The MuRay telescope

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What do we want from a muography detector ?

- Tracking capability: direction of muons (flux and energy depends on azimuth).
- High spatial/angular resolution
- Uniform response
- Redundant background suppression capability
- Low cost/channel: larger telescope area and/or higher resolution
- Resistant and modular structure: usage in volcanic area
- Low energy consumption : usage in volcanic area
- …and possibly make coffee, too !

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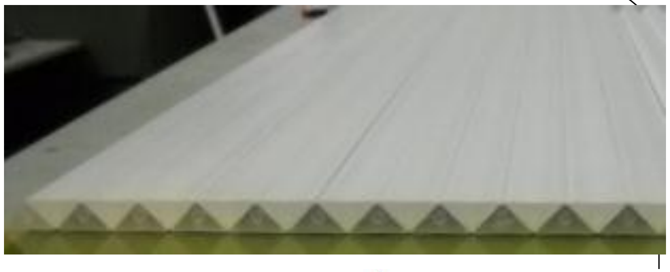
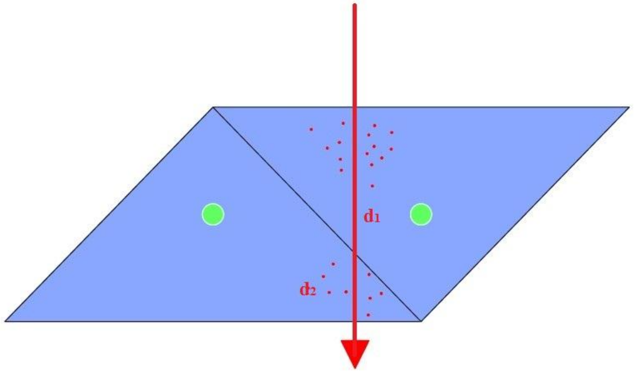
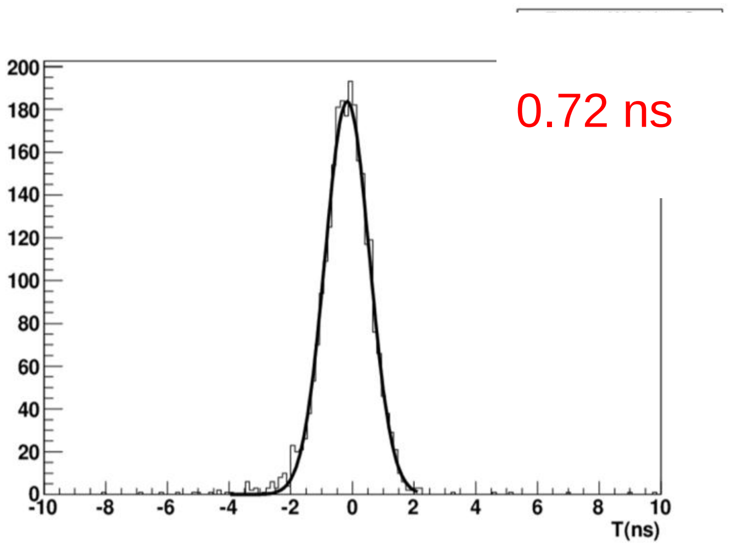
The Mu-Ray scintillator



- Triangular scintillator bars with WLS fibers
  - No cracks, self porting structure
  - Allows **spatial resolution** (3mm) better than half the fibers pitch (17 mm)
  - **Cheap** and easily glued co-extruded scintillator (produced at Fermilab)



- Fast re-emission WLS fibers
  - Allow for < 1 ns time resolution !
  - Allow maximum **uniformity** even for cheap scintillator



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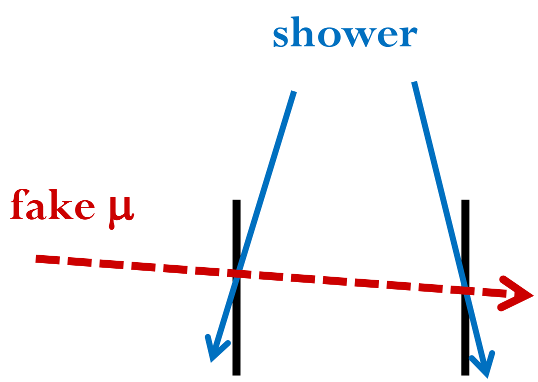
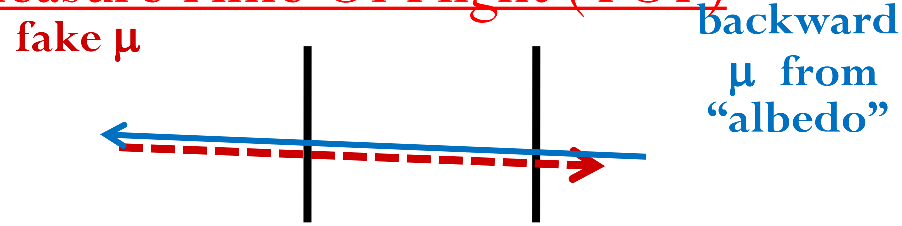
A note on background

- Showers of charged particles created in the atmosphere can mimic a straight track -> use at least 3 planes, increase resolution!



- At low angle rescattered «albedo» muons coming from the oppsite direction (where there is no volcano….) can mimic the muon-> measure Time Of Flight (TOF)



The Mu-Ray solution

- Several solutions originally proposed by Mu-Ray are nowadays «standard» in the muography field:
  - At least three planes, each with both X and Y measurement
  - Azimuthal rotation for flux calibration

- Time of flight is still unique to Mu-Ray, due to its unique time resolution which allows to distinguish the direction of the traveling muons.

The telescope structure

Planes height can be modified

Adjustable feet

Distance between planes can be modified

Telescope can be easily rotated, to acquire calibration runs

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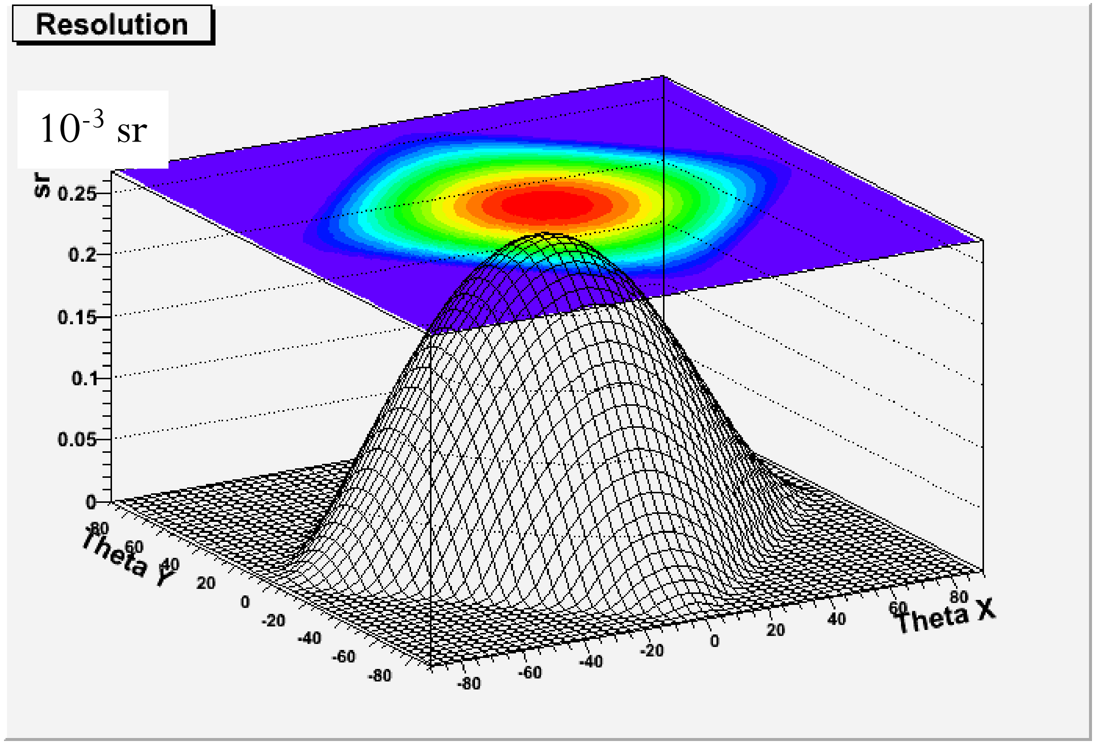
The resolution/acceptance tradeoff

- The problem of muon radiography: we want to have our cake…and eat it too !

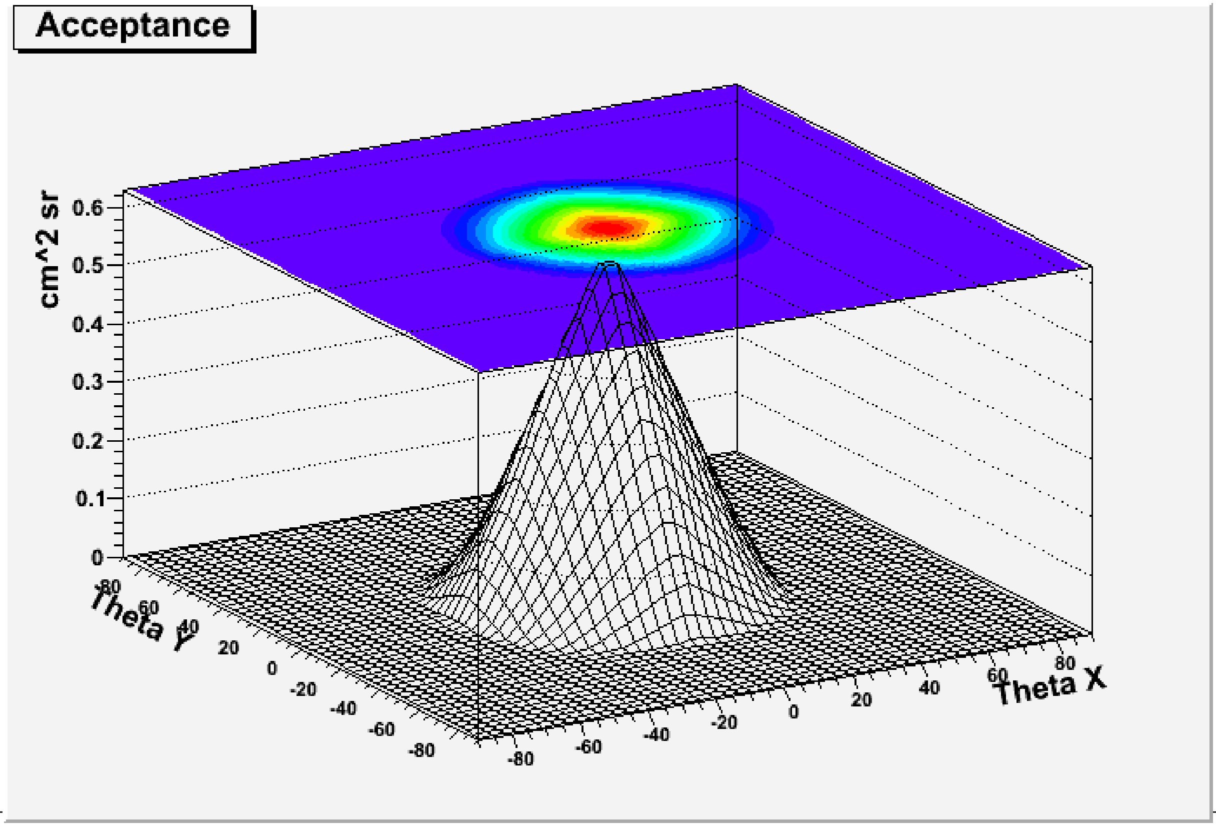
Resolution (e.g. MuRay : 0.00025 sr) vs



The resolution/acceptance tradeoff

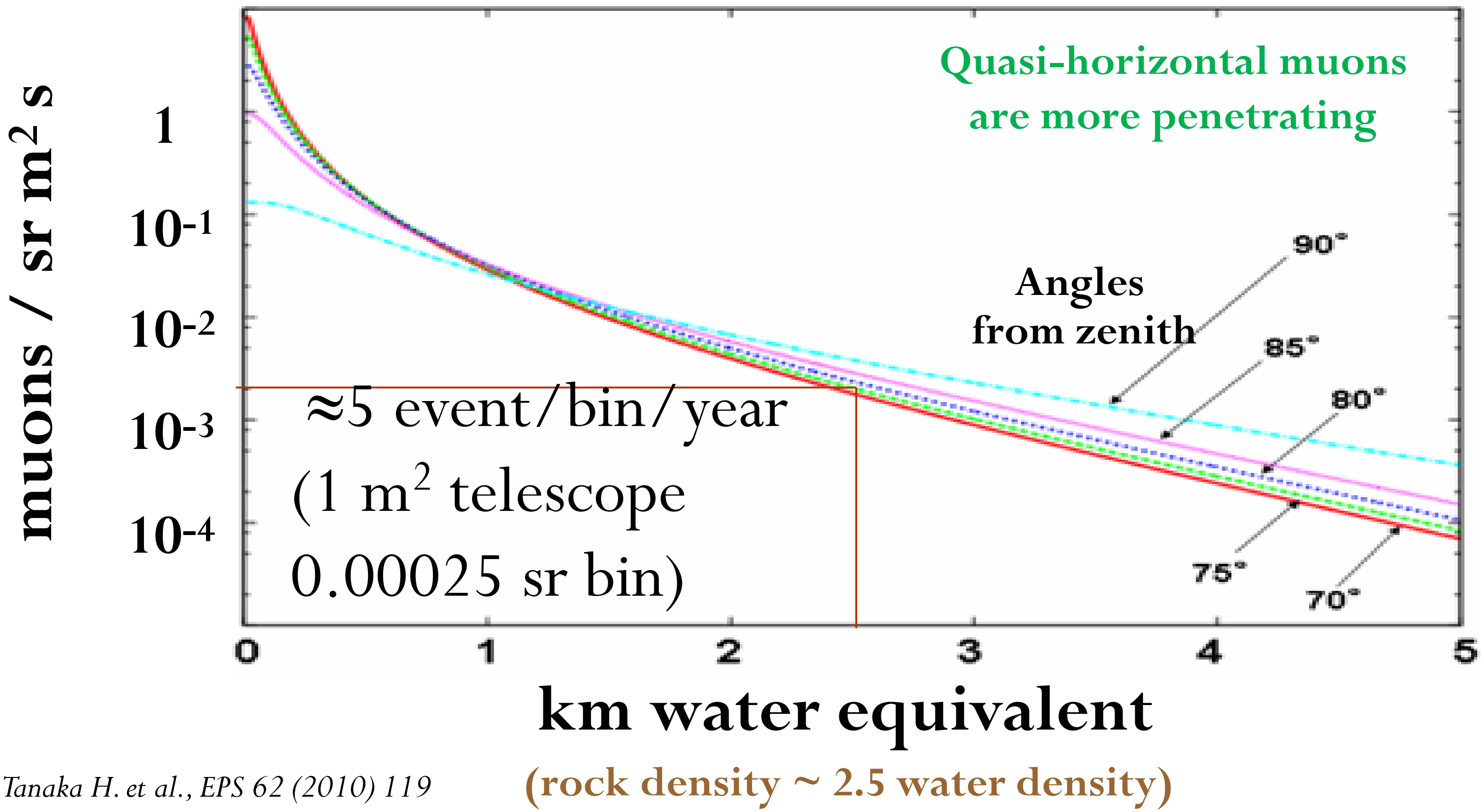
- The problem of muon radiography: we want to have our cake…and eat it too !

Acceptance ! (e.g. 1 m^2 MuRay @0.00025 sr: < 1 cm^2 sr)



…and very low fluxes to cope with!

- The problem of muon radiography: we want to have our cake…and eat it too!



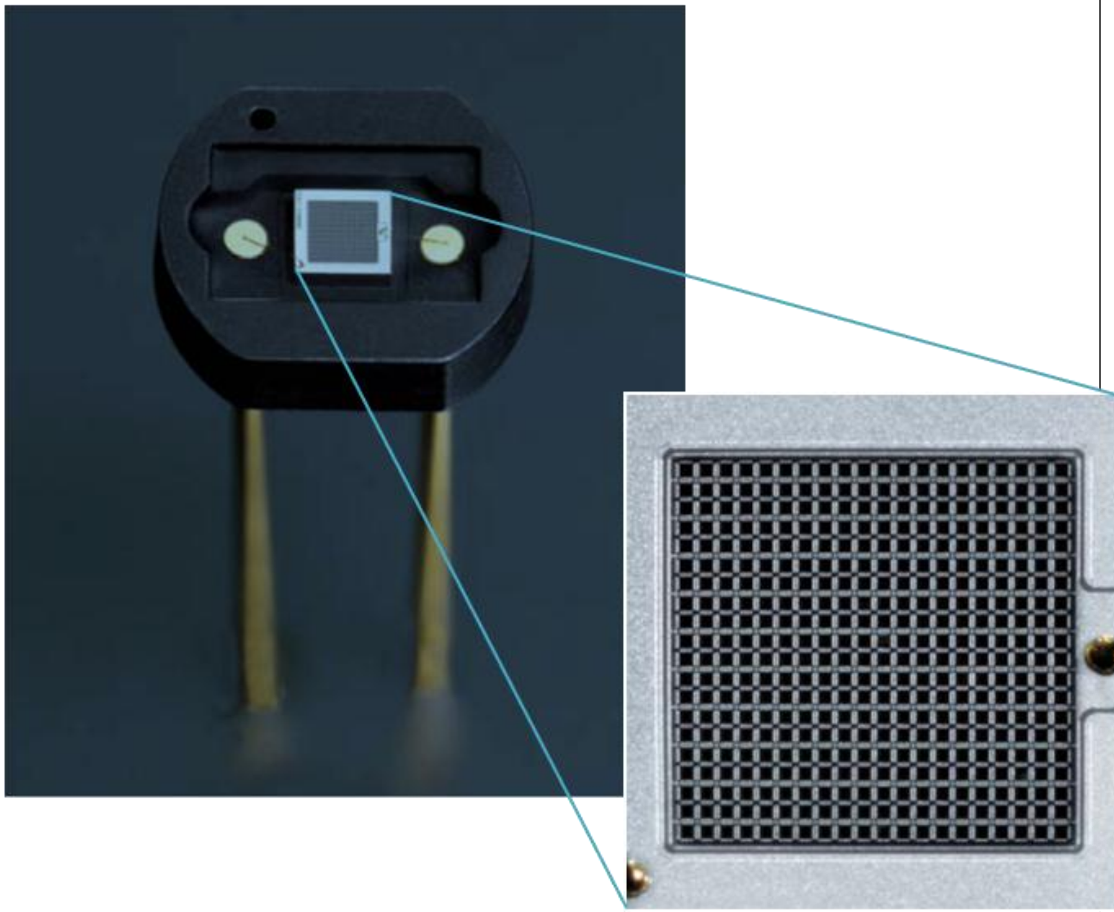
Plot from Tanaka H. et al., EPS 62 (2010) 119

Channels, channels (and more channels)

- The only way to obtain a reasonable amount of events in a reasonable time is to enlarge surfaces
- High intrinsic resolution can help in providing smart and adaptive re-binning to enhance sensitivity to localized density anomalies and in reducing shower background.
- Moreover one can profit of the optimal resolution in case of high fluxes (e.g. thin rock layers, shallow structures)
- If you want both high res and large surface: **large number of channels !** (e.g. MuRay 128 X 3 ch / 1m^2 telescope)
- Need **high level of integration and low cost/channel**

SiPMs for pedestrians

- New concept in light detection
- Array of APD cells working in self-quenching Geiger mode
- High level of miniaturization and integration
- Light detection efficiency higher, and gain comparable to traditional PMTs
- "Digital" linear response (each APD cell works in on/off mode)

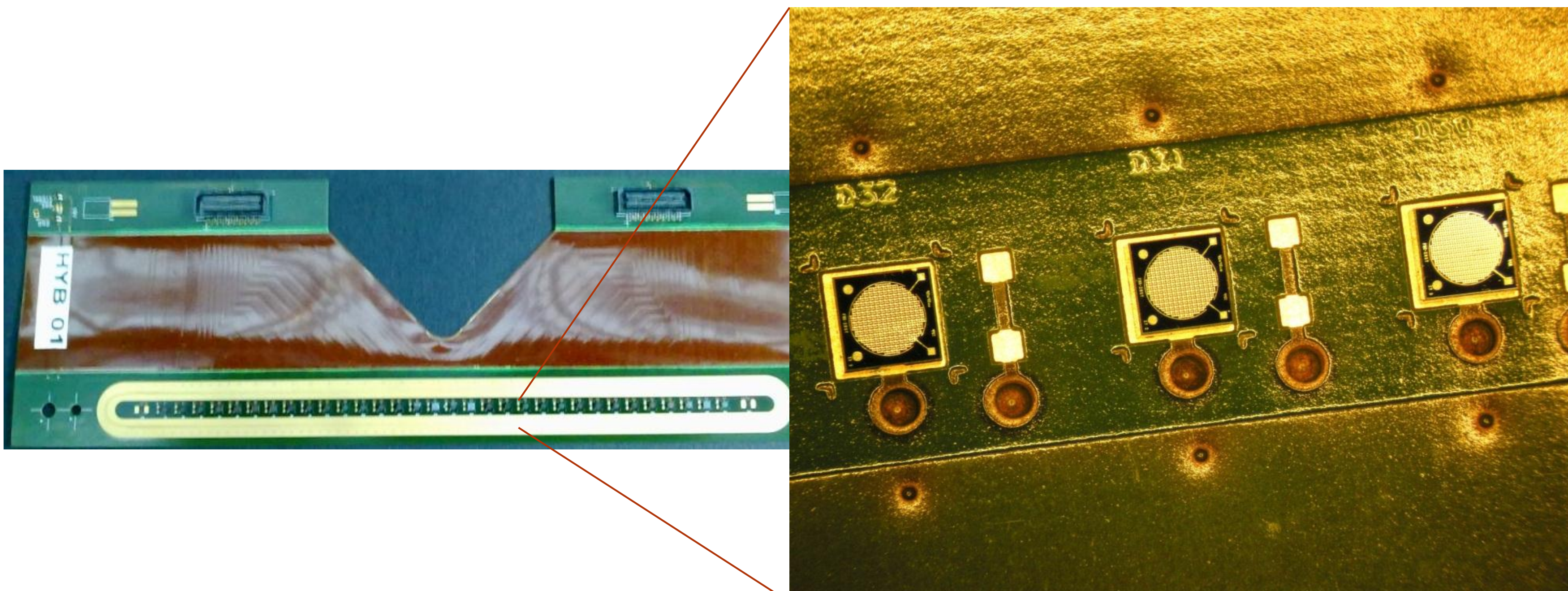


SiPMs in one slide

- **high photo-detection efficiency (25%-70%)**
- Linearity (if n photons << n cells)
- High gain (10^5-10^6)
- Single photon detection sensitivity
- no excess noise factor (at first order..)
- fast (≈ 1 ns rise time)
- good time resolution (< 100 ps)
- Low bias voltages (< 100 V) very low power consumption (**10 μW**)
- Insensitive to B field
- **Extremely compact and robust**
- **Breakdown voltage and dark rate depend on temperature**

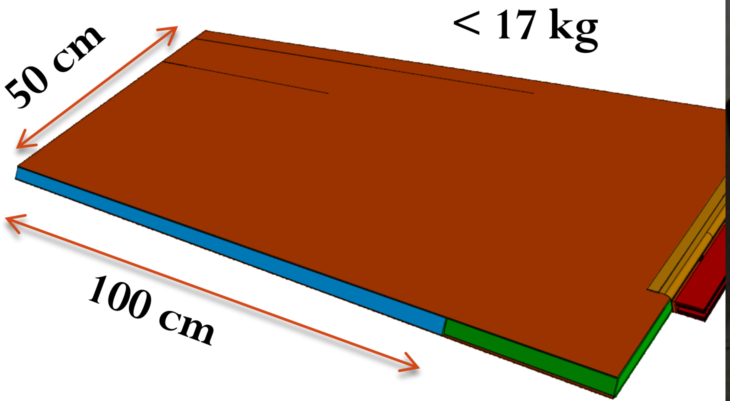
The Mu-Ray hybrid PCB

- 32 SiPM channels on a single, mechanically flexible board
- Allows for thermal conditioning of the sensor from the rear side using apposite conductiong vias



The Mu-Ray module

- Compact, relatively light weight (<17 kg) module containing 32 channels with all the electronics.



MuRay DAQ strategy

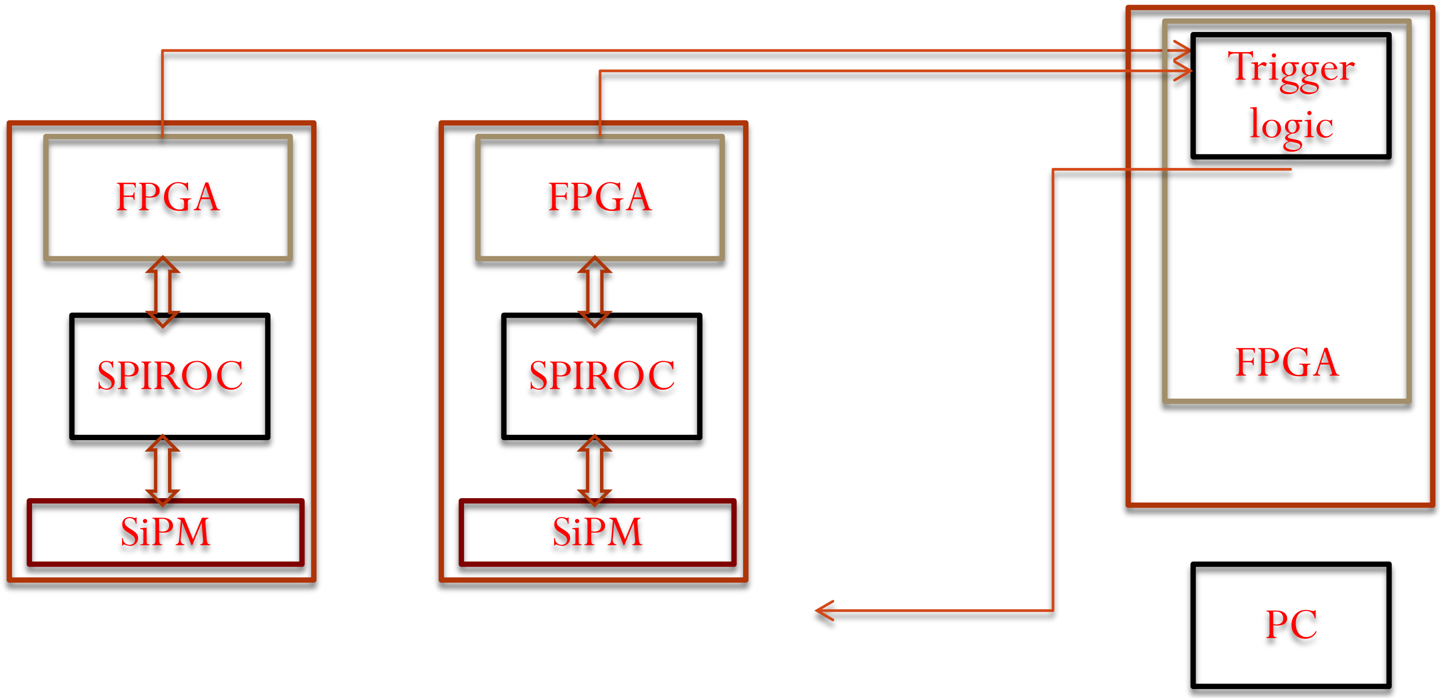
Based on SPIROC chips, able to control 36 ch each (32 used)

SPIROCs are host in boards controlled by FPGA (SLAVES)

One MASTER provides the trigger logic.

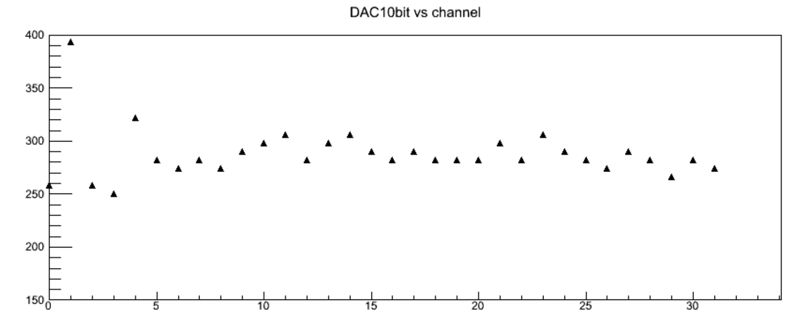
All the SLAVEs work in RUN mode, i.e. until a trigger is produced the FPGA clock is OFF and all the logic is combinatorial and power consumption is limited.

<u>Power consumption about 1.5 W /slave board (3 W for the Master)</u>

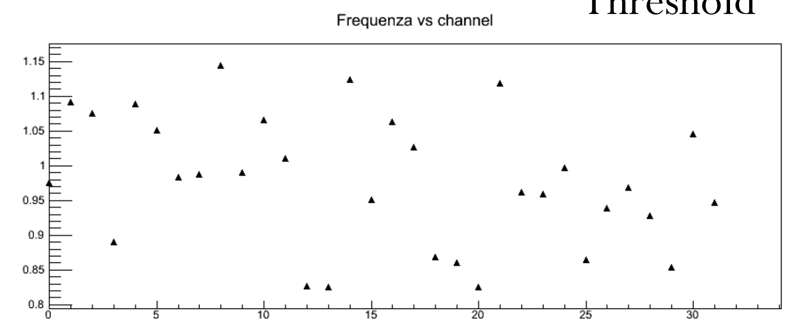


Commissioning

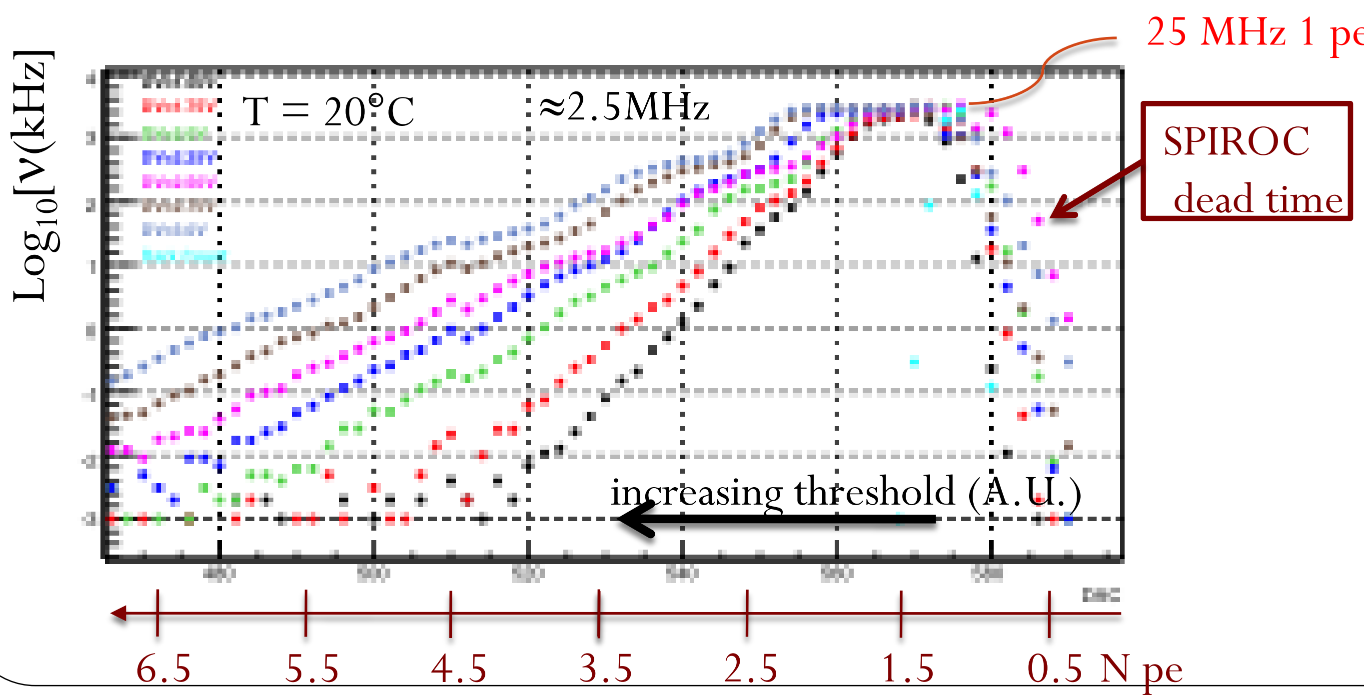
- Detector mounted in the lab spotting at vertical muons
- Choice of working point (threshold and Vbias equalization)
- Testing of reconstruction/analysis software



Threshold

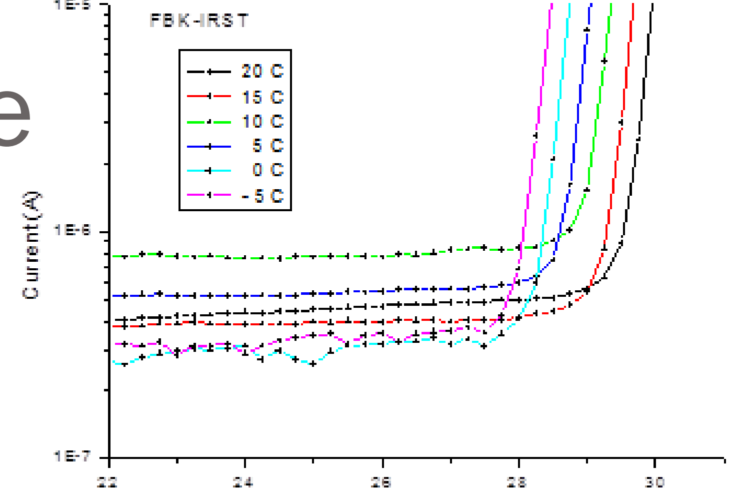


Rate (kHz)

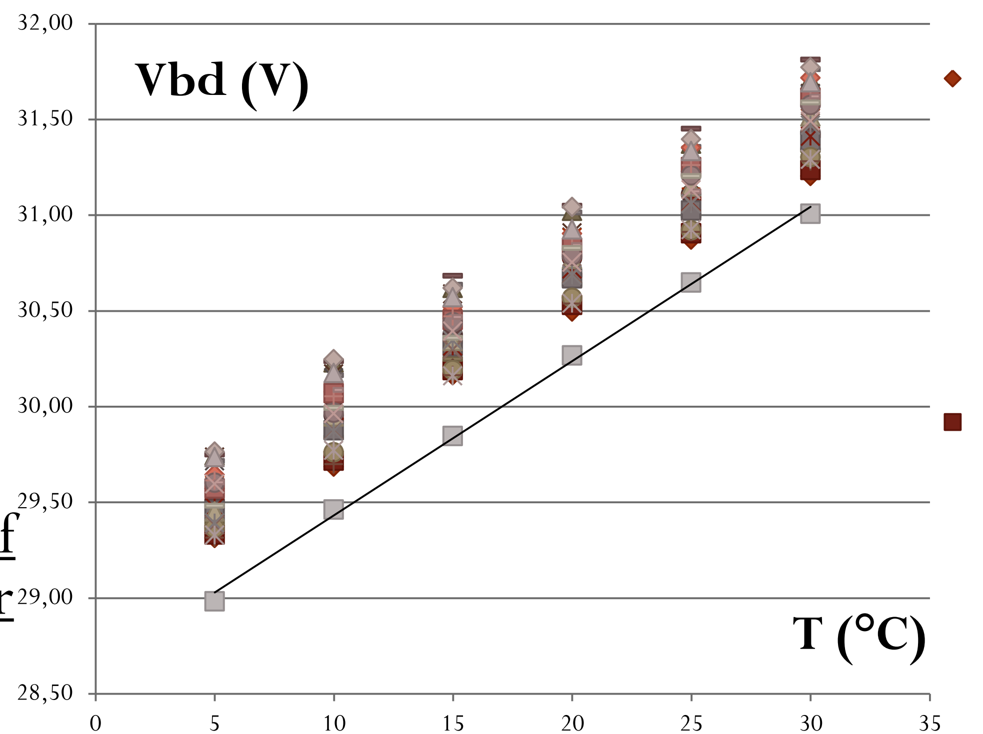


The temperature issue

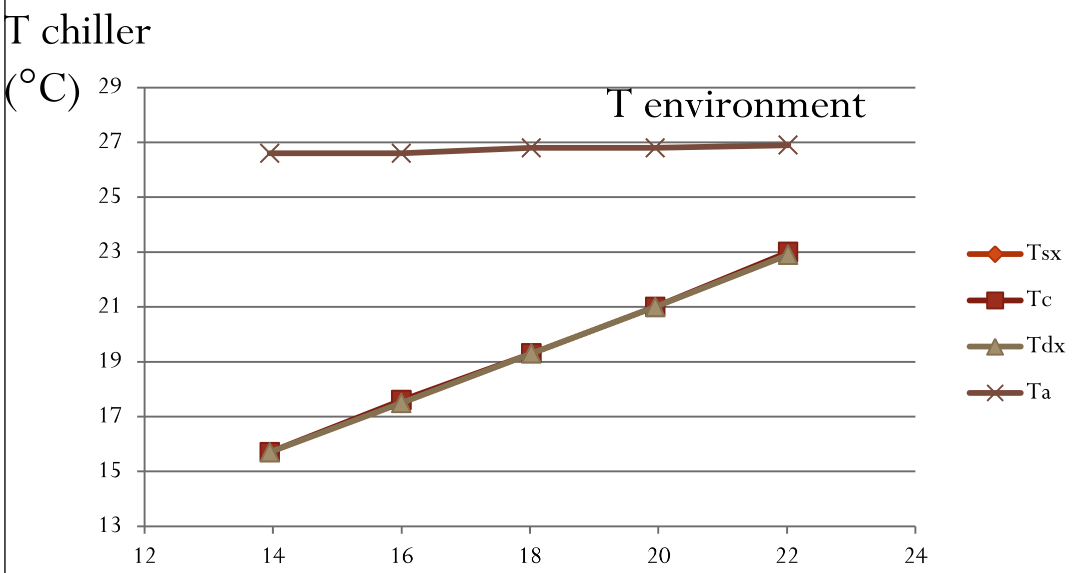
- Two possible approaches:
  - Keep SiPM temperature fixed (e.g. using Peltier cells)
  - Routinely compensate the temperature drift by changing Vbias to keep (Vbias-Vbd) fixed
- A mix of the two is the current MuRay approach: work at fixed T working points within 5-10 °C from ambient temperature in order to save power.
- Need <u>full characterization of SiPMs Vbd at least for one value of T (the slope is almost the same for all sensors)</u>

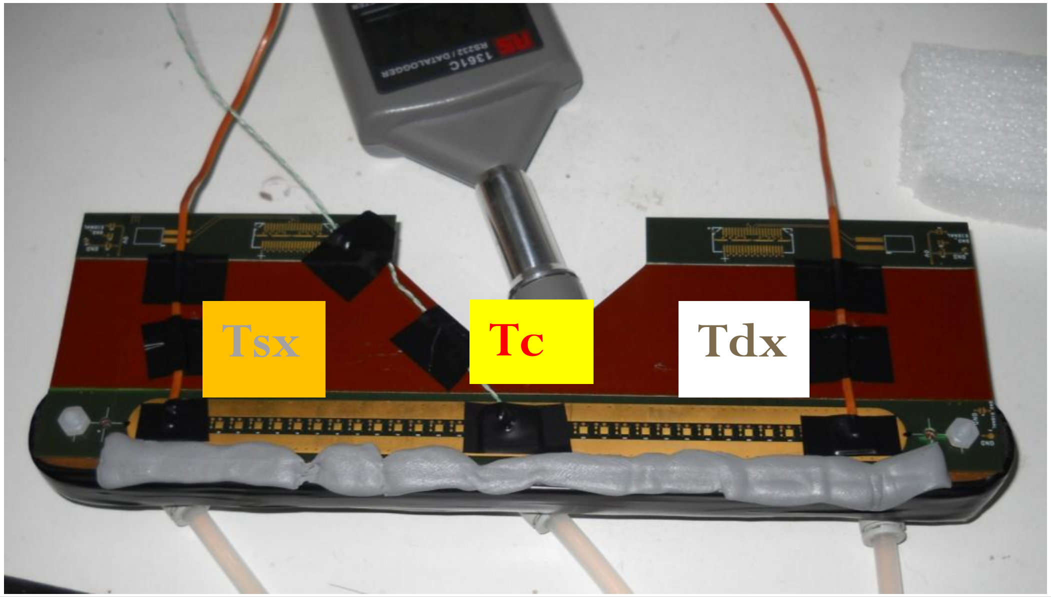


The slope is similar for all the SiPM: ≈80 mV/°C



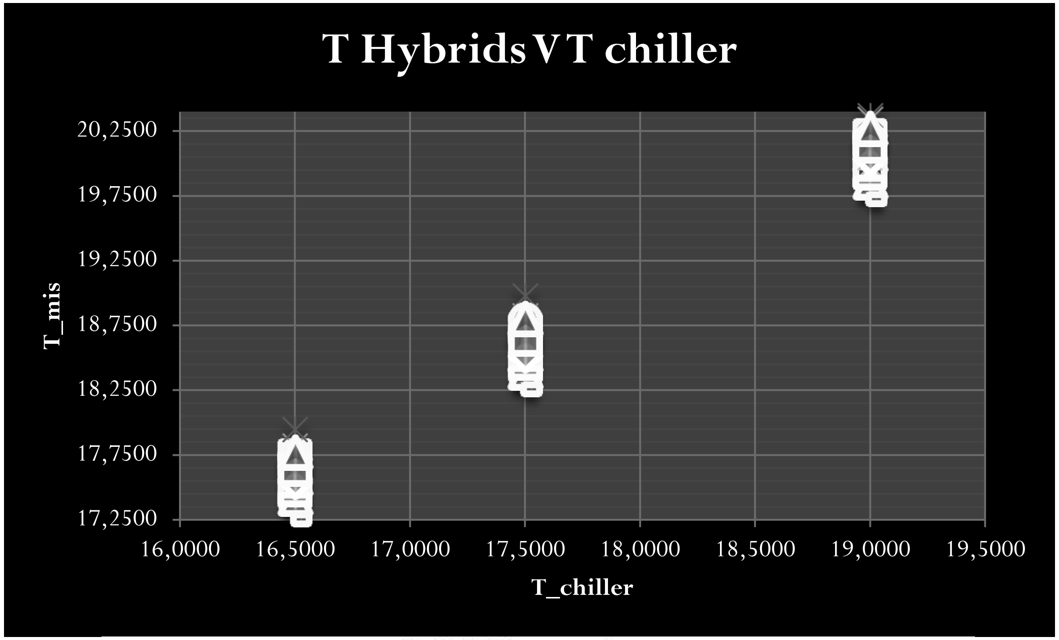
The temperature issue (2)

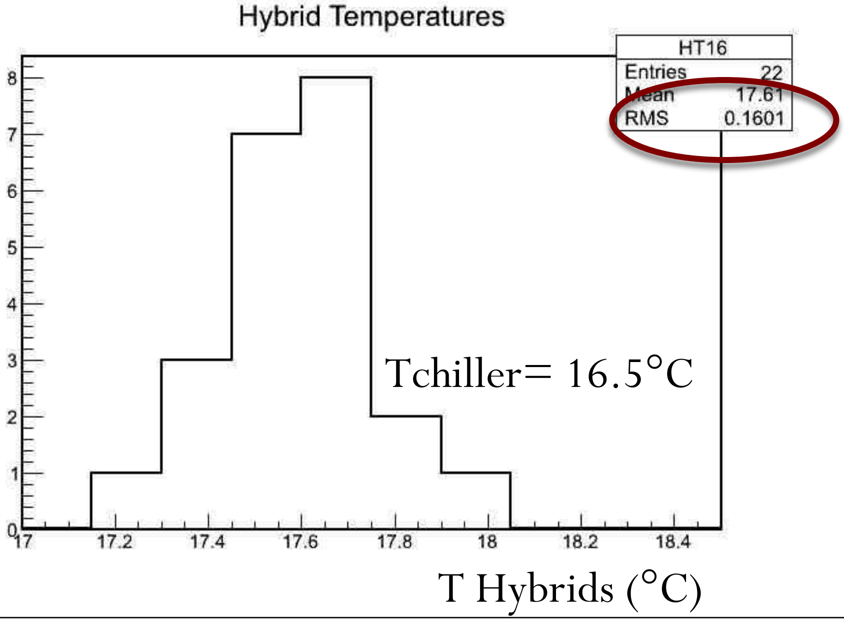




Excellent uniformity of temperature inside one hybrid…

The temperature issue (3)

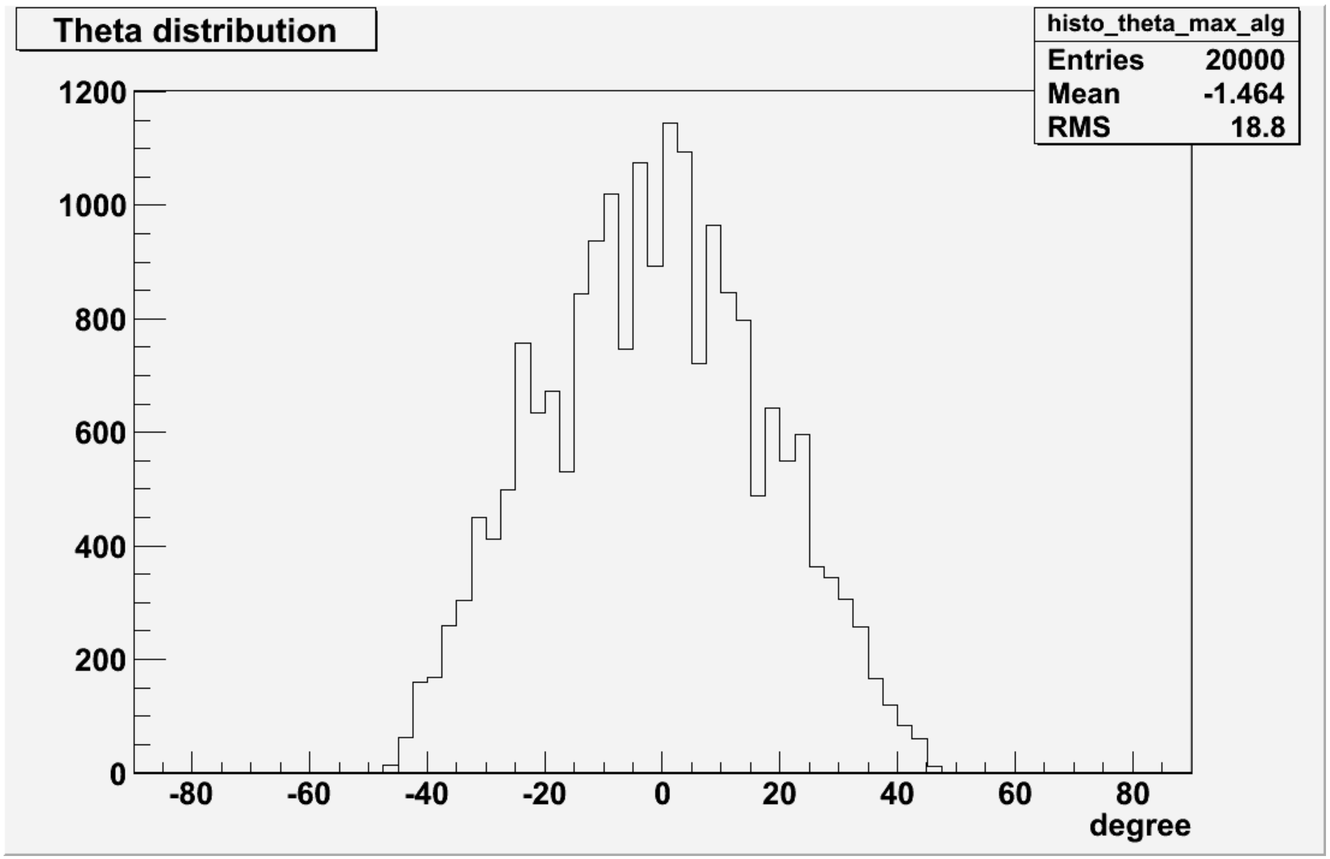




..and excellent uniformity of all hybrids' temperatures for a given value of T (RMS = 0.16 °C)

Looking at the sky…

- The very first short run using Cosmic Ray Trigger



Conclusions and outlook

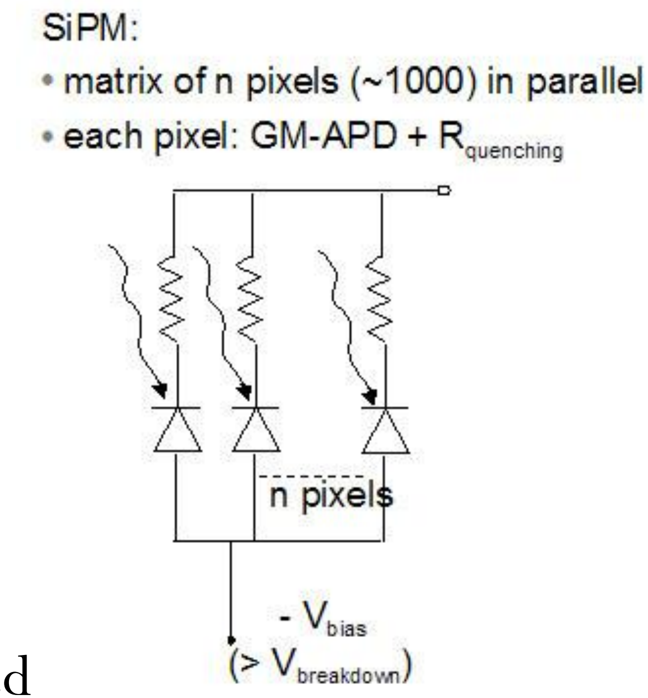
- The first 1m^2 Mu-Ray telescope has been built and successfully operated.
- We are going to start measurements on the field at Mt. Vesuvius (other possibilities: Monte Olibano , others ?)
- Progress is foreseen with new RO based on EASIROC (see D.Alessandro's talk tomorrow) and on Peltier based temperature control
- We took a long way when we started to think from scratch to a new detector using several technically challenging solutions, but now we have in our hands a flexible, modular and powerful tool.

SPARE SLIDES

SiPMs for pedestrians (2)

Some relevant features:

- Breakdown ("switch on") voltage V_{bd}
  - Few 10 V (O(30) for FBK-IRST)
  - Depends on manifacturer and (slightly) differs for each device
  - **Depends on temperature**
- Thermal noise ("dark rate")
  - Single photoelectron rate: few 100 kHz to few MHz/mm^2 at 25°C
  - **Depends on temperature**
  - Multiple photoelectron emission suppressed



The SPIROC chip: a user perspective

- Highly integrated ASIC
- Up to 36 channels management (32 used in MuRay boards)
- Individual Vbias adjusting (0-4 V, 175 mV step)
- Fast discriminator response (ONLY for the logical OR of all channels)
- Low power consumption (25 μW/ch)

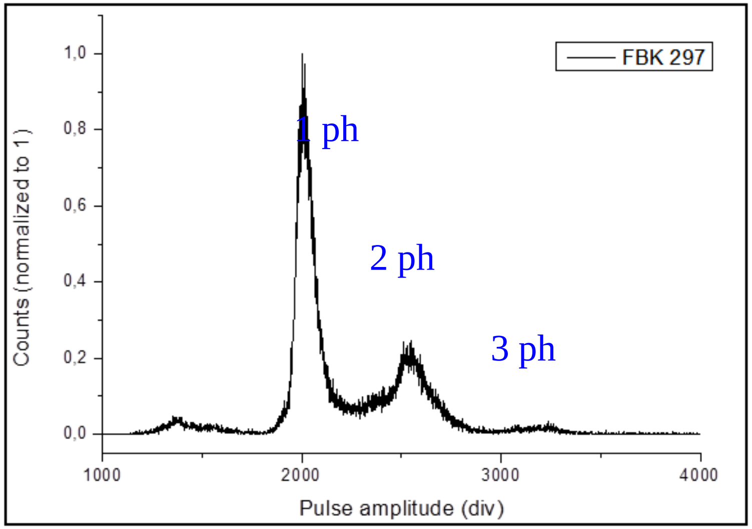
Issues: Designed for syncronous, triggered applications;
Learning curve; (SPIROC *is* user friendly:
it is just very selective on who his friends are ;-))
Known features/limitations

The (next) future: EASIROC

- Better adapted to asynchronous operation
- Greater granularity for a more versatile triggering
- Less components integrated on a die
  - Lower power consumption
  - More flexibility in deployment

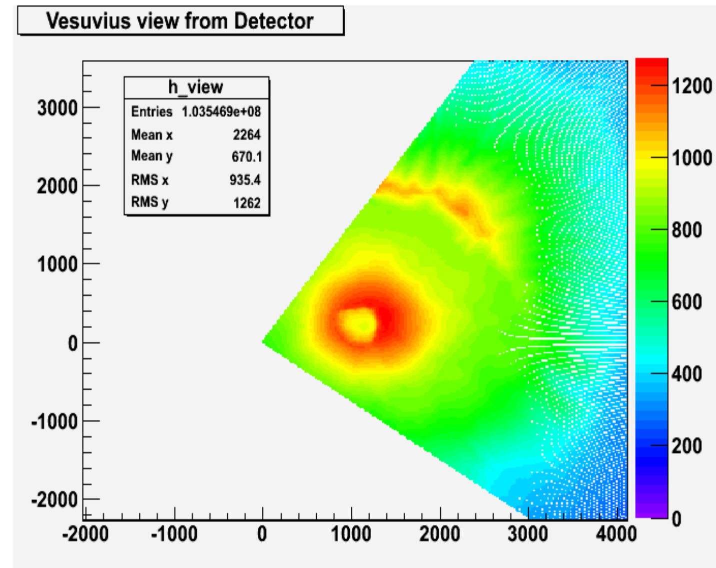
Adapting existent VFE from SPIROC to EASIROC is «straightforward»

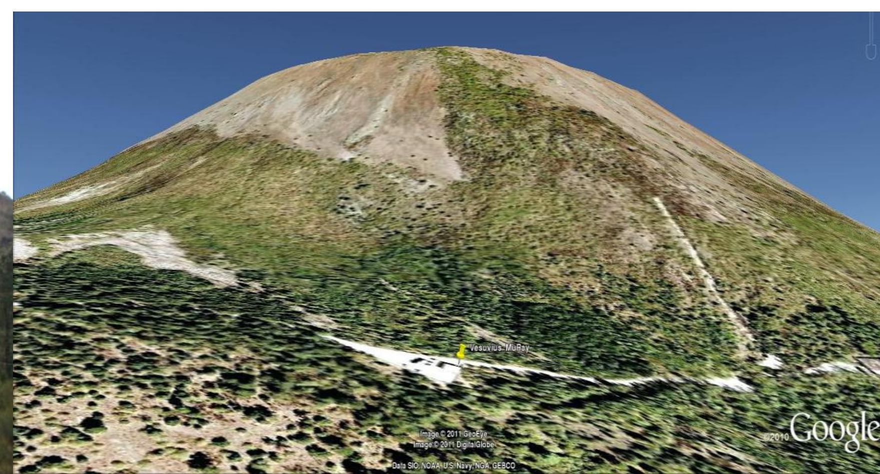
First tests in Florence VERY ENCOURAGING



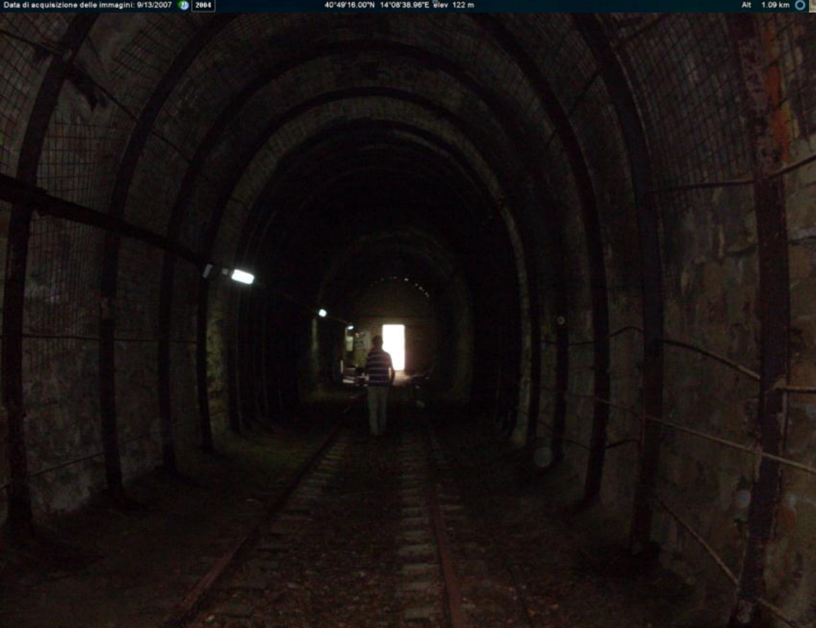
First on-field measurement

After the commissioning and characterization of the detector in the laboratory we plan to move the detector to Mt Vesuvius, where infrastructure is already available





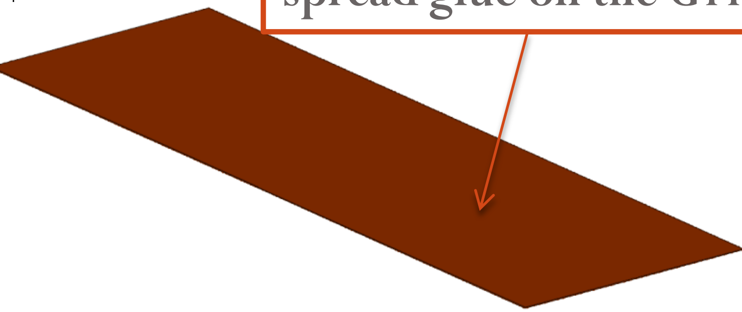
Monte Olibano



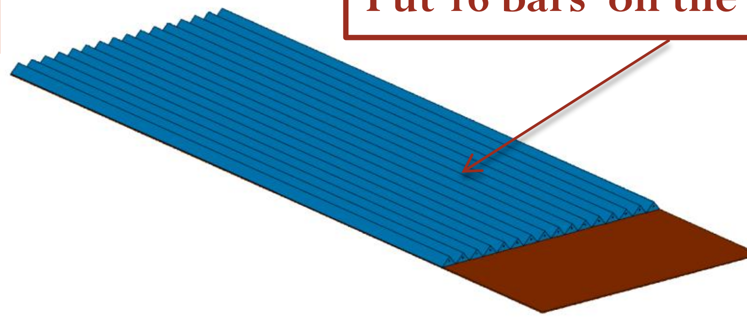
Modules construction (I)

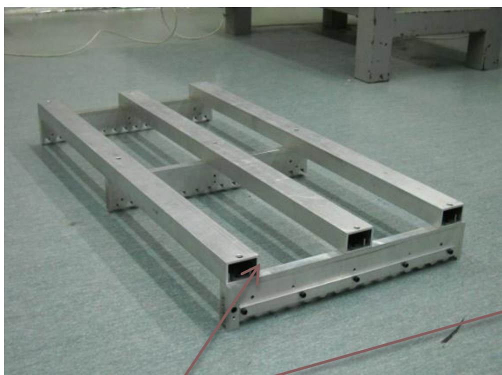
12 modules have been constructed in spring 2011

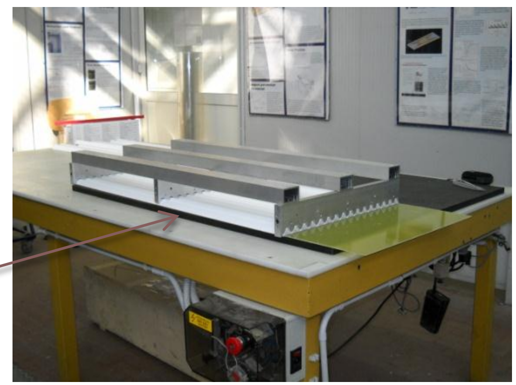
spread glue on the G11 plate

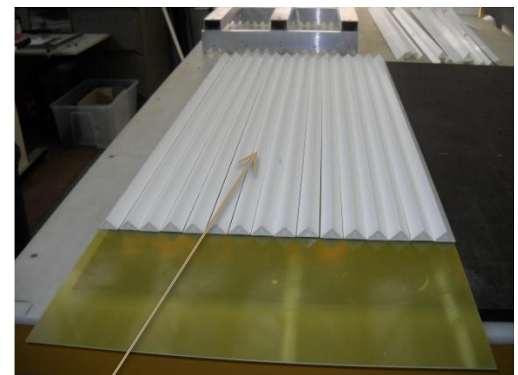


Put 16 bars on the plate



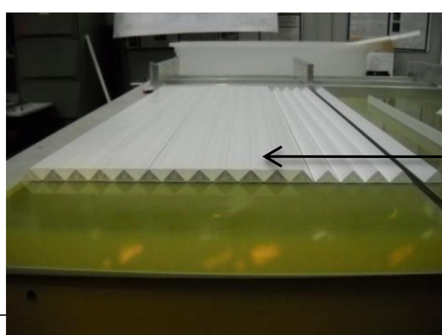






By a special jig, bars are spaced correctly

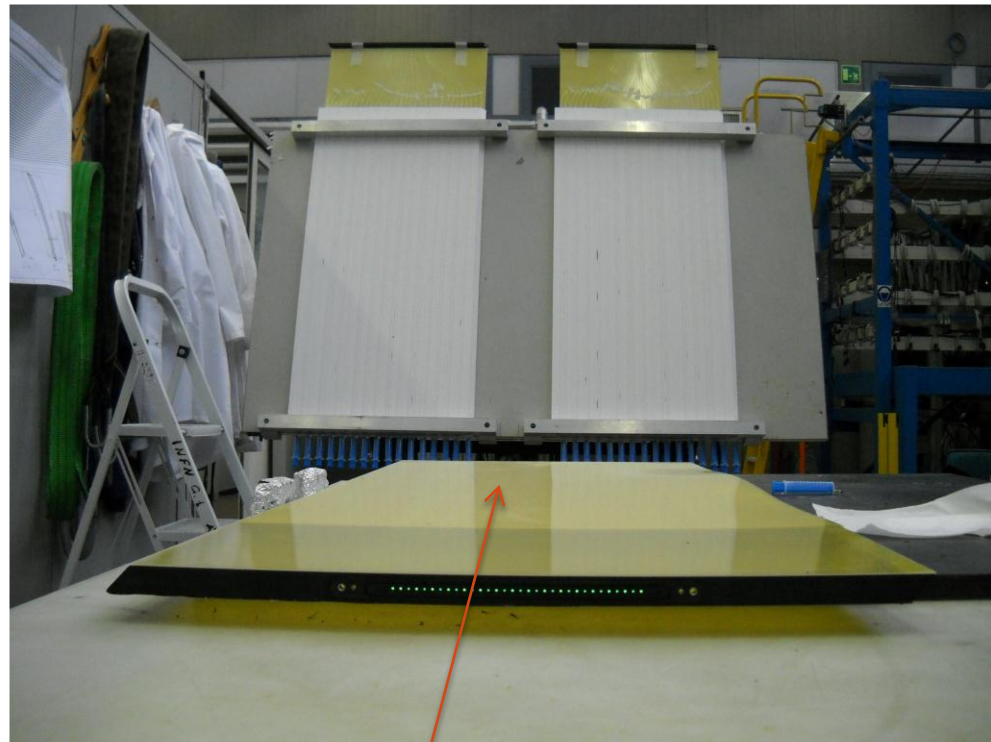
After a glue setting, the jig is removed



Now it's possible to glue
the second scintillators layer

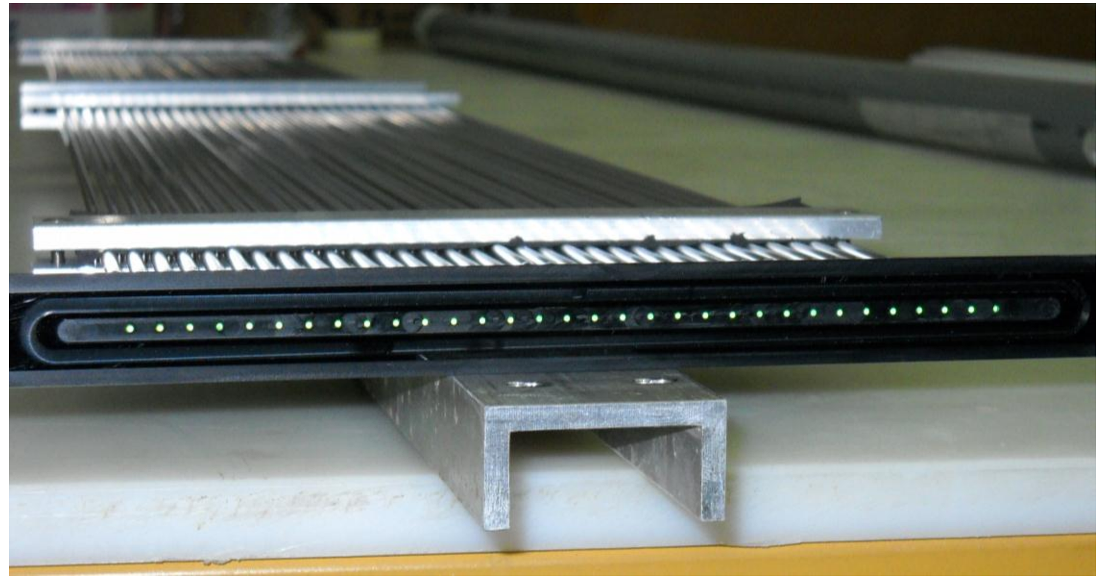
Modules construction (II)
Fibers-scintillators gluing

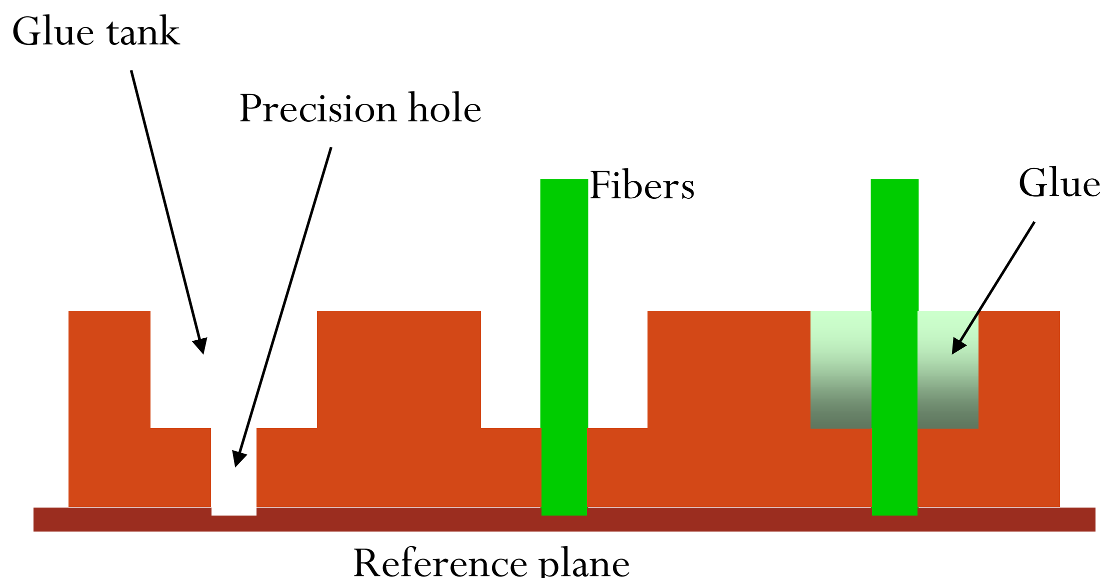
Fibers, already glued in the fibers-connector, are inserted in the scintillator's holes



The optical glue is inserted by syringe from the bottom

Fibers connector

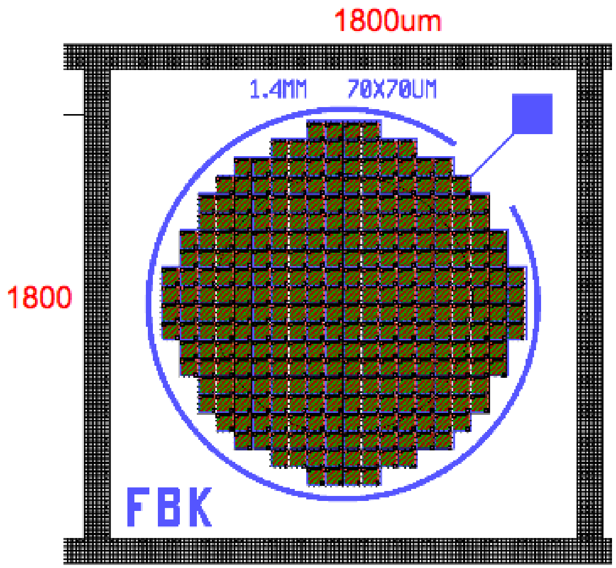




SiPM

Produced by FBK-IRST in a multi-project run with MU-RAY specifi

- SiPM active area: circular 1.4mm diam.
- pixel size: 70 µm x 70 µm

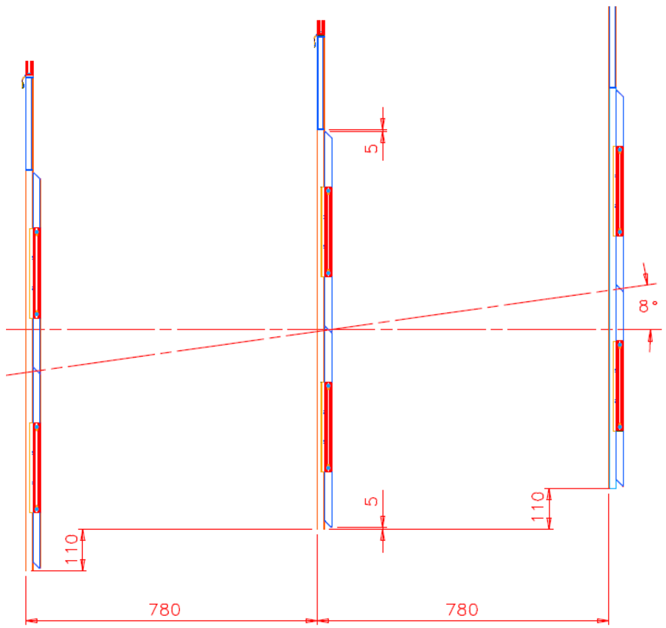


Wafer	Epoxy thickness	1.4mm diameter	1.2mm diameter
W1	35	235	40
W2	35	227	37
sub-totale		**462**	**77**
W5	65	220	36
W6	65	226	38
W8	65	214	34
W11	65	227	40
W12	65	226	40
W13	65	229	38
W15	65	218	38
W3,4,7,10,14	65	1138	0
sub-totale		**2698**	**264**
	Totale	**3160**	**341**
		numero totale SiPM	**3501**

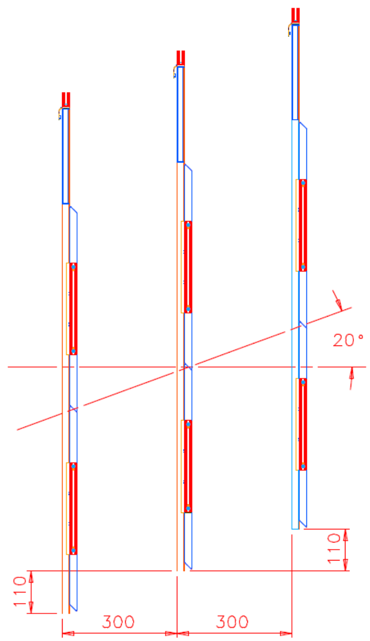
They are provided bare, with only a thin transparent protective epoxy layer
The SiPM are glued and bonded on a multilayer PCB (hybrid)

Axis tilting

Side view



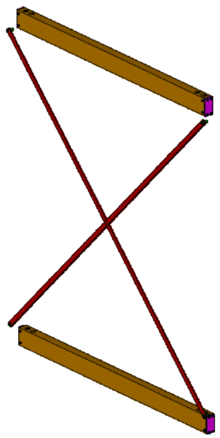
When double planes are at the maximum distance (780mm), the telescope axis can tilt by ±8°



When double planes are at the minimum distance (300mm), the telescope axis can tilt by ±21°

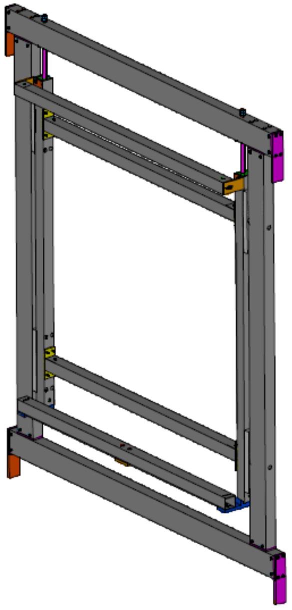
The telescope structure

The telescope frame has three main parts. Each one weighs less than 15 Kg in order to be carryed easly by a person



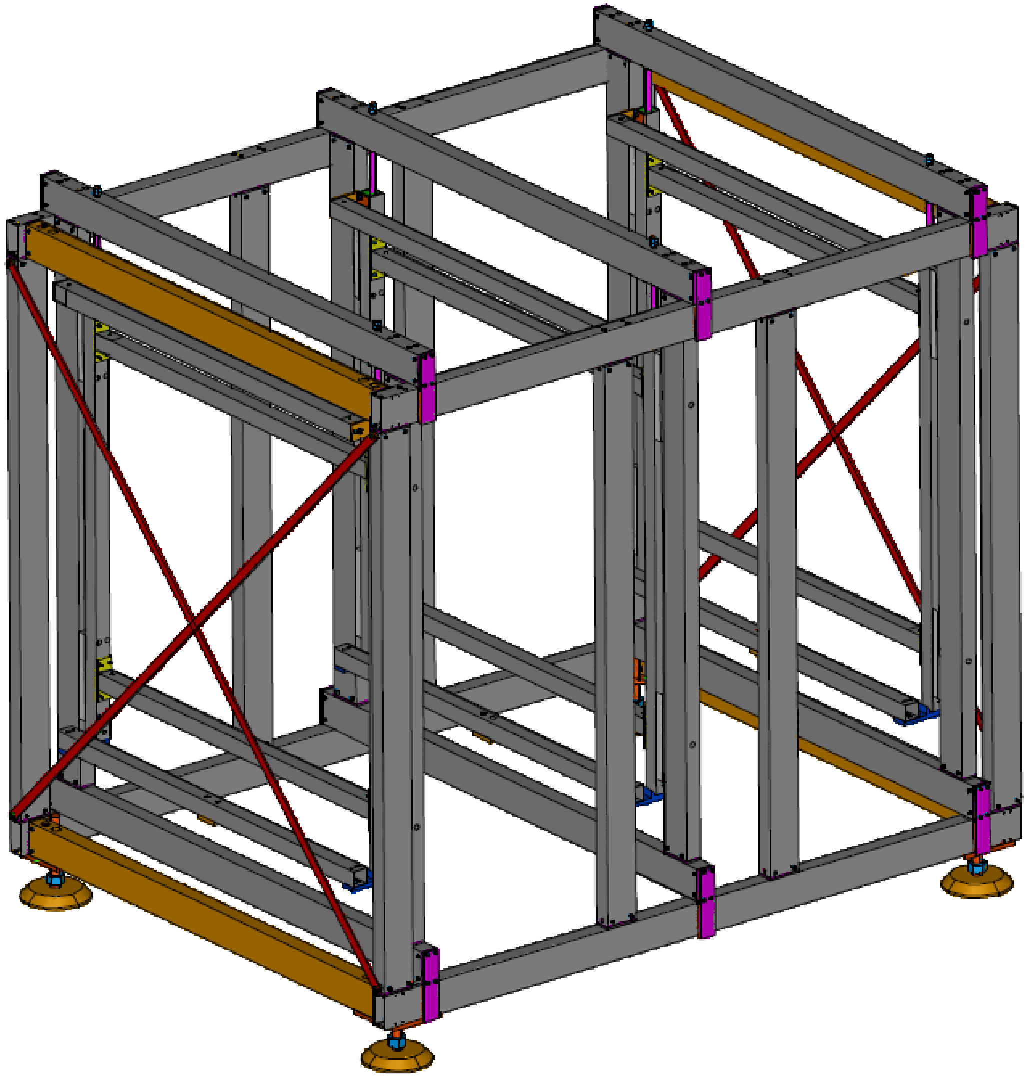
Front frame < 5 Kg

Side frame < 13 Kg



Double plane frame < 15 Kg

The structure assembled



The structure assembly on site
needs only 30 min and one wrench!