Towards high counting rate RPC-based neutron detectors: current state and perspectives

Luís Margato
A. Morozov, A. Blanco, L. Lopes, P. Fonte
LIP - Coimbra, Dep. Física, Universidade de Coimbra (PT)
ISEC - Instituto Superior de Engenharia de Coimbra (PT)

L. Chung-Chuan Lai, L. Robinson
Per-Olof Svensson
R. Hall-Wilton
ESS - European Spallation Source ERIC (SE)

L. Naumann, K. Roemer, D. Stach
Helmholtz-Zentrum Dresden-Rossendorf (DE)

K. Zeitelhack
Heinz Maier-Leibnitz Zentrum (MLZ), FRM-II, (DE)

T. Wilpert
Helmholtz-Zentrum Berlin für Materialien und Energie (DE)

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

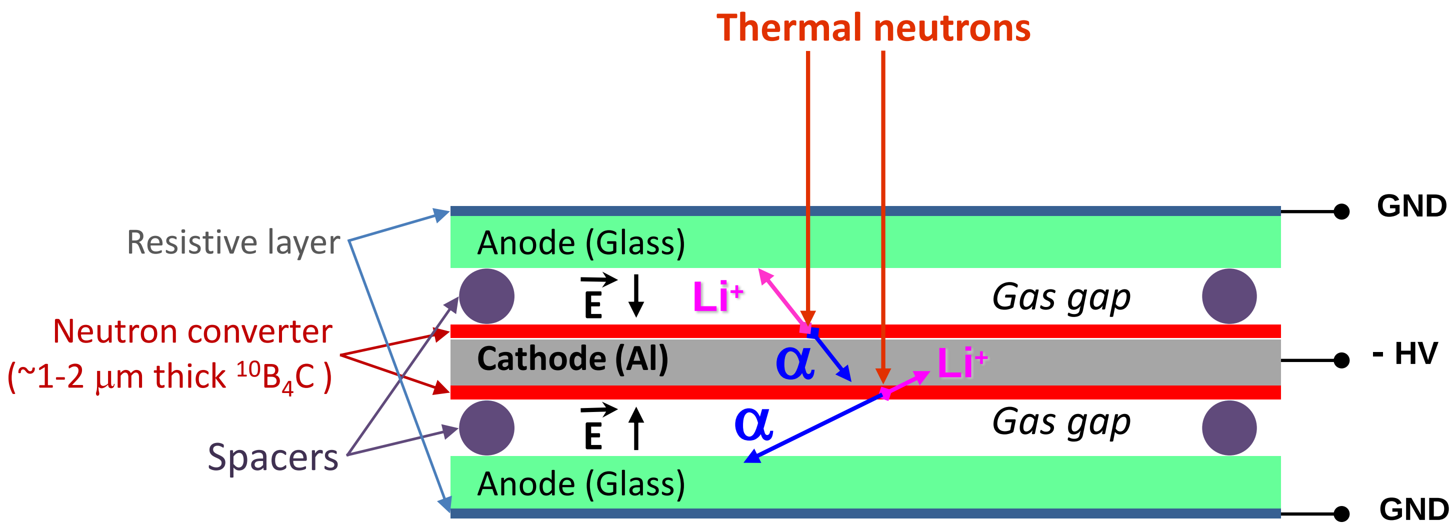
Outline

- RPC-based neutron imaging detectors
- Counting rate measurements at a neutron beam
- Gamma sensitivity study
- Conclusions

Motivation

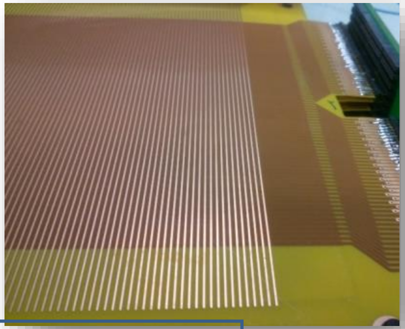
- RPCs can offer:
  - Very high spatial and time resolution in comparison with competitive technologies.
  - Practical advantages, such as, e.g.: high modularity of the design, robustness, good scalability and low cost per unit area.
- The high-brightness expected for the European Spallation Source (ESS) is pushing for the development of high precision neutron detectors with high counting rate capability.
- To full demonstrate the advantages of the RPCs for NSS applications we have to reach at least:
  - Gamma sensitivity $< 10^{-5}$ (@ 1 MeV)
  - Counting rate > 100 kHz/cm^2

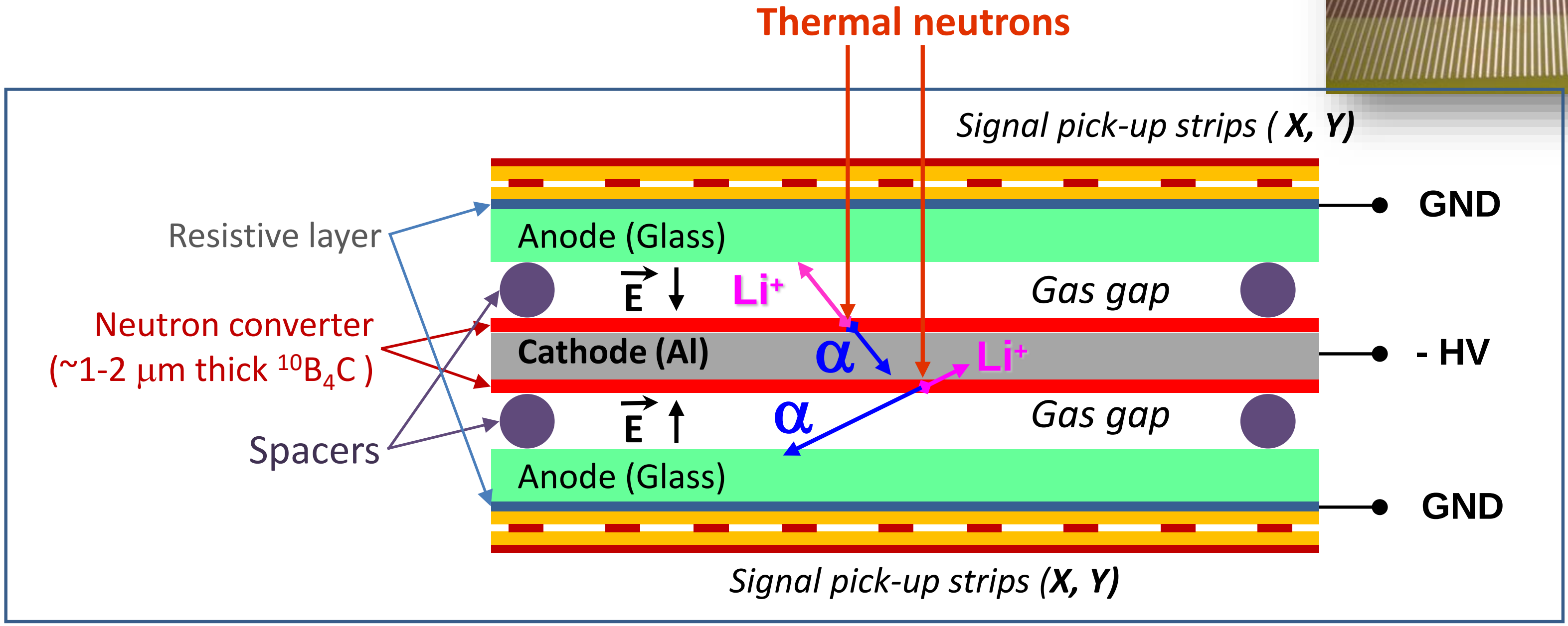
RPC-based neutron imaging detectors



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

RPC-based neutron imaging detectors



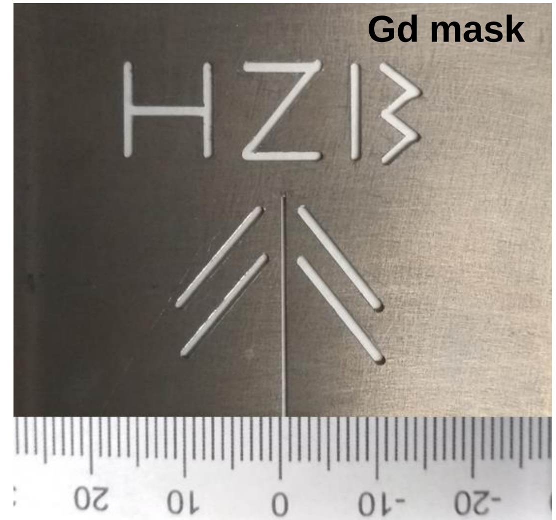


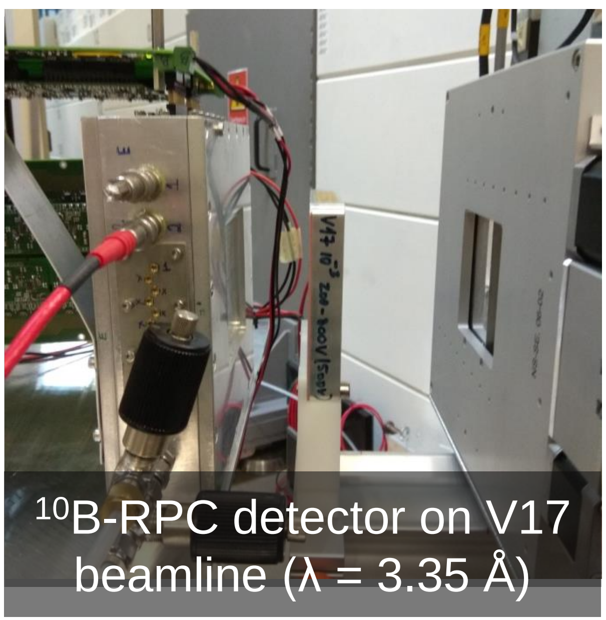
Double gap hybrid RPC → Basic detector module

Imaging neutrons with RPC detector at a beamline at HZB-Berlin

Gd mask: 0.25 mm thick
Letters and oblique slits: 1mm width

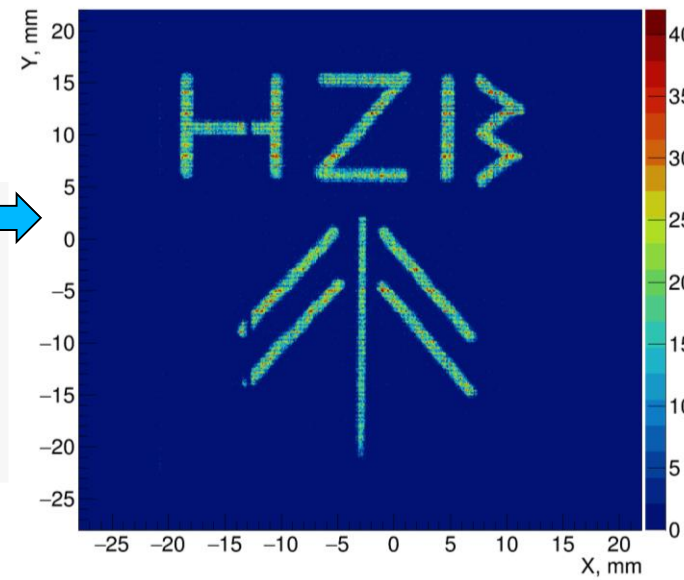
Vertical slit: 0,4 mm width





2D Image
Gd mask installed directly in front of the detector

Position reconstruction: COG algorithm

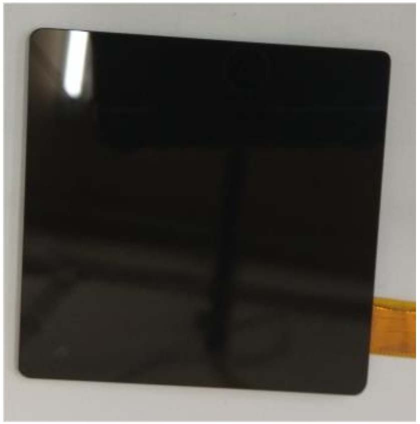


Neutron beam tests of RPCs with anodes made of different electrical resistivity materials

Float glass
0.28 and **0.35 mm** thick
$\rho \approx 10^{13}\ \Omega$ cm at 24 °C

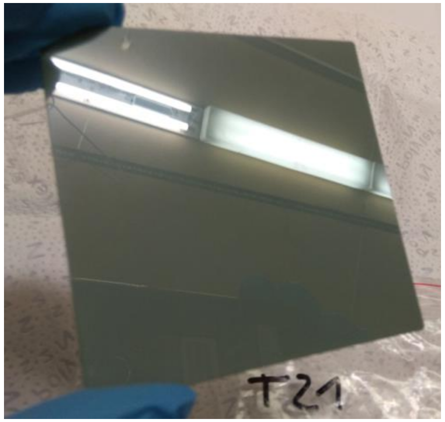
Commercial glass

Low resistivity glass
1 mm thick
$\rho \approx 4 \times 10^{10}\ \Omega$ cm at 24 °C



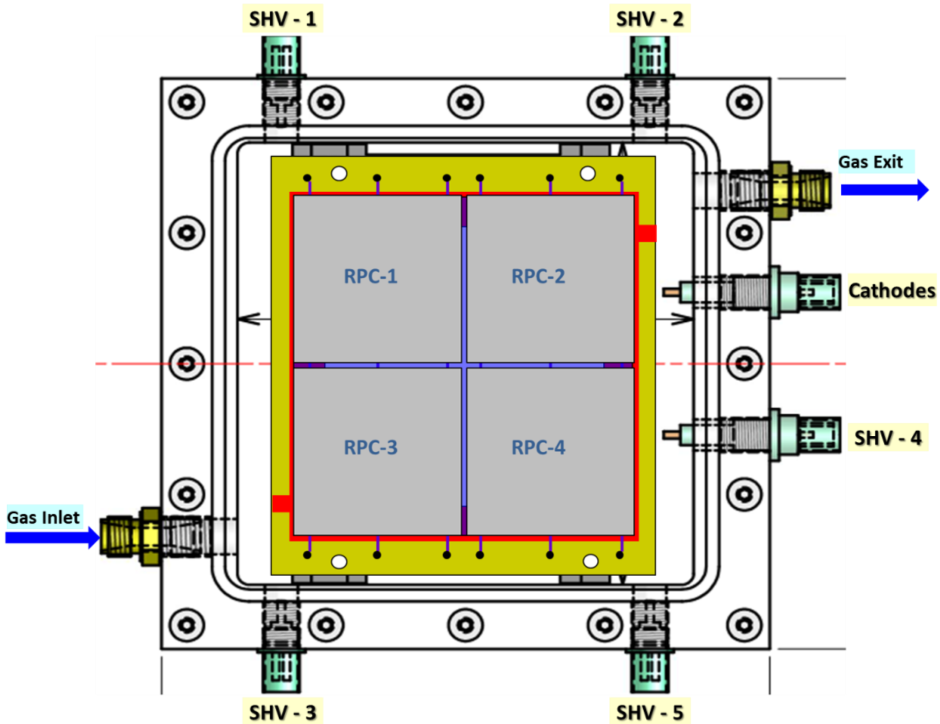
Yi Wang, Tsinghua University, Beijing

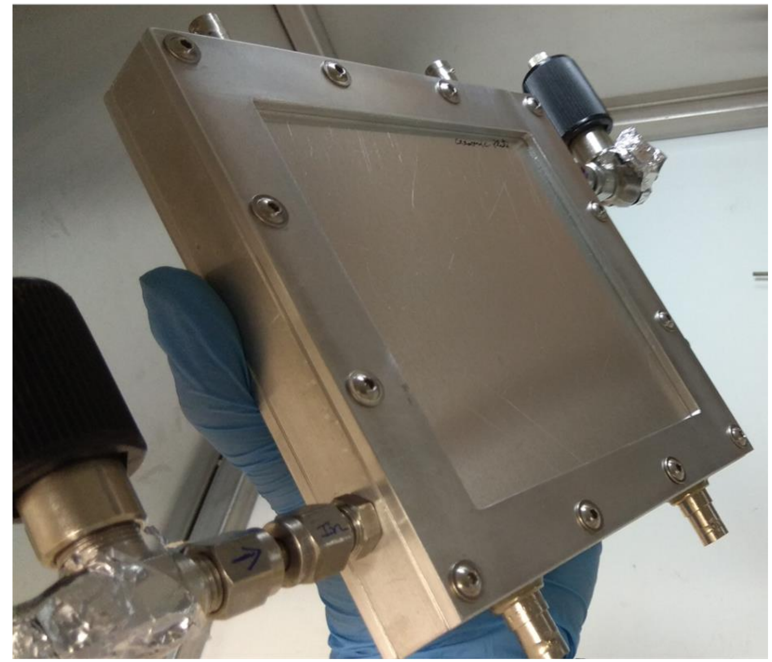
Ceramic composite
2 mm thick,
$\rho \approx 2 \times 10^{10}\ \Omega$ cm at 24 °C

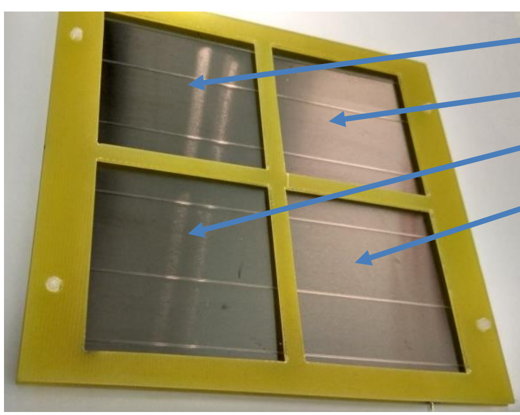


L. Naumann, HZDR, Dresden-Rossendorf

Detector details







RP1 and **RPC2**: Low resistivity glass

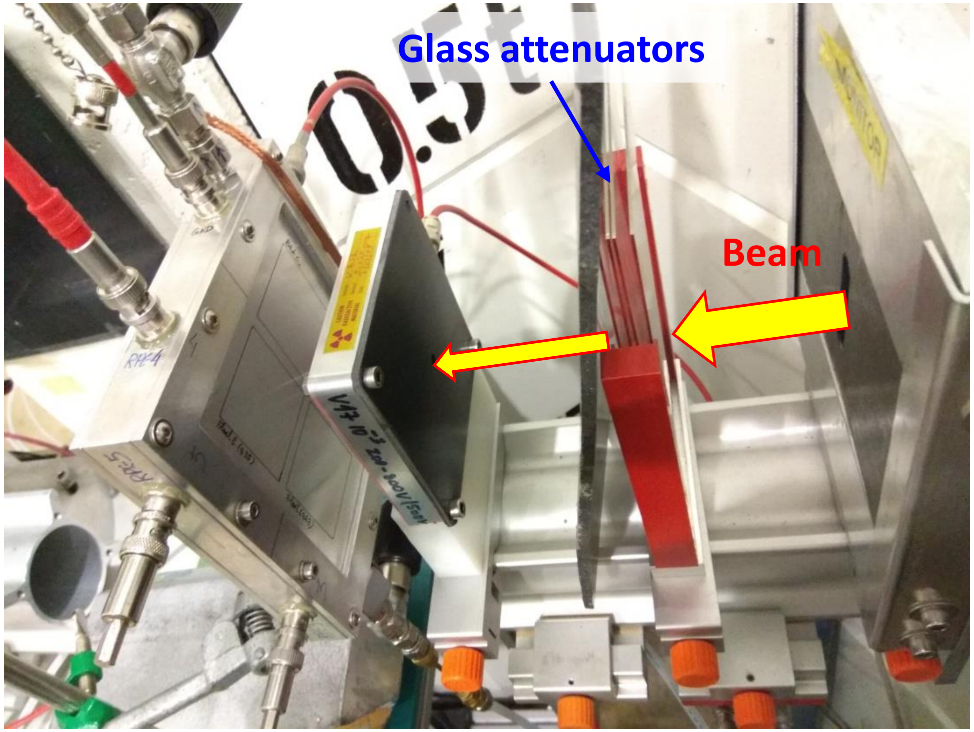
RP3 and **RPC4**: Float glass

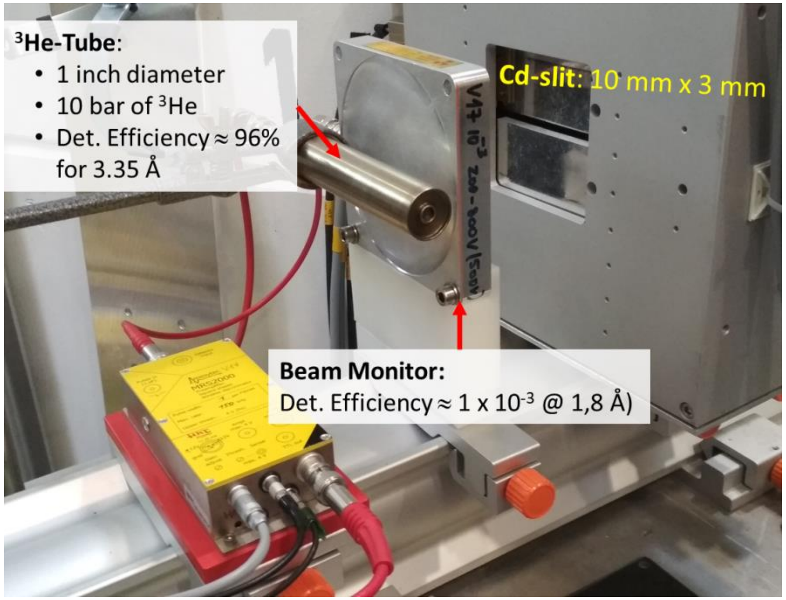
Gas gap: 0,35 mm

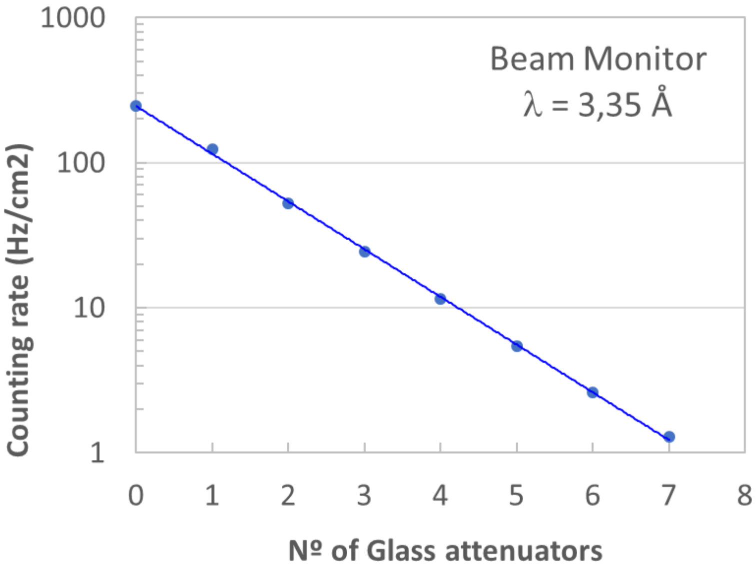
Cathode (100 mm x 100 mm): **Al Plate** (0.5 mm thick) with a **1.15 μm thick layer of $^{10}B_4C$**

RPC5 (ceramics on the back side)

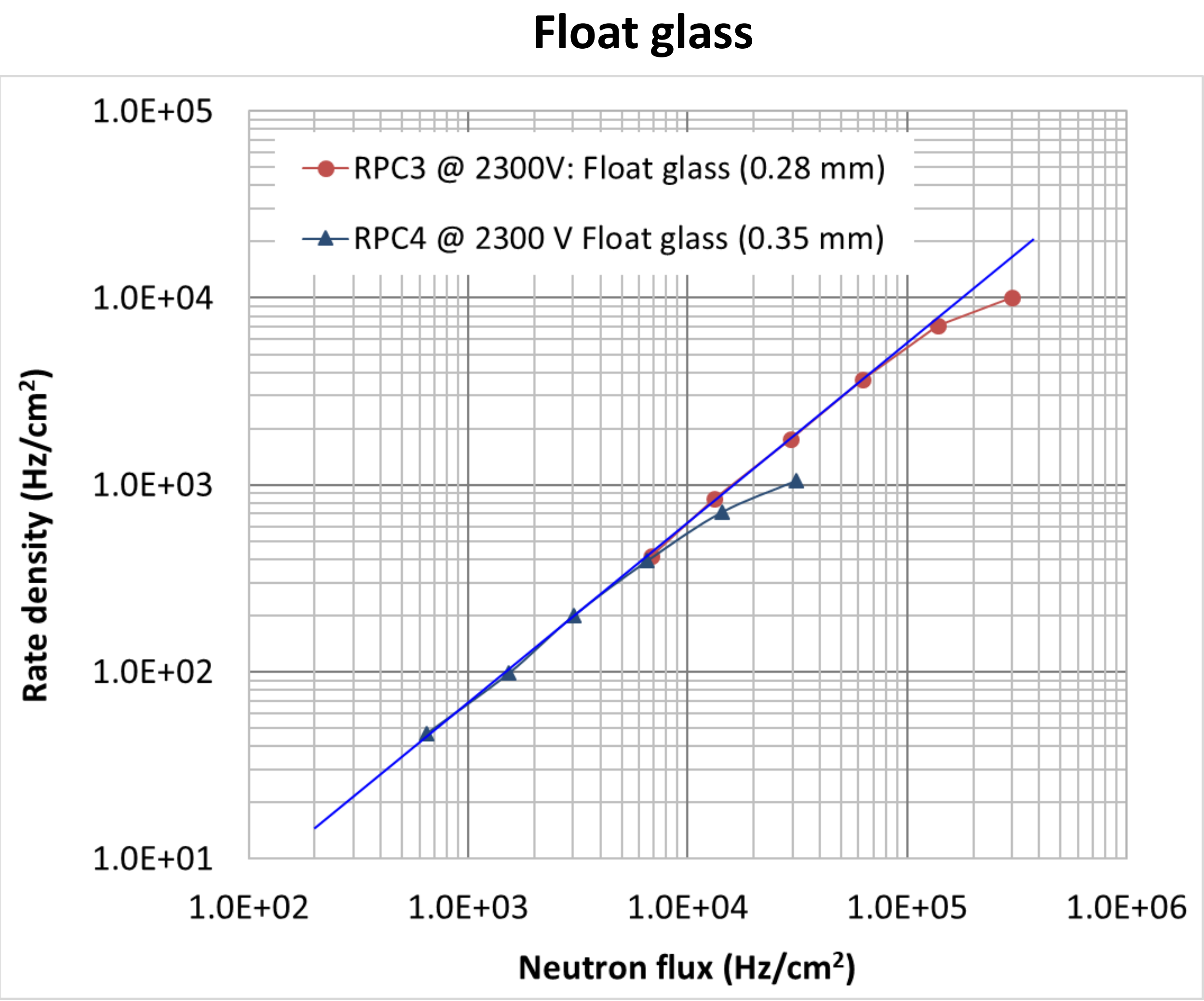
Detector at V17 neutron beamline (λ = 3.35 Å) at HZB-Berlin





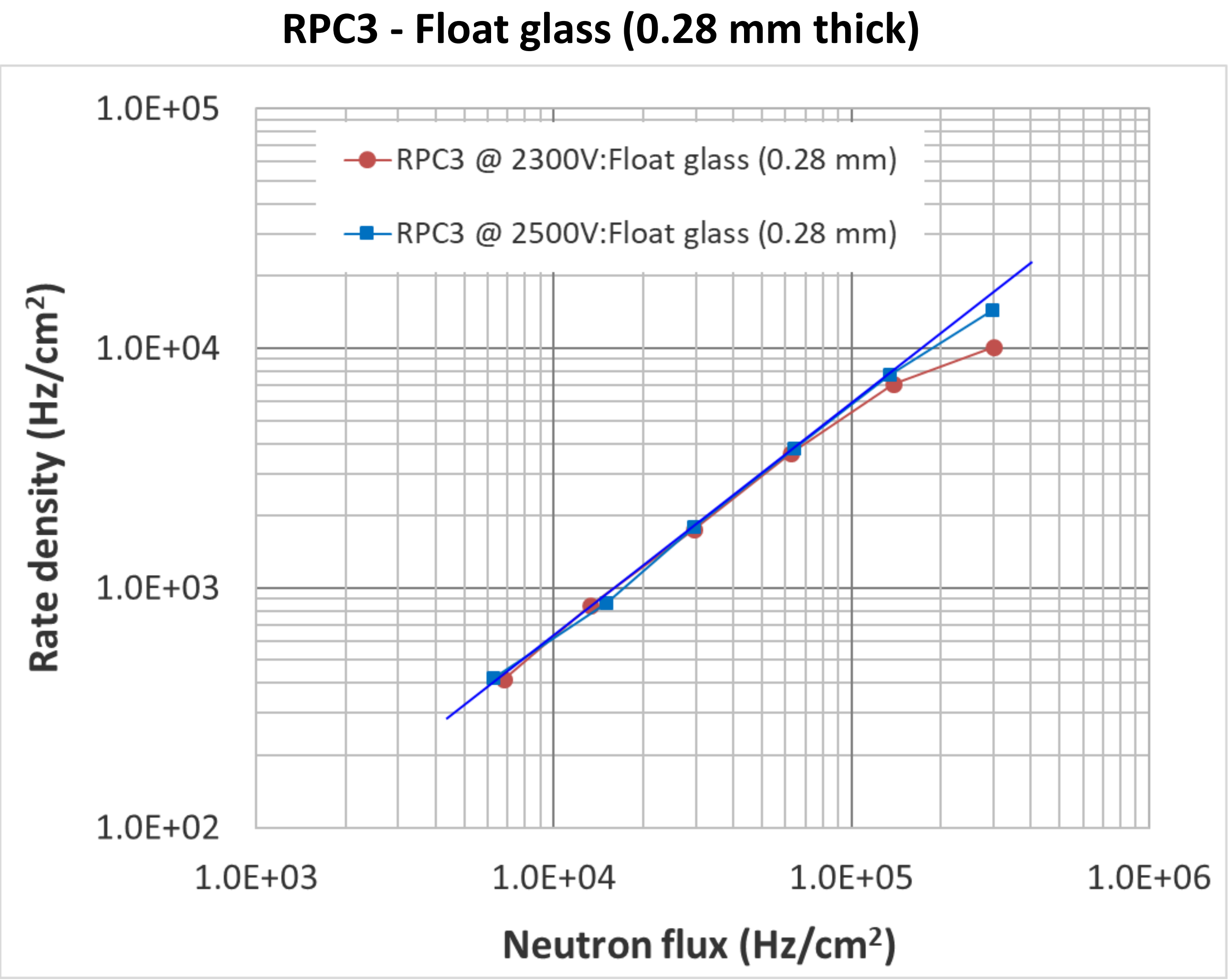


Beam test results: rate vs neutron flux



Det. Efficiency: experimental value ≈ 5.9%; Geant4 value≈ 6.1%

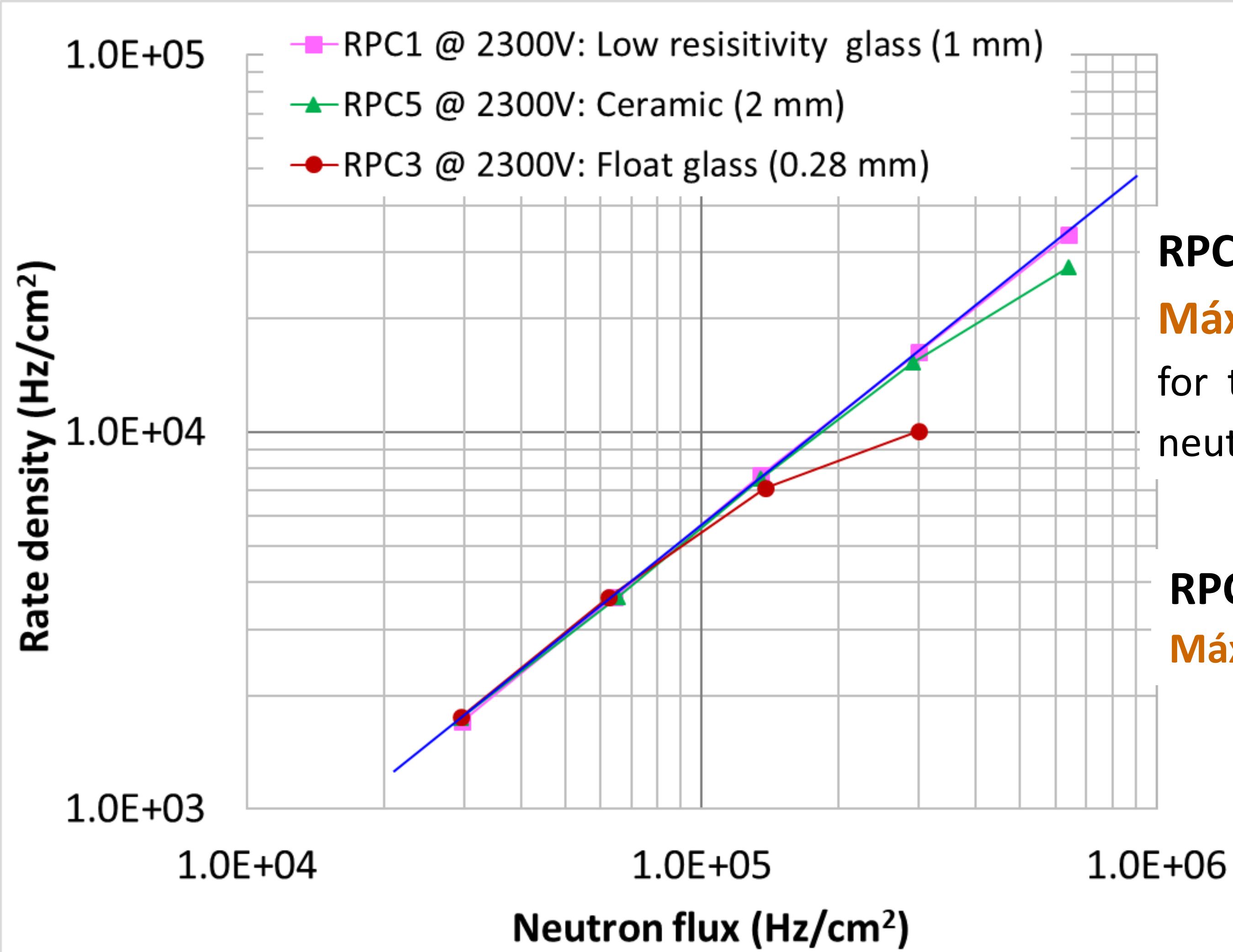
Beam test results: rate vs neutron flux



Increasing HV from 2300 V to 2500 V, maximum rate increases by a factor of ~ 2

Beam test results: rate vs neutron flux

RPC1: resistivity glass and RPC5: Ceramics)

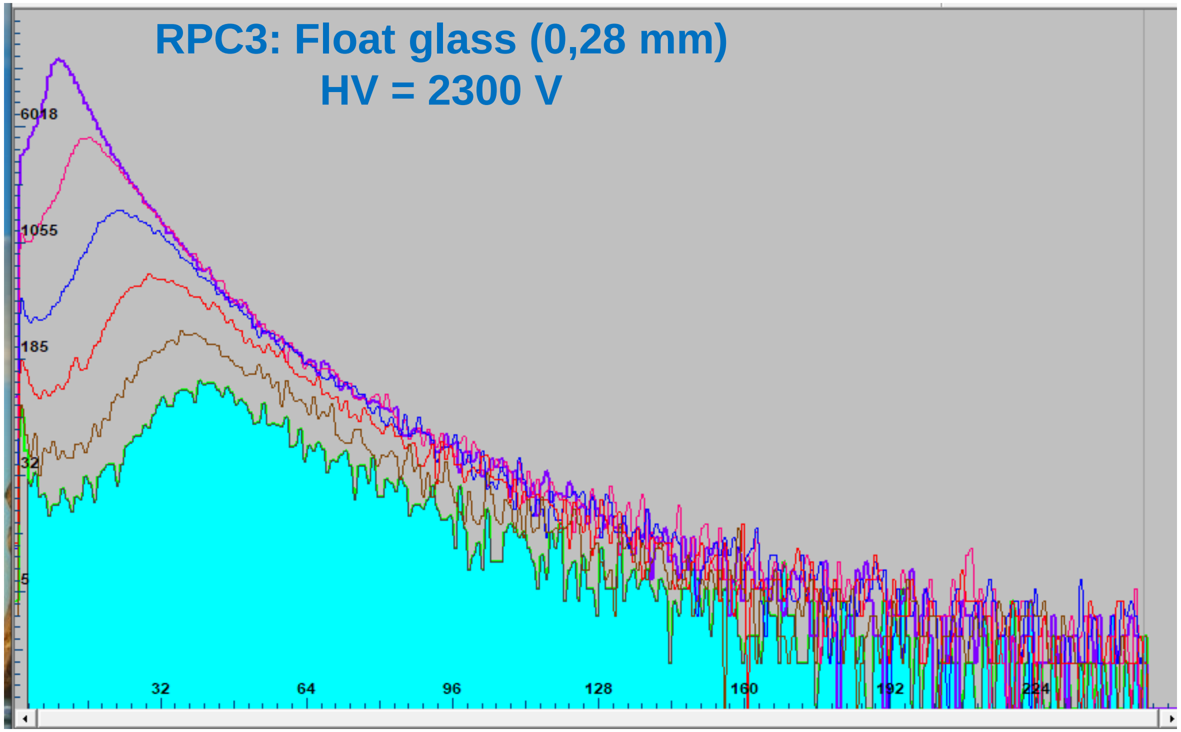


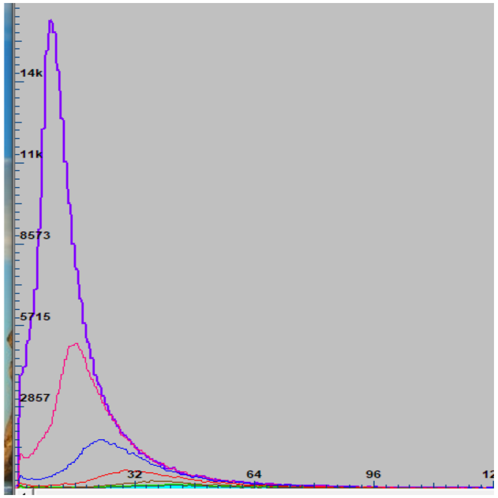
RPC1 (low resistivity glass):
Máx. Rate > 30 kHz/cm^2
for the maximum available neutron flux

RPC5 (ceramics):
Máx. rate > 15 kHz/cm^2

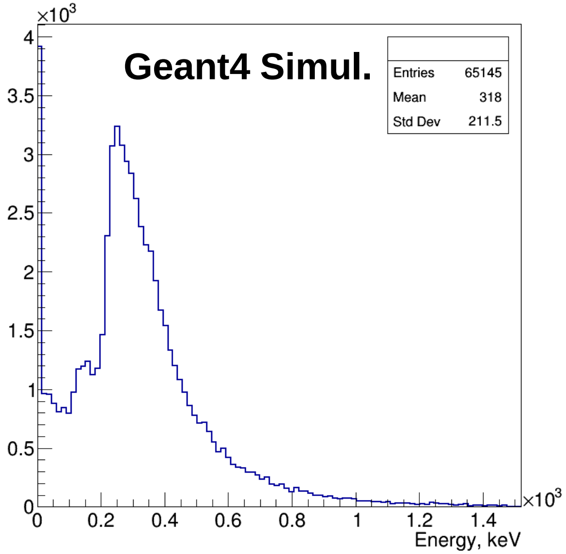
Beam test results

PHS recorded at several neutron fluxes





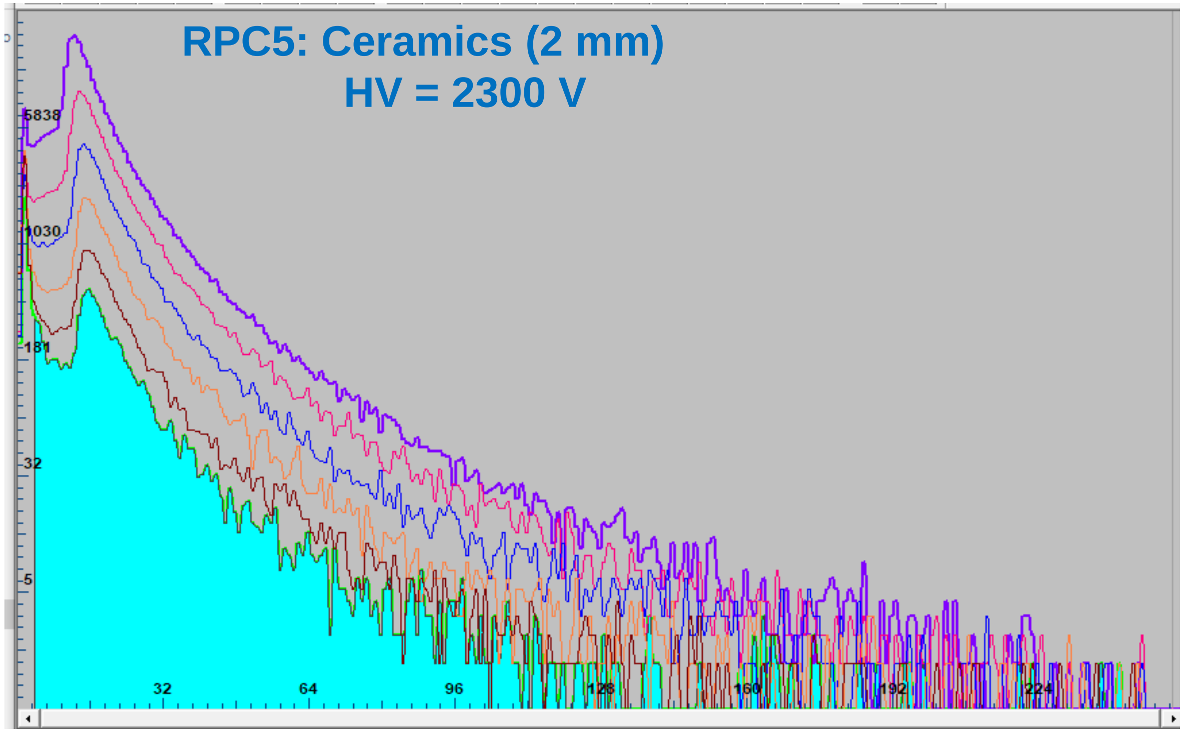
Deposited energy

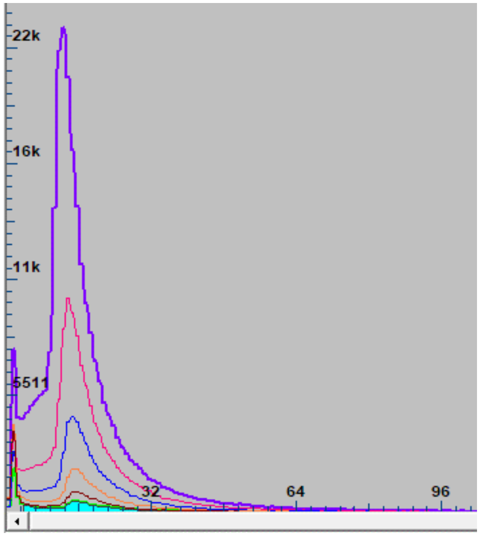


PHS with higher amplitude peaks correspond to higher neutron flux

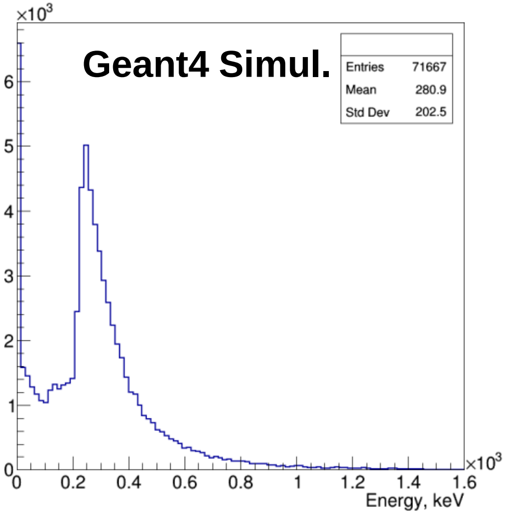
Beam test results

PHS recorded at several neutron fluxes





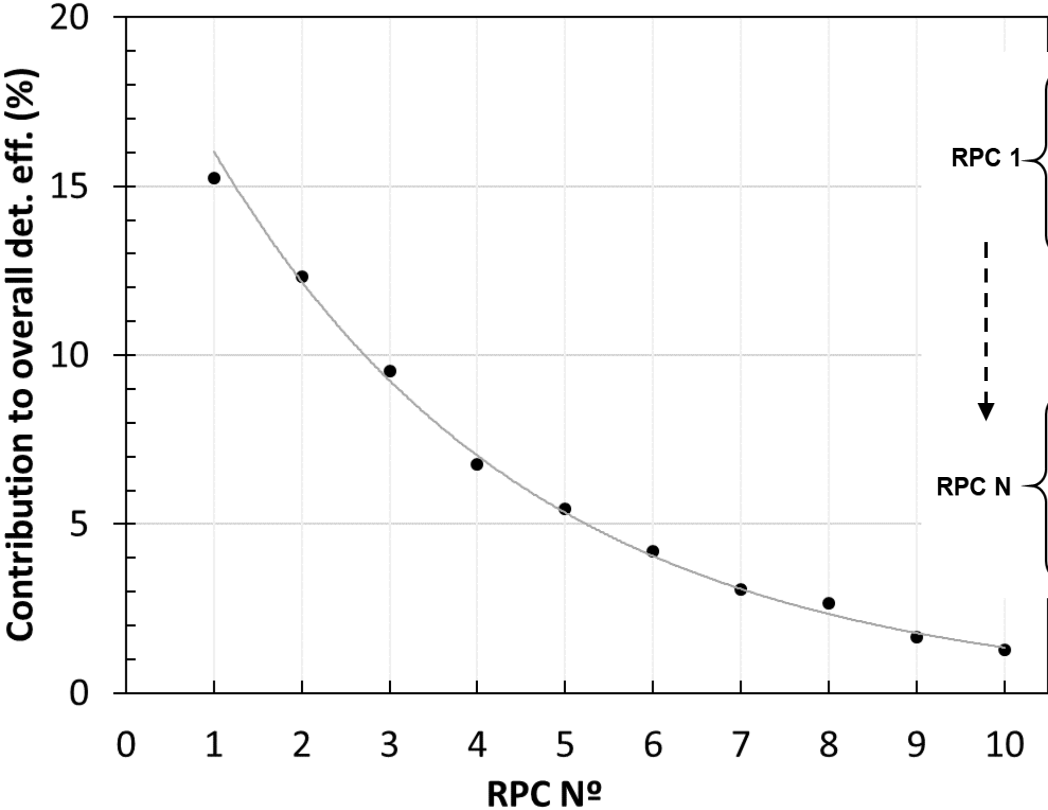
Deposited energy

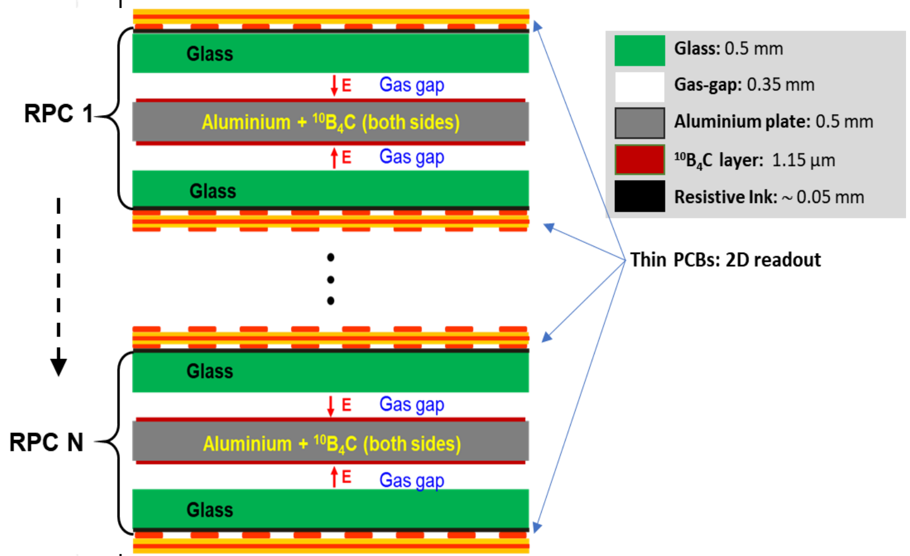


PHS with higher amplitude peaks correspond to higher neutron flux

Prospects to reach 100 kHz/cm²

Multilayer detector: detection efficiency > 50%✓





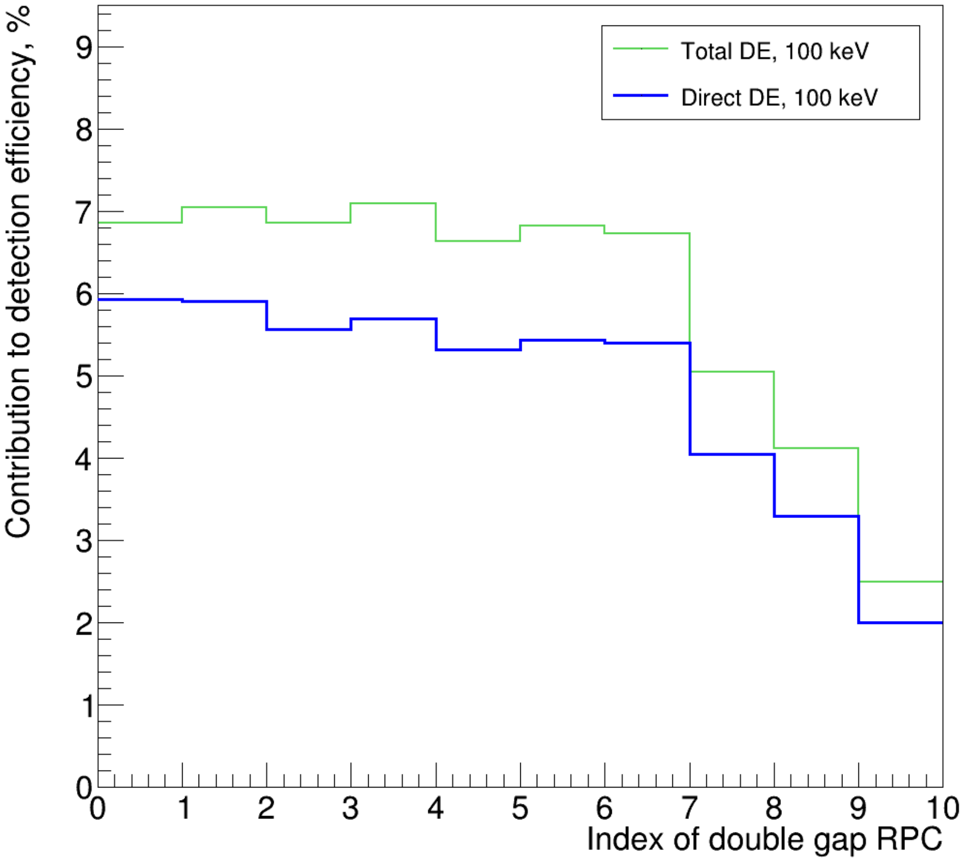
Overall detection efficiency of **62.1%** (λ = 4.73 Å)

[L.M.S. Margato et al., arXiv:2002.00991 [physics.ins-det]]

Prospects to reach 100 kHz/cm^2

Multi-parameter optimization in ANTS2

[Morozov et al., arXiv:2002.02284 [physics.ins-det]]



- **Stack with 10 Double gap RPCs**
- Pencil beam (λ = 4.7 Å, 3.656 meV)
- N = 10^6 neutrons

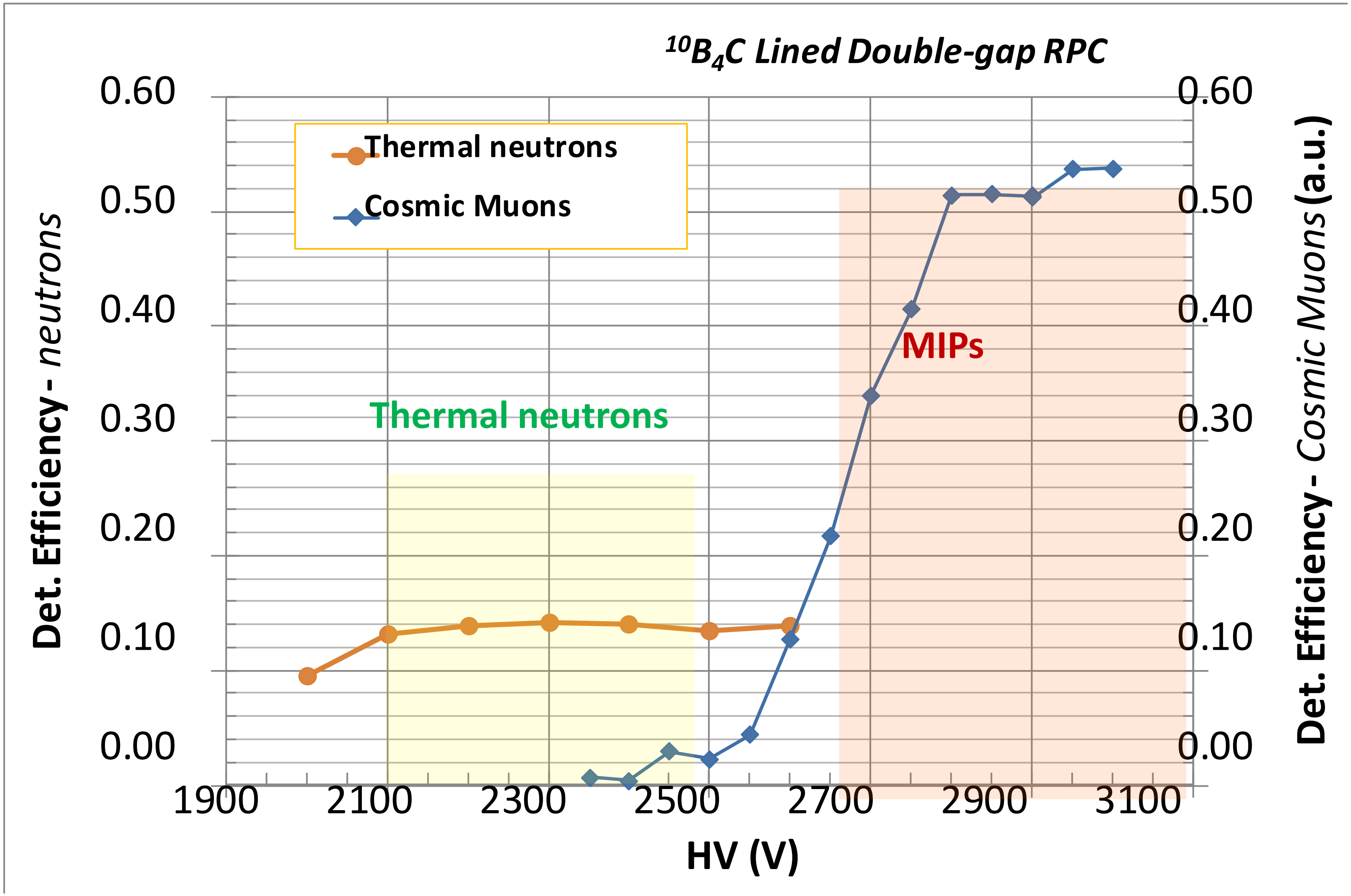
Each RPC should contribute equally (ideally) to the total detection efficiency

An increases of the counting rate capability of a **factor of > 16,** relatively to one single-gap RPC, is expected

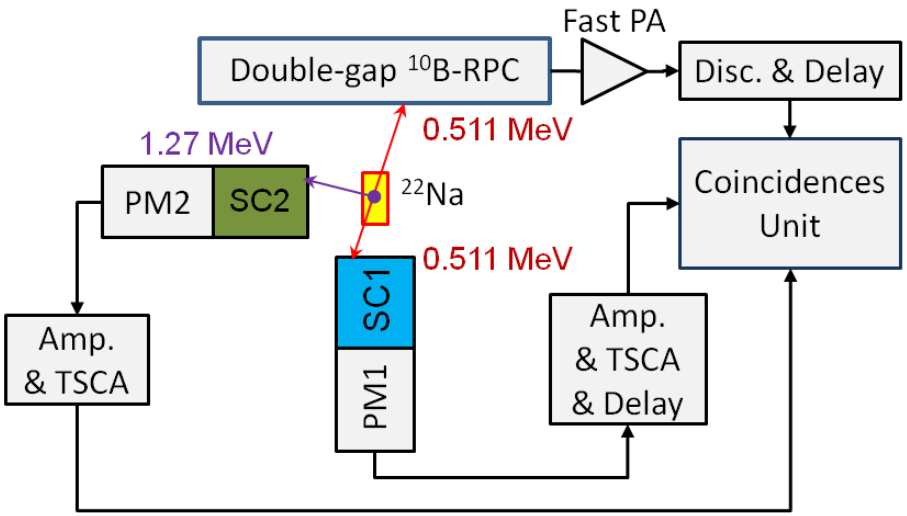
Layer thicknesses:
0.34 (t1,t2); 0.39 (t3,t4); 0.44 (t5,t6); 0.54 (t7,t8); 0.60 (t9,t10); 0.83 (t11,t12); 1.19 (t13,t14); 1.25 (t15,t16); 2.07 (t17,t18) and 3.33µm (t19,t20).

Gamma sensitivity

^{10}B-RPC Plateau: thermal neutrons vs cosmic rays



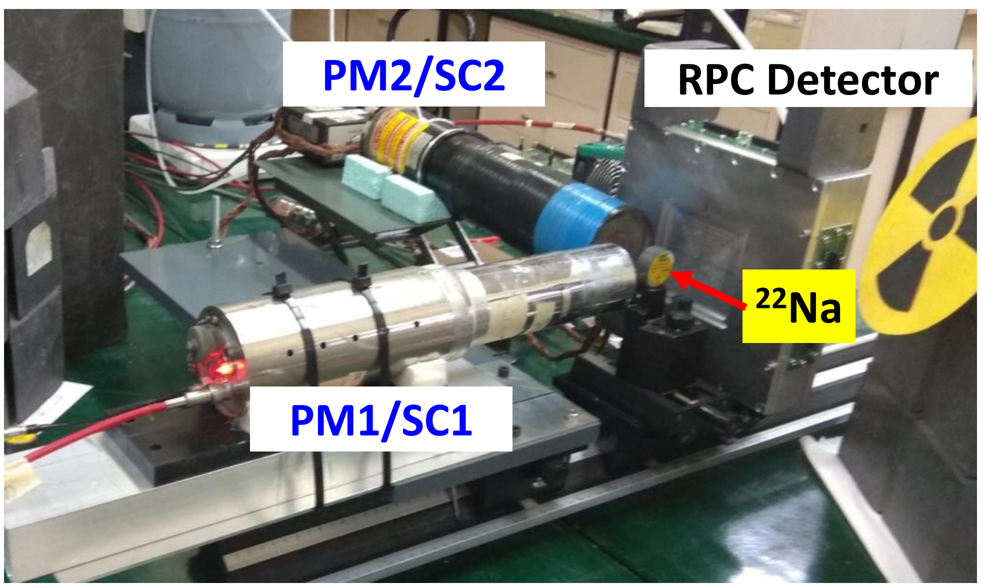
Setup1: gamma sensitivity for 0.511 MeV photons

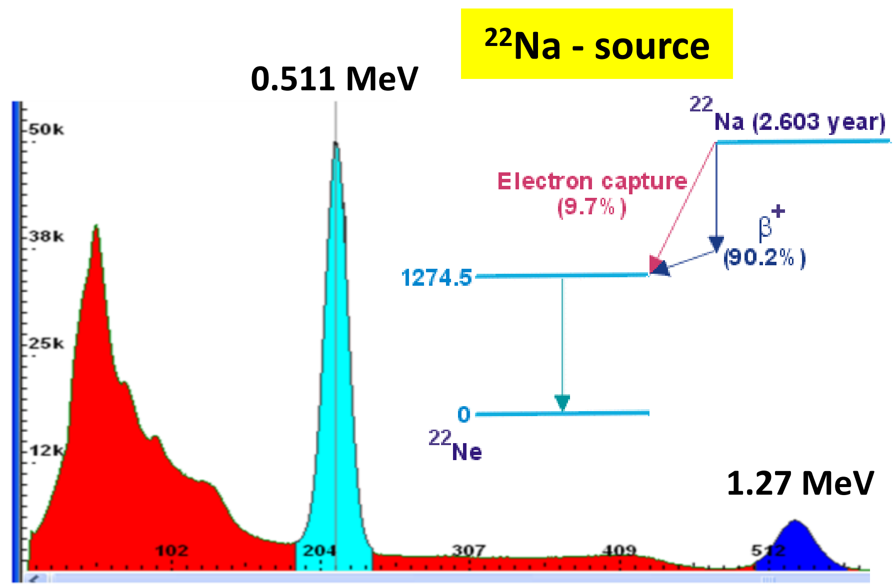


Det. Efficiency = N1/N2

N1=PM1 & PM2 & RPC

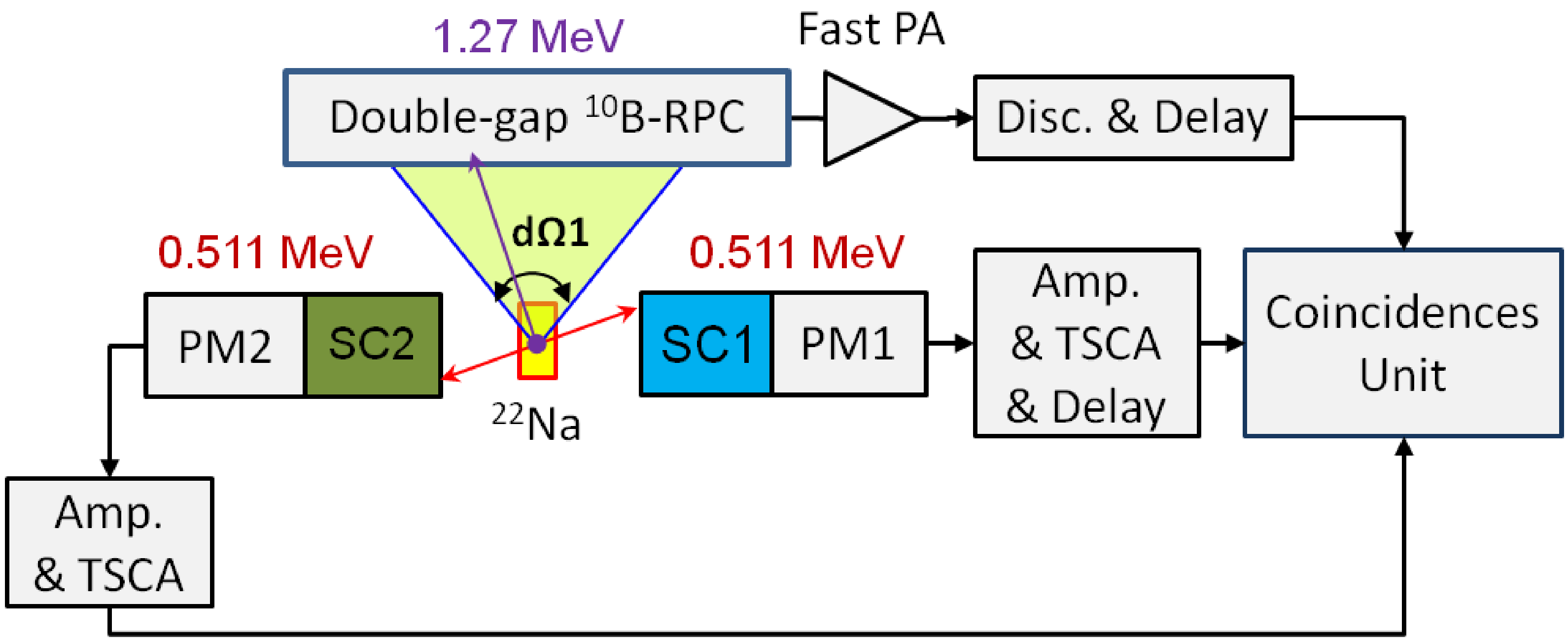
N2=PM1 & PM2





Energy windows are set by the TSCAs

Setup2: gamma sensitivity for 1,27 MeV photons



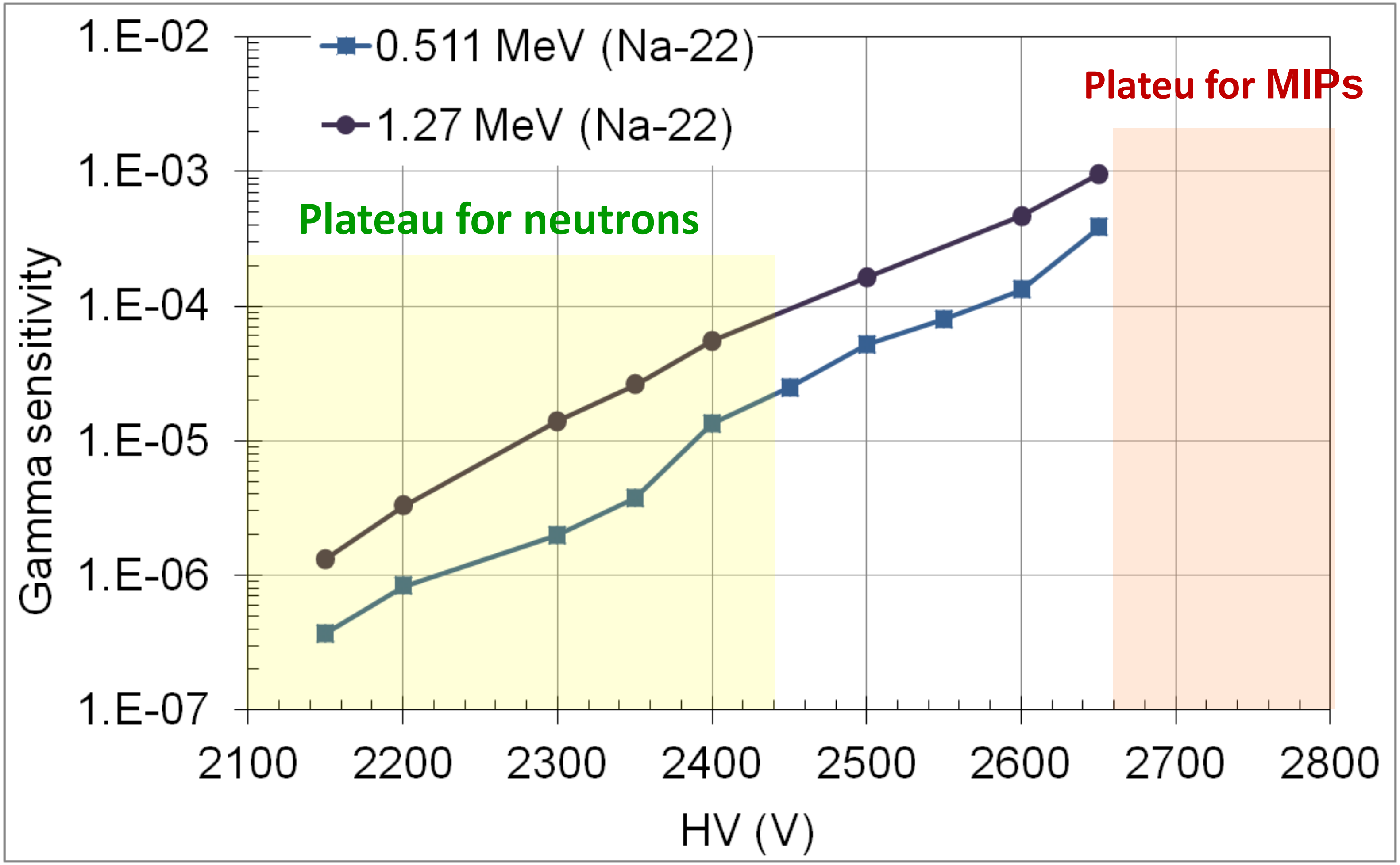
Det. Efficiency = N1/(N2 x dΩ1)

N1=PM1 & PM2 & RPC

N2=PM1 & PM2

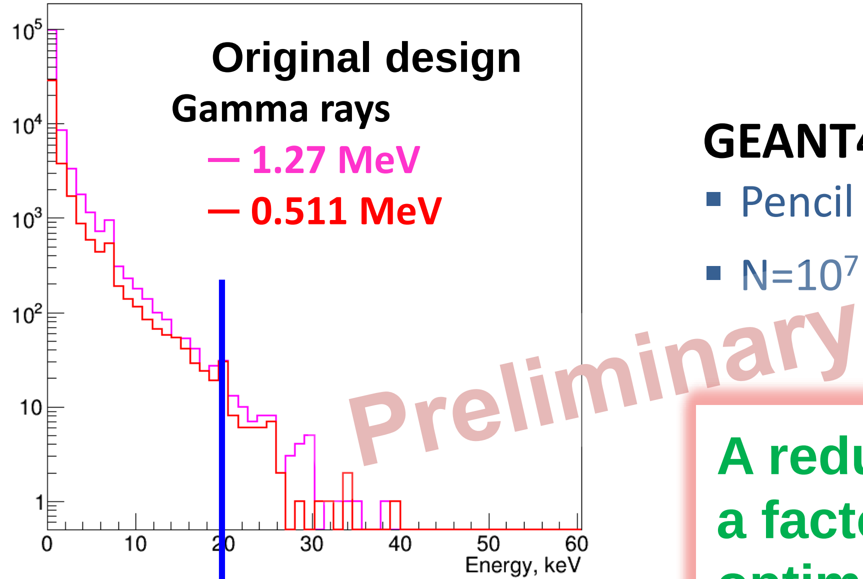
Solid angle computed with ANTS2 assuming (^{22}Na disk source): $\Omega 1/4\pi = 0{,}1163$

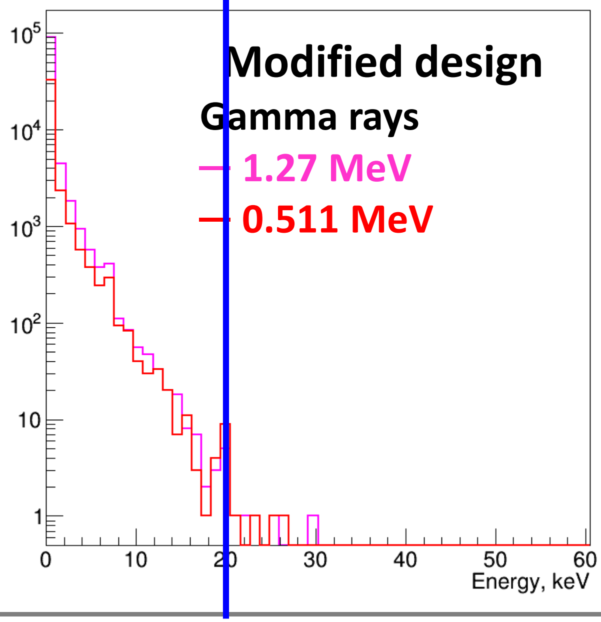
Gamma sensitivity results



Double gap ^{10}B-RPC

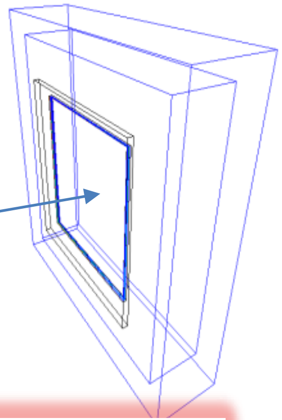
Prospects to decrease ^{10}B-RPCs gamma sensitivity





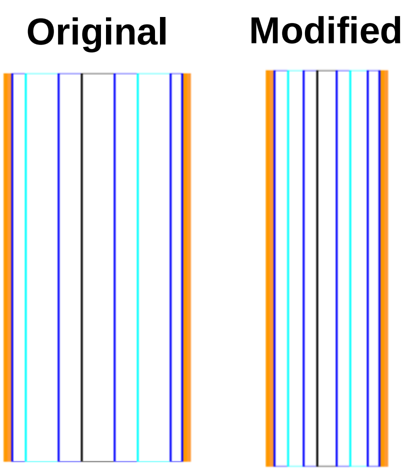
GEANT4 (QGSP-BIC-HP)

- Pencil beam perpendicular to the RPC
- N=10^7 gammas for each energy



A reduction in the gamma sensitivity of a factor > 5 in principle can be reach by optimizing the detector design

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



Conclusions

- It seems to be possible to reach 100 kHz/cm^2 with a ^{10}B-RPC based neutron detector by combining low resistive electrodes and a multilayer configuration

  - Counting rates of the order of 10 kHz/cm^2 are demonstrated for single gap RPCs

  - A further factor of 10 increase in the counting rate can be provided by using a Multilayer configuration

- Gamma sensitivity $< 10^{-6}$ was demonstrated for 0,511 MeV

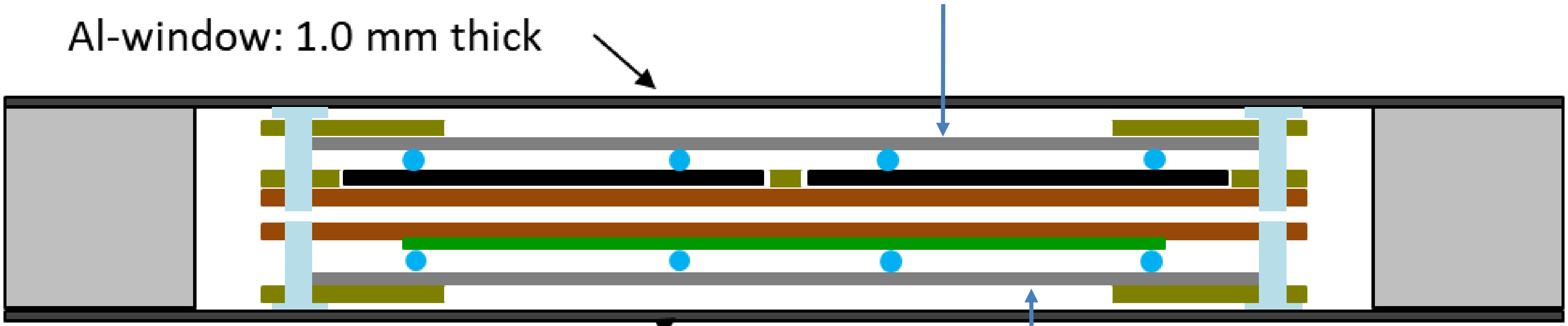
Thank you for your attention

Backup Slides

Detector details

Cathode (100 mm x 100 mm): Al Plate (0.5 mm thick)
1.15 μm thick layer of $^{10}B_4C$

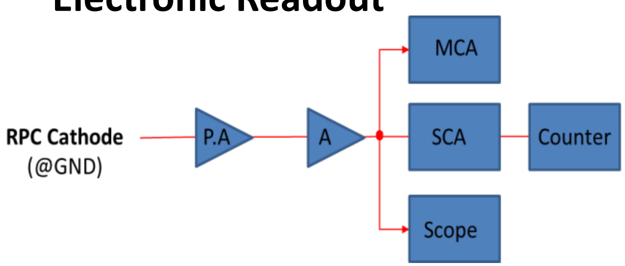
Al-window: 1.0 mm thick



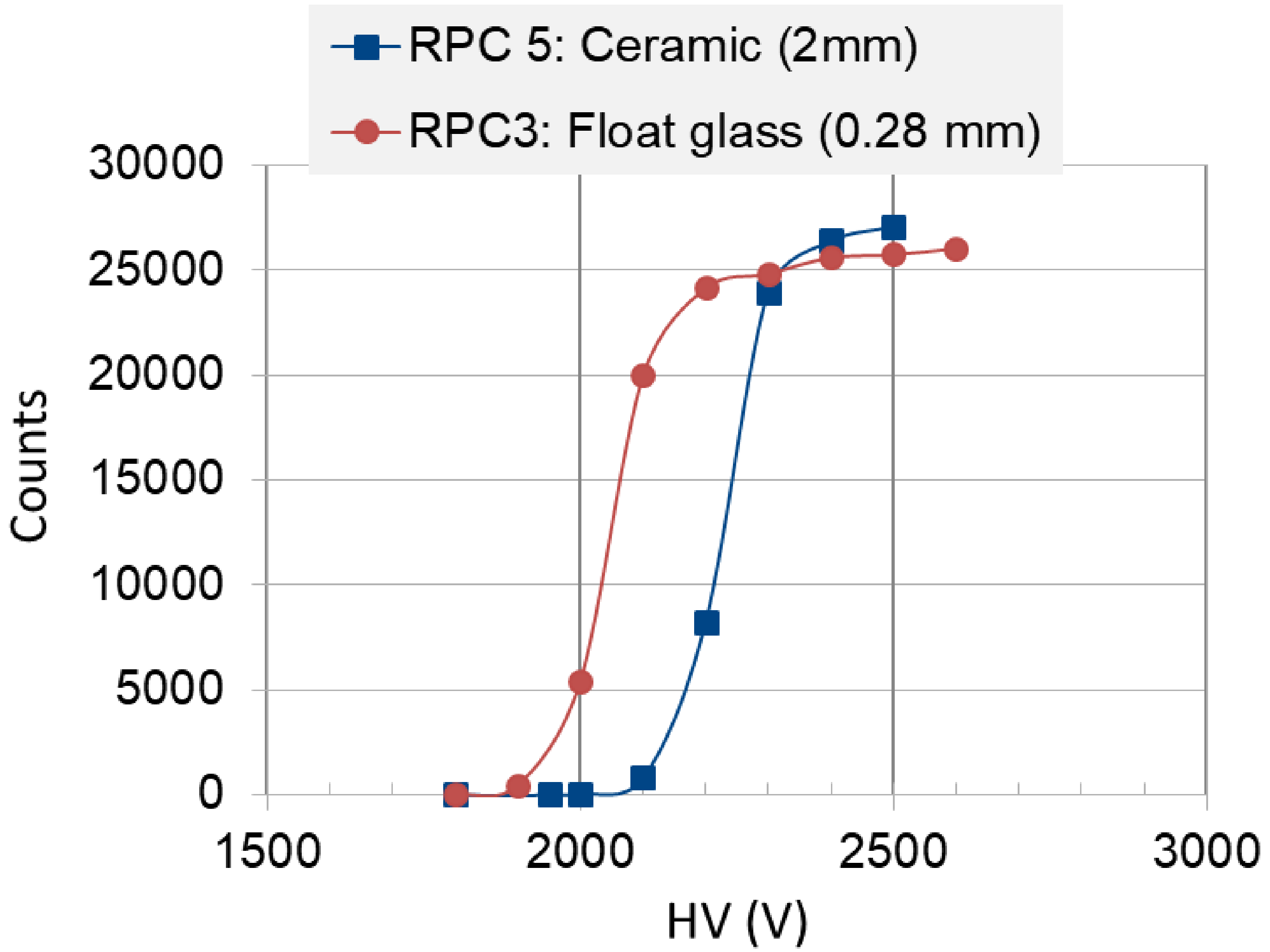
Al-window: 1.0 mm thick

Cathode (80 mm x 80 mm): 1mm thick
Al lined with 2 um thick layer of $^{10}B_4C$

Electronic Readout

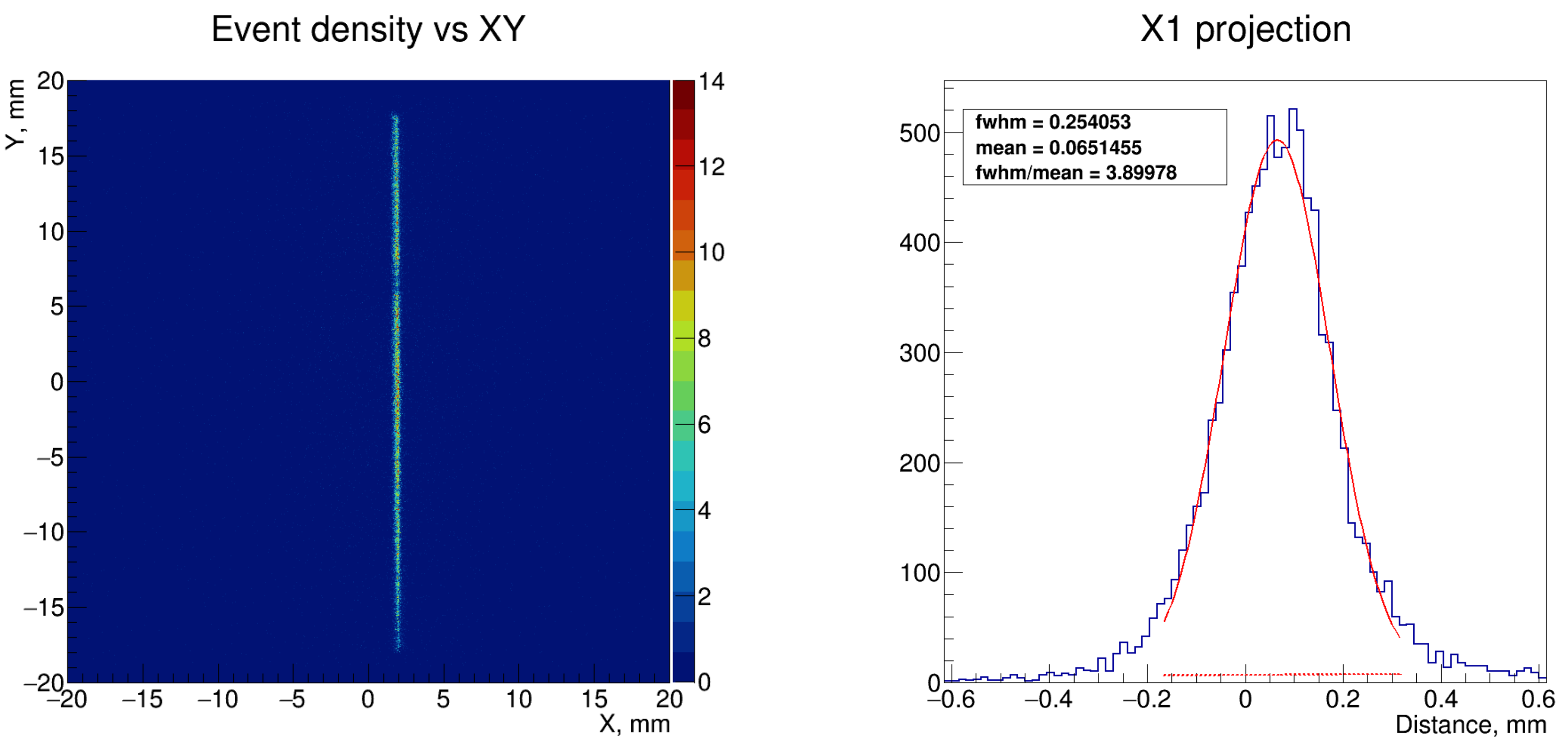


Backup Slide



Backup Slide

Vertical Slit (X-coord.): Cd slit: 0.1 mm x 35 mm



Position reconstruction: COG reconstruction: strongest signal strip and 4 neighbouring strips

FWHM (X) ≈ 0.25 mm