International Symposium on Future Directions in UHECR Physics

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A conceptual design for a large ground array of Fluorescence Detectors

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Context

- We have now a clearer picture of UHECRs:

  "GZK-like" cutoff, change in composition/cross section?, weak anisotropy

- We are successfully operating large arrays of cosmic ray detectors. We know how to do it. We have considerably improved our detector design and refined the data analysis. We know what could be further improved and what could be simplified.

- Time is favorable for a coherent action of the major actors in the field towards a very large ground array experiment. Synergies with space projects. "Future directions in UHECR Physics" at CERN is a first step, apparently very successful from its large attendance.

- The scientific case for the future of UHECR will become clearer with data collected in the next five years. A strong scientific case is necessary to justify THE next generation experiment.

- The design of this next generation experiment must proceed in parallel. The community should start very soon the process of evaluating different detector options.

My view on the future of UHECR

- Focus on the highest energies, > $10^{19.5}$ eV, with X_{max} measurement

  spectrum, composition/hadronic interactions, anisotropy

- At least the same statistics of Auger above $10^{19.5}$ eV, but with high quality X_{max} measurement

  - maybe radio (MHz/GHz/radar) technique will work, but what if not?

  ➡ A ≥ 40000 km^2 area with a Fluorescence Detection technique

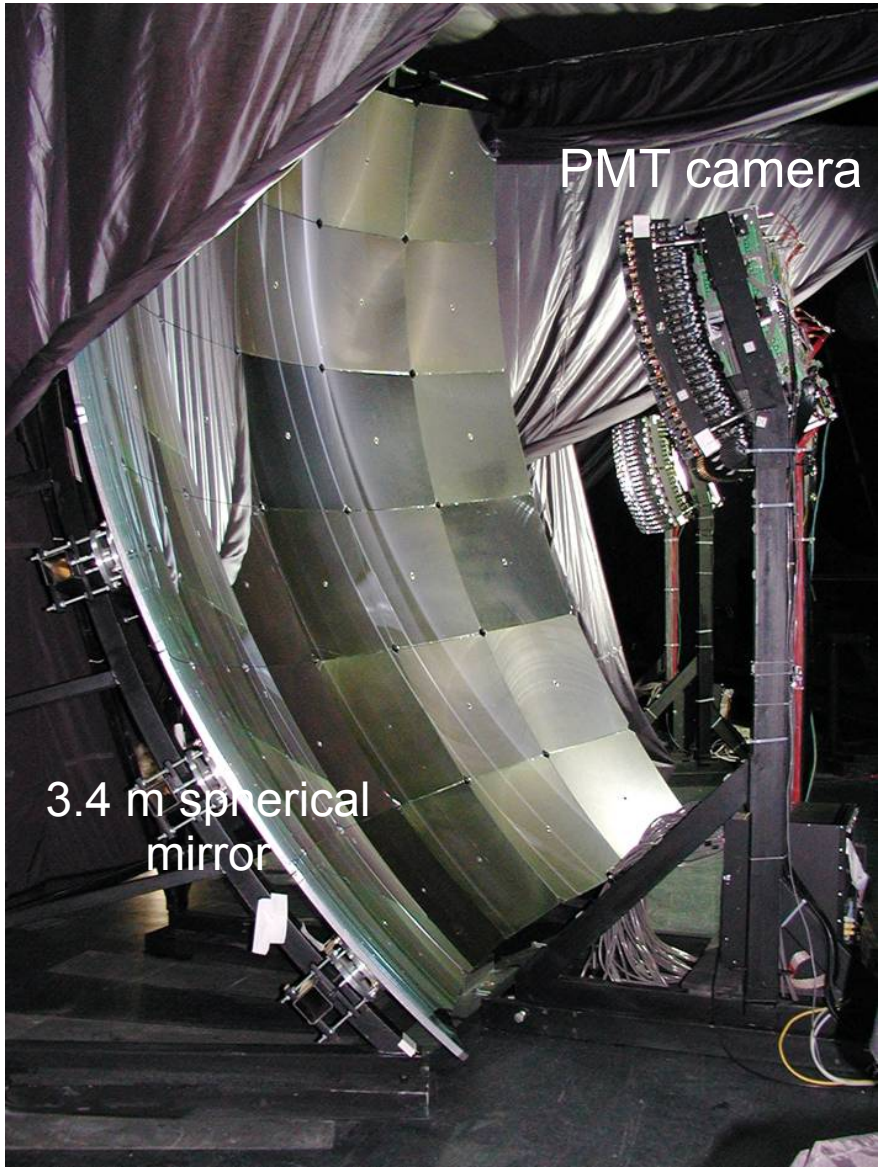
(ambitious enough?)

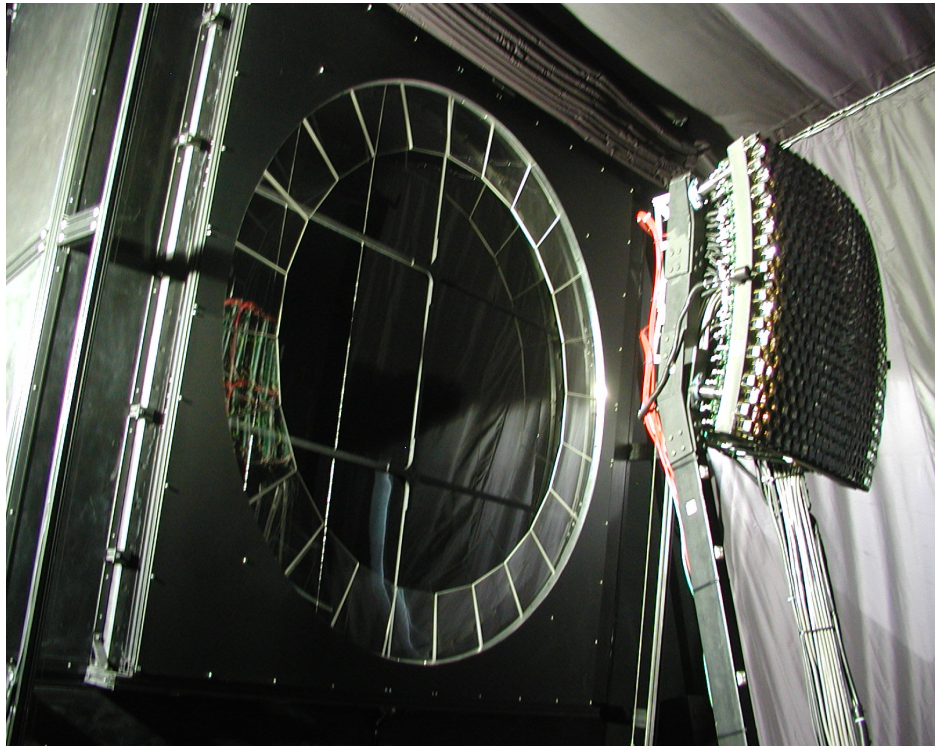
- Funding for a >100 M$ project based on a conventional SD/FD design may not be easy

We need a radical reduction of the cost

- maybe the radio technique will work and be very cheap, but what if not?

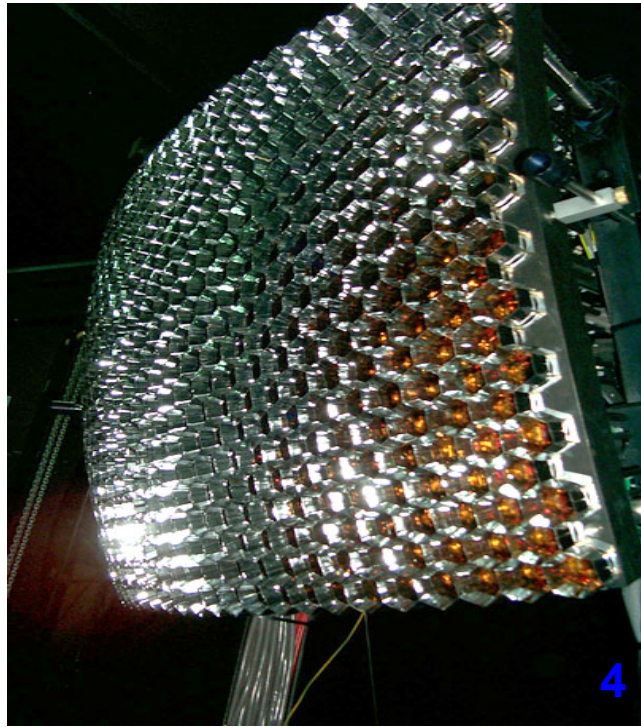
  ➡ think out of the box: a new look to the Fluorescence Detection technique





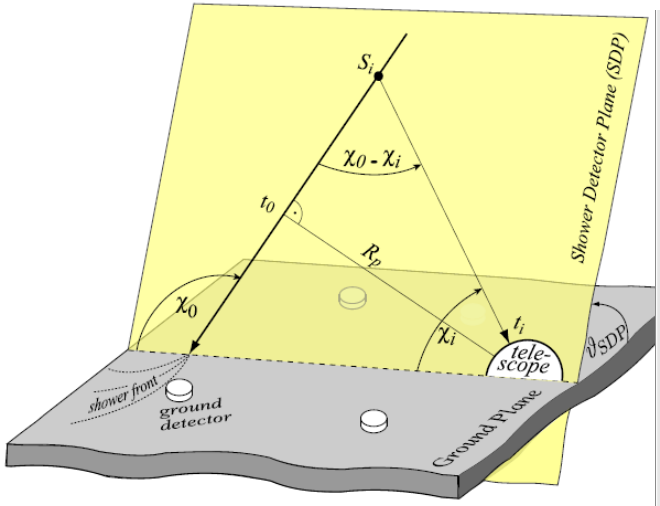
The Auger FD

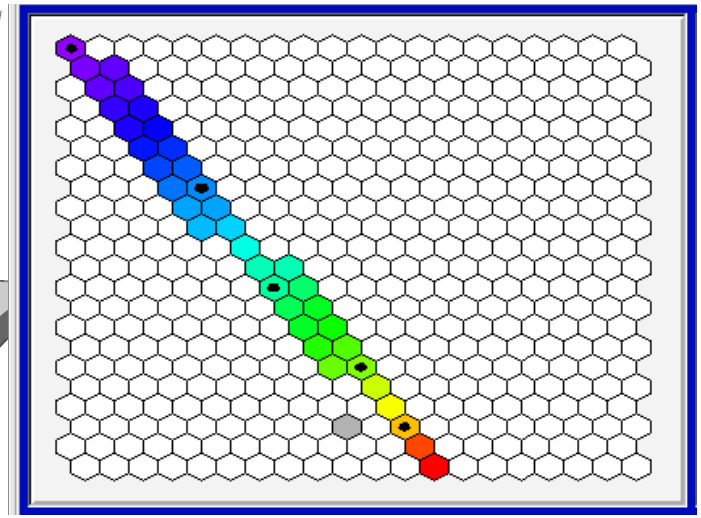
Schmidt optics with corrector ring
Spherical surface camera
440 PMT with light collectors
Large $30^0 x 30^0$ field of view
1.5^o pixel fov
(spot 1/3 of pixel)

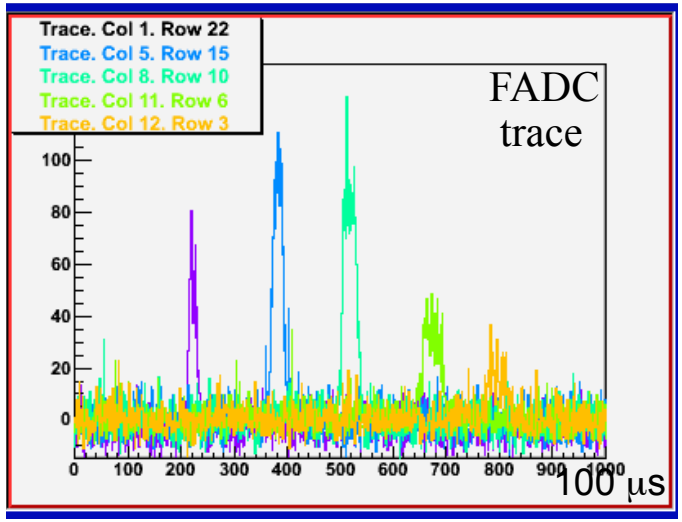


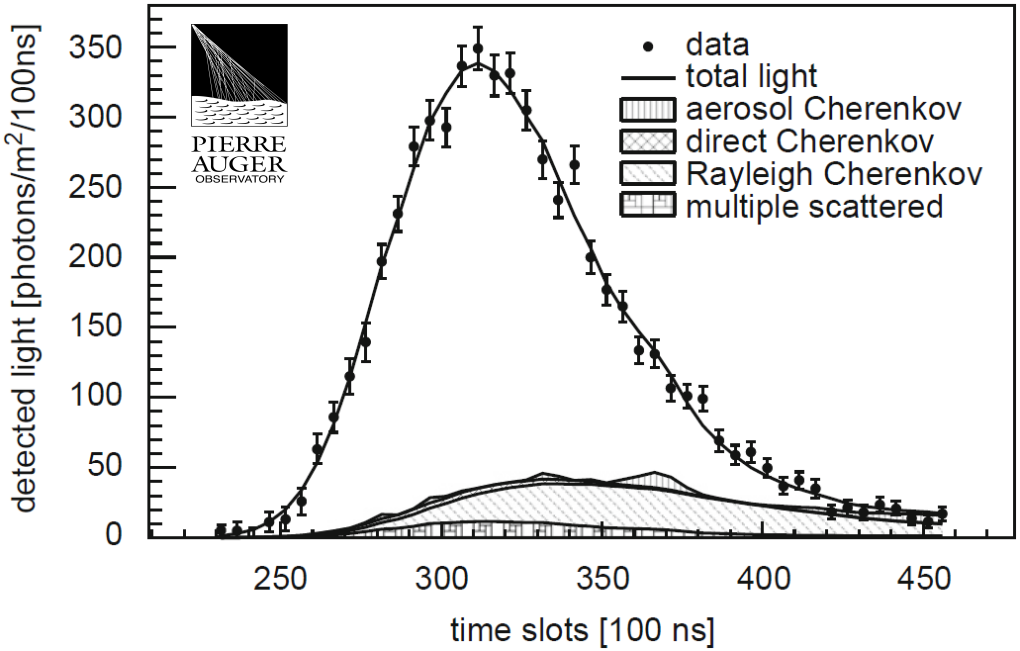
The TA FD

The conventional FD telescope









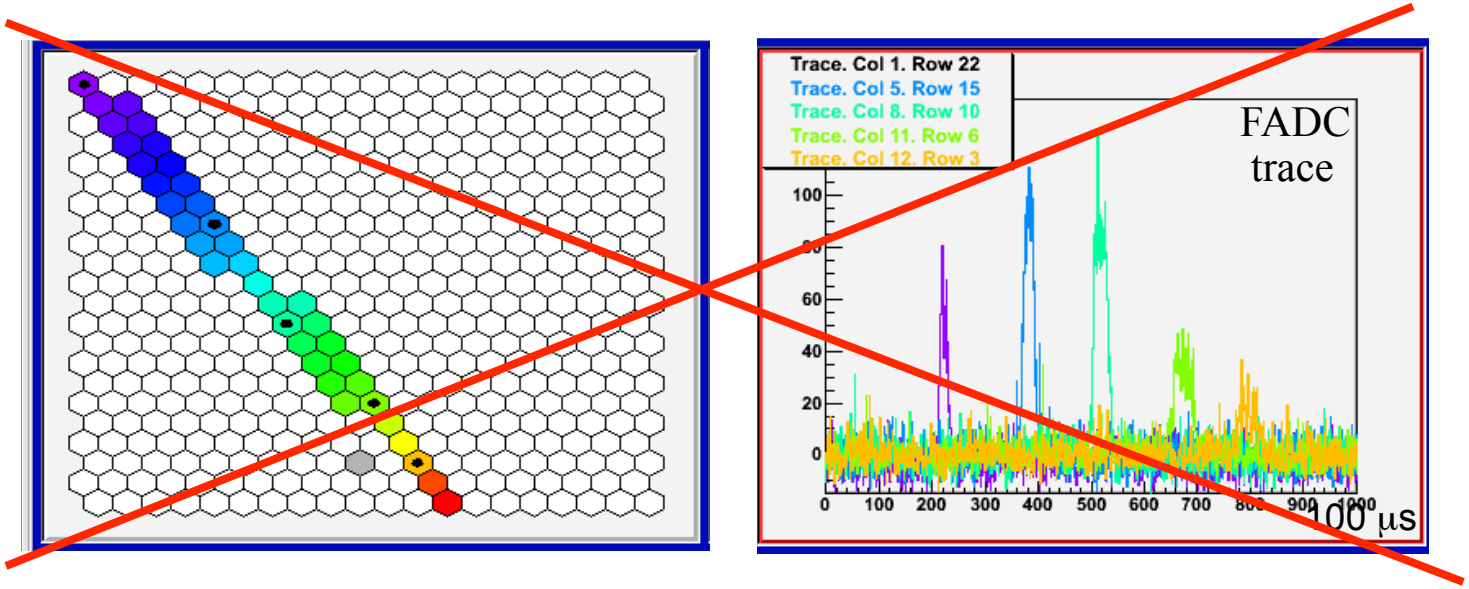
- Geometry from shower detector plane + timing (tank if hybrid)
- Once geometry is known, photon at diaphragm can be estimated
- With proper corrections for Cherenkov and atmosphere, X_{max} is obtained from Gaisser-Hillas fit

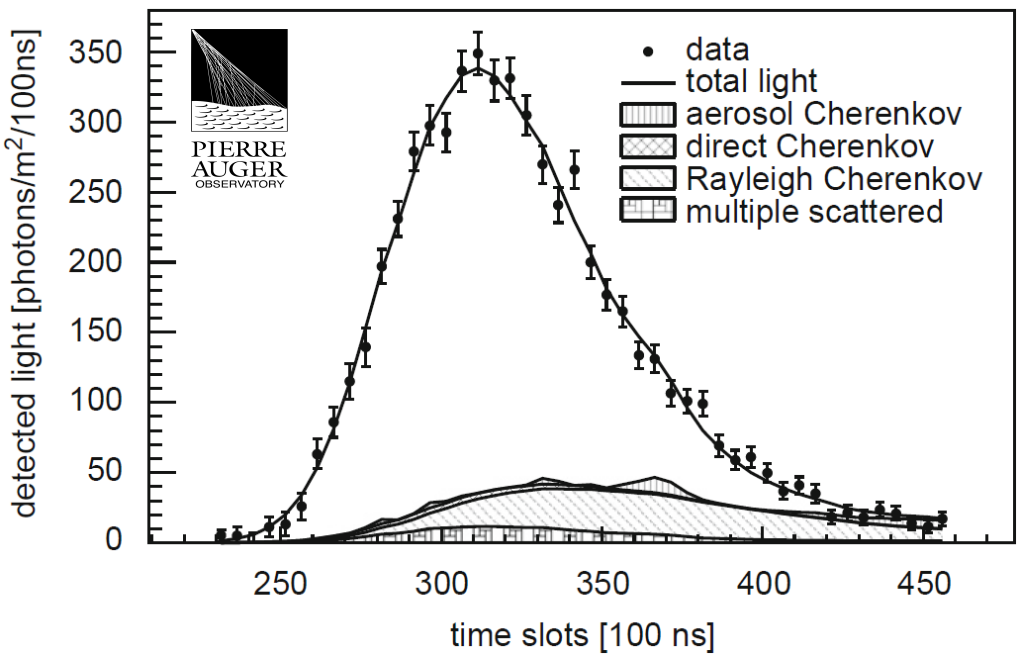
A new concept for the FD telescope

- Instead of 440 pixels

ONLY ONE PIXEL

(or few)



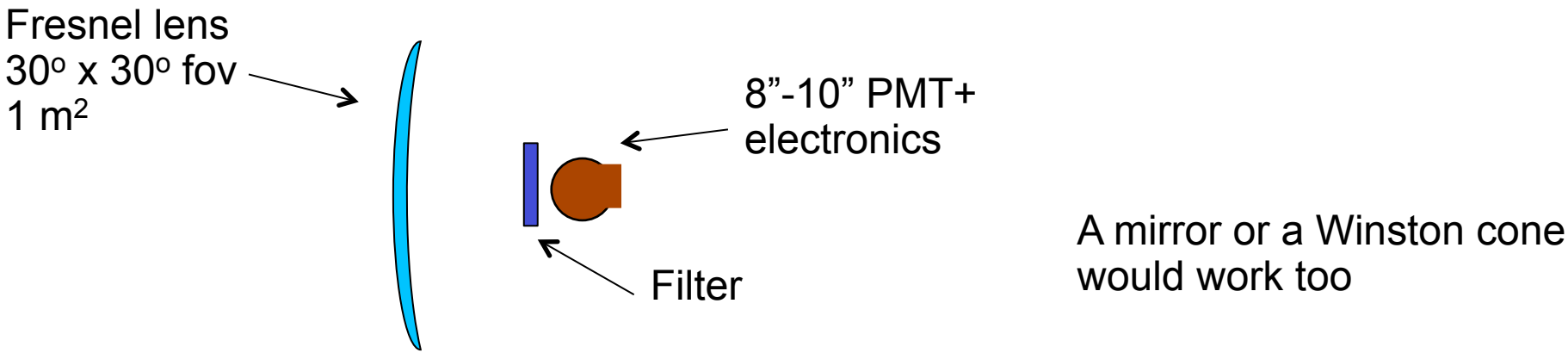


- ~~Geometry from shower detector plane + timing (tank if hybrid)~~

'Somebody' provides the geometry

- Once geometry is known, photon at diaphragm can be estimated
- With proper corrections for Cherenkov and atmosphere, X_{max} is obtained from Gaisser-Hillas fit

A simple (low cost) design



NOTE: in the conventional design, aberrations (e.g. coma) spread the signal over several pixels reducing the S/N, and considerable effort was put in improving the design (Schmidt optics , spherical camera in Auger). Aberrations are much less important in this simplified design, since light is distributed over the large PMT photocathode but at the same time

- NOTE: we are integrating the night sky bkg over a wide fov. S/sqrt(N) significantly worse than conventional FD, but

  - we are focusing on the highest energies $>10^{19.5}$ eV

  - we can work on the design parameters of the telescope and the array to achieve this energy threshold: lens collecting area, fov, more than one pixel, filters, distance between eyes.

A 40000 km^2 FD-array

Example:

- 12 PMTs/ 360° station
- 120 stations
- 1248 PMTs total

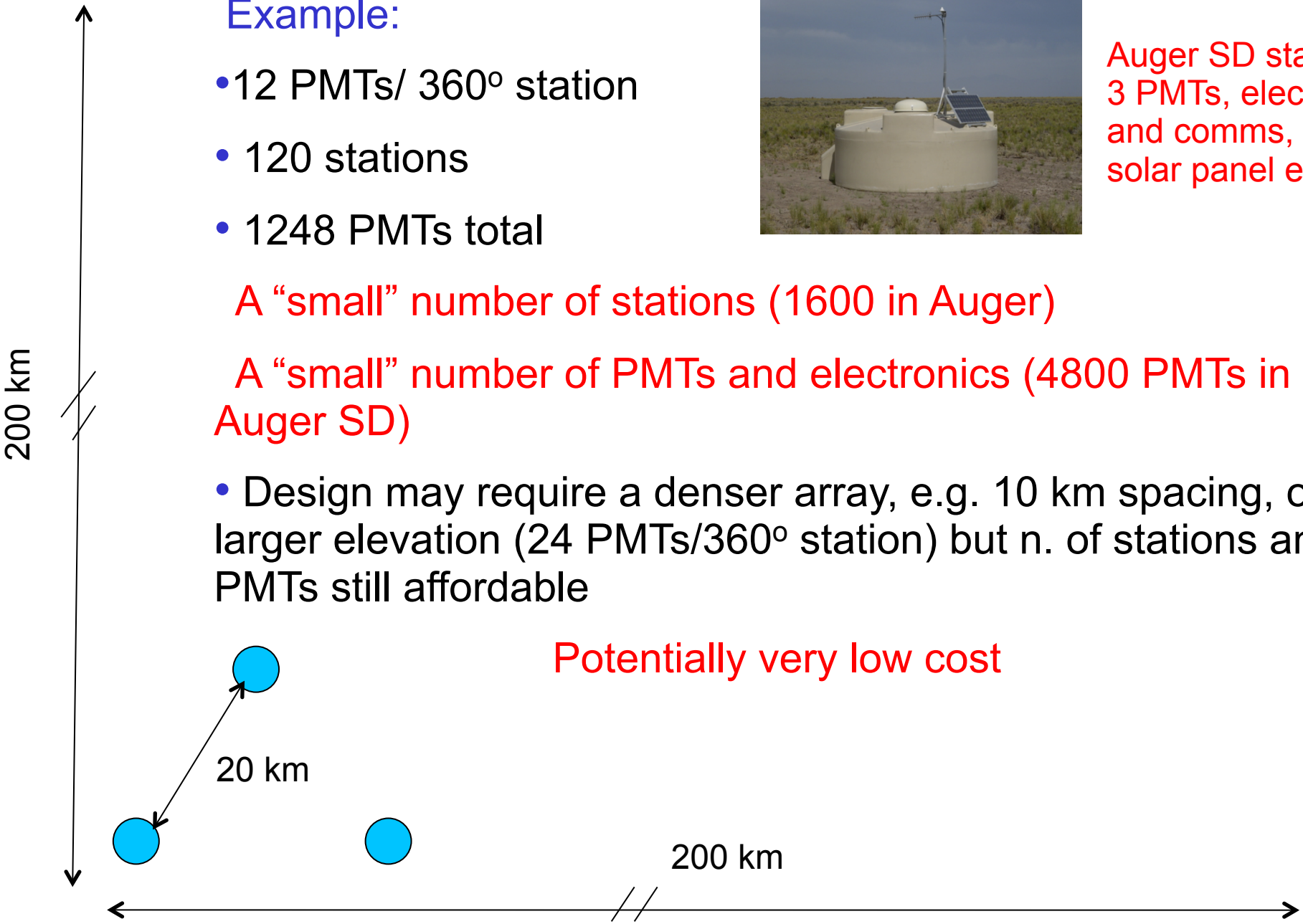
Auger SD station: 3 PMTs, electronics and comms, small solar panel enough

A “small” number of stations (1600 in Auger)

A “small” number of PMTs and electronics (4800 PMTs in Auger SD)

- Design may require a denser array, e.g. 10 km spacing, or larger elevation (24 PMTs/360° station) but n. of stations and PMTs still affordable

Potentially very low cost



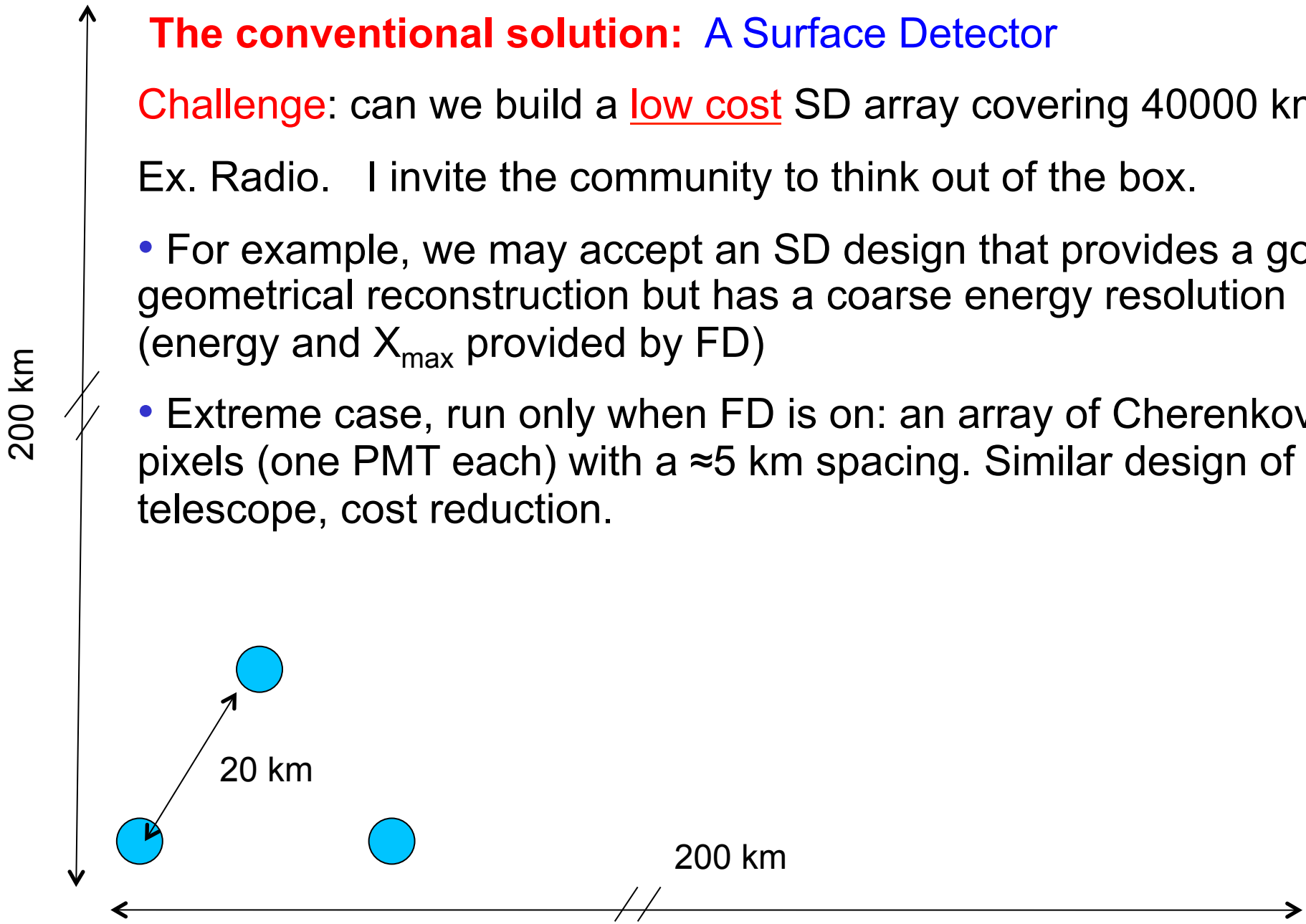
Who provides the geometry?

The conventional solution: A Surface Detector

Challenge: can we build a low cost SD array covering 40000 km^2?

Ex. Radio. I invite the community to think out of the box.

- For example, we may accept an SD design that provides a good geometrical reconstruction but has a coarse energy resolution (energy and X_{max} provided by FD)
- Extreme case, run only when FD is on: an array of Cherenkov/FD pixels (one PMT each) with a ≈5 km spacing. Similar design of FD telescope, cost reduction.



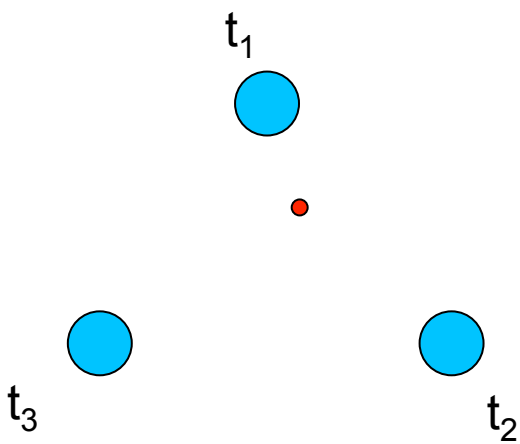
Who provides the geometry?

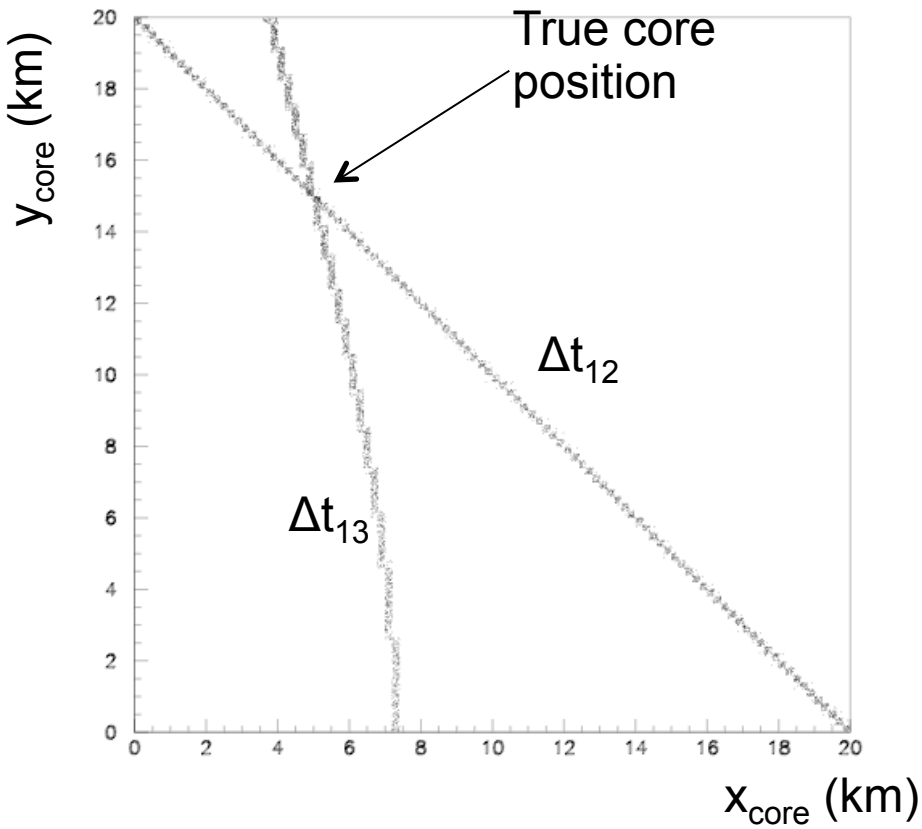
An unconventional and cost-attractive solution

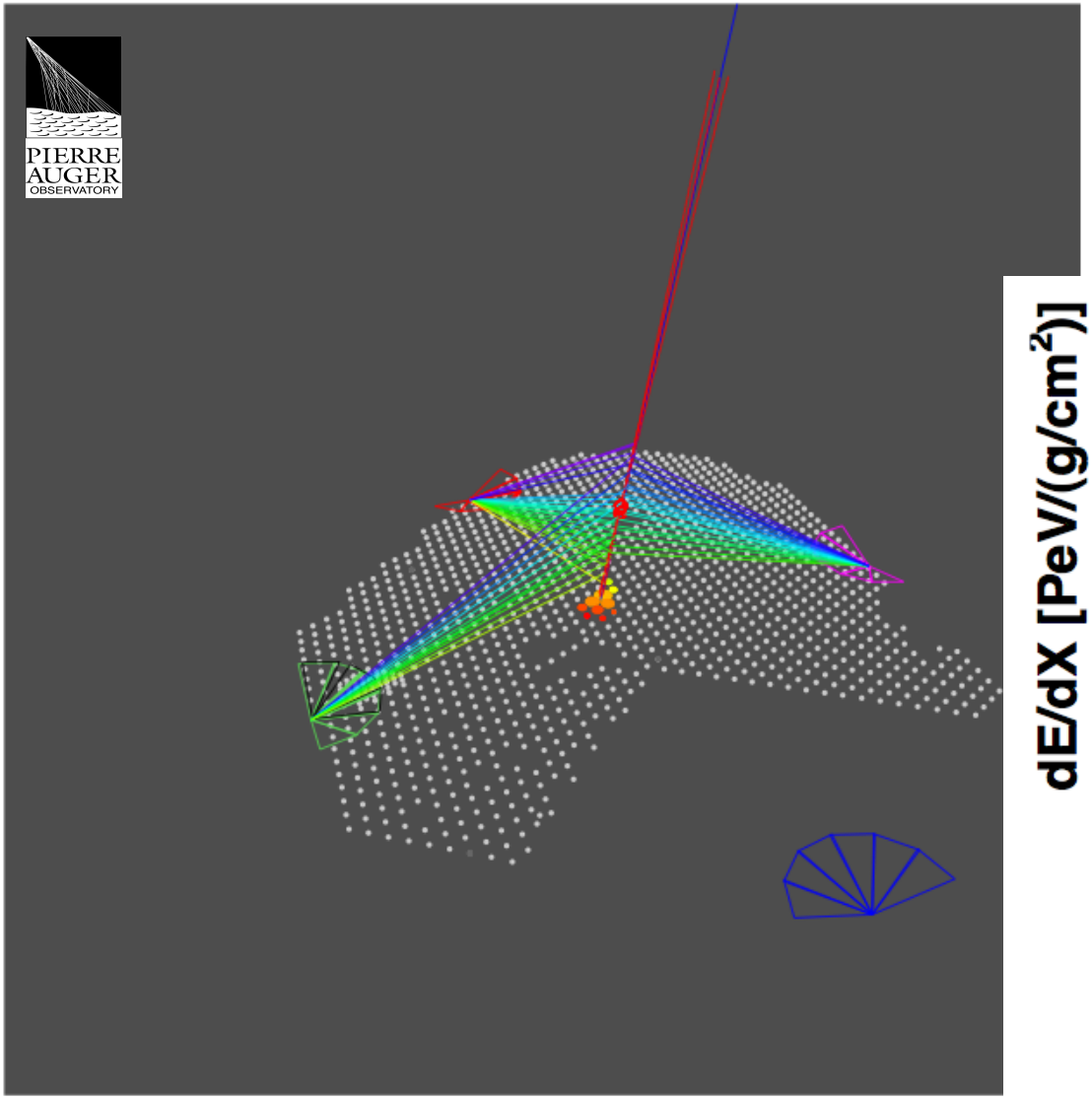
- Geometry from FD timing only: No SD

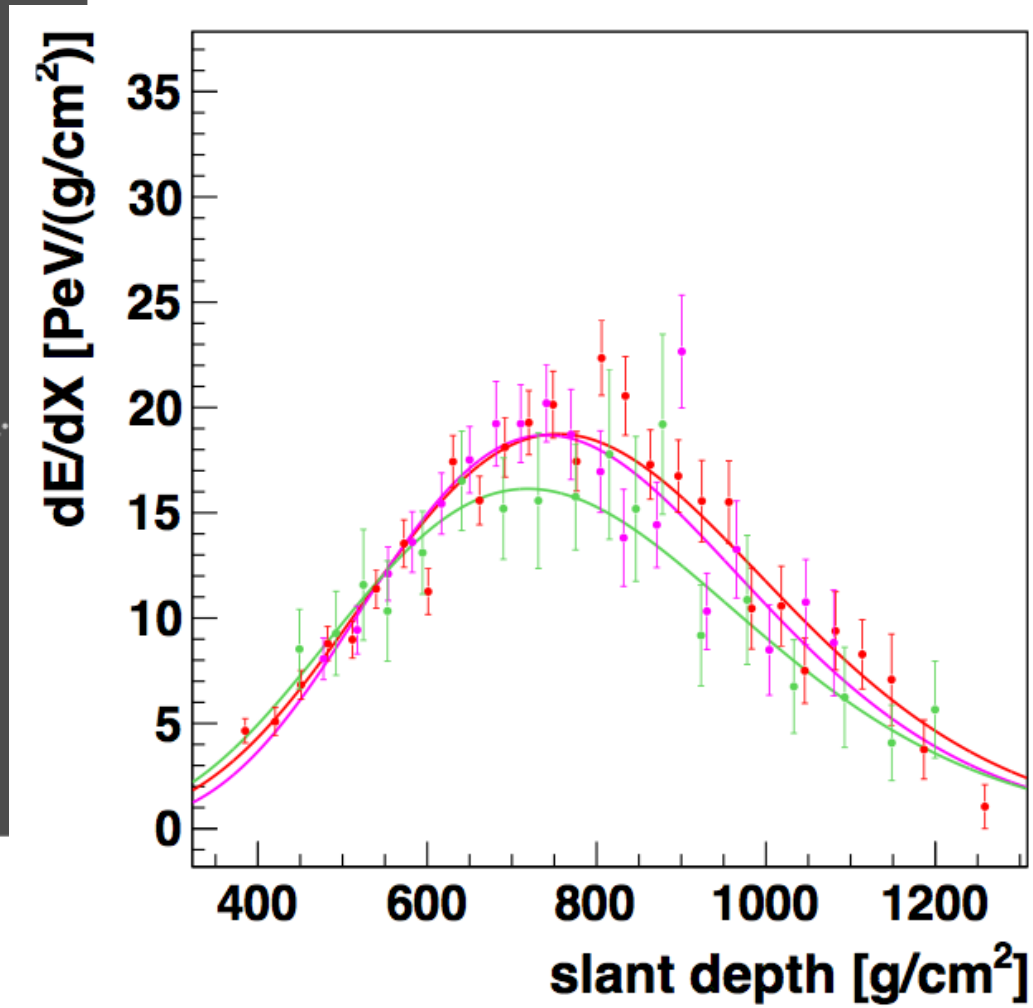
Example:

Shower core reconstruction from time at ground (0º elevation) measured by three FD telescopes









A constrained fit of the time profile from three telescopes to determine the geometry. First simulations encouraging.

Scripta manent

IONIZATION GLOW OF AIR AND THE POSSIBILITY OF UTILIZING THIS EFFECT FOR RECORDING EXTENSIVE AIR SHOWERS

– V.A.Belyaev & A.E.Chudakov

Bulletin of the Academy of Science of the USSR (1966)

(from A. Watson)

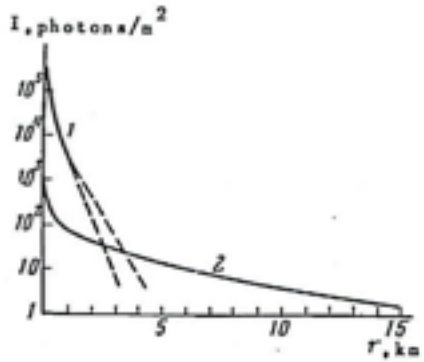


Fig.2. Lateral distributions: 1 – Cerenkov radiation and 2 – ionization glow of a vertical shower with $E = 10^{15}$ eV.

Let us evaluate the energy threshold for recording showers by observation of the ionization glow. The installation could consist of some tens of detecting points disposed at distances of 10 km from each other. One must take into account the background due to the night air glow, the area of the PM photocathodes at each point and the duration of the signal (in the order of $(1\text{-}2) \times 10^{-5}$ sec). For a photocathode area of 1000 cm^2 and a signal-to-noise ratio of 3:1 there would be required a light flux of $\sim 3 \times 10^5$ photons/m^2, which is 3×10^4 times greater than value for $r = 6$ km in Fig.2. It follows that the energy threshold of such an installation should be 3×10^{19} eV so that for $E = 10^{20}$ eV we can obtain detailed significant information.

Plan B

Auger technical memo from Paul Sommers, Bruce Dawson, and Stan Thomas
September 15, 1995

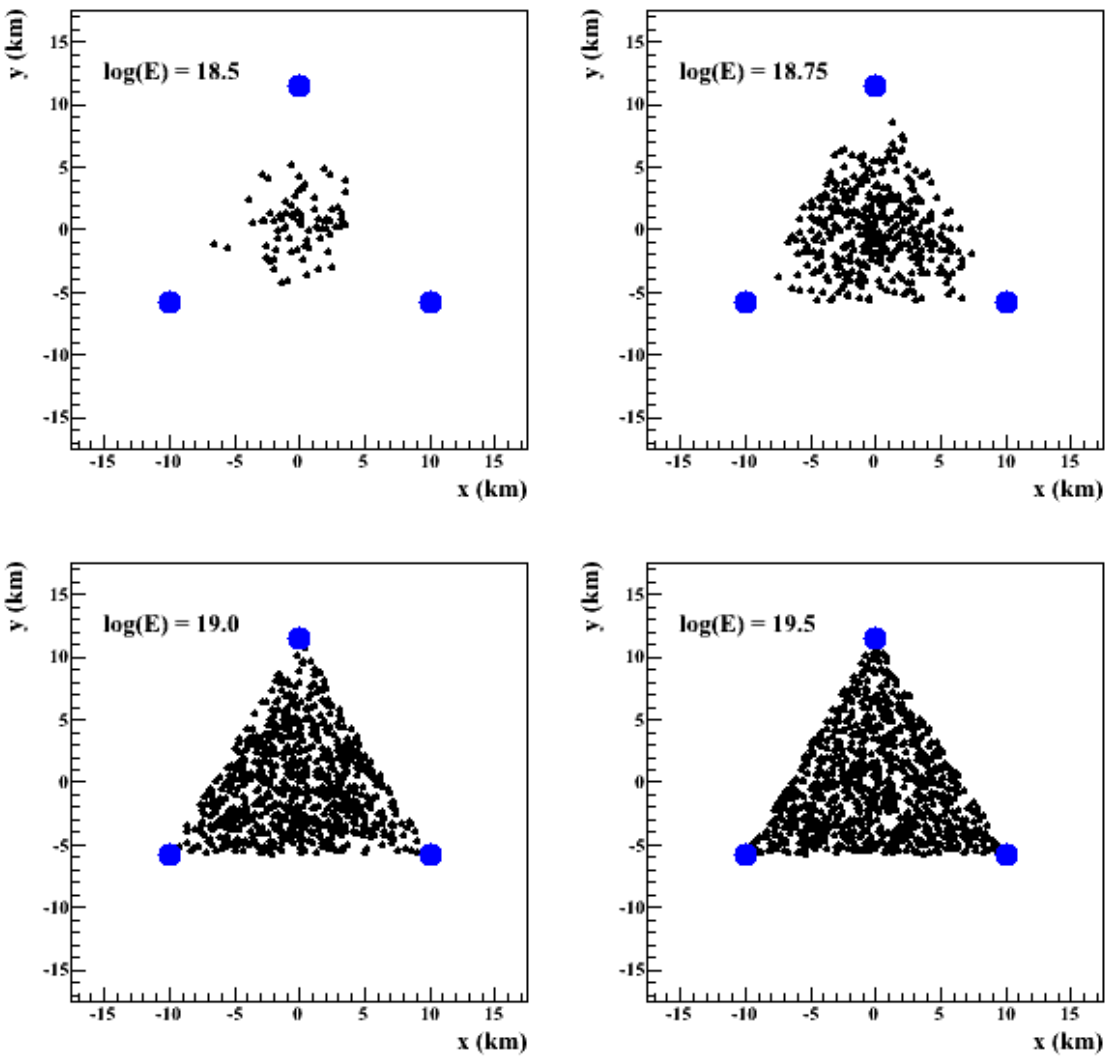
(from P. Sommers)

7.5 km spacing, 82 pixels / station, stereo reconstruction

First simulations

- We have performed simulations of three stations, 20 km spacing, 12 telescopes/station, 30^0x30^0 FOV, 1 m^2 area

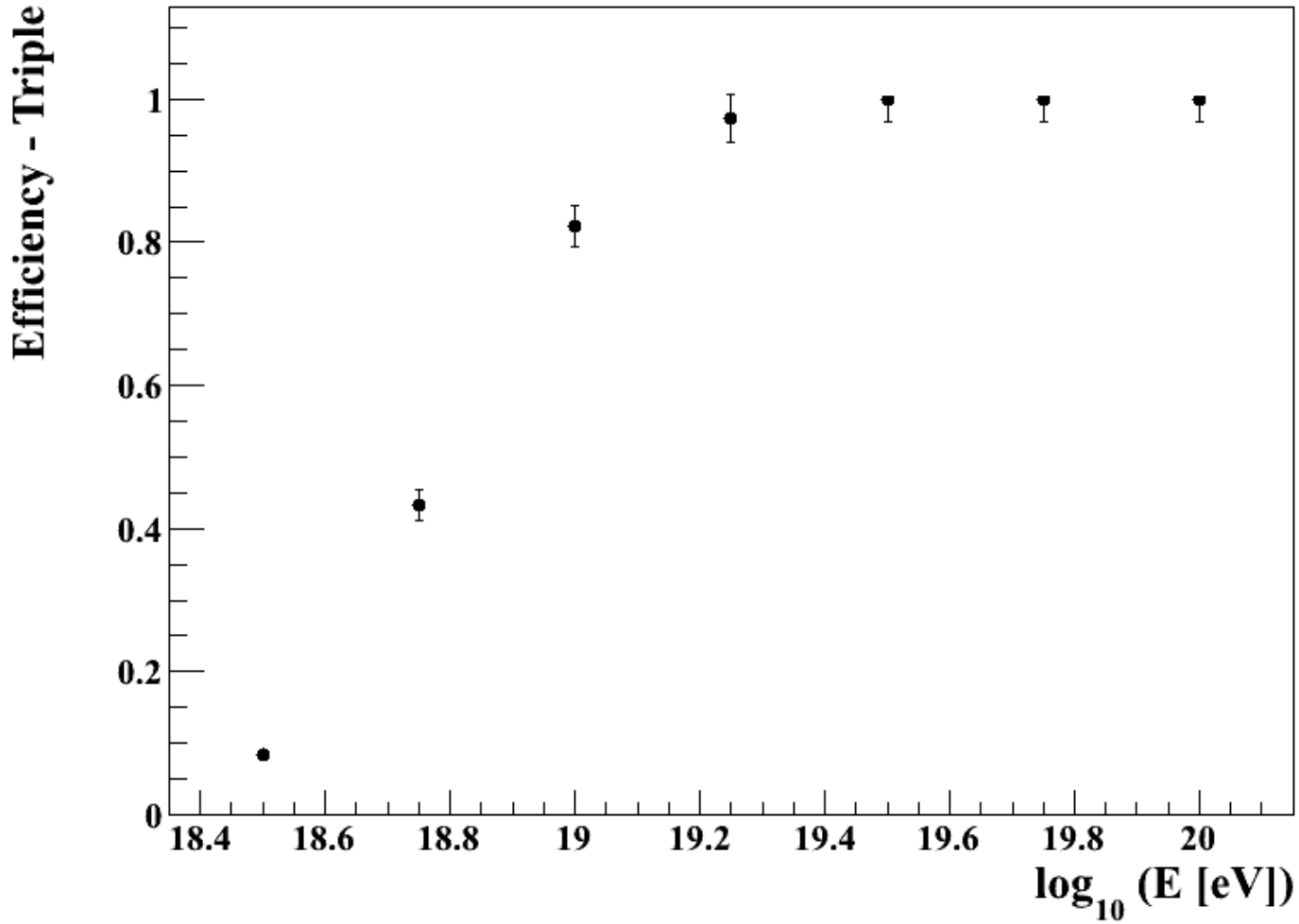
Realistic: modified Auger FD simulation (includes atmosphere, Cherenkov, night sky bkg., etc.). Trigger: running sum over threshold (as FD first level trigger in Auger)



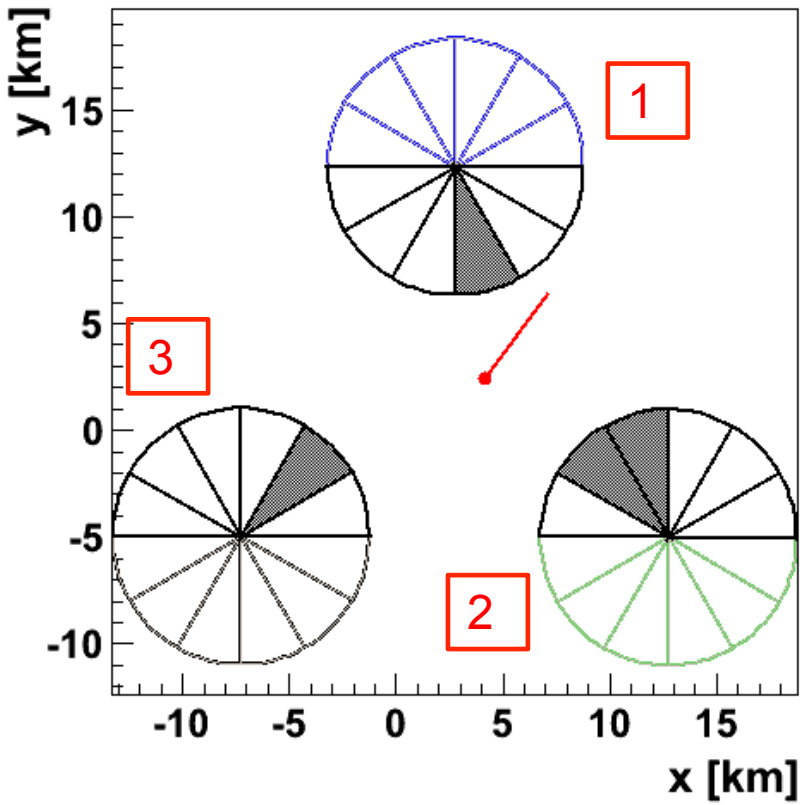
Core position of triple events (triggered by all three stations)

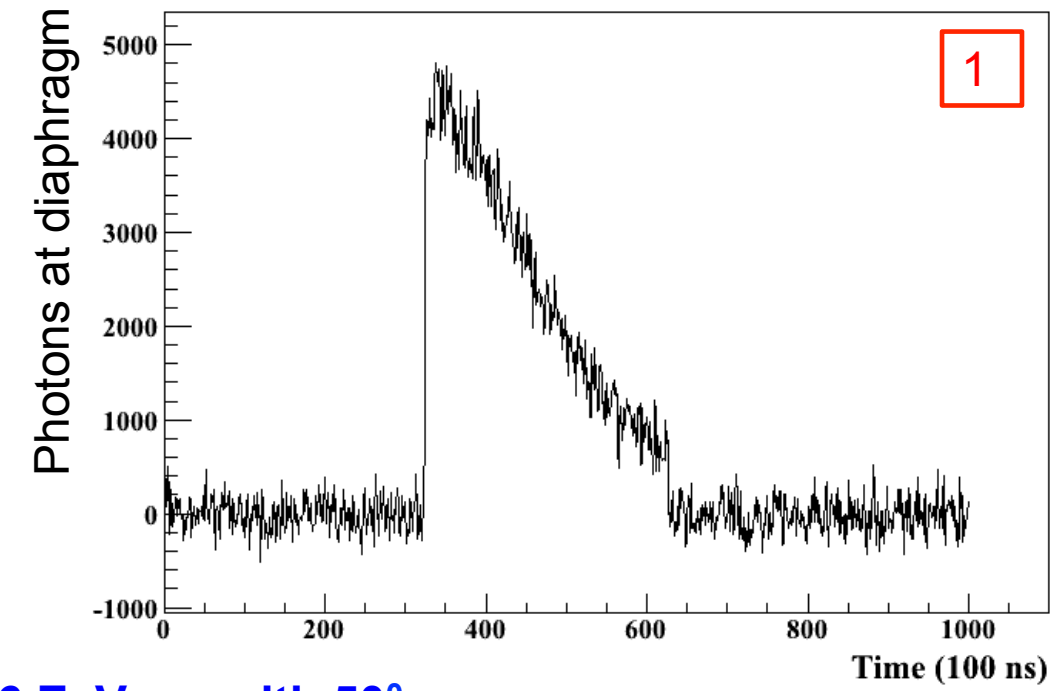
Trigger efficiency for triple detection

(event triggered by the three stations)

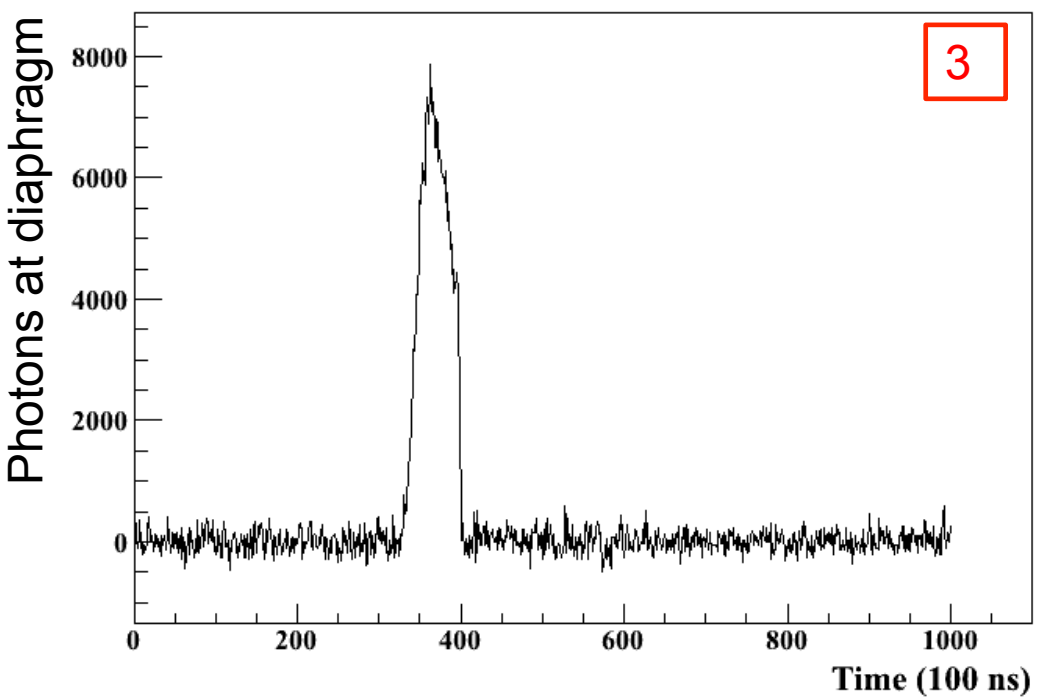


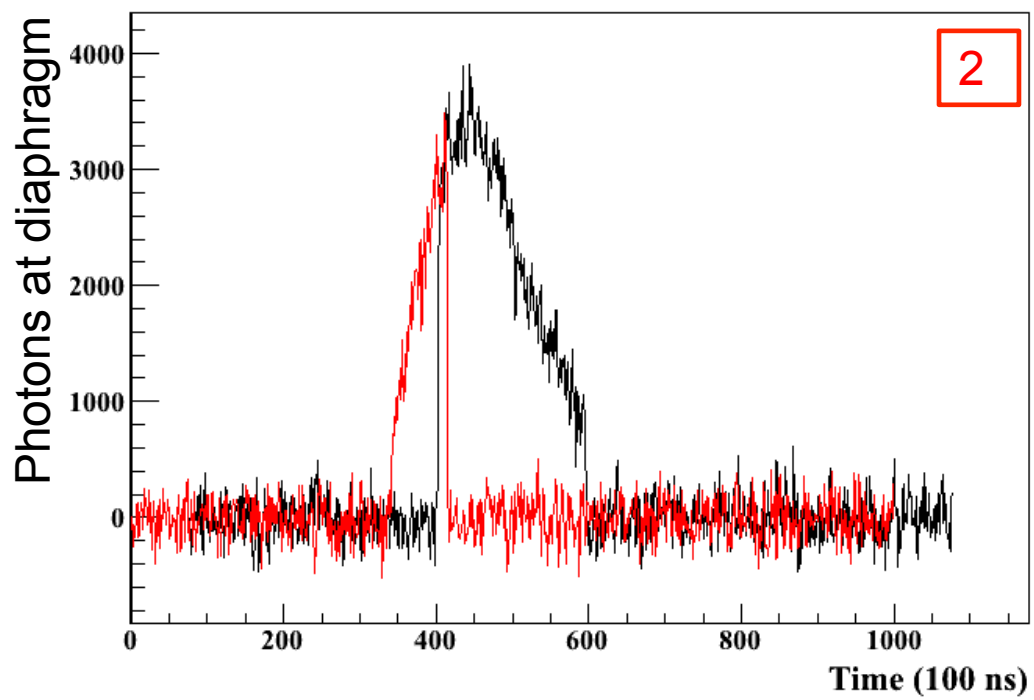
100% efficient above $10^{19.4}$ eV





56 EeV zenith 50⁰



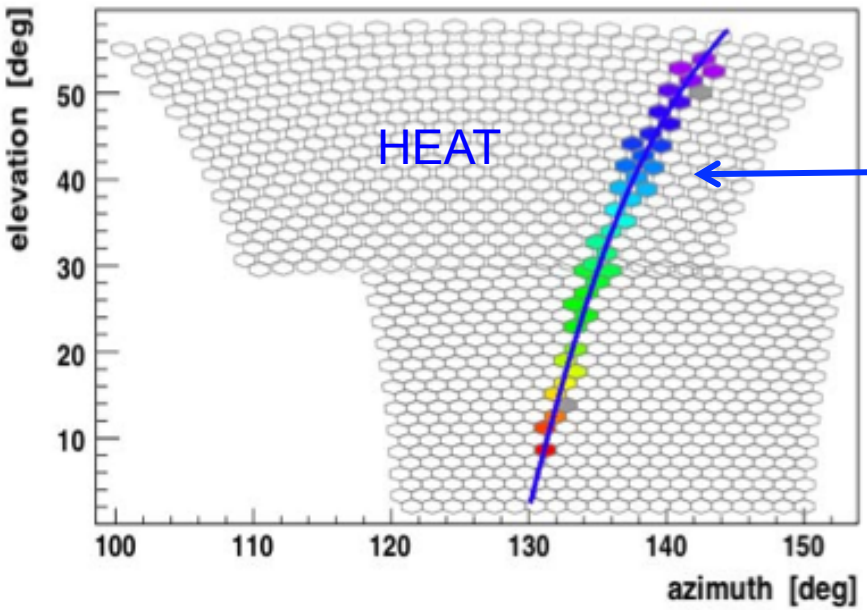


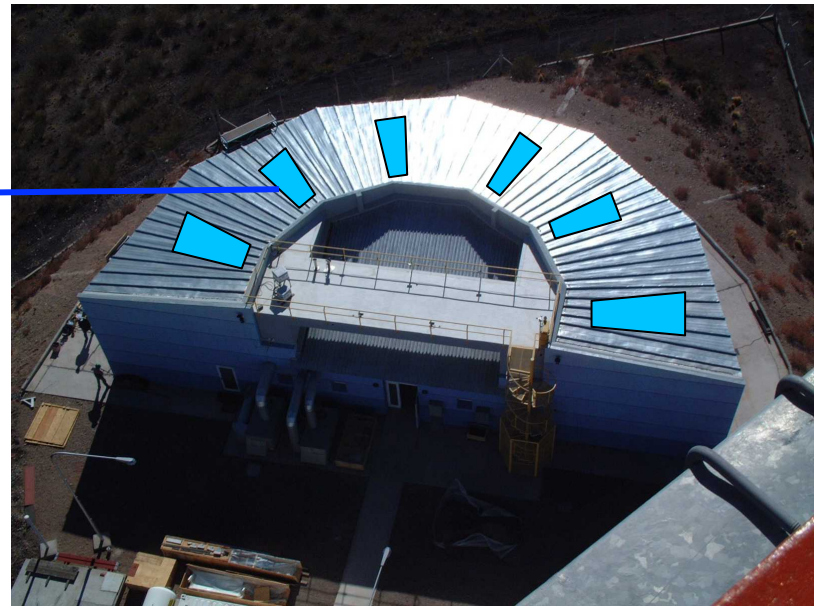
From concept to design

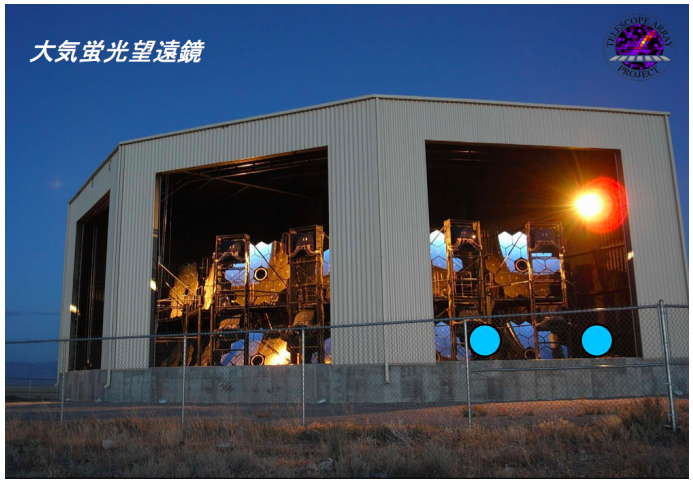
- Rich R&D program (keynote: low cost)
  - simulations to clarify design options and FD only geometrical reconstruction (preliminary tests encouraging)
  - light collection optics
  - Photon detectors (high QE - area)
  - filters (to increase duty cycle)
  - trigger and comms (high energy threshold, low single station rate)
  - station design (elevated, doors, solar panel, etc.)
  - a low cost, station distributed, atmospheric monitoring
  - ……..

- Prototyping, upgrades, staging

Test of concept at Auger/TA







- Upgrade of existing FDs:
30^0 to 60^0 FOV (HEAT like in Auger), use hybrid geometry from existing SD and FD

e.g. 24 FD units + 12 units at the center of the Auger array

Conclusions

- Driven by studying UHECR at the highest energies, $> 10^{19.5}$ eV, with X_{max} measurement
- We have presented a conceptual design for a low cost O(10M$), very large ($\geq$ 40000 km^2) array of Fluorescence Detectors
- Simulations encourage the next step: design and prototyping phase
- I am not advocating an FD-only solution for the next generation experiment. Rather, I am asking the community to think out of the box for a new low cost design for a very large SD array.
  NOTE: Scope different from potential upgrades of current experiments (e.g. muon detection), both need to be pursued
- Lot of progress in this Symposium towards putting the community together, particularly on understanding of the data (working groups).
  I hope to see many contributions towards the design of the next generation experiment in the next Symposium.