Scintillator based detectors with SiPM readout

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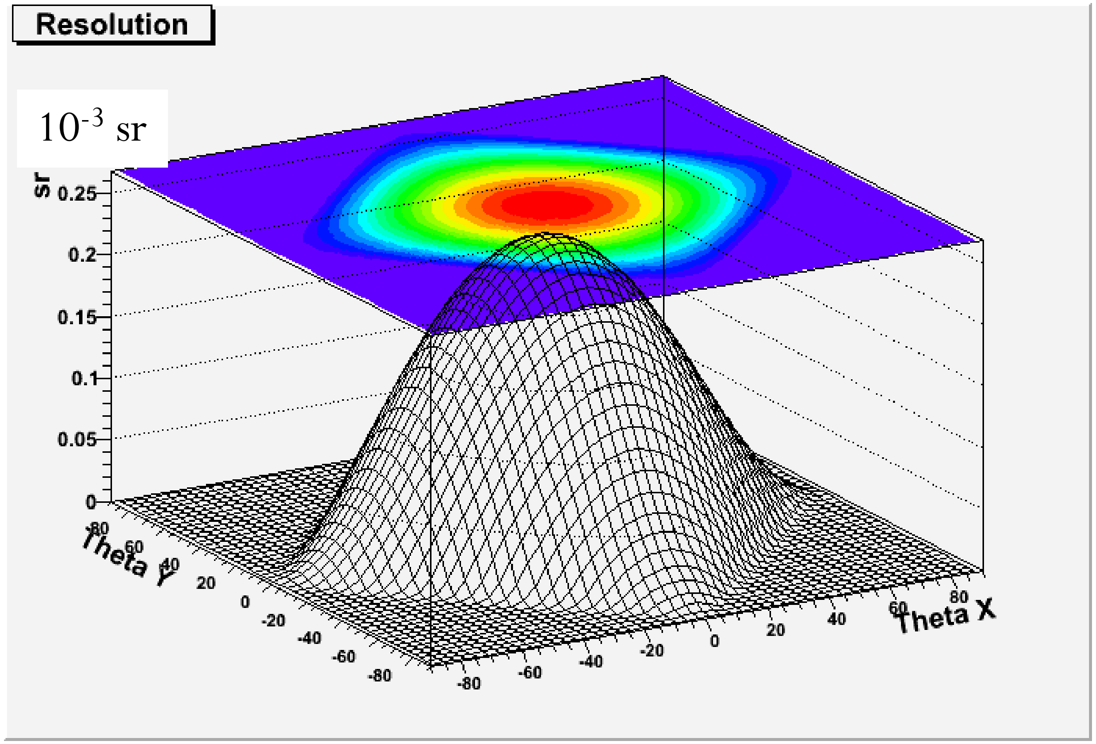
Round table on detectors for muon radiography

Preamble

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

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



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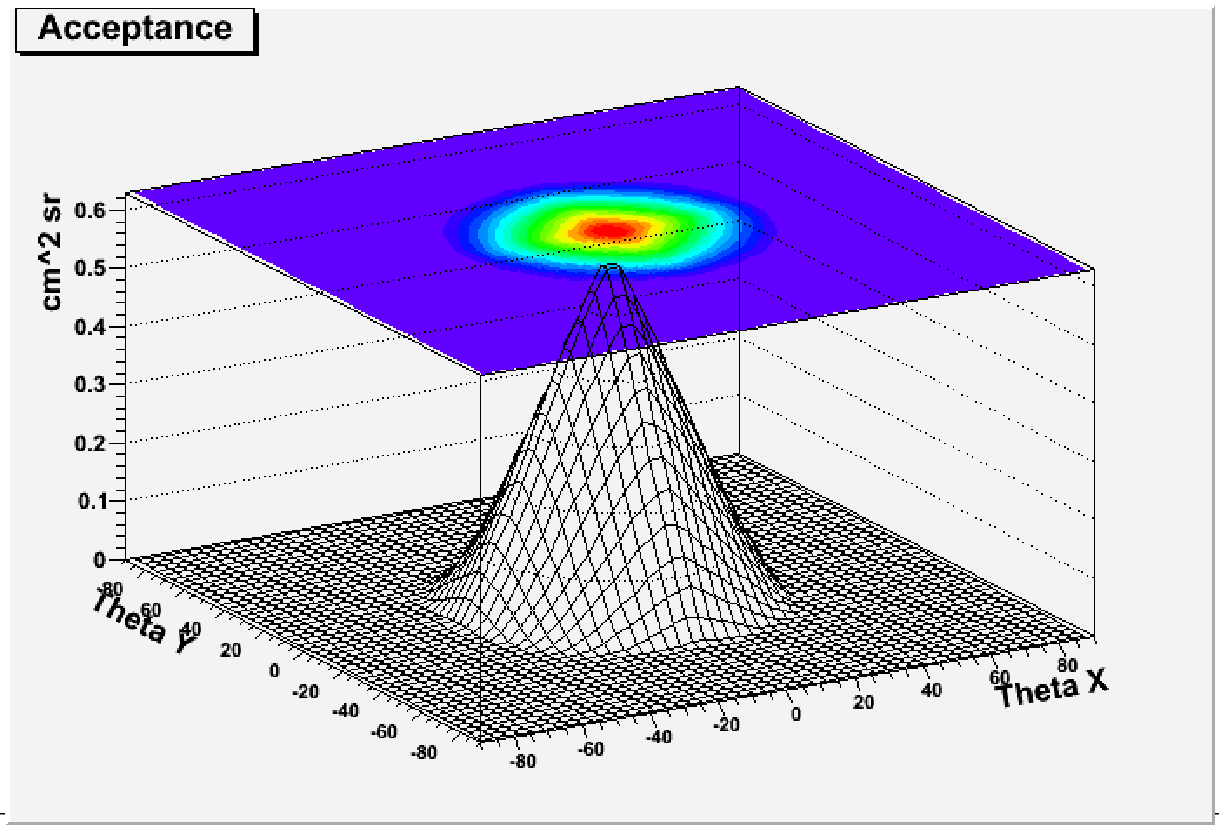
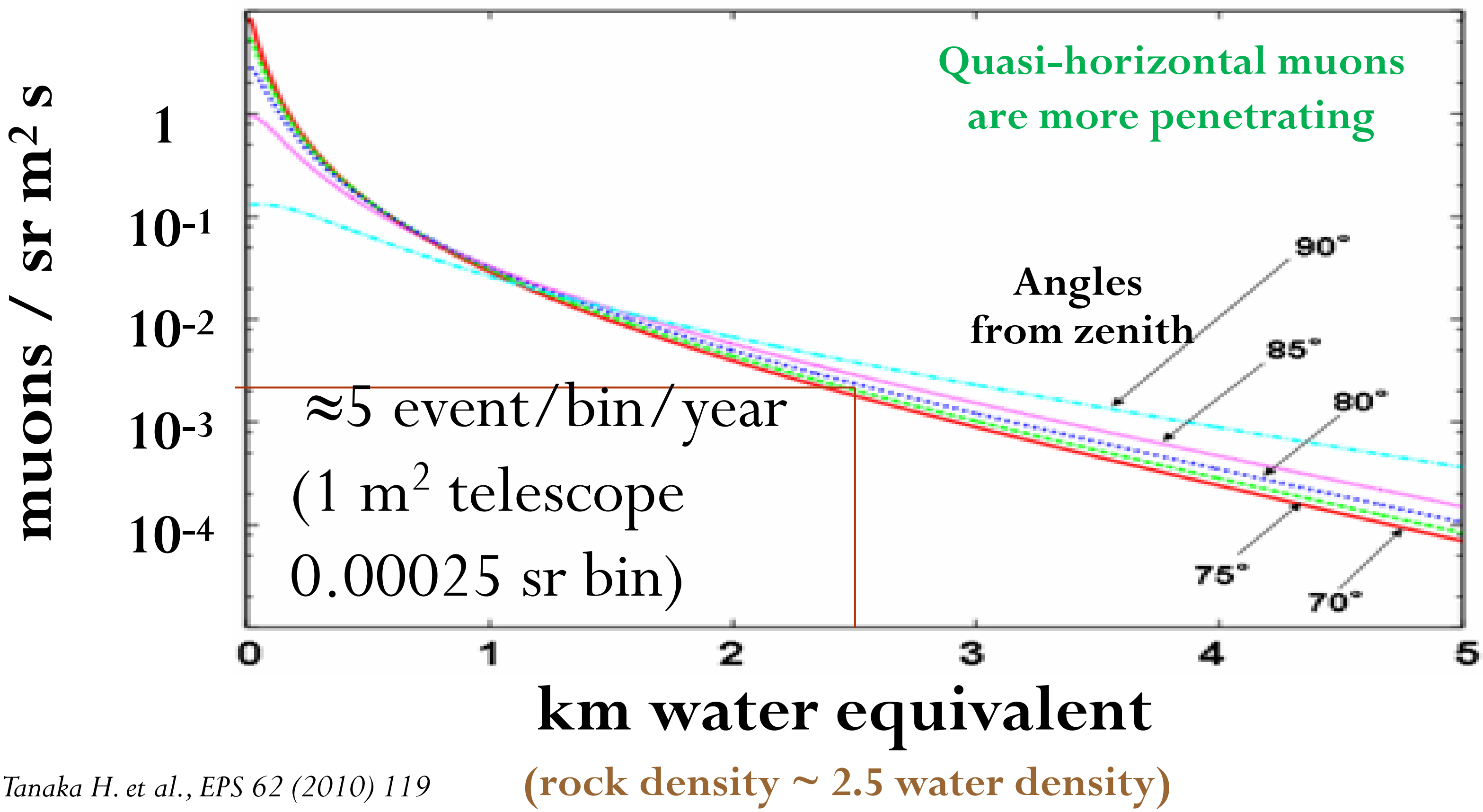
Acceptance ! (e.g. 1 m^2 MuRay @0.00025 sr: < 1 cm^2 sr)



Preamble

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



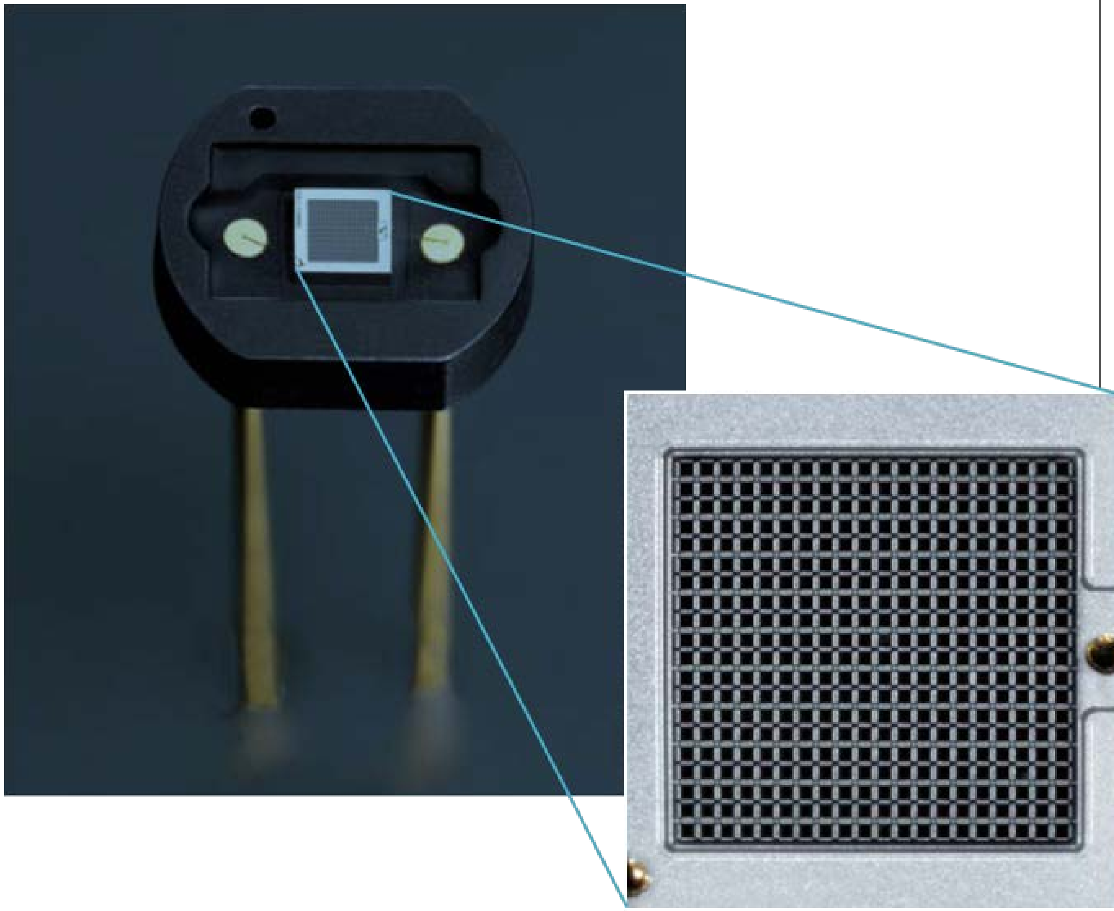
Plot from Tanaka H. et al., EPS 62 (2010) 119

High resolution (and large surfaces)

- The only way to obtain a reasonable amount of events in a reasonable time is to enlarge surfaces
- High <u>intrinsic resolution</u> can help in providing smart and adaptive re-binning to enhance sensitivity to localized density anomalies
- 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: <u>**large number of channels !**</u> (e.g. MuRay 128 X 3 ch / 1m^2 telescope)
- Need <u>**high level of integration and low cost/channel**</u>

SiPMs for pedestrians

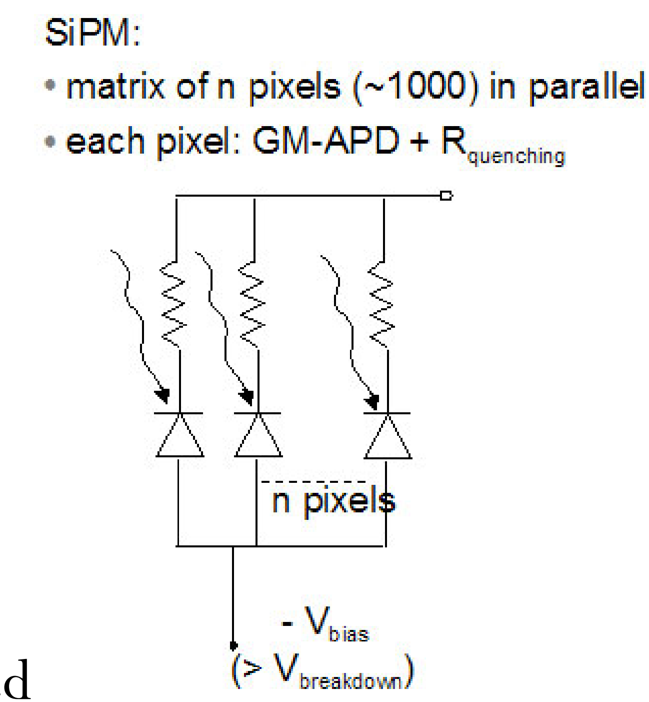
- New concept in light detection
- Array of APD cells working in self-quenching Geiger mode
- High level of miniaturization and integration
- Light detection efficiency higher, and gain comparable to traditional PMTs
- “Digital” linear response (each APD cell works in on/off mode)



SiPMs 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
  - **<u>Depends on temperature</u>**
- Thermal noise ("dark rate")
  - Single photoelectron rate: few 100 kHz to few MHz/mm^2 at 25°C
  - **<u>Depends on temperature</u>**
  - Multiple photoelectron emission suppressed



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

Why SiPMs for Muon Radiography ?

- “Natural” matching with WLS fibers dimensions
- Possibility of <u>integration</u>
- Low power consumption
- Robust and compact
- No HV system
- <u>Cost/channel</u>

Why SiPMs for Muon Radiography ?

- "Natural" matching with WLS fibers dimensions
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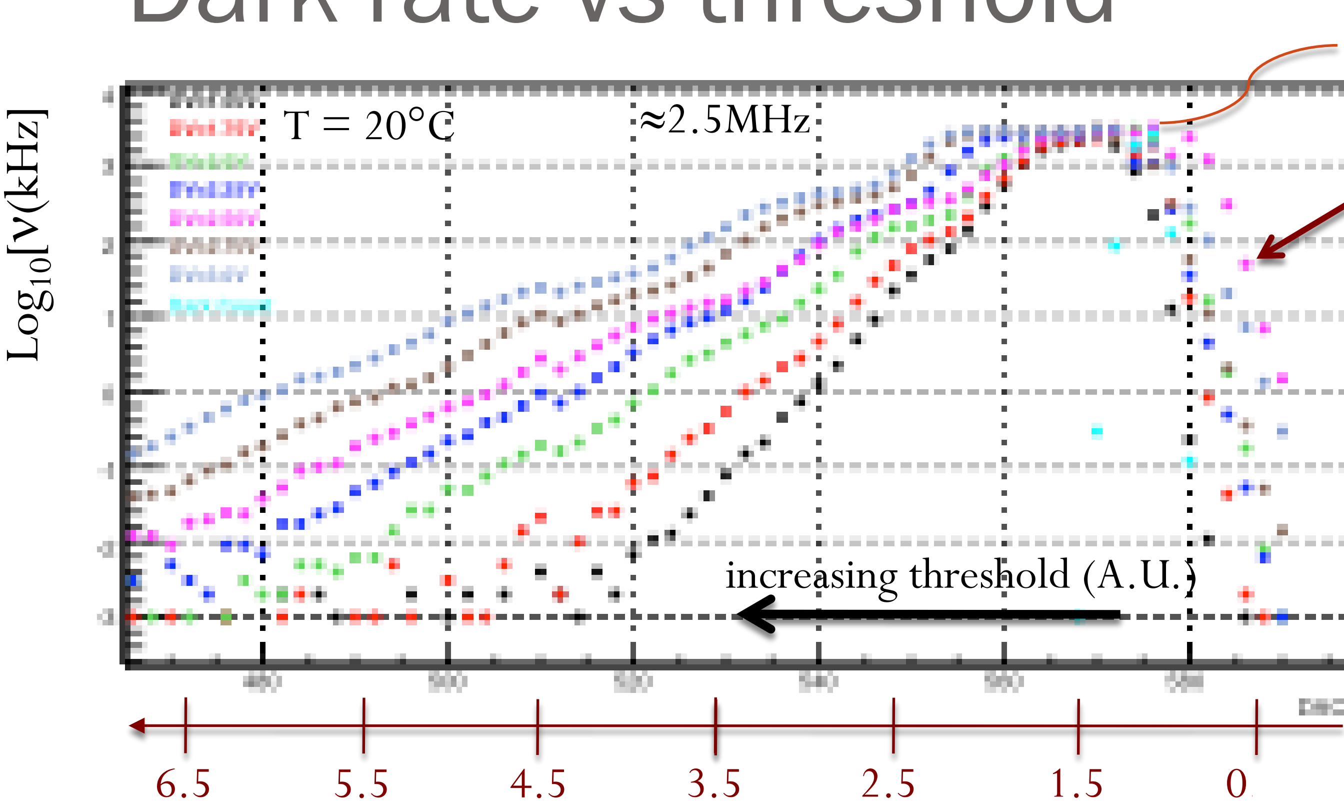
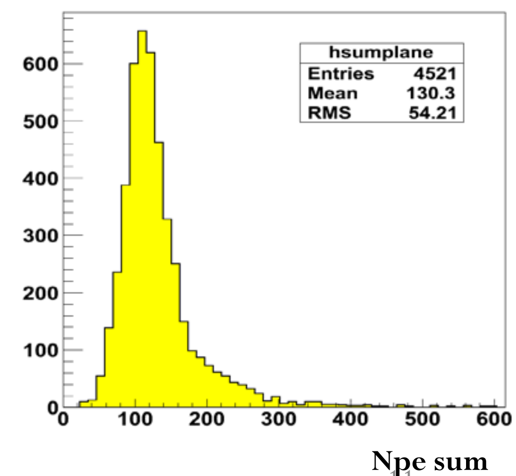
- Need to control temperature
- Need to cope with dark rate

Dark rate vs threshold

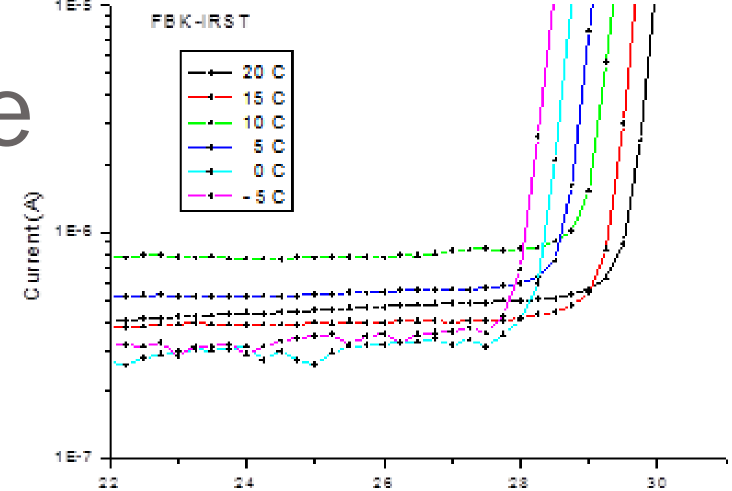


On each board's FPGA a counter is implemented in order to acquire the dark rates

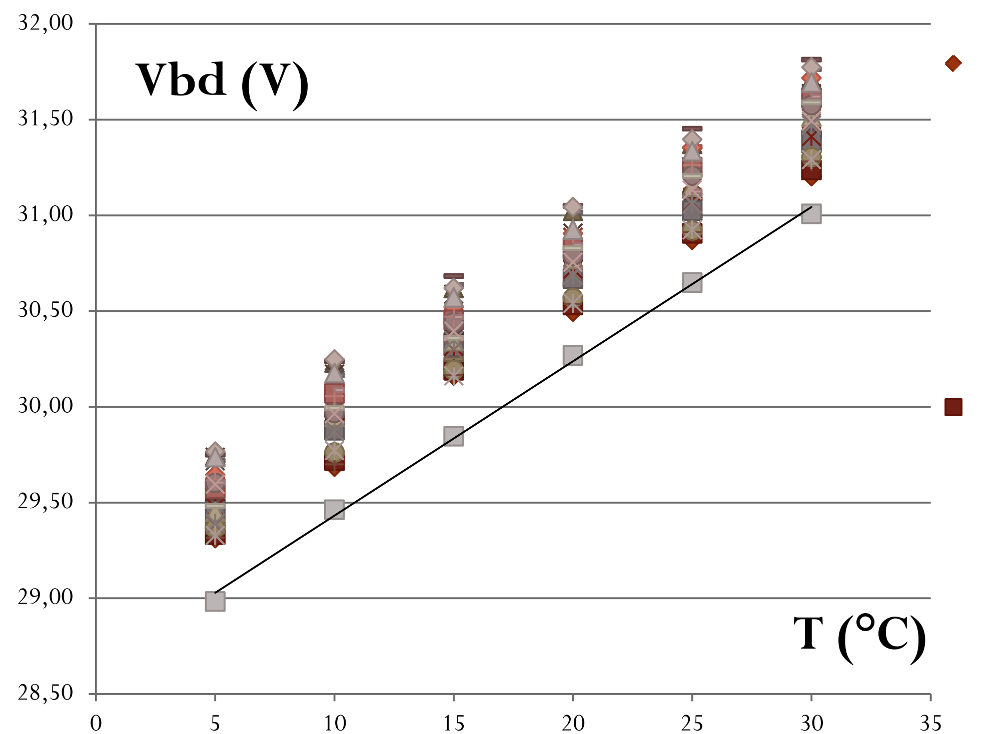
The rate decreases of one order of magnitude per p.e DAC threshold vs. n p.e. calibration: **dark rate is not an issue** if you have a large number of photoelectrons per Minimum Ionizing Particle crossing the detectos (cfr. NA62-CHANTI, same technology of MuRay has >100 pe/plane/MIP)



The temperature issue

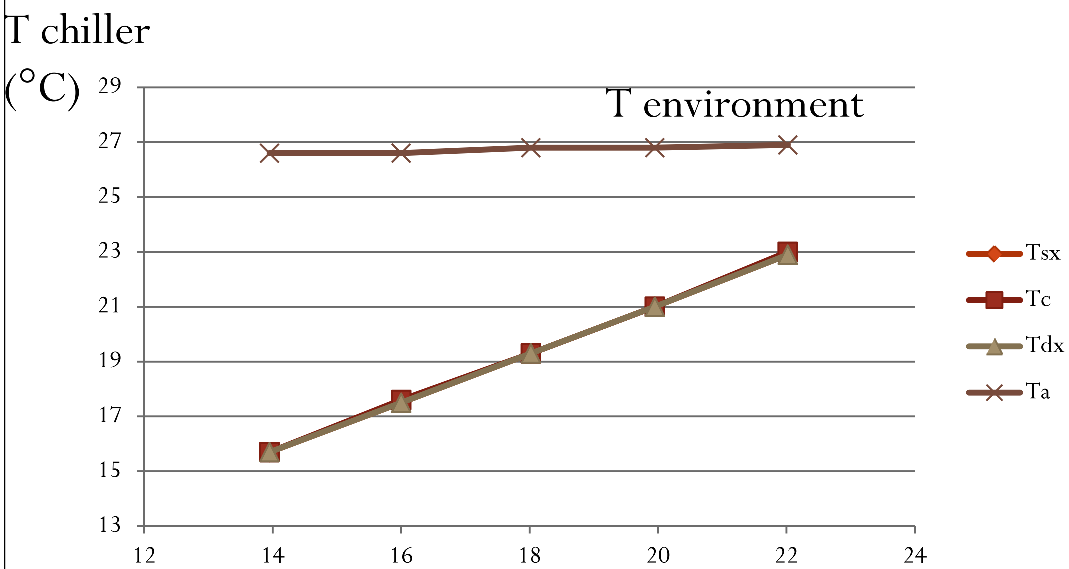


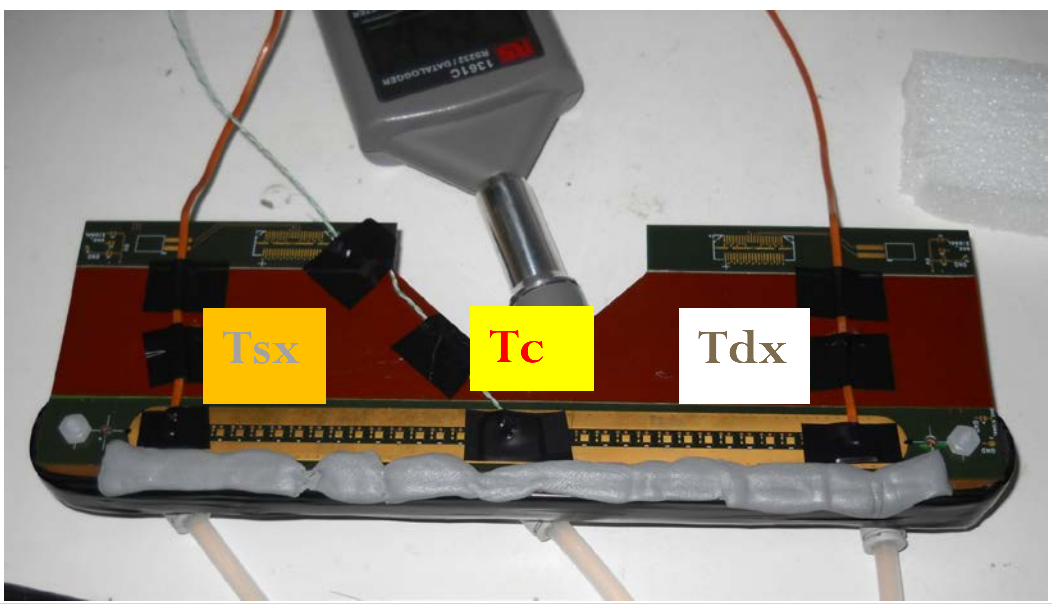
The slope is similar for all the SiPM: ≈80 mV/°C



- 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 full characterization of SiPMs Vbd at least for one value of T (the slope is almost the same for all sensors)

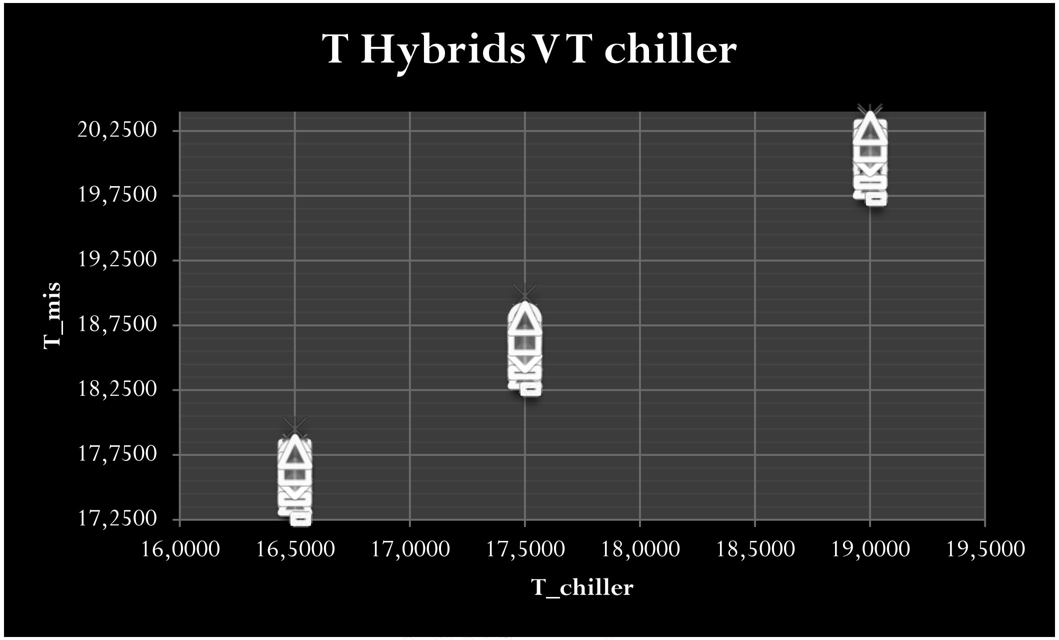
The temperature issue (2)

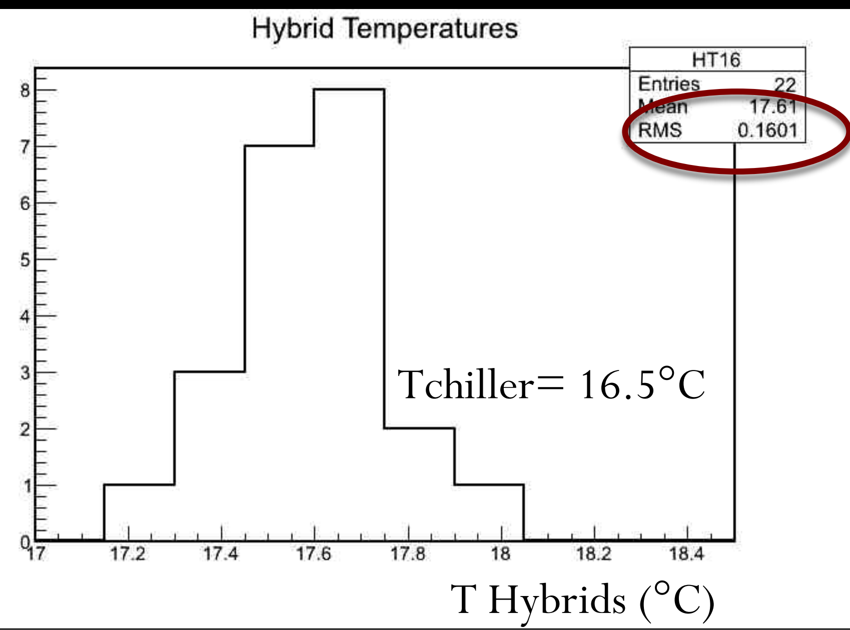




Excellent uniformity of temperature inside one hybrid…

The temperature issue (3)





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

SiPM choice

- Two main producers investigated for SiPM choice (but there are more…):
  - FBK-IRST (used in current MuRay prototype)
  - Hamamatsu (used e.g. in NA62-CHANTI)

FBK-IRST

- Die format allows to create custom hybrid
- Low cost for non encapsulated sensors (< 10 euro/ch)
- Large operative range (overvoltage 0-6V)

- High thermal noise
- Lower Photon Detection Efficiency

Hamamatsu

- High Photon Detection Efficiency
- Low thermal noise
- Matrices available
  (e.g. monolithic 4x4 @<20 euro/ch)
- Can provide customized monolithic matrices

- Only encapsulated
- Higher cost for single sensors (about 50 euro/ch)
- Smaller operative range (< 2V)

Conclusions

- The SiPMs, though not as mature as a technology as conventional PMTs offer several advantages in Muon radiography applications:
  - High level of integration
  - High efficiency even for relatively low light yield
  - Compactness and robustness
  - Ideal matching with WLS fiber dimensions
  - Low power consumption
  - Low cost/channel

- They are in a fast developing phase, with costs (e.g. for SiPM matrices) going rapidly down and performances going up
- They are currently being used in MuRay where the main issues concerning thermal noise and temperature dependence of the Vbd have been thoroughly addressed .
- We currently see no showstoppers to their use in muon radiography
- Currently addressing the choice: FBK-IRST vs Hamamatsu