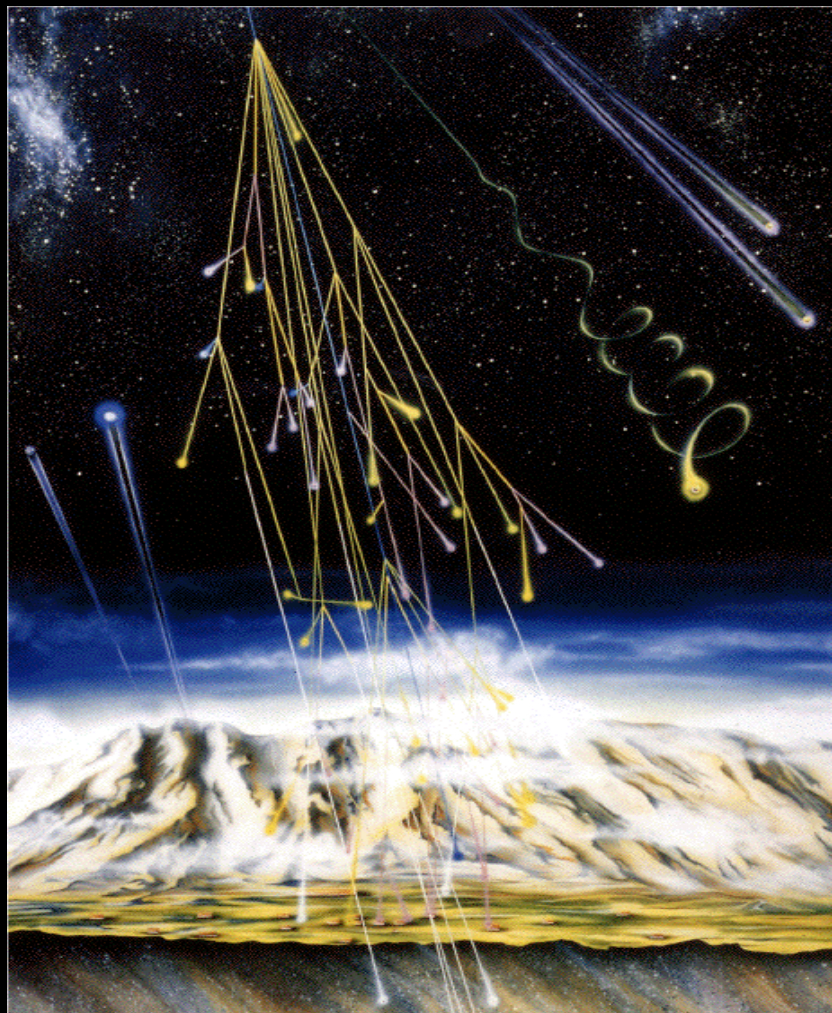
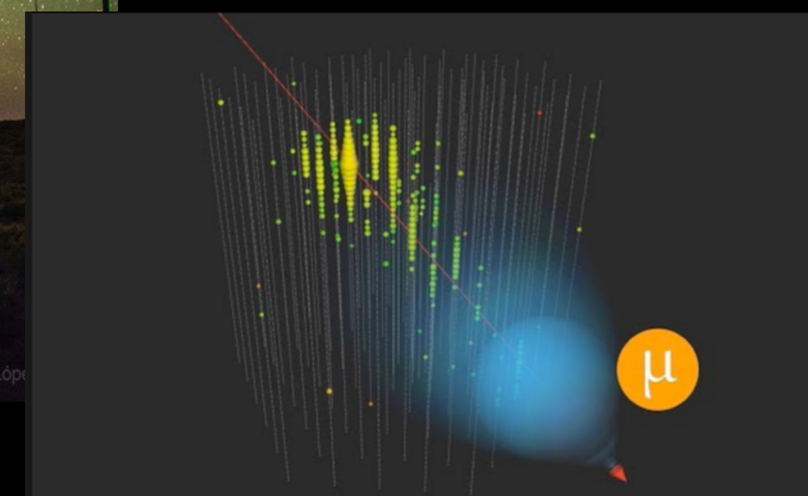
Astro-particle and Cosmic Radiation experimental group

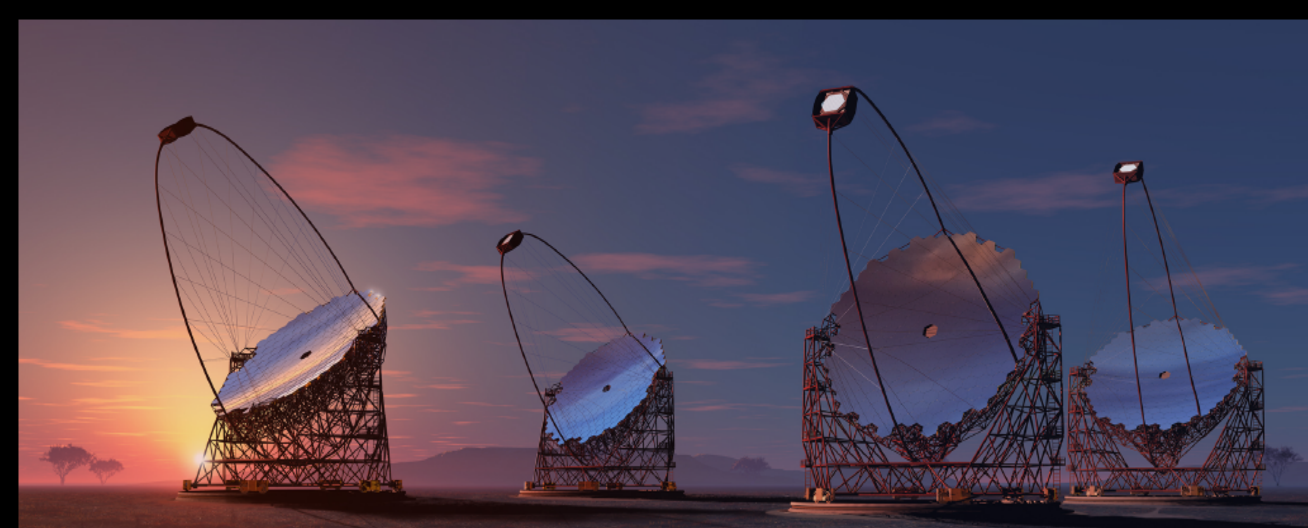




Review of activities, expertise, interests and experimental development

Mosè Mariotti
DFA and INFN Sezione Di Padova

On behalf of many



Astro-particle and Cosmic Radiation experimental group

Mose' Mariotti
group leader

Alessandro de Angelis PO

Michele Doro
PA

Eugenio Bottacini
PA

Elisa Prandini
RTDA

Riccardo Rando
RC

Manuela Mallamaci
postdoc

Ruben Lopez
Ricercatore

Maria Isabel Bernardos
Assegno

Denis Bastieri
PA

Giovanni Busetto
PO

Giampiero Naletto
PA

Alessia Spolon
PhD

Michele Fiori
Pos doc

?
PhD
student

+ 3

Elisa bernardini
PA

Razvan
Dima

Sandro Ventura
Tecnologo

Daniele Corti

Technical supporters

outline

- Cherenkov telescopes for gamma ray astronomy
  MAGIC - CTA

- Satellite detectors for gamma ray astronomy
  FERMI – E-Astrogam

- Wide FoV experiment for gamma ray astronomy
  SWGO, Machete

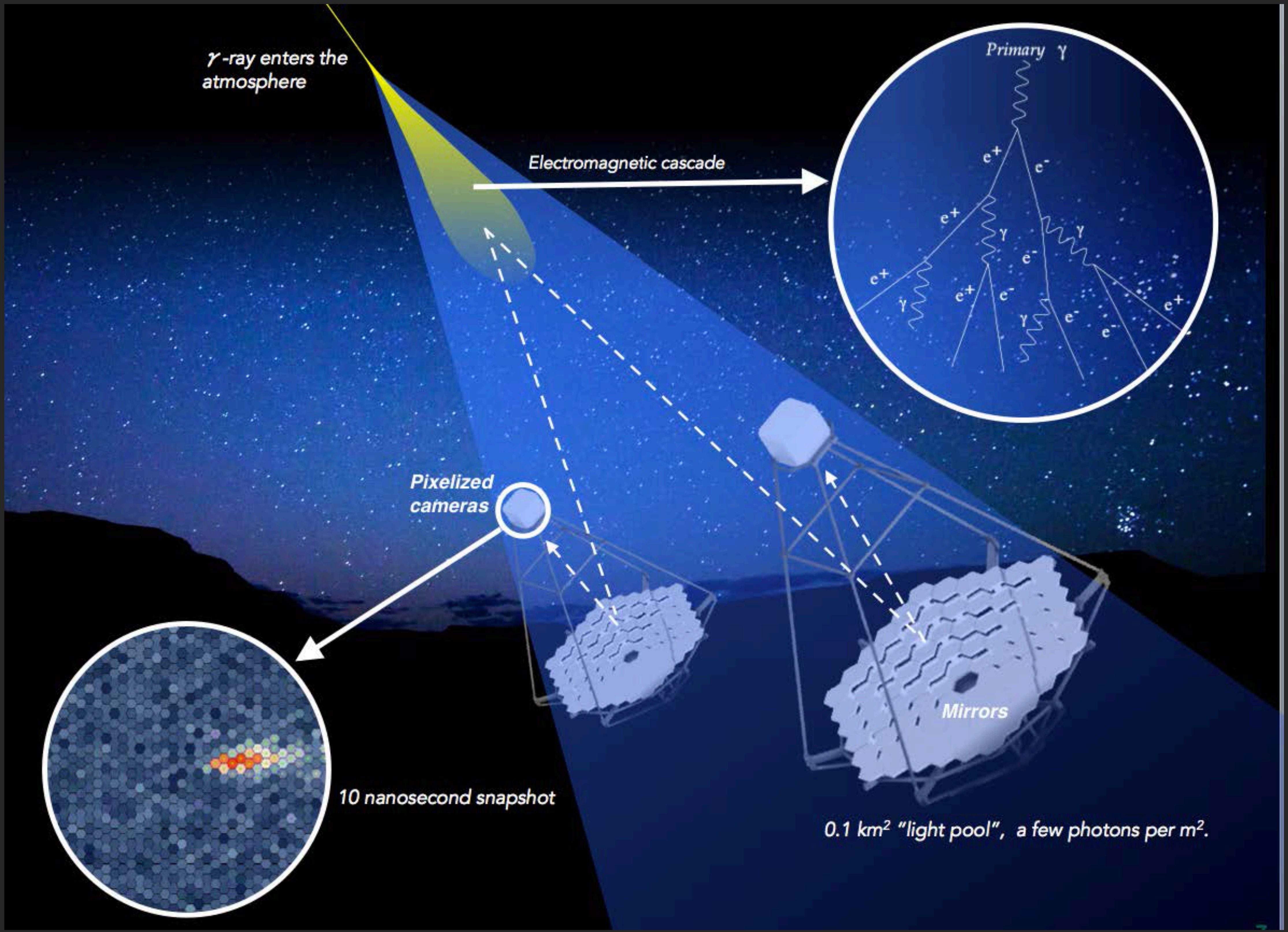
- Neutrino hearth skimming telescope R&D
  TRINITY

- Intensity interferometry technology R&D

- Direct Dark matter searches technology R&D

IACT Telescopes

IACT context

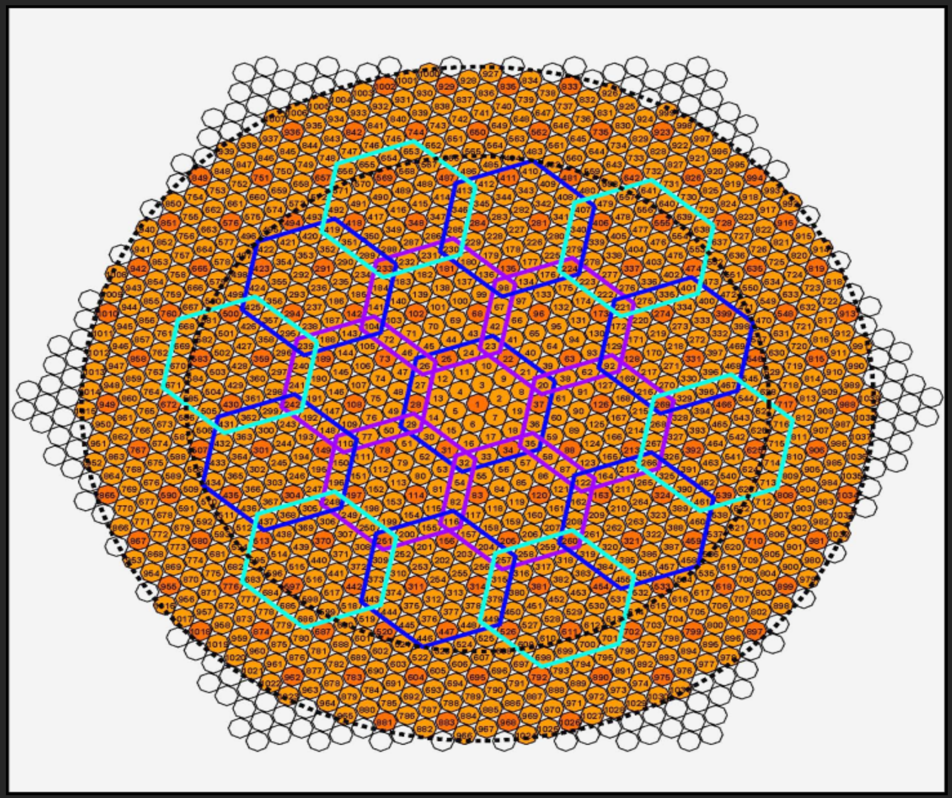


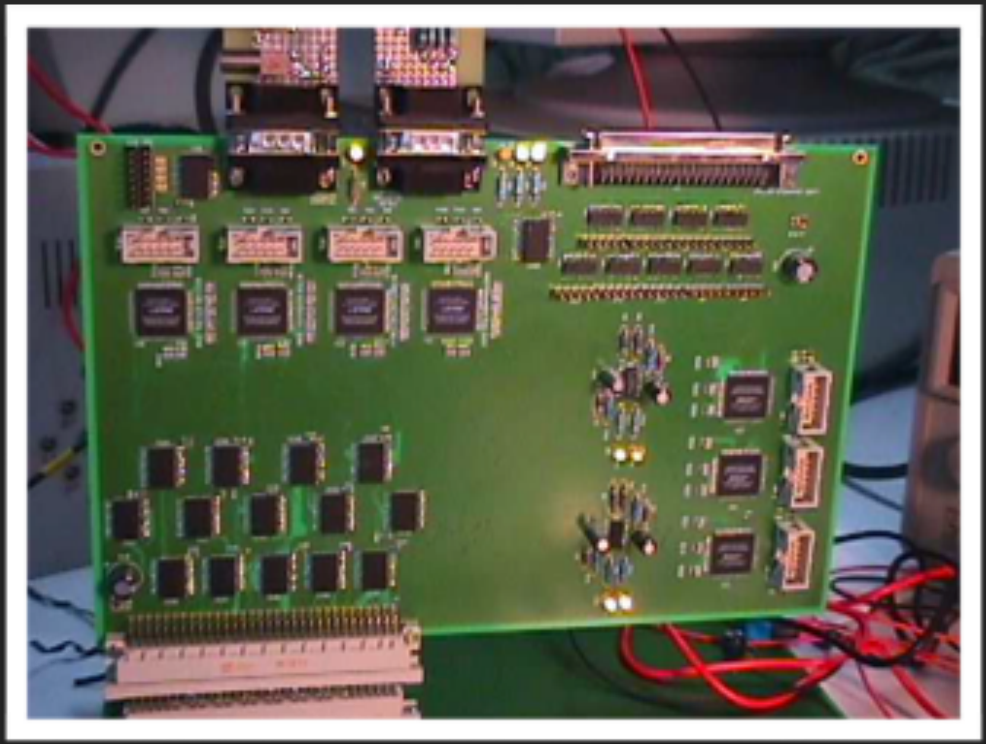
IACT: Activity of Padua group

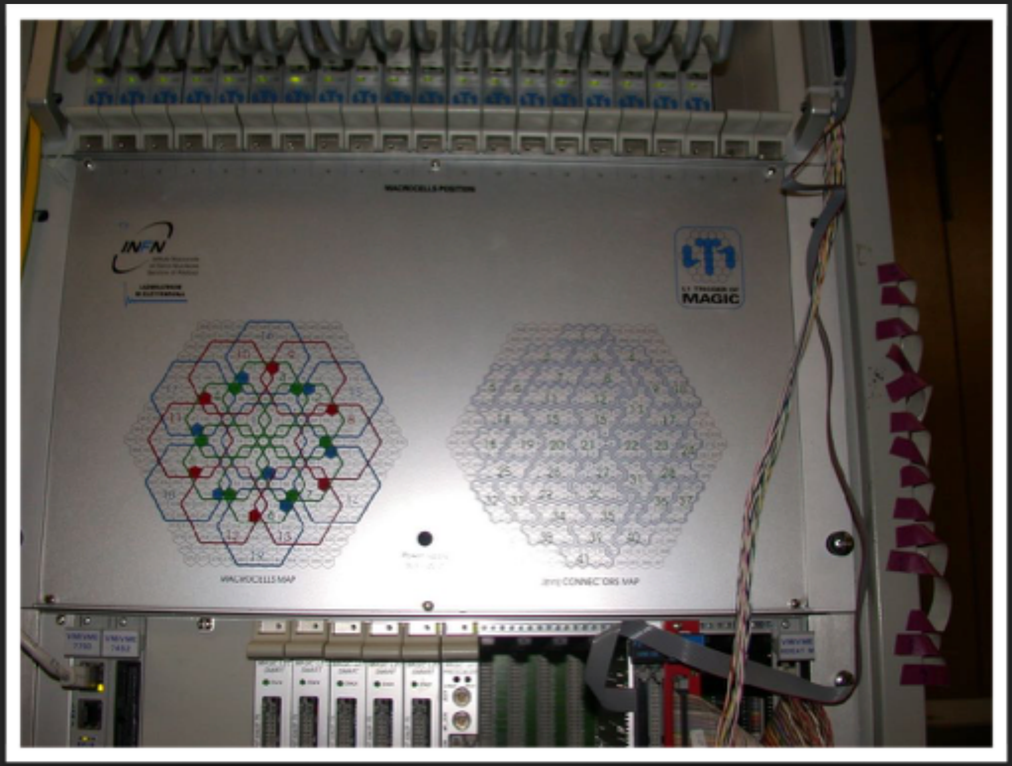
- Fast Trigger electronics
- Mirrors development productions
- New photosensors R&D for camera

- Mirrors R&D
- New advanced camera R&D

Trigger system for MAGIC I and II telescopes



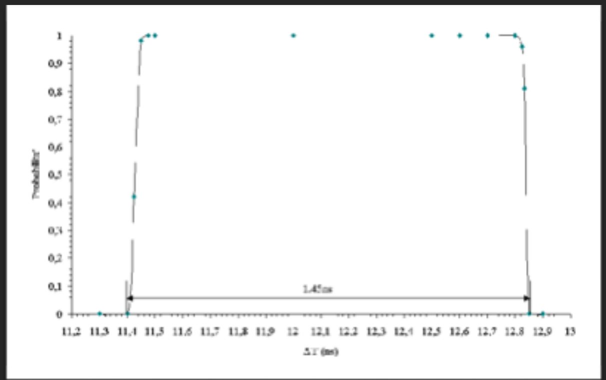




Pattern trigger:
close compact next neighbor logic

- 2NN
- 3NN
- 4NN
- 5NN

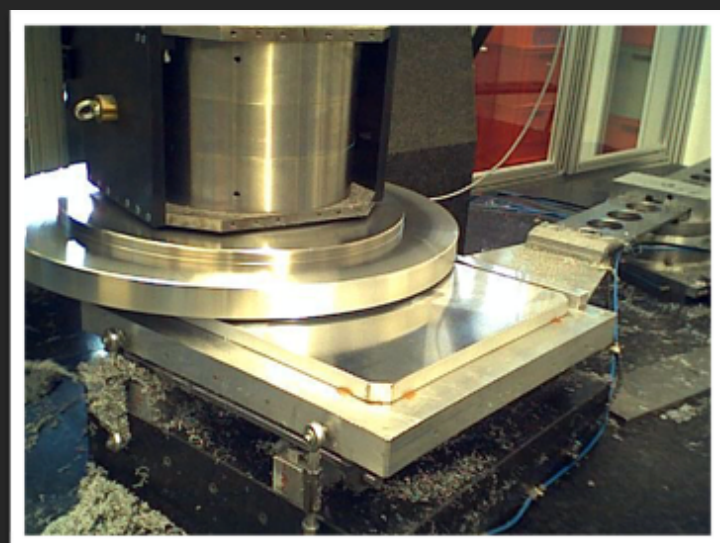
Up to 1.5 ns “trigger gate”



Logic transitions ~100 ps

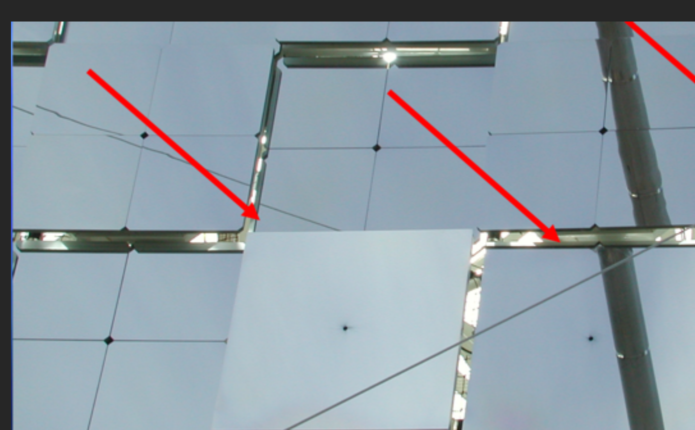
Mirrors development and production MAGIC I

Diamond milling technology for production



50x50 cm
Diamond milled, 80nm quartz coated to have
for protection and enhanced reflectivity at 320 nm

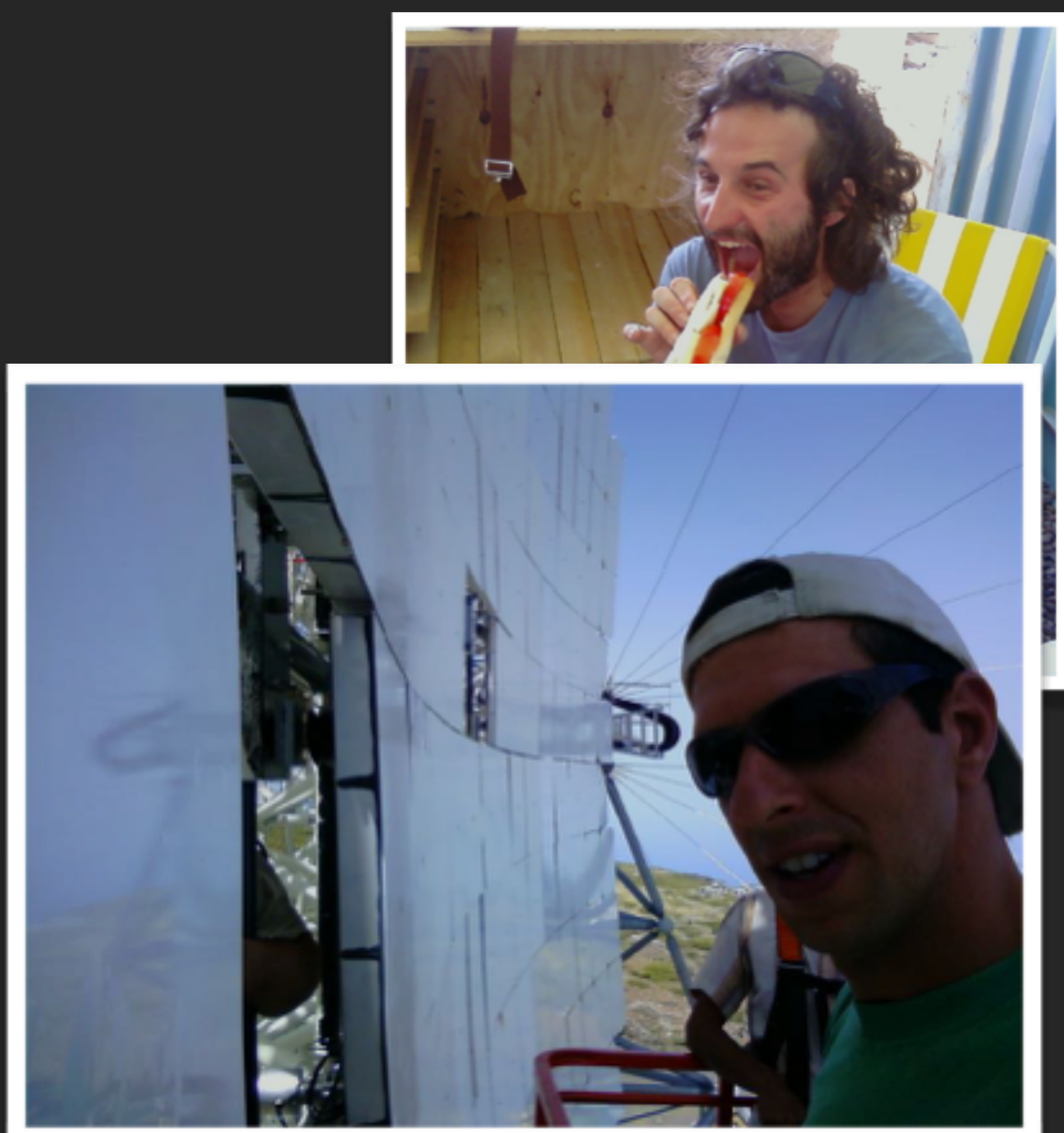
For the magic II telescope the mirror
size increased to 1 m^2



Alignement

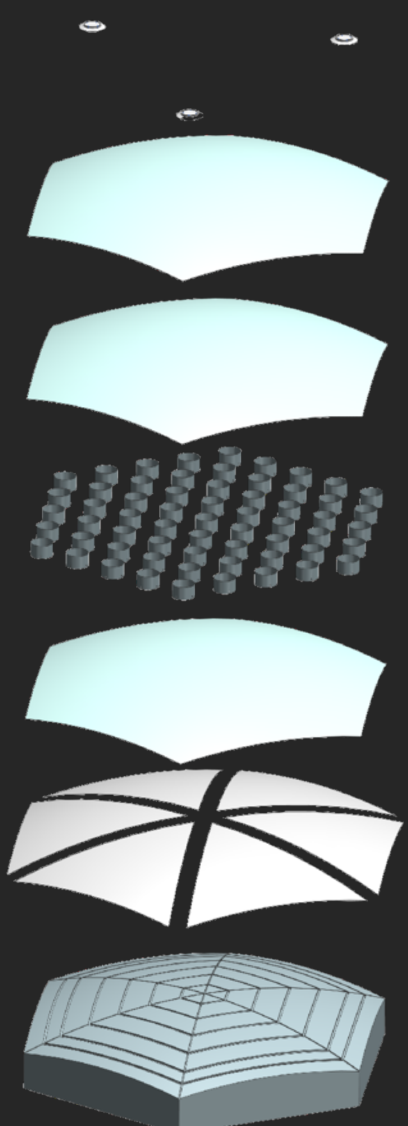
Mirrors development and production MAGIC II

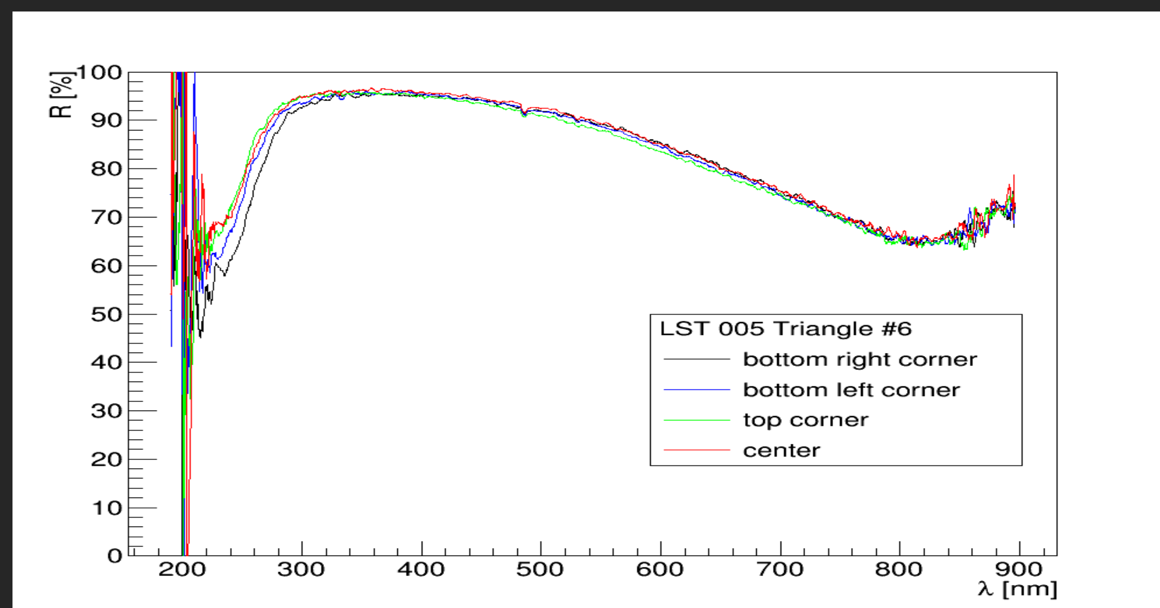
1 m^2 stiff panel mirrors, self supporting, much easy to handle install, and aligne



Mirrors development for CTA

Latest mirror technology development for CTA big telescope: replica method with front Aluminum coated glass: enhanced reflectivity with 3 layers of dielectric coating. Spherical shape 54 m radius of curvature





Large Mirror produced in Padua with replica technology

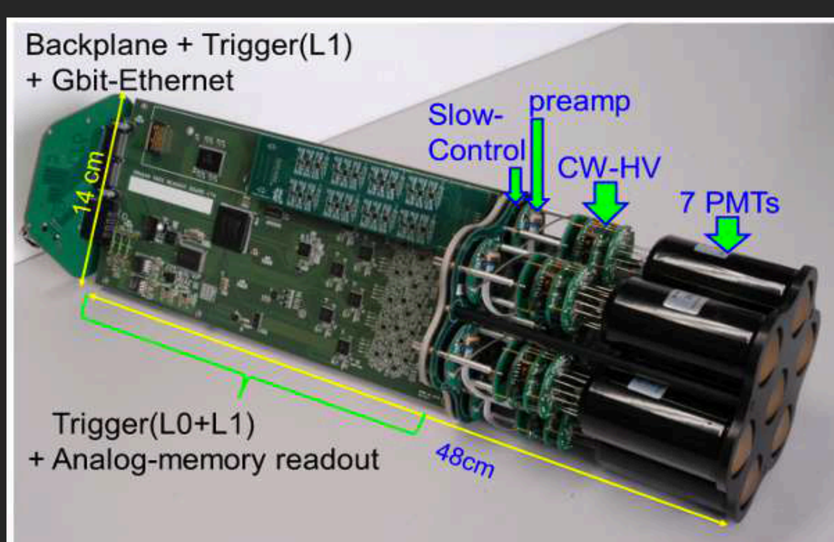
R&D in Advanced SiPM camera for LST of CTA

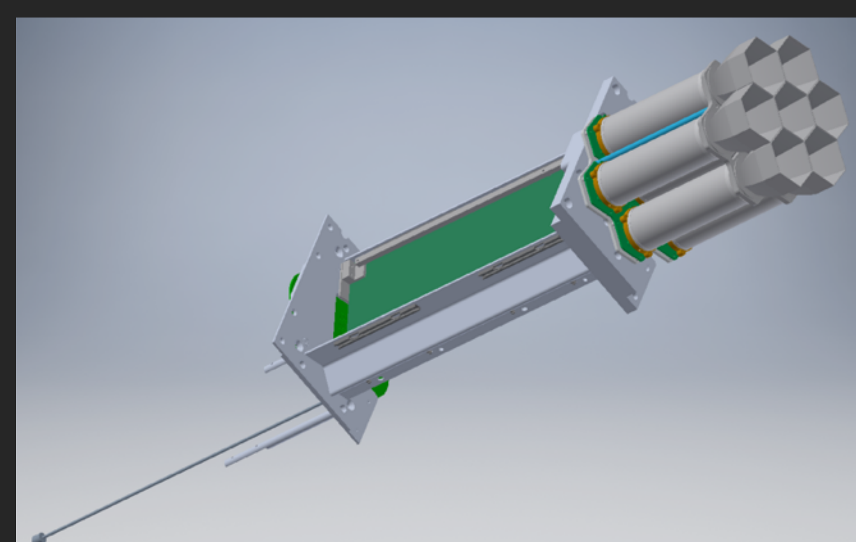
Design of a SiPM-based cluster for the Large Size Telescope camera of CTA

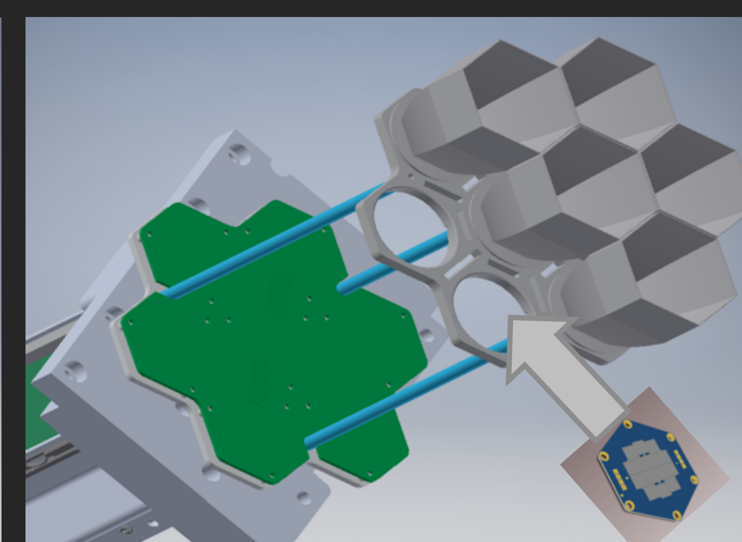
Manuela Mallamaci[1*], Daniele Corti[1], Luigi Lessio[2], Mosè Mariotti[1,3], Riccardo Rando[1,3], Bagdat Baibussinov[1], Giovanni Busetto[3], Alessandro De Angelis[1,2,4,5], Federico Di Pierro[6], Michele Doro[1,3], Elisa Prandini[3], Piero Vallania[6,7], Carlo Francesco Vigorito[6,8]

[1] INFN Padova, [2] INAF Padova, [3] Università di Padova, [4] Università di Udine, [5] IST and LIP Lisbon, [6] INFN Torino, [7] INAF OATo Torino, [8] Università di Torino
*manuela.mallamaci@pd.infn.it

A Silicon Photomultiplier (SiPM)-based photodetector will be built to be possibly used in the Large Size Telescope (LST) camera of the Cherenkov Telescope Array (CTA). It has been designed to match the size of the standard Photomultiplier Tube (PMT) cluster unit and to be compatible with mechanics, electronics and focal plane optics of the first LST camera. Here, we describe the overall SiPM cluster design along with the main differences with respect to the currently used PMT cluster unit. The fast electronics of the SiPM pixel and its layout are also presented. In order to derive the best working condition for the final unit, we measured the SiPM performances in terms of gain, photodetection efficiency and cross-talk. A pixel, a unit of 14 SiPMs, has been built. We will discuss also some preliminary results regarding this device and we will highlight the future steps of this project.







Advanced SiPM camera for IACT

SiPM pixel characterization and future studies

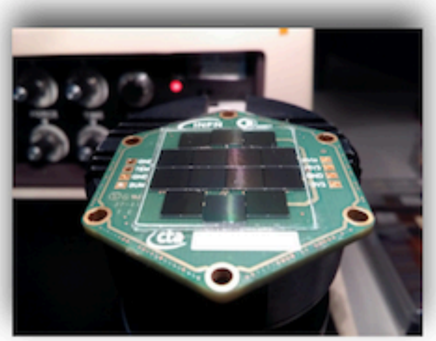


Fig. 9: View of one of the pixels built for this project.

This project of a SiPM cluster is based on the production of 7 pixels of SiPMs. Following the design here described, we built and characterized two sensors with 14 6x6mm² SiPMs of the model described above.

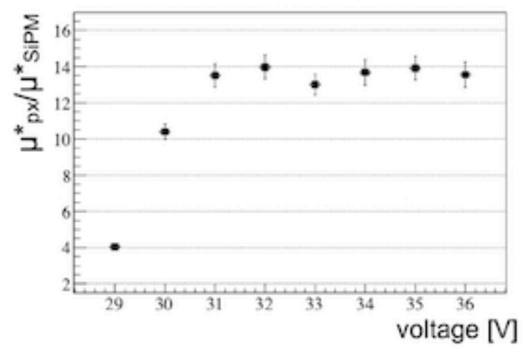


Fig. 10: Ratio of μ between the pixel and a single SiPM used as reference*

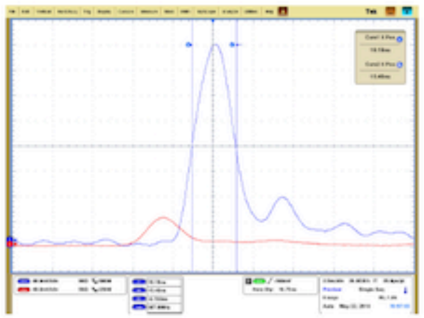
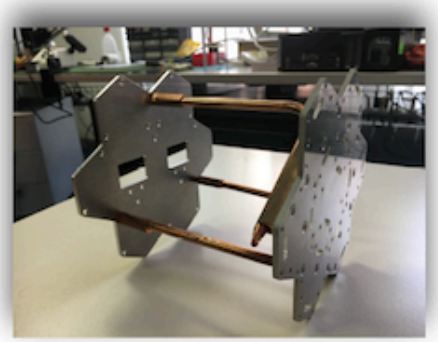


Fig. 10: Pixel (blue line) and single SiPM (red line) signals from the oscilloscope.

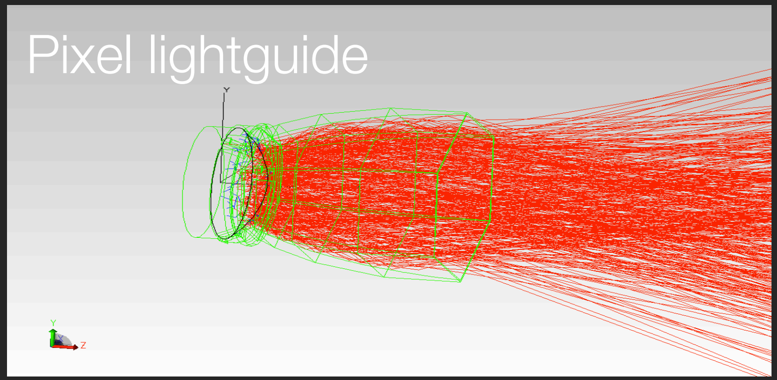
The pixel behaves as a sum of 14 objects, within the errors and preserves the peak width of the single SiPMs, being the FWHM less than 2.7 ns.

The electronic noise is 0.78 mV and the dynamical range is around 1000 (defined as the ratio A^*/σ_e, with A^* amplitude of the signal before saturation and σ_e, electronic noise).

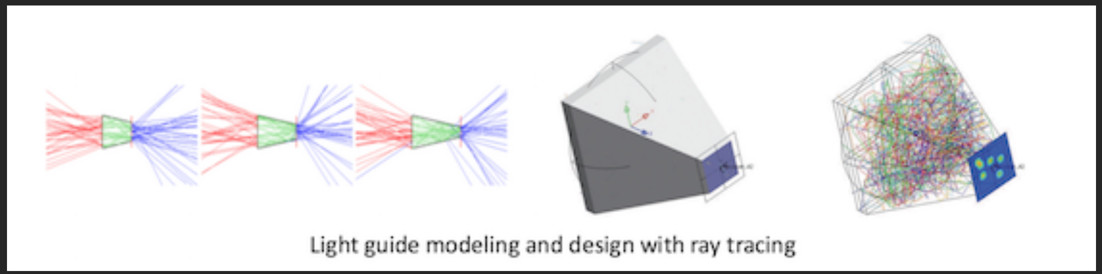
One of the next steps for this project is to design an optical system. We will also test how to drive the heat from the power control board to the cooling plate, which is 15 cm below. For this purpose a set of heat pipes will be applied and tested.



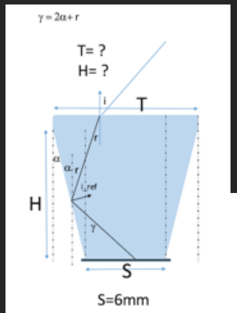
Focal plane Optics :
Lightguide ray tracing simulation

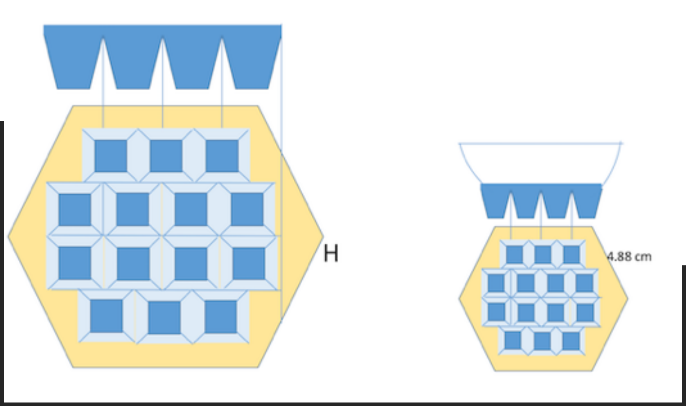


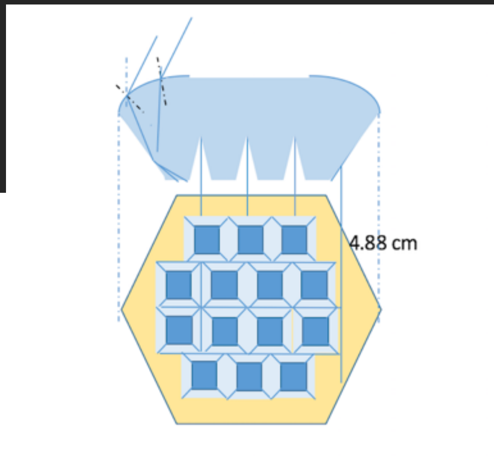
Single SiPM lightguide options



Matrix lightguide option



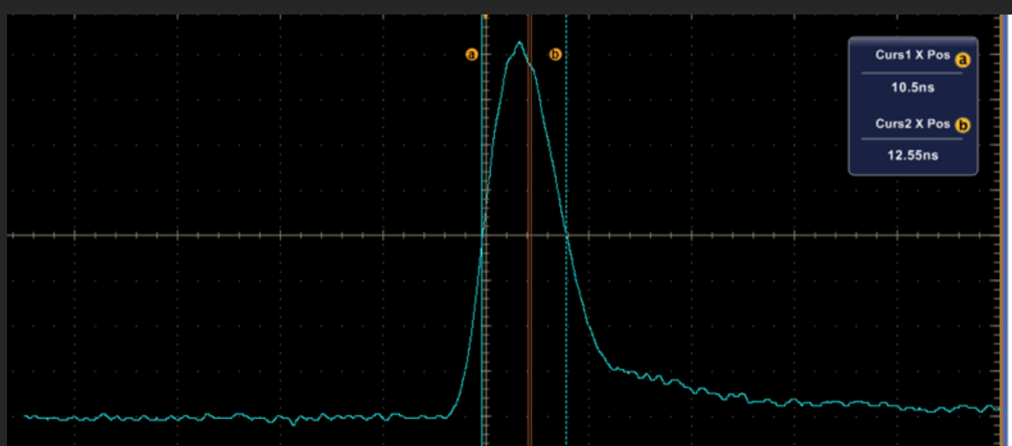


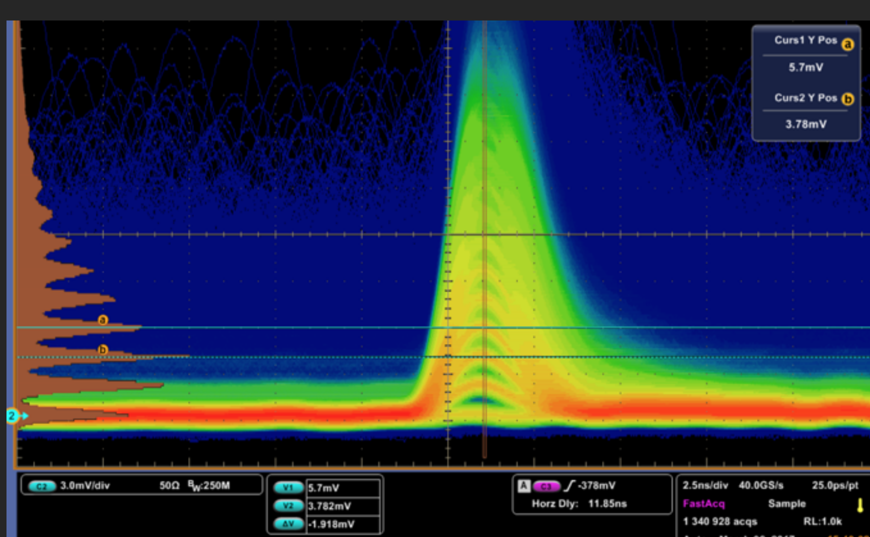


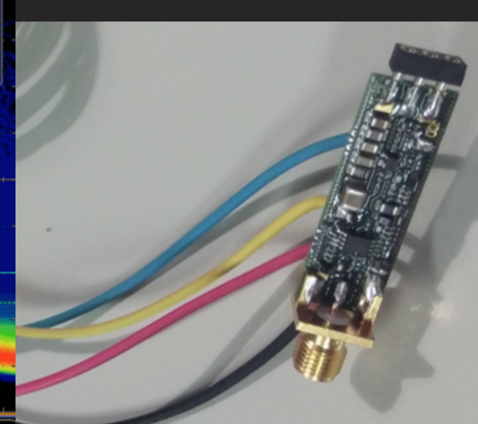
R&D SiPM camera for LST of CTA

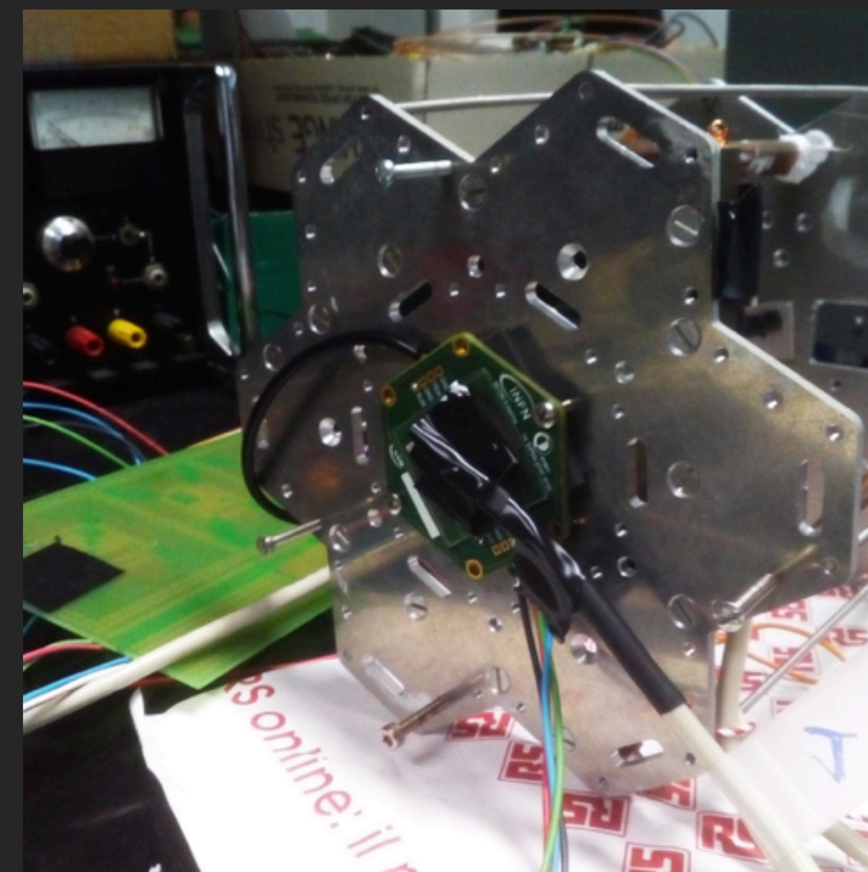
Progettato prodotto e realizzato un amplificatore per SiPm con prestazioni da record:

FWHM = 2ns
Conservando un eccezzionale rapporto segnale rumore

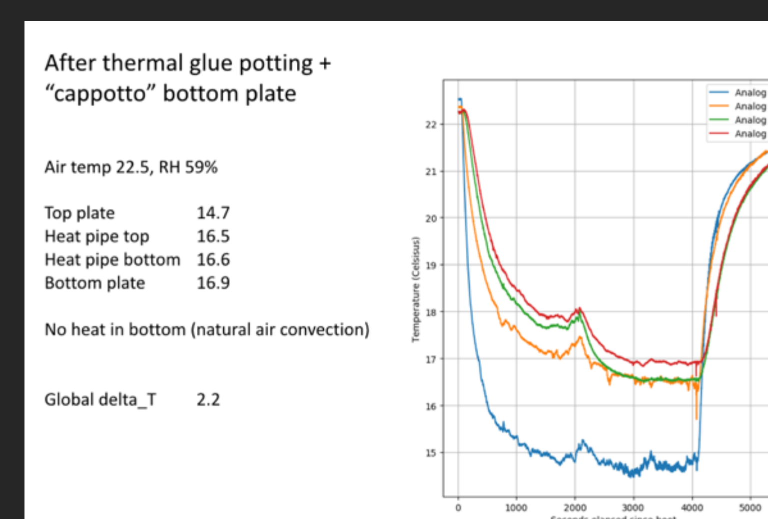








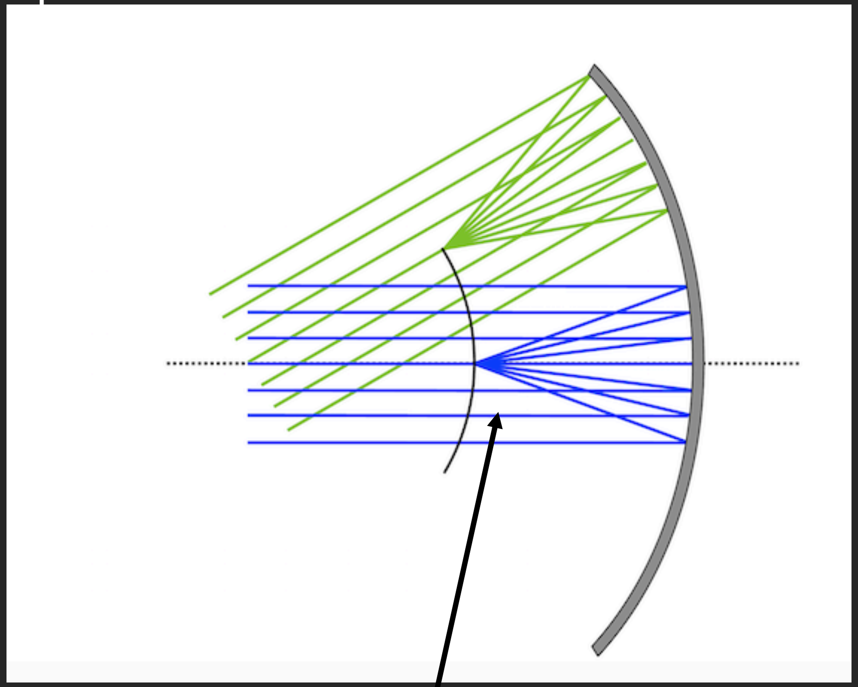
Cooling study for the entire cluster electronic

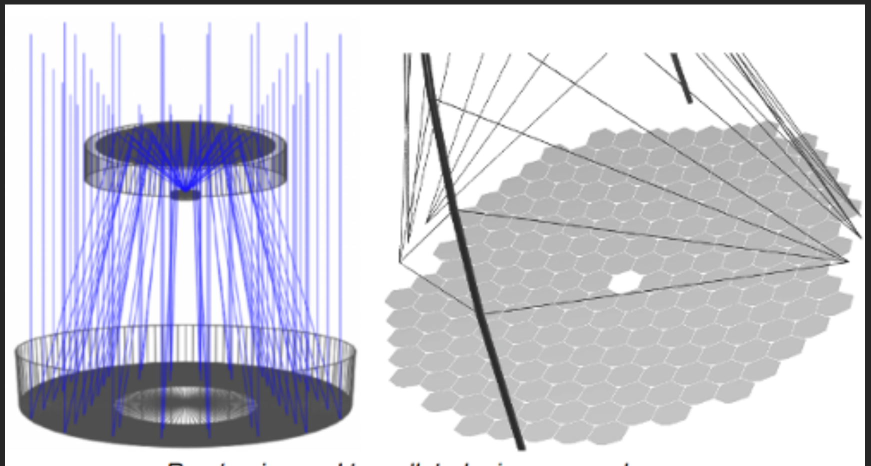


Wide FoV
IACT Telescopes
R&D

Wide FoV Cherenkov telescopes R&D

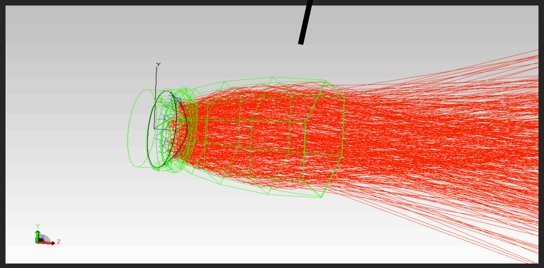
- Spherical reflector, curved focal plane, aberration mitigated by reduced acceptance of focal plane optics



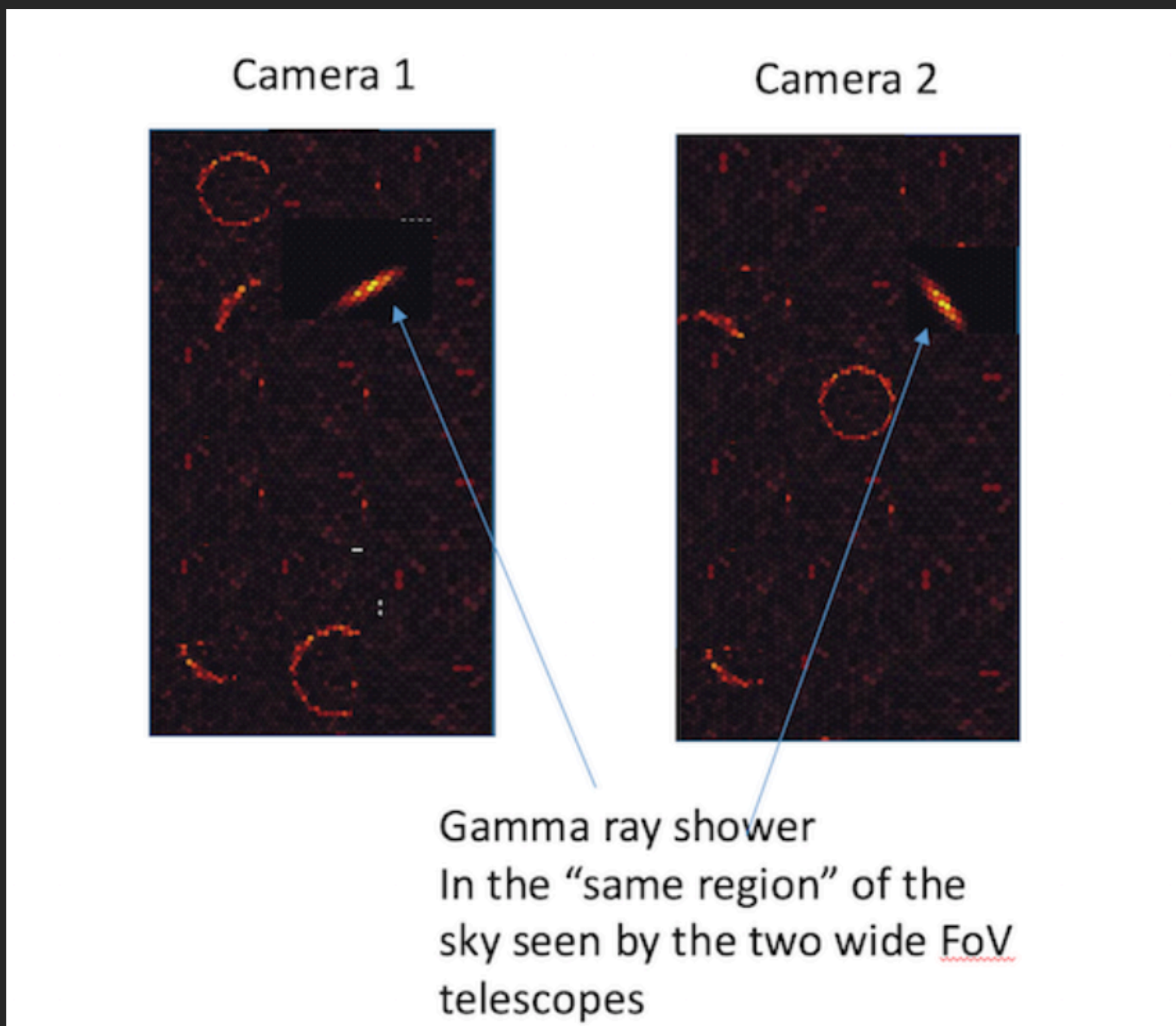


Ray-tracing and tessellated mirror examples

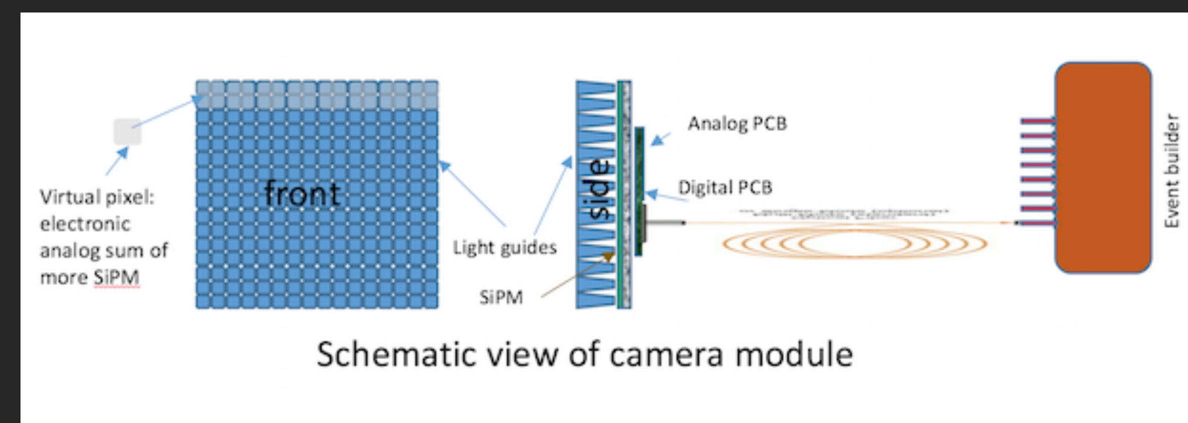
- Swarshild-Couder optical design: double reflection compact image

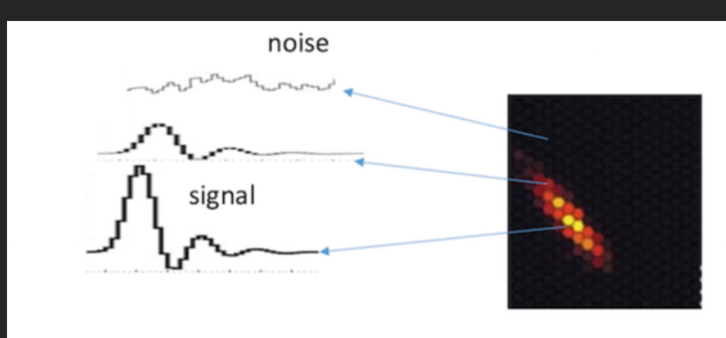


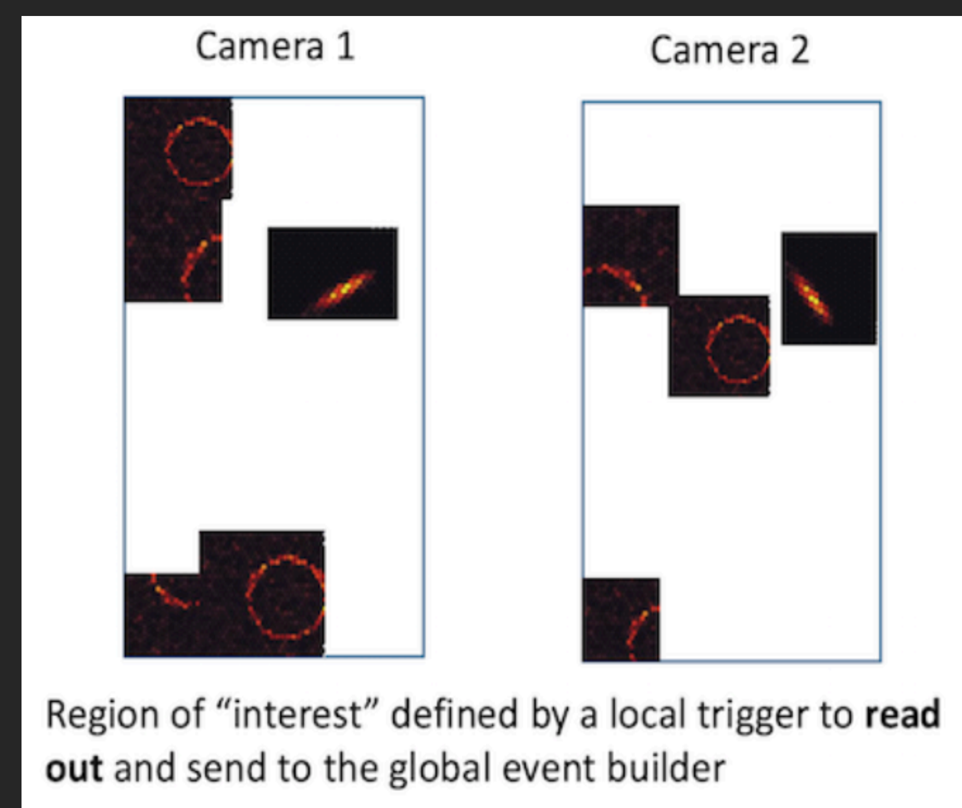
Advanced camera for Cherenkov telescopes R&D (both for Wide FoV and LST next camera)



o 200K pixels! novel electronic concepts to adopt: modularity, fully digital, local trigger smart readout







Satellite detectors

Gamma ray astrophysics from space

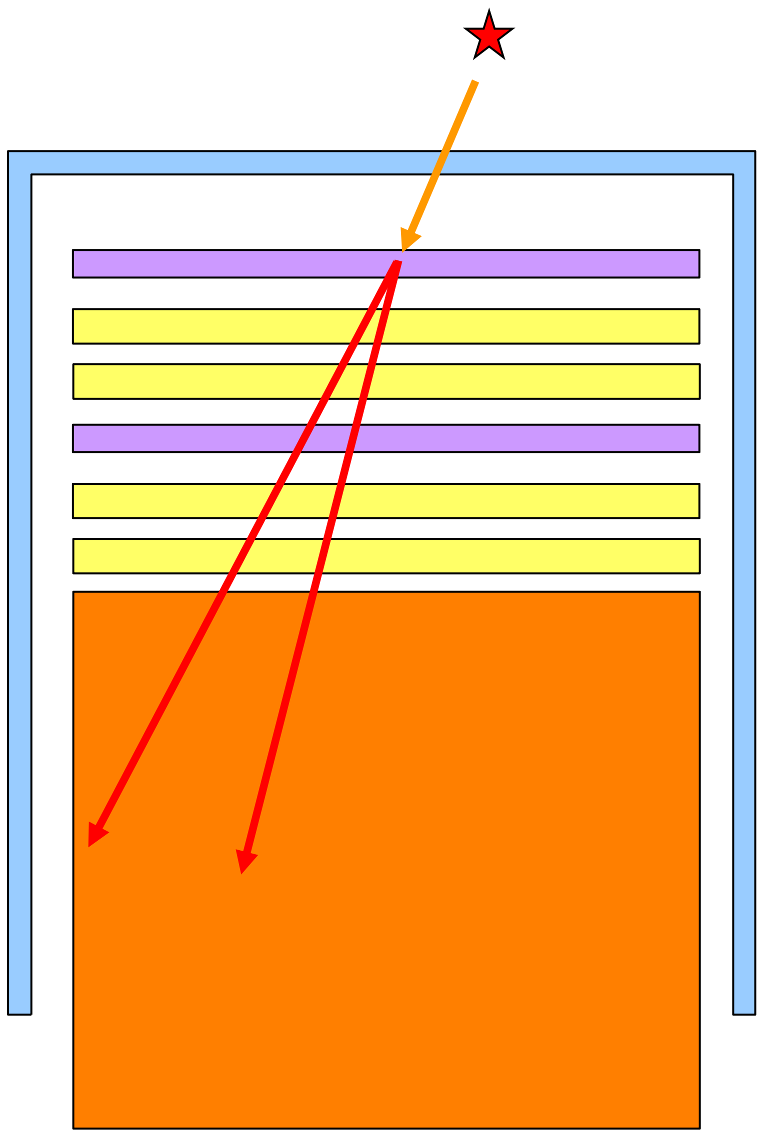
Many sources at all scales and distances: the Earth atmosphere (due to impinging cosmic protons), the Sun, Galactic pulsars, supernova remnants, active galaxies, Gamma-Ray Bursts…

Very high energies (>10 MeV to ~ 2 TeV): main interaction is pair production

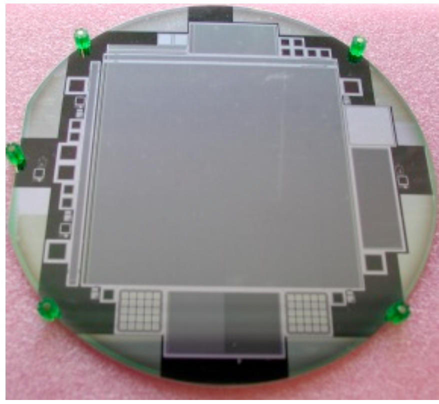
Silicon microstrip detectors, from high energy physics
Need to add dense converter foils (W) to promote interaction
This degrades the energy resolution at the lower energies (<10 GeV)
Pair e+/e- is tracked in the Silicon plane, direction of gamma reconstructed
Thick calorimeter at the bottom to absorb and measure energy of event

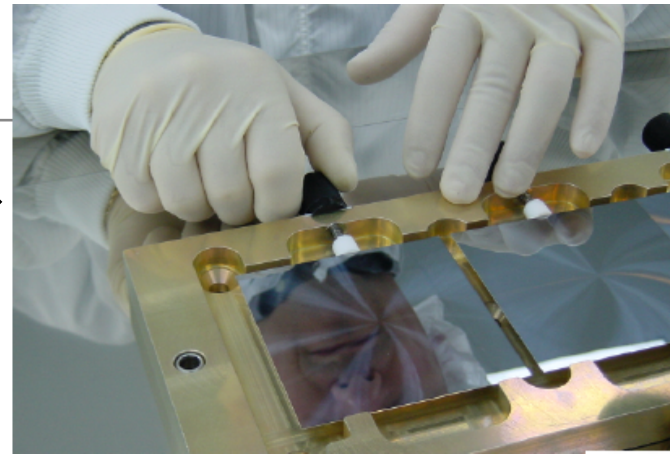
In space: LOTS of charged particles (10^6:1 to gammas): need a way to ignore these
Plastic anti-coincidence shield all around: gammas pass without interacting, charged particles cause ionization

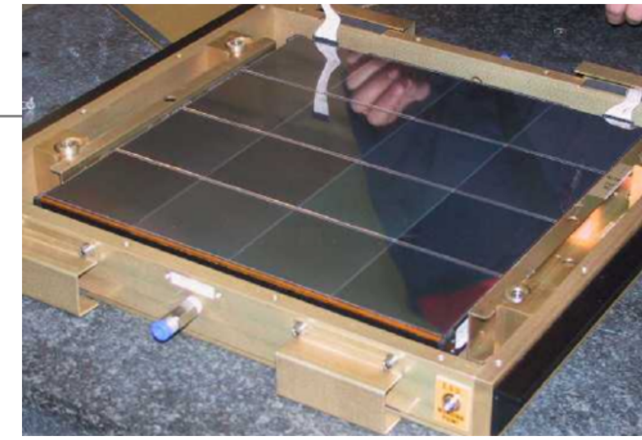
Fermi observatory (2008 – present)
Main instrument: Large Area Telescope
Silicon tracker: INFN Italy

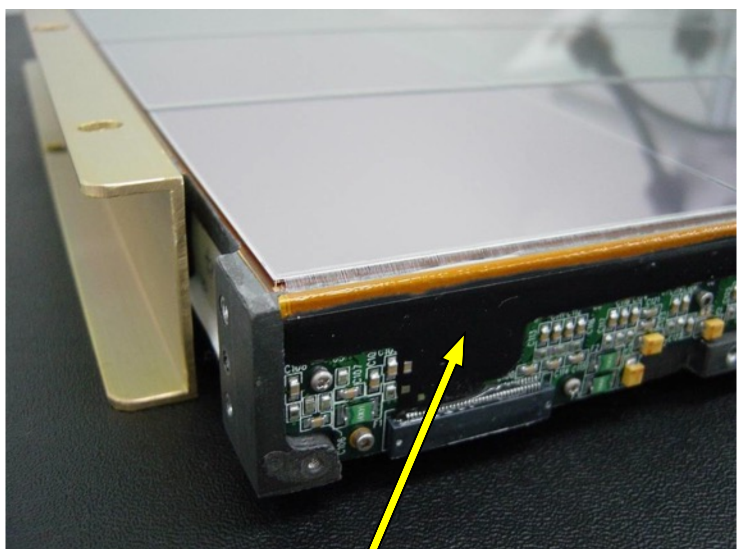


Fermi LAT tracker: assembly in Pisa

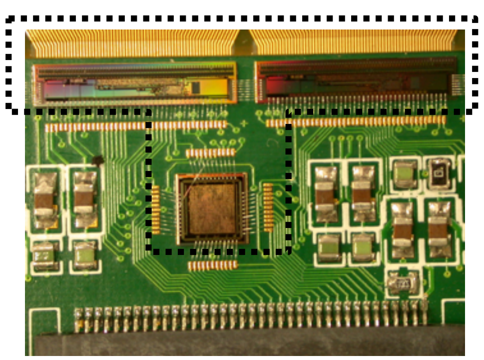








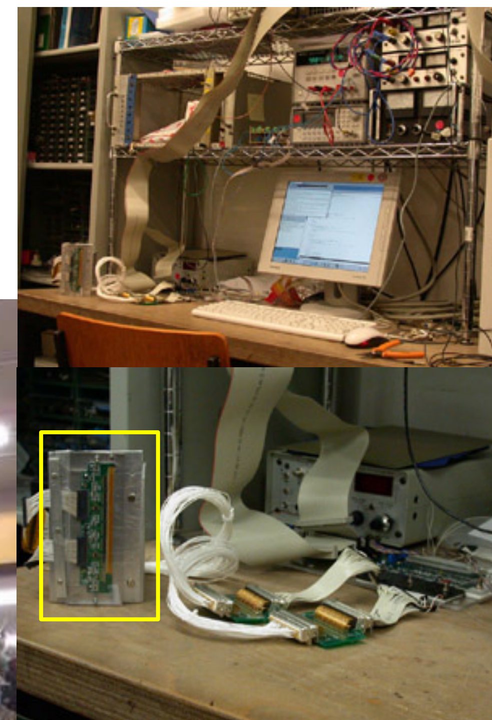
Readout ASICs are under here

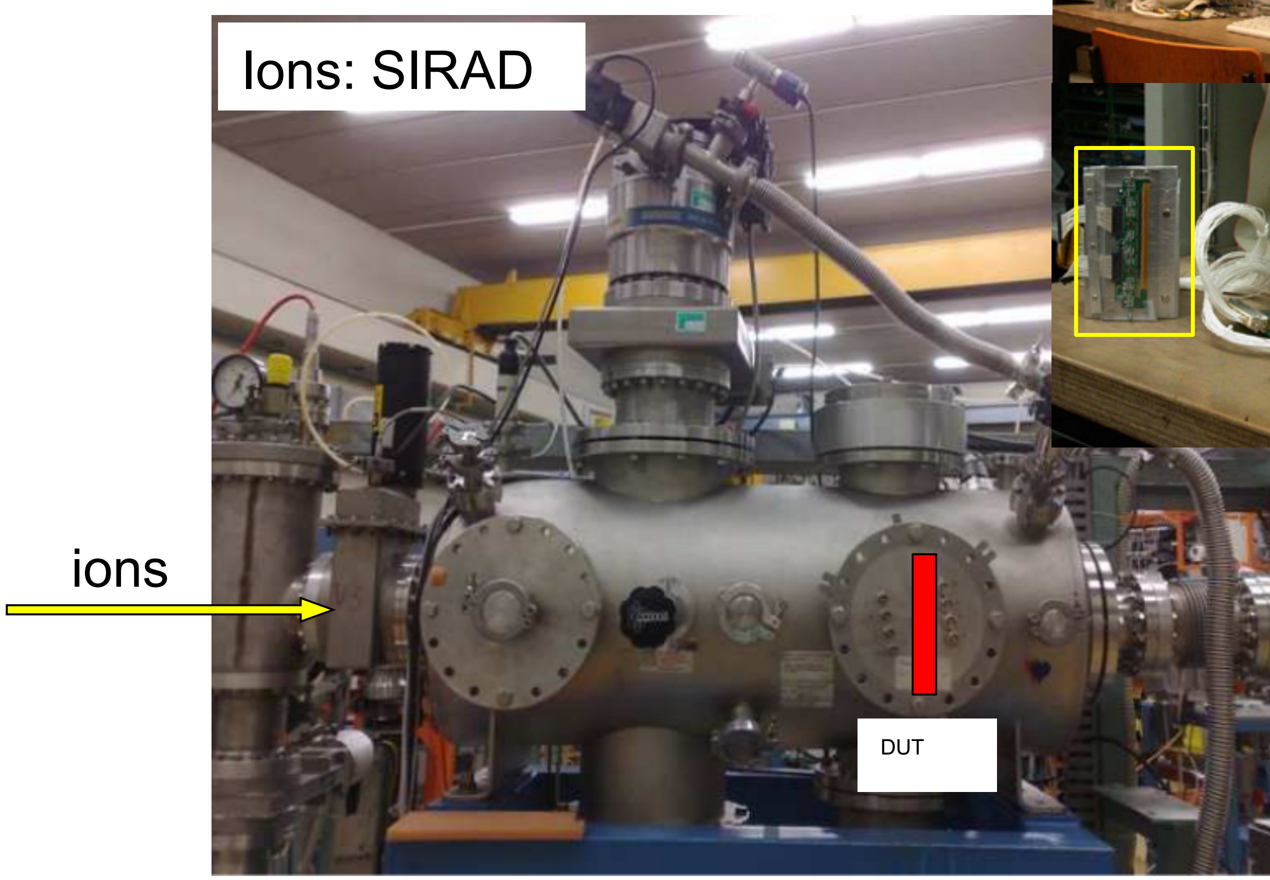


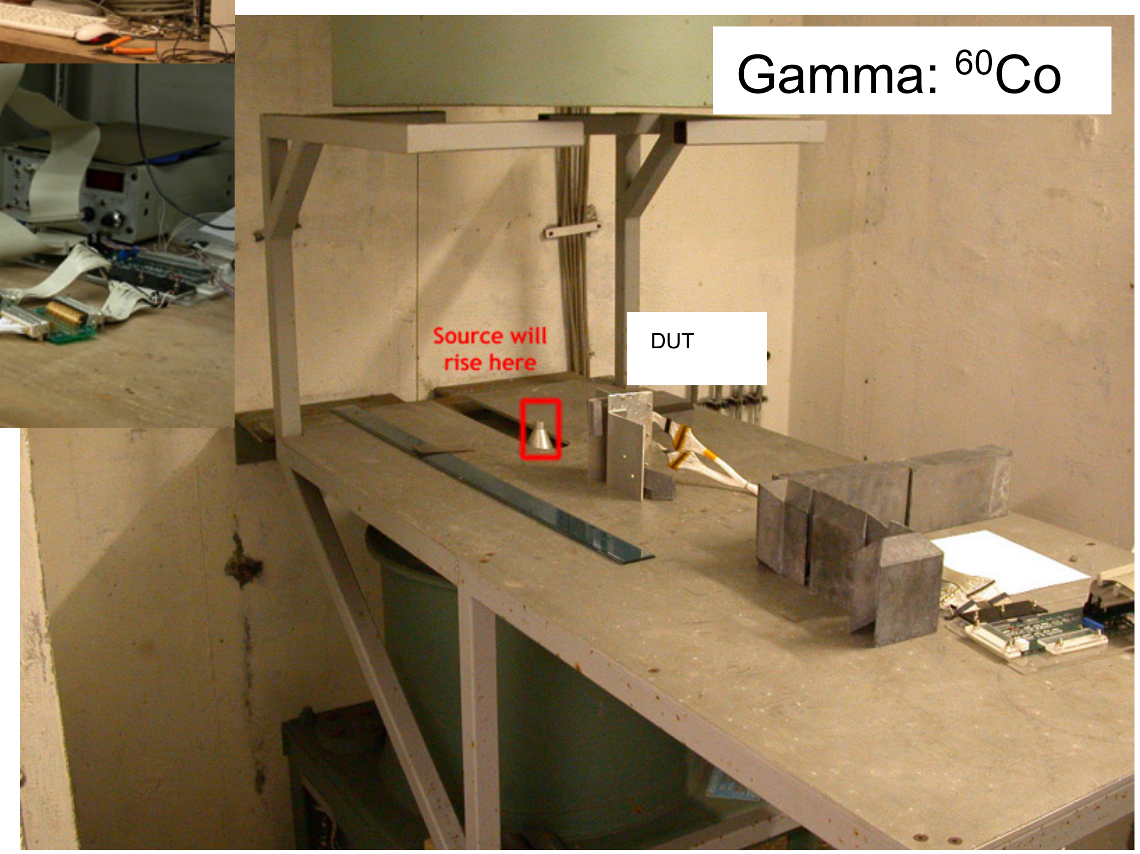
… to NASA

Activities in Padova

- LAT Silicon tracker
  - Radiation hardness: tested **Tracker microstrip sensors** and **Tracker & Calorimeter readout electronics** at INFN facilities in Legnaro
  - Irradiation: ions (Tandem/SIRAD) and gamma (^{60}Co / CNR ISOF)
  - Procedures and software written in PD





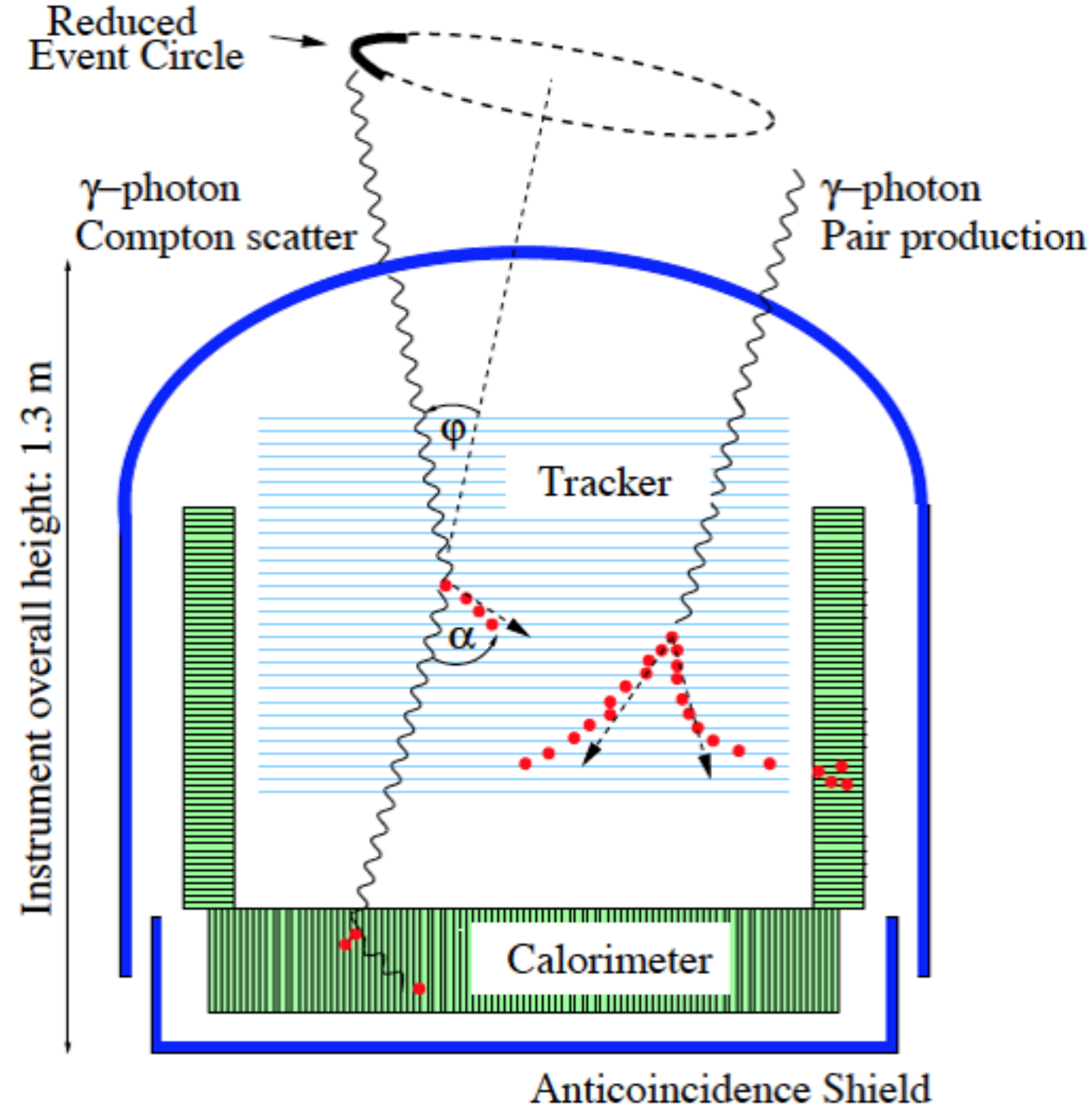


Medium energy gamma rays

Below the threshold for pair-production: Compton scattering
Quite complex event topology and reconstruction
Origin uncertainty: event circle (current instruments)
Smaller arc if electron is tracked

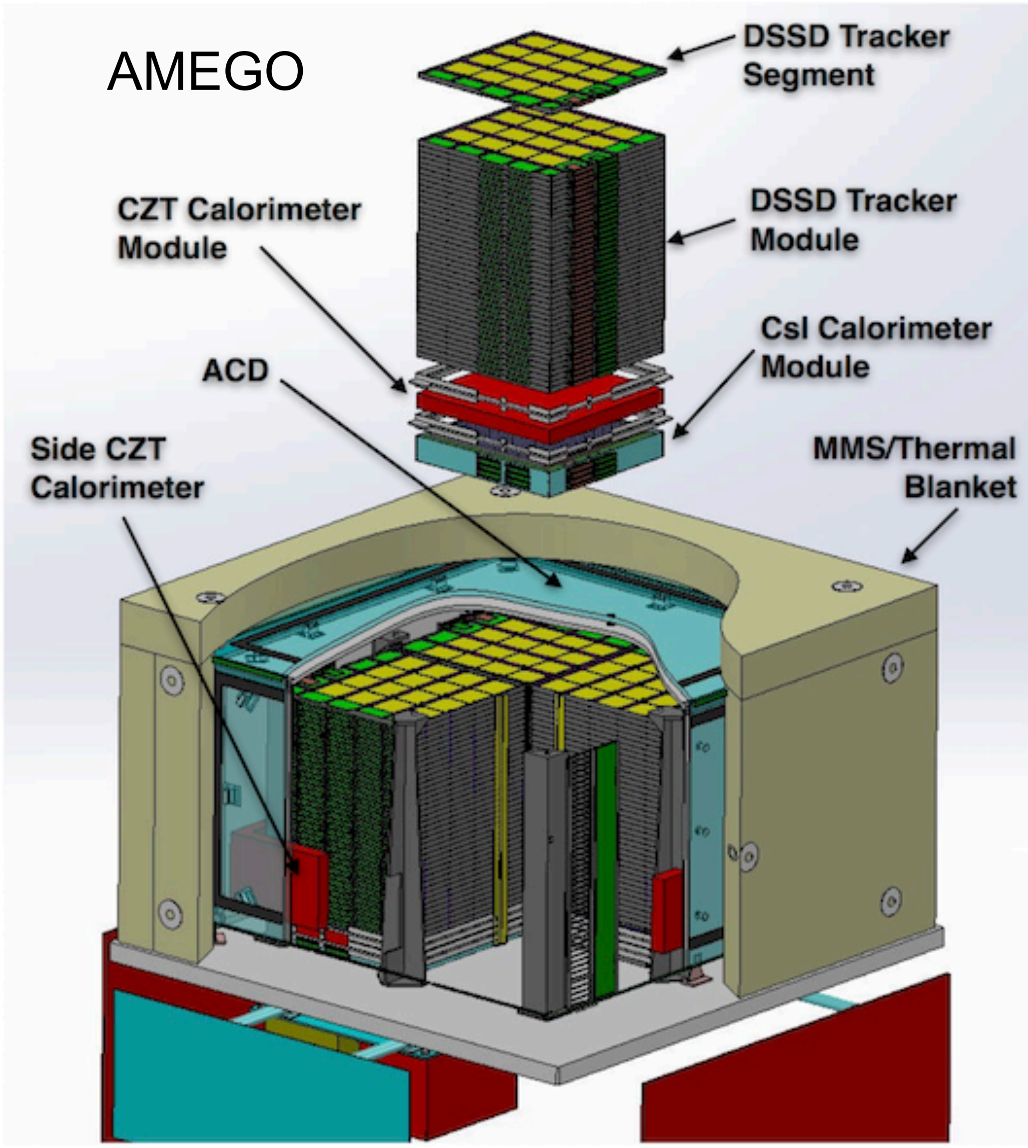
New solution: tracker similar to *Fermi* LAT,
but without dense conversion foils: only Si
Finely segmented calorimeter all around

Sensitivity: from 100's keV to ~10 MeV
Also sensitive to pair-production events:
two instruments in one

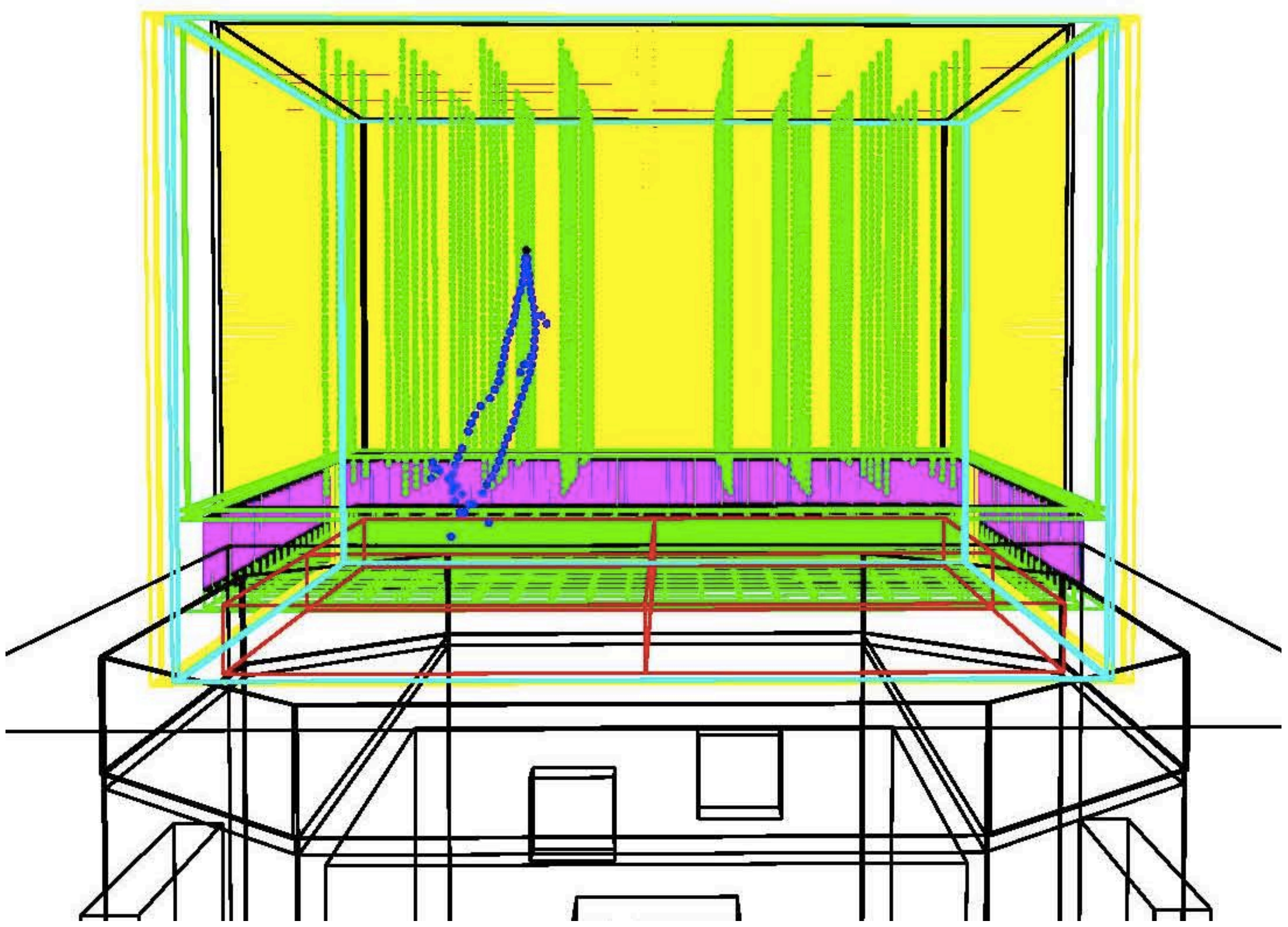


AMEGO/ASTROGAM

Two proposals (to NASA & ESA respectively)
Same concept, two slightly different realizations (actually a few ***-ASTROGAM proposals)
Up to now: simulations of sensitivity, background, etc. for proposal



e-ASTROGAM



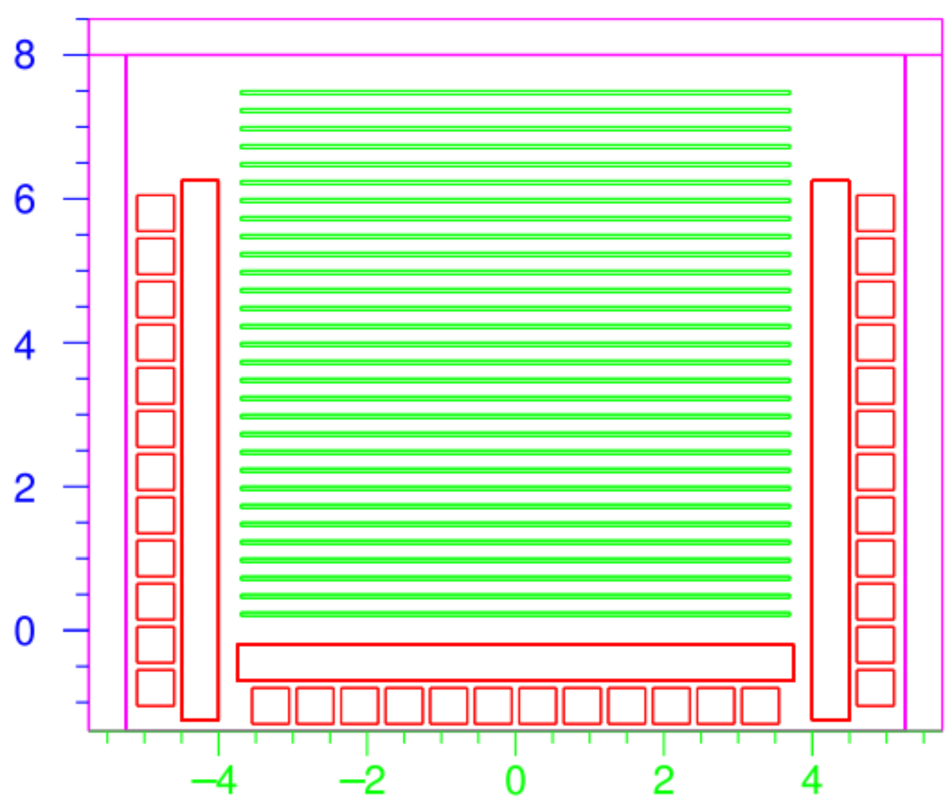
Nanoscale demonstrator R&D

The technologies for MeV observatories are the same as in the GeV range: the instrumentation is well tested (*Fermi* and others) but the operation and reconstruction is not

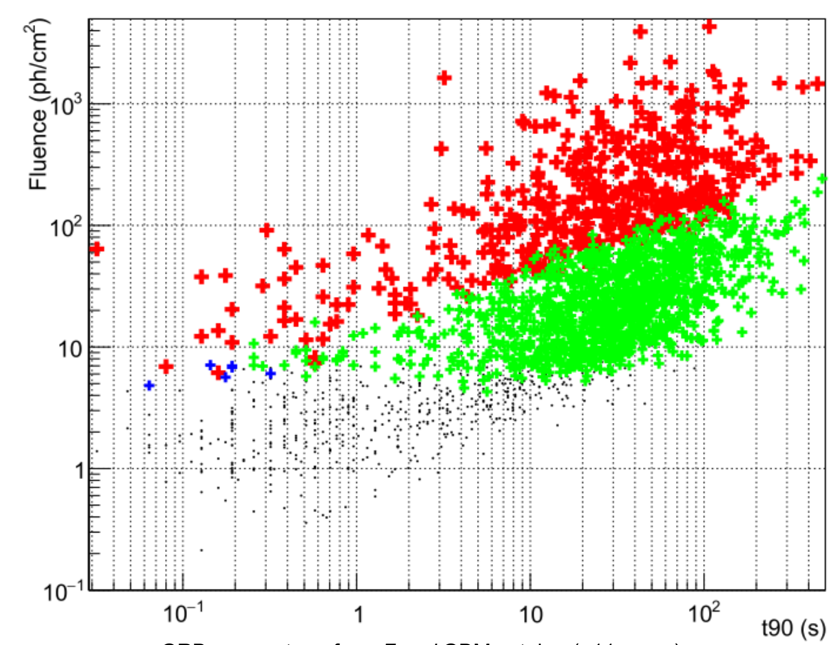
Proposed a nanoscale (1 ℓ) demonstrator, to evaluate the MeV-specific issues (backgrounds, activation of materials, Compton/pair event reconstruction, …). Same structure (Si planes, CAL crystals all around)

Carried out entirely as a series of thesis projects

Current design of detetctor



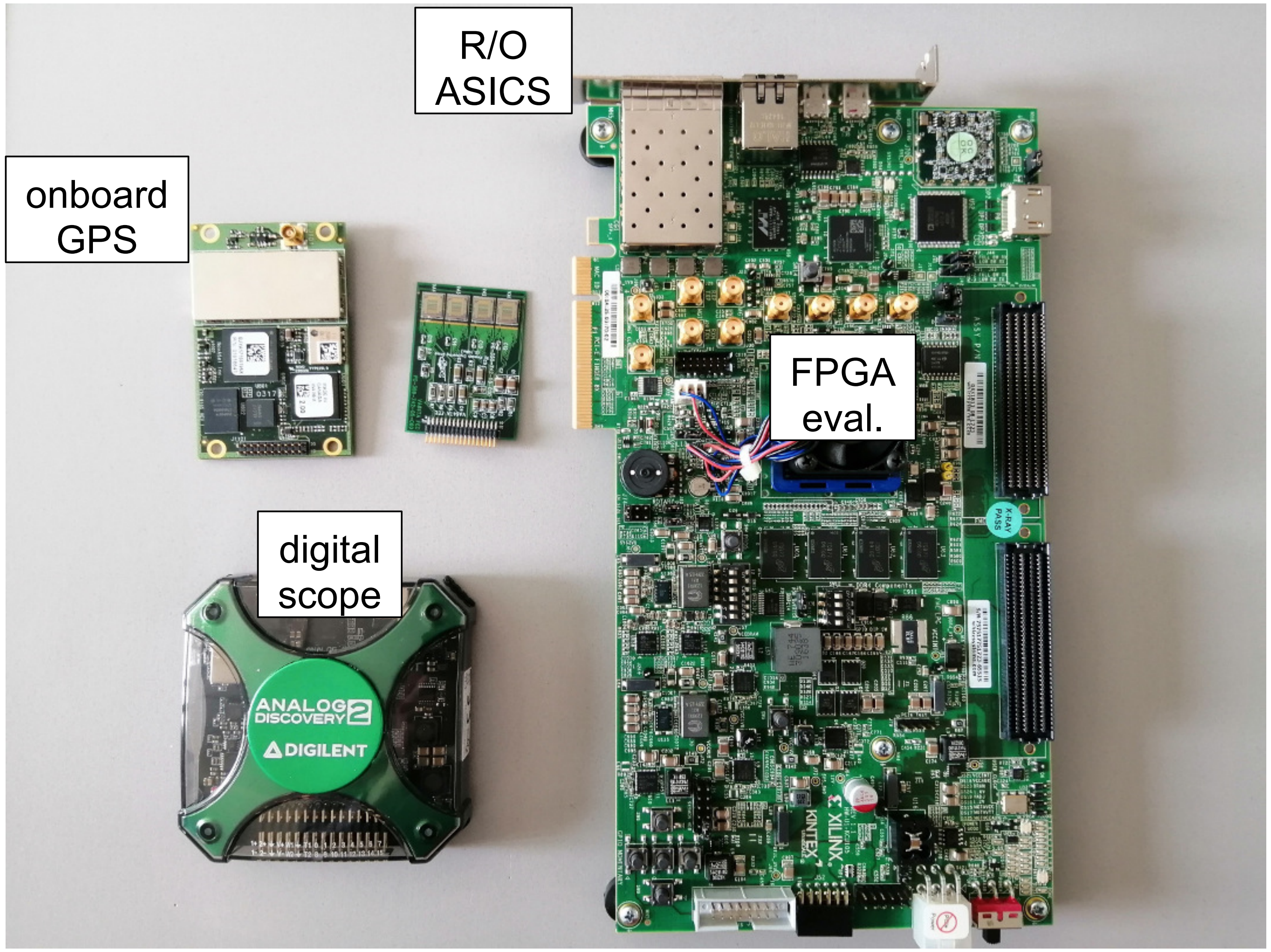
Sensitivity to GRBs
Red: observable, all other colors: too faint



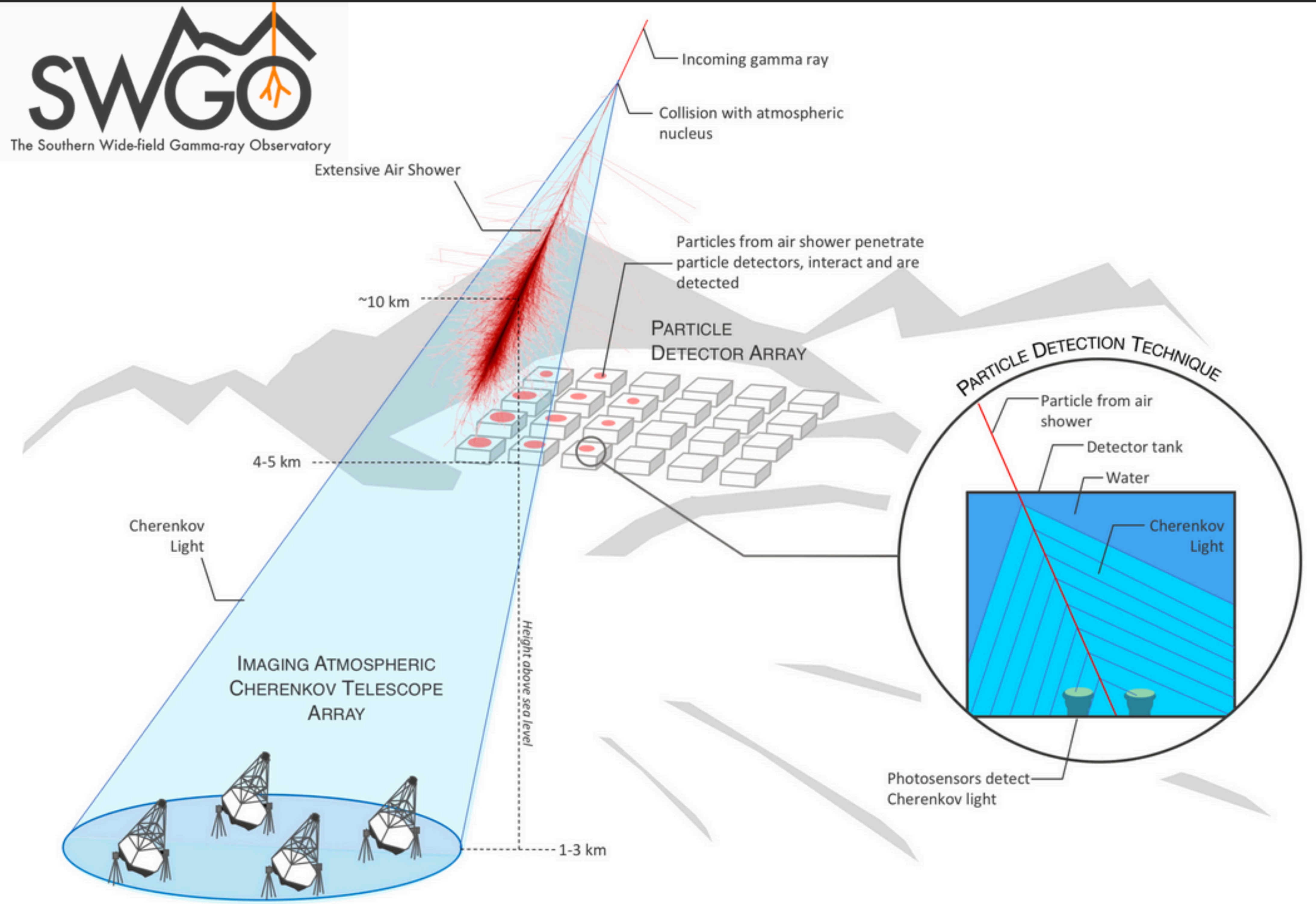
GRB parameters: from *Fermi* GBM catalog (~11 years)

Current activities

Procured some hardware for the detector, test sensors (SSD, CAL crystals) from old spares
Next step: evaluate event readout and time-stamping (with onboard GPS)
Good time resolution (~few μs) necessary to reconstruct timing of pulsars

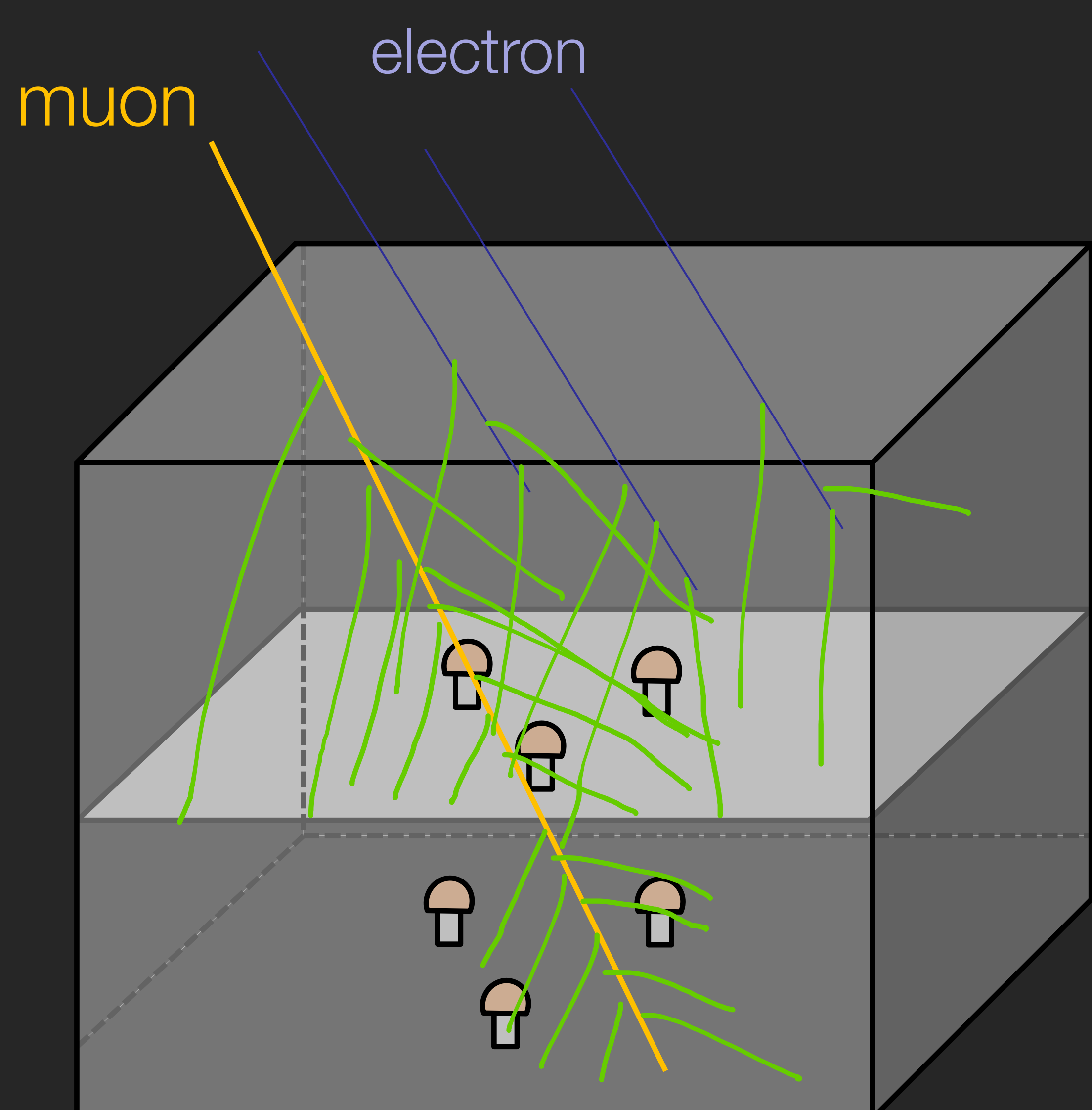


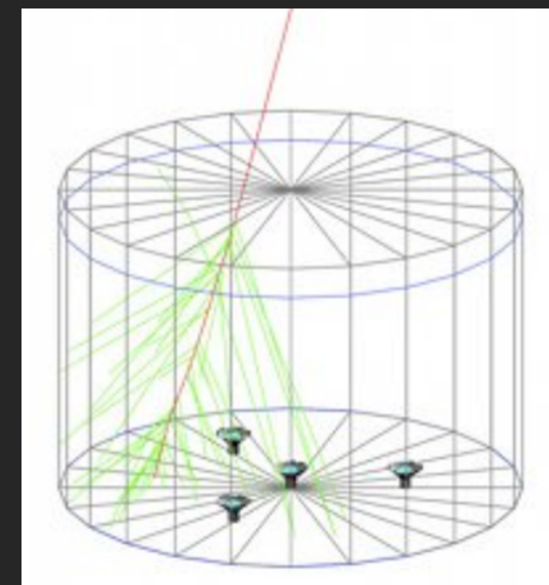
Wide FoV front shower gamma ray detector



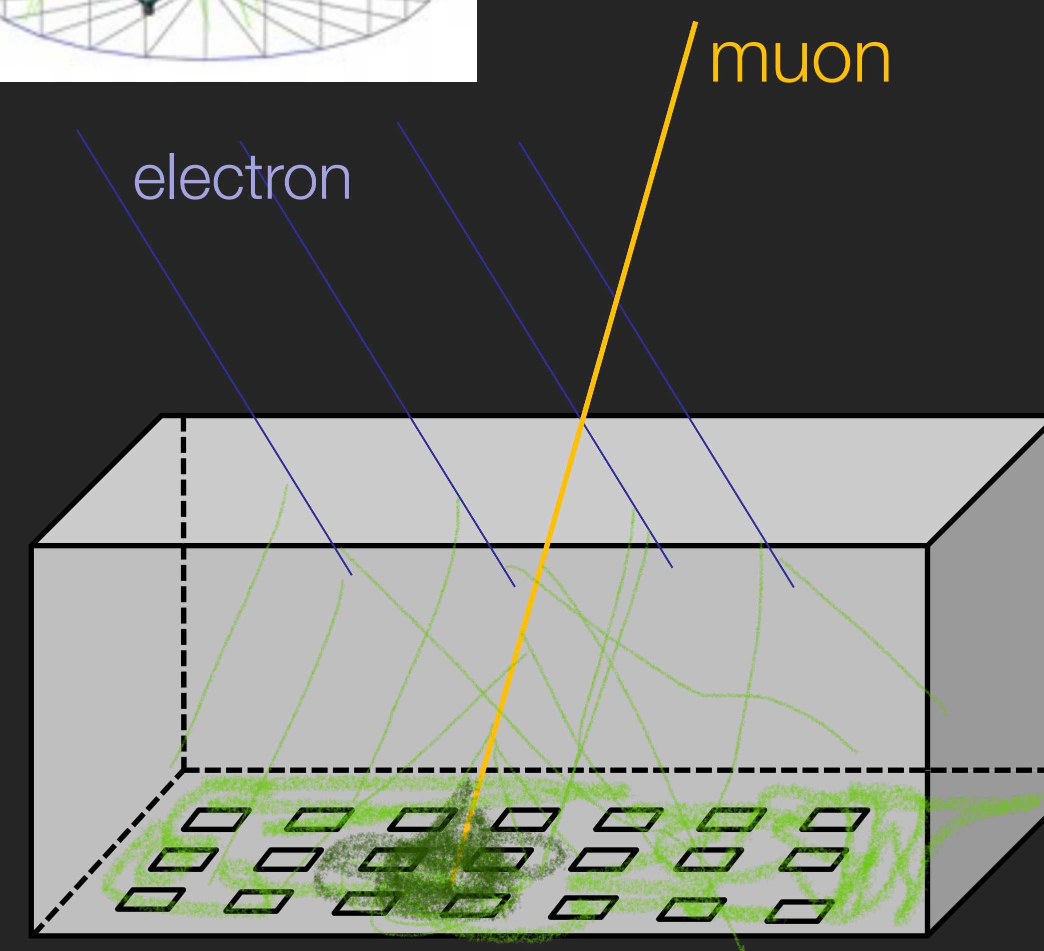
Shower image, 100 GeV γ-ray adapted from: F. Schmidt, J. Knapp, "CORSIKA Shower Images", 2005, https://www-zeuthen.desy.de/~jknapp/fs/showerimages.html

Water Cherenkov Detector “evolution”

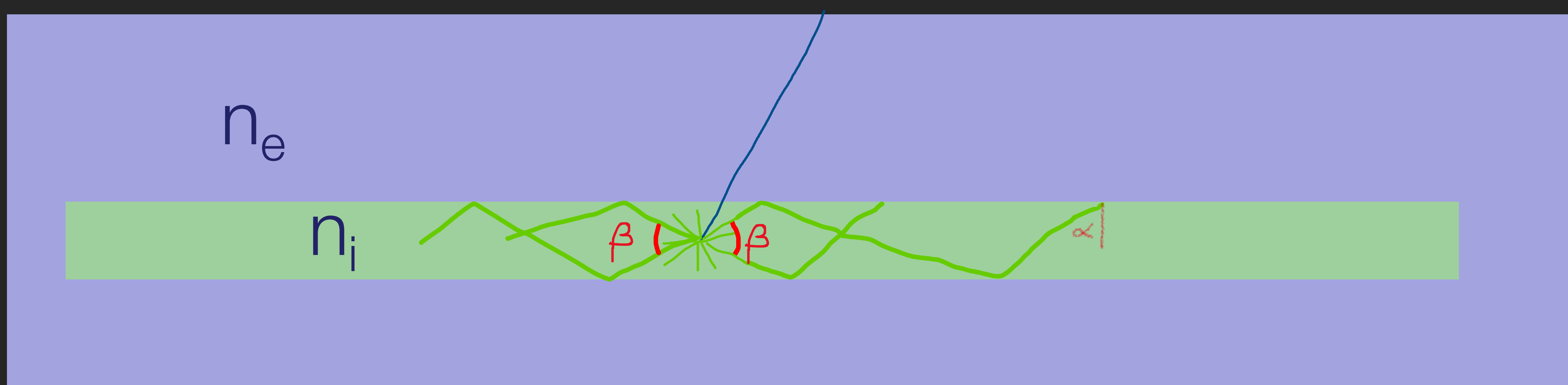




Hawc
State of the art



Light trap with wavelength shifters

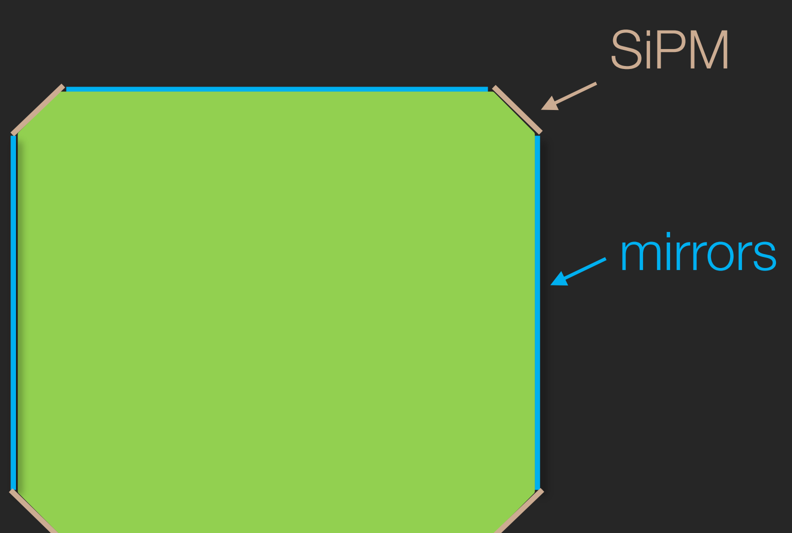


$$\alpha = \arcsin\left(\frac{n_e}{n_i}\right) \Rightarrow \% = \frac{\beta}{\pi/2}$$

$$\beta = \frac{\pi}{2} - \alpha$$

30.6 % — $n_e = 1.33$, $n_i = 1.5$

53 % — $n_e = 1$, $n_i = 1.5$



Geom_eff

$\sim L_{SiPM}/L_{mirrors}$

$+ R(1 - L_{SiPM}/L_{mirrors}) L_{SiPM}/L_{mirrors}$

$+ R^2 (1 - L_{SiPM}/L_{mirrors} + R(1 - L_{SiPM}/L_{mirrors}) L_{SiPM}/L_{mirrors}) L_{SiPM}/L_{mirrors}$

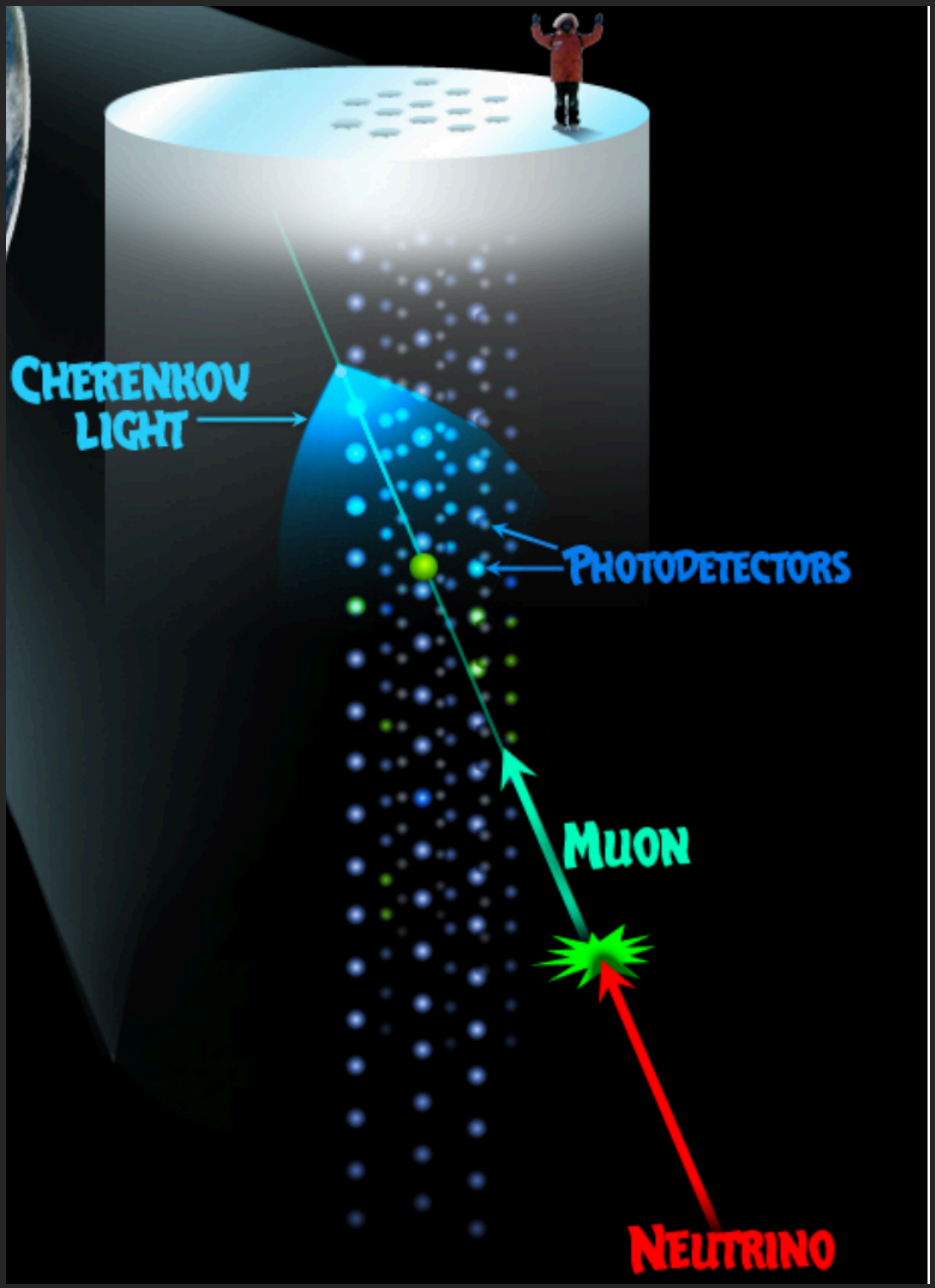
$+ R^3 \ldots$

15 cm 3 cm, R=0.8 Eff = 20% + 12.8% + 8.2% + 6% ~ 47% (4 reflection)

Overall photon geometric efficiency = 14.4% water 25% air

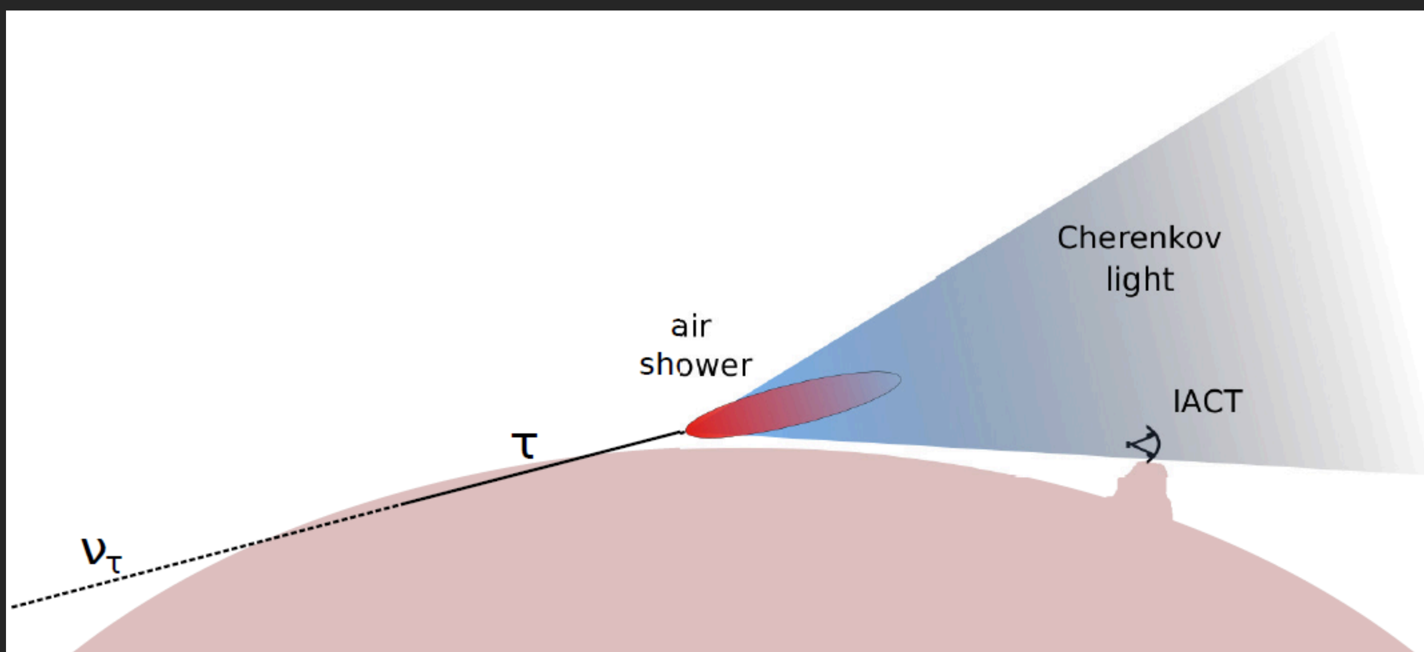
to be multiplied by SiPM efficiency 45% -> 6.5% water 12% air

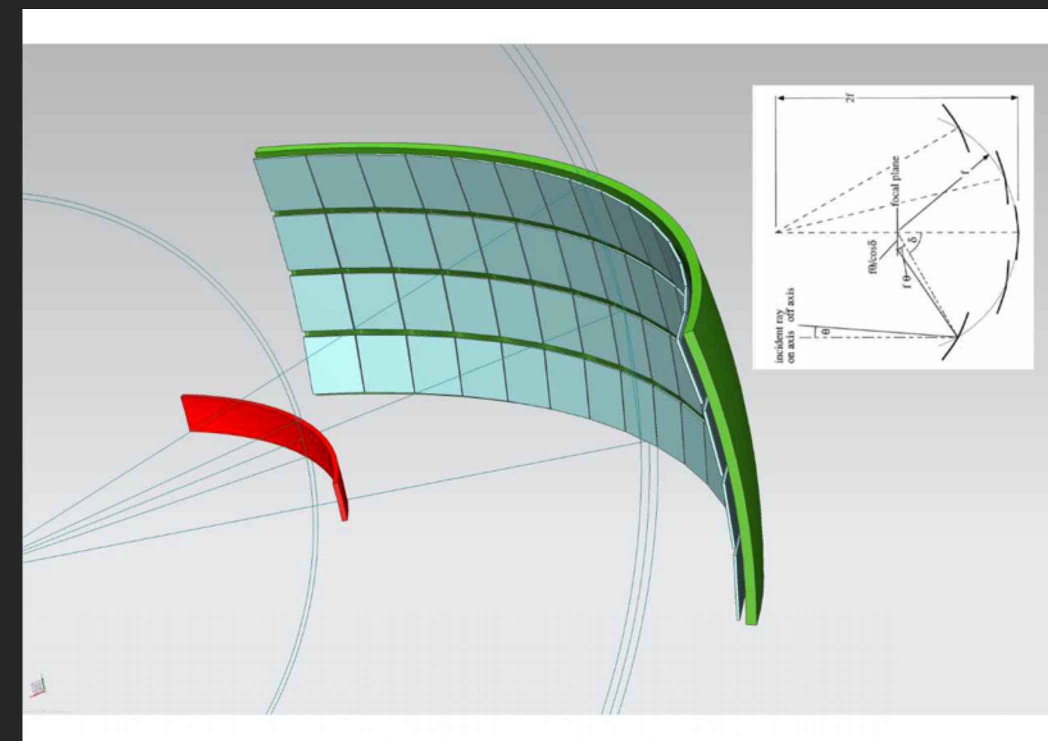
Light trap with wavelength shifters

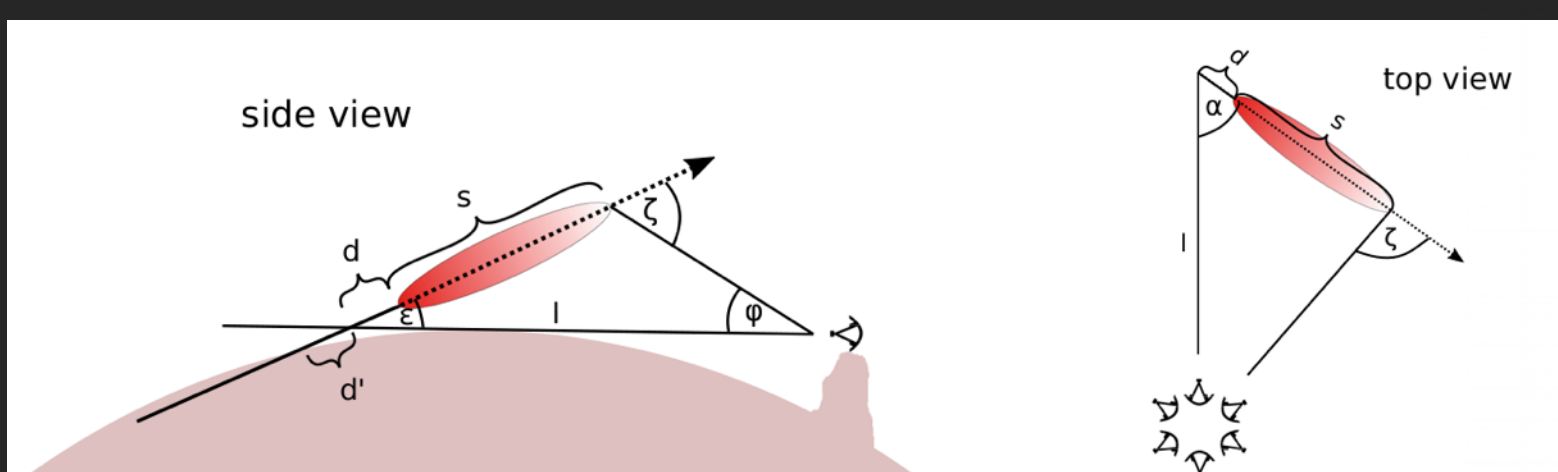


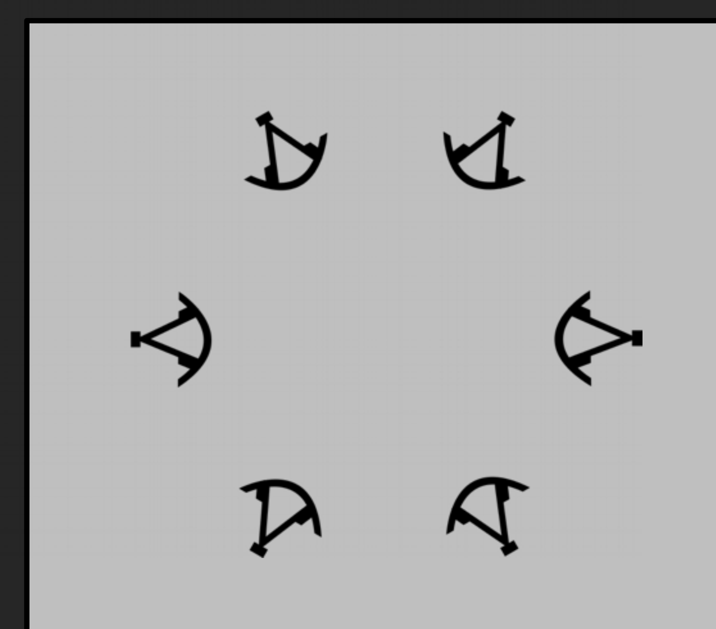
Earth skimming tau Neutrino detector

Earth skimming tau neutrino shower

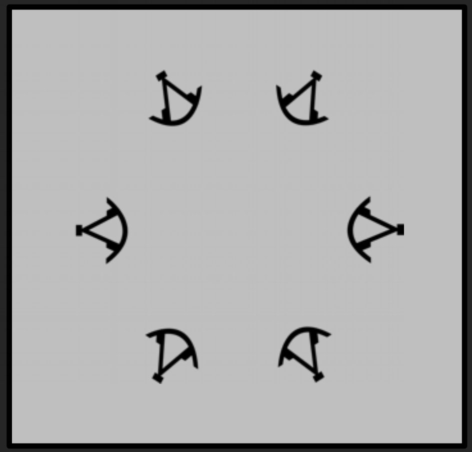


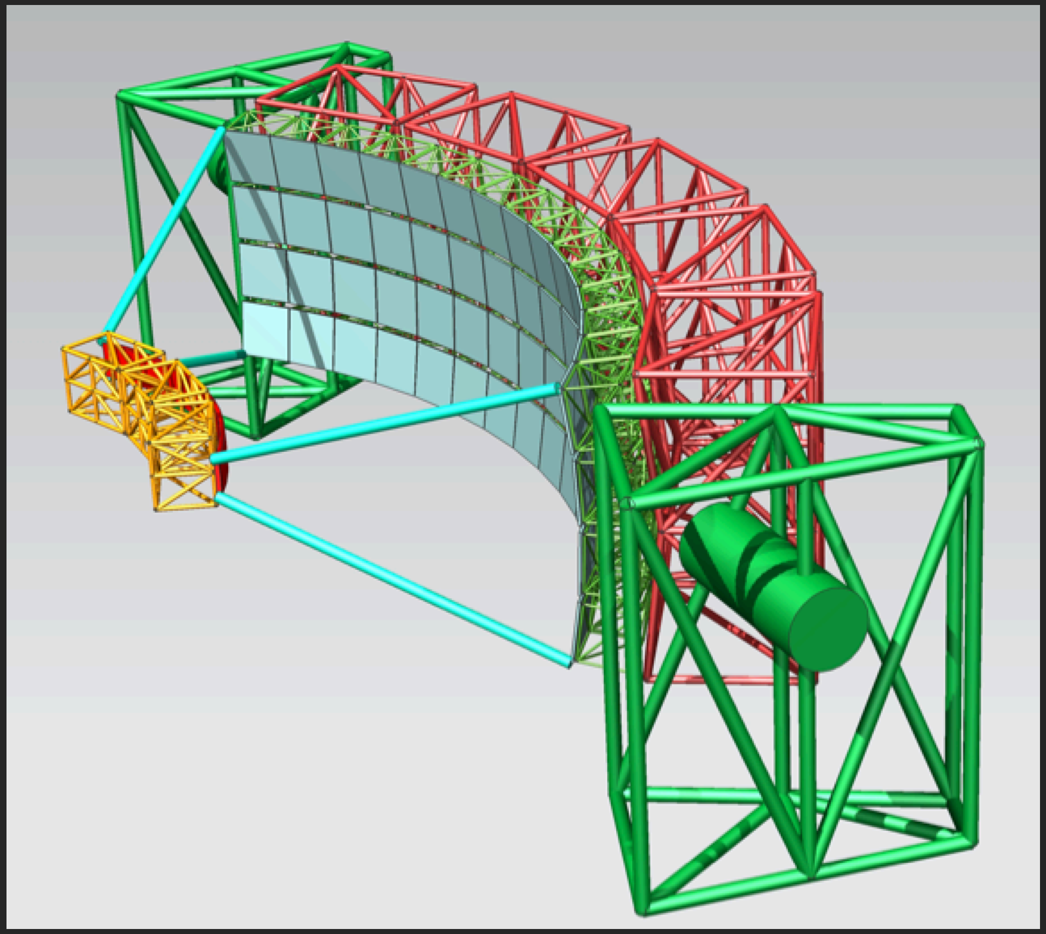






Trinity: A large Field-of-View Air-Shower Imaging Instrument to explore the UHE-Neutrino Sky down to PeV Energies

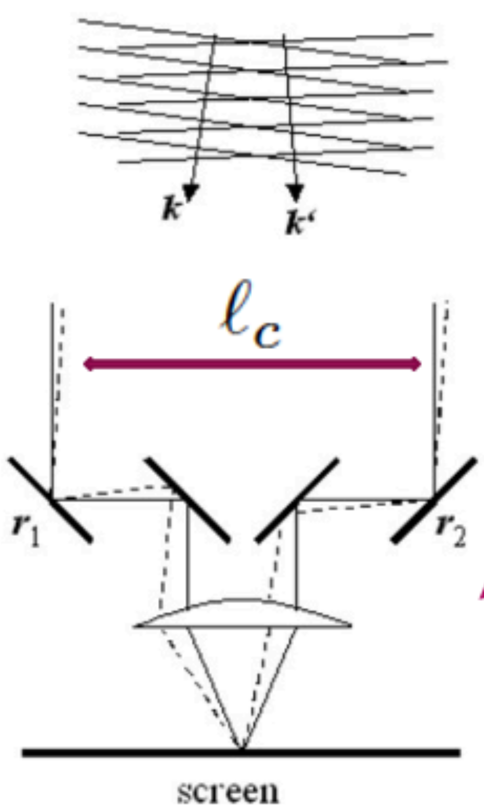




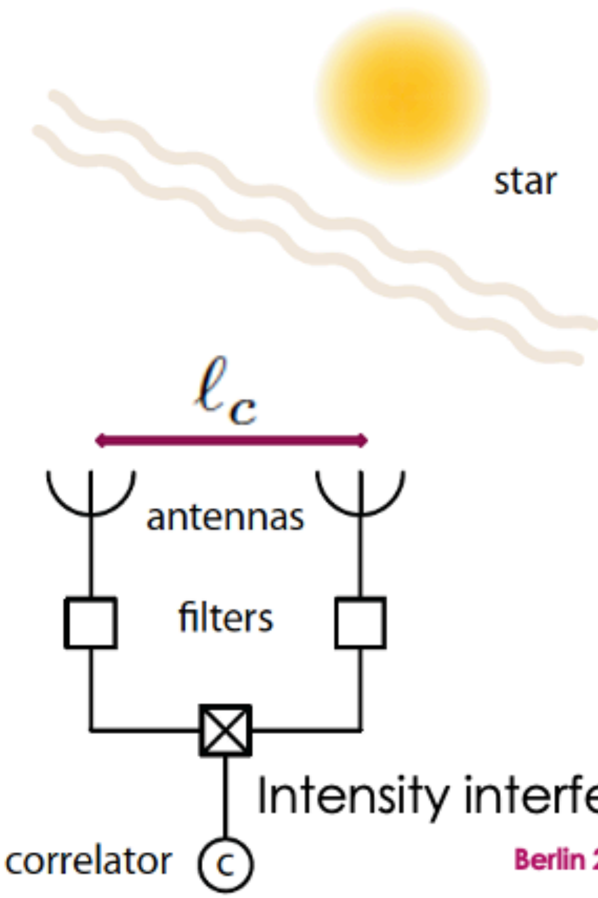
Intensity interferometry

First and second order coherence

$$\Delta\theta = \frac{\lambda}{\ell_c} \quad .$$

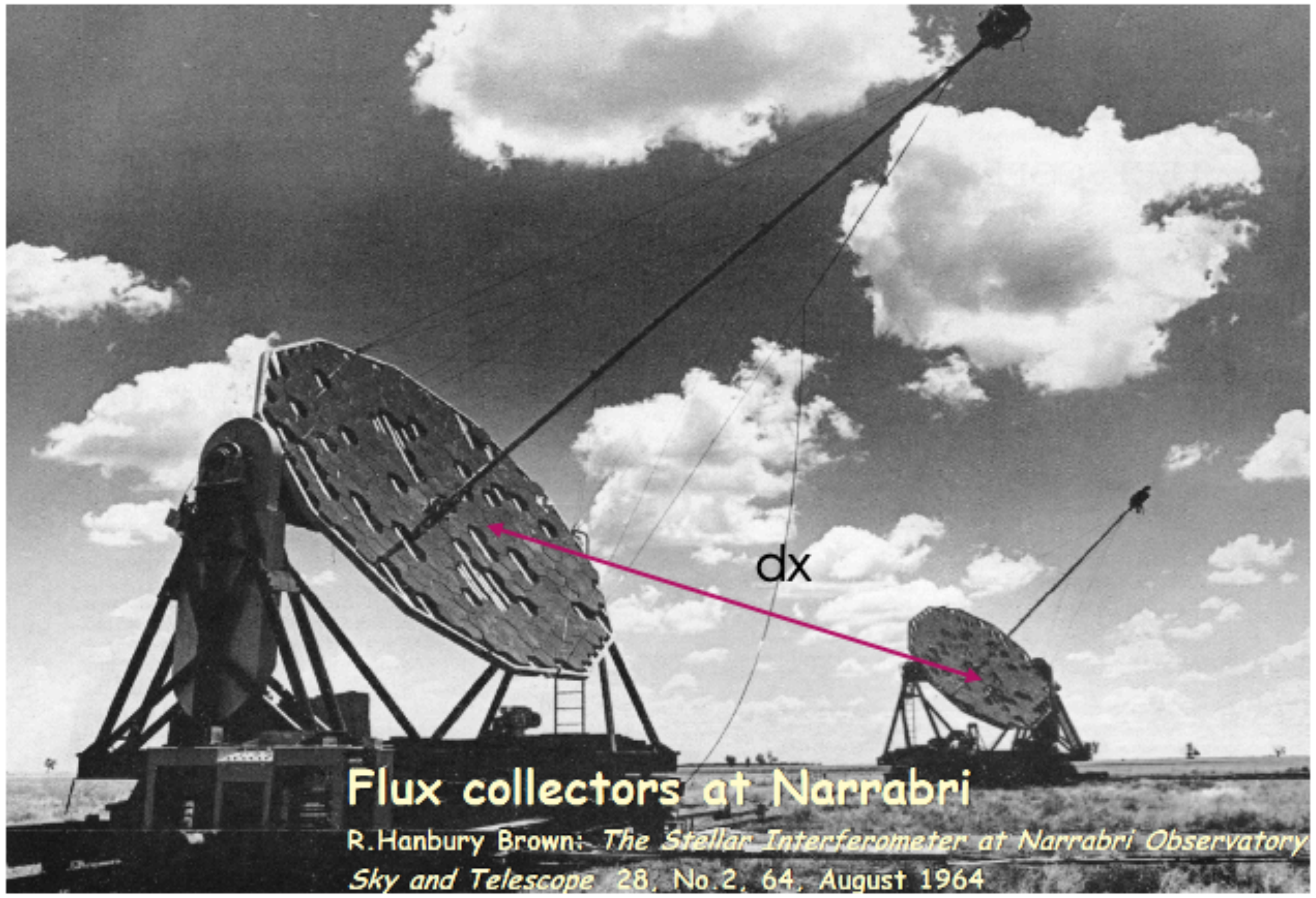


Michelson stellar interferometer

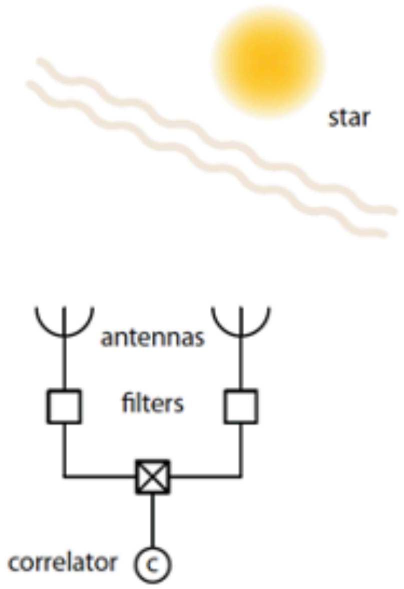


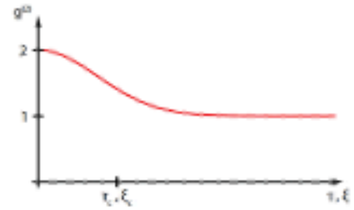
Intensity interferometer

Second order coherence



$$C = \langle I(\boldsymbol{r}_1) I(\boldsymbol{r}_2) \rangle = I_0^2 g^{(2)}(\boldsymbol{r}_1, \boldsymbol{r}_2)$$



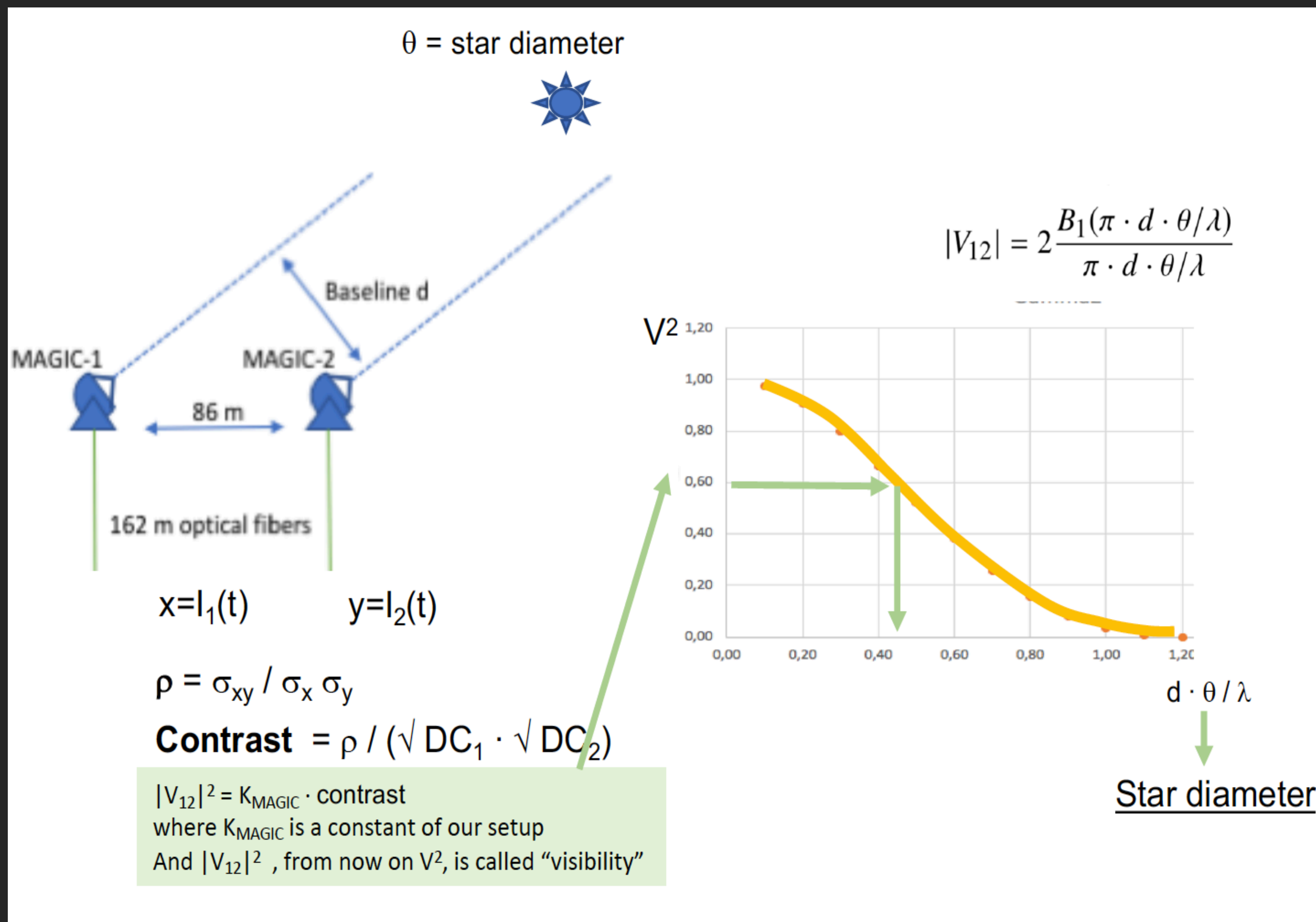


$$\Delta\theta = \frac{\lambda}{\ell_c} \quad .$$

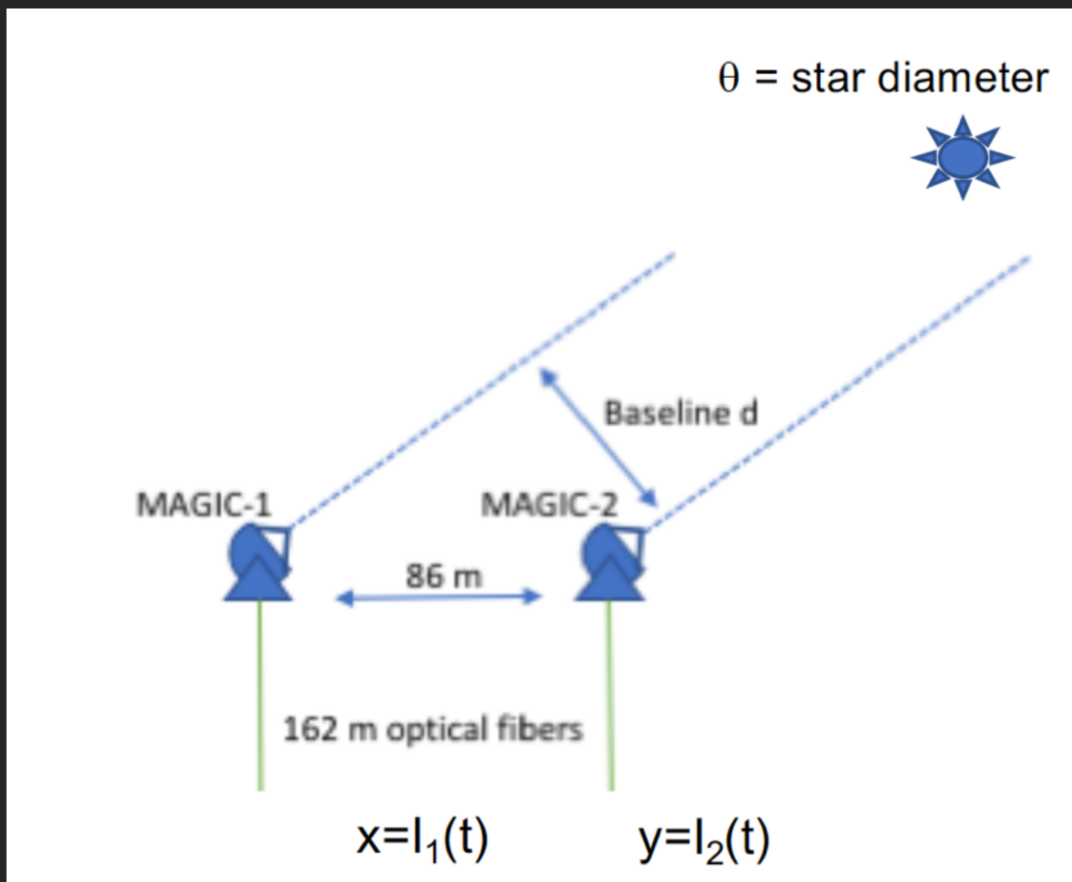
The correlation with the intensity gives directly $g^{(2)}$

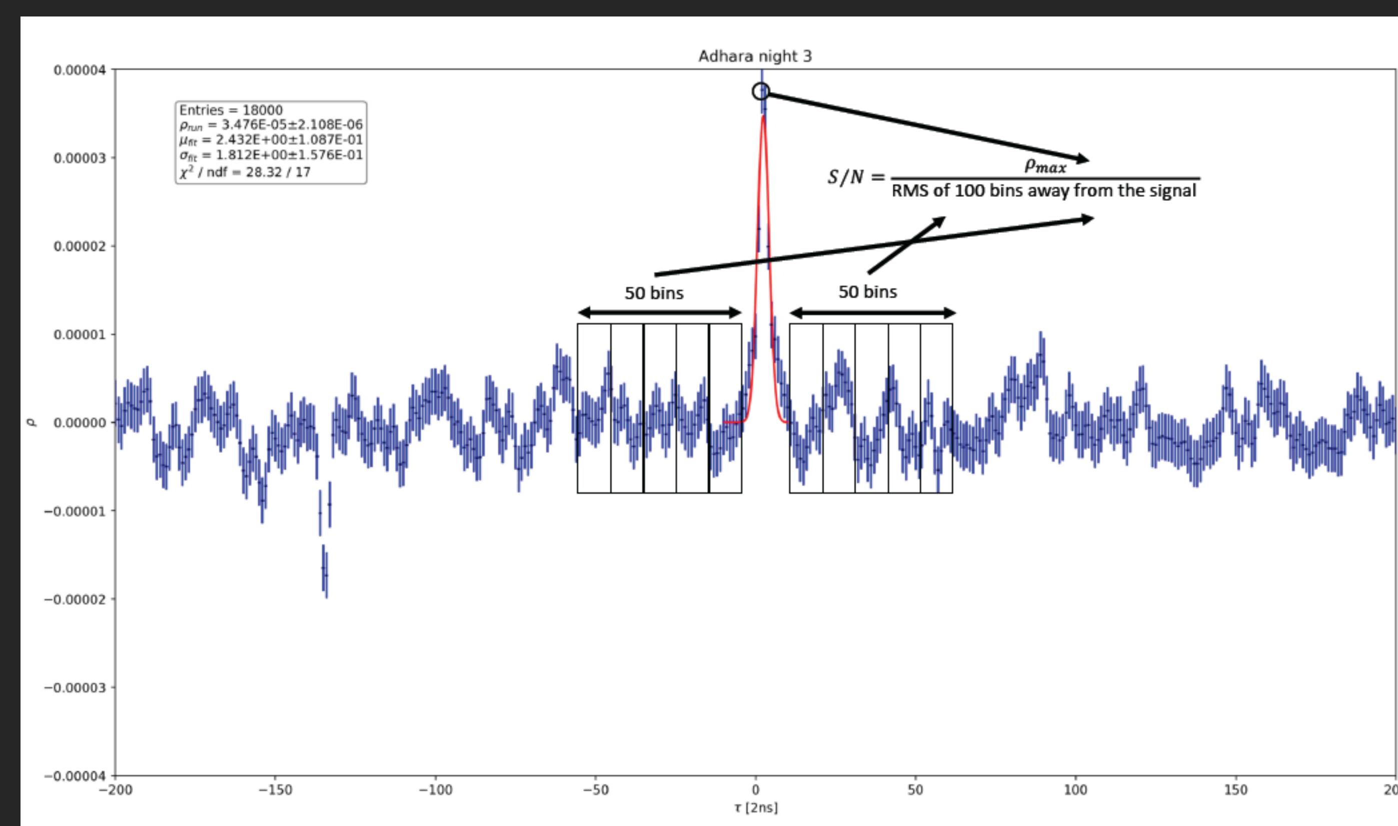
Stellar interferometry

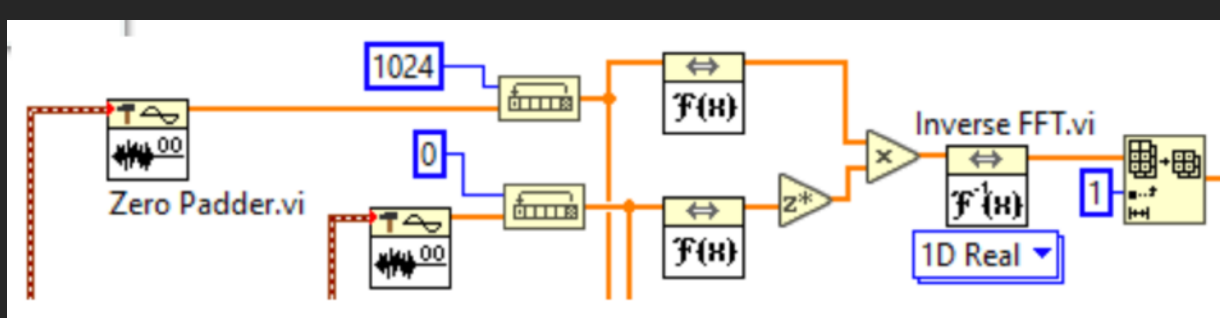
Nearby telescopes like MAGIC



Stellar interferometry with MAGIC







Cross correlation via FFT algorithm in LabView

Stellar interferometry: single photon offline correlators

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INAF-ASTRONOMICAL OBSERVATORY OF PADOVA

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UNIVERSITY OF PADOVA
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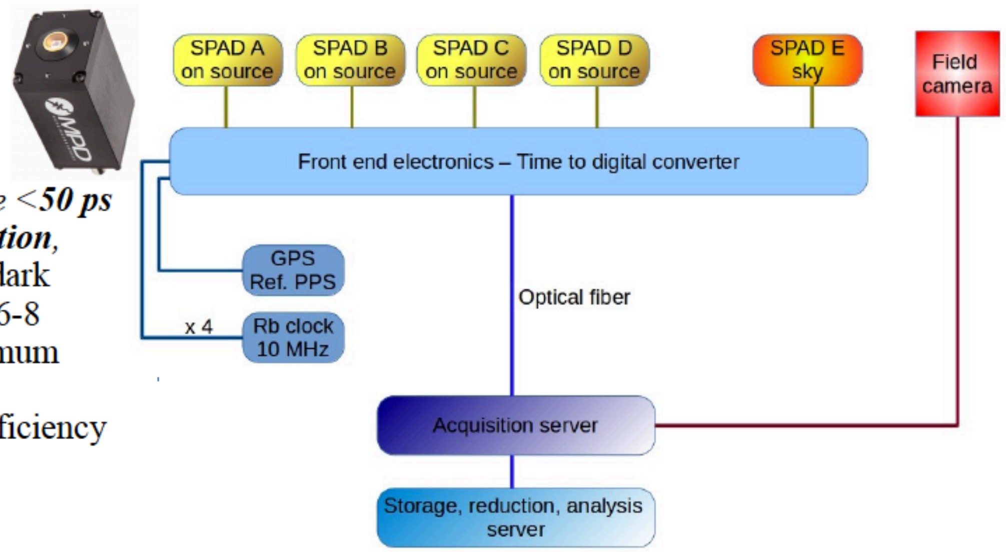
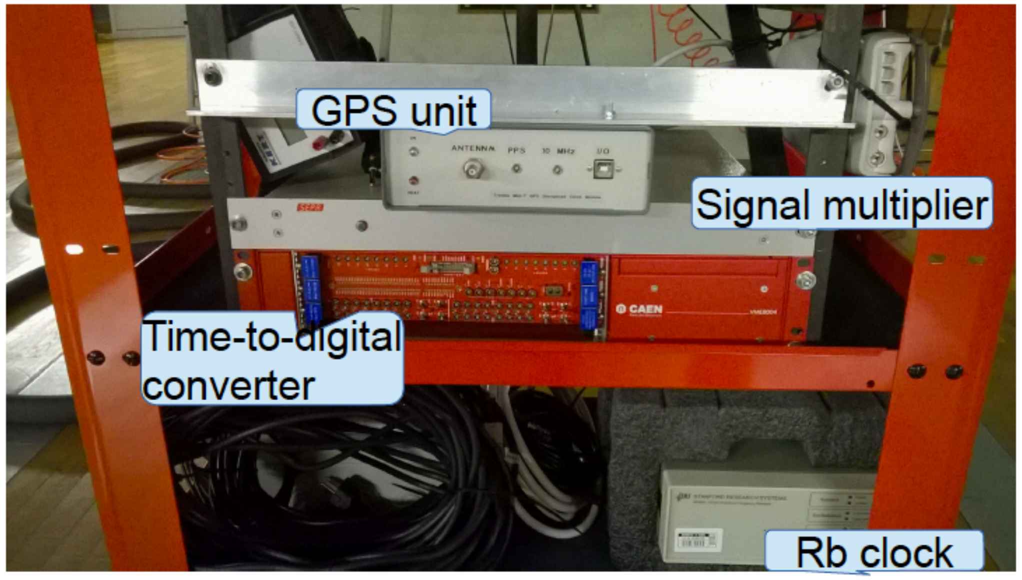
A very accurate acquisition and timing system



SPADs have <50 ps ***time resolution***, ~100 cts/s dark count rate, 6-8 MHz maximum count rate, quantum efficiency up to 60%



Our instruments time tag and store the arrival time of each detected photon with a <100 ps relative time accuracy and <500 ps absolute time accuracy (wrt UTC)

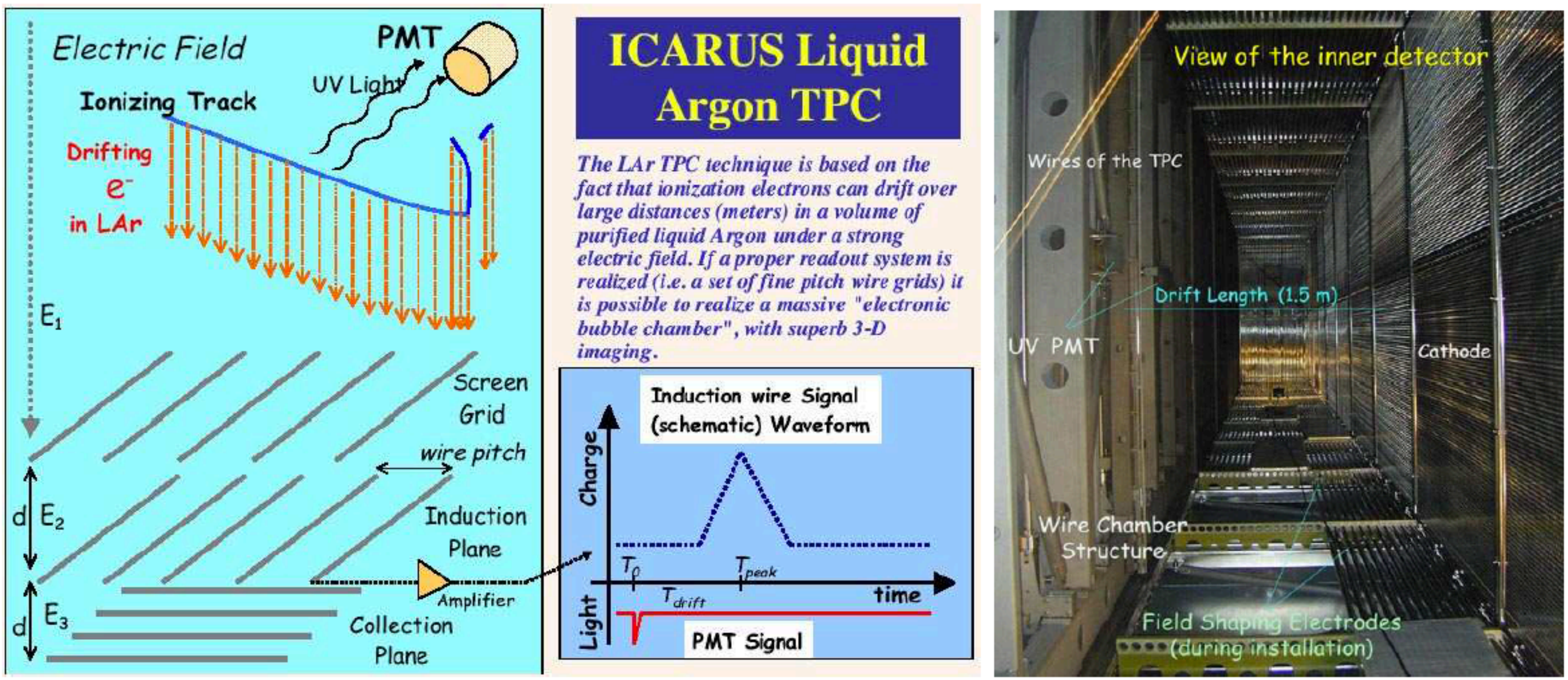
All times are stored in event lists that can be analyzed in post-processing

At present the maximum data rate is of the order of few MHz (in the linear regime)

Direct dark matter searches R&D

Liquid detectors

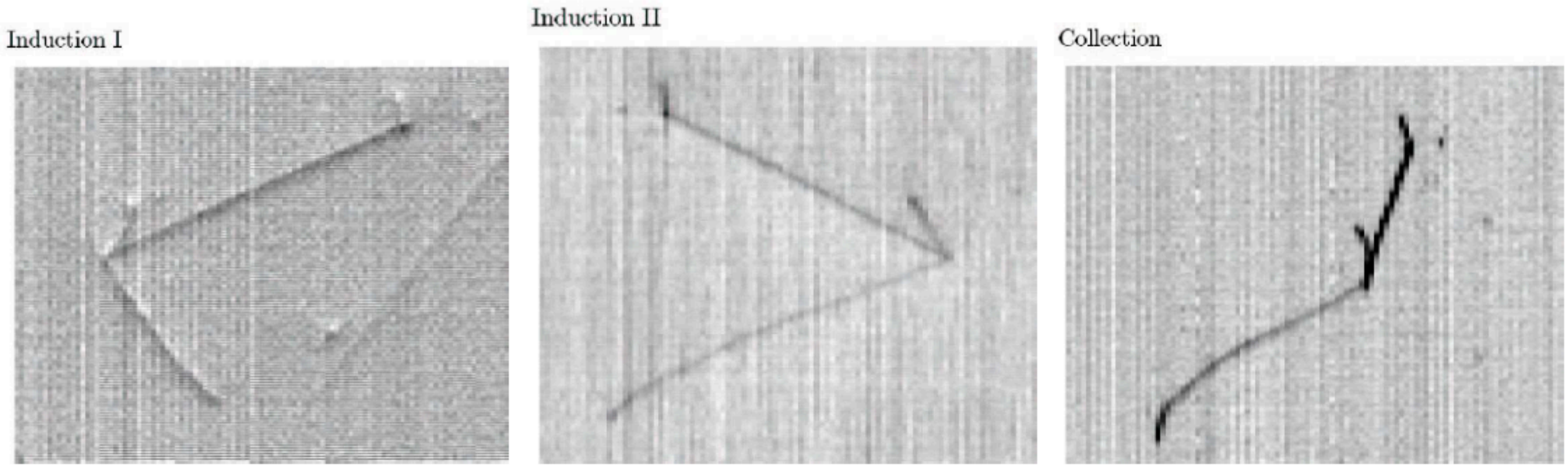
ICARUS Liquid Argon TPC



Liquid argon time projection chamber conceived by C. Rubbia (1977).

Liquid detectors

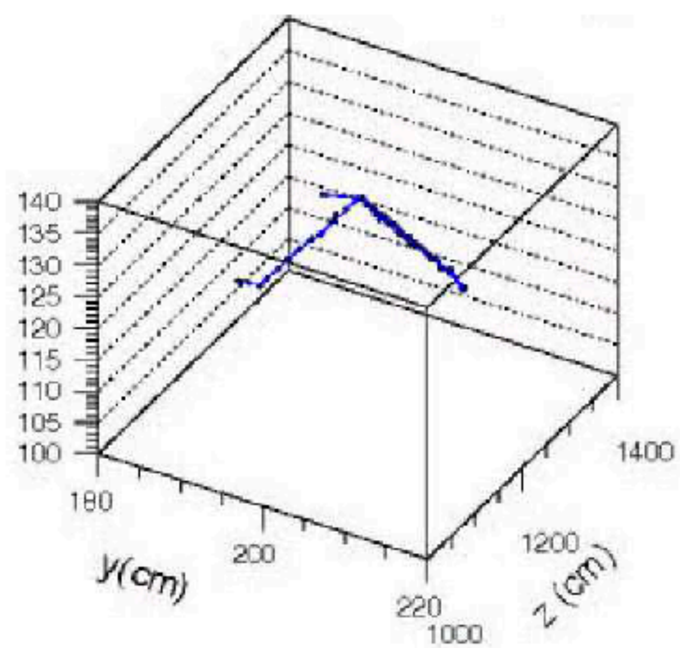
Events from the ICARUS T300 Cosmic Ray Test

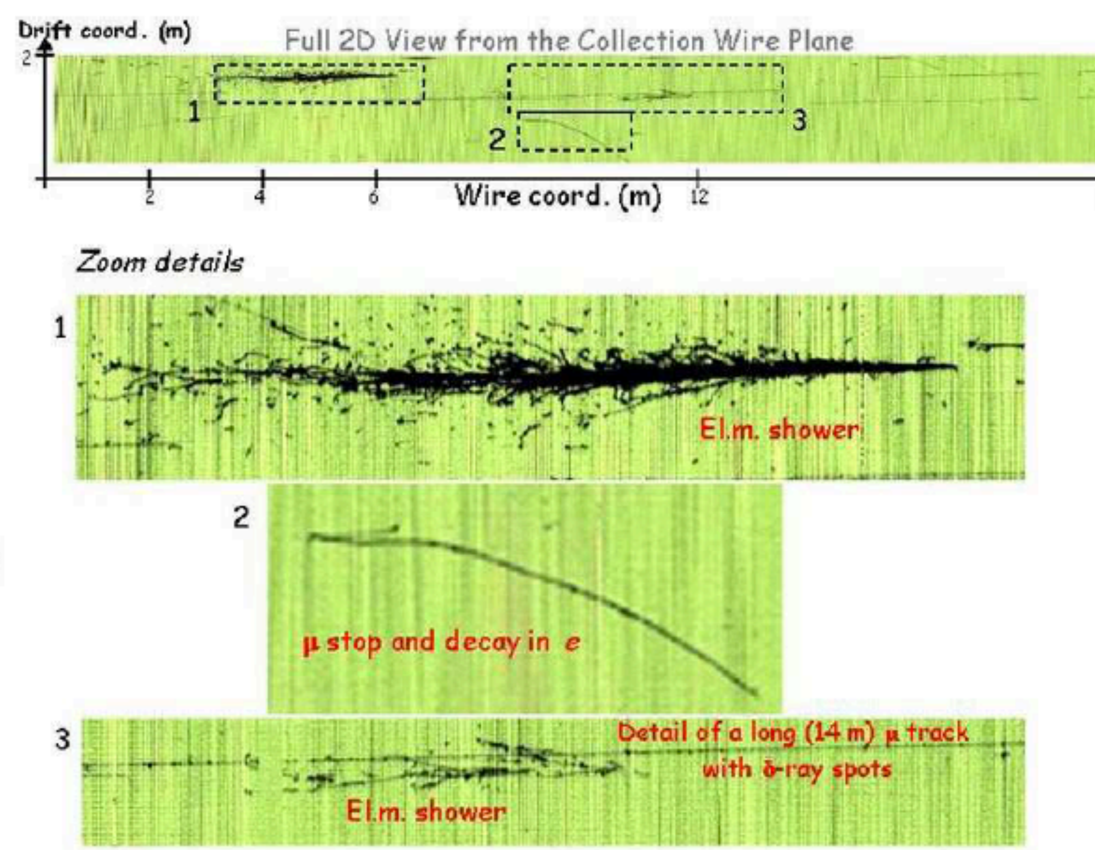


Above: 3 views of a low-energy hadronic interaction.

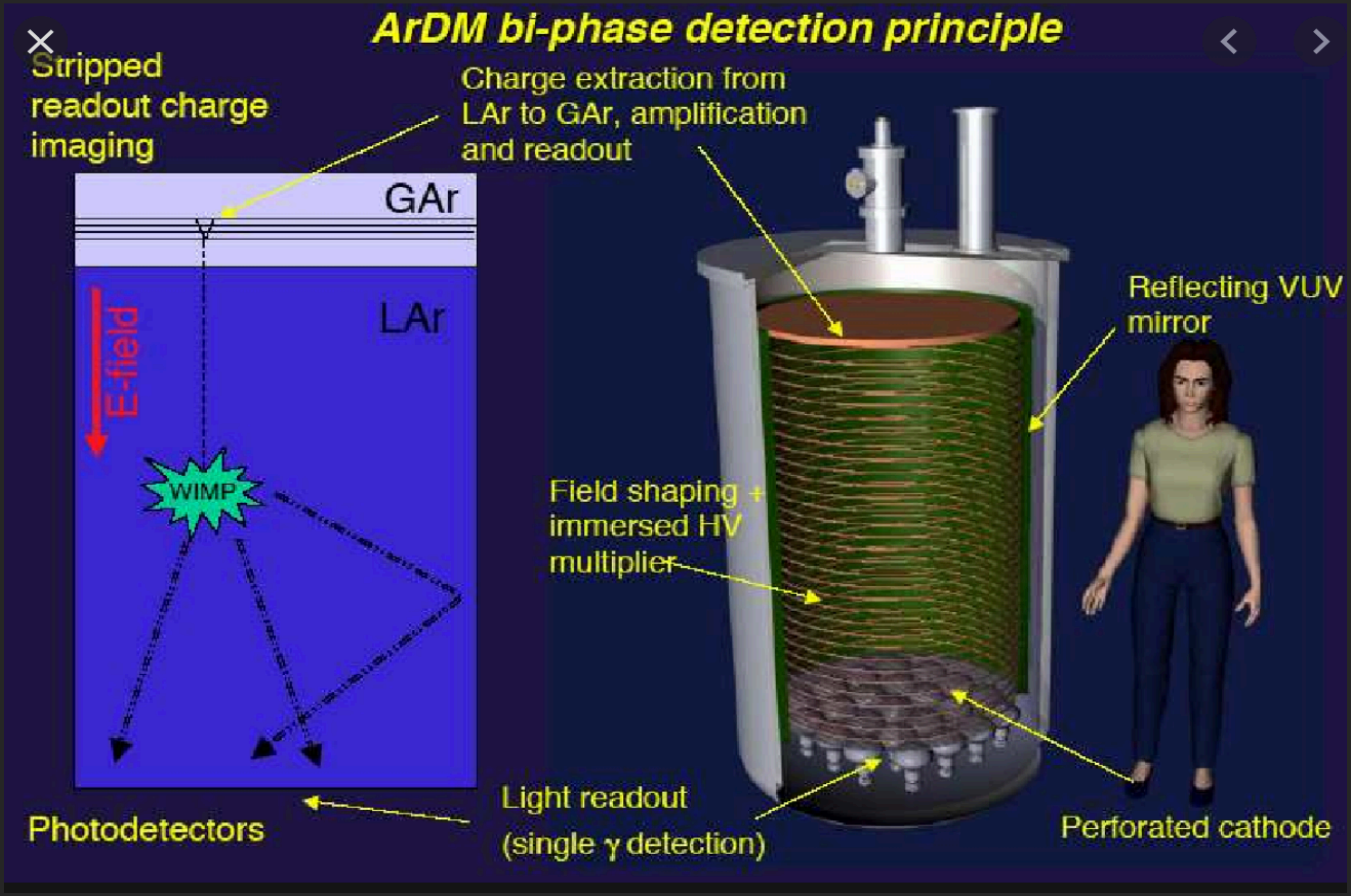
Right: Computer reconstruction.

Far right: Cosmic ray shower that includes a muon with a δ-ray, a stopping muon, and an electromagnetic shower.

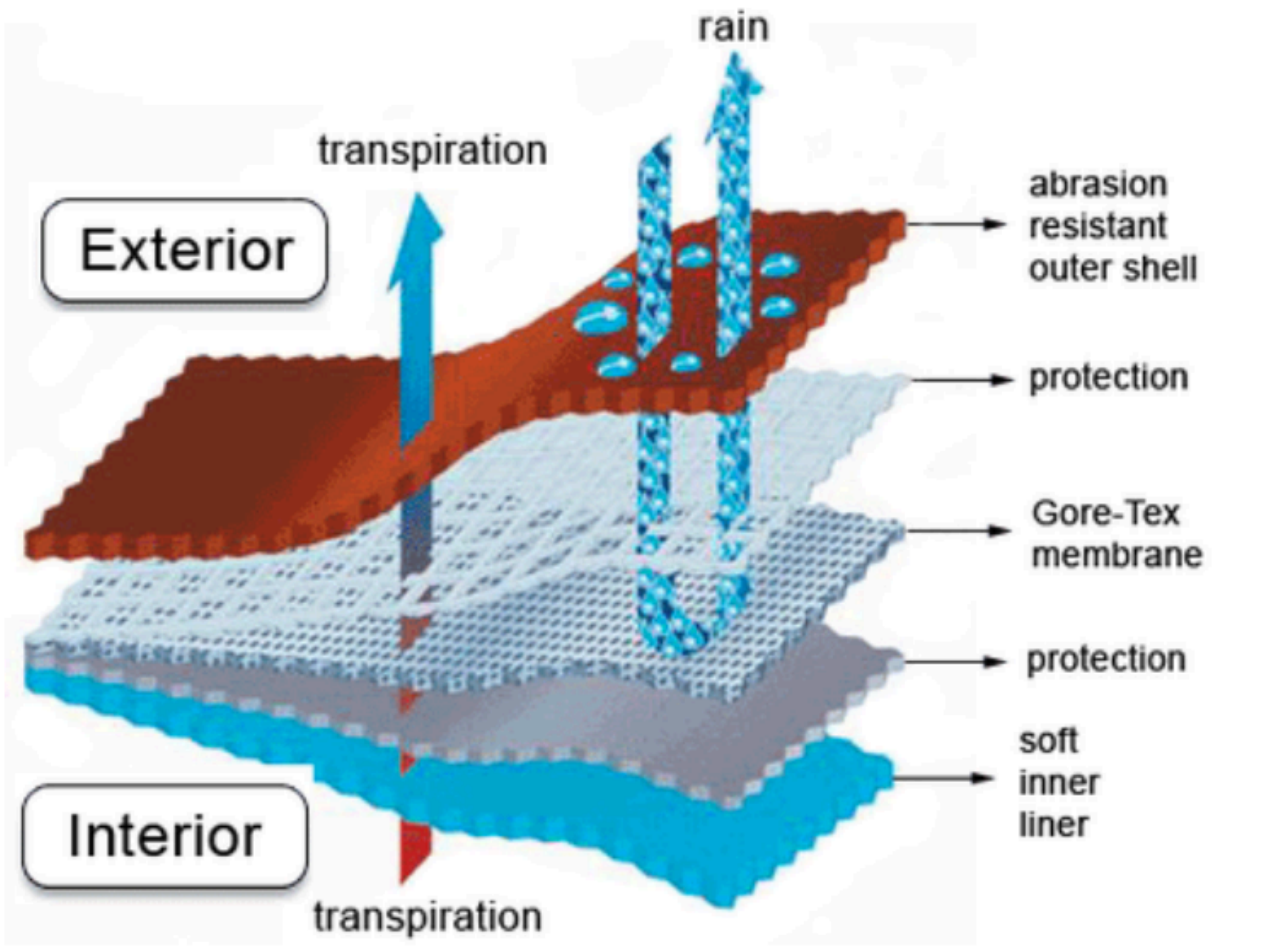




Double phase detectors for low ionization events

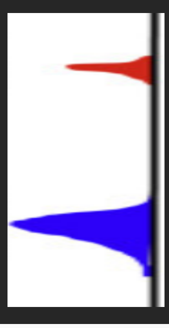


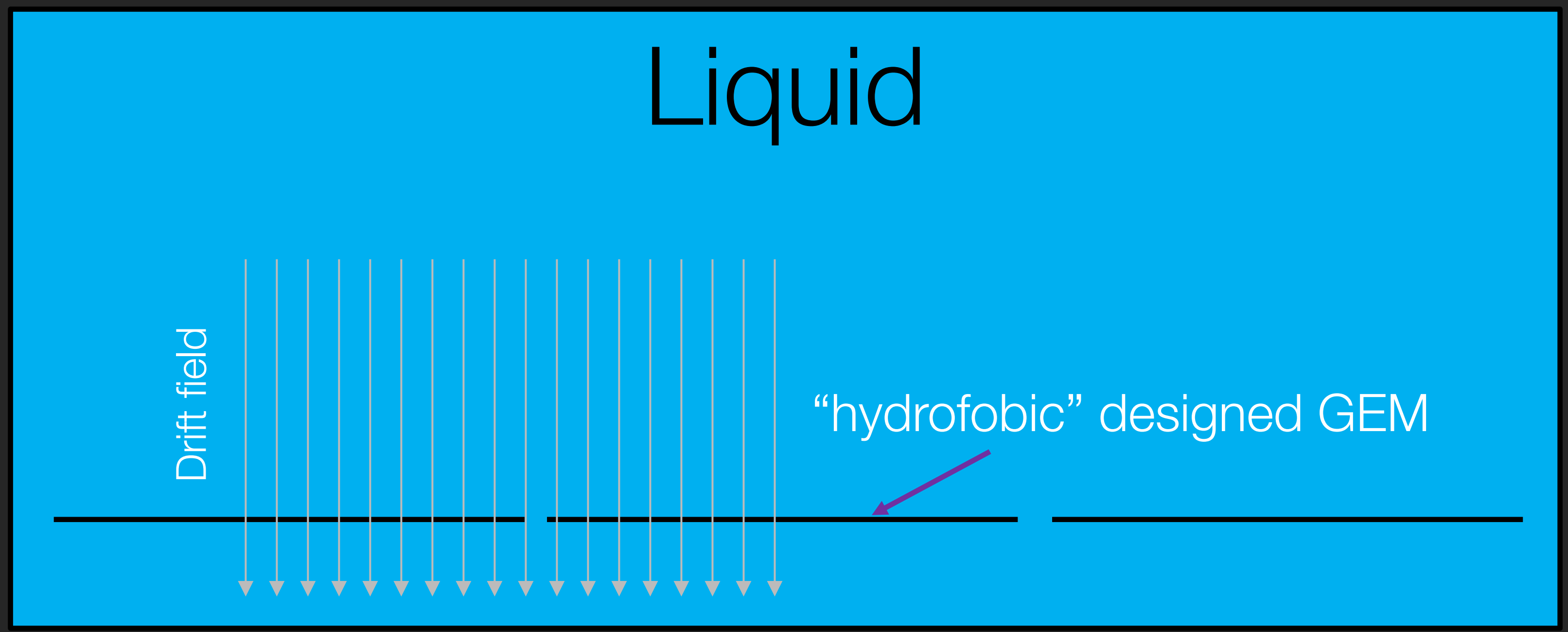
Local double phase liquid electron multiplier

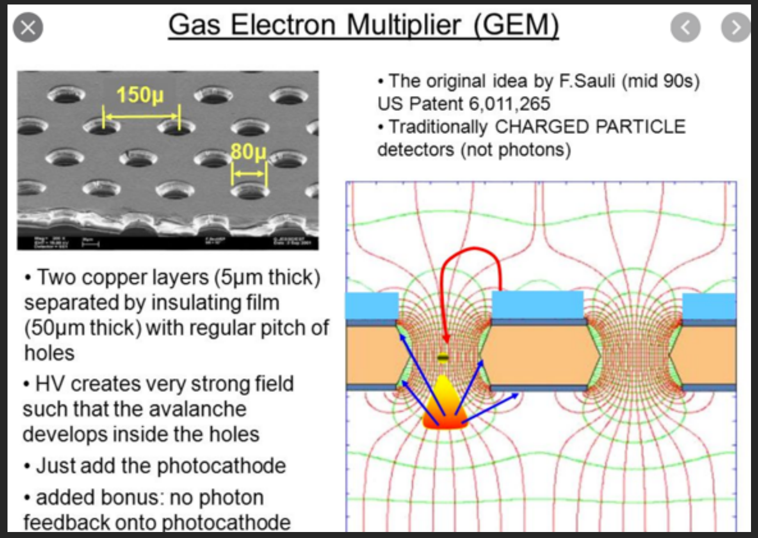


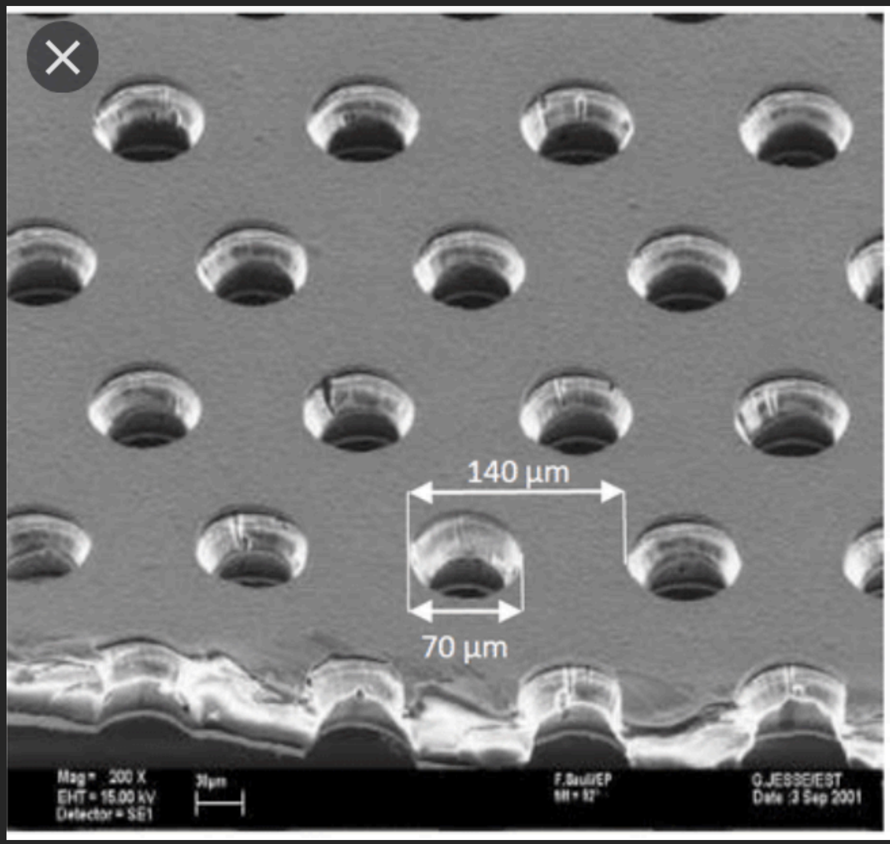
Schematic of a composite Gore-Tex fabric for outdoor clothing

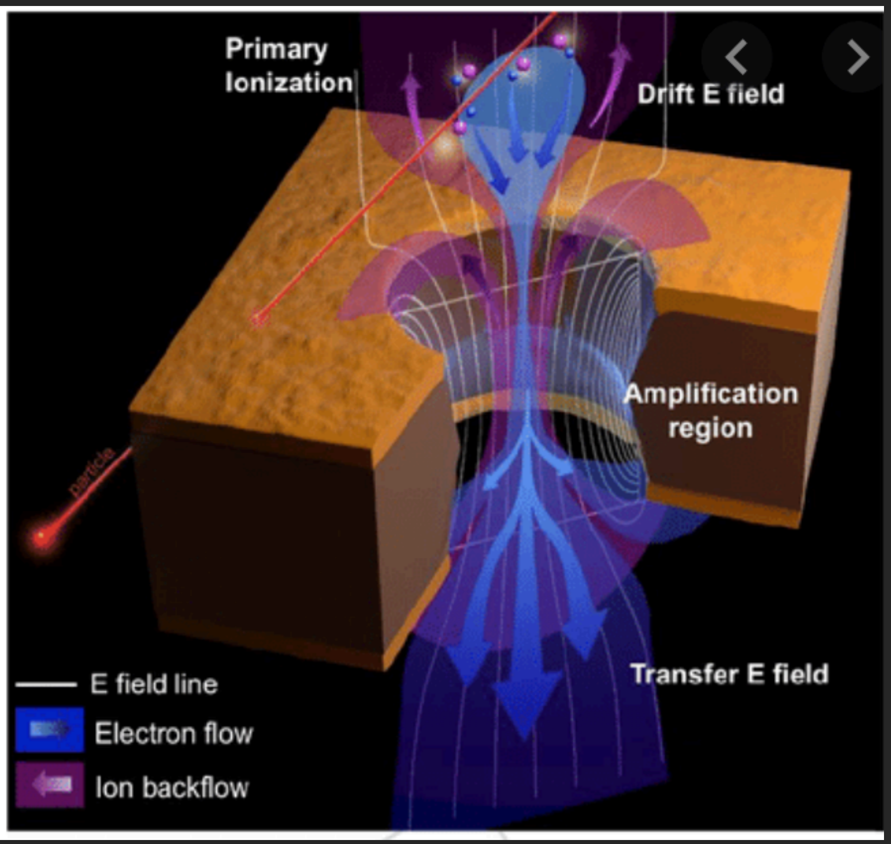
Local double phase liquid electron multiplier











Helpful discussion already started started with "structure of matter colleagues"

- Chiara Maurizio
- Matteo Pienrno

Keys of design are

- Holes diameters
- Surface treatments

Thanks