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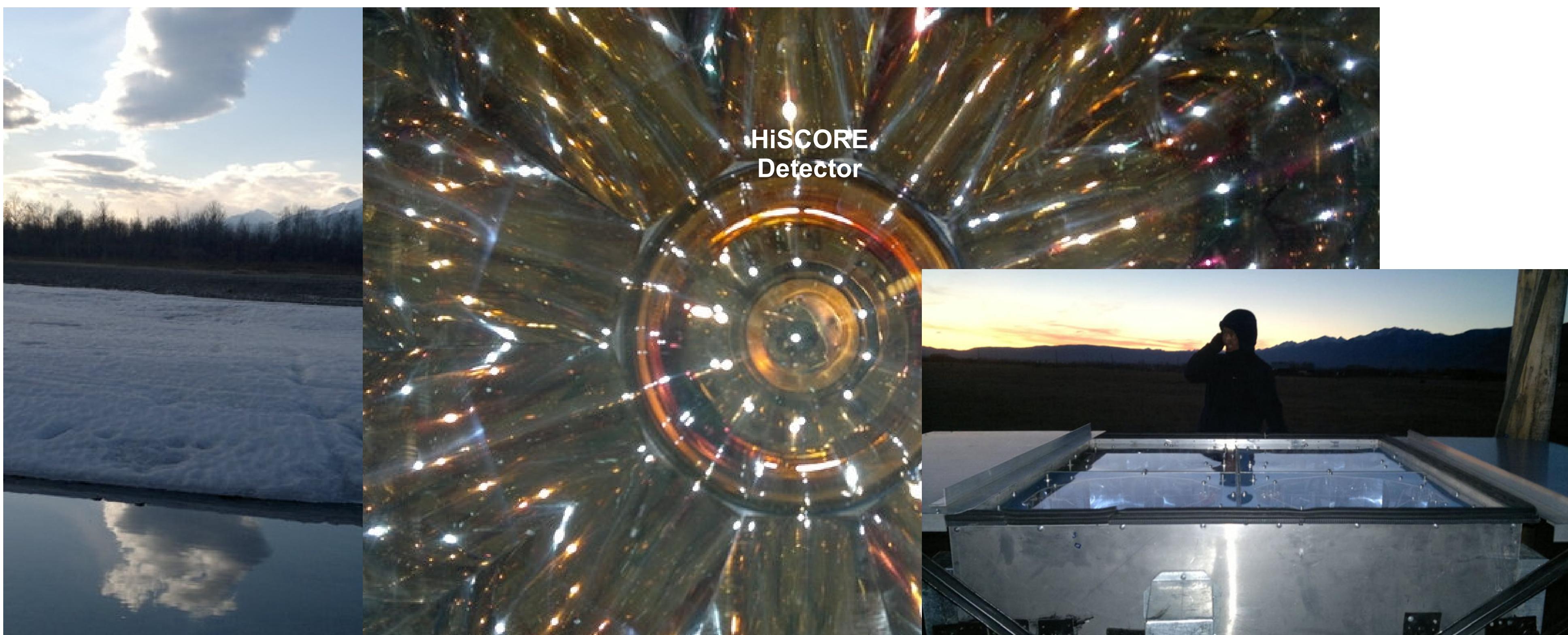
Status of the HiSCORE Project

M. Tluczykont, D. Horns
Tunka-HiSCORE,
TAIGA



- Physics motivations & The HiSCORE concept
- Status of the 9-station Tunka-HiSCORE array
- Future plans: TAIGA and further prototyping

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HiSCORE

Hundred***i** **S**quare-km **C**osmic **OR**igin **E**xplorer

Concept: non-imaging air Cherenkov technique

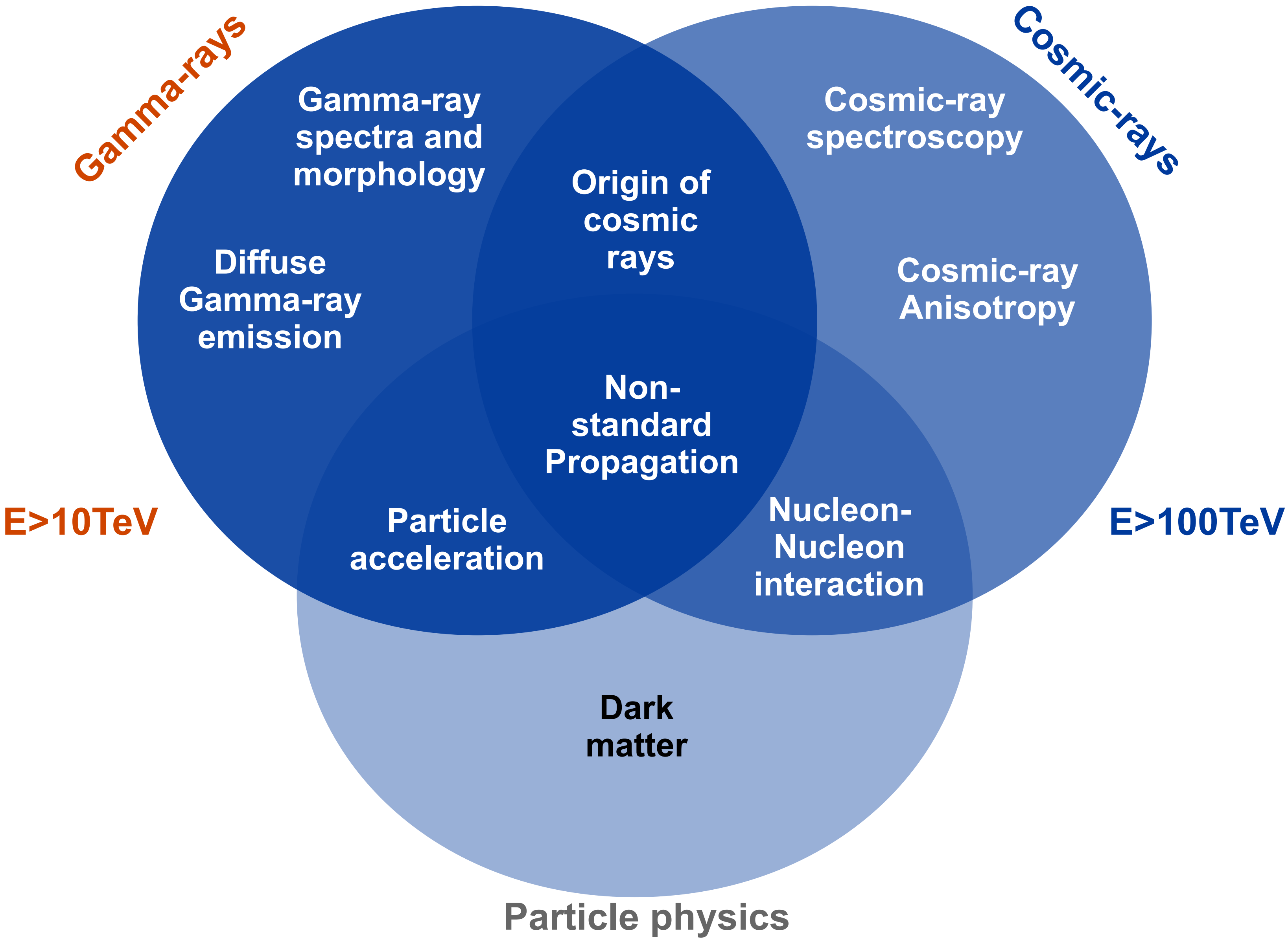
Large area: up to few 100 km²

Large Field of view: ~ 0.6 sr

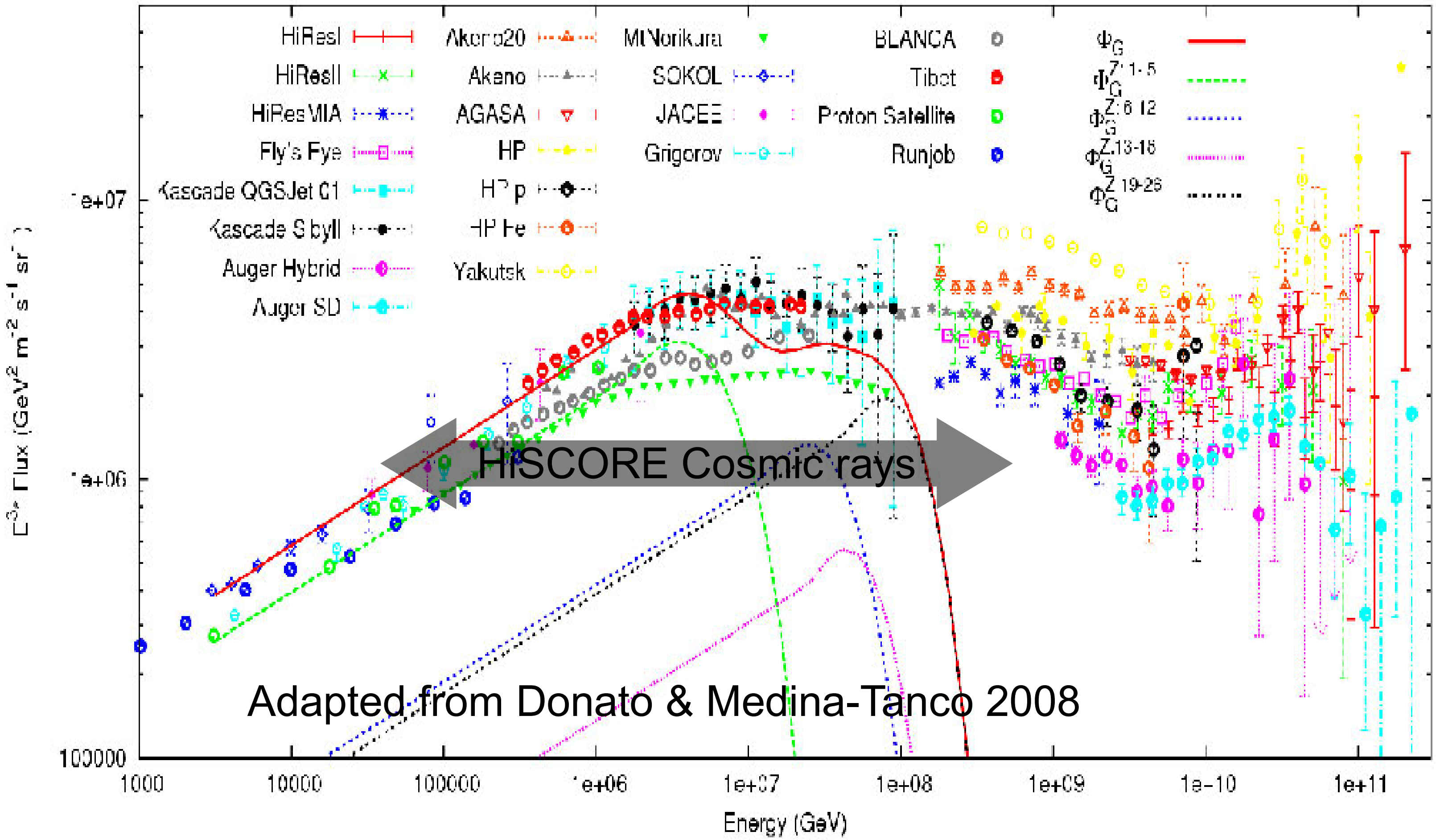
Sky-coverage: > π sr @ 200 h / year

2014: Astroparticle Physics, in press, 2014arXiv1403.5688T
2013NIMPA.712..137H, arXiv:1302.3957
2011AdSpR..48.1935T, astro-ph/1108.5880
http://wwwiexp.desy.de/groups/astroparticle/score/
http://tunka-hrjrg.desy.de/
http://de.wikipedia.org/wiki/HiSCORE

Physics motivations



Cosmic rays



Spectrum & composition
in transition range
Galactic / extragalactic origin

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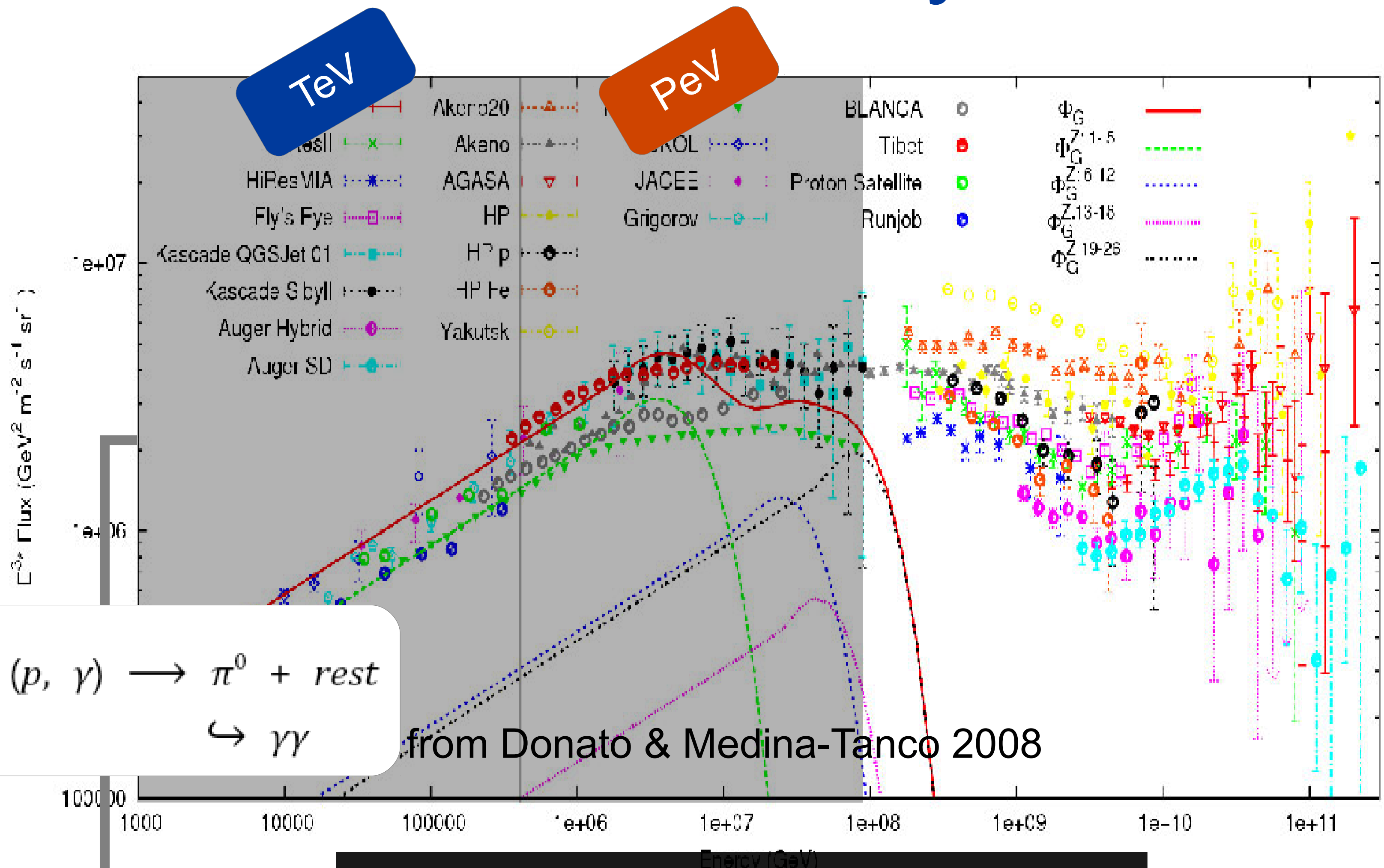
Cosmic rays

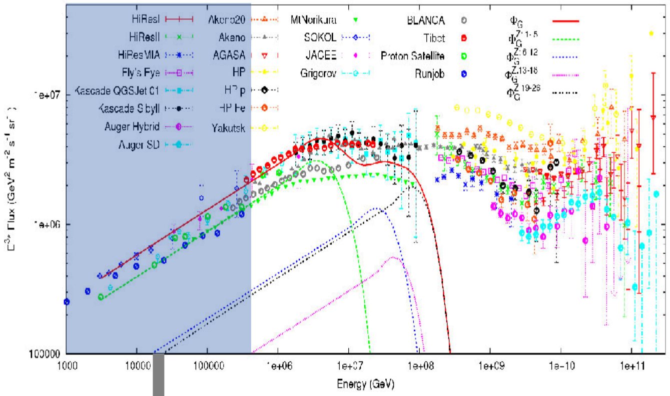


from Donato & Medina-Tanco 2008

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

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

Tevatron sky



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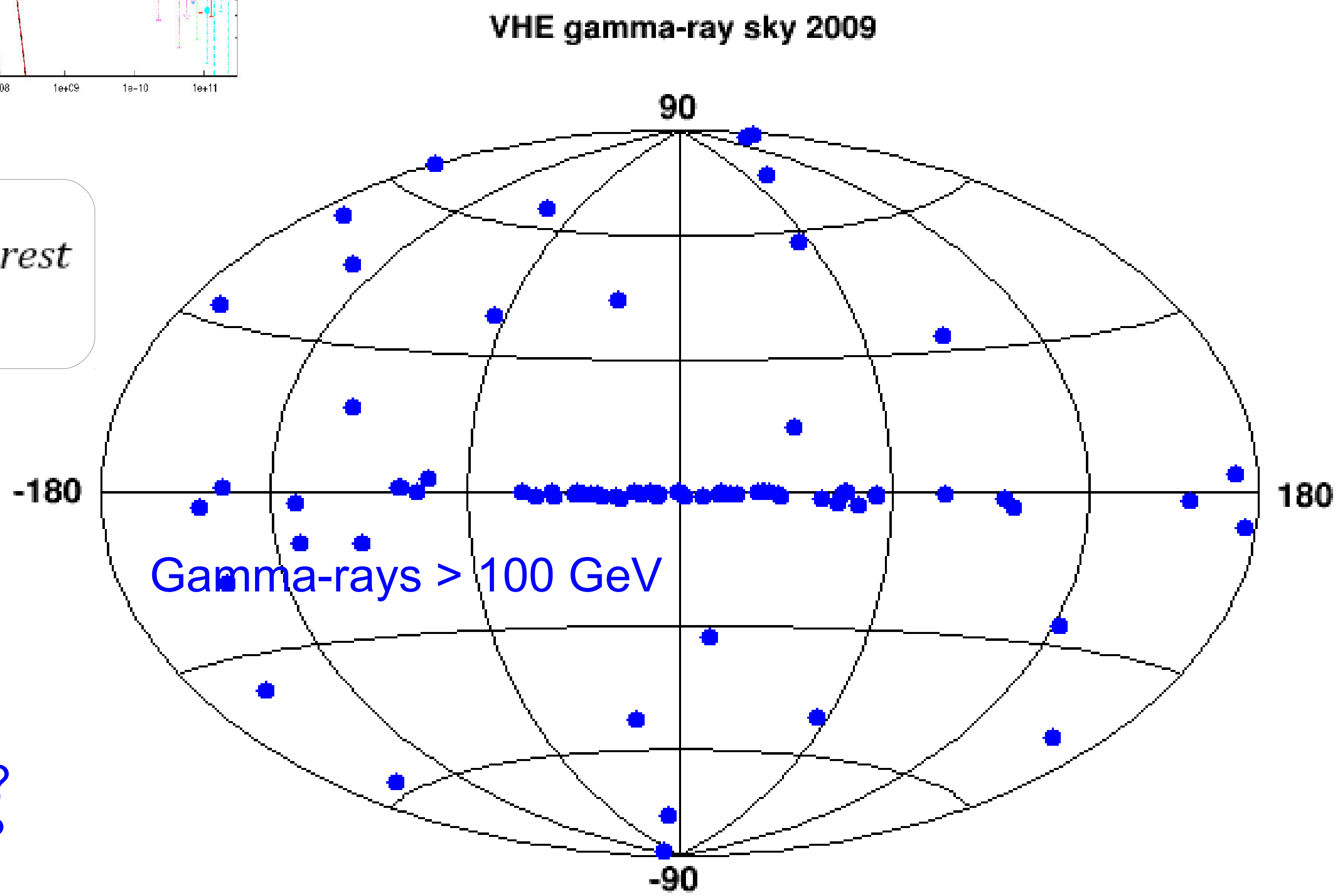

Gamma-rays > 100 GeV

Hadronic ?
Leptonic ?

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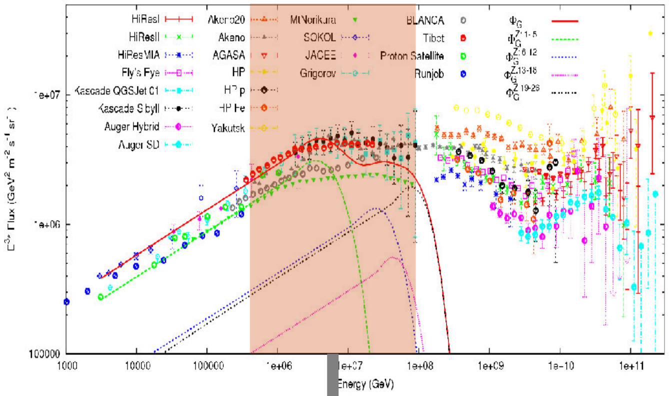
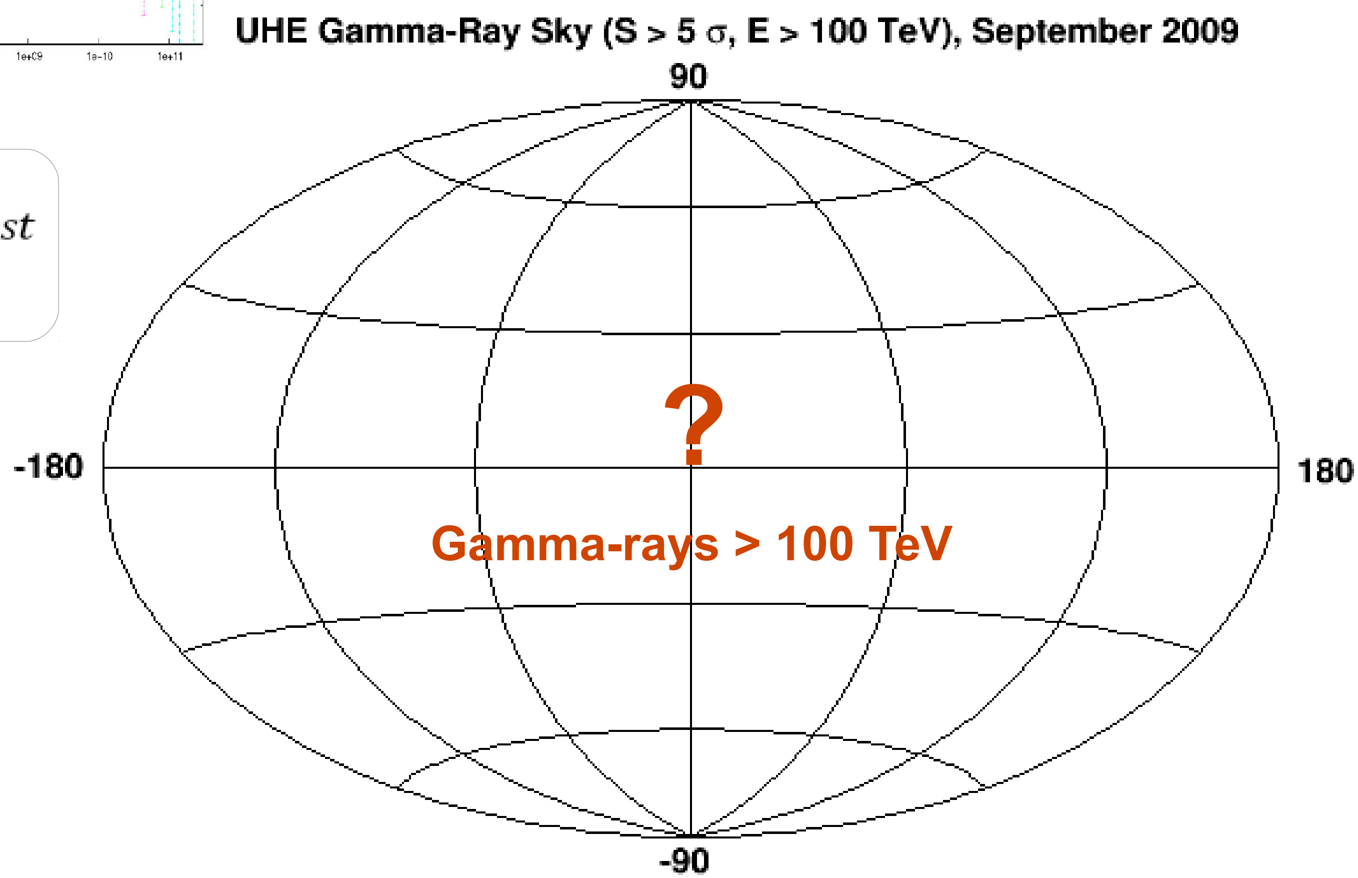
Pevatron sky



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



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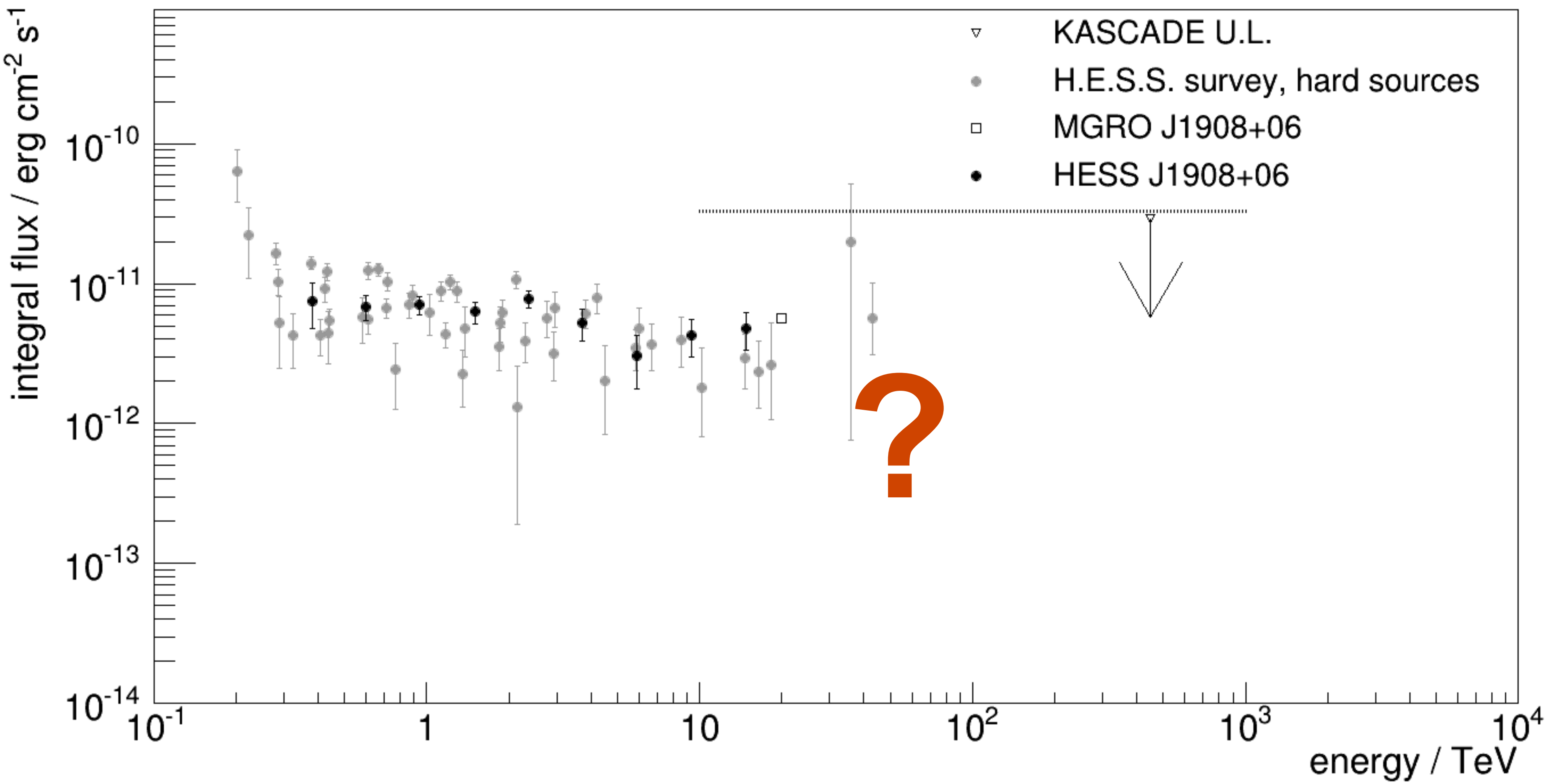
The Pevatron energy range



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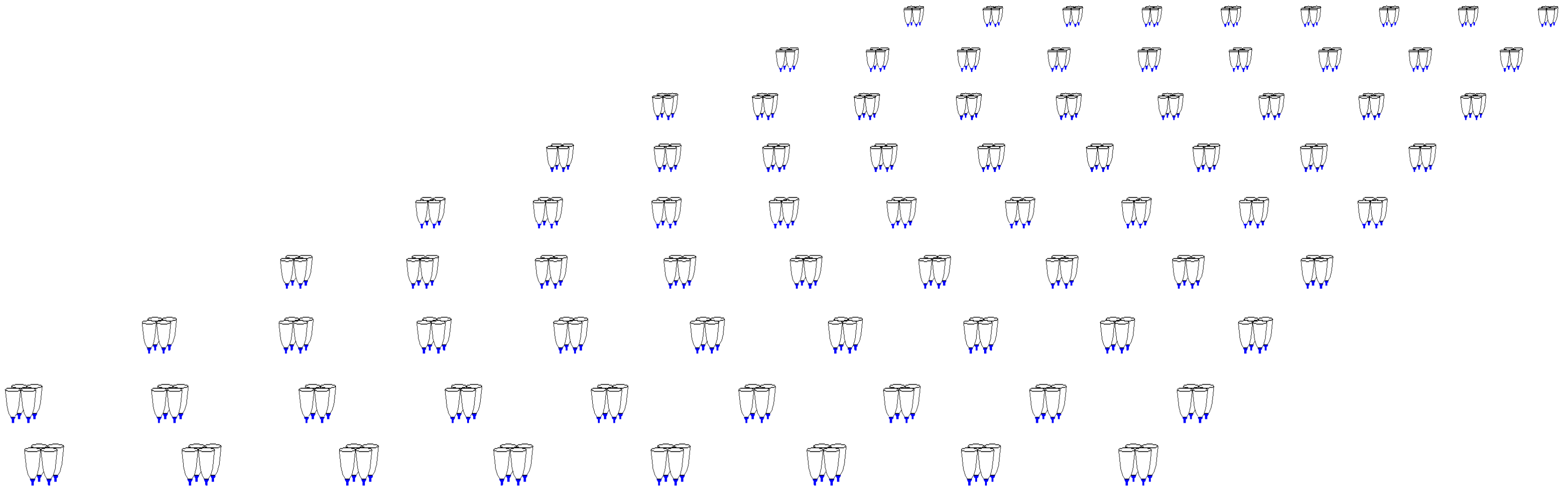
Accessing the pevatron sky → very large area

The HiSCORE concept

The HiSCORE concept

Picture: Serge Brunier

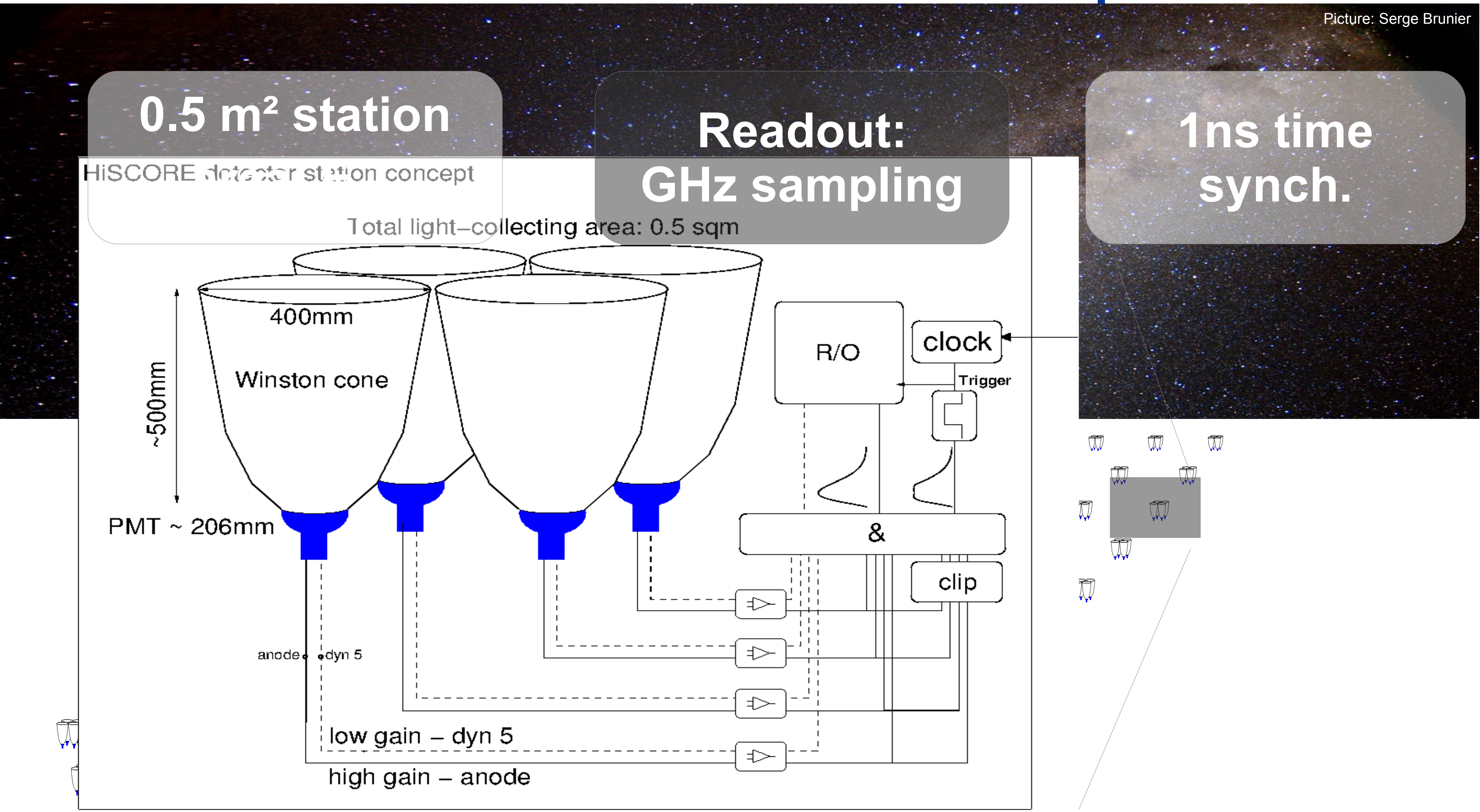
Efficient instrumentation of very large areas:

- **Imaging air Cherenkov telescopes:** O(1000) channels / km^2
- **Non-imaging air Cherenkov technique:** O(100) channels / km^2

The HiSCORE concept

0.5 m² station

Readout: GHz sampling

1ns time synch.



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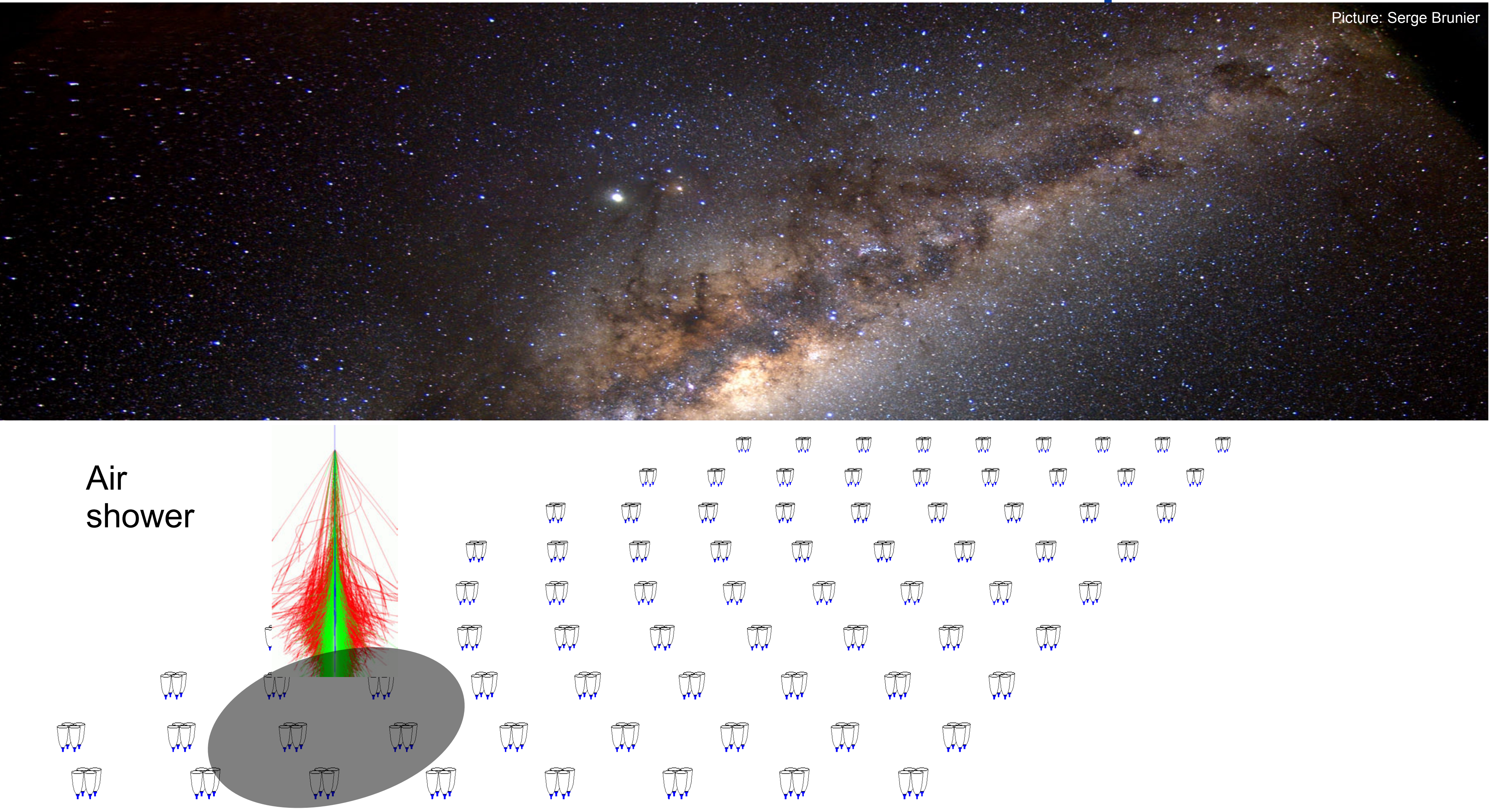
The HiSCORE concept



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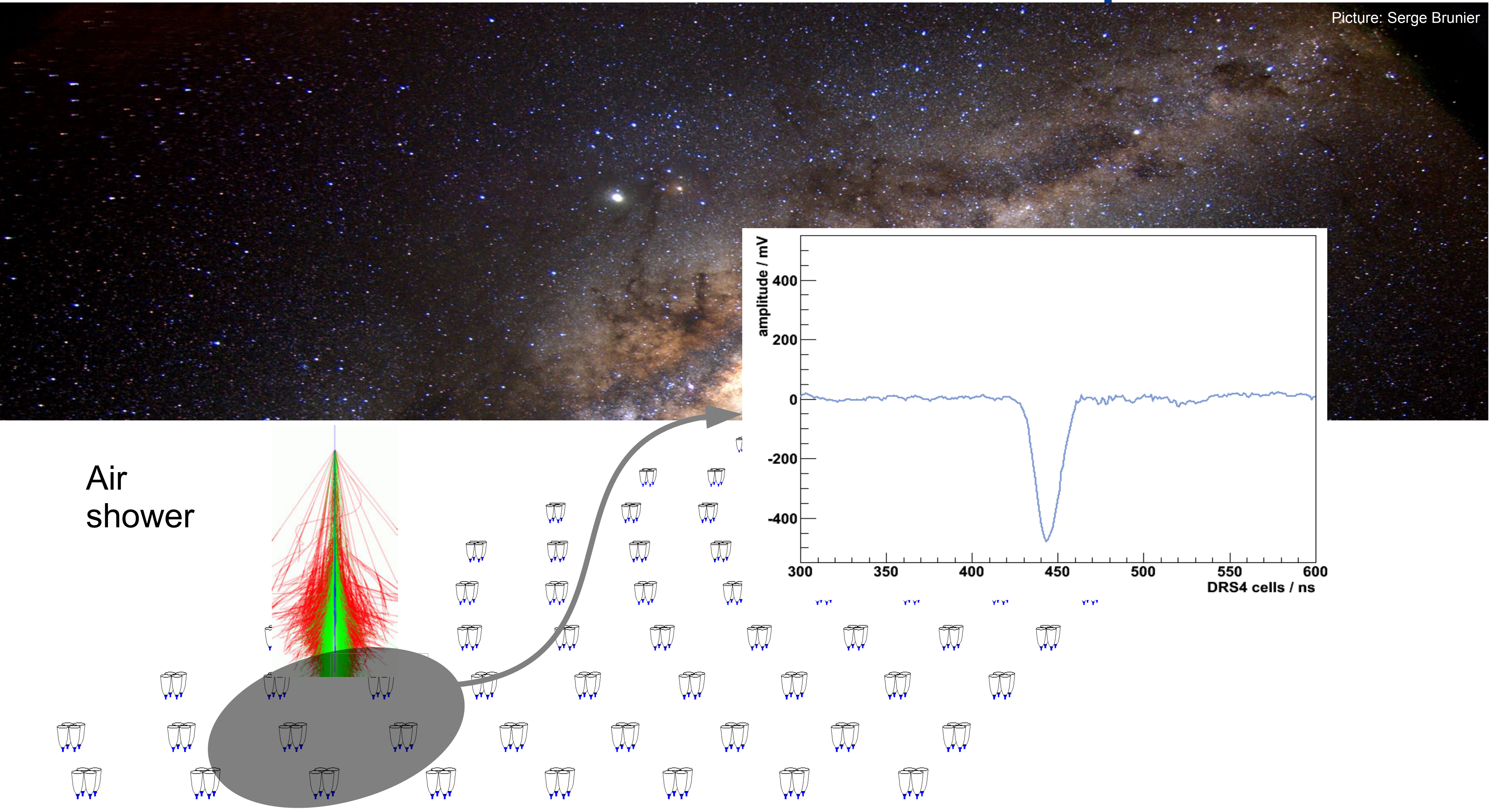
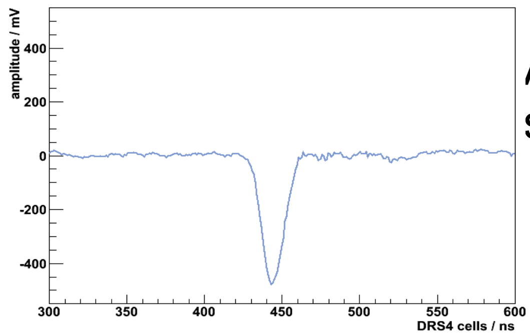
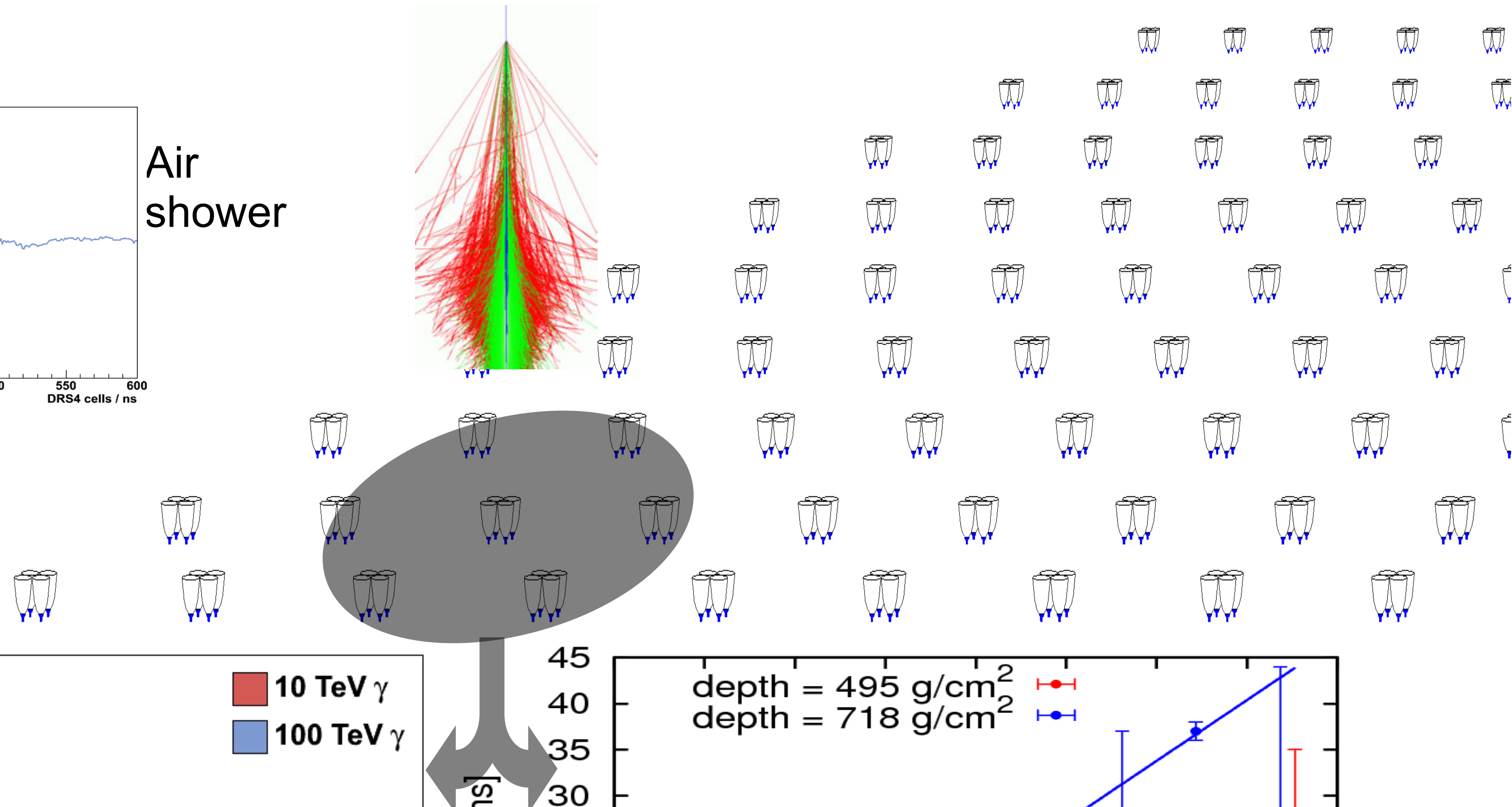
The HiSCORE concept

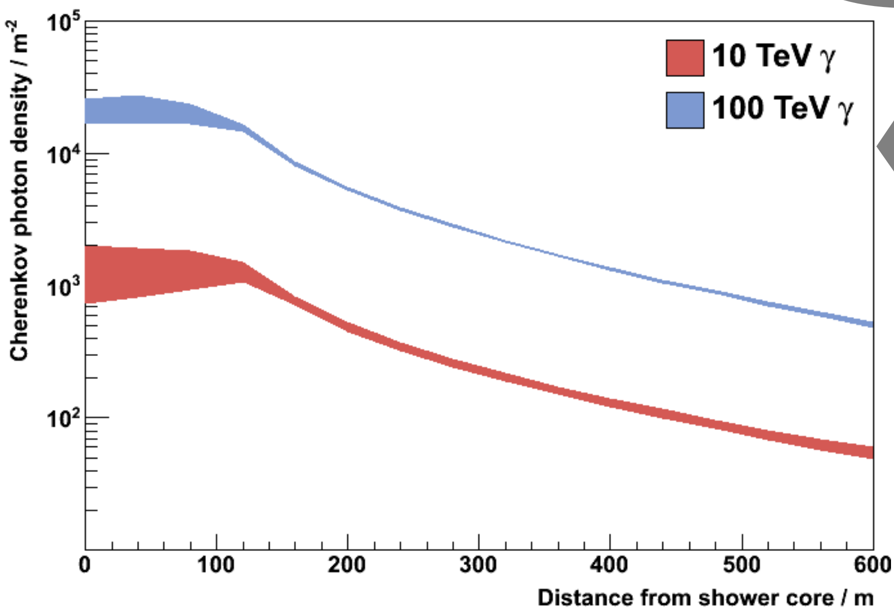


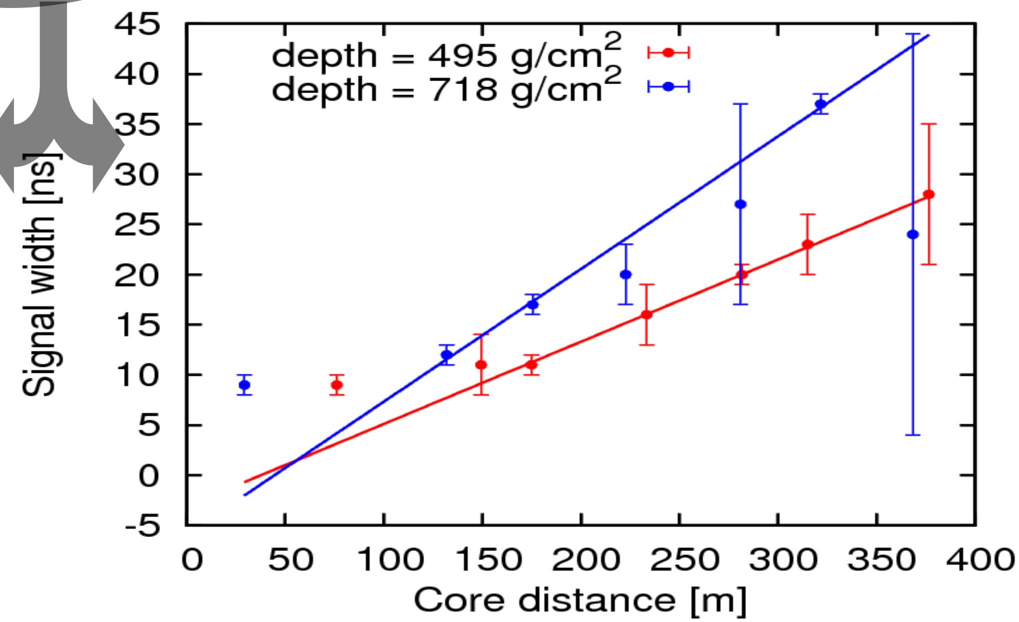
The HiSCORE concept



Air shower







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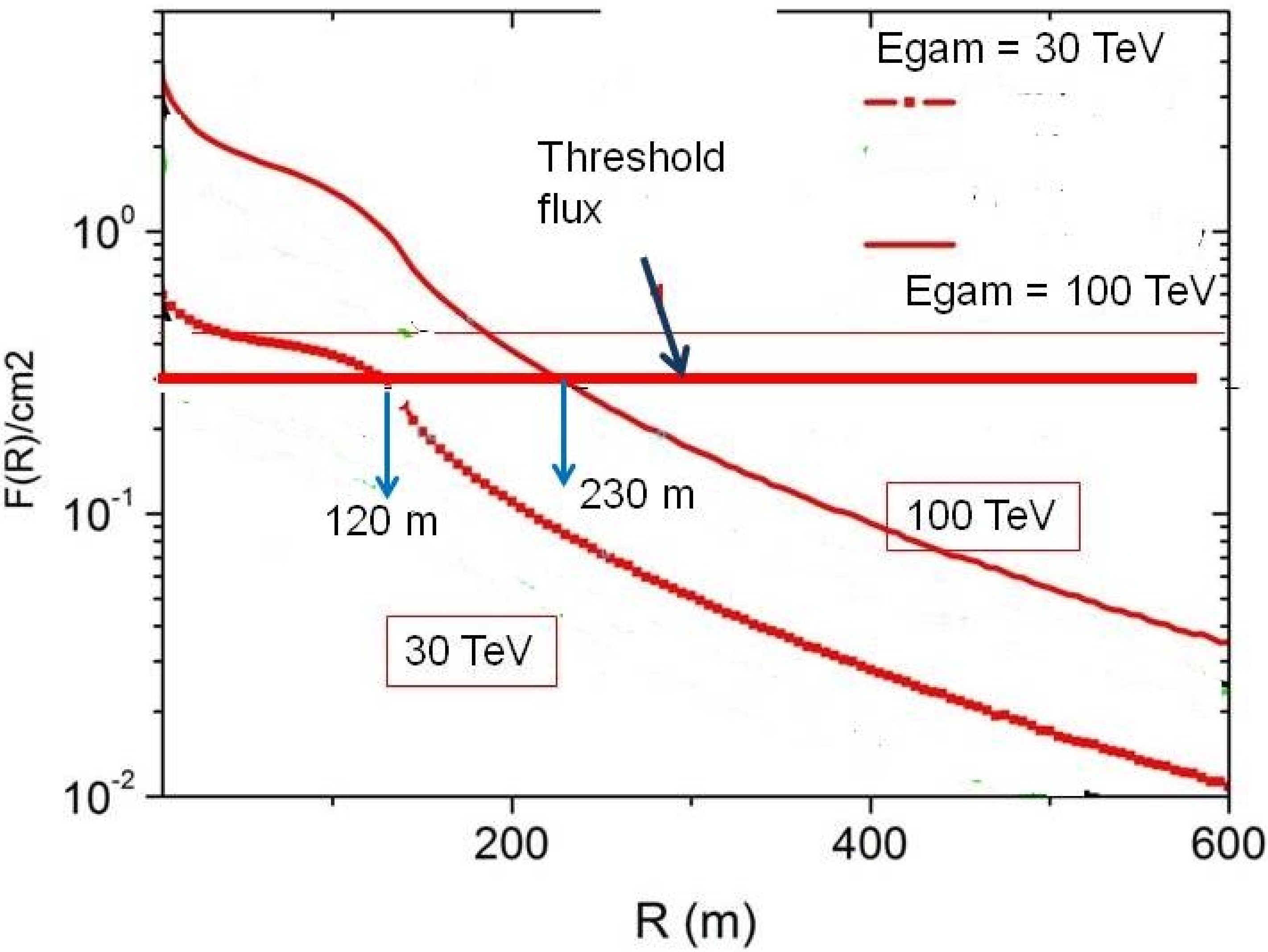
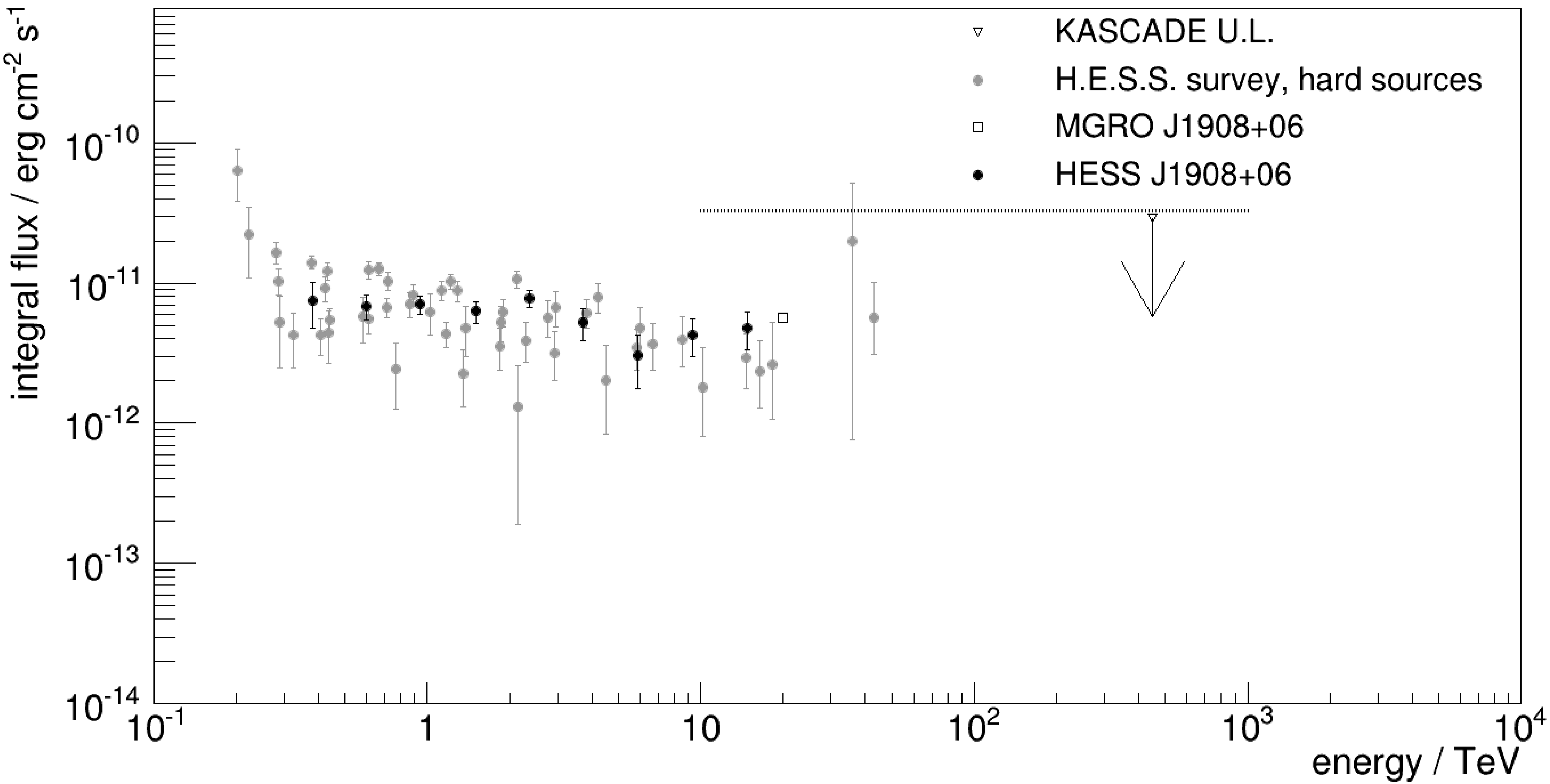
The HiSCORE concept



Physics potential of HiSCORE

(gamma-ray astronomy)

Opening up the Pevatron range



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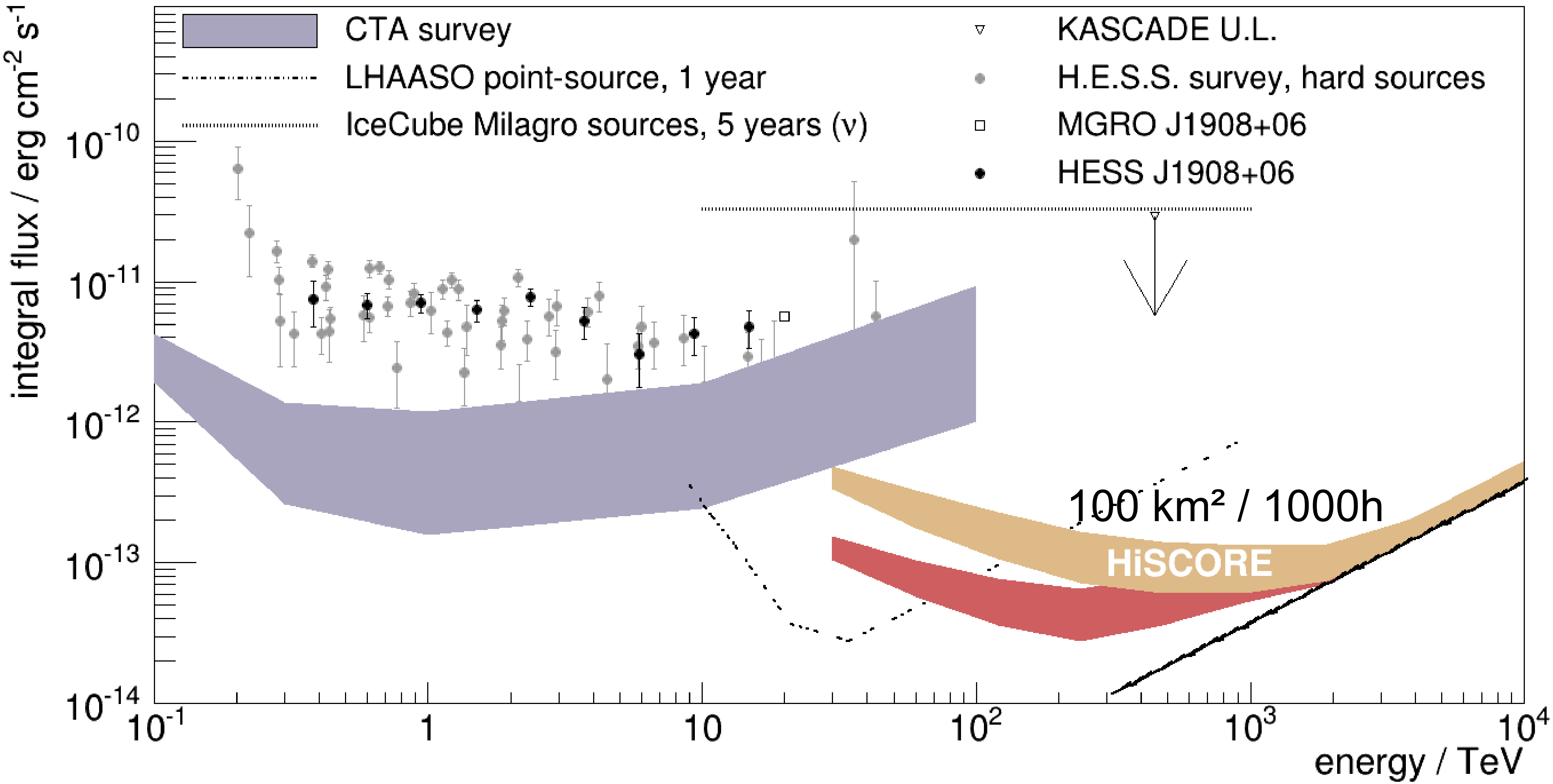
Opening up the Pevatron range



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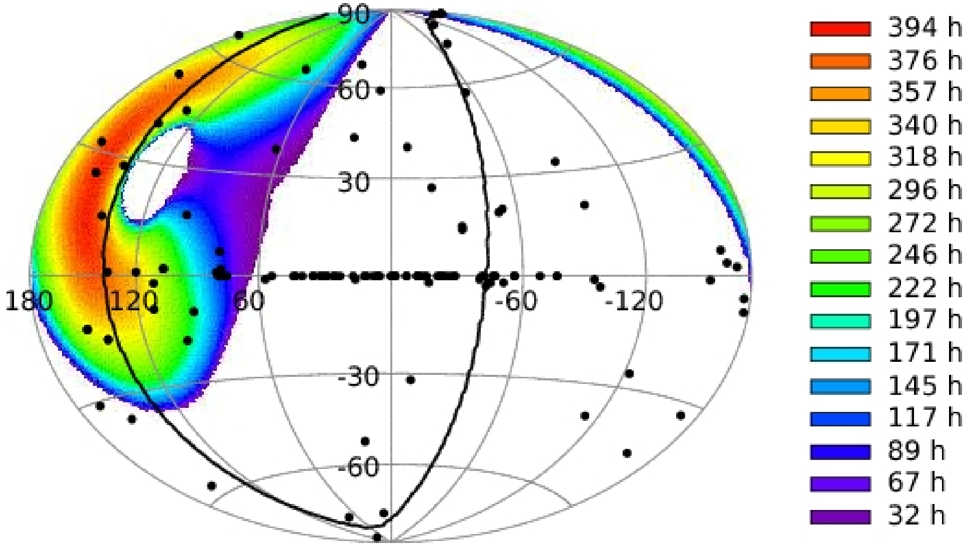
Tunka site exposure map



Tunka site exposure map

Field of view: π steradian

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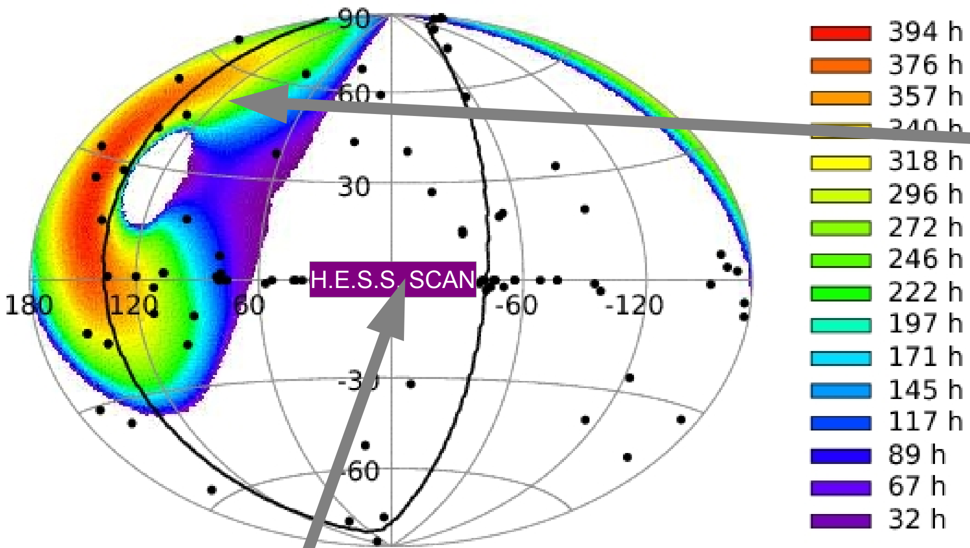
Tunka site exposure map



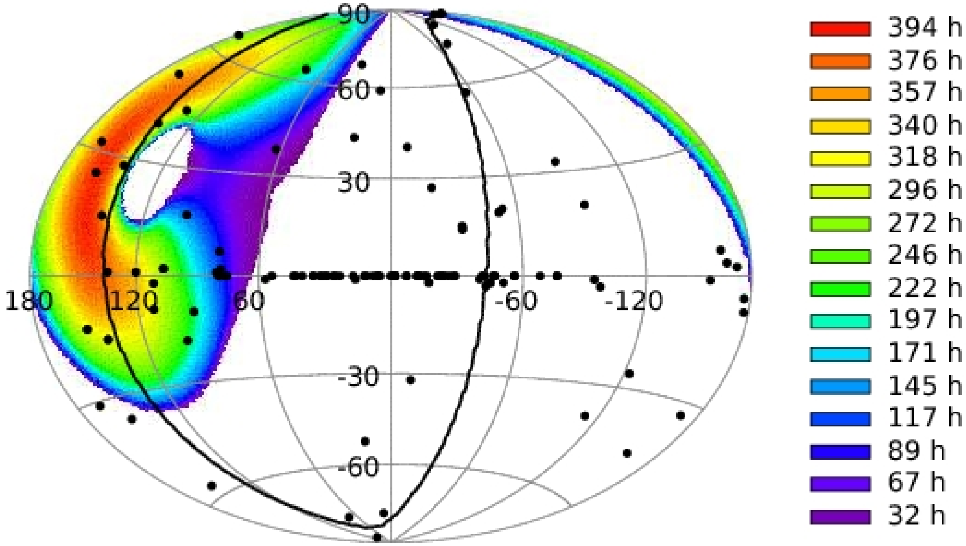
HiSCORE scan normal mode

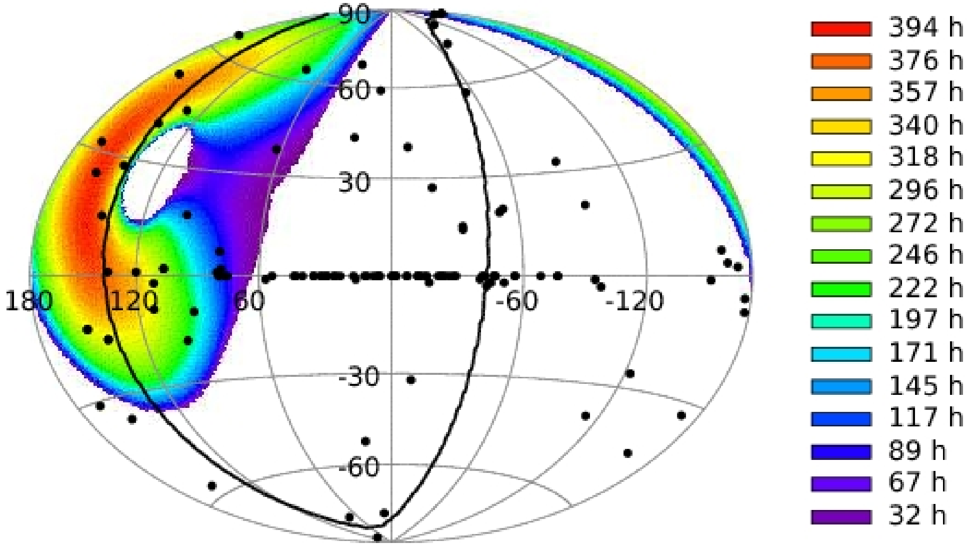
First H.E.S.S. Galactic plane scan

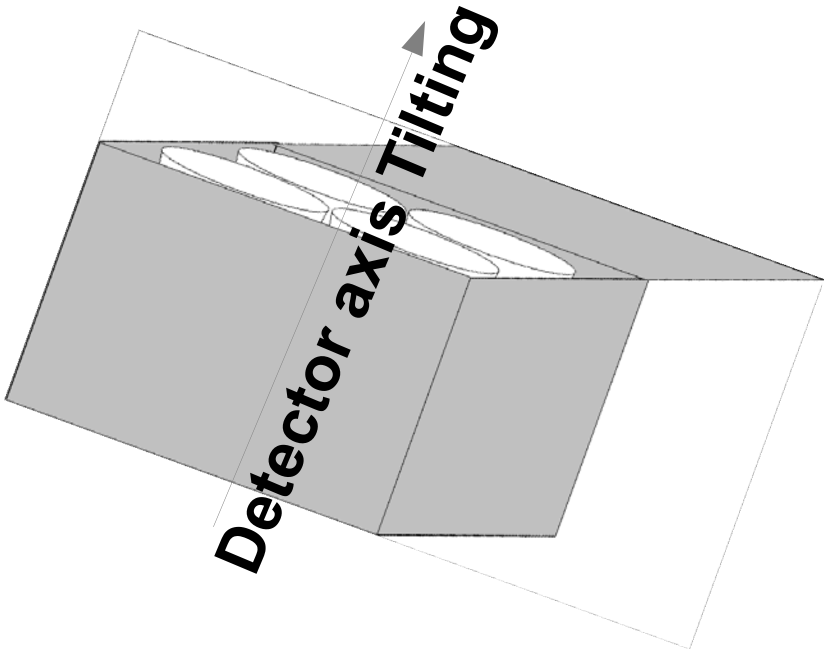
Tunka site exposure map

Field of view: π steradian

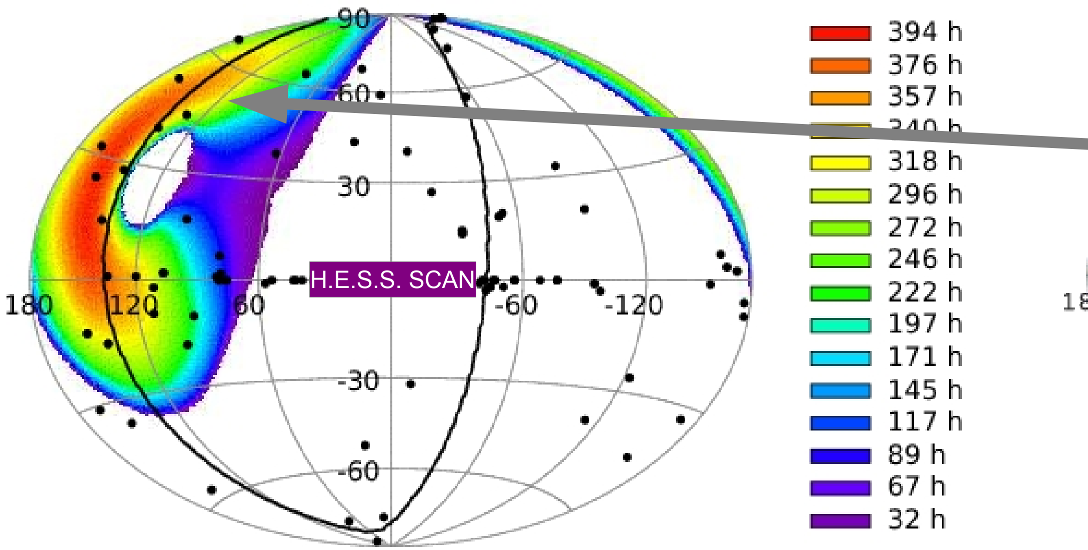
Tunka site exposure map

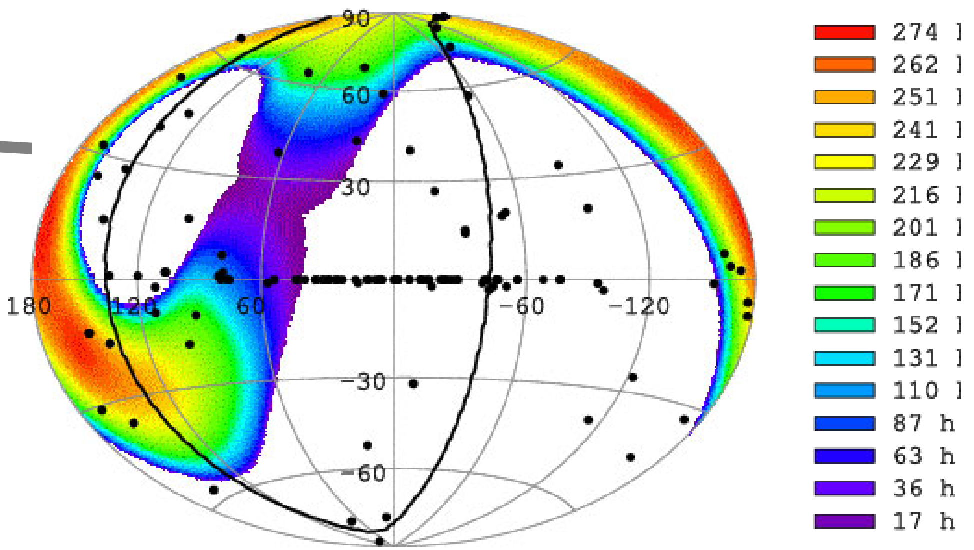


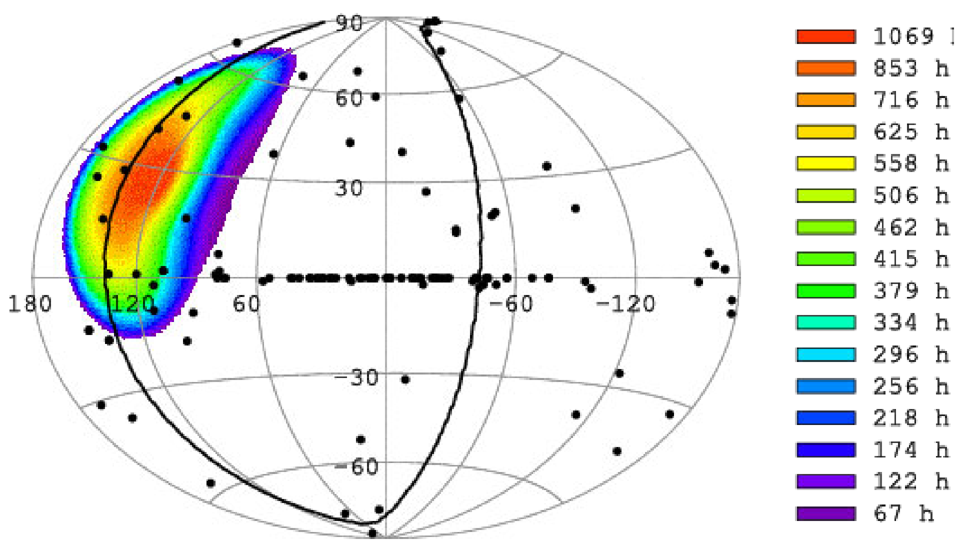


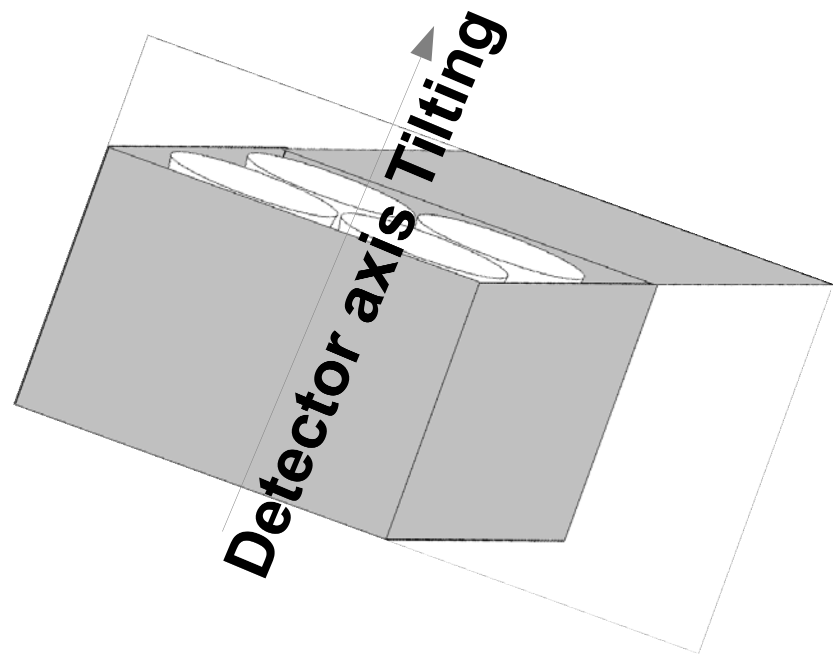


Tunka site exposure map









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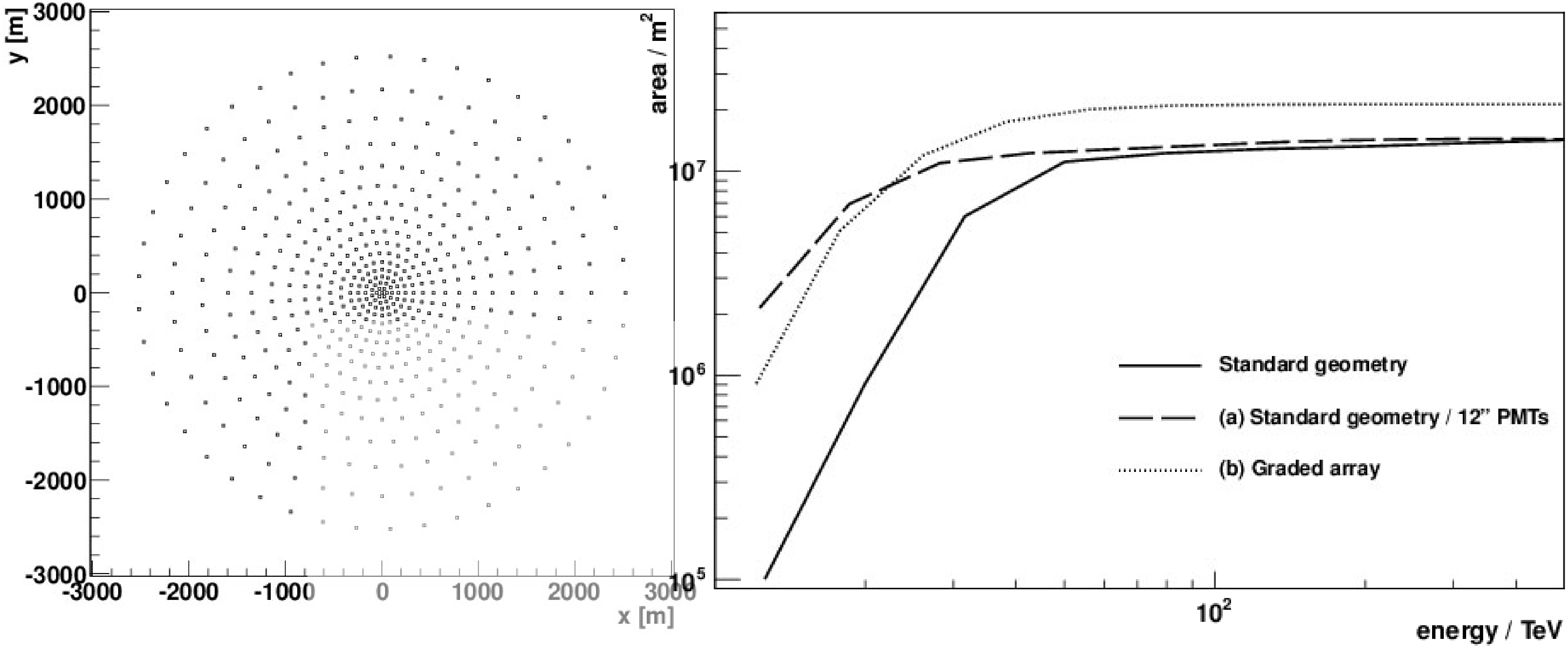
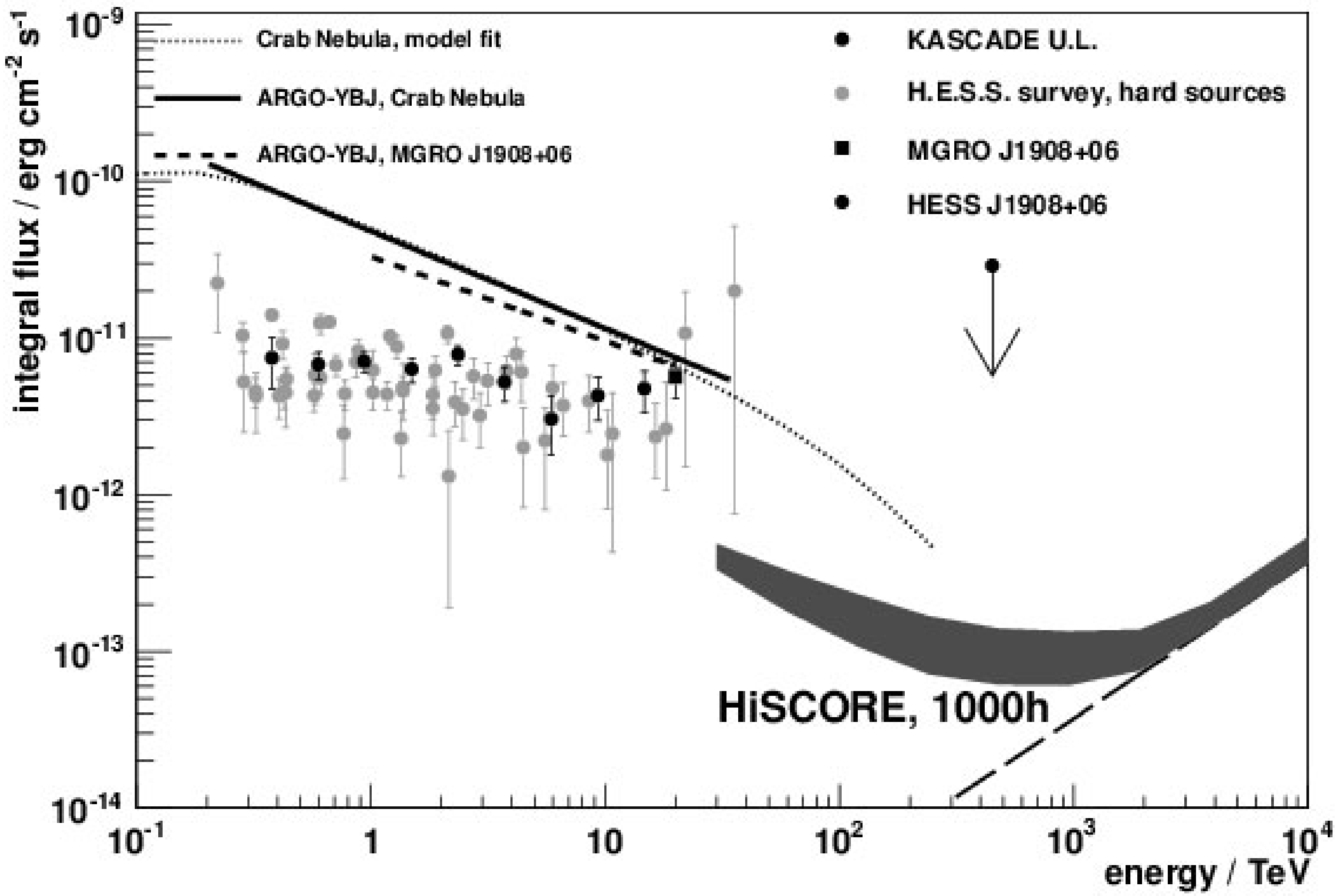
Array optimization

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

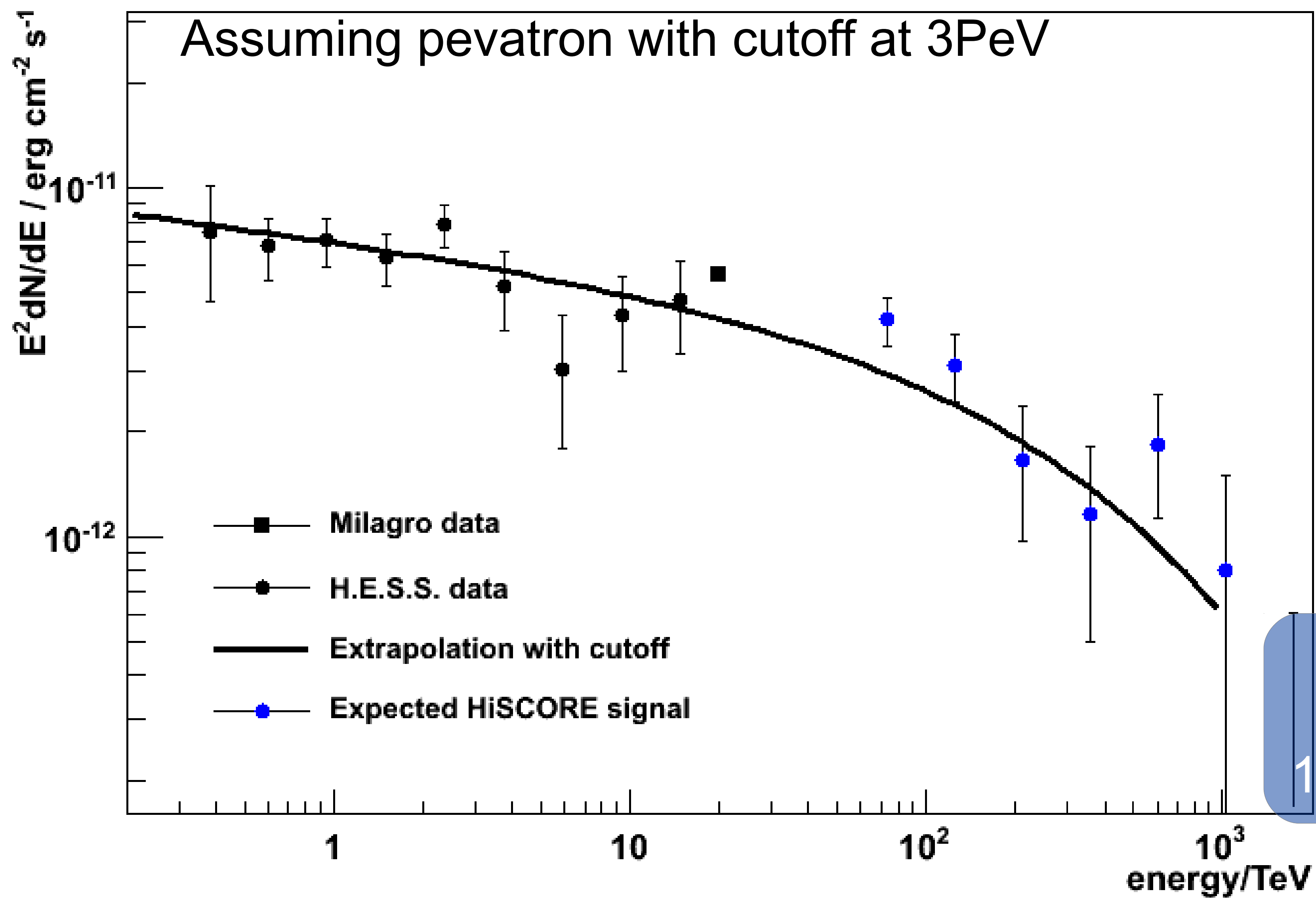


Physics Potential



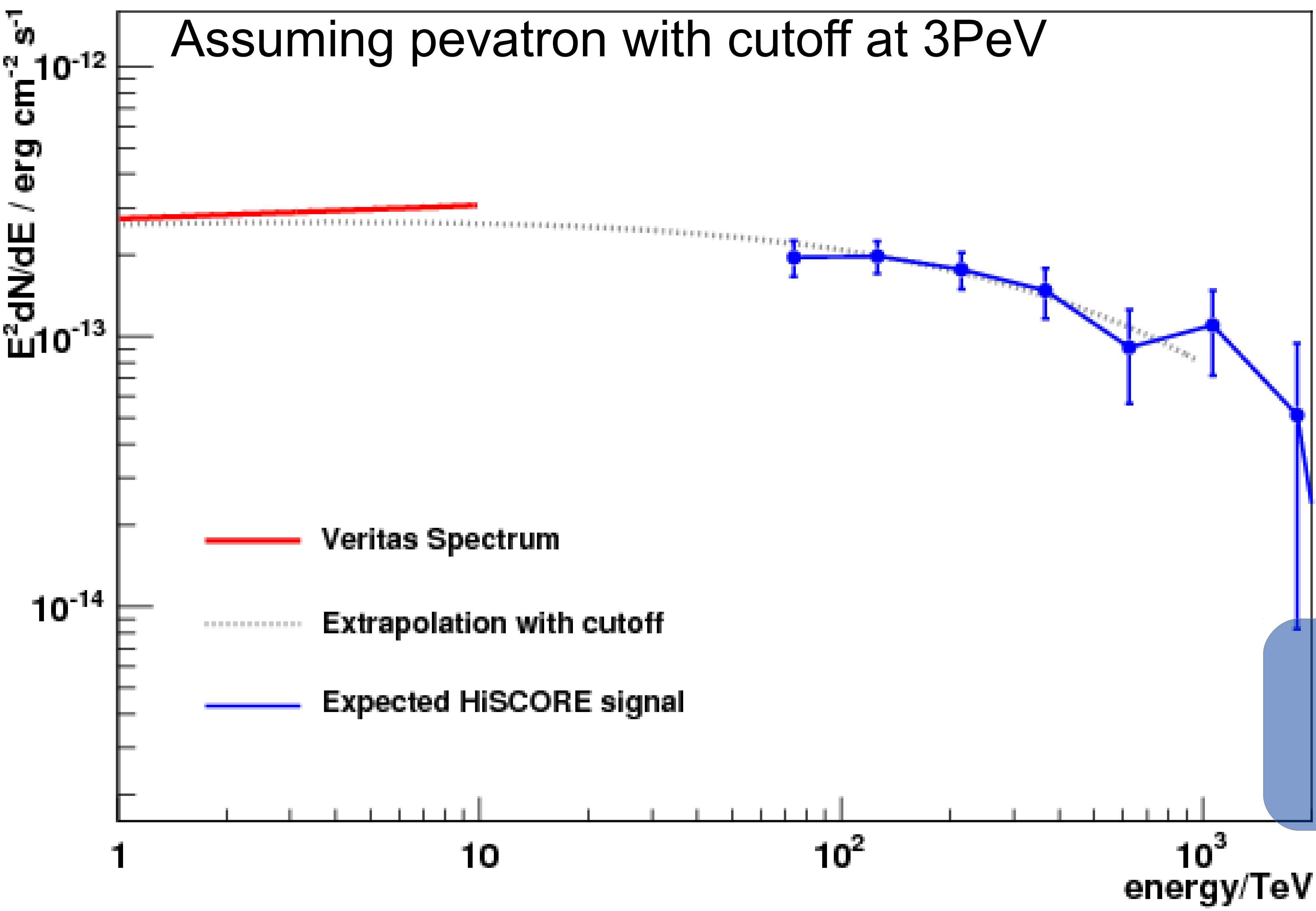
→ Tluczykont et al. (2014) 2014APh....56...42T

MGRO J1908+06



10 km²
No μ det.
1 year (200h)

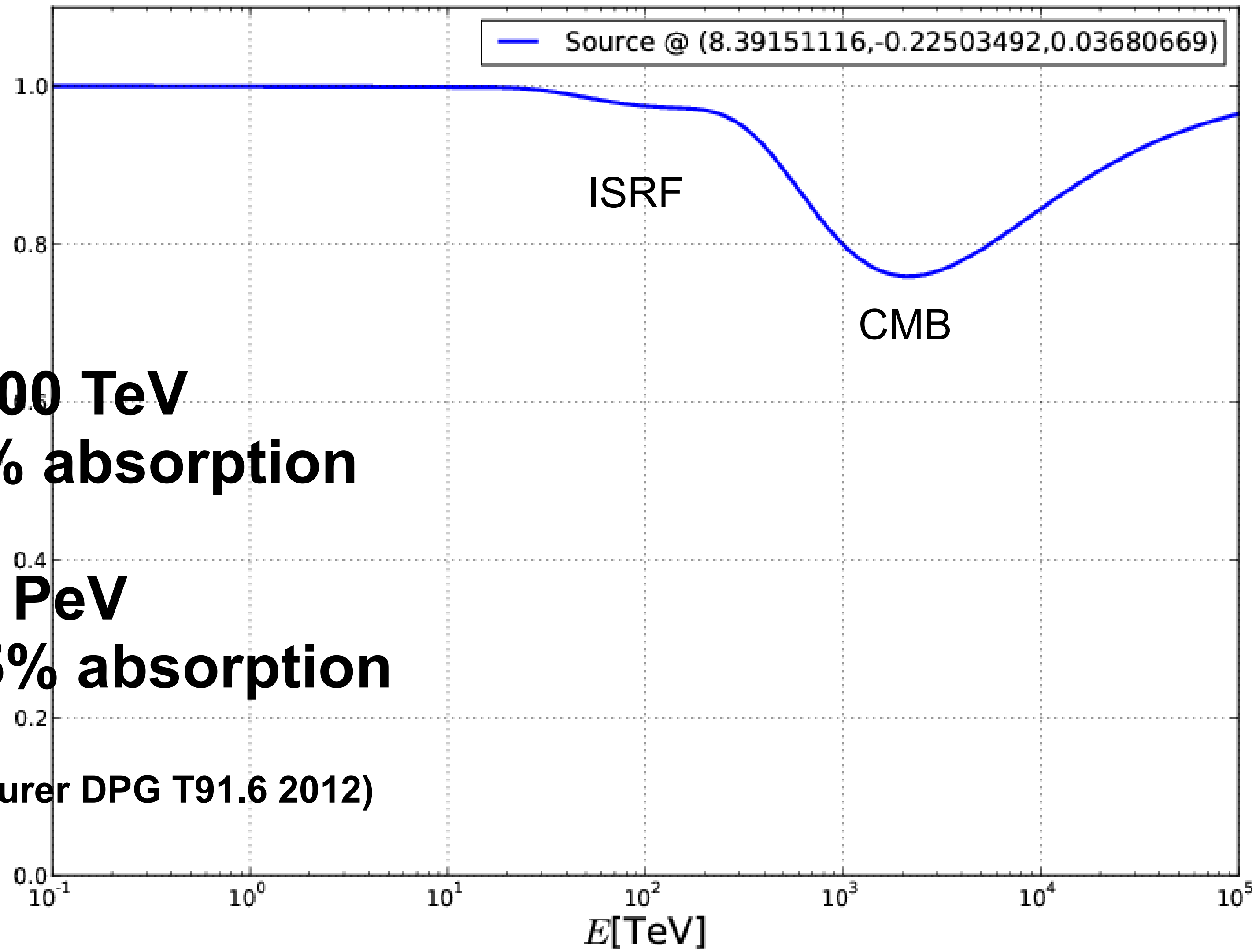
Tycho Supernova remnant



100 km²
No μ det.
3 years

e⁺e⁻ pair production

MGRO J2031



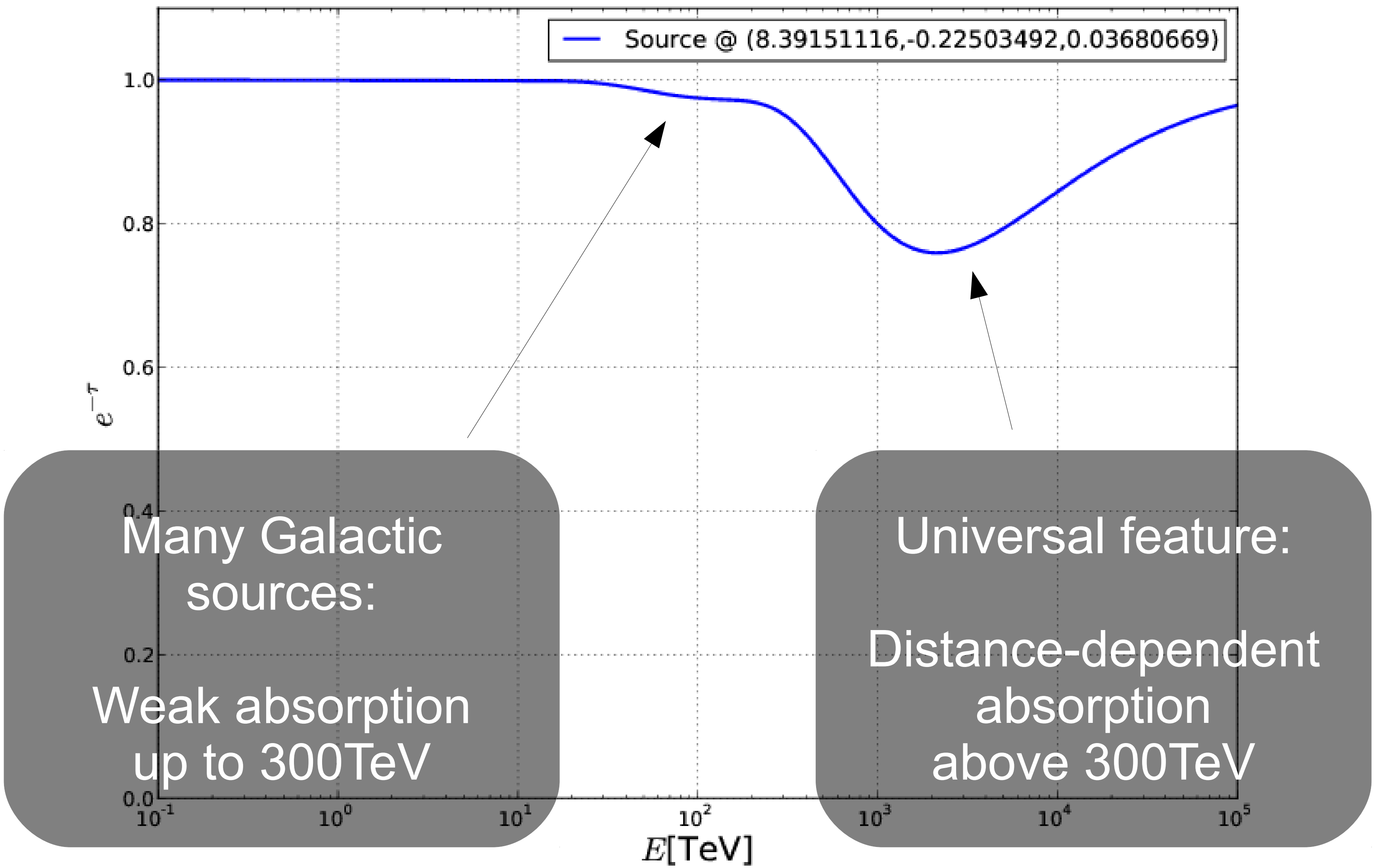
@ 100 TeV
< 3% absorption

@ 3 PeV
< 25% absorption

(A. Maurer DPG T91.6 2012)

e^+e^- pair production

MGRO J2031



The Tunka-HiSCORE project

First realization of the HiSCORE concept

- Helmholtz-Russia Joint Research Group HRJRG-303
- Russian “Mega-grant”

M. Brückner[3], N. Budnev[5], O. Chvalaev[5], A. Dyachok[5], S. Epimakhov[1], O. Gress[5], D. Hampf[1], D. Horns[1], A. Ivanova[5], S. Kiruhin[5], E. Konstantinov[5], E. Korosteleva[4], M. Kunnas[1], L. Kuzmichev[4], B. Lubsandorzhiev[6], N.B. Lubsandorzhiev[4], R. Mirgazov[5], R. Monkhoev[5], R. Nachtigall[1], A. Pakhorukov[5], V. Poleschuk[5], A. Porelli[2], V. Prosin[4], G.I. Rubtsov[6], M. Rüger[2], 3 P.S. Satunin[6], Yu. Semeney[5], D. Spitschan[1], L. Sveshnikova[4], M. Tluczykont[1], R. Wischnewski[2], A. Zagorodnikov[5]

February 17, 2014

1 : Institute for Experimental physics, University of Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany

2 : DESY, Platanenallee 6, 15738 Zeuthen, Germany

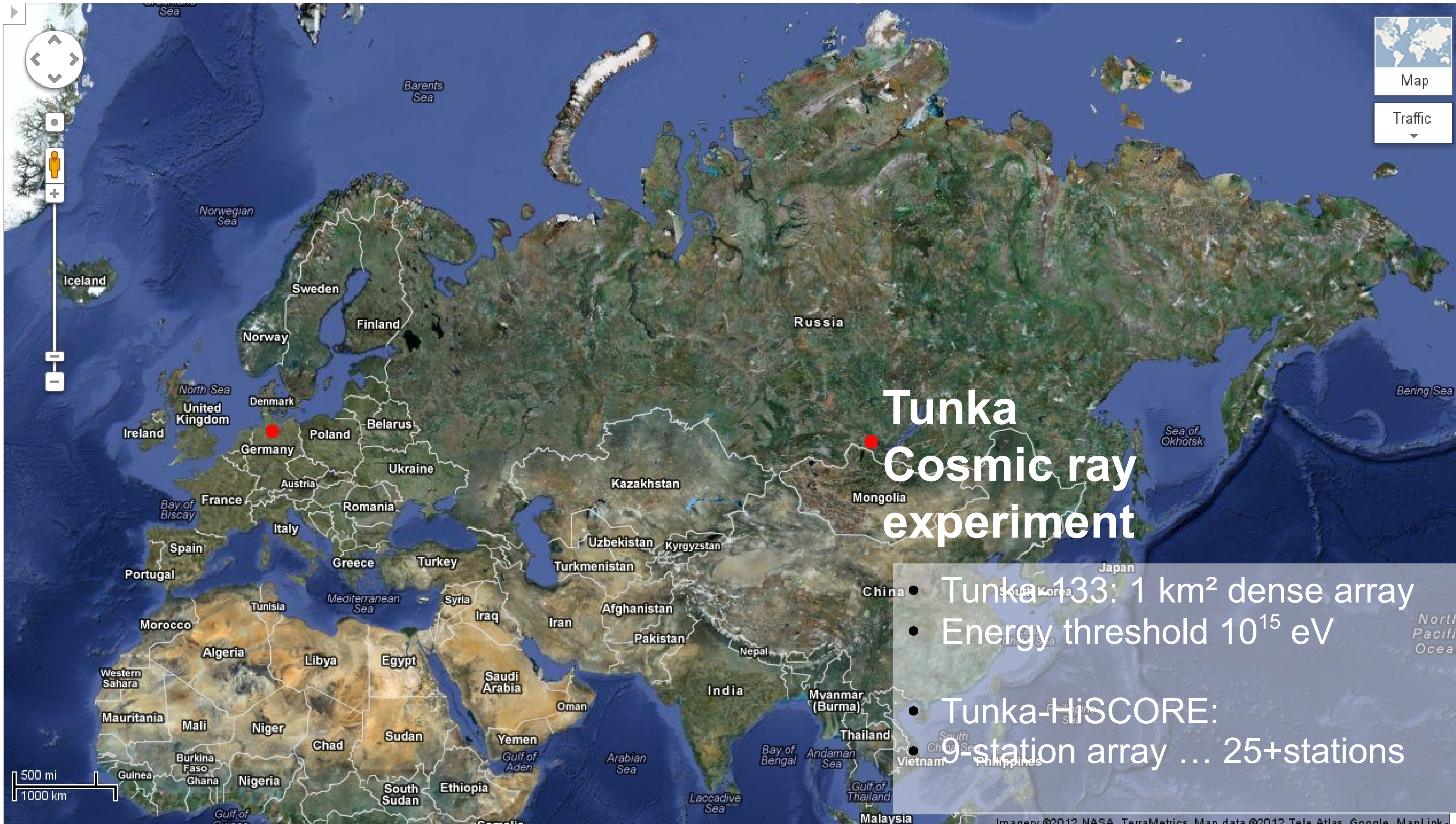
3 : Institute for Computer Science, Humboldt-University Berlin, Rudower Chaussee 25, 12489 Berlin, Germany

4 : Skobeltsyn institute for Nuclear Physics, Lomonosov Moscow State University, 1 Leninskie gory, 119991 Moscow, Russia

5 : Institute of Applied Physics ISU, Irkutsk, Russia

6 : Institute for Nuclear Research of the Russian Academy of Sciences 60th October Anniversary st., 7a, 117312, Moscow, Russia

Tunka-HiSCORE



- Tunka-133: 1 km² dense array
- Energy threshold 10^{15} eV

- Tunka-HiSCORE:
- 9-station array … 25+stations

Status

- 1st light prototype 2012
- 3-station array 2012/13
- 9-station array since October 2013

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Status

Prototype-array:

- 9 stations, 300m X 300m
- 150m inter-station distance
- 4 channels (PMT+Cone)
- 2 parallel DAQ systems
- Gamma-ray energy threshold: <100TeV

Future improvements:

- Graded array and clipping
- + 25 stations
- + IACTs

Status

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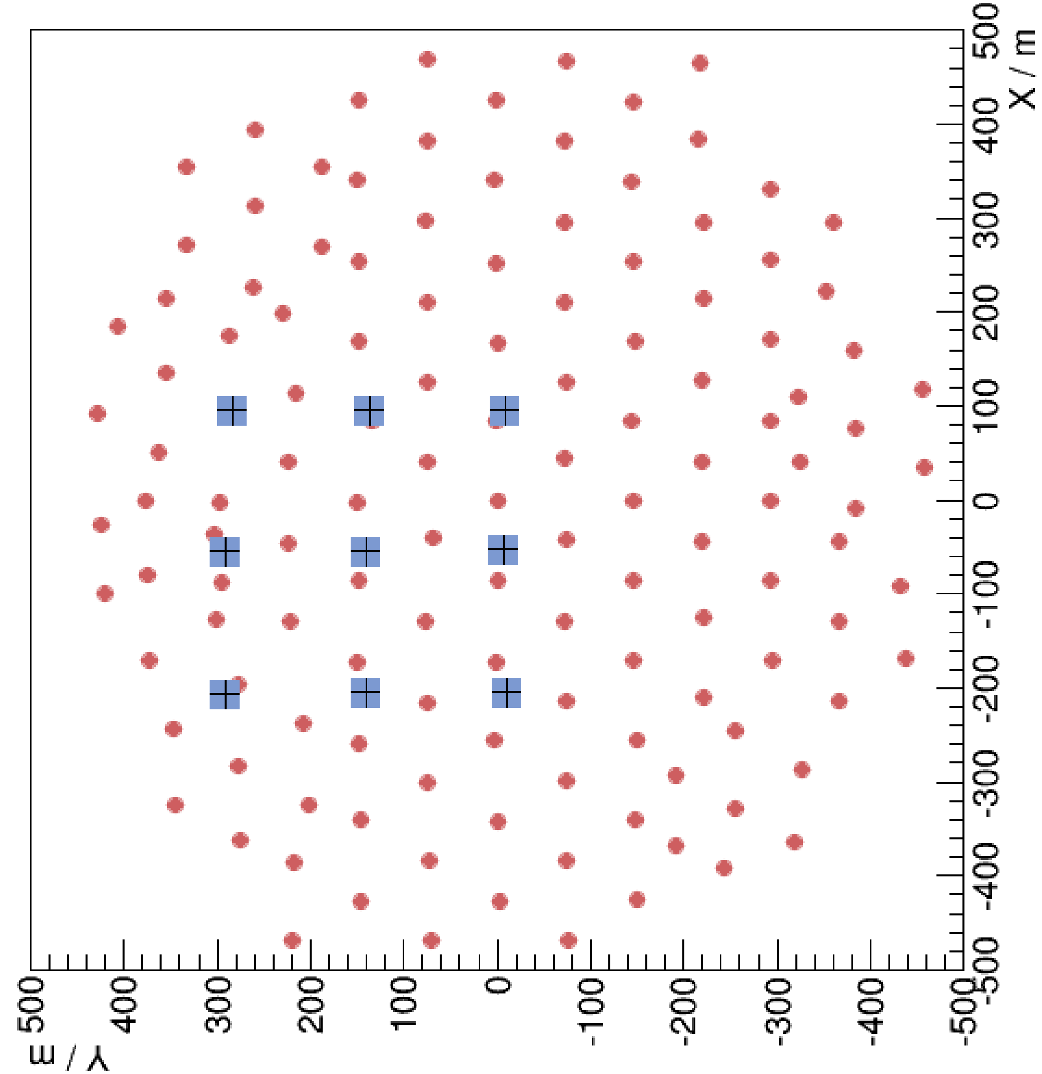
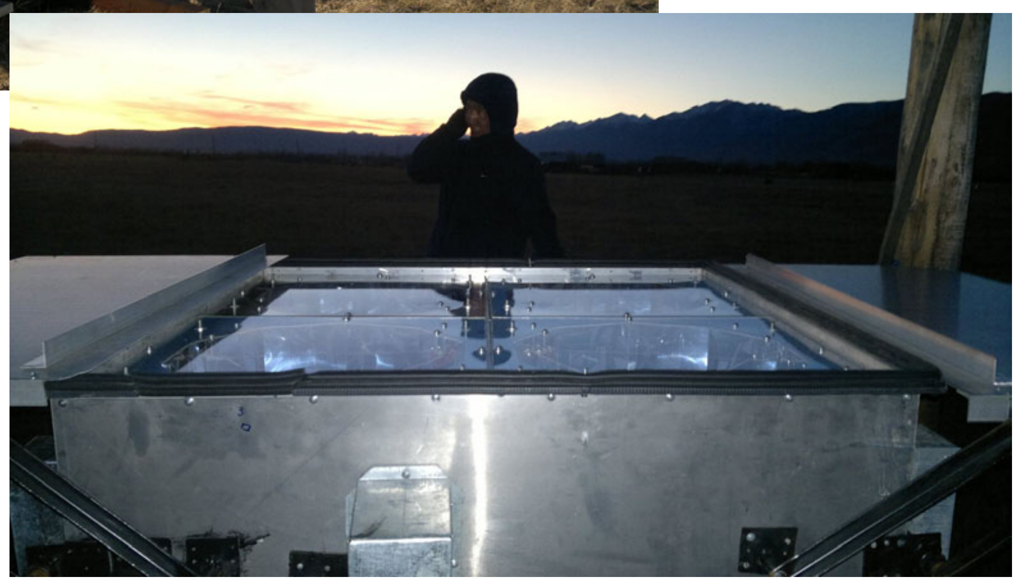


Detector components

Optical station

Electronic box



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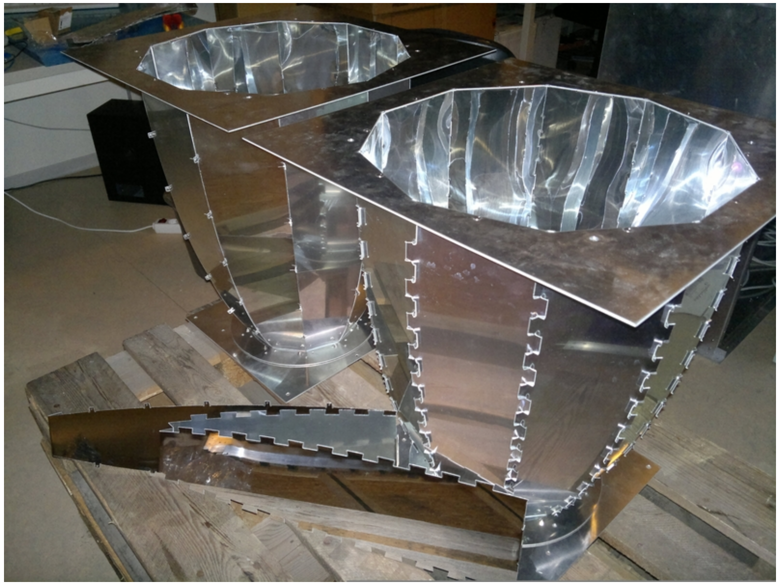
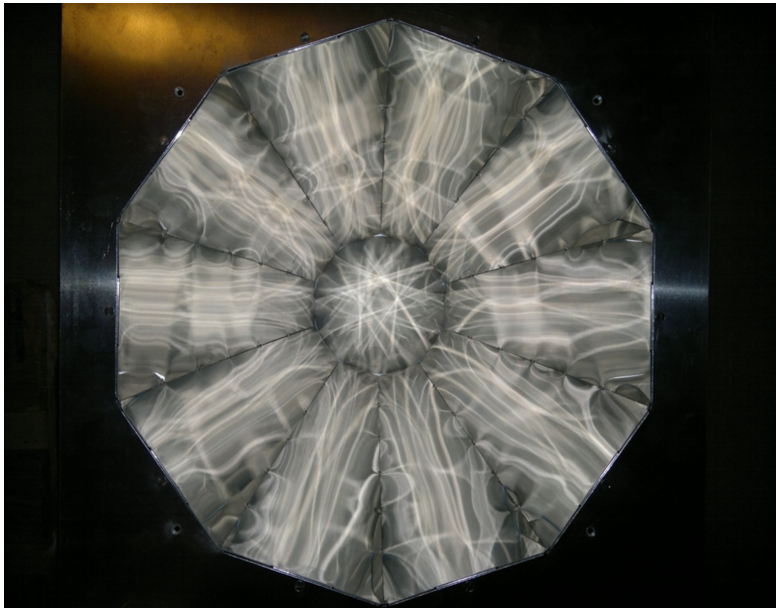
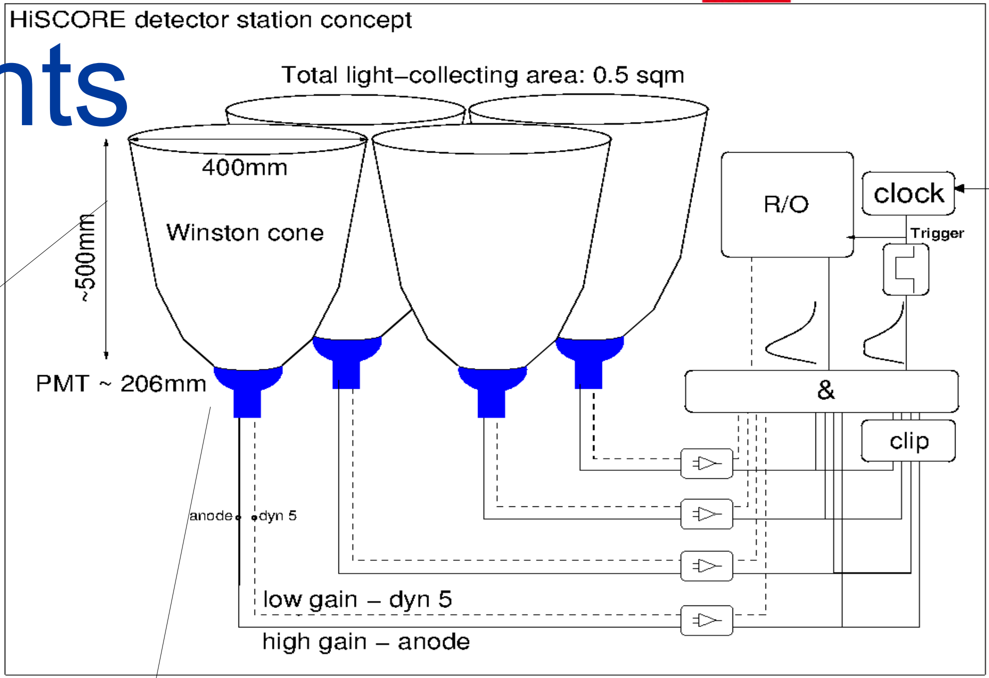
Detector components





Alanod 4300UP reflective sheets



8" PMTs (Hamamatsu & ElectronTubes)

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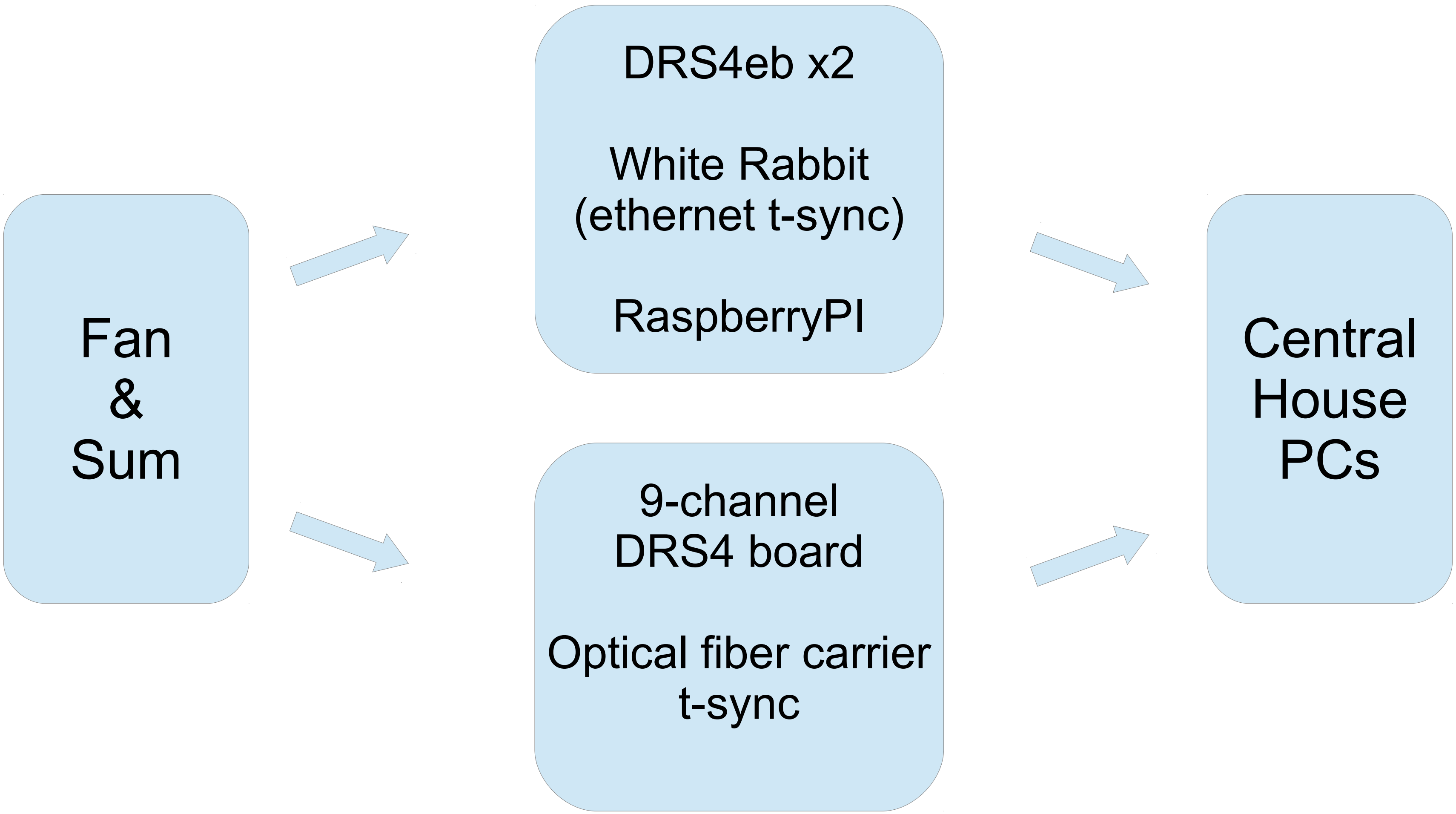
9-station array DAQ



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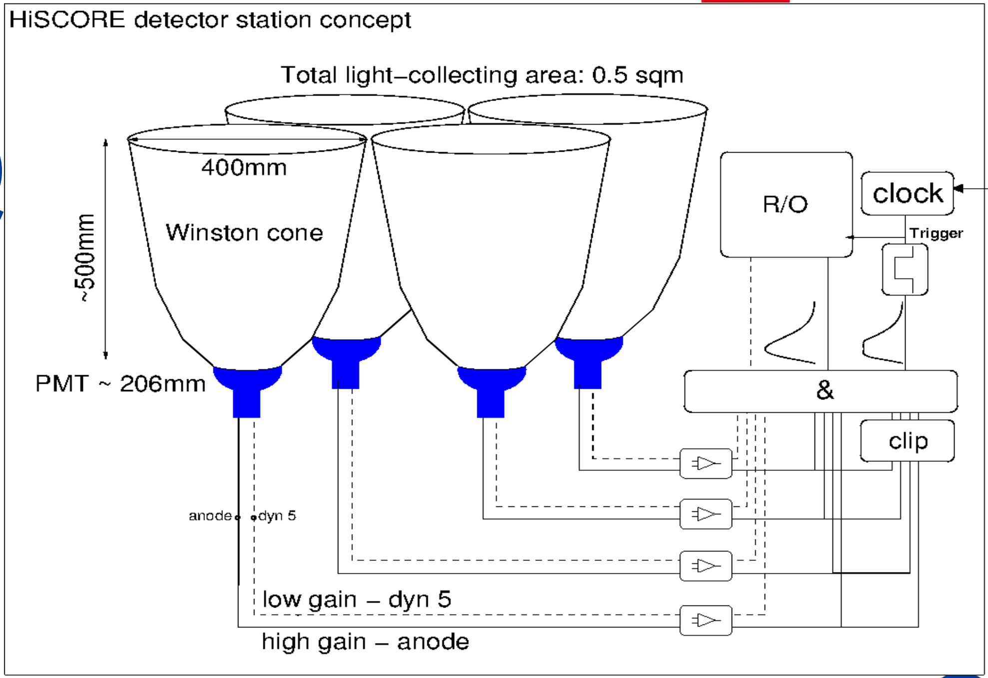
9-station array DAQ



- Slow control system (High voltage, lid control, monitoring)

- **Analog sum trigger: $\Sigma_{i=1..4}\, a_i > A_{thr}$**
- **Plan: clipped sum trigger (reduction of noise)**

Low threshold trigger

- **2 independent DRS4-based DAQ systems**

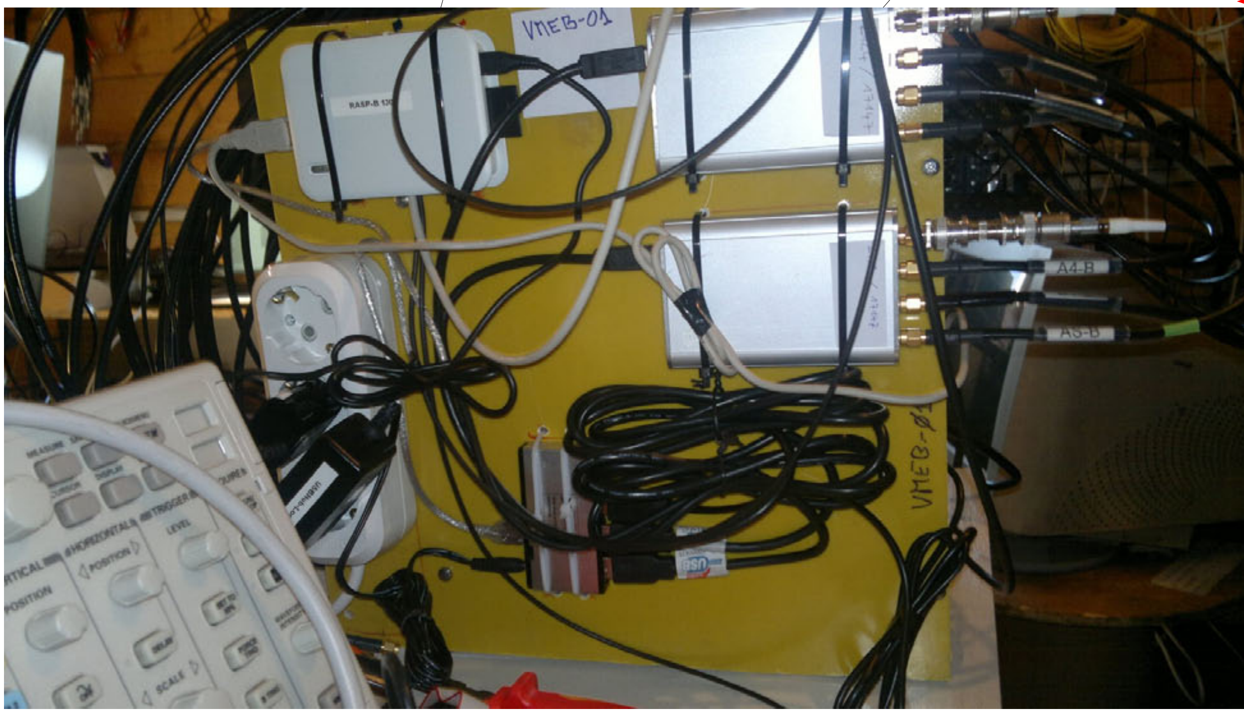
➔ DRS4 custom board + t-sync system

➔ DRS4 evaluation board + WhiteRabbit sub-ns time- synchronization

GHz sampling and sub-ns precision !

RaspberryPI

DRS4



WR FPGA TRIGGER INPUT

Anodes

Dynode

Anode Sum

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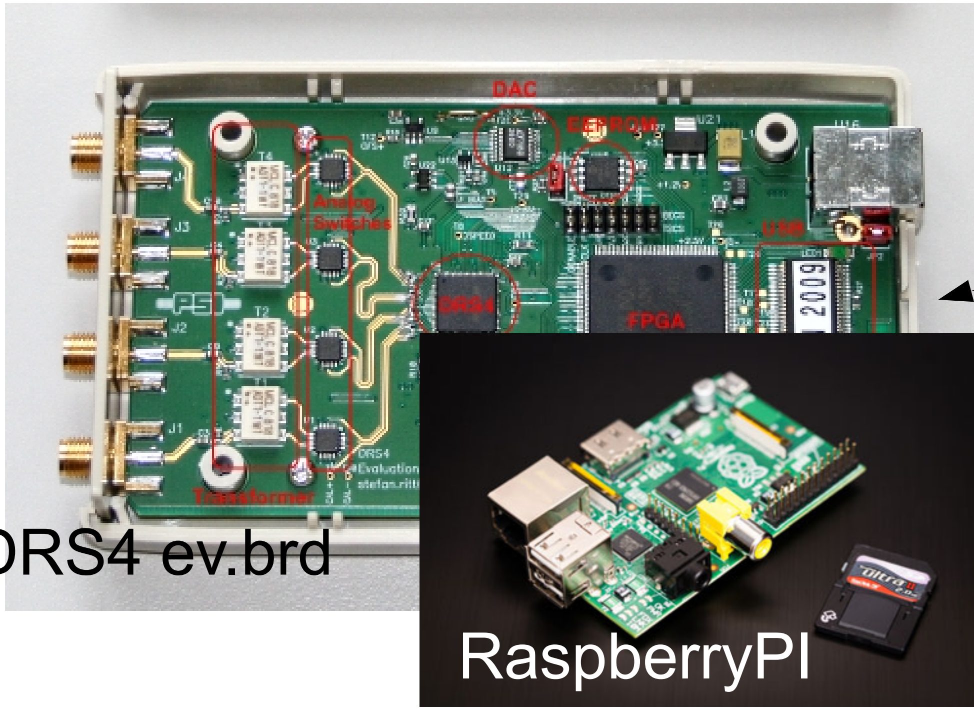
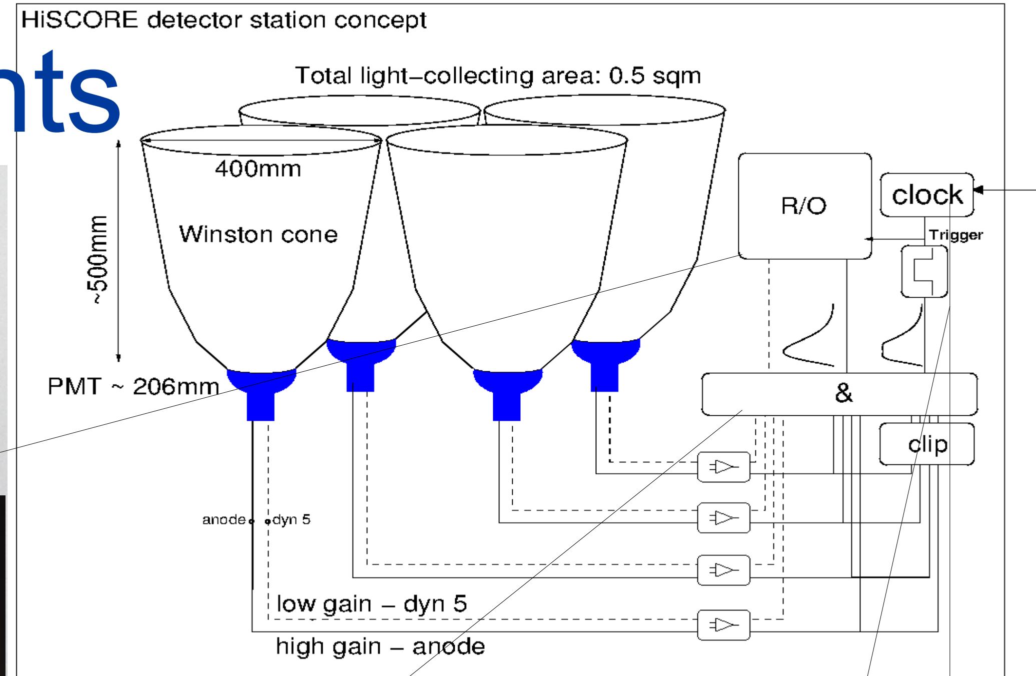
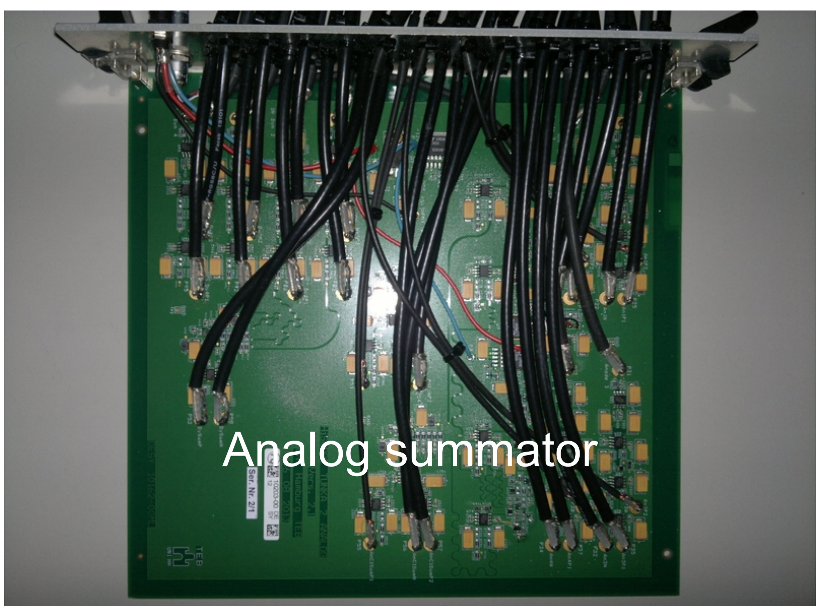
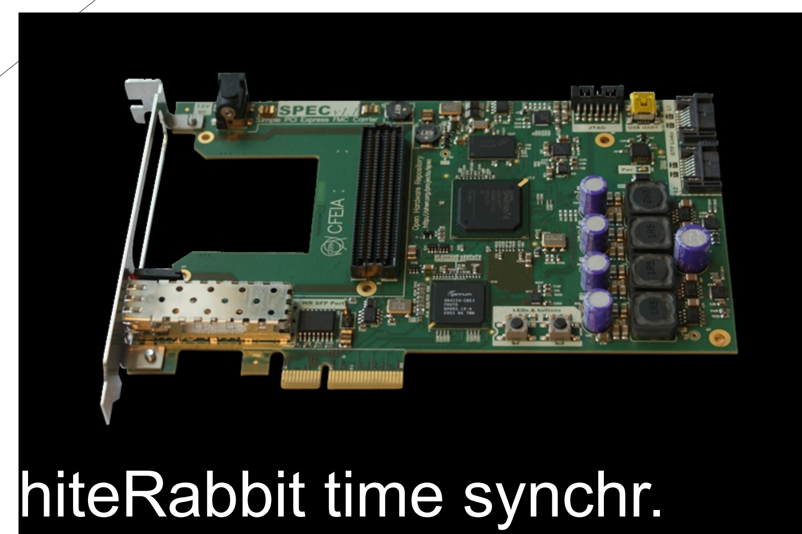
Detector components



DRS4 ev.brd
RaspberryPI




Analog summator


hiteRabbit time synchr.
System (Talk by A. Porelli)
Onboard FPGA : triggering

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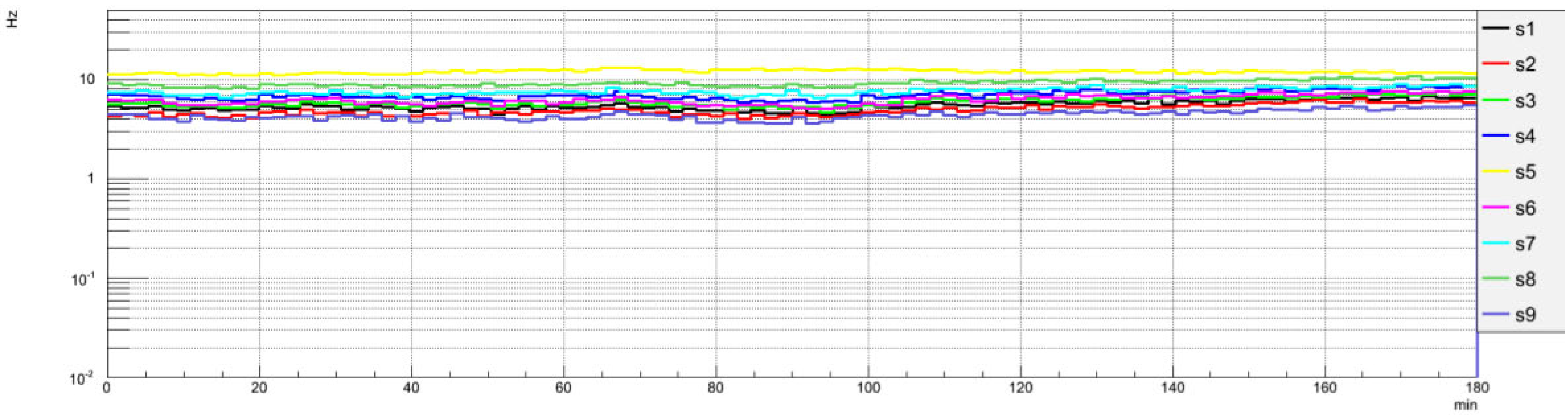
Data quality

- Operation since 10/2013
- Daily quality checks (rate stability, amplitude spectra, tie difference distributions,...)



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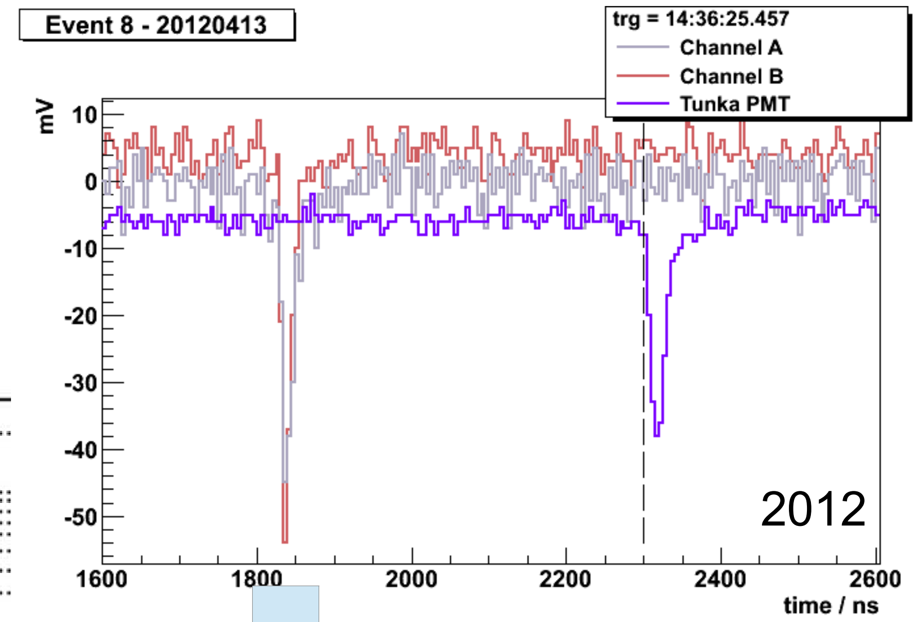
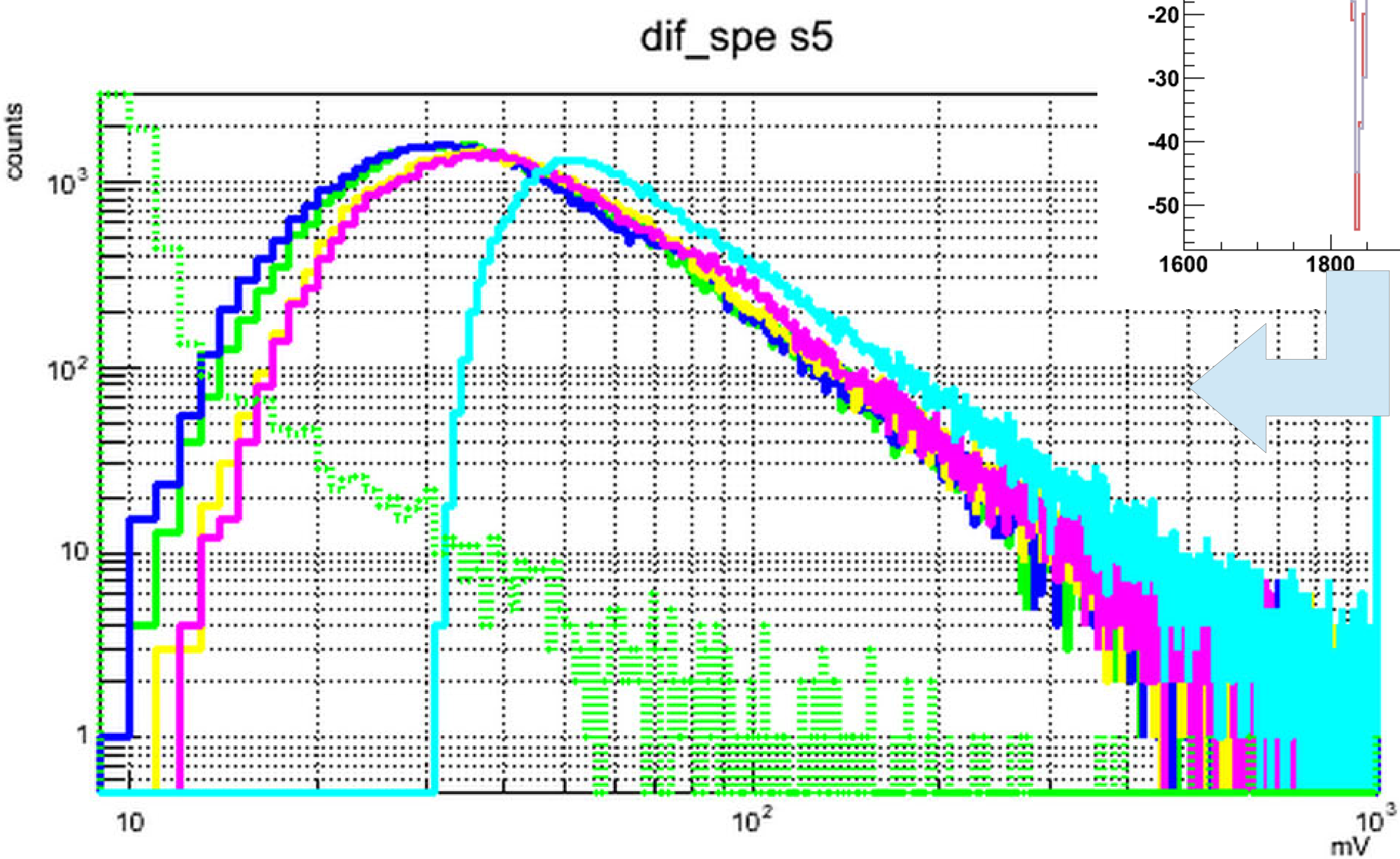
Raw data

- Amplitude distributions





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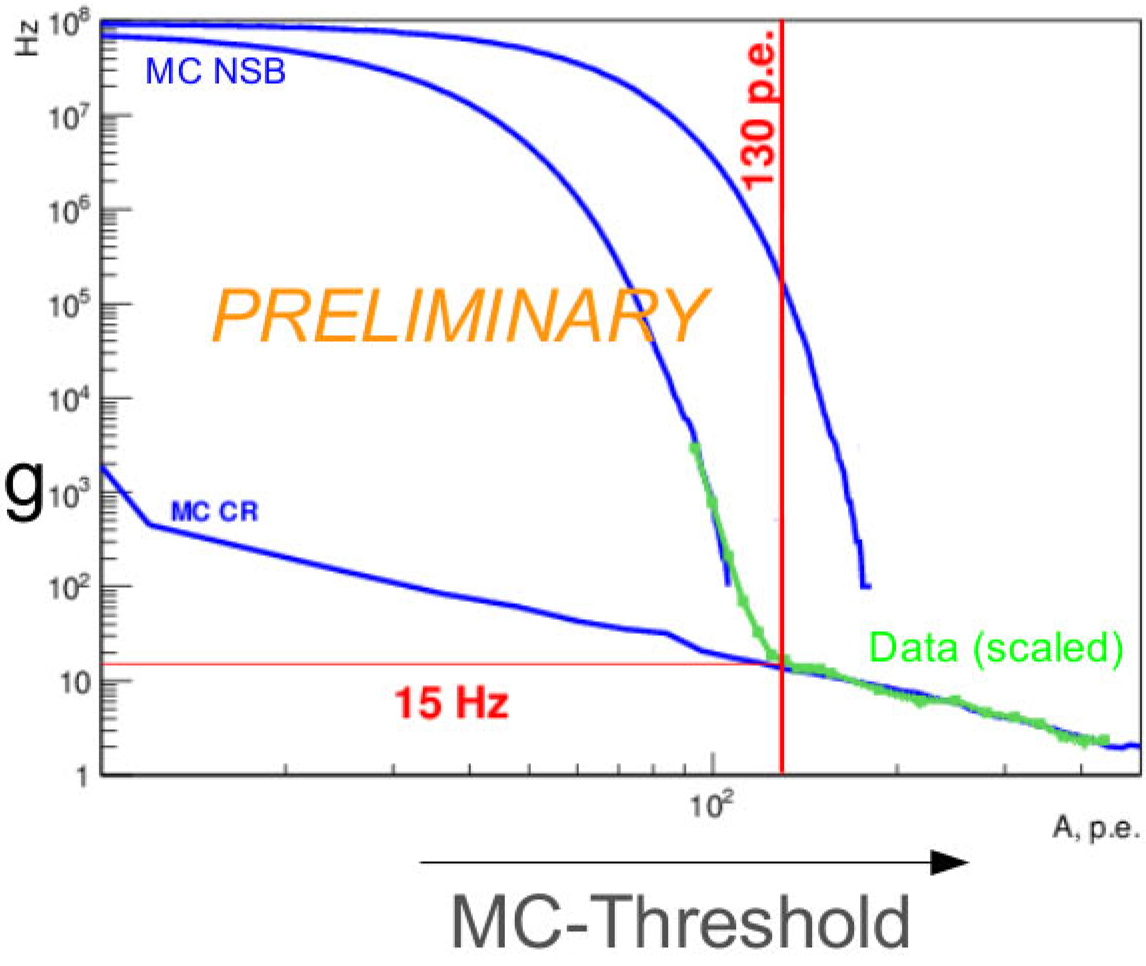
Noise and Cosmic triggers

Trigger rate vs. threshold

→ Cosmic ray branch

→ noise wall

→ Simulation
attempt p.e./mV Scaling



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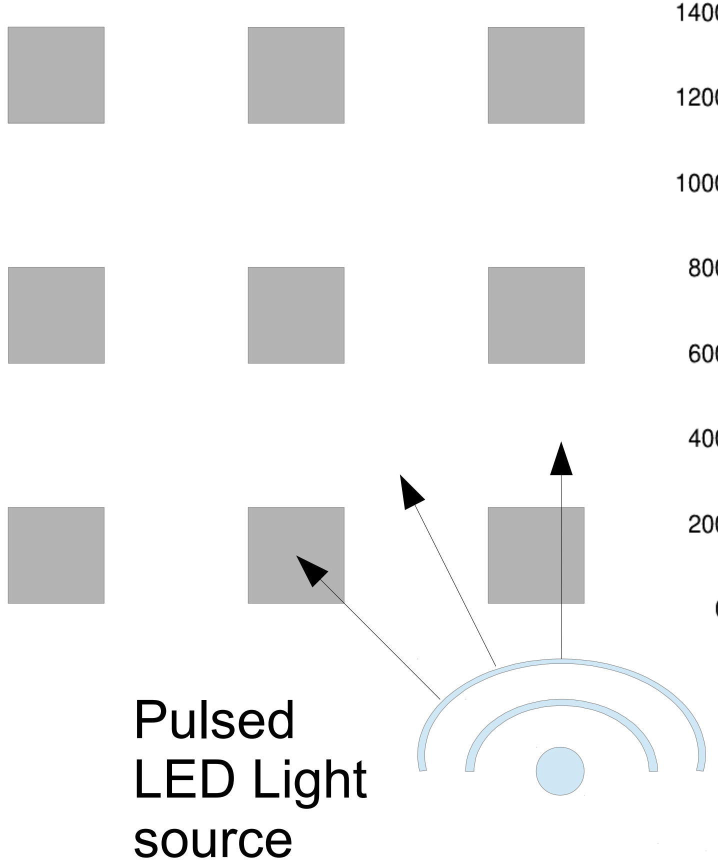
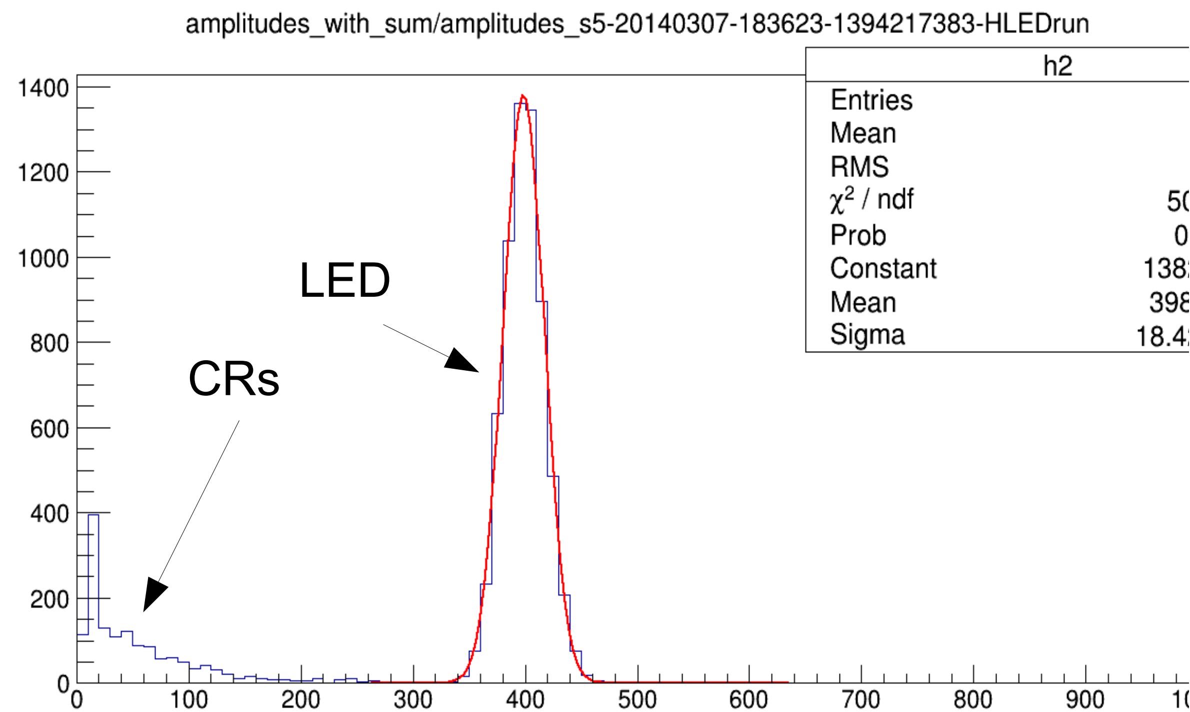
Timing verification





Spherical wave fit:
→ sub-ns timing resolution

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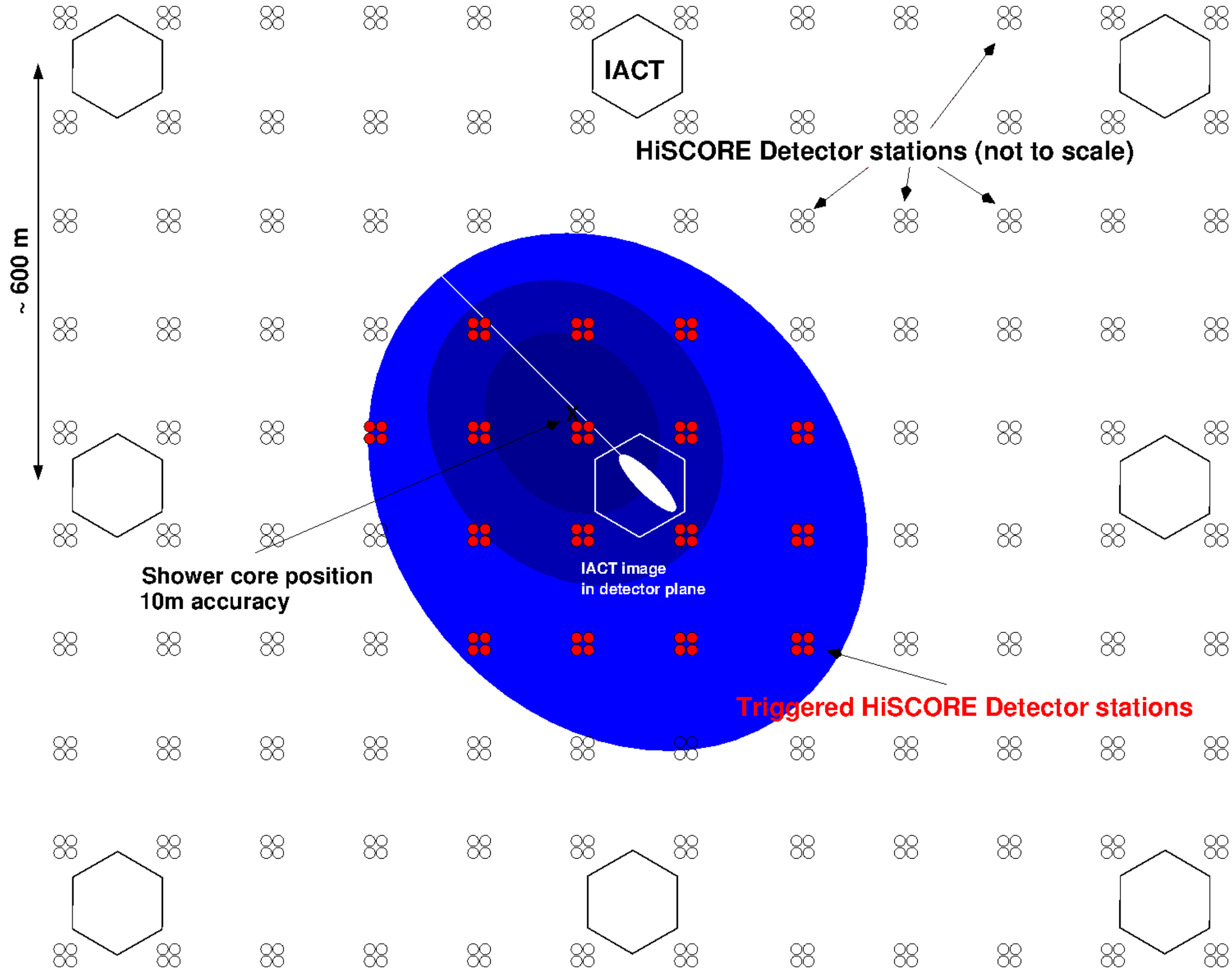
Combining HiSCORE with telescopes

Non-imaging and imaging hybrid detection

HiSCORE + IACTs

Central reconstruction parameter: Shower core position



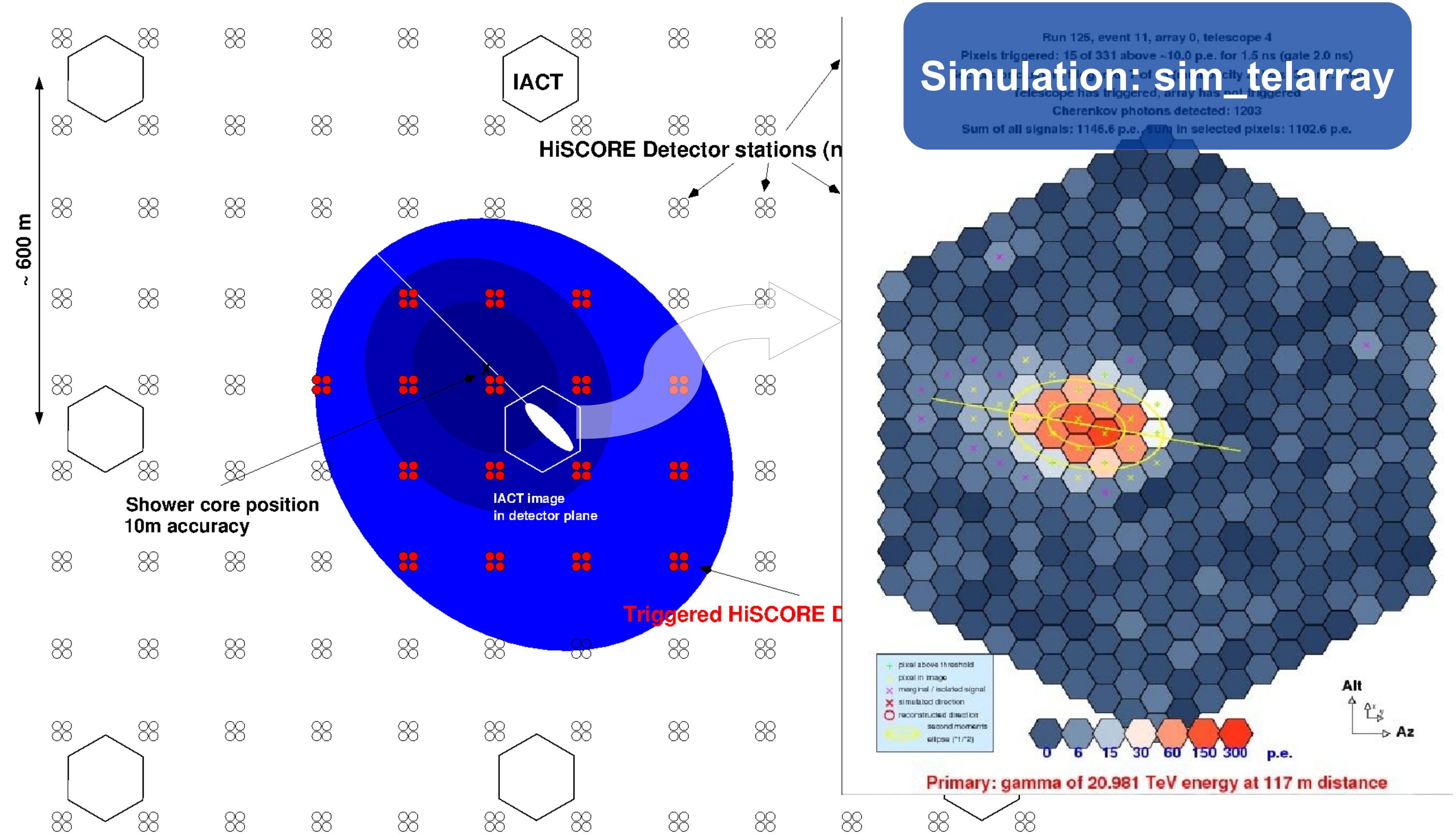
IACT image scaling

Monoscopic operation

Increased area / telescope

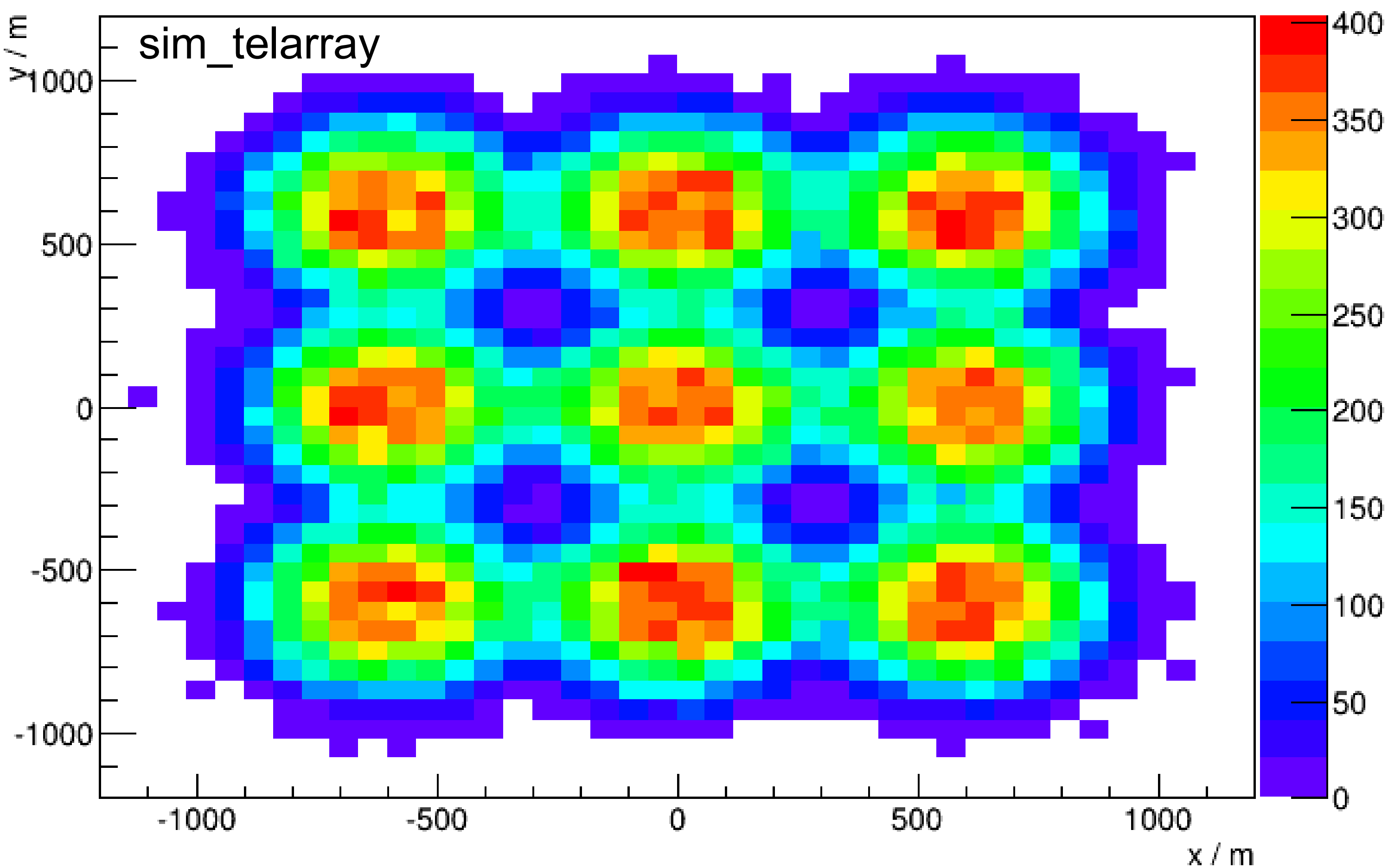
HiSCORE + IACTs

Central reconstruction parameter: Shower core position



martin.tluczykont@physik.uni-hamburg.de

HiSCORE + IACTs



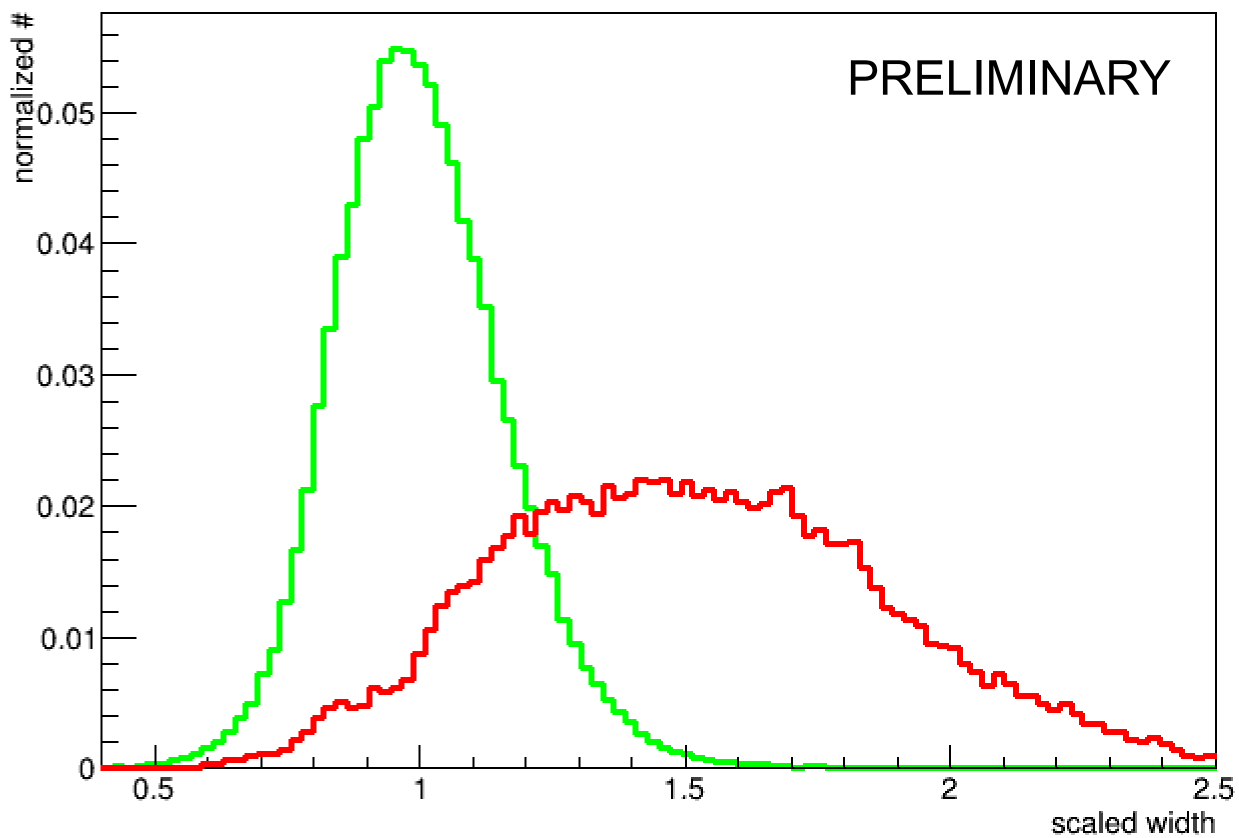
Test width scaling with IACT+HiSCORE "toy-MC-test"

- Full simulation sim_telarray
- 2D-lookup-table for MC-width w_{MC}(core, size)
- MC-core **randomized** with HiSCORE resolution
- Use randomized core position for width scaling

HiSCORE + IACTs

Preliminary results hybrid width scaling:

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



Apply scaled width cut:

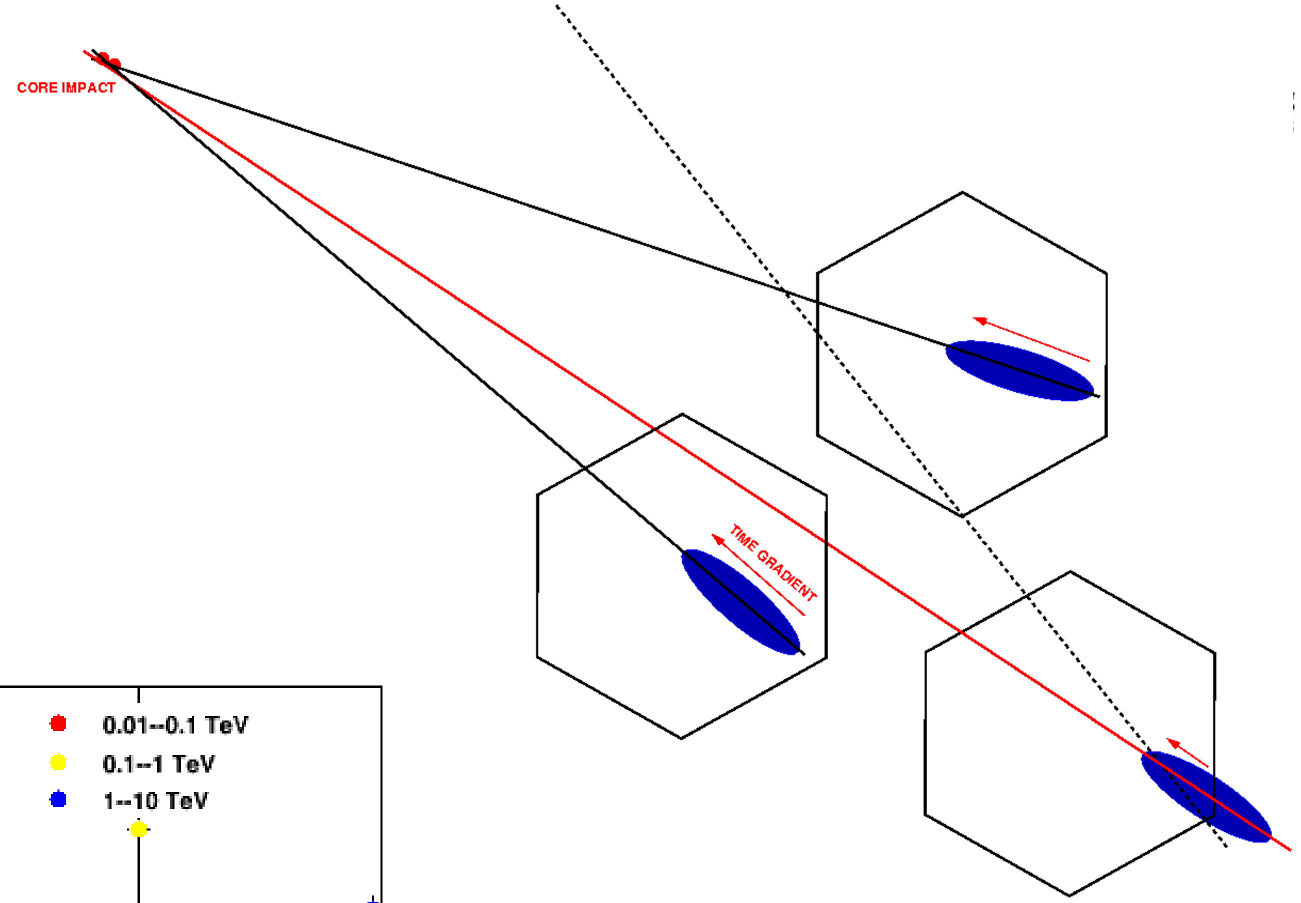
Q-factor ~2.2

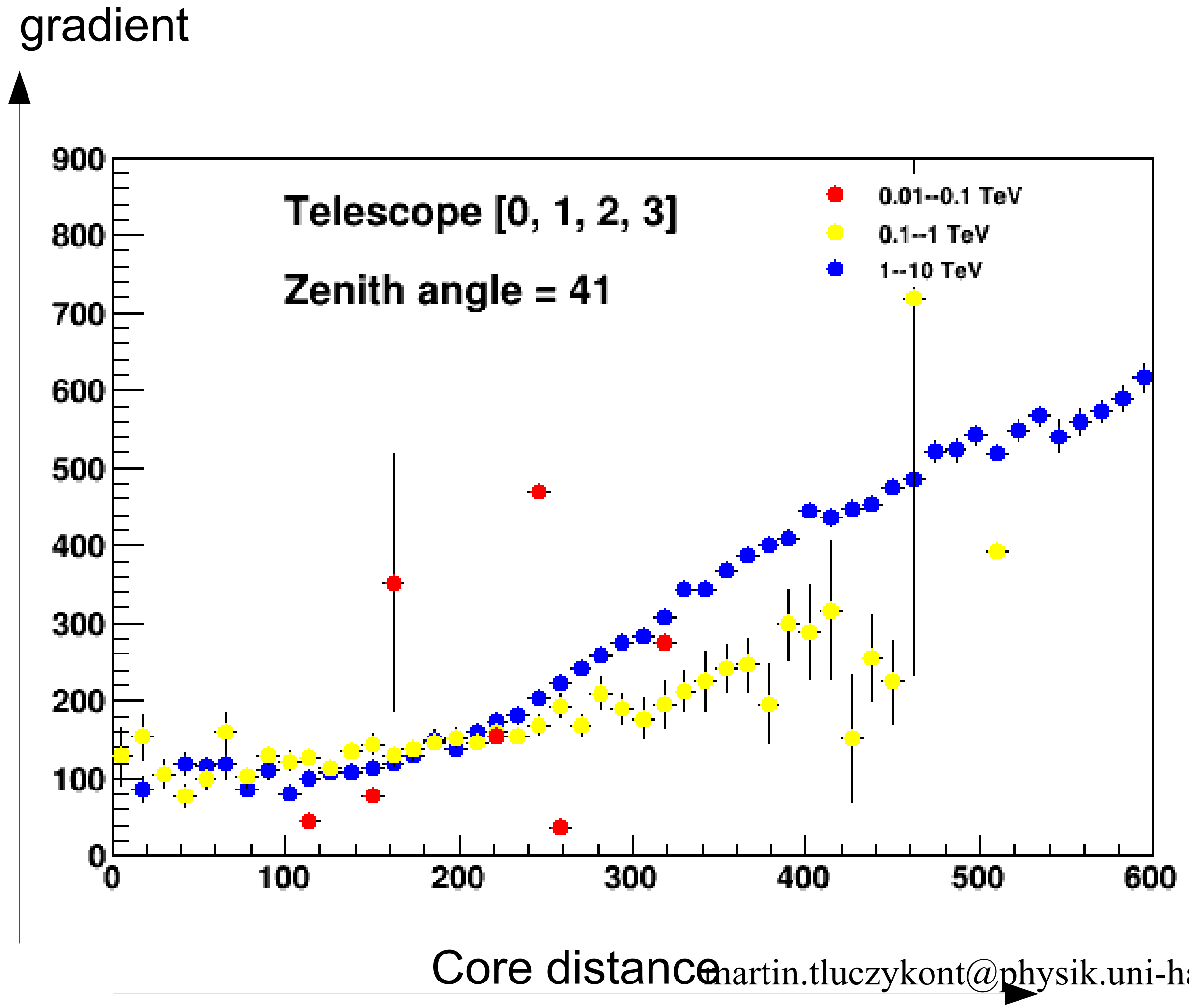
(Simulated granularity: 0.5°)

Hybrid events: more reconstruction

- Expect sensitivity boost:
  - Scaled width cut (Q>2)
  - Further g/h separation: Angular cut, length, …
    (+ more sophisticated methods)
  - Improved angular resolution from hybrid events: e.g. treat telescope as part of array (not yet simulated)
  - Consider time-development of image → independent direction reconstruction

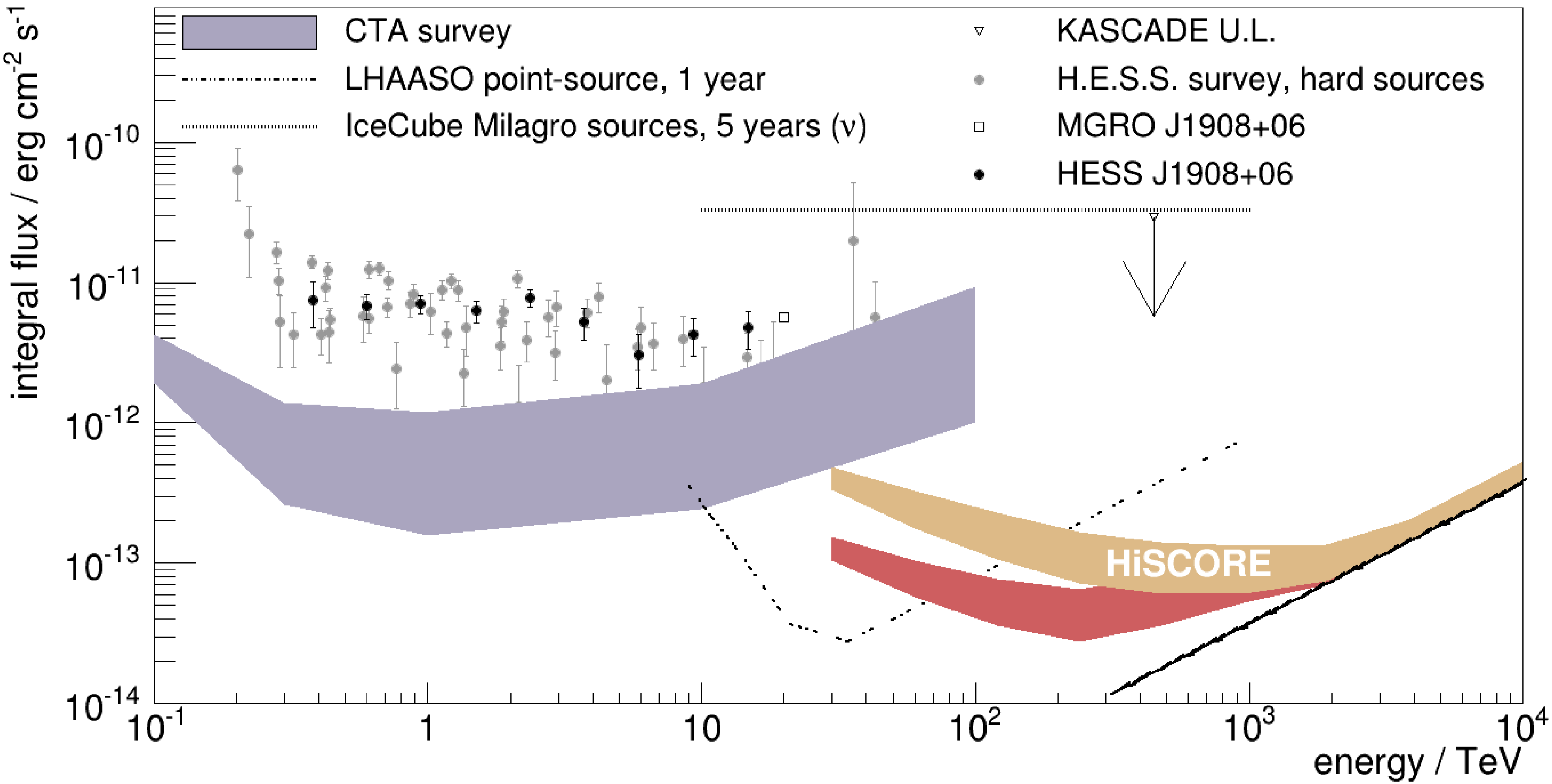
Large zenith angle: outside HiSCORE viewcone





sim_telarray simulation, 2010

Hybrid events: Sensitivity



Summary & outlook

Tunka-HiSCORE 9-Station array:

- Operational since 10/2013
- Data verification and analysis ongoing

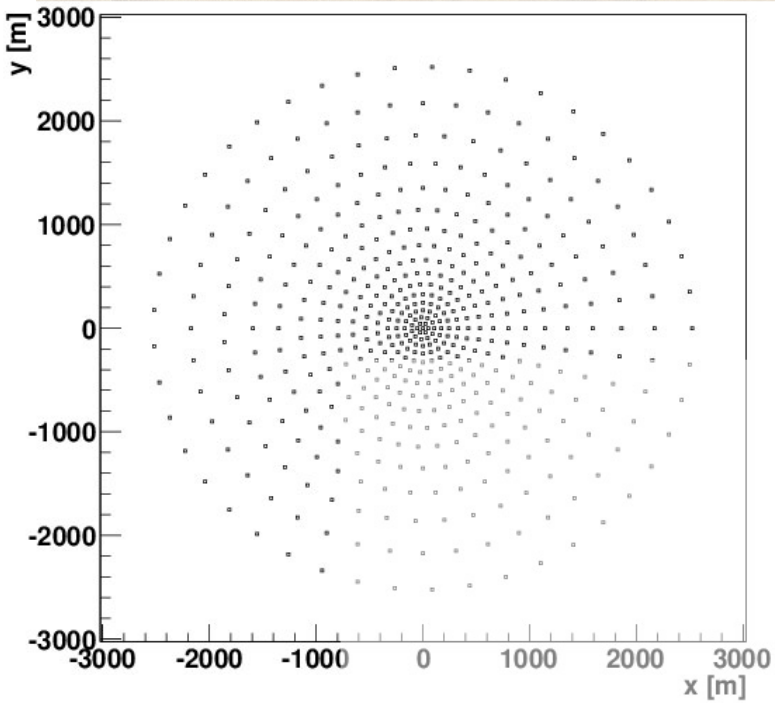
TAIGA, 2014+

- **T**unka **A**rea **I**nternational **G**amma-ray and cosmic ray **A**strophysics

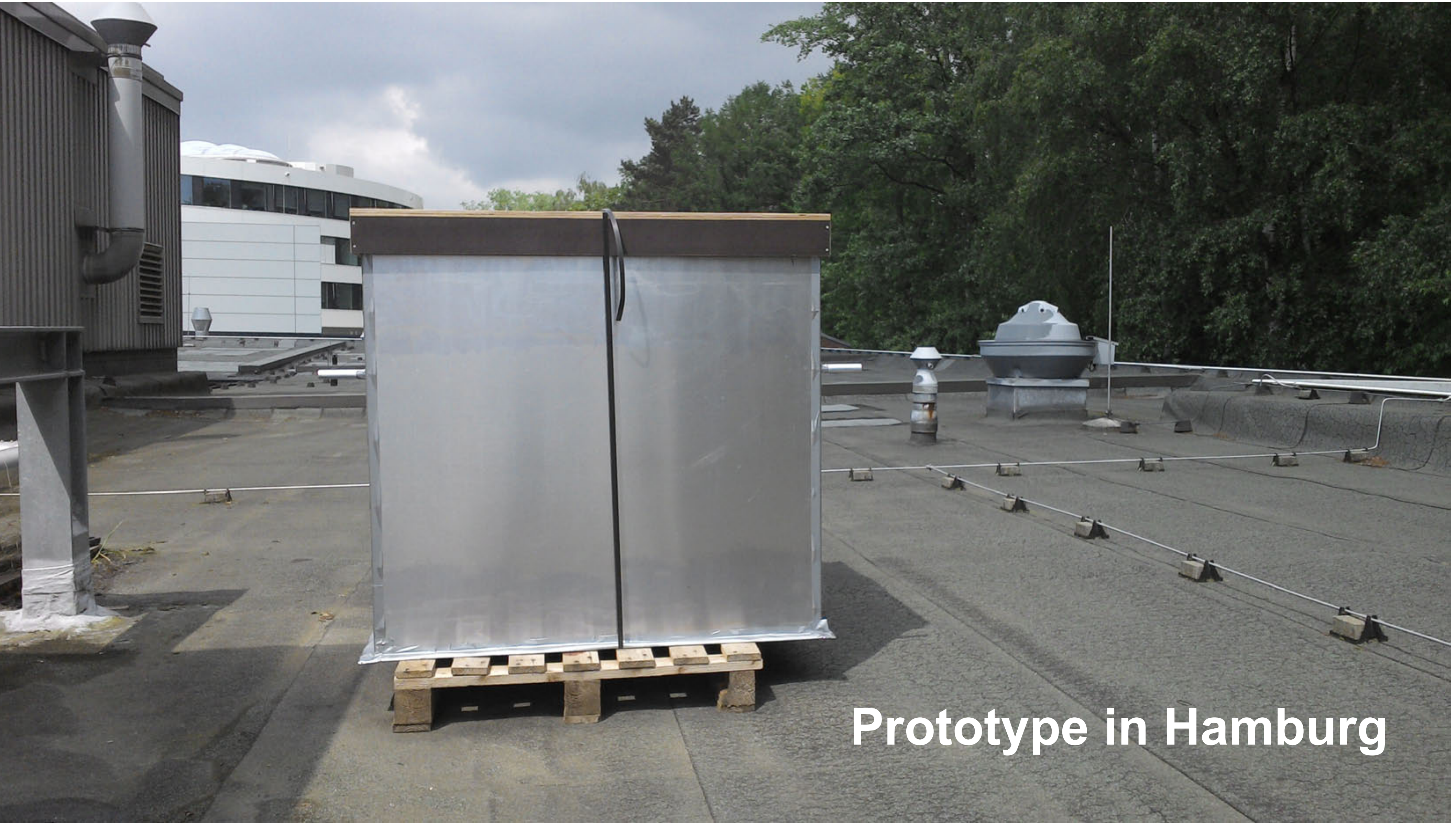
- 1 km² engineering array
- HiSCORE + imaging telescopes
- Expect 1st physics results

HiSCORE @ PAO

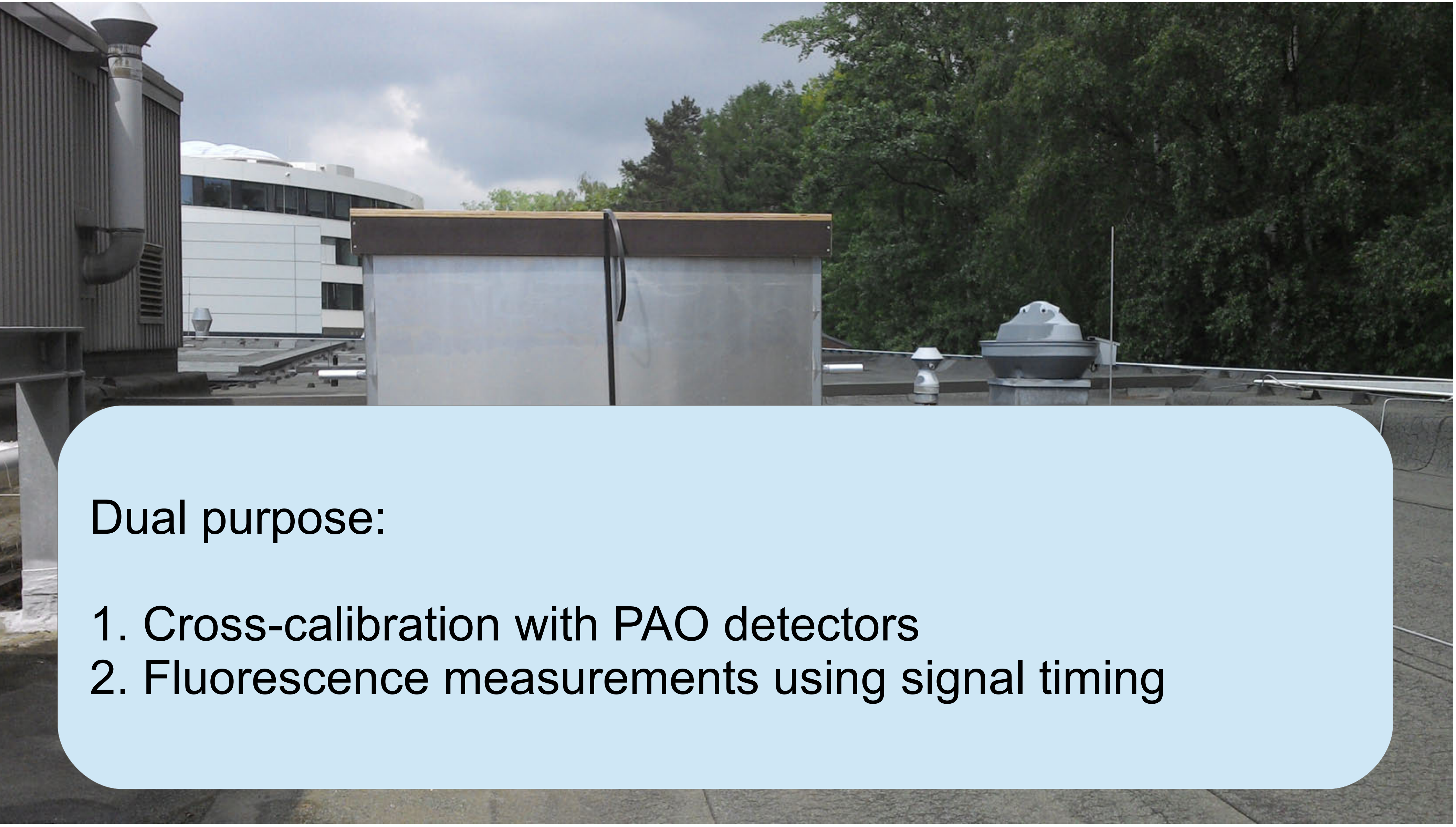
- Prototypes planned for deployment 2015



Outlook 2: HiSCORE at Pierre Auger Observatory



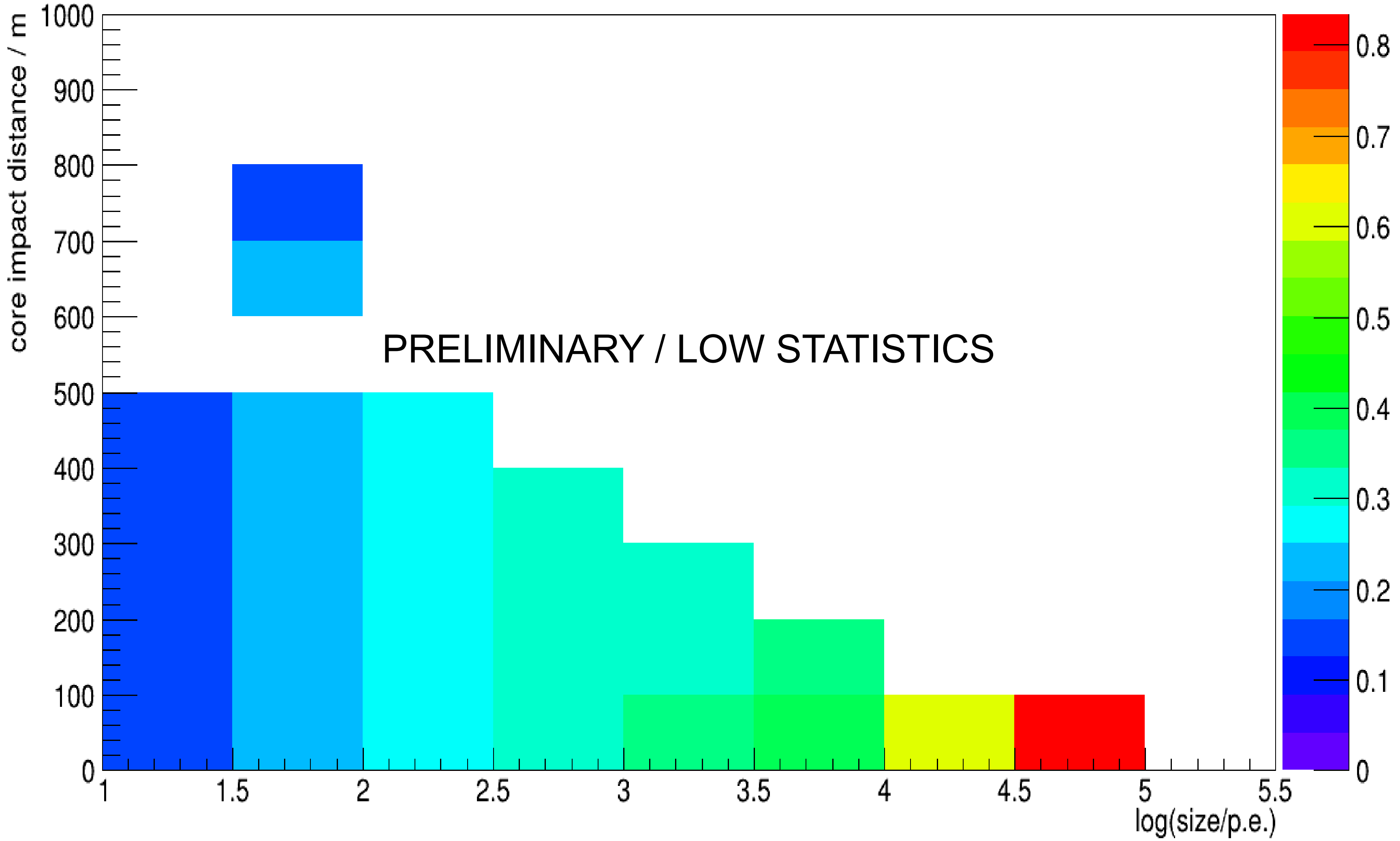
Outlook 2: HiSCORE at Pierre Auger Observatory



Dual purpose:

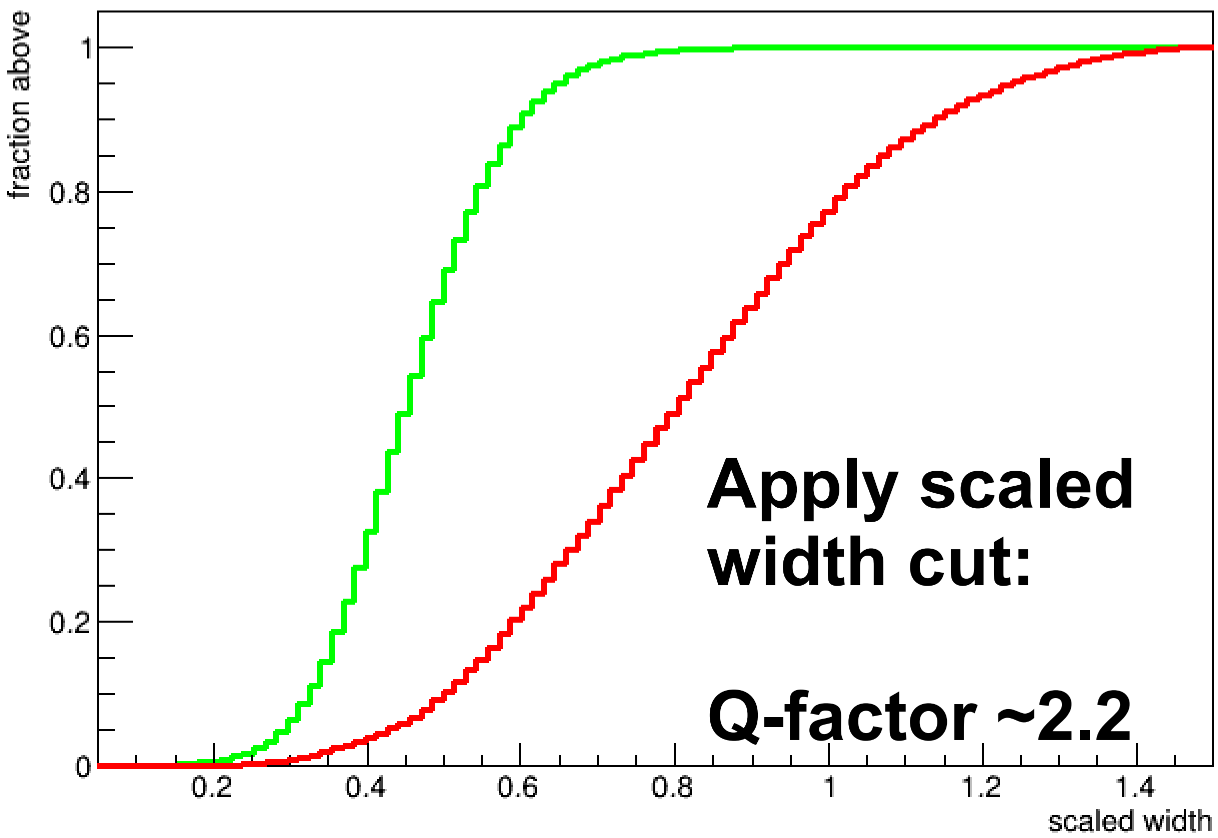
1. Cross-calibration with PAO detectors
2. Fluorescence measurements using signal timing

2D-lookup-table



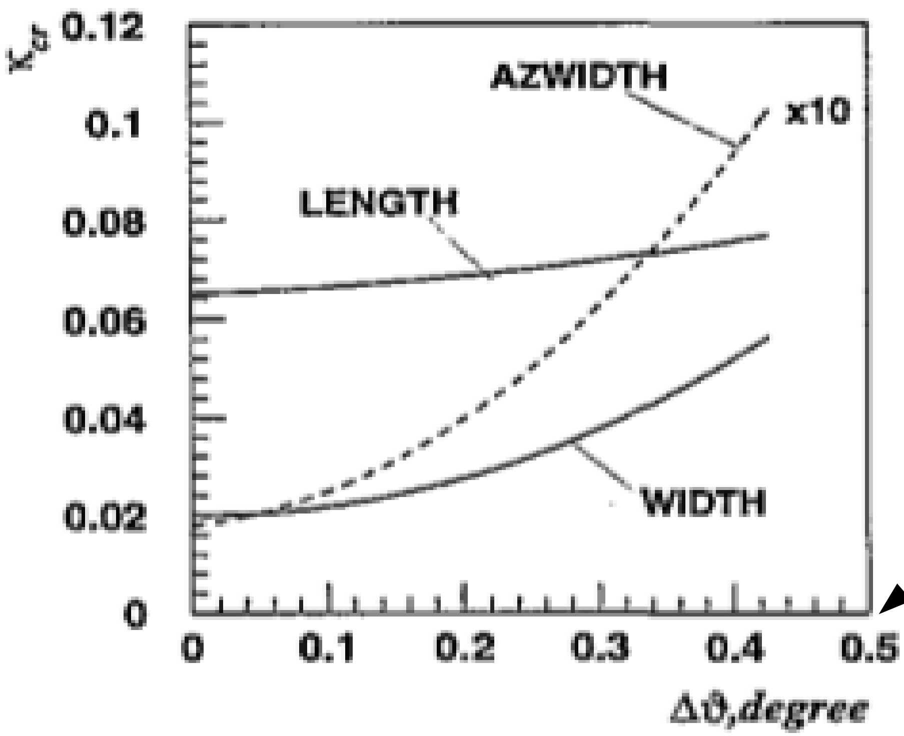
HiSCORE + IACTs

- Assuming HiSCORE core resolution ~20m



(Simulated granularity: 0.5°)

Hadron rejection (width) and camera granularity

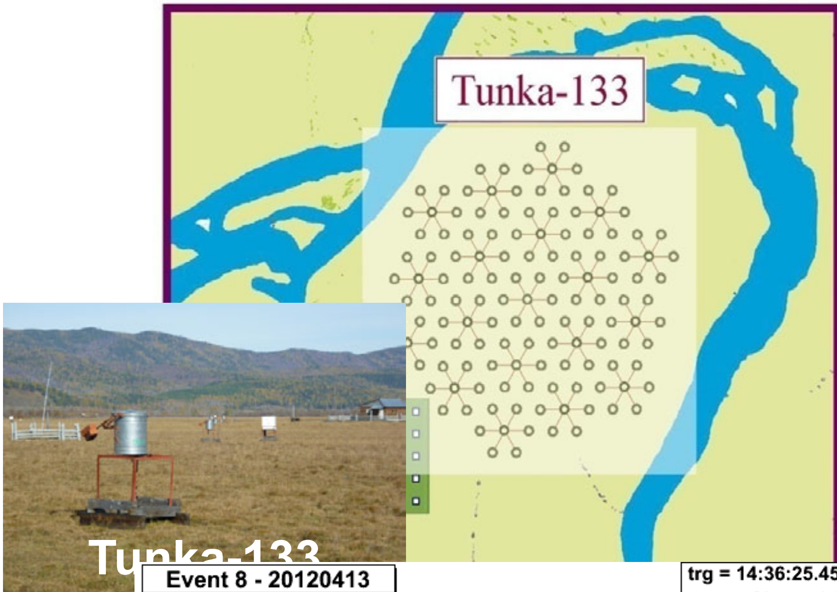


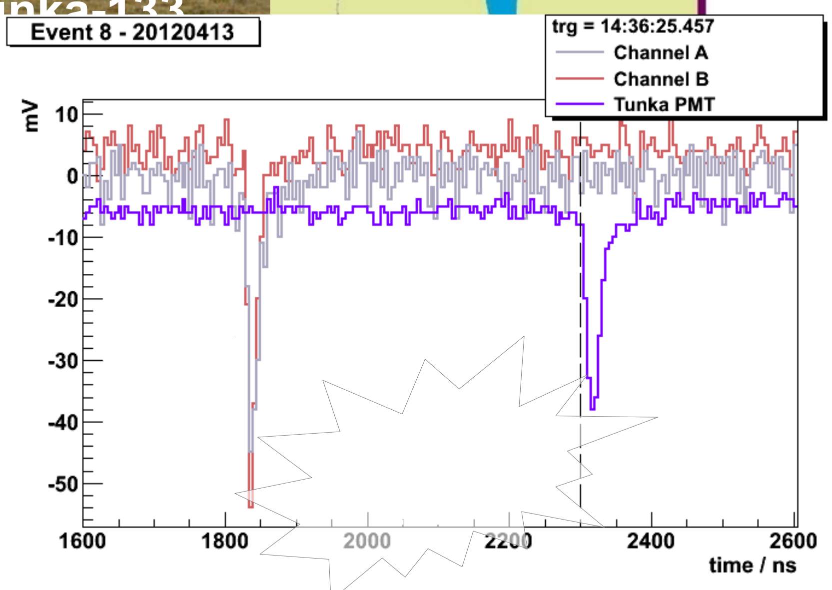
This simulation

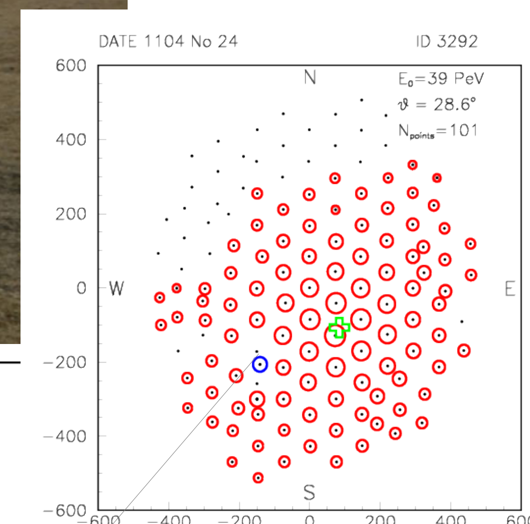
Figure 2. The dependence of cosmic-ray rejection factor κ_{cr} after application of the *Width*, *Length* and *Azwidth* cuts on the camera granularity $\Delta\vartheta$. The camera field of view $\Theta_0 \simeq 4°$, the trigger multiplicity $m = 2$. The cuts are chosen from the condition that the γ-ray acceptance efficiency $\kappa_\gamma = 0.5$.

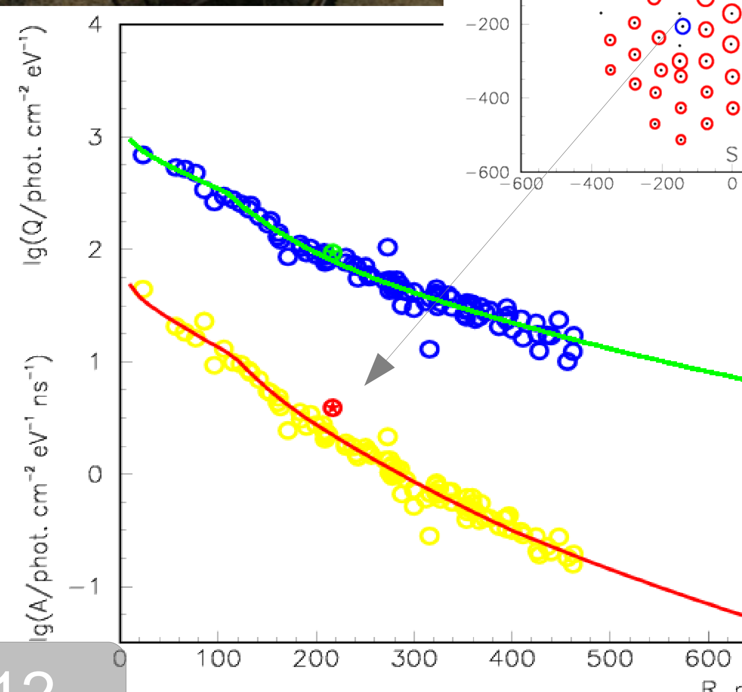
Aharonian et al. 1995

First HiSCORE prototypes



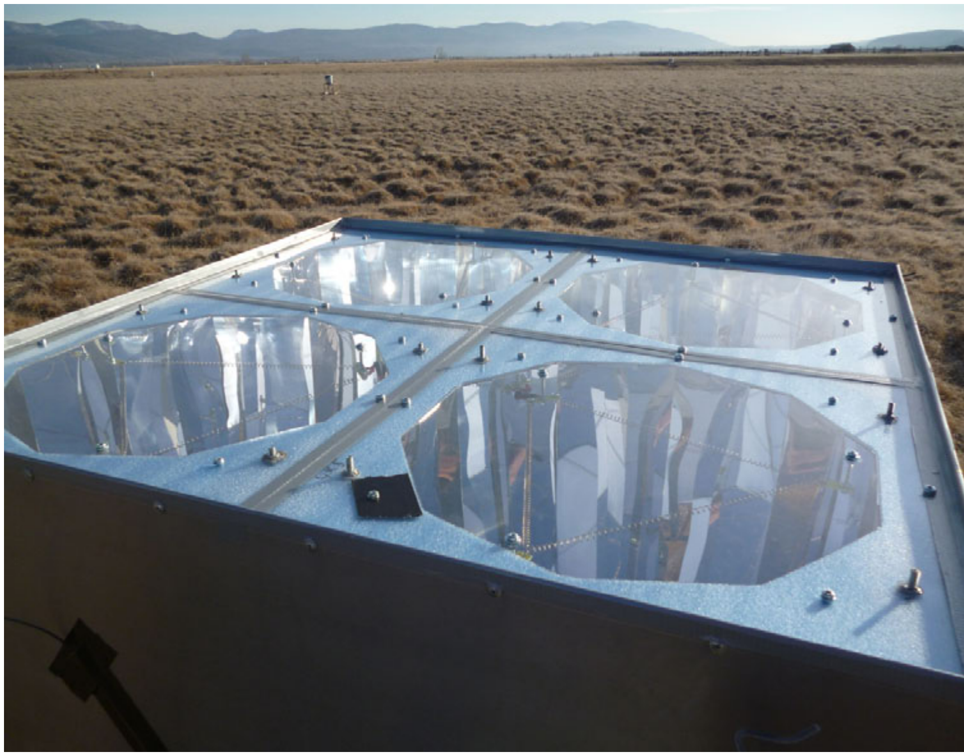






04/2012

3 Station array 10/2012 – 04/2013



10/2012 – 04/2013

3 Station array 10/2012 – 04/2013

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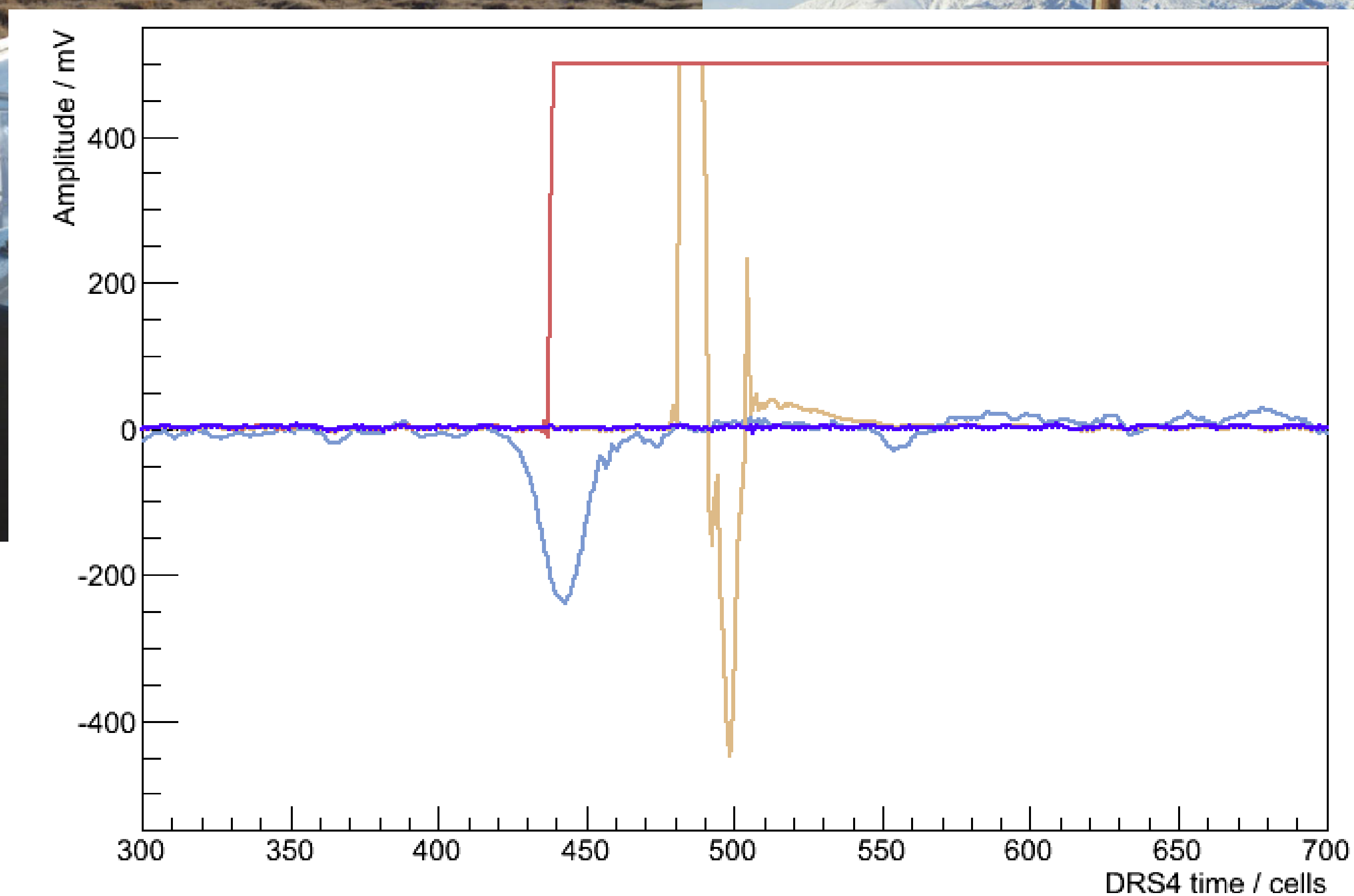
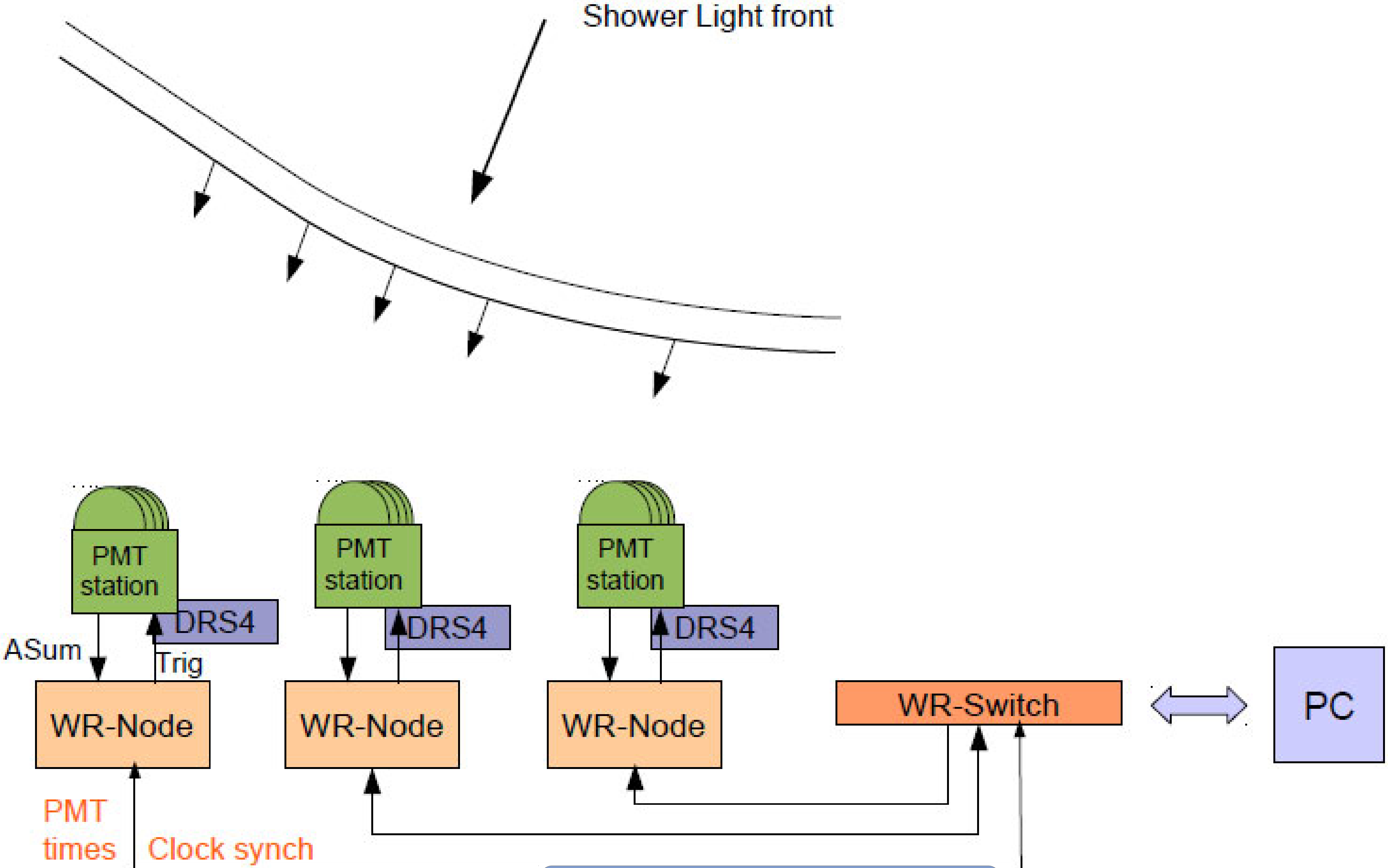


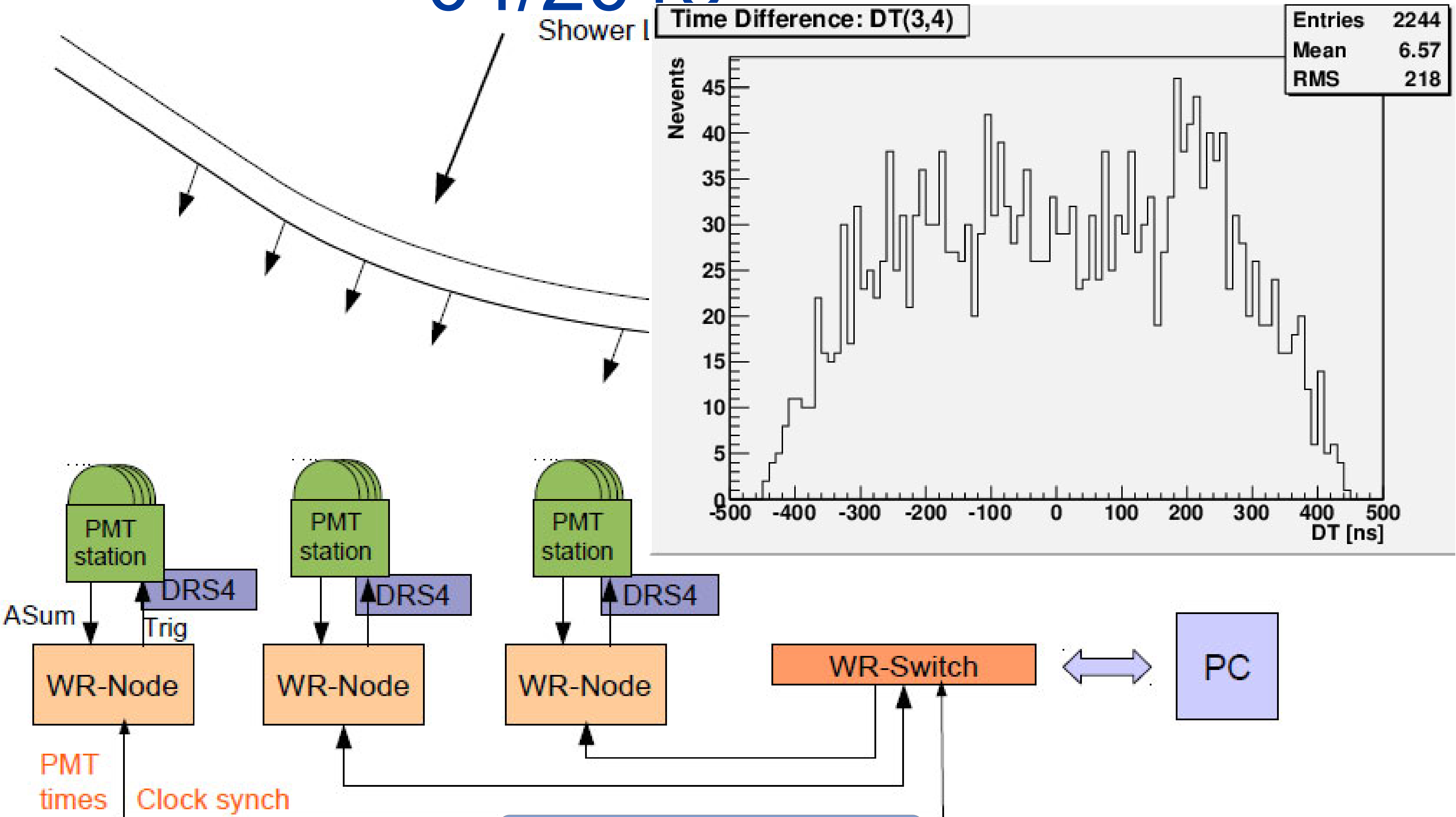
10/2012 – 04/2013

3 Station array 10/2012 – 04/2013

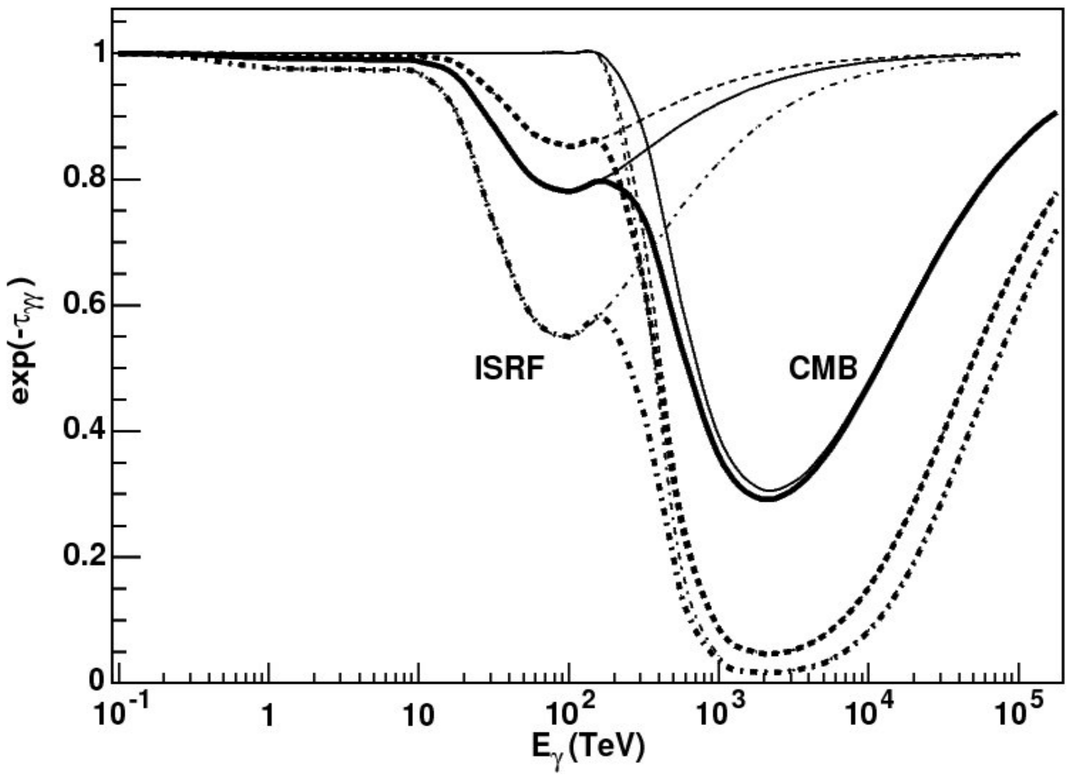


10/2012 – 04/2013

3 Station array 10/2012 – 04/2013



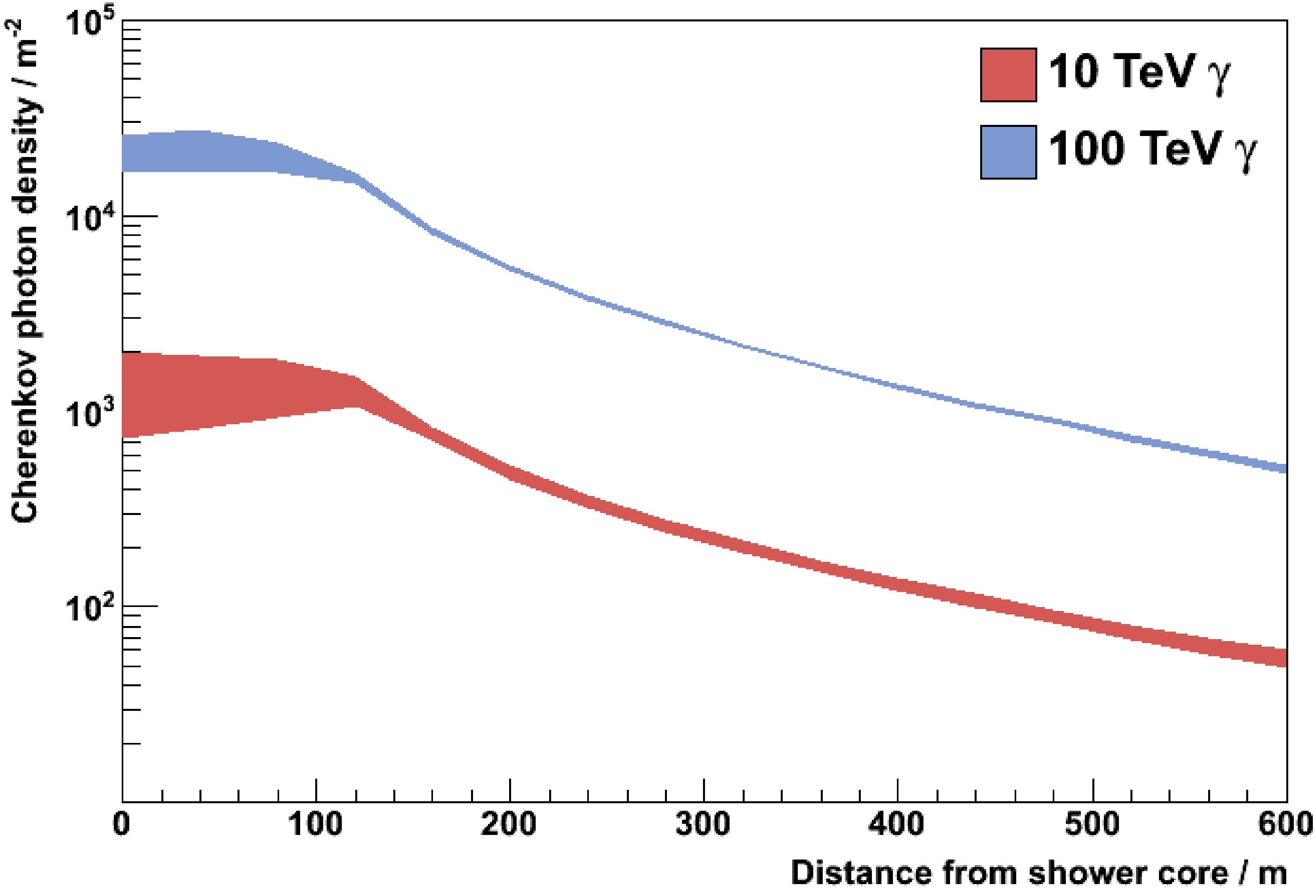
10/2012 – 04/2013



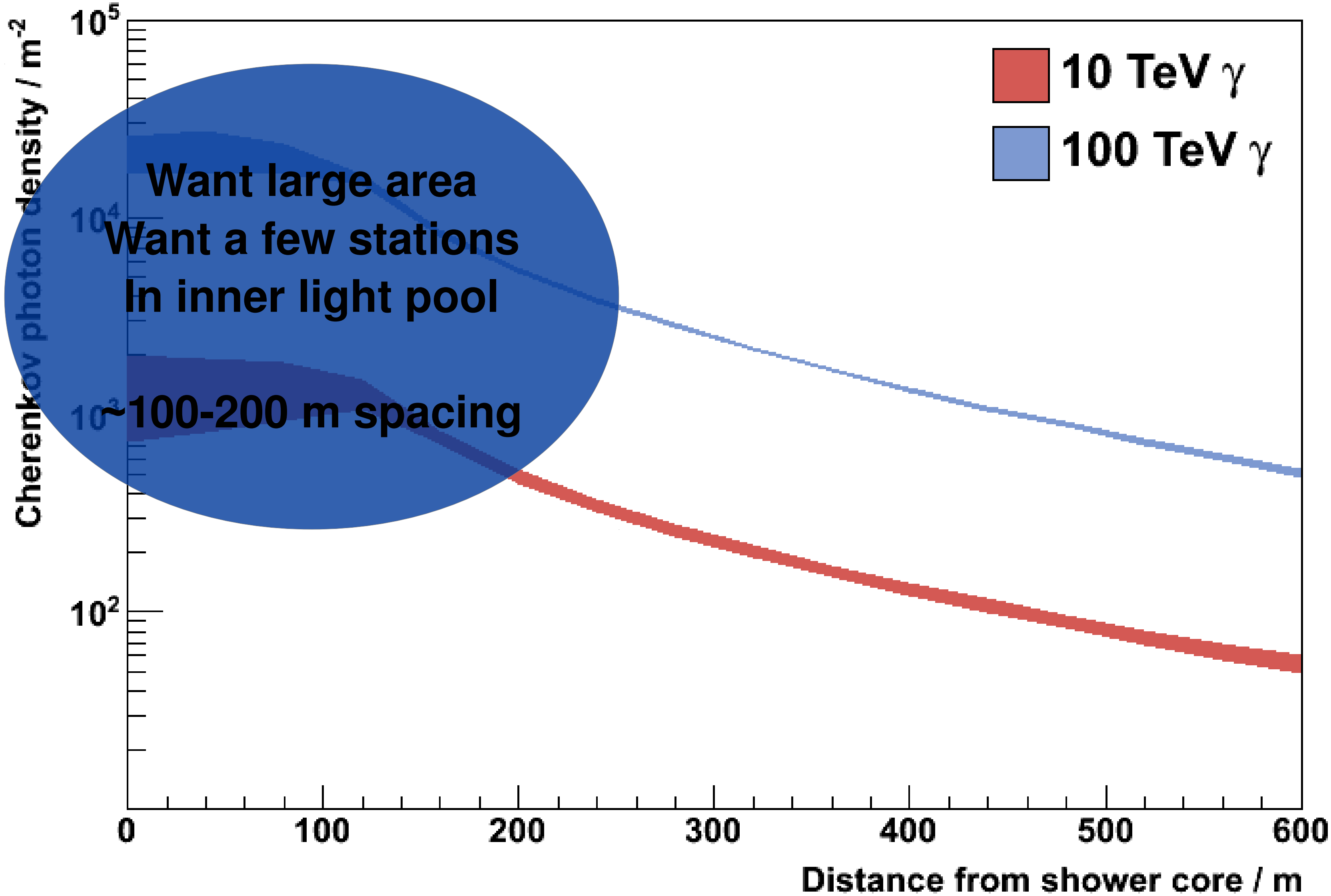
Absorption of gamma-rays by e+e- pair production with low energy photons (Moskalenko et al. 2006):

- Interstellar radiation field
- Cosmic Microwave Background

Lateral Cherenkov Photon Distribution



Lateral Cherenkov Photon Distribution



Lateral Cherenkov Photon Distribution

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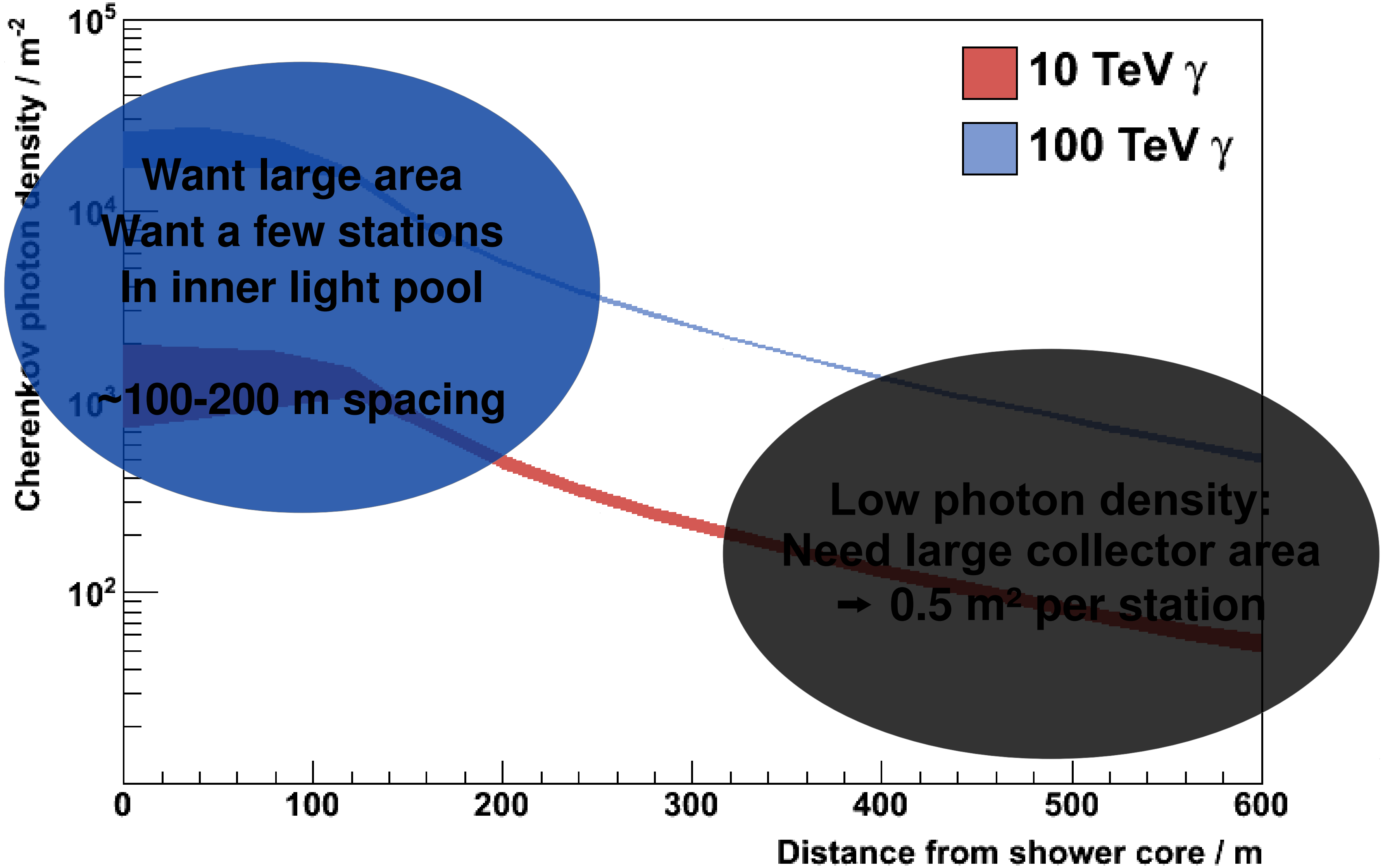

The HiSCORE detector

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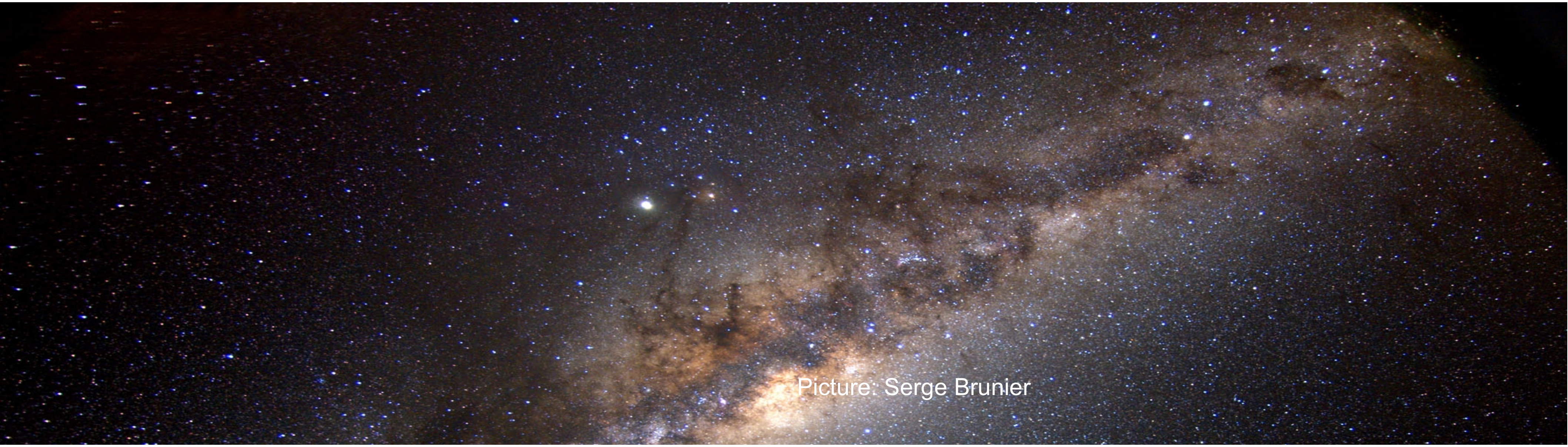
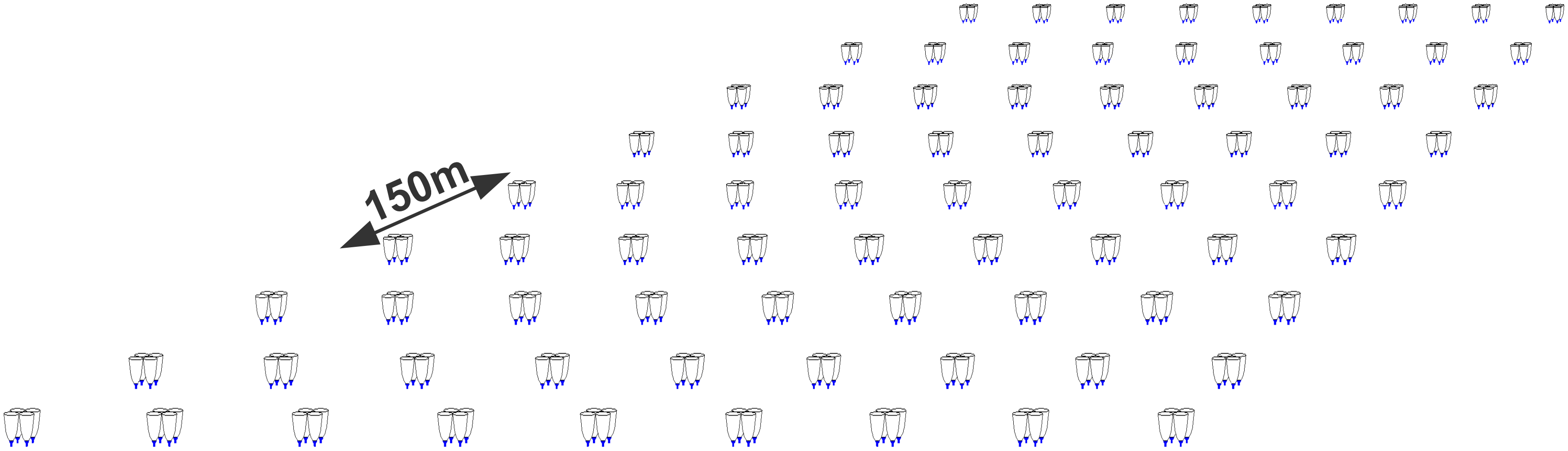
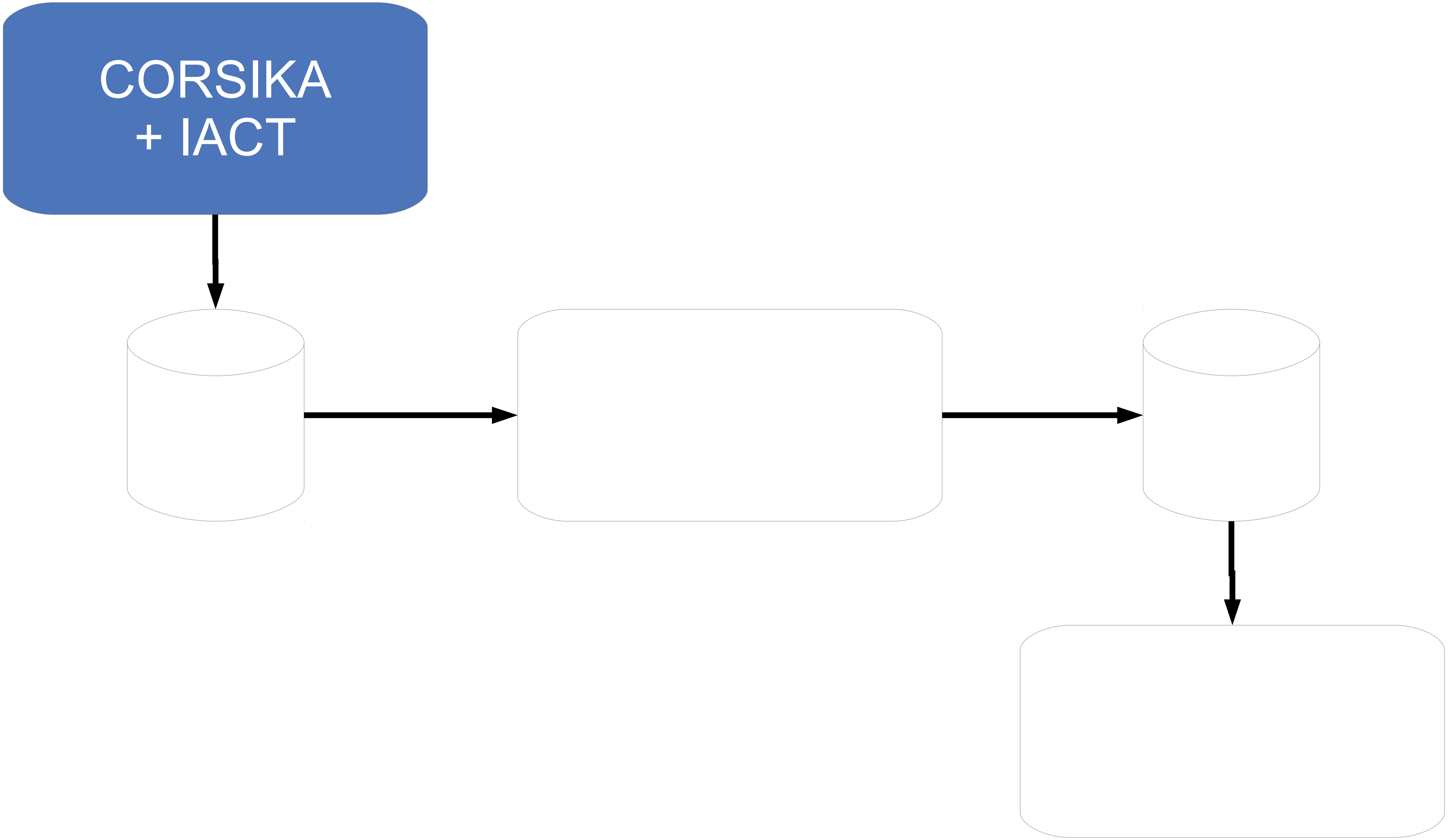


Simulation & reconstruction



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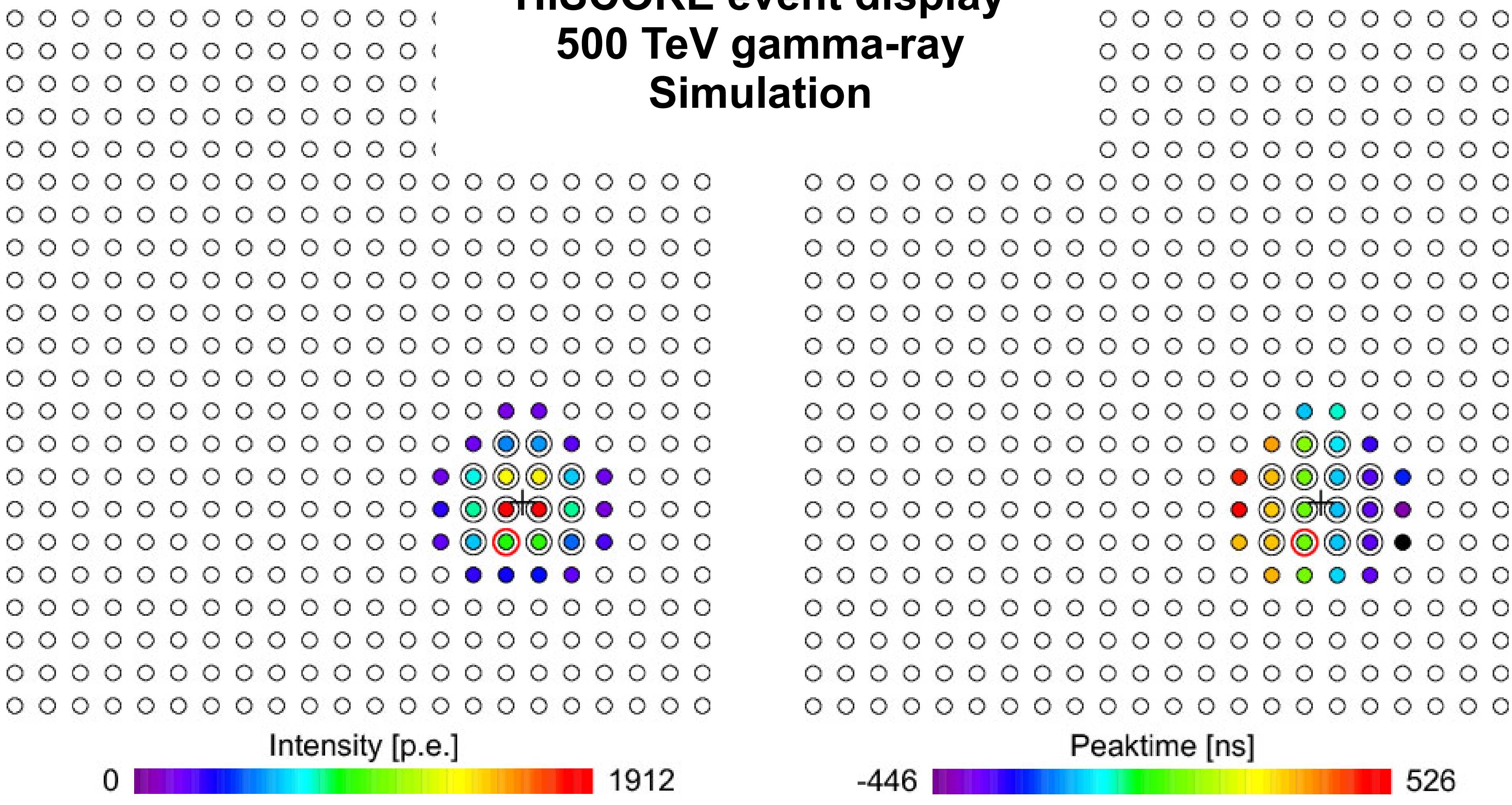
Simulation & Reconstruction

Reconstruction

Major topic of PhD thesis, daniel.hampf@physik.uni-hamburg.de

HiSCORE event display
500 TeV gamma-ray
Simulation

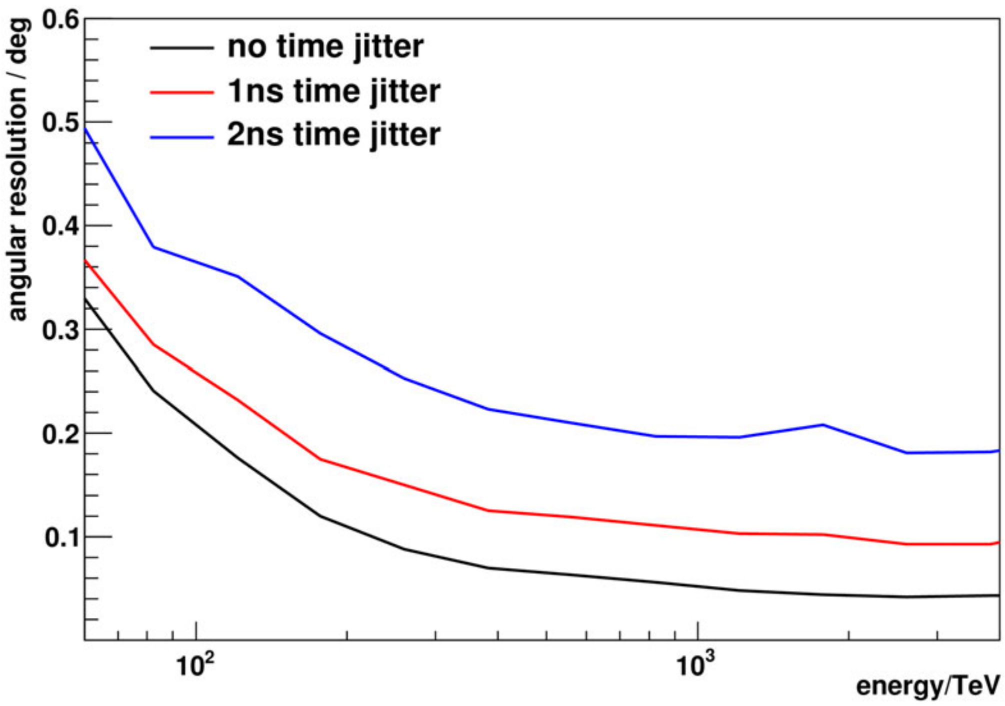


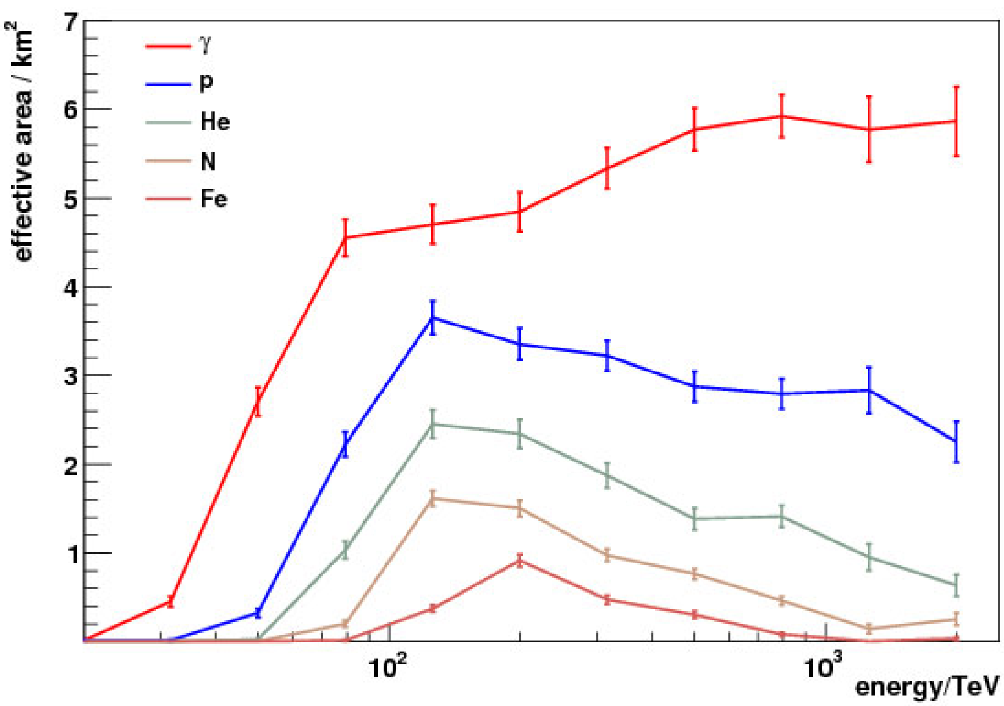
Reconstruction

Direction: photon arrival time model

Energy: Value of LDF @ 220 m

Particle type: Shower depth and Signal rise-time





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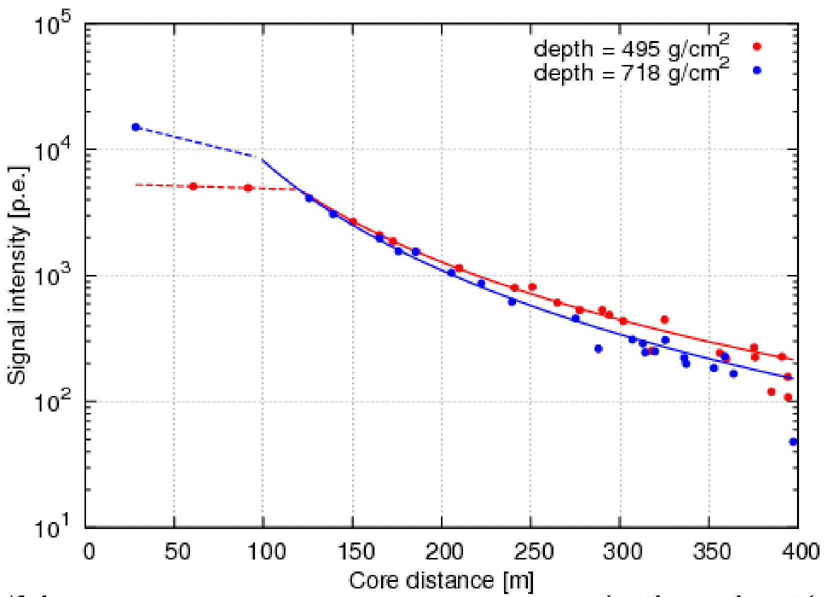
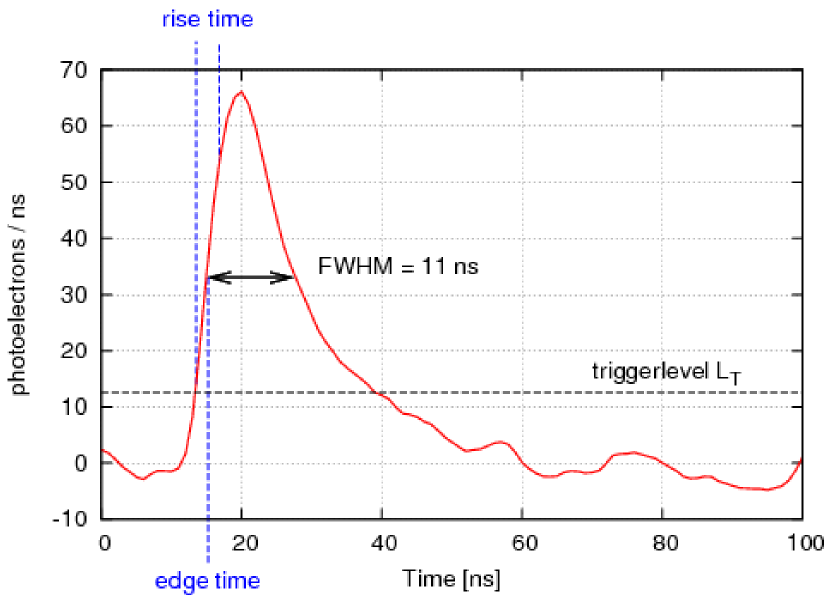
Reconstruction

- Extract PMT signal parameters
- Preliminary shower core position (cog)
- Preliminary direction (time plane fit)
- Improved core position:
  light distribution function (LDF) fitting
- Improved direction: arrival time model
- Fit of signal widths

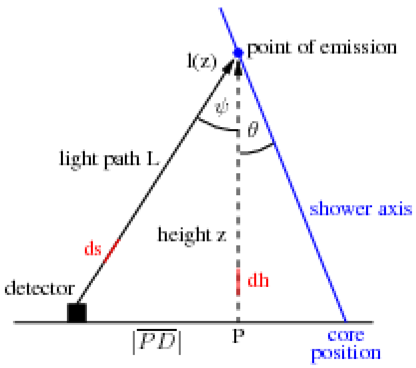




Direction reconstruction

>3 stations: model fit adapted from Stamatescu et al. 2008,

Parametrization of time-delay *dt* at detector position



$$dt(k,z) = \frac{1}{c}\left(\sqrt{k} - \frac{z}{\cos(\theta)} + \frac{8.0}{z}\sqrt{k}\,\eta_0\left(1 - \exp\left(\frac{-z}{8.0}\right)\right)\right)$$

$$k(r,z) = r^2 + z^2\frac{1}{\cos(\theta)^2} + 2\,r\,z\,\tan(\theta)\,\cos(\delta)$$

$$\delta = \phi + \mathrm{atan2}\left((x_{Det} - x_{core}),(y_{Det} - y_{core})\right)$$

Direction reconstruction

>3 stations: model fit adapted from Stamatescu et al. 2008,

Parametrization of time-delay *dt* at detector position

r: Distance from shower core to detector

Slope of atmospheric refractive index

Shower height in km

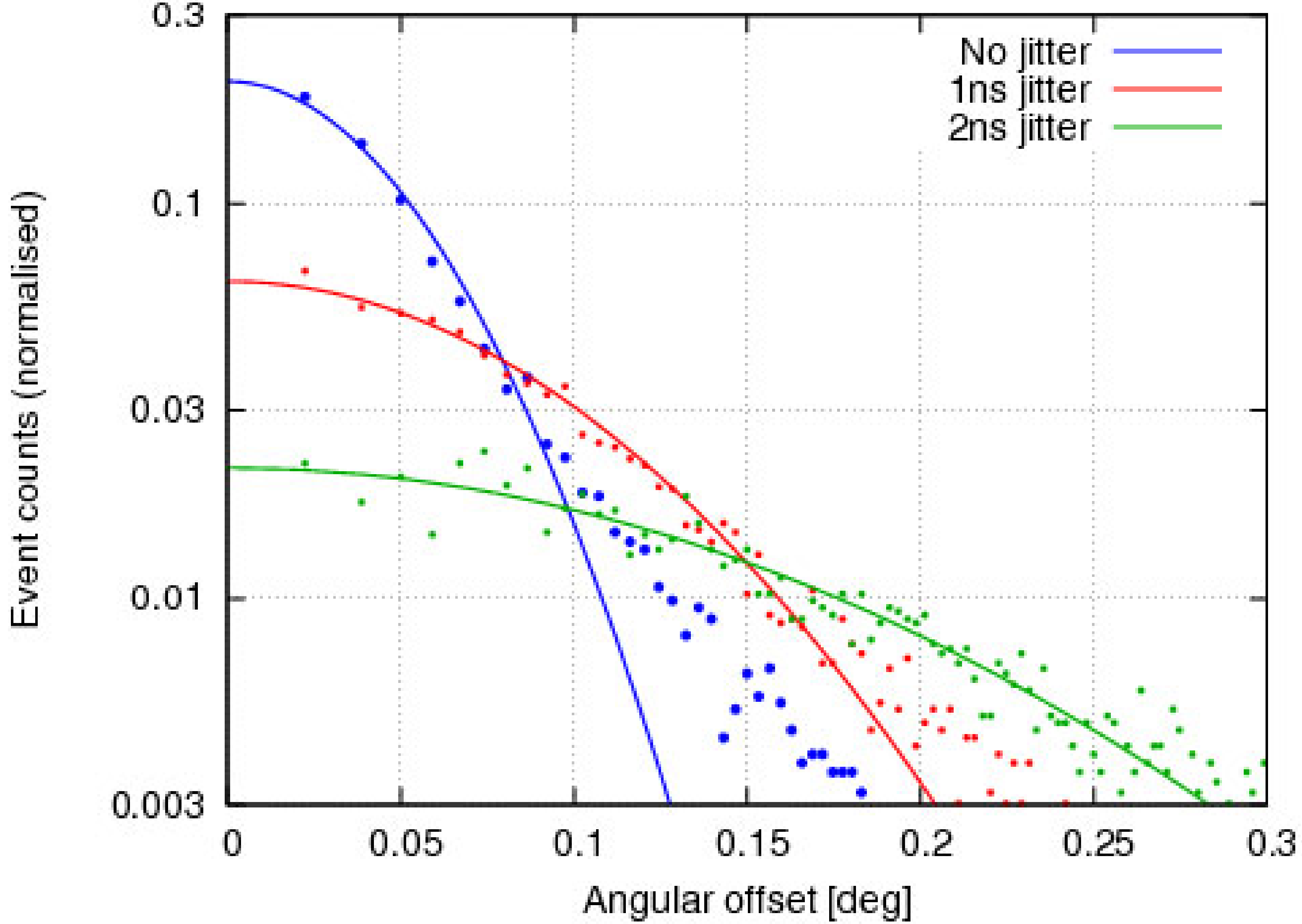
$$dt(k,z) = \frac{1}{c}\left(\sqrt{k} - \frac{z}{\cos(\theta)} + \frac{8.0}{z}\sqrt{k}\,\eta_0\left(1 - \exp\left(\frac{-z}{8.0}\right)\right)\right)$$

$$k(r,z) = r^2 + z^2\frac{1}{\cos(\theta)^2} + 2\,r\,z\,\tan(\theta)\,\cos(\delta)$$

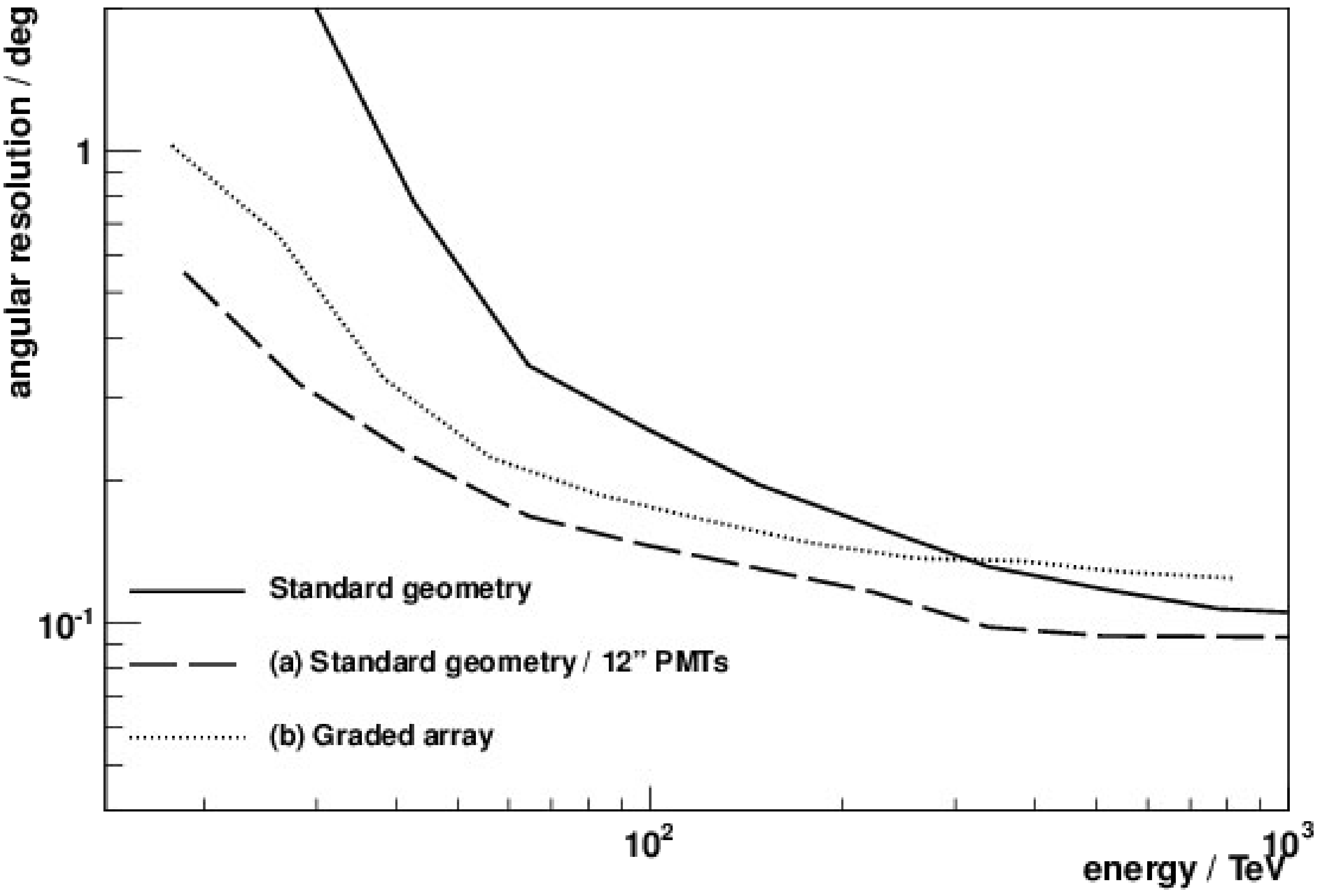
$$\delta = \phi + \mathrm{atan2}\left((x_{Det} - x_{core}),(y_{Det} - y_{core})\right)$$

Zenith angle

Direction reconstruction

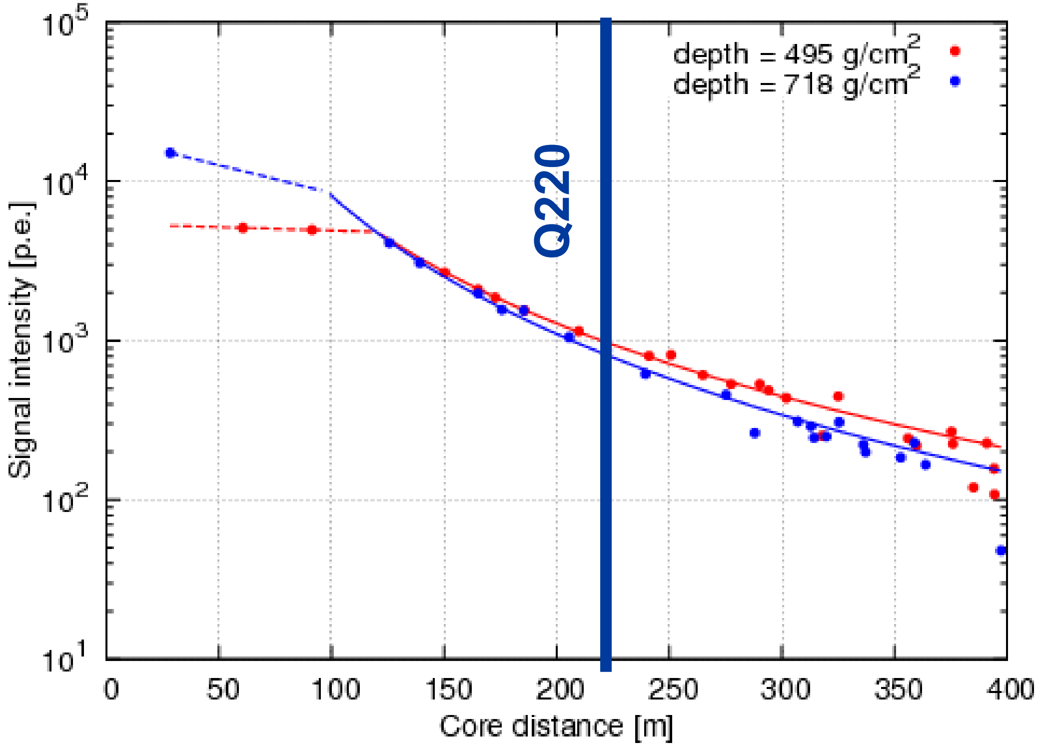


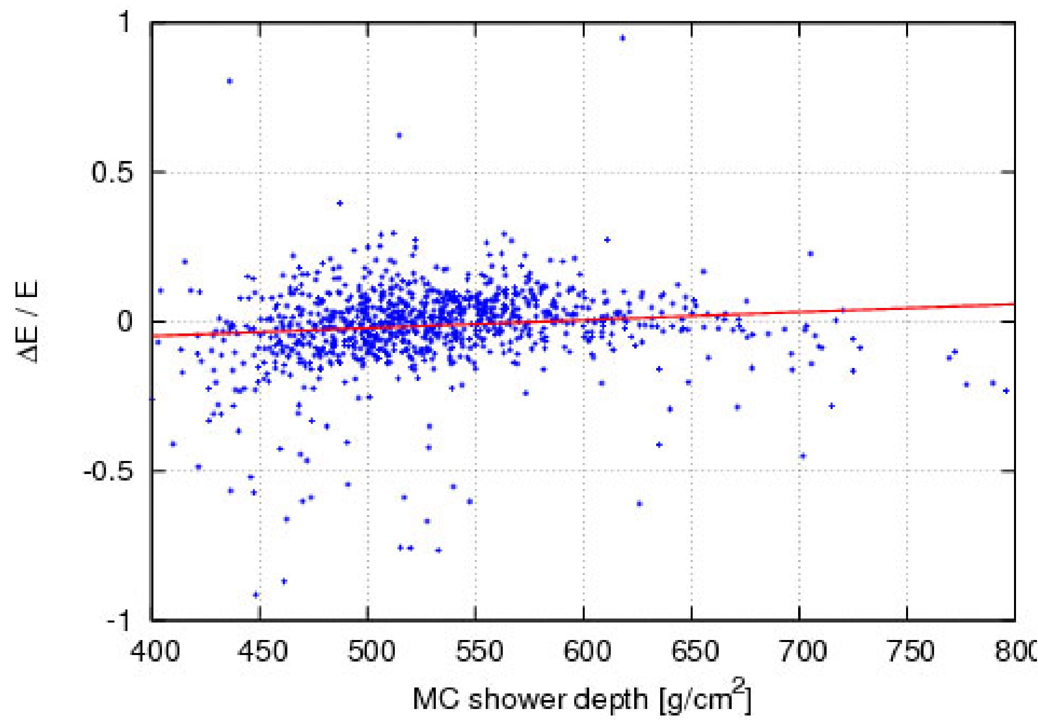
Angular resolution of alternative layouts



Energy reconstruction

Particle energy: **Q220 = Value of LDF at 220m**





Energy reconstruction

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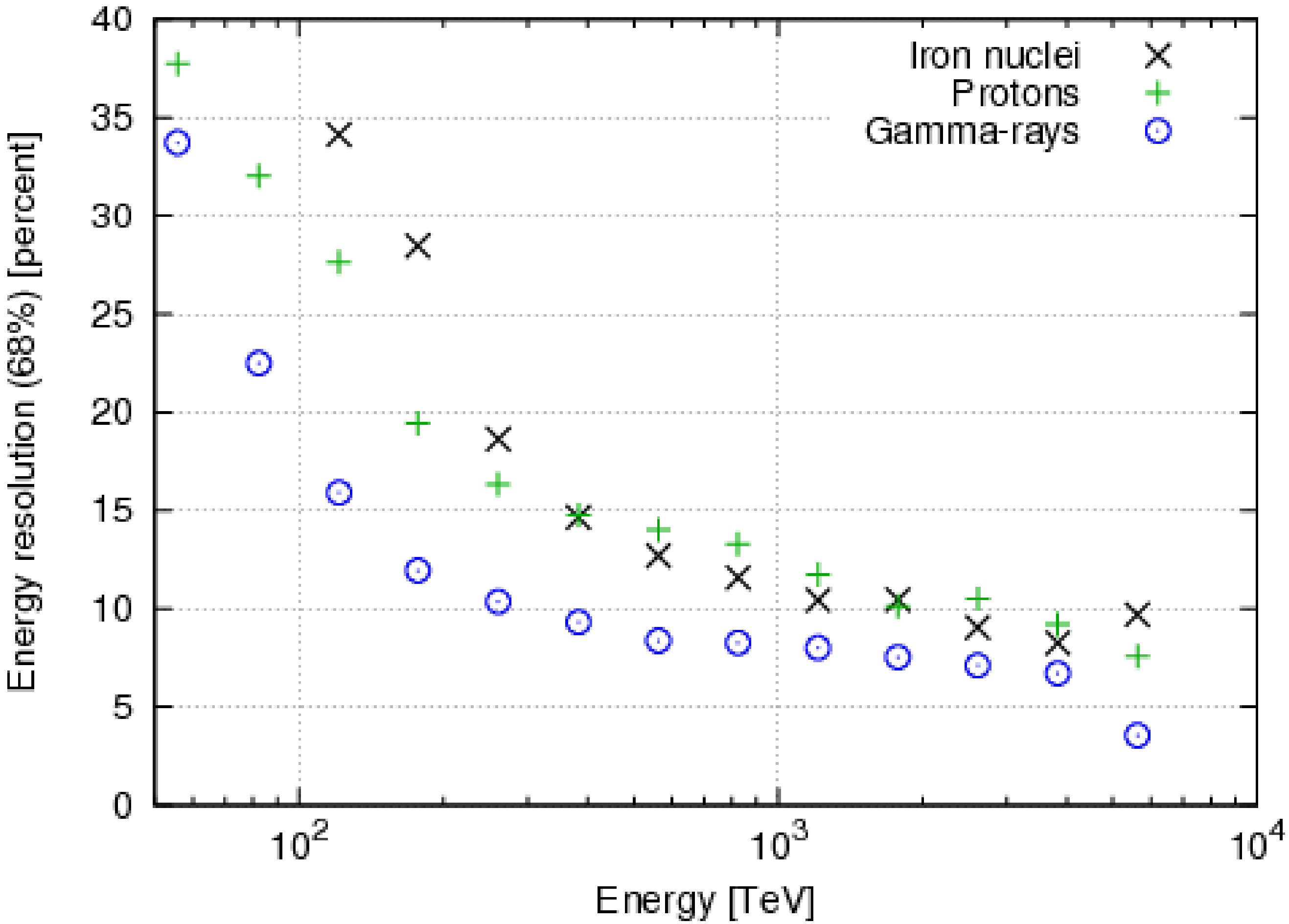
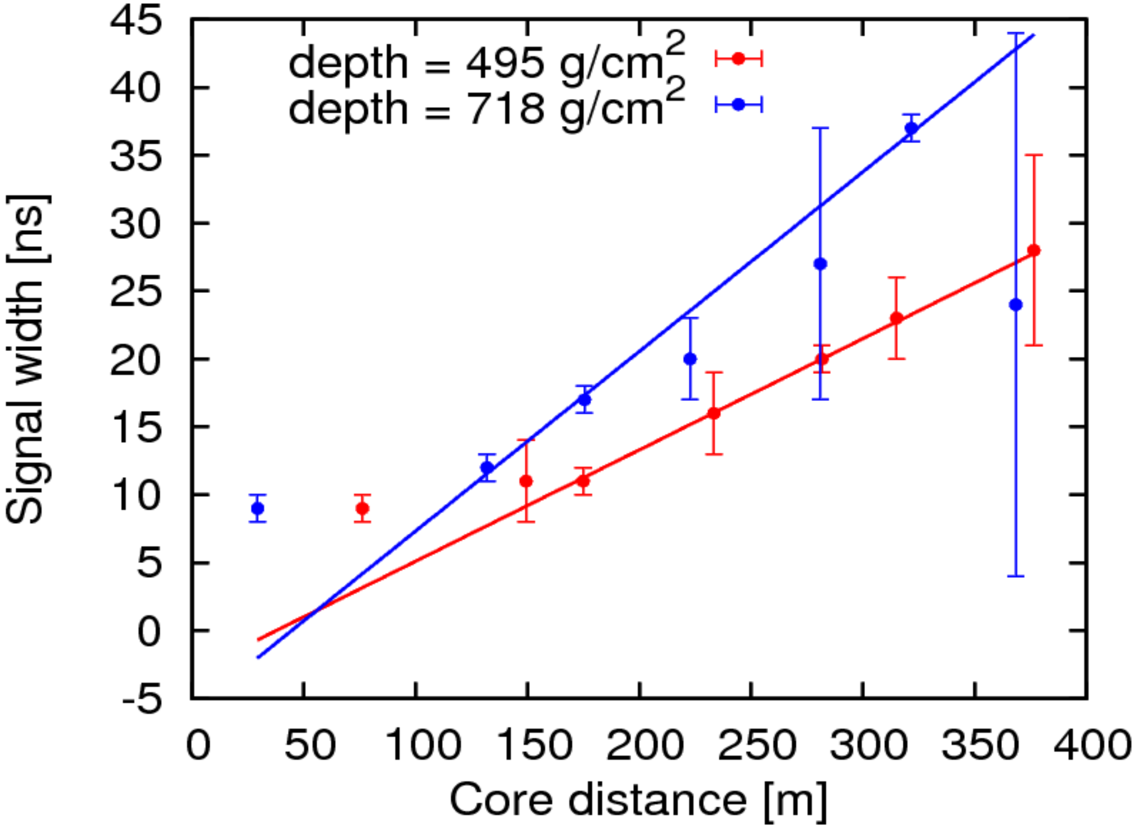


Shower depth reconstruction

- **Time model method:** one free parameter in arrival time model
- **LDF method:** Depth from LDF slope, Q50/Q220
- **Width method:** Depth from signal width



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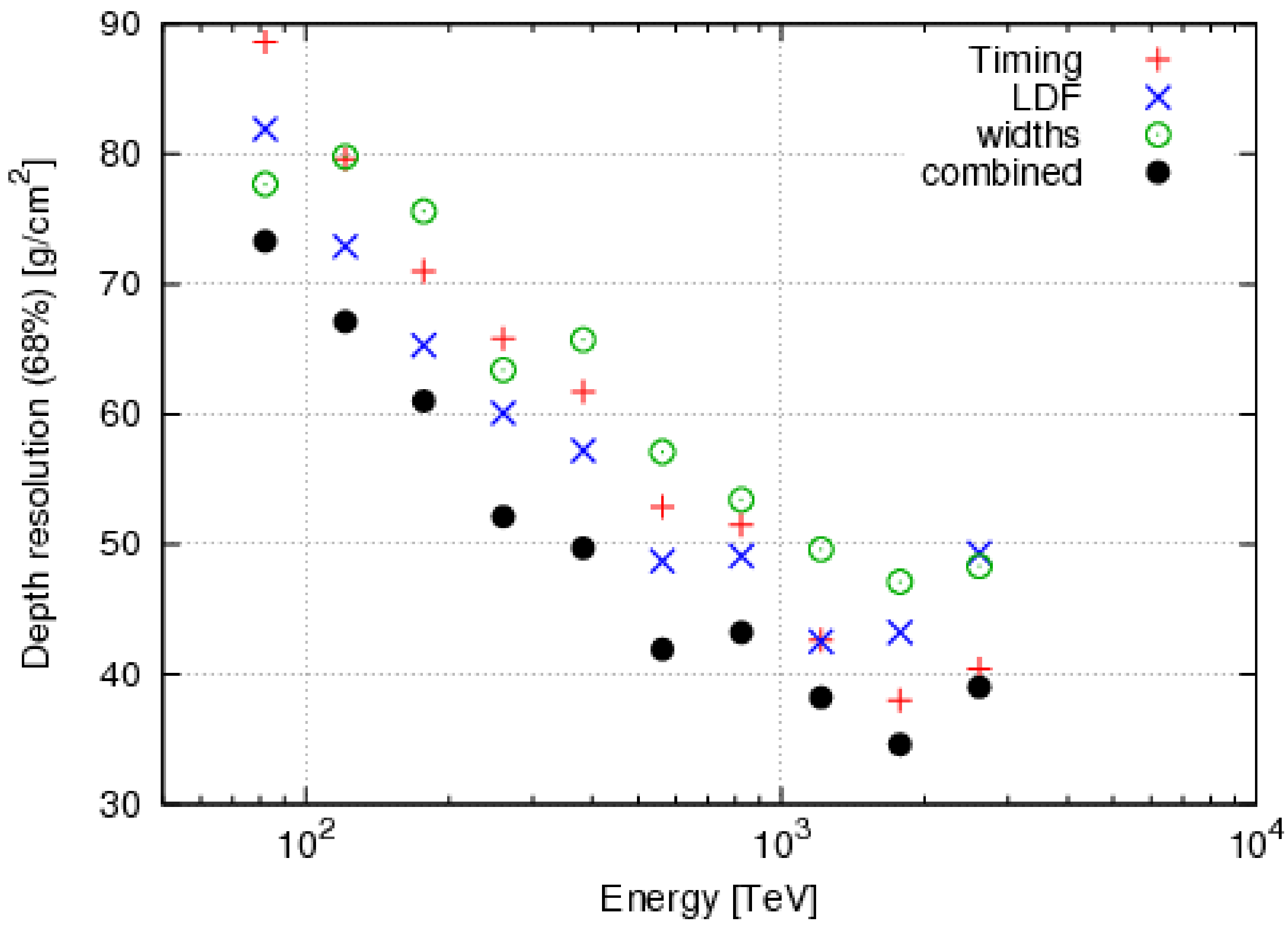
Shower depth

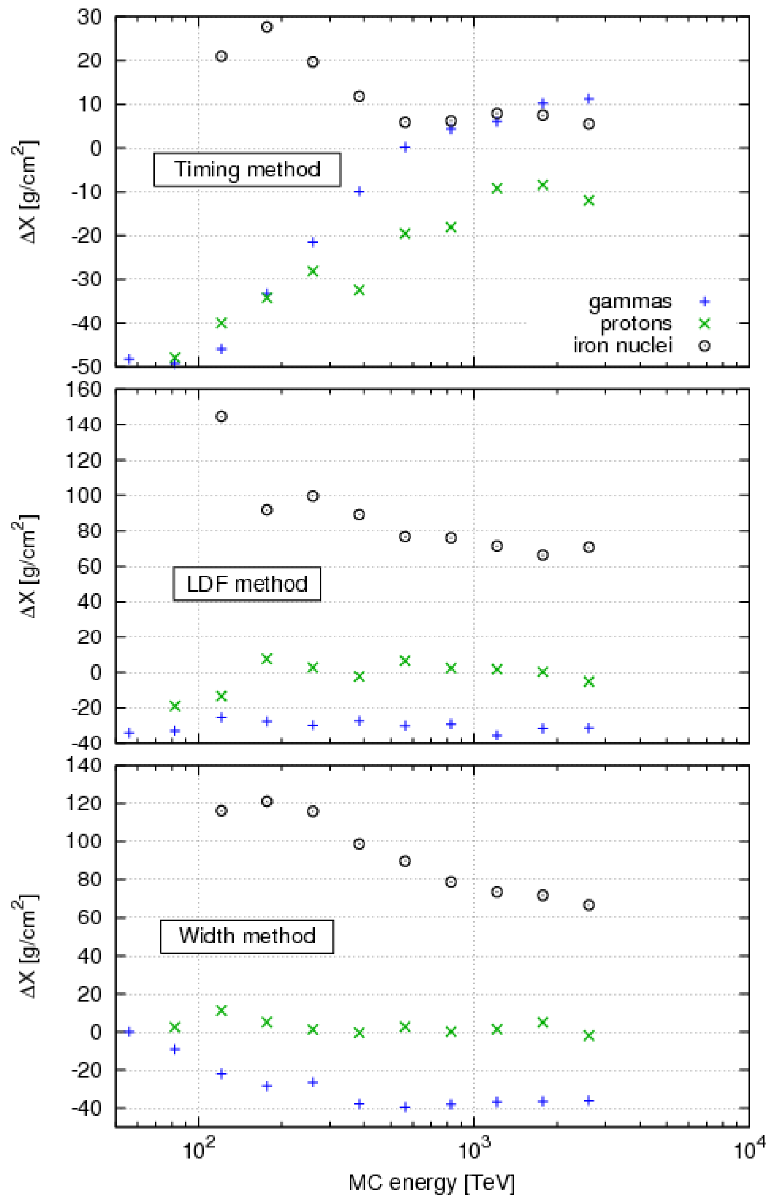
Depth of shower maximum



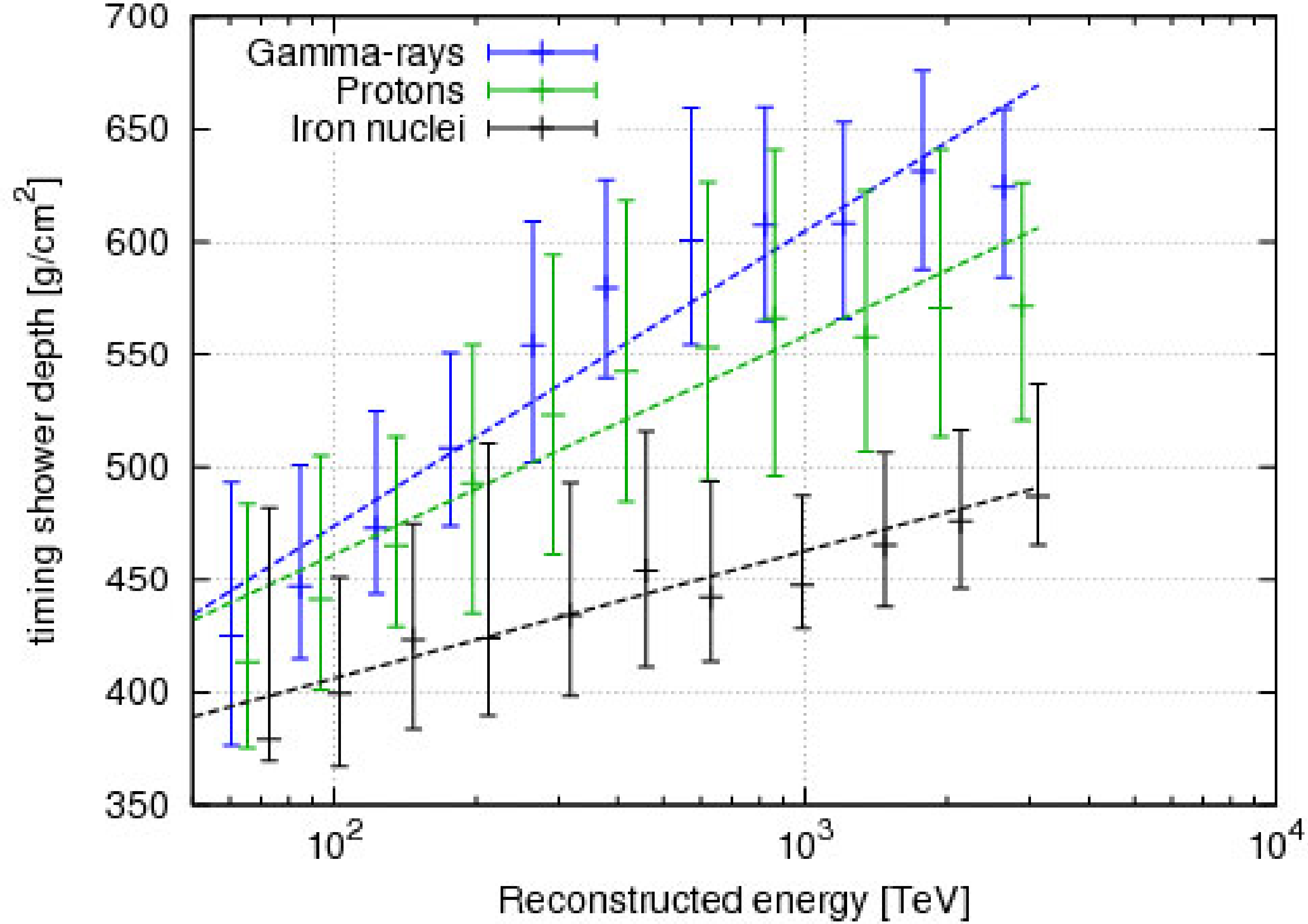
Shower depth bias

Systematic bias

- LDF & widths : sensitive to whole shower
  Large overestimation for heavy particles
  (long tails)
- Timing : sensitive to specific point
  (edge time)
  Small overestimation for heavy particles

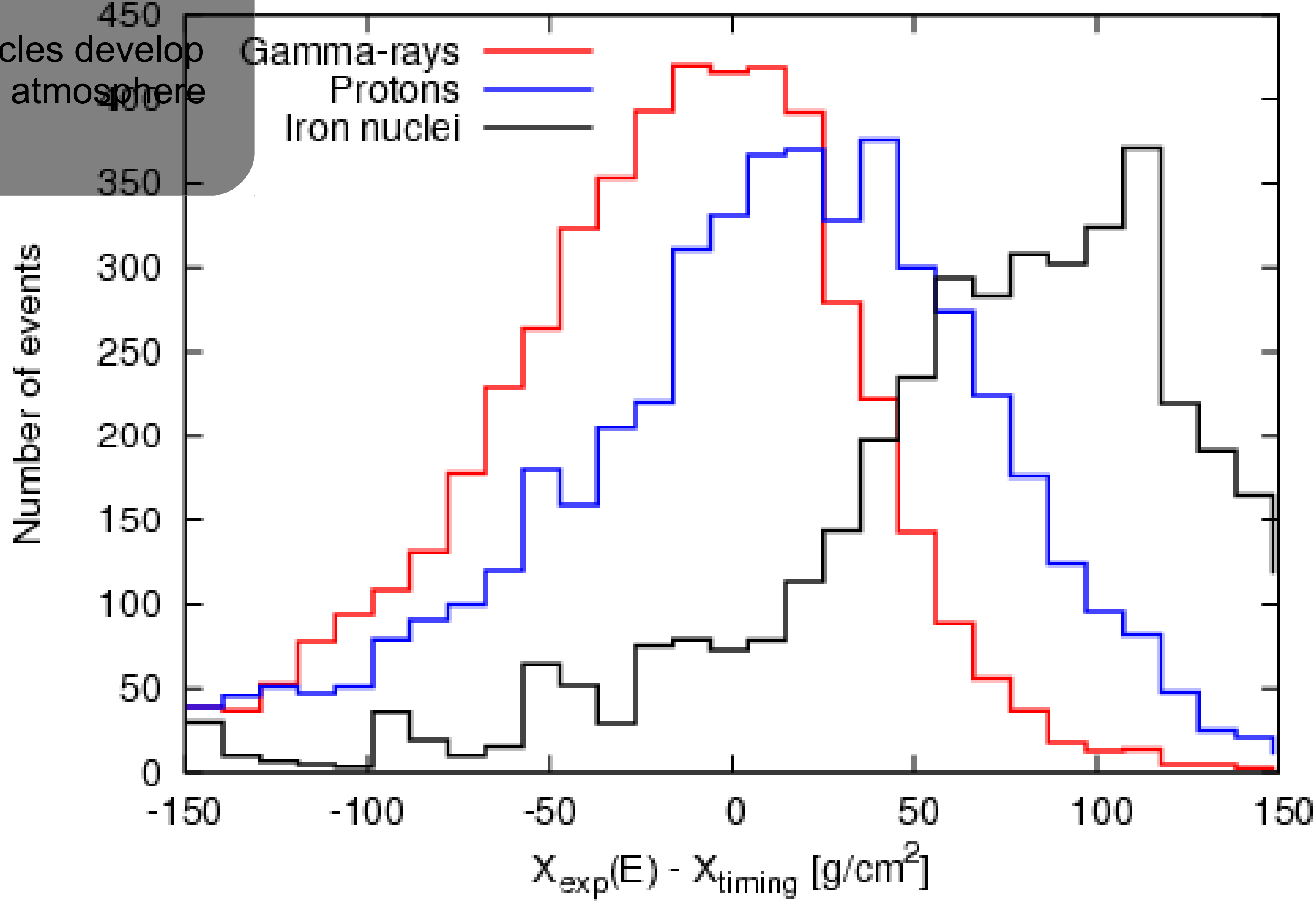


Particle separation



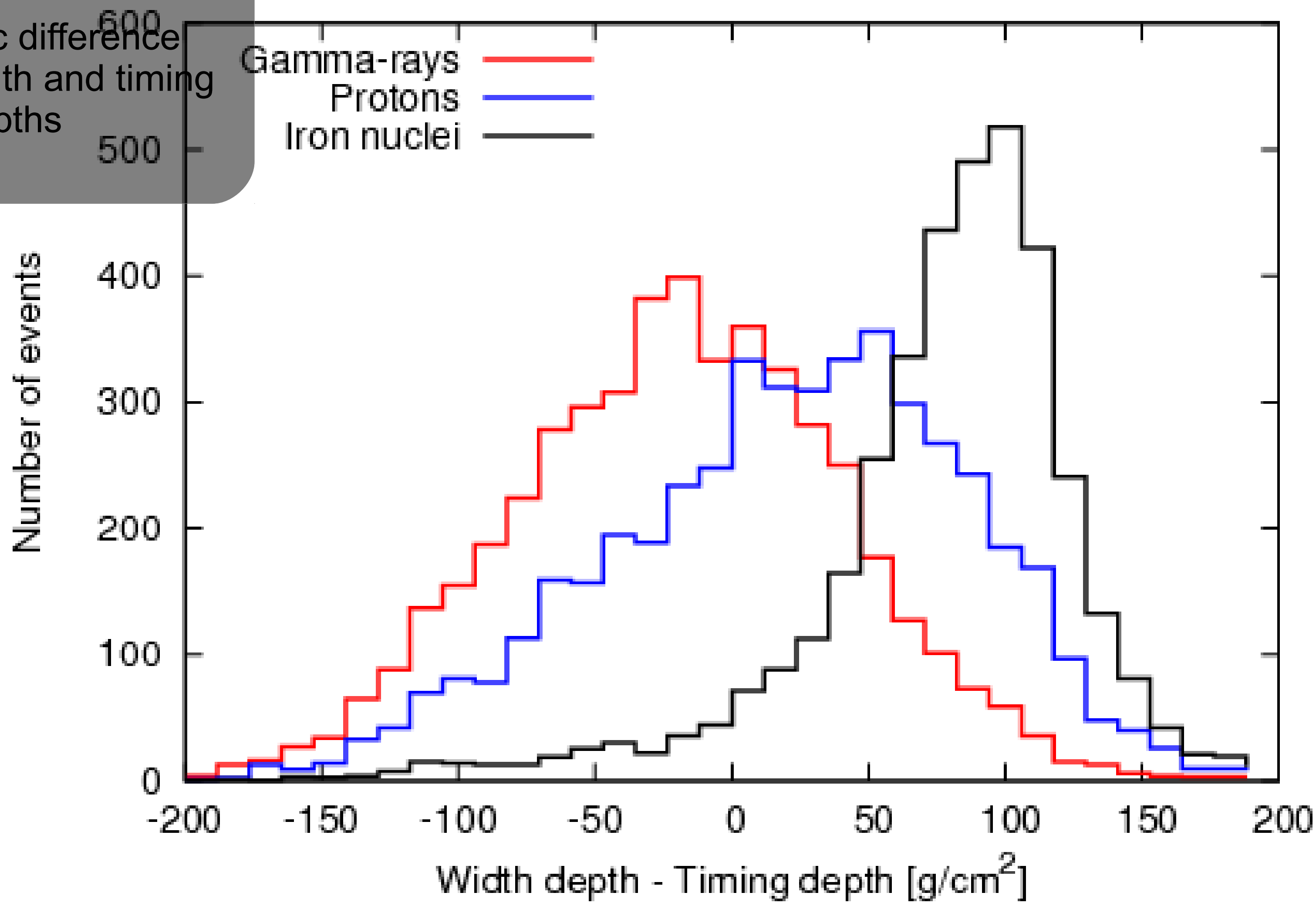
Particle separation (1)

Lighter particles develop
Higher up in atmosphere



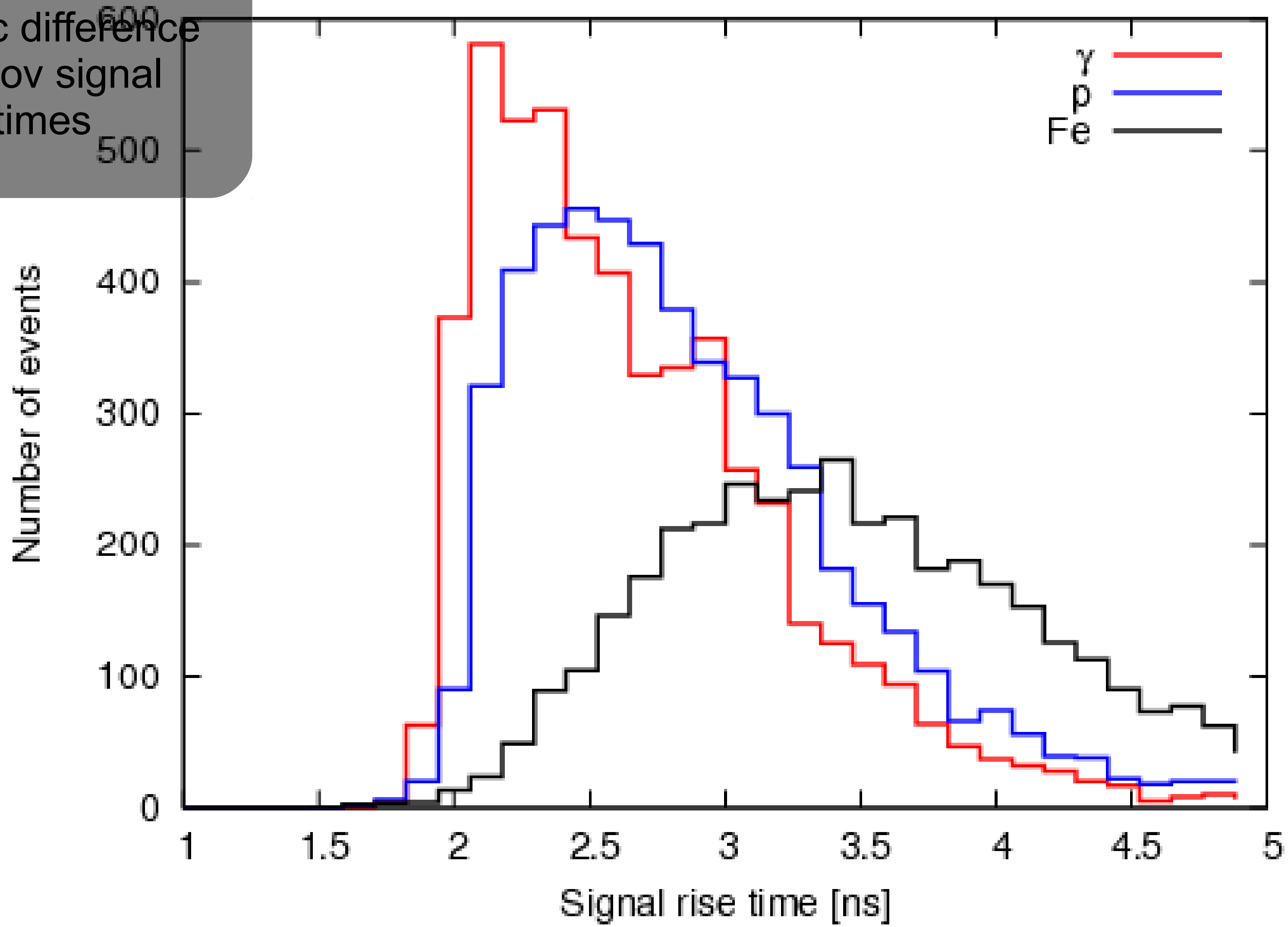
Particle separation (2)

Systematic difference
Between width and timing
Depths



Particle separation (3)

Systematic difference Cherenkov signal rise times



HRJRG-303
Helmholtz Russia Joint Research Group

“Measurements of Gamma Rays and Charged Cosmic Rays in the Tunka-Valley in Siberia by Innovative New Technologies”

04/2012 – 04/2015

G. Rubtsov, I. Tkatchev (*INR)*

A. Konstantinov, L. Kuzmichev (*MSU)*

R. Vasilyev, N. Budnev (*ISU)*

R. Wischnewski, C. Spiering (*DESY)*

F. Schröder, A. Haungs (*KIT)*

M. Tluczykont, D. Horns (*U. Hamburg)*

HiSCORE and Radio detectors @ Tunka

Innovation
Proof-of-principle
Synergies