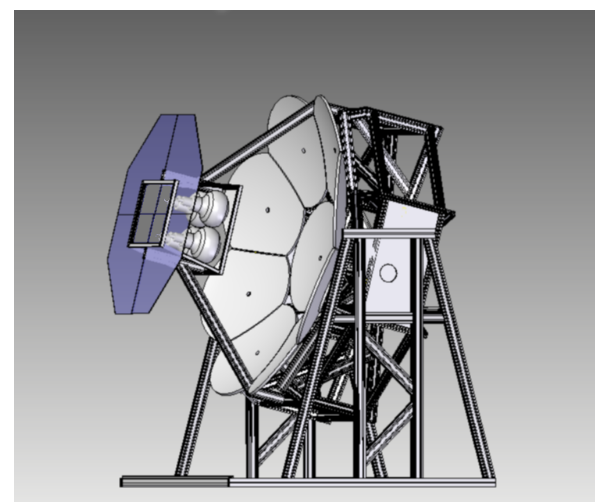
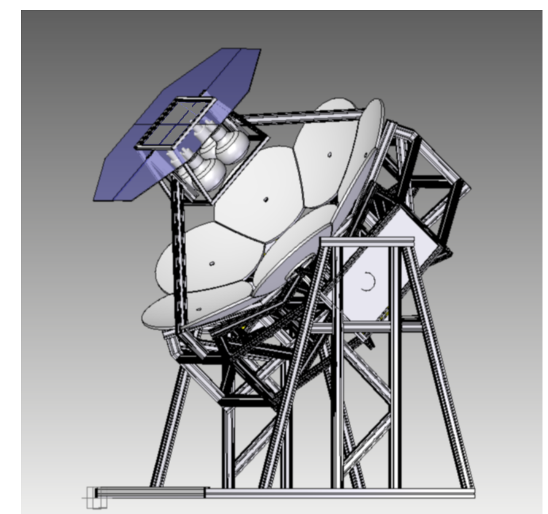
FAST

Fluorescence detector Array of Single-pixel Telescopes

Kavli Institute for Cosmological Physics AT THE UNIVERSITY OF CHICAGO

Development of a prototype for Fluorescence detector Array of Single-pixel Telescopes (FAST)





T. Fujii[1,2], P. Privitera[1], J. Jiang[1], A. Matalon[1], P. Motloch[1], M. Casolino[3], Y. Takizawa[3], M. Bertaina[4], J. N. Matthews[5], K. Yamazaki[6], B. Dawson[7], M. Malacari[7]

[1]KICP University of Chicago, [2]ICRR University of Tokyo, [3]RIKEN, [4]University of Torino, [5]University of Utah, [6]Osaka City University, [7]University of Adelaide

2014/Oct/15, UHECR 2014

fujii@kicp.uchicago.edu

Physics Goal and Future Prospects

Origin and Nature of UHECRs

Particle Interaction 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 detector,
FD or SD

"Precision" measurement
Auger Muon Upgrade
Low energy enhancement (TALE+TA-muon+NICHE, Auger infill+HEAT+AMIGA)

10 - 20 years

Next Generation Observatories
In space (100×exposure)
Ground (10×exposure with high quality events)

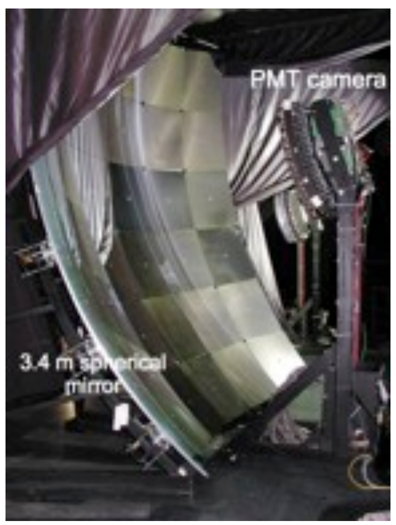
P. Privitera et al., KICP workshop, September, 2013

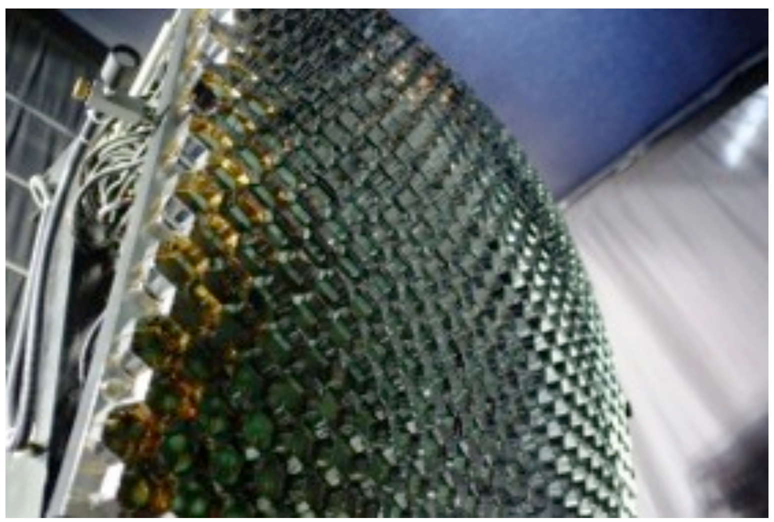
Fluorescence detector Array of Single-Pixel Telescopes (FAST)

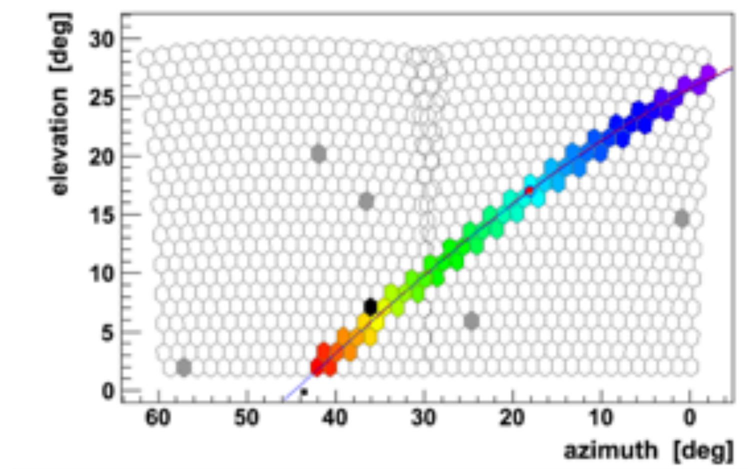
- Target : > $10^{19.5}$ eV, UHE nuclei and neutral particles
- Huge target volume ⇒ Fluorescence detector array

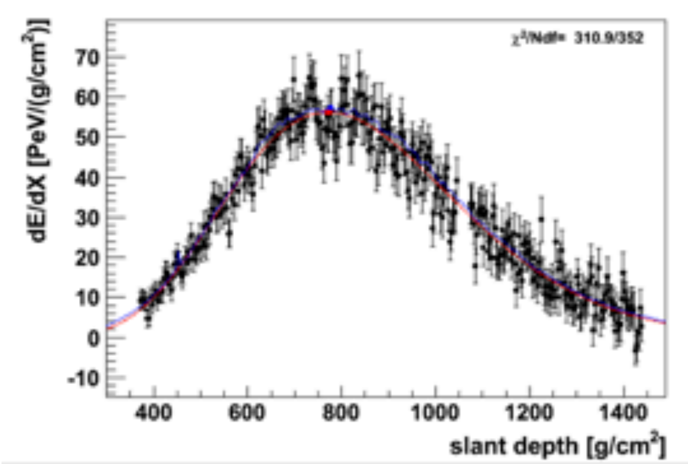
Fine pixelated camera (Auger, TA)

Too expensive to cover a large area



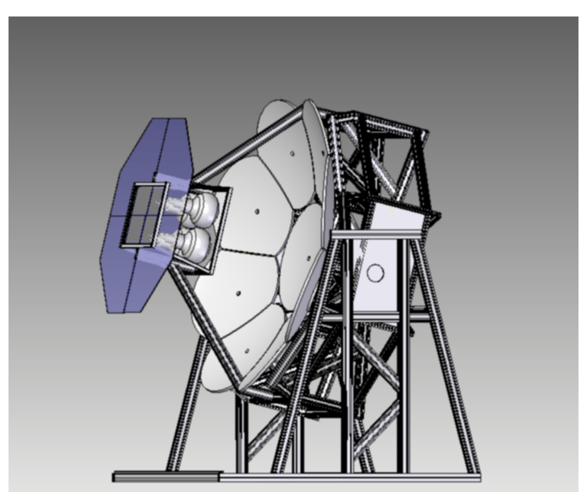


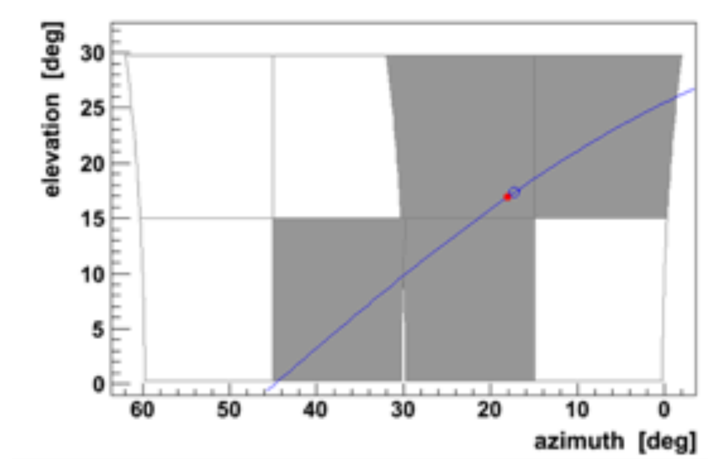


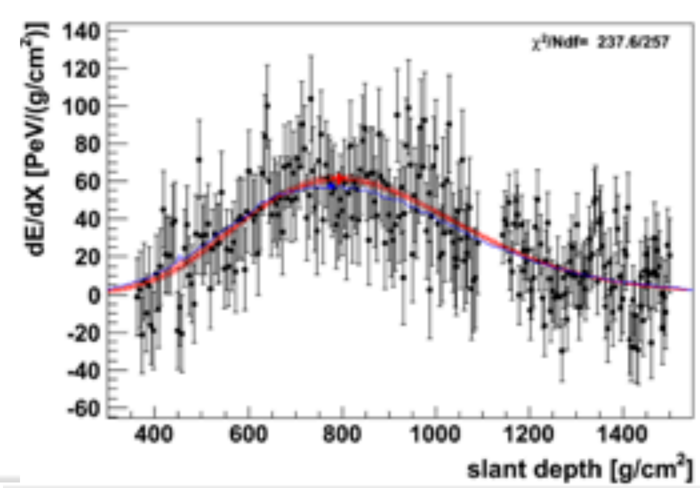


Low cost single pixel telescope (FAST)

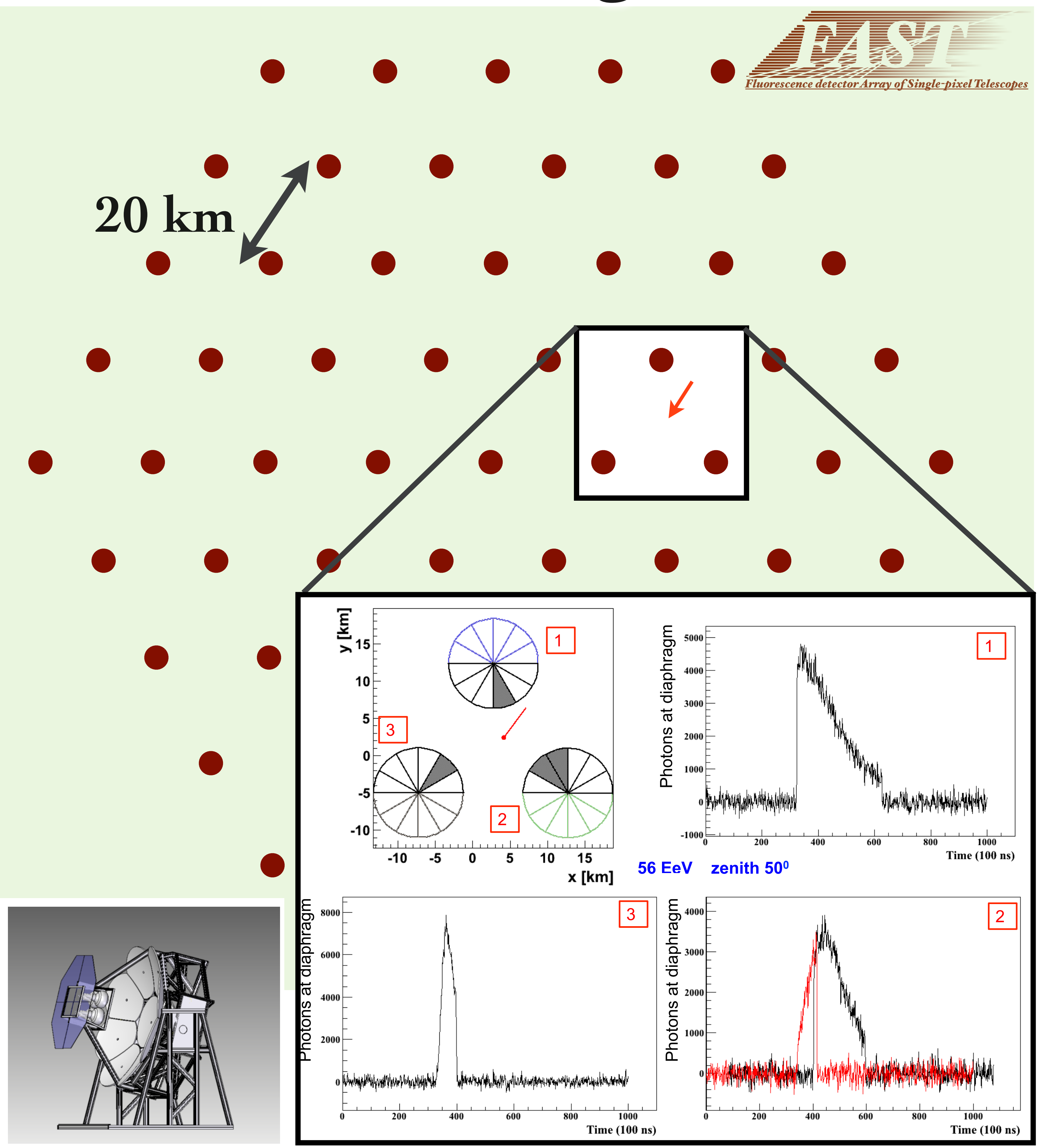
Shower profile reconstruction by given geometry







Fluorescence detector Array of Single-Pixel Telescopes (FAST)

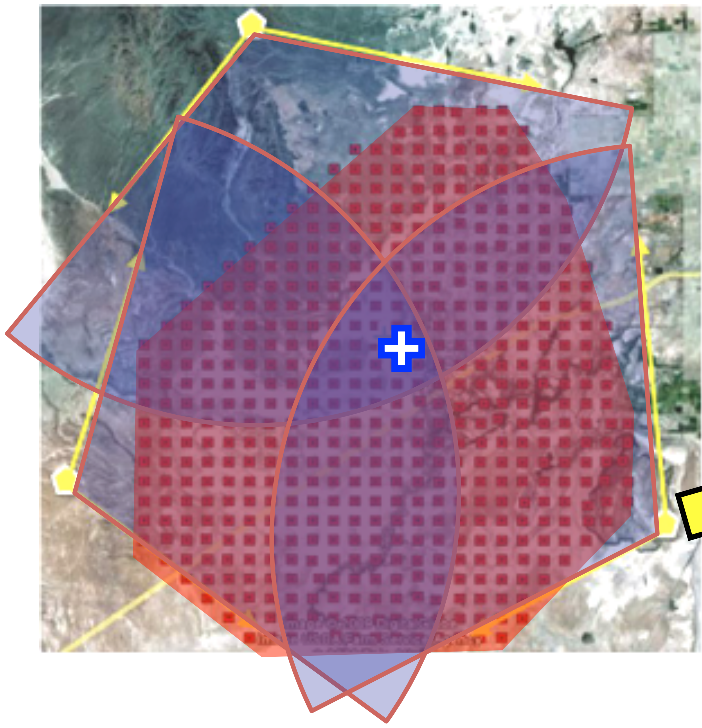


- Reference design: 1 m^2 aperture, 15°×15° FoV per single PMT
- 12 Telescope, 48 PMTs, 30°×360° FoV in each station.
- If 127 stations are installed with 20 km spacing, a ground coverage is ~ 40,000 km^2
- Geometry: Radio, SD or three coincidence of FAST.

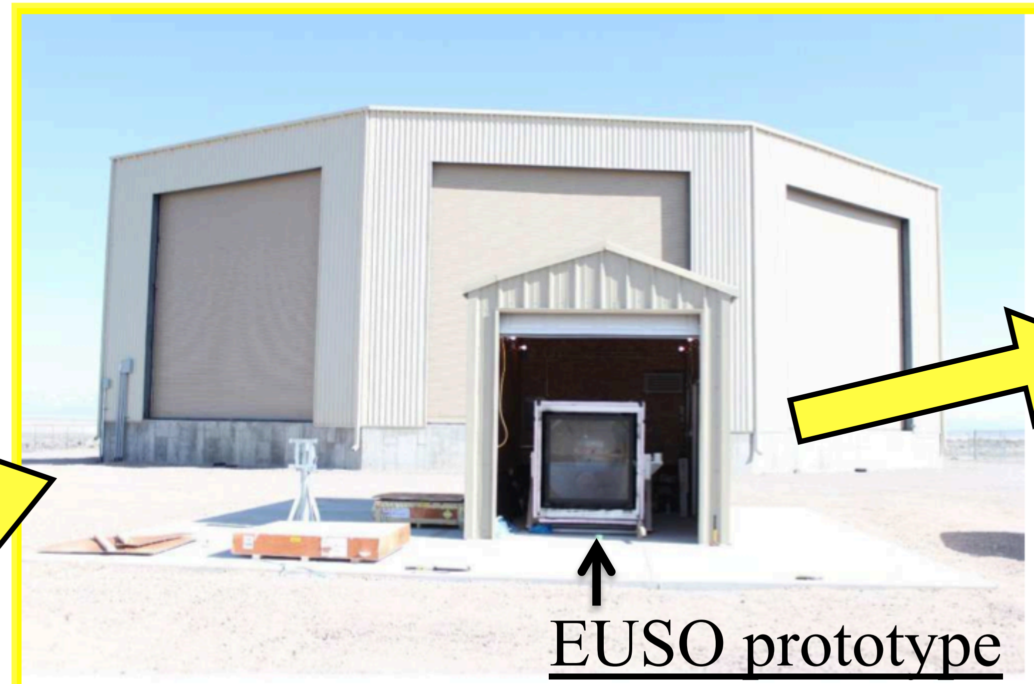
Window of Opportunity at EUSO-TA

Fluorescence detector Array of Single-pixel Telescopes

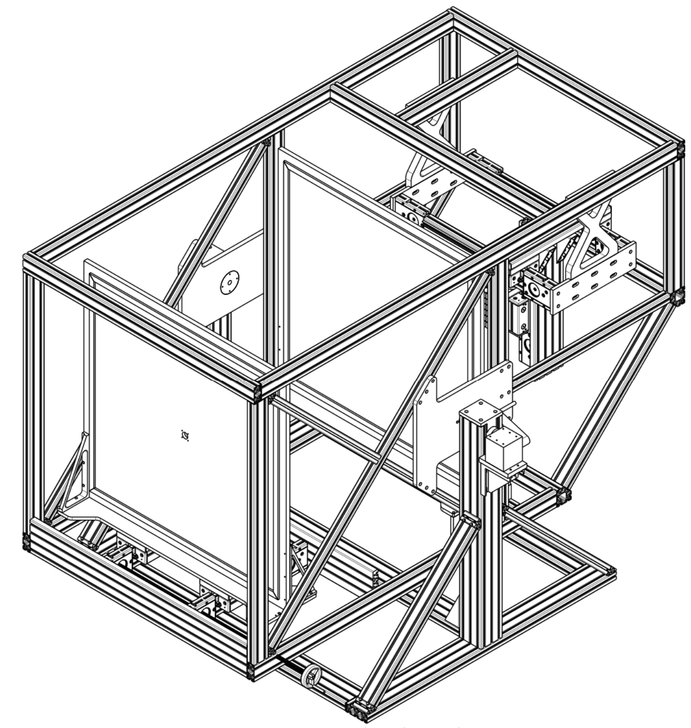
Telescope Array, Utah, USA



Black Rock Mesa site



EUSO-TA optics

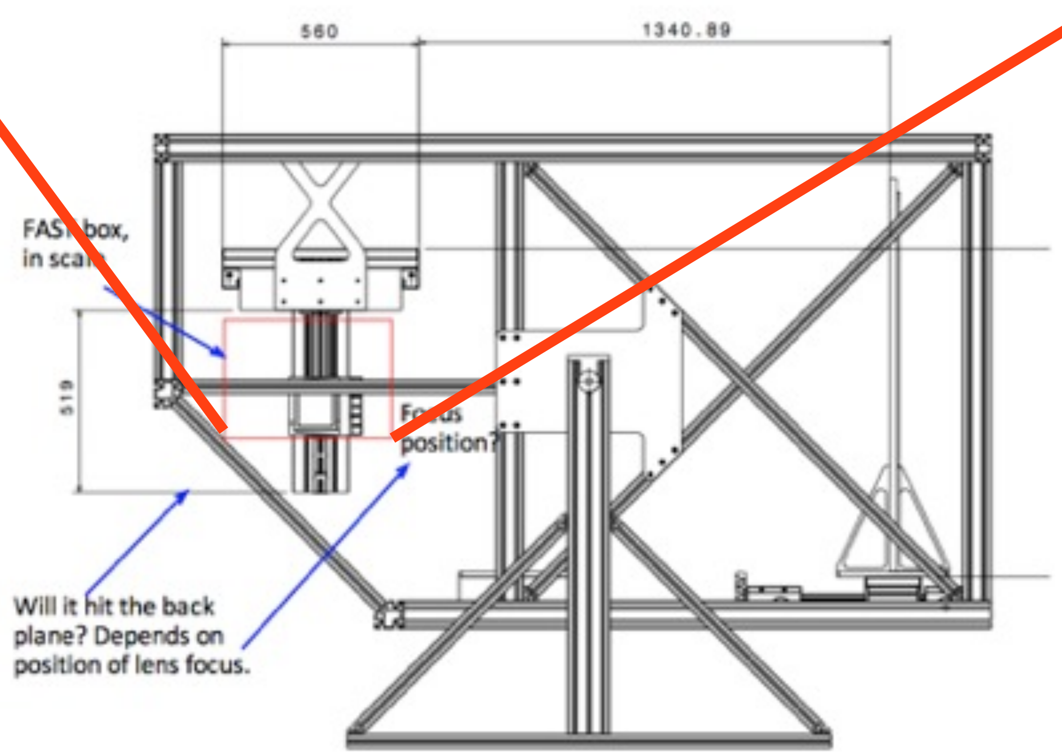


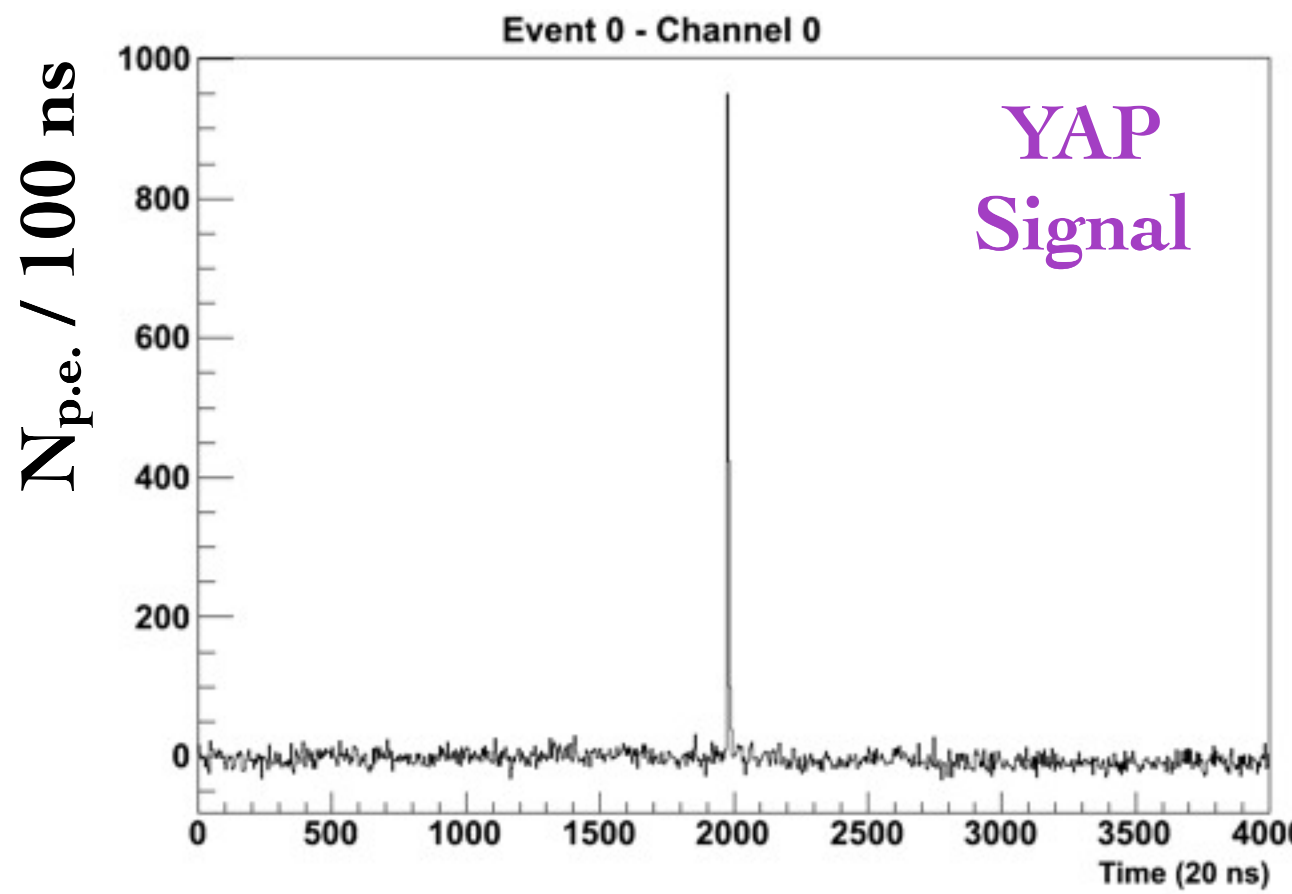
M. Casolino (RIKEN), M. Bertaina, M. Marengo, F. Borotto, B. Giraudo (INFN-Torino)

- Temporally borrow 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.**
- Installation in February 2014, test measurements in April and June 2014.
- Collaboration between Pierre Auger, Telescope Array and JEM-EUSO.

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.





FAST
Fluorescence detector Array of Single-pixel Telescopes

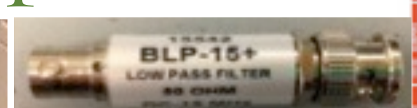
DAQ System

TAFD external trigger, 3~5 Hz

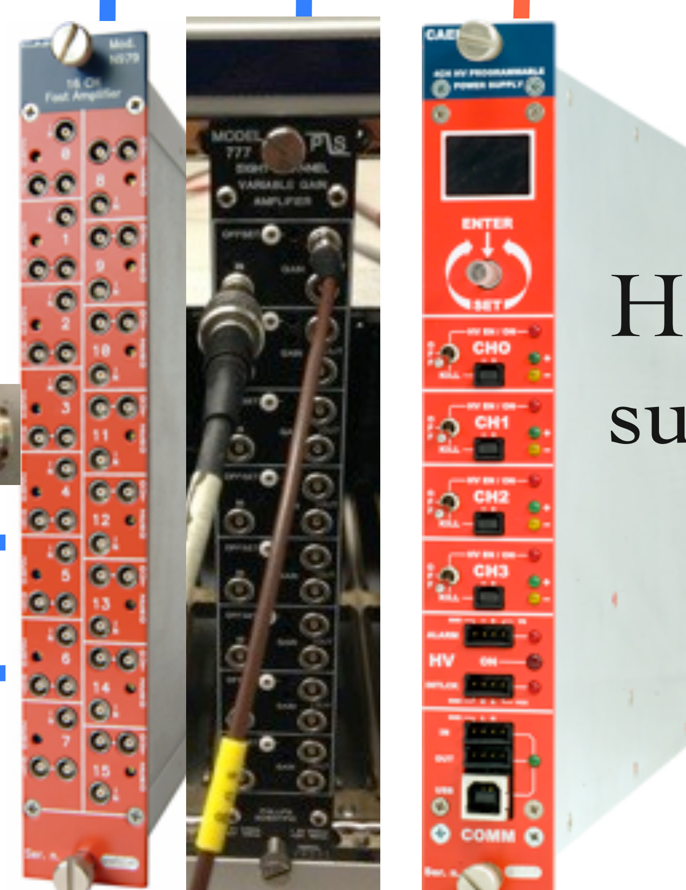
Anode & dynode Signal

Camera of FAST

15 MHz low pass filter



Portable VME Electronics
- Struck FADC 50 MHz sampling, SIS3350
- GPS board, HytecGPS2092



High Voltage power supply, N1419 CAEN

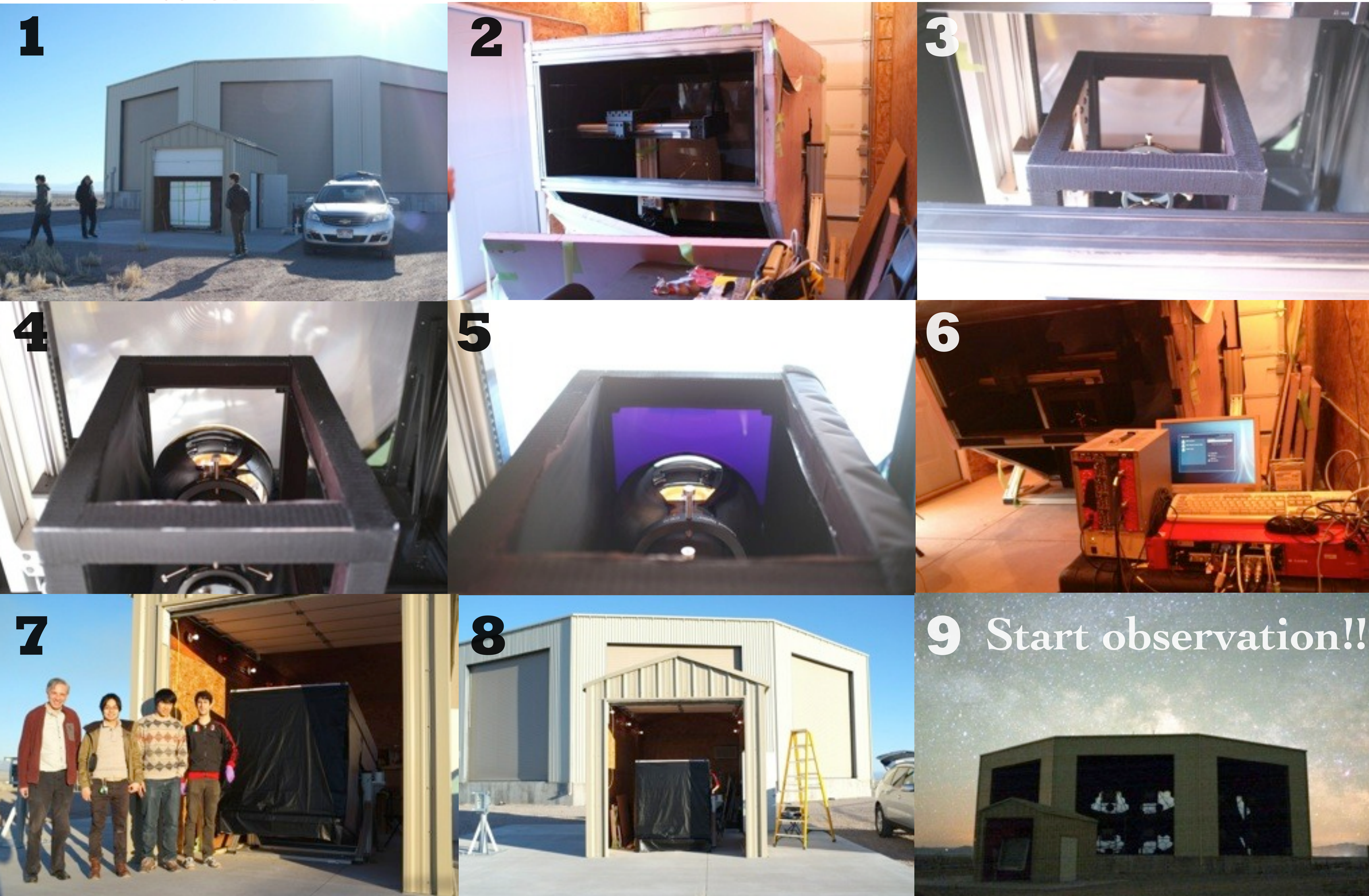
All modules are remotely controlled through wireless network.

Amplifiers
R979 CAEN
Signal×10

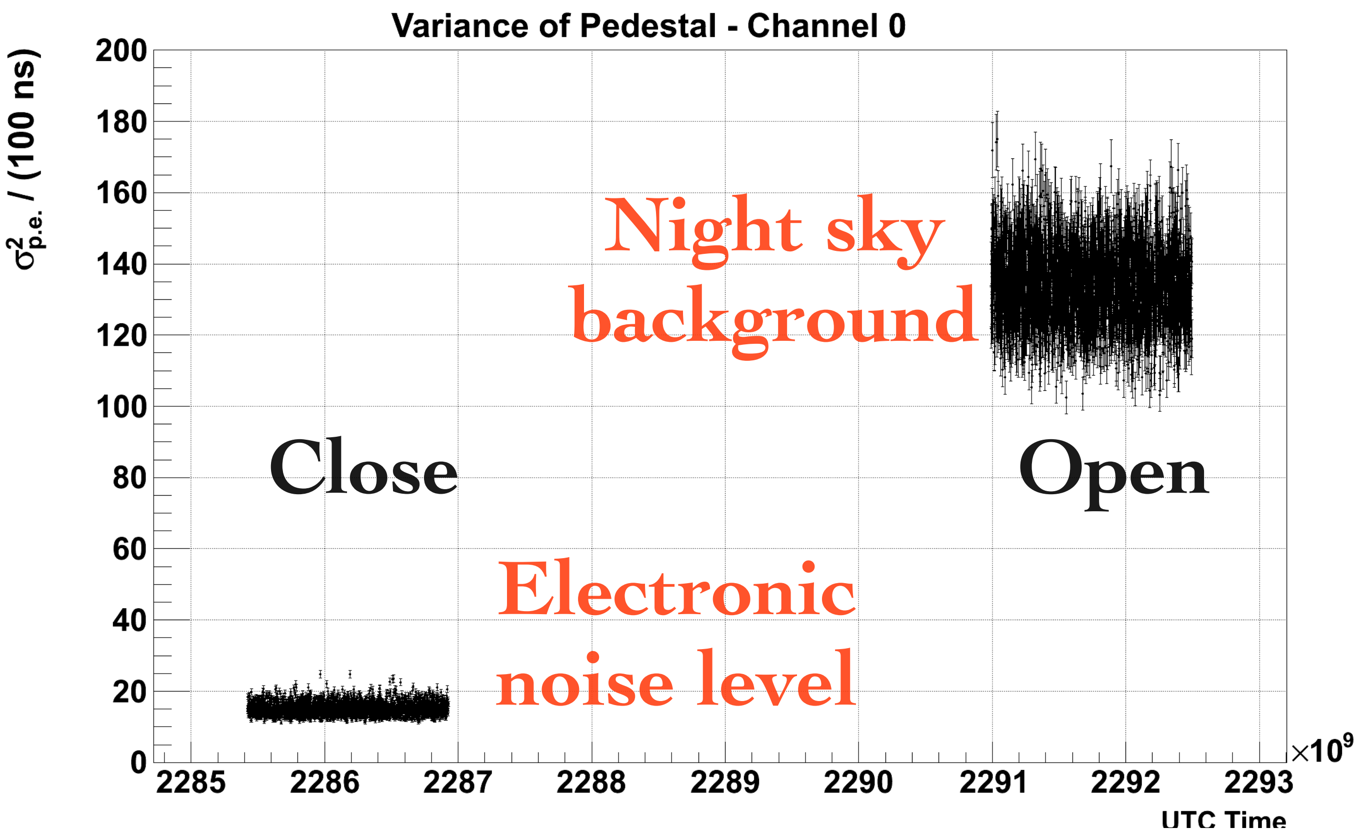
777,Phillips scientific
Signal×50

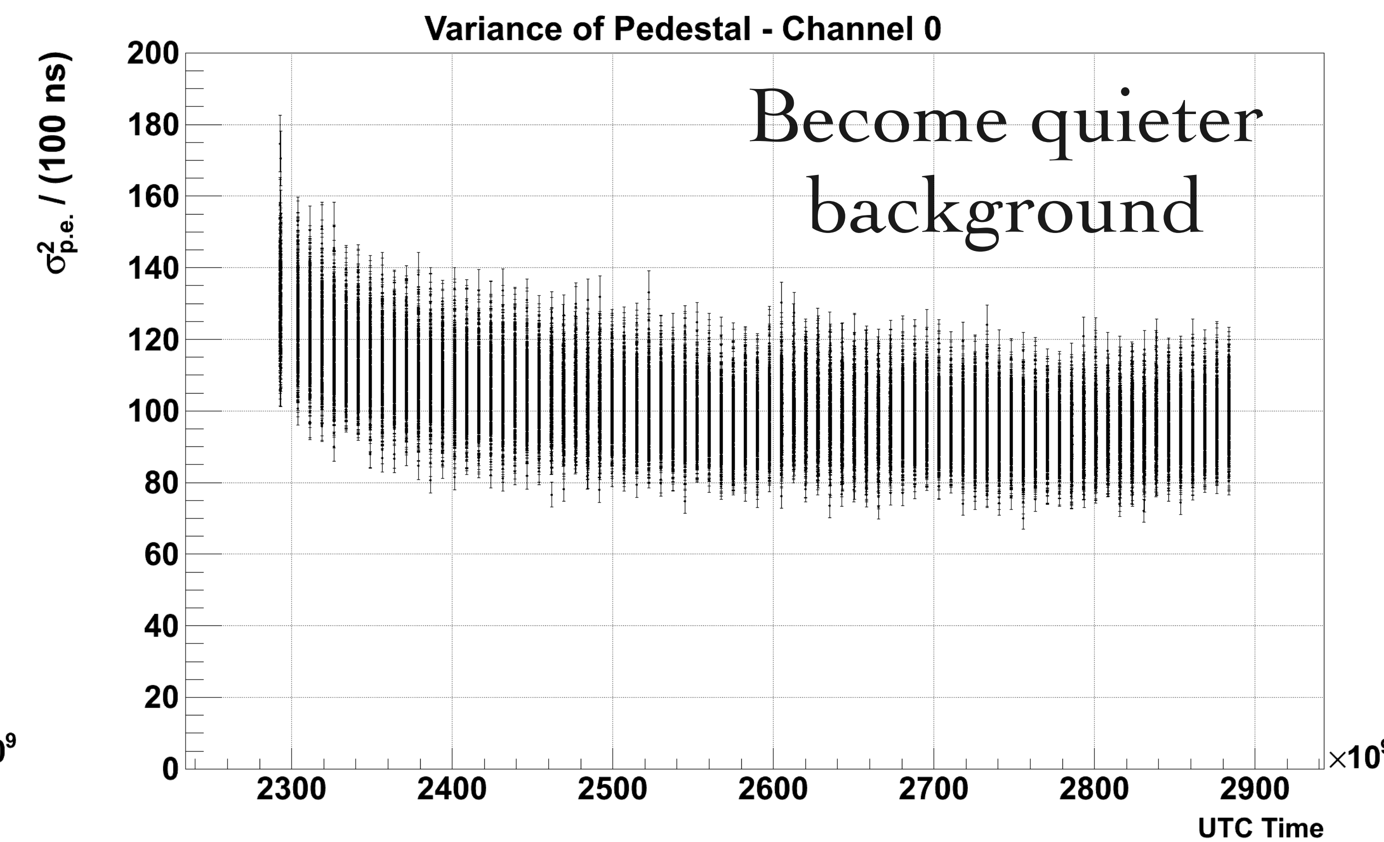
FAST
Fluorescence detector Array of Single-pixel Telescopes

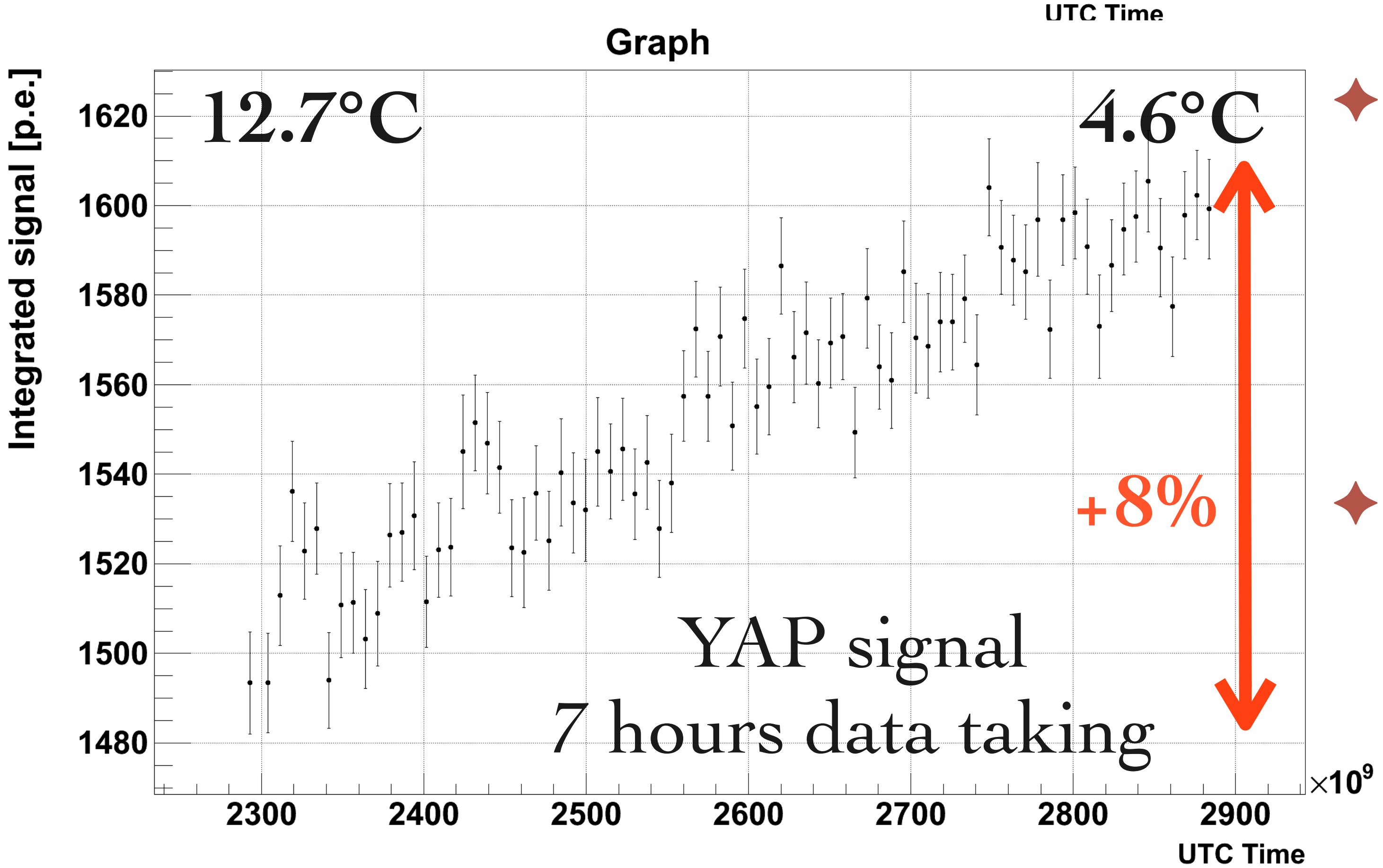
Installation in February 2014



Operation in Clear Night







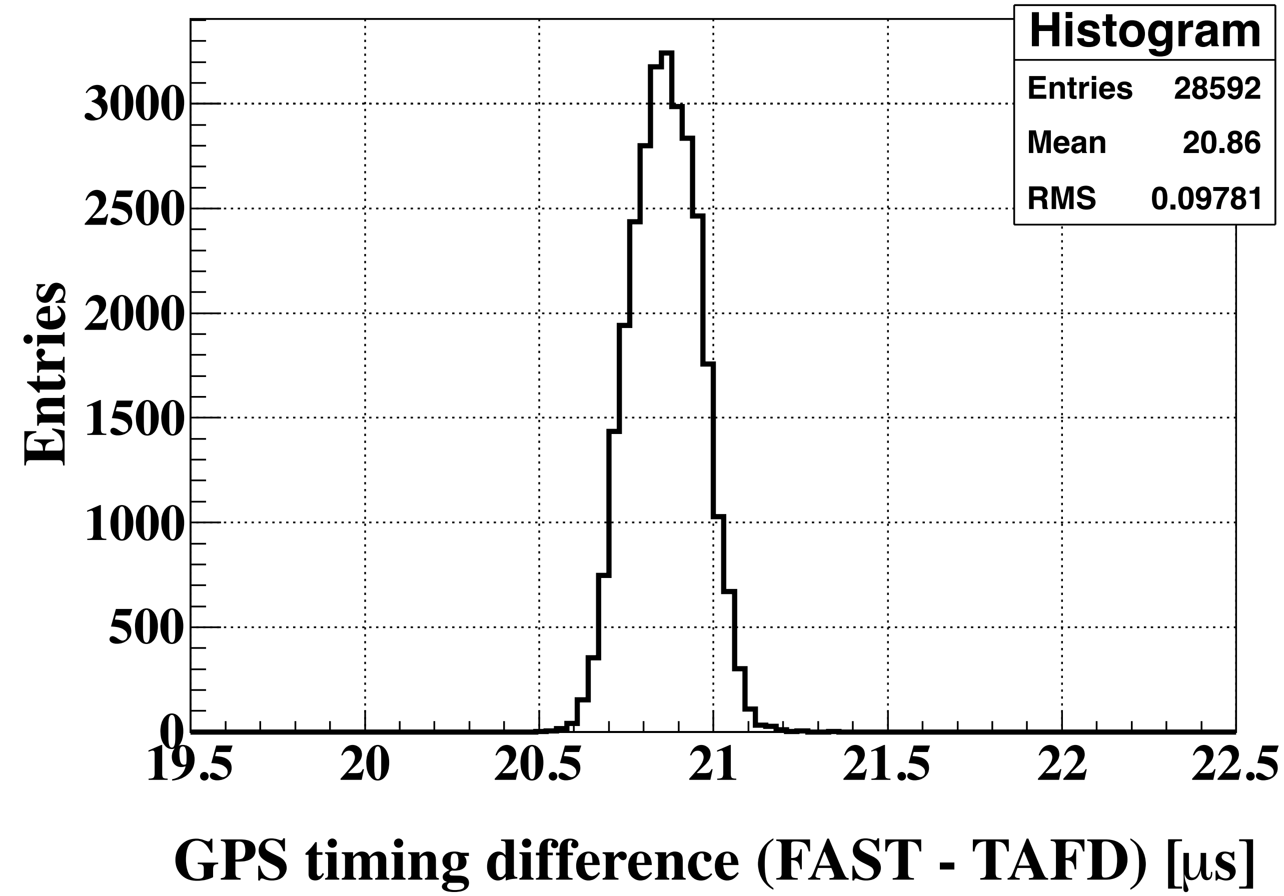
- Variance is proportional to PMT current. Electronic noise is negligible with regard to night sky background.
- Good gain stability during data taking, consistent with PMT gain temperature dependence of -1%/℃

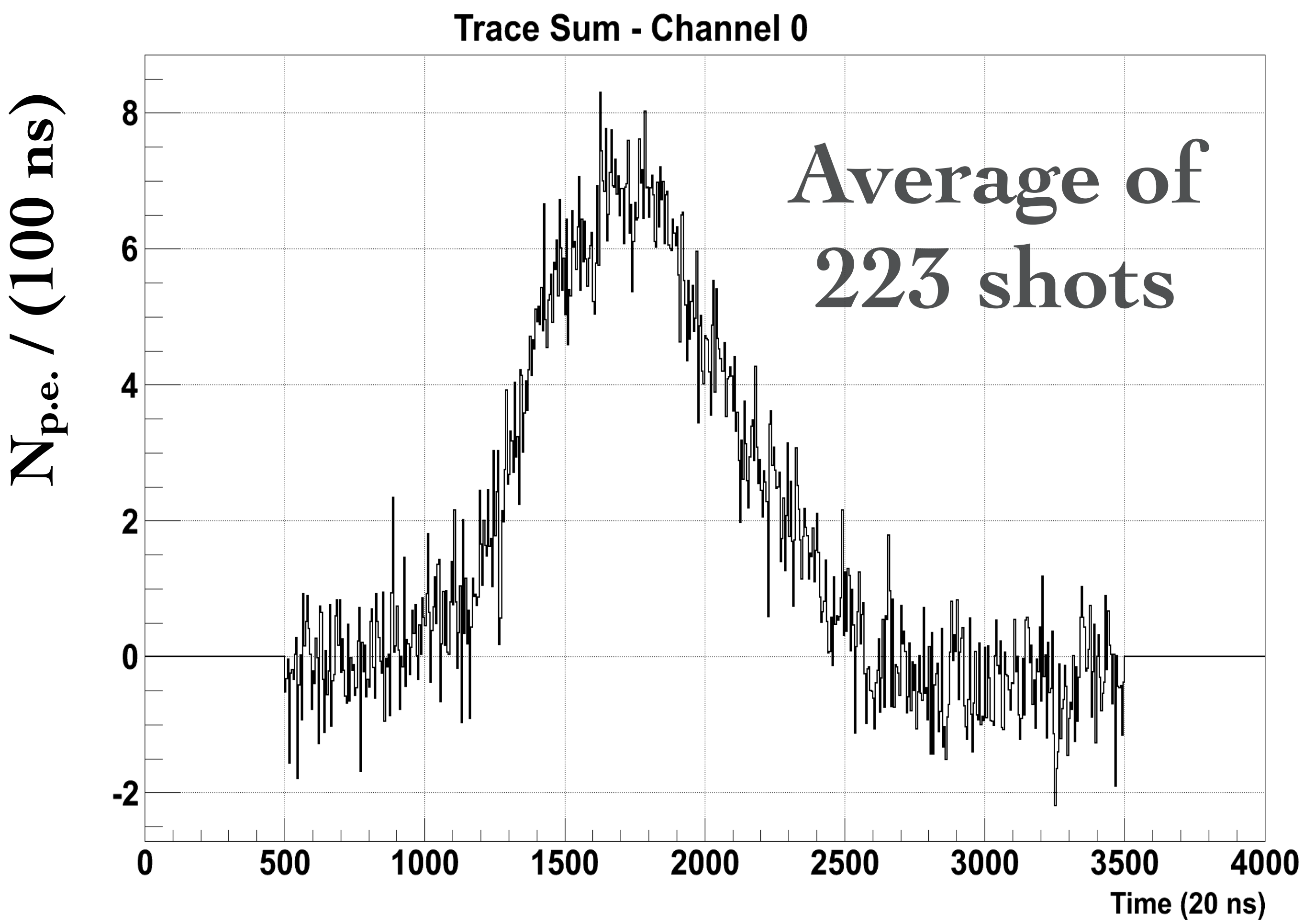
GPS Timing and CLF Signal

Fluorescence detector Array of Single-pixel Telescopes

Central Laser Facility

Vertical UV laser shooting every 30 minutes, **21 km from FAST**, 10 Hz, 2.2 mJ, 300 shots

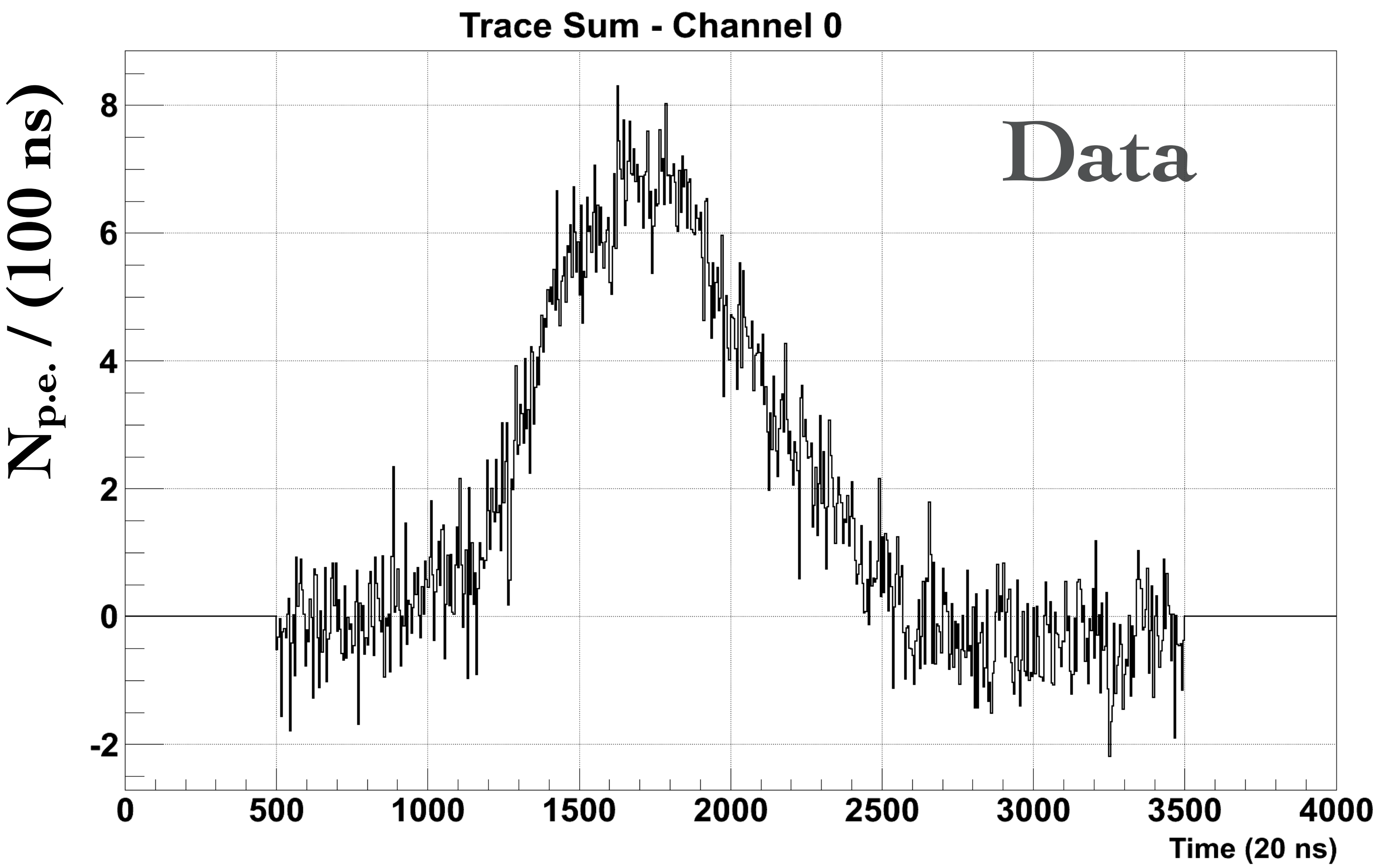




- FAST-TAFD timing resolution, 100 ns. (20.9 μs is the TAFD trigger processing time.)
- laser signal ~ $10^{19.5}$ eV at 21 km
- peak signal ~ 7 p.e. / 100 ns ($\sigma_{p.e.}$ = 12 p.e.) at the limit of detectability

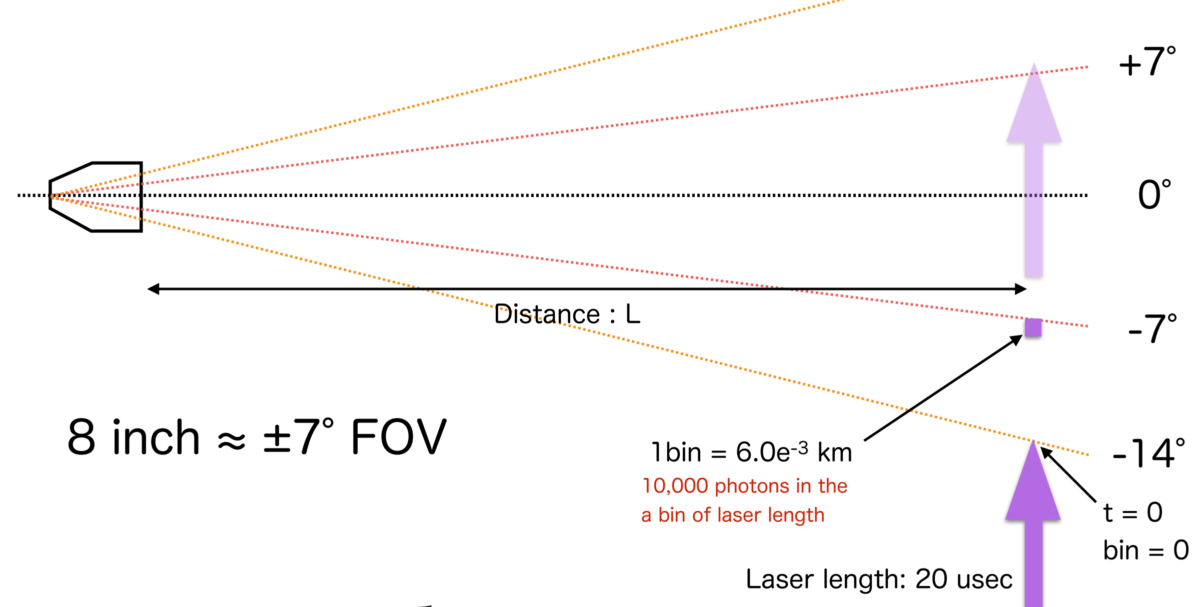
Fluorescence detector Array of Single-pixel Telescopes

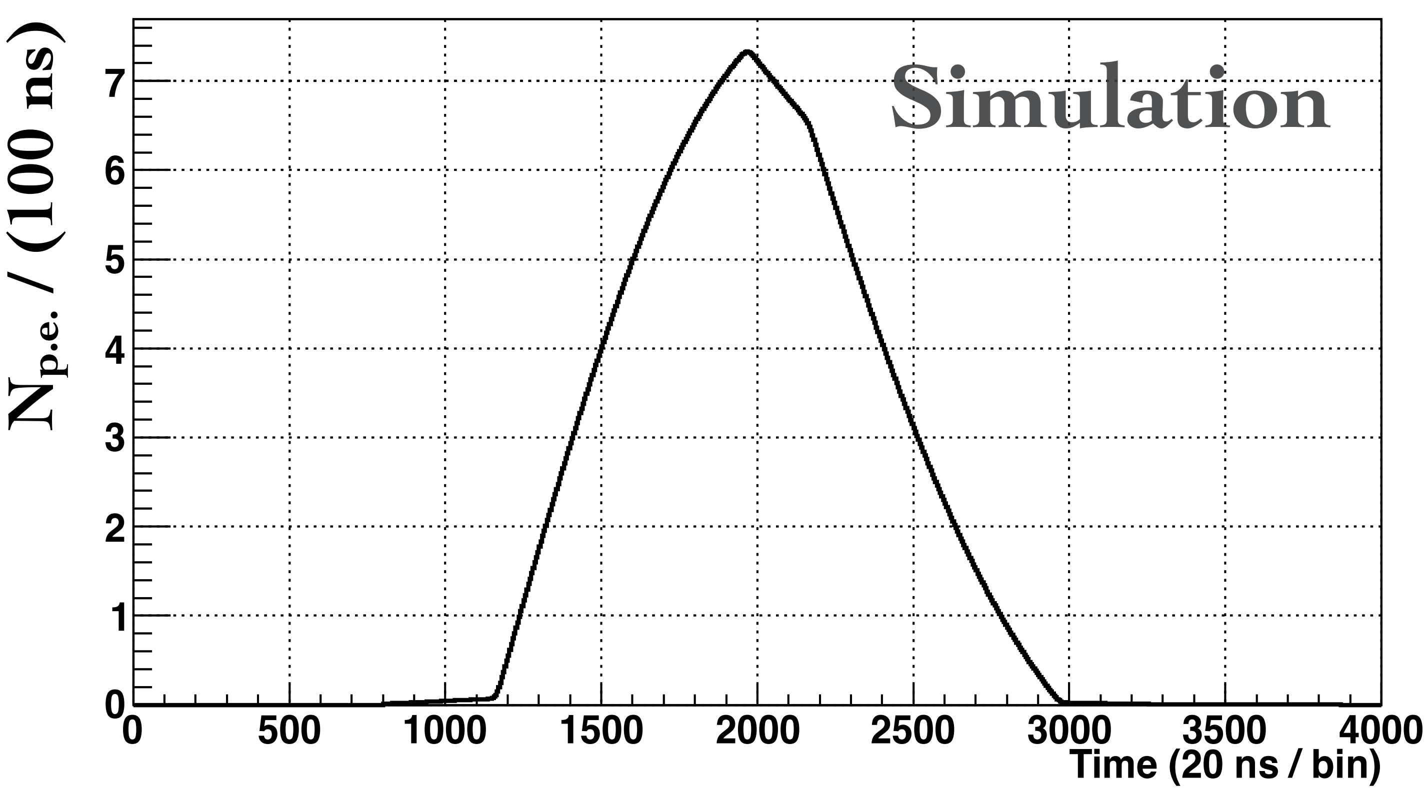
Preliminary CLF Simulation



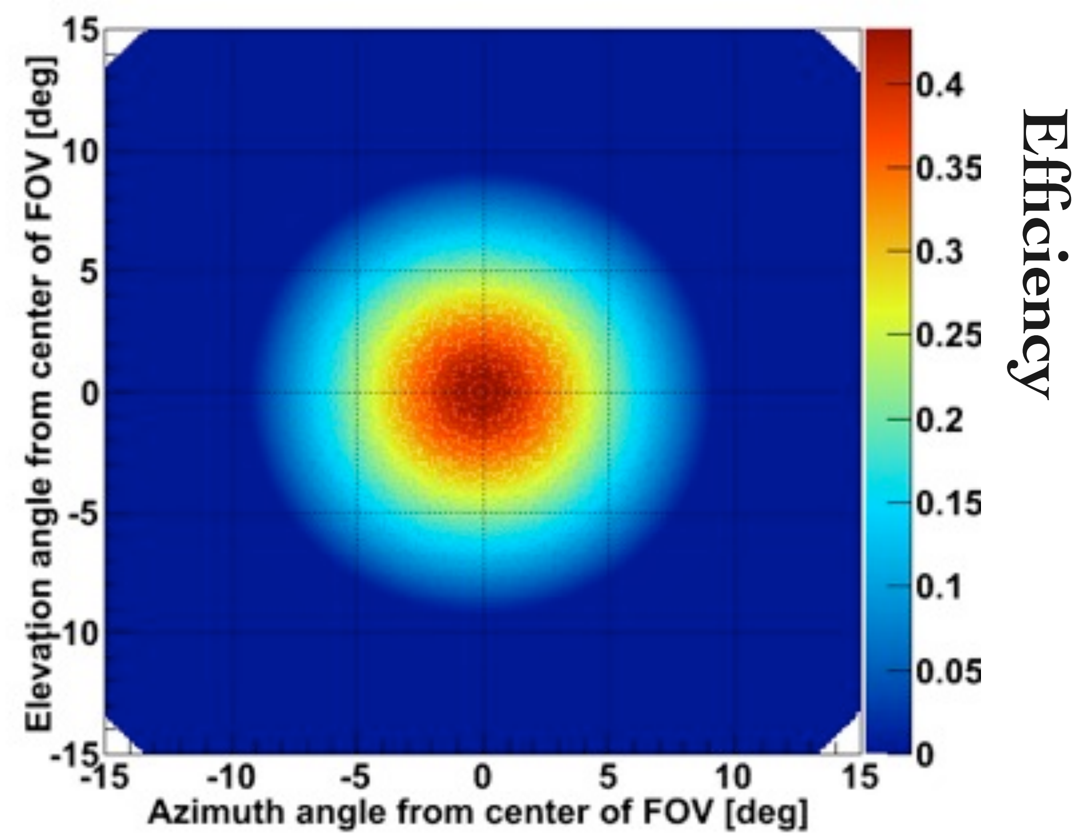
Raytracing

Y. Takizawa (RIKEN)



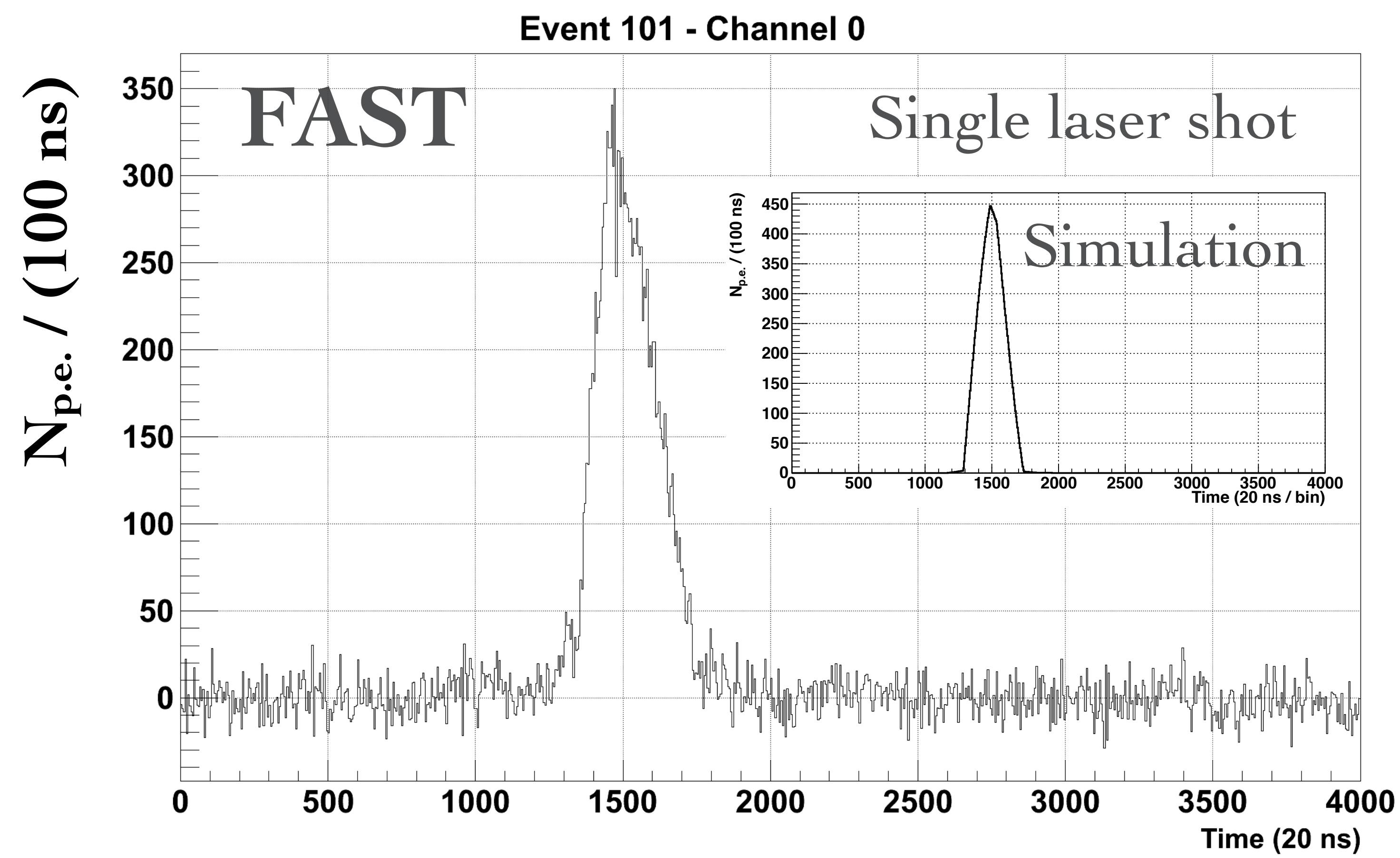


Directional sensitivity



Fluorescence detector Array of Single-pixel Telescopes

Portable Laser Signal

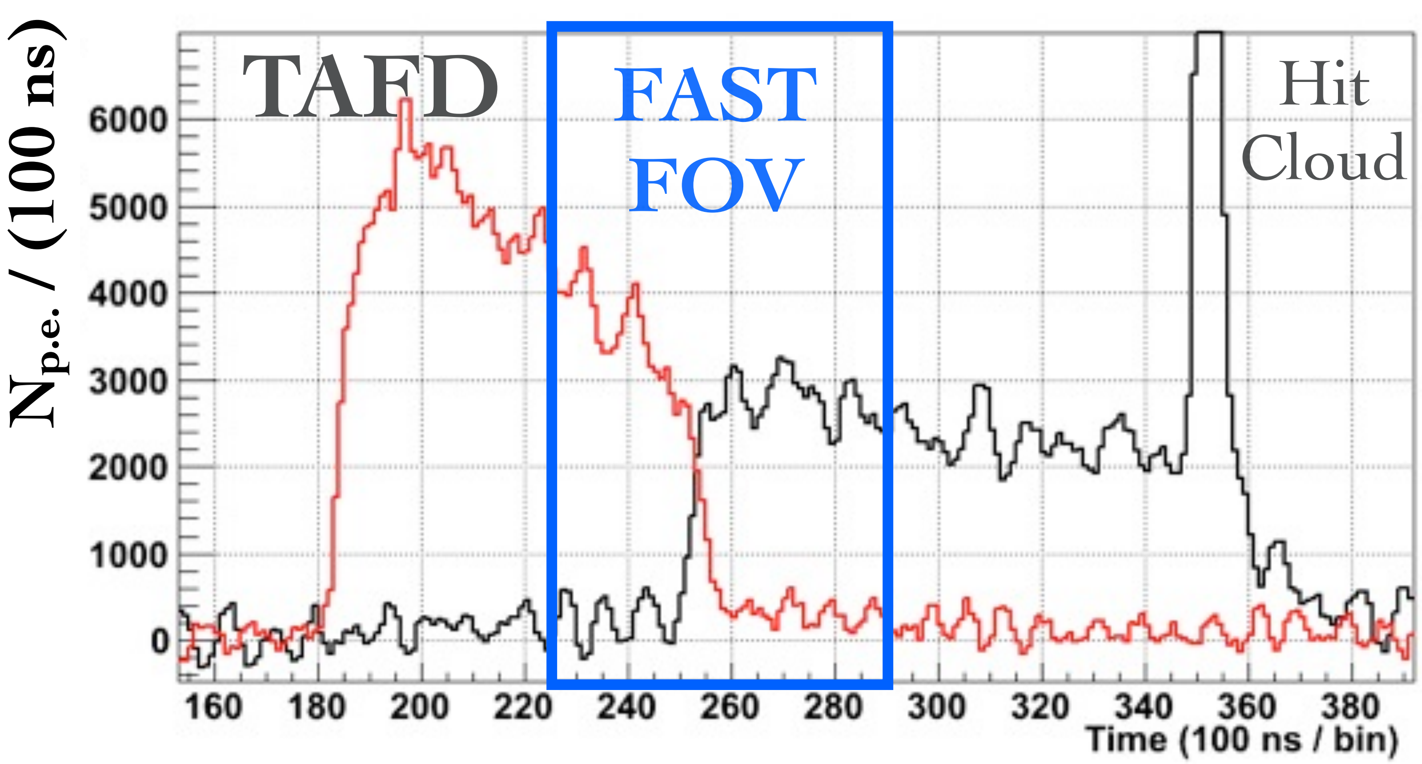


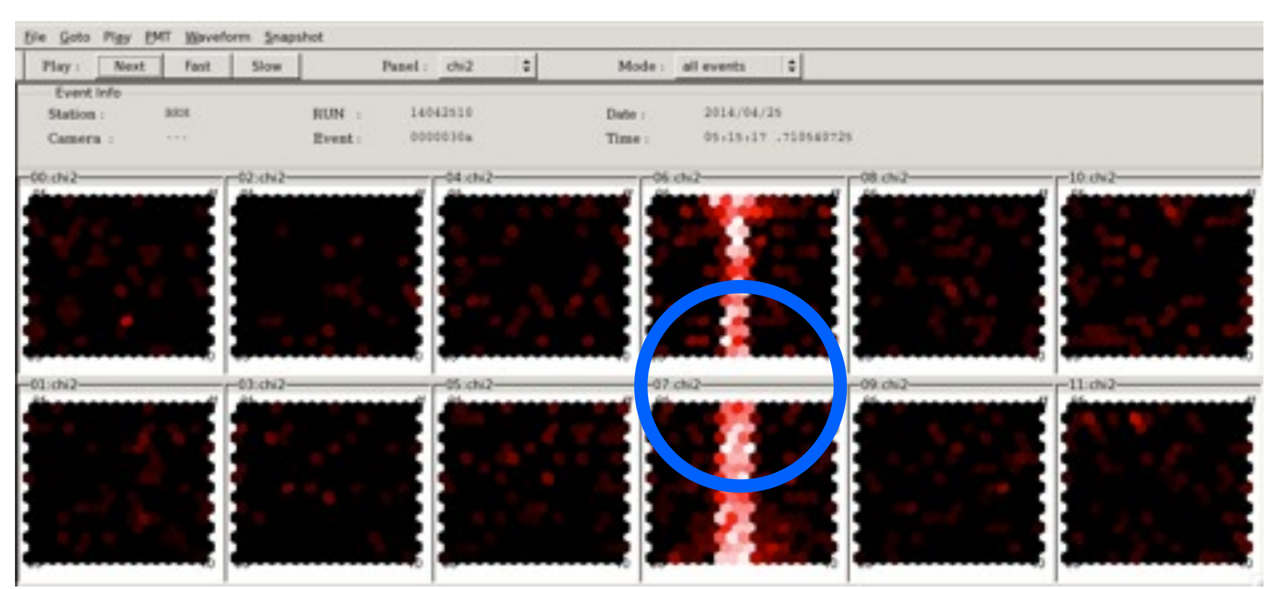
- Vertical UV laser with same energy of CLF (~$10^{19.5}$ eV) **at 6 km from FAST.**

  Operated by K. Yamazaki (OCU)

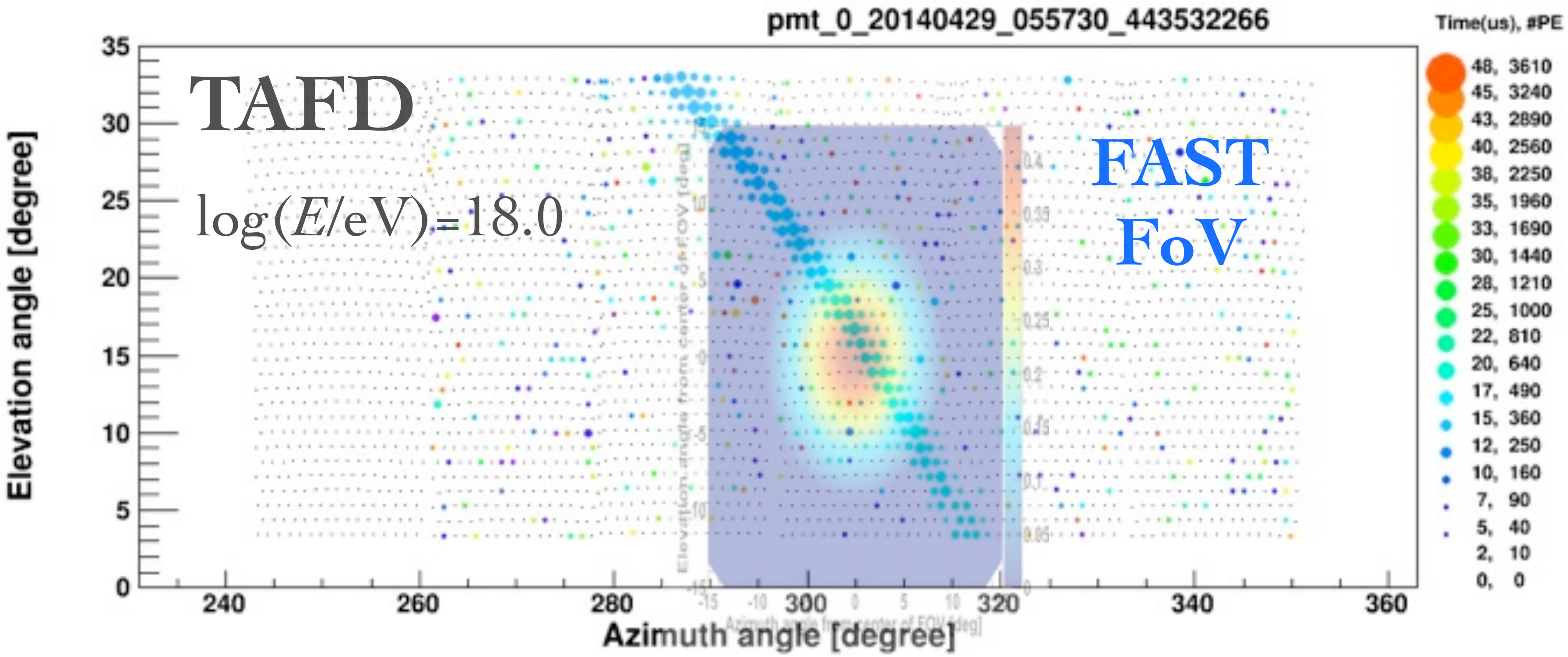
- **Peak signal ~ 300 p.e. / 100 ns. All shots are detected.**

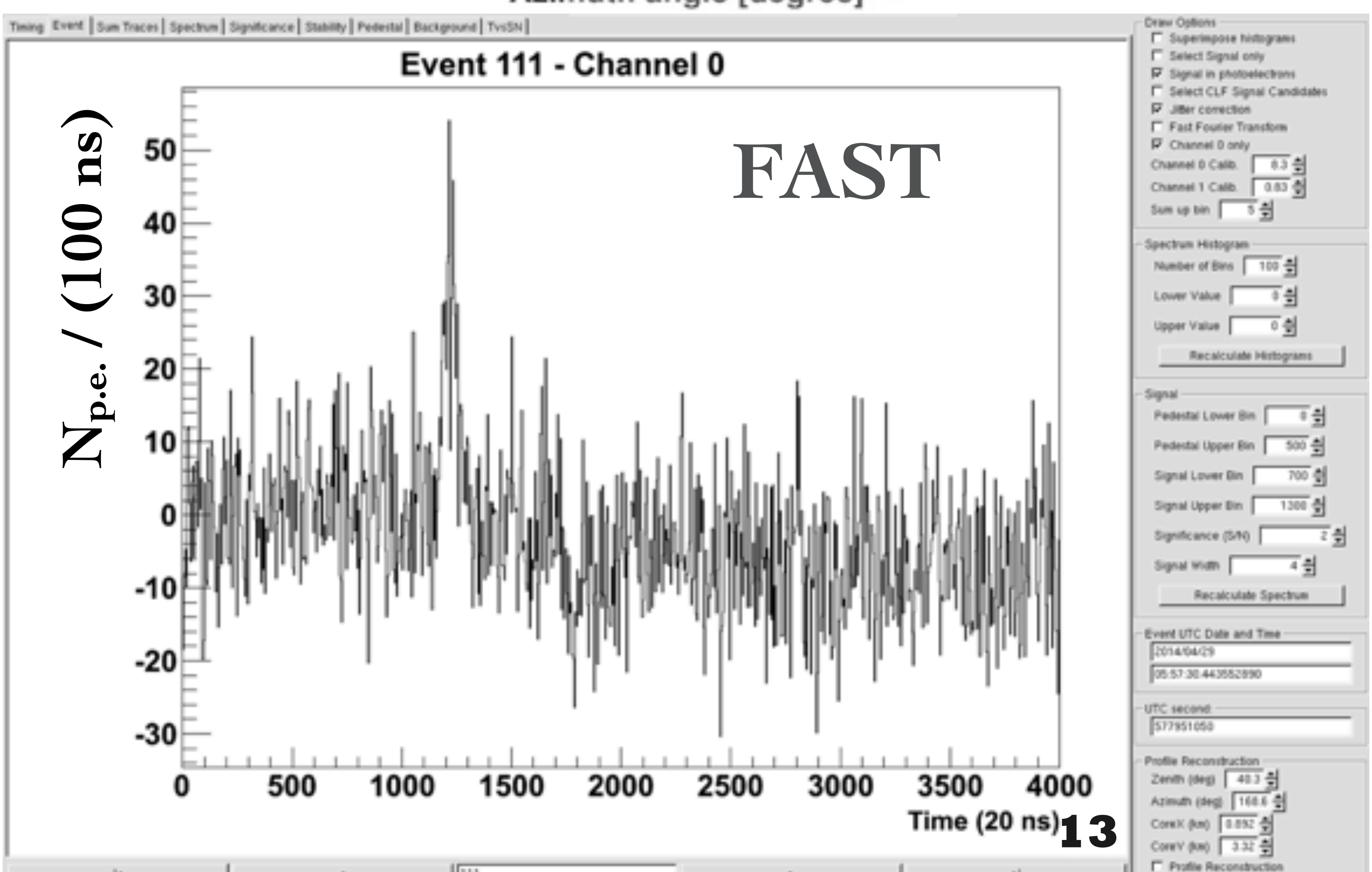
- Expected signal TAFD/FAST: (7 m^2 aperture × 0.7 shadow × 0.9 mirror) / (1 m^2 aperture × 0.43 optics efficiency) ~ 10





Shower Signal Search





- We searched for FAST signals in coincidence with TAFD showers in the FAST FoV.
- Data set: April and June observation, 19 days, 83 hours.
- **16 candidates found.**
- Low energy showers as expected.

Example of Signal Candidates

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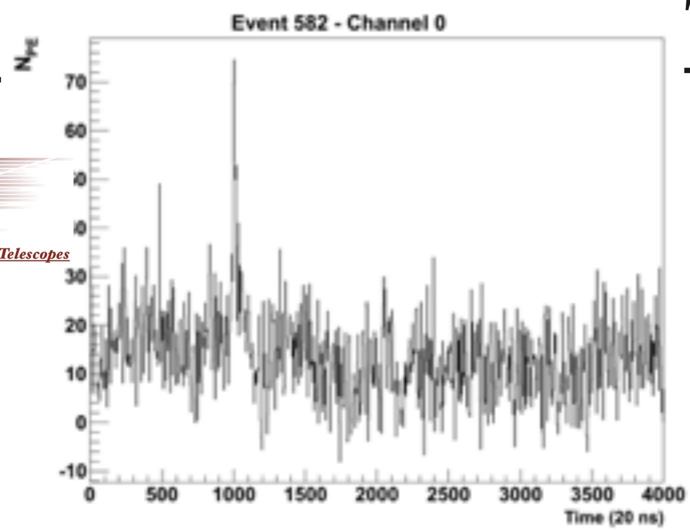
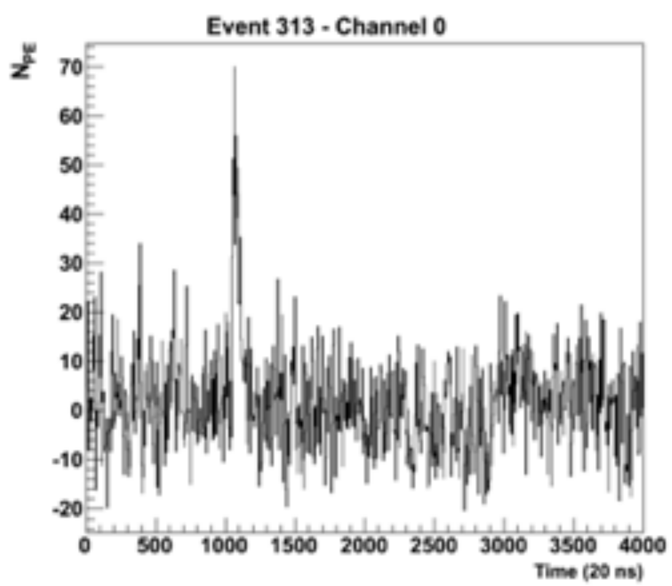
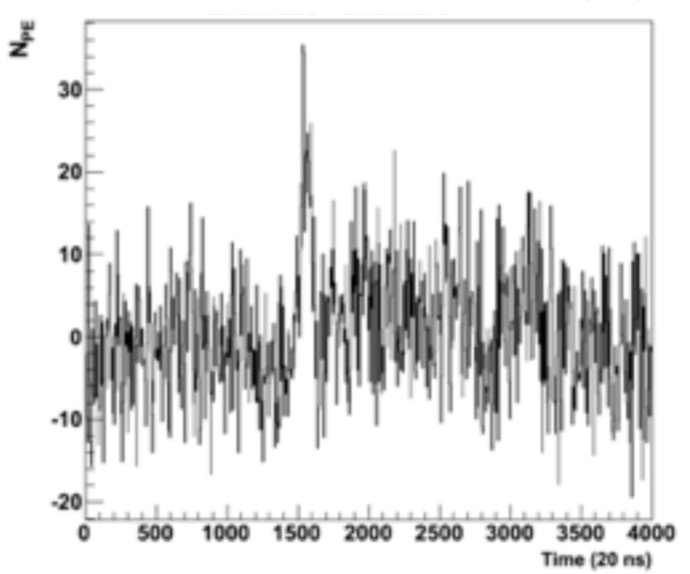
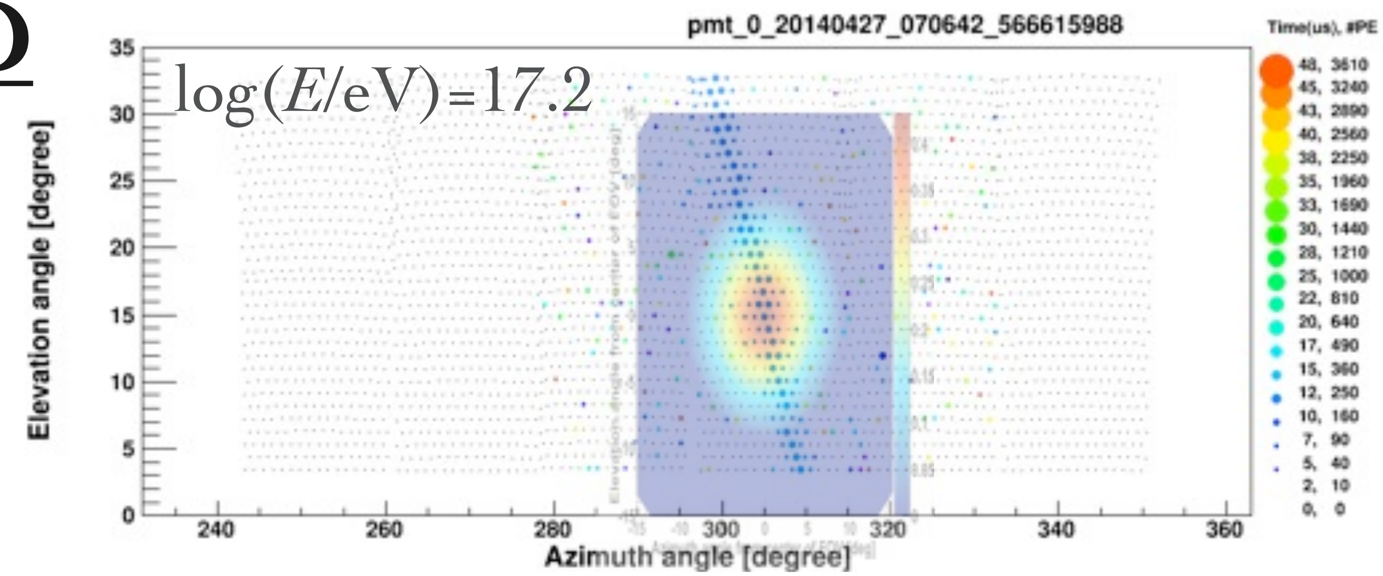
FAST

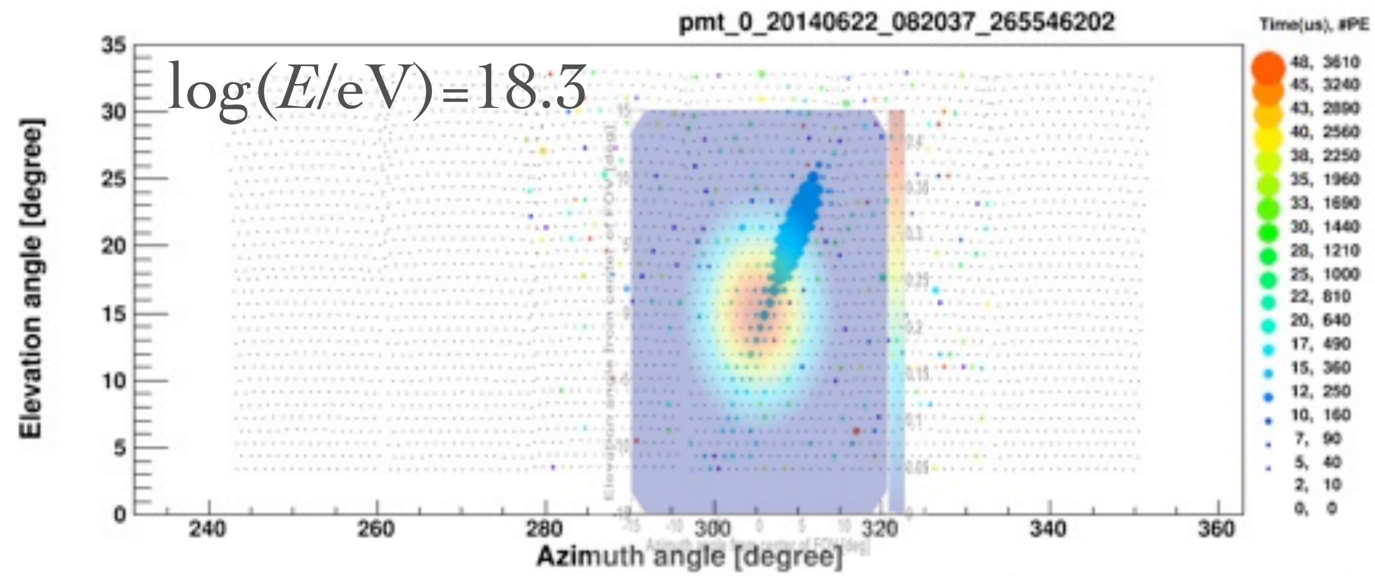


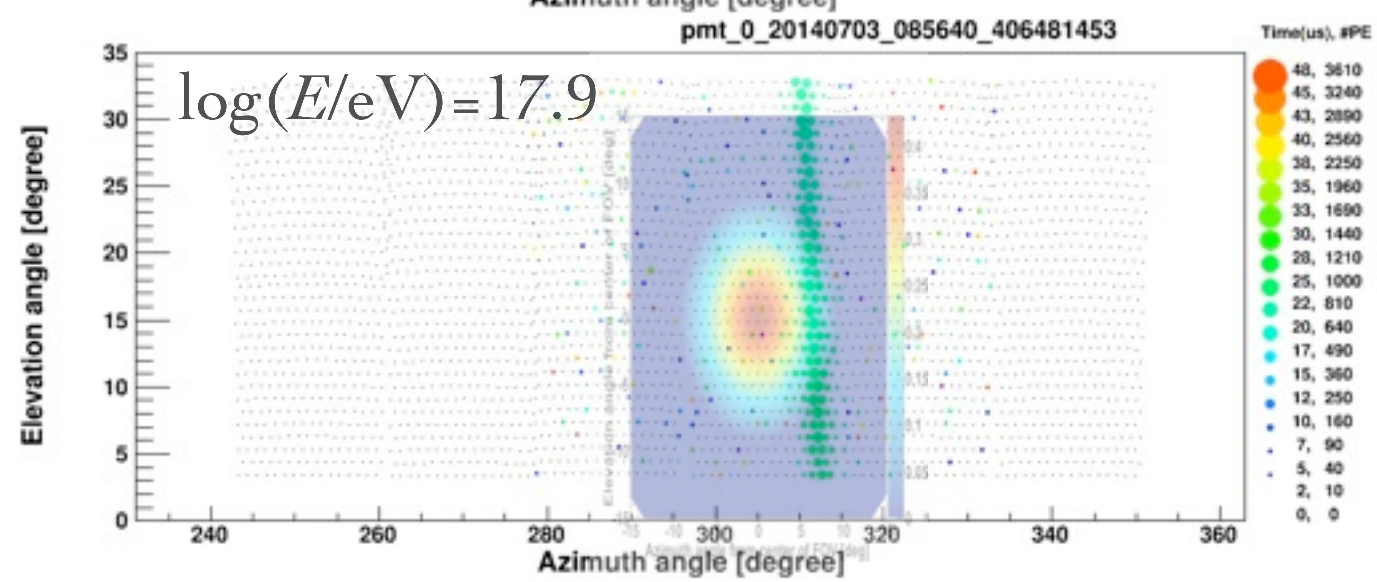




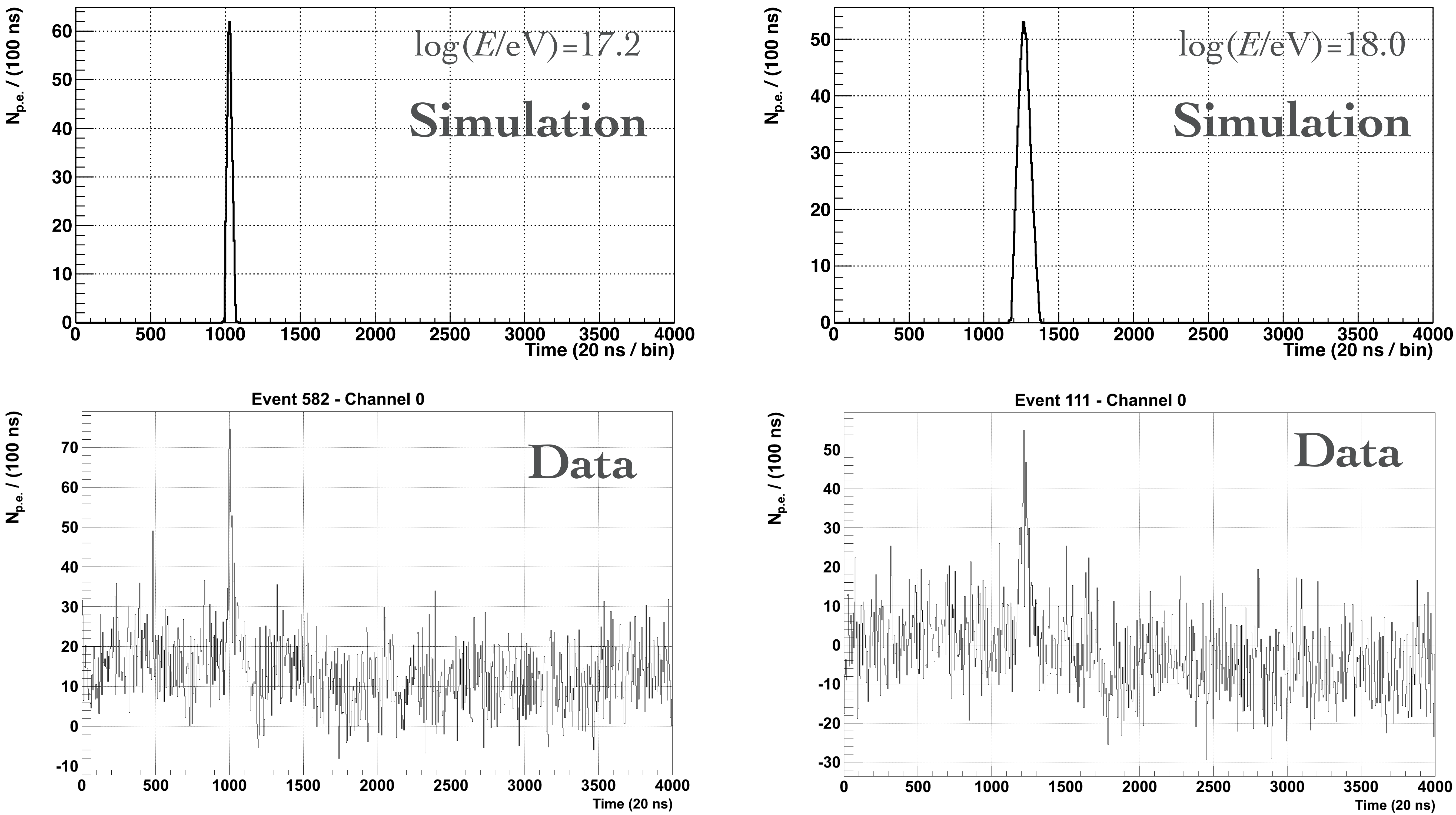
TAFD







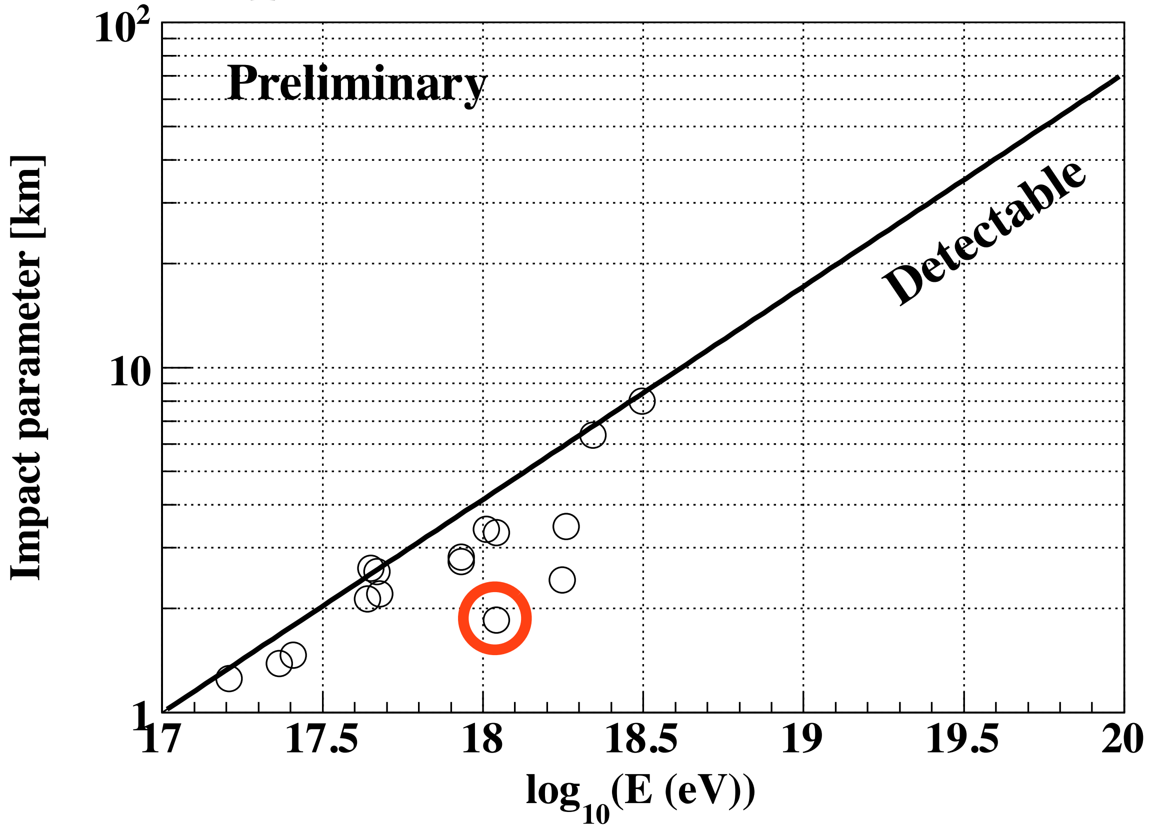
Comparison with simulated signal using result reconstructed by TAFD



A signal location is fluctuated within the TAFD trigger frame of 12.8 μs.

Distance vs Energy (from TAFD) for Candidates

April+June RUN



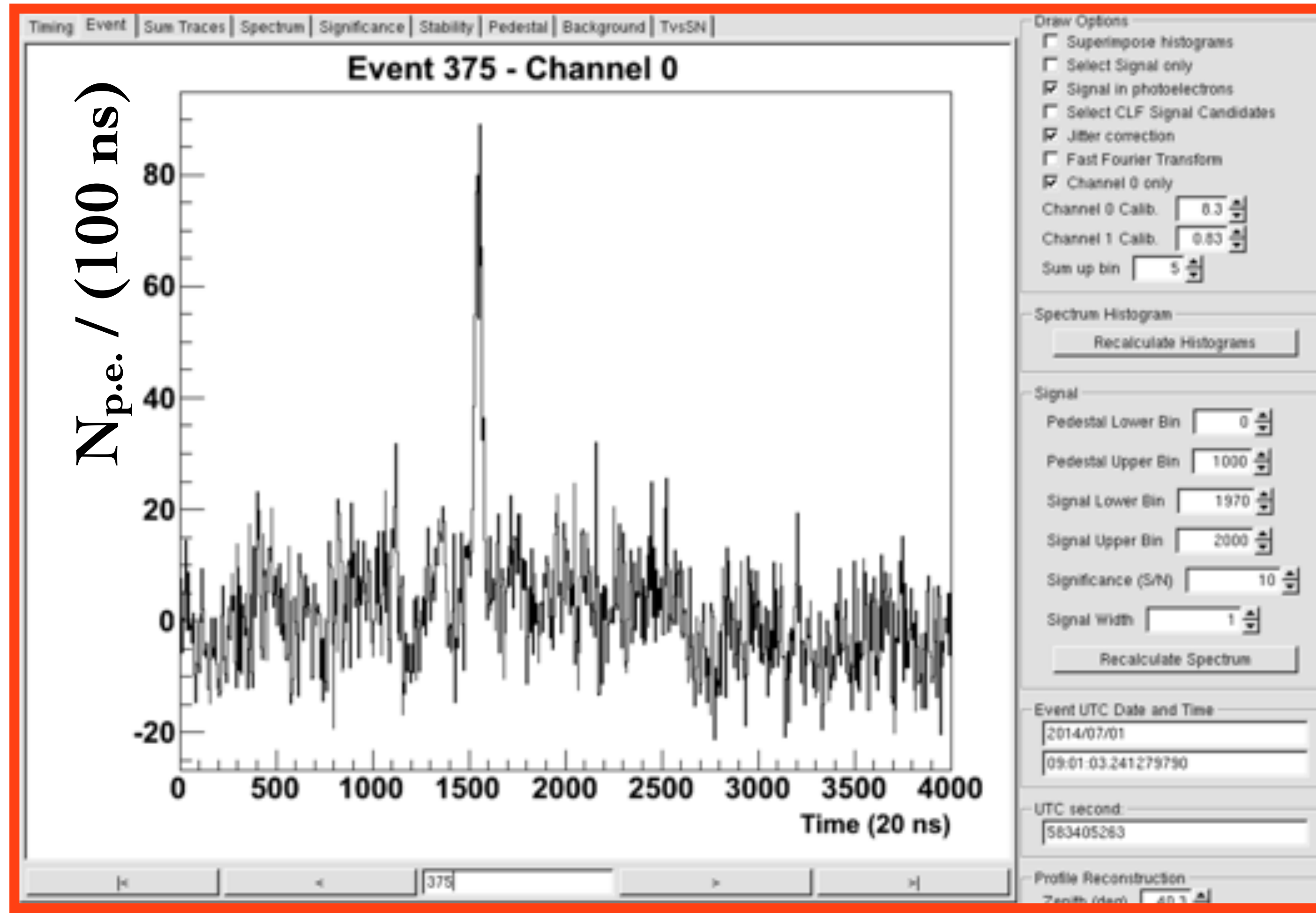
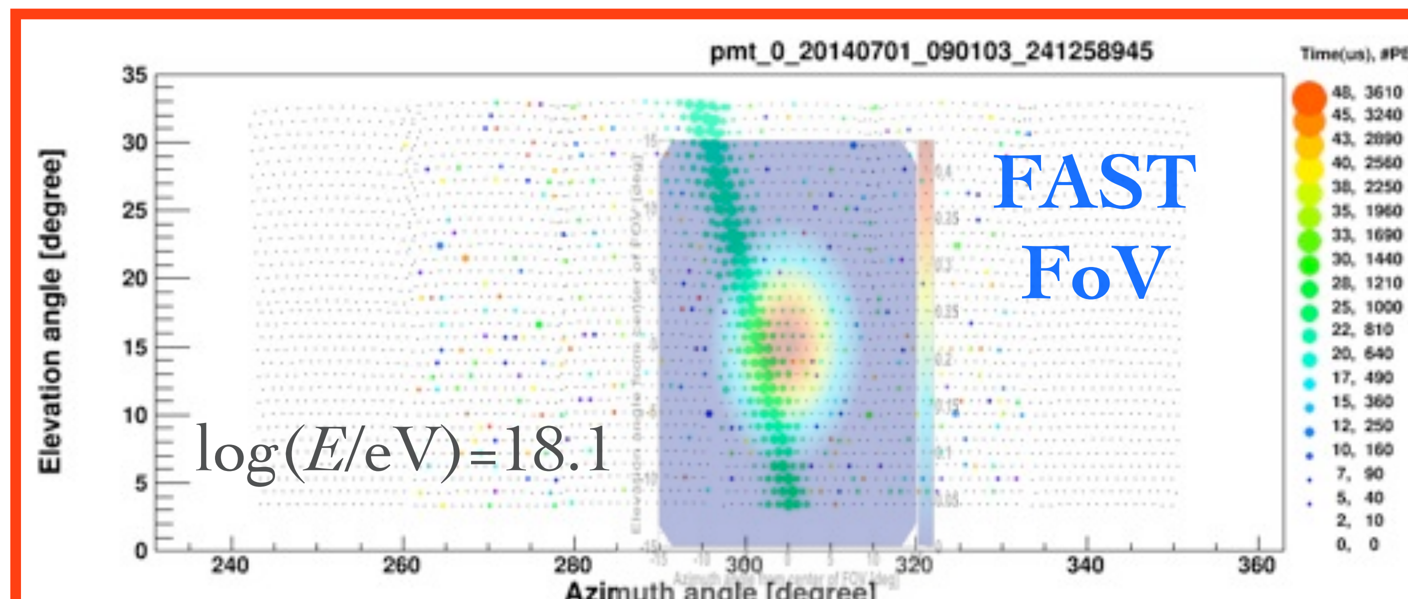
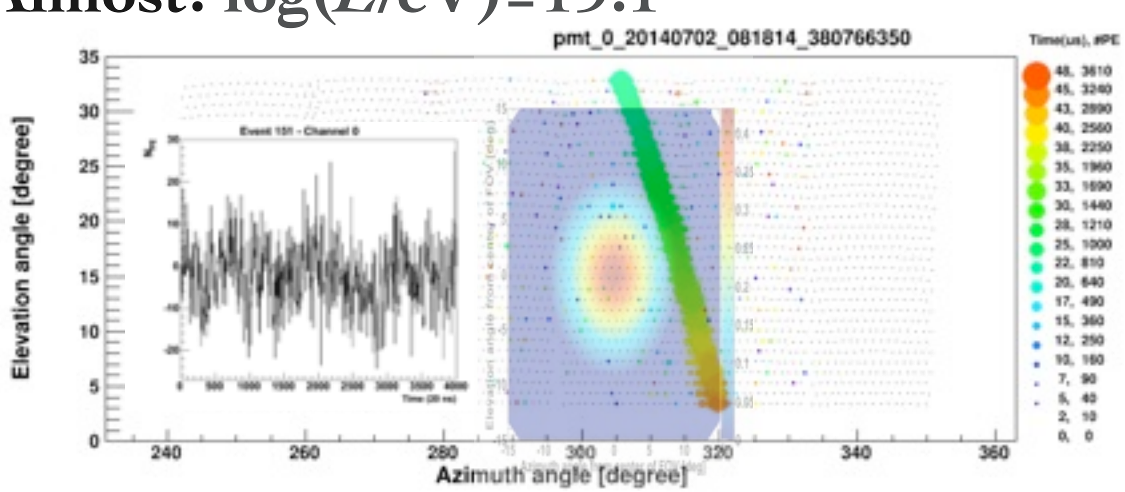


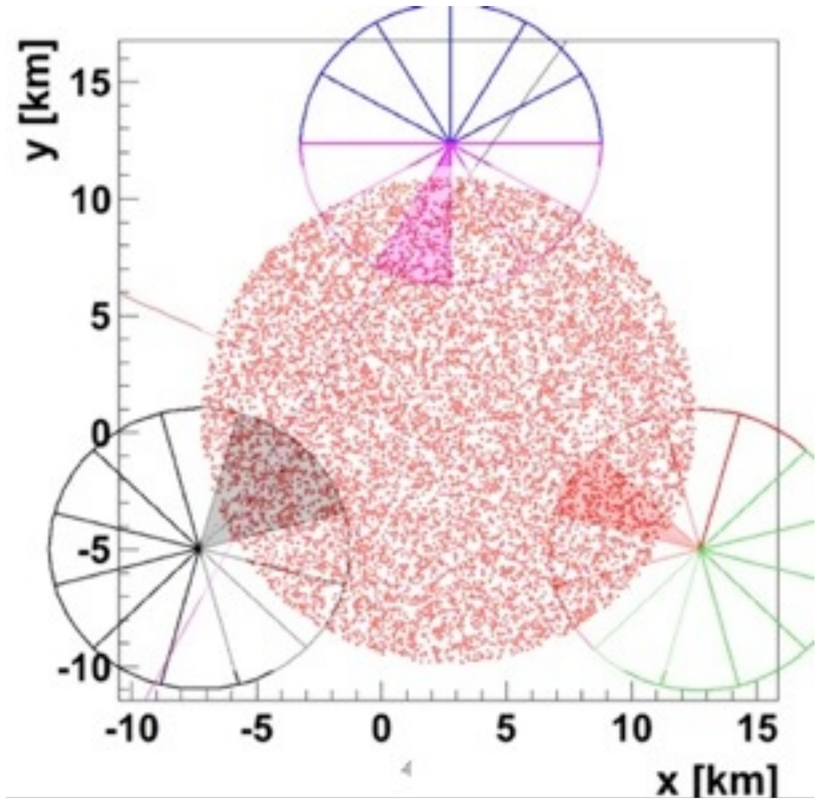
Figure 14: Distribution of the impact parameter as a function of the primary energy reconstructed by TA for shower candidates detected by the FAST prototype. The line indicates the maximum detectable distance by the FAST prototype (not fitted).



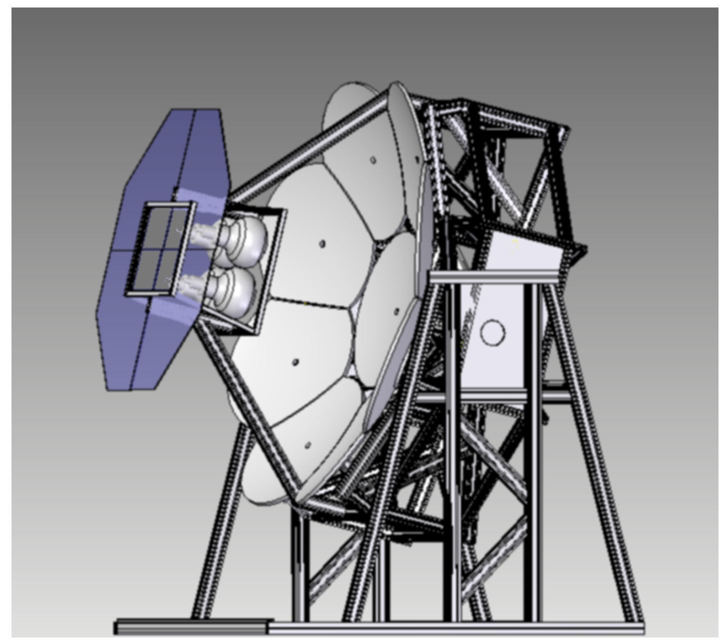
Almost! log(*E*/eV)=19.1



Simulation Study



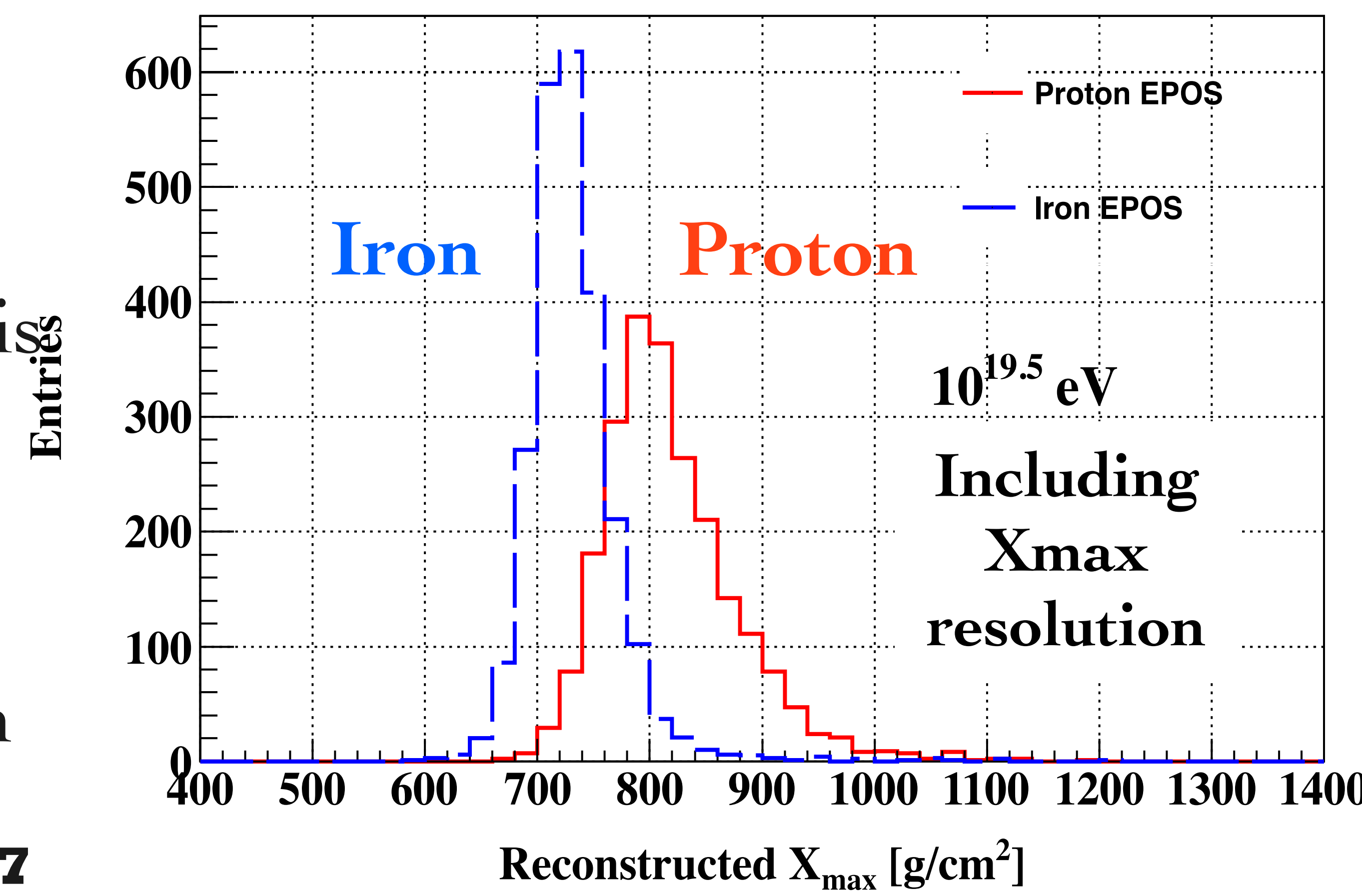
- 4 PMTs Telescope



- Reconstruction efficiency

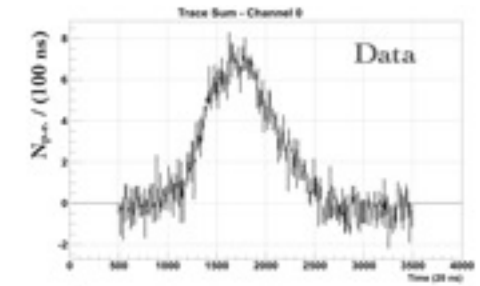
logE	Proton	Iron
18.5	0.65	0.56
19.0	0.88	0.89
19.5	0.99	1.00

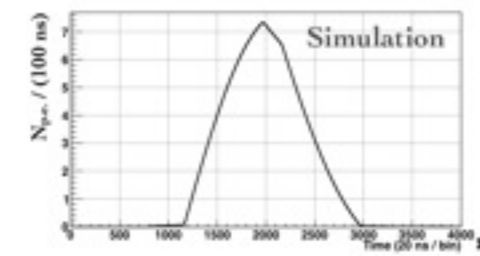
- FAST with 20 km spacing
- With smearing SD accuracy of geometry, Xmax resolution of FAST is 30 g/cm^2 at $10^{19.5}$ eV.
- 100% efficiency at $10^{19.5}$ eV
- Under implementing a reconstruction by only FAST.

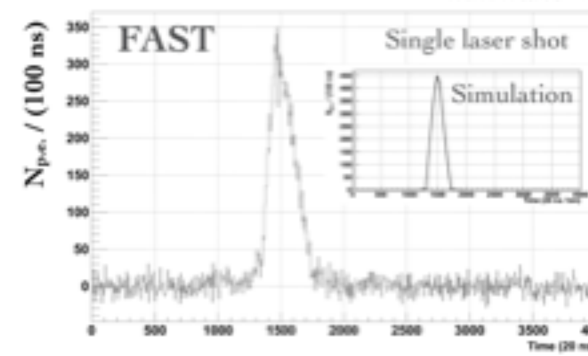


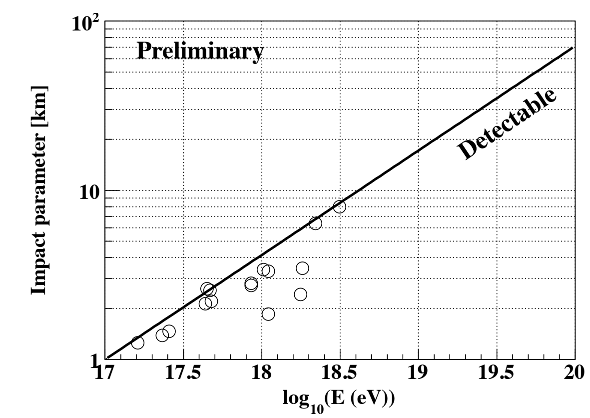
Summary and Future Plans

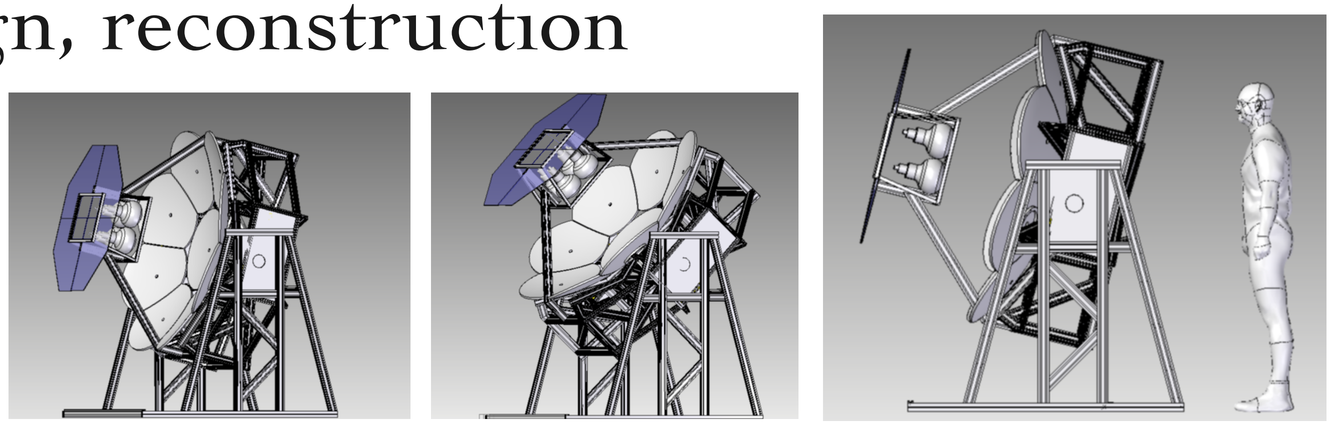
- Promising results from the first field test of FAST concept:
  - very stable and simple operation
  - robust behavior under night sky background (gain stability, a single bright star does not matter when integrating over the large FAST FOV)
  - laser shots and shower candidates detected
  - sensitivity is consistent with simulated expectation
- Very successful example of Auger, TA, JEM-EUSO collaboration.
- Several improvements possible, e.g. high Q.E. PMT, narrow UV pass filter, mirror design, reconstruction method, etc.
- Next step: full 30°×30° prototype.





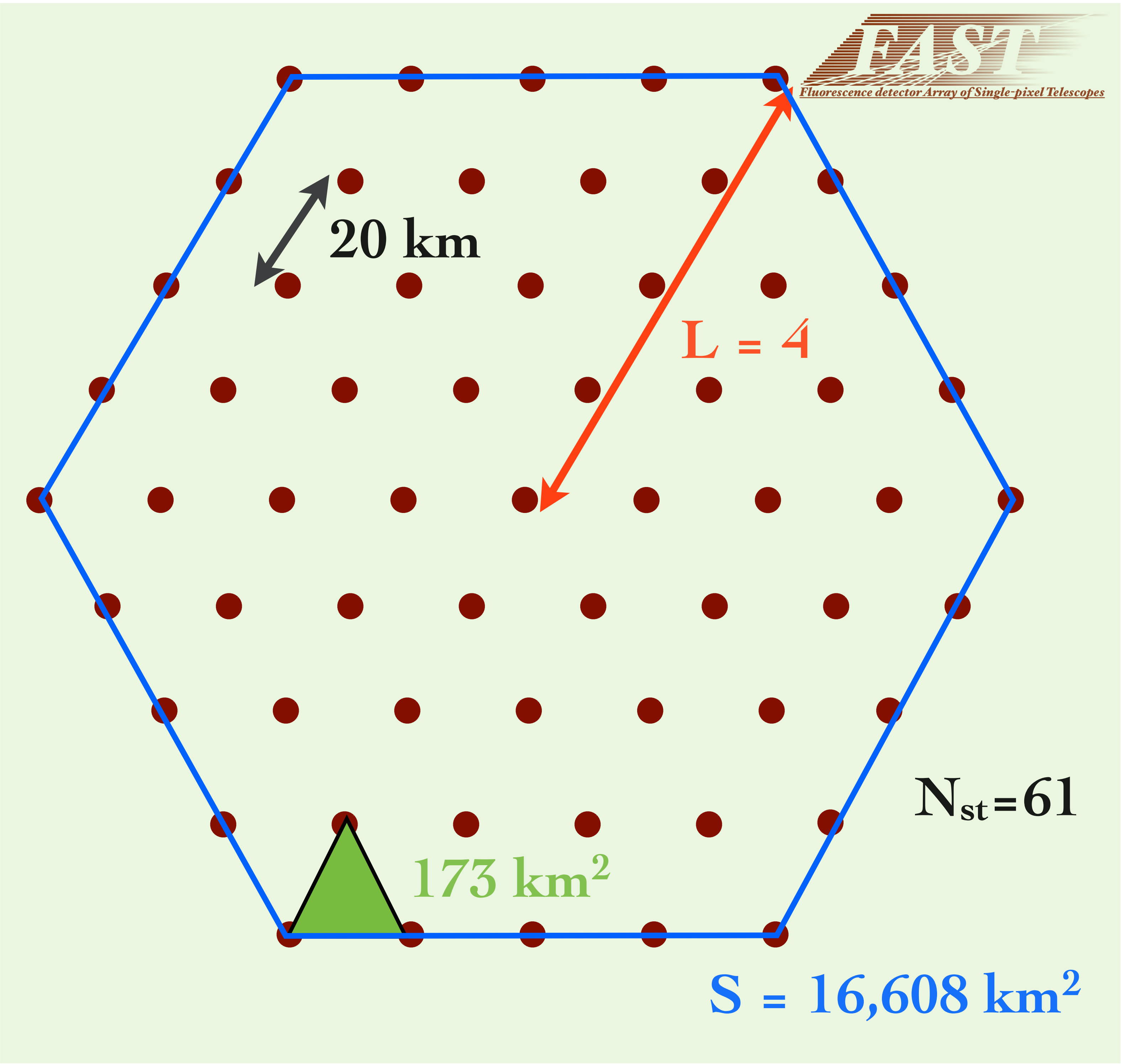






Backup

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

Gain Calibration by LED in Laboratory