# TeV to PeV Gamma-ray Astronomy with TAIGA

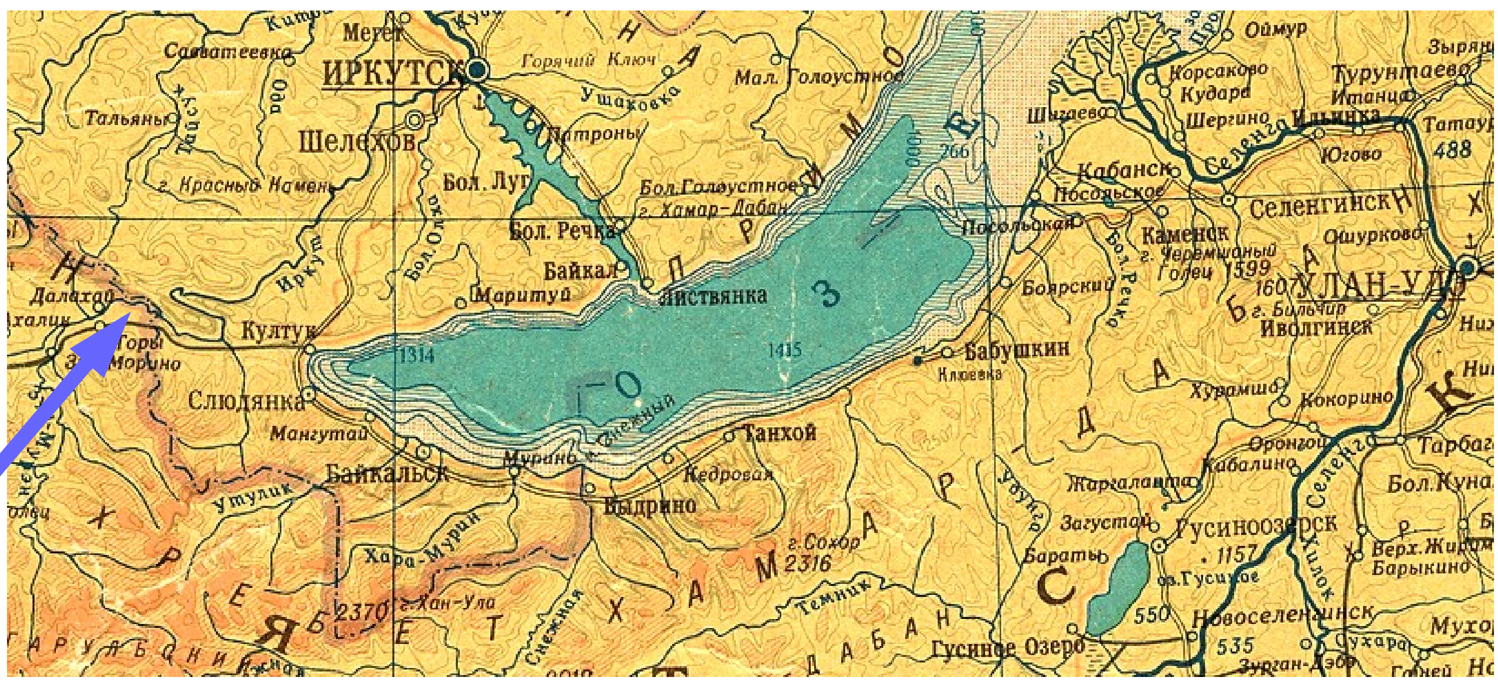
http://taiga-experiment.info/

M. Tluczykont for the TAIGA Collaboration

Marcel-Grossmann-Meeting 2018, Roma

# TAIGA collaboration

- *Skobeltsyn Institute of Nuclear Physics MSU, Moscow, Russia*
- *Institute of Applied Physics, ISU, Irkutsk, Russia*
- *Institute for Nuclear Research of RAN, Moscow, Russia*
- *Max-Planck-Institute for Physics, Munich, Germany*
- *Institut für Experimentalphysik, University of Hamburg, Germany*
- *IZMIRAN, Moscow Region, Russia*
- *DESY, Zeuthen, Germany*
- *National Research Nuclear University MEPhI, Moscow, Russia*
- *JINR, Dubna, Russia*
- *Novosibirsk State University, NSU, Novosibirsk, Russia*
- *Budker Institute of Nuclear Physics SB RAS, Novosibirsk, Russia*
- *ISS, Bucharest, Romania*




**Tunka-133 site**

Detection techniques

Astrophysics with TAIGA

The TAIGA timing array (HiSCORE) status

The TAIGA IACT status and hybrid events

# TAIGA: Tunka Advanced Instrument for cosmic ray physics and Gamma-ray Astronomy

## TAIGA-HiSCORE timing array

## TAIGA-IACT imaging telescopes

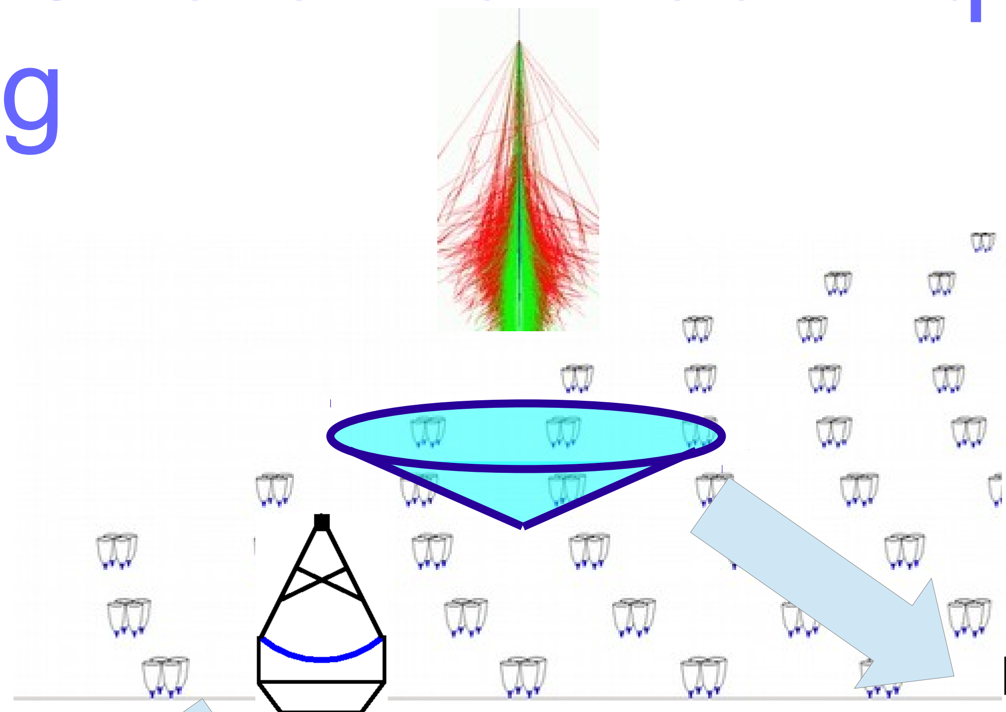
## TAIGA muon counters


Timing array:
2015: 0.25 km² / 28 stations
2017: 0.5 km² / 43 stations
2019: 1.0km² / 100 stations

Imaging:
2016/17: 1 IACT
2019: 3 IACTs

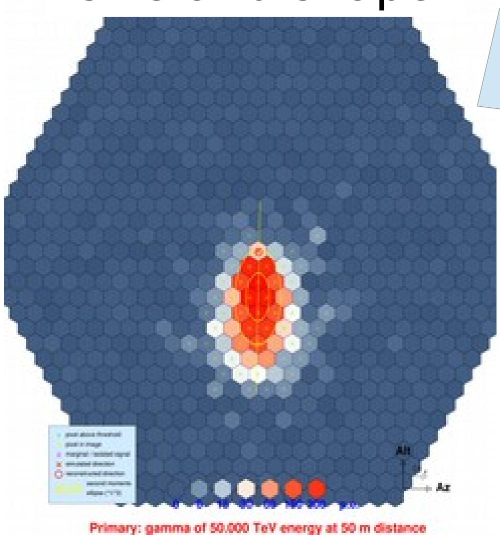
Muon scintillation detectors
Currently on-site: Tunka-Grande
Plan: (C8H8)n / 2000 m²

# Air Cherenkov techniques:
# Imaging timing



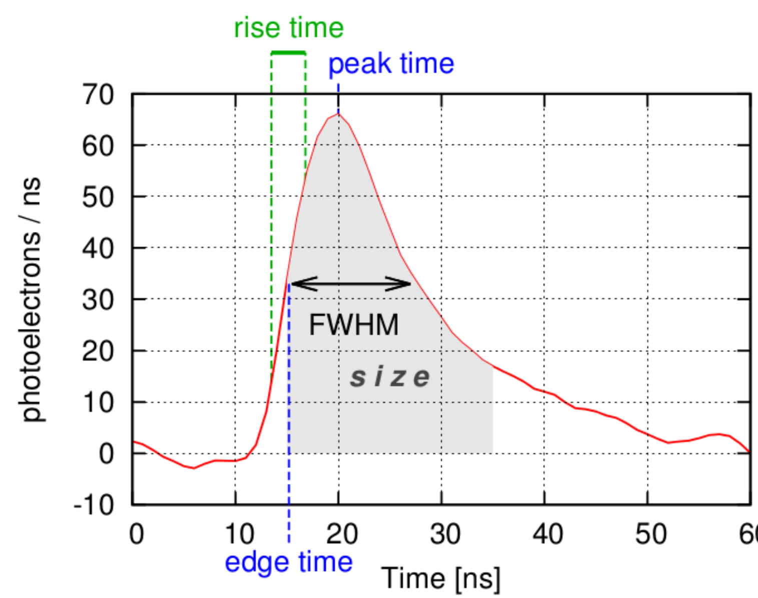
**Telescope image:**

Orientation,
size and shape

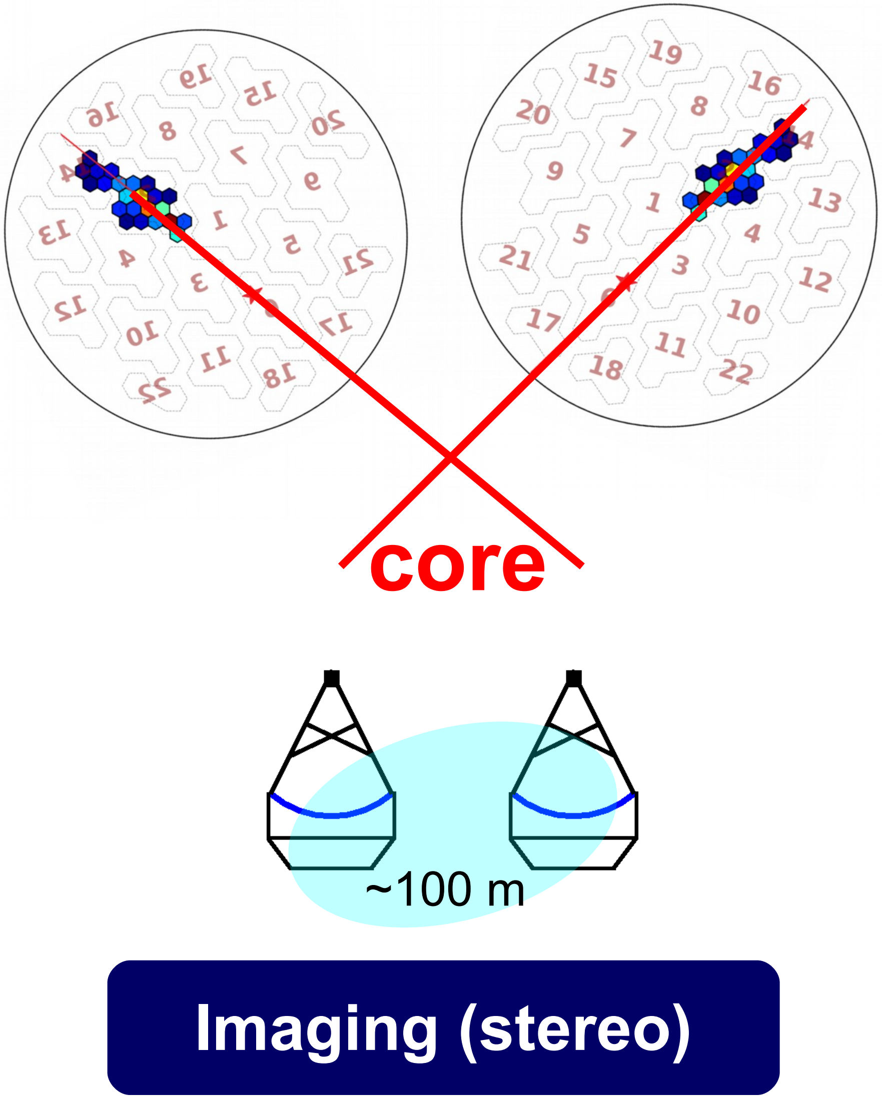


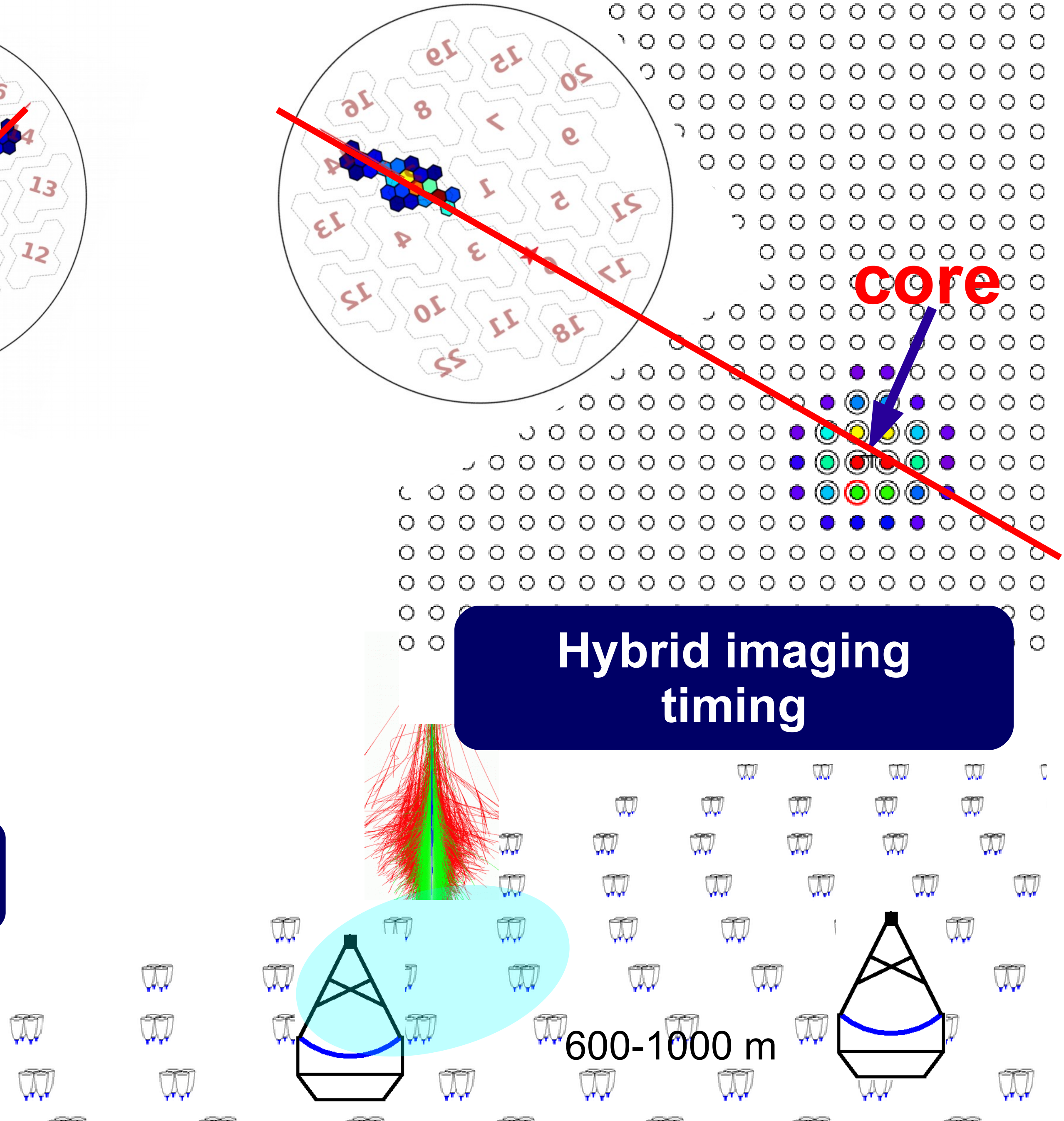

**Timing station:**

Edge time
Rise time, amplitude



# Imaging Hybrid mode



# Performance characteristics of detection techniques

| Method | $E_{thr}$ | Angular resolution | ΔE/E | γ / hadron sep. | Duty cycle |
|---|---|---|---|---|---|
| Particles | ~3 TeV<br>Water: 100 GeV | ~1°<br><0.5° | 30-50% | ~1<br>~6 | 100% |
| Cherenkov | IACTs: 5GeV<br>NonI: 10 TeV | 0.1-0.2° | 10-15% | ~4<br>~1.5-2 | 10% |
| Fluoresc. | $10^{17}$ eV | >1° | 10-15% | ? | 10% |
| Radio | $10^{17}$ eV | >1° | 10-15% | ? | 100% |

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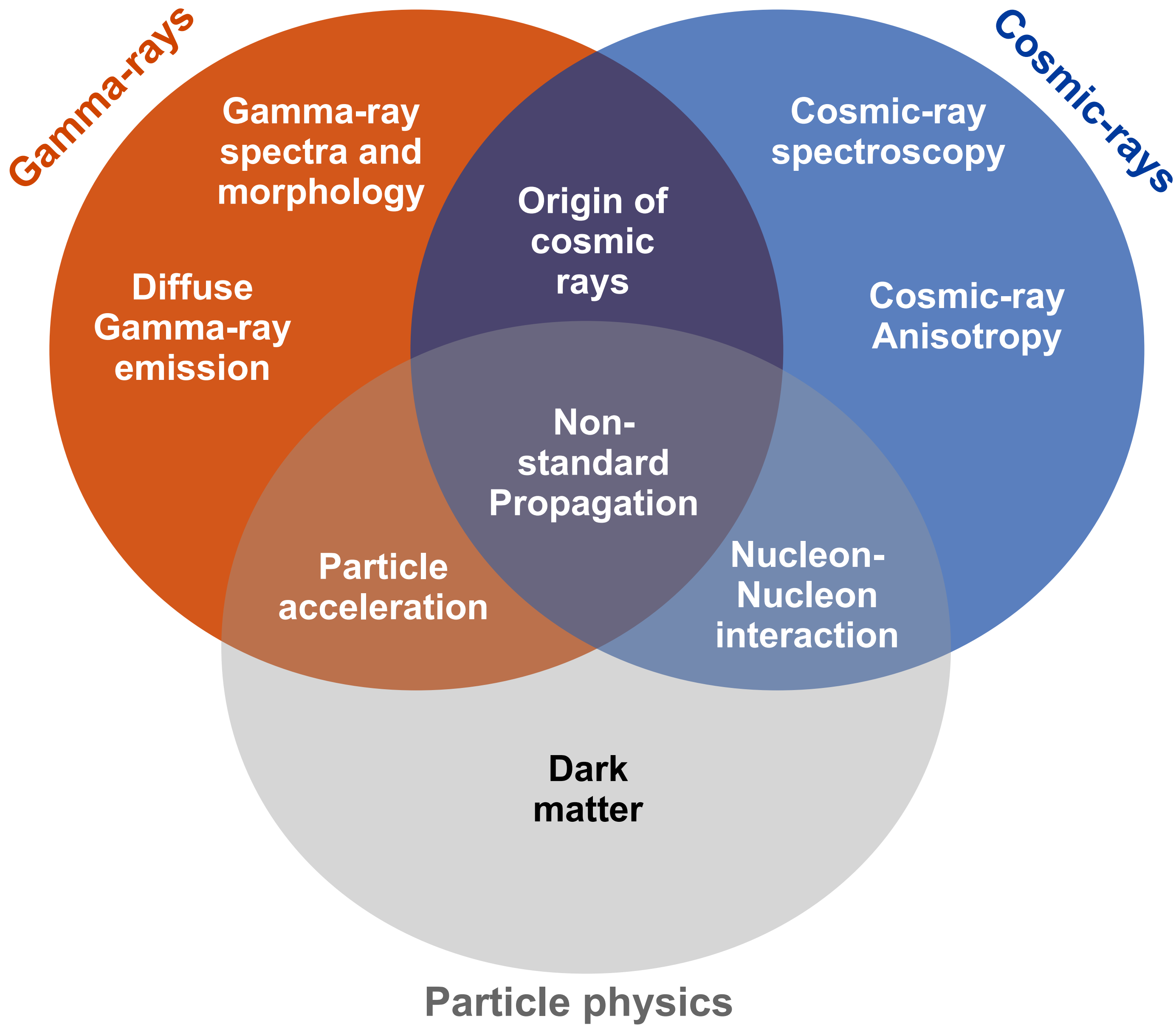
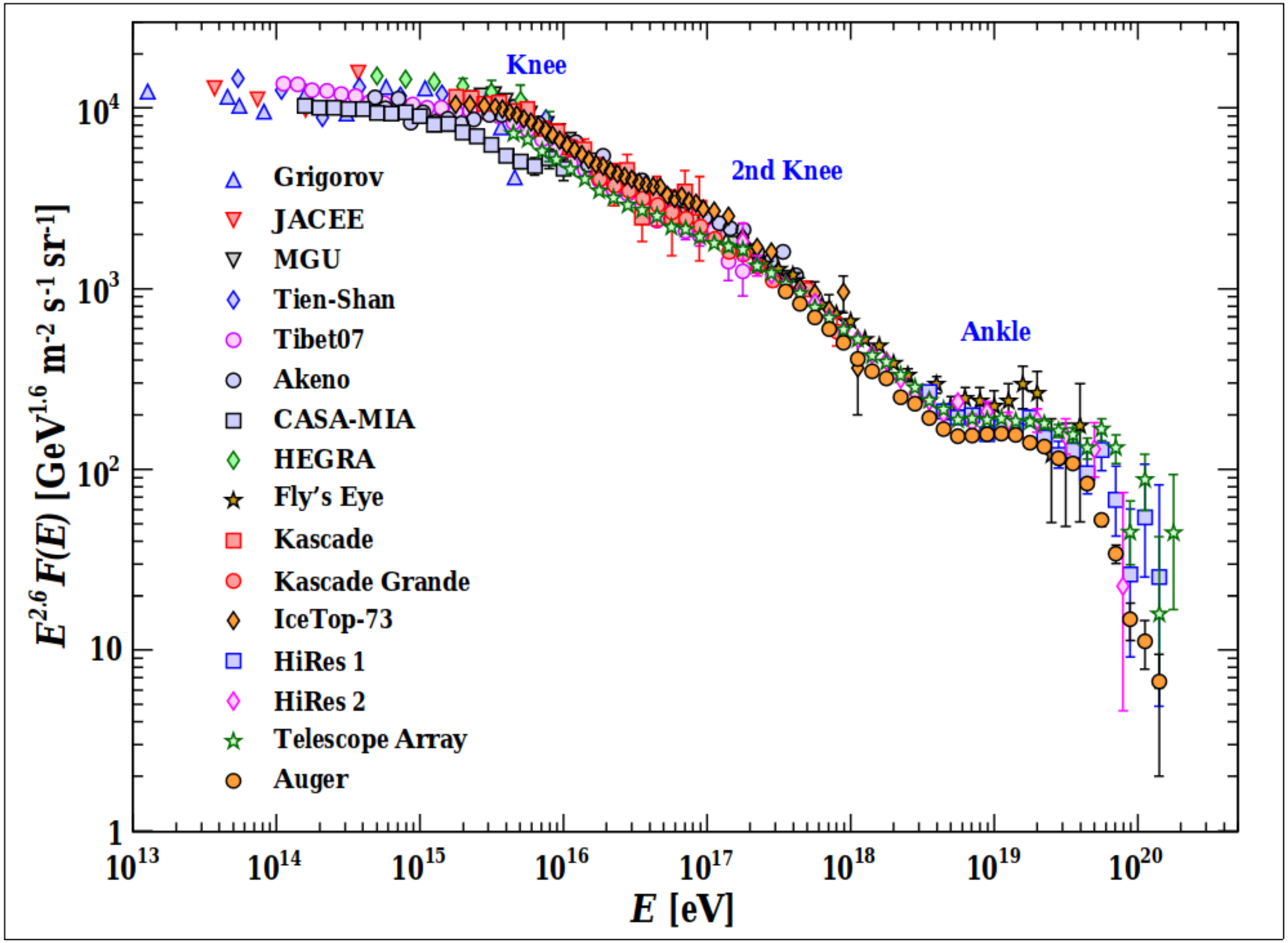
# Astrparticlephysics motivations



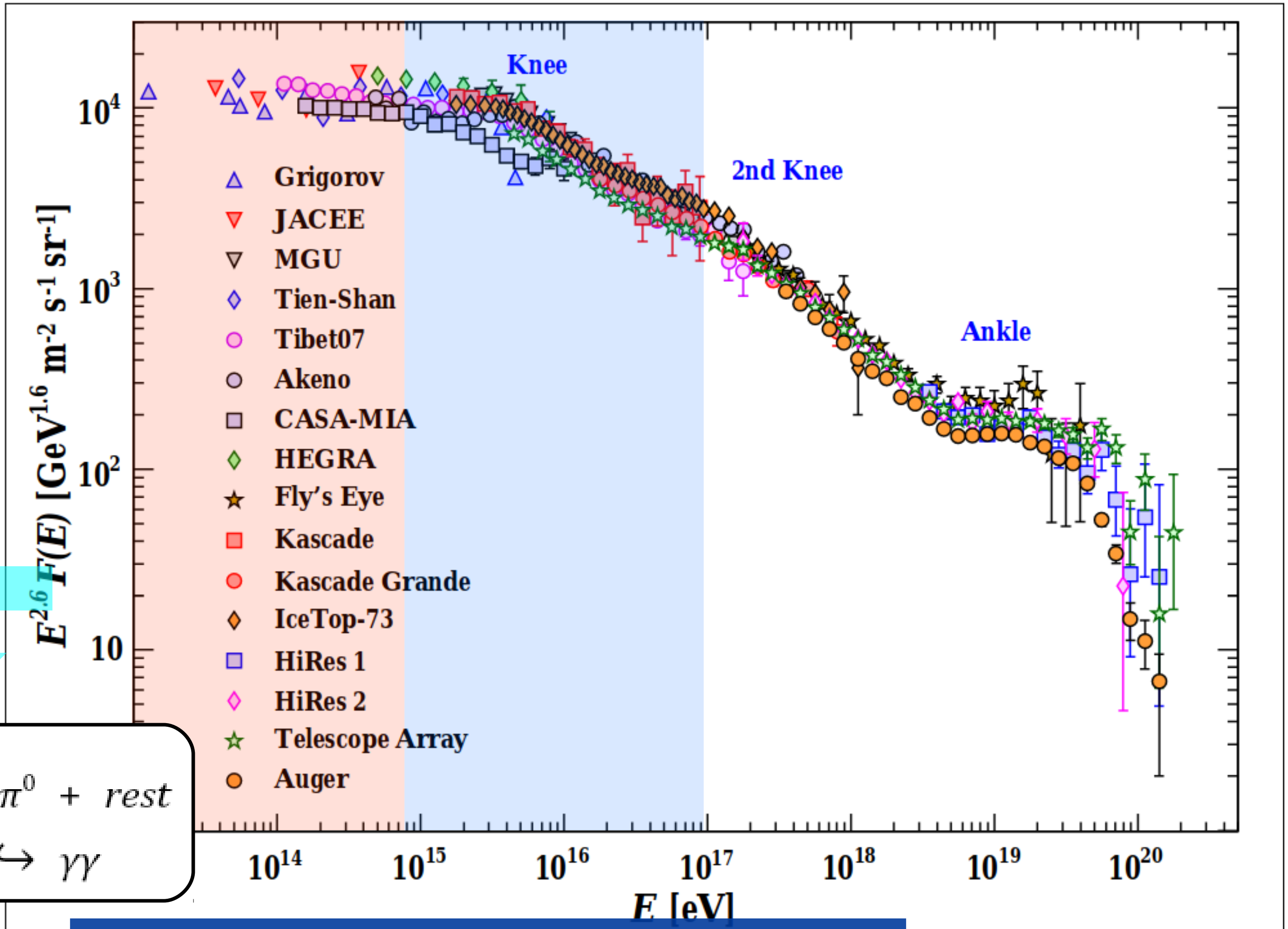
# Origin of cosmic rays




[PDG, Beatty, Mathews and Wakely 2018]

Spectrum&composition in transition range
Galactic / extragalactic origin

# Origin of cosmic rays

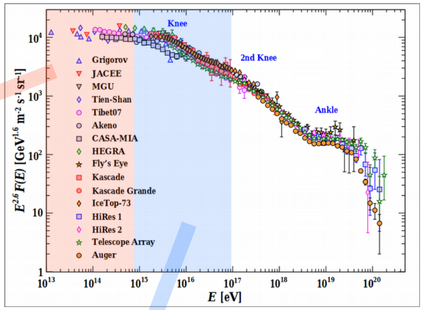


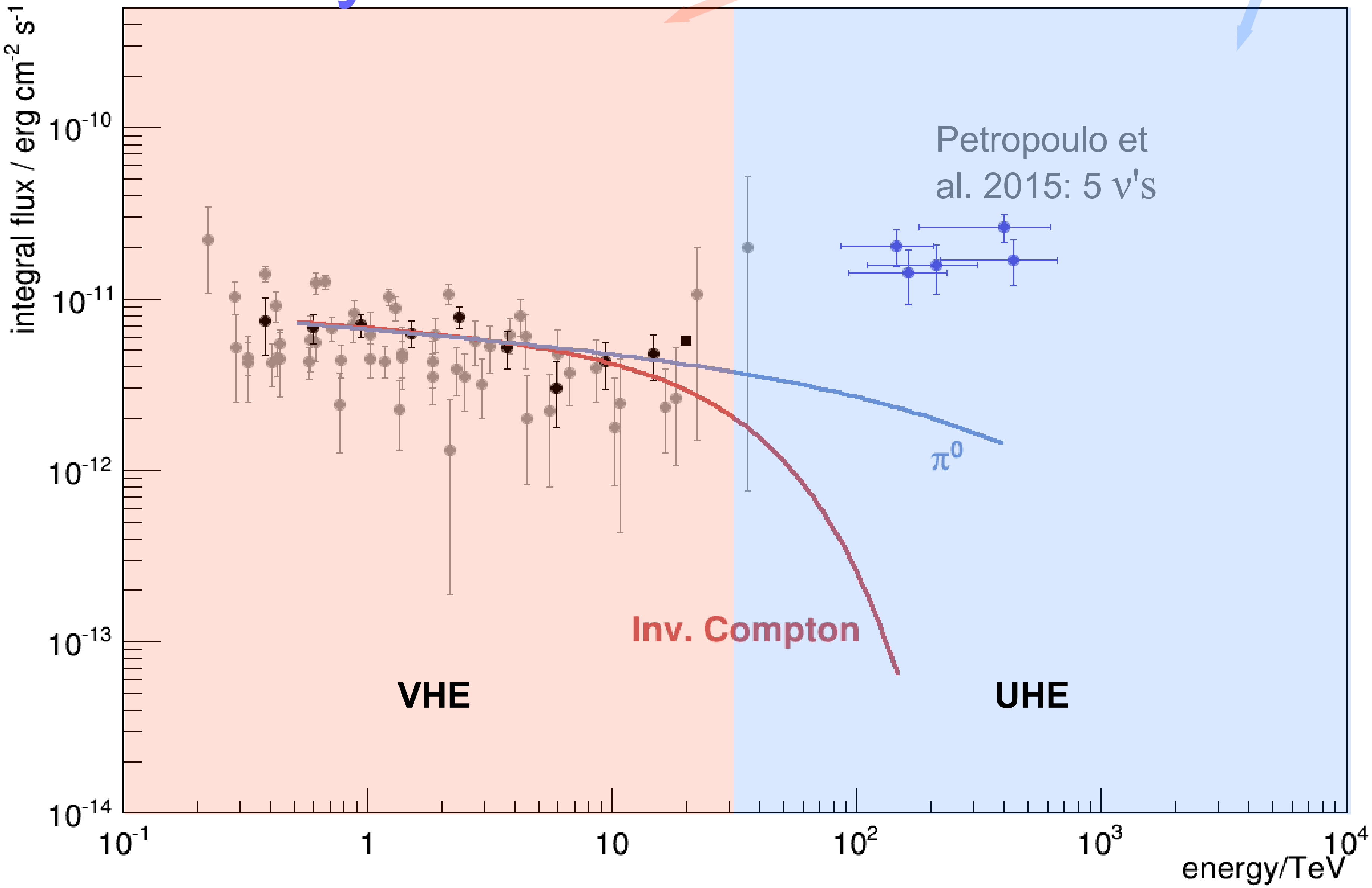

[PDG, Beatty, Mathews and Wakely 2018]

$$p \ (p, \ \gamma) \longrightarrow \pi^0 + rest$$
$$\hookrightarrow \gamma\gamma$$

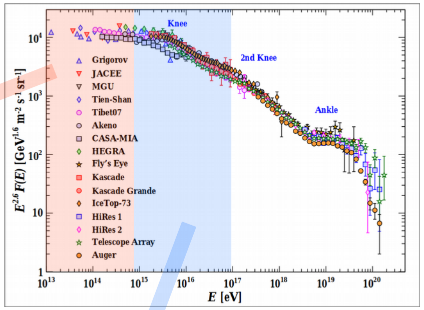
**Gammas from Galactic Cosmic rays:**
**$E_\gamma \sim E_{CR}/10$**

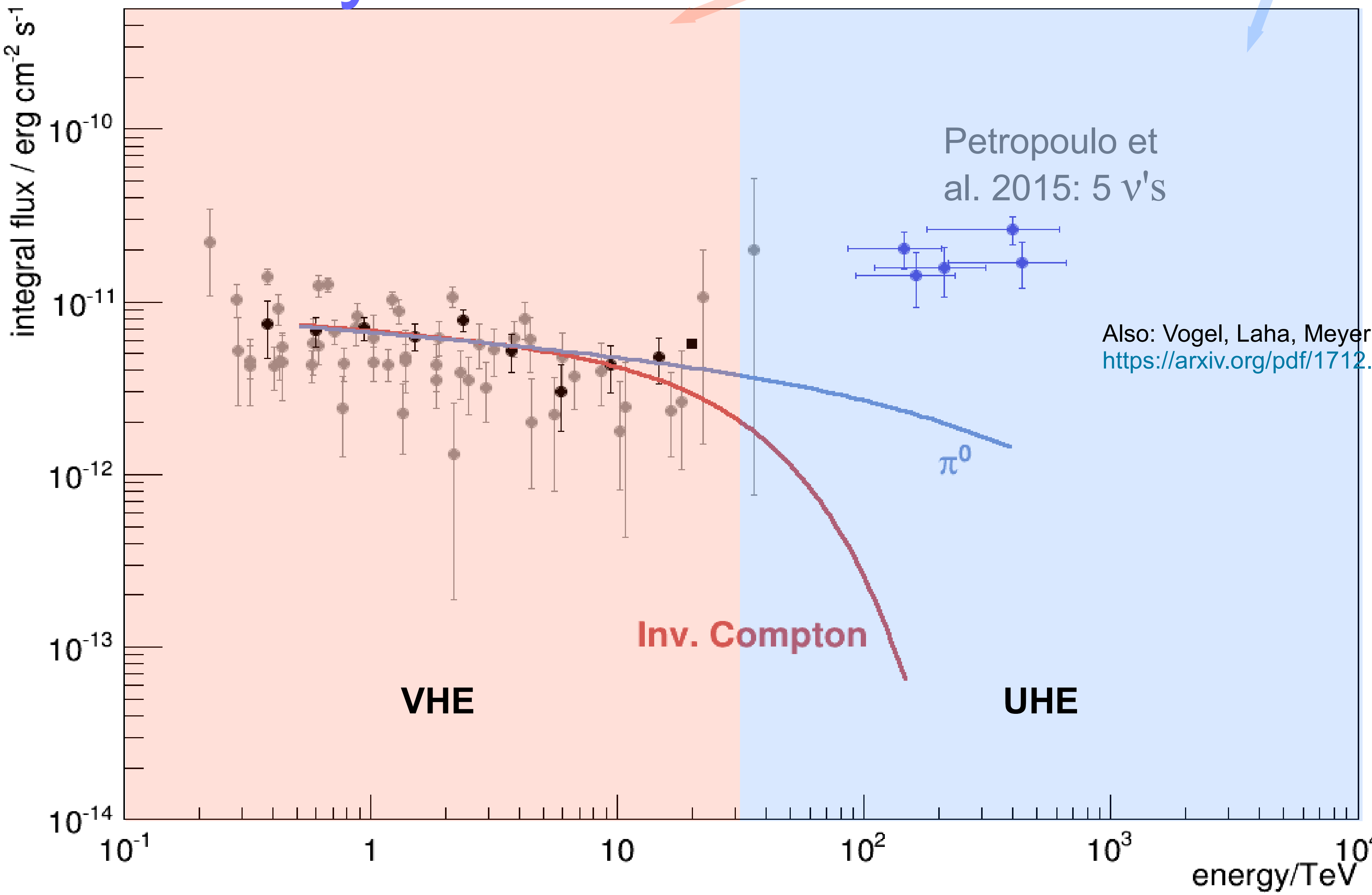
# VHE-UHE Gamma-ray astronomy



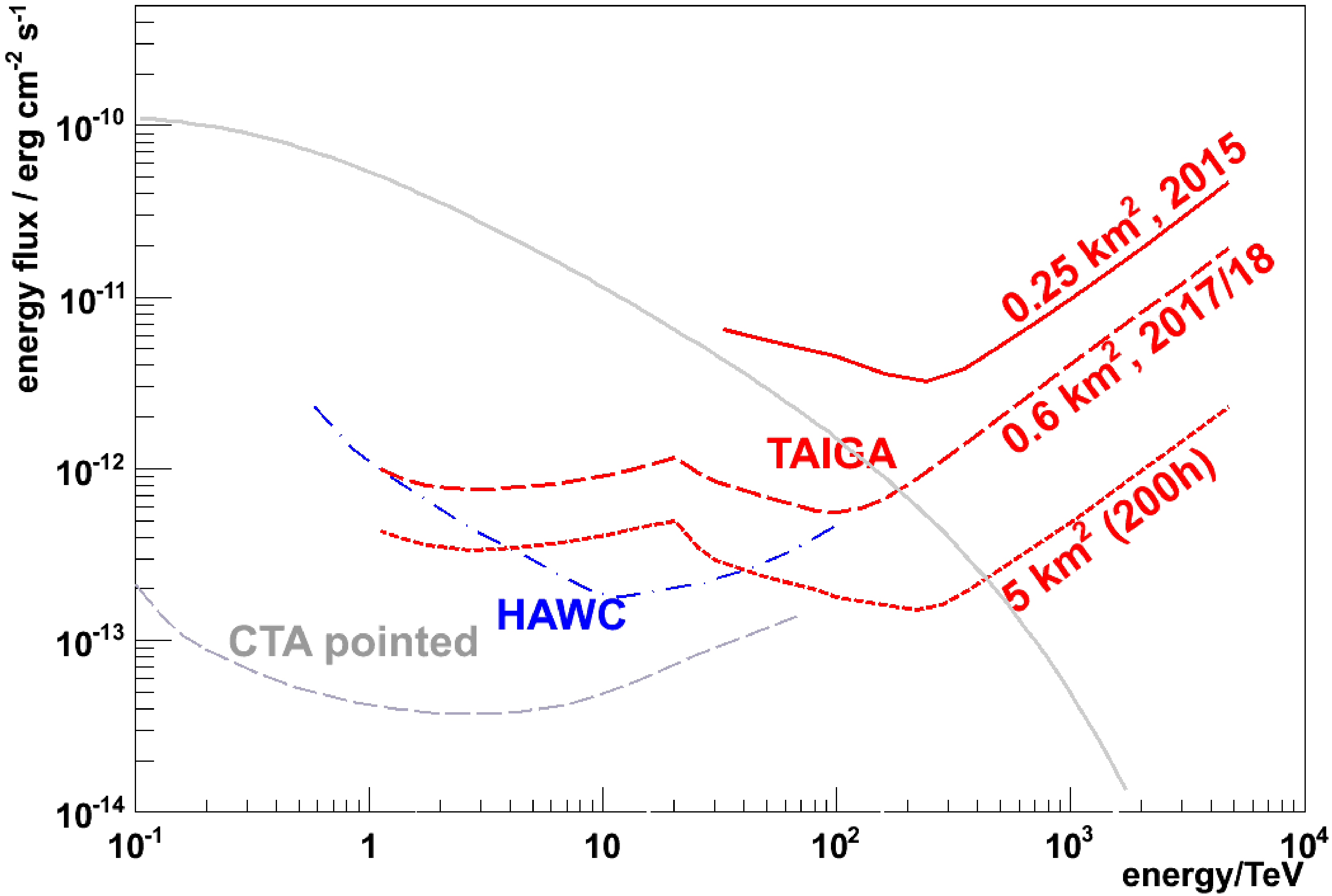
# VHE-UHE Gamma-ray astronomy




Also: Vogel, Laha, Meyer
https://arxiv.org/pdf/1712.01839.pdf

# VHE-UHE Gamma-ray Astronomy

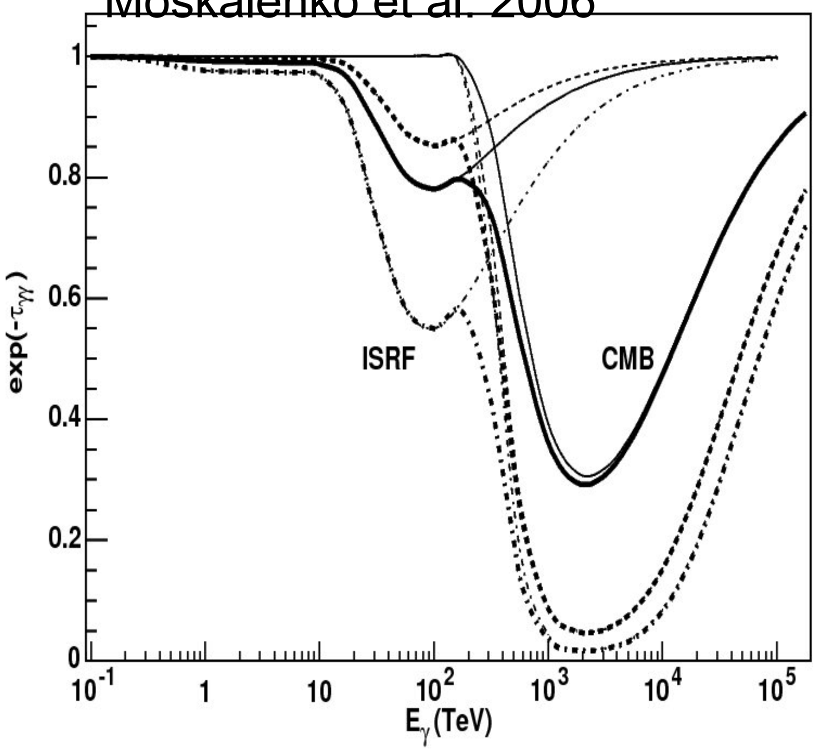



TAIGA-HiSCORE: 200 h
TAIGA-IACT: 50 h

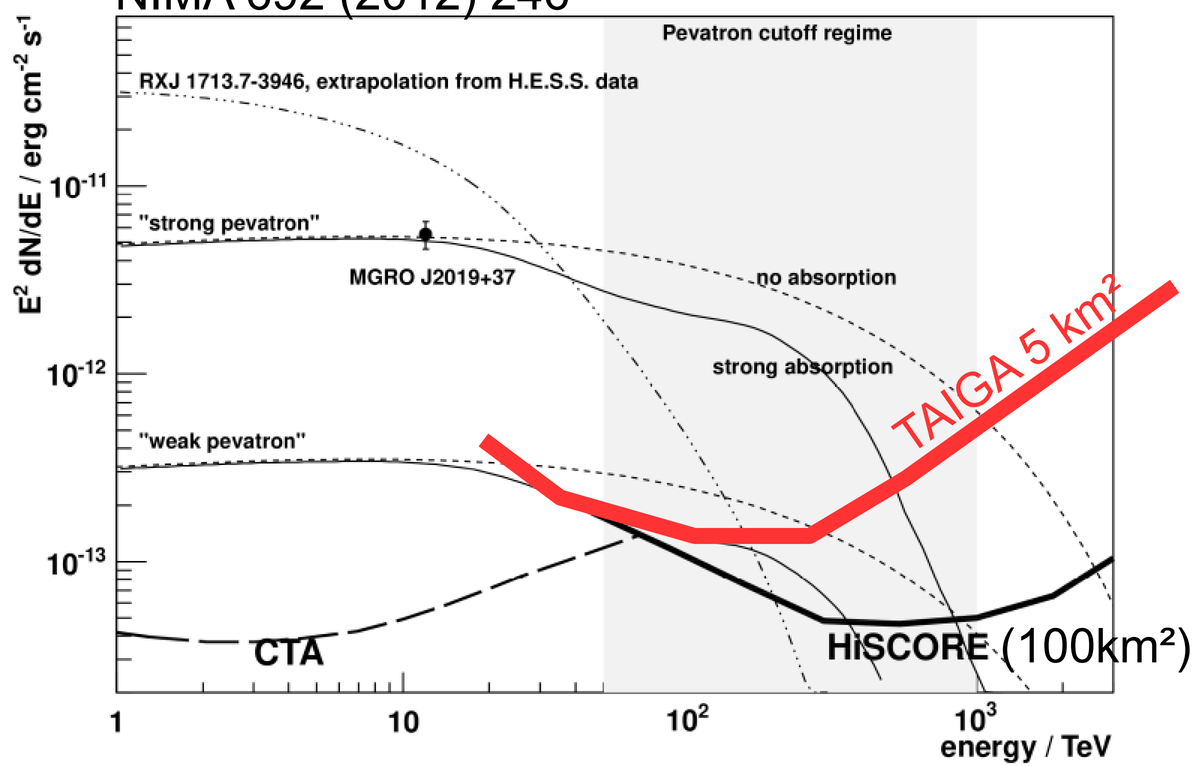
Spectral resolution: 10-20%

# Limited transparency: ISRF / CMB

Moskalenko et al. 2006

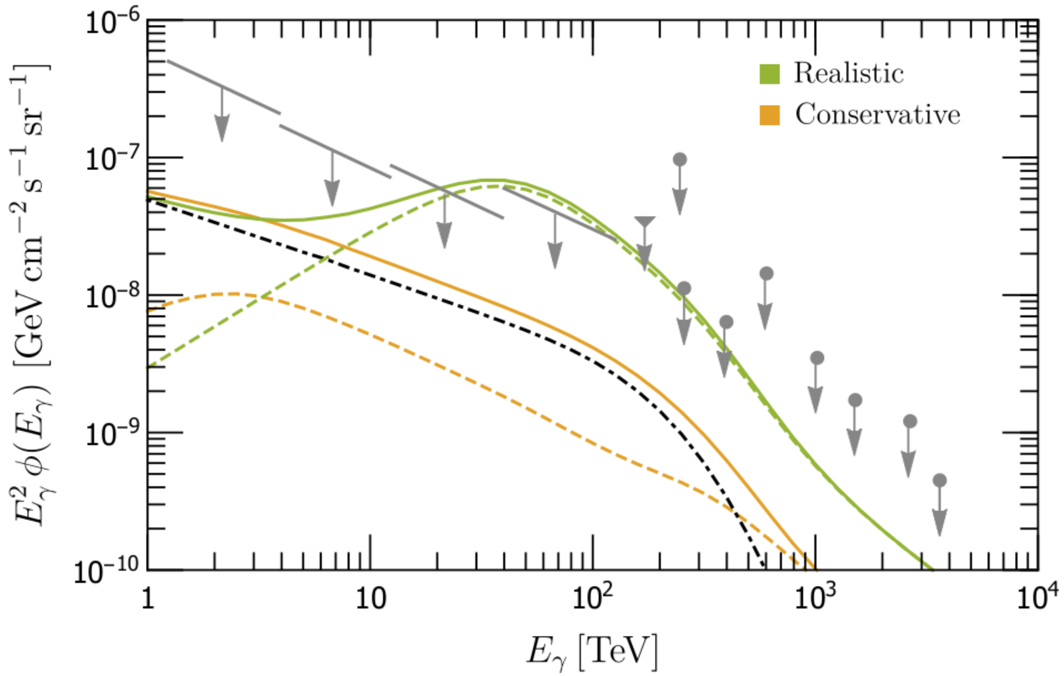



NIMA 692 (2012) 246



# Enhanced transparency: ALPs

- Photon – ALP conversion: absorption-free propagation



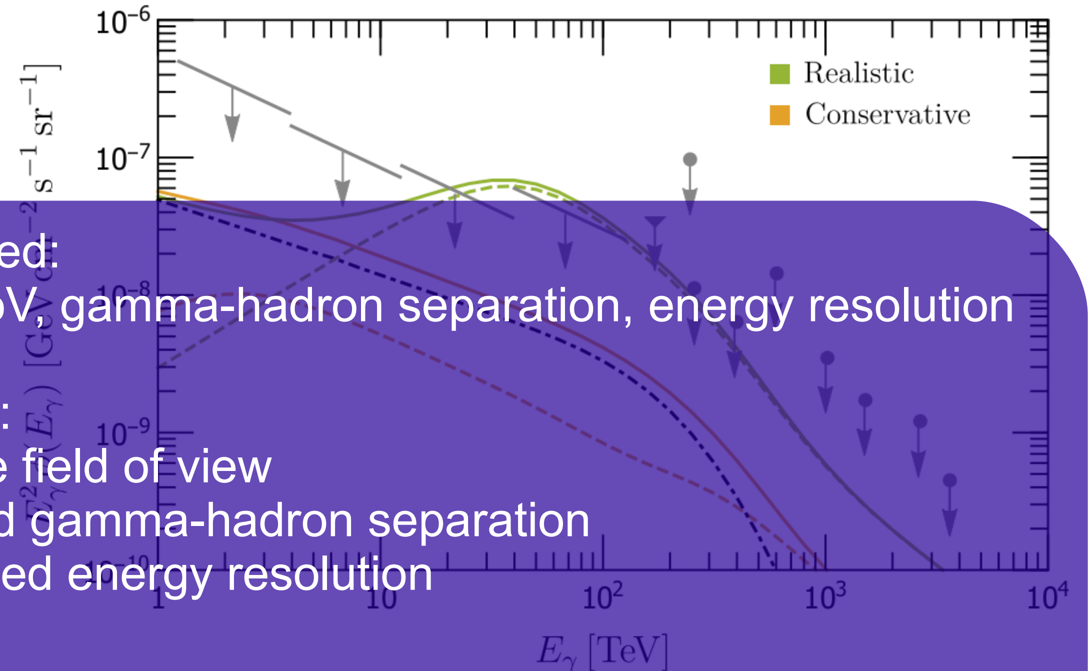

Vogel, Laha, Meyer
https://arxiv.org/pdf/1712.01839.pdf

VHE ν imply γ
Possible ALP conversion / back-conversion → diffuse γ flux

- Also see: M. Roncadelli, this session

# Enhanced transparency: ALPs

- Photon – ALP conversion: absorption-free propagation

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VHE ν imply γ
Possible ALP conversion / back-conversion → diffuse γ flux

Required:
wide foV, gamma-hadron separation, energy resolution

HAWC:
- Wide field of view
- Good gamma-hadron separation
- Limited energy resolution

TAIGA:
- Field of view: 60° (HiSCORE), 10° IACT and hybrid
- Good gamma-hadron separation in hybrid mode
- Good energy resolution

- Also see: M. Roncadelli, this session

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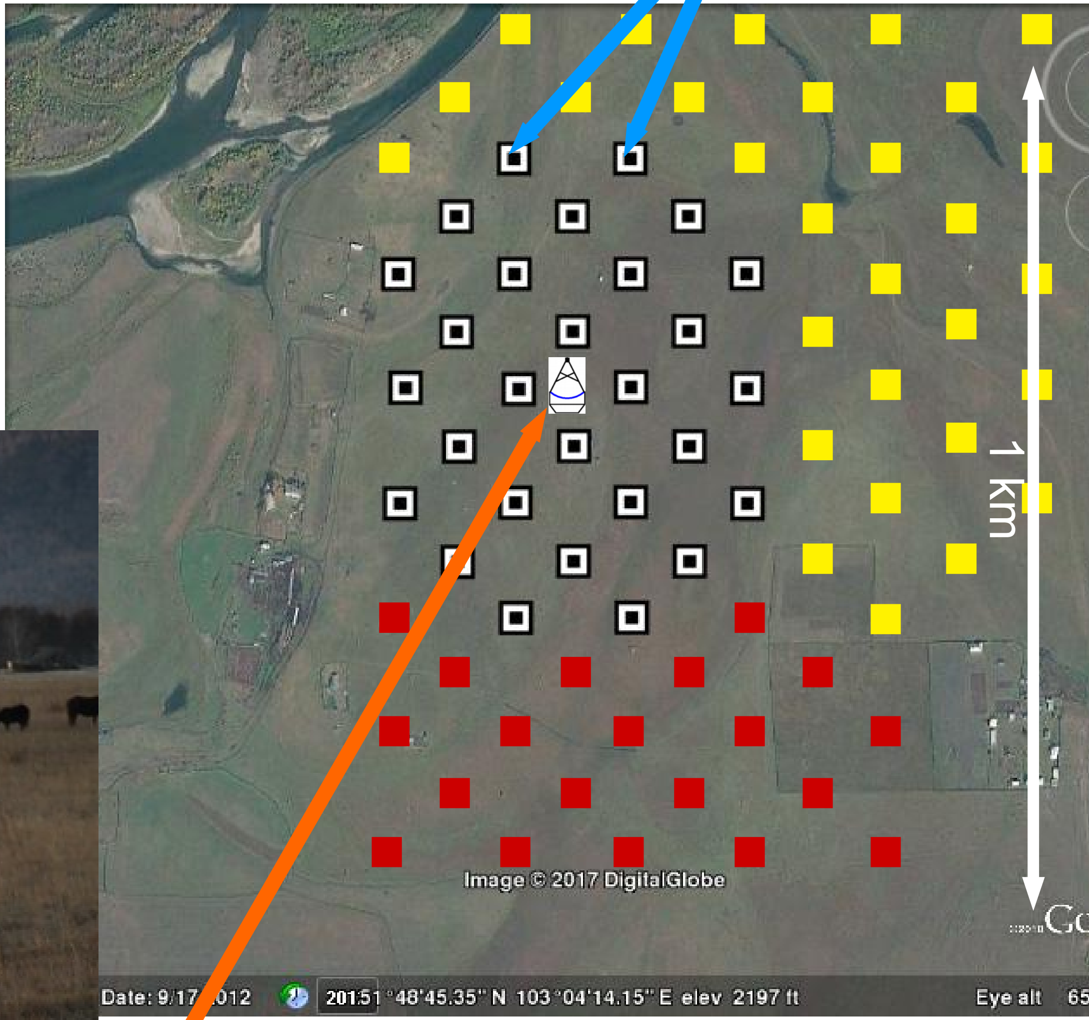
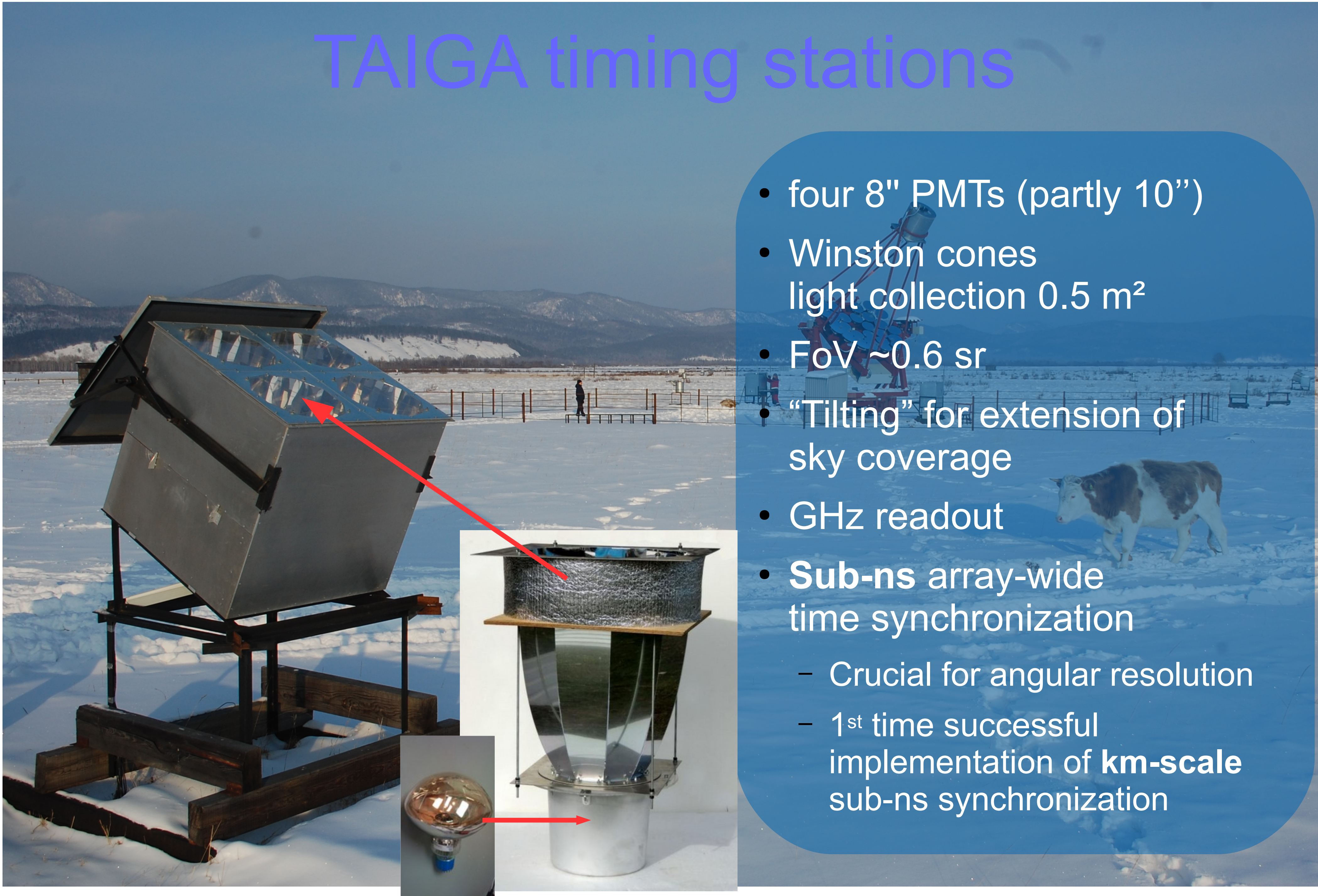
# TAIGA-HiSCORE: timing stations

- average spacing 106 m
- Recently added stations: ■
- Planned extension ■
- 2018: instrumented area 0.5km²




TAIGA timing stations
• four 8" PMTs (partly 10'')
• Winston cones
light collection 0.5 m²
• FoV ~0.6 sr
• "Tilting" for extension of sky coverage
• GHz readout
• Sub-ns array-wide time synchronization
– Crucial for angular resolution
– 1st time successful implementation of km-scale sub-ns synchronization

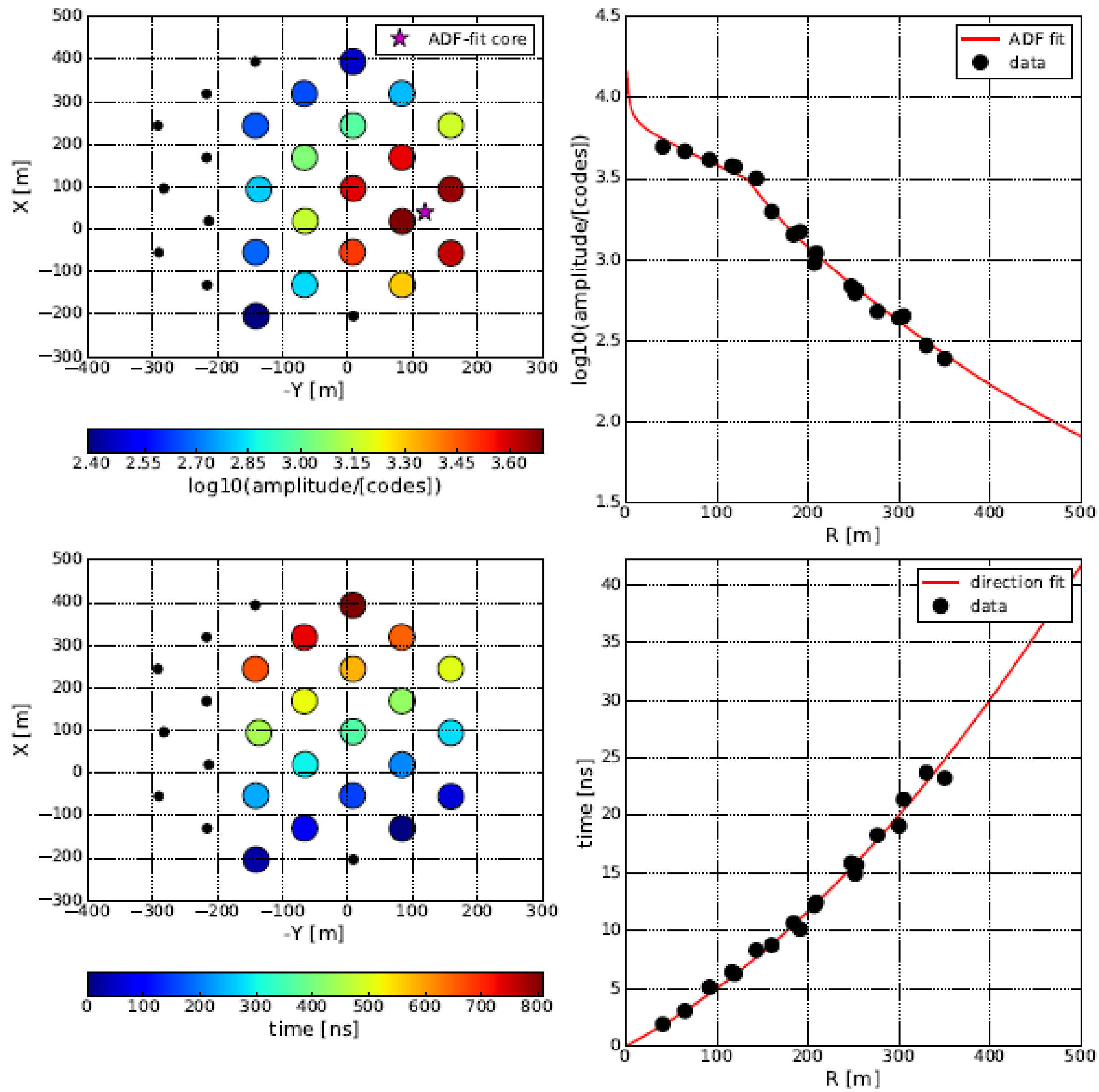
# Event reconstruction

- **Station amplitudes** (LDF/ADF)

  → core impact
  → shower depth
  → primary energy

- **Station timing:** (cone fit / time-model)

  → primary direction

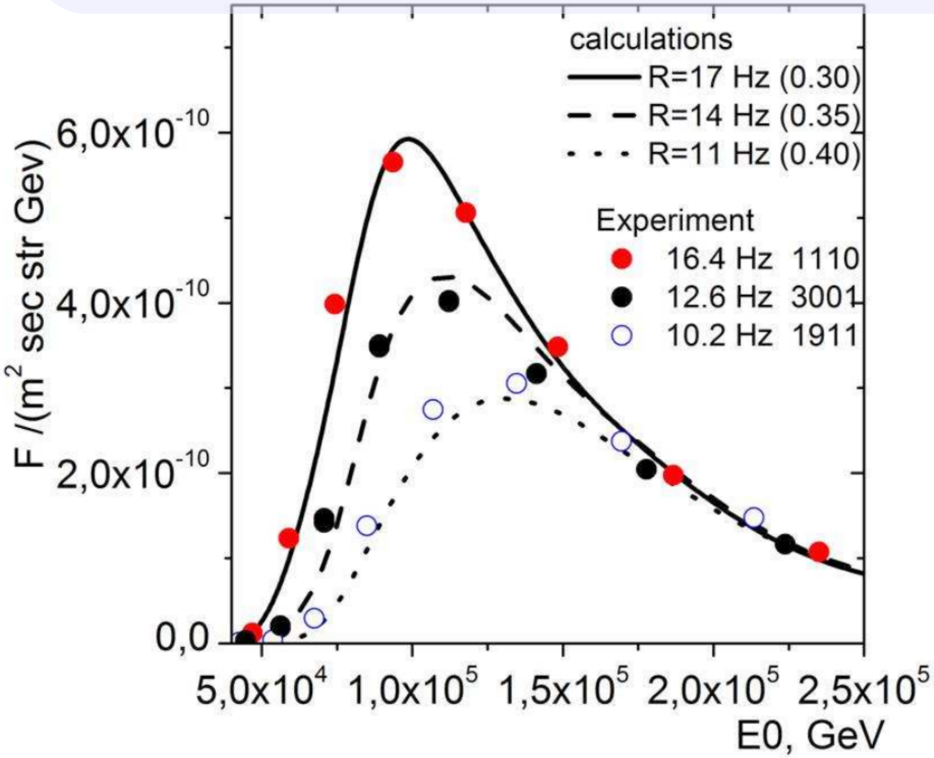


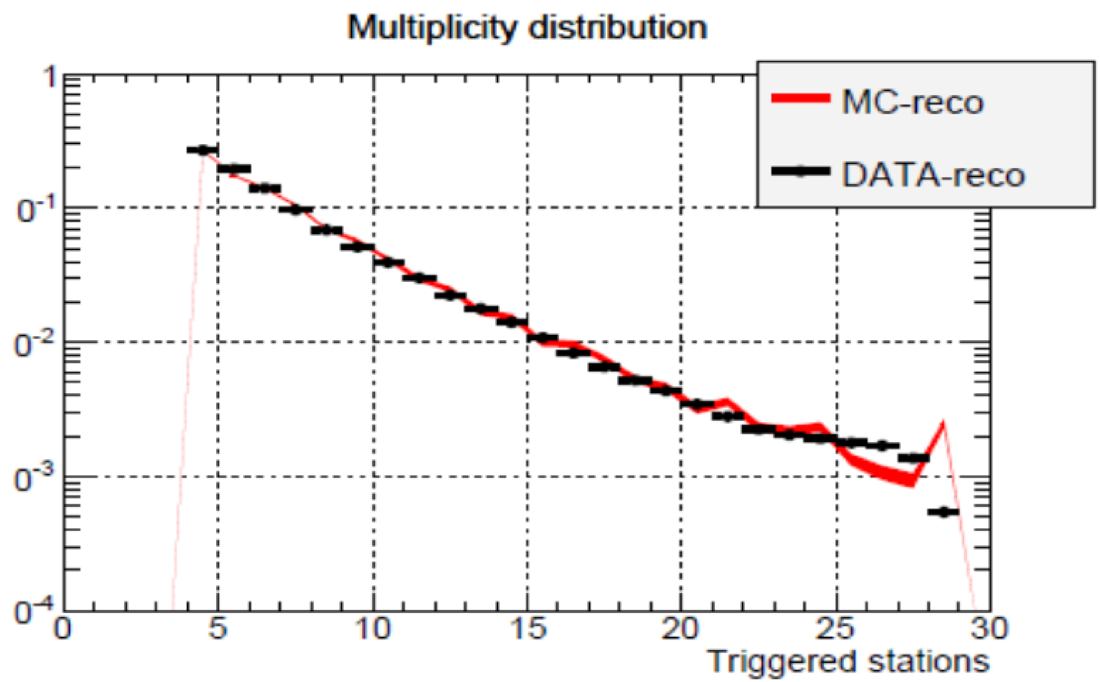
# Data-MC comparison: rates

Single station trigger rates
Data reproduced with MC-$A_{thr}$ ~ 250 p.e.

Multiplicity

28 station array: Data / MC

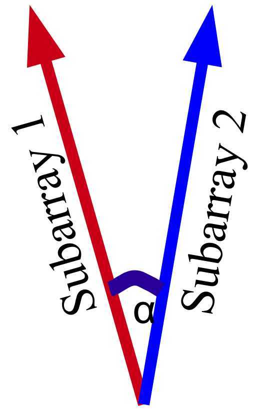


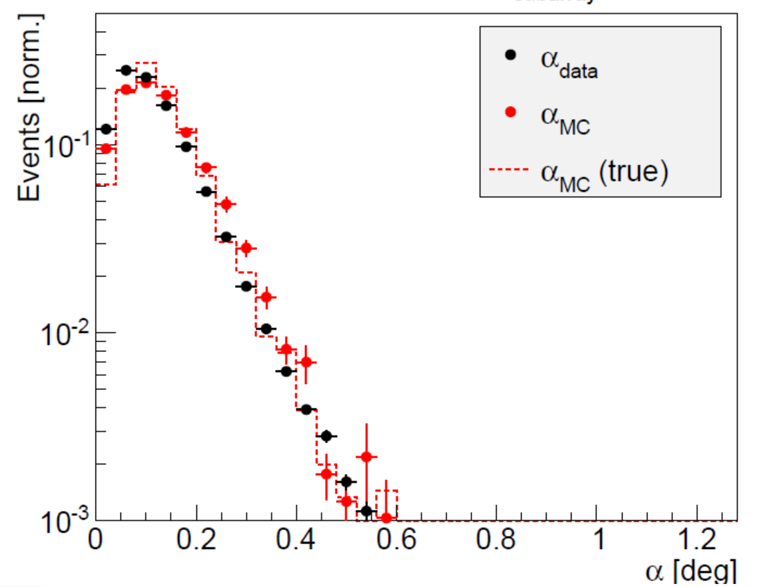



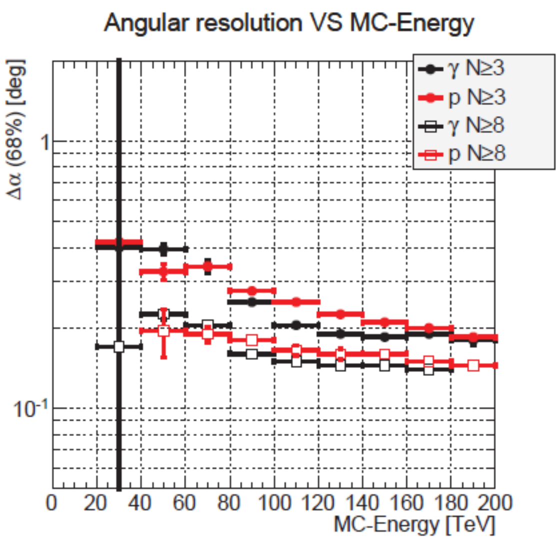

Protons: Ethr ~ 100 TeV
Gammas: Ethr ~ 50 TeV

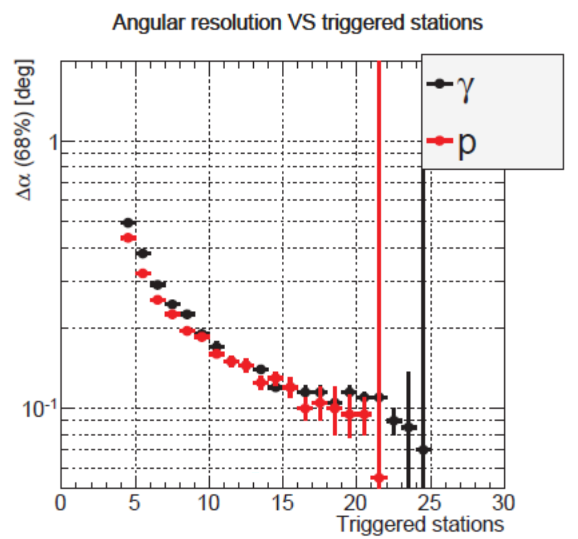
# Resolution chessboard method

Reconstruction using two different subarrays



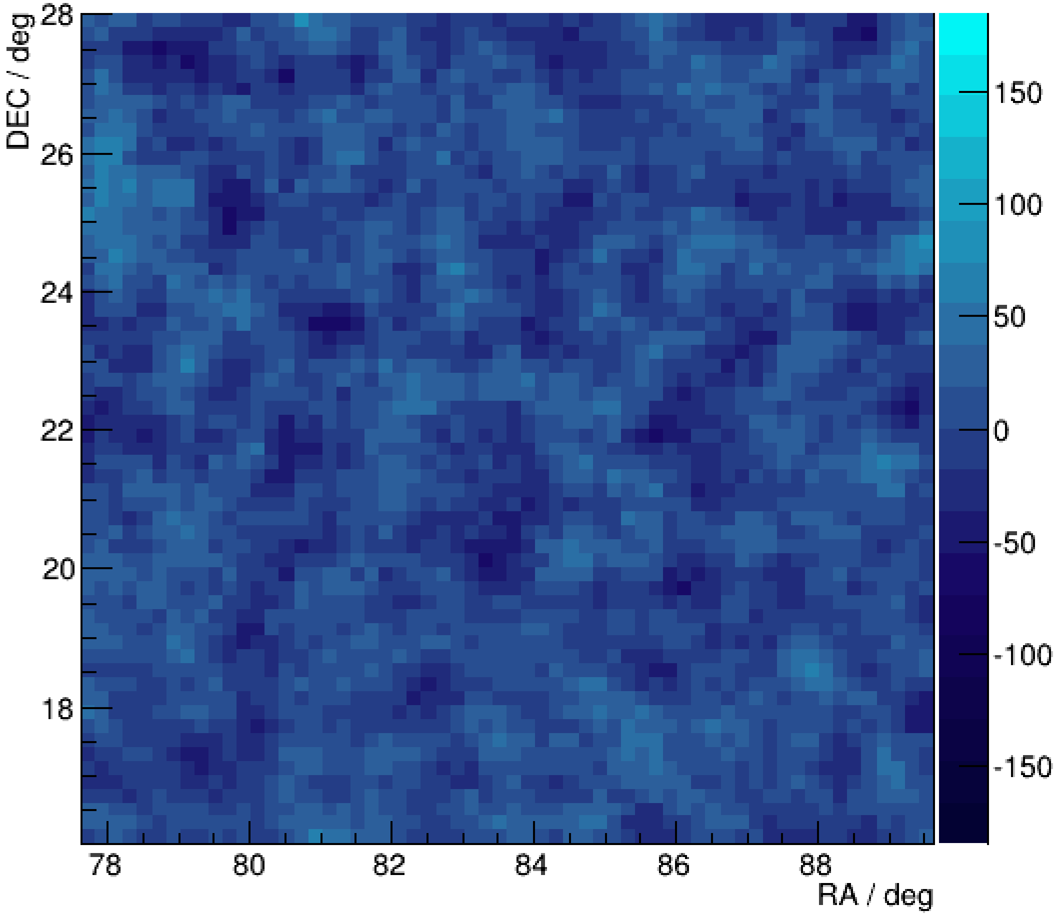



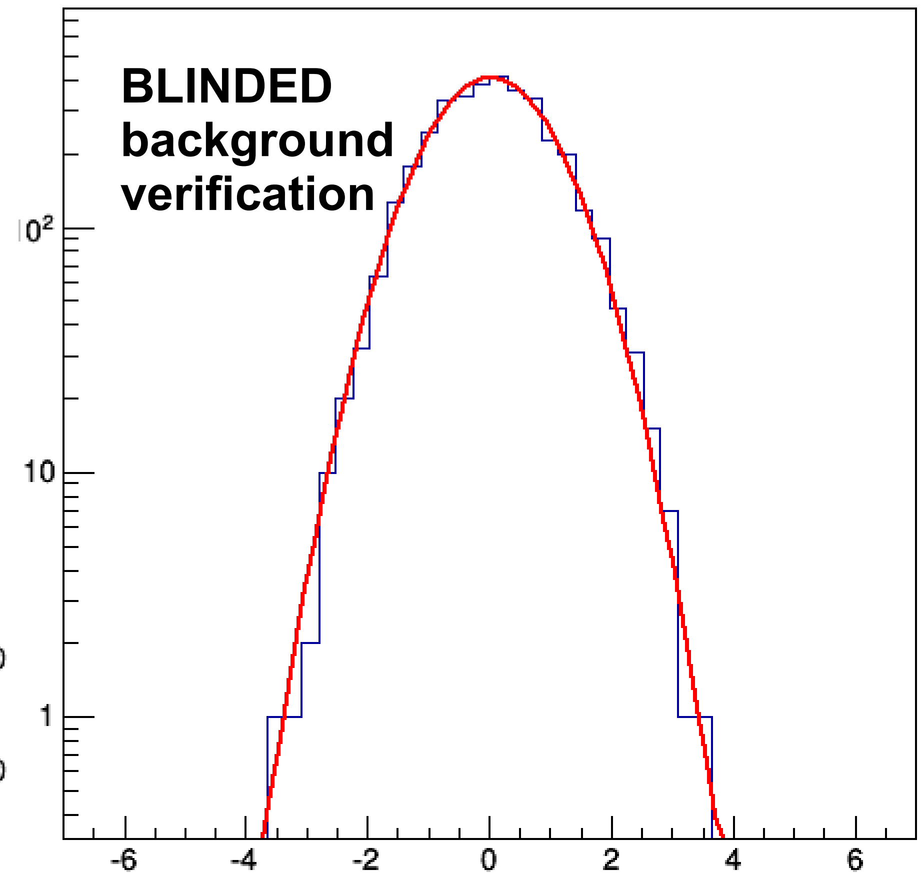




Verification of MC

# Background verification




**Excess skymap**

Excess = Non – α Noff (α = 0.05)

**Significance distribution in foV**

(Li&Ma, Eq. 9)

Blinded data

# A first Point-source

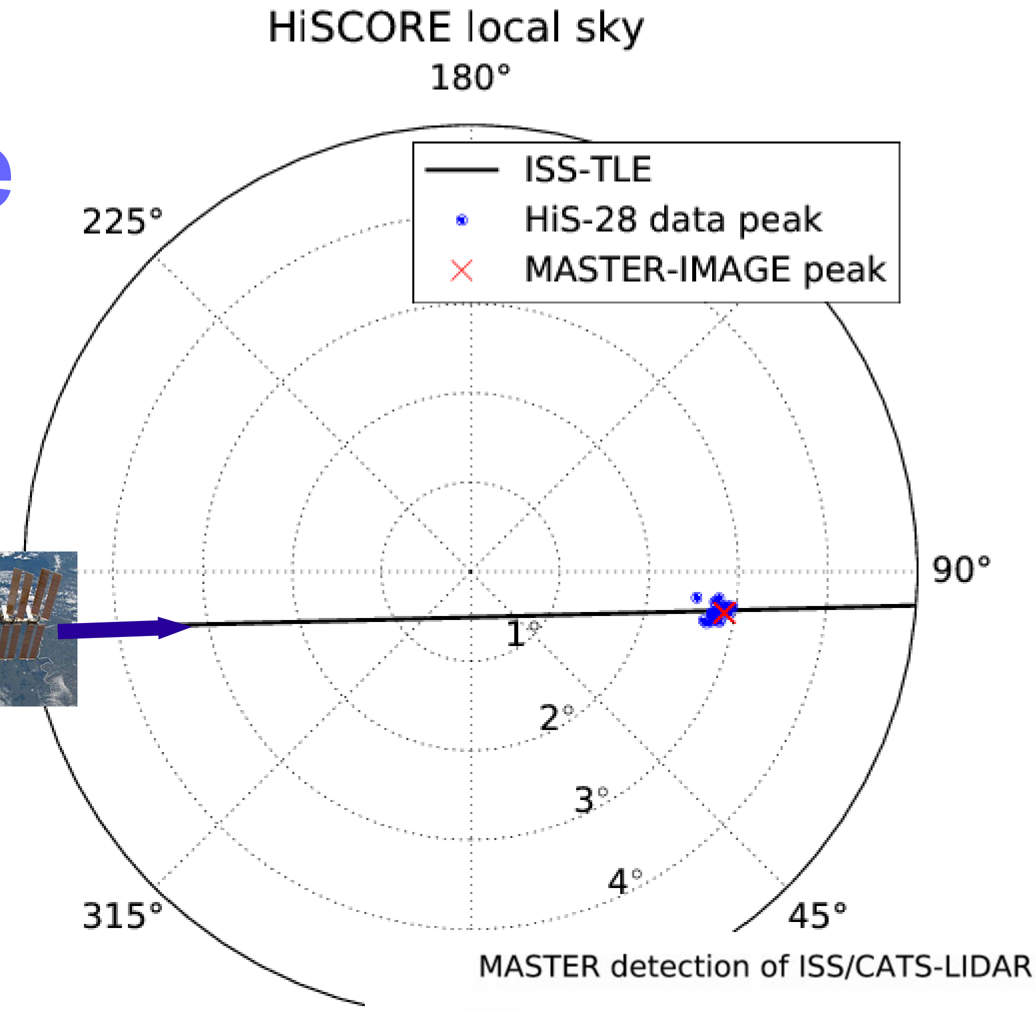
**In several nights:**

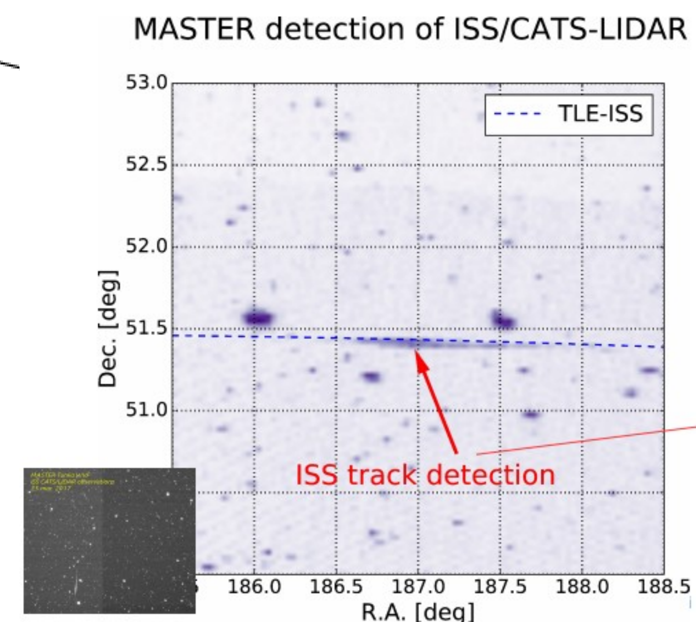
- O(s) trigger-rate “flares”,
  4 kHz pulsed emission

- Point-like emission,
  fast moving source position

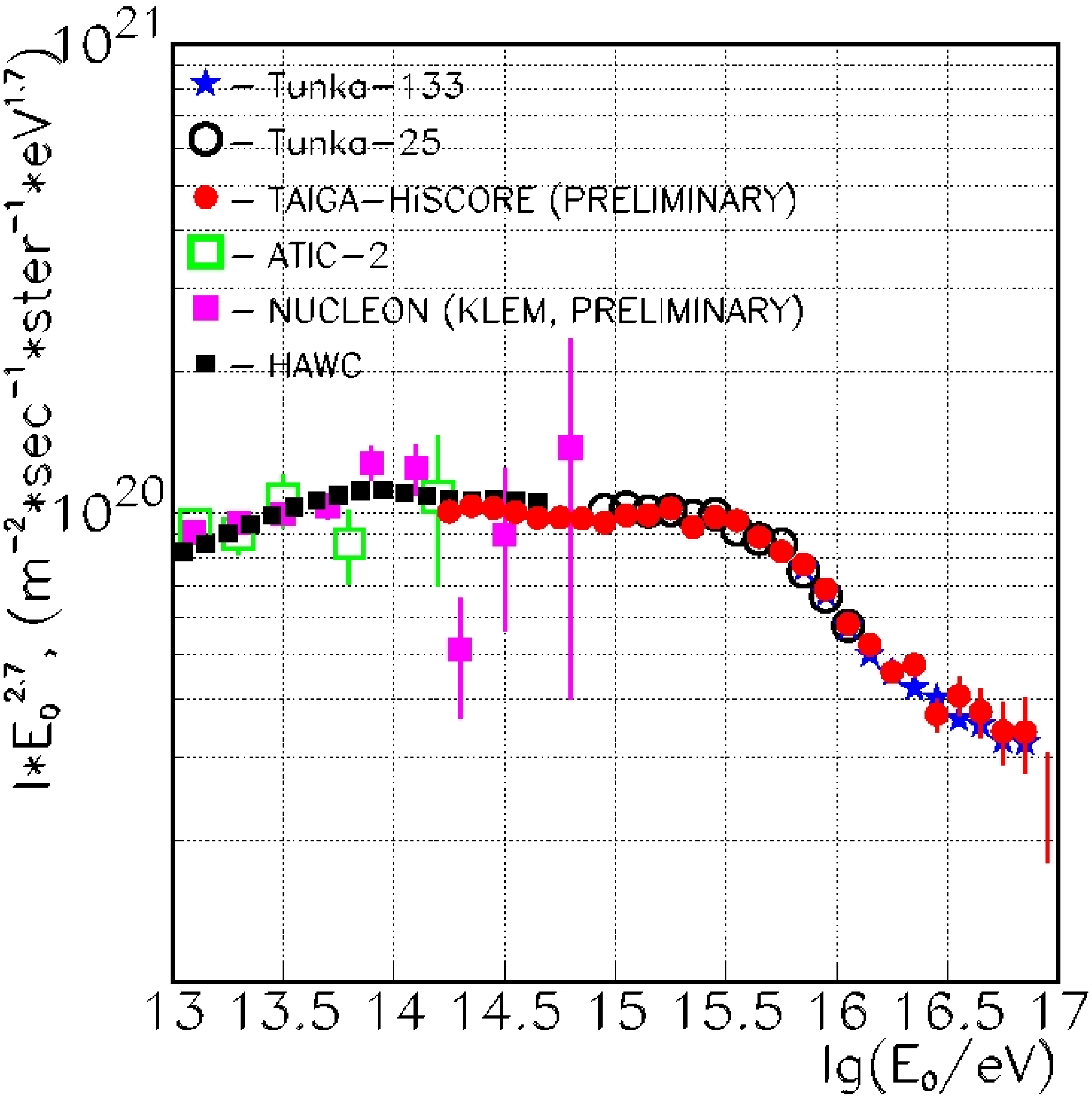
- Coincidence with ISS
  CATS LIDAR, 1.3mJ

- Data used for
  <u>absolute pointing calibration <0.1°</u>



# Cosmic ray spectrum



# TAIGA IACT status

Detection techniques

Astrophysics with TAIGA

The TAIGA timing array (HiSCORE) status

**The TAIGA IACT status and hybrid events**

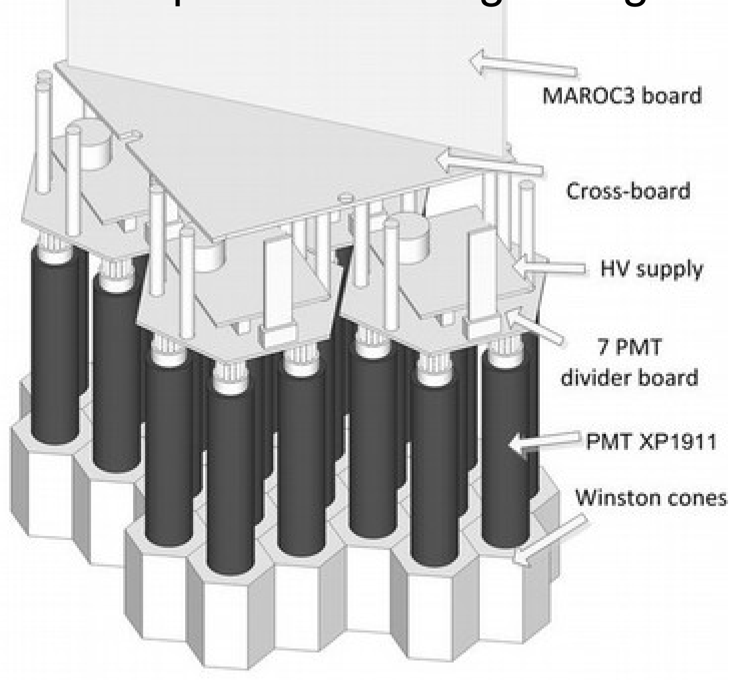
# The first TAIGA-IACT

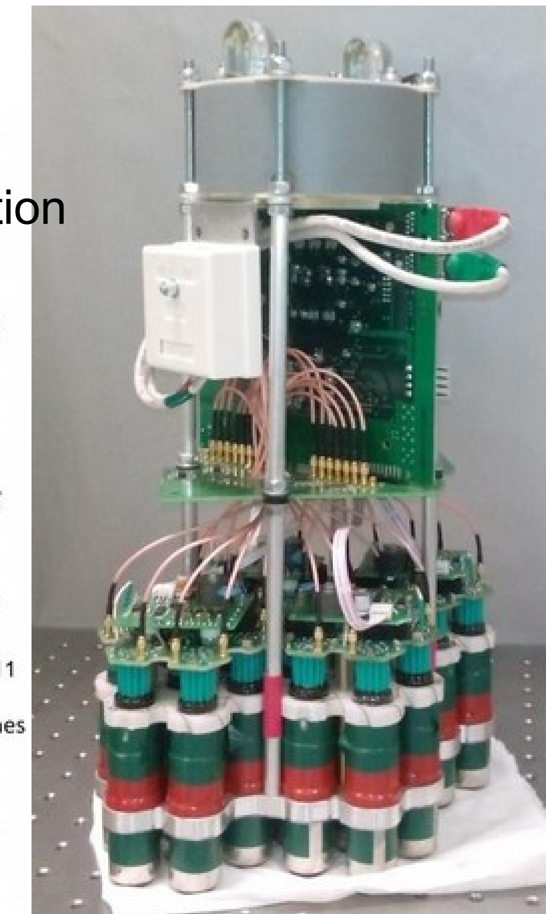
- **Camera:**
  - **547 XP1911 PMTs, 15mm diameter**
  - **Winston cones: 30mm diameter**
  - **Total FoV: 9.6°x9.6°**
- **Mount and mirrors:**
  - **60 cm mirrors (30 per telescope)**
  - **Mirror facet control mechanics manual adjustment**
- **Status:**
  - **Telescope mount constructed, equipped with 29 mirrors**
  - **Camera deployed**
  - **Onsite testing: mirror alignment, mirror heating, first Cherenkov light**
  - **Comparisons to MC & first data analyses ongoing**

# The first TAIGA-IACT

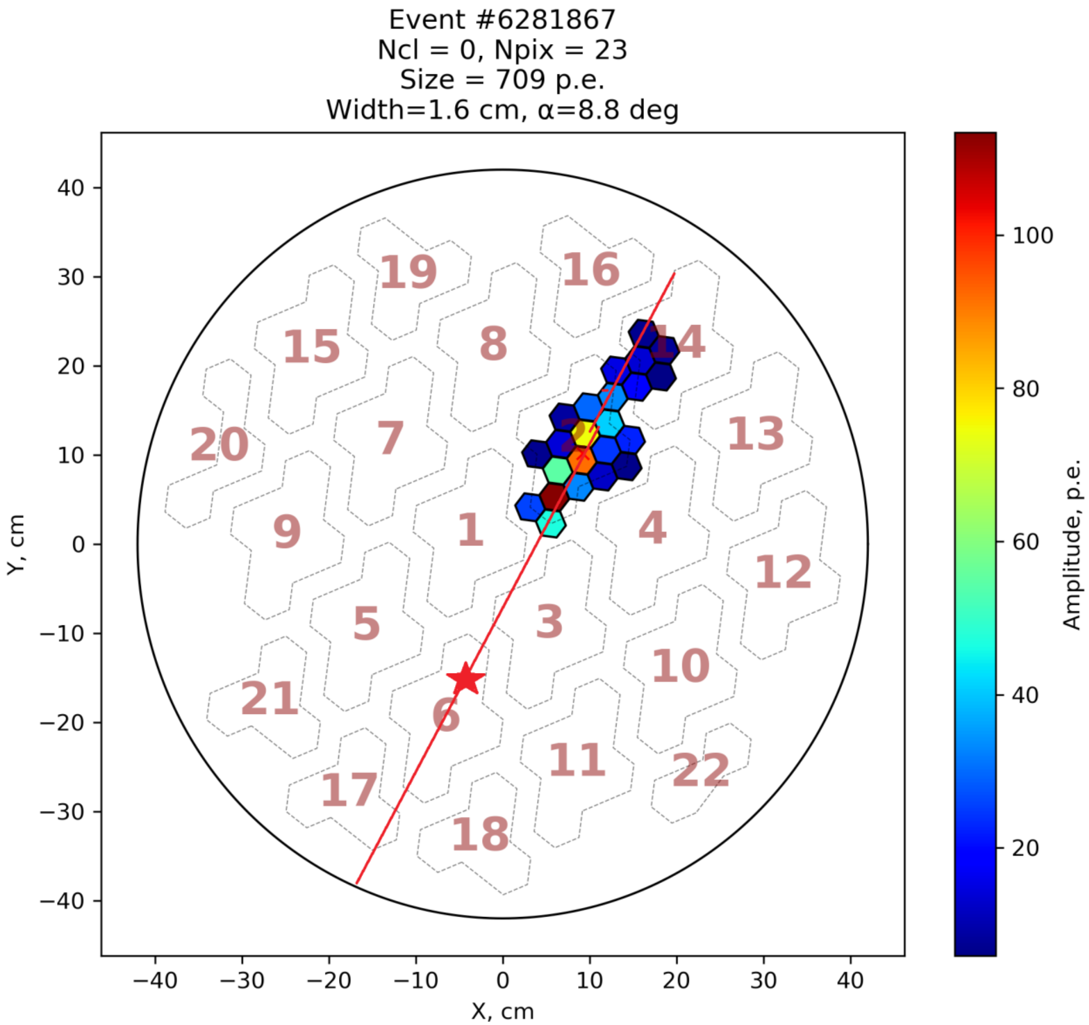
# The first TAIGA IACT

**MAROC3 board**
Fast shaper: trigger
Slow shaper: 35ns charge integration



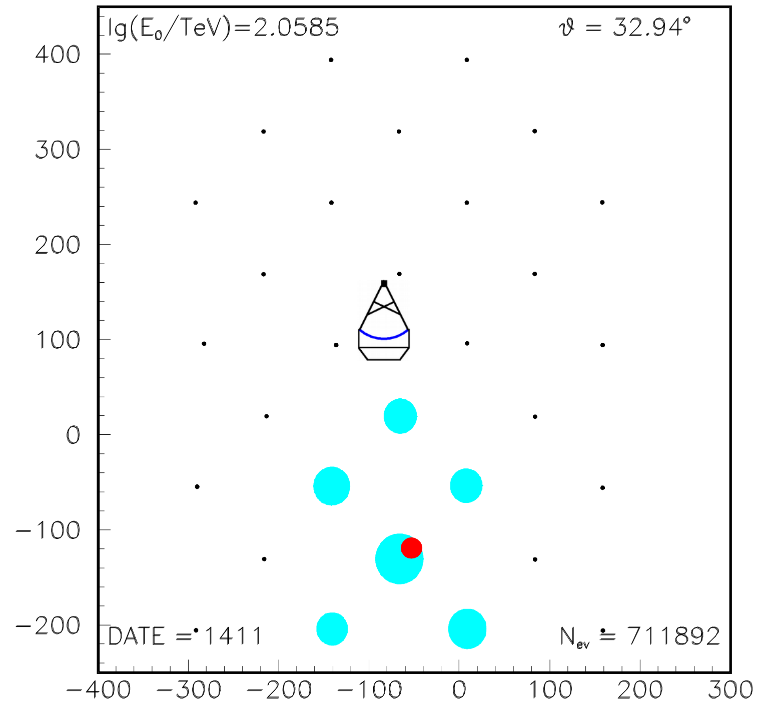



# TAIGA IACT real data




Preliminary reconstruction:

- Tet = 32.9°
- Fi = 33.58°
- Image width = 0.19°



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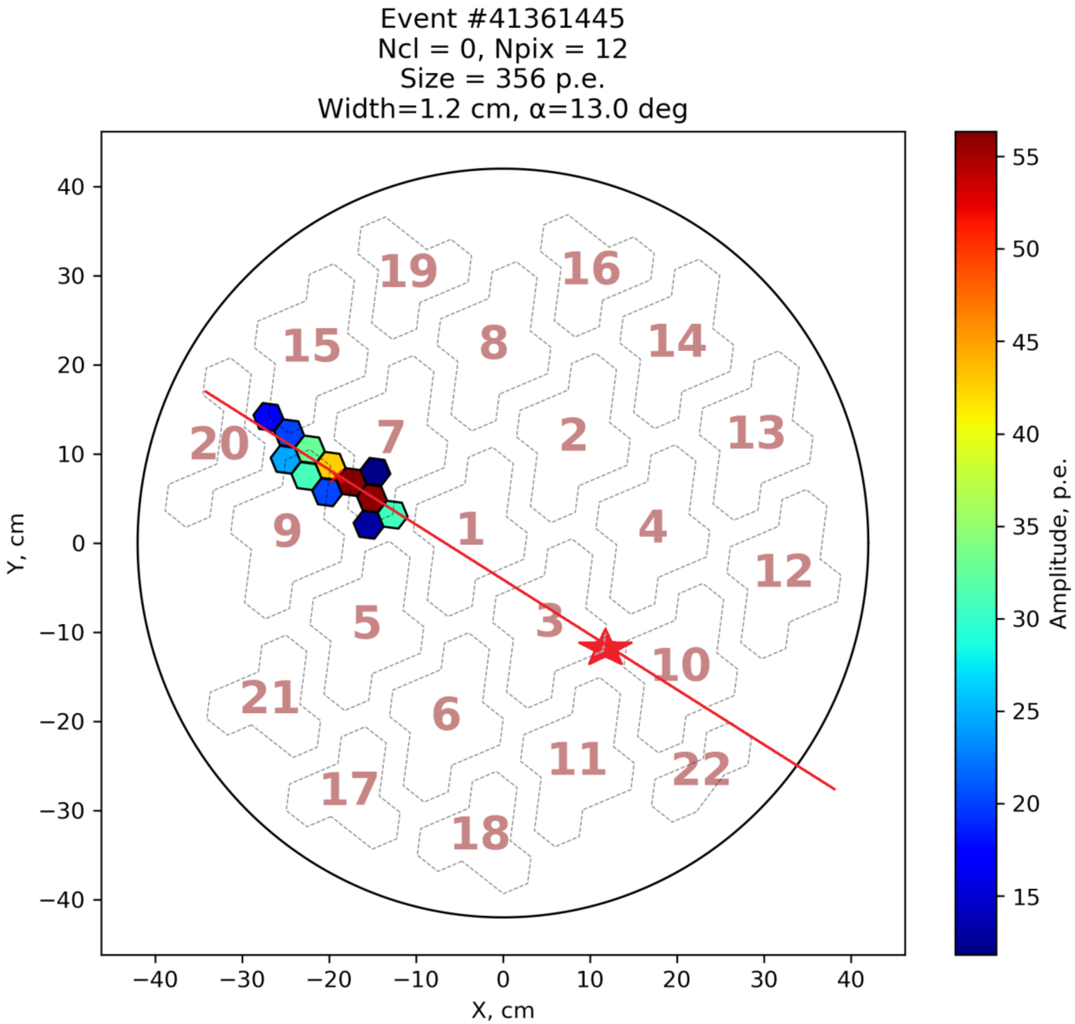


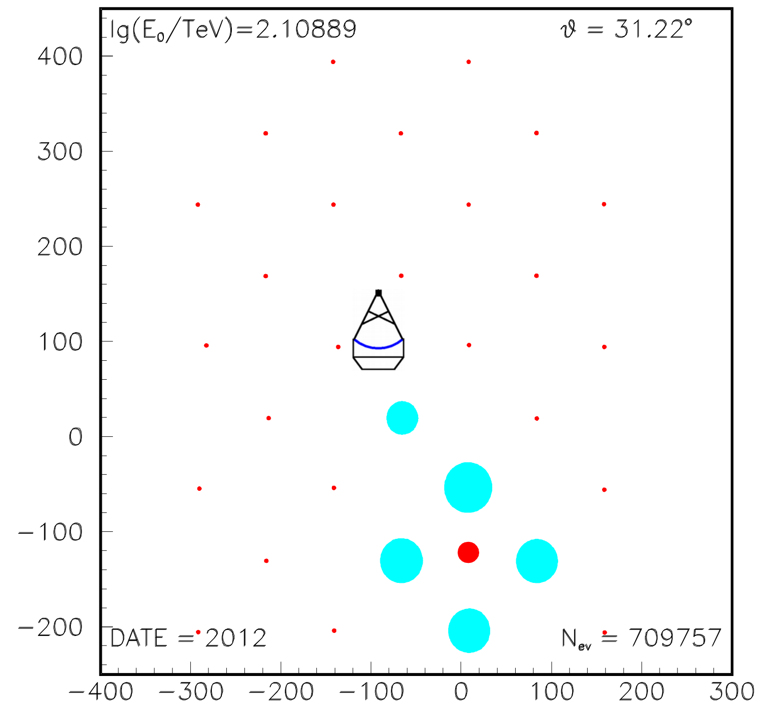

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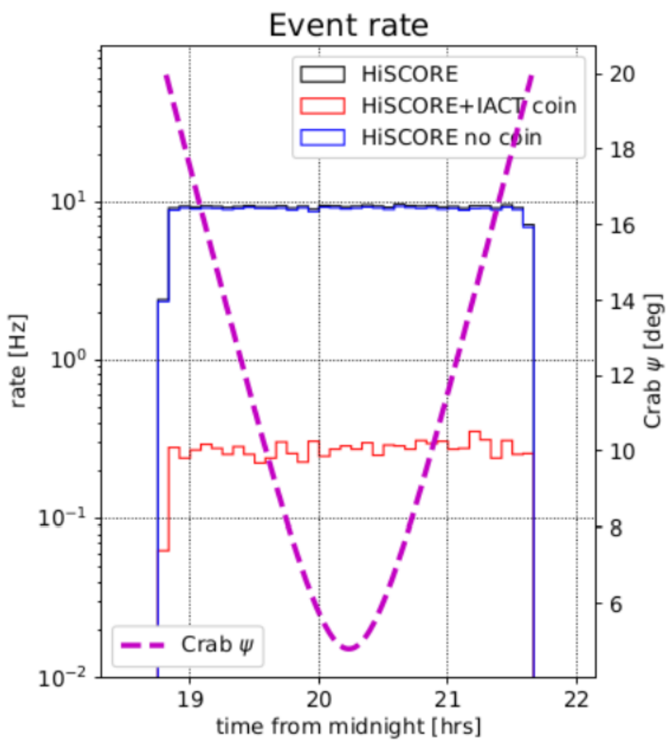
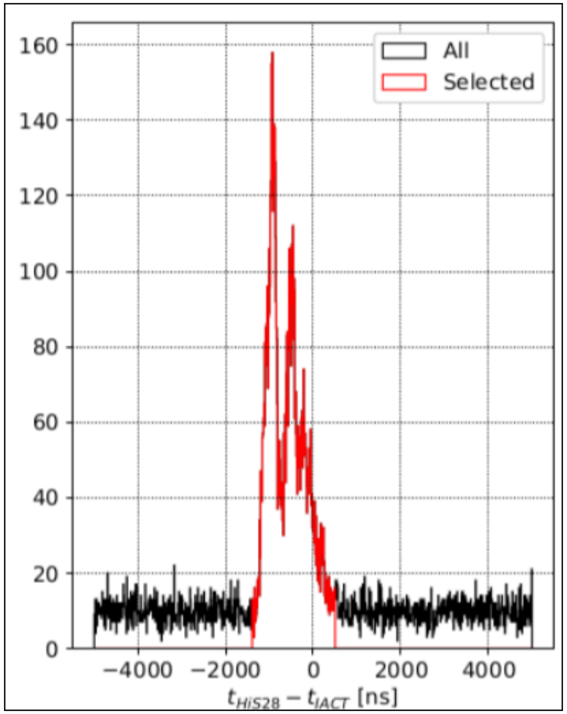
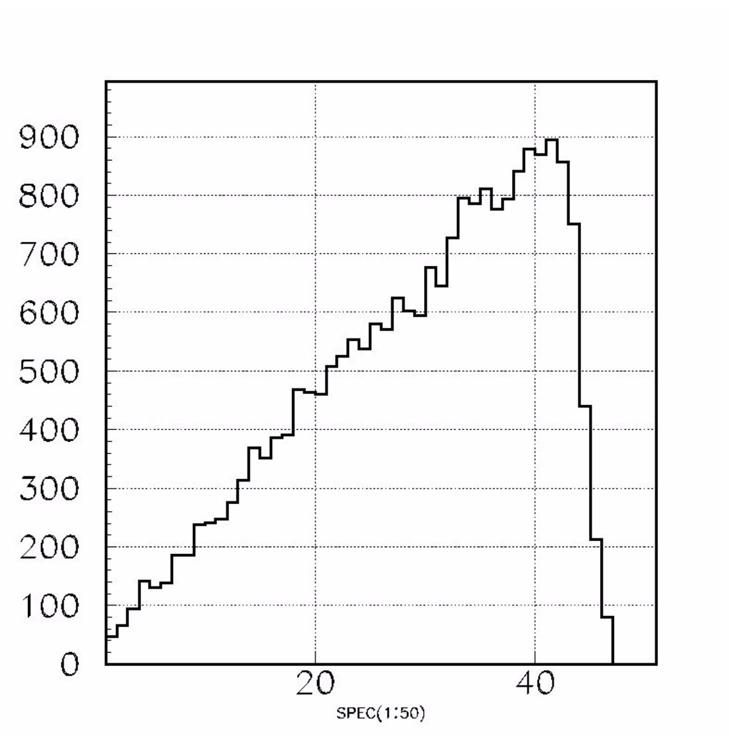



Coincident event rate
Crab Nebula



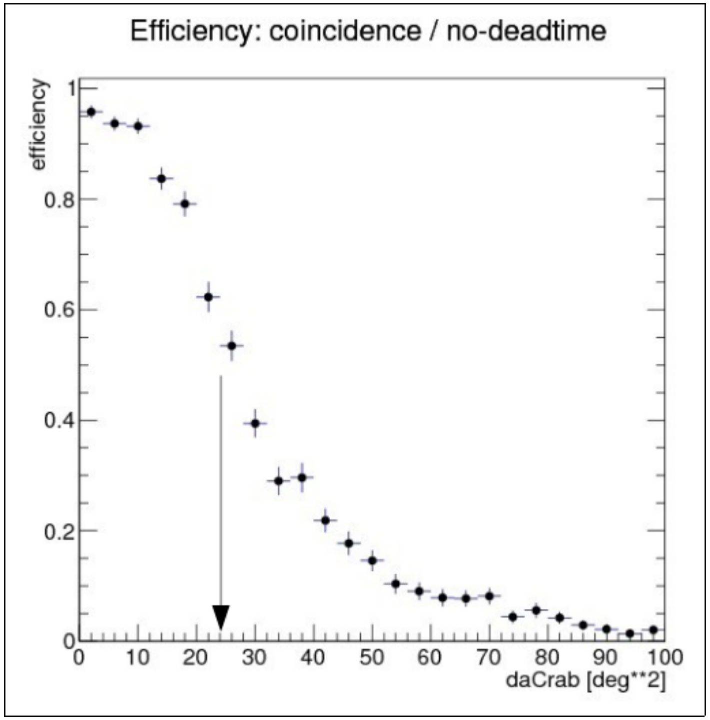

time coincidence hybrid

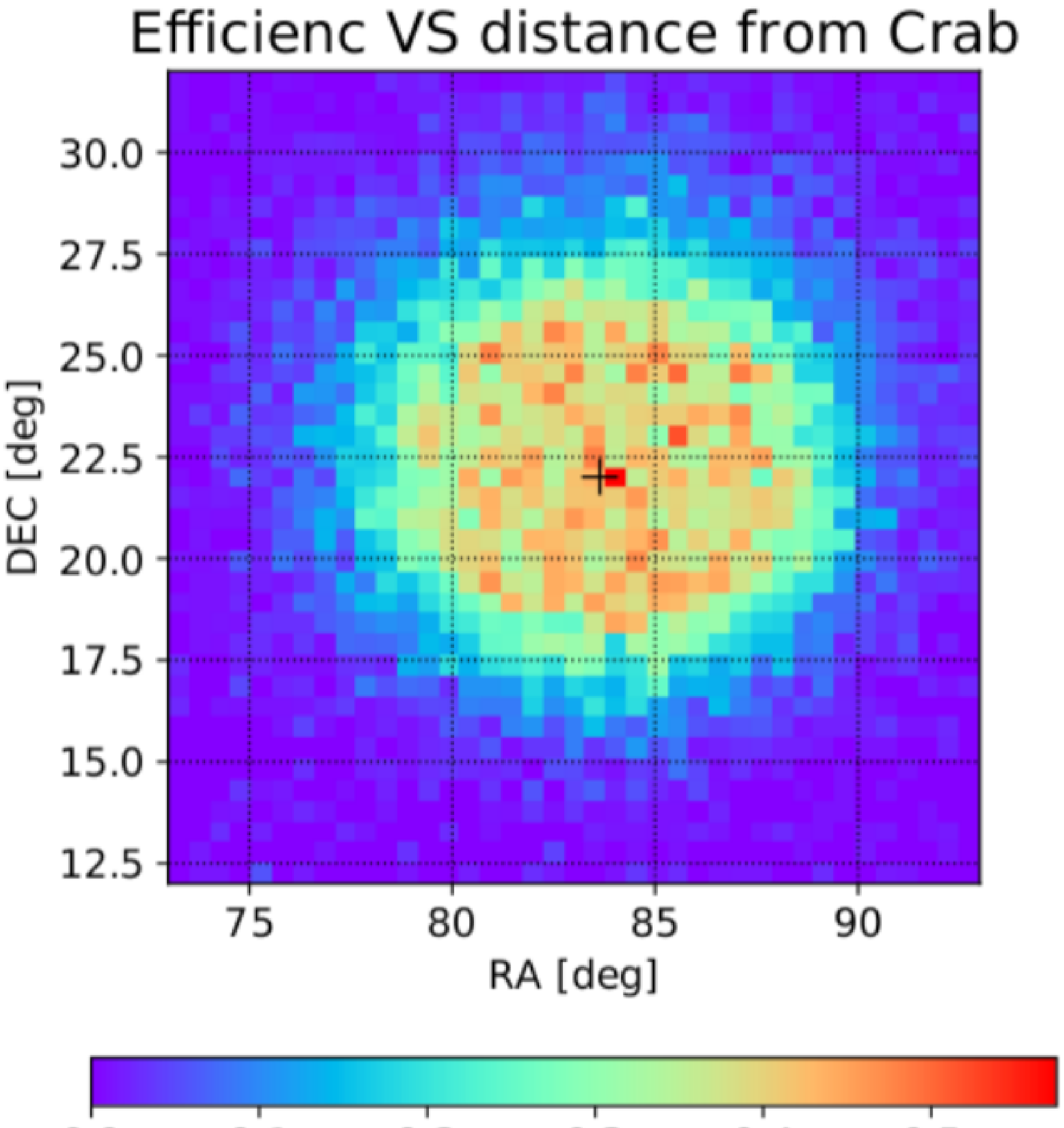



Dist from data (CR)

# TAIGA real data

- Coincident HiSCORE + IACT events
- Cross: Position of Crab Nebu
- Flat acceptance up to 3°
- High coincident efficiency up to 4.8°



# TAIGA data & MC

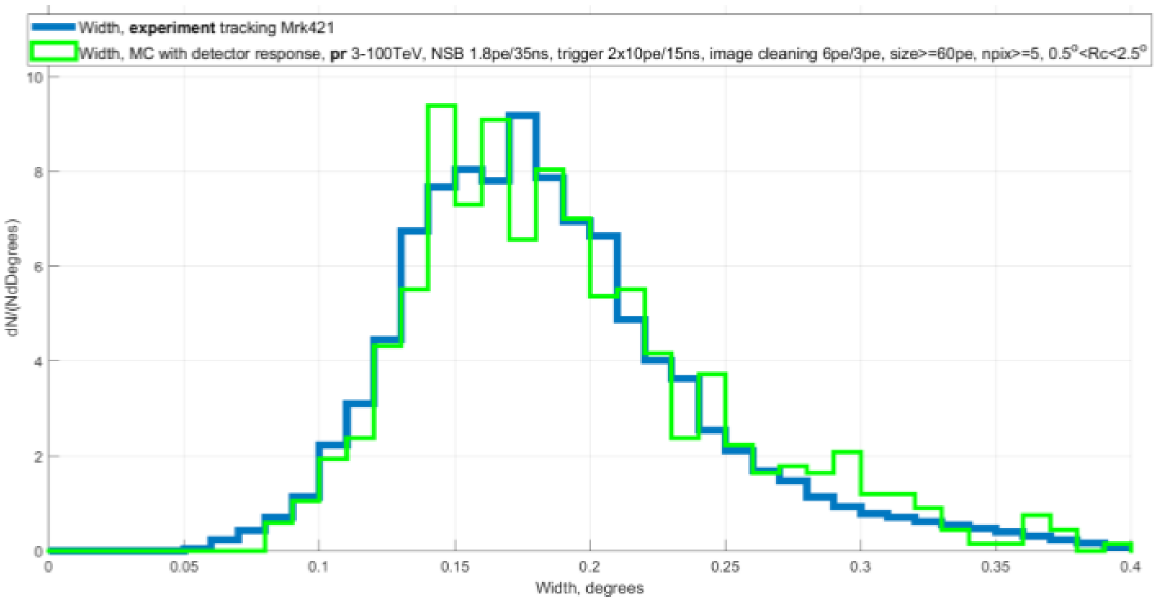
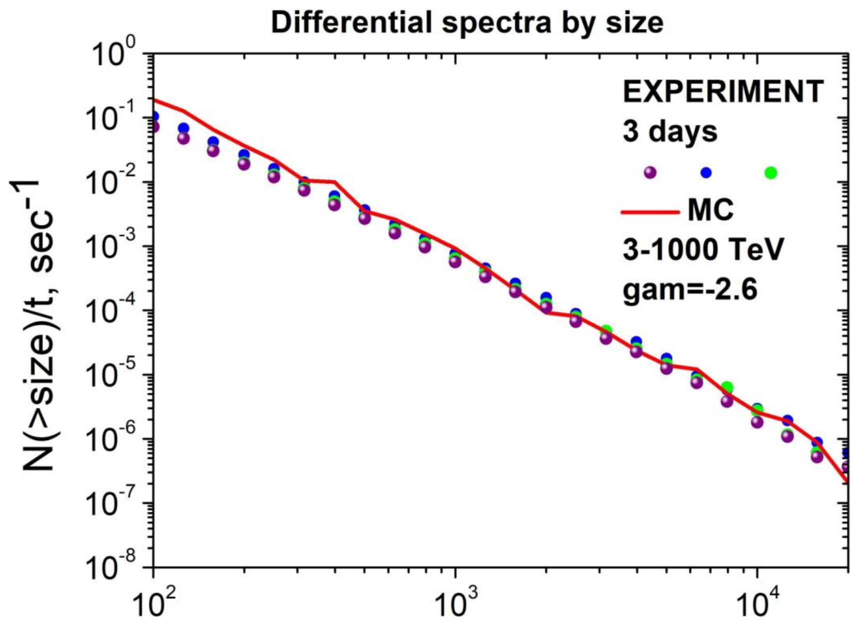
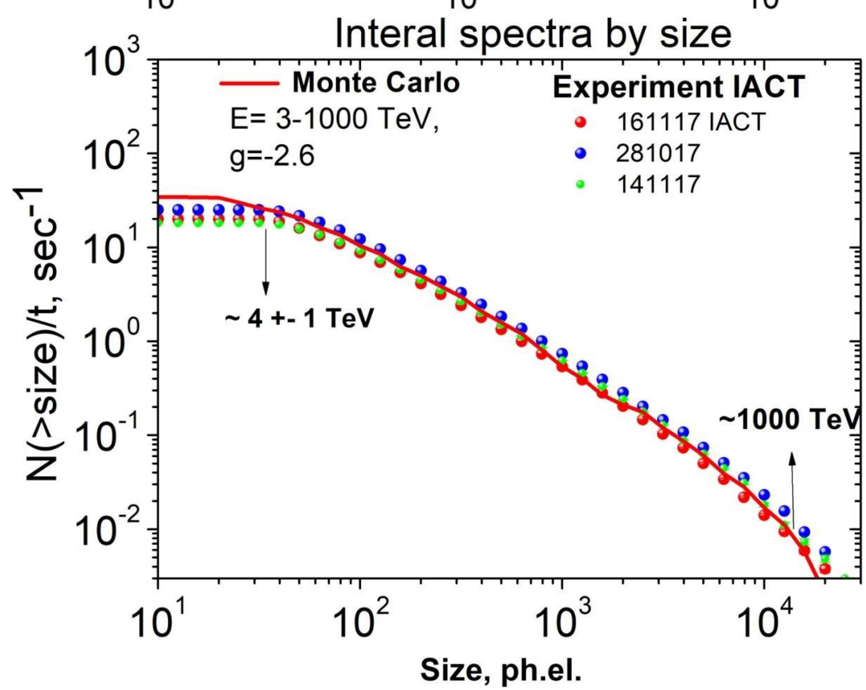



Image width: data & MC (protons)



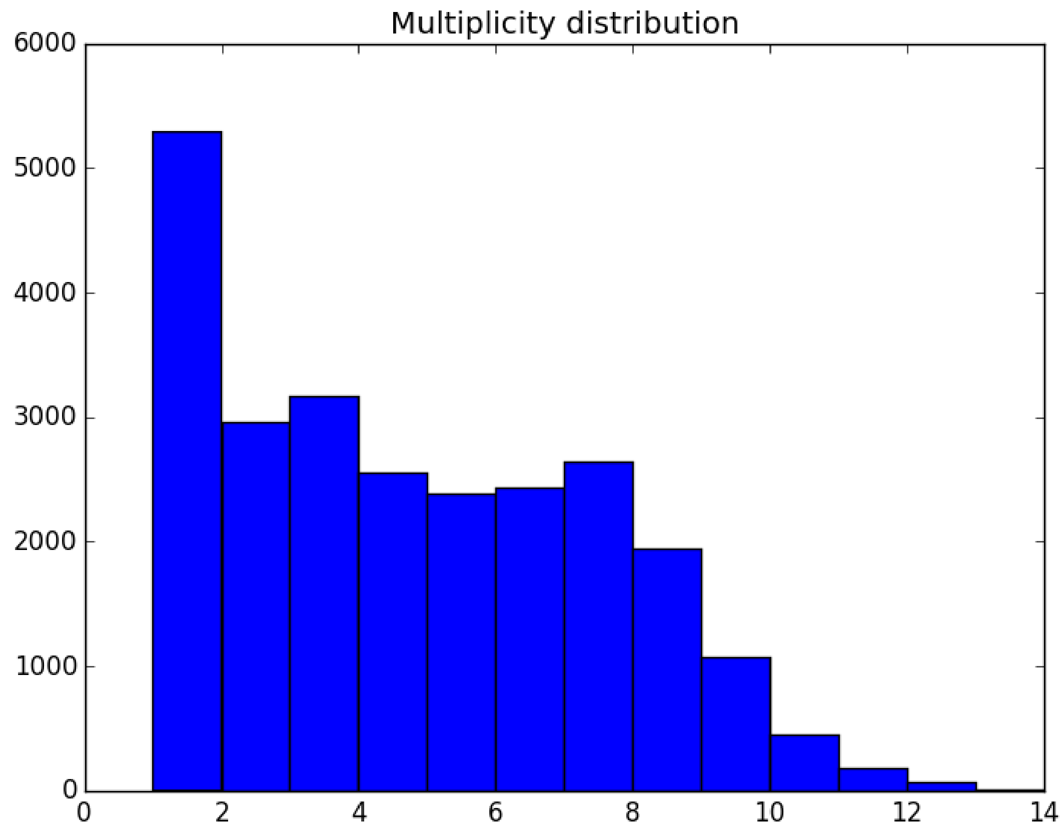



# TAIGA IACT real data

- Comparisons of real data to MC ongoing
- First results encouraging
- Coincident IACT/HiSCORE events
- First source analyses ongoing, promising

# Extend analysis to low energies

- MC study: coincident hybrid events
  - Standard approach: >= 4 stations
  - 50% data at <4 stations
  - Method development ongoing
  - Possible improvement in few TeV regime

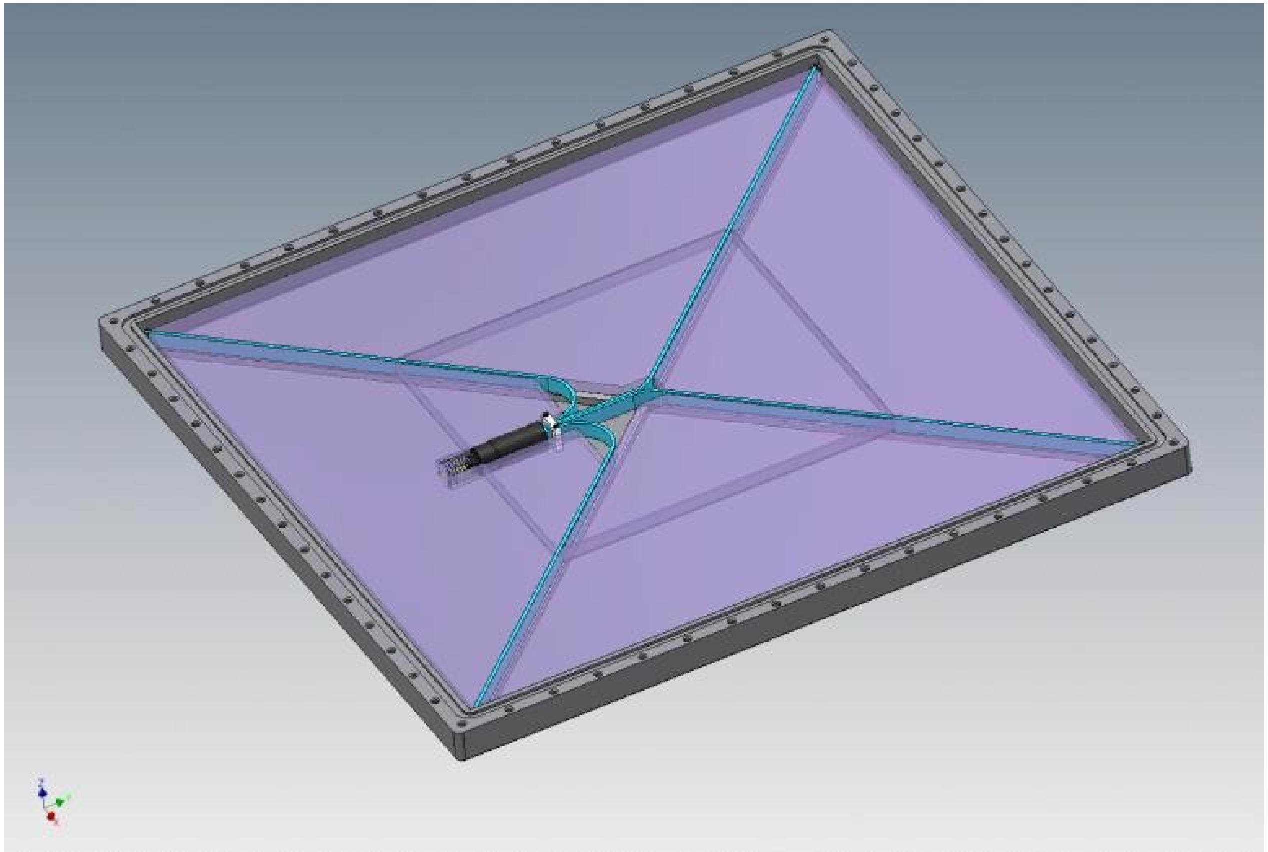


# Muon detectors

- Measurement of the muon component
  - Gamma-hadron separation
  - Composition
- Scintillation counters

  + Wavelength shifters

  + PMT
- 23 p.e. per μ
- 2000 m² planned



# Summary

- UHE gamma-ray Astronomy with
  new hybrid imaging+timing approach

  Goal: $<10^{-13}$ erg cm$^{-2}$ s$^{-1}$ @ 100 TeV

- TAIGA-HiSCORE timing array 0.5 km$^2$ operational

- 2019: 1km$^2$ / 3 IACTs

- Coincident hybrid events are seen

- Data on known sources are consistent with expectations

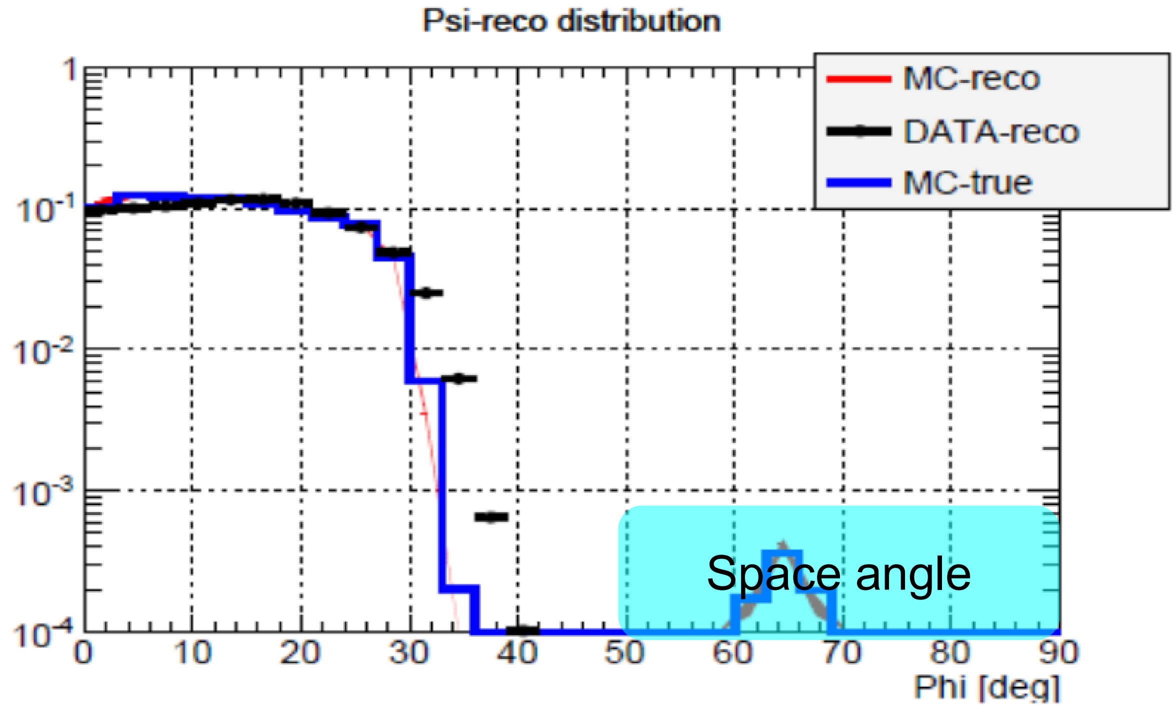
- 10 km$^2$ extension with 16 IACTs
  submitted to Russian research infrastructure

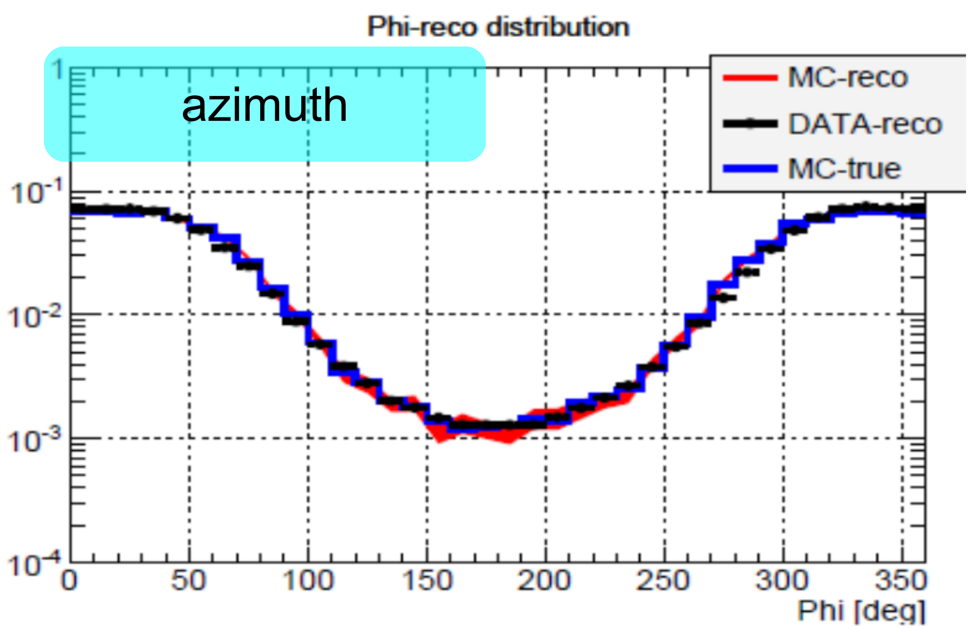
# BACKUP SLIDES

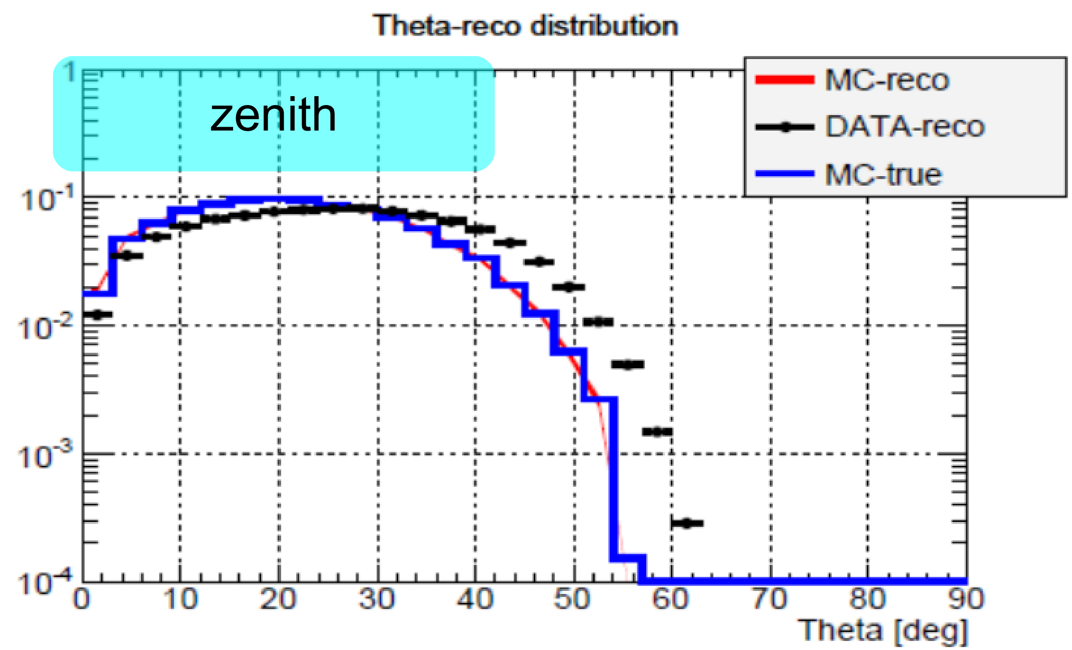
# Reconstruction

**Reconstructed direction**

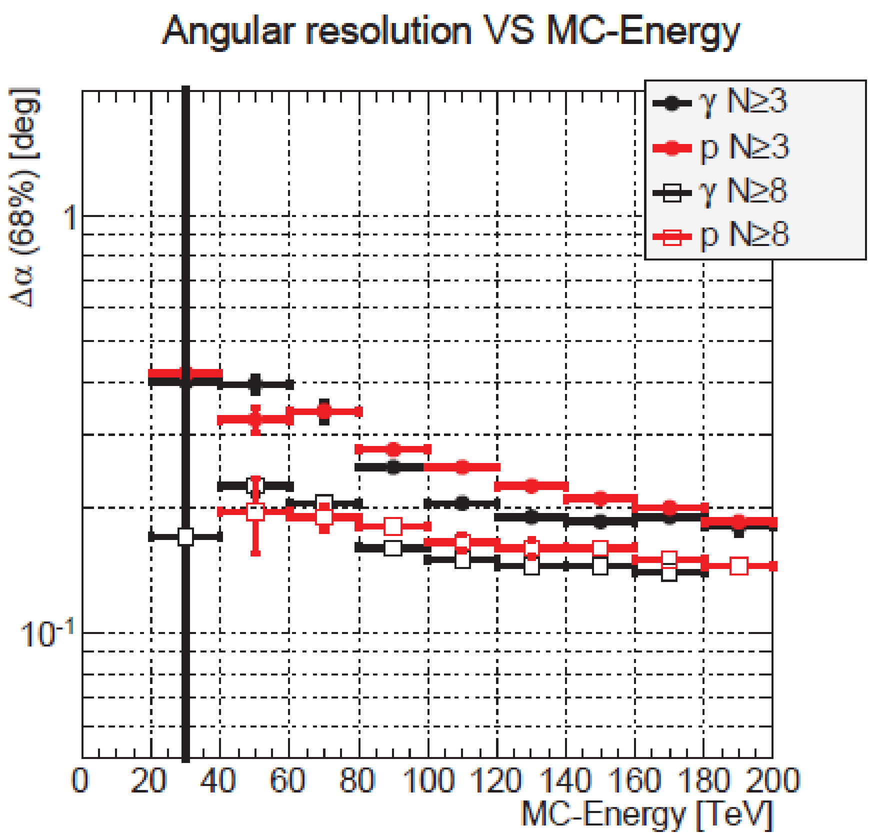
**Data & MC**

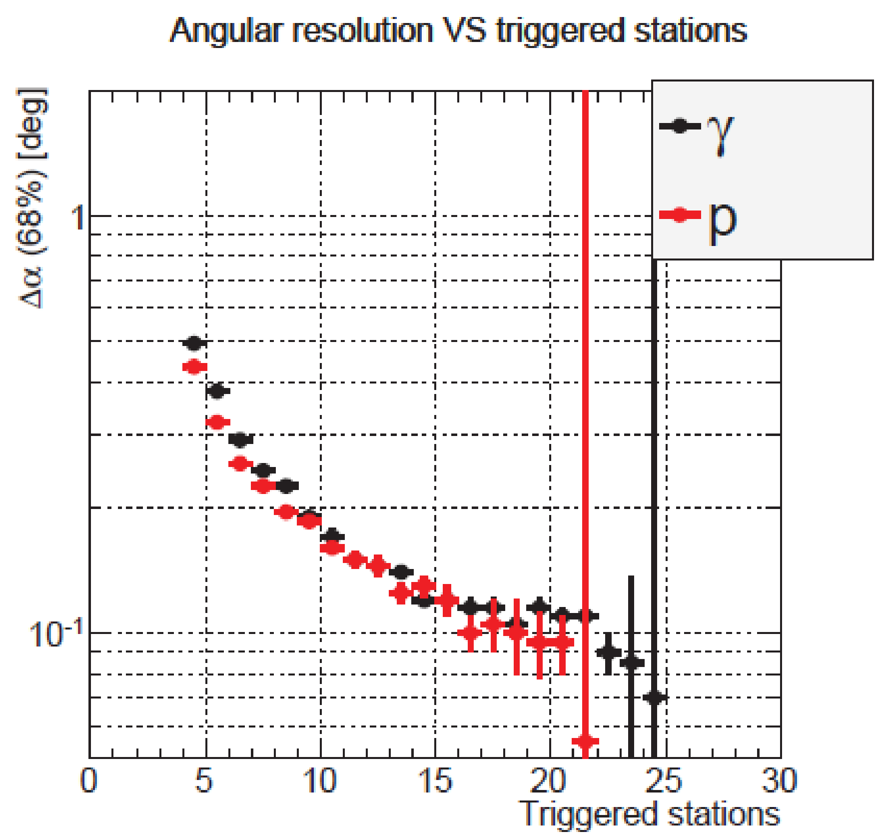


# Angular resolution 28 station array

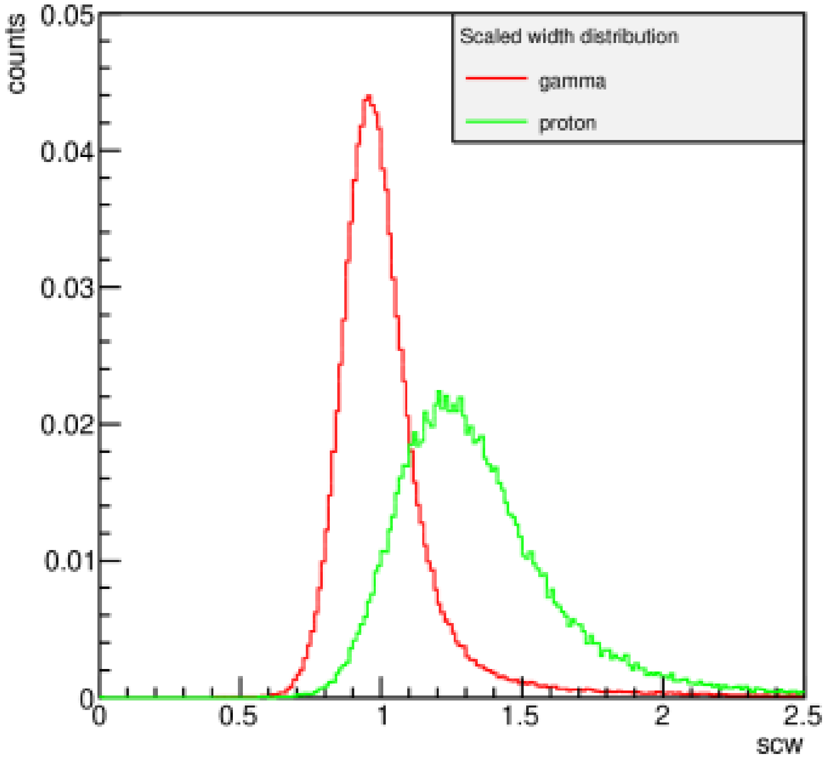


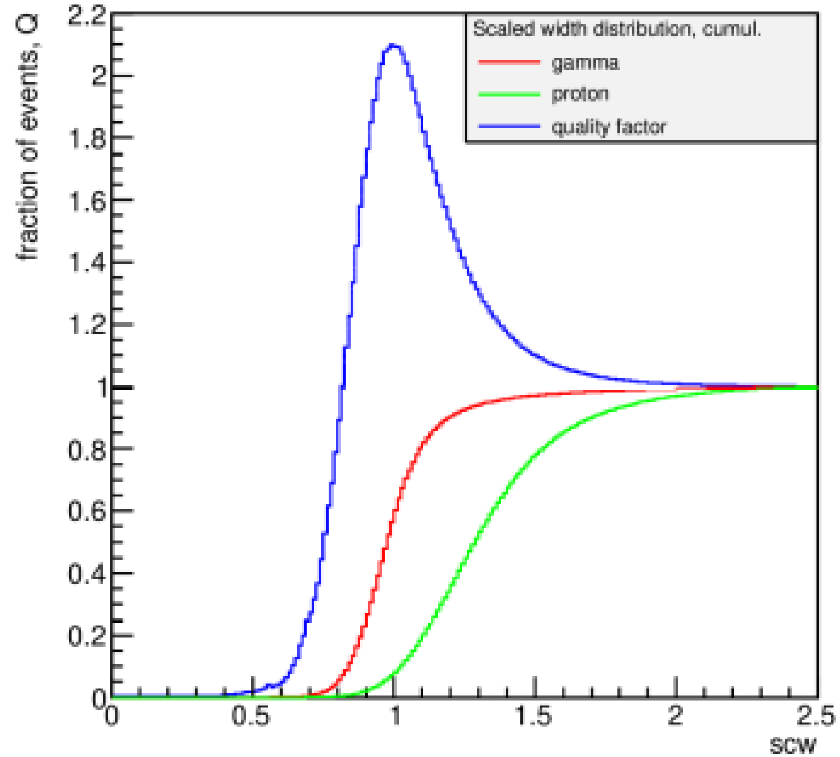




Verified MC resolution <0.2°, E>80TeV
<0.1°, E ~ PeV

# g/h separation

Hybrid scaled width (SCW)

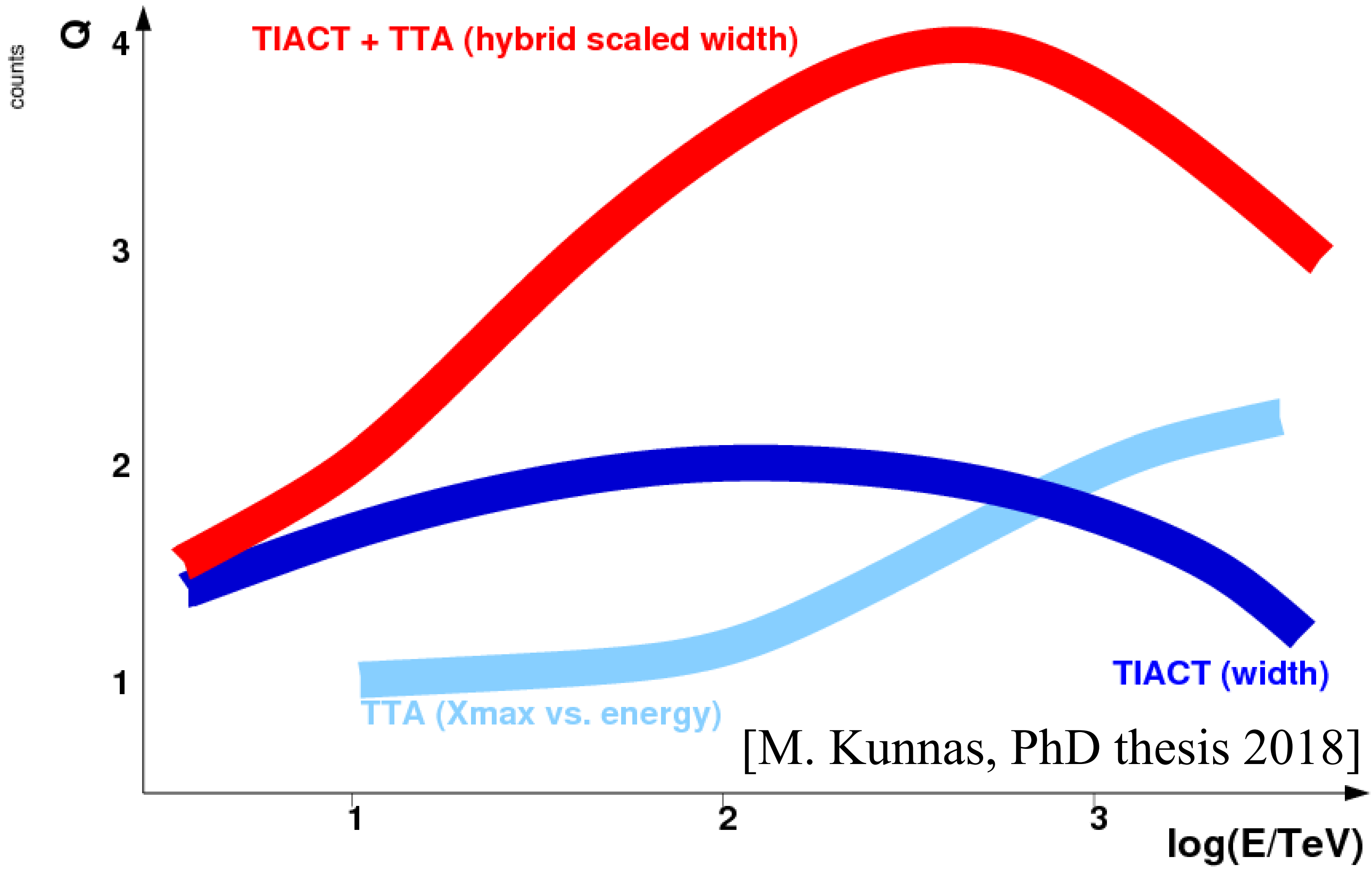



Other separation parameters based on shower depth and timing.
When using event selection cuts (e.g. distance, etc.), possible to reach Q = 5

# g/h separation

## Hybrid scaled width (HSCW)



# Spectroscopy with TAIGA