Status of the ongoing studies of ^{10}B-RPCs for position-sensitive neutron detectors

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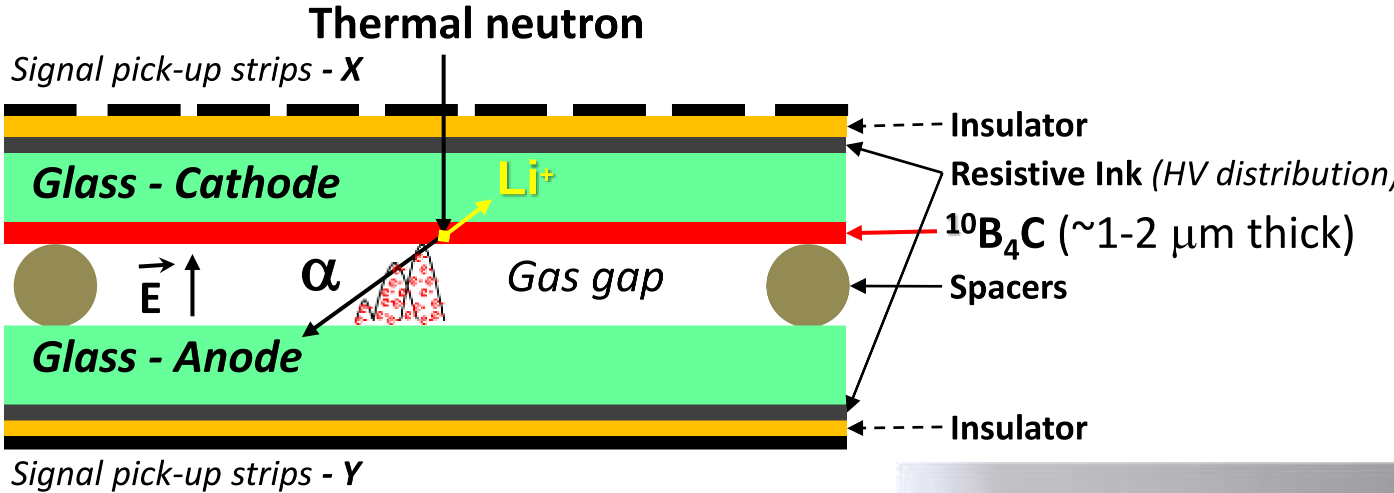
This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 654000

Outline

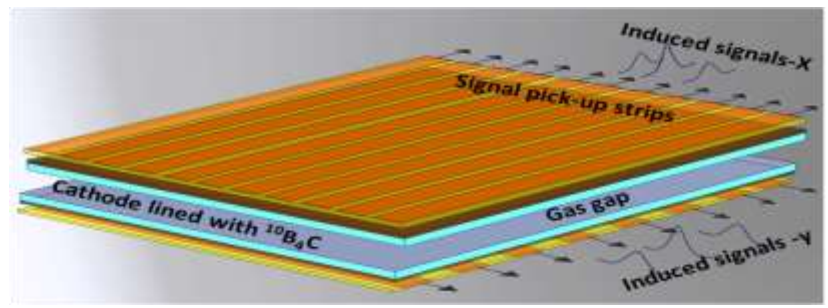
- The ^{10}B-RPC concept
- ^{10}B-RPCs – Single-gap studies
- A Multilayer Architecture
- Results from tests with neutrons at FRM II
- Summary and future plans

^{10}B-RPCs: The Concept



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

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



Operation Regimes

- **Avalanche mode**

Lower signal amplitude but more favourable for high rate operation

- **Streamer mode**

Higher signal amplitude allows a simpler design of the front-end electronics

Typically

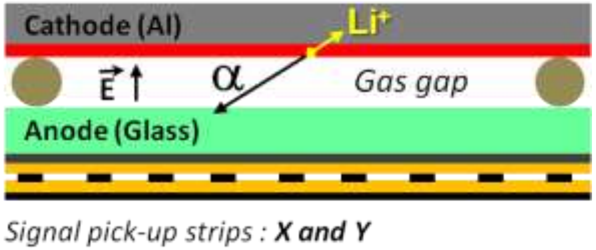
- **Resistive plates:** Float glass or Bakelite
- **Plates thickness: 0.2 – 2 mm**
- **Gas-gap width: 0.2 – 5 mm**
- **Working gas: $C_2H_2F_4$ based mixtures**

^{10}B-RPCs: Hybrid Design

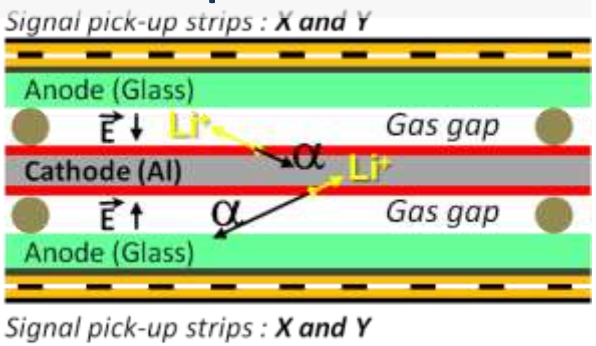
❑ Metallic cathodes

- Deposition of $^{10}B_4C$ on Al substrates is already a well established technique [1]
- But, 2D-position readout must be implemented on the same plane – Resistive anode side

Single-Gap RPC



Double-Gap RPC



Advantages of RPCs

- Modular detector designs and good scalability
- Well suited for multilayer architectures
- Good spatial and time resolution (**< 1ns**)
- Well-established technique (e.g. large area detectors for high energy physics) and low cost per unit area
- **Safe detector:** current limited by the resistive plates and readout is decoupled from HV

Challenges

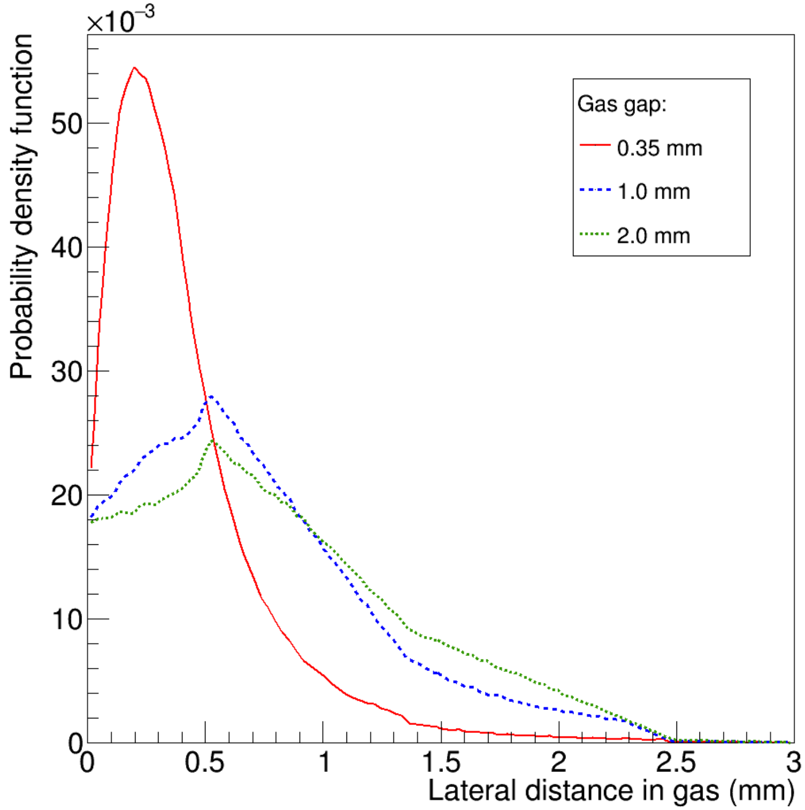
- Low thermal neutron detection efficiency of single neutron converter layers
- Gamma sensitivity and counting rate

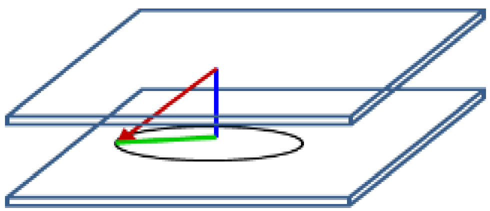
[1] Carina Höglund et al., Stability of $^{10}B_4C$ thin films under neutron radiation, Radiation Physics and Chemistry, Vol. 113 (2015) Pg. 14–19.

^{10}B-RPCs: Single-gap studies

Wide or narrow gas-gap width?

Distributions of the ^{4}He and ^{7}Li particles ranges in the gas-gap, projected in the lateral direction (parallel to the RPC plates) – Computed with ANTS2



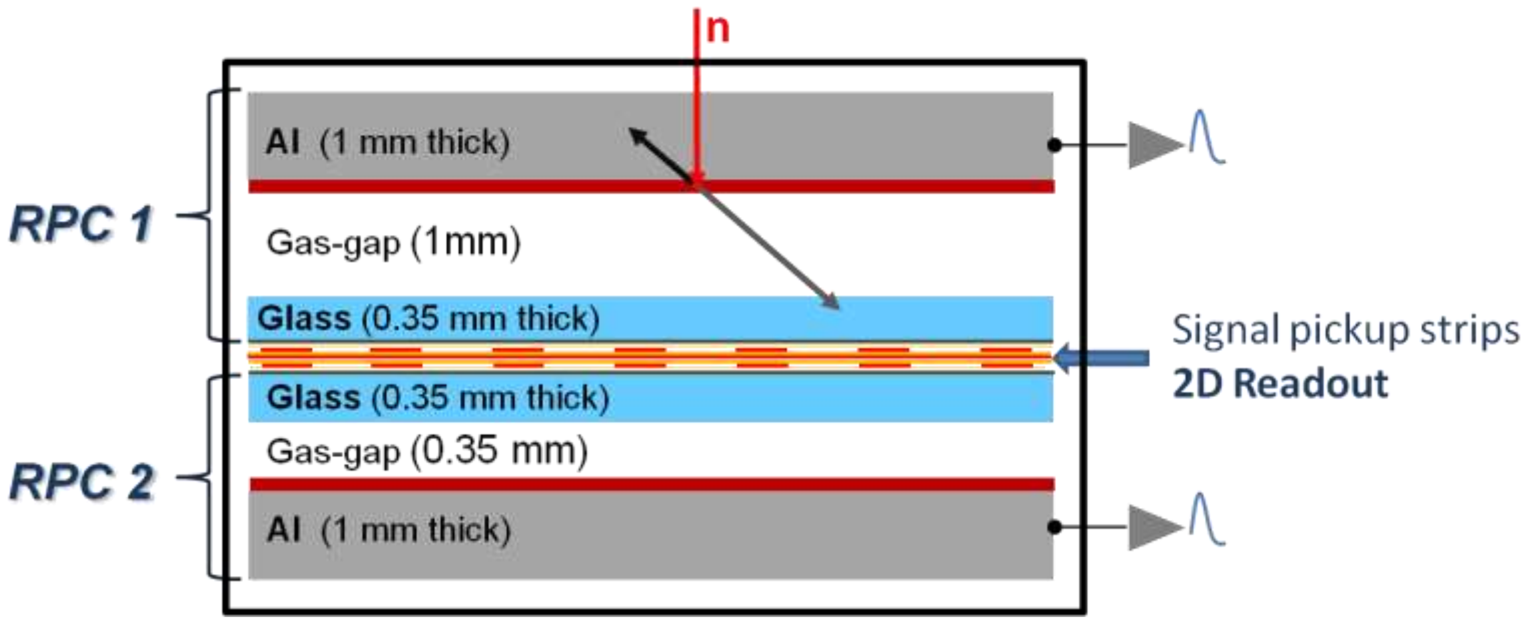


Simulation parameters

- **$^{10}B_4C$ thickness**: 2 µm
- **Neutron wavelength**: 1.8 Å
- **Gas-gap widths**: 0.35, 1.0 and 2 mm
- **Gas**: $C_2H_2F_4$ (20ºC and 1 atm)

Two RPCs with different gaps were constructed

RPC1: gas-gap width = 1 mm; **RPC2:** gas-gap width = 0.35 mm

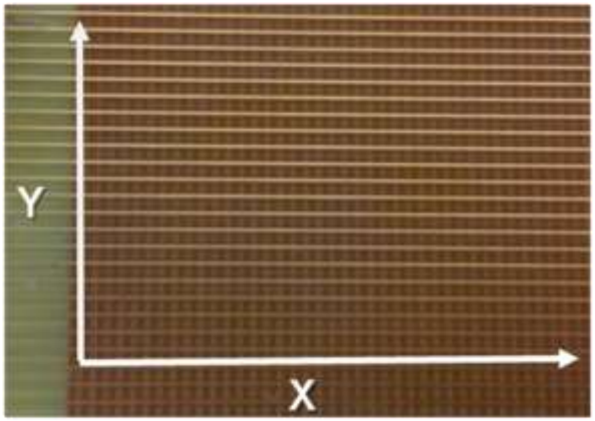


- **$^{10}B_4C$ coating made at ESS Detector Coatings Workshop:**
  - 2 µm thick layers of $^{10}B_4C$ on 1mm thick Al plates (80 mm x 80 mm)
- **Working gas:** $C_2H_2F_4$ (Tetrafluoroethane) at atmospheric pressure

^{10}B-RPCs: Single-gap studies

2D Readout

Arrays of parallel Cu-strips mutually orthogonal



- Each strip is readout by a charge sensitive amplifier
- Vertical strips (X)
  - Pitch = 1.5 mm
  - Width = 1.3 mm
- Horizontal strips (Y)
  - Pitch = 2.0 mm
  - Width = 0.5 mm

FEE & DAQ System

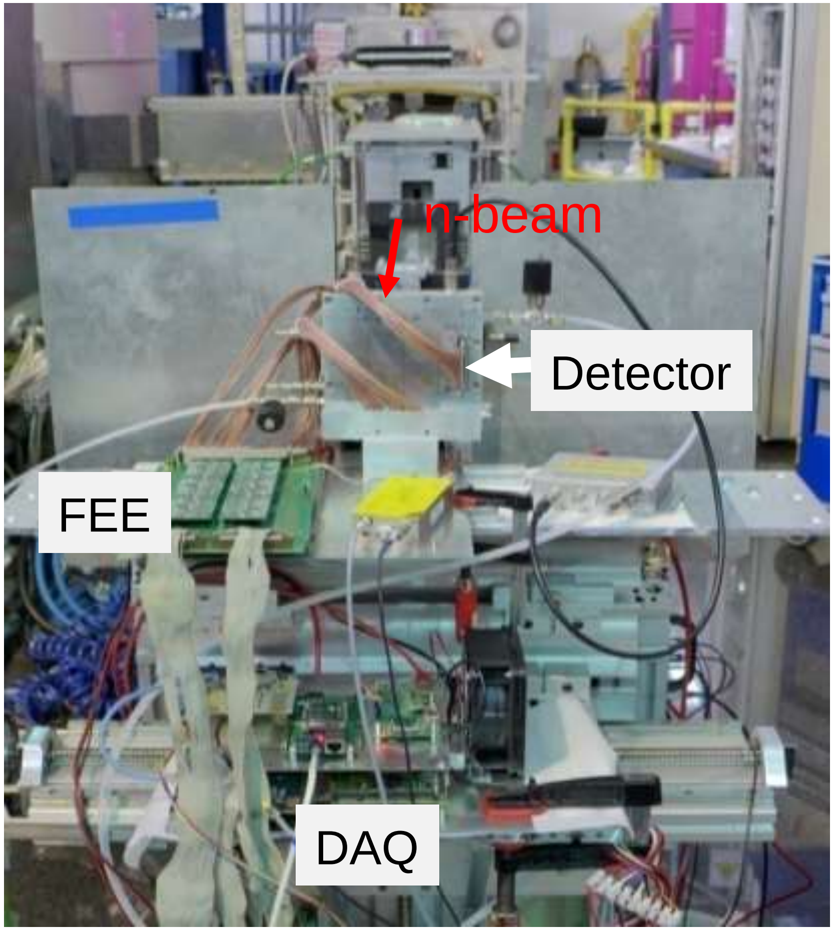
FEE: boards with 24 channels (designed and assembled at LIP)
The output of the charge sensing amplifiers is digitized by 40 MHz streaming ADCs (AD9219)

DAQ: Based on the TRB3 platform (http://trb.gsi.de/)

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

^{10}B-RPCs: Single-gap studies

Tests with neutrons at FRM II



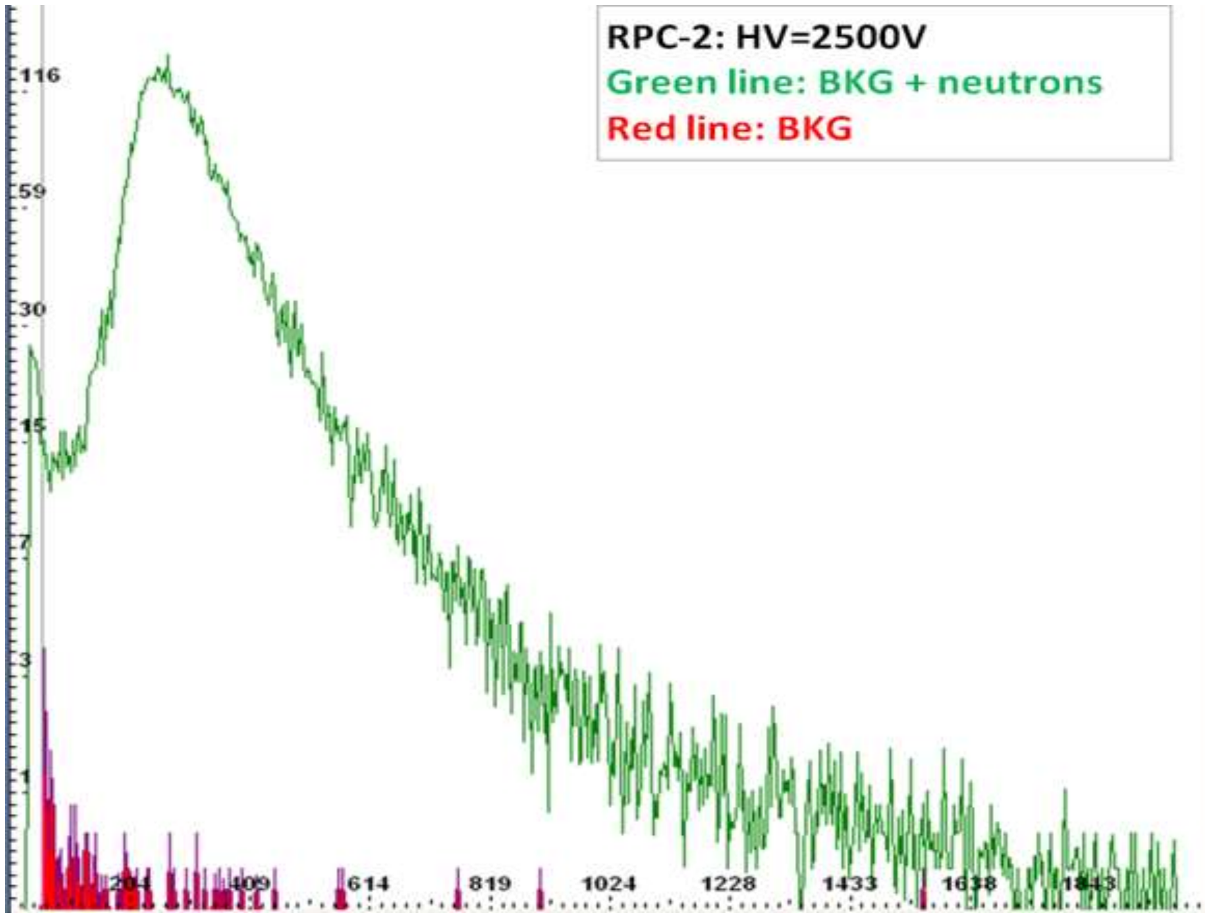
Detector prototype at TREFF neutron beam line (λ= 4.7 Å)

RPC1 and RPC2 stacked back to back

Aluminium chamber

^{10}B-RPCs: Single-gap studies - Tests with Neutrons

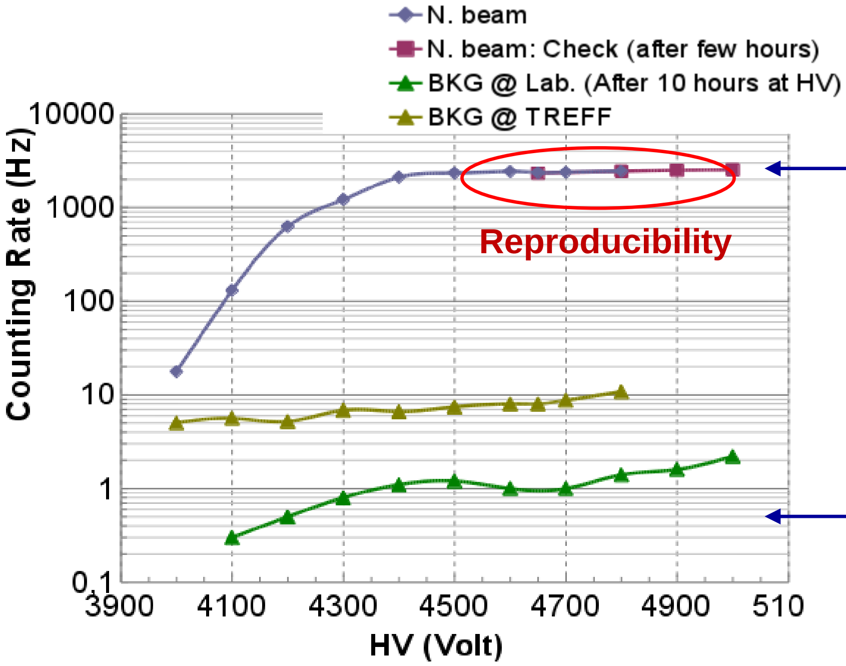
PHS of the cathode signals (log scale)



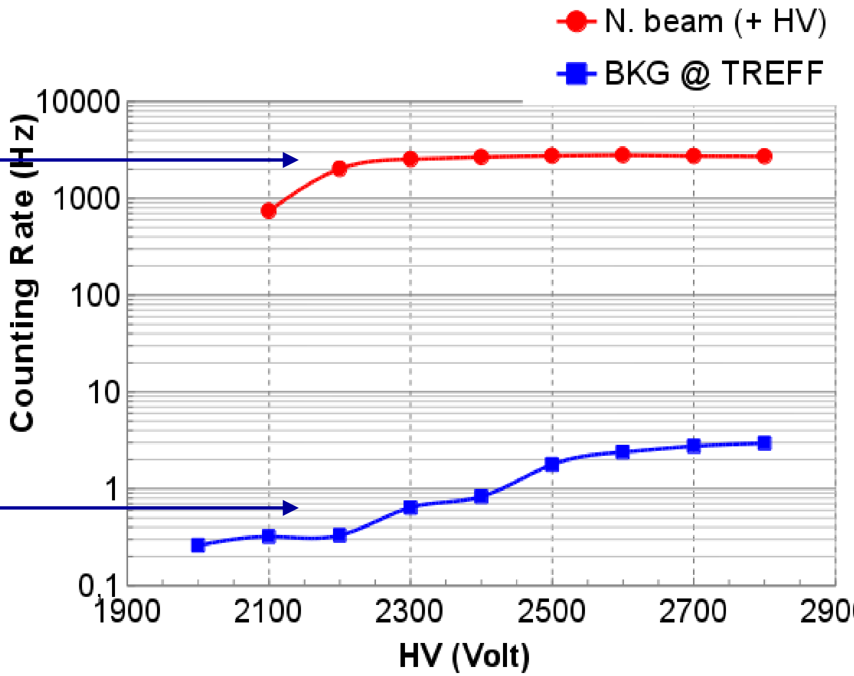
^{10}B-RPCs: Single-gap studies – Tests with Neutrons

Plateau measurements

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



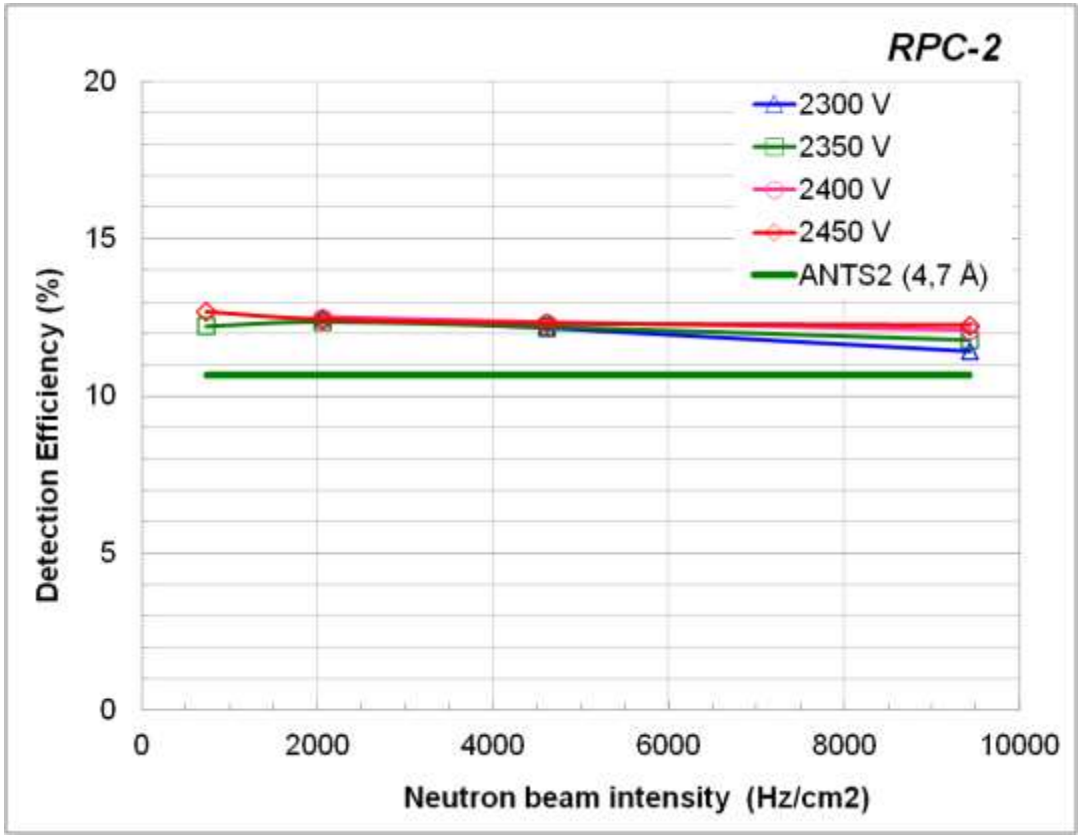
RPC-2 (gas-gap width: 0.35 mm)



^{10}B-RPCs: Single-gap studies – Tests with Neutrons

Detection Efficiency (RPC2) ≈ 12.5% (λ = 4.7 Å)

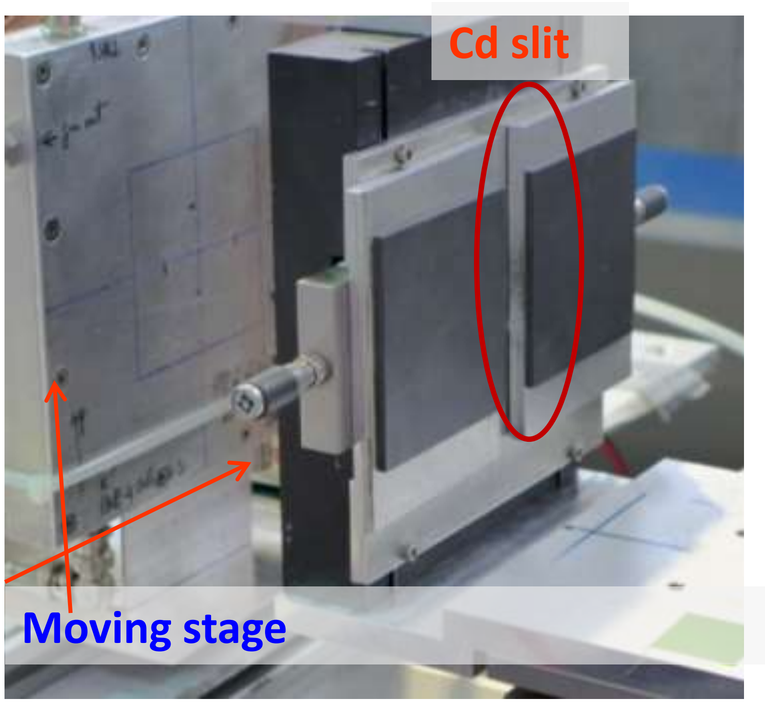
Det. Efficiency calculated with ANTS2 ≈ 11%

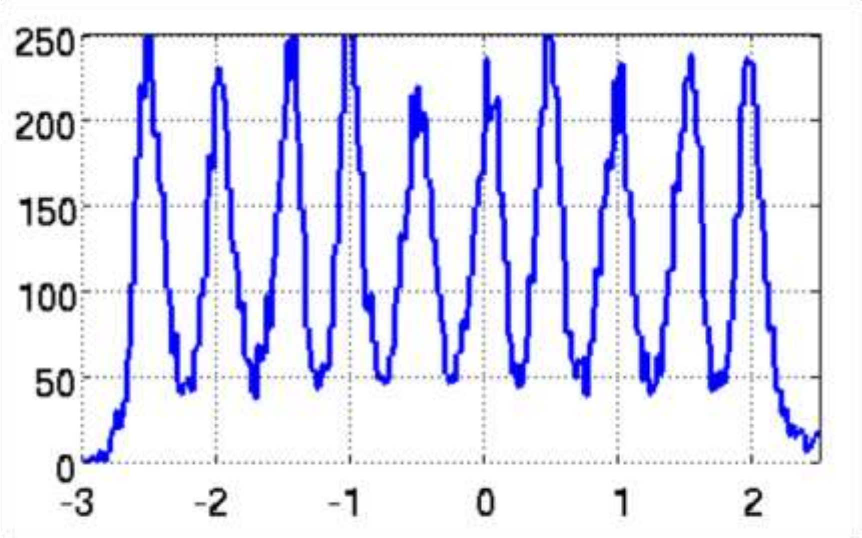


Detection efficiency was estimated using a ^{3}He - Tube as a reference (efficiency ~ 97 % @ 4.7 Å)

^{10}B-RPCs: Single-gap studies – Tests with Neutrons

Spatial resolution (RPC-2)





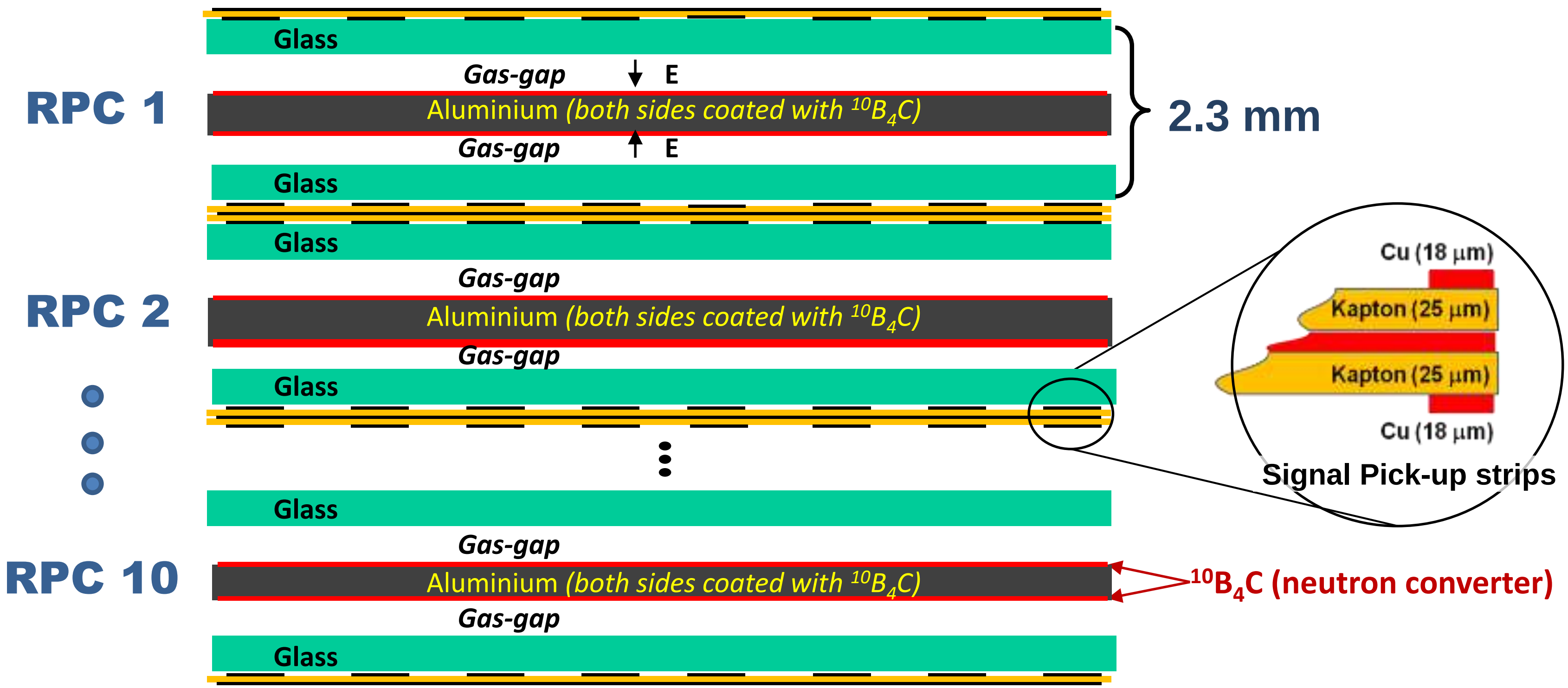
Spatial resolution better than 236 µm FWHM
(for both X and Y-coordinates)

Cadmium slit width: 0.2 mm

Detector shifted in steps of 0.5 mm

Towards High Detection Efficiency – The Multilayer Architecture

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



Glass (Anode): 0.5 mm thick

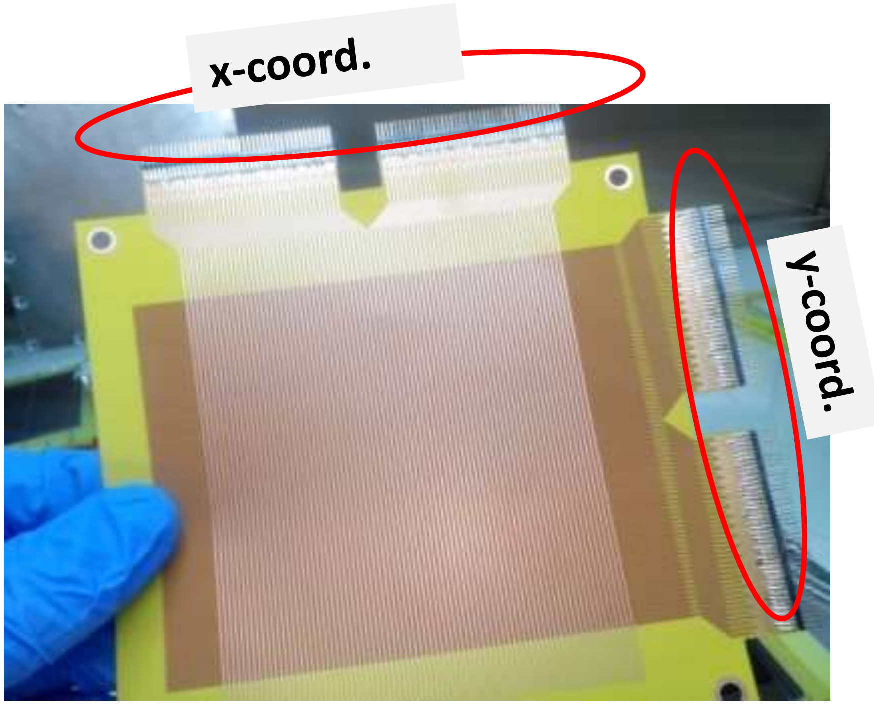
Gas-gap: width = 0. 35 mm

$^{10}B_4C$ layers : 1.15 μm thick

Aluminium (Cathode): 0.5 mm thick

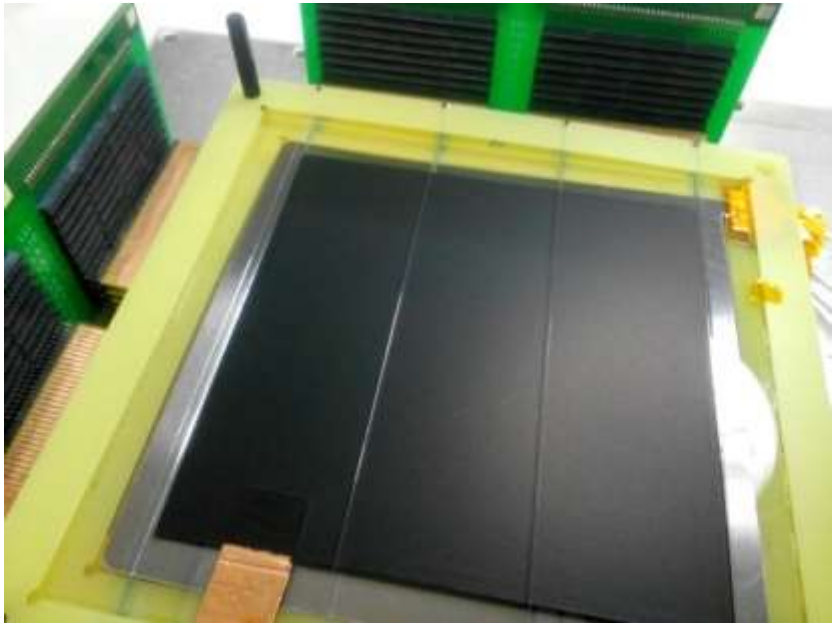
Resistive Ink layers: 0.04 mm thick

Multilayer Architecture



Thin Kapton PCBs with 3 layers of Cu-strips mutually orthogonal

- **X: Pitch = 1 mm; strip width = 0.3 mm**
- **X: Pitch = 1 mm; strip width = 0.9 mm**



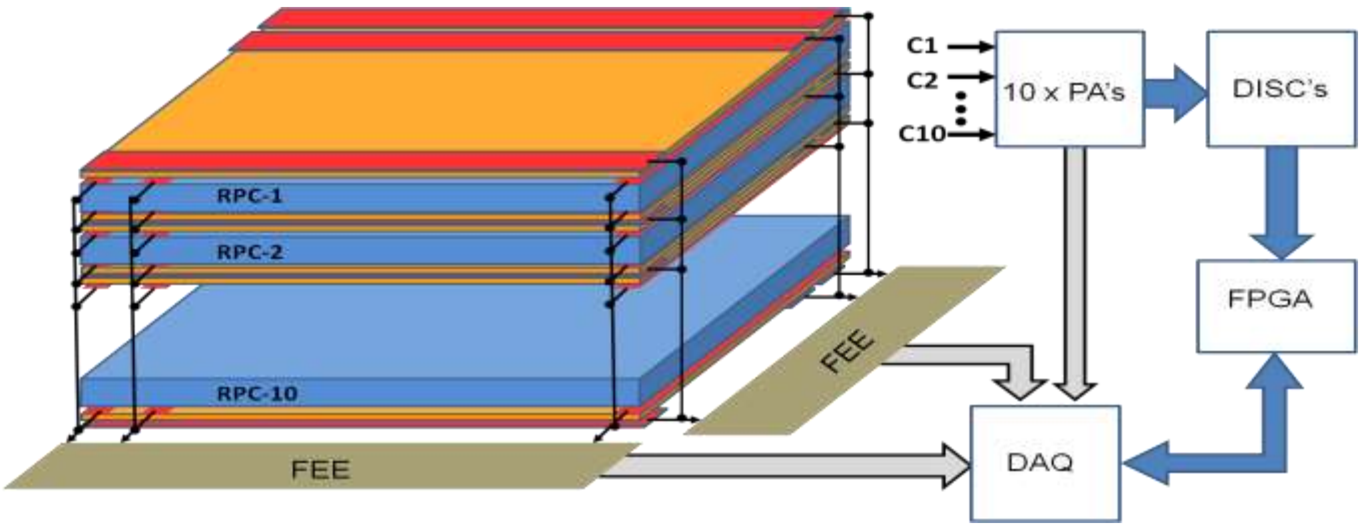
Glass plate (outer surface lined with a resistive layer) **facing an Al plate**

Al plates double coated with a 1.15 µm thick layer of $^{10}B_4C$

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

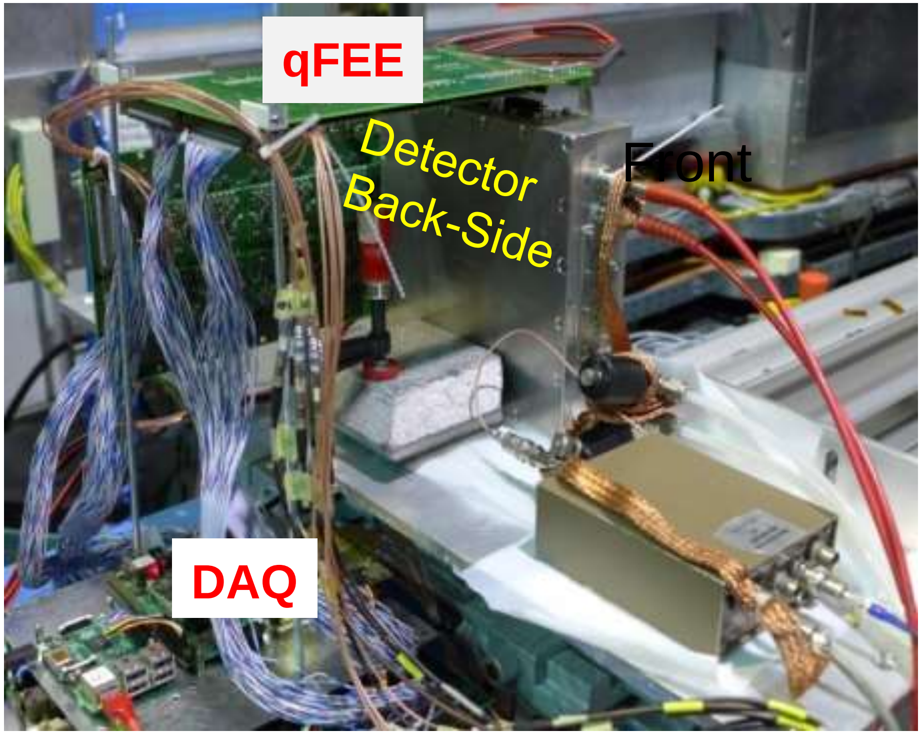
Multilayer Architecture

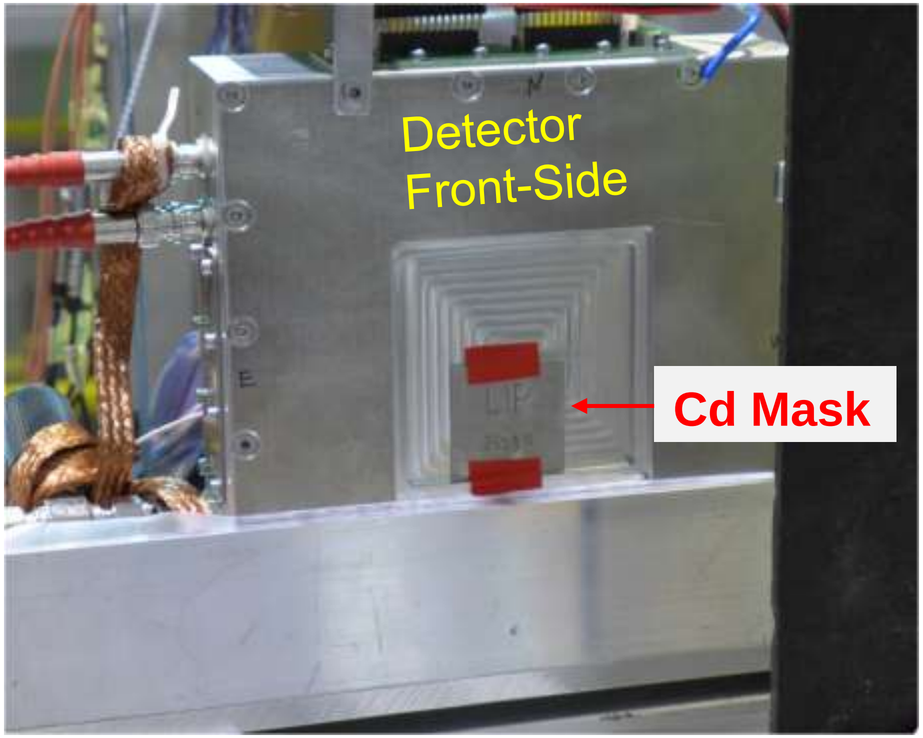
Readout setup



- DAQ triggered by the cathode signals
- Inner plane of strips (Y) shared by the two gas-gaps from adjacent RPCs
- The X (Y) strips with the same index are interconnected for all planes (reduces the number of readout channels but does not allow to resolve multiple events on the planes of strips)
- The counting rate was given by the trigger of each individual cathode: C1, C2, …, C10

Detector Prototype at FRMII/ TREFF beam line





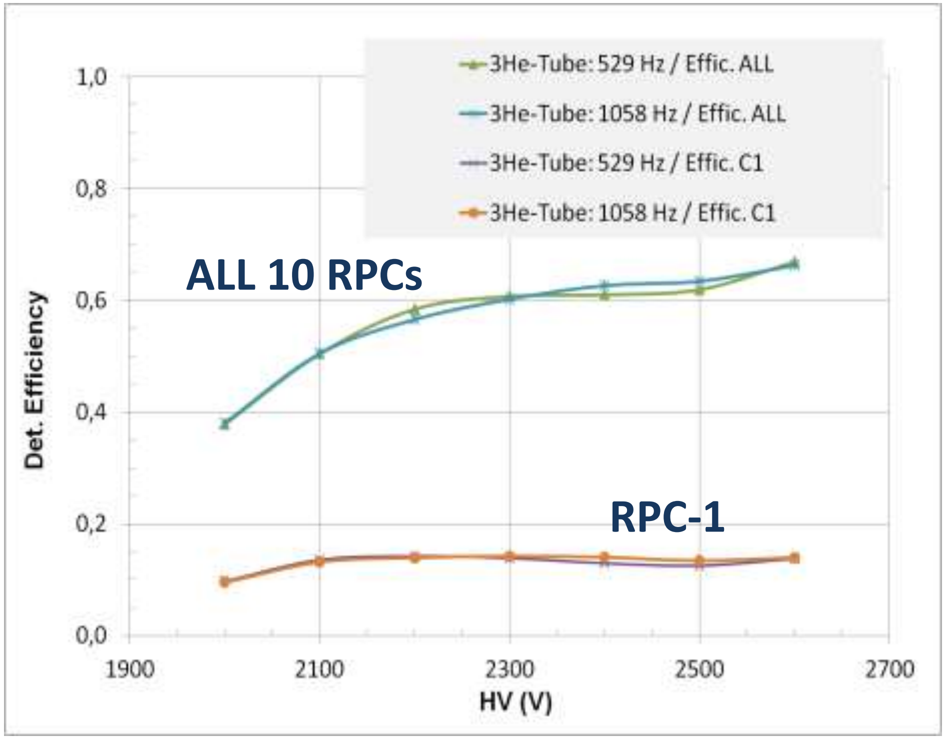
Prototype seated on the moving stage at TREFF (λ= 4.7 Å)

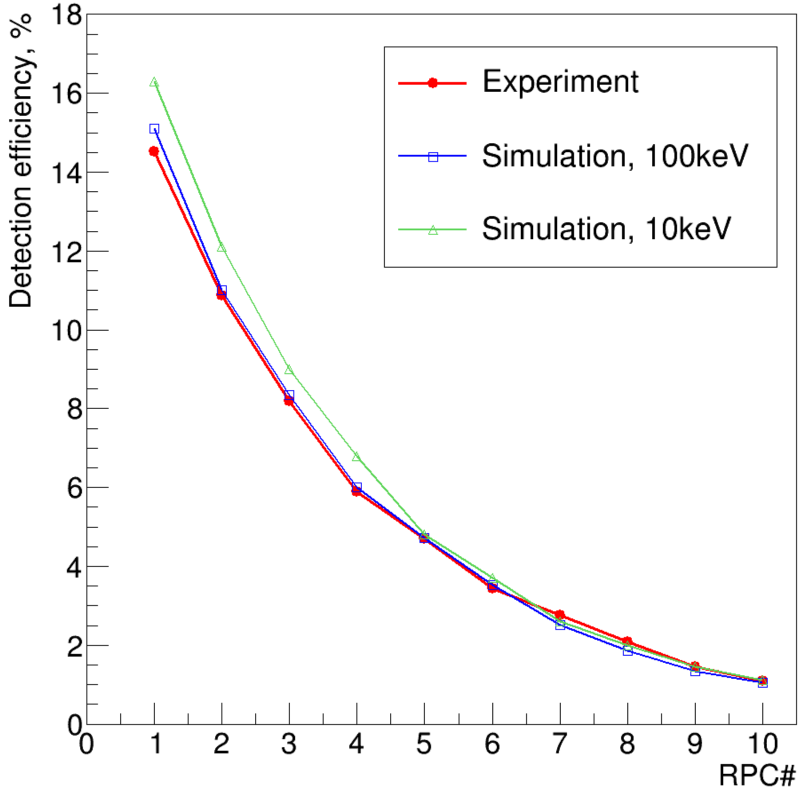
Aluminium gas-tight vessel (1mm thick neutron entrance window)

Working gas: $C_2H_2F_4$ (Tetrafluorethane) circulated in open loop mode (~ 2 cc/min)

Tests on TREFF neutron beam line (λ= 4.7 Å) @ FRM II

Detection efficiency



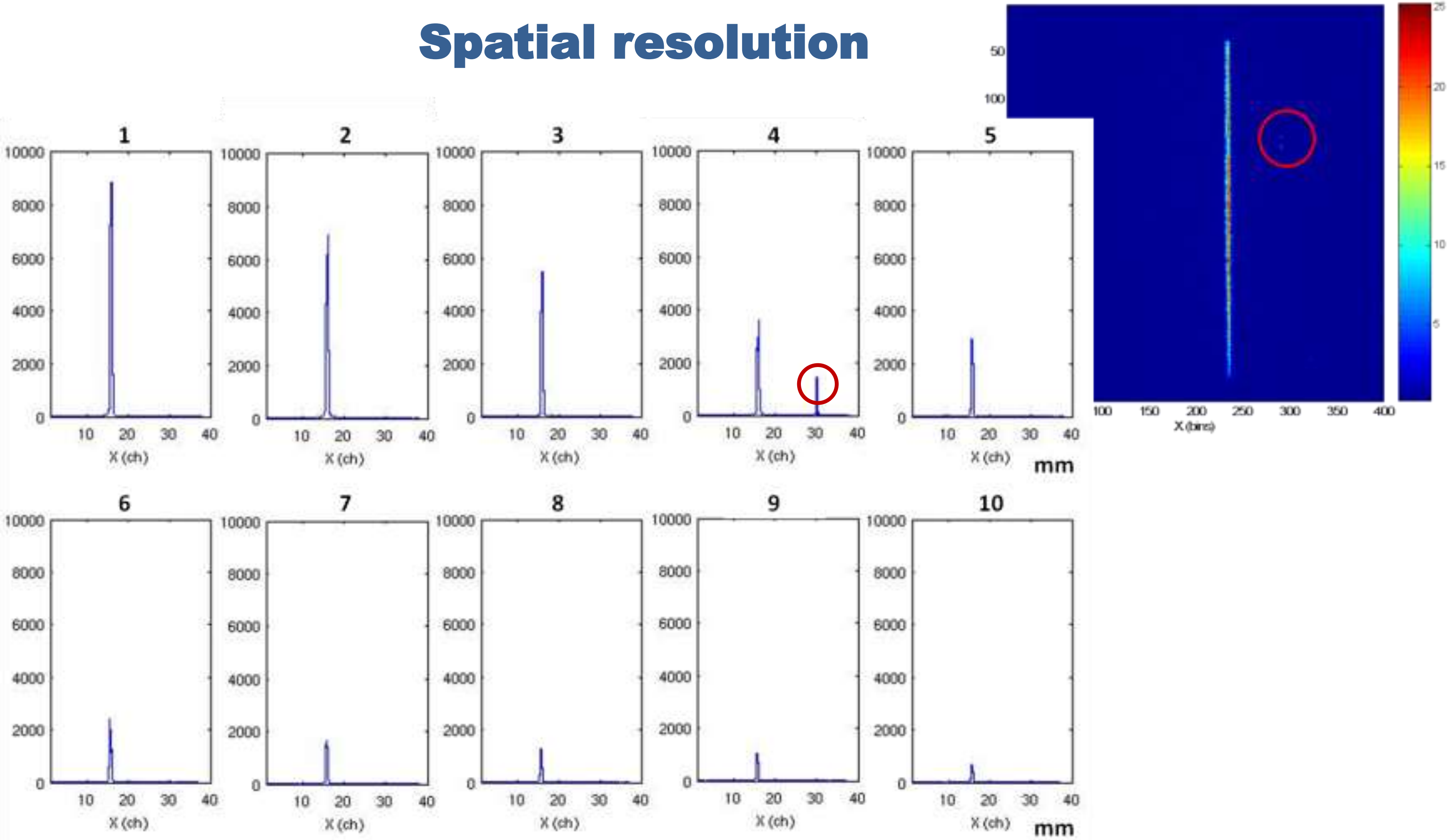


A ^{3}He -Tube was used as the reference (efficiency of ≈ 97 % at 4.73 Å)

Efficiency computed by ANTS2 Toolkit:
all $^{10}B_4C$ layers with the same thickness (1.15 μm)

Tests on TREFF beam line (λ= 4.7 Å) @ FRM II

Spatial resolution



Data acquired with a vertical Cd slit (0.1 mm x 35 mm)

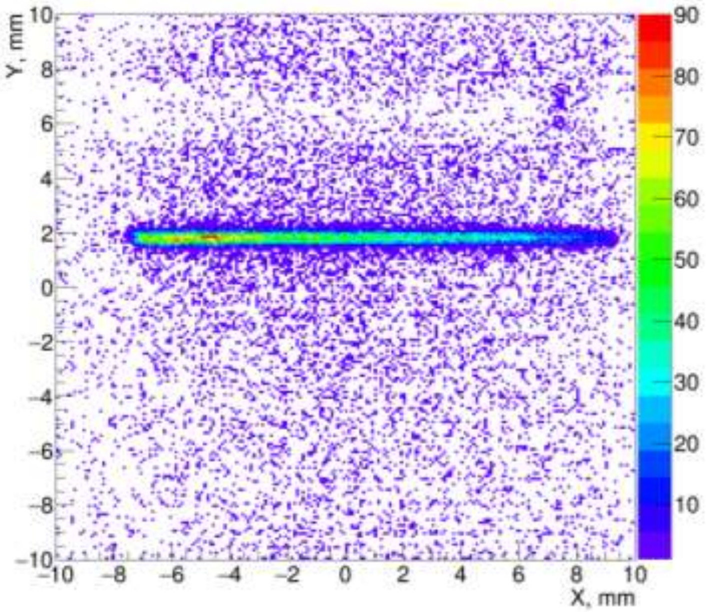
The spatial resolution seems to not be worsen going deep in the stack

Tests on TREFF beam line (λ= 4.7 Å) @ FRM II

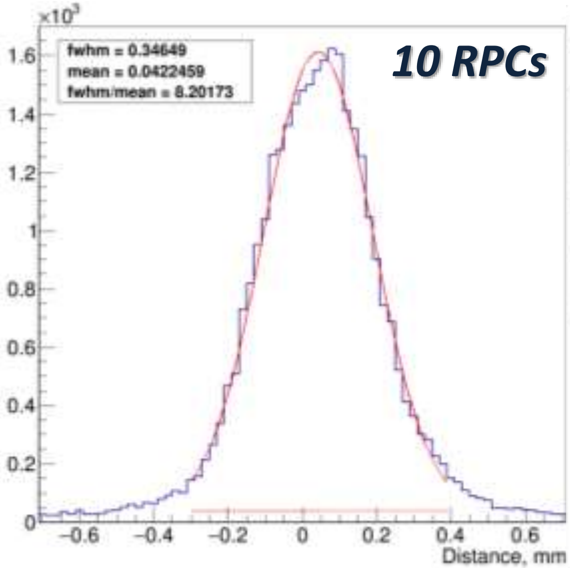
Spatial resolution

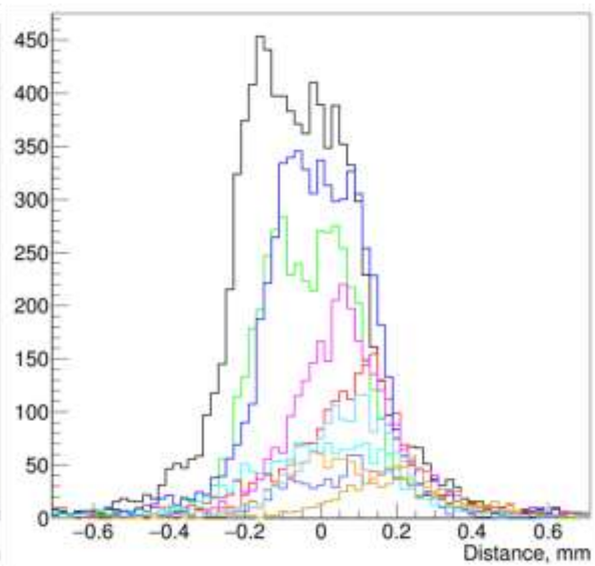
Horizontal Slit (Y-coord.)

Run204 (HV = -2.3 kV)



FWHM (Y) ≈ 350 µm





Cd Slit: 0.1 mm x 16 mm

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

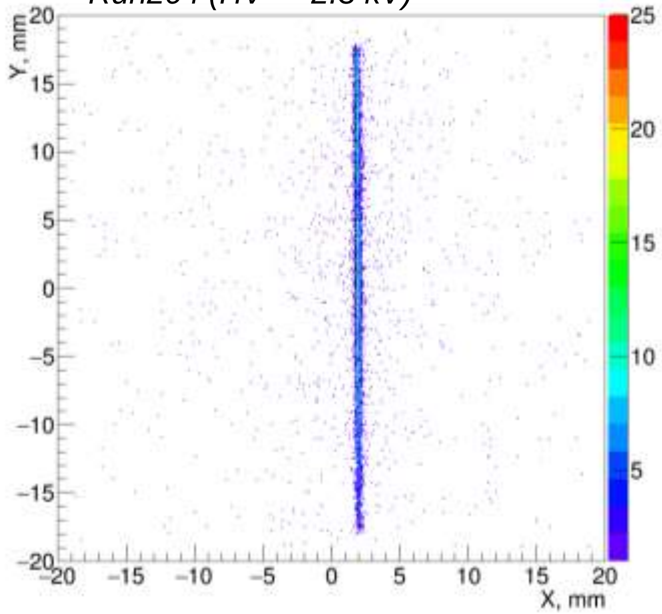
Tests on TREFF beam line (λ= 4.7 Å) @ FRM II

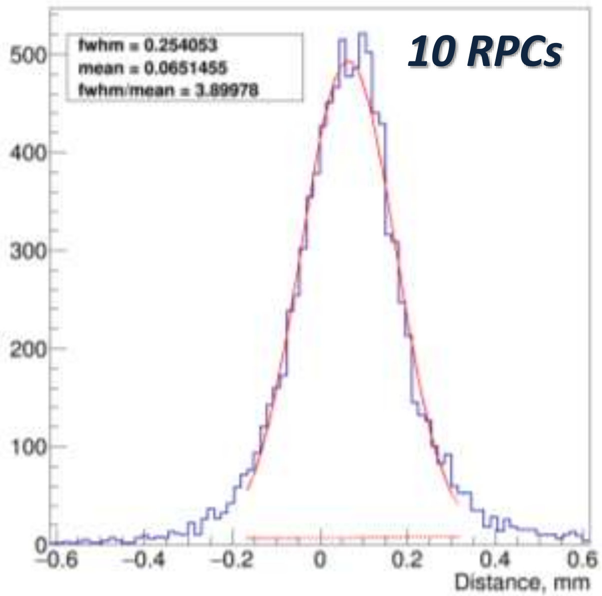
Spatial resolution

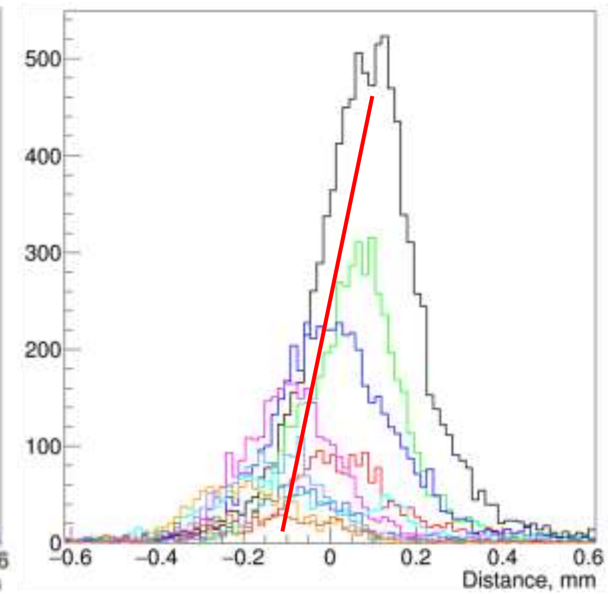
Vertical Slit (X-coord.)

FWHM (X) ≈ 250 µm

Run204 (HV = -2.3 kV)







Cd slit: 0.1 mm x 35 mm

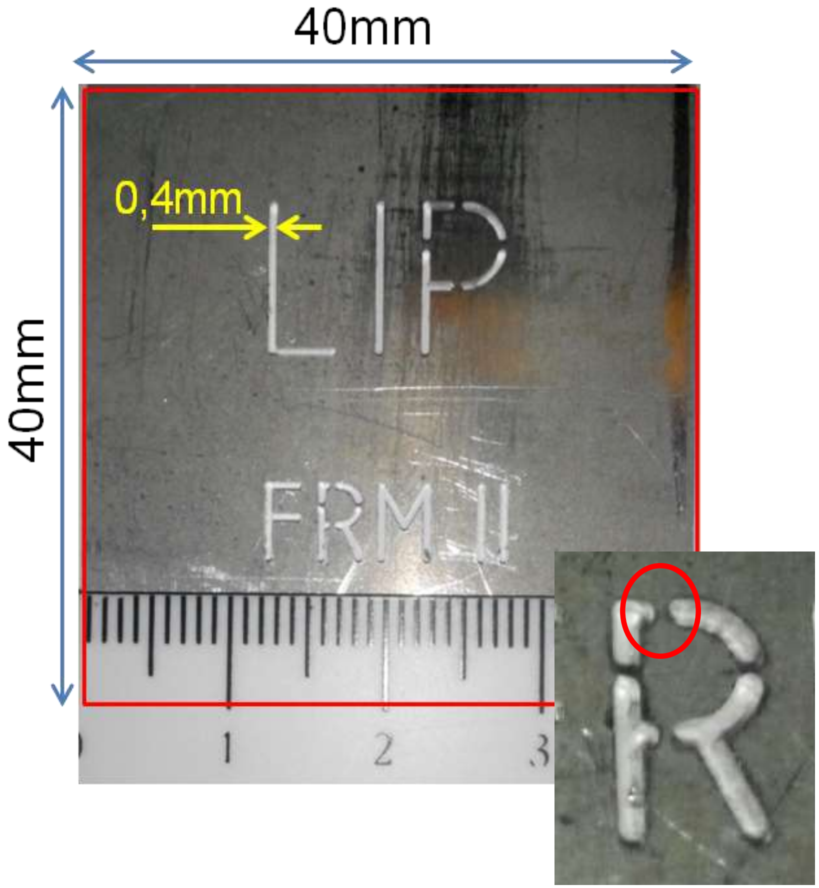
The **systematic shift** suggests **non-normality** of the beam to the RPCs of ≈ 0.4º (0.2 mm over 30 mm) ;

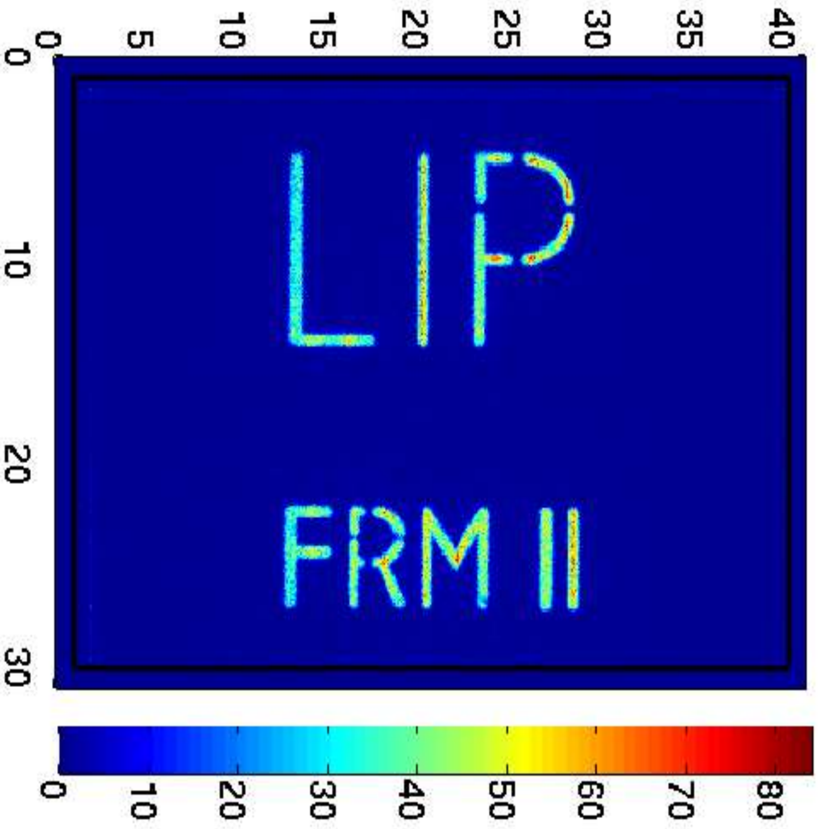
The **misalignments** of the PCBs in the stack are about 0.05 mm

Tests on TREFF beam line (λ= 4.7 Å) @ FRM II

Cd Mask (1mm thick)

Letters: line width of 0.4 mm





Summary

- **An extended counting plateau is observed in a HV region where the RPCs have low sensitivity to MIPs**

- **Tests of $^{10}B_4C$ lined thin gap RPCs with thermal neutrons demonstrated spatial resolution better than 250 µm FWHM**

- **A first prototype comprising a stack of 10 double-gap RPCs tested at FRMII/TREFF neutron beam line showed:**

  – A detection efficiency higher then 50% (good agreement with ANTS2 simulation)

  – Spatial resolution (≈ 0.25 mm FWHM) is not worse than for the single-gap RPC case

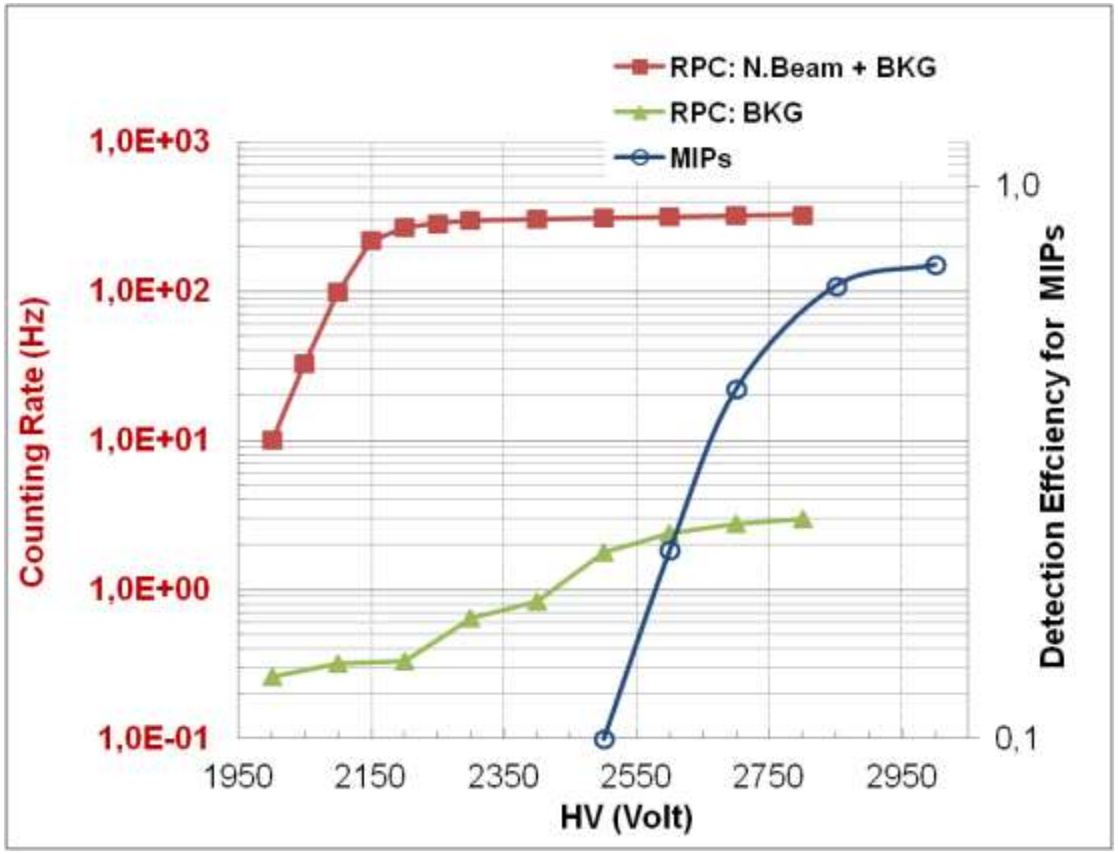
- **High spatial resolution combined with nanosecond time resolution is possible to be achieved with a detector based on ^{10}B lined RPCs**

Future plan

- ❑ **Characterization of the gamma sensitivity with ^{60}Co and ^{22}Na gamma sources**
- ❑ **Detector modelling (GEANT4 and ANTS2 toolkits) to improve the detector design and supports the selection of suitable materials focused on:**
  - Efficiency and counting rate optimization
  - Neutron scattering and gamma sensitivity minimization
- ❑ **Study of the feasibility of a ^{10}B Multigap RPC design should pursue**
- ❑ **Basic studies:**
  - Working gas optimization
  - Difference in response of ^{10}B lined RPCs to MIPs and HIPs

Thank you for your attention

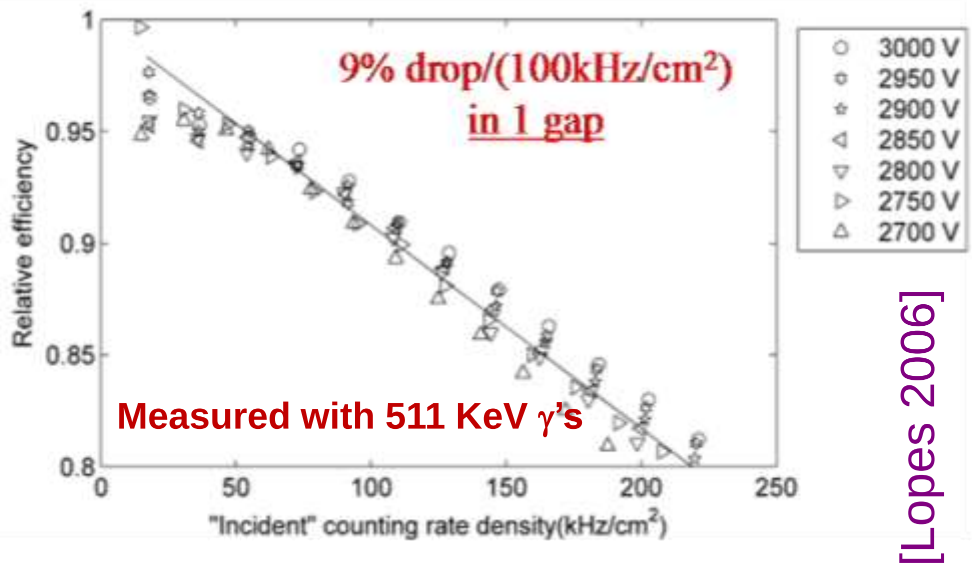
Backup Slides

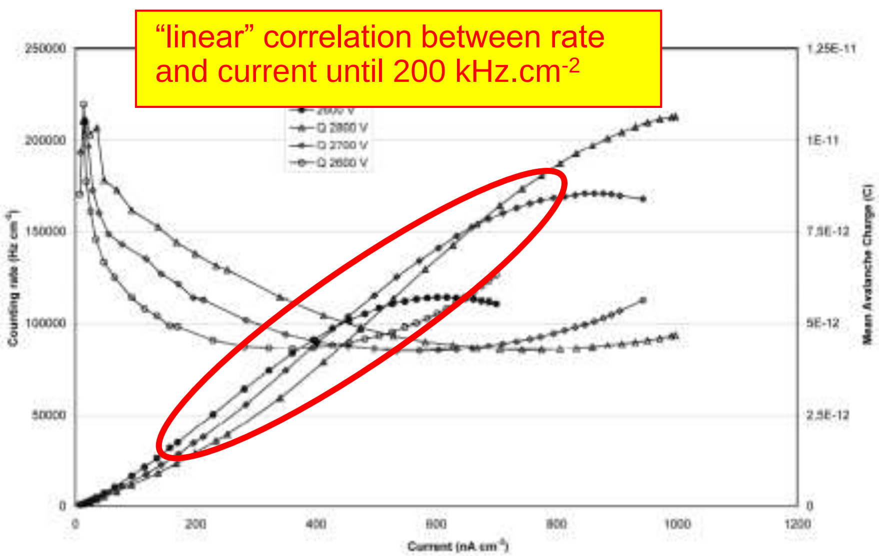


RPC: N.Beam + BKG
RPC: BKG
MIPs
1,0E+03
1,0E+02
1,0E+01
1,0E+00
1,0E-01
Counting Rate (Hz)
1,0
0,1
Detection Effciency for MIPs
1950
2150
2350
2550
2750
2950
HV (Volt)

RPCs - Counting Rate

Ceramic RPCs

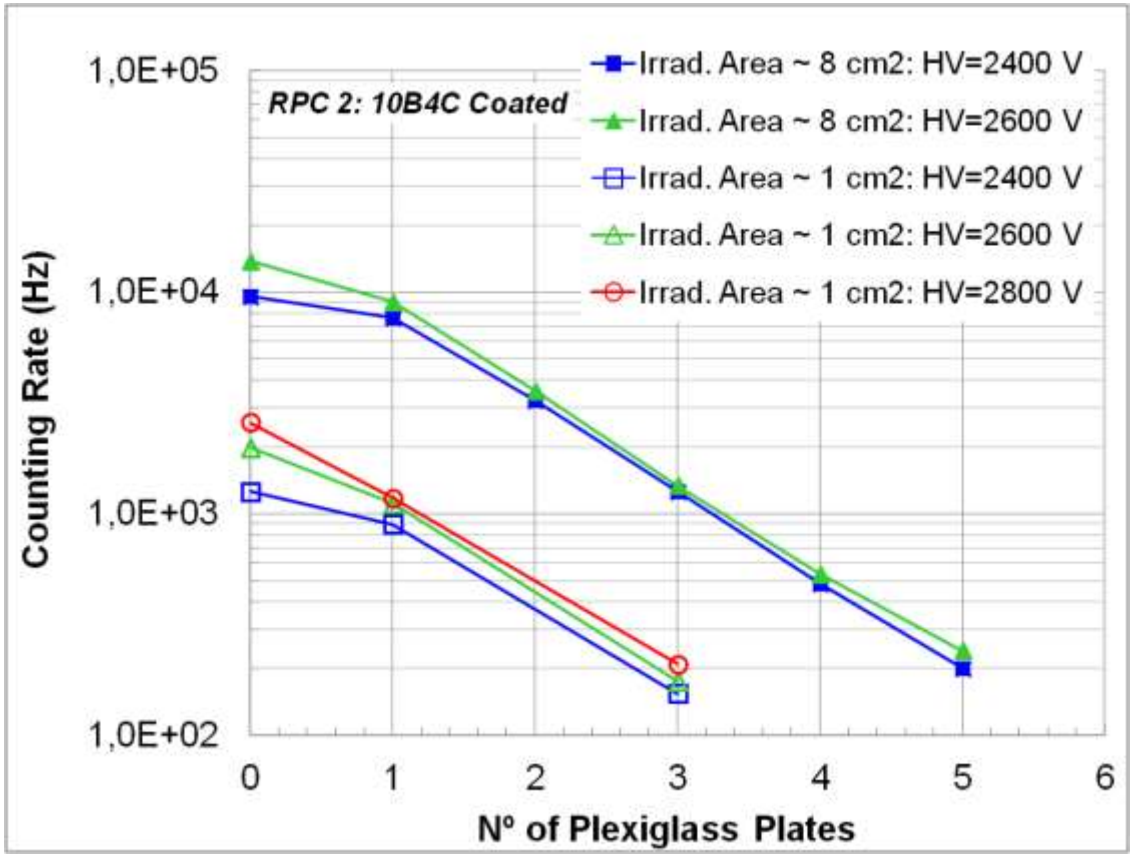




Counting rate improvement

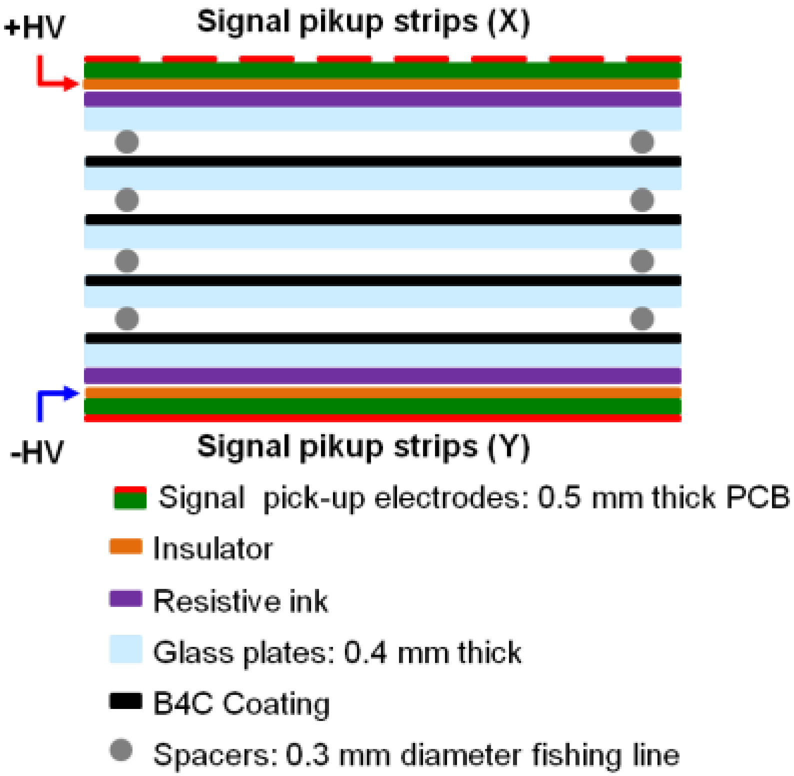
- **Thinner resistive electrodes**
- **Front end electronics with higher sensitivity**
- **Increase the temperature (glass resistivity decreases)**
- **Low resistivity materials:** e.g. Ceramics, doped glass, PEEK loaded with Carbon ($\rho =$ 1-3 x10^9 Ω.cm) .

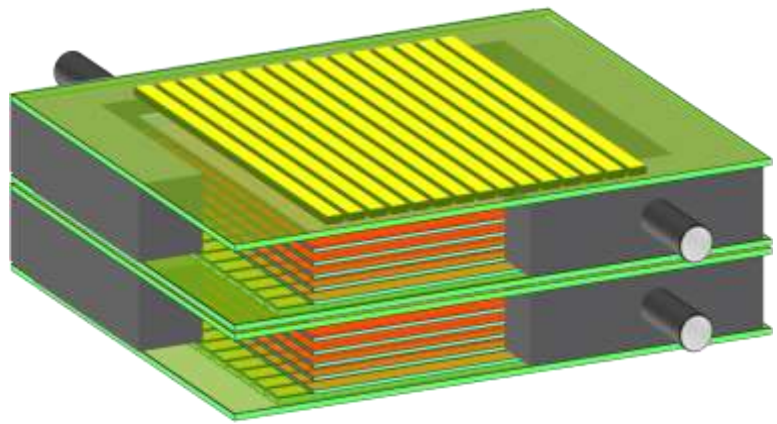
Efficiency as a function of the beam intensity



Attenuators: Plates of Plexiglass 3mm thick

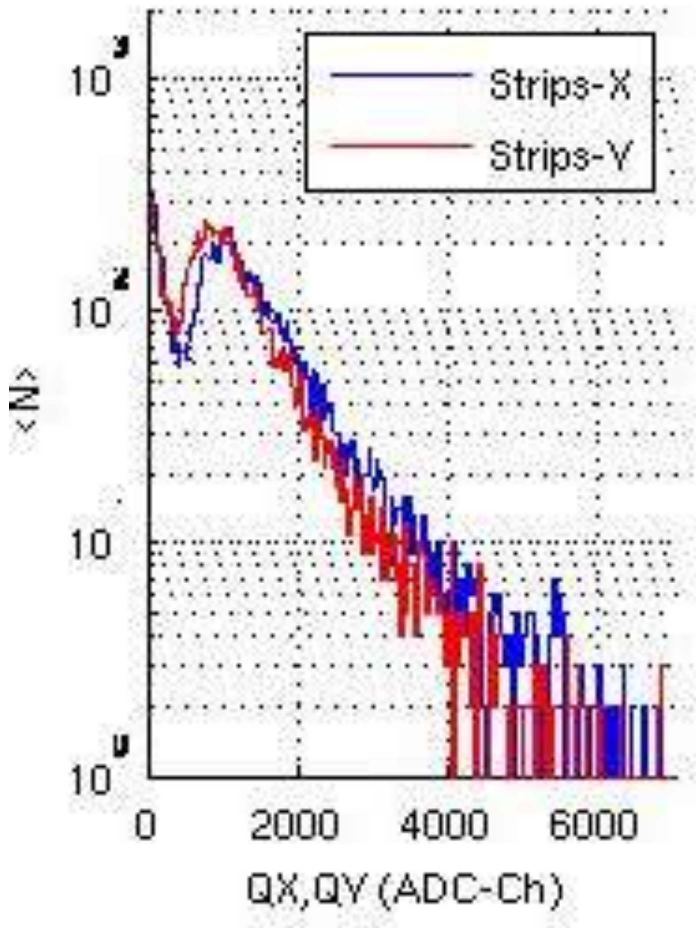
Multigap-RPC (MGRPC)





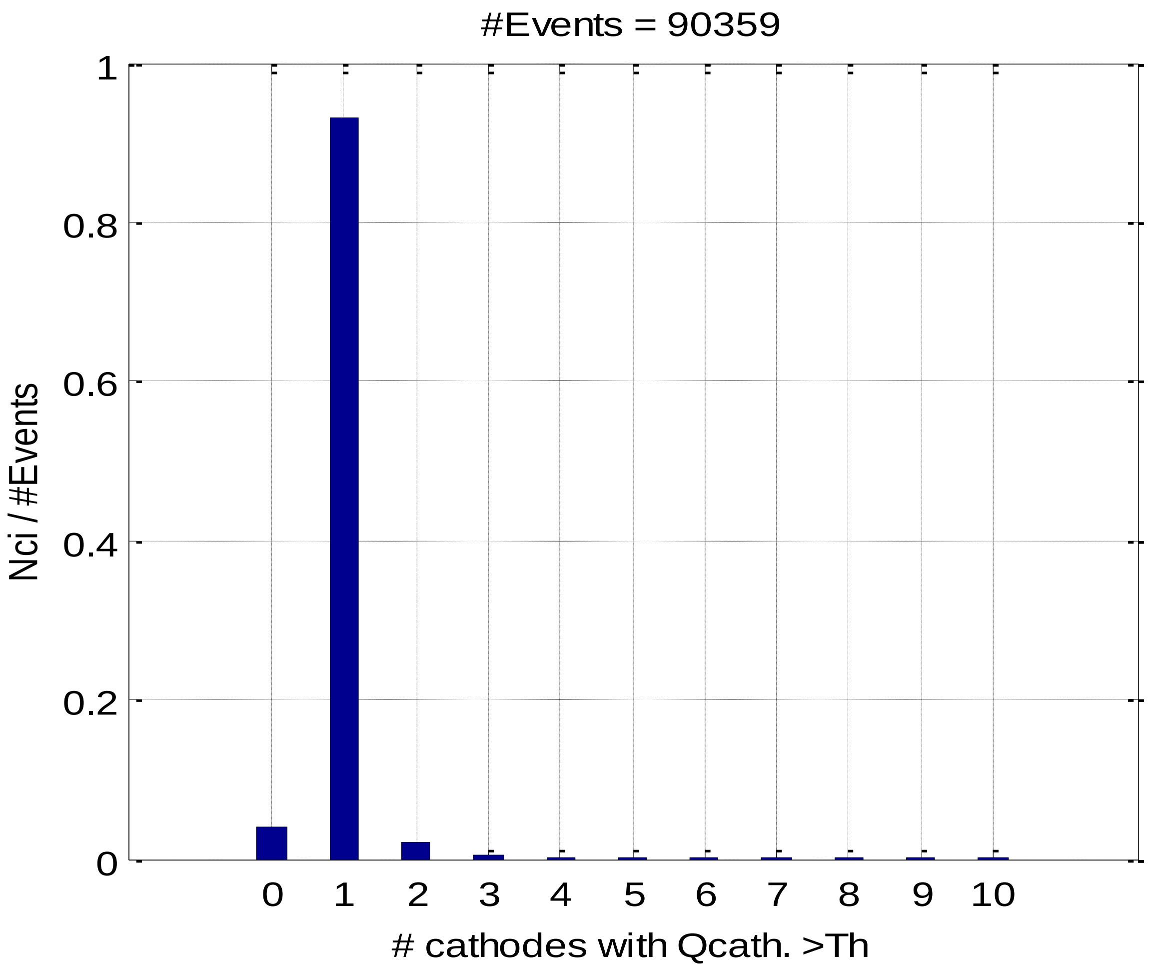
- **Challenges: ^{10}B4C coatings deposited onto resistive substrates (e.g. soda lime glass, ceramics) must shows:**
  - **— Good adhesion properties**
  - **— High surface resistivity (> 10^6 Ω/□)**

Induced signal is fairly shared by two adjacent planes strips



PHS of the signals from X and Y strips

Event multiplicity for the cathodes



RPCs – Resistive Plate Chambers

Typical gas mixture:

- Freon R134a (tetrafluoroethane): high electron affinity (electron capture ⇒ avalanche confinement);
- SF6 (sulphur hexafluoride): 1 to 10% (to suppress streamer discharges);
- C4H10 (Iso-Butane): 0 to 5% (to prevent photon induced streamers.