^{10}B-RPC based Neutron Imaging Detectors

LIP

Jornadas LIP, Braga, 16 February 2020

Luís Margato on behalf of the neutron detectors group

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ess EUROPEAN SPALLATION SOURCE

ill NEUTRONS FOR SOCIETY

FRM II Forschungs-Neutronenquelle Heinz Maier-Leibnitz

Science & Technology Facilities Council

Motivation

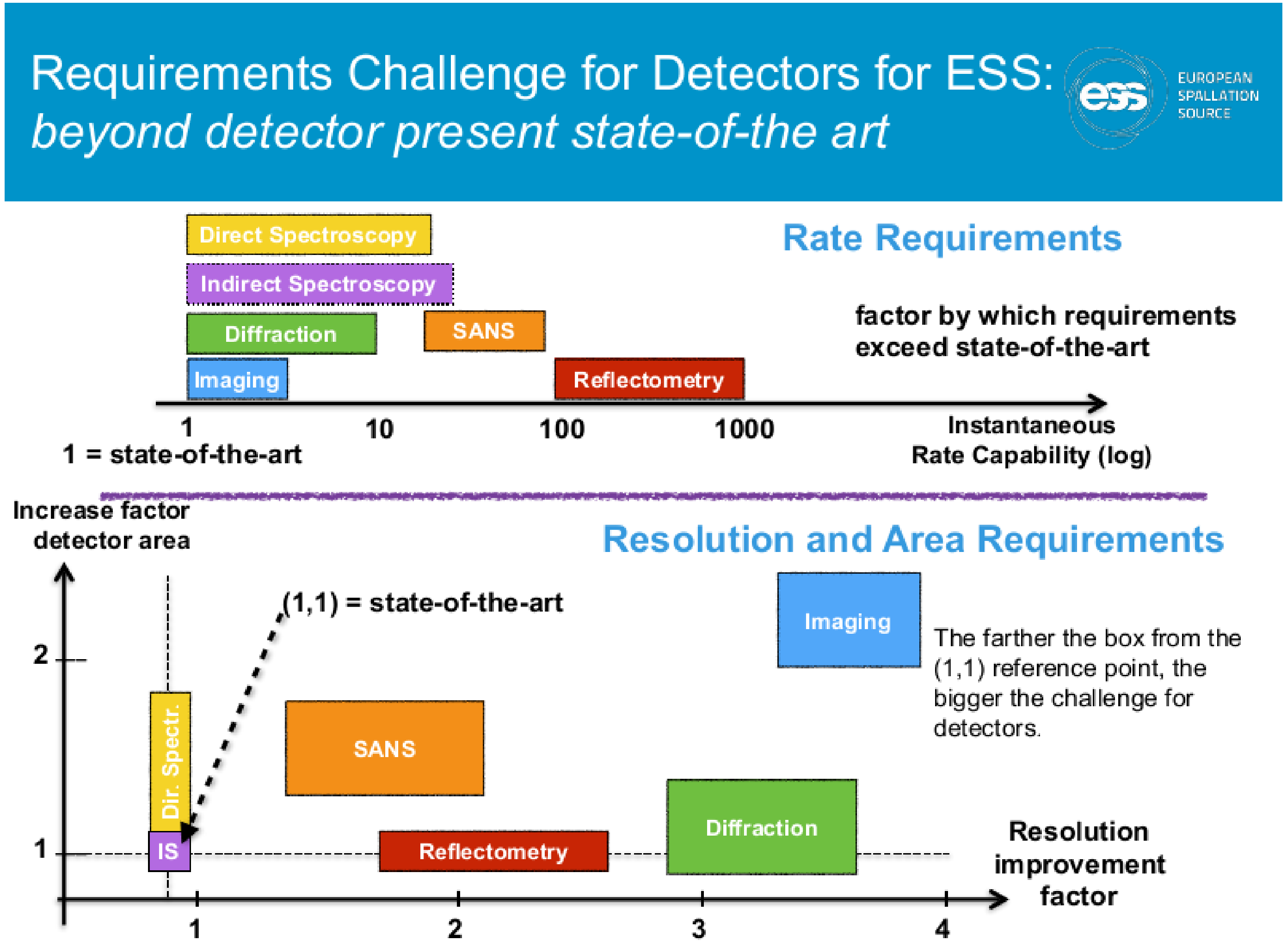
The high-brightness expected for the European Spallation Source (ESS) is pushing for the development of high precision neutron detectors with high counting rate capability.

Currently a solution does not exist!

Why RPCs?

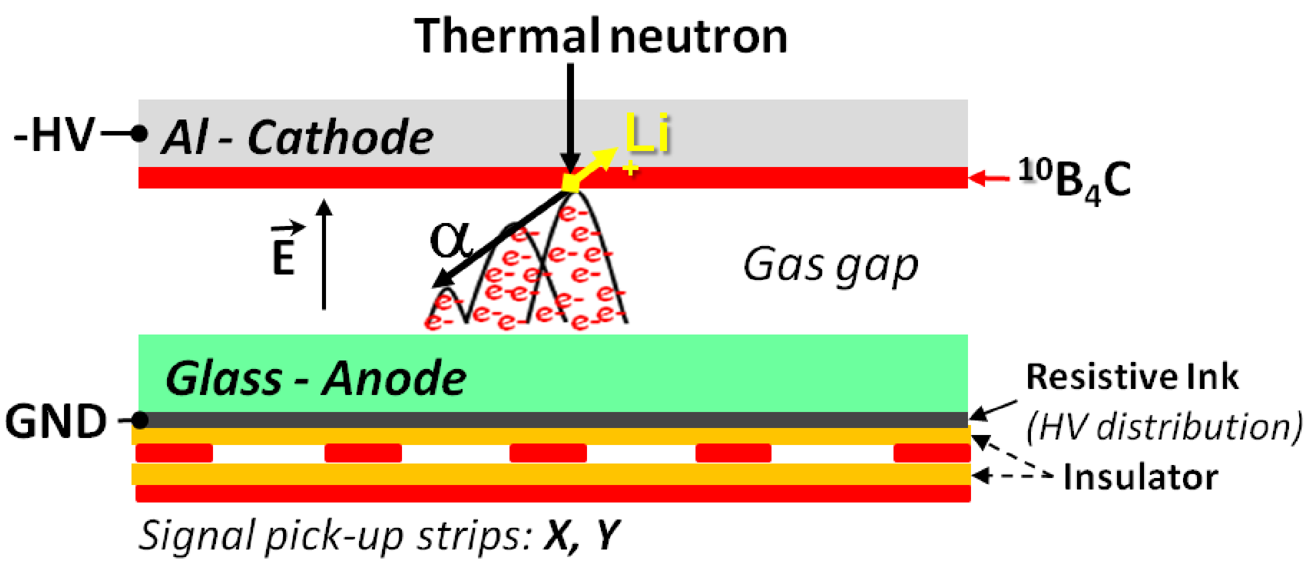
Very high time and spatial resolution in comparison with competitive technologies.

Practical advantages, such as, e.g.: high modularity of the design, robustness, good scalability and **low cost per unit area**.



© Richard Hall-Wilton, Leader of ESS Detector Group

Thermal neutron detection with RPCs

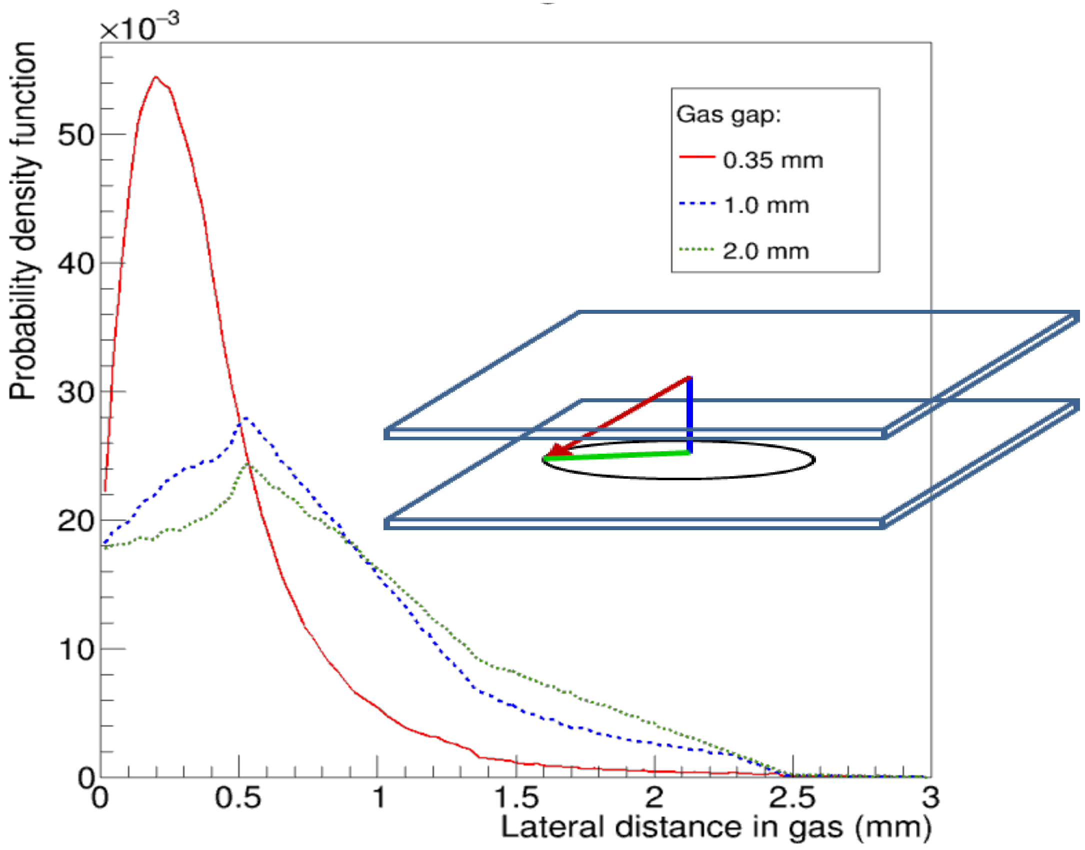


$$n + {}^{10}B \rightarrow \begin{cases} {}^{7}\mathrm{Li}(0.84\ \mathrm{MeV}) + {}^{4}\mathrm{He}(1.47\ \mathrm{MeV}) + \gamma(0.47\ \mathrm{MeV}), & 94\% \\ {}^{7}\mathrm{Li}(1.01\ \mathrm{MeV}) + {}^{4}\mathrm{He}(1.78\ \mathrm{MeV}), & 6\%. \end{cases}$$

Good spatial resolution can be expected

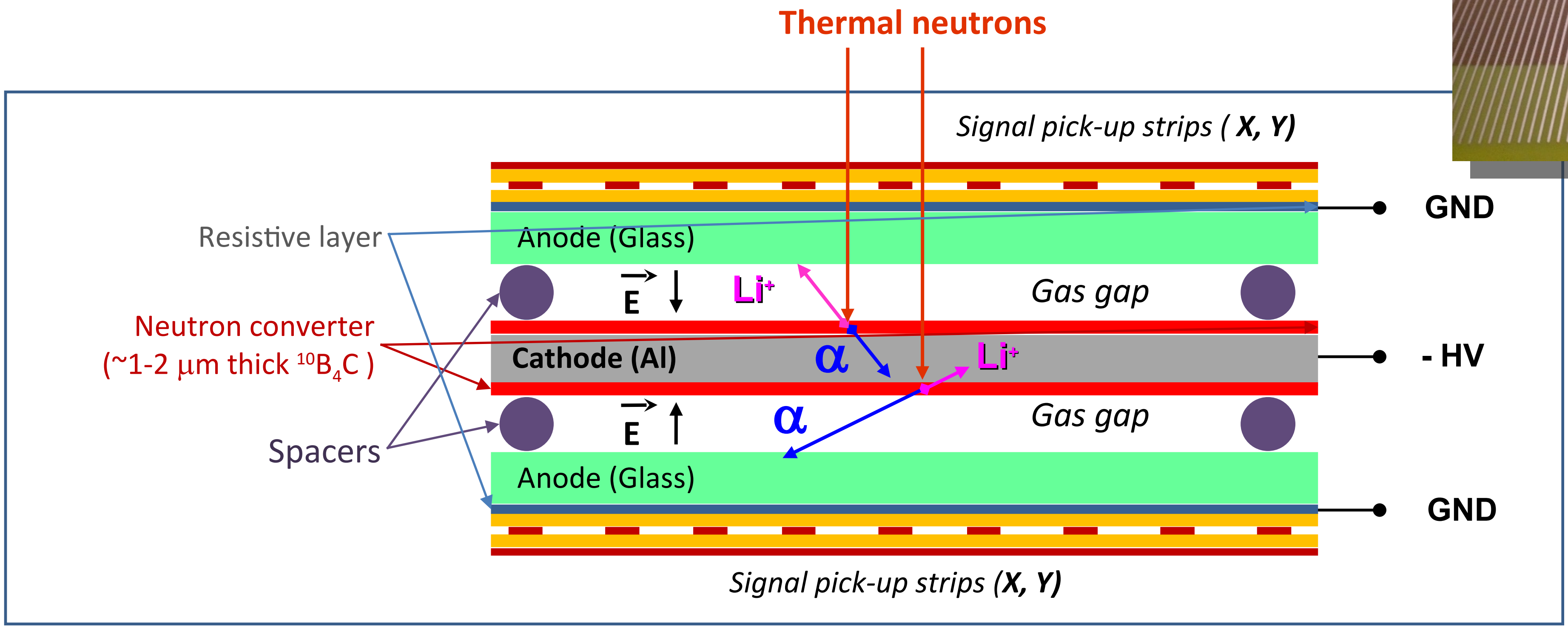
- Anti-parallax effect
- The possibility to build RPCs with very thin gas-gaps (down to 0.1 mm)

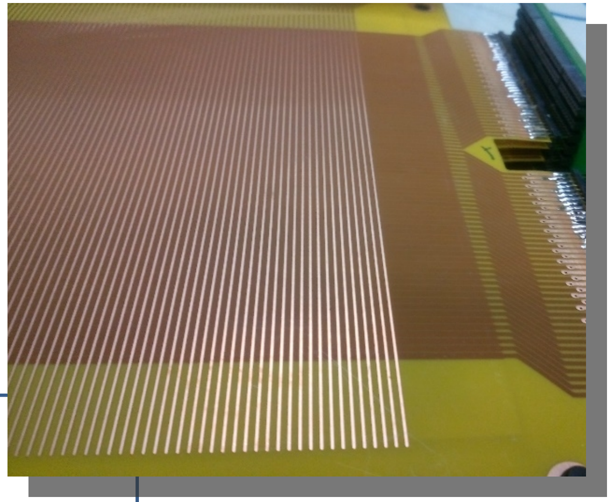
^{4}He and ^{7}Li ranges in the gas-gap projected along the horizontal direction



- **$^{10}B_4C$ 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)

RPC-based neutron imaging detector

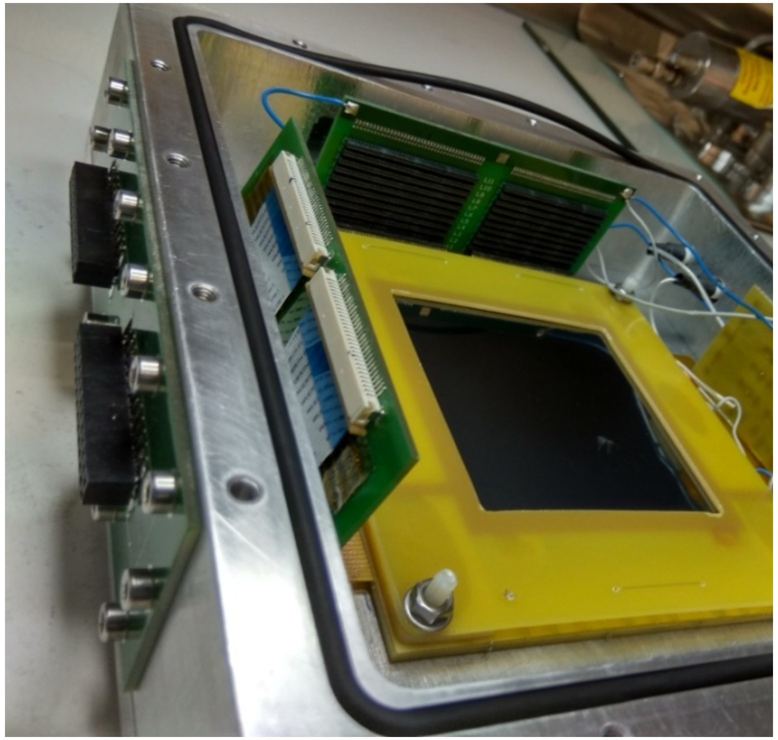




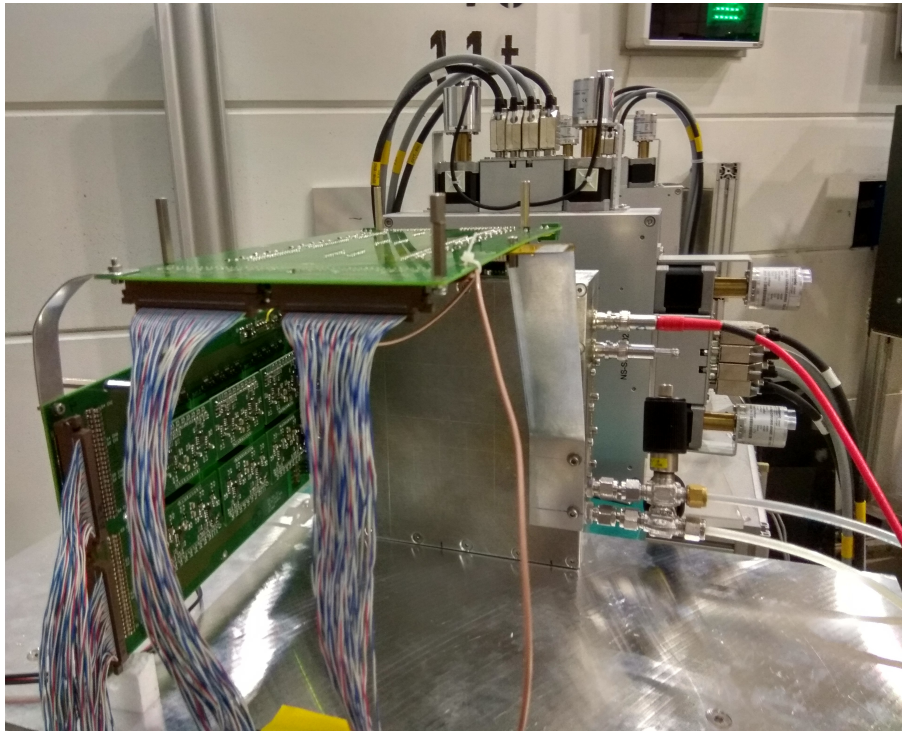
Double gap hybrid RPC → Basic detector module

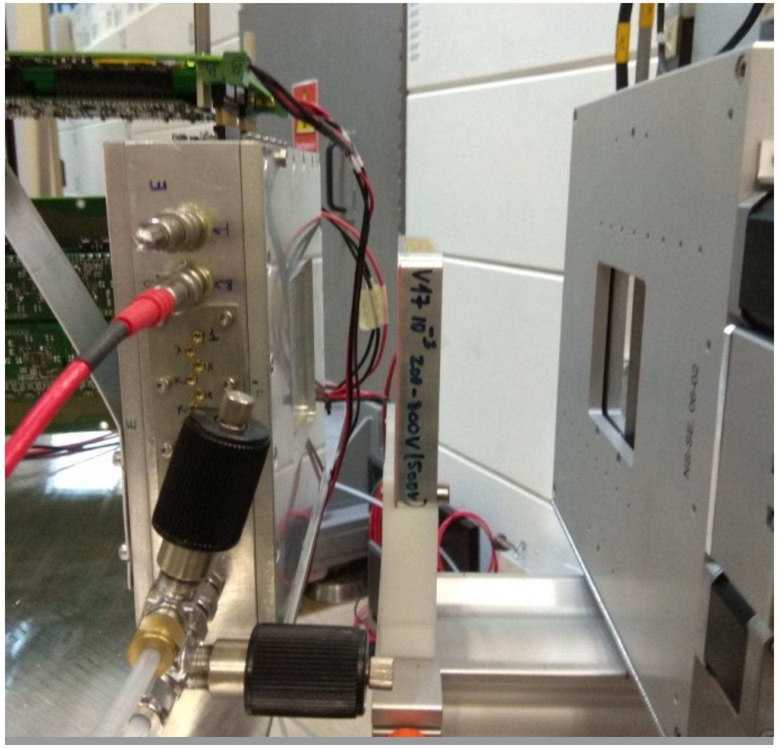
RPC-based neutron imaging detector at V17 beamline at HZB-Berlin

Detector housing



^{10}B-RPC detector on V17 beamline (λ = 3.35 Å)





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

ís Margato LIP - Coimbra, Dep. Fisica, Universidade de Coimbra (PT)

LIP Coimbra is very busy group

Summary of RPC2020

Crispin Williams

ed

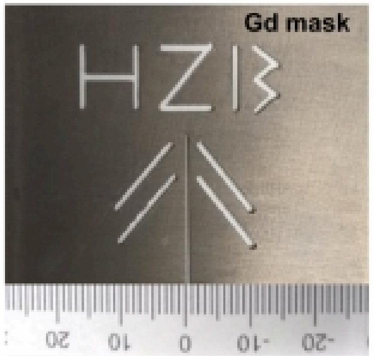
be

❑ Gamma sensitivity < 10 ... eV

RPC detector at a beamline at HZB-Berlin

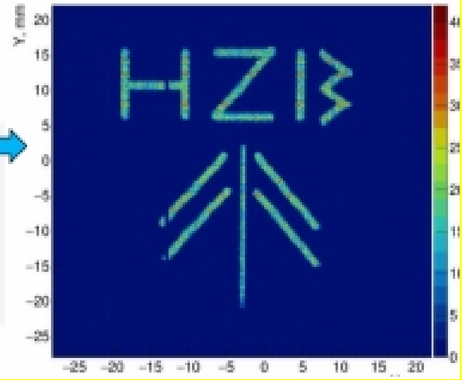
Gd mask: 0.25 mm thick
Letters and oblique slits: 1mm width

Vertical slit: 0,4 mm width



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

Position reconstruction: COG algorithm

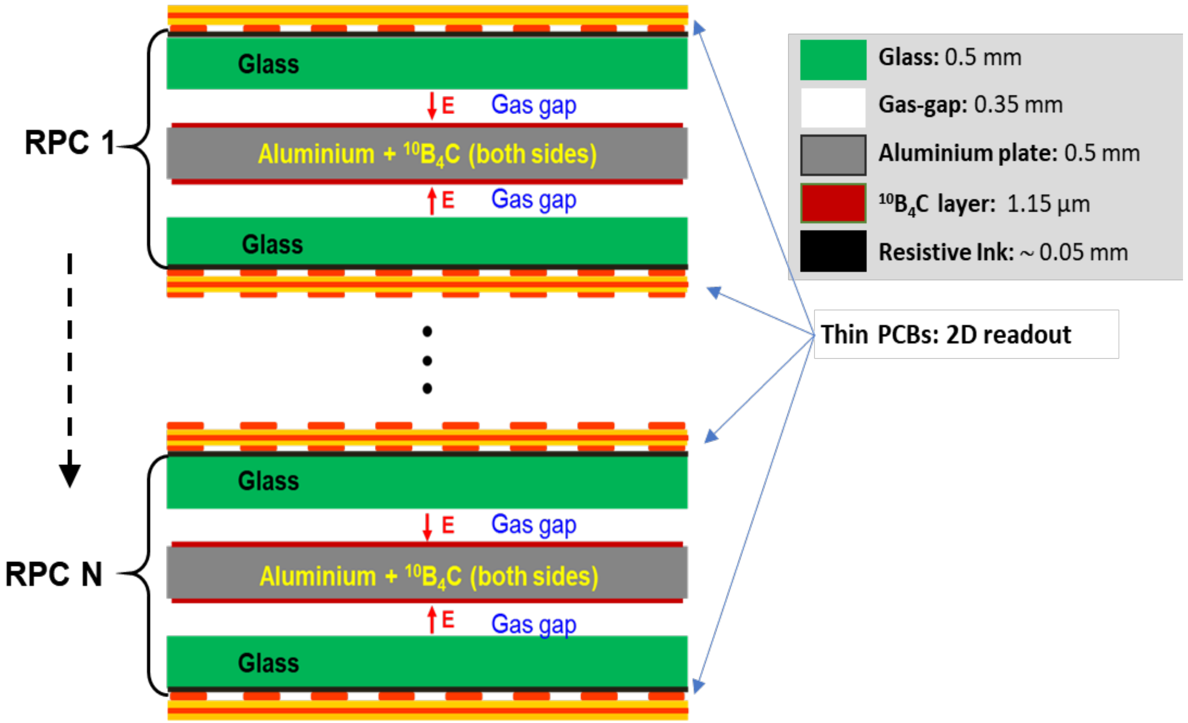


Very impressive results

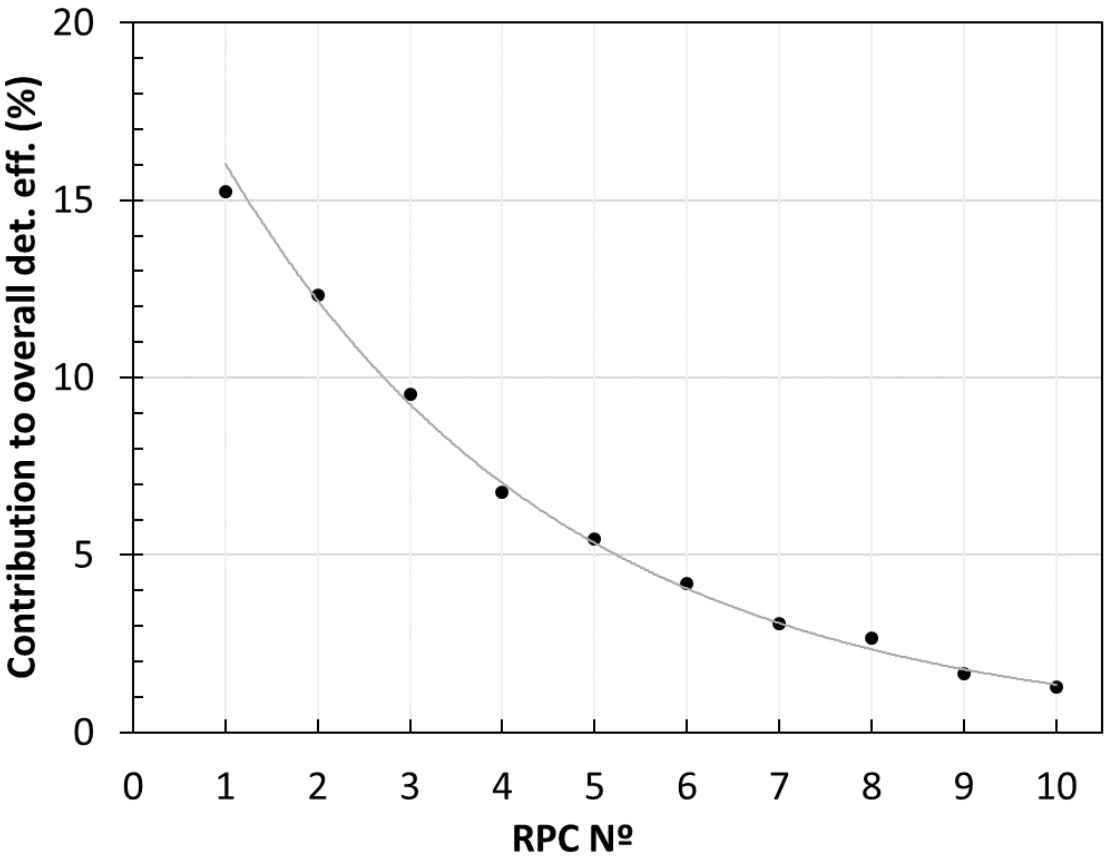
RPC-based neutron imaging detector

Multilayer architecture

- Detection efficiency > 50% ✓
- Submillimeter spatial resolution ✓



[L.M.S. Margato and A. Morozov 2018 JINST 13 P08007]



- ❑ Overall detection efficiency of 62.1% (λ = 4.73 Å)
- ❑ Spatial resolution < 0.25 mm FWHM

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

To full demonstrate the advantages of a RPC-based neutron detector technology we have to reach:

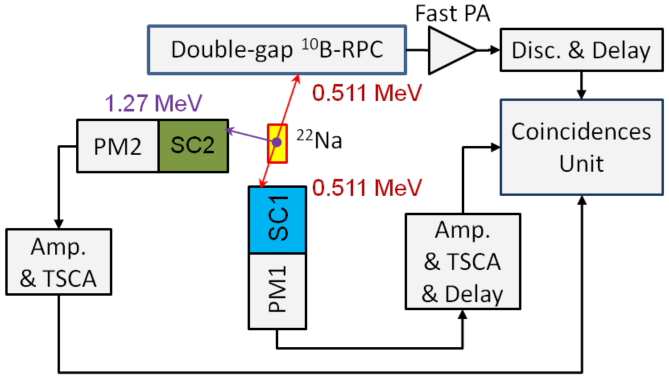
- Counting rate > 100 kHz/cm^2
- Gamma sensitivity < 10^{-5} (@ 1 MeV)

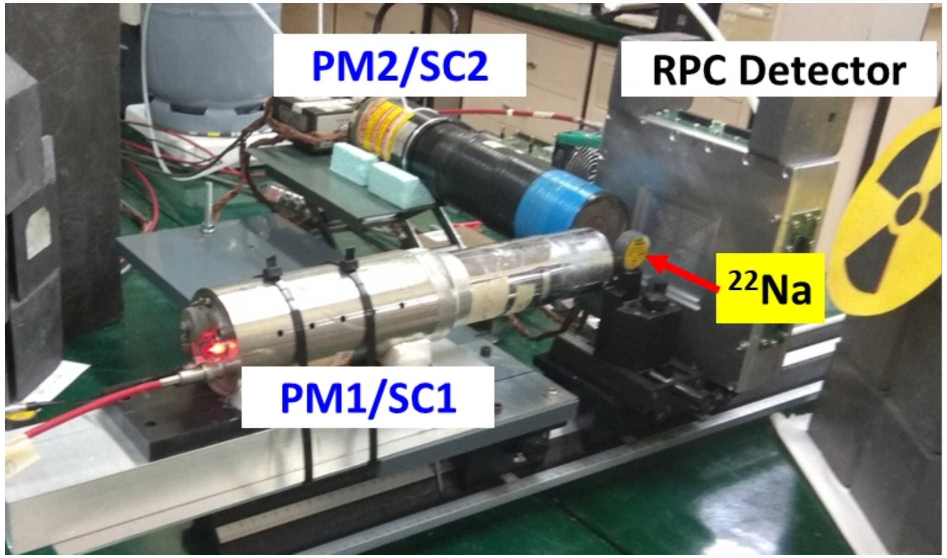
Some possible approaches:

- RPCs made with **lower resistivity materials**
- Thinner electrodes
- Increase the operating temperature
- Lower the gas gain
- RPC - detector design (e.g. multilayer or inclined configuration)

Gamma sensitivity: double gap RPC

Setup1: 0.511 MeV



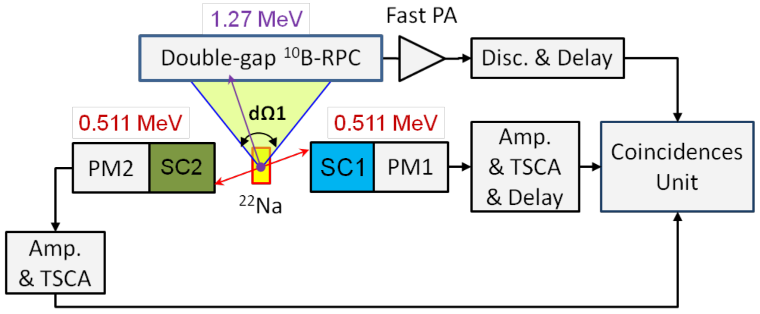


Det. Efficiency = N1/N2

N1=PM1 & PM2 & RPC

N2=PM1 & PM2

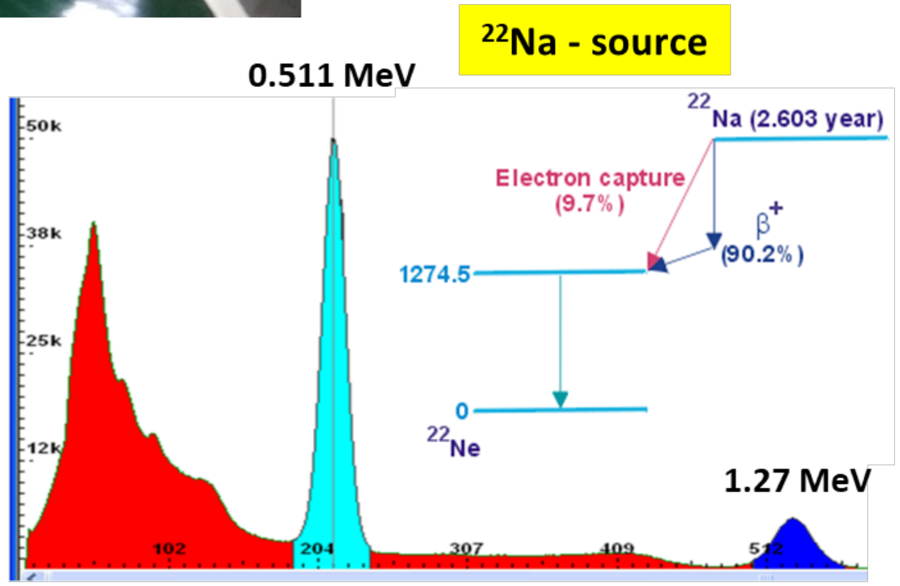
Setup2: 1.27 MeV



Det. Efficiency = N1/(N2 x dΩ1)

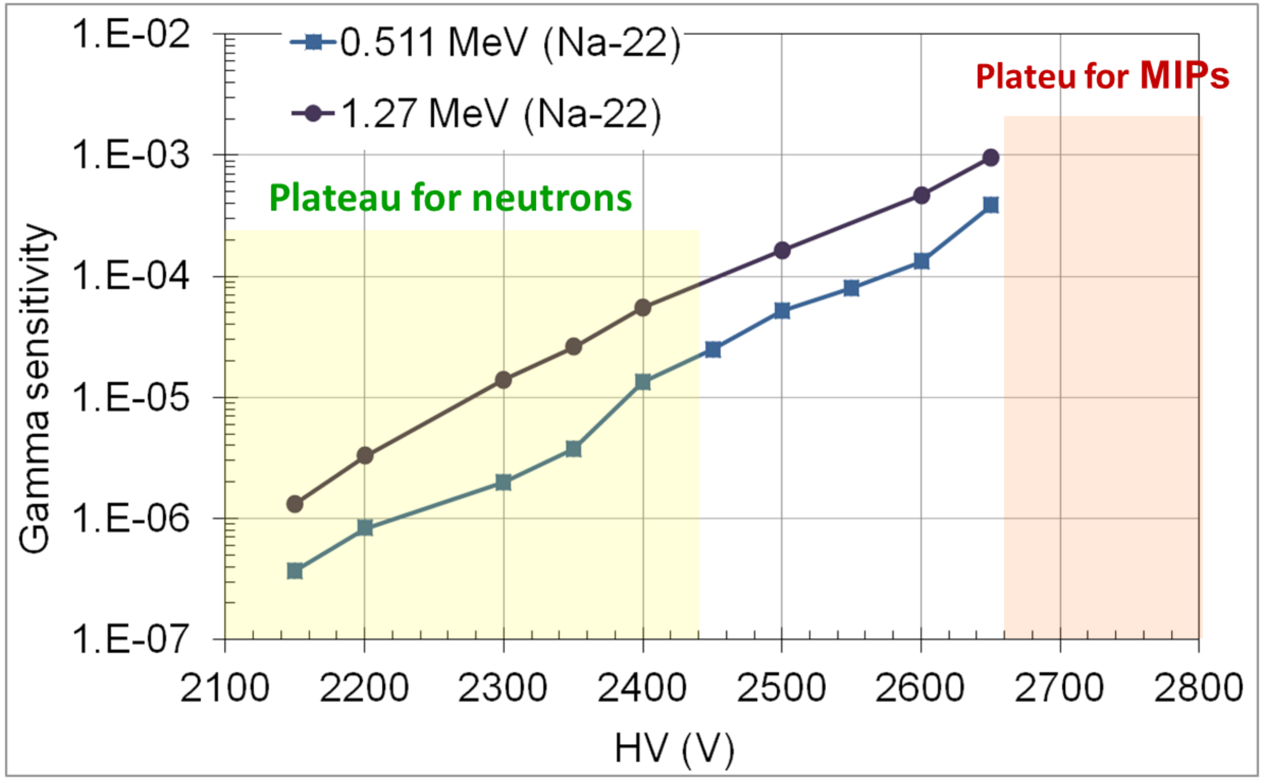
N1=PM1 & PM2 & RPC

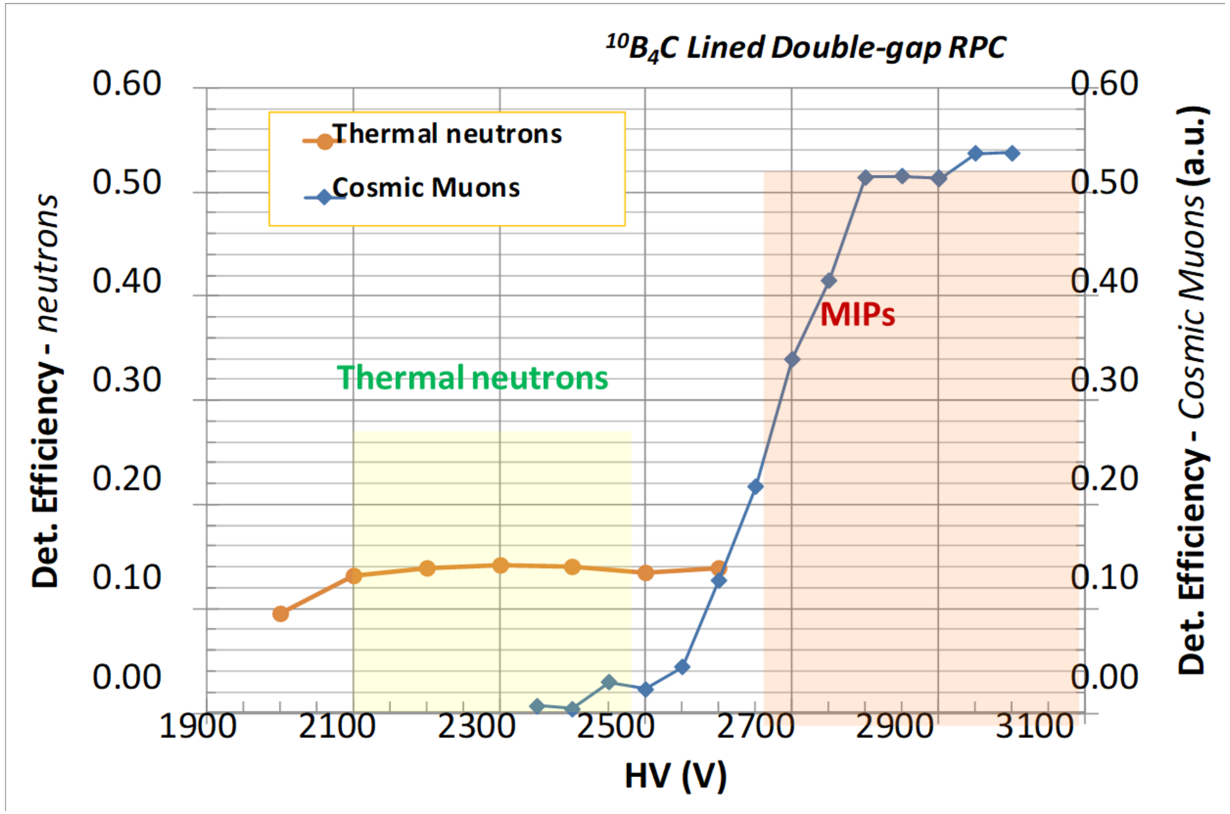
N2=PM1 & PM2



Energy windows are set by the TSCAs

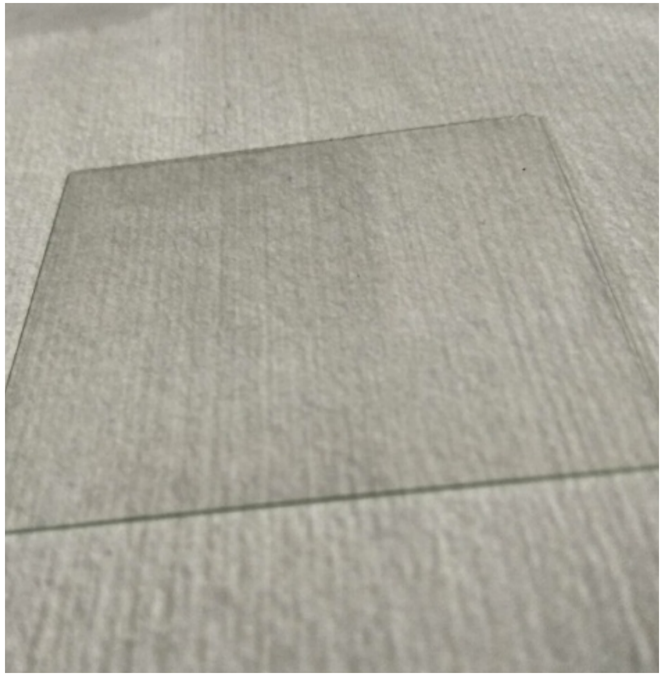
Gamma sensitivity: double gap RPC





First tests of RPCs made from low resistivity materials at a neutron beam

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

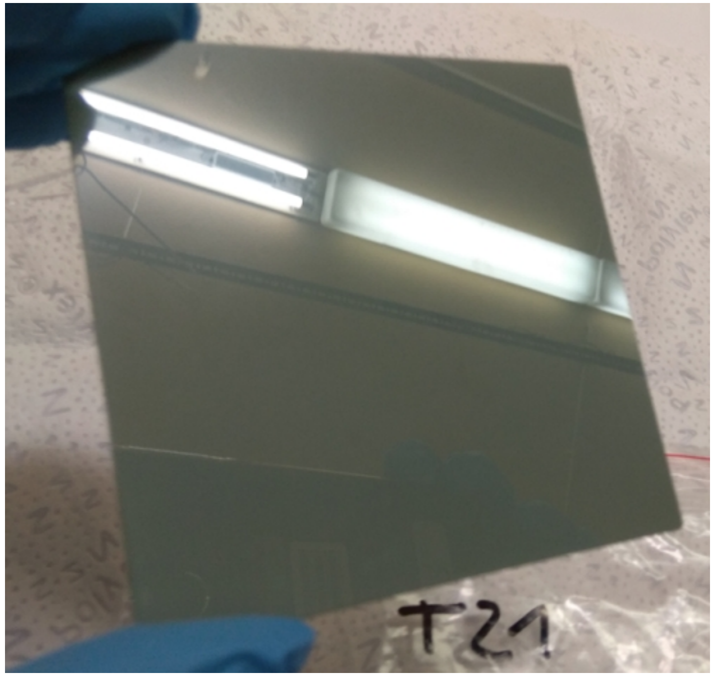


Commercial glass

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

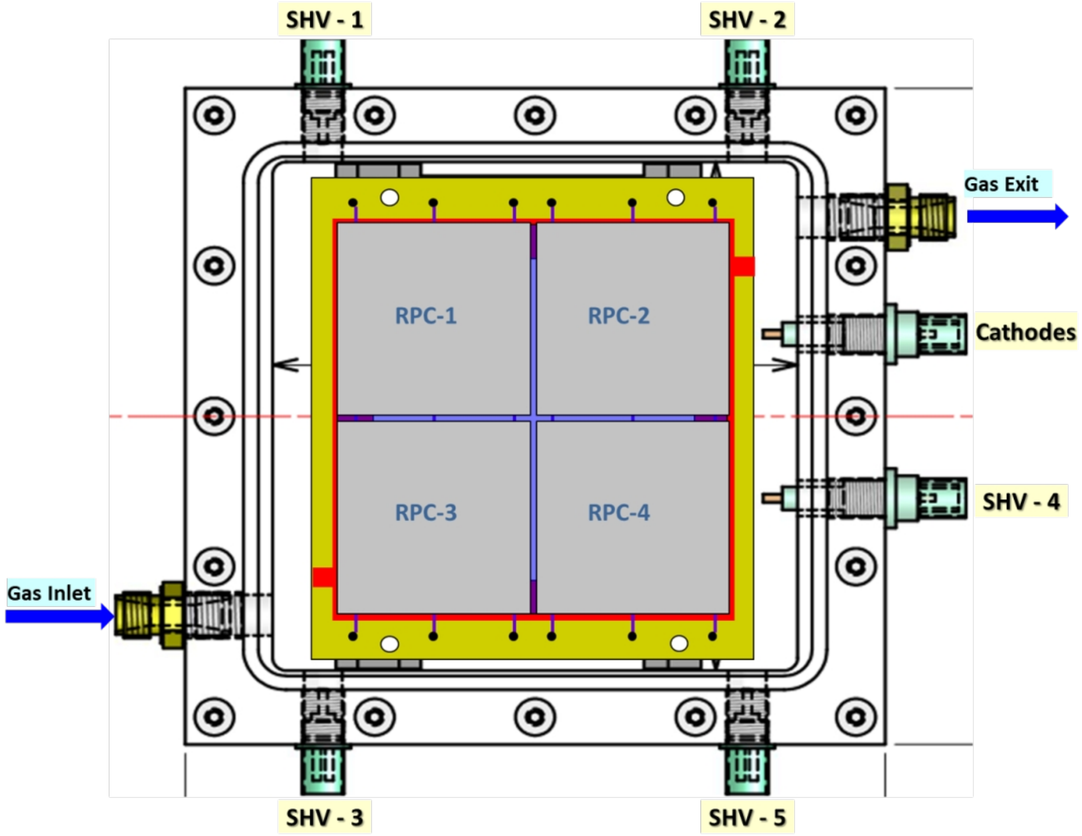
Yi Wang, Tsinghua University, Beijing

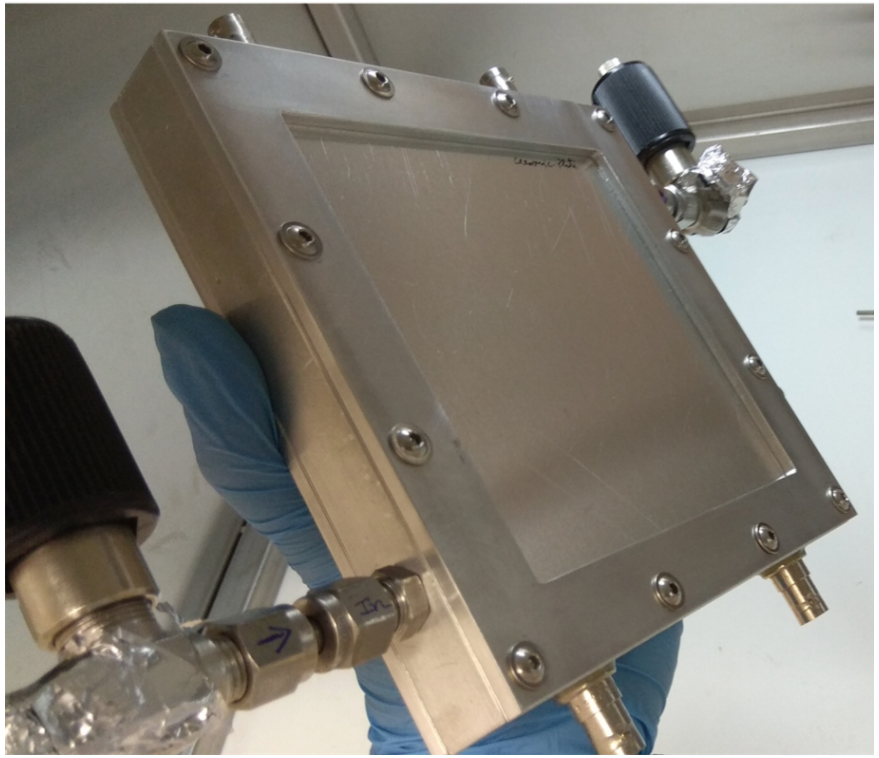
Ceramic composite
2 mm thick,
$\rho \approx 2 \times 10^{10}\ \Omega$ cm at 24 °C



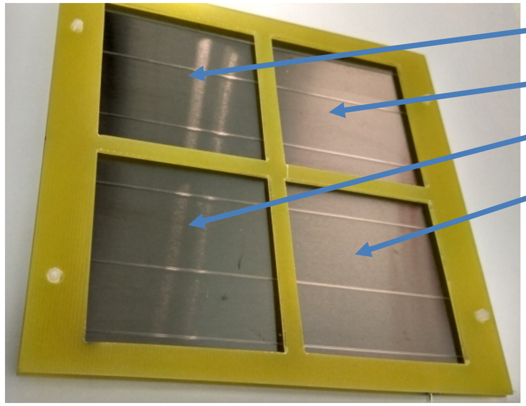
L. Naumann, HZDR, Dresden-Rossendorf

Detector details





$^{10}B_4C$ lined on Al-plates provided by ESS Detector Coatings Workshop (SE)



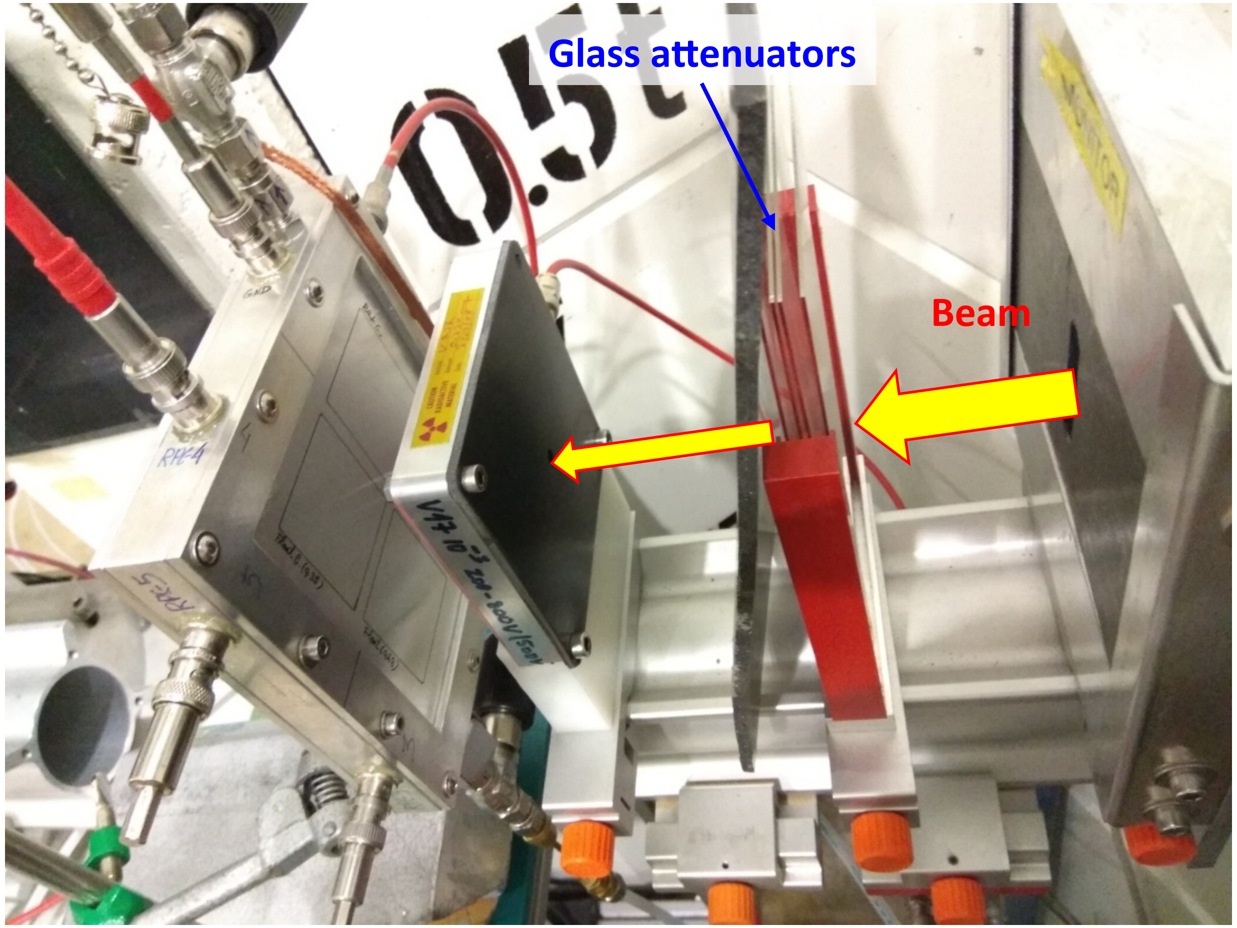
RP1 and **RPC2**: Low resistivity glass

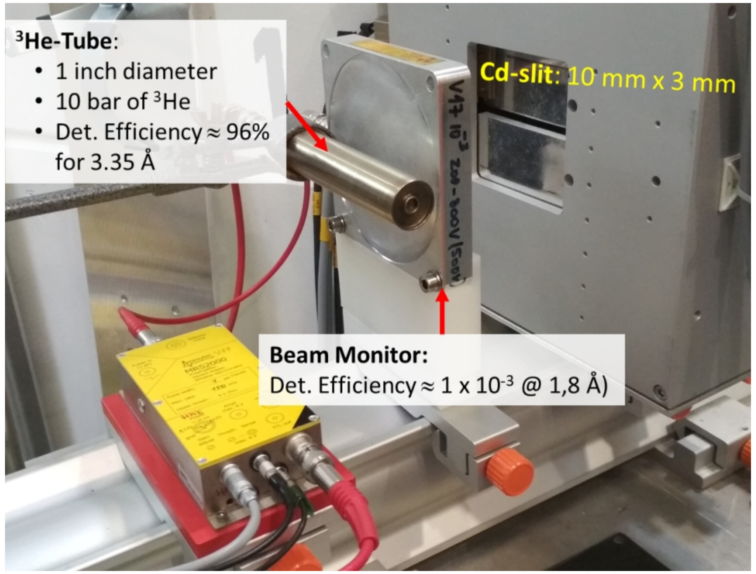
RP3 and **RPC4**: Float glass

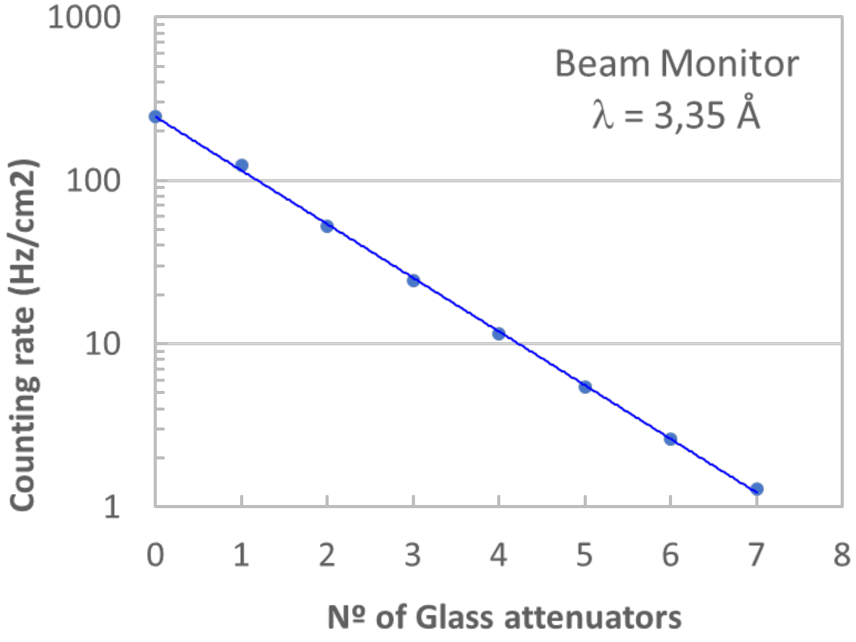
Gas gap: 0,35 mm
Cathode (100 mm x 100 mm): **Al Plate** (0.5 mm thick) with a **1.15 µm thick layer of $^{10}B_4C$**

RPC5 (ceramics on the back side)

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

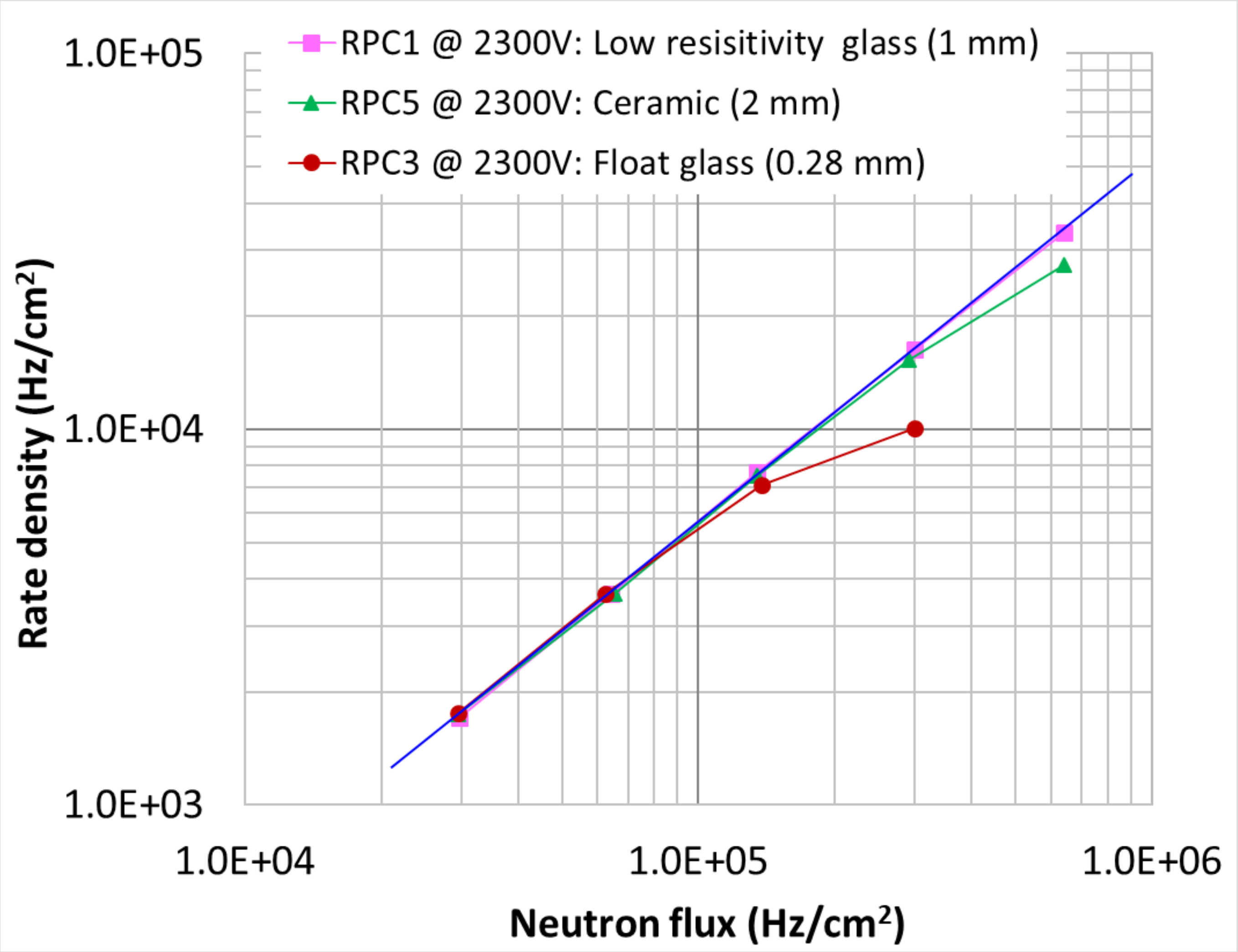






Beam test results: rate vs neutron flux

RPC1: resistivity glass and RPC5: Ceramics)



RPC1 (low resistivity glass): **Máx. Rate > 30 kHz/cm²** for the maximum available neutron flux

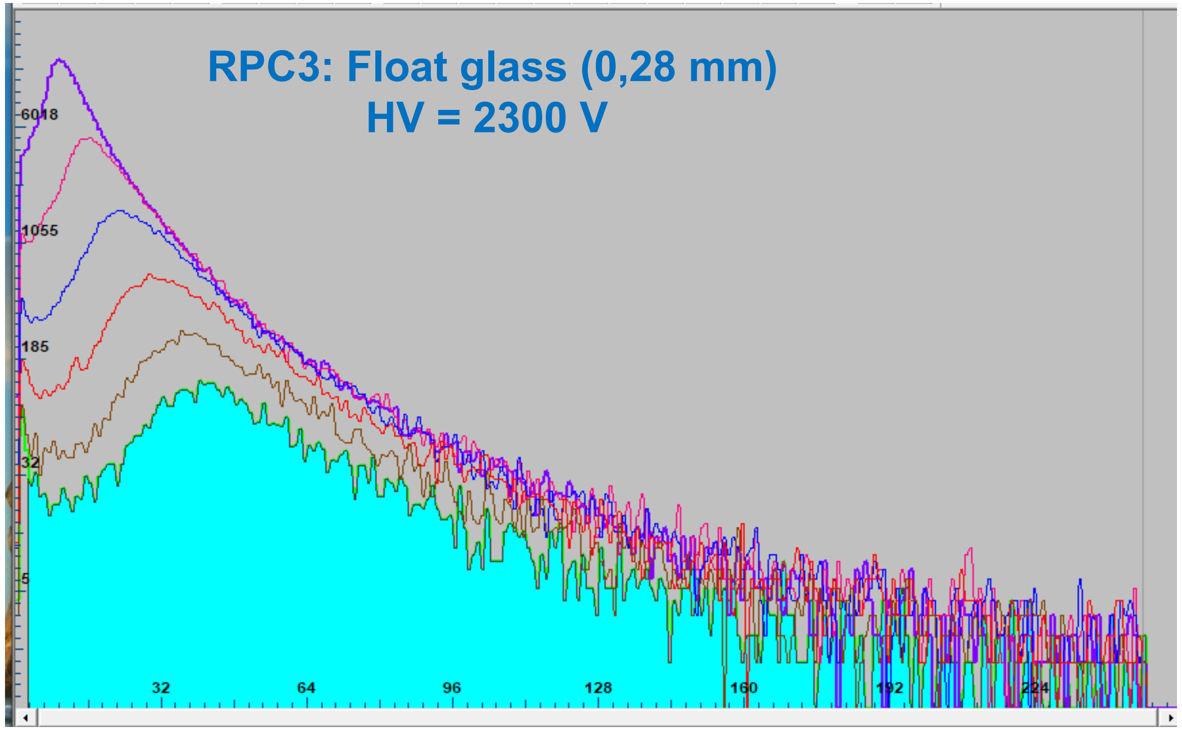
RPC5 (ceramics):
Máx. rate > 15 kHz/cm²

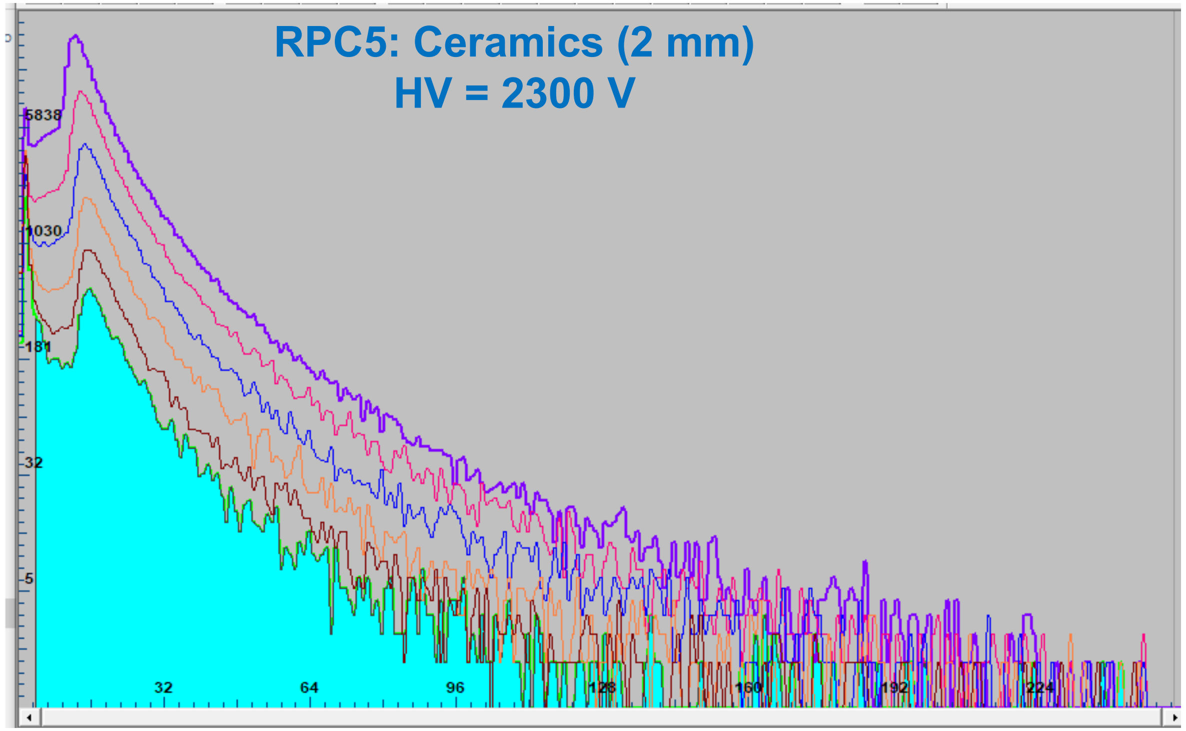
Det. Efficiency ≈ 5.9%
Good agreement with the value obtained from simulation with Geant4 (Det. Efficiency ≈ 6.10%)

Beam test results

PHS recorded at several neutron fluxes

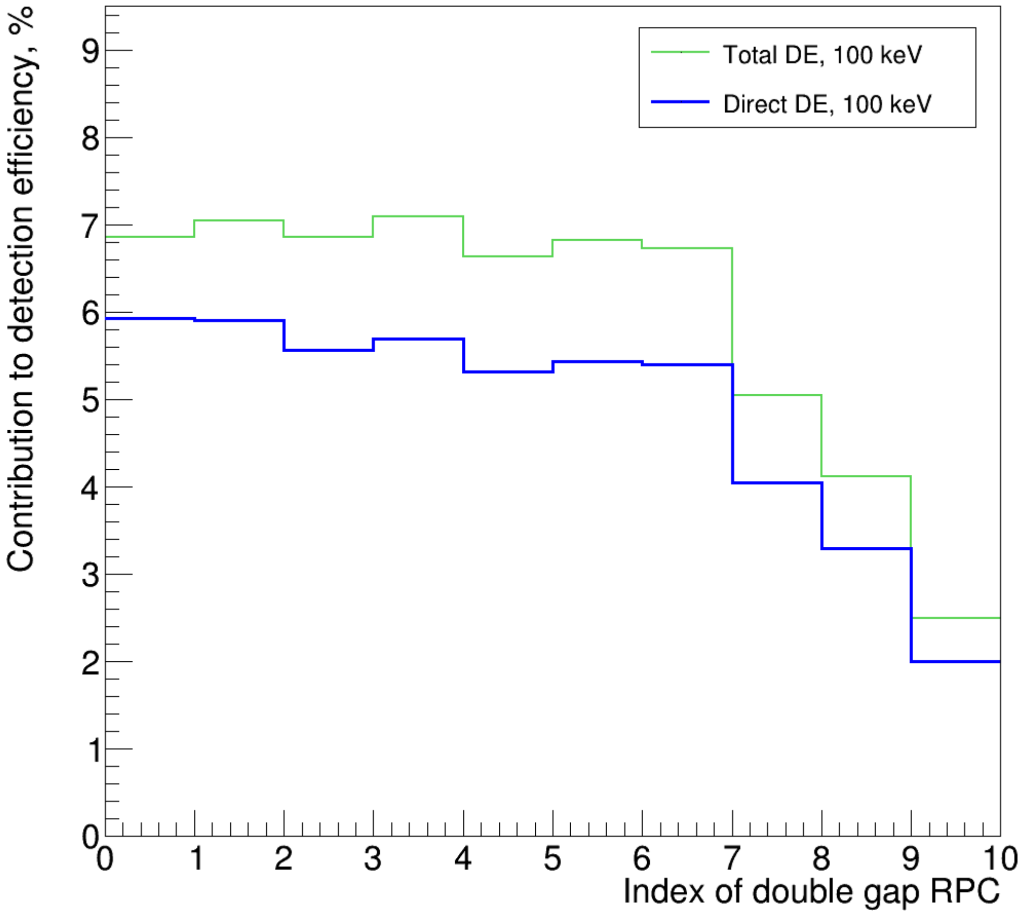
(higher amplitude peaks correspond to higher neutron flux)





Prospects to reach 100 kHz/cm²

Multi-parameter optimization in ANTS2



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

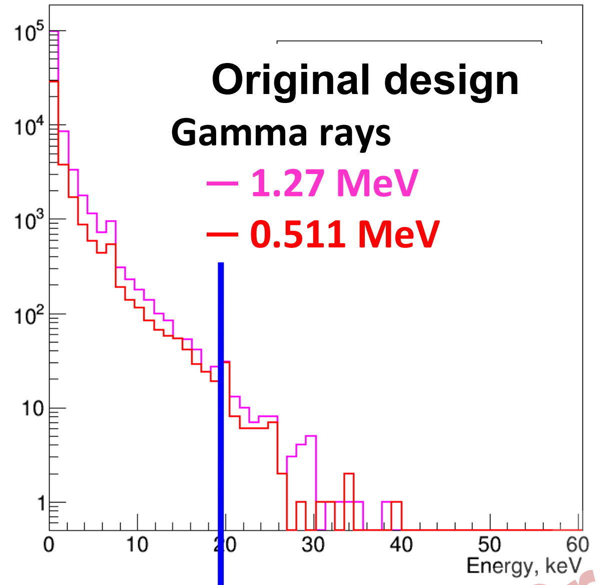
Layer thicknesses:
0.34 (t1,t2); 0.39 (t3,t4); 0.44 (t5,t6); 0.54 (t7,t8); 0.60 (t9,t10); 0.83 (t11,t12); 1.19 (t13,t14); 1.25 (t15,t16); 2.07 (t17,t18) and 3.33µm (t19,t20).

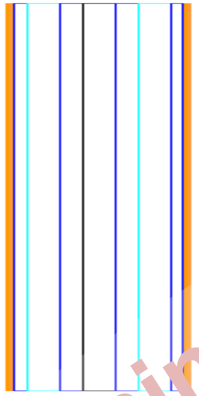
- **Stack with 10 Double gap RPCs**
- Pencil beam (λ = 4.7 Å, 3.656 meV)
- N = 10^6 neutrons

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

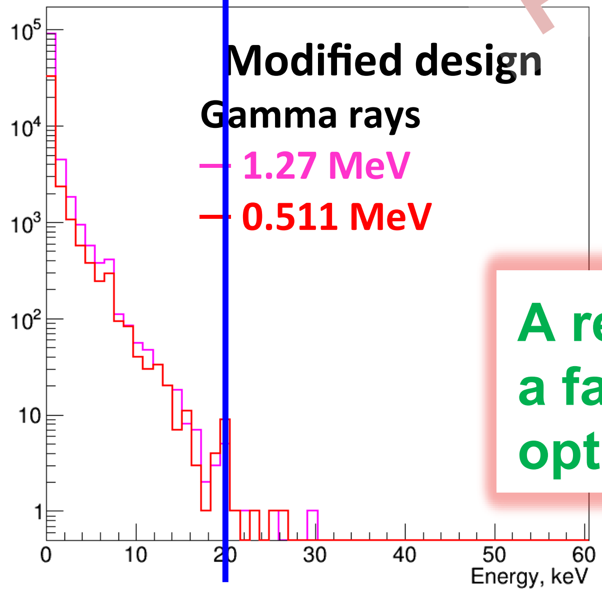
An increases of the counting rate capability of a **factor of > 16,** relatively to one single-gap RPC, is expected

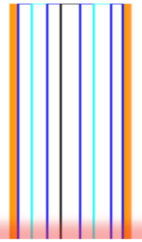
Prospects to decrease ^{10}B-RPCs gamma sensitivity





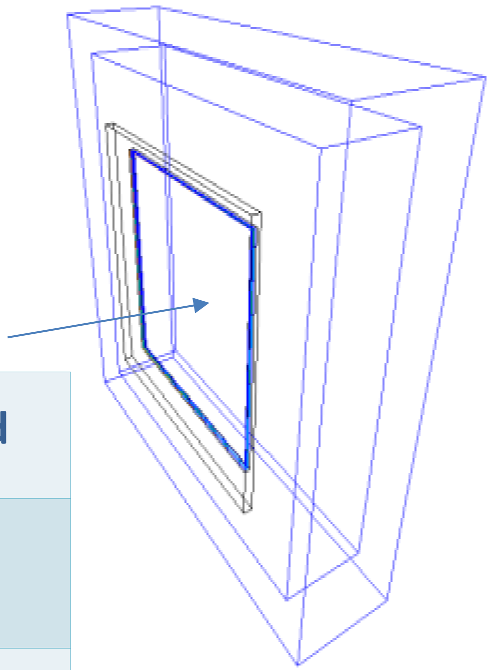
Preliminary





GEANT4 (QGSP-BIC-HP)

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



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

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

Summary and future work

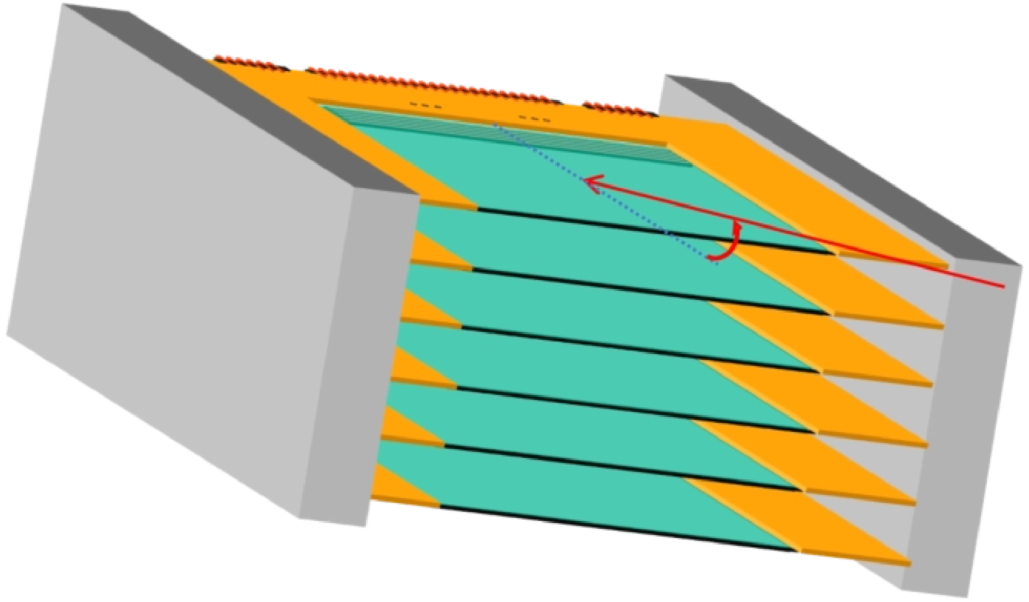
- It seems to be possible to reach **100 kHz/cm²** with a ^{10}B-RPC based neutron detector by **combining lower resistivity electrodes** and a **multilayer configuration**
  - Counting rates of the **order of 10 kHz/cm² are demonstrated** for single gap RPCs
  - A further **factor of 10 increase** in the counting rate can be achieved by using a multilayer configuration
- Gamma **sensitivity < 10^{-6} demonstrated** for 0,511 MeV
- An **optimized prototype** integrating the developments made so far should be designed/built

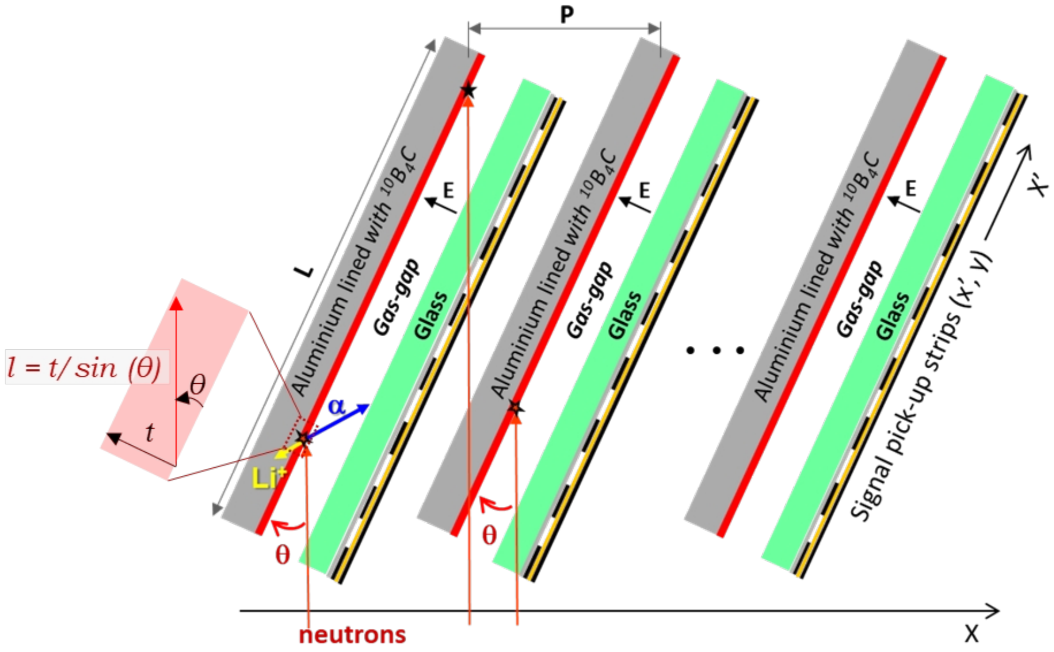
Involves: *design optimization; Geant4 simulation; material validation studies, readout electronics; signal processing and filtering; reconstruction algorithms; detector tests at a Neutron Facility of our partners (ILL, FRM II and ISIS)*

Thank you for your attention

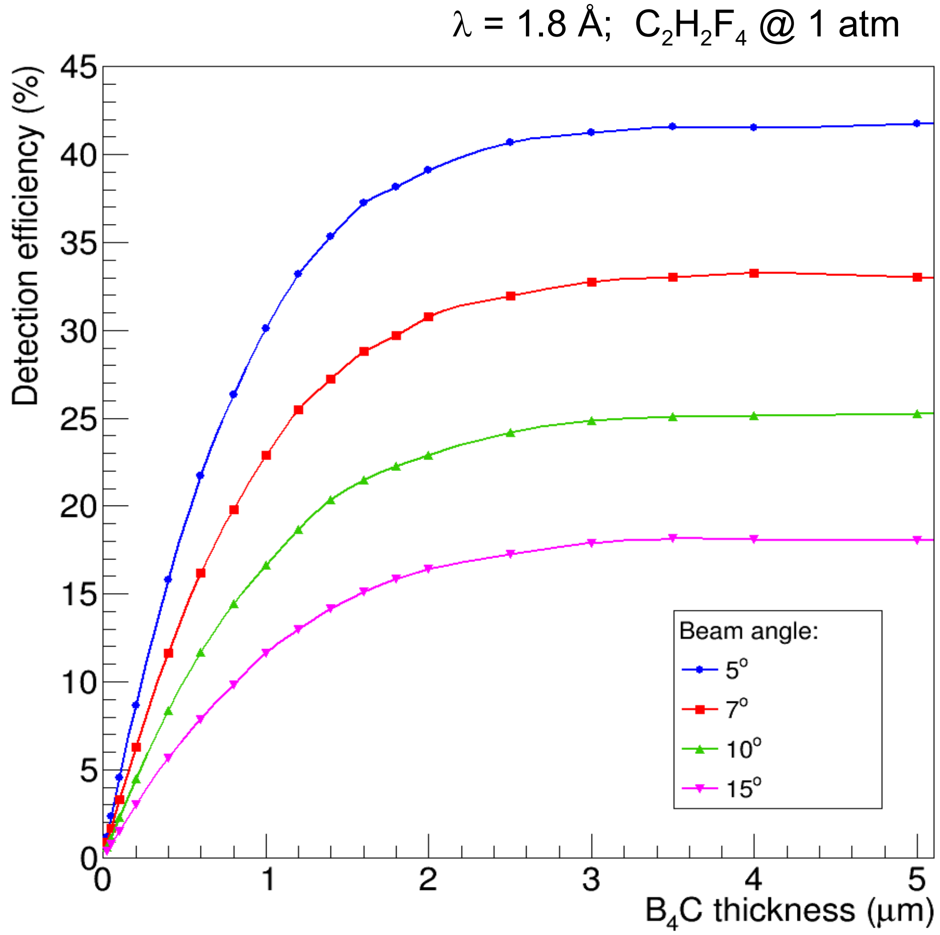
Backup Slides

Inclined geometry

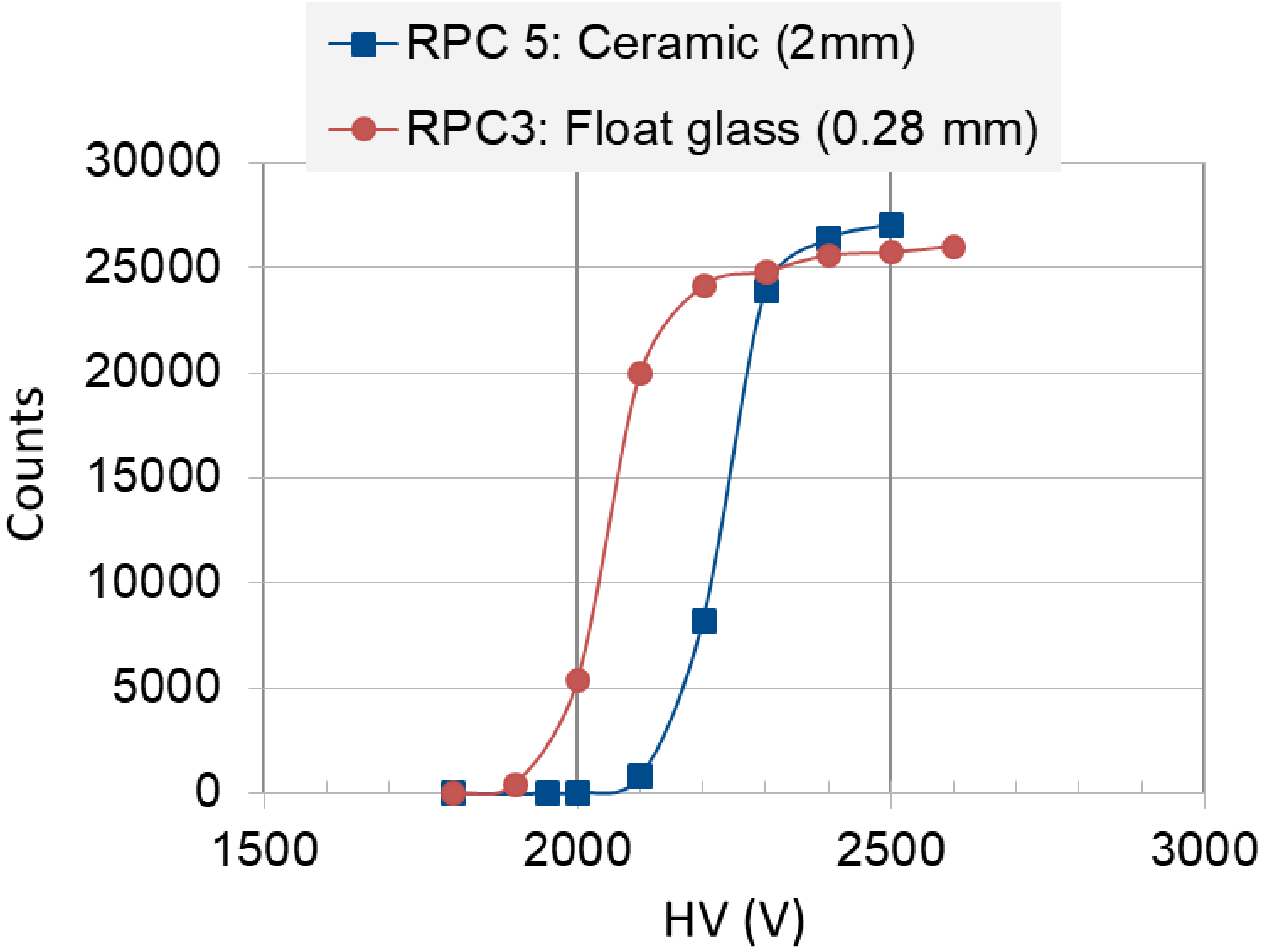




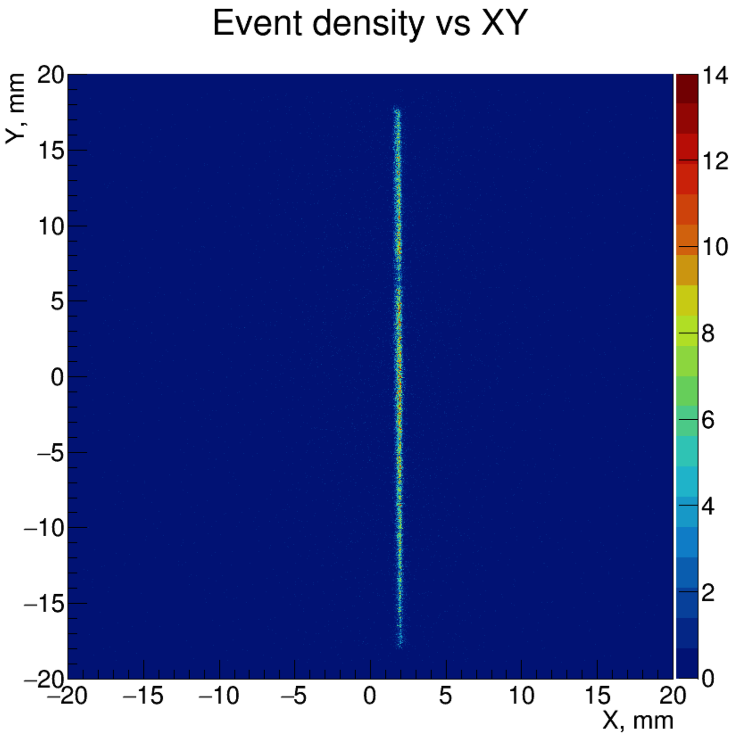
Detection efficiency vs $^{10}B_4C$ thickness for several angles of incidence of the neutron beam

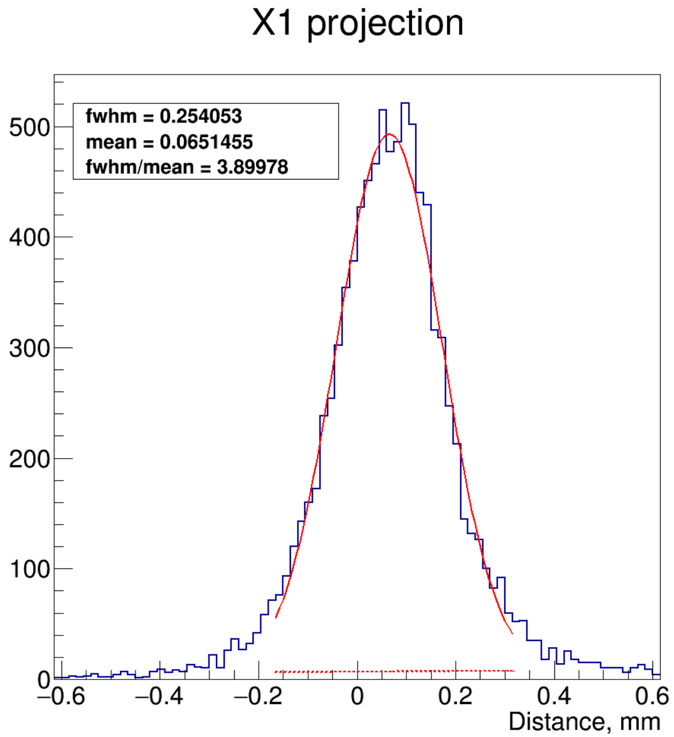


[L.M.S. Margato and A. Morozov 2018 JINST 13 P08007]


RPC 5: Ceramic (2mm)
RPC3: Float glass (0.28 mm)
30000
25000
20000
15000
10000
5000
0
Counts
1500
2000
2500
3000
HV (V)

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

Neutron Position Sensitive Detectors for the ESS

Instrument	**Detector area** [m^2]	**Wavelength range** [Å]	**Time resolution** [μs]	**Spatial resolution** [mm]
Multi-Purpose Imaging[a] (ODIN)	1	1 - 10	1	0.001 - 1
Broad-Band Small Sample SANS[a] (LOKI)	[8 - 16]	3 - 20	100	2 - 8
General Purpose Polarised SANS[b] (SKADI)	2.0674	2 - 18	100	5 - 10
Horizontal Reflectometer[b] (FREIA)	0.25	2 - 23	100	1×8
Vertical Reflectometer[a] (ESTIA)	0.16	5 - 9.4	100	0.5×2
Bi-Spectral Powder Diffractometer[a] (POWTEX)	11.69	0.5 - 20	< 10	2×2
Thermal Powder Diffractometer[b] (HEIMDAL)	15.002	1 - 13	100	3×3
Material Science & Engineering Diffractom.[a] (BEER)	6.4925	0.1 - 7	10	2×5
Macromolecular Diffractometer[a] (NMX)	1.08	1.8 - 3.5	1000	0.2
Cold Chopper Spectrometer[a] (C-SPEC)	47.47	1.5 - 20	10	25×25
Bi-Spectral Chopper Spectrometer[a] (VOR)	25.65	0.8 - 20	10	20×20
Inverse TOF Spectrometer[b] (CAMEA)	2.4	1 - 8	< 10	5×5
Total	**[130 - 138]**			

Table 1: Estimated detector requirements for the 22 reference instruments in terms of detector area, typical wavelength range of measurements and desired spatial and time resolution. The foot notes indicates the tranche in which the instruments is presently intended to be delivered.