WP 9 Instrumentation: Detectors

Bilbao 29 May 2019

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This project is funded by the European Union (GA no. 654000)

1. Objectives

AIMS

Develop neutron detectors for reflectometry applications relevant to the ESS

- **Spatial resolution 1 – 3 mm**
- **Time resolution better than 100 µs**
- **Local instantaneous rate capability of several kHz/mm^2**

Evaluation of the latest silicon PMs and devices for MuSR, particularly with regard to rate capability and fast timing applications

TASKS

- **Task 9.1: Involvement of industry and the wider European neutron and muon detector communities in detector development**
- **Task 9.2: Development of scintillation detectors with high rate capability for reflectometery**
- **Task 9.3: 3He based microstrip gas chamber with a novel 2D readout**
- **Task 9.4: Emergent Detector Technologies for neutron scattering and muon spectroscopy**
- **Task 9.4.5: Single neutron detection in scintillators using CMOS cameras**

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WP 9: Task 9.1

TASK 9.1:

Involvement of industry and the wider European neutron and muon detector communities in detector development (All)

- **Invite manufacturers of critical detector componenents to selected RTD meetings**
- **Invite would-be manufactureres of detectors to selected RTD meetings**

    Stimulate transfer of detector requirements to industry

First extended RTD meeting in 13-14 June 2017 - Deliverable 9.1

Representatives from 6 companies attended - KPI W9.1

A mixture of firms building detectors and building components for detectors

- **Invite detector personnel from groups outside RTD to participate in RTD meetings**

    Promotes exchange and desemmination of information

UMB and ENEA have given invited talks at the Abingdon RTD meeting

Prof. Paulo Fonte gave an excellent overview of RPC detectors at the Coimbra meeting

UMB and JCNS gave invited talks at the PSI RTD meeting

SINE 2020 WP9 talks embeded in Position Sensitive Detector Workshop May 2018 at Juelich

Representatives from 7 companies exhibited and others attended

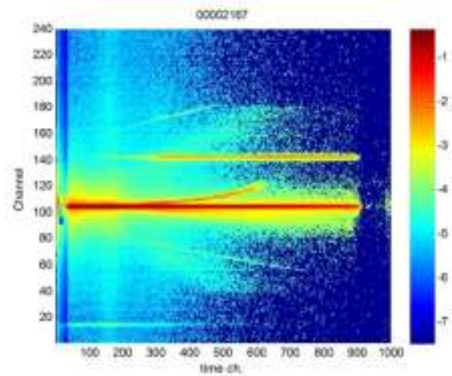
WP 9: Task 9.2.1

TASK 9.2:

Development of scintillation detectors with high rate capability for reflectometry

- **9.2.1 ZnS scintillation detector with WLS fibre readout (STFC)**

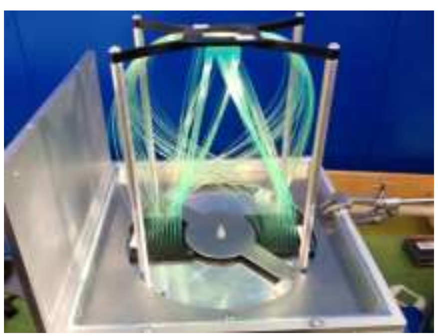
768 pixels
0.5 x 60 mm^2

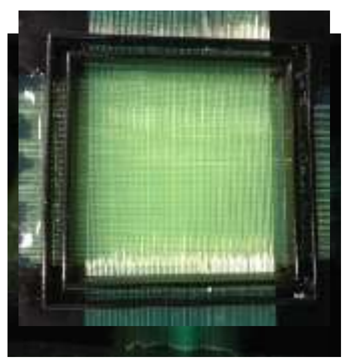


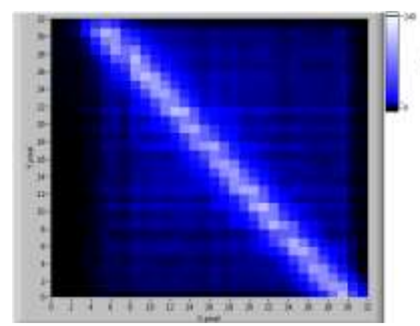
192 PMT pixels, but most of the data goes into just two PMT pixels

Distribute data high intensity data across all PMTs rather than just a few

Adjacent horizontal and vertical pixels deliberately coded to different PMTs







0.7 mm^2 resolution
Need to eliminate ghosting

4096 pixels 0.5 x 0.5 mm^2 **First detector hardware** **Deliverable 9.1**

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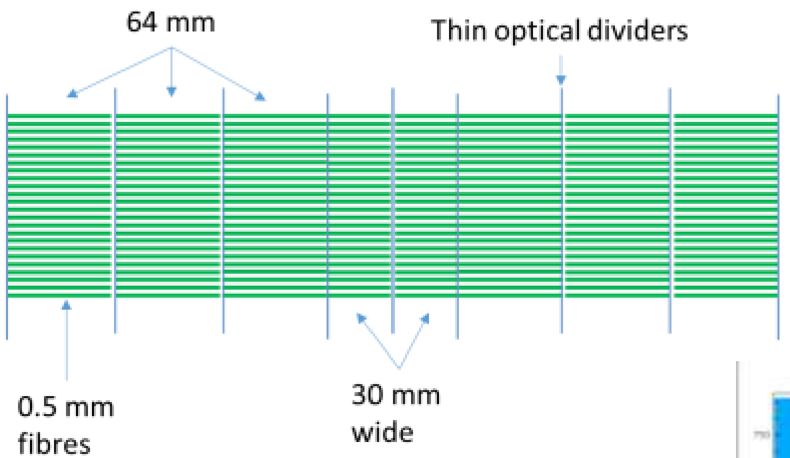
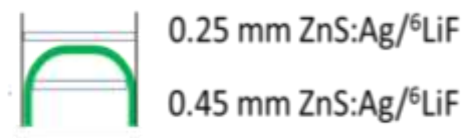
WP 9: Task 9.2.1

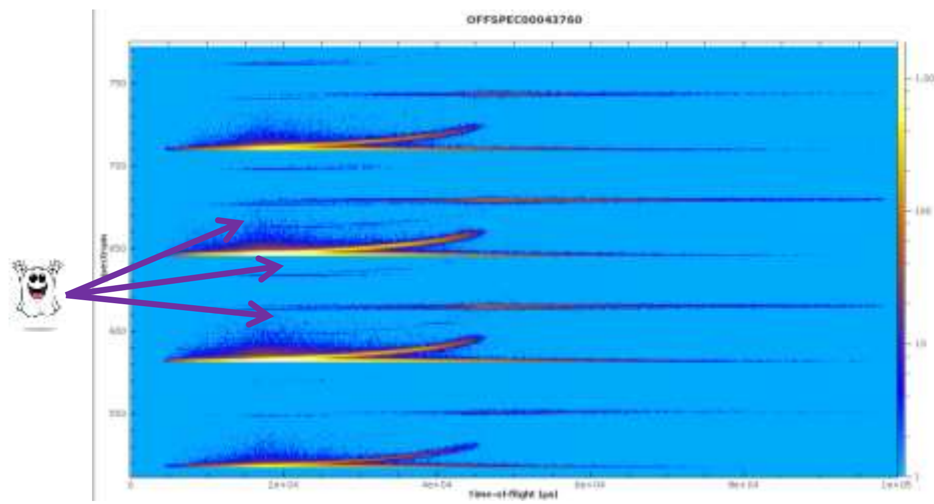
- **9.2.1 ZnS scintillation detector with WLS fibre readout (STFC)**

Focusing guides are increasing the required detector width 60 – 450 mm

Can improve count rate capability by course pixelation in width







SHARD2 Detector: Segmented high aspect ratio 2D 4 x 64 element detector into one 64 channel PMT

Segmentation works well,, but code not optimised. Still Ghosting

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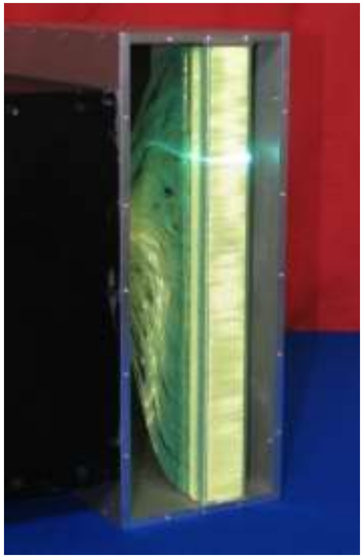
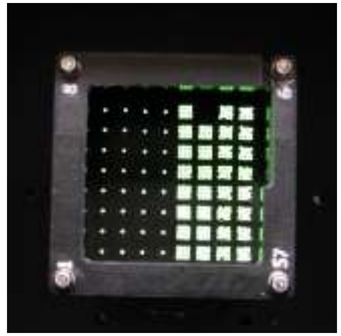
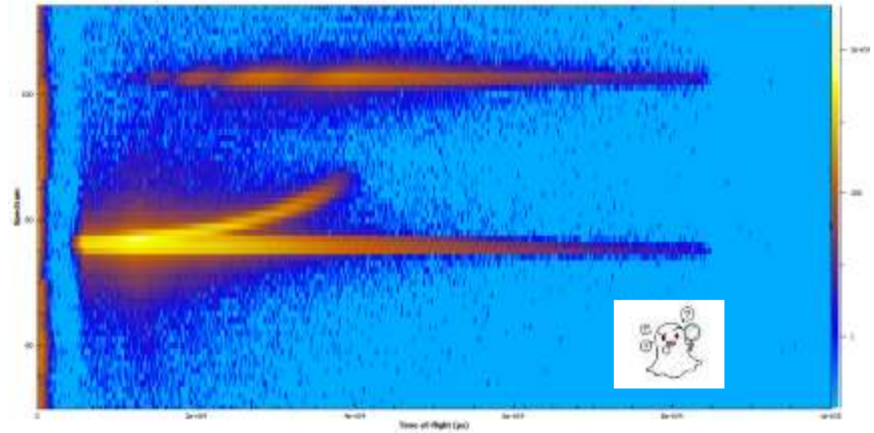
WP 9: Task 9.2.1



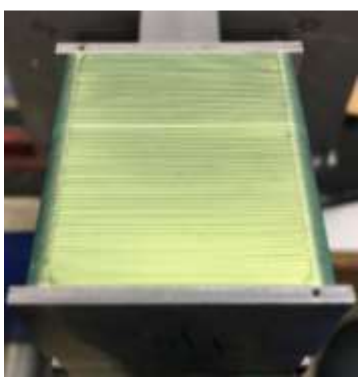




High rate region – low code
Low rate regions – high code
Optical separators to limit cross talk

No Ghosting

~ 1mm resolution



~ 0.6 mm resolution

	Requirements	SHARD2
Neutron Detection Efficiency	40% at 1.8 A	45% (0.25mm front scint) 60% (0.45mm front scint) at 1.8 Å
Gamma Sensitivity	10^{-6} at 1MeV	3×10^{-7} at 1MeV
Position Resolution	1-3 mm	0.6 mm
Timing Resolution	100 µs	10 µs
Rate Capability	(several) kcps/mm²	1 kcps/mm²
Placement Accuracy	99.99%	99.99%

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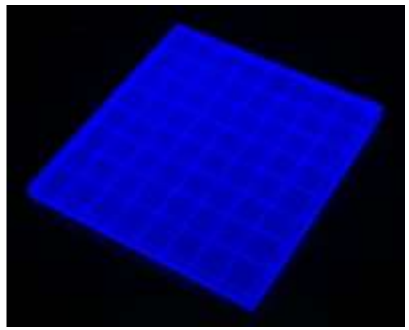
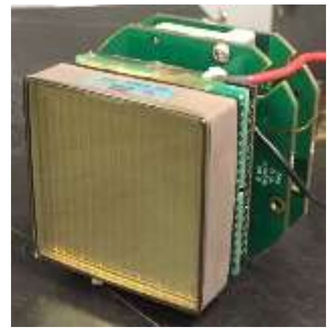
WP 9: Task 9.2.2

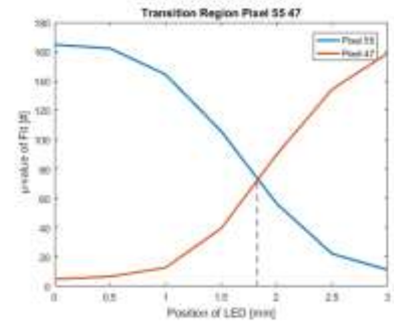
- **9.2.2 Scintillation detector with direct PMT readout (FZJ)**

Use of Li glass scintillator drectly coupled to PMT for high light collection

64 channel H8500 PMT gives 6 x 6 mm intrinsic resolution



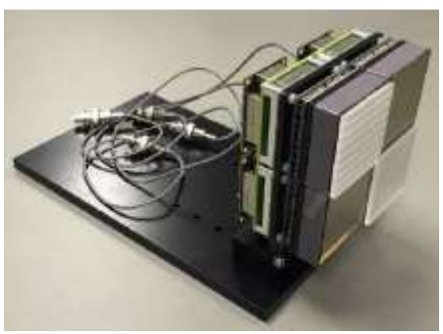


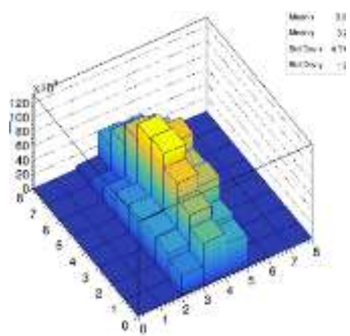


Transparent scintillator grooved and grooves filled with reflector

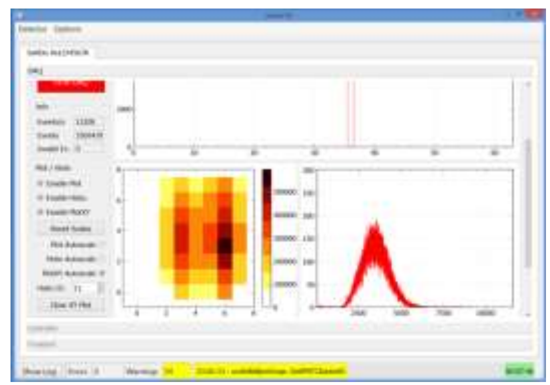
Rosmap electronics used for initial evaluation

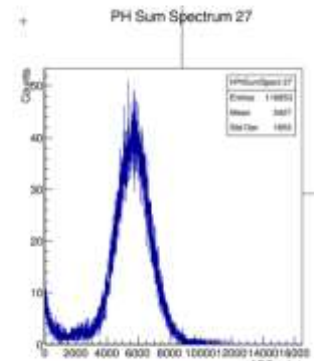
Fast electronics system now developed





High Rate Mode 250 kHz / mod
125 kHz per pixel 6 x 6 mm² resln.





Screenshot of the readout and control Software for the Detector Module and a pulse height spectra

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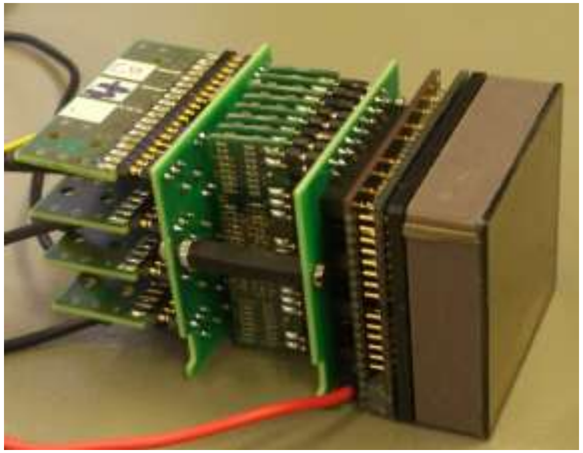
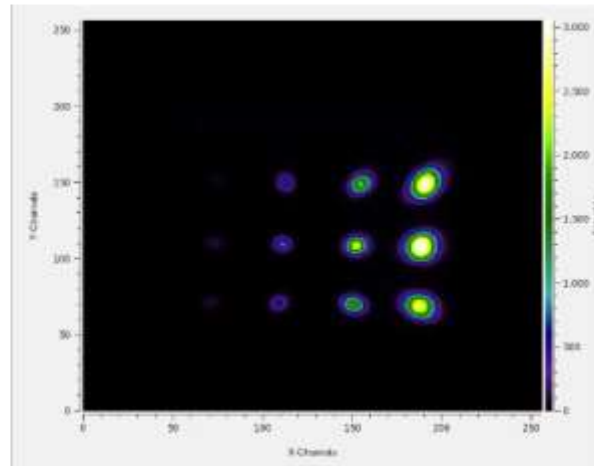
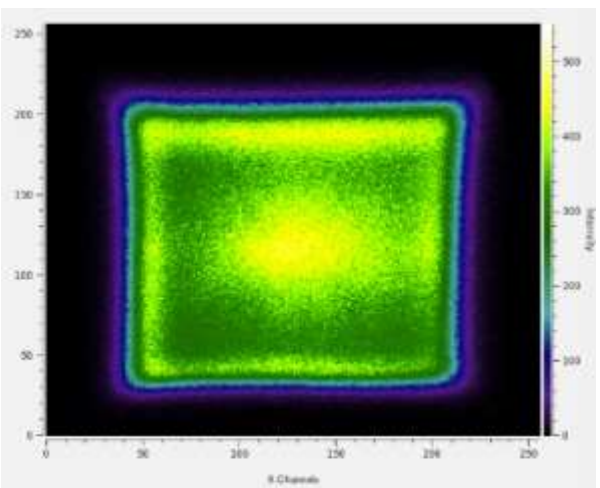
WP 9: Task 9.2.2



Module fitted with Anger Camera Electronics for High Resolution

Neutron Measurements at TREFF and at KWS-3





Empty beam; no sample; open thresholds to be used for calibration

Thin Cd and Boron Carbide Diaphragm in front of the detector.
Hole size 0.5; 1.0; 2.0 and 4 mm with 10 mm spacing => Spatial resolution < 0.7 mm FWHM

6 mm PMT pixels giving sub mm resolution

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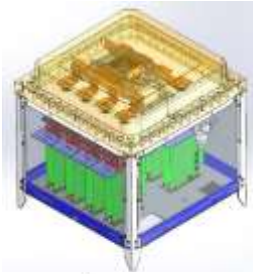
WP 9: Task 9.3

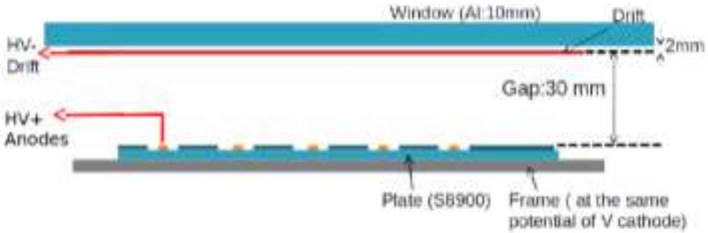
TASK 9.3:

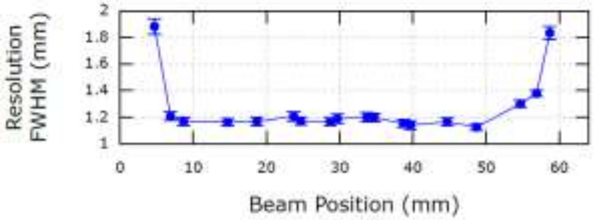
Development of a 3He based microstrip gas chamber with a novel 2D readout (ILL)

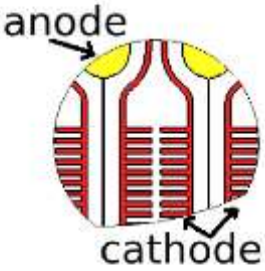
The microstrip gas chamber is intrinsically a 1D position sensitive device

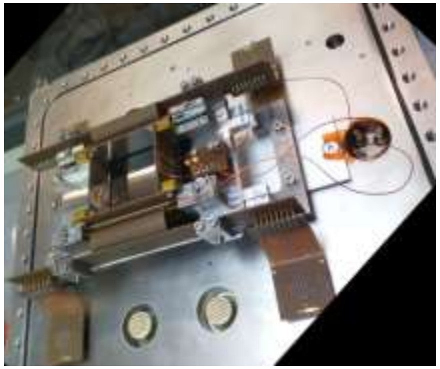
The aim is to make it 2D position sensitive by laying down resistive cathodes



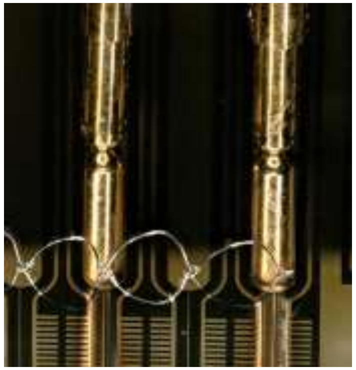




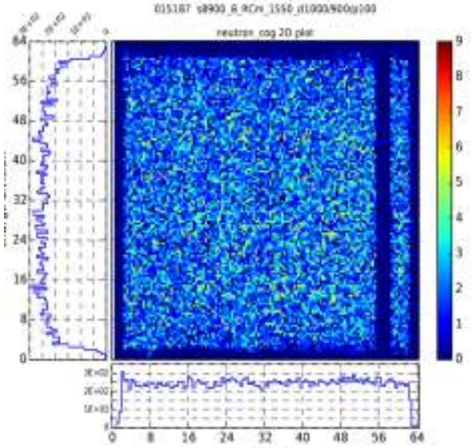




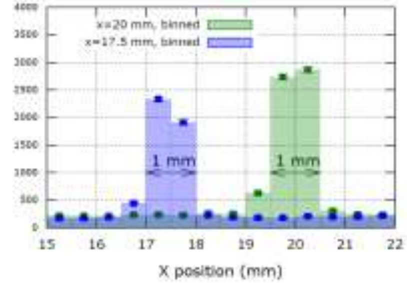
Active area 64 x 76 mm^2



Wire bonding of anodes solved sparking issue



Uniform response after calibration



Good resolution.
1 mm x 1.2 mm.
Charge division on cathodes works!!!

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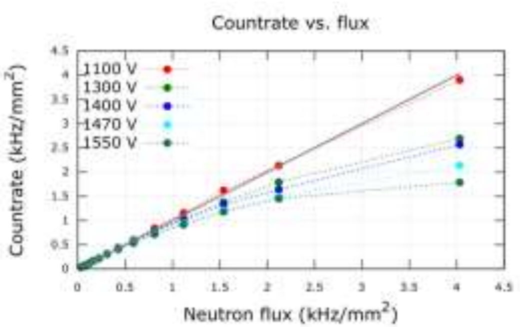
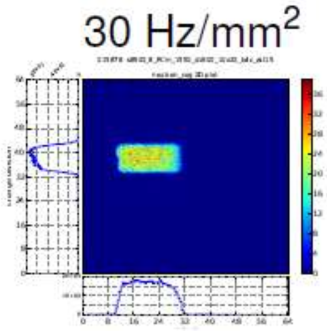
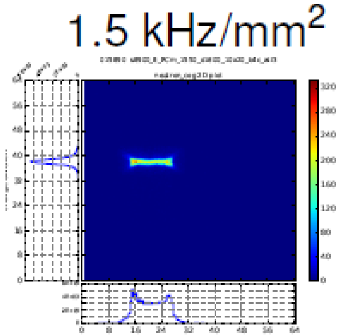
WP 9: Task 9.3



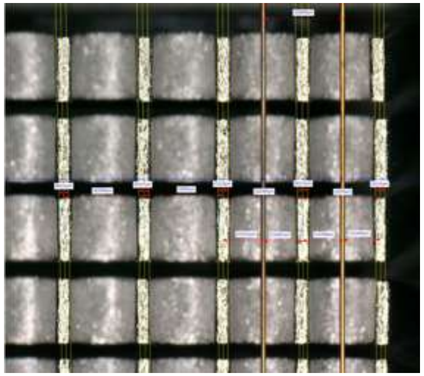


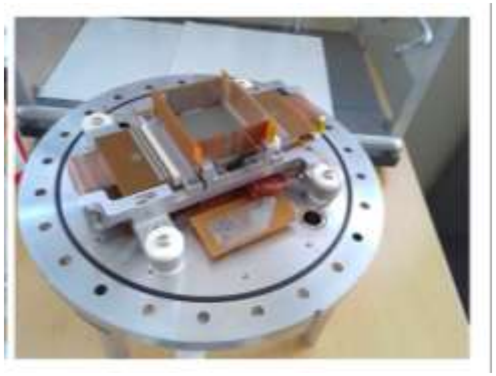


Count rate and shrinkage at high gain is being investigated

Attributed to ion back flow

Plan B: Applied the trench-MWPC technique (introduced for the XtremeD project) to SINE2020





The trench MWPC shows a similar dependance of the gain versus and shrinkage vs Flux.

This work is giving a better understanding of what is happening in gas detectors

However, since it can be operated at a gain 10 times lower than the MSGC, we expect a local counting rate of 10 kHz/mm^2 instead of 1 kHz at similar drift field

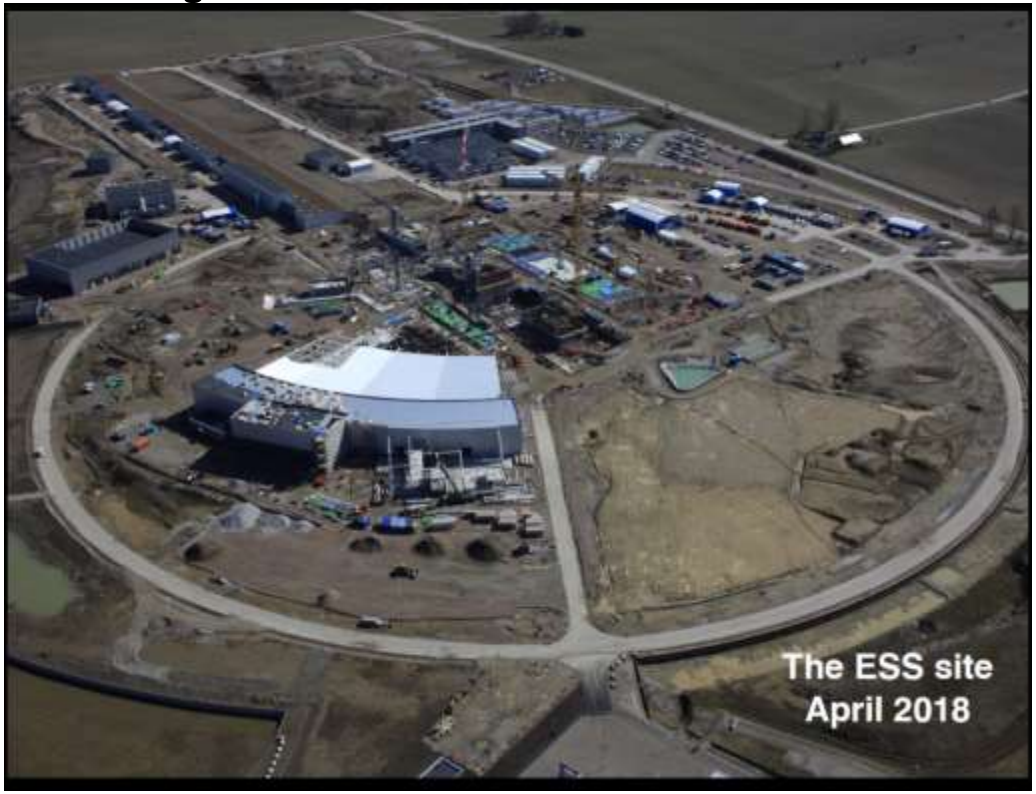
This project is funded by the European Union (GA no. 654000)

WP 9: Task 9.4

TASK 9.4:

Emergent Detector Technologies for neutron scattering and MuSR

- **9.4.1 $^{10}B_4C$ coated Resistive Plate Chambers for Position Sensitive Neutron Detectors**
- **9.4.2 Silicon Photomultipliers for Neutron scattering**
- **9.4.3 Silicon Photomultipliers for MuSR**
- **9.4.4 Micromegas detectors**



Irina Stefanescu et al. (EDG) keep us up to date with progress at the ESS

Particularly with regard to the detector development and the ESS detector performance requirements

$^{10}B_4C$ coatings for tasks 9.4.1. and 9.4.4 carried out at ESS

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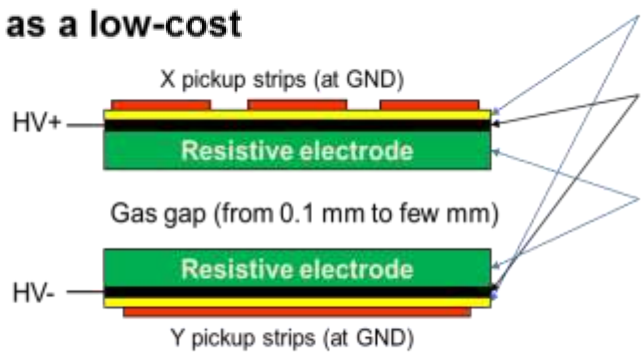
WP 9: Task 9.4.1

Task 9.4.1 Development of neutron sensitive resistive plate chamber (RPC) (LIP)

Gas detector developed in the early 1980's as a low-cost alternative to large scintillator planes

ATLAS@CERN
CMS@CERN
HARP@CERN (TOF)
ALICE@CERN (TOF)
HADES@GSI (TOF)
FOPI@GSI (TOF)
STAR@RHIC (TOF)
BELLE@KEK
OPERA@LNF
ARGO@Tibet
Etc.

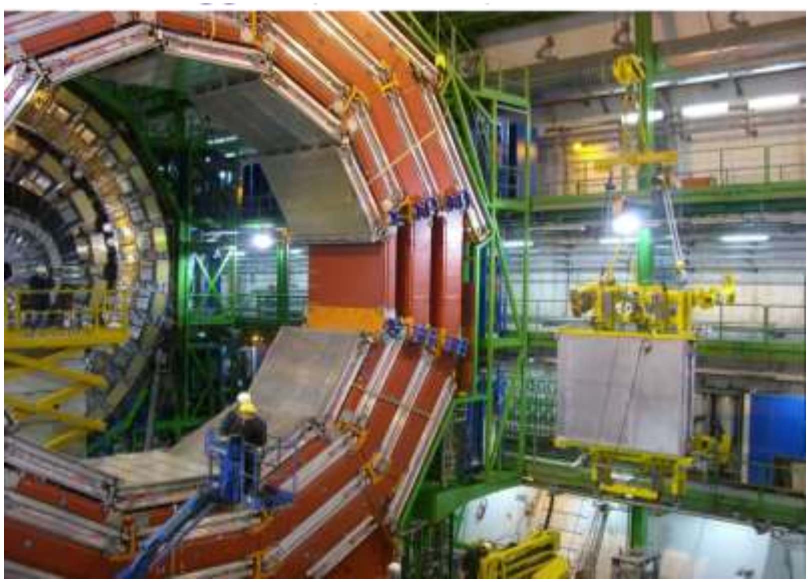


Typical RPC Structure

"Standard" gas mixture:
$C_2H_2F_4$ (tetrafluoretane or R134a)
1 to 10% SF_6 (sulphur hexafluoride)
0 to 5% C_4H_{10} (isobutane)

RPCs are used in many physics experiments

Argo Tibet 6700 m^2



CMS Trigger 2953 m^2

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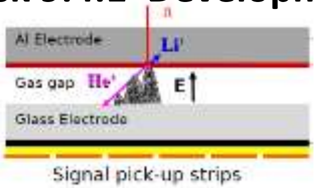
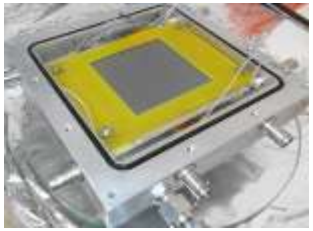
WP 9: Task 9.4.1

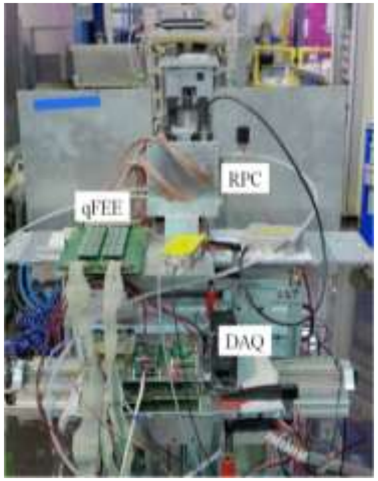
Task 9.4.1 Development of neutron sensitive resistive plate chamber (RPC)



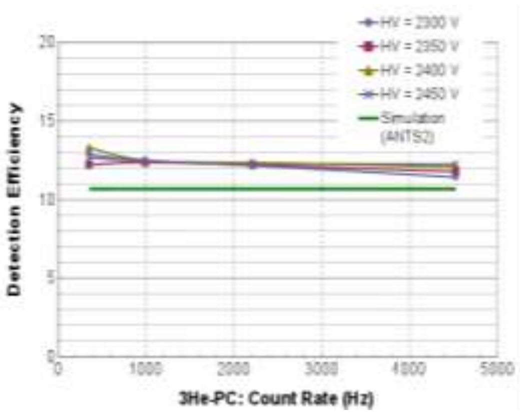
1 layer 2 µm $^{10}B_4C$



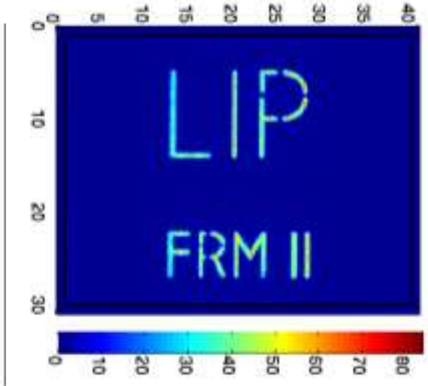
Active area 70 x 70 mm^2



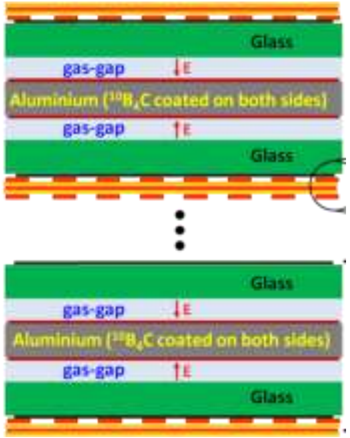
Tested at TREFF FRM II



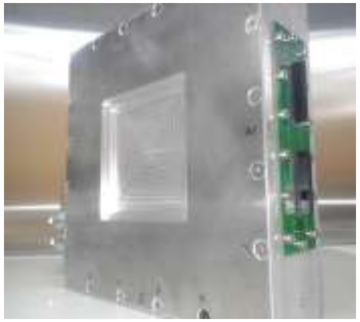
Efficiency 12.5% at 4.7Å



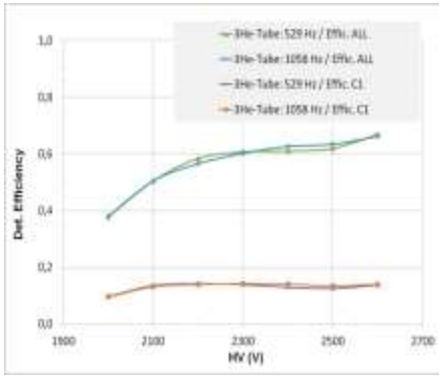
Resolution 236 µm FWHM



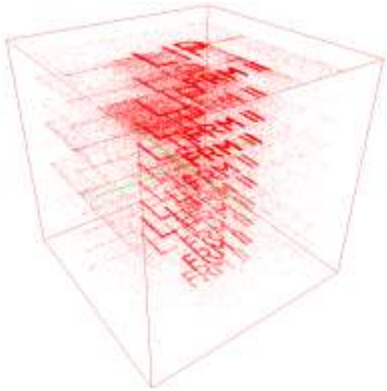
10 double gap RPCs
23 µm $^{10}B_4C$



$^{10}B_4C$ coatings provided by the ESS



Efficiency 60% at 4.7Å



Resolution ~300 µm FWHM

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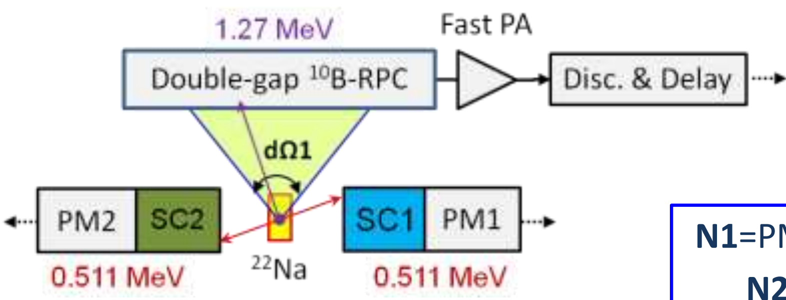
Double-gap ^{10}B-RPC: sensitivity to gamma rays

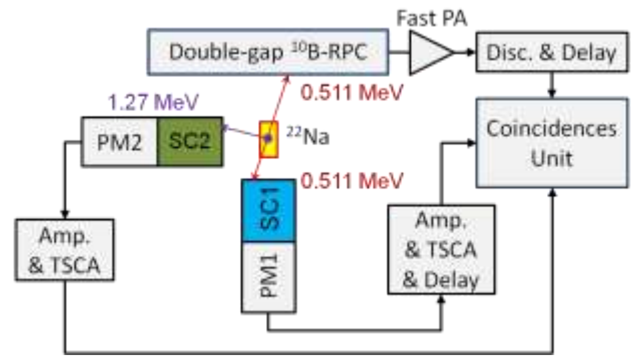
^{22}Na - 1.27 MeV photons



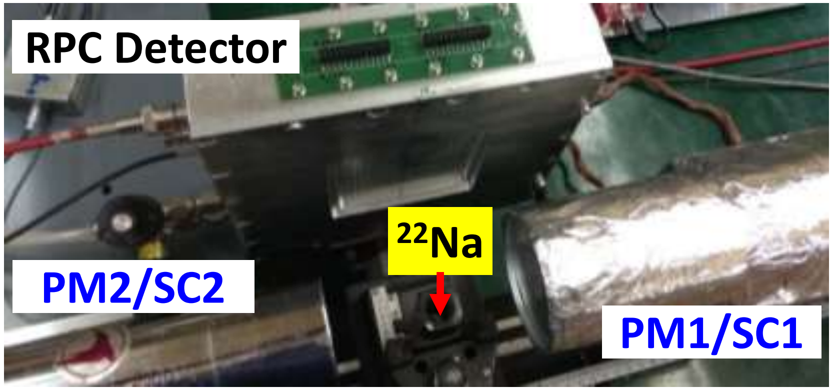
Det. Efficiency = N1/(N2 x dΩ1)

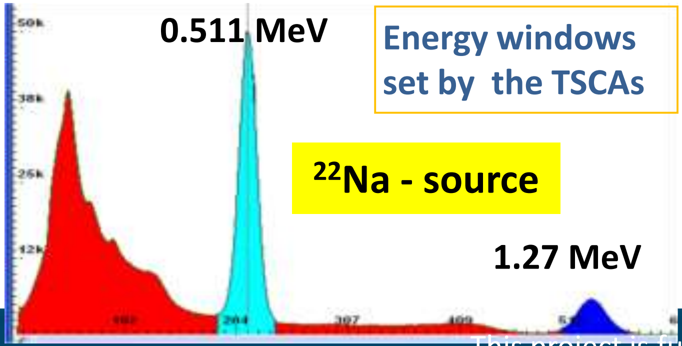
N1=PM1 & PM2 & RPC
N2=PM1 & PM2

^{22}Na - 0.511 MeV photons

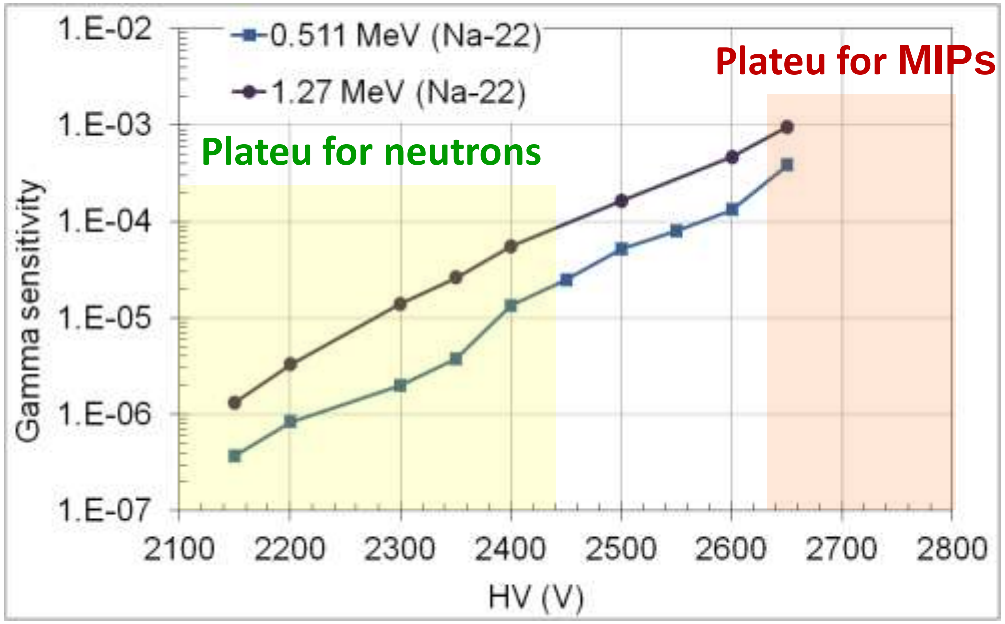


Det. Efficiency = N1/N2





Sensitivity to 0.511 MeV and 1.27 Mev gamma rays



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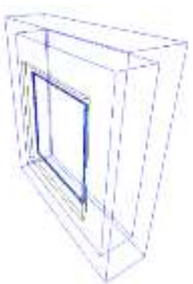
Double-gap ^{10}B-RPC: sensitivity to gamma rays

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

Detector model

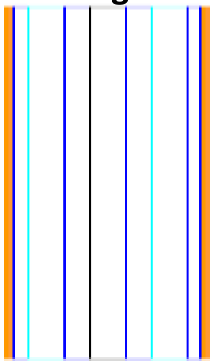


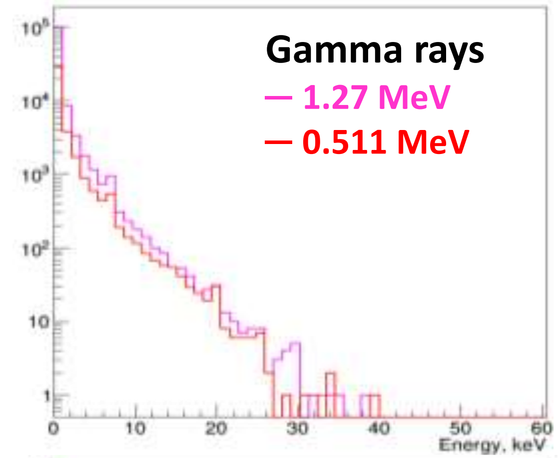
- Double-gap ^{10}B-RPC inside in an Al box
- Al-cathode coated (both sides) with 1.15 um thick $^{10}B_4C$ layer (97% enrichment)
- Area:10x10 cm^2

Two RPC designs were simulated

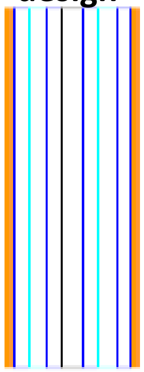
	Original	Modified
Gas-gap width	0.35 mm	0.2 mm
Al plate thickness	0.5 mm	0.3 mm
Glass plate thickness	0.5 mm	0.25 mm

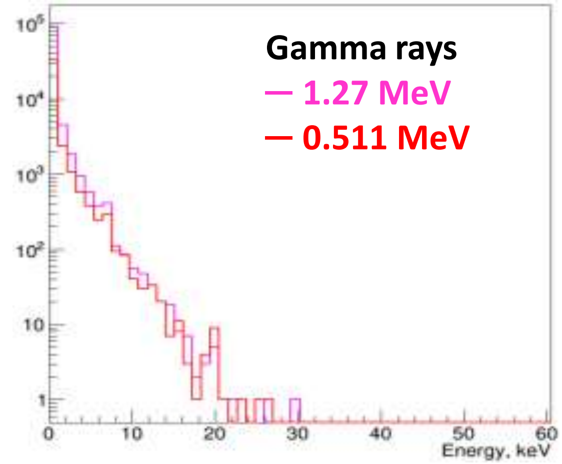
Original design





Modified design





Further reduction of x8 with new design

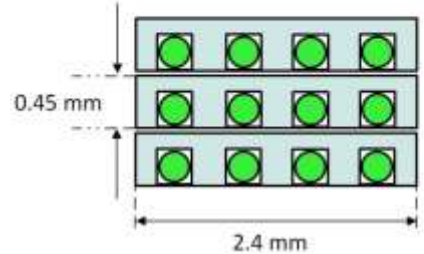
This project is funded by the European Union (GA no. 654000)

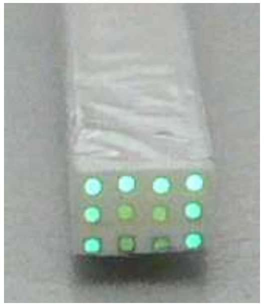
WP 9: Task 9.4.2

Task 9.4.2 Development of SiPM based detectors for neutron scattering

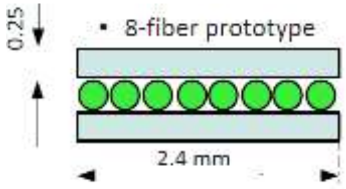
Light sharing detector

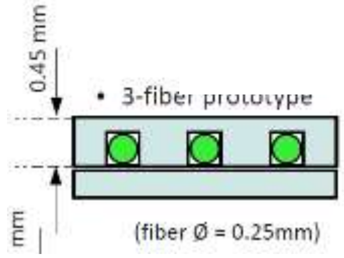
- ZnS:^{6}LiF detection unit
  - sensitive area (2.4×200) mm^2
  - neutron screen ND2:1 (Scintacor)

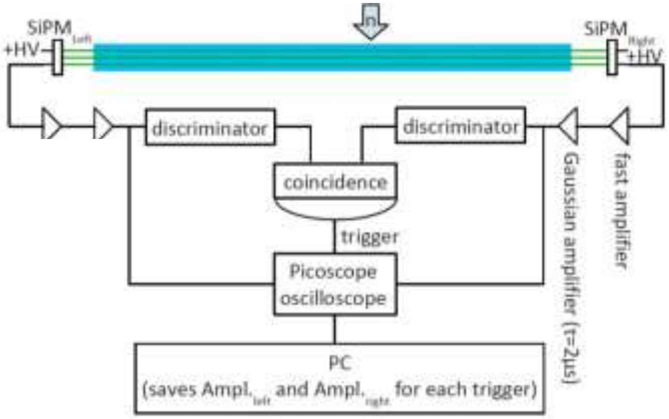




- WLS fibre
  - $\varnothing = 0.25$ mm
  - attenuation length ≈ 19 cm
    fibre core doped with 2wt% PMMA
  - each fibre verified before assembly
    - → uniform attenuation length over length
    - → all have same attenuation length





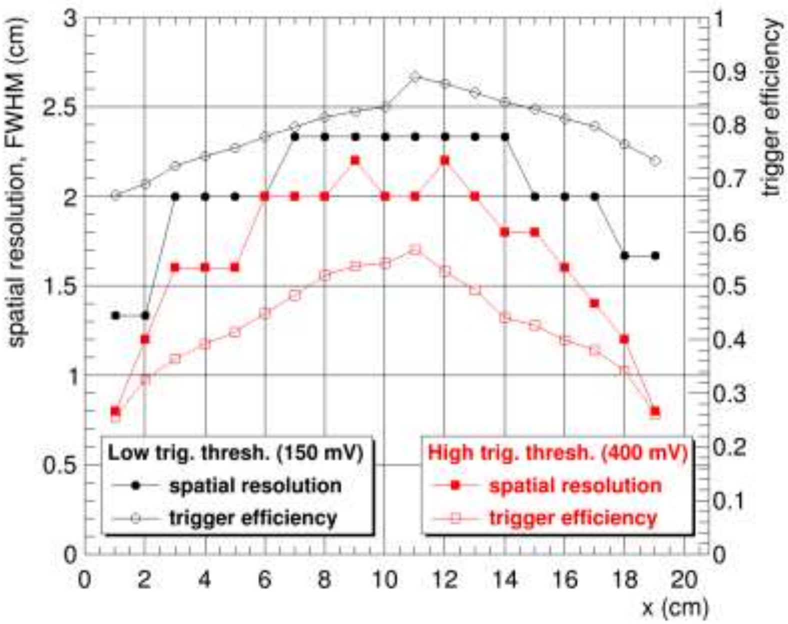


This project is funded by the European Union (GA no. 654000)

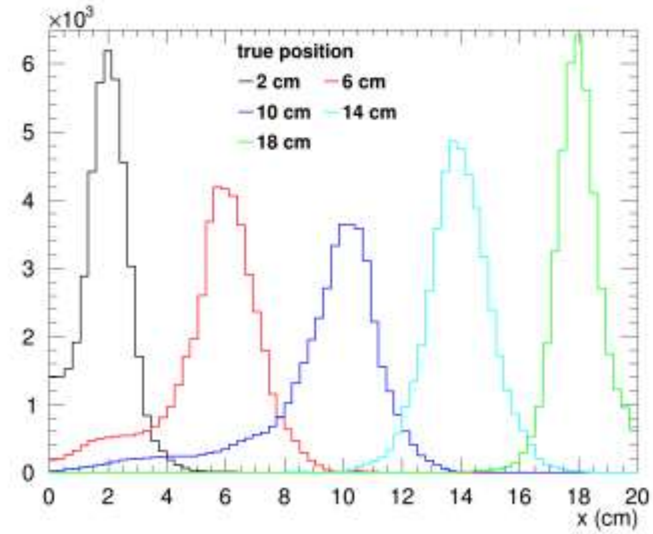
WP 9: Task 9.4.2

Task 9.4.2 Development of SiPM based detectors for neutron scattering (PSI)

- Spatial resolution and trigger efficiency as a function of the position, measured up to a trigger rate of ~3 kHz



Distribution of the reconstructed position (trigger threshold = 150 mV)



Performance parameters at a trigger threshold of 150 mV

Trigger efficiency $\varepsilon_{trigger}$	70% < $\varepsilon_{trigger}$ < 90%
Spatial resolution, FWHM	1.5 cm < FWHM < 2.3 cm
Gamma sensitivity (^{60}Co)	< $3 \cdot 10^{7}$
Quiet background rate	< $3 \cdot 10^{-3}$ Hz

This project is funded by the European Union (GA no. 654000)

WP 9: Task 9.4.3

Silicon photomultipliers for muon spectroscopy

Start
1 October 2015

Oct 2015
Kick-off
Copenhagen

Jan 2016 WP
Abingdon, UK

June 2016 WP
PSI, Switzerland

Sep 2016 GA
Coimbra, Portugal

May 2018 WP
Forschungszentrum
Jülich, Germany

June 2018 GA
Parma, Italy

May 2019 GA
Bilbao, Spain

End
30 Sept 2019

D9.8 Report discussing an evaluation of commercial SiPMs for muon spectroscopy detector arrays (month 24).

D9.13 Report discussing alternative detector technologies for scintillation-based arrays for muon spectroscopy (month 48).

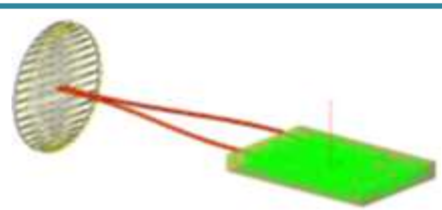
Scintillator Arrays and Optical Components

SiPM Evaluation

Gas Detectors

Flat Panel Photo-Multipliers (64 Channel)

Large Scintillator Arrays



This talk:

Progress since last WP meeting

Two highlight slides

This project is funded by the European Union (GA no. 654000)

WP 9: Task 9.4.3

- **Task 9.4.3 Silicon Photomultipliers and other scintillation readout devices for µSR (STFC)**

First half of the task has concentrated on SiPMs

Systematic testing of emerging commercial SiPMs D9.8, M 24 (new series every few months)

Continuous source requires excellent timing resolution

Pulsed source requires excellent dead time (many positrons per detector per pulse)

Three pronged approach

Testing of scintillation detector with SiPM on muon beam line

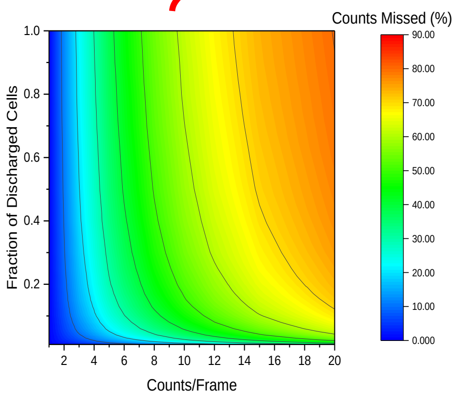
Testing of SiPM with laser response

Modeling of detector response

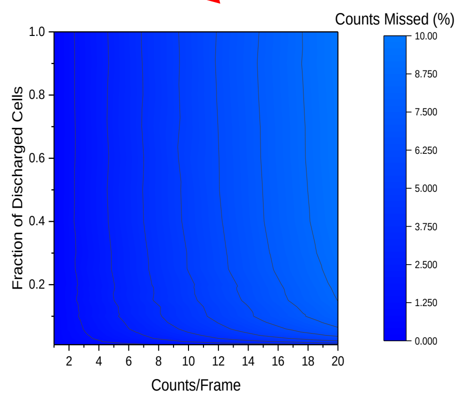
SensL 50µm

Differentiated signal

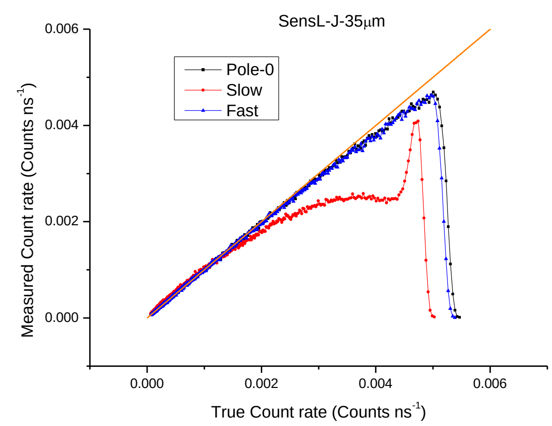
SensL 50µm



2 counts per frame
10% dead time



20 counts per frame
10% dead time



Mostly about the signal processing electronics

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WP 9: Task 9.4.3

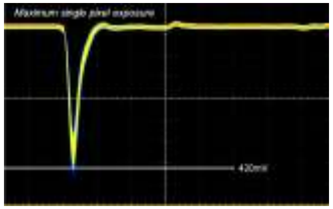
Multianode Photomultipliers Tubes for muon spectroscopy

- **Timing resolution**

Normally timing resolution for MuSR at ISIS is dominated by width of proton pulse

Super MuSR with pulse slicer will require higher timing resolution ~ 2 – 4 ns.

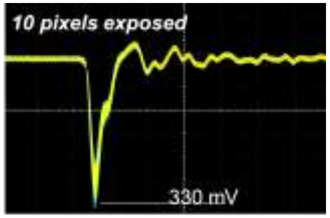
Measured timing resolution of PMT, fibre and scintillator – OK for small signals



Amplitude	dt_{PMT}	dt_{Fiber}	$dt_{Scintillator}$	dt
60mV	0.1944 ns	0.981 ns	1.1395 ns	**1.52 ns**
100mV	0.1474 ns	0.735 ns	0.7892 ns	**1.09 ns**

- **3 pixel module installed on EMU**

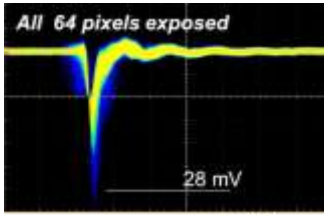
Gives similar rate capabilities compared with EMU's SA PMTs and adiabatic light guides



- **Lab tests**

PMT pixels illuminated simultaneously show signal degradation

Julich have also seen this and suggest it might be an issue with the PMT VDN

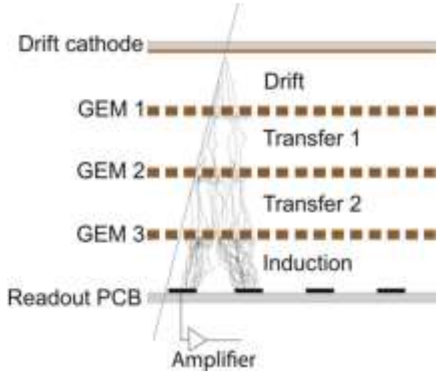


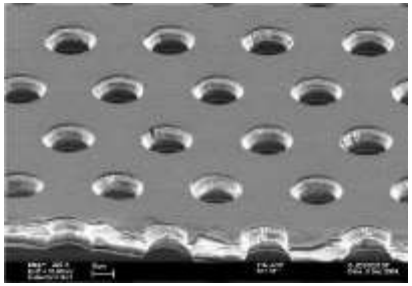
Hope to build a 64 channel demonstrator by end of SINE 2020

This project is funded by the European Union (GA no. 654000)

WP 9: Task 9.4.3

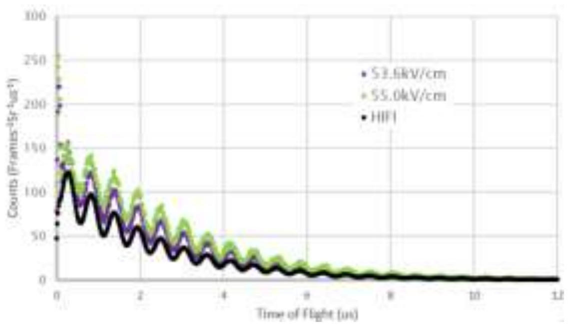
- **Task 9.4.3 Other readout devices for µSR (STFC)**
- **Evaluating a GEM detector for MuSR at ISIS**



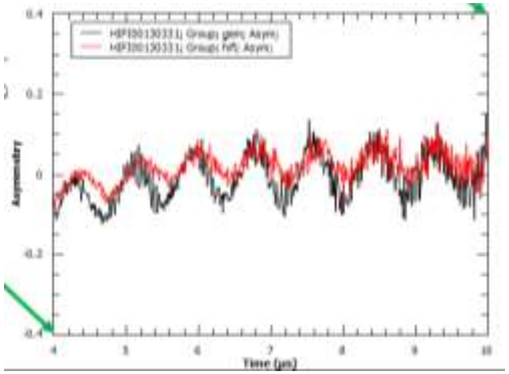


Triple GEM detector purchased from CERN

Efficiency



Resonance Frequency Expts



Initial results look encouraging:

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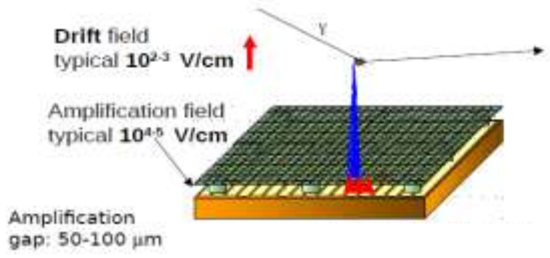
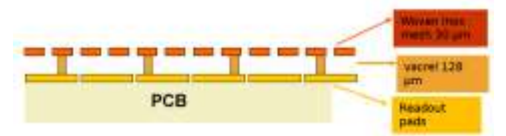
Task 9.4.4 Development of Micromegas Detectors for neutron scattering (CEA)

Micromegas detectors are one of the family of micro pattern gas detectors



Gas gain takes place between grid and readout plane

Bulk



Microbulk (Dupont™ Cu-Kapton-Cu foils)

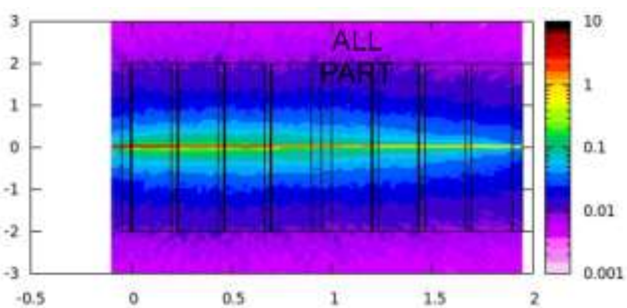
Two technology options

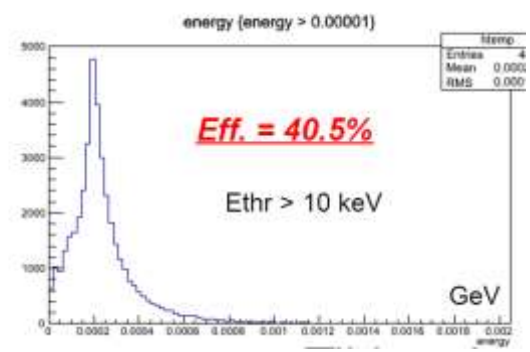
Drift electrode and grid coated with $^{10}B_4C$

No PCB layer in microbulk detector

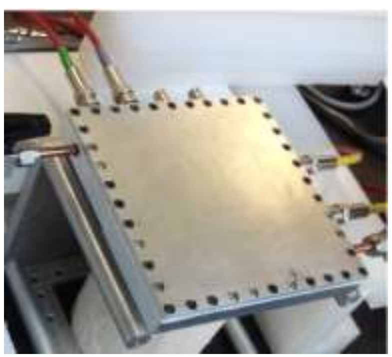
Allows stacking

Stack of 4 pairs of micromegas detectors





Simulations show 40% efficiency at 1.8 Å



Prototype 15 x 15 cm² detector waiting for coatings

This project is funded by the European Union (GA no. 654000)

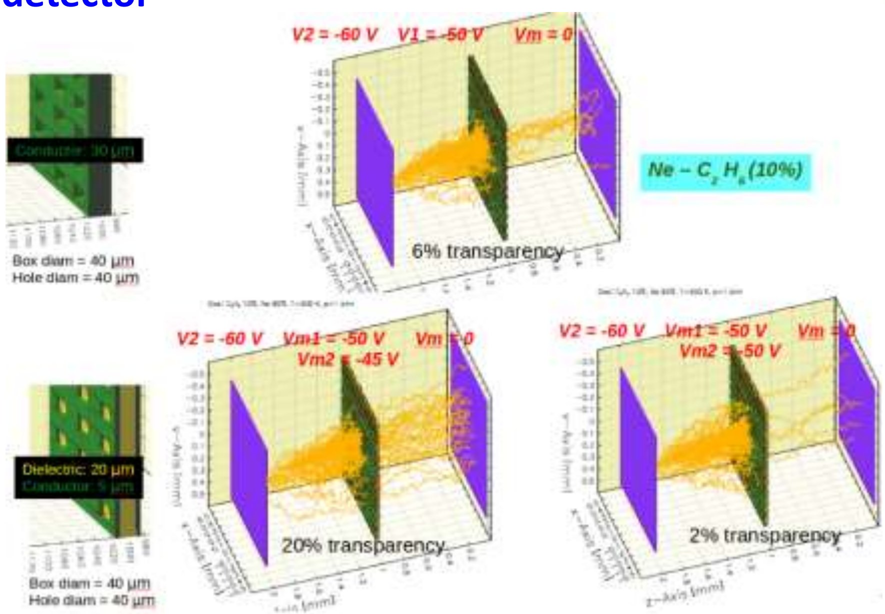
WP 9: Task 9.4.4

Task 9.4.4 Development of Micromegas Detectors for neutron scattering (CEA)

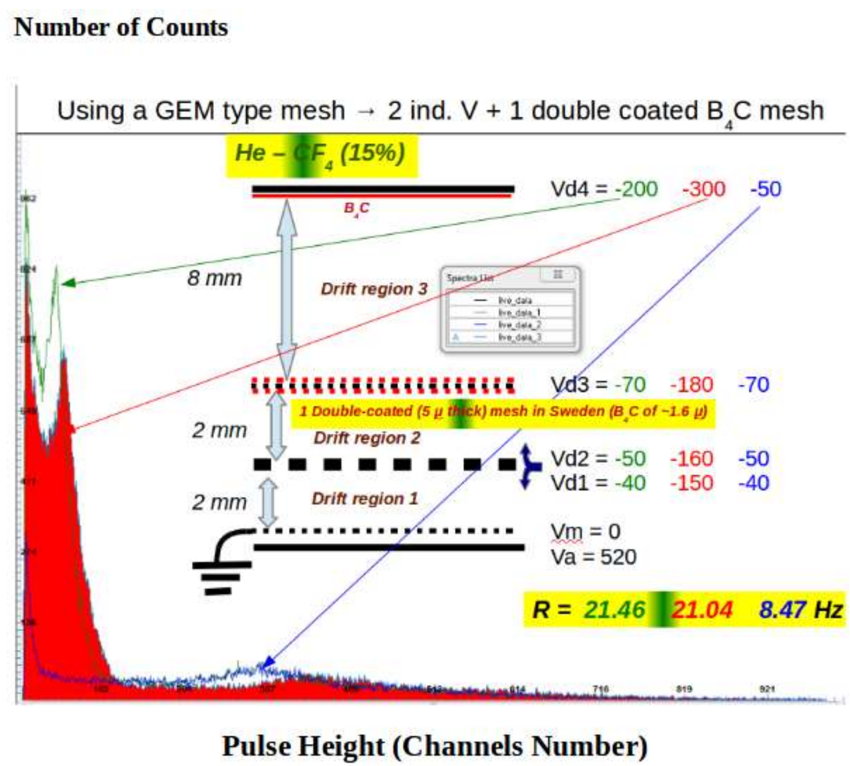
Initial trials of coating B_4C onto the Cu coated kapton foil failed

Investigations are ongoing with ESS-Linkopin, CDT and at Scalay to resolve this issue

In the meantime inserting a Cu coated Kapton foil into a bulk micromegas detector has been shown to improve electron transmission simulations and improve pulse height spectra in a real detector



Garfield/neBEM simulations of the electron transmission



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WP 9: Task 9.4.5

Task 9.4.5: Single neutron detection in scintillators using CMOS cameras (ESSBilbao)

sCMOS cameras are being rapidy developed by industry

Imagined that in the near future they will have sufficent timing resolution for ToF neutron applications

ESSBilbao looking at possibility of detecting individual neutrons.

- **Use state of the art Hamamatsu camera**
- **Start with ZnS/6LiF scintillator**
- **Identify suitable lens and optical set up**
- **Identify siutable image processing for neutron identification**
- **Ensure count rate is kept below limit event superposition on image.**
- **Tests to date have been carried out at ILL and PSI**
- **Will report findings into D12 at end of project**

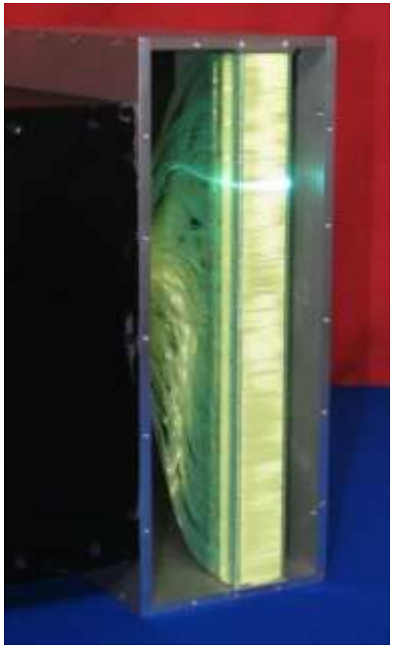
Apologies for lack of pictures

This project is funded by the European Union (GA no. 654000)

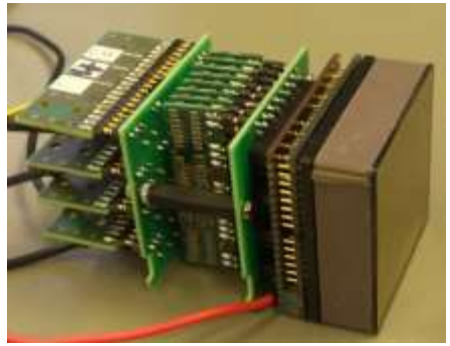
WP 9: DELIVERABLES

No.	Deliverable Title	LEAD	TYPE	DOMAIN	DUE(M)	STATUS
9.1	First extended RTD meeting	STFC	DEC	PU	18	+3 Complete
9.2	Initial WLS fibre detector hardware	STFC	DEM	PU	18	Complete
9.3	Initial direct PMT readout hardware	FZJ	DEM	PU	24	Complete
9.4	Interim report on scintillation detector development programme	STFC	R	PU	24	Complete
9.5	Novel MSGC detector hardware	ILL	DEM	PU	24	Complete
9.6	Interim report on MSGC detector development programme	ILL	R	PU	24	Complete
9.7	Interim report on Emergent Neutron Detector Technologies development programme	ESS	R	PU	24	Complete
9.8	Report discussing an evaluation of commercial SiPMs for µSR detector arrays	STFC	R	PU	24	Complete
9.9	Second extended RTD meeting	STFC	DEC	PU	36	
9.10	Final report on scintillation detector development programme	STFC	R	PU	48	
9.11	Final report on MSGC detector development programme	ILL	R	PU	48	
9.12	Final report on Emergent Neutron Detector Technologies development programme	ESS	R	PU	48	
9.13	Report discussing alternative detector technologies for µSR	STFC	R	PU	48	
9.14	Website containing all presentations	STFC	DEC	PU	48	

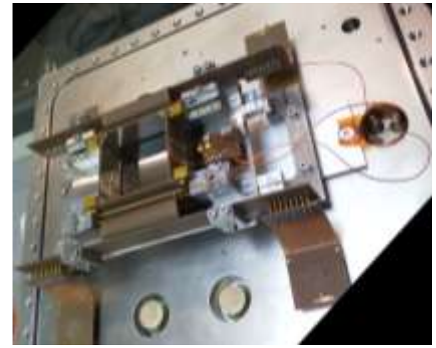
WP 9: DELIVERABLES



ZnS +WLSF + MaPMT

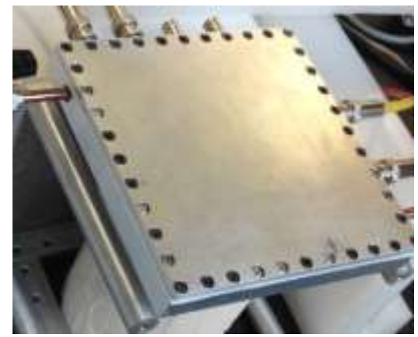


GS20 + MaPMT (Anger)



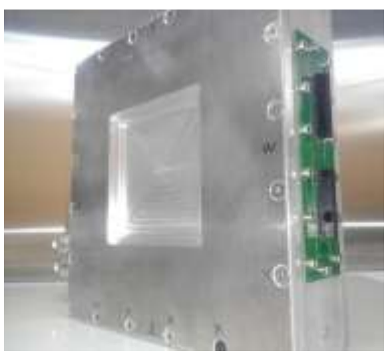
3He + 2D MSGC

Different detector technologies developed in SINE 2020 for neutron reflectometry and MuSR applications



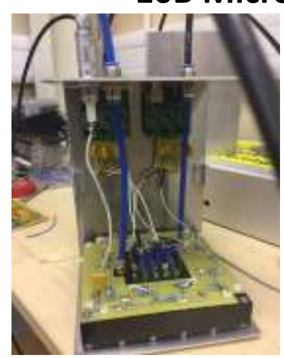
10B Micromegas

ZnS +WLSF + SiPM



10B RPC

Plastic Scint + SiPM/MaPMT (μ)



GEM (μ)

ZnS + CMOS Camera

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