Future Prospects on UHECR and UHE Photon

F A S T
Fluorescence detector Array of Single-pixel Telescopes

http://www.fast-project.org

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MACROS 2016 workshop, June 20th 2016

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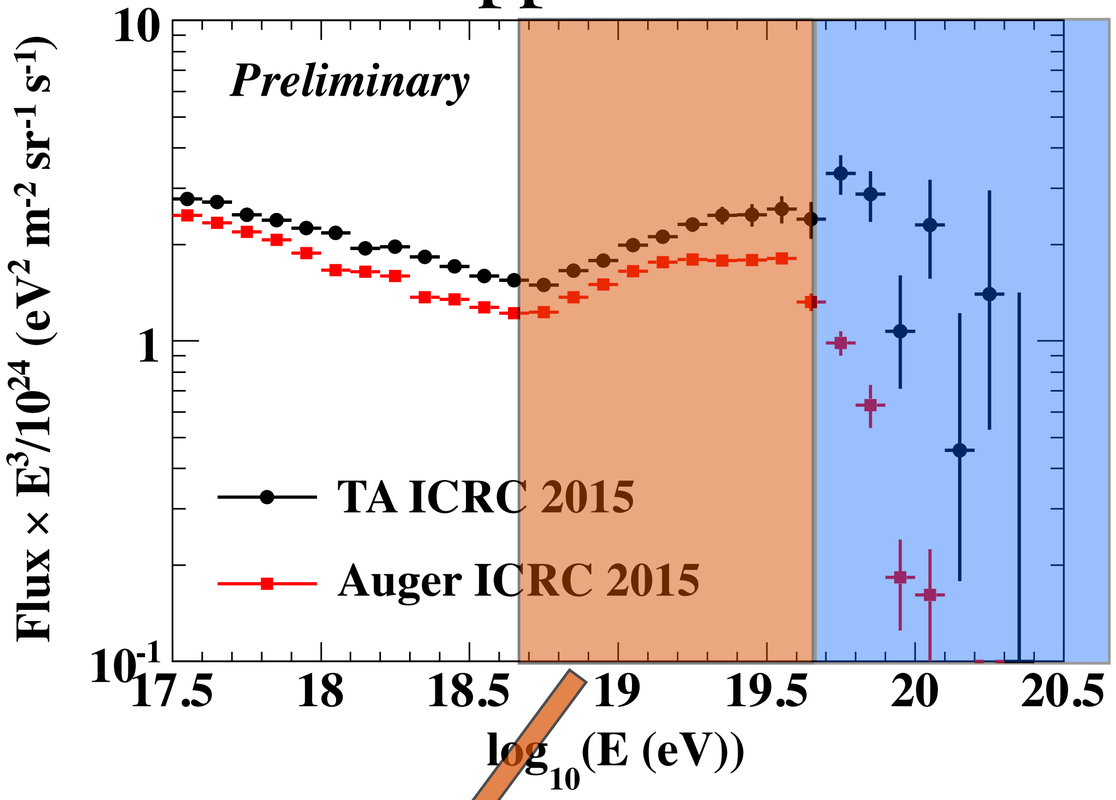
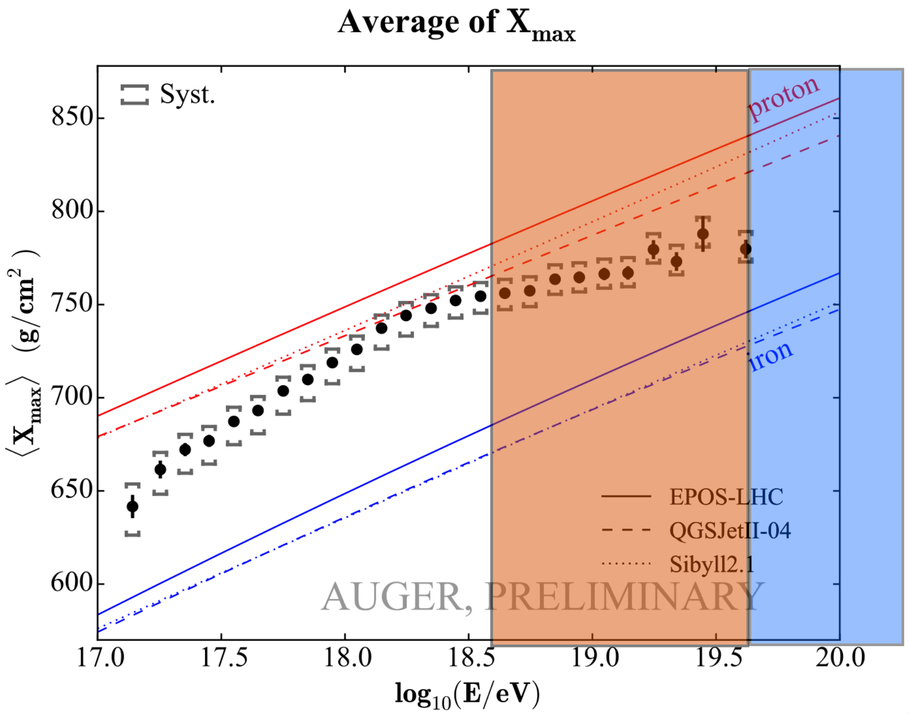
Highlights on UHECR

Spectrum discrepancy at suppression



No anisotropy seen

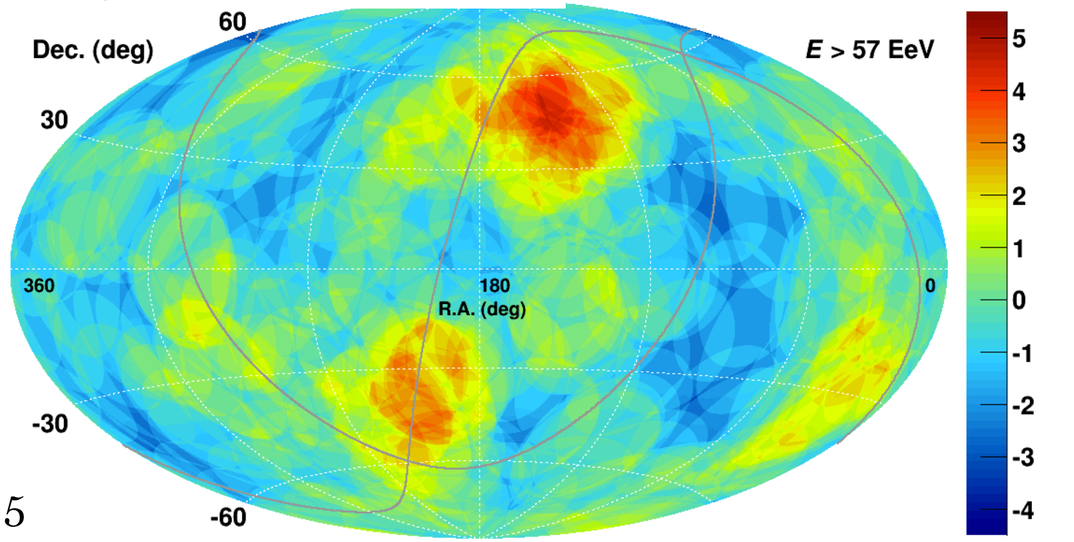
ApJ, 794 172 (2014)



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

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

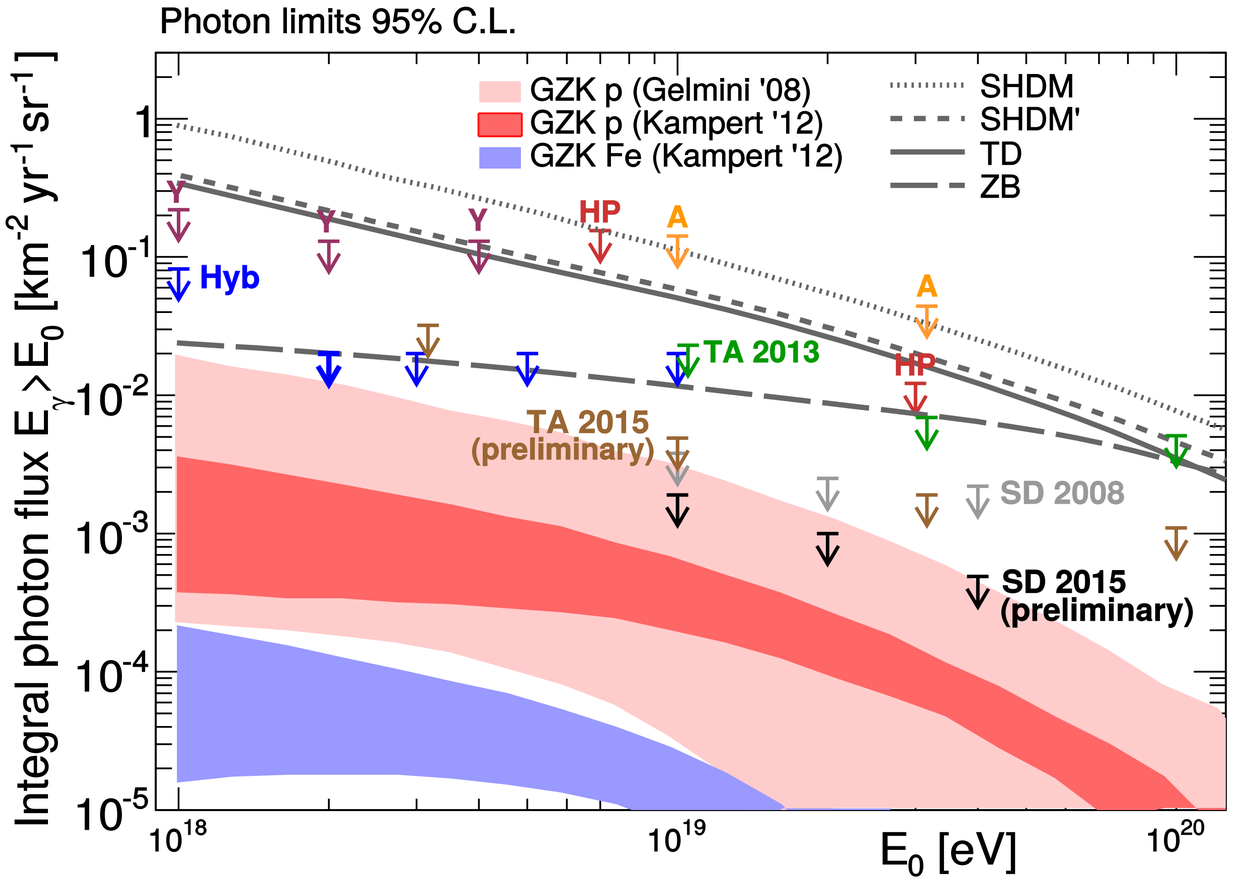
Hotspot/ Warmspot

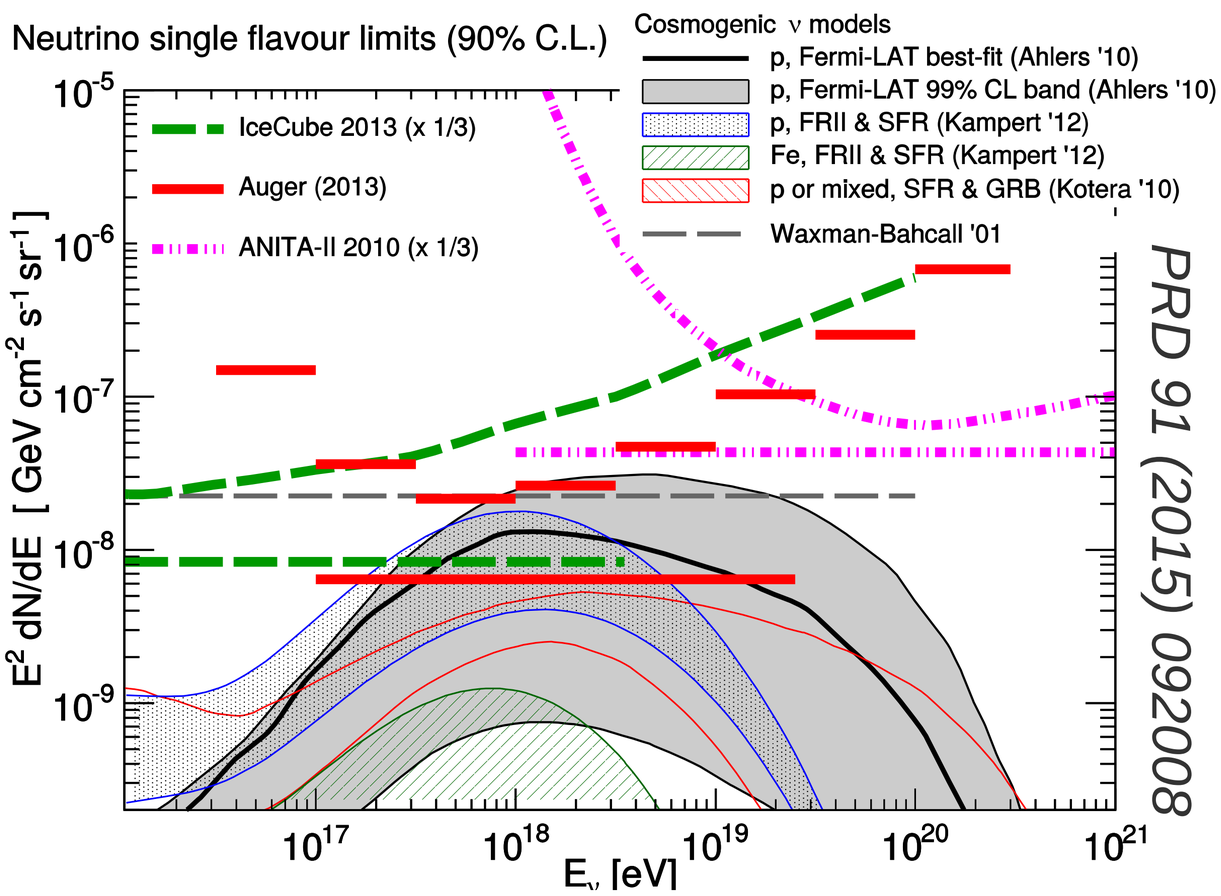


K. Kawata et al, ICRC 2015

Highlights on UHE Photon/Neutrino

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



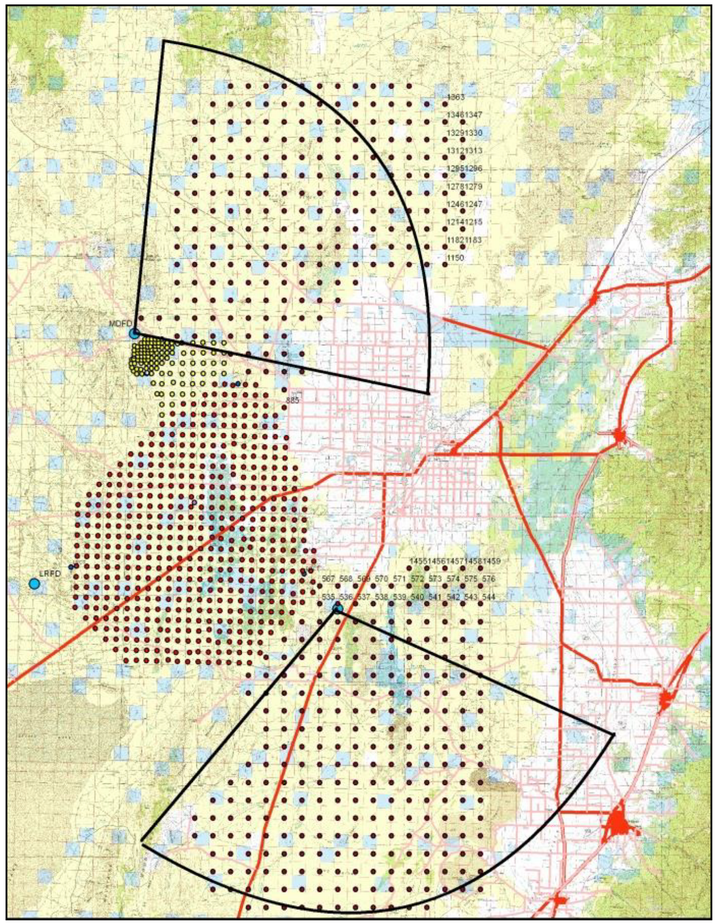


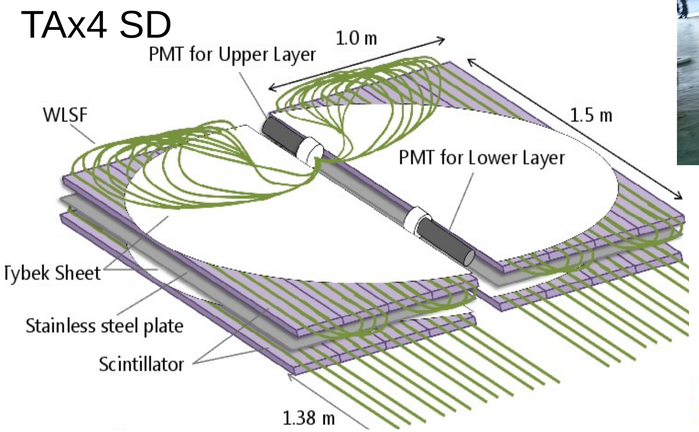
C. Bleve ICRC 2015

On-going Upgrade: TA×4

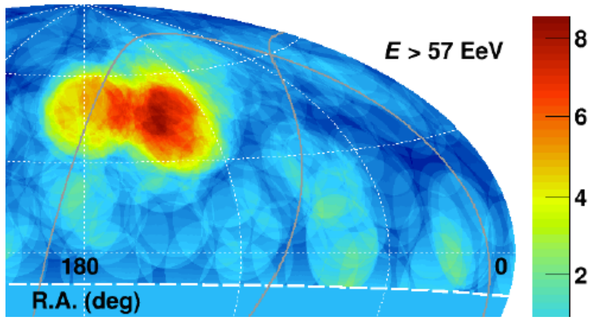
Detailed measurement on Hotspot

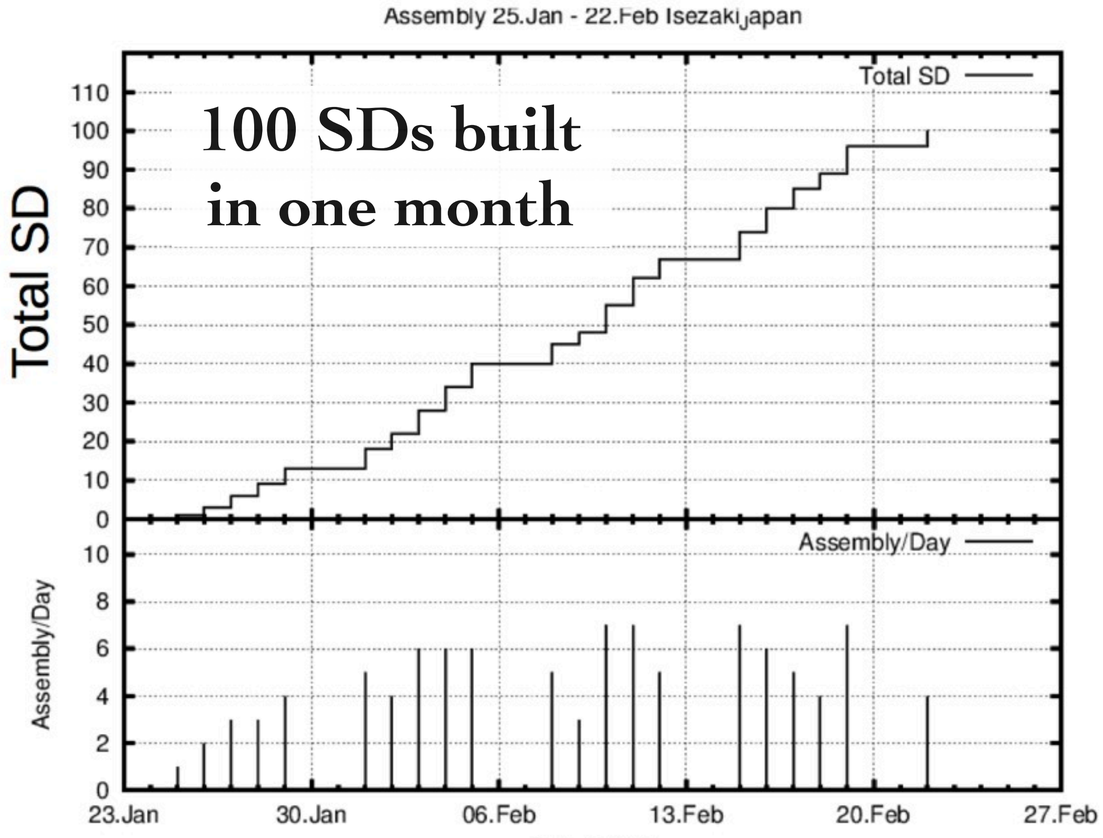
Enlarge the fourfold coverage to TA×4 = Auger,
3000 km^2





Expected in 2020 (Simulation)

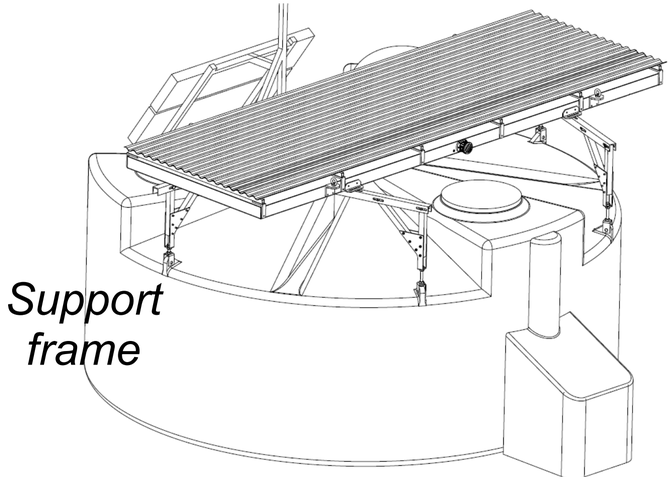


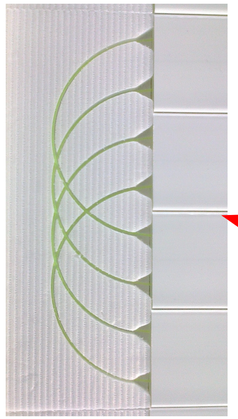


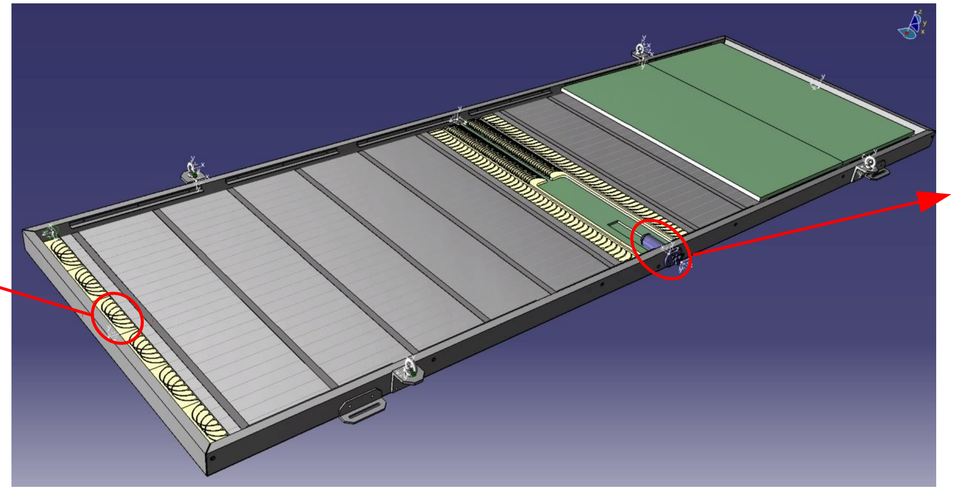
H. Sagawa ICRC2015, T. Nonaka UHEAP2016

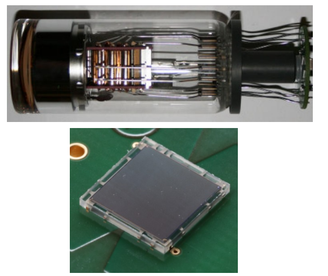
On-going Upgrade: AugerPrime

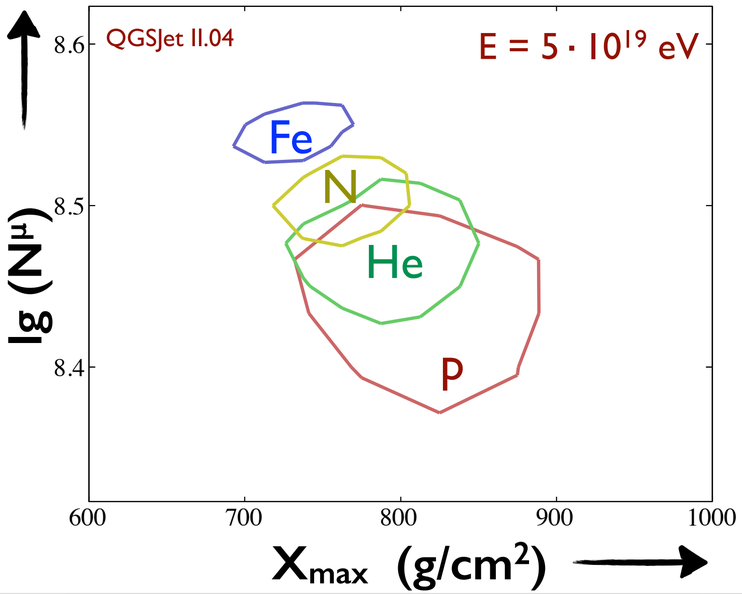
Install 4 m^2 Scintillator to measure the mass composition by SD.







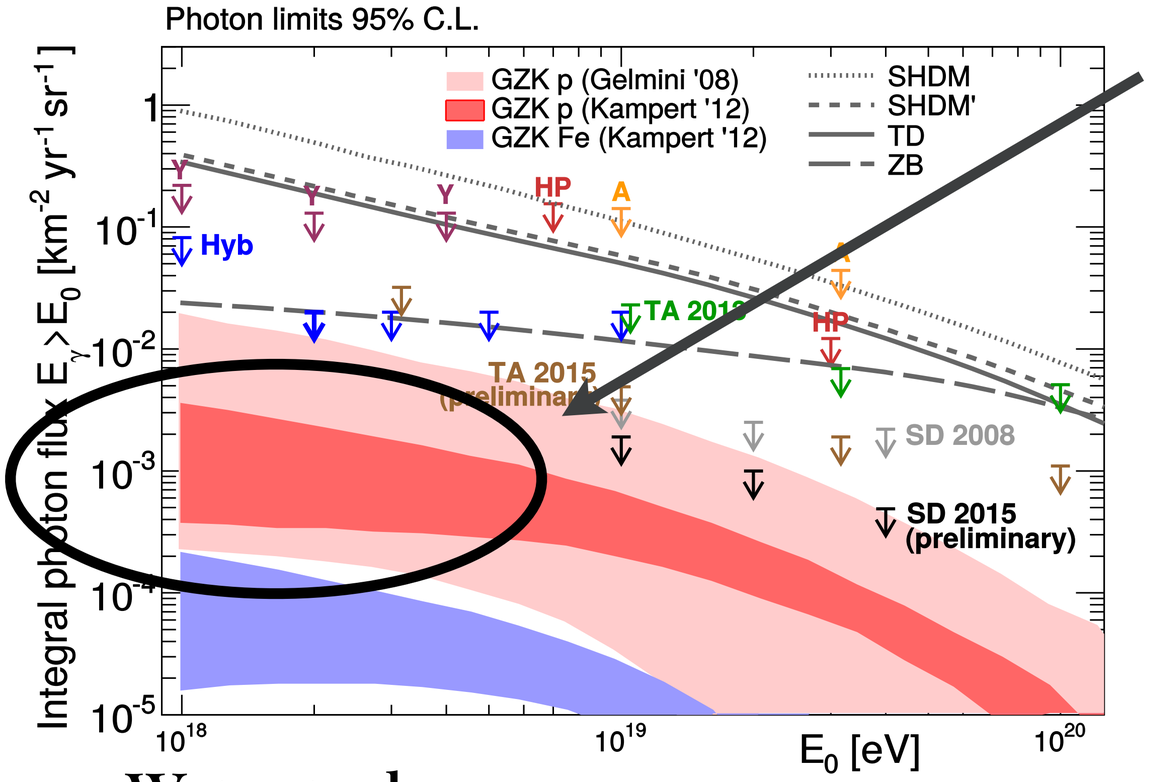




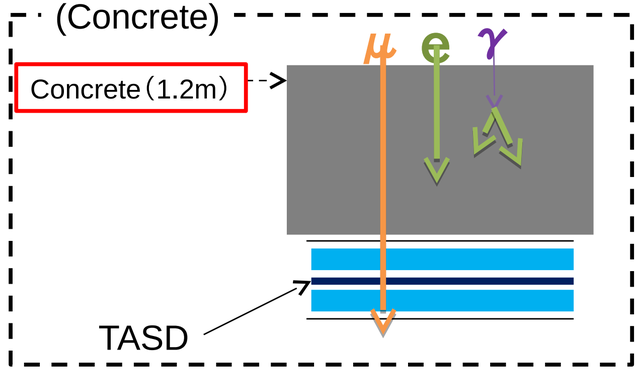
R. Engel ICRC2015, R. Smida UHEAP2016

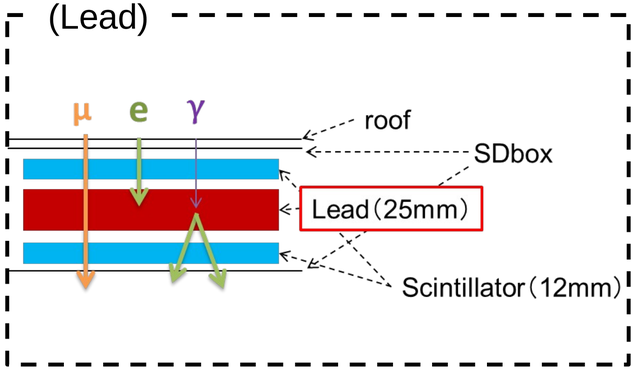
- Improve electromagnetic/muon separation of **SD** to measure the **mass composition above $10^{19.7}$ eV.**
  - Boost in statistics by a factor of ~ 10 compared to FD *X*max analysis.
- Small PMT in the water tank, FD operation during moon night.
- **Origin of flux suppression, proton contribution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

Strategy to detect UHE photon

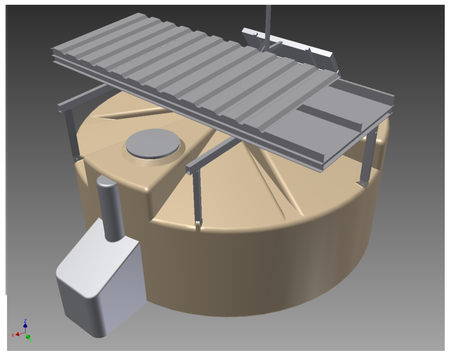


- Target : GZK photon around 10^{18} eV
- Surface array with mass composition sensitivity
  - >500 km^2 ground array, dense array with ~750 m spacing to be 100% efficiency at $10^{18.0}$ eV.
  - Better γ/Hadron separation by 10^{-5} required.

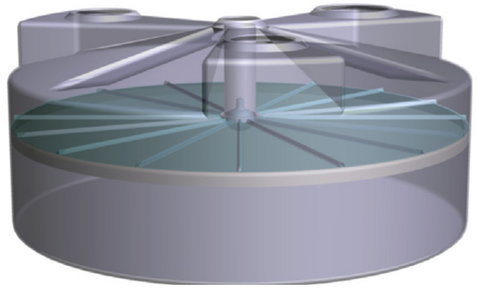




Water tank + Scintillator



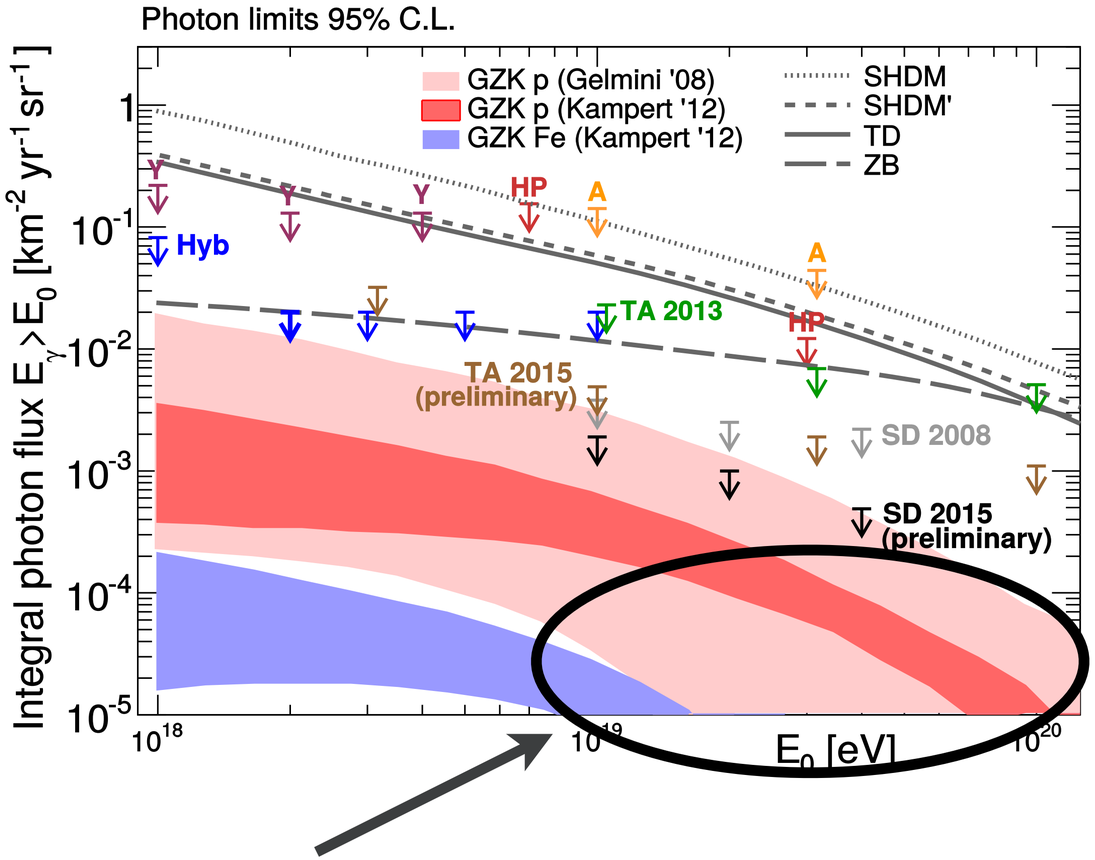
Layered water tank



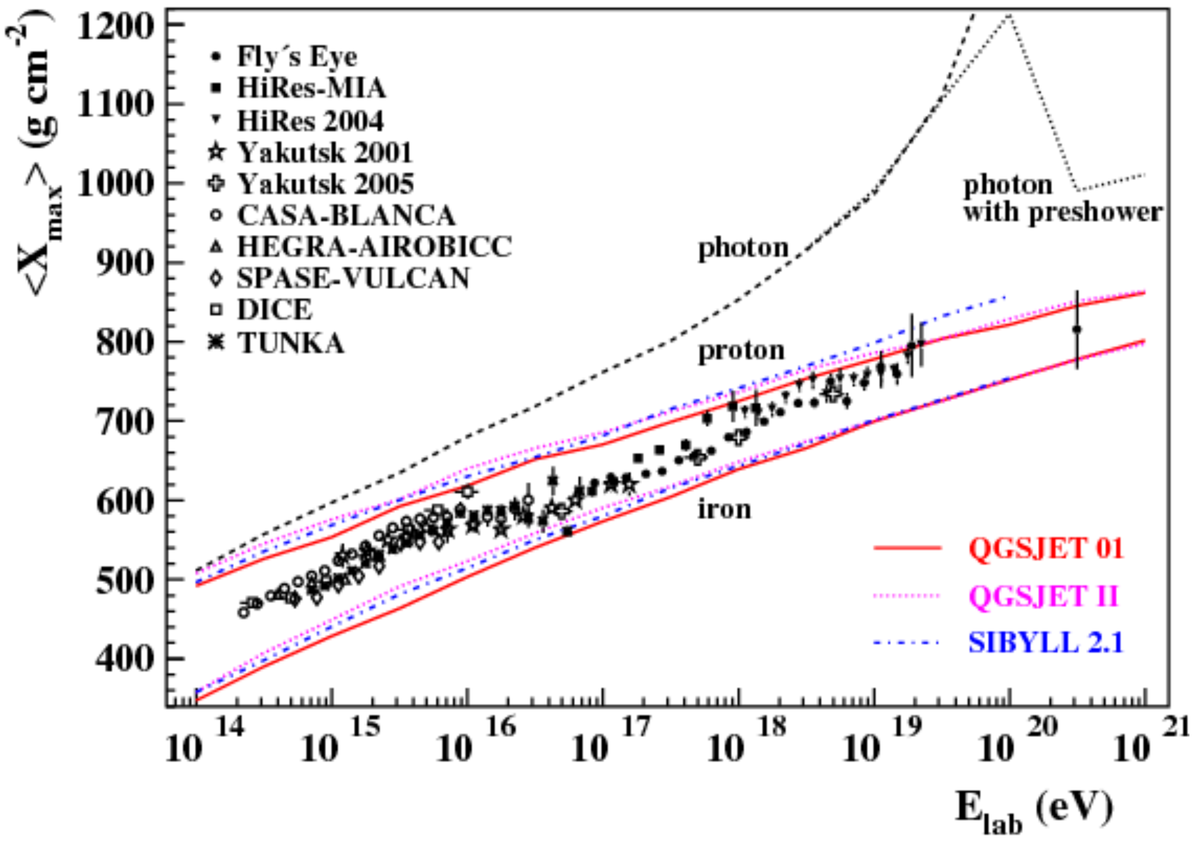
A. Letessier-Selvon et al., NIMA *767* (2014) 41

N. Nonaka UHEAP2016

Strategy to detect UHE photon



Graciela B. Gelmini,
J.Phys.Conf.Ser. 171 (2009) 012012

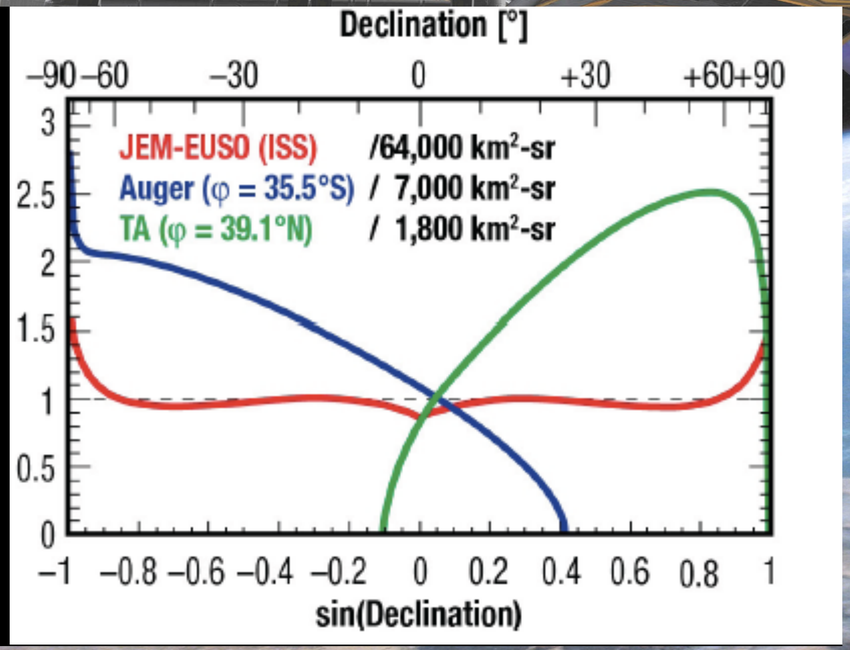


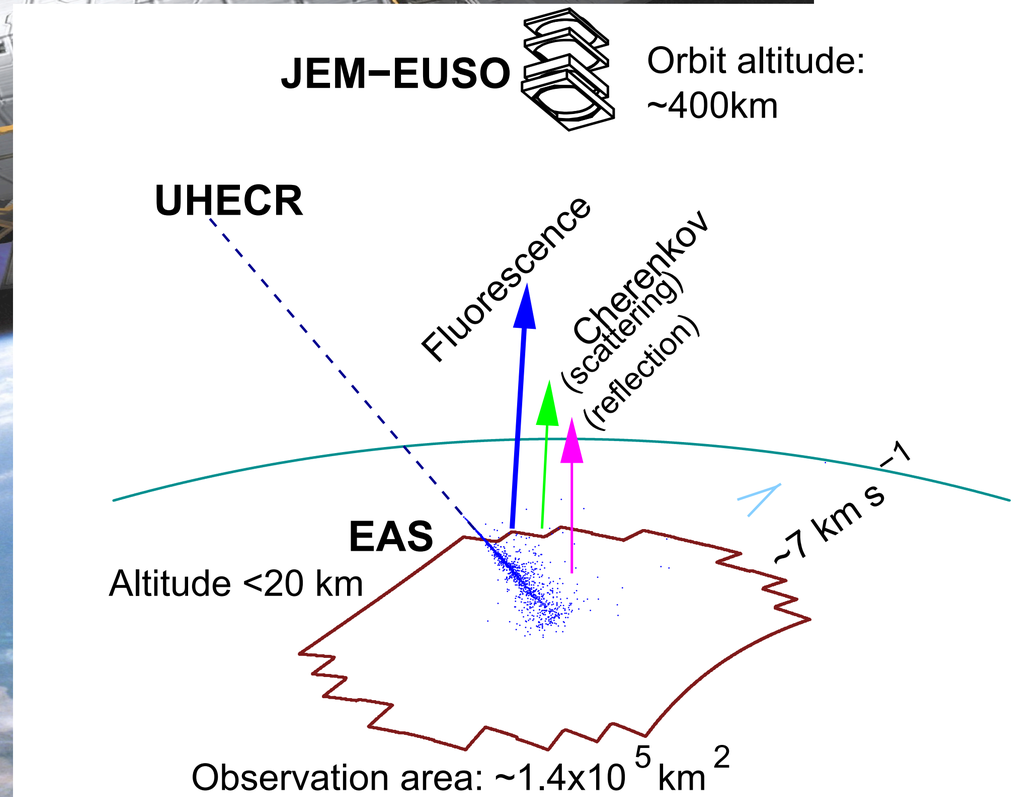
- Target: GZK photon above 10^{19} eV.
- Search for deep *X*max showers by fluorescence technique.
- 10×Auger effective area needed: JEM-EUSO mission or FAST project

JEM-EUSO

Extreme Universe Space Observatory onboard Japanese Experiment Module

Pioneer detection of UHECRs from space



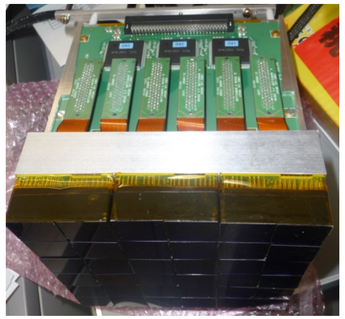


A. Olinto, ICRC2015

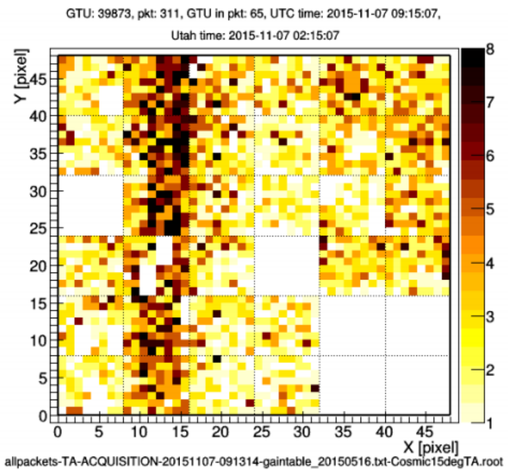
J.H. Adams Jr. et al., Physics 44 (2013) 76–90

R&D for JEM-EUSO

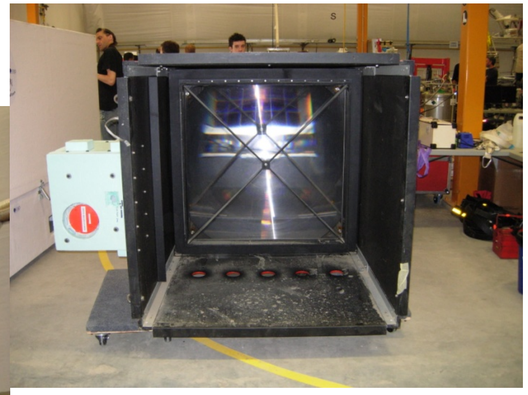
EUSO-TA



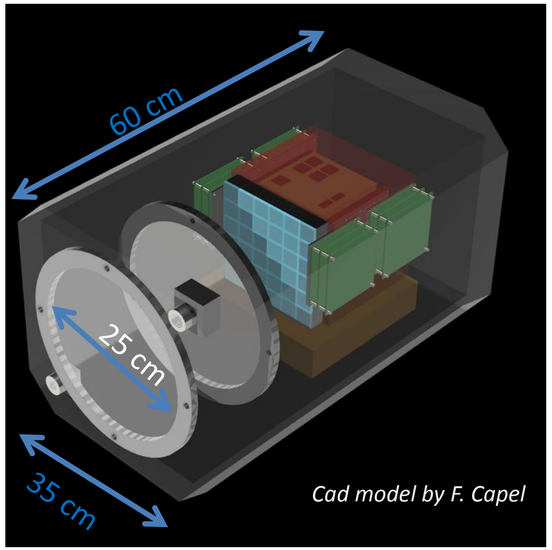
- $E \simeq 10^{18.36}$ eV (highly uncertain)
- Distance: 2.6 km



EUSO-Balloon



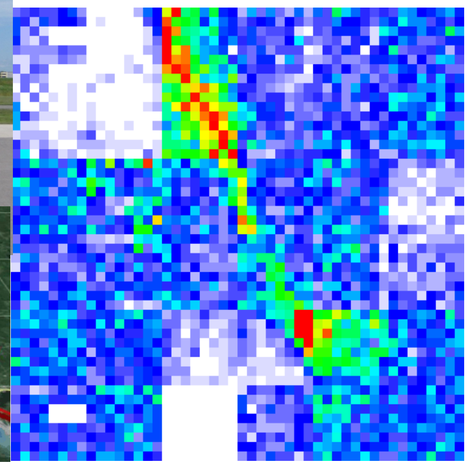
MINI-EUSO in 2017



Helicopter with light sources

Helicopter track

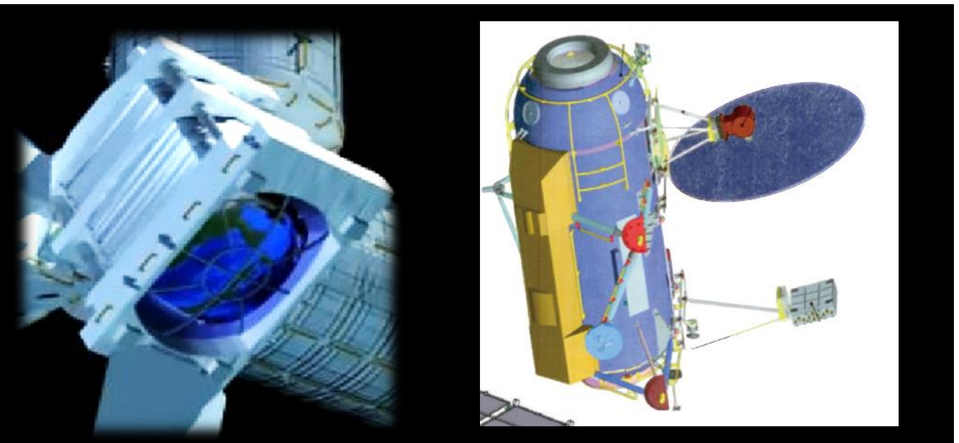
Observed Laser



EUSO-SPB(Super Pressure Balloon) will be launched in March 2017

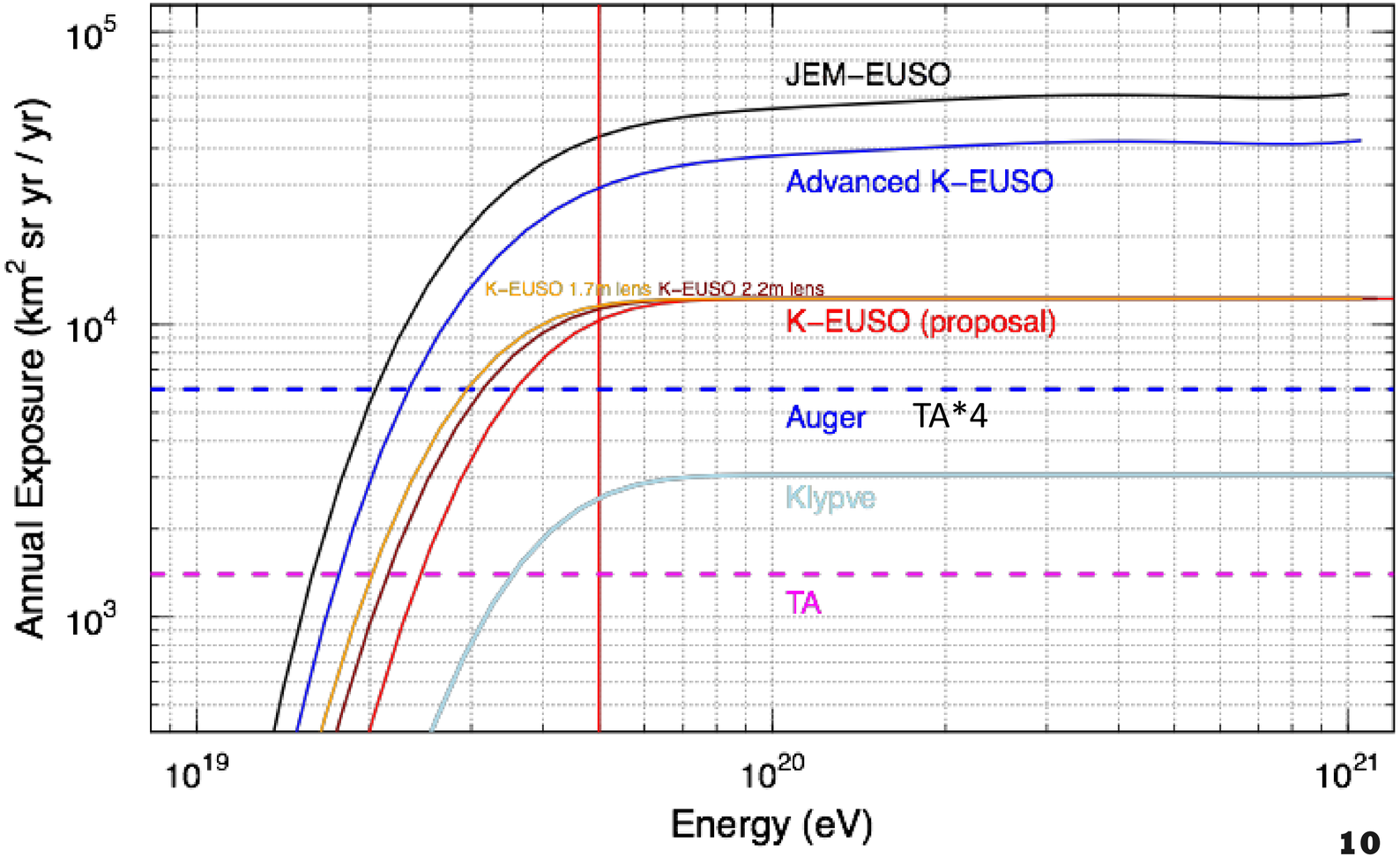
JEM-EUSO and K-EUSO

- In the Russian Federal Space program. Mission of opportunity launch in FY2019



Japan-led
JEM module
Refractor
2.5 t
2kW
10*Auger

Russian-led
MRM module
Reflector (mirror)
600kg
600W
2*Auger



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

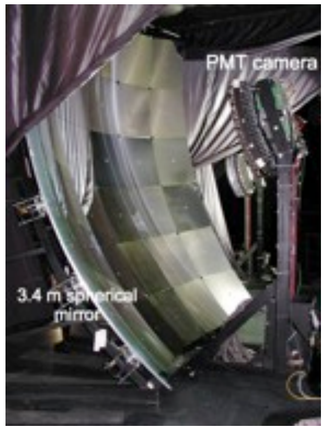
FAST
Fluorescence detector Array of Single-pixel Telescopes

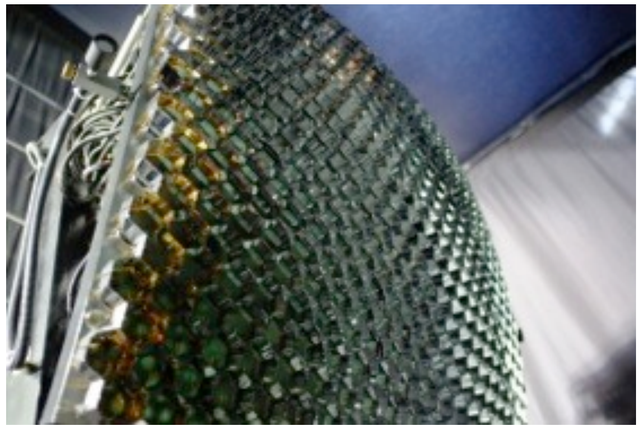
Fluorescence detector Array of Single-pixel Telescopes

Fluorescence detector Array of Single-pixel Telescopes

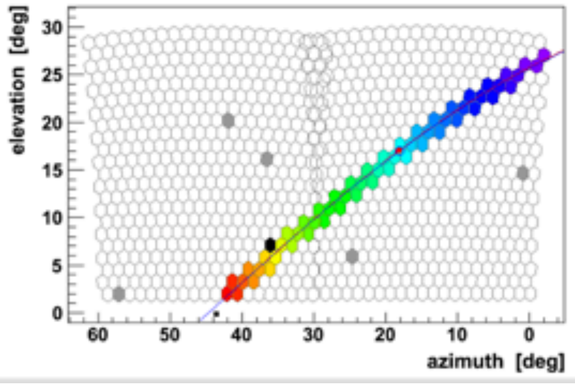
- **Target : > $10^{19.5}$ eV, ultra-high energy cosmic rays (UHECR) and neutral particles**
- **Huge target volume ⇒ Fluorescence detector array**

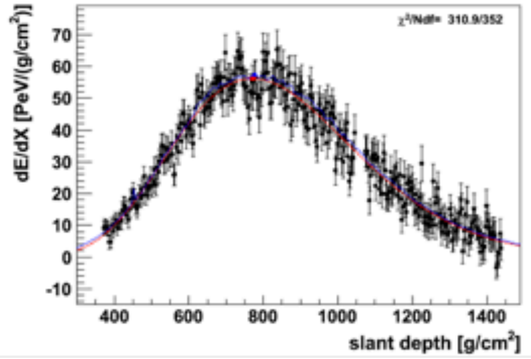
Fine pixelated camera



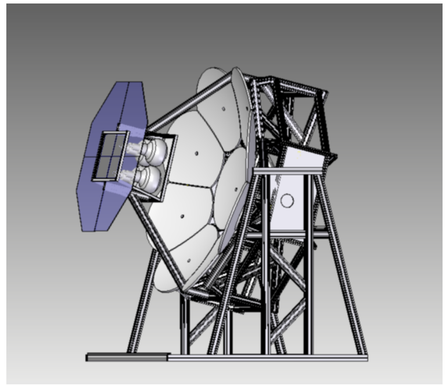


Too expensive to cover a huge area

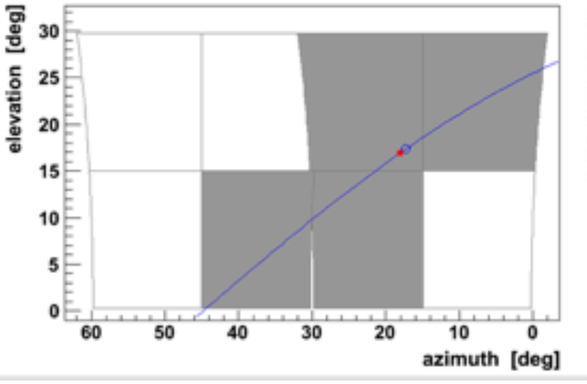


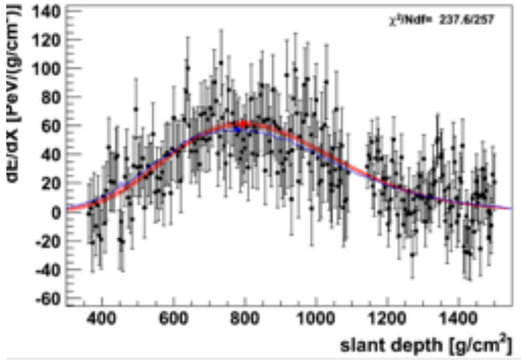


Single or few pixels and smaller optics



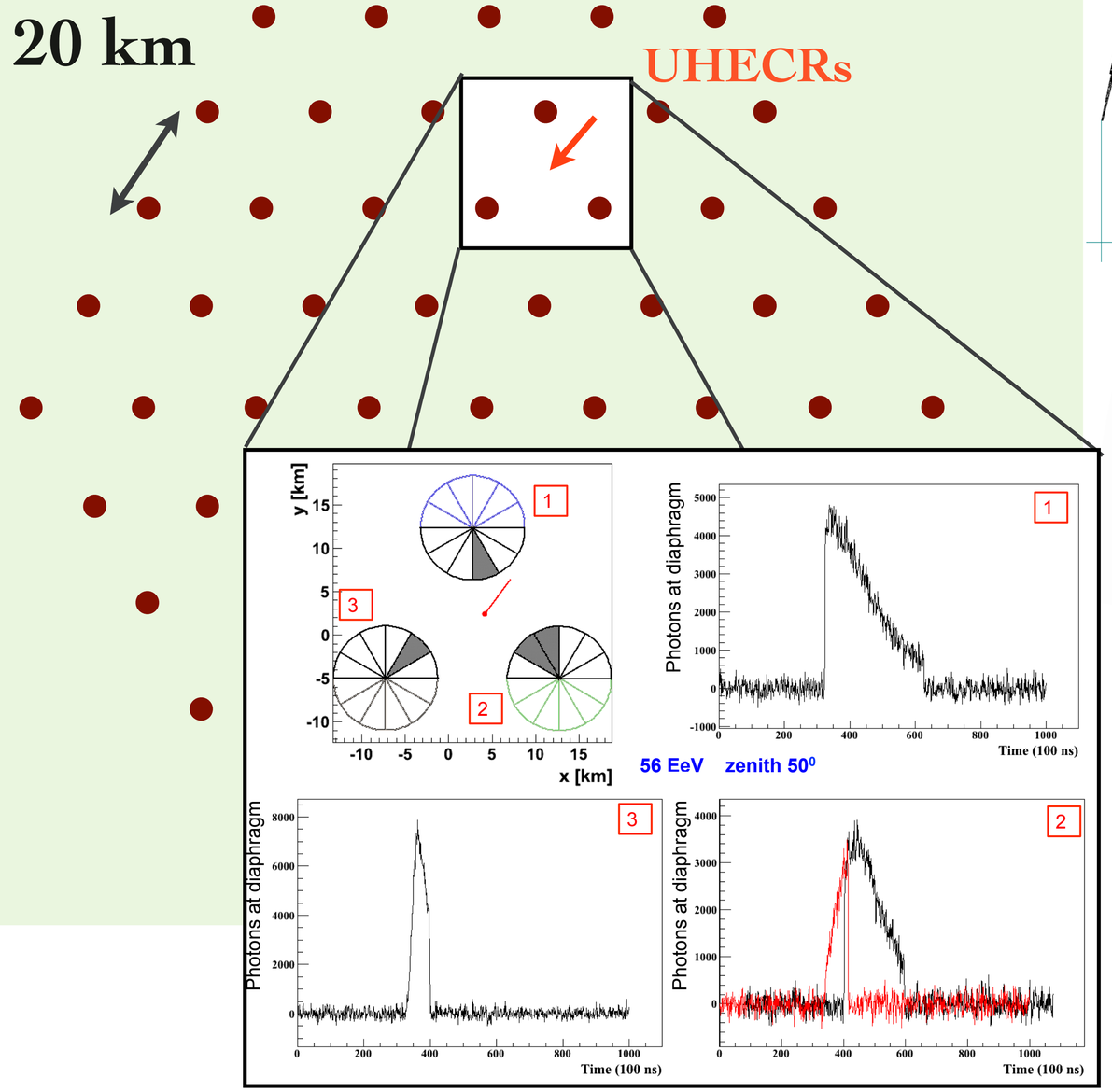
Low-cost and simplified/optimized FD

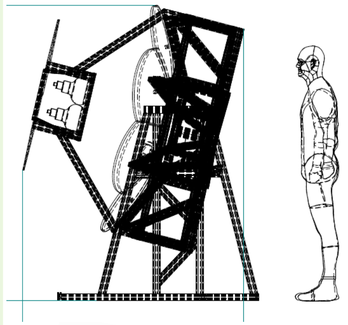


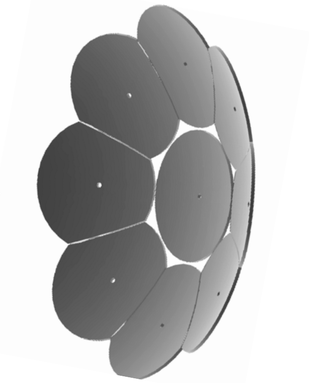


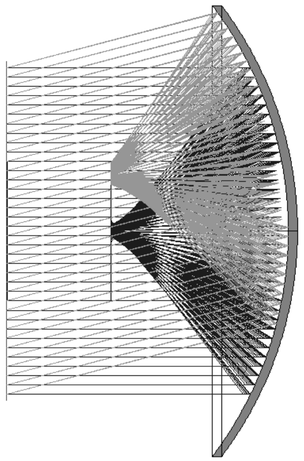
Fluorescence detector Array of Single-pixel Telescopes

Fluorescence detector Array of Single-pixel Telescopes





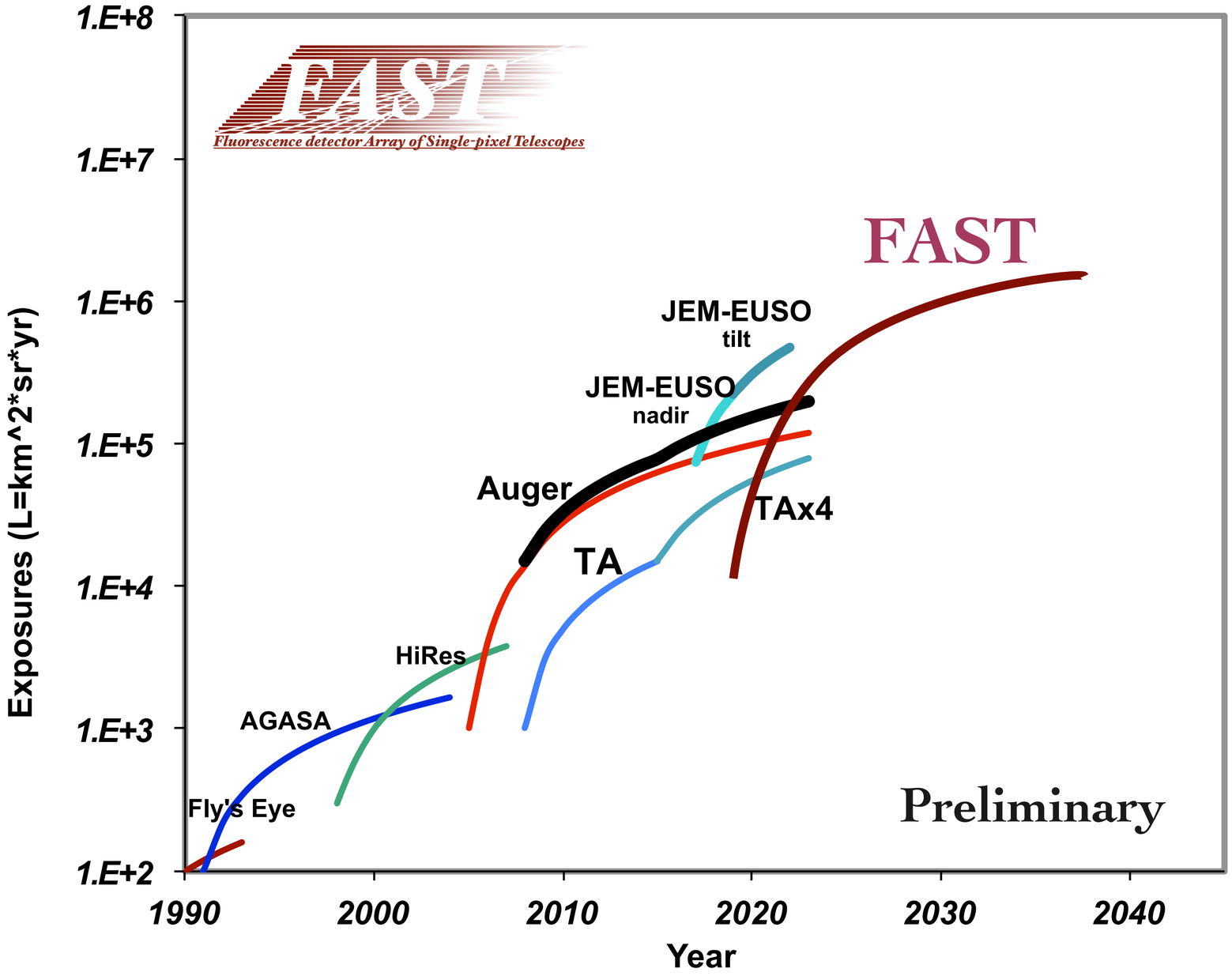




- Each telescope: 4 PMTs, 30°×30° field of view (FoV).
  - **Reference design: 1 m² aperture, 15°×15° FoV per PMT**
- Each station: 12 telescopes, 48 PMTs, 30°×360° FoV.
- Deploy on a triangle grid with **20 km** spacing, like **"Surface Detector Array".**
- If 500 stations are installed, a ground coverage is ~ 150,000 km².
- Geometry: Radio, SD, coincidence of three stations being investigated.

FAST
Fluorescence detector Array of Single-pixel Telescopes

FAST Exposure

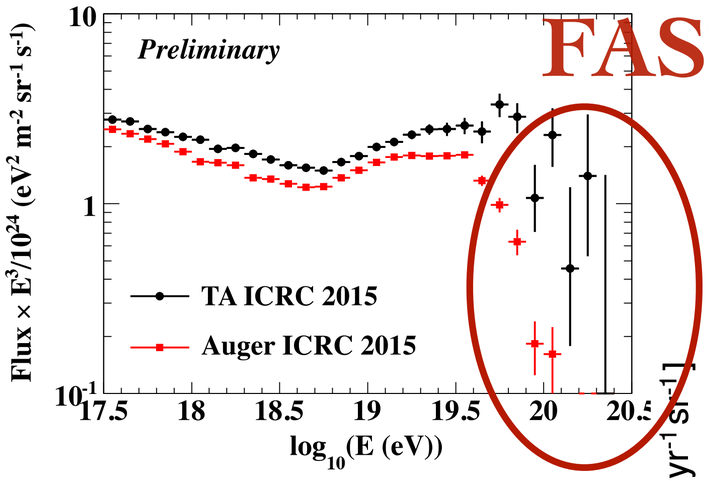


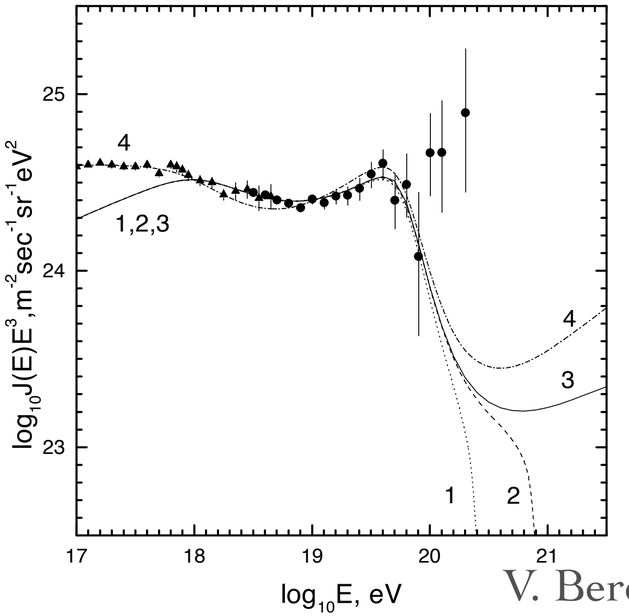
- Conventional operation of FD under 10~15% duty cycle
  - Target: $>10^{19.5}$ eV
- Observation in **moon night** to achieve **25%** duty cycle,
  - Target: **$>10^{19.8}$ eV = Super GZK events (Hotspot/Warmspot)**
    - Test operation in moon night with Auger FD (Radomir Smida).
- Ground area of 150,000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

FAST
Fluorescence detector Array of Single-pixel Telescopes

Physics Target

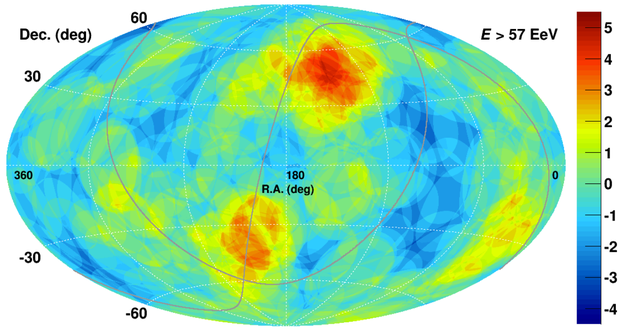
GZK Recovery



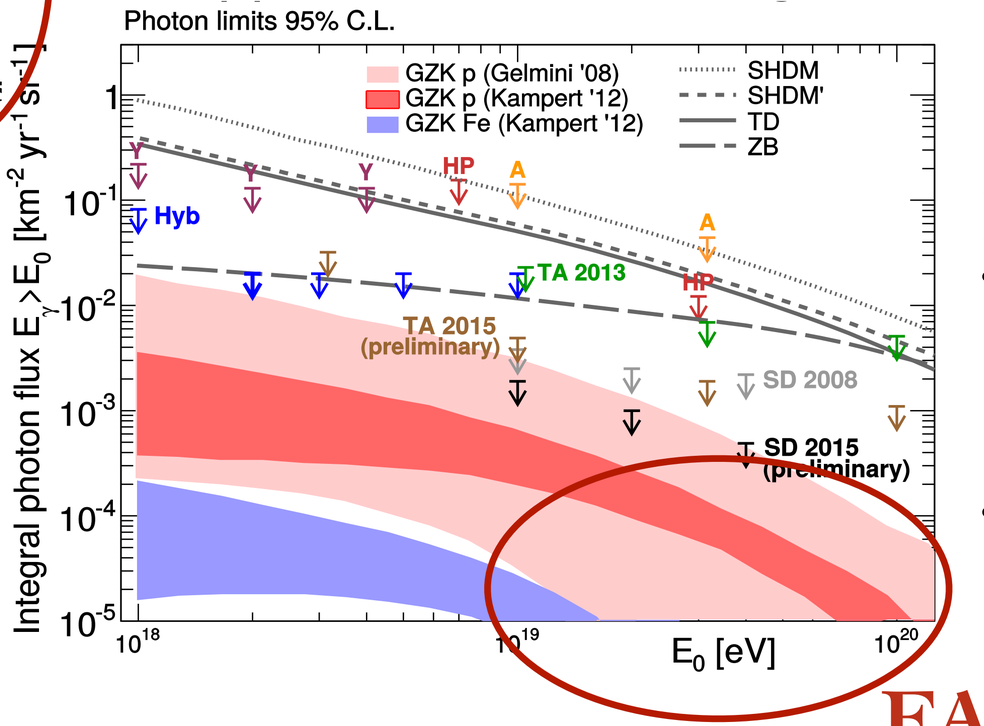


V. Berezinsky et al., (2001)

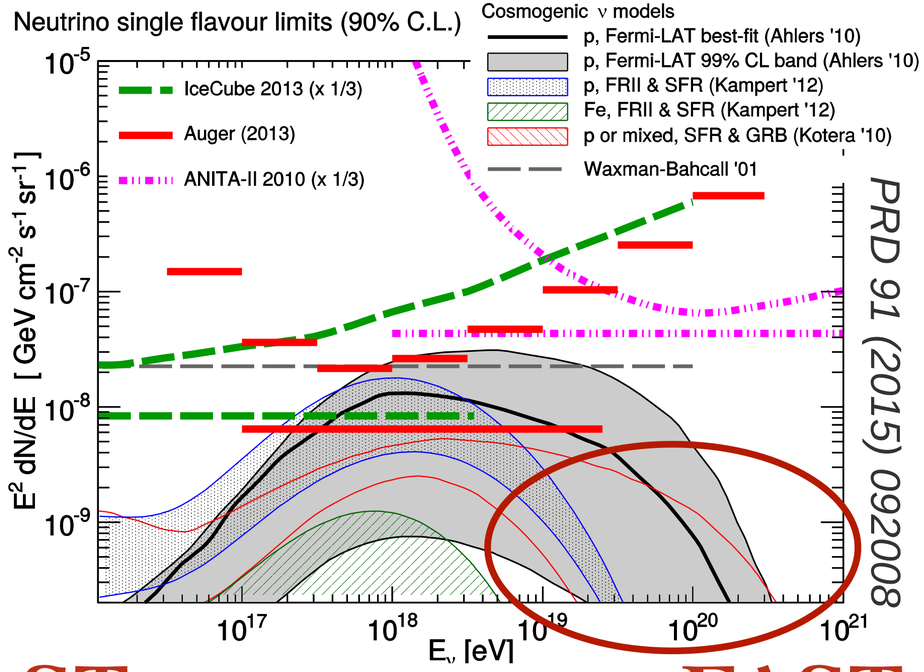
UHECR Anisotropy with ~10x statistics



First detection of UHE photons and neutrinos



FAST

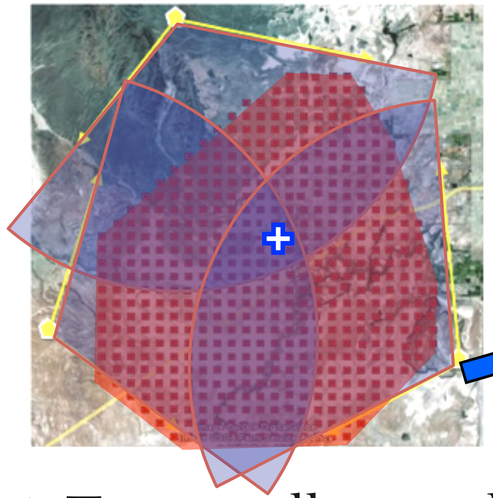


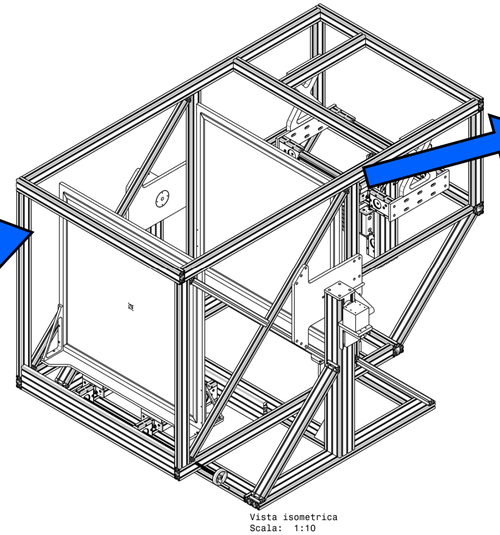
FAST

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)

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2

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4

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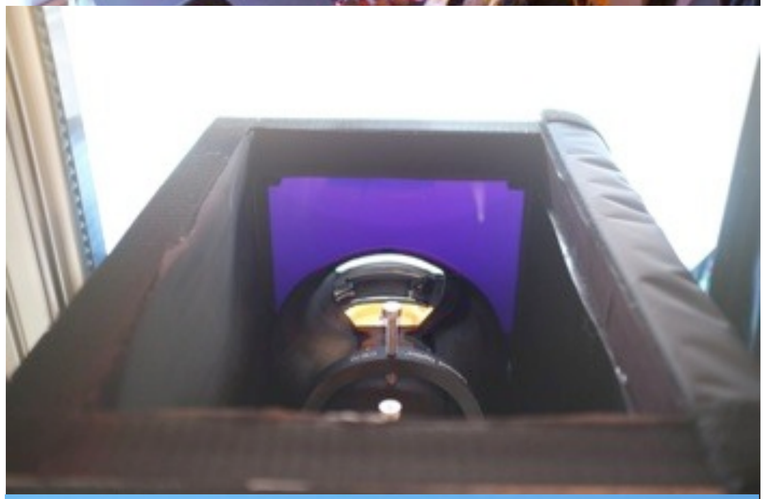

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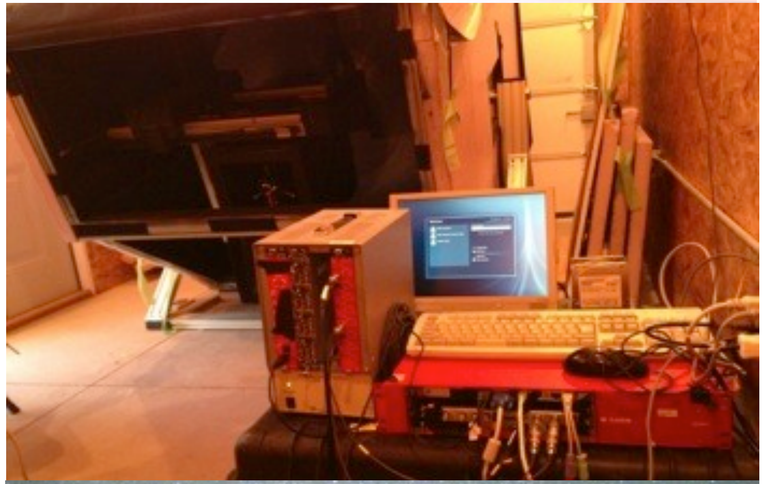

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8

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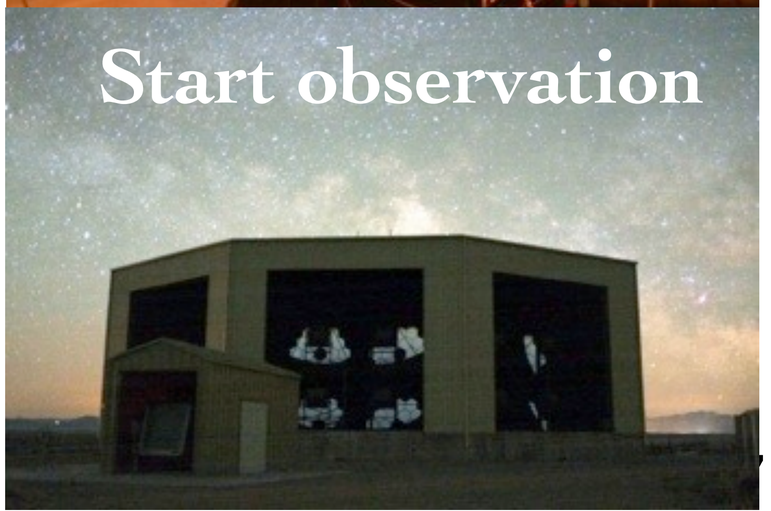
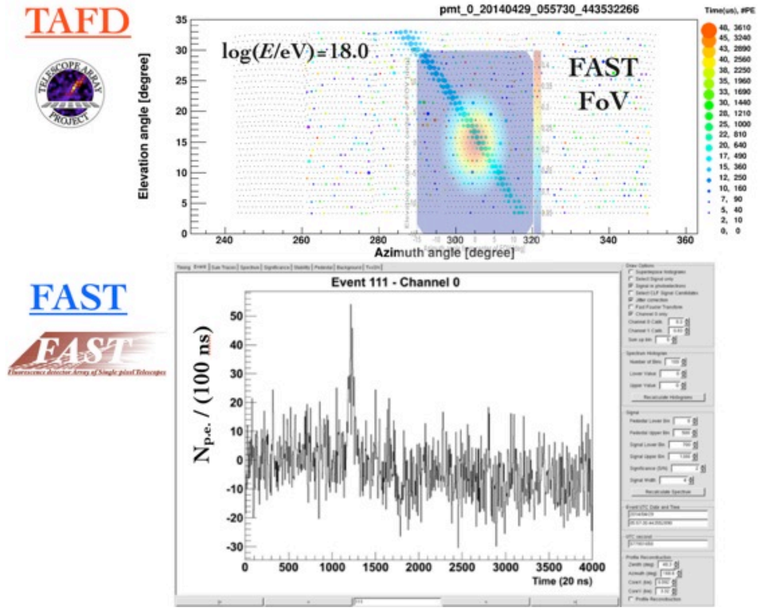
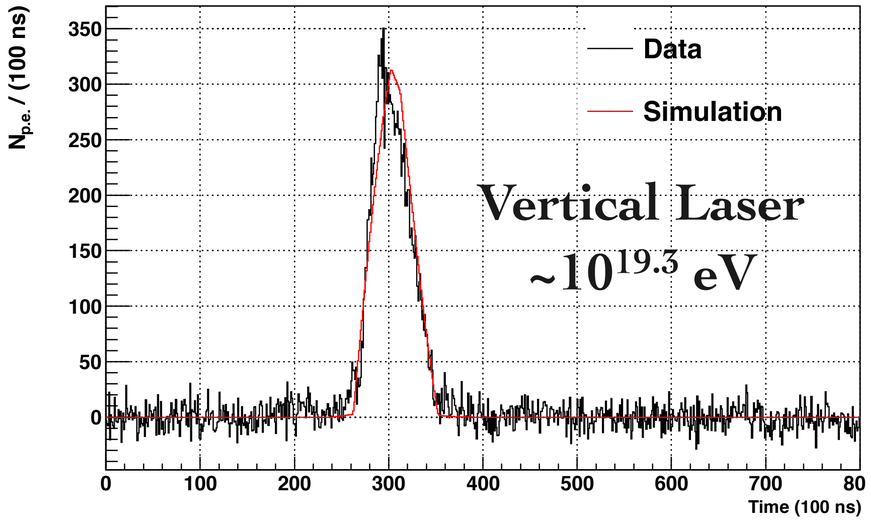
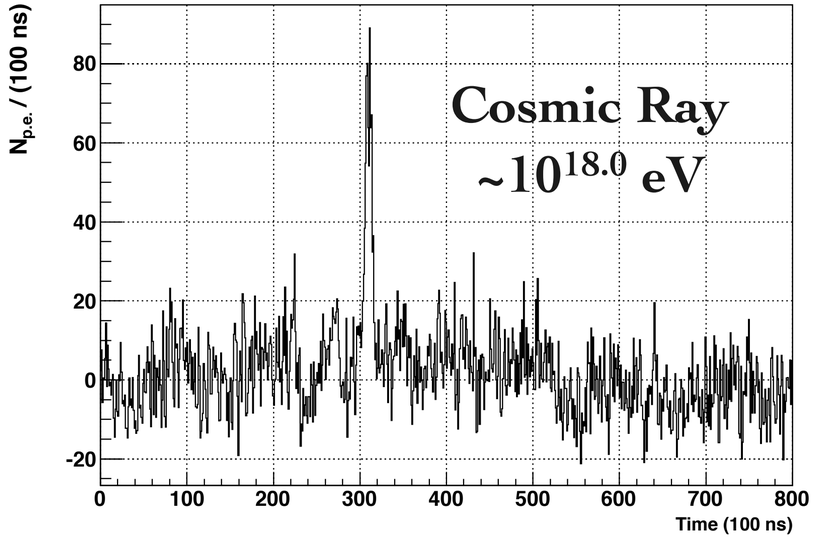


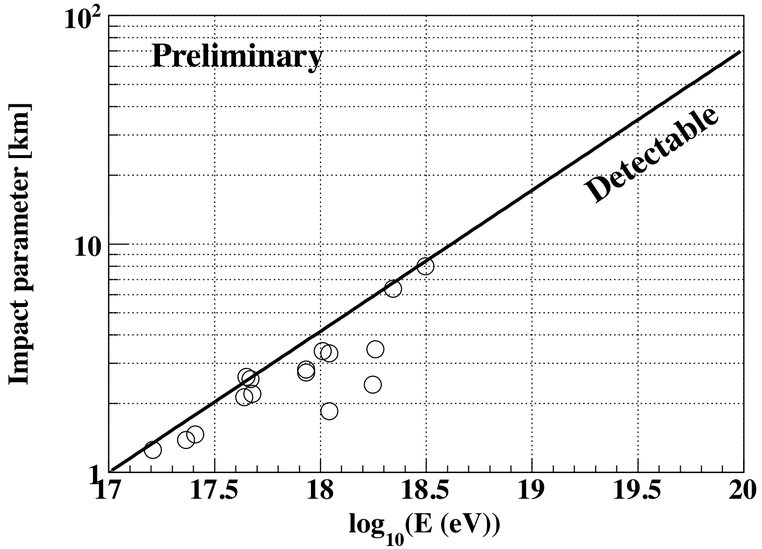
Results on the First Field Observation

- 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.







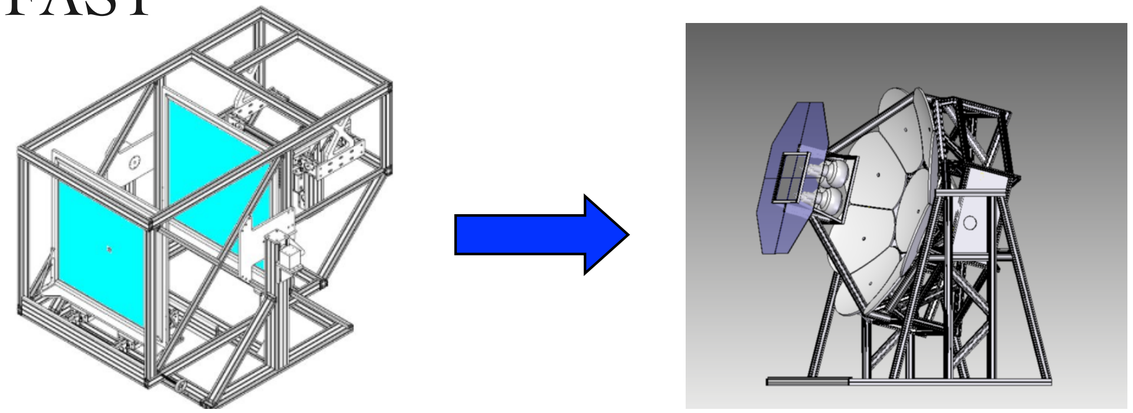


Astroparticle Physics 74 (2016) 64-72, arXiv: 1504.00692

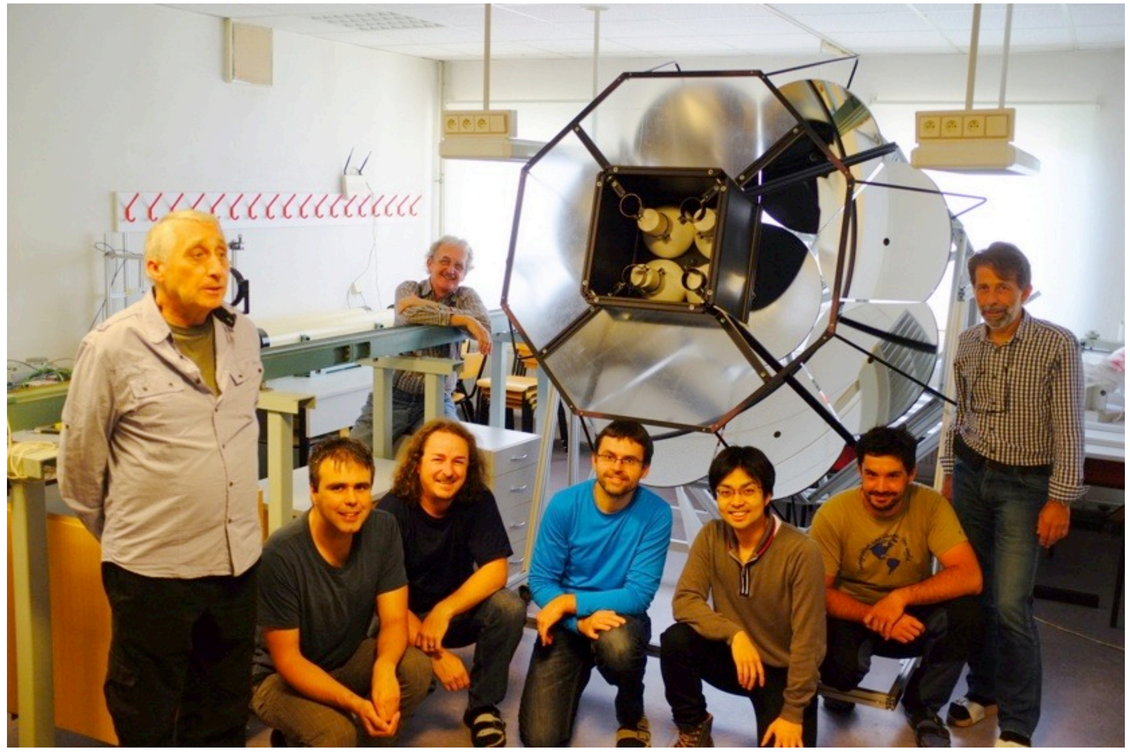
FAST
Fluorescence detector Array of Single-pixel Telescopes

Full-scale FAST Prototype

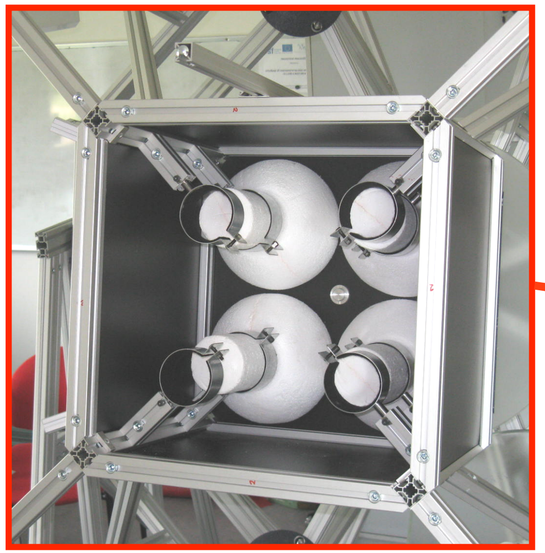
- **Confirmed milestones by EUSO-TA Telescope**
  - Stable operation under high night sky backgrounds.
  - UHECR detection.
- **Next milestones by new full-scale FAST prototype**
  - Establish the FAST sensitivity.
  - Detect a shower profile including ***X*max** with FAST



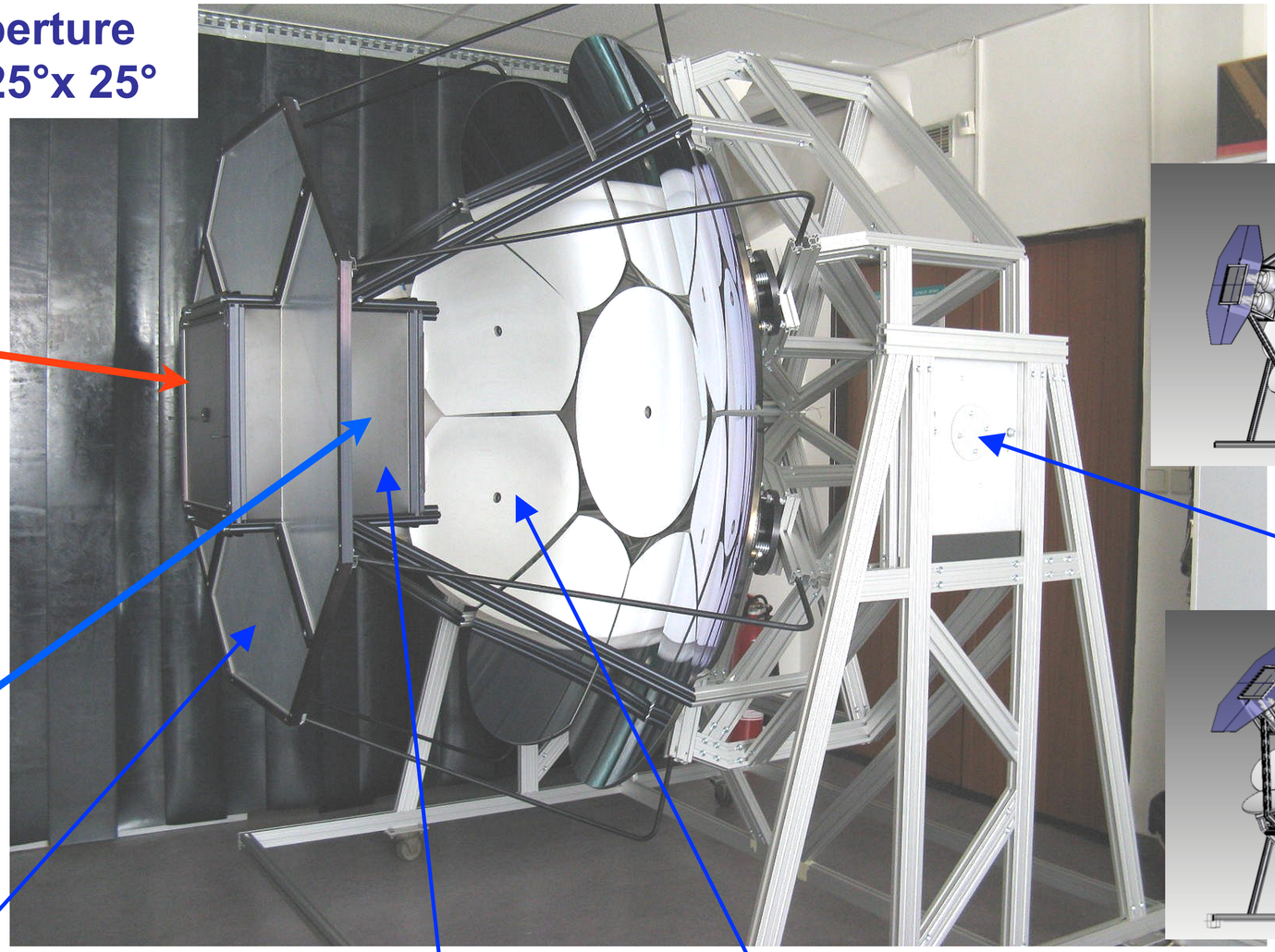
FAST meeting in December 2015
(Olomouc, Czech Republic)

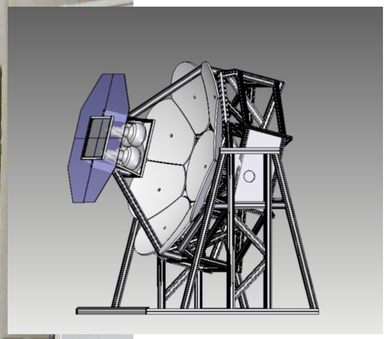


Full-scale FAST Prototype



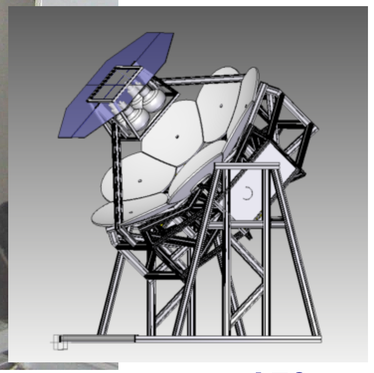
1m^2 aperture
FOV = 25°x 25°





15°

variable tilt



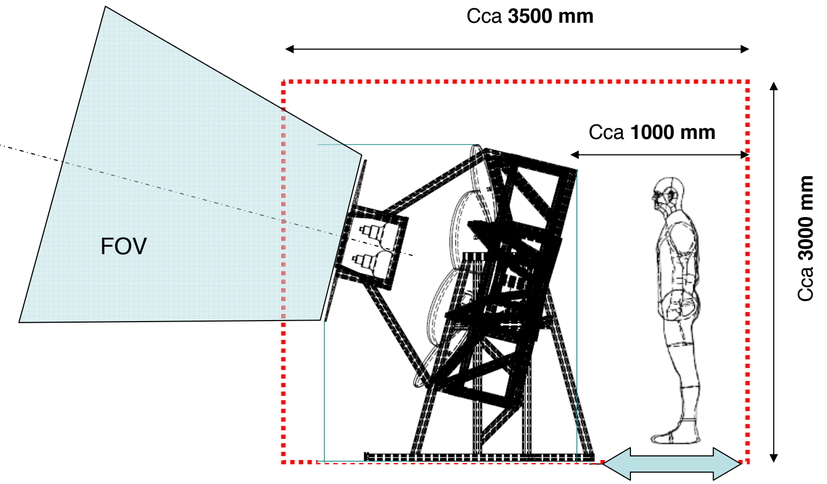
45°

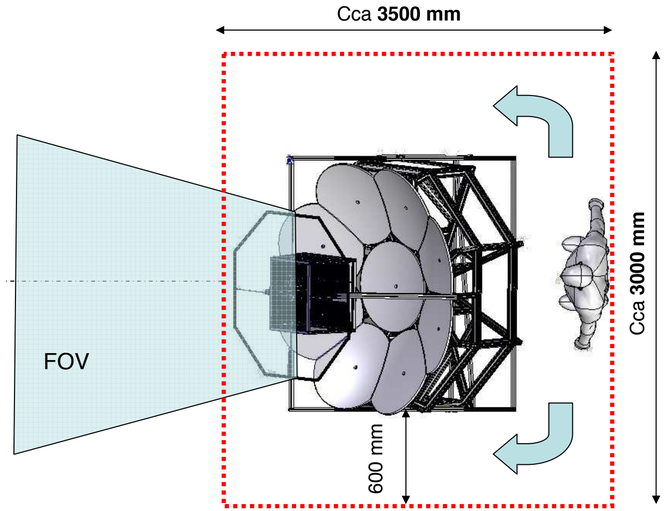
UV Plexiglass

8 inch PMT camera
(2 x 2)

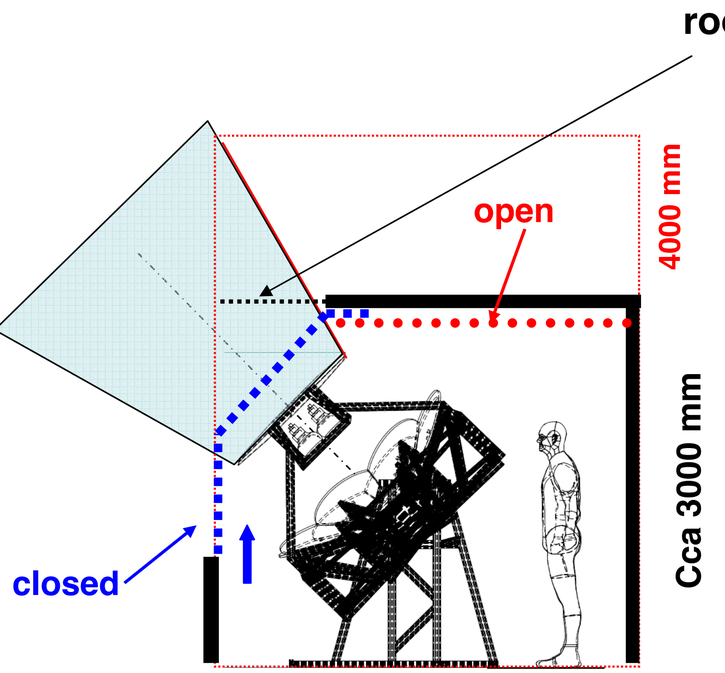
Segmented primary mirror

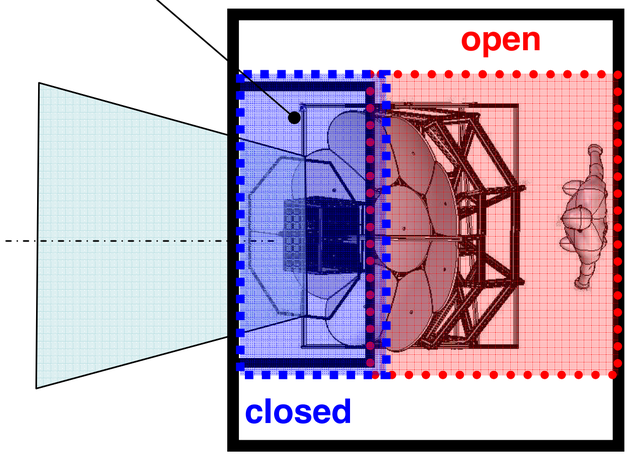
Robust Design of Telescope

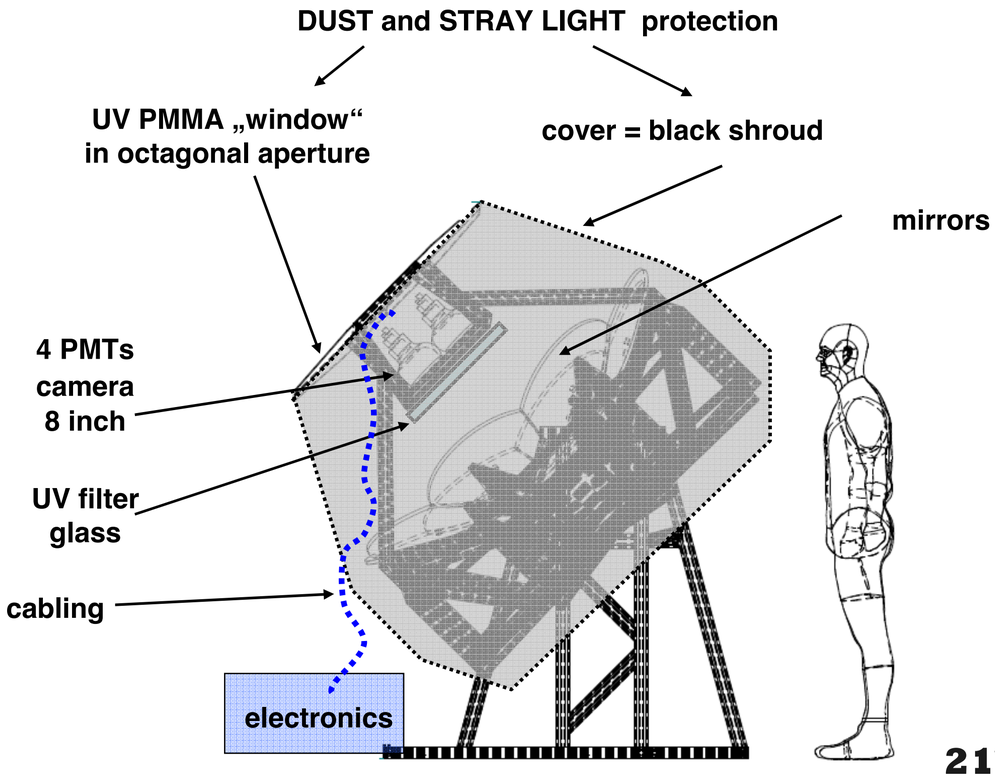




- Robust design for maintenance free and stand-alone observation.
- Adjustable elevation 15° or 45° to enlarge the FoV of the current FD.

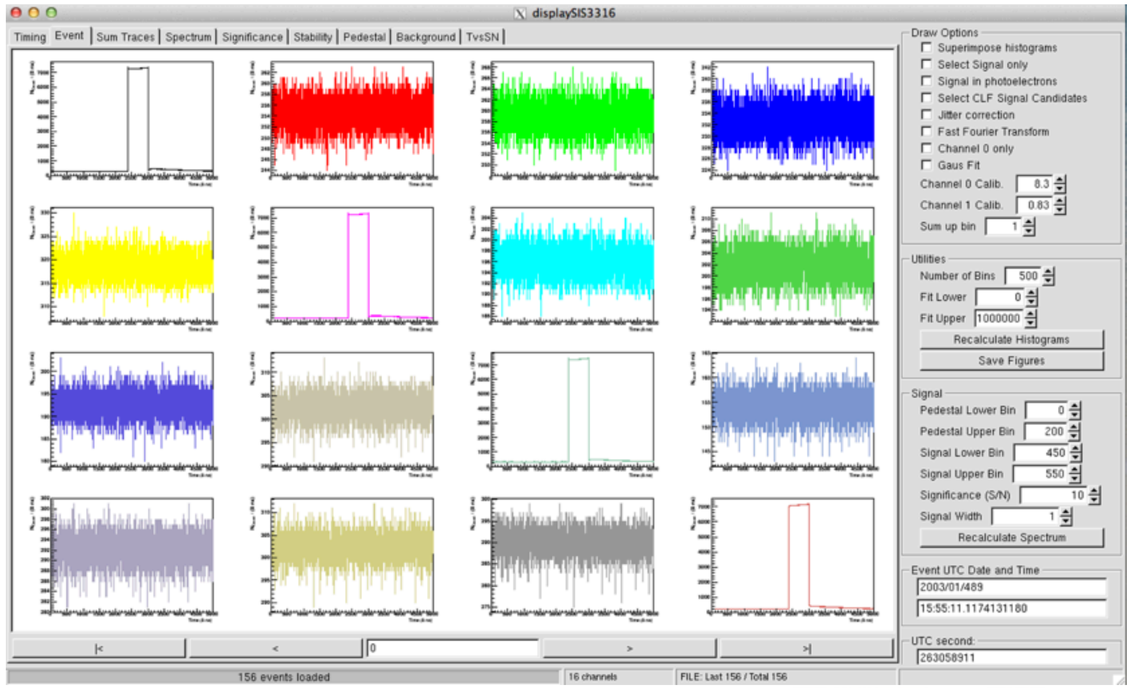






FAST
Fluorescence detector Array of Single-pixel Telescopes

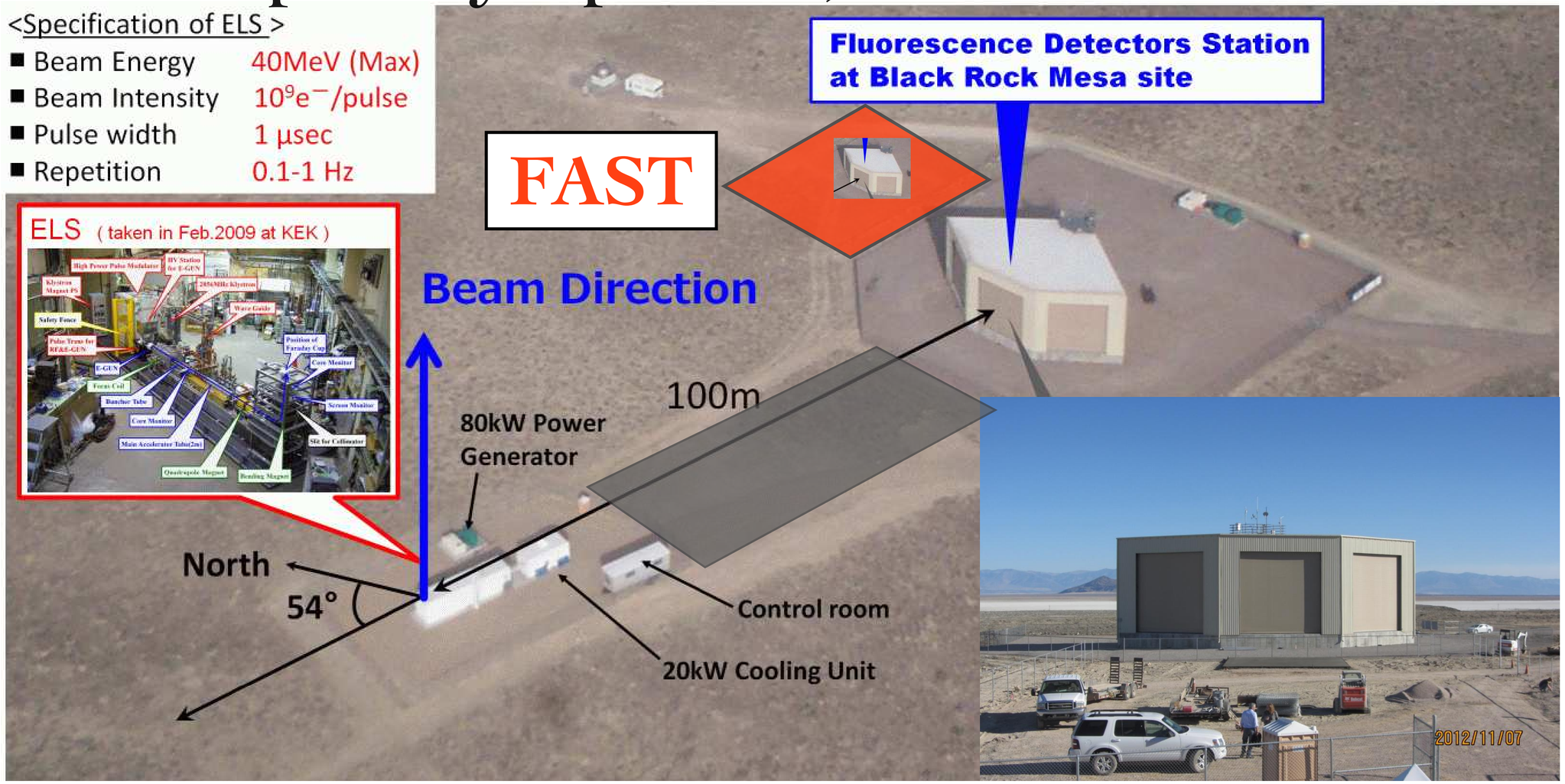
Full-scale FAST Prototype



FAST
Fluorescence detector Array of Single-pixel Telescopes

Concrete pad and hut being constructed

Telescope Array experiment, Black Rock Mesa site

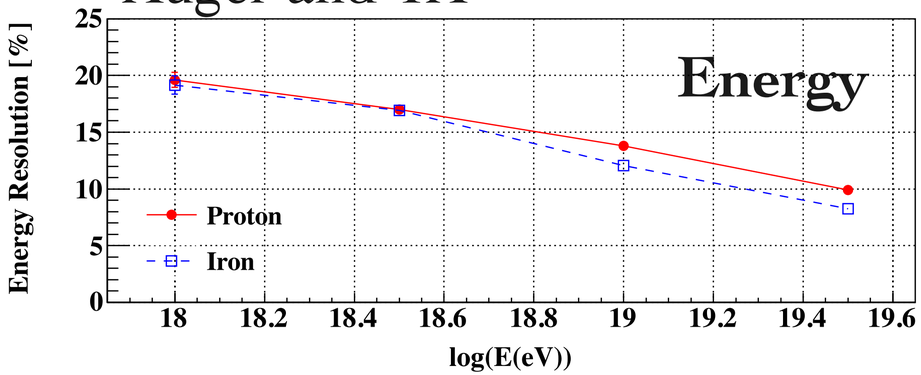


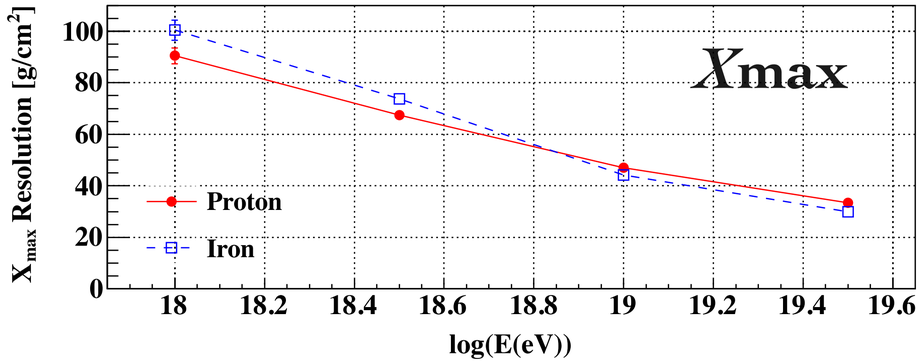
We will plan to install the full-scale FAST telescope in September 2016

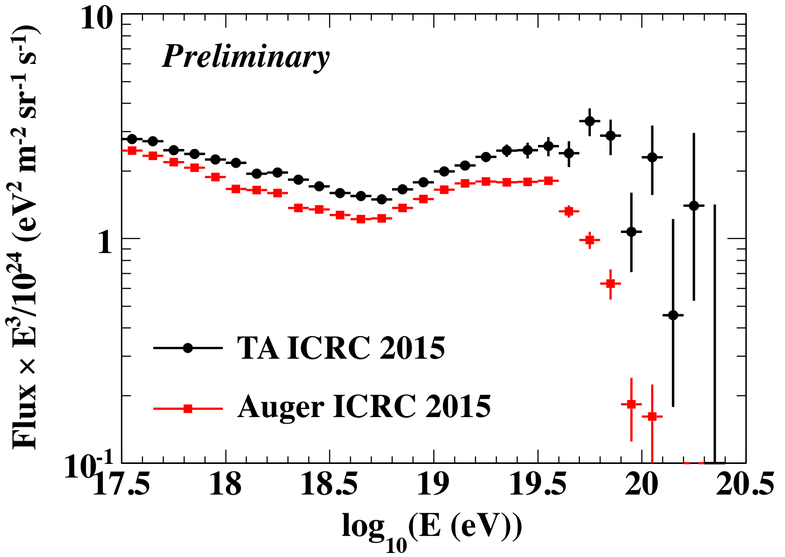
Possible Application of the FAST Prototype

Fluorescence detector Array of Single-pixel Telescopes

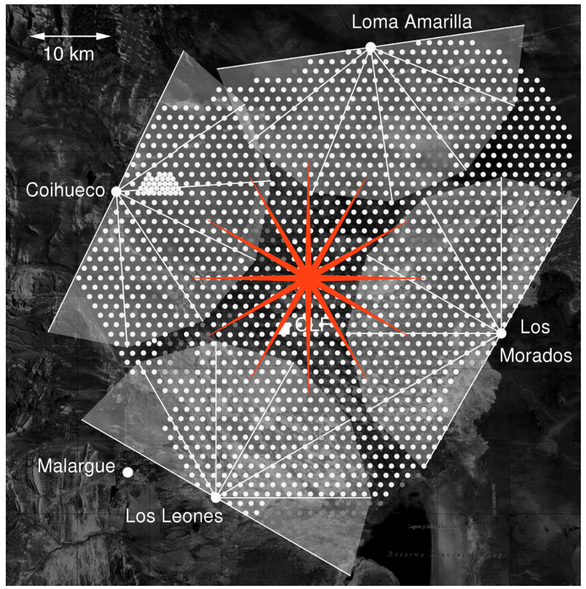
- Install FAST at Auger and TA for a cross calibration.
- Profile reconstruction with geometry given by SD (smearing gaussian width of 1° in direction, 100 m in core location).
  - Energy: 10%, *X*max : 35 g/cm^2 at $10^{19.5}$ eV
  - Independent cross-check of **Energy and *X*max** scale between Auger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





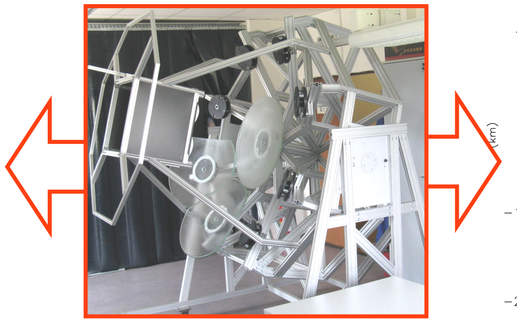


Pierre Auger Observatory

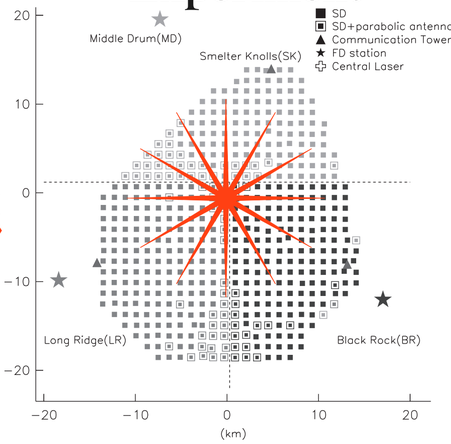


Pierre Auger Collaboration, NIM-A (2010)

Identical simplified FD



Telescope Array Experiment



Telescope Array Collaboration NIM-A (2012)

Summary and Future Prospects

- On-going upgrades of UHECR Observatories
  - TA×4: 3,000 km^2 area equivalent with Auger
  - AugerPrime: 3,000 km^2 area, mass composition sensitive measurement by water tank + scintillator
- Next-generation observatories
  - JEM-EUSO
    - ~30,000 km^2 from the space, R&D tasks: EUSO-TA, EUSO-Balloon, Mini-EUSO, EUSO-SPB, K-EUSO
  - Fluorescence detector Array of Single-pixel Telescopes (FAST)
    - Deploy the economical fluorescence detector array, UHECRs and neutral particles with ~30,000 km^2 on the ground

Advertisement : UHECR2016

International Advisory Committee:

S.W. Barwick, V.S. Berezinsky, P. Blasi, T. Ebisuzaki,

R. Engel, P.L. Ghia, F.L. Halzen, Y. Itow,

K.-H.Kampert(Chair), P. Lipari, K. Makishima,

S. Ogio, A.V. Olinto, M.I. Panasyuk, I.H. Park,

P. Picozza, P. Privitera, D. Ryu, H. Sagawa, P. Sokolsky,

R. Yamazaki

Local Organization Committee:

Y. Kawasaki, K. Kawata, S. Nagataki,

T. Nonaka,S. Ogio(Secretary), H. Sagawa(Chair), T. Sako,

M. Takeda, Y. Tsunesada, S. Udo, T. Yamamoto

Starts 11 Oct 2016 08:00
Ends 14 Oct 2016 18:00
Japan

October 11-14
@ Kyoto, Japan

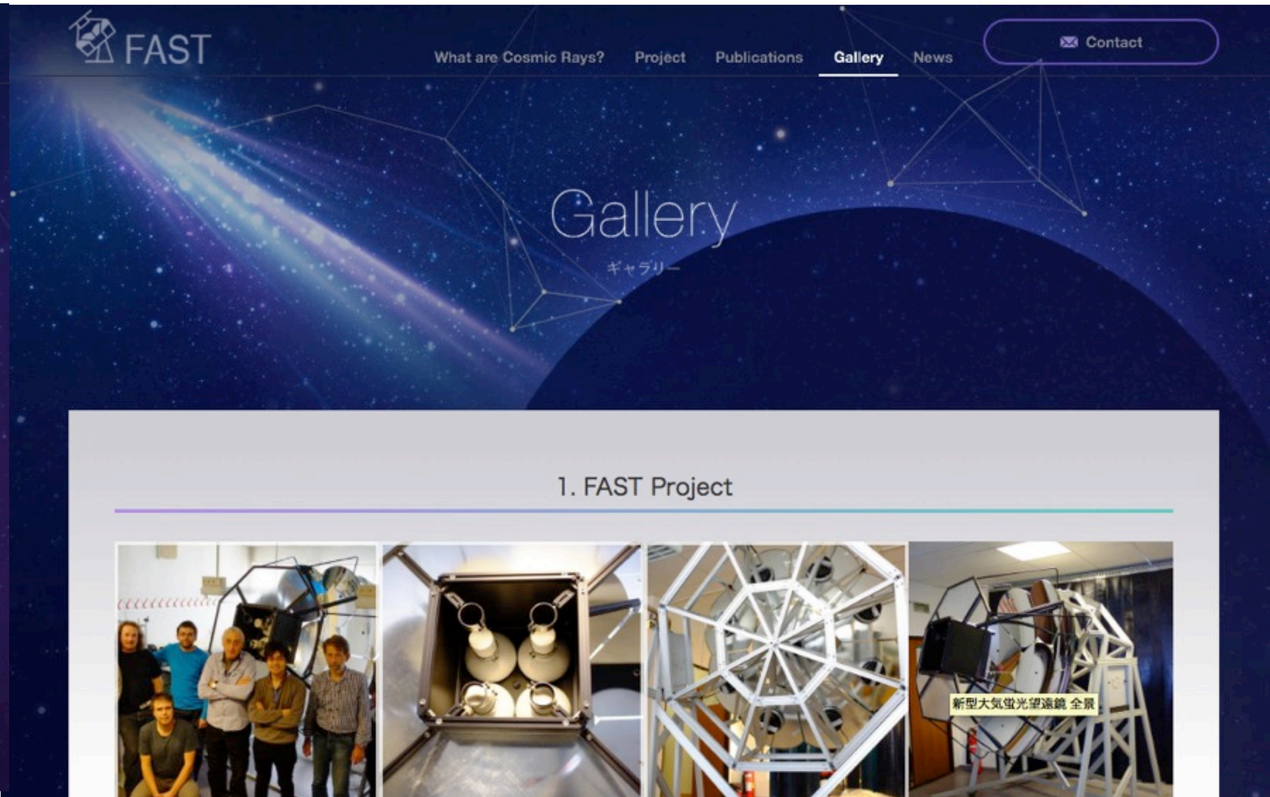
https://indico.cern.ch/event/504078/

Backup

Fluorescence detector Array of Single-pixel Telescopes

FAST
Fluorescence detector Array of Single-pixel Telescopes

FAST Webpage



FAST
Fluorescence detector Array of Single-pixel Telescopes

FAST

FAST

FAST
Fluorescence detector Array of Single-pixel Telescopes

http://www.fast-project.org


FAST
地中海
チュニジア
シリア
レバノン
イラク
イラン
イスラエル
モロッコ
アルジェリア
リビア
エジプト
西サハラ
ペルシャ湾
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الرياض
アラブ首長国連邦
サウジアラビア
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ニジェール
ダカール
Dakar
セネガル
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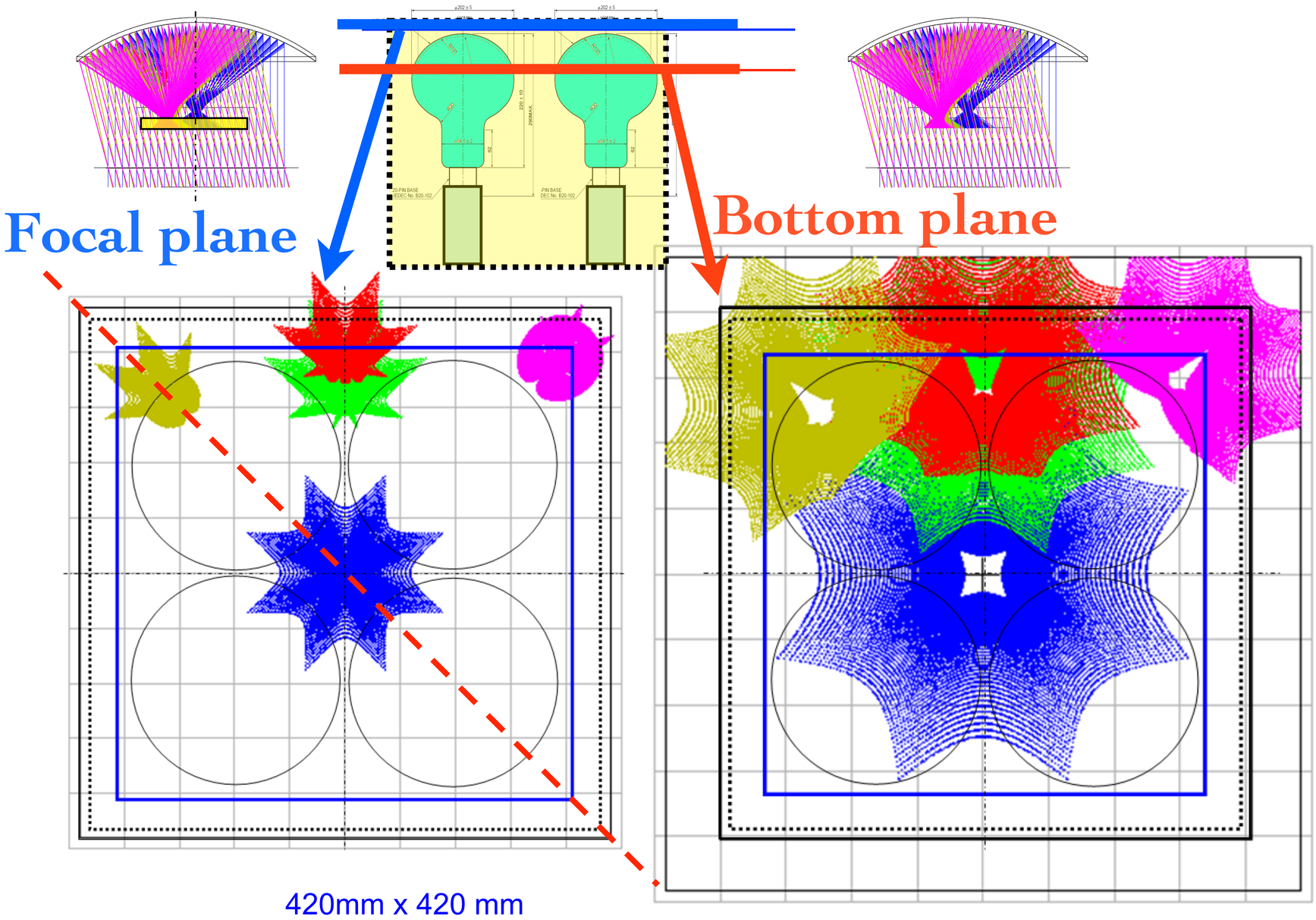
利用規約
プライバシー
フィードバックの送信
1000 km

EAST
Fluorescence detector Array of Single-pixel Telescopes

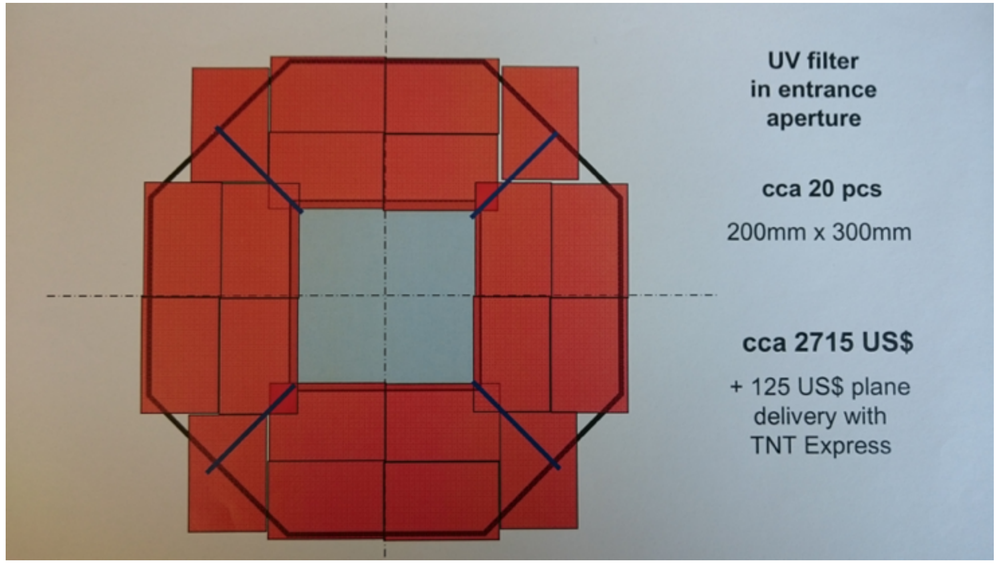
“Easy” to Change Elevation

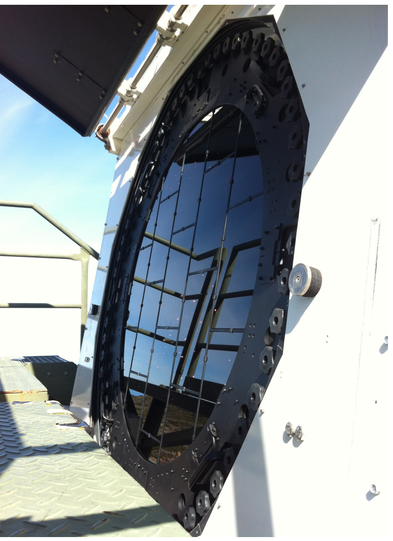
Ray-Trace Simulation

- 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.

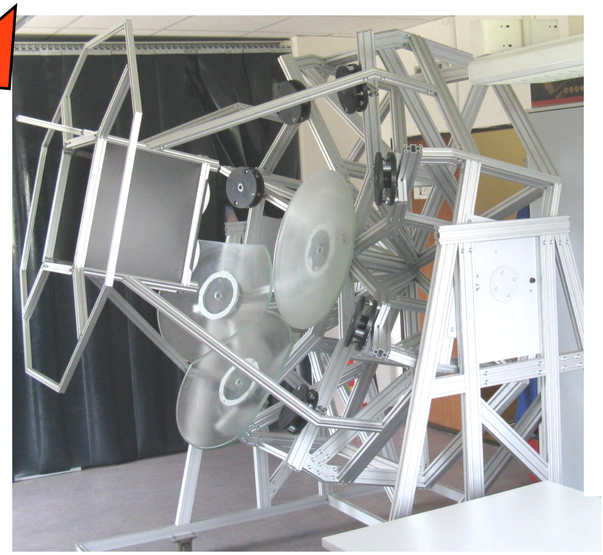


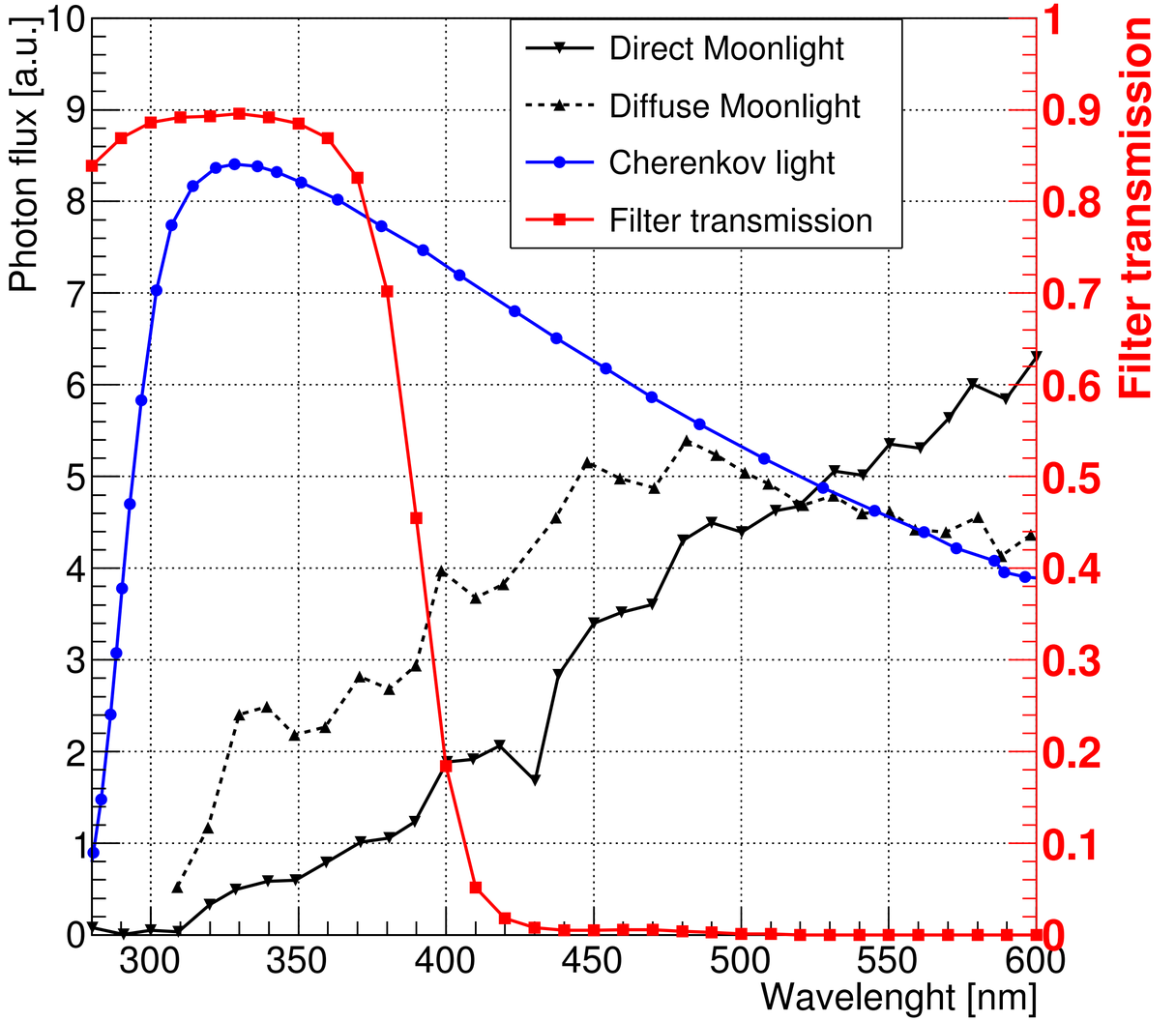
UV Band-pass Filter





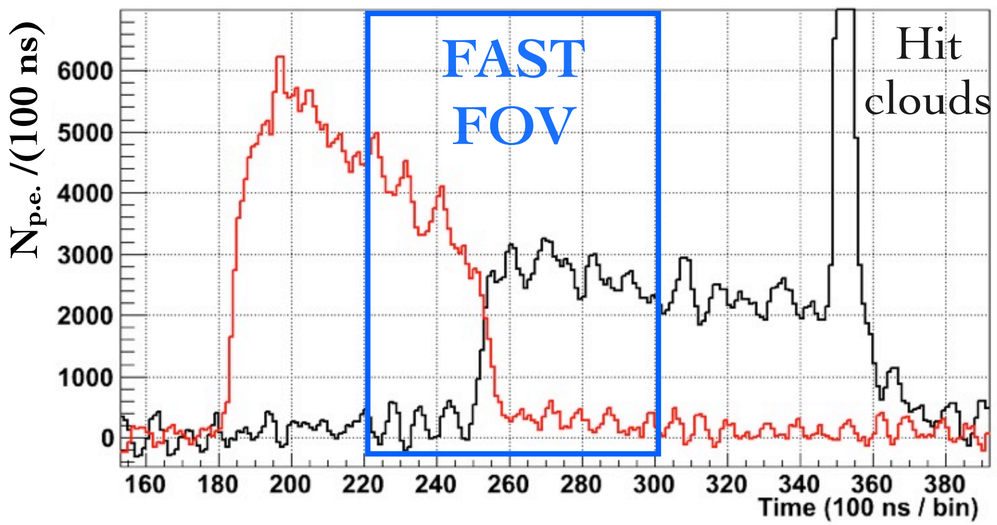
UV band pass filter used in MAGIC



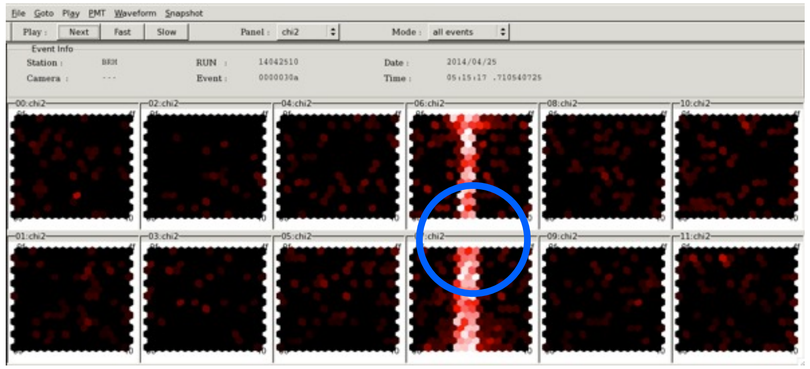


http://arxiv.org/pdf/1509.02048v2.pdf

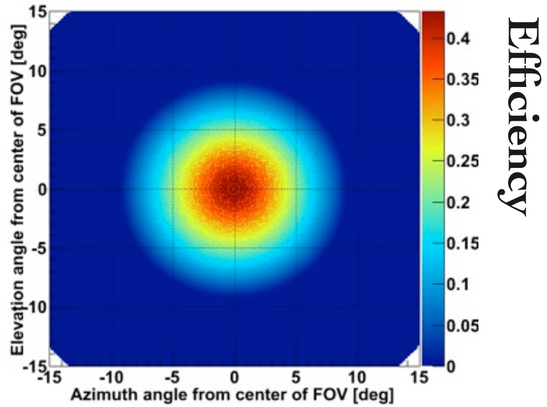
Laser Signal to Check Performance

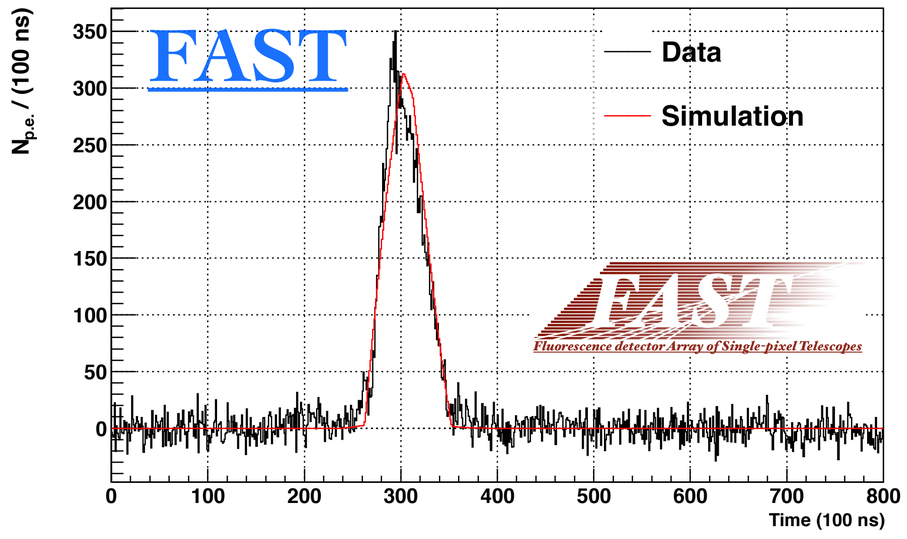


TAFD



Directional sensitivity by RayTrace of EUSO-TA telescope

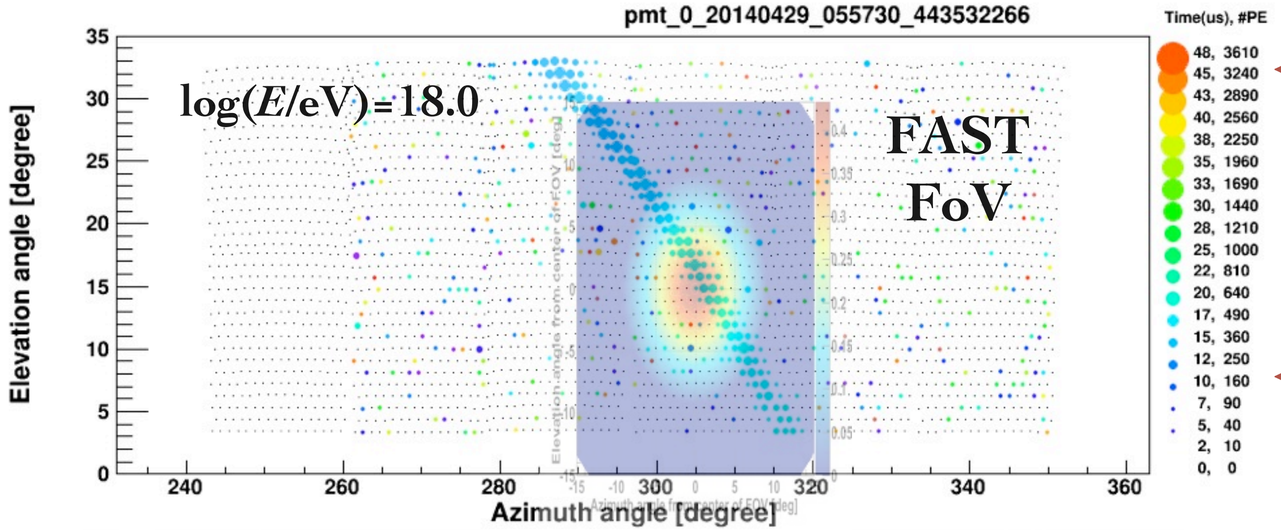




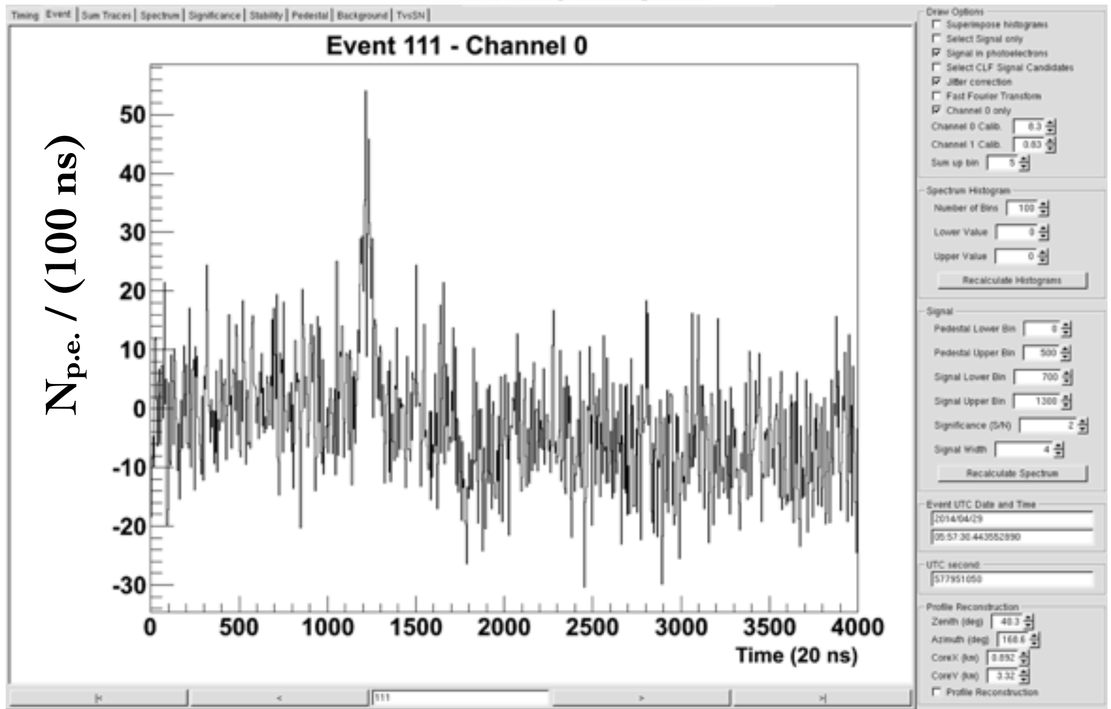
- Vertical Ultra-Violet laser at 6 km from FAST ≒ ~$10^{19.2}$ eV
- Expected signal TAFD/FAST: (7 m^2 aperture × 0.7 shadow × 0.9 mirror) / (1 m^2 aperture × 0.43 optics efficiency) ~10
  - TAFD Peak signal : ~3000 p.e. / 100 ns
  - FAST Peak signal : ~300 p.e. / 100 ns. All shots are detected significantly.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

UHECR Signal Search

TAFD



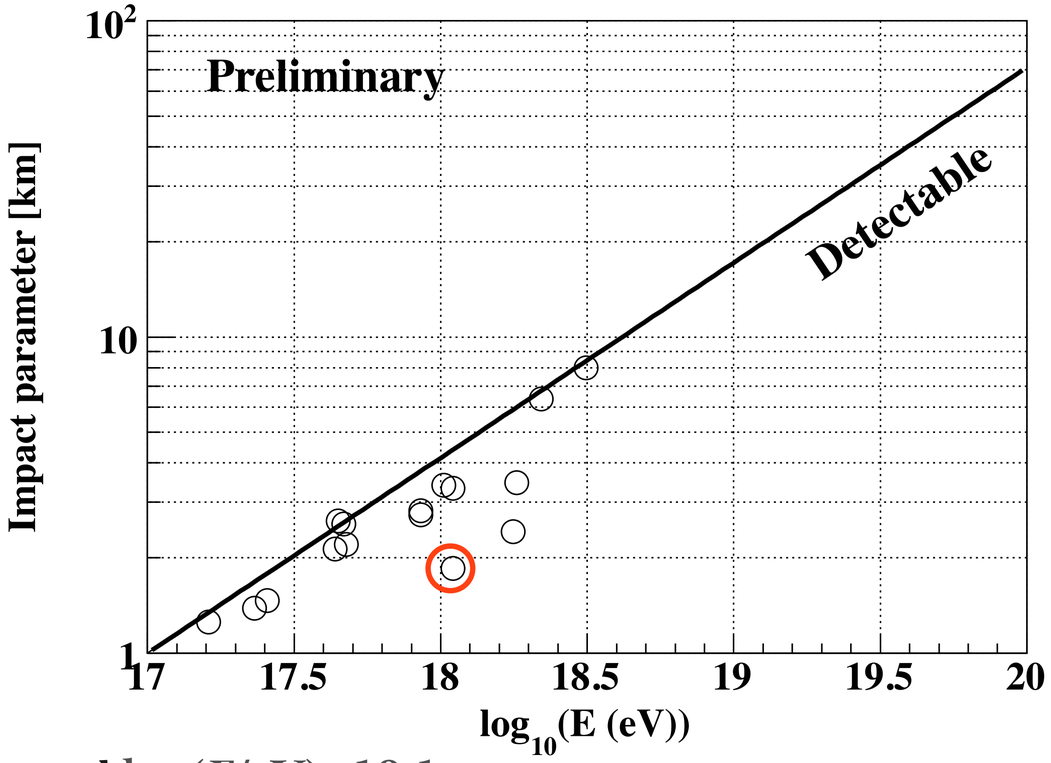
FAST

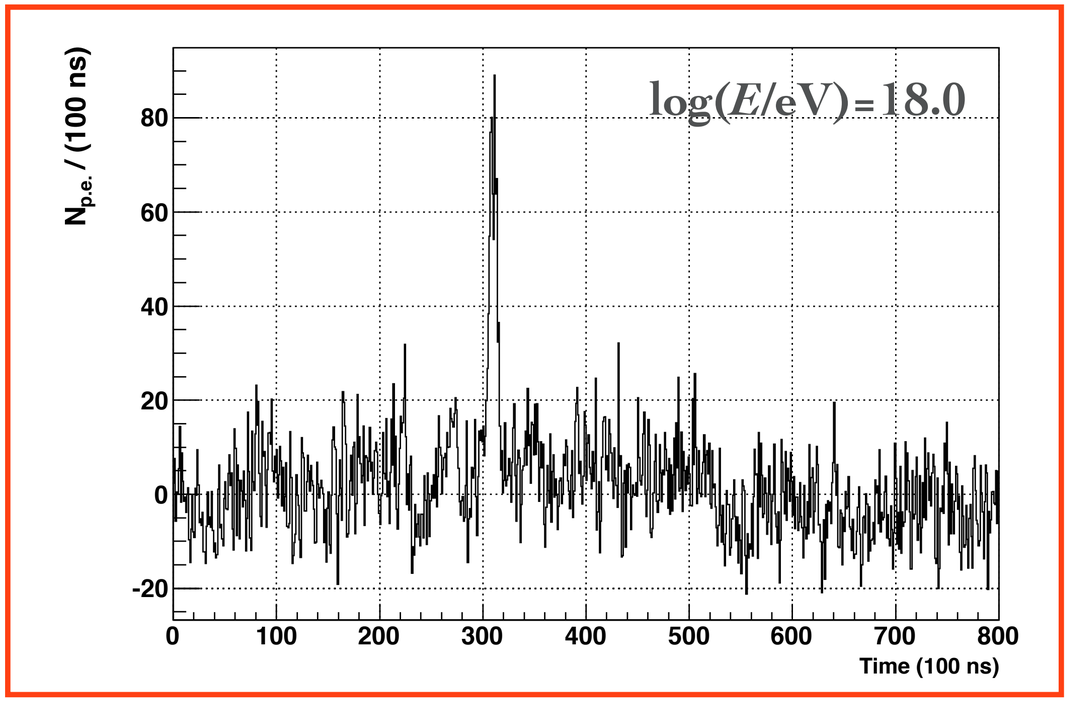


- Data set: April and June 2014 observation, 19 days, 83 hours.
  - Stable observation.
- We searched for UHECR signal in coincidence between FAST and TAFD.
  1. Search for TAFD signal crossing the field of view (FoV) with FAST.
  2. Search for a significant signal (>5σ) with FAST waveform at the same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

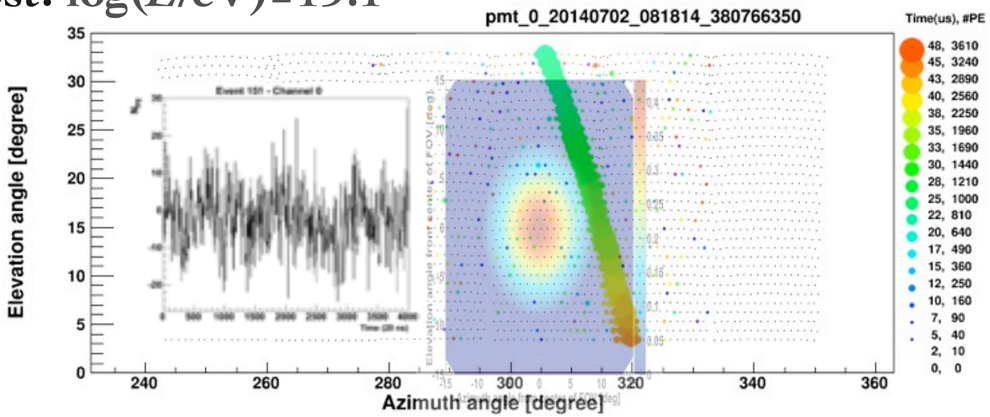
Distance vs Energy (from TAFD) for Candidates

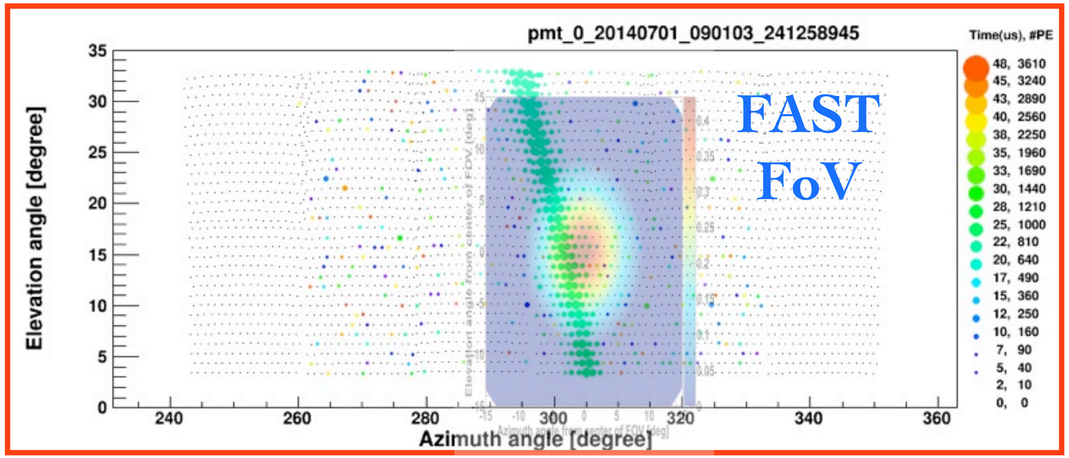
Fluorescence detector Array of Single-pixel Telescopes



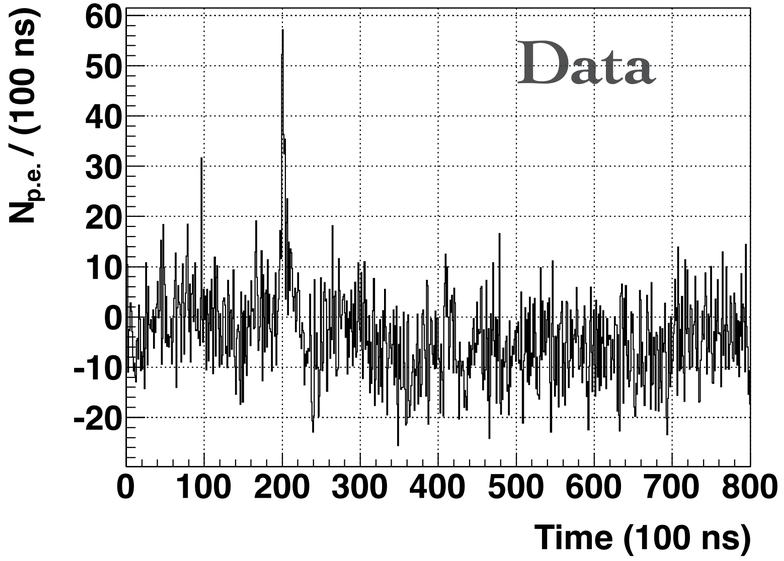


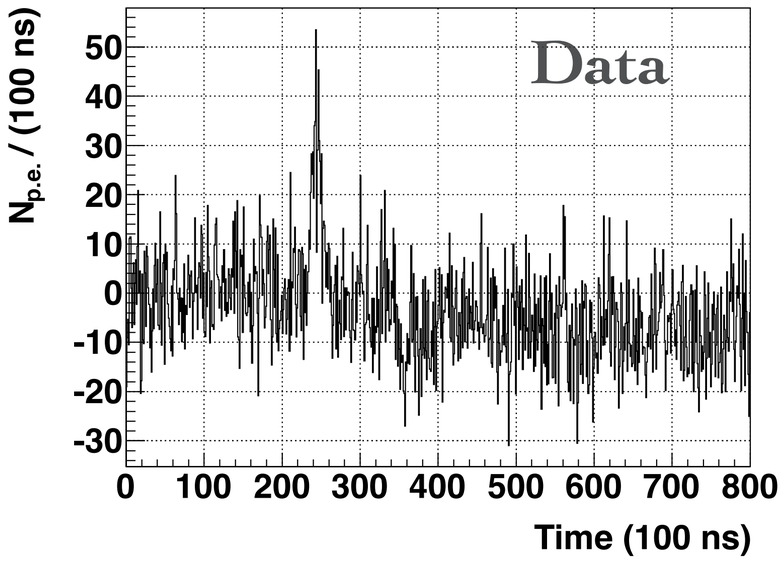
Almost! log(*E*/eV)=19.1

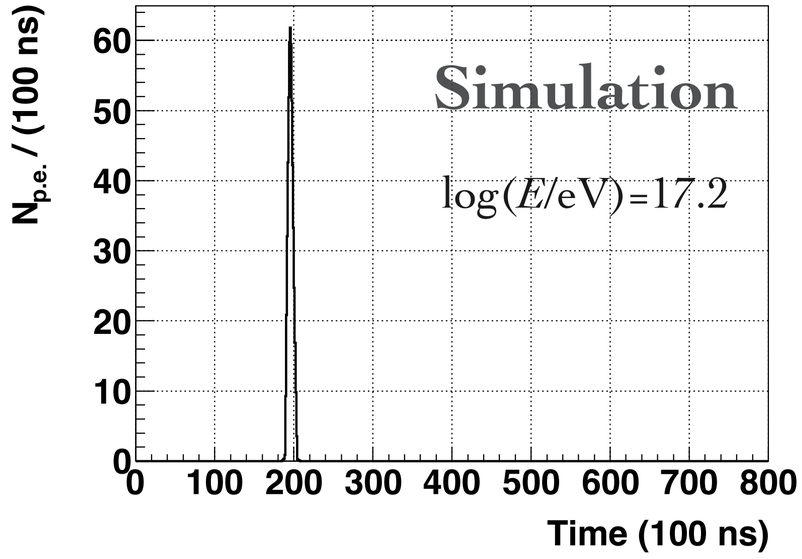


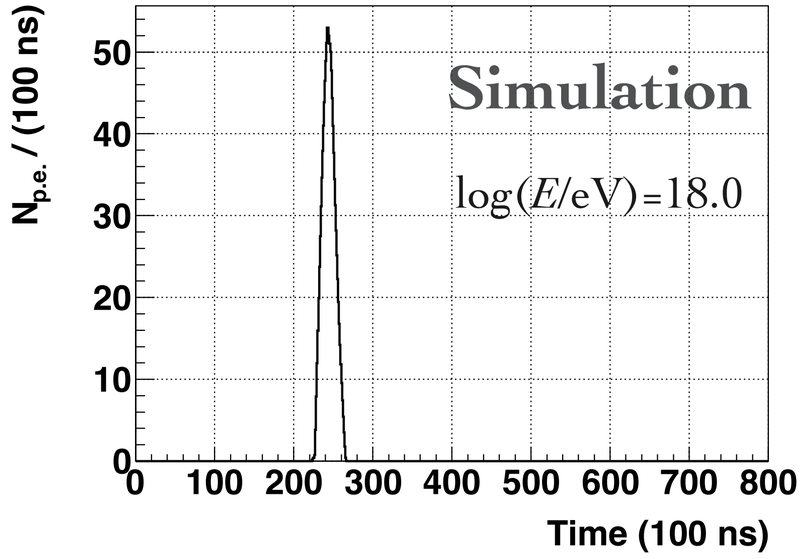


Comparison to Expected Signal from UHECRs





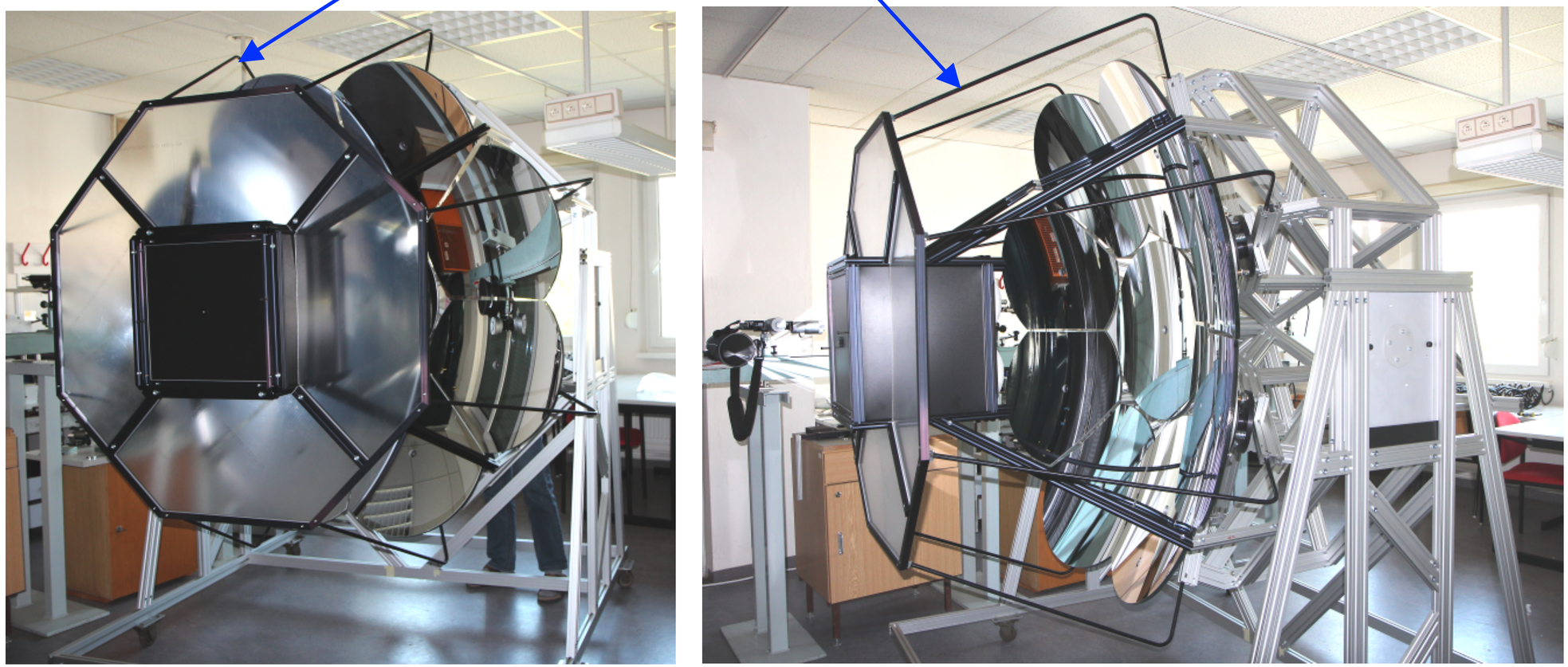




- Geometry, Energy and *X*max was reconstructed by the TAFD monocular analysis.
- Based on these information, we calculate expected signal by FAST prototype.
- Size, shape and width are consistent with expectation.
  - A signal location is fluctuated within the TAFD trigger frame of 12.8 μs.

Robust Design for Long Term Operation

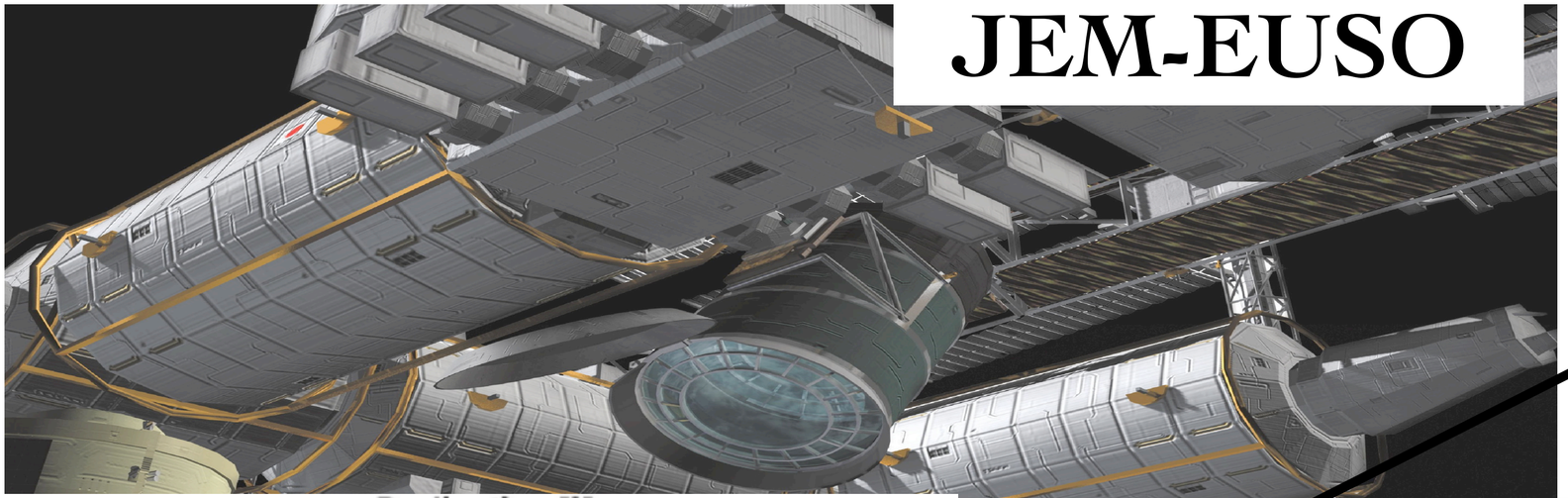
frame for dark shroud (DUST and STRAY LIGHT protection)



horizontal parking position
(testing of opto-mechanical construction)

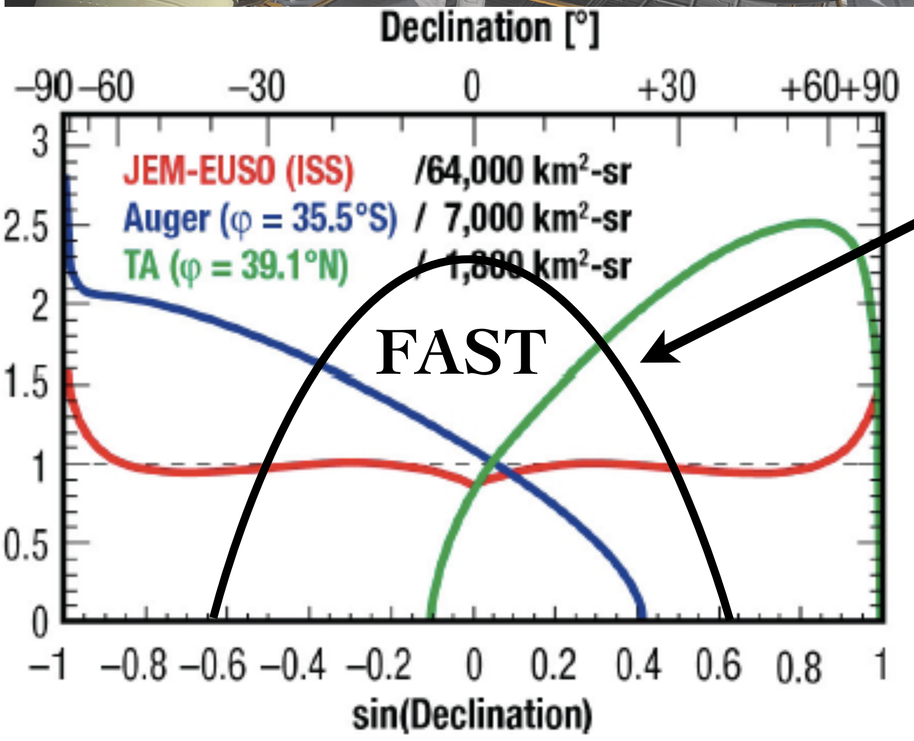
Hut for FAST (3 telescopes)

Site Candidates



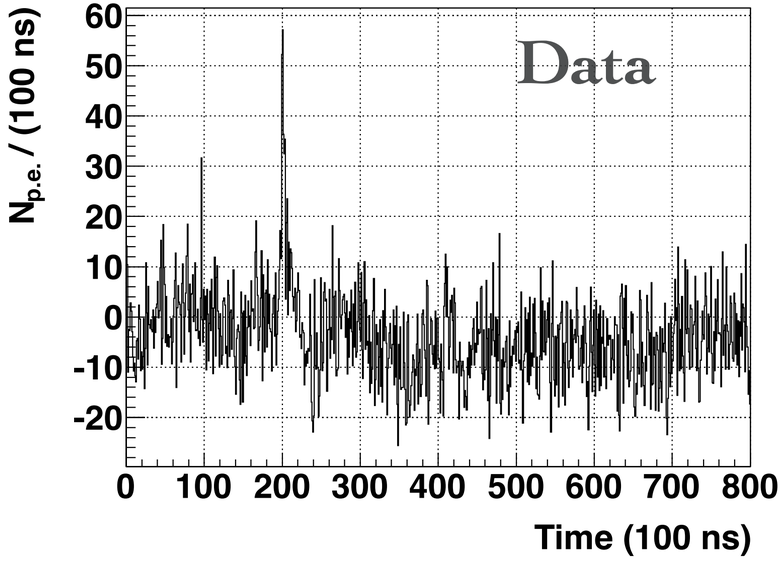
JEM-EUSO

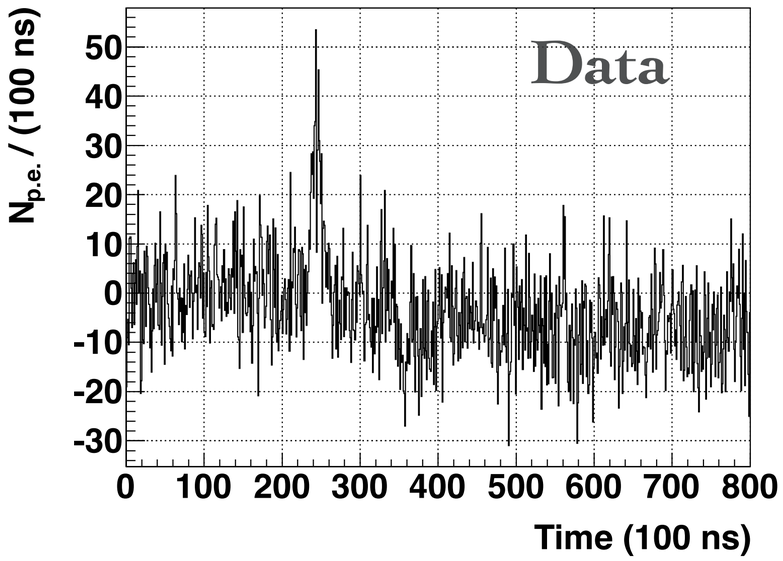
Flat efficiency on ground combined with FAST+Auger+TA

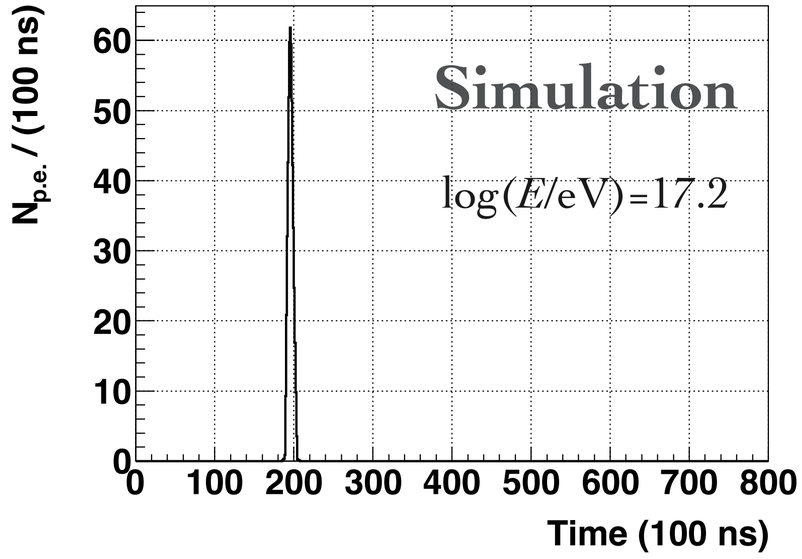


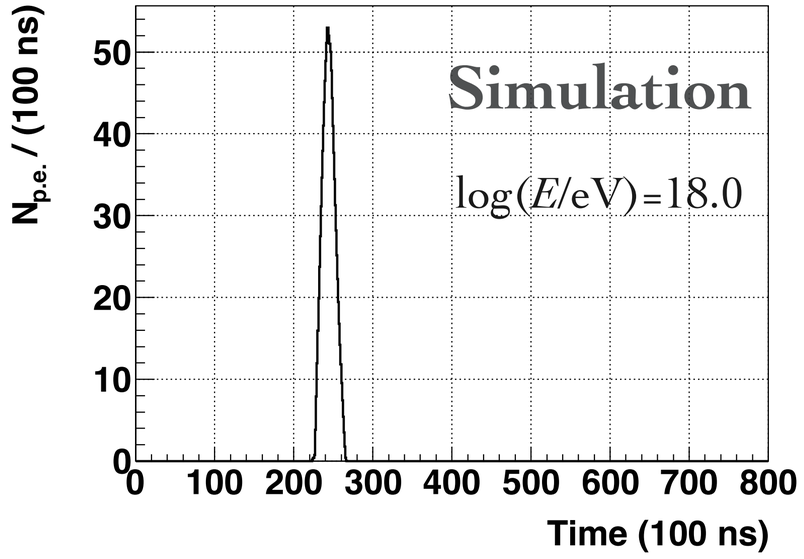
Where?

Comparison to Expected Signal from UHECRs









- Geometry, Energy and *X*max was reconstructed by the TAFD monocular analysis.
- Based on these information, we calculate expected signal by FAST prototype.
- Size, shape and width are consistent with expectation.
  - A signal location is fluctuated within the TAFD trigger frame of 12.8 μs.

Fluorescence detector Array of Single-pixel Telescopes

FAST DAQ System

TAFD external trigger, 3~5 Hz

15 MHz
low pass filter

Anode & dynode
Signal

Camera of FAST

High Voltage power supply,
N1470 CAEN

All modules are remotely controlled through wireless network.

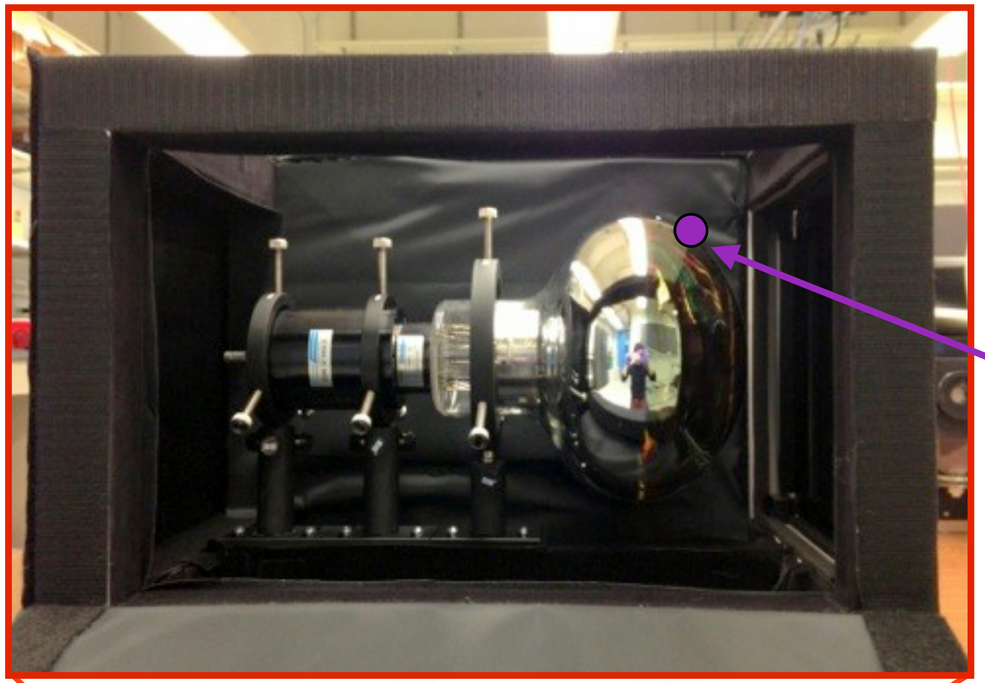
Portable VME Electronics
- Struck FADC 50 MHz sampling, SIS3350
- GPS board, HYTEC GPS2092

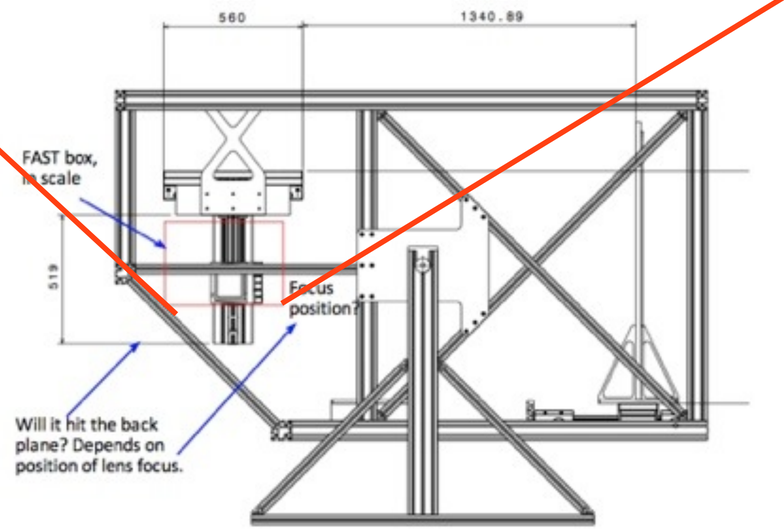
Amplifiers
R979 CAEN
Signal×10

777,Phillips scientific
Signal×50

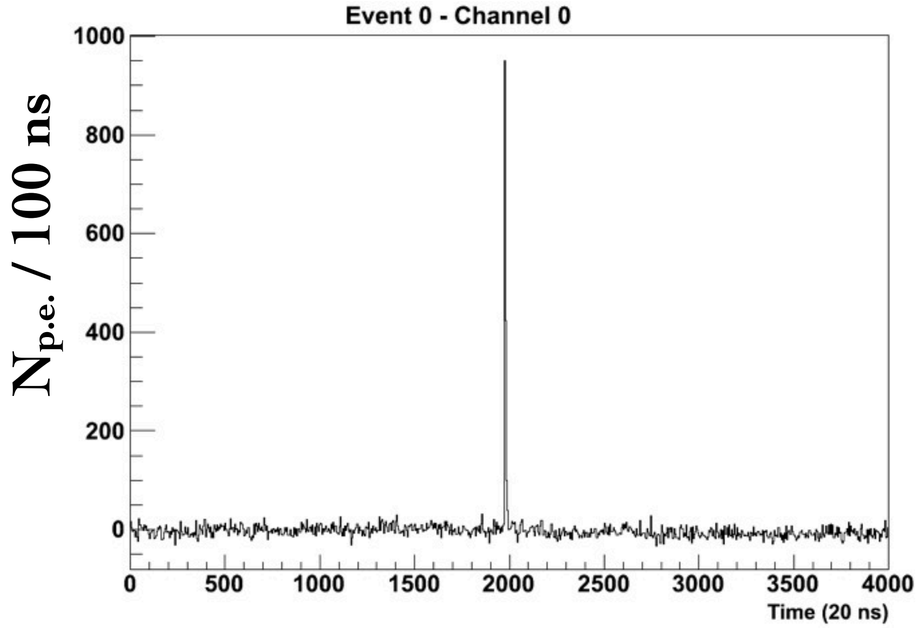
Fluorescence detector Array of Single-pixel Telescopes

Camera of FAST



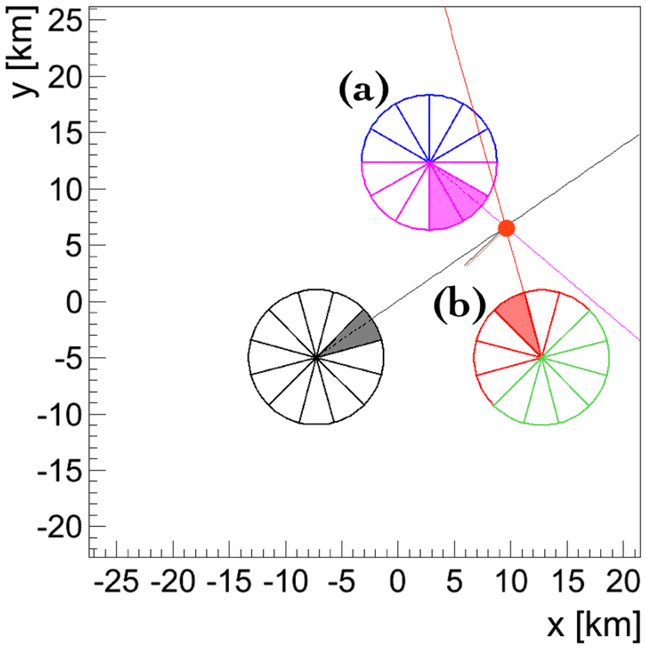


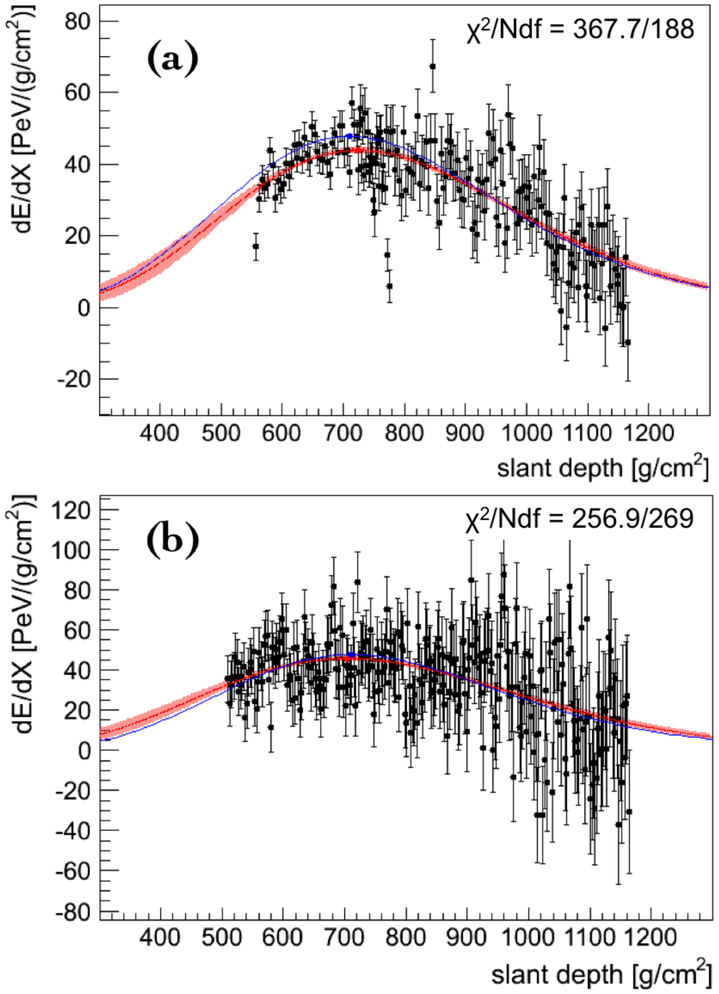
- PMT 8 inch R5912-03
- E7694-01(AC coupling)
- MUG6 UV band pass filter
- YAP ($YAIO_3$: Ce) scintillator with ^{241}Am (50 Hz) to monitor gain stability.

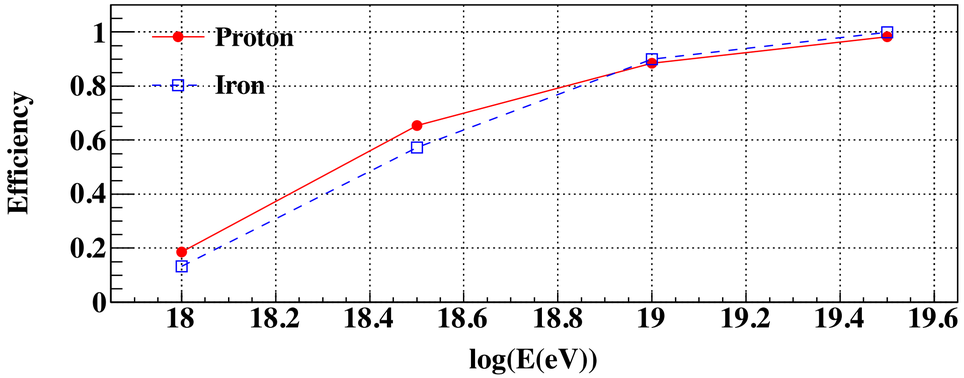


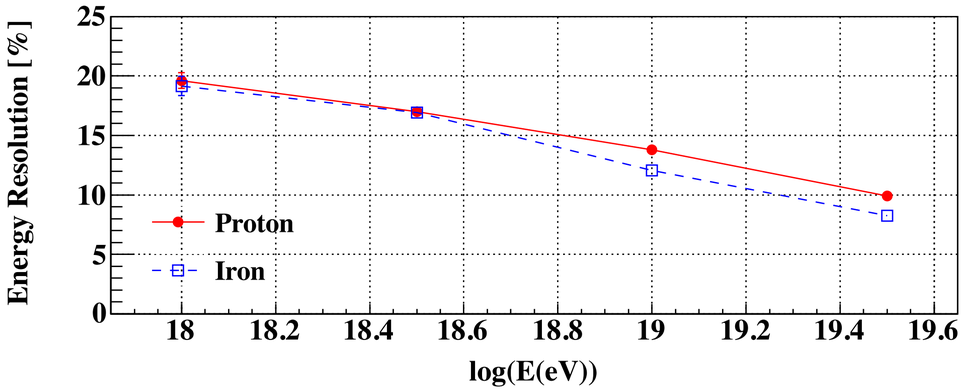
YAP Signal

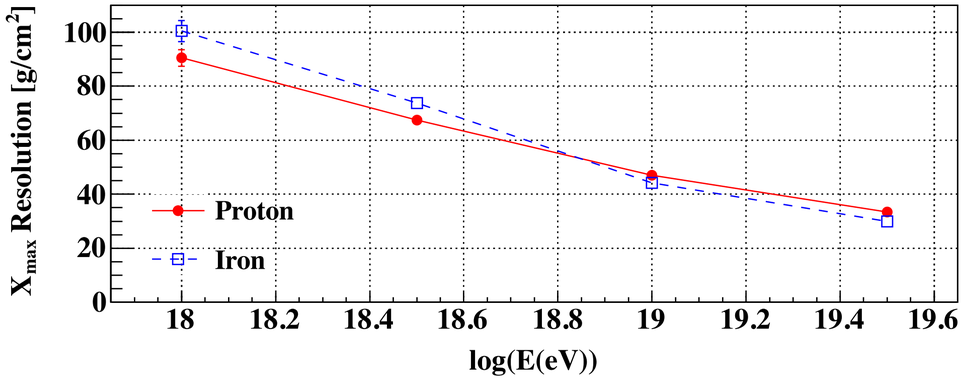
Efficiency and Resolution of FAST











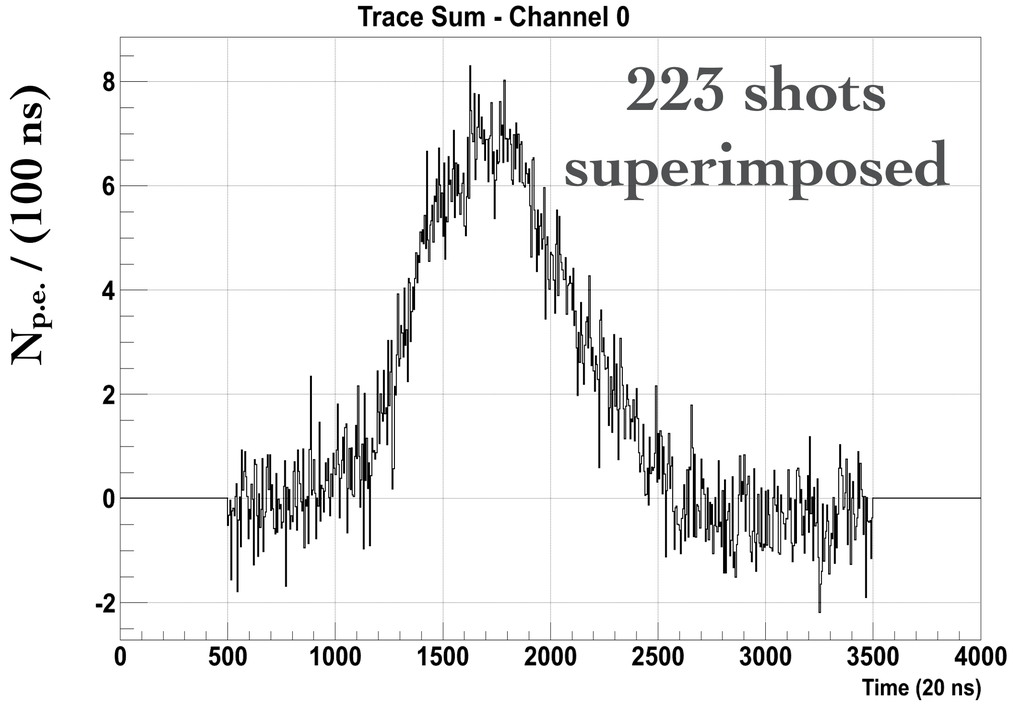
GPS Timing and CLF Signal

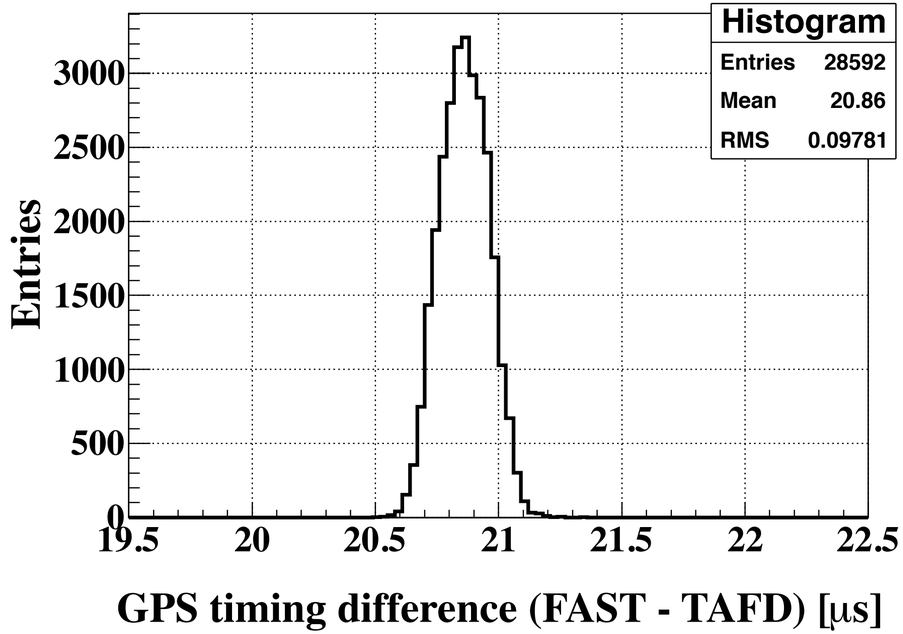
Central Laser Facility

Vertical UV laser shooting every 30 minutes,

21 km from FAST,

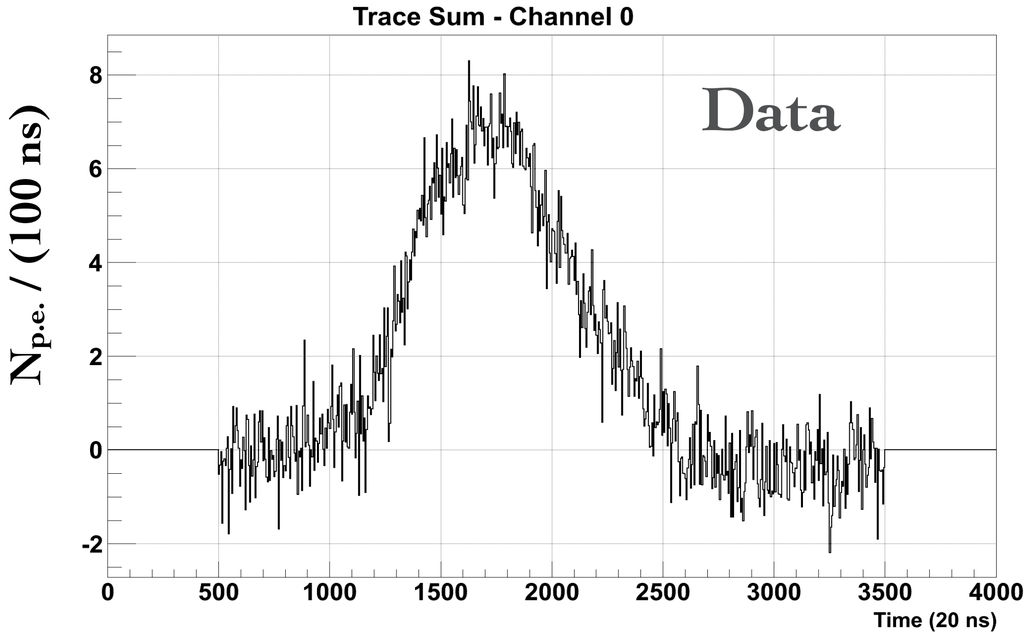
10 Hz, 2.2 mJ, 300 shots

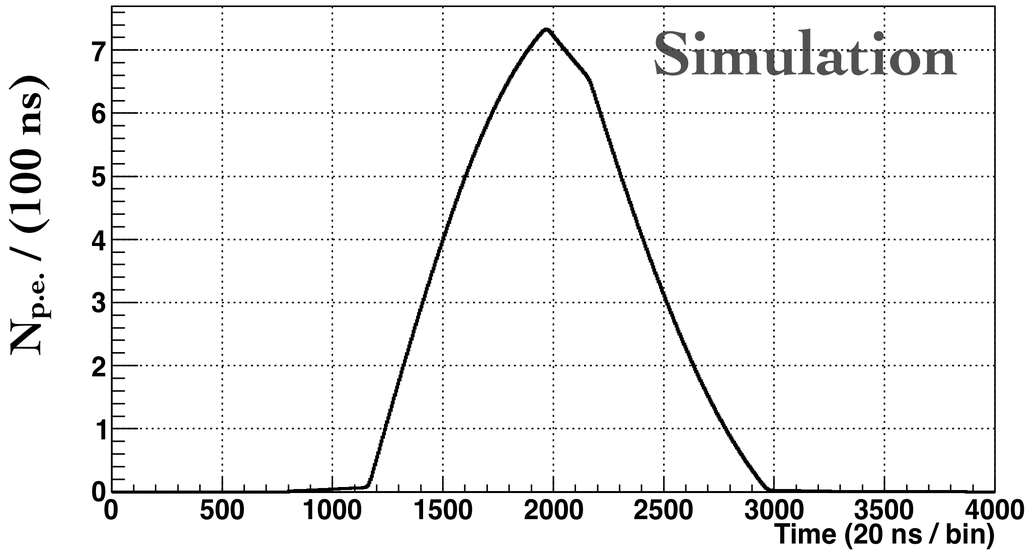




- FAST-TAFD timing resolution, 100 ns. (20.9 μs is the TAFD trigger processing time.)
- laser signal > $10^{19.2}$ eV at 21 km
- peak signal ~ 7 p.e. / 100 ns ($\sigma_{p.e.}$ = 11 p.e.) at the limit of detectability

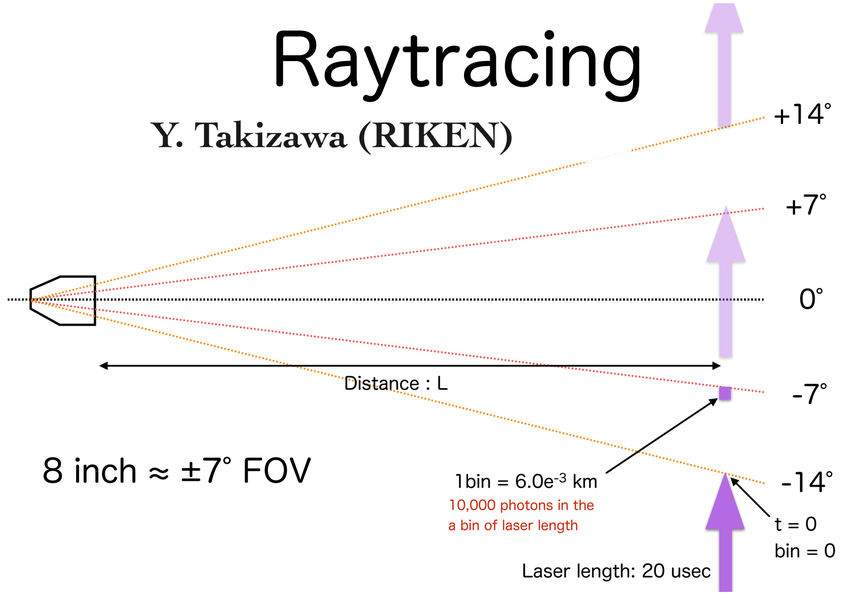
CLF Simulation





Raytracing

Y. Takizawa (RIKEN)



Directional sensitivity