Università degli Studi dell'Insubria

INFN Sez. Milano

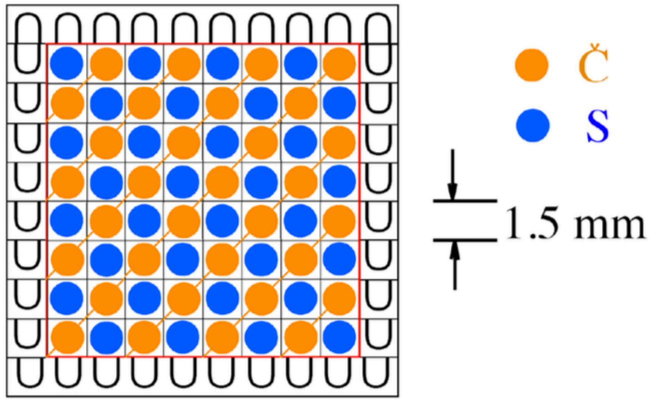
Dual-Readout SiPM-based module

status and updates

Massimiliano Antonello

SiPM-based module

- A 112 cm long, 15 x 15 mm² wide, module was built from stacked **brass** layers, housing 1 mm diameter clear & scintillating fibres* with a **pitch of 1.5 mm**



- **X_0 = 29 mm, R_M = 31 mm**
- The calorimeter is **39 X_0** deep with an effective radius of **0.22 R_M**
- According to GEANT4 simulations the em shower **containment** is **45% (S)** and **36% (C)**

Different beam energy and type:
e^- beams @ 6, 10, 20, 30, 40, 50, 60, 80, 100, 125 GeV
μ beams @ 50, 60, 125 GeV

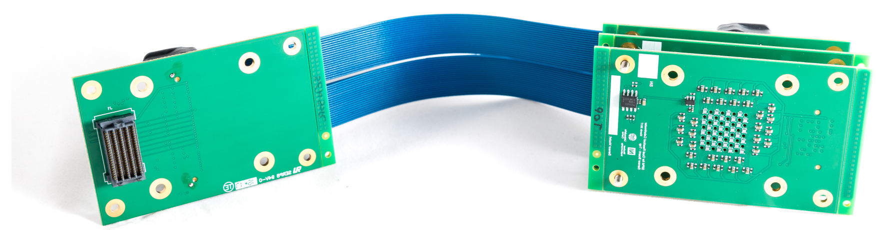
- **Delay Wire Chamber**: selects events in central region
- Trigger: $(T_1.T_2.\overline{T_H})$
- **Preshower** detector: identifies e^-
- **Muon** counter: identifies μ

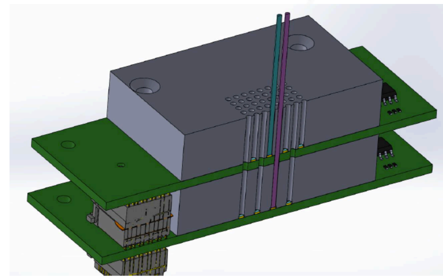
SiPM-based module

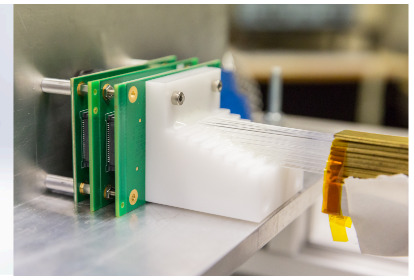
SiPM

HAMAMATSU S13615-1025	
Sensitive area	1×1 mm^2
Cell pitch	25 μm
No. of pixels	1584
Peak Photon Detection Efficiency	25%
Breakdown voltage V_{br}	53 V
Recommended operational voltage V_{op}	V_{br} + 5V
Gain at V_{op}	7×10^5
Dark Count Rate at V_{op}	50 kps
Optical Crosstalk at V_{op}	1%

Two different layers: C upstream, S downstream



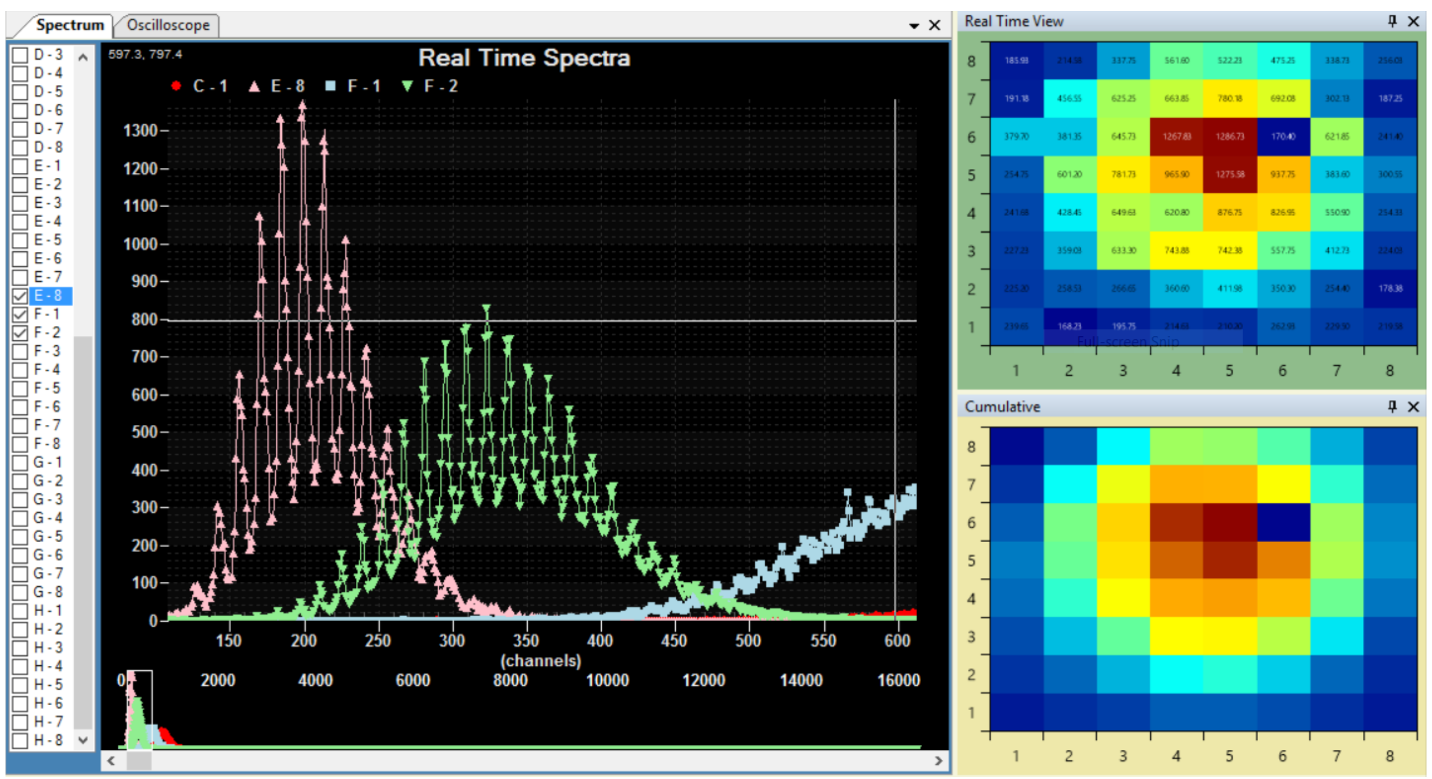




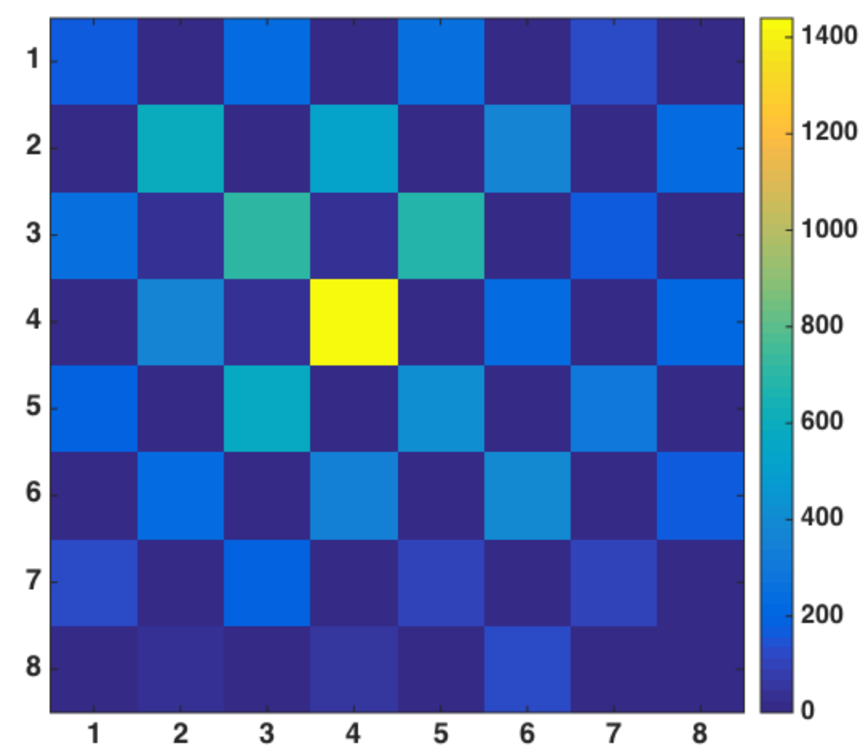
MADA: Multichannel Analog to Digital Acquisition system

- 32 channel digitizer
- Sampling rate **80MSpS/14-bit ADC**
- FPGA-based: real-time charge integration

Real-time equalization of the sensor response



Event display: 10 GeV e- beam

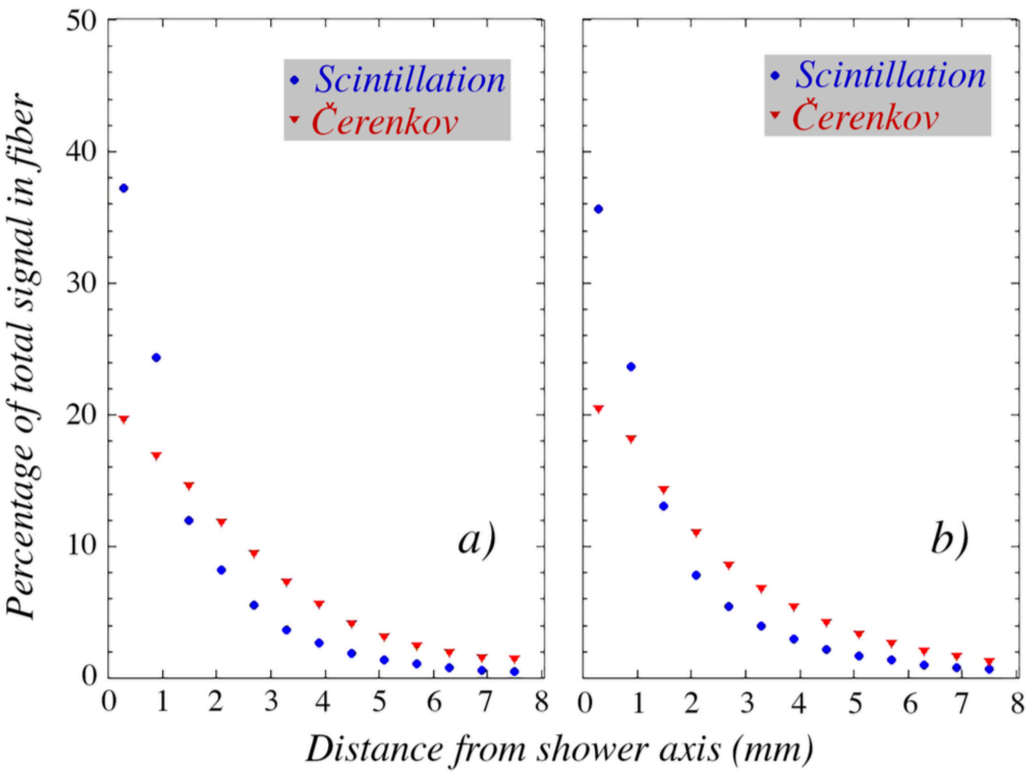


Lateral shower profiles

- The possibility of separately reading each fibre allows:
  - To sample em showers with a **millimeter spatial resolution**
  - To measure the **lateral profiles** very close to the shower axis

Data

Simulation



For each selected event:

- Shower axis (using CoG):

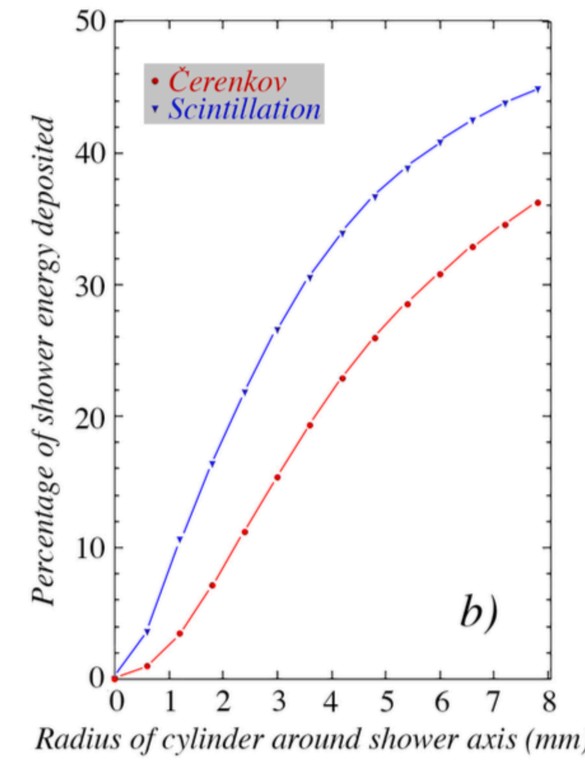
$$\bar{x} = \frac{\sum_i x_i E_i}{\sum_i E_i}, \quad \bar{y} = \frac{\sum_i y_i E_i}{\sum_i E_i}$$

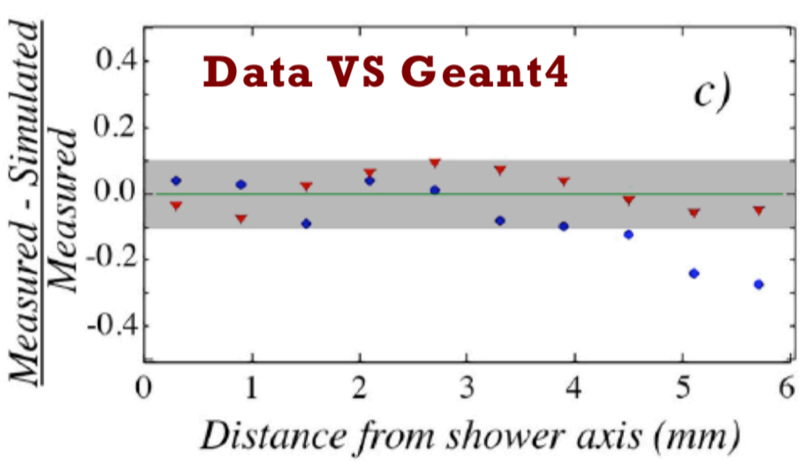
- Distance of each fibre to the shower axis:

$$r = \sqrt{(x_i - \bar{x})^2 + (y_i - \bar{y})^2}$$

- bin data (0.6 mm pitch) and find average

Cumulative





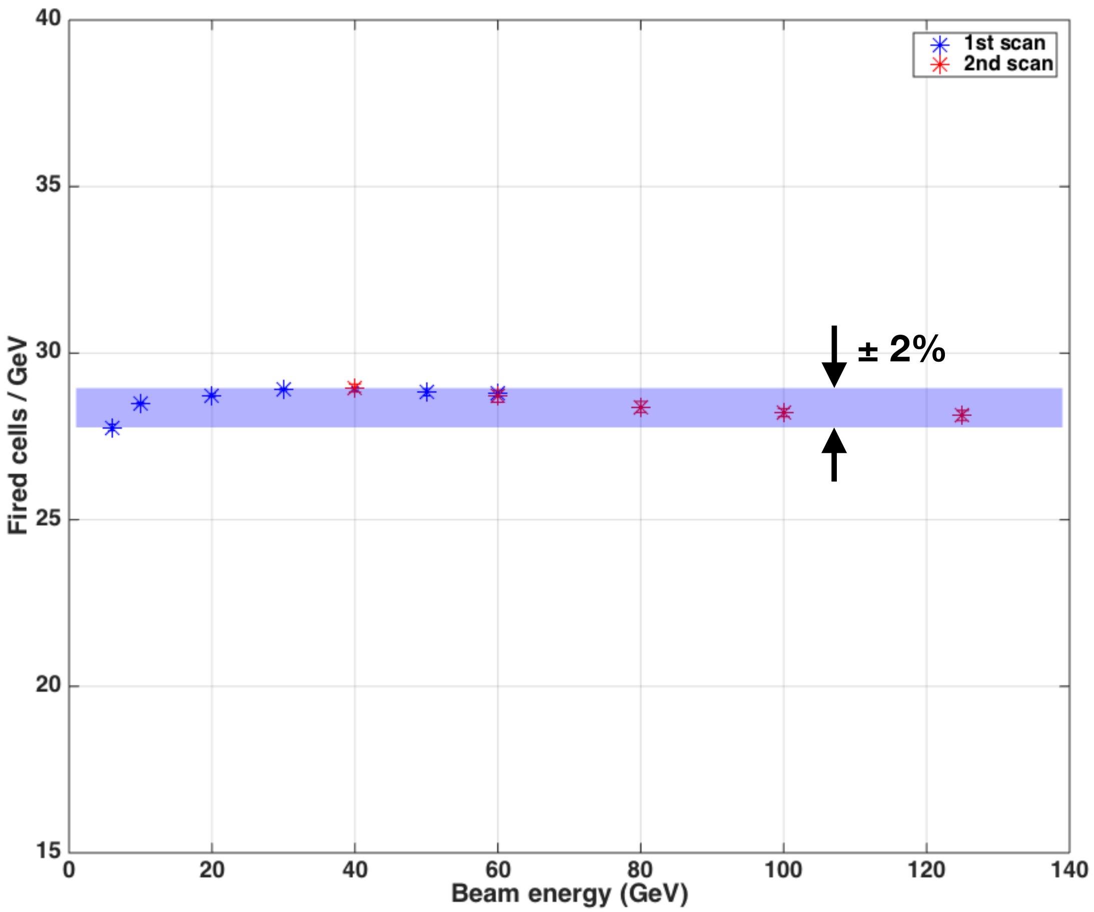
2017 BEAM TEST RESULT

About **10%** of an electromagnetic shower energy is deposited within 1mm from the shower axis (i.e. in a single fibre)

Cherenkov light yield

- **Cherenkov** signal: V_{op} = 5.5 V_{ov} (57.5 V) and **PDE** ~ **25%**
  - Temperature stability correction:
    - < 0.5°C during a single run (negligible)
    - <   2°C during the full scan (considered)
  - Mean number of fired cells: ~ **28.6 ± 0.4** fired cells/GeV
  - Energy containment predicted by simulation is about **36%**
    - It is independent from beam energy
    - It is almost constant when a geometrical cut of 3 mm in the center is applied in the selection

* Value already corrected for the measured S contamination



2017 BEAM TEST RESULT

For a full contained electromagnetic shower, the **C light yield*** is expected to be about: **69 ± 5 fired cells/GeV**

More than **2 times larger** than what measured with the previous PMT-based modules (stochastic term improved from 13.9%/√E up to **10%/√E**)

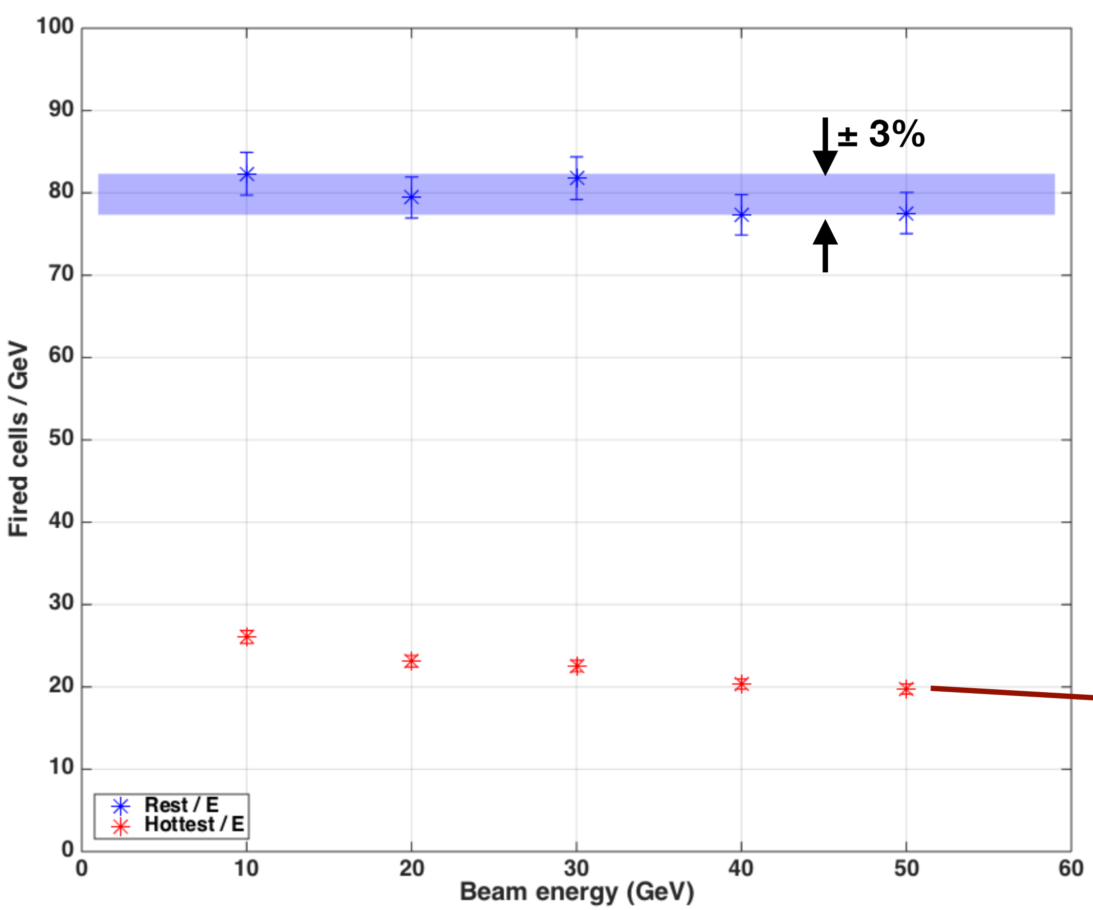
2018 NEXT STEP

The L.Y. could be further increased adding an **aluminized glass mirror** at the upstream end of the C fibres

Scintillation light yield

- **Scintillation** signal: $V_{op} = 0.5\ V_{ov}$ (52.5 V) and **PDE** ~ **2%**
  - Temperature stability correction:
    - < 0.5°C during a single run (negligible)
    - < 2°C during the full scan (considered)
  - PDE corrected for temperature variation
  - Number of fired cells @ **10 GeV** (corrected for non-linearity response): ~ **108.4** fired cells/GeV
  - Energy containment predicted by simulation is about **45%**

* Value already scaled to the typical SiPM PDE of the C channel (25%)

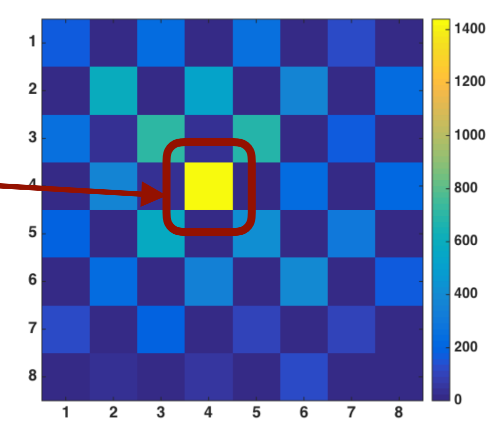


2017 BEAM TEST RESULT

For a full contained electromagnetic shower, the **scintillating light yield*** is expected to be about:

3200 ± 200 fired cells/GeV

The S signal is ~ **50 times larger** than the C signal



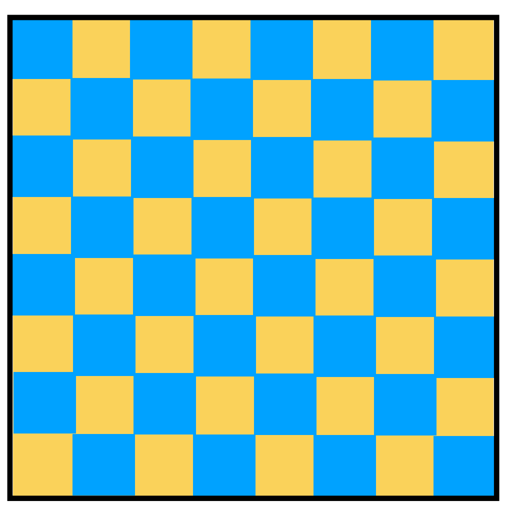
2018 NEXT STEP

More accurate measurement of the **scintillation L.Y.** (@ 25% PDE)

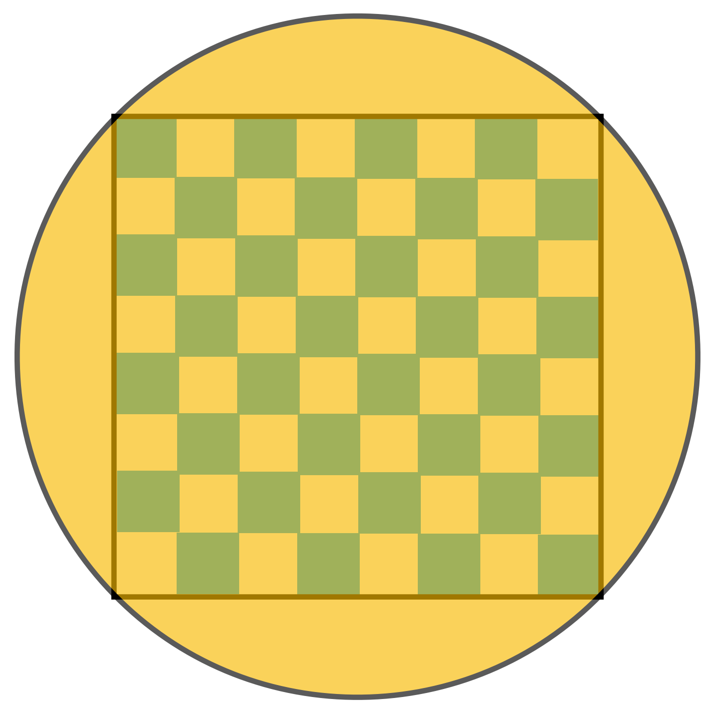
Scintillation light yield

- In the latest beam test, **saturation** and **non-linearity** were experimentally evident and affecting the prototype performances (V_{op} = 0.5 V_{ov} (52.5 V) and **PDE ~ 2%** were used)
- To avoid saturation and non-linearity two solutions can be considered:
  - SiPM with highest density of cells (**future studies**)
  - Reduce the scintillating light using **ND/Yellow filters** between fibres and sensors (**2018 beam test**)

- **ND** (OmegaFilters ND2) will be ordered (2 different type for 2 different mechanic designs)



32 filters: one for each S SiPM



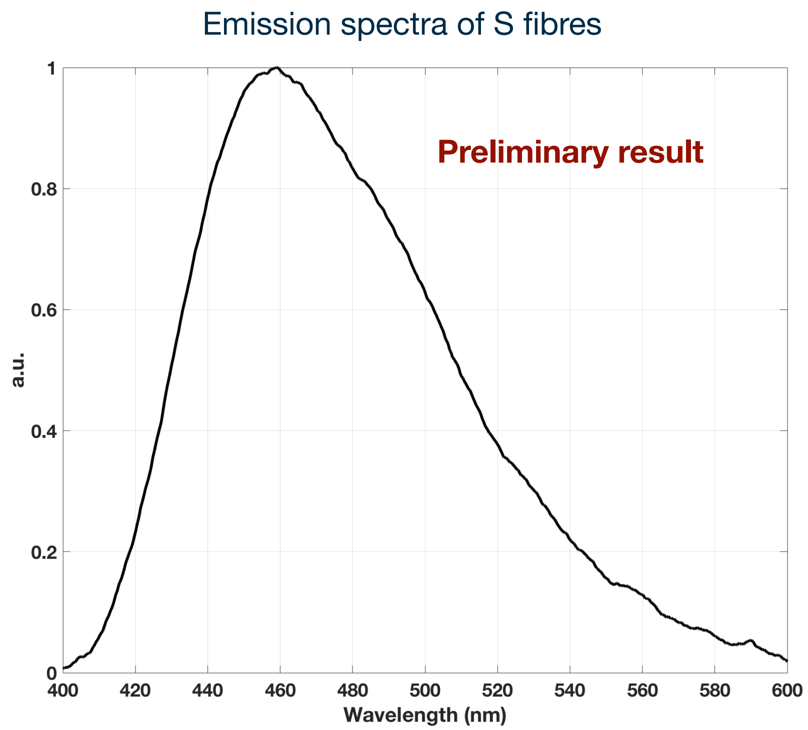
1 big filter for all the SiPM

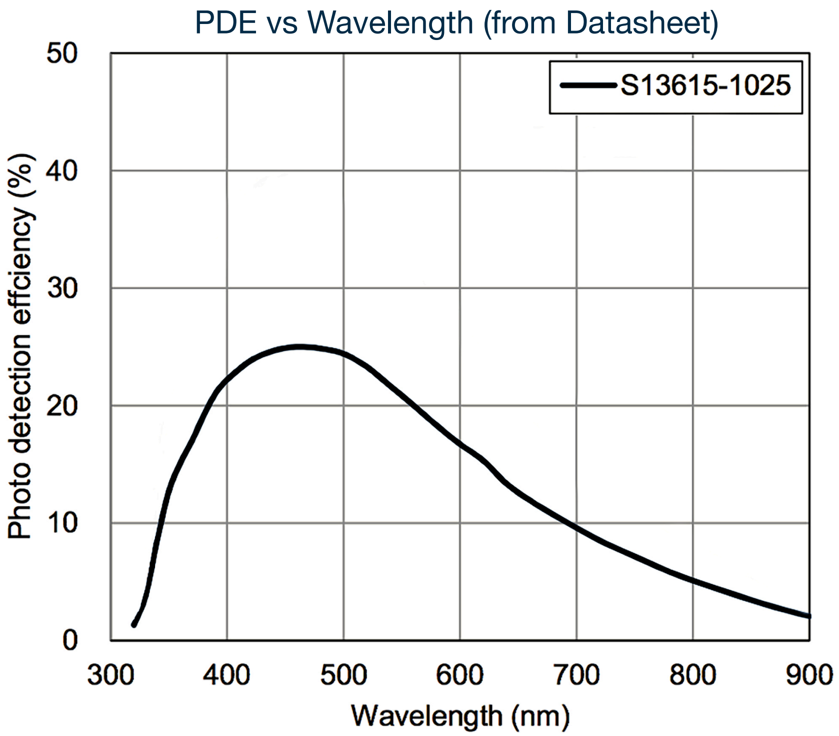
Scintillation light yield

- In the latest beam test, **saturation** and **non-linearity** were experimentally evident and affecting the prototype performances (V_{op} = 0.5 V_{ov} (52.5 V) and **PDE** ~ **2%** were used)
- To avoid saturation and non-linearity two solutions can be considered:
  - SiPM with highest density of cells (**future studies**)
  - Reduce the scintillating light using **ND/Yellow filters** between fibres and sensors (**2018 beam test**)

- **ND** (OmegaFilters ND2) will be ordered (2 different type for 2 different mechanic designs)

- **Yellow filters** may be preferable since, absorbing the blue component of the emitted S light spectrum, it could also improve the **response uniformity** as a function of the shower development depth
- **Emitted S light spectrum** will be measured (in the **next weeks**) → combined with the sensor PDE curve provides the **real light attenuation** obtained with yellow filters

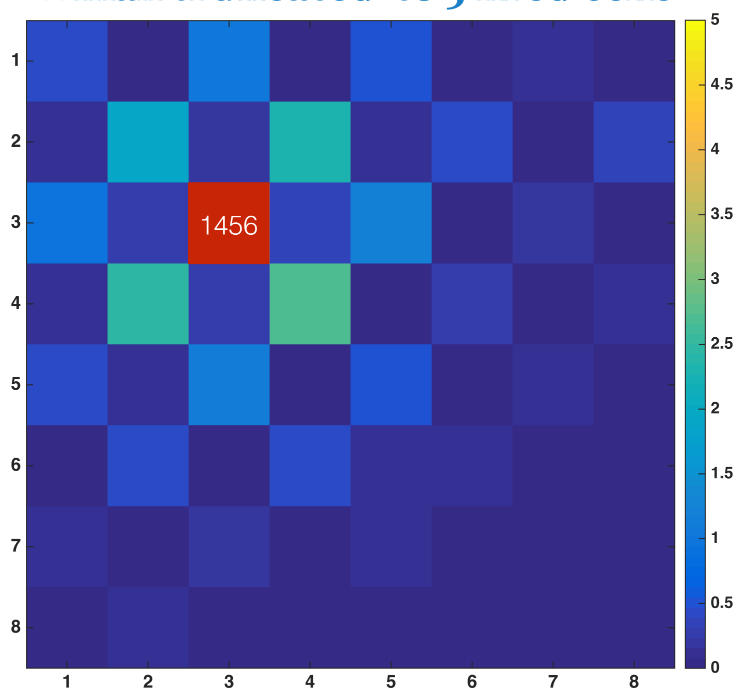


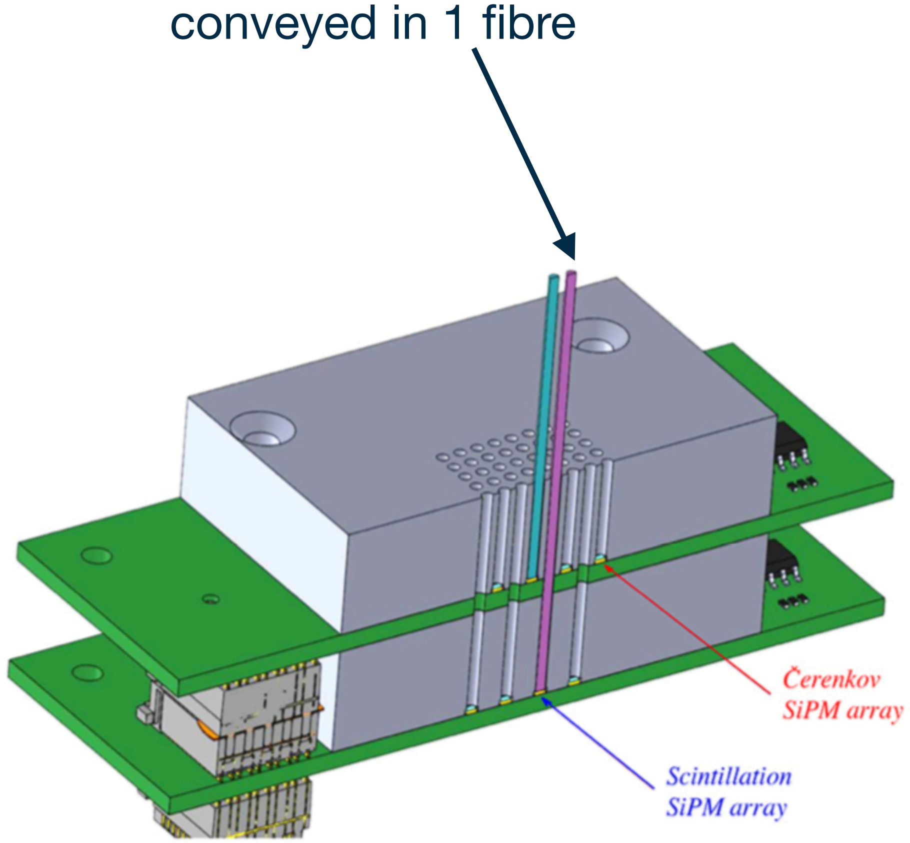


- Since the two types of fibres are **located very close** to each other and carry light signals that differ by more than **an order of magnitude** in intensity, the **optical crosstalk** between the signals is a major challenge

- Direct measurement:
  - Only one uncovered S fibre illuminated (**1456** fired cells)
  - The sum of all 32 C signals recorded
  - The matrix shows the **mean number of fired cells** read out by each SiPM

z max truncated to 5 fired cells

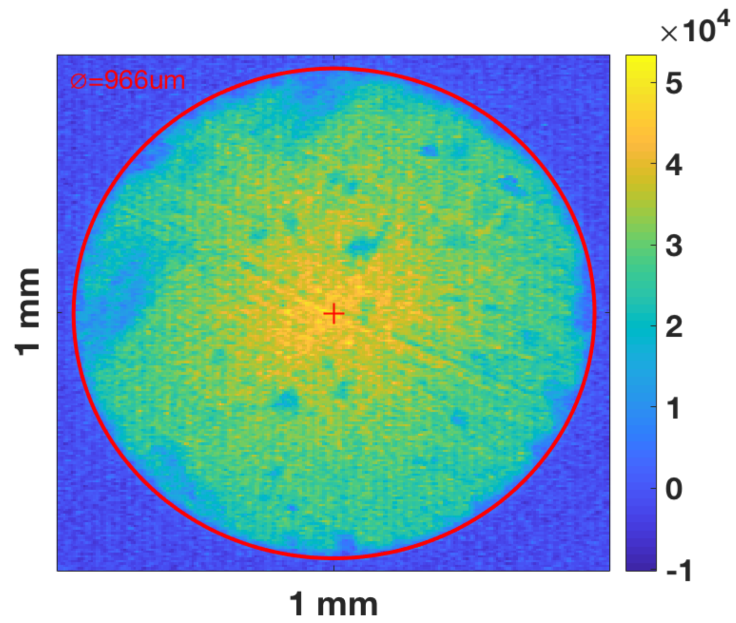


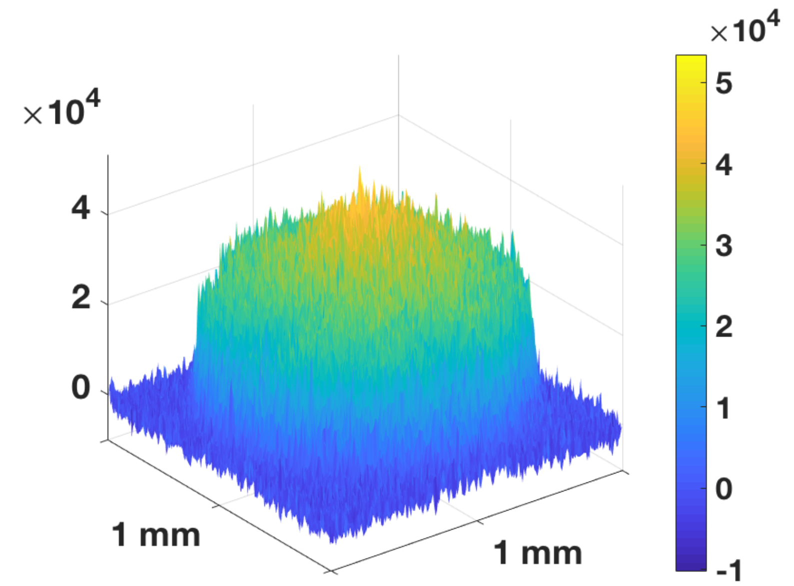


Optical crosstalk: reduced from **25%** to **0.3%** of the S signal

Optical crosstalk between fibres

- The measurement is an **upper limit**:
  - Possible presence of **direct light** in the Cherenkov fibres coming from LED
  - Light from S fibre is not **homogeneously distributed** → correction for non-linearity sensor response is underestimated



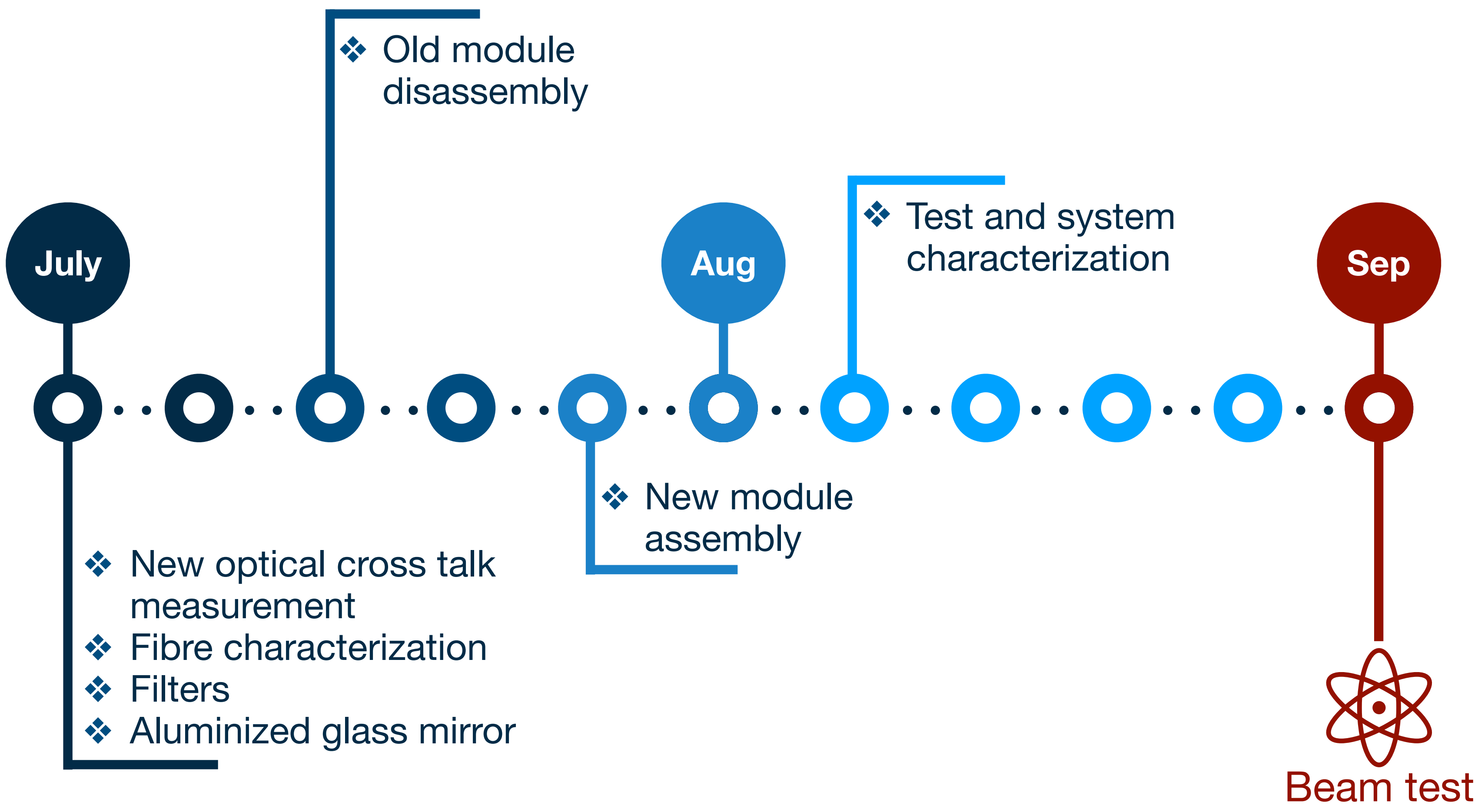


- New measurement with more homogeneous light and **better insulation** (**next week**)
- Measurement in which S fibre is interrupted between the end of module and SiPM can confirm/ exclude the presence of direct light

- More precise measurements will be performed during the next **beam test:**
  - comparison between the **Cherenkov signal** measured when scintillating fibres will be inside the module or physically removed

Goals and timeline

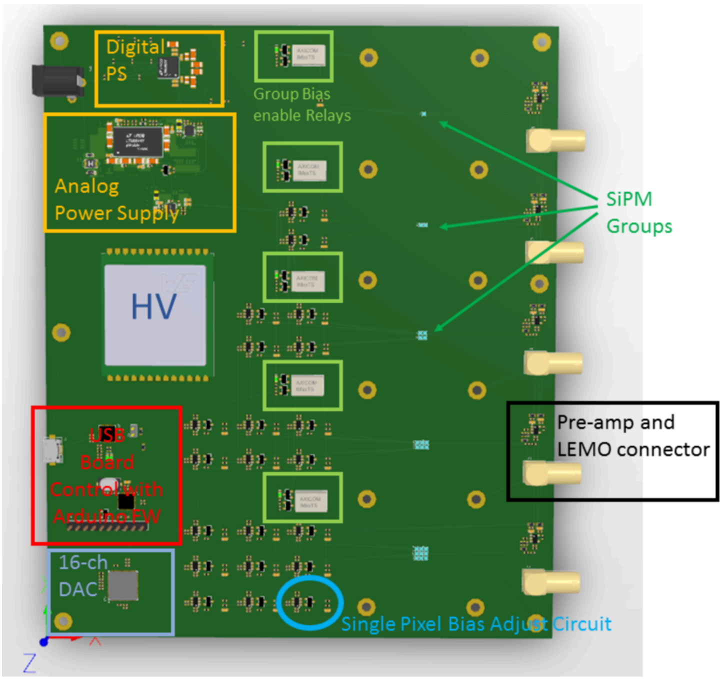
- Using the **same sensors and readout electronics** of the latest beam test:
  - Measure with more accuracy the real **number of fired cells/GeV for the scintillation** channel (with 25% PDE and less light impinging the sensors)
  - Study different configuration and type of **filters (Yellow/ND)**
  - Try to improve the **number of fired cells/GeV for the Cherenkov** channel
  - Reduce and test the **optical crosstalk** between fibres

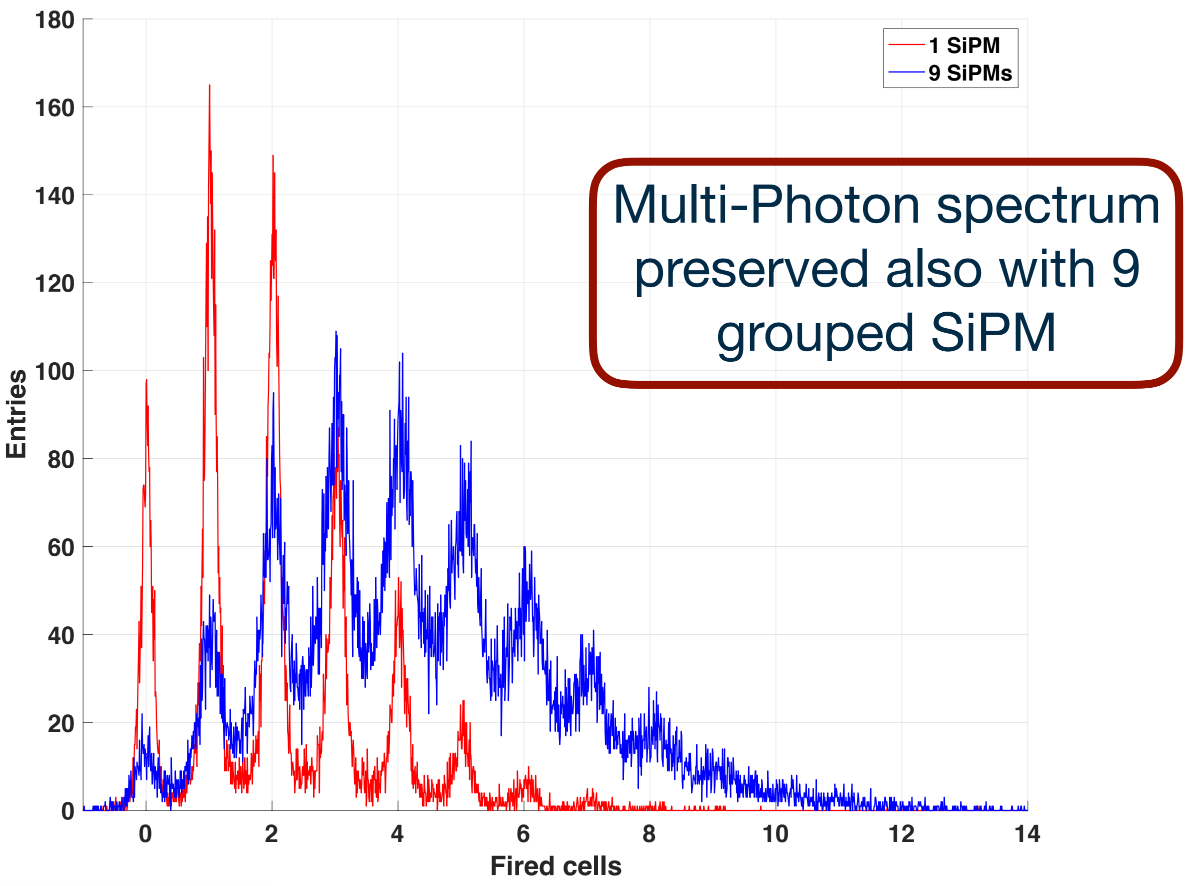


- In a full scale module, the number of **readout channels** will be of the order of $\mathbf{10^8}$
- The possibility to **sum up the analog output** is under study

- **Main question** to be addressed:
  - Number of SiPM that can be grouped guarantying the Multi-Photon spectrum (for a real-time information about the sensor equalization and the temperature variations)
  - SiPM dynamic range: sensors have to operate in a linear regime

- First test performed using a dedicated board that allows to investigate the SiPM performances when the signals are analogically grouped (for 1, 2, 4, 6 and 9 SiPM)
  - each SiPM is individually biased
  - same FEE used in the beam test 2017





We know it is still a long way to go…

…but we follow a DREAM and we have an IDeA

Additional Slides

Expected EM resolution

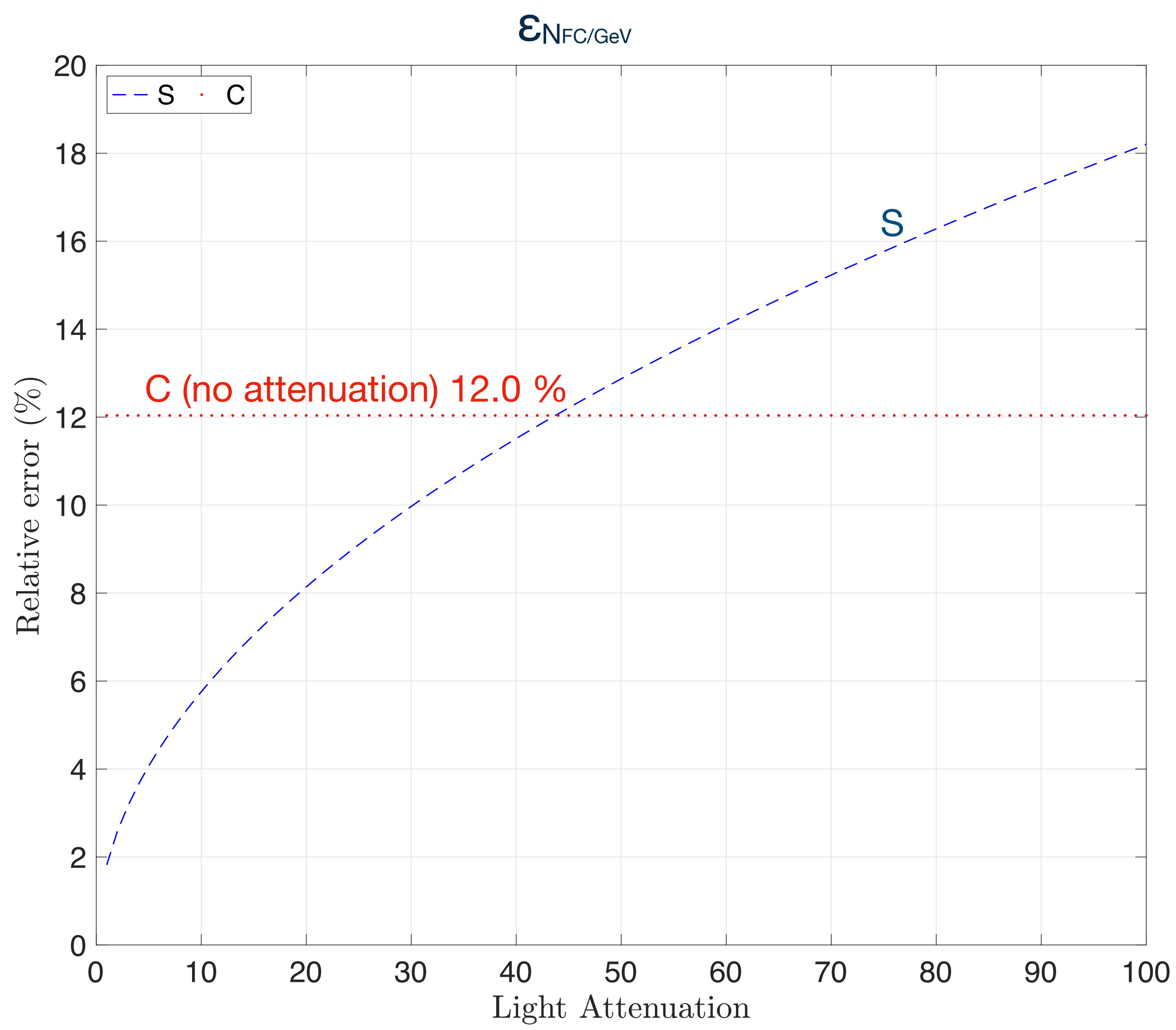
- The error from sampling fluctuations for both S and C channels is: $\varepsilon_{Sampling} \sim 10.5\%$
- The relative error of the number of fired cells/GeV is: $\varepsilon_{N_{FC/GeV}} = \frac{1}{\sqrt{N_{FC/GeV}}}$
- The combined error for each channel is: $\varepsilon_{Combined} = \sqrt{\varepsilon^2_{Sampling} + \varepsilon^2_{N_{FC/GeV}}}$
- The stochastic term in the EM resolution is: $\varepsilon_{C+S} = \frac{\sqrt{\varepsilon^2_{Combined}(S) + \varepsilon^2_{Combined}(C)}}{2}$

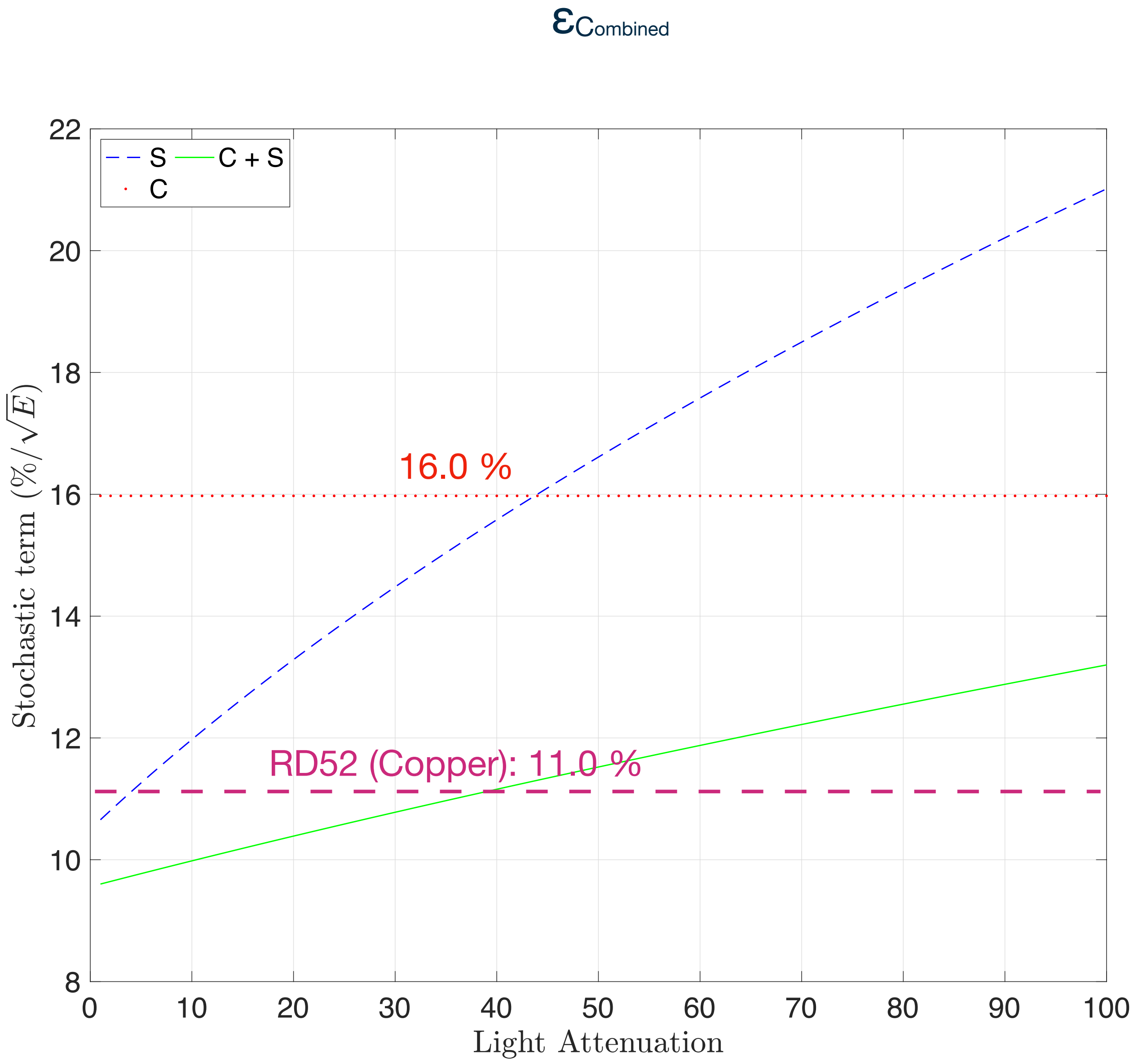
- Cherenkov channel (no attenuation, **25% PDE**):
  - Total ~ **69.0 fired cells/GeV***
  - ⇒ Relative error: ~ **12.0**% ⇒ Combined*: **16.0%**
- Scintillation channel (no attenuation, **25% PDE**):
  - Total ~ **3017.8 fired cells/GeV***
  - ⇒ Relative error: ~ **1.8**% ⇒ Combined*: **10.7%**

} C+S = **9.6%**

*from test beam data

*A sampling of **10.5**% is used

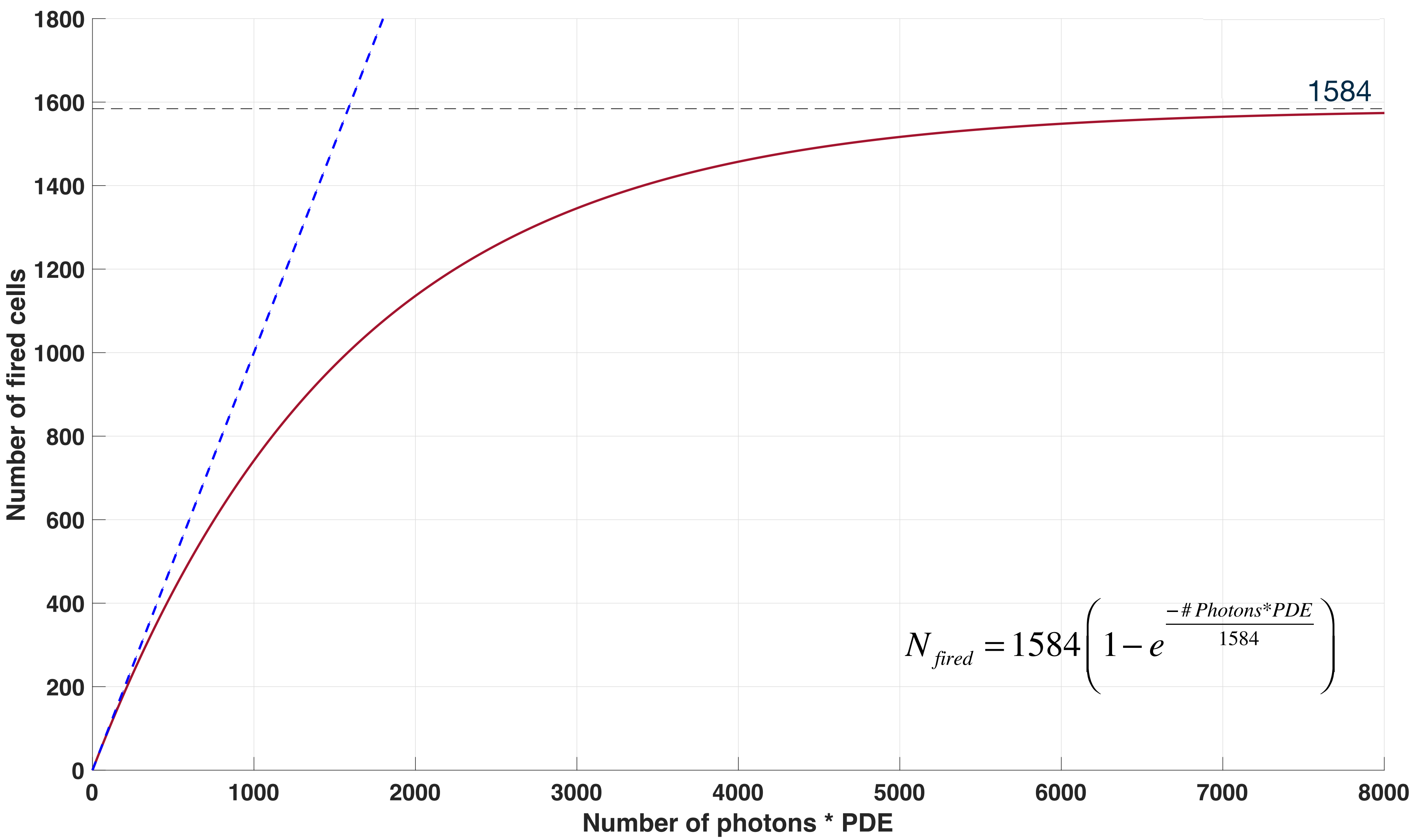




Occupancy/Discrepancy on Seed

- SiPM Occupancy: $Occupancy(\%) = \frac{N_{FC\_measured}}{N_{tot}}\%$ with $N_{tot}(S) = N_{tot}(C) = 1584$ cells
- Discrepancy between the corrected and uncorrected values:

$$N_{FC\_corrected} = N_{Photons} \cdot PDE = -N_{tot} \cdot \ln\left(1 - \frac{N_{FC\_measured}}{N_{tot}}\right) \longrightarrow Discrepancy(\%) = \frac{N_{FC\_corrected} - N_{FC\_measured}}{N_{FC\_measured}}\%$$



Occupancy/Discrepancy on Seed

- SiPM Occupancy: $Occupancy(\%) = \frac{N_{FC\_measured}}{N_{tot}}\%$ with $N_{tot}(S) = N_{tot}(C) = 1584$ cells
- Discrepancy between the corrected and uncorrected values:

$$N_{FC\_corrected} = N_{Photons} \cdot PDE = -N_{tot} \cdot \ln\left(1 - \frac{N_{FC\_measured}}{N_{tot}}\right) \longrightarrow Discrepancy(\%) = \frac{N_{FC\_corrected} - N_{FC\_measured}}{N_{FC\_measured}}\%$$