Detectores para Neutrões Térmicos
Active Scintillators for Neutron Detectors
RPCs for Neutron Detectors

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Thermal Neutron Detectors

- nuclear reactions to convert neutrons

- \( n + 3\text{He} \rightarrow 3\text{H} + 1\text{H} + 0.764 \text{ MeV} \)  
  Gaseous detectors (CF4, prop.)

- \( n + 6\text{Li} \rightarrow 4\text{He} + 3\text{H} + 4.79 \text{ MeV} \)  
  Scintillators

- \( n + 10\text{B} \rightarrow 7\text{Li}^* + 4\text{He} \rightarrow 7\text{Li} + 4\text{He} + 0.48 \text{ MeV} \gamma + 2.3 \text{ MeV} \)  
  \[ 7\text{Li} + 4\text{He} \rightarrow 7\text{Li} + 4\text{He} + 0.48 \text{ MeV} \gamma + 2.8 \text{ MeV} \)  
  (93%) (7%)

- \( n + 155\text{Gd} \rightarrow \text{Gd}^* \rightarrow \gamma\text{-ray spectrum} \rightarrow \text{conversion electron spectrum} \)

- \( n + 157\text{Gd} \rightarrow \text{Gd}^* \rightarrow \gamma\text{-ray spectrum} \rightarrow \text{conversion electron spectrum} \)

- \( n + 235\text{U} \rightarrow \text{fission fragments} + \sim 160 \text{ MeV} \)

- \( n + 239\text{Pu} \rightarrow \text{fission fragments} + \sim 160 \text{ MeV} \)
Gaseous detectors

\( n + 3\text{He} \rightarrow 3\text{H} + 1\text{H} + 0.764 \text{ MeV} \)

CF4 should be added to control the range -3 bar for 1mm FWHM

- CF4 is a good scintillator, but only a few primary photons
- Secondary scintillation ~ .3 photon per secondary electron
For neutron reflectometers, there is a need for fast thermal neutron detectors with 20 cm x 20 cm sensitive area with improved 2D spatial resolution.

The aim of this JRA is the development of new detector technologies based on Gaseous Scintillation Proportional Counters (GSPC).

Our goal is to demonstrate the feasibility of a detector with the following performances:

- Resol 0.5 mm in X and Y / Area 20 cm x 20 cm
- Counting rate > 10 kHz (local) / 1 MHz (global)

Solution proposed: MSGC Light readout with a matrix of PMTs
WP22 Detectors

Objectives

- Development of new detector technologies based on Gaseous Scintillation Proportional Counters (GSPC)
- Explore their potential to overcome the limitations in light output and rate capability of existing scintillation detectors
- Investigate their potential as high resolution detectors for Reflectometry or time resolved SANS.
- Built and study small scalable prototypes

The aim of this JRA is the development of new detector technologies based on Gaseous Scintillation Proportional Counters (GSPC). These devices have the potential of improving the performance of high position resolution detectors used in reflectometry and time resolved SANS. Present state of the art detectors, such as 3He-based Multi Wire Proportion Chambers already limit the performance of existing reflectometers due to their moderate count rate capability. They only provide limited spatial resolution of $x \sim 1-2$ mm and a time resolution in the microsecond range. More advanced devices based on solid ELI doped glass scintillators with Anger camera readout, e.g. as recently developed at the SNS, can partially improve the performance achieving high position resolution ~1 mm and providing good timing resolution due to the fast scintillation light pulse with a duration of about 200 ns. The low light output of ELI glass however, diminishes the count rate capability due to the signal integration time required. A major drawback of ELI based glass scintillation detectors is a non negligible sensitivity to a high gamma background environment.

More fast light amplifying structures like MSGCs have been shown to be very efficient in the production of fast scintillation light in the visible region when operated in the proportional mode in gas mixtures of 3He:CF4. Photon yields per detected neutron can be ~100 times larger than that of ELI glass and light signal durations of less than 80 ns have been observed. In the proposed JRA particular emphasis is therefore placed on the development and study of new technologies based on these Gaseous Scintillation Proportional Counters with light readout. The application of this new technology in neutron detection could enable the design of neutron counting detectors with superior performance that exhibit a high count rate capability of up to 10 MHz, a high spatial resolution (~1 mm) and a low gamma sensitivity on a par with gaseous detectors.

Neutron Detection with a GSPC

GSPC with Anger Camera readout mounted for a test at ILL beam station CT4
**W22 - Detectors - Participants**

<table>
<thead>
<tr>
<th>Partners</th>
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<tbody>
<tr>
<td>ILL - Institut Laue-Langevin</td>
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<tr>
<td>LIP - Laboratório de Instrumentação e Física Experimental de Partículas, Portugal</td>
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<tr>
<td>STFC - Science and Technology Facilities Council</td>
</tr>
<tr>
<td>FZJ - Forschungszentrum Jülich</td>
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<tr>
<td>CNR - National Research Council, Italy</td>
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<td>TUM - Technischen Universität München</td>
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<tr>
<th>Observers</th>
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<td>ToU - University of Tokyo</td>
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* LIP gas scintillation, simulation of the detector
The LIP team

Francisco Fraga Researcher (LIP/FCTUC) 80
Andrey Morozov Researcher (LIP) 70
Luis Margato Post-Doc (LIP) 15
Luis Pereira PhD student (LIP) 100
Margarida Fraga Researcher (LIP/FCTUC) 70
Our first prototype and a view of the detector being built by the collaboration
CF4 emission spectra

Emission spectra from different pressures are scaled using the ph/el ratios discussed below.
Ph/el ratios for the charge gain of \(~70\) from experimental series where either the gas pressure or the charge gain was the fixed parameter.
CF4 Secondary Scintillation

Time Spectra: Setup 2

Validation of the method

Visible component
MS ILL6C: CF4 - 5.0 bar

- Sec. Scint.: Ch-PM2 (Fe-55)
- Sec. Scint.: PM1-PM2 (Fe-55)

5 bar CF4: Setup 1 performance vs. Setup 2

Start trigger: PMT R5070A (pulse mode)

Stop trigger: PMT R4124 (single photon counting mode)
CF4 Secondary Scintillation

Time Spectra: CF$_4$ at 1 bar

ILL6C MSGC “DESAG D263 glass substrate” vs. Elect. glass MSGC “Shott S8900 glass substrate”

An overlap between the time-spectra for both MSGCs is observed and this either for the emission in the UV and visible ranges.

Time spectra recorded with the MSGC on S8900 glass shows a lower jitter in the start trigger.
UV reveals a multi-component scintillation decay time profile

Increasing the pressure the faster decay shows at 1 bar \( (\tau_f \sim 2 \text{ ns}) \) tends to be slower \( (\tau_f \sim 10 \text{ ns}) \) and remains approximately constant from 3 to 5 bar.

For a time above 80 ns the decay curve does not change significantly with pressure \( (\tau_s \sim 40 \text{ ns}) \)
CF4 Secondary Scintillation

Time Spectra: 1, 3 and 5 bar CF$_4$

Elect. Glass MSGC

Visible emission:

– Decay time profile appears to be insensitive to the CF$_4$ pressure (1 to 5 bar)

– Produces single time constant secondary scintillation showing a fast decay time

Typical effective lifetime of $\tau \sim 15$ ns
New features in ANTS: Distortion corrections

☑ Experimental data (text array or .bmp file) can be processed

Shift + rotation to match the experimental geometry, then corrections for the distortions due to the localization algorithm

New features for neutron mask simulation mode:
- um/pixel for the mask file;
- 100 → 20 um tracking array step;
- Possible to save data as an array or .bmp file with an arbitrary step

A. Morozov et al, LIP Coimbra
Schematic view and cross section of the GSPC prototype developed at ILL

2D-position spectrum of 2.5Å neutrons with a multi-hole / slit mask mounted in front of the GSPC recorded with the 32-channel readout system. Data analyzed with ANTS, using adaptive algorithms.
Final results: Position resolution (FWHM) as a function of gas gain and CF$_4$ pressure.
Global $^3$He shortage

- Annual production <30kl, demand >60kl (R. Cooper, Oak Ridge at ILL seminar Sep 2009)
- Cost has risen over ~2 years from $75/l to ~$6500/l
- But cost is irrelevant as effectively unavailable

Helium-3 cost per litre

- US stock pile now "strategic asset"
- Production based on tritium decay, 12 year half-life so no short term solution

R.L. Kouzas, US Department of Energy PNNL report 18388
Table 1. Projected demand of helium-3 for neutron detectors at neutron scattering facilities in the period 2009–2015.

<table>
<thead>
<tr>
<th>Facility</th>
<th>Maintenance [litre/year]</th>
<th>small detectors [litre]</th>
<th>large detectors [litre]</th>
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<tr>
<td>ORNL (SNS)</td>
<td>100</td>
<td>1,300</td>
<td>17,100</td>
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<tr>
<td>ORNL (HFIR)</td>
<td>100</td>
<td>1,210</td>
<td>1,060</td>
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<td>Los Alamos</td>
<td>100</td>
<td>1,994</td>
<td>12,362</td>
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<tr>
<td>NIST</td>
<td>100</td>
<td>560</td>
<td></td>
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<tr>
<td>BNL</td>
<td>50</td>
<td>180</td>
<td></td>
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<tr>
<td>FRM II</td>
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<td>650</td>
<td>4,500</td>
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<td>1,000</td>
<td>3,000</td>
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<tr>
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<td>LLB</td>
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<td>600</td>
<td>600</td>
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<td>PSI</td>
<td>50</td>
<td></td>
<td>2,000</td>
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<tr>
<td>STFC</td>
<td>100</td>
<td>400</td>
<td>11,300</td>
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<tr>
<td>J-PARC</td>
<td>100</td>
<td>40</td>
<td>16,100</td>
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<td>JRR-3</td>
<td>31</td>
<td>71</td>
<td></td>
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<tr>
<td>BNC/KFKI</td>
<td>50</td>
<td>118</td>
<td>500</td>
</tr>
<tr>
<td>Sum</td>
<td>1,171</td>
<td>8,658</td>
<td>83,572</td>
</tr>
</tbody>
</table>

But cost is irrelevant if He-3 are not available.
Research and development of B4C coated Multi-Gap RPCs for position sensitive thermal neutrons

Common nuclear Reactions for Neutron Detectors

- $n + ^3\text{He} \rightarrow ^3\text{H} + ^1\text{H} + 0.764 \text{ MeV}$ \hspace{1cm} ($\sigma_c = 5330 \text{ barns for } 1.8 \text{ Å}$)
- $n + ^6\text{Li} \rightarrow ^4\text{He} + ^3\text{H} + 4.79 \text{ MeV}$ \hspace{1cm} ($\sigma_c = 937 \text{ barns for } 1.8 \text{ Å}$)
- $n + ^{10}\text{B} \rightarrow ^7\text{Li}^* + ^4\text{He}$ \hspace{1cm} \rightarrow ^7\text{Li} + ^4\text{He} + 2.31 \text{ MeV} + \text{ gamma (0.48 MeV)} \hspace{1cm} (93\%)$
  \hspace{1cm} \rightarrow ^7\text{Li} + ^4\text{He} + 2.79 \text{ MeV} \hspace{1cm} (7\%)
  \hspace{1cm} ($\sigma_c = 3840 \text{ barns for } 1.8 \text{ Å}$)
- $n + ^{14}\text{N} \rightarrow ^{14}\text{C} + ^1\text{H} + 0.626 \text{ MeV}$
- $n + ^{157}\text{Gd} \rightarrow \text{Gd}^* \rightarrow \text{gamma-ray spectrum} + \text{conversion electron spectrum (~70 keV)}$
- $n + ^{235}\text{U} \rightarrow xn + \text{fission fragments} + \sim 160 \text{ MeV} \hspace{1cm} (<x> \sim 2.5)$

Natural fraction

$^{10}\text{B}: 19.8\%$
$^6\text{Li}: 7.6\%$
$^{157}\text{Gd}: 15.7\%$
Research and development of B4C coated Multi-Gap RPCs for position sensitive thermal neutrons
Research and development of B4C coated Multi-Gap RPCs for position sensitive thermal neutron detectors

Range of He and Li in B4C

\[ \text{n} + ^{10}\text{B} \rightarrow (^{11}\text{B})^* \]

\[ ^{7}\text{Li}^*(0.84 \text{ MeV}) + ^{4}\text{He} (1.47 \text{ MeV}) \quad Q = 2.31 \text{ MeV (94\%)} \]

\[ ^{7}\text{Li} (1.02 \text{ MeV}) + ^{4}\text{He} (1.78 \text{ MeV}) \quad Q = 2.79 \text{ MeV (6\%)} \]
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Induced Signals

Neutron beam

Readout Electrodes (X-axis)

Resistive paint to apply High Voltage

Plate of glass coated with \(^{10}\)B4C

Readout Electrodes (Y-axis)

\[ n + ^{10}\text{B} \rightarrow (^{11}\text{B})^* \]

\[ ^{7}\text{Li}^* (0,84 \text{ MeV}) + ^4\text{He} (1,47 \text{ MeV}) \quad Q = 2,31 \text{ MeV (94\%)} \]

\[ ^{7}\text{Li} (1,02 \text{ MeV}) + ^4\text{He} (1,78 \text{ MeV}) \quad Q = 2,79 \text{ MeV (6\%)} \]
Research and development of B4C coated Multi-Gap RPCs for position sensitive thermal neutrons

Multi-gap Configuration Detector Concept

2 x 5 layers of $^{10}$B4C converter
Research and development of B4C coated Multi-Gap RPCs for position sensitive thermal neutrons

Project of the RPC detectors prototypes

Geometry
- Area: 8 cm x 8 cm;
- Gap thickness: ~ 0.30 mm;
- Number of gap’s: 1 to 5;

Boron Layers
- B4C Layers deposited on glass by DC-Sputtering;
- Layers thickness: ~ 1 µm;

Gases
- Freon R134a: F_3C – CH_2F (Tetrafluoroethane);
- Iso-Butane
- SF6;
Research and development of B4C coated Multi-Gap RPCs for position sensitive thermal neutrons

Deposit of B4C layers by DC-Sputtering in the Engineering Surfaces Group at the Mechanical Engineering Research Center - University of Coimbra

Plate of soda lime glass (0.4 mm thick) coated with a 0.5 μm layer of B4C
Research and development of B4C coated Multi-Gap RPCs for position sensitive thermal neutrons

RPC detector prototype
Concursos de Projectos de I&D
Calls for R&D Projects

**Título do projeto (em português)**
Project title (in portuguese)
RCPs revestidas com boro para detectores de neutrões

**Título do projeto (em inglês)**
Project title (in english)
Boron coated RPCs for thermal neutron detectos
Título do projeto (em português)  Project title (in portuguese)  
Investigacao e desenvolvimento de Multi-Gap RPCs com revestimentos de B4C para detectores de neutroes termicos sensiveis a posicao

Título do projeto (em inglês)  Project title (in english)  
Research and development of B4C coated Multi-Gap RPCs for position sensitive thermal neutron detectors
Expressions of Interest submitted to NMI3 for a possible Joint Research development in High resolution, High rate Neutron detectors

- **Task 1**: $^{10}$Boron gas detector development
  Partners: ICMA, HZG, BNC, ILL, TUM, ESS, LLB, CNR Milano, LIP
  
  *One detector technology that has not been explored extensively for neutron scattering applications is resistive plate chamber technology. RCPs lend themselves very well to a layered configuration and are used in HEP as time projection chambers. LIP, who has been developing RCPs for 15 years, will explore the potential of these devices, interspersed with layers of $10B_4C$, for neutron scattering applications. Advantages include sub-millimetre position resolution, nanosecond time resolution and large area coverage with many square meters currently in operation in other applications.*

- **Task 2**: Scintillation detector development
- **Task 3**: 3He detector development
- **Task 4**: Imaging detector development