UNIVERSITÀ DEGLI STUDI DI TORINO

Karlsruher Institut für Technologie

Caratterizzazione e installazione di filtri ottici per la SiPM camera del progetto EUSO-SPB

Tesi di laurea in fisica, 5/12/2016

Relatore
Prof. Mario Edoardo Bertaina

Tutor aziendale
Dott. Andrea Haungs (KIT)

Correlatori:
Dott. Francesco Fenu (UNITO)
Dott. William Painter (KIT)

Candidato:
Alberto Bortone

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My Erasmus collaboration

From the 25th of April to te 25th of June in Karlsrhue

My closer tutors

The whole Cosmic rays group

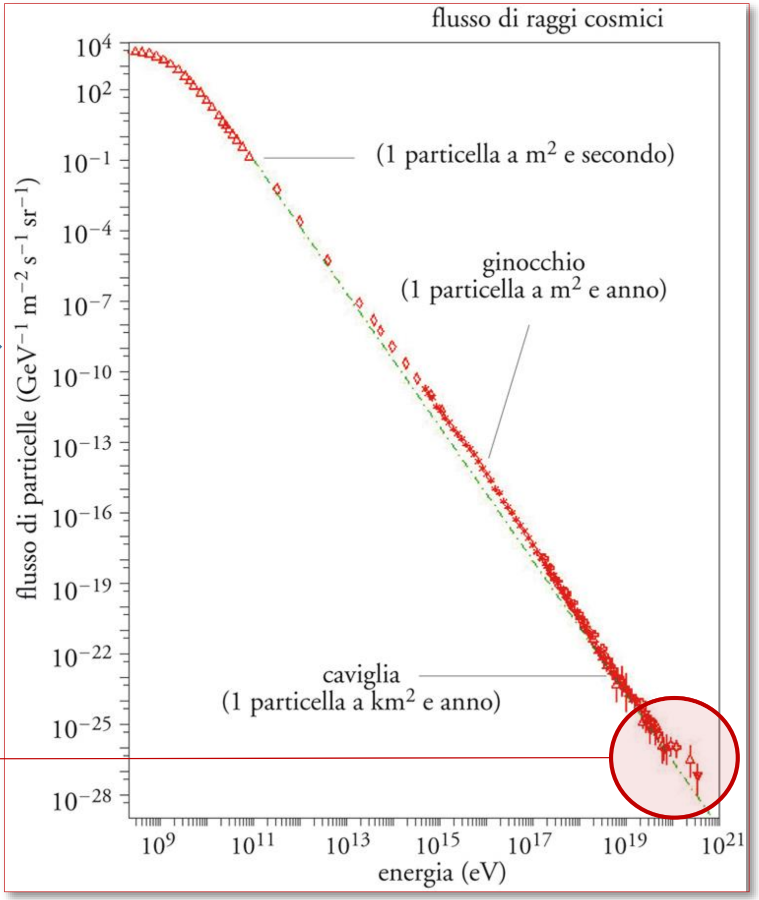
The KIT North Campus

Karlsrhue

Extreme energy comsmic rays

Cosmic rays are nuclei of various elements traveling in the space at relativistic speed

They interact with atmosphere and generate a shower of photons and particles that we can detect in different ways



Flux for E $> 5 \cdot 10^{19}$ eV:
1 event/km^2/century

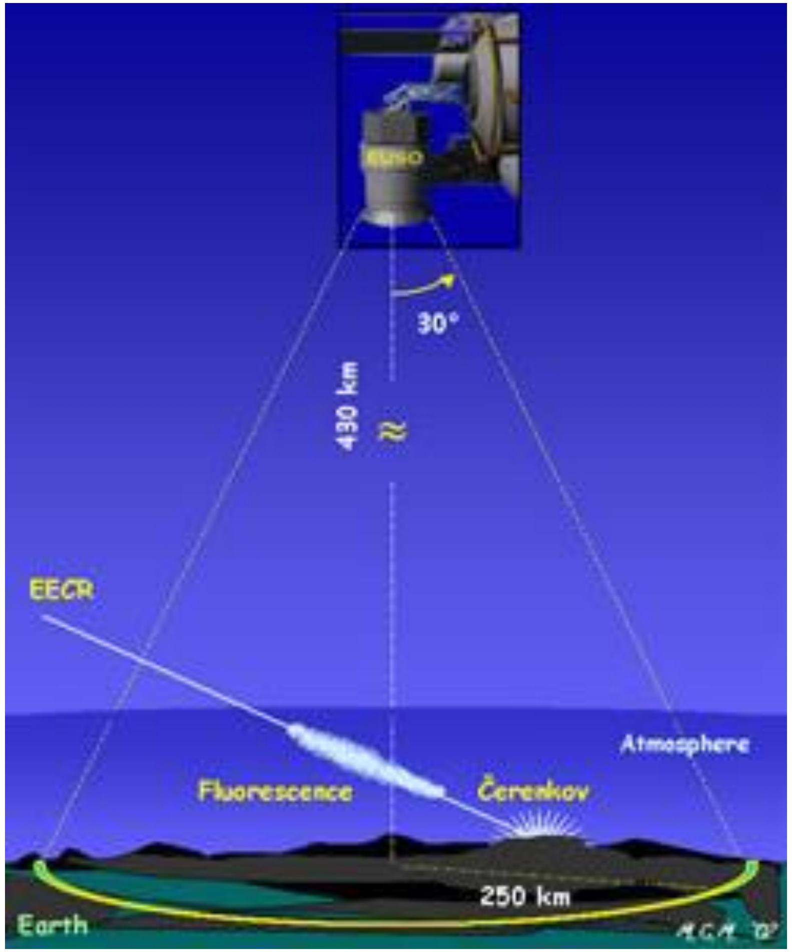
We need to integrate on a big area or on a long time in order to get a good statistic

THE JEM-EUSO PROJECT

The Extreme Universe Space Observatory is a program with the main goal of observing very high energy cosmic rays (E $> 5 \cdot 10^{19}$ eV). The main object of the project will be to build a space telescope pointing to the Earth atmosphere.

Observation principle

Cosmic rays interaction with the atmosphere generates a shower of particles.

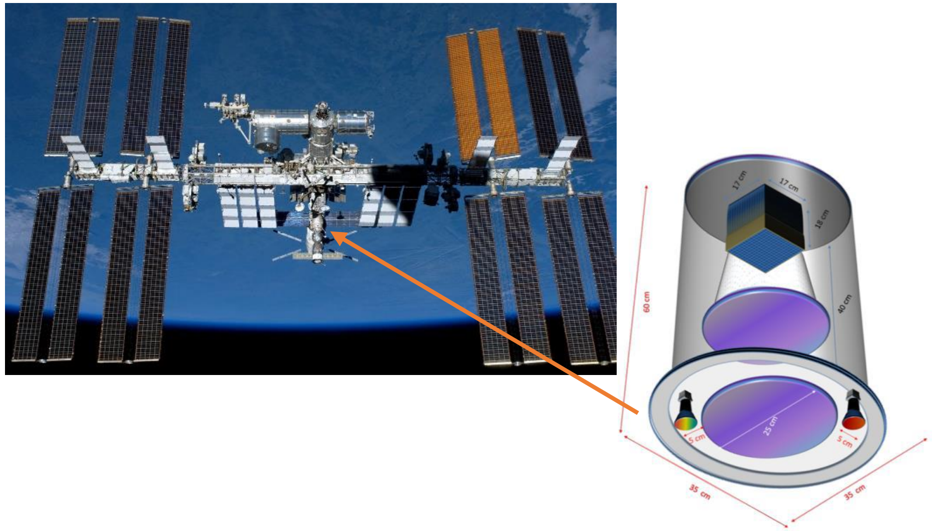


The instruments will detect fluorescence and Cerenkov photons from the interaction between the shower and the atmosphere in a very big area ($r \sim 250\ km$)

Pathfinders

EUSO TA
On ground calibration facility in USA (running since 2013)

EUSO Balloon
The first flying prototype of EUSO launched in 2014

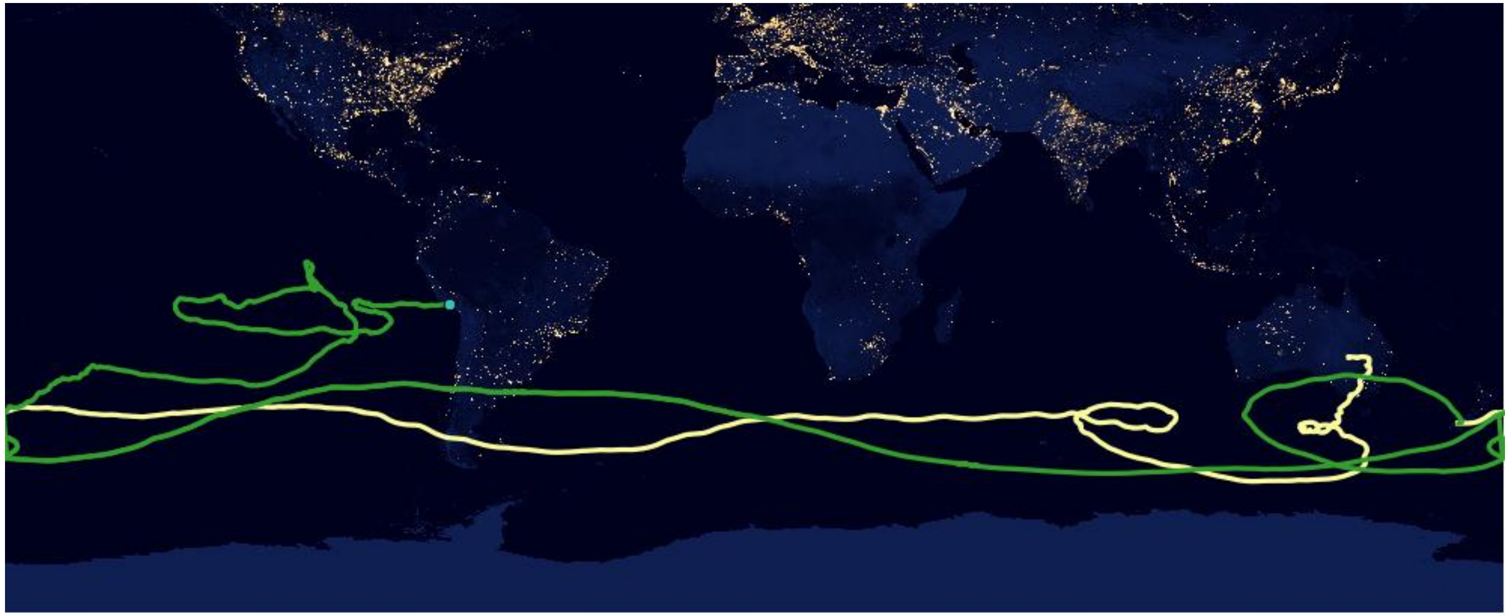


MINI-EUSO
Smaller version of the EUSO PDM will fly on the ISS in 2017

EUSO-SPB
Spring 2017

EUSO-SPB

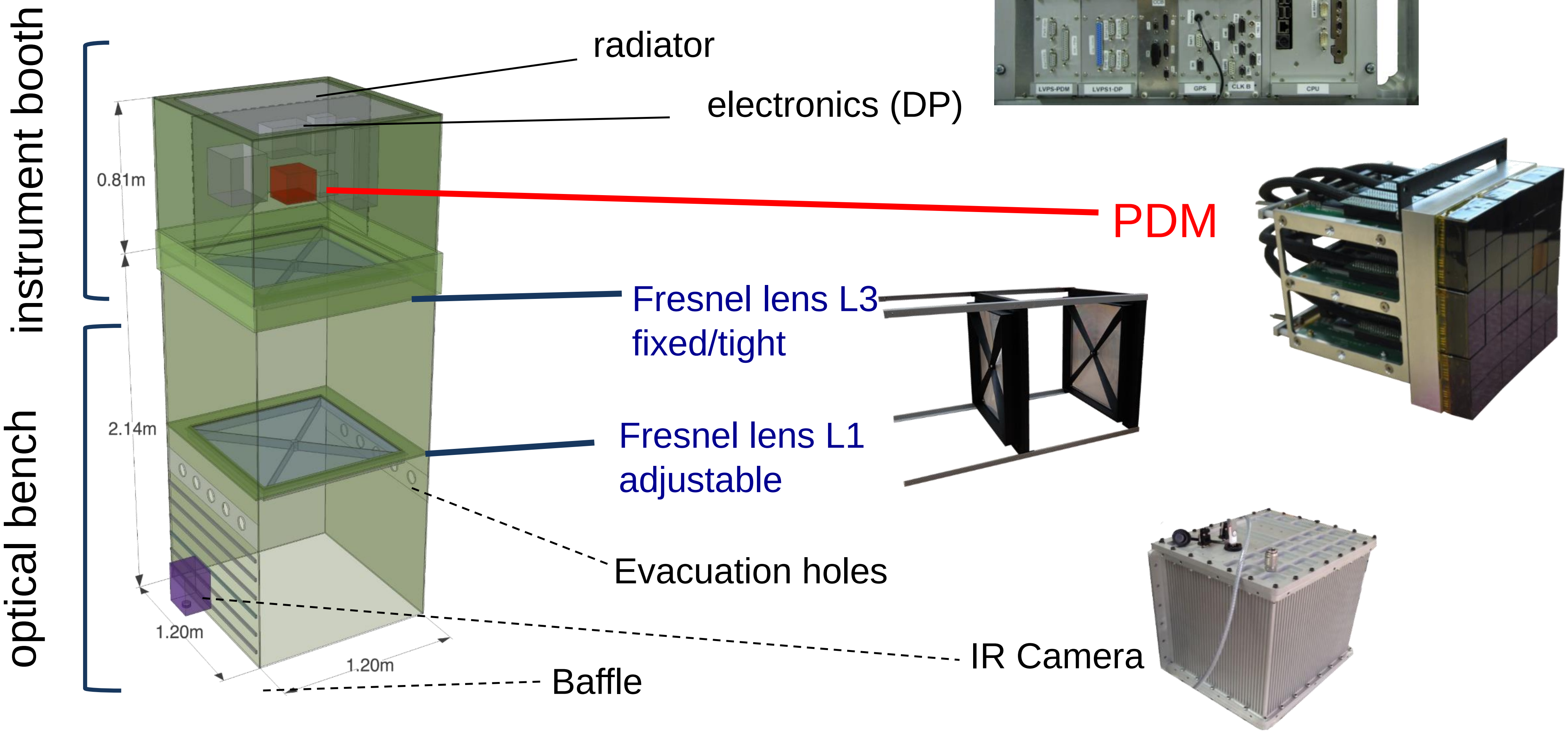
EUSO-SPB has the objective of detect extreme high energy cosmic ray from the upper atmosphere, using a Super Pressure Balloon provided by Nasa which can fly at $\sim 30/40km$.



First 2 flight of the NASA SPB

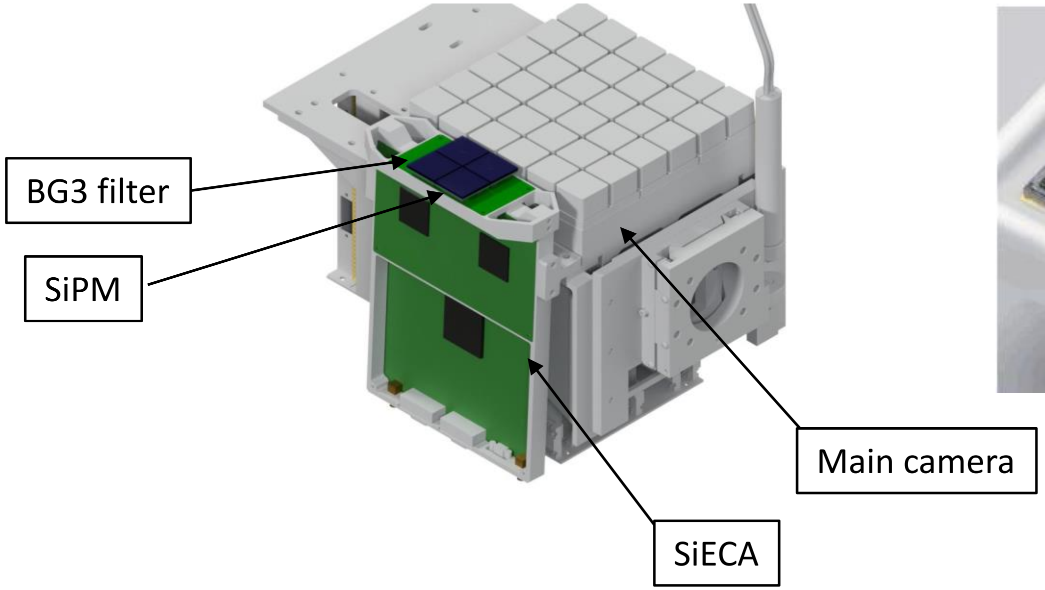
This fly with be a lower altitude than the ISS, but still it should be able to detect come events in an area on ground with a side of $\sim 6/8\ km$

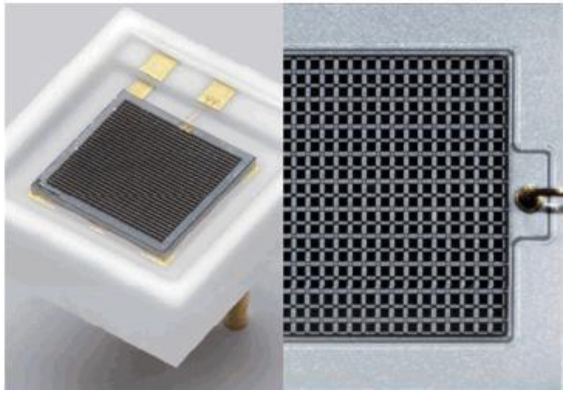
EUSO-SPB structure



(SiECA) Silicon-photomultiplier Elementary Cell Add-on

On the EUSO-SPB there will be an array of new Silicon Photomultiplier (SiPM) beside the standard photomultiplier tubes (MAPts) in order to test the actual possibilities of this technology.





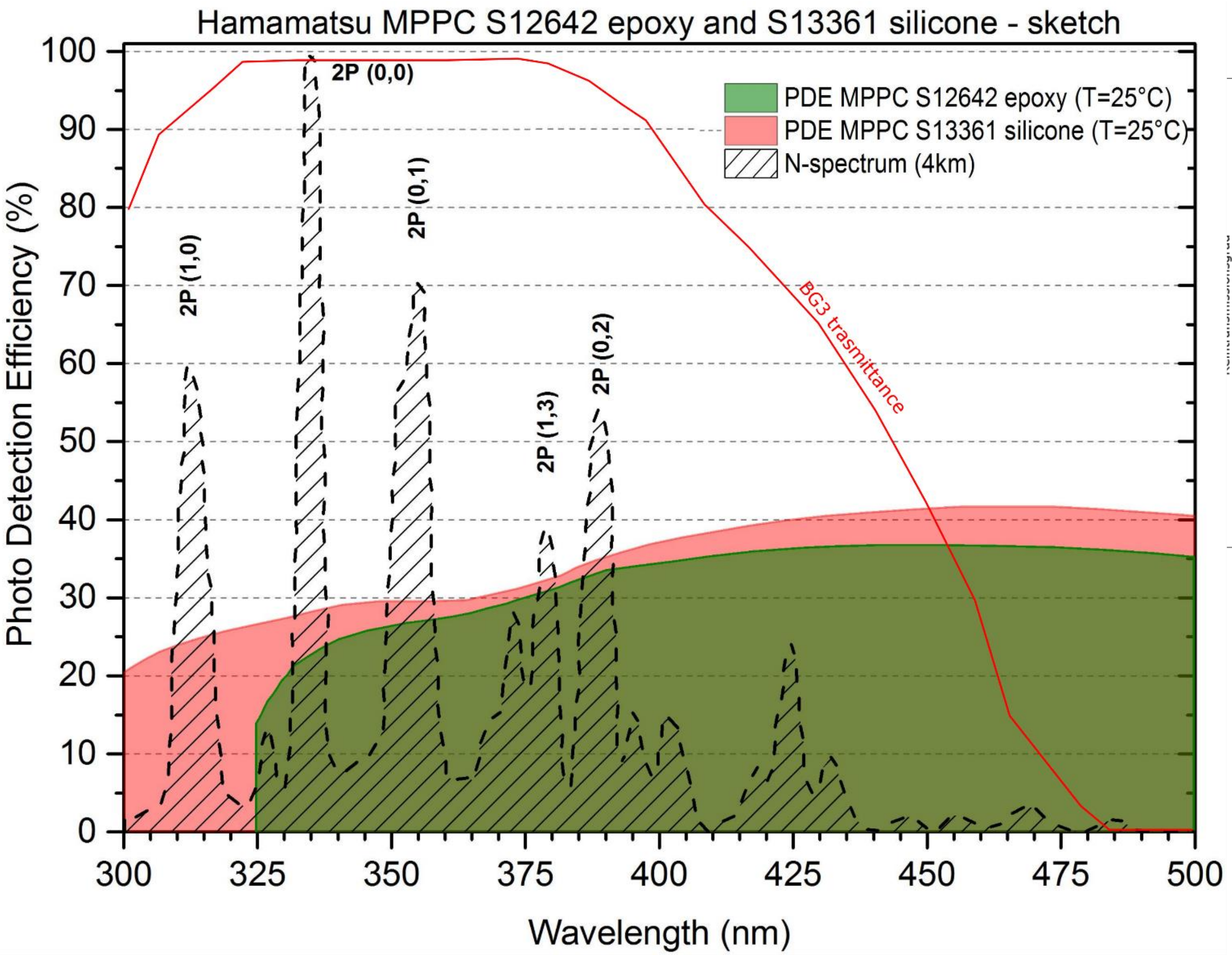
A SiPM

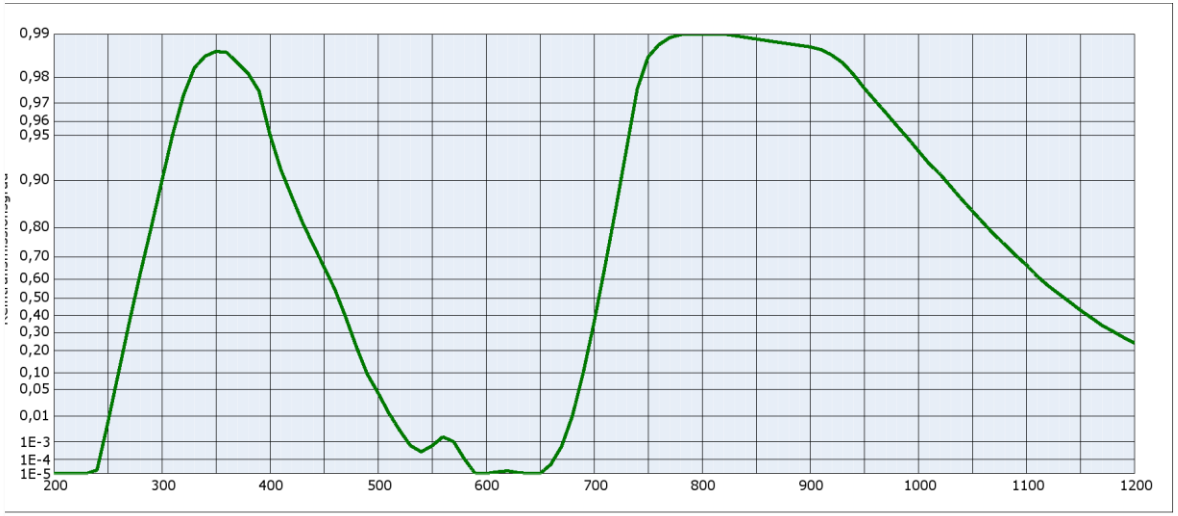
SiPMs pros:
- More durables
- Slower ageing
- More lightweight
- More sensible
- No high voltage required

Cons:
- Bigger dark noise
- Big noise temperature dependence

My work was focused on testing and assembling the opticals filters for this camera

Schott BG3 filters

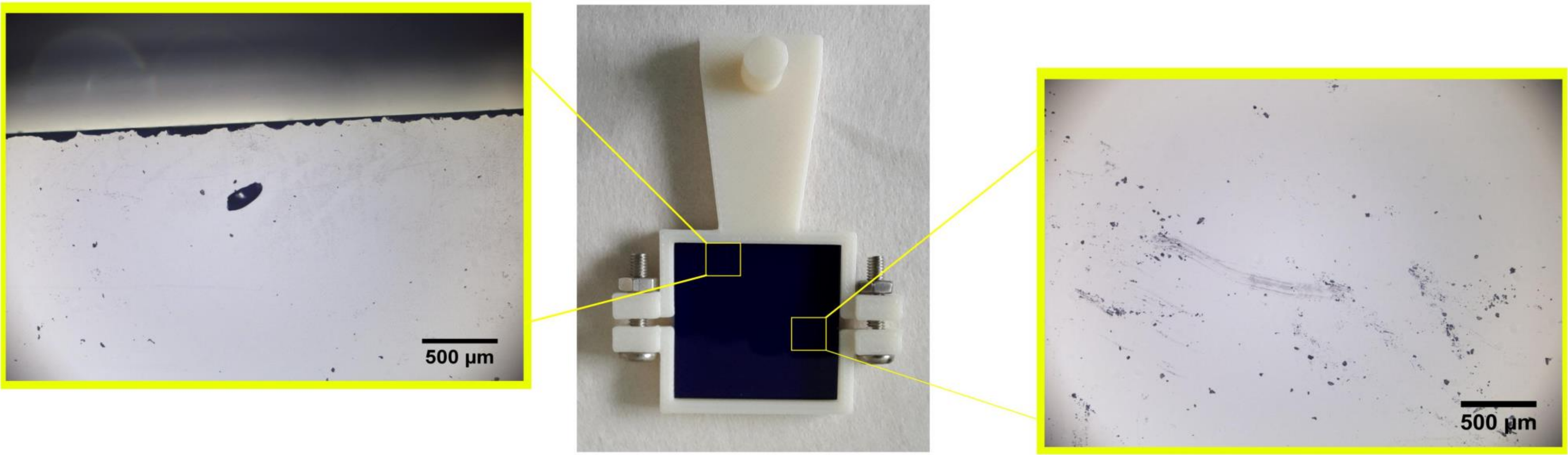




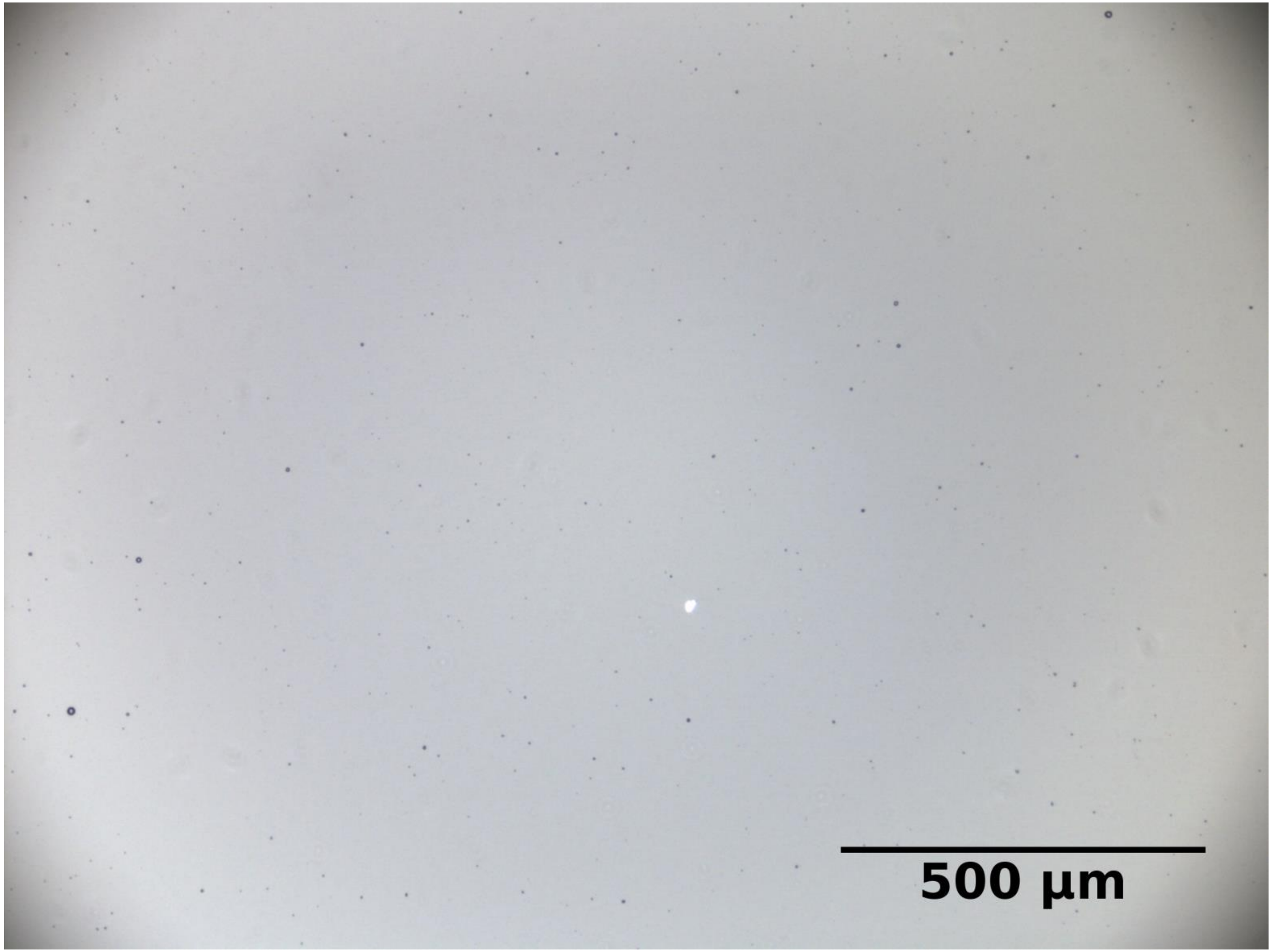
BG3 filter trasmittance (1mm)

Microscope analysis of the filters

The nanotechnology department helped me with a visual analysis of the filters' surfaces. They are resulted nearly perfects for our propose. There aren't big scratches or holes, or, at least, they are several orders of magnitude smaller than a dust particle. We use a 5x objective microscope with a 2560x1920 resolution CCD.



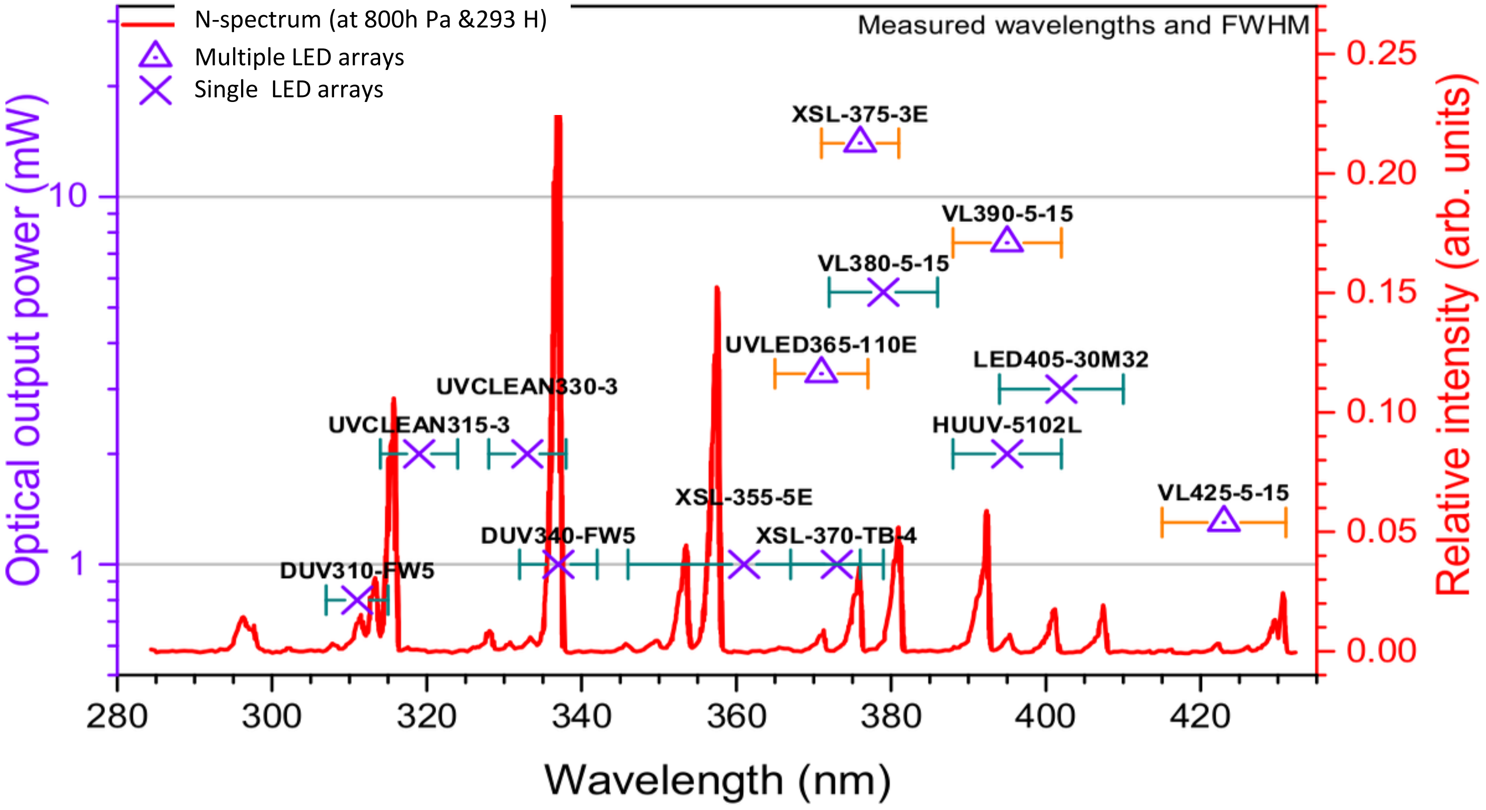
This filter is the one with most imperfections, because it's the one that has been handled more. As shown in the pictures, is the only filter which shows a dig (left picture), probably caused by a hit. The right picture shows the dirtest part of the filter, which is still quite clean.



Each channel of our SiPM will be a square with a 3,2mm side, so we can consider the filters' surface nearly optically perfect.

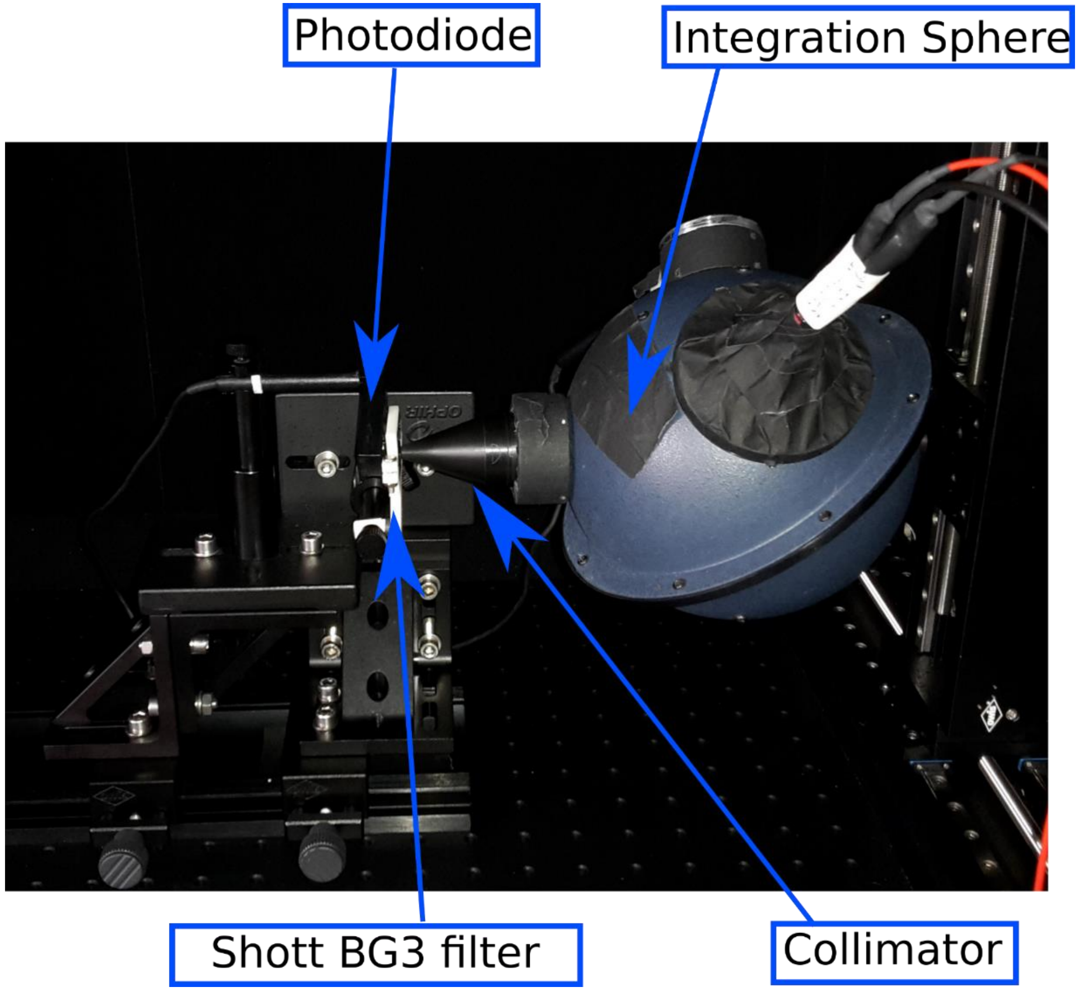
Filter transmittance properties

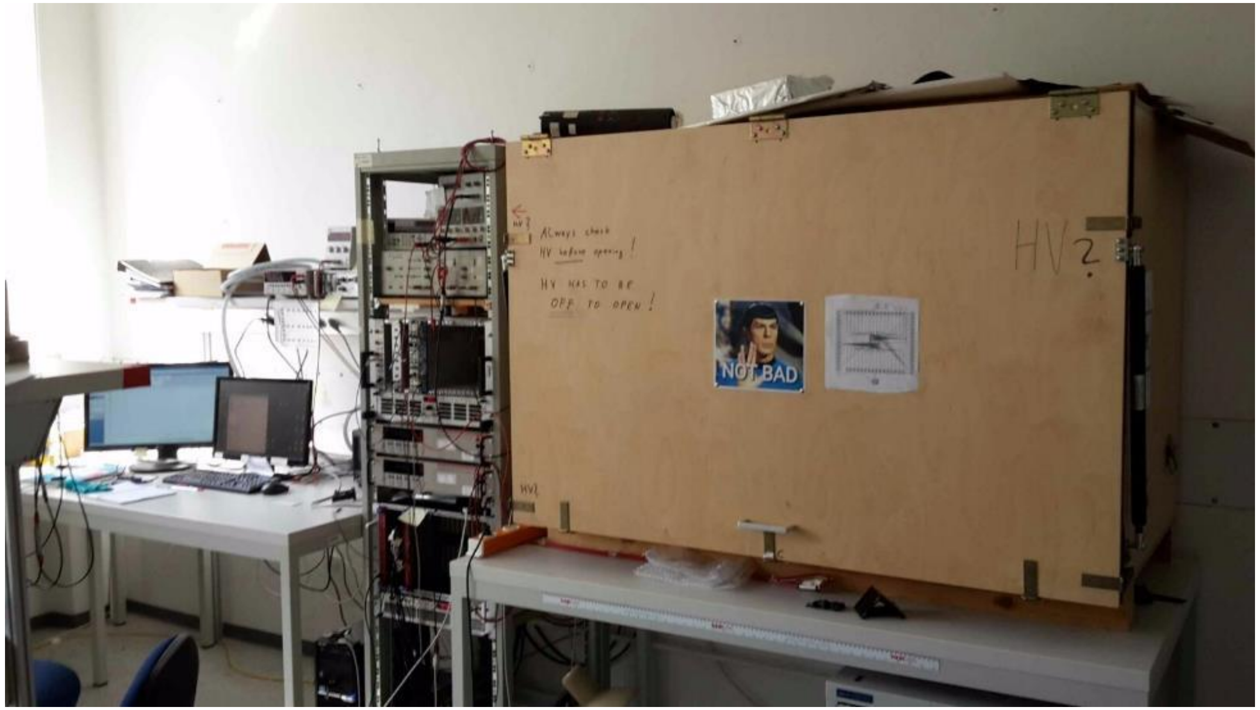
As next step I concentrate on the filters' transmittance properties, using different light sources and a photodiode (OphirPD39) for the power detection.



It was important to study the filter transmittance in the peaks' wavelength, but I can't use single LEDs for the measure with the SiPM because they light output was too low for the SiPMs' experimental system.

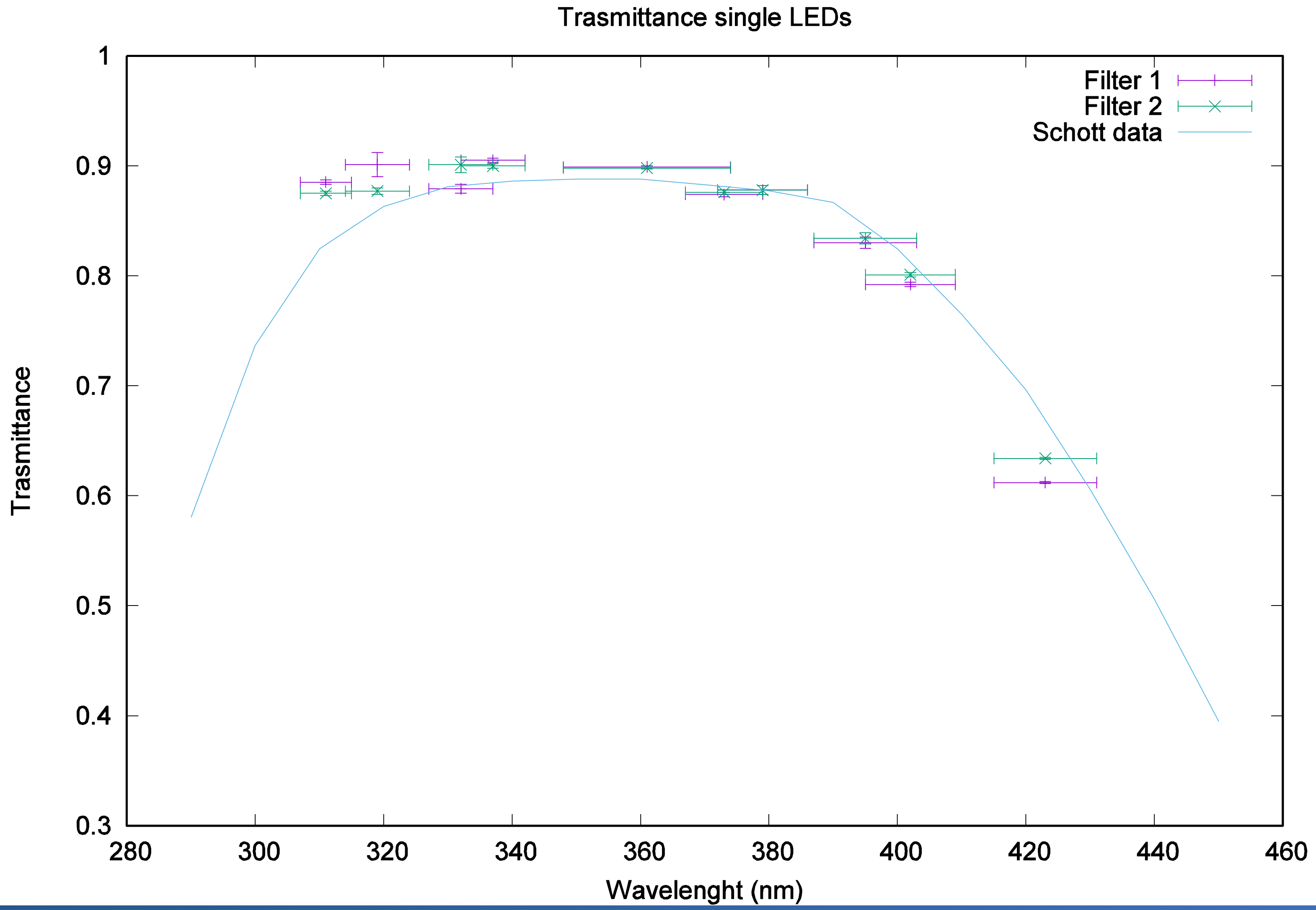
Experimental apparatus



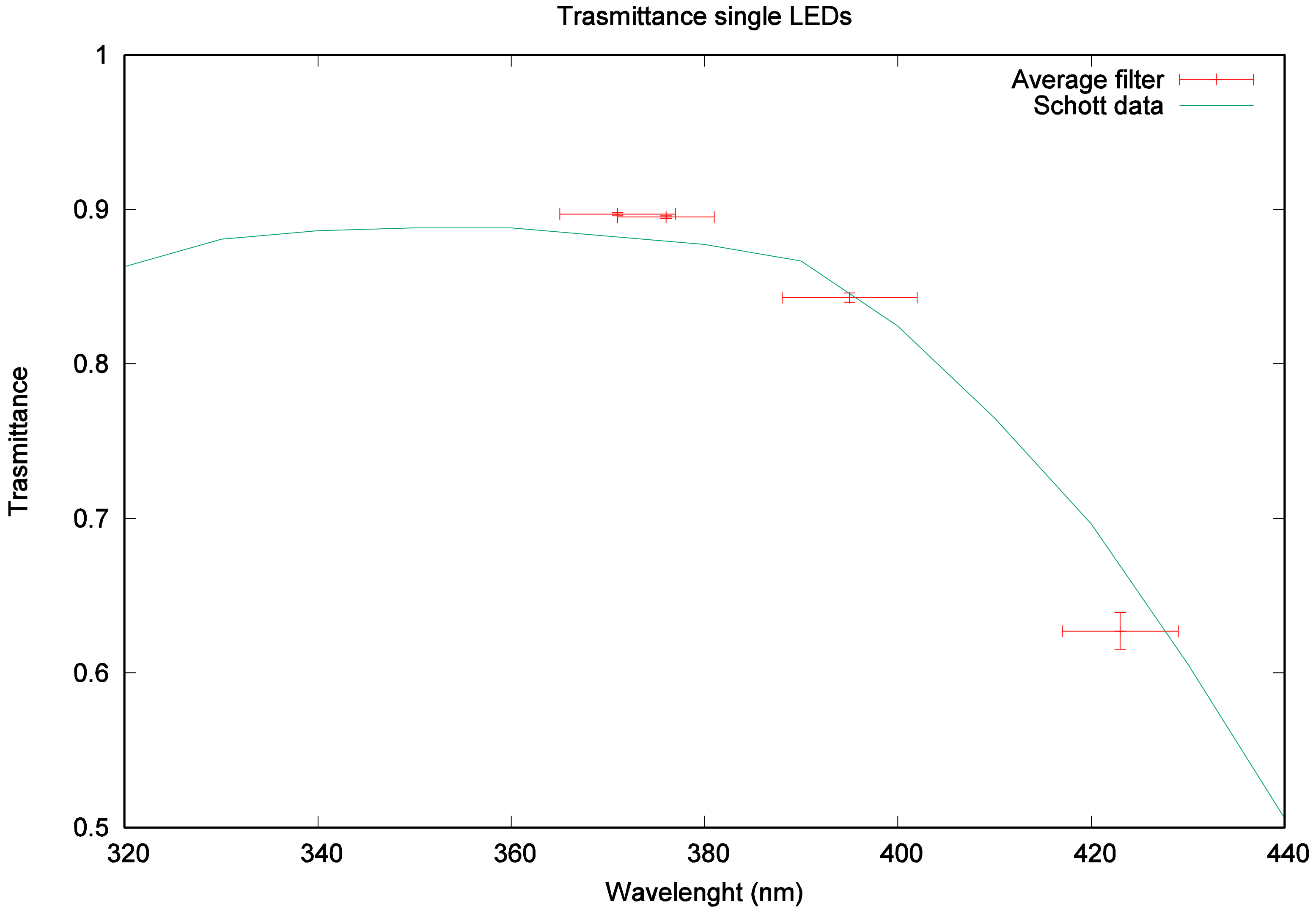


The dark chamber I used for my measures, part of SPOCK (Single PhOton Calibration stand at KIT)

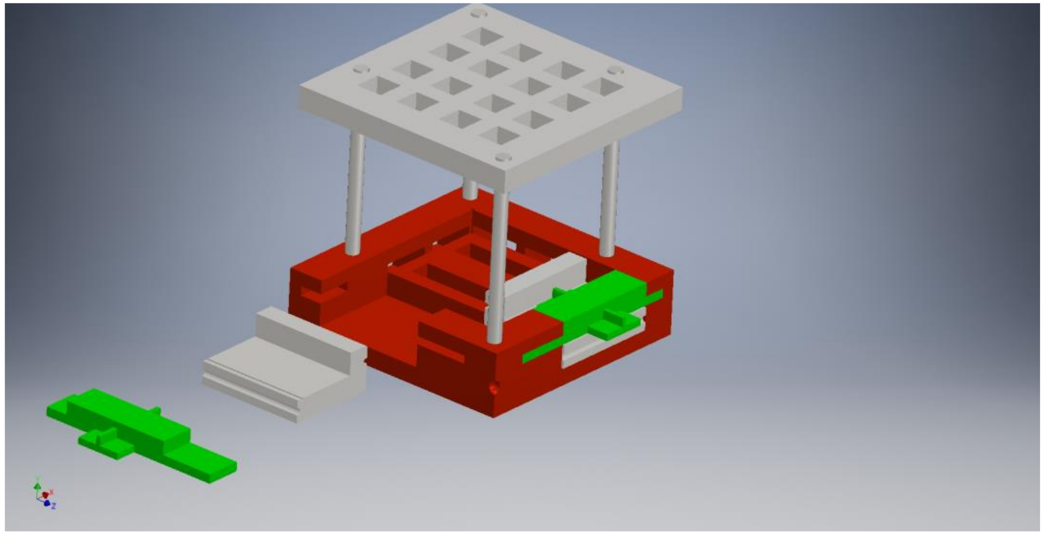
Single LED results

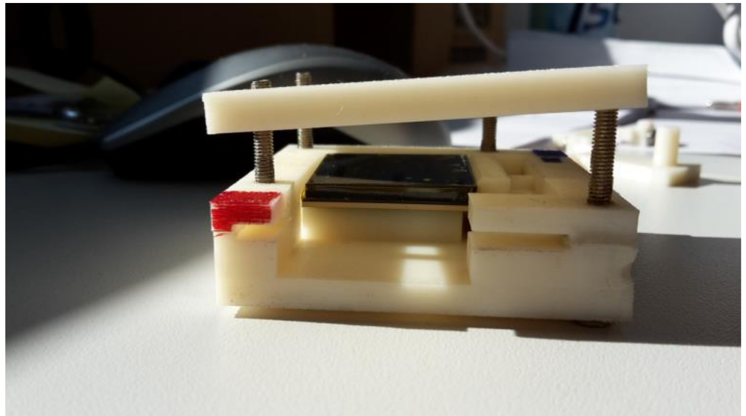


Multiple LED results

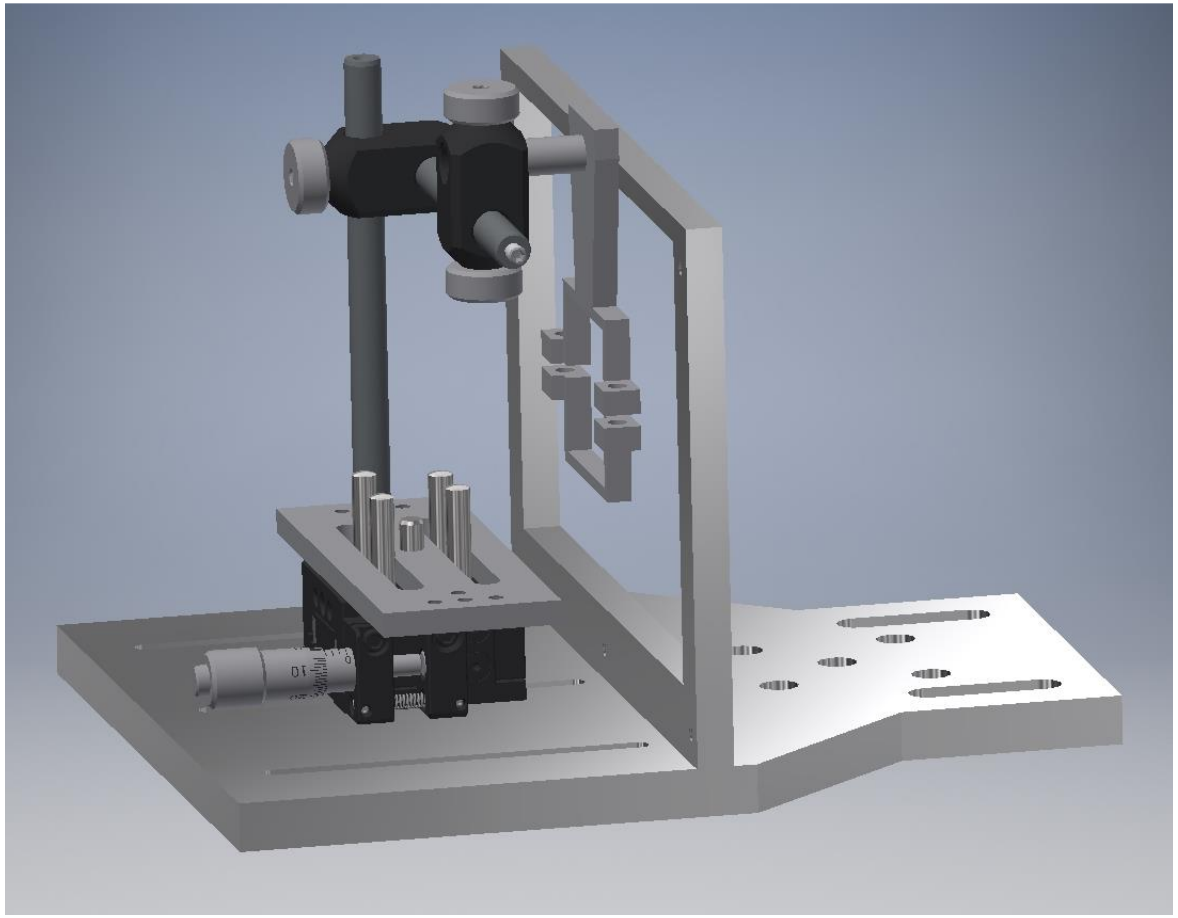


Design of mechanical devices





Gluing stand



Filter holder

Gluing process

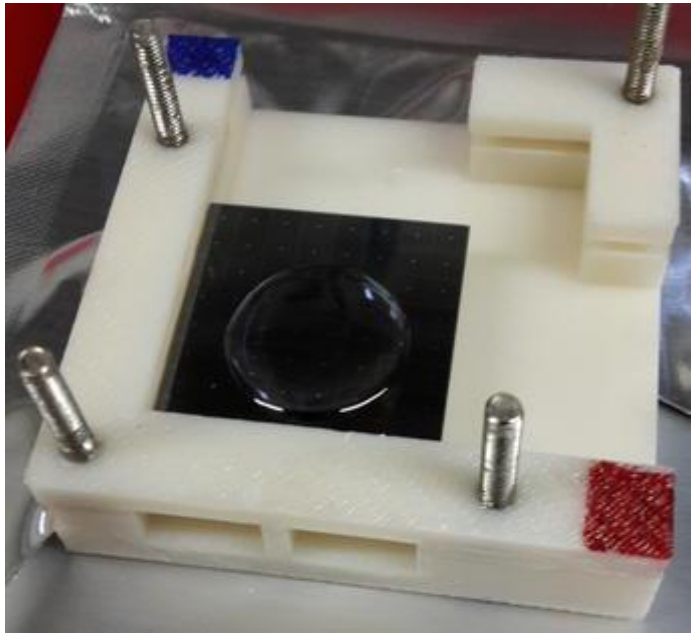
Glue:Epotex 301-2:

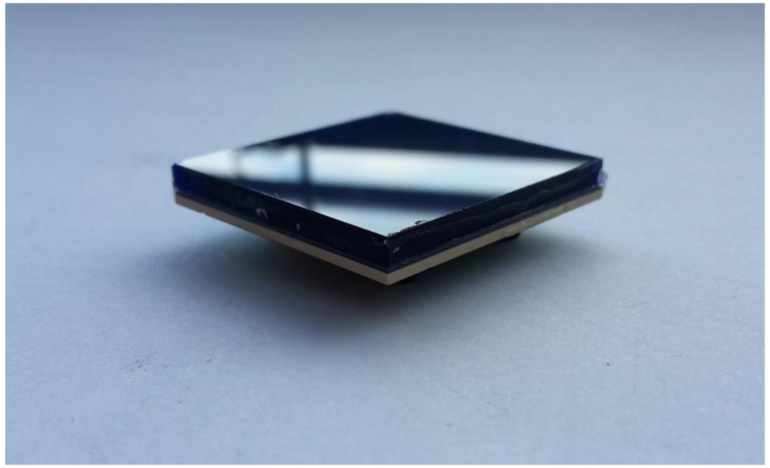
Pros:

- very good UV transparency (94% -99 % transmittency)
- easy to handle
- low temperature curing

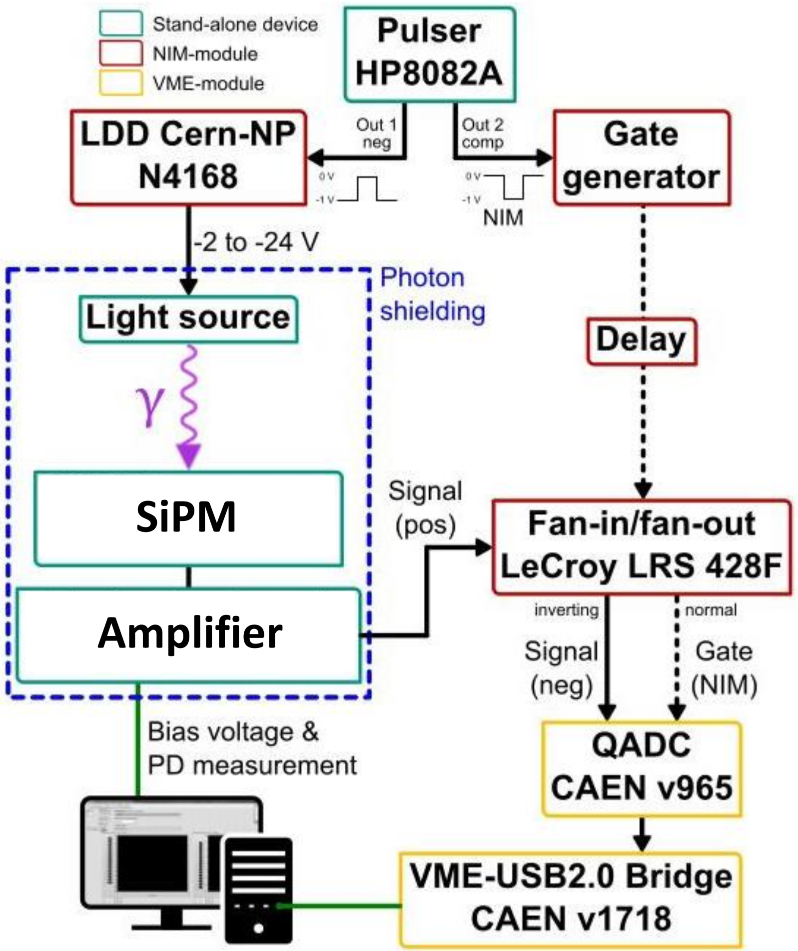
Cons:

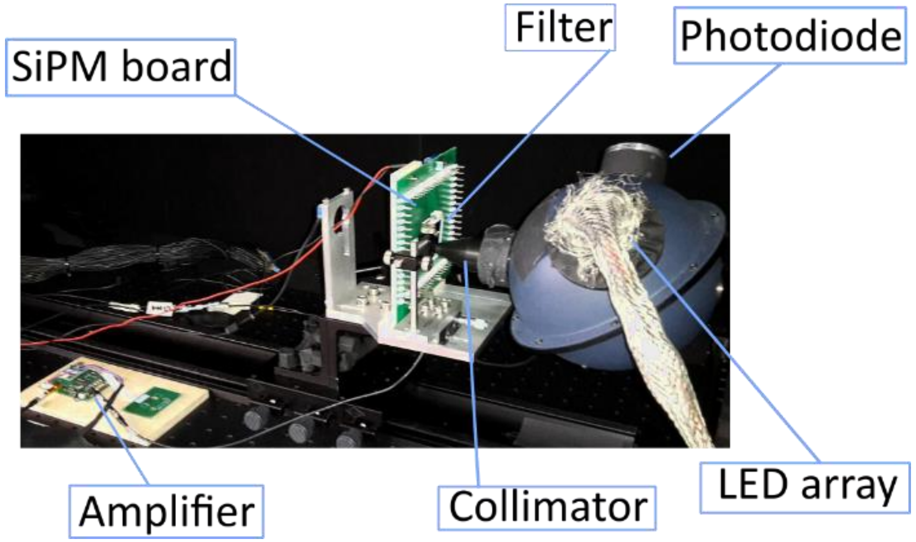
- Silicone and epoxy can have bad behaviour together
- very low viscosity

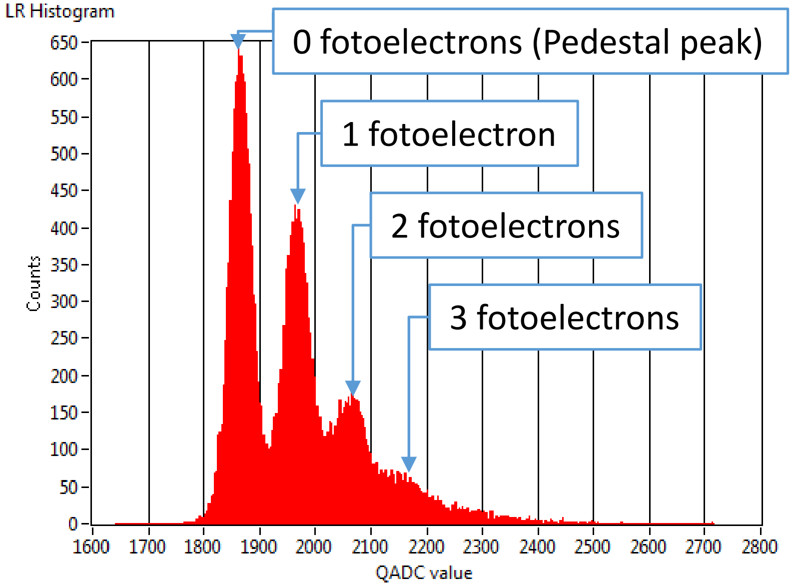




SiPM measurement







First measure result

The SiPM for the first test was not working before the gluing, after the gluing those are the results for 423 nm light

	Channel 1	Channel 44
Emitted photons (pulse)	3.06±0.06	3.06±0.06
Detected photons (pulse)	0.89±0.03	0.91±0.03
PDE (photon detection efficiency)	29.0% ± 1.2%	29.5% ± 1.2%

Photo detection efficency calculation

$$PDE = \frac{N_r}{N}$$

N: Incoming photons

$$N = \frac{P \cdot R \cdot \lambda}{h \cdot c \cdot f}$$

With:
N: Number of incoming photons
P: Optical power of one pulse
R: Collimation Ratio
λ: wavelength if LED light
h: plank constant
c: speed of light
f : pulse frequency

N_{r}: Detected photons

$$N_r = ln\left(\frac{N_{Dark}}{N_{TOT}}\right) - ln\left(\frac{N_{Light}}{N_{TOT}}\right)$$

With:
N_r :Number of detected photons
N_{Dark} : Pedestal peak area with no light
N_{TOT} : Number of pulses
N_{Light} : Pedestal peak area with light

Errore sources (numeric values for channel 1)

Channel 1	Incoming photons	Detected photons	PDE
	3.06±0.06	0.89±0.03	29.0% ± 1.2%

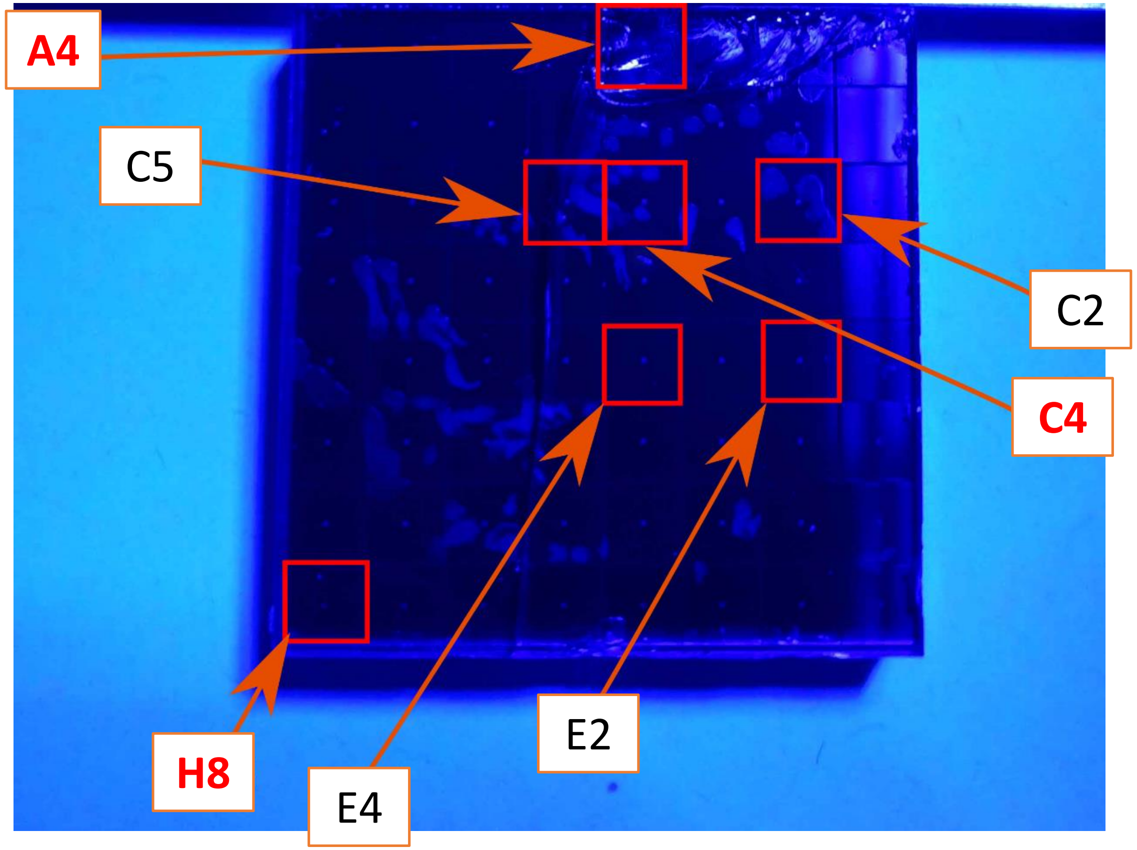
0.058 from collimation error

0.01 from wavelengths' error

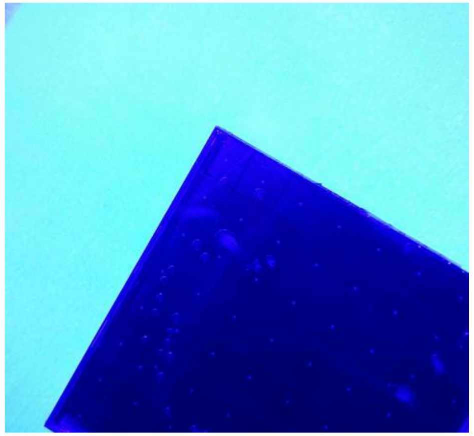
Other minor error sources

Mostly from pedestral area error (Gauss) and QADC non linearity

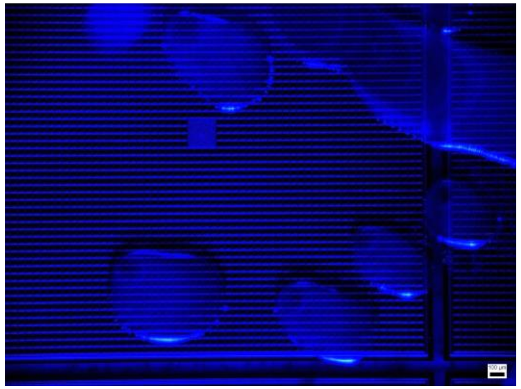
Gluing problems and defects



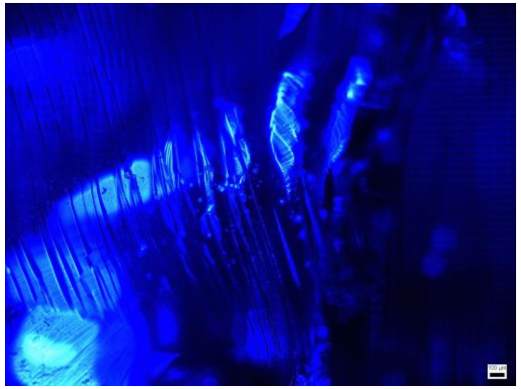
Analysed channels



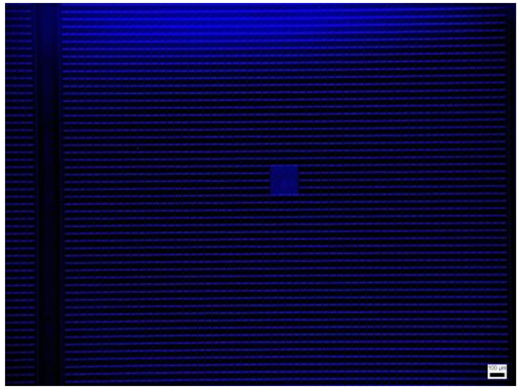
First gluing attempt



Bubbles (**C4**)



Damage (**A4**)



Clean (**H8**)

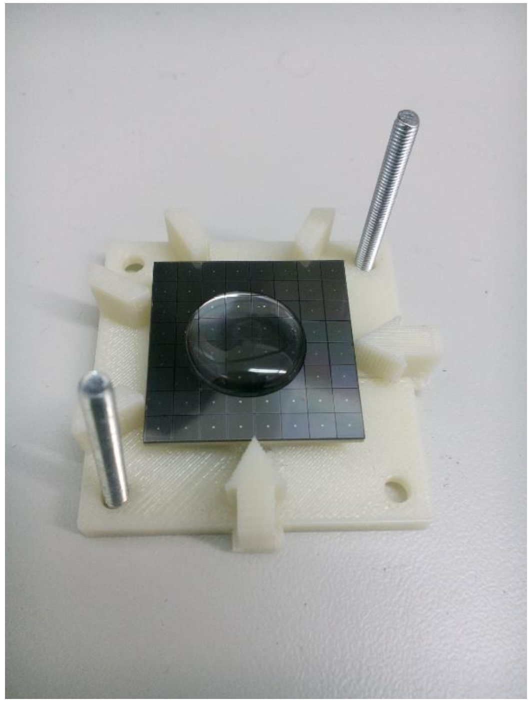
Results

Channel	PDE	Status
A4	27.8 ±1.6%	under the dig
C2	26.3 ±1.6%	bubbles
C4	26.0 ±1.6%	bubbles
C5	27.1 ±1.6%	crack
E2	27.4 ±1.6%	clear
E4	27.2 ±1.6%	clear
H8	27.0 ±1.6%	clear

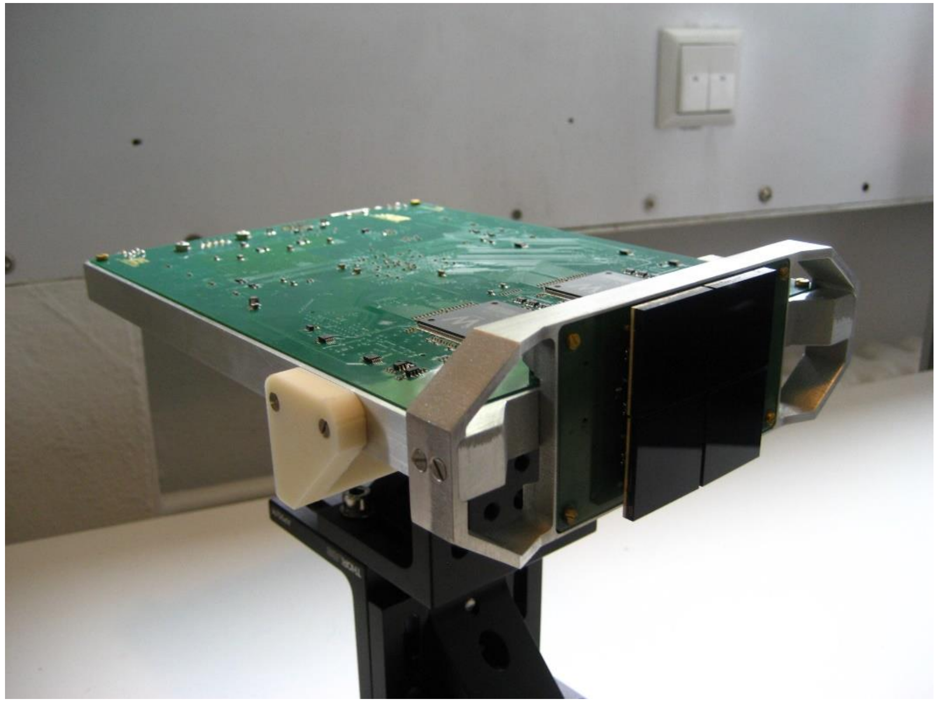
Wavelength	Without filter	With filter
371	20,7±0,8%	20,0±1,0%
394	38,5±1,2%	36,4±1,5%
420	41,6±1,4%	27,4 ±1,0%

Final gluing

Degassing process

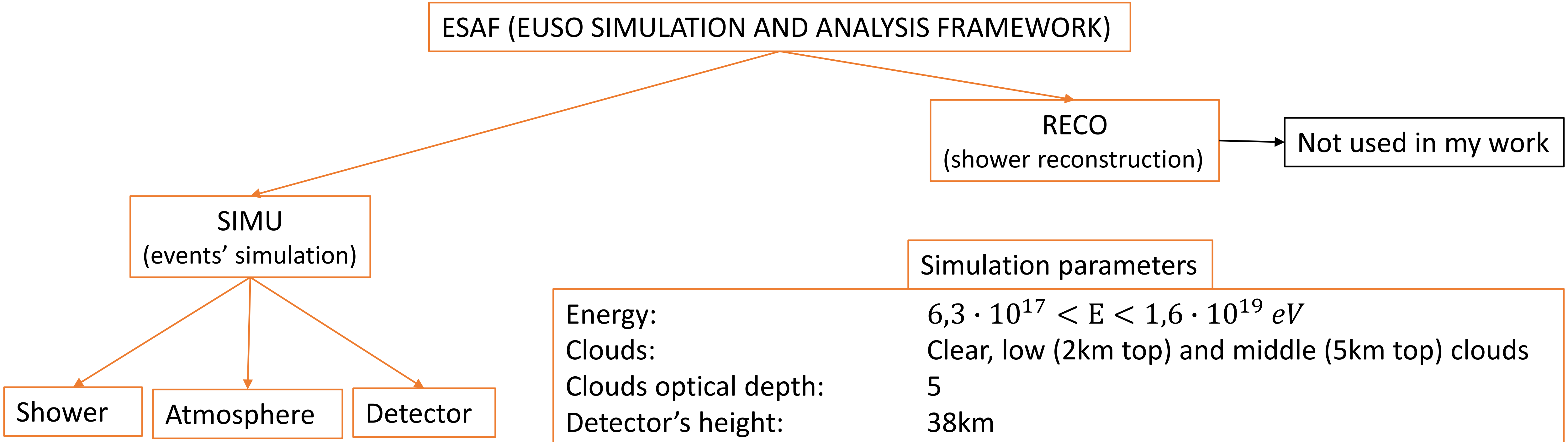


New gluing stand



SiECA Assembled

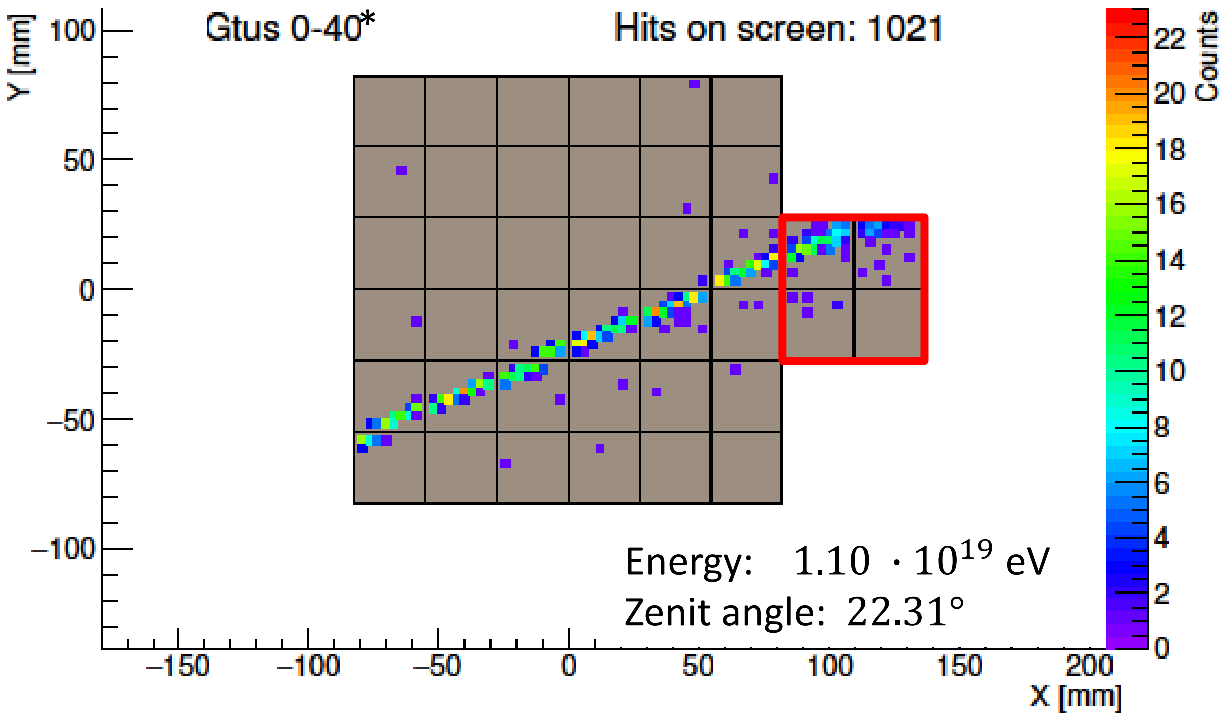
SiECA simulation-the ESAF software



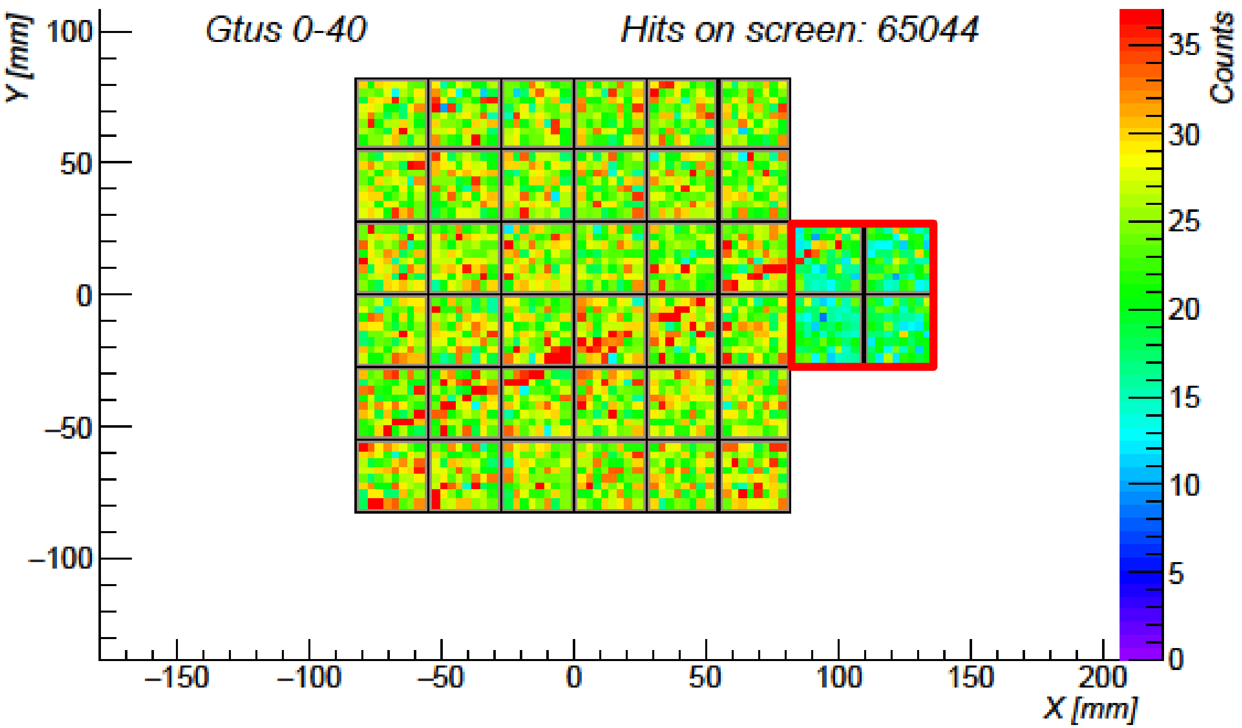
Simulation parameters

Energy:	$6{,}3 \cdot 10^{17} < \mathrm{E} < 1{,}6 \cdot 10^{19}\ eV$
Clouds:	Clear, low (2km top) and middle (5km top) clouds
Clouds optical depth:	5
Detector's height:	38km
PDE (MAPTs):	10%
PDE (SiPMs):	13.3%
Generated events:	10000

Event example



Event with no background



Event with background

*GTU=Gate Time Unit= 2,5μs

Triggered spectra calculation

Trigger performances evaluated in term of events collected in a spectrum

$$\Delta N(E) = \frac{d\phi(E)}{dE} \cdot \Delta(E) \cdot \Psi(E)$$

- $\Delta N(E)$: Number of events per energy bin
- $\frac{d\phi(E)}{dE}$: Differential flux (Auger Flux –ICRC 2013)
- $\Delta(E)$: Energy range
- $\Psi(E)$: Detector exposure

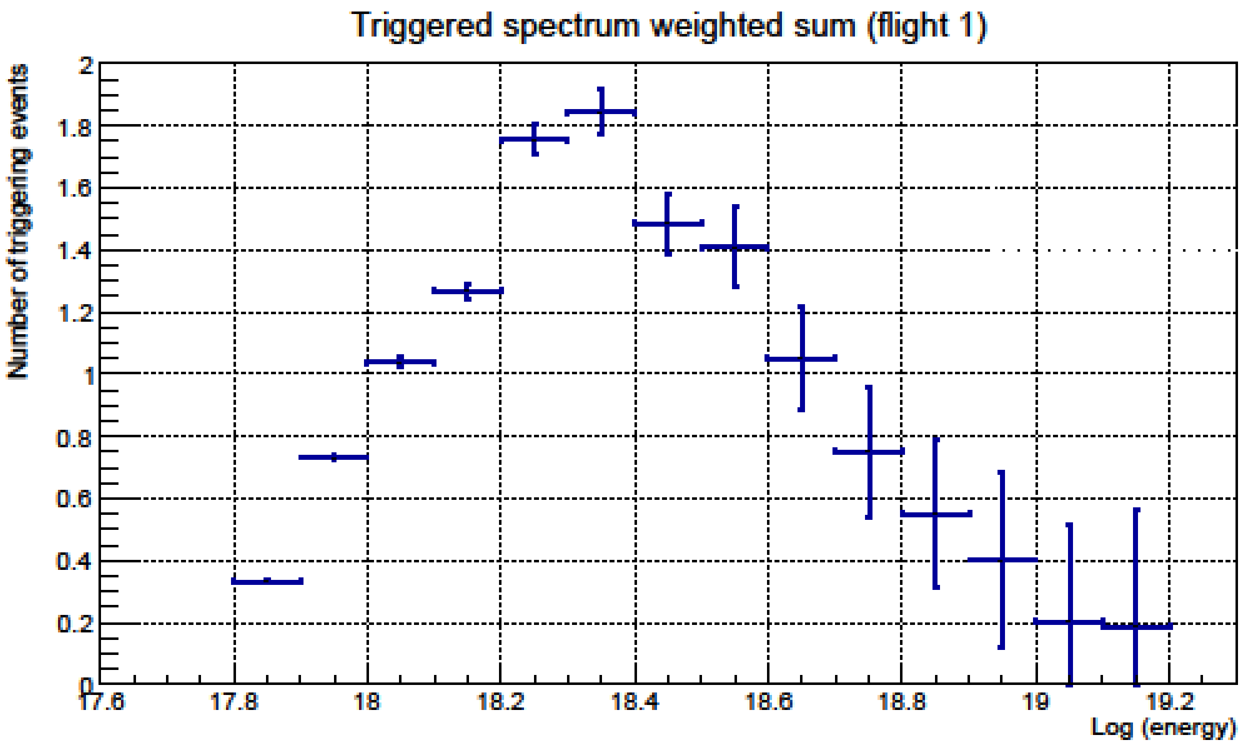
$$\Psi(E) = \varepsilon(E) \cdot A_{fov} \cdot \pi \cdot t \cdot DC$$

- $\varepsilon(E)$: detector efficiency;
- A_{fov}: detector field of view area
- π: solid angle
- t: triggering time
- DC: duty cycle

Triggered events

Total number (N_i) of triggered events in 118h

	Main camera trigger
Clear sky	5,7 ±0,6
Low clouds	16,8 ±0,6
Middle clouds	13,6 ±0,2



Cloud fractions (f_i) in previous flights*

	Clear sky	Low clouds	Middle clouds
Flight 1	23%	37%	25%
Flight 2	40%	25%	22%

Total number of triggered events in realistic conditions

	Main camera trigger
Weighted sum flight 1(W)	12,1 ±0,4
Weighted sum flight 2(W)	13,0 ±0,5

$$W = \frac{\sum_i f_i N_i}{\sum_i f_i}$$

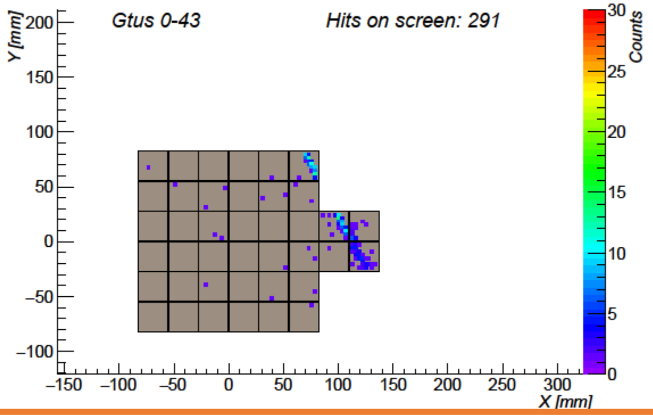
*From A. Veneziani Thesis

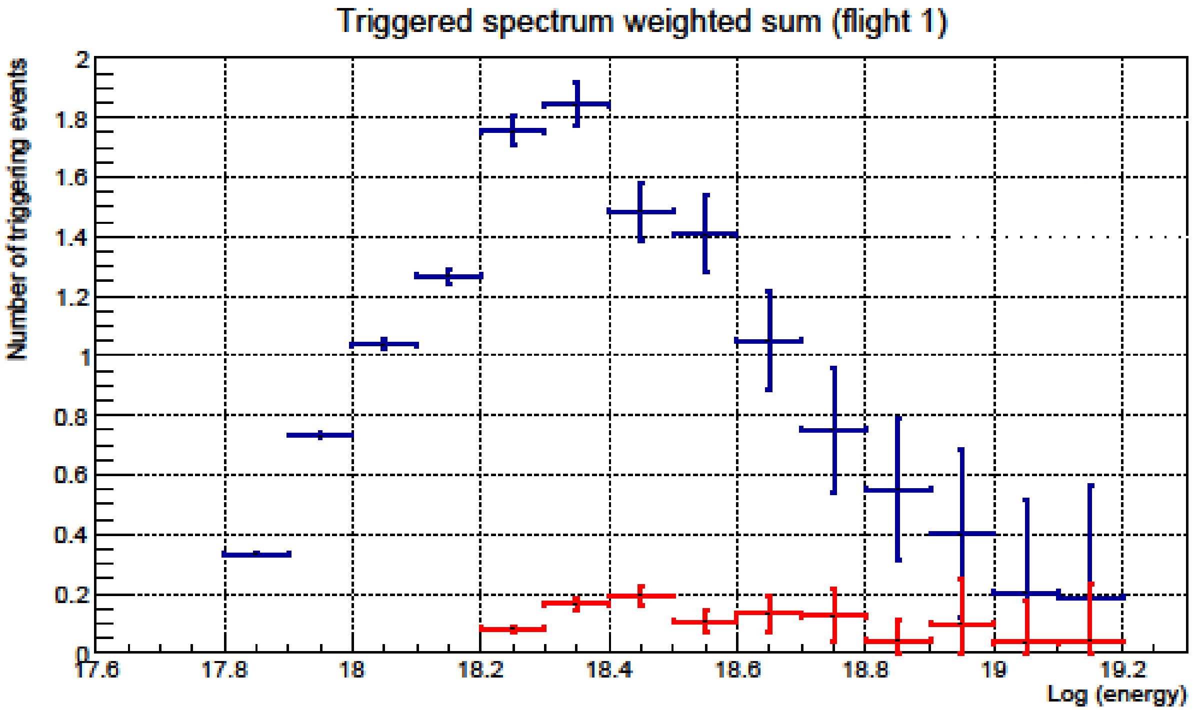
Different thresholds

SiECA doesn't have any trigger (it will use the main trigger for the data aquistion), so we decide to use different arbitrary thresholds.

	Events flight 1	Events flight 2
Main trigger	12,1 ±0,4	13,0 ±0,5
5 counts/pixel in 1 GTU	1,0 ±0,3	1,0 ±0,3
8 counts/pixel in 1 gtu	0,4±0,2	0,4±0,2
20% of total signal	1,2±0,2	1,1±0,2
40% of total signal	0,4±0,1	0,4±0,1

Simulation parameters:
Energy: $9.46 \cdot 10^{18}$ eV
Zenit angle:61°
Low clouds



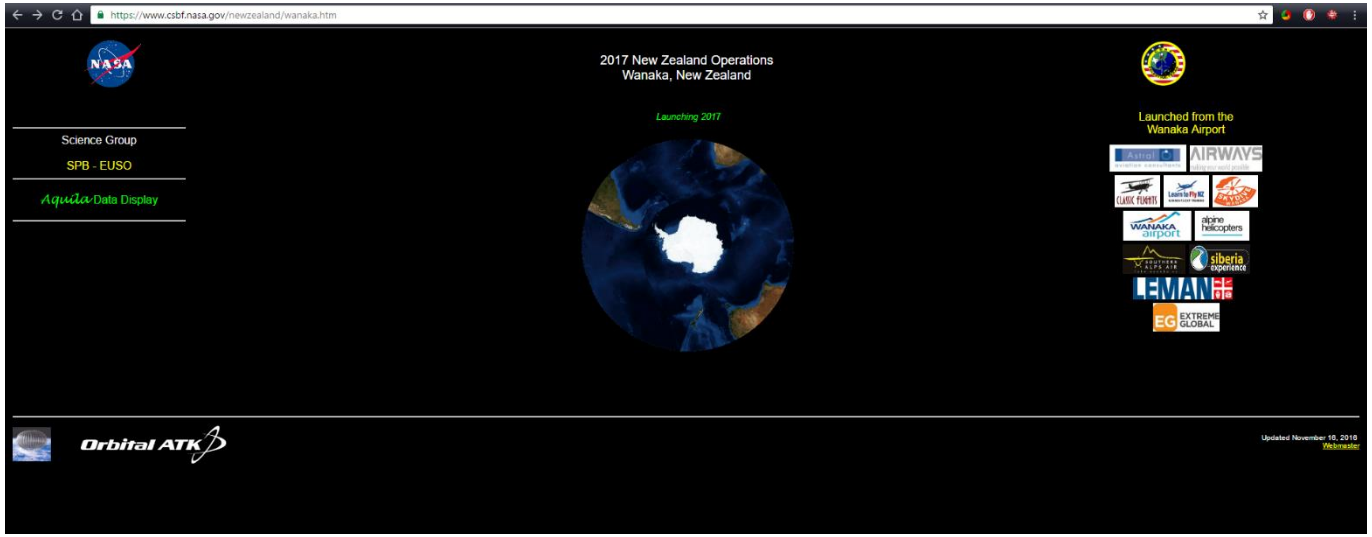


Conclusions

The optical filters are now mounted on SiECA and we know how they should perform

Bettwen 370 and 423 nm the filter transimittance is between 90% and 60% and the assembled SiPM’s PDE is between 20% and 36%.

The simulations show that the camera will likely detect at least 1 event during the flight
We should be able test on the SiMPTs’ functionalities for cosmic rays detection.



The NASA website of the mission

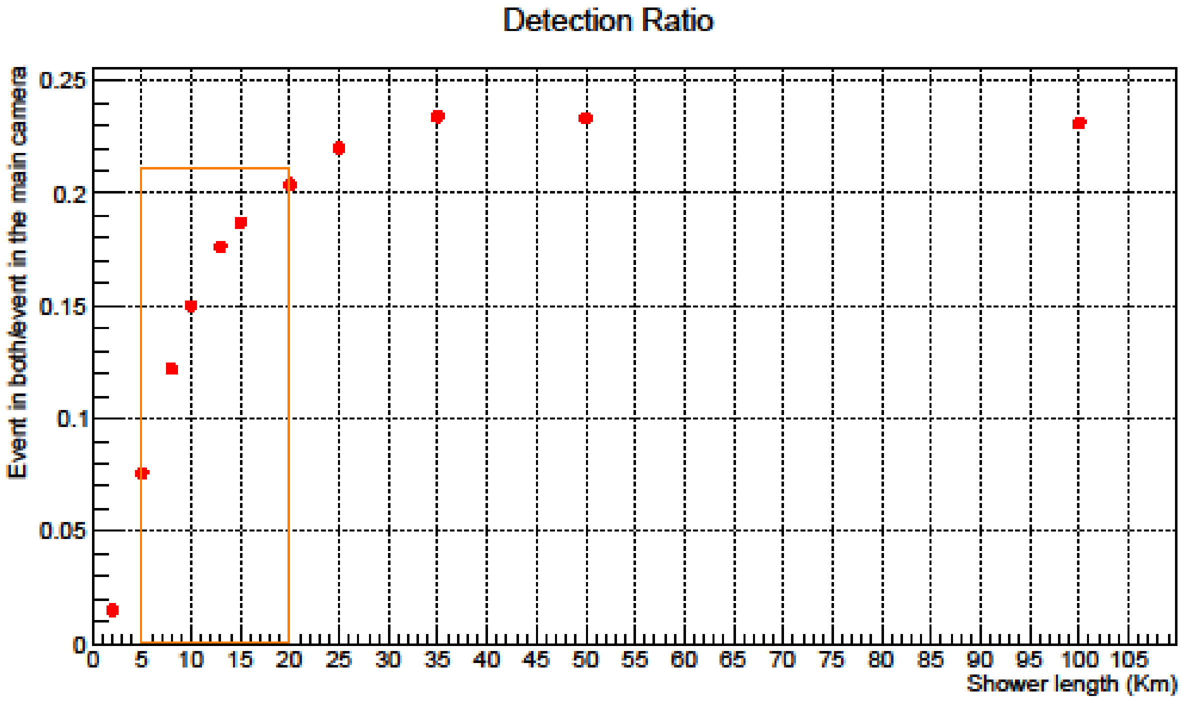
Euso-SPB during the hang test at the NASA CS-BS (Palestine-Texas)

Grazie per l’attenzione

Thanks to:
- Mario Edoardo Bertaina (UNITO)
- Francesco Fenu (UNITO)
- Andreas Haungs (KIT)
- William Painter (KIT)
- Thomas Huber (KIT)
- Max Renschler(KIT)
- Francesca Bisconti (KIT)

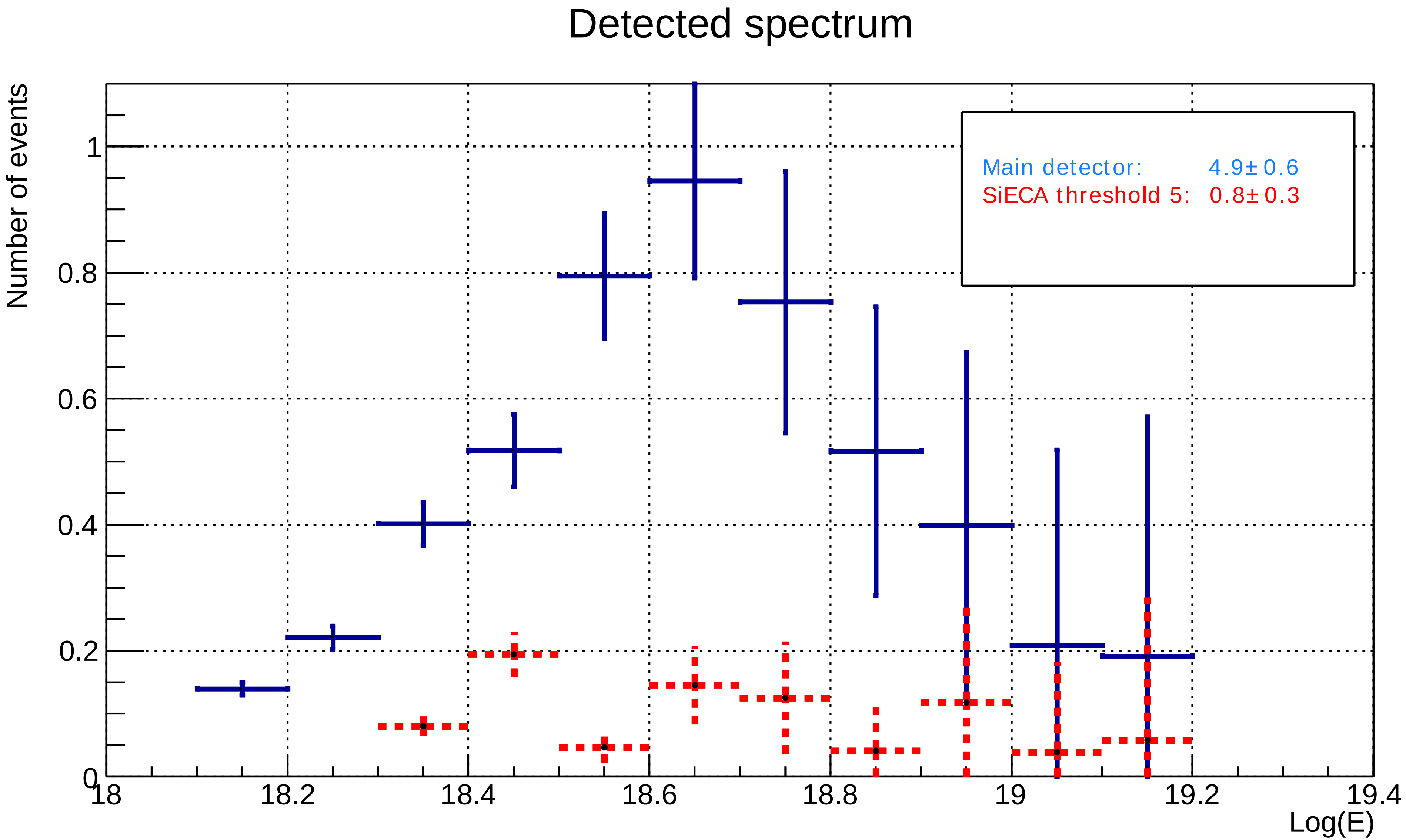
Geometrical anlysis

For have a check on the simulated result I did a simple geometrical analysis of the asset. We can simulate the showers like segments casually generated in an area bigger than the FOV of both the camera. Then I took the ratio between the "events" which pass trough the main camera and the "events" which pass trough both SiECA and the main detector.



Filter trasmittance

Wavelenghts (nm)	Trasmittance
311 ± 4	88,0% ± 0,5%
319 ± 5	89% ± 1%
332 ± 5	89% ± 1%
337 ± 5	90,3% ± 0,2%
361 ± 13	89,8% ± 0,1%
373 ± 6	87,5% ± 0,1%
379 ± 7	87,8% ± 0,4%
395 ± 7	83,2% ± 0,5%
402 ± 8	79,7% ± 0,5%
423 ± 8	62% ± 1%


Detected spectrum
Number of events
Log(E)
Main detector: 4.9± 0.6
SiECA threshold 5: 0.8± 0.3
0
0.2
0.4
0.6
0.8
1
18
18.2
18.4
18.6
18.8
19
19.2
19.4