TAIGA-HiSCORE - first results

www.http://taiga-experiment.info/

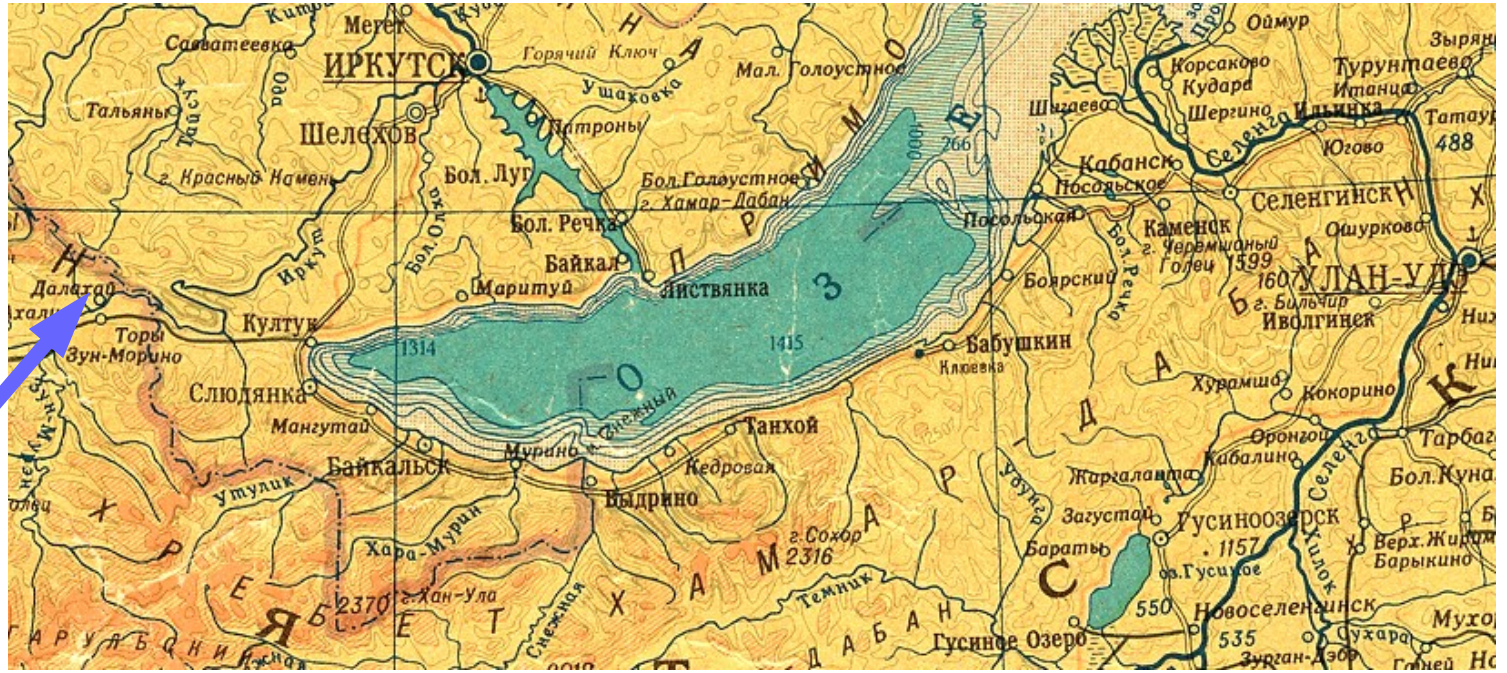
DPG Münster 2017

Martin Tluczykont

Universität Hamburg
DER FORSCHUNG | DER LEHRE | DER BILDUNG

TAIGA collaboration

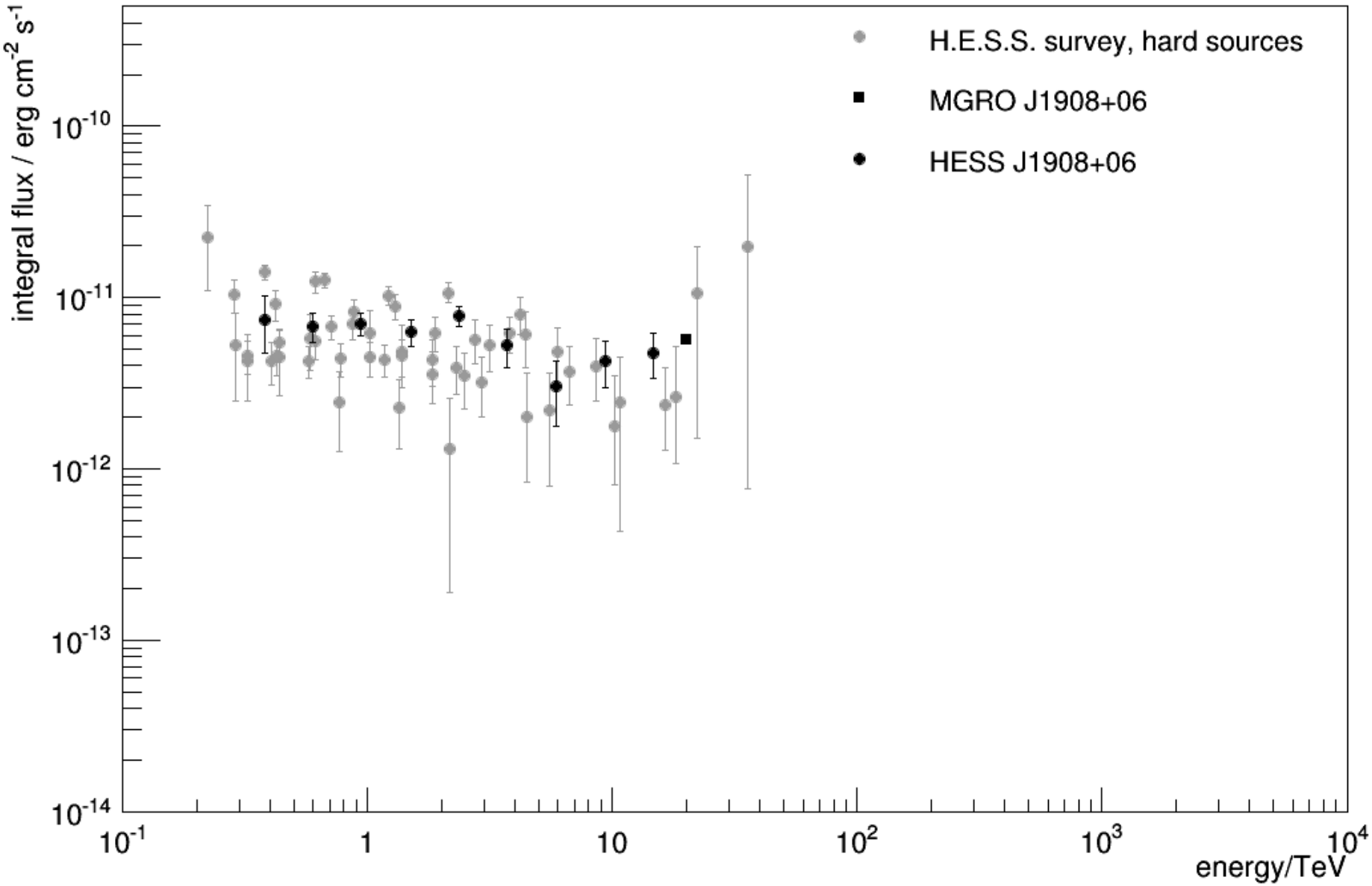
Skobeltsyn Institute of Nuclear Physics MSU, Moscow, Russia
Institute of Applied Physics, ISU, Irkutsk, Russia
Institute for Nuclear Research of RAN, Moscow, Russia
Dipartimento di Fisica Generale Universiteta di Torino and INFN, Torino, Italy
Max-Planck-Institute for Physics, Munich, Germany
Institut 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



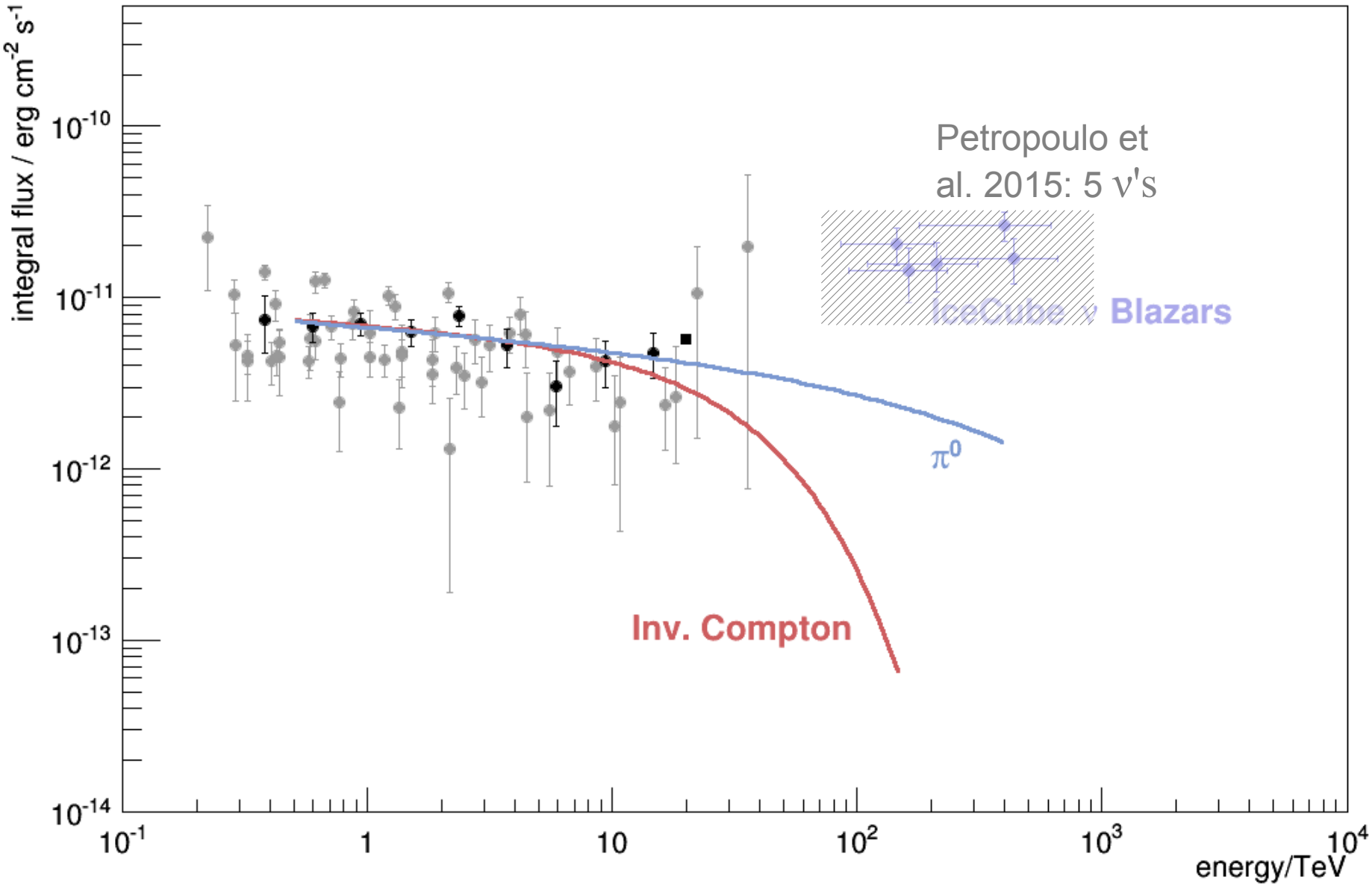
Tunka-133 site

Physics motivation

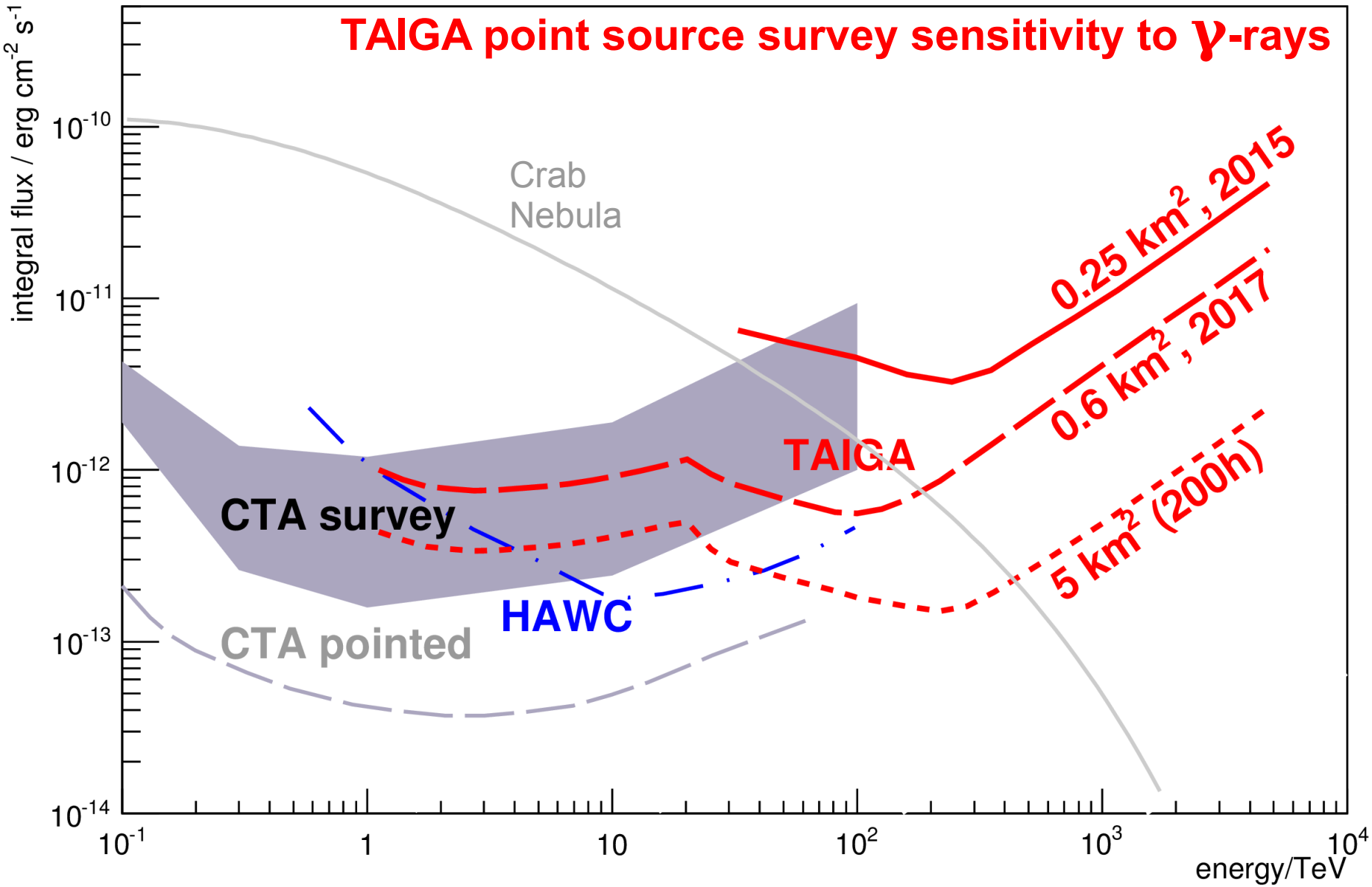
VHE-UHE Gamma-ray astronomy



VHE-UHE Gamma-ray astronomy



VHE-UHE Gamma-ray Astronomy



TAIGA: Tunka Advanced International Gamma-ray and cosmic ray Array

TAIGA-HiSCORE timing array

TAIGA-IACT imaging telescopes

TAIGA muon counters

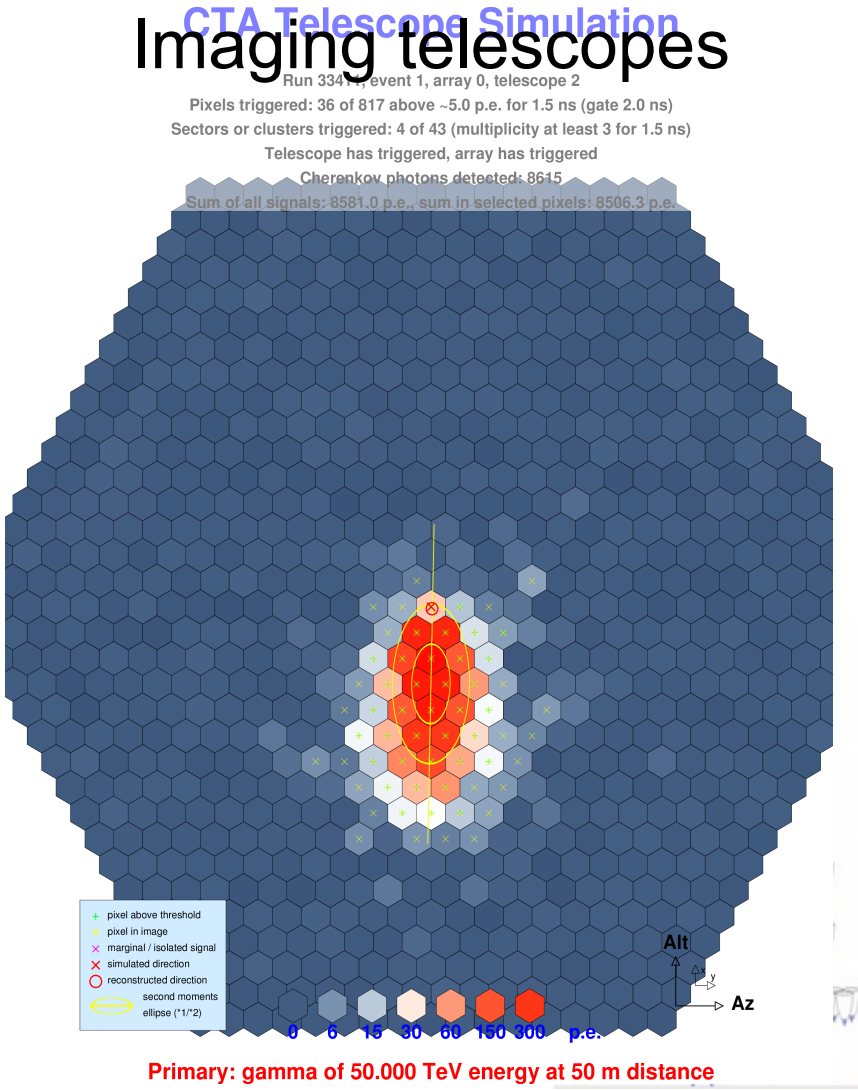
Timing array: planned 5 km²
(~500 stations)

Imaging: planned 16 IACTs

planned 2 10³ m²

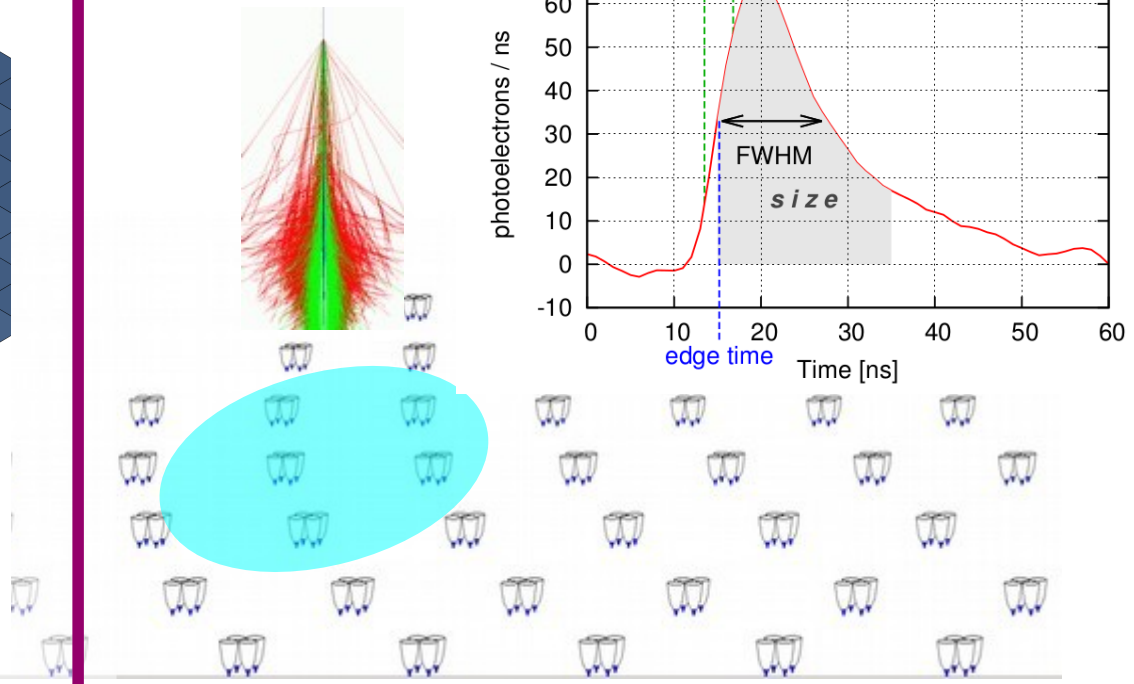
Air Cherenkov imaging and timing

Imaging telescopes



Primary: gamma of 50.000 TeV energy at 50 m distance

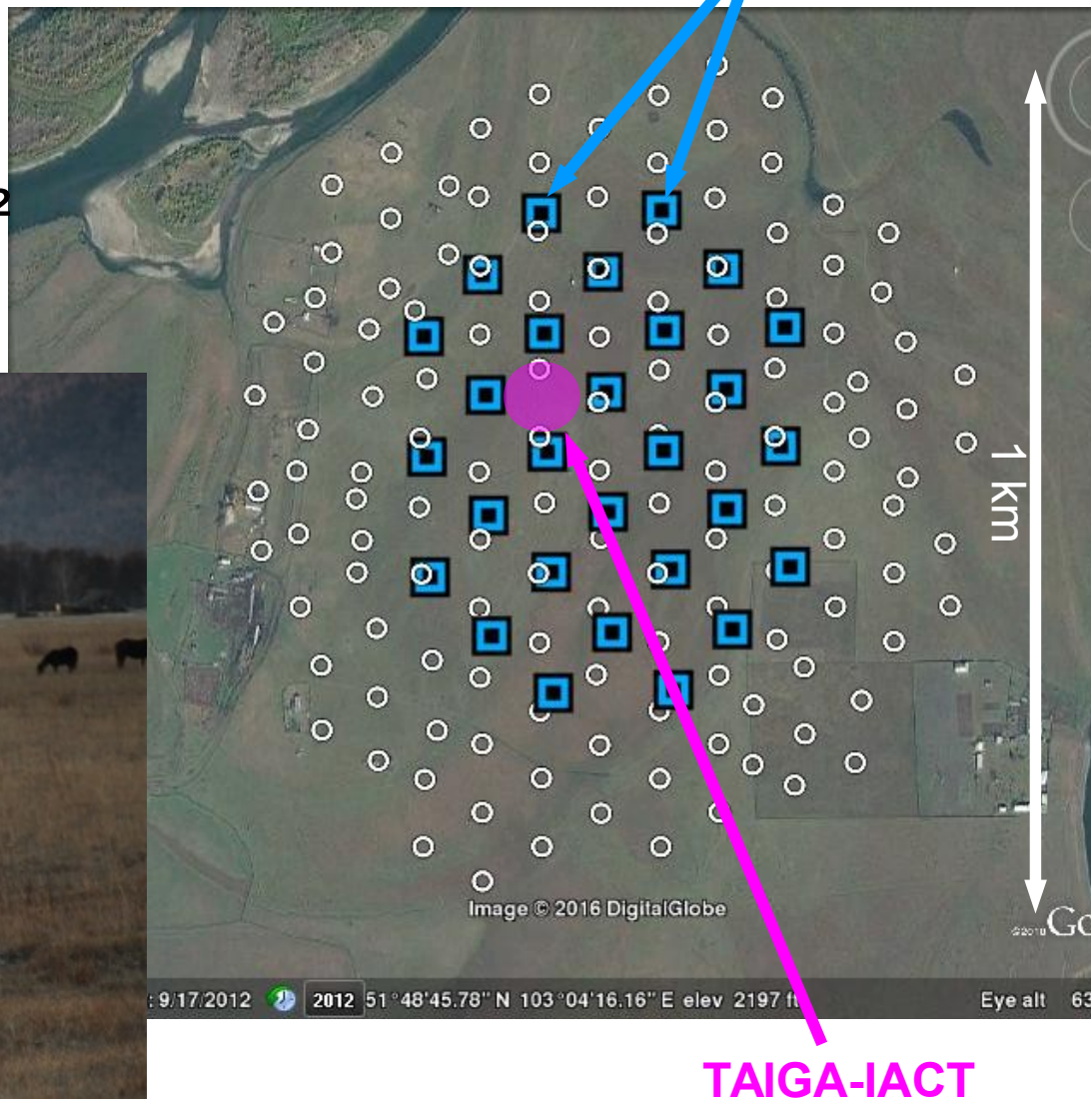
Timing arrays non-imaging shower front sampling



TAIGA-HiSCORE: timing array

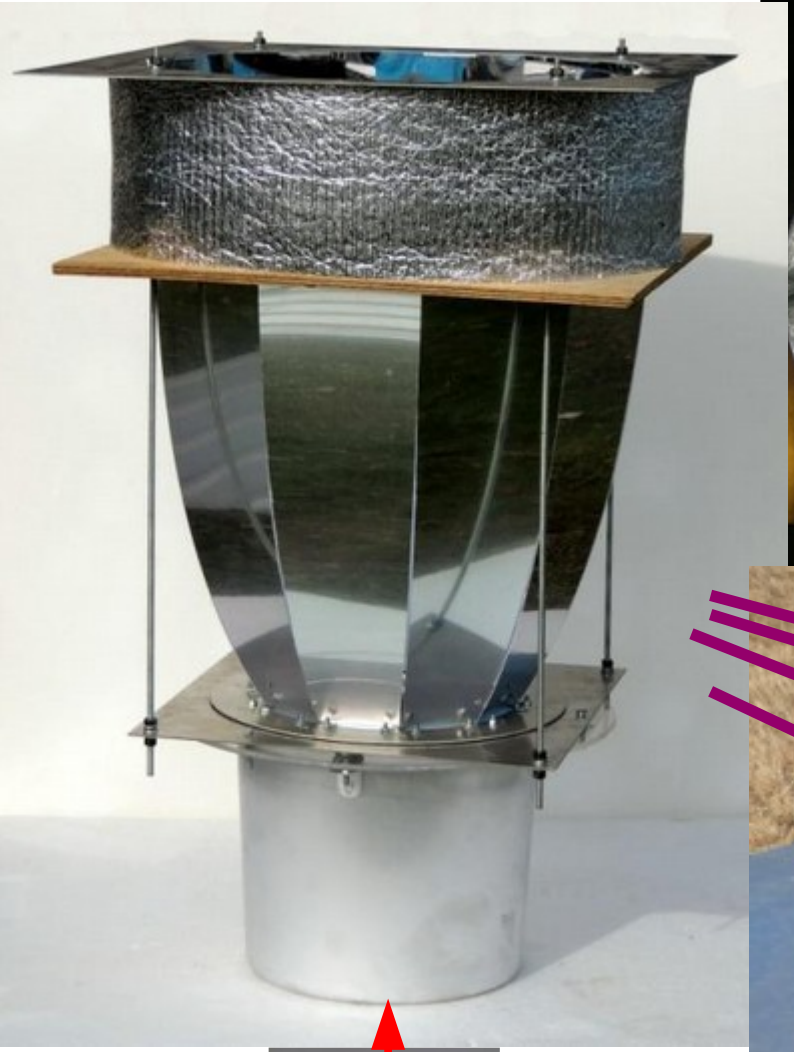
TAIGA-HiSCORE: timing stations

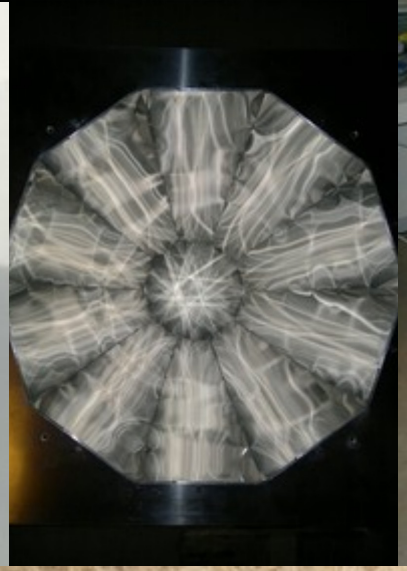
- Total: 28 stations
- average spacing 106 m
- instrumented area 0.25km²



TAIGA timing stations

- Three-four 8" PMTs
- 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





TAIGA-HiSCORE

Comparison of Monte Carlo simulation to Real Data

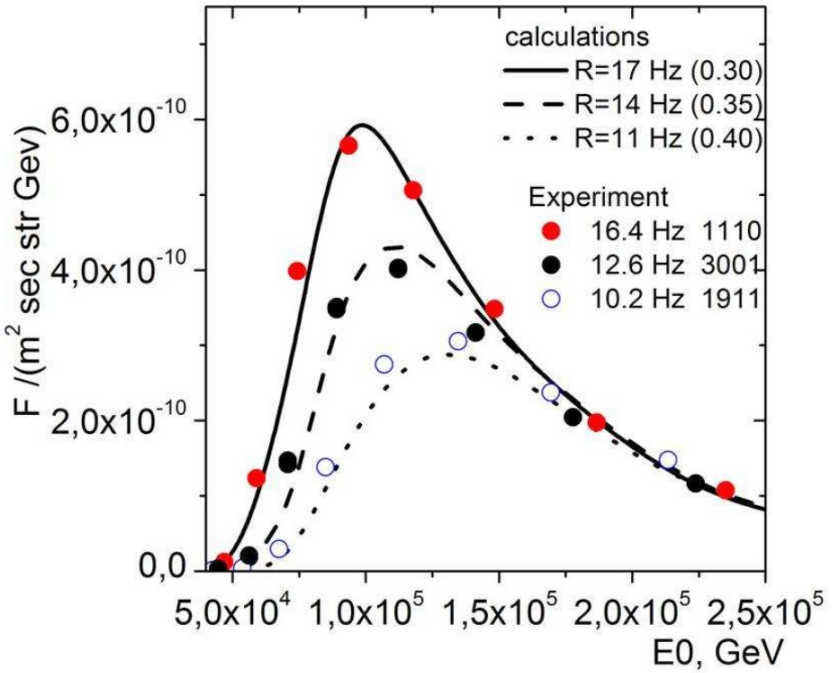
Data-MC comparison

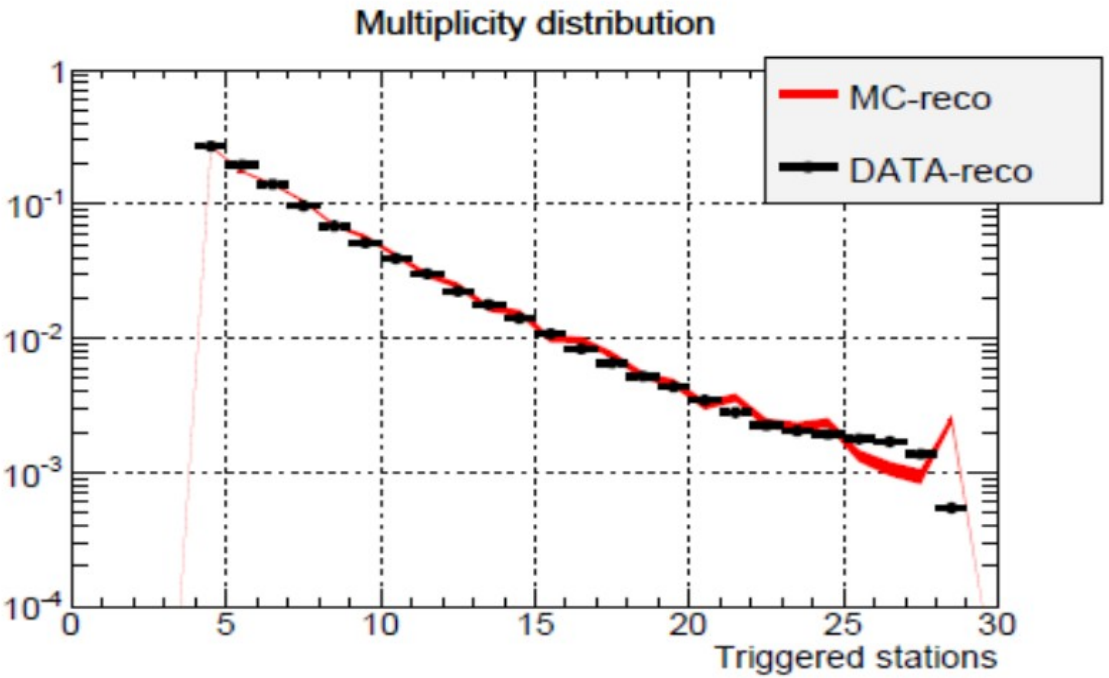
Trigger rates – Data / MC (A_{thr} ~ 250 p.e.)

- single station: 8-12 Hz / 10 Hz
- 4-station coincidence: 10-17 Hz / 15 Hz

Multiplicity

28 station array: Data / MC

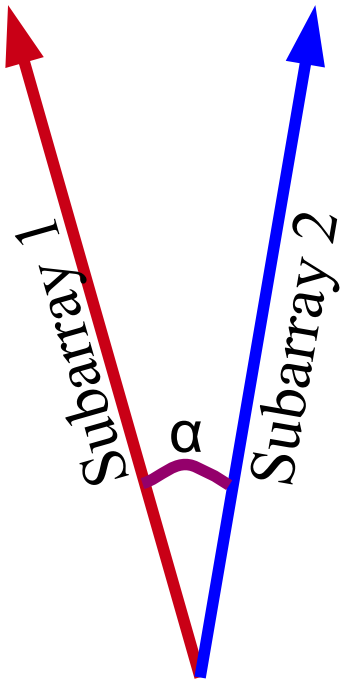




Protons: Ethr ~ 100-130 TeV
Gammas: Ethr ~ 50-70 TeV

Resolution chessboard method

Reconstruction using two different subarrays

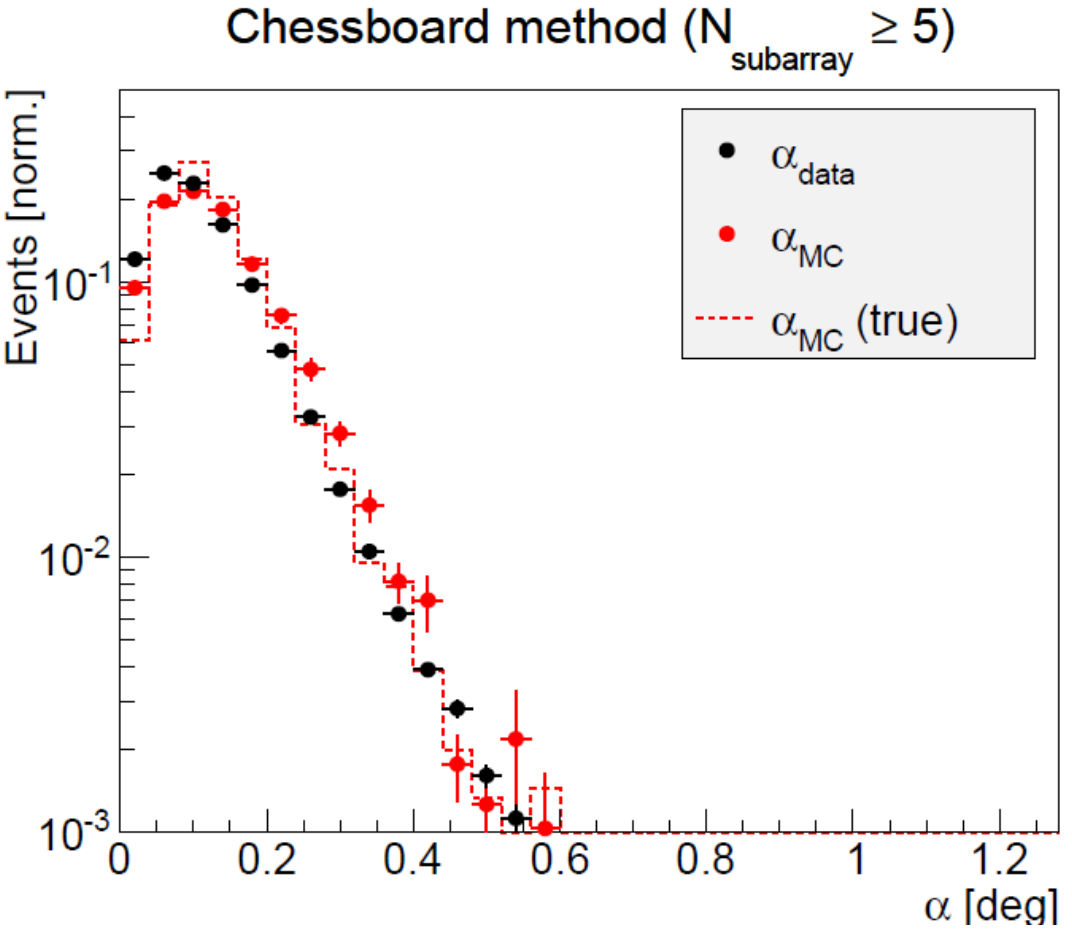


Chessboard direction:

Resulting angle α

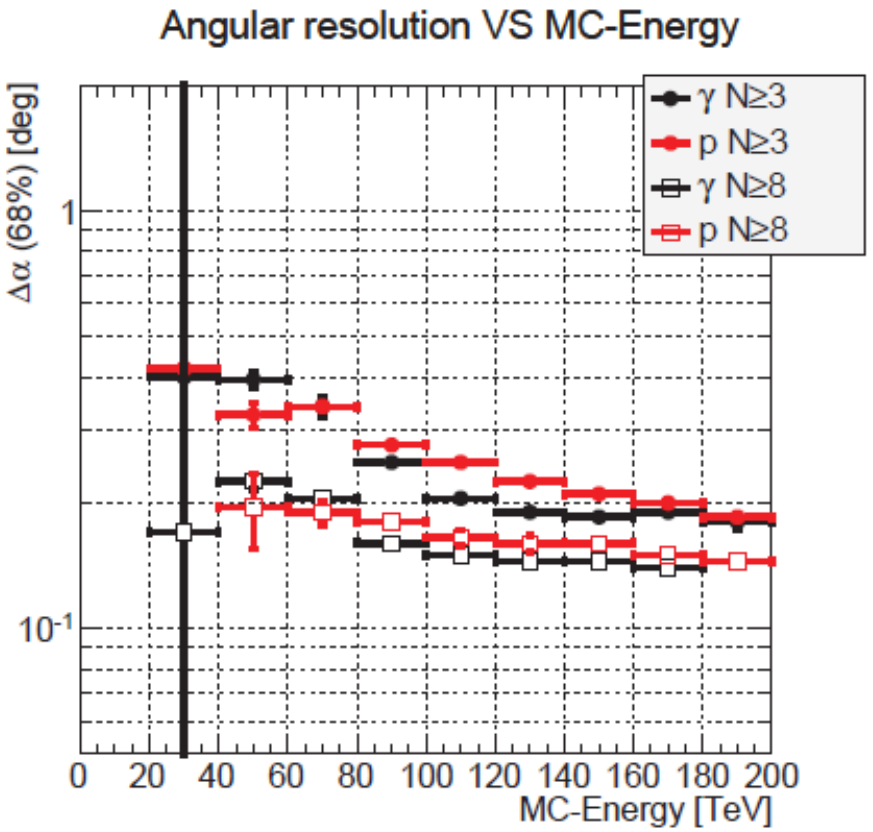
DATA
MC

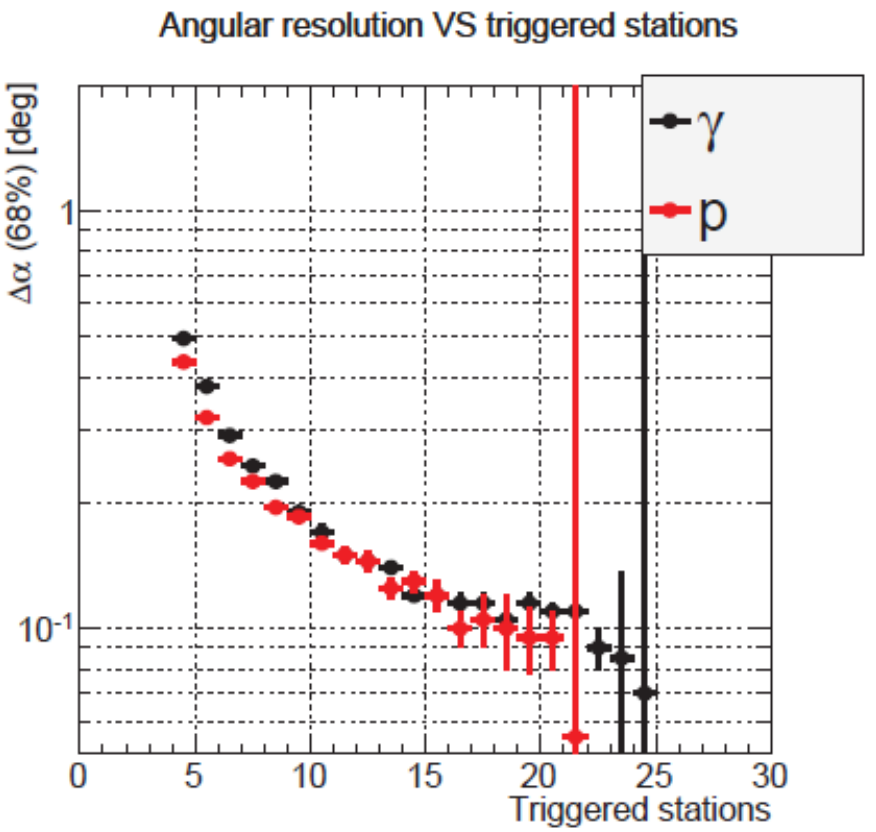
Verification



Verification of MC

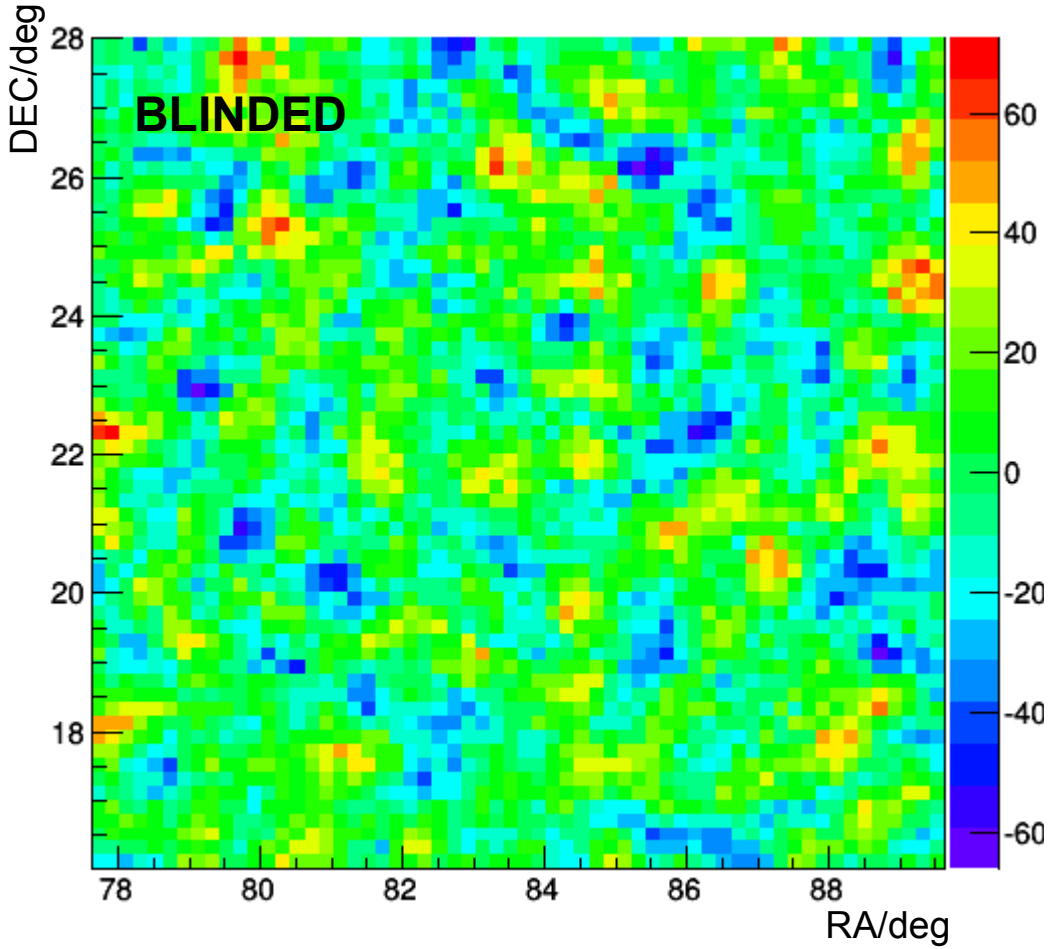
Angular resolution 28 station array



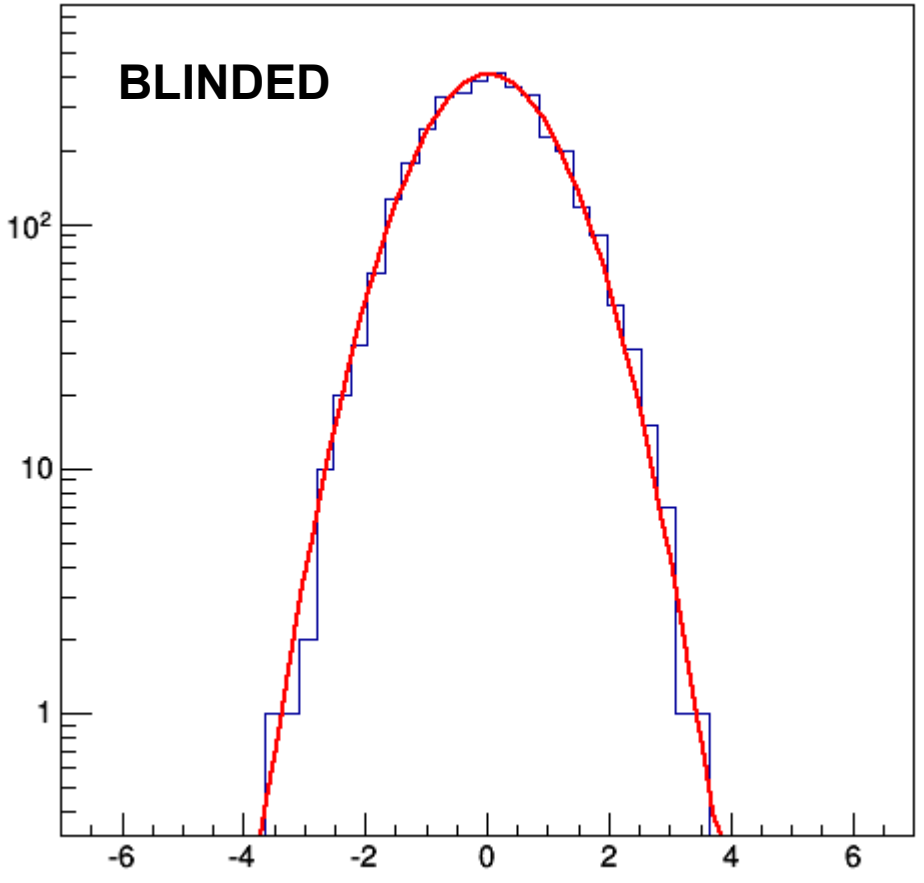


Verified MC resolution <0.2°, E>100TeV
<0.1°, E ~ PeV

Background for pointsource search



Excess skymap



Significance distribution in foV

Excess = Non – α Noff (α = 0.05)

Blinded data, 0.4° search bin, ring-background

Significance following Li&Ma, Eq. 9

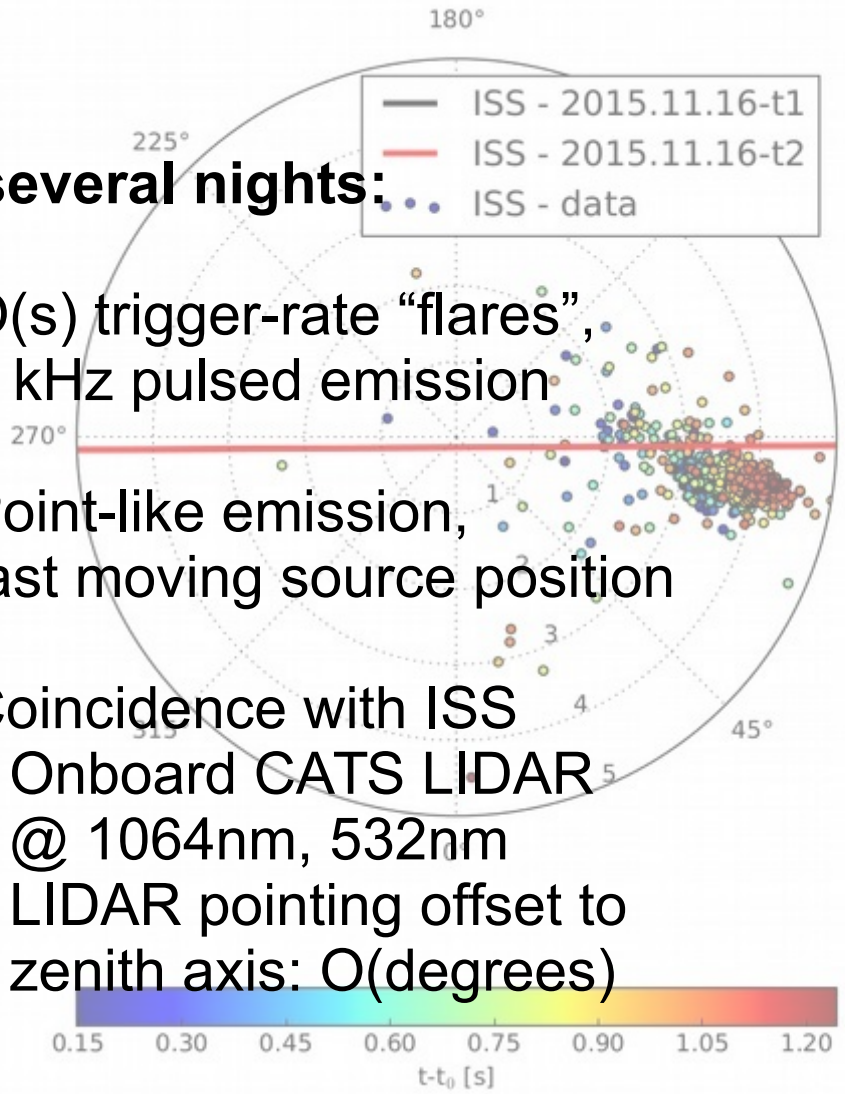
Crab Nebula data commissioning season 2015/16

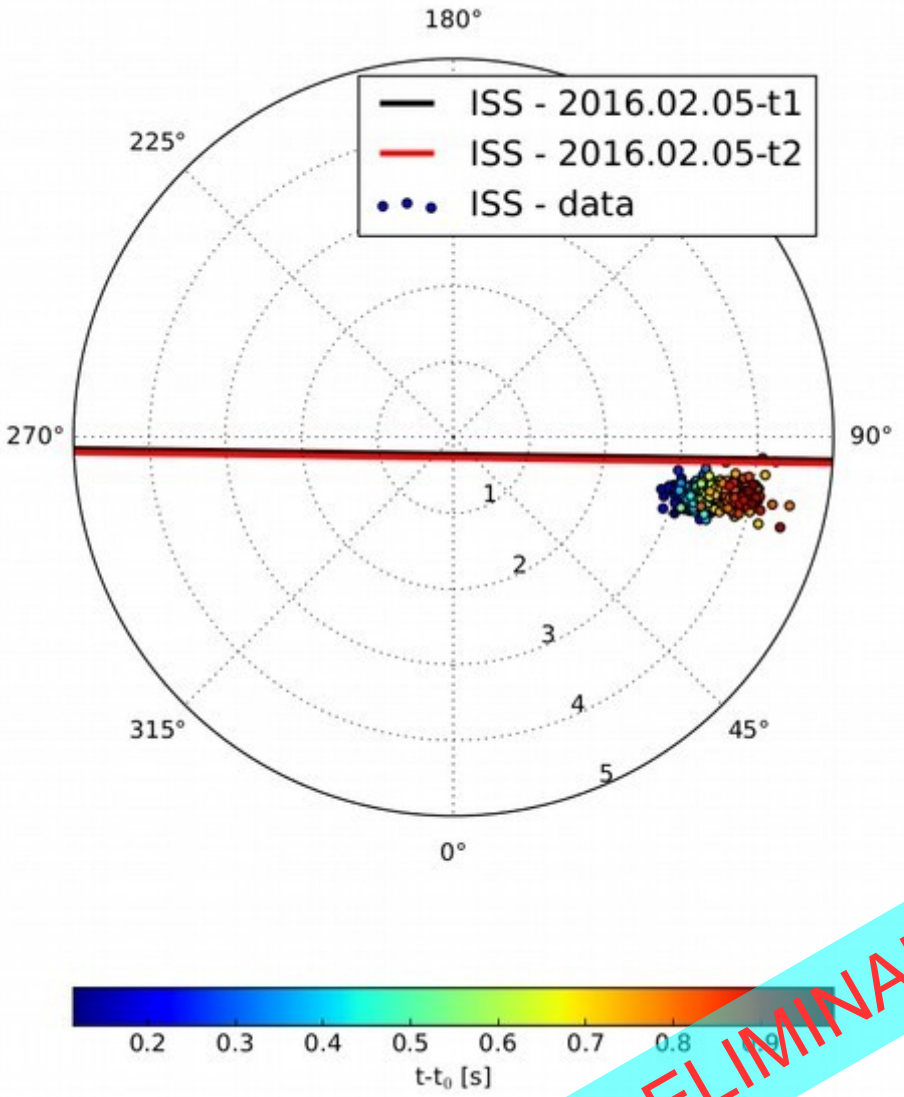
- ~60 h good weather exposure on Crab Nebula
- Expected 10-25 events / 100h from Crab for 0.25 km²
  Observed excess: 20 (background 380)
  - ➔ Observations compatible with prototype sensitivity
  - ➔ Analysis / optimization ongoing
- Potential for improvement in future:
  - New season data (x2)
  - larger area → 0.6 km²
  - TAIGA: +IACT

A first HiSCORE Point-source

In several nights:

- O(s) trigger-rate “flares”, 4 kHz pulsed emission
- Point-like emission, fast moving source position
- Coincidence with ISS
  - ➔ Onboard CATS LIDAR @ 1064nm, 532nm
  - ➔ LIDAR pointing offset to zenith axis: O(degrees)





PRELIMINARY

A first HiSCORE Point-source

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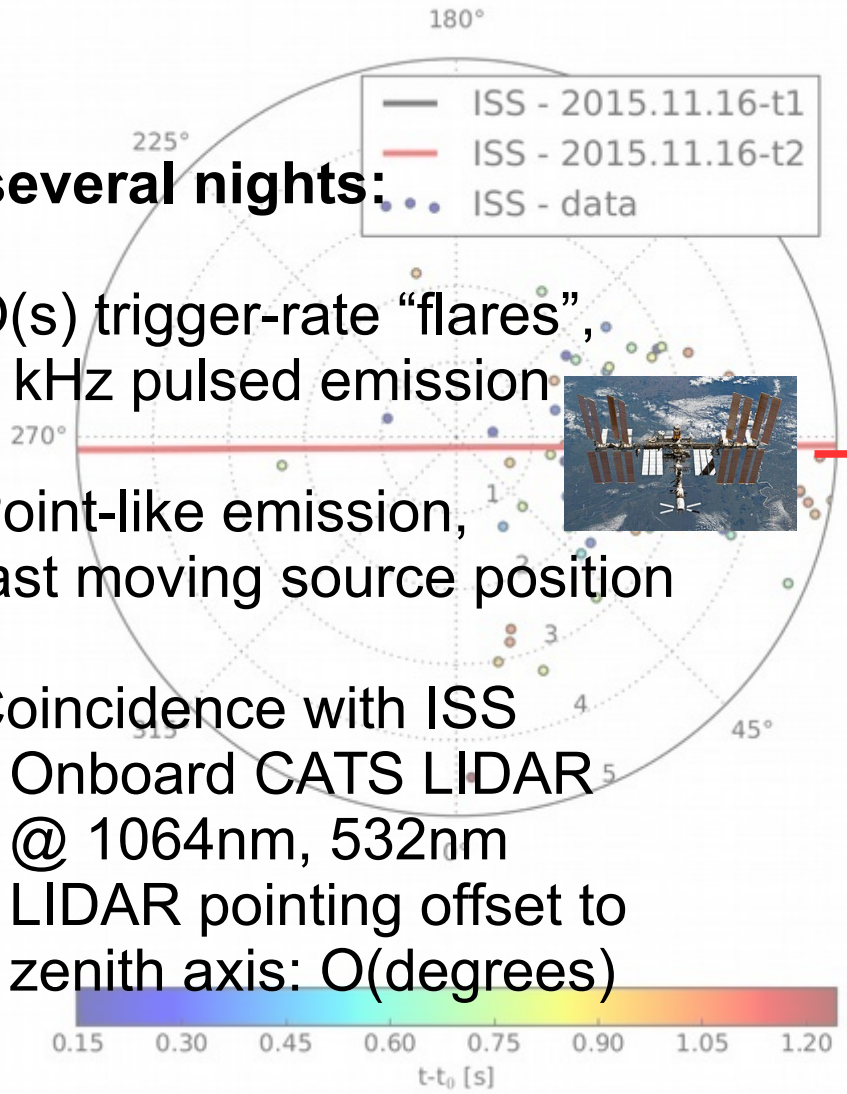
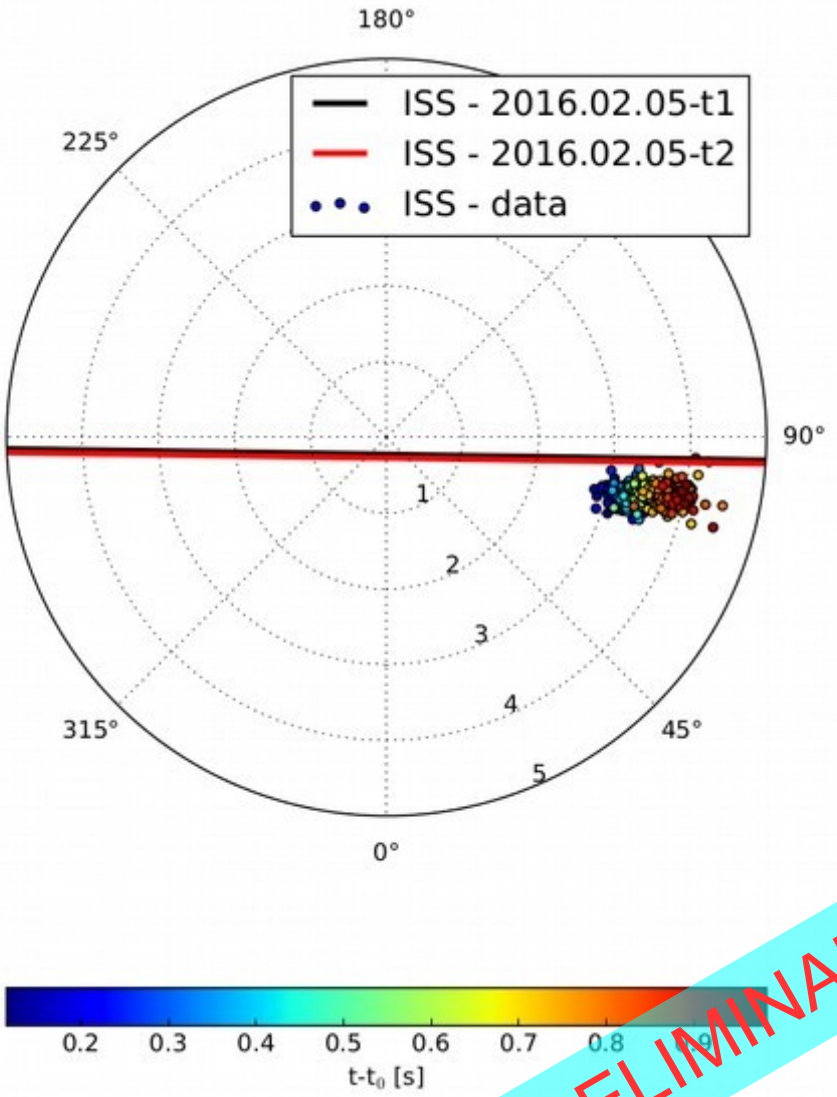
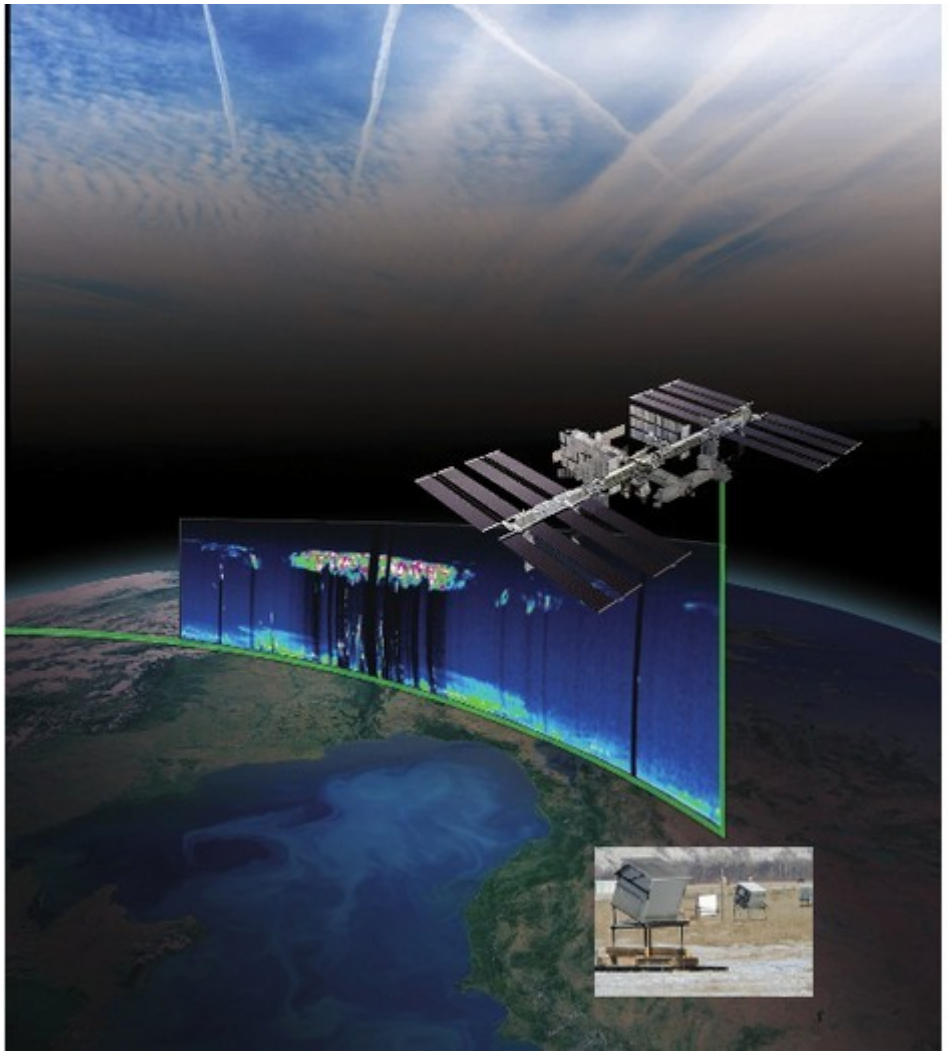
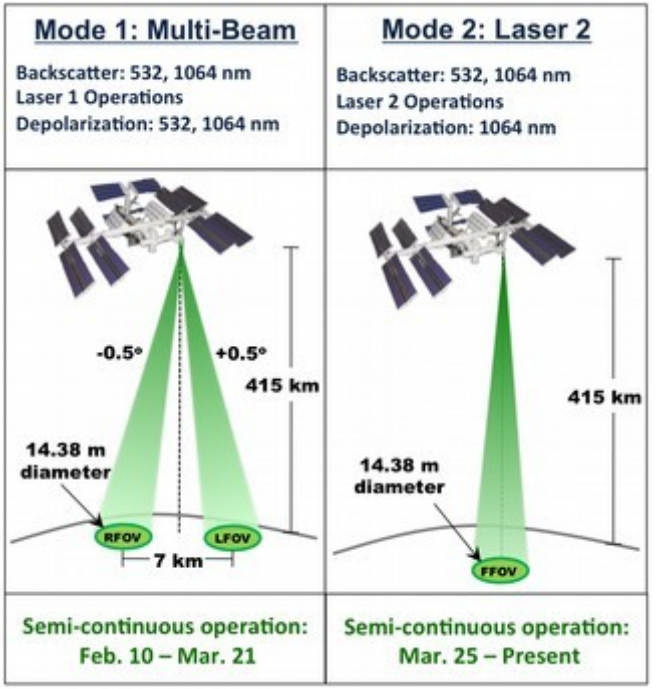




PRELIMINARY

A first HiSCORE Point-source



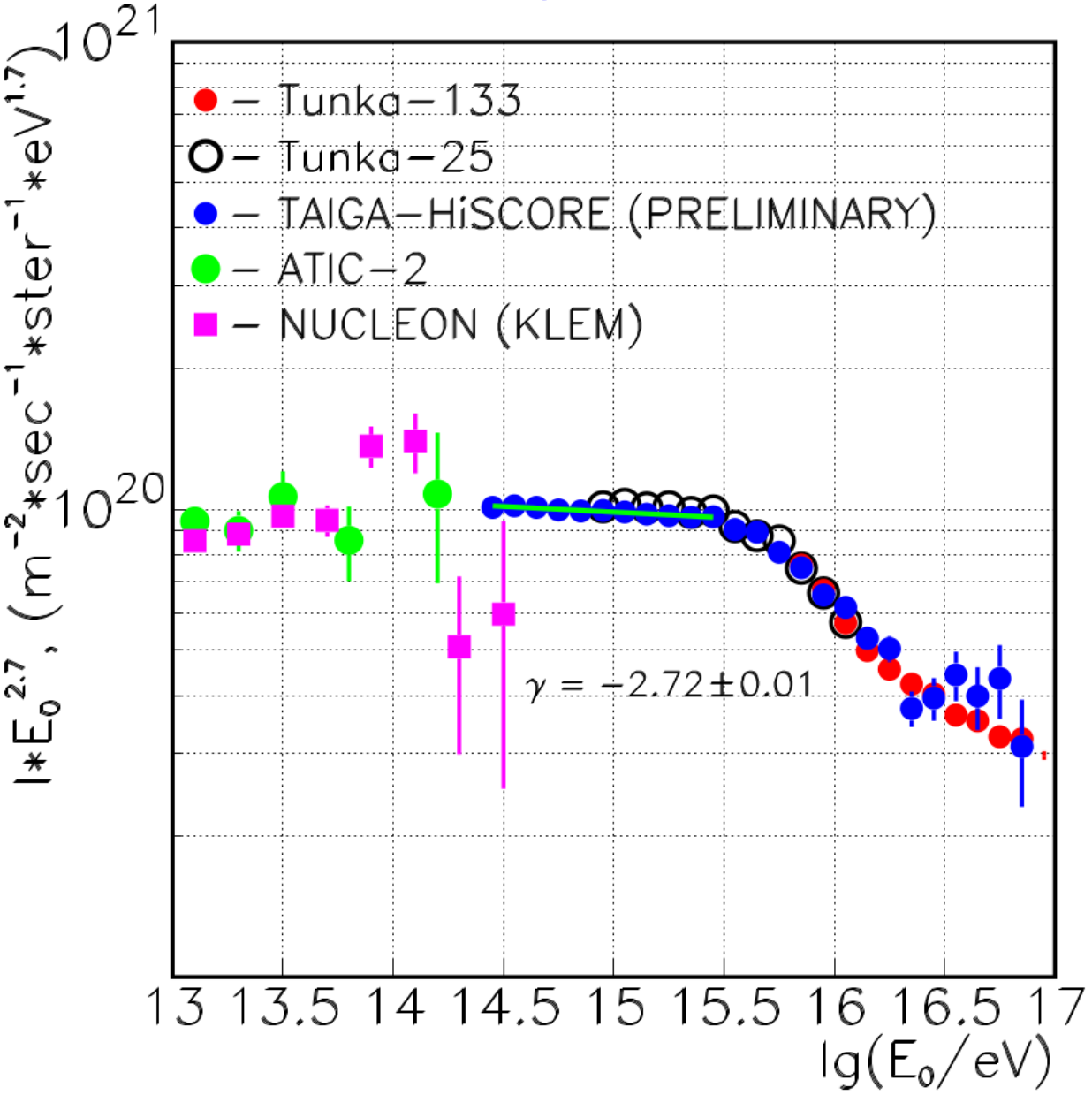


Event directions depend on
Height of orbit, Orientation angles of
ISS and of Lidar, atmospheric scattering
Understanding geometry is **work in progress**

Opportunities:

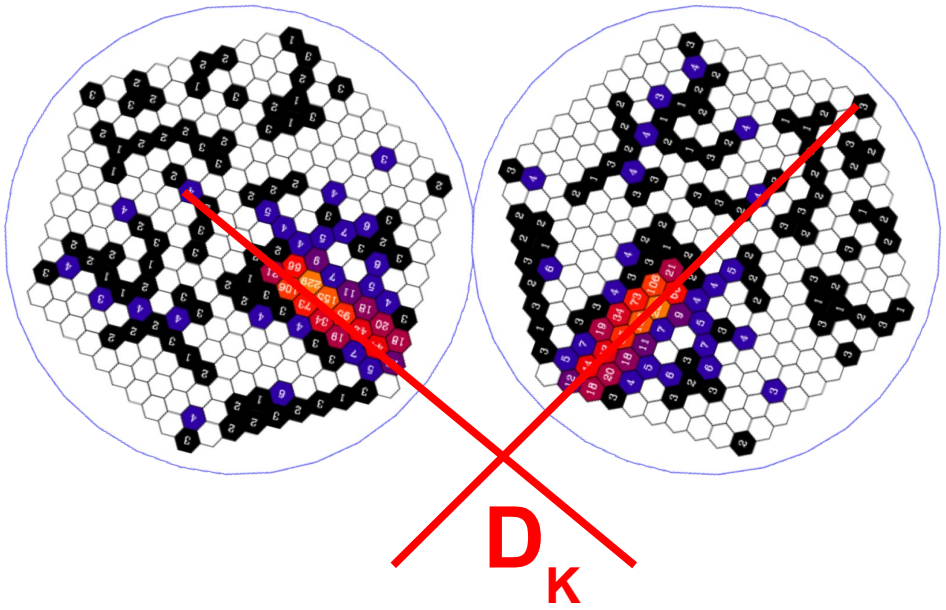
- TAIGA-HiSCORE calibration
- Atmospheric studies

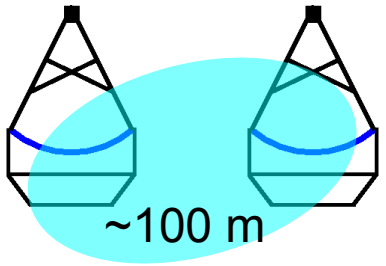
Cosmic ray spectrum



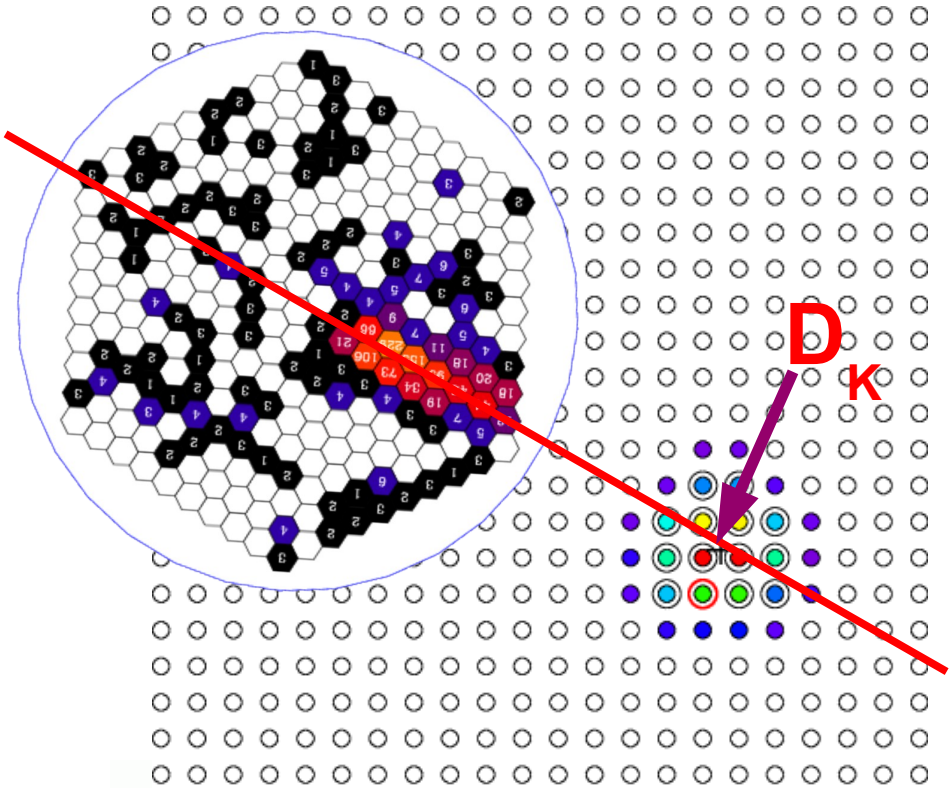
TAIGA-IACT: Imaging Air Cherenkov Telescopes

Imaging Hybrid mode



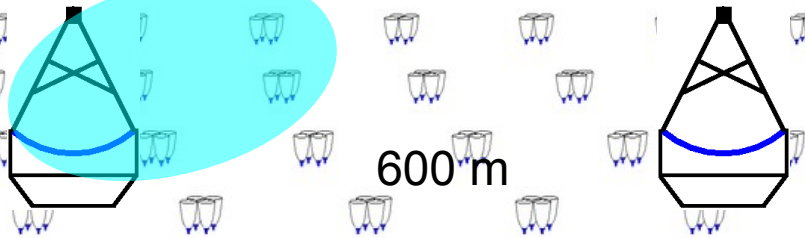


Imaging (stereo)



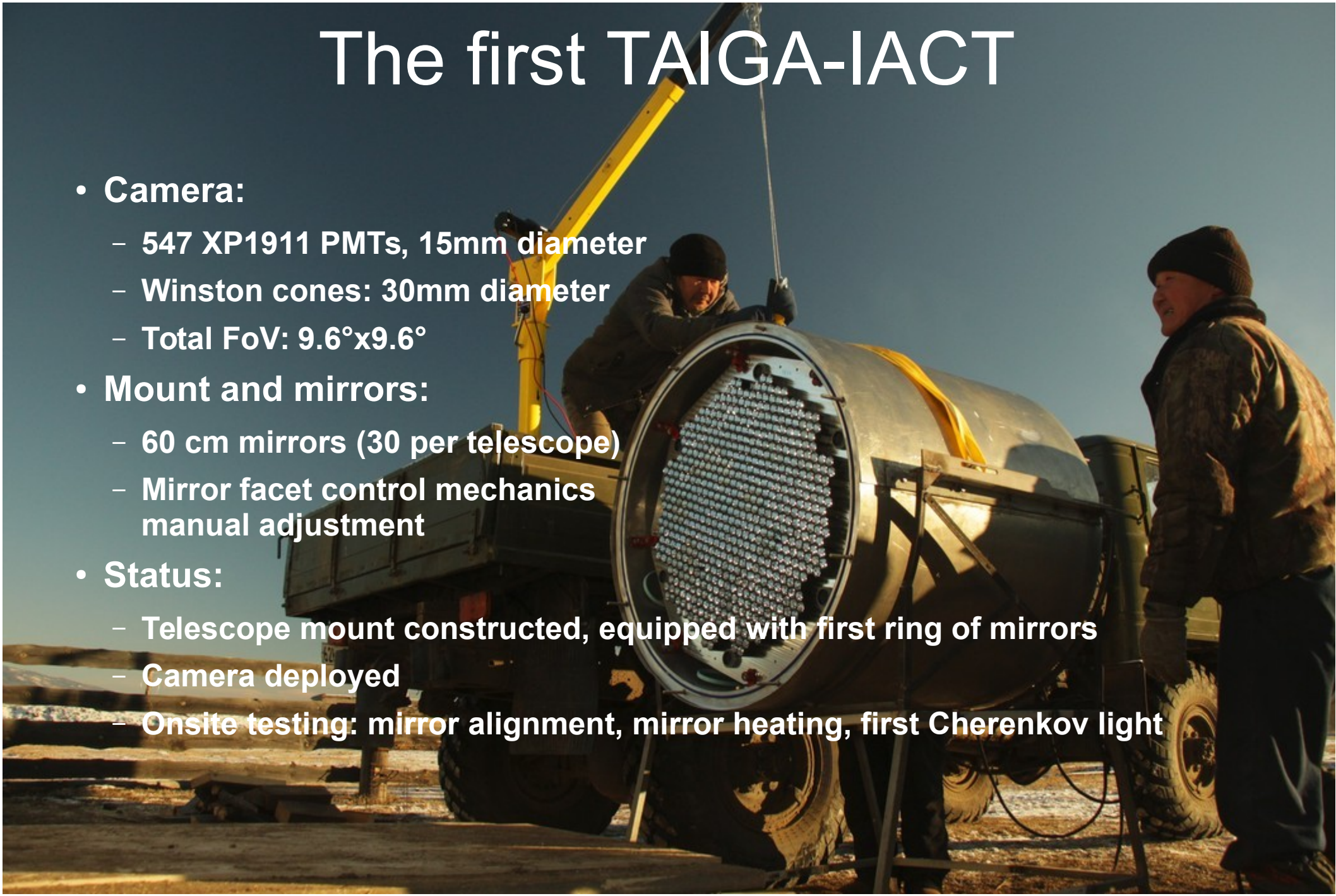
Intensity [p.e.]

Hybrid imaging + non-imaging



g/h separation → Maike ?

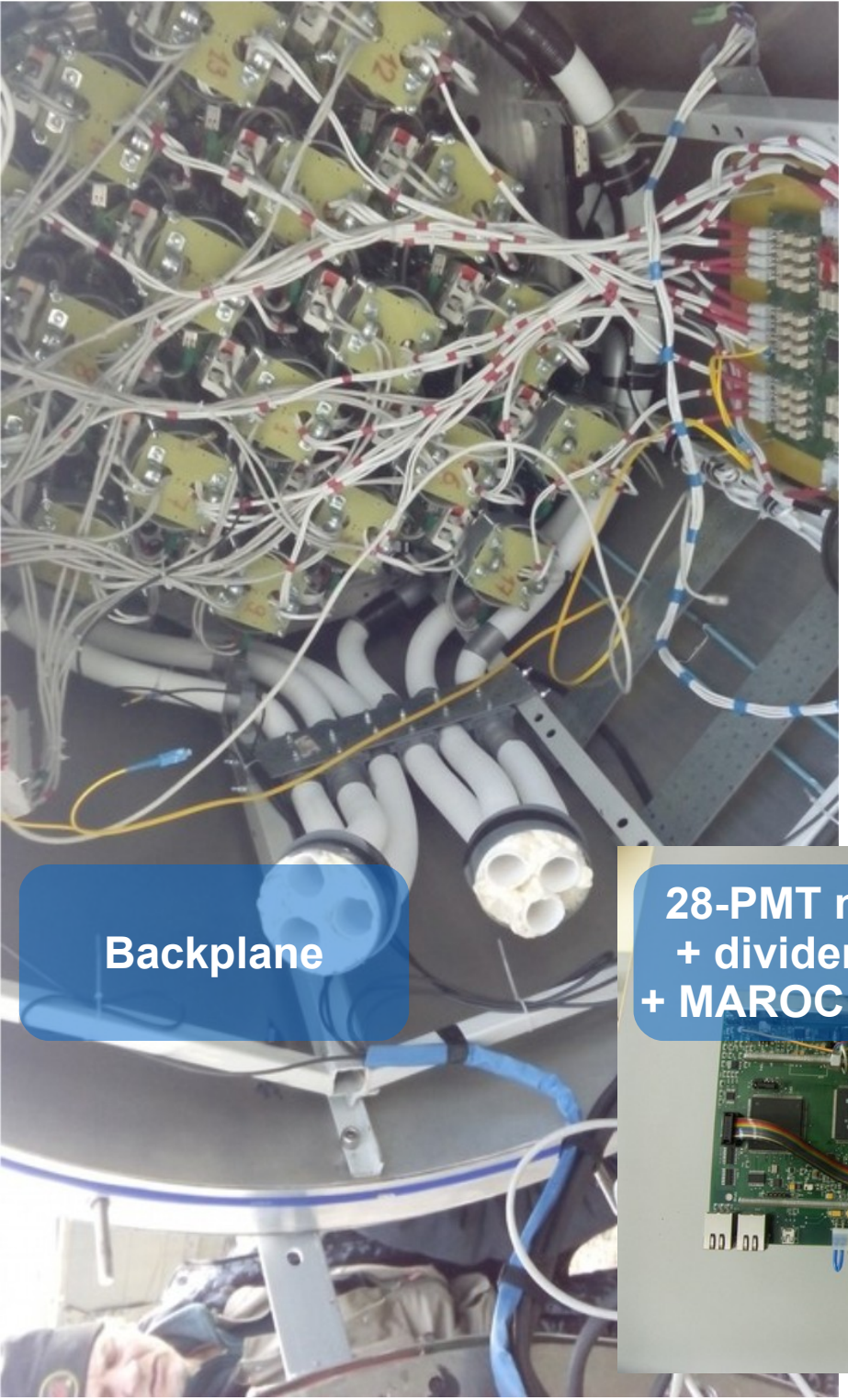
The first TAIGA-IACT

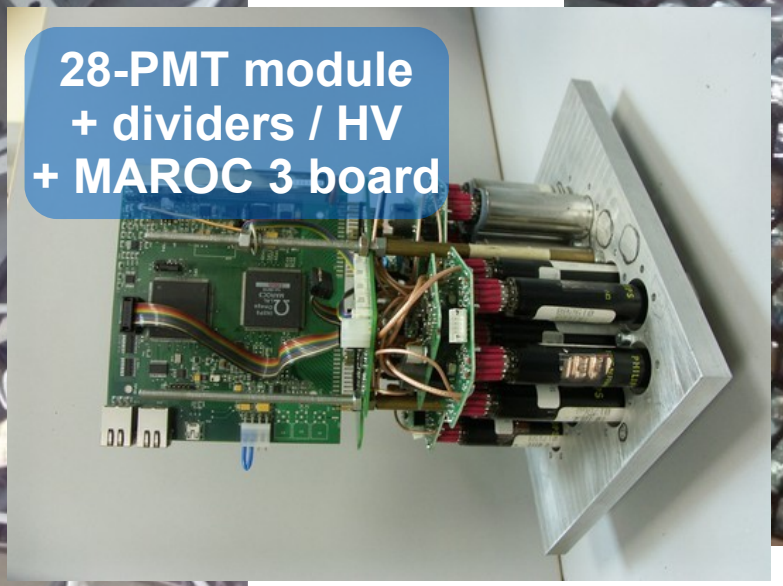


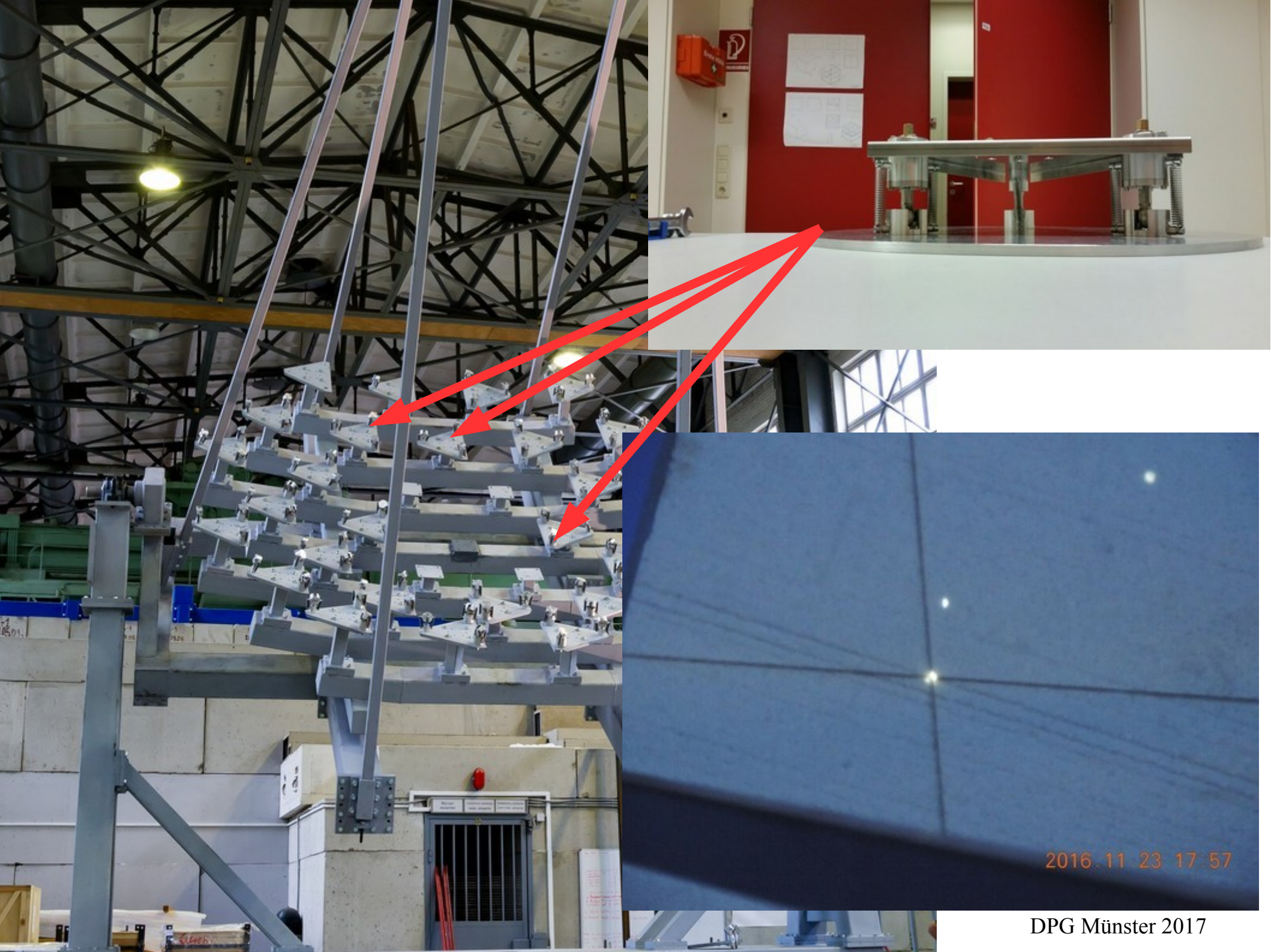
- **Camera:**
  - **547 XP1911 PMTs, 15mm diameter**
  - **Winston cones: 30mm diameter**
  - **Total FoV: 9.6°x9.6°**
- **Mount and mirrors:**
  - **60 cm mirrors (30 per telescope)**
  - **Mirror facet control mechanics manual adjustment**
- **Status:**
  - **Telescope mount constructed, equipped with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

The first TAIGA-IACT

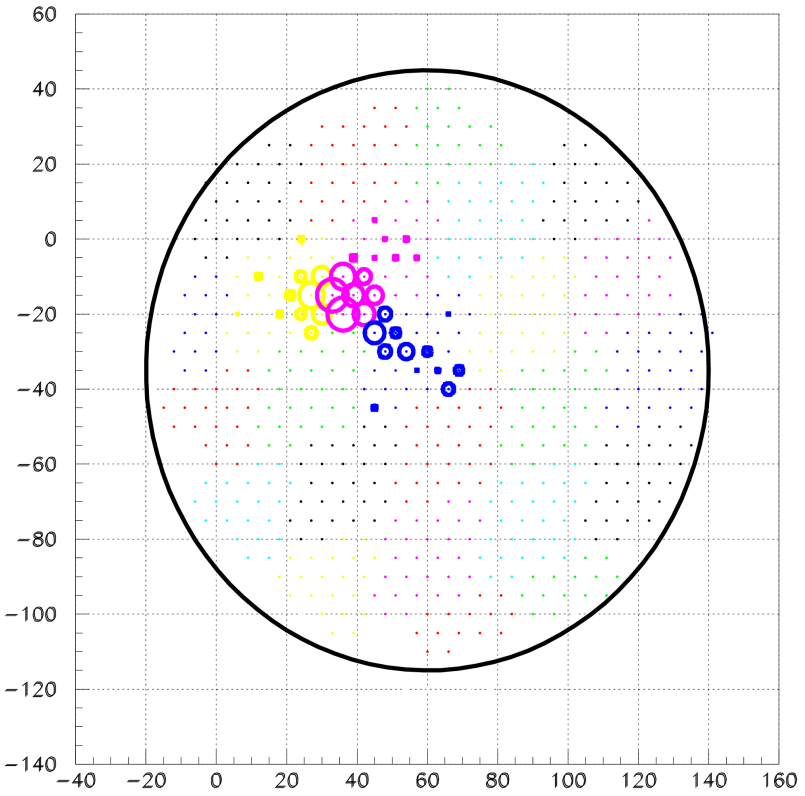
1st TAIGA-IACT

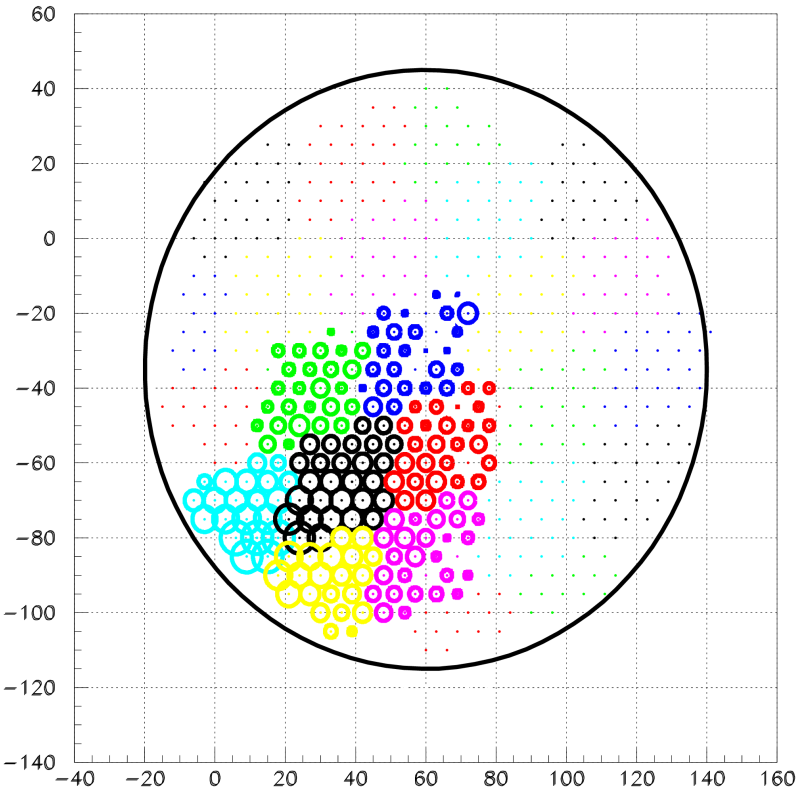





2016.11.23 17:57

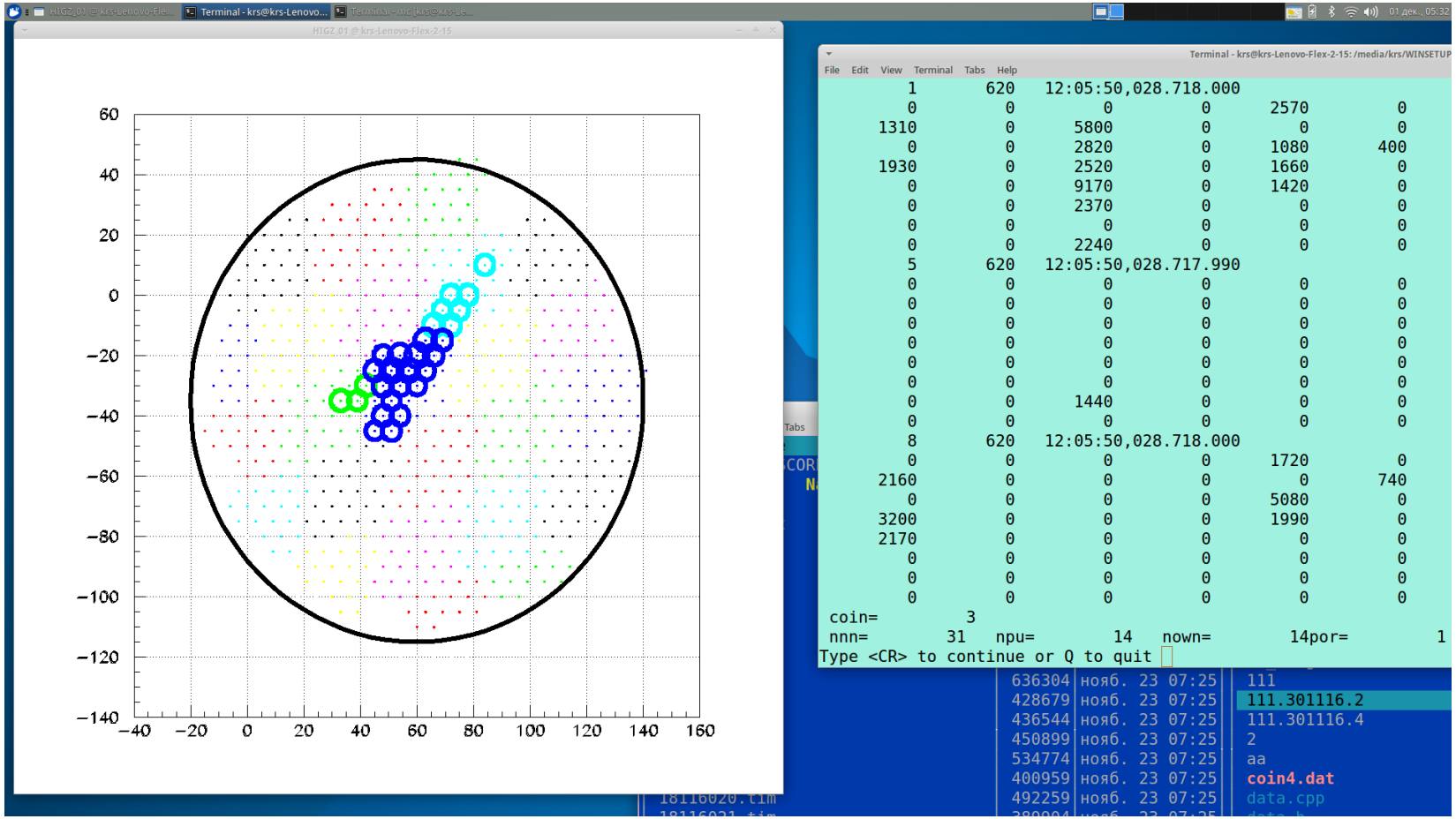
The first TAIGA IACT



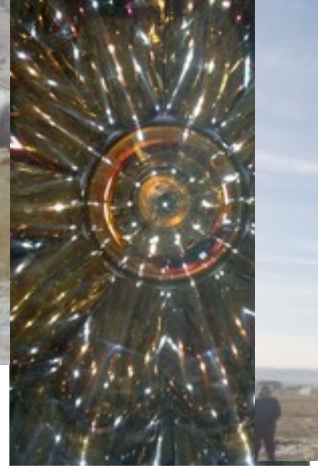


First events

The first TAIGA IACT



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 0.25 km² operational

- First results within expectations: on-track

- Ongoing extension→ 0.6 km²

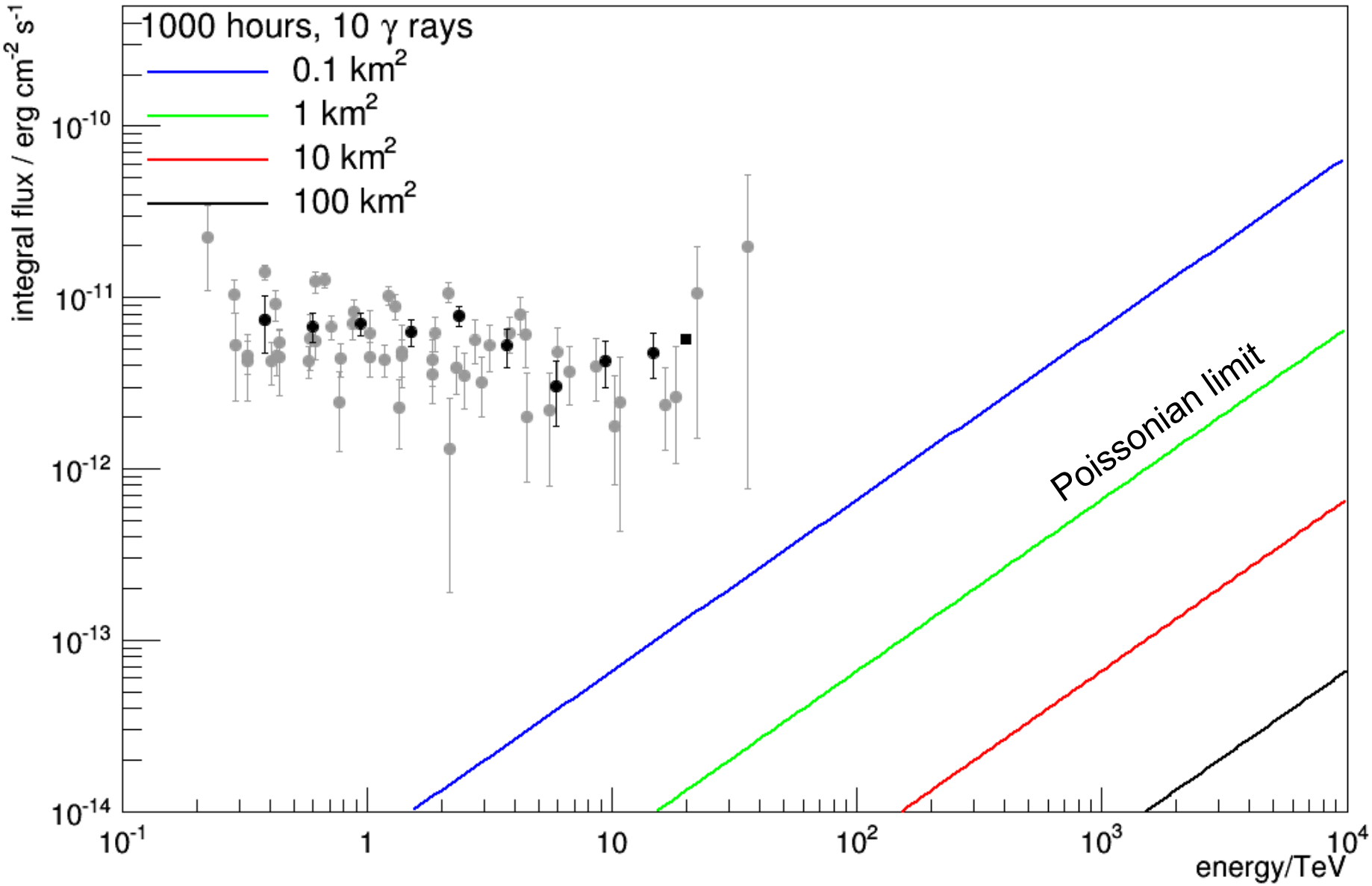
- First TAIGA IACT in commissioning

2016: “TAIGA-HiSCORE in the Tunka Valley: design, composition and commissioning”, to appear
2015: Journal of Physics: Conference Series (2015) 632 012042
2015: PoS(ICRC2015)1041
2014: Astroparticle Physics, 2014arXiv1403.5688T
2013 NIMPA.712..137H, arXiv:1302.3957
2013: ICRC 1146, 1158, and 1164
2011AdSpR..48.1935T, astro-ph/1108.5880
http://wwwiexp.desy.de/groups/astroparticle/score/
http://tunka-hrjrg.desy.de/

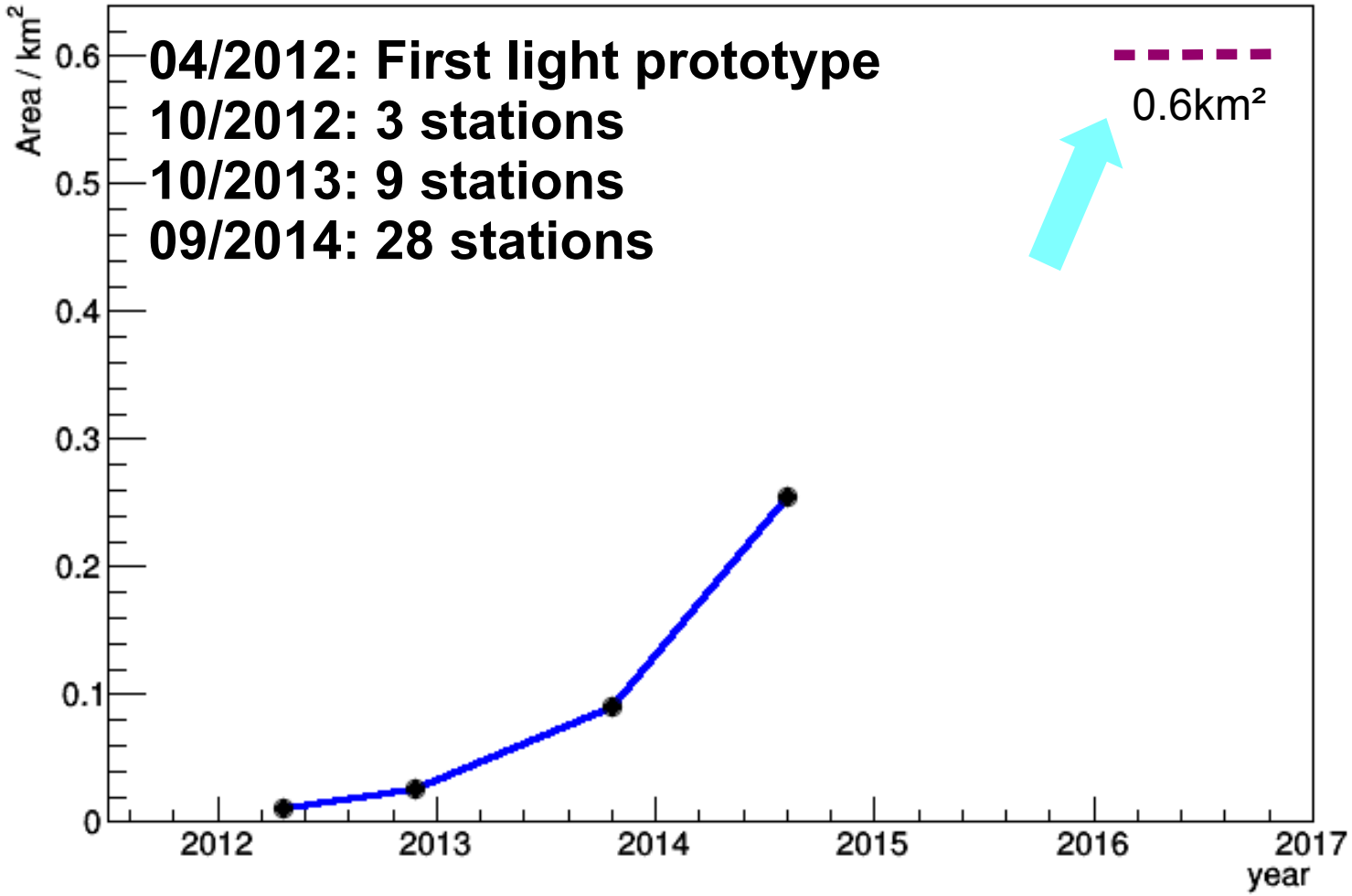
HiSCORE ⊂ TAIGA

BACKUP

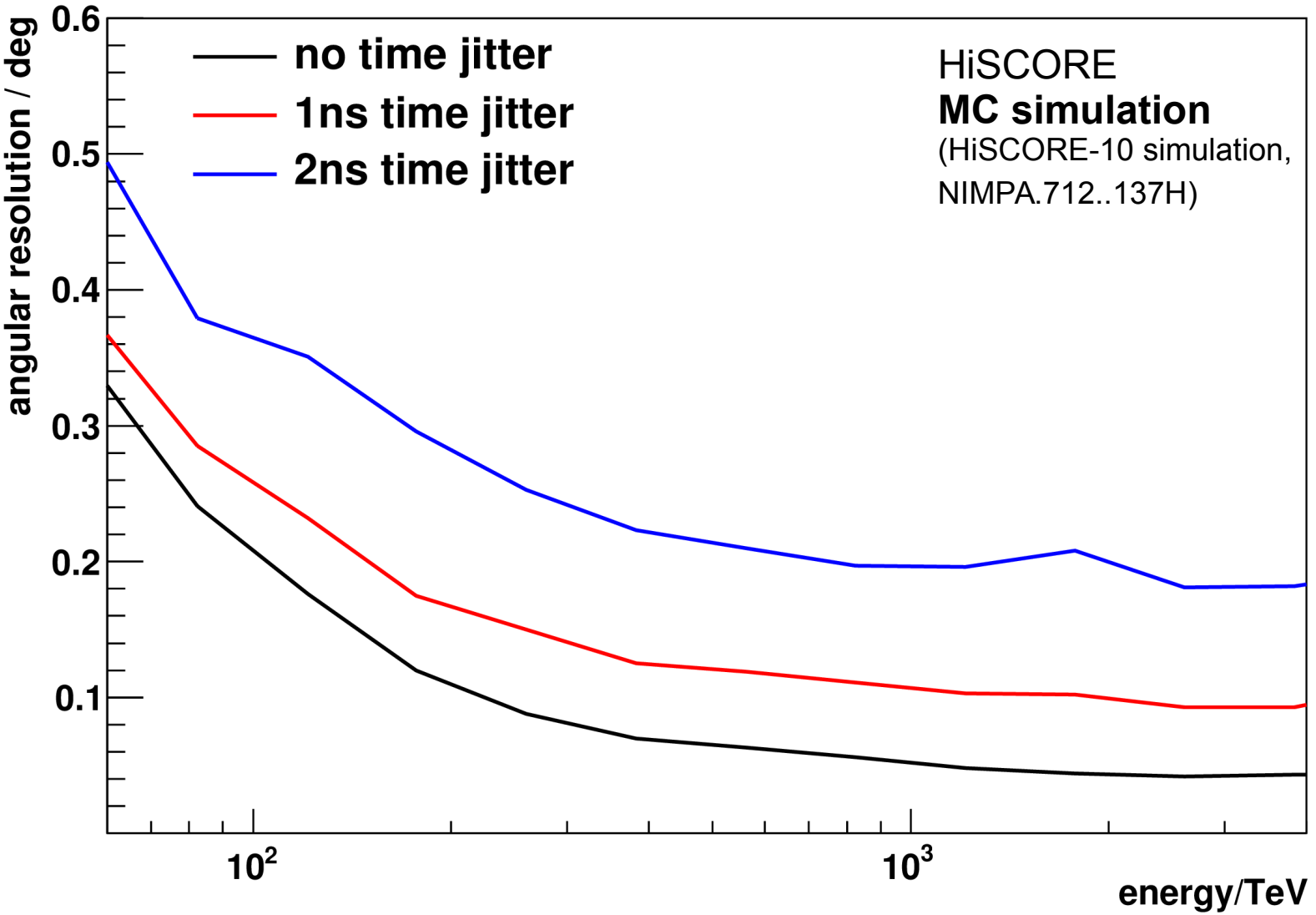
Key to Multi-TeV-PeV: Area



Evolution of effective area

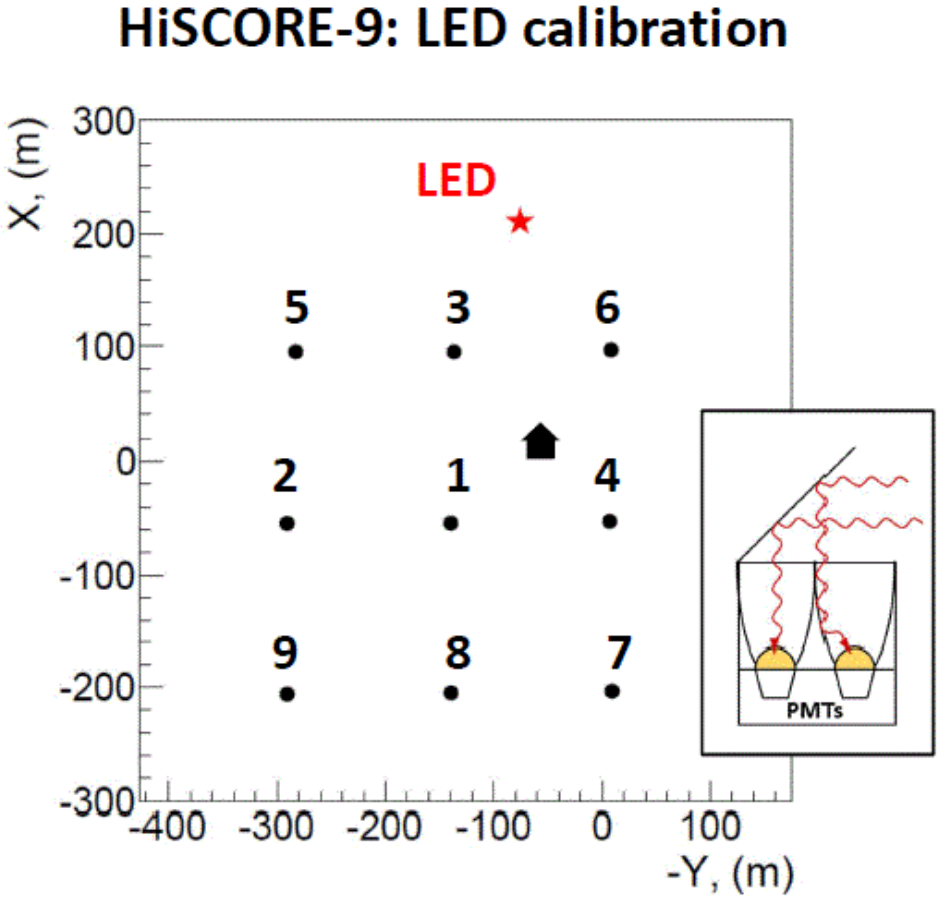


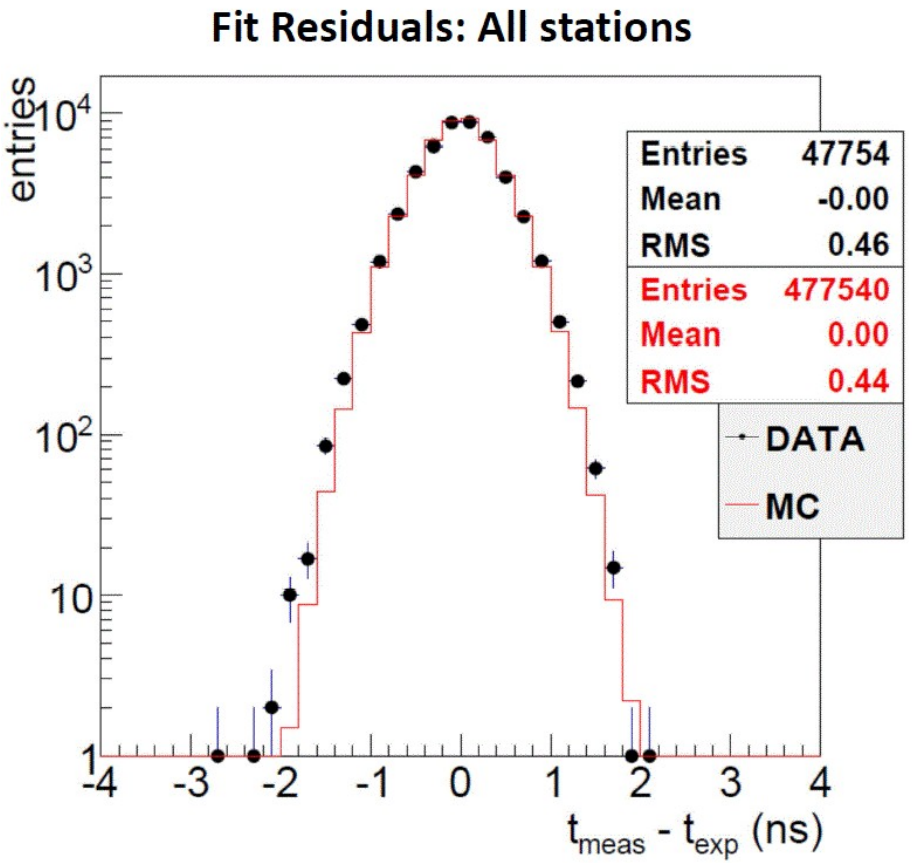
Angular resolution



Crucial: relative time-synchronization <1ns

Time calibration





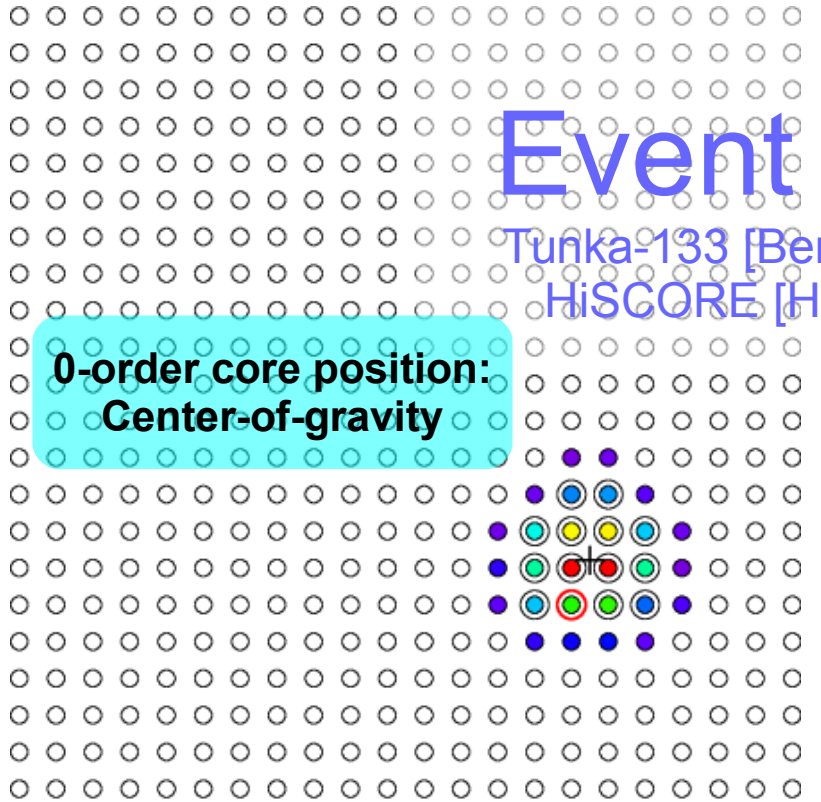
2013 HiSCORE-9

2 independent t-cal systems yield comparable accuraccies (<0.5 ns)

Event Reconstruction

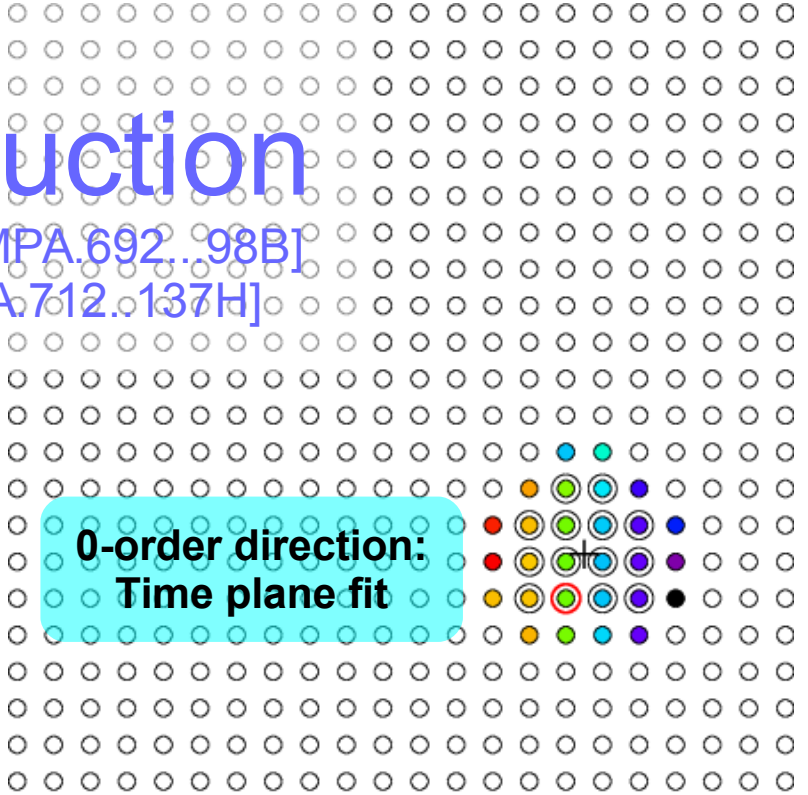
Tunka-133 [Berezhnev et al. 2012NIMPA.692..98B]
HiSCORE [Hampf et al. 2013NIMPA.712..137H]

0-order core position: Center-of-gravity

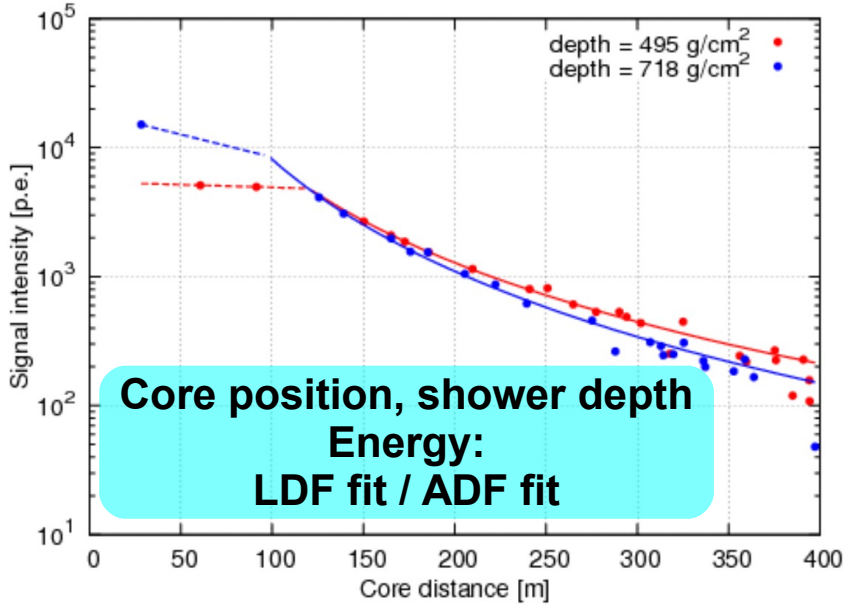


Intensity [p.e.]
0 — 1912

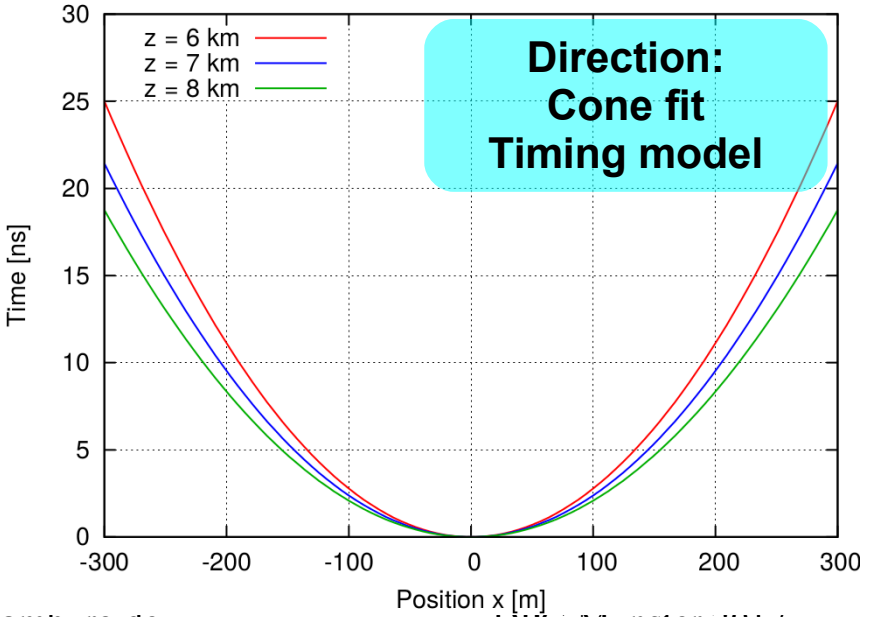
0-order direction: Time plane fit



Peaktime [ns]
-446 — 526

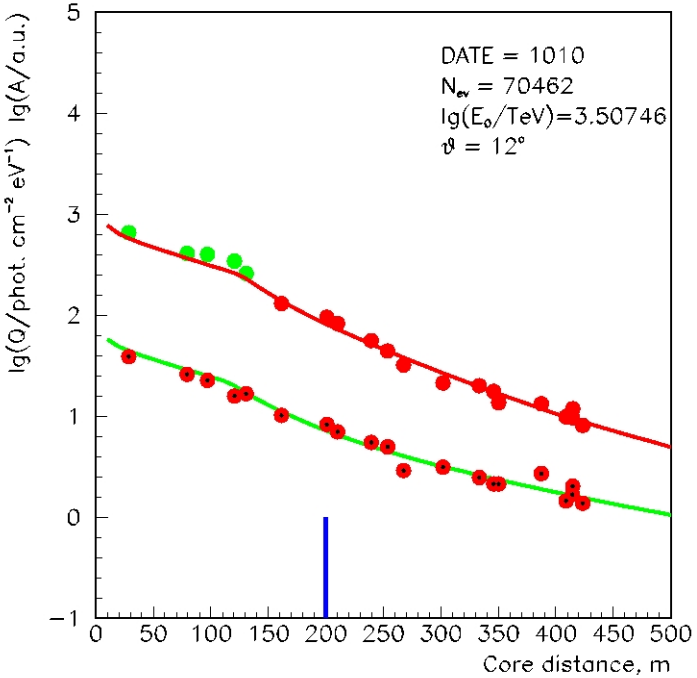


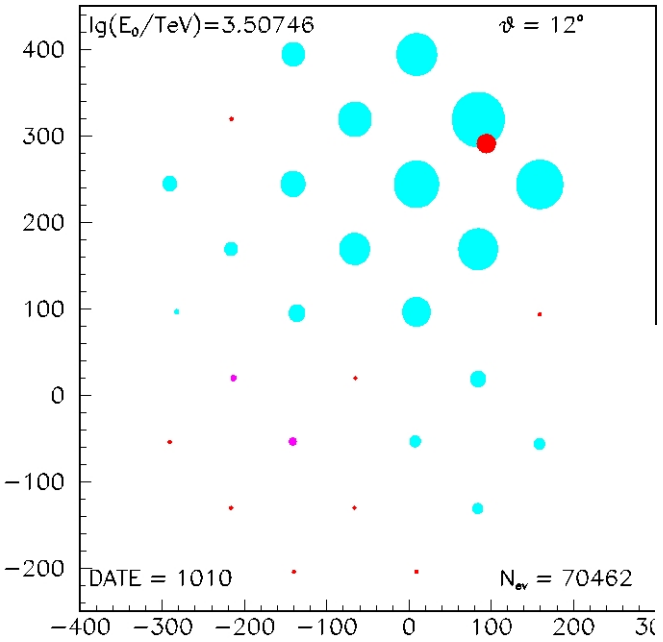
Core position, shower depth Energy: LDF fit / ADF fit

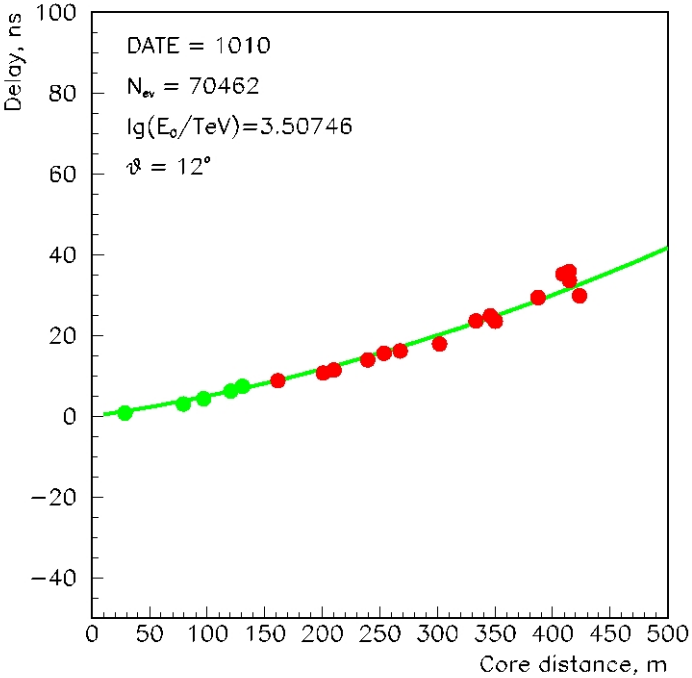


Direction: Cone fit Timing model

Event reconstruction



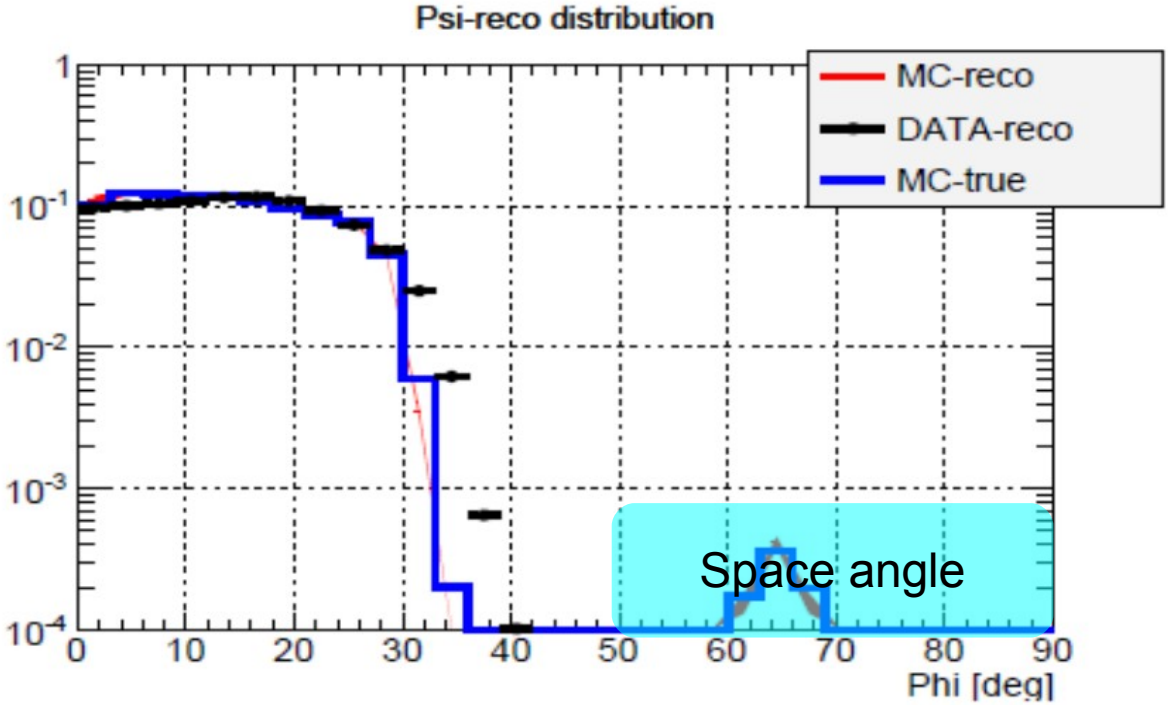


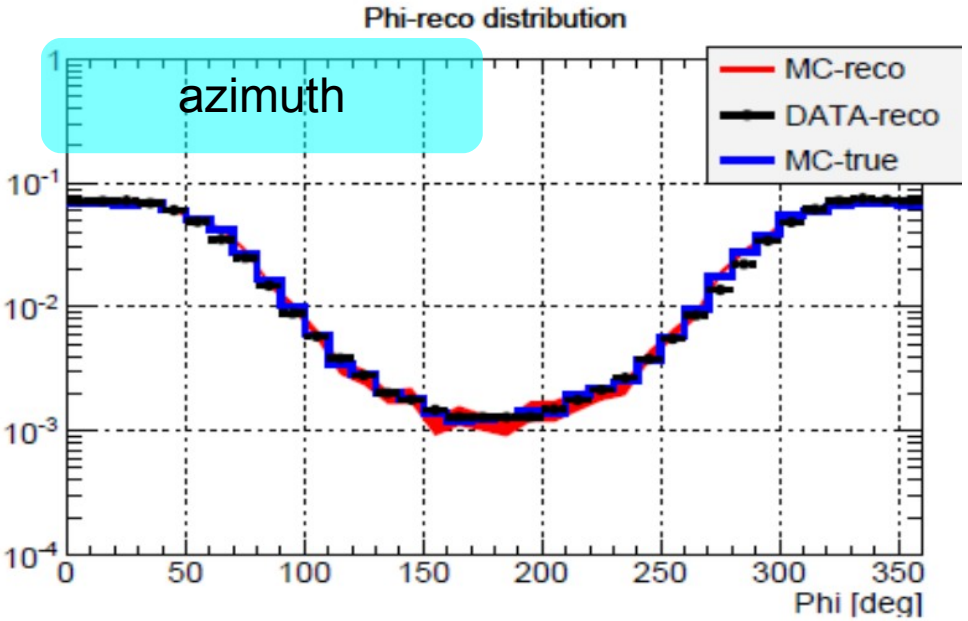


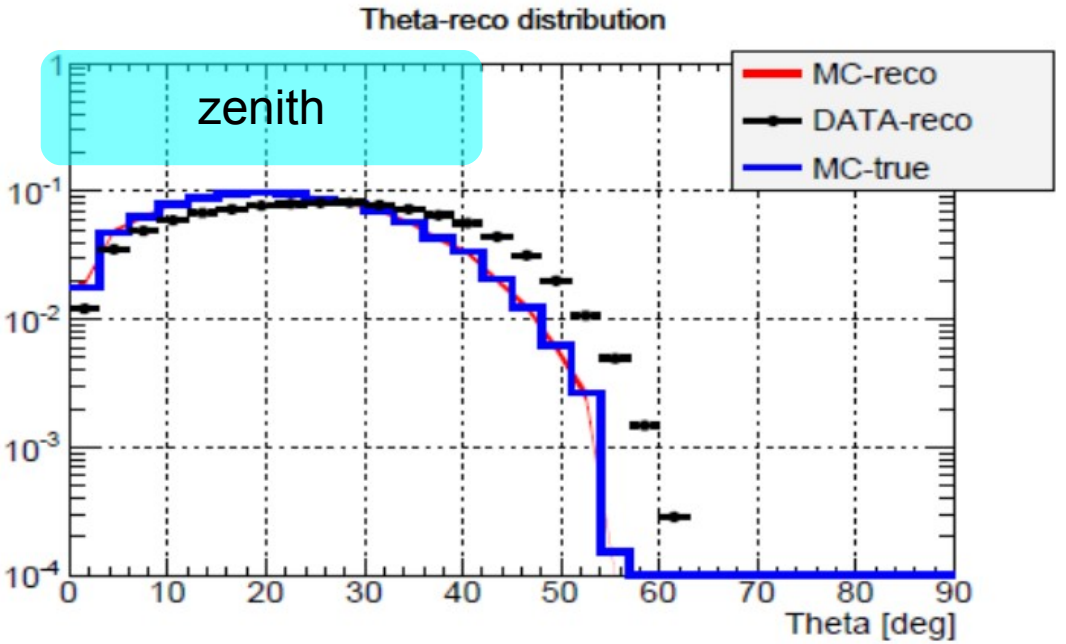
Reconstruction

Reconstructed direction

Data & MC

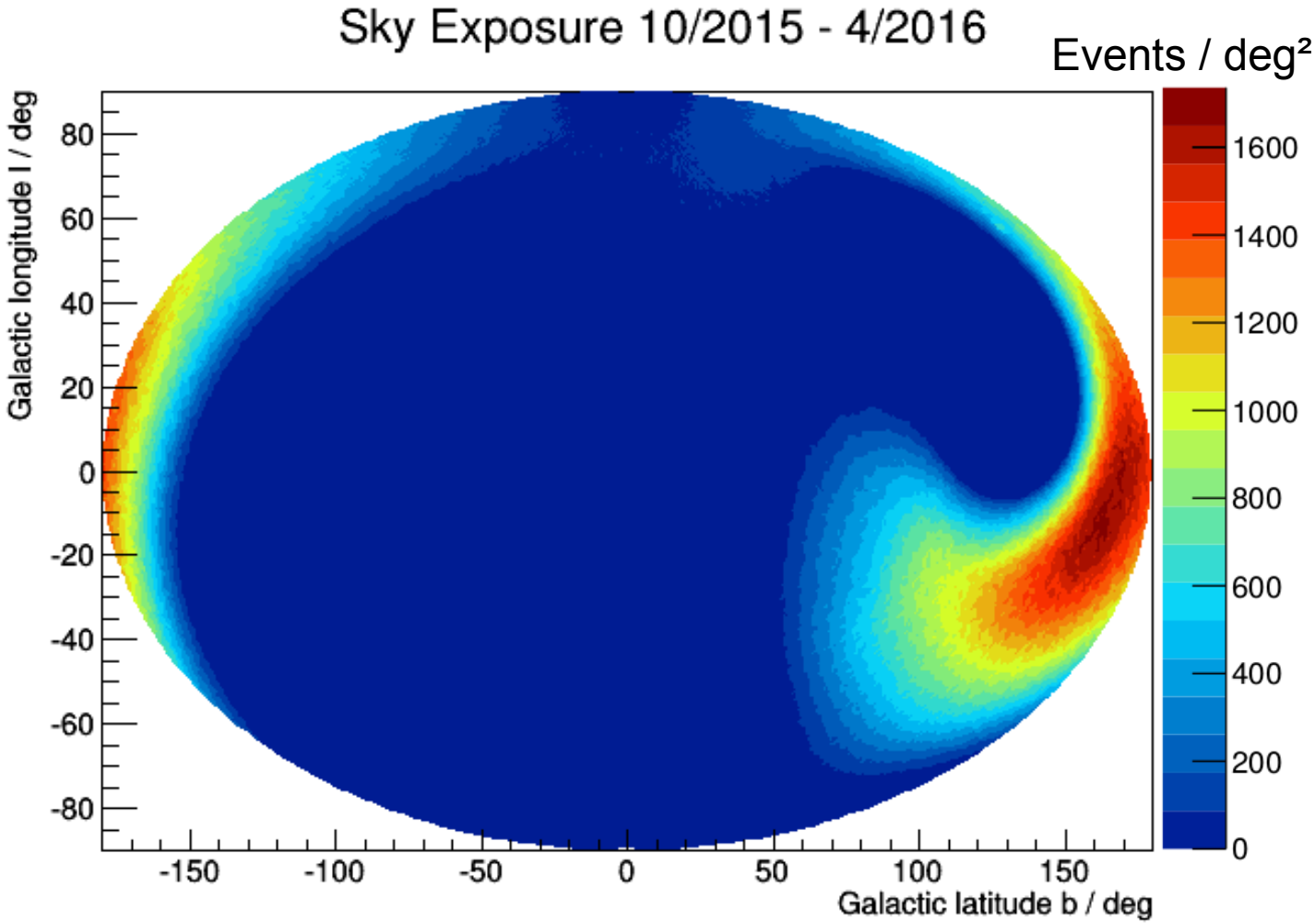






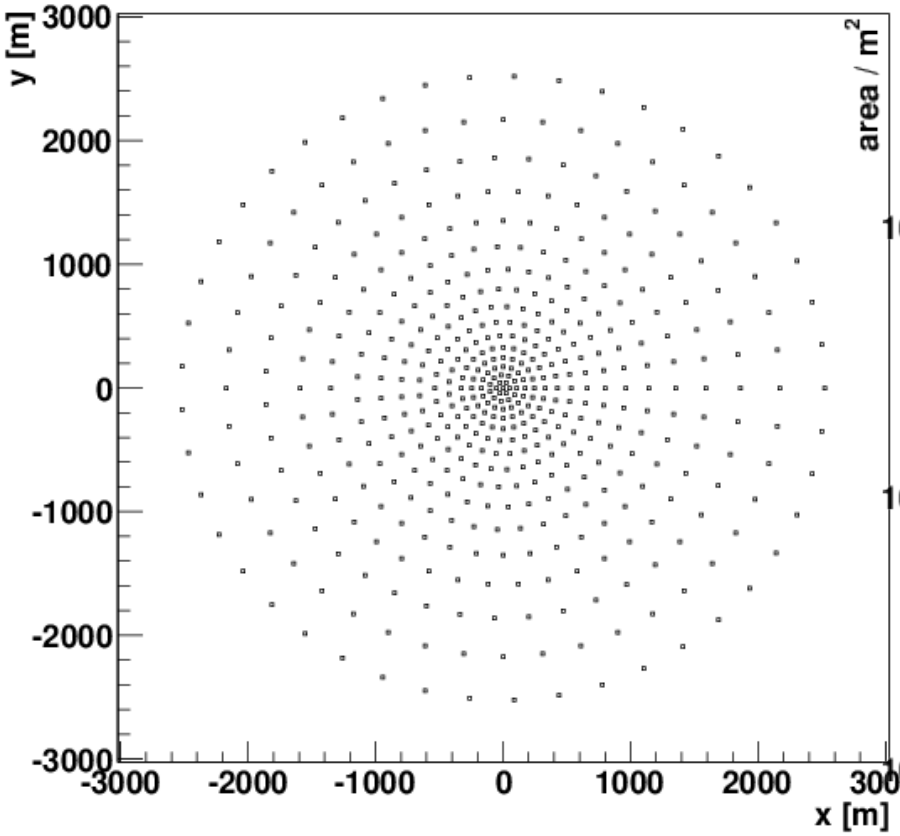
Data and Exposure

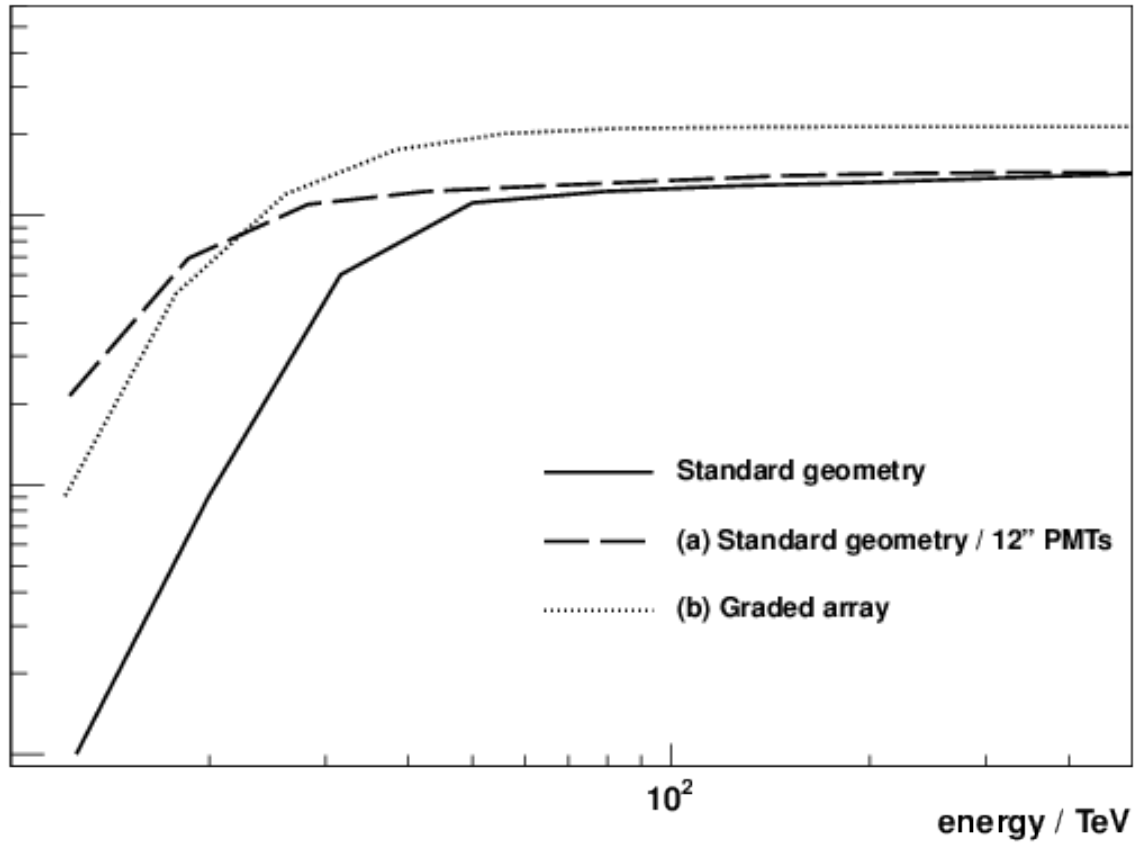
- Observations during commissioning phase of 28-station array October 2015 – April 2016
- Total 250 h observation time
- ~10^7 events



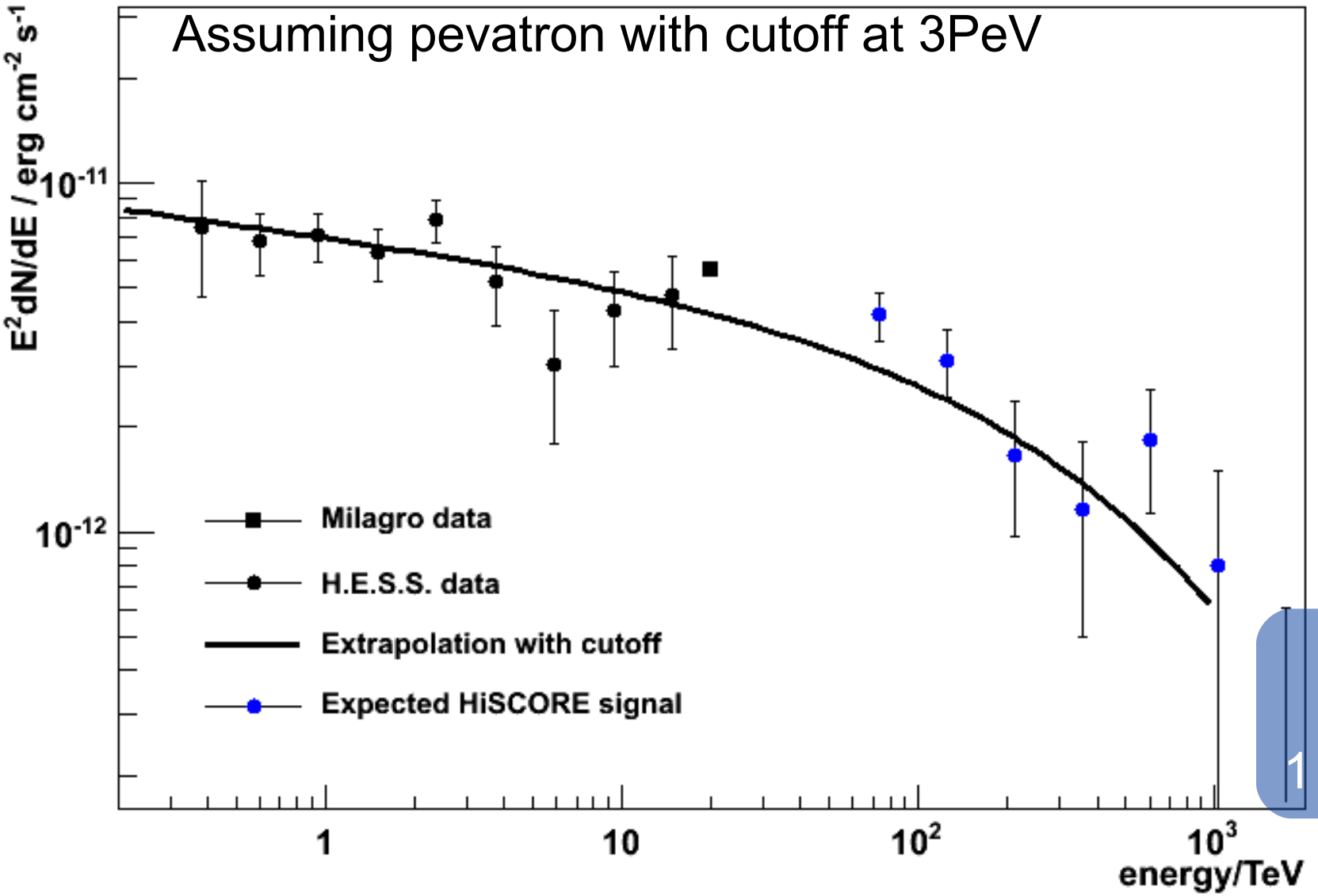
Array optimization

Simulation studies:
→ Large PMTs (12")
→ Graded array layout



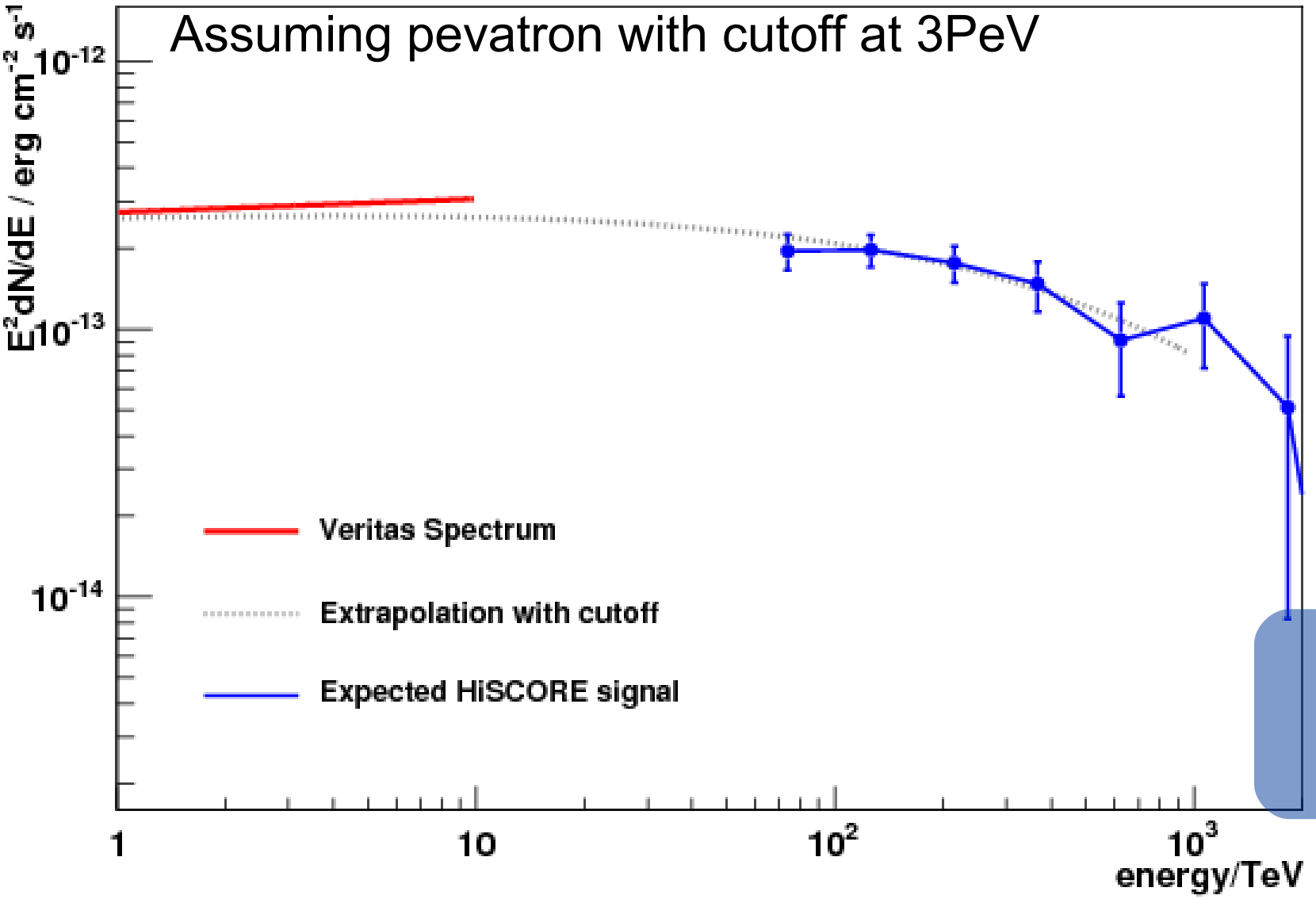


MGRO J1908+06



10 km²
No μ det.
1 year (200h)

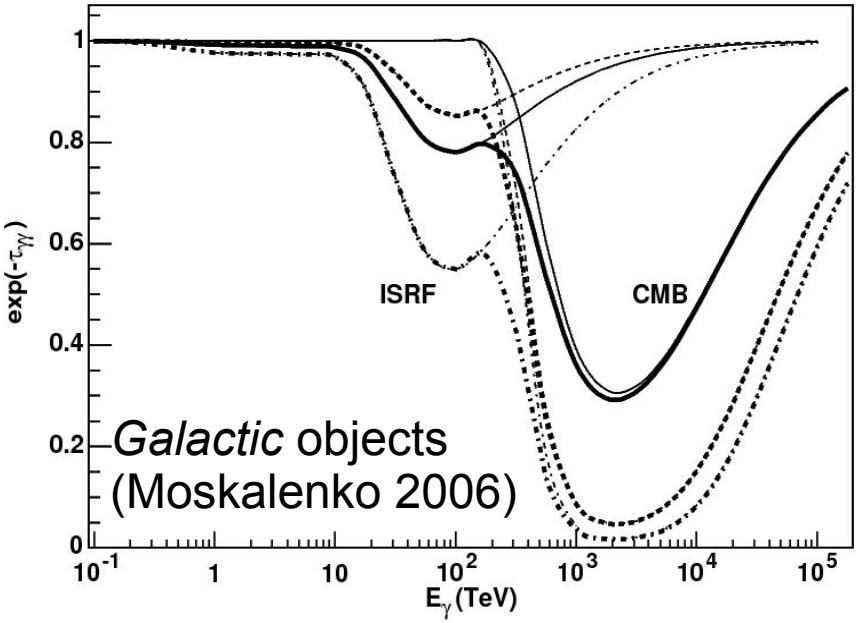
Tycho Supernova remnant



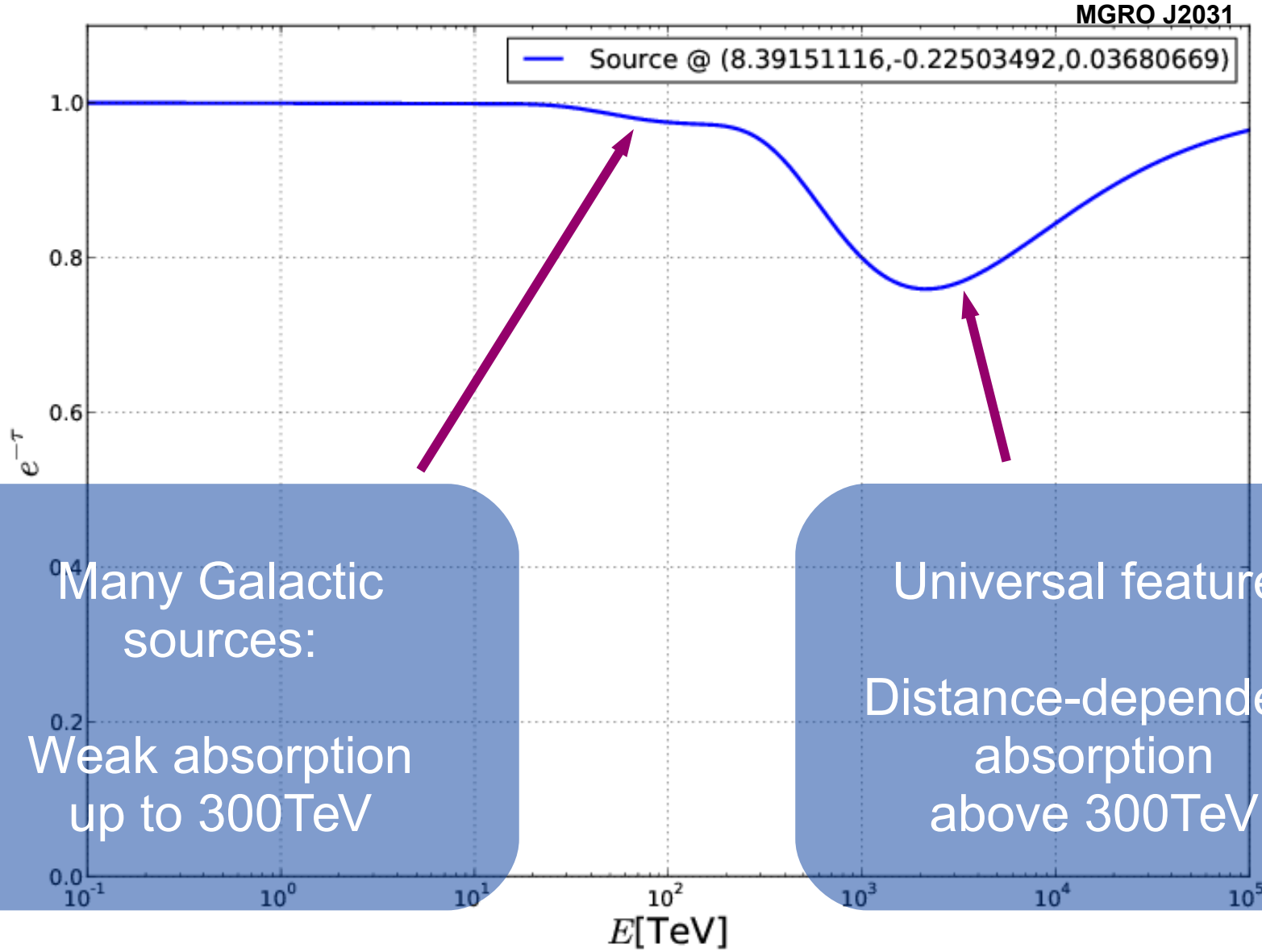
100 km²
No μ det.
3 years

Multi-TeV to PeV Gamma rays

- Spectroscopy of cutoff regime of Galactic sources
  - Extension of known hard source spectra
  - Search for cosmic ray PeVatrons
- No hadronic/leptonic ambiguity:
  - IC: Klein-Nishina regime → steep spectra
  - Pi° decay: hard spectra possible
- Absorption e+e-:
  - 20+TeV: Mid- to far-infrared EBL *(Extragal.)*
  - 100 TeV: ISRF (*Galactic*)
  - 3 PeV: CMB (*Galactic*)



Absorption (e^+e^-), Galactic



A. Maurer

Many Galactic sources:

Weak absorption up to 300TeV

Universal feature:

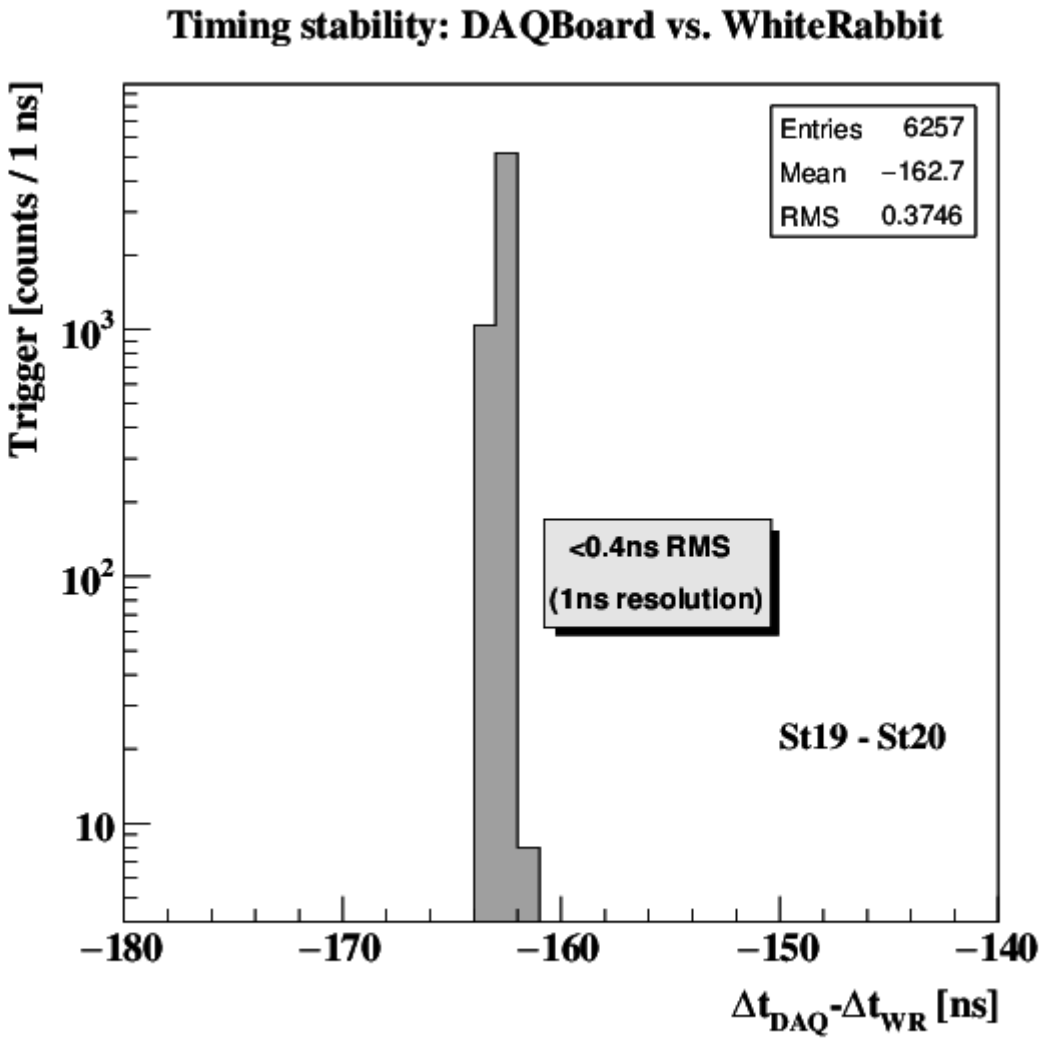
Distance-dependent absorption above 300TeV

Time calibration

T-cal systems yield comparable accuraccies:

Cross check of timing stability between DAQBoard and WhiteRabbit:

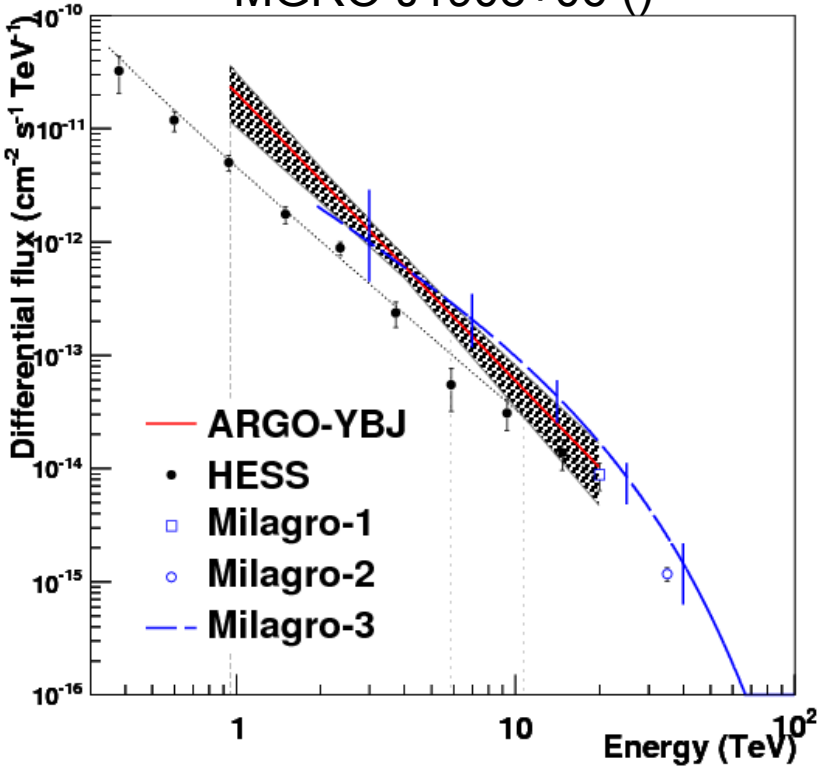
RMS<0.4 ns

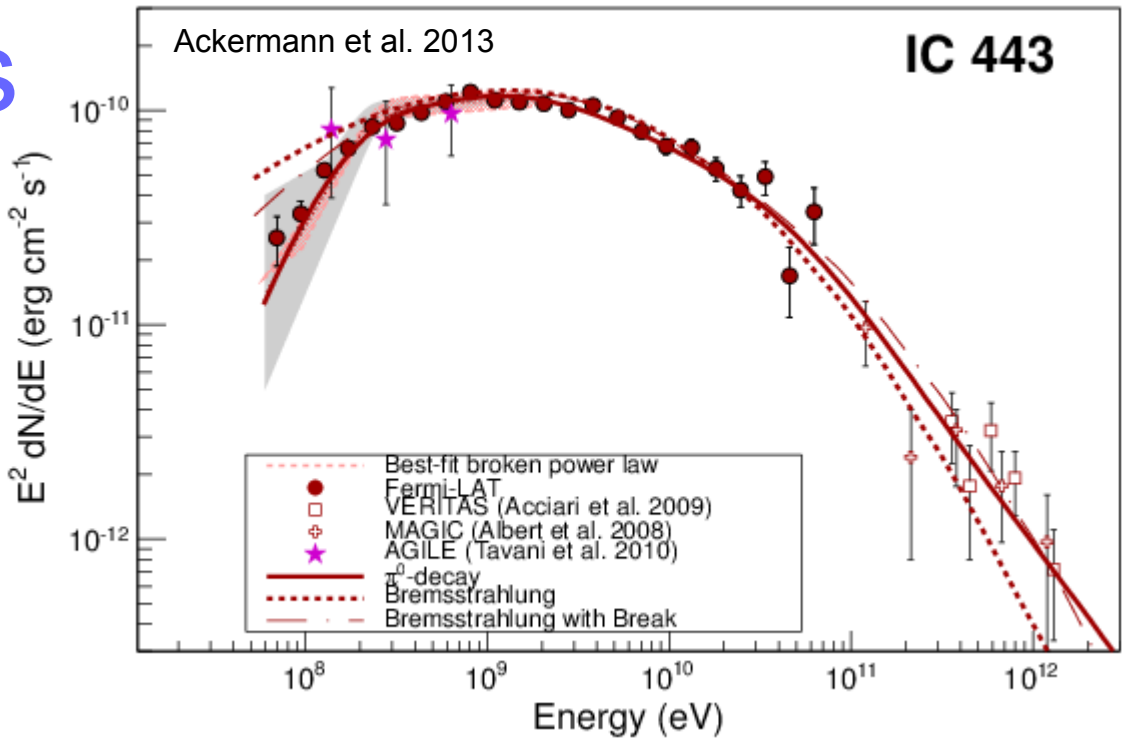


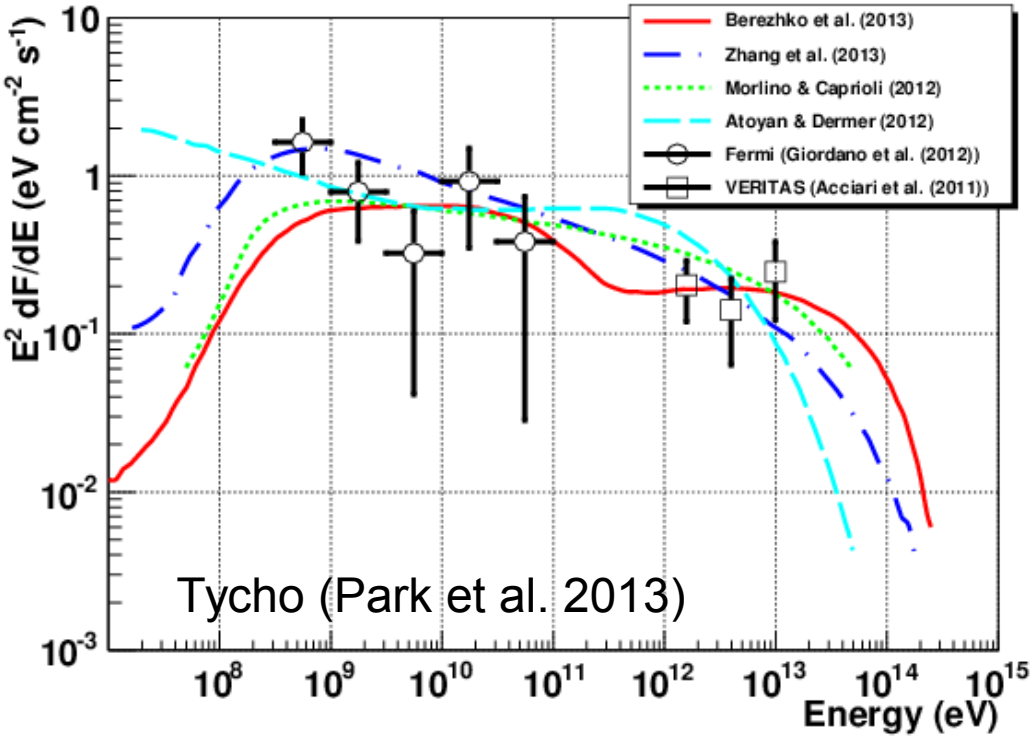
Detection methods for gamma astronomy

Method	E_{thr}	Angular resolution	ΔE/E	γ/h	Duty cycle
Particles	~3 TeV	~1°	20-50%	~1	100%
	Water: 100 GeV	<0.5°	30-50%	~6	
Air Cherenkov photons	IACTs: 5GeV	0.1-0.2°	10-15%	~6	10%
	NonI: 10 TeV			~1.5-2	
Fluoresc.	10^{17} eV	>1°	10-15%	?	10%
Radio	10^{17} eV	<1°	10-15%	?	100%

Galactic Gammas beyond 10 TeV



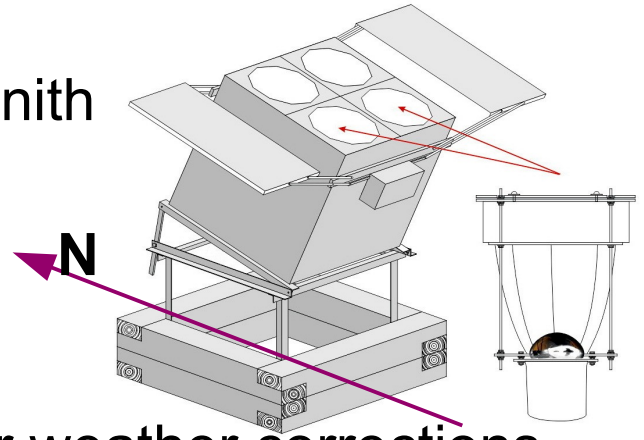




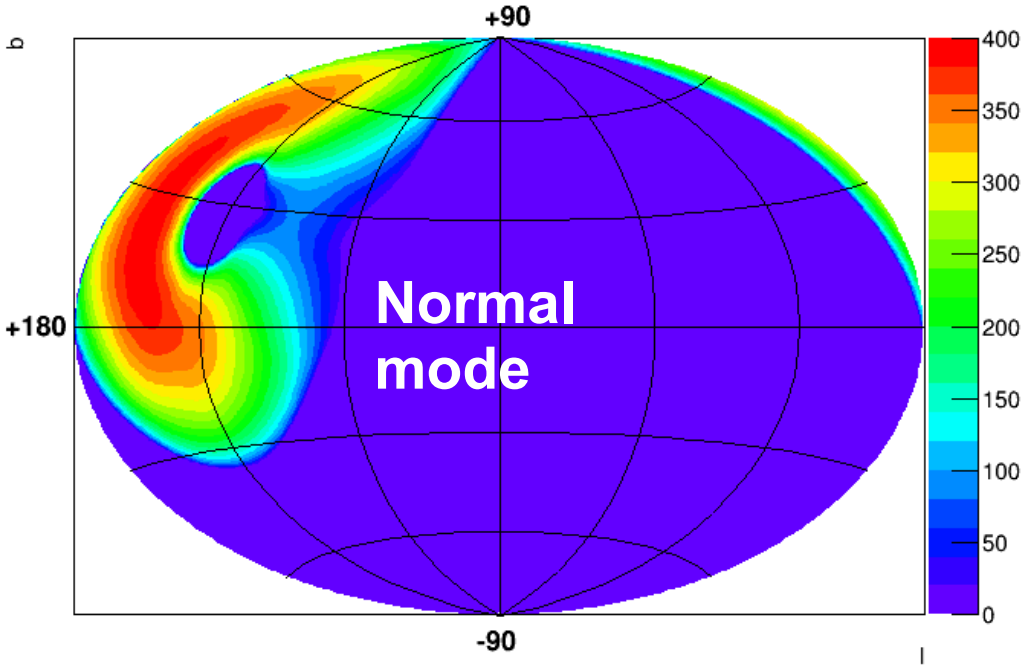
Sky coverage

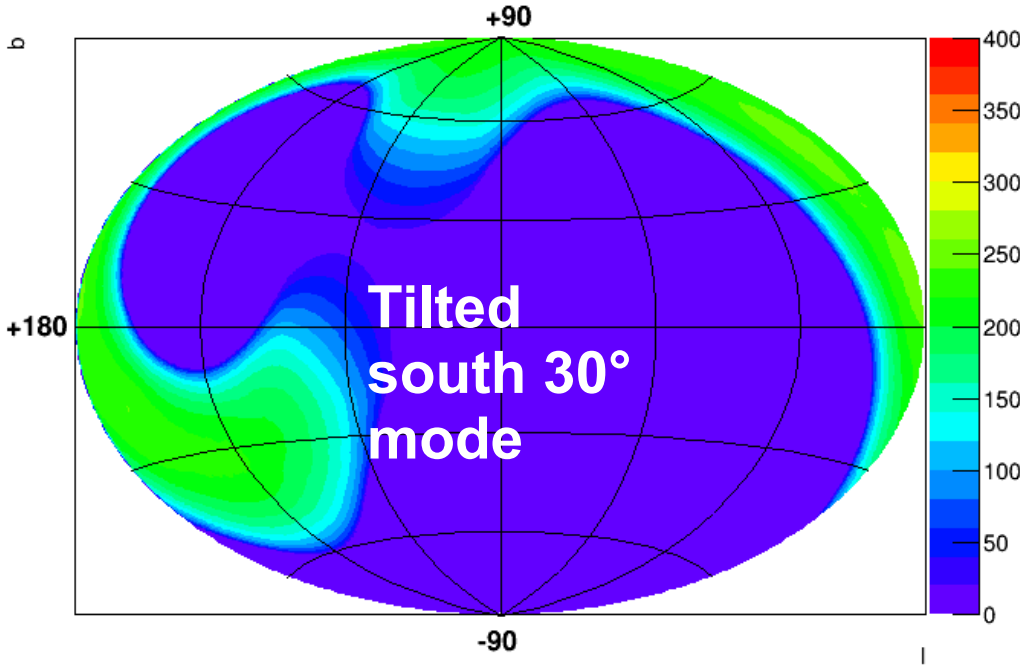
Standard observation mode: station points to zenith
Tilted mode: inclined along the north-south axis.

Tilting: coverage of different parts of the sky.

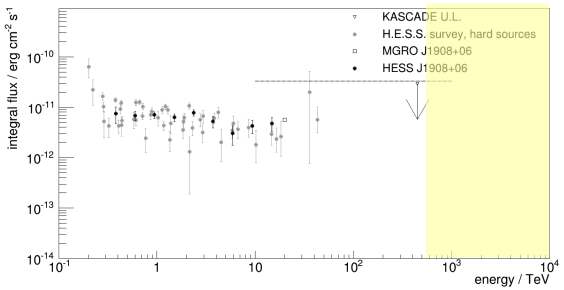


Tilted south mode: 110 h on the Crab Nebula, after weather corrections.



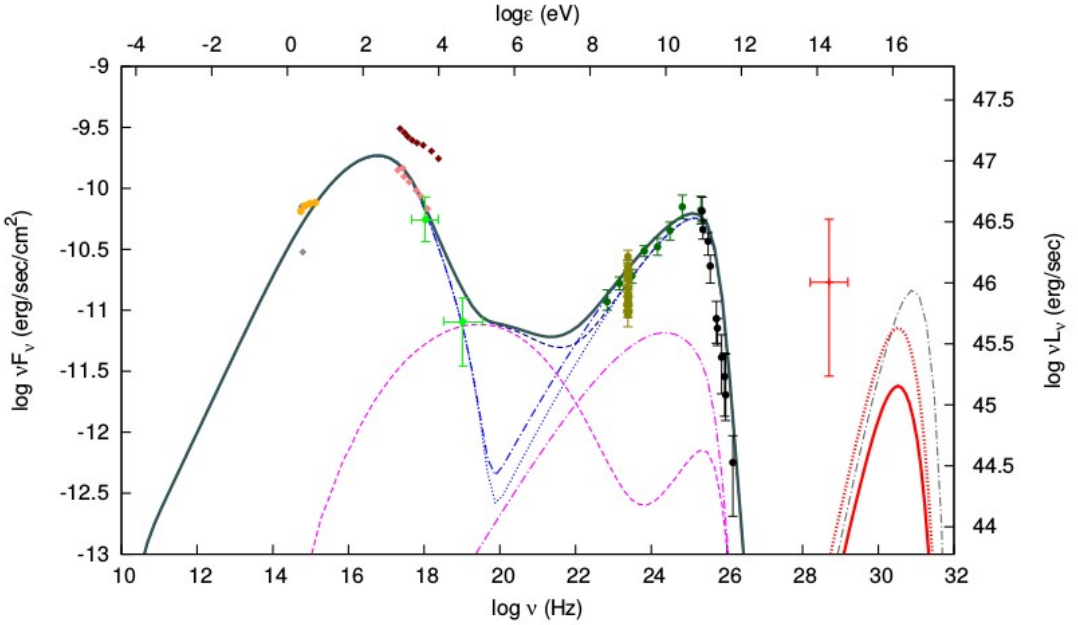


Extragalactic UHE gamma-rays

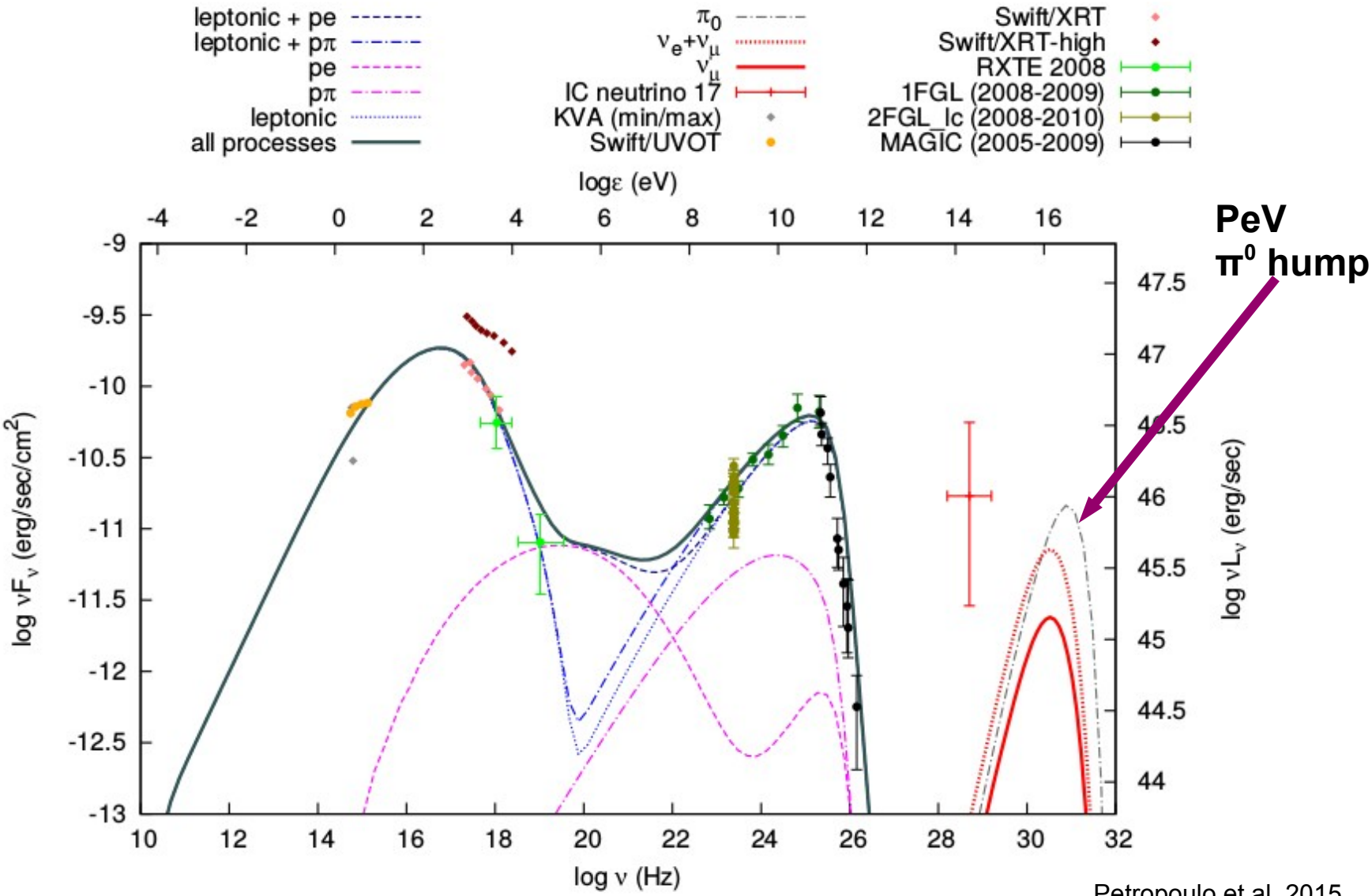


- **The IceCube signal (Aartsen et al. 2013, 2014)**
  - 1st 3 years of full IceCube data: 37 UHE neutrinos (30 TeV – 2 PeV)
  - Presence of astrophysical component favoured (5 σ).
  - Identification of 8 BL Lac objects as likely neutrino event counterparts (Padovani&Resconi 2014)

- **Lepto-hadronic emission model (Petropoulo et al. 2015)**
  - blob + B-field with Doppler factor δ, isotropic proton and electorn injection interaction with B-field and secondaries → particle populations:
  - protons
    - synchrotron radiation
    - Bethe-Heitler (pe) pair production
    - photopion (pπ) interactions
  - electrons and positrons
    - synchrotron radiation
    - inverse Compton scattering
  - photons
  - (+ neutrons, neutrinos)

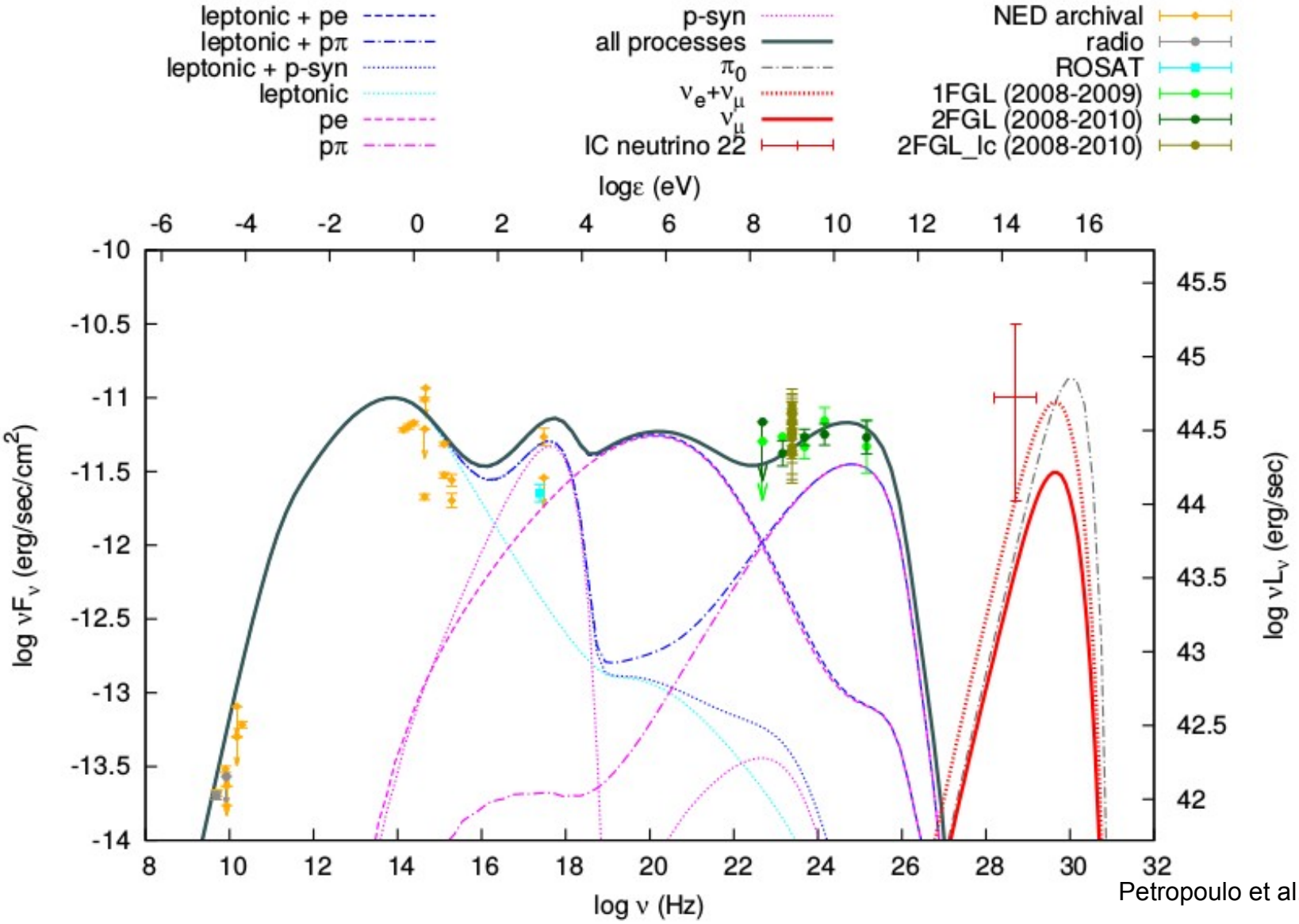


PG 1553+113 (z = 0.4)



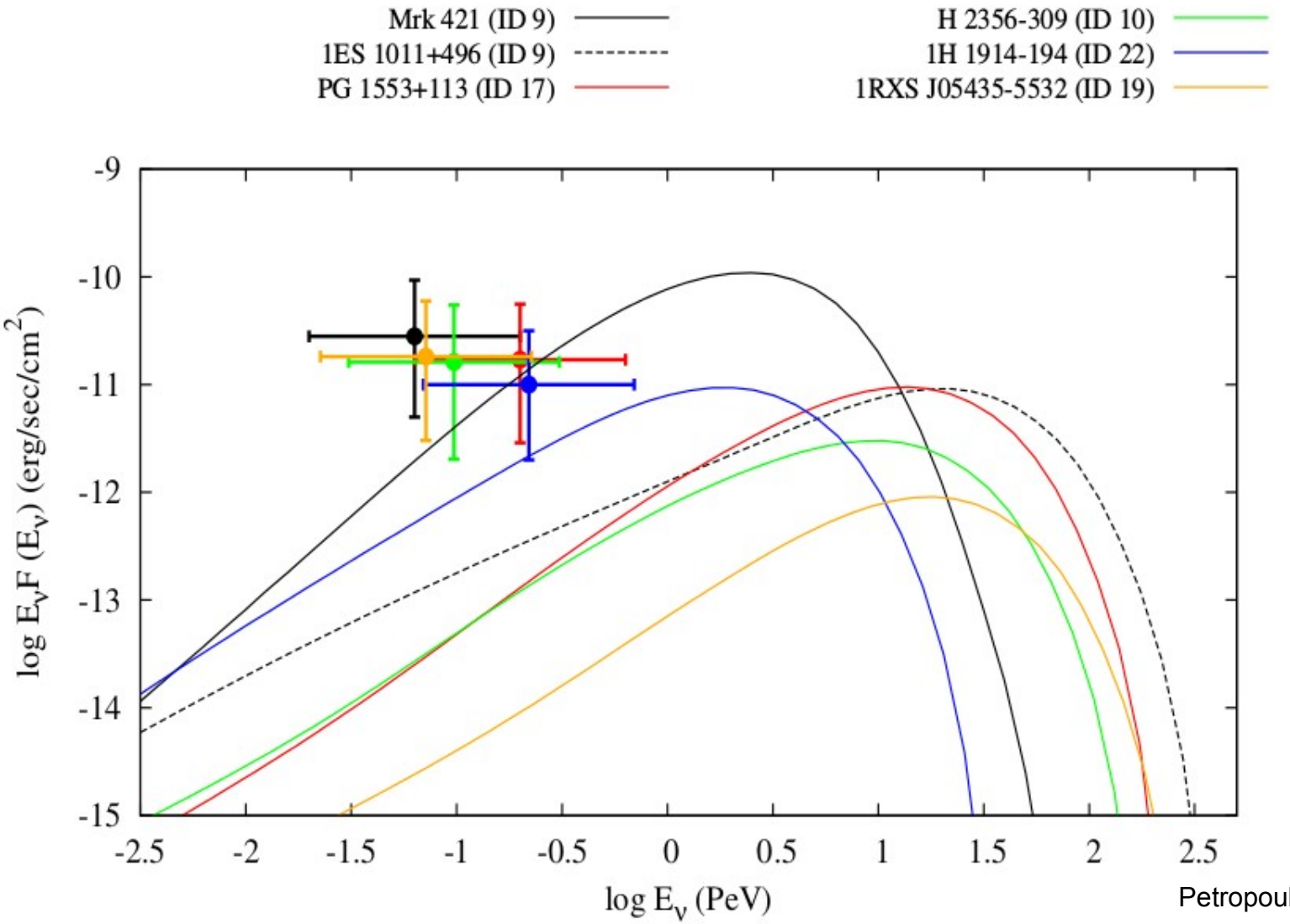
Petropoulo et al. 2015

H 1914-194 (z=0.137)



Petropoulo et al. 2015

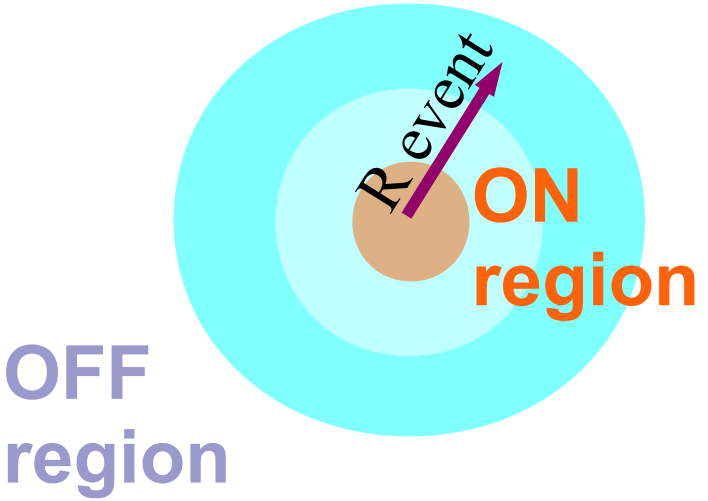
π^0 hump and neutrino event fluxes



Petropoulo et al. 2015

Background for pointsource search

- **Ring background model**
  - **On source:** < 0.4°
  - **Off source:**
    from ring around source
    position 1.6°< R < 2.4°

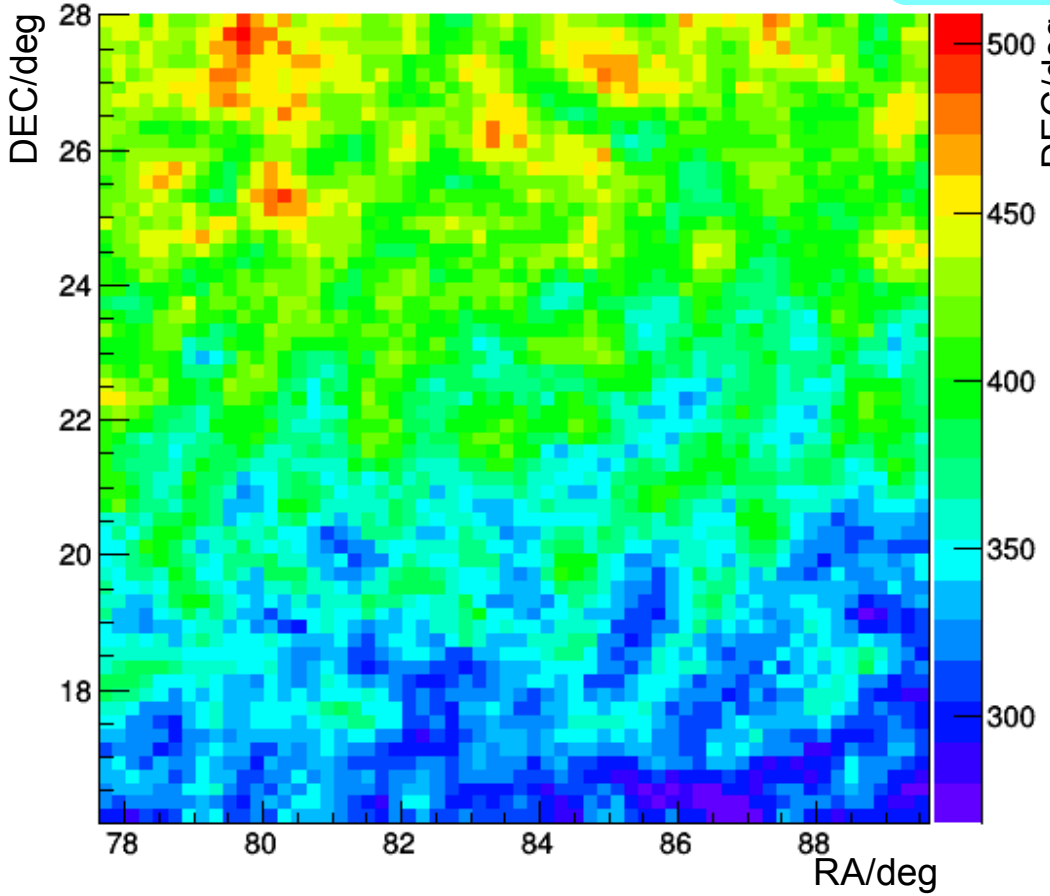


- **Testing the background model**
  - **Data blinding:**
    local ra/dec randomization by Gaussian width σ= 1°
  - Apply P.S. search to blinded data
  - Expectation: normal Gaussian distribution of significances in field of View

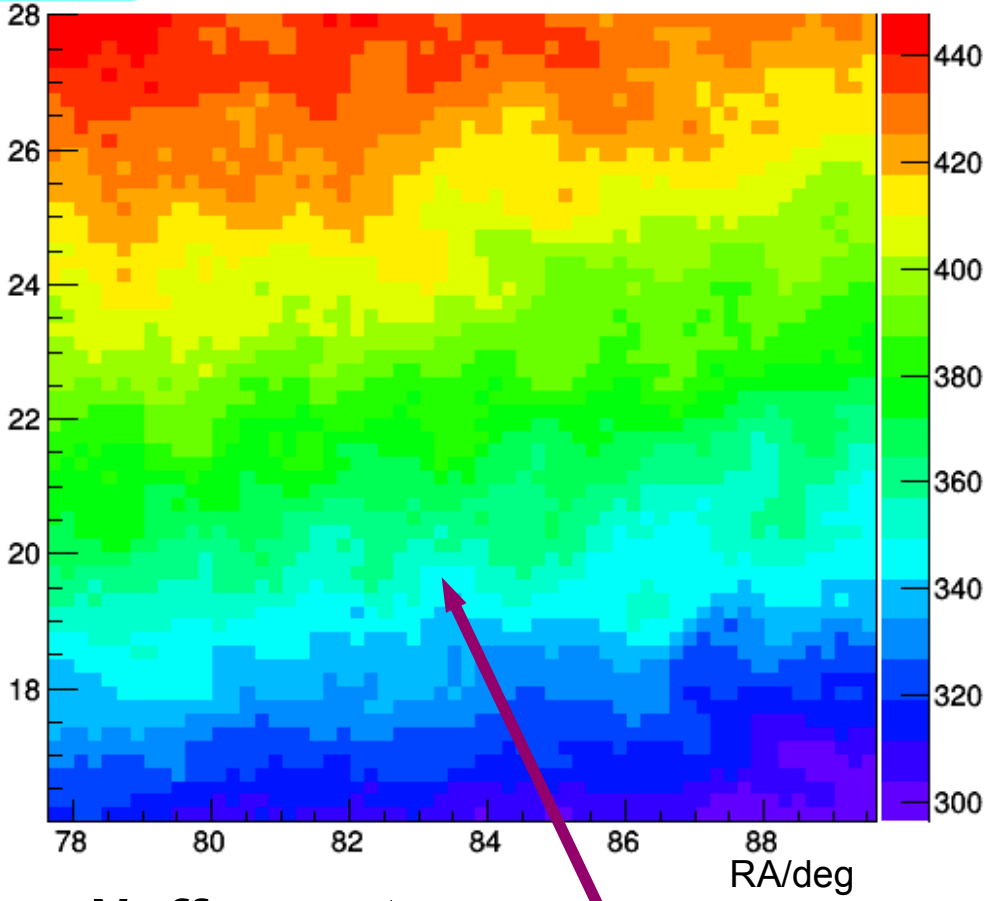
Background for pointsource search

BLINDED DATA

PRELIMINARY



Non count map



α Noff count map

Oversampled skymaps 6° x 6°

Preselection 10° x 10° (reducing computing requirement)