Status of the development of hybrid reconstruction techniques for TAIGA

ICRC 2021

M.Blank M. Tluczykont A. Kuotb Awad D. Horns A. Porelli

for the TAIGA Collaboration

TAIGA

Tunka Advanced Instrument for cosmic ray and Gamma Ray Astronomy

Russia
MSU (SINP), Moscow
ISU (API), Irkutsk
INR RAS, Moscow
JINR, Dubna
MEPhI, Moscow
IZMIRAN, Moscow
BINR SB RAS, Novosibirsk
NSU, Novosibirsk
ASU, Barnaul

Germany
MPI, Munich
University of Hamburg (Iexp), Hamburg
DESY, Zeuthen

Italy
Torino University, Torino

Romania
ISS, Bucharest


8/2019
1985
2021
TAIGA 2019
500 m
Image © 2021 CNES / Airbus
Google Earth
497 m
1985
Bildaufnahmedatum: 8/16/2019
Breite 51.812268°
Länge 103.076949°
Höhe 670 m
sichthöhe 2.89 km

The Hybrid TAIGA Experiment

TAIGA-HiSCORE

Integrating air Cherenkov Timing array
2020: 89 stations
2021: 120 stations

TAIGA-IACT

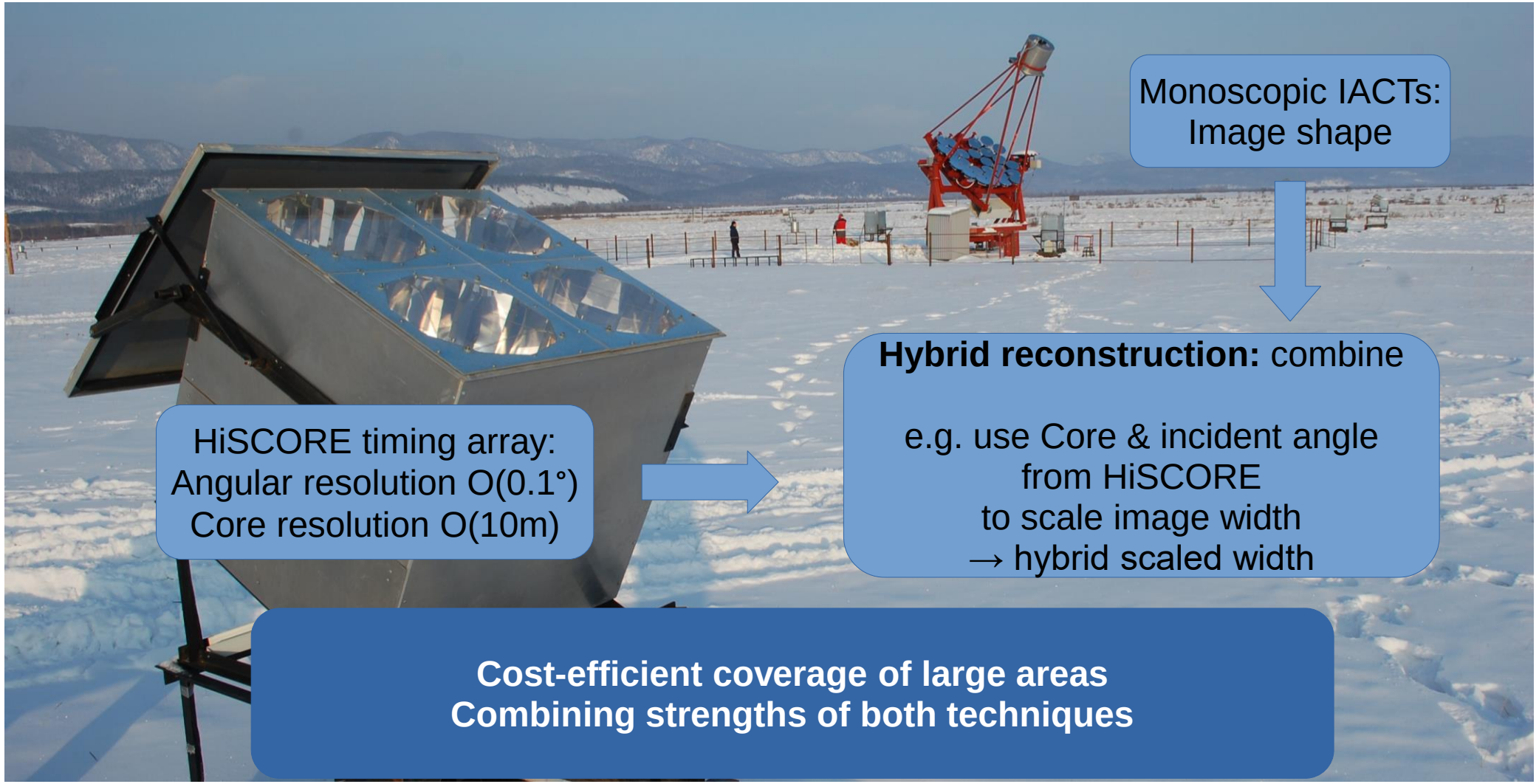
IACT-1: first results available
IACT-2: data taking started
IACT-3: in construction

TAIGA-Muon

240 m² surface and underground particle detectors

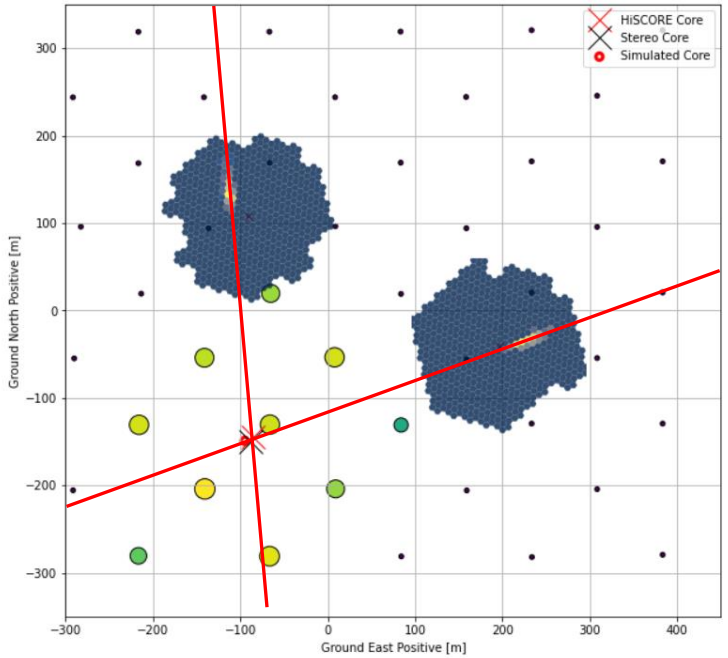
More info: TAIGA overview talk - N. Budnev

The hybrid air Cherenkov approach

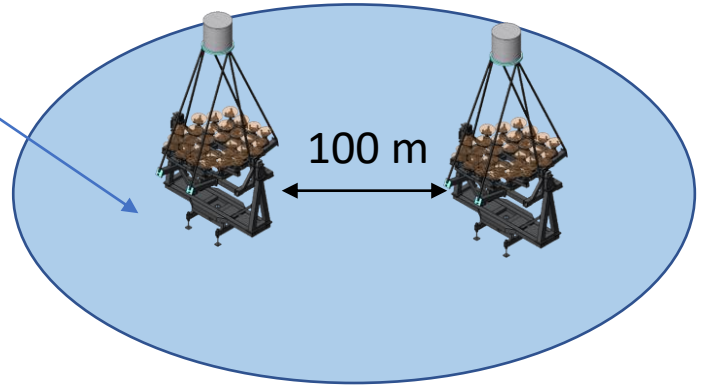


Imaging Hybrid Mode

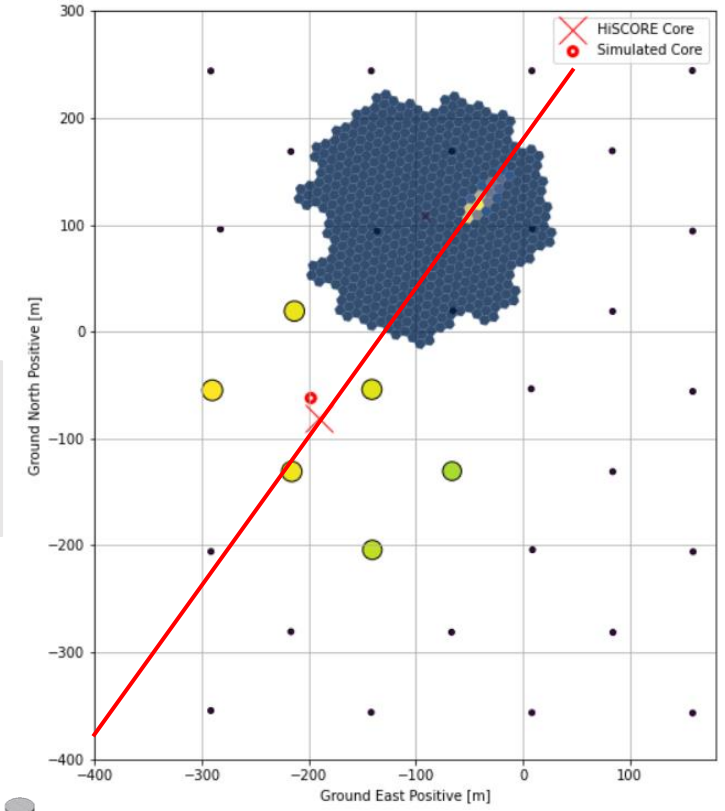
Stereo

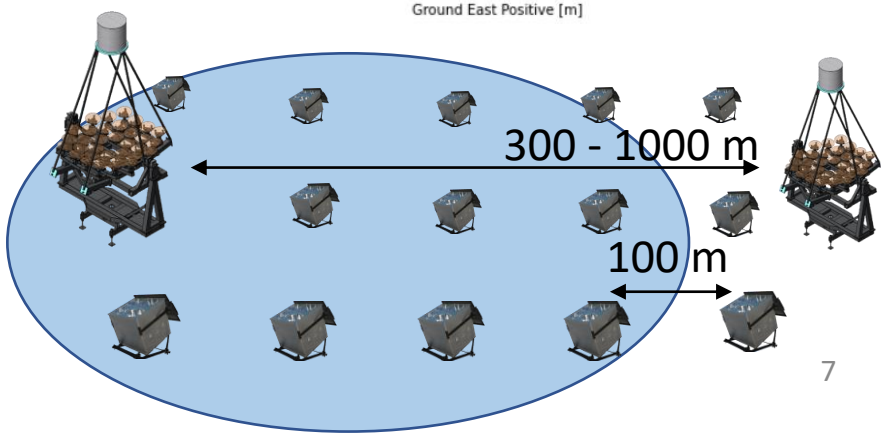


Light Pool



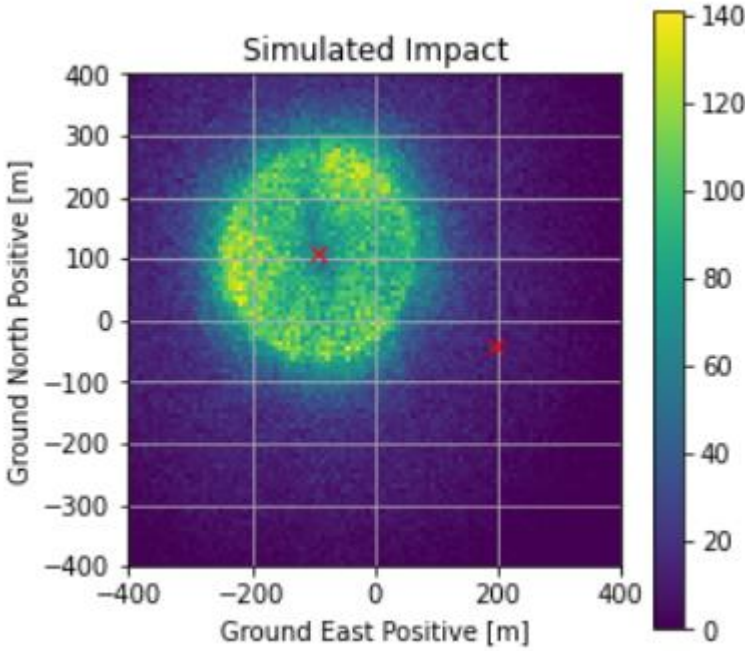
Imaging Hybrid



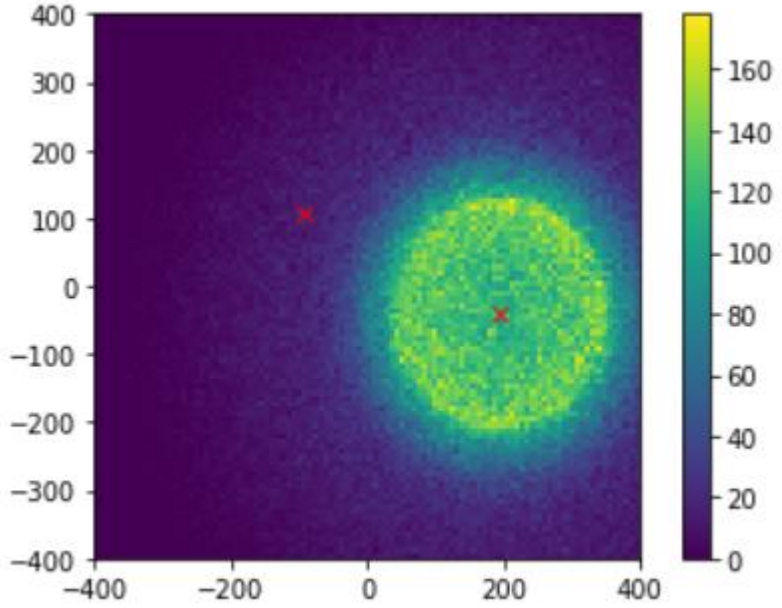


Point Source Gamma Simulation

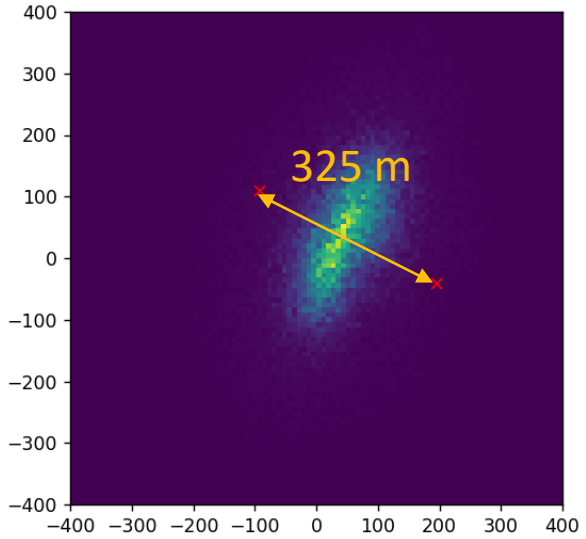
IACT 1



IACT 2



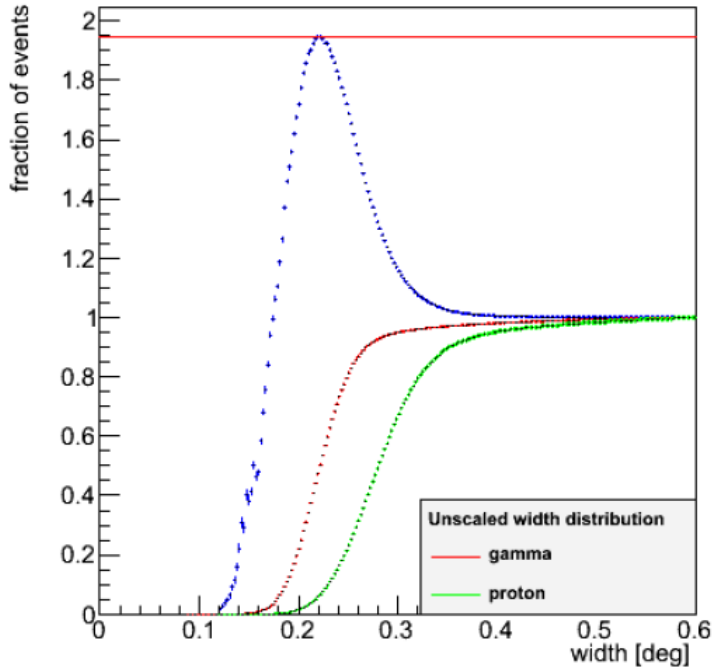
Stereo Events
(not needed)

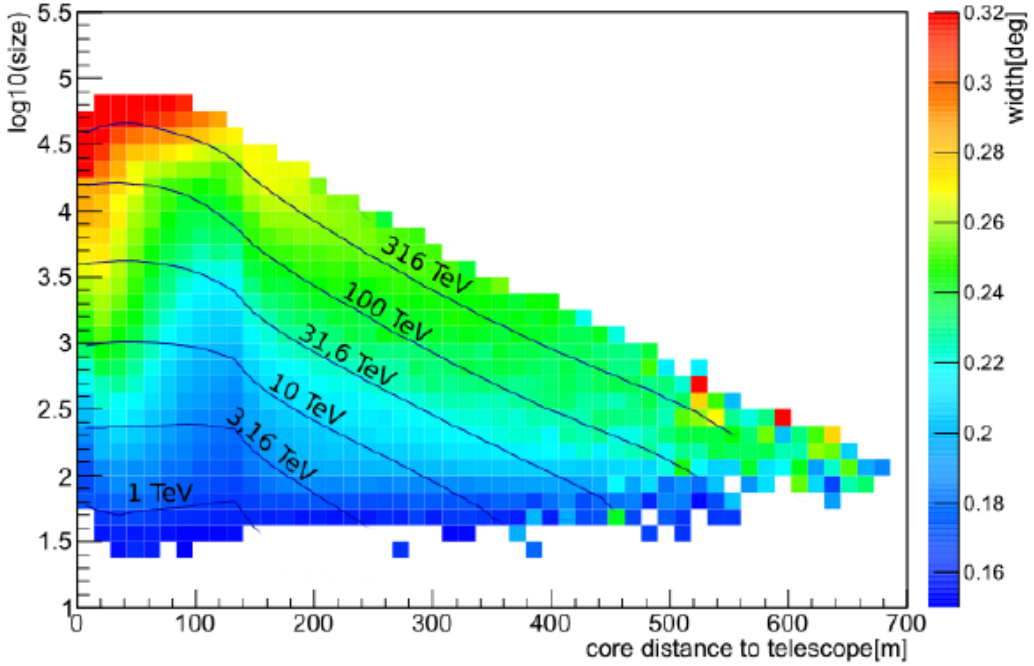


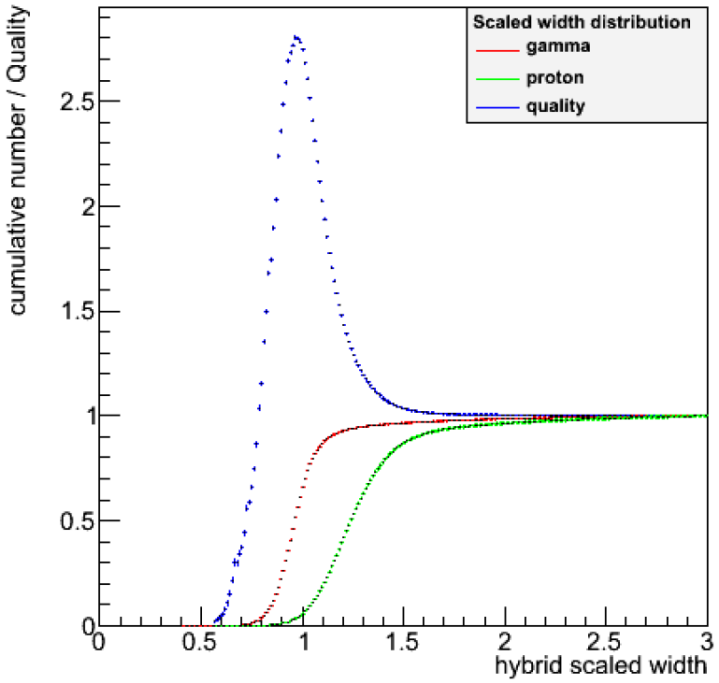
- Large distance between telescopes
- Operation mode: independent telescopes
- **All events are usable**

Reconstruction Idea: Hybrid Scaled Width

- Thesis of Maike Kunnas, 2017
- Take reconstructed core position from timing array
- Scale width by mean width at that core position
- Additional possibility: take single station core position (Wertz 2019)





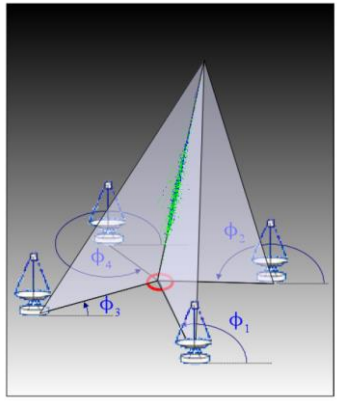


Current Status

	Data	Simulation
HiSCORE	End of 2021: 121 Stations in 4 clusters	Sim_score MC Processing ongoing
IACT 1	Operational since 2018	Adapted version of sim_telarray Reasonable agreement
IACT 2	Operational since Feb 20	Adapted version of sim_telarray Work in progress
IACT 3	Mount ready, camera to be installed soon	-
Datasets		Corsika v7.64 with IACT option: Point Source: Gamma 0.5 TeV – 50 TeV: 11M Viewcone 35 deg: Proton 0.65 TeV – 682 TeV: 100 M Helium 0.7 TeV – 743 TeV: 43 M Nitrogen 0.8 TeV – 83 TeV: 11 M Iron 0.9 TeV – 96 TeV: 11 M

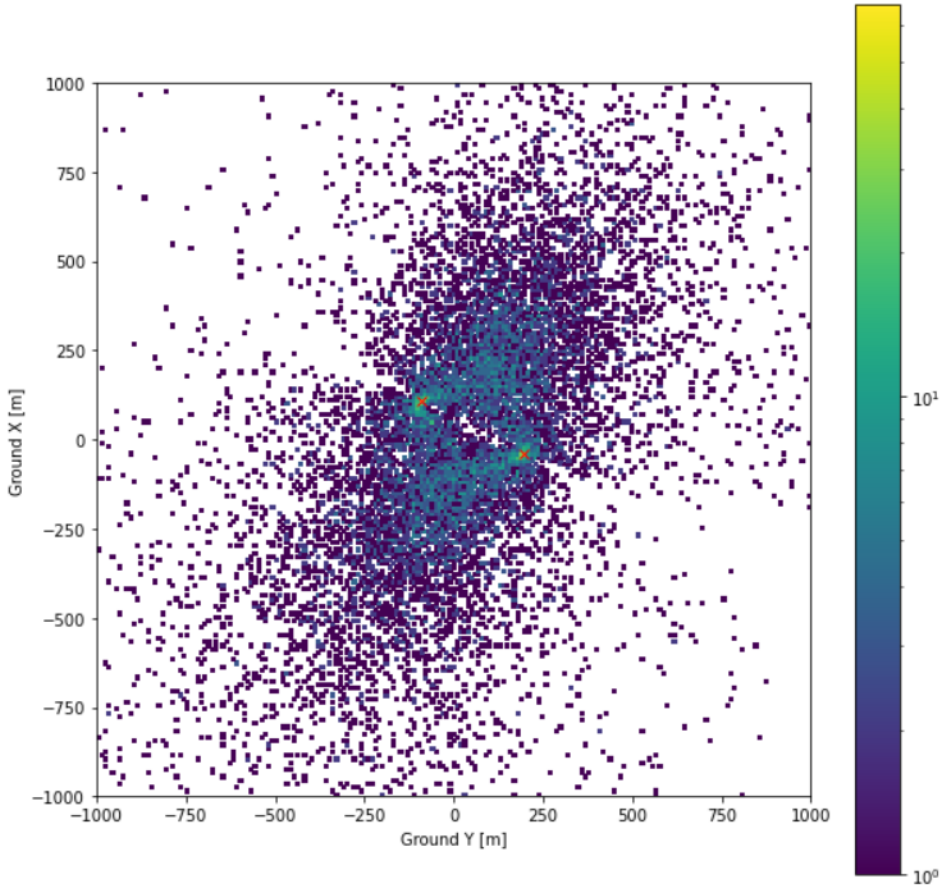
Status: Exploring 2 IACT + HiSCORE events

arXiv:1511.00463
[astro-ph.IM]

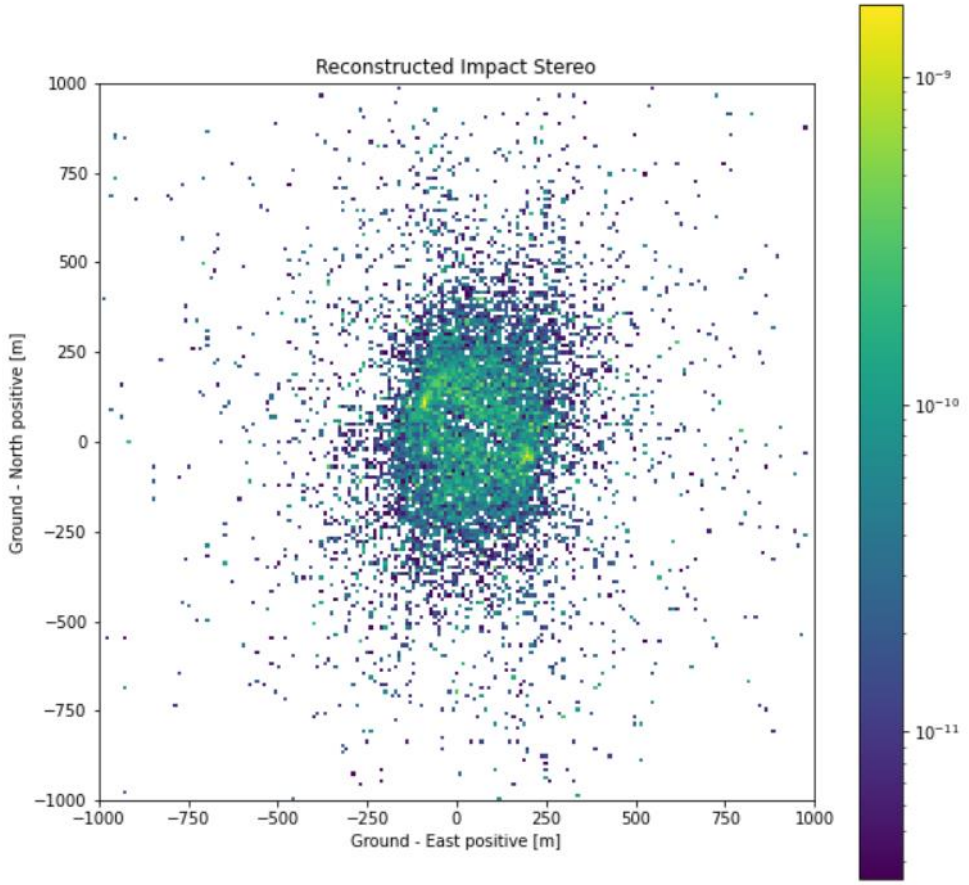


Stereo Plane Intersection

Data:
Pointing: zd 30 - 42, mean az 210

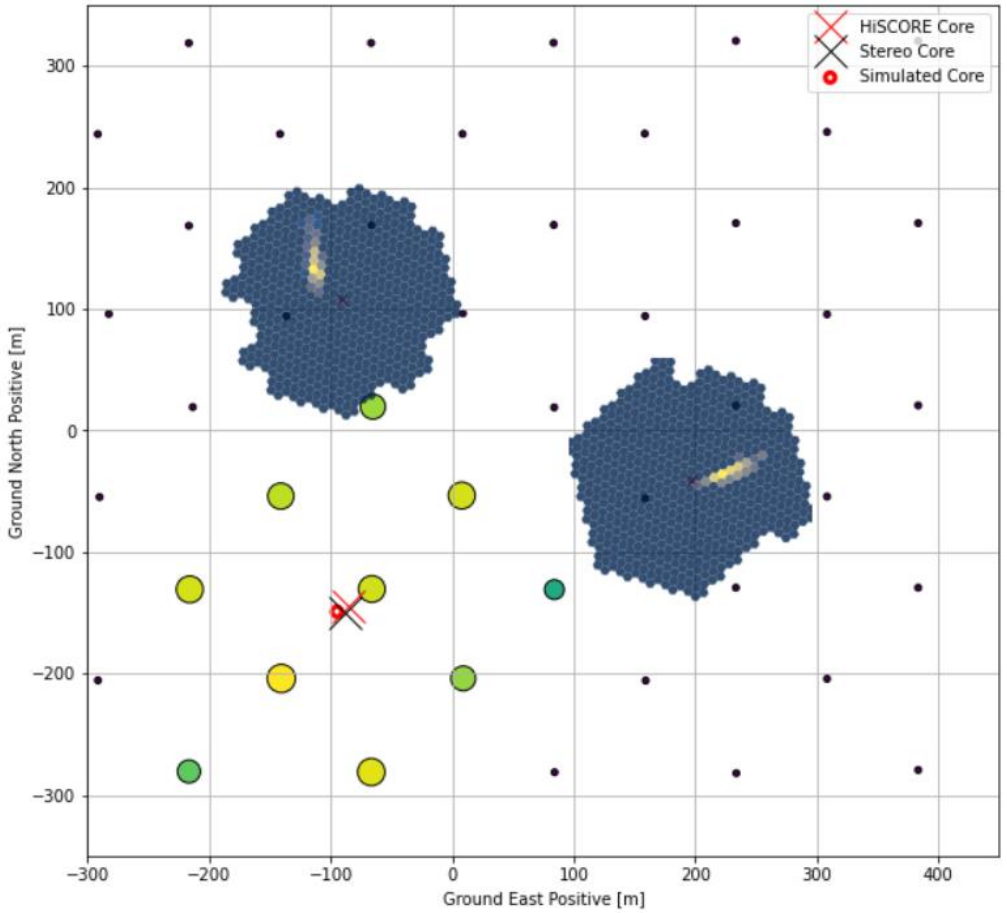


Simulation:
Pointing: zd 31 deg, az 180 deg

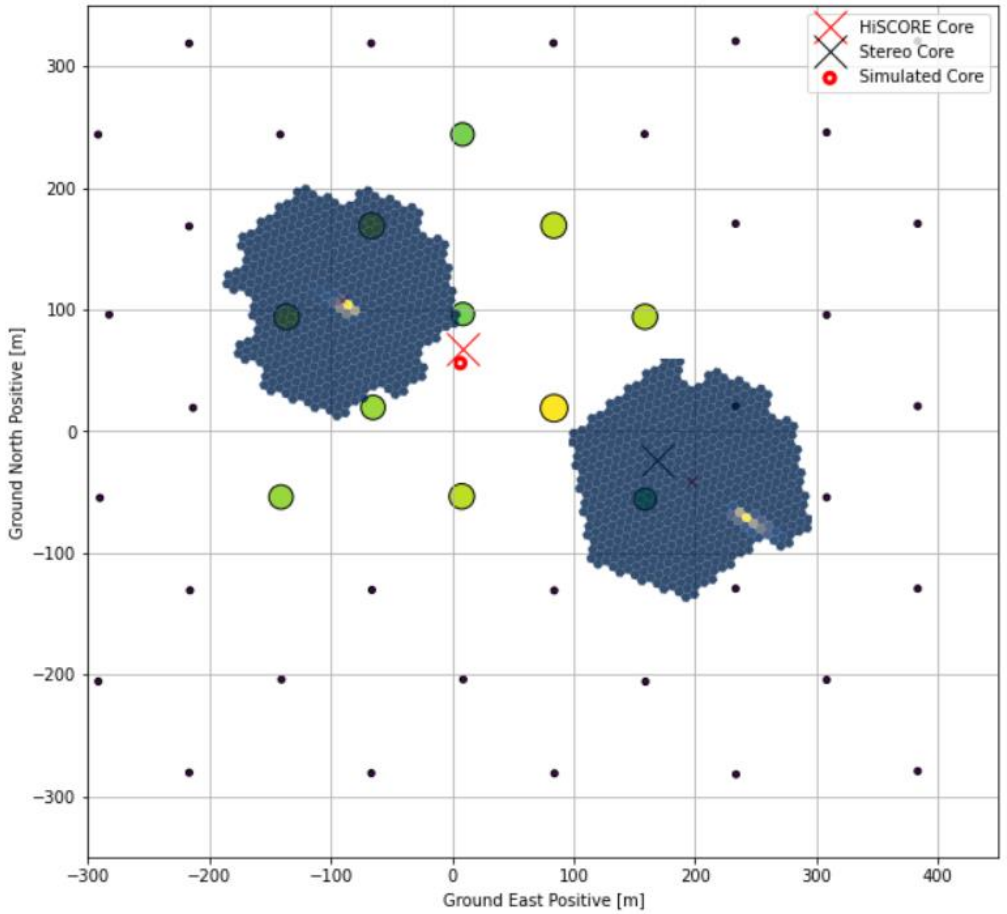


Stereo + HiSCORE

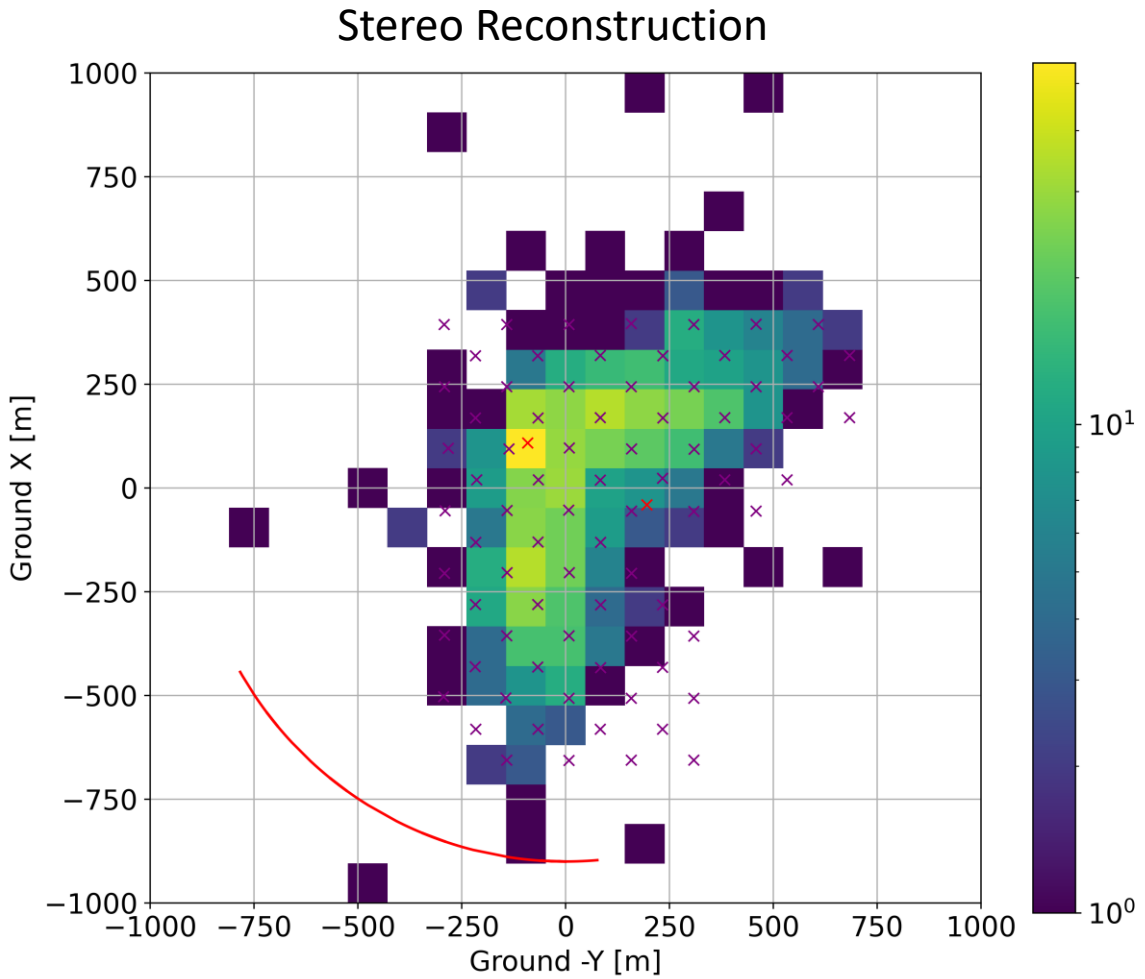
Hybrid event

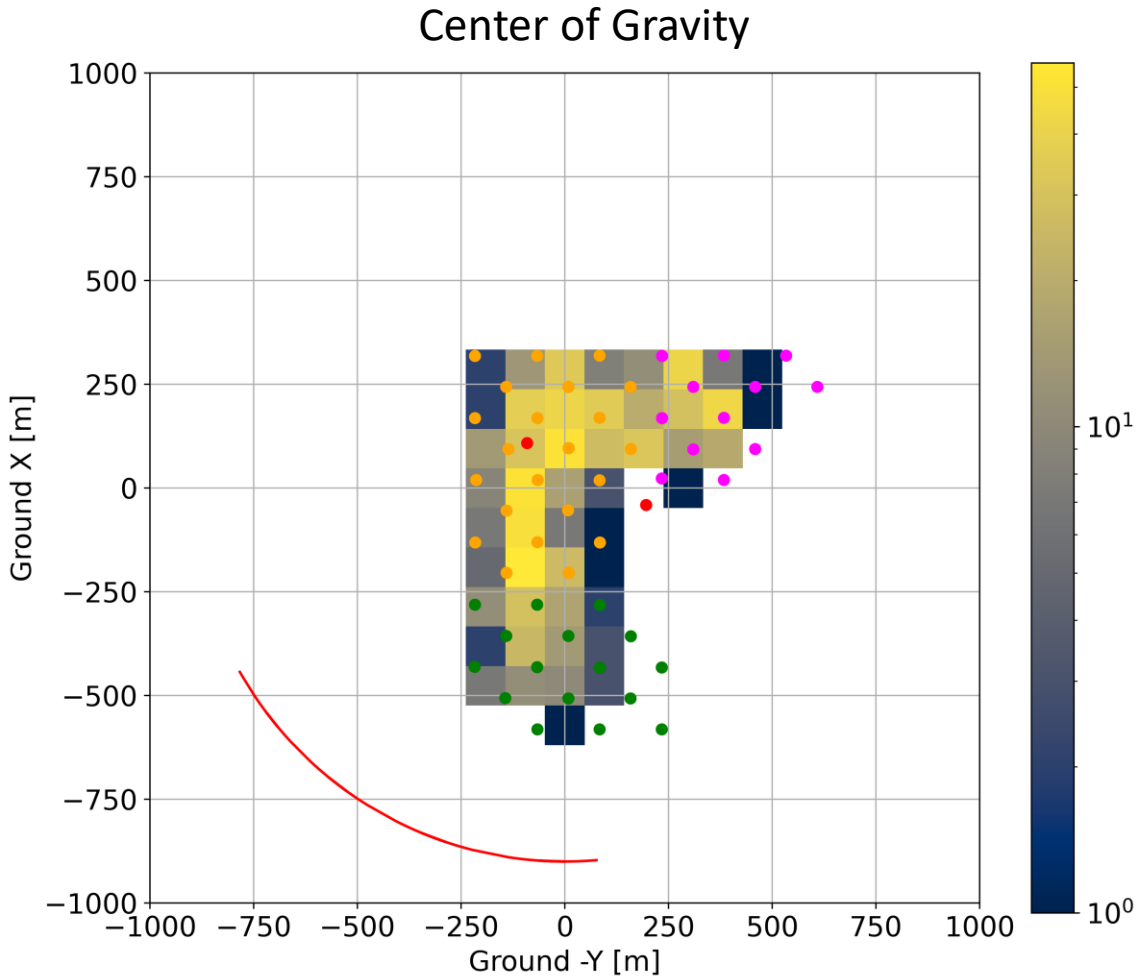


Recover core

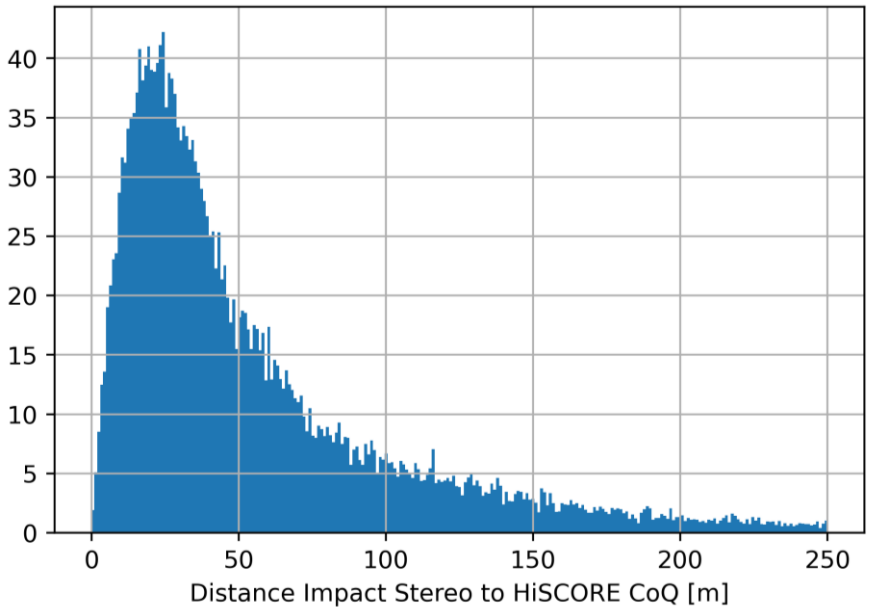


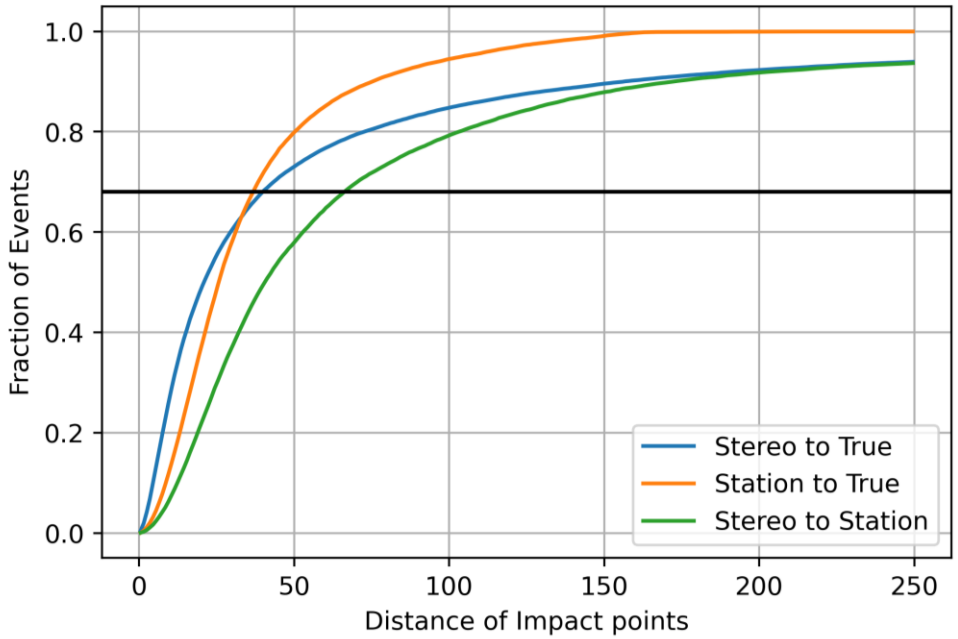
Coincident Data Events (IACTs + HiSCORE)





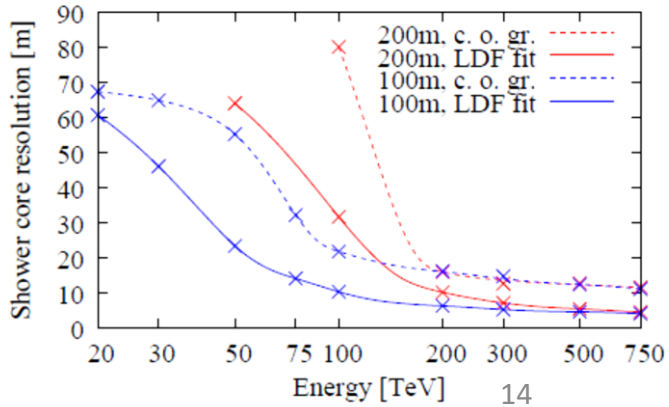
Coincident Events (IACTs + HiSCORE)





- **Gamma Simulation**
  - ~20 to 50 TeV, weighted to E^(-2.6)
  - CoG reconstruction only -> even better with LDF fit

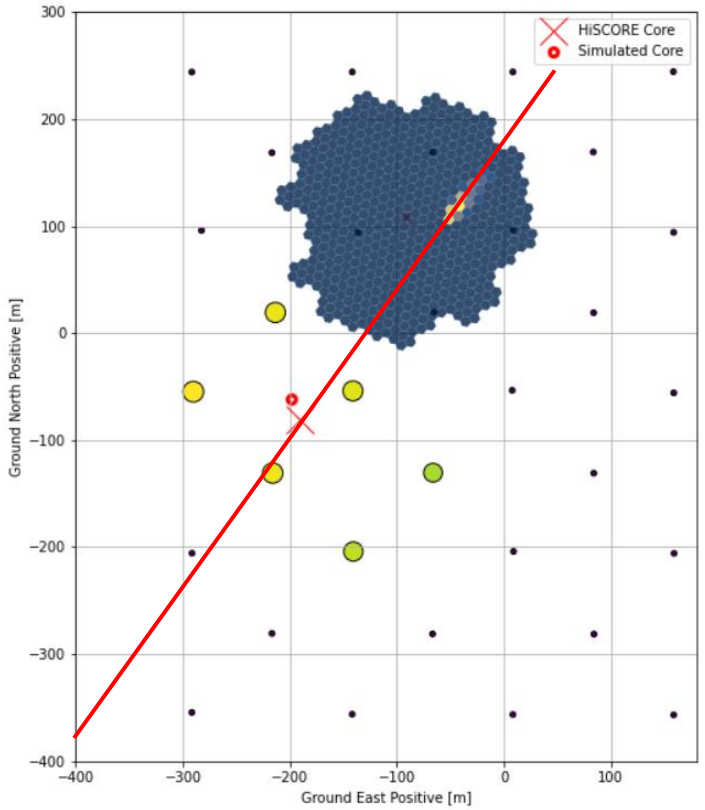
arXiv:0909.0663
[astro-ph.IM]

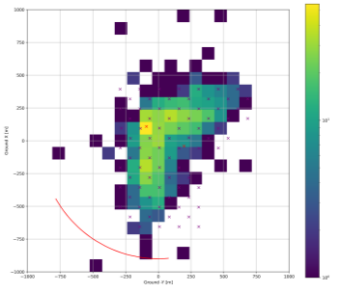


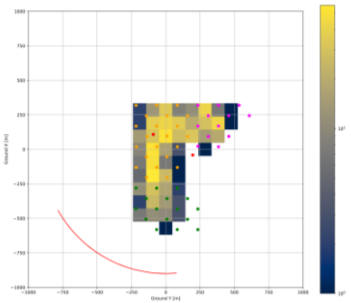
Summary and Outlook

- Summary:
  - 2 IACTs and 89 HiSCORE stations in operation
  - coincident events seen in data and simulation

- Outlook:
  - 2 IACT + HiSCORE events:
    - cross calibration
    - systematic simulation checks
  - 1 IACT + HiSCORE events (operational goal)
    - Verify Hybrid Scaled Width
    - Fix major axis via HiSCORE core
    - …
  - Single IACTs:
    - Improve analysis
    - Verify IACT 2





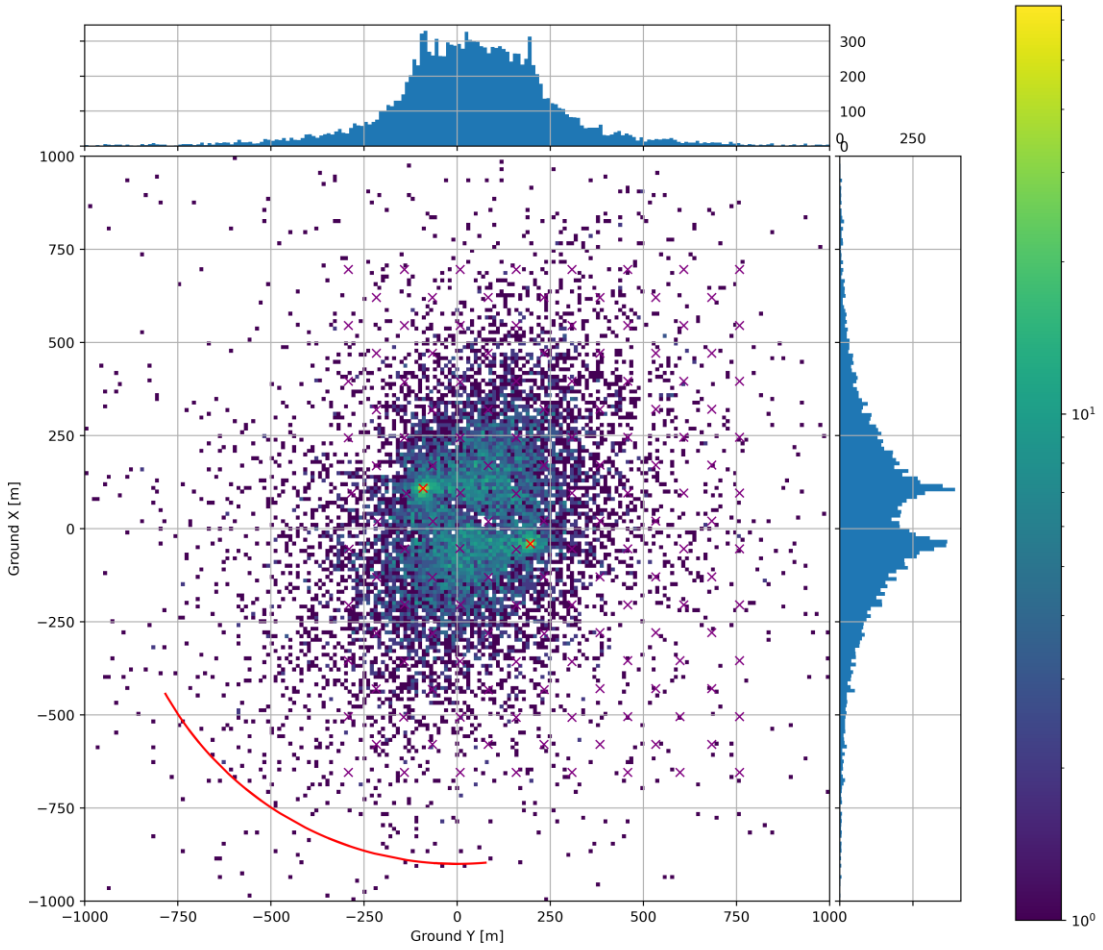


Other contributions

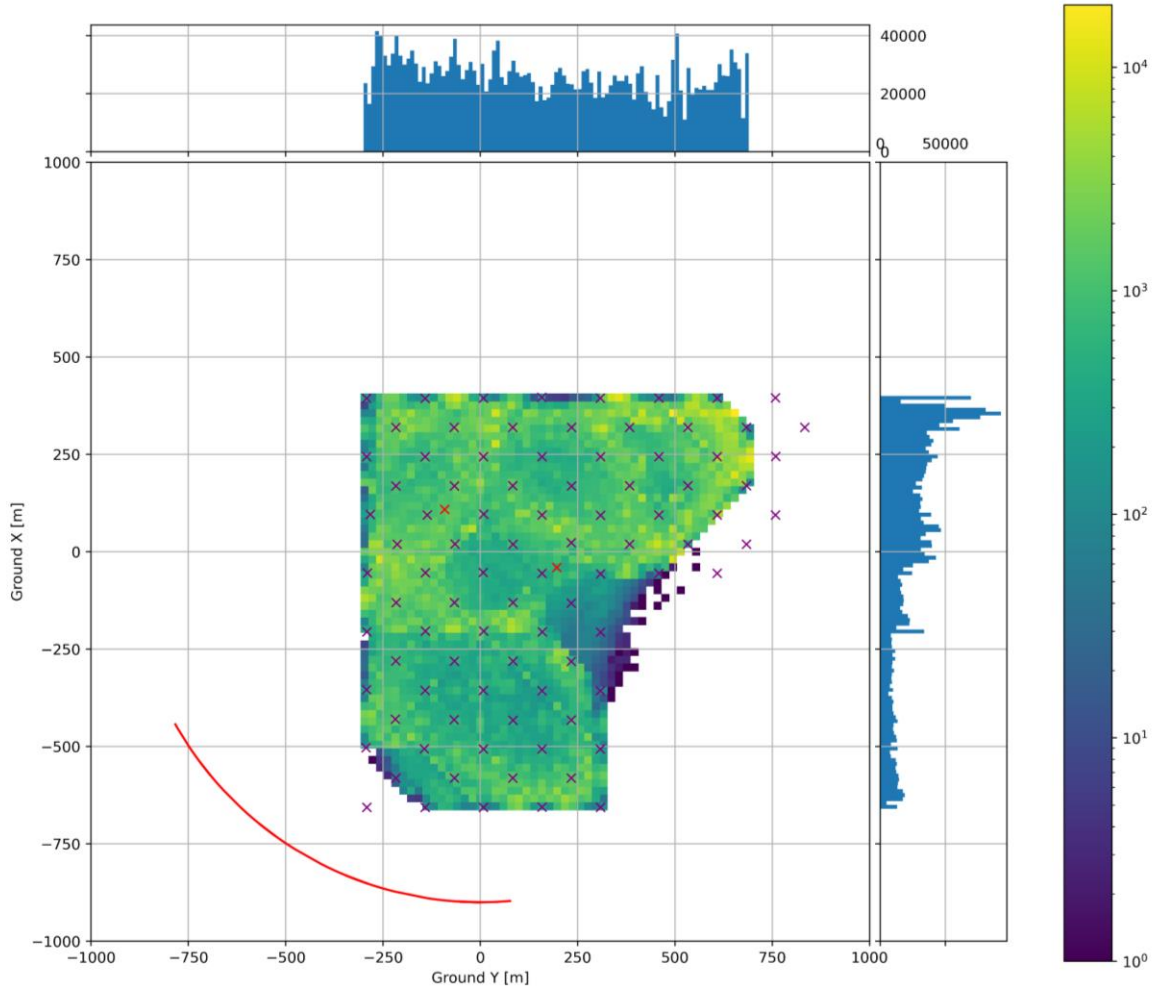
Speaker	Contribution
N. Budnev	The-TAIGA-an-advanced-hybrid-detector-complex-for-astroparticle-physics-cosmic-ray-physics-and-gamma-ray-astronomy
R. Wischnewski	White-Rabbit-in-the-TAIGA-Observatory-From-Precision-Timing-to-Fast-Event-Classification
A. Porelli	TAIGA-Observatory-First-5-years-of-operation-of-the-HiSCORE-Air-Cerenkov-Array
A. Porelli	Satellite-based-Calibration-of-the-TAIGA-HiSCORE-Cerenkov-Array-by-the-LIDAR-on-board-CALIPSO
L. Sveshnikova	The-detection-of-high-energy-gamma-rays-larger-40-TeV-from-Crab-Nebular-by-a-hybrid-method-of-TAIGA-installation
A. Borodin	The-precision-of-the-IACT-mechanical-mounts-of-the-TAIGA-observatory
A. Ivanova	Tunka-Grande-array-for-high-energy-gamma-ray-astronomy-and-cosmic-ray-physics-preliminary-results
P. Volchugov	Plans-and-Tests-for-Stereoscopic-and-Monoscopic-Operation-of-Four-IACTs-of-the-TAIGA-Hybrid-Experiment
D. Zhurov	TAIGA-IACT-control-and-monitoring-software-status
A. Panov	Search-for-nanosecond-fast-optical-transients-with-TAIGA-HiSCORE-array
J. Dubenskaya	Fast-simulation-of-gammaproton-event-images-for-the-TAIGA-IACT-experiment-using-generative-adversarial-networks
S. Polyakov	The-use-of-convolutional-neural-networks-for-processing-images-from-multiple-IACTs-in-the-TAIGA-experiment

Backup

Reconstructed Core Positions (Not coincident)



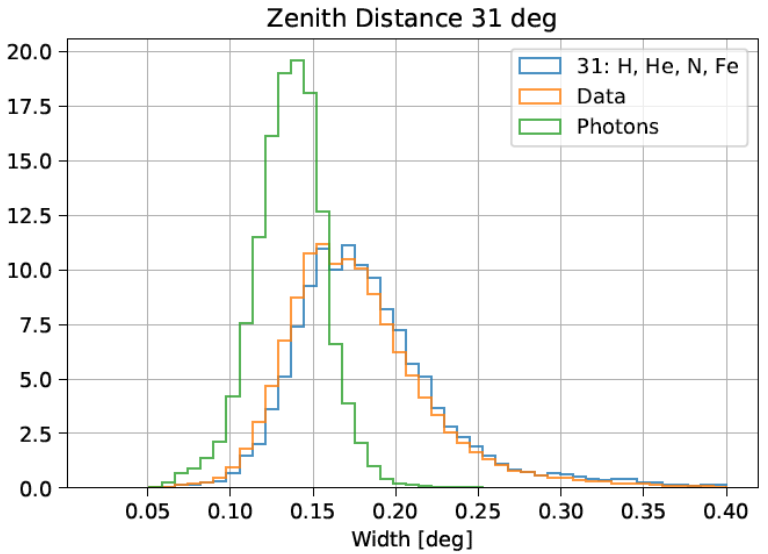
2 IACT Stereo

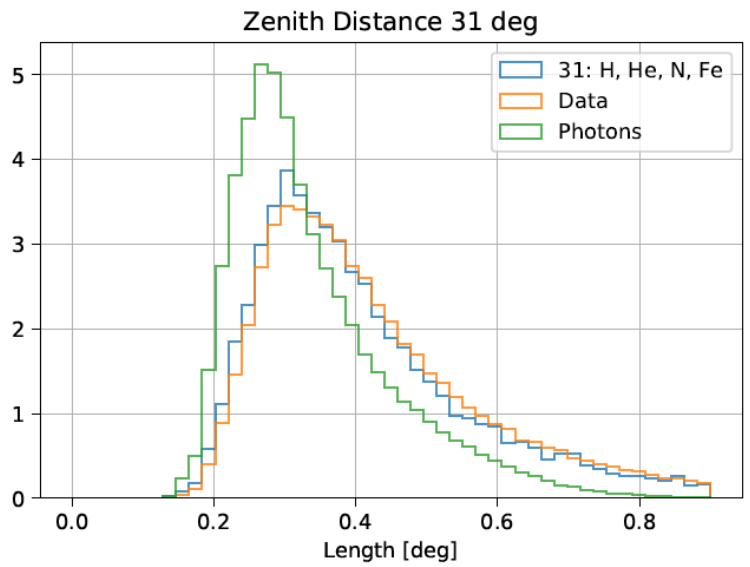


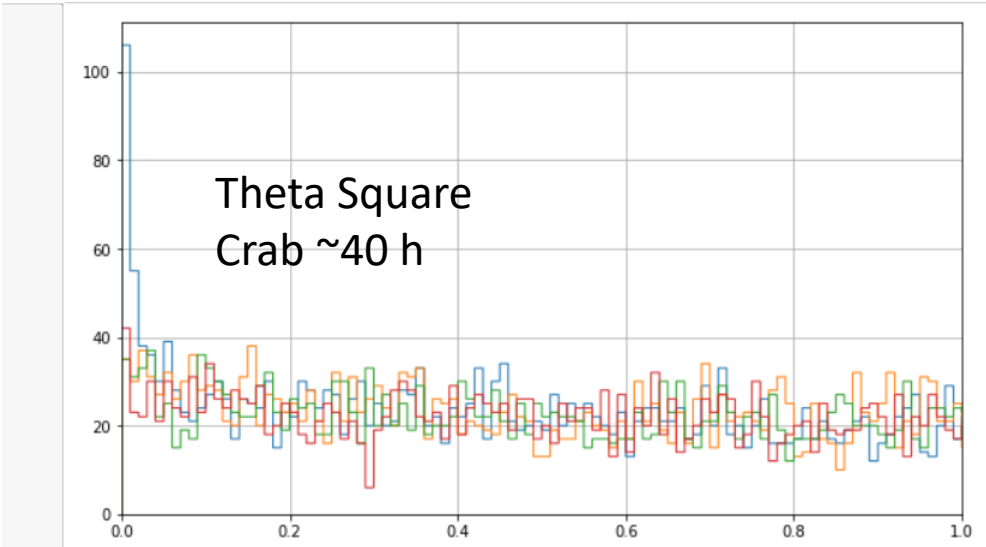
HiSCORE

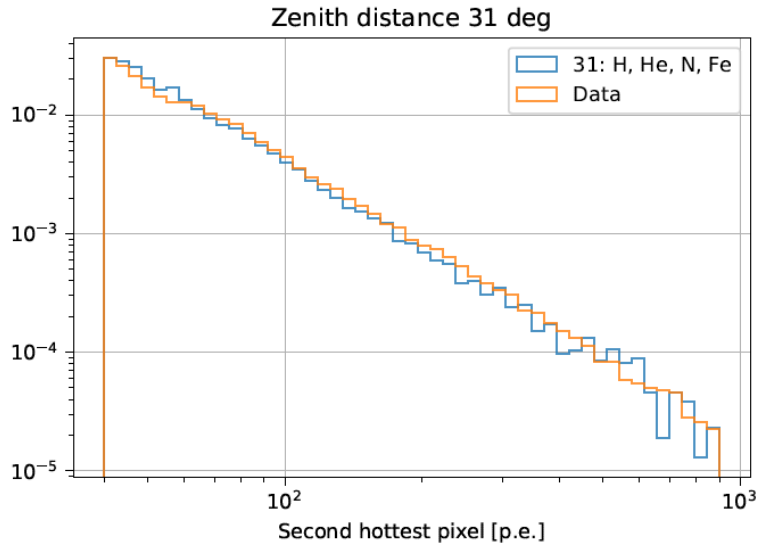
IACT 1

First simple analysis:
- Random Forest g/h separation
- Random Forest Disp estimation





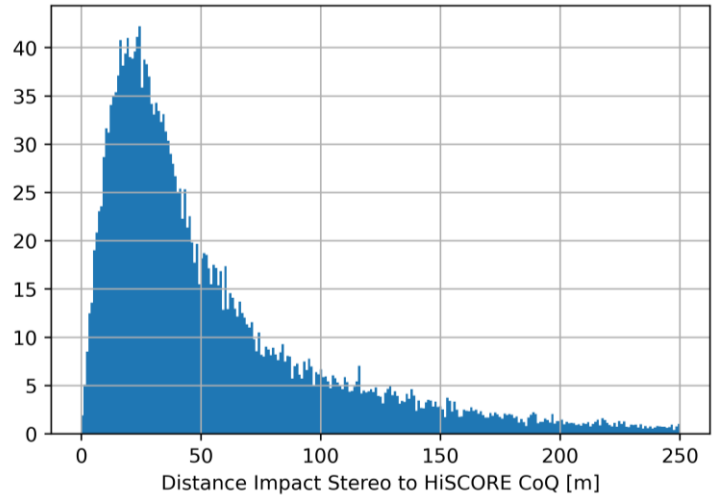


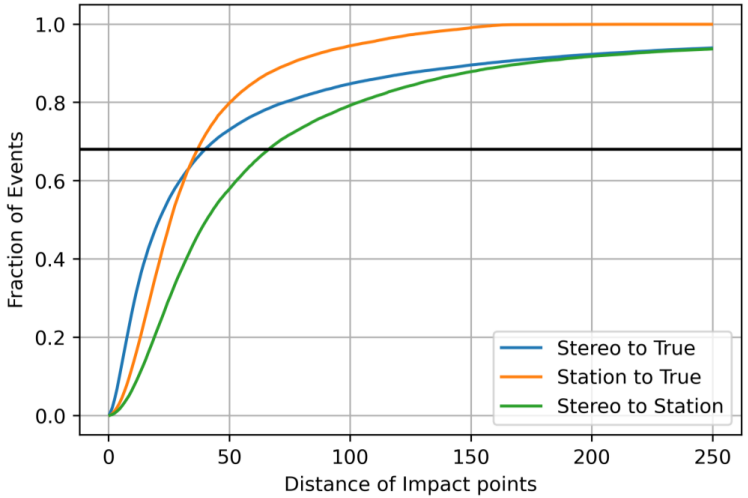


Coincident Events (IACTs + HiSCORE)

Gamma Simulation

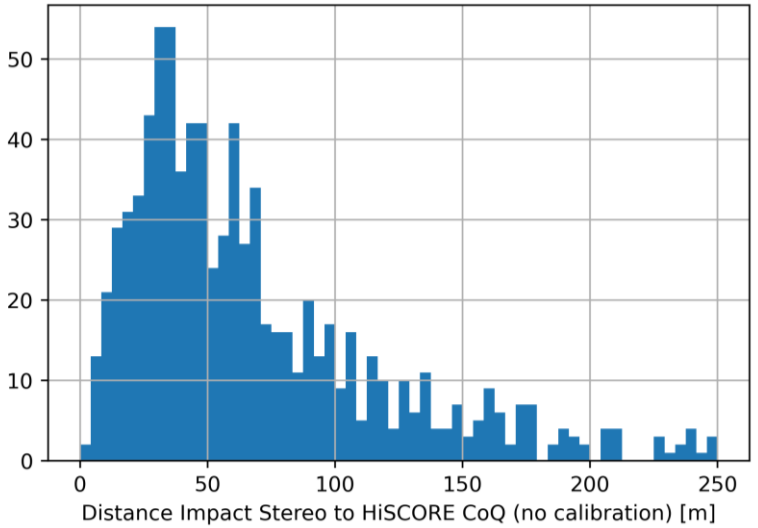
~20 to 50 TeV

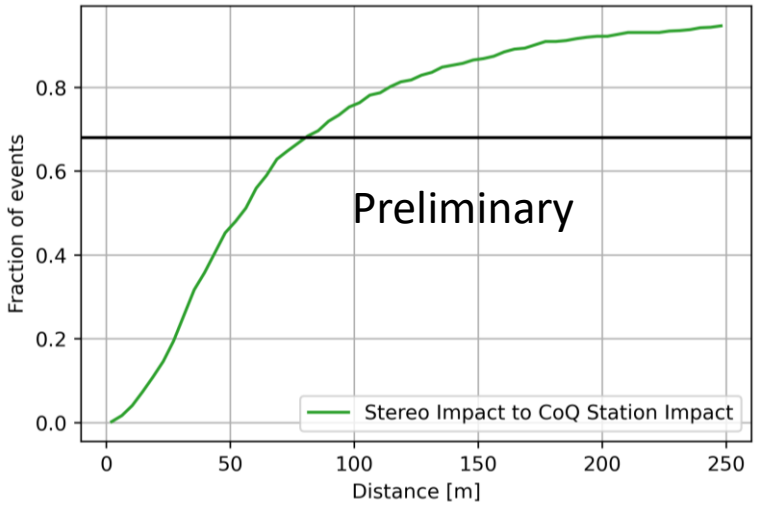




Data

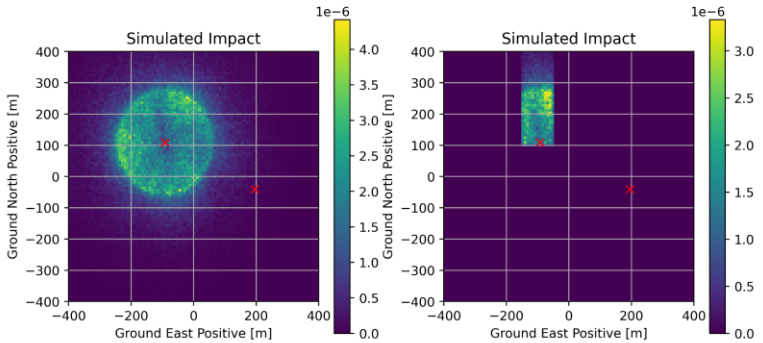
(Not only Gammas)

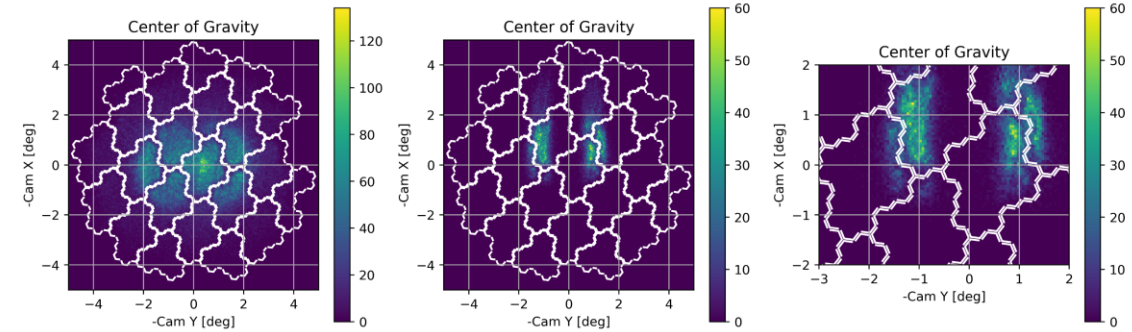




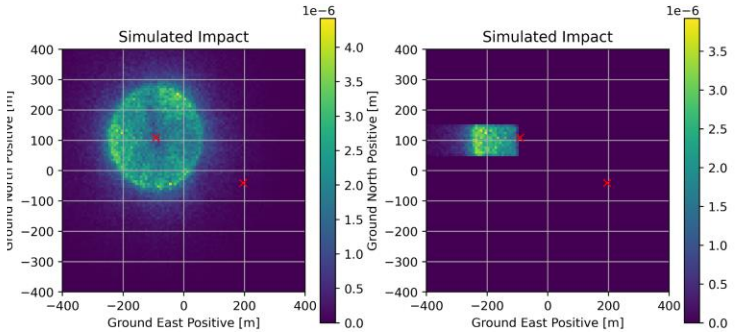
„Shadowing“ in Impact Distribution

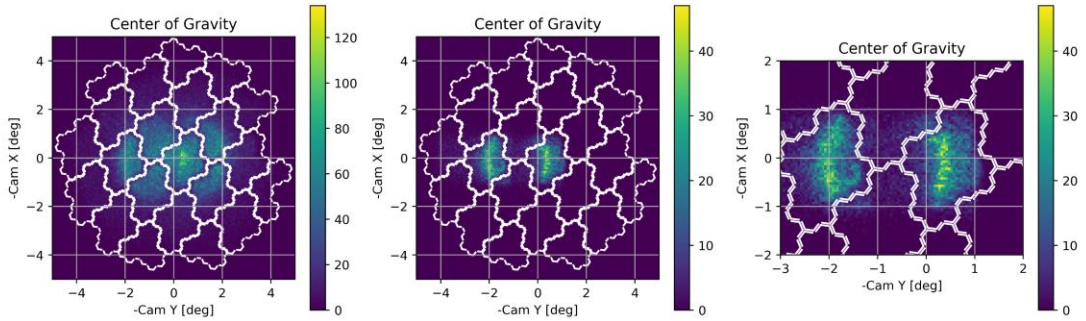
‚Depleted‘ region



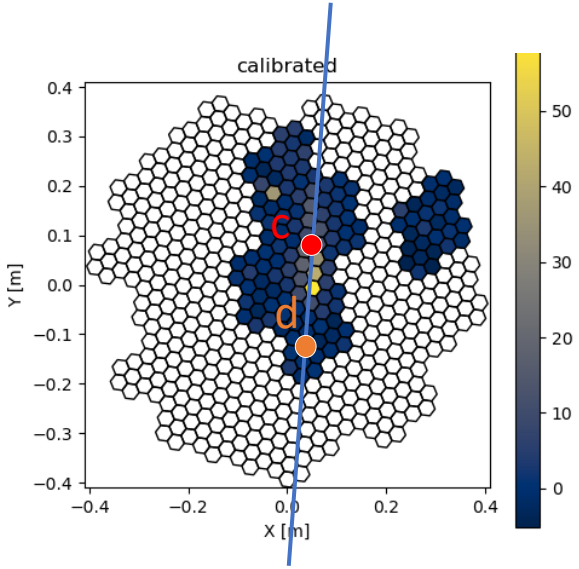


Bright region





Stereo reconstruction method

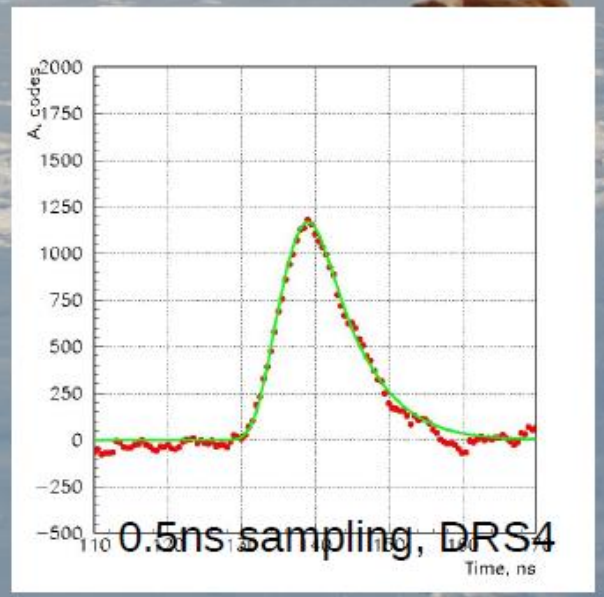


- Center of Gravity c
- Point along major axis d

1. Get alt and az of c and d
2. Get unit vectors $\overrightarrow{c_i}$ and $\overrightarrow{d_i}$ for c and d in ground coordinates: $\begin{pmatrix} \cos alt \cos az \\ \cos alt \sin az \\ \sin alt \end{pmatrix}$
3. Calculate plane normals via cross product $\overrightarrow{n_i} = \overrightarrow{c_i} \times \overrightarrow{d_i}$
4. Define planes via normals and telescope positions $\overrightarrow{P_i}$: $\overrightarrow{n_i} \cdot (\vec{X} - \overrightarrow{P_i}) = 0$
5. Intersect planes at Z = 0

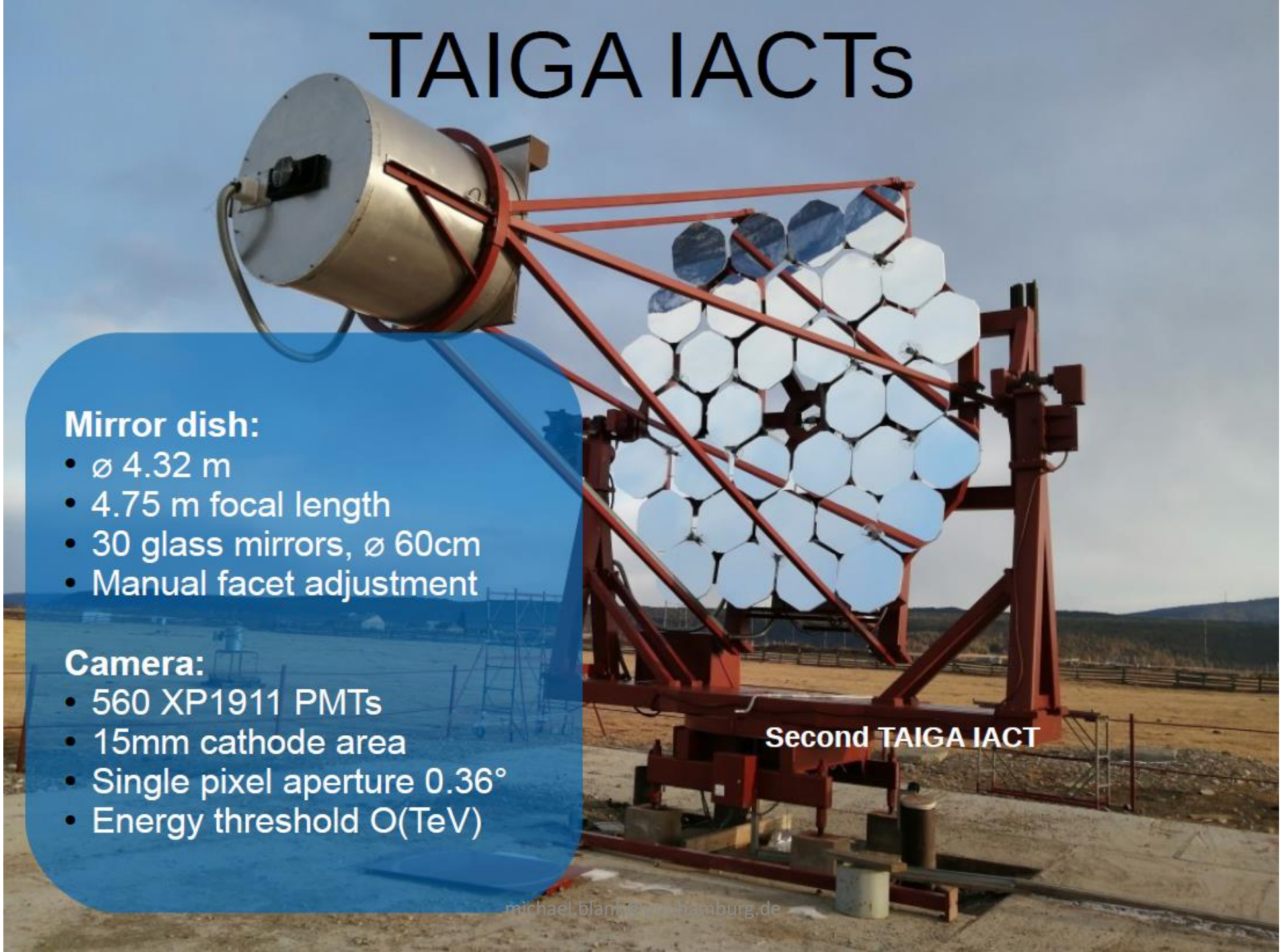
TAIGA timing stations

- 0.5 m² light collection, FoV ~0.6 sr
- “Tilting” for extension of sky coverage
- **Sub-ns** array-wide time synchronization



0.5ns sampling, DRS4

TAIGA IACTs



Mirror dish:
- ⌀ 4.32 m
- 4.75 m focal length
- 30 glass mirrors, ⌀ 60cm
- Manual facet adjustment

Camera:
- 560 XP1911 PMTs
- 15mm cathode area
- Single pixel aperture 0.36°
- Energy threshold O(TeV)

Second TAIGA IACT