The FAST Project
-Next Generation UHECR Observatory-

Fluorescence detector **A**rray of **S**ingle-pixel **T**elescopes

http://www.fast-project.org

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

RICAP 16

Roma International Conference on Astroparticle Physics

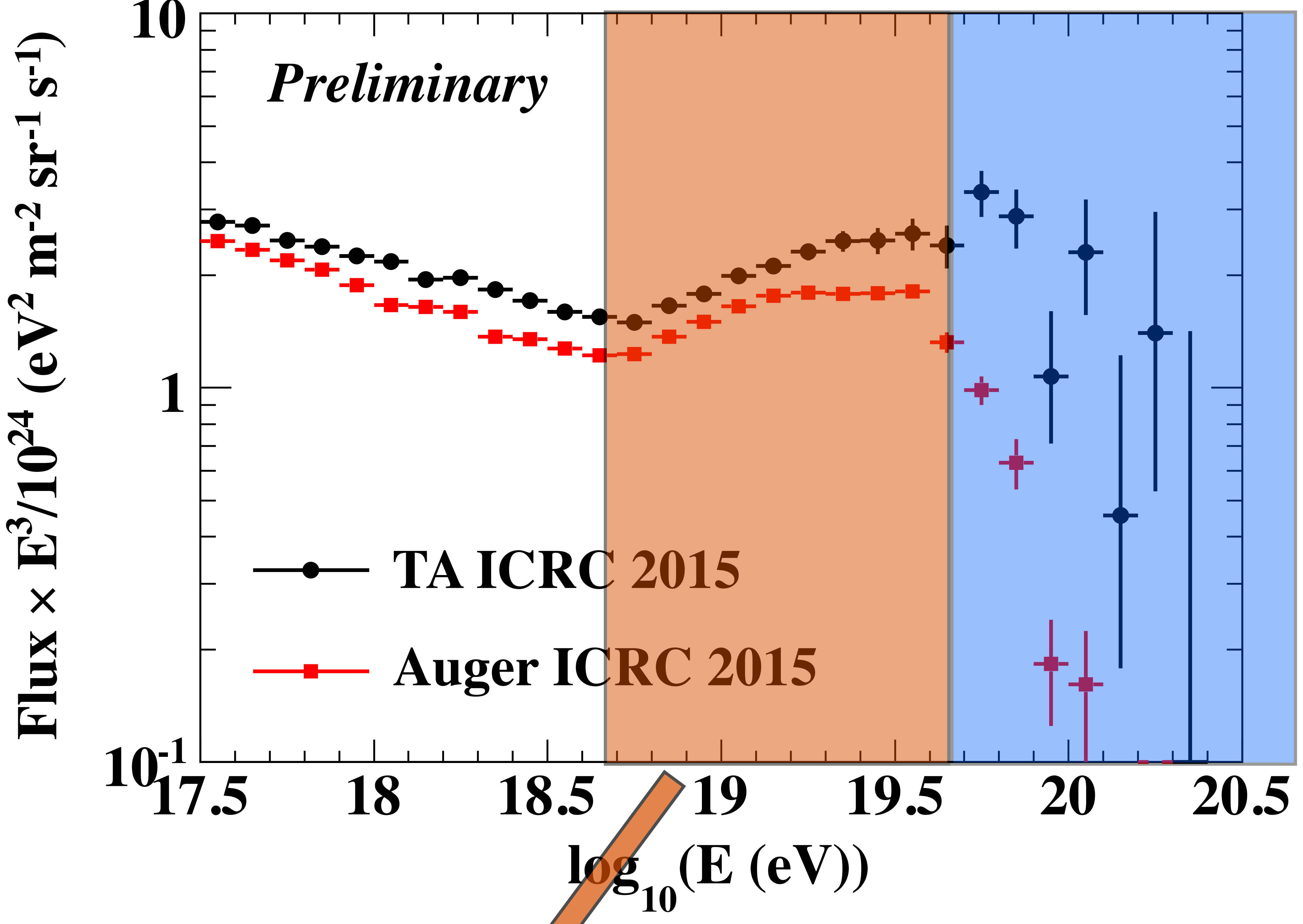
Web Page: Ricap16.roma2.infn.it

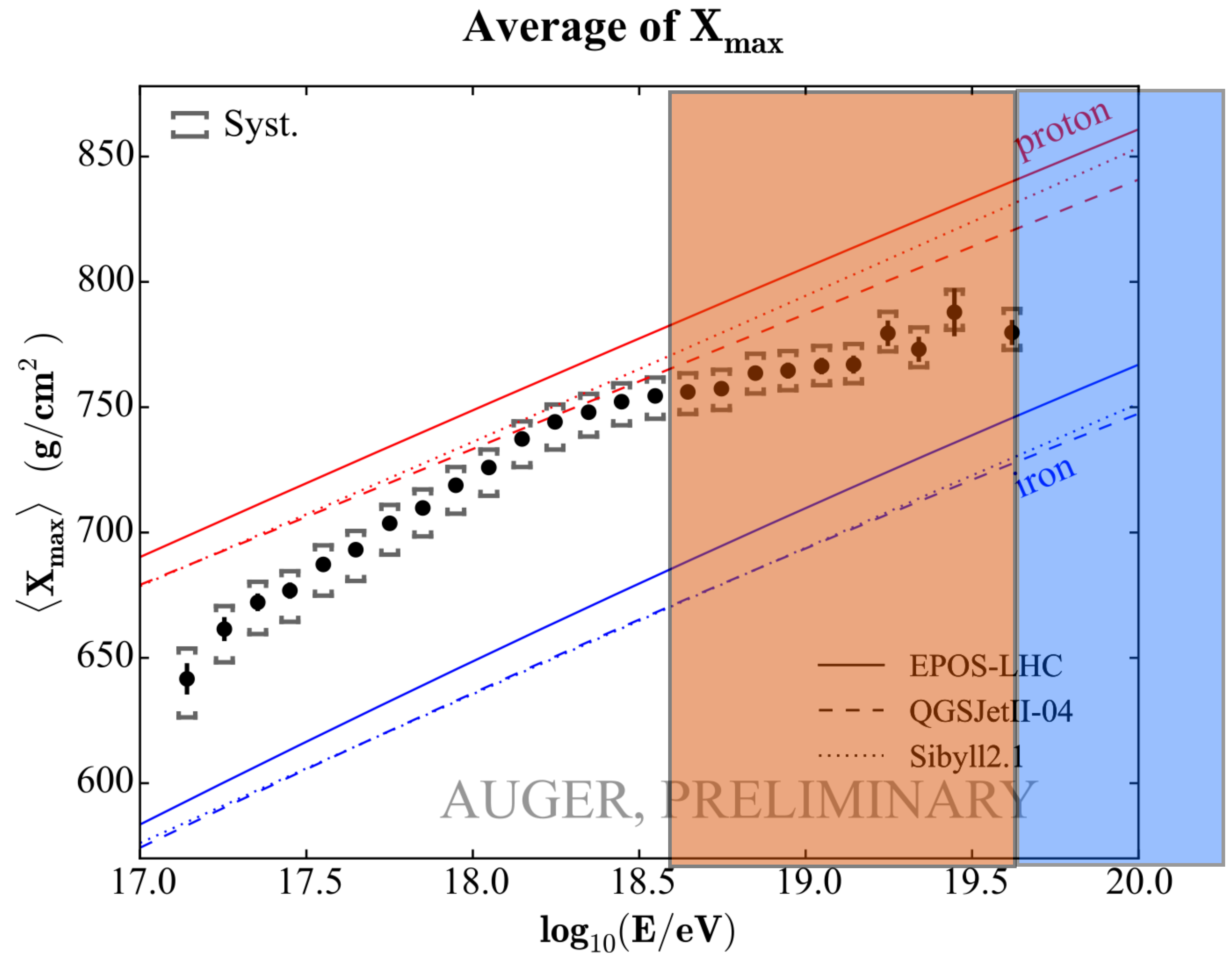
June 21 – 24 , 2016
Villa Tuscolana, Frascati, Roma, Italy

RICAP2016, June 23rd, 2016, fujii@icrr.u-tokyo.ac.jp

Highlights on UHECR

Spectrum discrepancy at suppression





Intermediate composition or models, no information above $10^{19.7}$ eV

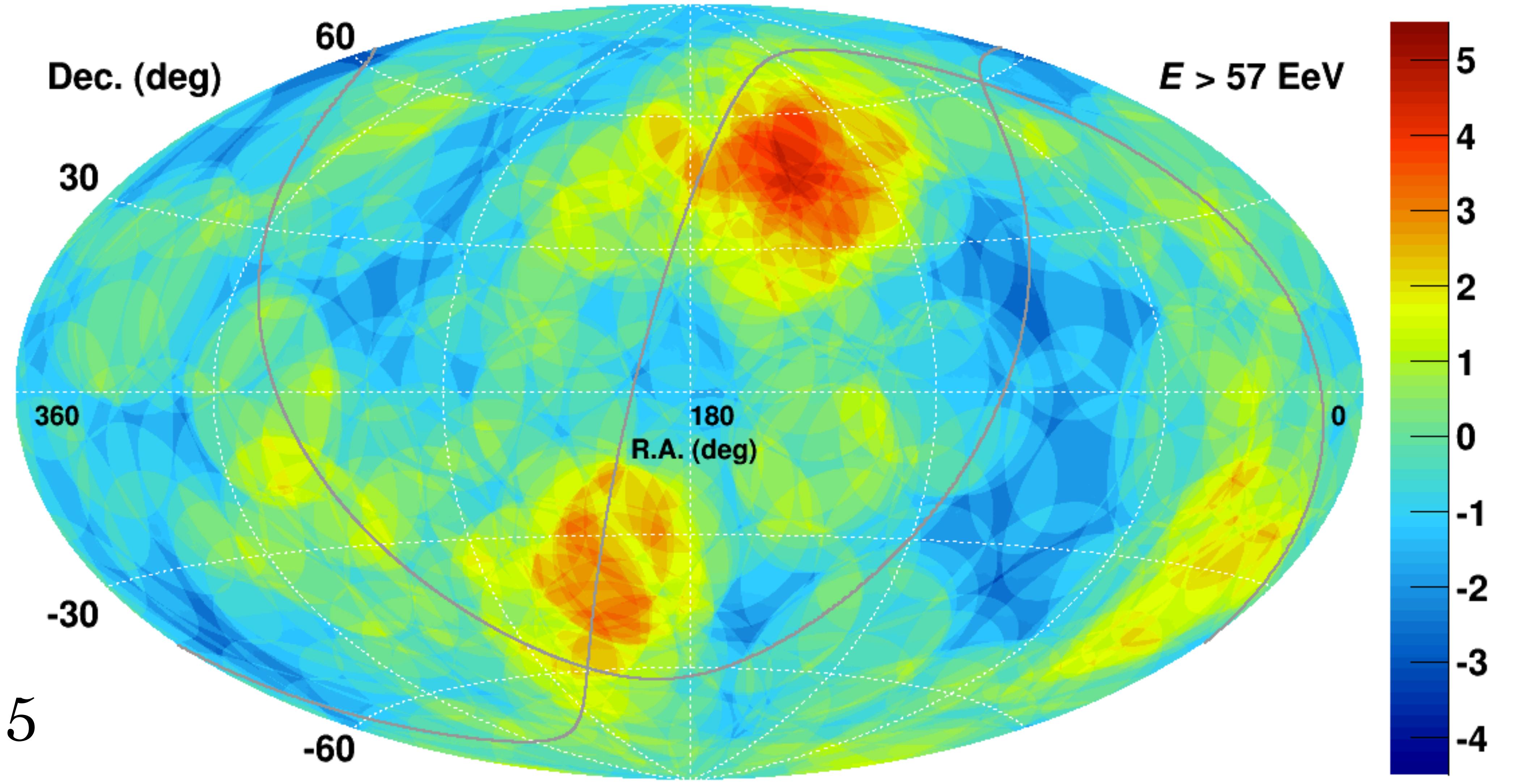
A. Porcelli, ICRC 2015, A. Yushkov, ICRC 2015, PRD 90 122005 (2014)

No anisotropy seen

ApJ, 794 172 (2014)

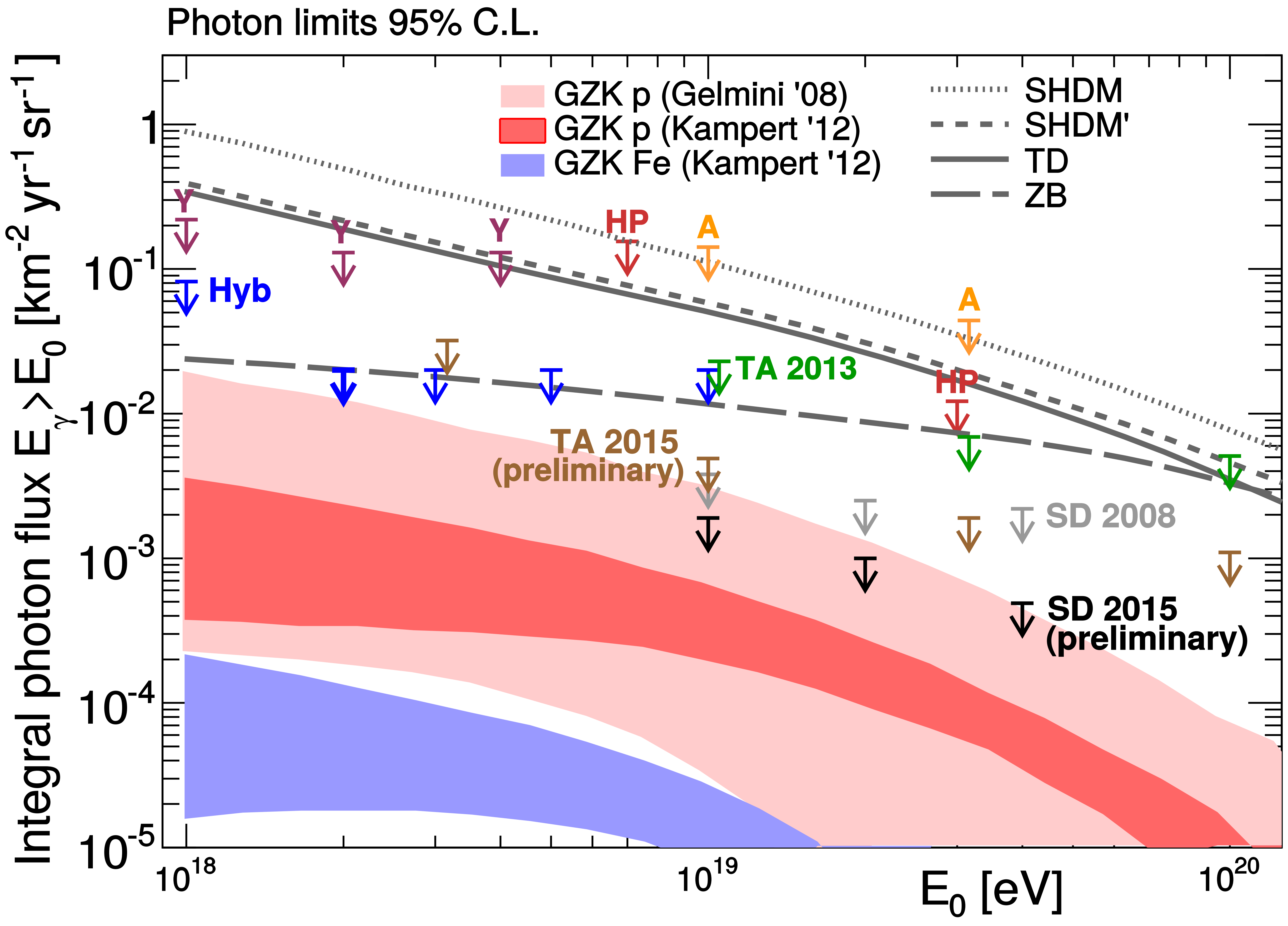
Hotspot/ Warmspot

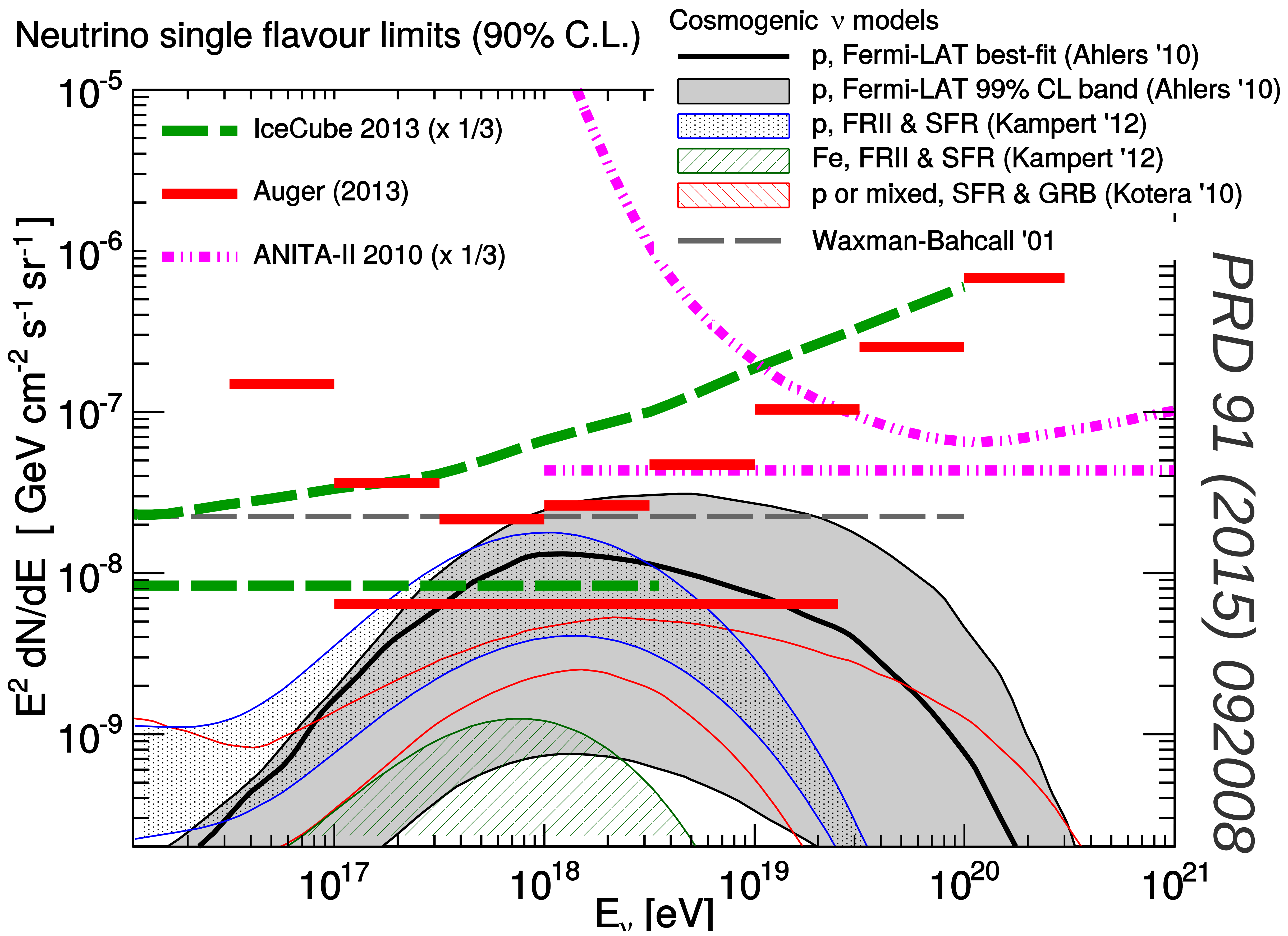
K. Kawata et al, ICRC 2015



Highlights on UHE Photon/Neutrino

Top-down model disfavored, close to GZK photon/neutrino





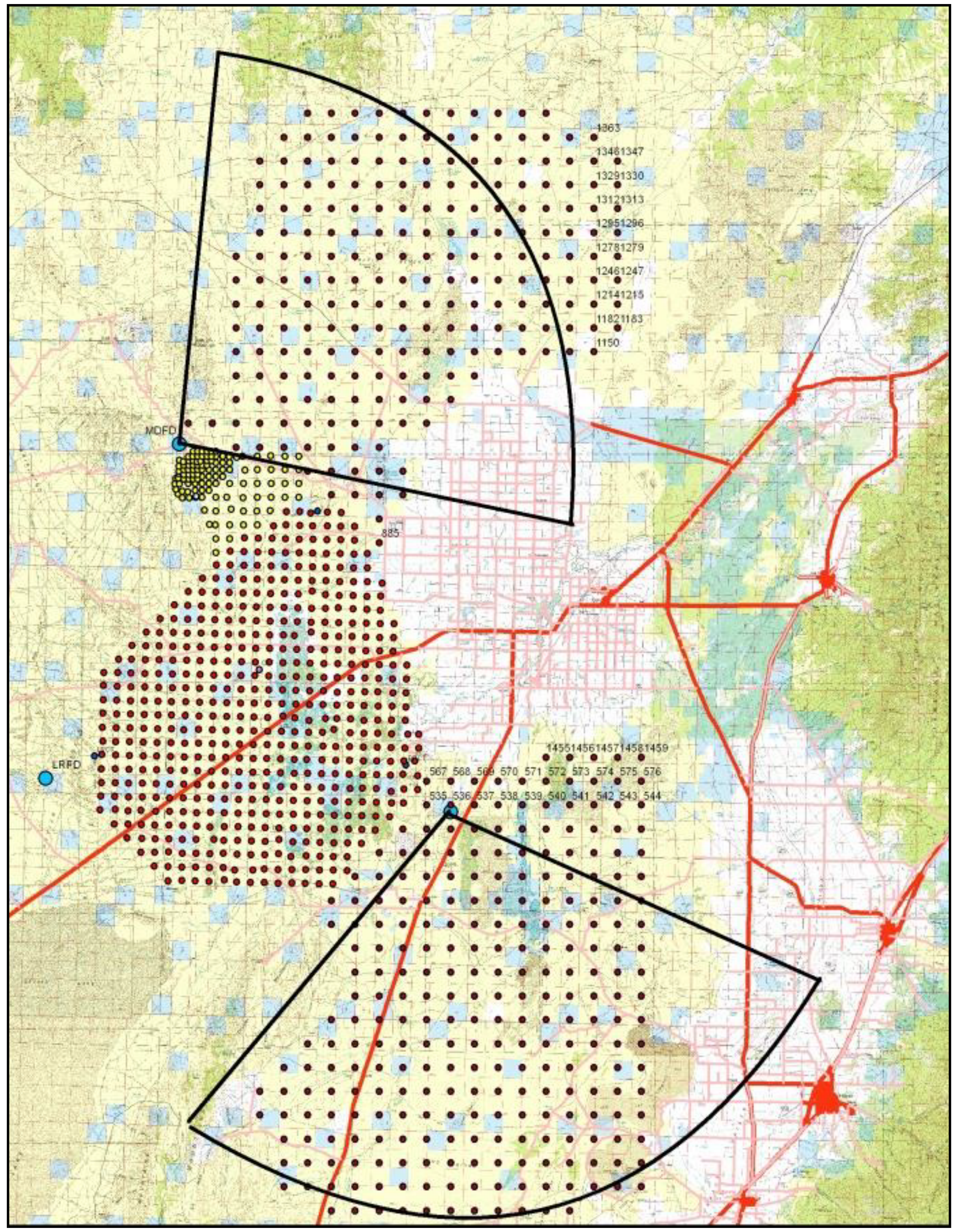
PRD 91 (2015) 092008

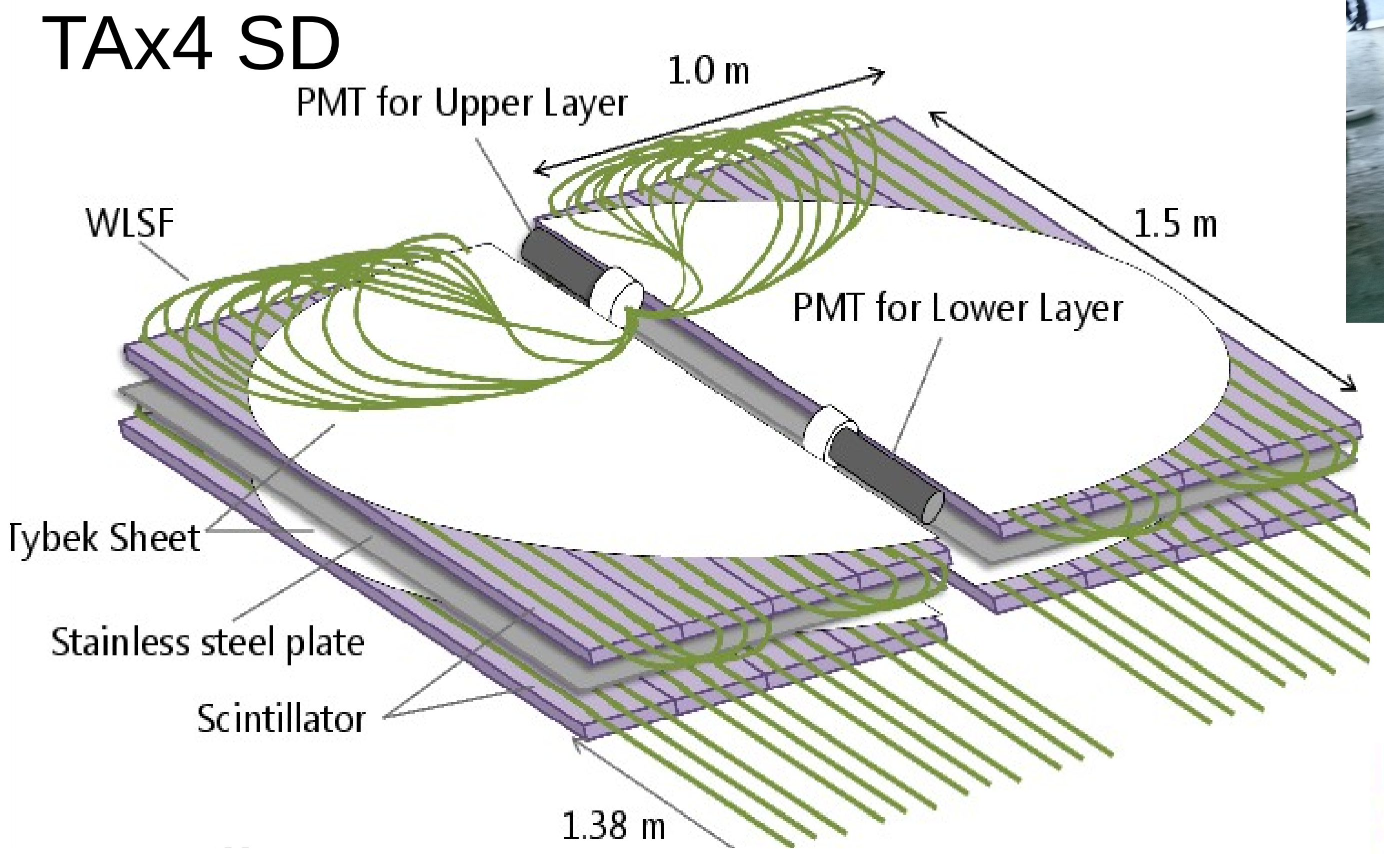
C. Bleve ICRC 2015

On-going Upgrade: TA×4

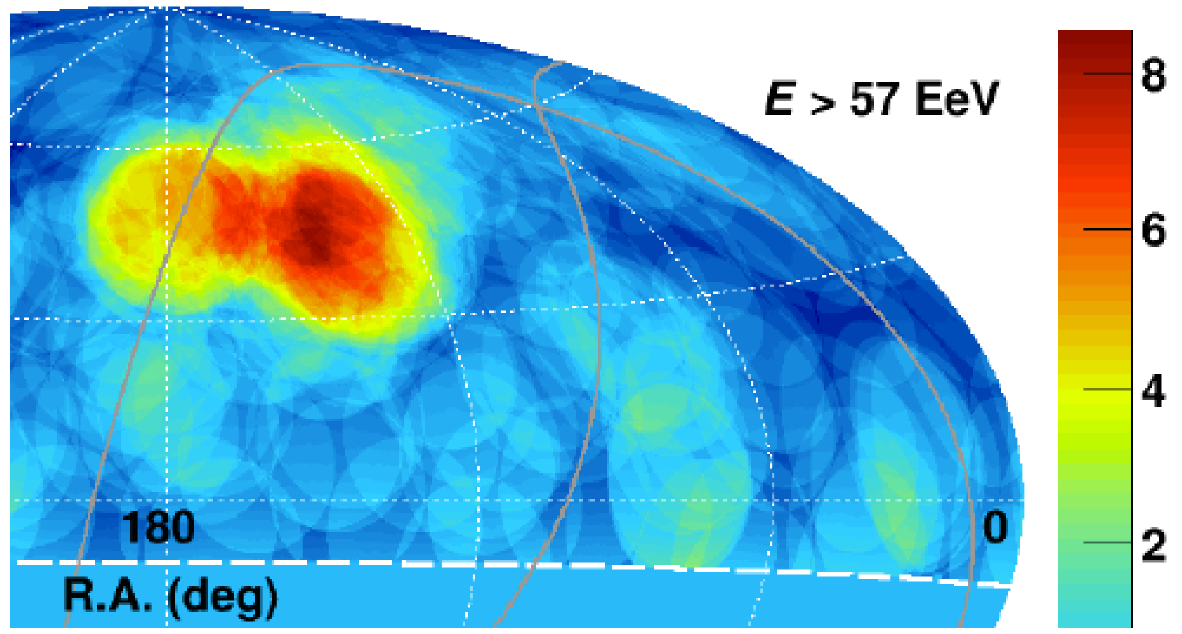
Detailed measurement on Hotspot

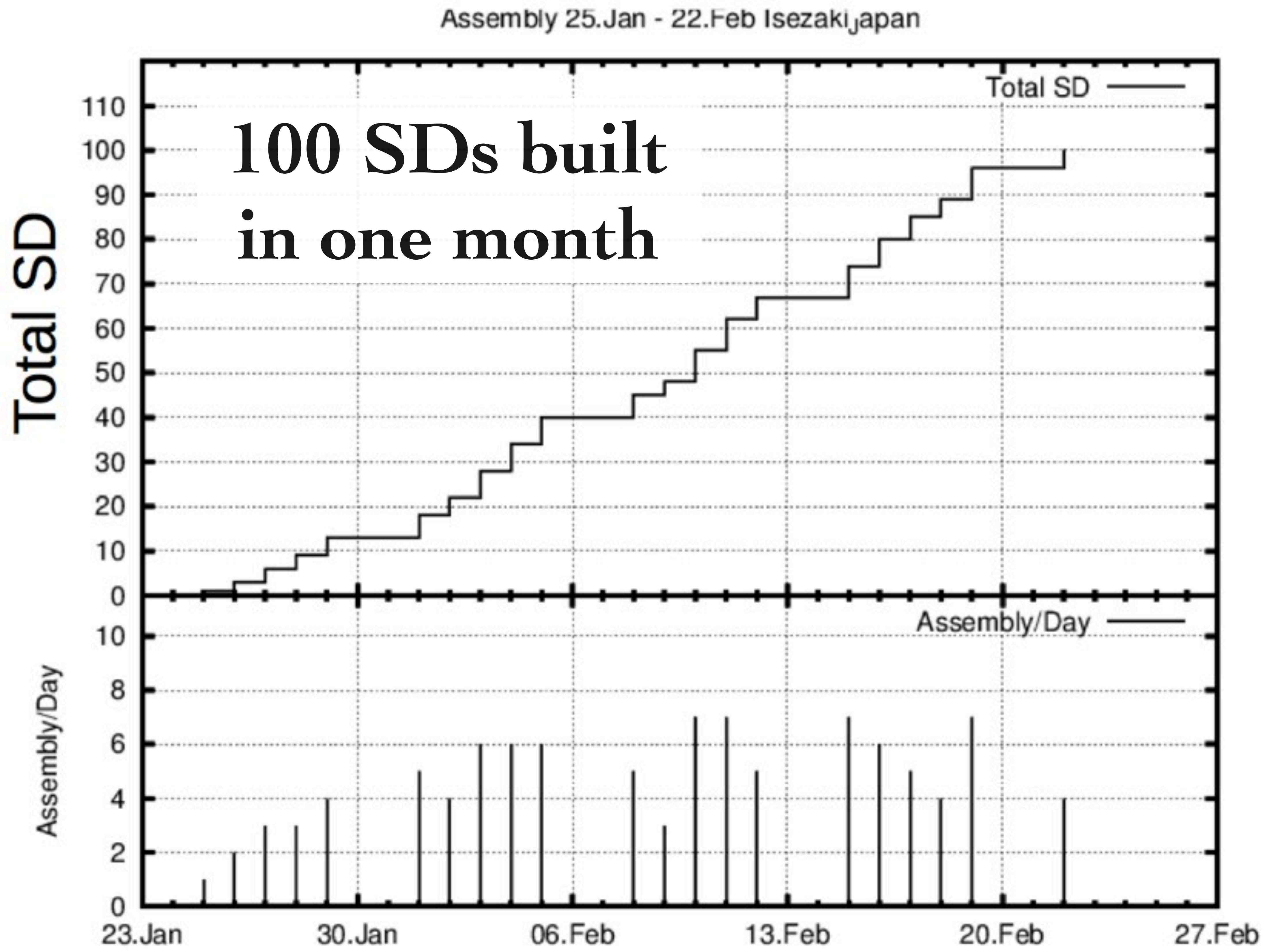
Enlarge the fourfold coverage to TA×4 = Auger,
3,000 km^2





Expected in 2020 (Simulation)

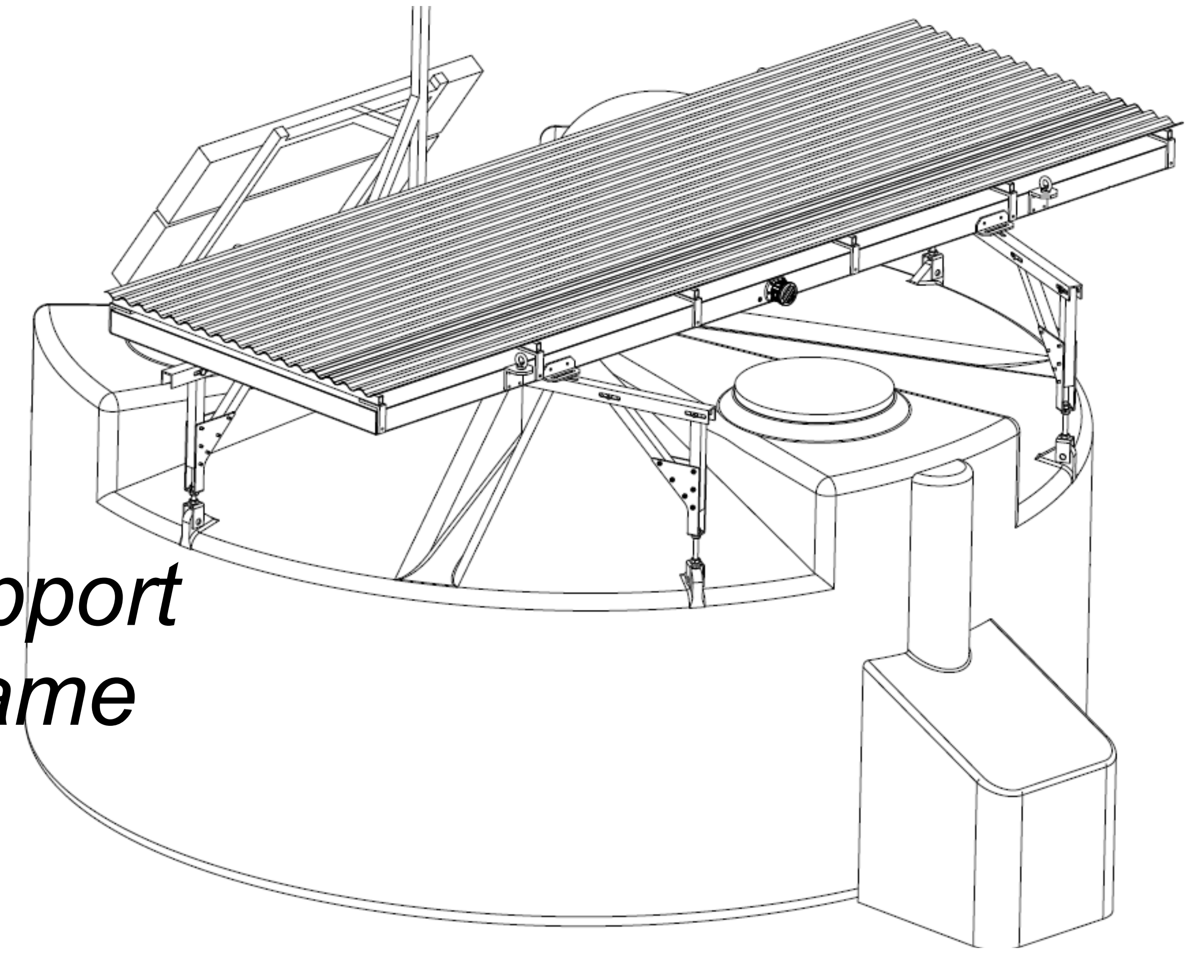


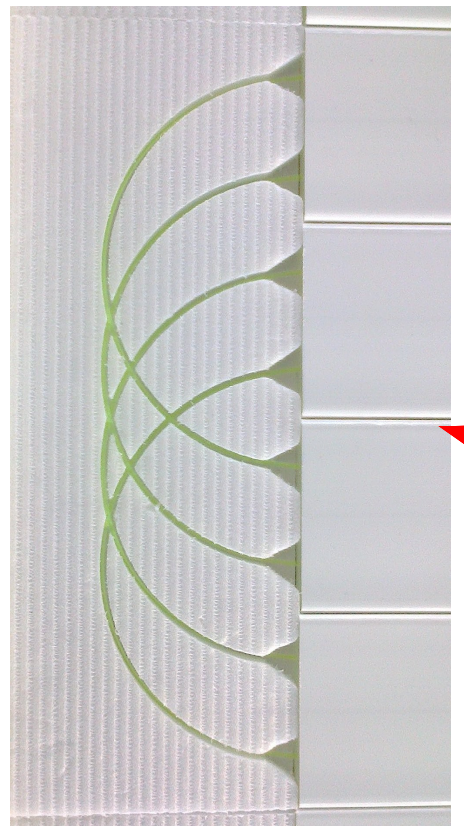


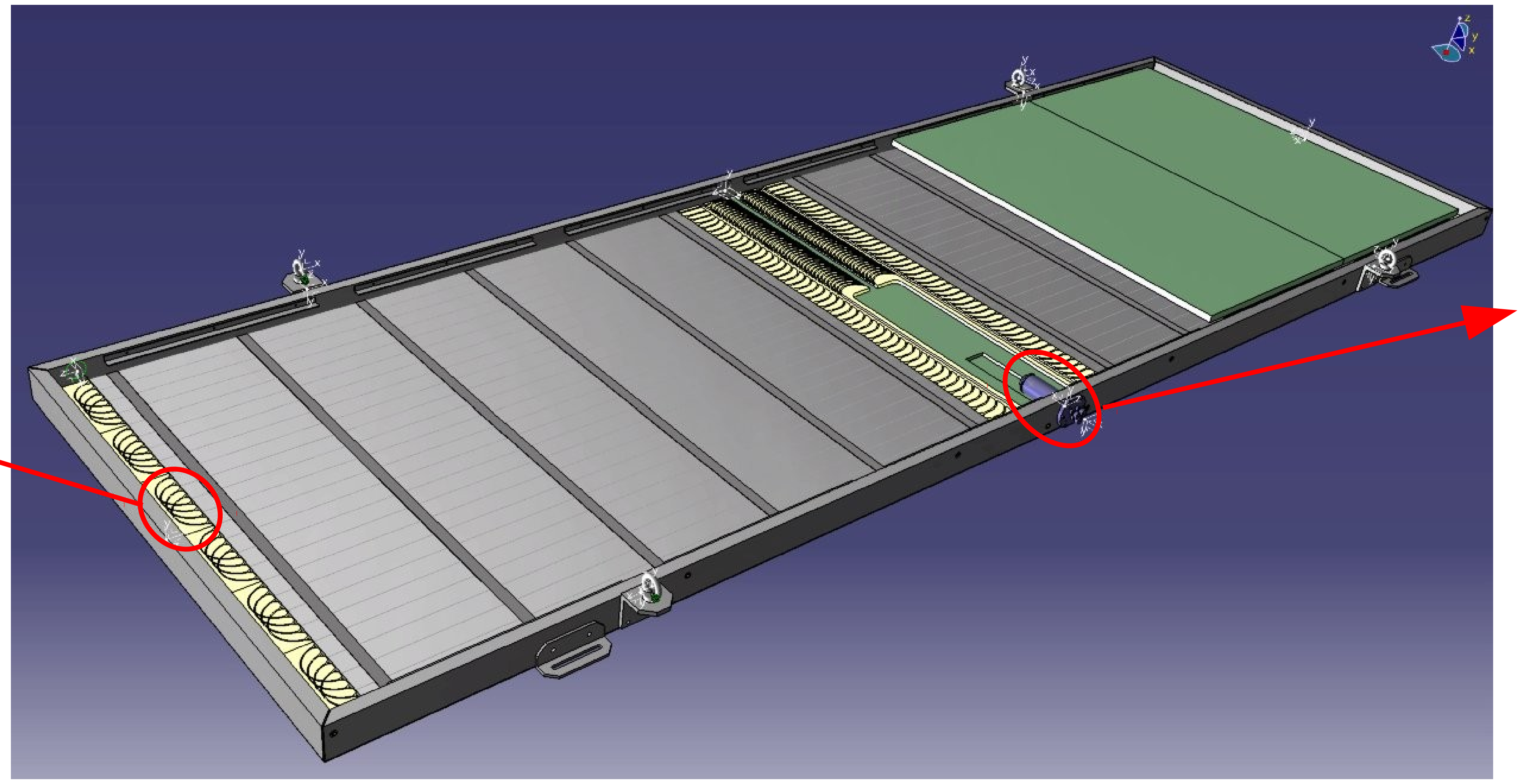
H. Sagawa ICRC2015, T. Nonaka UHEAP2016

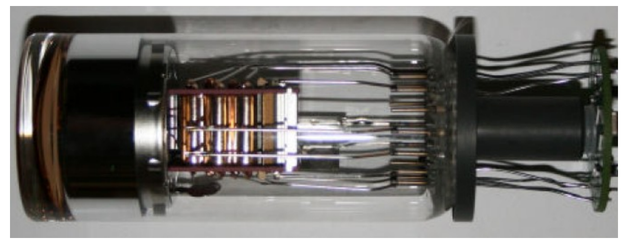
On-going Upgrade: AugerPrime

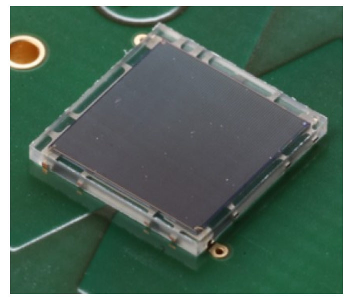
Install 4 m^2 Scintillator to measure the mass composition by SD.

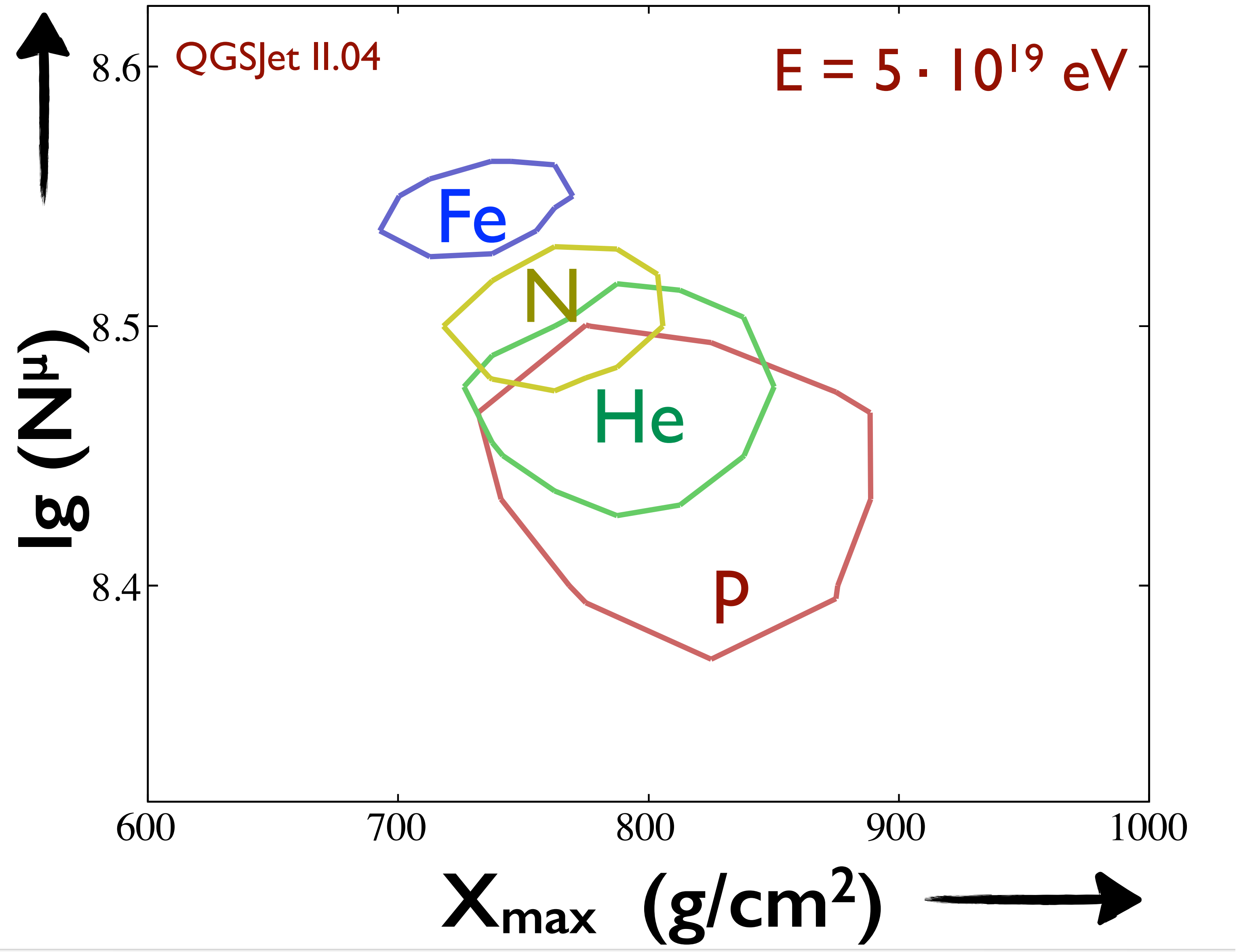












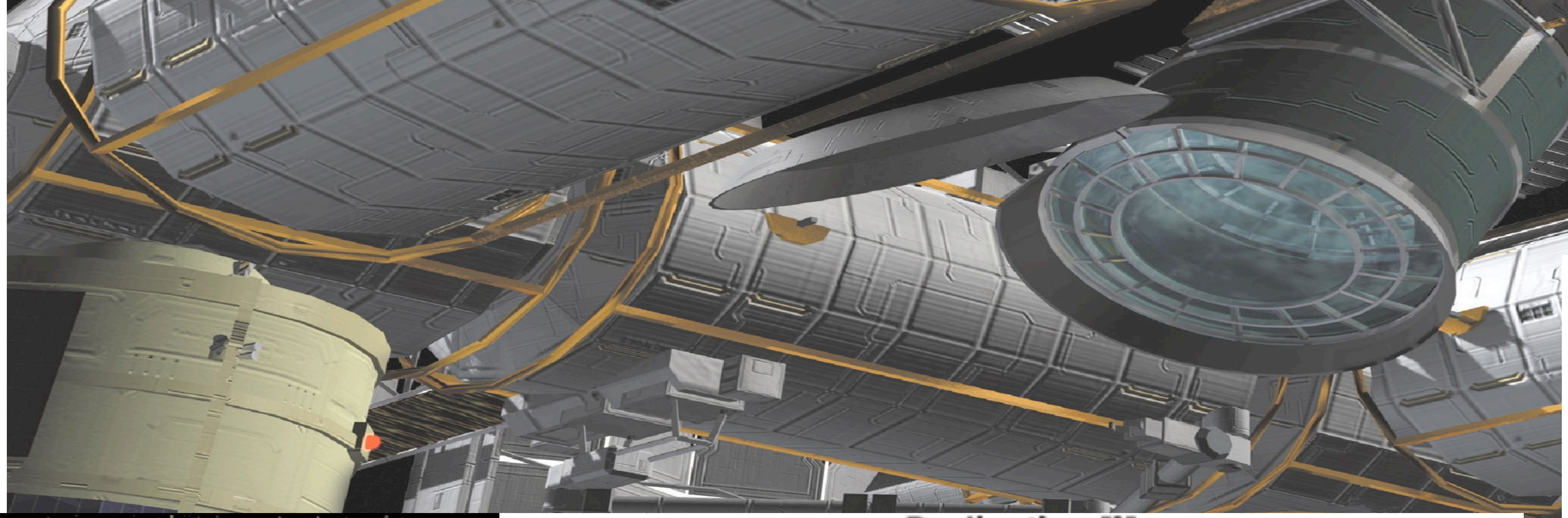
- Improve electromagnetic/muon separation of **SD** to measure the **mass composition above 10$^{19.7}$ eV.**
  - Boost in statistics by a factor of ~ 10 compared to FD *X*max analysis.
- Small PMT in the water tank, FD operation during moon night.
- **Origin of flux suppression, proton contribution above 10$^{19.7}$ eV, new particle physics beyond the human-made accelerator.**

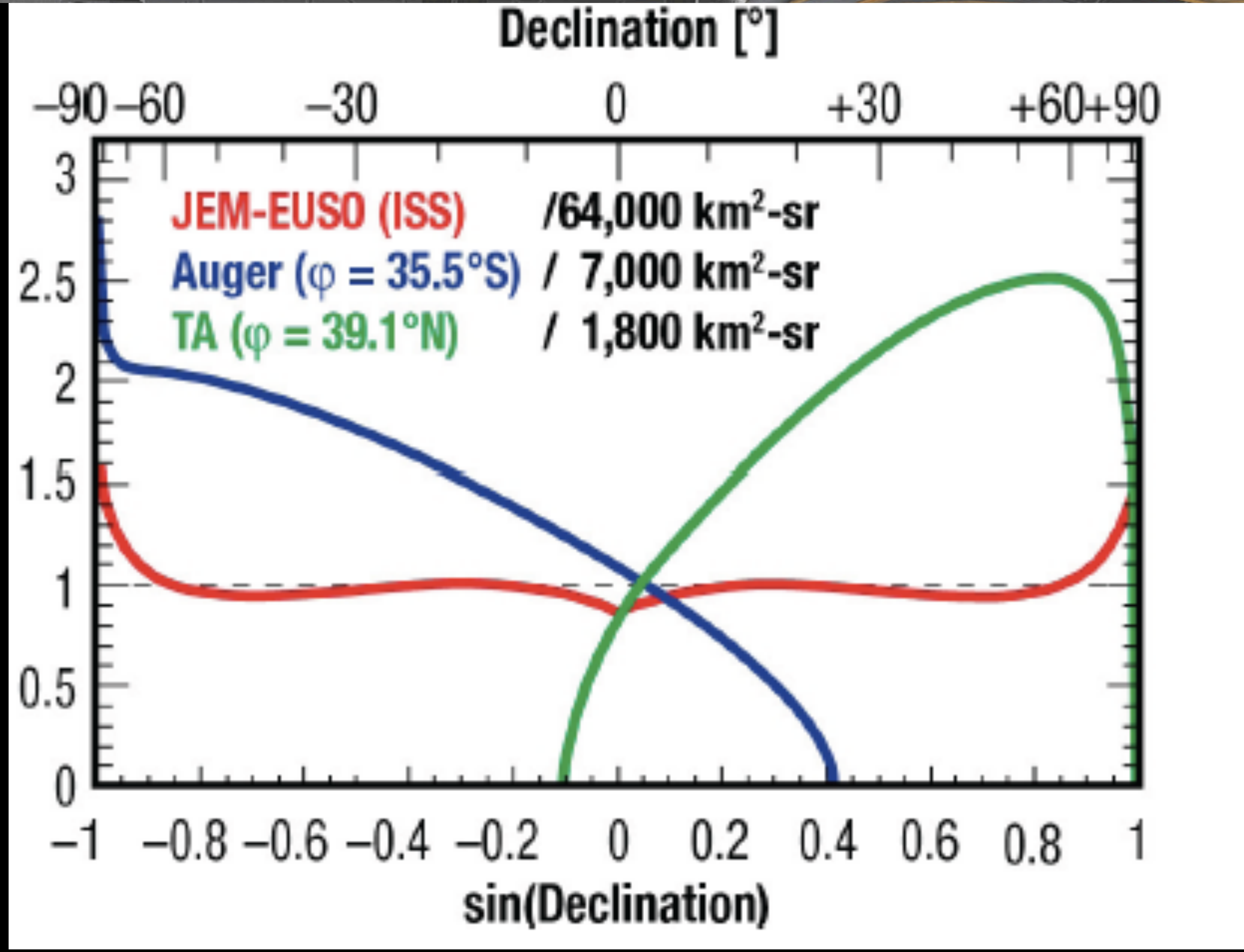
R. Engel ICRC2015, R. Smida UHEAP2016

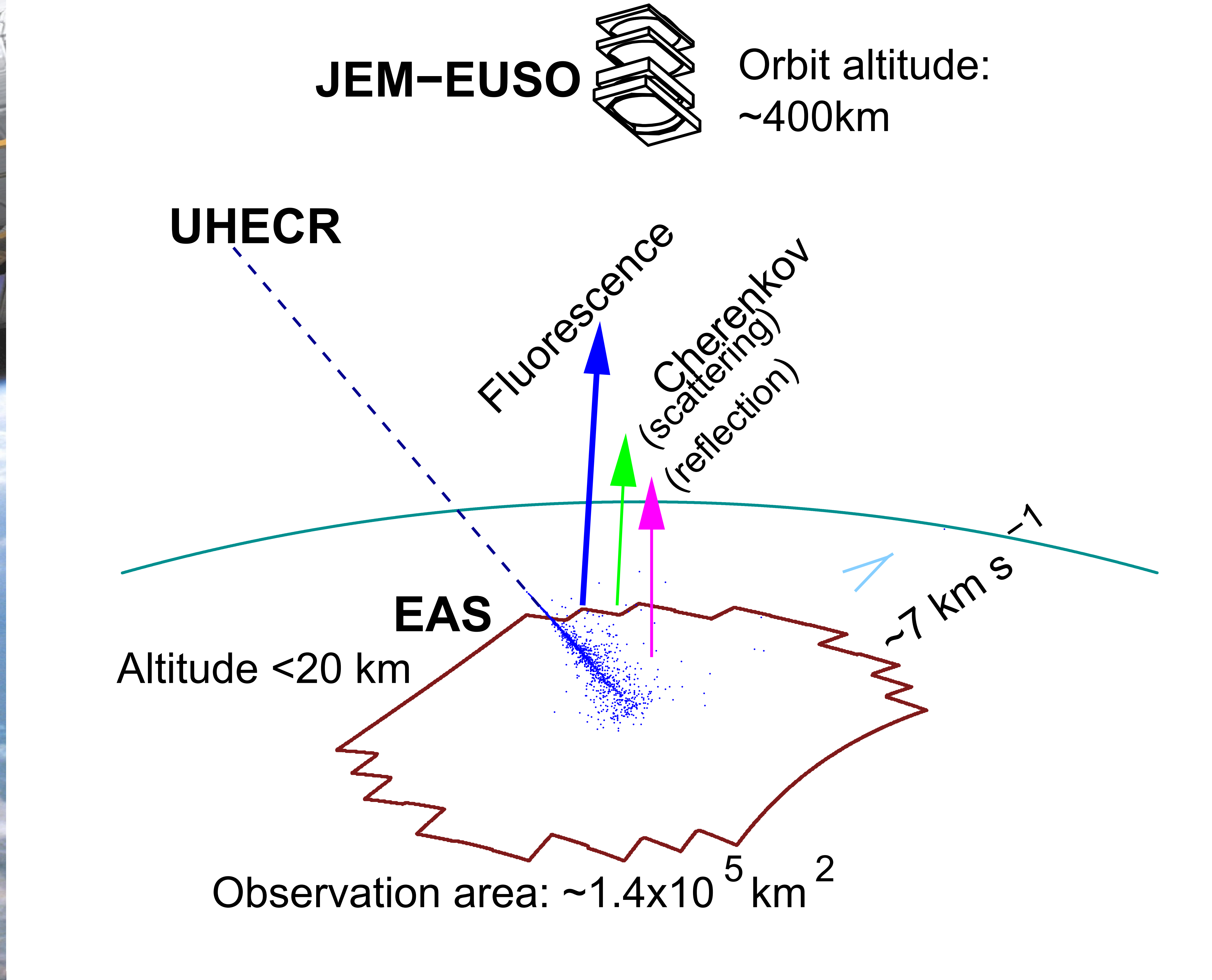
JEM-EUSO

Extreme Universe Space Observatory onboard Japanese Experiment Module

Pioneer detection of UHECRs from space







J.H. Adams Jr. et al., Physics 44 (2013) 76–90

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

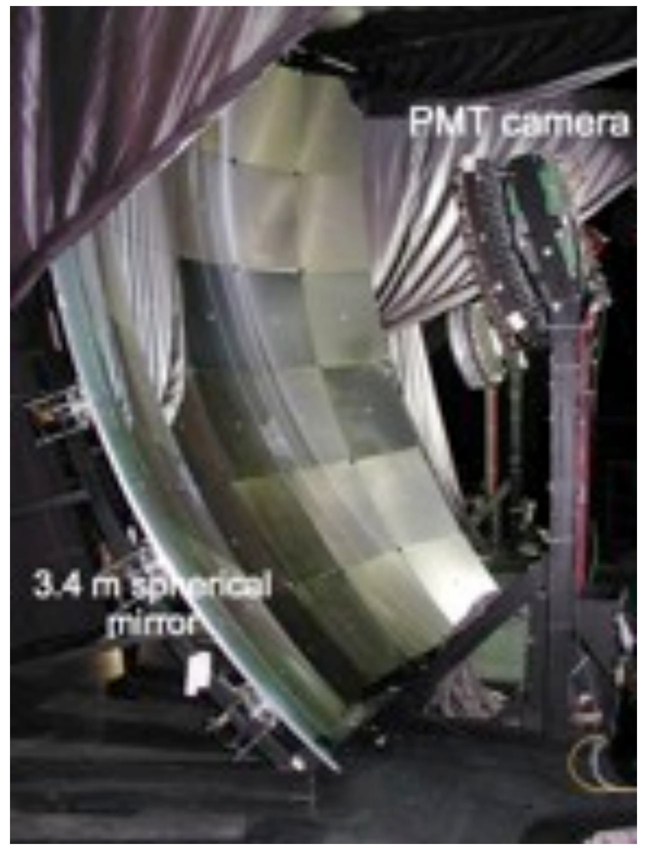
Next Generation Observatories
In space (100×exposure): EUSO-NEXT
Ground (10×exposure with high quality events): Giant Ground Array, FAST

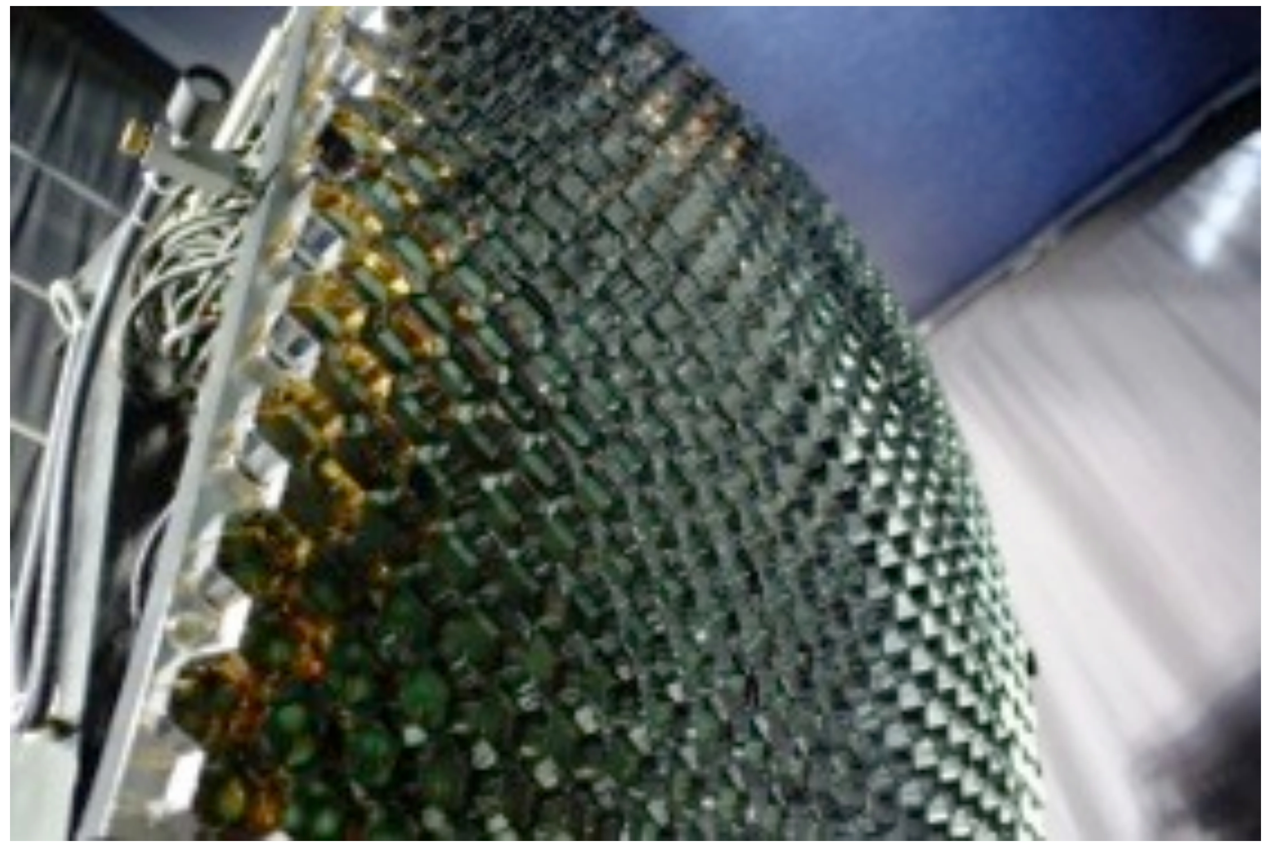
Fluorescence detector Array of Single-pixel Telescopes

FAST Fluorescence detector Array of Single-pixel Telescopes

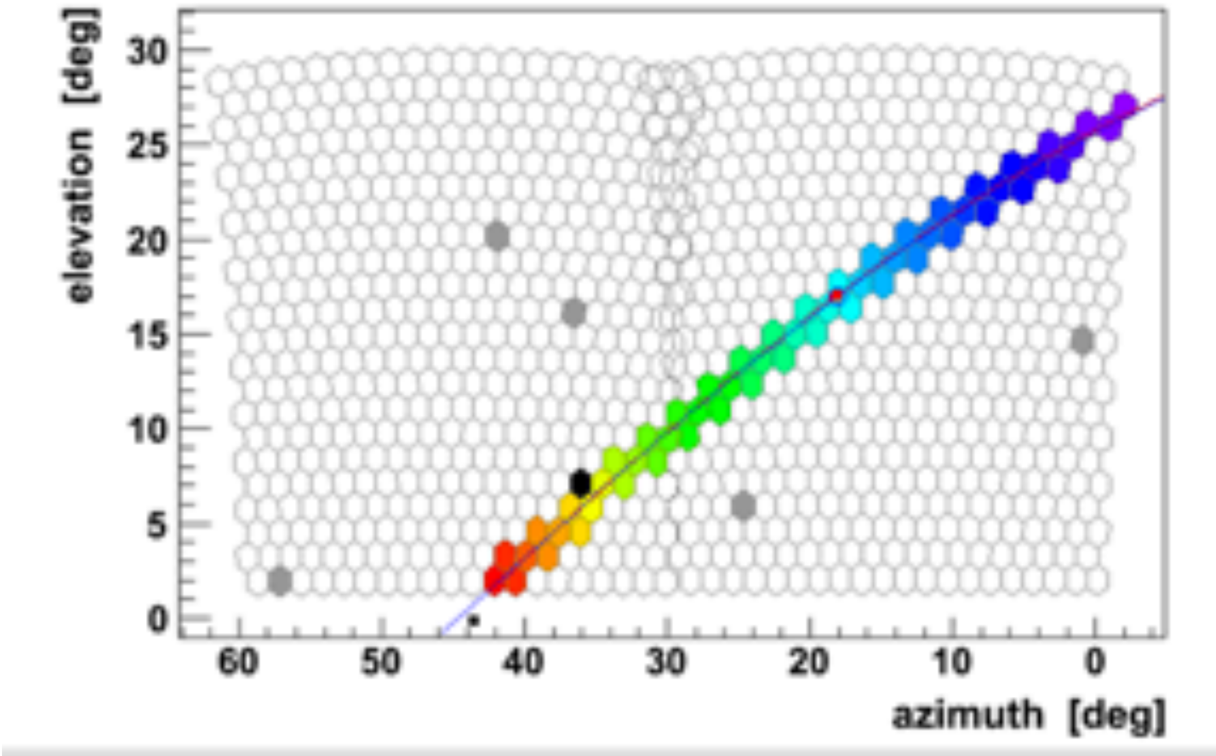
- ✦ Target : > $10^{19.5}$ eV, ultra-high energy cosmic rays (UHECR) and neutral particles
- ✦ Huge target volume ⇒ Fluorescence detector array

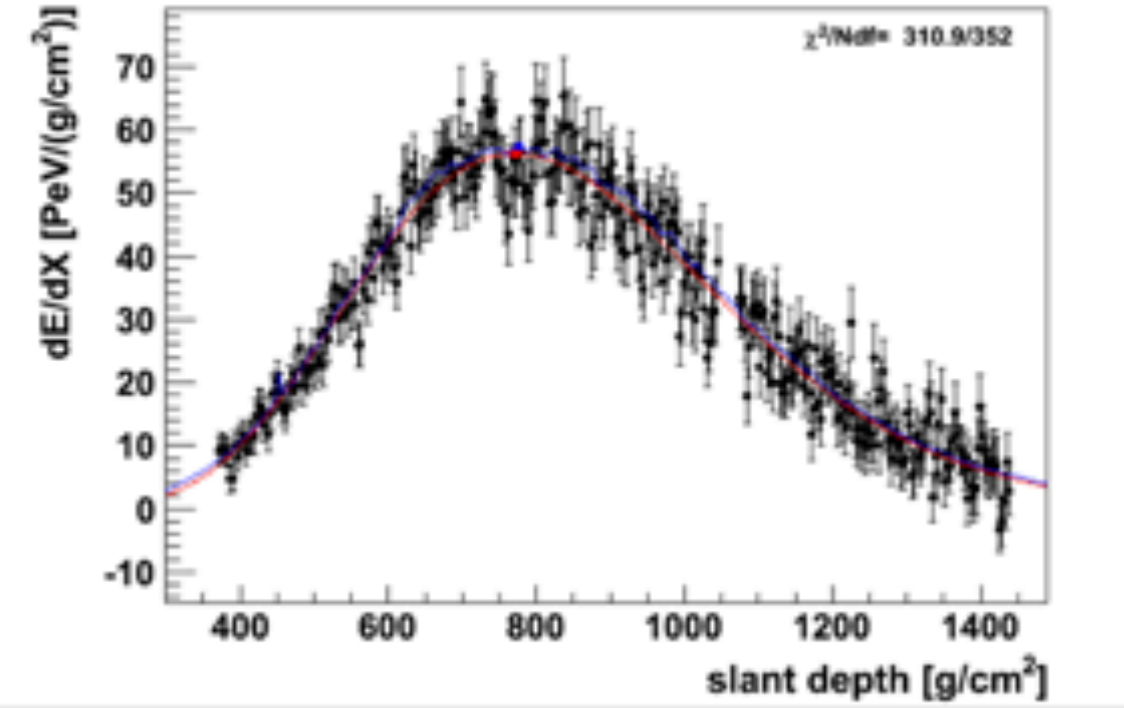
Fine pixelated camera



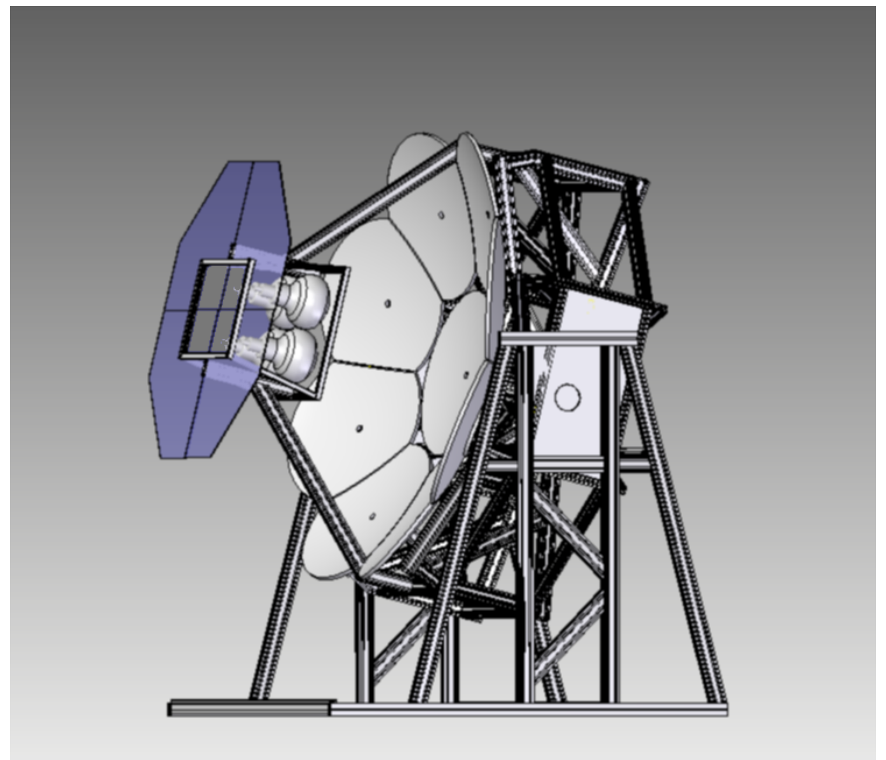


Too expensive to cover a huge area

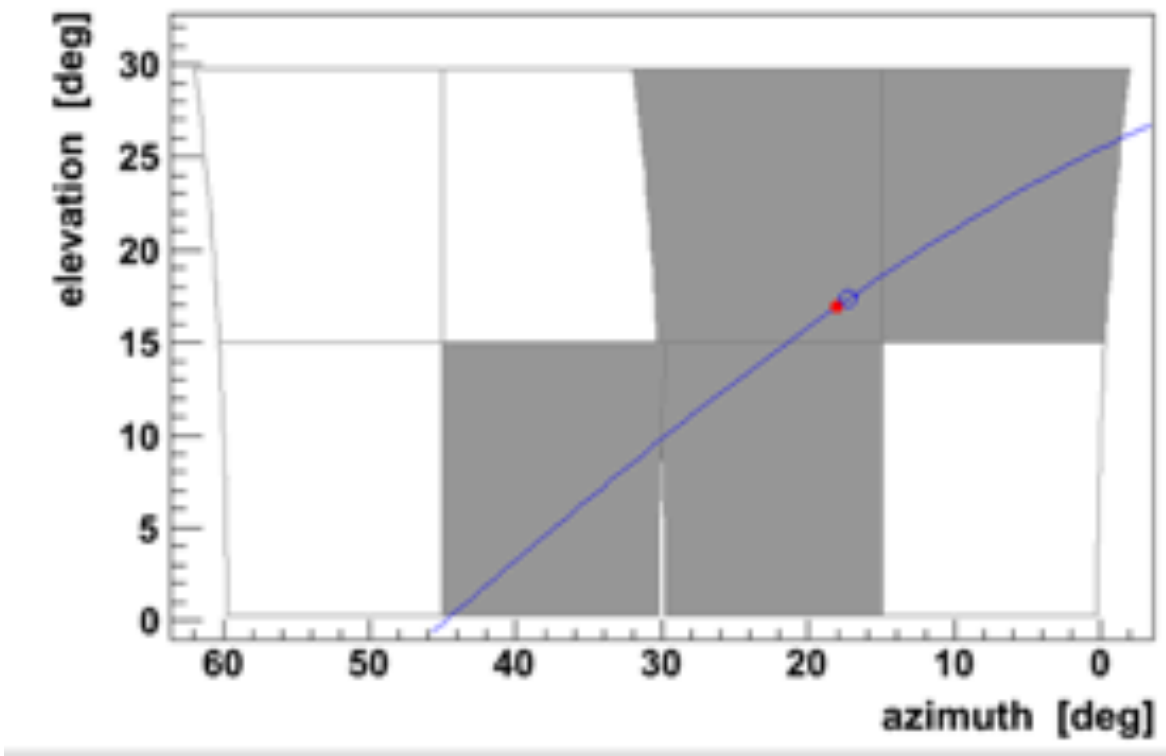


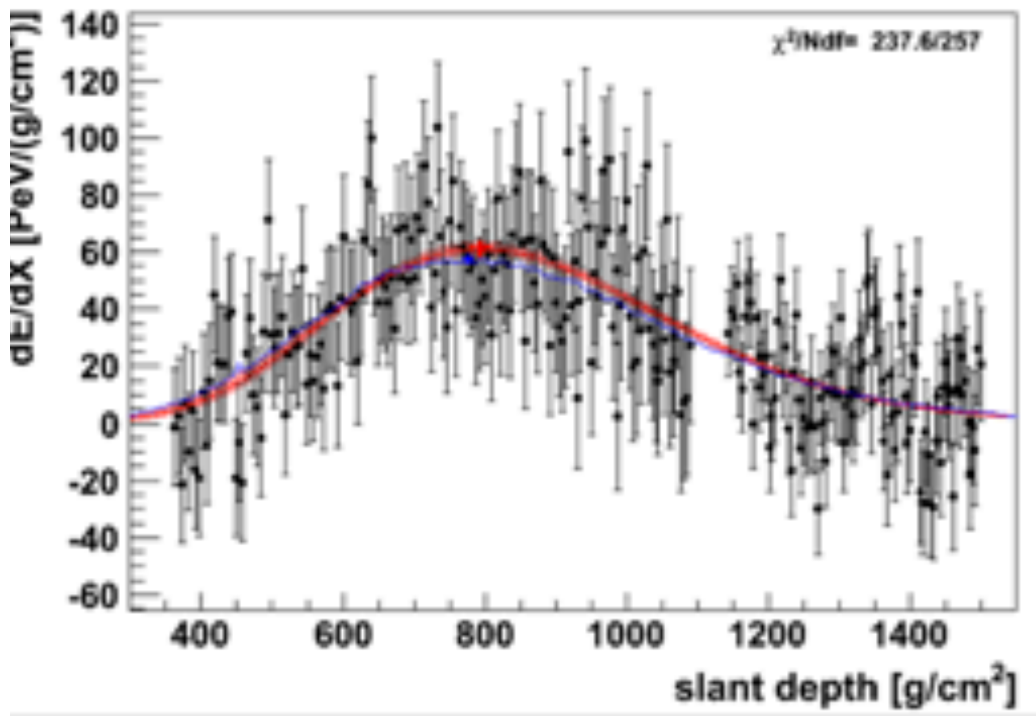


Single or few pixels and smaller optics

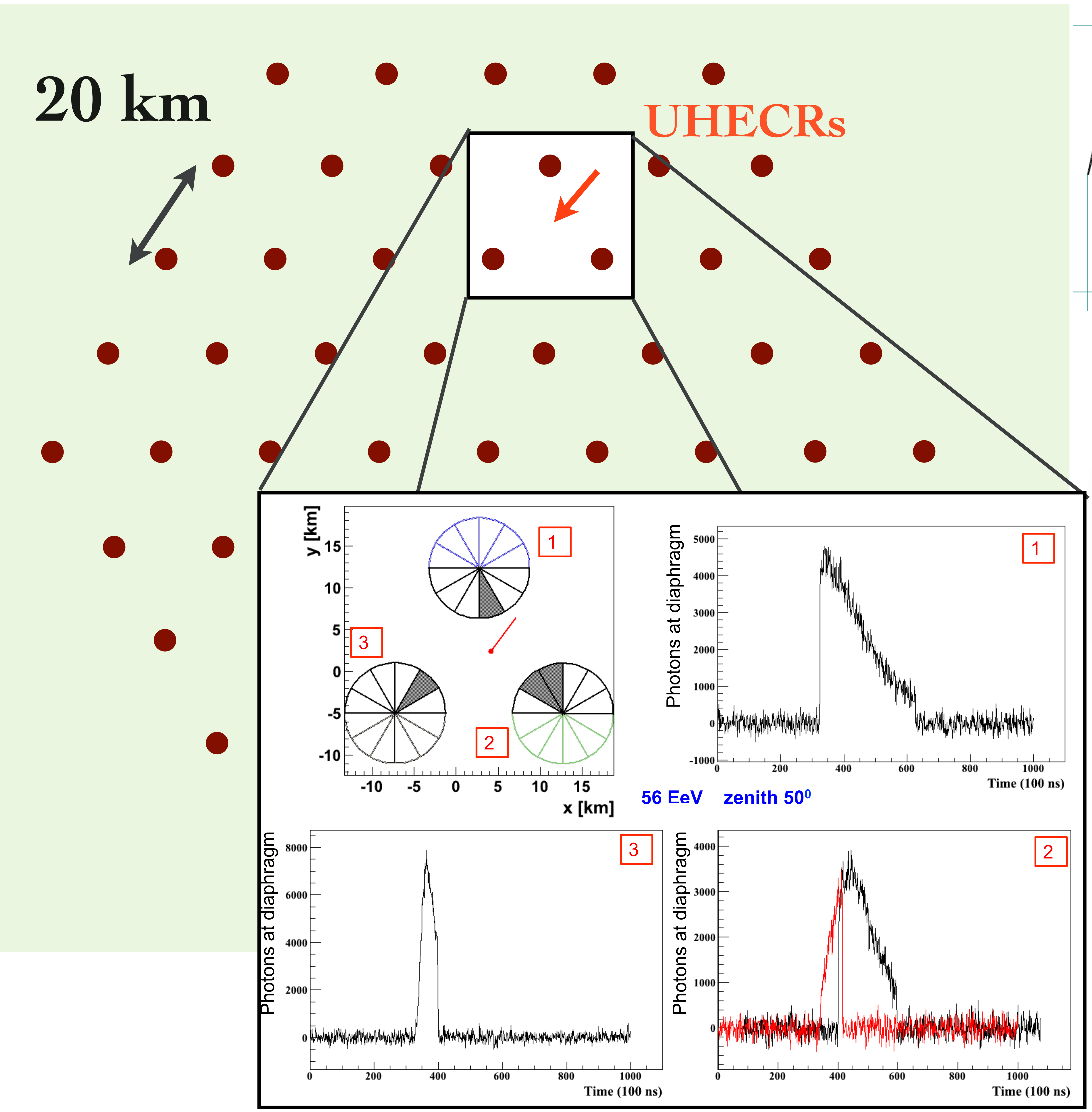


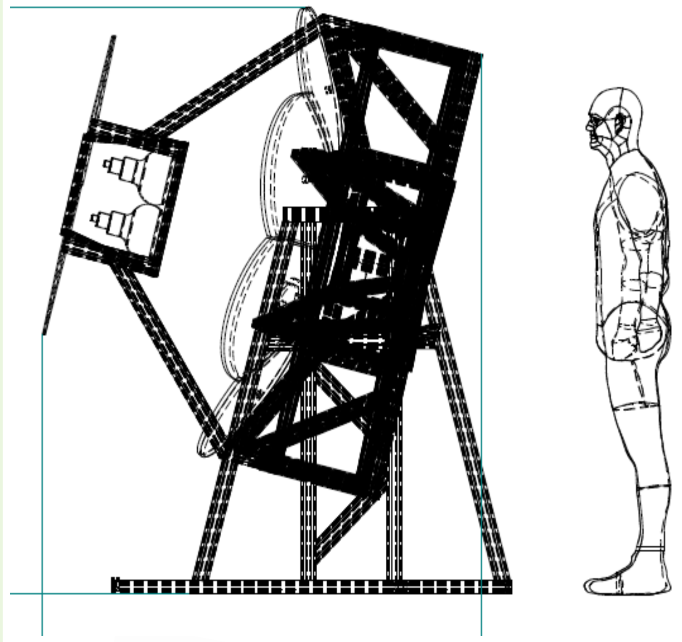
Low-cost and simplified/optimized FD

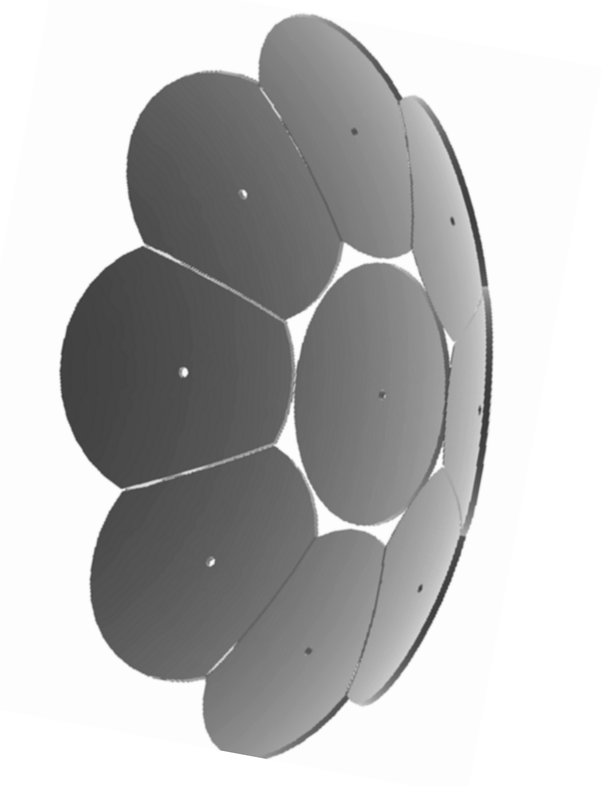


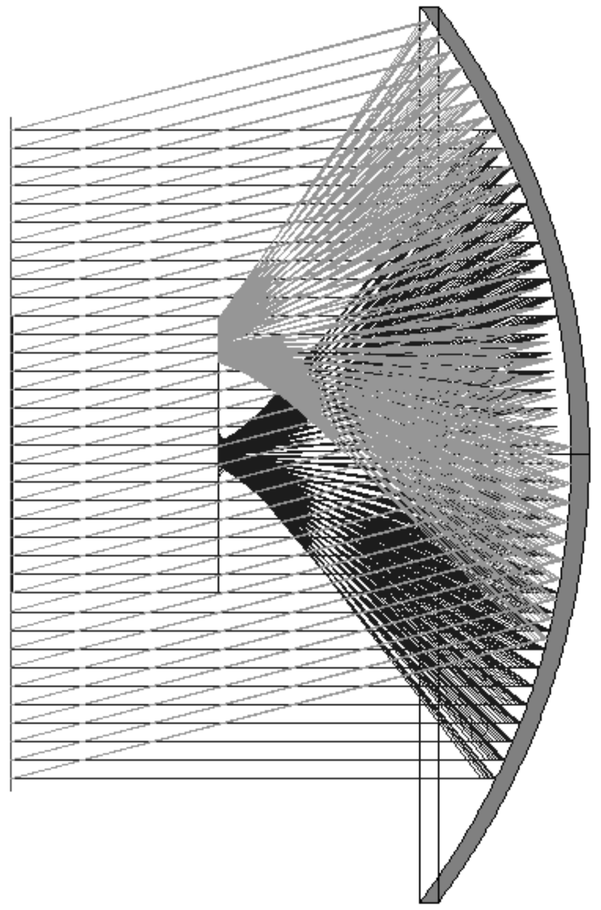


Fluorescence detector Array of Single-pixel Telescopes



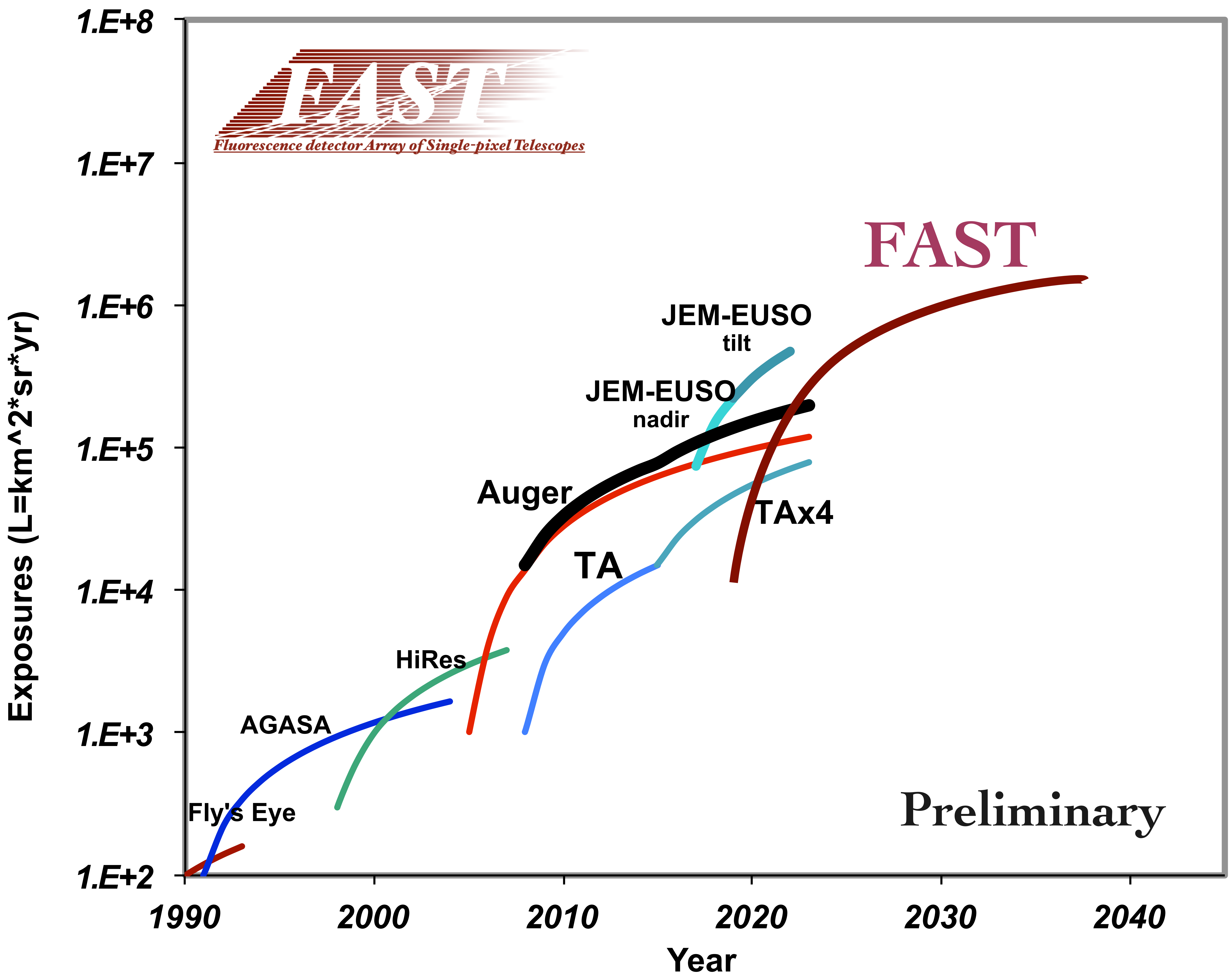






- Each telescope: 4 PMTs, 30°×30° field of view (FoV).
  - **Reference design: 1 m^2 aperture, 15°×15° FoV per PMT**
- Each station: 12 telescopes, 48 PMTs, 30°×360° FoV.
- Deploy on a triangle grid with **20 km** spacing, like **"Surface Detector Array"**.
- If 500 stations are installed, a ground coverage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

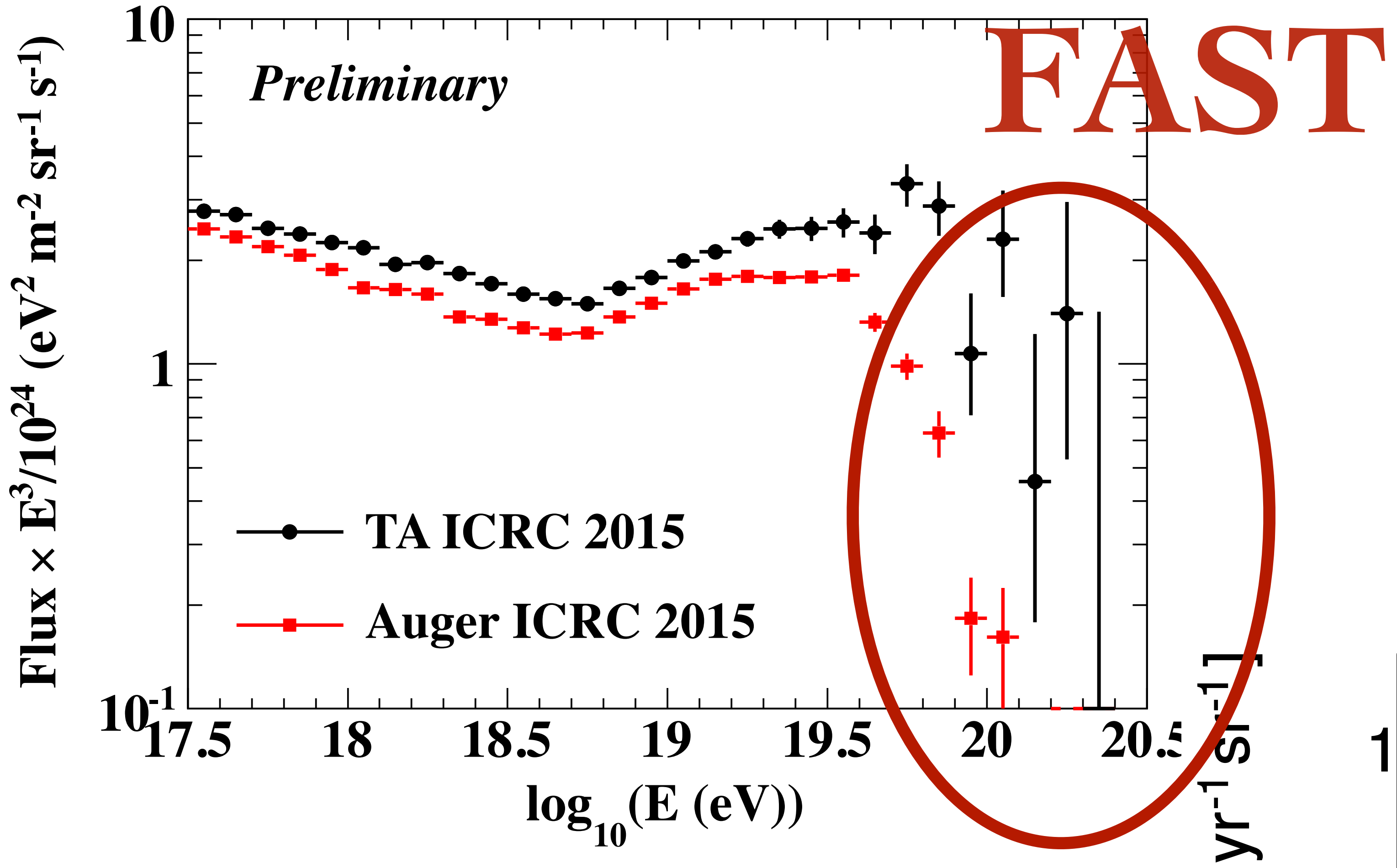
FAST Exposure

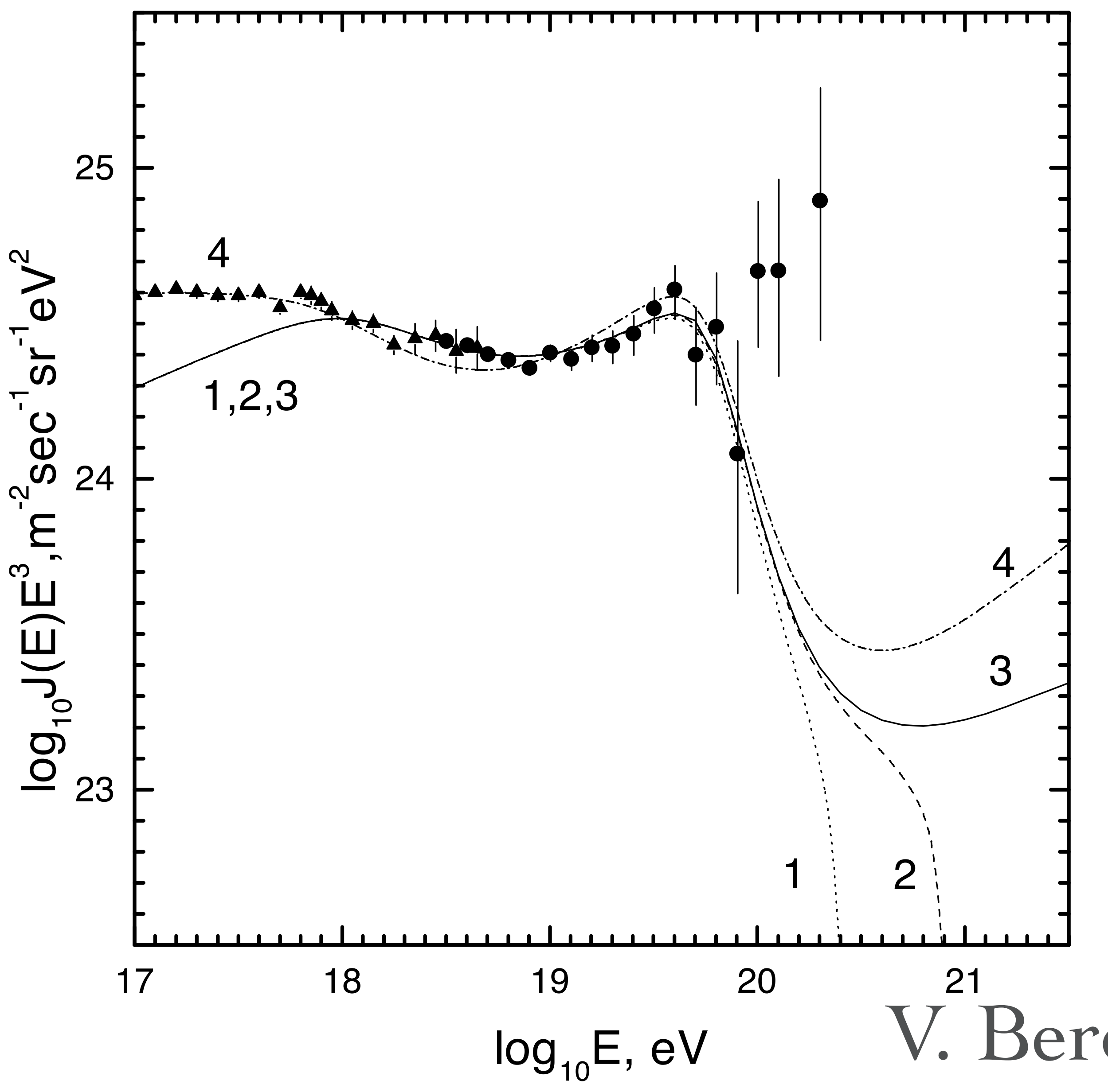


- Conventional operation of FD under 10~15% duty cycle
  - Target: $>10^{19.5}$ eV
- Observation in **moon night** to achieve **25%** duty cycle,
  - Target: **$>10^{19.8}$ eV = Super GZK events (Hotspot/ Warmspot)**
    - Test operation in moon night with Auger FD (R. Smida)
- Ground area of 150,000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

Physics Target

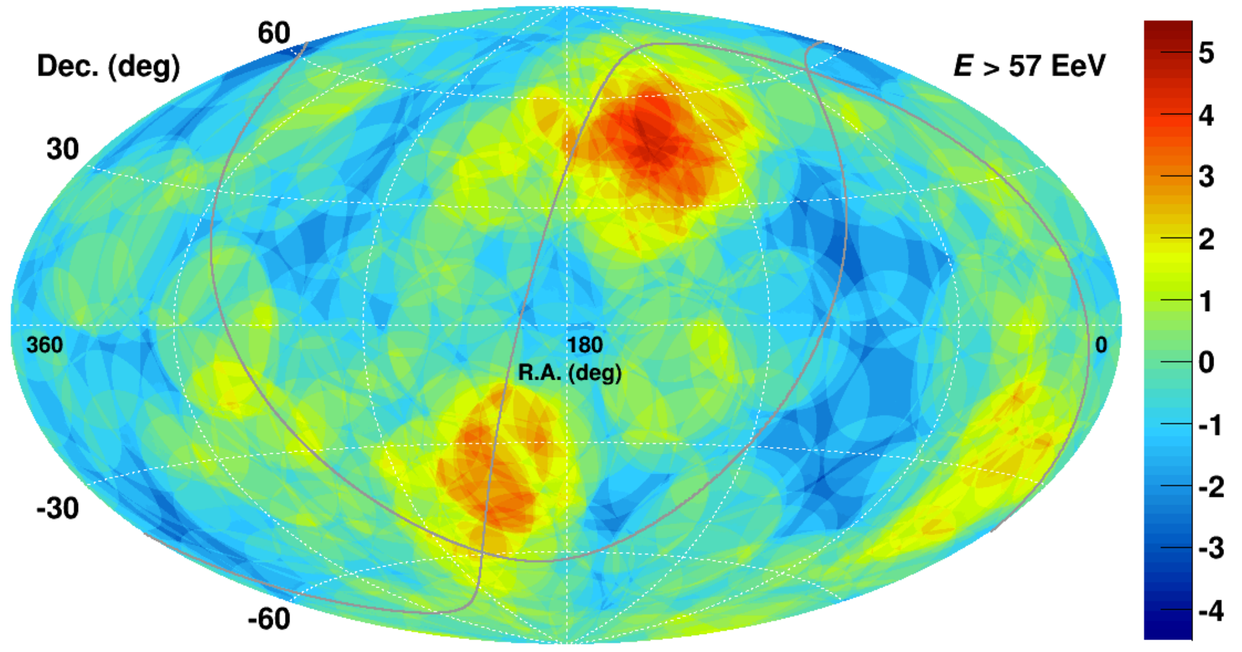
GZK Recovery



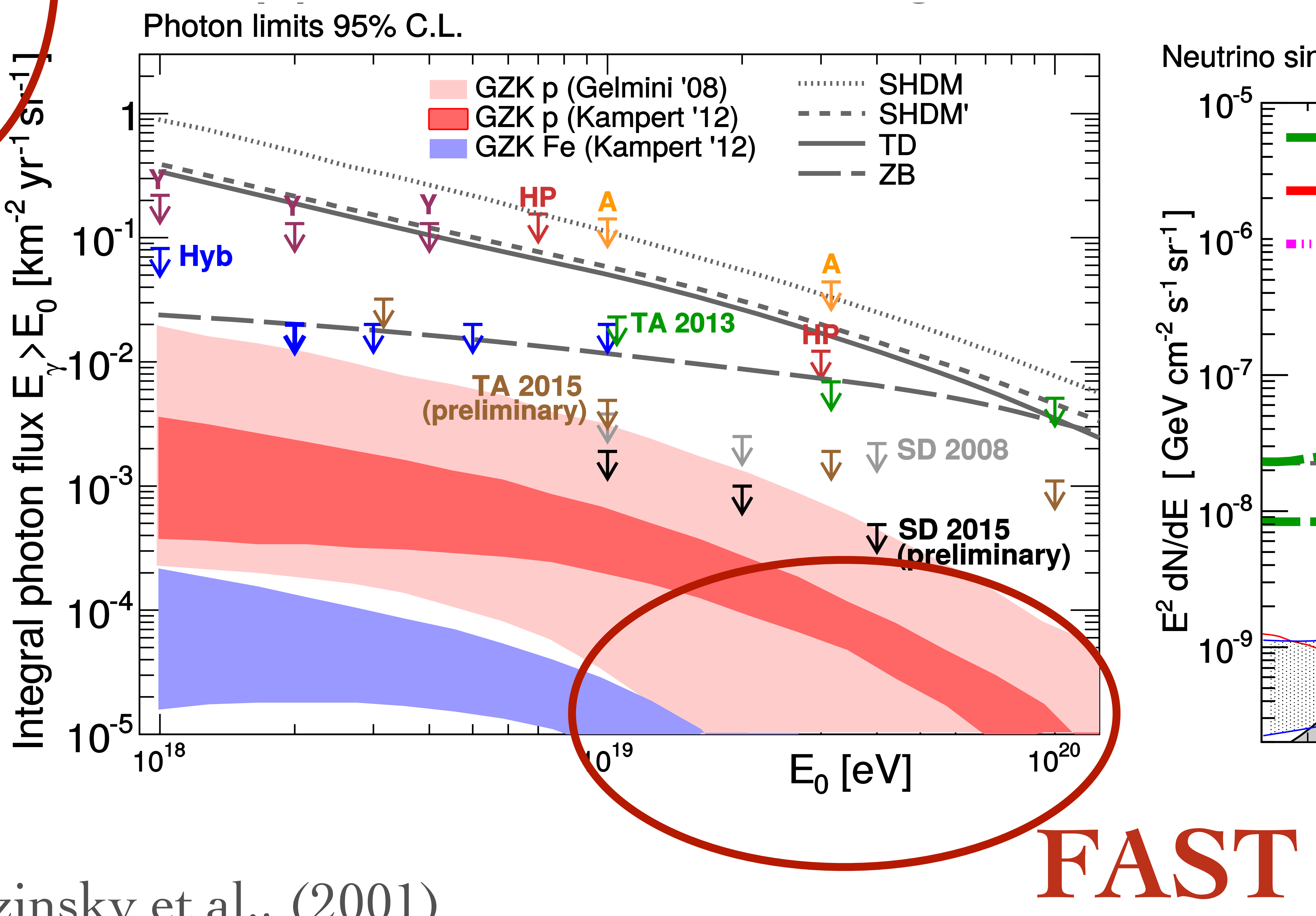


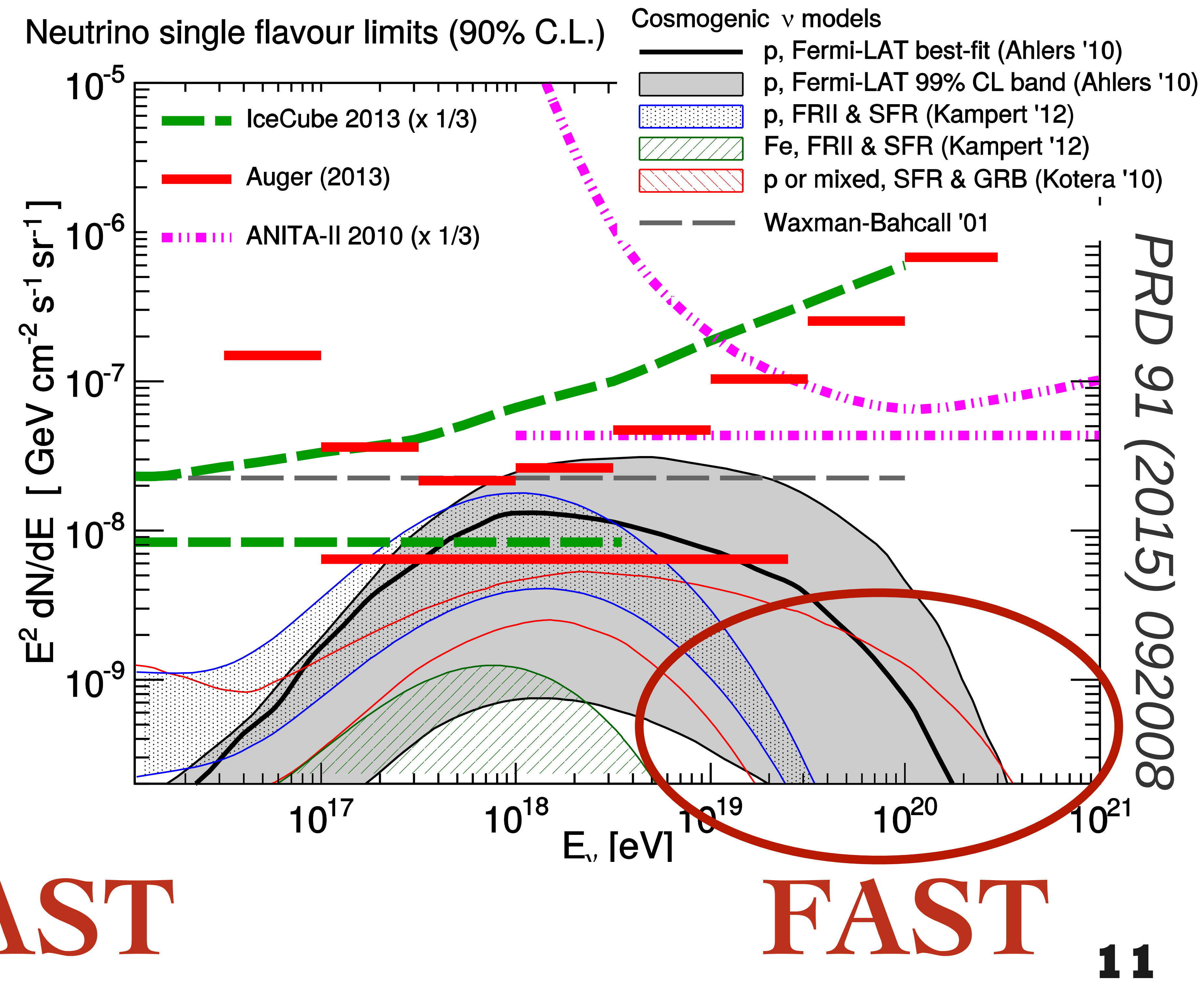
V. Berezinsky et al., (2001)

UHECR Anisotropy with ~10x statistics



First detection of UHE photons and neutrinos

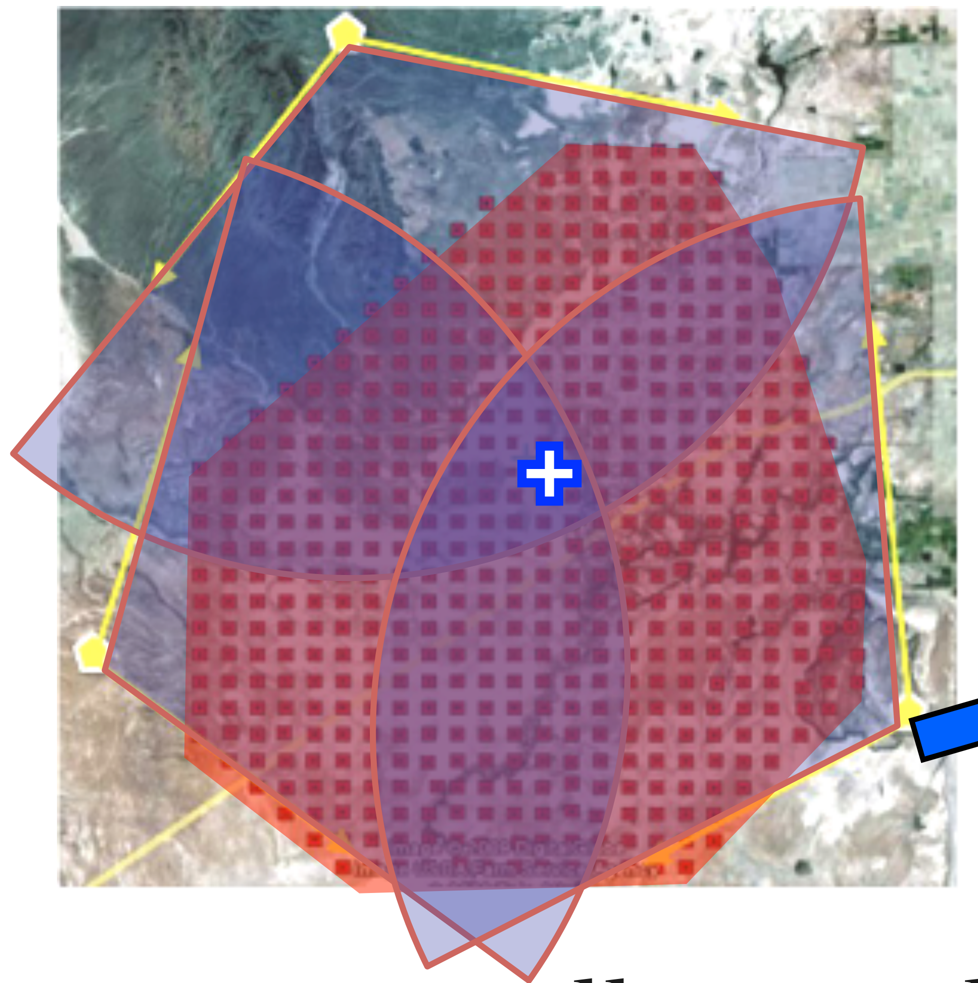


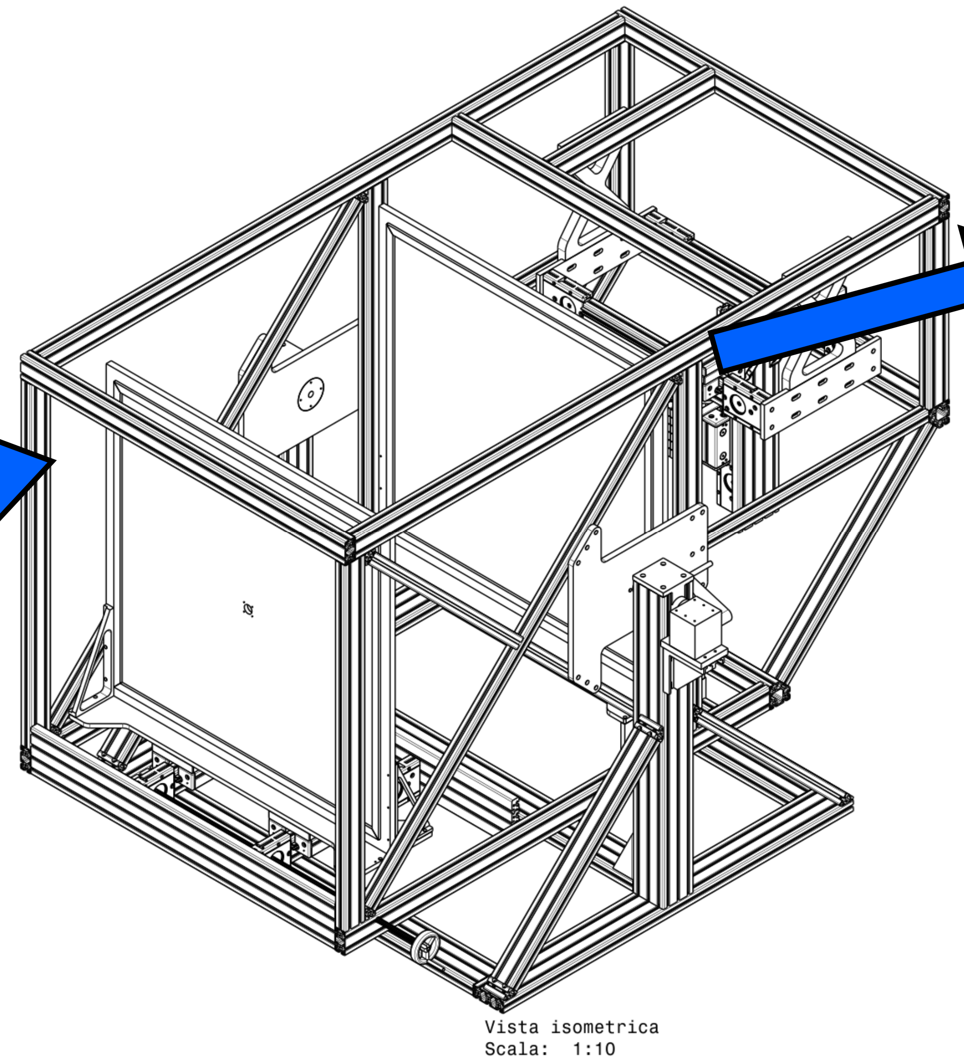


FAST Window of Opportunity at EUSO-TA

Fluorescence detector Array of Single-pixel Telescopes

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





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

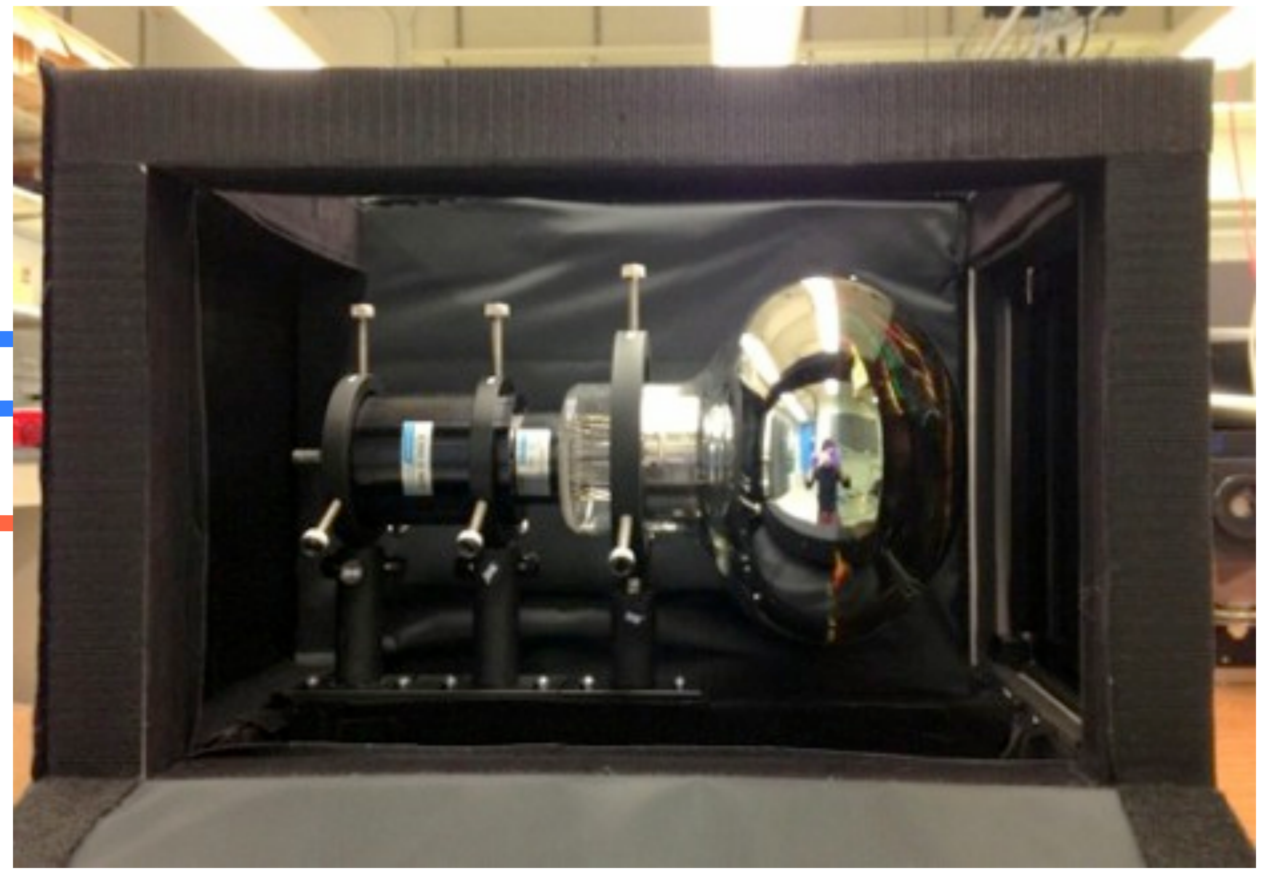
- Temporally use the EUSO-TA optics at the TA site.
    - Two Fresnel lenses (+ 1 UV acrylic plate in front for protection)
    - **1 m^2 aperture, 14°×14° FoV ≒ FAST reference design.**
- Install FAST camera and DAQ system at EUSO-TA telescope.
- Milestones: Stable observation under large night sky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

FAST DAQ System

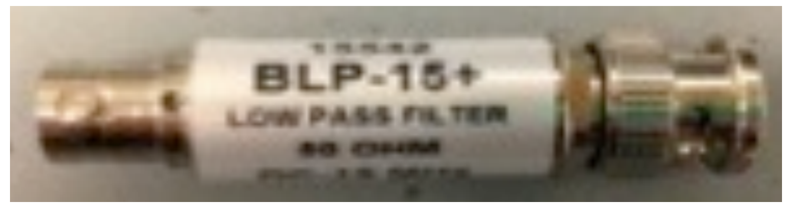
TAFD external trigger, 3~5 Hz

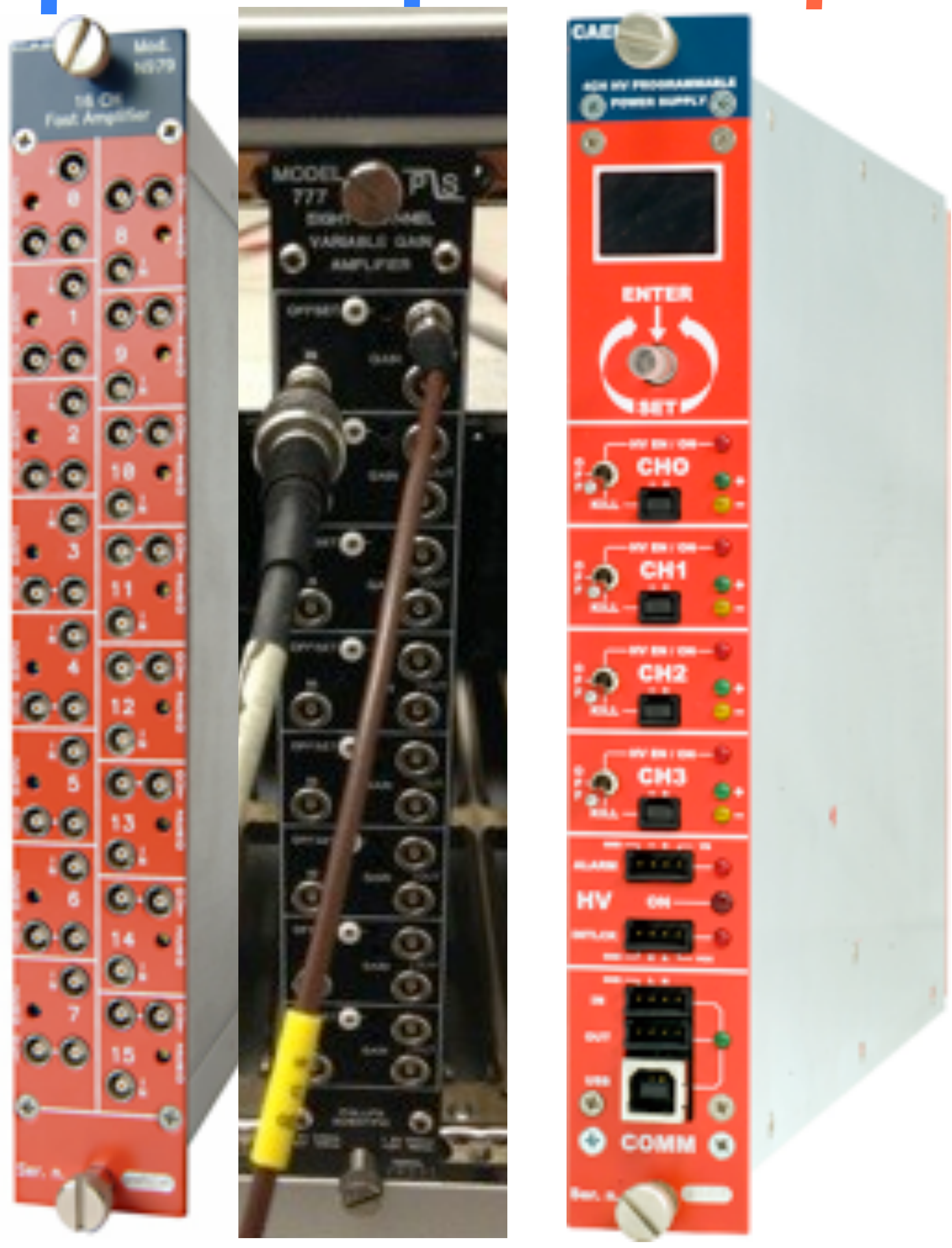
Anode & dynode
Signal

Camera of FAST



15 MHz
low pass filter





High Voltage power supply,
N1470 CAEN

All modules are remotely controlled through wireless network.

Portable VME Electronics
- Struck FADC 50 MHz sampling, SIS3350
- GPS board, HYTEC GPS2092

Amplifiers
R979 CAEN
Signal×10

777,Phillips scientific
Signal×50

Fluorescence detector Array of Single-pixel Telescopes

1

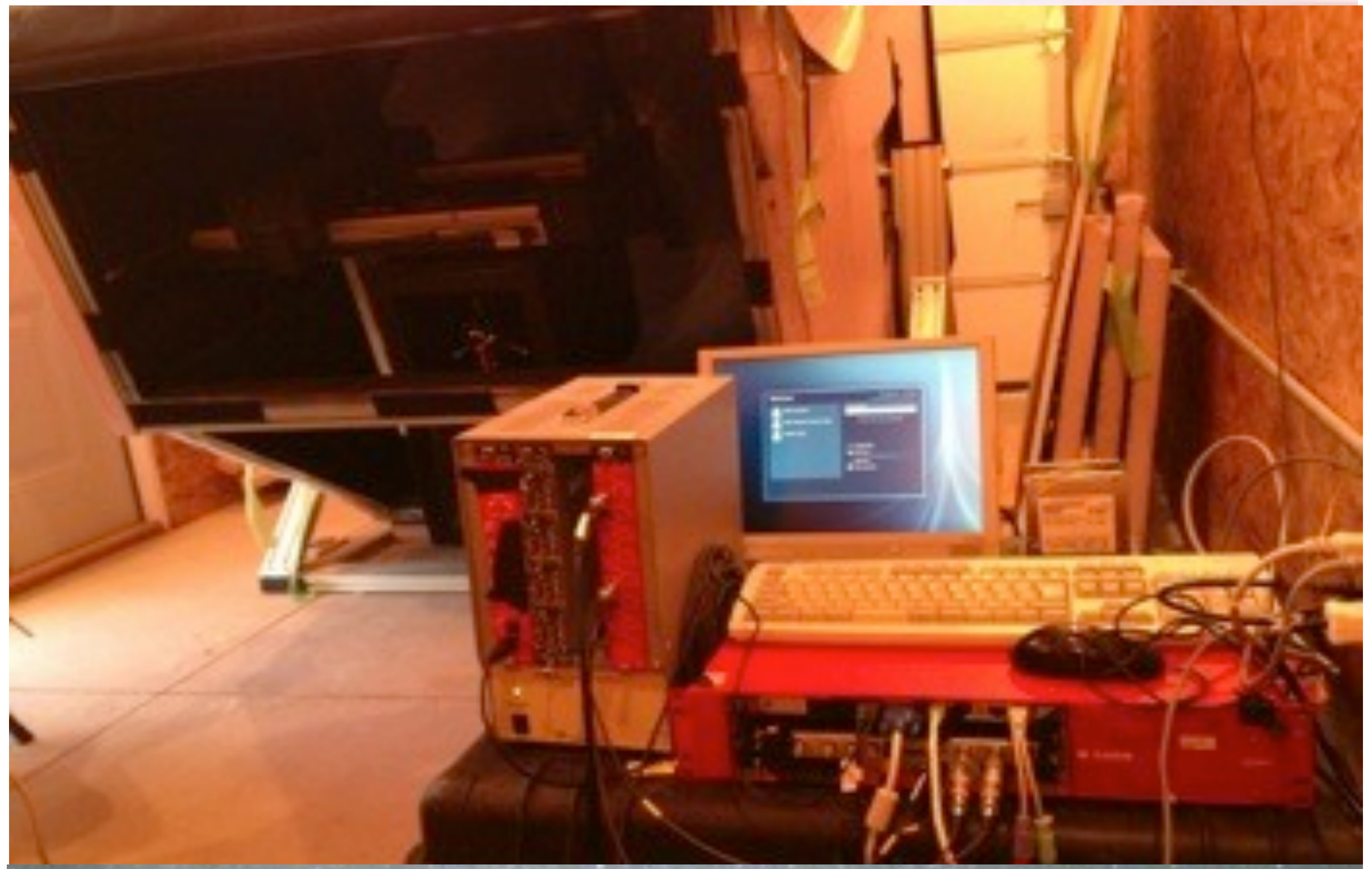
2

3

4

5

6



7

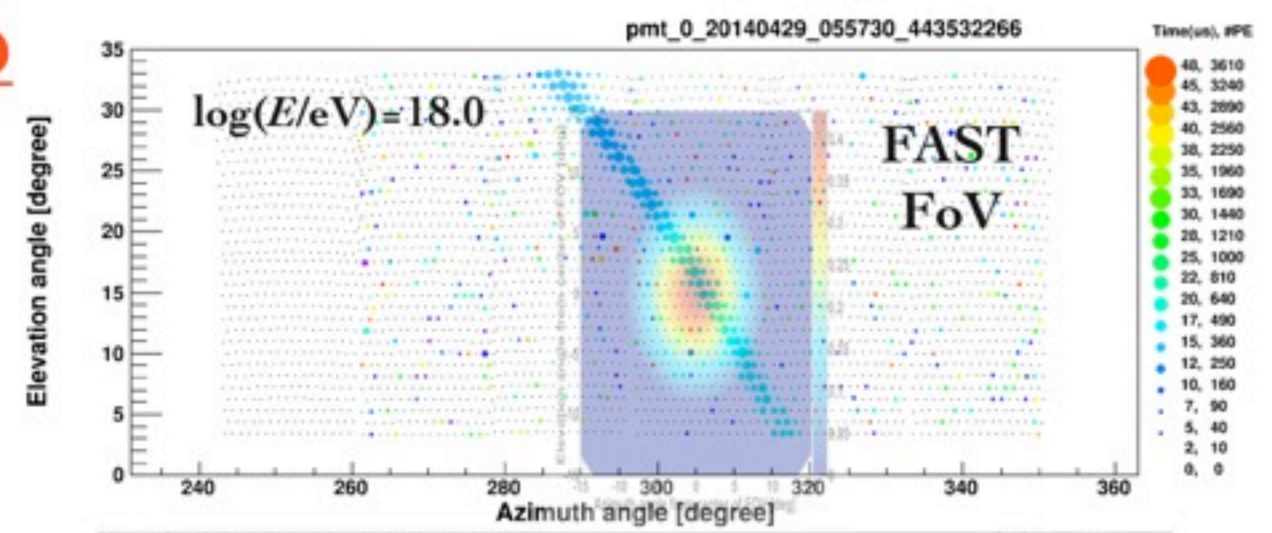
8

9

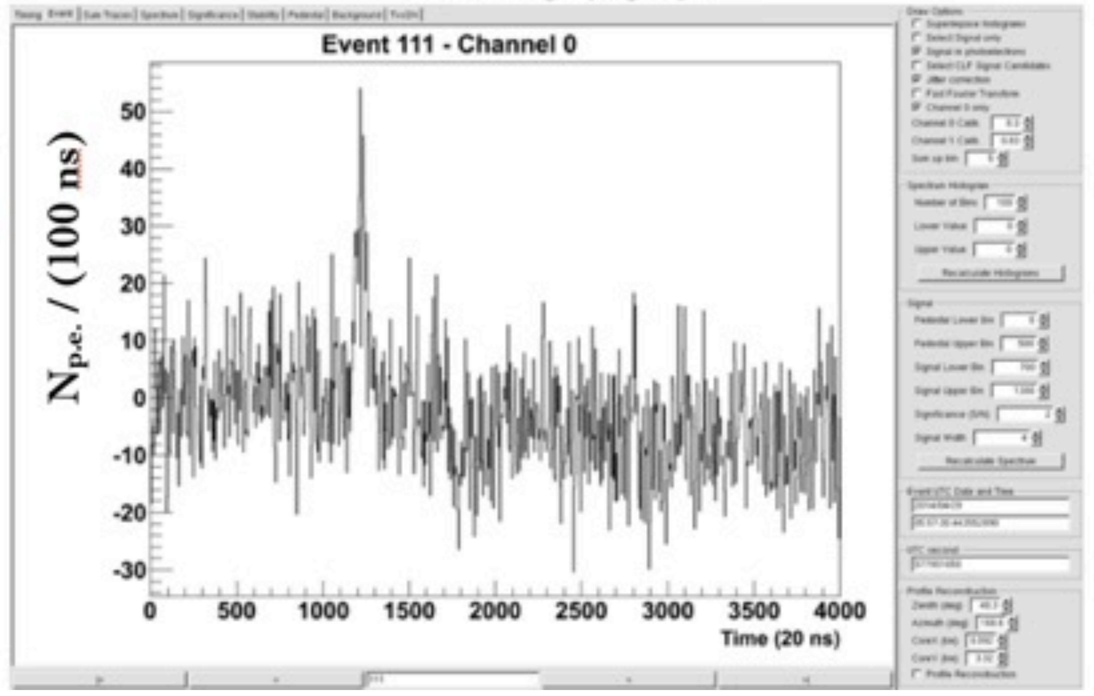
Results on the First Field Observation

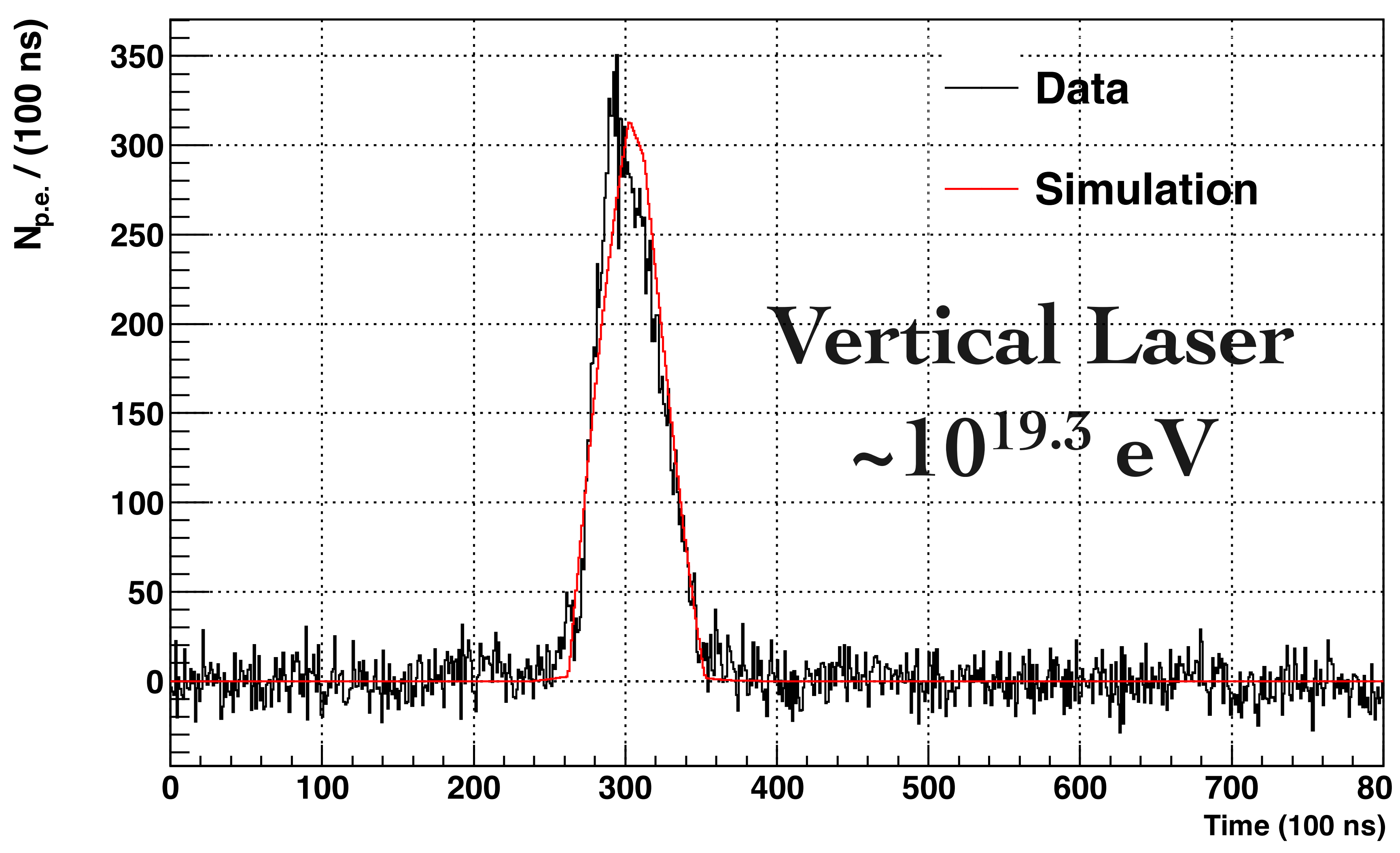
- Data set: April and June 2014 observation, 19 days, 83 hours
  - Very stable observation under large night sky backgrounds
- Laser detection to confirm a performance of the prototype
- UHECR search : 16 candidates coincidence with TA-FD
- Very successful example among Telescope Array, JEM-EUSO, Pierre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

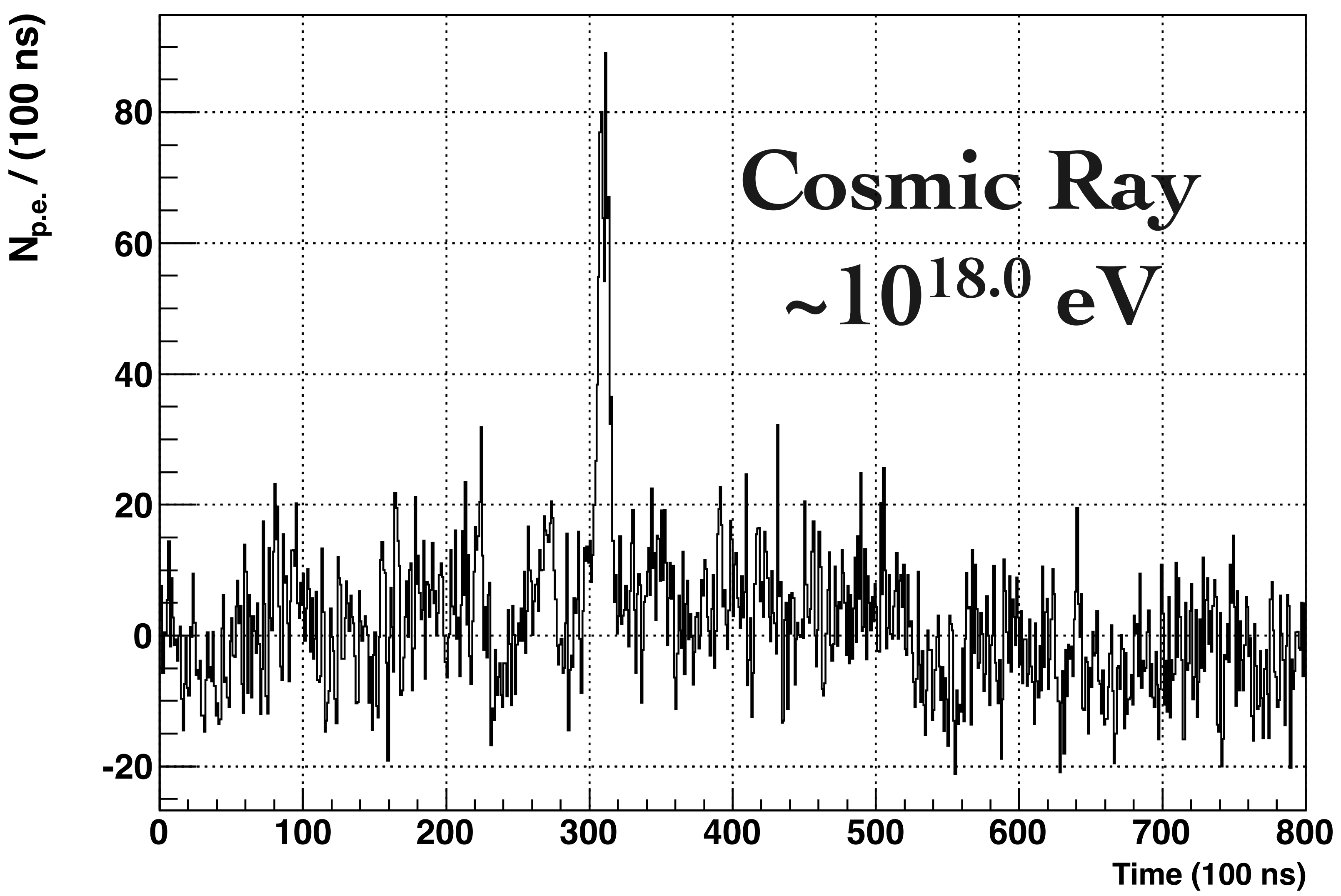
TAFD

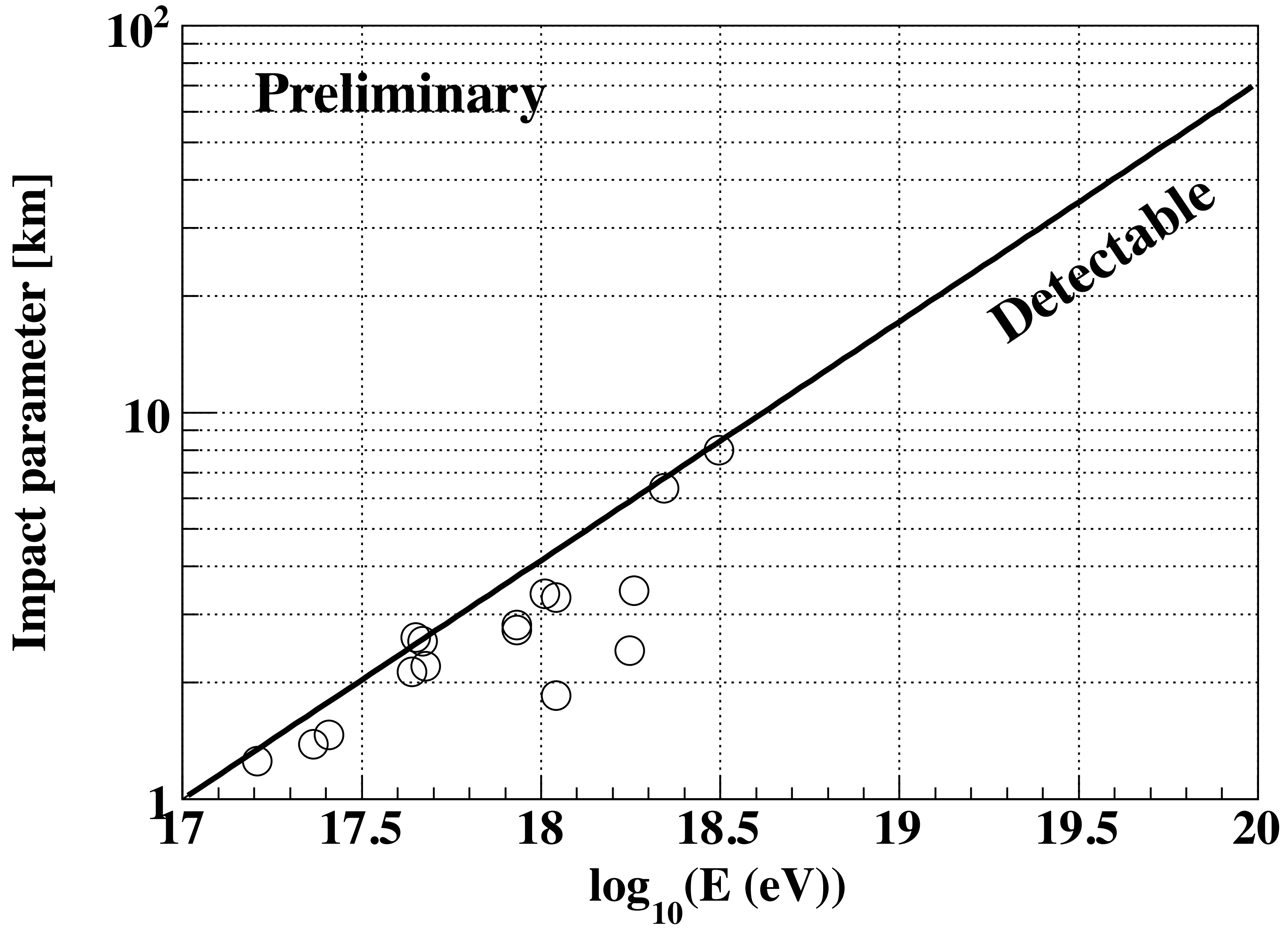


FAST





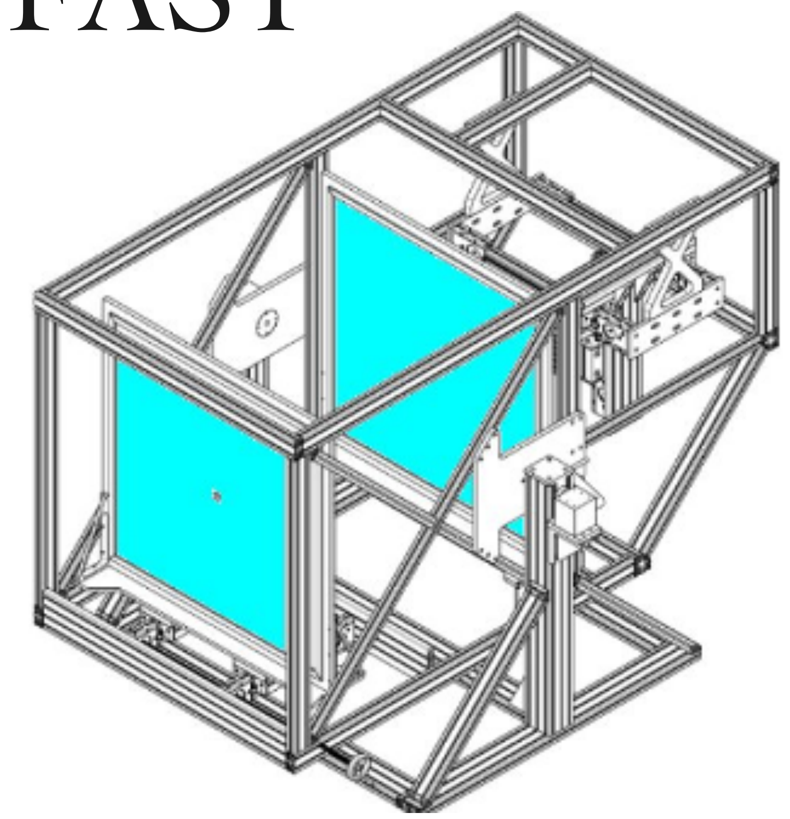


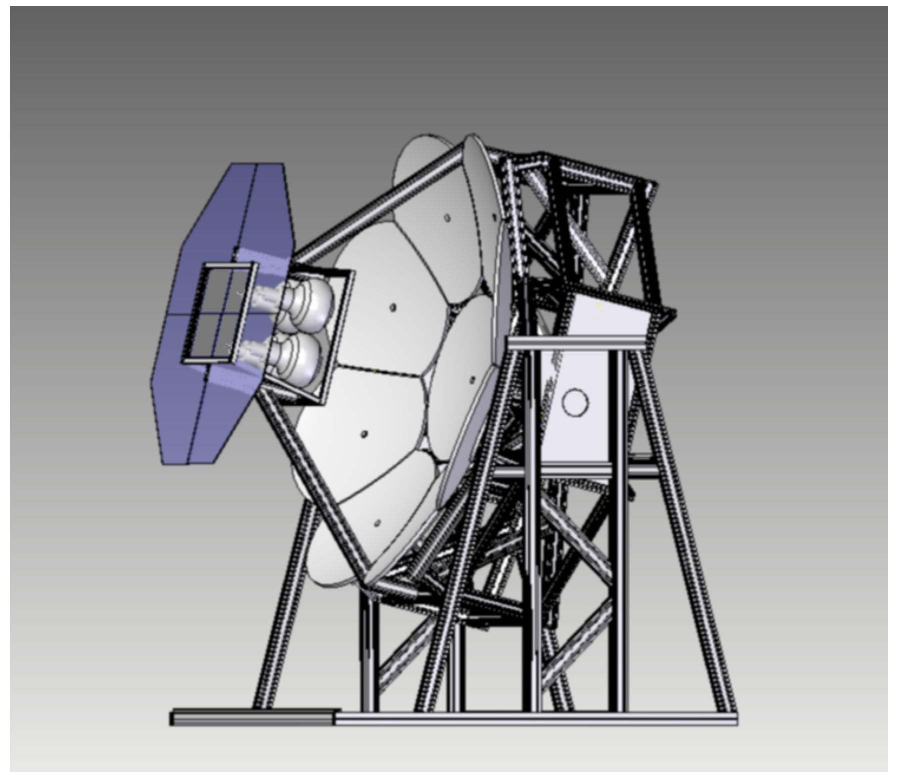


Astroparticle Physics *74* (2016) 64-72, arXiv: 1504.00692

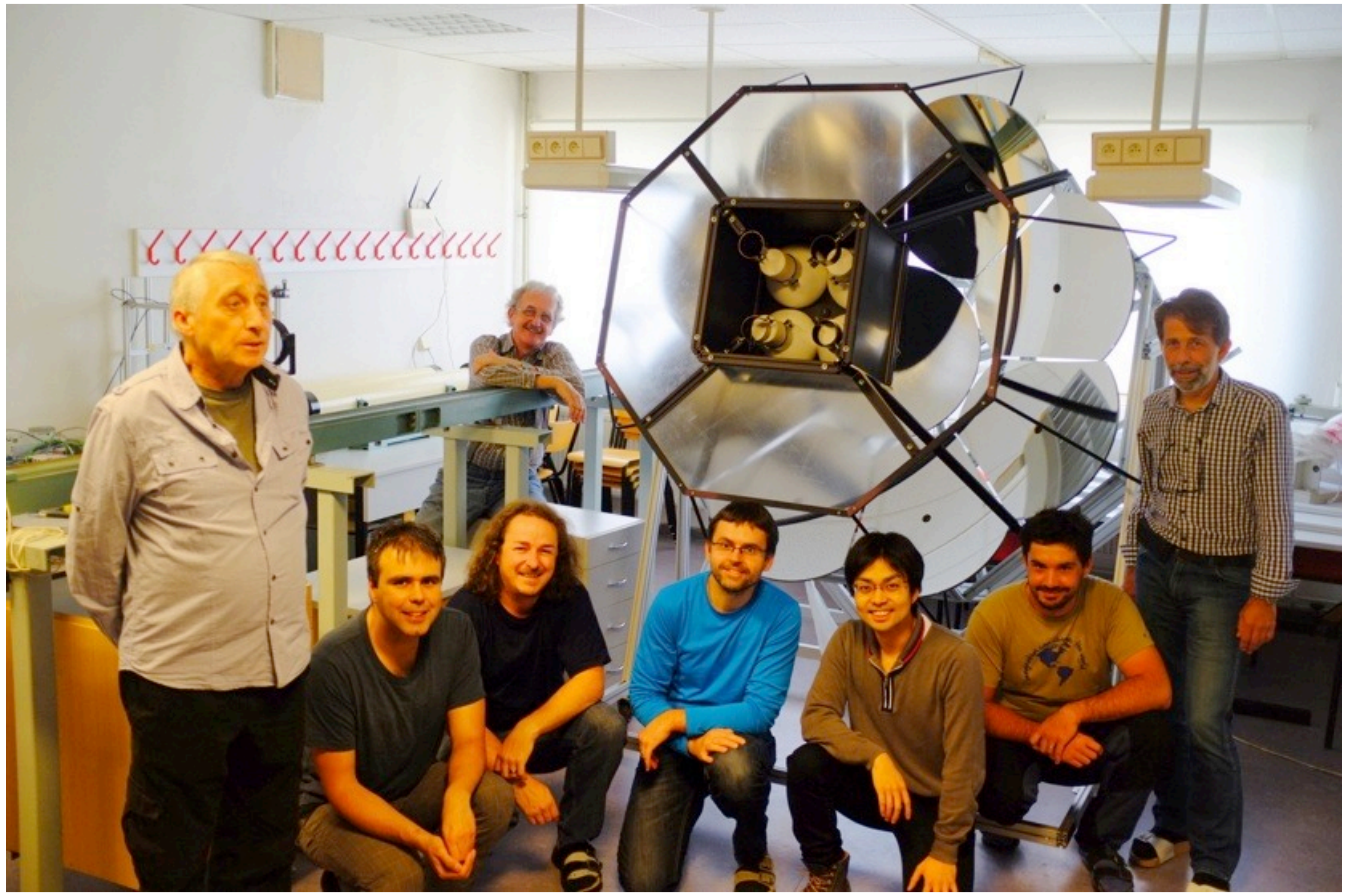
Full-scale FAST Prototype

- **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 ***X*max** with FAST



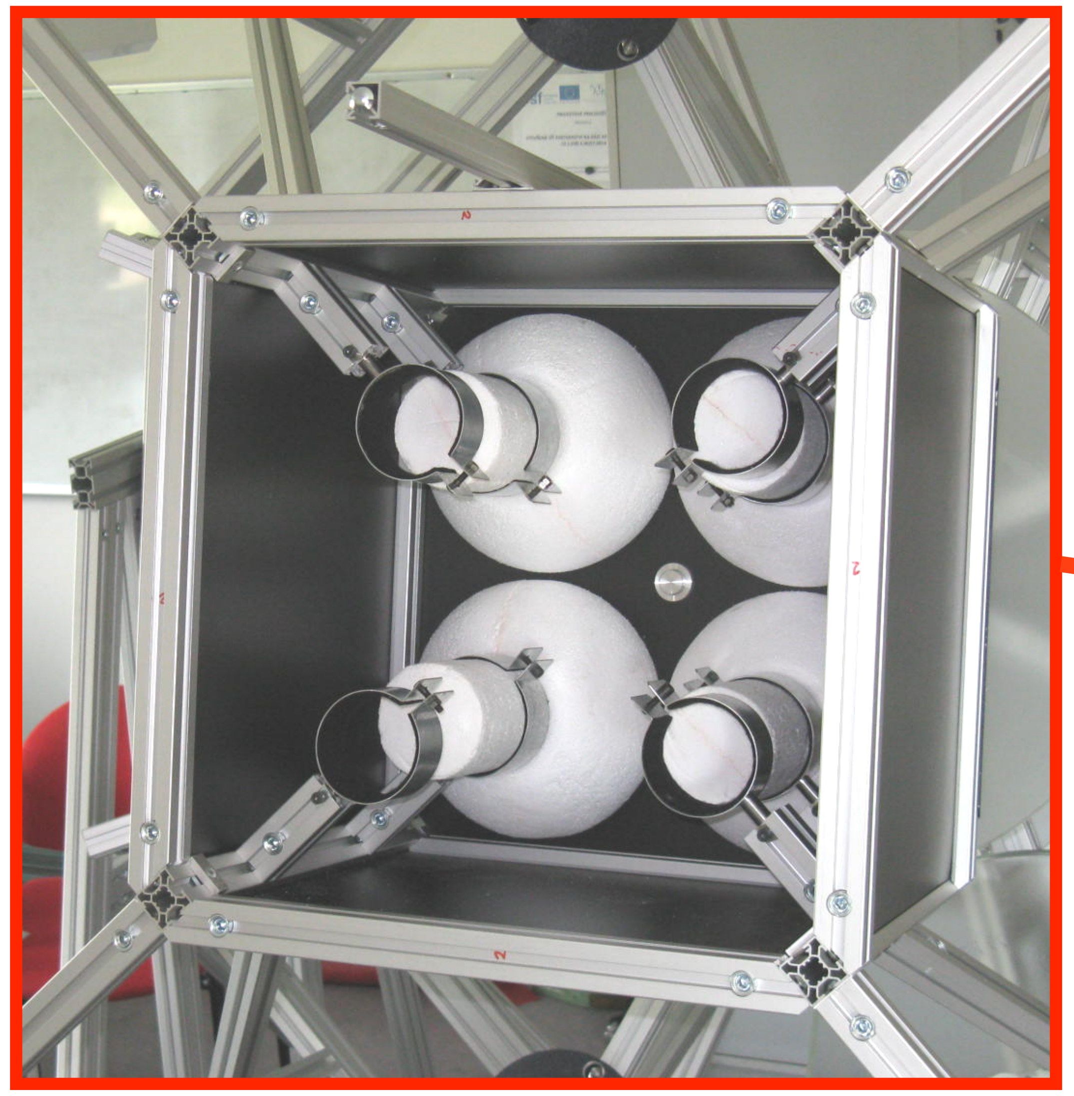


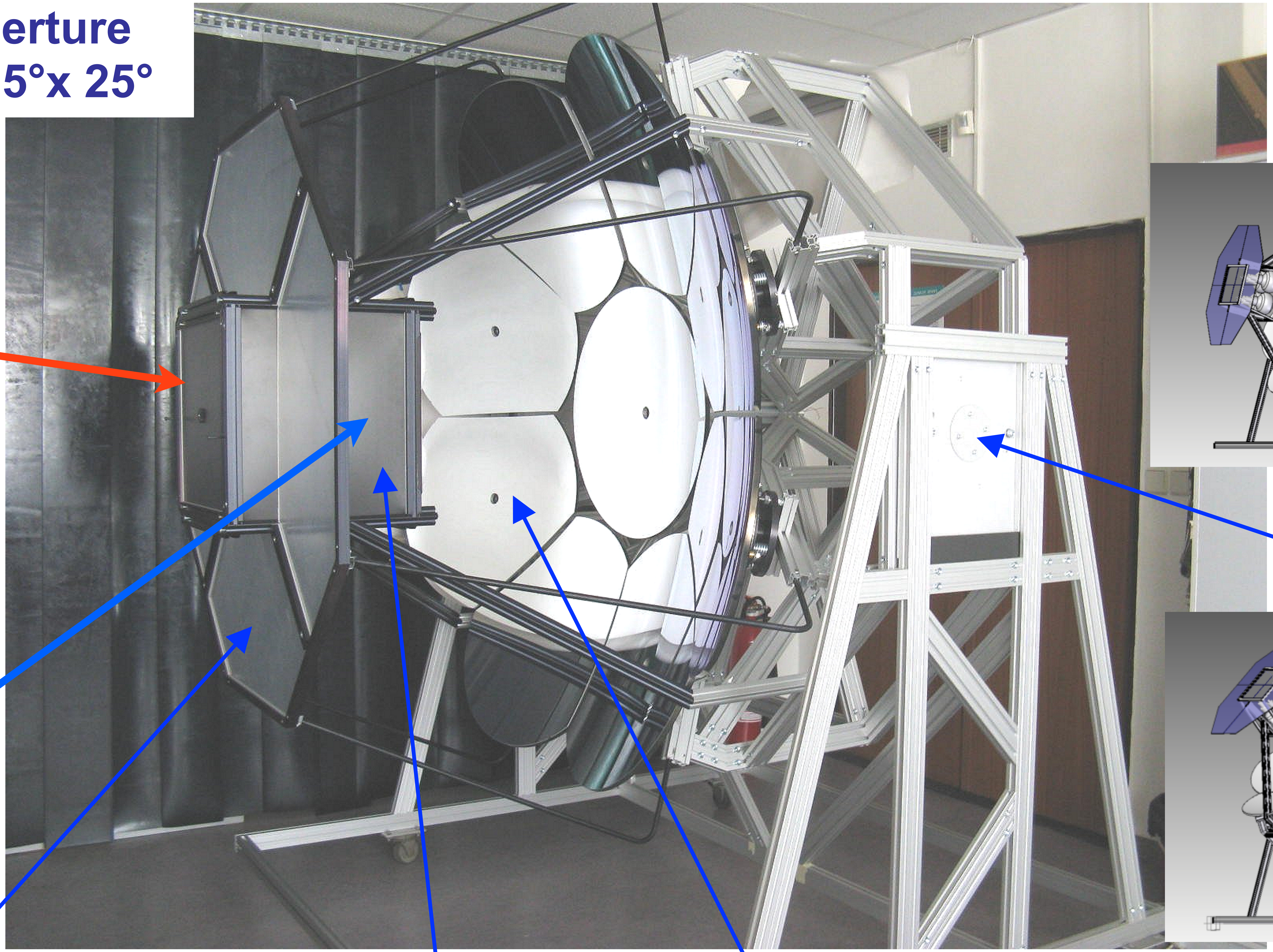
FAST meeting in December 2015
(Olomouc, Czech Republic)



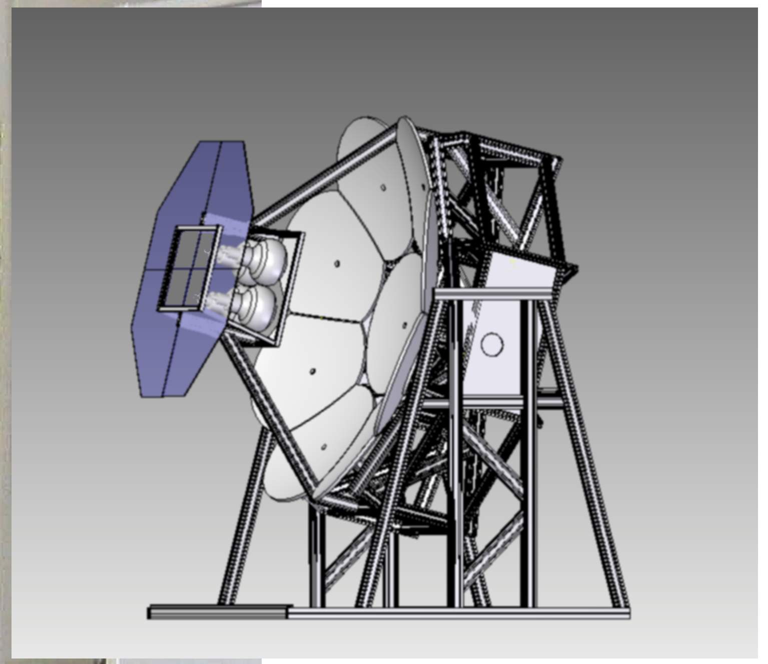
Full-scale FAST Prototype

1m² aperture
FOV = 25°x 25°

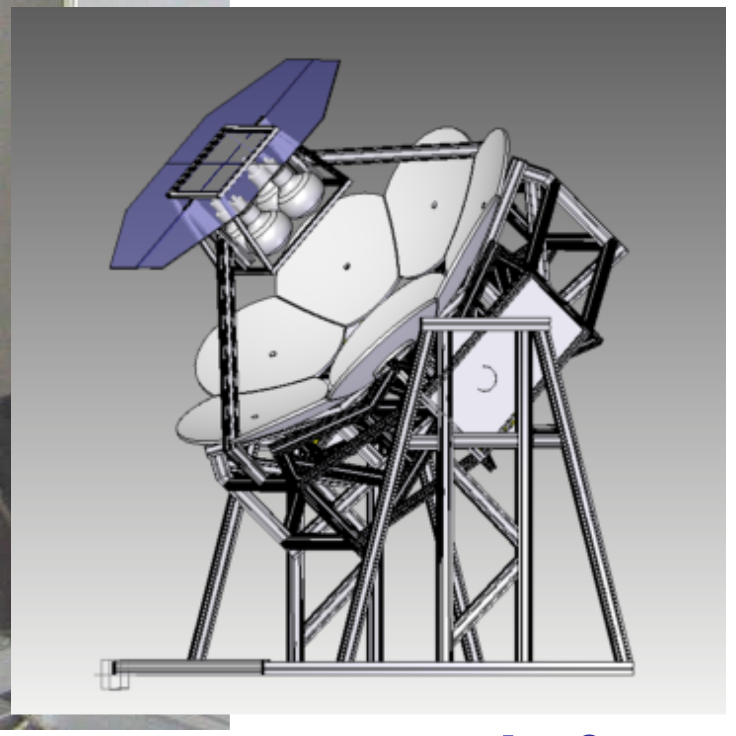




15°



variable
tilt



45°

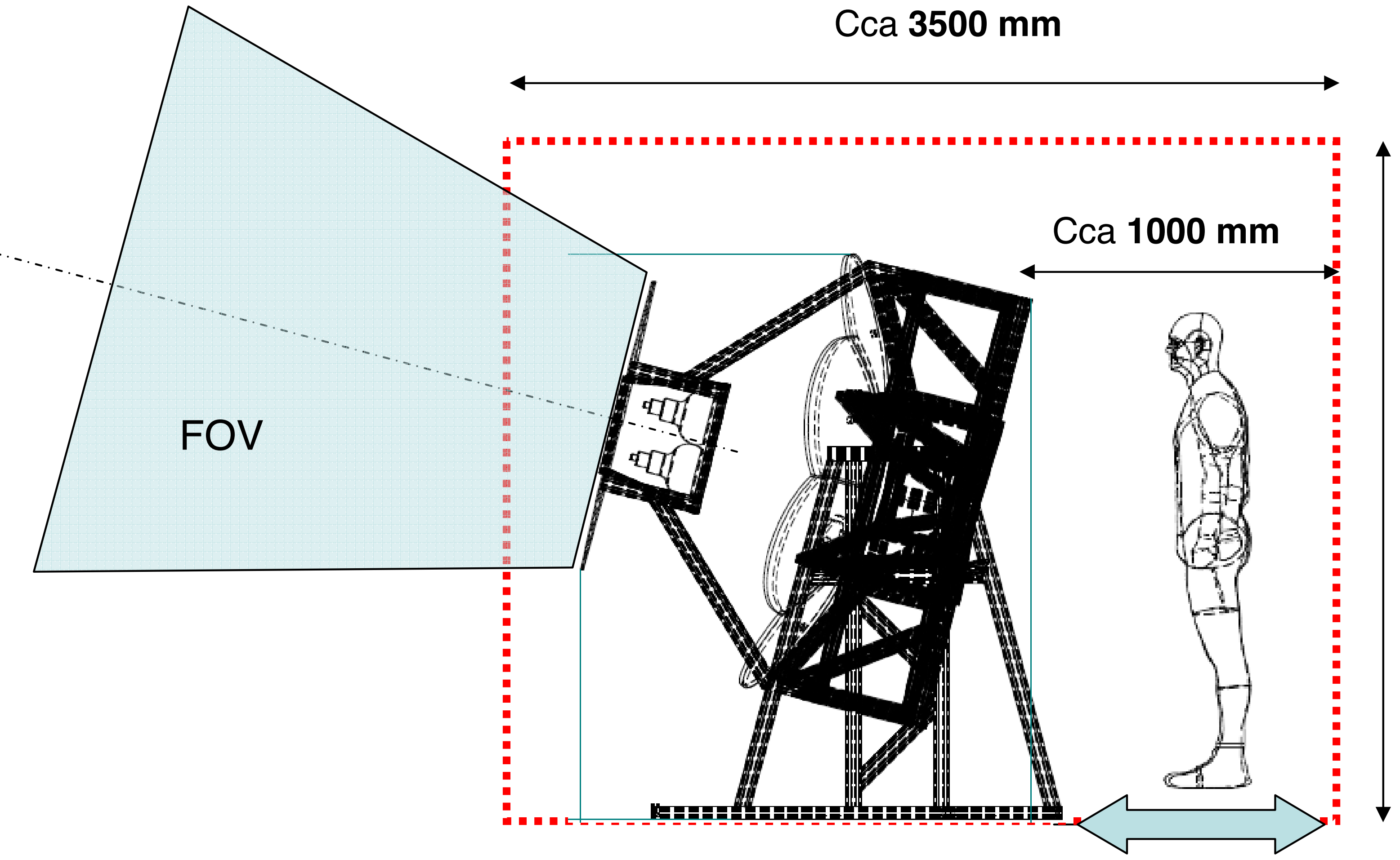
UV Plexiglass

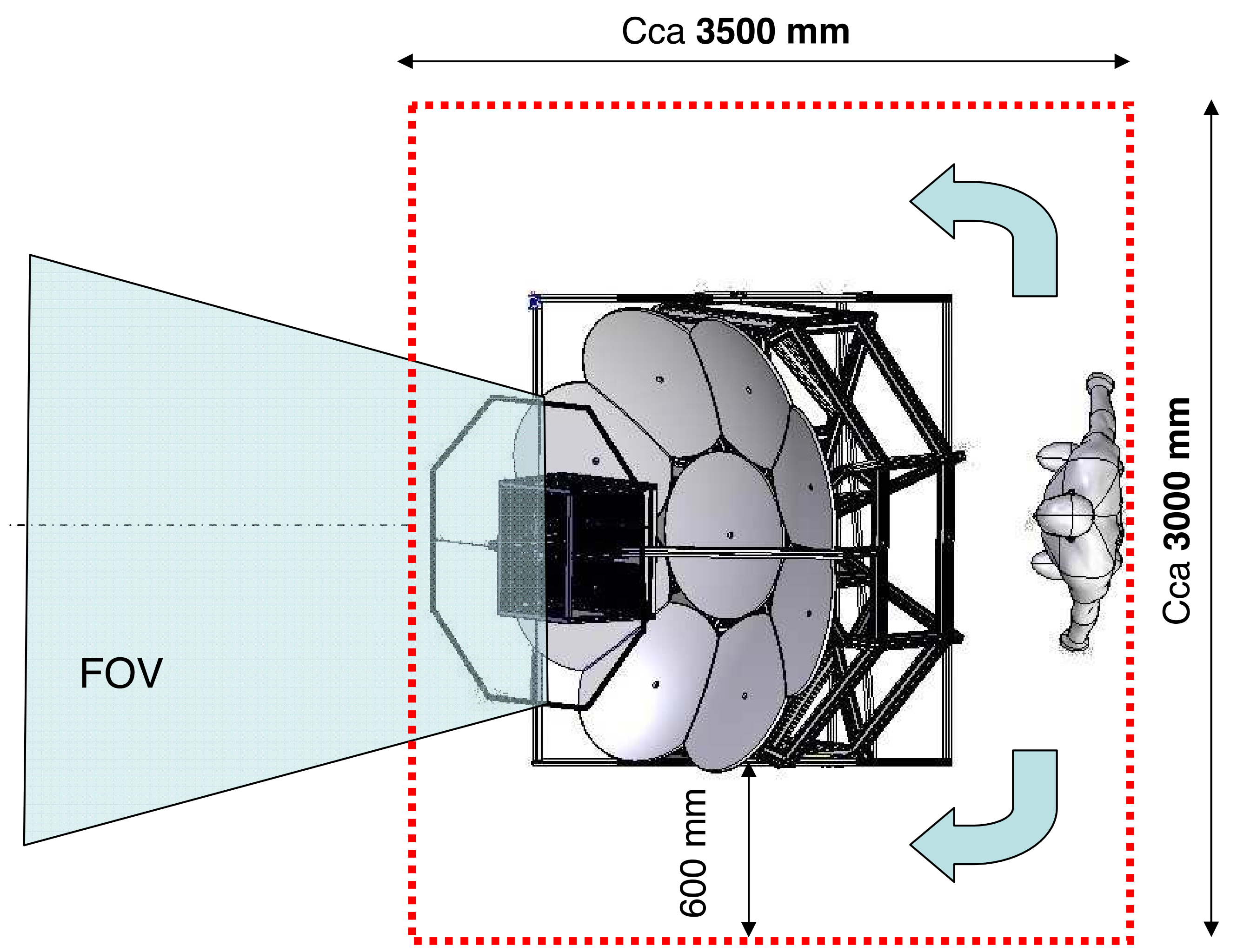
8 inch PMT camera
(2 x 2)

Segmented primary mirror

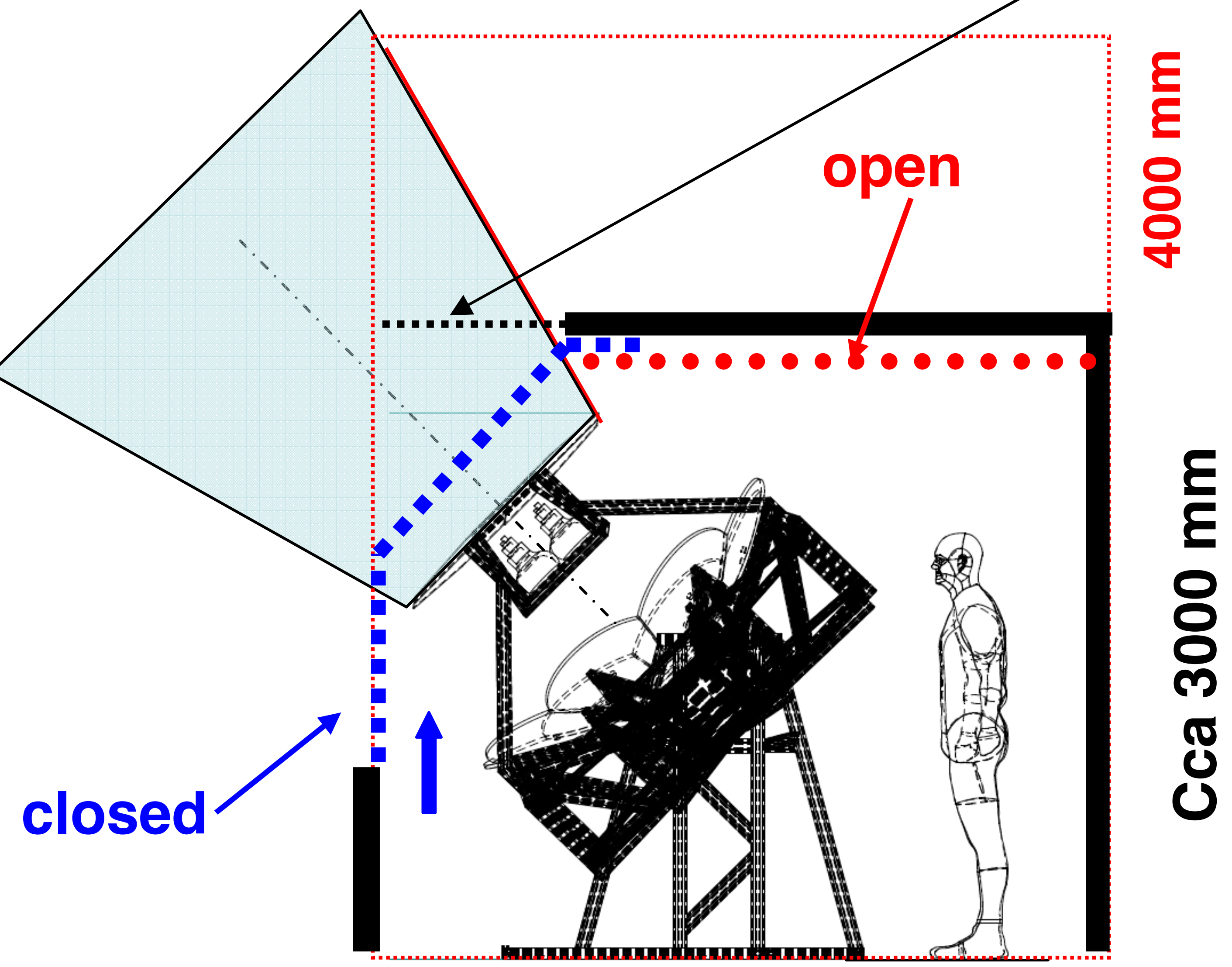
Robust Design of Telescope

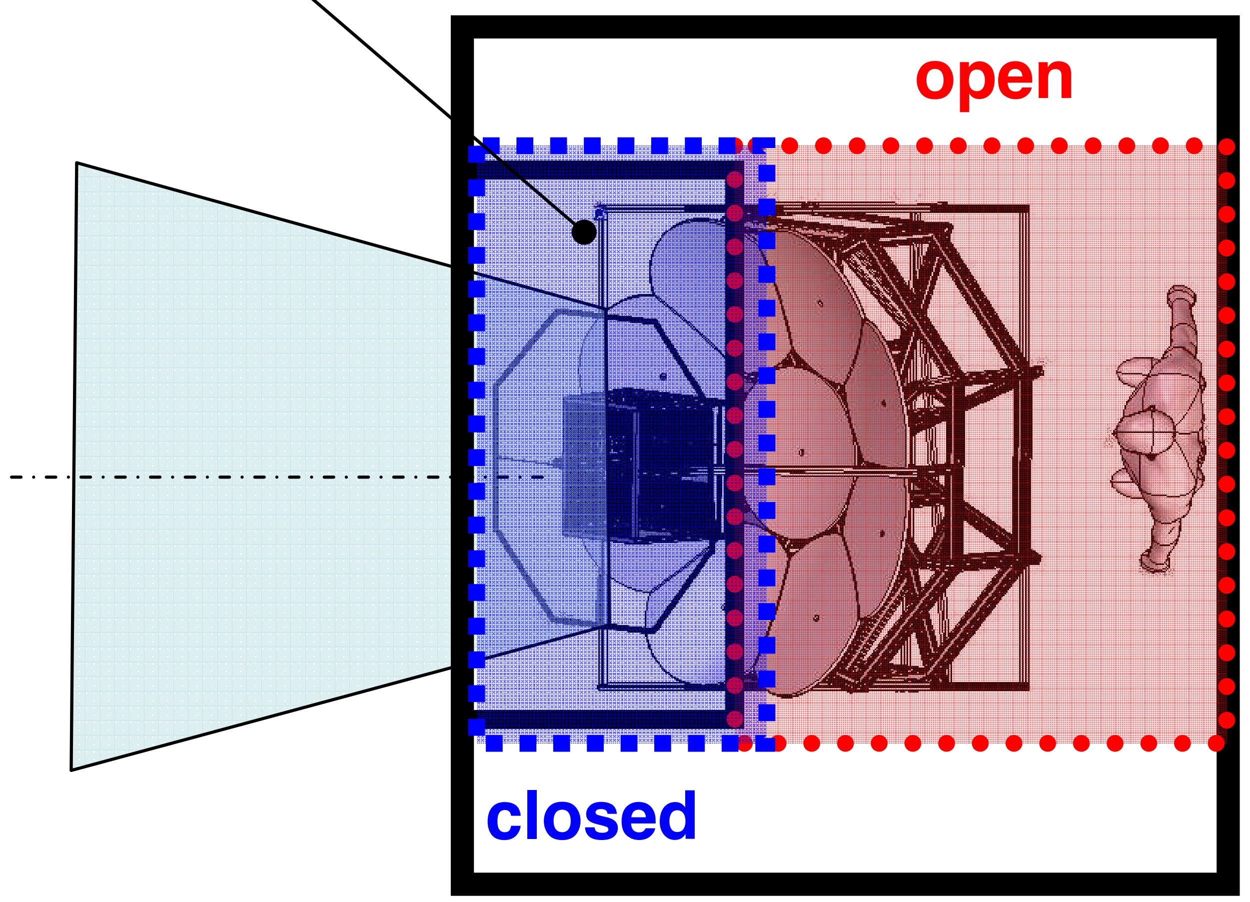
- Robust design for maintenance free and stand-alone observation.
- Adjustable elevation 15° or 45° to enlarge the FoV of the current FD.

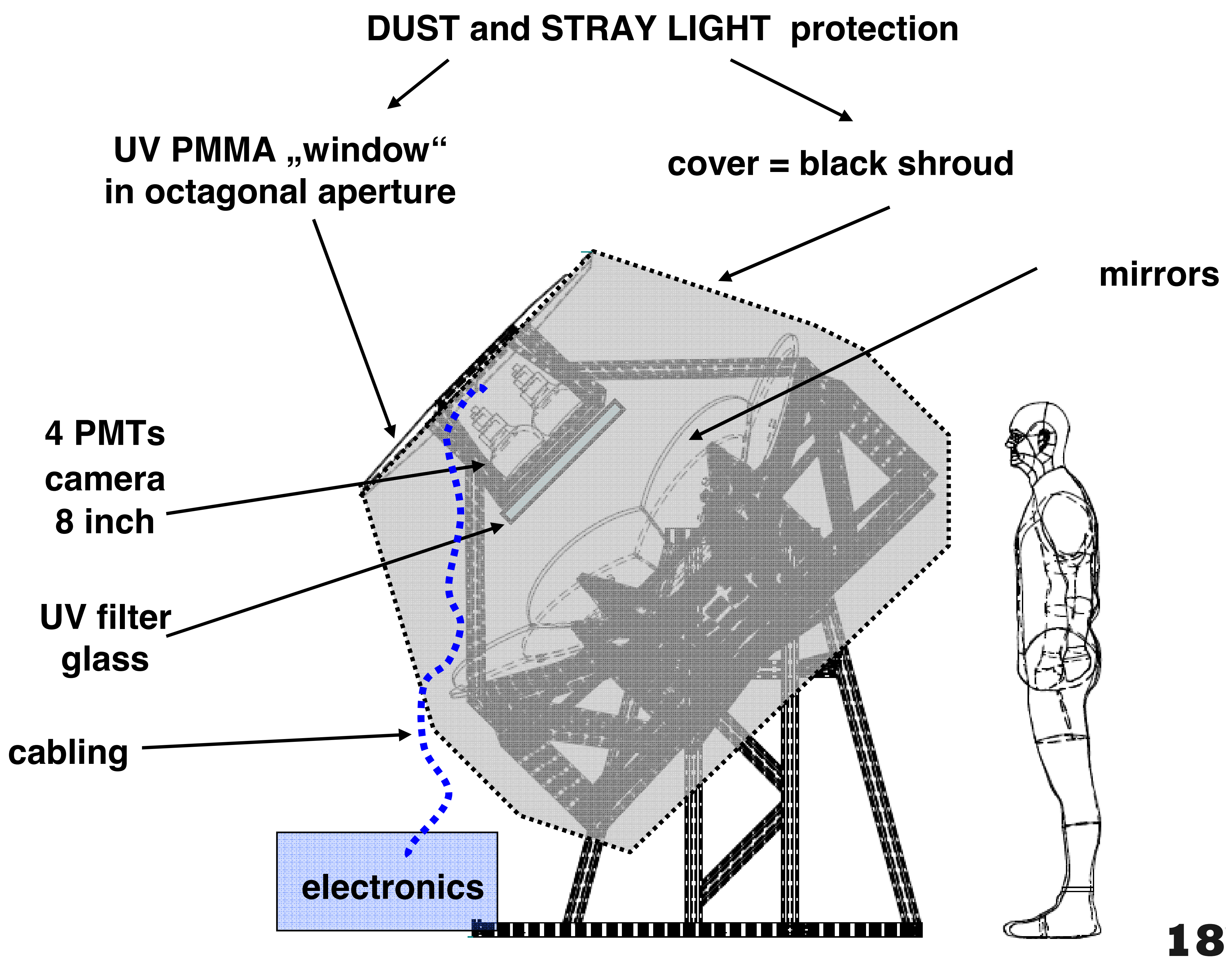




roof „window“

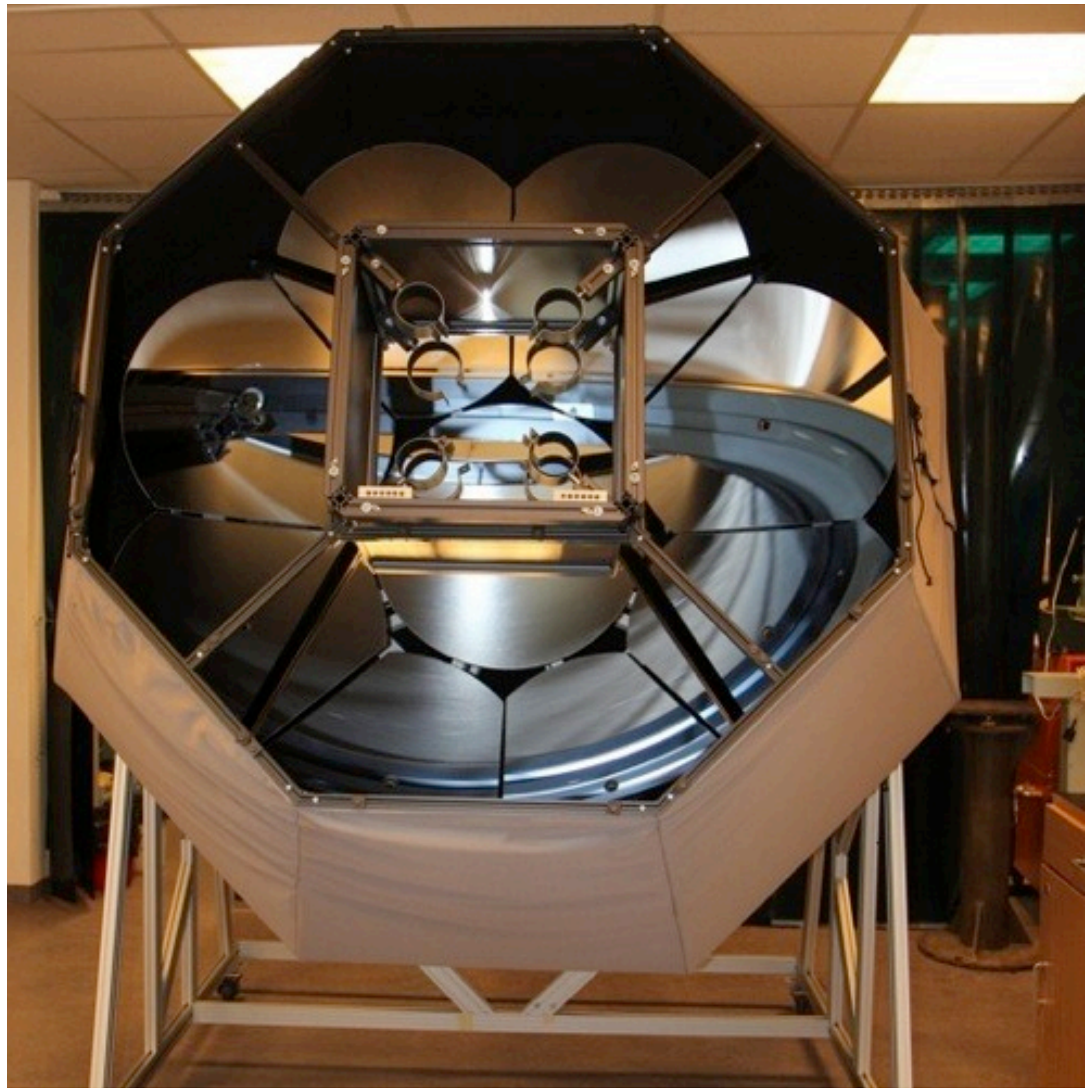


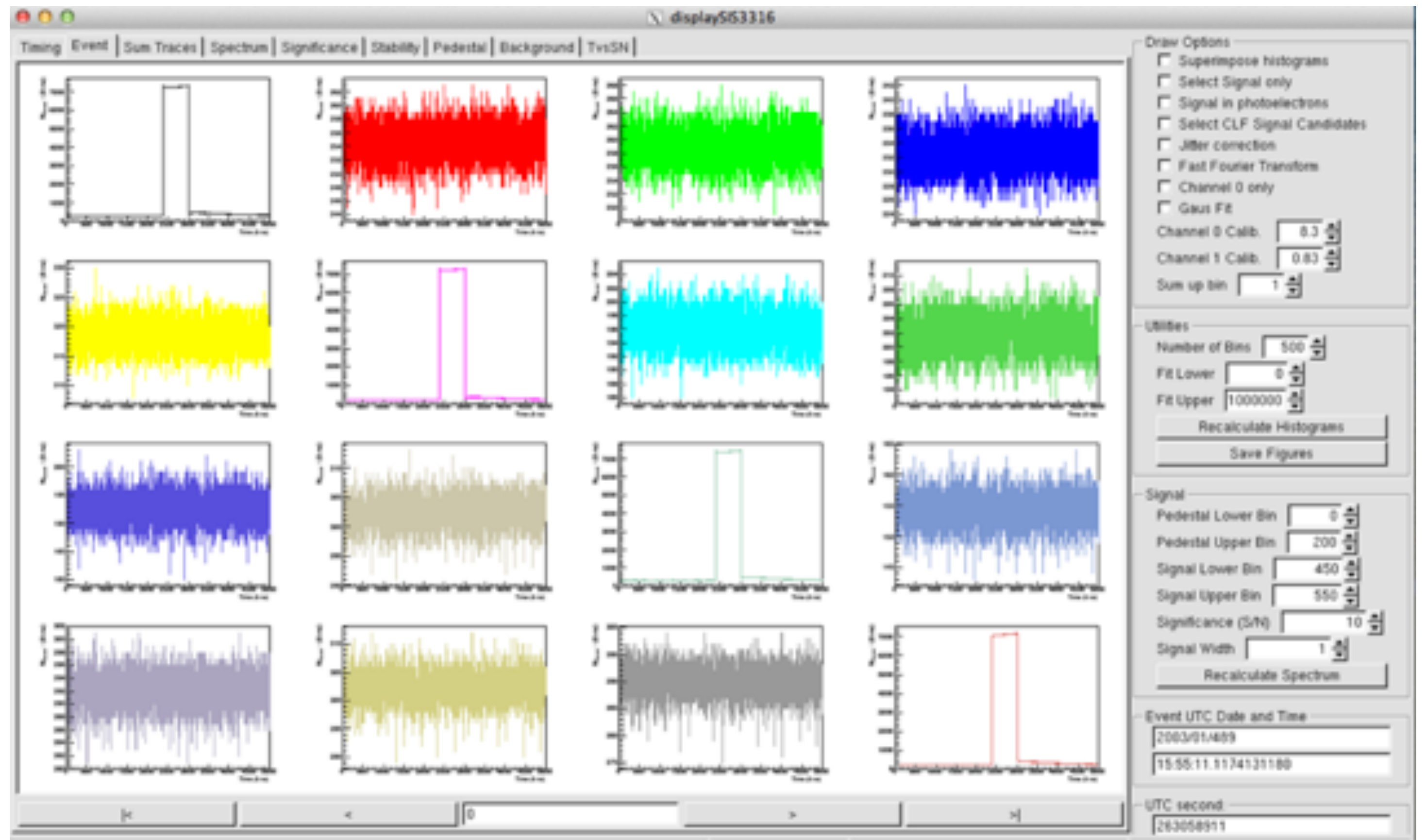


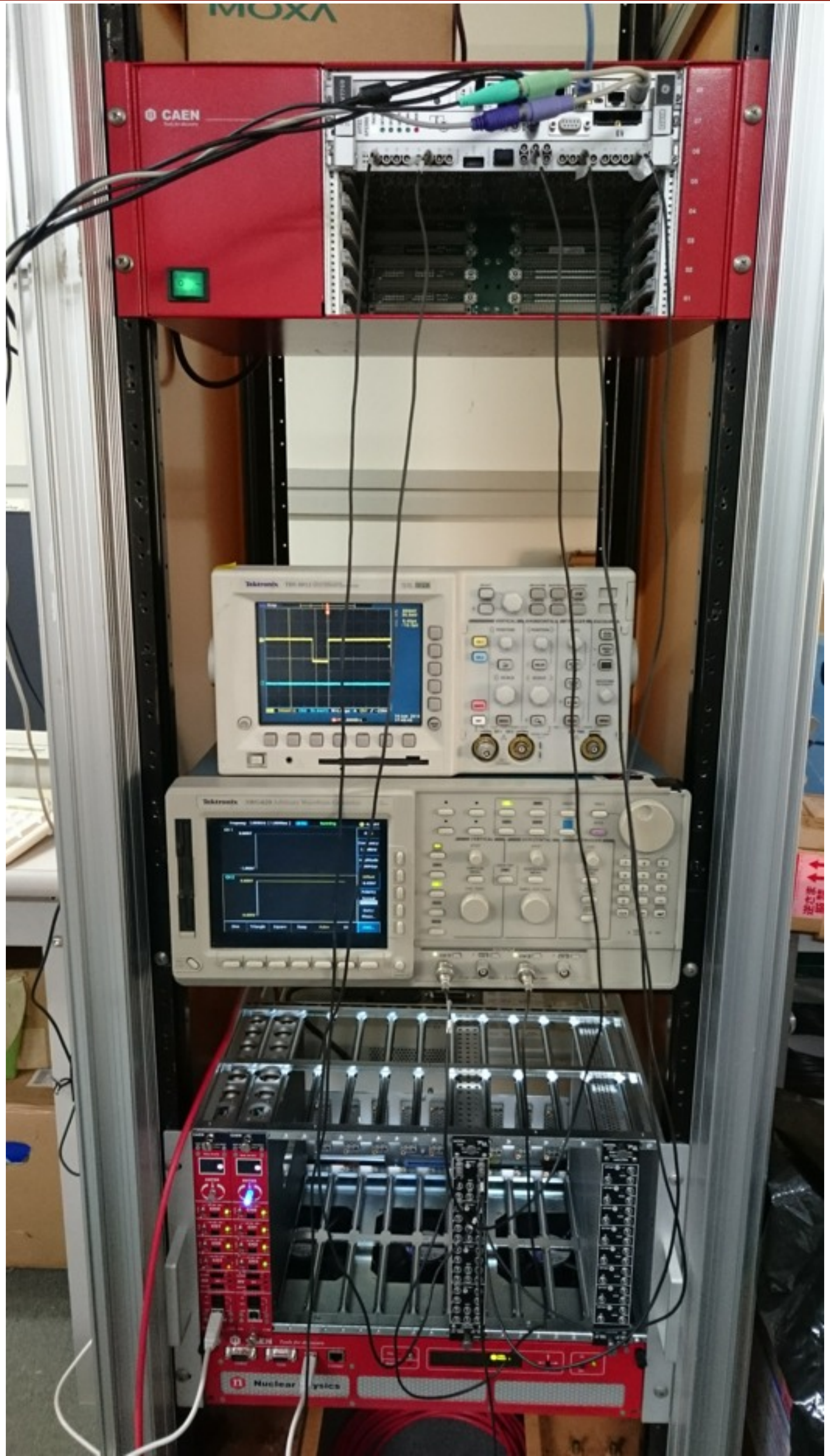


Fluorescence detector Array of Single-pixel Telescopes

Full-scale FAST Prototype



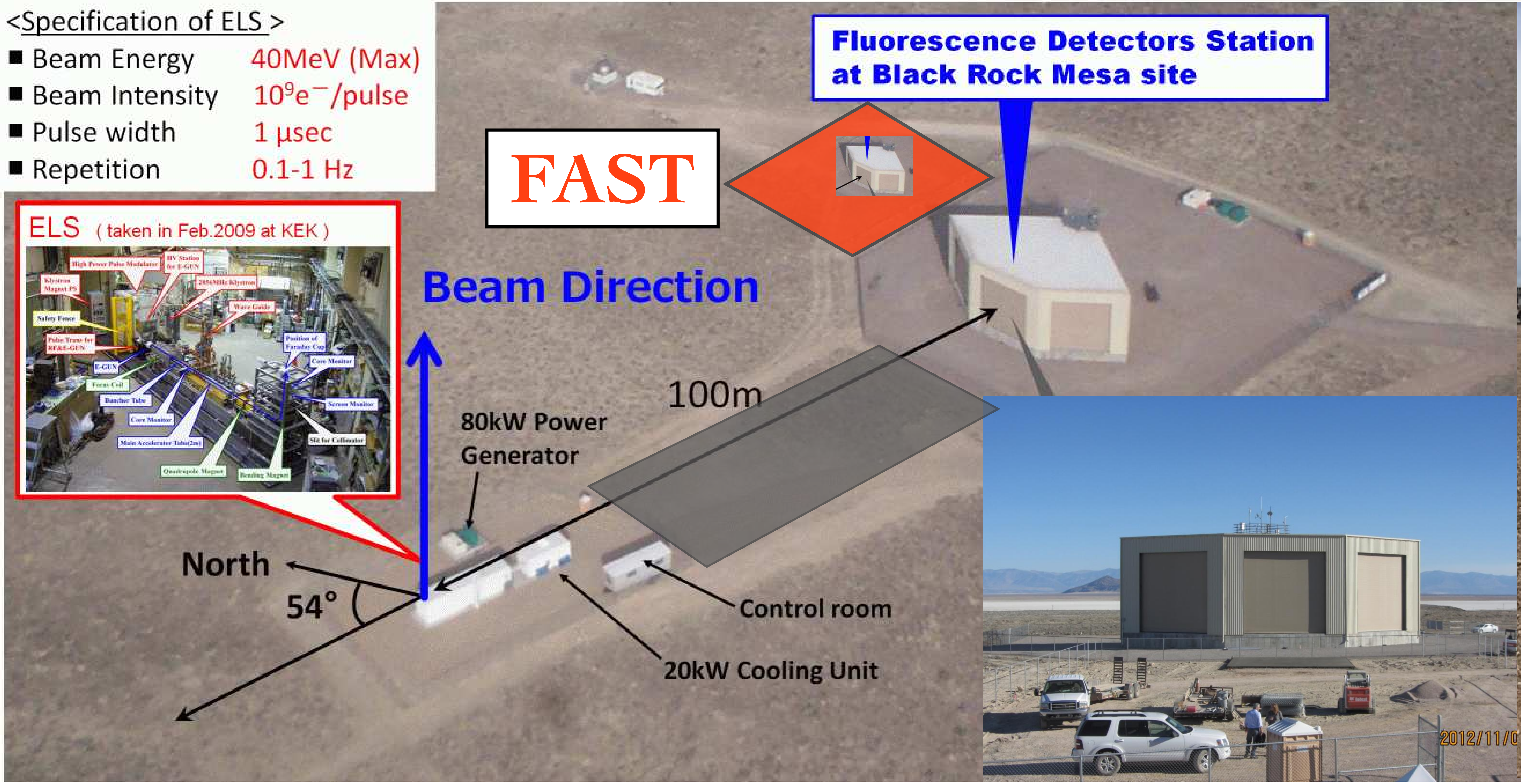




- 8 inch PMT Hamamatsu (R5912-03)
- Commercial electronics
  - VME Crate (CAEN, VME8008B)
  - Single board PC (V7768-330000, GE)
  - GPS module (GPS2092, Hytec)
  - 16 ch, 14-bit Digitizer (SIS3316-250-14, Struck Innovative Systeme)
- NIM crate (CAEN, NIM8301)
- HV power supply (CAEN, N1470)
- 8 ch fast amplifier (Phillips Scientific 777)

Concrete pad and hut being constructed

Telescope Array experiment, Black Rock Mesa site

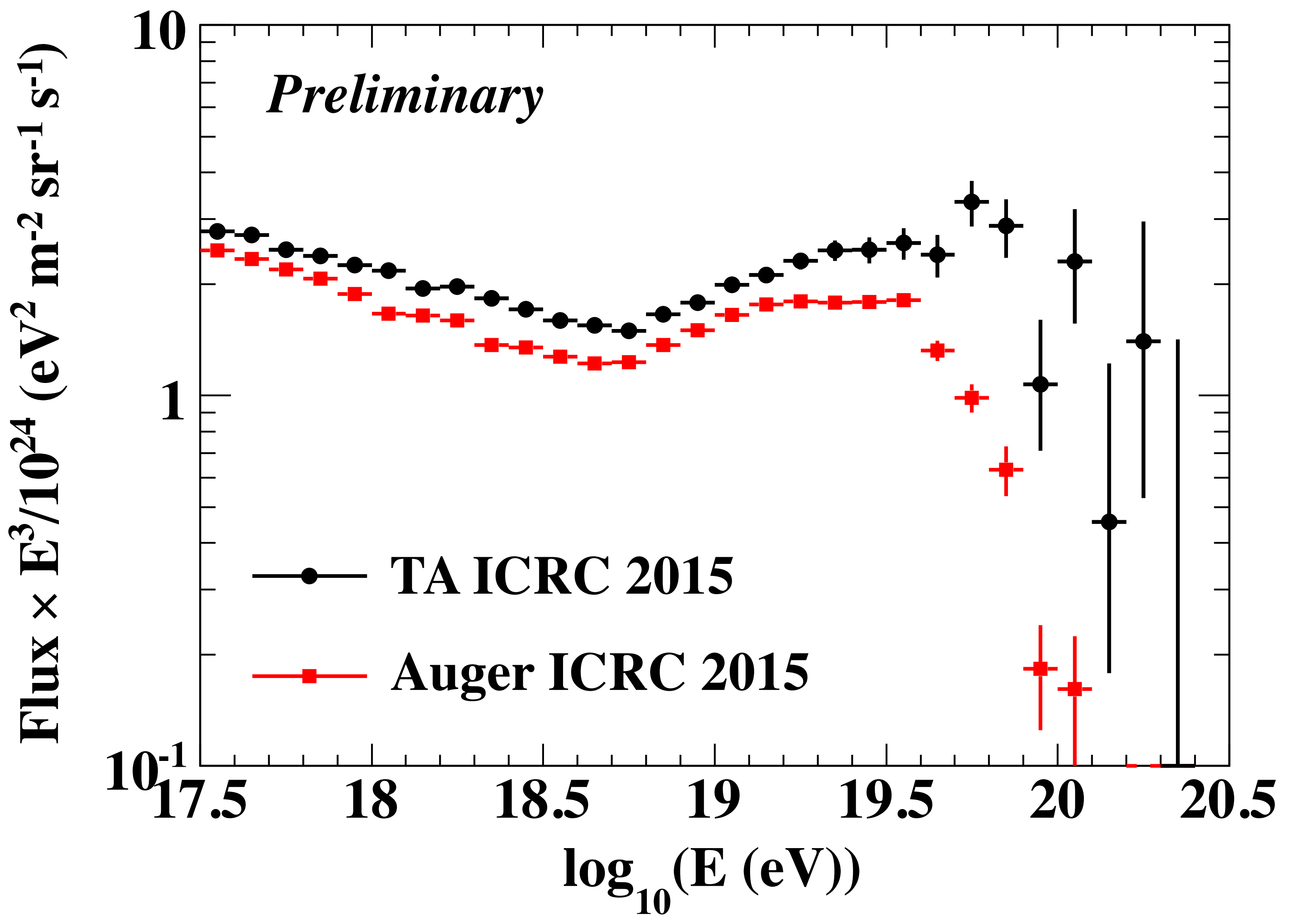


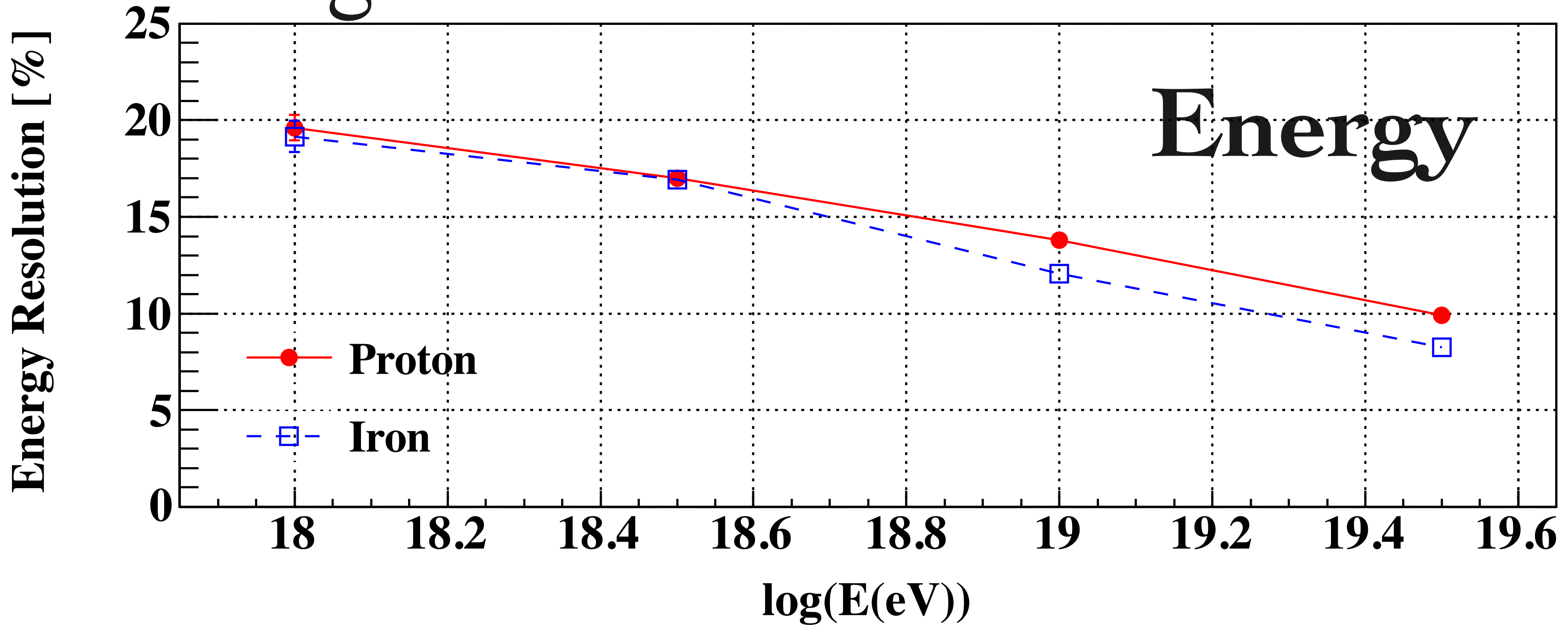
We will plan to install the full-scale FAST telescope in September 2016

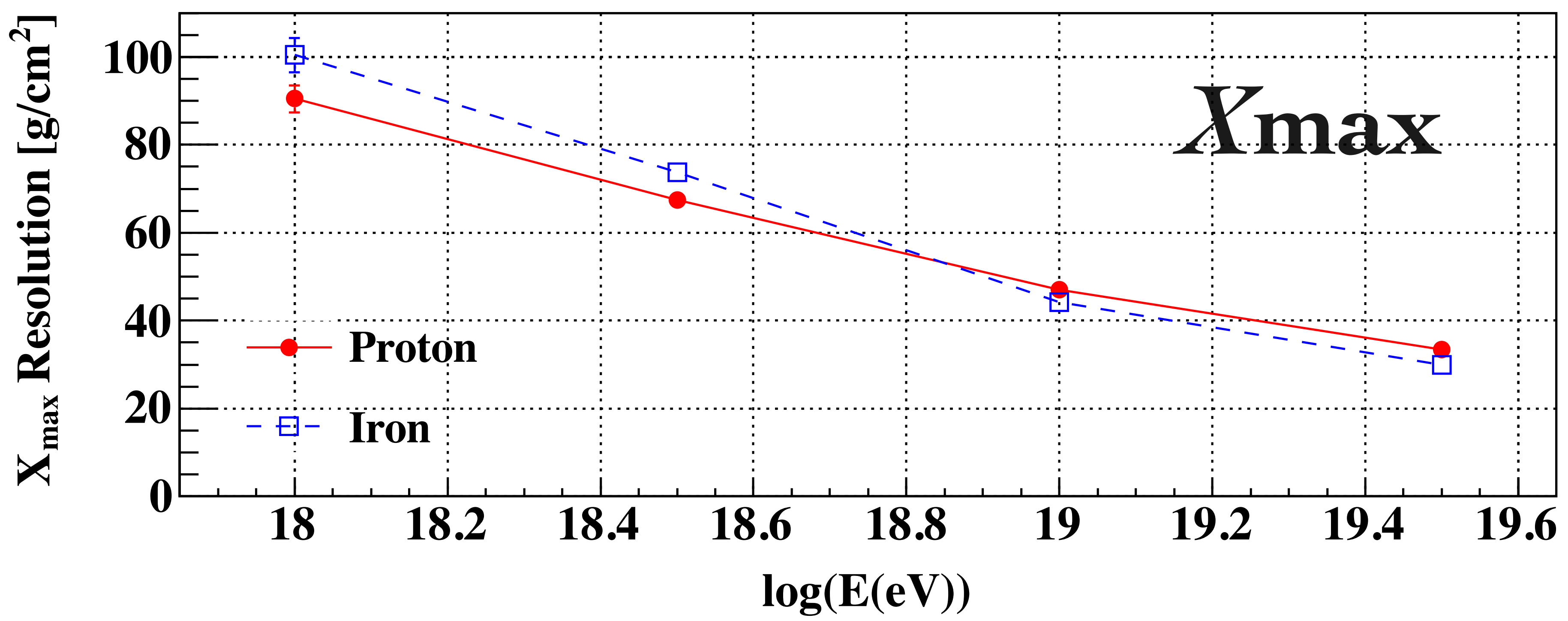
Possible Application of the FAST Prototype

Fluorescence detector Array of Single-pixel Telescopes

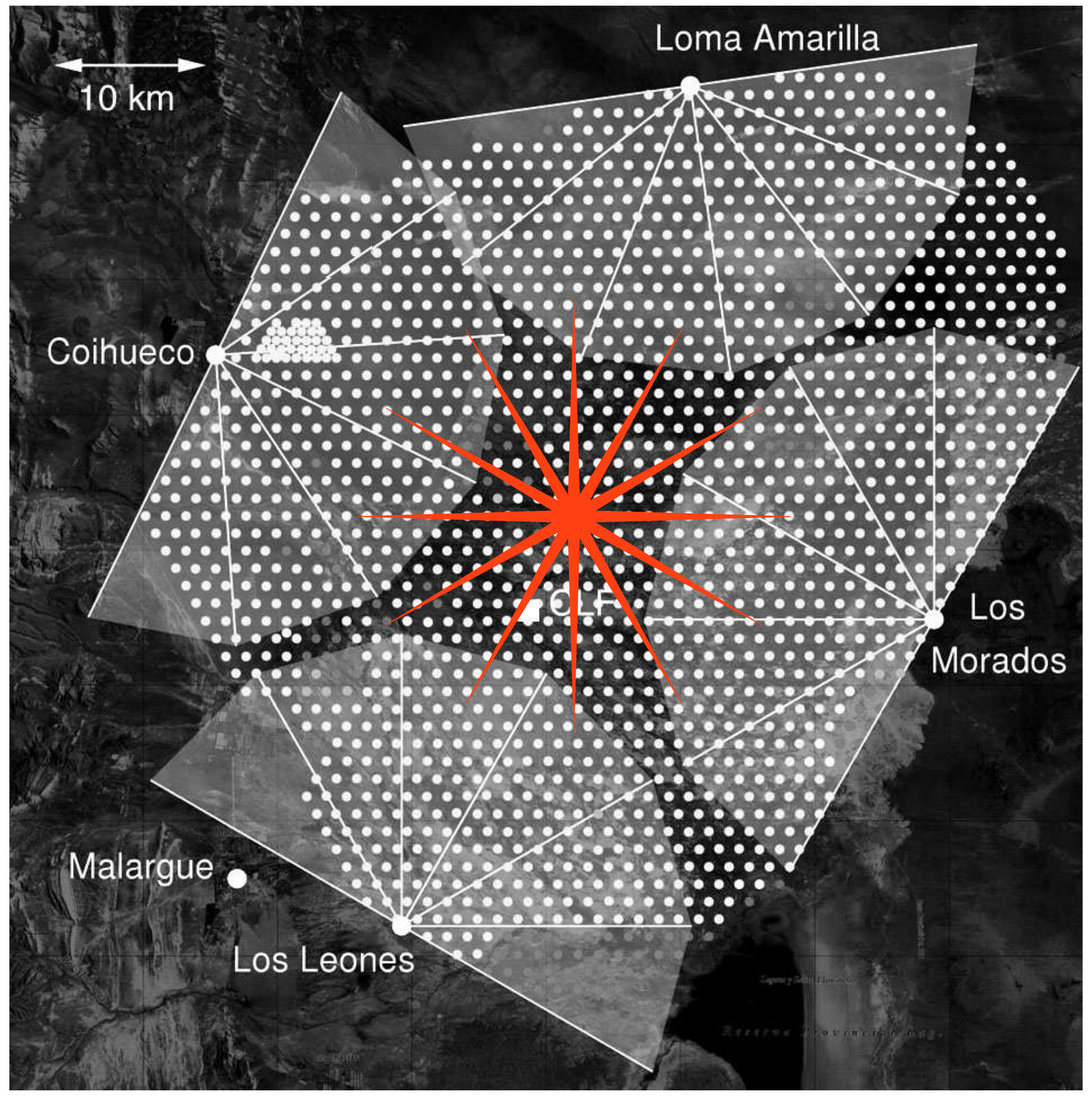
- Install FAST at Auger and TA for a cross calibration.
- Profile reconstruction with geometry given by SD (smearing gaussian width of 1° in direction, 100 m in core location).
  - Energy: 10%, Xmax : 35 g/cm^2 at $10^{19.5}$ eV
  - Independent cross-check of **Energy and** $\boldsymbol{X}$**max** scale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





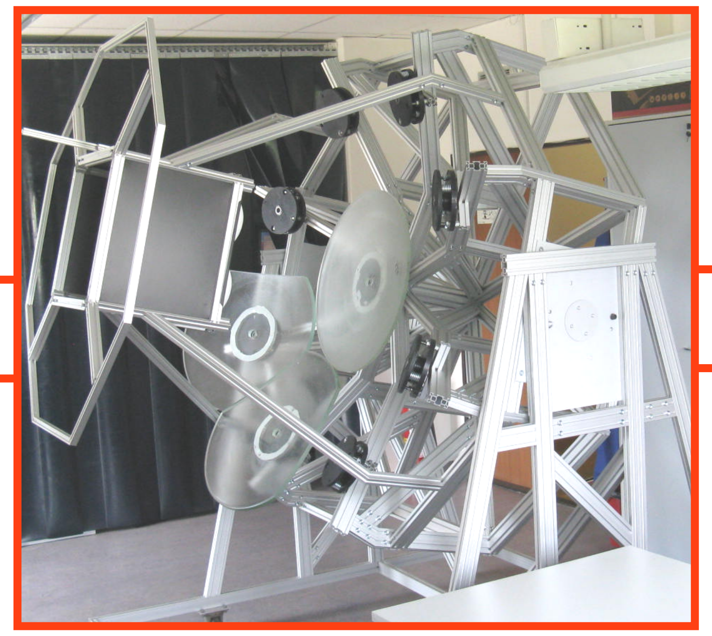


Pierre Auger Observatory

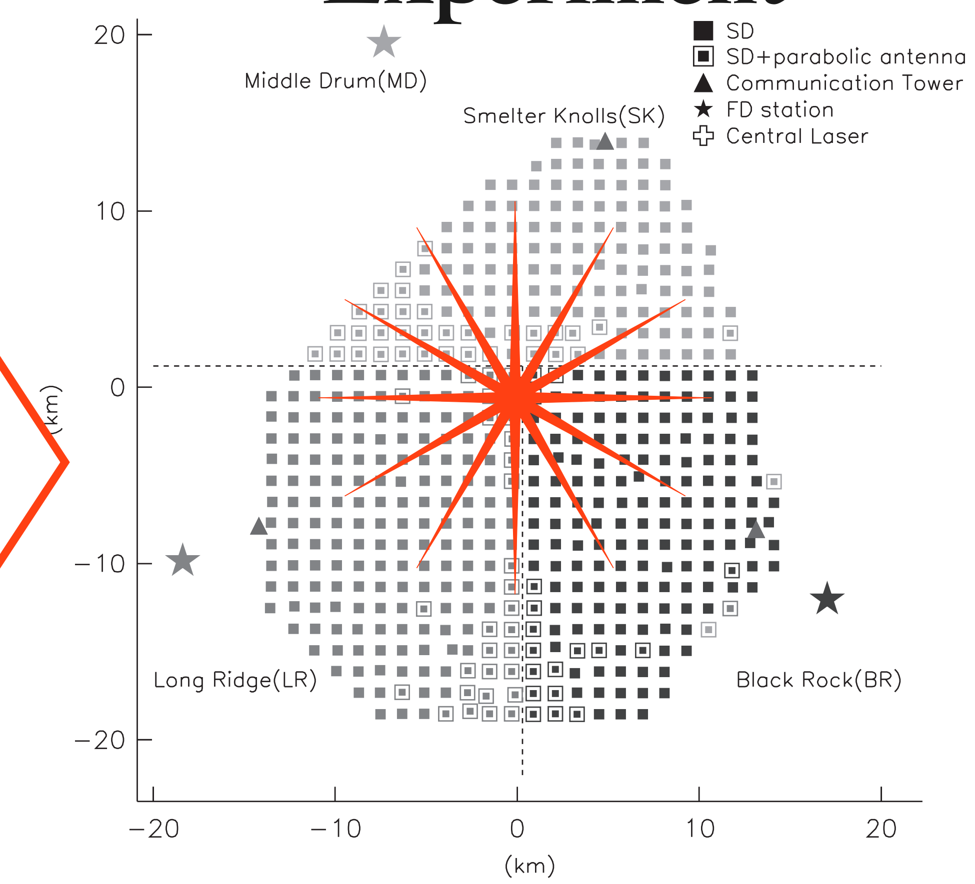


Pierre Auger Collaboration, NIM-A (2010)

Identical simplified FD



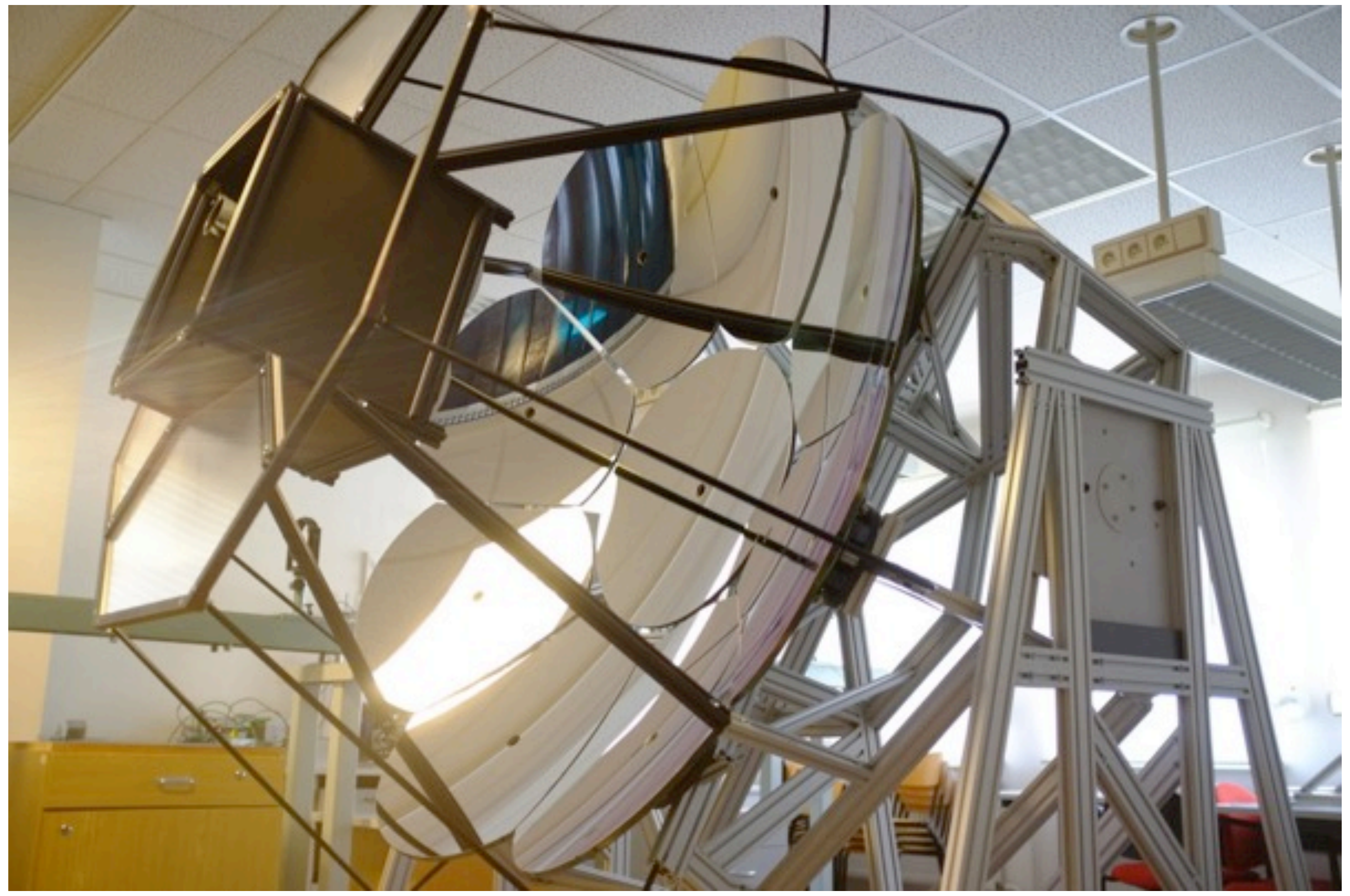
Telescope Array Experiment

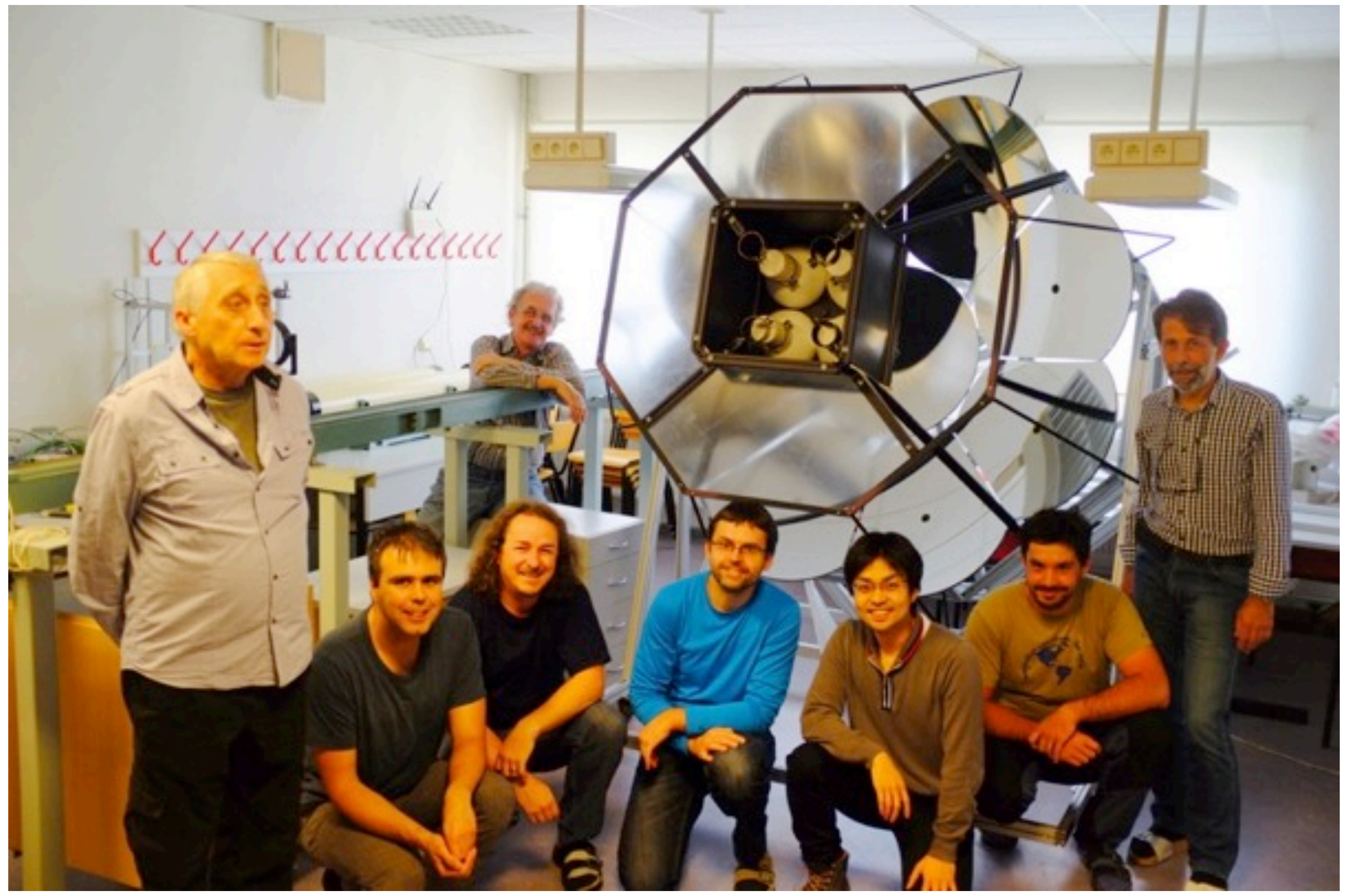


Telescope Array Collaboration NIM-A (2012)

Summary and Future Plans

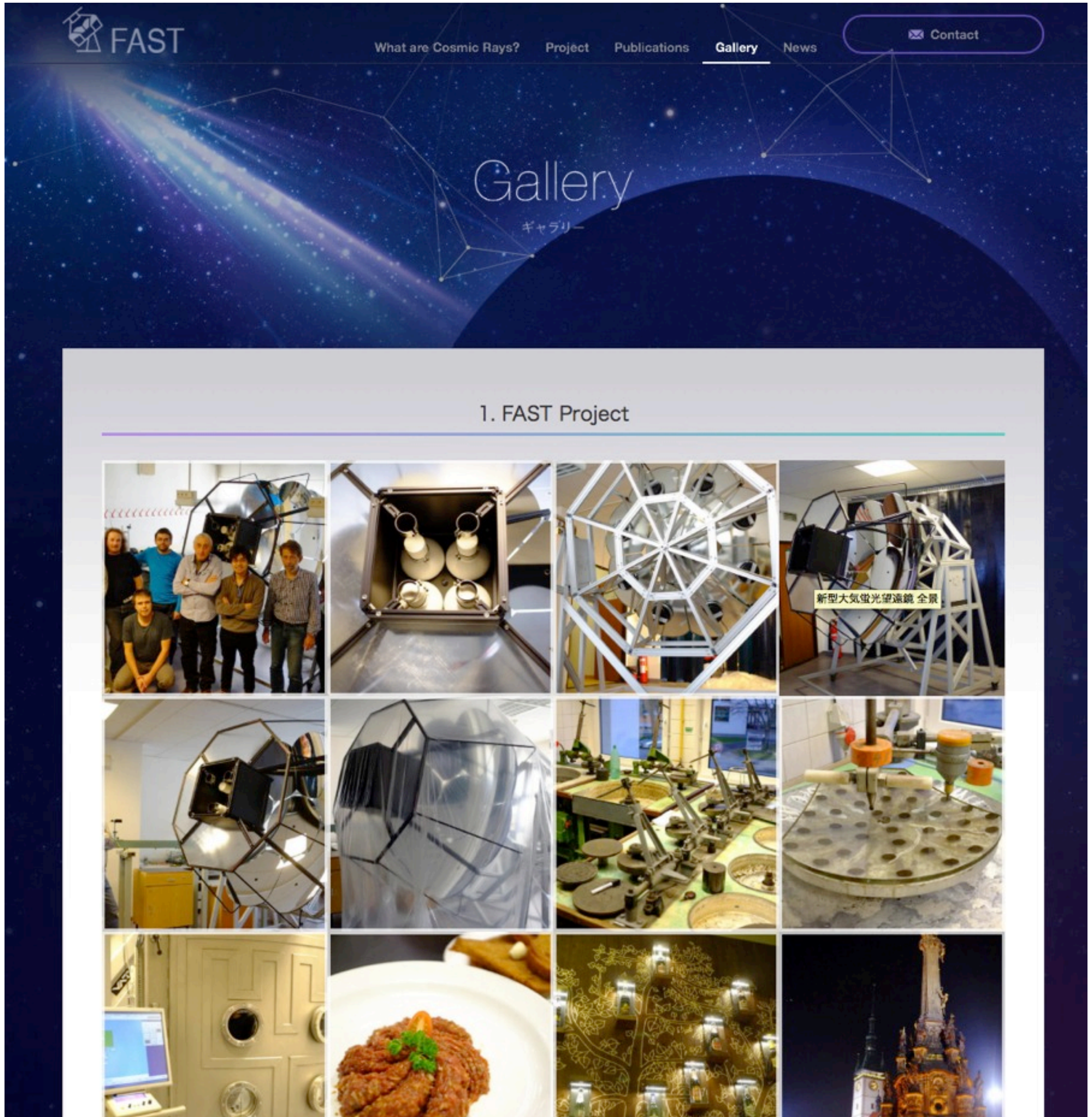
- **Fluorescence detector Array of Single-pixel Telescopes (FAST)**
  - Deploy the economical fluorescence detector array.
  - Detect UHECRs and neutral particles with >10×Auger effective area.
- This concept of single-pixel telescope was confirmed by the field measurements using the EUSO-TA optics.
  - Published in Astroparticle Physics *74* (2016) 64-72
- The full-scale FAST prototype is being constructed, and almost ready to install to Utah.
  - We plan to install in September 2016 to observe *X*max
- New collaborators are welcome.





FAST
Fluorescence detector Array of Single-pixel Telescopes

FAST Webpage



FAST
Fluorescence detector Array of Single-pixel Telescopes

http://www.fast-project.org