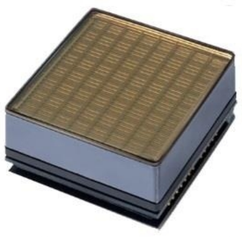
INSTITUTE OF SPACE SCIENCE – INFLPR SUBSIDIARY

Cosmic muons detection using a scalable 3D scintillator configuration coupled to SiPM arrays

This study proposes a solution for ***Cosmic muons detection*** using a 3d shaped stack of multiple layers of parallelepiped prism scintillators, each scintillator being optically coupled to a silicon photomultiplier (SiPM) in a SiPM array of 8x8. As muons traverse the stack, they produce fast scintillation pulses detected with high sensitivity by the SiPMs. The multilayer configuration is scalable and enables time-coincidence techniques for background suppression and ***trajectory reconstruction***, allowing precise determination of the angular distribution of incident muons. In addition, the use of charge-sensitive electronics allows for the measurement of the energy deposited in each layer, enabling indirect estimation of the muon's electric charge magnitude and energy loss through the detector. This compact and scalable system offers a robust platform for angular and charge-resolved cosmic muon studies, with applications in astro-particle physics, environmental monitoring, and educational research.

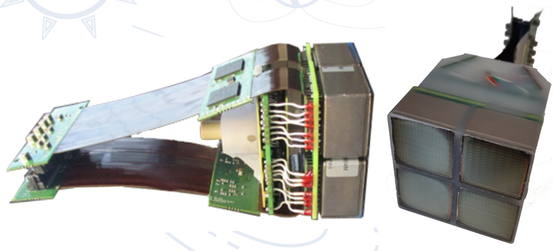
Our expertise in SiPM based detection applications comes from the **SUVDET** project (an ESA-PRODEX project) which assessed the research and the development of a SiPM ECM for the super-wide-field telescope for the **JEM-EUSO** program (**J**oint **E**xperiment **M**issions for **E**xtreme **U**niverse **S**pace **O**bservatory), as a more compact and performant alternative of the current MAPMT FSD.

8x8 MAPMT module



- Gain: >10^6
- Weight: ~ 200g
- Bias Voltage: > 1kV
- Gap on perimeter and between PMTs
- Performance affected by magnetic fields
- Can be damaged by ambient light
- Mechanically fragile, needs rugged setup

2 x 2 MAPMT array configuration with readout ASICs and FPGA control (16x16 PMT "pixels")



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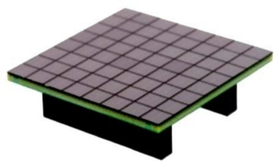
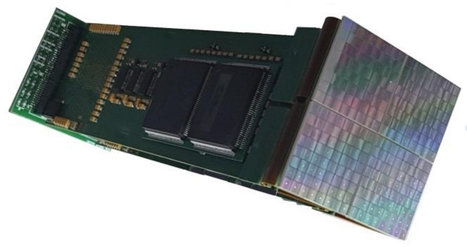
2304-pixel focal surface made of 36 MAPMT modules (6 x 6) , each of 64 (8x8) PMT "pixels"

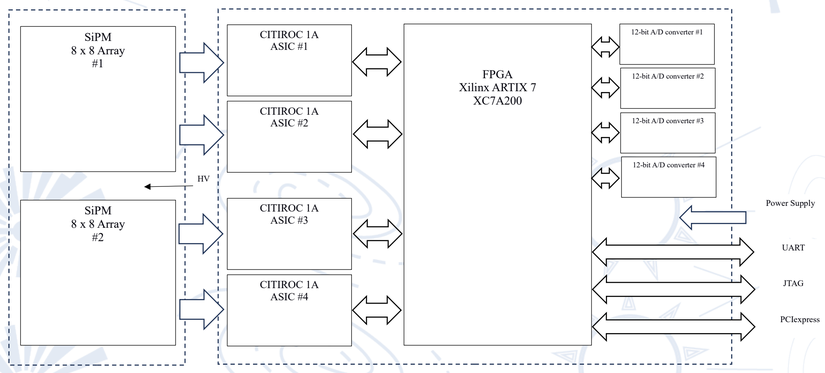
8x8 SiPM matrix module (MPPC)
Hamamatsu S13361-3050AS-08

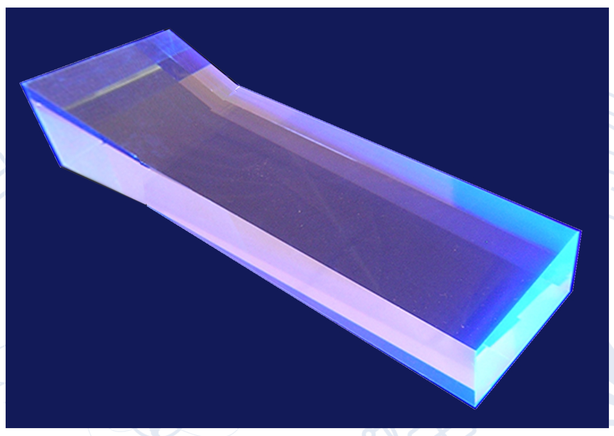


- **Gain: >10^6**
- **Weight: few grams**
- **Bias Voltage: 20 – 60V**
- **No gap on perimeter, 0.2mm between SiPMs**
- **Not affected by magnetic fields**
- **Cannot be damaged by ambient light**
- **Solid state technology**
- **SiPM cell size: 3x3 mm**
- **MPPC cell count: 64 (8x8 configuration)**

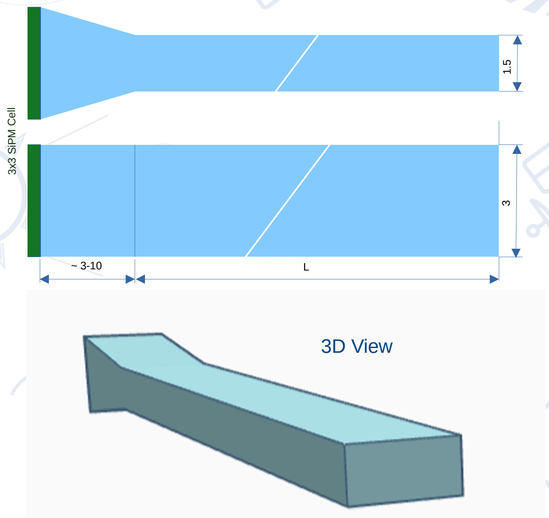
2 x 2 SiPM array configuration with readout ASICs and FPGA control (16x16 SiPM "pixels")



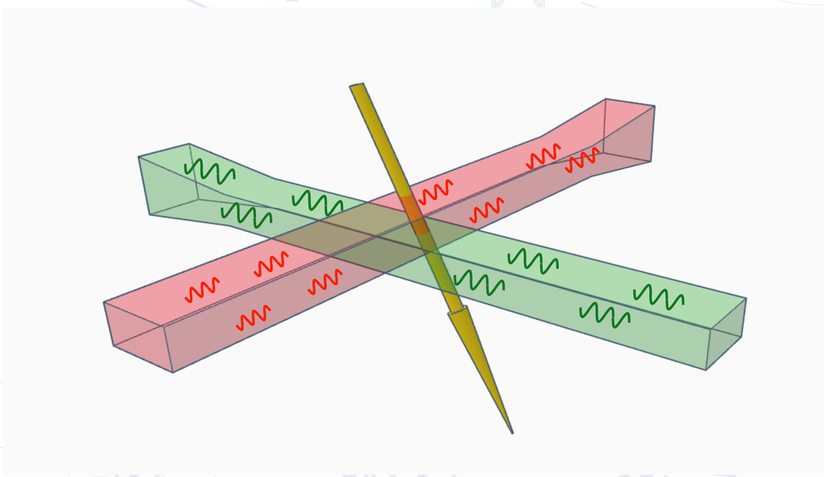




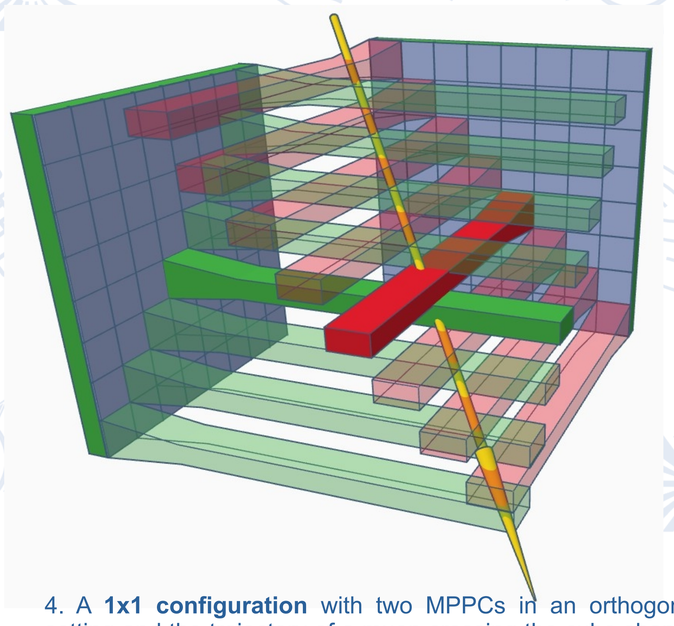
1. **Scintillator rod** shaped for optical coupling to a SiPM cell of 3x3 mm from a MPPC matrix of 64 (8x8) cells.
Ex.: EJ-200 from ELJEN Technology (decay time: 2.1ns, pulse width: 2.5ns, λ=425nm).
For maximum detection efficiency, the sides of the rod, except the side optically coupled with the SiPM, should be covered in reflective coating.



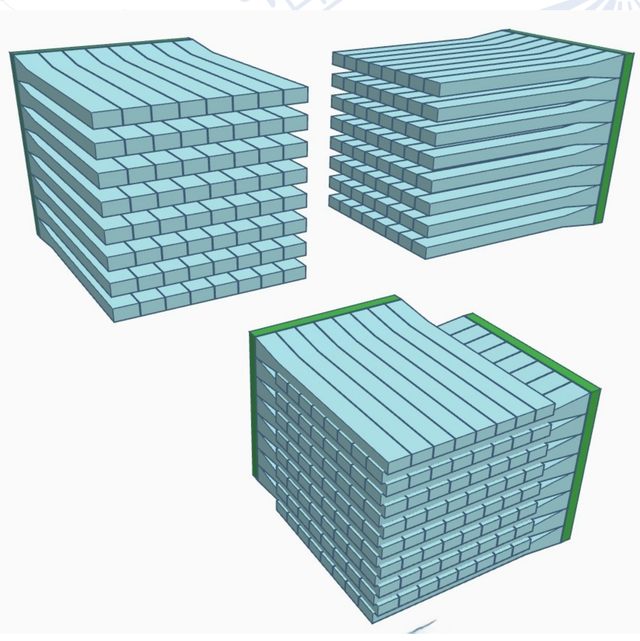
2. **Dimensions of a scintillator rod.**
L = 26 x k mm, where k varies with the number of MPPCs used in the detection configuration.
Ex. For a 1x1 configuration (two MPPCs in an orthogonal configuration, see figure 4), all rods (64 x 2 pieces) will have k=1. A 2x1 configuration will demand 64 rods with k=1 and 64 rods with k=2.



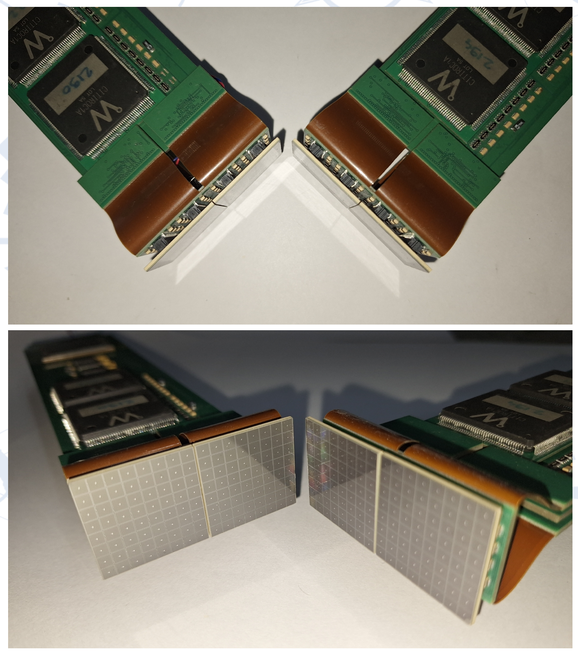
3. **How it works**
A muon passing an orthogonal pair of adjacent scintillation rods generates optical pulses which are collected at the wide end of the rod (the 3x3mm end), by the optically connected SiPMs, each belonging to one of the MPPCs in the configuration. Each SiPM generates electrical pulses in perfect sync with the optical pulses, and the simultaneous detection of the pulses by both detectors points out that a muon crossed the space where the two rods overlap.



4. A **1x1 configuration** with two MPPCs in an orthogonal setting and the trajectory of a muon crossing the cube shaped volume.
Only the rods which are crossed by the muon's trajectory are shown (mostly in transparency display) in order to distinguish the "triggered" SiPM cells. The electrical pulses from the "trigerred" SiPM are further processed in order to obtain a spacial image of the trajectory.



5. The **Full 1x1 configuration** with two MPPCs in an orthogonal, each MPPC optically connected to 64 scintillation rods.
The compact pack of interlaced scintillation rods generates a volume where the trajectory of a muon can be precisely determined.



6. **The Current Status**
Using the legacy UV detection design used in the SUVDET project unfold, a complete detection configuration can be used and/or upgraded for any 1x1, 2x1 and 2x2 configuration and made ready to be populated with customized scintillation rods.

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