TERZINA on-board NUSES: a pathfinder for EAS Cherenkov Light Detection from space

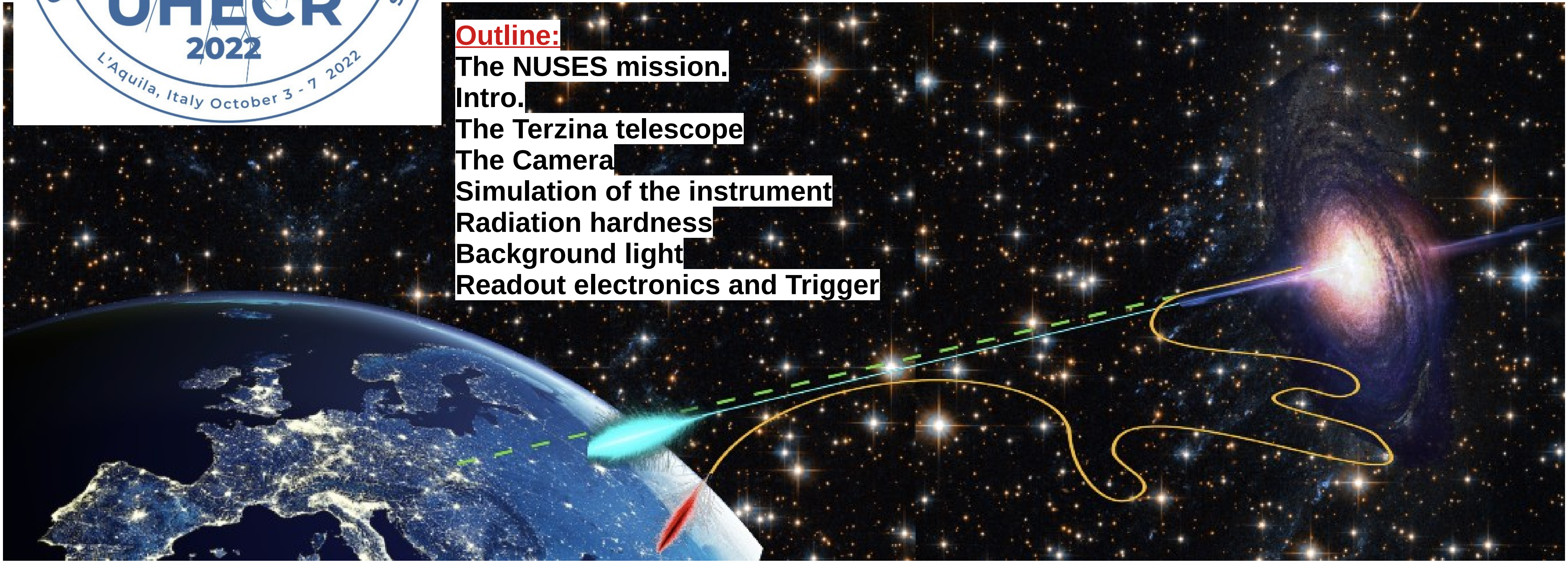
L. Burmistrov

(on behalf of NUSES collaboration)

GRAN SASSO SCIENCE INSTITUTE
SCHOOL OF ADVANCED STUDIES
Scuola Universitaria Superiore

ThalesAlenia Space
a Thales / Leonardo company

6th International Symposium on Ultra High Energy Cosmic Rays
UHECR 2022
L'Aquila, Italy October 3 - 7 2022



Outline:

The NUSES mission.
Intro.
The Terzina telescope
The Camera
Simulation of the instrument
Radiation hardness
Background light
Readout electronics and Trigger

The NUSES Collaboration

60+ persons from many institutions.

Large expertise (and sinergies) from space missions/R&D :
AMS, DAMPE, eASTROGAM, FERMI, GAPS, HERD, LIMADOU, PAMELA, POEMMA, SPB2 , ….

GSSI is leading the mission

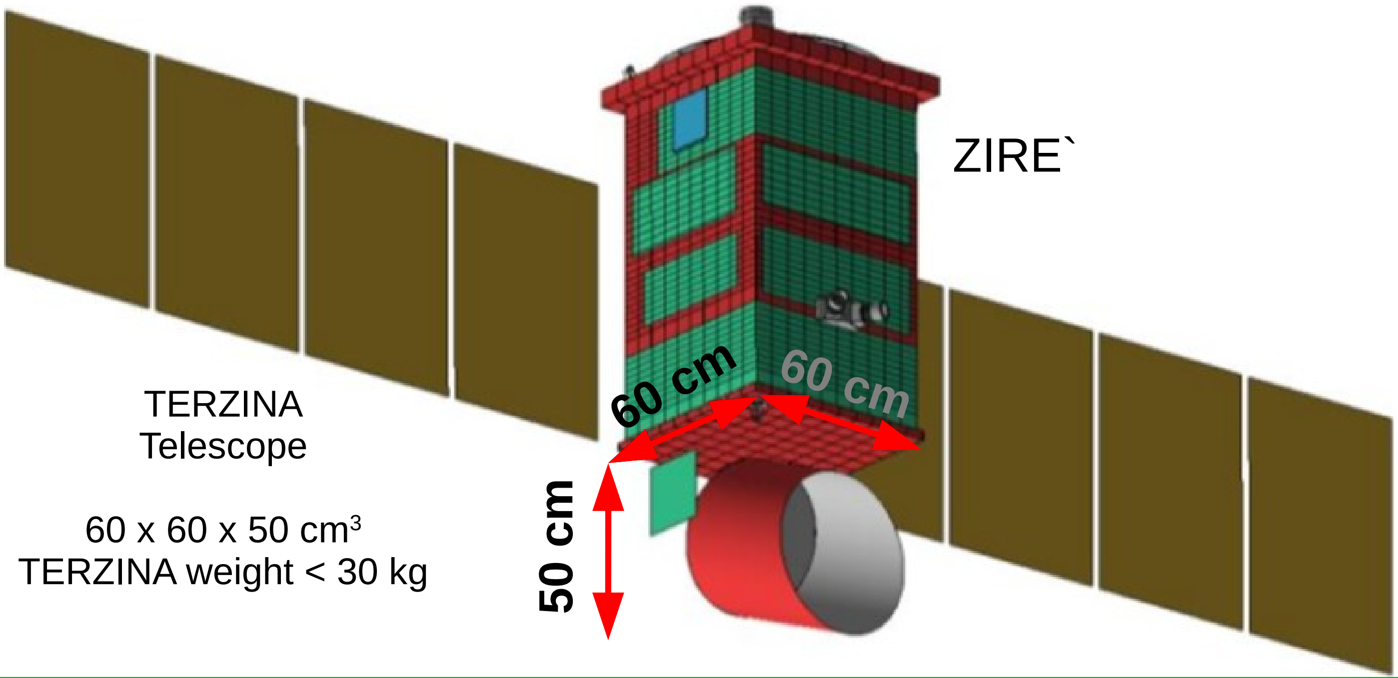
Current list of the italian groups:

- Gran Sasso Science Institute
- INFN – Laboratori Nazionali del Gran Sasso
- Università dell'Aquila
- Università di Roma "Tor Vergata" and INFN-Roma2
- Università di Torino and INFN Torino
- Università di Trento and INFN-TIFPA
- Università di Bari and INFN
- Università di Padova and INFN
- Università "Federico II" and INFN Napoli
- Università del Salento and INFN

University of Geneva +
Possible interests from:
- US institutions
- Spanish institutions
-……

UNDER CONSTRUCTION COMING SOON

The NUSES mission composed of two payloads.



ZIRE`

TERZINA
Telescope

60 x 60 x 50 cm^3
TERZINA weight < 30 kg

Two main components :

ZIRE

TERZINA

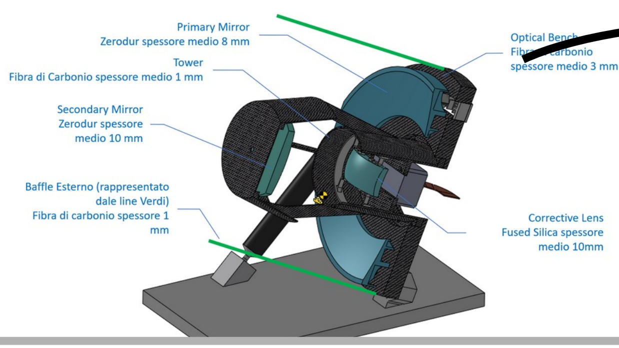
TERZINA

Demonstrator of Cherenkov light detection produced by Extensive Air Showers
- First measurement of showers with Cherenkov light from space (E>100PeV)
- Proves the technology for detecting Earth skimming muon and tau neutrinos
- Measure the background conditions
- Further Development of SiPM technology for space

ZIRE`

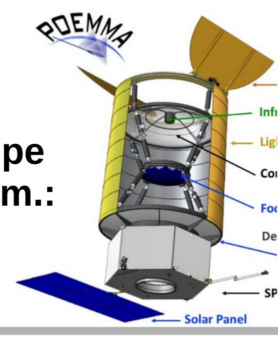
Monitors the fluxes of low energy cosmic rays (< 250 MeV),
- Electrons and protons to study Van Allen radiation belts
- Space weather and the magnetosphere-ionosphere-litosphere couplings
- And much more ….

TERZINA Telescope primary mirror daim.: 0.4m



Probe

POEMMA Telescope primary mirror daim.: 4m



Telescope:	Instrument	
Optics	Schmidt	45° full FoV
	Primary Mirror	4 m diam.
	Corrector Lens	3.3 m diam.
	Focal Surface	1.6 m diam.
	Pixel Size	3×3 mm^2
	Pixel FoV	0.084°
PFC	MAPMT (1μs)	126,720 pixels
PCC	SiPM (20 ns)	15,360 pixels
Observatory	Each Telescope	
	Mass	1,550 kg
	Power (w/cont)	700 W
	Data	< 1 GB/day

Mission	(2 Telescopes)
Lifetime	3 year (5 year goal)
Orbit	525 km, 28.5° Inc
Orbit Period	95 min

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Cherenkov light detection from space : intro.

Drawing is in scale

Dense layer of the atmosphere ~ 30 - 50 km (corresponds to the thickness of the line)

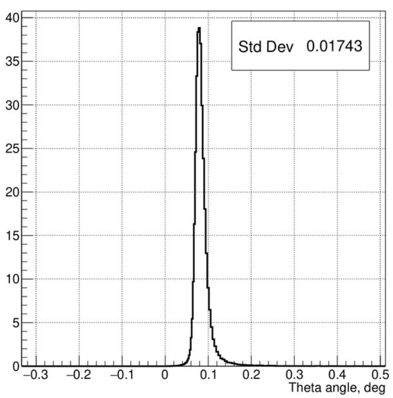
Red dot (telescope)

Green dot point of interaction with the Earth atmosphere.

Looking at the atmosphere limb for UHECR detection.

The Cherenkov angle opening is small

https://pypi.org/project/easchersim/1.1/



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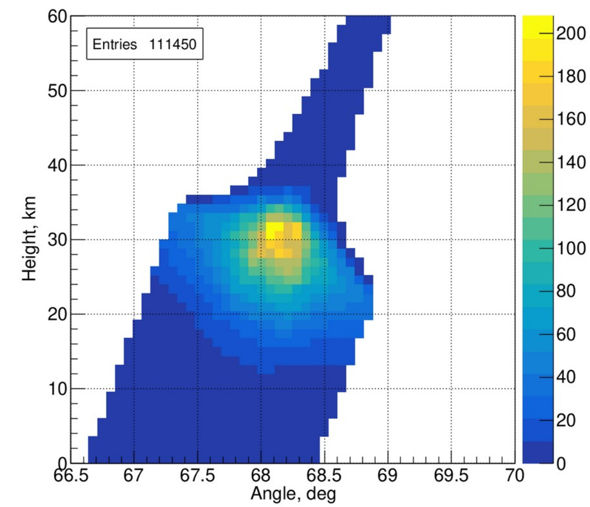

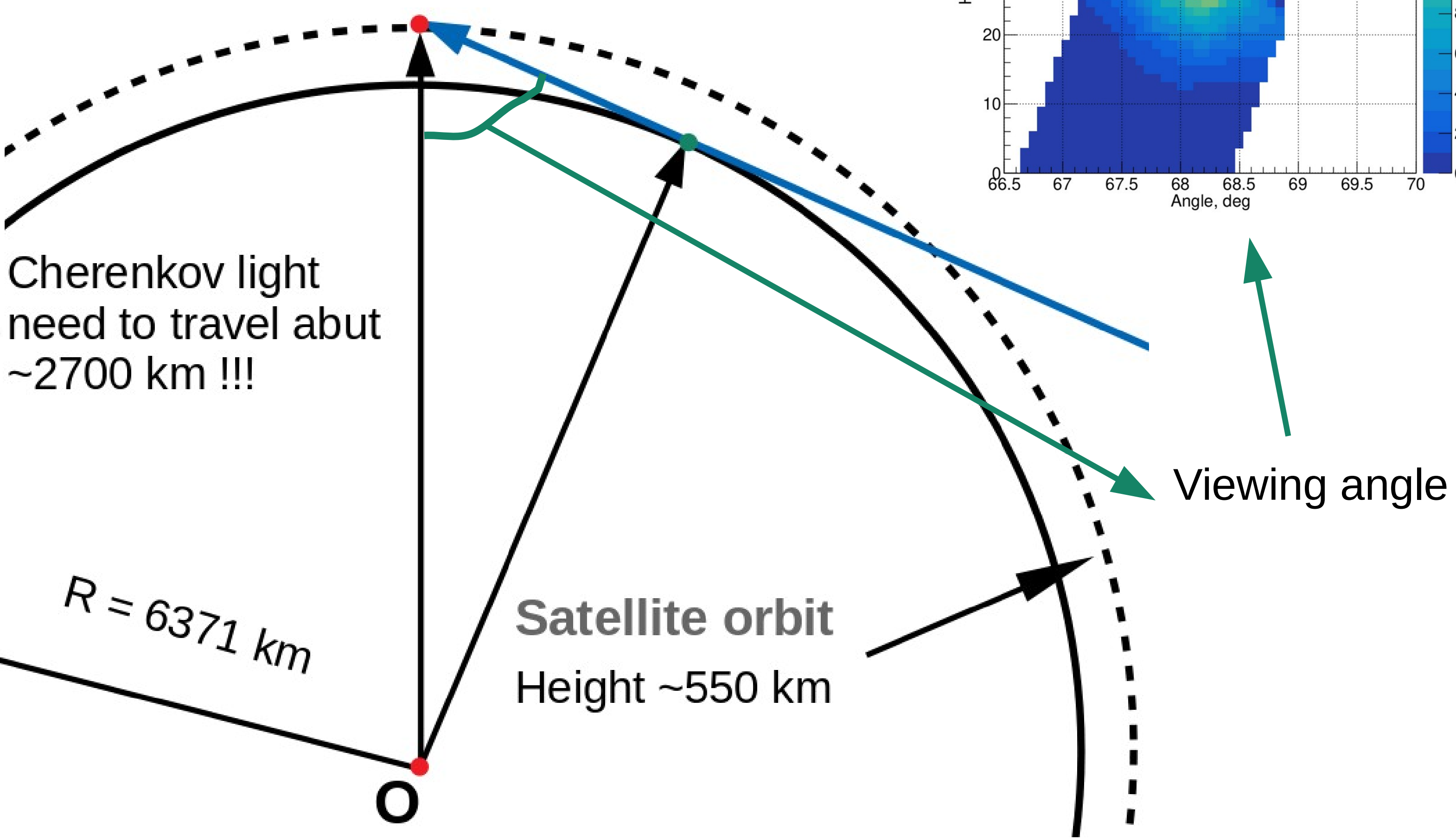

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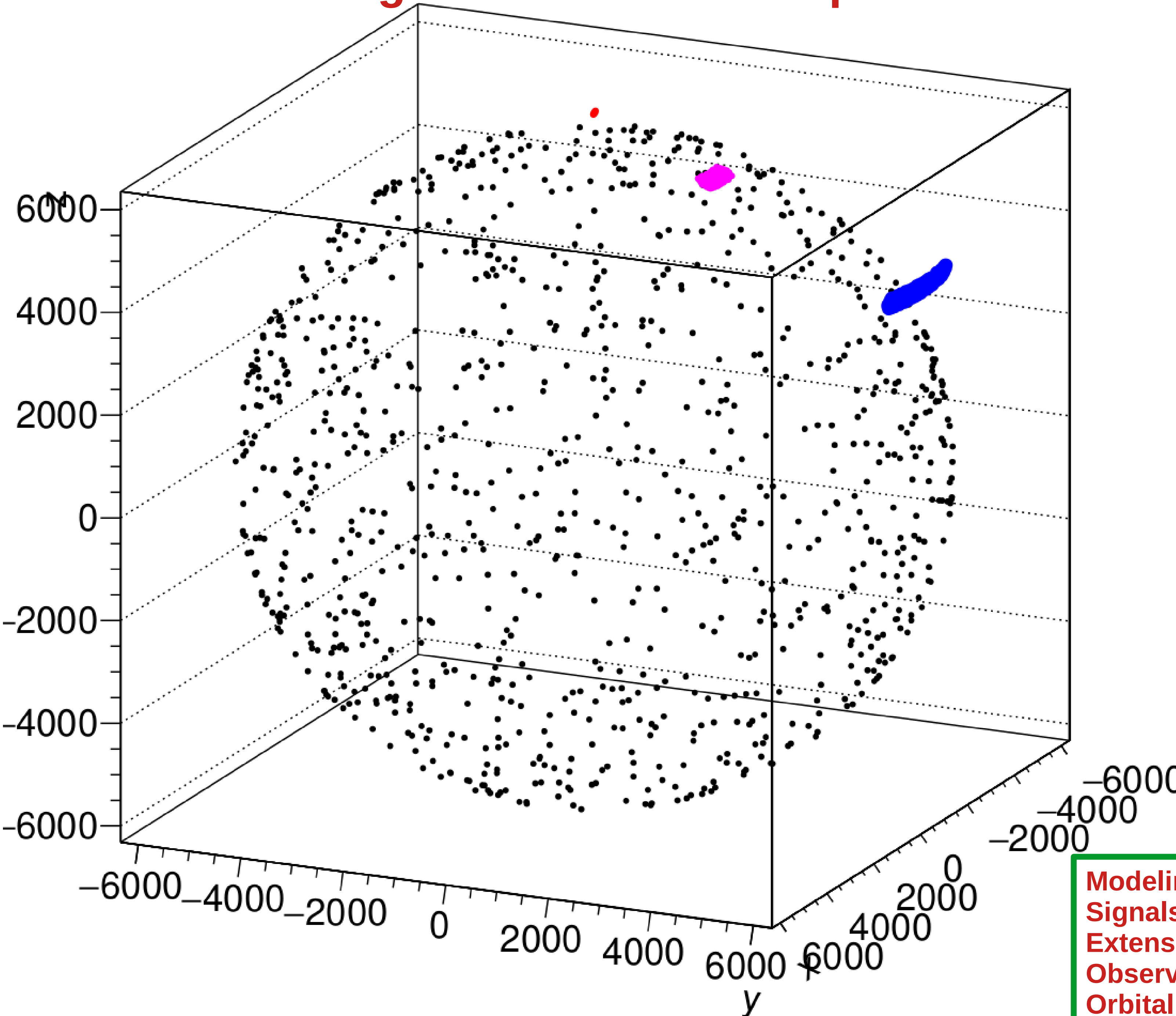
Modeling the Optical Cherenkov Signals by Cosmic Ray Extensive Air Showers Directly Observed from Sub-Orbital and Orbital Altitudes. https://arxiv.org/abs/2105.03255

Cherenkov light detection from space : what can wee see ?



Point cloud in back represents the Earth

Red dot : telescope

Magenta dots : beginning of the shower development

Blue dots: Initial position of generated protons.

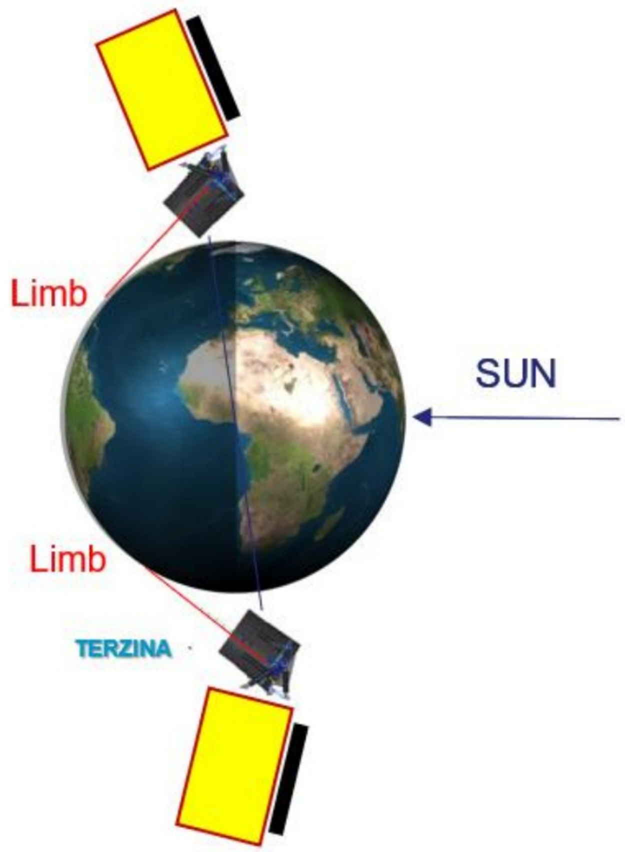
Magenta dots: Shows vast “sensitive” volume.

Modeling the Optical Cherenkov Signals by Cosmic Ray Extensive Air Showers Directly Observed from Sub-Orbital and Orbital Altitudes.

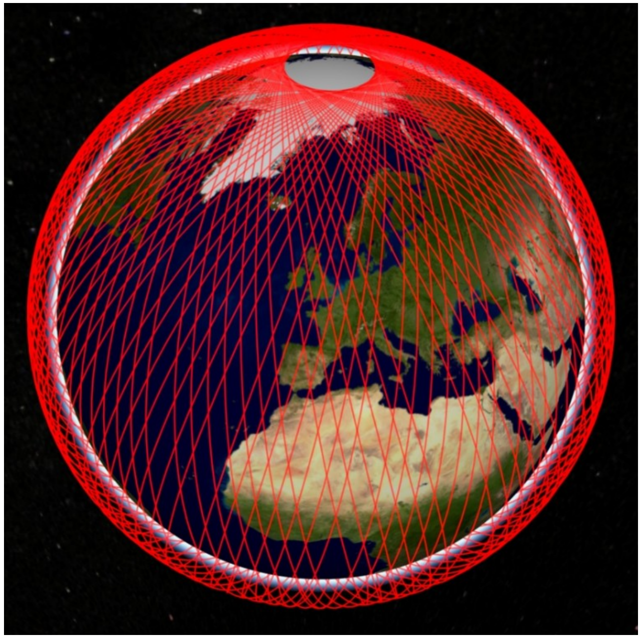
https://arxiv.org/abs/2105.03255

The Orbit

- Synchronous orbit
- Strictly circular orbit.
- Mission duration 3 years
- Every year altitude drops by ~11 km



Beginning-of-Life (BoL)



Mean Altitude (km): 550

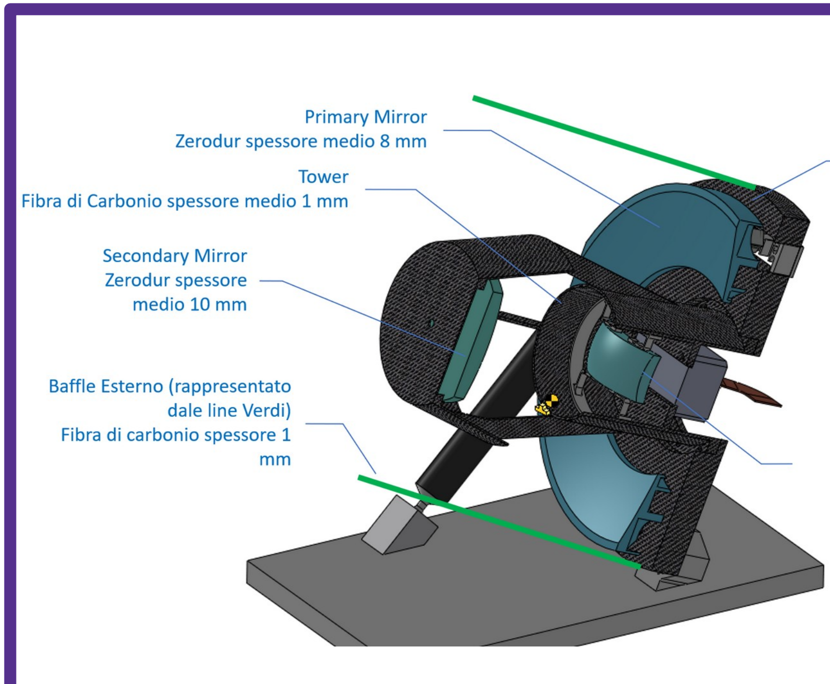
Semi-major axis (km): 6928.137

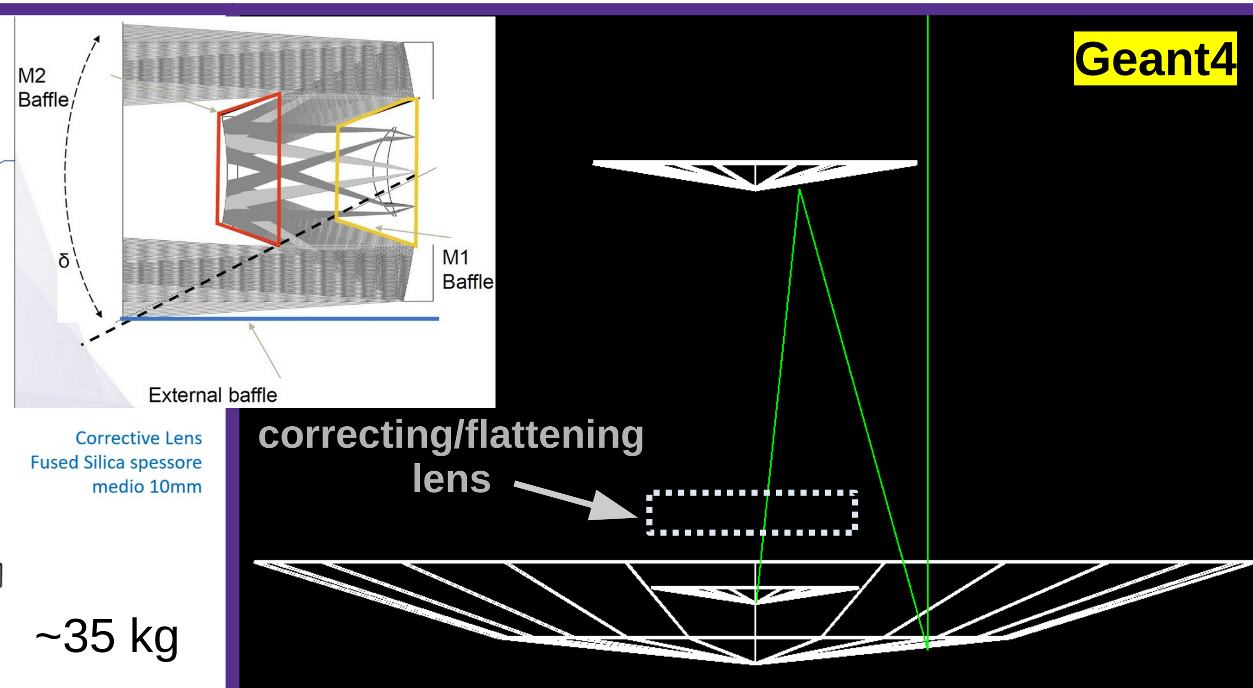
Eccentricity: 0

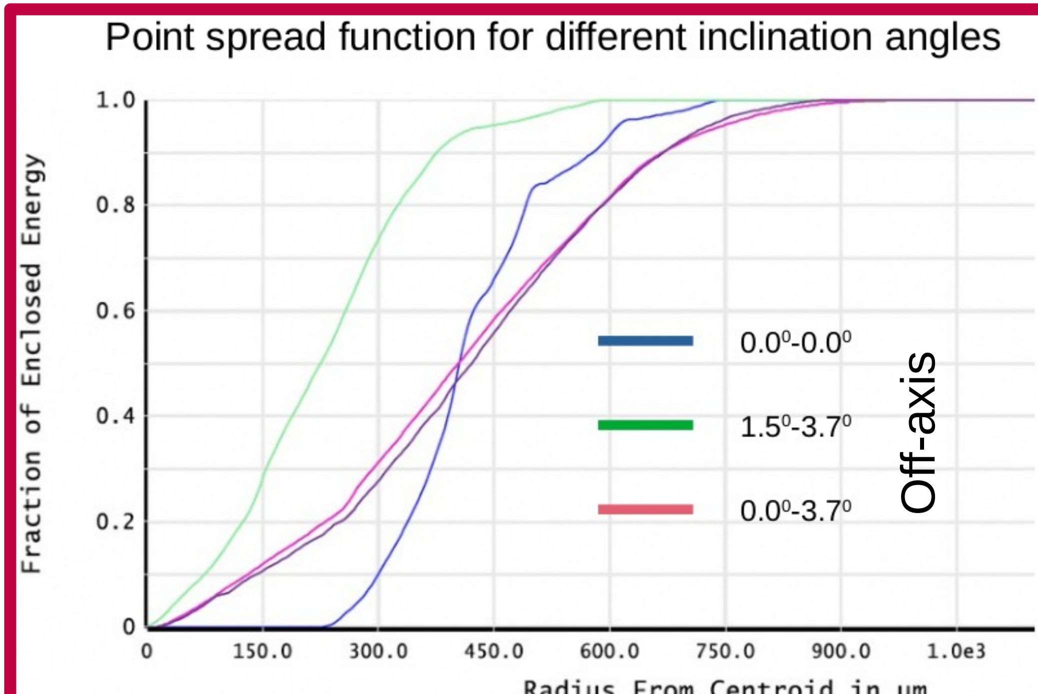
Inclination (deg): 97.5976

LTAN: 18:00:00

The Telescope







Optics:

Dual mirror + correcting/flattening lens
Equivalent focal length 925 mm
Field of View (FoV) : 7.2°
Point spread function (PSF) : <1.0 mm
Effective area of the telescope : 0.1 m

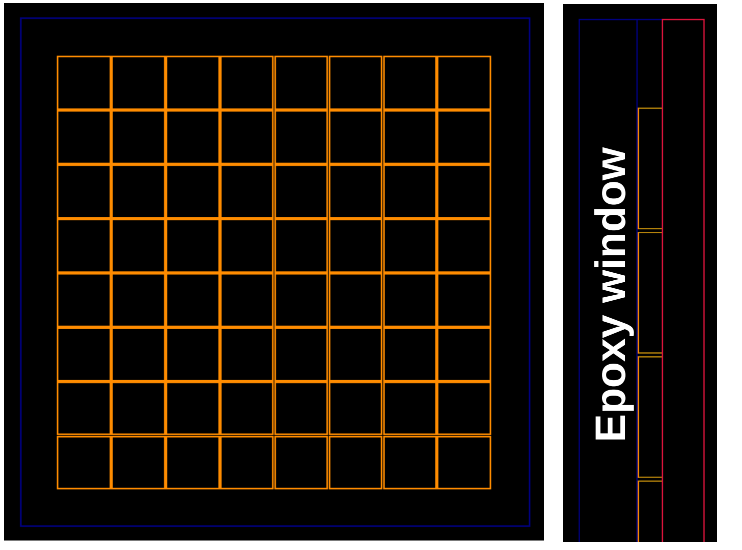
M1 paraboloid, M2 hyperbole
Spherical lens for field flattening.

SiPM (FBK) camera plane

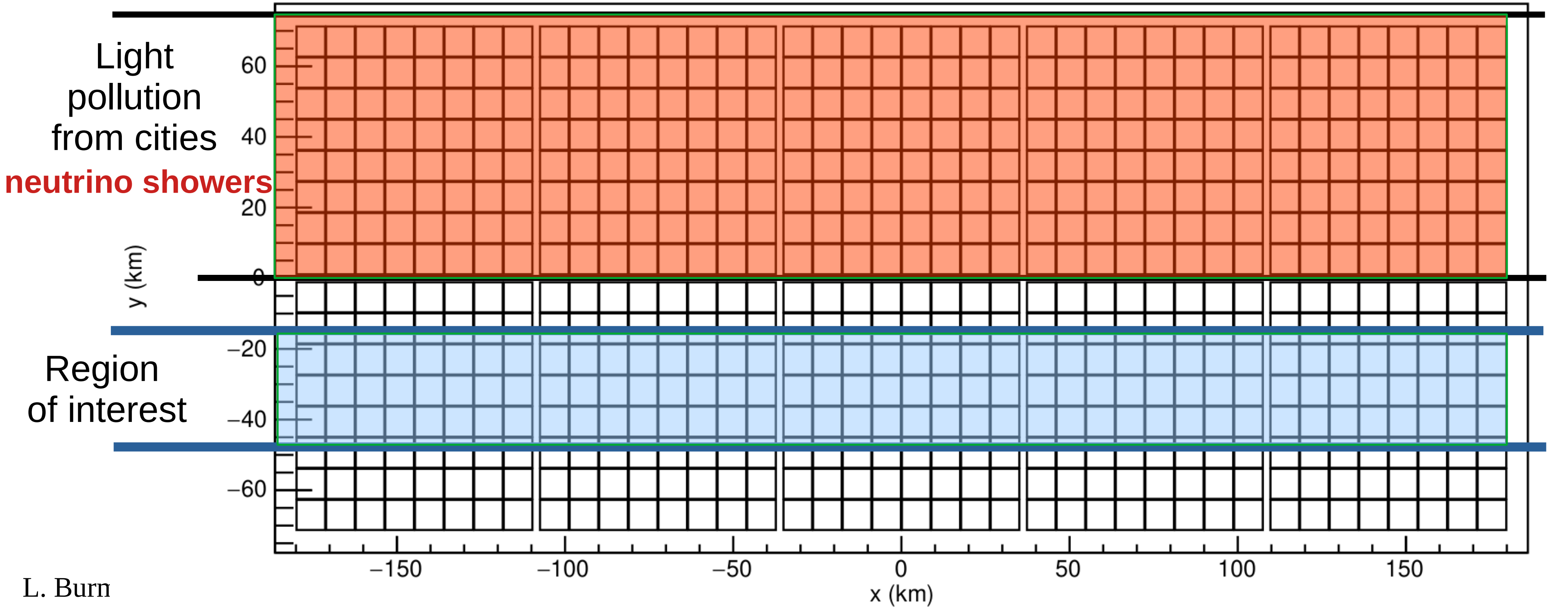
We have 5 x 2 = 10 SiPM arrays In total
We have 40 x 16 = 640 SiPM

Array dim. : 25.3 x 25.3 mm²
Array Eff. area : 24 x 24 mm²

SiPM arrays of : **8 x 8 channels**
Pixel : **3 x 3 mm²**
Pixel pitch : **3.1 mm**
Dead area from the edges of a single SiPM array : **0.3 mm**
Distance between two arrays : **0.2 mm**



Camera plane : what can we see from Terzina (projection on the earth)



L. Burn

Full simulation pipeline

Track fast sim → Fast simulation of the tracks to choose potentially interesting events which can be detected.

~10^{13} simulated events

Easchersim → Monte Carlo simulation of the UHECR and photon propagation to the telescope

~10^{5} simulated events

Geant4 photon Propagation → Monte Carlo simulation of the photon propagation in the Telescope.

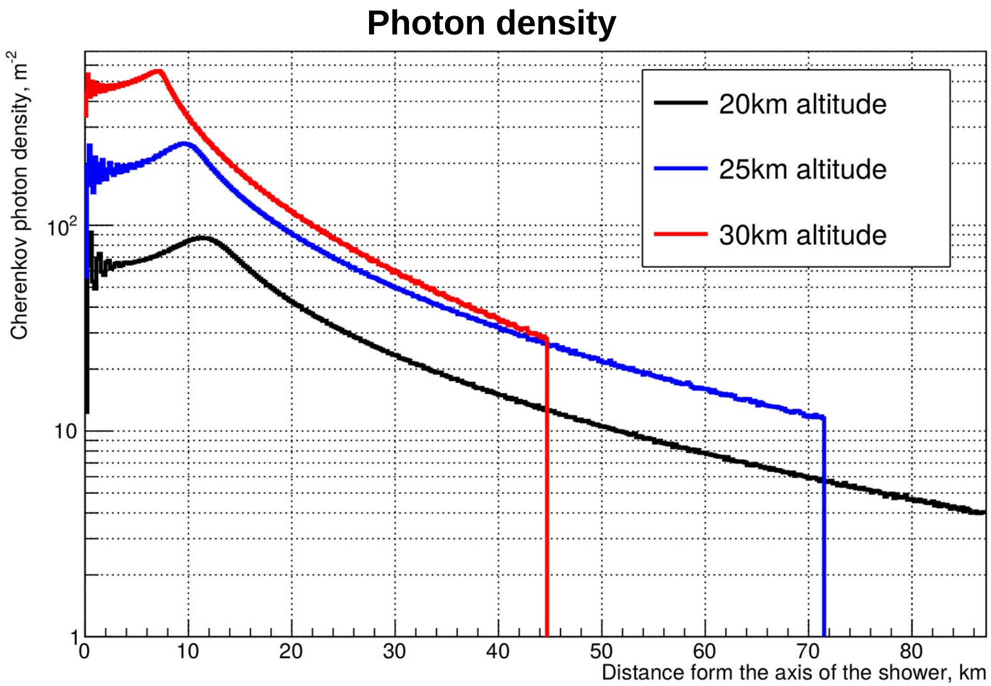
~10^{8} simulated events

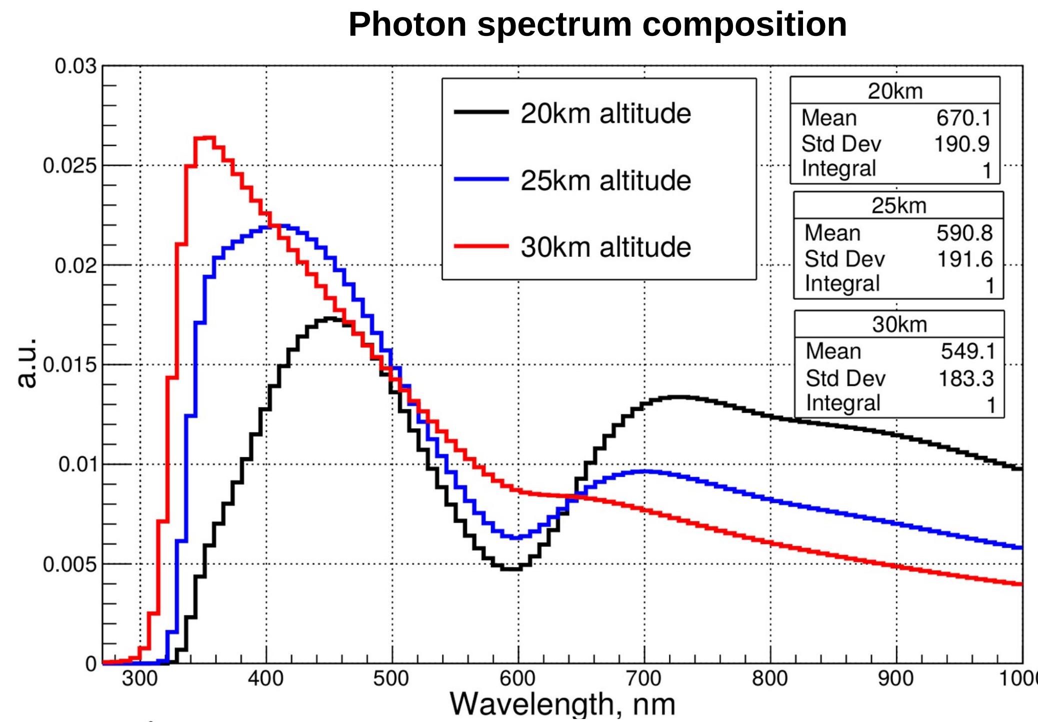
Digitization/wf. sim → Simulating the SiPM response includes cross-talk, after-puls, PDE, preamplifier bandwidth

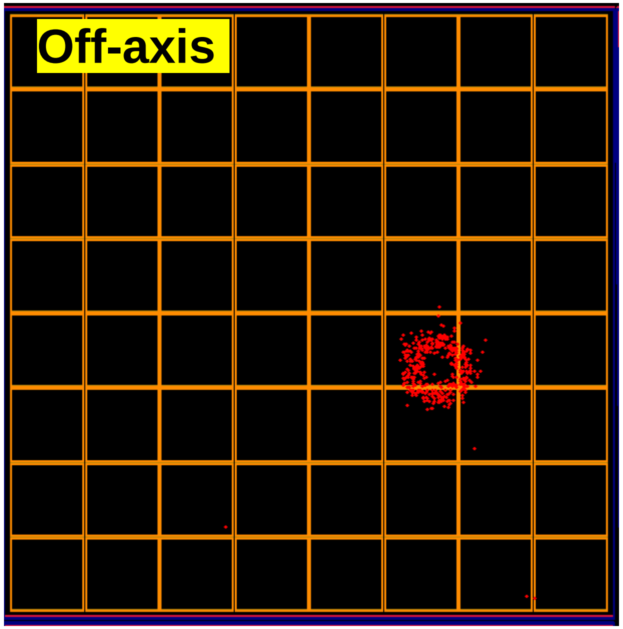
~10^{8} simulated events

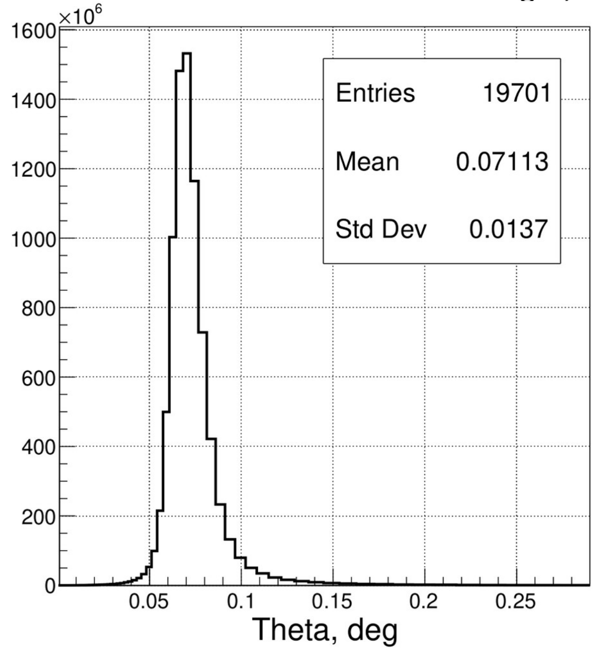
Easchersim - the cherenkov light emission for extensive airshowers with trajectories below and above the limb as a full Monte Carlo simulation

https://pypi.org/project/easchersim/1.1/









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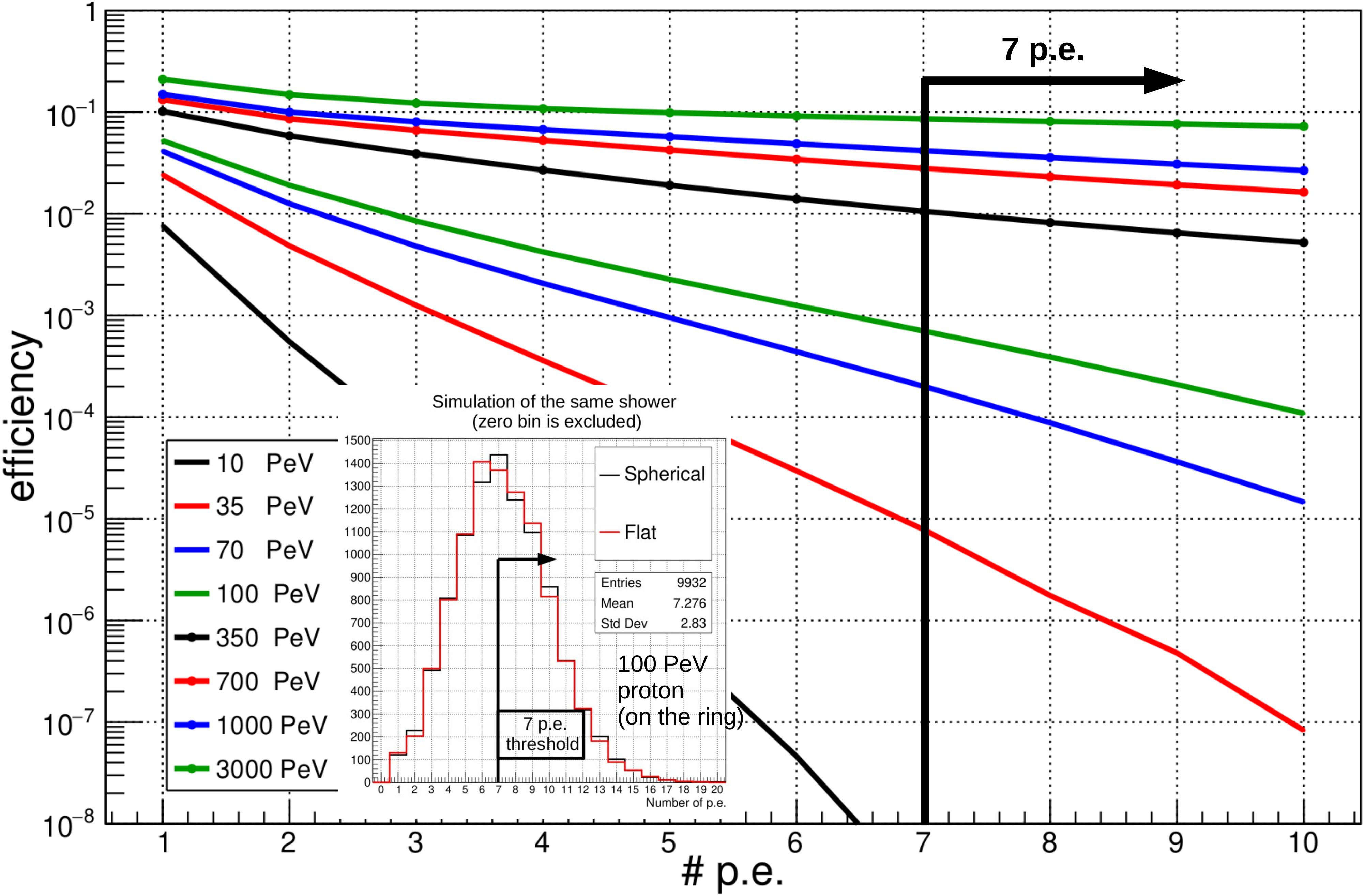
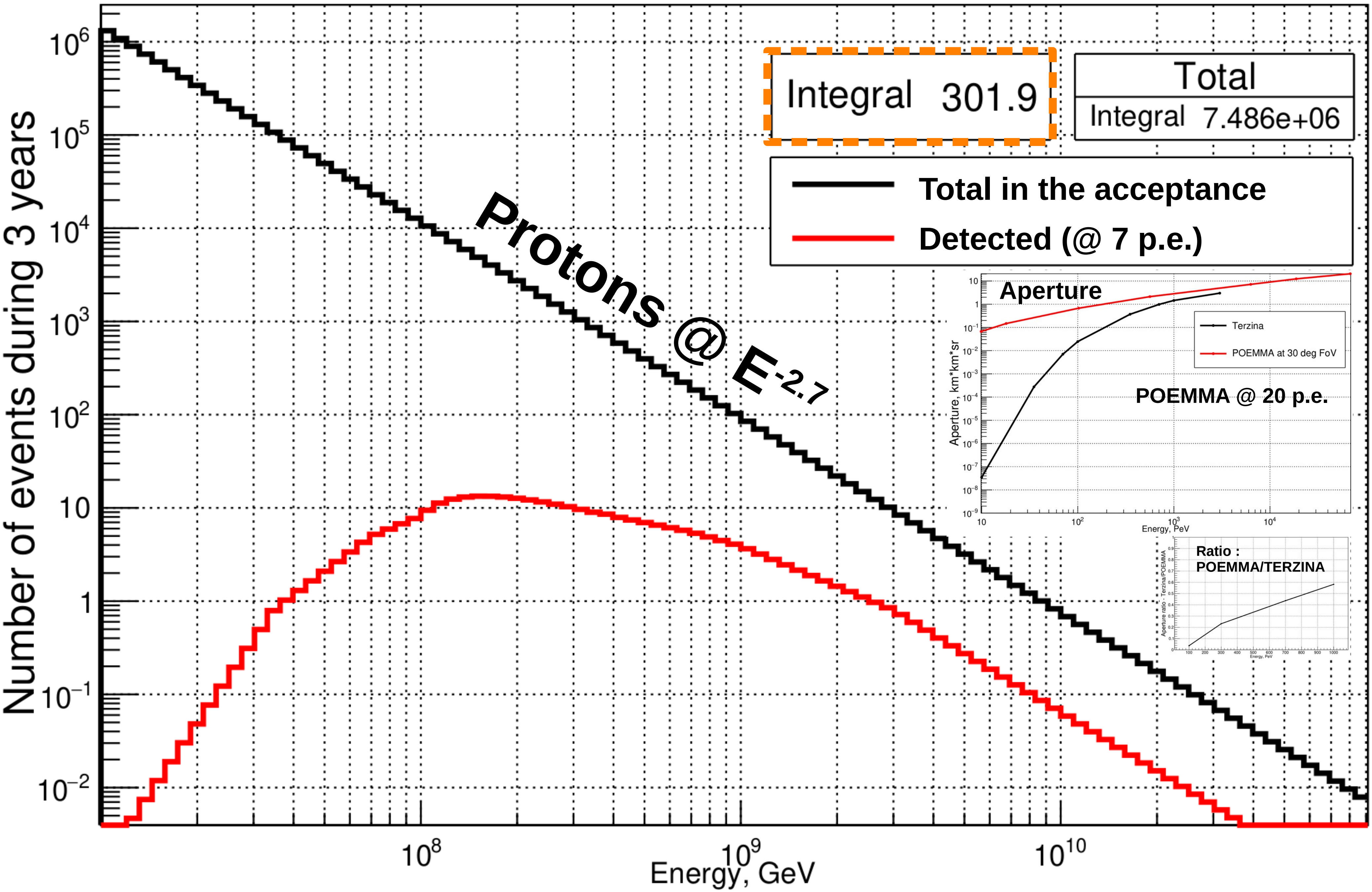
Efficiency vs number of p.e. for different particles energies

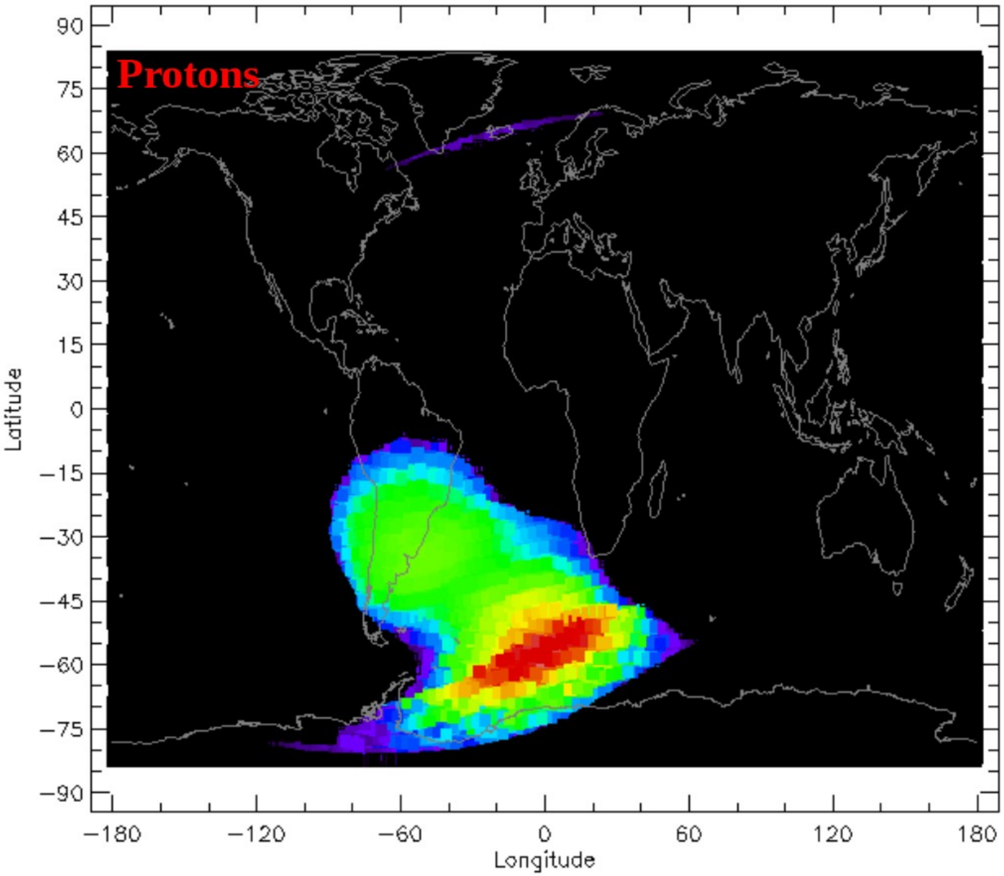


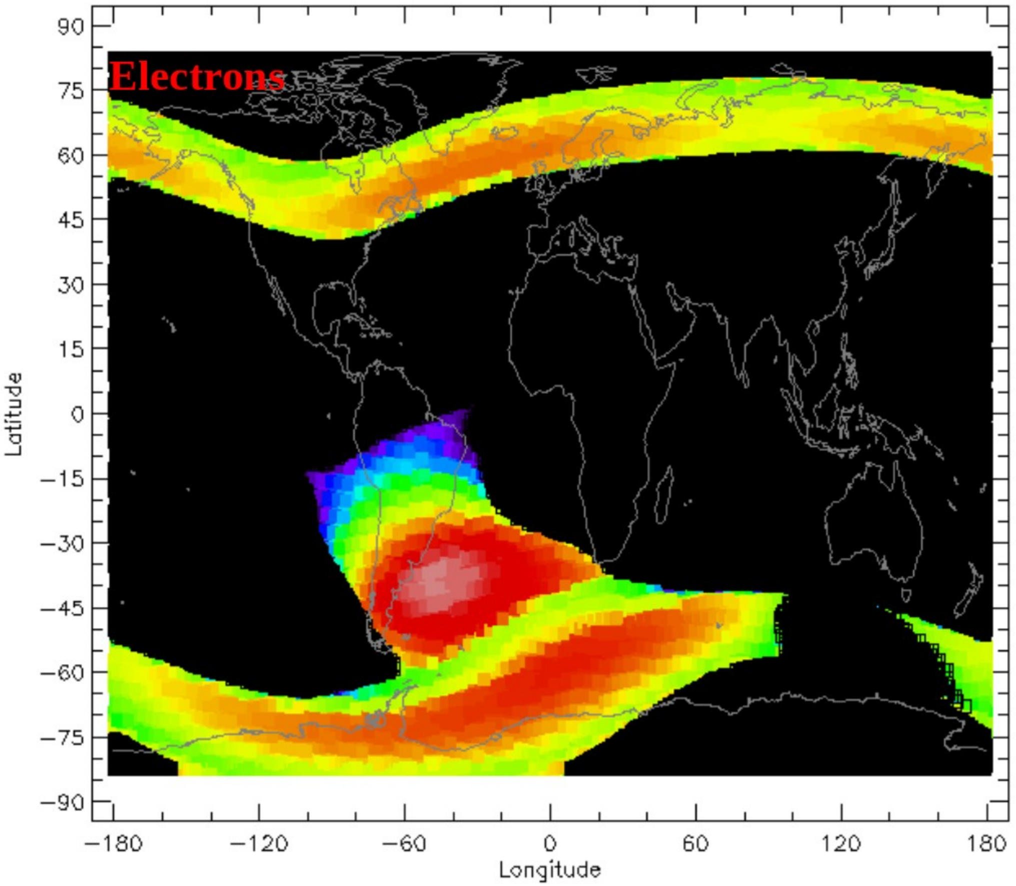
Please note this is efficiency of preselected events (include acceptance).

Measured spectrum of protons with 7 p.e. threshold.



Terzina background study with SPENVIS and Geant4



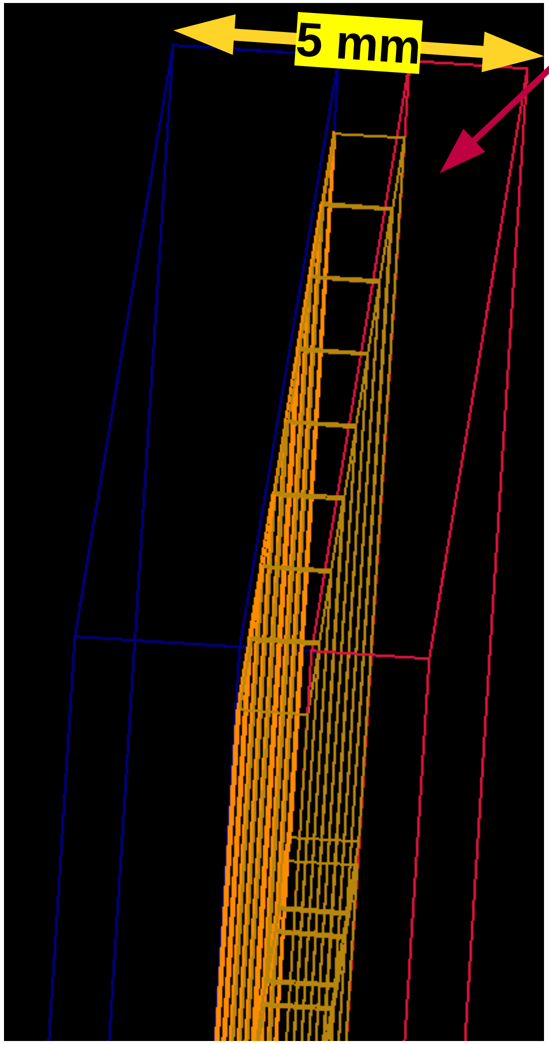


- SiPM and electronics will get the radiation damage
- Scintillation, fluorescent materials and Cherenkov radiator materials will produce background photons.
- Low energy and high charge ions potentially can induce the signal directly in SiPM.

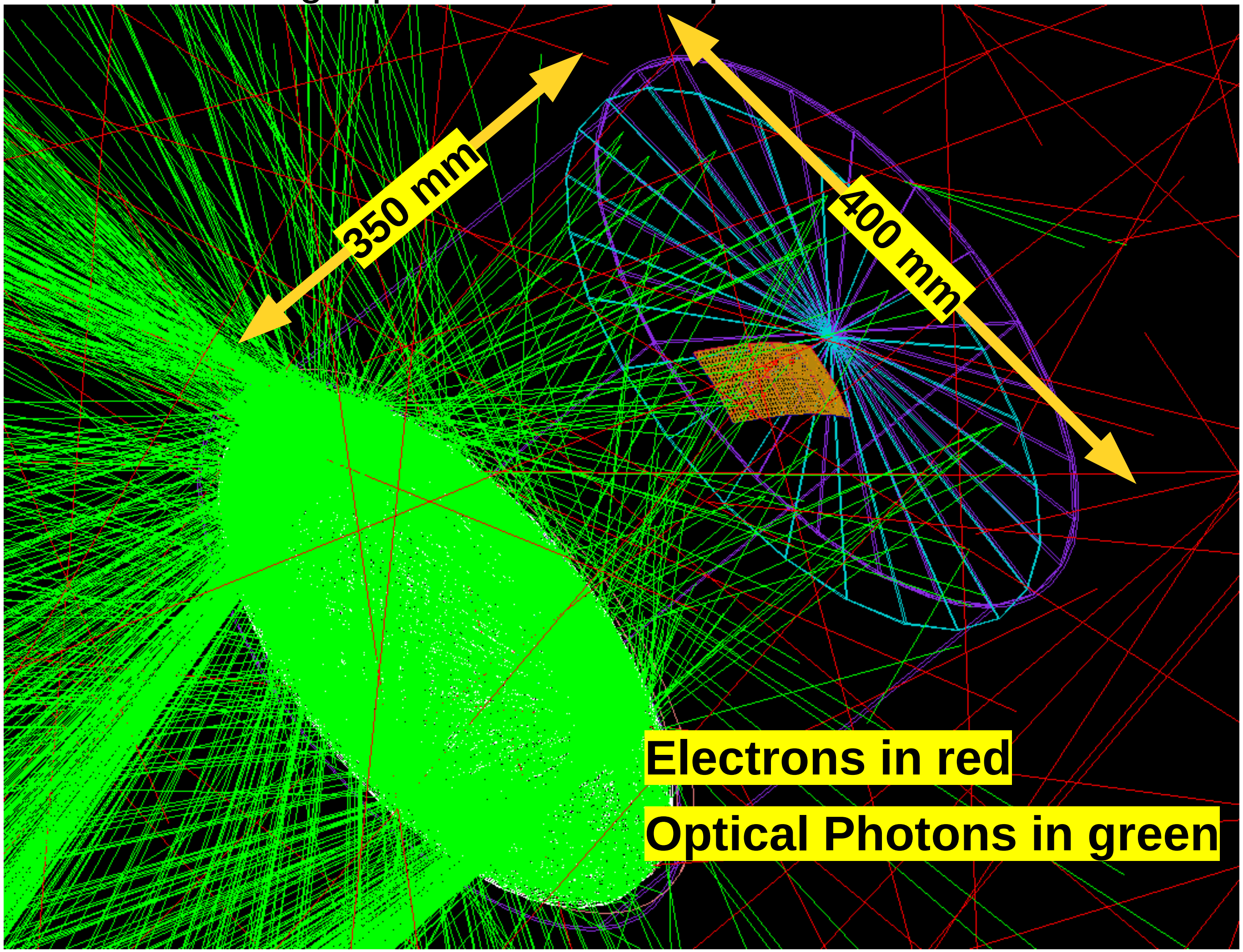
Background study

- We simulate approximate geometry of Terzina telescope composed from fused silica and aluminum mechanical structure.
- We count the energy deposition in the volume made of silicon (shown in magenta color).

Radiation dose



Light produced in the optical elements



~7.2 Gy = 720 rad/year

Electrons

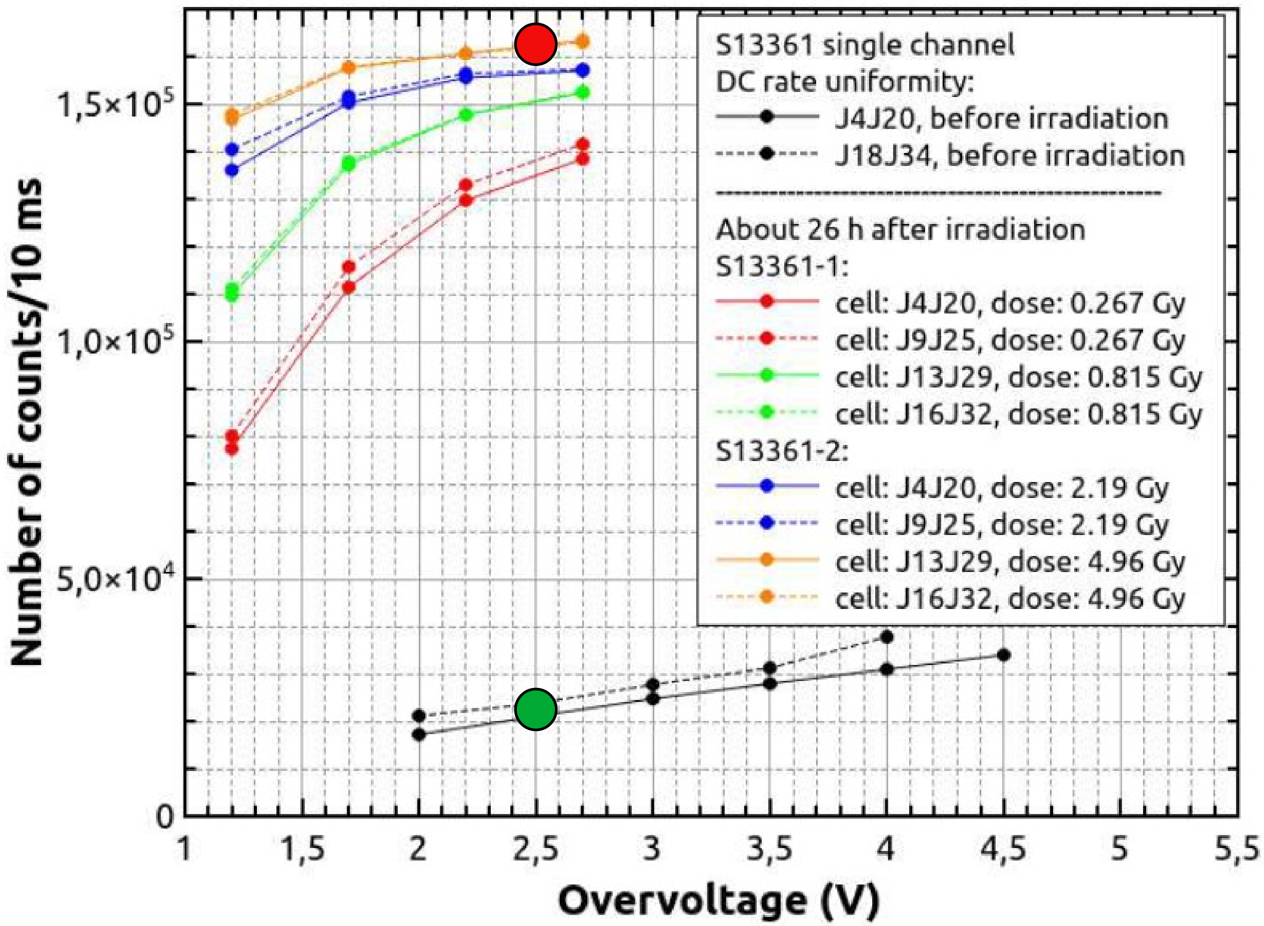
~3.1 Gy = 310 rad/year

Protons

10 Gy per year

Radiation dose : expected effect on SiPM Dark Count Rate (DCR)

Proton Irradiation of SiPM arrays for POLAR-2



https://www.researchsquare.com/article/rs-1650151/v1

- (green) 2.0×10^4 cont/ 10 ms
- (red) 16×10^4 cont/ 10 ms

It increase by factor of **8 for 5 Gy** irradiation dose

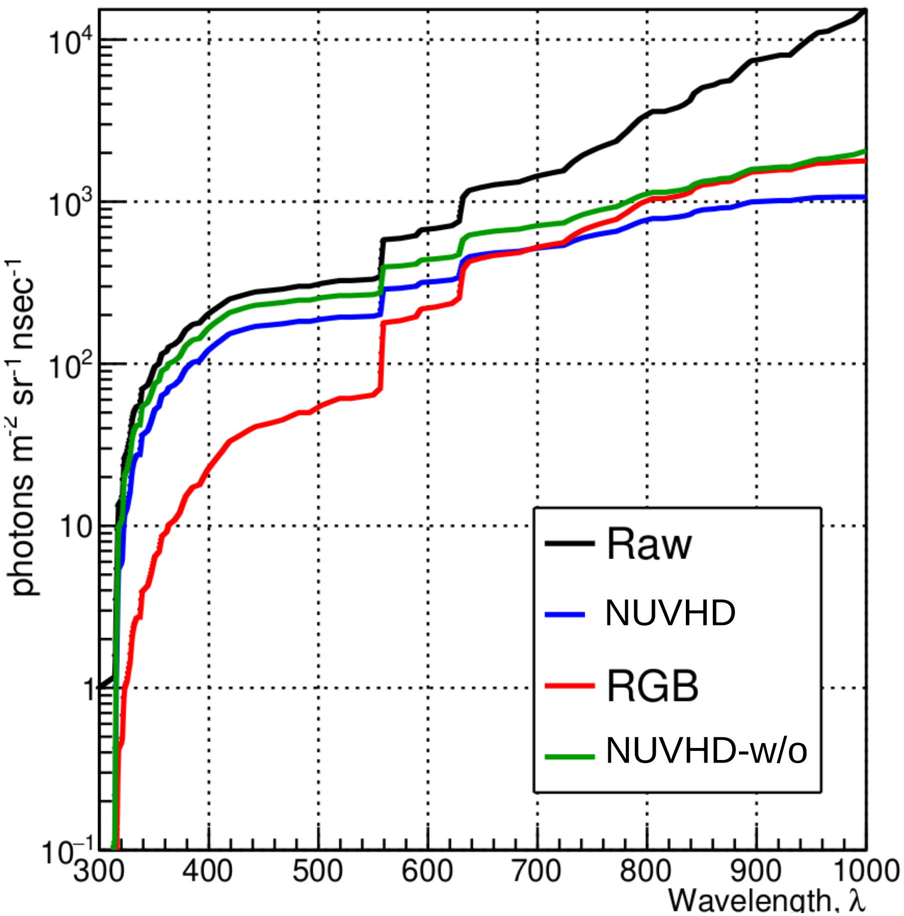
Our guess

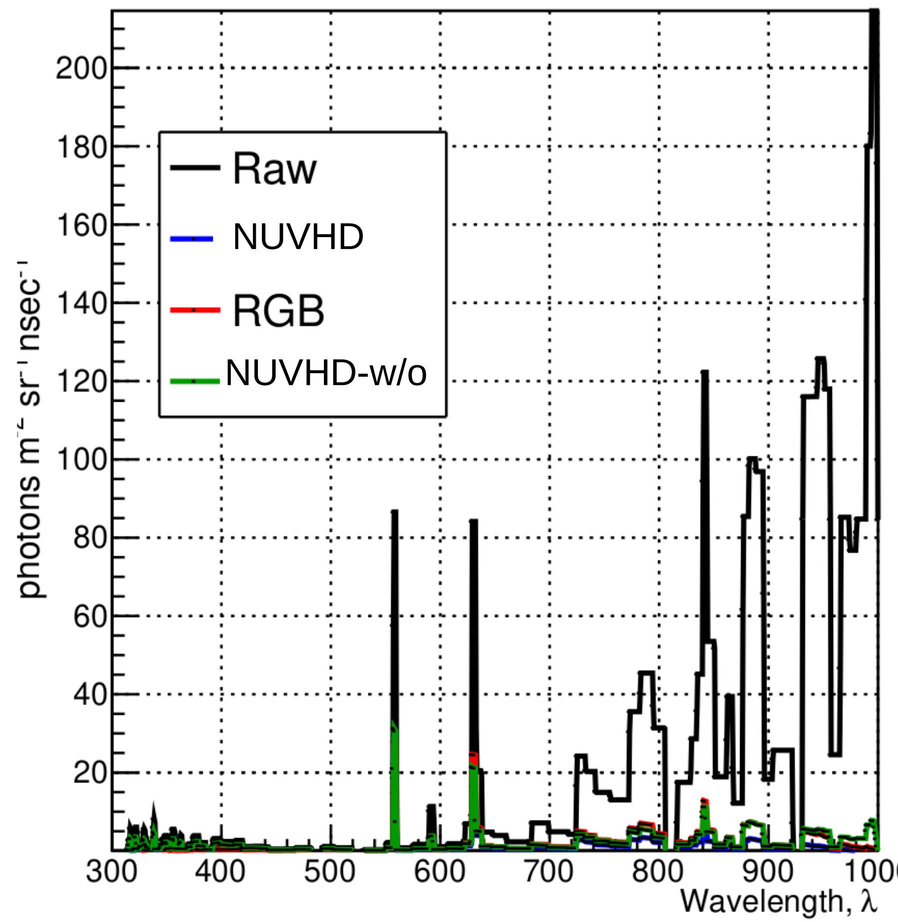
It increase by factor of **16 for 10 Gy** irradiation dose

If we consider 50 kHz / mm than in the end of the mission (3 years) we will have 2.4 MHz/mm.

Expected DCR after 3 years of operation : **22 MHz per pixel**

Night glow background (NGB) rate estimation





$$\text{Rate per pixel} = 1.7\ \text{MHz}$$

NGB

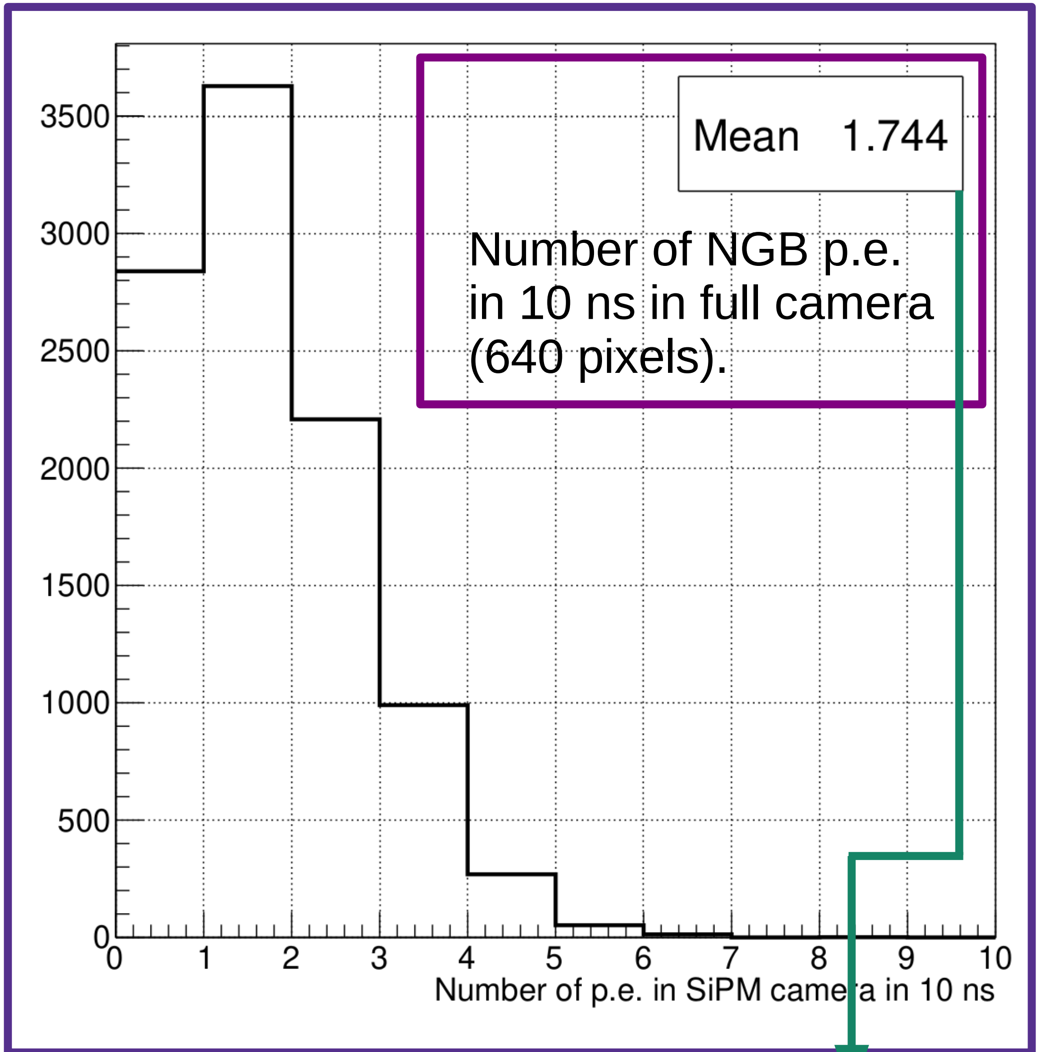
No safety factor included

J.C. Krizmanic estimate
(Personal communication)
1.55 MHz

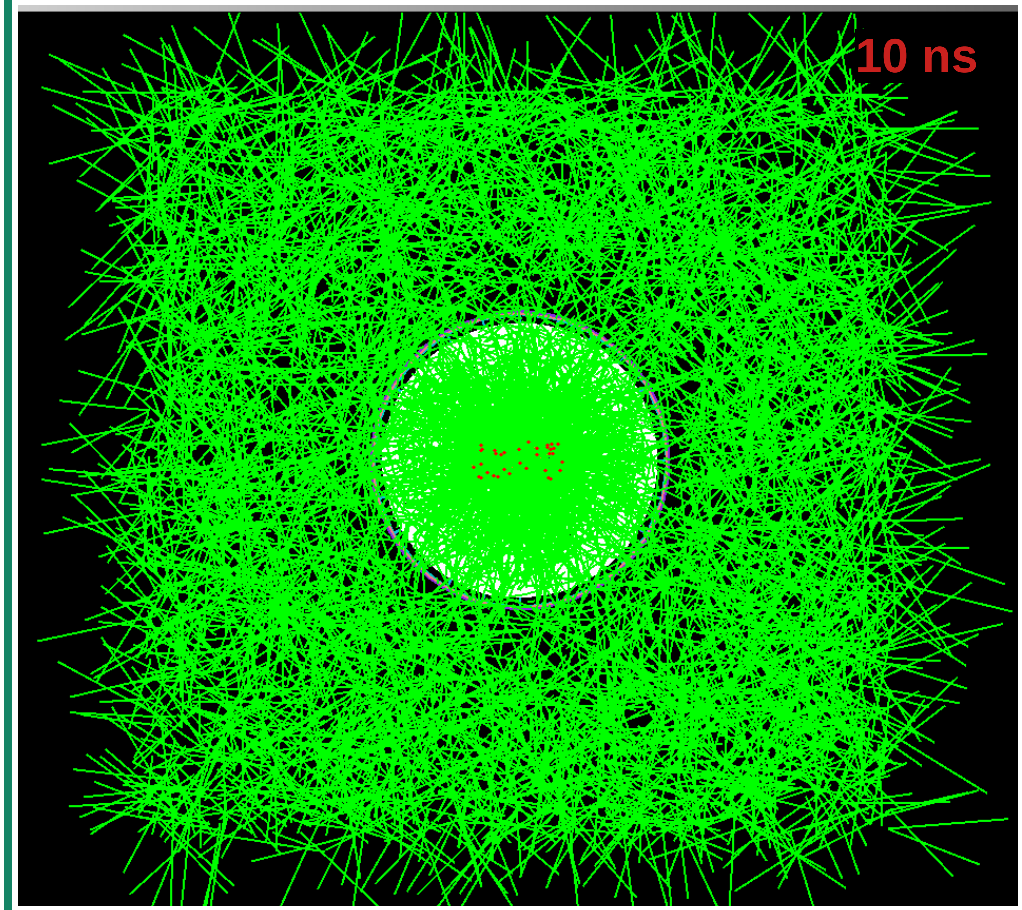
No safety factor included

NUVHD – is our baseline choice with 25 um mu-cell size
@ 15 % cross-talk,
3% after-pulse and
50 % PED at 420

NGB estimation with MonteCarlo



Spread angle up to **10º (FoV/2 = 3º).**
Phi and cos(Theta) have uniform distribution.



NGB

$$\text{Rate per pixel} = \frac{1.744 \times \pi \times [\frac{\text{p.e.}}{10\ \text{ns}}] \times 10^{8}[\text{ns}]}{640} = 0.86\ \text{MHz}$$

No safety factor included

NGB with safety factor : 0.86 MHz x 8 = 7 MHz **~ 10 MHz**

Readout electronics chain

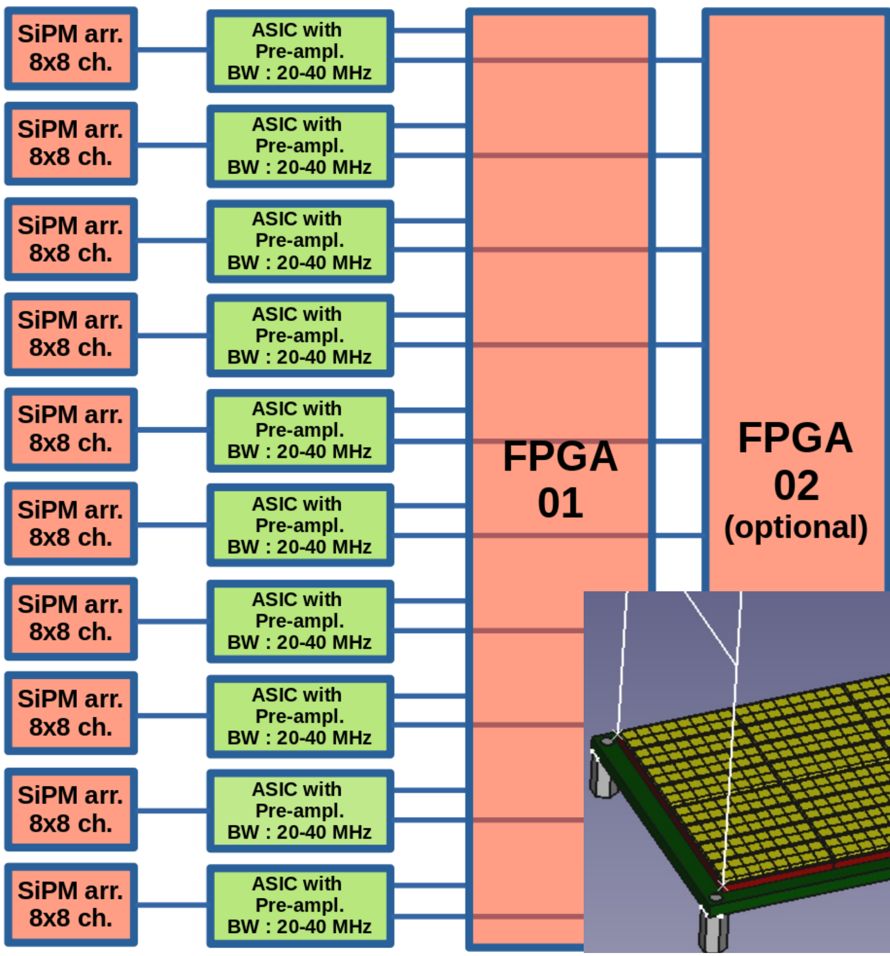
NGB : **~ 10 MHz (single p.e.)**

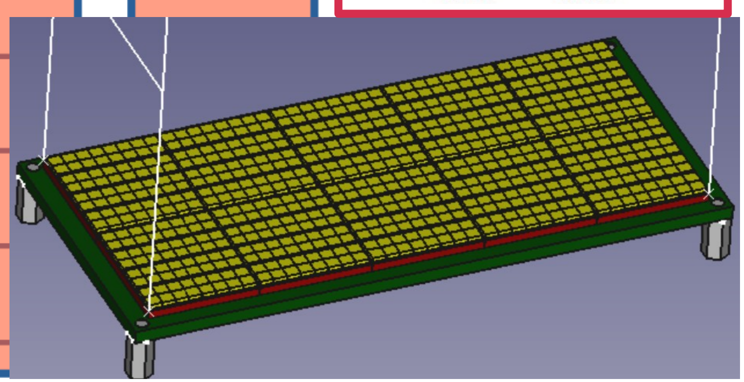
Power consumption (~30 W)

DCR after 3 years of operation :
22 MHz per pixel (single p.e.)

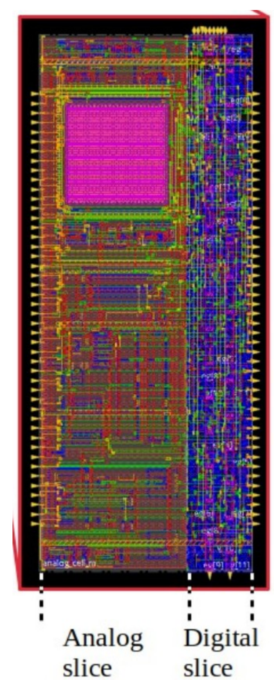
Data throughput 15-20(Gbit/day)

Second FPGA can be used to merge events from two – four ASICs.

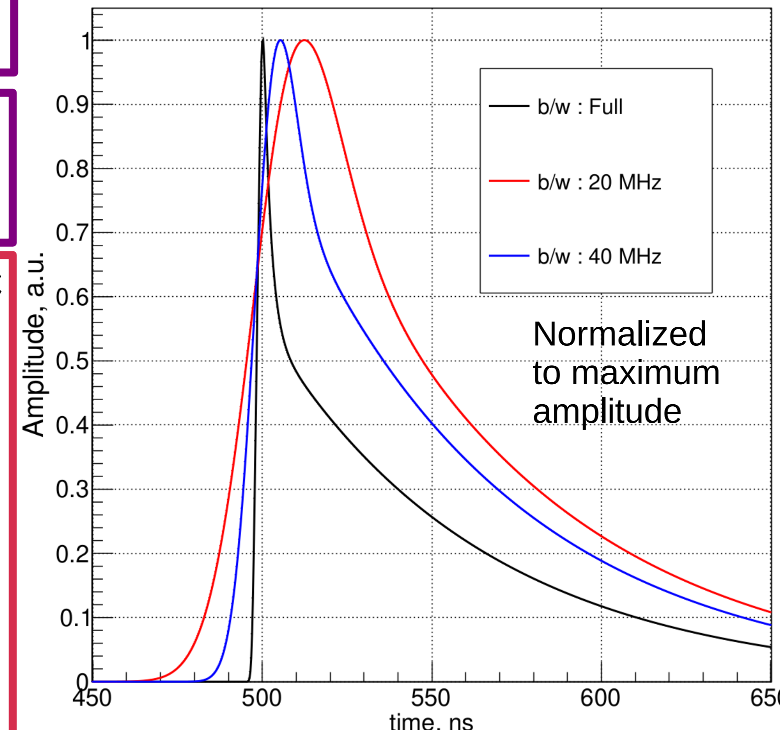


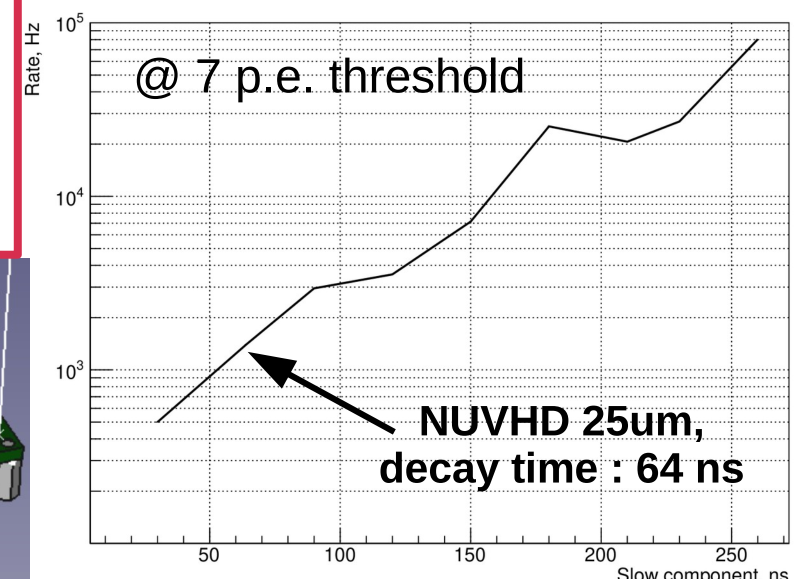


Single cell of ASIC

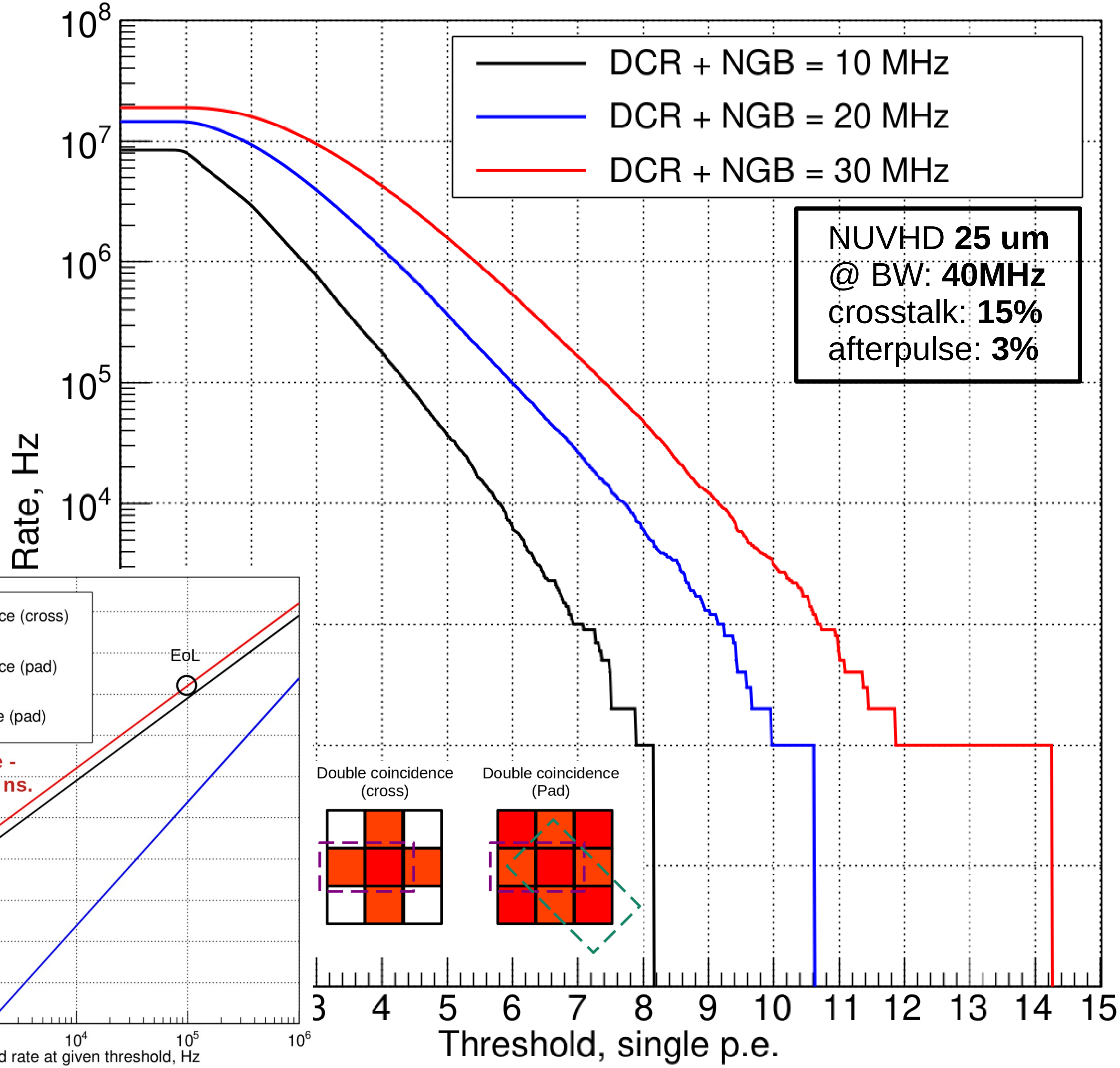


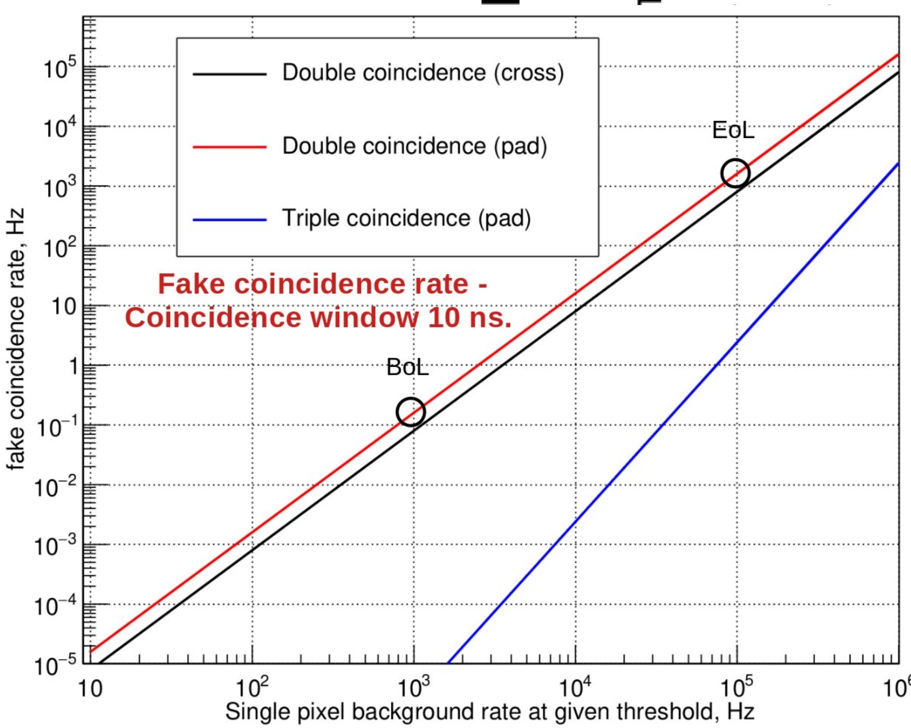
Single p.e. signal "degradation" due pre-ampl. bandwidth



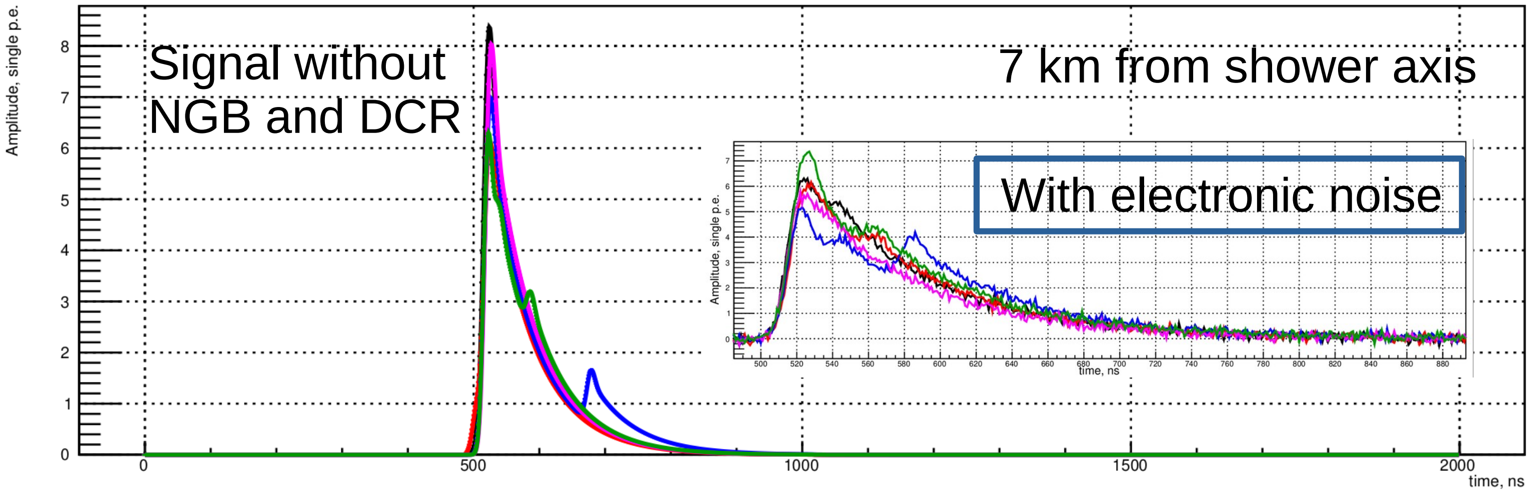


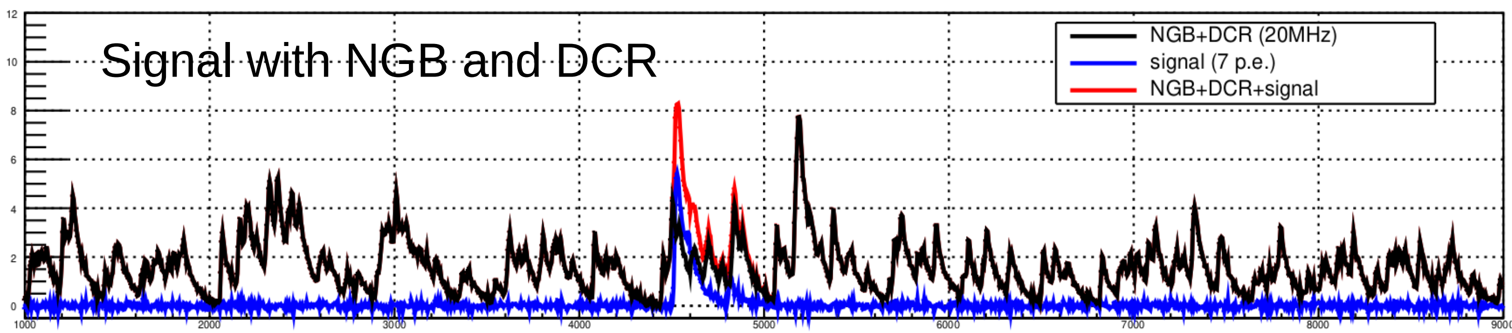
Terzina : total rate estimation without coincidence





Conclusions





- Full simulation chain have been developed.
- Estimated background rate at 7 p.e. threshold is ~1 kHz and will rise up to 200 kHz
- Estimated signal event rate ~ 100 events per year.
- Dominant source of the background are electrons and protons.
- Total dose received by SiPM and electronics estimated with simulation to be ~1 krad/year
- Baseline SiPM is FBK 25um NUVHD, 3 x 3 mm^2. 10 arrays with 8 x 8 pixels.
- NGB ~ 10 MHz with safety factor(~8)
- DCR in the end of the mission ~ 22 MHz.