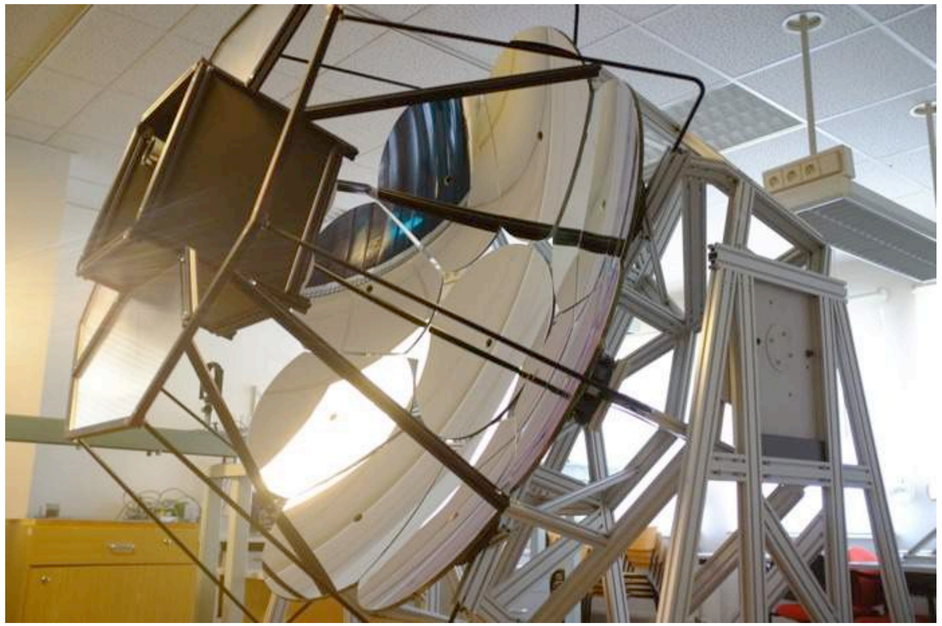
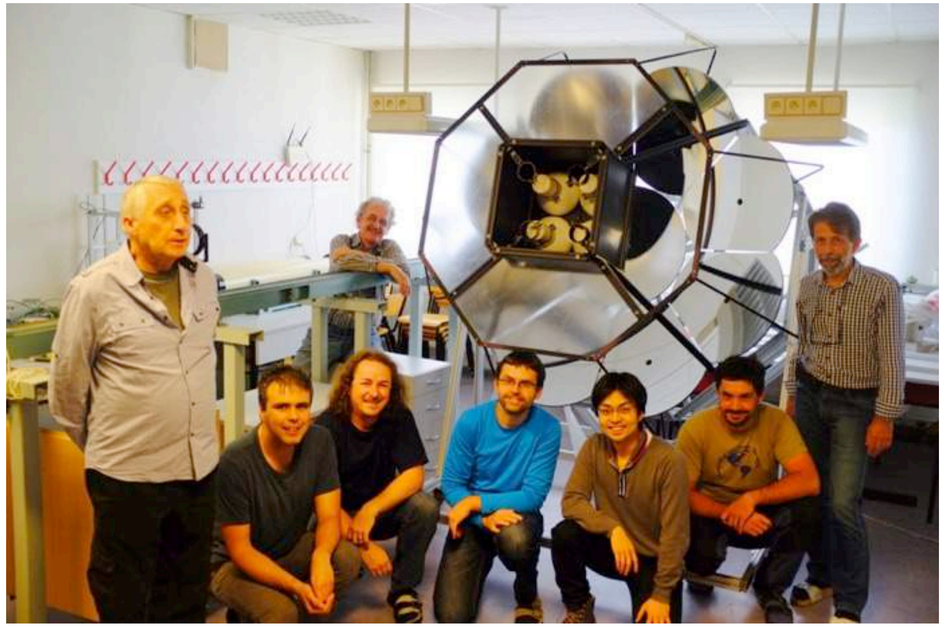
Next-Generation Observatory: Fluorescence detector Array of Single-pixel Telescopes (FAST)





Toshihiro Fujii, Max Malacari, Jose A. Bellido, Bruce Dawson, Pavel Horvath, Miroslav Hrabovsky, Jiaqi Jiang, Dusan Mandat, Ariel Matalon, John N. Matthews, Pavel Motloch, Libor Nozka, Palatka, Miroslav Pech, Paolo Privitera, Petr Schovanek, Stan B. Thomas, Petr Travnicek

2016/Feb/29, UHEAP 2016 workshop

Physics Goal and Future Prospects

Origin and Nature of Ultra-high Energy Cosmic Rays and Particle Interactions at the Highest Energies

5 - 10 years

Exposure and Full Sky Coverage

TA×4 + Auger

JEM-EUSO : pioneer detection from space and sizable increase of exposure

Detector R&D

Radio, SiPM, Low-cost Detectors

"Precision" Measurements

AugerPrime

Low energy enhancement (Auger infill+HEAT+AMIGA, TALE+TA-muon+NICHE)

10 - 20 years

Next Generation Observatories

In space (100×exposure): EUSO-Next

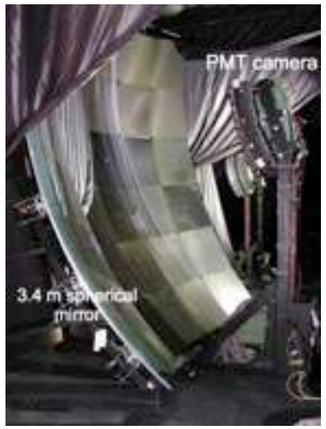
Ground (10×exposure with high quality events): Giant Ground Array, FAST

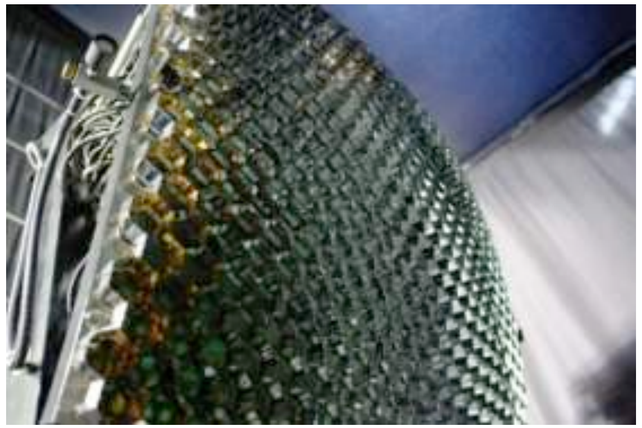
EAST Fluorescence detector Array of Single-pixel Telescopes

Fluorescence detector Array of Single-pixel Telescopes

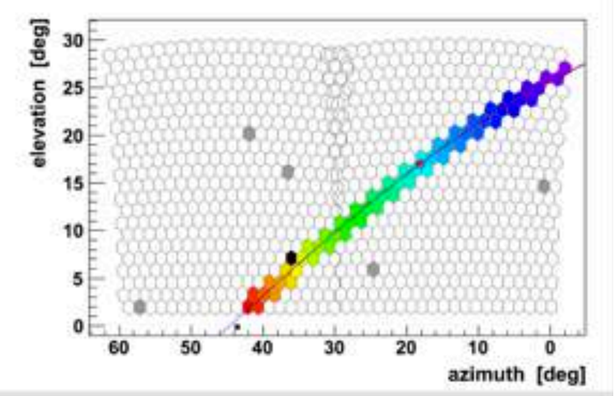
- Target : > $10^{19.5}$ eV, ultra-high energy cosmic rays (UHECR) and neutral particles
- Huge target volume ⇒ Fluorescence detector array

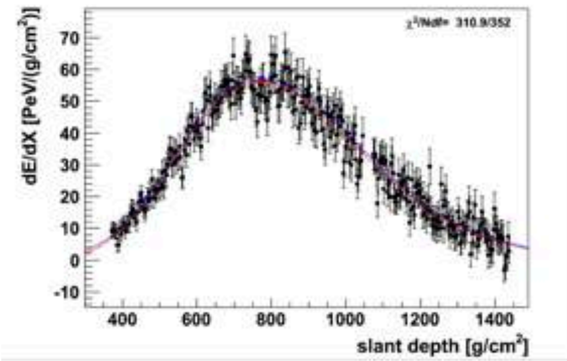
Fine pixelated camera



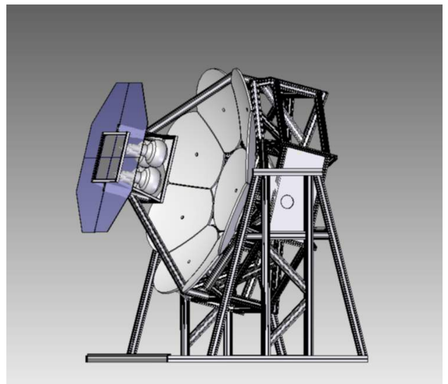


Too expensive to cover a huge area

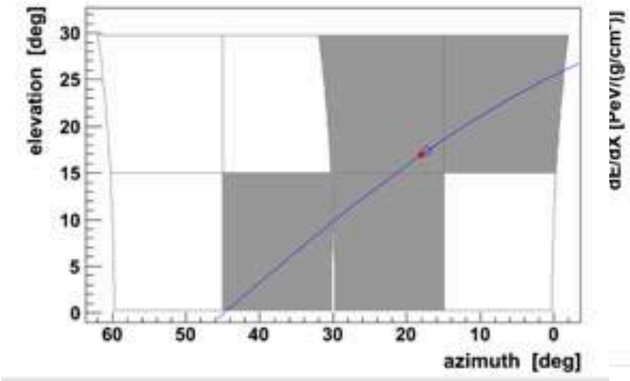


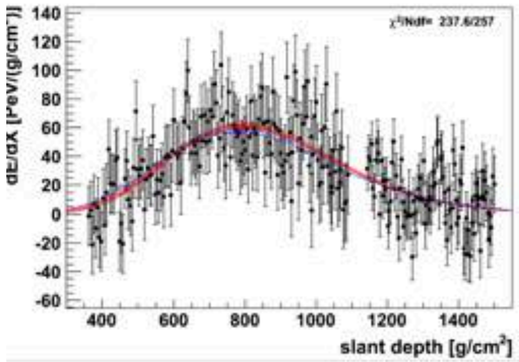


Single or few pixels and smaller optics

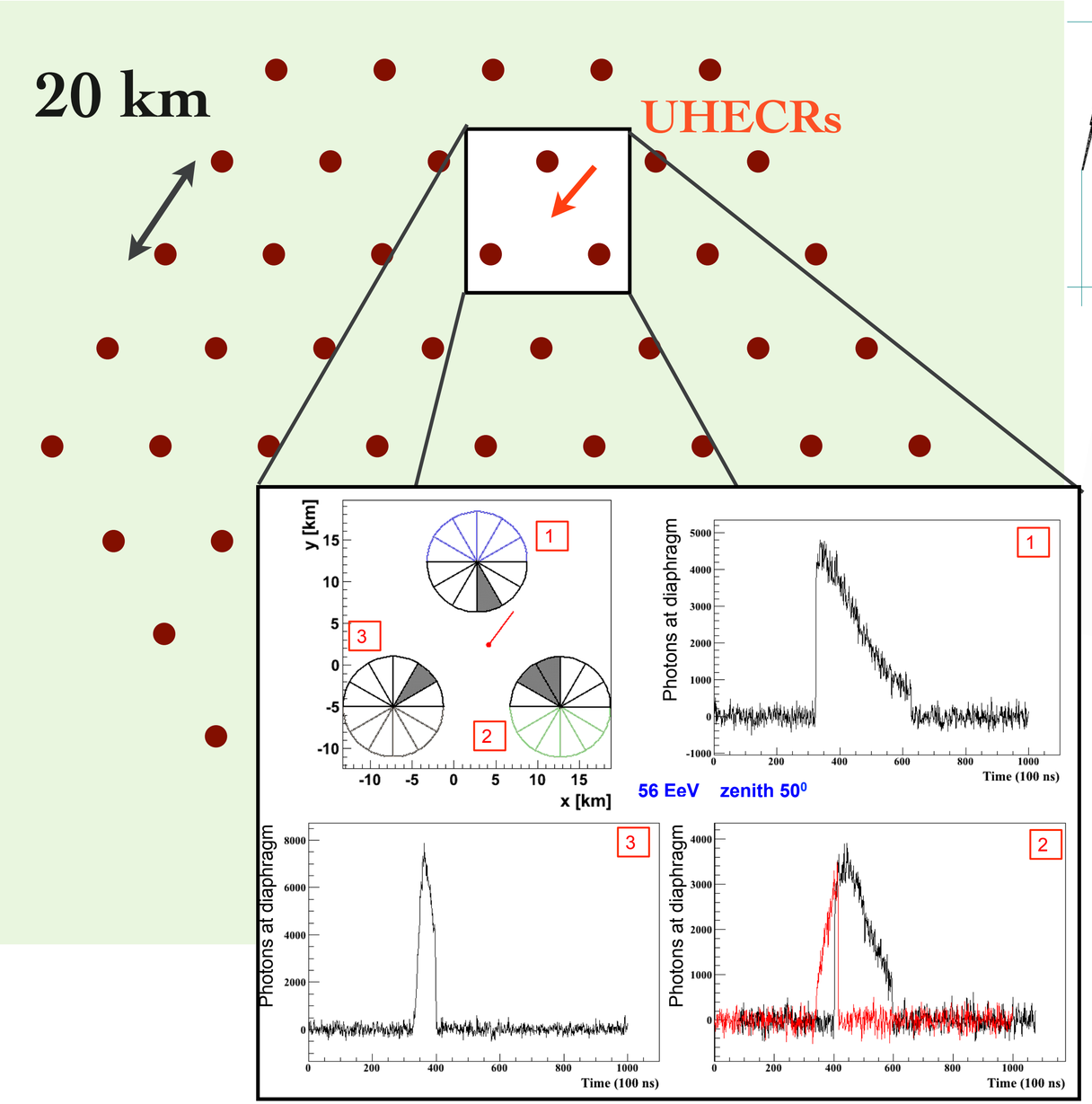


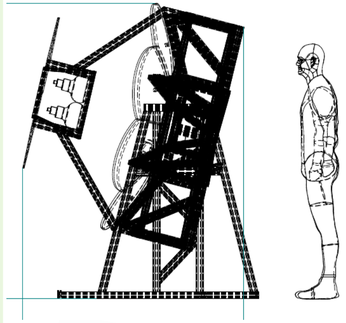
Low-cost and simplified/optimized FD

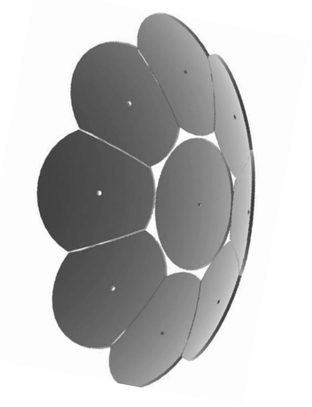


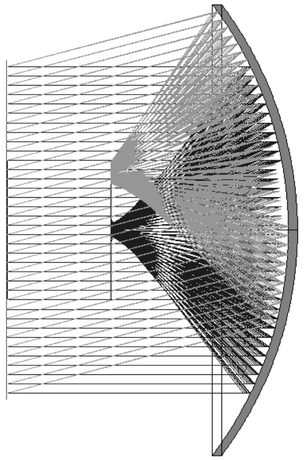


Fluorescence detector Array of Single-pixel Telescopes



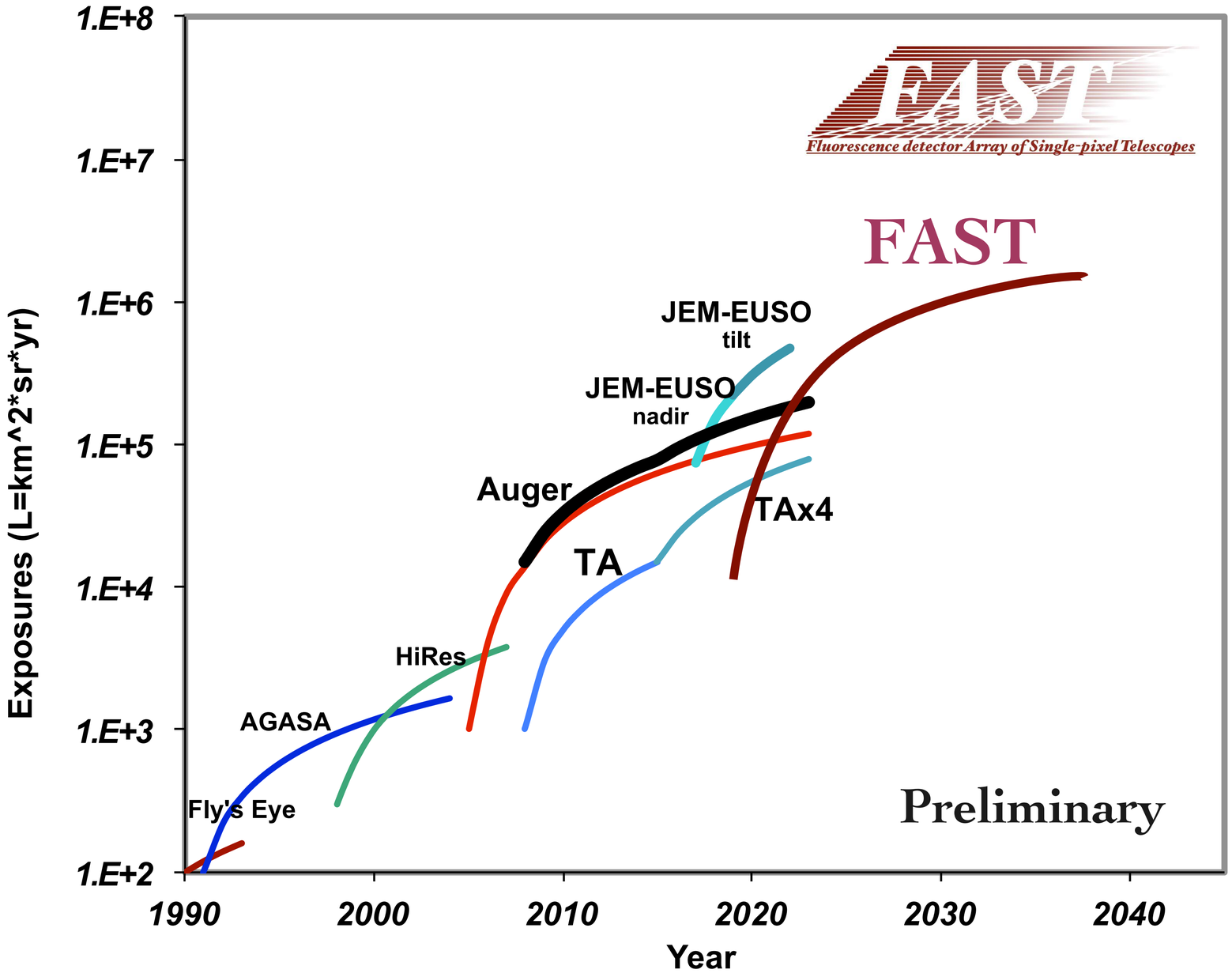






- Each telescope: 4 PMTs, 30°×30° field of view (FoV).
  - **Reference design: 1 m^2 aperture, 15°×15° FoV per PMT**
- Each station: 12 telescopes, 48 PMTs, 30°×360° FoV.
- Deploy on a triangle grid with **20 km** spacing, like **"Surface Detector Array"**.
- If 500 stations are installed, a ground coverage is ~ 150,000 km^2.
- Geometry: Radio, SD, coincidence of three stations being investigated.

FAST Exposure

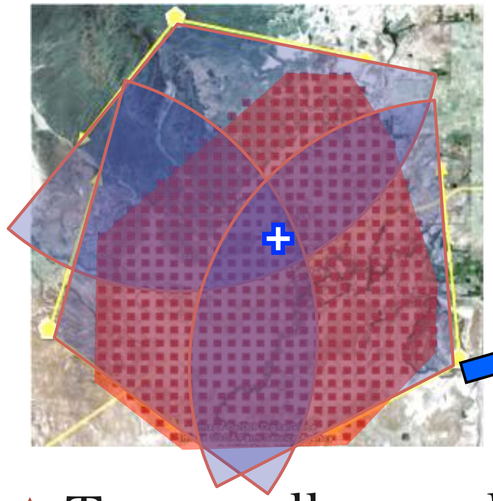


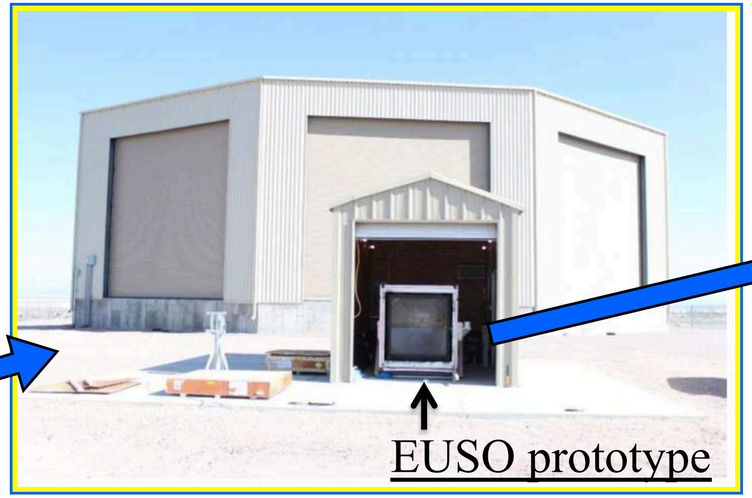
- Conventional operation of FD under 10~15% duty cycle
  - Target: $>10^{19.5}$ eV
- Observation in **moon night** to achieve **25%** duty cycle,
  - Target: **$>10^{19.8}$ eV = Super GZK events (Hotspot/ Warmspot)**
    - Test operation by Auger FD (Radomir Smida).
- Ground area of 150,000 km^2 with 25% duty cycle = 37,500 km^2 (12×Auger, cost ~50 MUSD)

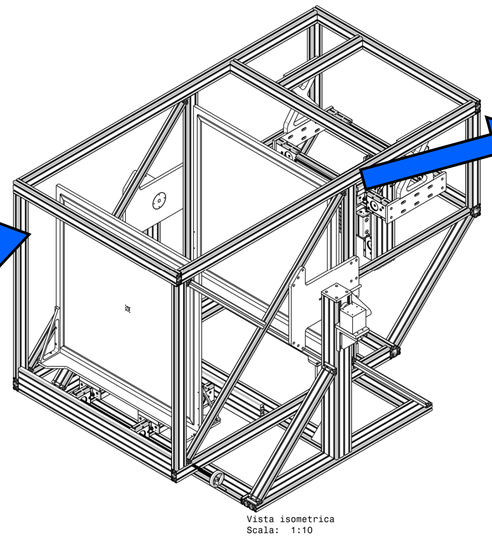
Window of Opportunity at EUSO-TA

FAST
Fluorescence detector Array of Single-pixel Telescopes

Telescope Array site | **Black Rock Mesa station** | **EUSO-TA telescope** | **FAST camera**







- Temporally use the EUSO-TA optics at the TA site.
  - Two Fresnel lenses (+ 1 UV acrylic plate in front for protection)
  - **1 m^2 aperture, 14°×14° FoV ≒ FAST reference design.**
- Install FAST camera and DAQ system at EUSO-TA telescope.
- Milestones: Stable observation under large night sky backgrounds, UHECR detection with external trigger from TAFD.

- 8 inch PMT (R5912-03, Hamamtsu)
- PMT base (E7694-01, Hamamatsu)
- Ultra-violet band pass filter (MUG6, Schott)

1

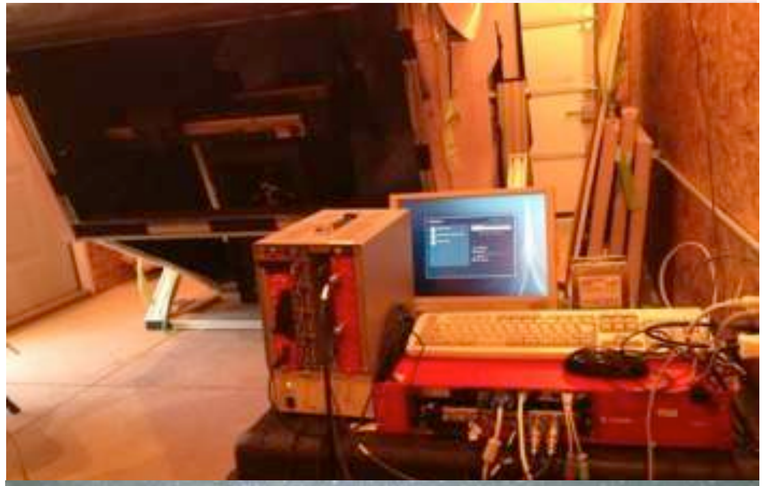
2

3

4

5

6

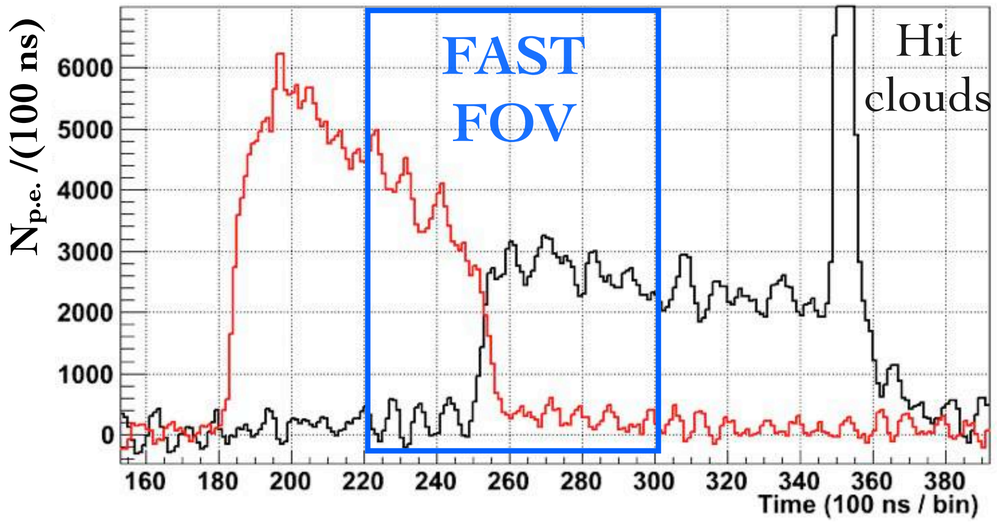


7

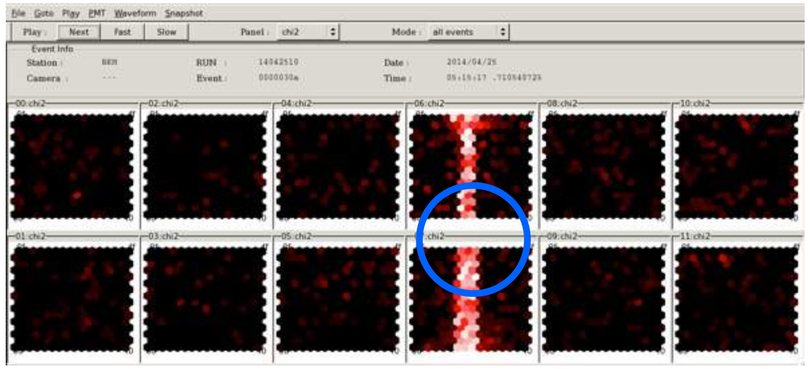
8

9

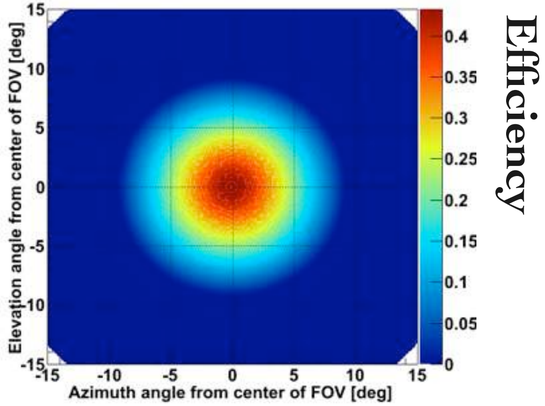
Laser Signal to Check Performance

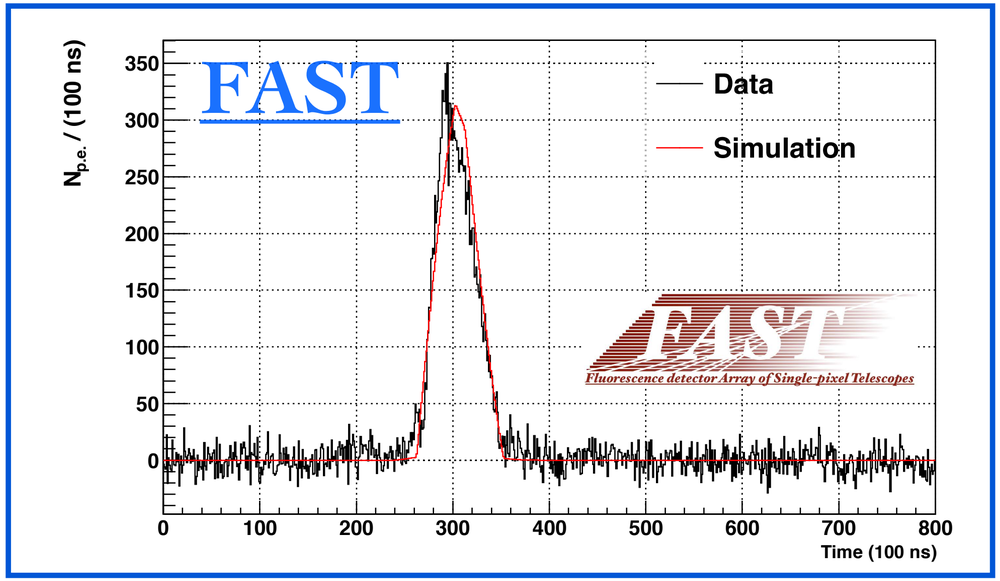


TAFD



Directional sensitivity by RayTrace of EUSO-TA telescope



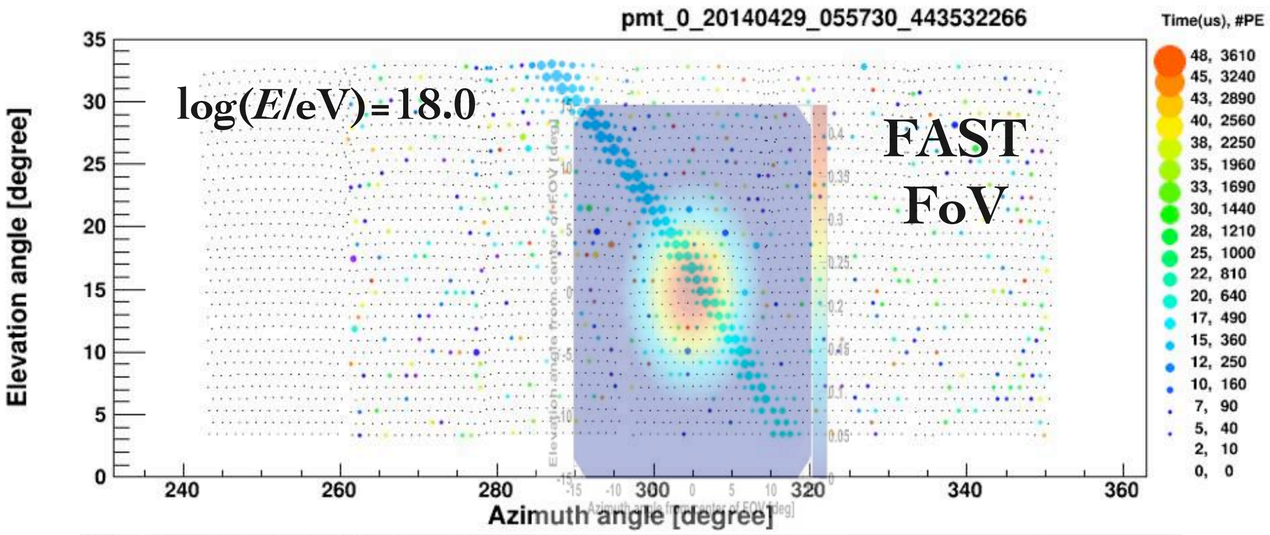


- Vertical Ultra-Violet laser at 6 km from FAST ≒ ~$10^{19.2}$ eV
- Expected signal TAFD/FAST: (7 m^2 aperture × 0.7 shadow × 0.9 mirror) / (1 m^2 aperture × 0.43 optics efficiency) ~10
  - TAFD Peak signal : ~3000 p.e. / 100 ns
  - FAST Peak signal : ~300 p.e. / 100 ns. All shots are detected significantly.
- Agreement of signal shape with simulation.

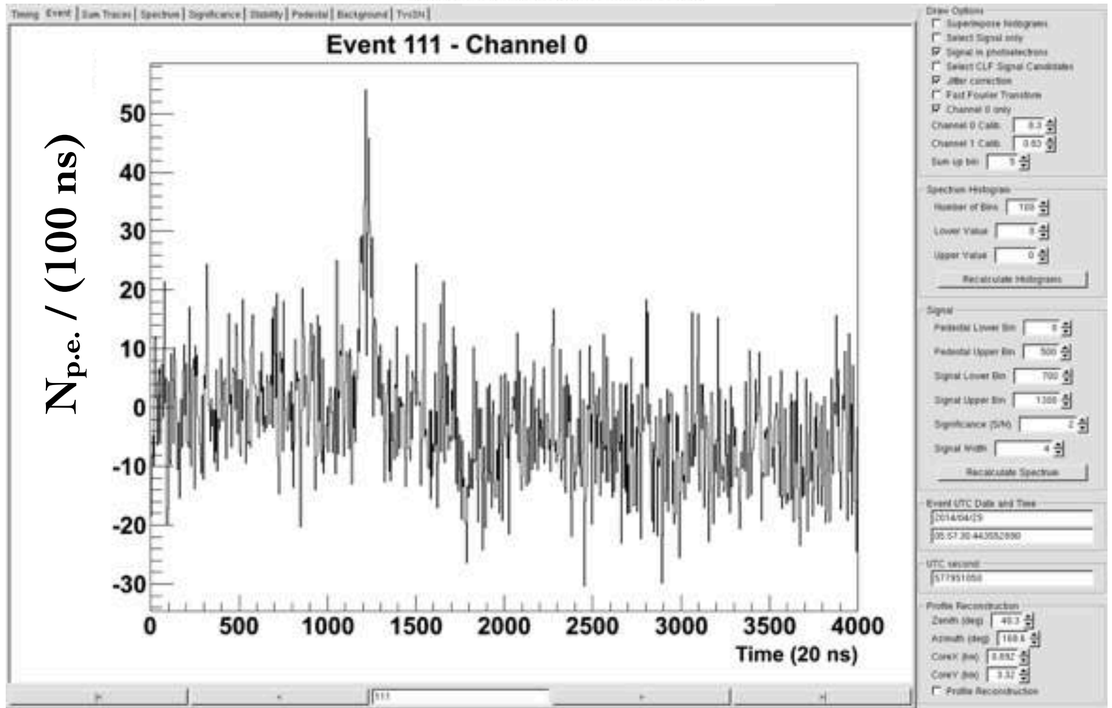
UHECR Signal Search

FAST
Fluorescence detector Array of Single-pixel Telescopes

TAFD



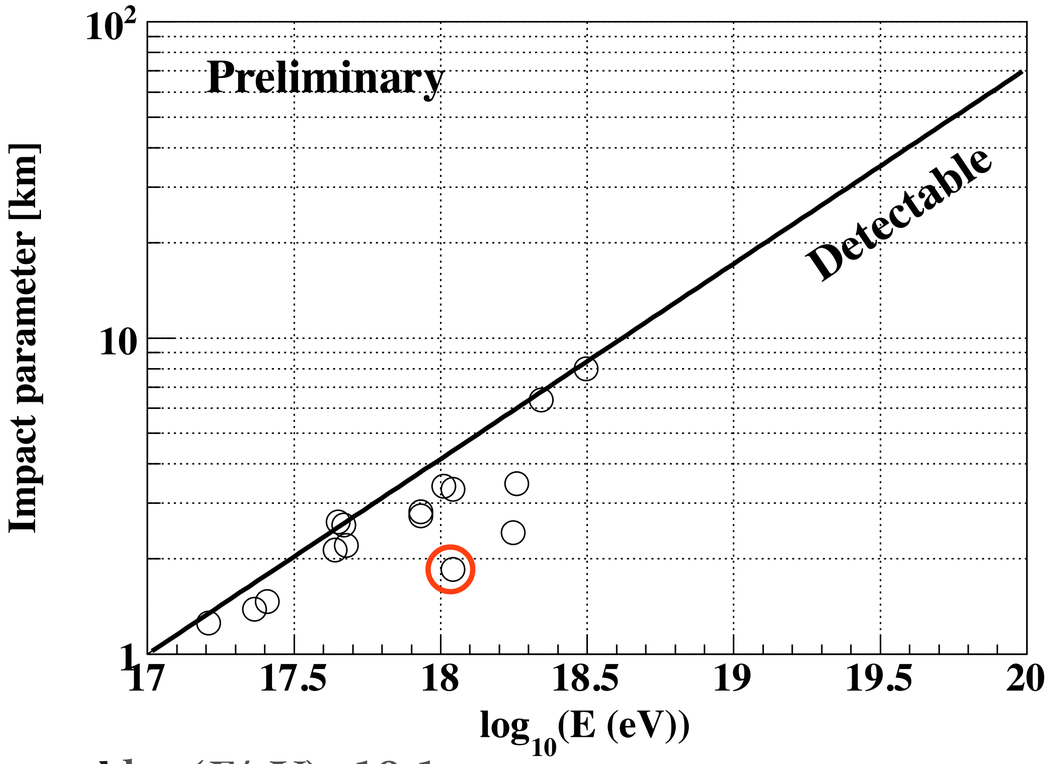
FAST

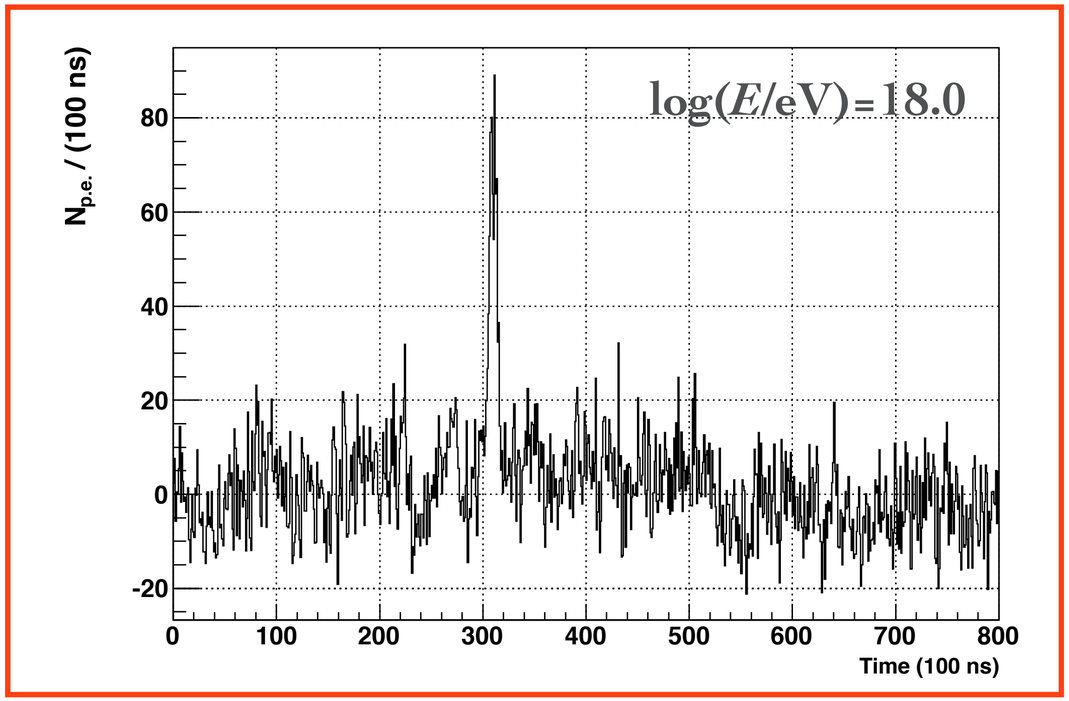


- Data set: April and June 2014 observation, 19 days, 83 hours.
  - Stable observation.
- We searched for UHECR signal in coincidence between FAST and TAFD.
  1. Search for TAFD signal crossing the field of view (FoV) with FAST.
  2. Search for a significant signal (>5σ) with FAST waveform at the same trigger.
- **16 candidates found.**
- Low energy showers as expected.

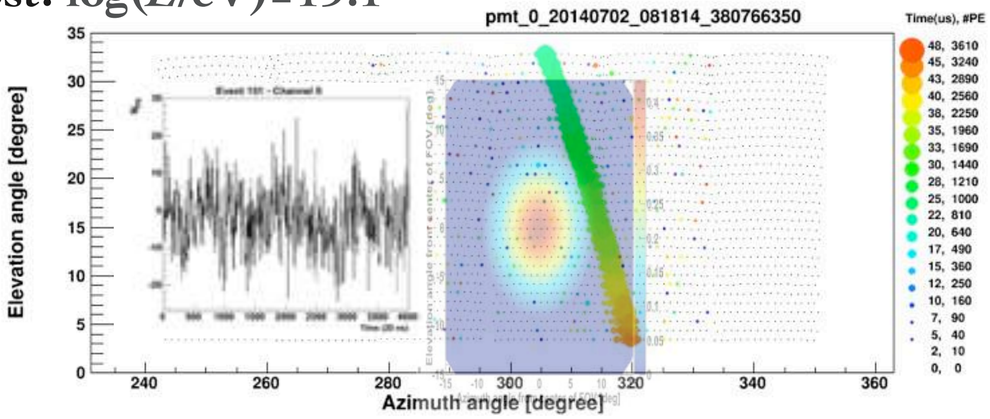
Distance vs Energy (from TAFD) for Candidates

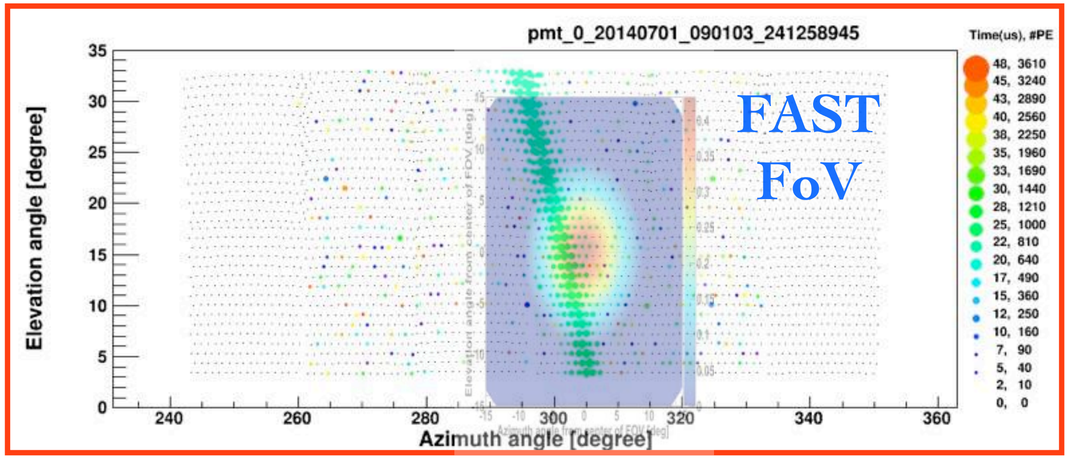
Fluorescence detector Array of Single-pixel Telescopes





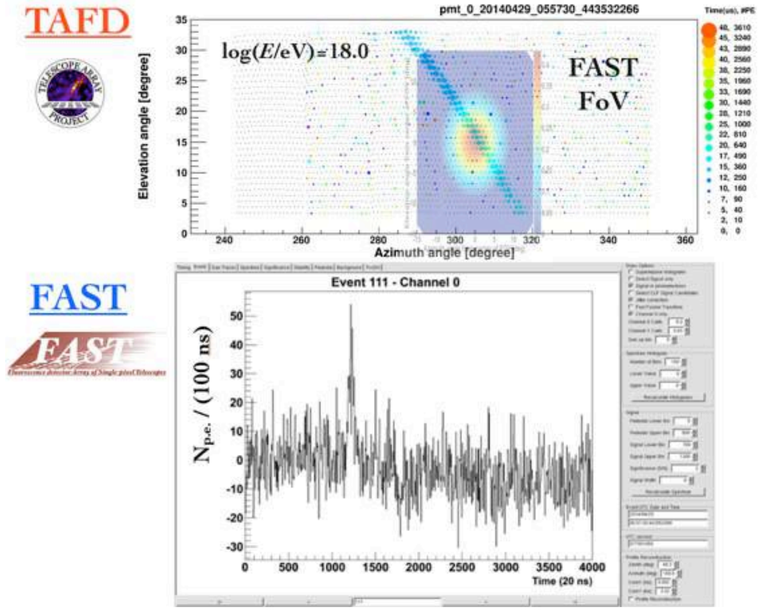
Almost! log(*E*/eV)=19.1

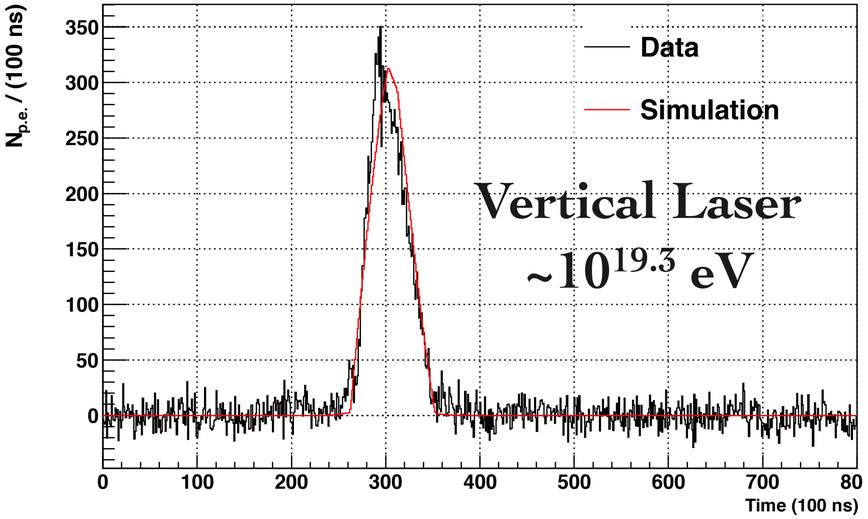


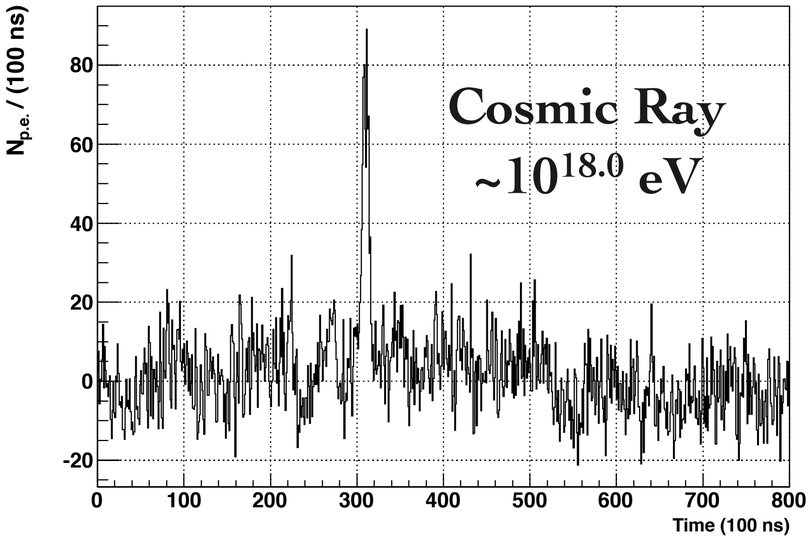


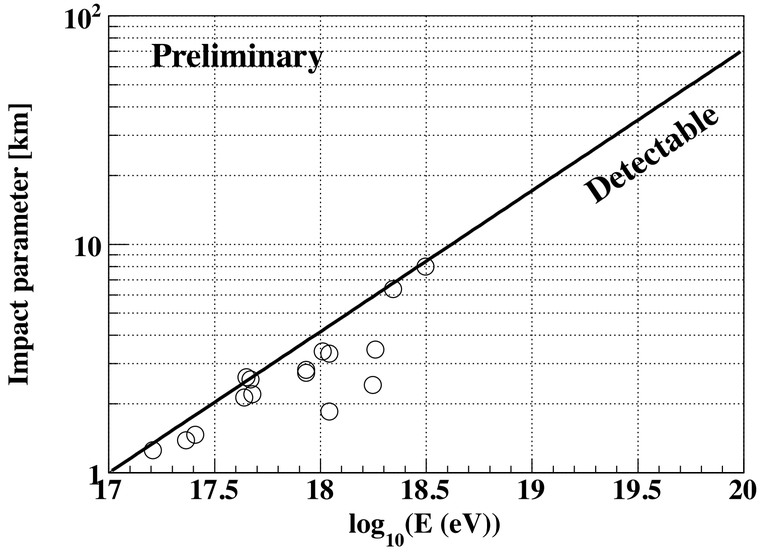
Results on the First Field Observation

- Data set: April and June 2014 observation, 19 days, 83 hours
  - Very stable observation under large night sky backgrounds
- Laser detection to confirm a performance of the prototype
- UHECR search : 16 candidates coincidence with TA-FD
- Very successful example among Telescope Array, JEM-EUSO, Pierre Auger Collaborations.





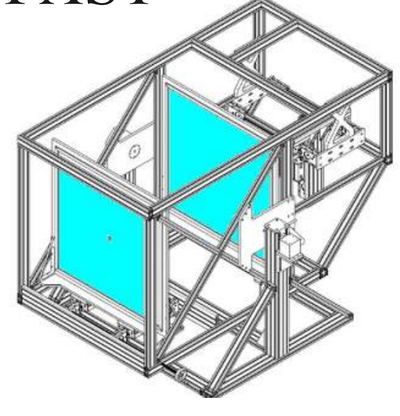


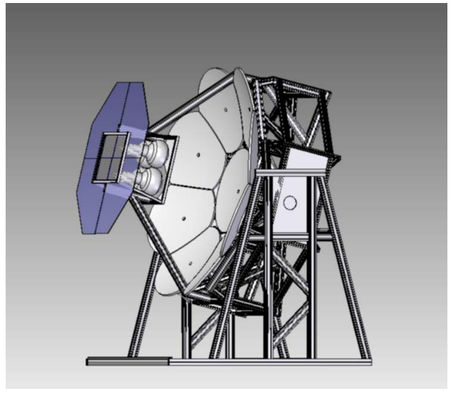


Astroparticle Physics 74 (2016) 64-72, arXiv: 1504.00692

Full-scale FAST Prototype

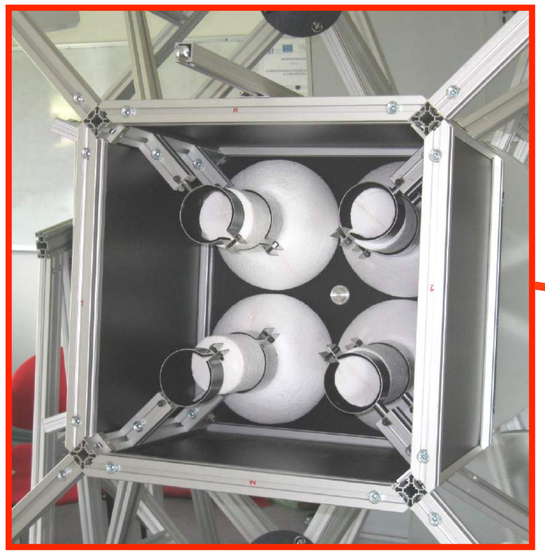
- **Confirmed milestones by EUSO-TA Telescope**
  - Stable operation under high night sky backgrounds.
  - UHECR detection.
- **Next milestones by new full-scale FAST prototype**
  - Establish the FAST sensitivity.
  - Detect a shower profile including ***Xmax*** with FAST



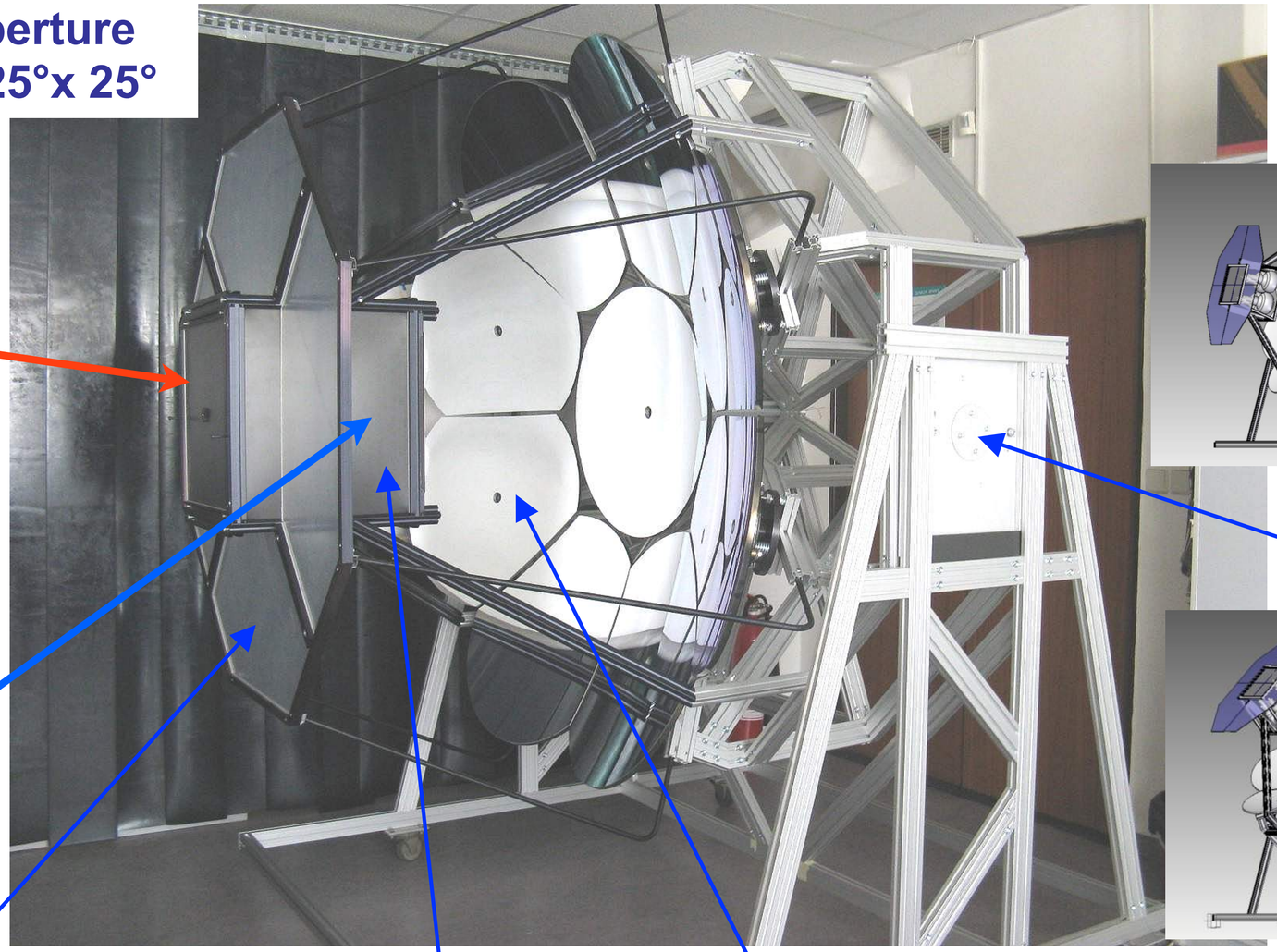


FAST meeting in December 2015
(Olomouc, Czech Republic)

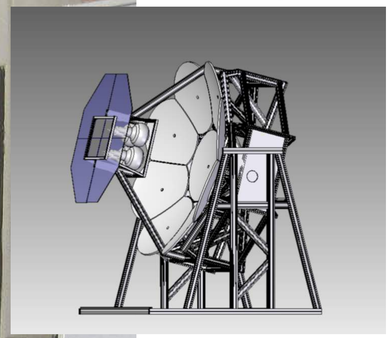
Full-scale FAST Prototype



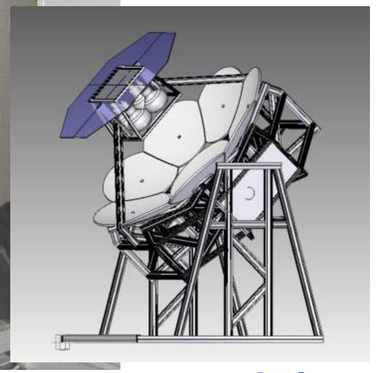
1m^2 aperture
FOV = 25°x 25°



15°



variable tilt



45°

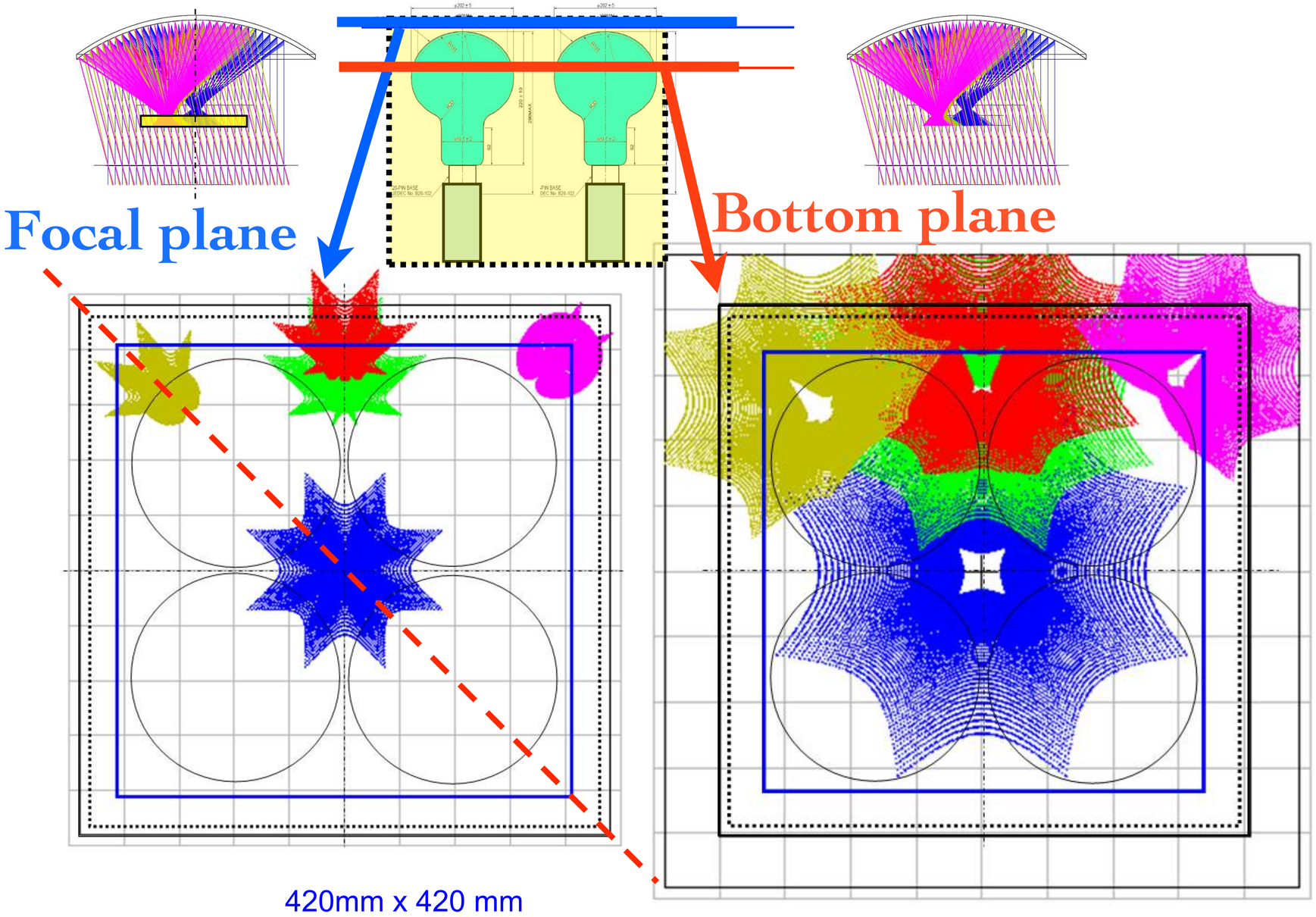
UV Plexiglass

8 inch PMT camera (2 x 2)

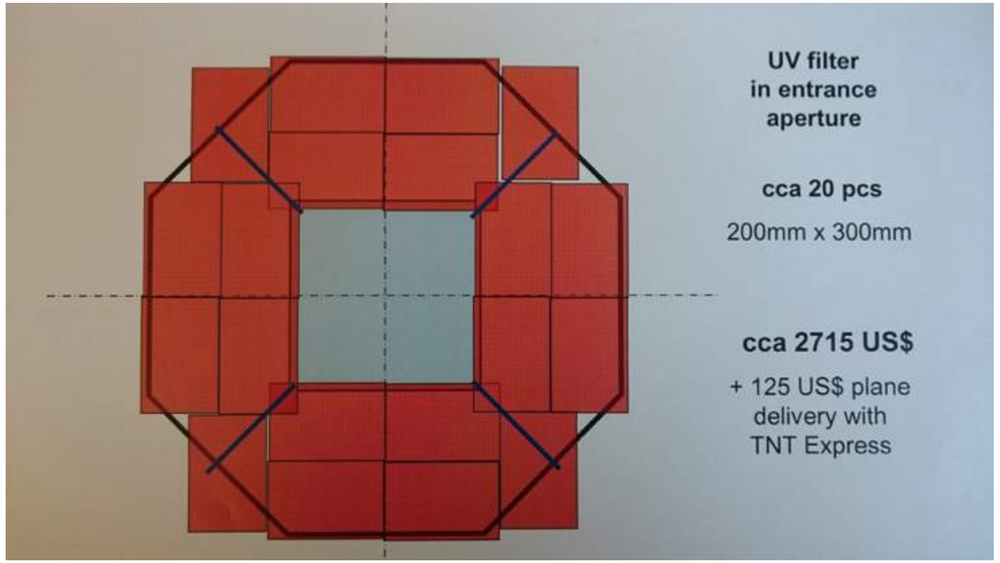
Segmented primary mirror

Ray-Trace Simulation

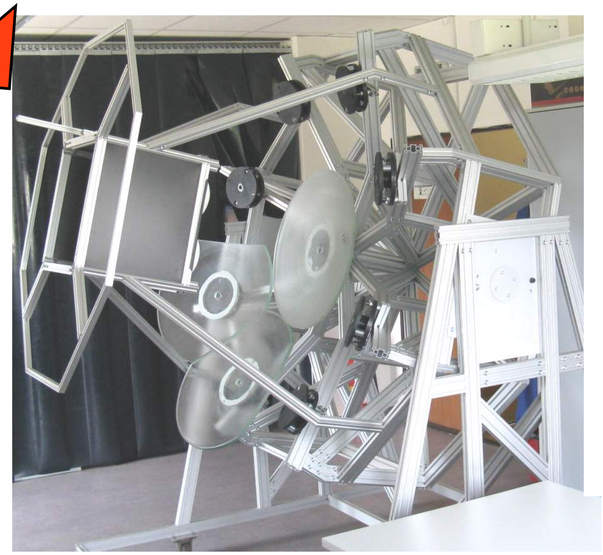
- The spherical surface on PMT has complicated point spread function.
- We need to calculation efficiency of optics.
  - It will be used in the offline analysis after data-taking is started.

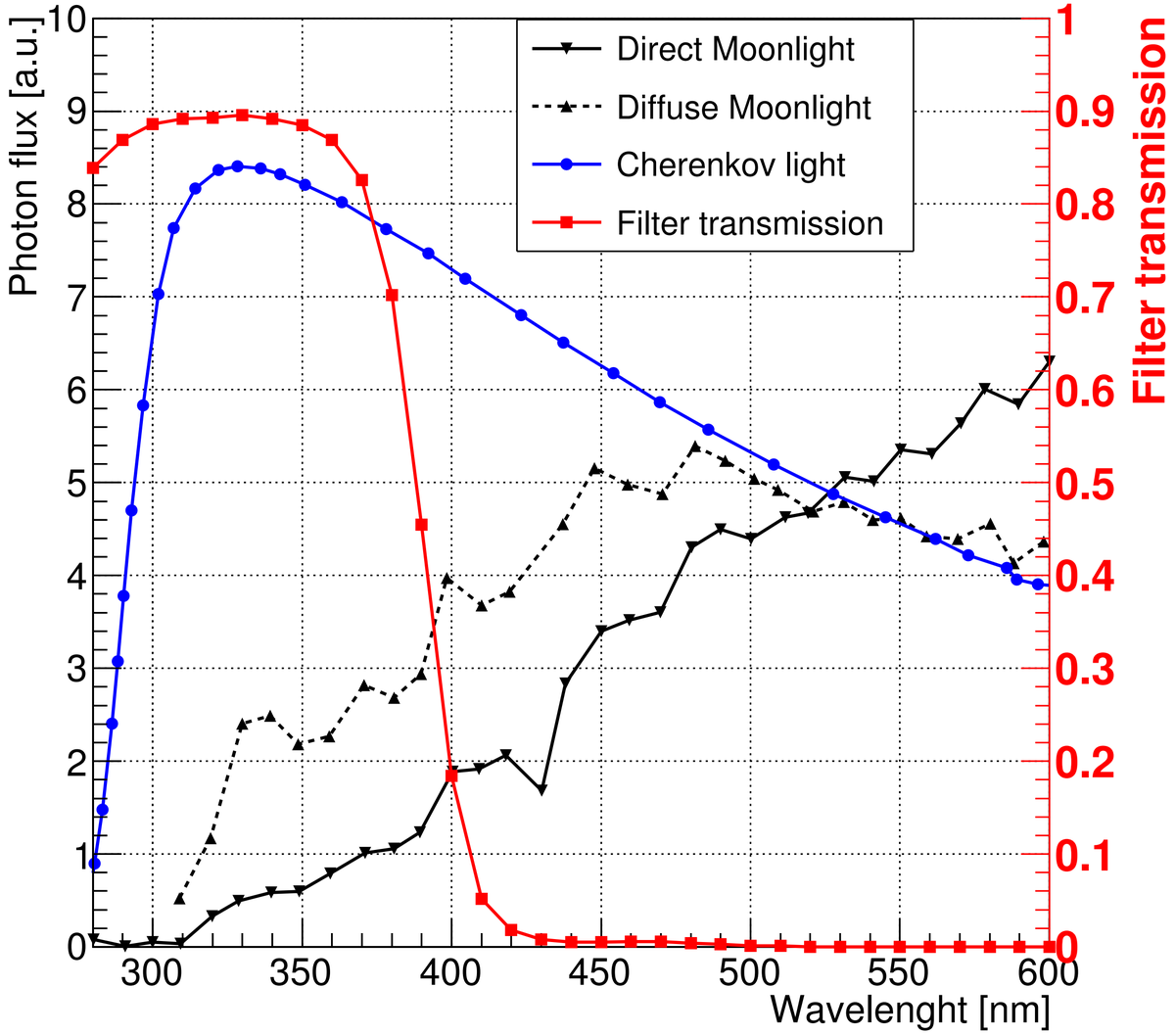


UV Band-pass Filter



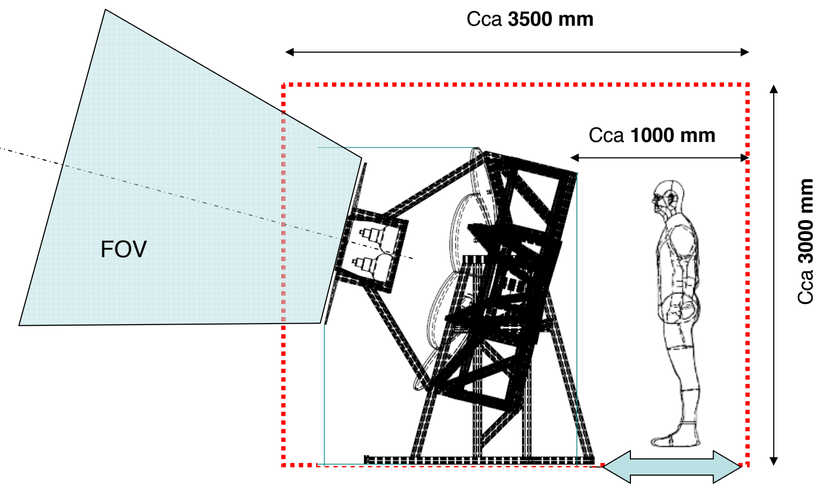
UV band pass filter used in MAGIC

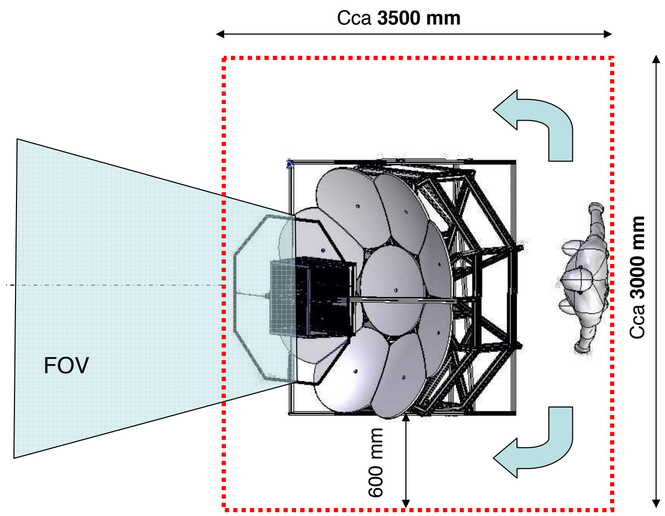




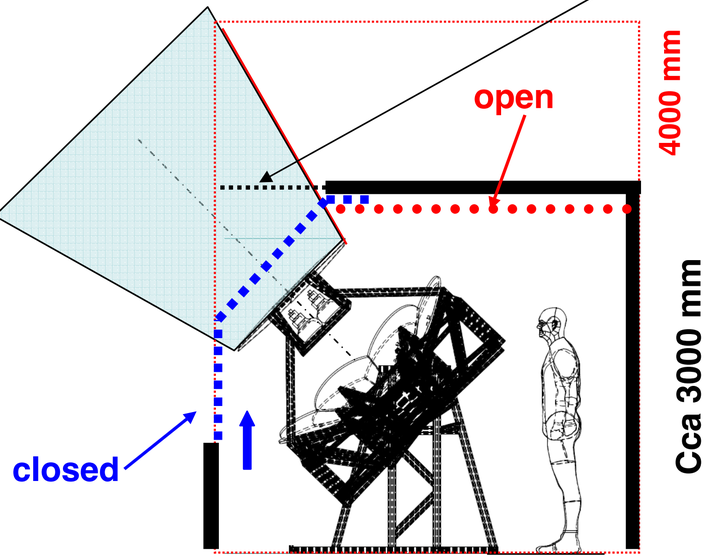
http://arxiv.org/pdf/1509.02048v2.pdf

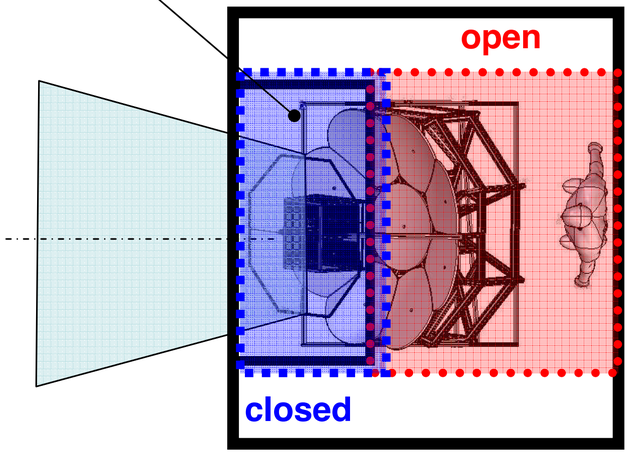
Design of Hut and Shutter



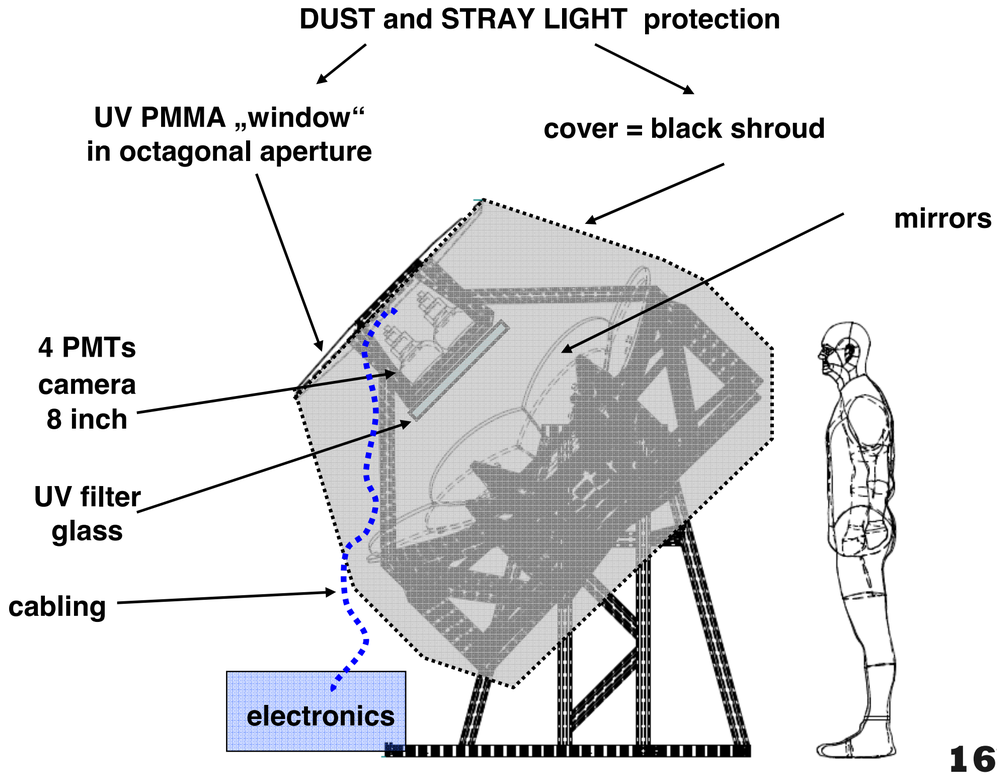


roof „window“





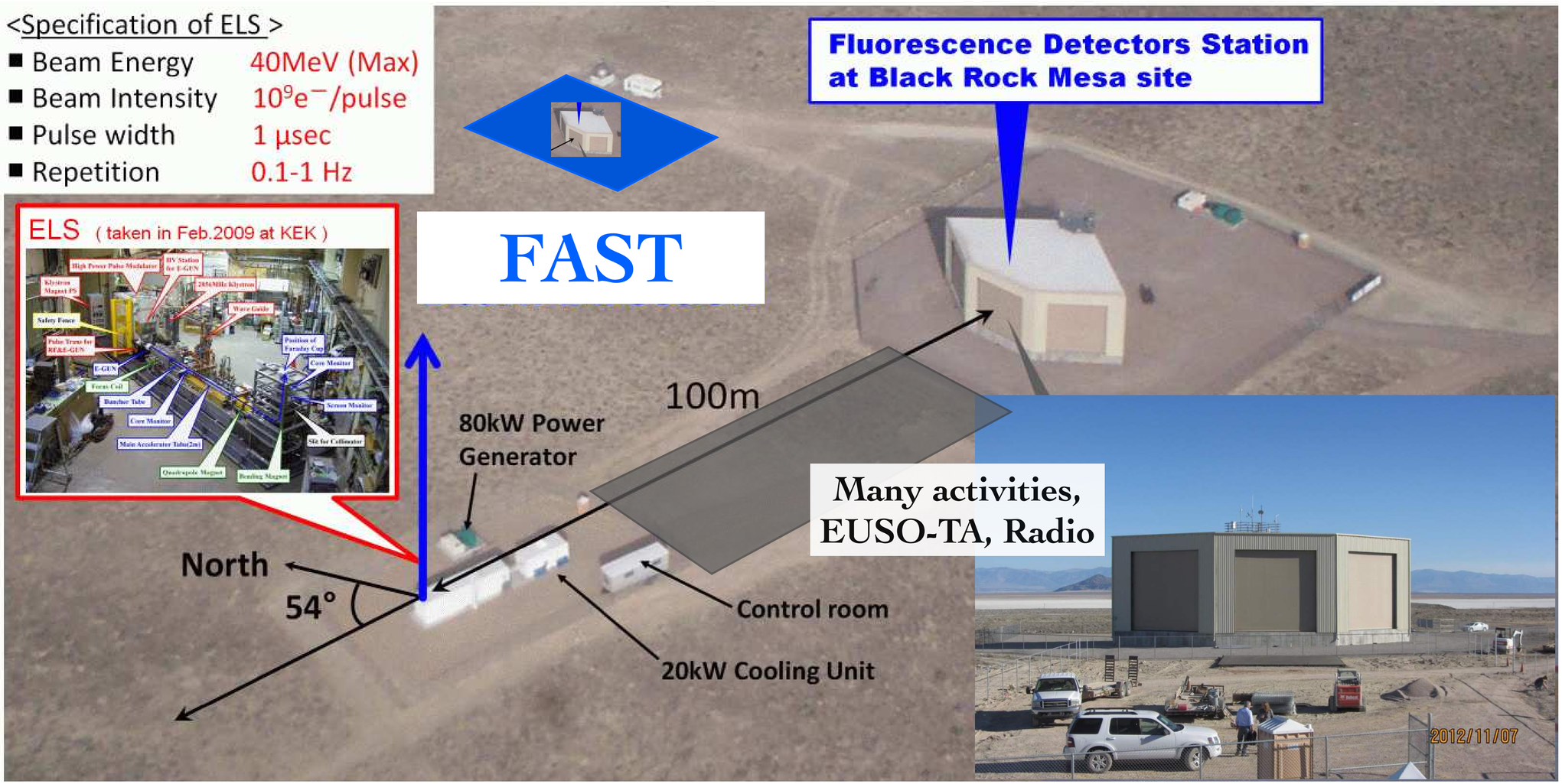
- Adjustable elevation 15° or 45°, like HEAT and TALE, to enlarge the FoV of the current FD.
- Robust design for maintenance free and stand-alone observation.



"Easy" to Change Elevation

FAST Prototype in February 2016

FAST Hut and Shutter

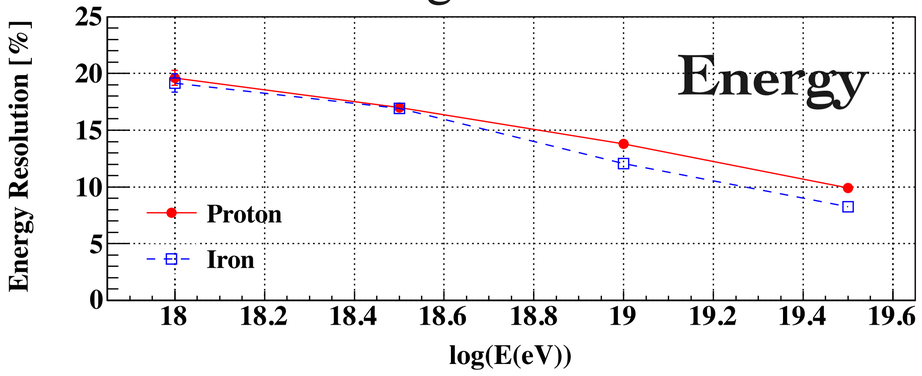


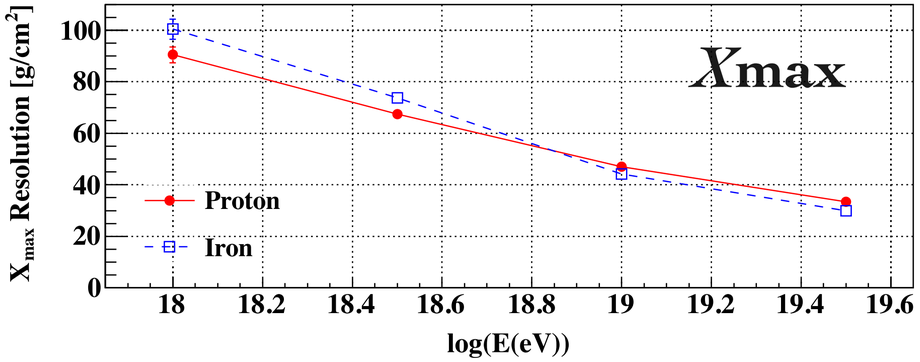
We will plan to install the full-scale FAST telescope on June 2016.

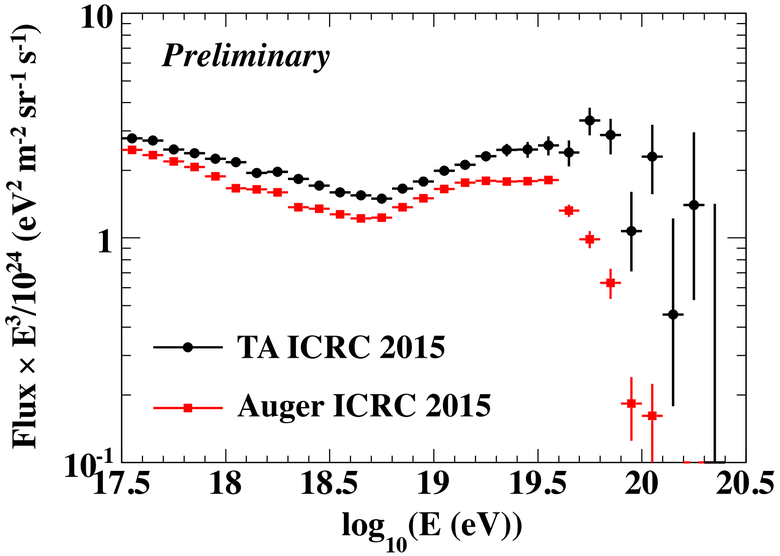
Possible Application of FAST Prototype

FAST — Fluorescence detector Array of Single-pixel Telescopes

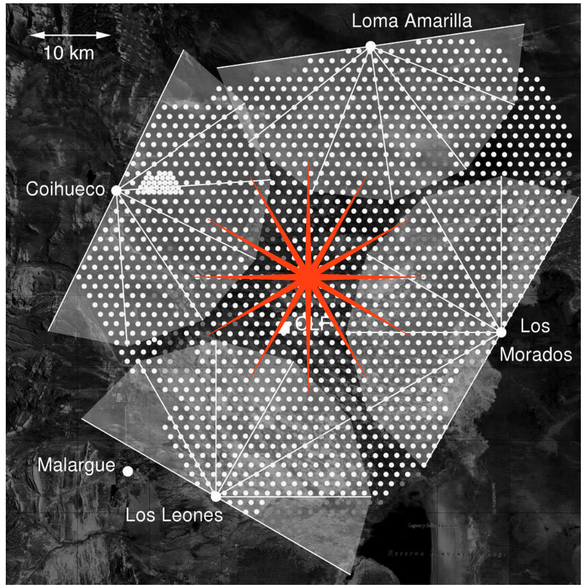
- Install FAST at Auger and TA for a cross calibration.
- Profile reconstruction with geometry given by SD (smearing gaussian width of 1° in direction, 100 m in core location).
  - Energy: 10%, *X*max : 35 g/cm^2 at $10^{19.5}$ eV
  - Independent cross-check of **Energy and *X*max** scale between Auger and TA





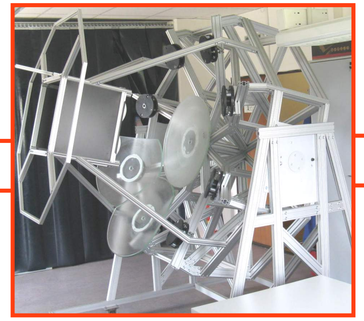


Pierre Auger Observatory

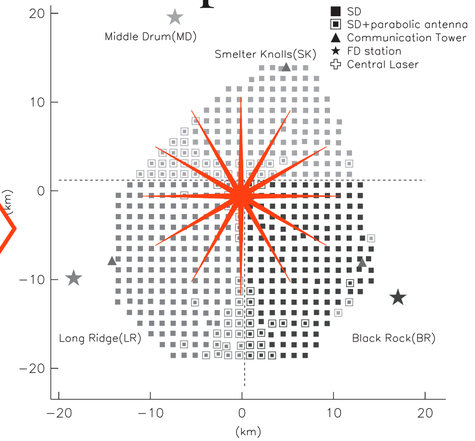


Pierre Auger Collaboration, NIM-A (2010)

Identical simplified FD



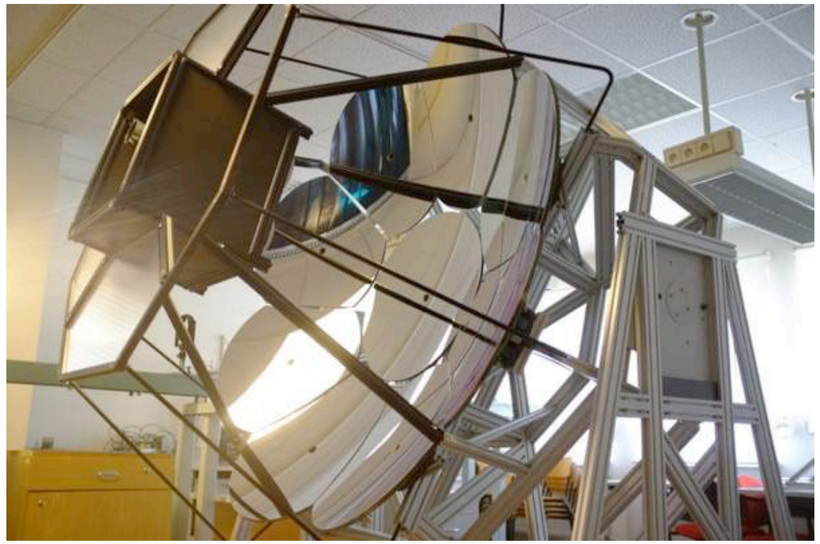
Telescope Array Experiment

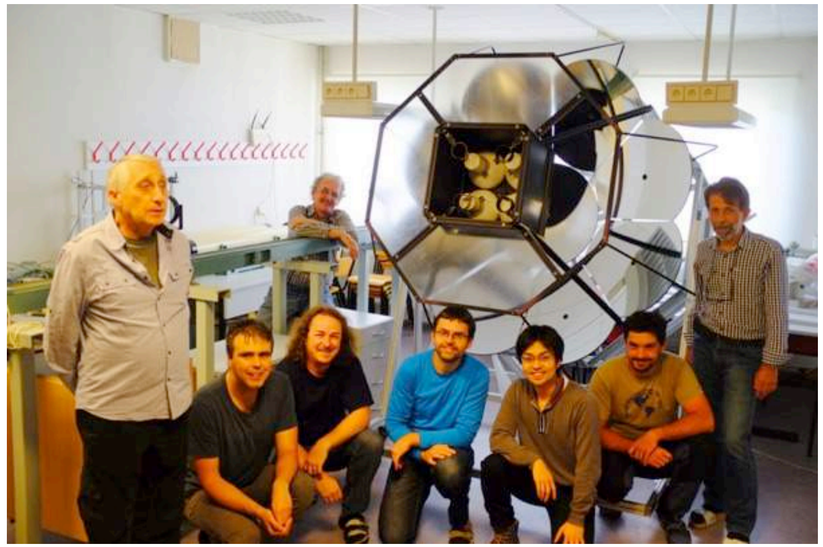


Telescope Array Collaboration NIM-A (2012)

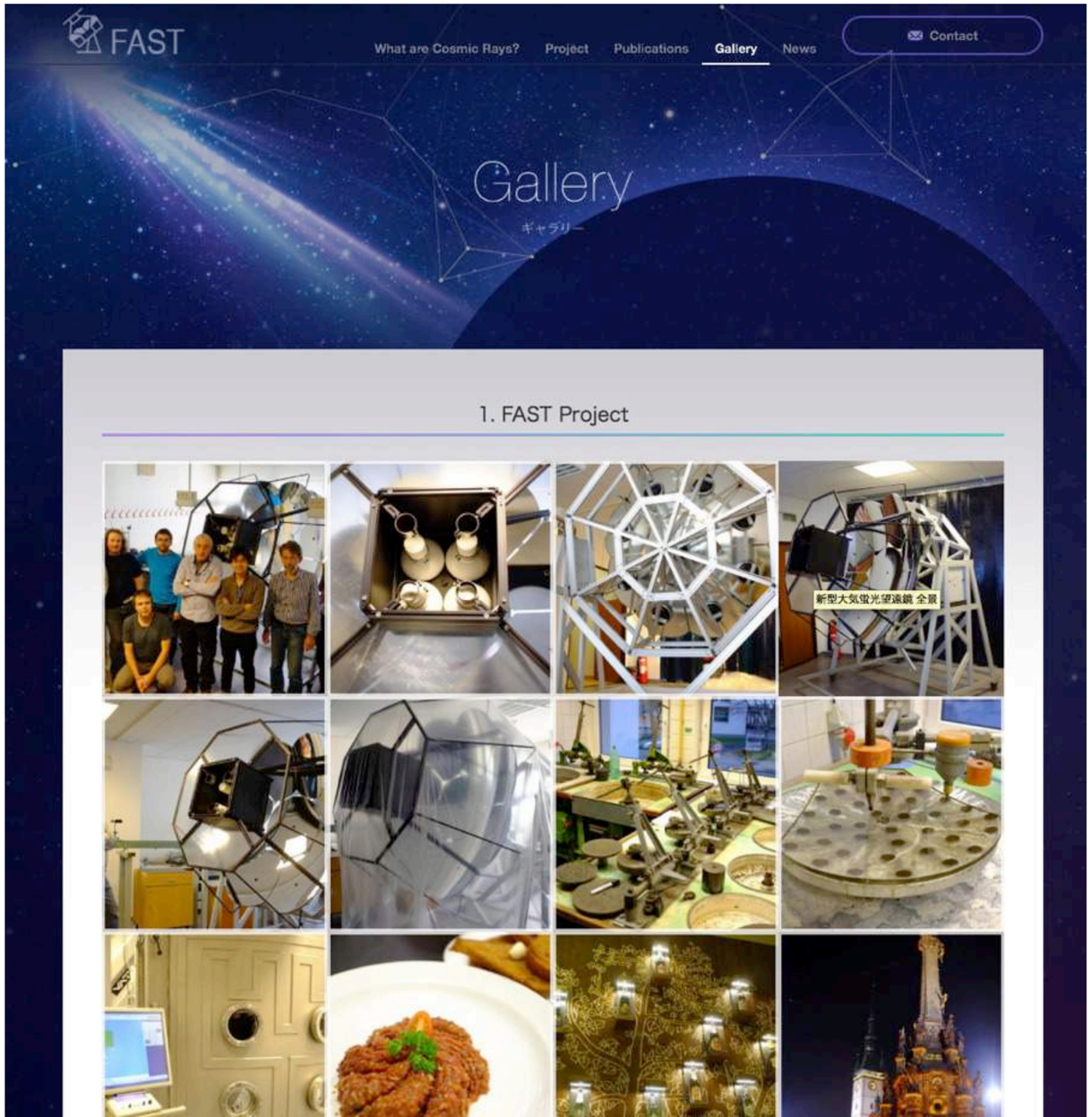
Summary and Future Plans

- **Fluorescence detector Array of Single-pixel Telescopes (FAST)**
  - Deploy the economical fluorescence detector array.
  - Detect UHECRs and neutral particles.
- This concept of single-pixel telescope was confirmed by the field measurements using the EUSO-TA optics.
  - Published in Astroparticle Physics 74 (2016) 64-72
- The full-scale FAST prototype is being constructed, and almost ready to ship to Utah.
  - We plan to install in June 2016.





FAST Webpage



FAST
Fluorescence detector Array of Single-pixel Telescopes

FAST

FAST

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Fluorescence detector Array of Single-pixel Telescopes

http://www.fast-project.org