XIV Workshop on Resistive Plate Chambers and related detectors (RPC2018)
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Neutron imaging with $^{10}B_4C$-lined thin-gap RPCs:
A multilayered architecture for high detection efficiency

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Motivation

PSNDs with cutting edge performance, based on He-3 alternatives, are a pressing need for "top level" instruments at ESS and other neutron Large Scale Facilities

Main goal

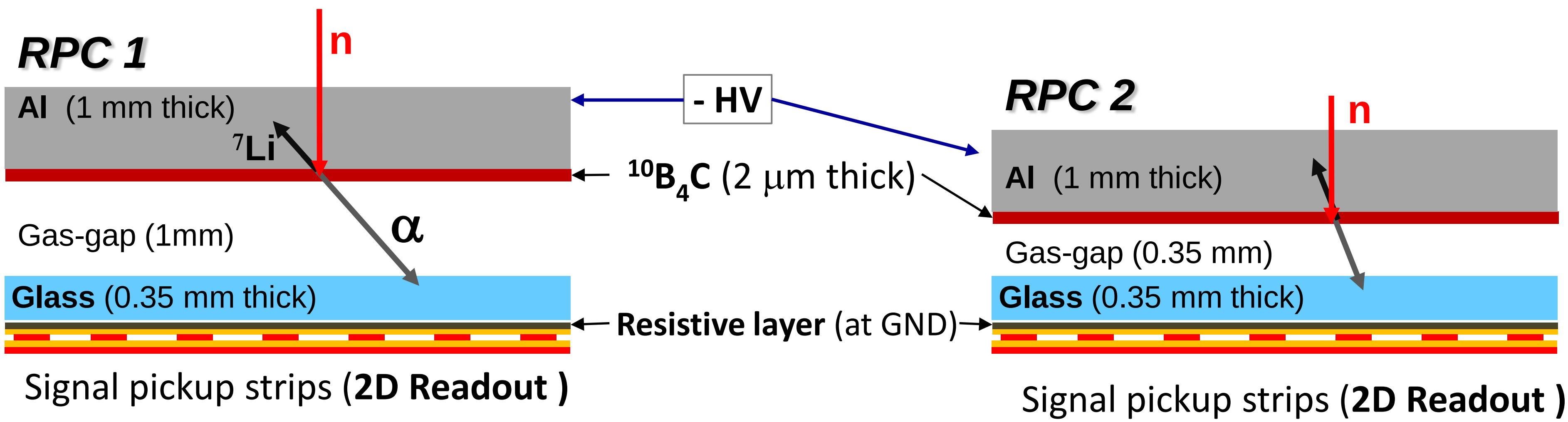
Evaluate the potencial of RPCs for high precision PSNDs

Performance capability should be expressed in therms of expected spatial resolution, detection efficiency, counting rate and gamma sensitivity

The work presented here is being developed in the framework of the SINE 2020 (Science & Innovation with Neutrons in Europe) collaboration - EU project No 654000

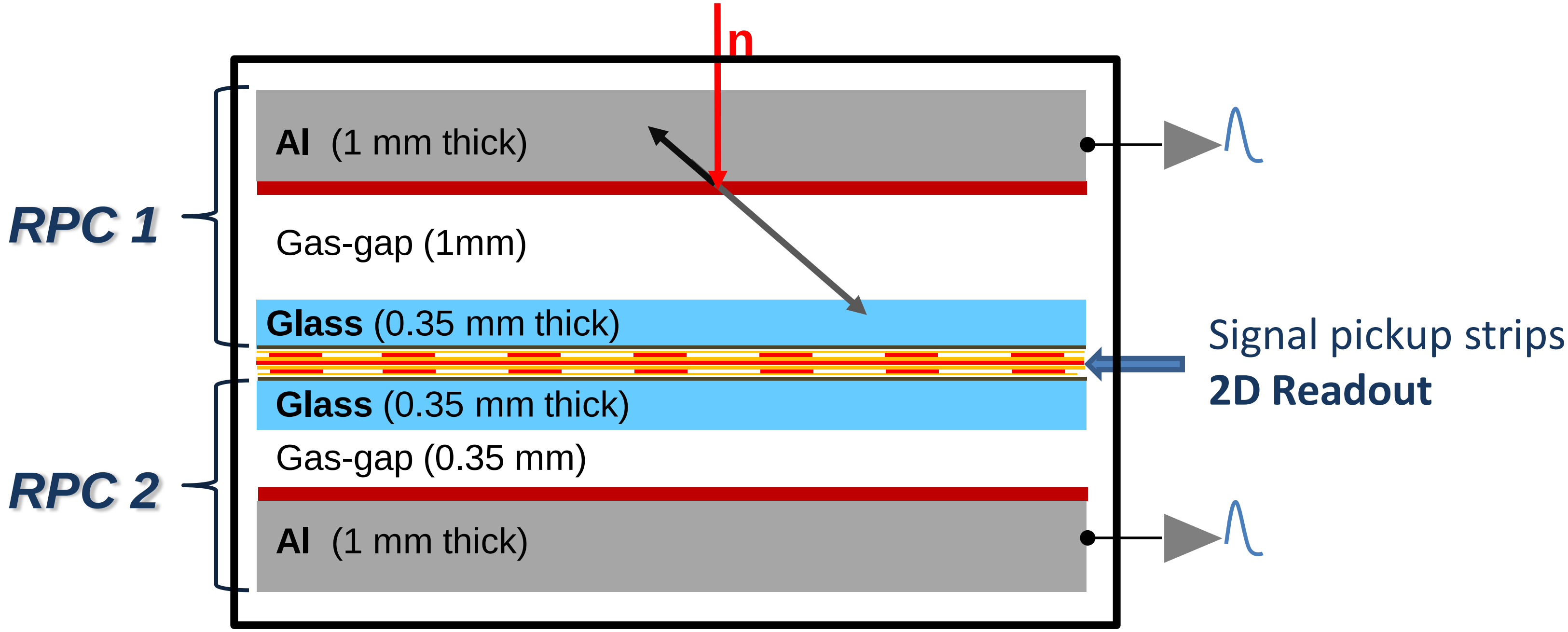
Wider or thinner gas-gaps?

- **Two RPCs were assembled: 0.35 and 1 mm gas-gap width**



Metallic cathode ⇒ 2D position encoding on the anode side

Detector configuration for the tests with neutrons



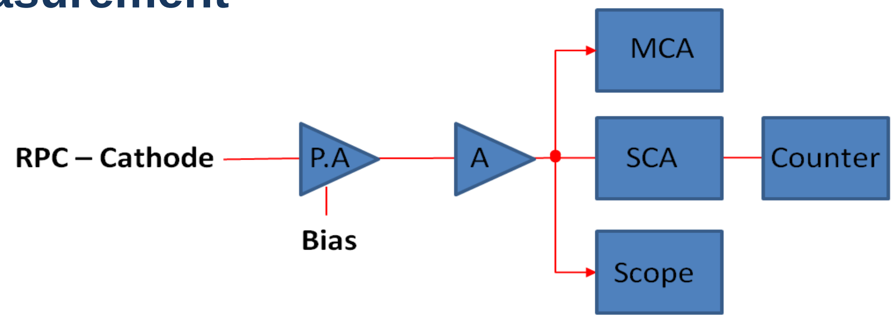
Working gas: $C_2H_2F_4$ at atmospheric pressure

$^{10}B_4C$ coating made at ESS Detector Coatings Workshop

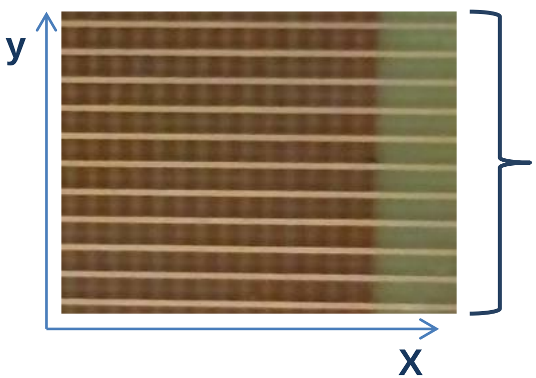
2 μm thick layer of $^{10}B_4C$ on Al plates (1mm thick)

Cathode and Cu-strips signals readout

❑ Efficiency measurement



❑ Position encoding

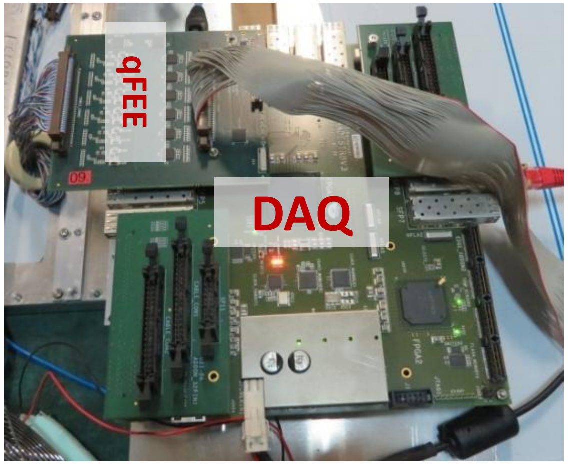


Each individual strip is readout by charge sensitive amplifiers

- PCB: FR4, 0.4mm; Strips: Cu, 18 mm
- Vertical strips (**X**-coord.): **1.5 mm pitch, 1.3 mm** width
- Horizontal strips (**Y**-coord.): **2.0 mm pitch; 0.5 mm** width

Area instrumented: *20 strips for both x, y* (30 mm, 40 mm)

DAQ is based in the new TRB3 platform developed at GSI, Germany (http://trb.gsi.de/)

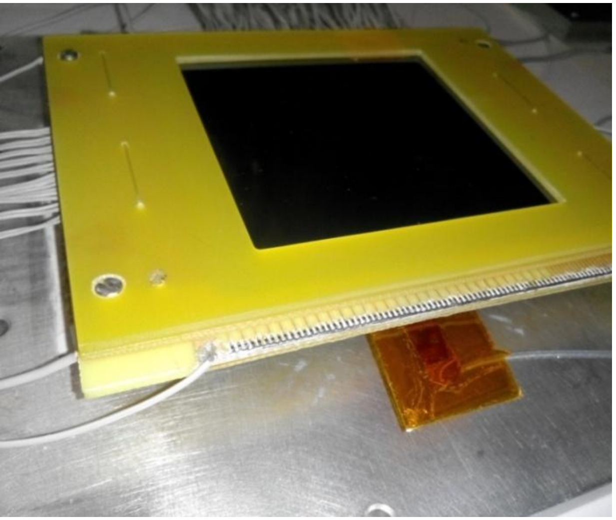


A Neiser et al 2013 JINST 8 C12043
doi: 10.1088/1748-0221/8/12/C12043

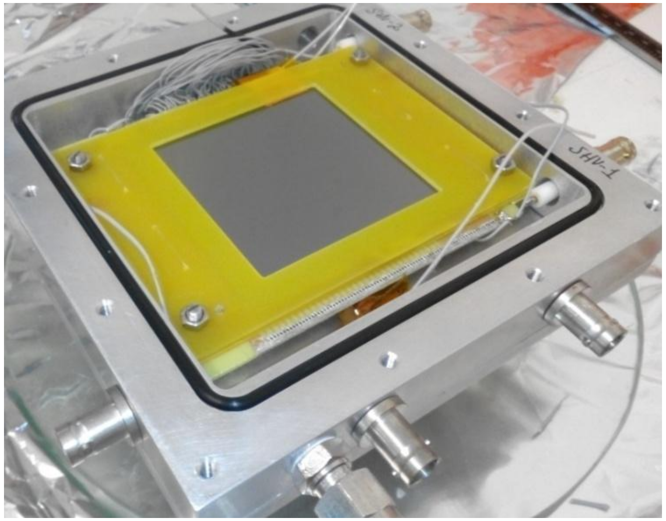
Detector ready for the tests at TUM-FRMII

Two RPCs were assembled inside an Al chamber:

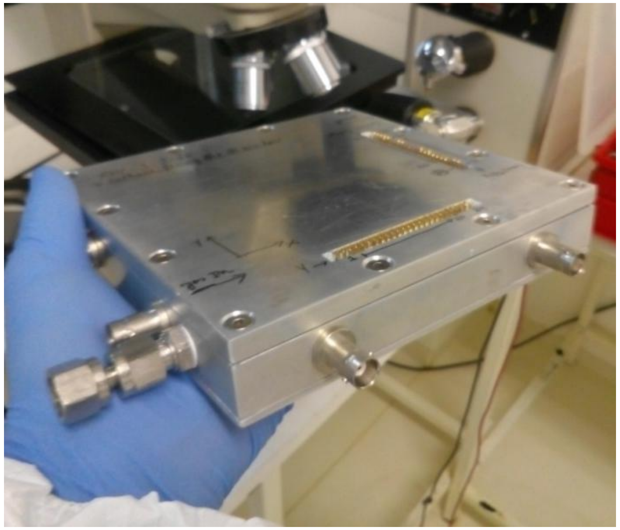
- **RPC-1:** ***gas-gap width*** **of 1 mm**
- **RPC-2**: ***gas-gap width*** **of 0.35** mm



RPC1 and RPC2 stacked with the 2D-readout structure in the center

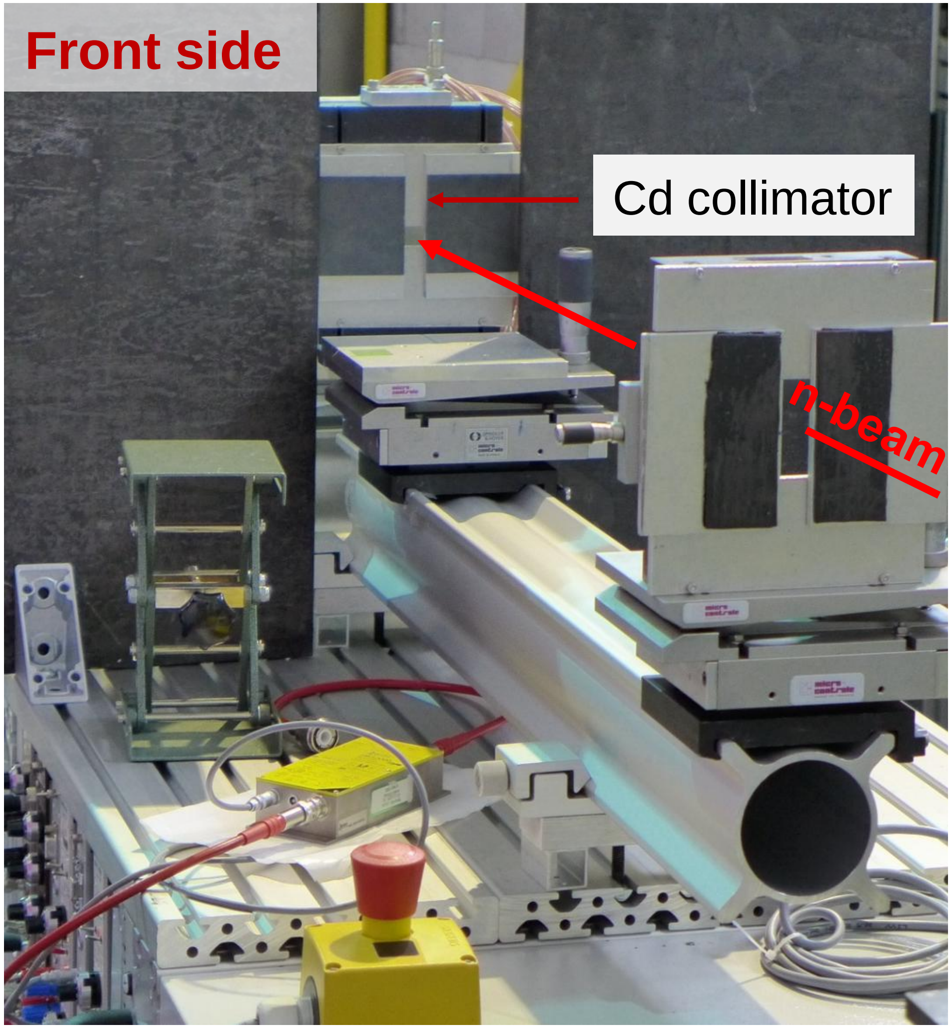


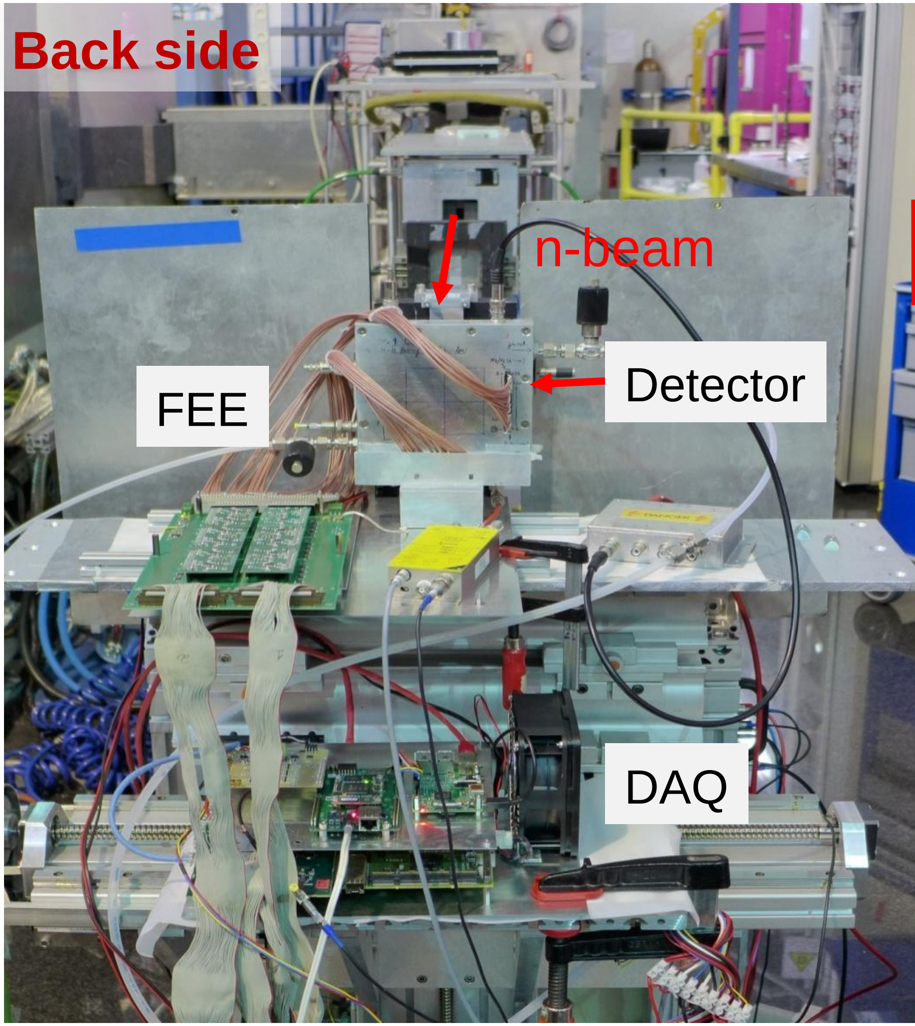
SHV feedthroughs for the high voltage (HV)



Detector ready to be tested

Detector at FRMII/ TREFF neutron beam line (λ= 4.7 Å)

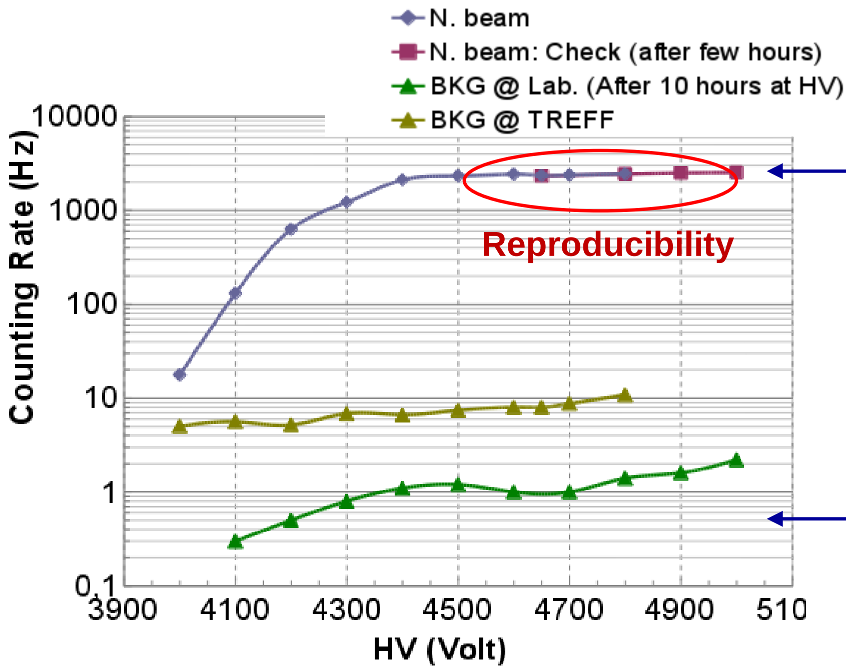




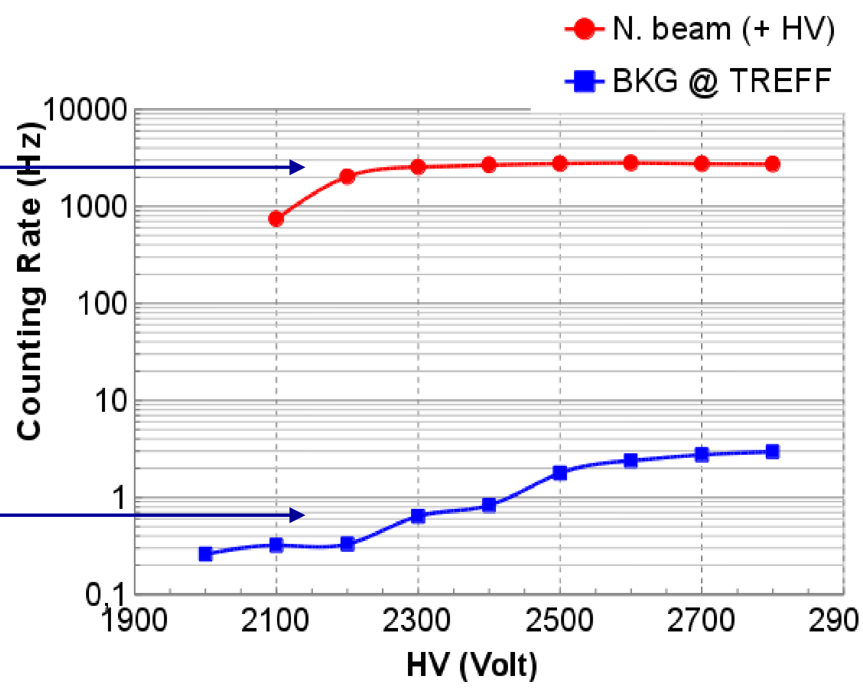
Experimental results

❑ Plateau

RPC-1 (gas-gap width: 1.0 mm)



RPC-2 (gas-gap width: 0.35 mm)



Wide HV plateau (> 500 V) for both RPCs

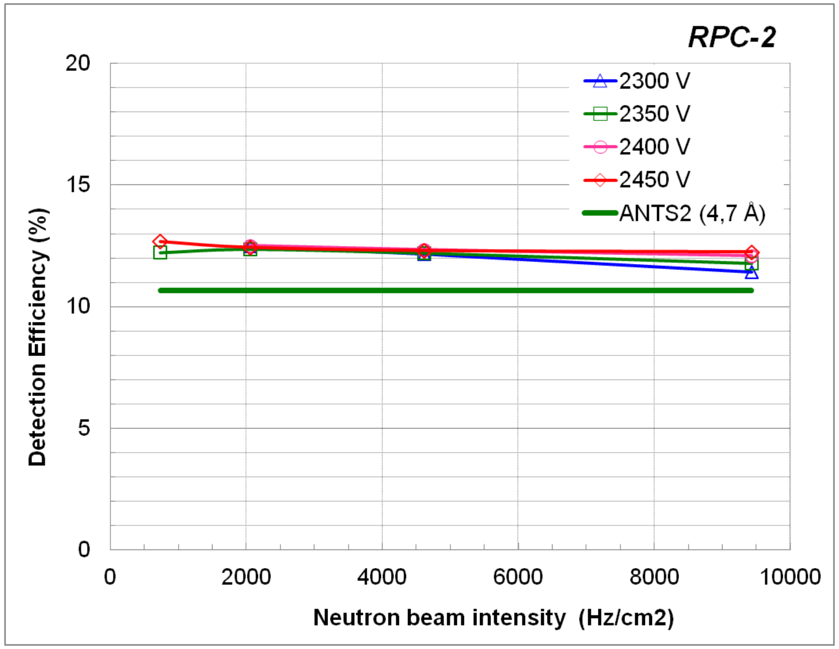
Experimental results

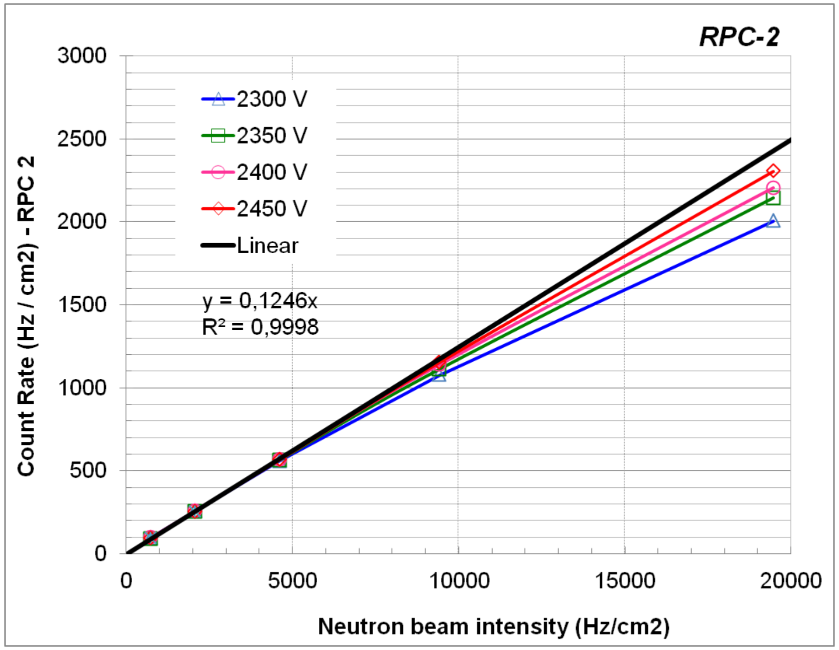
❑ Detection efficiency

Detection Efficiency (λ = 4.7 Å) ≈ 12.5%

It is in good agreement with ANTS2 simulation

http://coimbra.lip.pt/ants/ants2.html



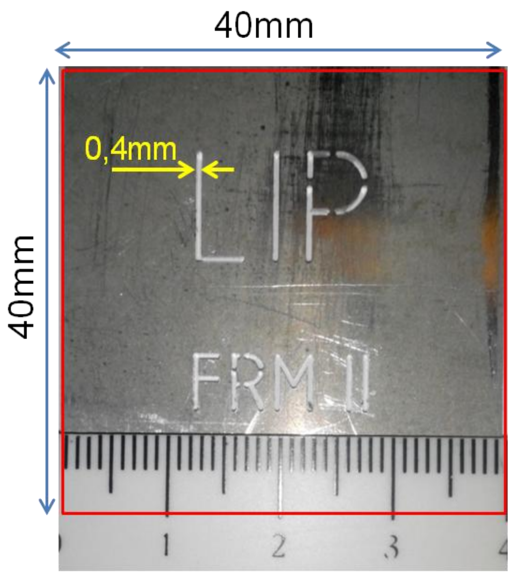


^{3}He-Proportinal Counter was used as the reference detector (Det. Efficiency of 97 % at 4.7 Å)

Experimental results

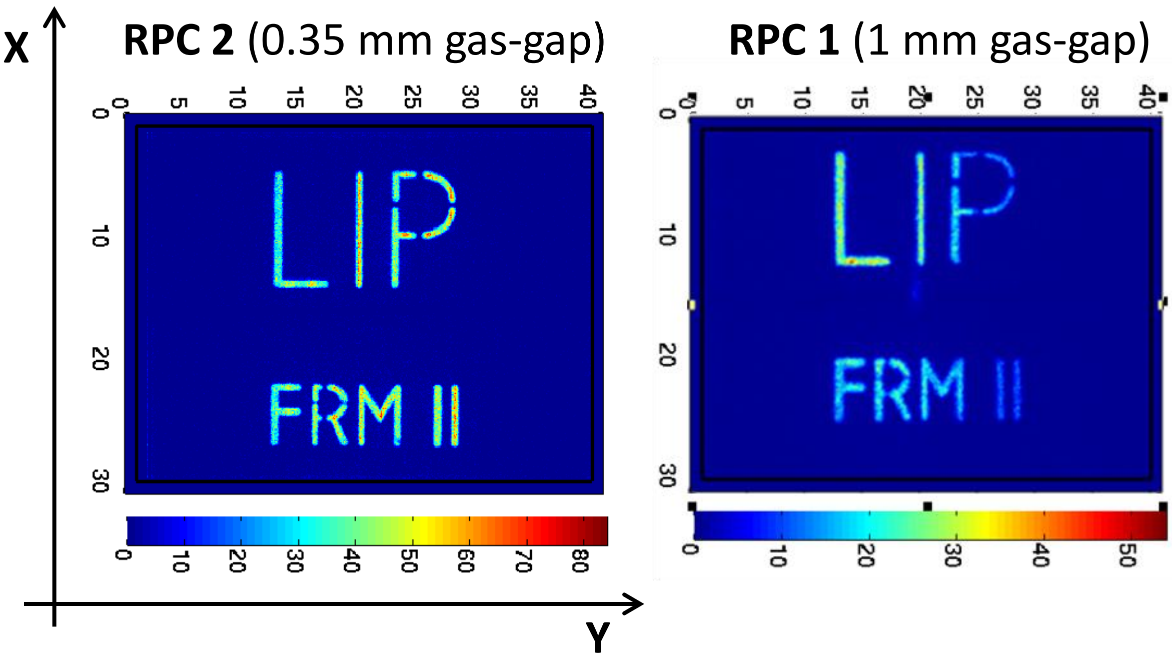
- **Spatial resolution** *(position calculation by COG)*

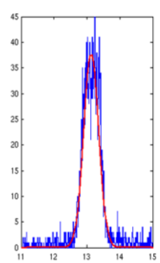
RPC 2 seems to perform better than RPC 1



Cd Mask (1mm thick)

Letters: line width of 0.4 mm



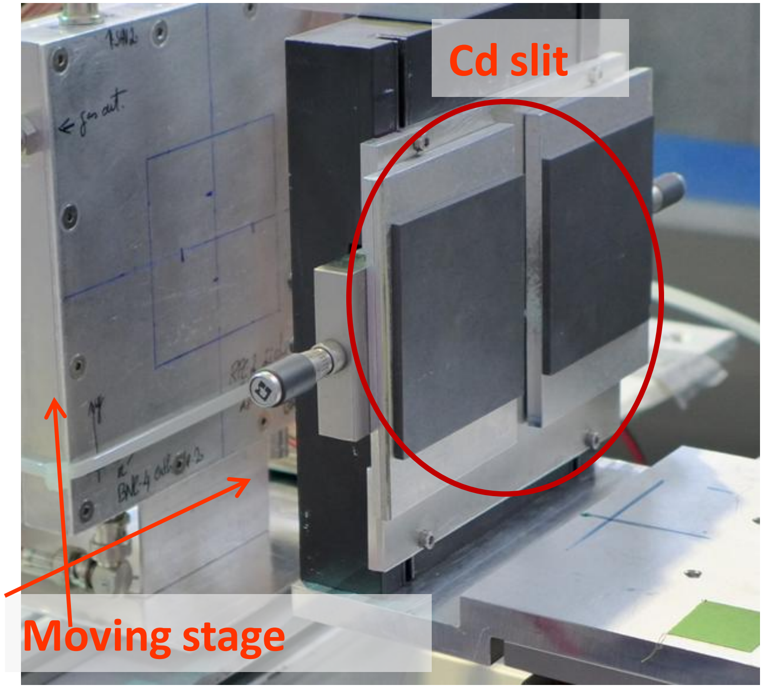


RPC 2	RPC 1
$\sigma_x \sim 0.198$ mm	$\sigma_x \sim 0.232$ mm
$\sigma_y \sim 0.233$ mm	$\sigma_y \sim 0.273$ mm

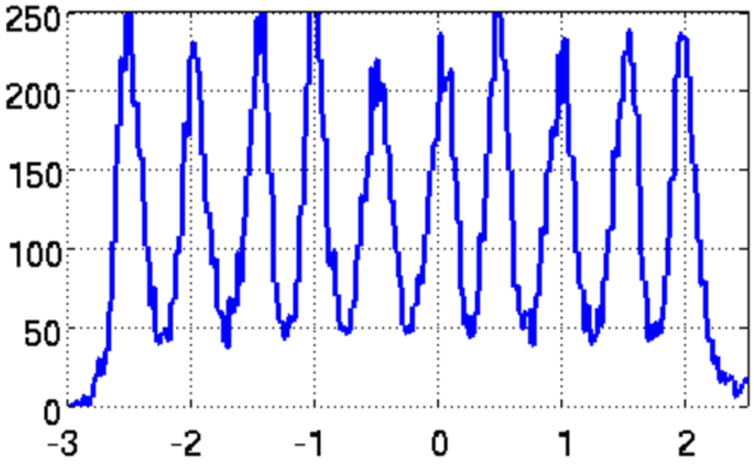
Experimental results

❑ Spatial resolution

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



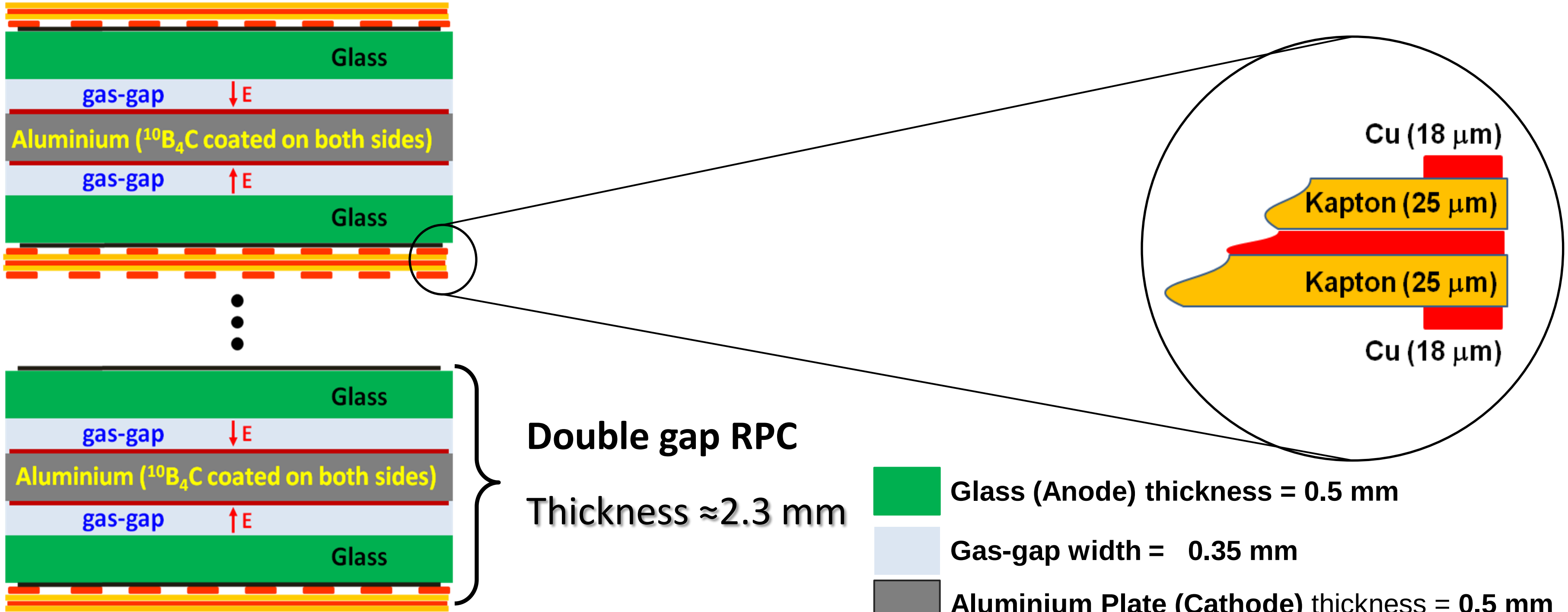
- slit width of ≈ **0.2 mm**
- Detector shifted in **steps of 0.5 mm**



Towards high detection efficiency

Evaluation of a multilayer architecture: 10 *Double-Gap RPCs*

20 Layers of $^{10}B_4C$



Double gap RPC

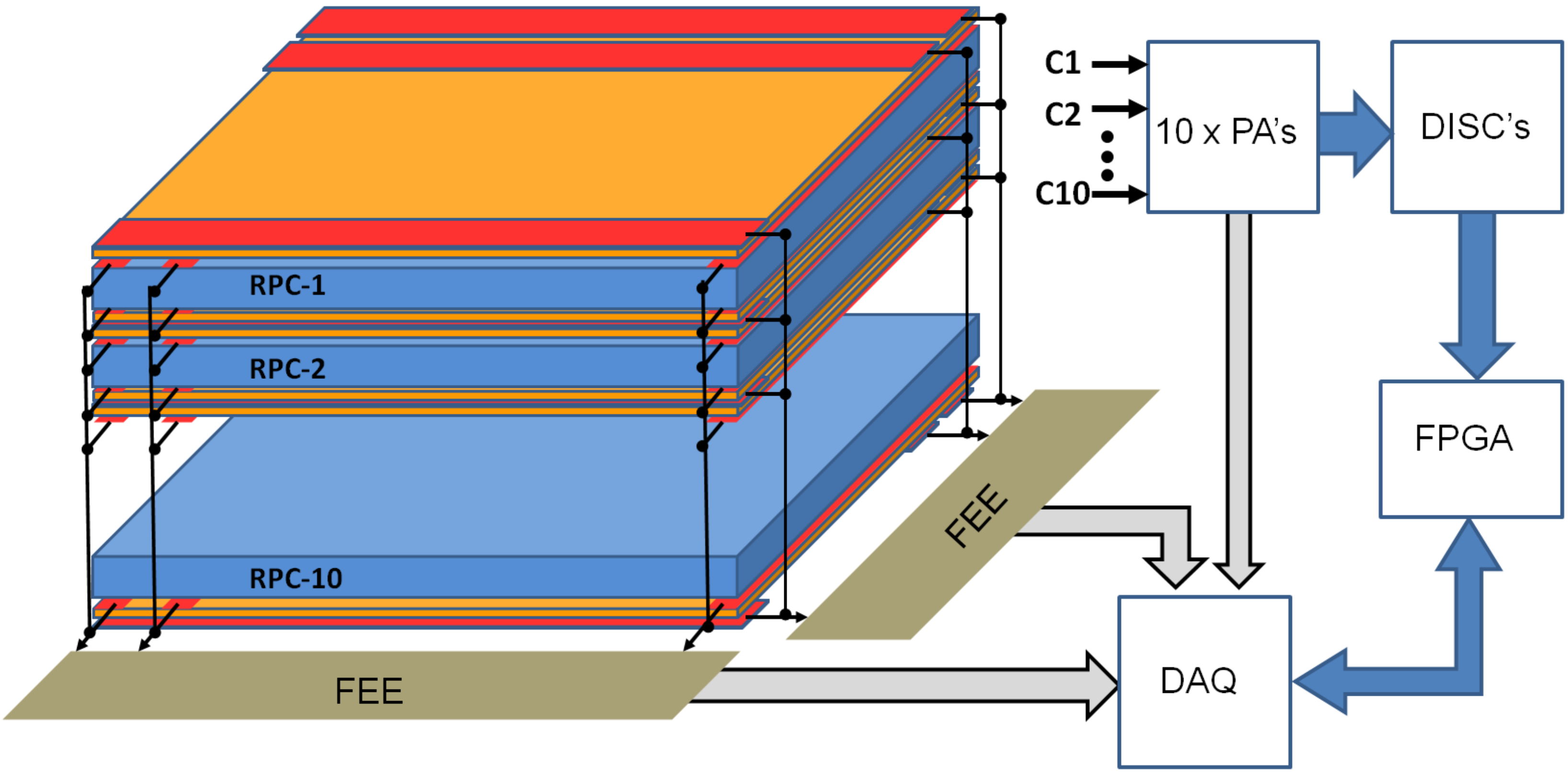
Thickness ≈2.3 mm

- **Glass (Anode) thickness = 0.5 mm**
- **Gas-gap width = 0.35 mm**
- **Aluminium Plate (Cathode)** thickness = **0.5 mm**
- **$^{10}B_4C$ layer: Thickness** ~ 1.15 **μm**
- **Resistive Ink:** thickness = **0.04 mm**

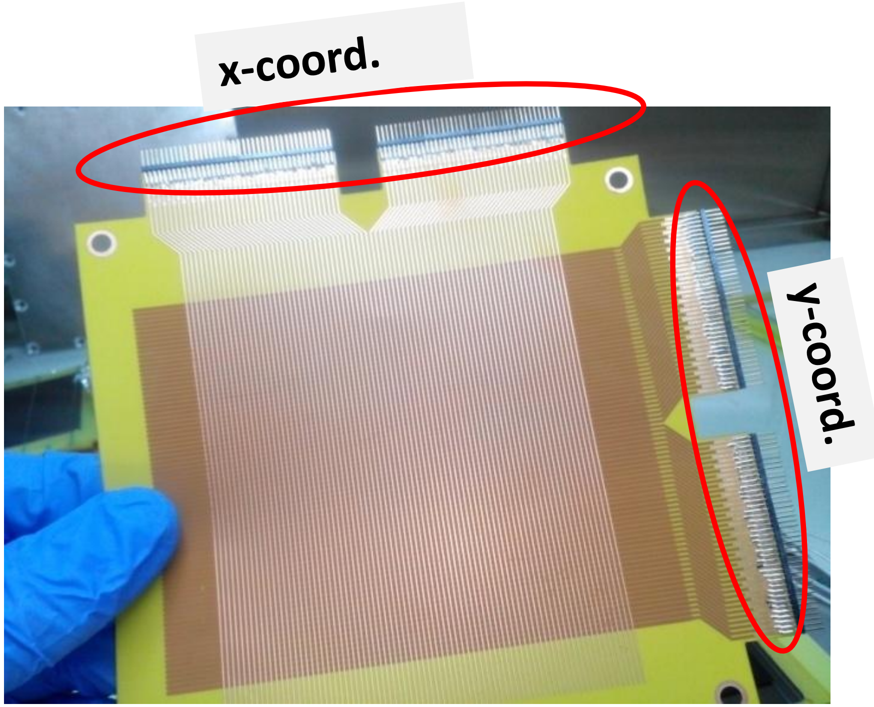
Towards high detection efficiency

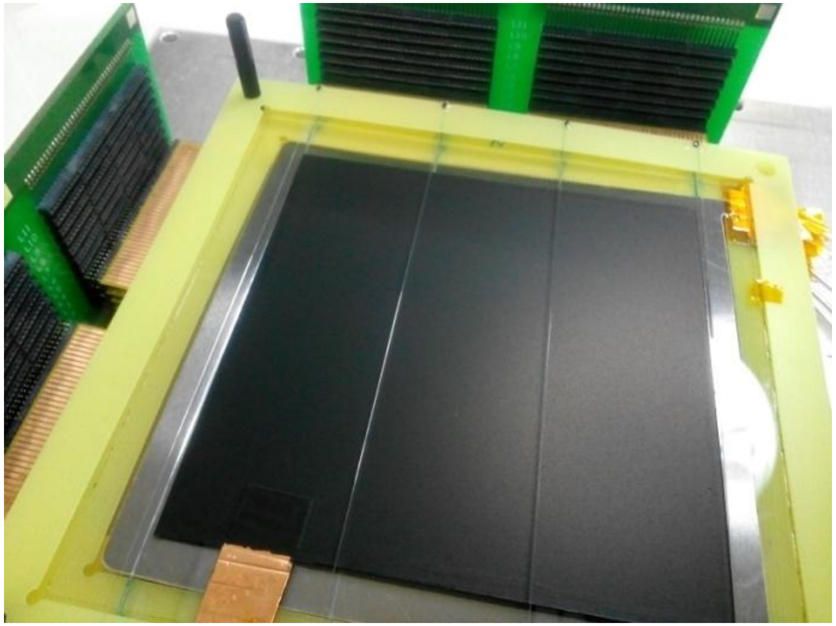
Evaluation of a multilayer architecture: 10 *Double-Gap RPCs*

Electronic readout



Few details of prototype assembly (10 double-gap RPCs)





Thin Kapton PCBs with signal pickup strips for the 2D readout:

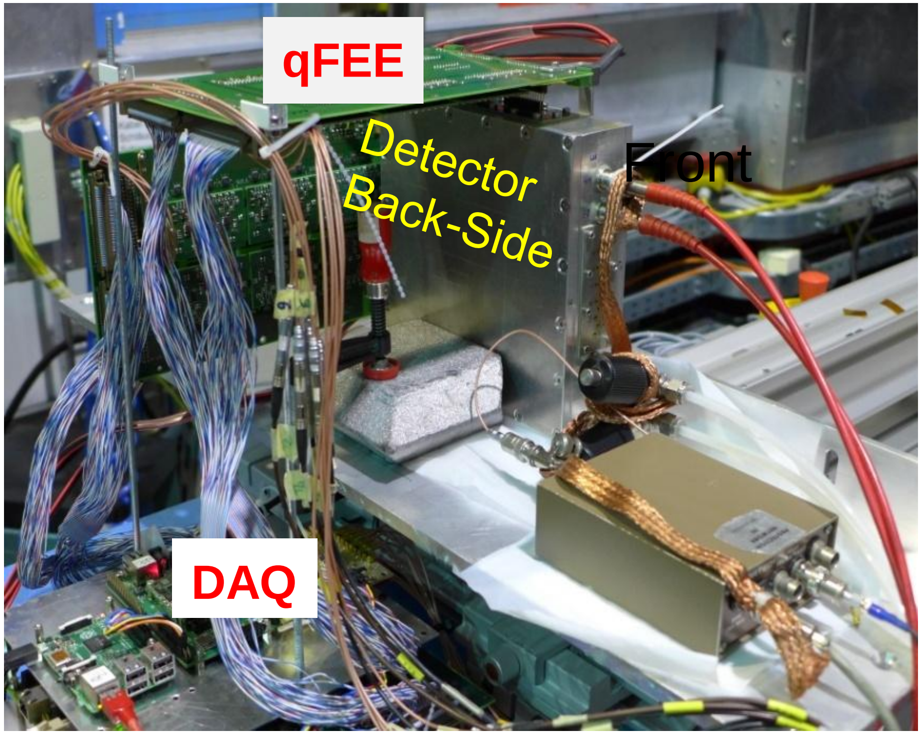
X-coord.: Pitch = 1mm; strip width = 0.3 mm

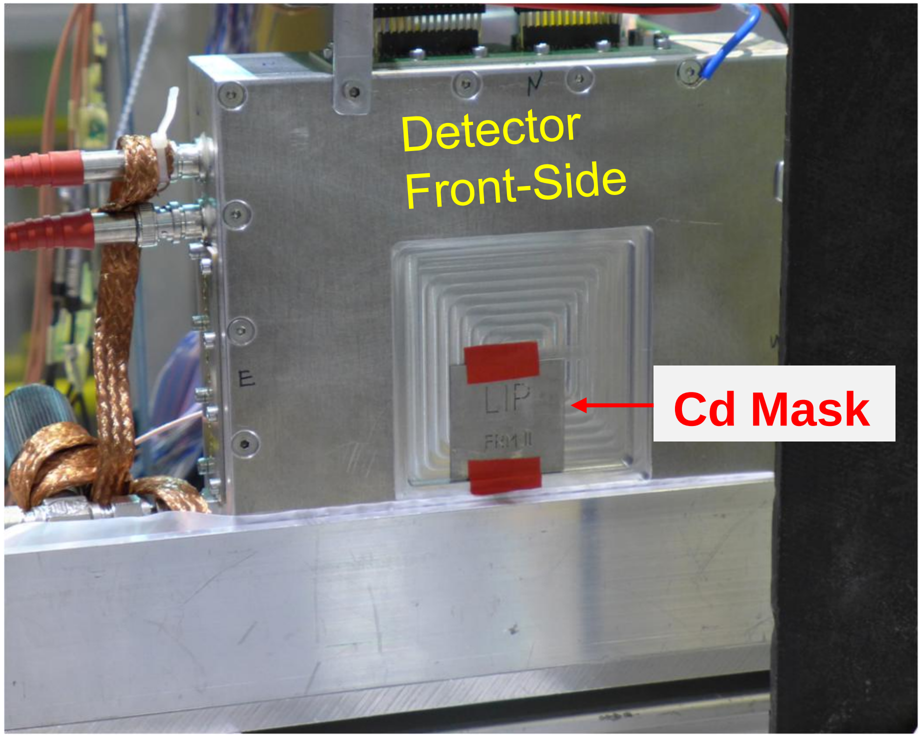
Y-coord.: Pitch = 1mm; strip width = 0.9 mm

Glass plate (outer side lined with a resistive layer) **facing an AL plate (lined on both faces with a 1.15 μm thick layer of $^{10}B_4C$**

$^{10}B_4C$ coating made at ESS Detector Coatings Workshop

Detector prototype at FRMII/ TREFF neutron beamline





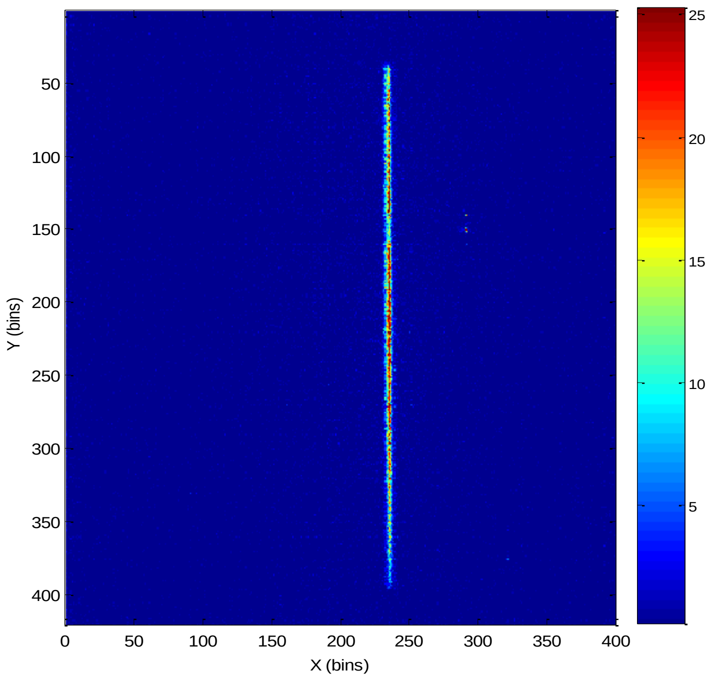
FEE – 2 x 48 channels (designed by P. Fonte and assembled at LIP)
DAQ is based on the new TRB3 platform developed at GSI, Germany (http://trb.gsi.de/)

Evaluation tests with neutrons (λ= 4.7 Å)

❑ Spatial resolution

FWHM (X – coord.) ≈ 0.25 mm

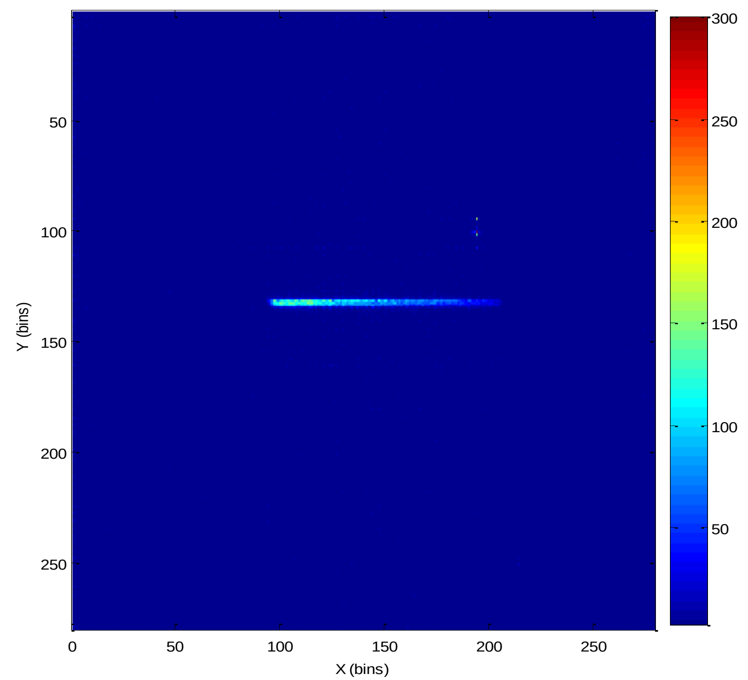
Run204 (HV = -2.3 kV)



Vertical Slit: 0.075 mm x 35 mm

FWHM (Y – coord.) ≈ 0.35 mm

Run208 (HV = -2.3 kV)



Horizontal Slit: 0.075 mm x 16 mm

Obs.: Beam divergence ~30 μm

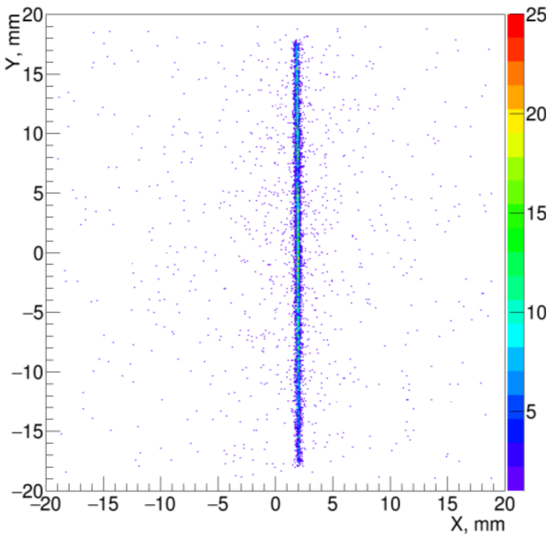
Evaluation tests with neutrons (λ= 4.7 Å)

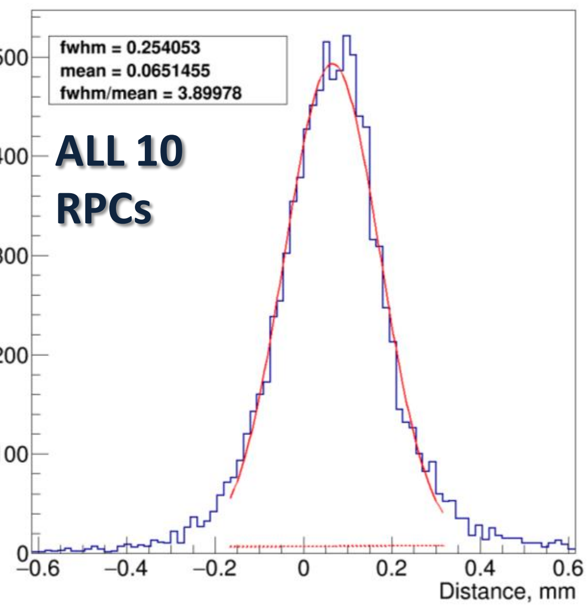
❑ Spatial resolution

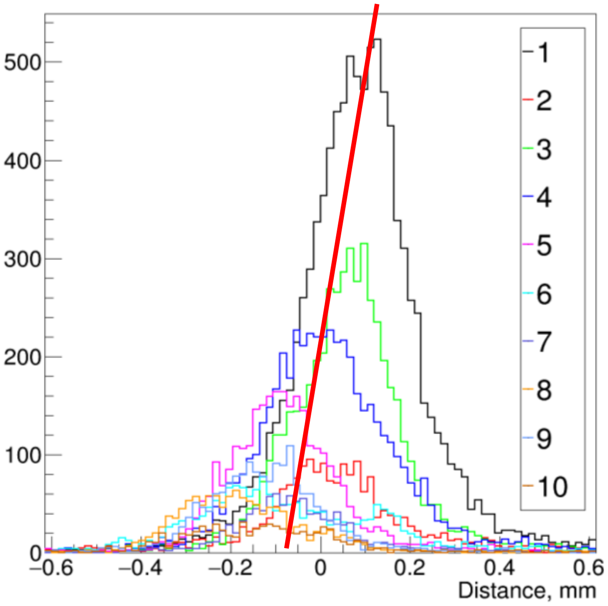
(COG reconstruction: strongest signal strip and 4 neighbouring strips)

Vertical Slit

FWHM (X) ≈ 0.25 mm







The **systematic shift** suggests **non-normality** of the beam to the RPCs of ≈ 0.4º (0.2 mm over 30 mm) ;

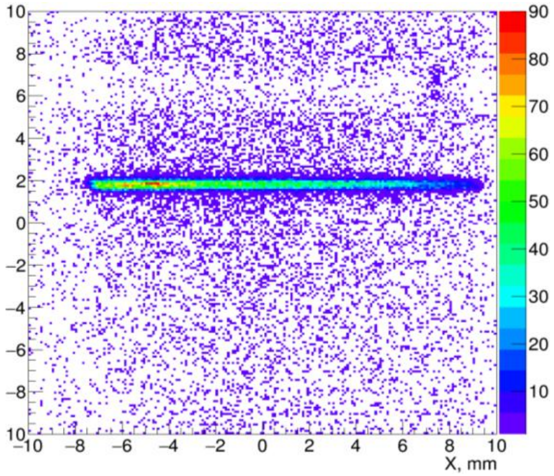
The **misalignments** of the PCBs in the stack are about 0.05 mm.

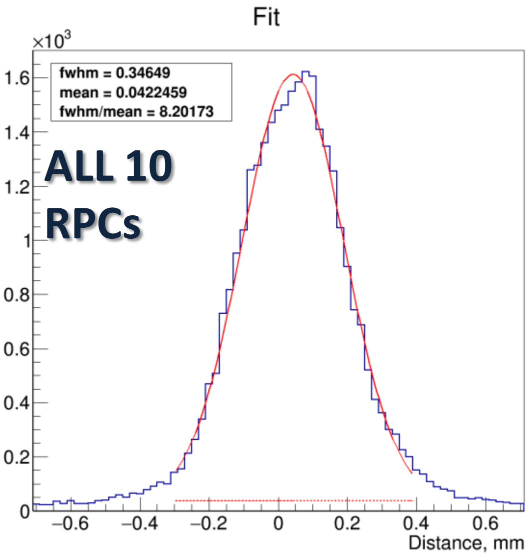
Evaluation tests with neutrons (λ= 4.7 Å)

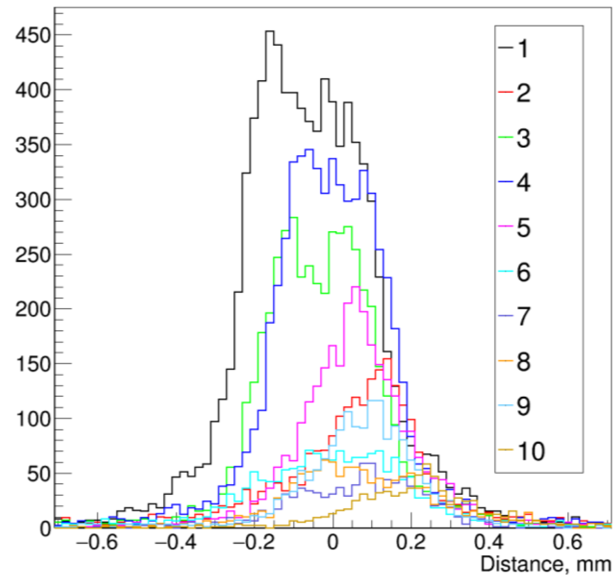
❑ Spatial resolution

FWHM (Y) ≈ 0.35 mm

Horizontal Slit





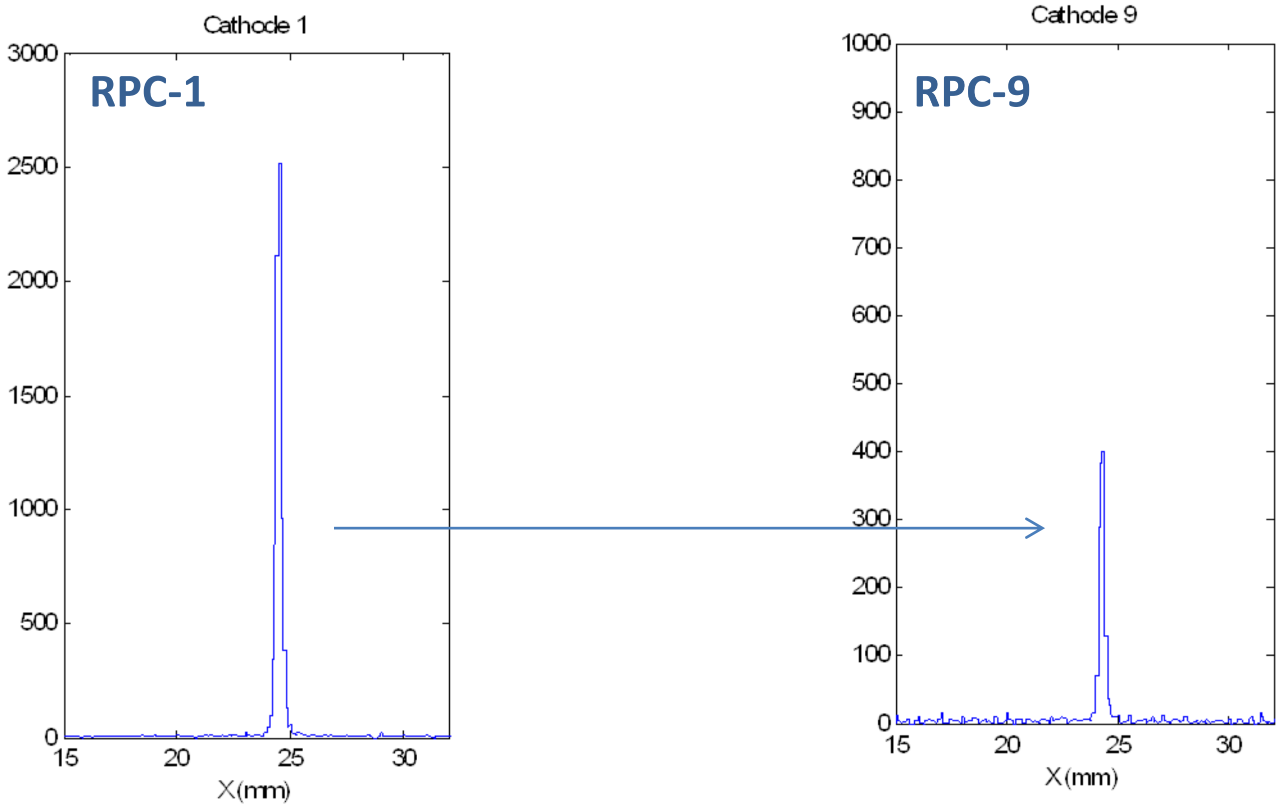


There are both a **systematic shift** and **random fluctuations** in the profile positions.

Evaluation tests with neutrons (λ= 4.7 Å)

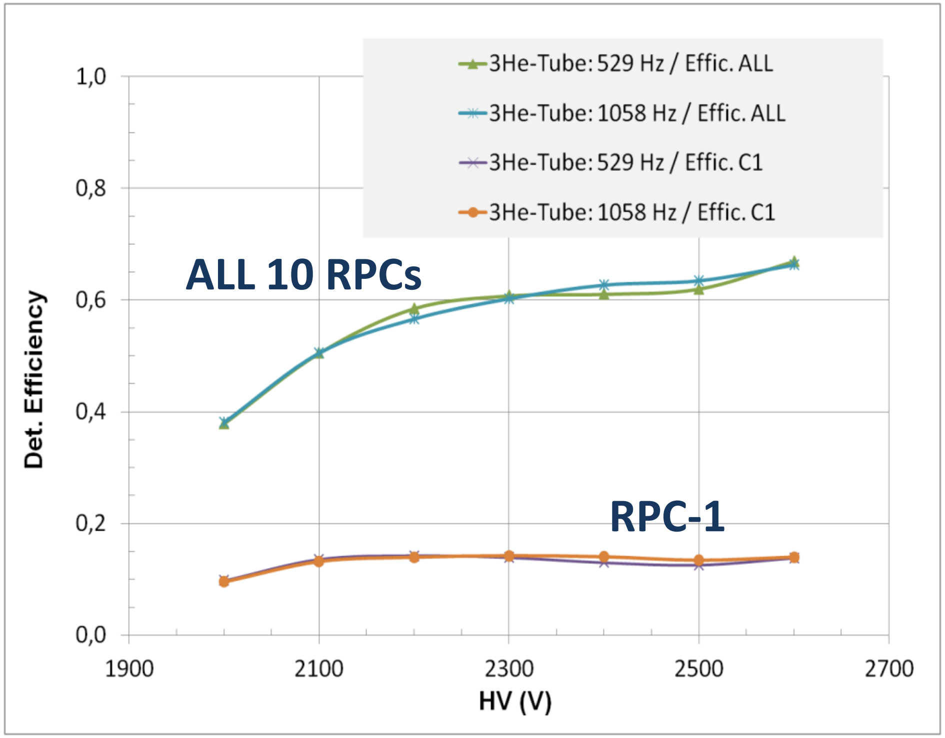
It seems that the spatial resolution is not get worse going deep in the stack

Vertical Slit



Evaluation tests with neutrons (λ= 4.7 Å)

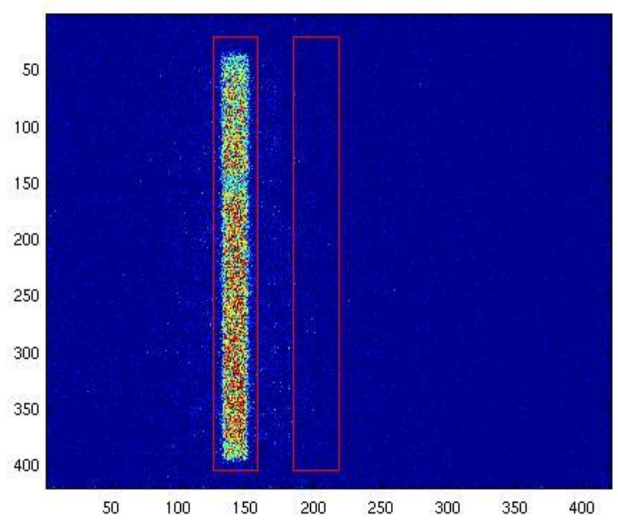
❑ Detection Efficiency



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



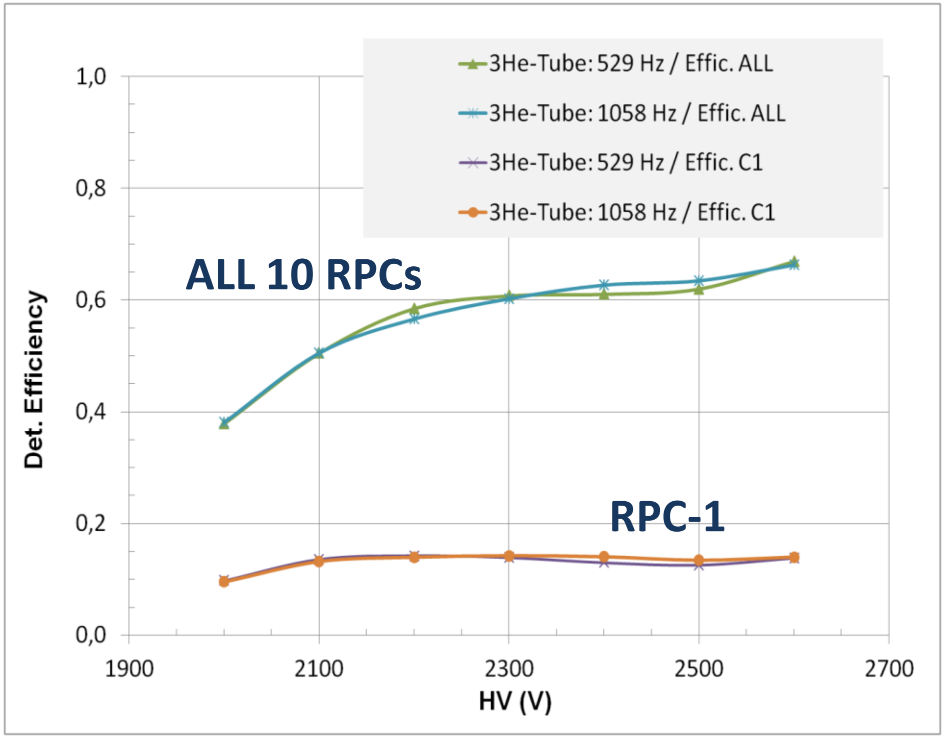
The counting rate was given by the trigger of each individual cathode: **C1, C2, C3, …, C10**

Cathode area = 90 x 90 mm

Readout area = 43 x 43 mm

Evaluation tests with neutrons (λ= 4.7 Å)

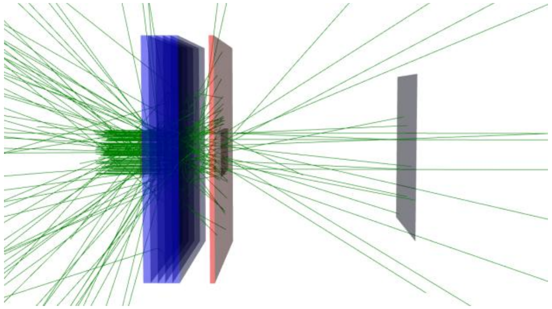
❑ Detection Efficiency



Efficiency computed by ANTS2

- 10 Double-Gap RPCs
- all $^{10}B_4C$ layers with the same thickness (1.15 μm)

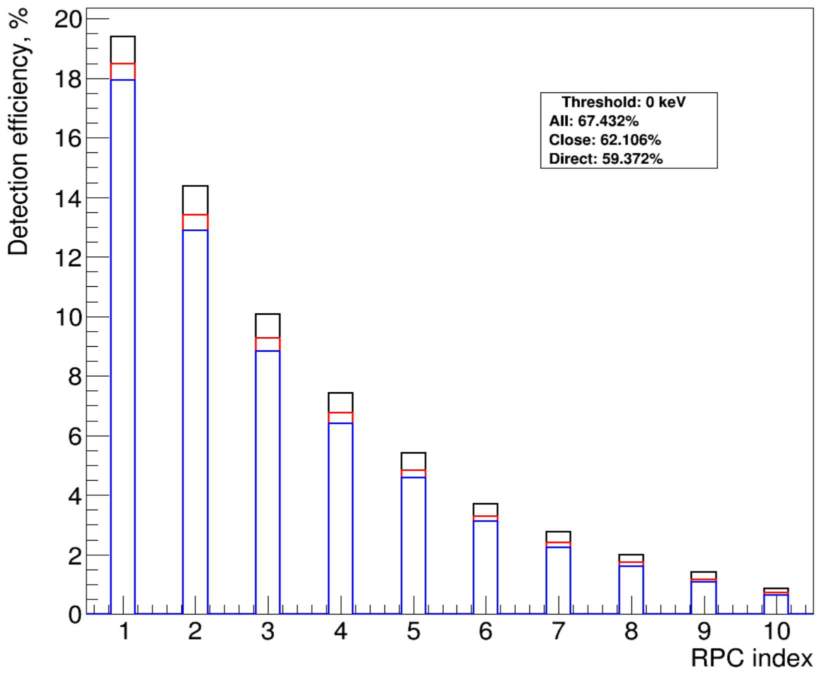
	Detection efficiency (%)			
λ (Å)	0 KeV	50 KeV	100 KeV	150 KeV
4.7	65.5	62.1	58.5	54.6



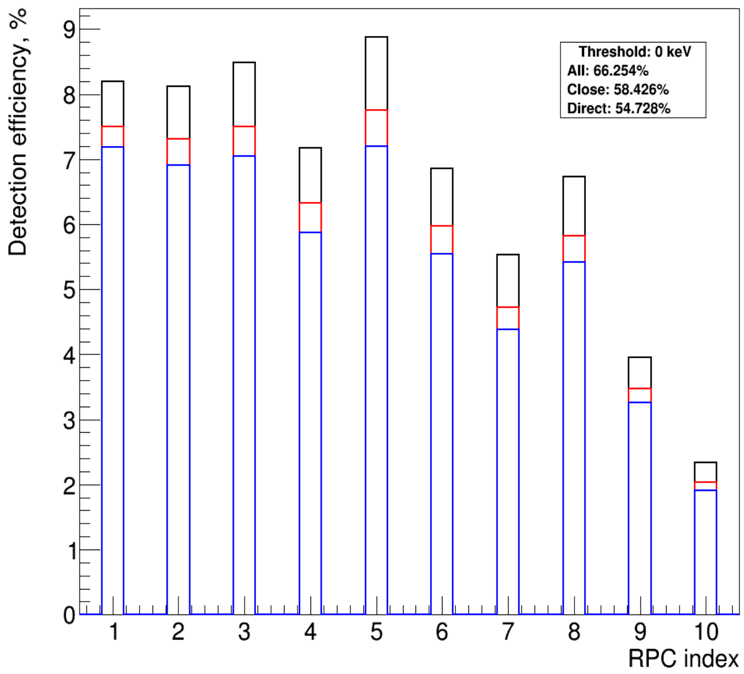
ANTS2: http://coimbra.lip.pt/ants/ants2.html

Conditional optimization of $^{10}B_4C$ 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.

1-1 / 2-2 / 3-3 / 3-3 / 4-4 / 4-4 / 4-4 / 5-5 / 5-5 / 5-5

Conclusions

- **Tests of B-10 lined thin-gap RPCs with thermal neutrons demonstrated spatial resolution well bellow 1mm FWHM;**
- **A first prototype comprising a stack of 10 double-gap RPCs tested at FRMII/TREFF neutron beamline showed:**
  - The capability of RPCs in a multilayer architecture to reach efficiency higher then 50%;
  - The spatial resolution (<0.25 mm FWHM) is not worse than that measured for single-gap RPCs in similar conditions;
- **Optimization of the thicknesses of $^{10}B_4C$ layers allows to approach equal counting rate for all RPCs without a significant reduction in the detection efficiency;**
- **Future: characterization of the gamma sensitivity, counting rate and stability have to be performed.**

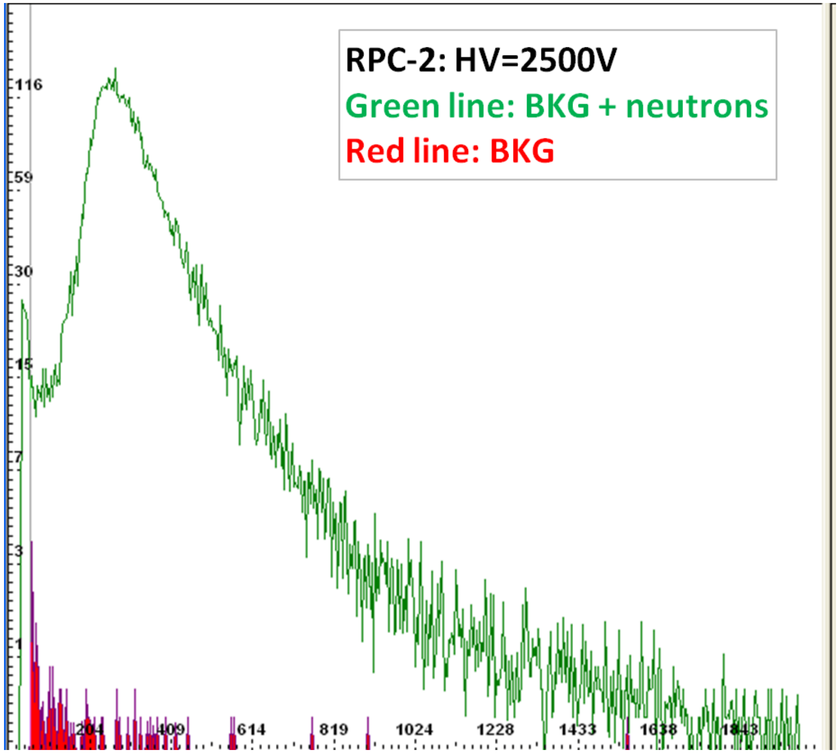
Thank you for your attention

Backup Slides

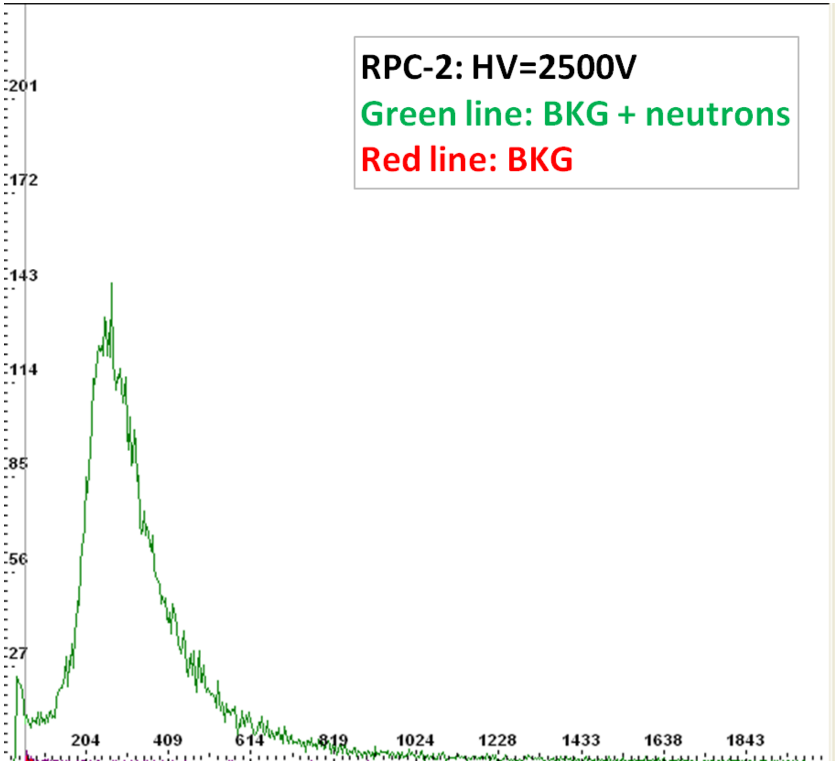
Experimental results

❑ **Pulse Height Spectra** (RPC-2, 0.35 mm gap width): *Cathodes*

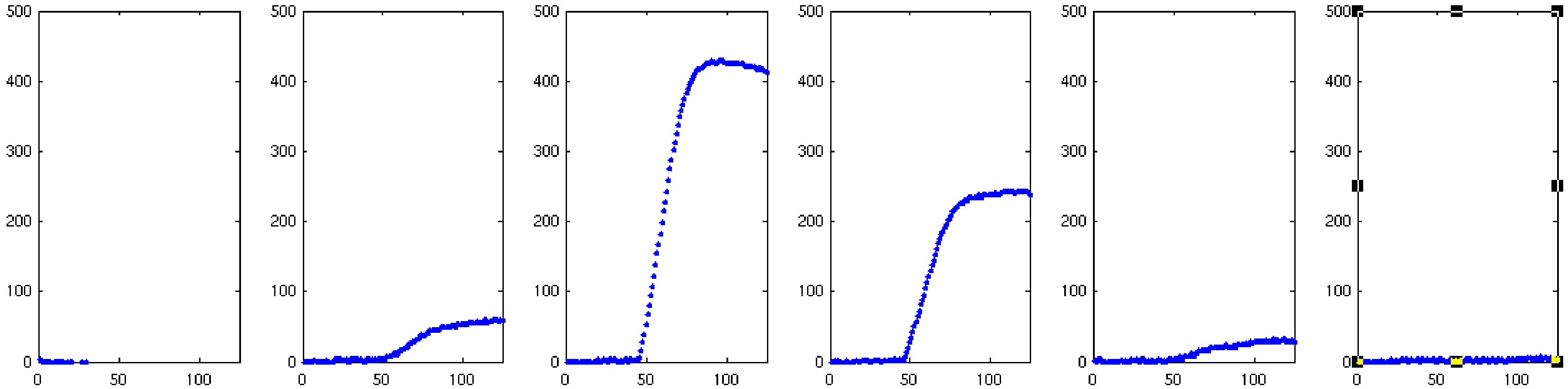
Log-scale



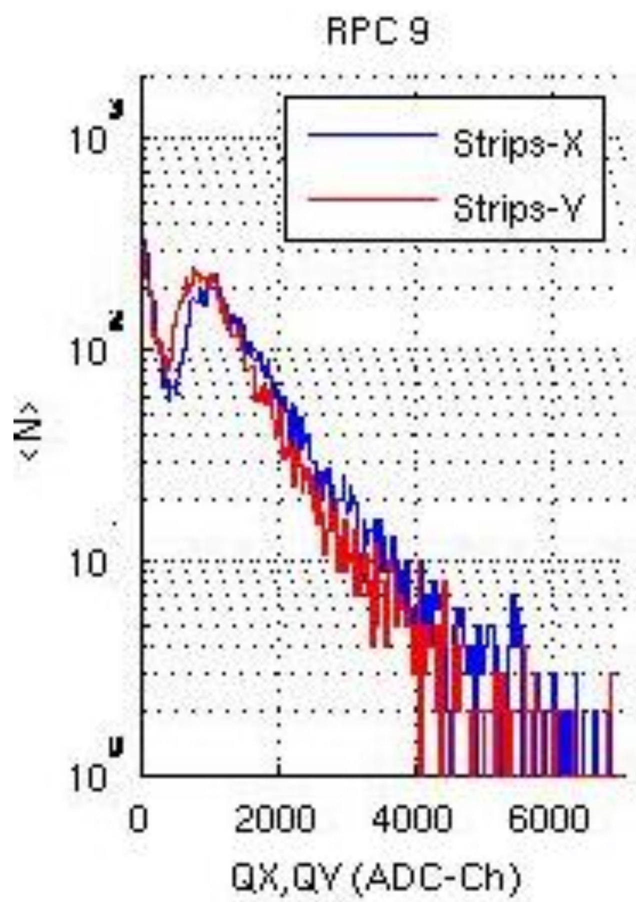
Linear-scale



Strip signals (-x)

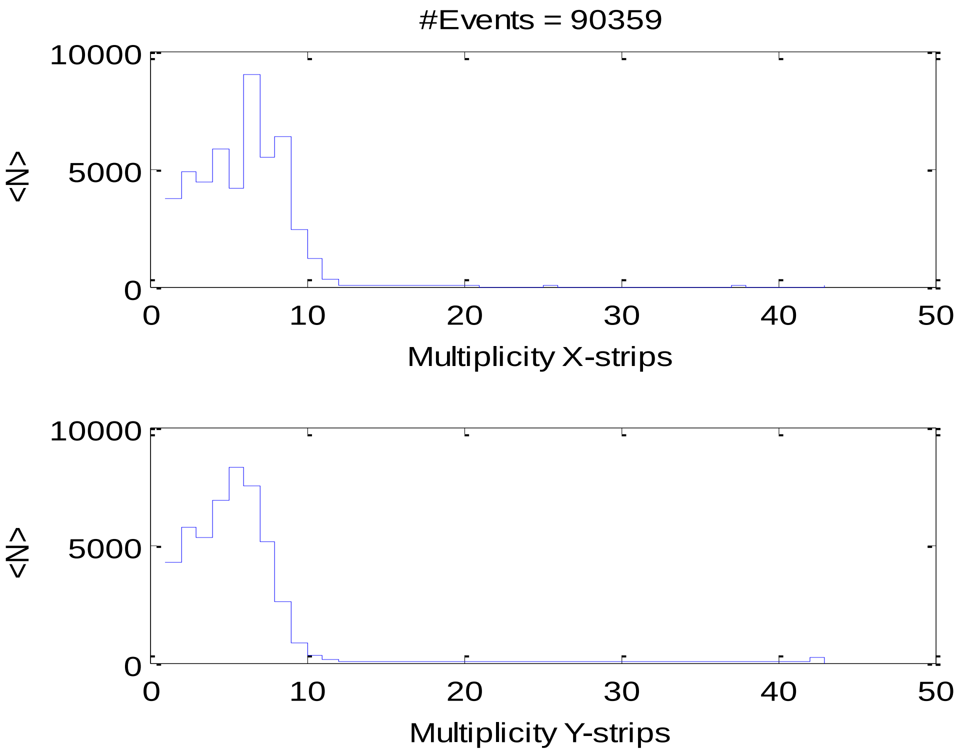


PHS - Charge (strips-X and strips-Y)

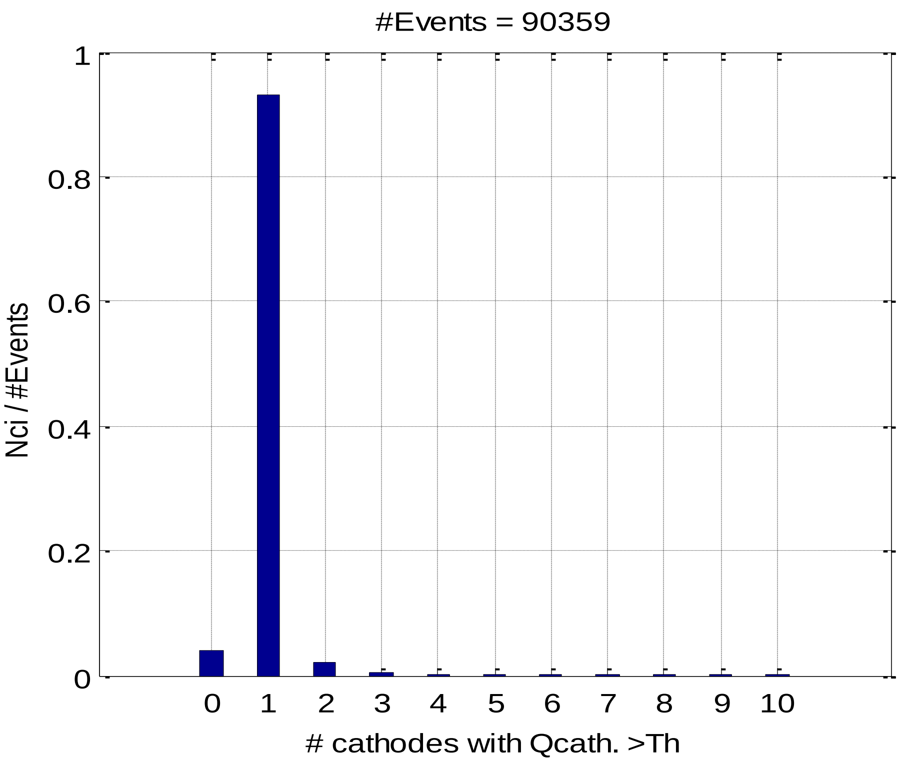


Multiplicities

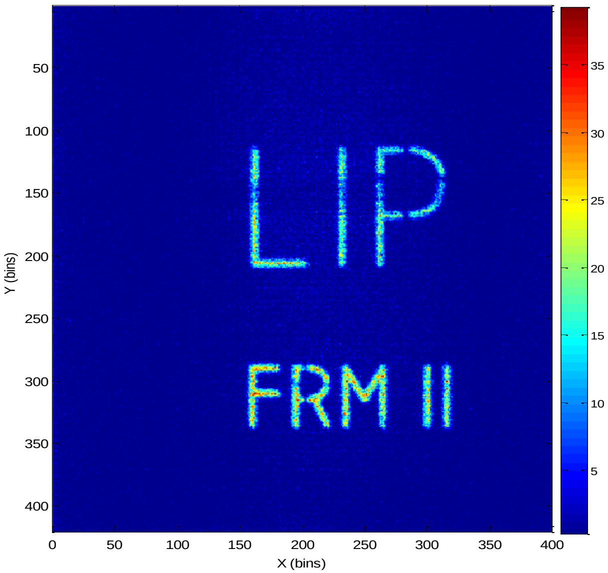
Multiplicity on the strips

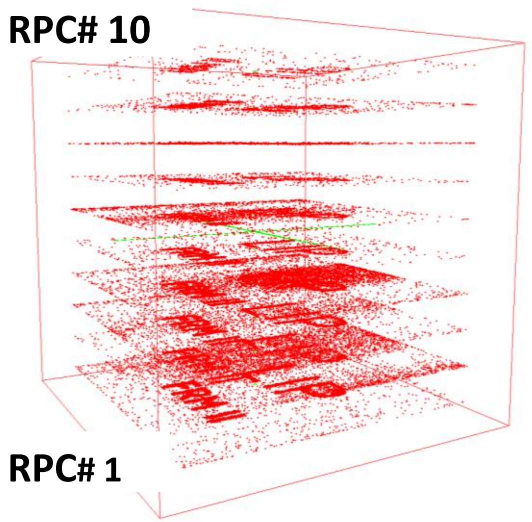


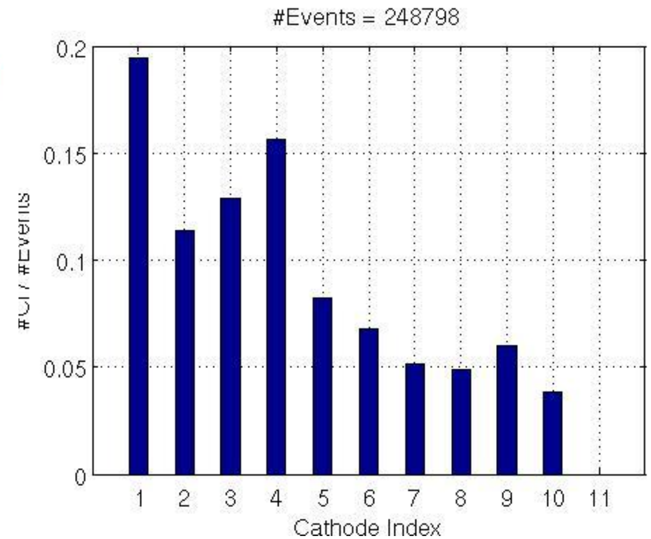
Multiplicity on the cathodes



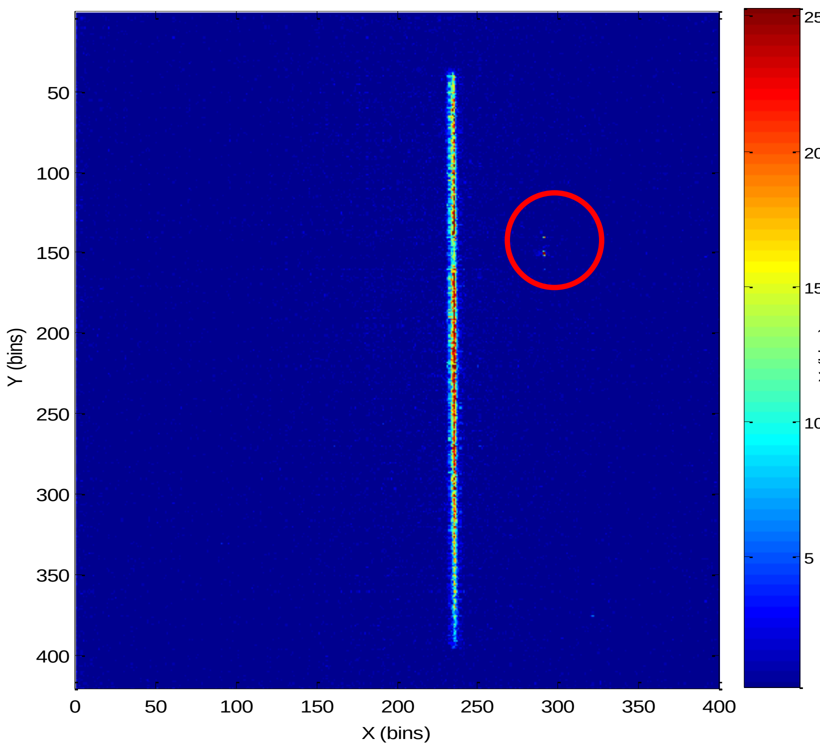
Triggers on cathodes



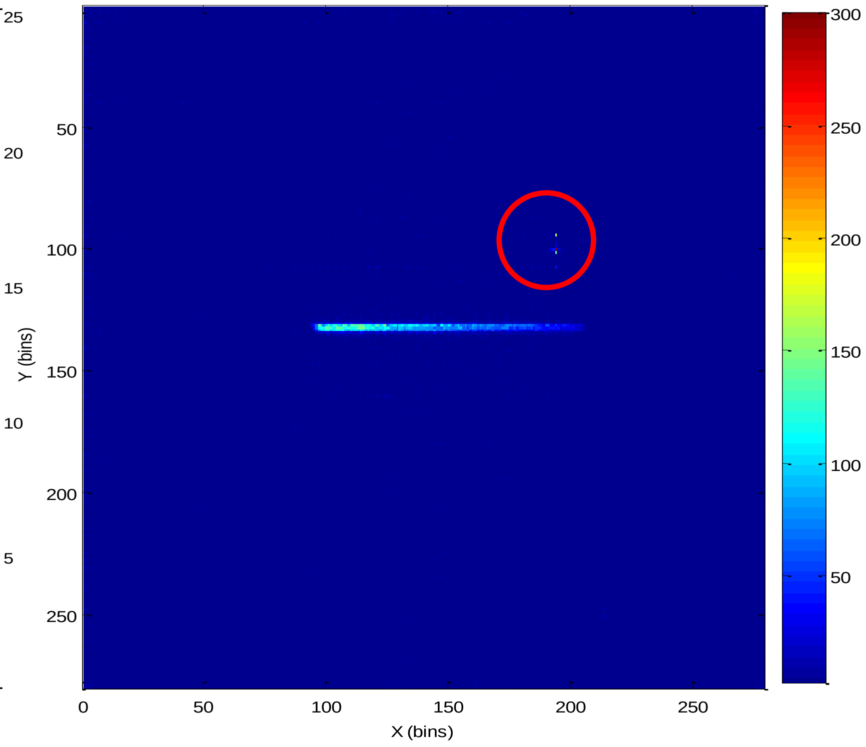


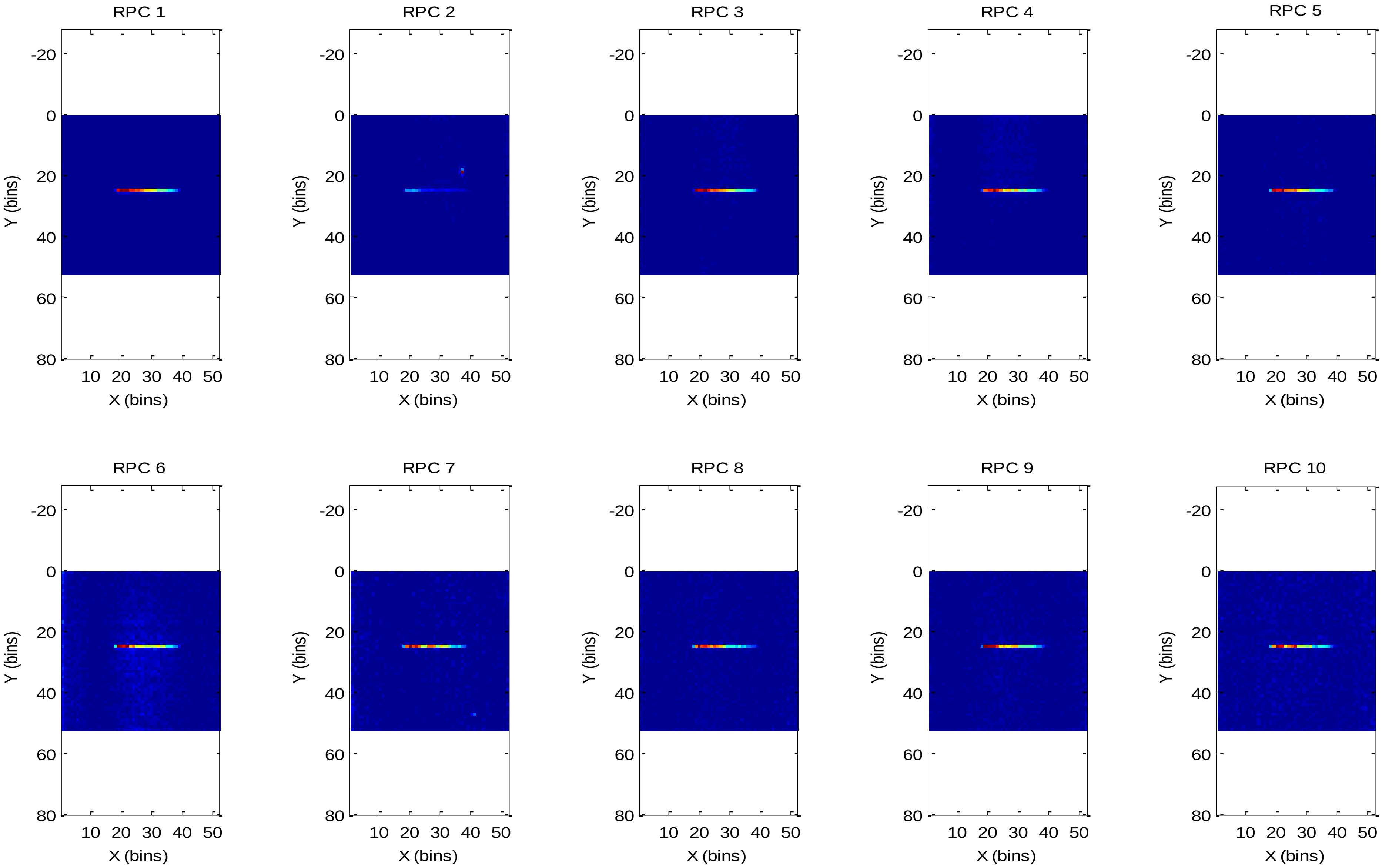


Run204 (HV = -2.3 kV)

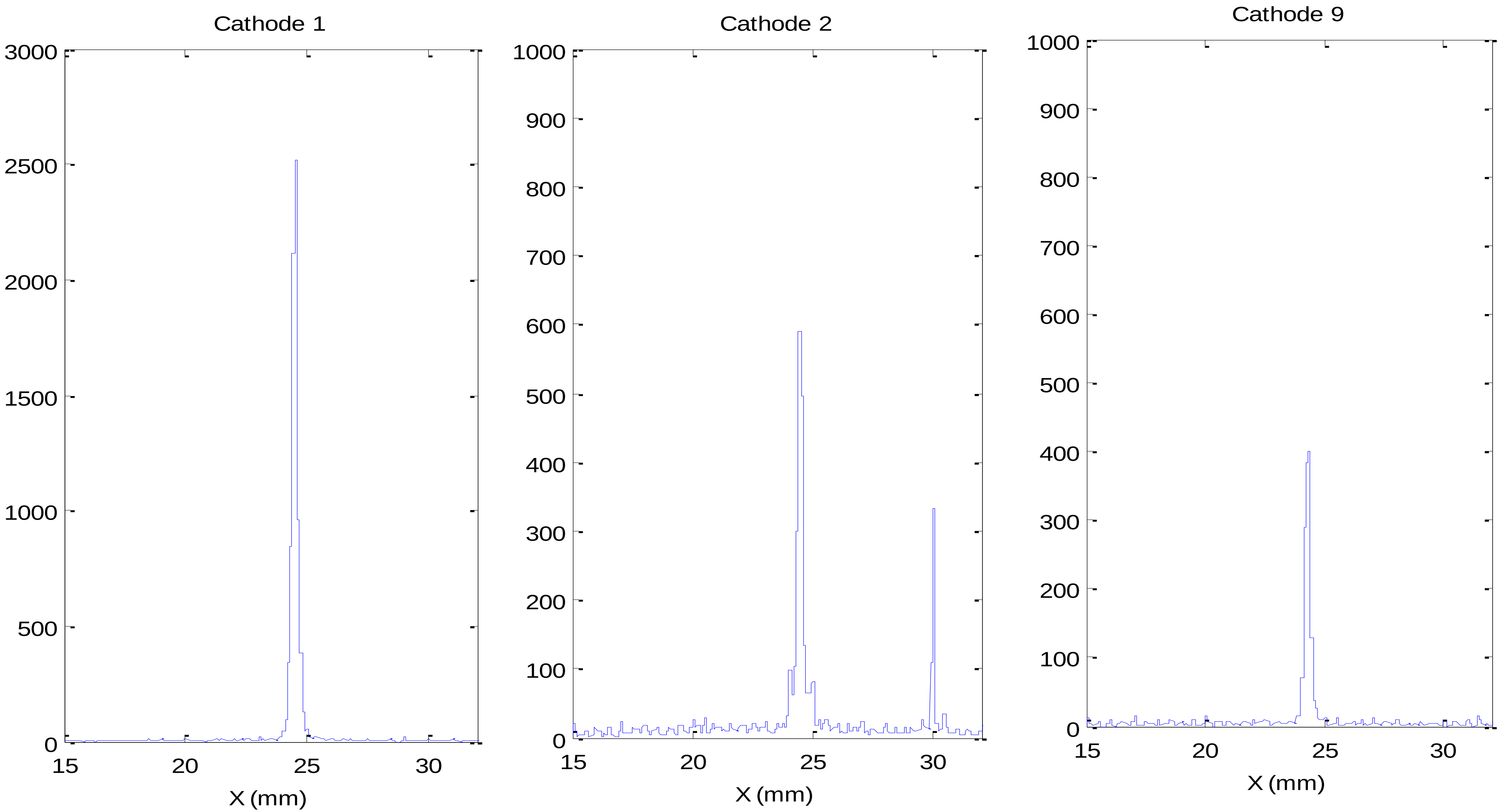


Run208 (HV = -2.3 kV)




RPC 1
RPC 2
RPC 3
RPC 4
RPC 5
RPC 6
RPC 7
RPC 8
RPC 9
RPC 10
Y (bins)
X (bins)
-20
0
20
40
60
80
10
20
30
40
50

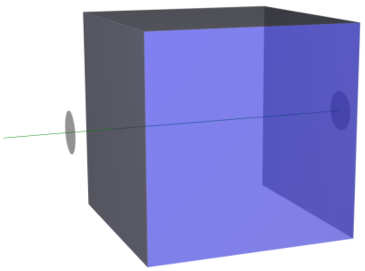
Vertical Slit



ANTS2 Simulations: http://coimbra.lip.pt/ants/ants2.html

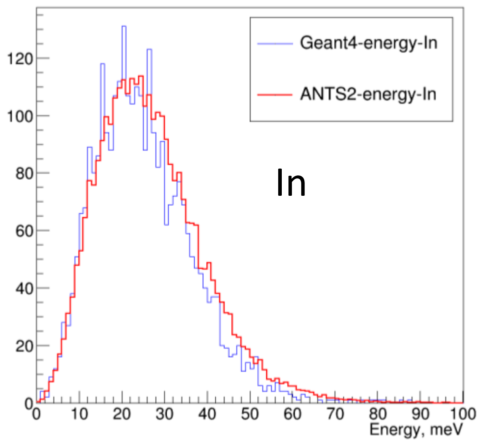
ANTSv4.1 vs Geant4 (Geant4 version 4.9.6.p02, QGSP_BIC_HP physics list / includes the G4NeutronHP model.)

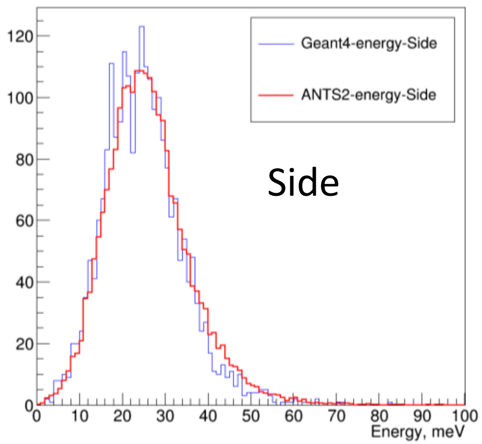
Case 1: Aluminium cube of 10 x 10 x 10 mm^3

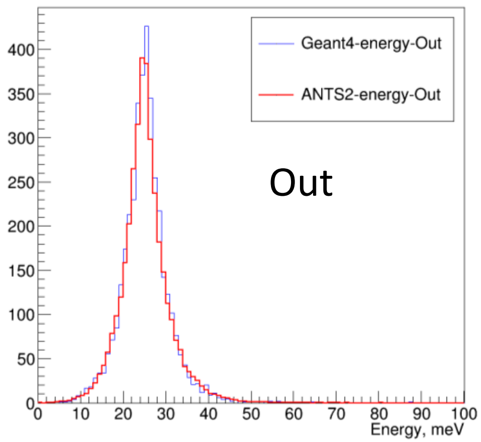


Mono-energetic (25.3 meV) neutrons enter the cube through the centre of the "In" face (normal direction).
The neutrons exiting the cube are monitored and the collected statistics obtained in simulations using Geant4 and ANTS2 is the following:

Energy distributions of the neutrons exiting the cube faces (non-interacted neutrons are suppressed):





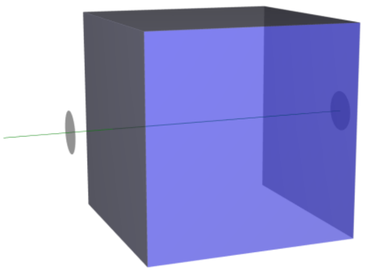


Total elastic cross section (N,EL) from **ENDF/B-VII.1** database ;
For missing data **JEFF-3.2** and **JENDL-4.0u2** databases were used.

ANTS2 Simulations: http://coimbra.lip.pt/ants/ants2.html

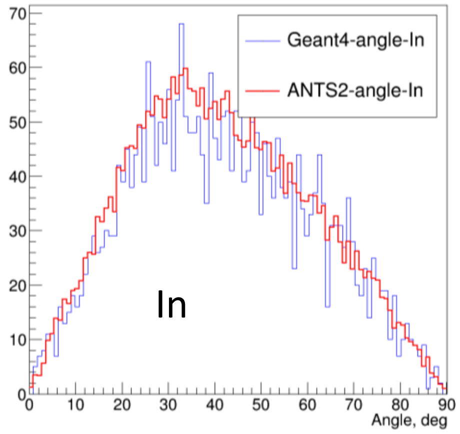
ANTSv4.1 vs Geant4 (Geant4 version 4.9.6.p02, QGSP_BIC_HP physics list / includes the G4NeutronHP model.)

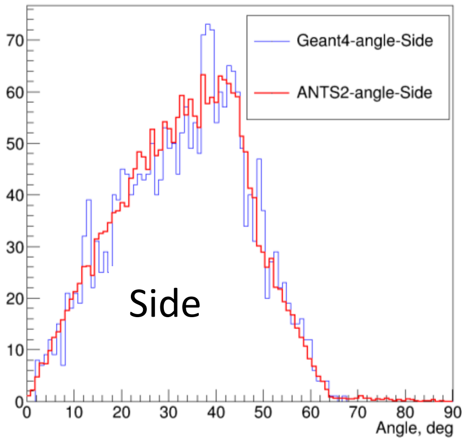
Case 1: Aluminium cube of 10 x 10 x 10 mm^3

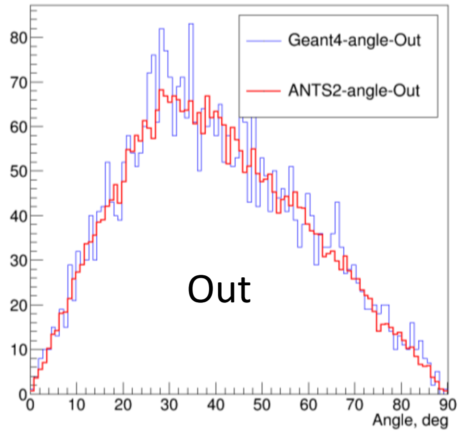


Mono-energetic (25.3 meV) neutrons enter the cube through the centre of the "In" face (normal direction).
The neutrons exiting the cube are monitored and the collected statistics obtained in simulations using Geant4 and ANTS2 is the following:

Distribution of the angles of exiting neutrons:

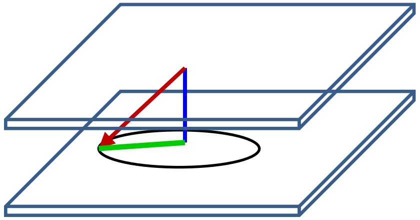




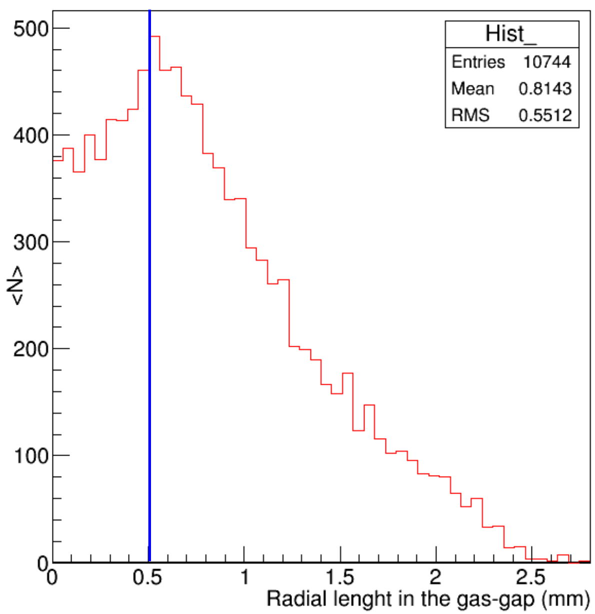


ANTS2 Simulations

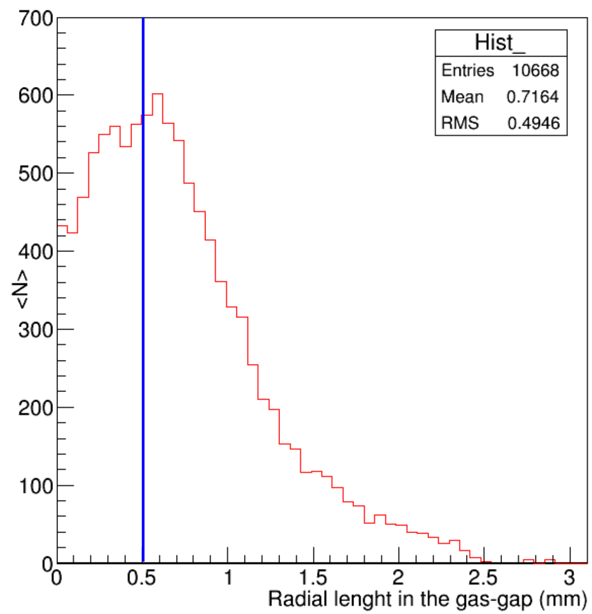
Ranges for the ^{4}He and ^{7}Li particles in the gas-gap



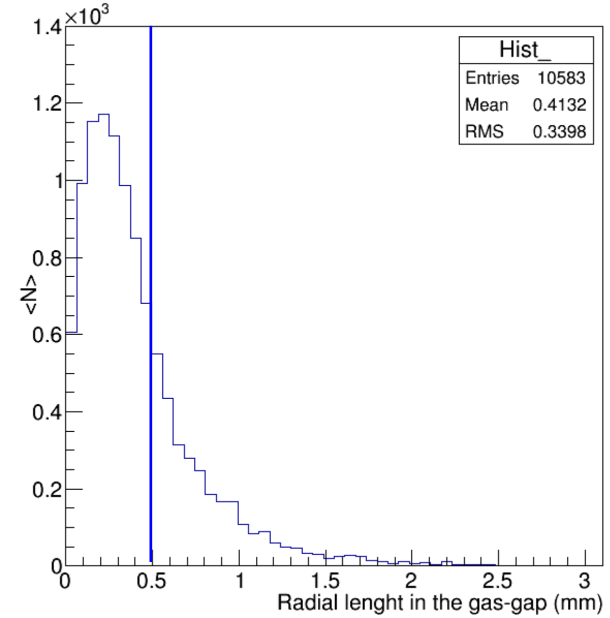
Distributions for the length of the Ranges (in the gas-gap) **projected in the direction parallel to the plane of the electrodes**



Gas-gap: 2 mm



Gas-gap: 1 mm



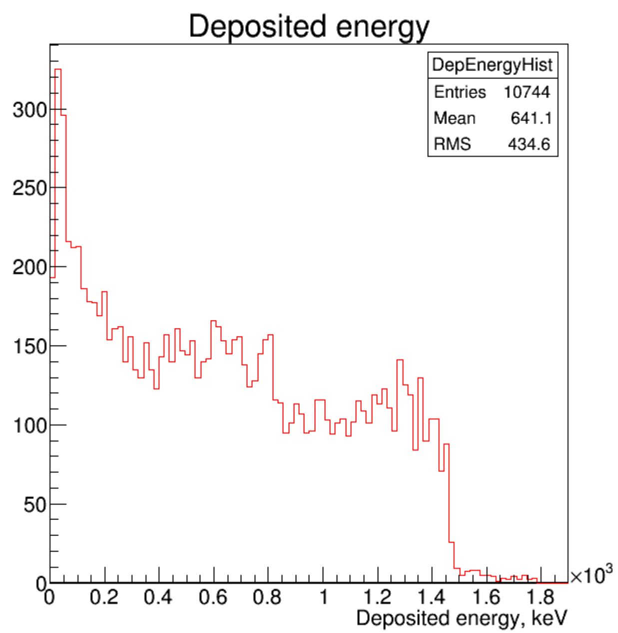
Gas-gap: 0.35 mm

$^{10}B_4C$ thickness = 2 μm; λ = 4.7 Å; C2H2F4 @ 1 atm

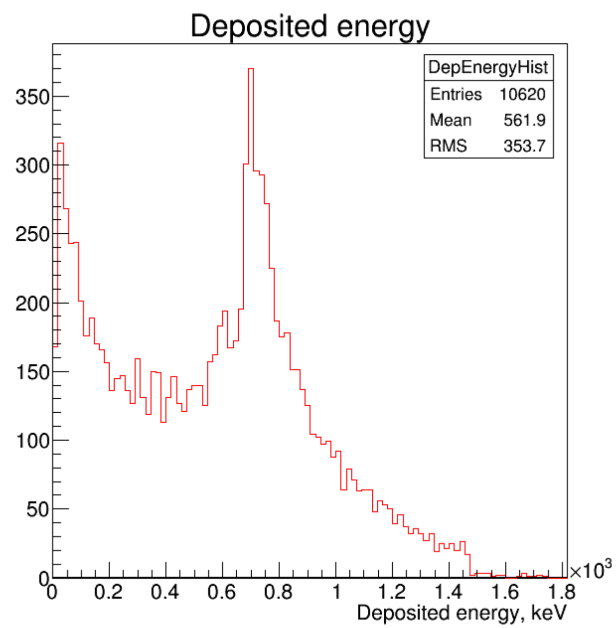
ANTS2 Simulations

Energy loss in the gas-gap

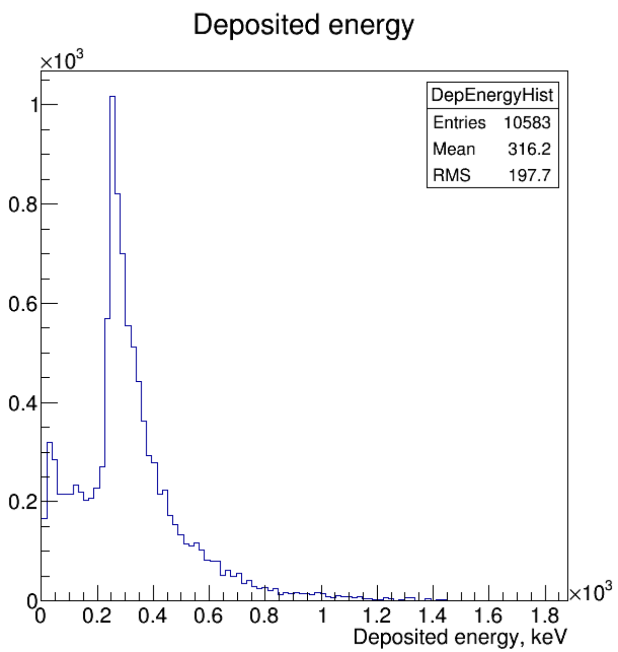
Deposited energy in the gas-gap for the ^{4}He and ^{7}Li fissions fragments



Gas-gap: 2 mm

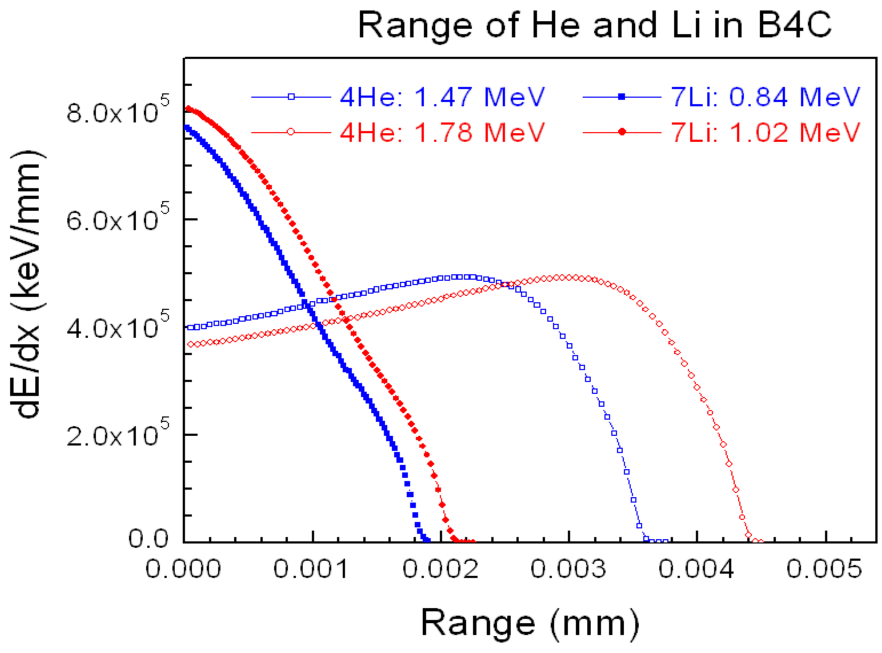


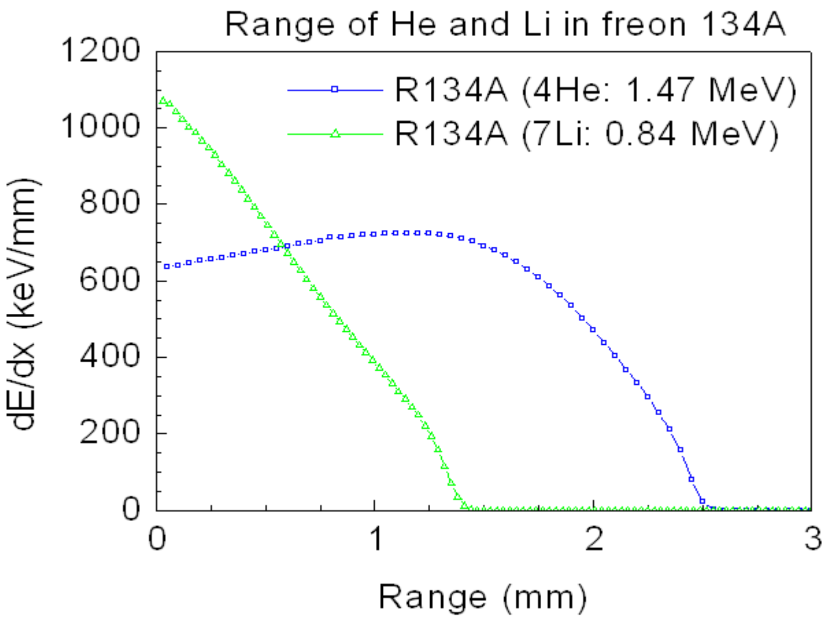
Gas-gap: 1 mm



Gas-gap: 0.35 mm

$^{10}B_4C$ thickness = 2 μm; λ = 4.7 Å; C2H2F4 @ 1 atm





$n + {}^{10}B \rightarrow ({}^{11}B)^*$

→ ${}^{7}Li^*$ (0,84 MeV) + ${}^{4}He$ (1,47 MeV) Q = 2,31 MeV (94 %)

→ ${}^{7}Li$ (1,02 MeV) + ${}^{4}He$ (1,78 MeV) Q = 2,79 MeV (6 %)