Development of Resistive Plate Chambers (RPCs)

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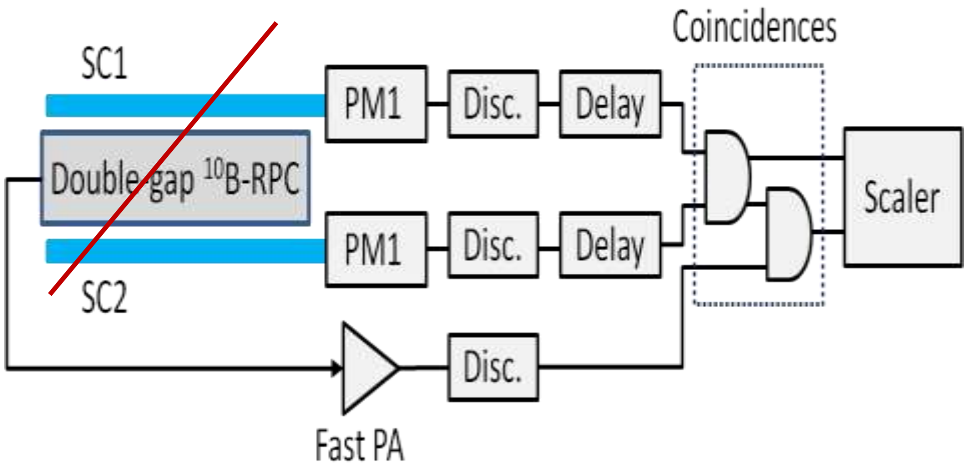
Outline

- Double-gap ^{10}B-RPC sensitivity to gamma rays
- Progress in ^{10}B-RPC development within SINE 2020
- Future work

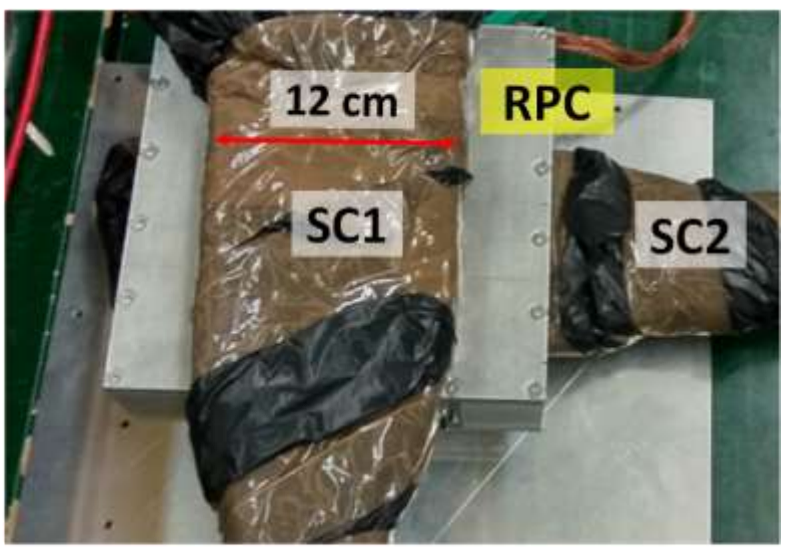
Double-gap ^{10}B-RPC

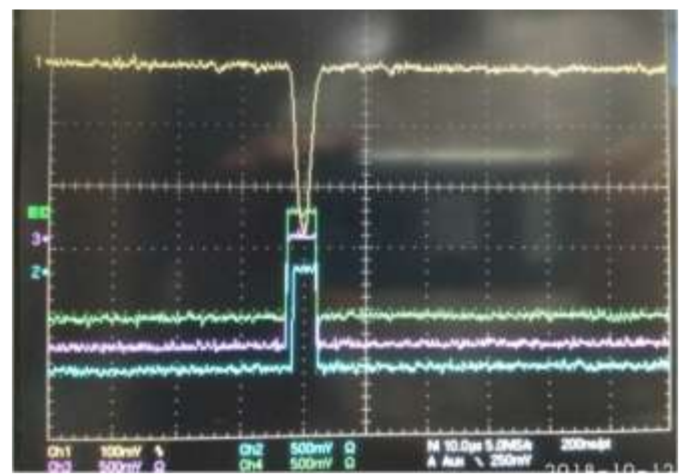
Plateau shift: cosmic muons (MIPs) *versus* thermal neutrons

Experimental setup: RPC plateau for cosmic muons (MIPs)



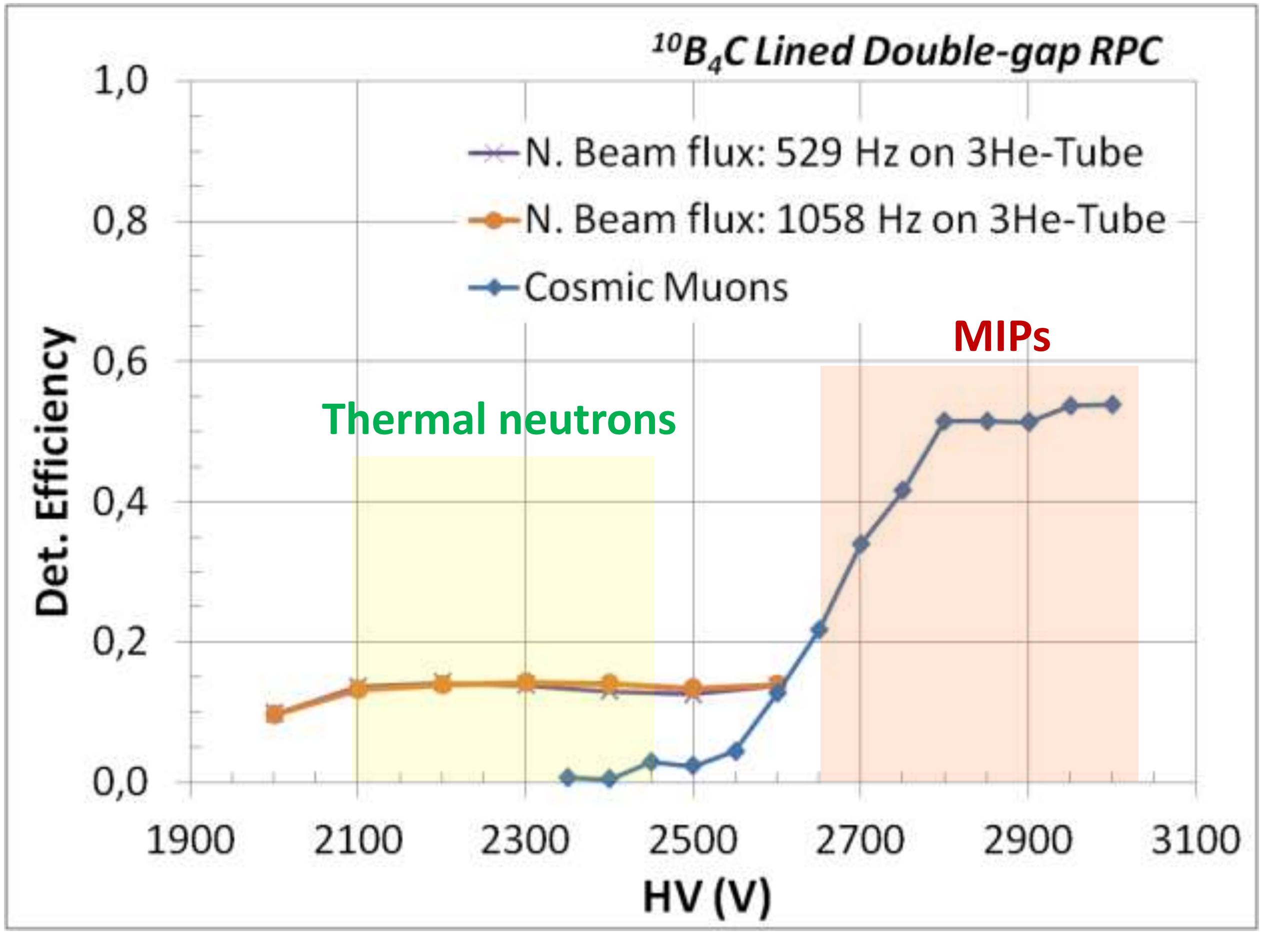
$$D.Efficiency = \frac{\Sigma\,(SC1 \wedge SC2 \wedge RPC)}{\Sigma\,(SC1 \wedge SC2)}$$





Double-gap ^{10}B-RPC

Plateau shift: cosmic muons (MIPs) *versus* thermal neutrons



Double-gap ^{10}B-RPC

Plateau shift: cosmic muons (MIPs) *versus* thermal neutrons

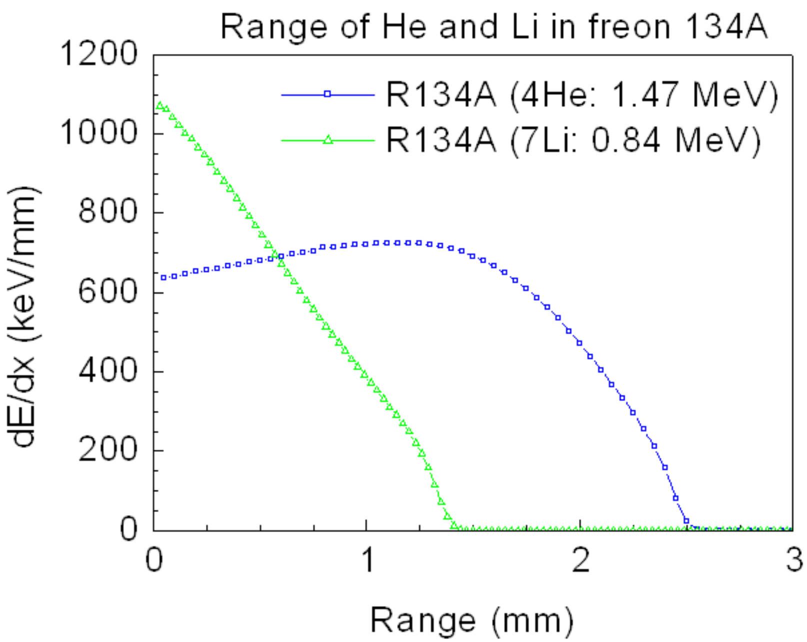
Energy loss in the working gas

- **Minimum ionizing particles (MIPs)**

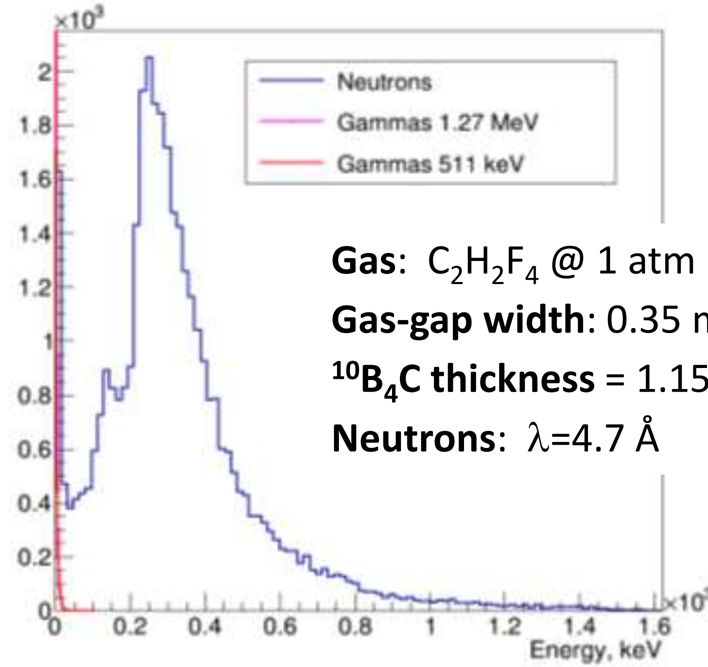
Gas	**Density** (1 atm, 20ºC) (g/cm^3)	**I** (eV)	**dE/dx** (keV/mm)	**Np** [cm^{-1}]
$C_2H_2F_4$ (R134a)	4.24×10^{-3}	95.029	0.7482	81.6

[arXiv:1505.00701v1 [physics.ins-det]]

- **^{4}He and ^{7}Li fission fragments**



Energy deposited in the RPC gas-gap computed with GEANT4



Gas: $C_2H_2F_4$ @ 1 atm

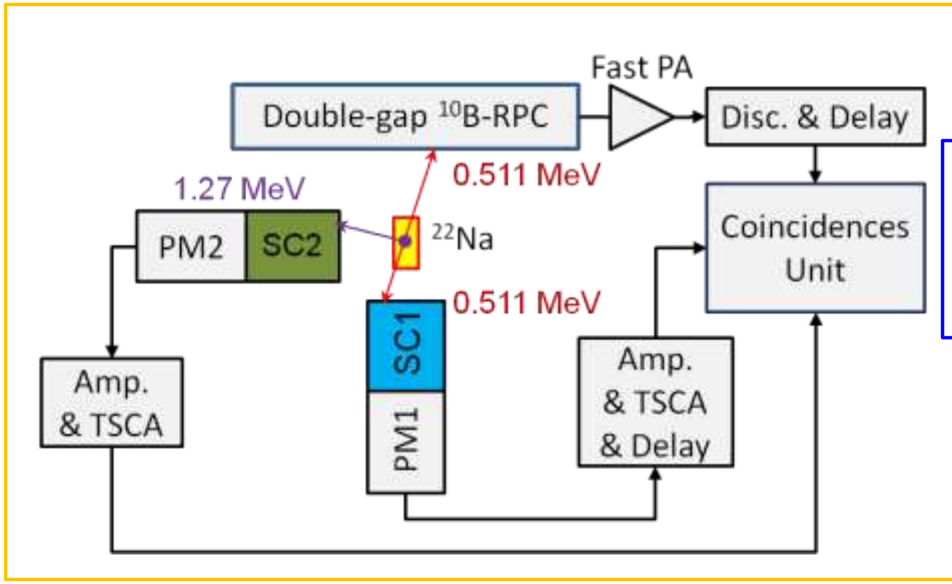
Gas-gap width: 0.35 mm

$^{10}B_4C$ thickness = 1.15 mm

Neutrons: λ=4.7 Å

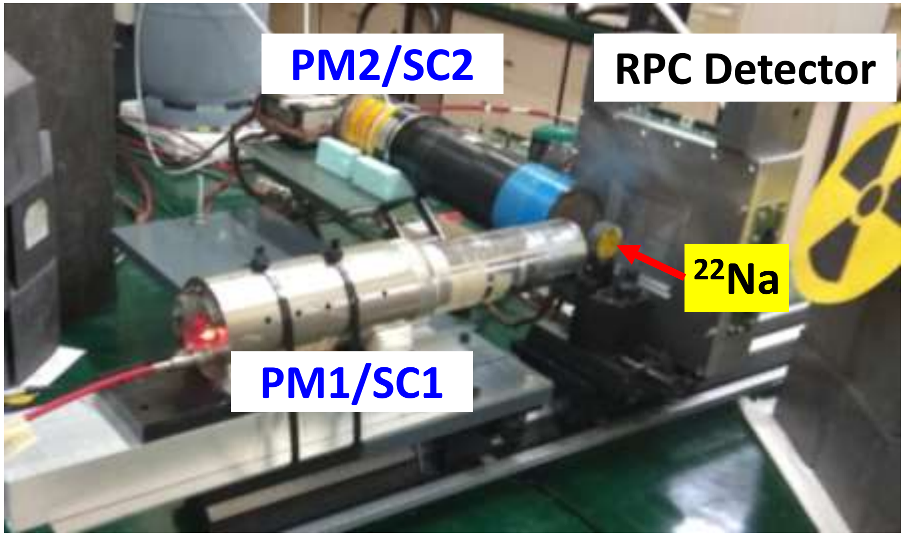
Double-gap ^{10}B-RPC: sensitivity to gamma rays

Experimental setup: gamma sensitivity for the 0.511 MeV gamma rays

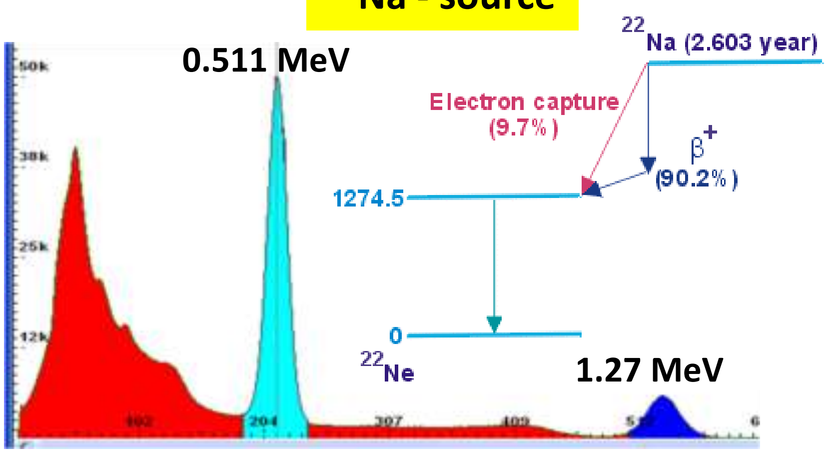


Det. Efficiency = N1/N2

- ▶ **N1**=PM1 & PM2 & RPC
- ▶ **N2**=PM1 & PM2

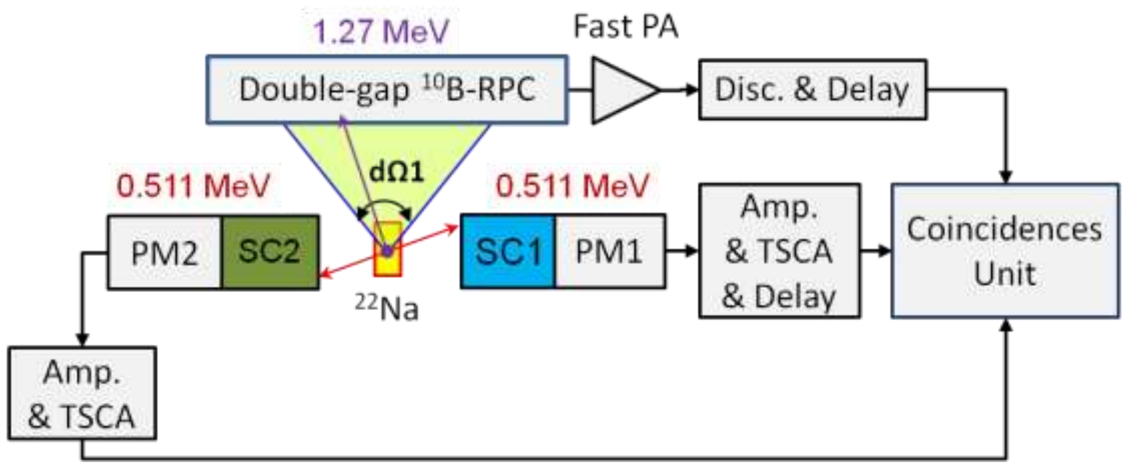


^{22}Na - source



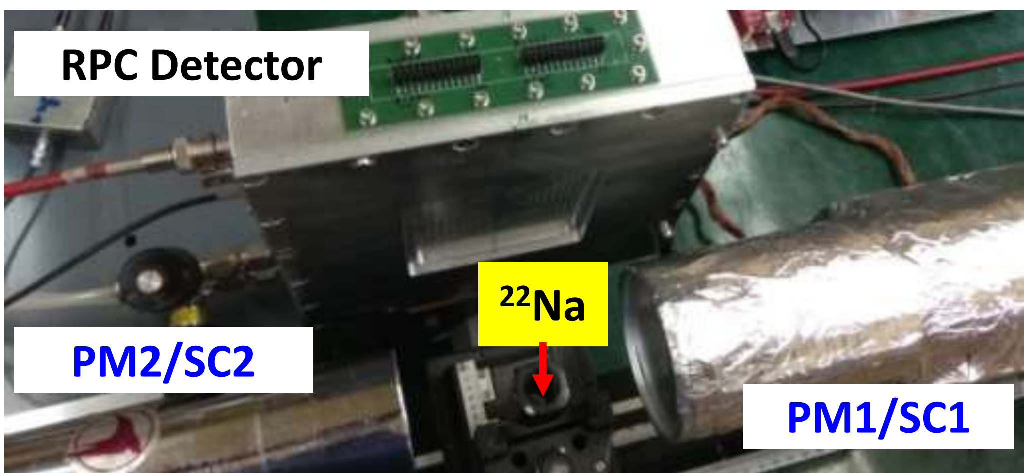
Energy windows are set by the TSCAs

Experimental setup: gamma sensitivity for the 1.27 MeV gamma rays



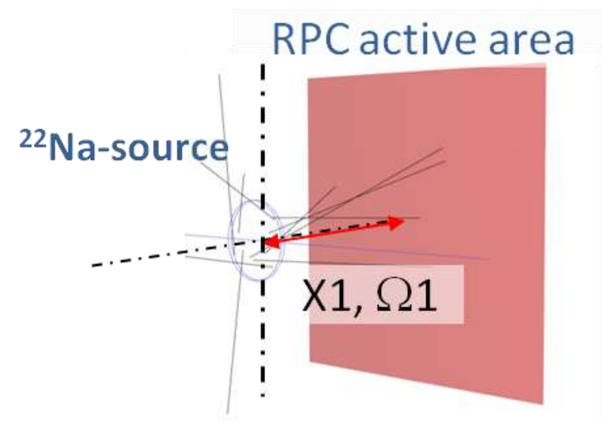
Det. Efficiency = N1/(N2 x dΩ1)

- ▶ **N1**=PM1 & PM2 & RPC
- ▶ **N2**=PM1 & PM2



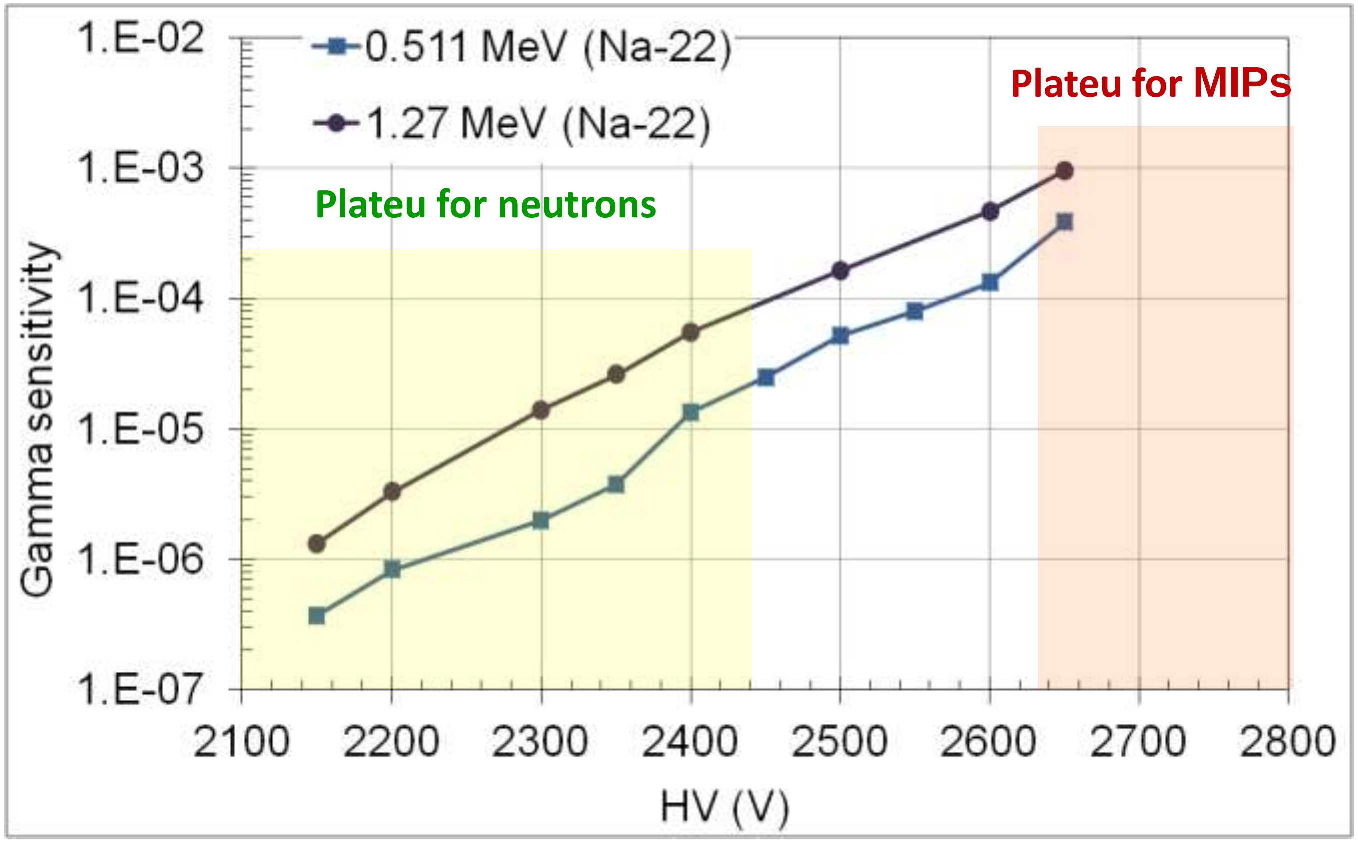
Solid angle (Ω1) computed with ANTS2

^{22}Na Disk source



Experimental results

Sensitivity to 0.511 MeV and 1.27 MeV gamma rays

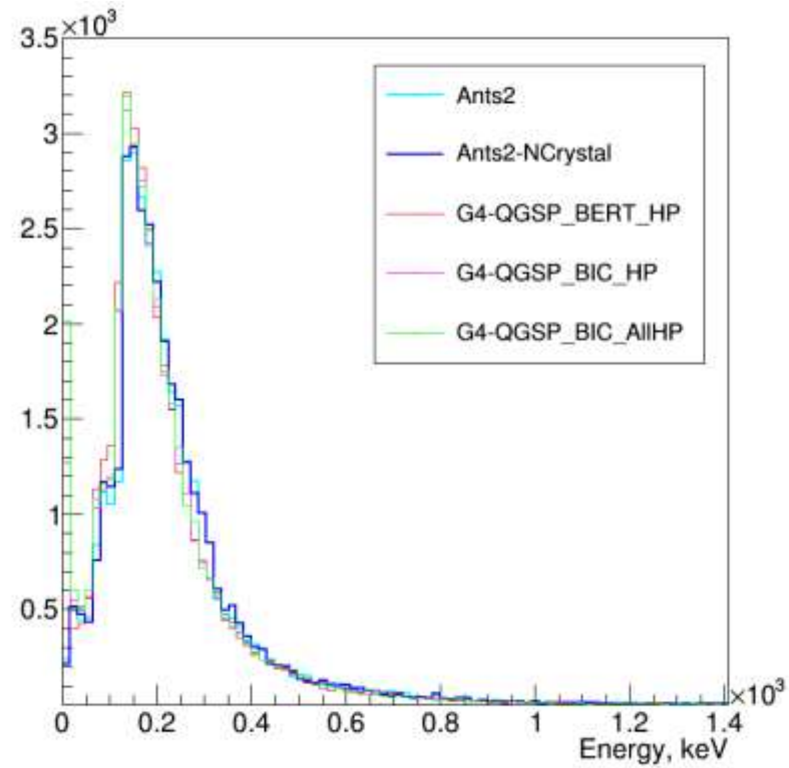


Double-gap ^{10}B-RPC: sensitivity to gamma rays

MC Simulations

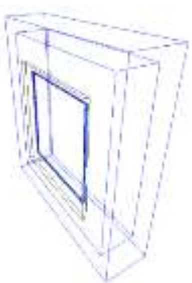
- Geant4 10.5.1 with QGSP-BERT-HP reference physics list
- Tests with other relevant physics lists (QGSP-BIC-HP and QGSP-BIC-AllHP): showed nearly identical results

Distribution of the energy deposited in the RPC gas-gap by the reaction products of neutron capture in ^{10}B for the **"Modified design"**



5 x10^5 neutrons (1.8 Å) were sent in a pencil beam perpendicular to the RPC

Detector model



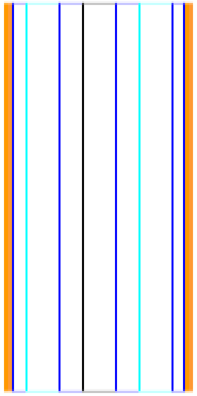
- Double-gap ^{10}B-RPC inside in an Al box
- Al-cathode coated (both sides) with 1.15 um thick $^{10}B_4C$ layer (97% enrichment)
- Area:10x10 cm^2

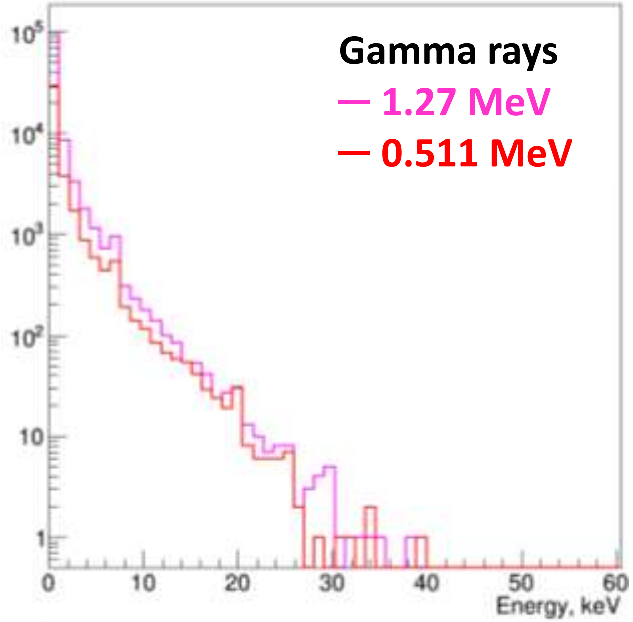
Two RPC designs were simulated

	Original	Modified
Gas-gap width	0.35 mm	0.2 mm
Al plate thickness	0.5 mm	0.3 mm
Glass plate thickness	0.5 mm	0.25 mm

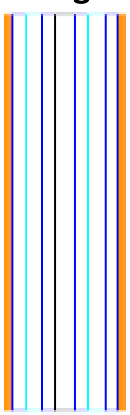
Double-gap ^{10}B-RPC: sensitivity to gamma rays

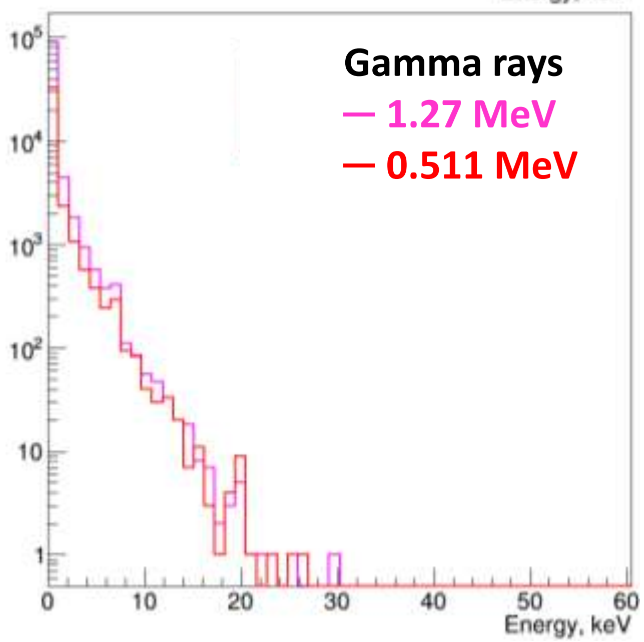
Original design





Modified design





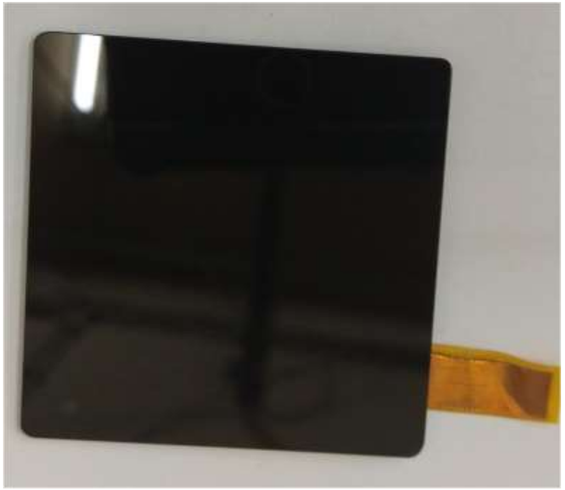
10^7 gammas were sent in a pencil beam perpendicular to the RPC for each energy (511 keV and 1.27 MeV)

Fractions of primaries resulting in energy deposition in the gas-gaps for a energy threshold of 20 keV

Gamma energy	RPC design	
	Original	Modified
0.511 MeV	6×10^{-6}	$\sim1\times10^{-6}$
1.27 MeV	8×10^{-6}	$\sim1\times10^{-6}$

- **High rate ^{10}B-RPCs:** prototypes with low resistivity electrodes are being assembled for beam tests

Plate of low-resistive silicate glass



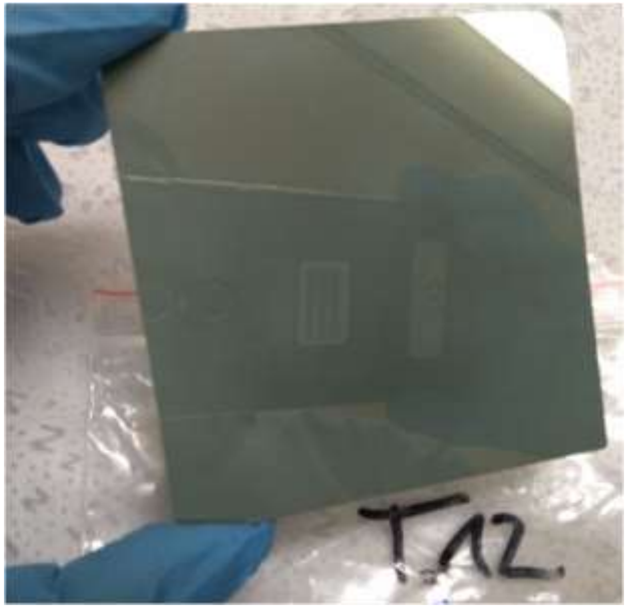
Bulk resistivity ~10^{10} Ω.cm)

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

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

V_{eff}: Effective voltage applied across the gap
V_{ap}: Applied voltage,
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

Plates of ceramics composite provided by L. Naumann, Forschungszentrum Dresden-Rossendorf

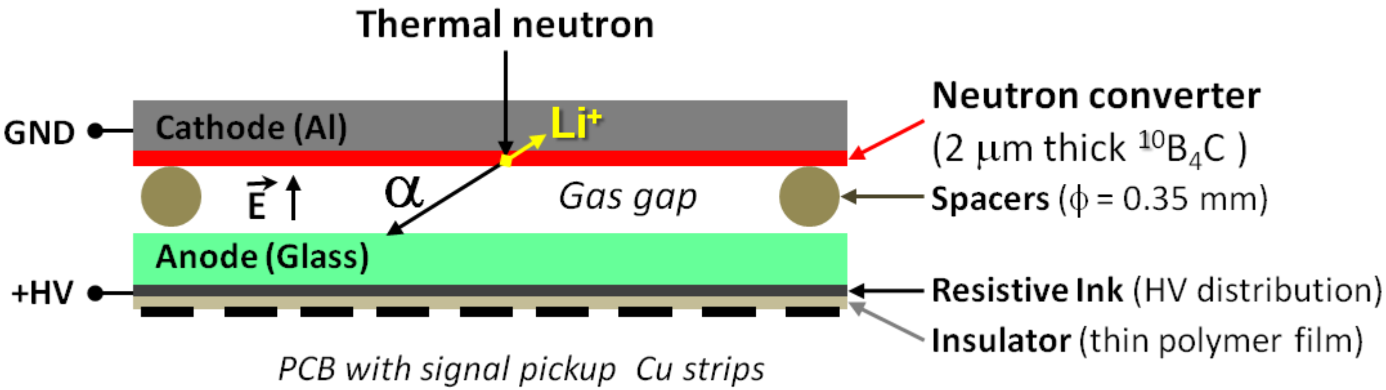


Bulk resistivity of the plates prepared for tests:
8.6×10^7 Ω.cm ; 1×10^8 Ω.cm and 2×10^{10} Ω.cm

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

^{10}B-RPC status before SINE 2020

- **Single-gap RPC in a hybrid configuration**
- **RPC cathode (Al) coated with 2um thick layer of $^{10}B_4C$ at the ESS Detector Coatings Workshop**



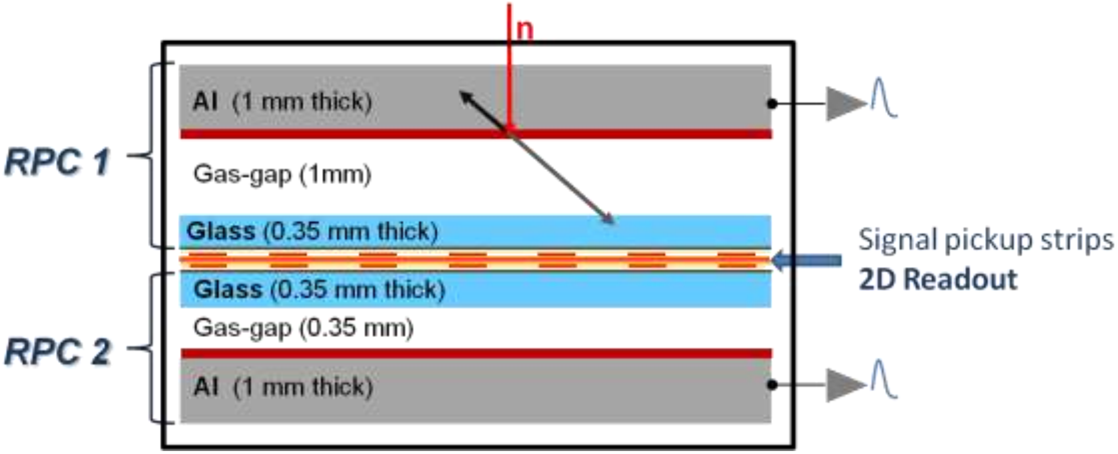
1D – sensitive!

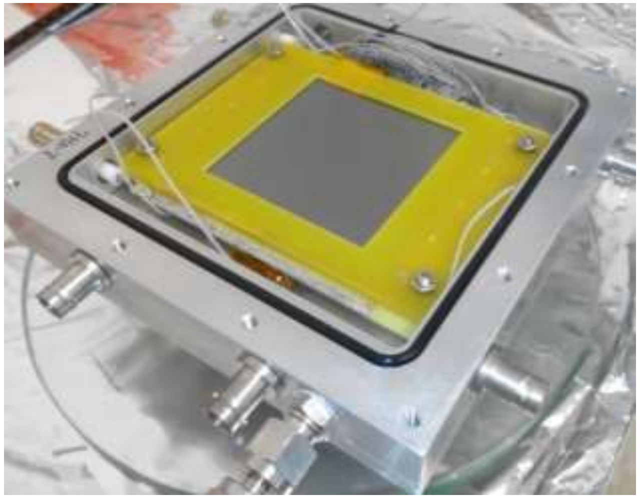
RPC Prototype developed in the Framework of an Exploratory Project Funded by FCT

- **The first prototype assembled in LIP and tested at ILL**
  - Sensitivity to thermal neutrons demonstrated
  - Sub-millimeter spatial resolution observed (**0.8 mm FWHM)**

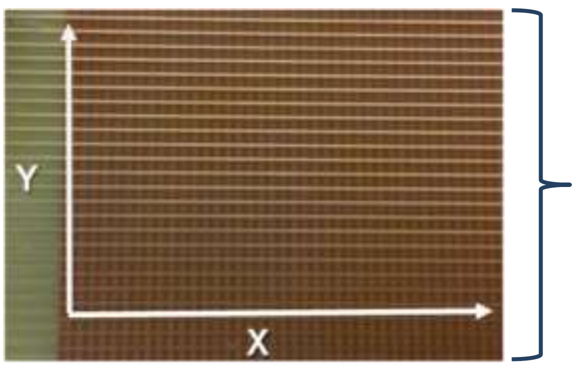
Progress in ^{10}B-RPC development within SINE 2020

- Single-gap RPCs with different gas-gap widths (0.35 mm and 1 mm) tested





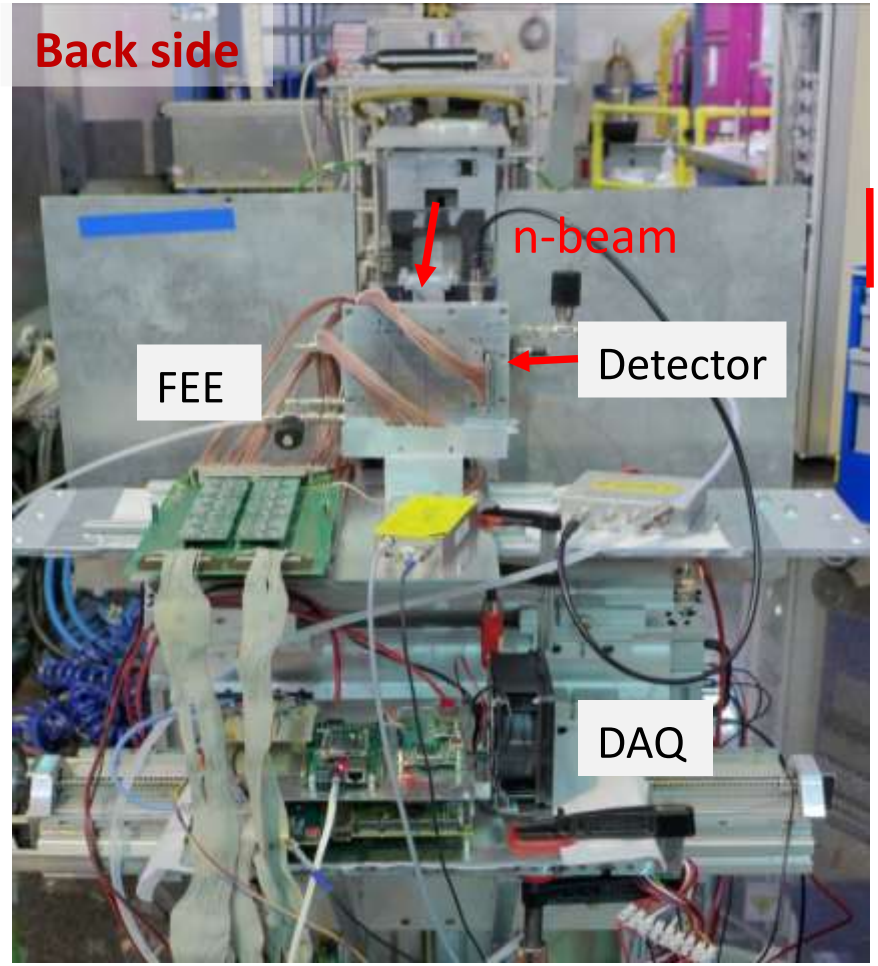
- For 2D position sensitivity a new scheme for signal pickup electrodes implemented



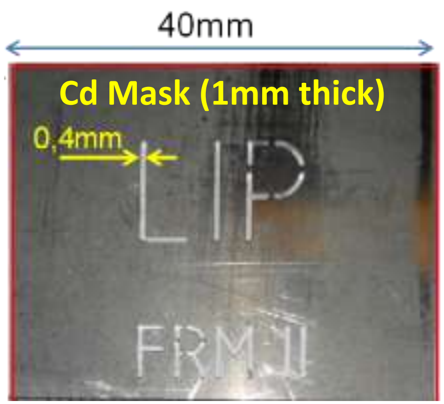
Each strip is readout by a charge sensitive amplifier

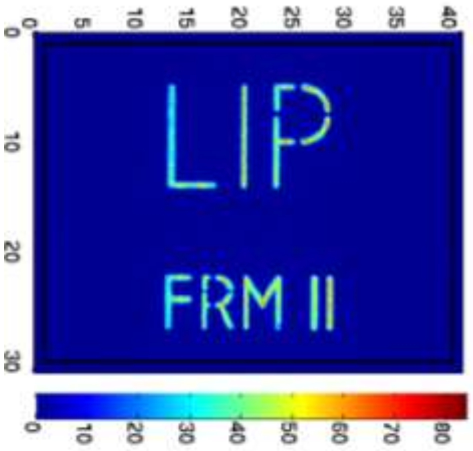
- **Vertical strips (X)**
  - Pitch = 1.5 mm
  - Width = 1.3 mm
- **Horizontal strips (Y)**
  - Pitch = 2.0 mm
  - Width = 0.5 mm

❑ Prototypes tested at FRMII/ TREFF neutron beam line (λ= 4.7 Å)



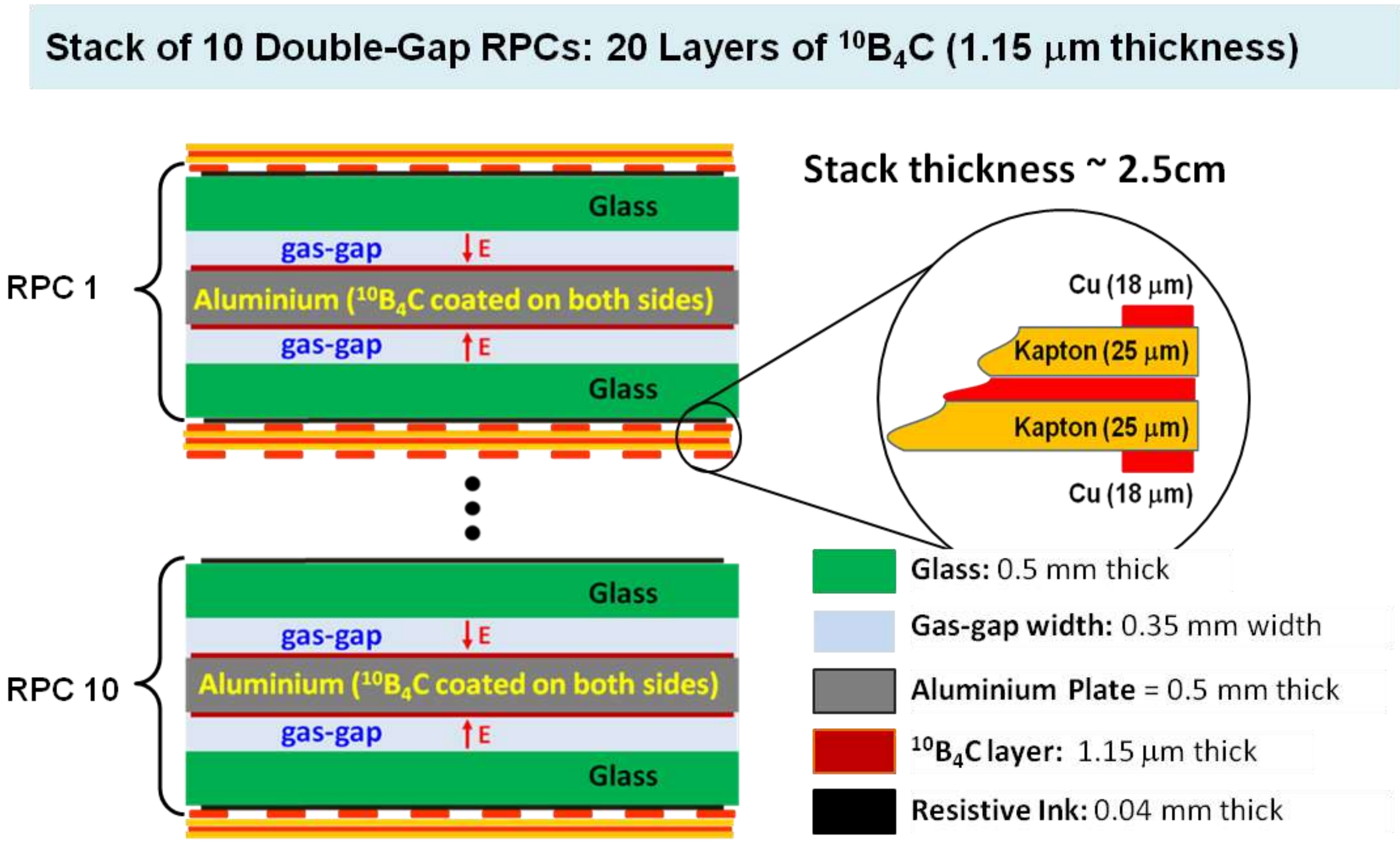
- Both RPCs showed a wide plateau
- Detection efficiency (single-gap) ≈ 12.5%
- The new 2D readout scheme is feasible
- Thinner gas-gap shows higher spatial resolution and requires lower voltage
- Spatial resolution better than 250 μm FWHM demonstrated for both coordinates (x,y)





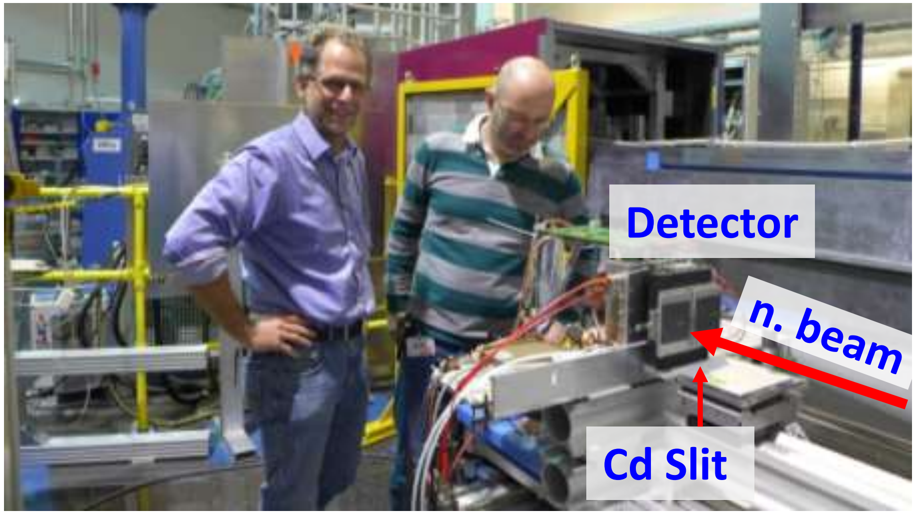
Progress in ^{10}B-RPC development within SINE 2020

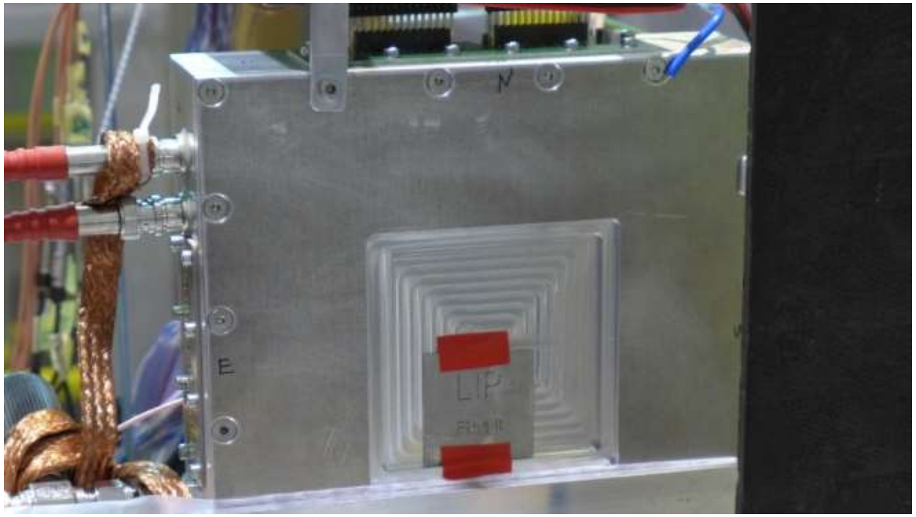
- Multilayer architecture introduced to address low detection efficiency



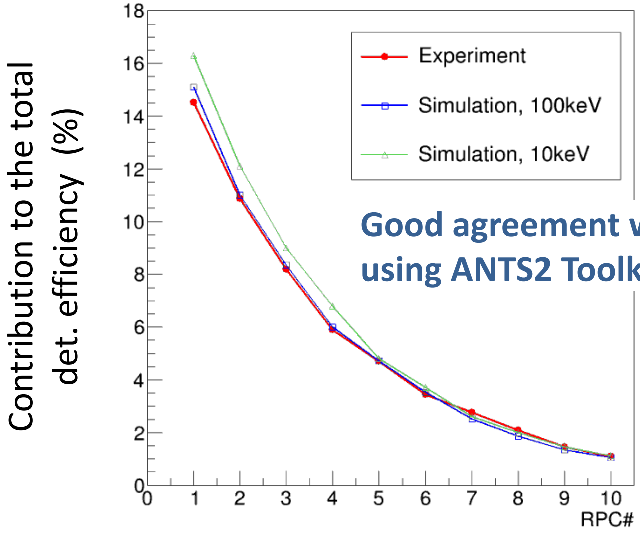
Progress in ^{10}B-RPC development within SINE 2020

- A prototype with 10 double-gap ^{10}B-RPCs (20 layers of $^{10}B_4C$) was build at LIP and tested at FRMII/ TREFF neutron beam line





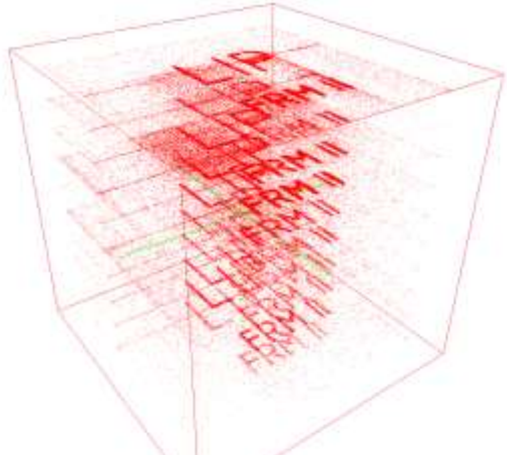
- Det. Efficiency (λ= 4.7 Å) > 50%



Good agreement with simulations using ANTS2 Toolkit

(all $^{10}B_4C$ layers with the same thickness : ≈ 1.15 μm)

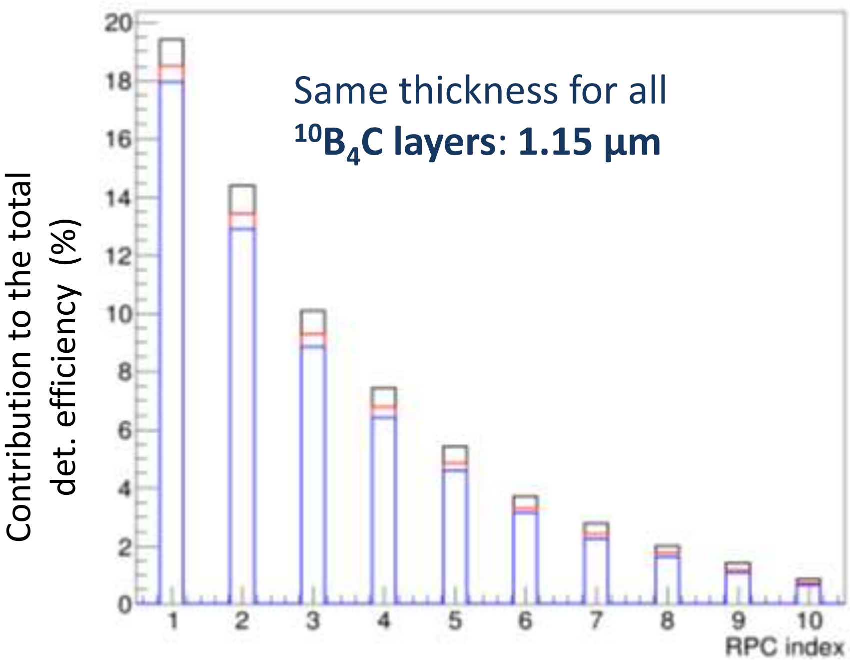
- Spatial resolution < 250 μm FWHM

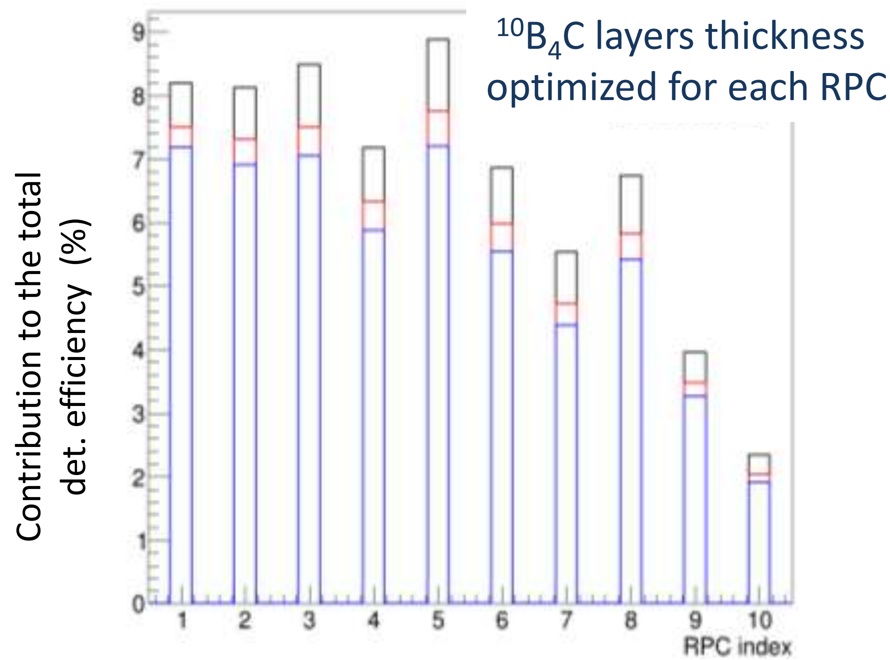


3D-positions of reconstructed neutron events

❑ Towards ^{10}B-RPC detector with high counting rate

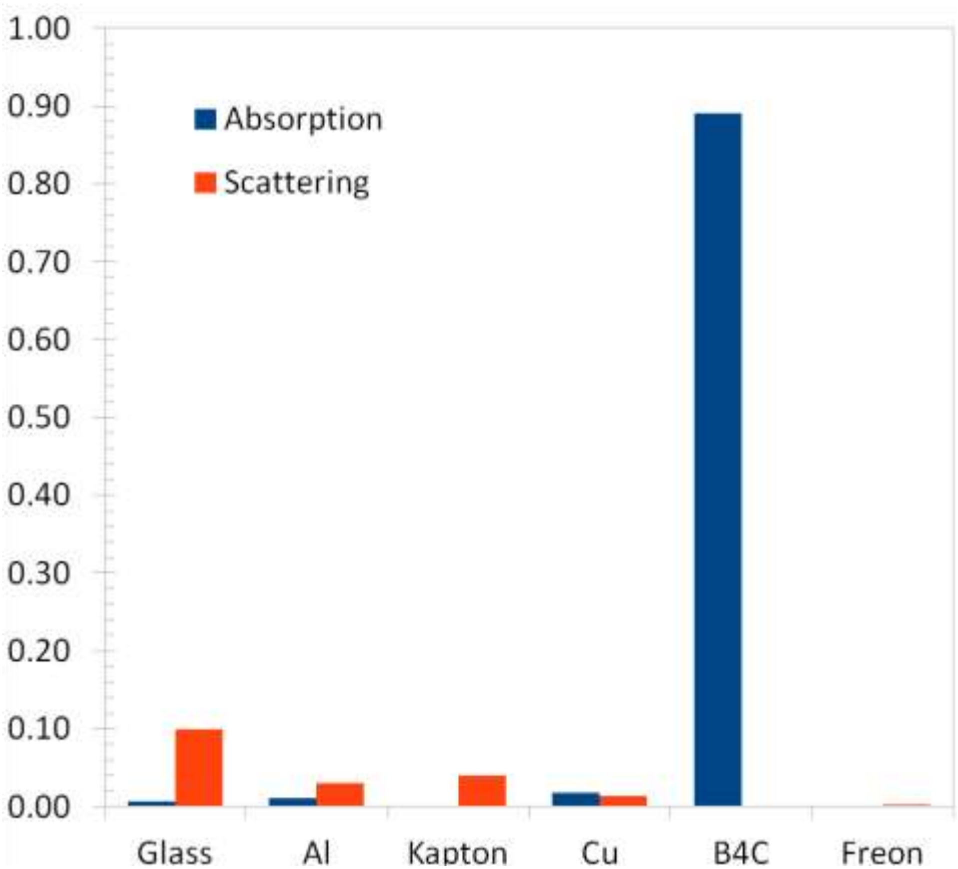
Optimization of individual thicknesses of converters layers
(semi-automatic optimization tool of ANTS2)





❑ Analysis of materials impact on detector performance

Neutron absorption and scattering in the Multilayer RPC detector materials (10 double gap ^{10}B-RPCs)



	Absorption	Scattering
Glass	0,007	0,10
Al	0,011	0,03
Kapton	0,00001	0,04
Cu	0,018	0,014
B4C	0,89	0,0003
Freon	0,00002	0,002
Sum	**0,93**	**0,19**
Obs.: Per incident neutron		

Future

- **Increase the counting rate capability**
  - Detector design optimization
  - Low resistivity materials for RPC electrodes
  - Front end electronics with higher sensitivity
  - Effect of the temperature
- **Reduce sensitivity to gamma rays**
  - Optimize geometry and materials
  - Pulse shape analysis for MIPs and HIPs
- **Improve spatial resolution and uniformity**
  - Statistical reconstruction

Thank you for your attention

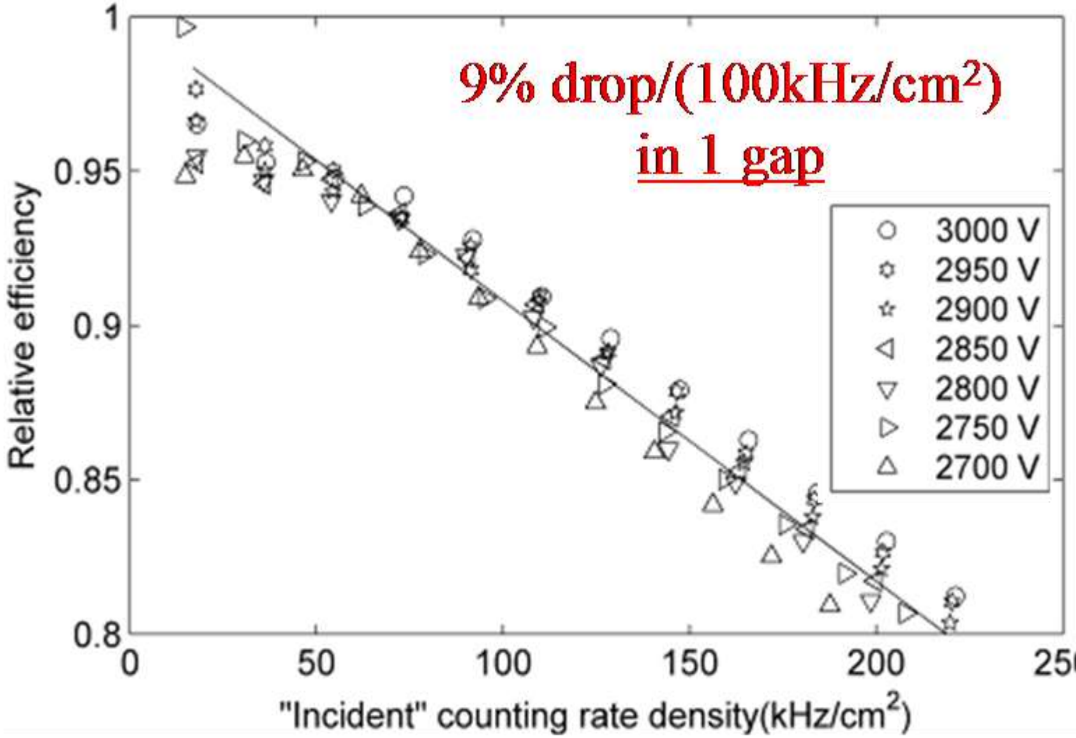
Counting rate improvement

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

Counting Rate

Ceramic RPC

Electrodes resistivity of ≈ $10^9\ \Omega\cdot cm$



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NUCLEAR PHYSICS B PROCEEDINGS SUPPLEMENTS

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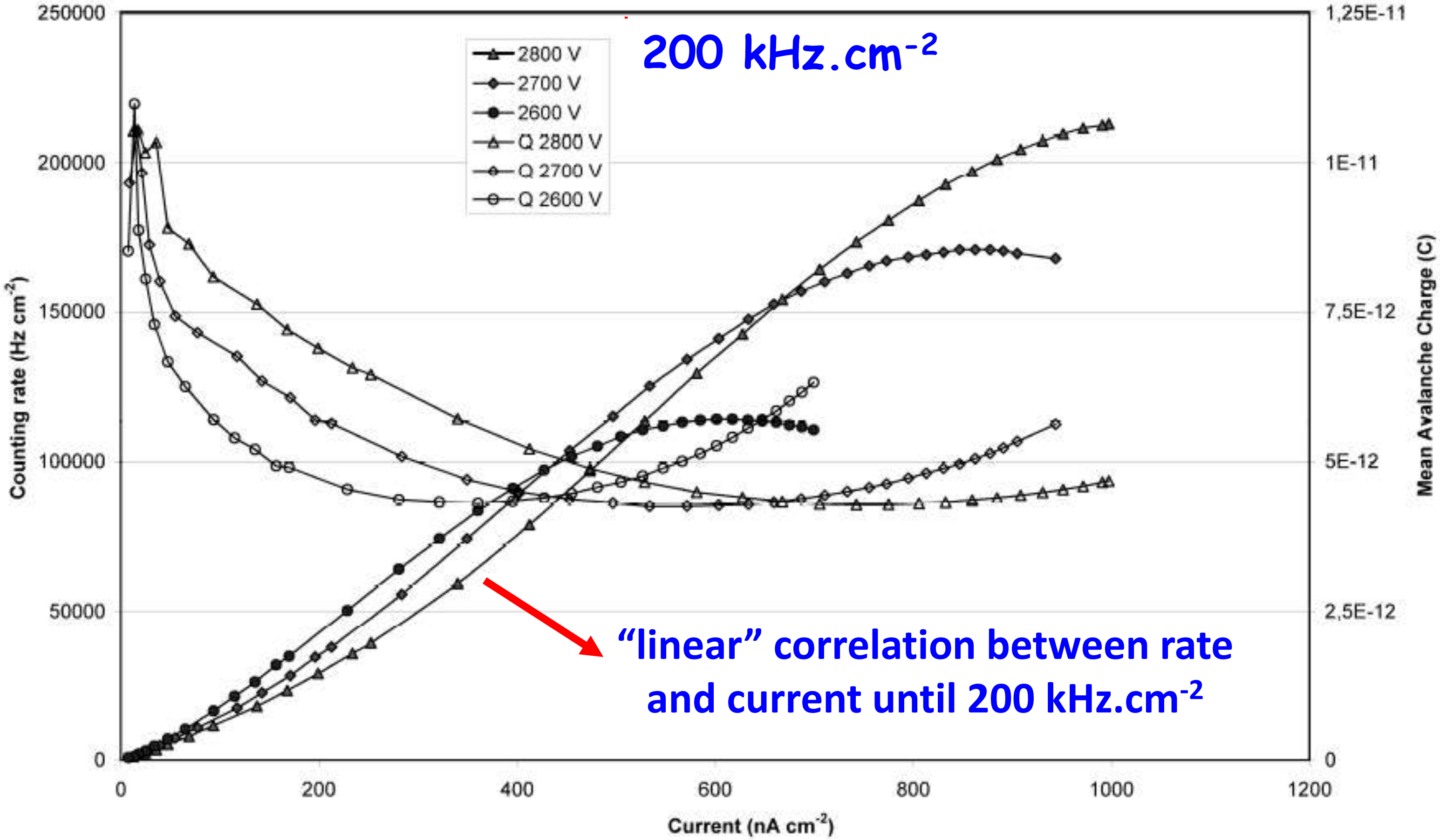
Ceramic high-rate timing RPCs

L. Lopes[a], R. Ferreira Marques[a,b], P. Fonte[a,c,*], L. Hennetier[d], A. Pereira[a], and A.M. Sousa Correia[d]

Counting Rate

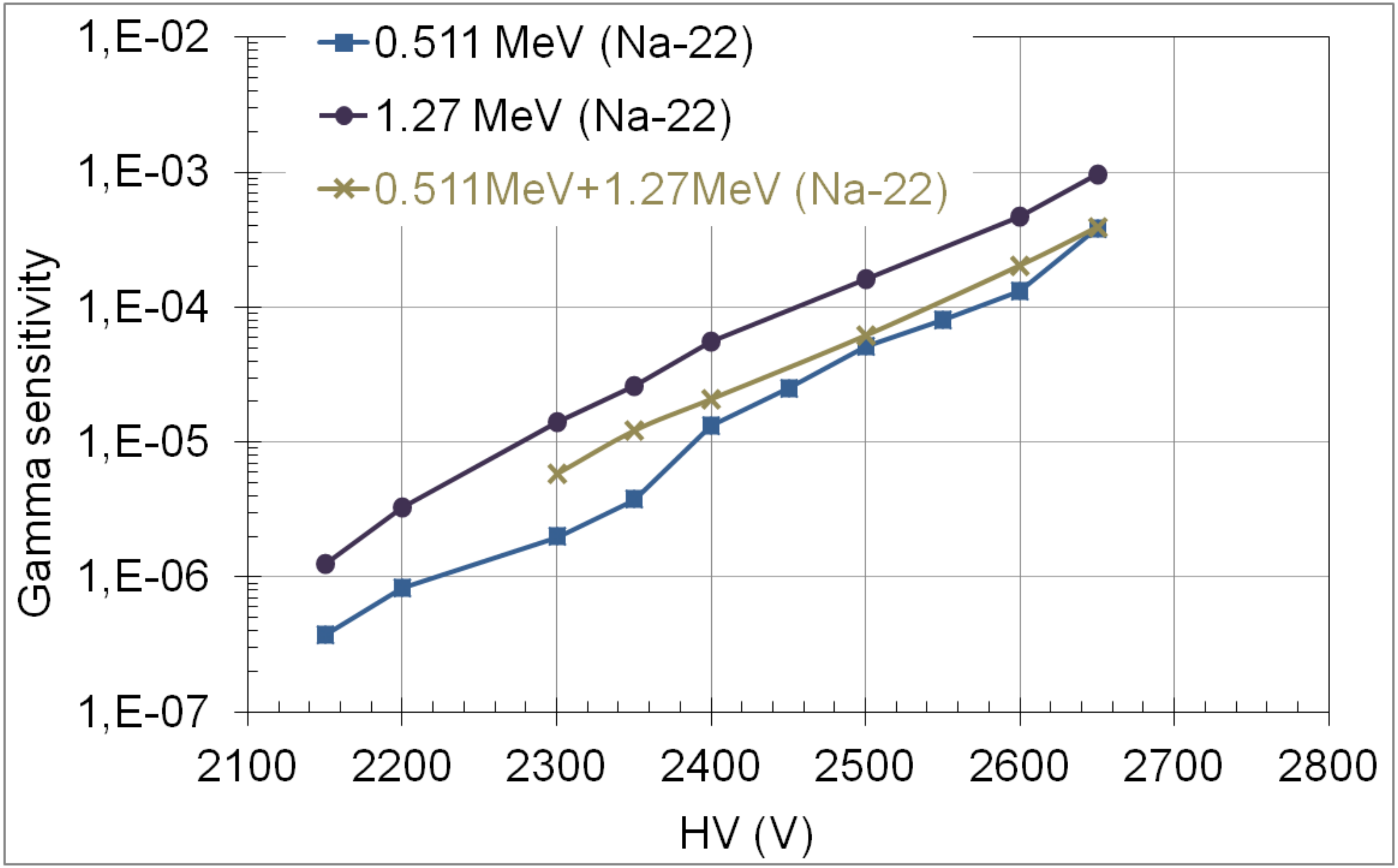
Other materials with lower bulk resistivity => higher counting rate capability RPCs
Work in progress @ LIP-Coimbra in the framework of a AIDA2020 project

New technology ESD material, Krefine



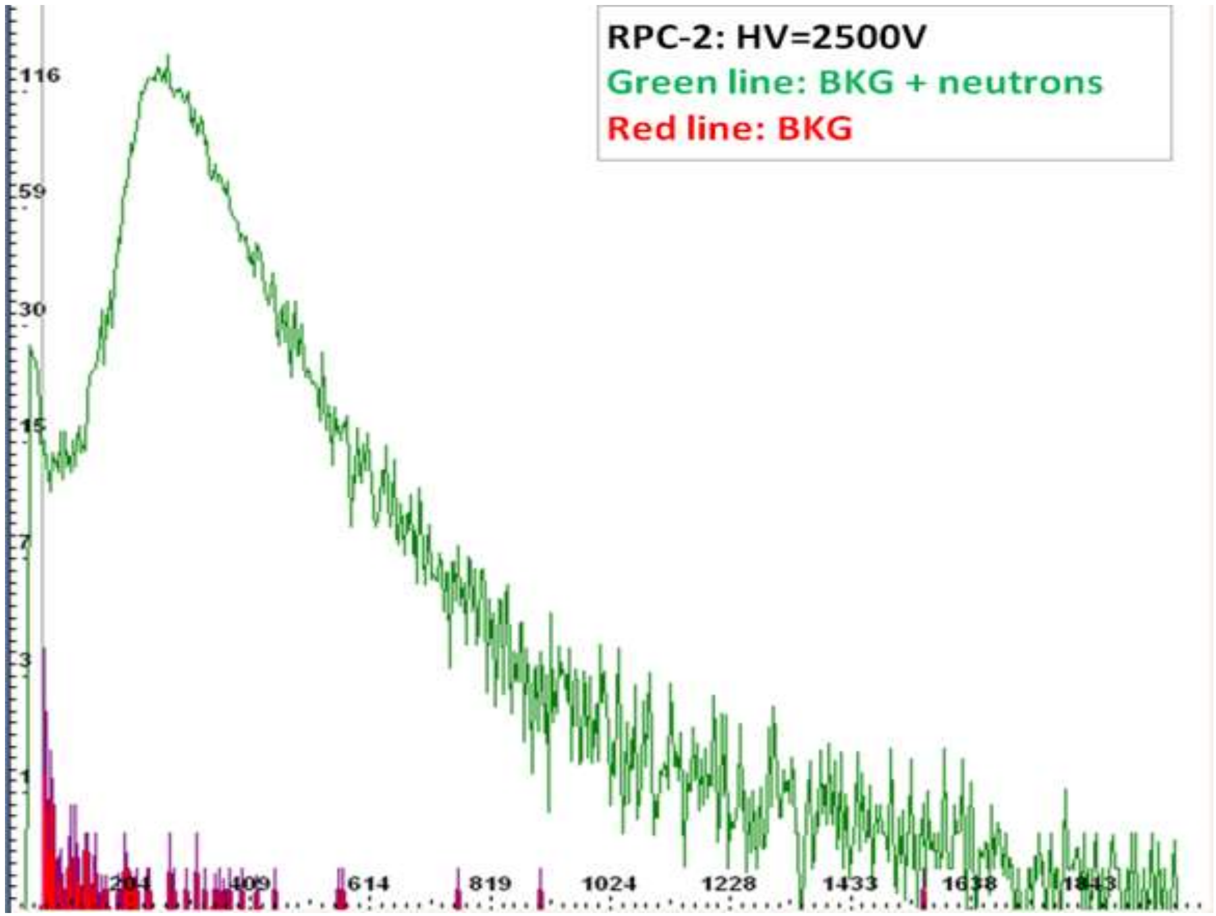
Double-gap ^{10}B-RPC: sensitivity to gamma rays

Experimental results



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

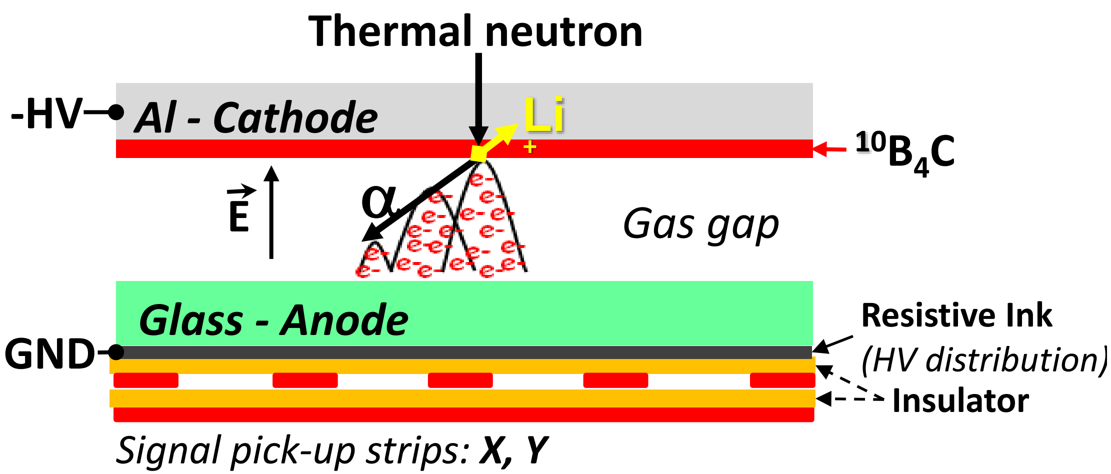
PHS of the cathode signals (log scale)



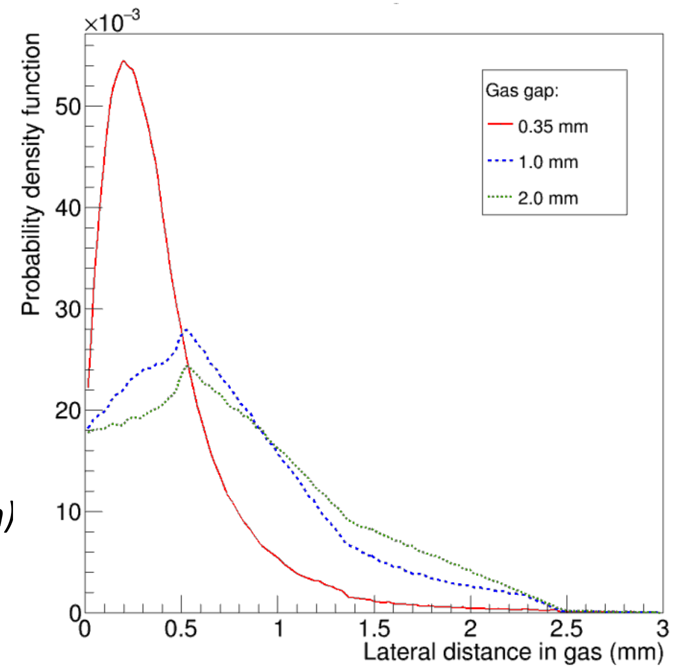
Spatial resolution considerations

The good spatial resolution can be explained by:

- Anti-Parallax effect
- The possibility to build RPCs with very thin gas-gaps (down to 0.1 mm)



Distributions of the ^4He and ^7Li particle ranges in the gas-gap, projected in the lateral direction (parallel to the RPC plates)



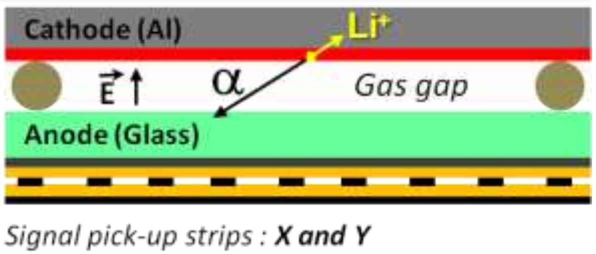
- **$^{10}B_4C$ thickness**: 2 μm
- **Neutron wavelength**: 1.8 Å
- **Gas-gap widths**: 0.35, 1.0 and 2 mm
- **Gas**: $C_2H_2F_4$ (20ºC and 1 atm)

^{10}B-RPCs: Hybrid Design

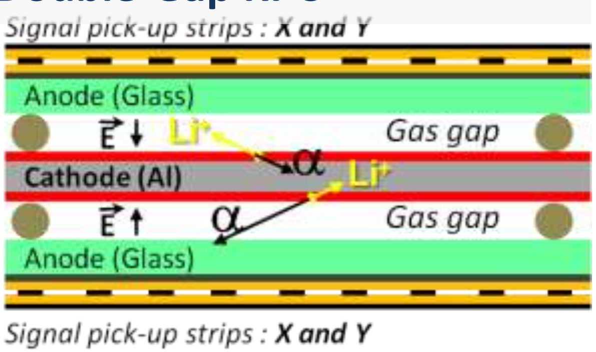
❑ Metallic cathodes

- 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.

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.