Proposal Title and Acronym

u-RWELL Advanced Neutron Imaging Apparatus

uRANIA

This proposal responds to challenges in the following domain

Sensors

Coordinator's name and email address

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Consortium Composition Table

	Organization full name	Organization short name / PIC number	Organization type[1]	Contact person name	Contact person email
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1 Research Infrastructure, University, SME, Large Corporation, Research & Technology Organization, Start-up. If other, please specify.

Project Public Summary

Structural alongside functional smart materials play an important role in modern industry and technology. The behavior of such materials is often governed by their structural properties. Knowledge on their specific grain formation and orientation is crucial for their development and use in prospective applications. Neutron diffraction plays a central role in the structural characterization of such materials, in particular when assessing the representative volumes in bulk specimen the superior penetration of neutrons, as compared to other transmitting radiation, is required for many materials. However, neutron techniques meet limitations, when high spatial resolution is required, e.g. to characterize protein crystals which typically can be grown only in tiny amounts. While the latest generation of neutron sources is meant to reach the flux to achieve the required performance, there is an immediate need of technological progress of neutron detectors providing flexible angular coverage and geometries, high spatial and temporal resolution. Only time resolutions better than µs allows taking advantage of state-of-the-art pulsed spallation neutron sources and a high space resolution (~100 µm) assessing the relevant structural in potentially down-sized experimental configurations.

We aim to develop an innovative detector for diffractive neutron imaging based on micro-Resistive WELL (µ-RWELL) technology: a compact, spark-protected, single-amplification stage Micro-Pattern Gas Detector. The proposed technology, developed in the framework of HEP experiments, can be exploited for high resolution thermal neutron imaging using a ^{10}B coated cathode as neutron converter. The envisioned detector specifications for diffraction imaging will also satisfy the needs for other cutting edge high resolution time-of-flight diffraction applications.

Key-points are the scalability and production of large-area detectors as well as the mechanical flexibility that allows to adapt the design to different geometries and applications: cylindrical µ-RWELL detectors are under study for HEP but could also be exploited for large acceptance neutron diffraction for crystallography studies constituting a breakthrough for neutron instrumentation. The µ-RWELL, based on standard rigid and flexible photolithography processes, leads to a straightforward technological transfer to industry, which is one of the main goals of this project.

The project aims to prove these characteristics by developing and testing small planar prototypes with readout boards suitably segmented with strip/mini-pad readout, equipped with existing electronics. A full characterization of the prototype will be done by means of a neutron beam test.
This proof of concept can lead to the development of detectors for direct neutron imaging for which a multi-pixel anode coupled with suitable front-end electronics will allow fine reconstruction at high rate. Such a device will constitute a breakthrough in neutron beam diagnostic.

1. Project Description

The advent of a new generation of powerful spallation neutron sources provides the precondition for significant advances in neutron science applications in condensed matter research. The increased source brilliance and the intrinsic time structure of the source on the one hand enable unprecedented resolutions and ever smaller samples to be sufficient for analyses [1]. On the other hand, these potentials set new higher requirements on detector technology in order to profit from the provided gains [2]. Novel detectors need to provide unparalleled spatial resolution in order to fully profit from measurements of small samples in downsized instruments and from increases in spatial resolution capabilities of the high flux neutron instrumentation. At the same time resolution has to be sufficient to exploit the intrinsic time-of-flight measurement capabilities. Examples are the foreseen advanced protein crystallography instrument at the European spallation neutron source, which utilizes the unique sensitivity of neutrons for hydrogen in order to fully assess protein structures in smallest single crystals, where x-rays fail to “see” the hydrogen atoms and their positions. Another example is posed by the newest developments of grain mapping in structural and functional materials through neutron Laue diffraction imaging. This method profits from a large detector coverage and a detector with sufficient spatial resolution being capable of time-of-flight measurements at a powerful pulsed spallation source can pave the way to unparalleled detail becoming available to the investigation of structural properties in key materials spanning the micro-, meso-, and macro-scale [3]. Availability of such wealth of knowledge on the specific grain formation and orientation in complex advanced structural and functional materials dependent on manufacturing and service conditions is crucial e.g. for progress in advanced manufacturing.

This project aims to investigate neutron detectors expanding beyond the present MPGD and neutron detection technology, and to develop a new generation of detectors, based on the μ-RWELL architecture [4]. This device, recently proposed at INFN-LNF, has the main characteristics of present-day MPGDs, but is more robust from the point of view of gas discharges, easier to build and can be completely manufactured with standard cost-effective industrial processes.

The novel MPGD, based on the resistive detector concept, ensuring an efficient spark quenching mechanism, is a highly reliable device. In addition, since the detector does not require any complex or time-consuming assembly procedures (neither stretching nor gluing), it becomes extremely simple to be assembled. The detector is composed of only two elements, i.e. the readout-PCB embedded within the amplification stage (the core of the detector named μ-RWELL_PCB) and the cathode. The amplification stage of the detector, realized by photolithography as a matrix of wells (with a pitch of 140 μm and a diameter of 60-70 μm) on a 50 μm thick polyimide substrate, is embedded through a resistive layer within the readout board. The manufacturing of such detector components is based on standard rigid and flexible photolithography processes typical of the PCB industry.

The resistive layer is realized by means of an industrial process with DLC (Diamond Like Carbon) sputtering by the Be-sputter Company in Japan. The required surface resistivity, typically ranging from few tens to hundreds of MOhm/square, is clearly a parameter that must be optimized as a function of the detector performance, such as rate capability, spark amplitude quenching and maximum achievable gain.

A cathode electrode defining the gas conversion-drift gap completes the detector mechanics: depositing few μm of ^{10}B on the cathode, will allow thermal-neutron detection. Few microns of ^{10}B deposition can activate the release of an alpha particle, inside the active volume of the device, and a ^{7}Li atom ($^{10}B + {}^{1}n \rightarrow {}^{7}Li + \alpha$).

The layout of the readout should then be very similar to the one proposed for X-rays detection, in order to perform a 3D reconstruction Boron-10-based detectors is one of the technologies being developed at ESS and has been demonstrated as an efficient and convenient alternative to the He-3-based technologies [5]. The geometry (shape and thickness) of the converter layer is crucial for the conversion efficiency of the detector.

A relevant part of the project is represented by the reconstruction software that allows to exploit the full potential of the readout electronics by means of processing charge and time information to estimate the position of the neutron interaction. Charge centroid and μTPC clusterization algorithms, developed for the BESIII Cylindrical GEM detector, will be adapted to the new detector configuration [8].

Prior to be characterized on a neutron beam line, the prototypes will be tested at the Source Testing Facility (STF) [6] of Lund University in Sweden, where the detector will be irradiated using neutron sources and characterized with the available Neutron Tagging setup. At STF, the prototypes can be directly compared with ESS detectors, to validate the characteristics in neutron detection. The final characterization with a neutron beam will be performed at PSI (Paul Scherrer Institut, Zurich, Switzerland) or at a partner lab of PSI, through PSI NIAG.

The target performance for a μ-RWELL based neutron detector is:

- spatial resolutions < 100 μm and time resolution < 20 ns
- rate capability up to MHz/cm^2
- neutron detection efficiency > 10 % @ 2.5Å (depending of the converter design)

2. Technology Benchmark

μ-RWELLs exploit solutions and improvements introduced in the last years for the most common MPGDs:

- inherits and improves the GEM amplifying scheme with the peculiarity of a well-defined amplifying gap, but ensuring higher and more uniform gain, with no transfer gap whose non-uniformity could affect the detector gain;
- inherits the MicroMegas resistive scheme that allows a strong suppression of the discharge amplitude.

From the construction point of view an obvious advantage of the proposed technology is that the detector does not require complex and time-consuming assembly procedures and is definitely much simpler than many other existing MPGDs (such as GEM and MM), being composed of only two main components.

In addition, since the manufacturing of the detector components is essentially based on standard rigid and flexible photolithography processes, the construction of the detector can be completely transferred to the industry. In particular, the anode PCB manufacturing, apart from the DLC coating, will be performed by ELTOS S.p.A. (Italy) that will be in charge of the construction of all components apart from the etching of the polyimide-based amplification stage that will be performed by TECHTRA (Poland), already involved in the manufacturing of GEM foils for the CERN store. The complete industrialization of the manufacturing process of the μ-RWELL is one of the key-points of the proposed technology, that opens the way towards possible large scale production (also in other fields of application w.r.t. the one proposed in this project). The micro-RWELL combining excellent spatial resolution, high time performance and the capacity to stand high fluences, with the possibility to cover a large active area together with a high mechanical/geometrical flexibility, would be a unique solution in the panorama of detectors for neutron and X-ray imaging.

We aim to carry out the full proof of concept which will lead to the technology development of large acceptance detectors for neutron diffraction, constituting a step forward in neutron instrumentation. This project will also lead to the study of detectors for direct neutron imaging for which the integration with some suitable high-density integrated electronics is needed [7]. Such a device will constitute a breakthrough in neutron beam diagnostics.

3. Envisioned Innovation Potential

By the beginning of the next decade ESS is going to provide the world's most powerful pulsed neutron source for world class experiments, playing a fundamental role in the science of everyday life (e.g. the development of better computer chips, cosmetics, detergents, textiles, paints, fuels, drugs, batteries and plastics). Nowadays, the use of 3He as neutron converter is severely restricted by to the shortage of commercial 3He worldwide, and a general effort is currently carried out for a replacement in neutron detectors.

With this project, we will provide an innovative neutron detection technology suitable for instruments for which high rate capability, large area, and sub-millimeter spatial resolution together with mechanical flexibility are required.

Compared to the state-of-the-art of the MPGD-based neutron detector we expect to prove that the μ-RWELL has the same excellent characteristics of GEM/MM detectors, with an improved reliability and operability, and a large reduction in the production costs thanks to the engineering and industrialization of the manufacturing process of the μ-RWELL technology.

This project will have a wide impact in neutron imaging especially for neutron diffractometry for crystallography studies that would exploit the mechanical flexibility of the μ-RWELL, an almost unique feature of such a technology.
In addition, taking into account the involvement of private industries in the R&D, this project is expected to positively affect all those fields of applications (from HEP to industrial, medical and homeland security applications as well as X-ray imaging) where large area tracking technology with high space and good time resolution, together with rad-hard characteristics, are required.

4. Project Implementation, Budget Breakdown and Final Deliverables

In the following we specify the project development, with the identification of the role of each unit with regards to expected targets, and related modalities of integration and collaboration.

Consortium composition
The Consortium is composed of four units: a research organization, the INFN, further divided into three sub-units Bologna (BO), Ferrara (FE) and Frascati Laboratories (LNF), the Lunds Universitet (LU), and two industrial partners (ELTOS and Techtra). The INFN groups provide the knowledge of the μ-RWell detector and the technology transfer to the industrial partners. LU provide direct access to the ESS Coating Workshop in Linköping, Sweden. The workshop has been created to optimize the deposition of $^{10}B_4C$ coatings for high quality neutron converters, needed for the construction of cutting-edge ^{10}B detectors. LU unit provides also direct access to ESS for the study possible applications of the new technology to the instruments currently under development.

Project implementation
The project will be subdivided into the following tasks:
Task 1: detector design & prototype construction (PCB, DLC deposition, amplification stage, Cathode preparation w/Boron-deposition, QC/QA, electronics integration) - M1-7
Task 2: optimization and industrialization of the production processes in collaboration with selected industrial partners (ELTOS, TECHTRA) - M1-12
Task 3: prototype characterization
- with X-rays (charge collection, gain, rate capability) - M8
- with alpha and neutron sources (conversion efficiency, charge collection) – M9-10

Task 4: development, test and tuning of reconstruction algorithms - M1-9
Task 5: test with thermal neutrons, data analysis and publication of the results – M11-12

A Gantt chart showing the project timeline is reported in Fig. 1 together with the units involved in each task.

Deliverables
Within one year, the project is expected to achieve the definition of the manufacturing processes of the PCB_RWELL at ELTOS and polyimide etching at TECHTRA which will lead to the possibility of industrial production of the new detector.
The project is expected to deliver the following items:
1. a μ-RWell prototype with Boron-10 cathode fully characterized for diffractive neutron imaging
2. a project summary, a poster and a scientific journal paper summarizing the main results of the project

Particular attention will be given to the dissemination of the results, that will presented to international conferences and seminars. A public web page of the project will also be available within one month from the beginning of the project.

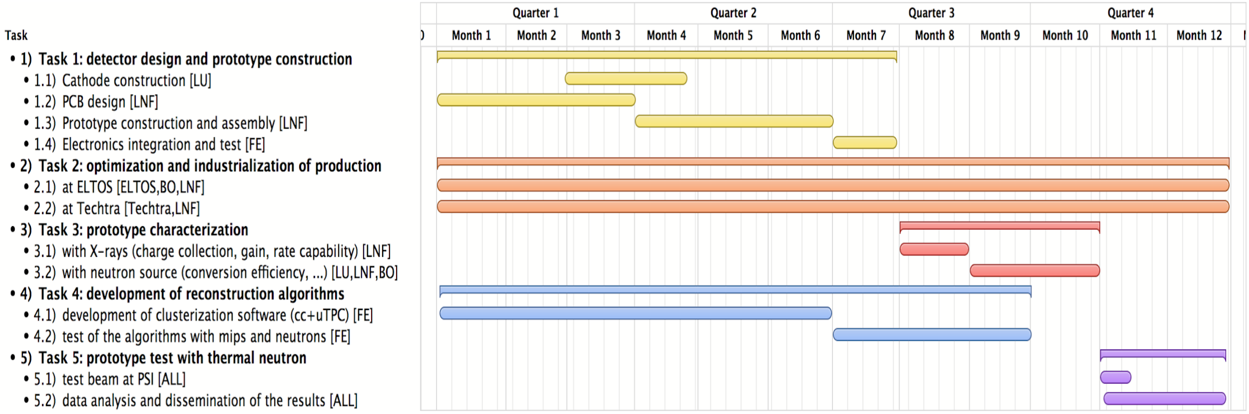

Figure 1: Gantt chart of the project.

Budget

	INFN FE	**INFN BO**	**INFN LNF**	**LU**	**Eltos**	**Techtra**	**Total**
Travels for meetings with collaborators	1	1	1	1	1	1	**6**
Travels for technology transfer		3	6				**9**
Travels for detector characterization and test	5	5	5	2			**17**
TT of the PCB_RWELL to ELTOS			24				**24**
TT of the Polyimide etching to TECHTRA			12				**12**
R&D on improved DLC+Cu sputtering			4				**4**
Boron target				19			**19**
DAQ and electronics	5						**5**
Neutron test beam	3						**3**
Open publications	1						**1**
	15	**9**	**52**	**22**	**1**	**1**	**100**
	11.7%	7.0%	40.6%	17.2%	0.8%	0.8%	78.1%

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