HiSCORE first results

Gamma-rays and Cosmic rays

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

Martin Tluczykont for the TAIGA Collaboration

HAP Workshop Topic 2, Erlangen 2016

HiSCORE ⊂ TAIGA
TAIGA collaboration

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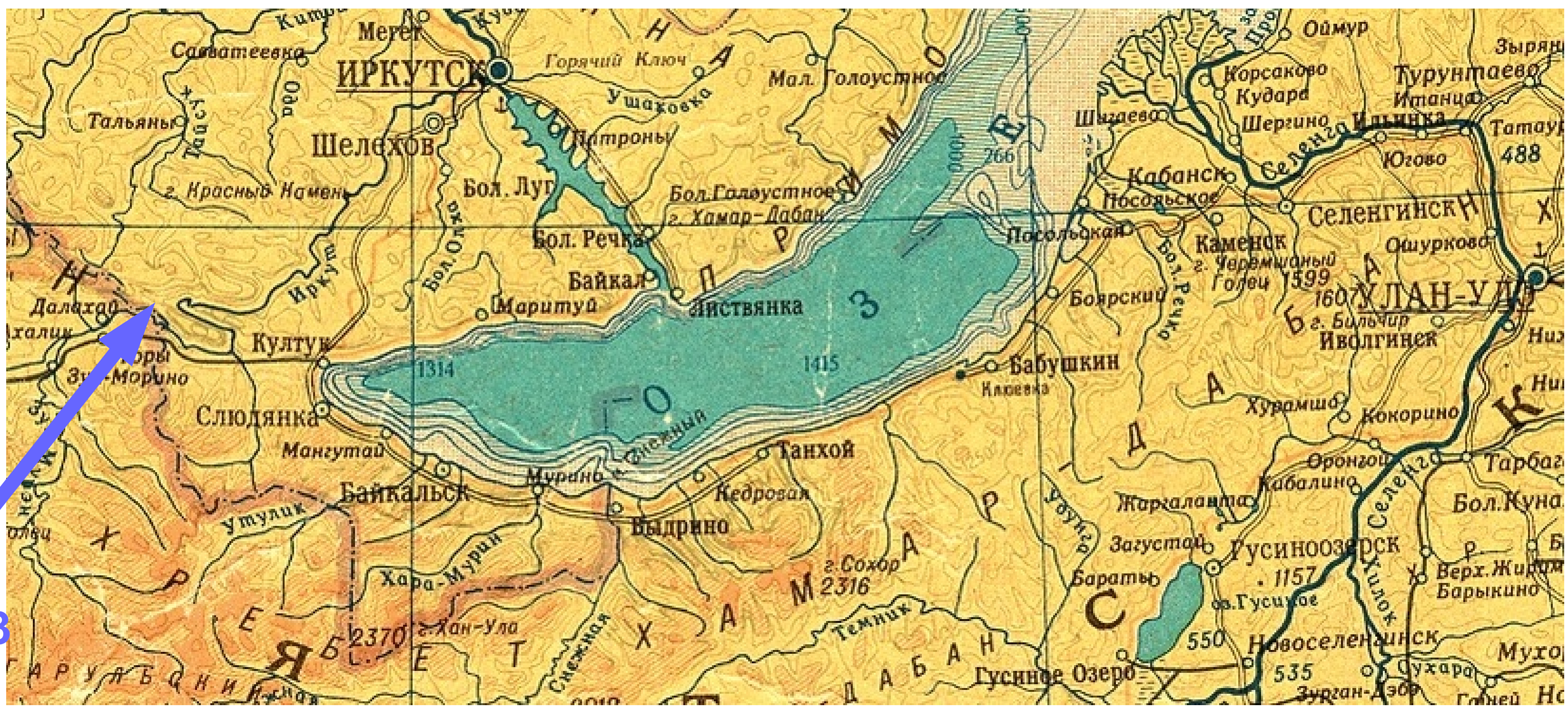
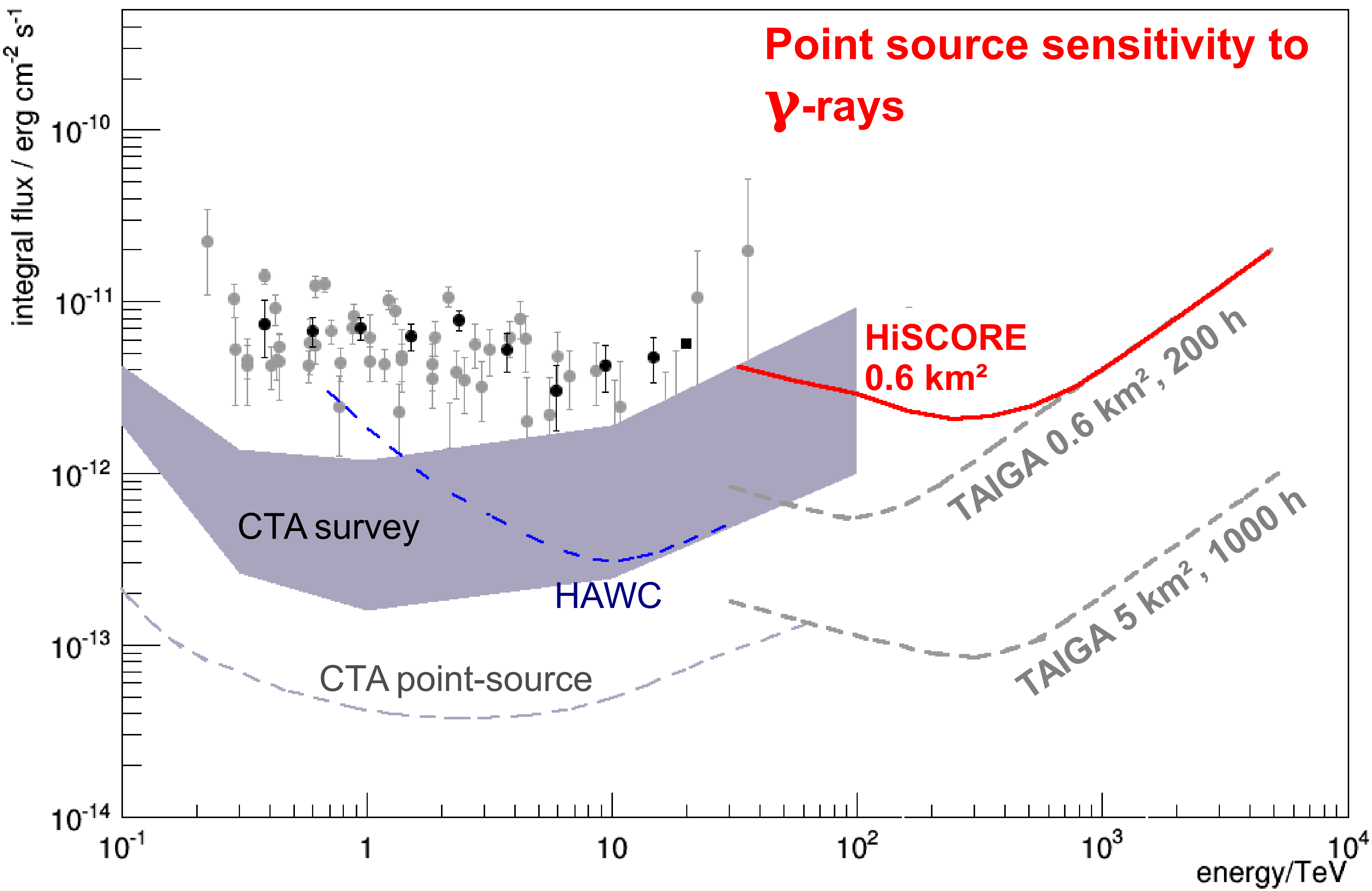
[4] *Dipartimento di Fisica Generale Universiteta di Torino and INFN, Torino, Italy*
[5] Max-Planck-Institute for Physics, Munich, Germany
[6] *Institut für Experimentalphysik, University of Hamburg, Germany*
[7] *IZMIRAN, Moscow Region, Russia*
[8] *DESY, Zeuthen, Germany*
[9] *NRNU MEPhI, Moscow,Russia*
[10] *JINR, Dubna, Russia*



Tunka-133 site

VHE-UHE Gamma-ray Astronomy



HiSCORE timing array
High Surface Cosmic ORigin Explorer

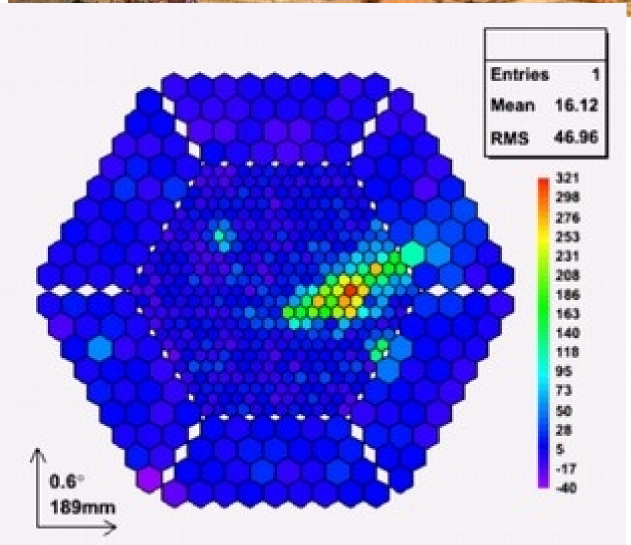
(TAIGA: HiSCORE timing array + IACTs)

Detection method

Air Cherenkov imaging and timing

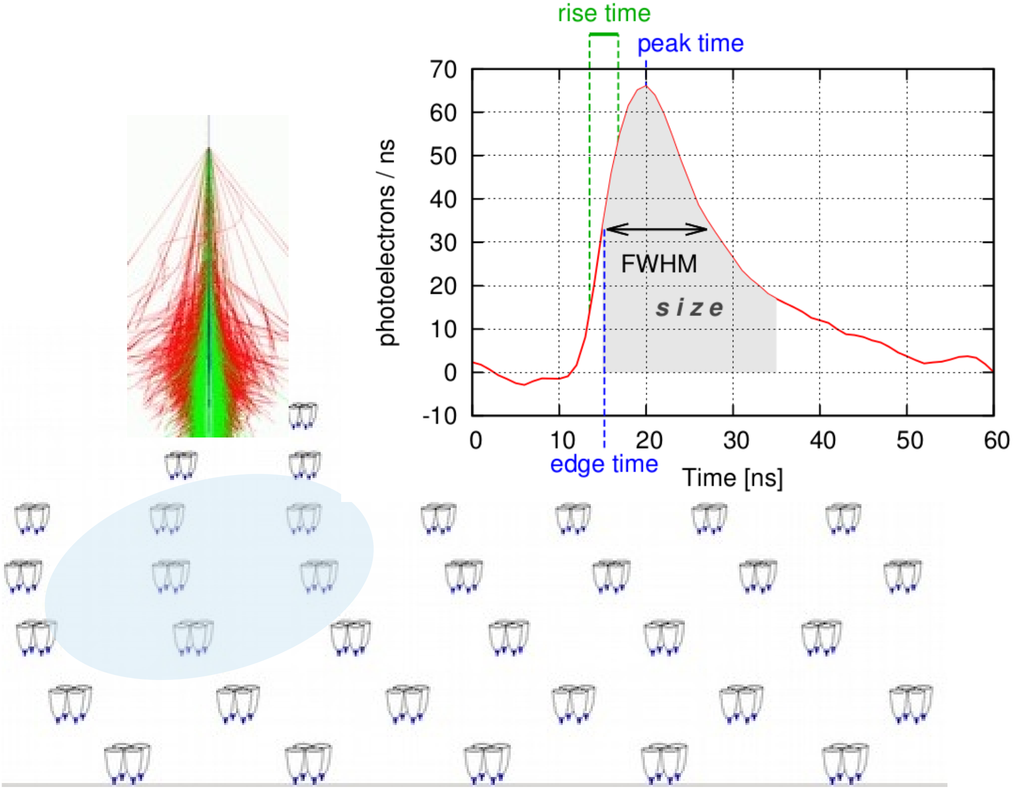
Imaging arrays

H.E.S.S. Telescopes

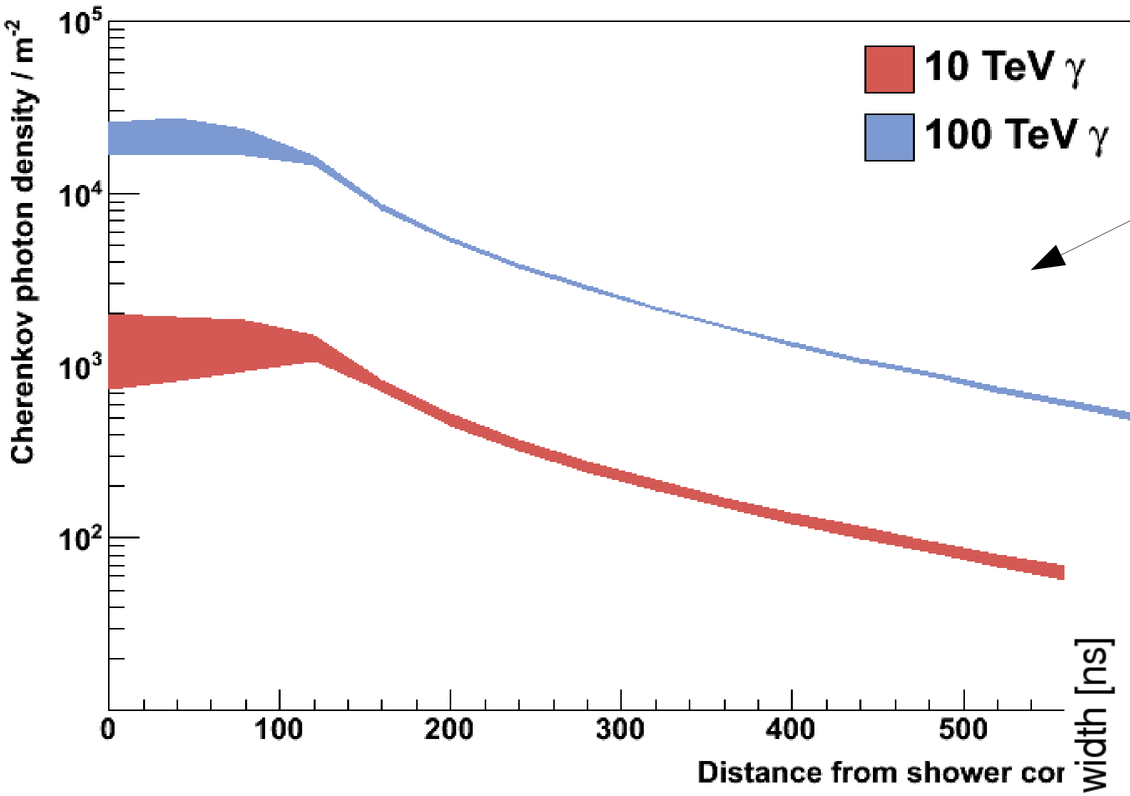


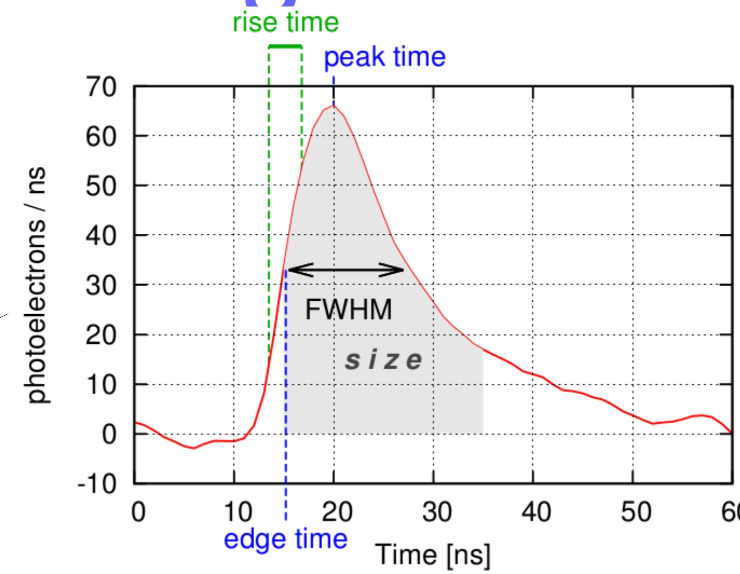
MAGIC camera image

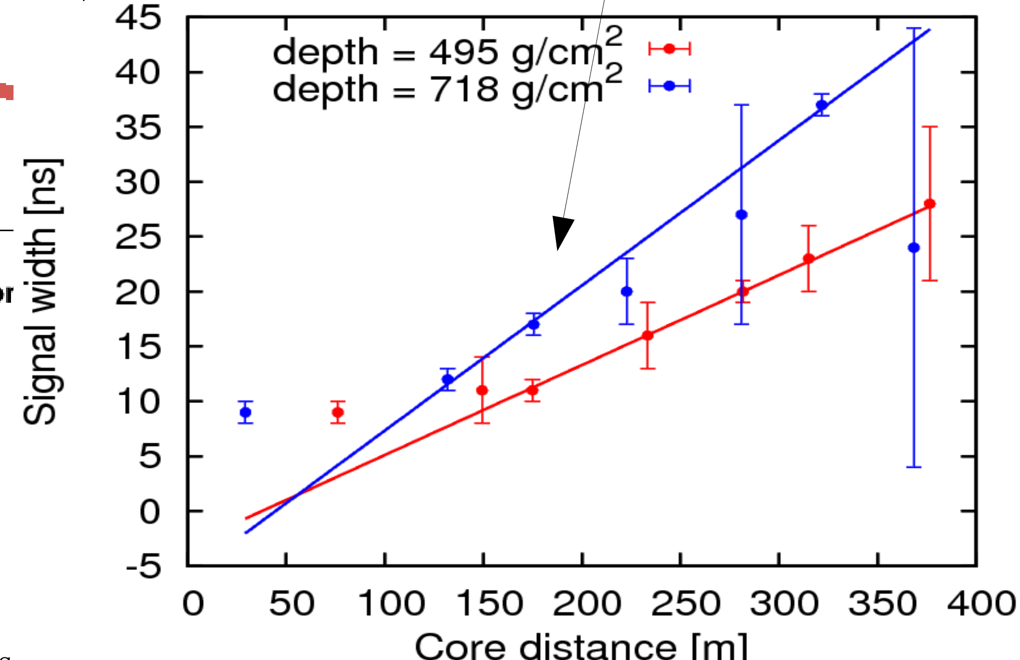
Timing arrays (non-imaging)



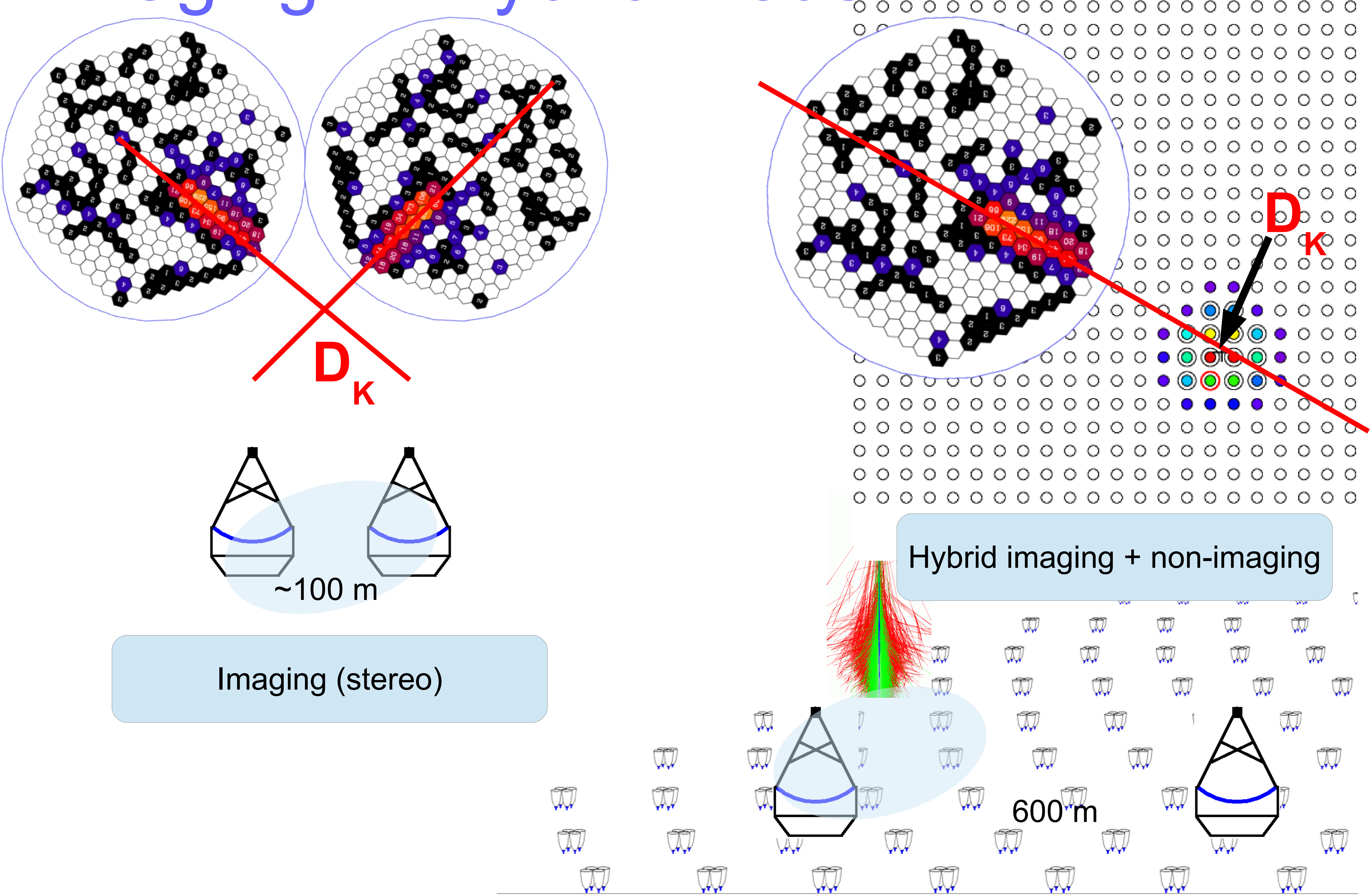
Air Cherenkov timing







Imaging → Hybrid mode



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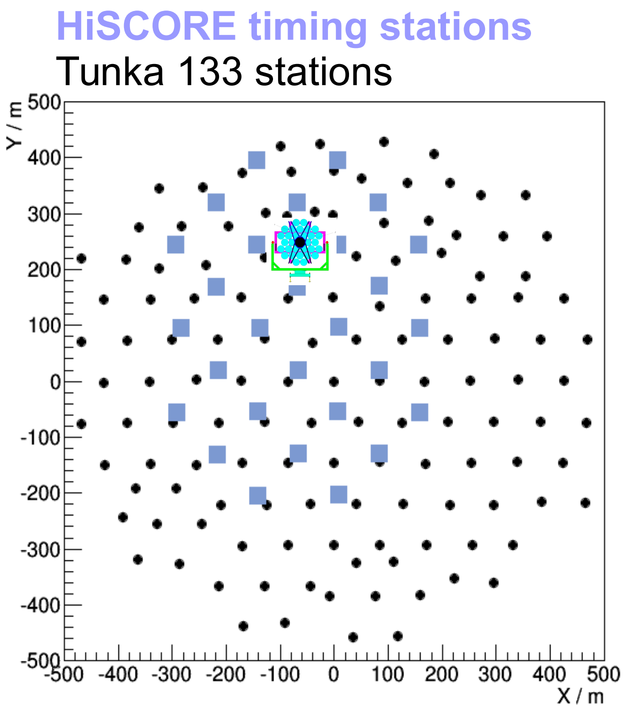
TAIGA

Since 2014

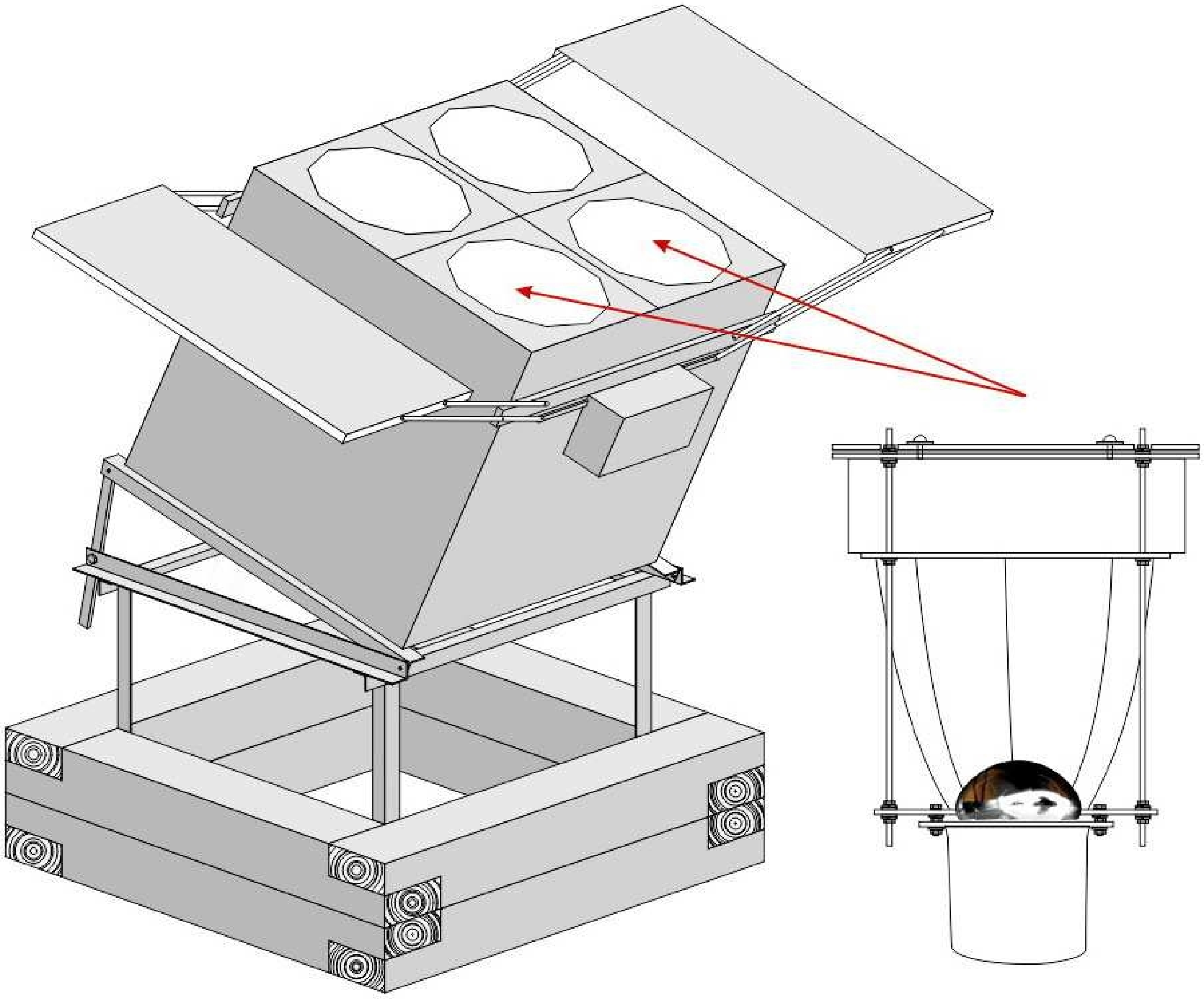
- 28 stations on 0.25 km²
- Tilting mode – 25° southwards

2016:

- First telescope
- Hybrid timing+imaging



HiSCORE = TAIGA timing stations



- 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 timing stations

- Four 8" PMTs
- Winston cones, light collection 0.5 m²
- FoV ~0.6 sr
- “Tilting” for extension of sky coverage
- GHz readout
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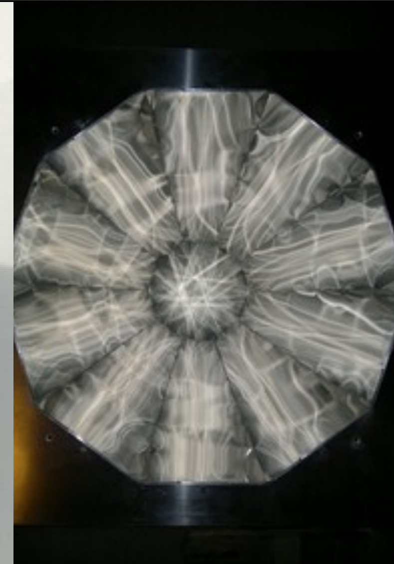
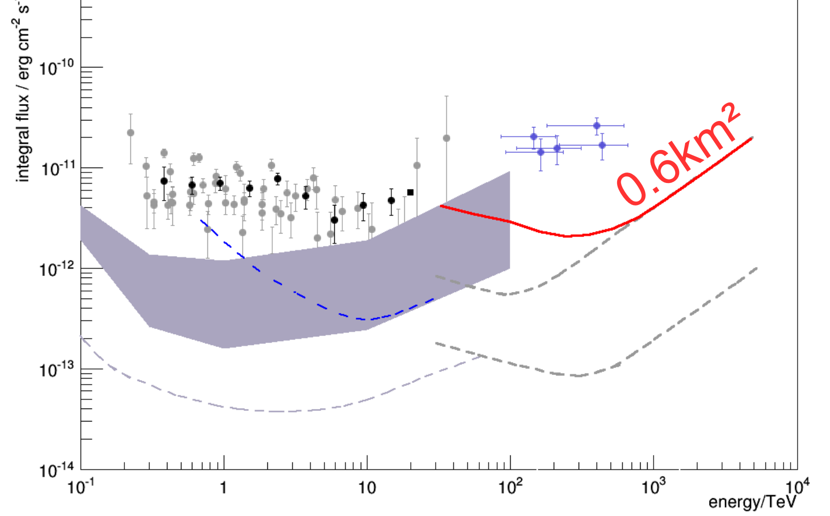
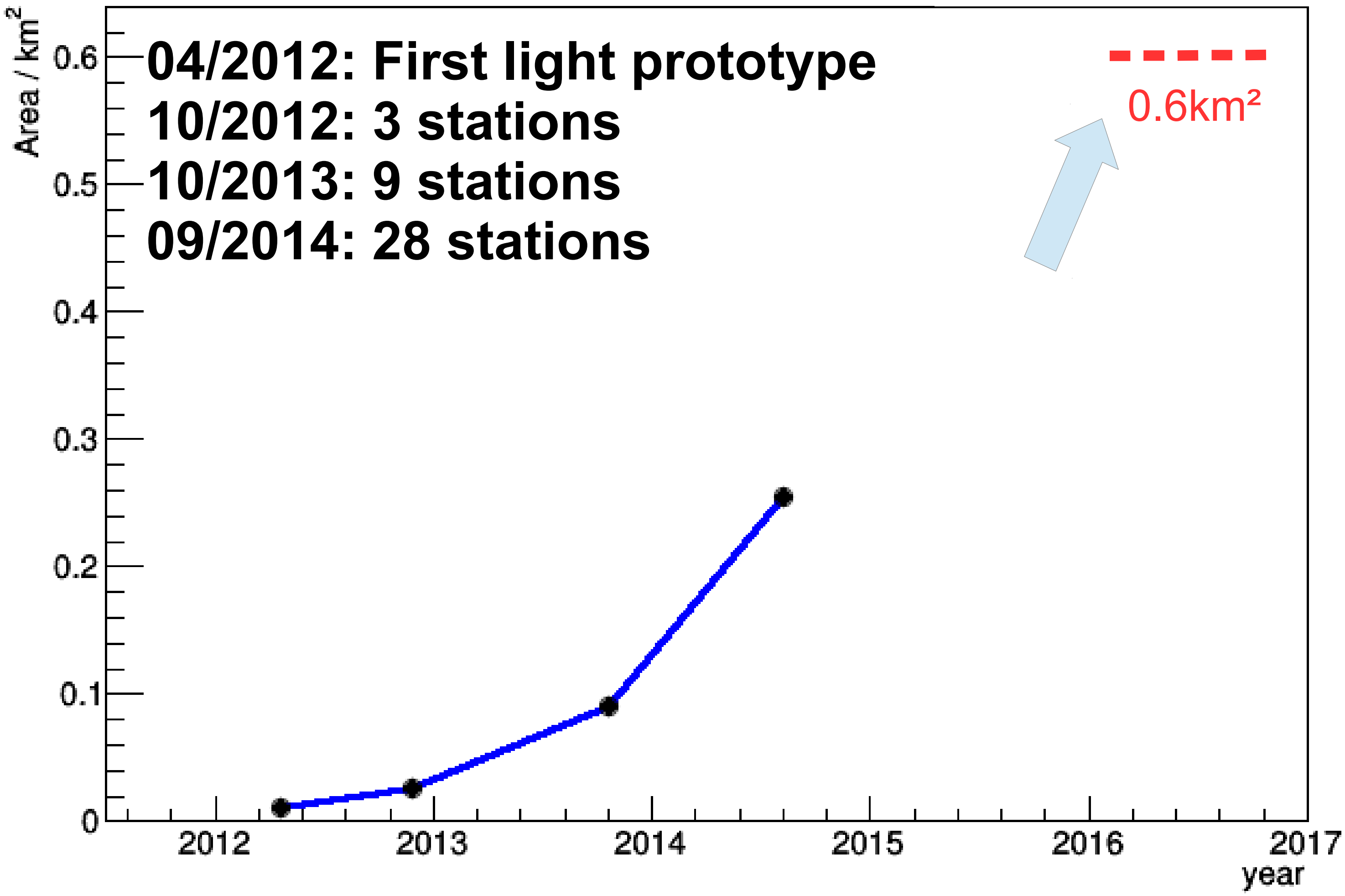



Evolution of instrumented area



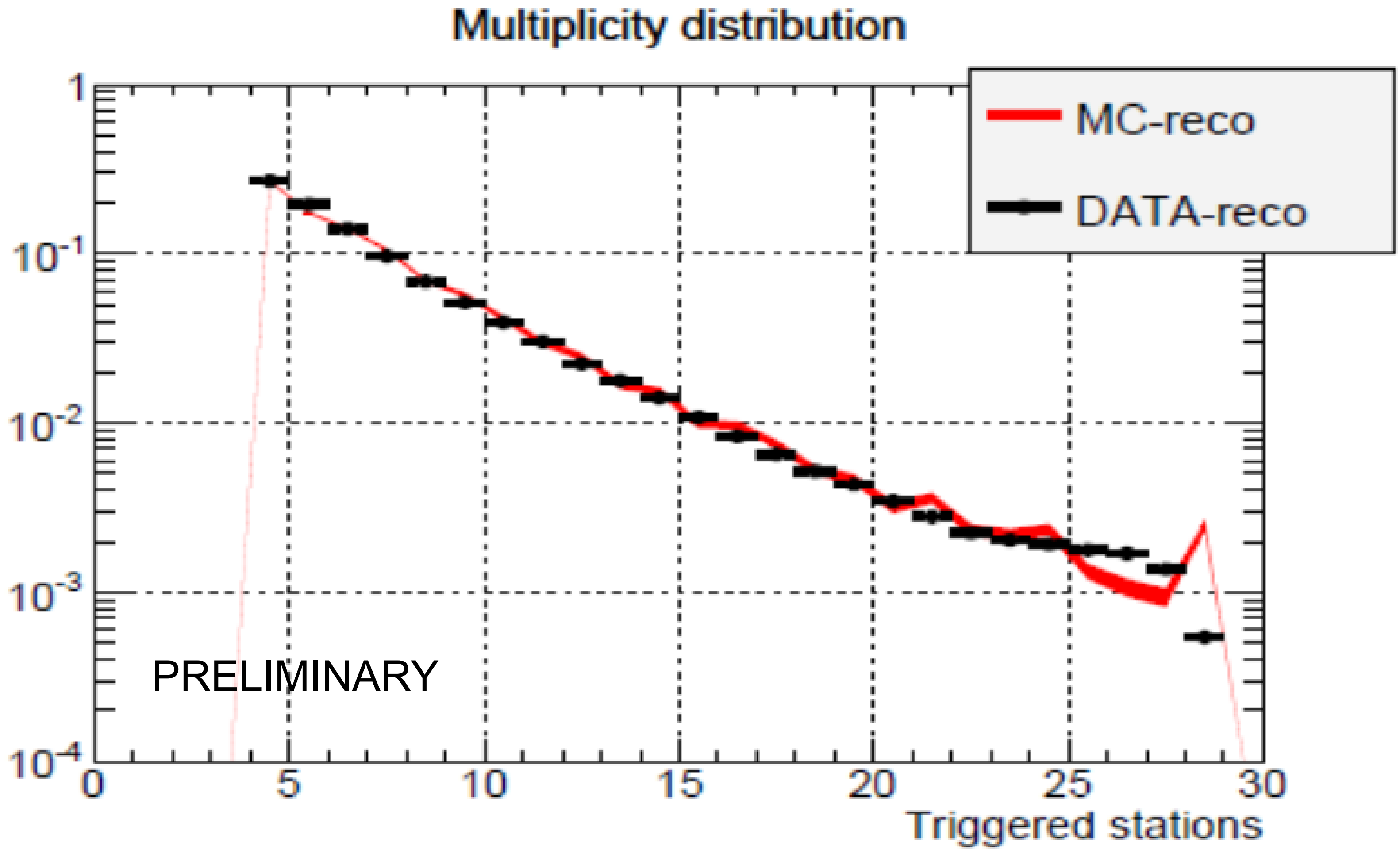


HiSCORE

Comparison of Monte Carlo simulation to Real Data

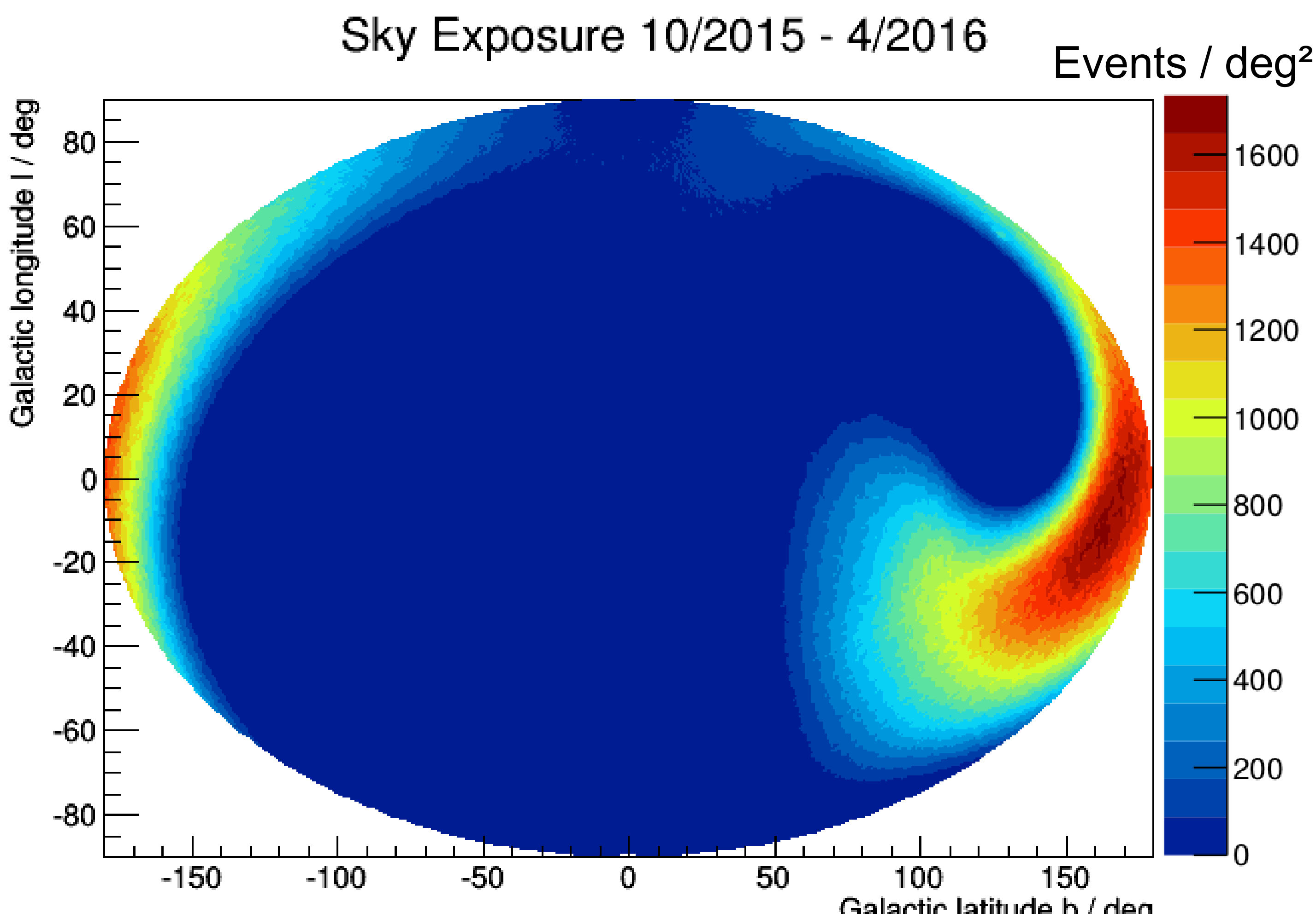
Data-MC comparison

- Multiplicity 28 station array



Data and Exposure

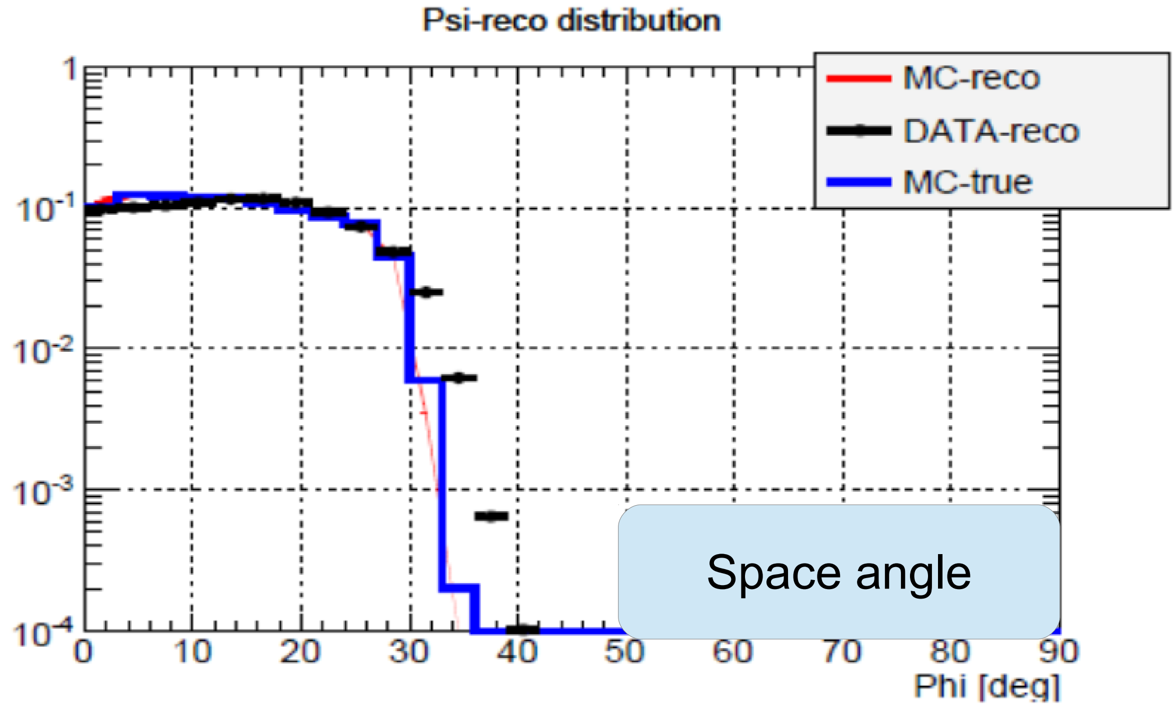
- Observations during commissioning phase of 28-station array October 2015 – April 2016
- Total 250 h observation time
- ~10^7 events

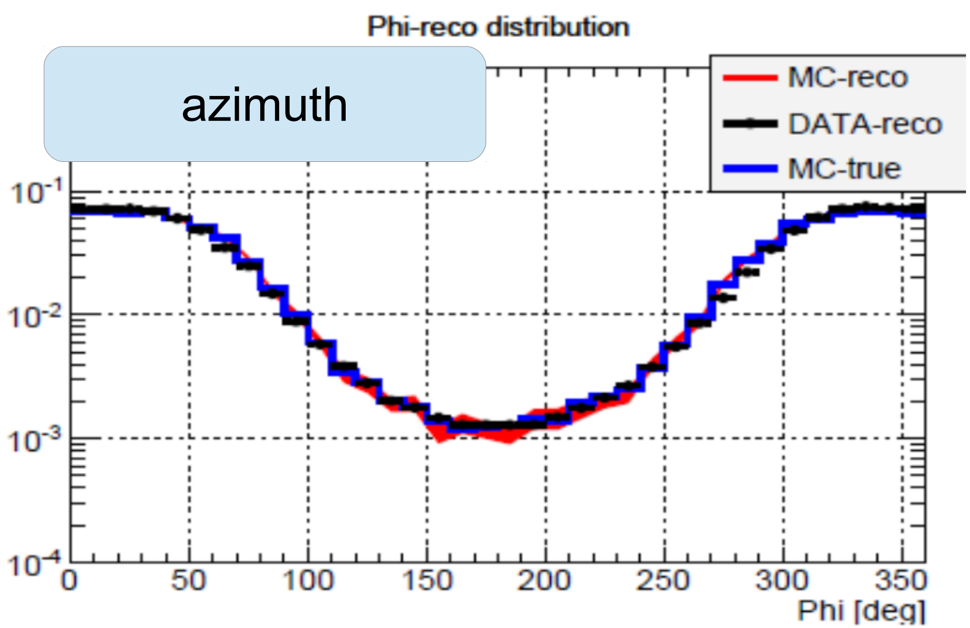


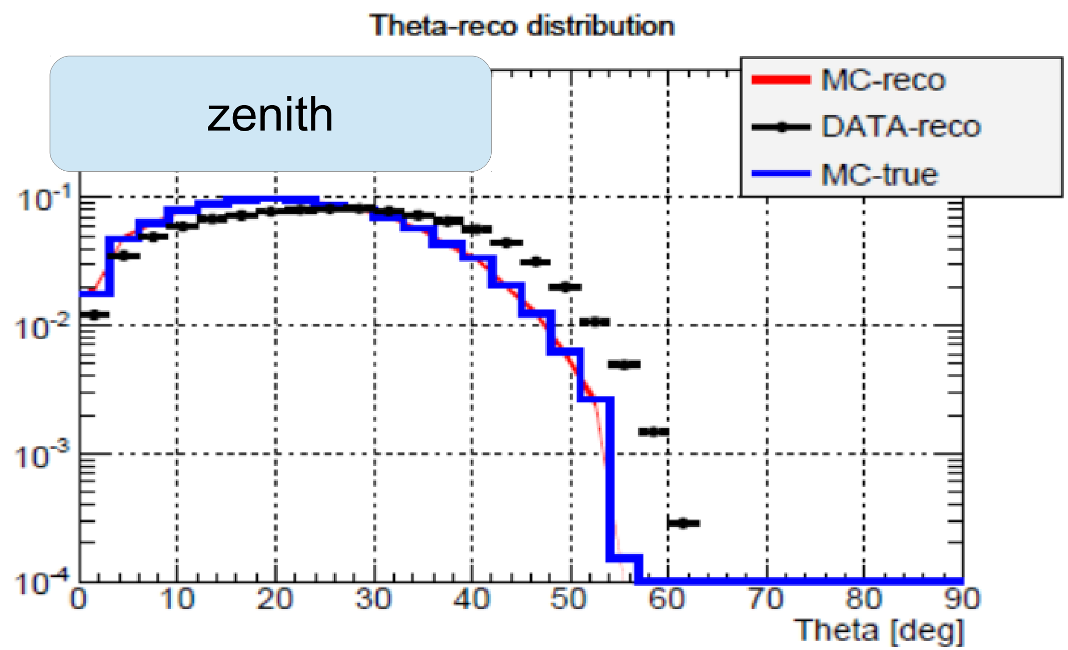
Event Reconstruction

Reconstructed direction

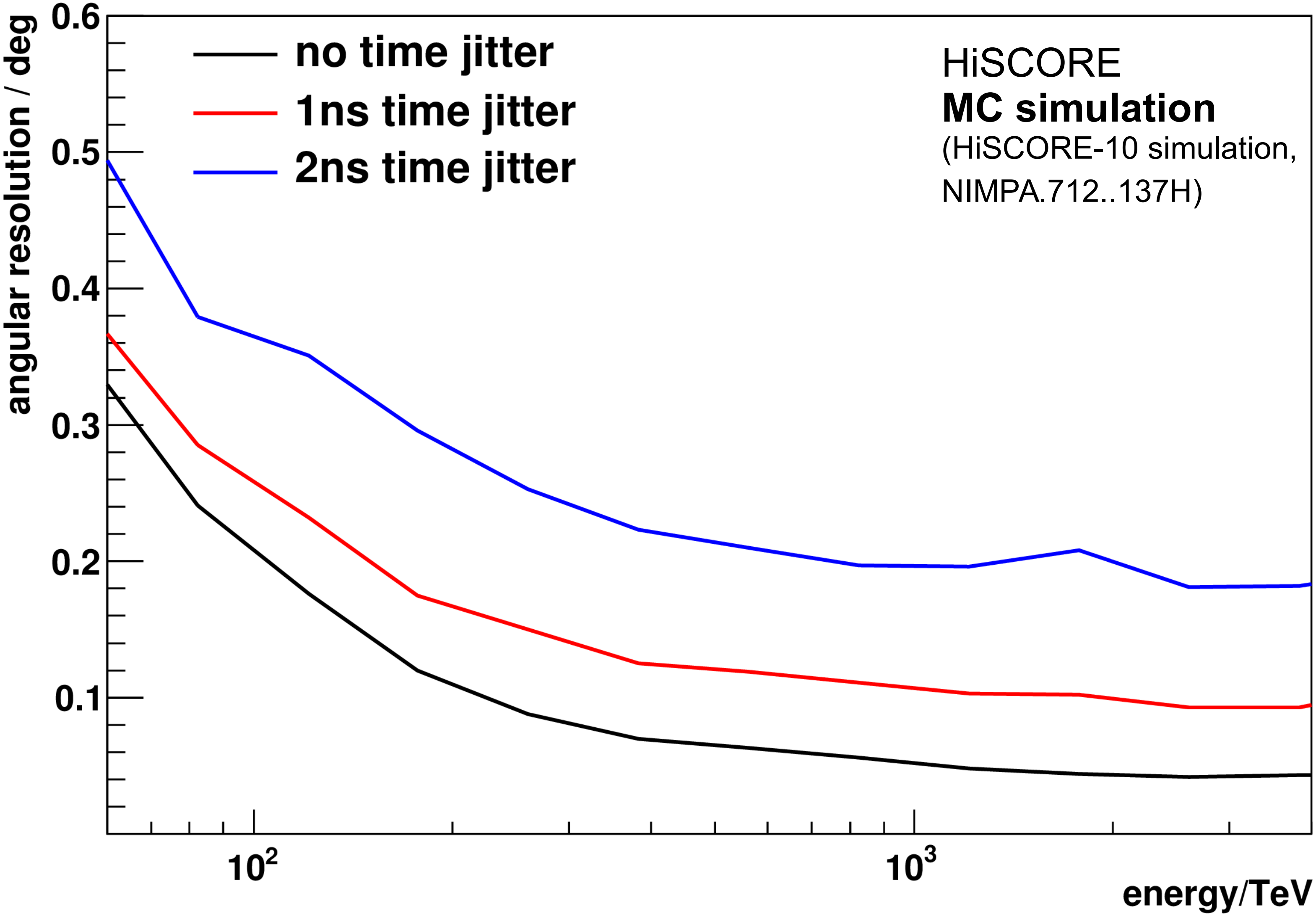
Data & MC





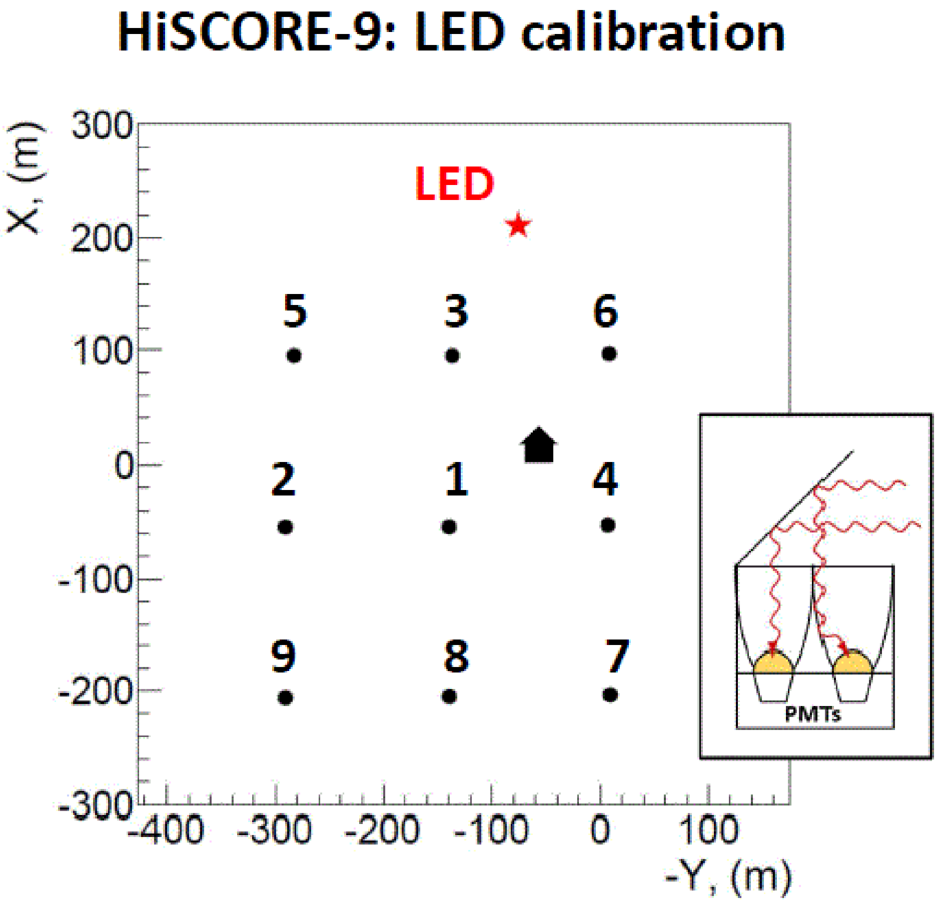


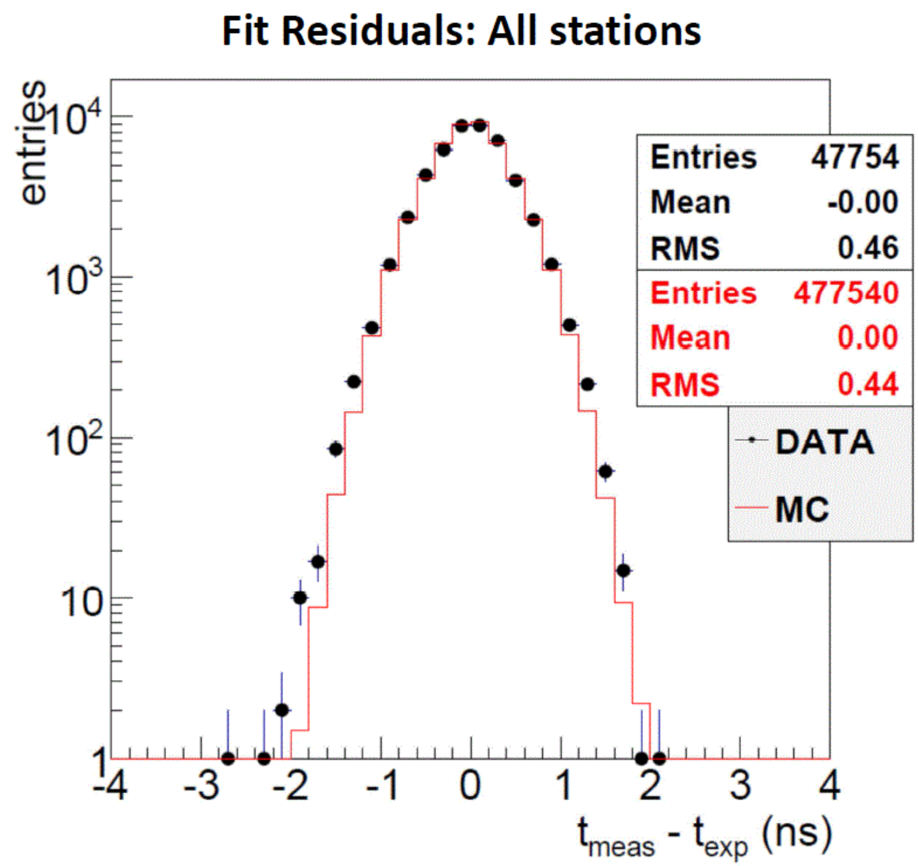
Angular resolution



Crucial: relative time-synchronization <1ns

Time calibration

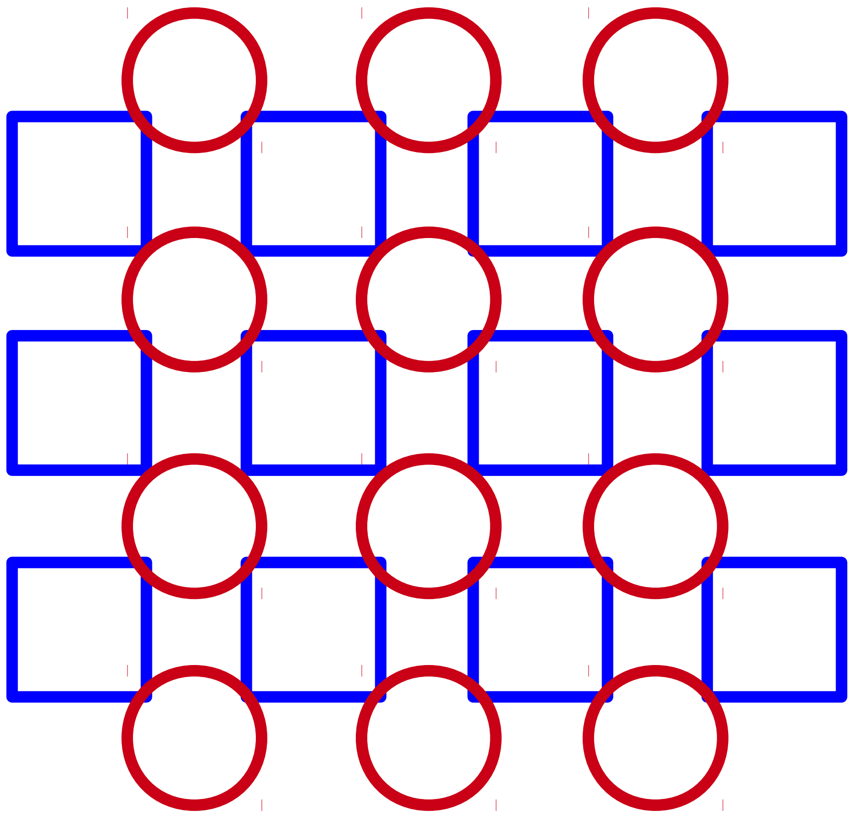




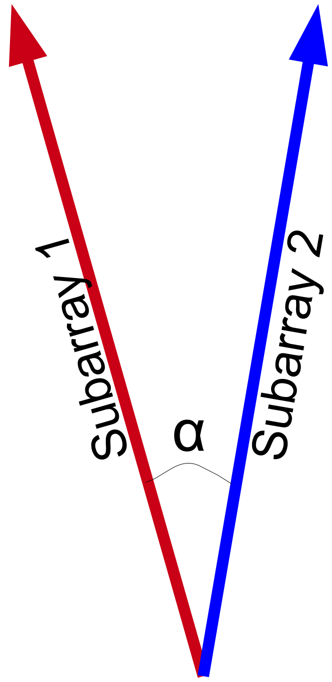
2013 HiSCORE-9

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

Resolution chessboard method



Reconstruction using two different subarrays



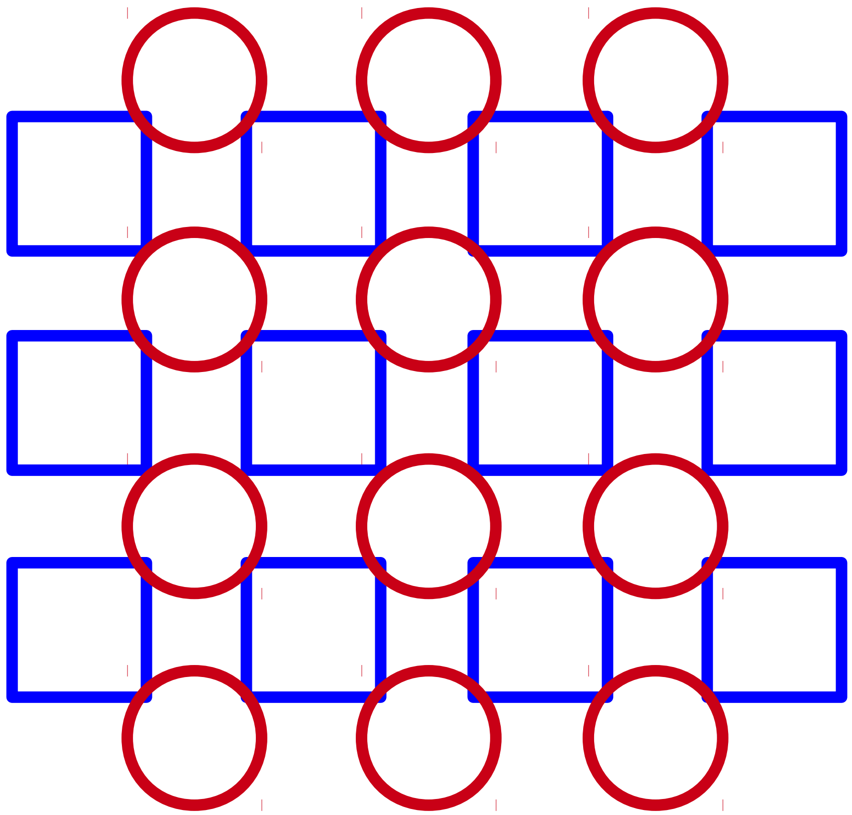
Chessboard direction:

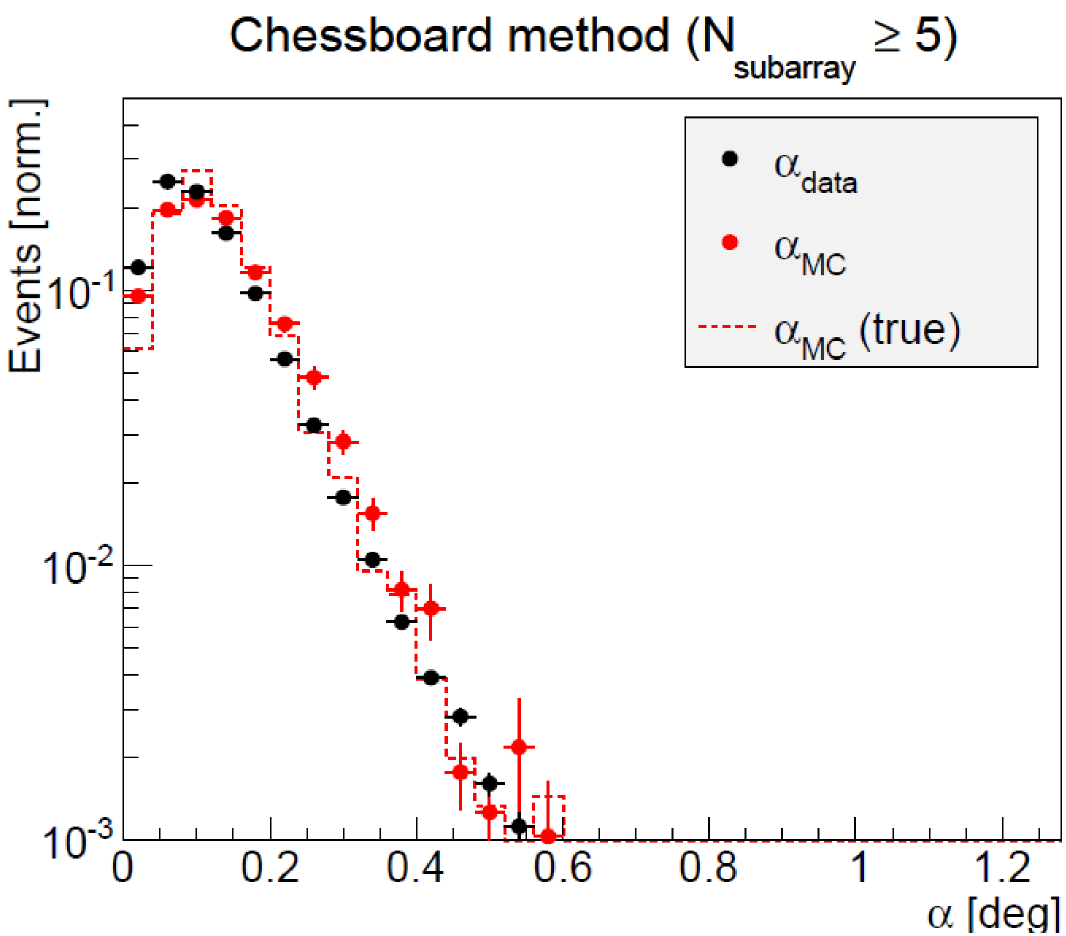
Resulting angle α

Tested for 9-station and 28-station array

Resolution chessboard method

DATA
MC
Verification

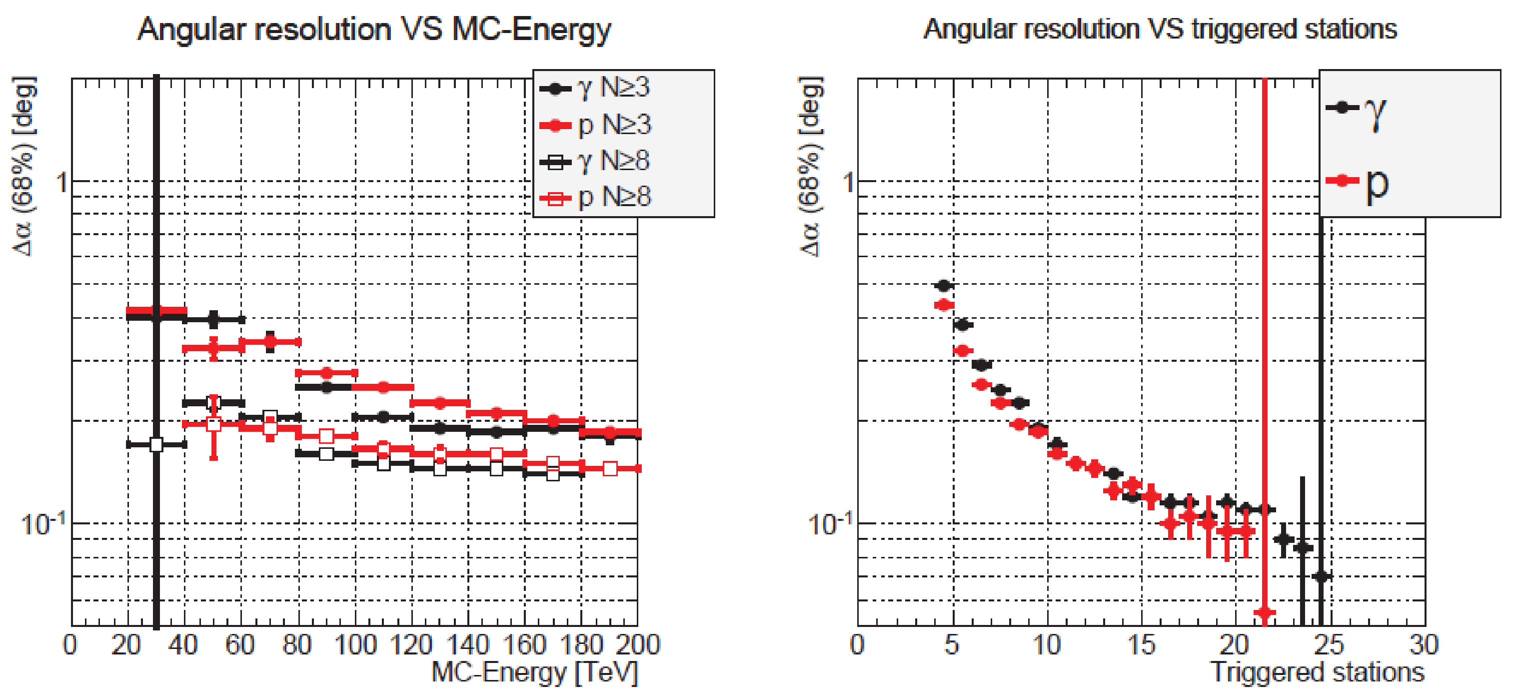




Reasonable agreement between MC and data

α / deg

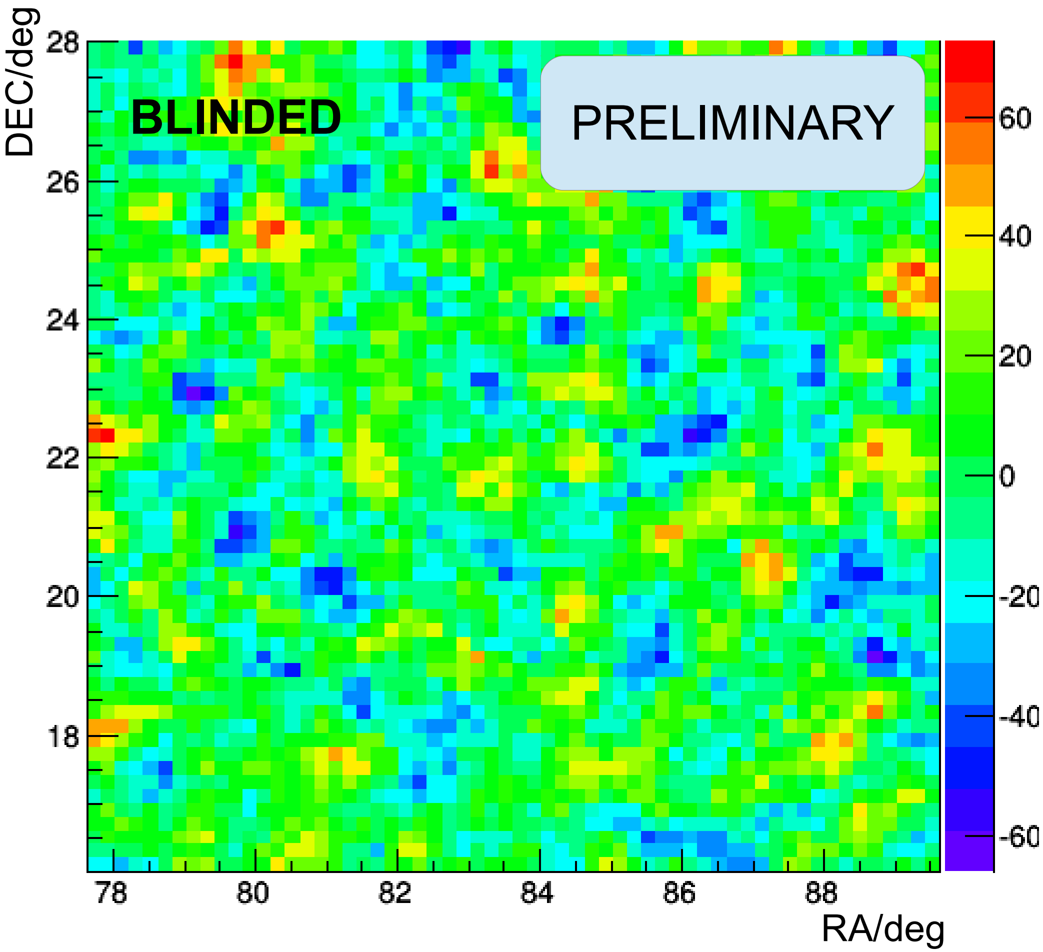
Angular resolution 28 station array

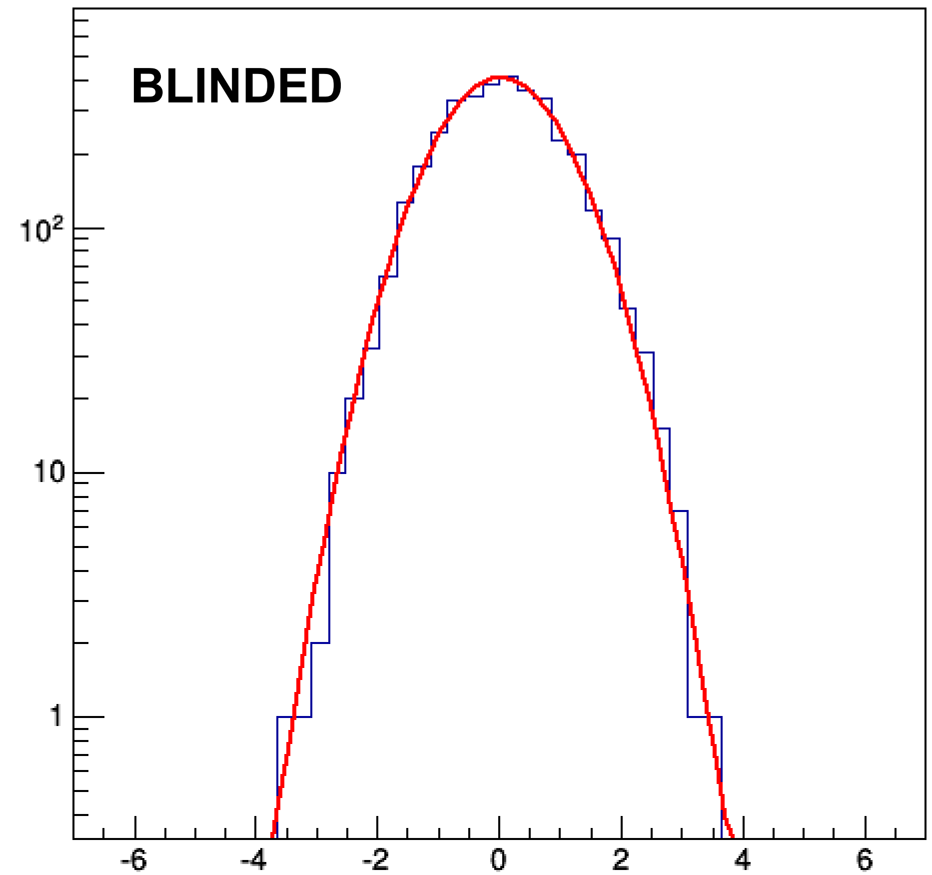


After verification of MC resolution (proton MC / real data)

Can trust MC resolution: <0.2°, E>100TeV

Background for pointsource search





Excess skymap

Excess = Non – α Noff (α = 0.05)

Blinded data

Significance following Li&Ma, Eq. 9

Significance distribution in foV

Crab Nebula data commissioning season

- ~60 h good weather exposure on Crab Nebula
- 10^4 events within 3 deg of Crab Nebula
- Preliminary analysis O(20) events (bg ~380, not significant)

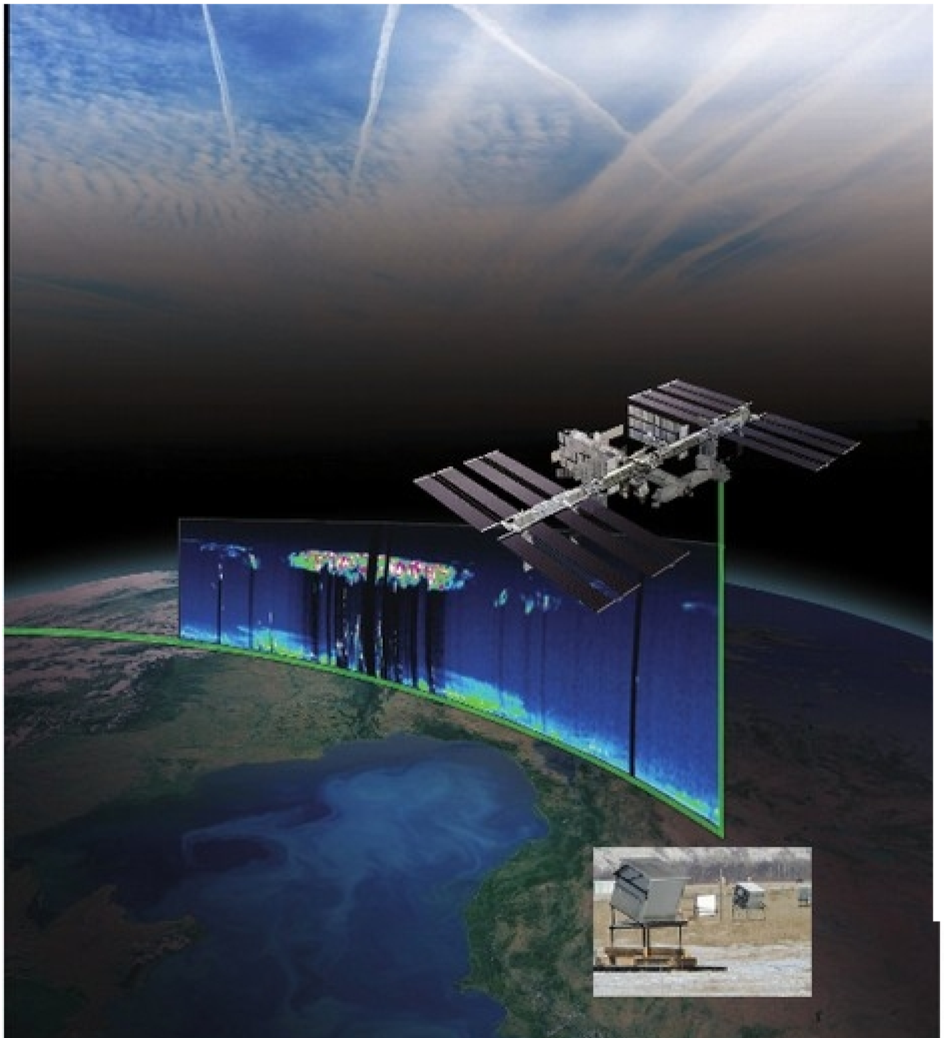
➔ As expected with 0.25 km² prototype sensitivity

➔ No analysis cuts / not optimized analysis

➔ Potential for improvement in future:
  - larger area → 0.6 km²
  - optimized analysis
  - TAIGA: +IACT

PRELIMINARY

A first HiSCORE Point-source



- 11/2015 & 02/2016 data:
  - High trigger-rate “flares”, 4 kHz pulsed emission
  - Point-like emission, moving source position
  - Coincidence with ISS (Analysis by A. Porelli)
    - Onboard CATS LIDAR @ 1064nm, 532nm
    - LIDAR pointing offset to zenith axis: O(degrees)

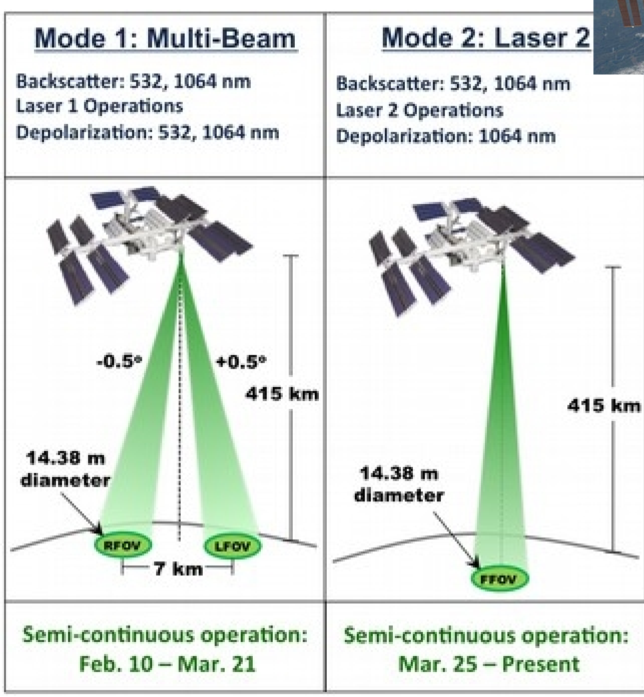
PRELIMINARY

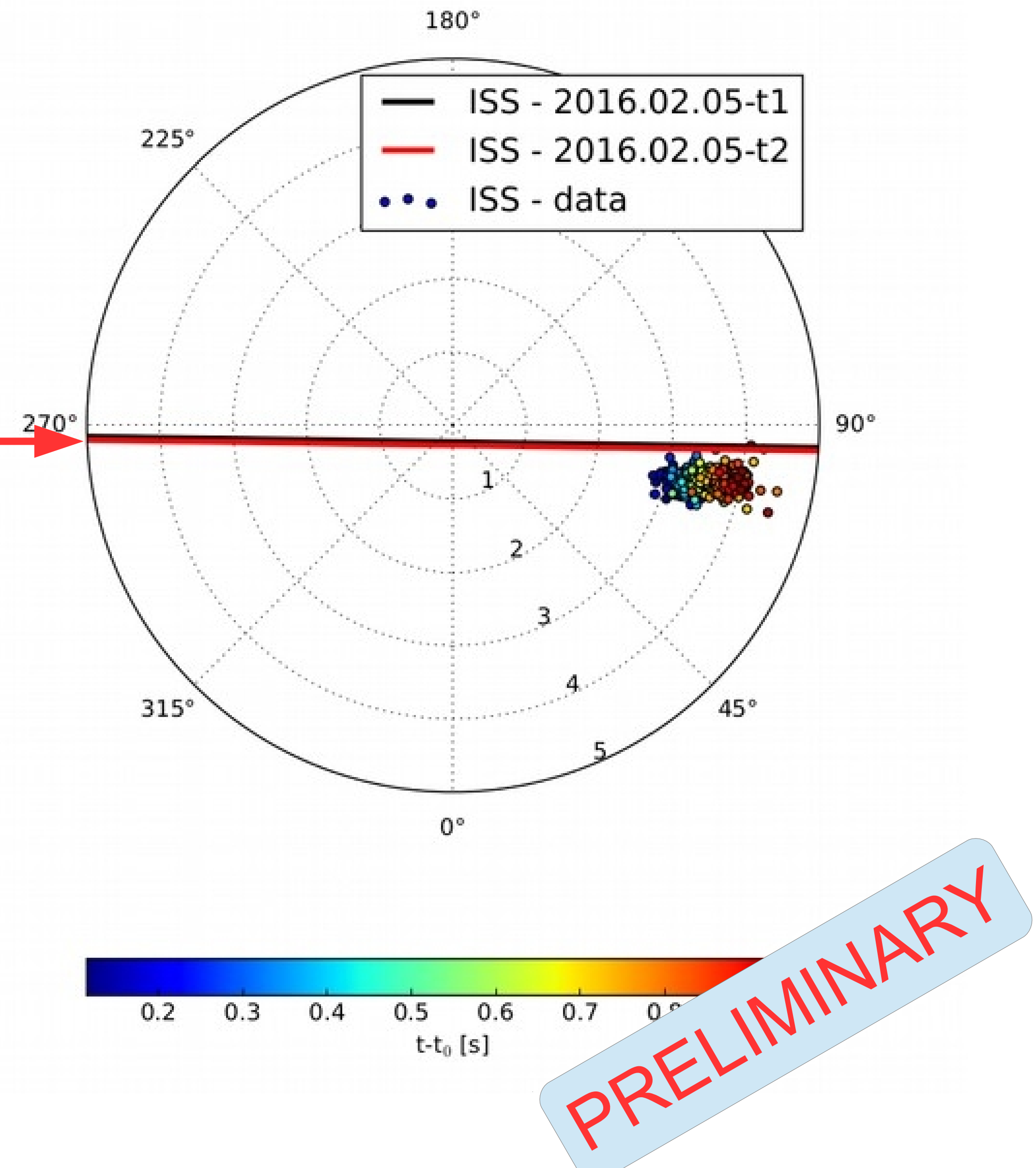
A first HiSCORE Point-source

Very recent results !

Height of orbit, Orientation angles of ISS and of Lidar have impact on actual observed event directions

Understanding geometry and operation modes **work in progress**





Summary

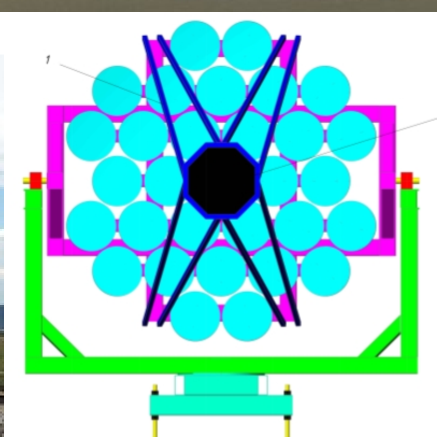


- UHE gamma-ray Astronomy with
  new hybrid imaging+timing approach

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

- HiSCORE timing array 0.25 km² operational as part of **TAIGA**
- First results within expectations: on-track
- **Surprising result: detection of ISS**
- Doubling of area in 2016/2017
  → 0.6 km² / 58 stations
- Upcoming: TAIGA-IACTs





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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/

END OF TALK

BACKUP

Non-imaging and imaging hybrid detection

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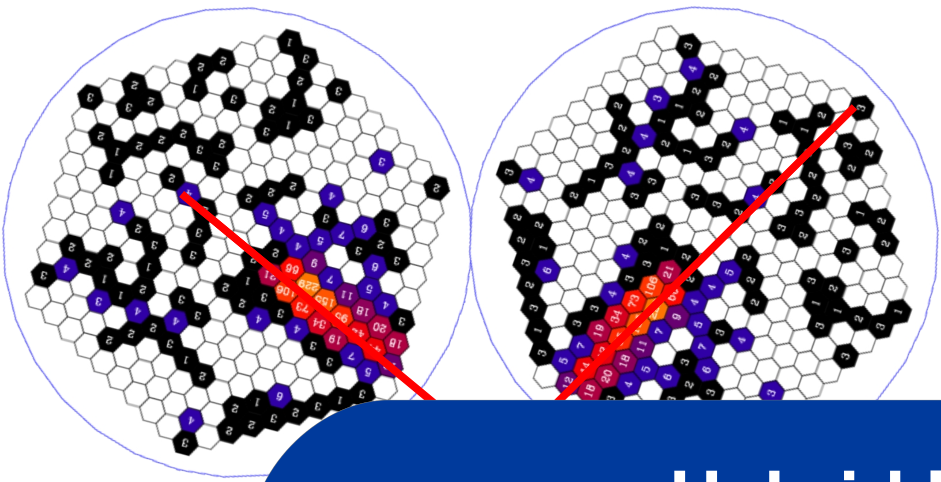
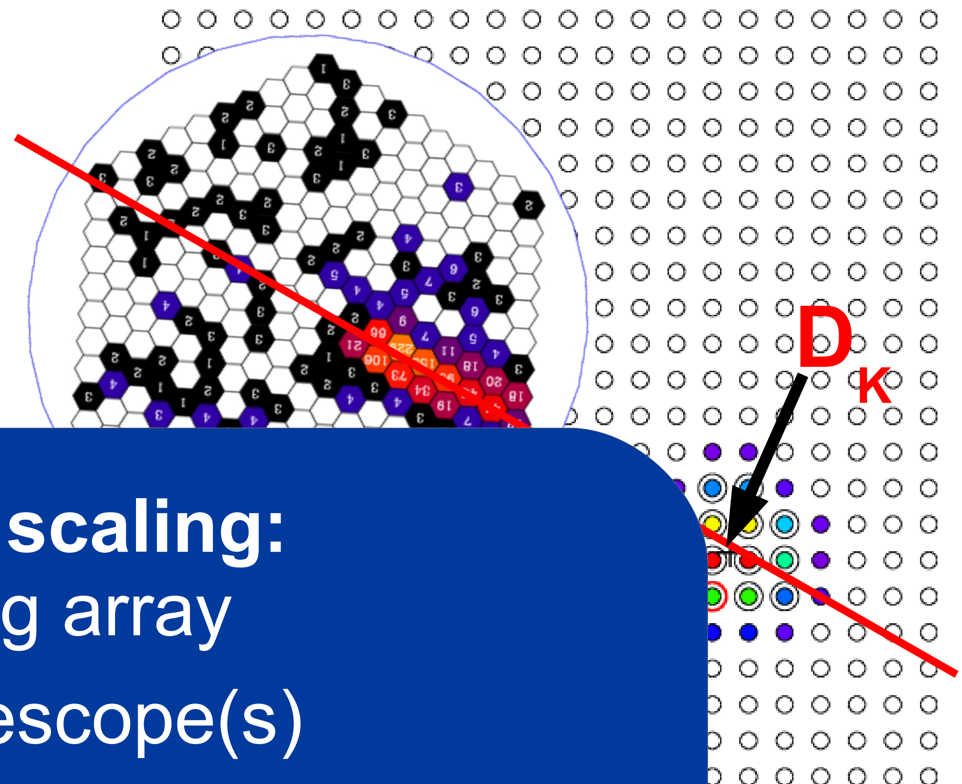
Telescope image scaling

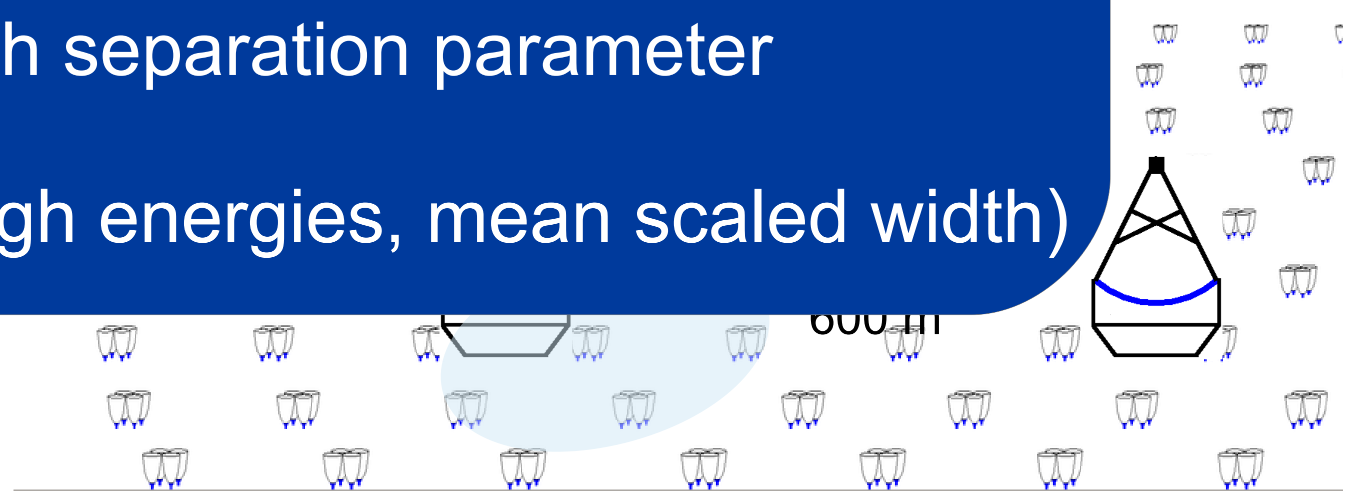
Central reconstruction parameter: Shower core position D_K

$$w_{MC} = w_{MC}(size, \mathrm{D_K}, \vartheta)$$

$$mscw = \frac{1}{\mathrm{N_{Tel}}} \sum_{\mathrm{k=1}}^{\mathrm{N_{Tel}}} \frac{width}{w_{MC}}$$







Hybrid Image scaling:

D_K from timing array

Image from telescope(s)

→ large inter-telescope distance = large A_{eff} !

→ scaled width separation parameter

(+ stereo at high energies, mean scaled width)

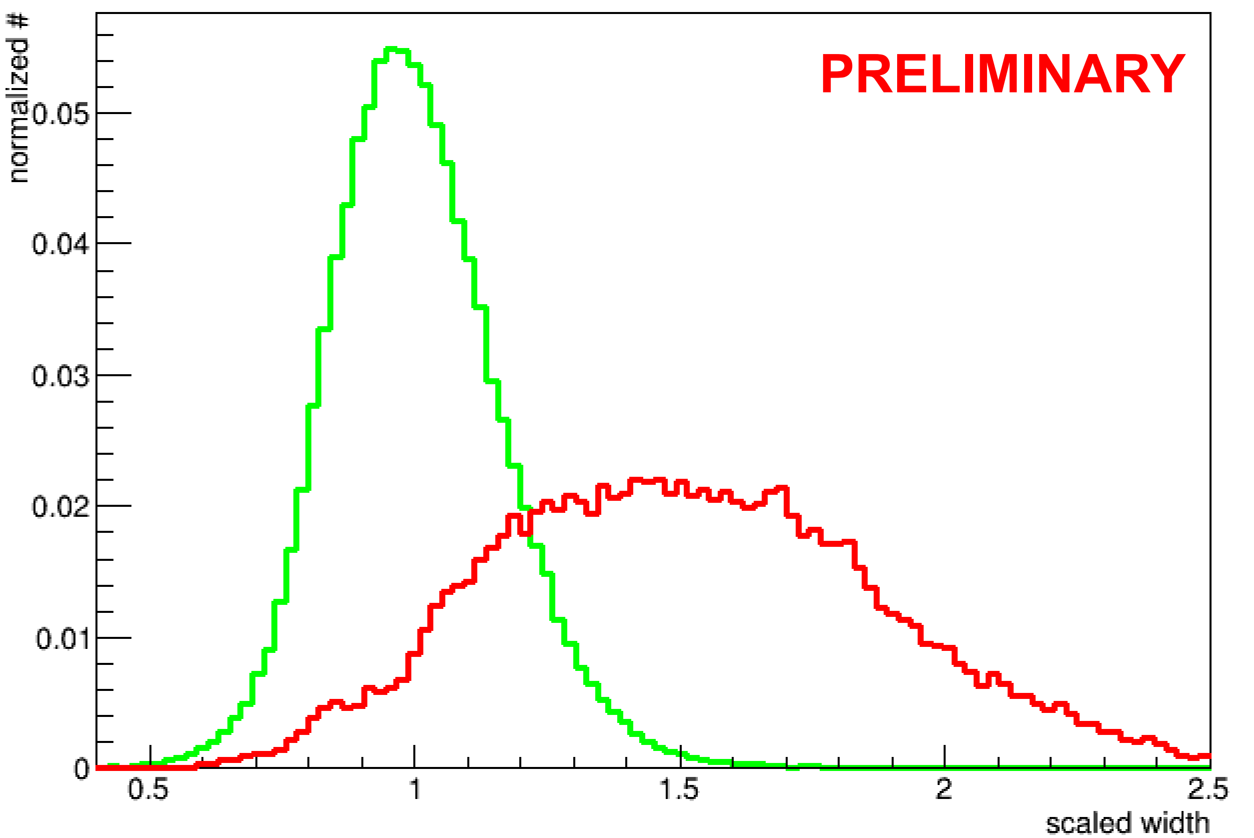
-imaging

HiSCORE + IACTs

Preliminary results hybrid width scaling:

- Improves gamma-hadron separation
- Increases total area as compared to stereoscopic array

Also see:
Kunnas, M.
"Simulation of TAIGA"



Apply scaled width cut:

Q-factor ~2.2

(Simulated granularity: 0.5°)

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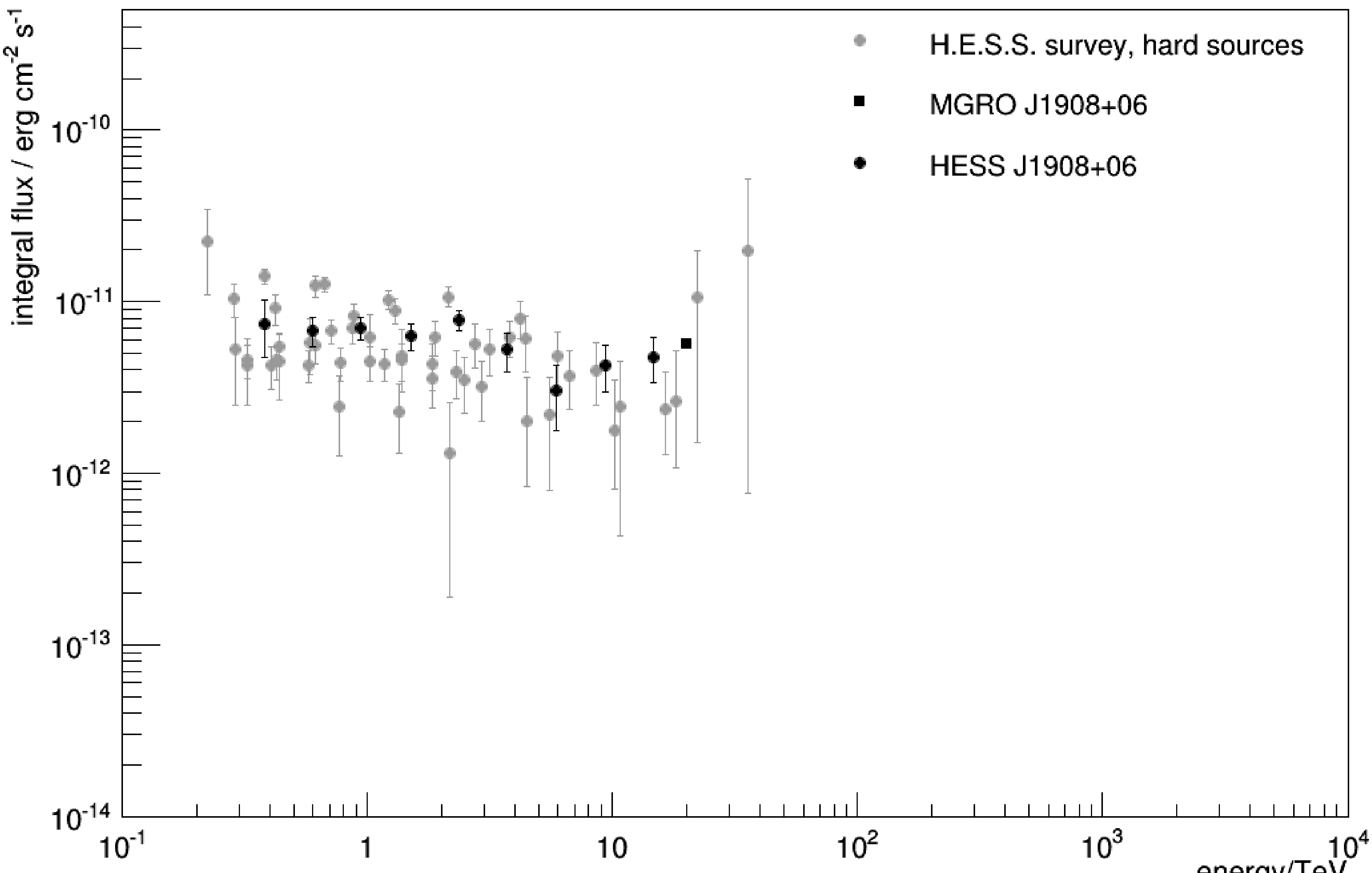
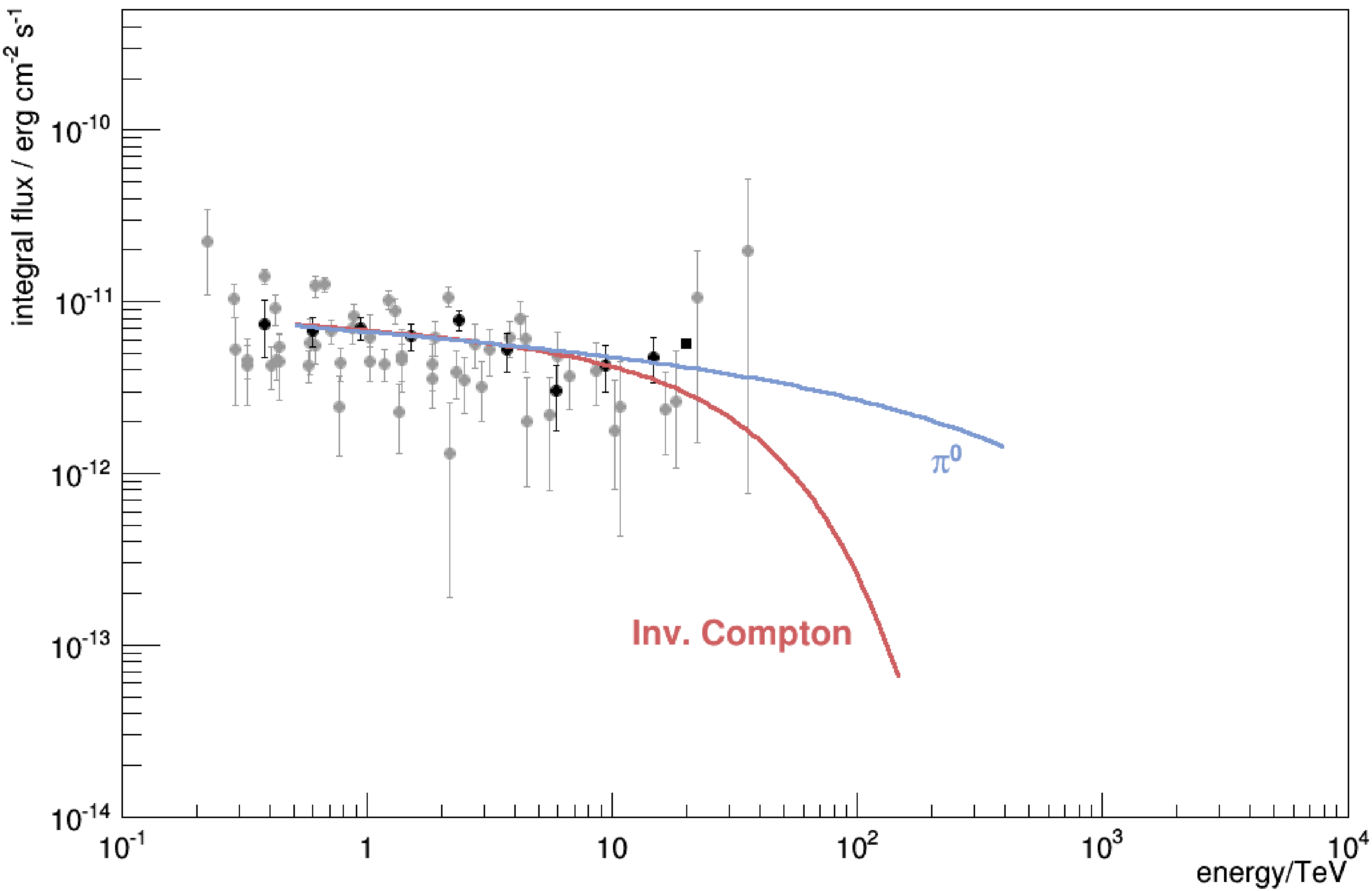
Physics motivation

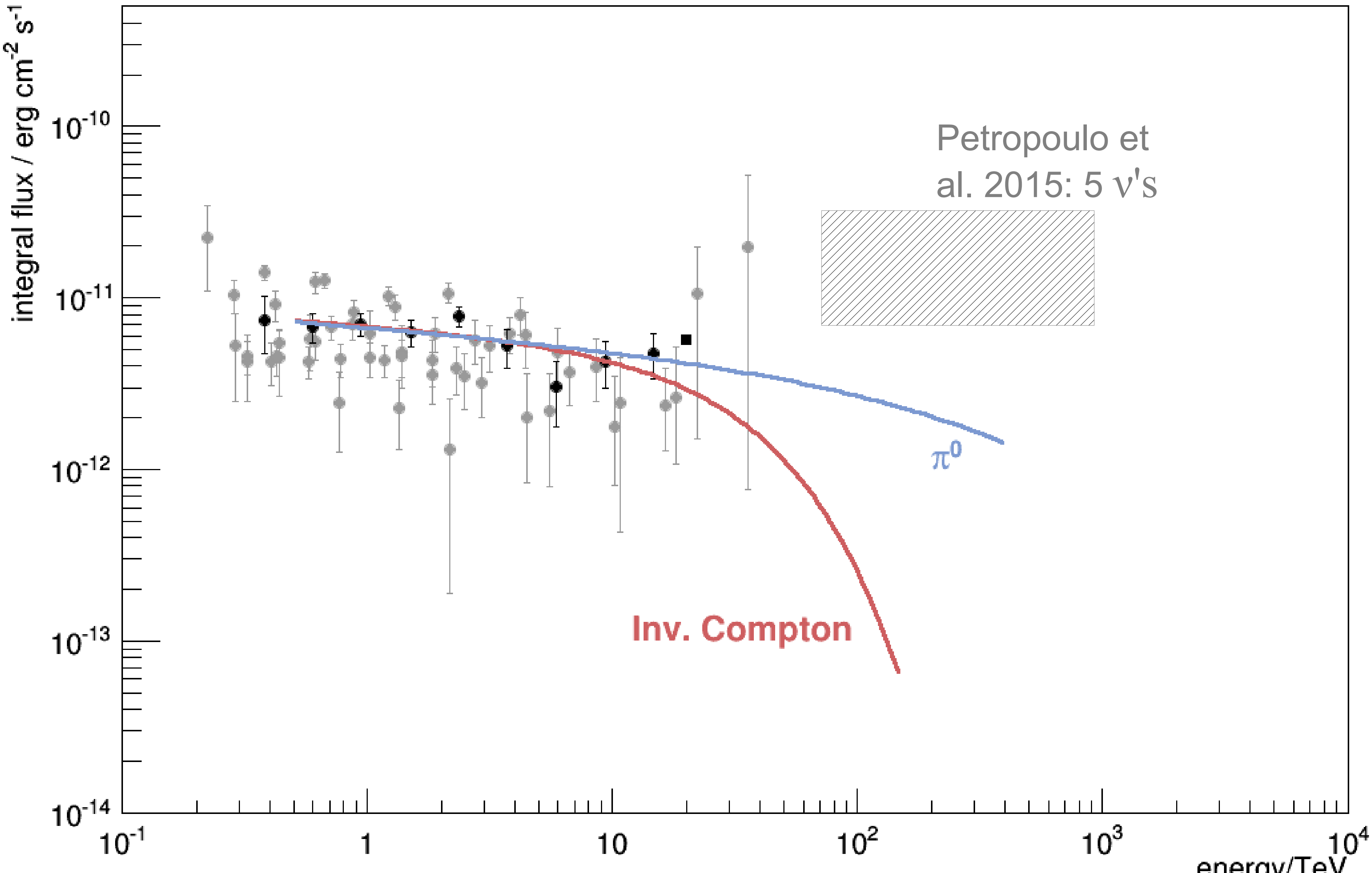
VHE-UHE Gamma-ray astronomy



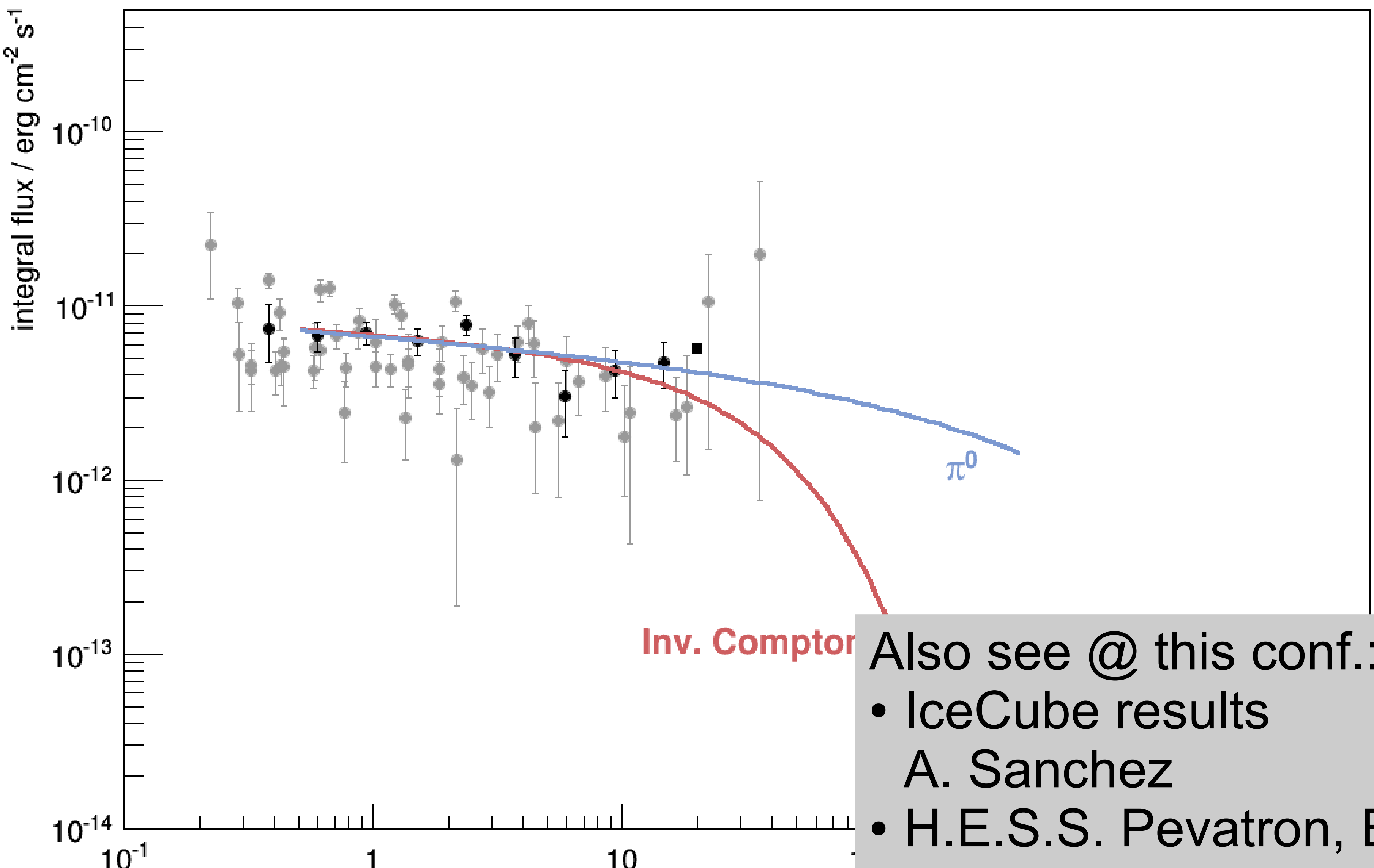
VHE-UHE Gamma-ray astronomy



VHE-UHE Gamma-ray astronomy

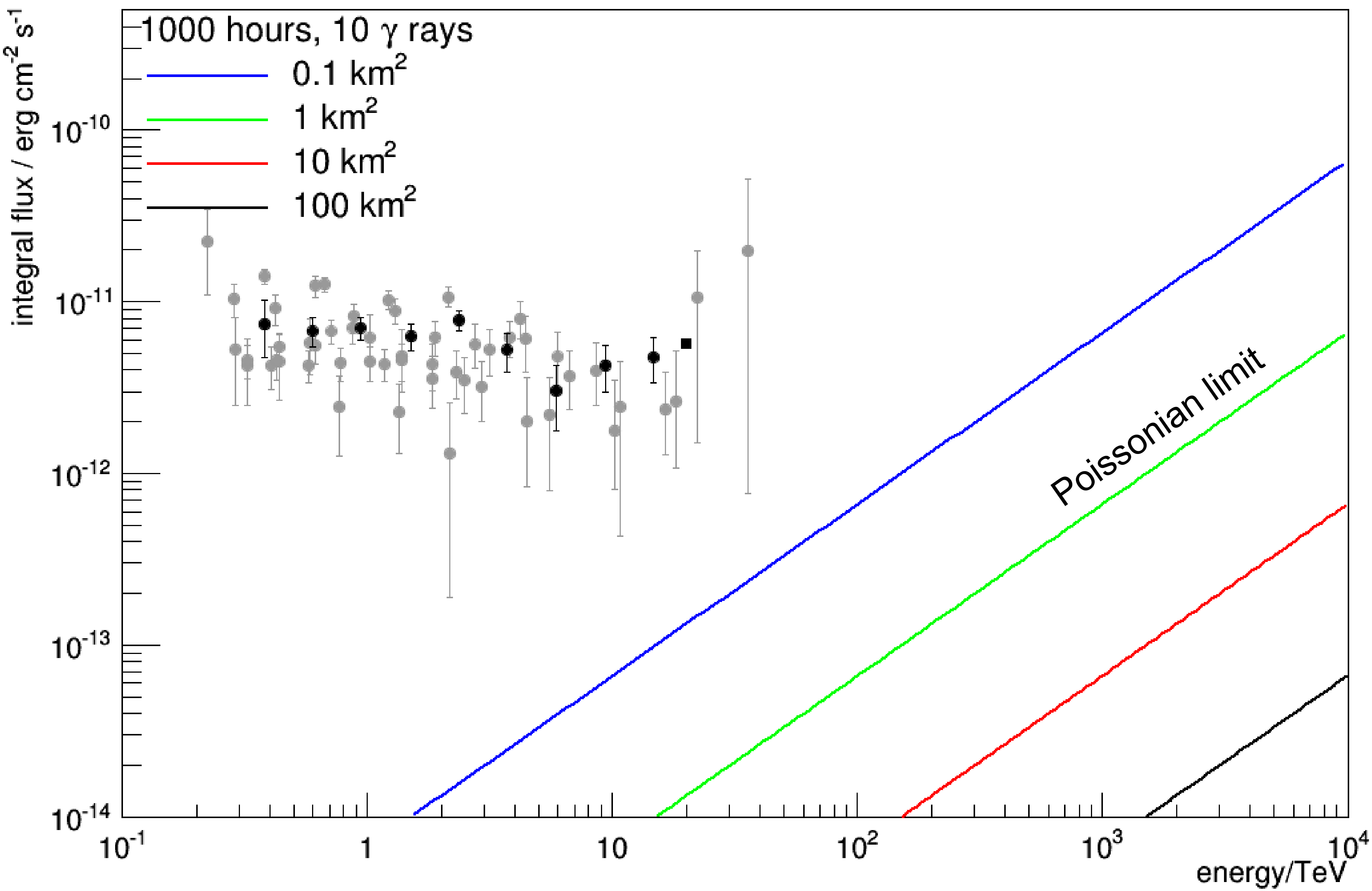


VHE-UHE Gamma-ray astronomy



Also see @ this conf.:
- IceCube results A. Sanchez
- H.E.S.S. Pevatron, E. Moulin

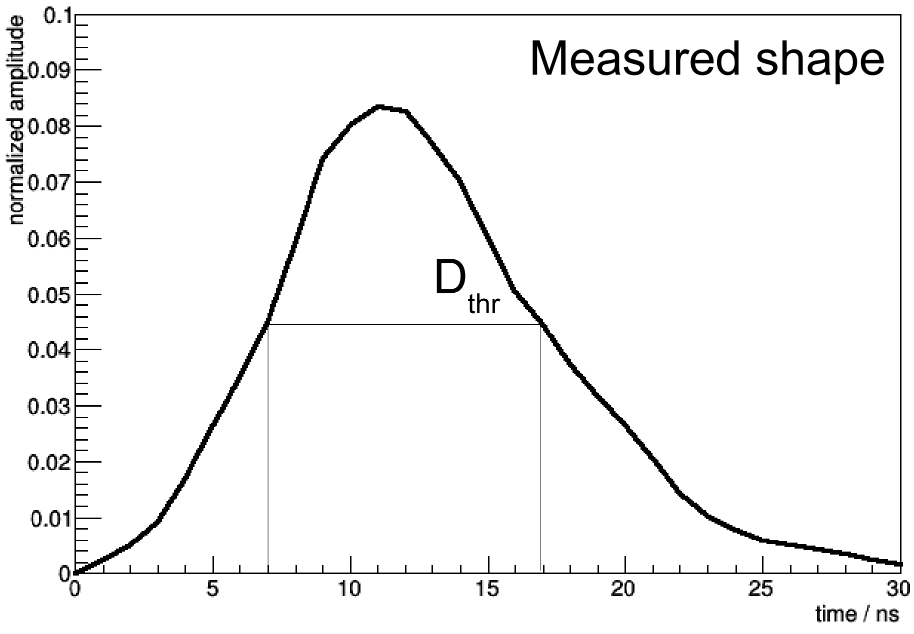
Key to Multi-TeV-PeV: Area



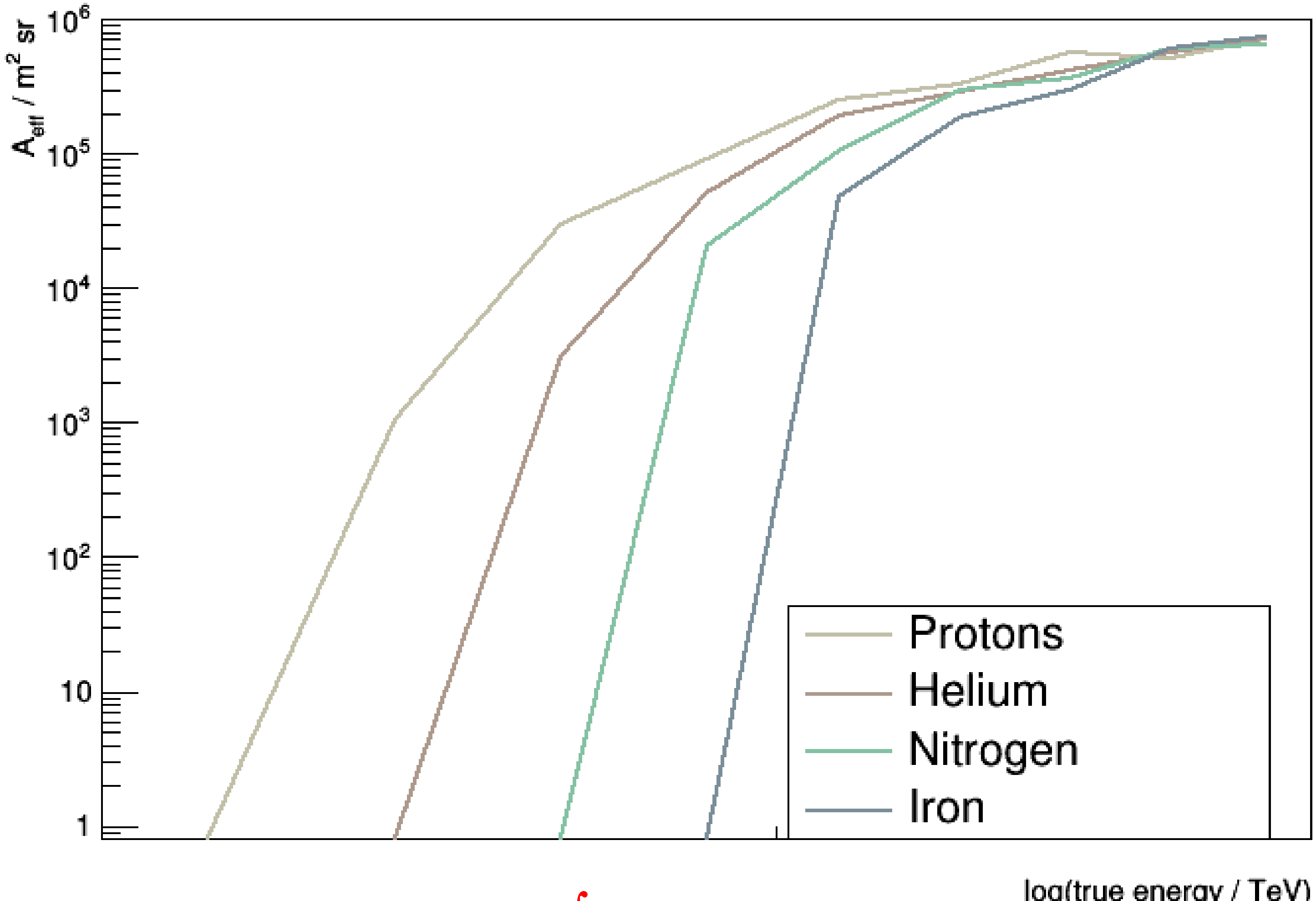
MC Simulation

- **Air showers** CORSIKA v6990, protons, He, N, Fe
- **Detector-simulation** sim_score:
  full simulation based on iact-package
  - Winston cone ray tracing
  - Atmospheric transmission (MODTRAN)
  - PMT quantum efficiency
  - Analog sum trigger, requiring sum > Dthr during τ ns
  - Night sky background simulation
  - Single p.e. pulse shaping

Astroparticle Physics, 2014arXiv1403.5688T



Effective trigger area

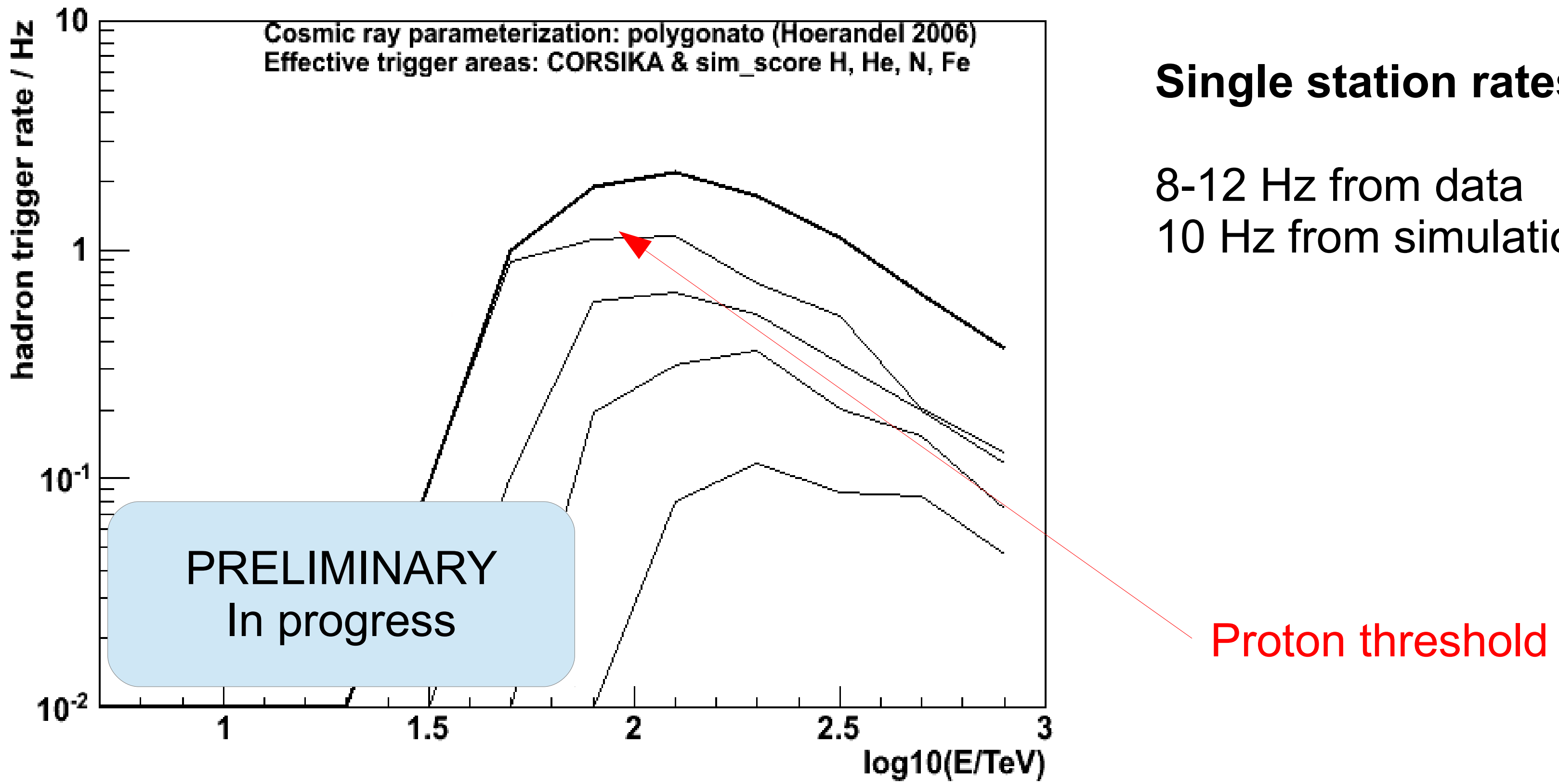


rate $R = \int dE\, \Phi(E)\, A_{eff}(E)$

$\Phi(E)$: polygonato model (Hörandel 2003) & ATIC p/He parametrization

Data – MC comparison

- Array trigger rate: minimum 4 stations triggered
  - 10-18 Hz
  - Reproduced for Athr = 250–350 p.e.

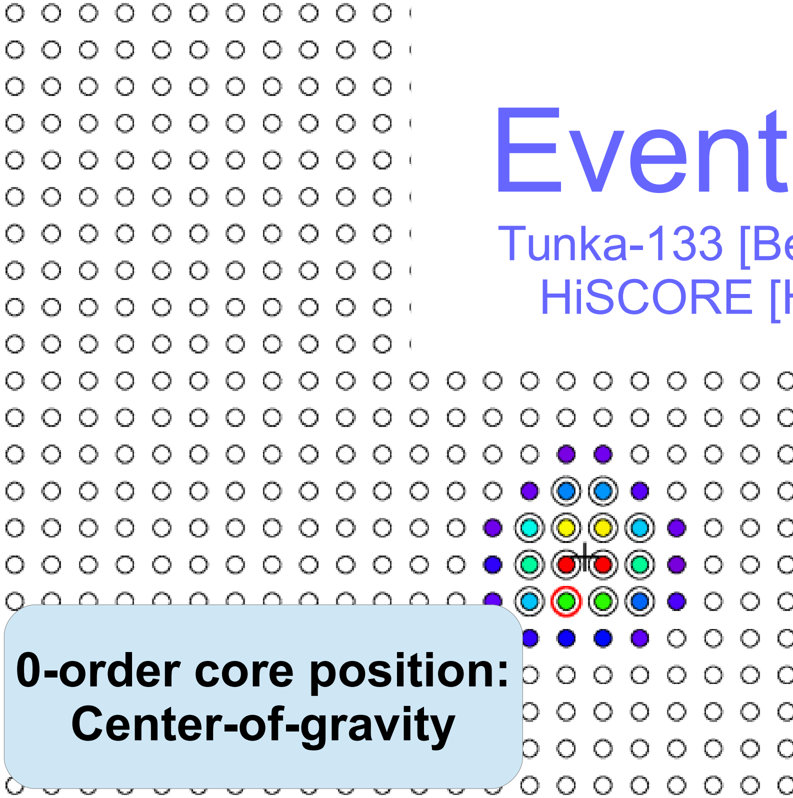


Single station rates:

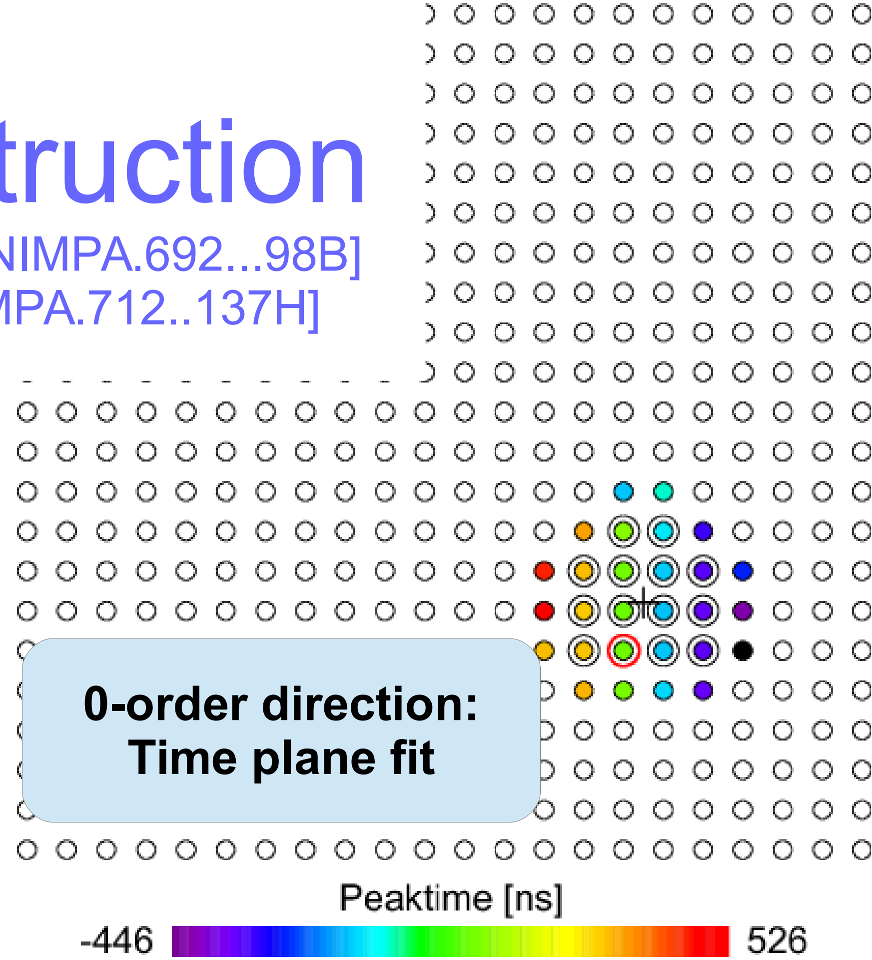
8-12 Hz from data
10 Hz from simulations

Event Reconstruction

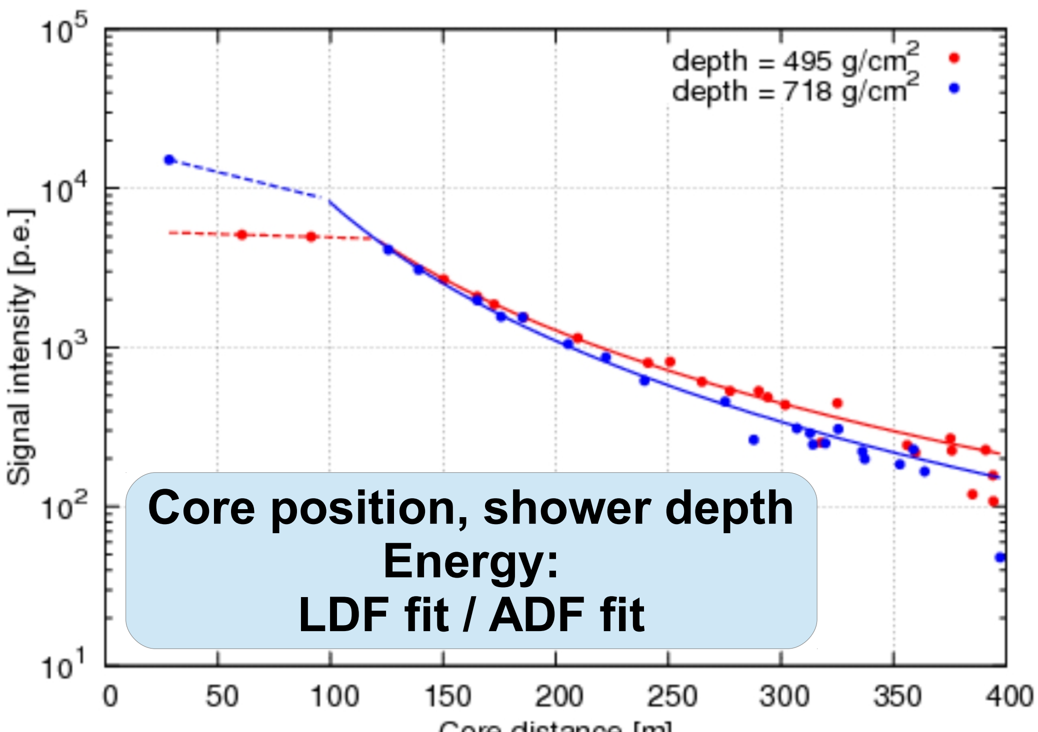
Tunka-133 [Berezhnev et al. 2012NIMPA.692...98B]
HiSCORE [Hampf et al. 2013NIMPA.712..137H]



0-order core position:
Center-of-gravity

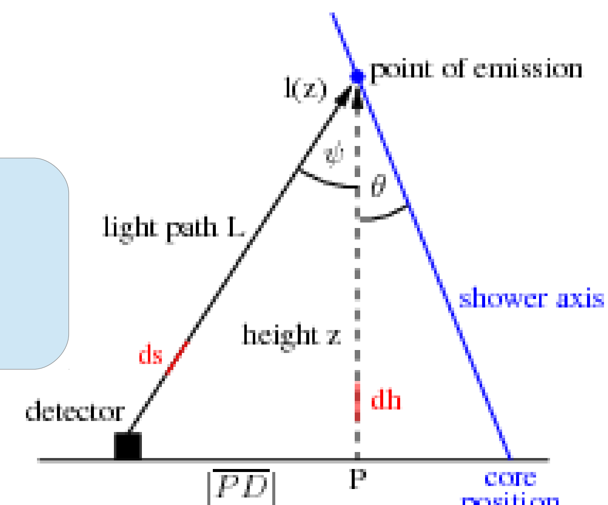


0-order direction:
Time plane fit

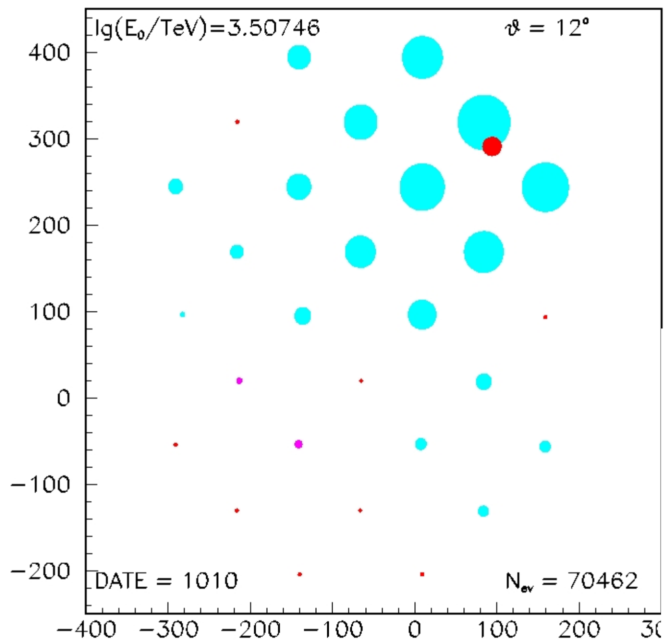


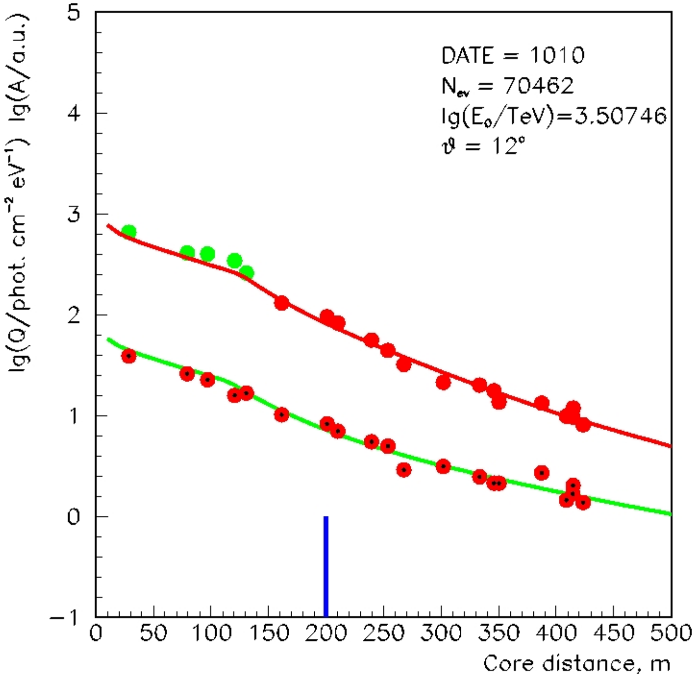
Core position, shower depth
Energy:
LDF fit / ADF fit

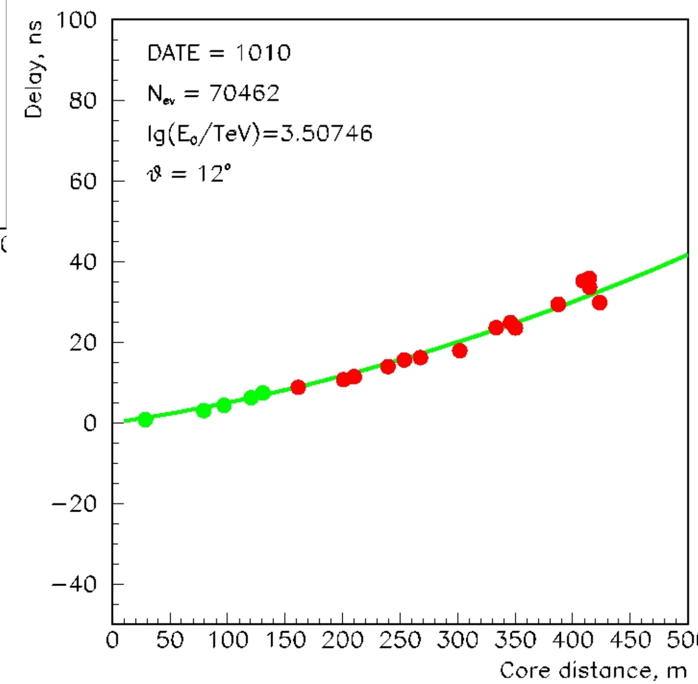
Direction:
Cone fit
Timing model



Event reconstruction

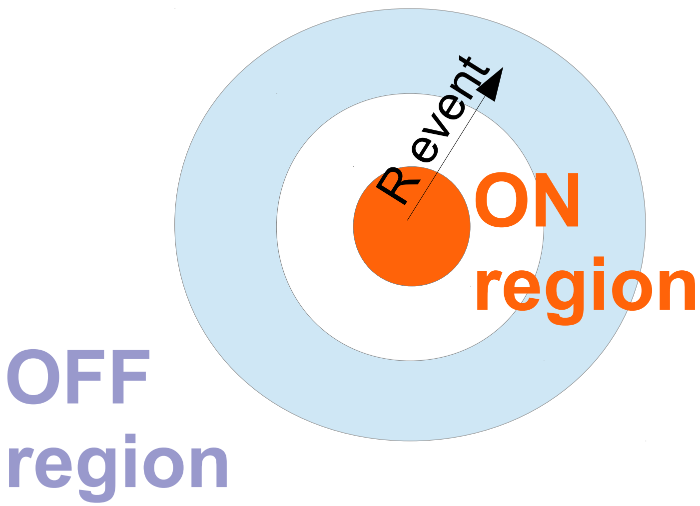






Background for pointsource search

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

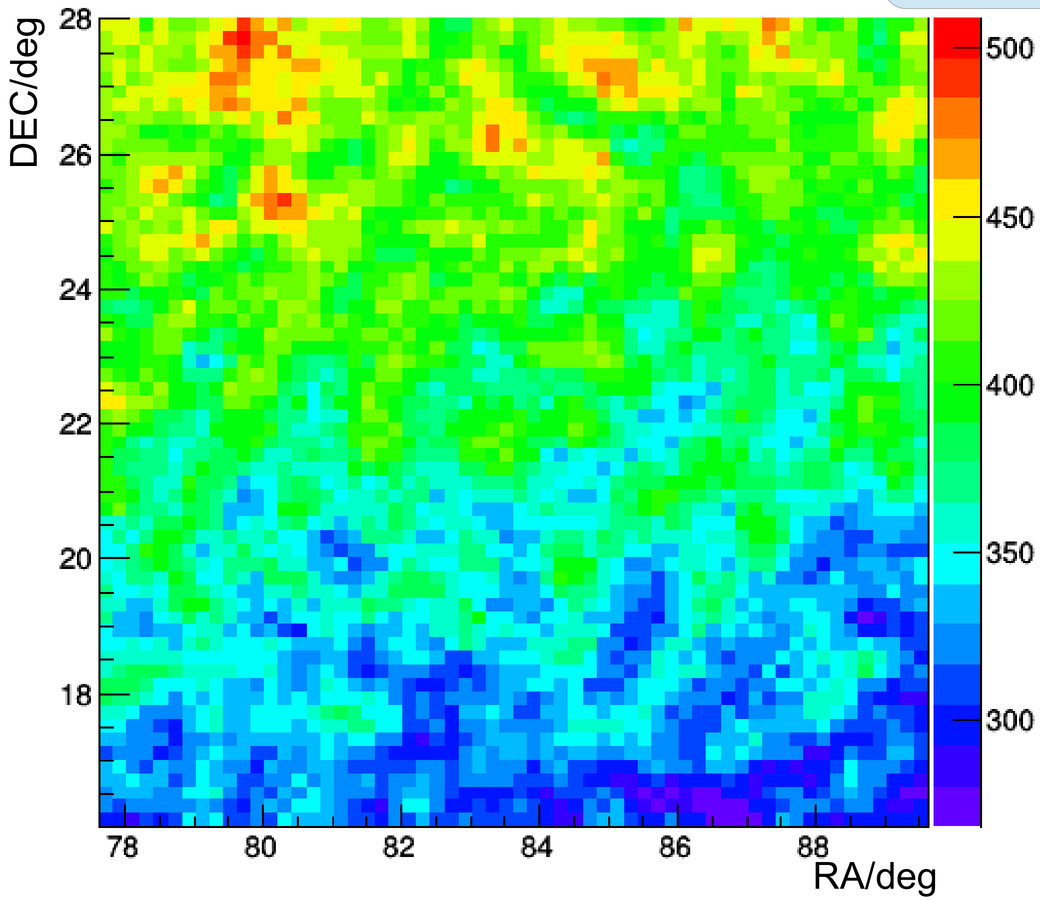


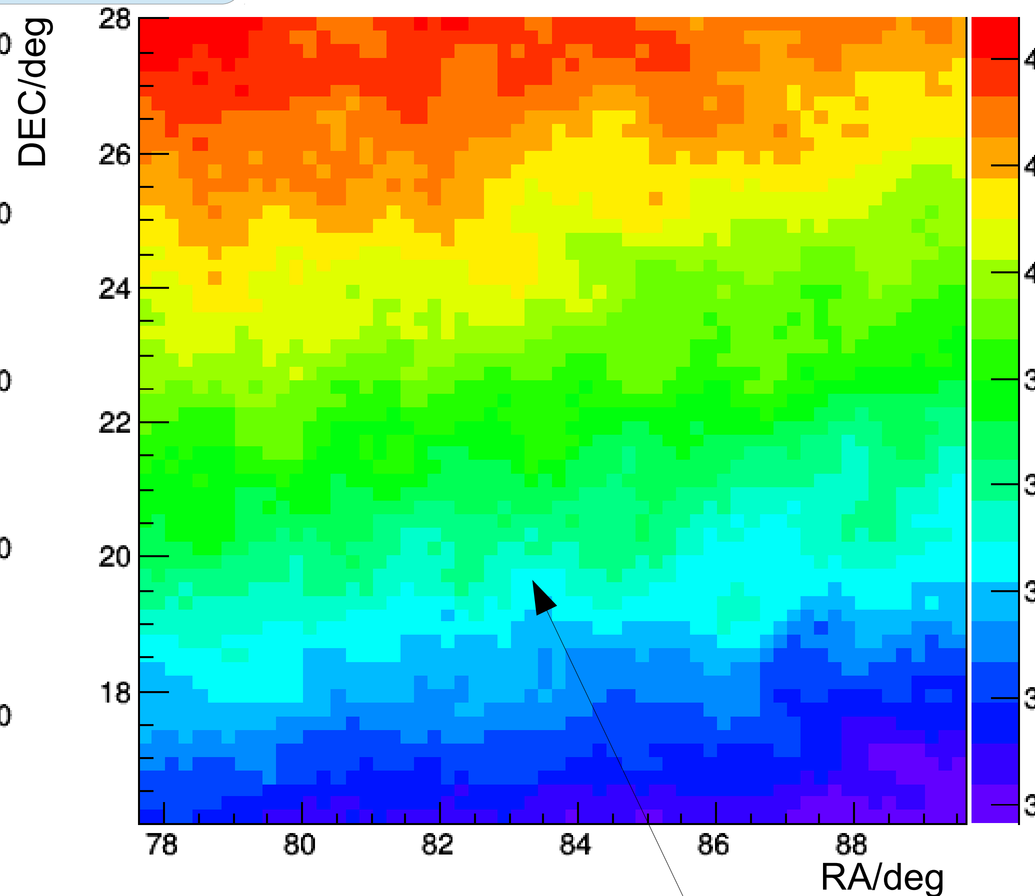
- **Testing the background model**
  - **Data blinding:**
    local ra/dec randomization by Gaussian width σ= 1°
  - Apply P.S. search to blinded data
  - Expectation: normal Gaussian distribution of significances in field of View

Background for pointsource search

BLINDED DATA

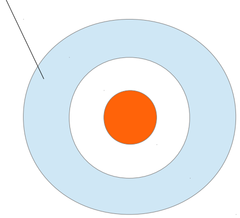
PRELIMINARY





Non count map

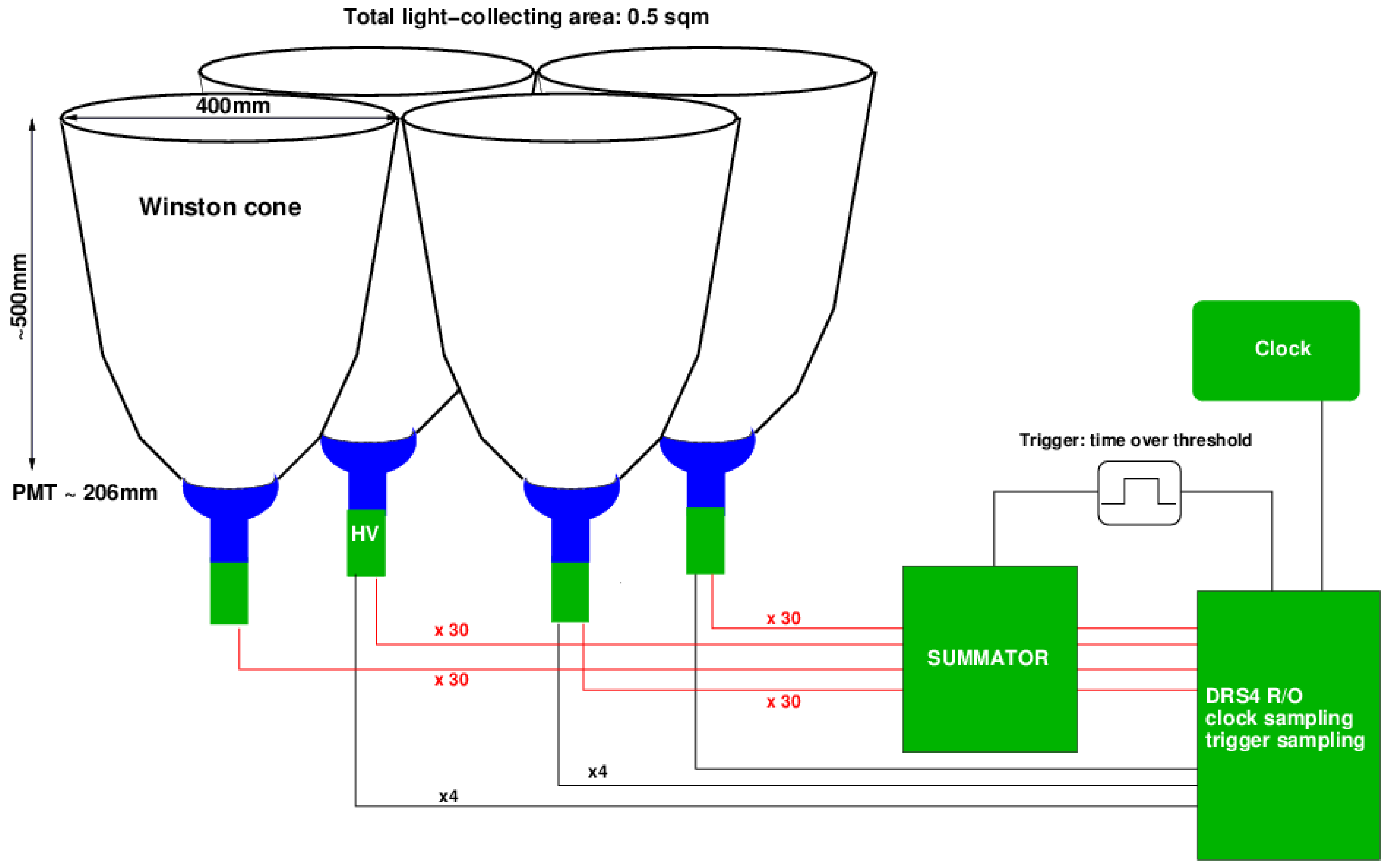
α Noff count map



Oversampled skymaps 6° x 6°

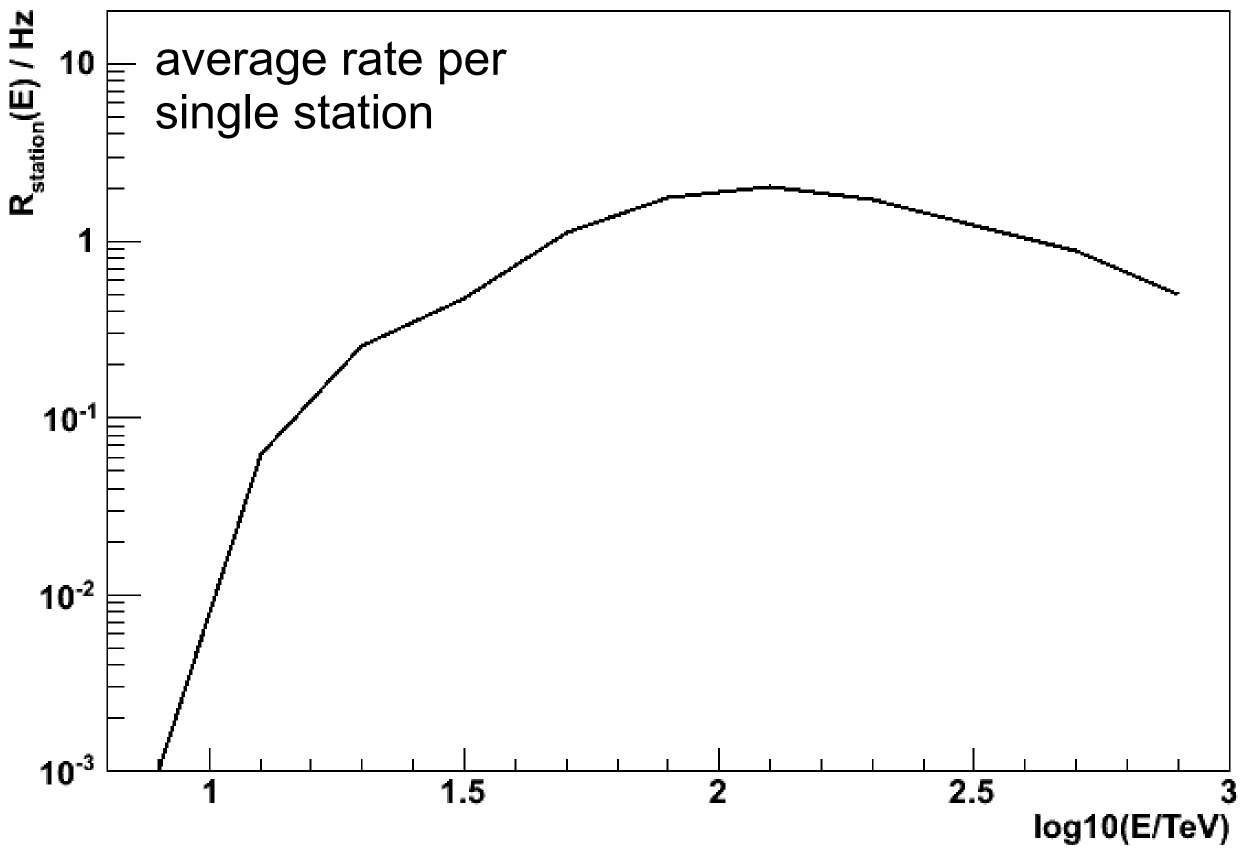
Preselection 10° x 10° (reducing computing requirement)

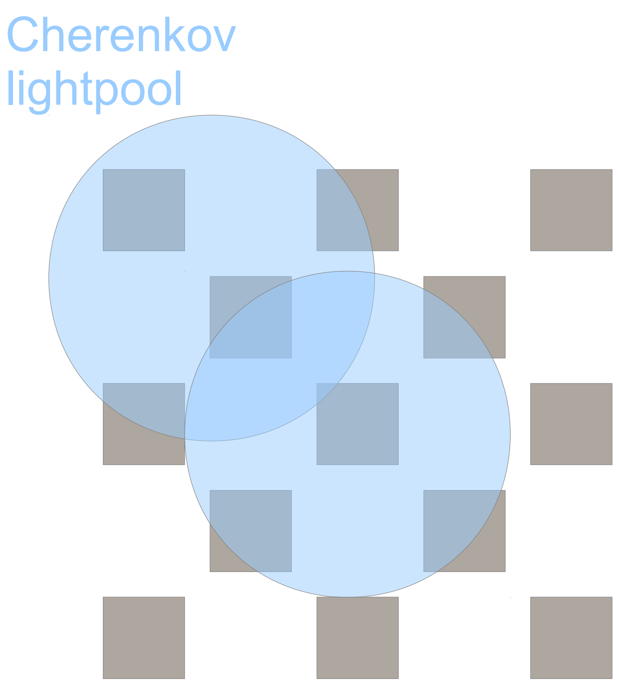
Triggering and Readout



Data – MC comparison

- Trigger rate: hadron-induced single station rate

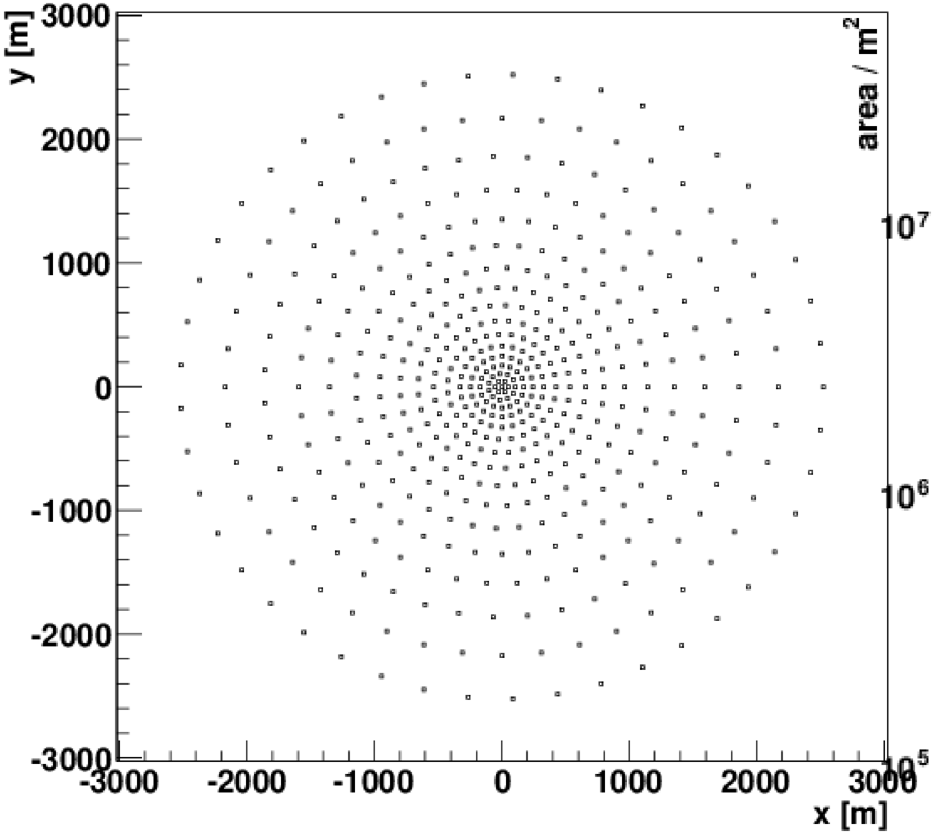


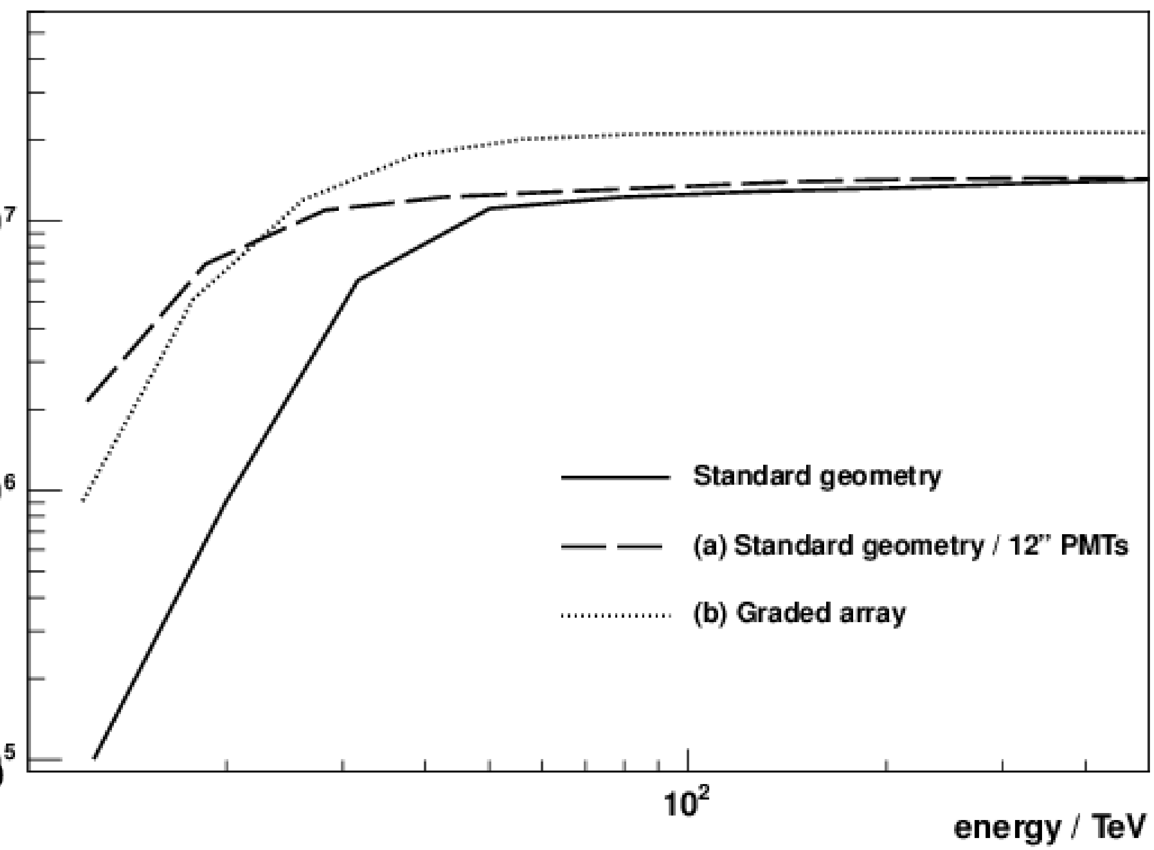


MC: 10 Hz
Data: 8 – 12 Hz

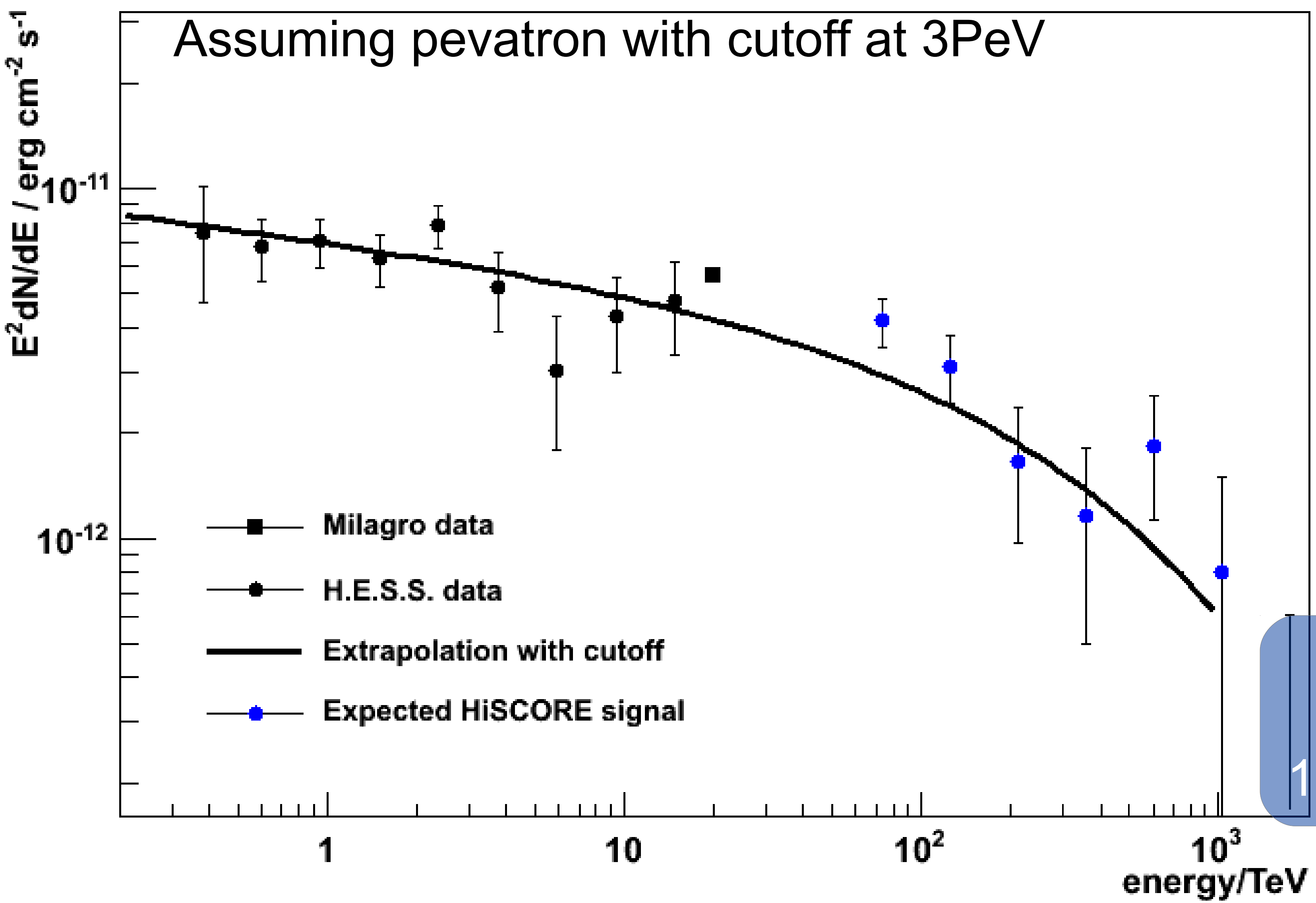
Array optimization

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



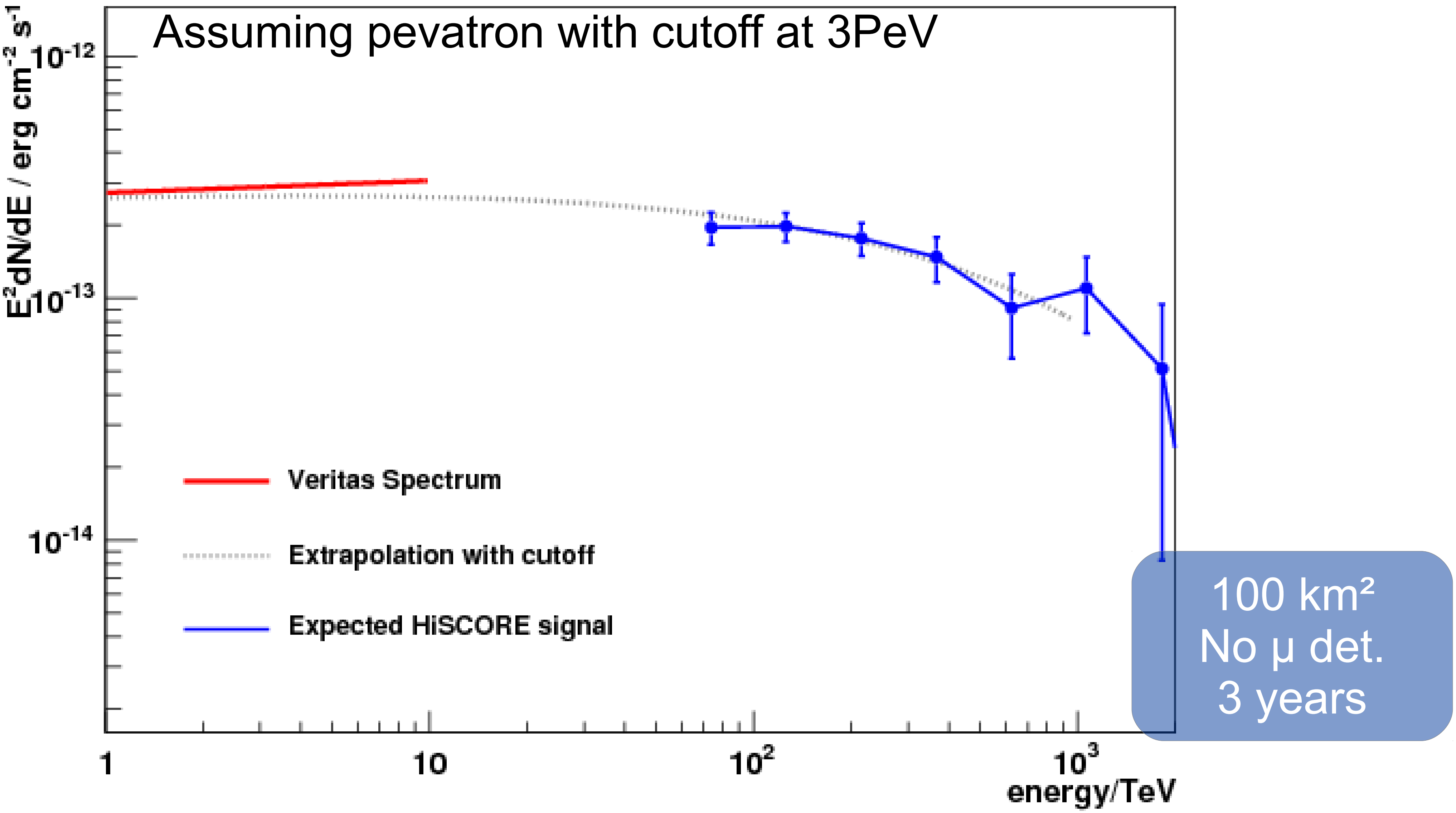


MGRO J1908+06

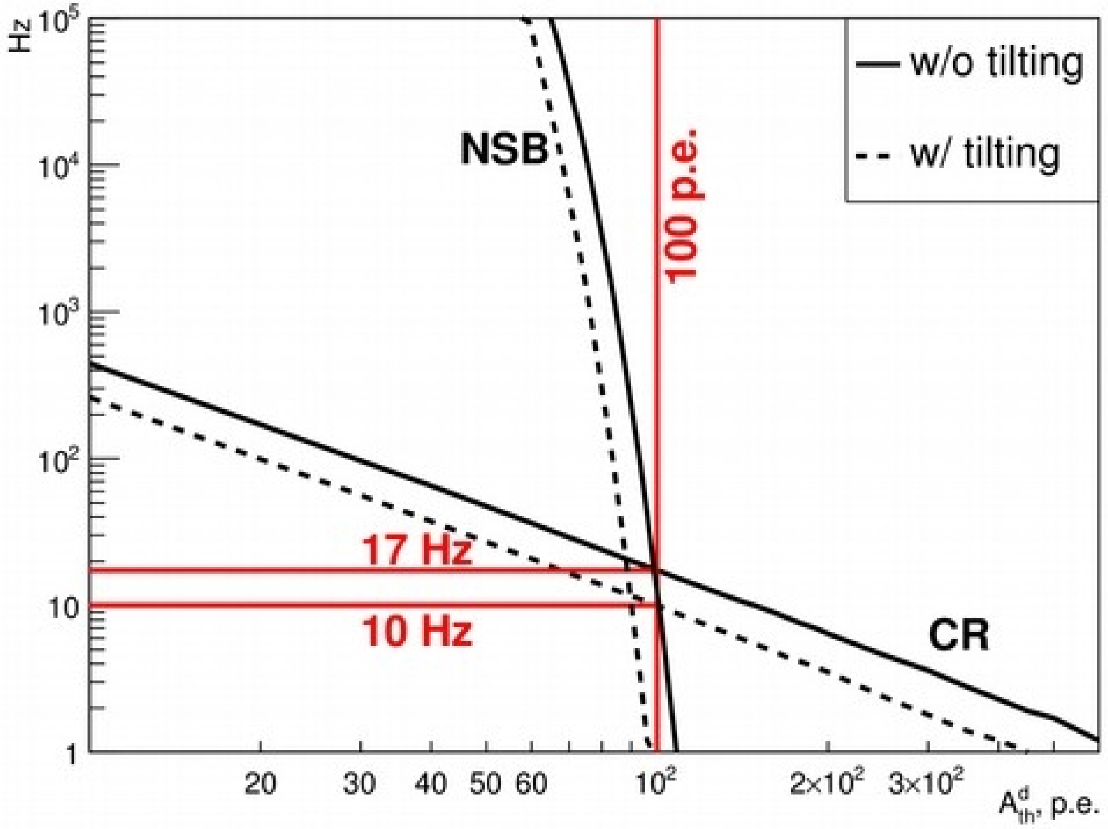


10 km²
No μ det.
1 year (200h)

Tycho Supernova remnant



Single station rate and Energy threshold



9-station array:

Comparison of MC simulation with data yields a threshold of 100 p.e. at discriminator level

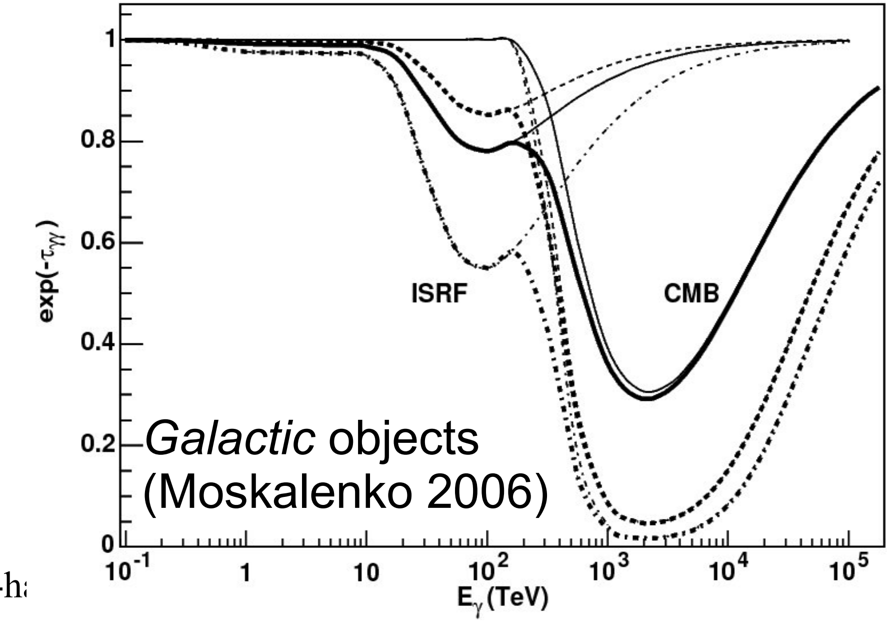
→ 180 p.e. threshold

Air Cherenkov imaging and timing

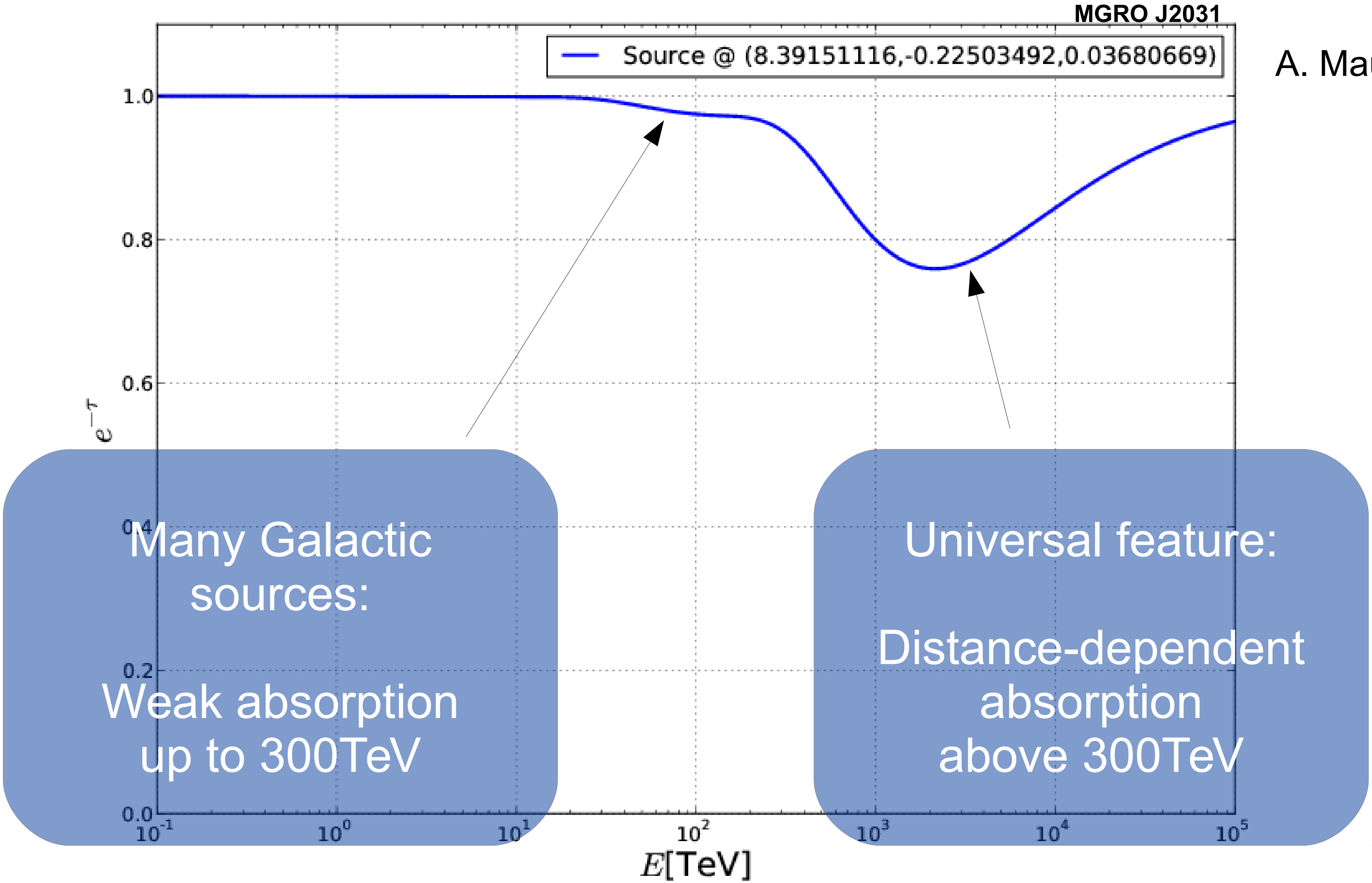
	Imaging ACTs	Timing arrays
Direction	Image orientation	Shower front arrival times
Particle type	Image shape	Lateral density function Arrival times Time width (FWHM)
Energy	Ch. photon count	Ch. photon count

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*)

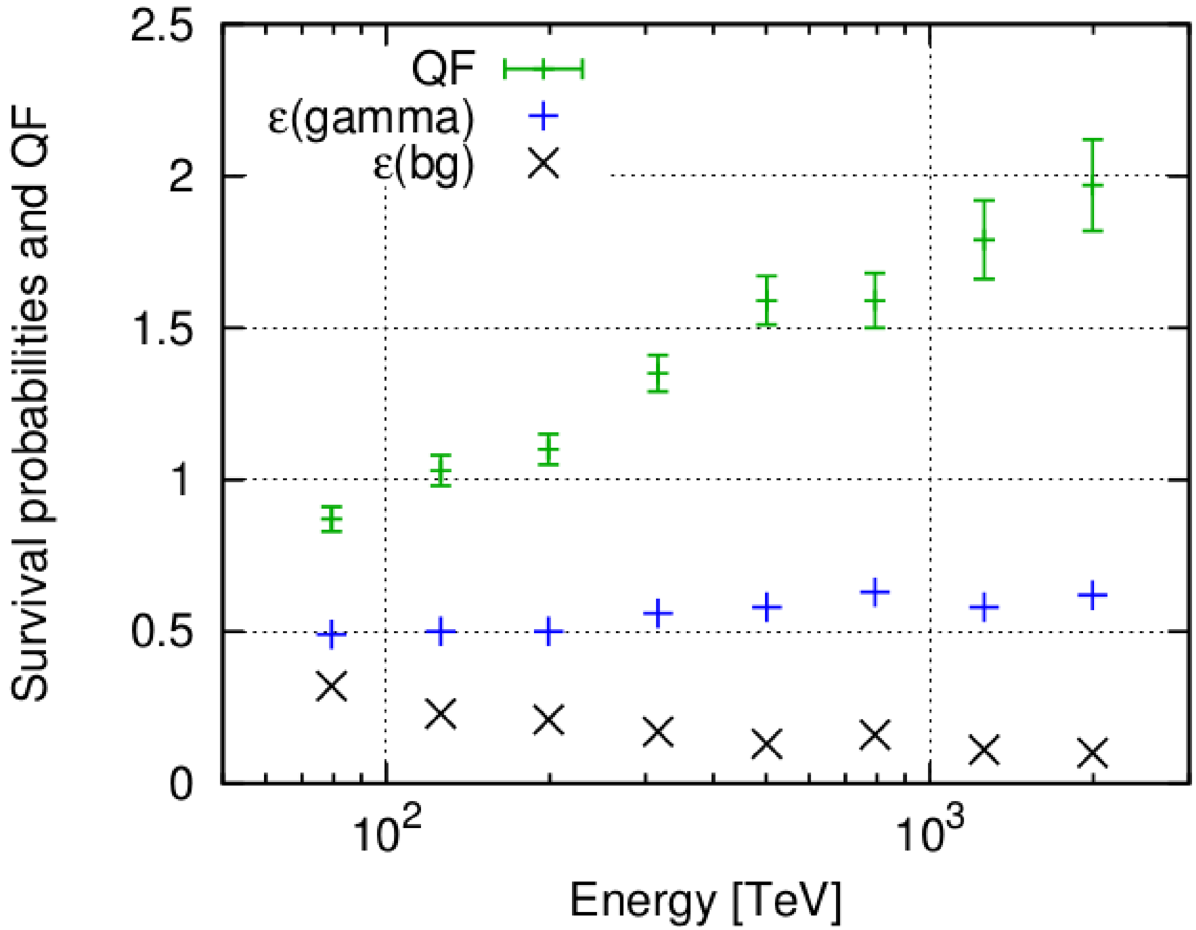


Absorption (e^+e^-), Galactic



A. Maurer

Particle separation Q-factor (only timing array)



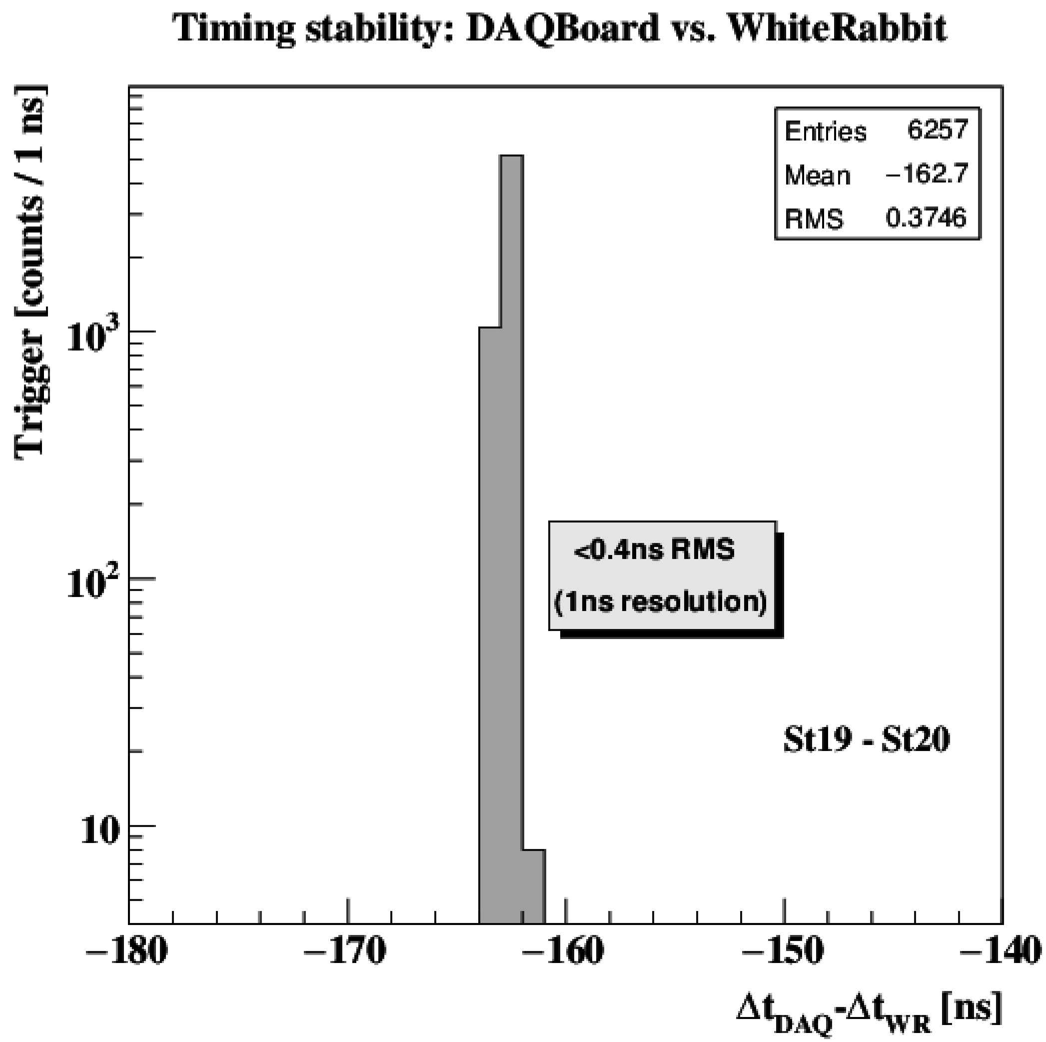
- Xmax vs. E
- Shower front rise time
- Systematic differences between Xmax reconstruction methods

Time calibration

T-cal systems yield comparable accuraccies:

Cross check of timing stability between DAQBoard and WhiteRabbit:

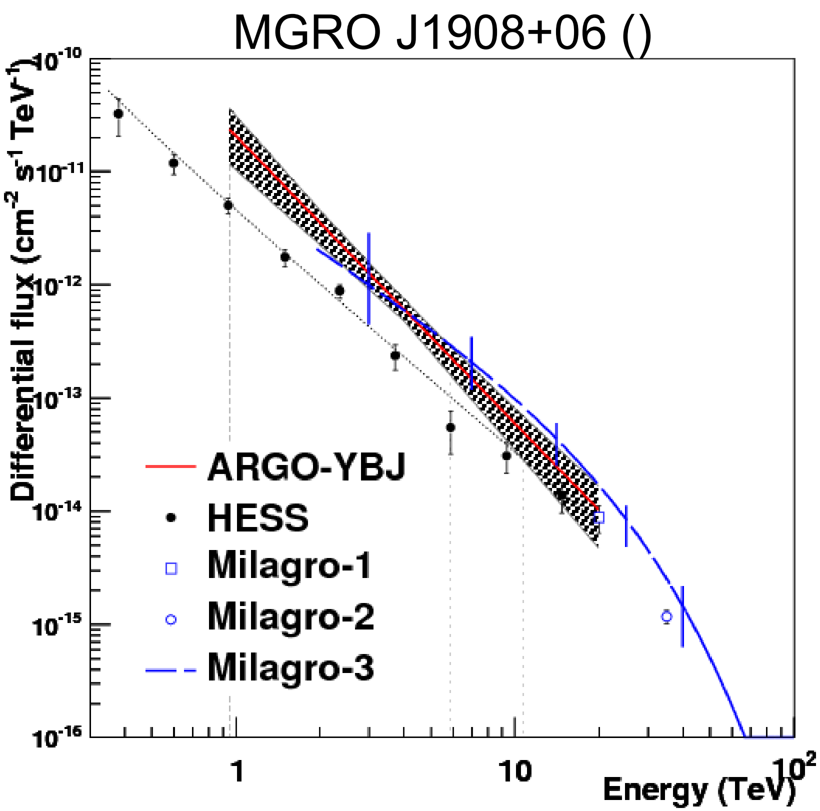
RMS<0.4 ns

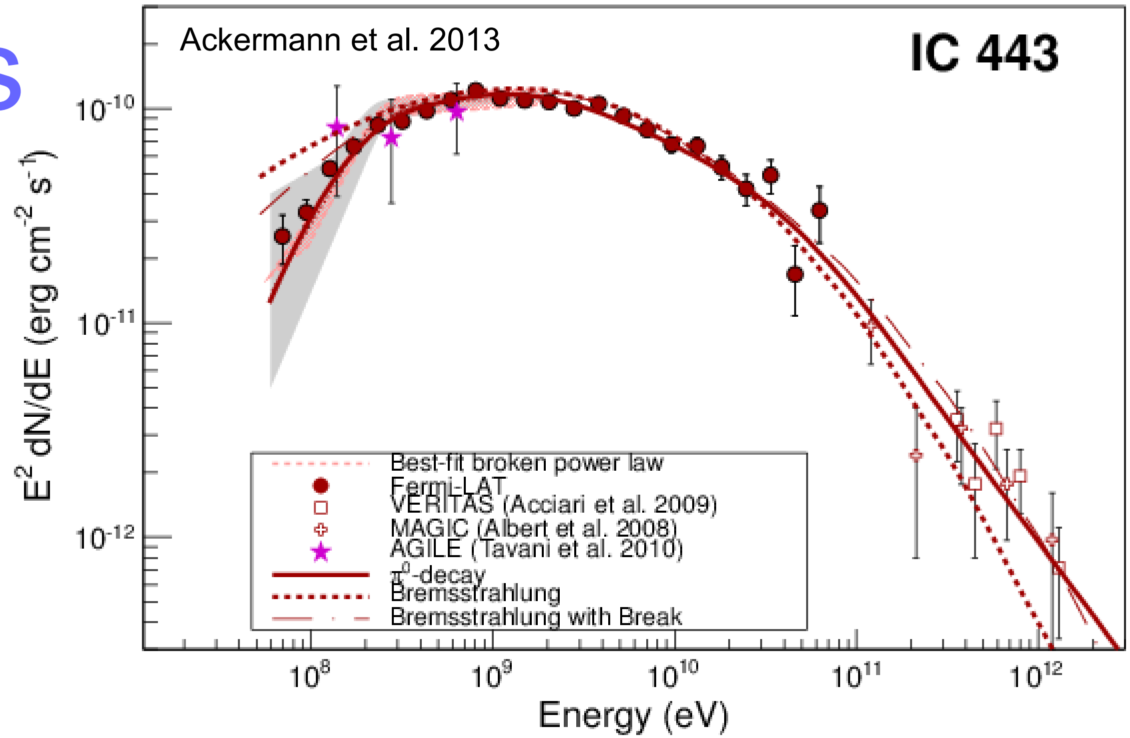


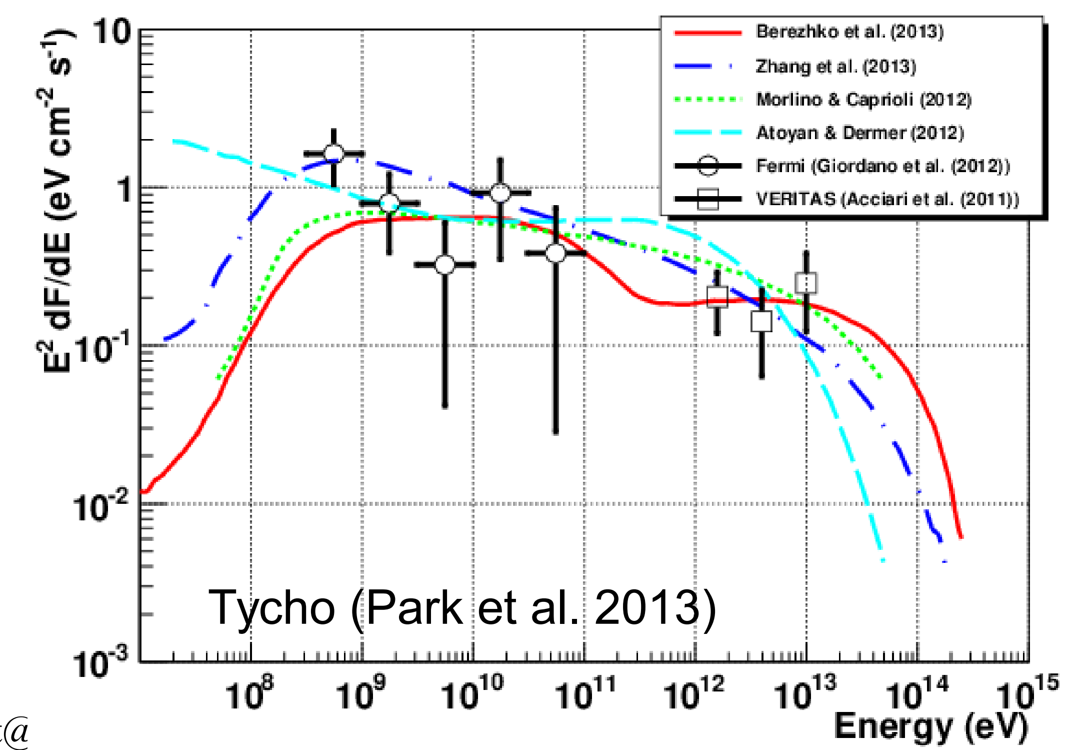
Detection methods for gamma astronomy

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

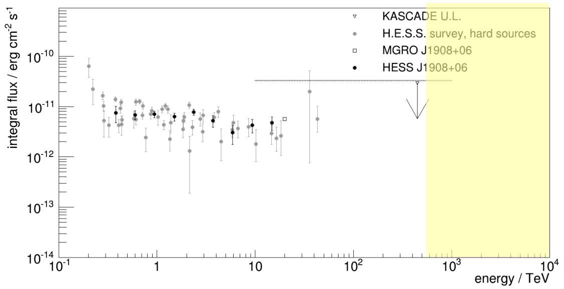
Galactic Gammas beyond 10 TeV





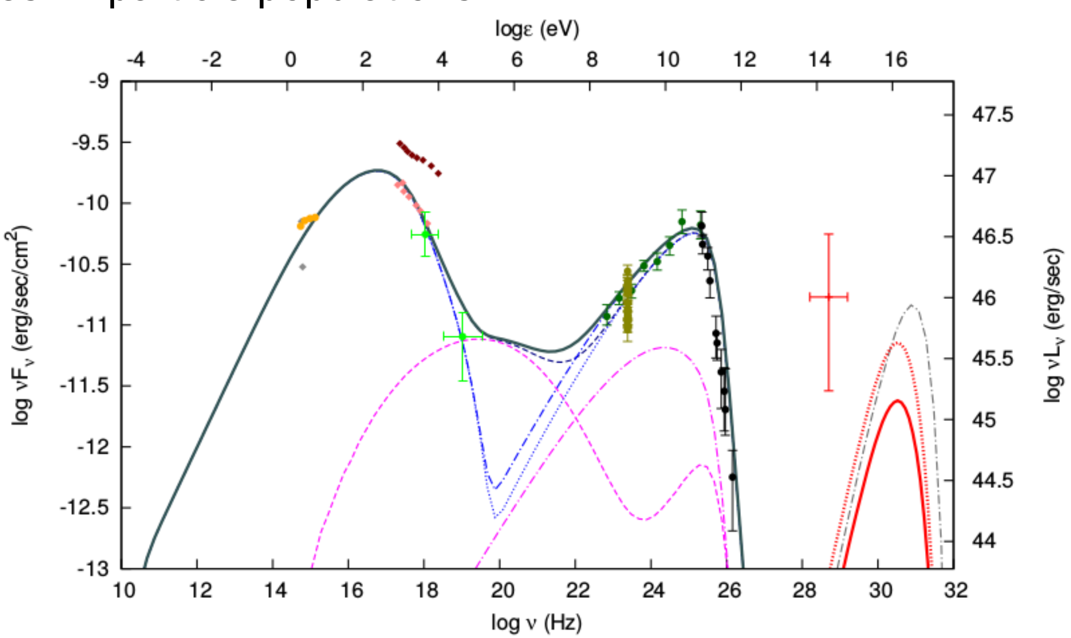


Extragalactic UHE gamma-rays

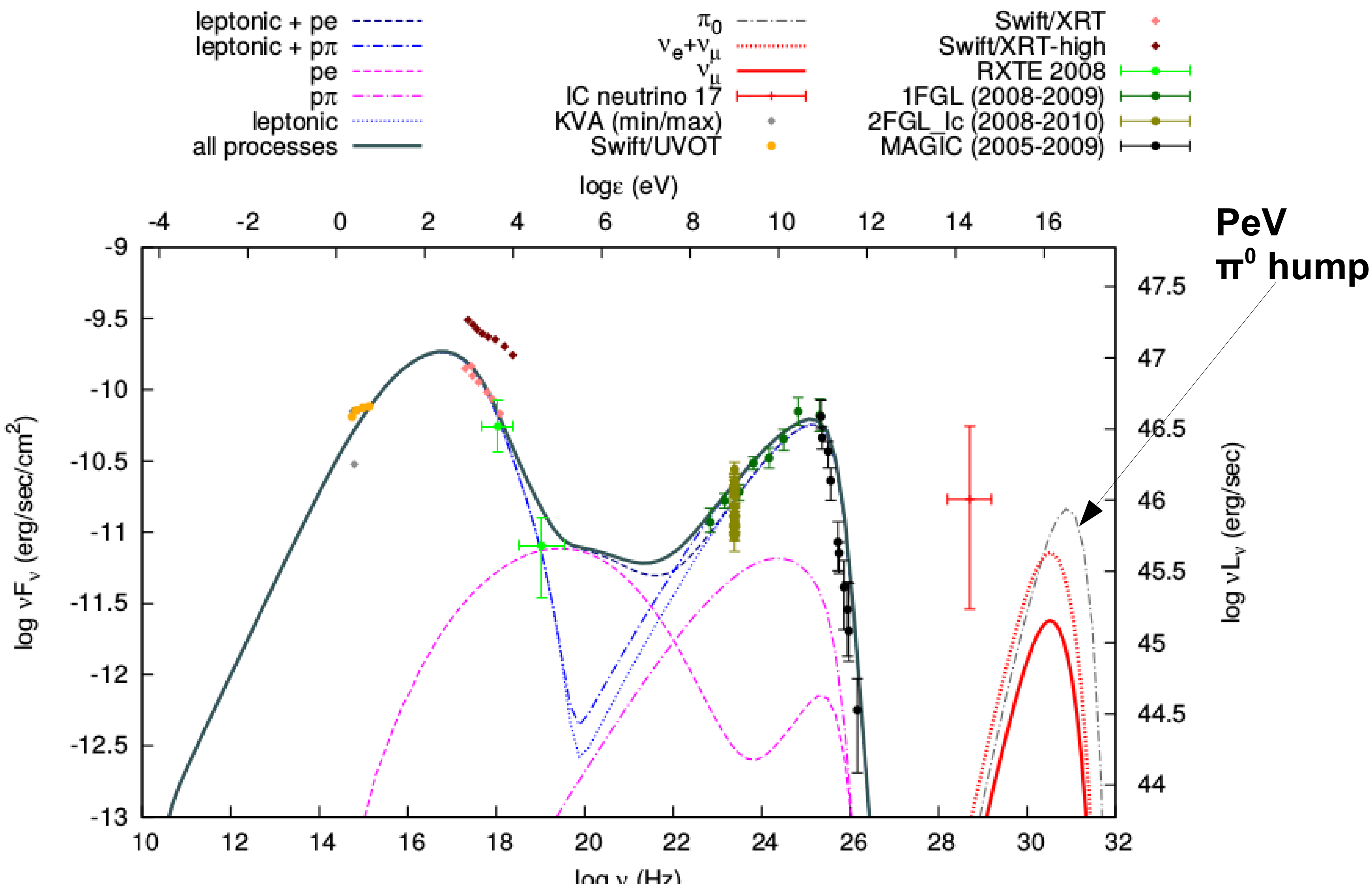


- **The IceCube signal (Aartsen et al. 2013, 2014)**
  - 1st 3 years of full IceCube data: 37 UHE neutrinos (30 TeV – 2 PeV)
  - Presence of astrophysical component favoured (5 σ).
  - Identification of 8 BL Lac objects as likely neutrino event counterparts (Padovani&Resconi 2014)

- **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)

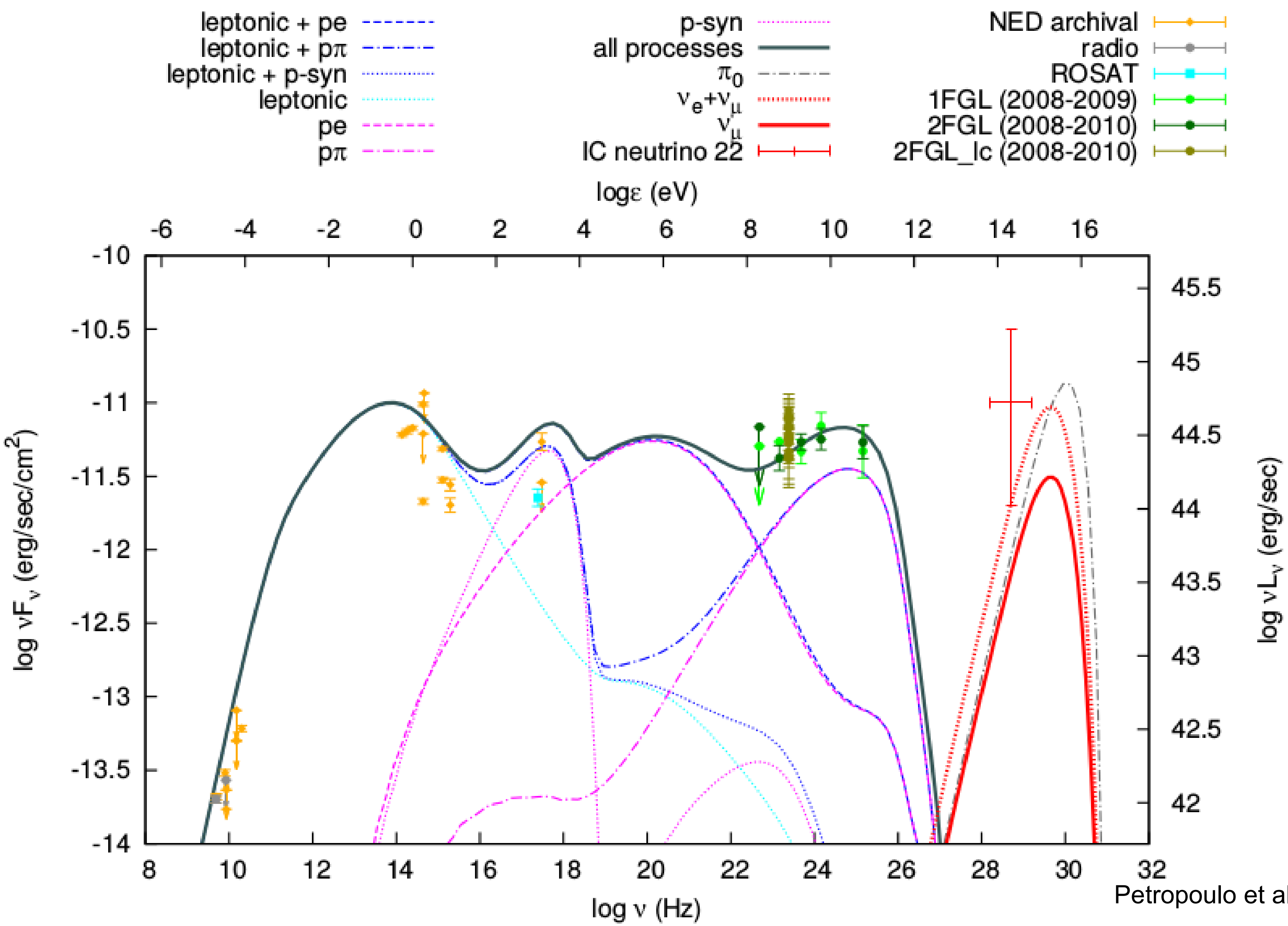


PG 1553+113 (z = 0.4)



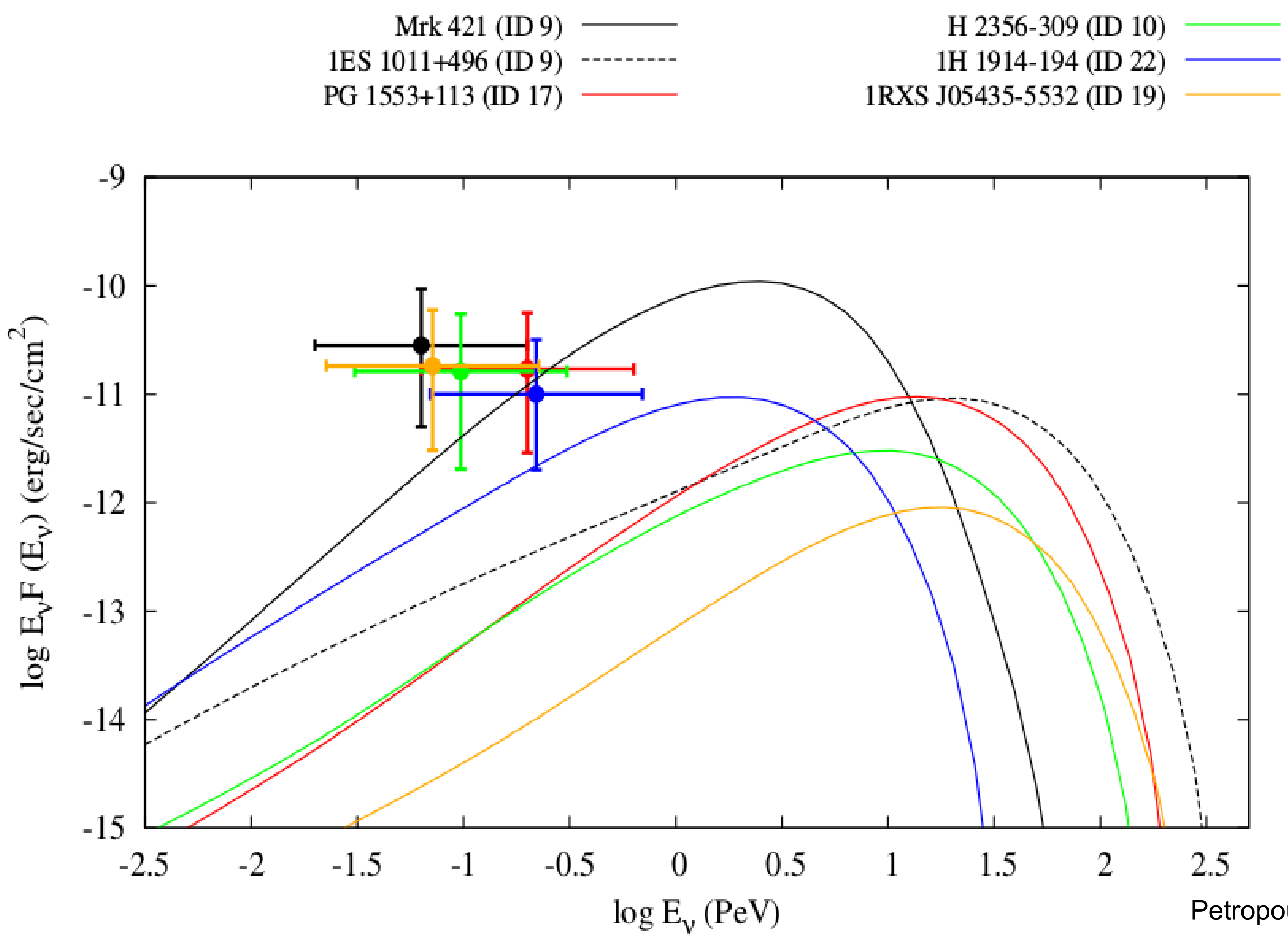
Petropoulo et al. 2015

H 1914-194 (z=0.137)



Petropoulo et al. 2015

π^0 hump and neutrino event fluxes



Petropoulo et al. 2015