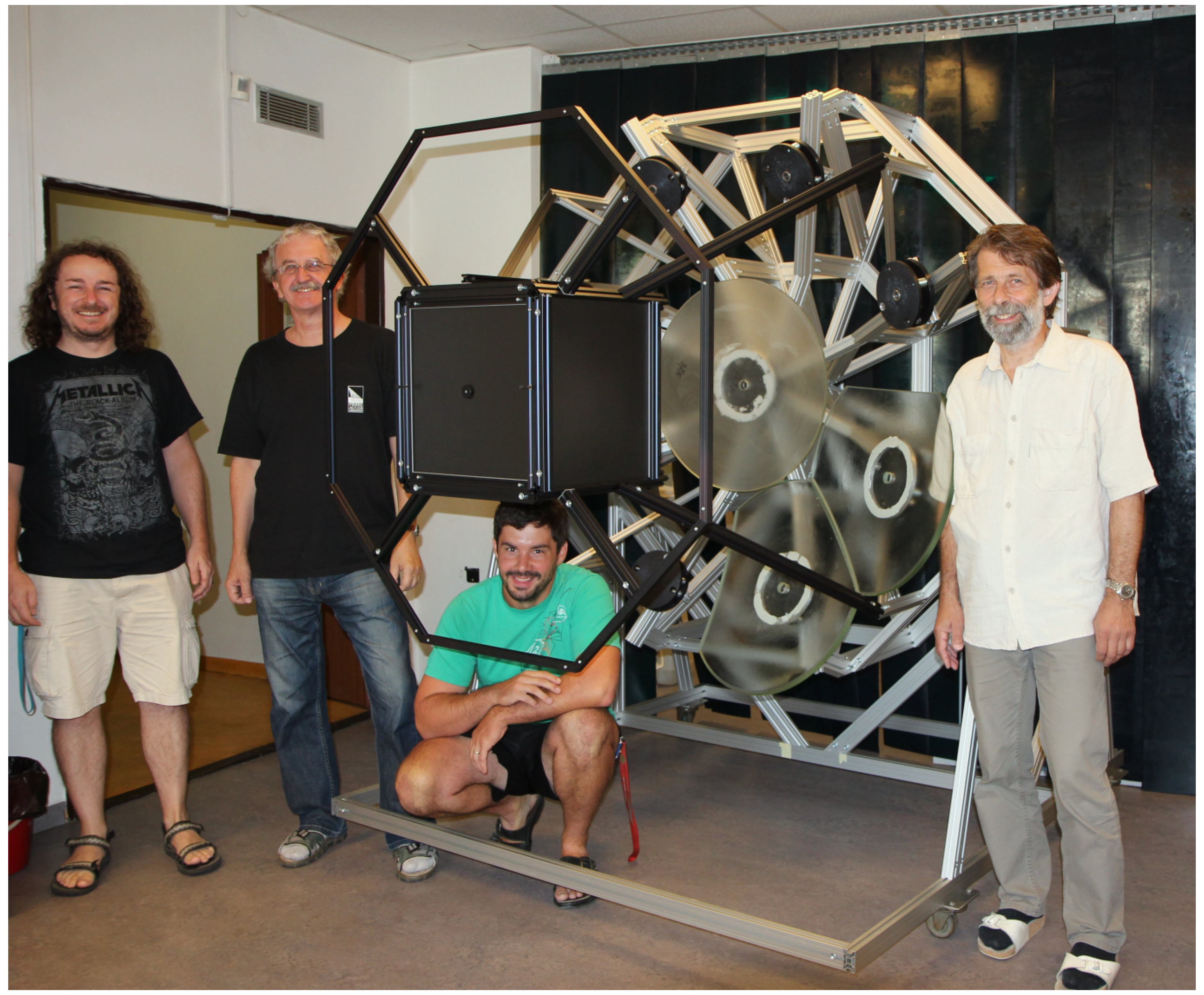
First results from a prototype for the Fluorescence detector Array of Single-pixel Telescopes

FAST
Fluorescence detector Array of Single-pixel Telescopes

ICRC
The Astroparticle Physics Conference
34th International Cosmic Ray Conference
July 30 - August 6, 2015
The Hague, The Netherlands

PoS (ICRC2015) 323
arXiv: 1504.00692



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Physics Goal and Future Prospects

Origin and Nature of Ultra-high Energy Cosmic Rays (UHECRs) 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 Fluorescence Detector (FD)

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

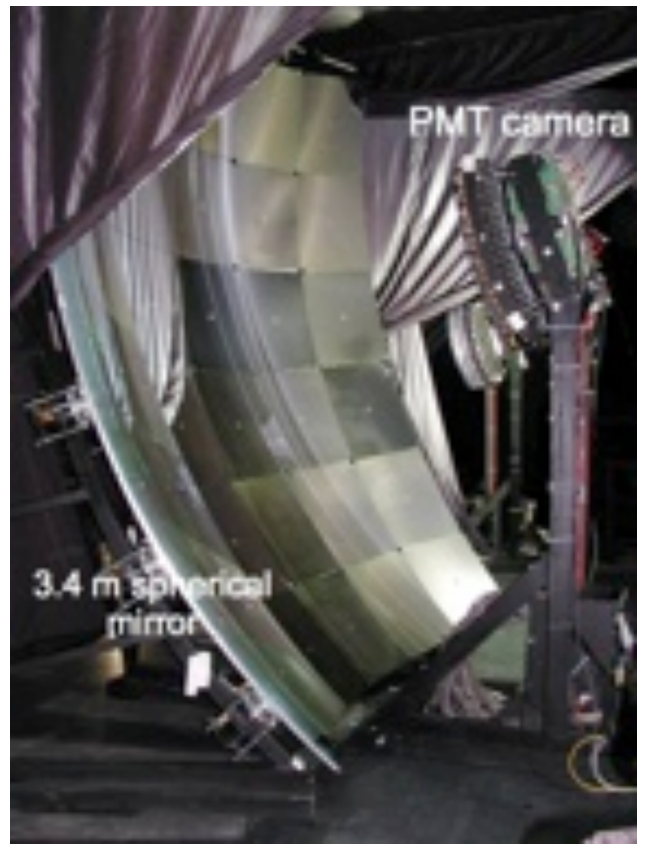
10 - 20 years

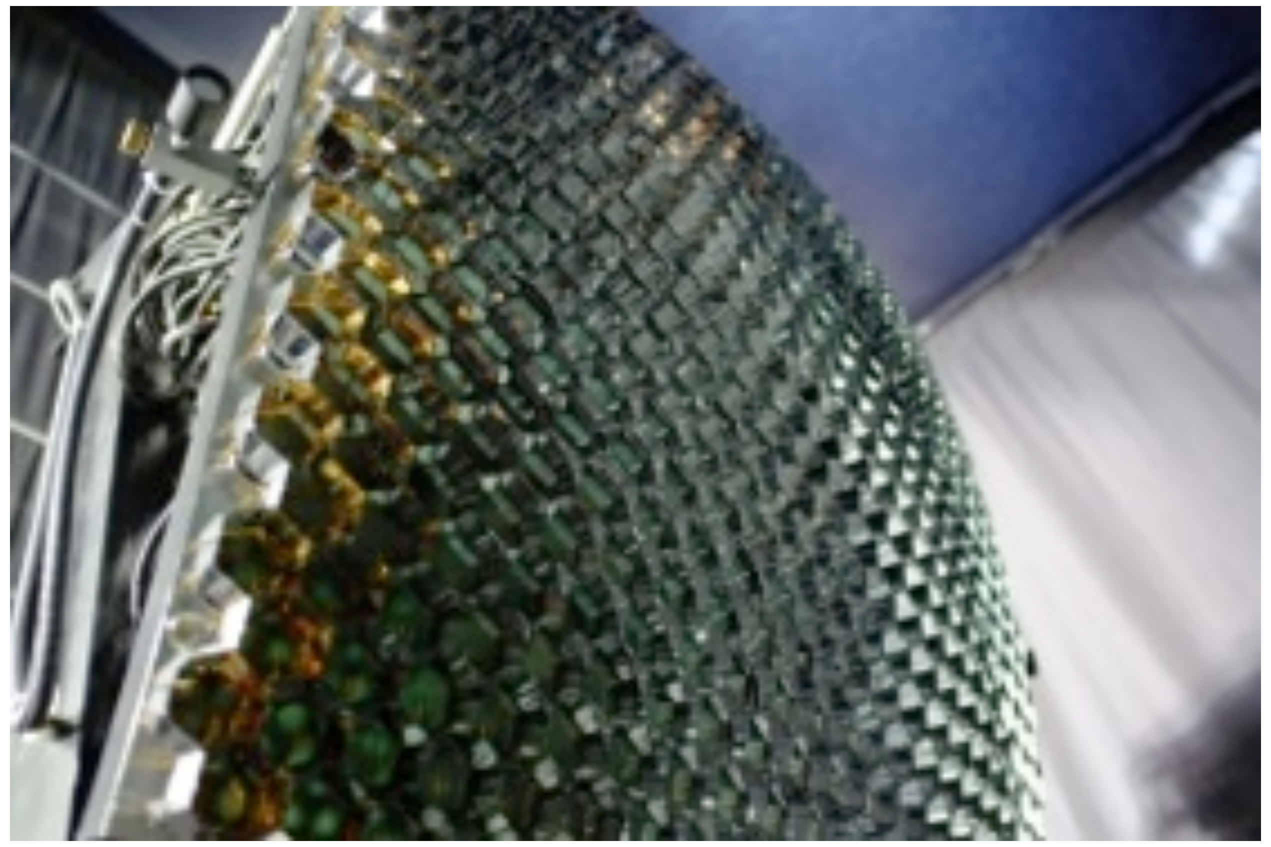
Next Generation Observatories
In space (100×exposure): Super-EUSO
Ground (10×exposure with high quality events): FAST (Fluorescence detector Array of Single-pixel Telescopes)

Fluorescence detector Array of Single-pixel Telescopes

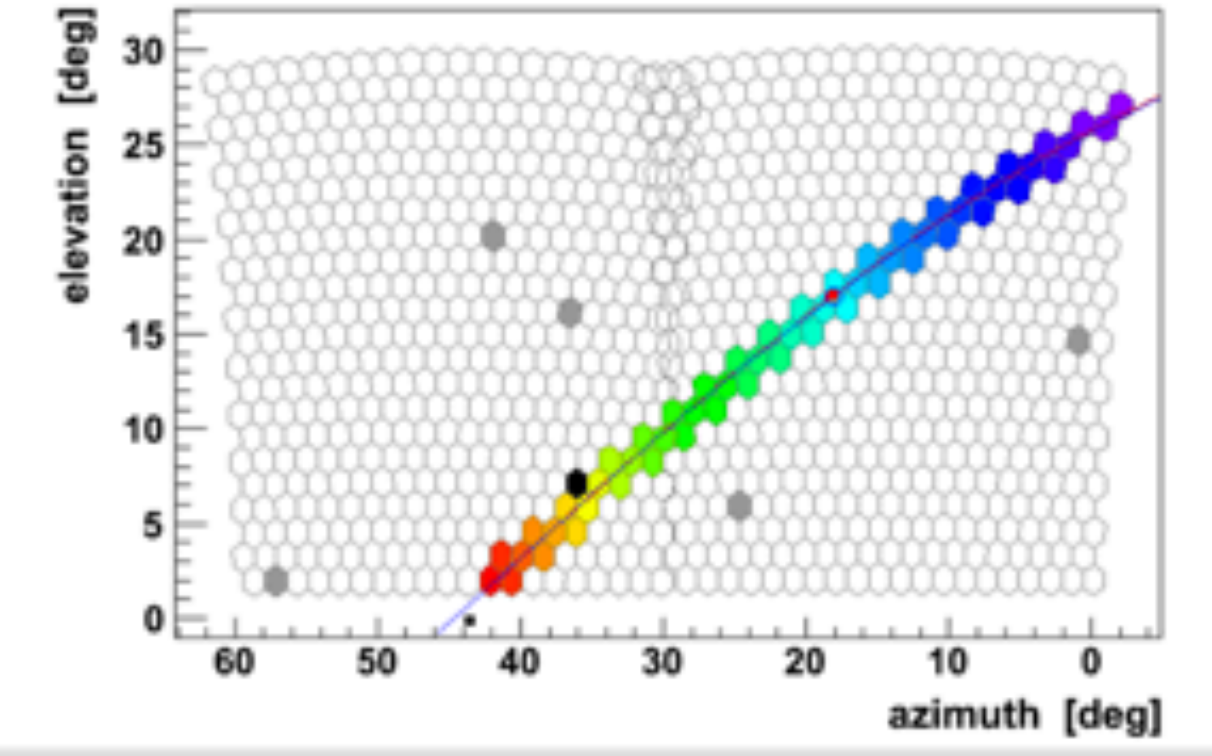
- Target : > $10^{19.5}$ eV, UHE nuclei and neutral particles
- Huge target volume ⇒ Fluorescence detector array

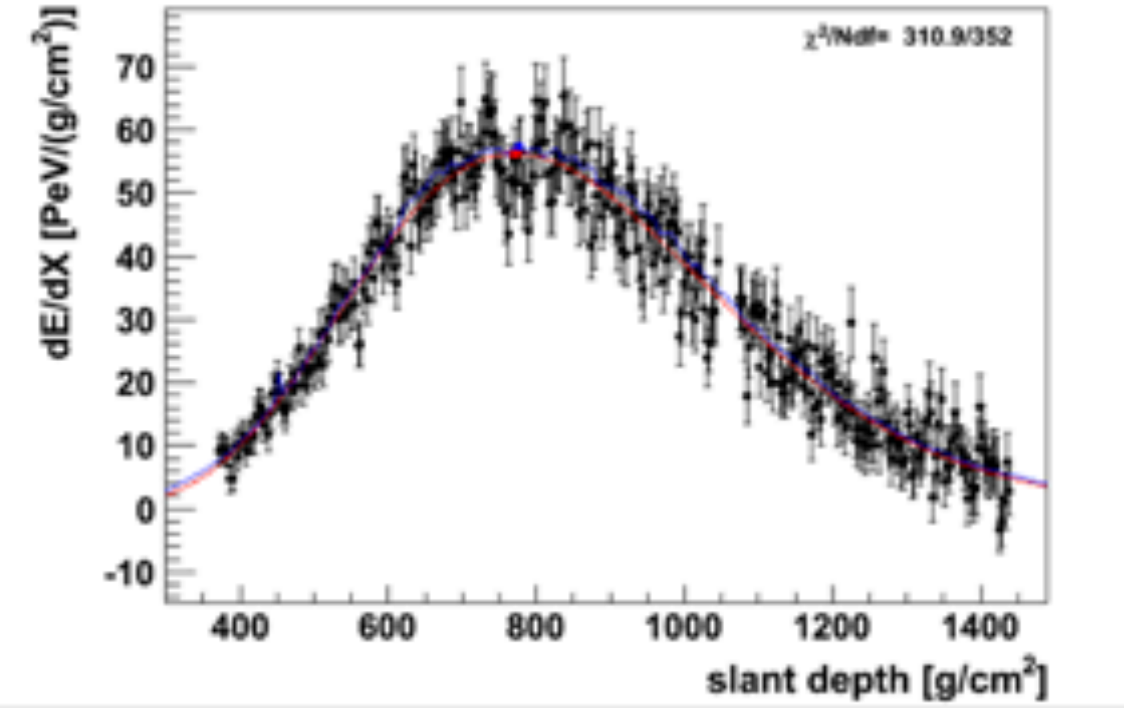
Fine pixelated camera



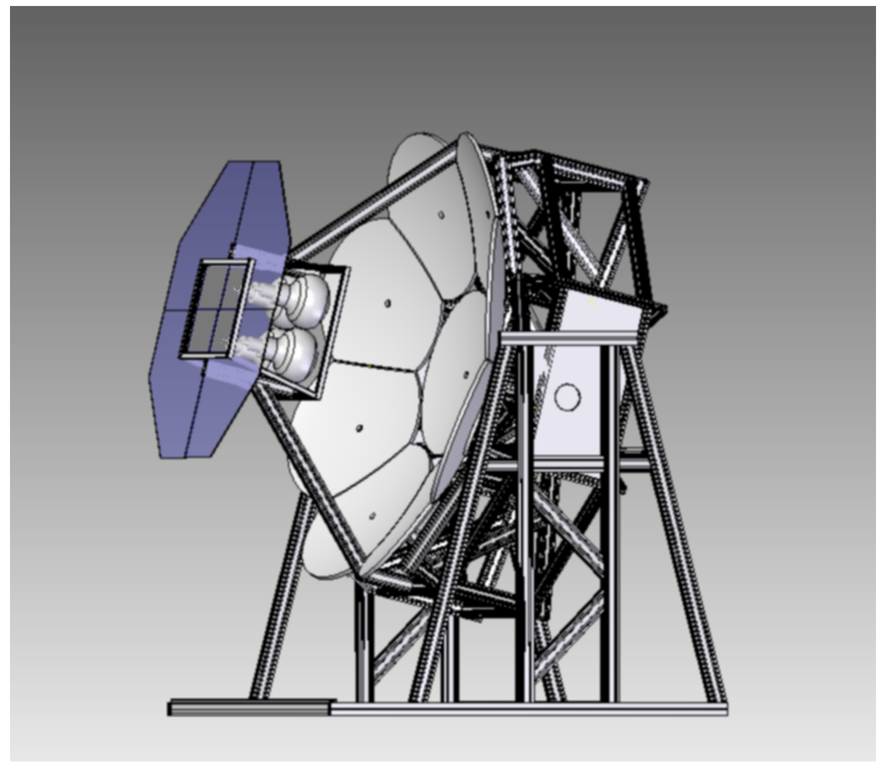


Too expensive to cover a huge area

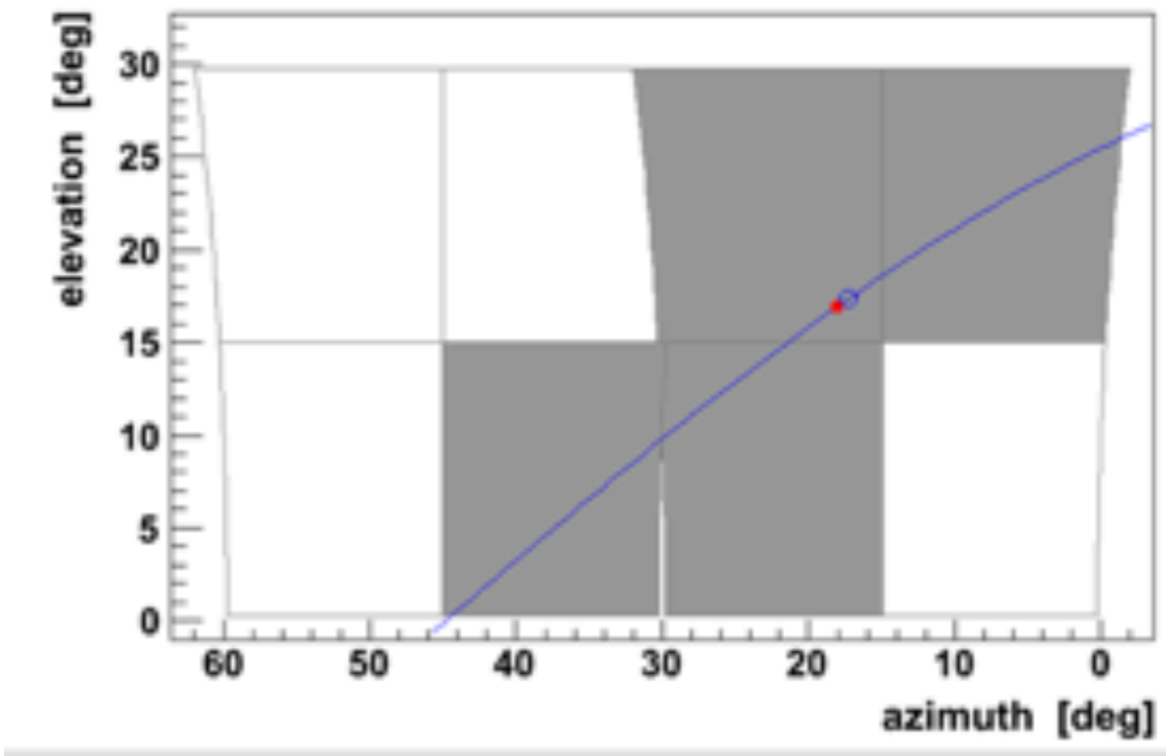


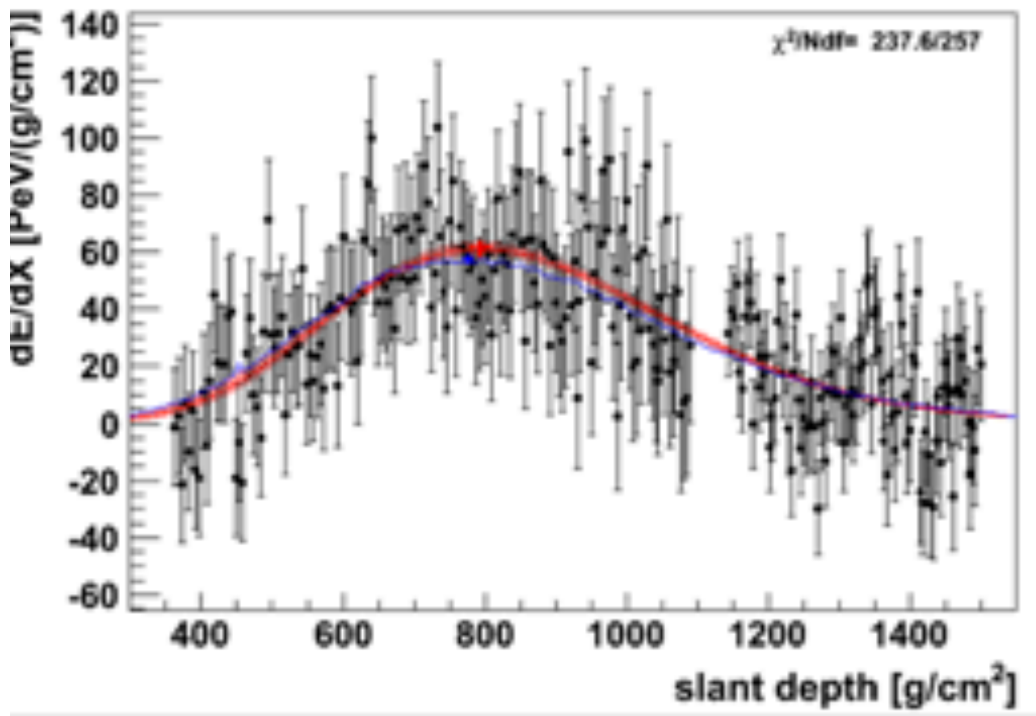


Single or few pixels and smaller optics

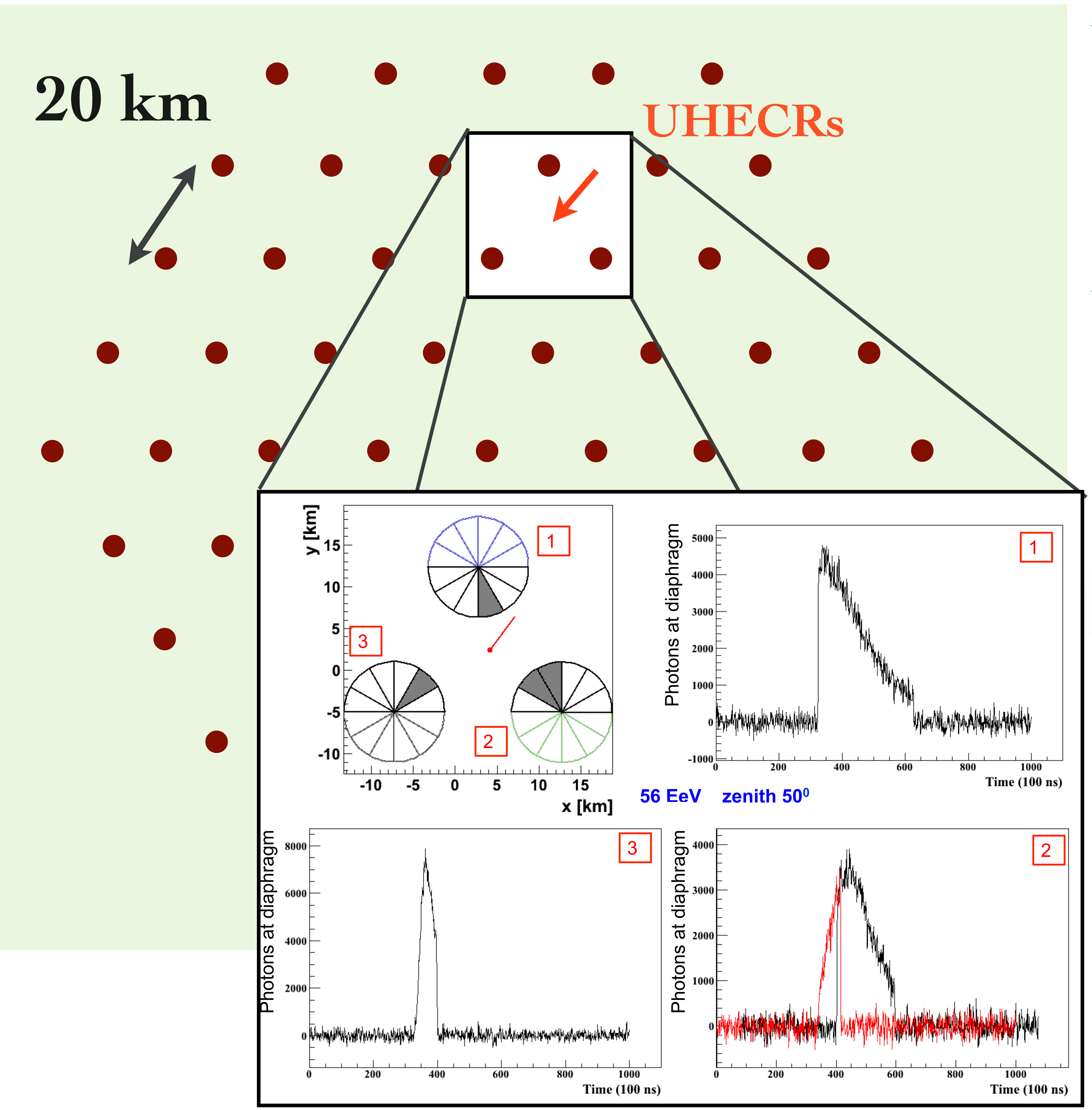


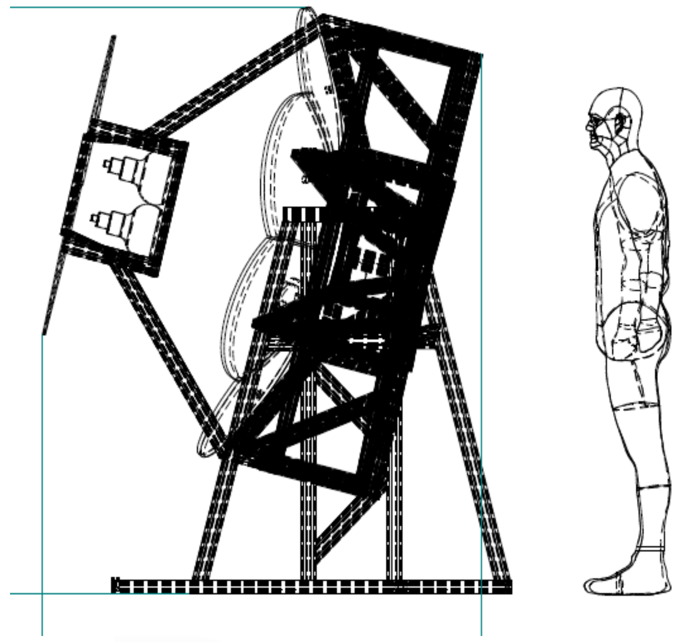
Low-cost and simplified/optimized FD

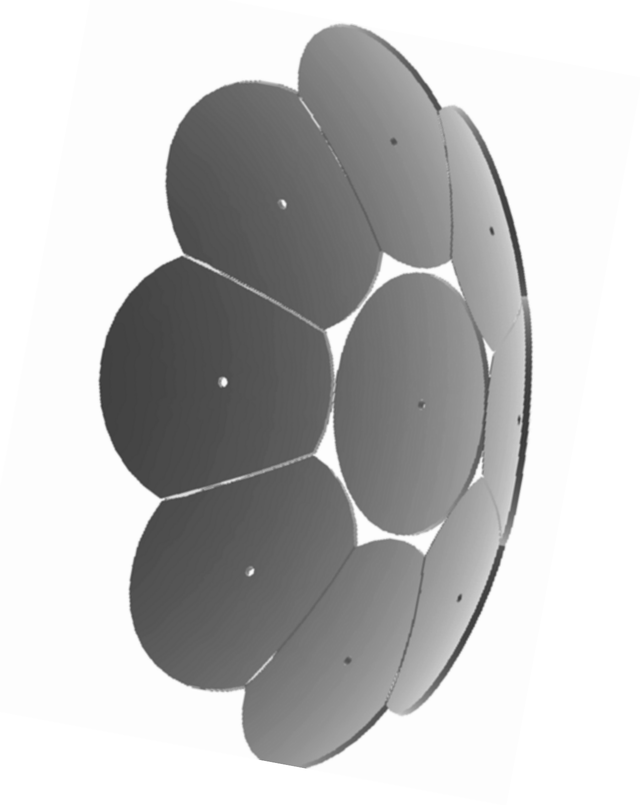


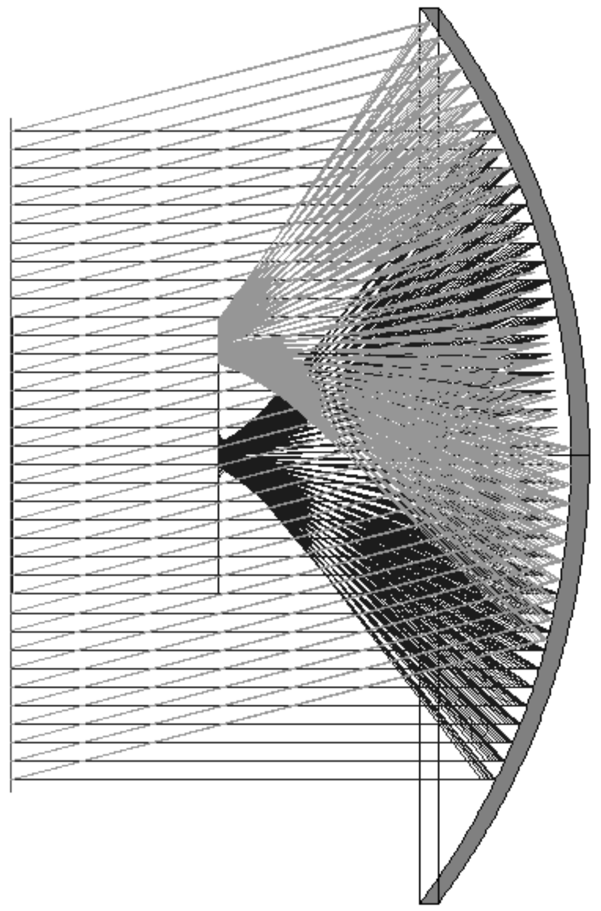


FAST Fluorescence detector Array of Single-pixel Telescopes







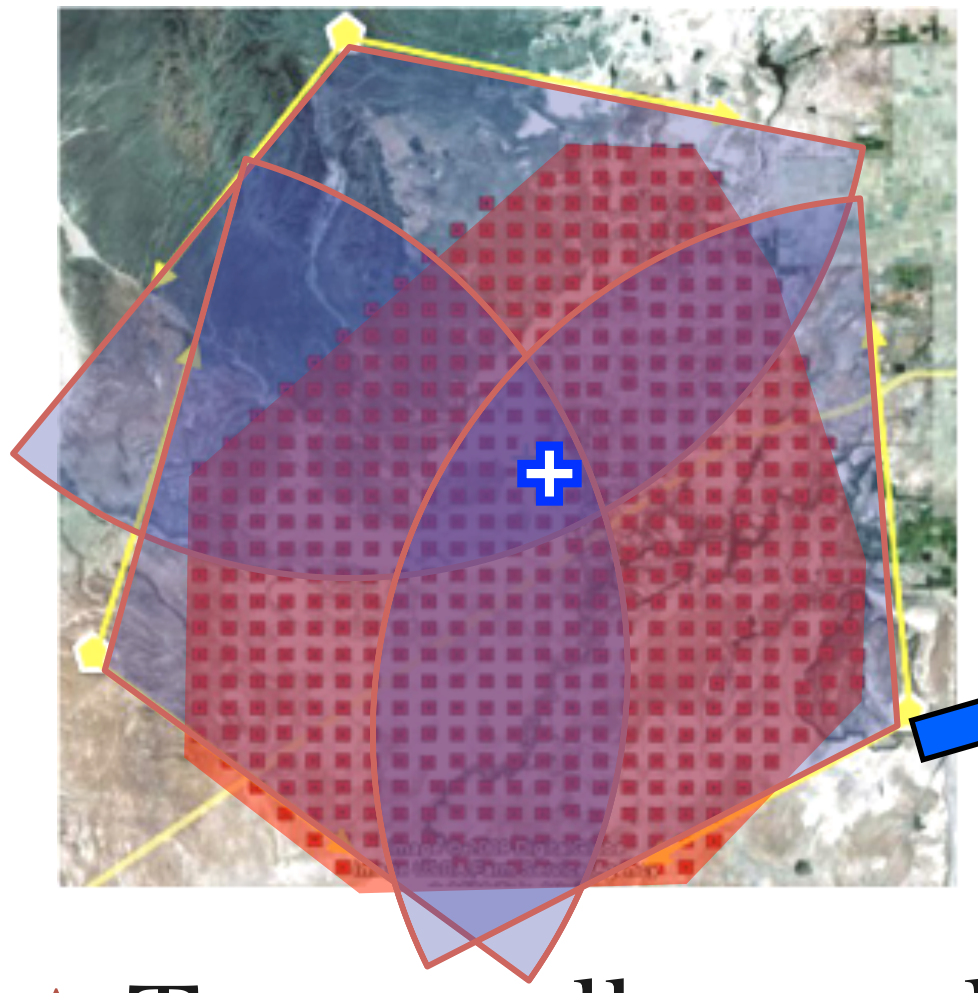


- Each telescope: 4 PMTs, 30°×30° field of view (FoV).
  - **Reference design: 1 m^2 aperture, 15°×15° FoV per PMT**
- Each station: 12 telescopes, 48 PMTs, 30°×360° FoV.
- Deploy on a triangle grid with 20 km spacing, like "surface detector array".
- If 127 stations are installed, a ground coverage is ~ 40,000 km^2.
- Geometry: Radio, SD, coincidence of three stations being investigated.

FAST Window of Opportunity at EUSO-TA

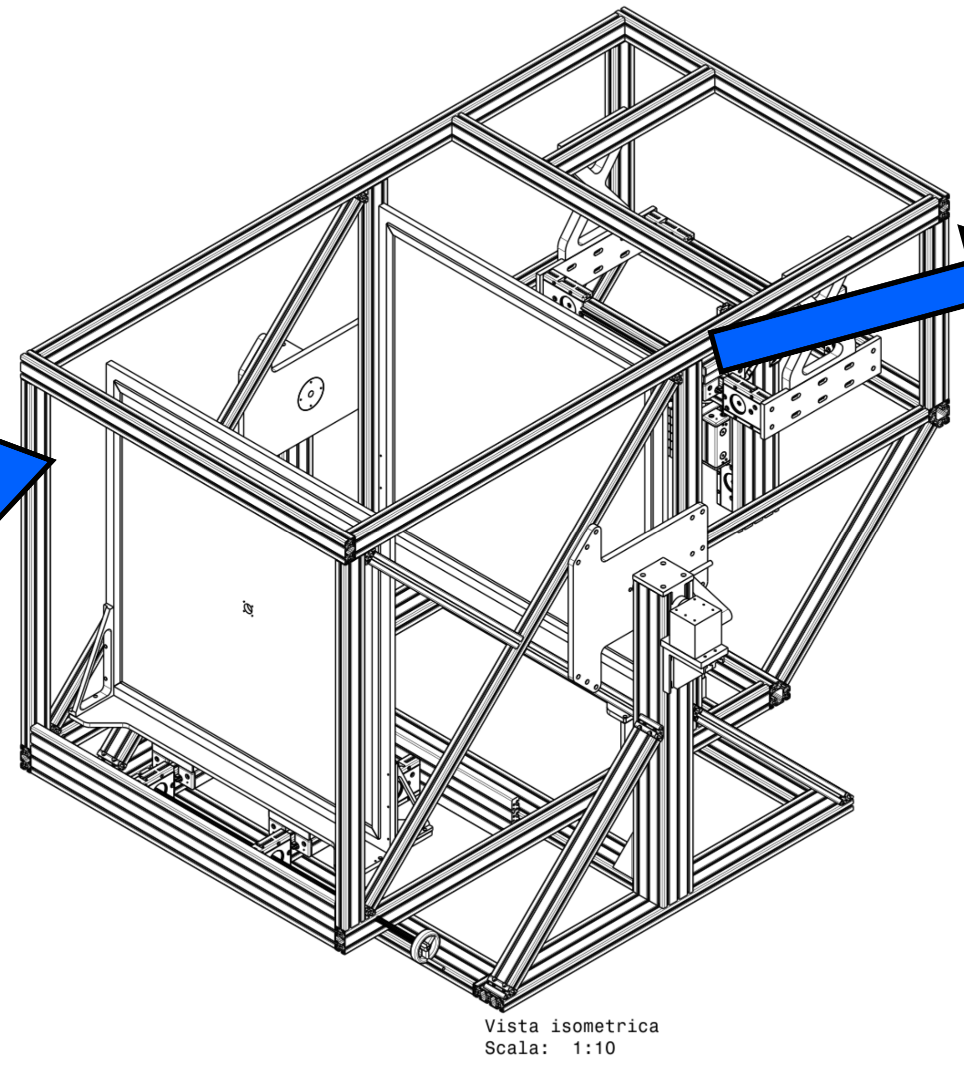
Fluorescence detector Array of Single-pixel Telescopes

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.


1
2
3
4
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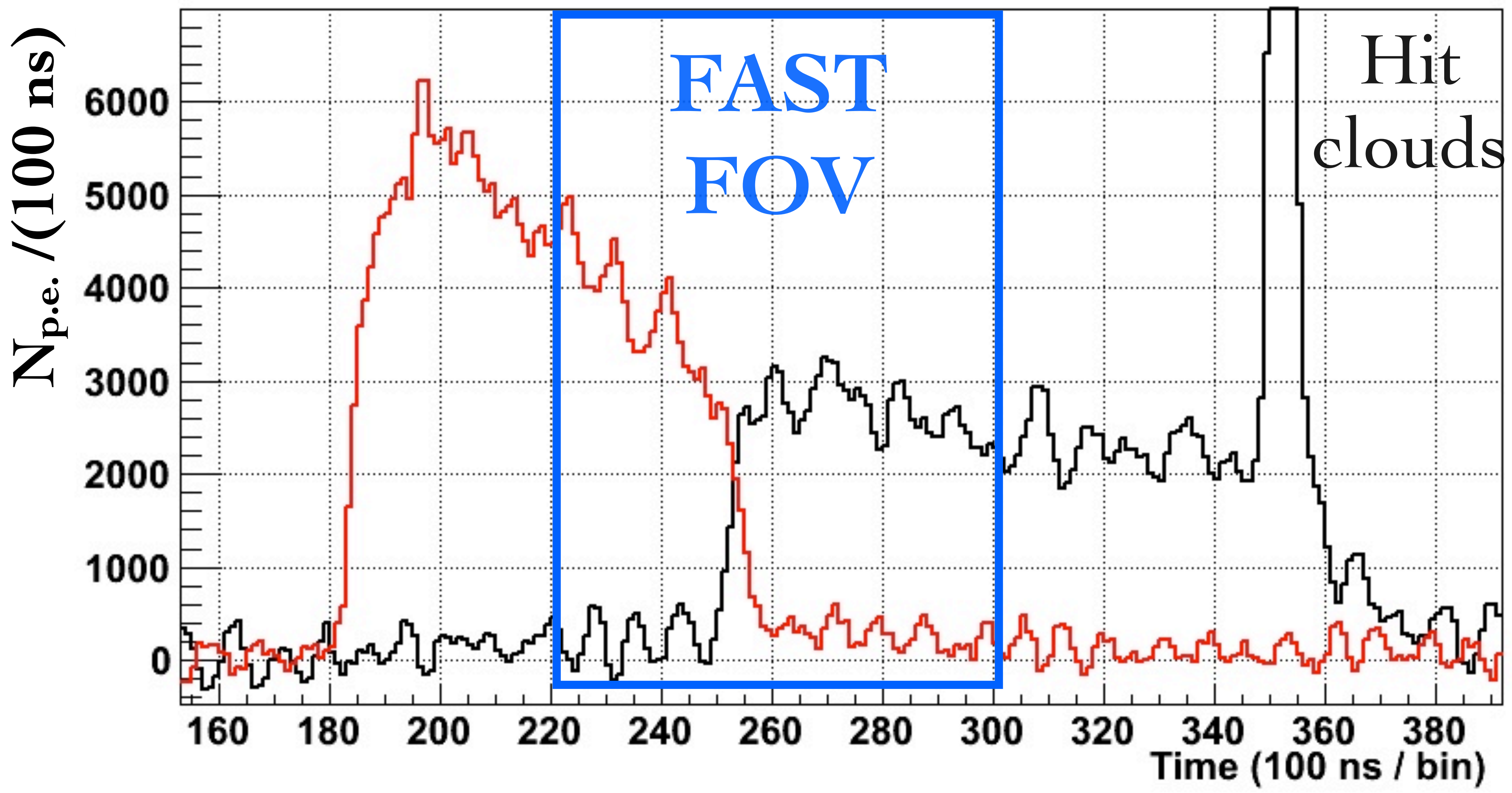
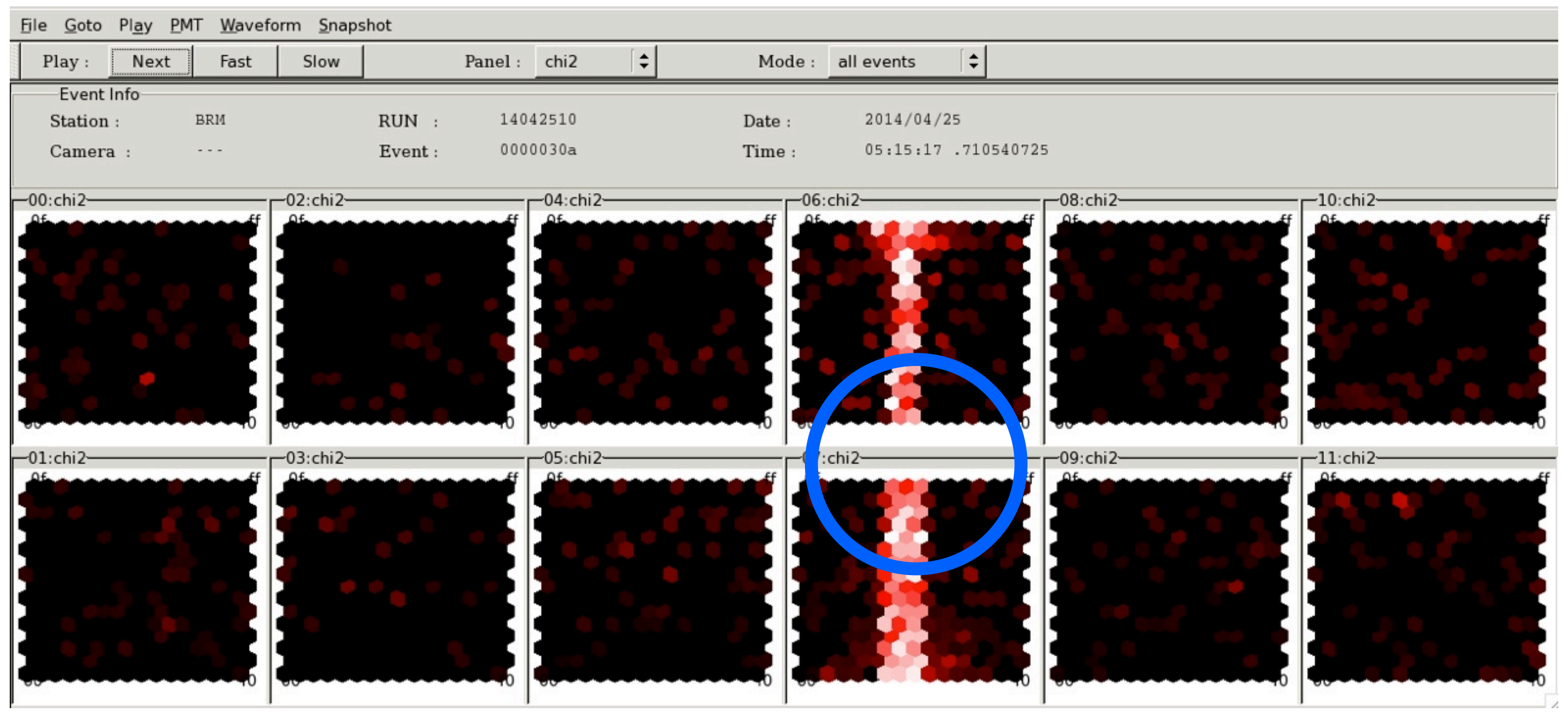
7
8
9
Start observation

Laser Signal to Check Performance

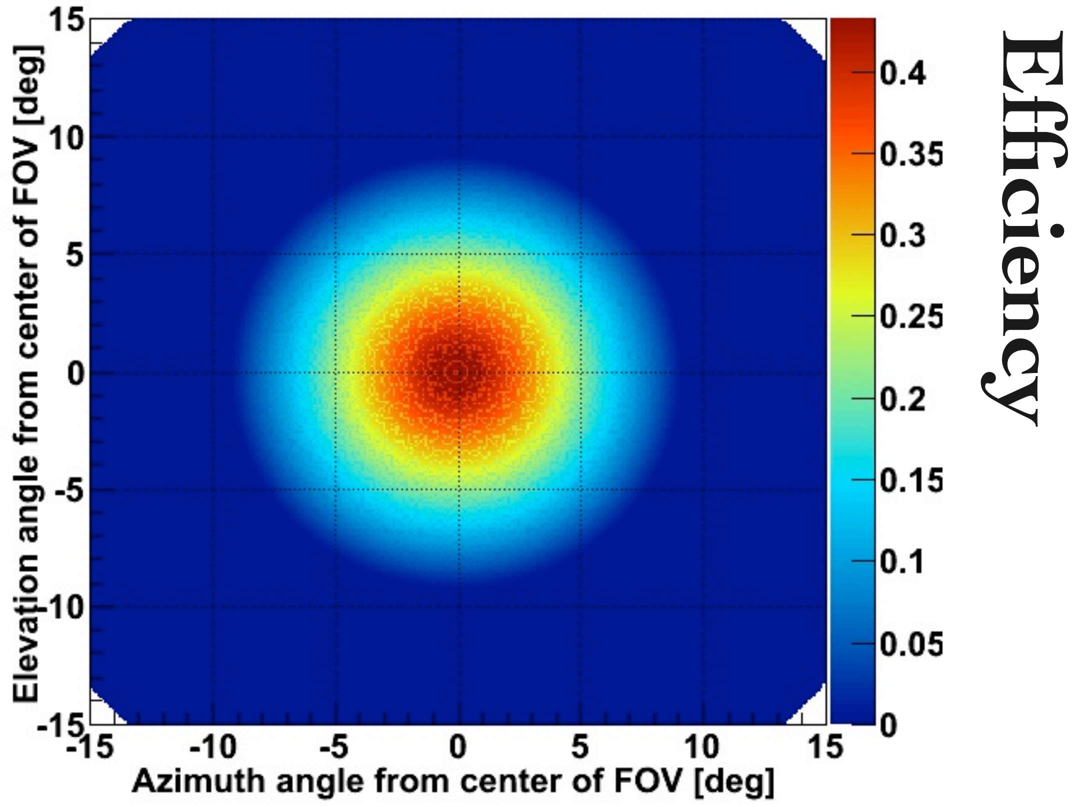
Fluorescence detector Array of Single-pixel Telescopes

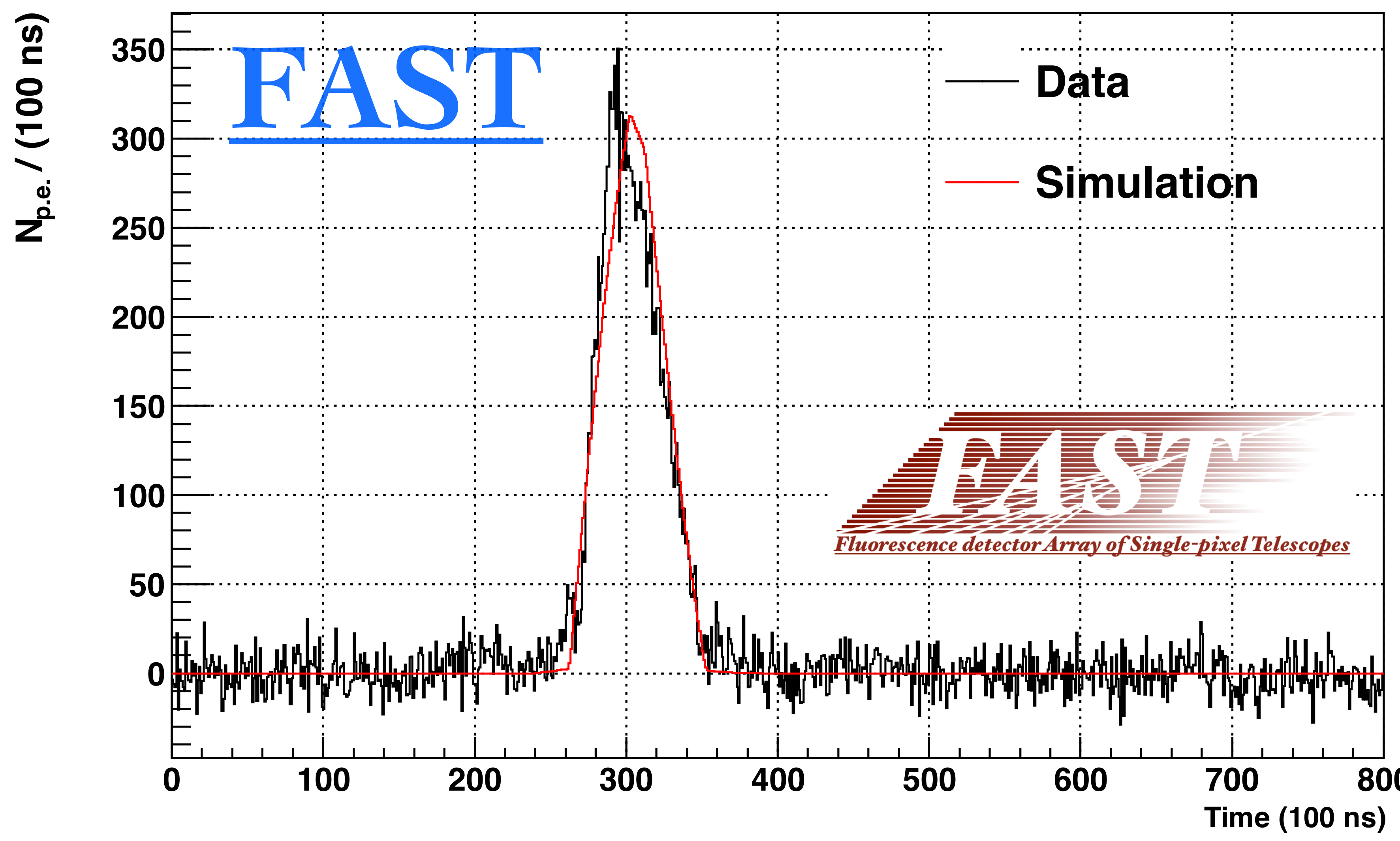


TAFD



Directional sensitivity by RayTrace of EUSO-TA telescope



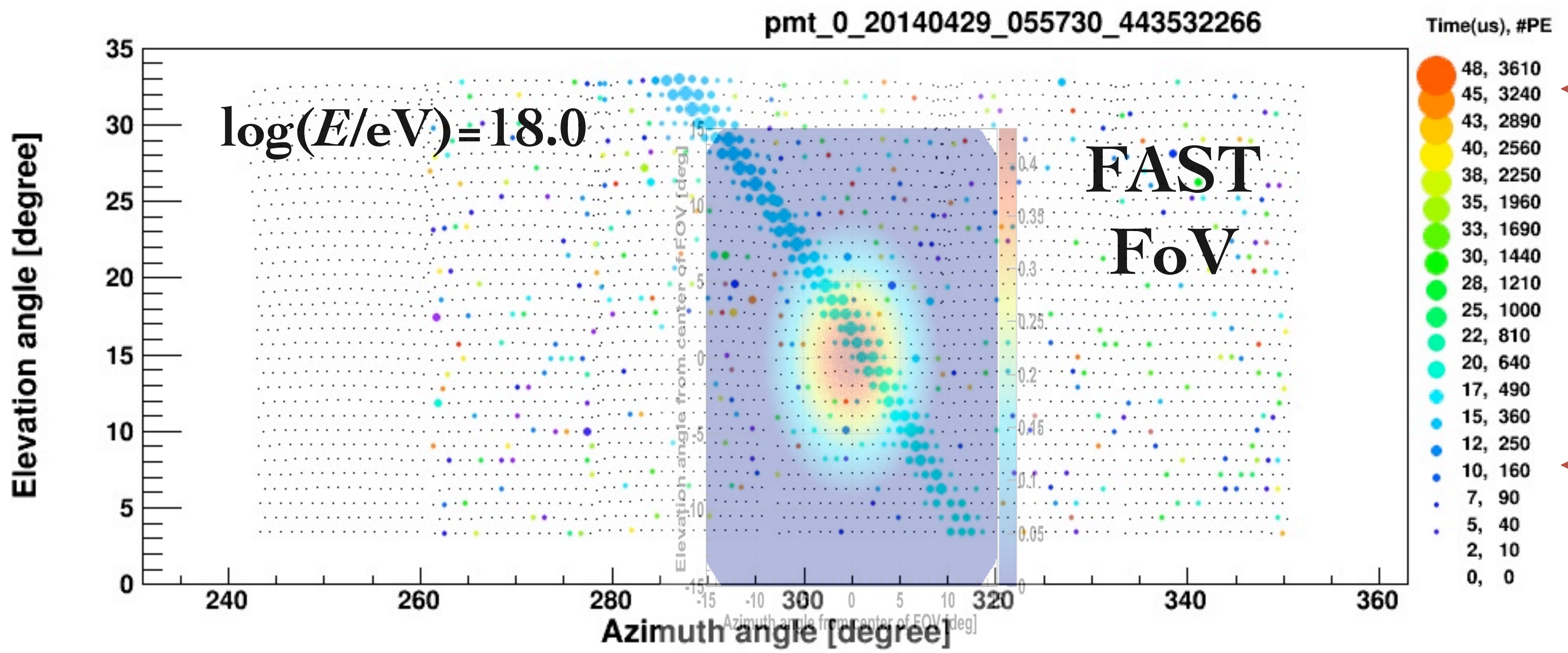


- Vertical Ultra-Violet laser at 6 km from FAST ≒ ~$10^{19.2}$ eV
- Expected signal TAFD/FAST: (7 m^2 aperture × 0.7 shadow × 0.9 mirror) / (1 m^2 aperture × 0.43 optics efficiency) ~10
  - TAFD Peak signal : ~3000 p.e. / 100 ns
  - FAST Peak signal : ~300 p.e. / 100 ns. All shots are detected significantly.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

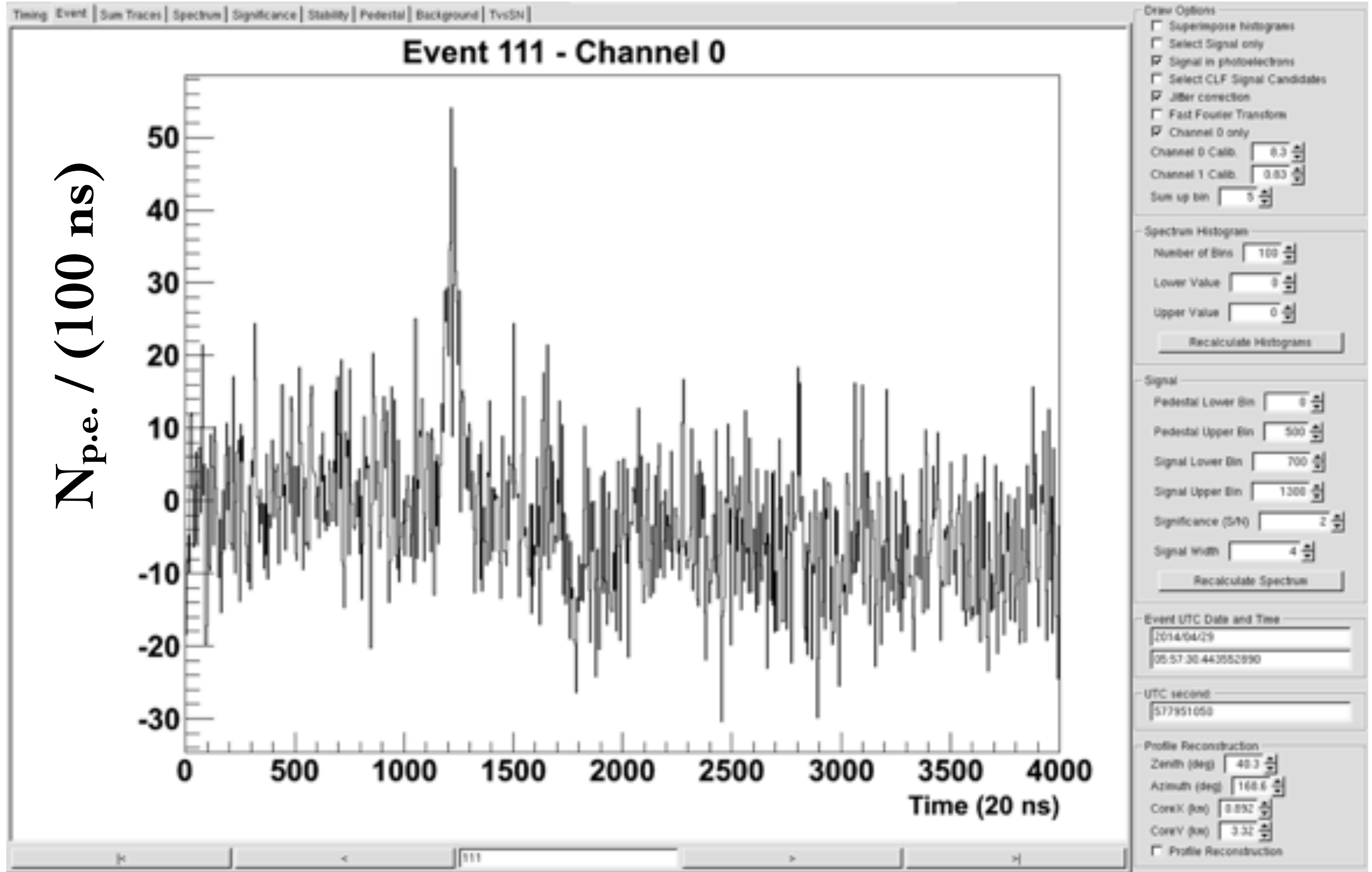
UHECR Signal Search

Fluorescence detector Array of Single-pixel Telescopes

TAFD

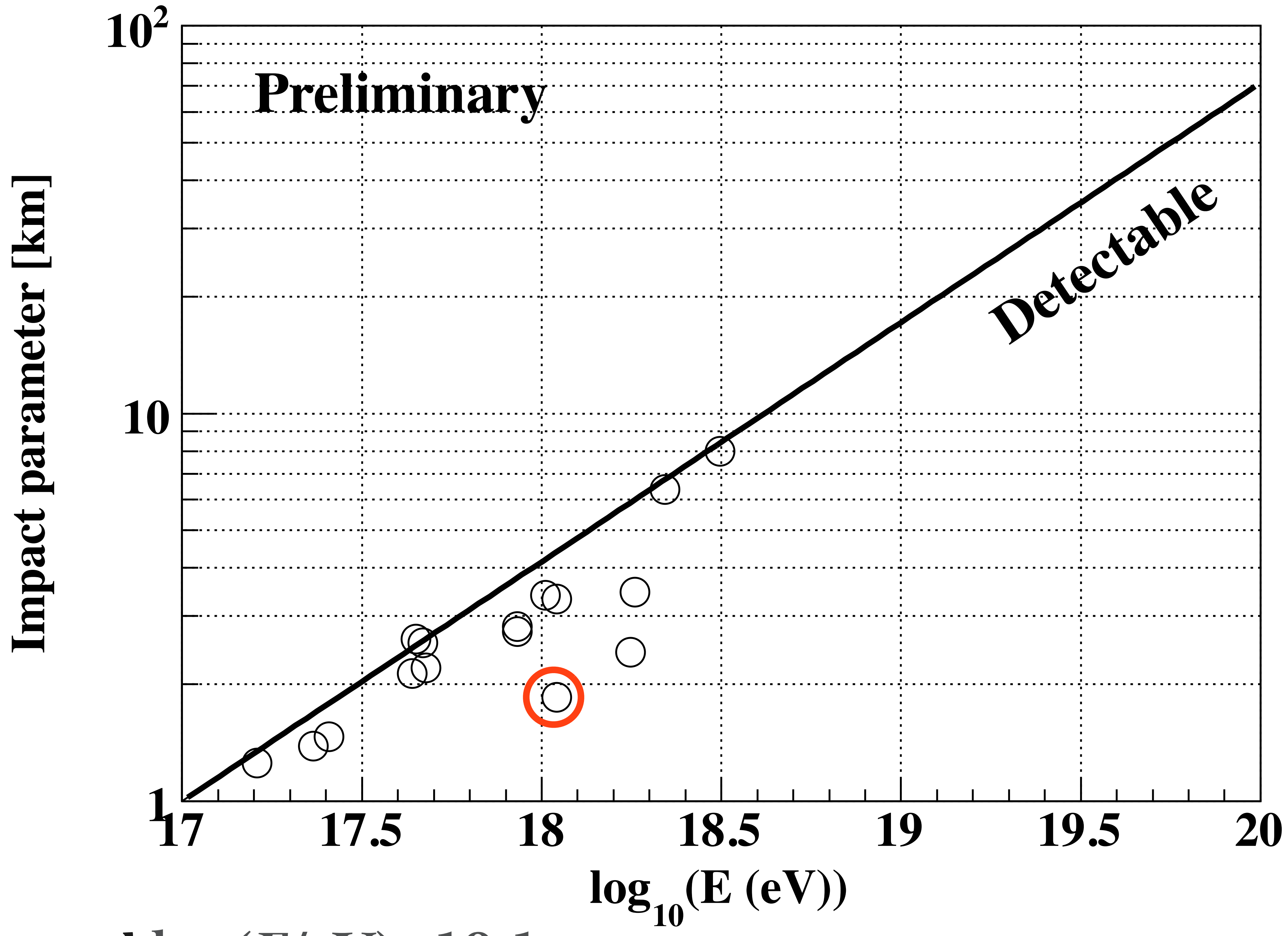


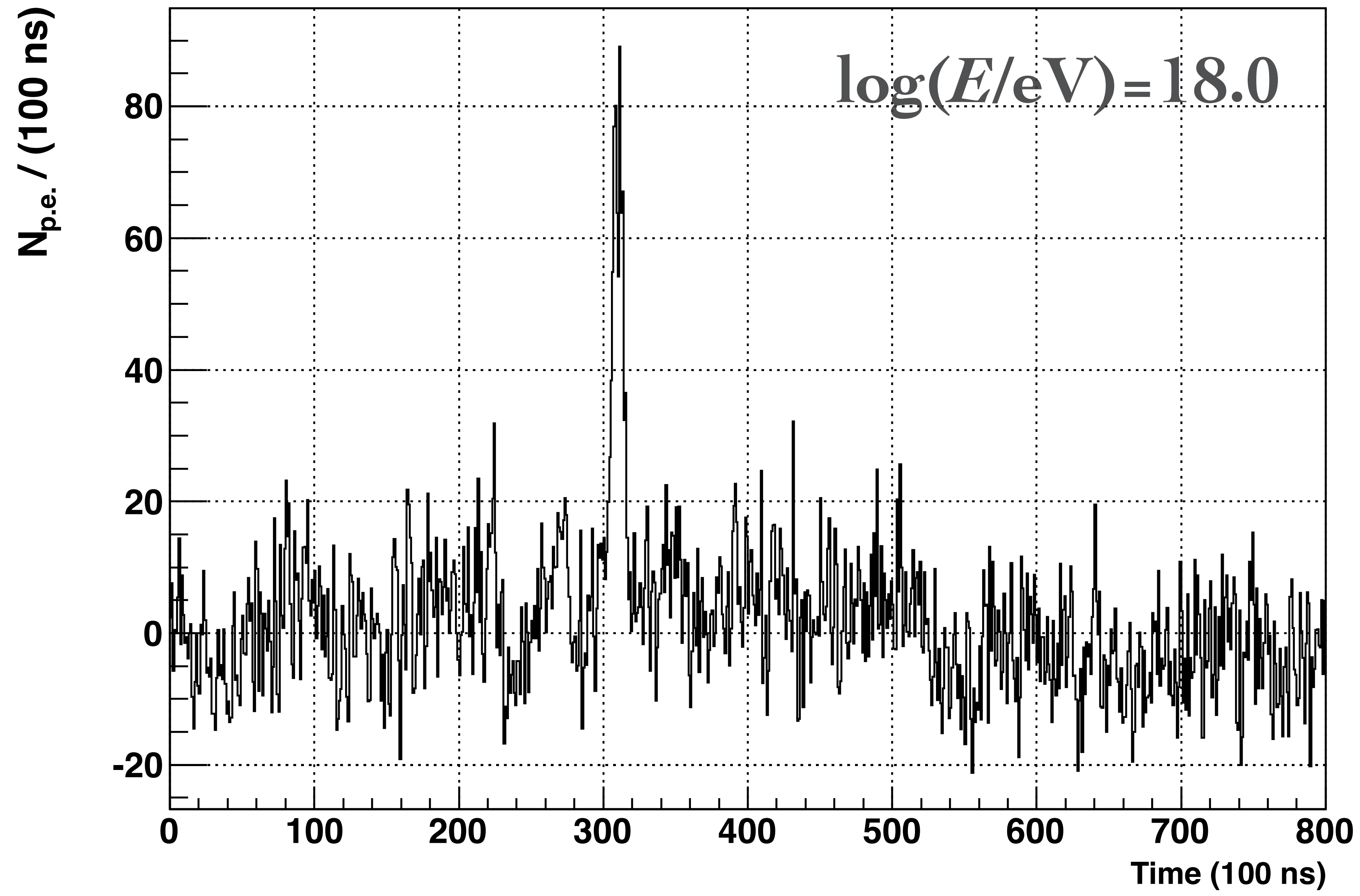
FAST



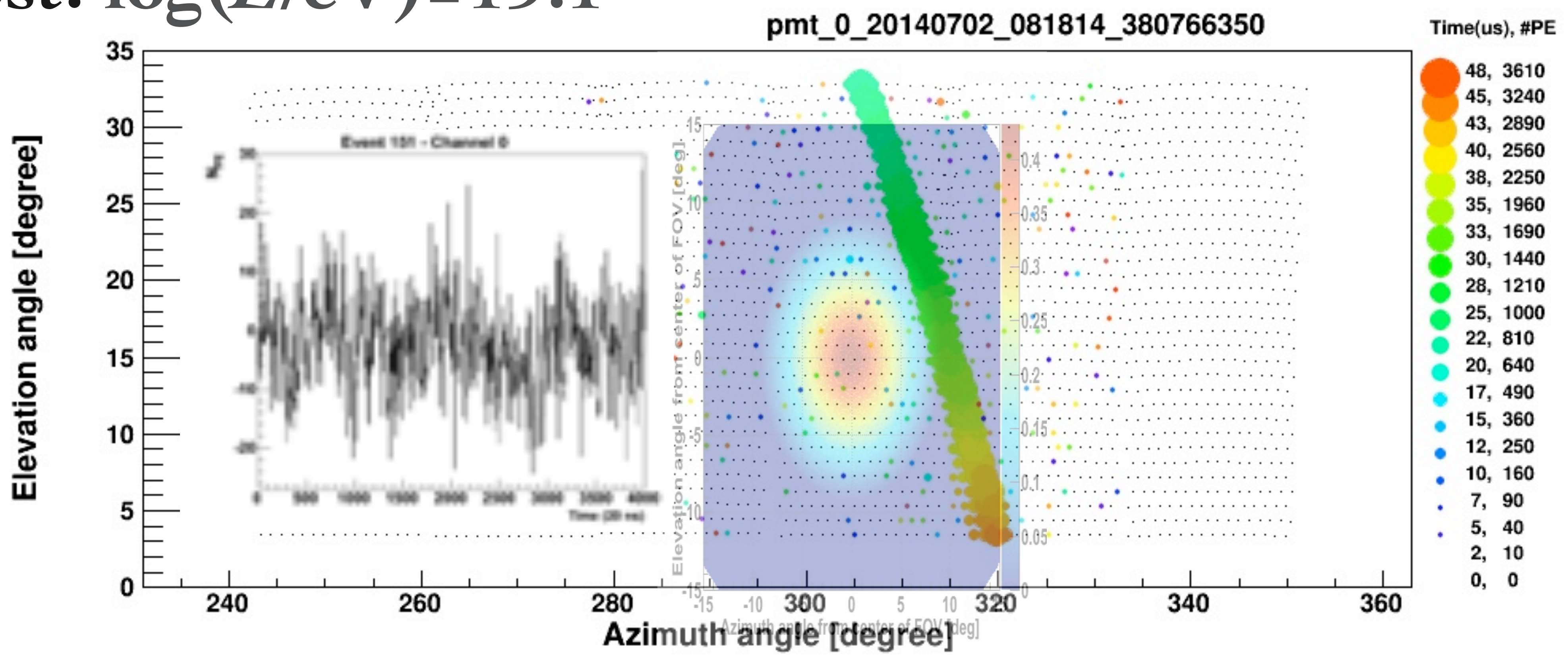
- Data set: April and June 2014 observation, 19 days, 83 hours.
  - Stable observation.
- We searched for UHECR signal in coincidence between FAST and TAFD.
  1. Search for TAFD signal crossing the field of view (FoV) with FAST.
  2. Search for a significant signal (>5σ) with FAST waveform at the same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

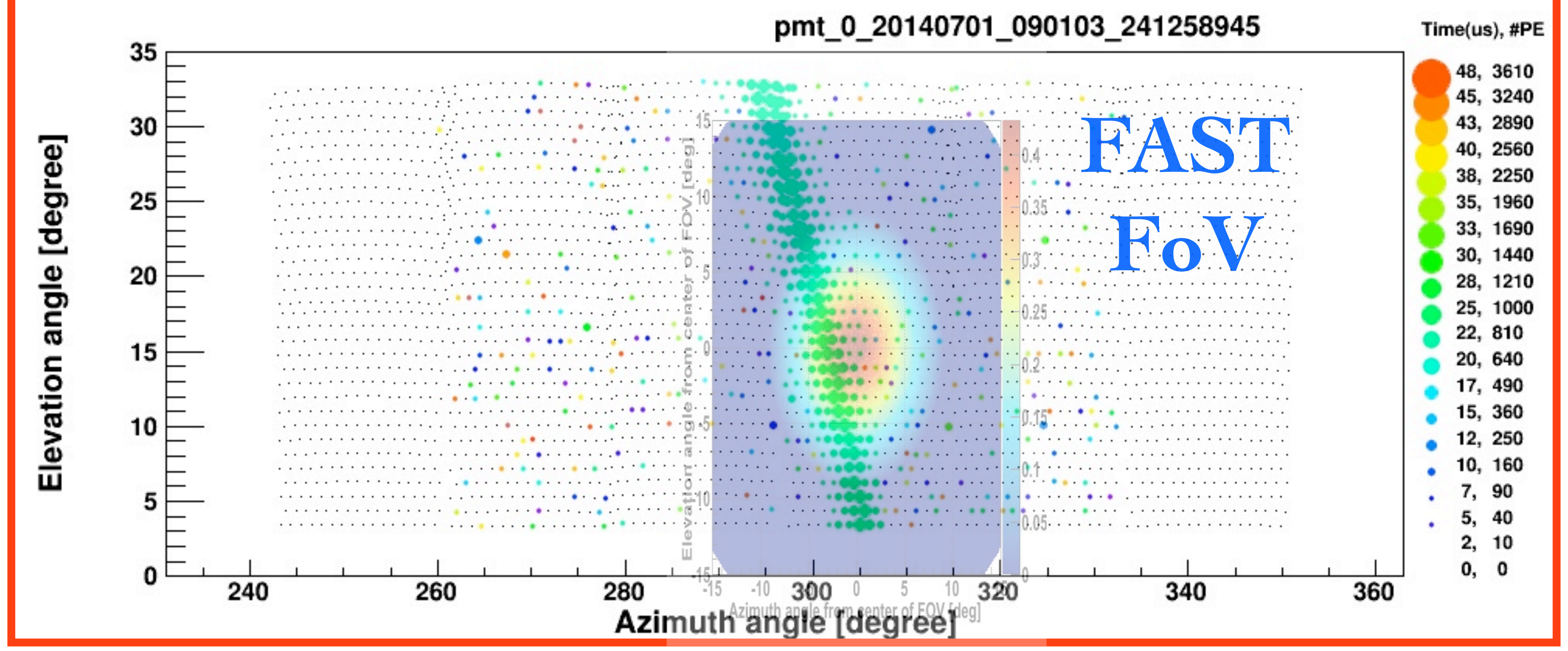
Distance vs Energy (from TAFD) for Candidates



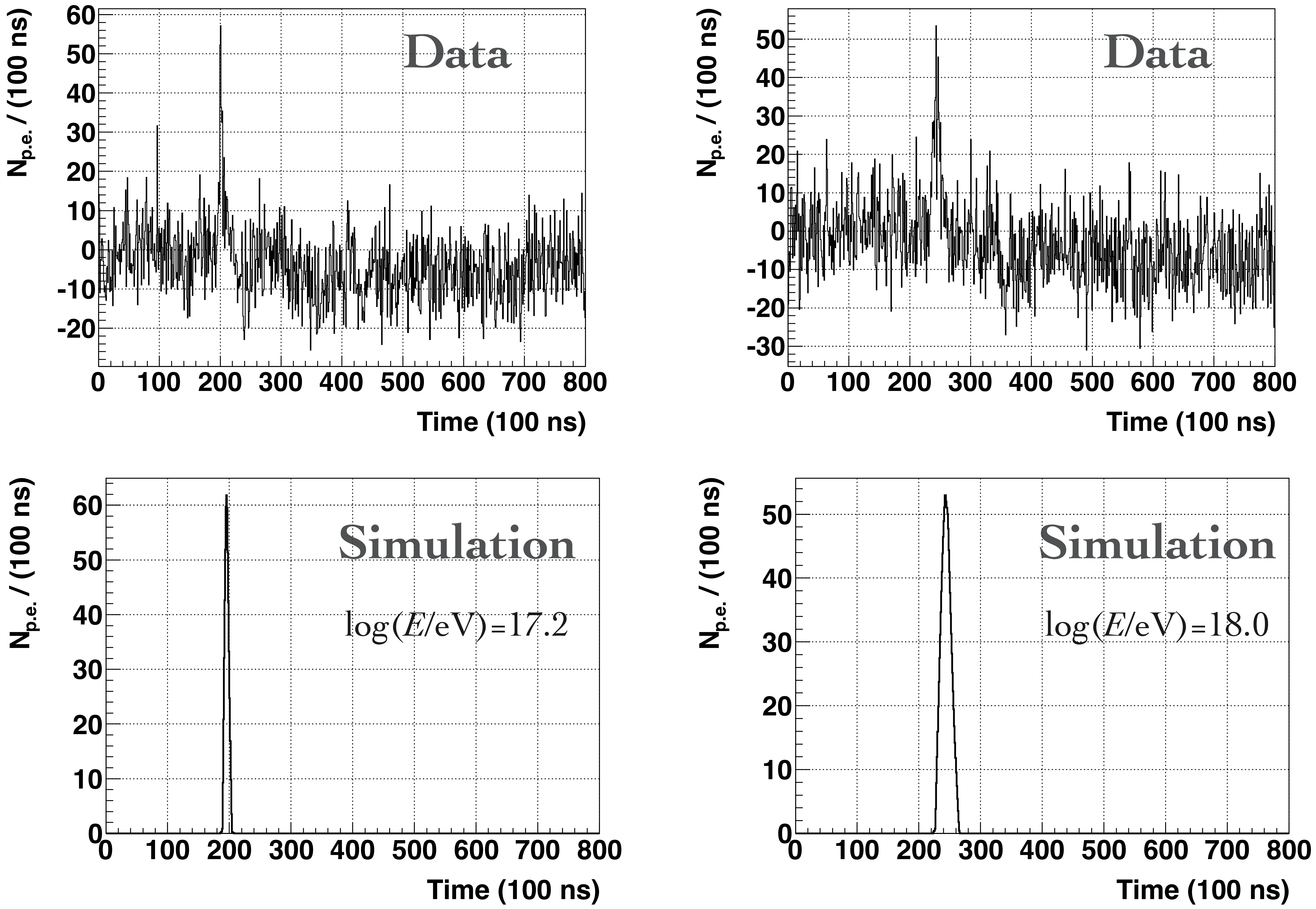


Almost! log(E/eV)=19.1





Comparison to Expected Signal from UHECRs

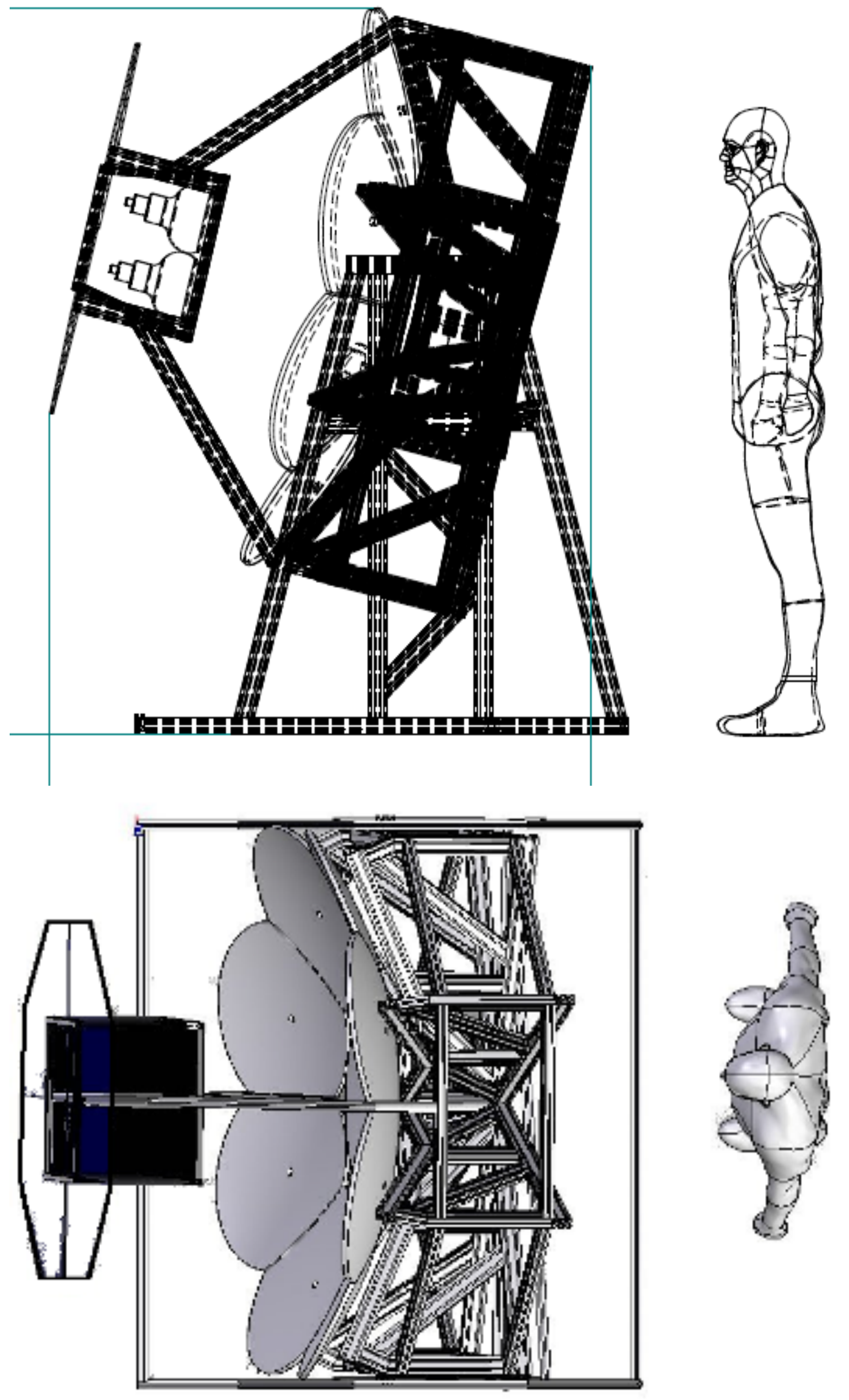


- Geometry, Energy and *X*max was reconstructed by the TAFD monocular analysis.
- Based on these information, we calculate expected signal by FAST prototype.
- Size, shape and width are consistent with expectation.
  - A signal location is fluctuated within the TAFD trigger frame of 12.8 μs.

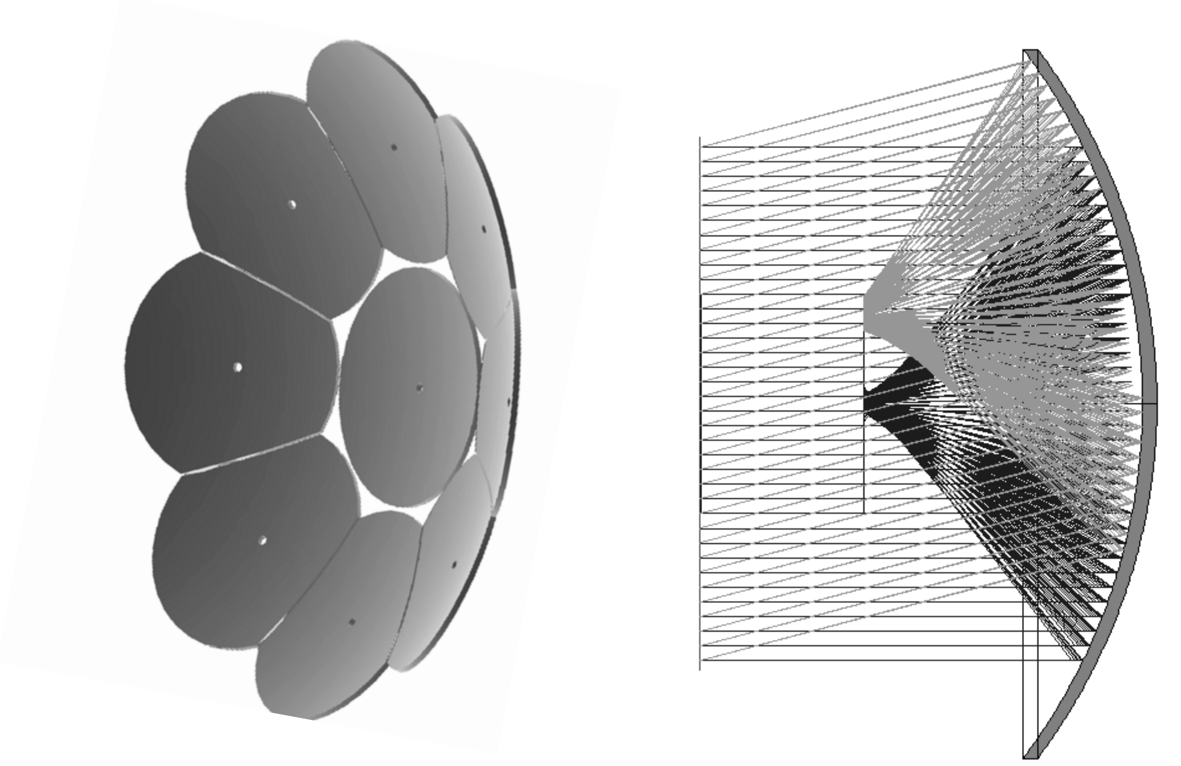
FAST
Fluorescence detector Array of Single-pixel Telescopes

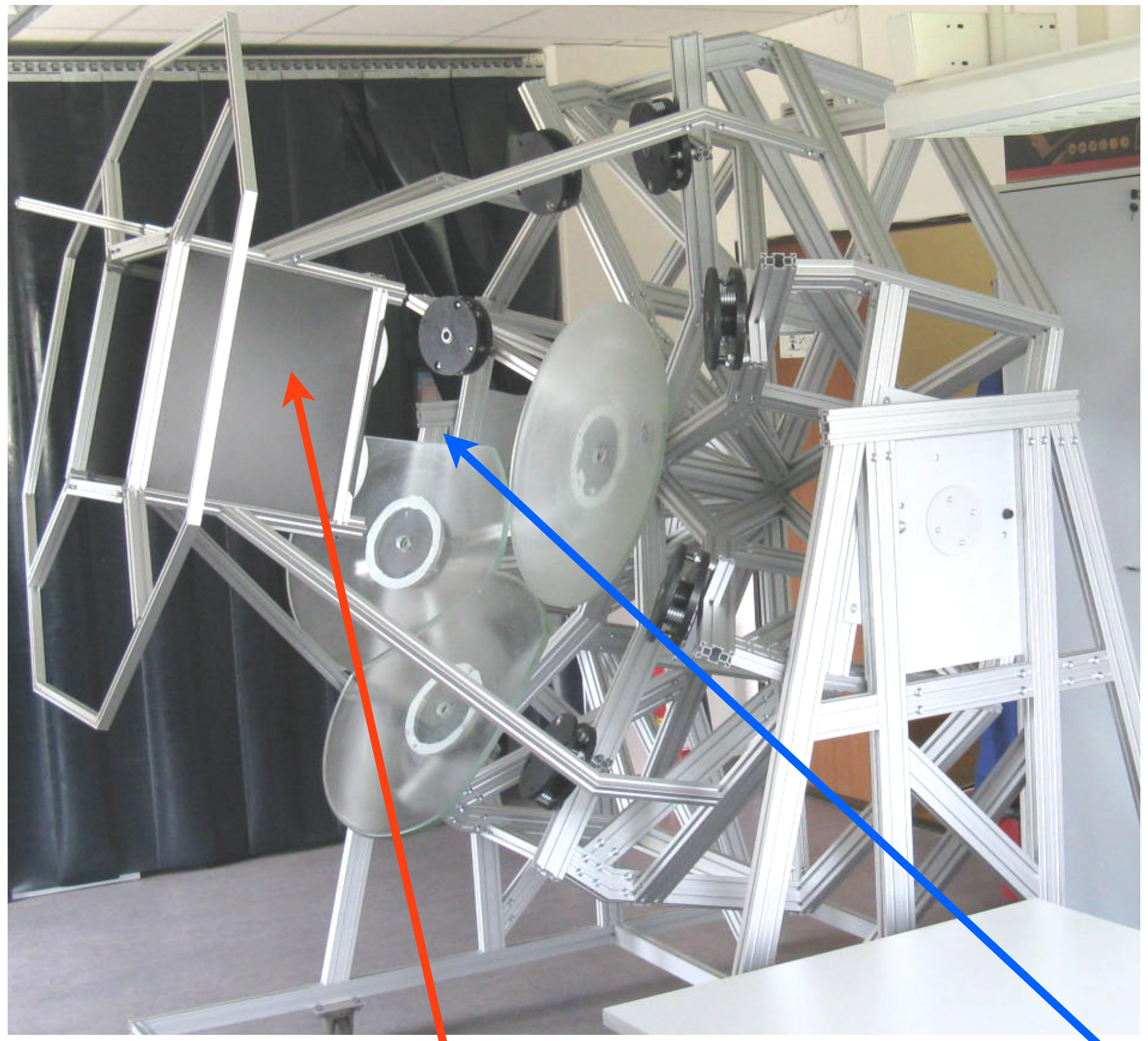
New FAST Prototype being Constructed

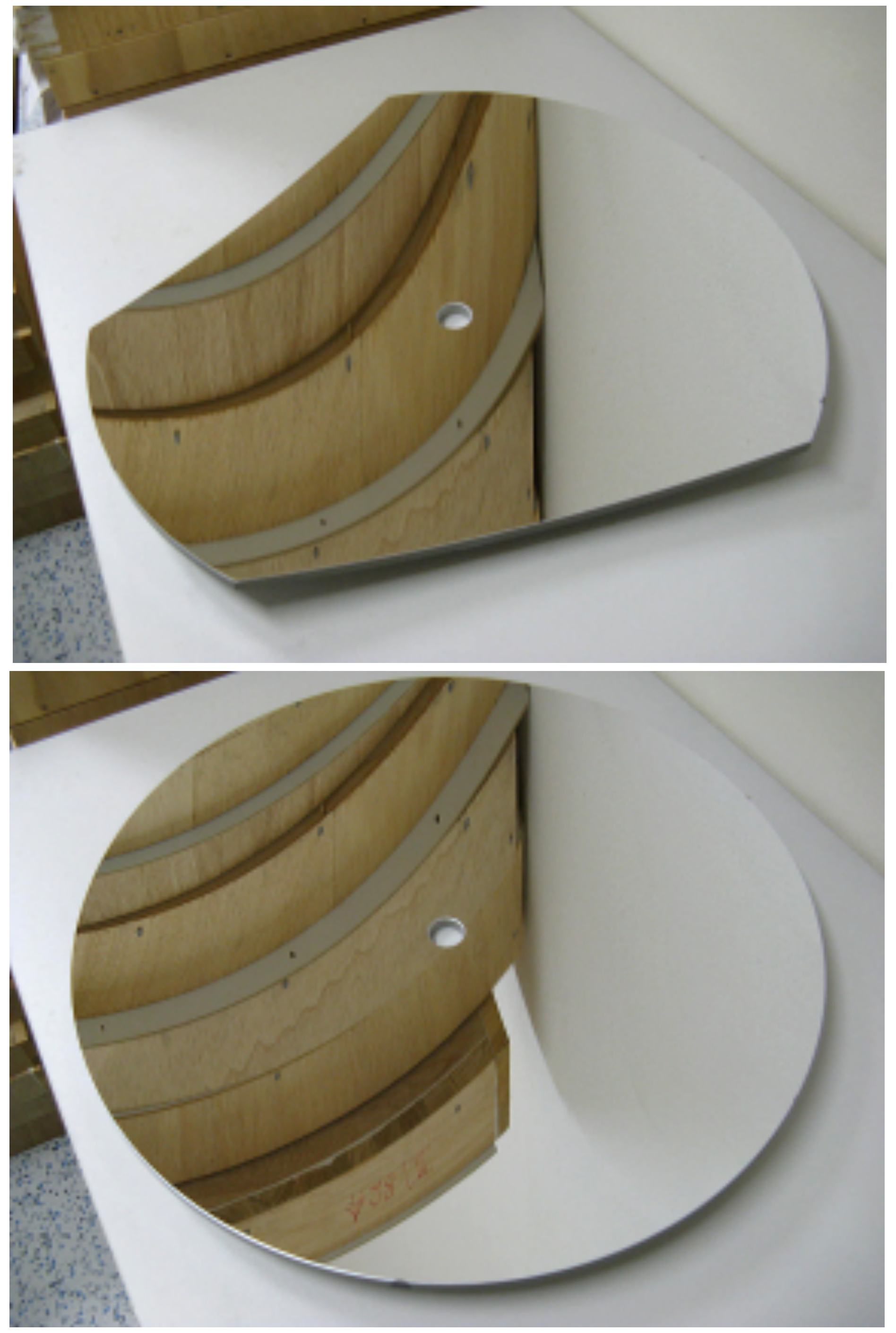
- **Confirmed milestones by EUSO-TA Telescope**
  - Stable operation under high night sky backgrounds.
  - UHECR detection.
- **Next milestones by new FAST prototype**
  - Establish the FAST sensitivity.
  - Detect a shower profile including ***X*max** with FAST

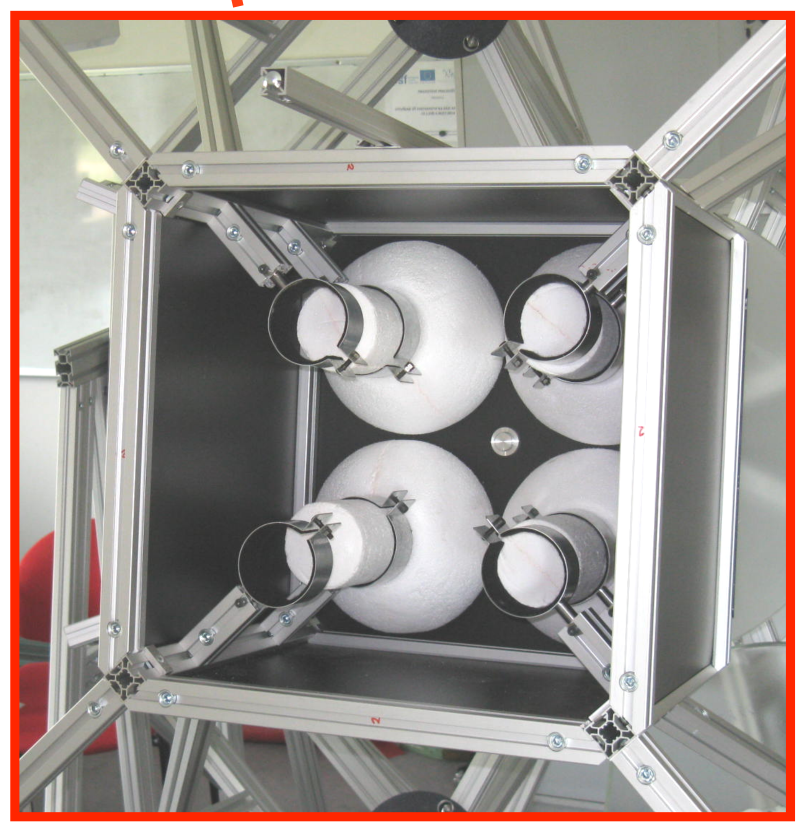


4 PMTs, 30°×30° FoV





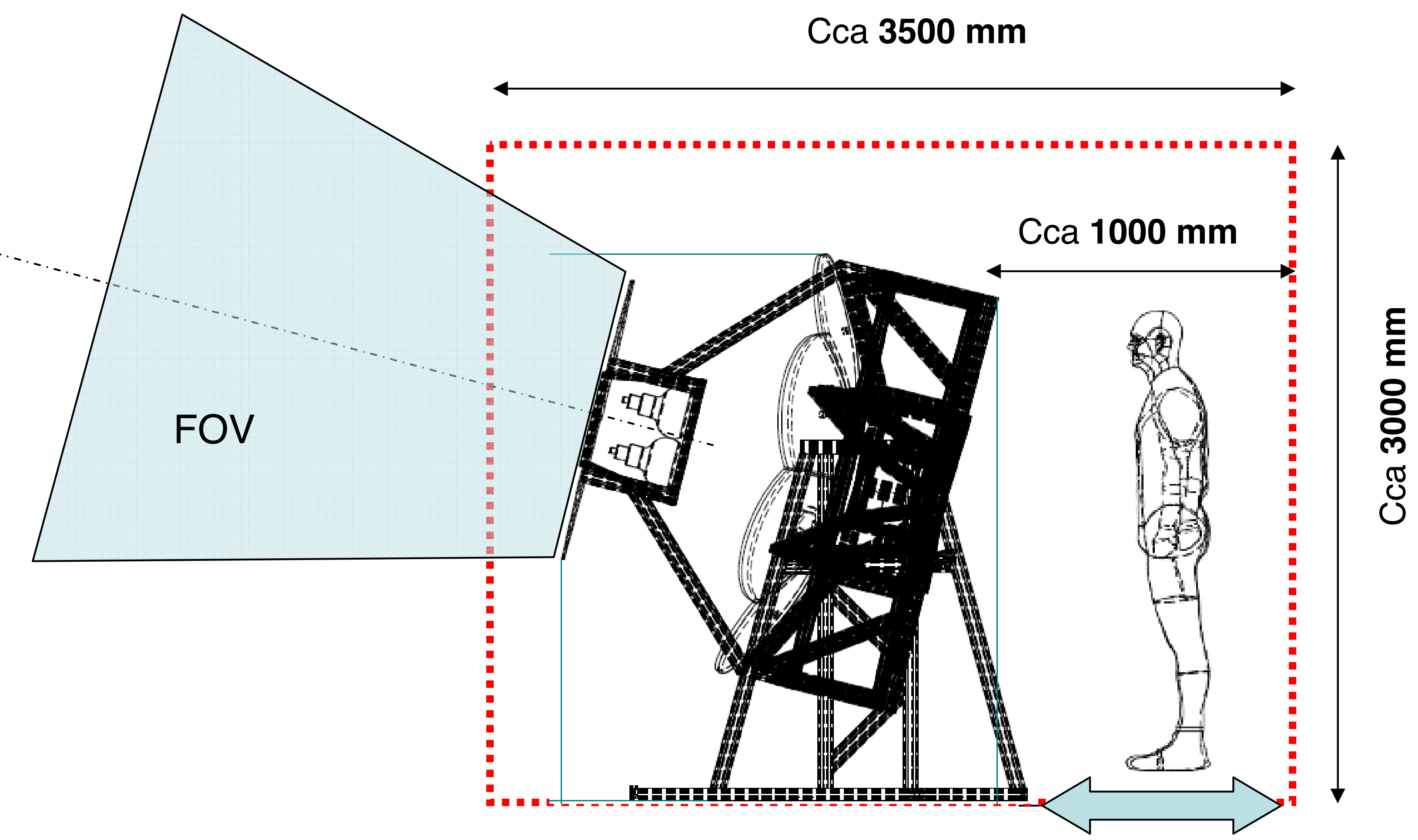


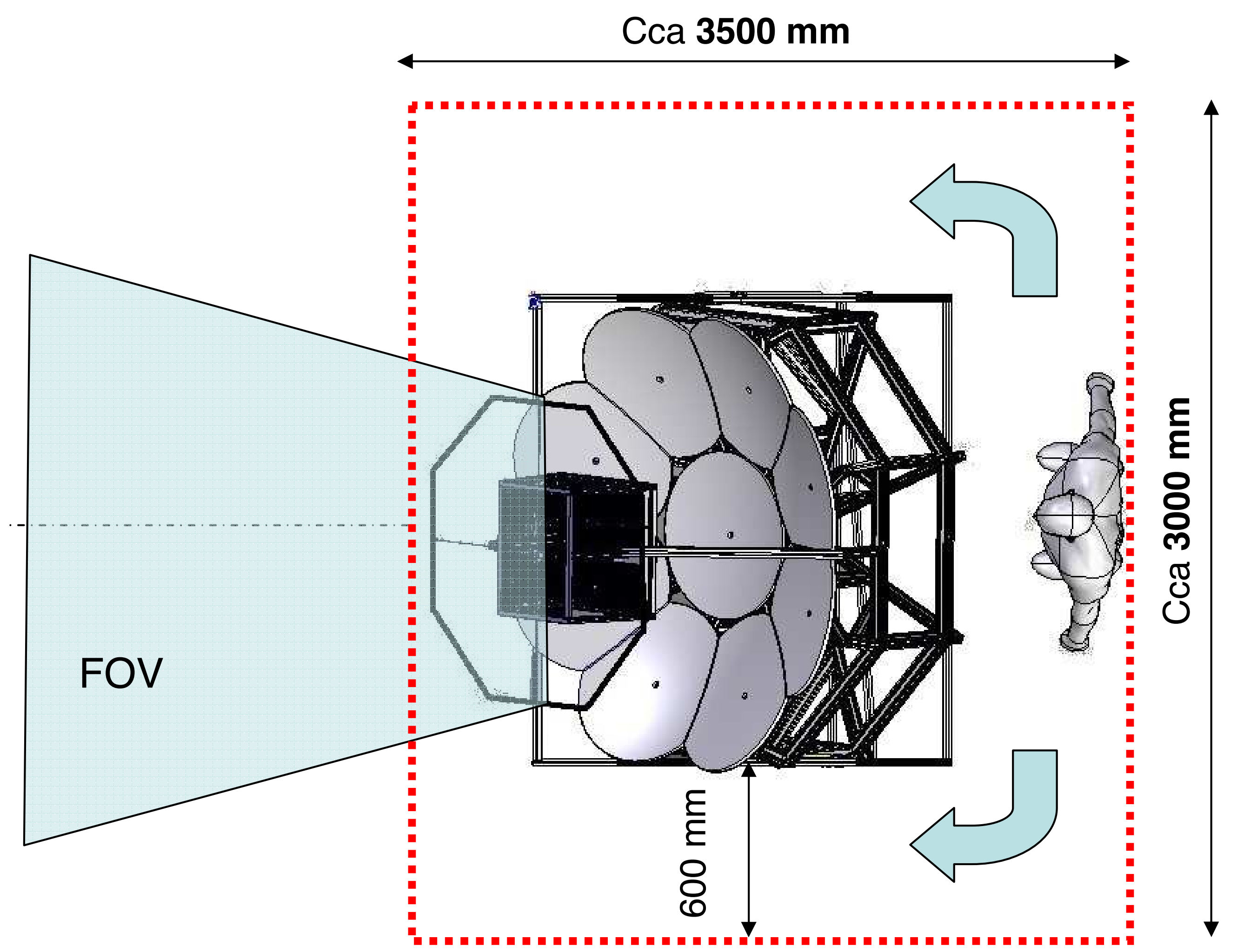


Joint Laboratory of Optics in Olomouc, Czech Republic

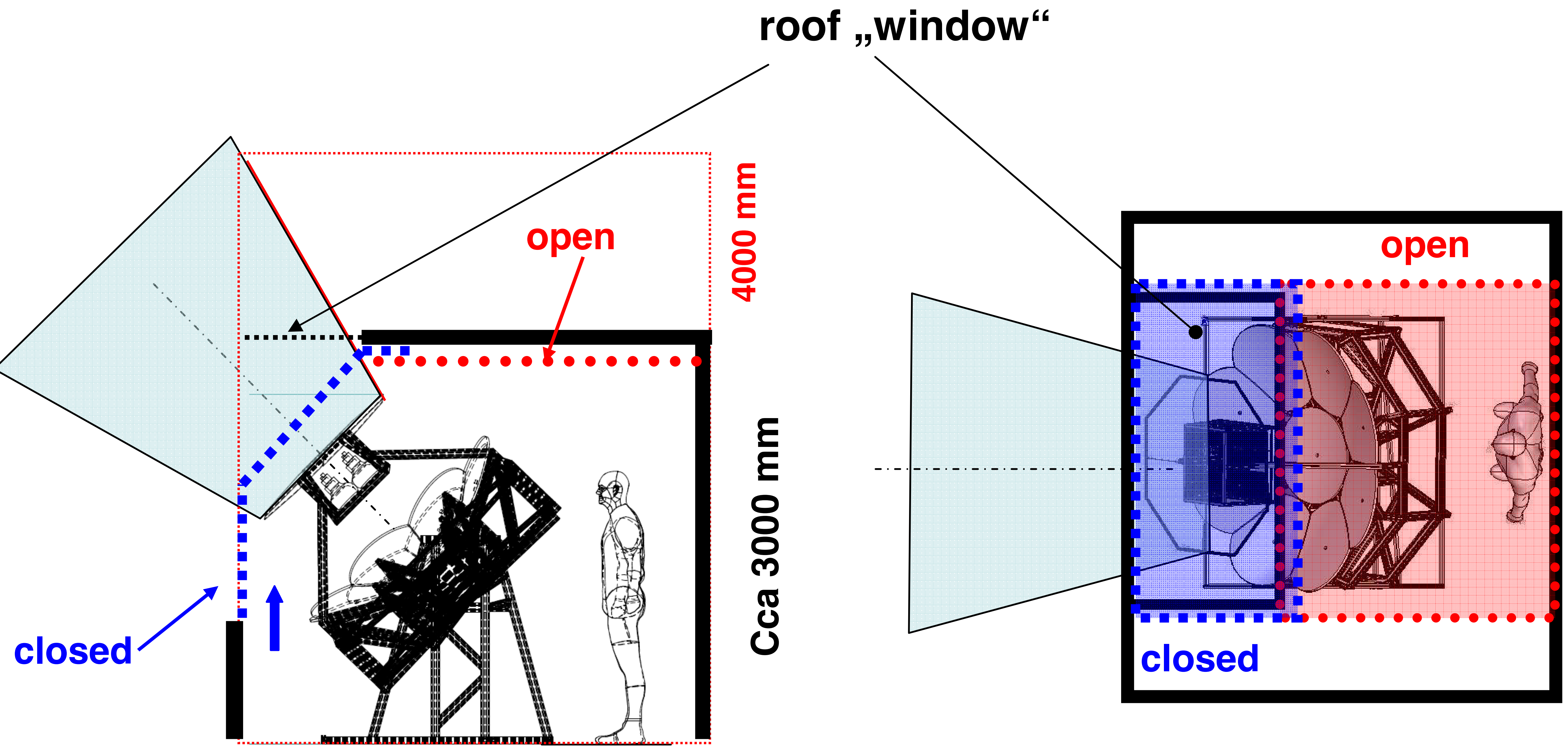
FAST
Fluorescence detector Array of Single-pixel Telescopes

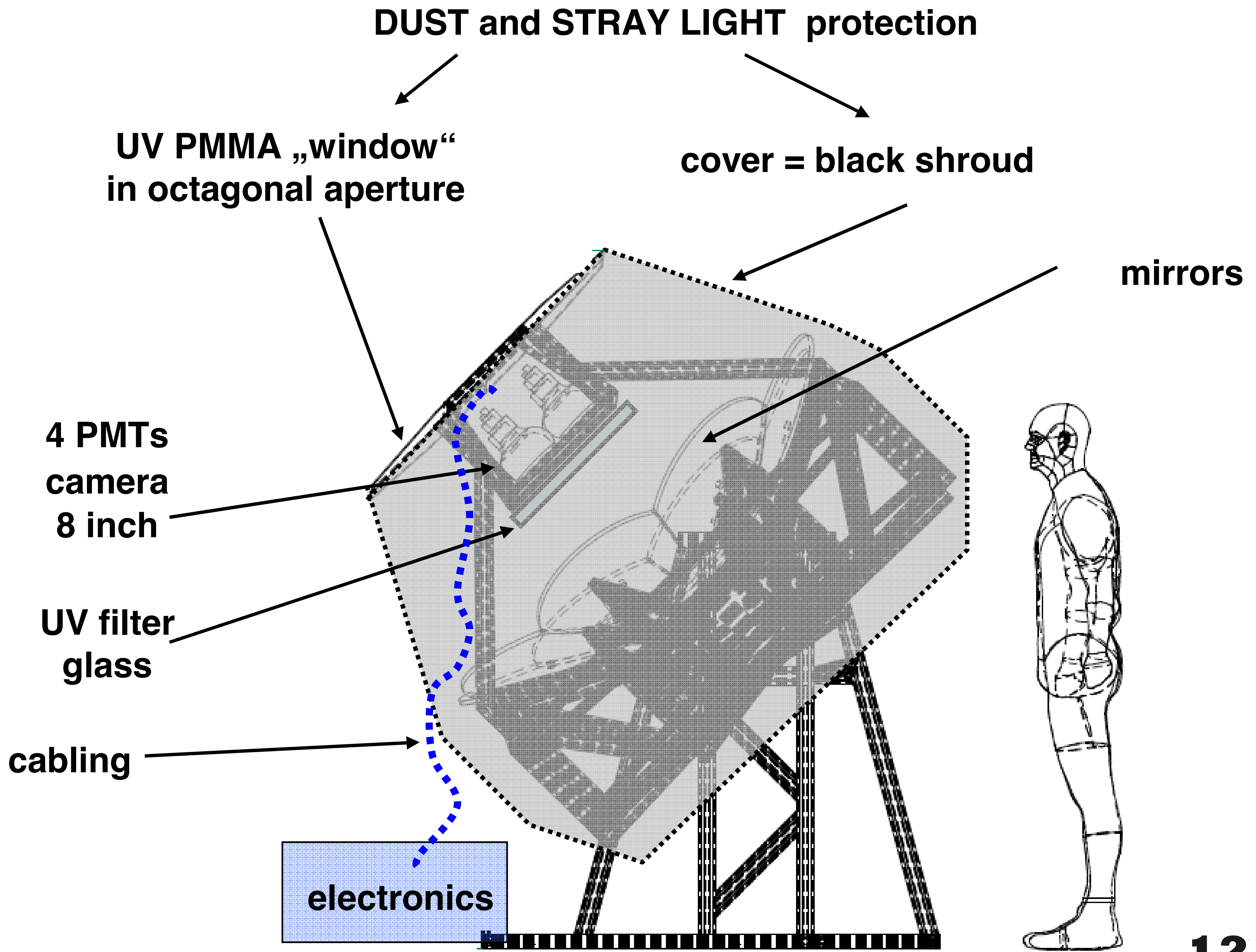
Design of Hut and Shutter





- ✦ 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.

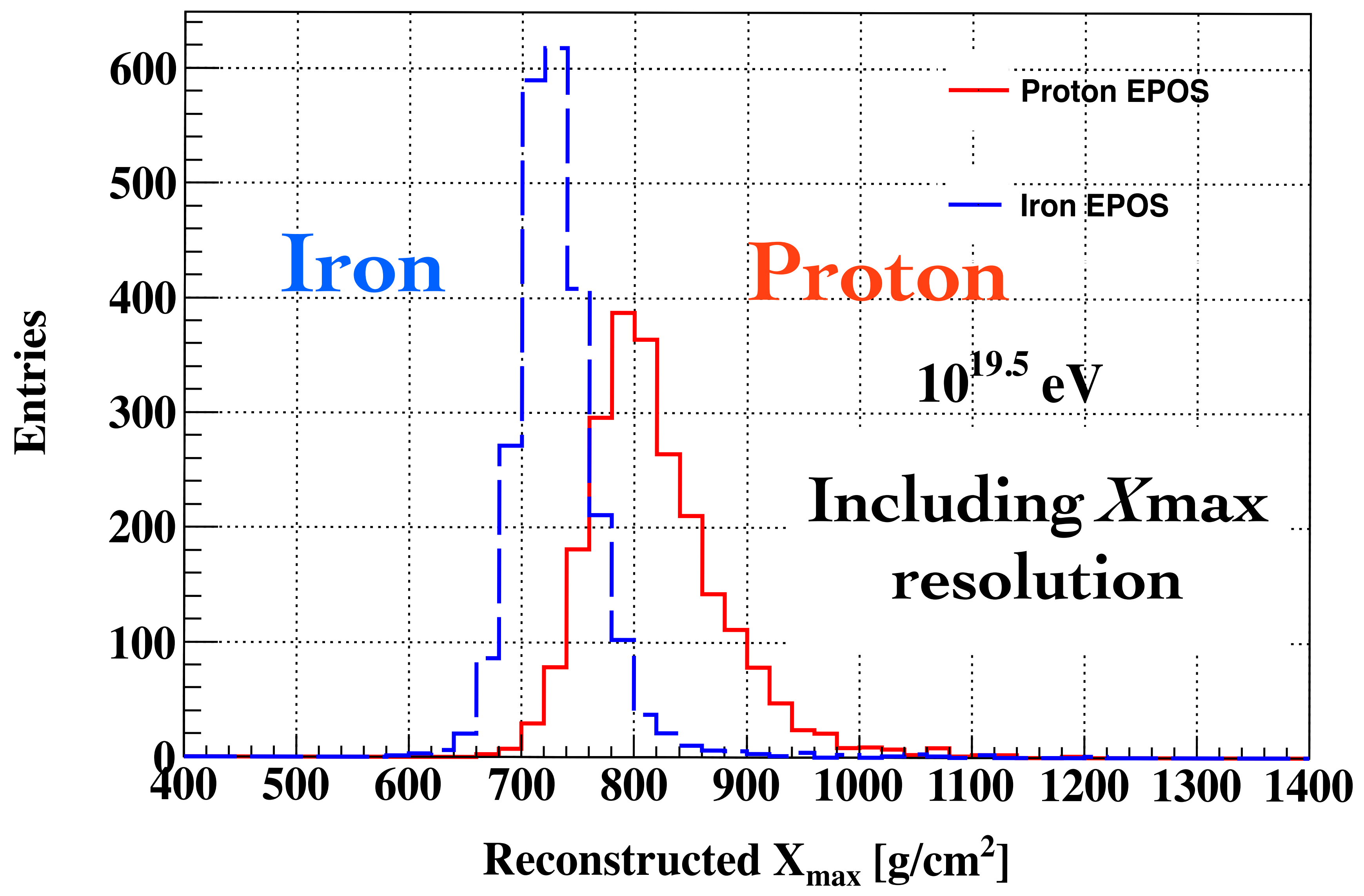


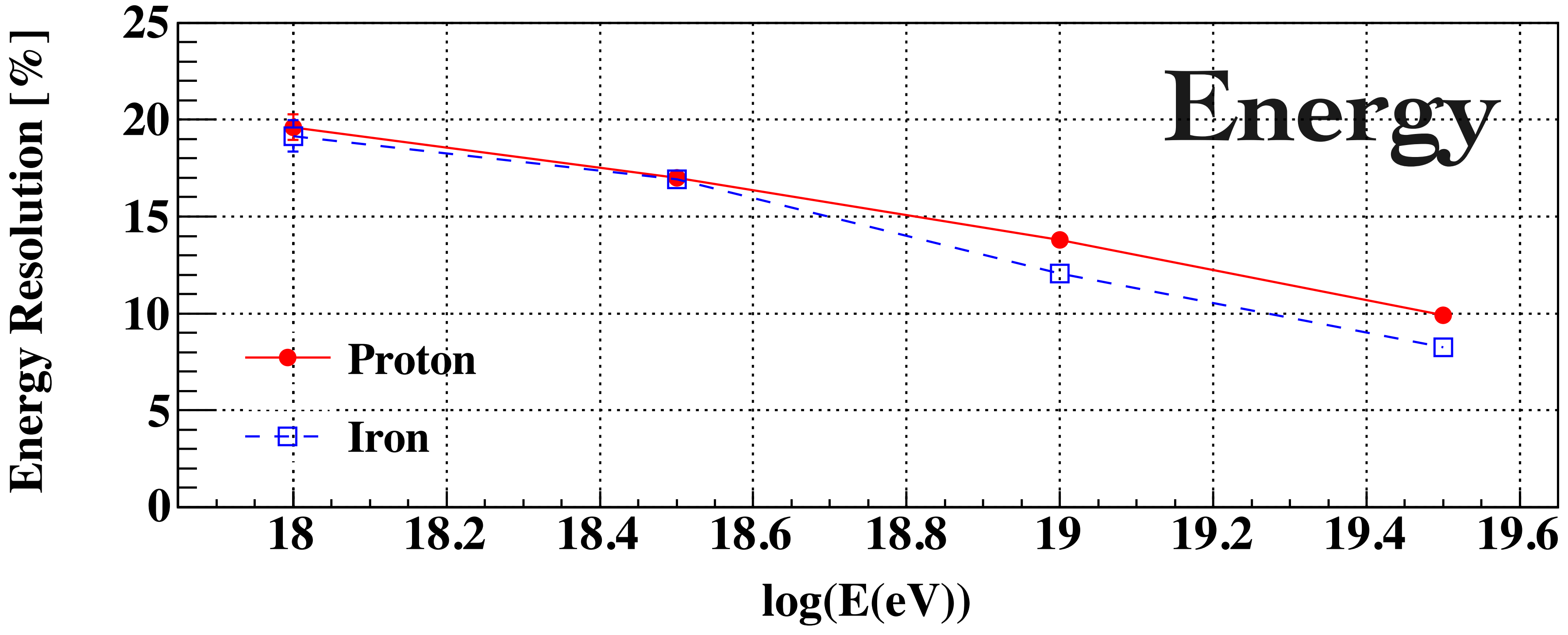


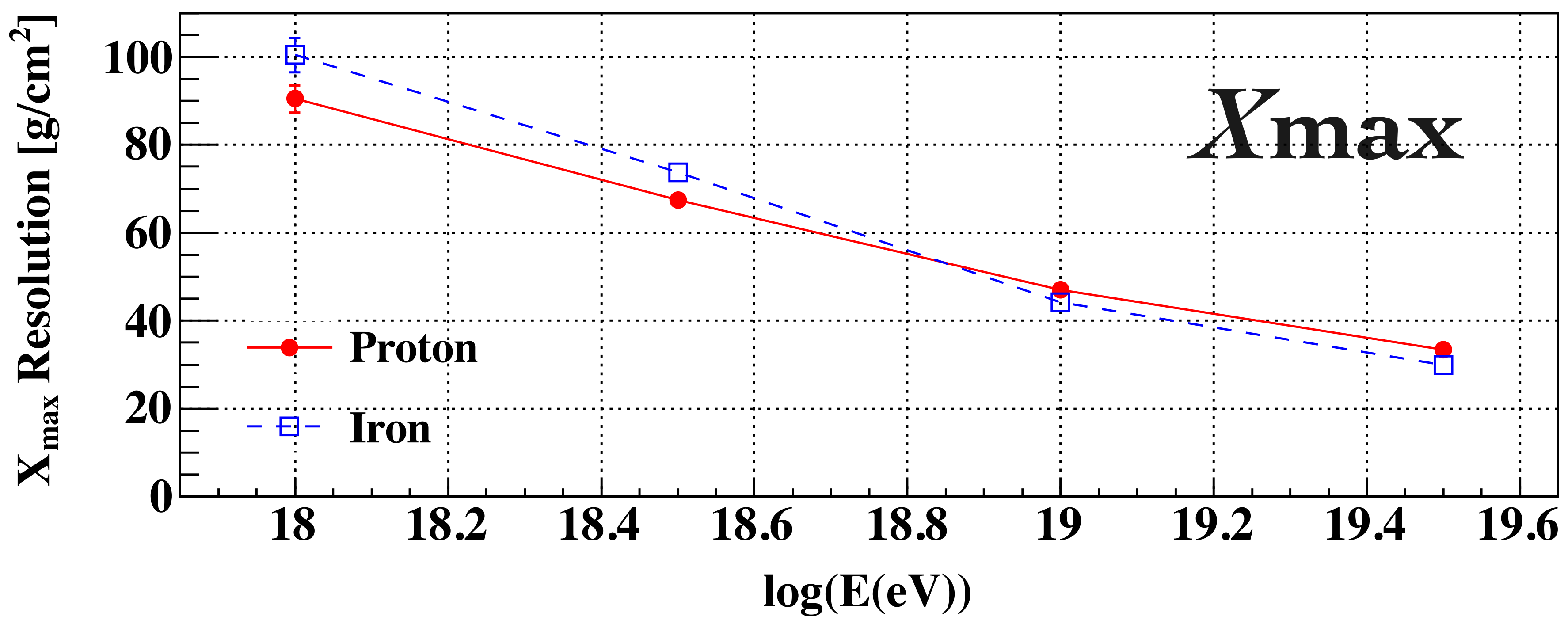
Possible Application of FAST Prototype

Fluorescence detector Array of Single-pixel Telescopes

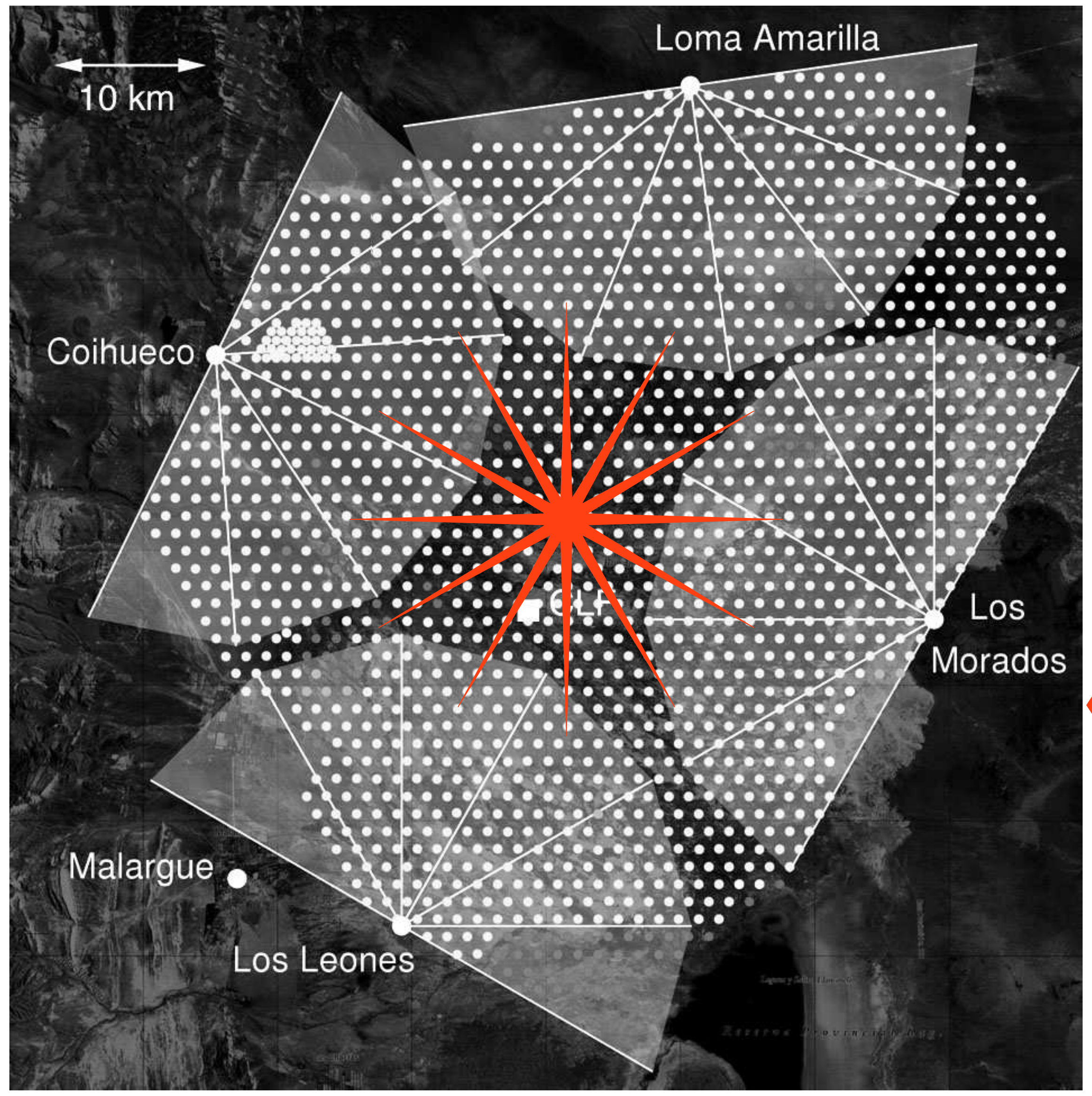
- Install FAST at Auger and TA for a cross calibration.
- Profile reconstruction with geometry given by SD (1° in direction, 100 m in core location).
  - Energy: 10%, *X*max : 35 g/cm^2 at $10^{19.5}$ eV
  - Independent check of **Energy and *X*max** scale between Auger and TA





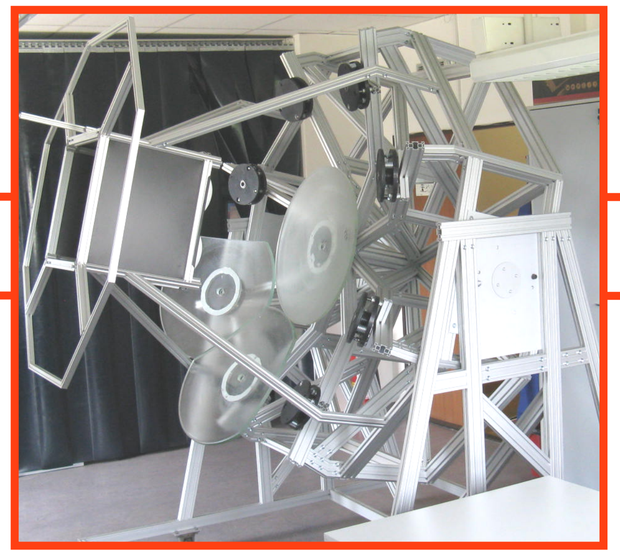


Pierre Auger Observatory

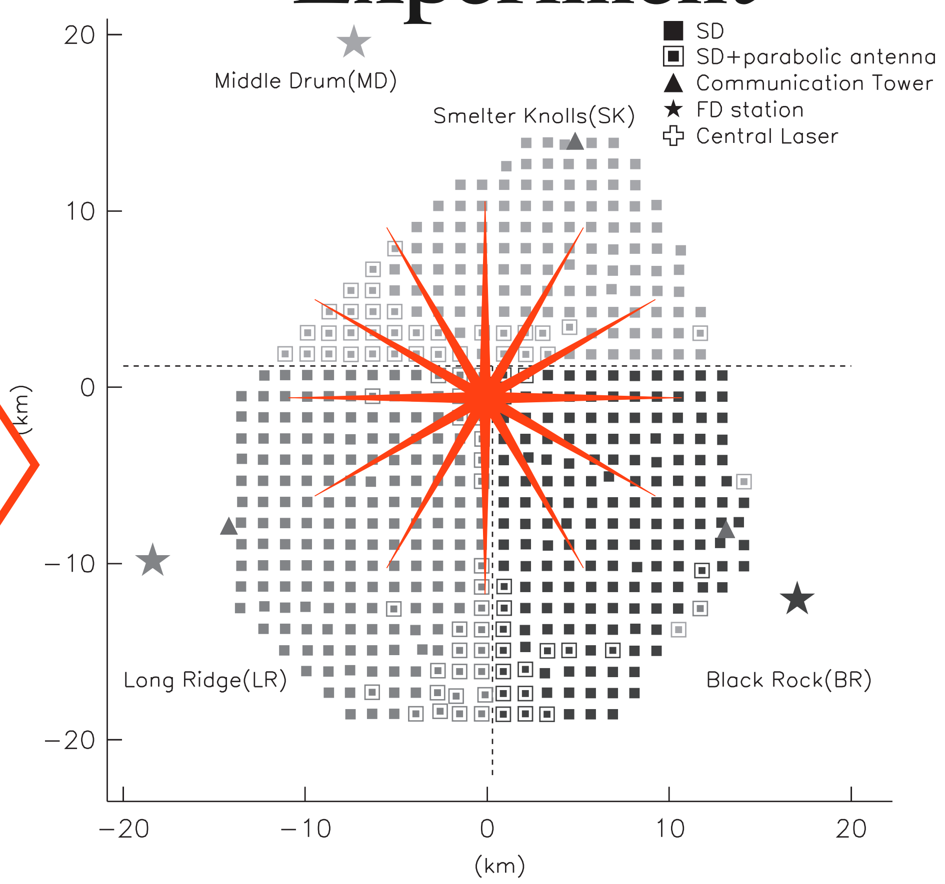


Pierre Auger Collaboration, NIM-A (2010)

Identical simplified FD



Telescope Array Experiment

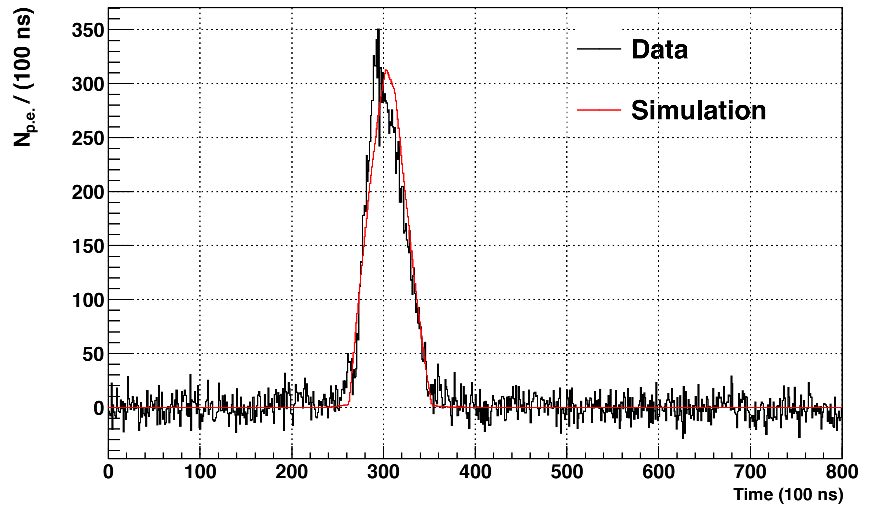


Telescope Array Collaboration NIM-A (2012)

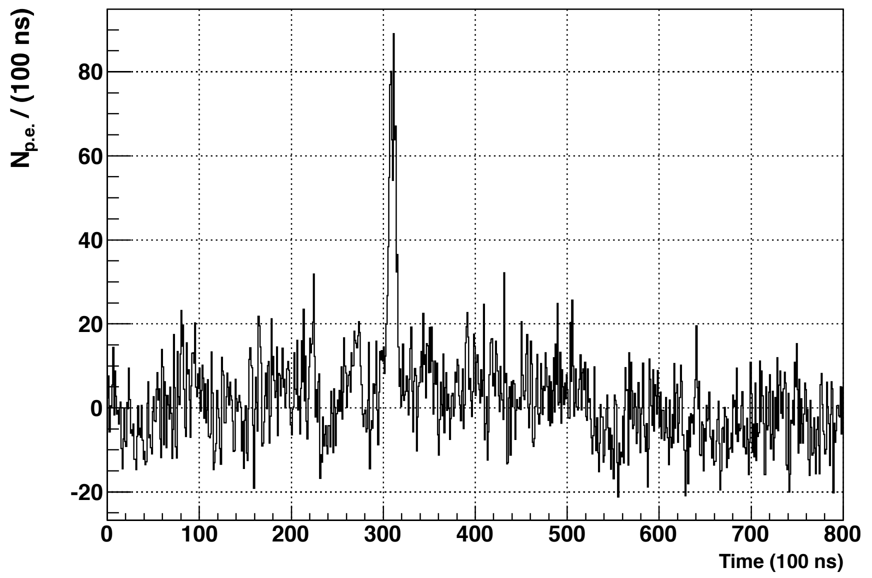
FAST
Fluorescence detector Array of Single-pixel Telescopes

Summery and Future Plans

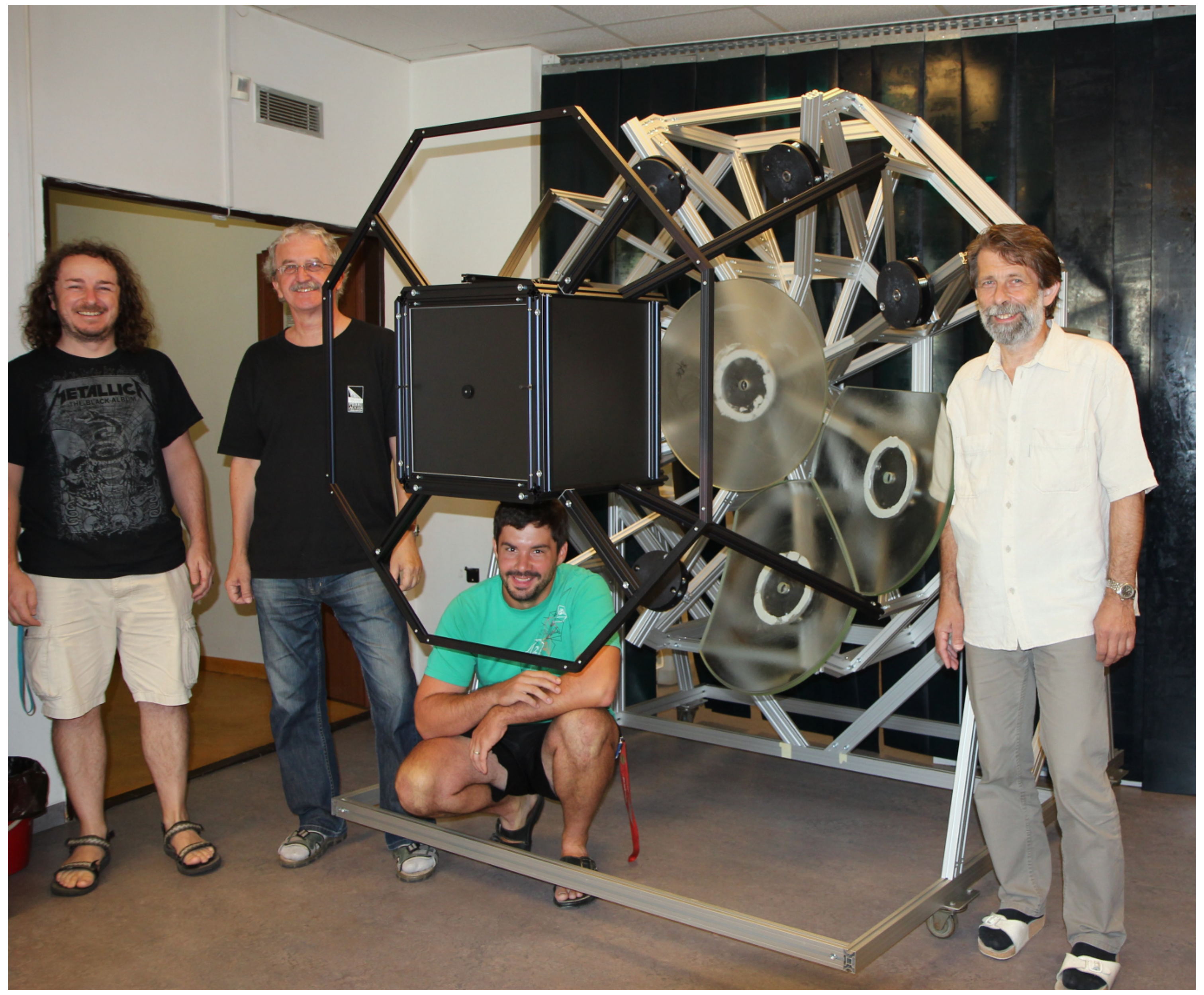
- A novel technique to observe UHECRs: Low-cost simplified and optimized FD array.
- Confirmed milestones from the first field test of FAST concept using EUSO-TA telescope:
  - Laser shots and UHECR candidates detected.
  - Stable operation under large night sky backgrounds.
- Very successful example among Pierre Auger, Telescope Array, JEM-EUSO Collaborations.
- Next milestones: detect a shower profile of UHECRs including ***X*max** with new FAST prototype being constructed.
- New collaborators are welcome.



Laser



UHECR



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PoS (ICRC2015) 323　　**arXiv: 1504.00692**

Backup

Fluorescence detector Array of Single-pixel Telescopes

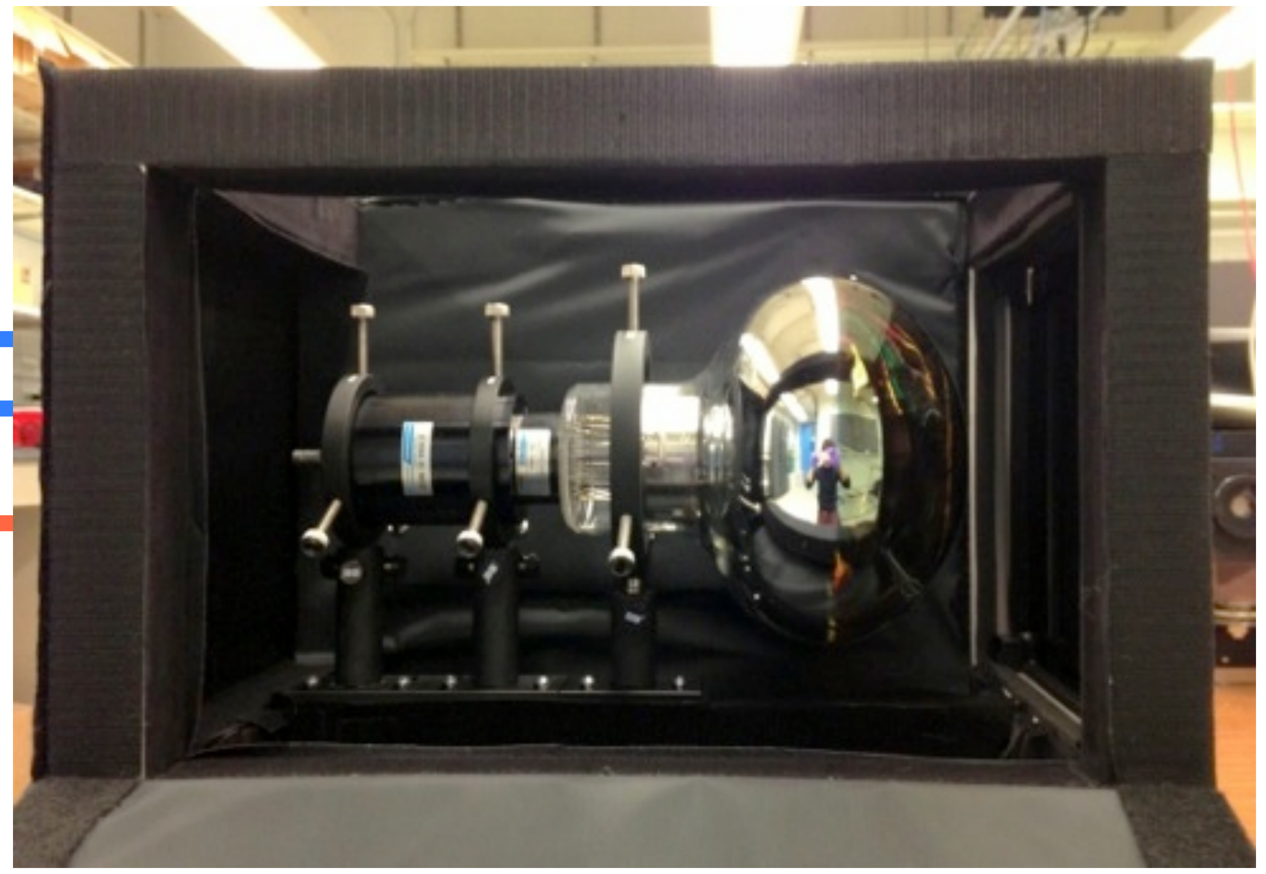
Fluorescence detector Array of Single-pixel Telescopes

FAST DAQ System

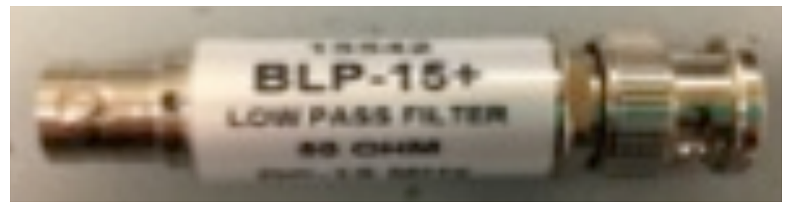
TAFD external trigger, 3~5 Hz

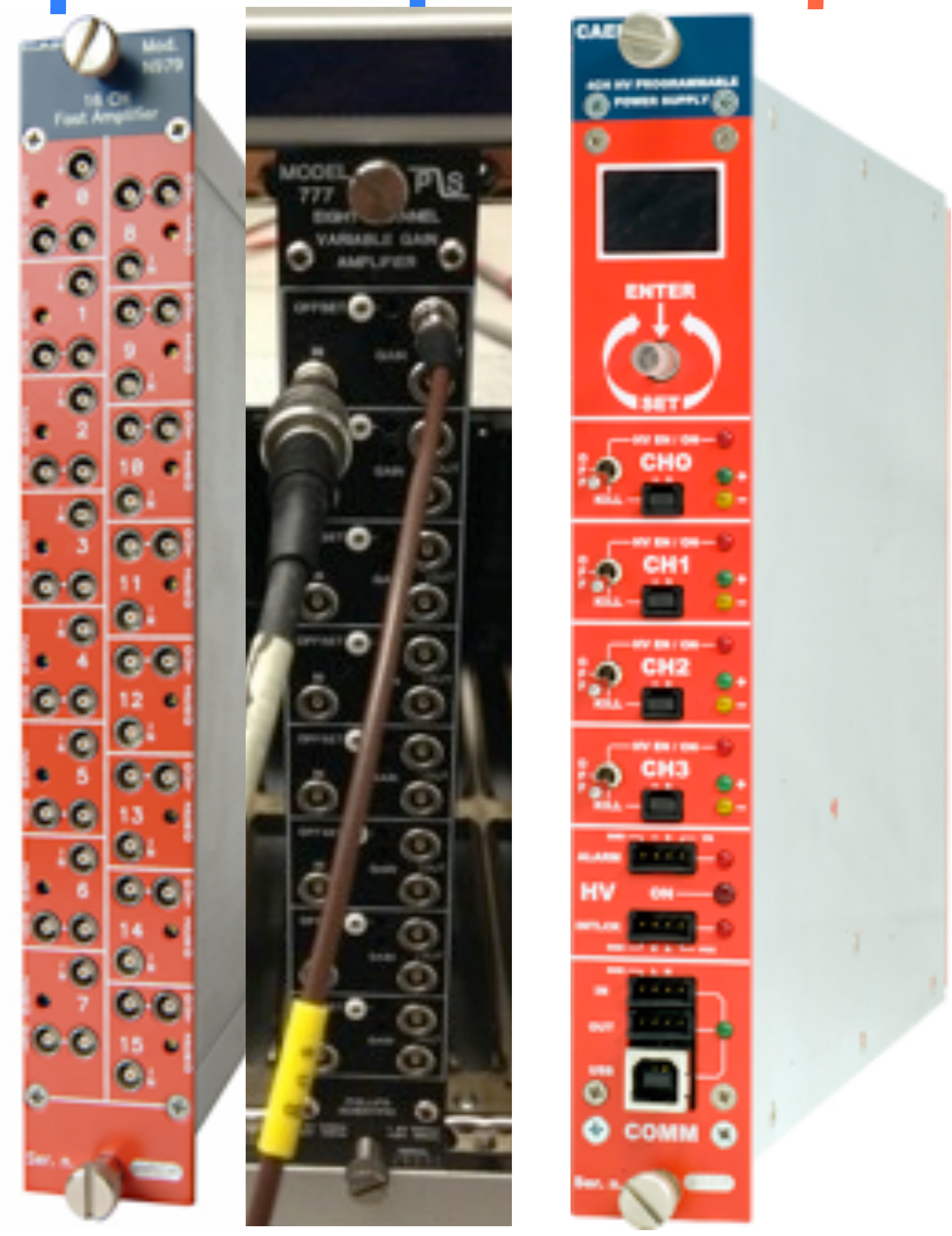
Anode & dynode Signal

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

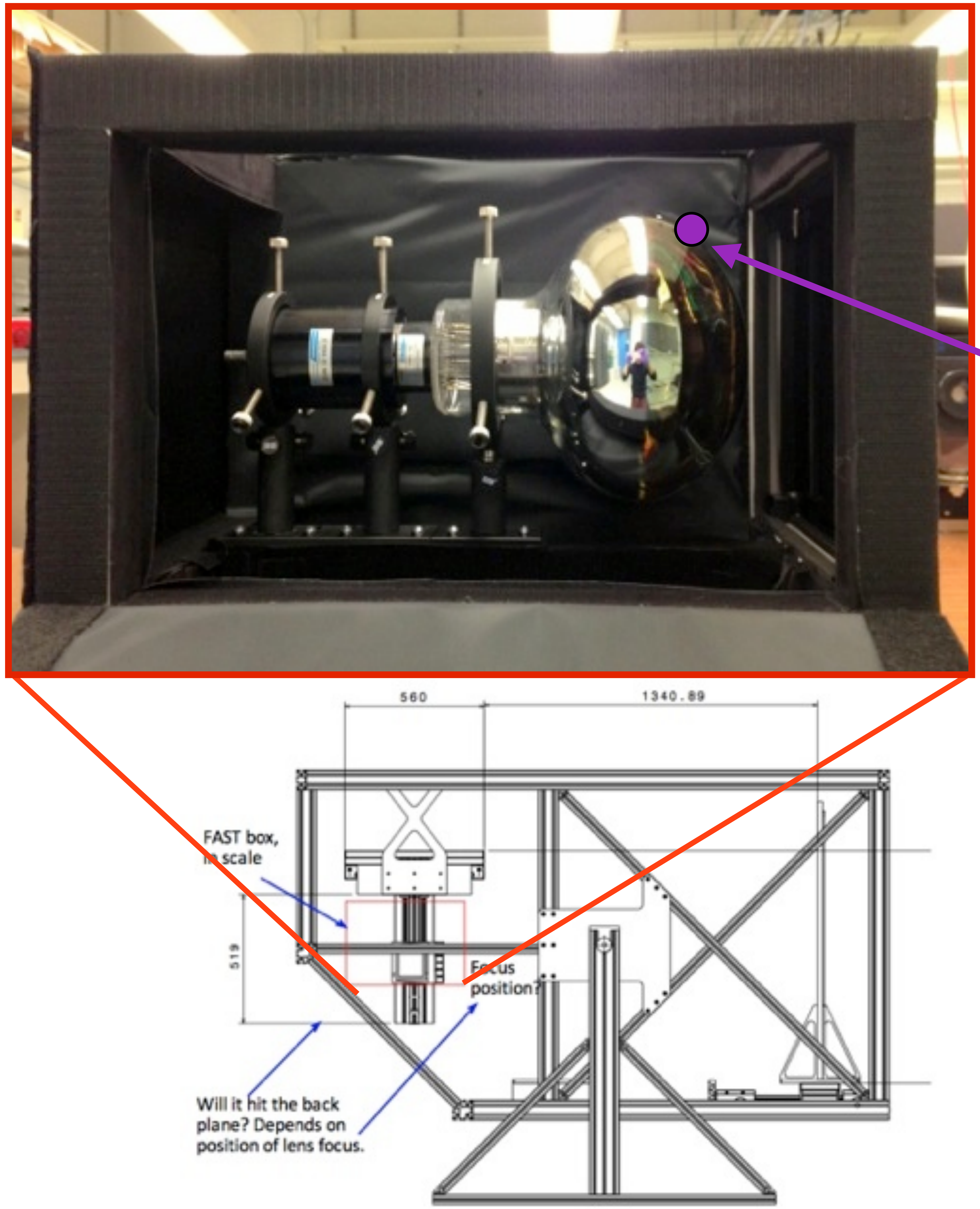
Amplifiers
R979 CAEN
Signal×10

777,Phillips scientific
Signal×50

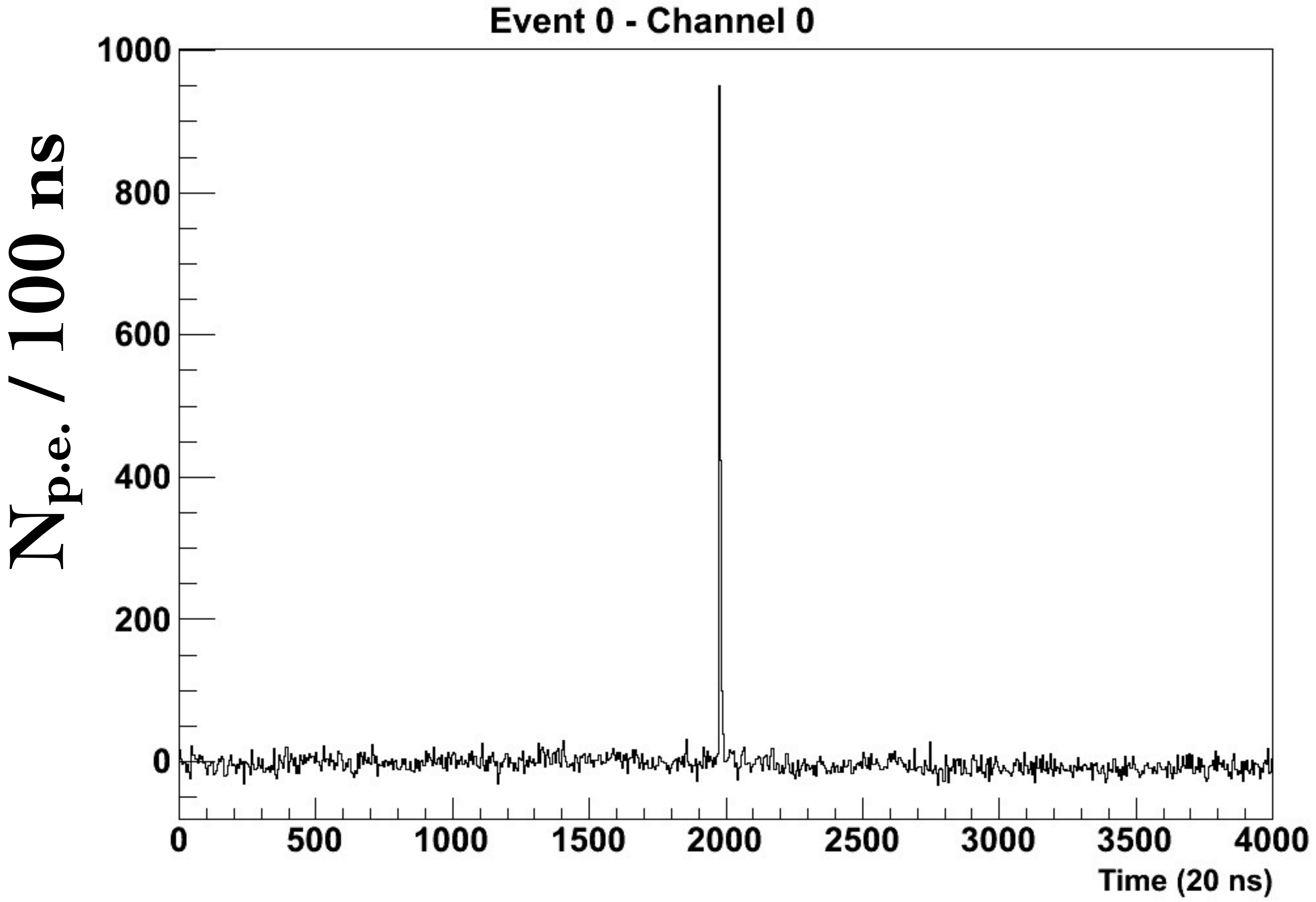
Fluorescence detector Array of Single-pixel Telescopes

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 ($YAlO_3$: Ce) scintillator with ^{241}Am (50 Hz) to monitor gain stability.

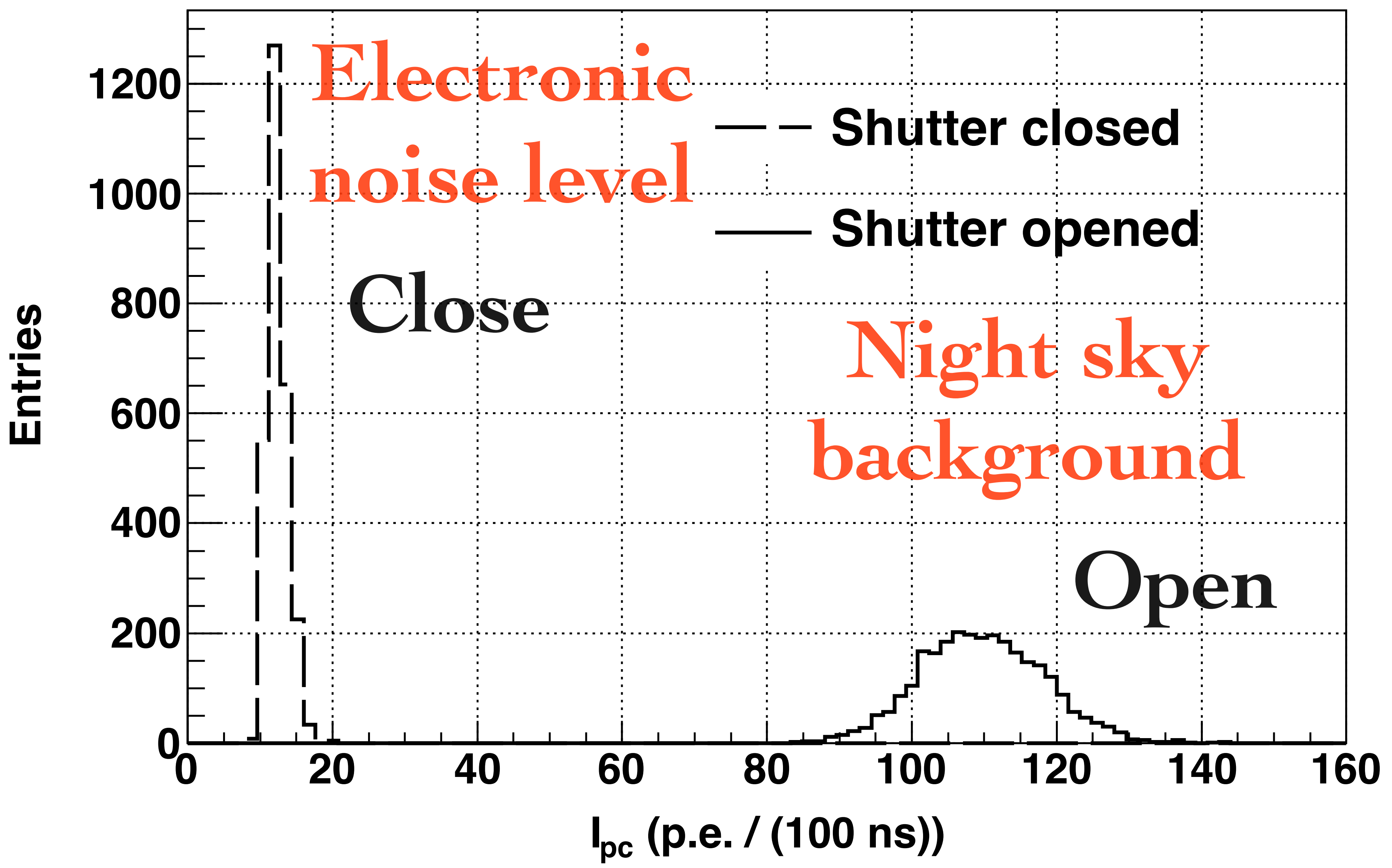


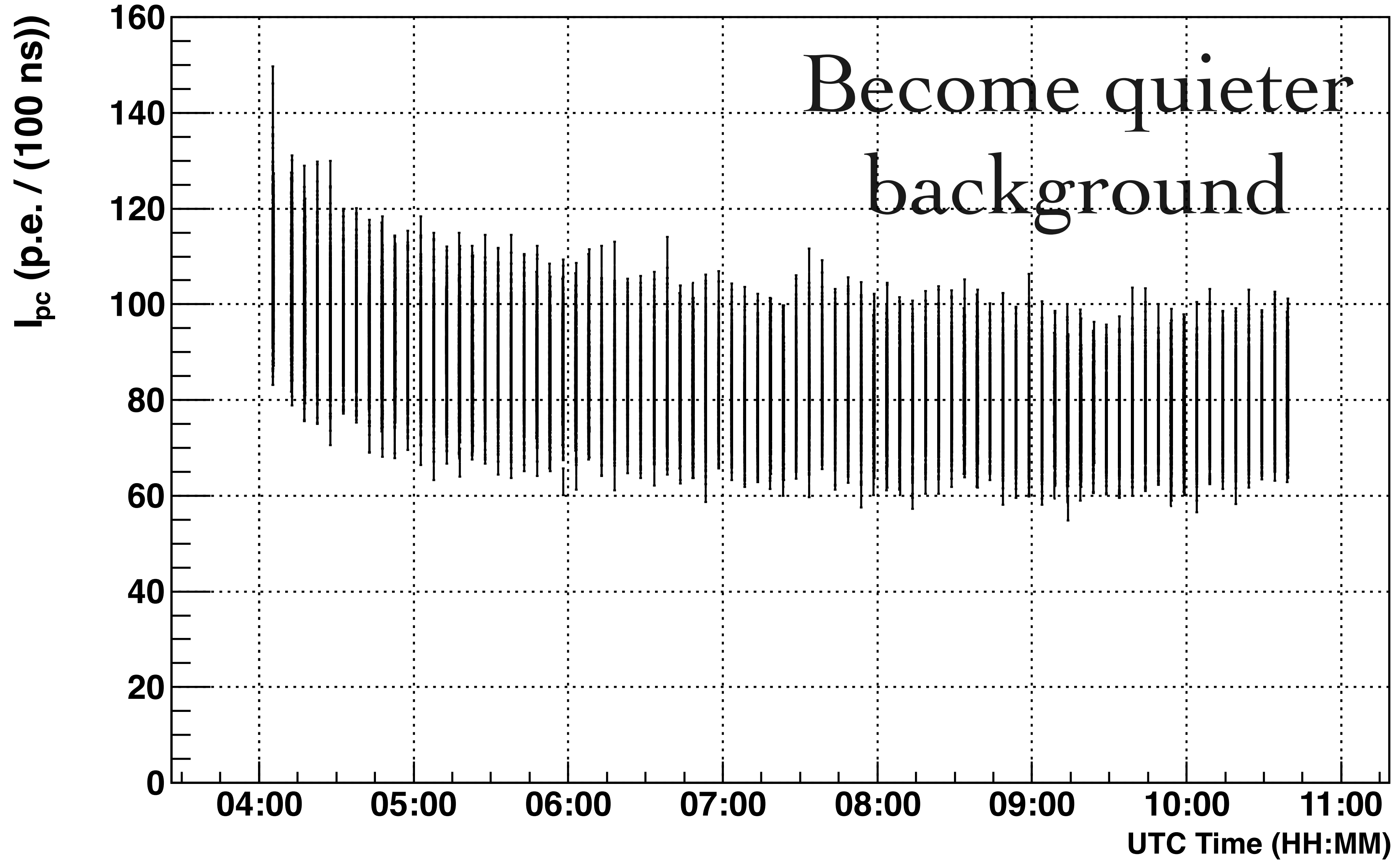
YAP Signal

Operation in Night Sky Backgrounds

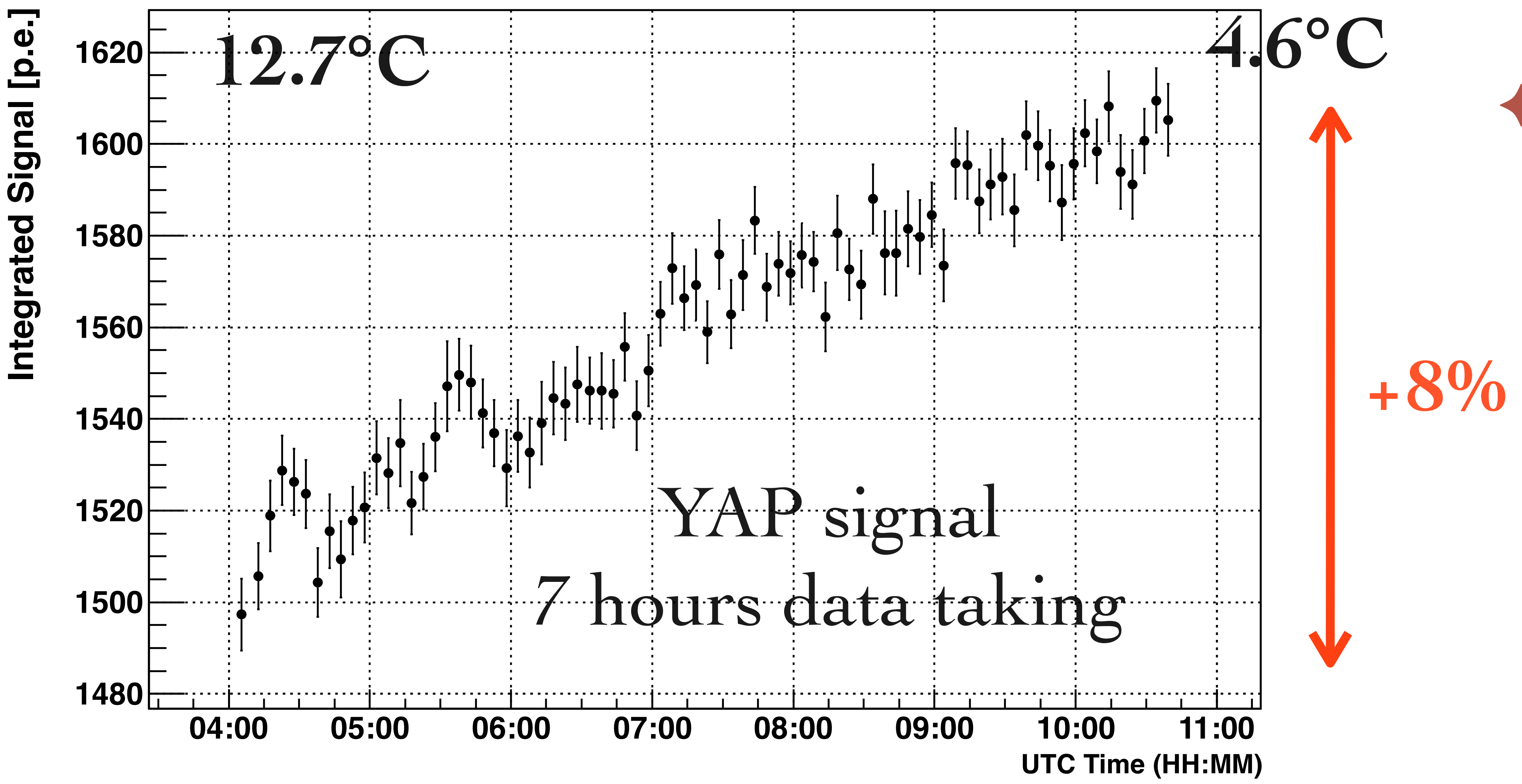
Fluorescence detector Array of Single-pixel Telescopes

Current monitor





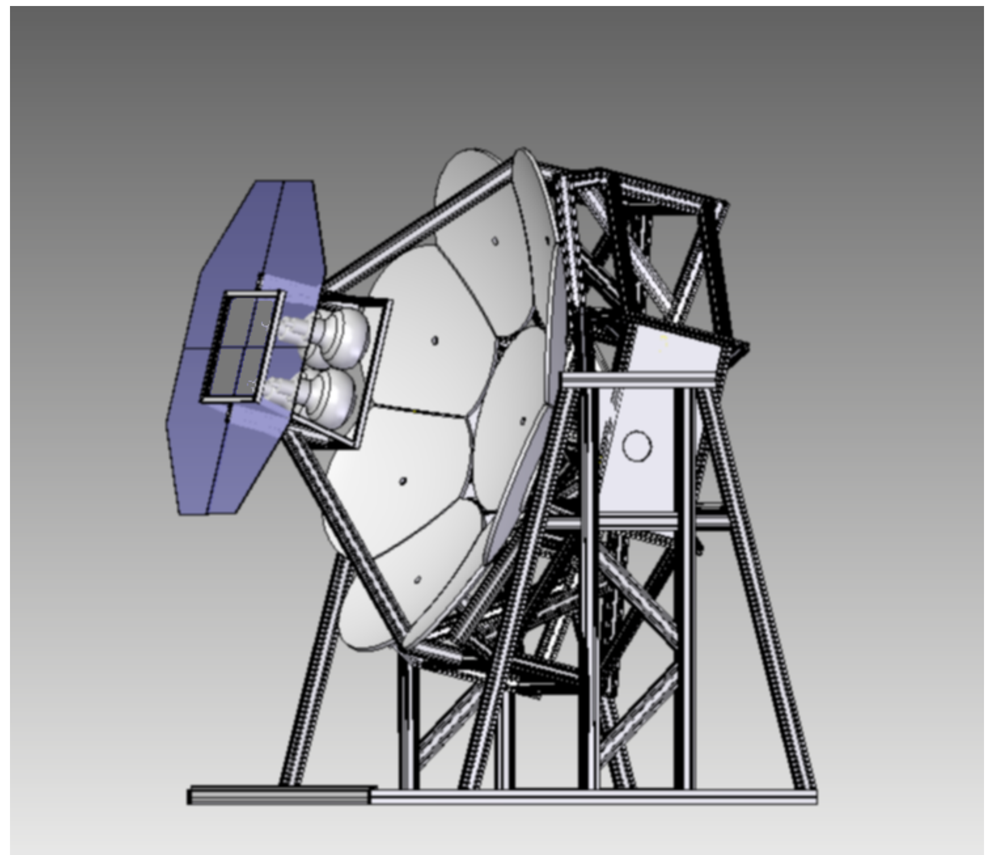
YAP signal

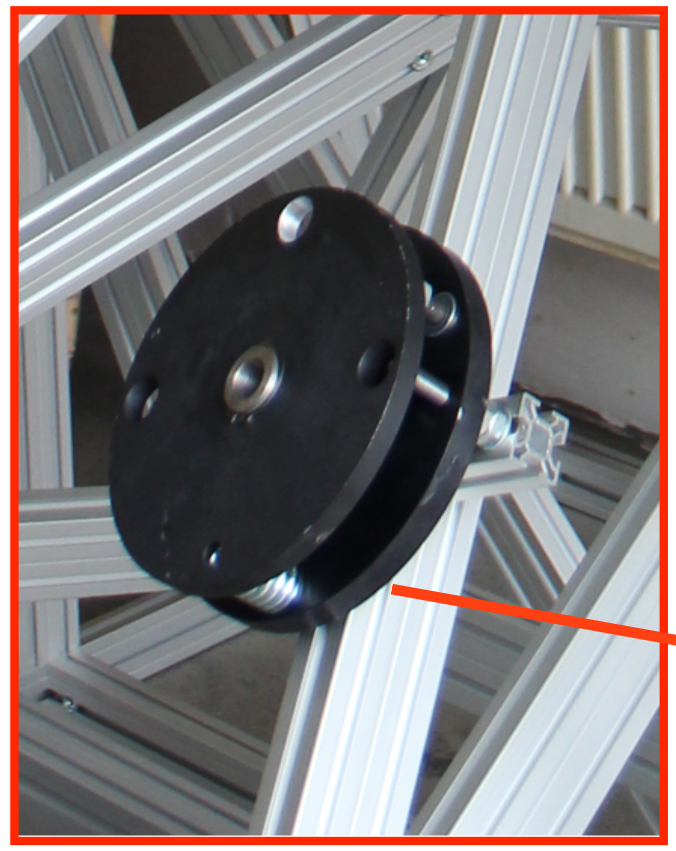


- Variance is proportional to PMT current. Electronic noise is negligible with regard to night sky background.
- Good gain stability during data taking, consistent with PMT gain temperature dependence of -1%/℃

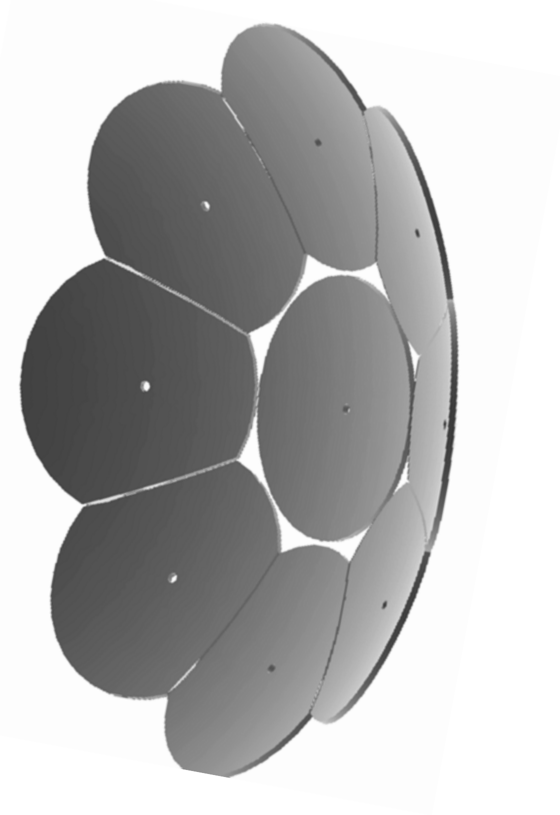
Mirror Construction

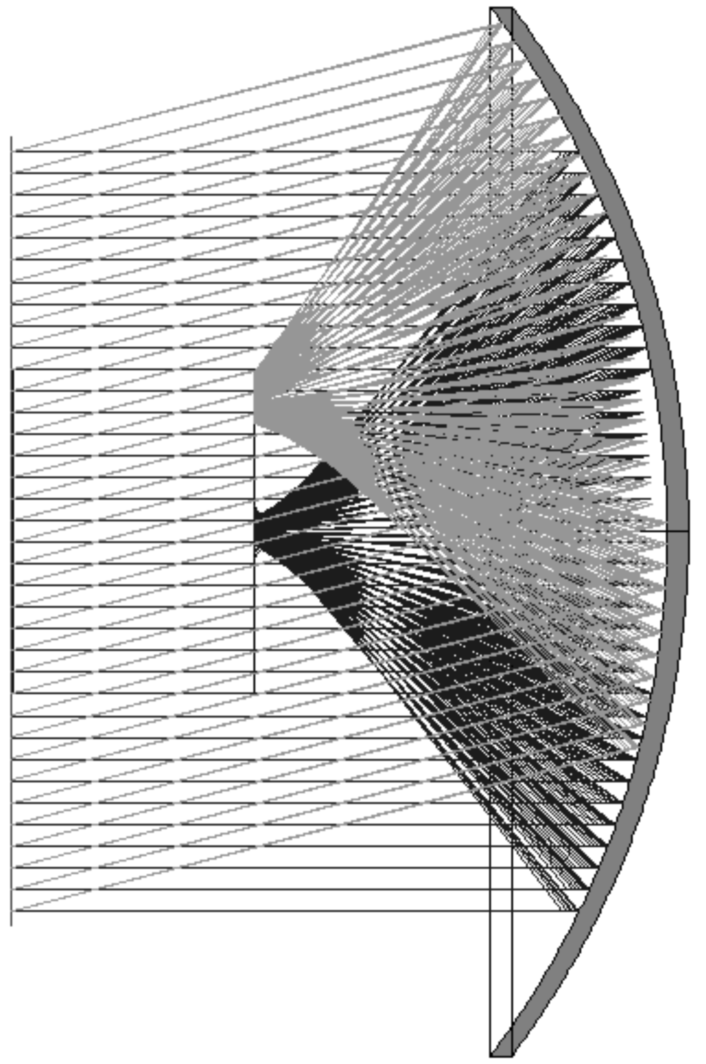
Joint Laboratory of Optics Olomuc

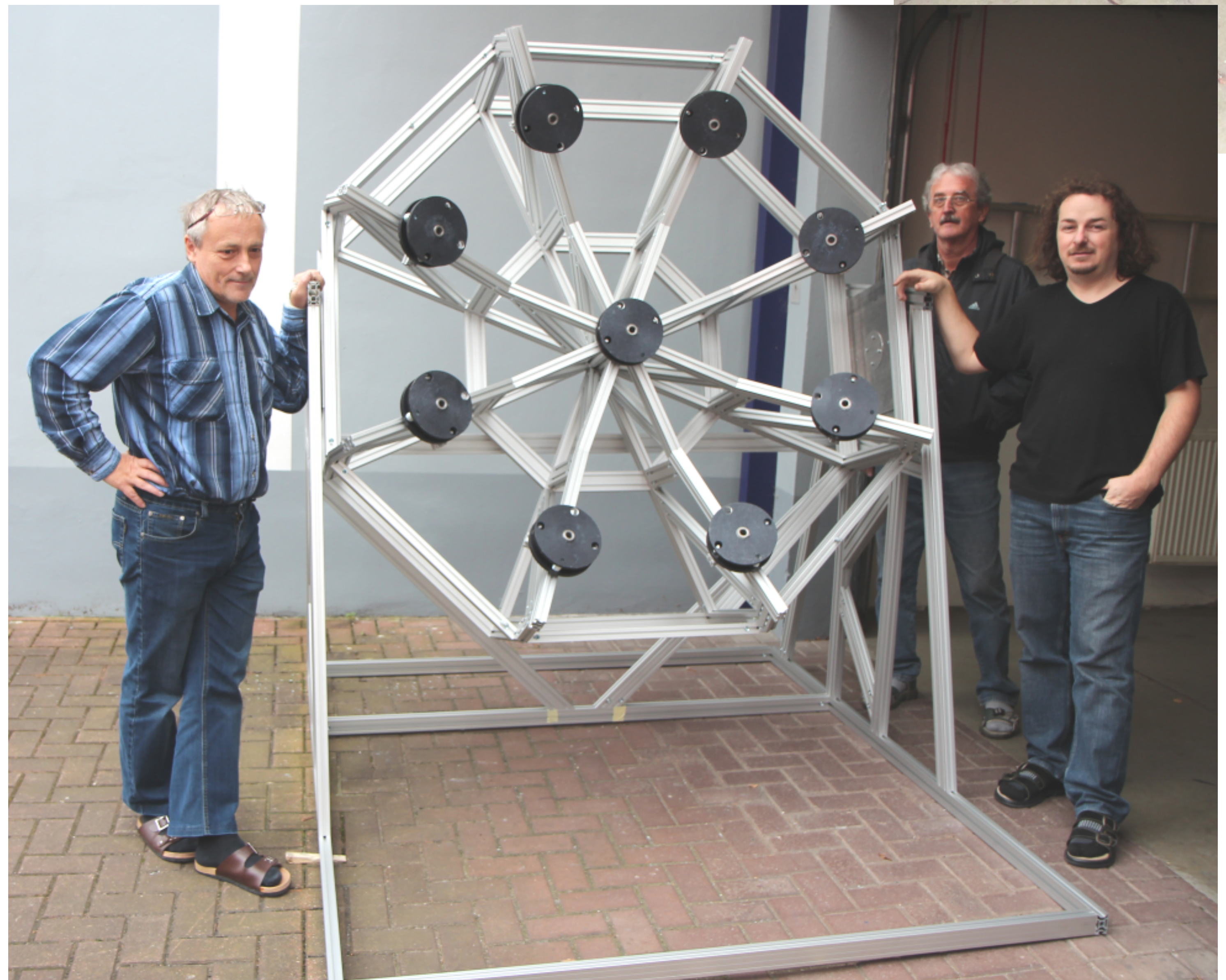


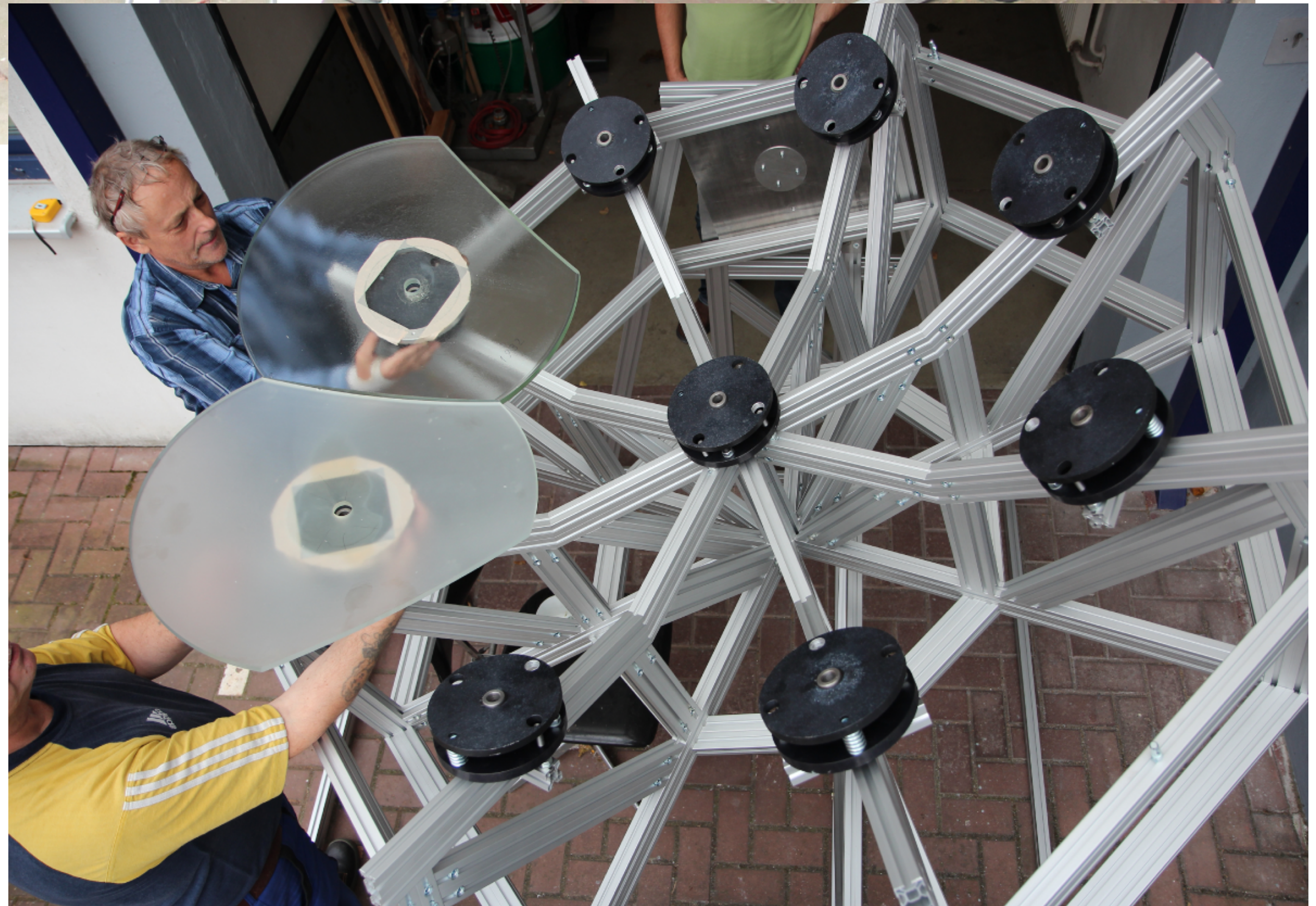


1 m^2 collection area, 30°×30° FoV

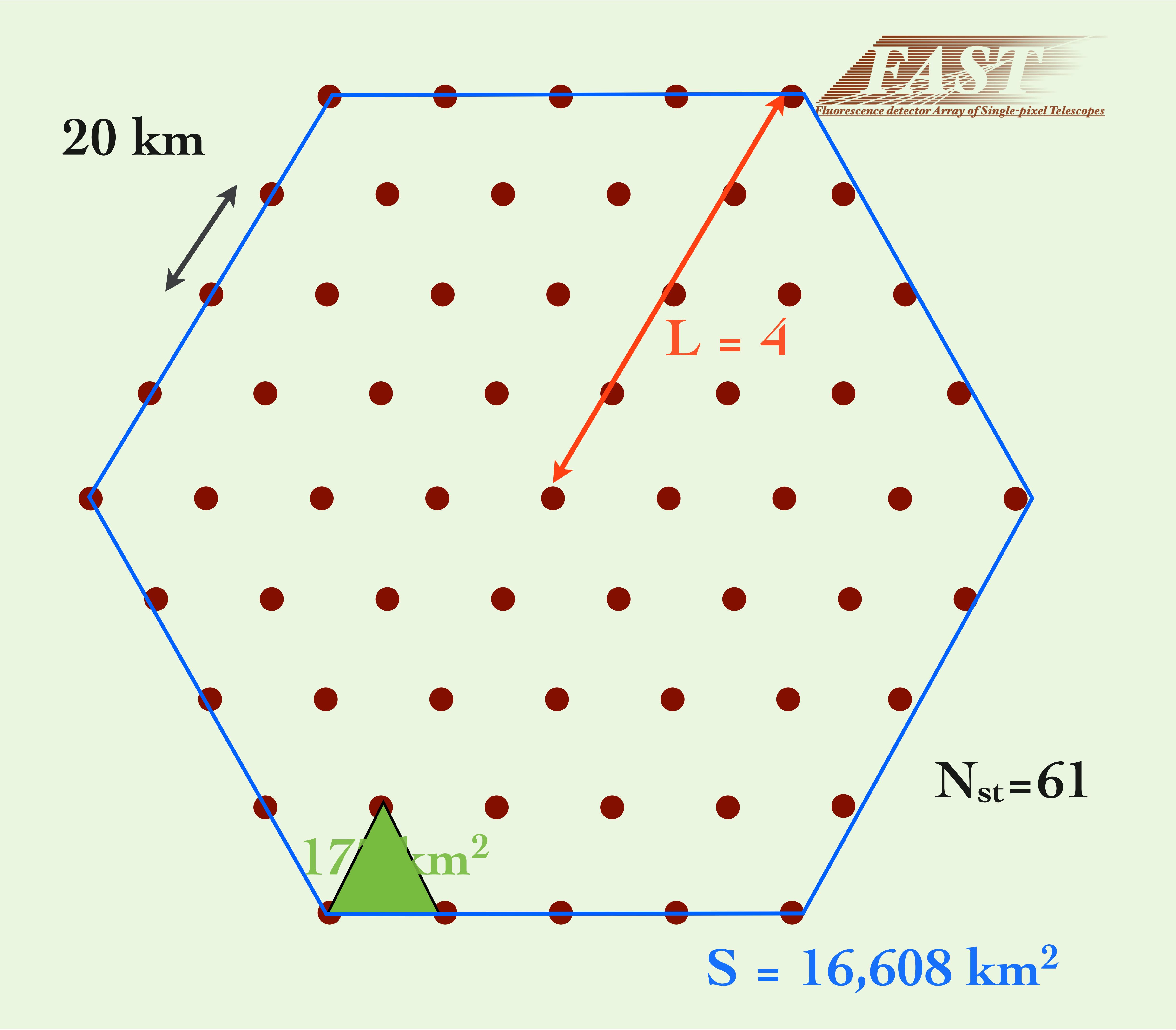






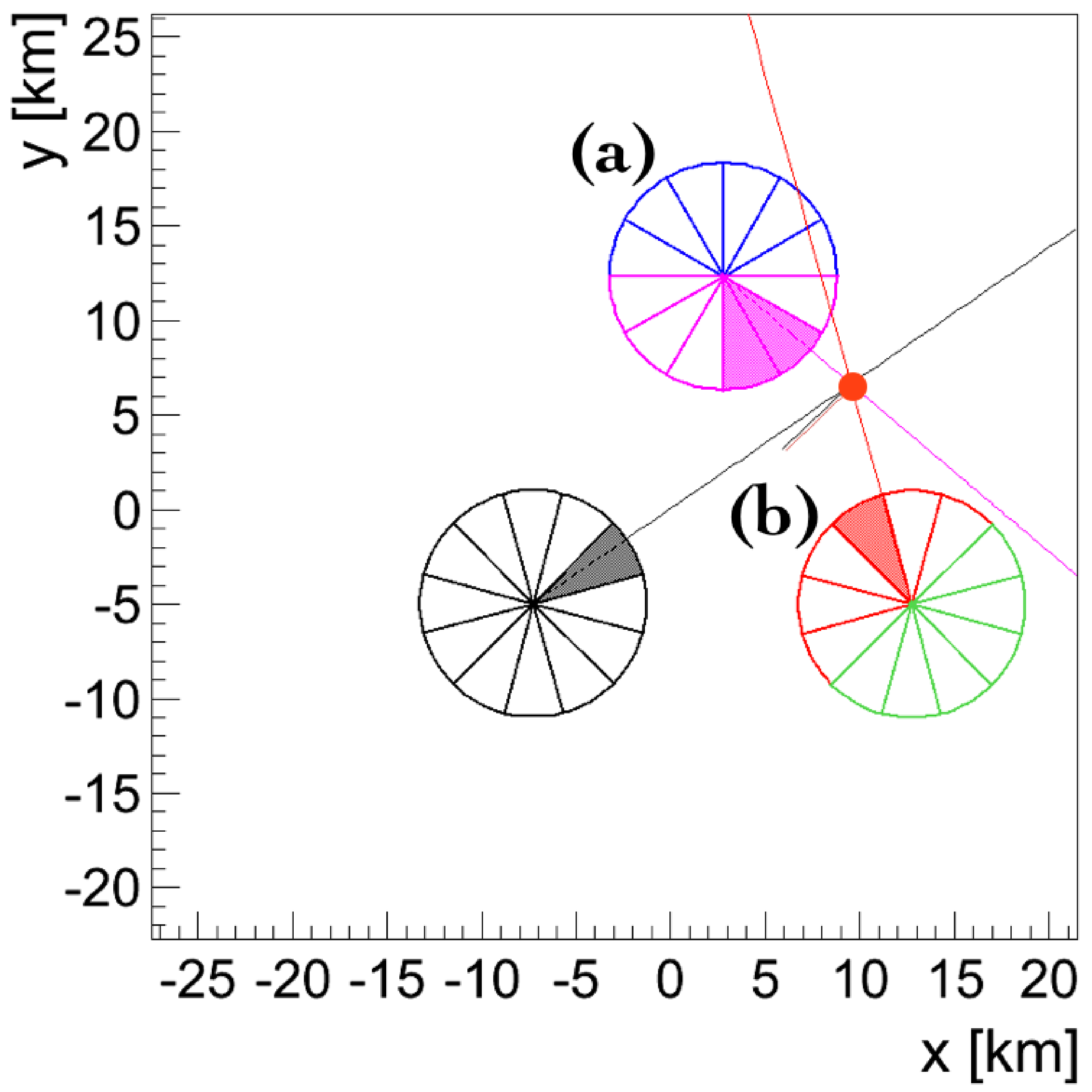


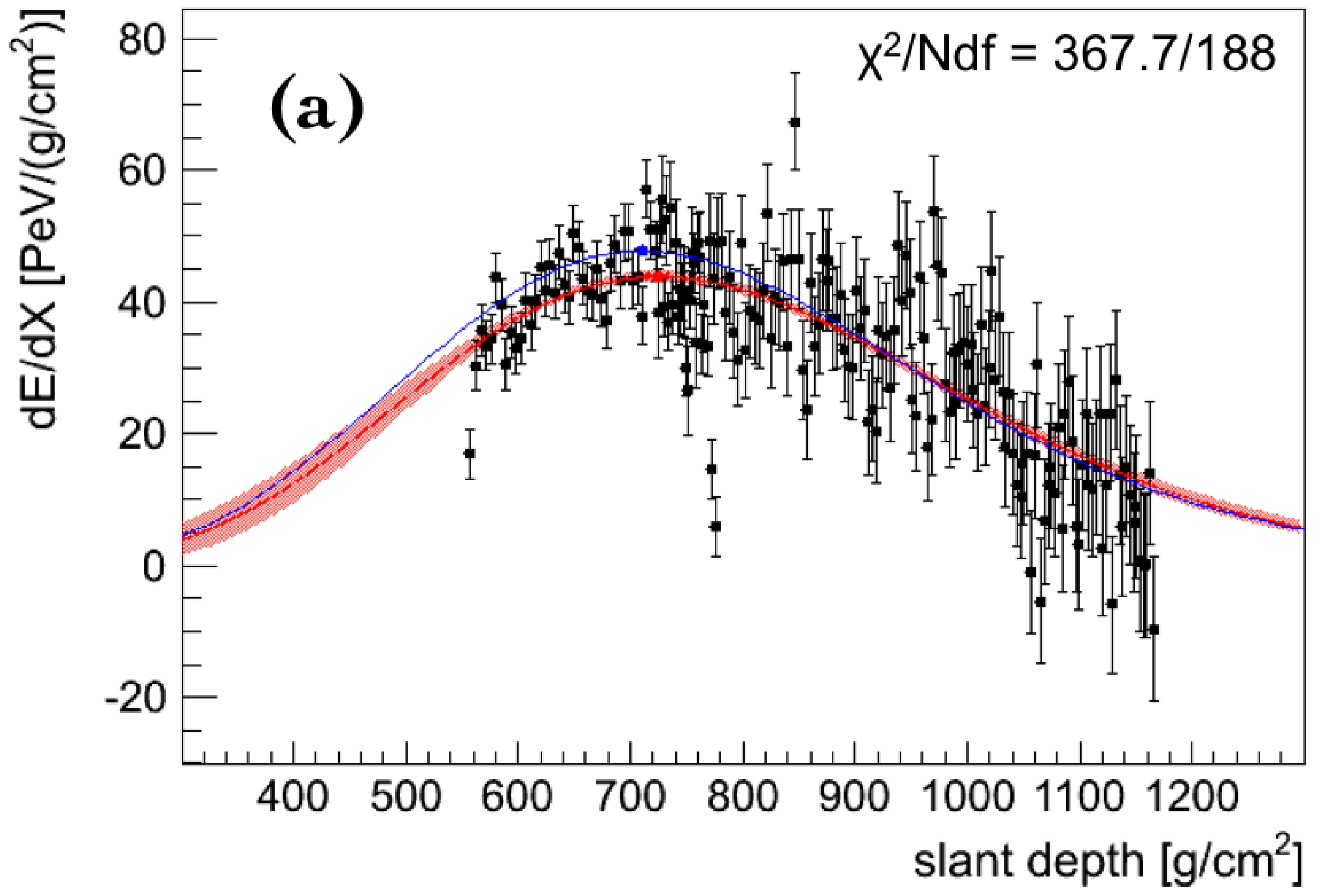
Coverage and the number of FAST stations

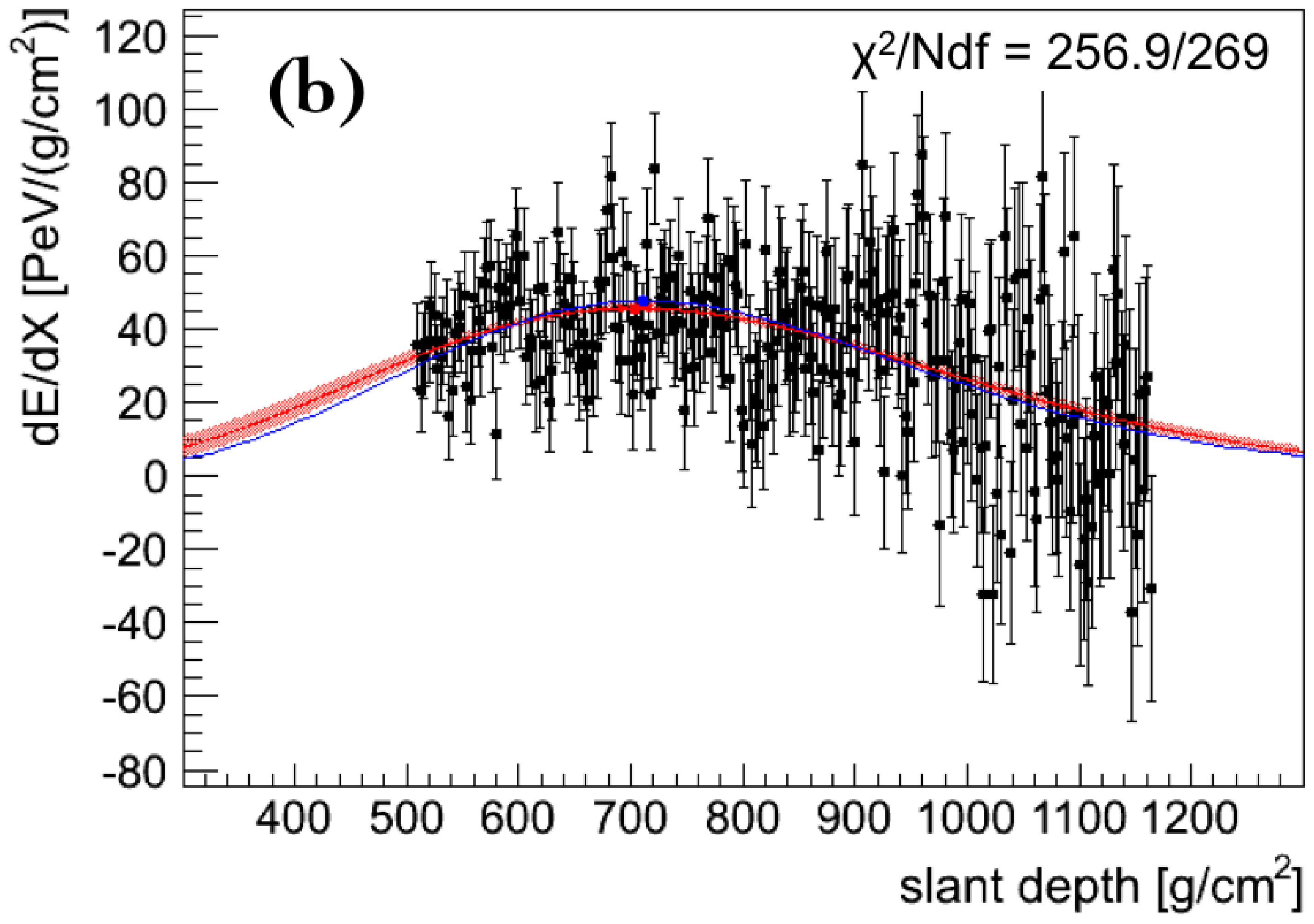


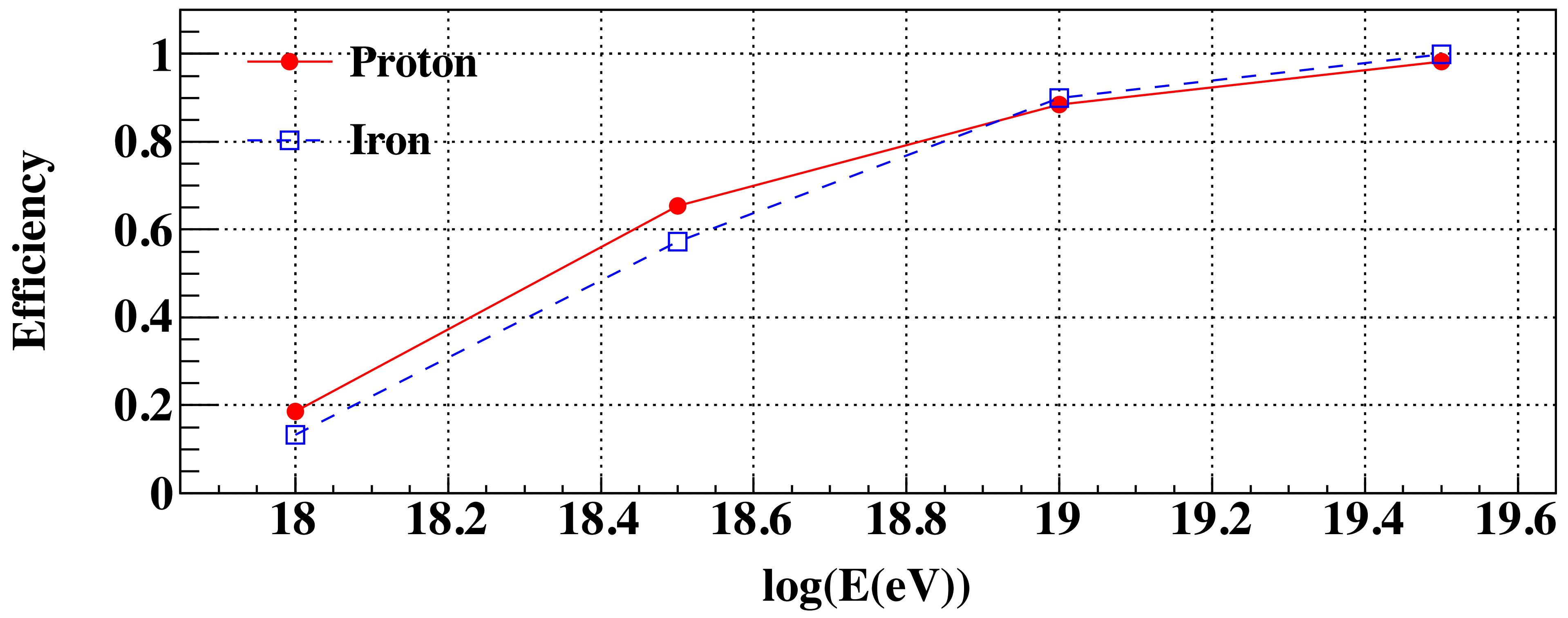
L	N_st	S [km^2]	Cost M$USD
0	1	0	0.1
1	7	1038	0.7
2	19	4152	1.9
3	37	9342	3.7
4	61	16608	6.1
5	91	25950	9.1
6	127	37368	12.7
7	169	50862	16.9
8	217	66432	21.7
9	271	84078	27.1
10	331	103800	33.1
11	397	125598	39.7
12	469	149472	46.9
13	547	175422	54.7
14	631	203448	63.1
15	721	233550	72.1
16	817	265728	81.7
17	919	299982	91.9
18	1027	336312	102.7
19	1141	374718	114.1
20	1261	415200	126.1

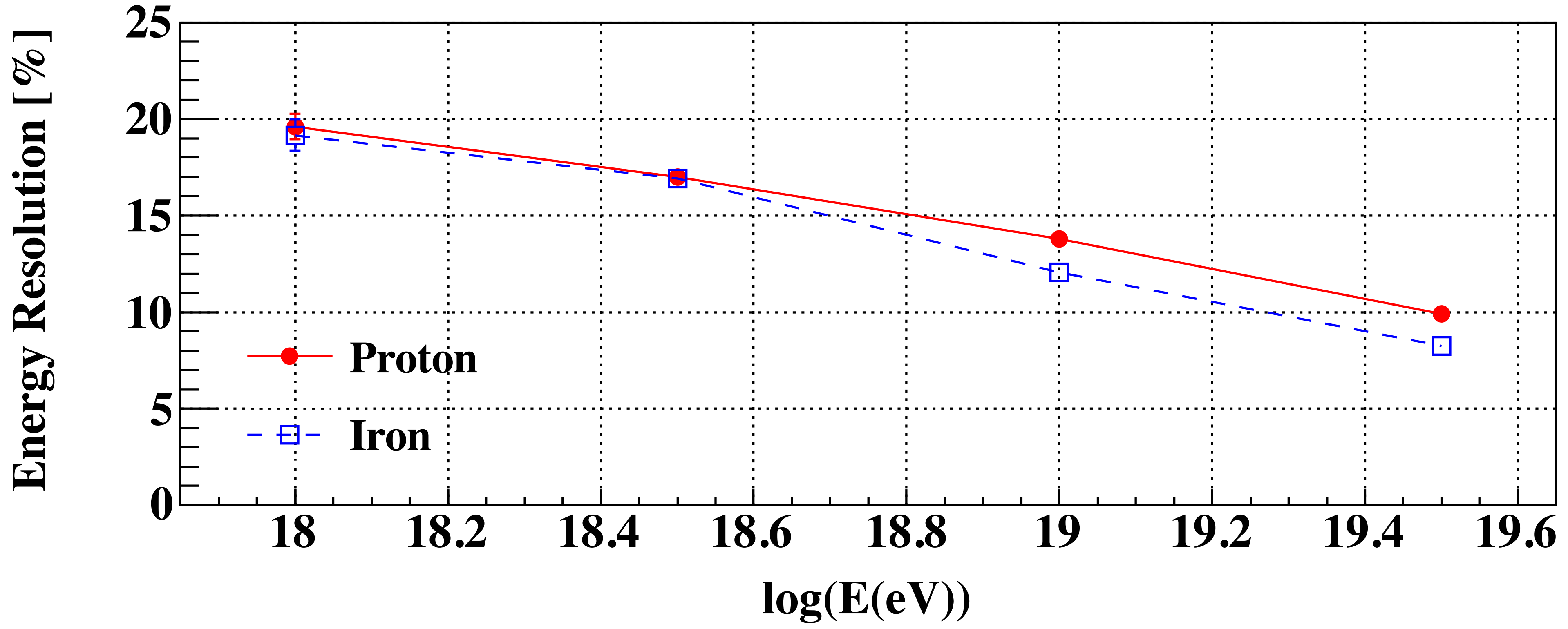
Efficiency and Resolution of FAST

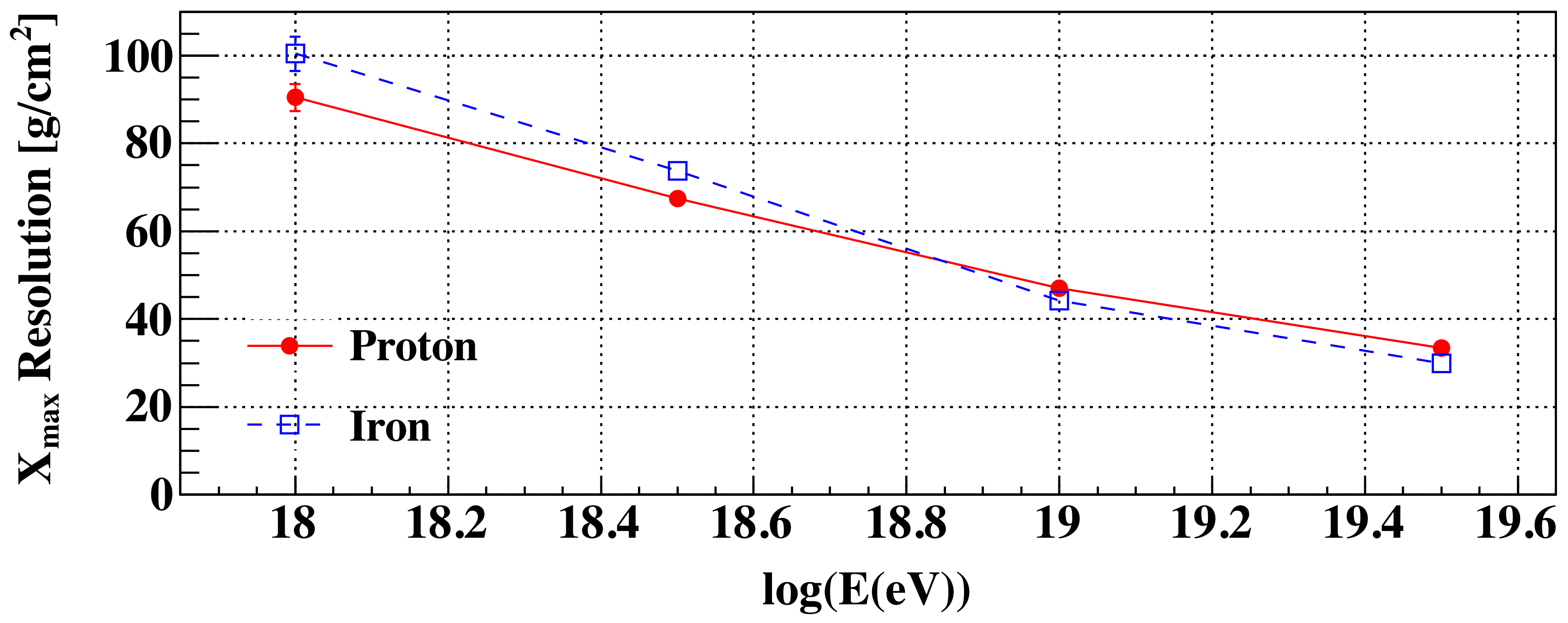




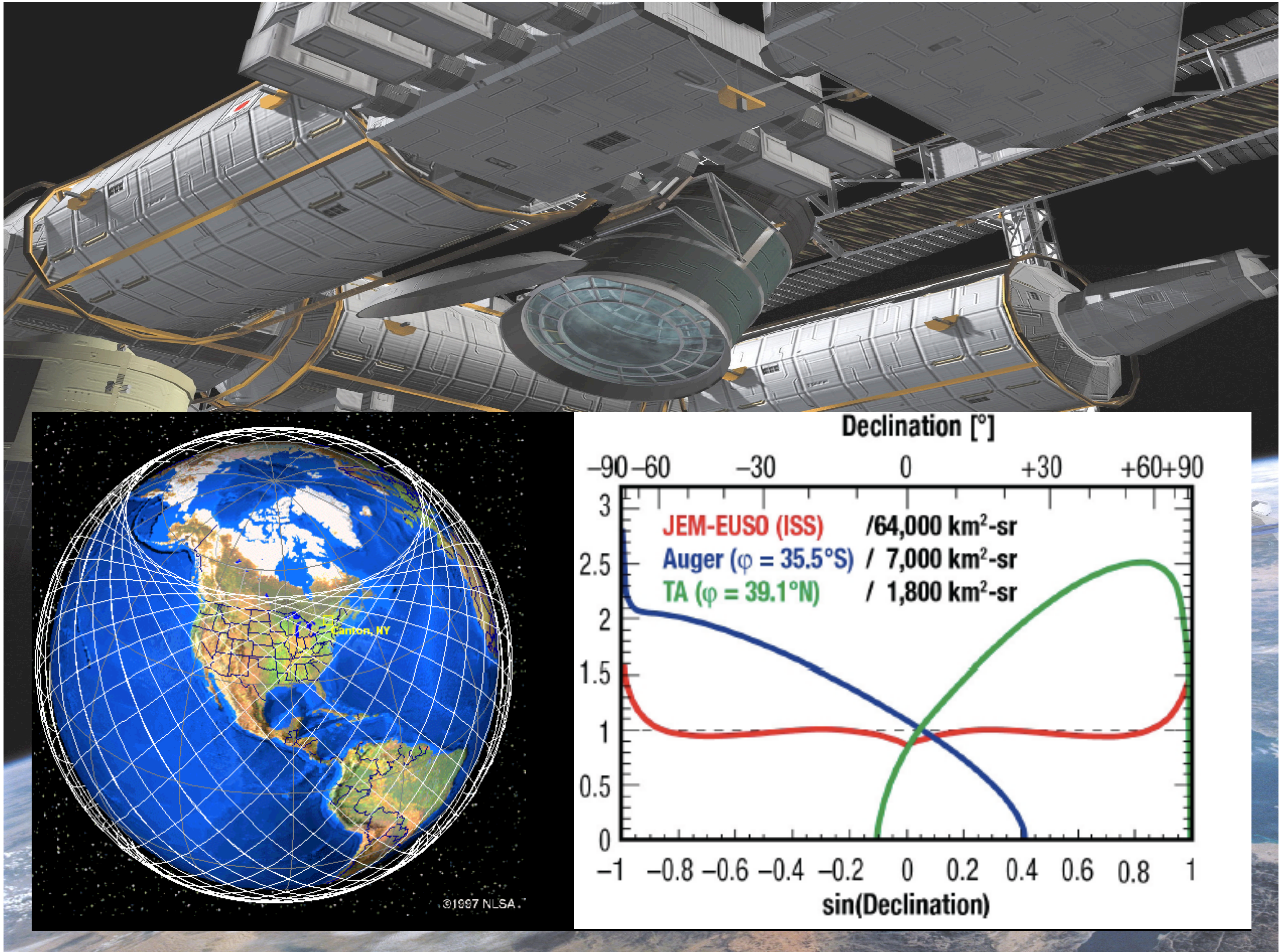








JEM-EUSO


Canton, NY
©1997 NLSA
Declination [°]
−90 −60 −30 0 +30 +60 +90
JEM-EUSO (ISS) /64,000 km²-sr
Auger (φ = 35.5°S) / 7,000 km²-sr
TA (φ = 39.1°N) / 1,800 km²-sr
0 0.5 1 1.5 2 2.5 3
−1 −0.8 −0.6 −0.4 −0.2 0 0.2 0.4 0.6 0.8 1
sin(Declination)

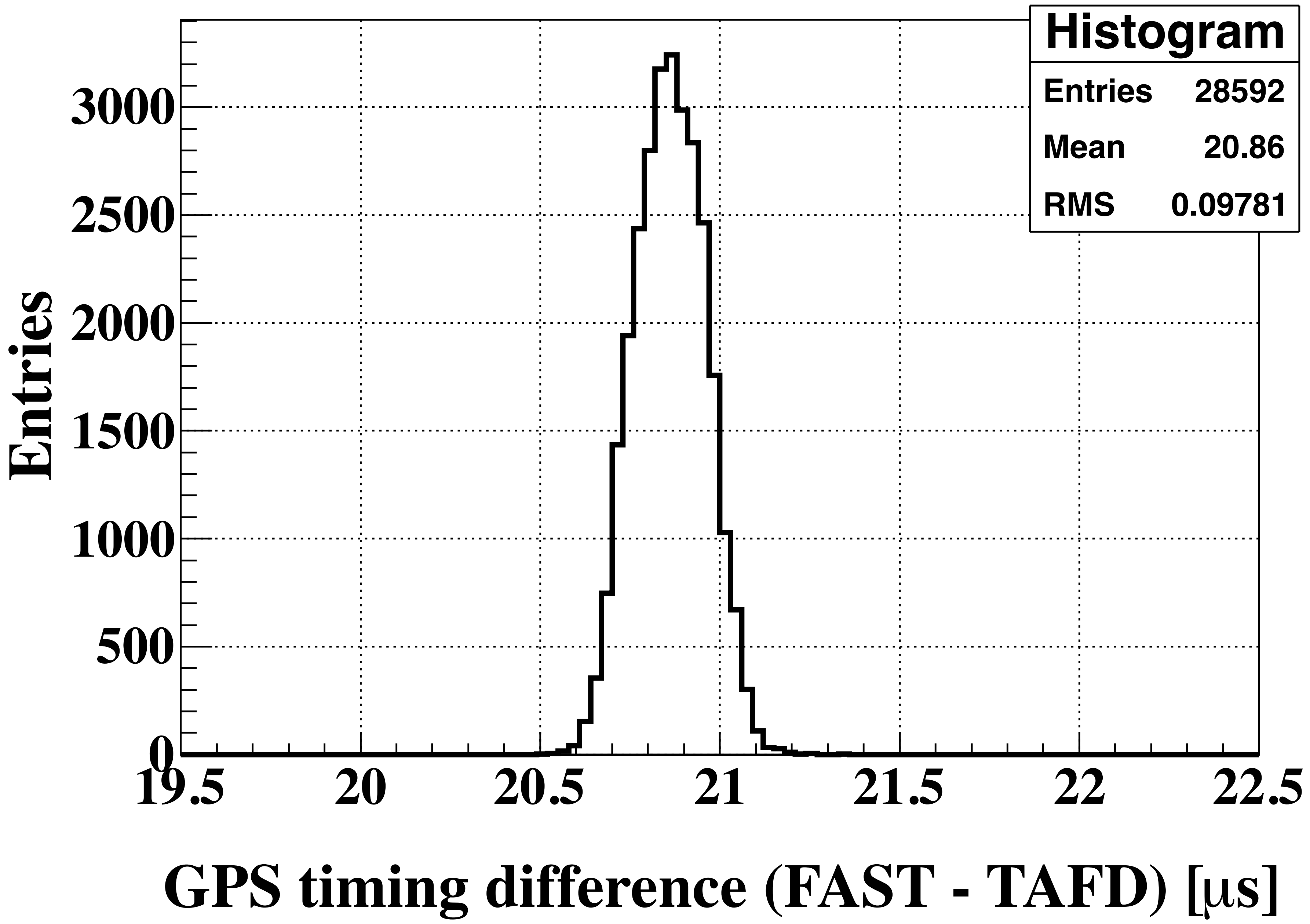
GPS Timing and CLF Signal

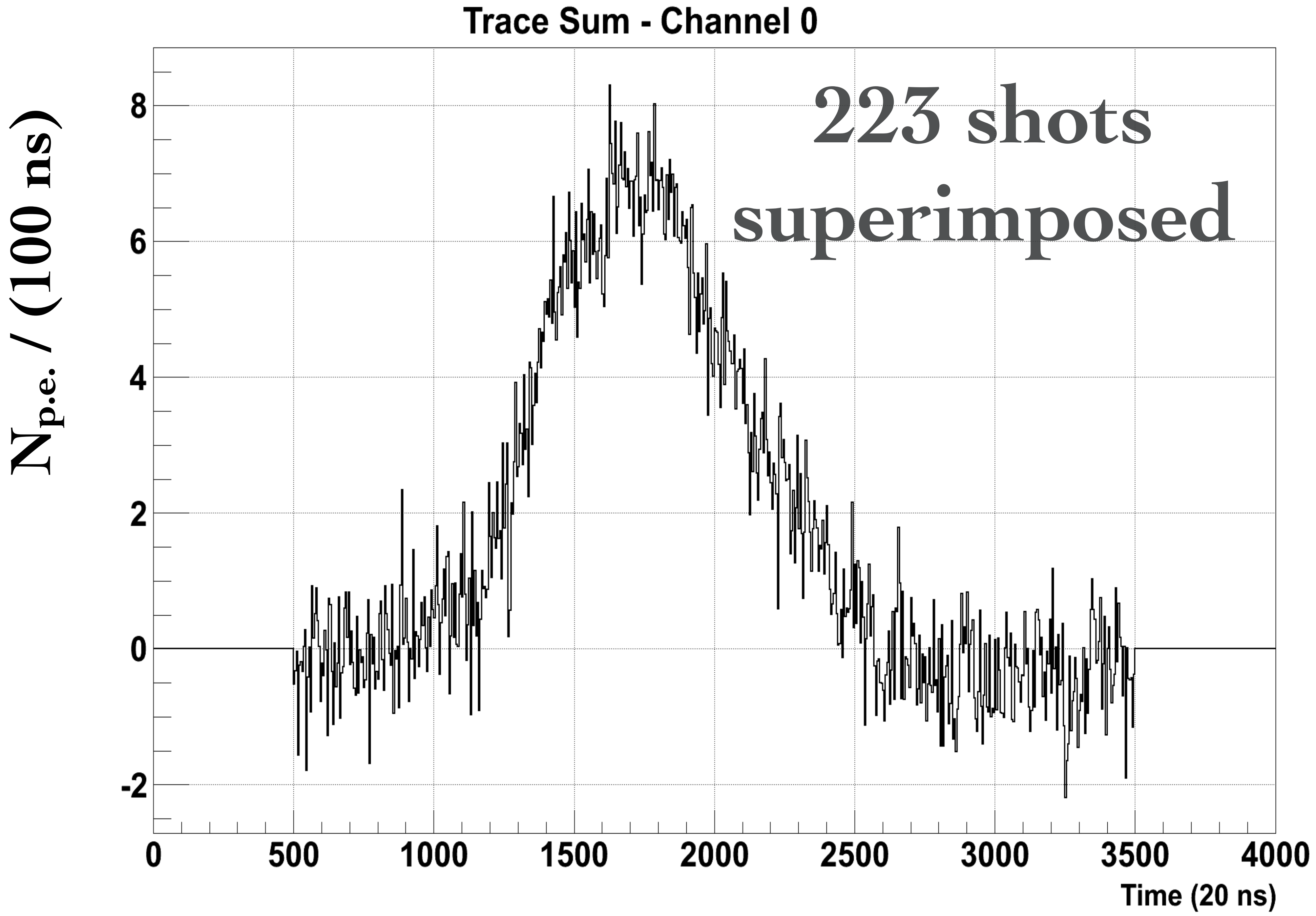
Central Laser Facility

Vertical UV laser shooting every 30 minutes,

21 km from FAST,

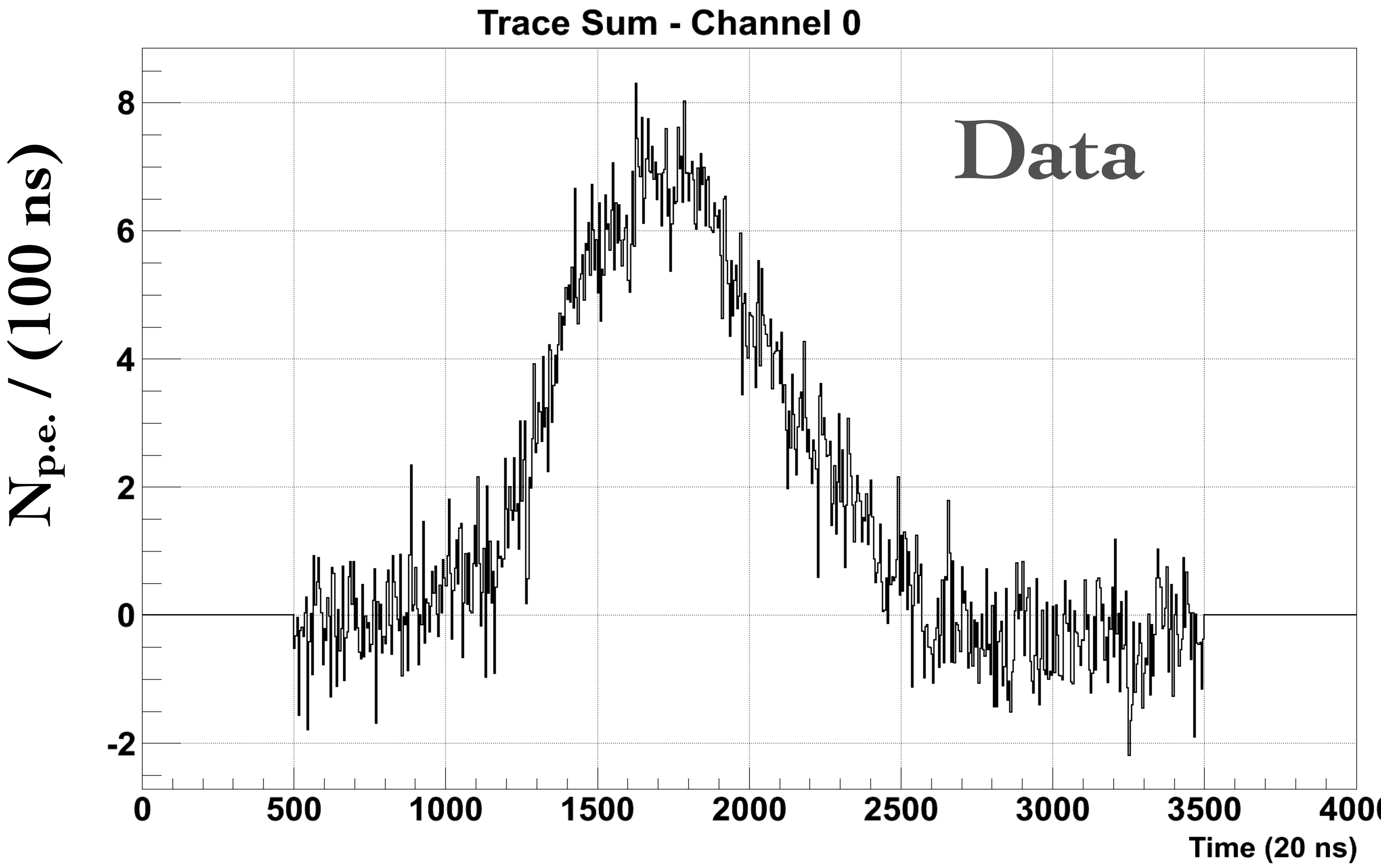
10 Hz, 2.2 mJ, 300 shots

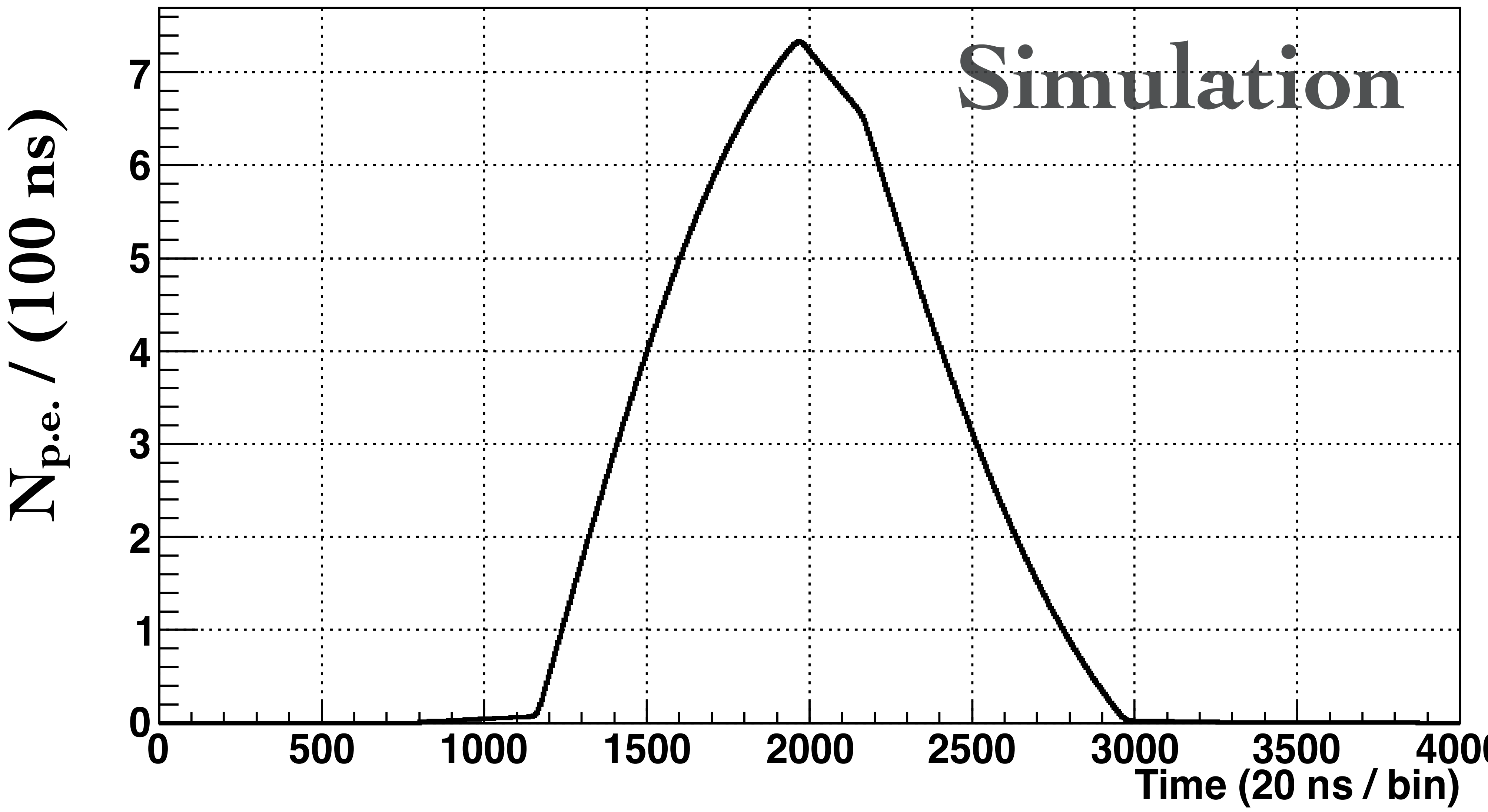




- FAST-TAFD timing resolution, 100 ns. (20.9 μs is the TAFD trigger processing time.)
- laser signal > $10^{19.2}$ eV at 21 km
- peak signal ~ 7 p.e. / 100 ns ($\sigma_{p.e.}$ = 11 p.e.) at the limit of detectability

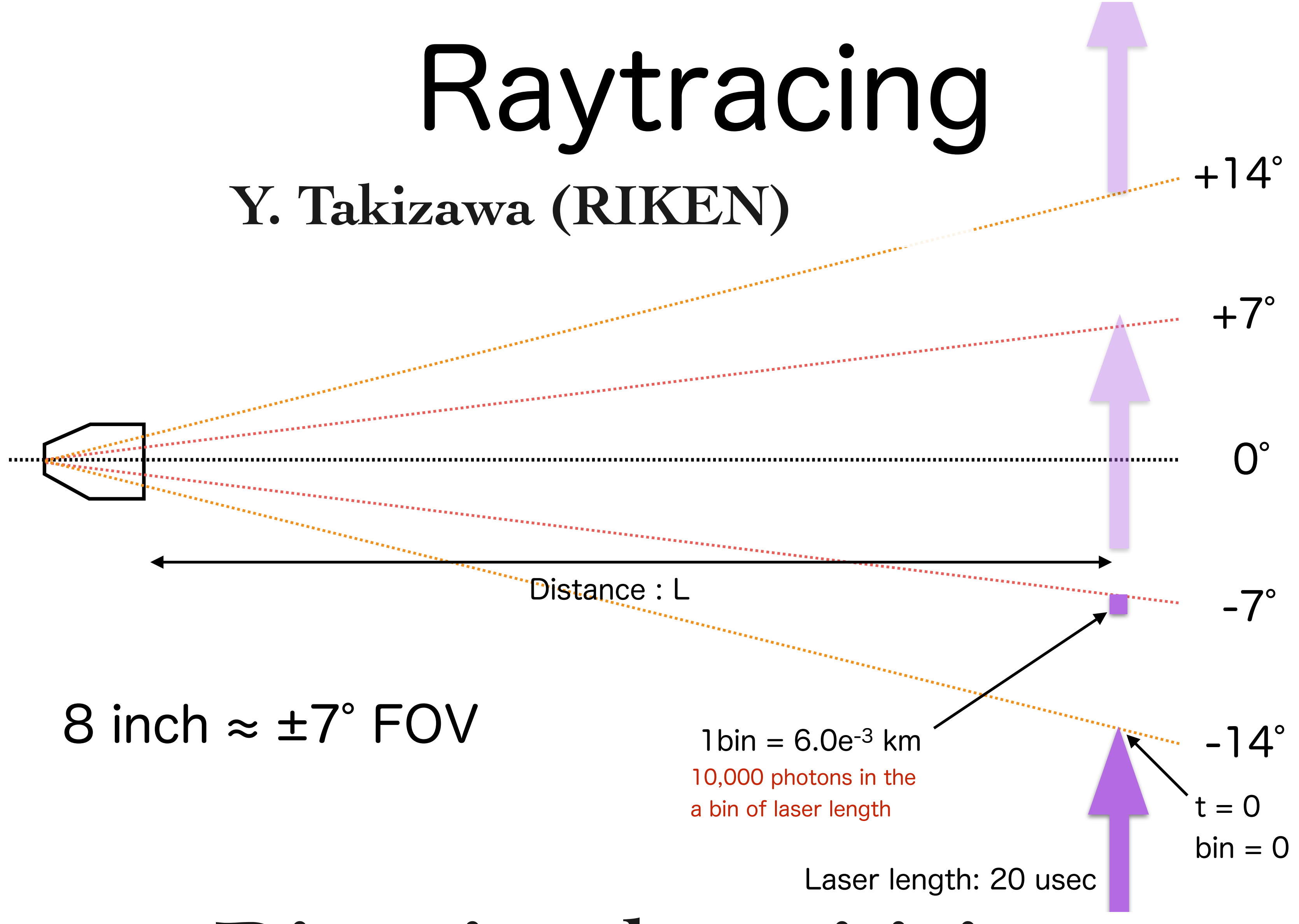
CLF Simulation



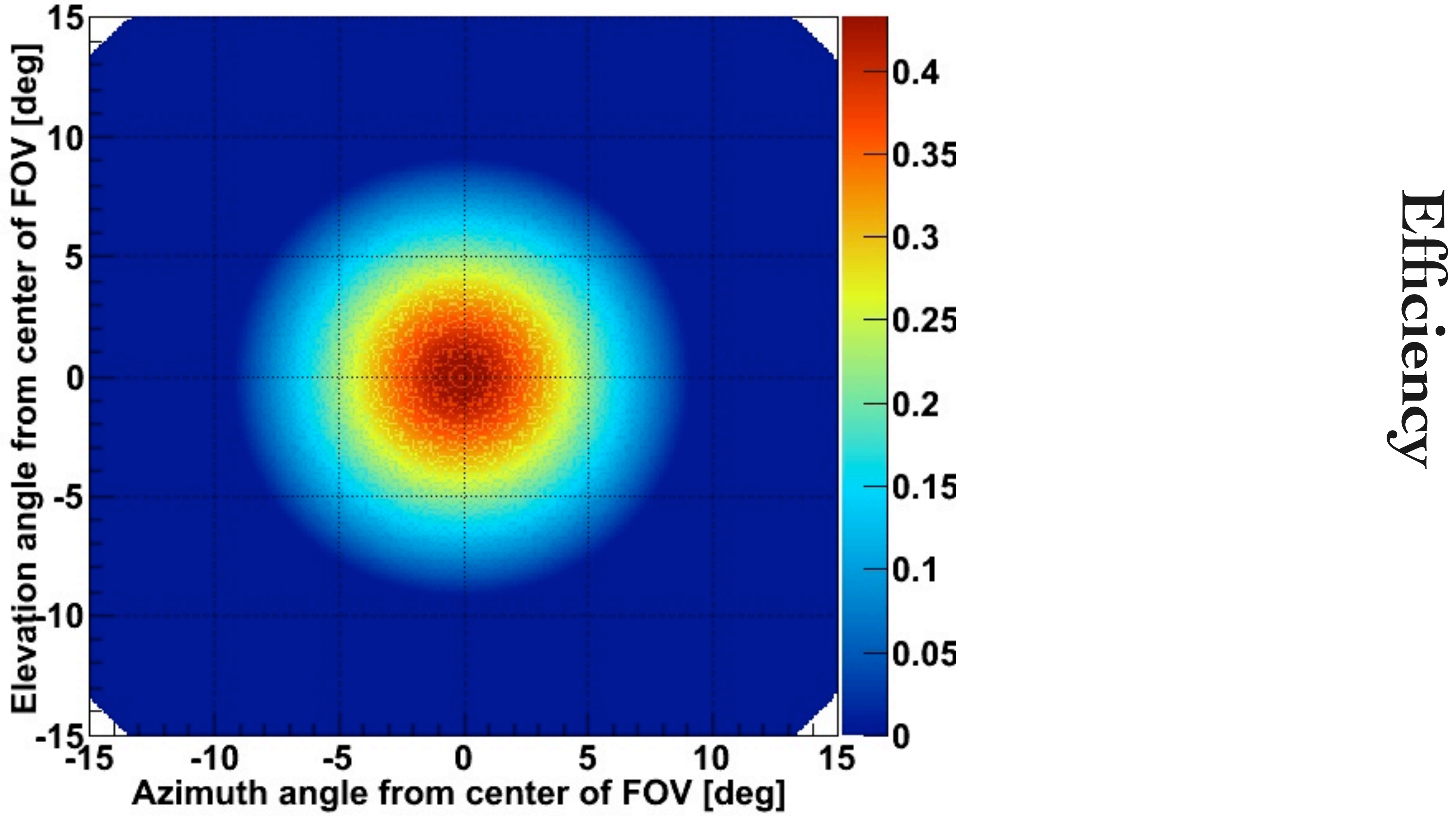


Raytracing

Y. Takizawa (RIKEN)

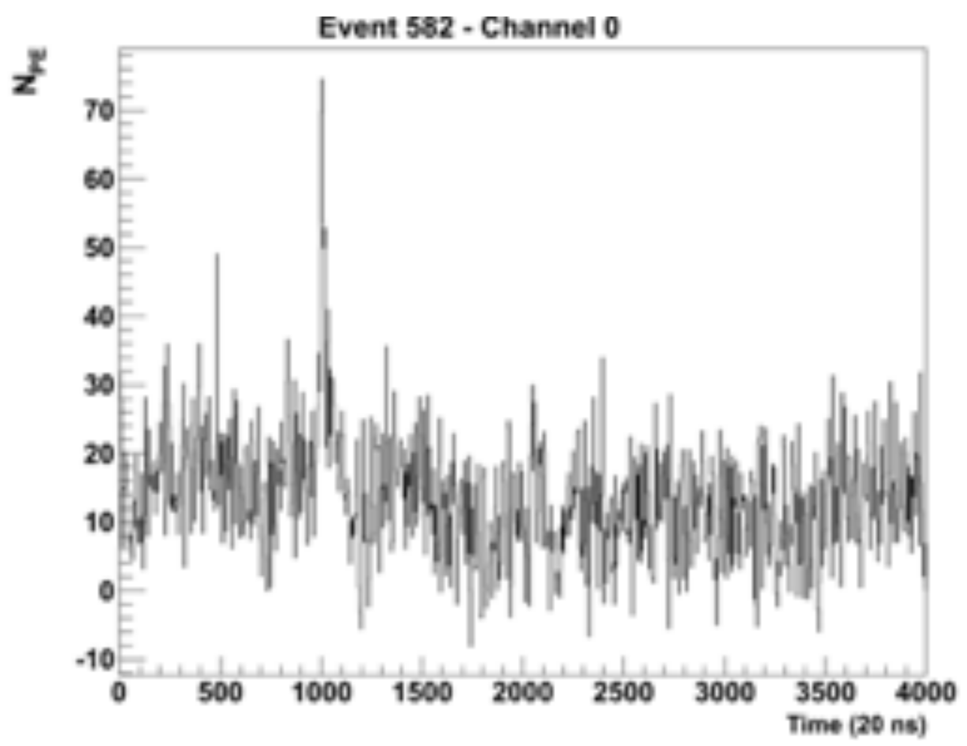


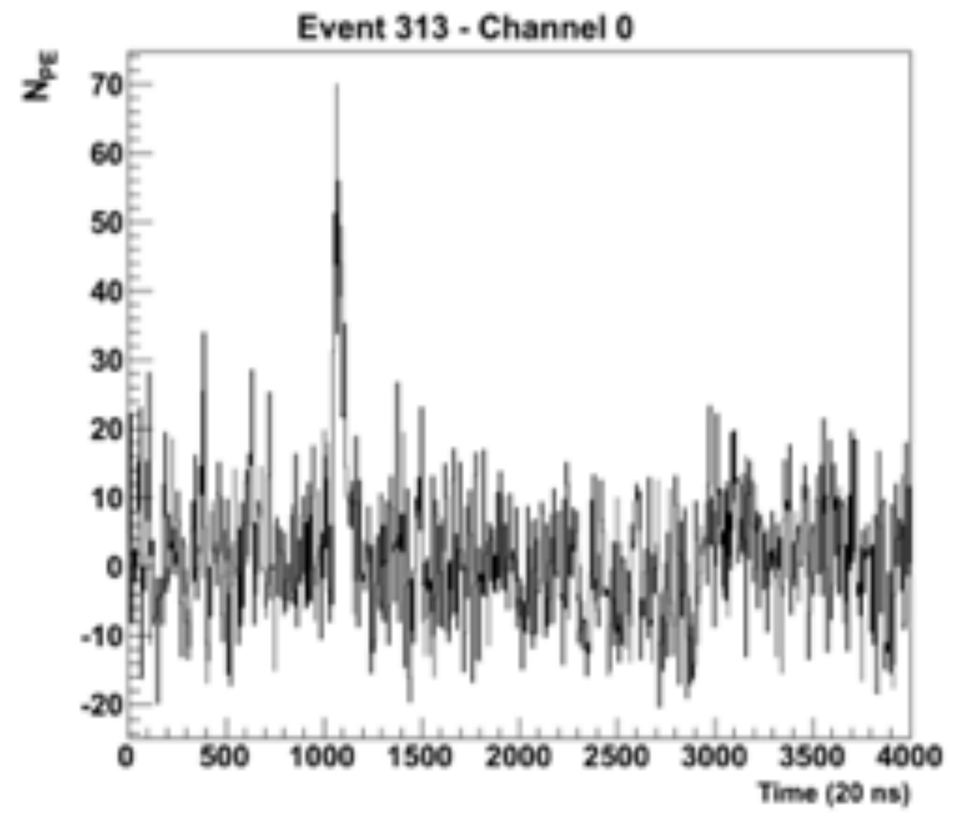
Directional sensitivity

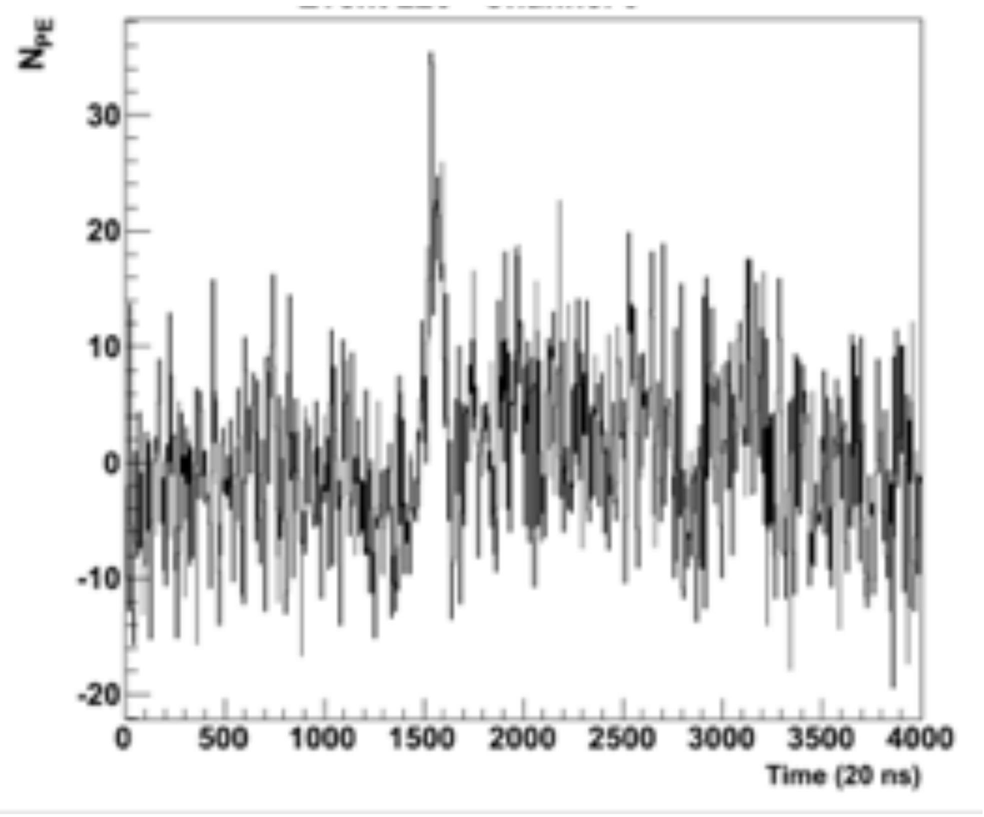


Example of Signal Candidates

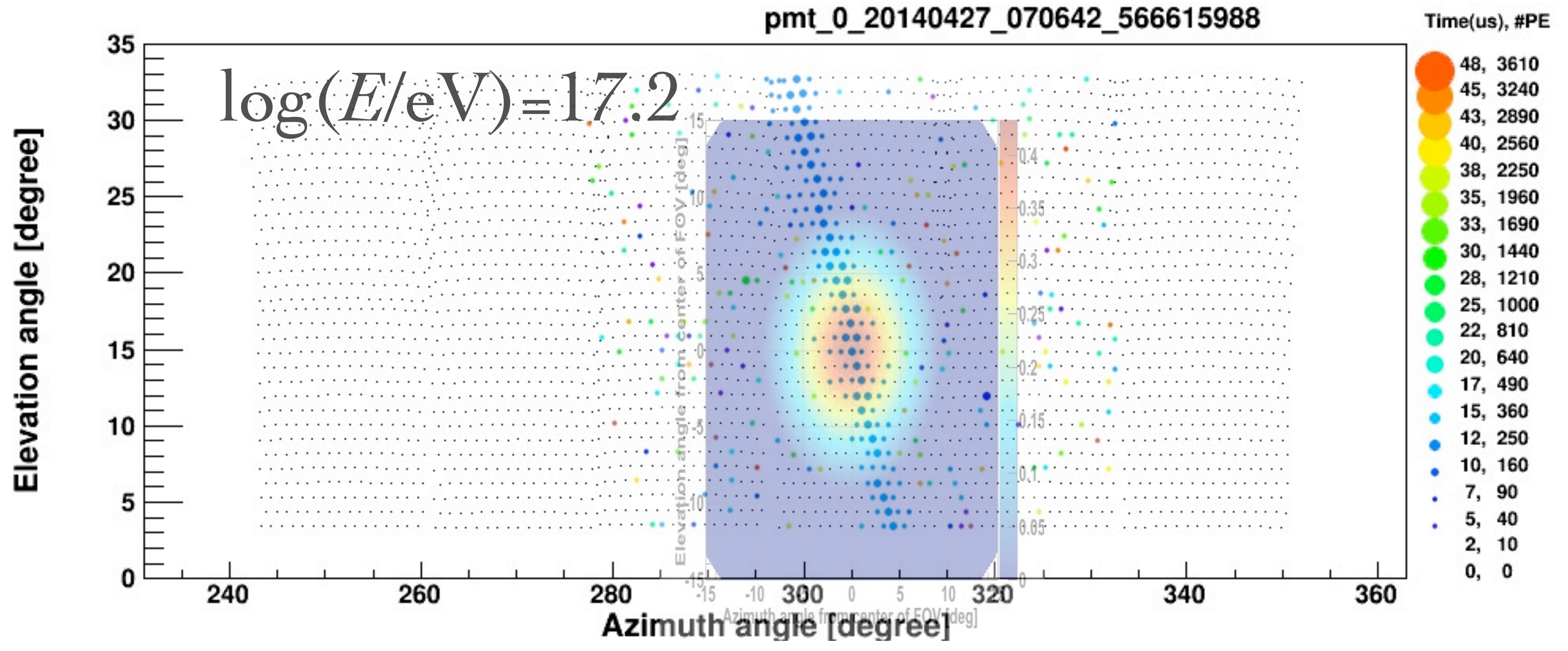
FAST

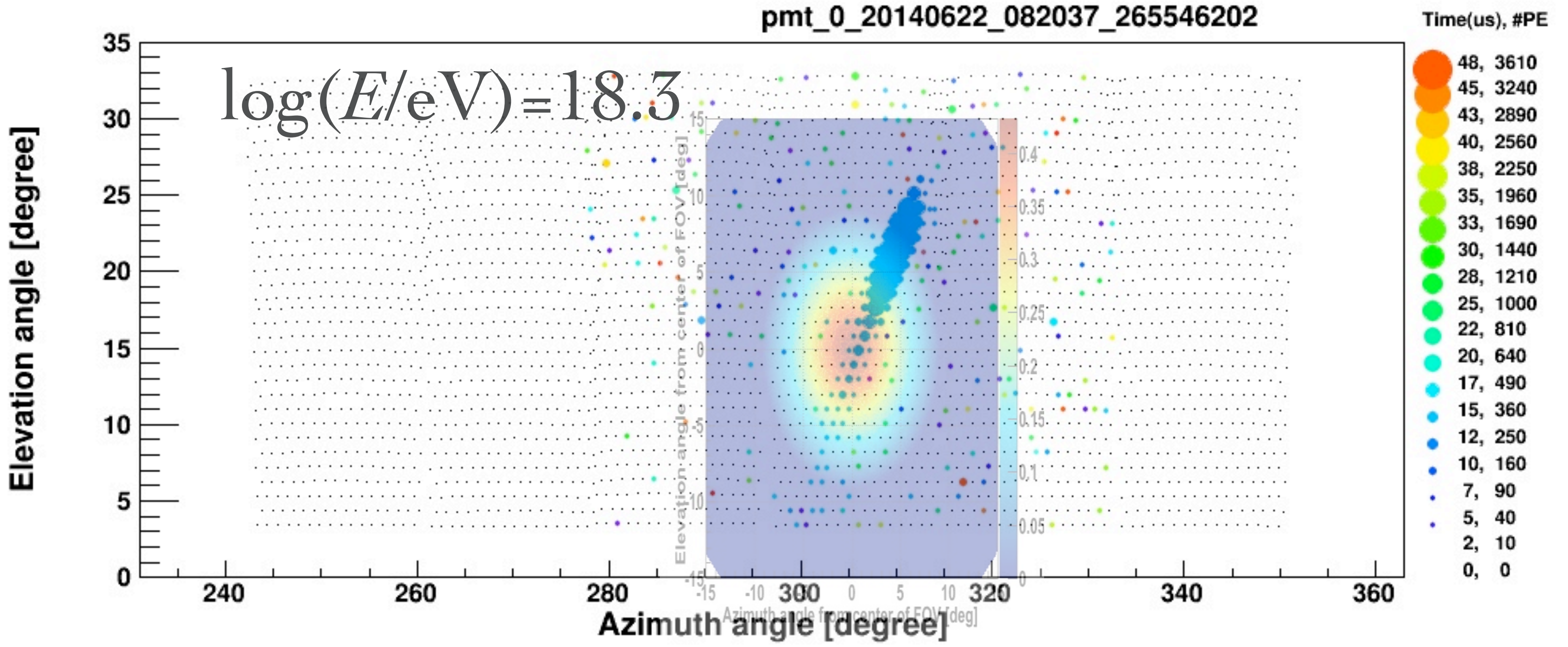


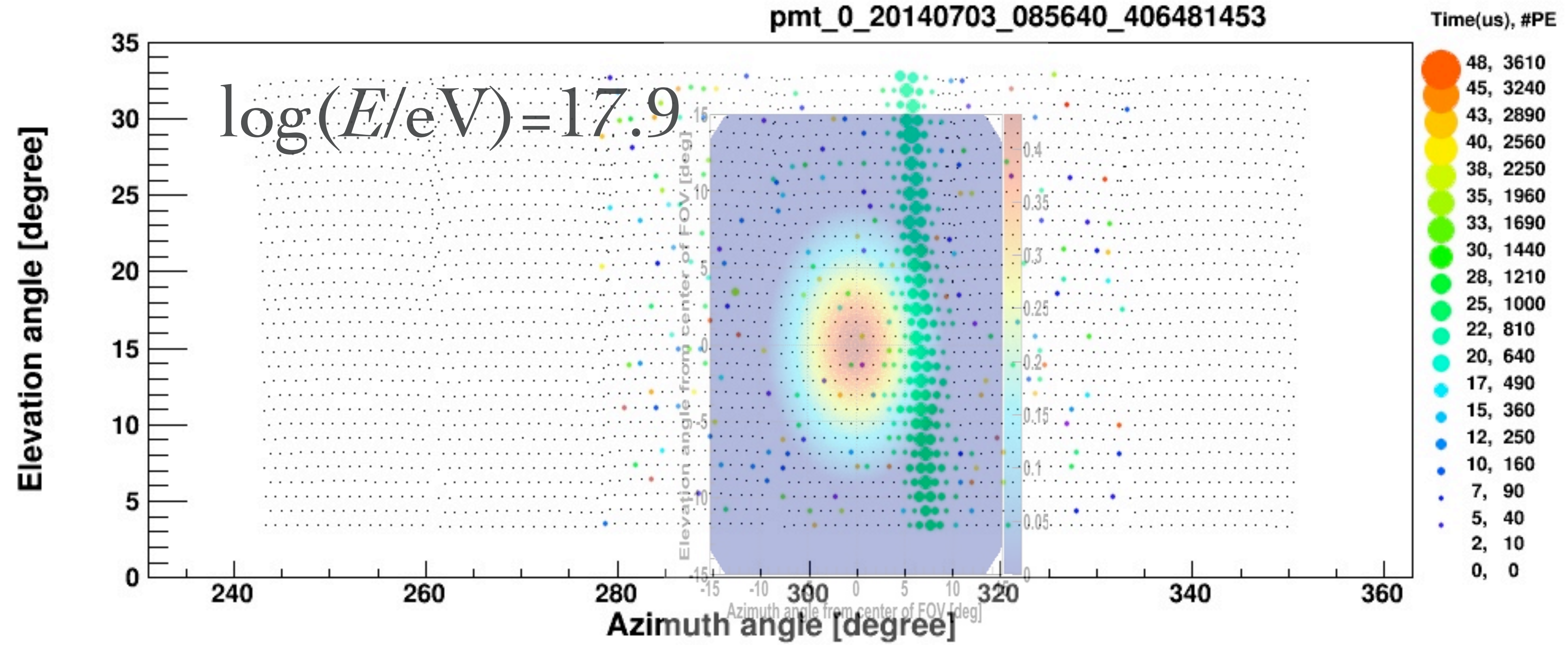




TAFD

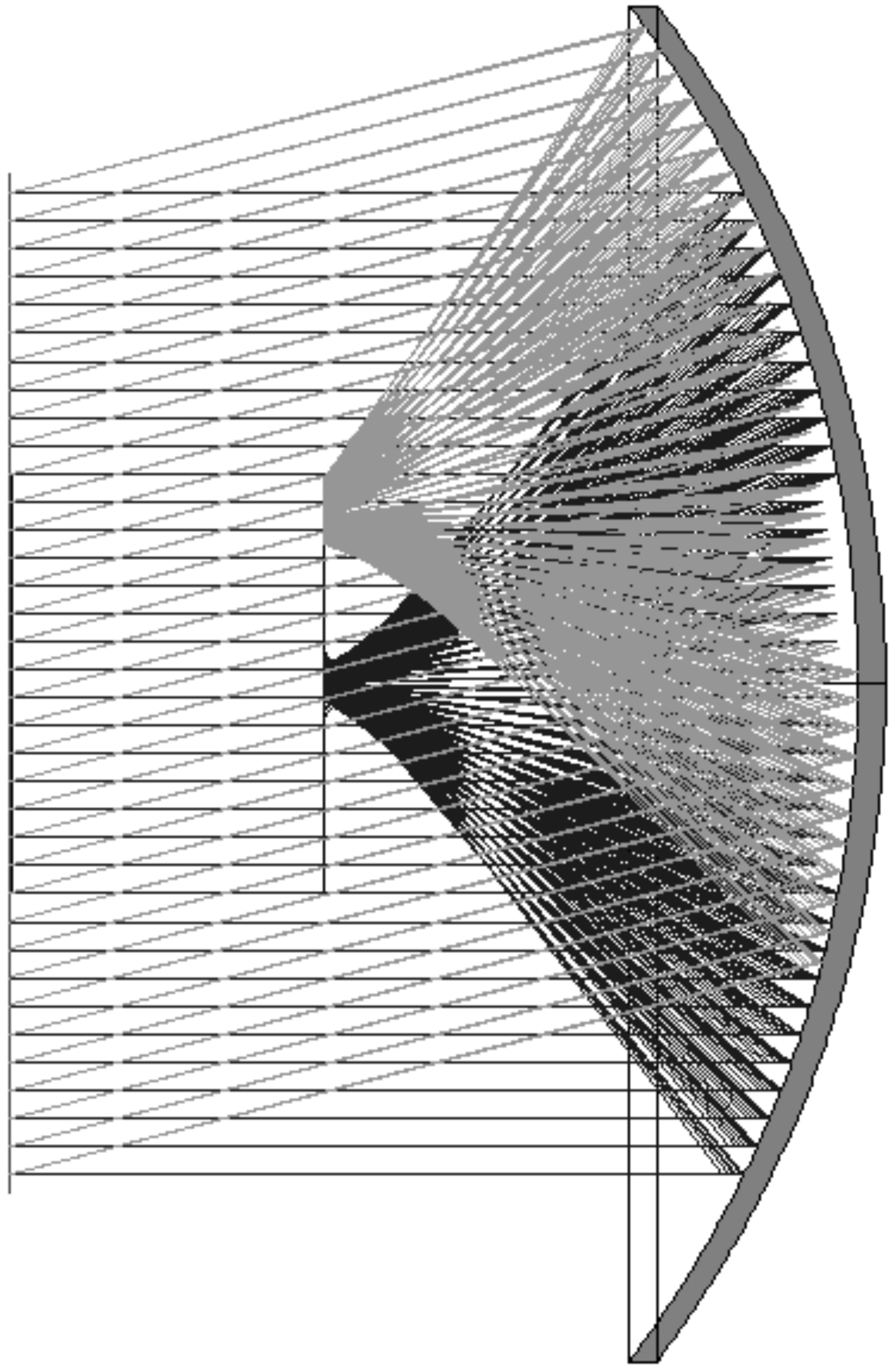




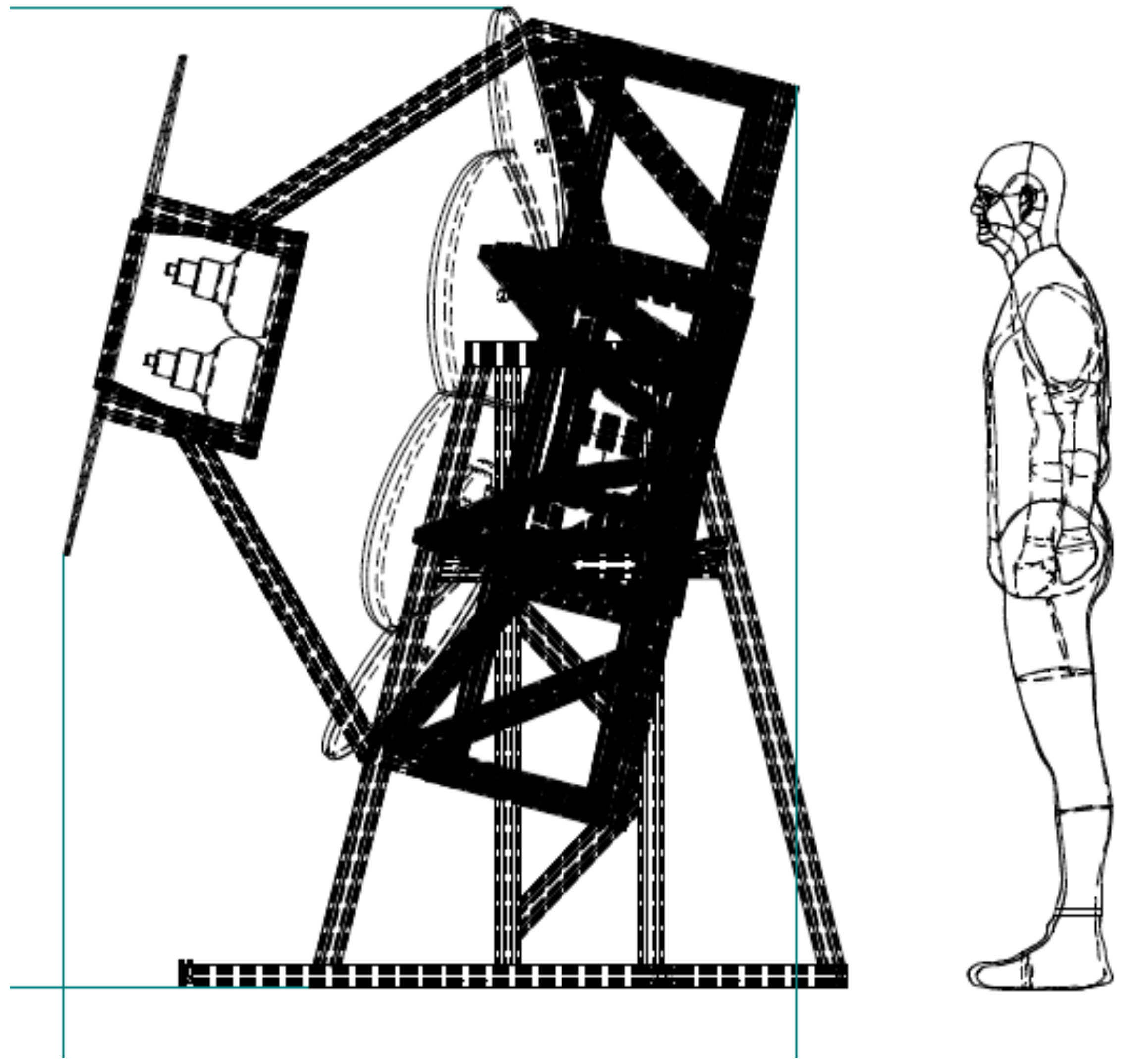


FAST
Fluorescence detector Array of Single-pixel Telescopes

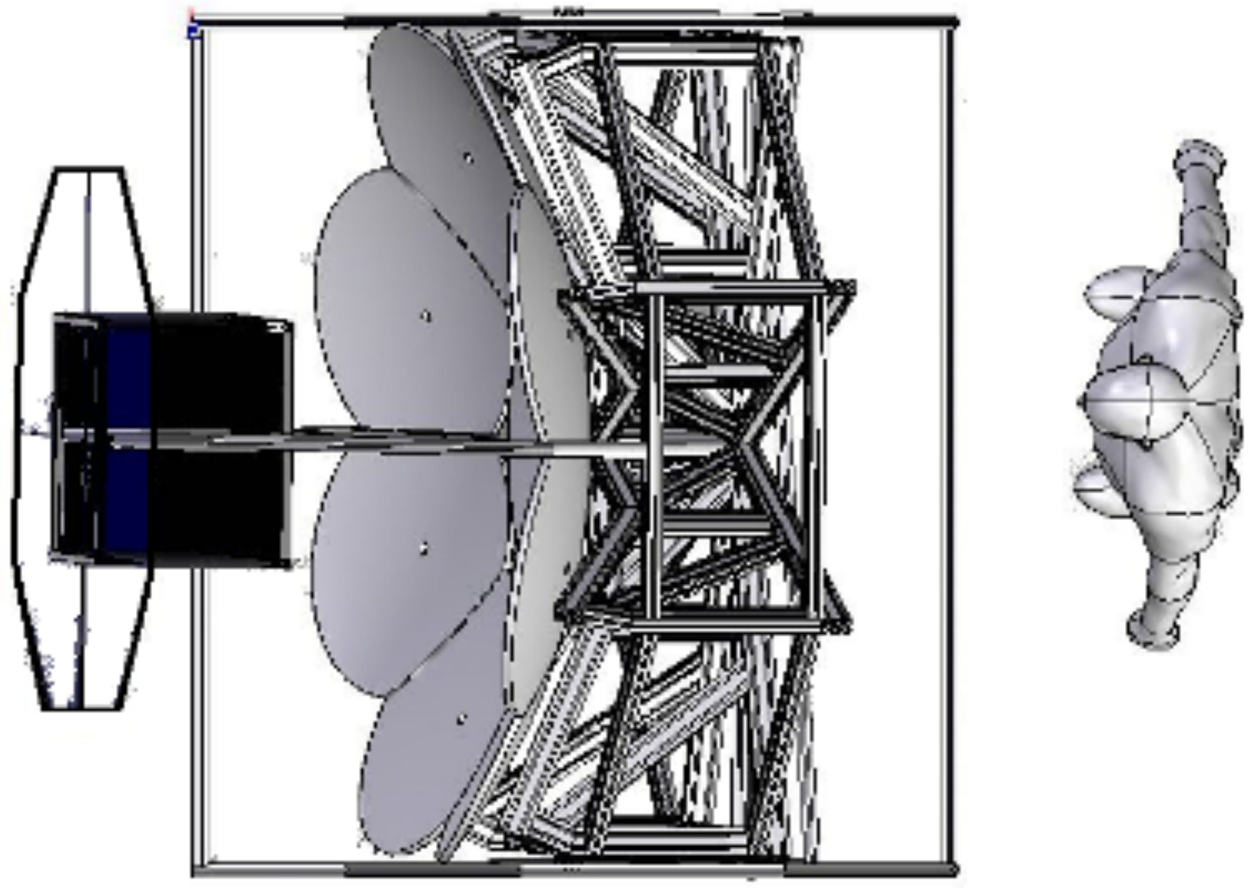
Full-scale FAST Prototype

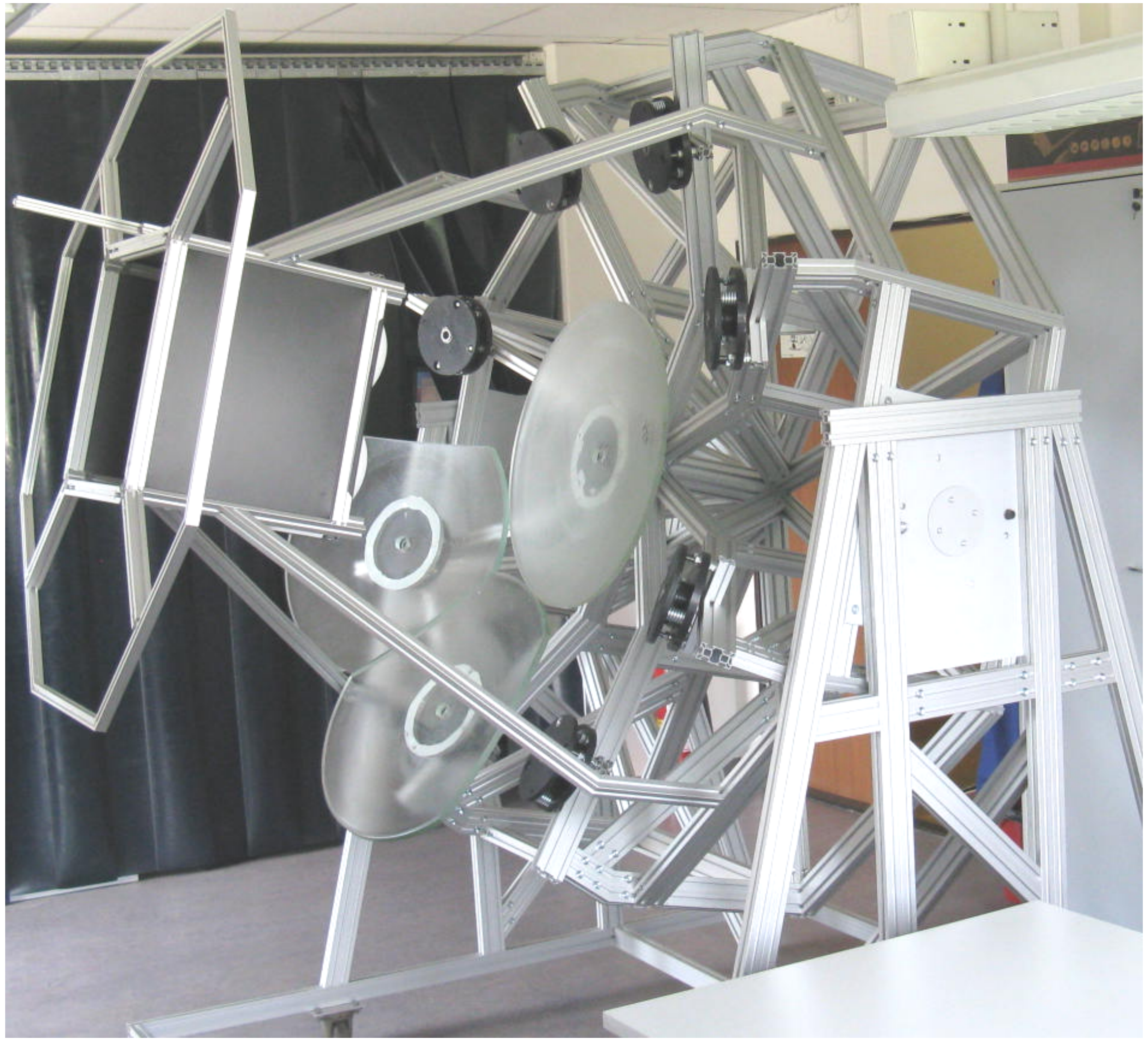


Side view

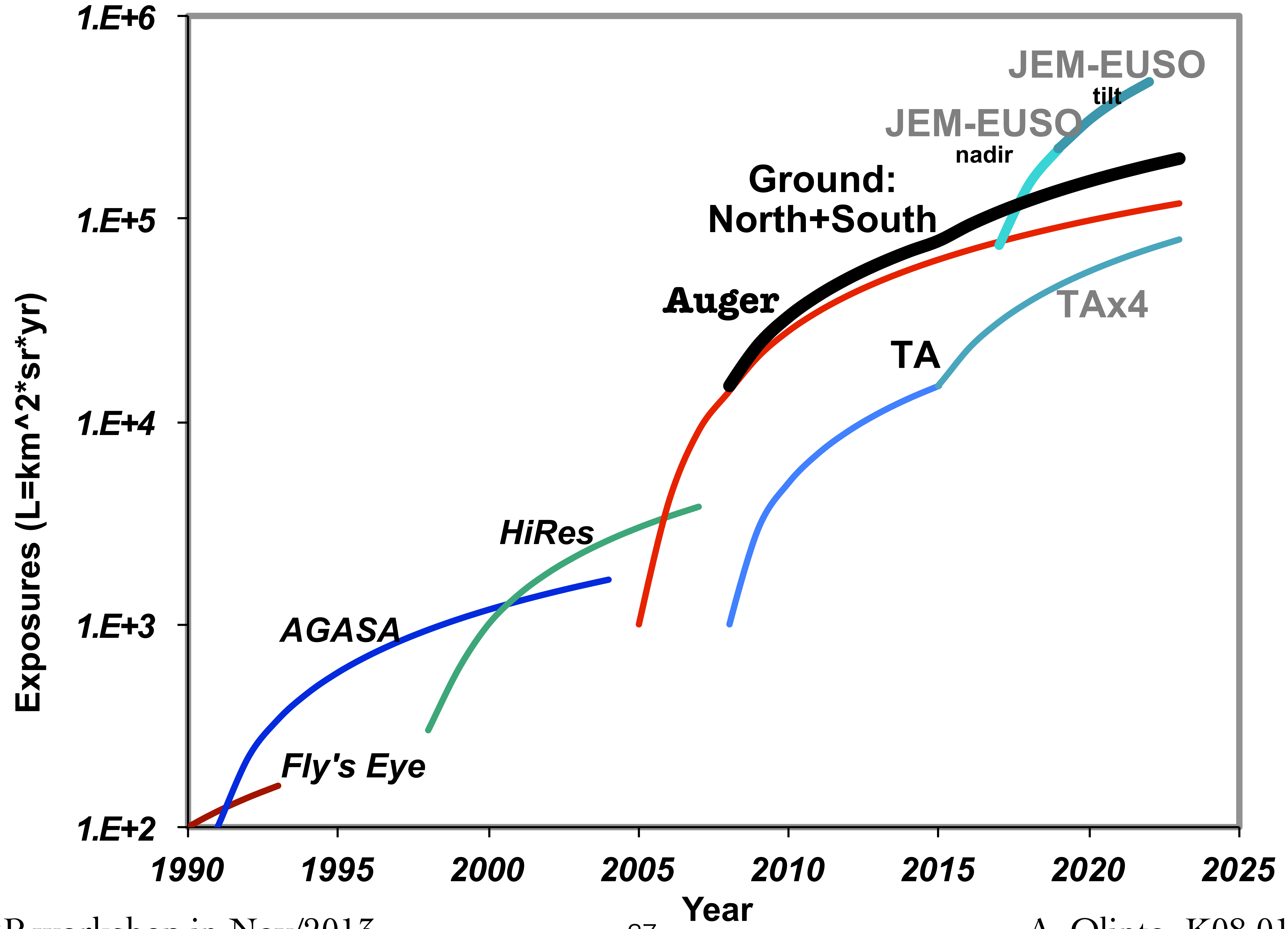


Top view



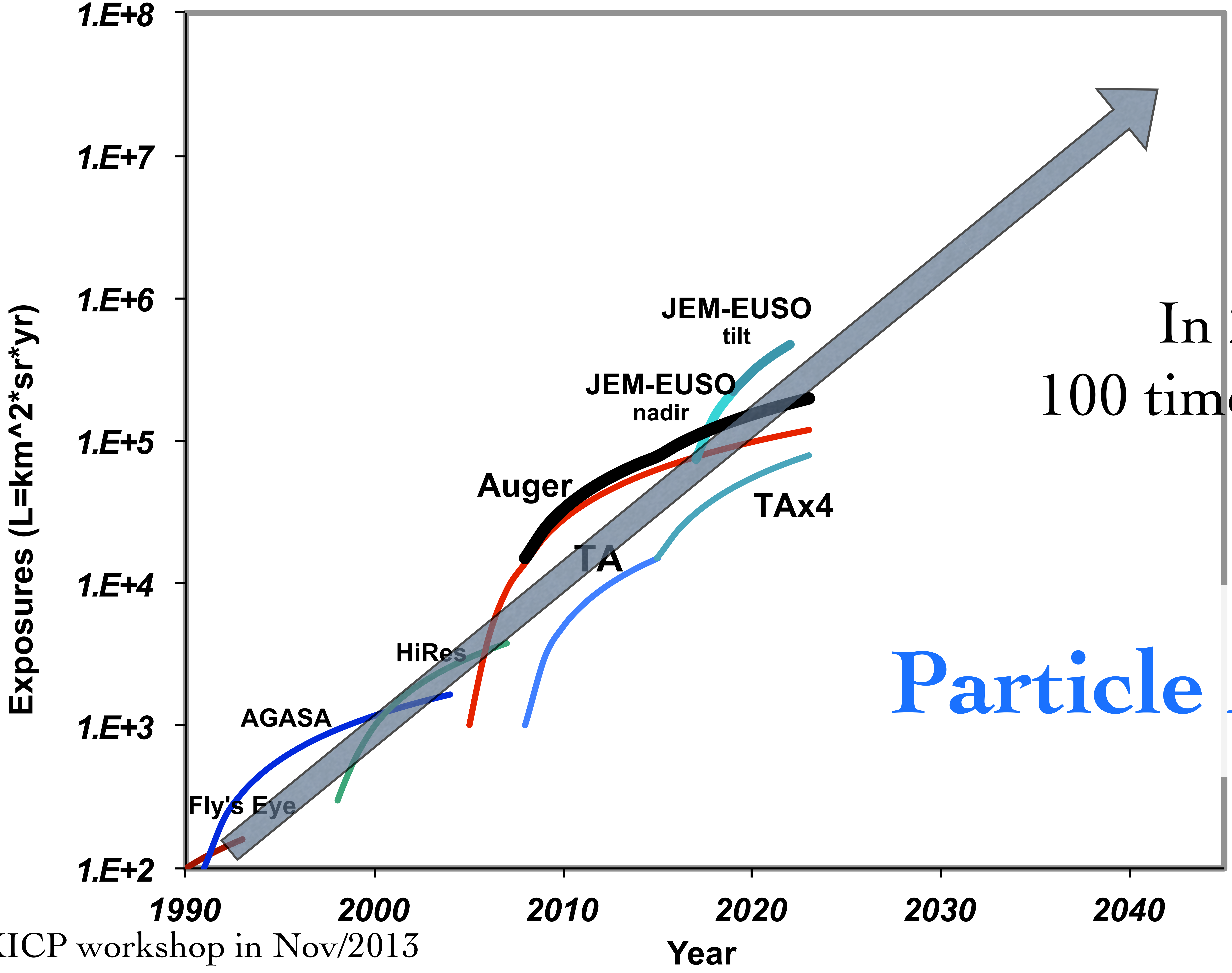


Exposure



KICP workshop in Nov/2013

Exposure (Extrapolation)



In 2035,
100 times statistic

Particle Astronomy

KICP workshop in Nov/2013