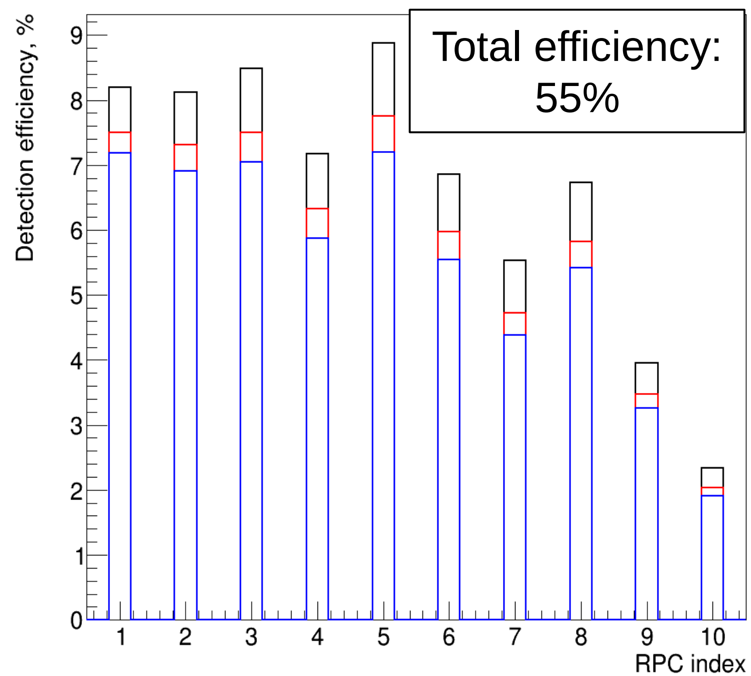
Simulations: detector optimization

Conditional optimization of B_4C converter layer thicknesses in ANTS2

- Equalize as much as possible the detection efficiency for all double-gap RPCs, keeping total efficiency as high as possible.
- Practical constrain: only 5 different converter layer thickness.



All layers have thickness of 1.15 µm: optimized for max total efficiency.



Conditional optimization: Converter thickness of 0.34, 0.39, 0.47, 0.74 and 1.94 µm.

Neutron Detectors

Summary

- Several B-10 RPCs prototypes were designed and three were tested on a thermal neutron beam at TUM-FRM II demonstrating sub-millimeter position resolution
- A multilayer detector with ten B-10 D-Gap RPCs was designed and assembled
- Tests with that detector at the FRMII /TREFF neutron beam have demonstrated:

  The capability of the multilayer detectors to reach efficiency > 50%

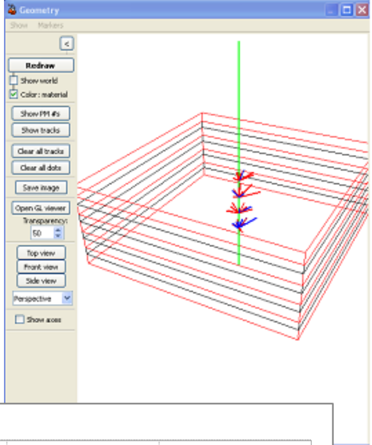
  The spatial resolution (<0.25 mm) is not worse than that measured for single-gap RPCs
- Next steps:

  Characterization of the gamma sensitivity

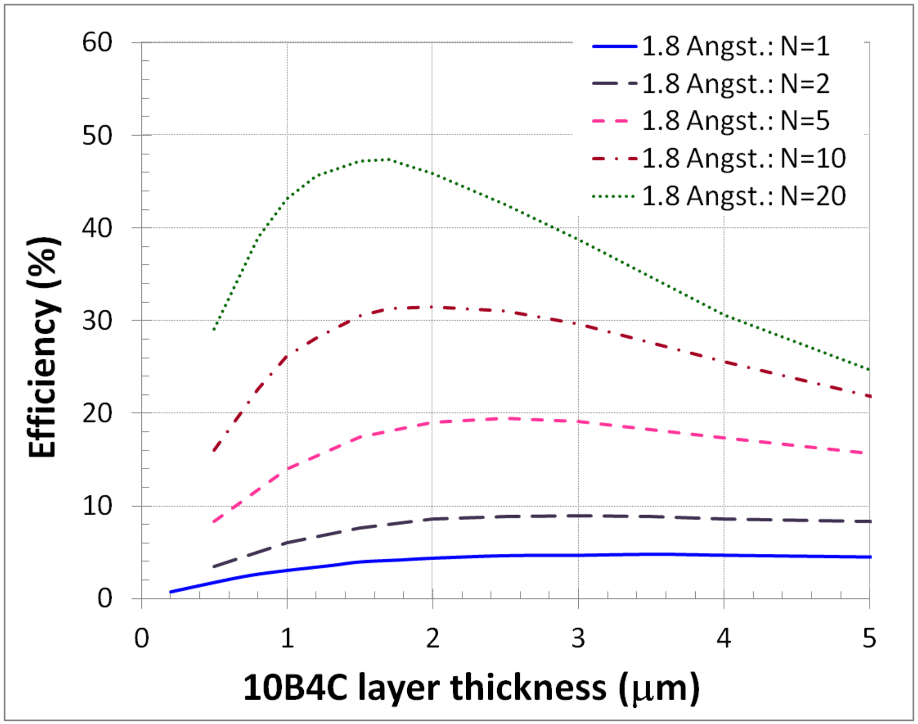
  Introduction of advanced position reconstruction algorithms to improve linearity and uniformity of high-resolution reconstructed images
- ANTS2 is being upgraded to include scattering of neutrons in all detector materials to evaluate its effect on the detector performance

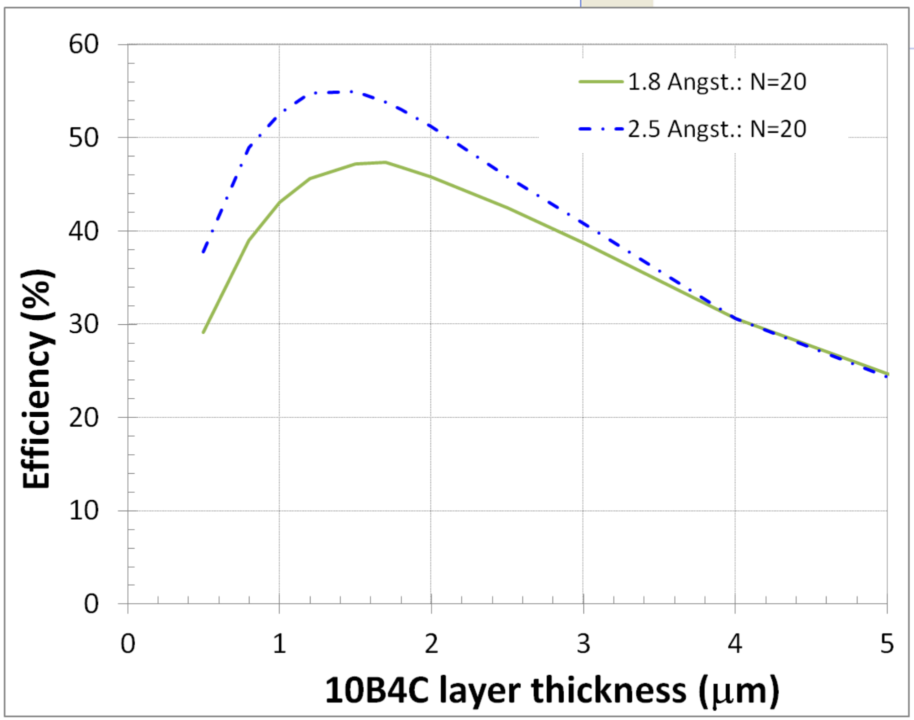
Thank you for your attention

ANTS2 Simulations



10B4C layers thickness optimization





ANTS2 Simulations

10B4C layers thickness optimization