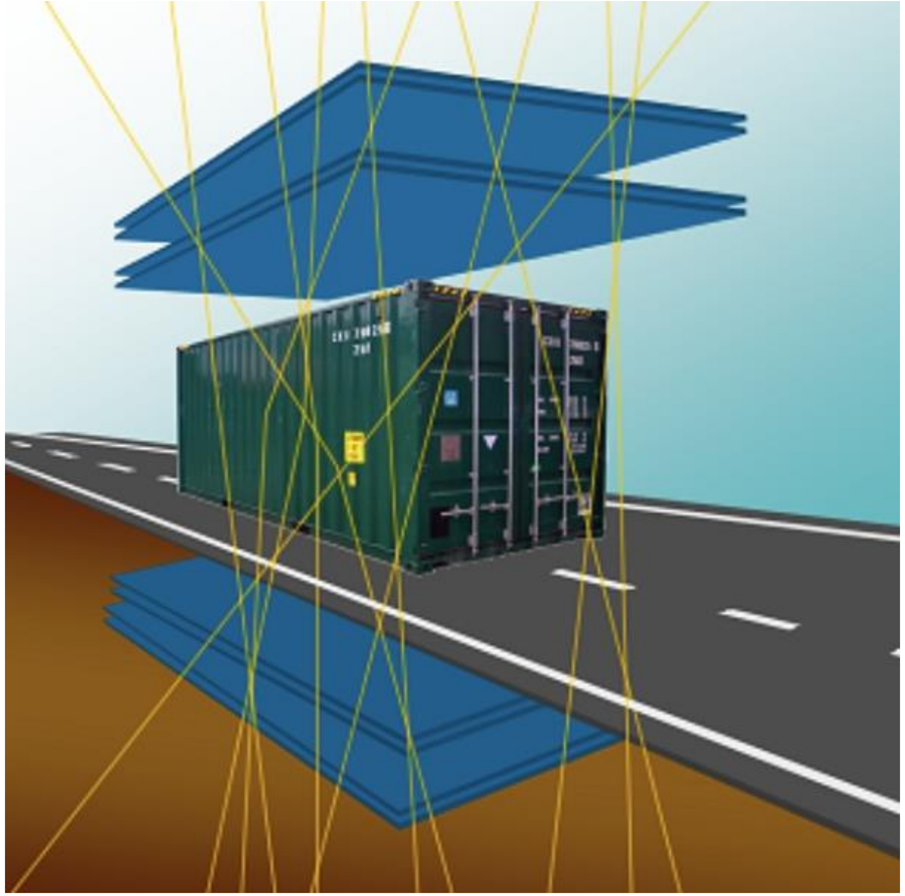
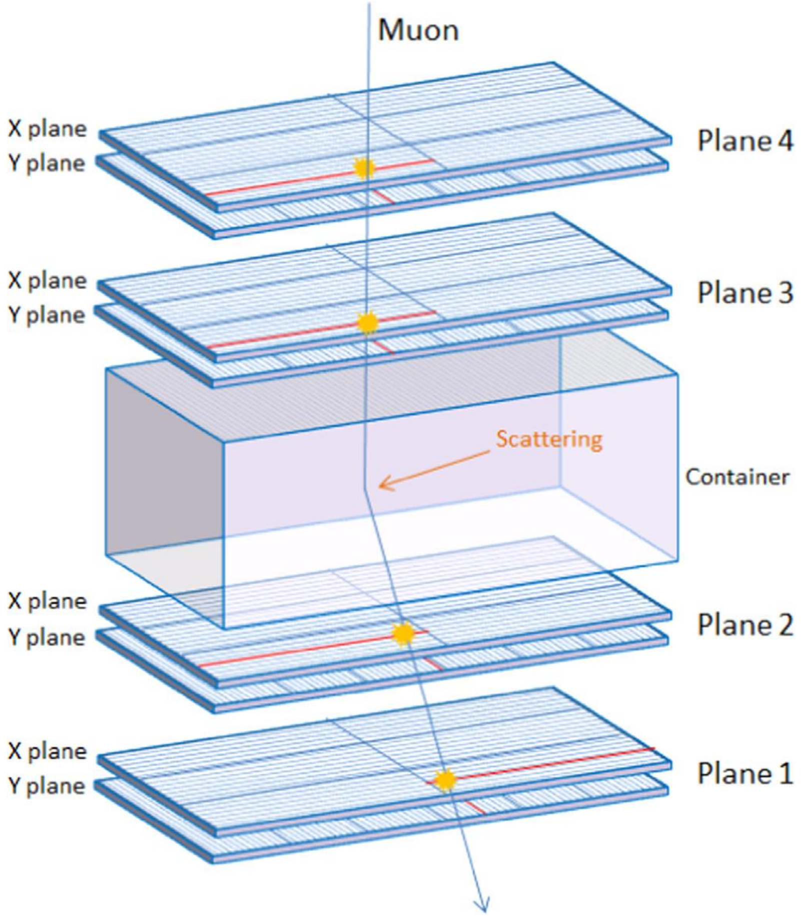
MUON PORTAL

Muons passing through the container to be inspected are tracked above and below the volume, to search for large angle scattering due to the presence of high-Z materials.





4 X Y planes
→ **8 planes 3x6 m^2**.

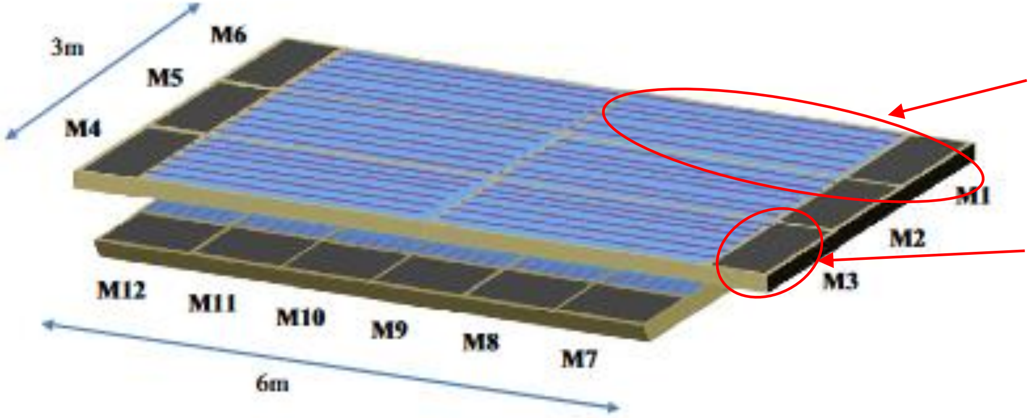
Each plane is constituted by 2 planes of 3 x 3 m^2
→ **16 planes 3x3 m^2**

Each 3 x 3 m^2 plane is constituted by 3 modules of 1 x 3 m^2
→ **48 modules 1 x 3 m^2**

Each module is made of 100 strips of extruded plastic scintillators, with 1x1 cm^2 section. At the end a SiPM take place.
→ **<u>4800 SiPMs 3 x 3 mm^2</u>**

MUON PORTAL **PHOTON DETECTION**

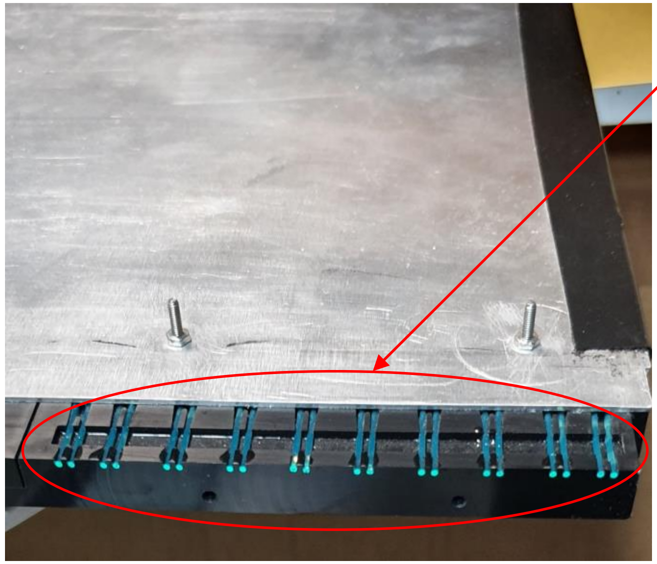
1 complete X Y plane → 6 + 6 modules 1x3 m^2

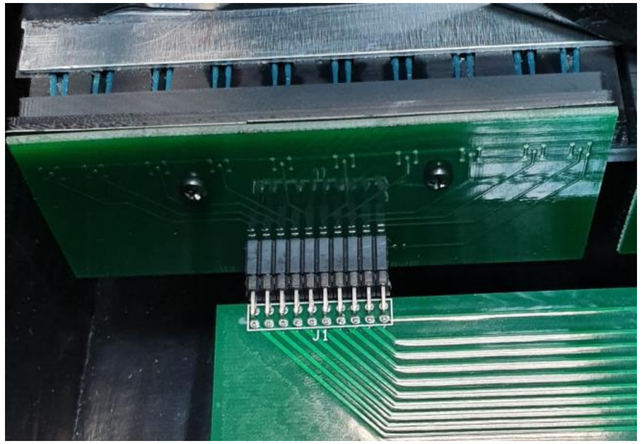


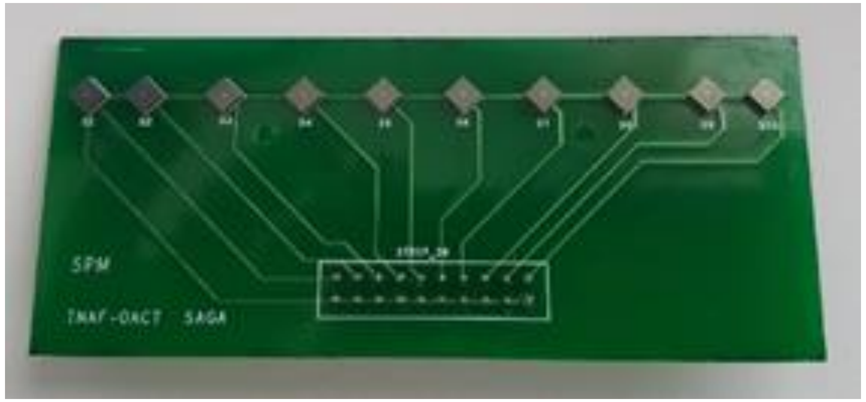
Each module is made of 100 strips of extruded plastic scintillators

At the end of each module a black box provides for encapsulating the 100 SiPM detectors and the relative front end electronics capable to handle 100 channels

The 100 strips are organized in 10 groups of 10. For each channel 2 fibres transfer the generated light to a SiPM detector

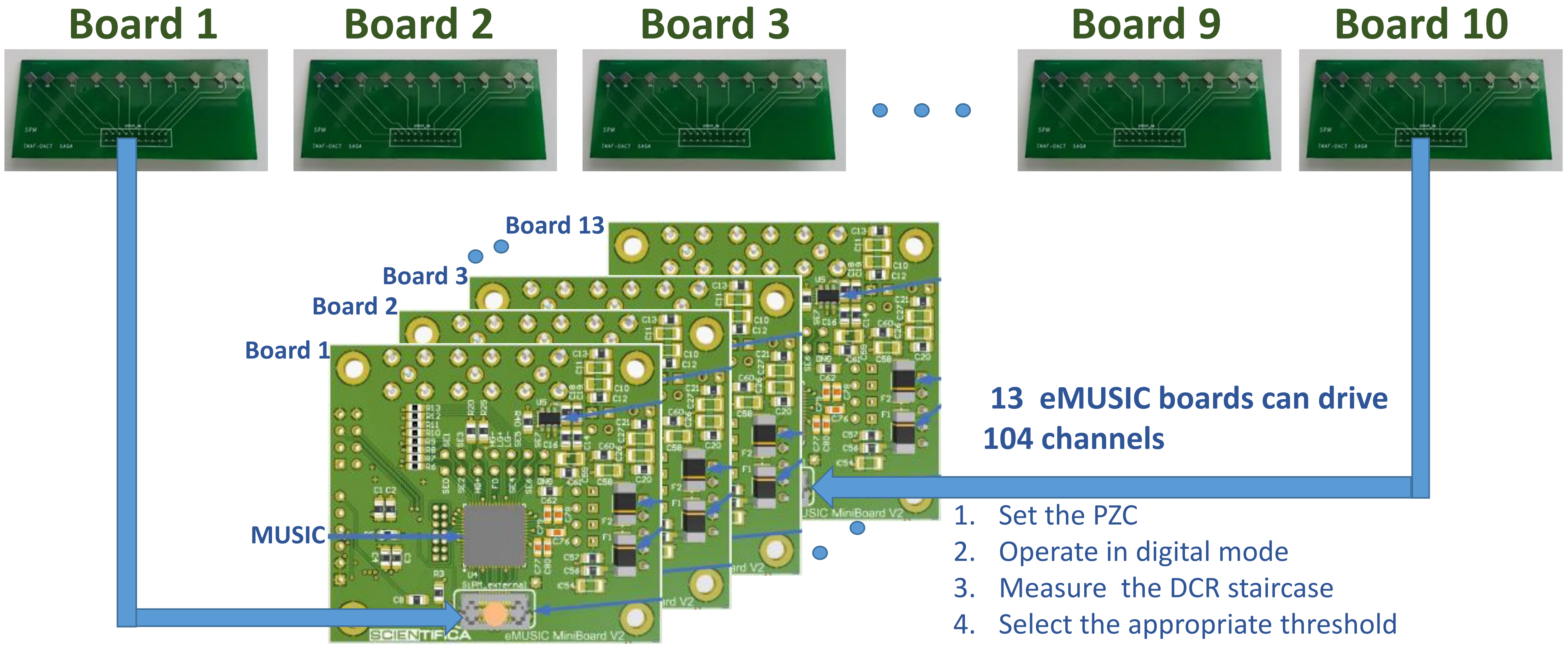






PRELIMINARY

MUON PORTAL ELECTRONIC FRONT-END

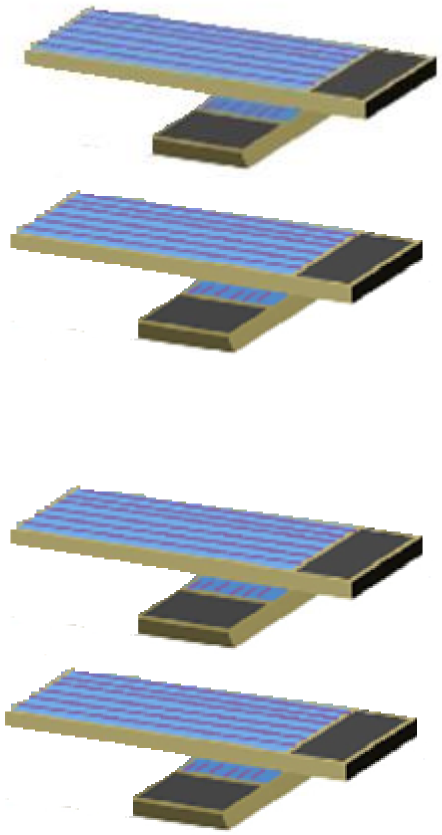


13 eMUSIC boards can drive 104 channels

1. Set the PZC
2. Operate in digital mode
3. Measure the DCR staircase
4. Select the appropriate threshold
5. Measure the count rate

PRELIMINARY

MUON PORTAL DEMONSTRATOR



What we need to realize a complete demonstrator of $1 \times 1\ m^2$?

8 x 100 SiPMs → 800 SiPMs

8 x 13 eMusic → 104 eMusic boards!!!

QUESTION:
104 eMusic boards or better to have 8 boards with 13 MUSIC each

MUOGRAPHERS 2019

ACCELERATING INNOVATION

September 25, 2019 - Tokyo, Japan

Recent Developments of the Muon Portal Project

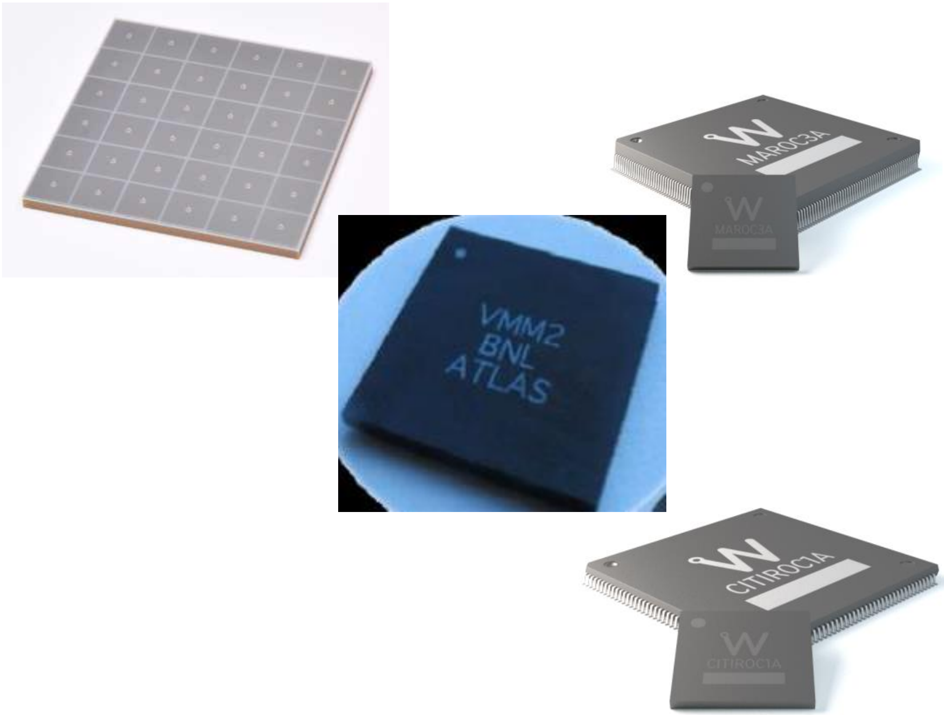
D. Bonanno[1,2] for the Muon Portal collaboration

[1] Department of Physics and Astronomy "Ettore Majorana", University of Catania

[2] INFN, Sezione di Catania

Topics:

- Short summary
- Possible upgrades
    - ✓New expertise
    - ✓Technological development



Original problem

About 200M containers are shipped yearly over the world. Only a small fraction of them may be checked by traditional inspection techniques, to search for the possible presence of illicit fissile material (Uranium, Plutonium...).

Security issues would require the implementation of fast and efficient methods to scan the interior of a container. Muon tomography provides 2D and 3D images of the content of a container, allowing to locate the presence of high-Z materials. For such reason it can be used as an alternative scanning method along the borders and in the ports to search for illegal hidden fissile material.

Several Projects on Muon Tomography are presently on going in different Countries.

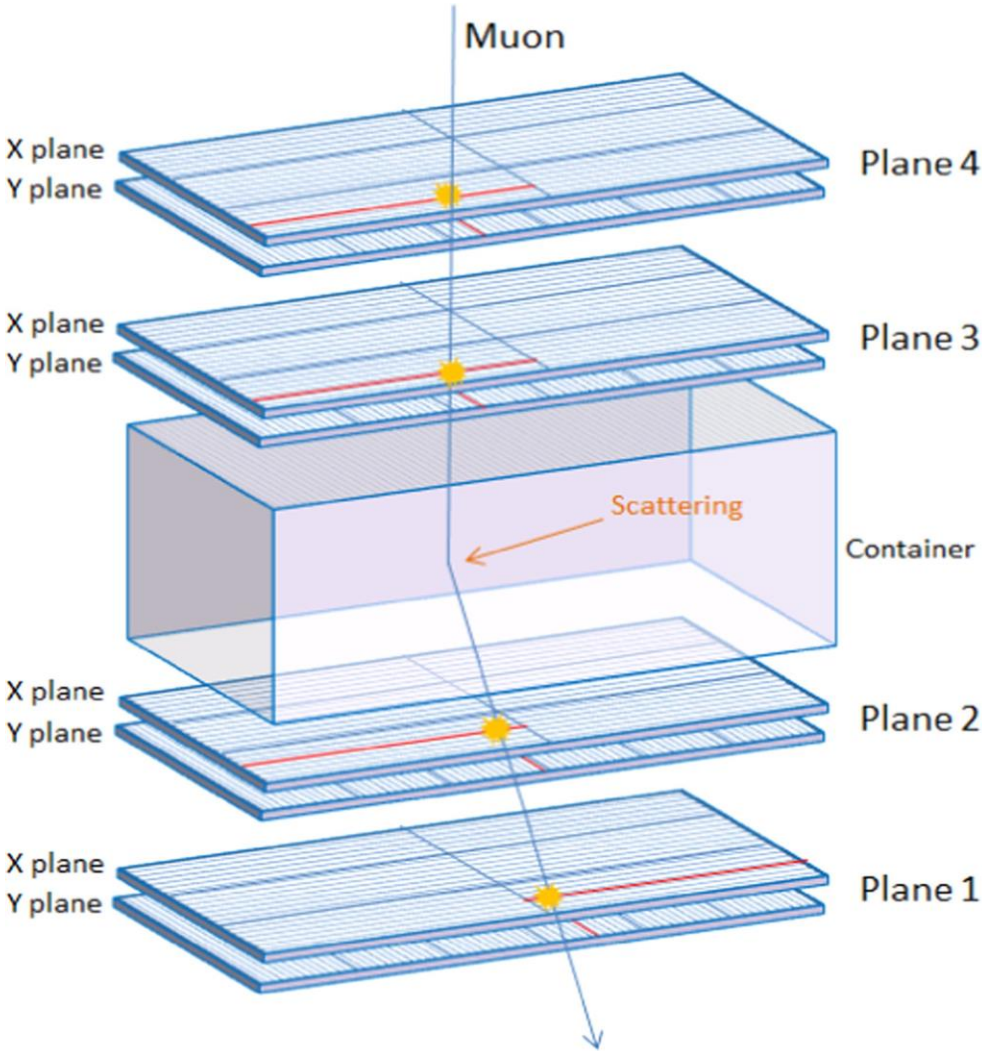
The detector

The detection setup is based on four position-sensitive detector (PSD), two placed above and two placed below the container volume to be inspected. The overall size of the detector fits that of a standard Twenty Foot Equivalent (TEU) container.

Each PSD is made by 12 modules (1 m × 3 m each) in a proper geometry, such as to cover both X and Y coordinates by the same type of modules.

Distances between planes:

- 1-2 (3-4) = 1 m;
- 2-3 = 3 m.



The detector

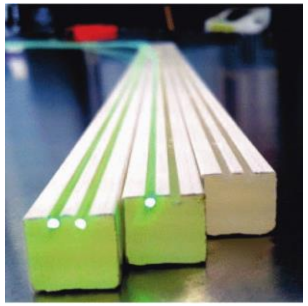
Each of the 48 detection modules is composed of 100 extruded plastic scintillator, 3 m long and with a section of 1 cm^2, manufactured by Amcrys.

2 WLS fibers of 1 mm diameter are embedded in each strip, to transport the photons to the photo-sensors, placed at one end of the strip. The photo-sensors used are SiPM designed by STMicroelectronics.

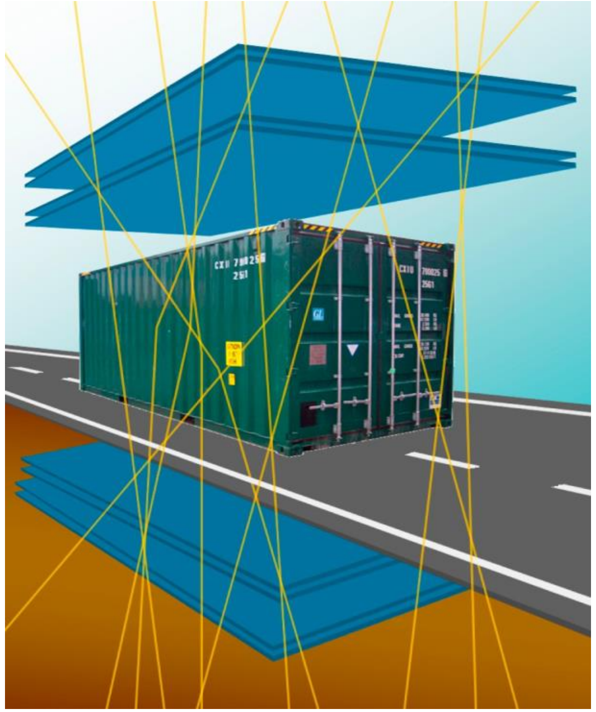
The overall number of channels would be:

2 fibers x 100 strips x 12 modules x 4 planes = **9600**

This number is reduced of a factor 10 (960) by the application of a stategy of compression of the read-out channels.



Numbers of the project



A schematic view of a possible detector layout for container inspection by muon tomography.

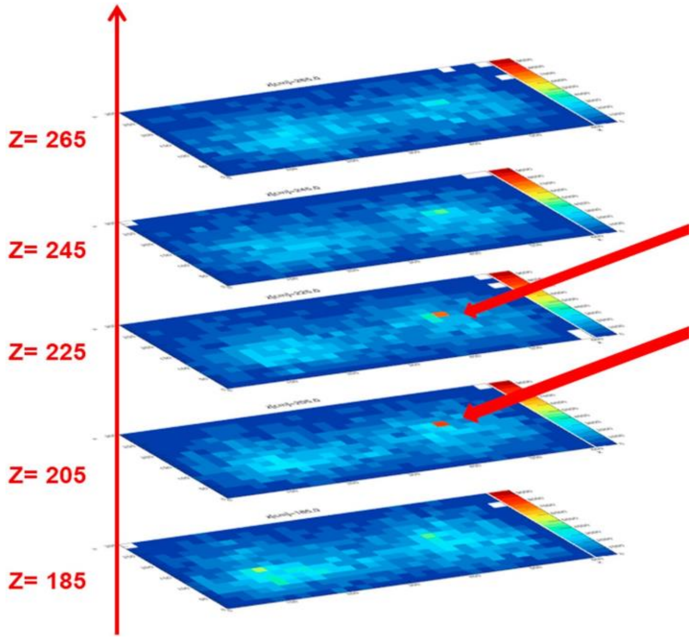
The Muon Portal Project has completed the construction of a real size prototype detector (6 m × 3 m × 7 m) for container inspection by the muon scattering technique.

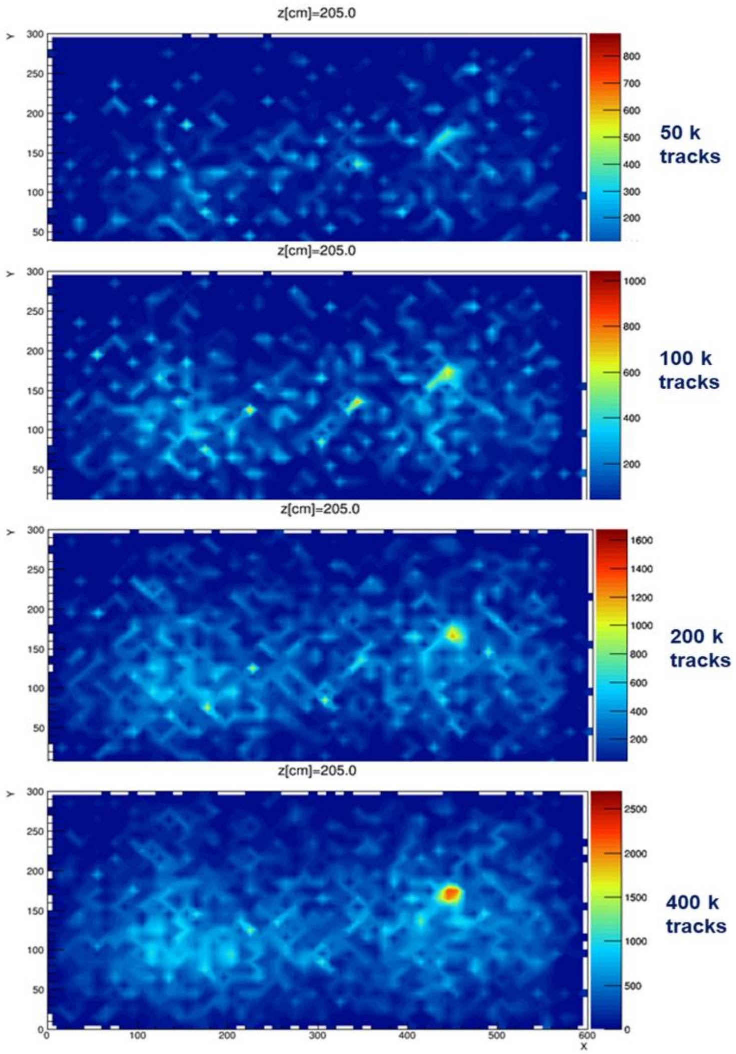
- 30 km WLS optical fibers
- 15 km Scintillating strips
- 9600 Silicon Photo-multipliers
- 130 m^3 Overall volume
- 0.1° Angular resolution
- 100 × 10^6 (×*efficiency*) Muons per day

The R&D phase ended in 2017 and the first tomographic image was produced

Results

- High-Z materials volume: 4 dm^3 of lead in between the two inner tracking planes, (Z = 215 cm).
- 2D tomographic images reconstructed using the POCA algorithm
- This images were reconstructed with 400k muon tracks.





However, a still acceptable image can be obtained even with a smaller statistics (100k tracks), useful to produce an alarm.

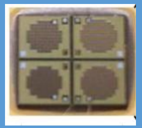
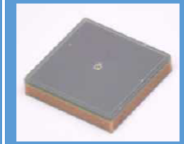
Efficiency issue

- Single module efficiency $\simeq$ 61%
  - ✓ Quality of the Photo-sensors
  - ✓ Electronic noise on Front-End
- Double coincidence to have a point on a PSD
  - ✓ PSD efficiency $\simeq (0.61)^2 \simeq 0.37$
- Useful track for POCA algorithm needs a point for each PSD
  - ✓ Overall efficiency $\simeq (0.37)^4 \simeq 0.02$

2% means about 2h to acquire 100K tracks needed to produce an alarm

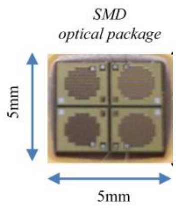
Courtesy by STMicroelectronics and Hamamatsu Photonics

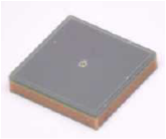
Photo–sensor solution

Characteristic		
Product	MUON60	S14160-3050HS
Effective photosensitive area (mm^2)	1.97 (round)	3.0 x 3.0
Number of pixels	548	3531
Pixel pitch (um)	60	50
fill factor	67.4%	74%
Typical breakdown voltage (V)	27.4	37
Optimal operation OV (V)	3-4	2.7
Gain	$6.8x10^6$	$2.5x10^6$
Typical dark current (uA)	2	0.6
PDE	28% (500-550nm)	50% (450nm)

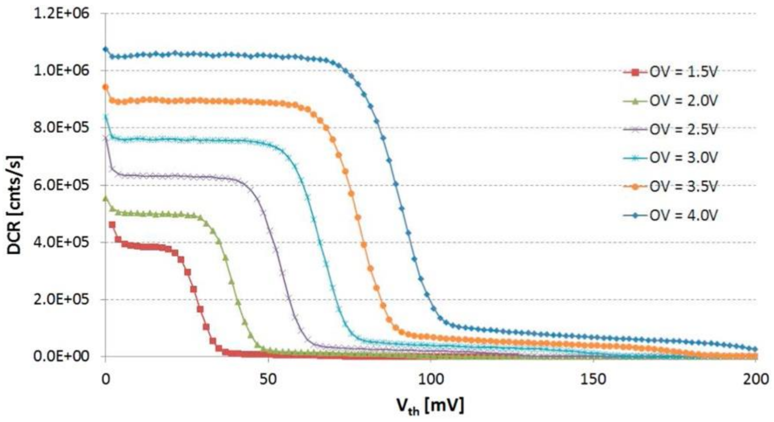
Photo–sensor solution

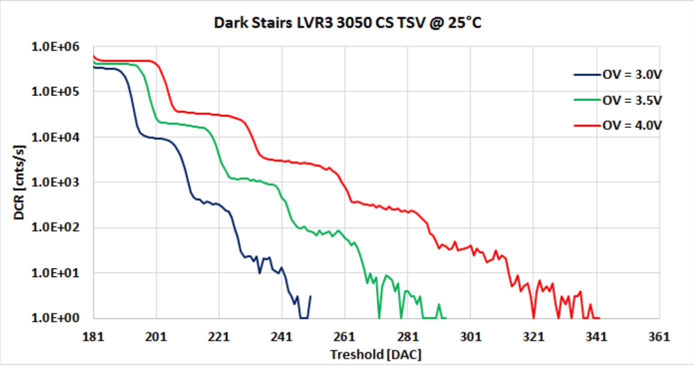
life.augmented

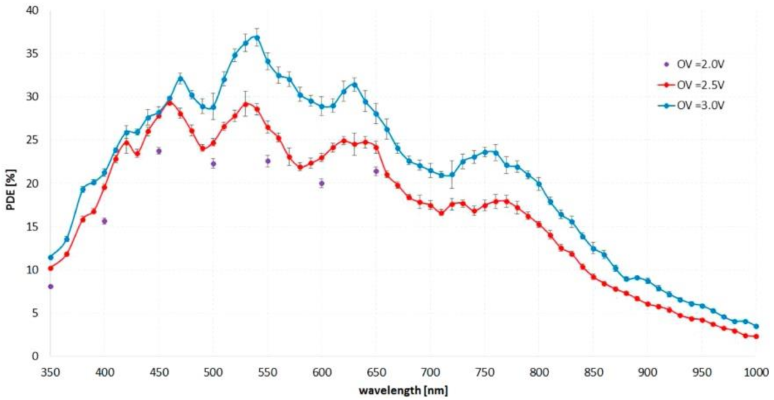


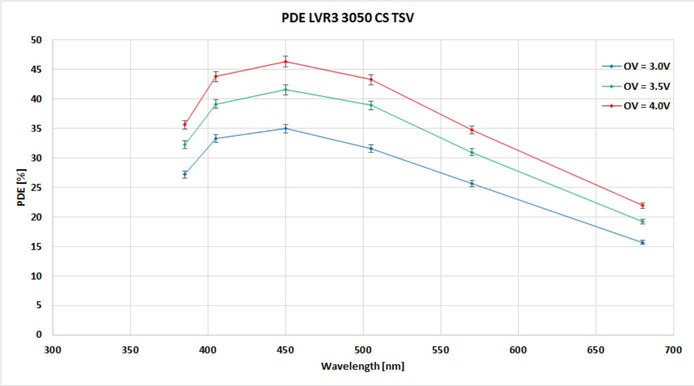


HAMAMATSU
PHOTON IS OUR BUSINESS









Front-End issue

FEPM-BOARD

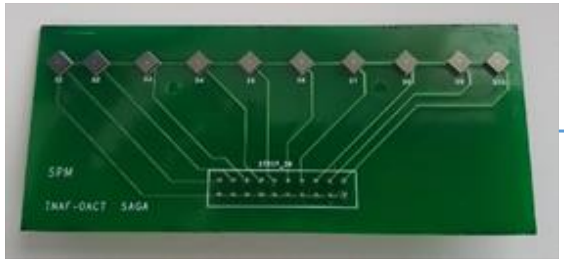
- Each FEPM board has 20 SiPM coupled to 10 strips
- 10 FEPM board for each detection module

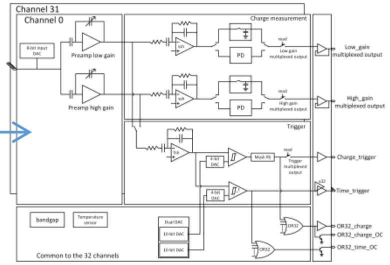
Courtesy by Weeroc, G. De Geronimo and ICCUB

Front-End solution

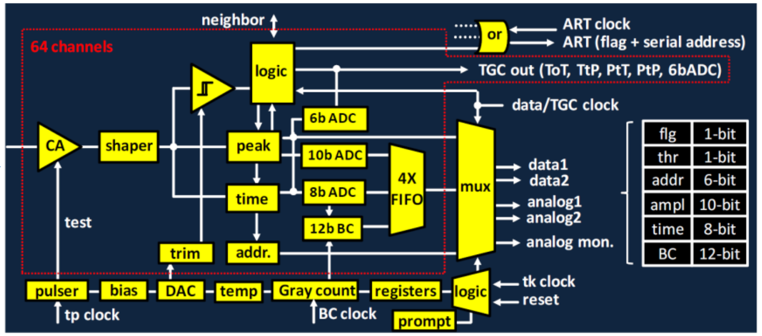
FE – ASIC

FEPM-Board v2.0

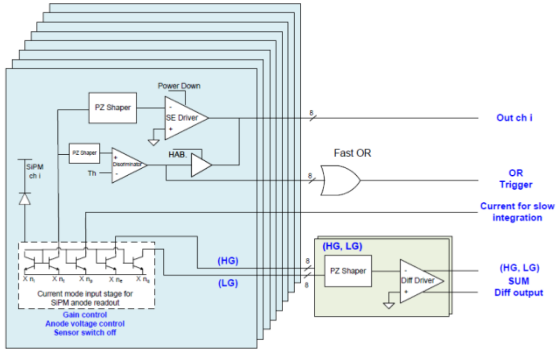




CITIROC 1A

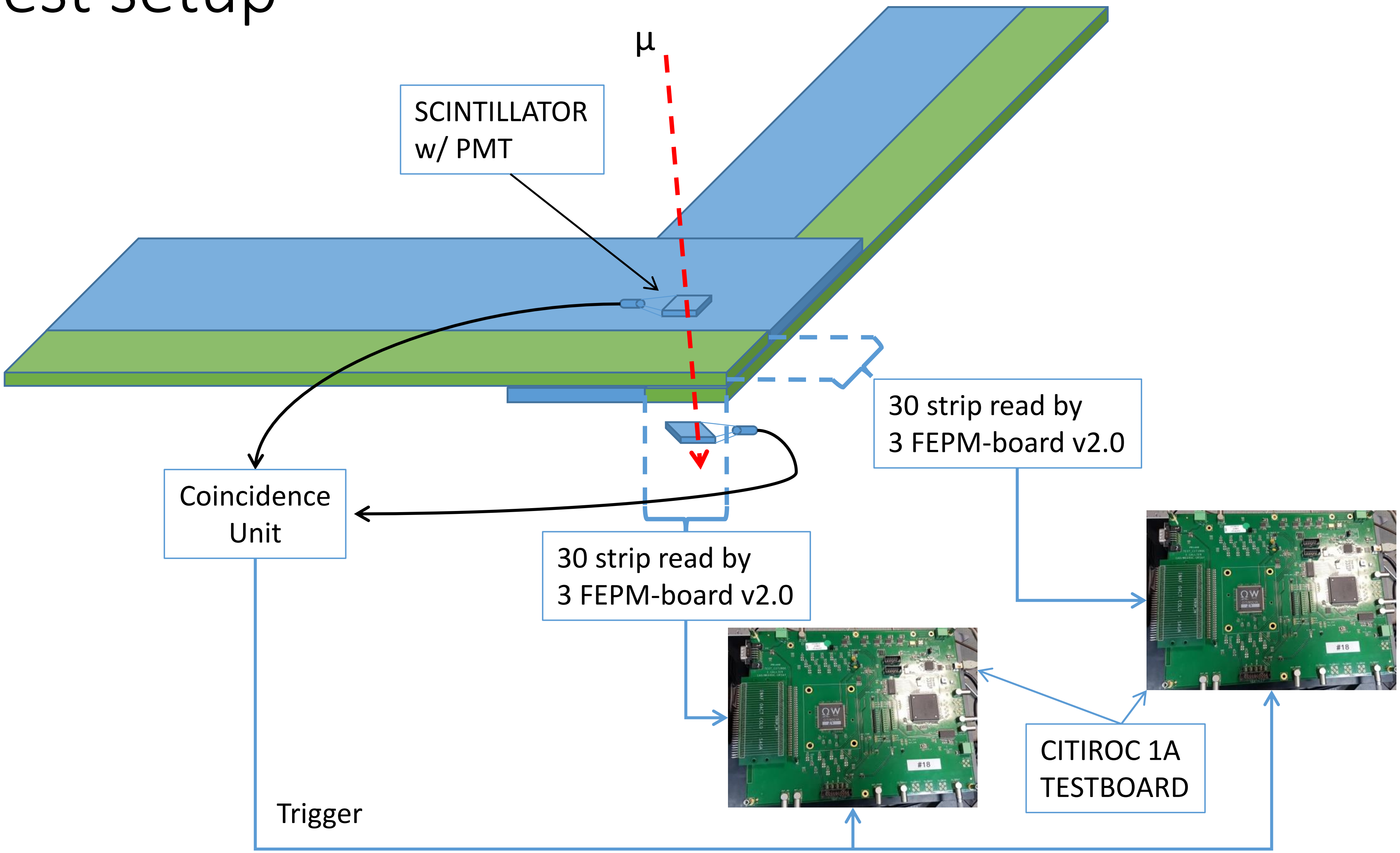


VMM3a



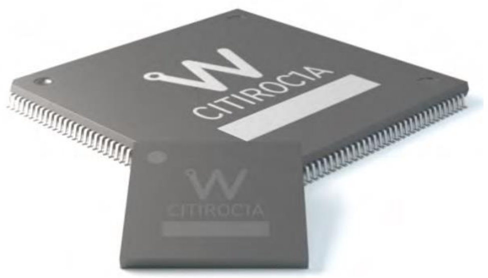
MUSICR2

Test setup



μ
SCINTILLATOR w/ PMT
30 strip read by 3 FEPM-board v2.0
Coincidence Unit
30 strip read by 3 FEPM-board v2.0
CITIROC 1A TESTBOARD
Trigger

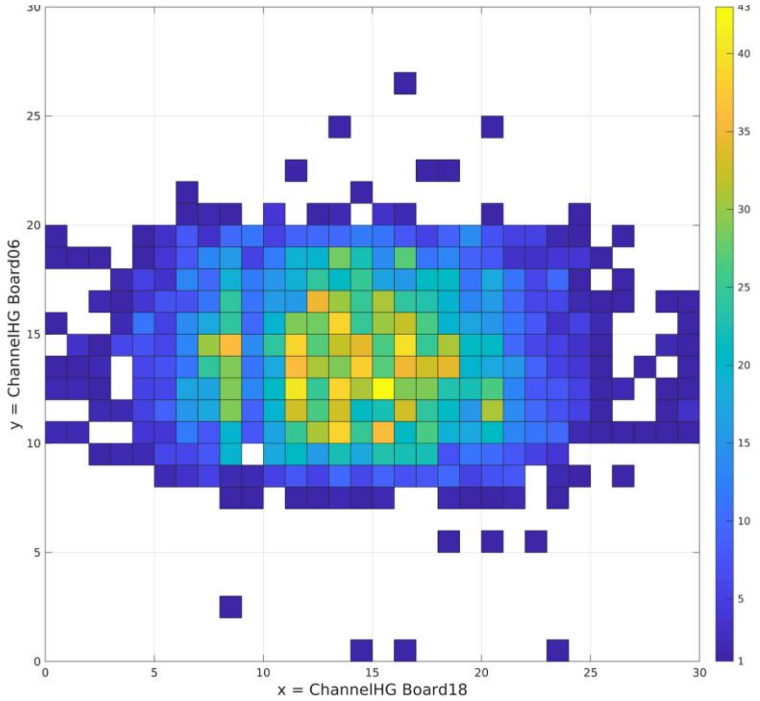
CITIROC 1A



Detector Read-Out	SiPM, SiPM array
Number of Channels	32
Signal Polarity	Positive
Sensitivity	Trigger on 1/3 of photo-electron
Timing Resolution	Better than 100 ps RMS on single photo-electron
Dynamic Range	0-400 pC i.e. 2500 photo-electrons @ 10^6 SIPM gain
Packaging & Dimension	TQFP 160 – TFBGA353
Power Consumption	225mW – Supply voltage : 3.3V
Inputs	32 voltage inputs with independent SiPM HV adjustments
Outputs	32 trigger outputs 2 multiplexed charge output, 1 multiplexed hit register 2 ASIC trigger output (Trigger OR)
Internal Programmable Features	32 HV adjustment for SiPM (32x8bits), Trigger Threshold Adjustment (10bits), channel by channel gain tuning, 32 Trigger Masks, Trigger Latch, internal temperature sensor

RESULTS

Parameter	Value
X-Y Active Area	30 x 30 cm^2
Scintillators Area	12 x 12 cm^2
PMT threshold	230 mV
Over Voltage	3 V
SiPM threshold	5 pe
Single module efficiency	**84.6%**



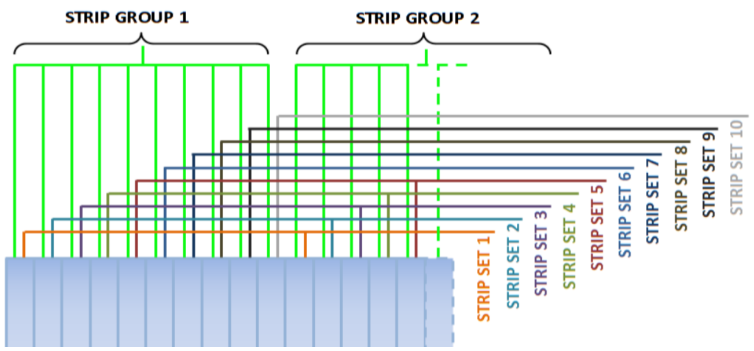
- Foreseen overall efficiency $\simeq (0.846)^8 \simeq 0.262$
- 13 times more efficient than before
- To acquire 100K tracks it should be needed a little bit more than 9 minute

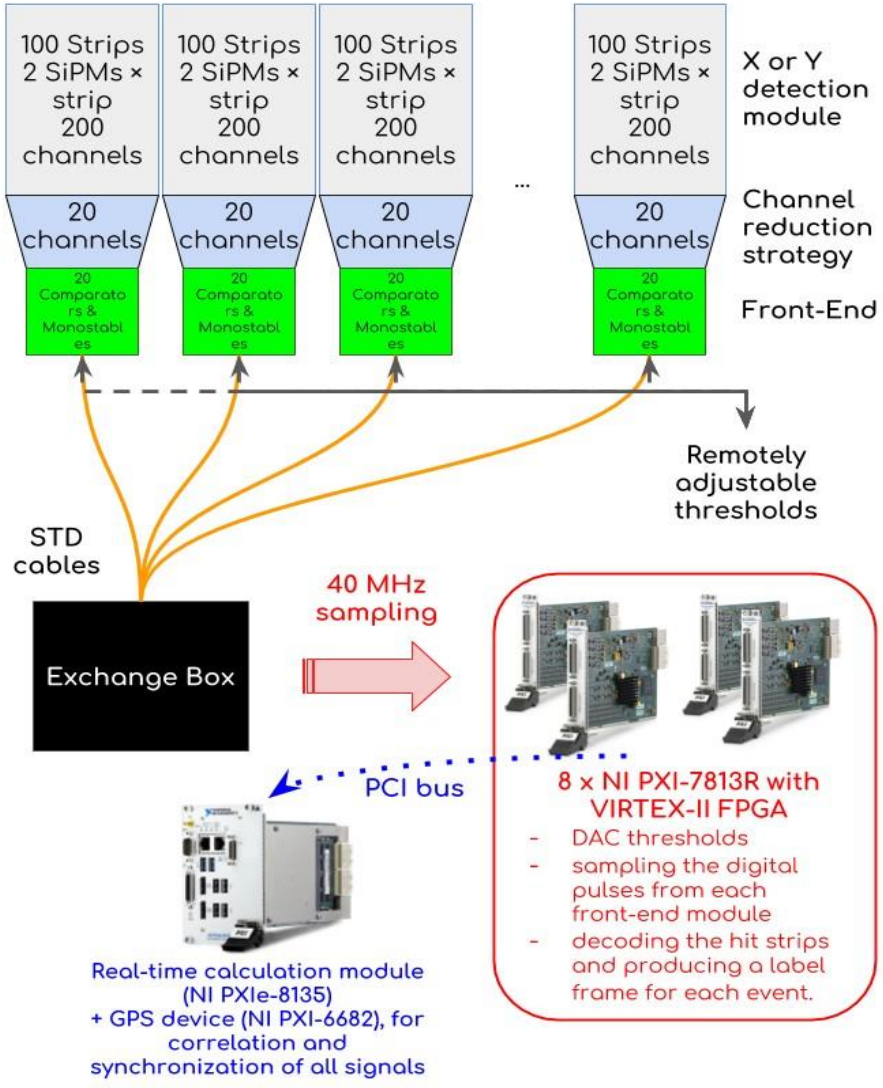
Conclusions

- The results seem promising to have a reasonable time to produce an alarm.
- We're near to the goal but we've to produce another effort.
- Fortunately we have some aspect that can still be improved
    - ✓ Optical coupling between WLS-Fiber and SiPM
    - ✓ Use a full custom board with the FE ASIC instead of a general pourpose Test-board
    - ✓ Choosing the best FE ASIC
    - ✓ Smarter algorithms

Acquisition strategy

According to the design specification, the number of channels would be of the order of 10^4. A compression strategy has been implemented to reduce the overall number of channels by a factor 10. This is achieved by the use of the two WLS running along the same strip and going to an equal number of SiPMs. The photo-sensors output are then properly combined in group of ten, resulting in 20 channels per module.





POCA - Algorithm

Identification of hits and clusters in each detection plane allows for the reconstruction of tracks in the upper and lower parts of the detector and for the estimation of the scattering angle between two tracks.
Several algorithms have been tested for the reconstruction of the muon scattering process. The simplest (and faster) is based on the Point-of-Closest-Approach (POCA) method.

$$\mathbf{P}_{poca} = \frac{1}{2}(\mathbf{P}_{in} + \mathbf{P}_{out})$$