Next-Generation Observatory: Fluorescence detector Array of Single-pixel Telescopes (FAST)

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**Physics Goal and Future Prospects**

**Origin and Nature of Ultra-high Energy Cosmic Rays and Particle Interactions at the Highest Energies**

### 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**
- **AugerPrime**
  - Low energy enhancement
  - (Auger infill+HEAT+AMIGA, TALE+TA-muon+NICHE)

### “Precision” Measurements

### 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**

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

Fine pixelated camera

Single or few pixels and smaller optics

Low-cost and simplified/optimized FD

Too expensive to cover a huge area
Fluorescence detector Array of Single-pixel Telescopes

- Each telescope: 4 PMTs, $30^\circ \times 30^\circ$ field of view (FoV).
- Reference design: $1 \text{ m}^2$ aperture, $15^\circ \times 15^\circ$ FoV per PMT
- Each station: 12 telescopes, 48 PMTs, $30^\circ \times 360^\circ$ FoV.
- Deploy on a triangle grid with 20 km spacing, like “Surface Detector Array”.
- If 500 stations are installed, a ground coverage is $\sim 150,000 \text{ km}^2$.
- Geometry: Radio, SD, coincidence of three stations being investigated.
FAST Exposure

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

- Temporally use the EUSO-TA optics at the TA site.
- Two Fresnel lenses (+ 1 UV acrylic plate in front for protection)
- 1 m² 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, Hamamatsu)
- PMT base (E7694-01, Hamamatsu)
- Ultra-violet band pass filter (MUG6, Schott)
Laser Signal to Check Performance

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.

Directional sensitivity by RayTrace of EUSO-TA telescope

Data
Simulation
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.
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).

Distance vs Energy (from TAFD) for Candidates

Almost! \( \log(E/\text{eV}) = 19.1 \)

Almost! \( \log(E/\text{eV}) = 18.0 \)
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.

![Graphs and Diagrams]

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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 $X_{\text{max}}$ with FAST

FAST meeting in December 2015 (Olomouc, Czech Republic)
1m² aperture
FOV = 25° x 25°

UV Plexiglass

8 inch PMT camera (2 x 2)

Segmented primary mirror

Joint Laboratory of Optics in Olomouc, Czech Republic
The spherical surface on PMT has complicated point spread function.

We need to calculate efficiency of optics.

It will be used in the offline analysis after data-taking is started.
The brightness of the sky in each situation is expressed in units of Dark NSB. Due to the relatively high brightness of the sky, the image cleaning settings for each sample were modified. The data was divided into four samples with different NSB conditions and it is summarized in table 1.

The mean current measured (DC) in one of the telescopes (MAGIC 1) is also shown in table 1. The data sample and analysis procedure.

To analyse the data and to evaluate the energy threshold, Monte Carlo (MC) simulations are needed. The MC for standard analysis in MAGIC (without filters and in dark conditions) was tuned to include the filters transmission, the shadowing in some pixels that is produced by the ribs of the frame and the increased NSB. With these modified MC simulations, the data has been analysed using the standard MAGIC analysis and reconstructions software, MARS.

After data quality selection a total of almost 15 observation hours of Crab Nebula with the UV-pass filters were recorded. The data were taken in the standard L1-L3 trigger condition.

The filters were bought in tiles of 20 cm x 30 cm and mounted on a light-weight frame. This frame design that holds the filters. The outer Al ring is screwed to the PMT camera. Filter tiles are held by plastic section ribs that are placed between the filter tiles (see figure 1). The filters are fixed to 30 cm frame consists on an outer aluminium ring that is screwed to the PMT camera and steel 6 section ribs.

The UV band pass filter used in MAGIC is shown in figure 2. Taking all into account, we selected commercial inexpensive UV-pass filter used in MAGIC.

The spectrum of Cherenkov light of showers depends mainly on the altitude of the shower (ray or a hadron) and its energy. For a vertical shower initiated by a TeV -ray, detected at 2200 m a.s.l., it peaks at 330 nm, as shown in figure 1.

The filters were produced by Subei (model ZWB3) with a thickness of 3 mm and a wavelength cut at 420 nm. Its transmission curve was measured and is also shown in figure 1. The blue curve shows the typical Cherenkov light spectrum for a vertical shower initiated by a TeV -ray, detected at 2200 m a.s.l. The black solid curve shows the shape of direct moonlight spectrum. The dashed black curve, the spectrum from diffuse moonlight. The three curves are scaled by an arbitrary normalization factor. The filters transmission curve is plotted in red.

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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.

UV PMMA "window" in octagonal aperture

DUST and STRAY LIGHT protection

cover = black shroud

mirrors

cabling

electronics

4 PMTs camera 8 inch

UV filter glass

Building - ground plan – required dimensions

Cca 3000 mm

Cca 3500 mm

FOV
“Easy” to Change Elevation
FAST Prototype in February 2016
We will plan to install the full-scale FAST telescope on June 2016.
Possible Application of FAST Prototype

- 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%, \( X_{\text{max}} \): 35 g/cm\(^2\) at \( 10^{19.5} \) eV
- Independent cross-check of Energy and \( X_{\text{max}} \) scale between Auger and TA

![Graph showing energy and \( X_{\text{max}} \) resolution for different elements (Proton, Iron).

**Preliminary**

![Graph showing flux \( \times 10^{24} \) (eV m\(^2\) s\(^{-1}\) sr\(^{-1}\)) for TA ICRC 2015 and Auger ICRC 2015.

**Pierre Auger Observatory**

**Identical simplified FD**

**Telescope Array Experiment**

Pierre Auger Collaboration, NIM-A (2010)
Summary and Future Plans

- **Fluorescence detector Array of Single-pixel Telescopes (FAST)**
  - Deploy the economical fluorescence detector array.
  - Detect UHECRs and neutral particles.
  - This concept of single-pixel telescope was confirmed by the field measurements using the EUSO-TA optics.
  - Published in Astroparticle Physics 74 (2016) 64-72
  - The full-scale FAST prototype is being constructed, and almost ready to ship to Utah.
  - We plan to install in June 2016.
FAST Webpage

Our Challenges

http://www.fast-project.org