FAST

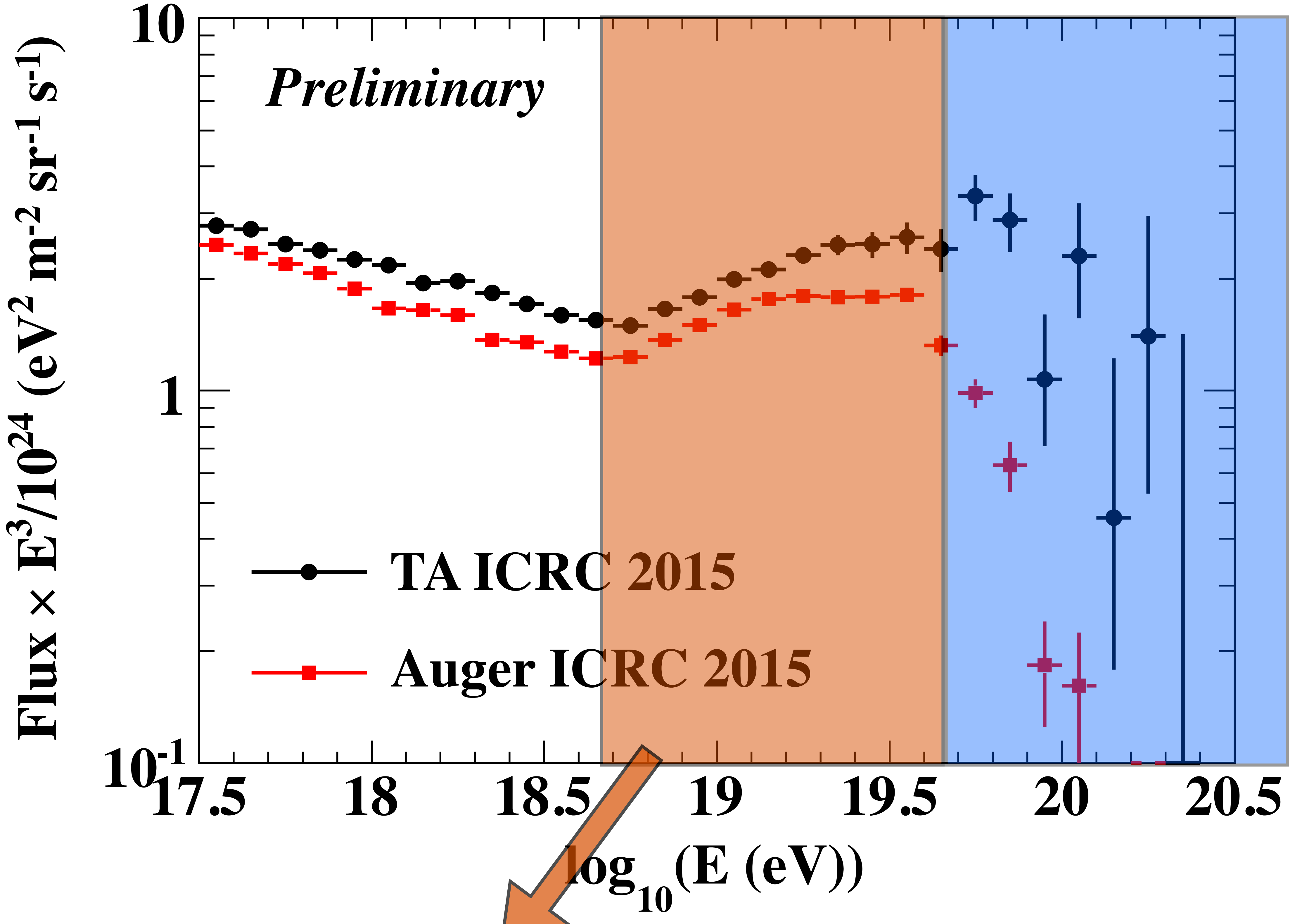
Fluorescence detector Array of Single-pixel Telescopes

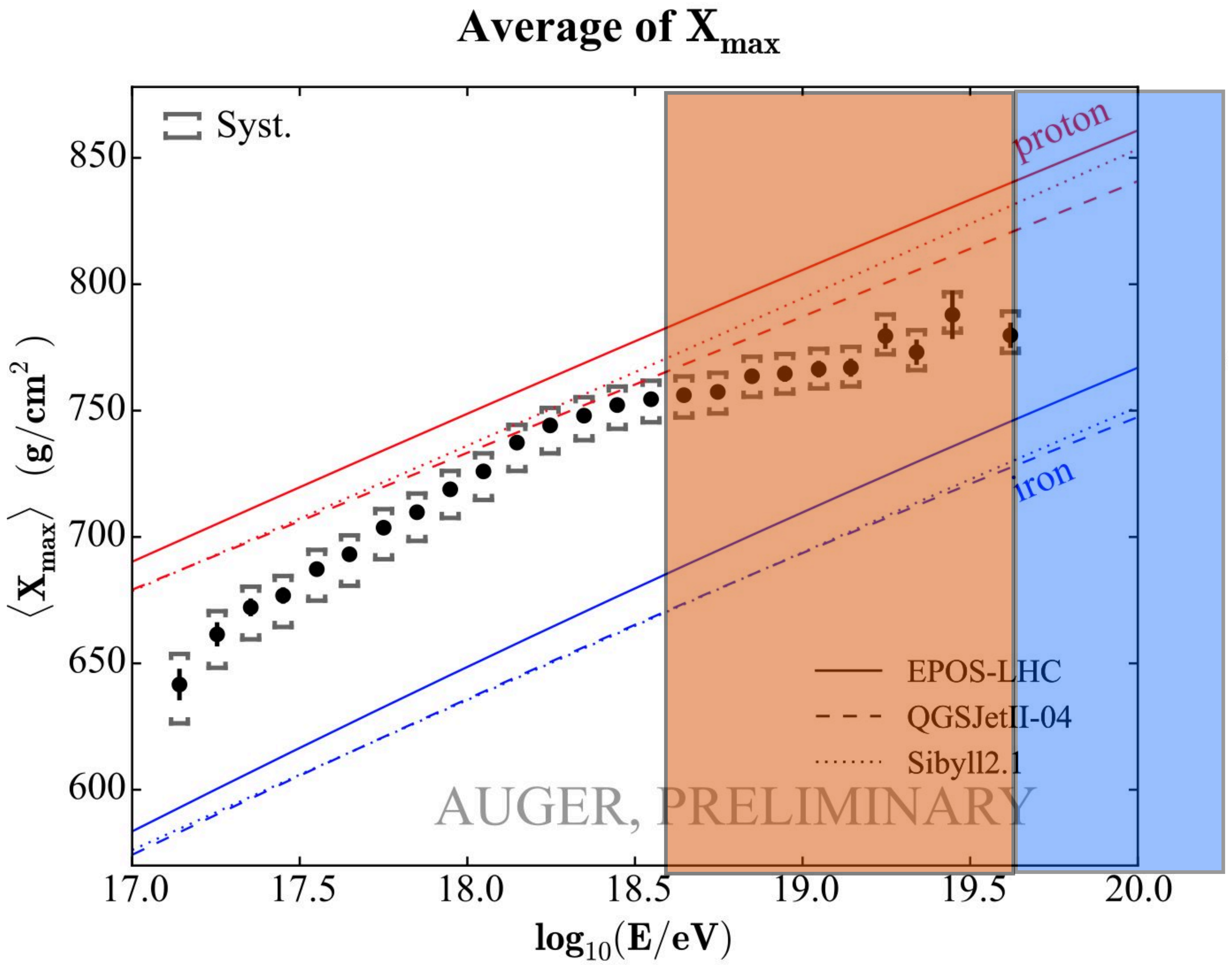
(+ Surface detector array of Layered Observational Water-cherenkov counters)

T. Fujii, M. Malacari, J. Albury, J.A. Bellido, J. Farmer, A. Galimova, P. Horvath, M. Hrabovsky, D. Mandat, A. Matalon, J.N. Matthews, M. Merolle, X. Ni, L. Nozka, M. Palatka, M. Pech, P. Privitera, P. Schovanek, S.B. Thomas, P. Travnicek

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)

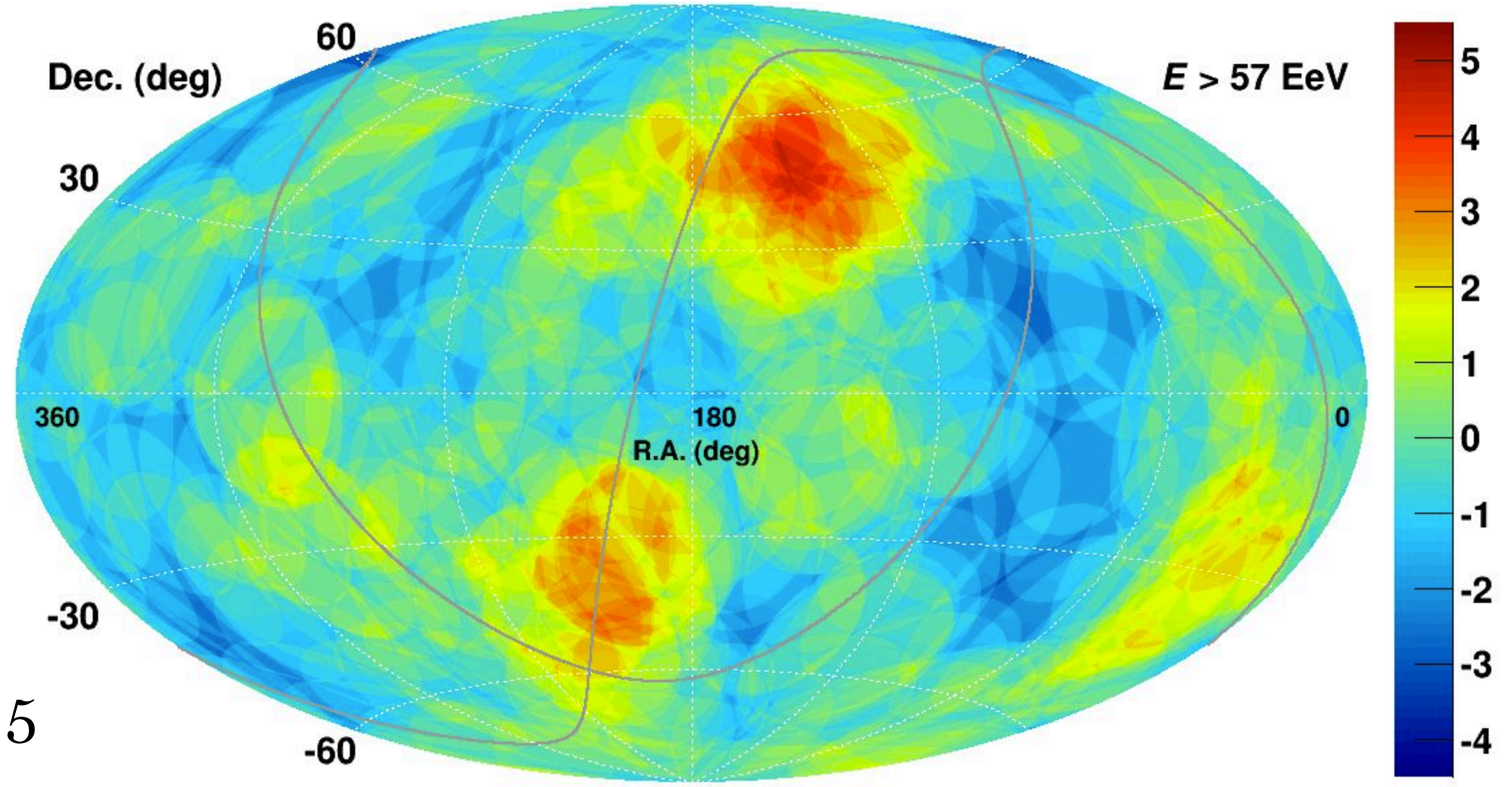
No anisotropy seen

ApJ, *794* 172 (2014)

Indication of a dipole at E > 8 EeV with Auger

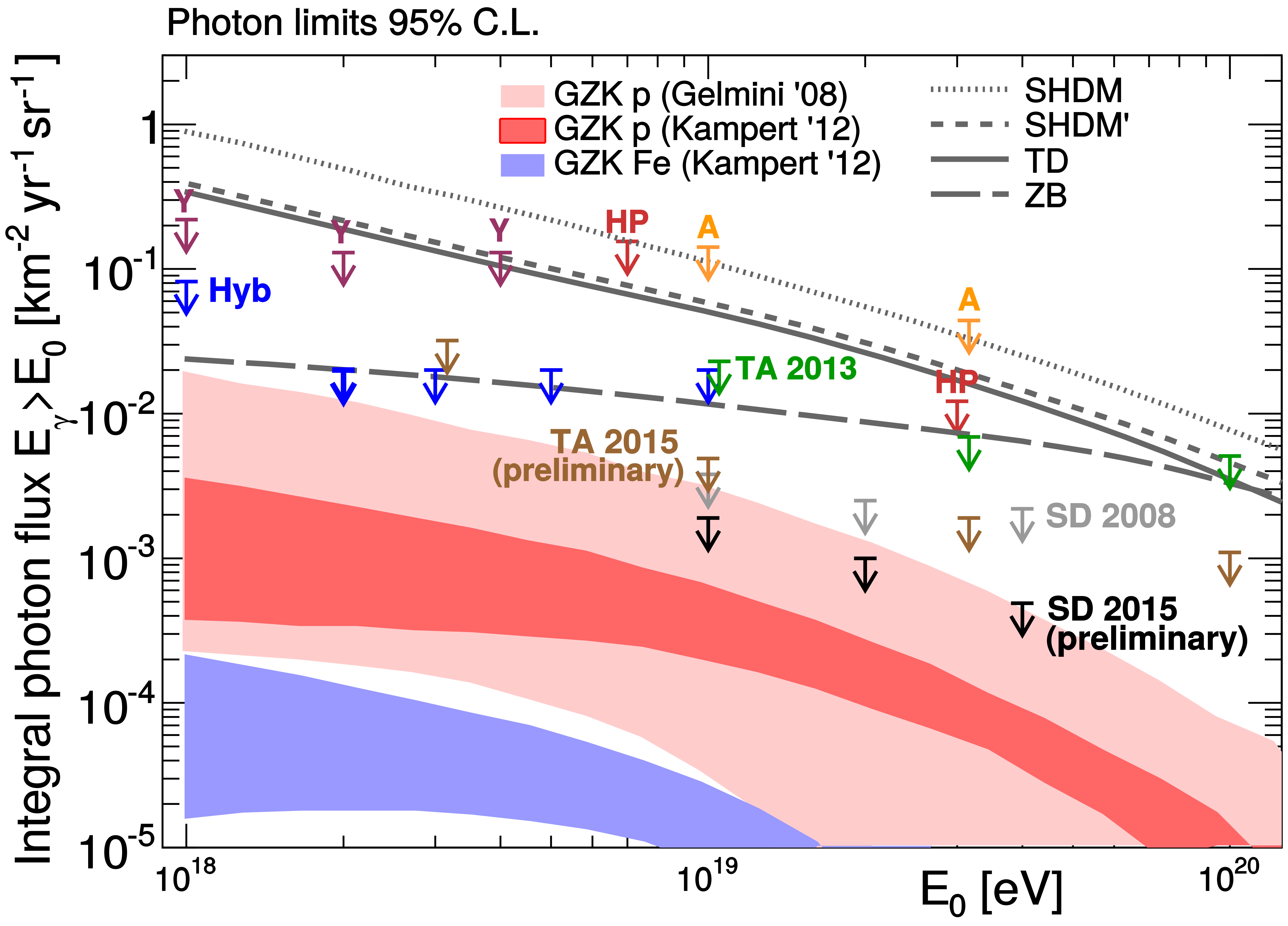
Hotspot/ Warmspot

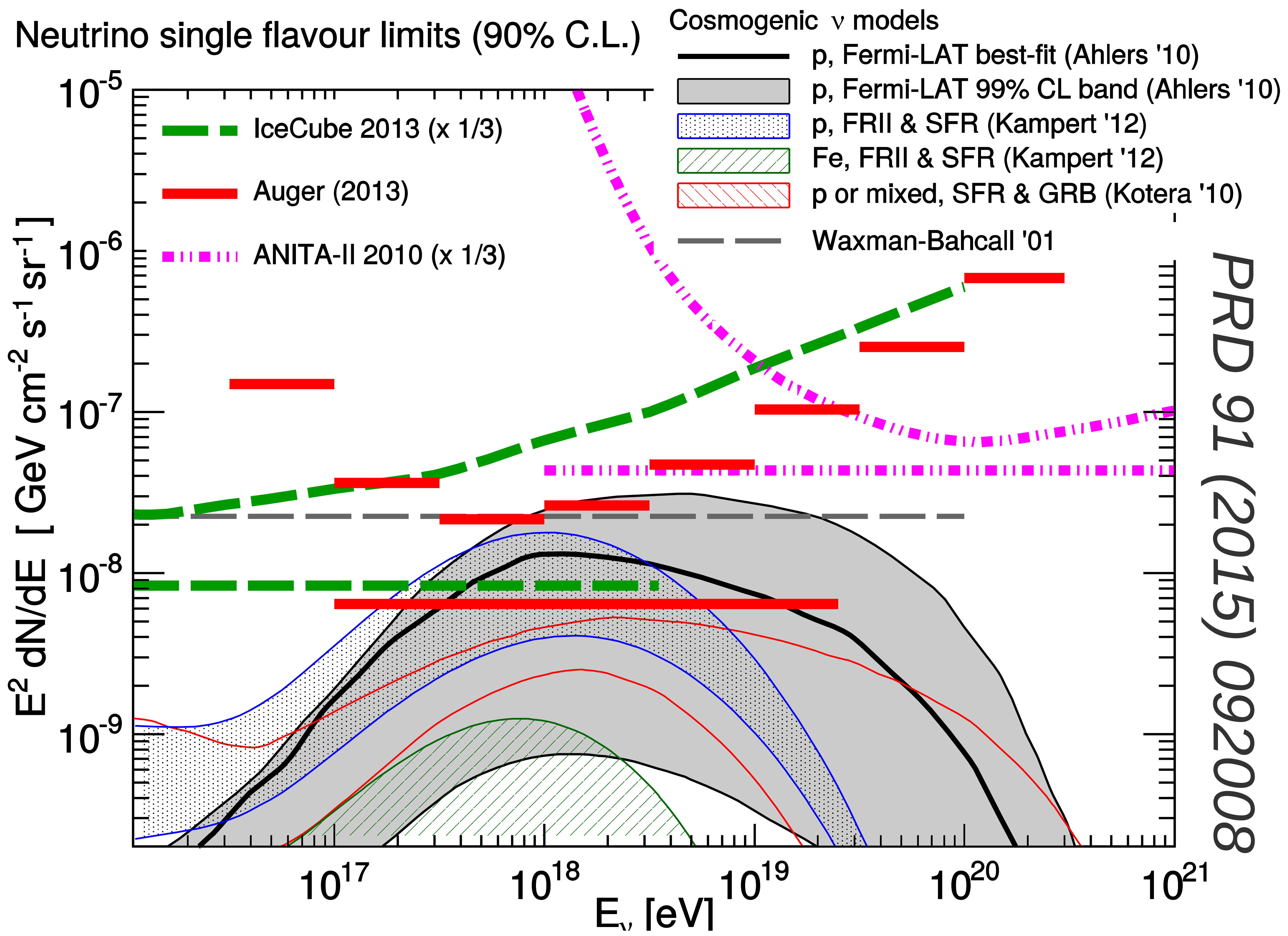
K. Kawata et al, ICRC 2015



Highlights on UHE Photon/Neutrino

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





PRD 91 (2015) 092008

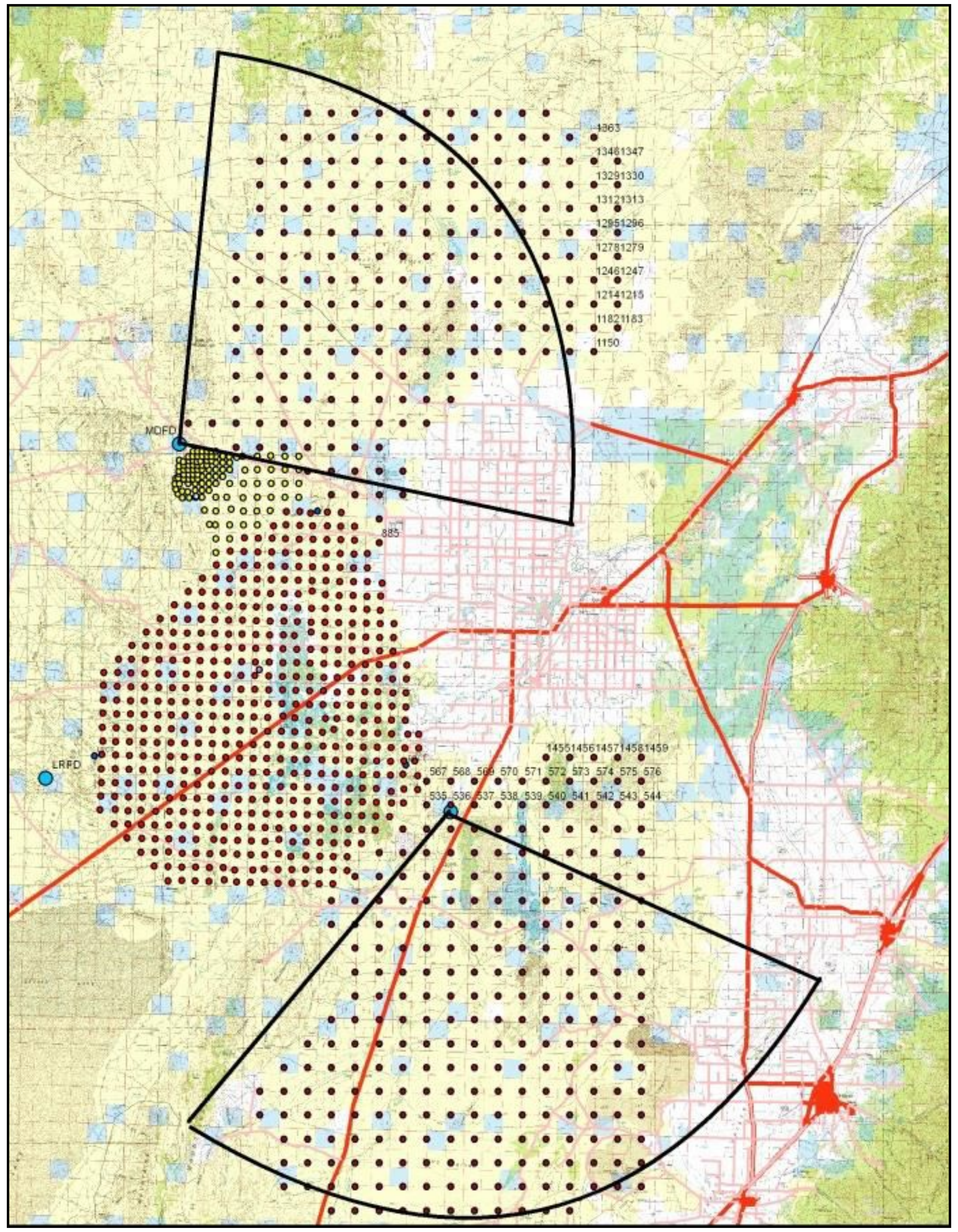
C. Bleve ICRC 2015

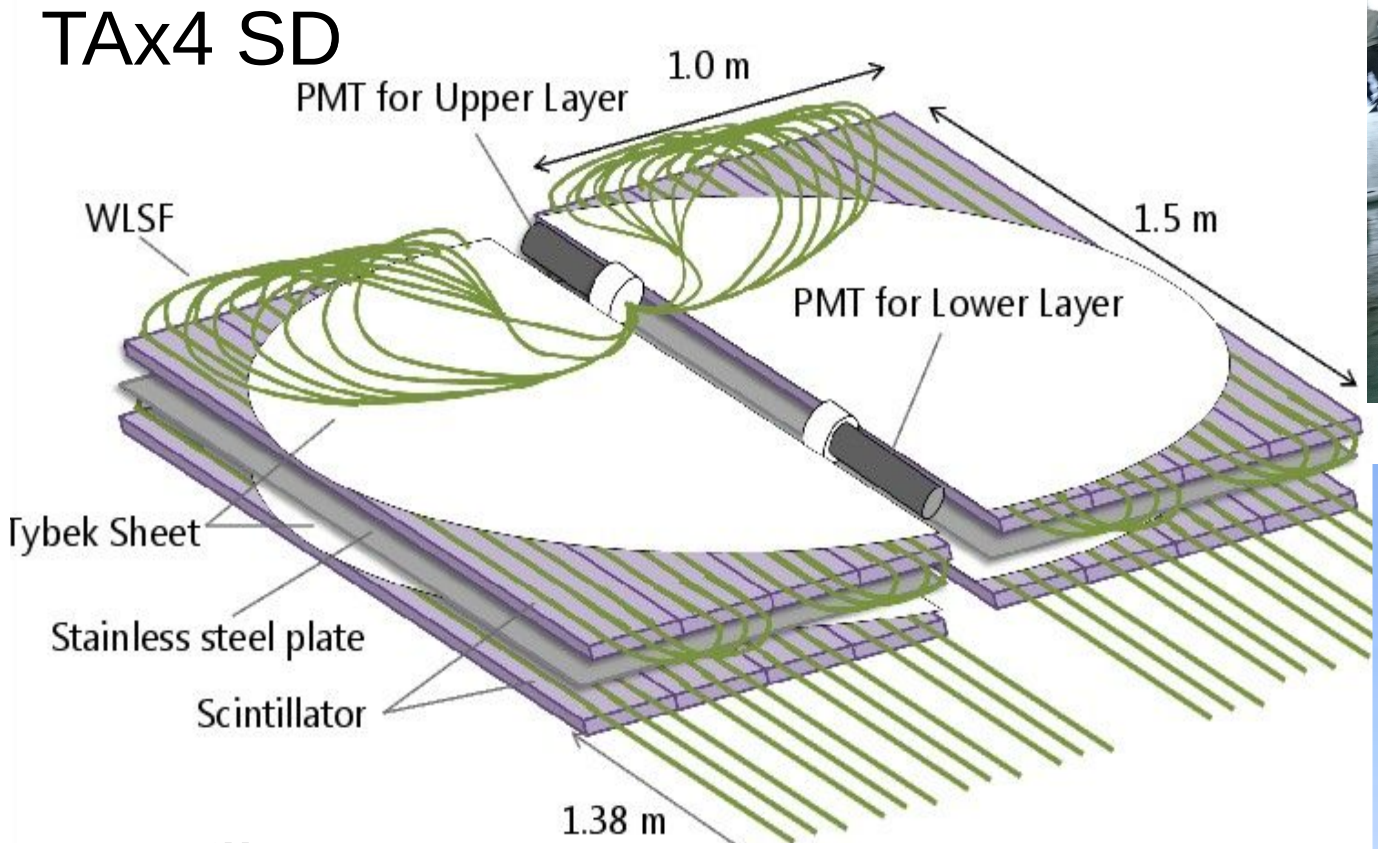
On-going Upgrade: TA×4

Detailed measurement on Hotspot

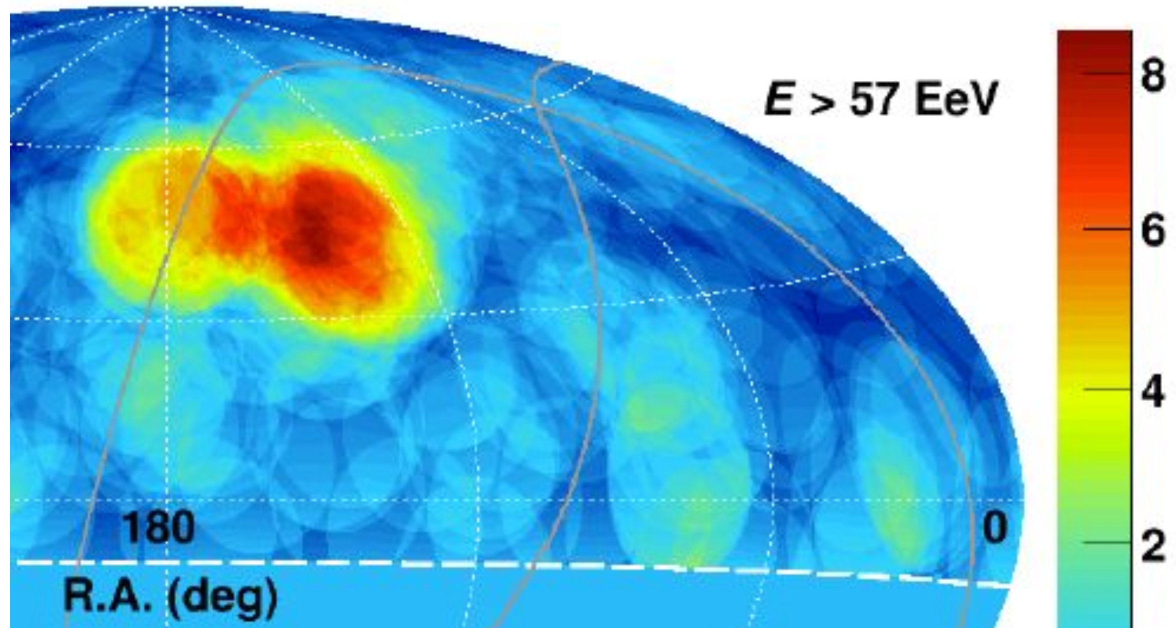
Enlarge the fourfold coverage to TA×4 = Auger,

3000 km^2





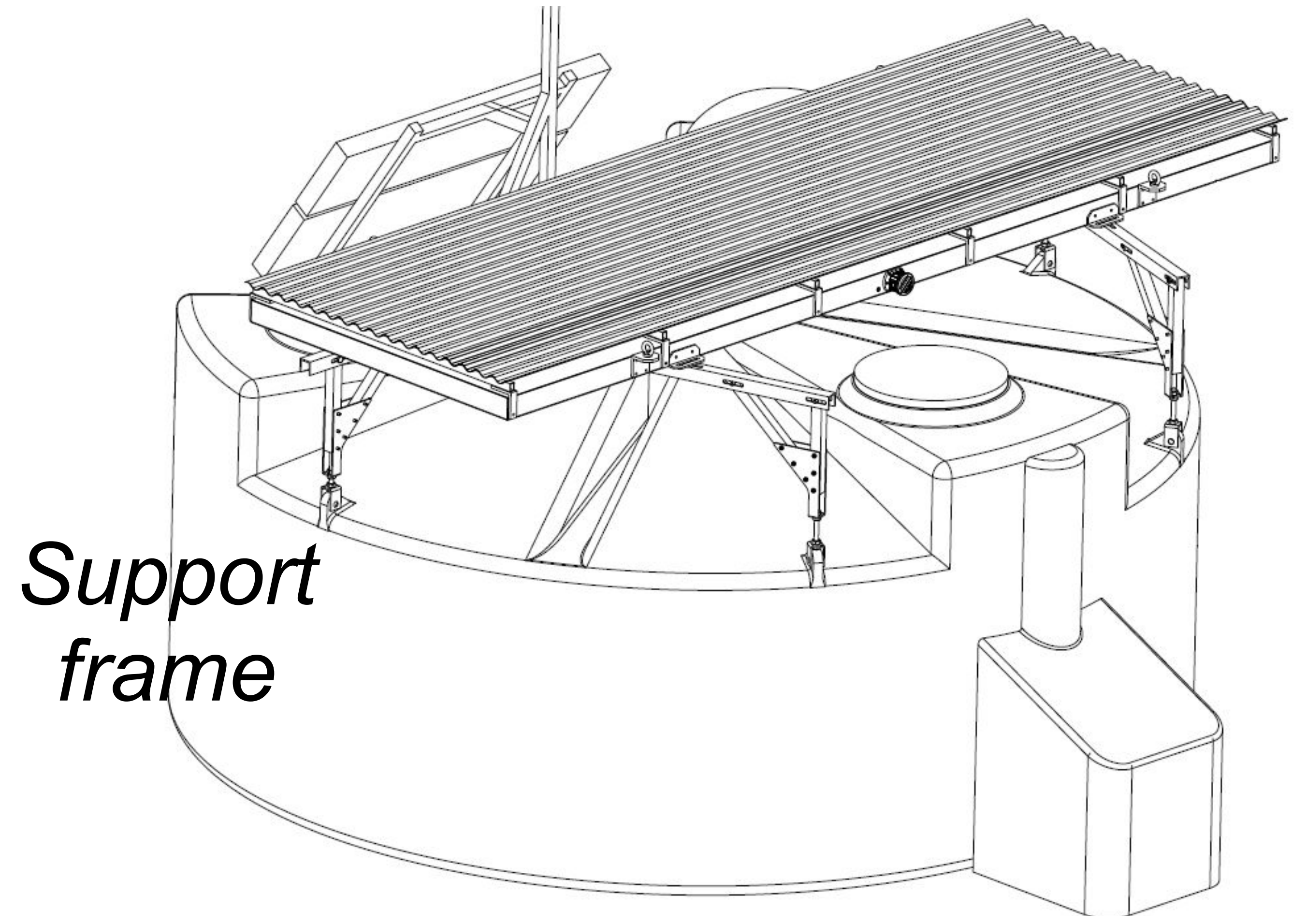
Expected in 2020 (Simulation)

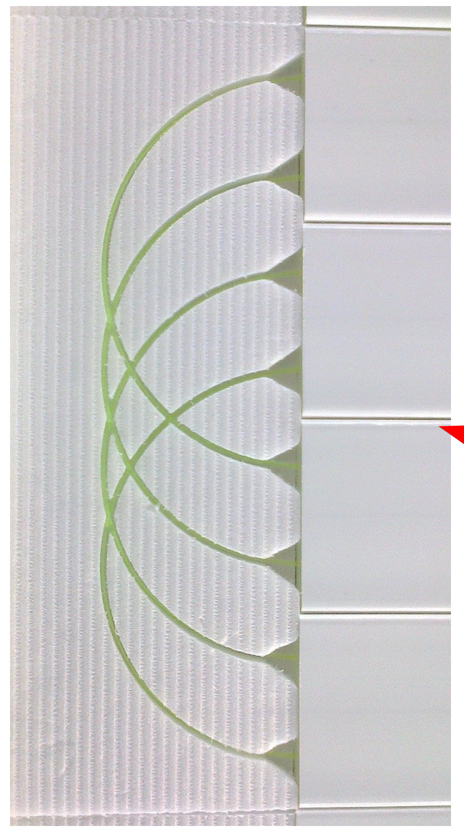


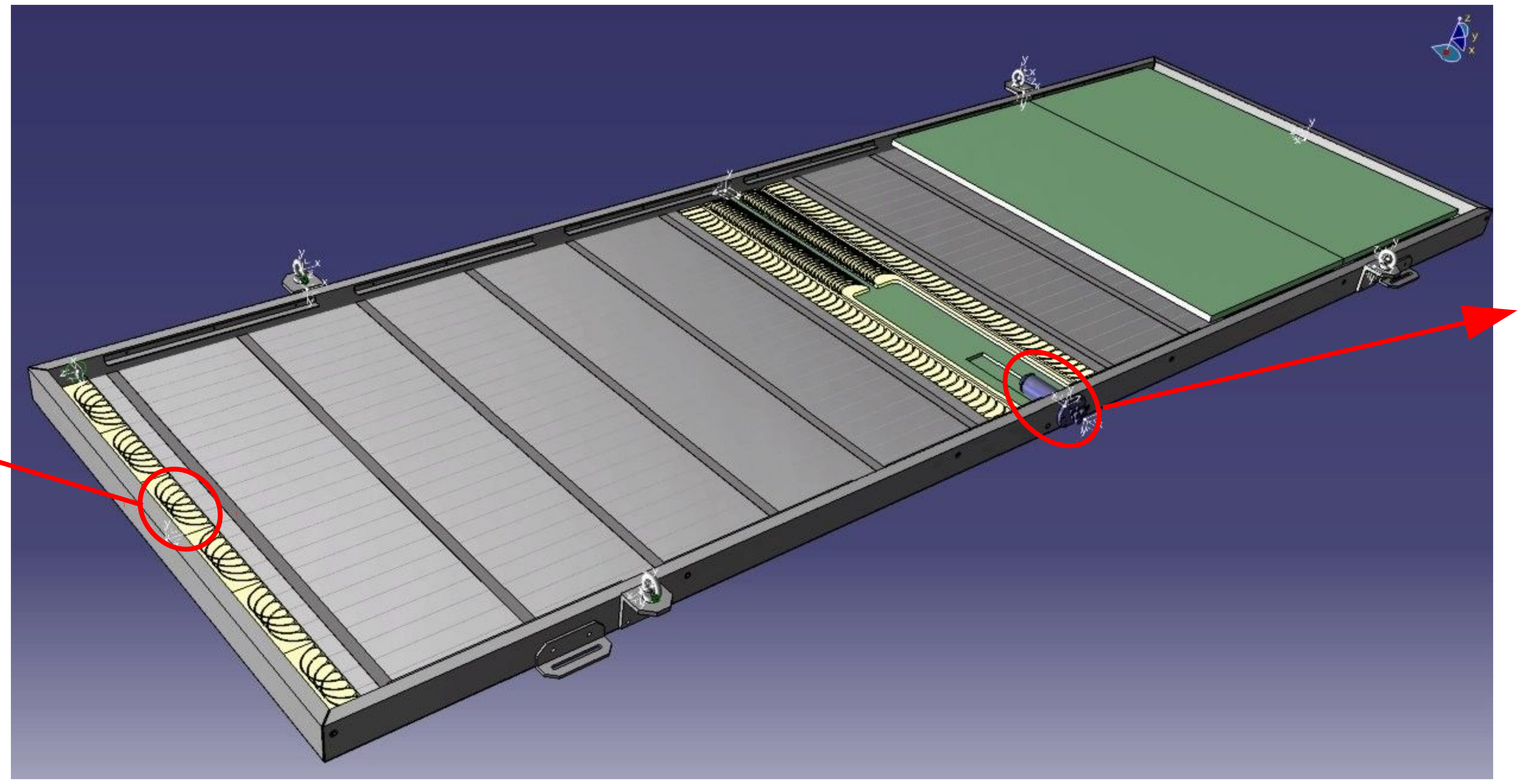
H. Sagawa ICRC2015, T. Nonaka UHEAP2016

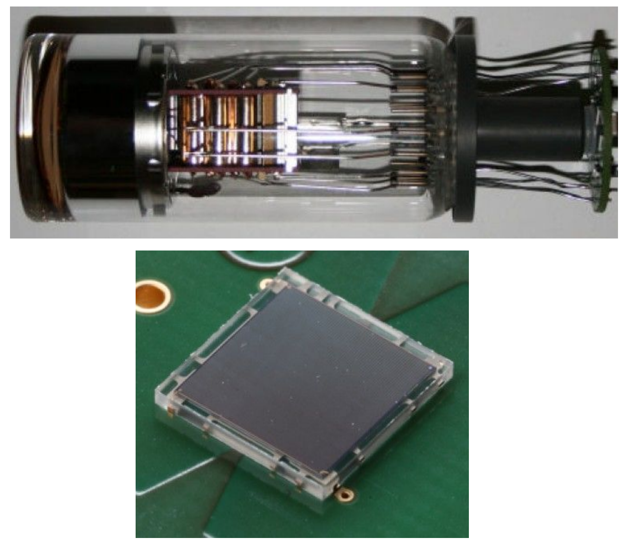
On-going Upgrade: AugerPrime

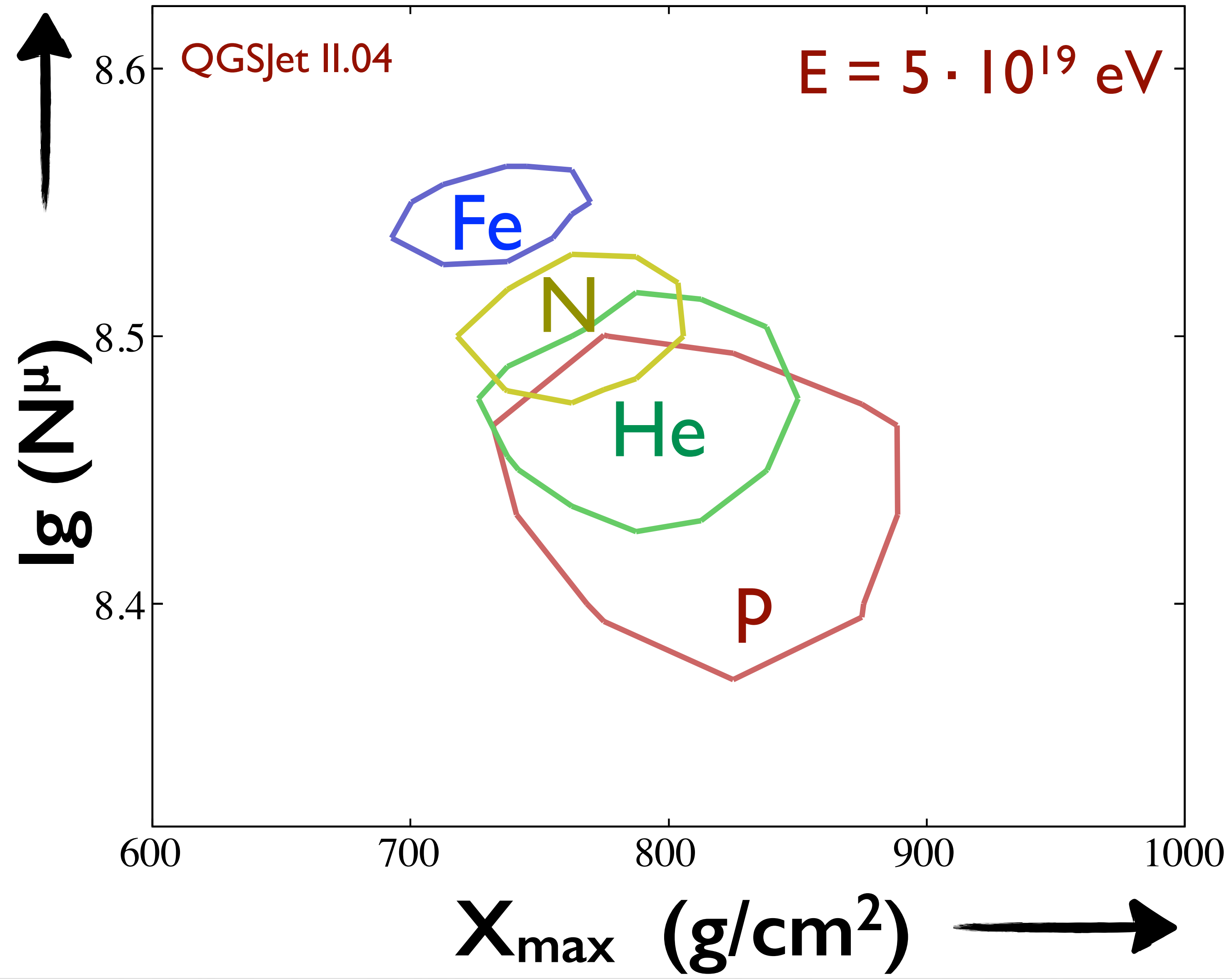
Install 4 m^2 Scintillator to measure the mass composition by SD.











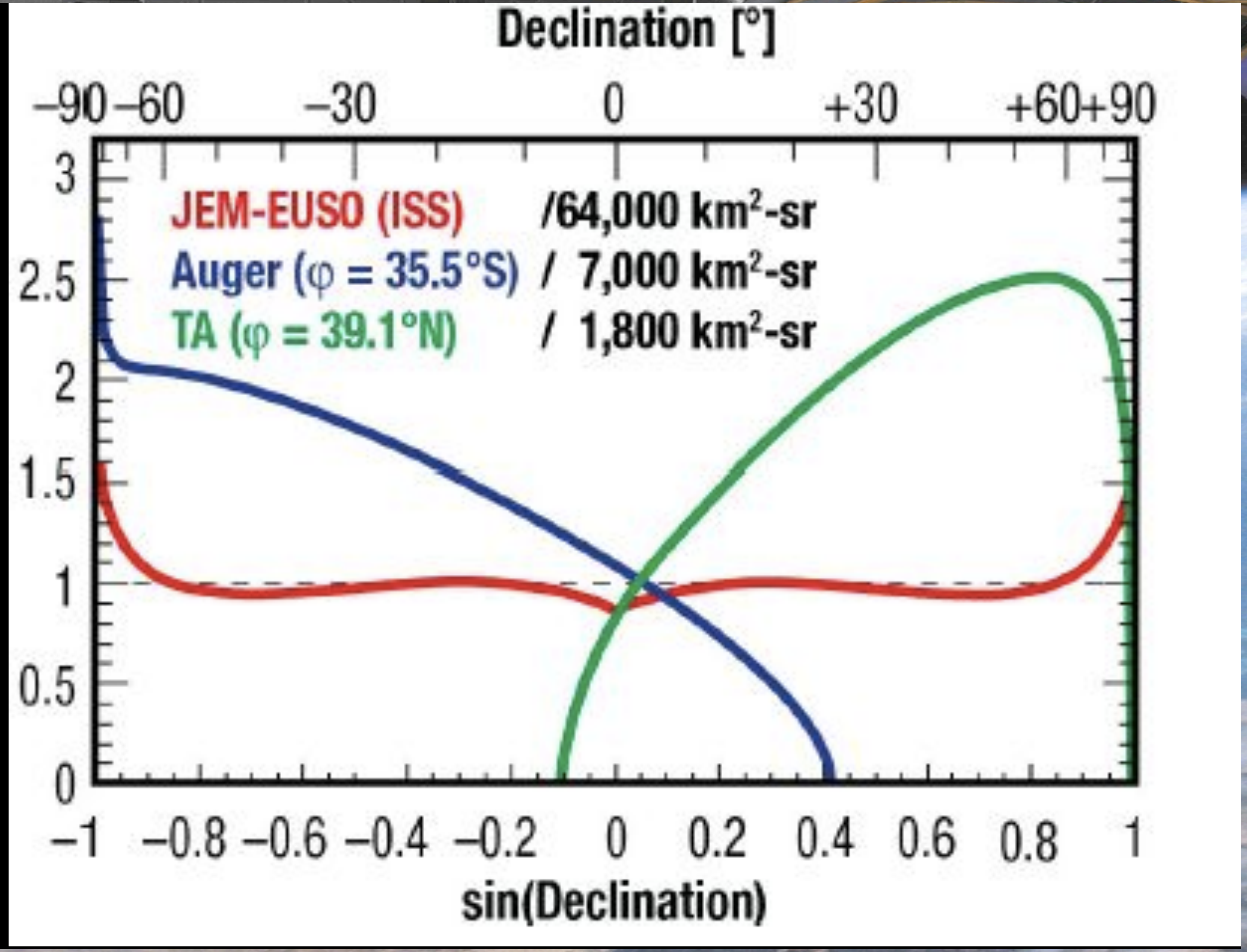
- Improve electromagnetic/muon separation of **SD** to measure the **mass composition above $10^{19.7}$ eV.**
  - Boost in statistics by a factor of ~ 10 compared to FD *X*max analysis.
- Small PMT in the water tank, FD operation during moon night.
- Origin of flux suppression, proton contribution above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

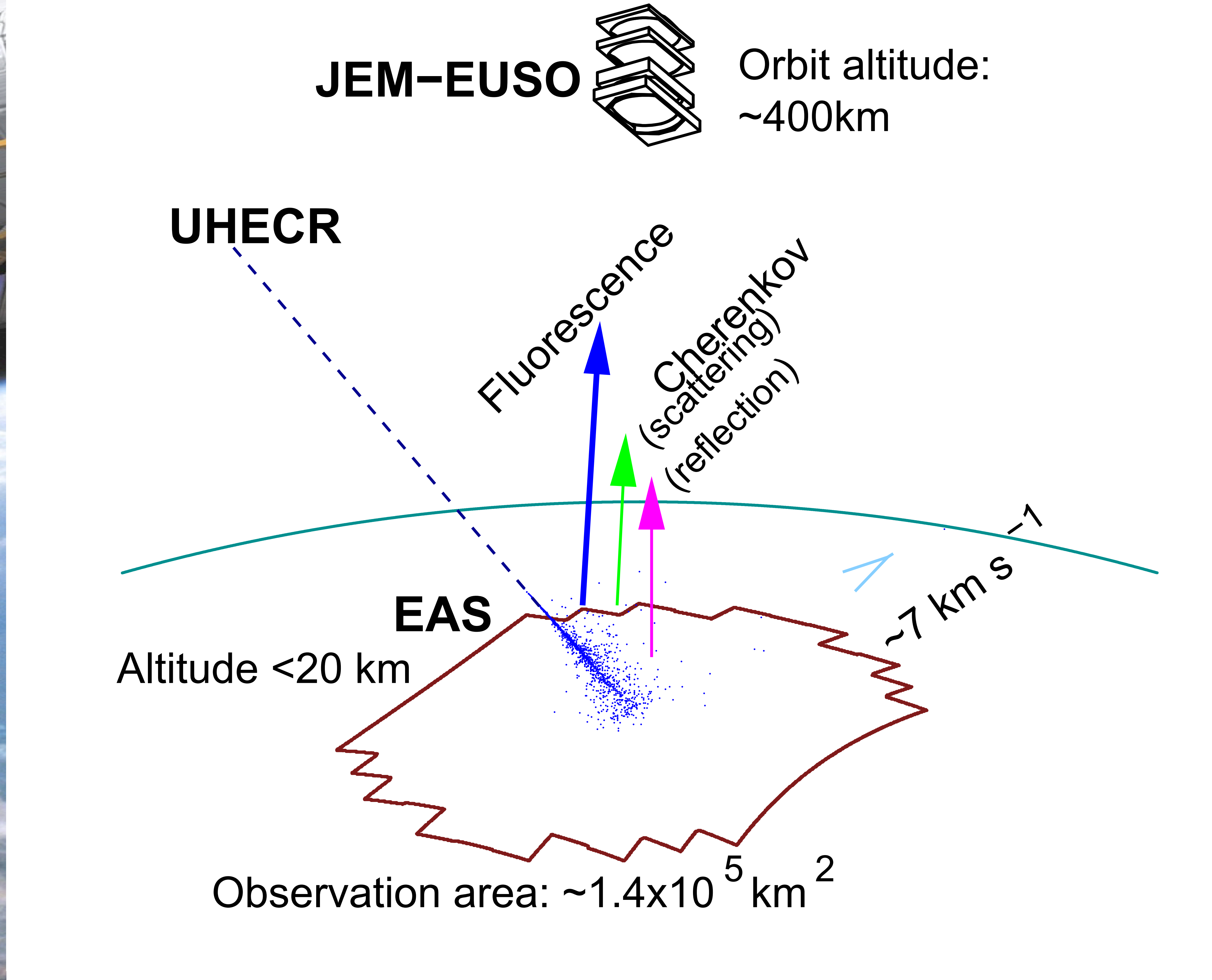
R. Engel ICRC2015, R. Smida UHEAP2016

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

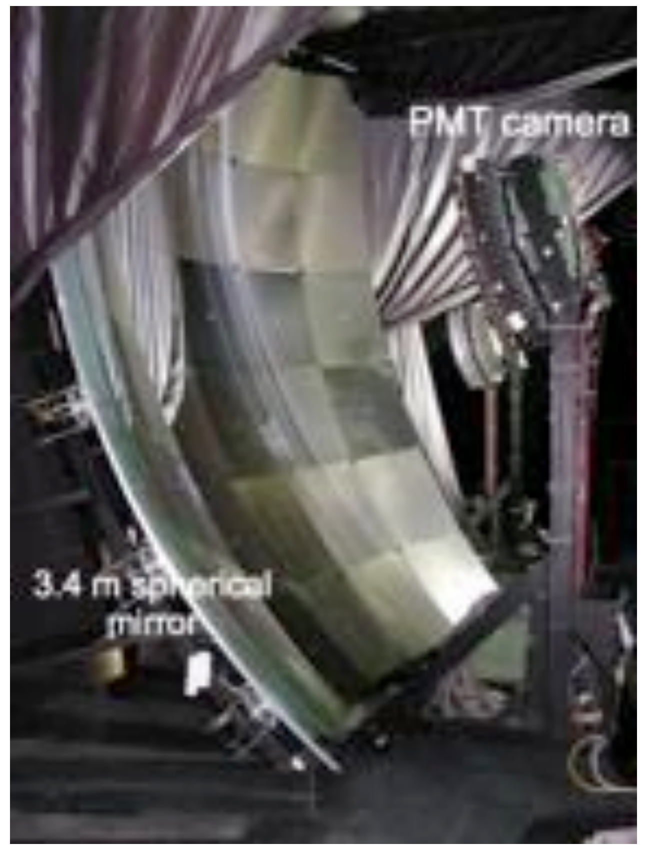
FAST

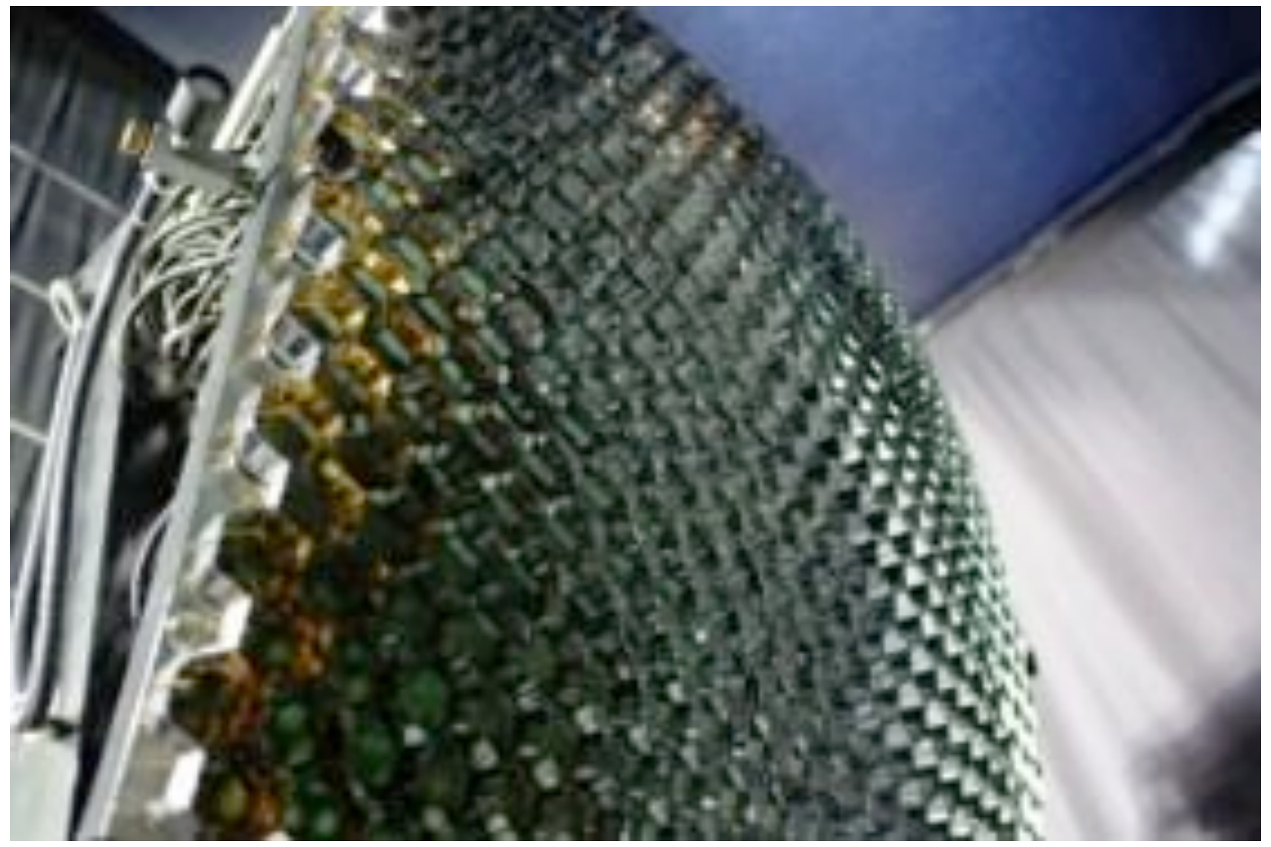
Fluorescence detector Array of Single-pixel Telescopes

Fluorescence detector Array of Single-pixel Telescopes

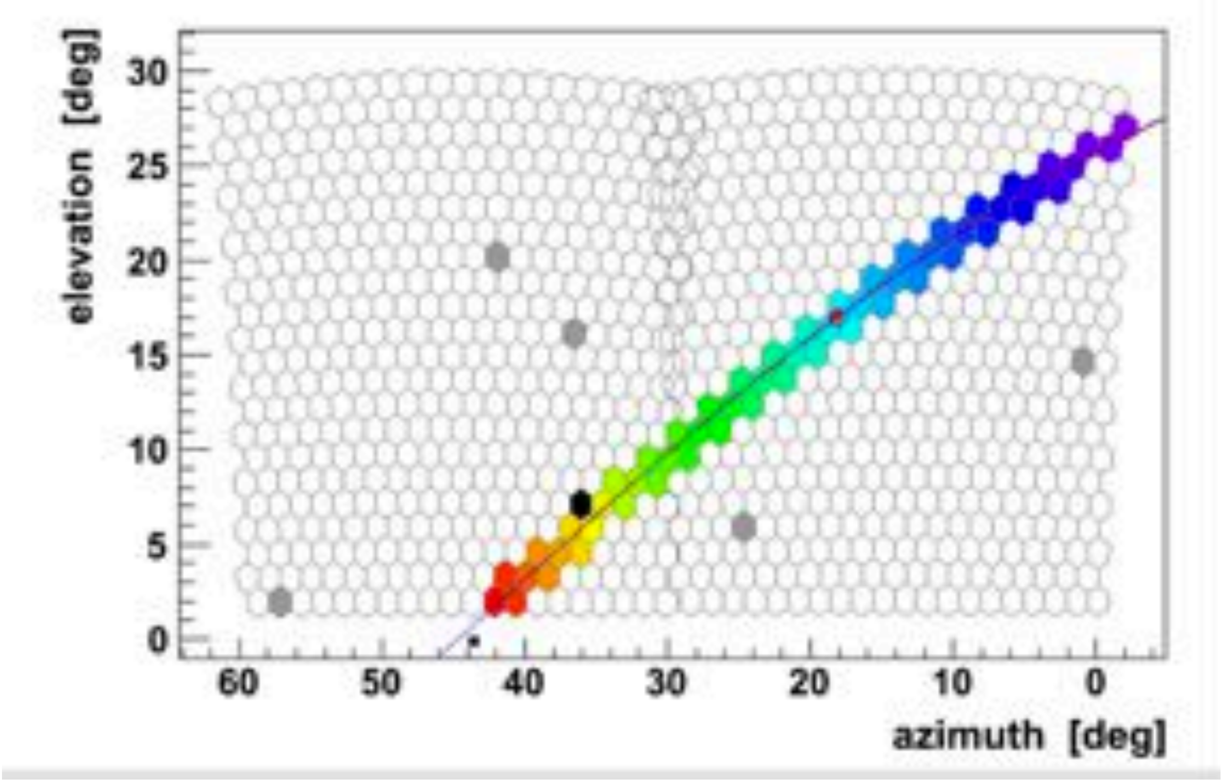
- Target : > $10^{19.5}$ eV, ultra-high energy cosmic rays (UHECR) and neutral particles
- Huge target volume ⇒ Fluorescence detector array

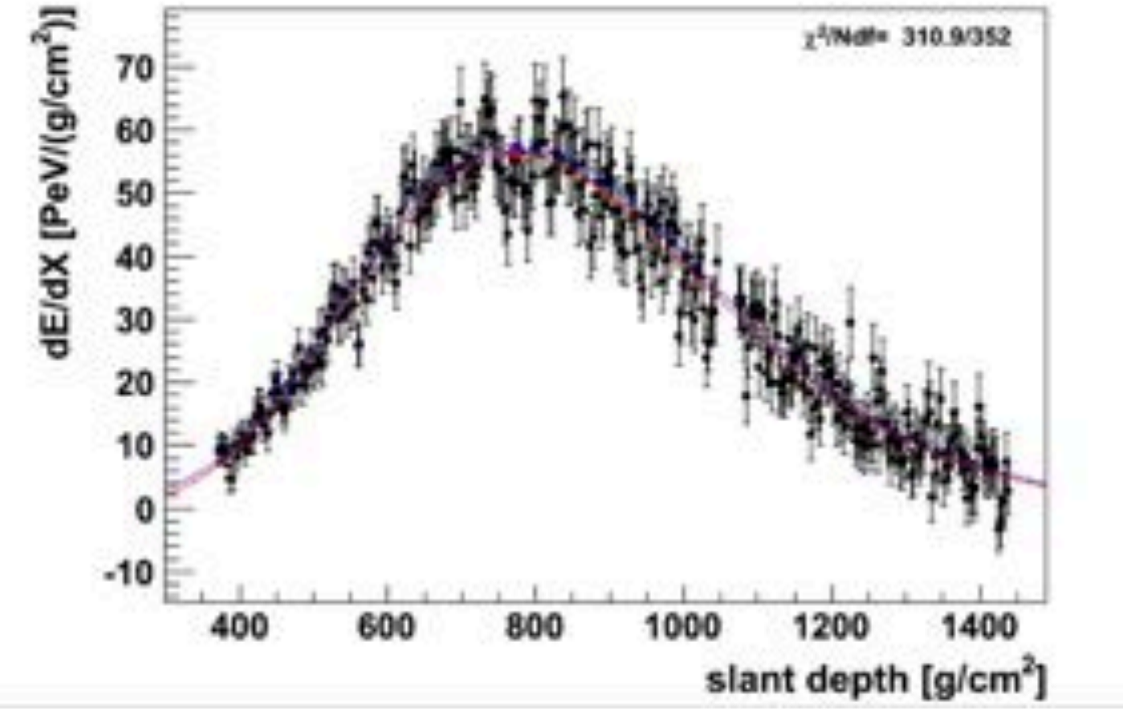
Fine pixelated camera



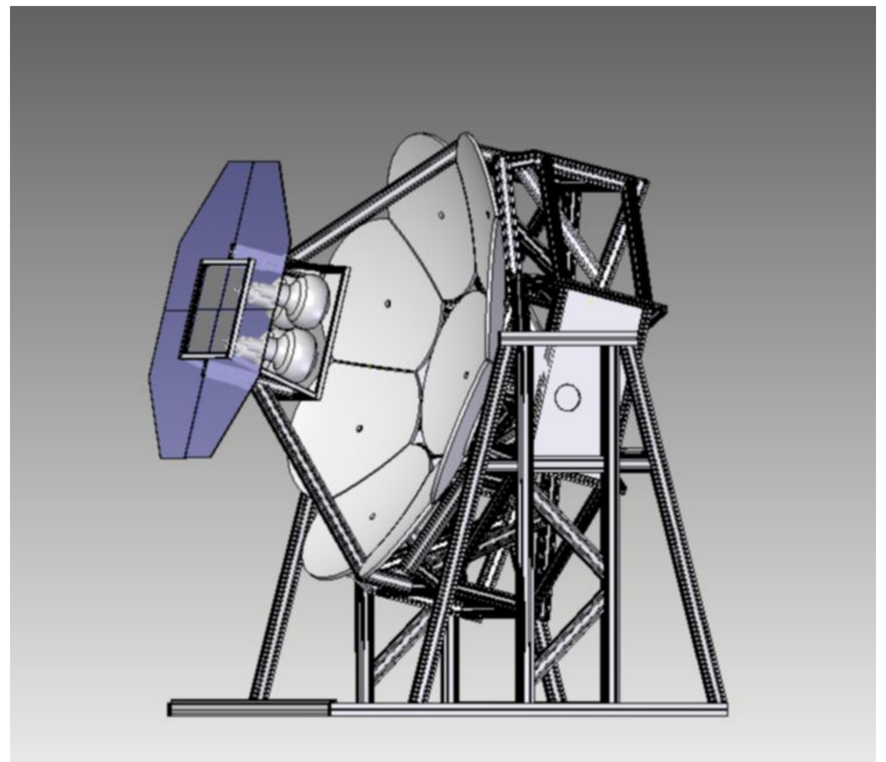


Too expensive to cover a huge area

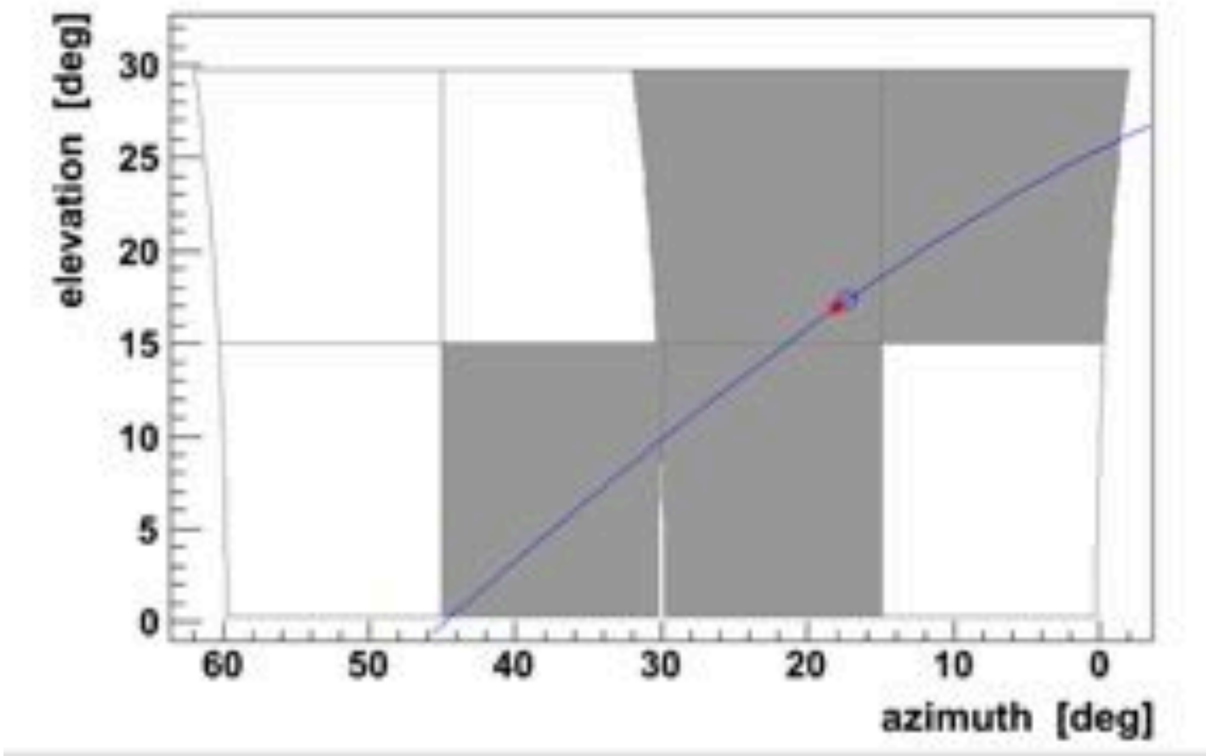


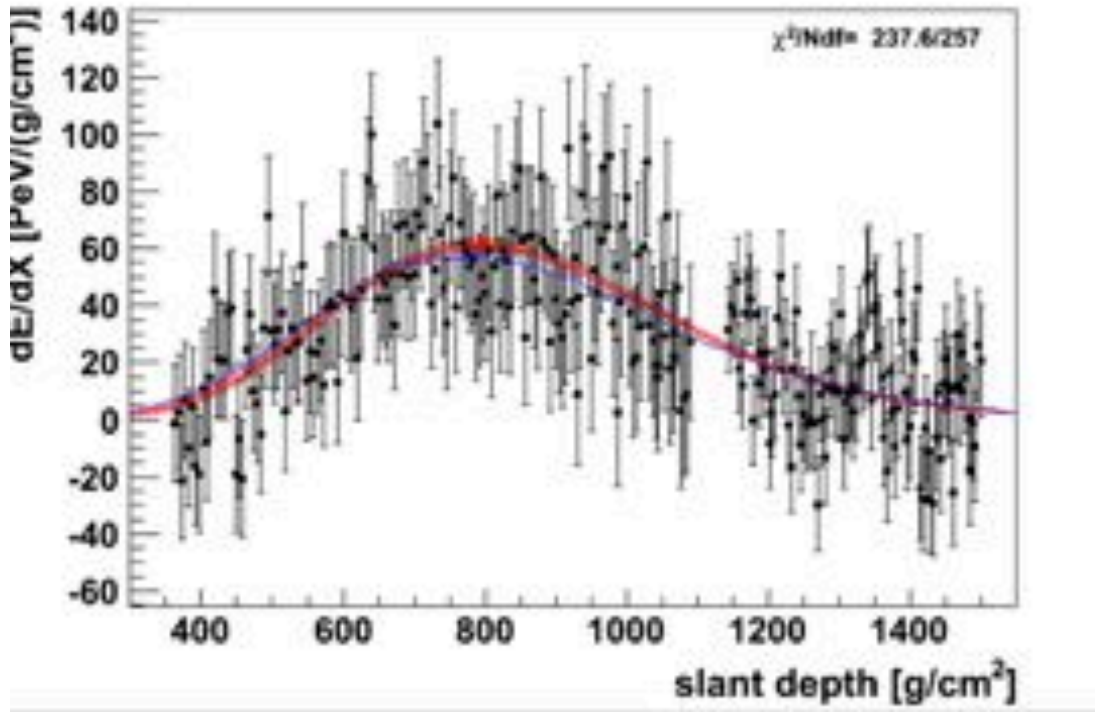


Single or few pixels and smaller optics

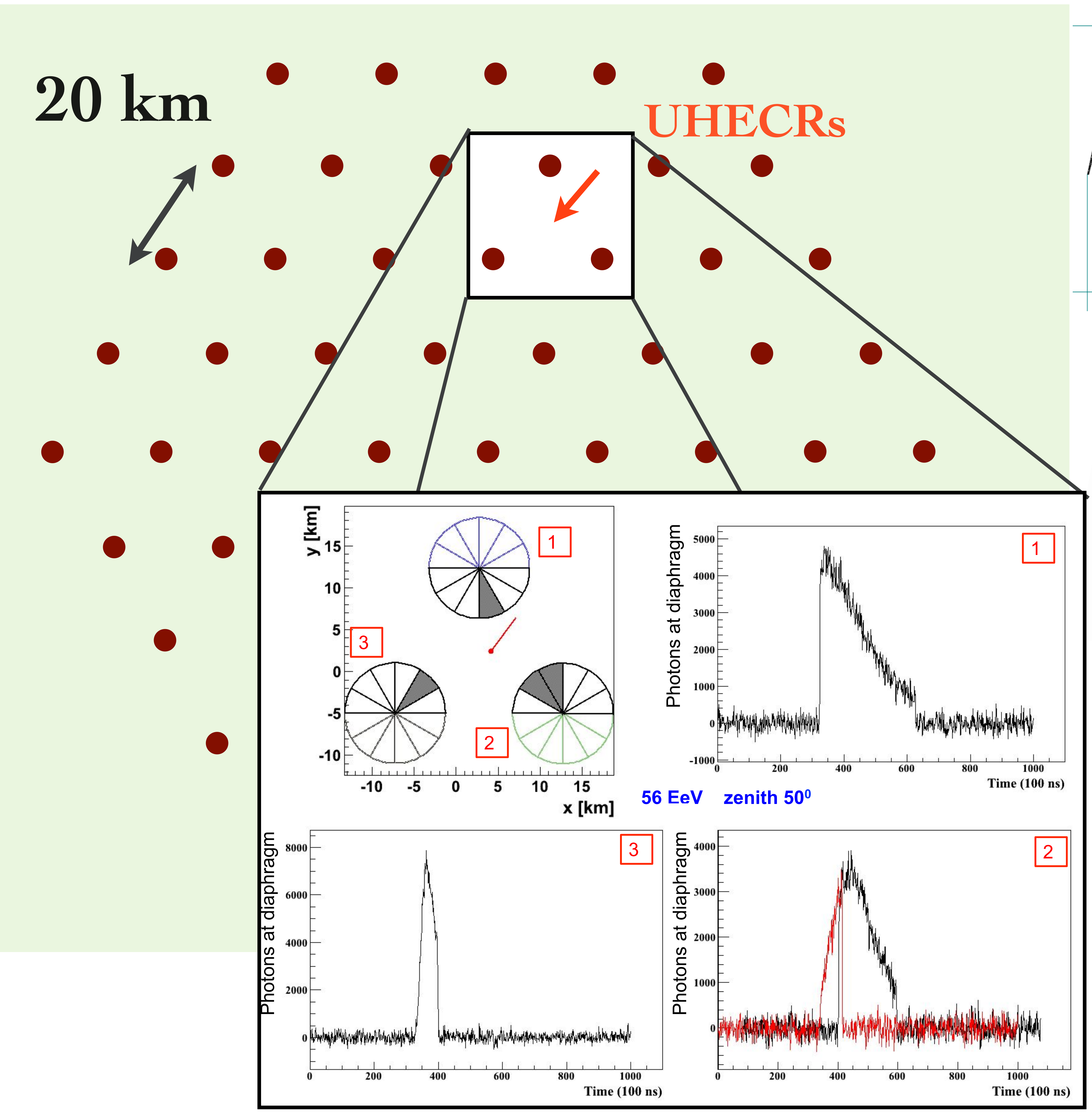


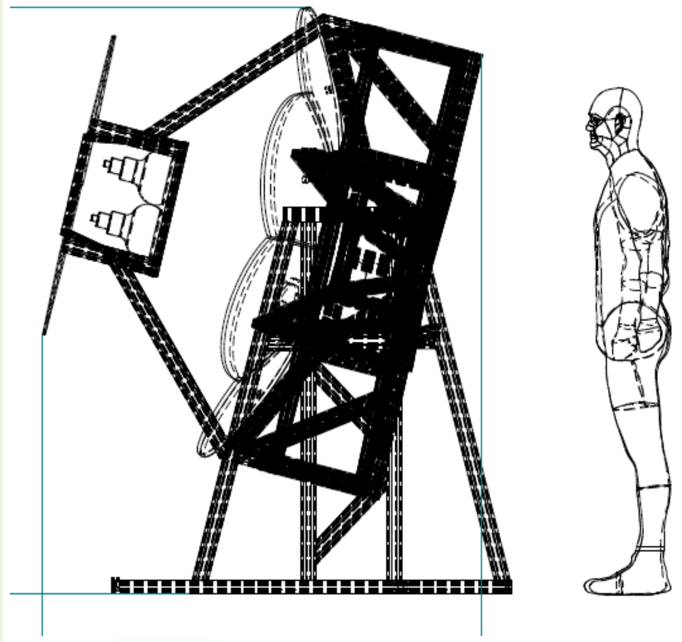
Low-cost and simplified/optimized FD

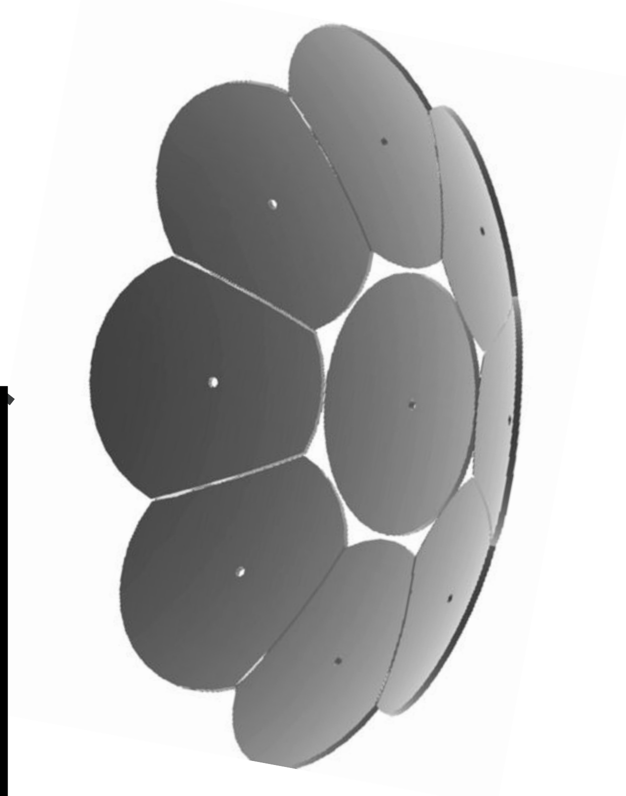


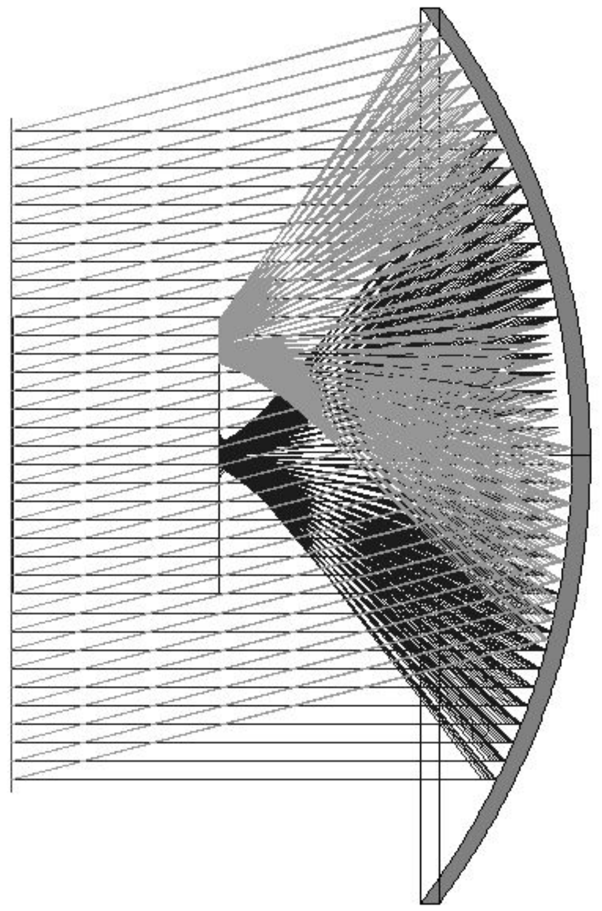


Fluorescence detector Array of Single-pixel Telescopes





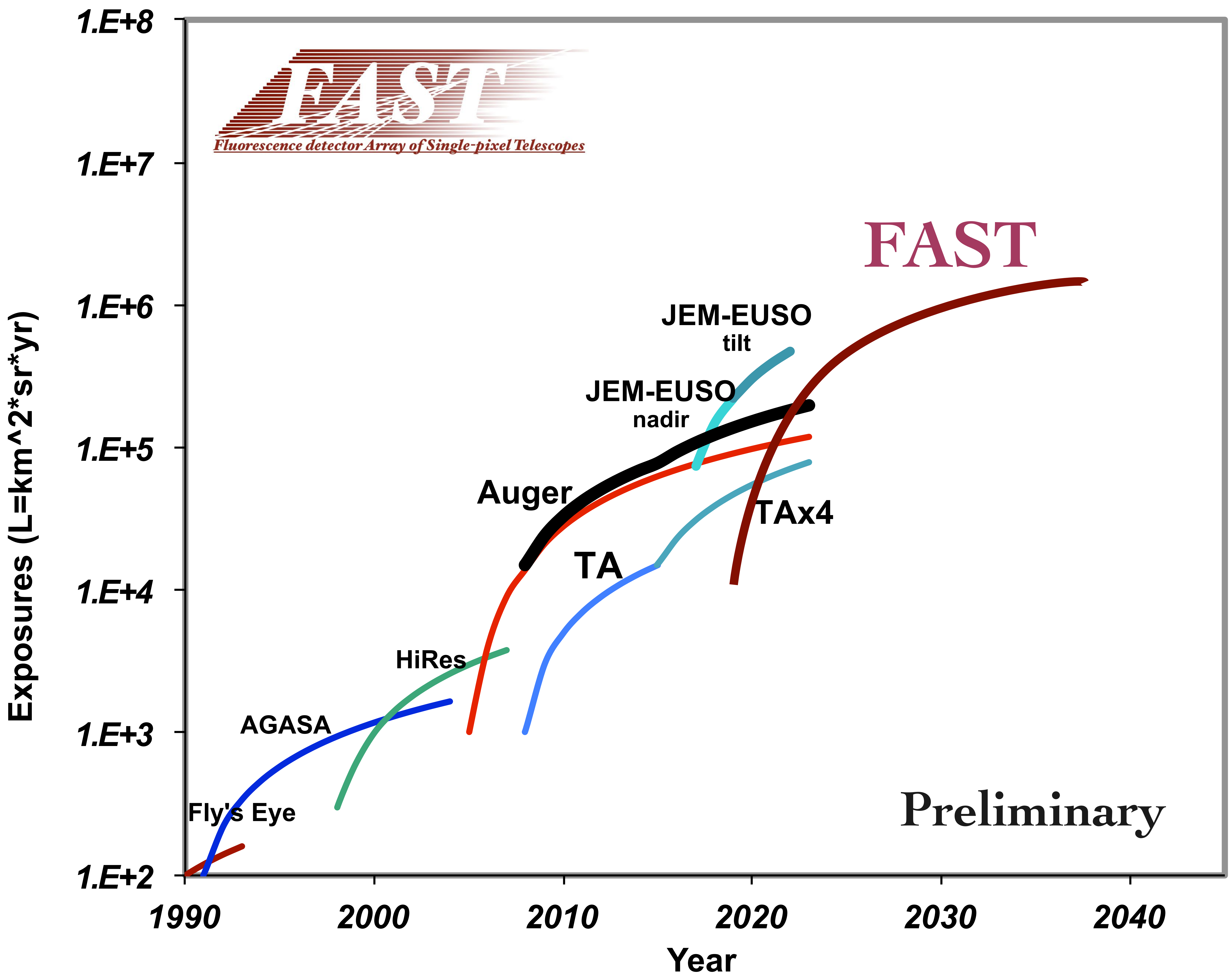




- Each telescope: 4 PMTs, 30°×30° field of view (FoV).
  - **Reference design: 1 m^2 aperture, 15°×15° FoV per PMT**
- Each station: 12 telescopes, 48 PMTs, 30°×360° FoV.
- Deploy on a triangle grid with **20 km** spacing, like **"Surface Detector Array"**.
- If 500 stations are installed, a ground coverage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

FAST Exposure

Fluorescence detector Array of Single-pixel Telescopes



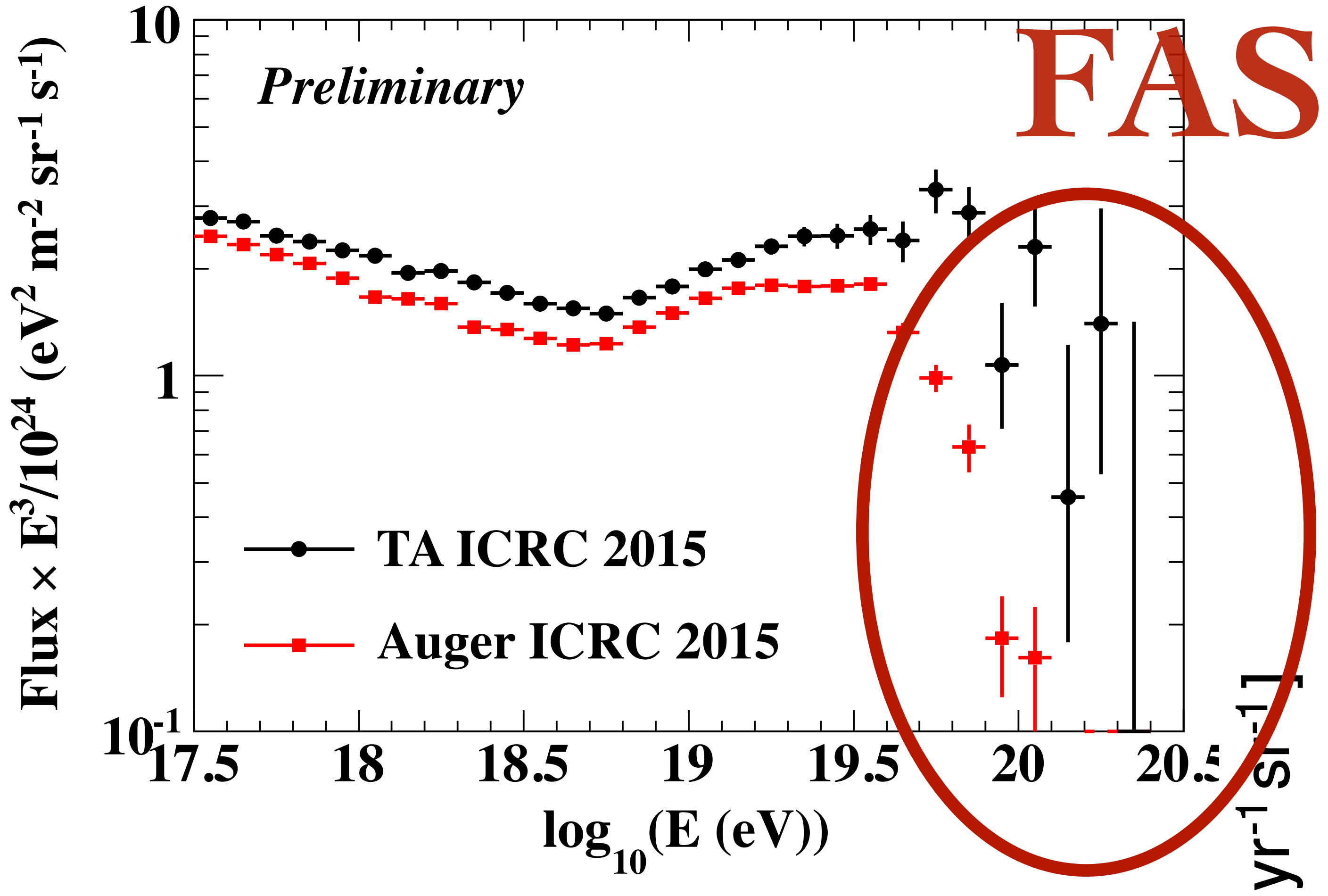
- Conventional operation of FD under 10~15% duty cycle
  - Target: $>10^{19.5}$ eV
- Observation in **moon night** to achieve **25%** duty cycle,
  - Target: **$>10^{19.8}$ eV = Super GZK events (Hotspot/ Warmspot)**
    - Test operation in moon night with Auger FD (R. Smida)
- Ground area of 150,000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

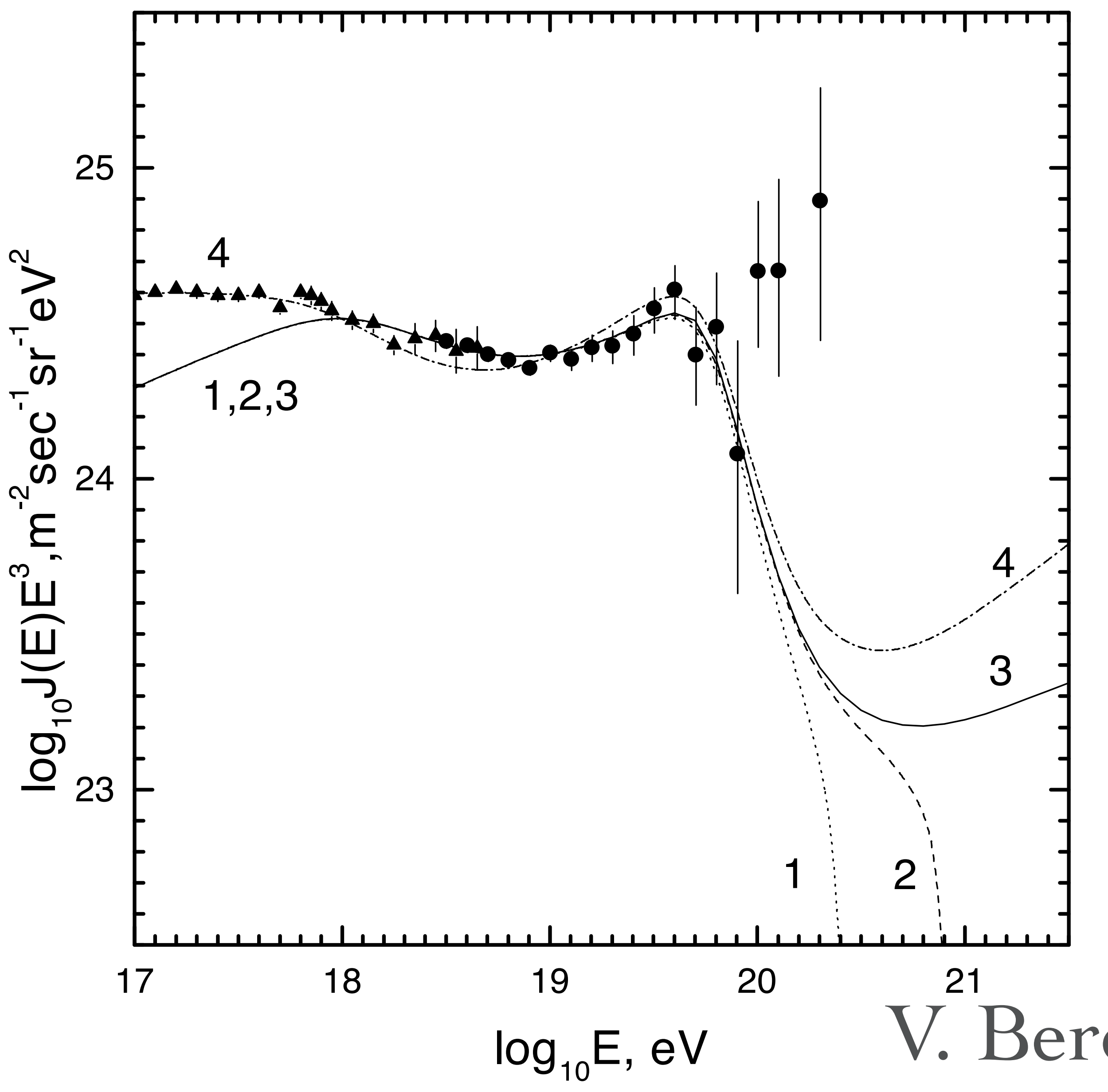

FAST
地中海
チュニジア
モロッコ
アルジェリア
リビア
エジプト
西サハラ
モーリタニア
マリ
ニジェール
チャド
スーダン
ダカール
Dakar
セネガル
ガンビア
ブルキナ
ファソ
ギニア
シエラレオネ
リベリア
ガーナ
トーゴ
ベナン
ナイジェリア
ラゴス
Lagos
アクラ
Accra
ギニア湾
カメルーン
中央アフリカ
共和国
南スーダン
赤道ギニア
ガボン
コンゴ
コンゴ民主
共和国
ウガンダ
ケニア
ルワンダ
ブルンジ
ナイロビ
Nairobi
エチオピア
ソマリア
エリトリア
ジブチ
アデン湾
イエメン
紅海
メッカ
مكة
サウジアラビア
リヤド
الرياض
ペルシャ湾
アラブ首長
国連邦
オマーン
シリア
レバノン
イスラエル
イラク
イラン
航空写真
Google
地図データ ©2016 ORION-ME　利用規約　プライバシー　フィードバックの送信　1000 km

Physics Target

GZK Recovery

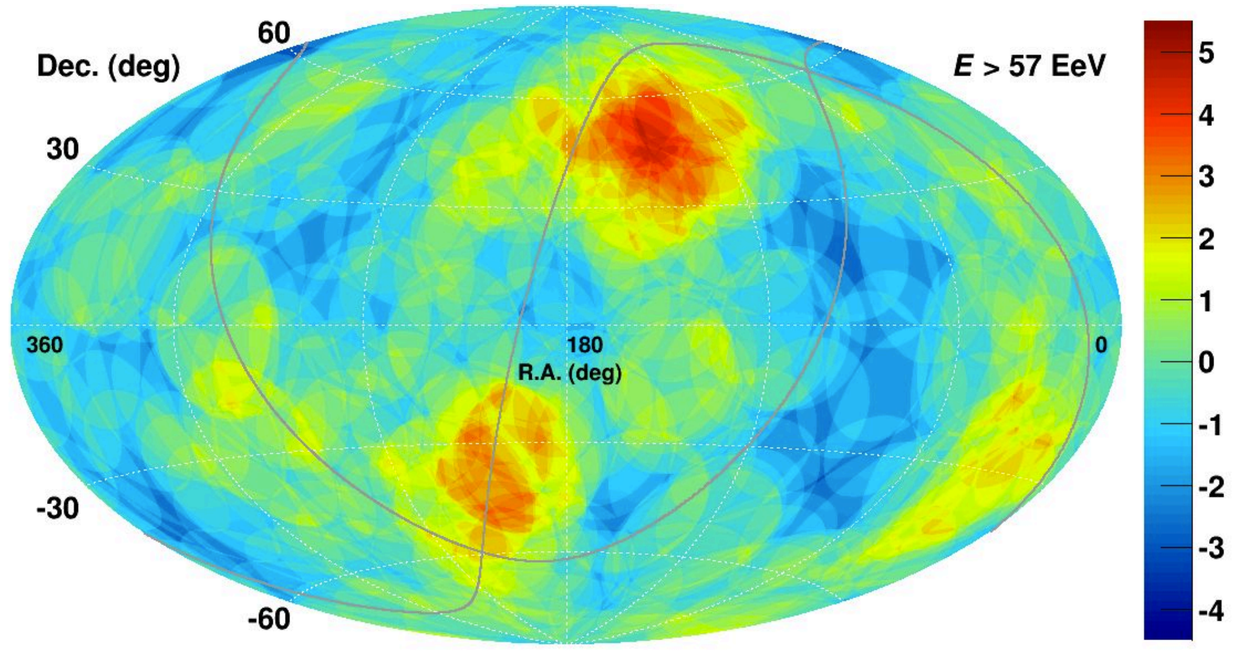
FAST



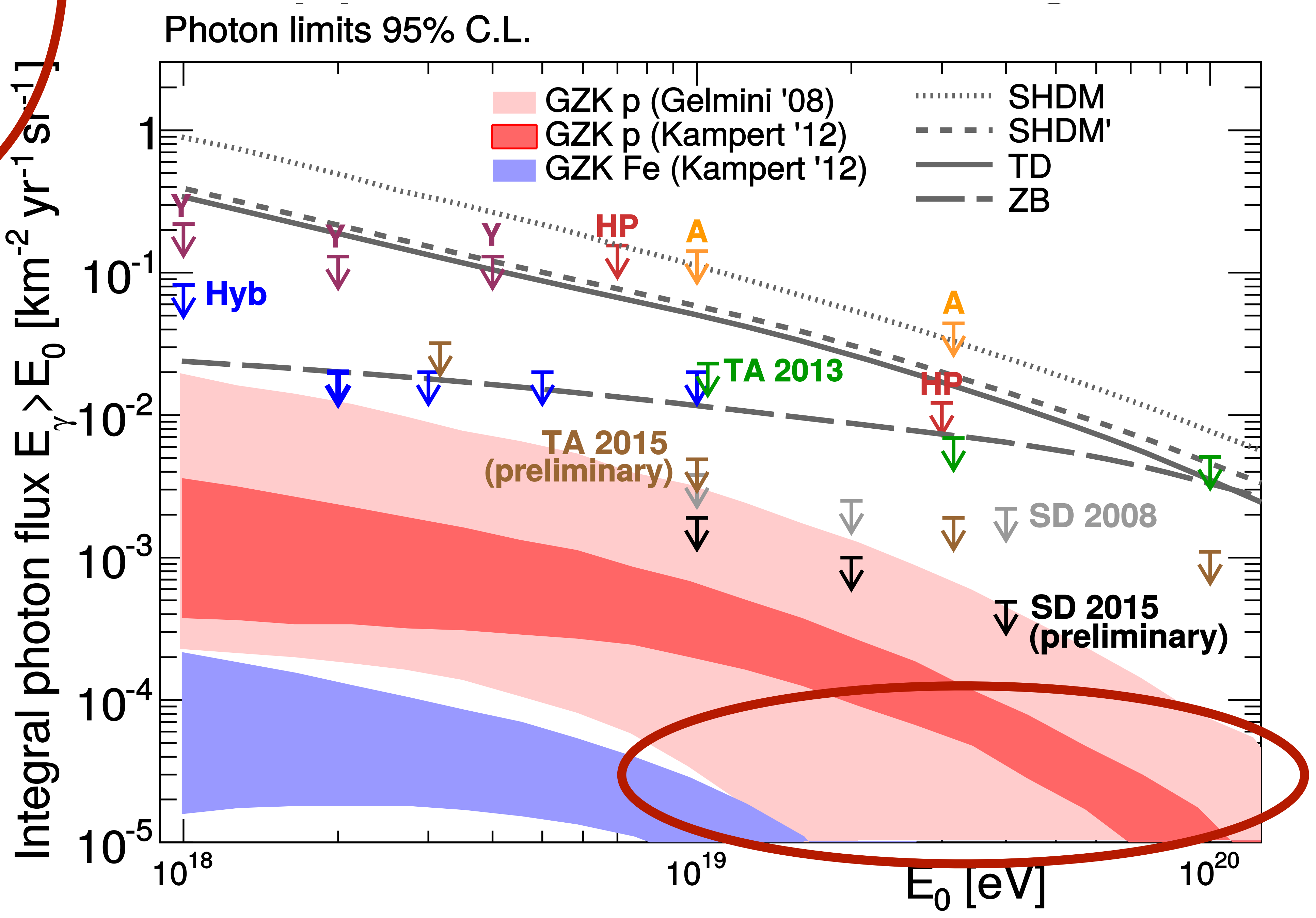


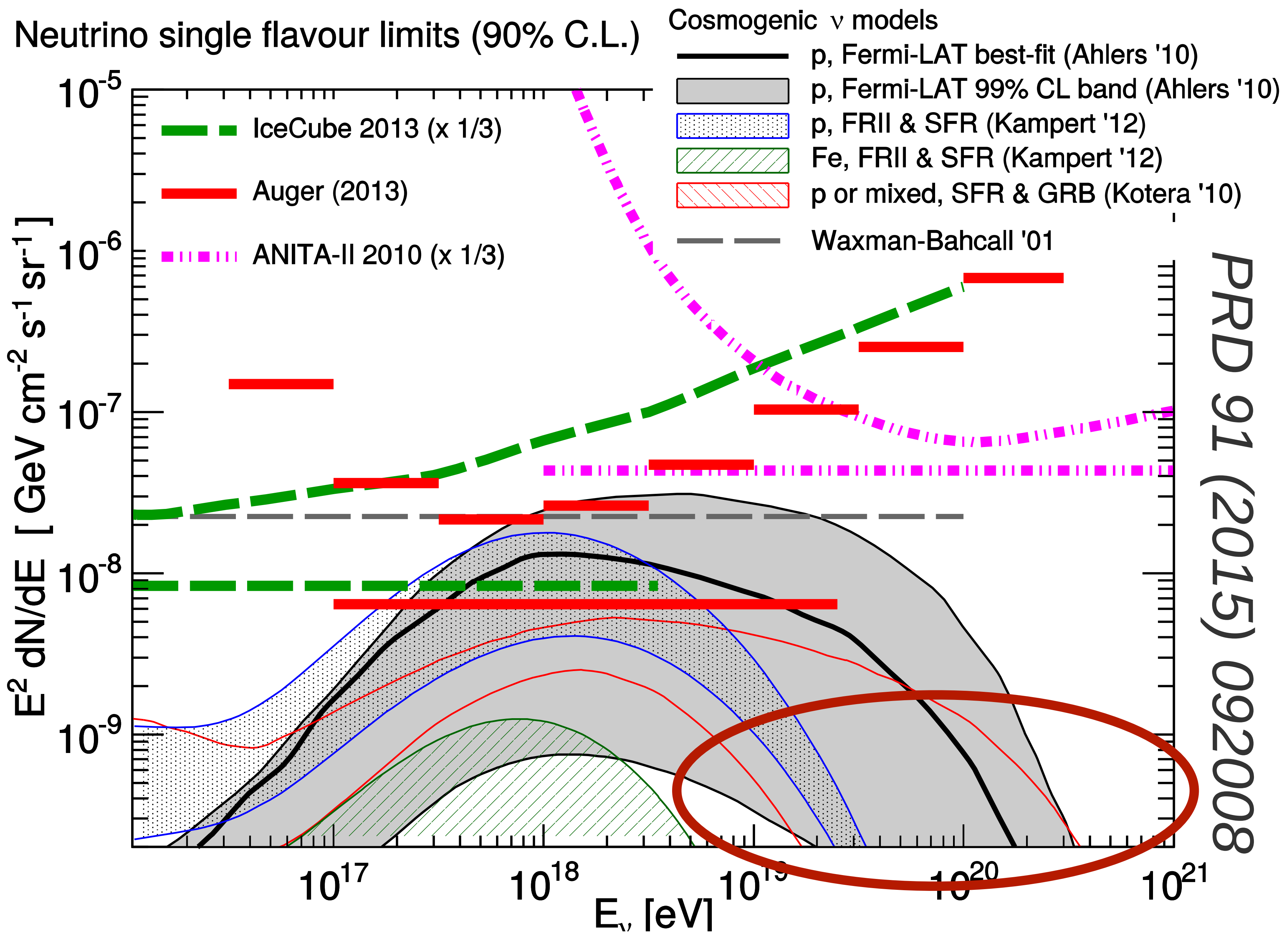
V. Berezinsky et al., (2001)

UHECR Anisotropy with ~10x statistics



First detection of UHE photons and neutrinos





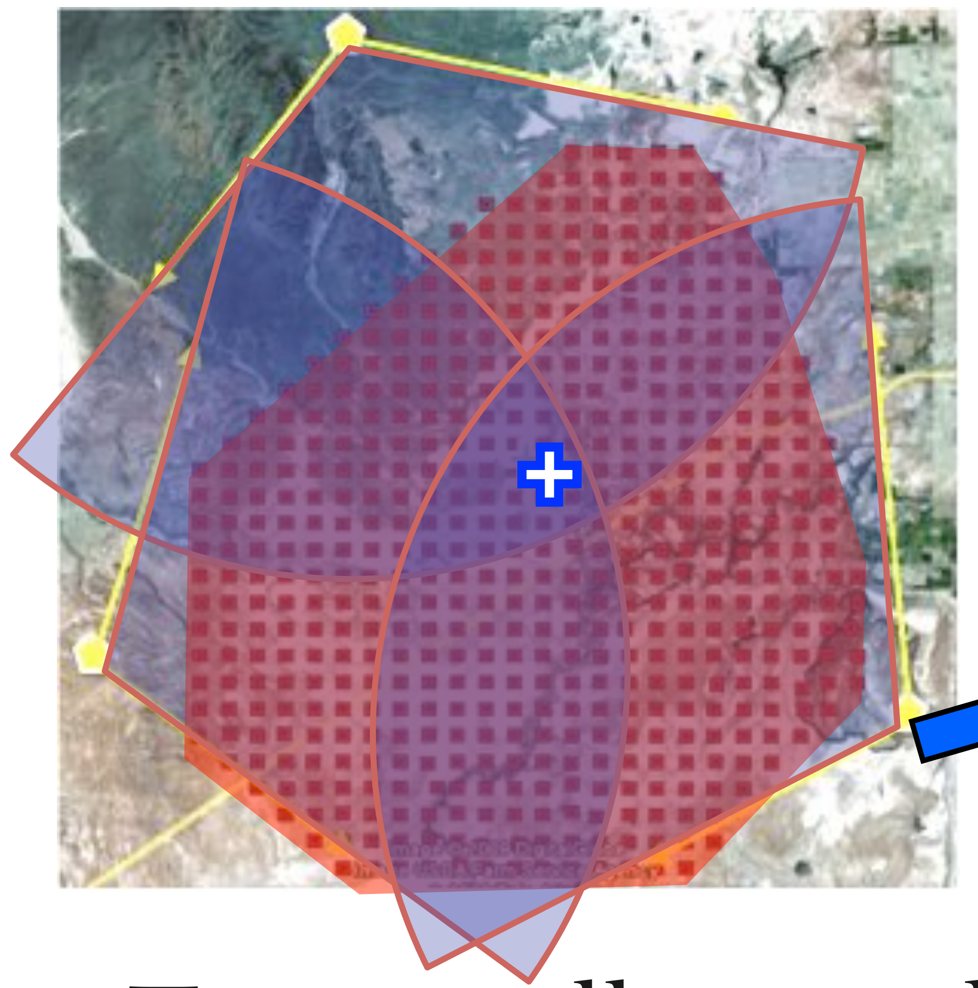
PRD 91 (2015) 092008

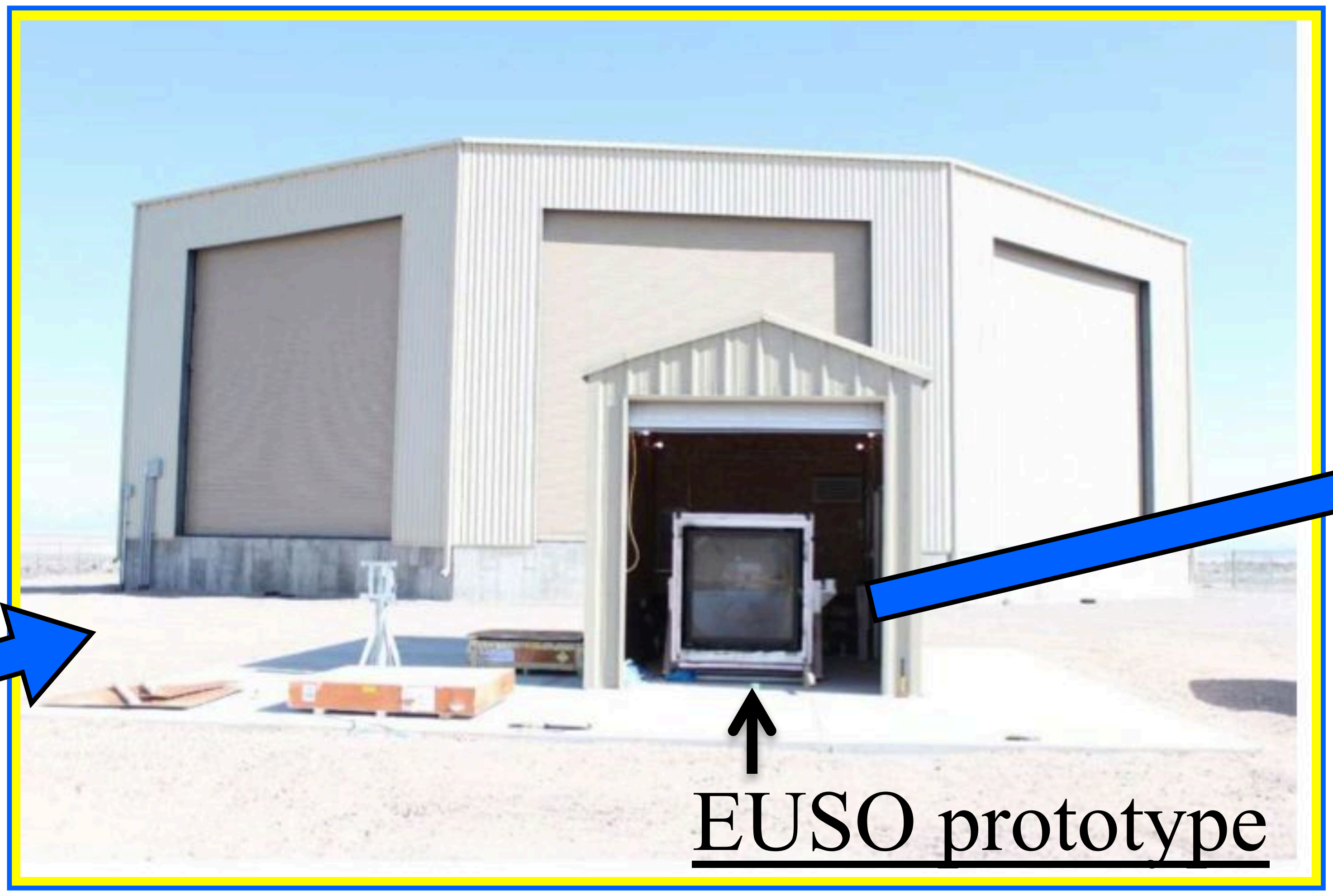
FAST FAST

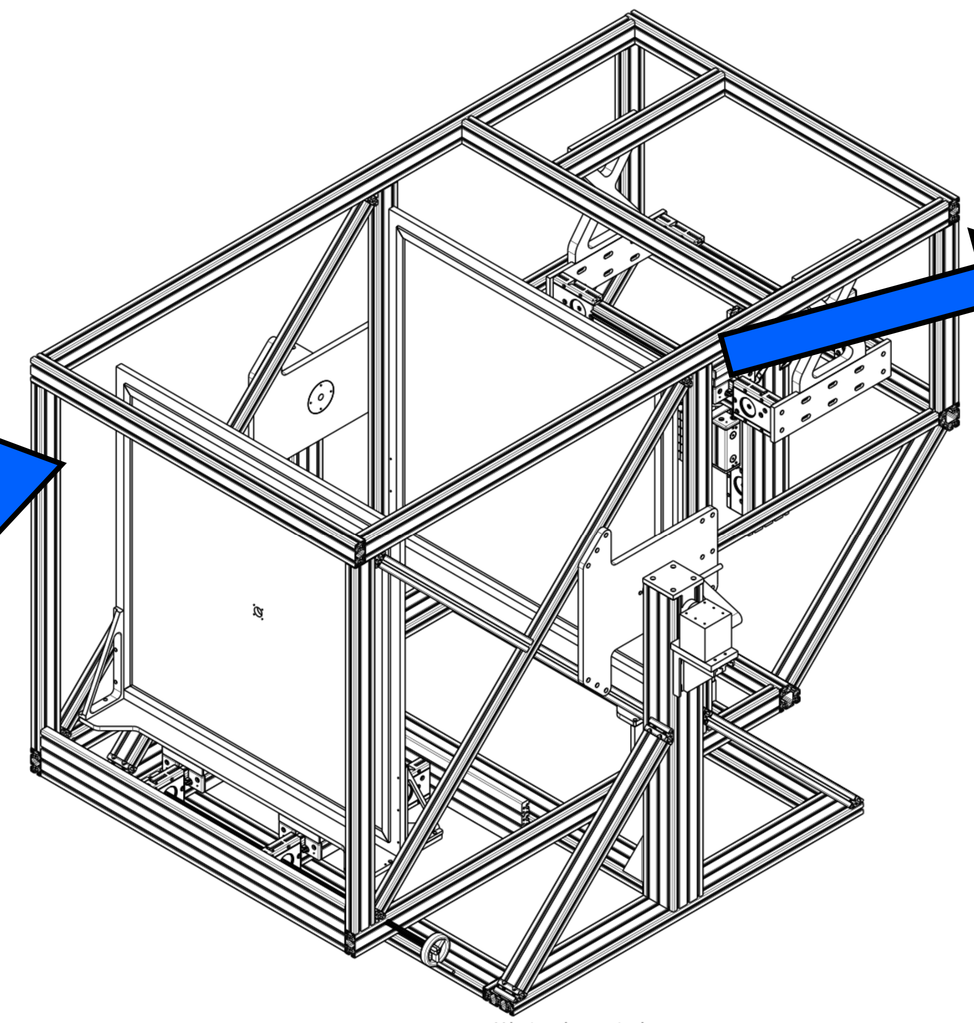
FAST
Fluorescence detector Array of Single-pixel Telescopes

Window of Opportunity at EUSO-TA

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)

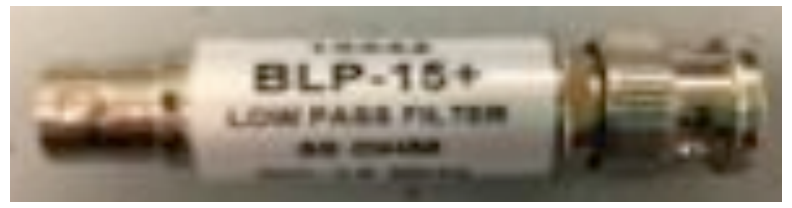
FAST DAQ System

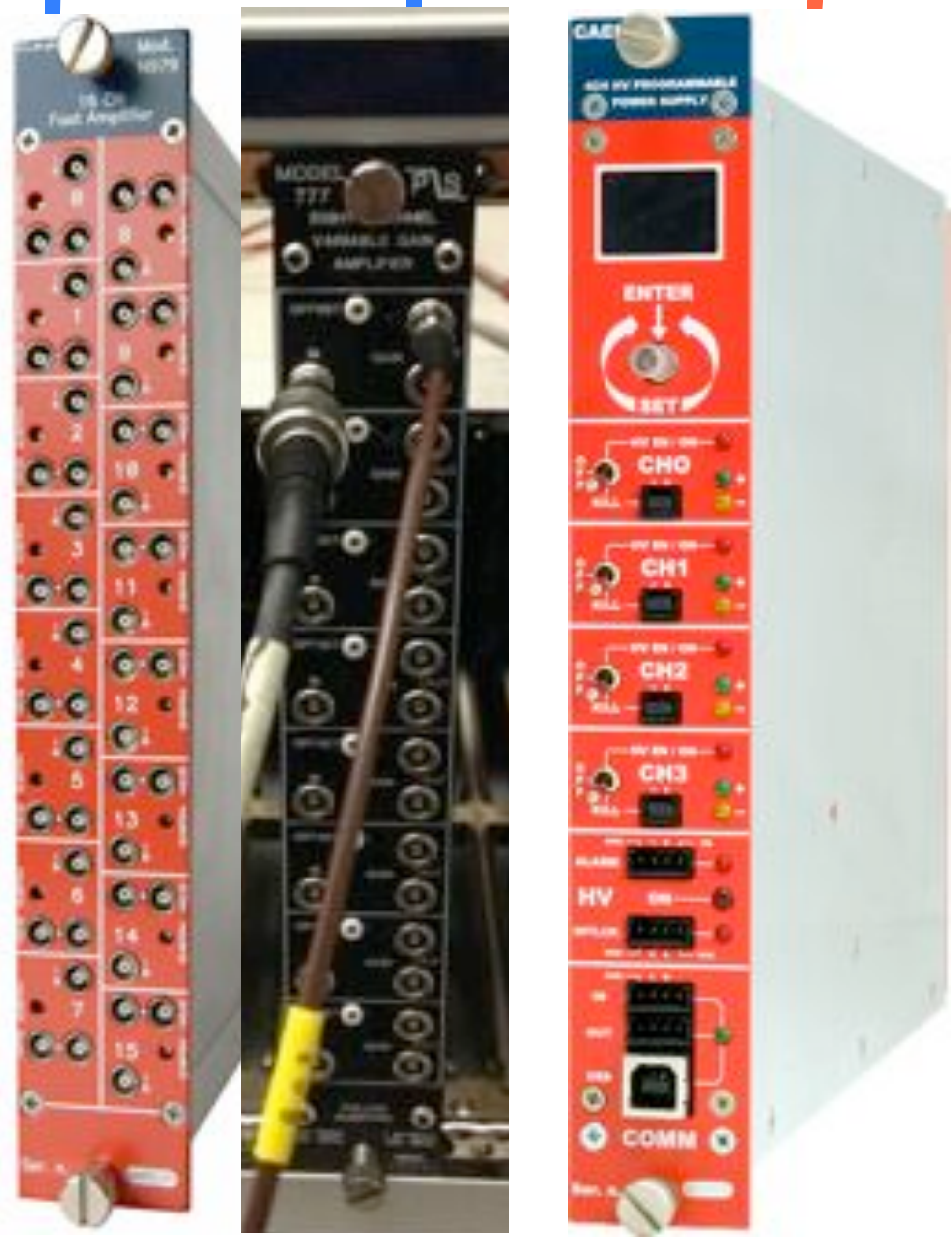
TAFD external trigger, 3~5 Hz

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

1

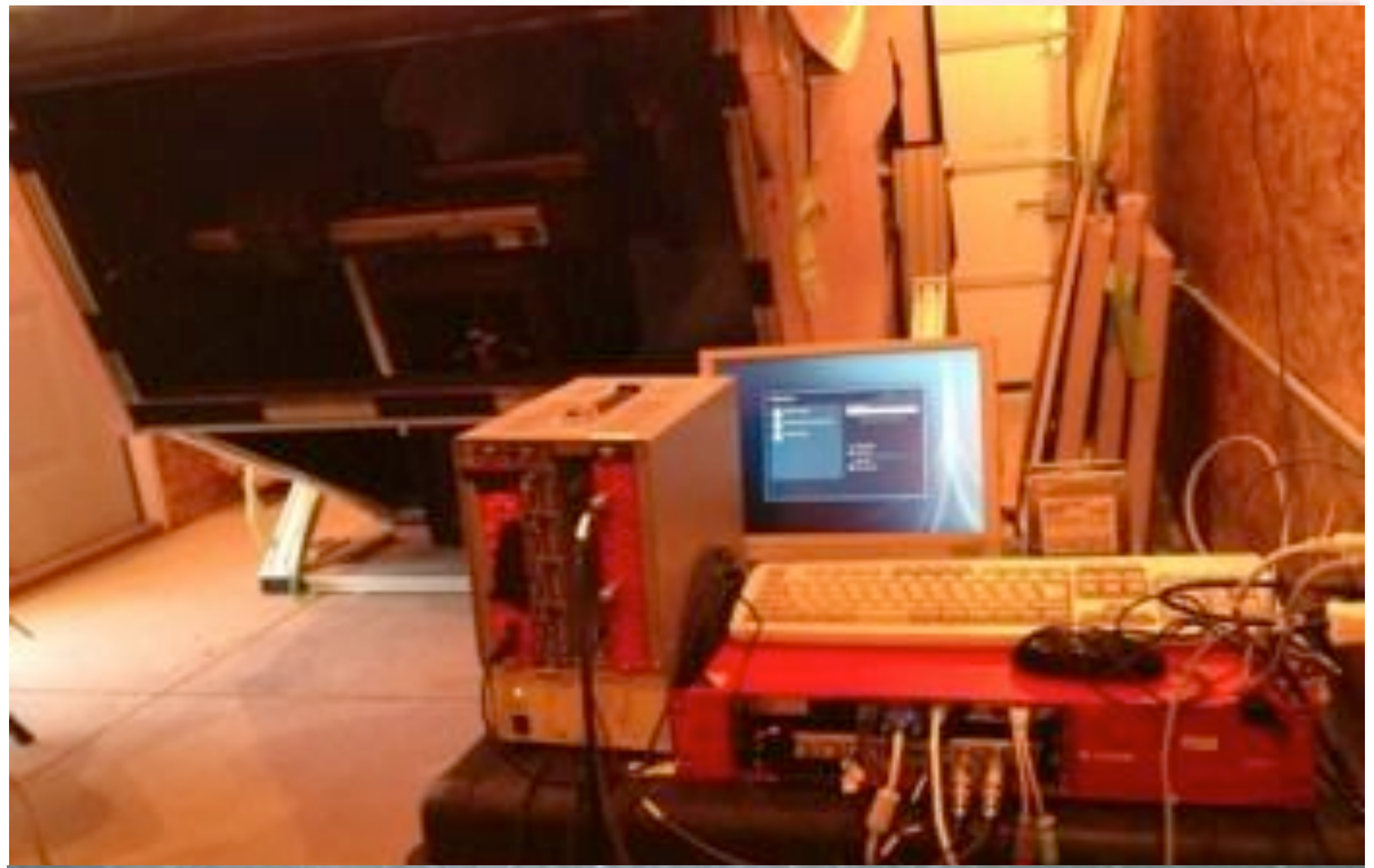
2

3

4

5

6



7

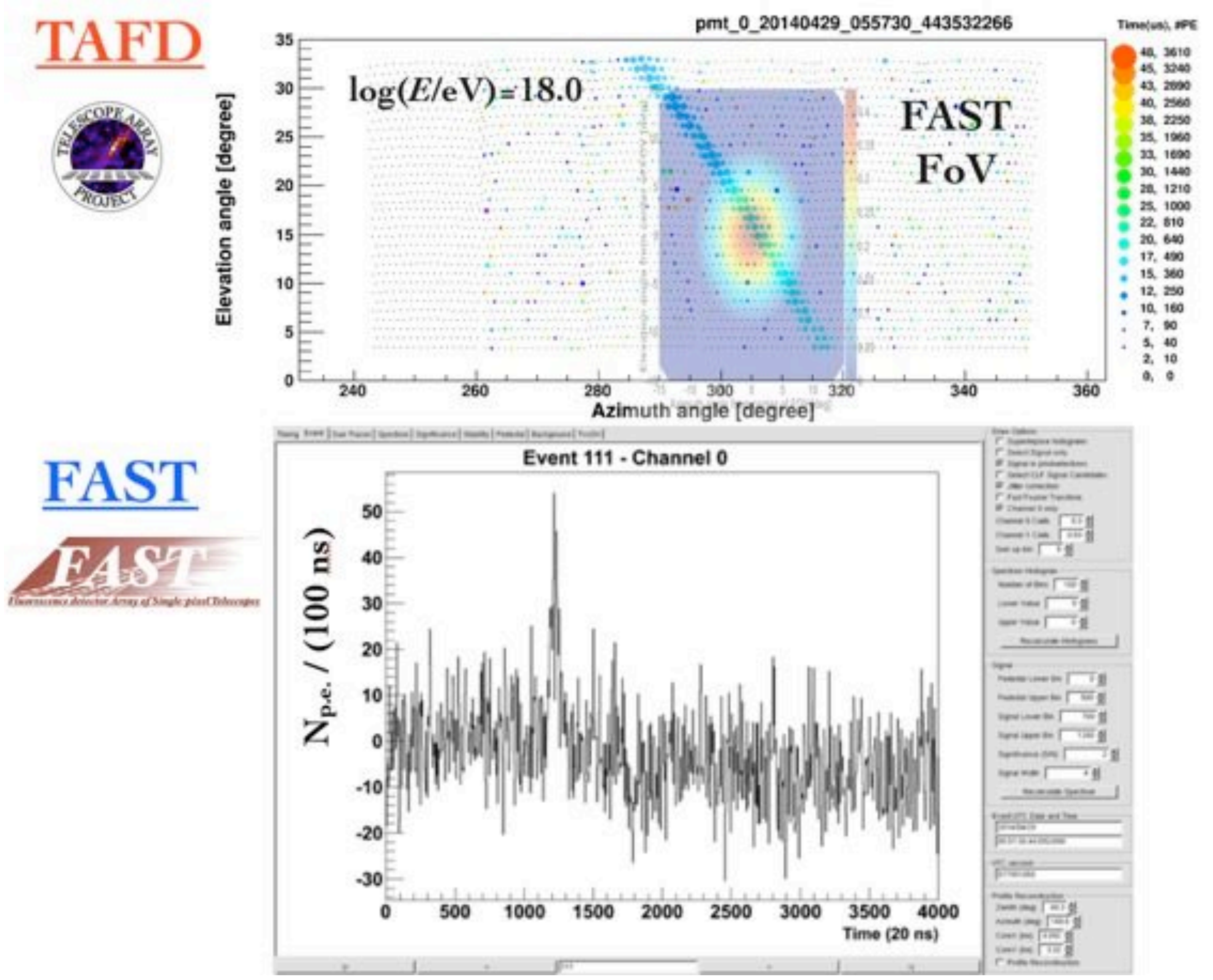
8

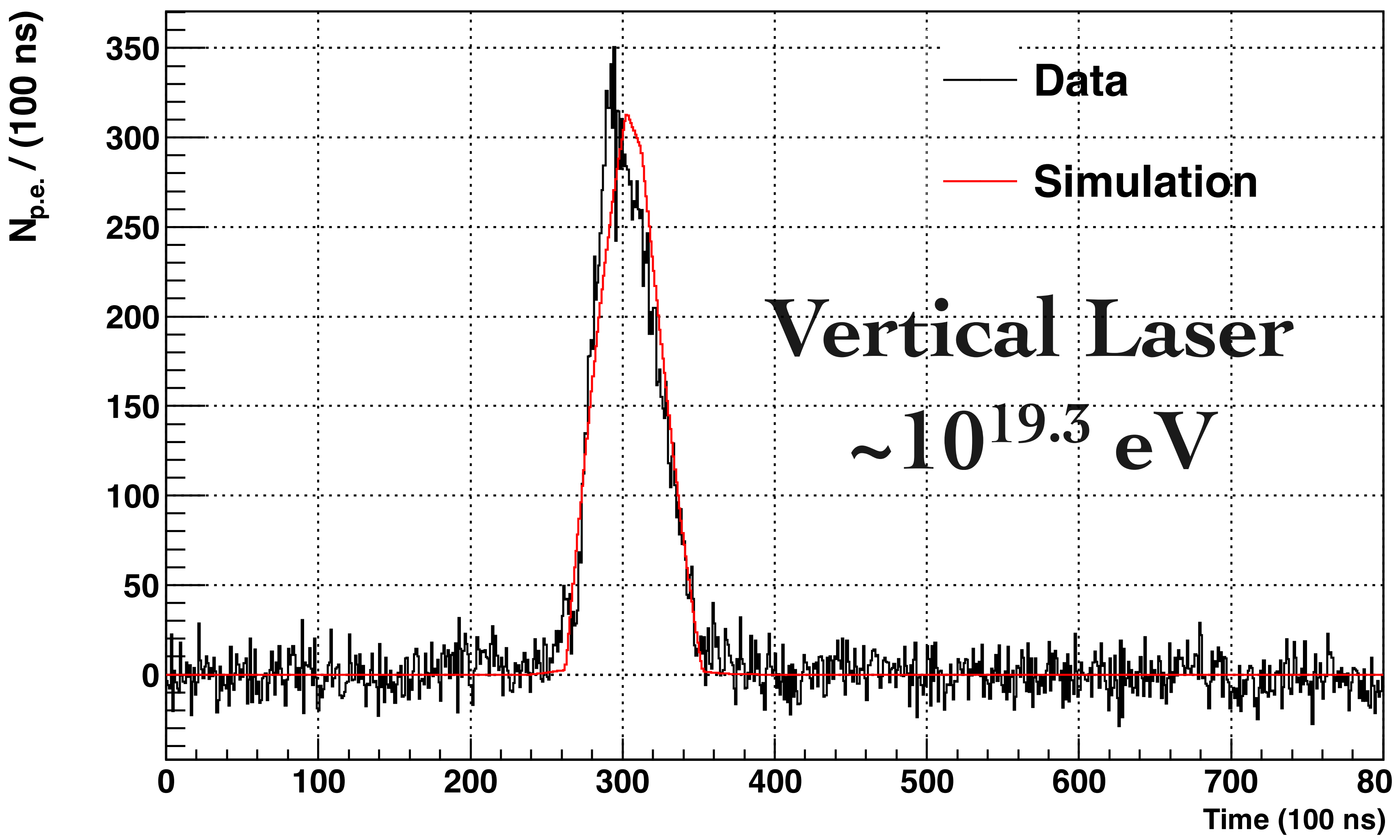
9

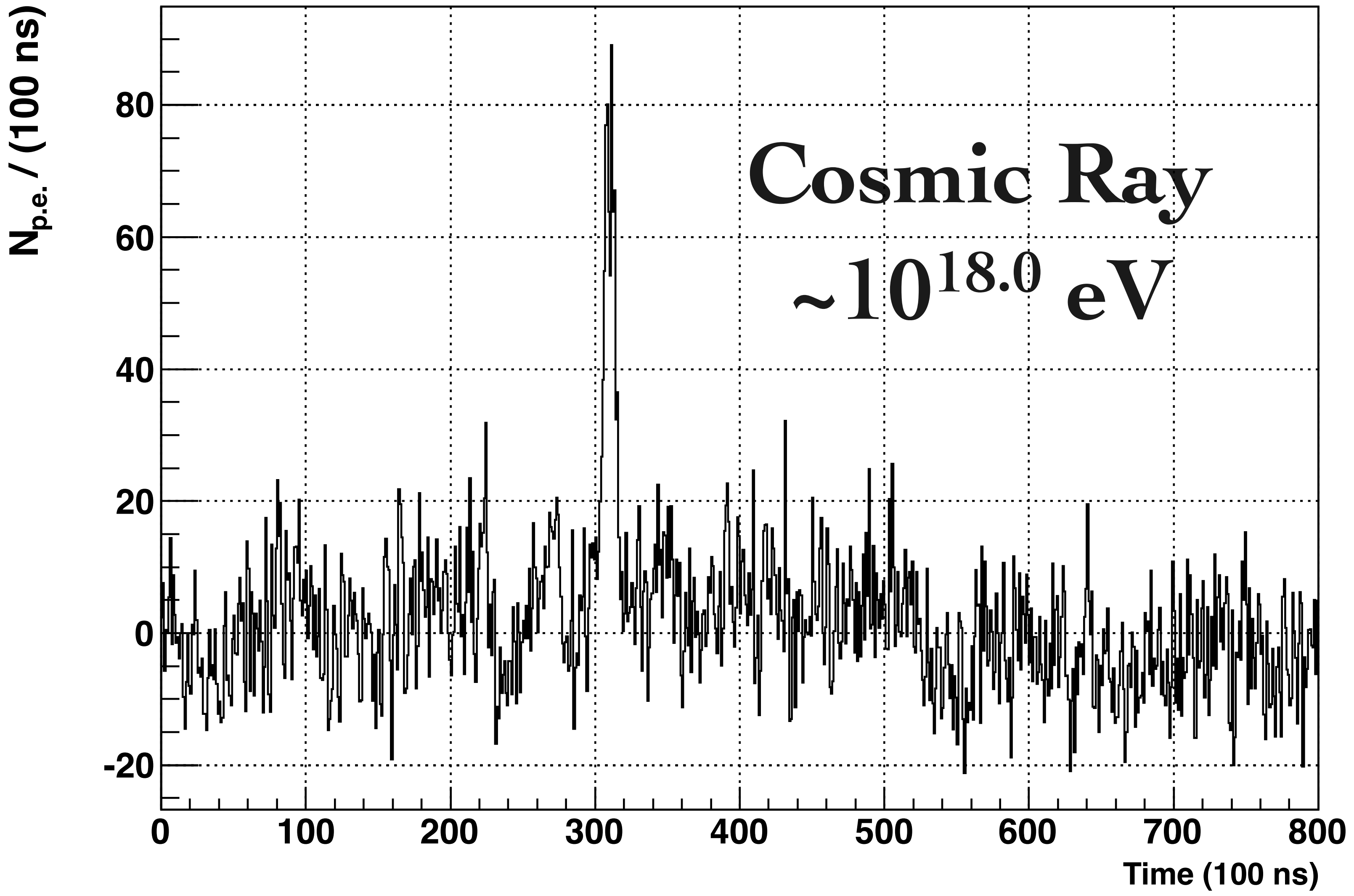
Results on the First Field Observation

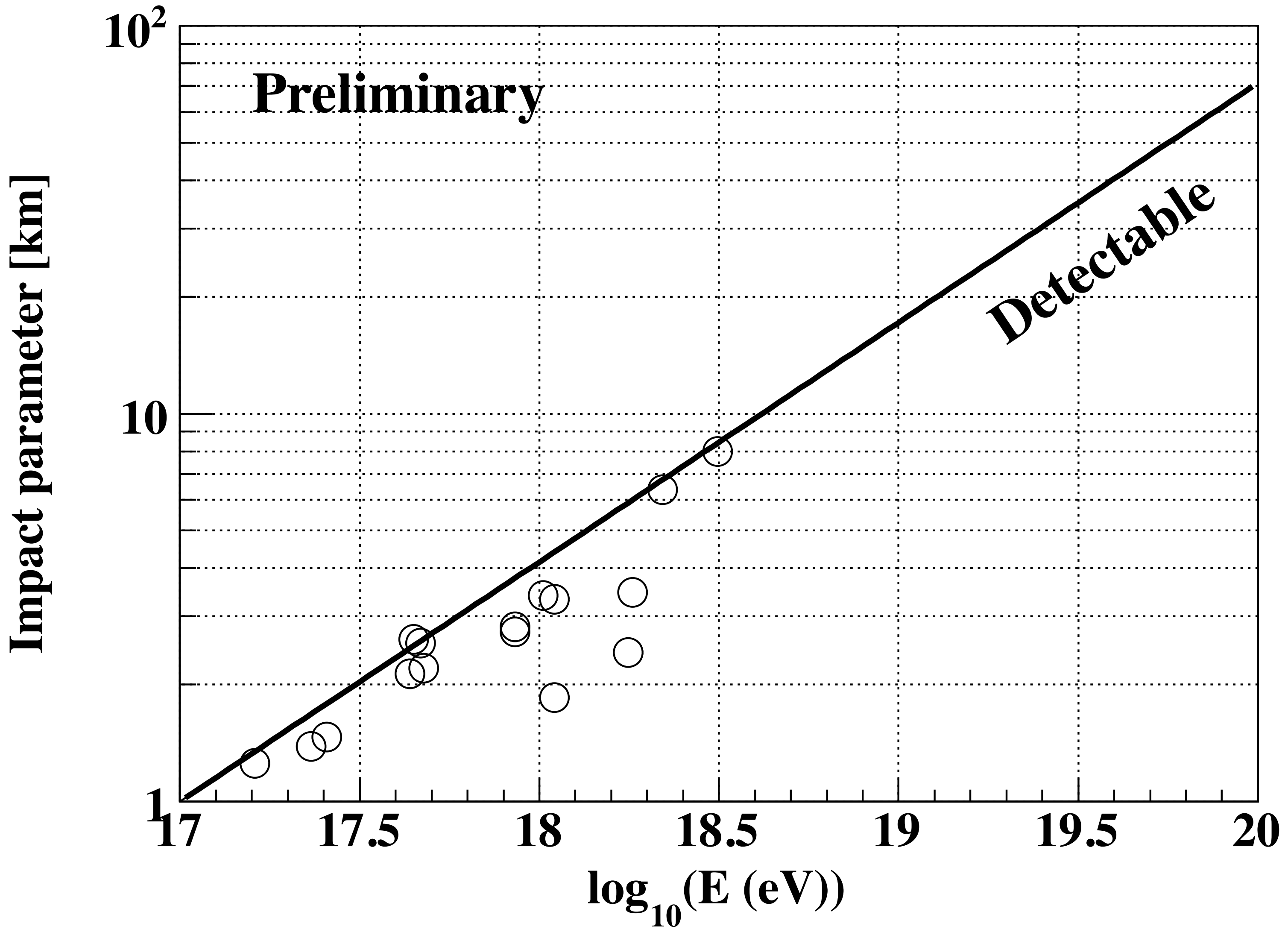
Fluorescence detector Array of Single-pixel Telescopes

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





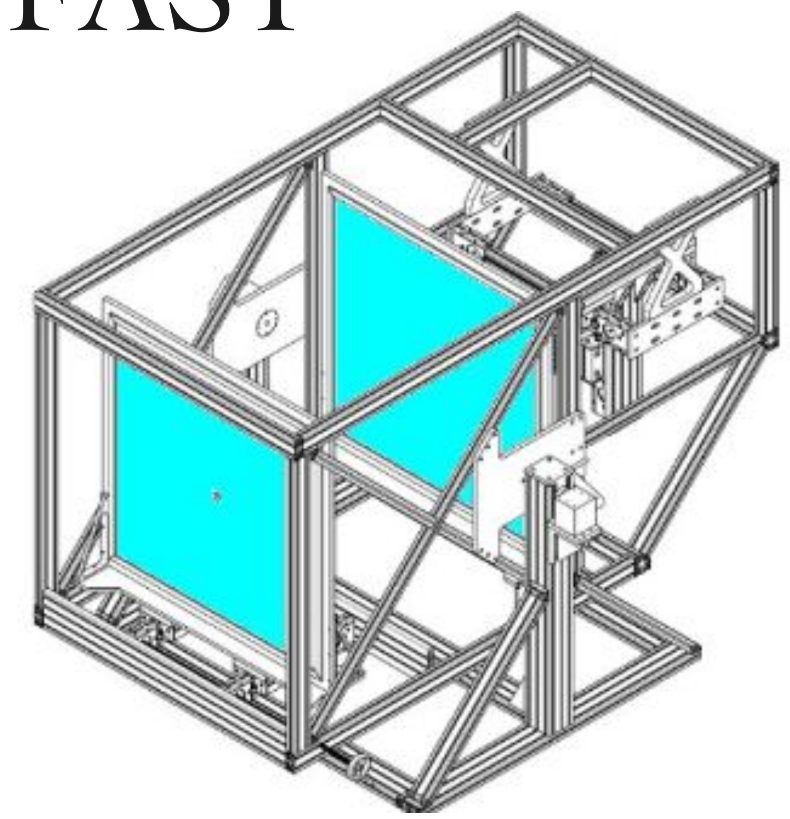


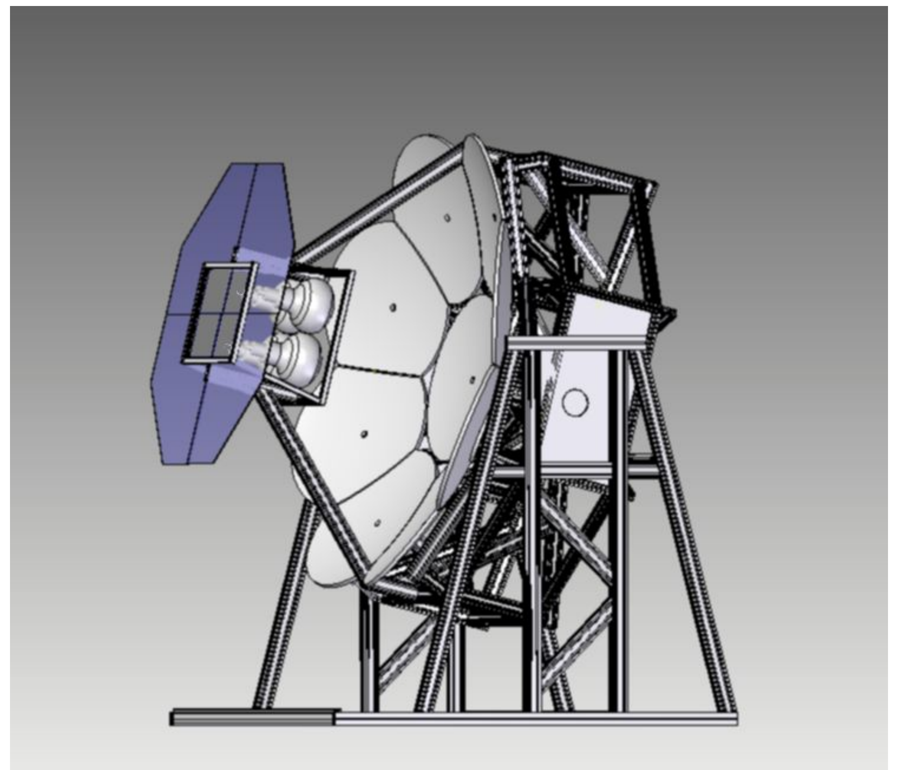


Astroparticle Physics 74 (2016) 64-72, arXiv: 1504.00692

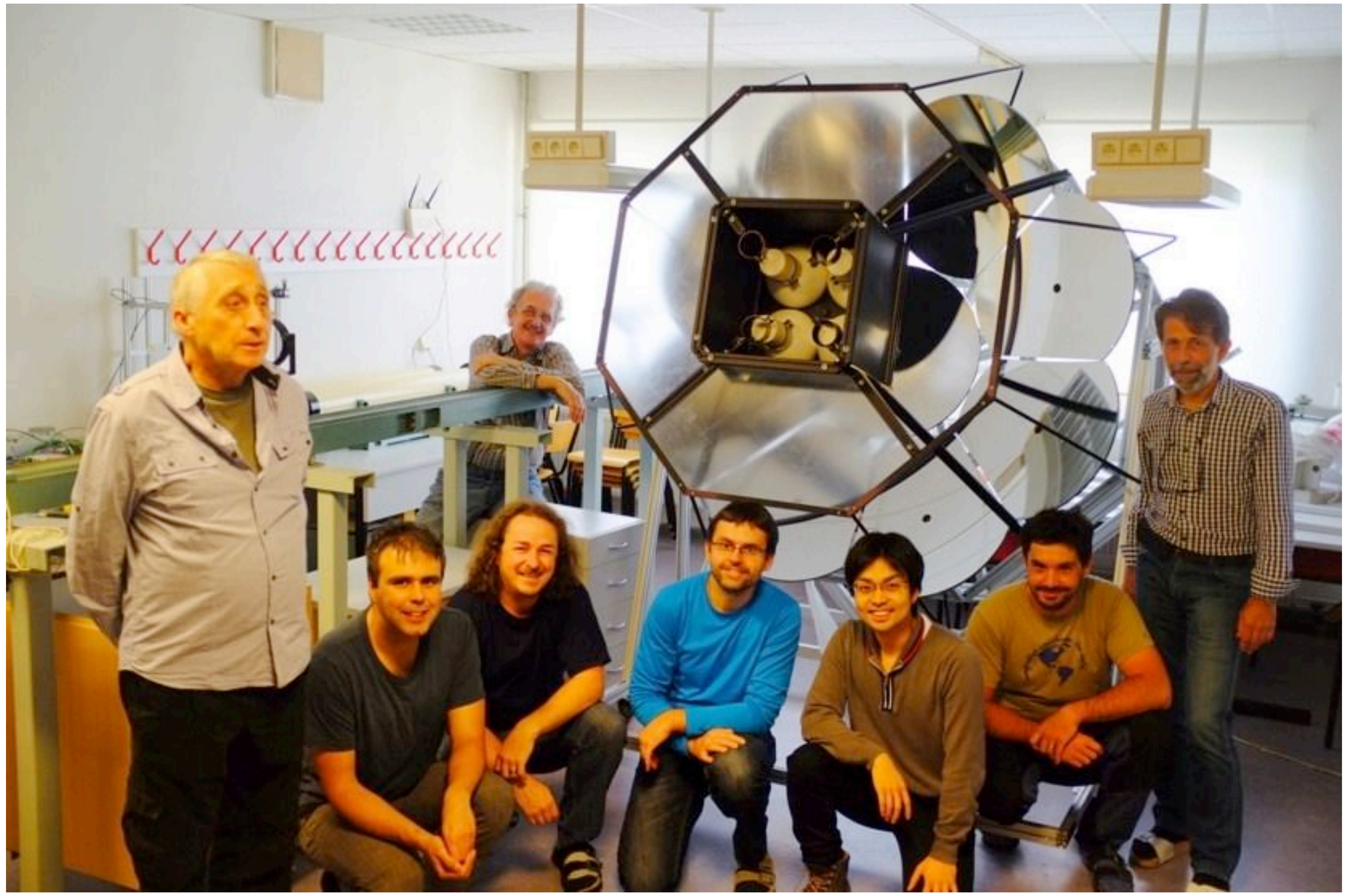
Full-scale FAST Prototype

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



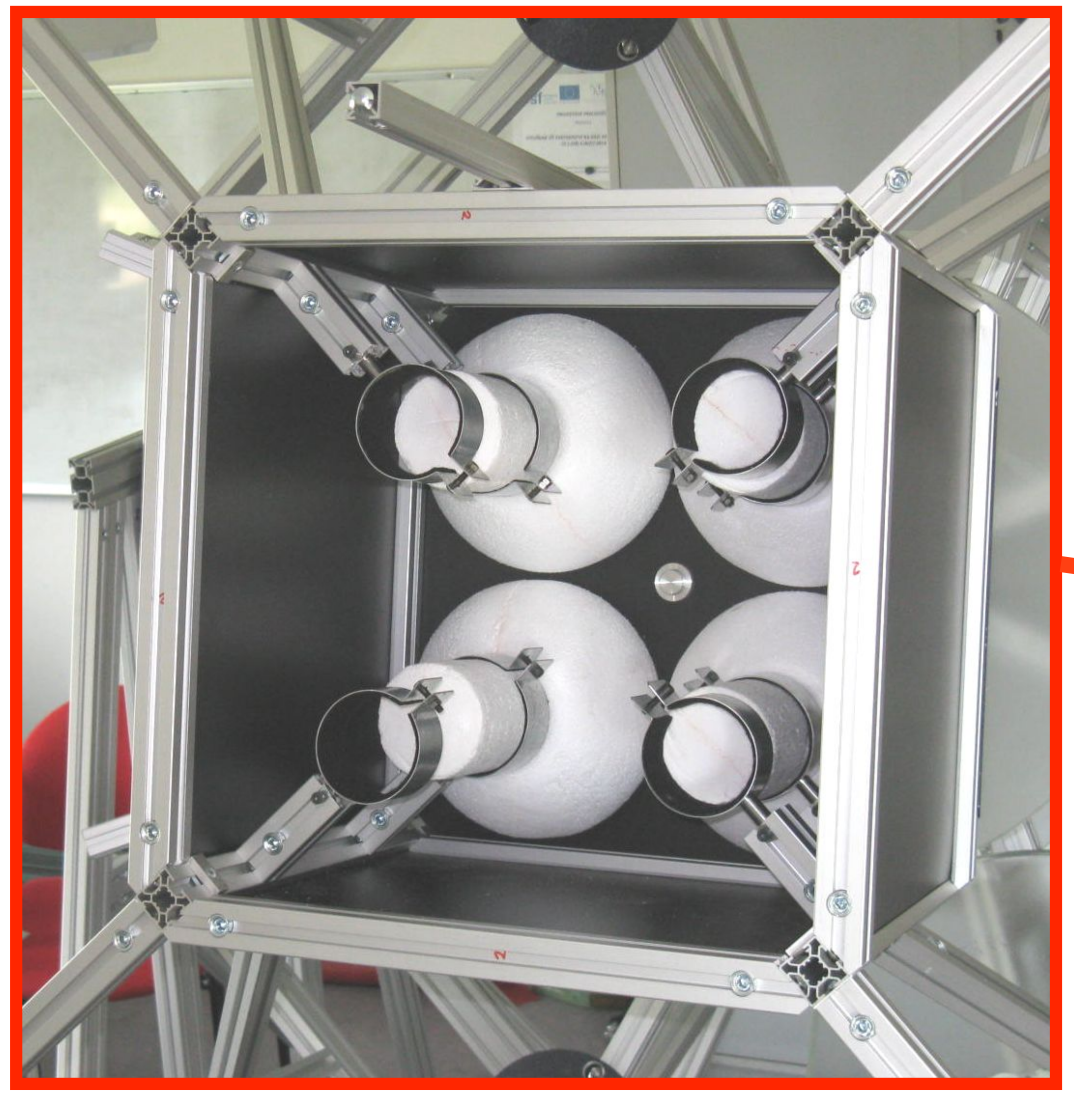


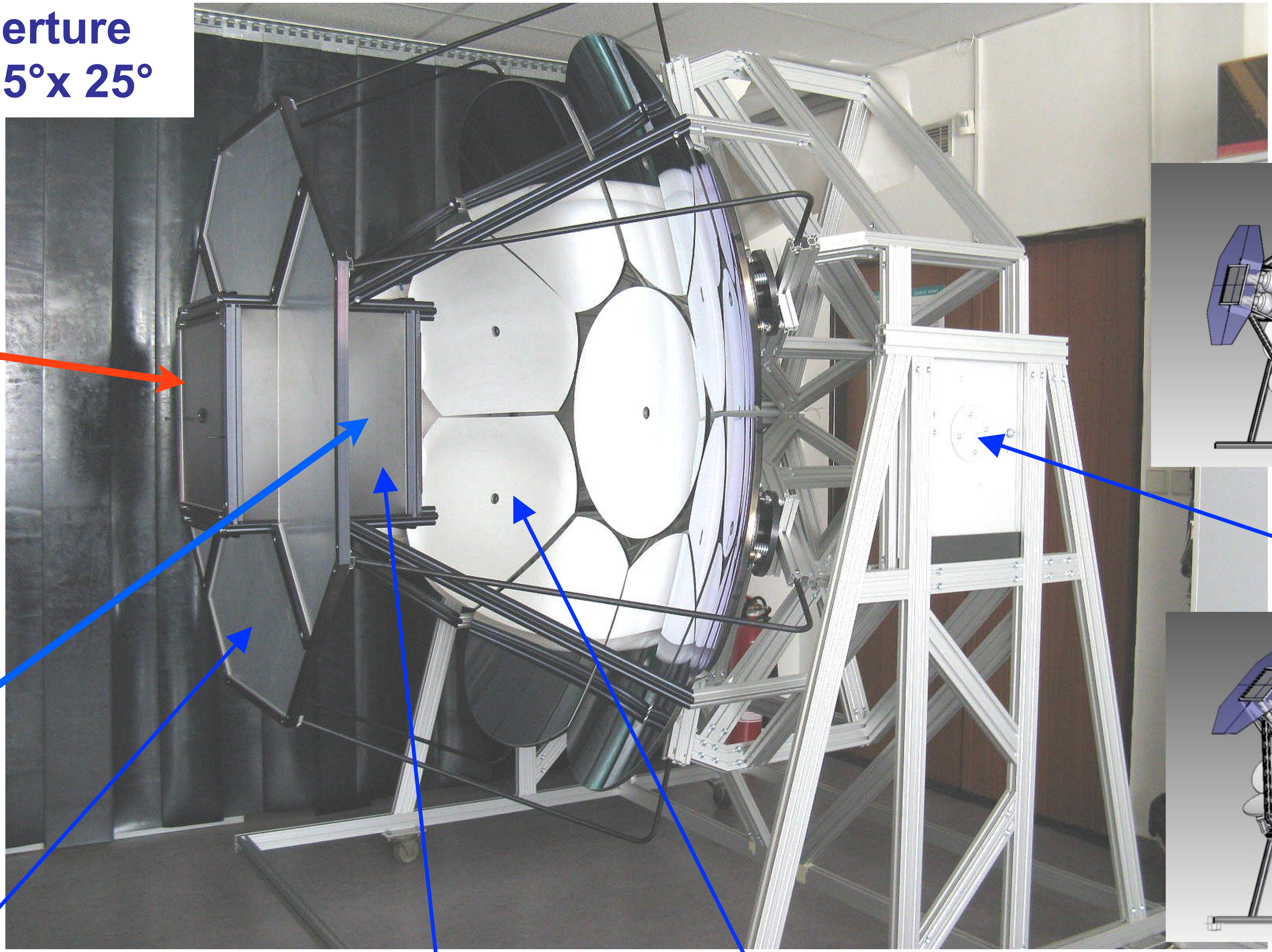
FAST meeting in December 2015
(Olomouc, Czech Republic)



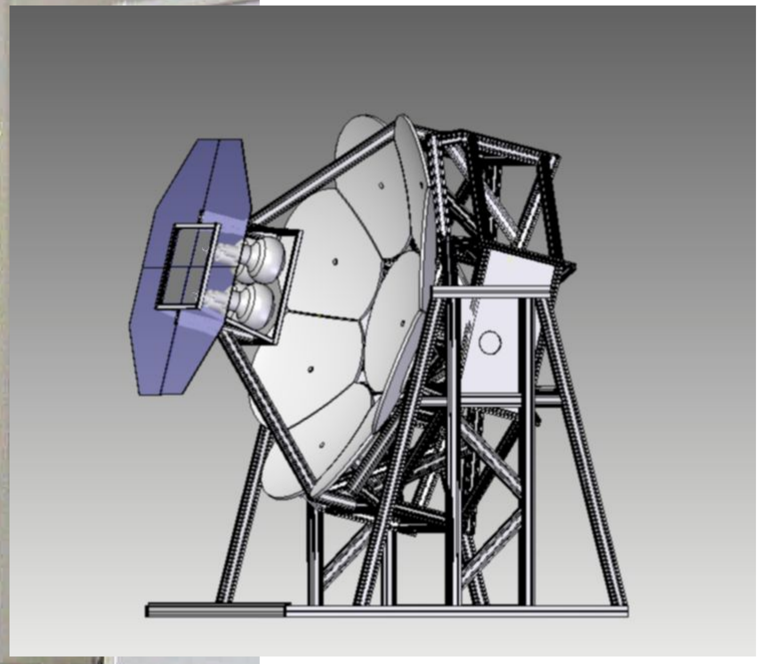
FAST
Fluorescence detector Array of Single-pixel Telescopes

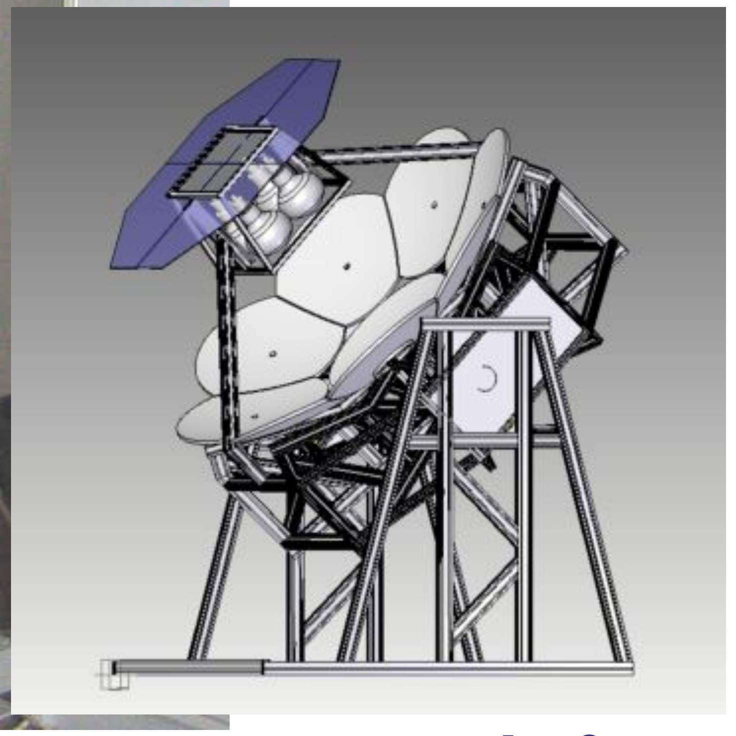
Full-scale FAST Prototype





15°





45°

FAST試作機設置

2016年10月

http://www.fast-project.org

Produced by D. Mandat and M. Malacari

FAST
Fluorescence detector Array of Single-pixel Telescopes

FAST試作機設置 (2016年10月)



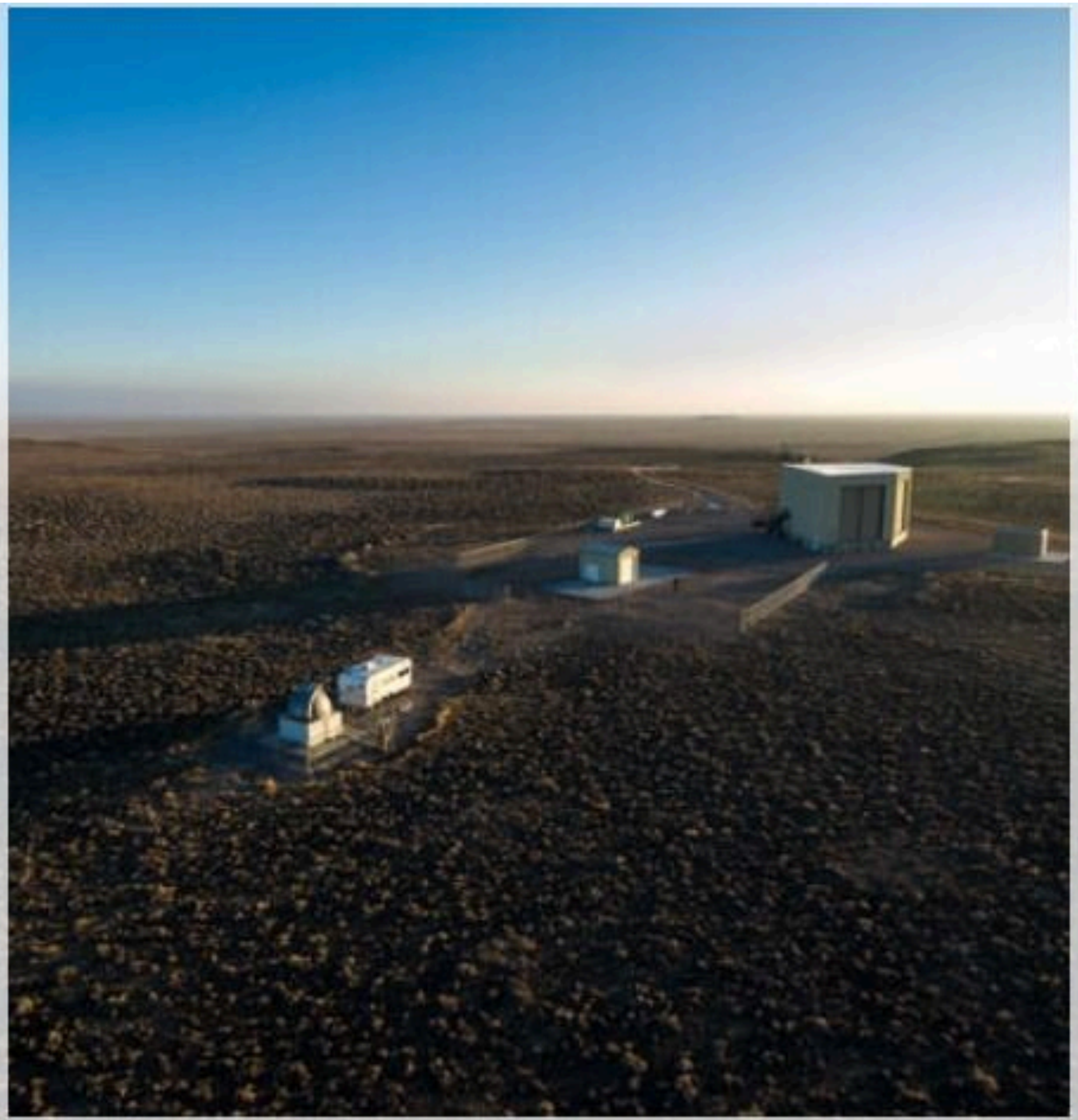
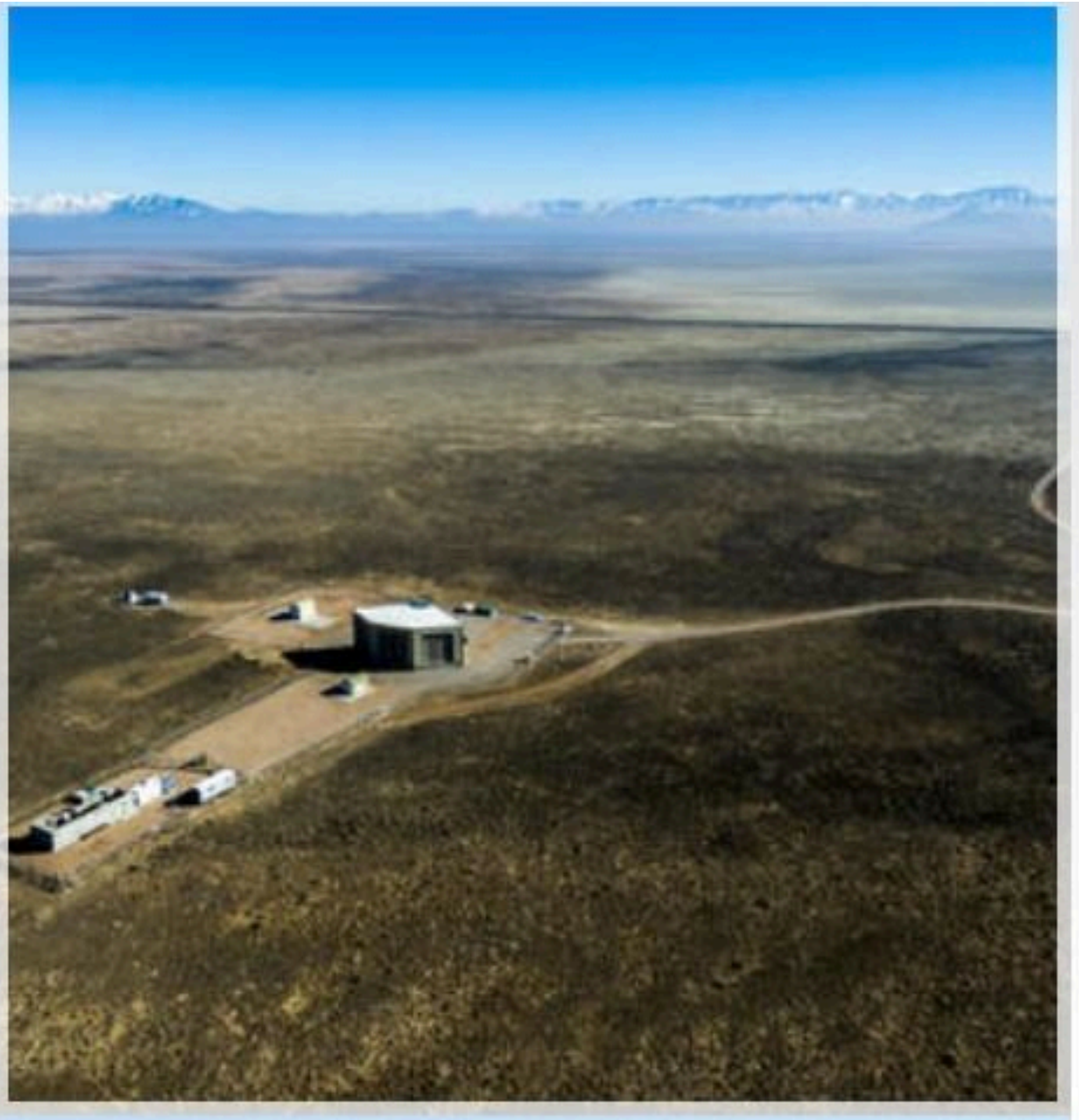




Fluorescence detector Array of Single-pixel Telescopes

Aerial photos

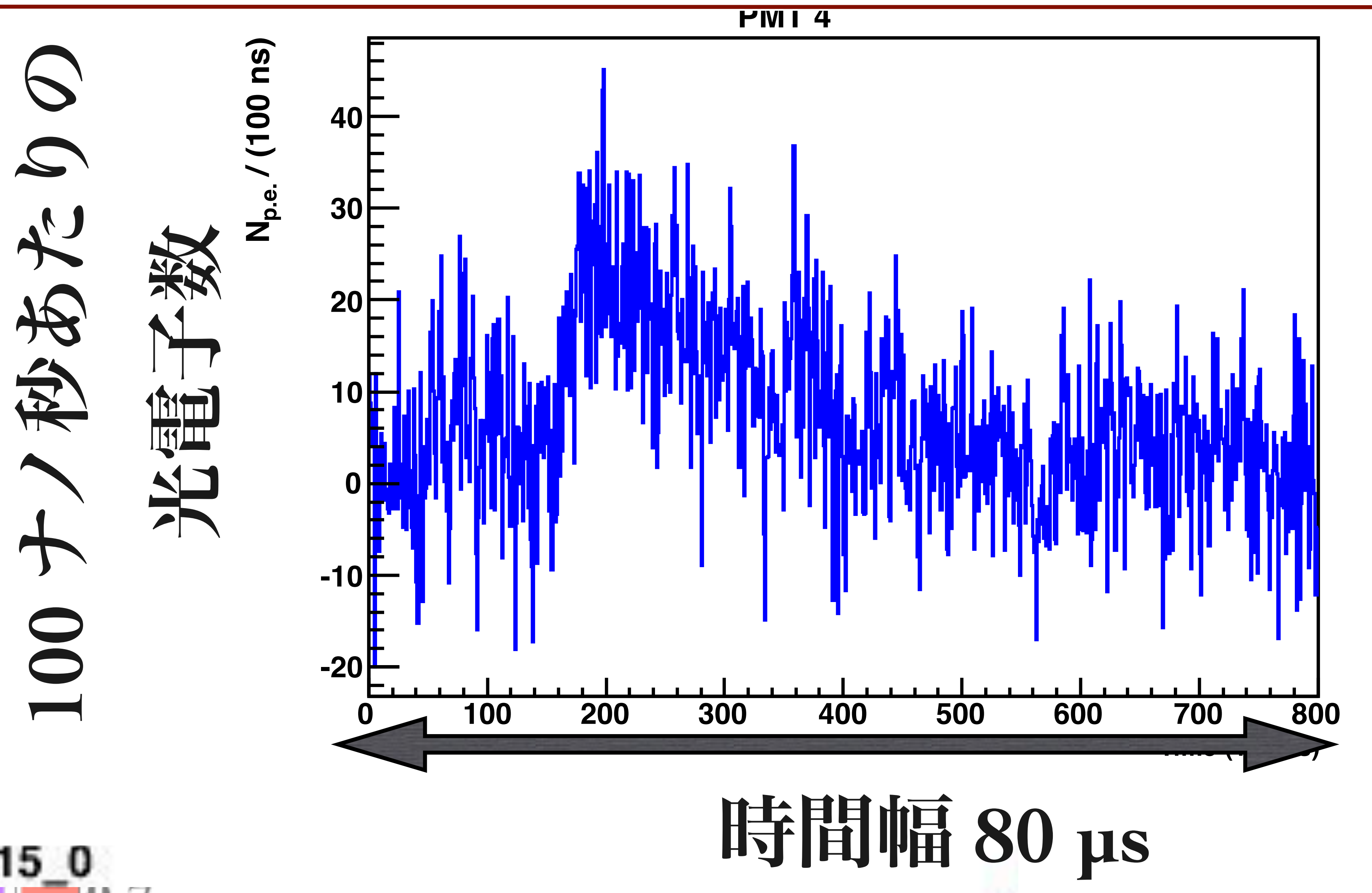


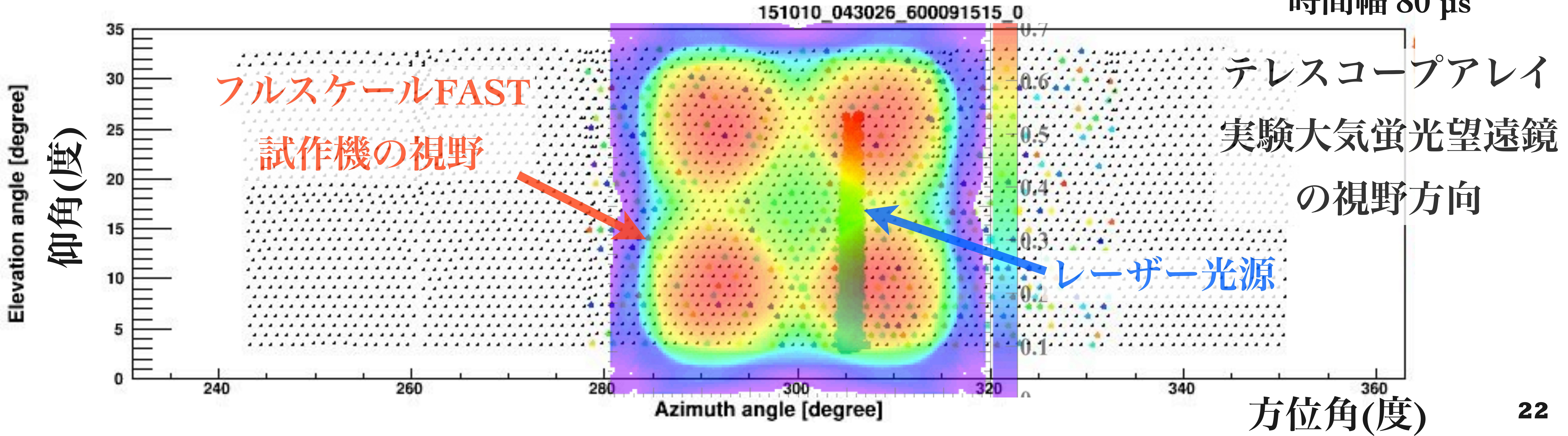





フルスケールFAST試作機のセットアップ

- テレスコープアレイ(TA)実験の大気蛍光望遠鏡から受け取った外部トリガーによるデータ収集を実施
    - 10 MHz，80 μsのトリガー幅
- TA実験の大気蛍光望遠鏡と同じ視野を持つように設置。21 km先の垂直紫外線レーザーが視野内に入る





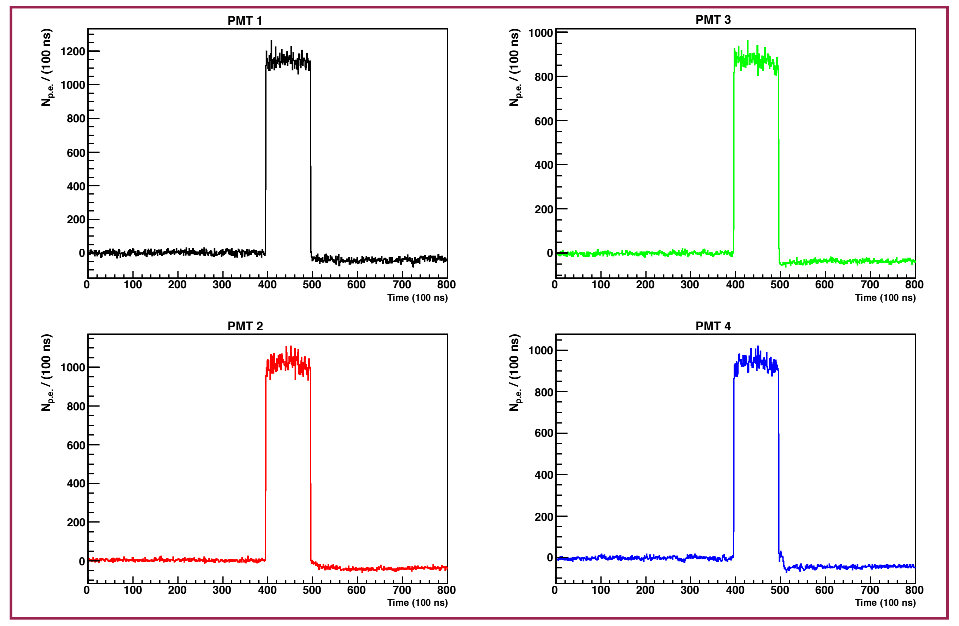
測定データの例: 2016年10月5日

✦全トリガー数: 62194 events

較正用光源

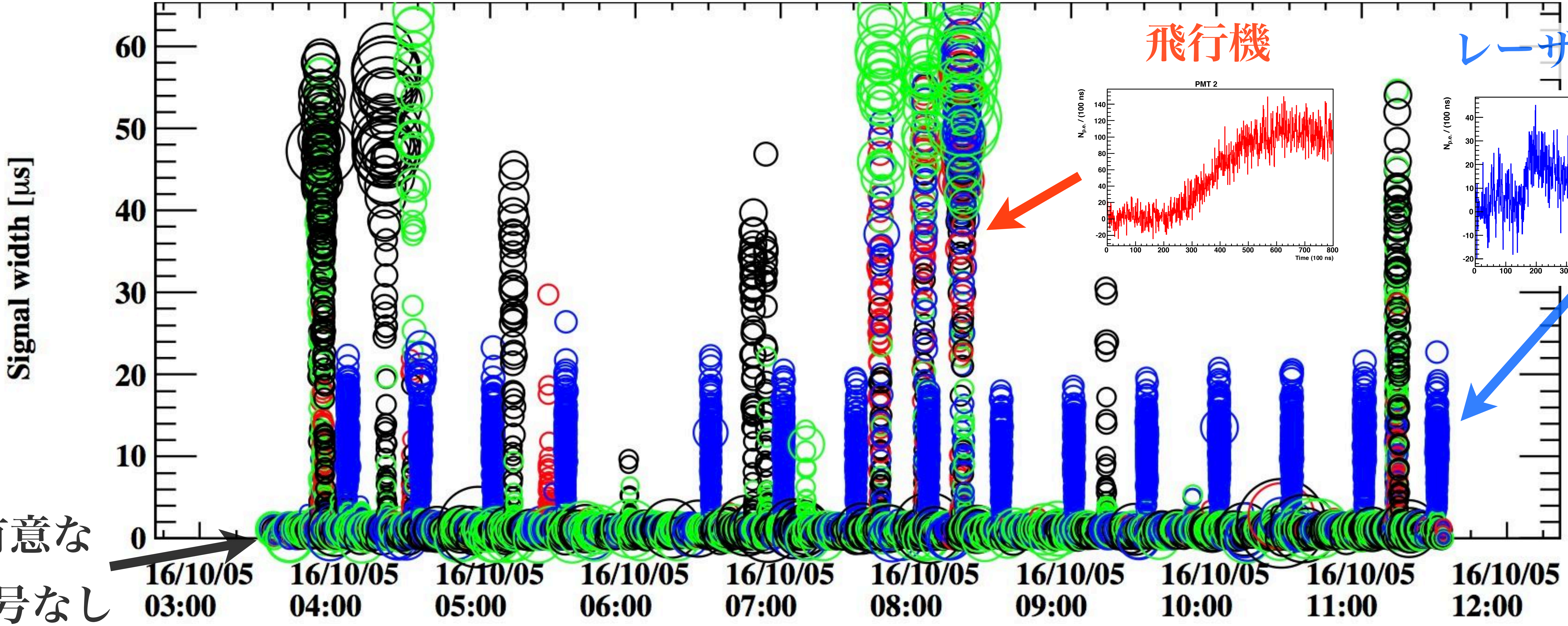
PMT 1 PMT 3

PMT 2 PMT 4



円の大きさ: 信号の有意度

信号の時間幅 [マイクロ秒]



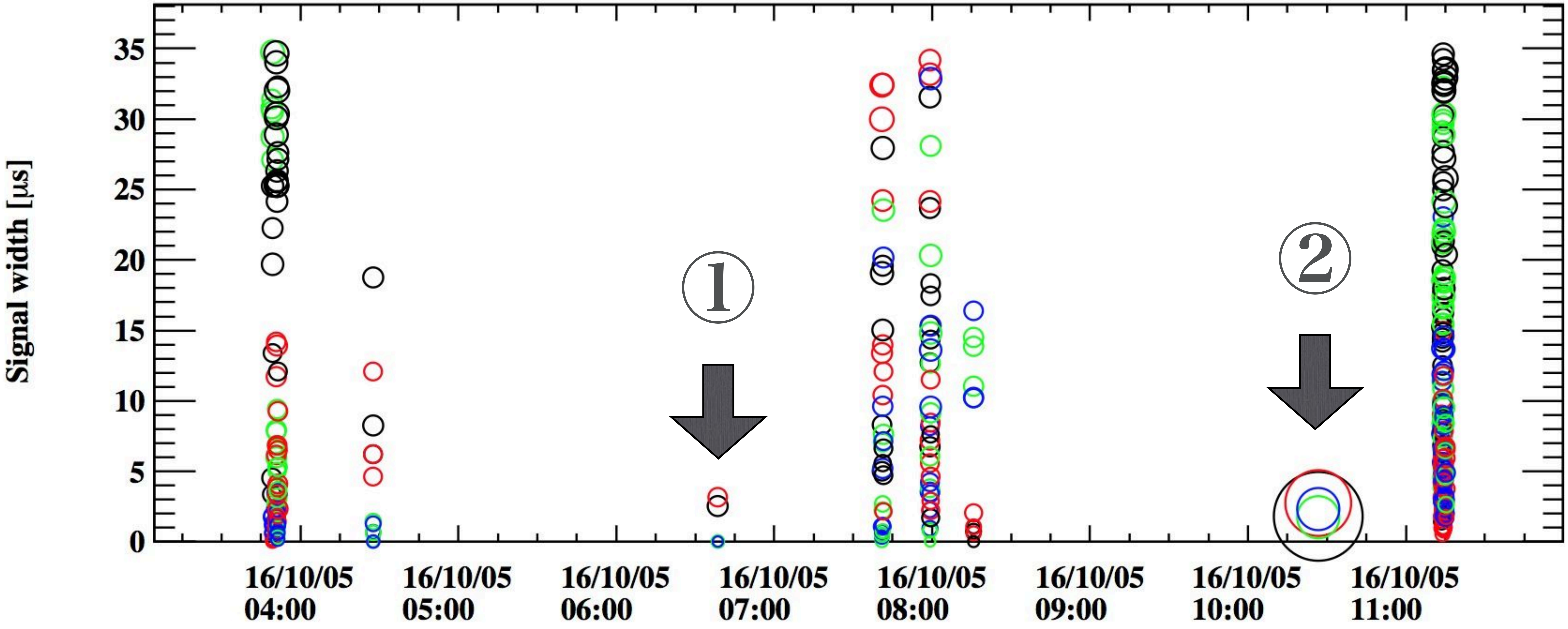
飛行機

レーザー光源

有意な信号なし

イベント選別: 2016年10月5日

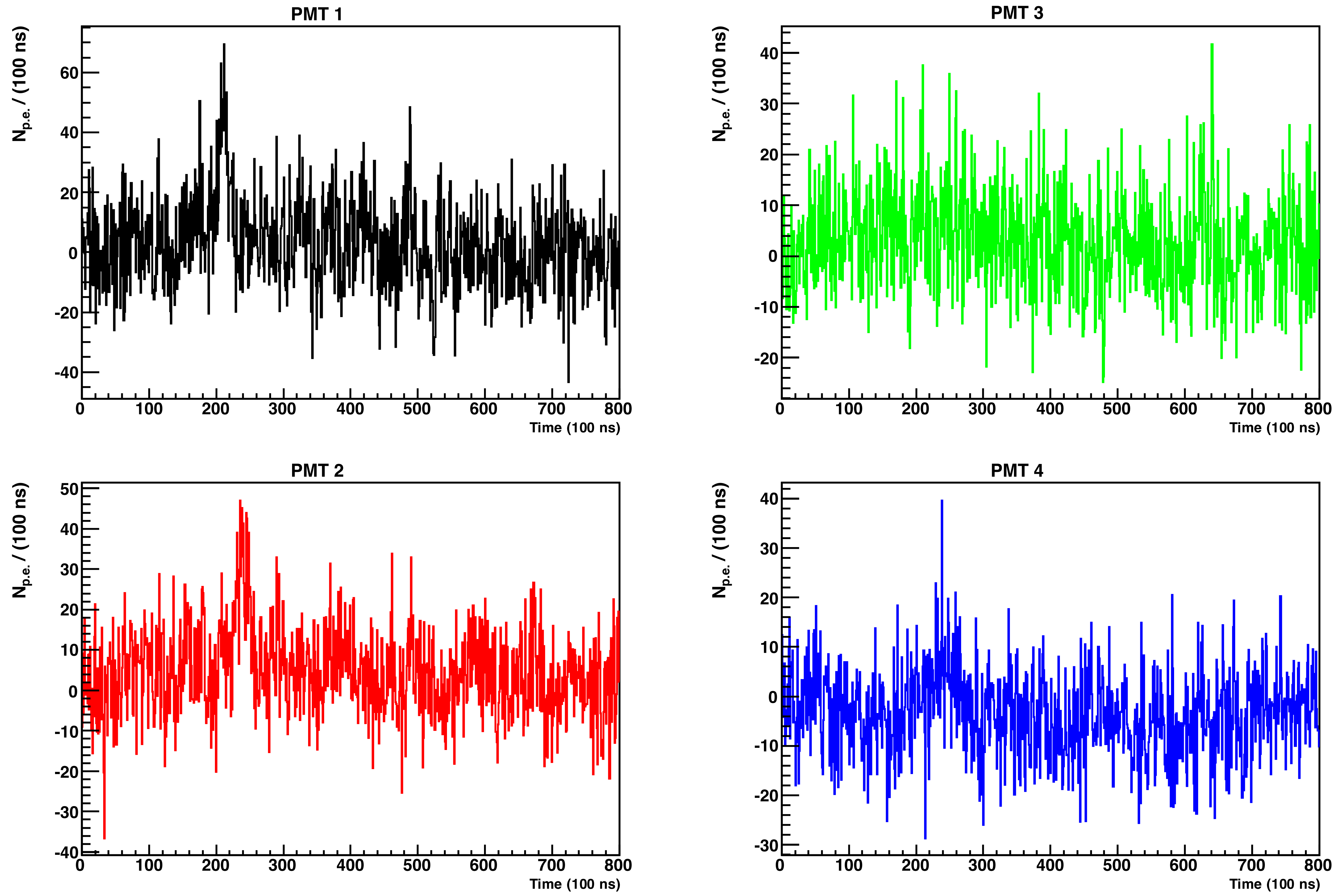
- カットなし->PMT信号あり->飛行機除去(>35 μs)->レーザー事象除去->2つ以上のPMT信号あり
    - **62194 -> 4290 -> 3950 -> 389 -> 90 events**

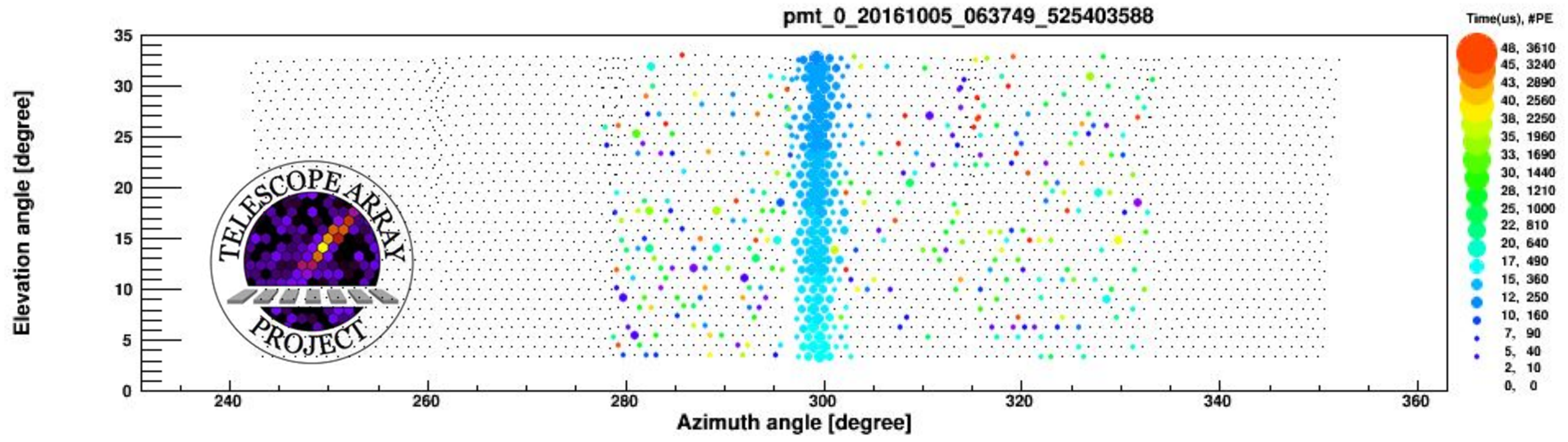


FAST
Fluorescence detector Array of Single-pixel Telescopes

極高エネルギー宇宙線事象

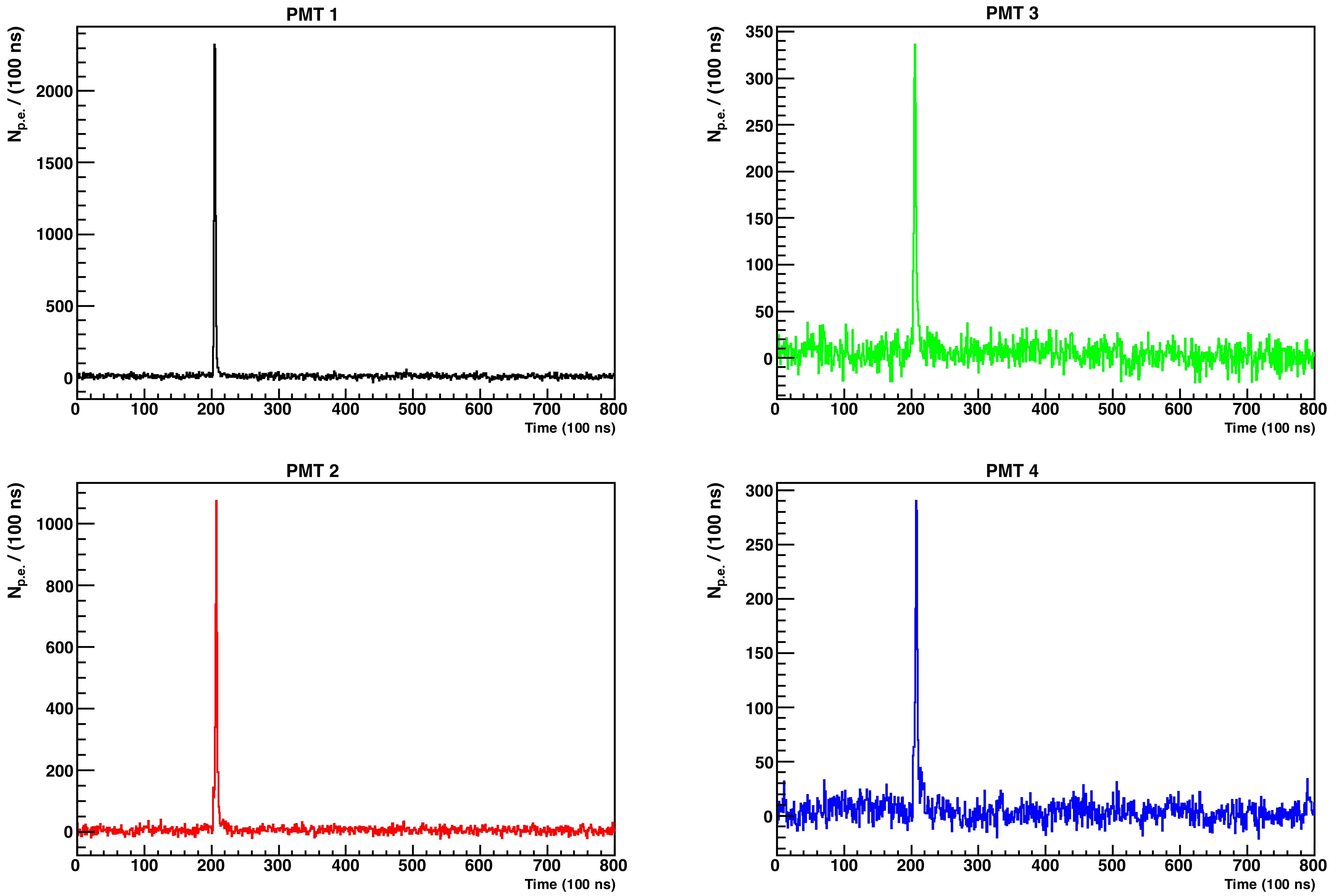
① 2016/10/05 06:37:49.525424540

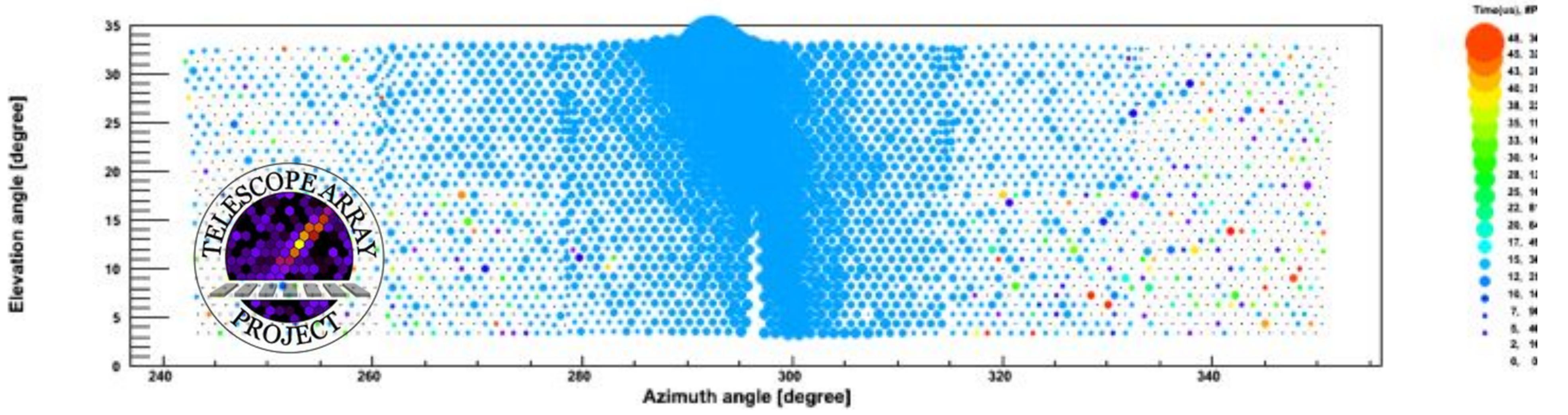




TAFD
log$E$ = 18.08
R_p = 2.40 km

② 2016/10/05 10:25:50.781802380

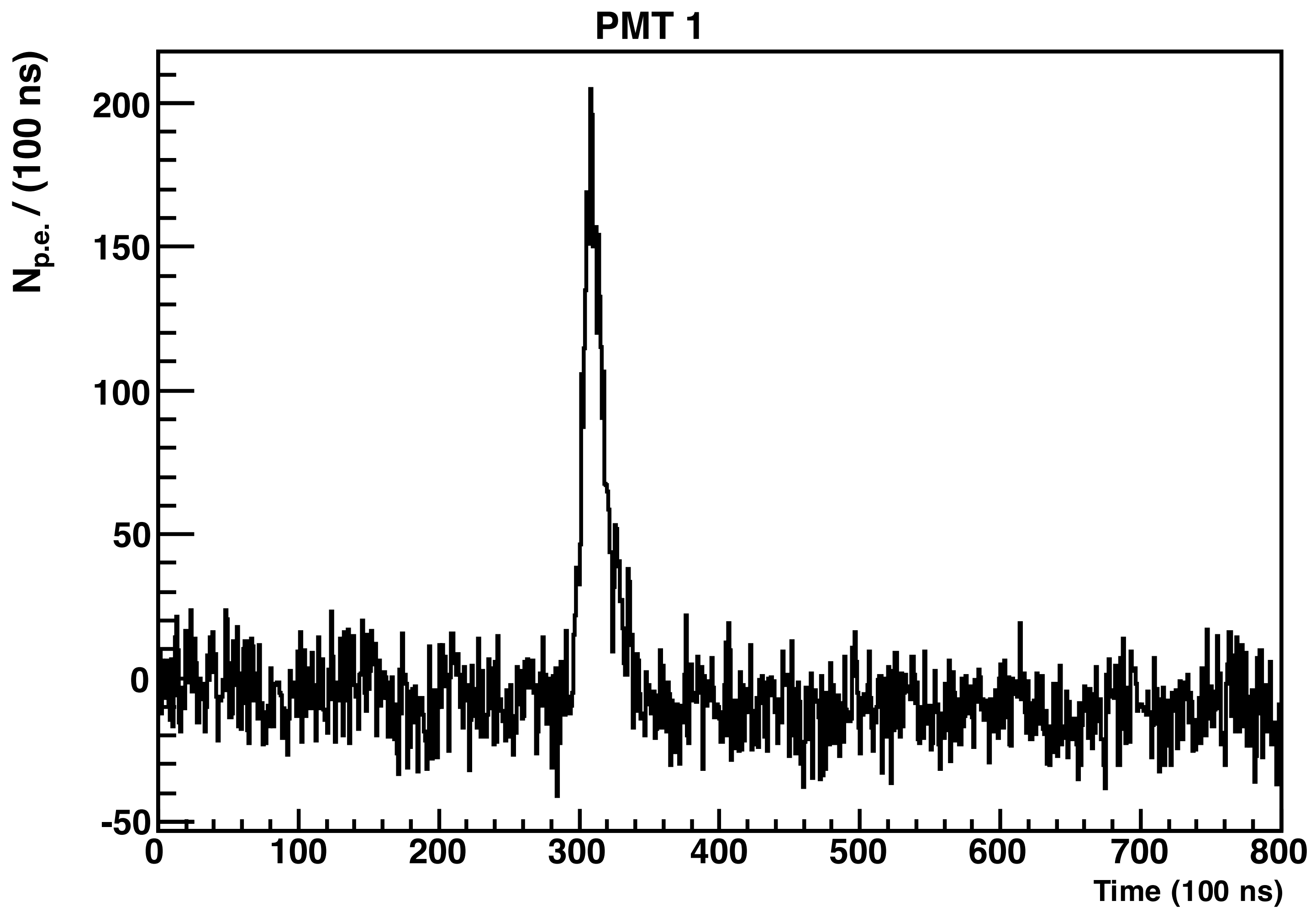


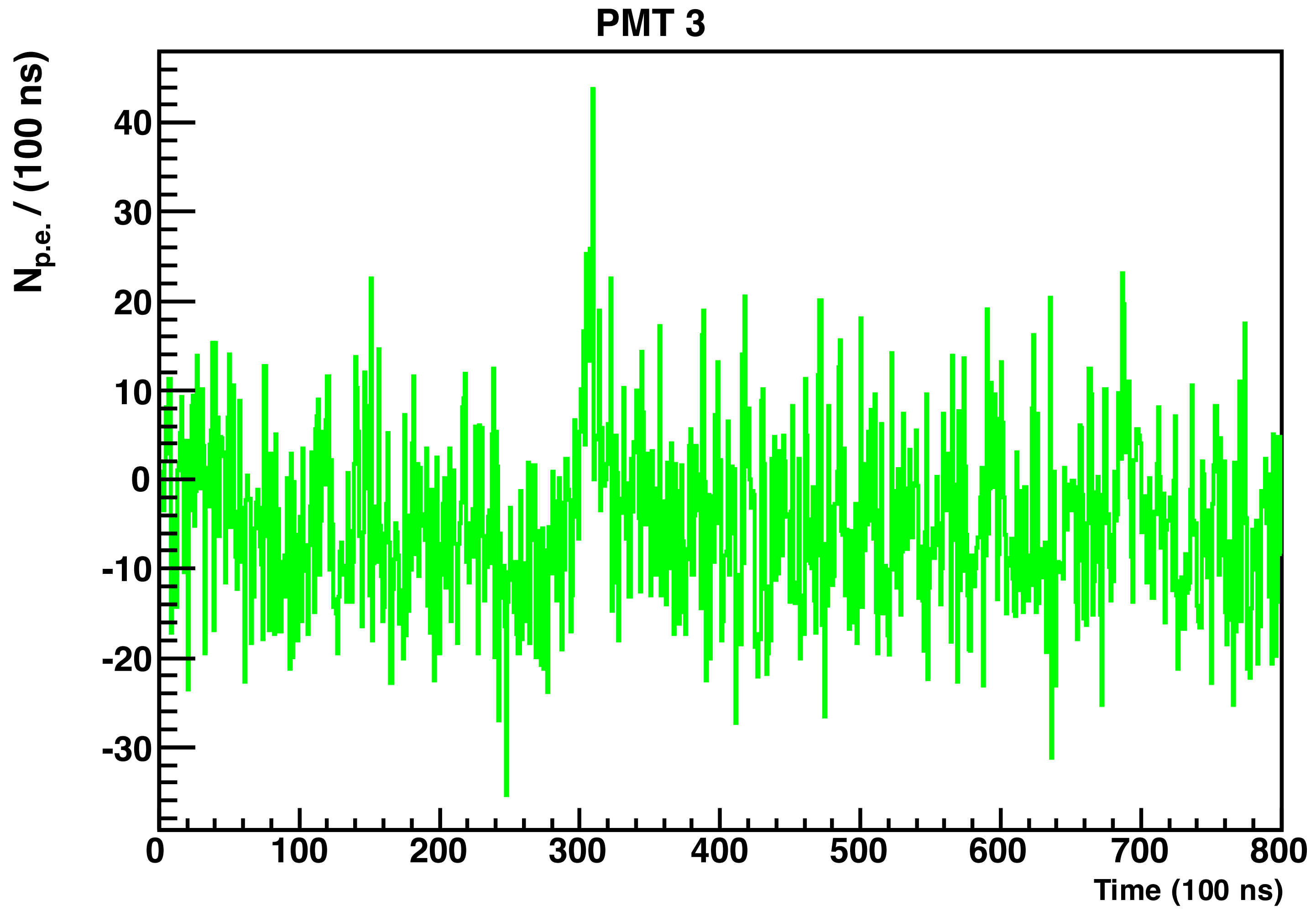


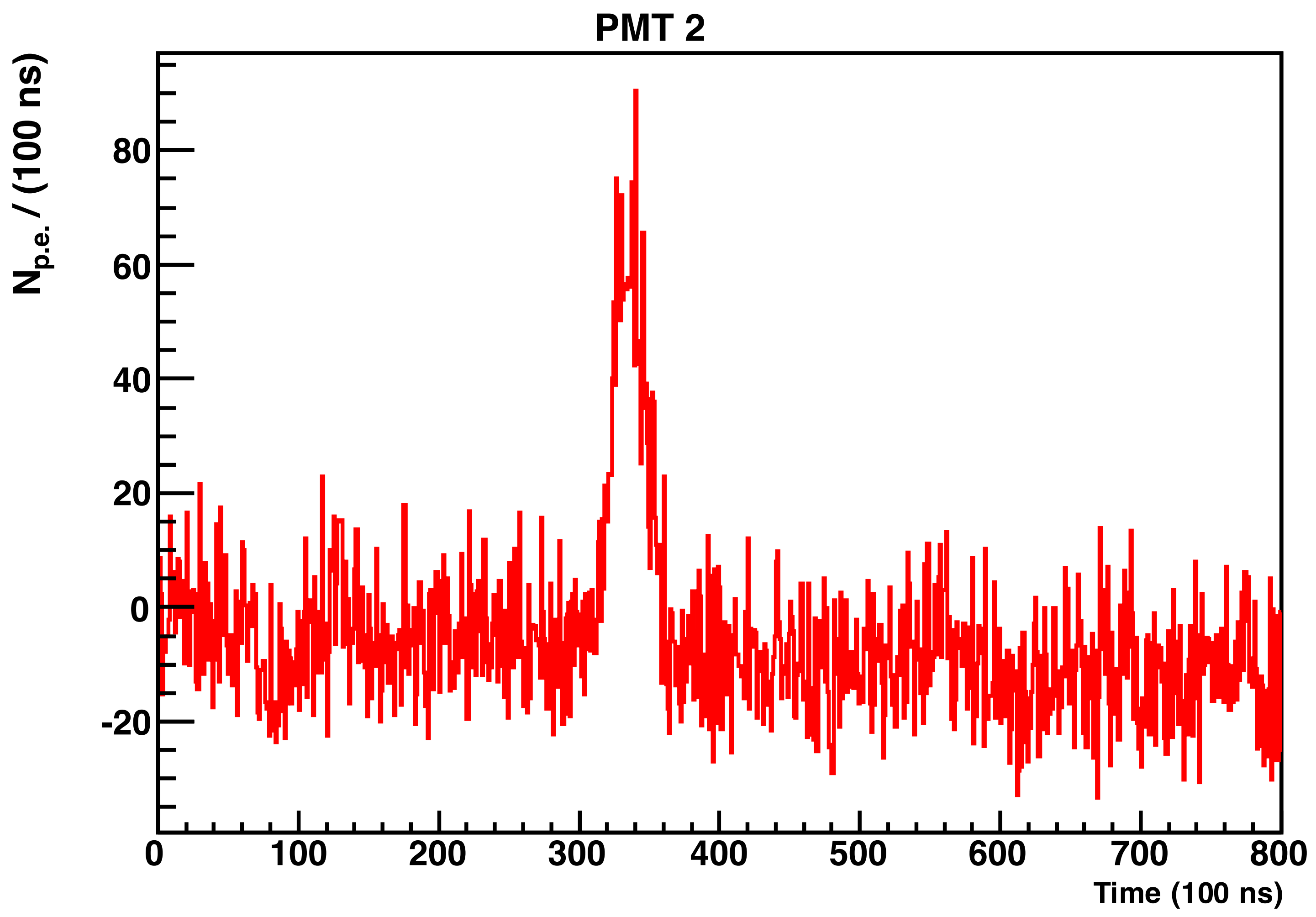
Too close

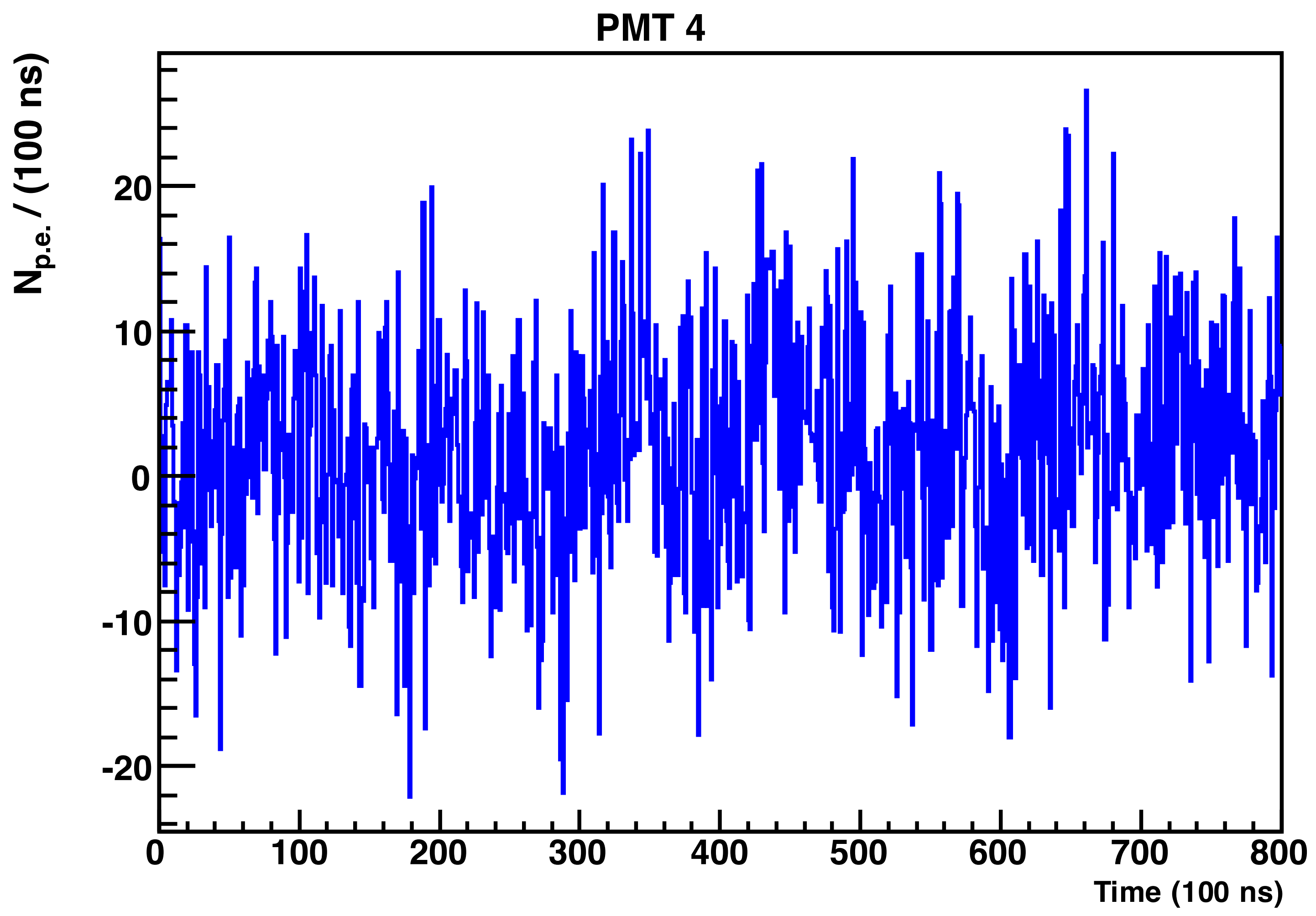
UHECR, $\log E = 18.55$

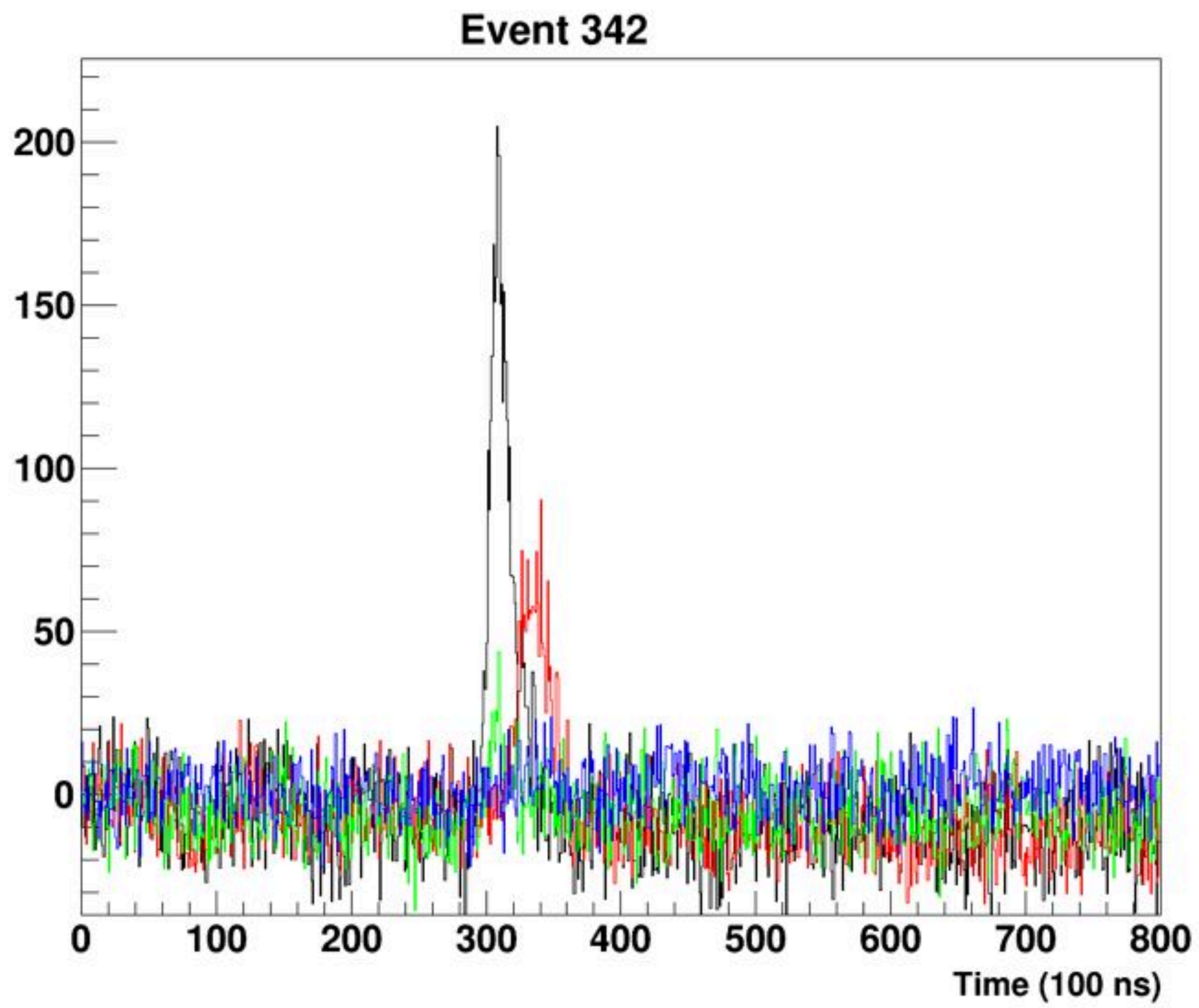
2016/10/07 05:44:07.307421810

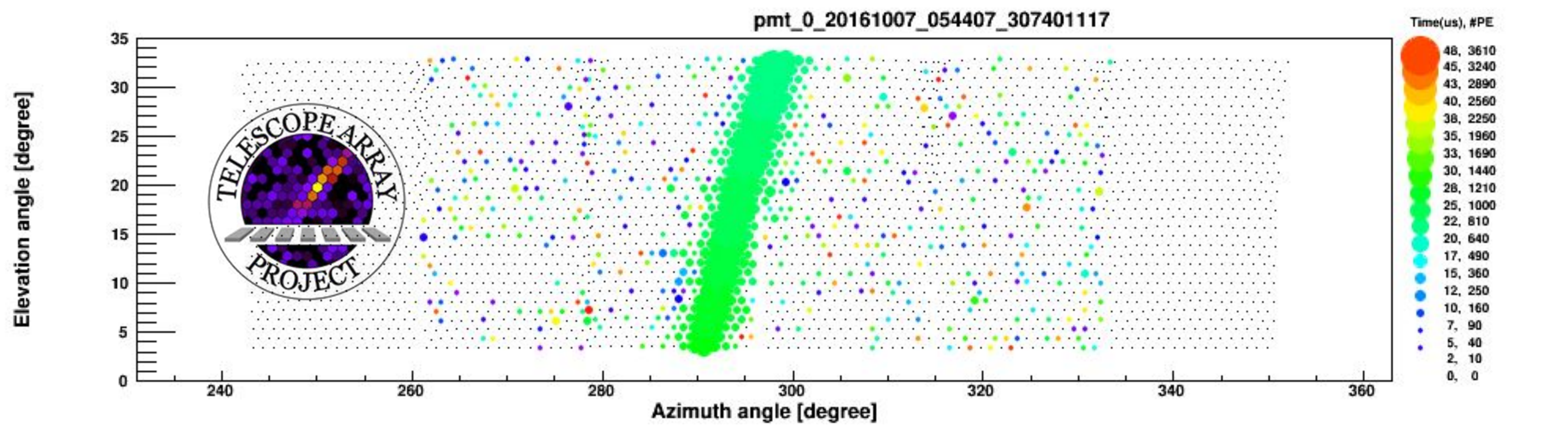








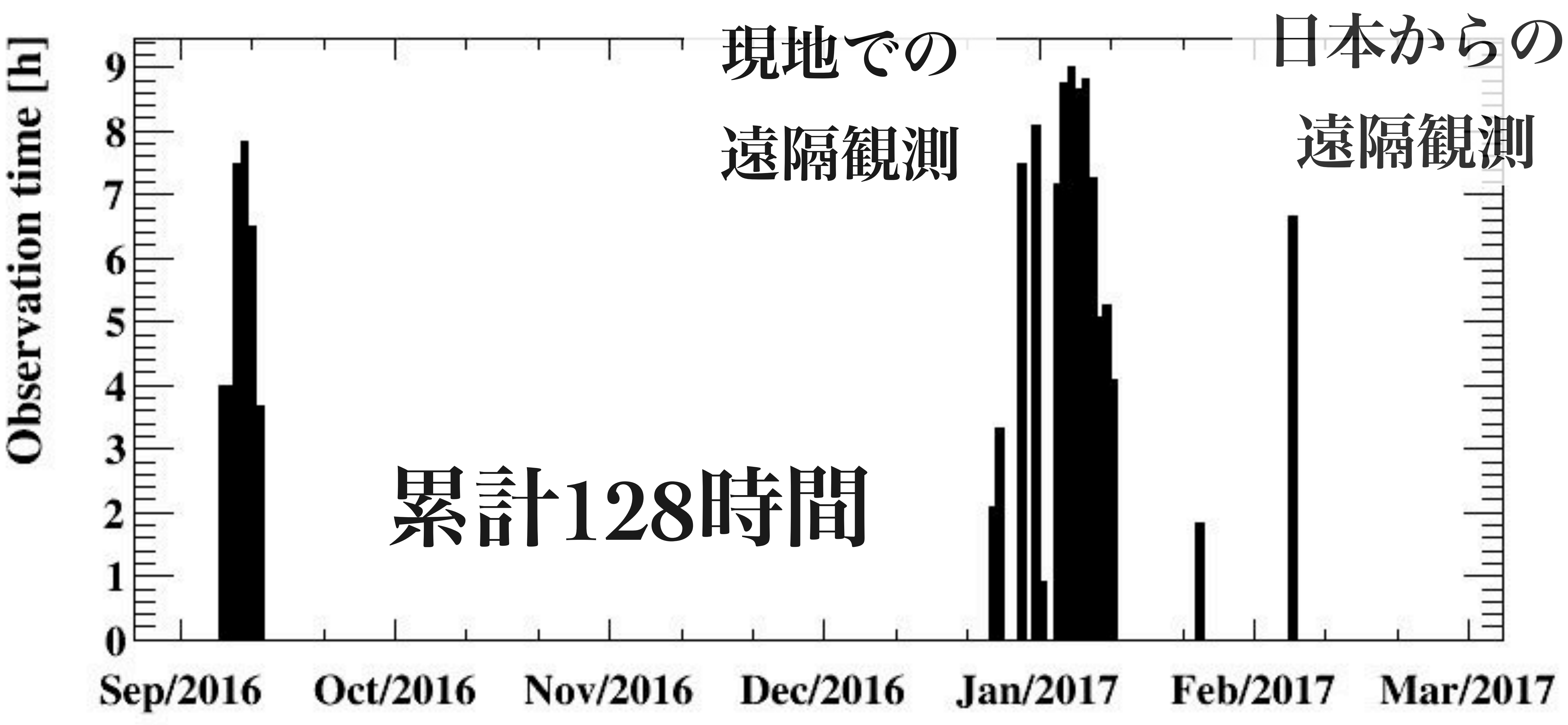


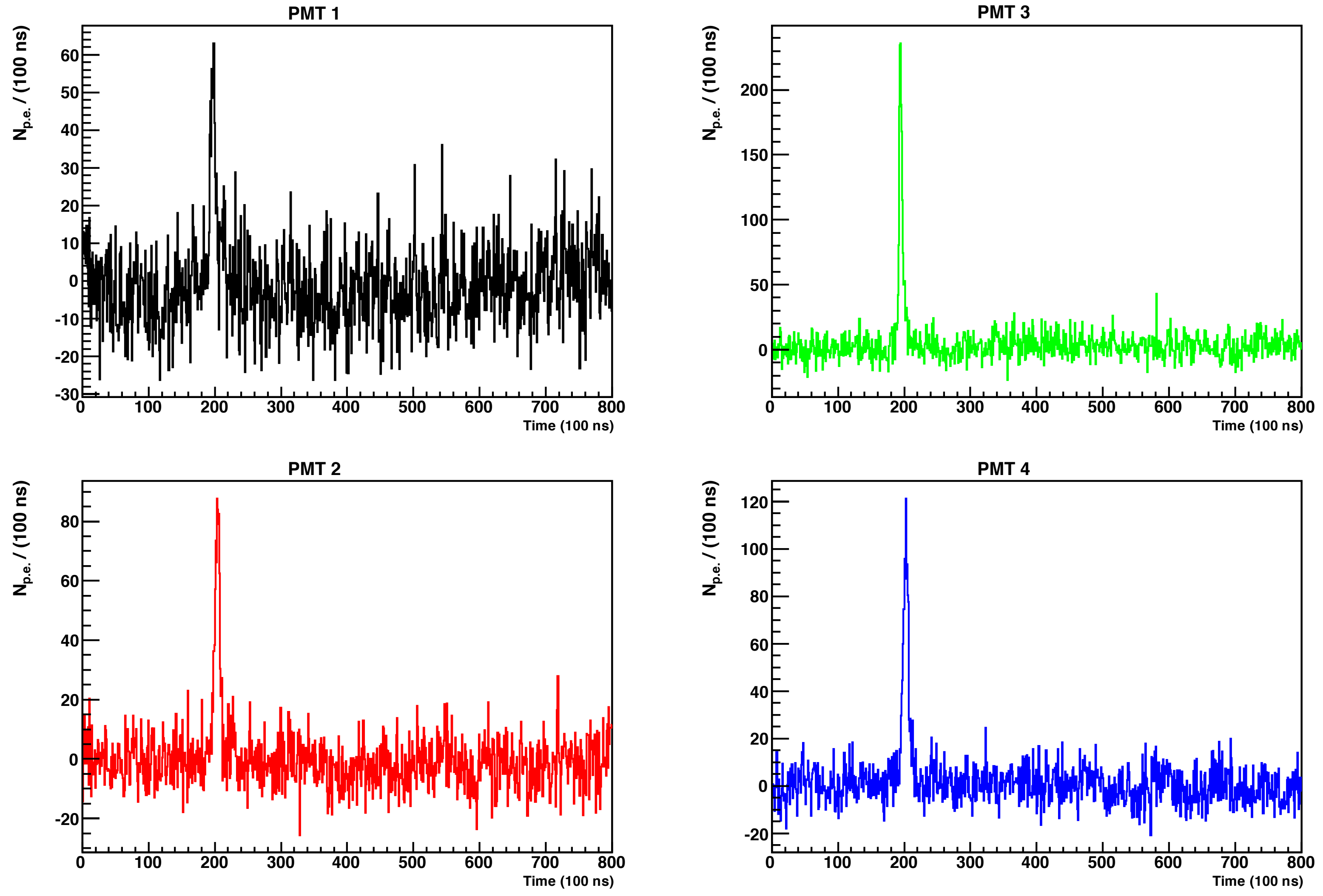


Event 531: $\log_{10}(E(\mathrm{eV}))$: 18.55, Zen: 22.3°, Azi: 71.3°, Core(14.02, -11.00), Rp: 3.03, Psi: 72.8°, Xmax: 675 g/cm^2 FoV(763 - 943), Date: 20161007, Time: 05:44:07.307401117

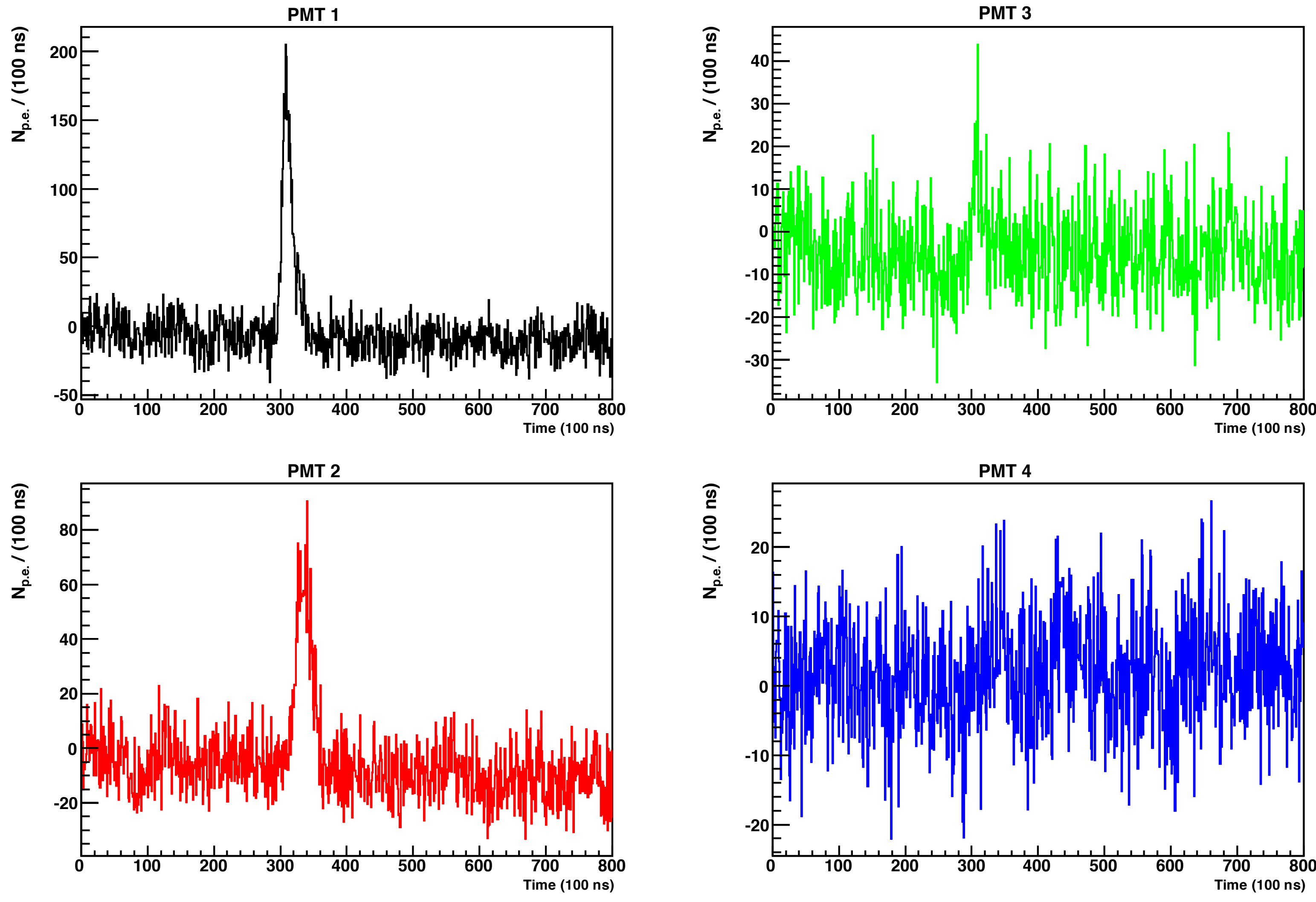
FAST
Fluorescence detector Array of Single-pixel Telescopes

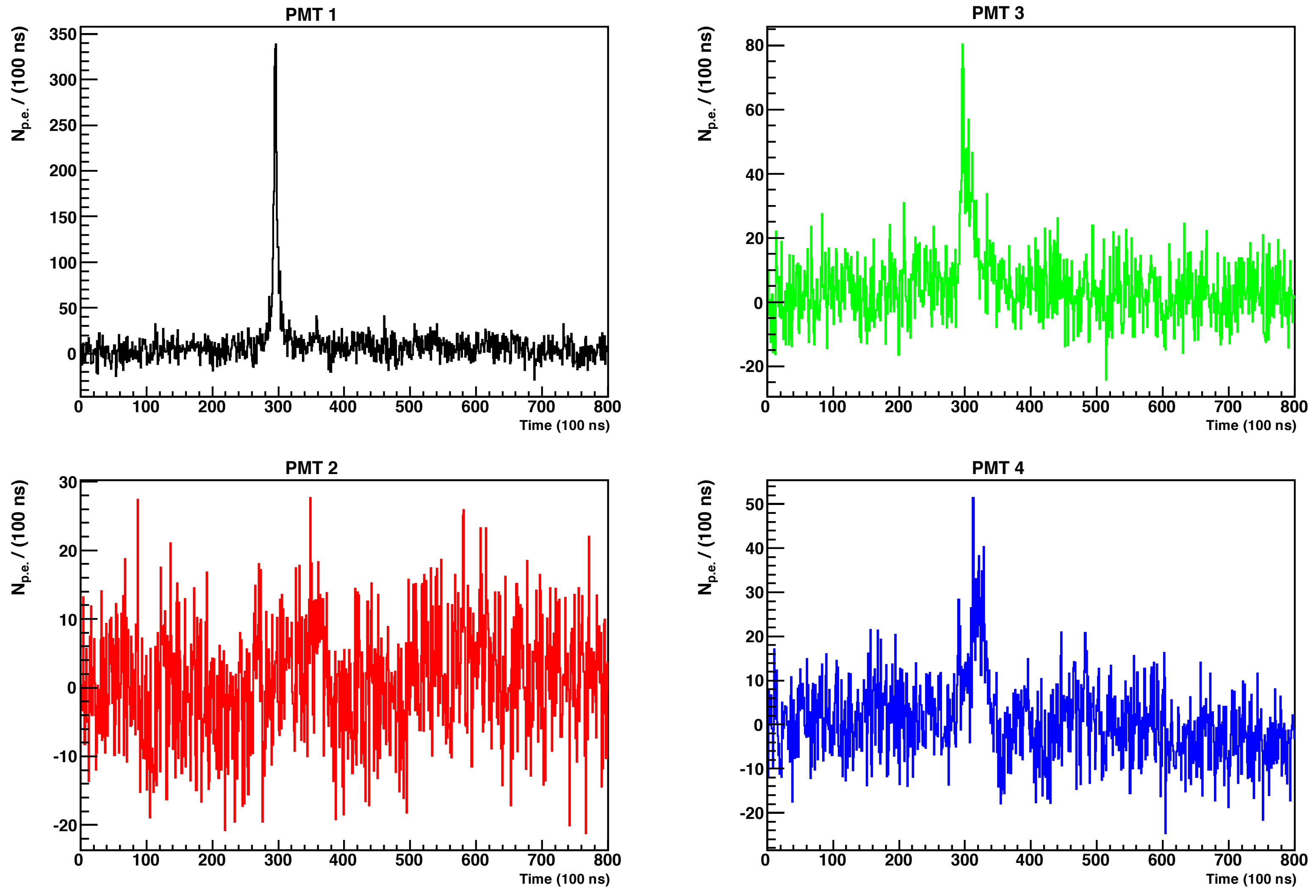
遠隔操作による観測

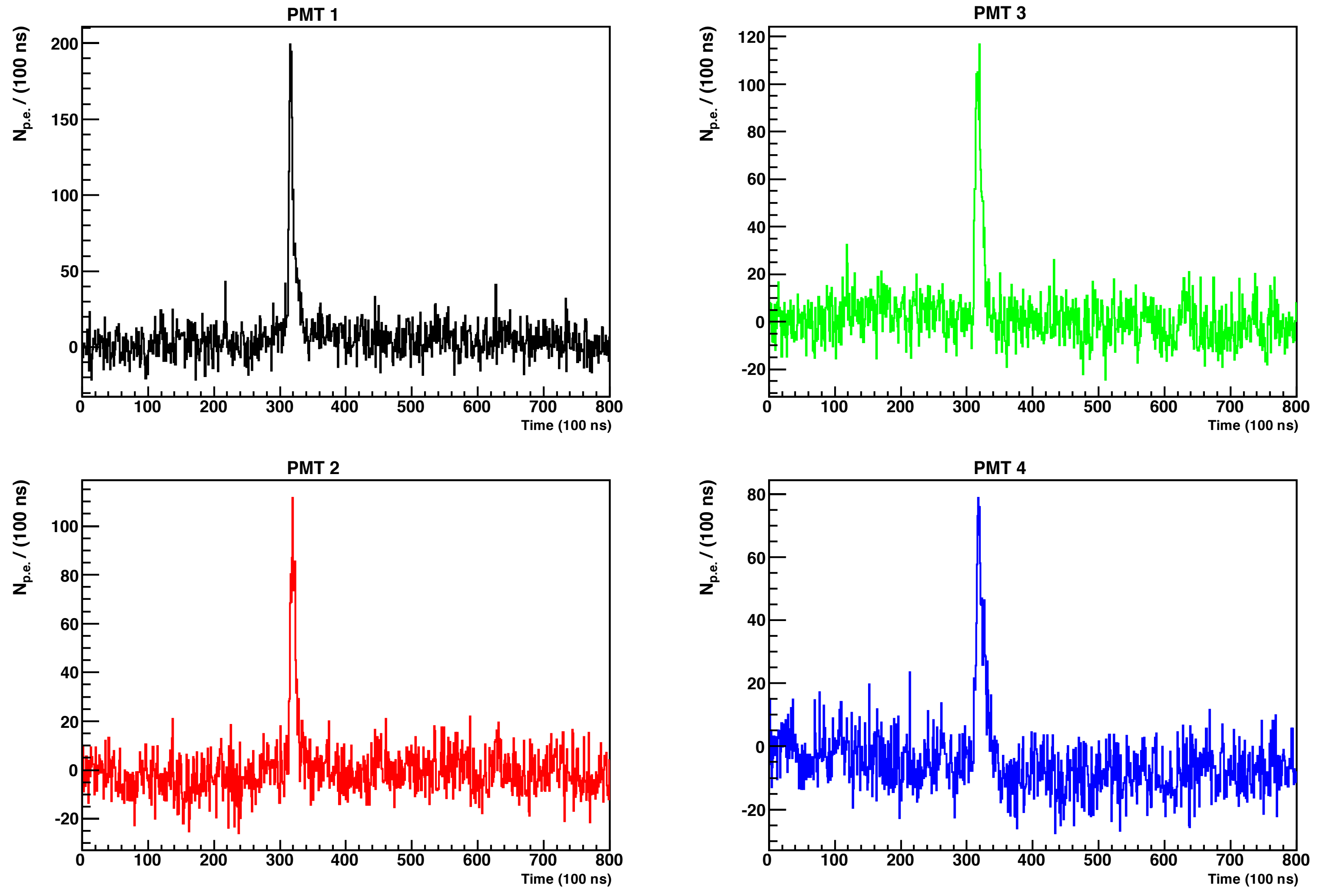




合計18個の宇宙線候補事象

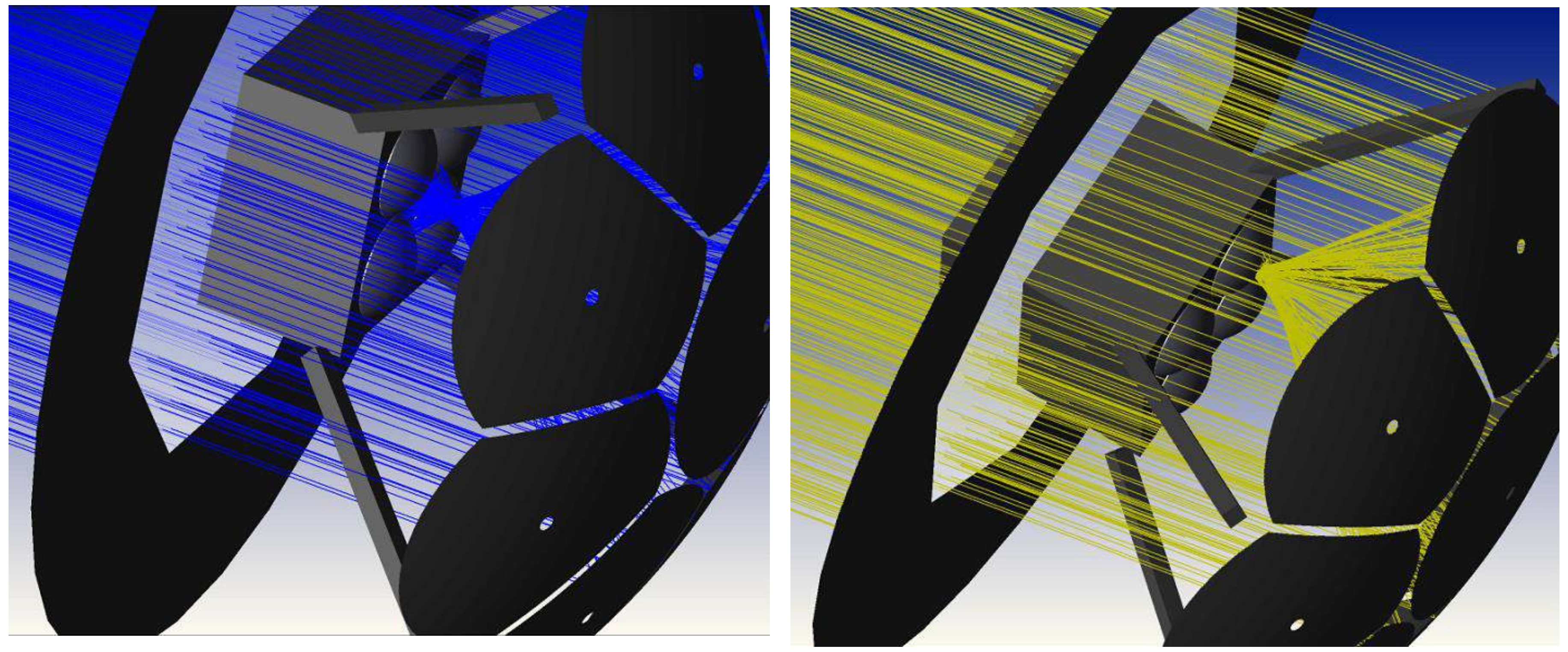


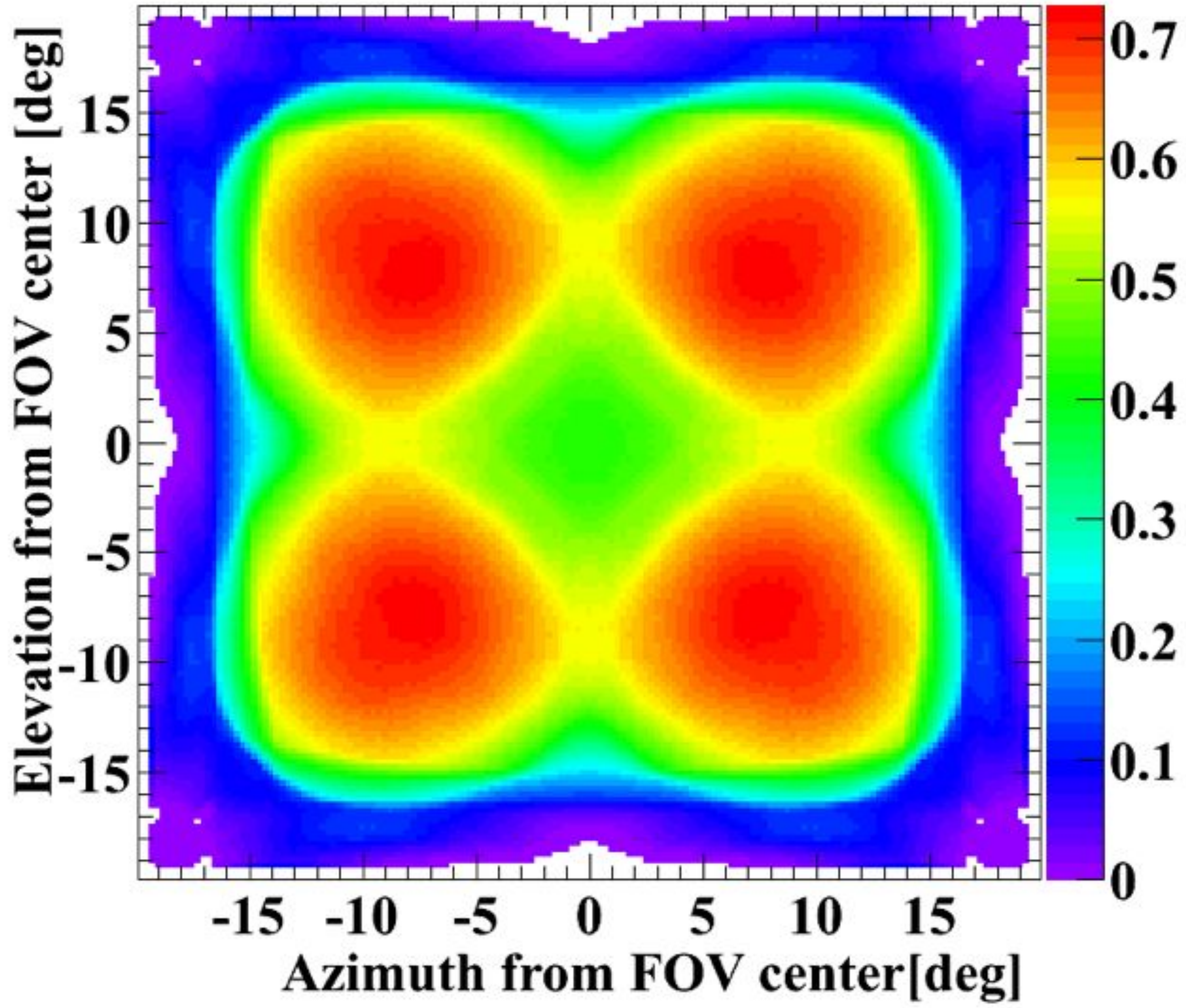


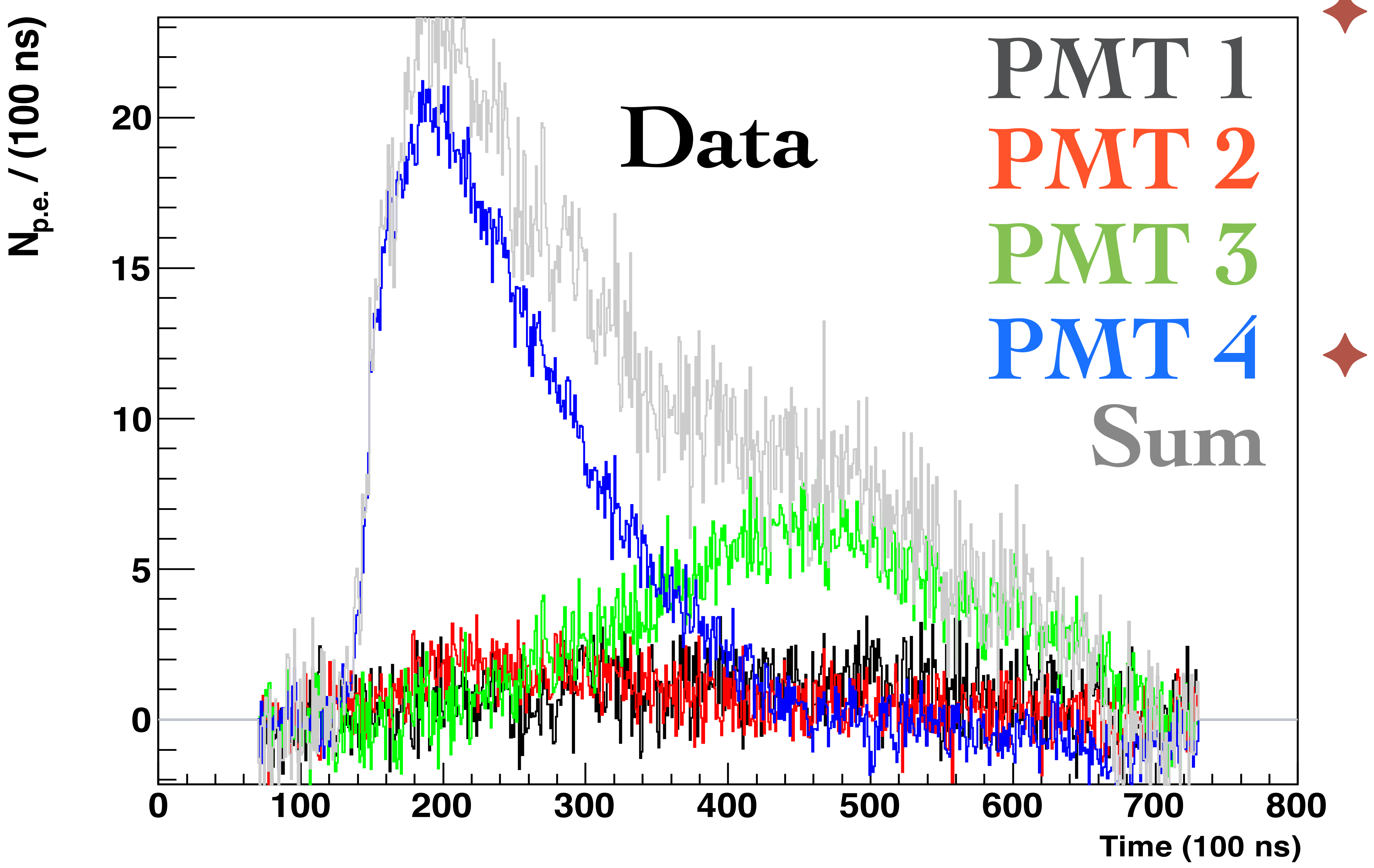


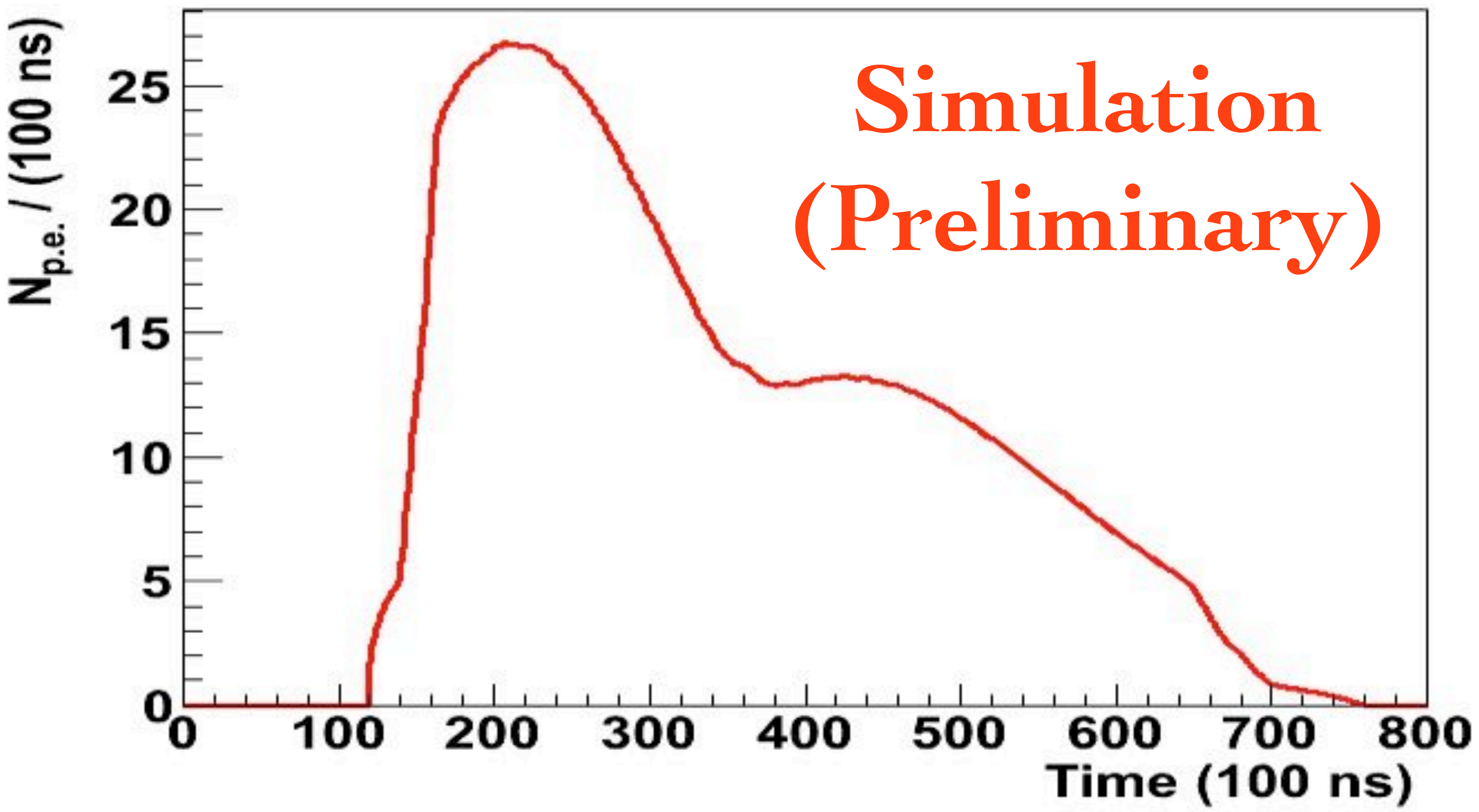
シミュレーションと観測データの比較

方向ごとの感度(レイトレース)







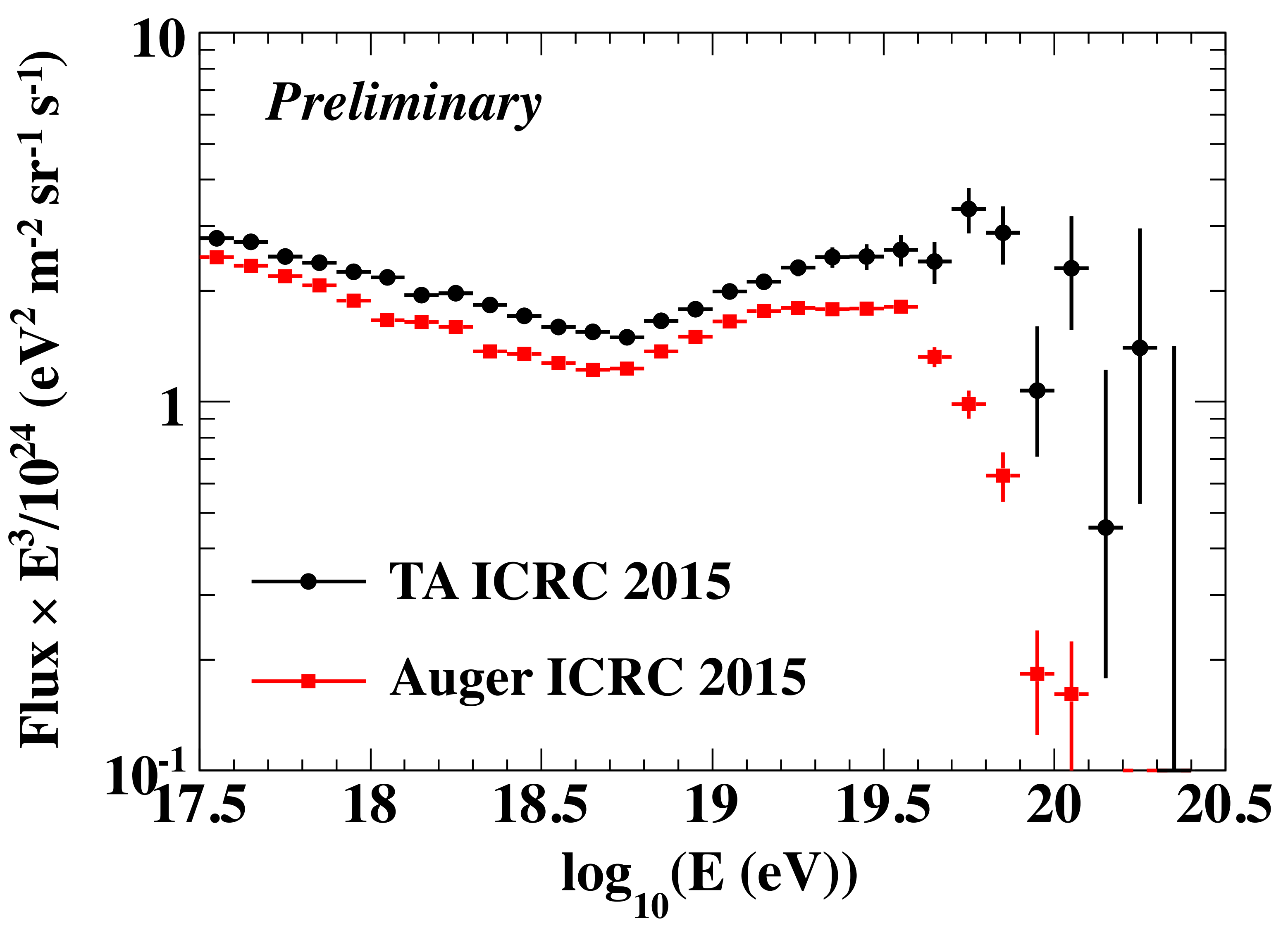


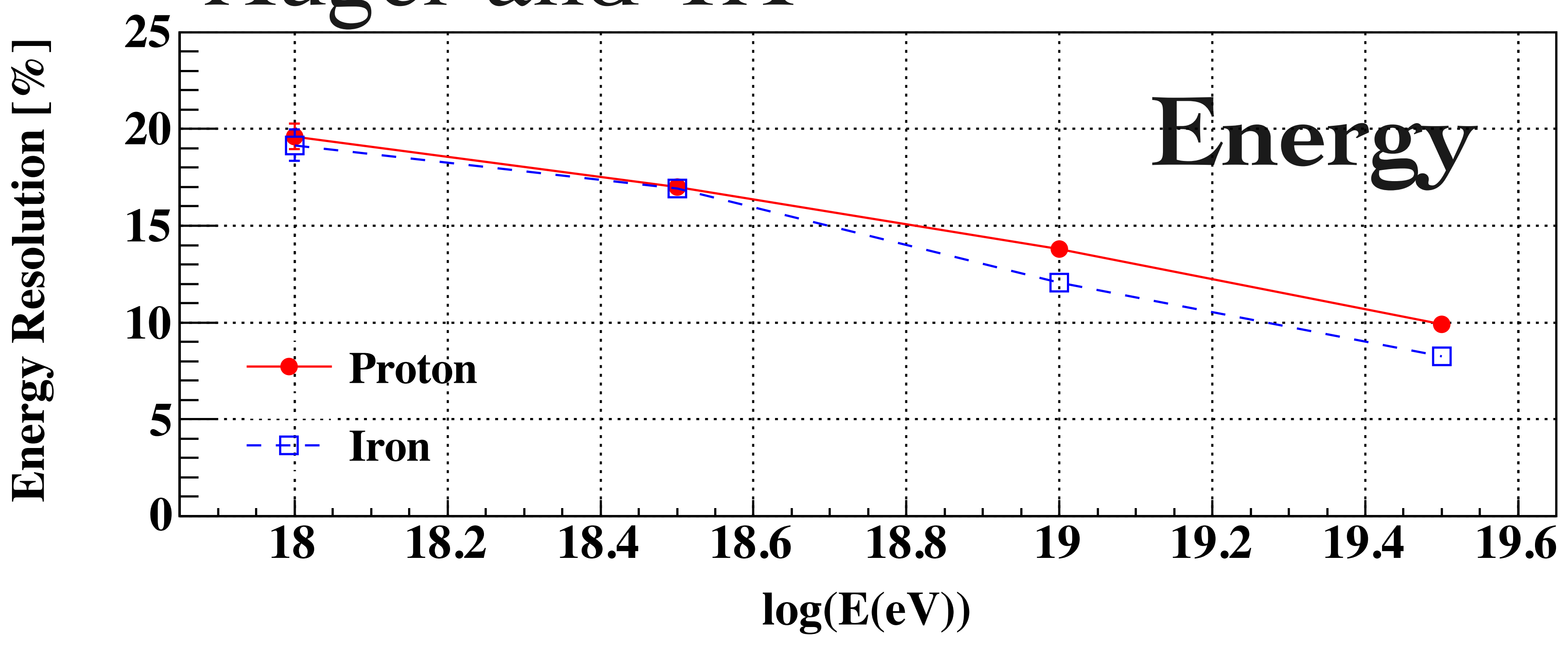
- 21 km先の紫外線垂直レーザー事象の284個の重ね合わせ波形
- シミュレーションで期待される信号と比較
  - 望遠鏡の感度(レイトレース)
  - 鏡の反射率、フィルターの透過率
  - PMTの検出効率
  - PMT表面での非一様性(未実装)
  - ゲインの温度補正(未実装)

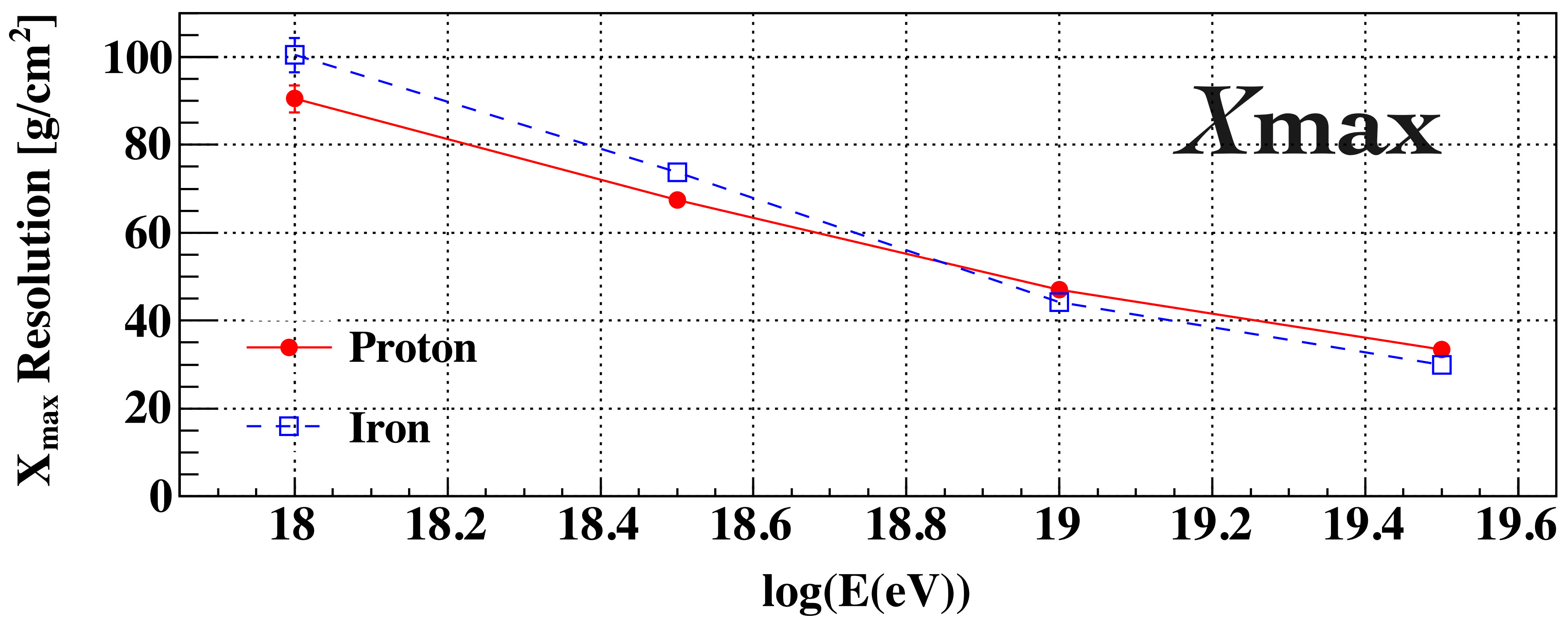
Possible Application of the FAST Prototype

FAST — *Fluorescence detector Array of Single-pixel Telescopes*

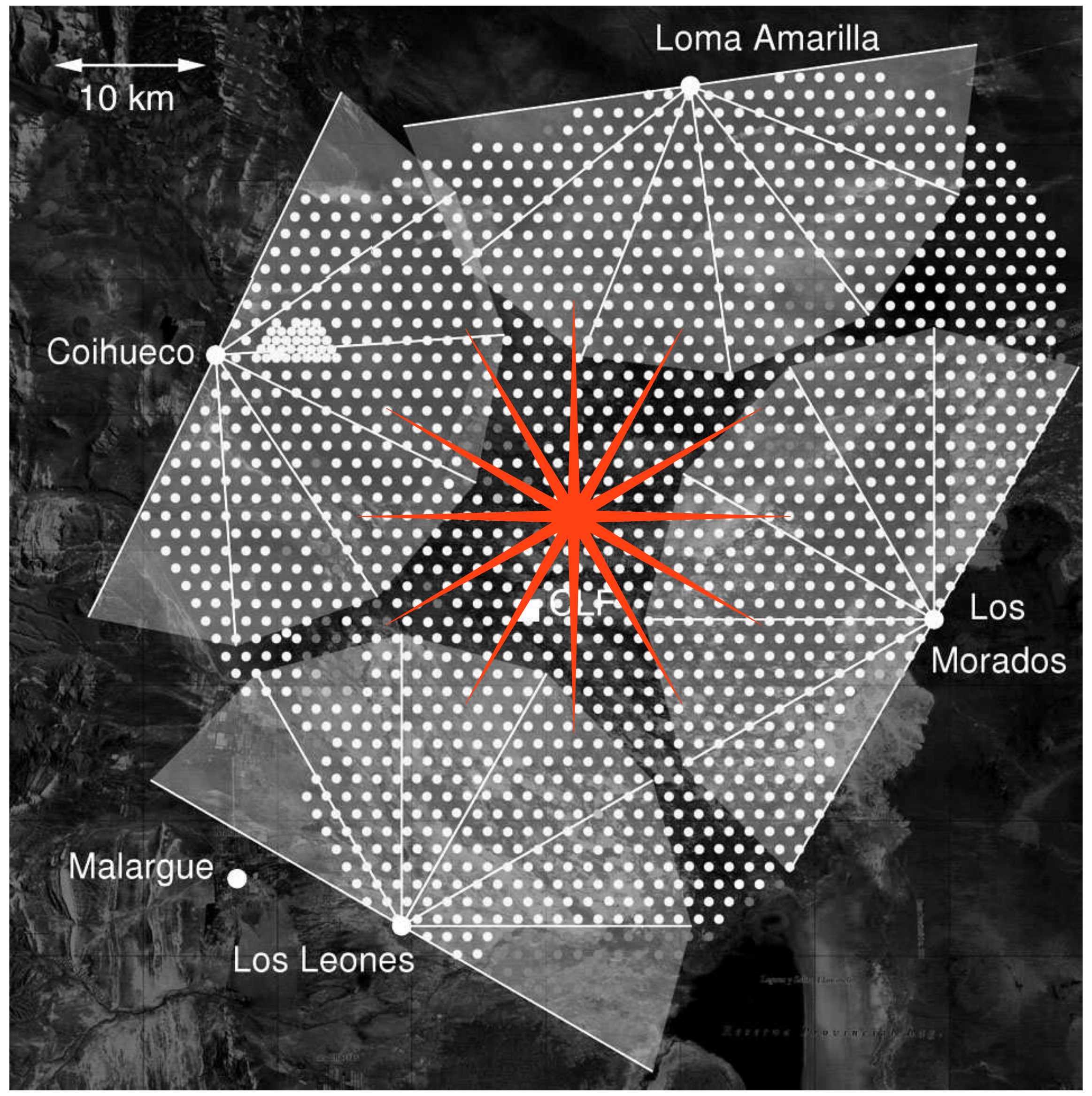
- Install FAST at Auger and TA for a cross calibration.
- Profile reconstruction with geometry given by SD (smearing gaussian width of 1° in direction, 100 m in core location).
  - Energy: 10%, Xmax : 35 g/cm^2 at $10^{19.5}$ eV
  - Independent cross-check of **Energy and Xmax** scale between Auger and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





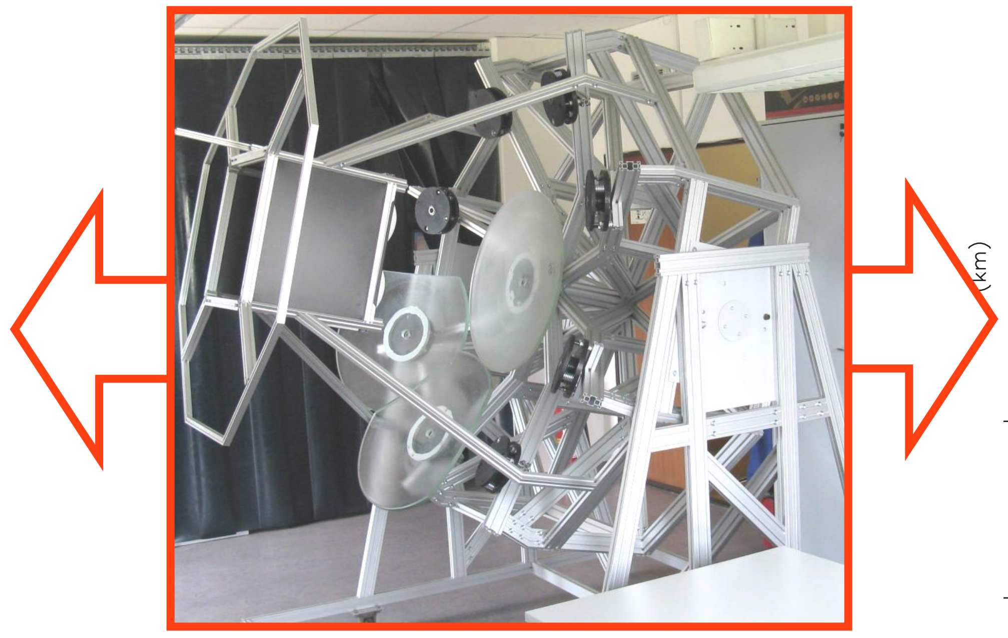


Pierre Auger Observatory

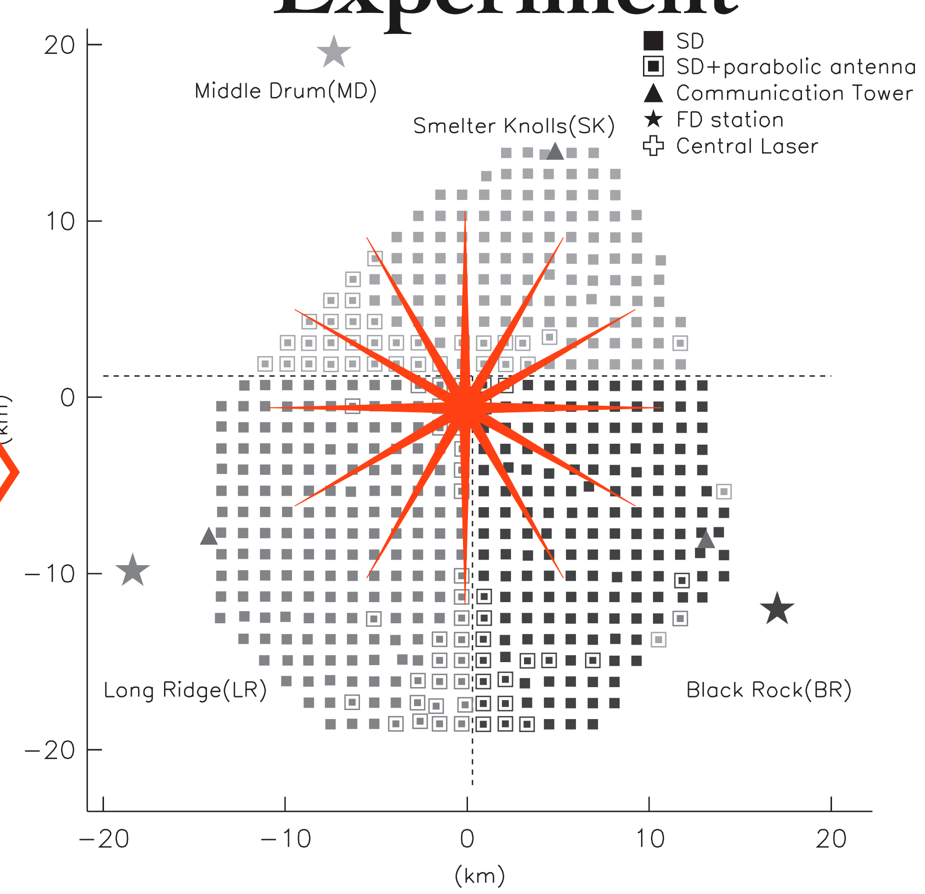


Pierre Auger Collaboration, NIM-A (2010)

Identical simplified FD



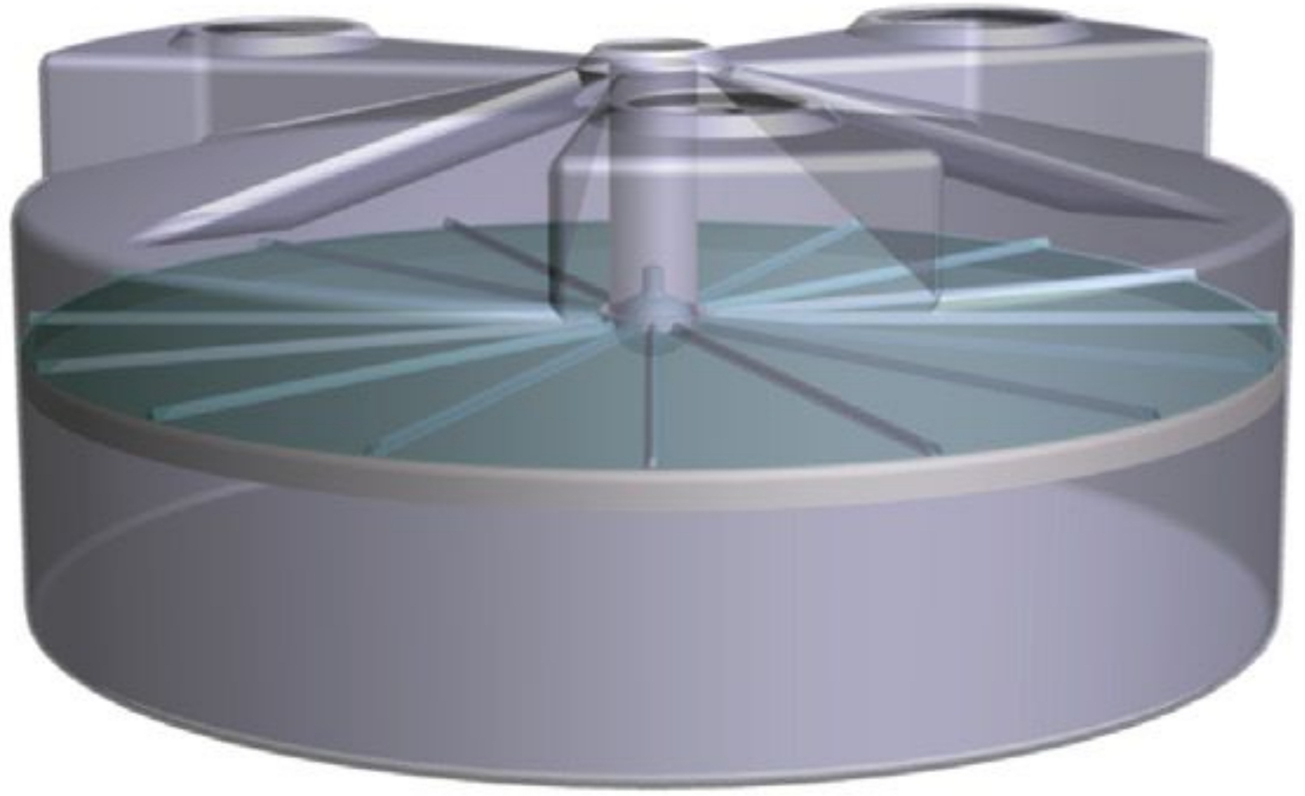
Telescope Array Experiment

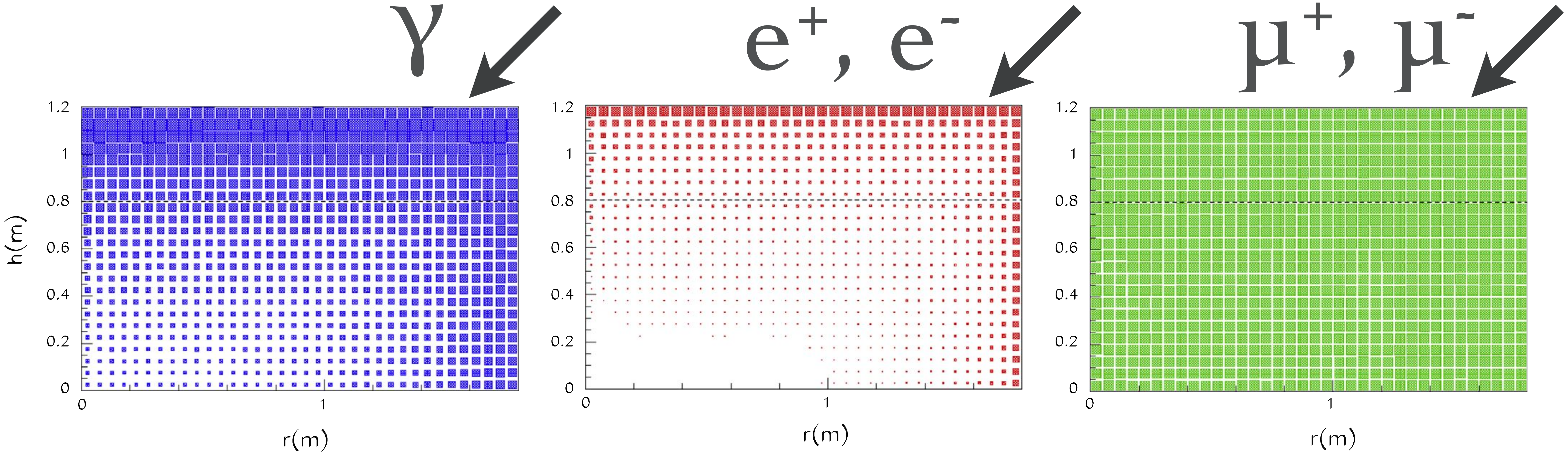


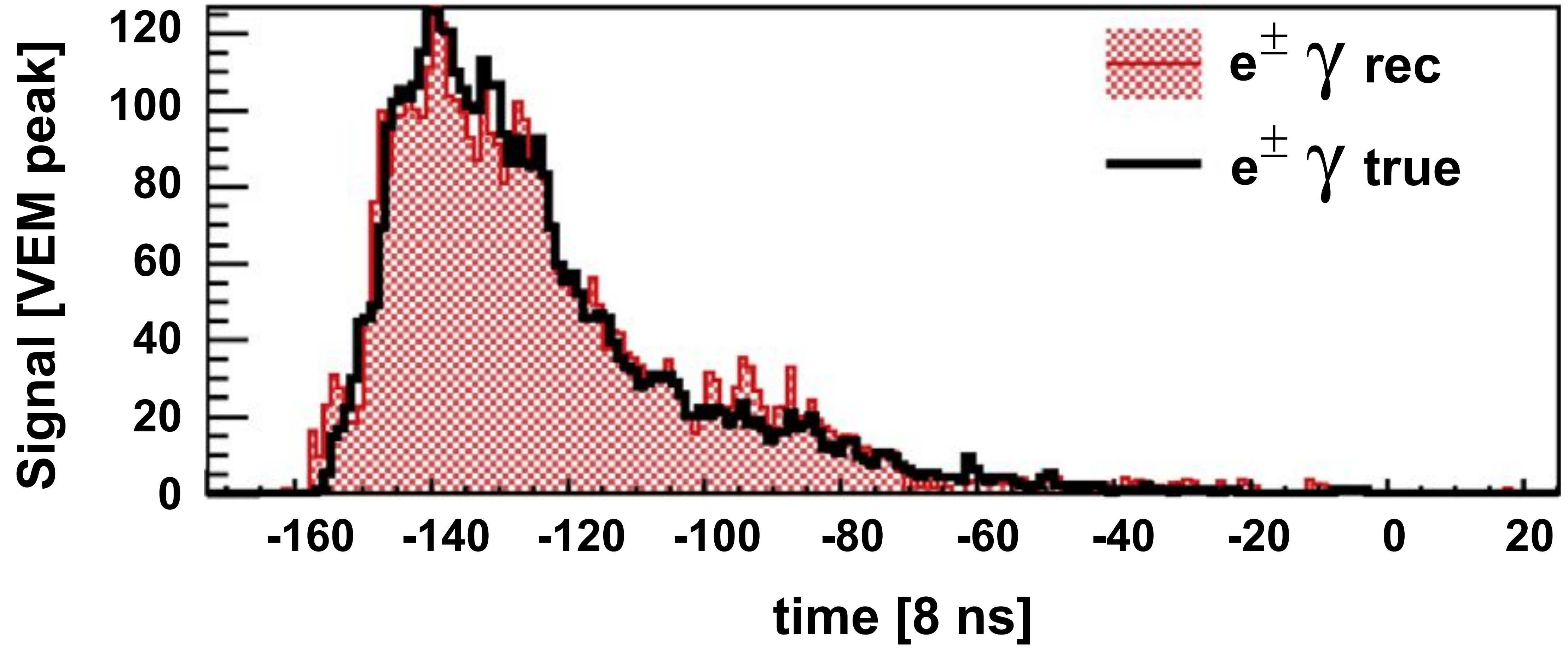
Telescope Array Collaboration NIM-A (2012)

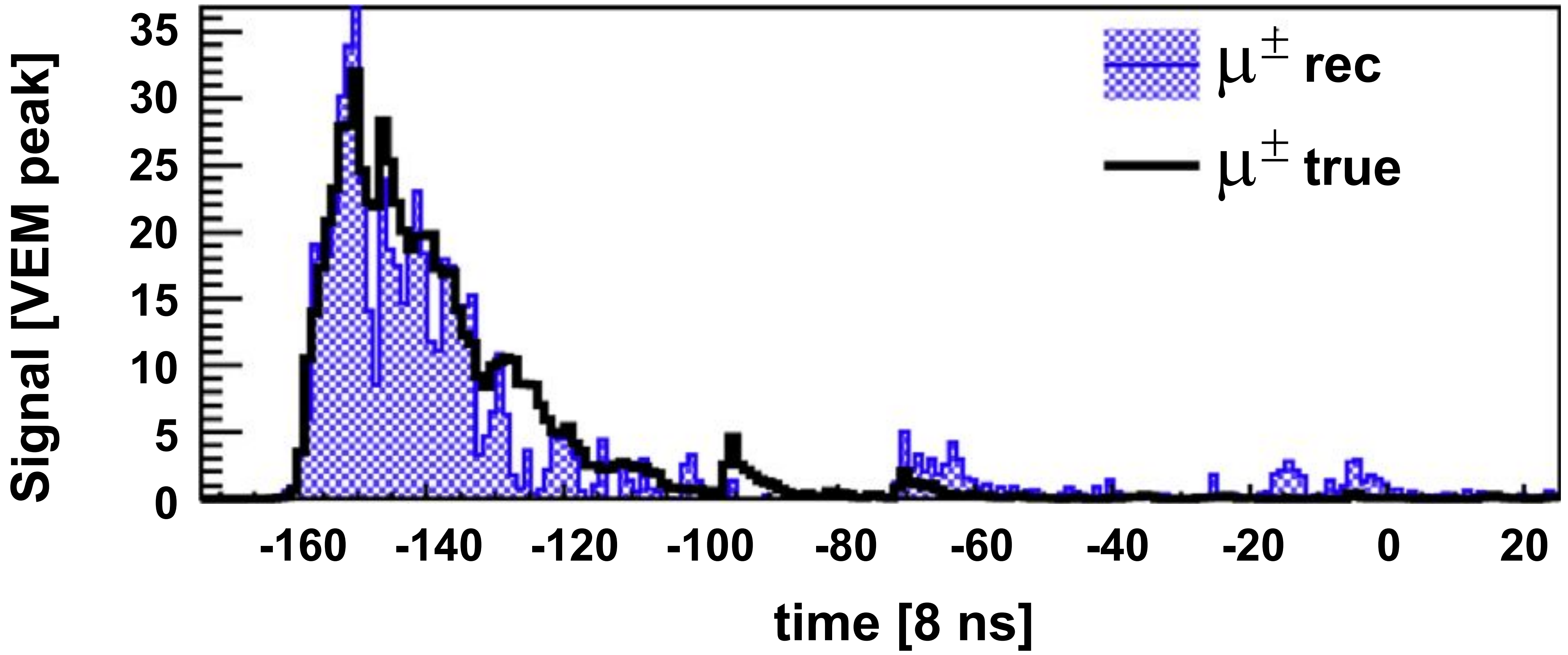
Counterpart: SLOW

Surface detector array of Layered Observational Water-cherenkov counters





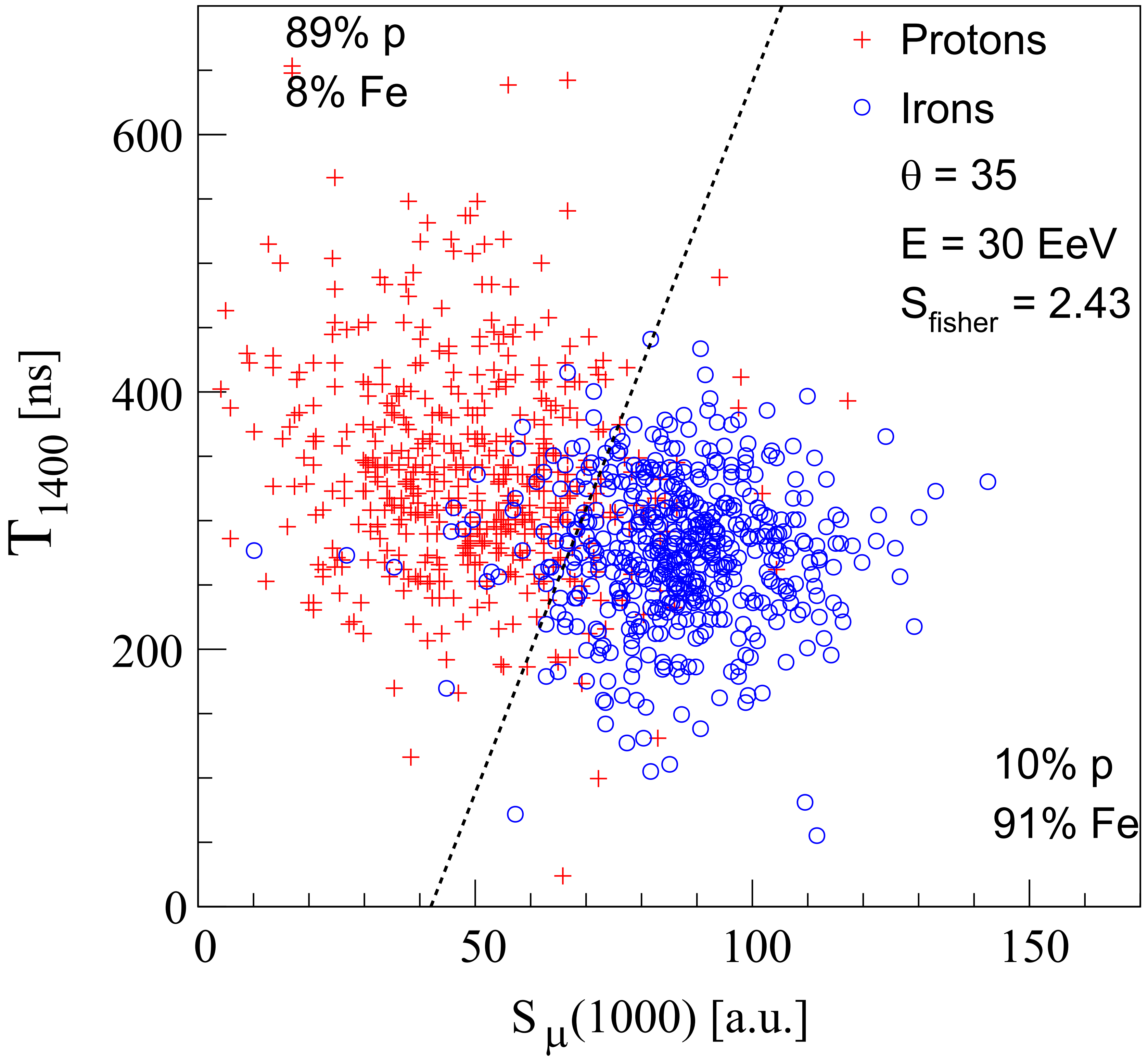


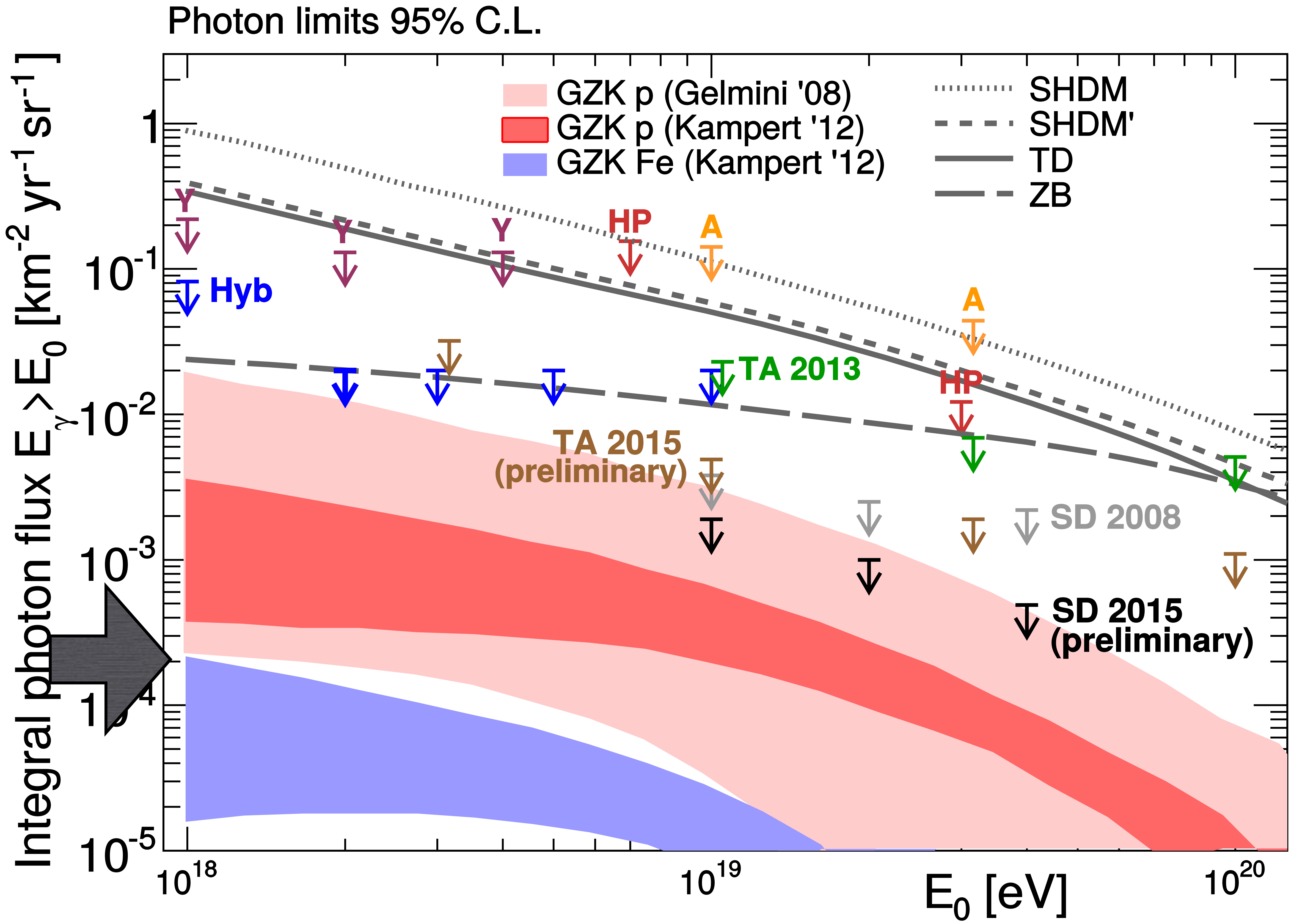


Nuclear Instruments and Methods in Physics Research A 767 (2014) 41–49

Antoine Letessier-Selvon [a,*], Pierre Billoir [a], Miguel Blanco [a], Ioana C. Mariş [a,b], Mariangela Settimo [a]

Physics Target





- 750 m spacing in triangular arrangement
- 10 m^2, 800 stations → ~200 km^2
  - 100% efficiency above $10^{17.5}$ eV
- Energy scale calibrated with FAST

- First GZK γ detection
- Hadron interaction model
- Mass composition

まとめと今後

- **Fluorescence detector Array of Single-pixel Telescopes (FAST)**
  - 極高エネルギー宇宙線観測に特化した新型大気蛍光望遠鏡を使い、望遠鏡アレイ展開して宇宙線への感度を一桁向上させる次世代宇宙線観測計画
- **フルスケールFAST試作機による宇宙線観測開始**
  - 2016年10月に試作機を設置し、観測を開始した。2017年1月から遠隔観測を実施
  - 現在まで128時間の観測時間を達成し、合計18事象の宇宙線候補事象を見つけた
  - 21 km先のレーザー光源のシミュレーションとデータの比較を開始した
  - 観測を継続し、極高エネルギー宇宙線の統計量を増やす
- **Surface detector array of Layered Observational Water-cherenkov counters**
  - 二層式水チェレンコフ地表粒子検出器アレイ