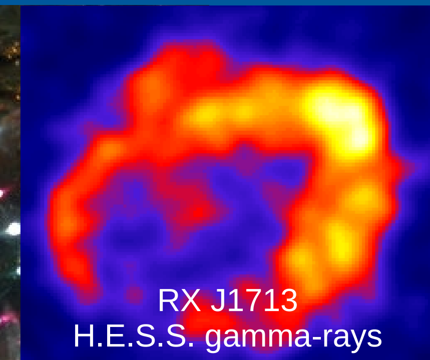
Measurements of Gamma Rays and Charged Cosmic Rays in the Tunka-Valley in Siberia by Innovative New Technologies – HRJRG 303



HiSCORE

M. Tluczykont for the HiSCORE Collaboration

Astroteilchenphysik in Deutschland
Zeuthen, 09/2012

HiSCORE

Universität Hamburg
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The **H**undred*__i__ **S**quare-km **C**osmic **OR**igin **E**xplorer

Cosmic-rays: 100 TeV < E_{CR} < 1 EeV

Gamma-rays: $E\gamma$ > 10 TeV, up to PeV, ultra-high energy regime

Particle physics: beyond LHC range

Concept: non-imaging air Cherenkov technique

Large area: up to few 100 km²

Large Field of view: ~ 0.6 sr

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

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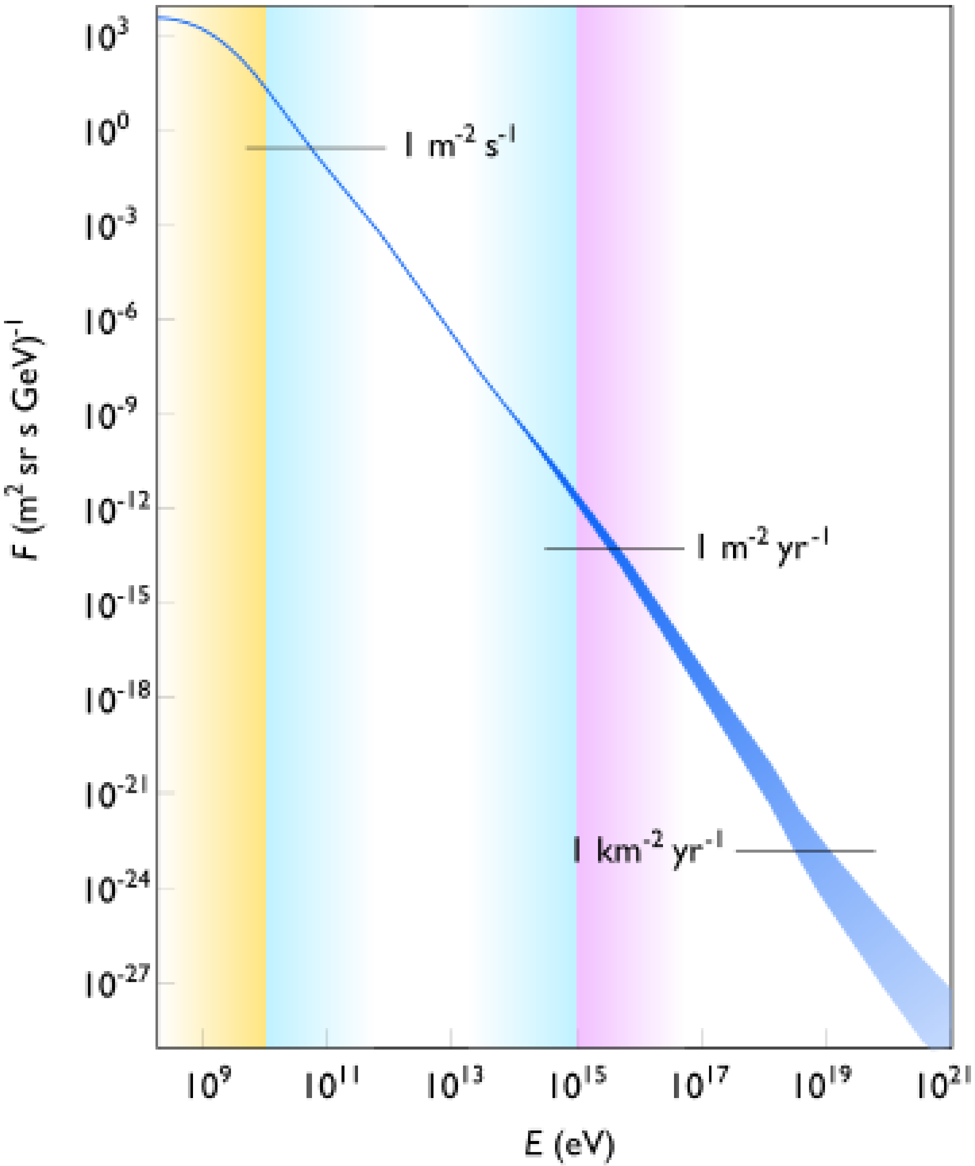
Why do we need a large area ?



Energetic events

are rare.

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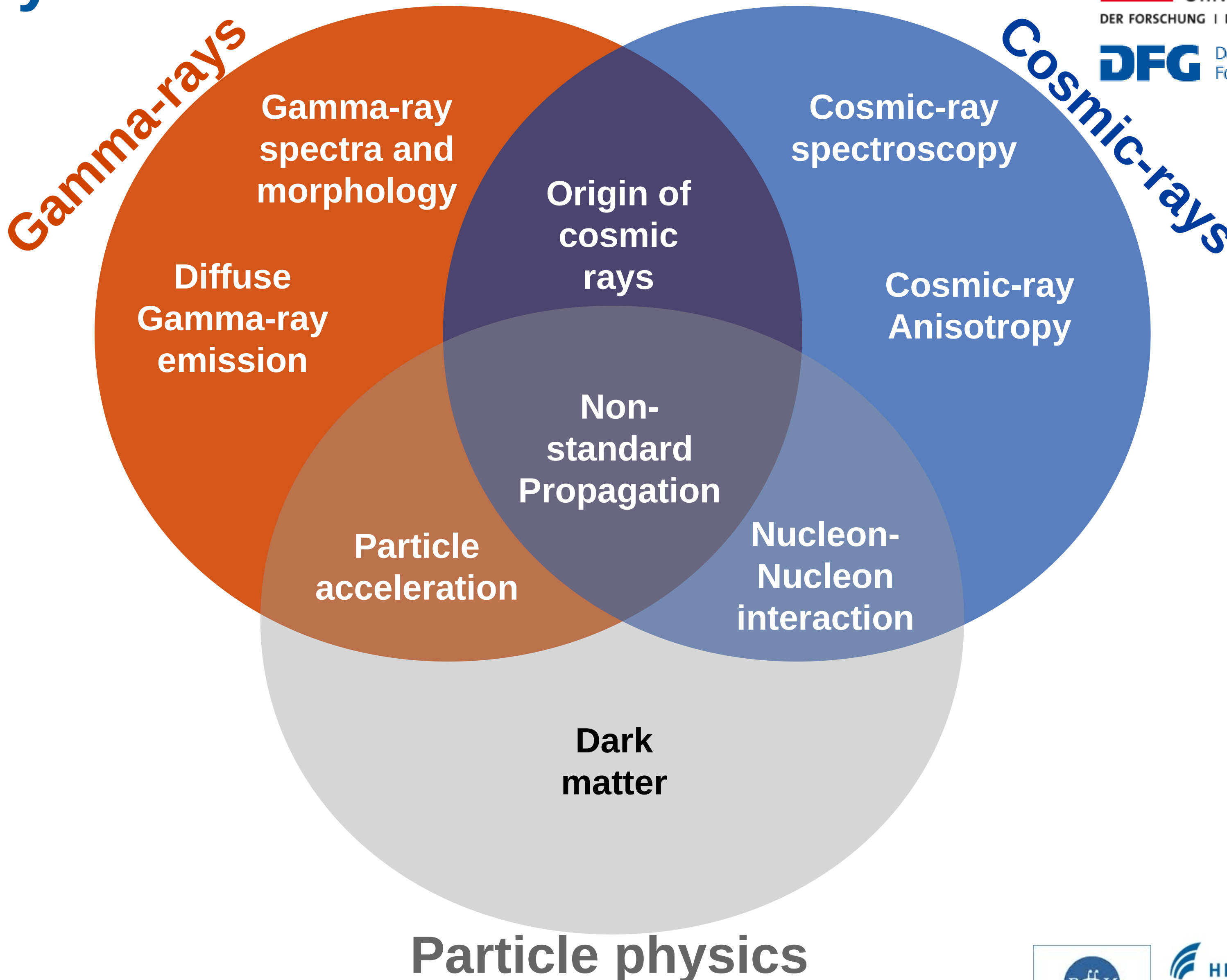
Physics motivations

Physics motivations



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Cosmic rays

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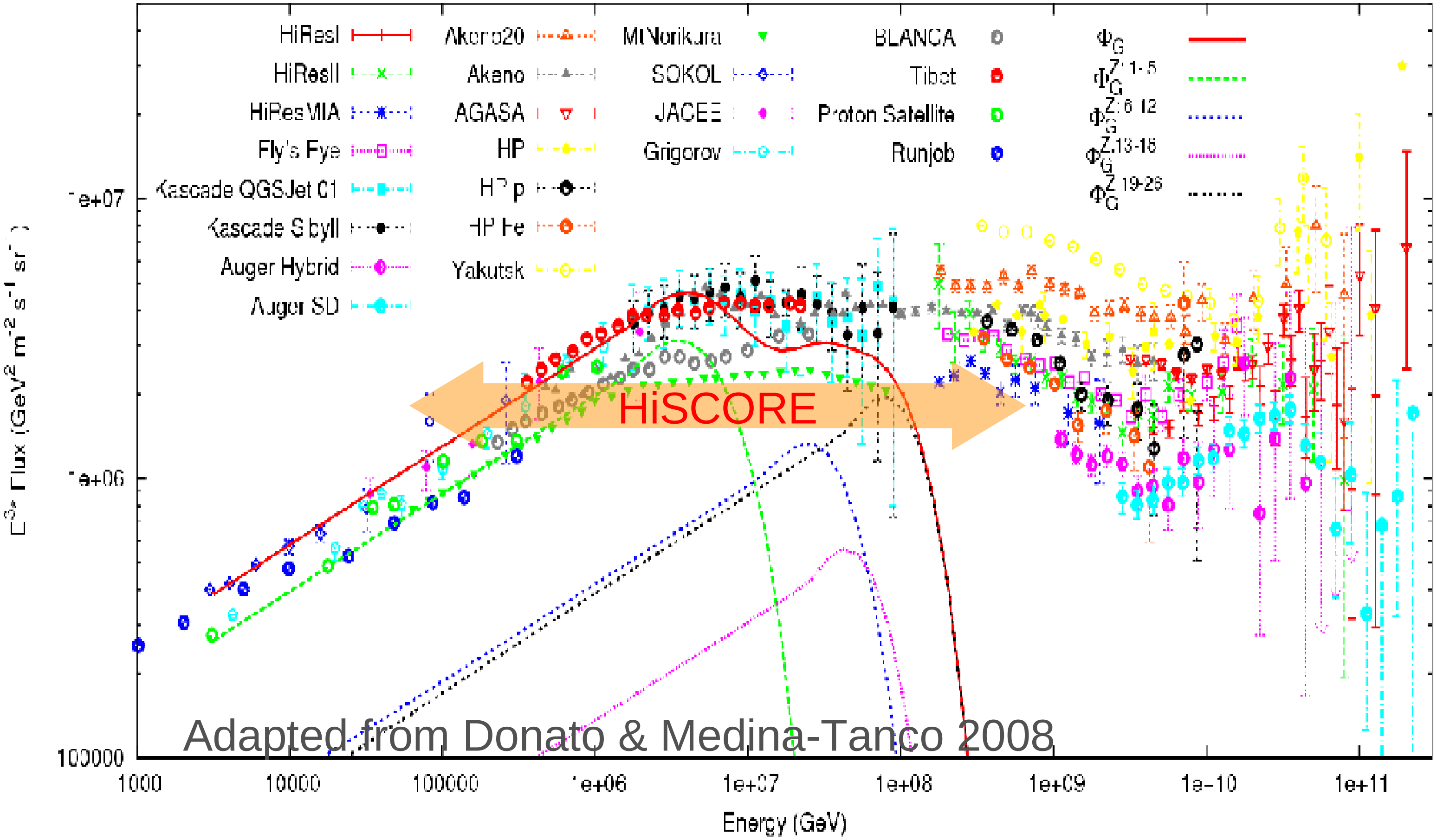

Spectrum&composition in transition range
Galactic / extragalactic origin

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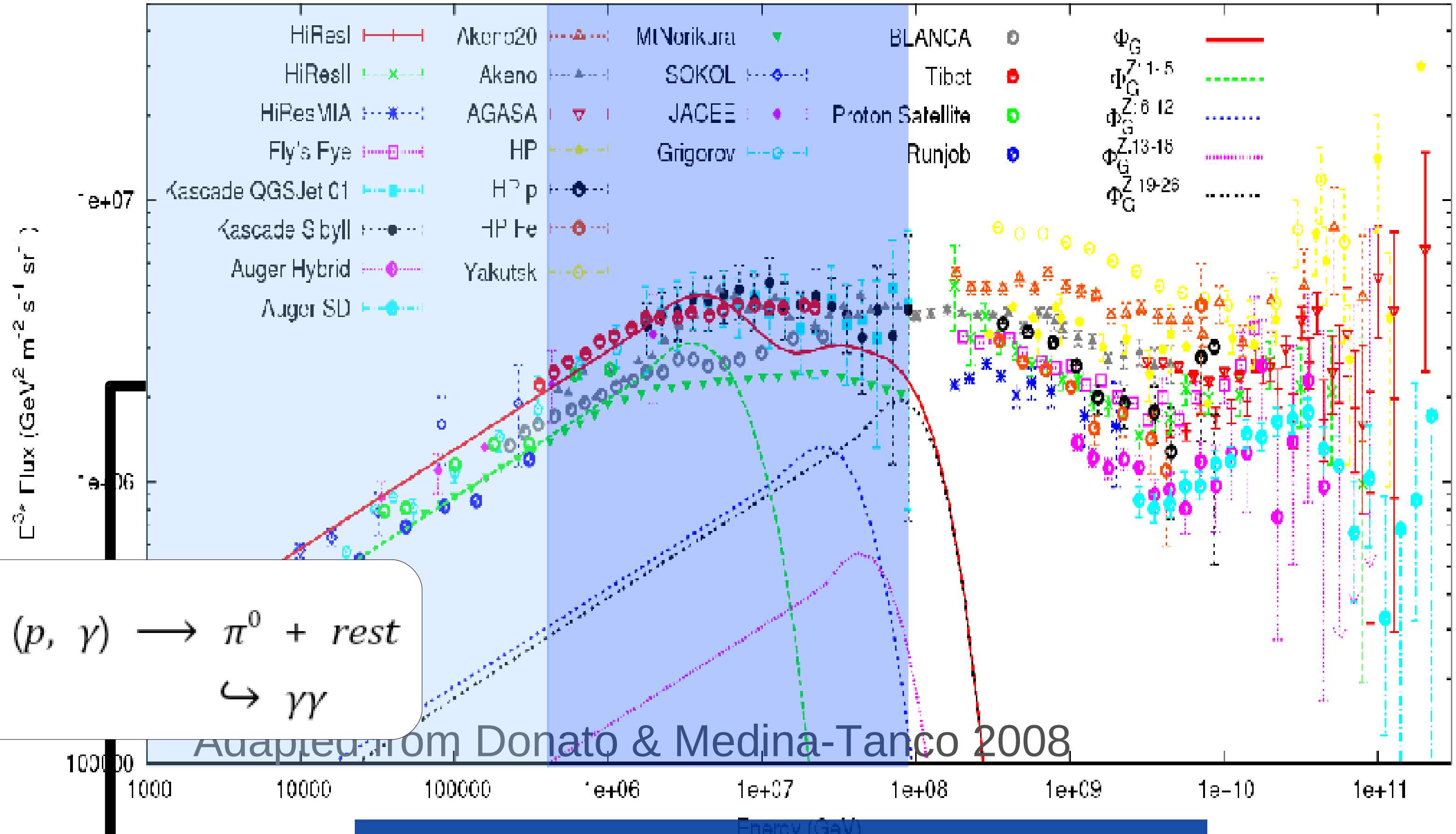
Cosmic ray *origin*



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

Adapted from Donato & Medina-Tanco 2008

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

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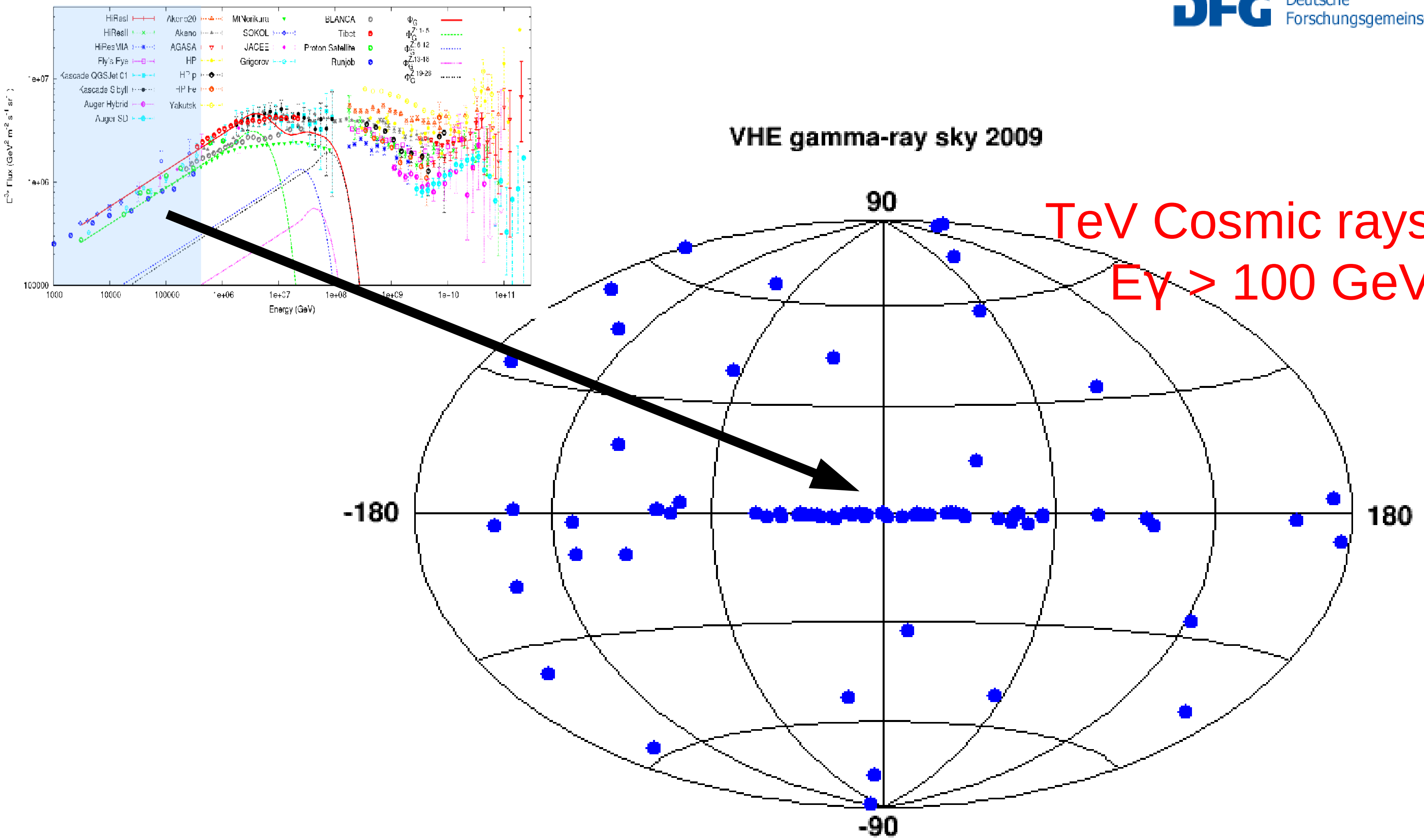
Tevatron sky



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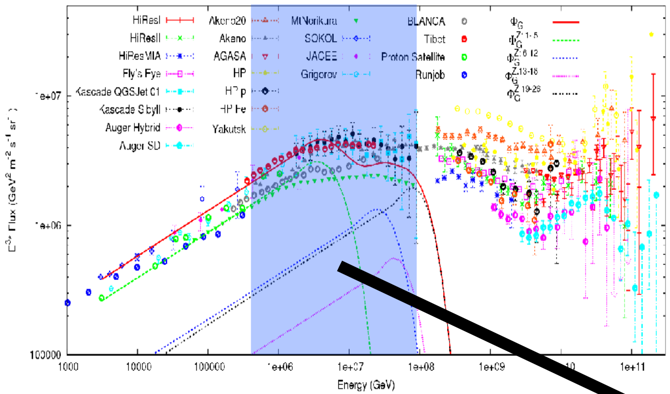
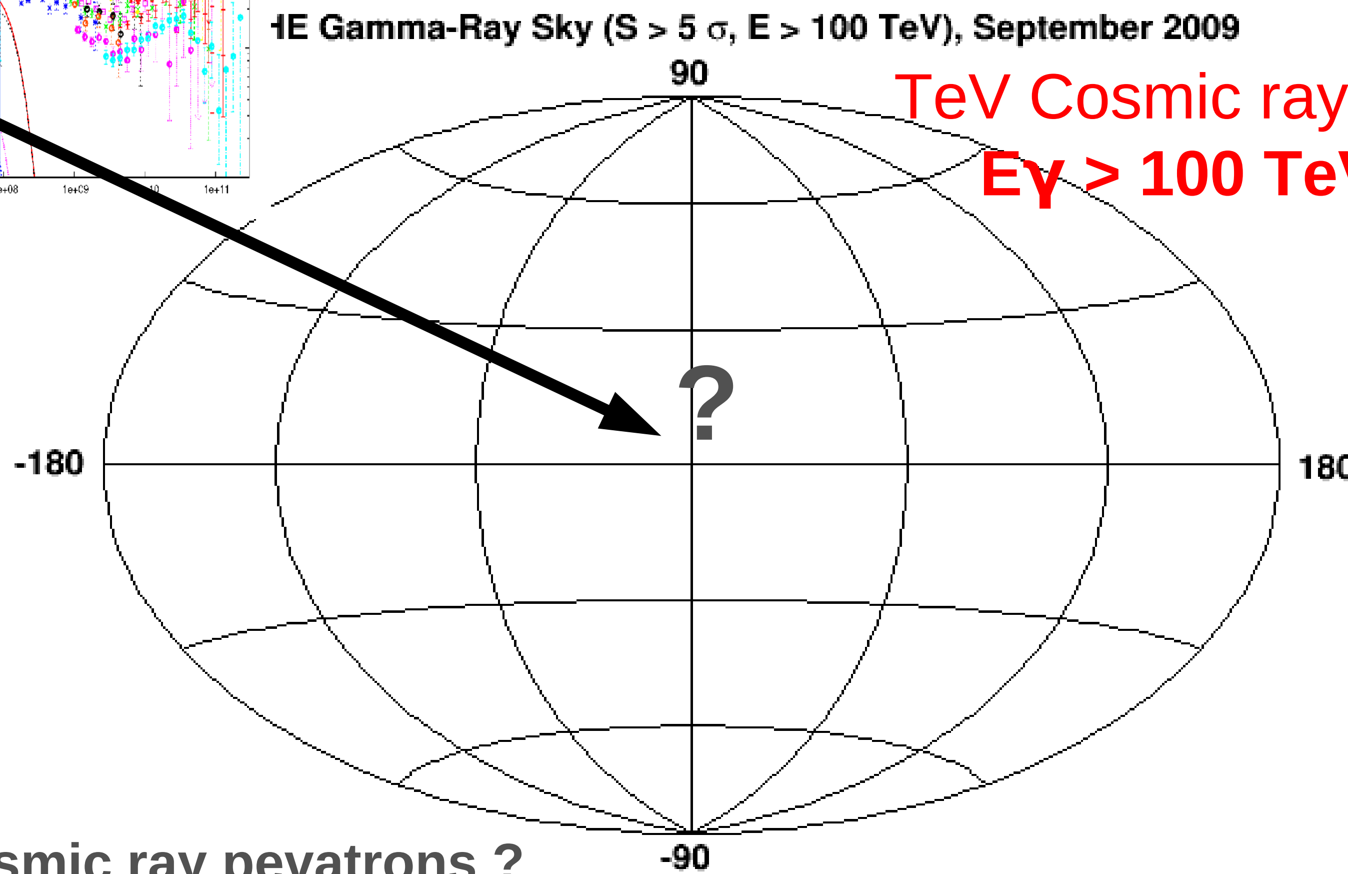
Pevatron sky





TeV Cosmic rays

Eγ > 100 TeV

Where are the cosmic ray pevatrons ?

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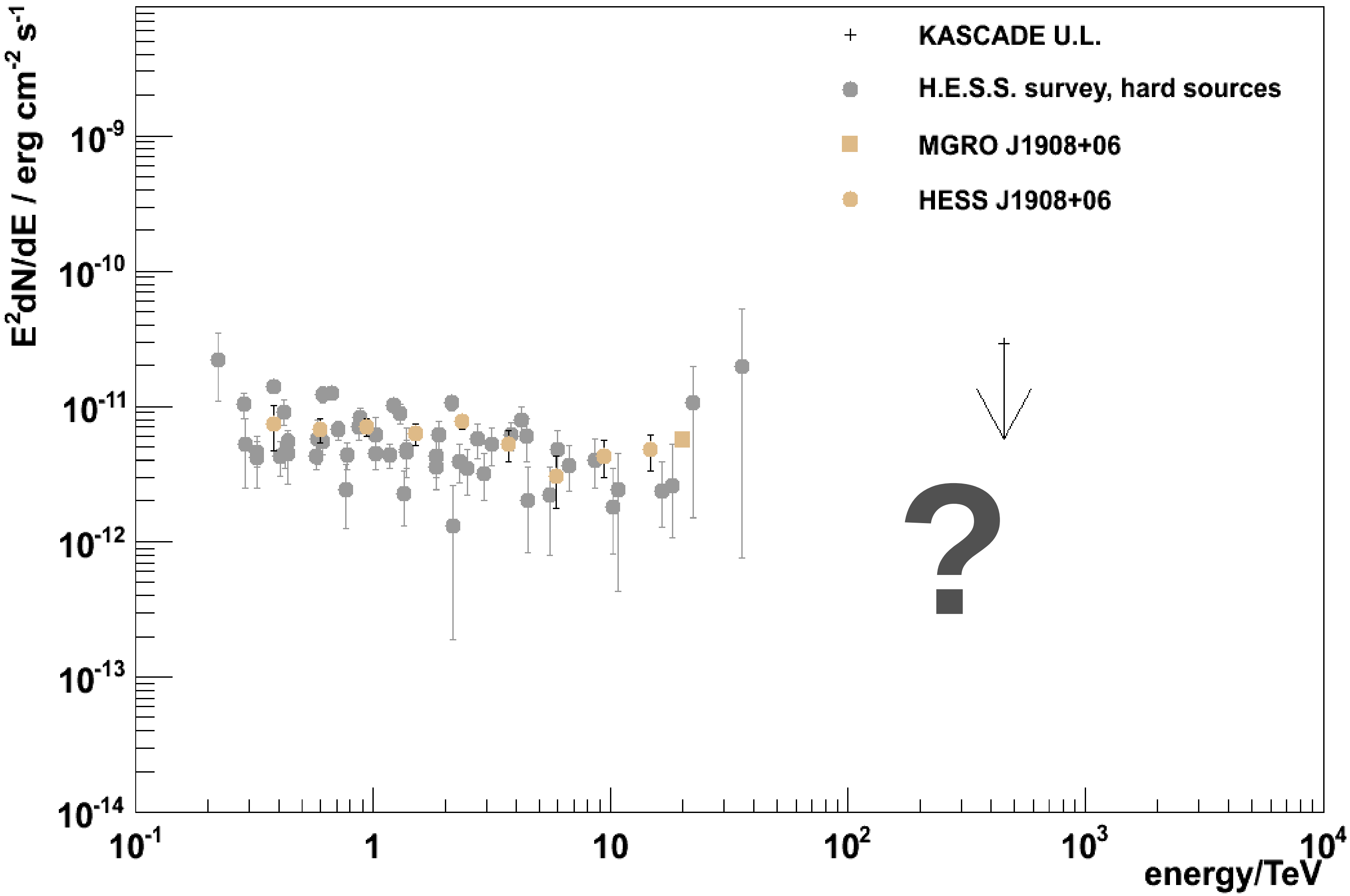
The Pevatron energy range



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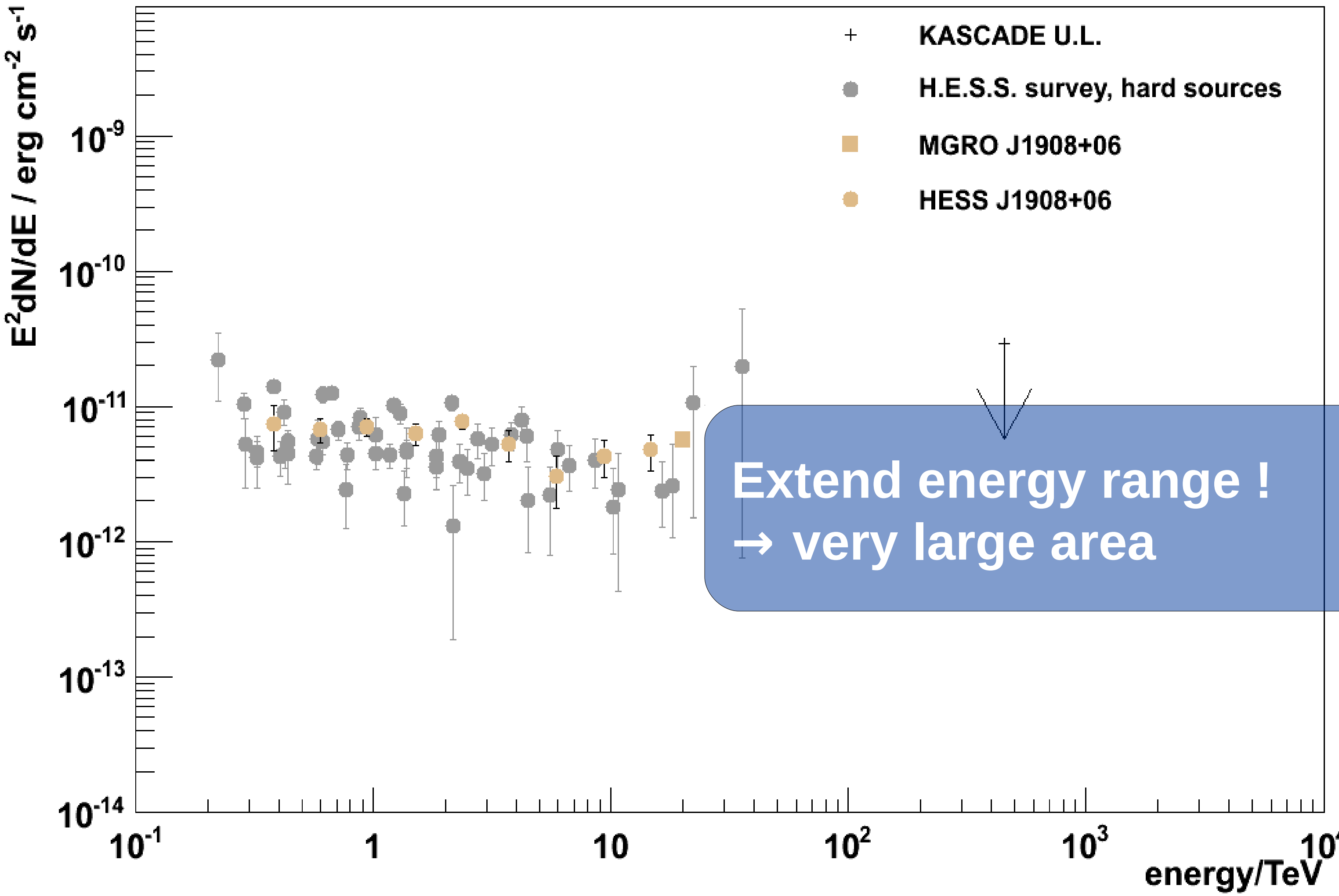
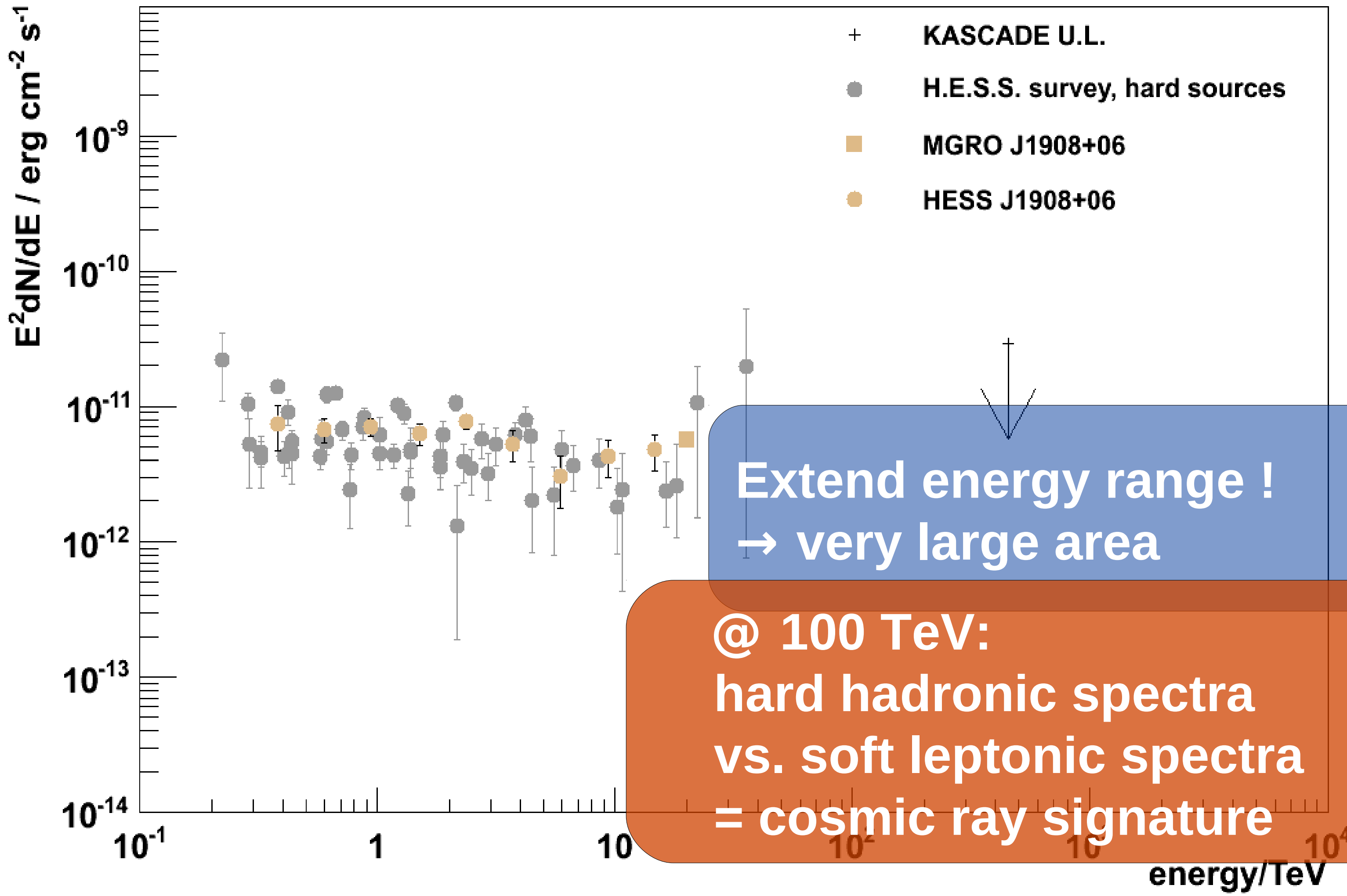
Opening the Pevatron range



Extend energy range !
→ very large area

Opening the Pevatron range



Extend energy range !
→ very large area

@ 100 TeV:
hard hadronic spectra
vs. soft leptonic spectra
= cosmic ray signature

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Accessing the pevatron sky: large area

The HiSCORE detector

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The HiSCORE detector

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How to achieve large effective area ?

- **Imaging air Cherenkov telescopes:**
  O(1000) channels / km²
- **Non-imaging air Cherenkov technique:**
  O(100) channels / km²

Picture: Serge Brunier

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The HiSCORE detector

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The HiSCORE detector

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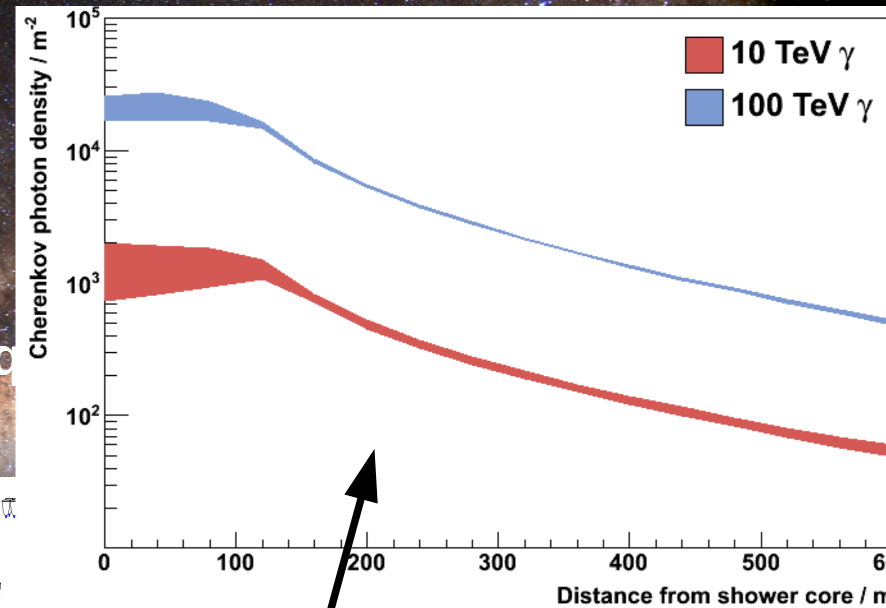

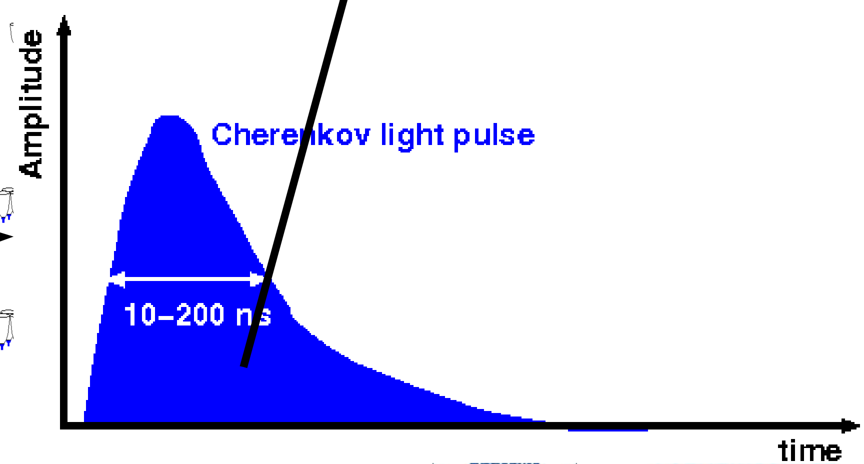

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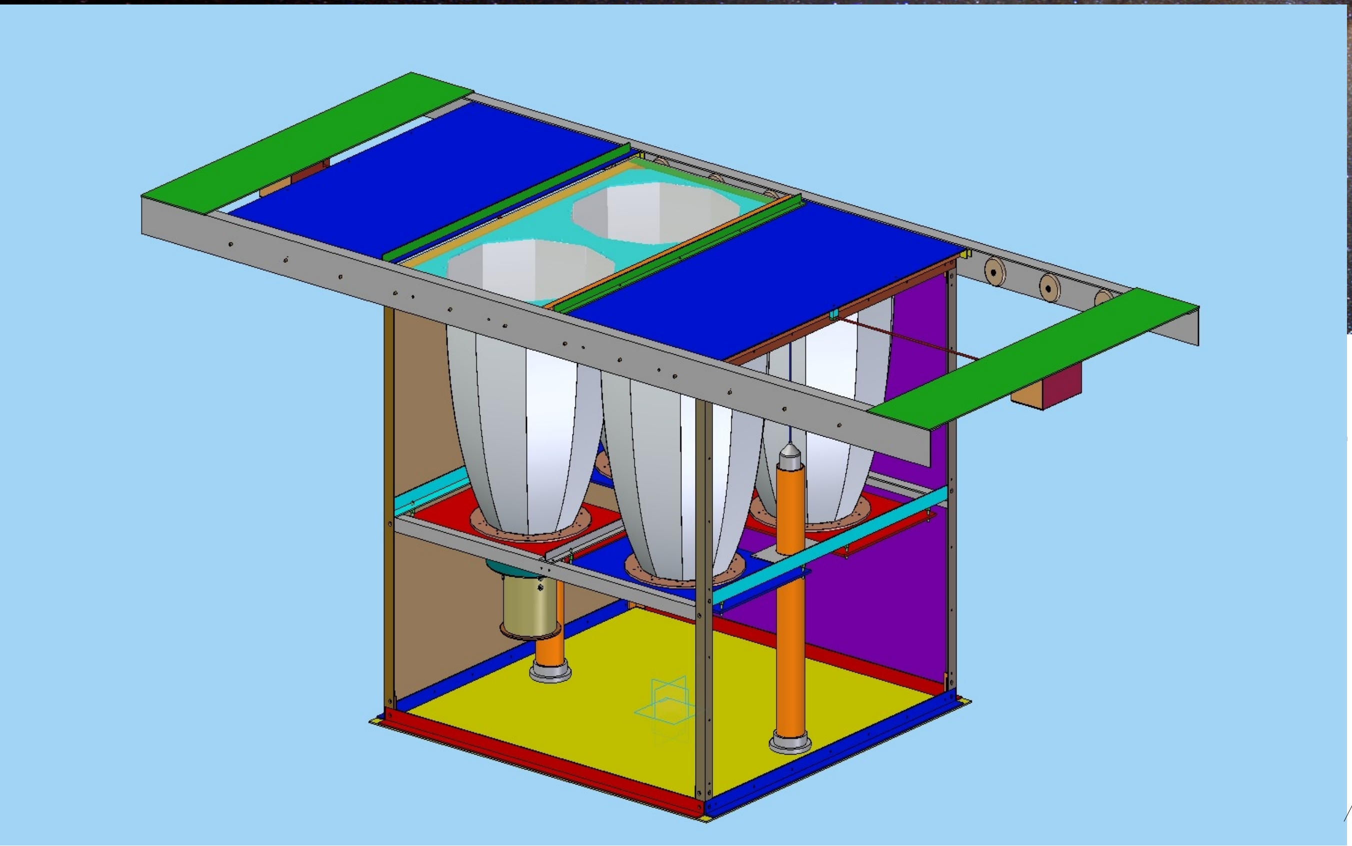
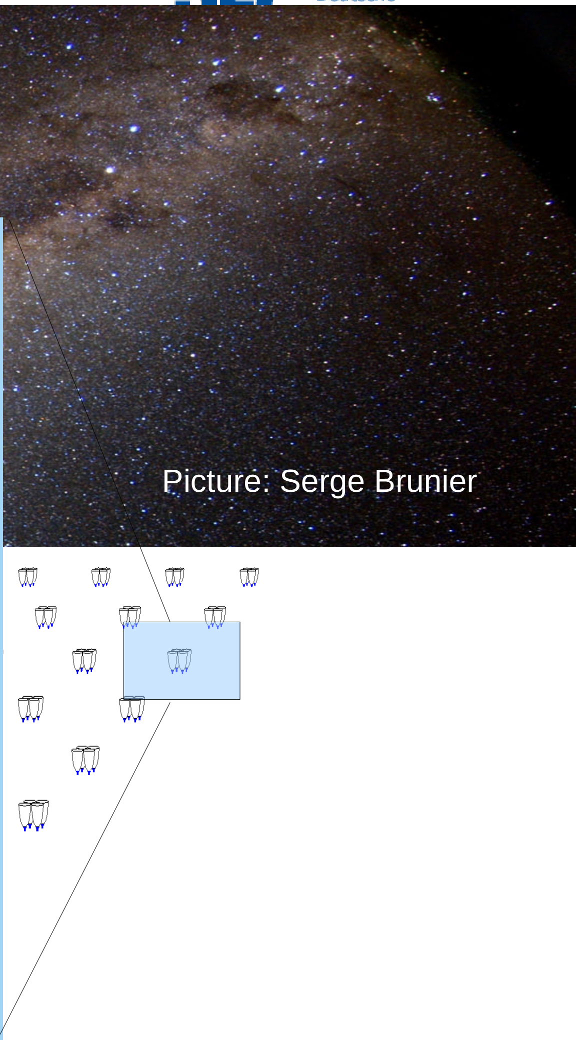
The HiSCORE detector

The HiSCORE detector



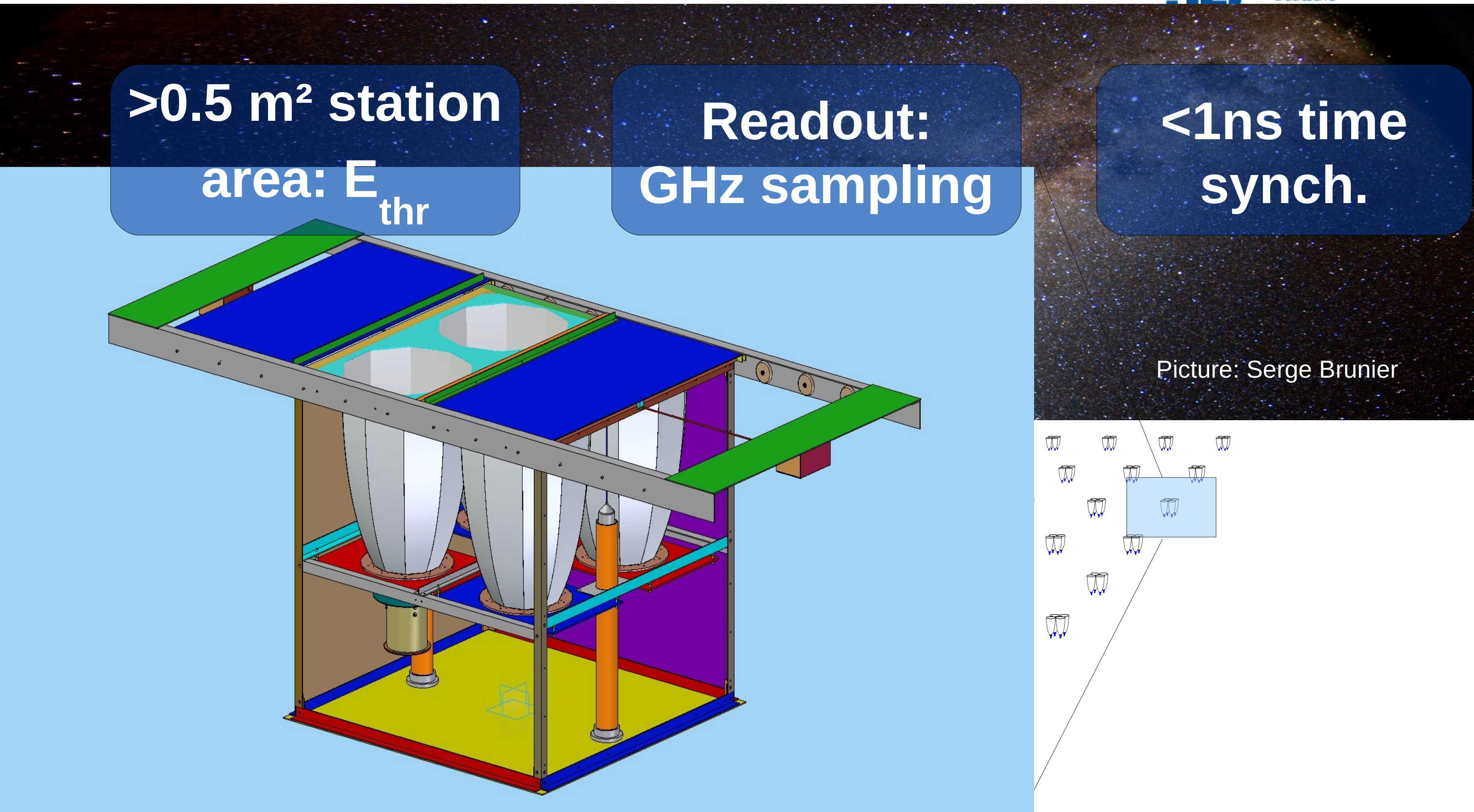


The HiSCORE detector

>0.5 m² station area: E_{thr}

Readout: GHz sampling

<1ns time synch.



Picture: Serge Brunier

Physics potential of HiSCORE

(gamma-ray astronomy)

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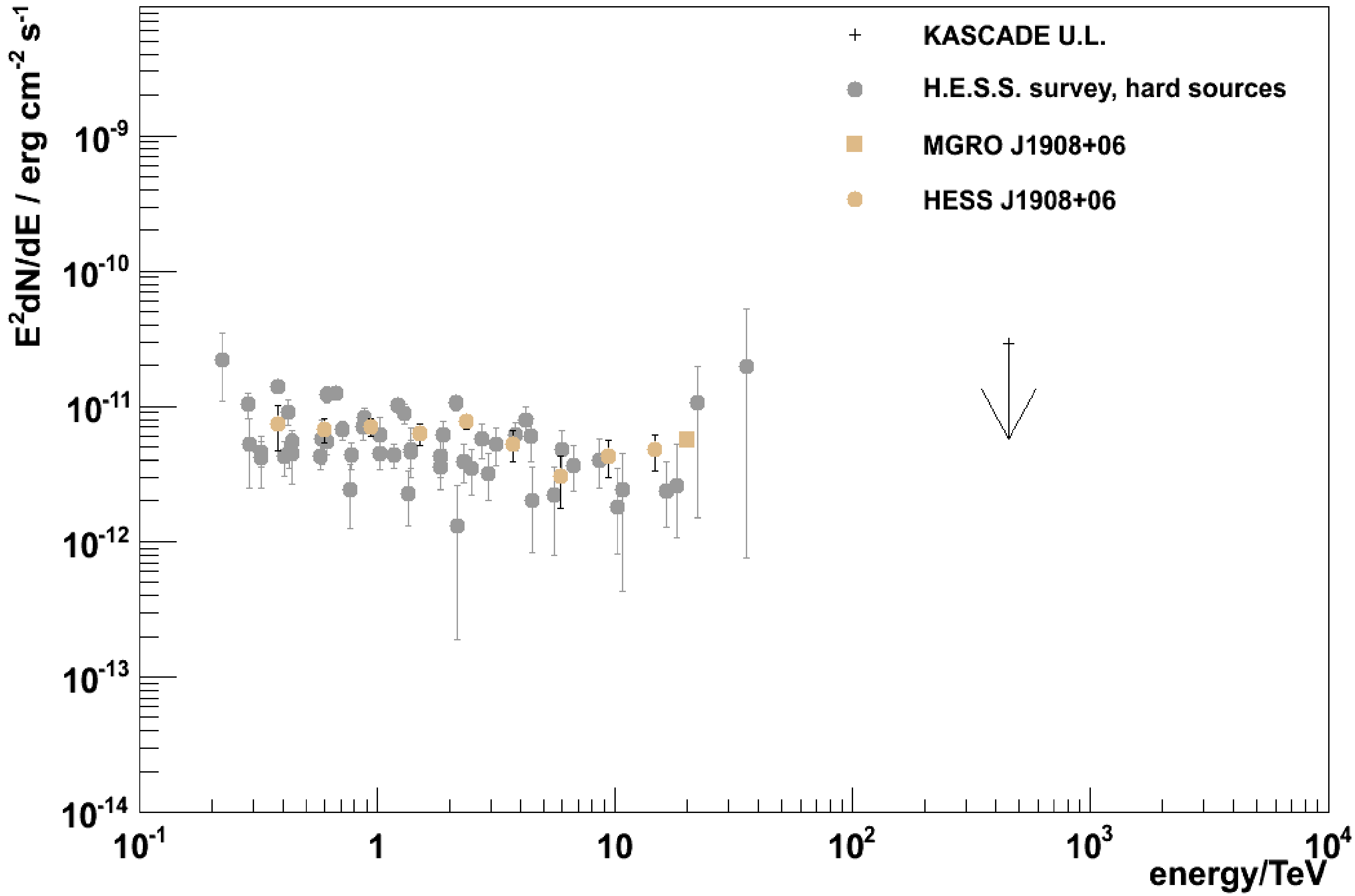
Opening the Pevatron range



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Opening the Pevatron range

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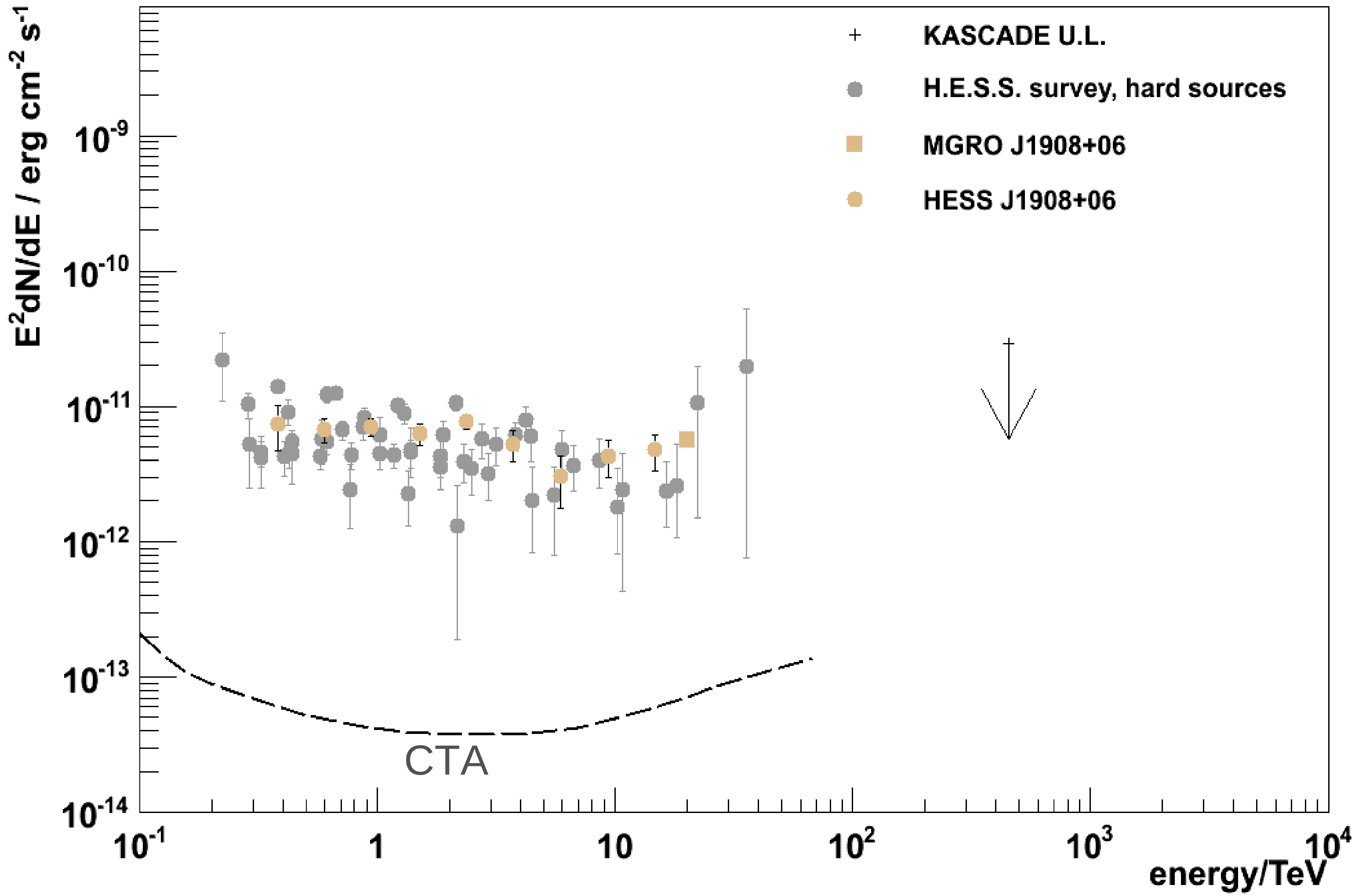

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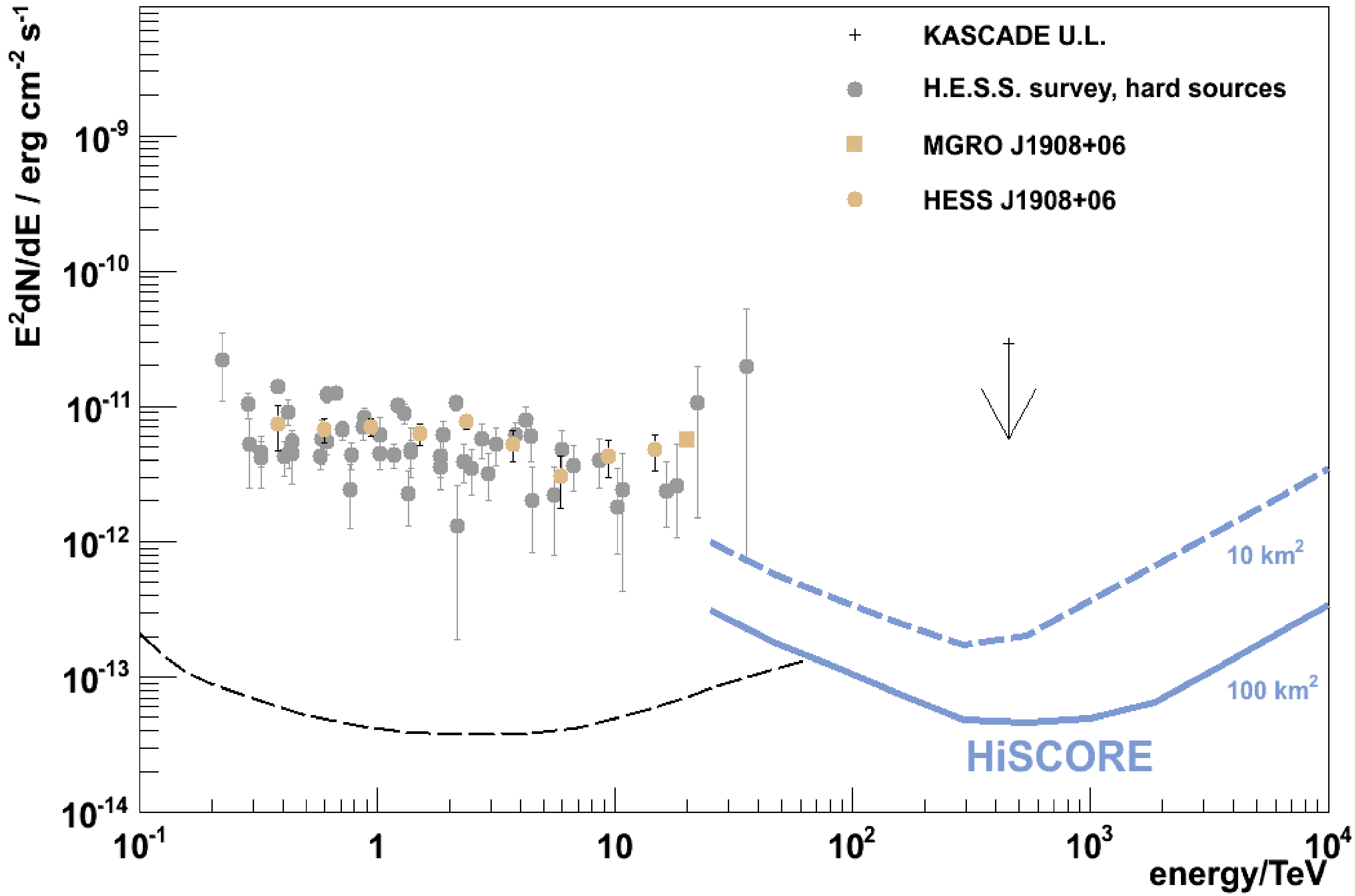
Opening the Pevatron range



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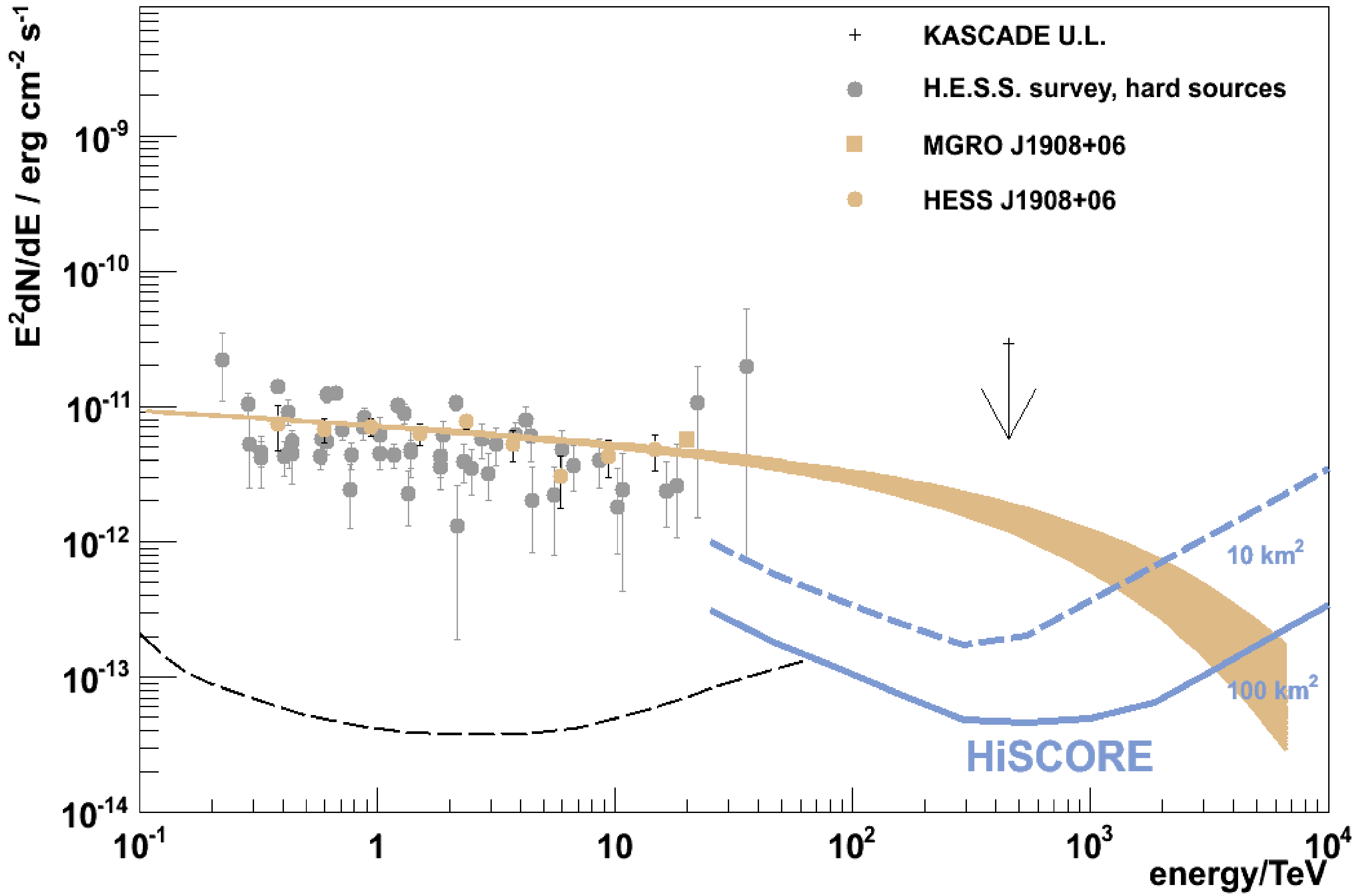

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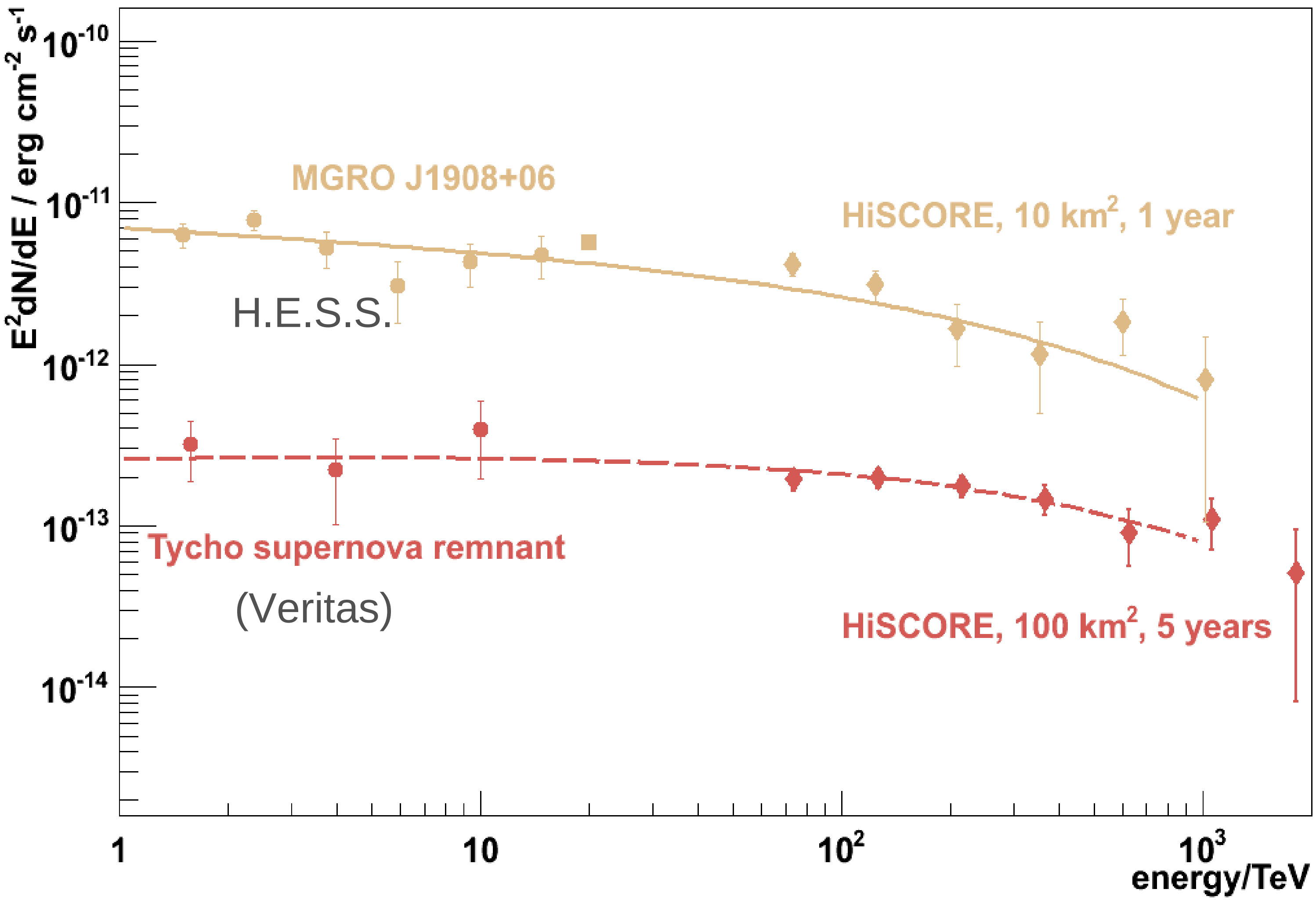
Potential HiSCORE detections



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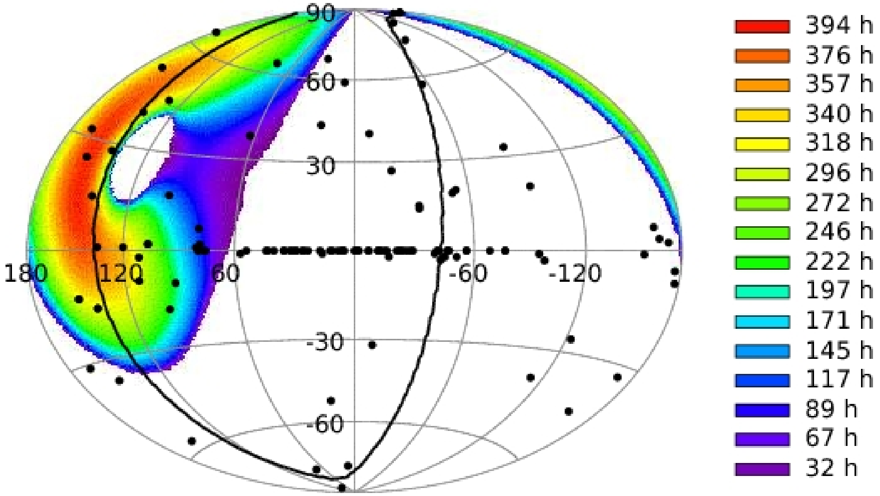
Tunka site exposure map



Tunka site exposure map

Field of view: π steradian

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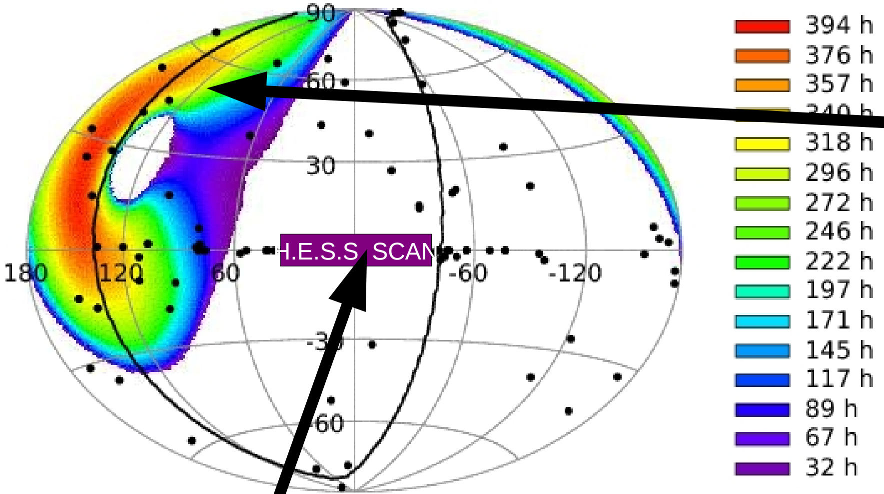
Tunka site exposure map



HiSCORE scan, 1 year

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

Tunka site exposure map
Field of view: π steradian

HiSCORE current status and plans

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Tunka valley

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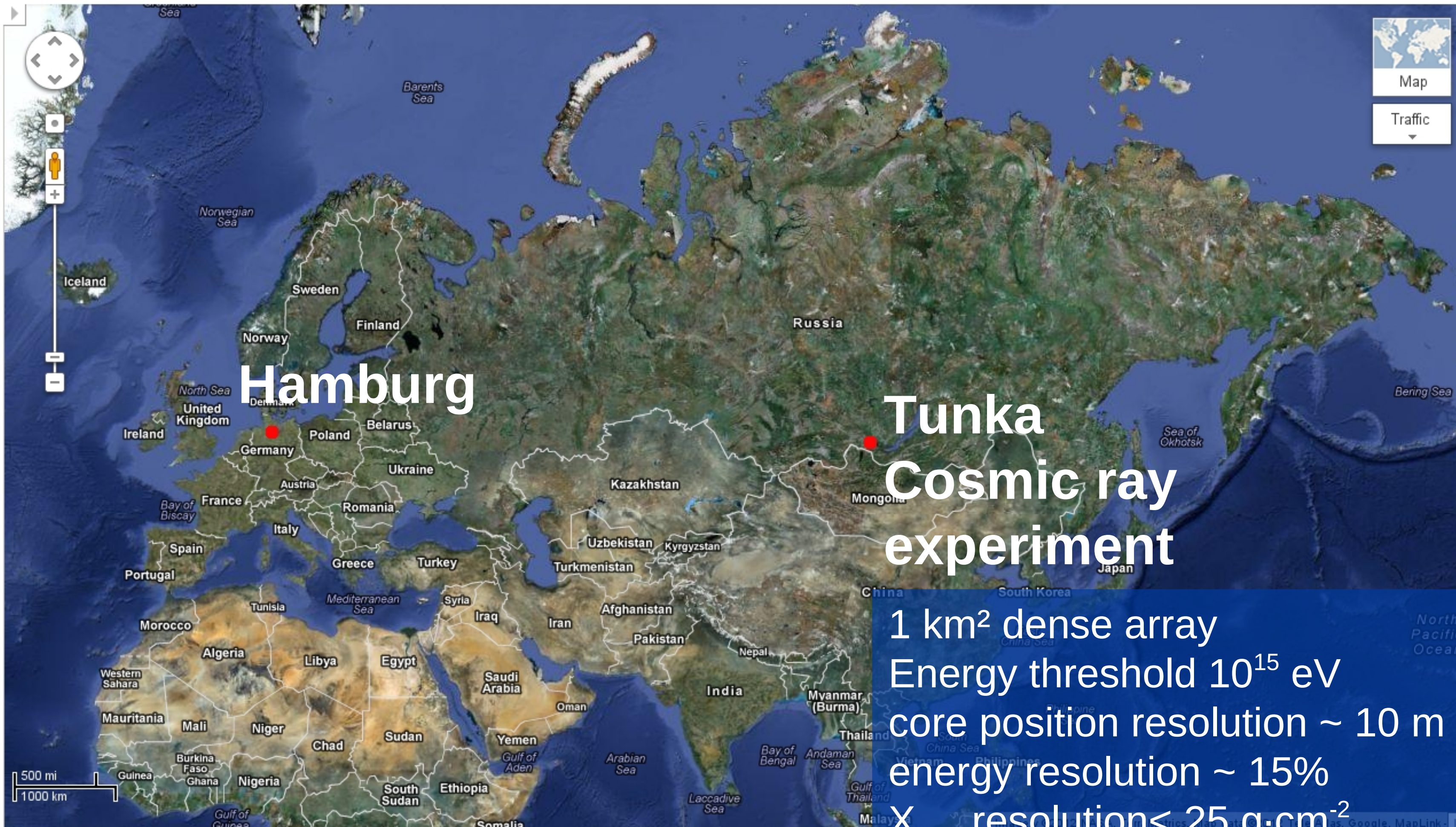
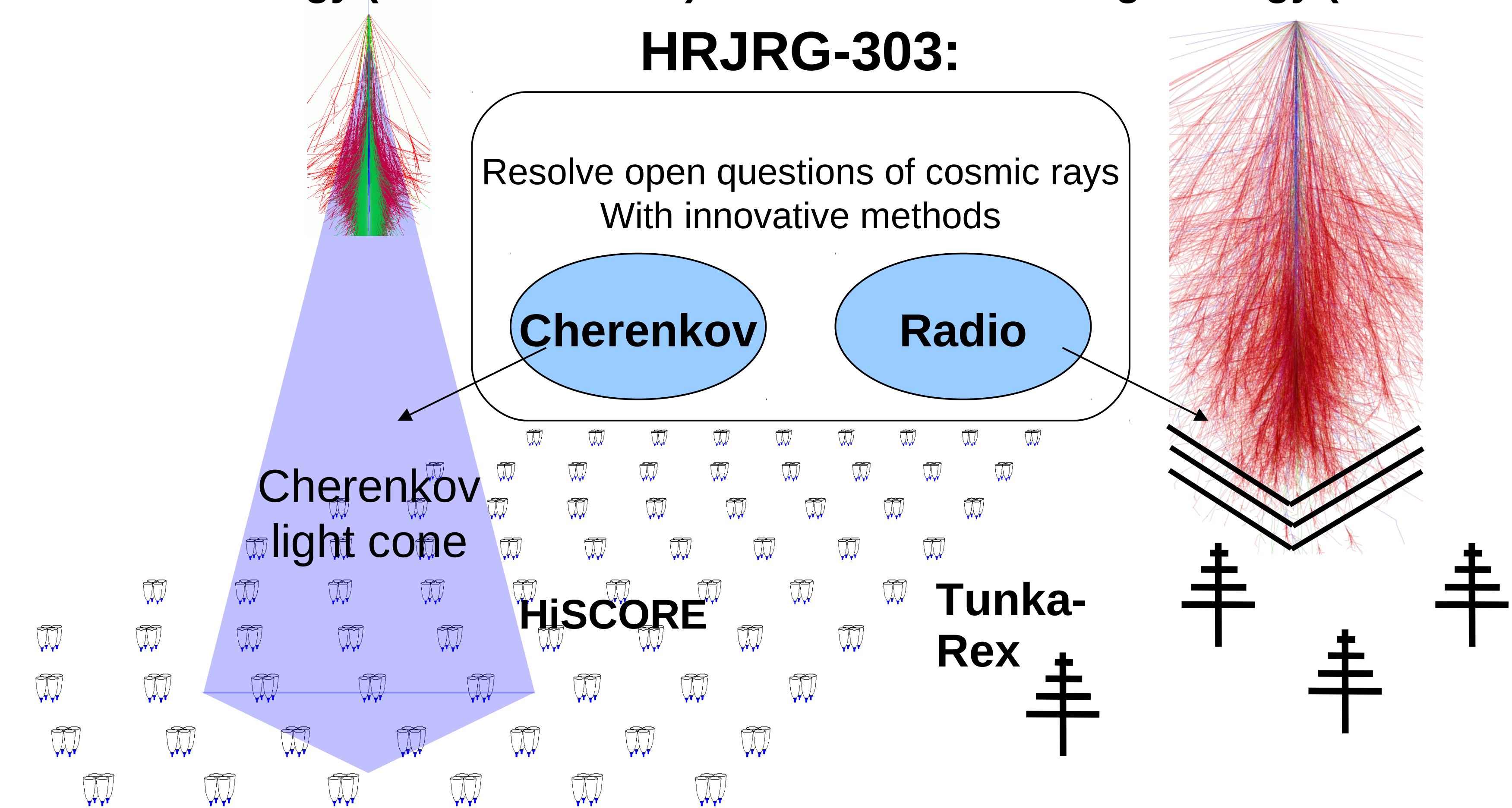


1 km² dense array
Energy threshold 10^{15} eV
core position resolution ~ 10 m
energy resolution ~ 15%
X_{max} resolution< 25 g·cm^{-2}

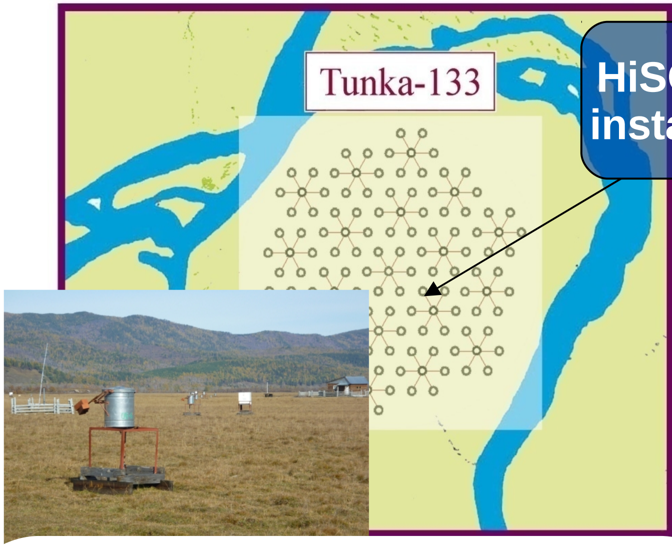
HRJRG-303

Helmholtz Russia Joint Research Group HRJRG-303
Measurements of Gamma Rays and Cosmic Rays in the Tunka-Valley in Siberia by innovative new technologies

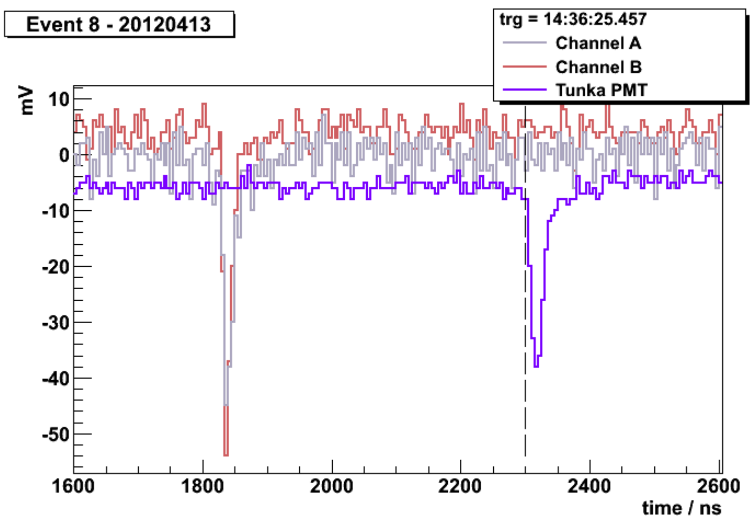
Low energy (GeV / TeV / PeV): **High energy (PeV - EeV):**



HiSCORE prototype @ Tunka



HiSCORE prototype installation @ Tunka



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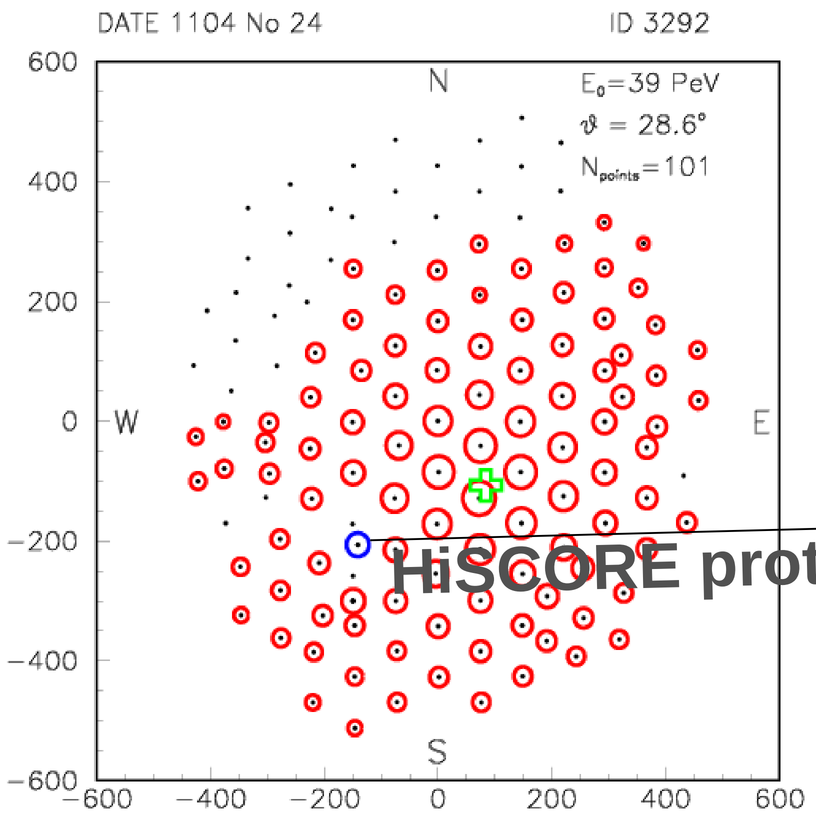
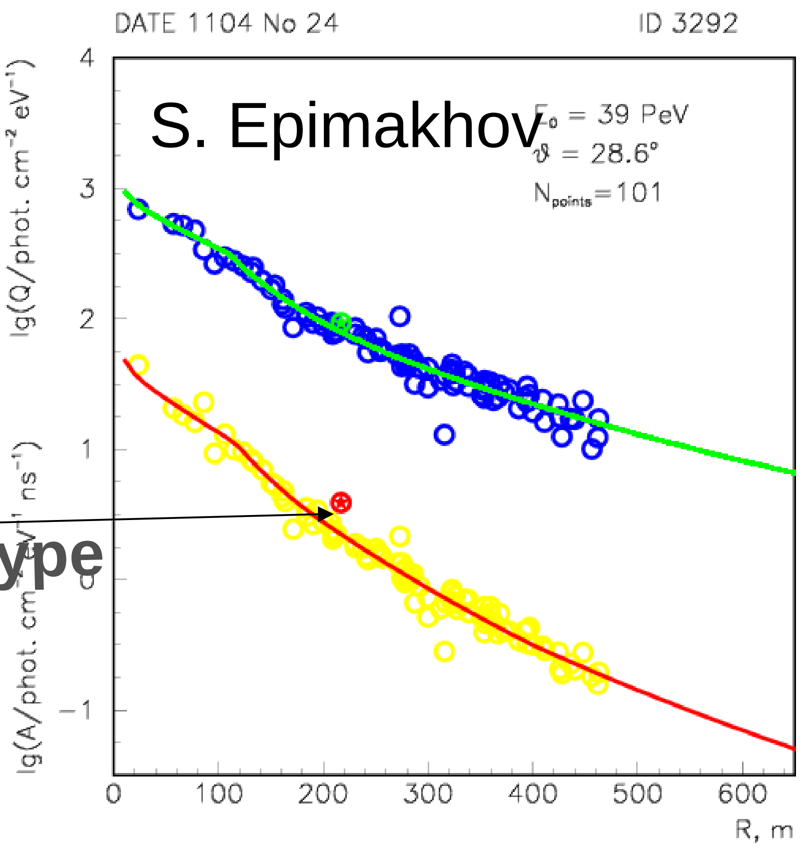
HiSCORE prototype @ Tunka





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Time synchronization

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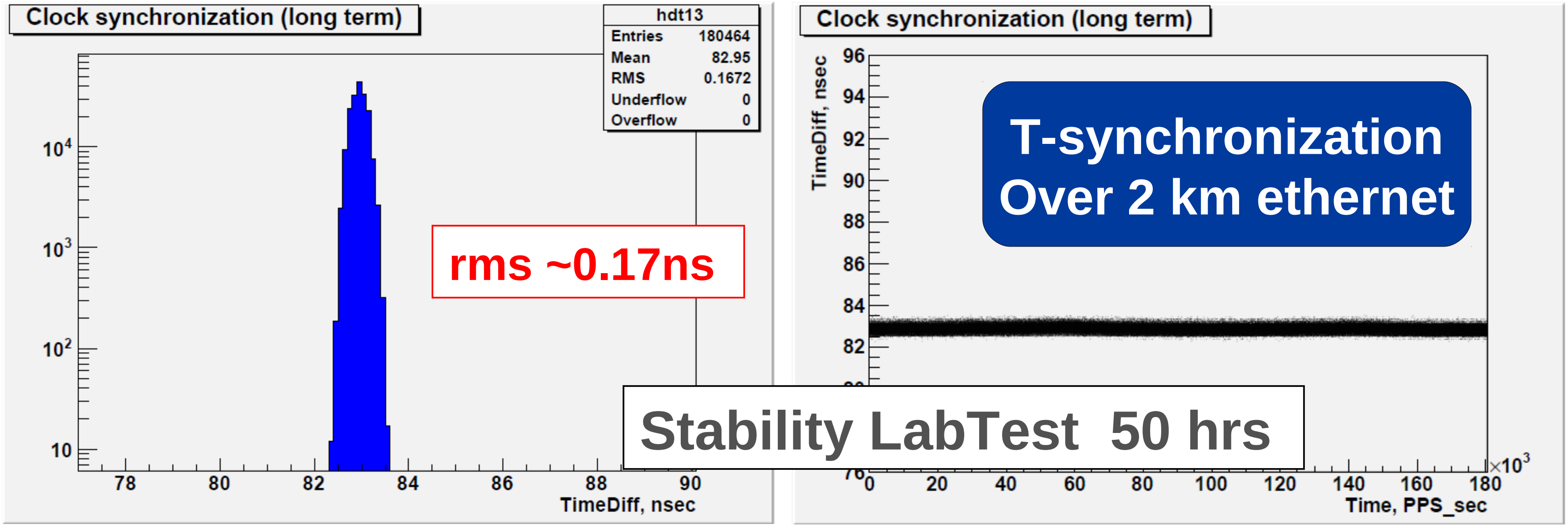
WhiteRabbit: PTP over synchronuous ethernet

- Synergies: CTA & HiSCORE – *same t-synch. geometry*
- Consistent lab & Tunka field-test results: **sub-ns resolution**



R. Wischnewski

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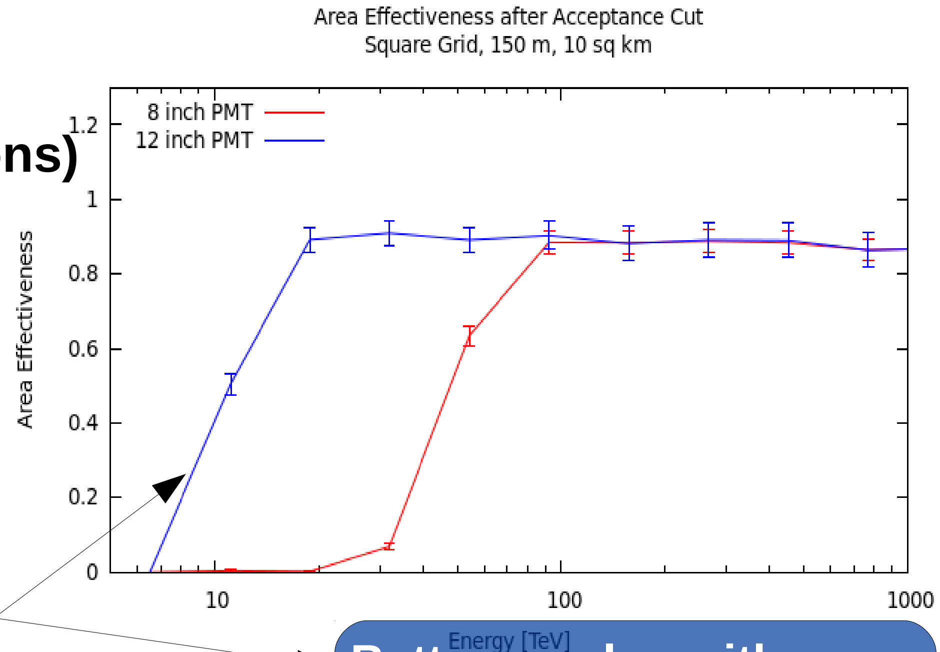
Plans

- **2012: further prototype deployments**
- **2013: engineering array (~60 stations)**
  - Proof-of-principle & optimization
  - Potentially first physics: strong pevatrons
- **~2015: 10 km² – 100 km²**
  - Low-energy core (8'' → 12'' PMTs)
  - Optimized layout: graded ?
  - Possible combination with imaging technique



Better overlap with
Gamma: CTA
C.R.: direct measurements

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Summary & outlook

HiSCORE goals:

- Ultra-high energy gamma-ray survey: pevatron search
- Cosmic ray physics from 100 TeV to 1 EeV
- Particle physics beyond LHC energy range

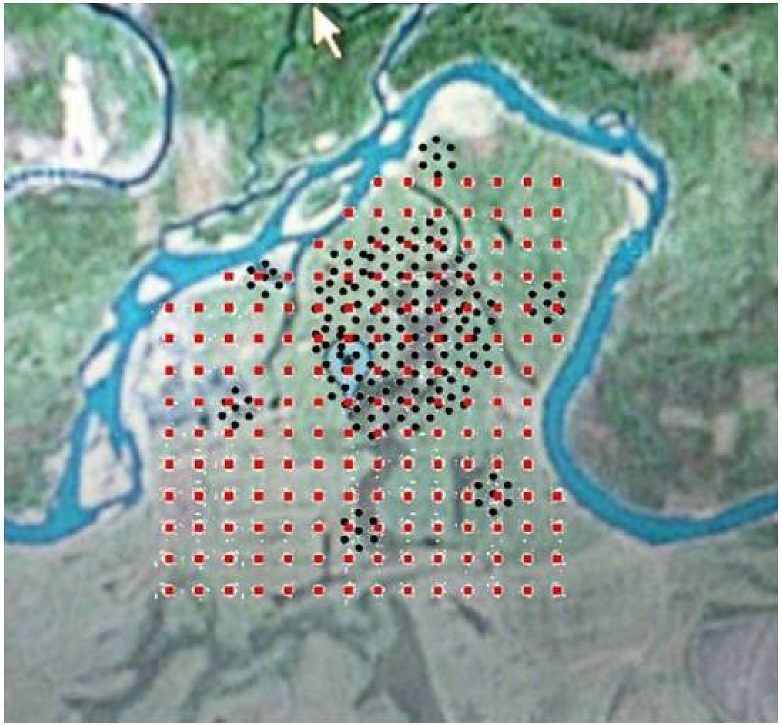
Prototype activities ongoing @ Tunka
(also planned later: PAO)

Engineering array (1 km²), HiSCORE-EA:

- Start 2013
- Potential for 1st physics results

10 km² – 100 km²

- ~2014
- Southern site ?



Tluczykont et al. 2012, The HiSCORE detector
Submitted to Astroparticle physics

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HiSCORE / HRJRG-303

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

[1]Institute for Experimental physics, University of Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany
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[3]Skobeltsyn institute for Nuclear Physics, Lomonosov Moscow State University, 1 Leninskie gory, 119991 Moscow, Russia
[4]Institute for Nuclear Research of the Russian Academy of Sciences 60th October Anniversary st., 7a, 117312, Moscow, Russia
[5]Institute of Applied Physics ISU, Irkutsk, Russia
[6]University of Adelaide 5005, School of Chemistry & Physics, Australia

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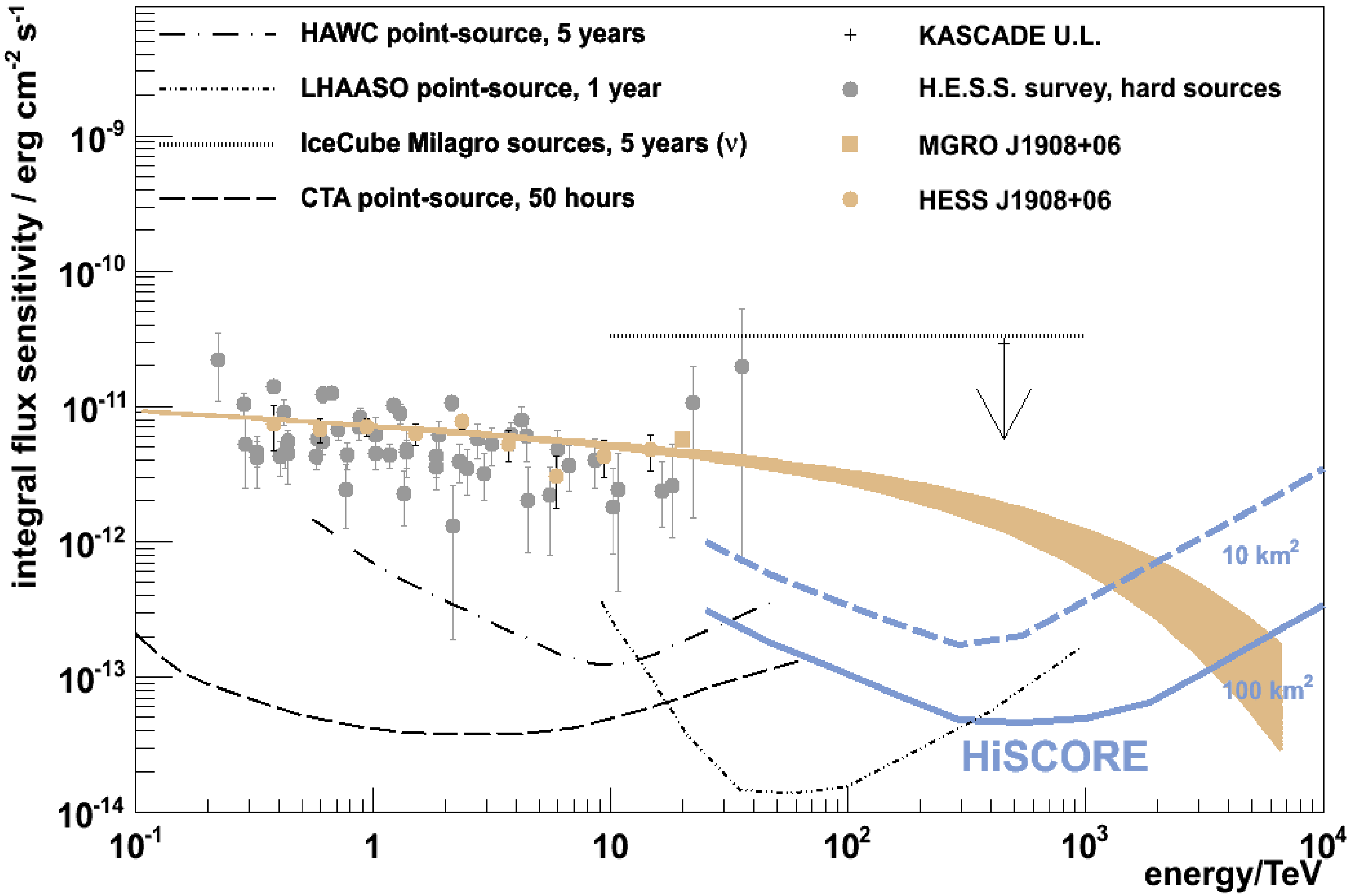
Opening the Pevatron range



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Backup slides

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Lateral Cherenkov Photon Distribution

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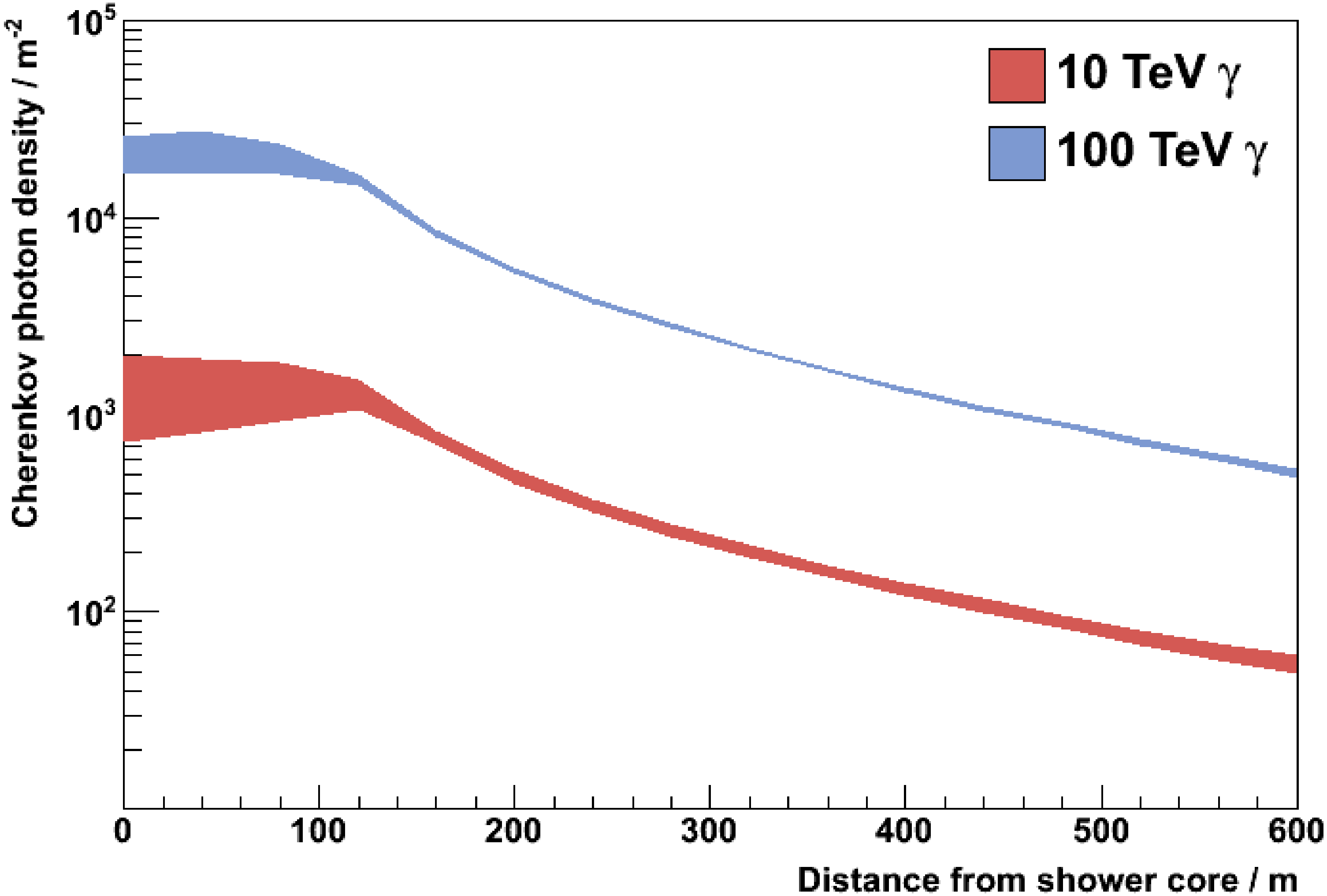

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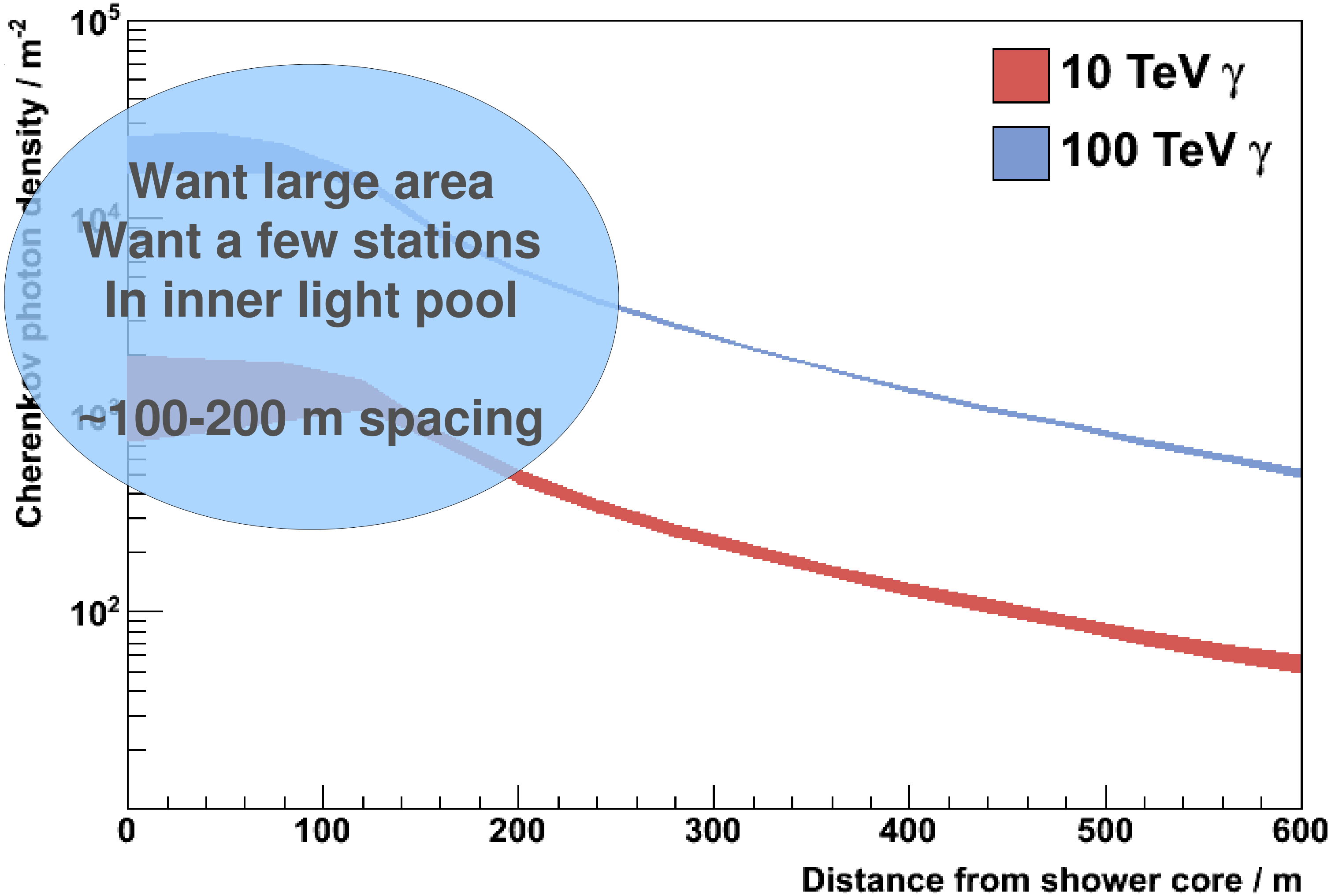
Lateral Cherenkov Photon Distribution



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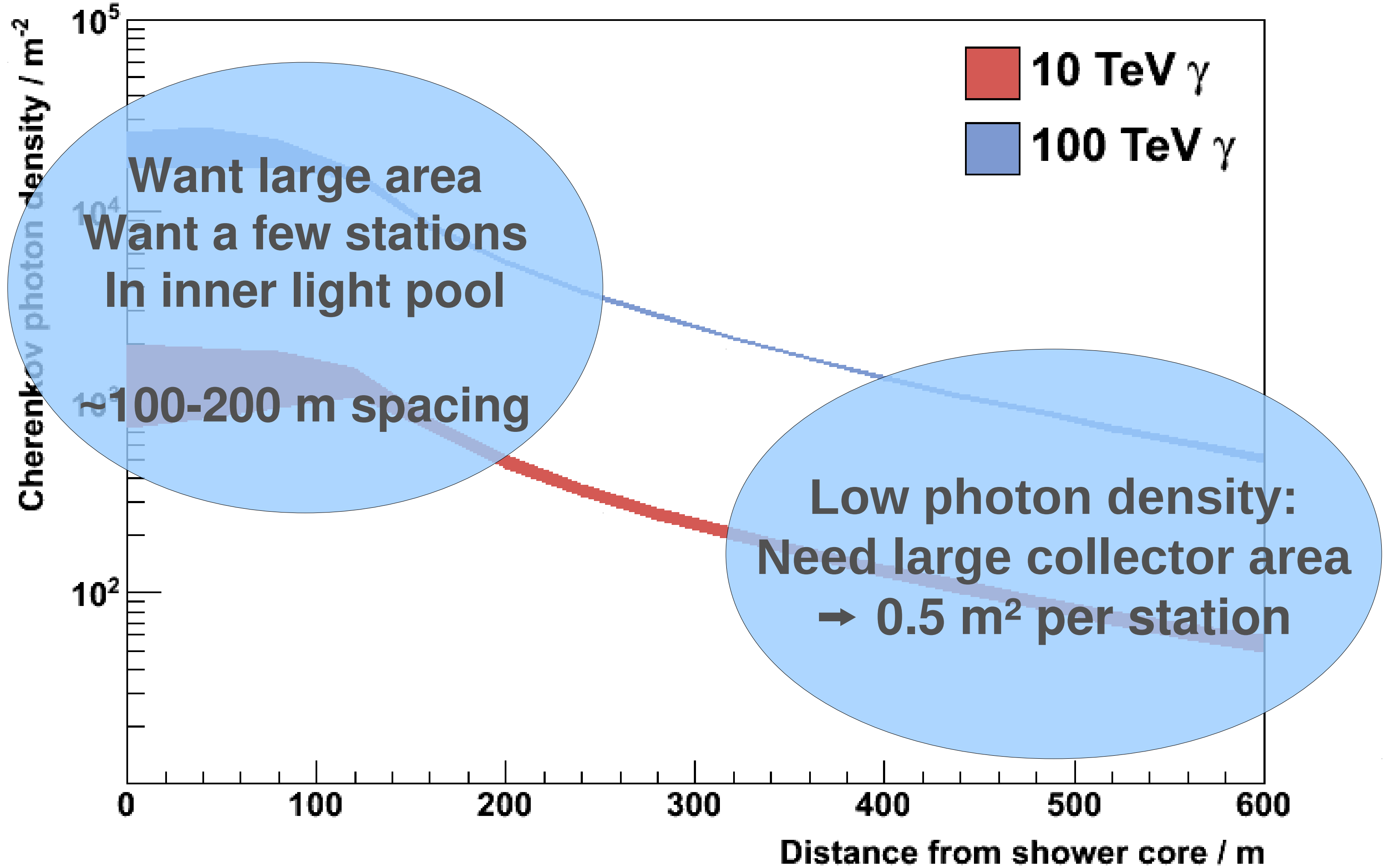
Lateral Cherenkov Photon Distribution



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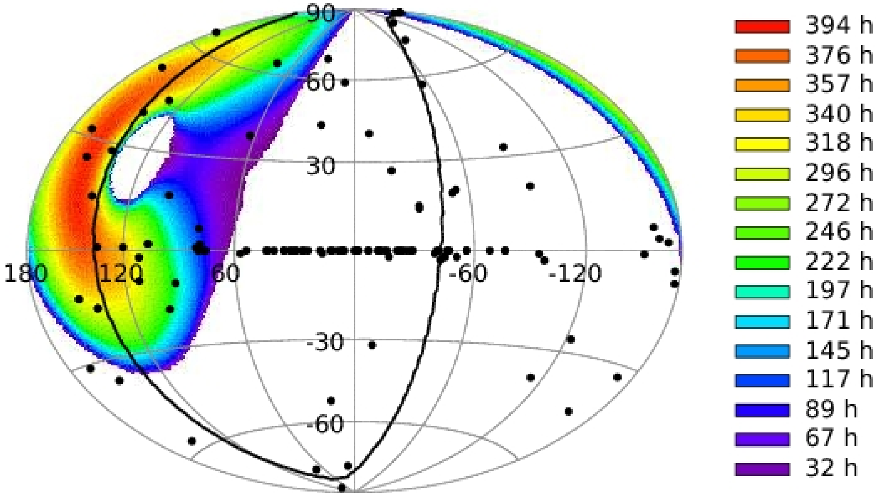
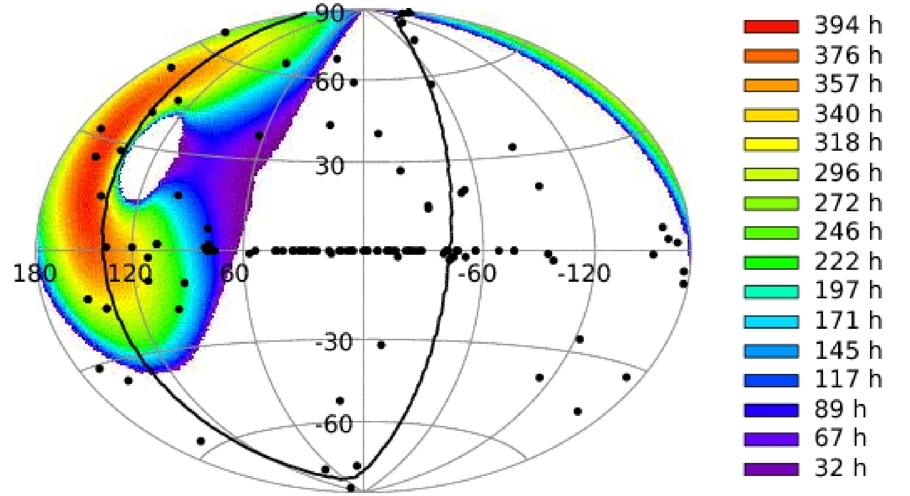
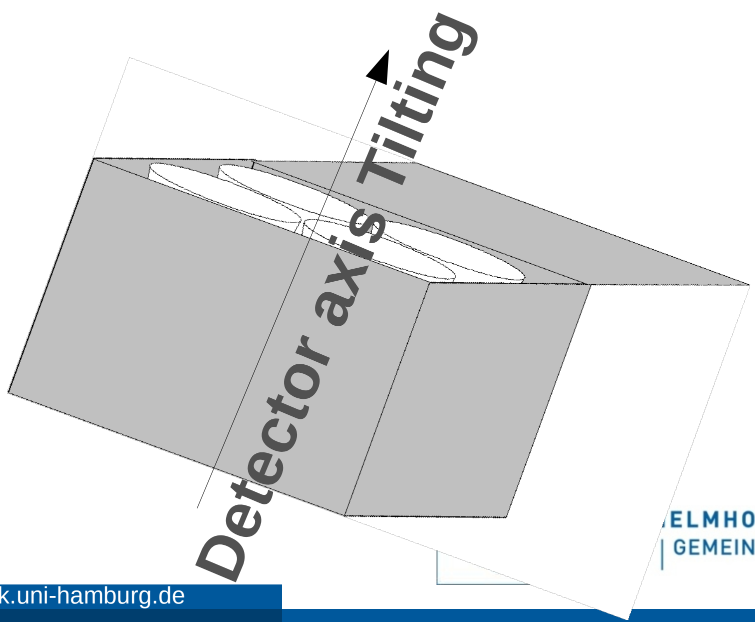
Tunka site exposure map







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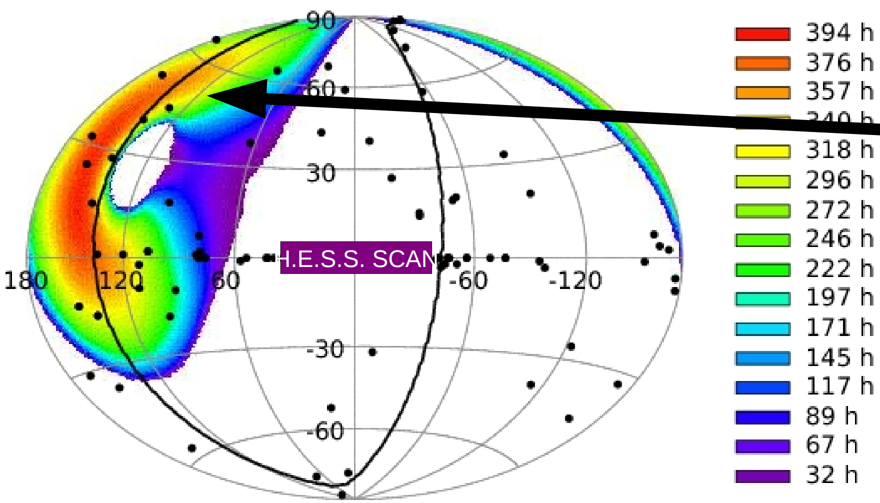

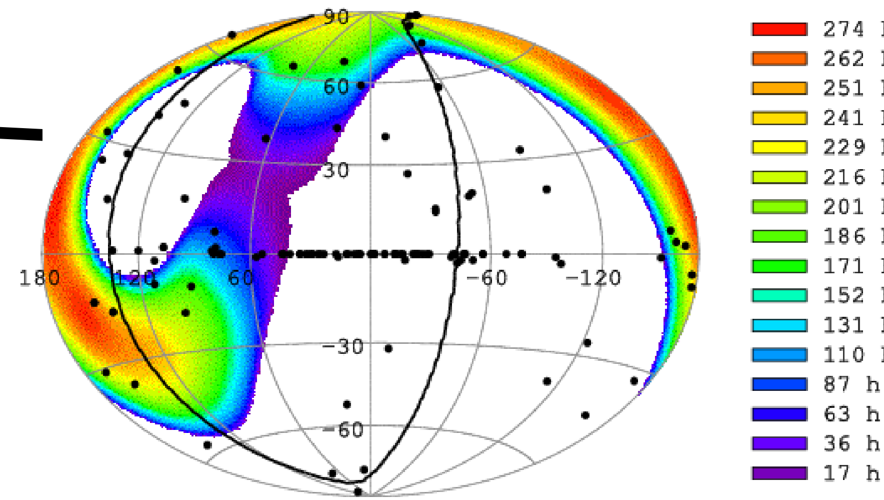

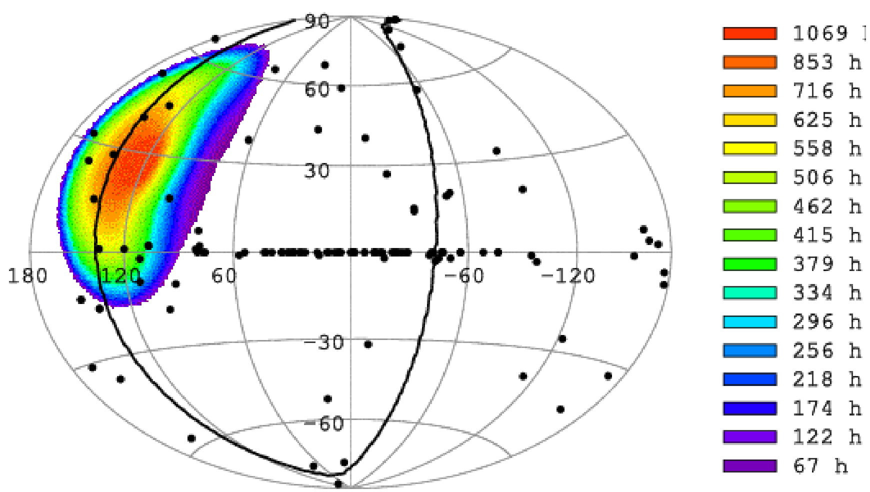

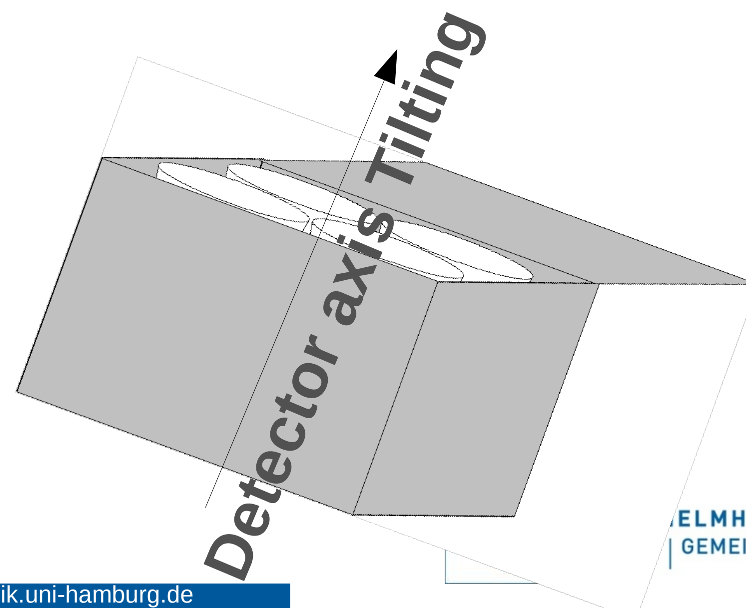

Simulation & Reconstruction

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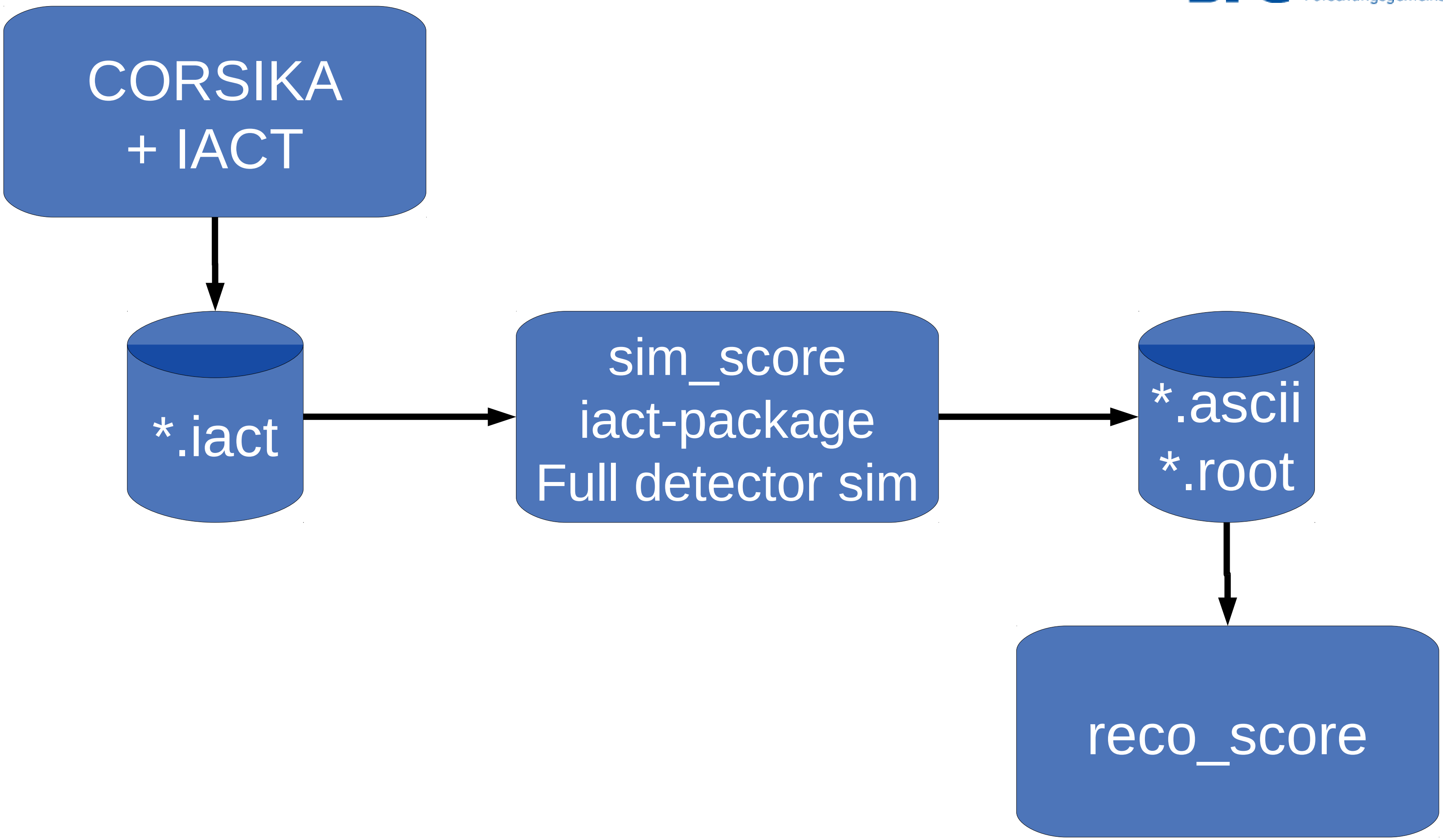
Simulation & reconstruction



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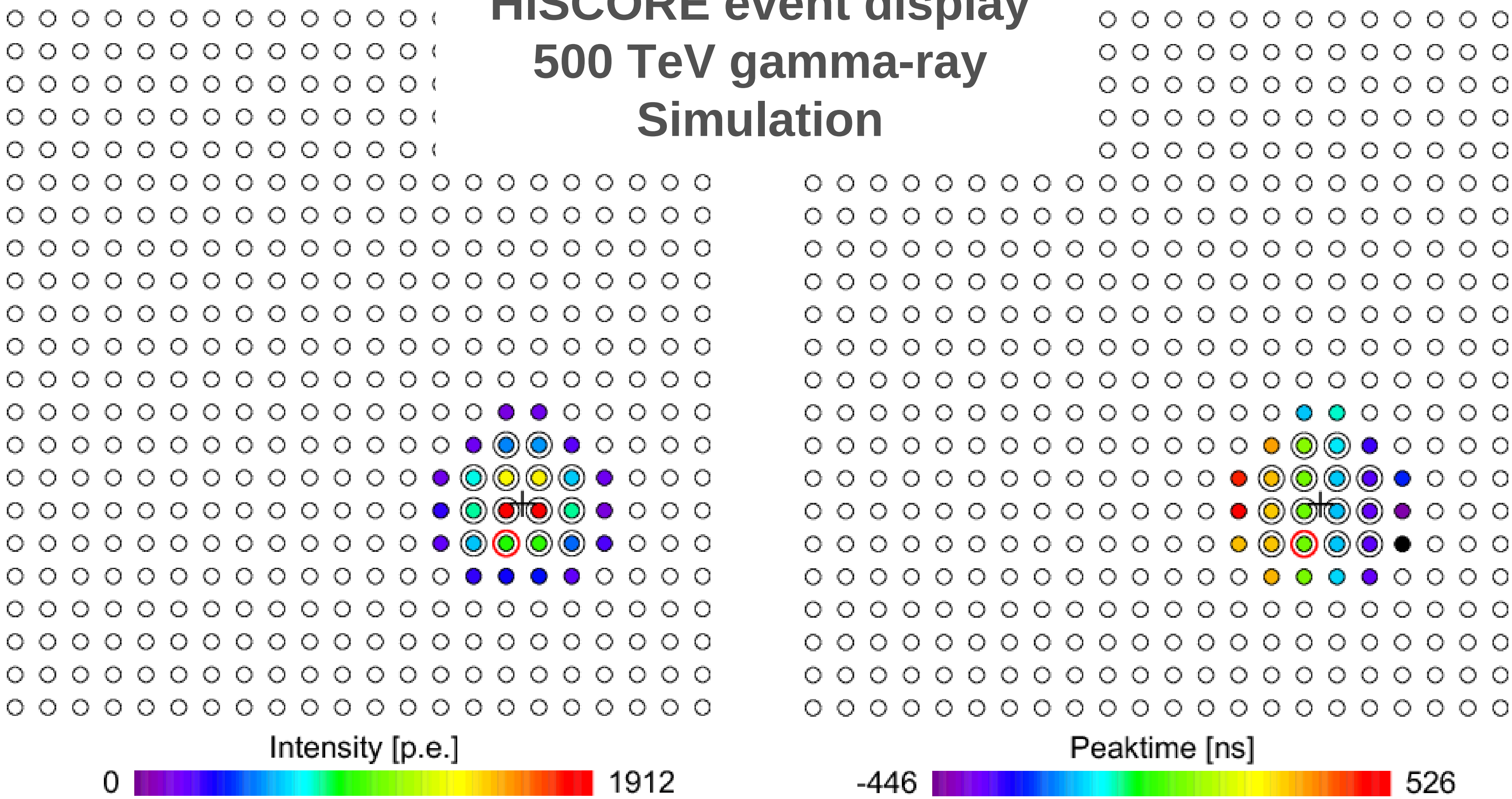
Reconstruction

HiSCORE event display
500 TeV gamma-ray
Simulation



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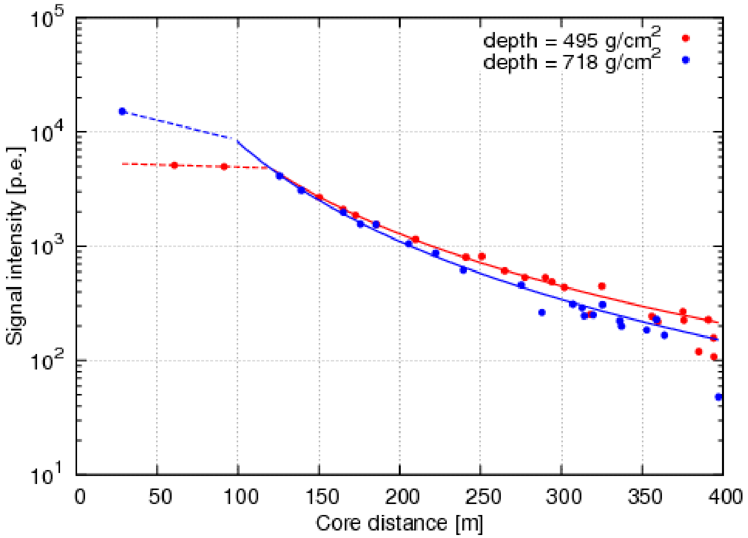
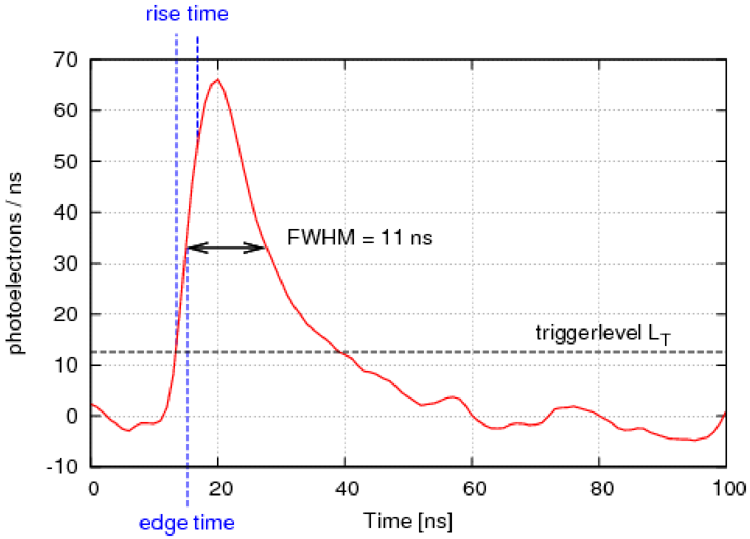
Reconstruction

- 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





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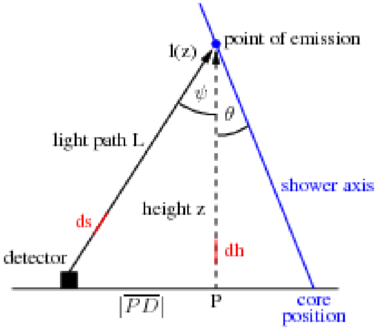
Direction reconstruction

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

Parametrization of time-delay *dt* at detector position



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

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

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

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Direction reconstruction

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>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

Shower height in km

Slope of atmospheric refractive index

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

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Zenith angle

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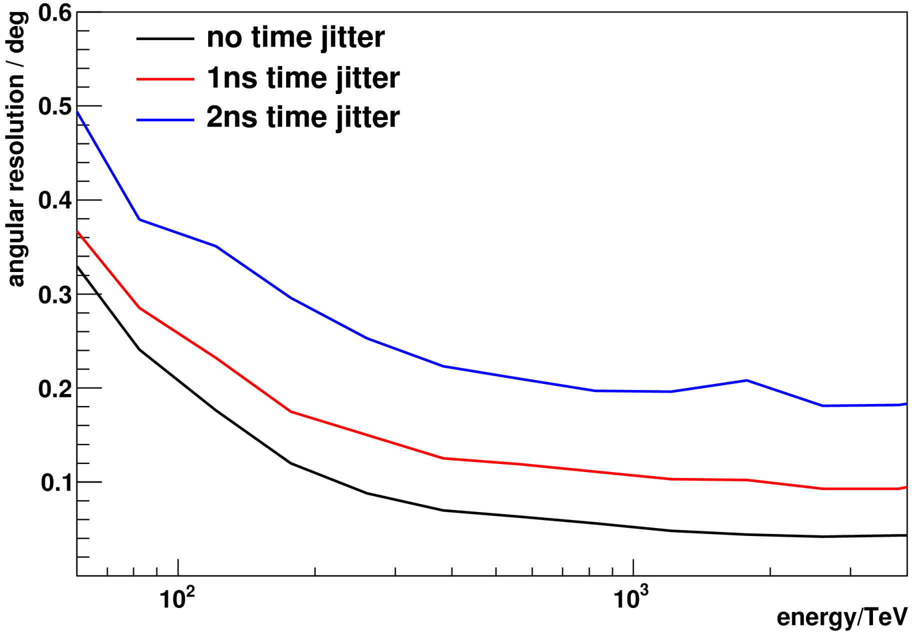
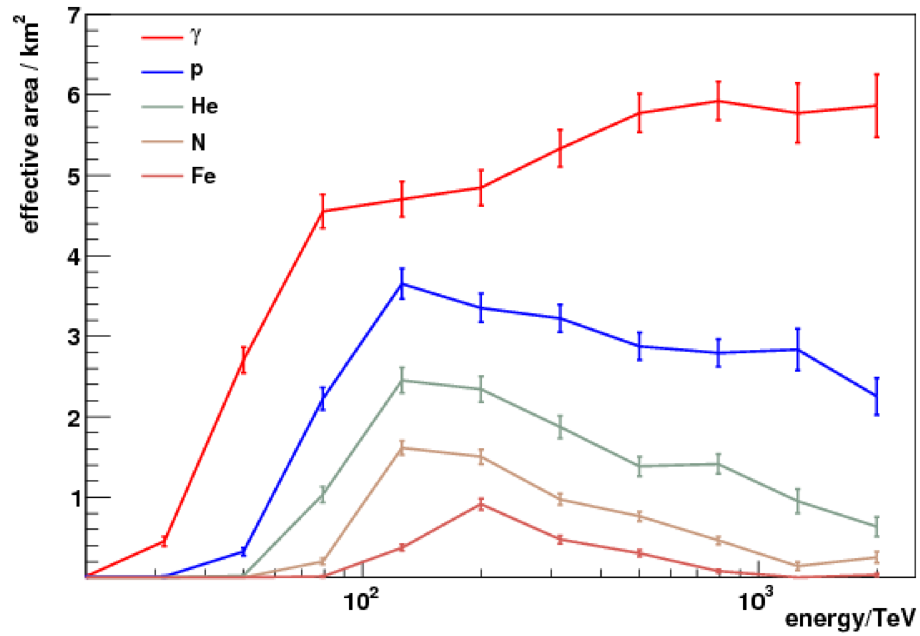
Reconstruction

Direction: photon arrival time model

Energy: Value of LDF @ 220 m

Particle type: Shower depth and Signal rise-time





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Direction reconstruction

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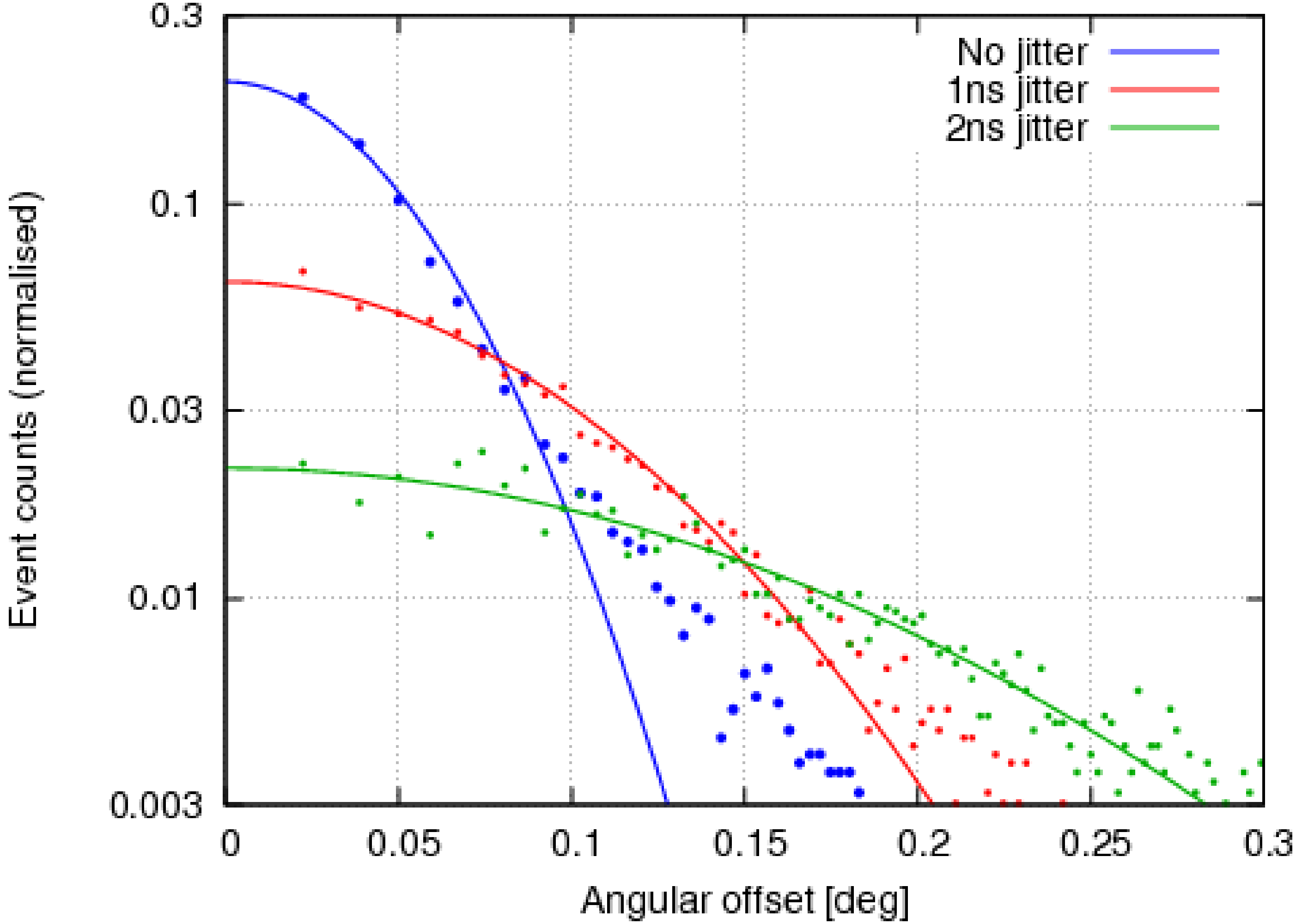

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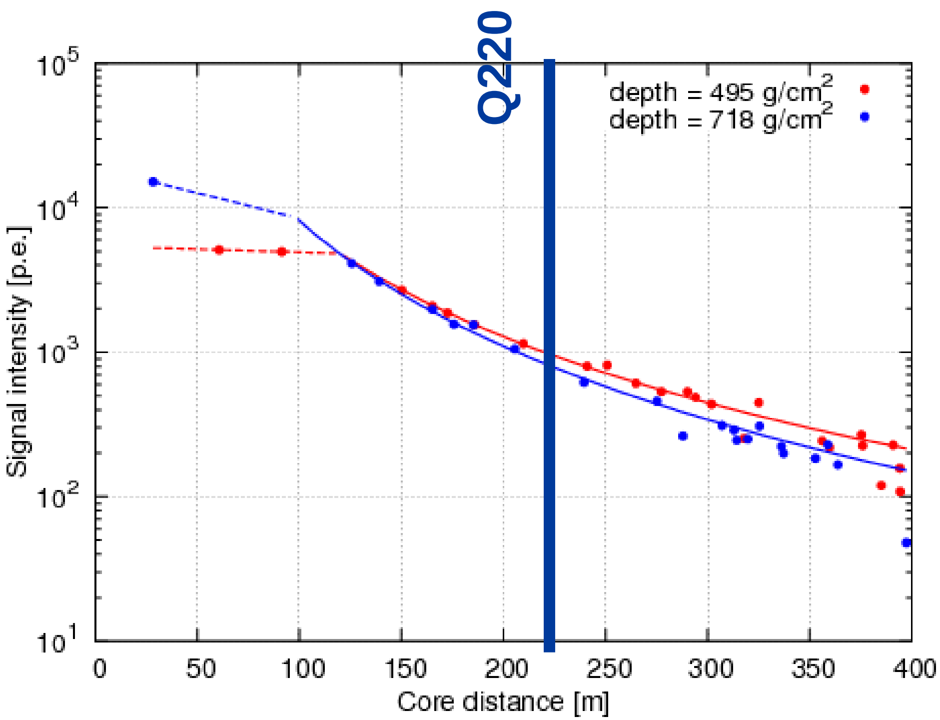
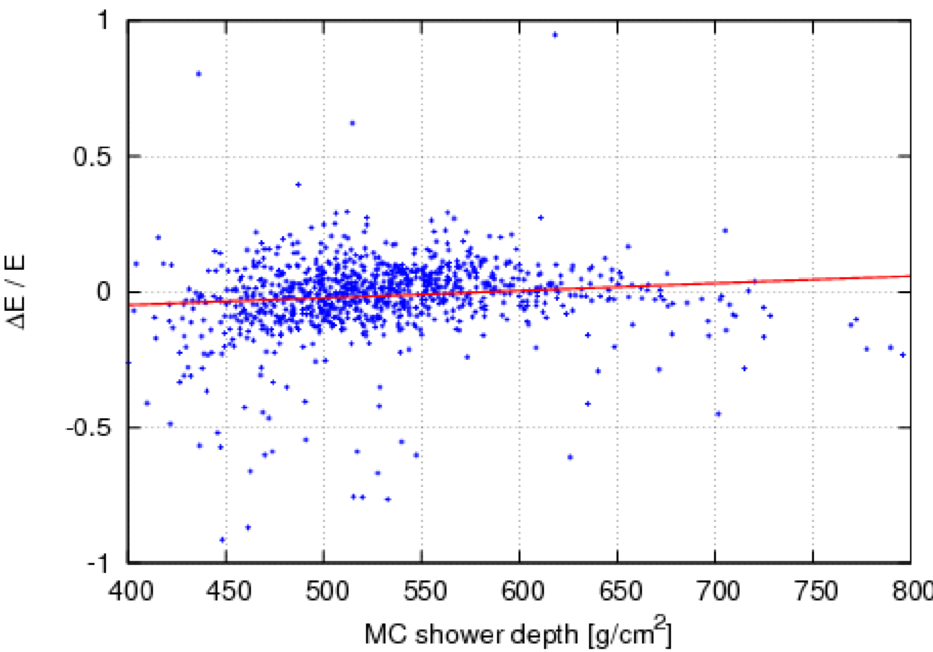
Energy reconstruction

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





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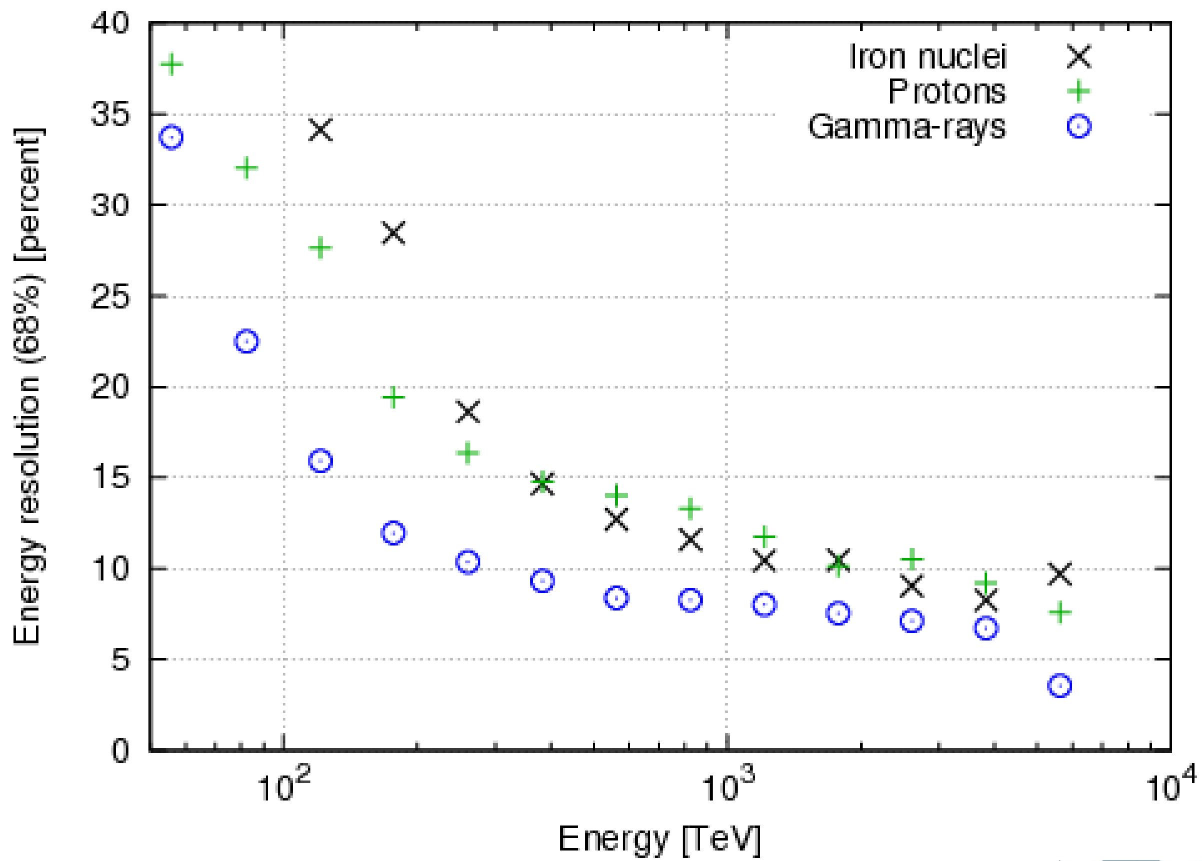
Energy reconstruction

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



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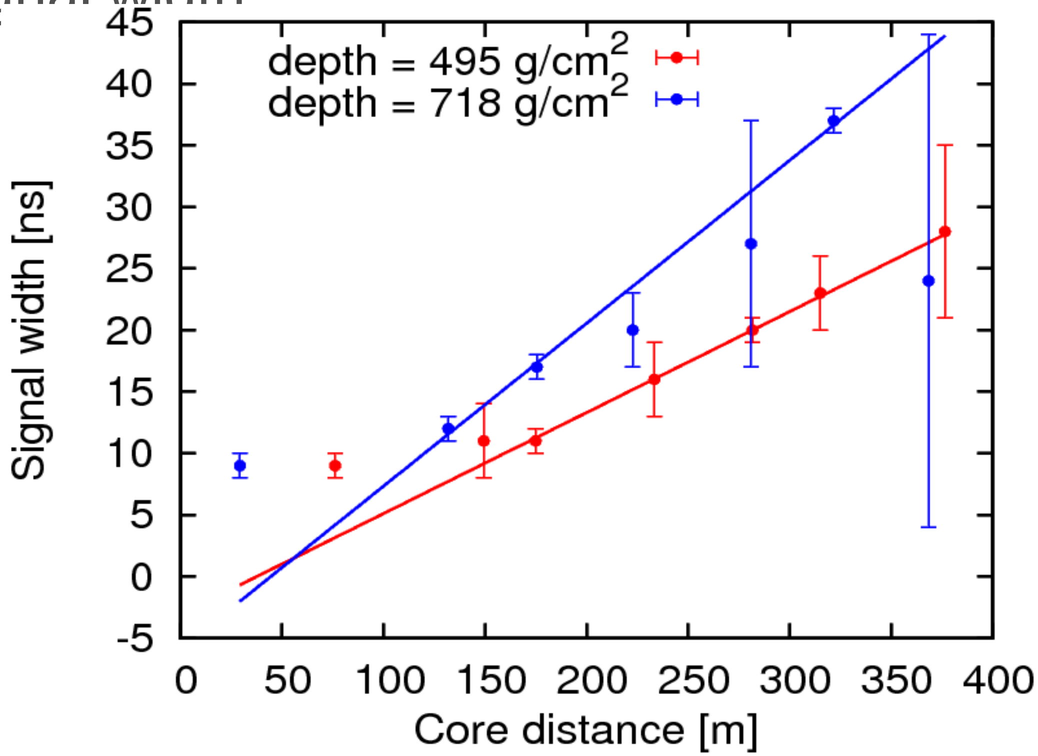
Shower depth reconstruction

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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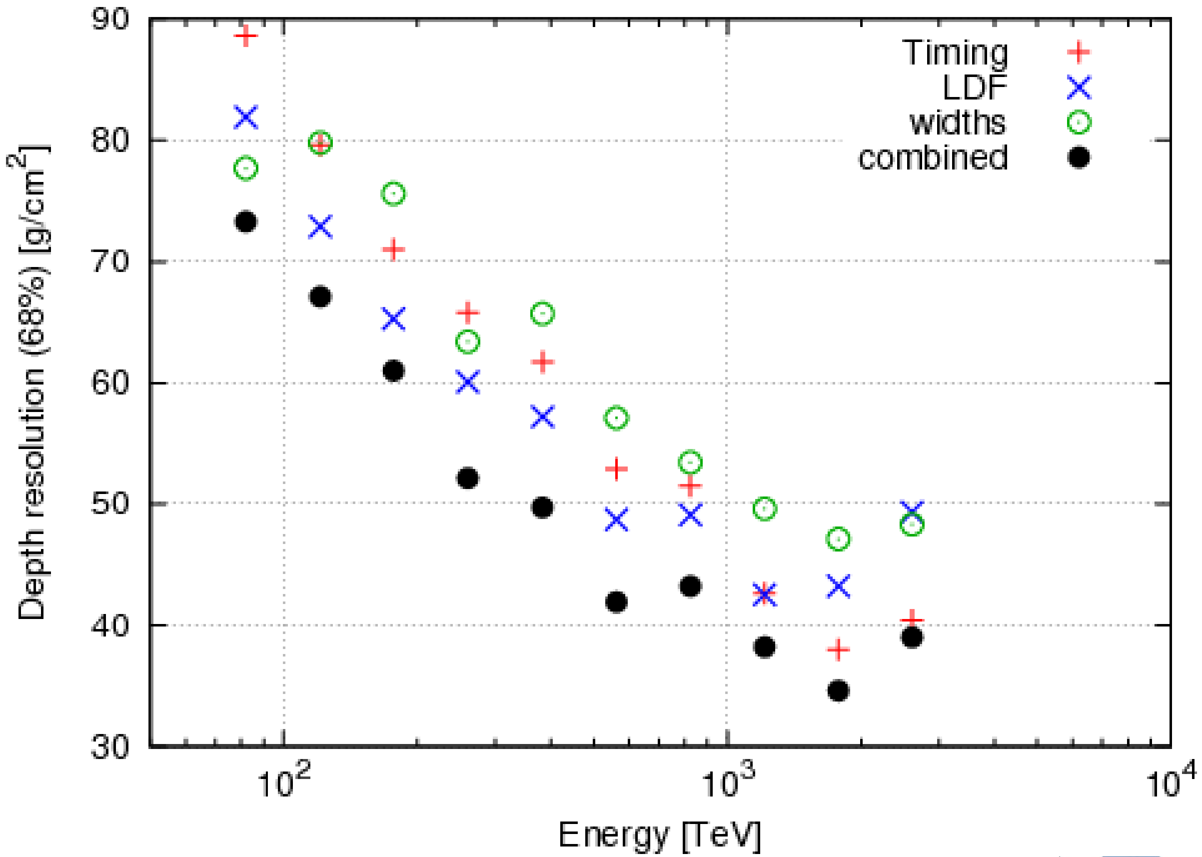
Shower depth

Depth of shower maximum



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Shower depth bias

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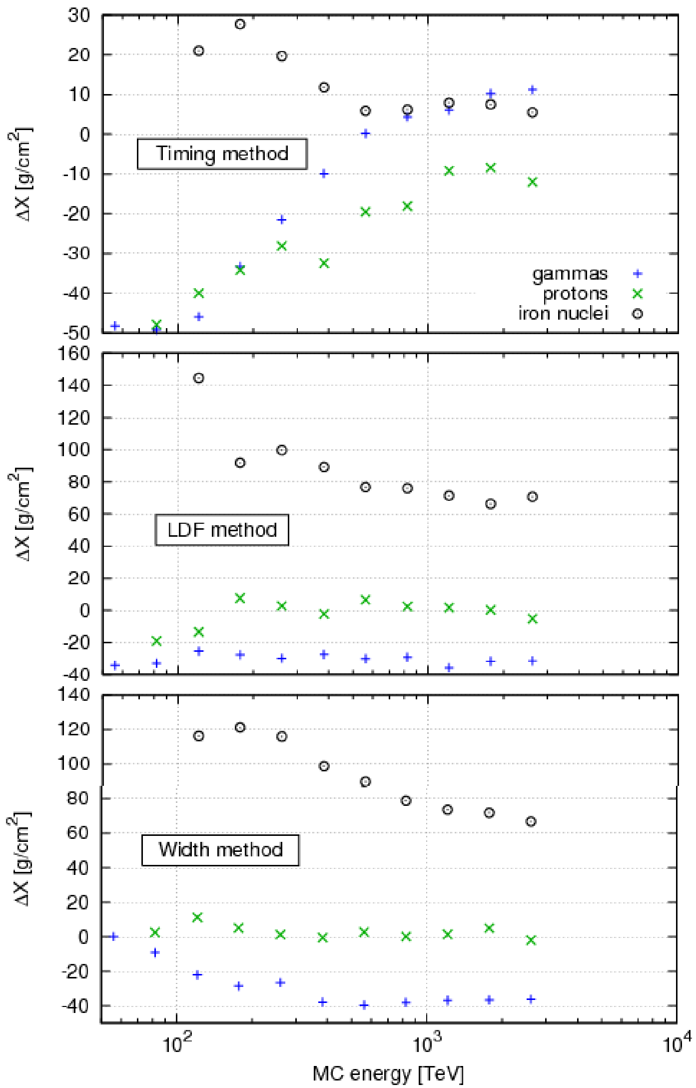

Systematic bias

- 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

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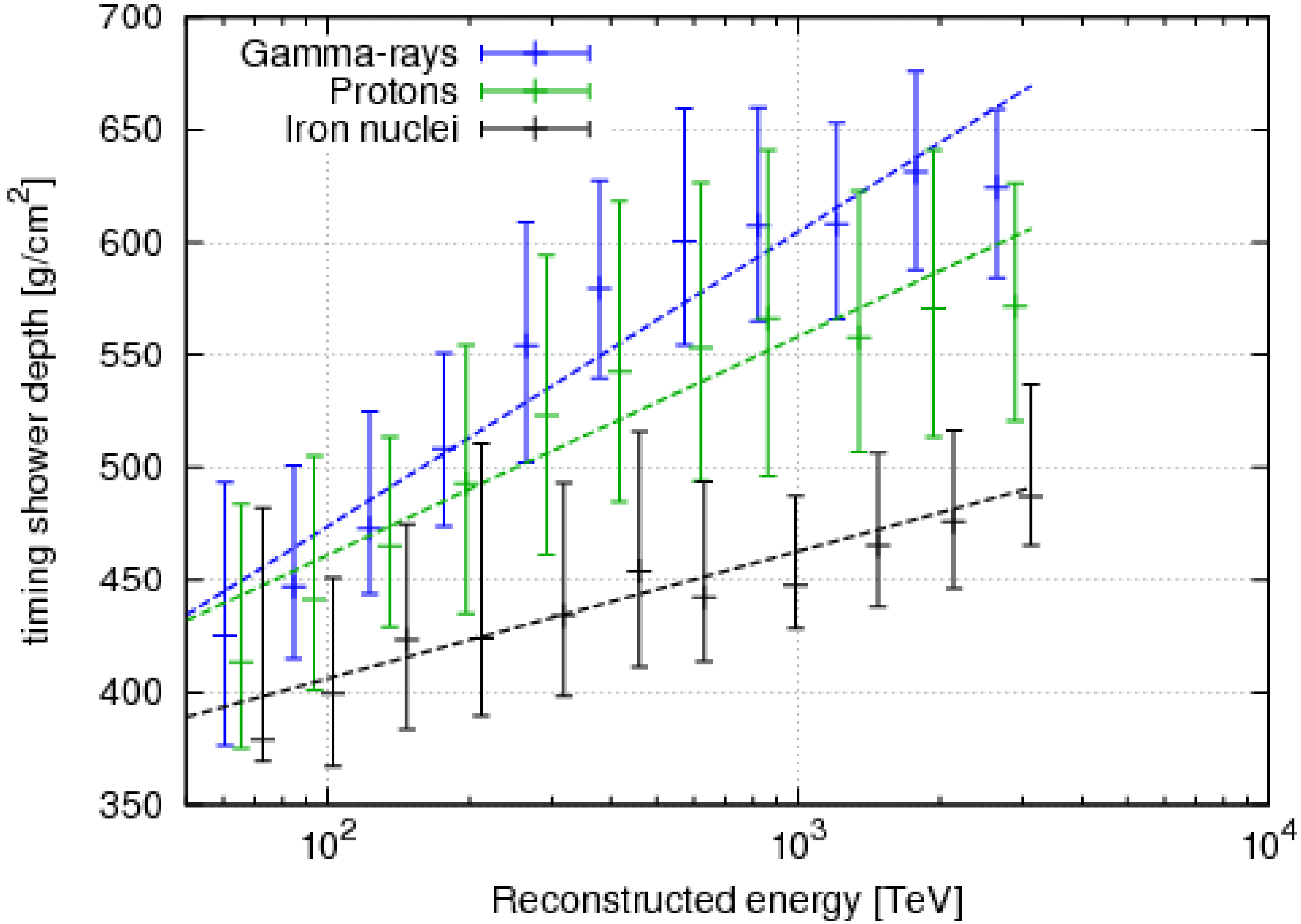
Particle separation



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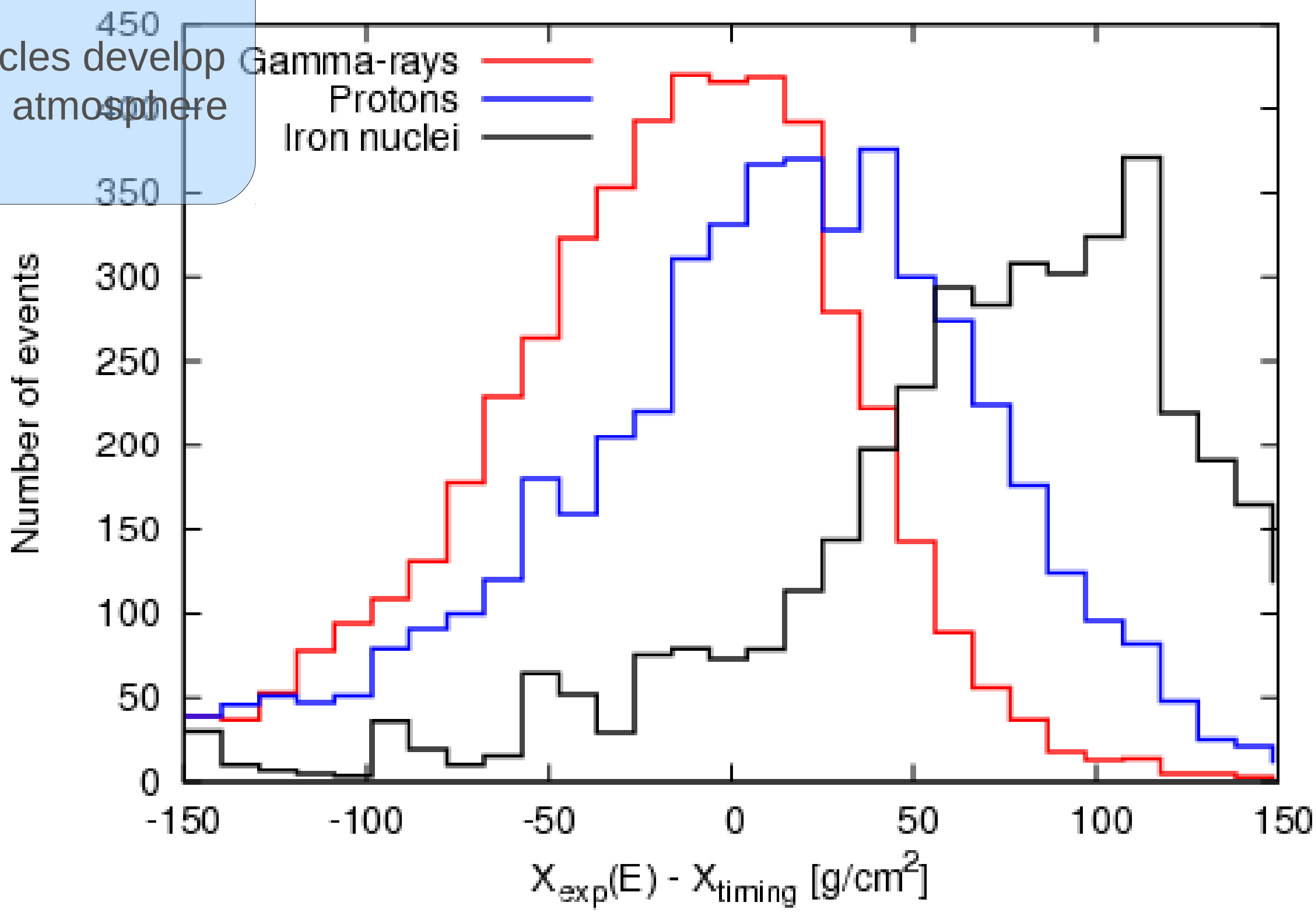
Particle separation (1)

Lighter particles develop
Higher up in atmosphere



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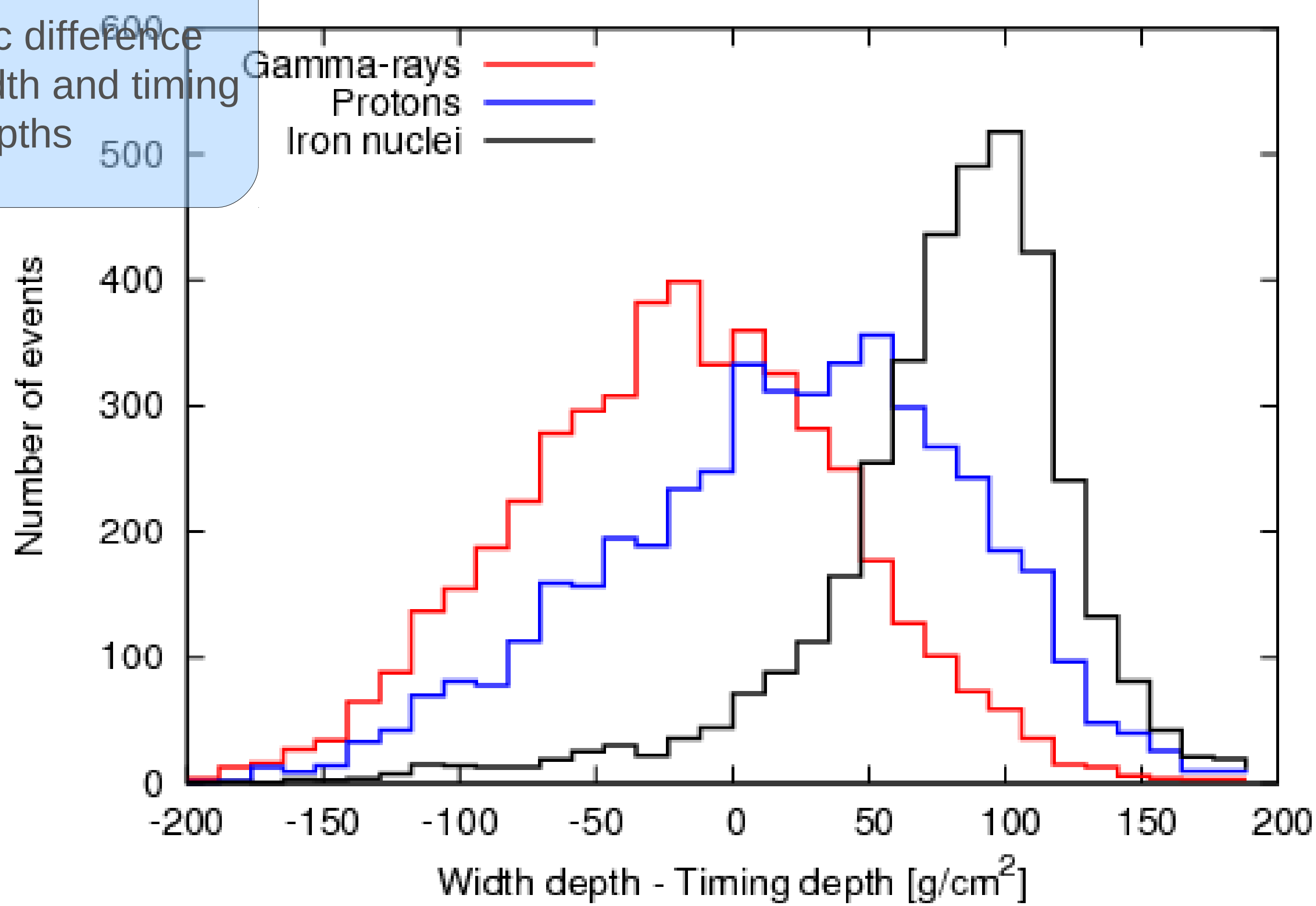
Particle separation (2)

Systematic difference
Between width and timing
Depths



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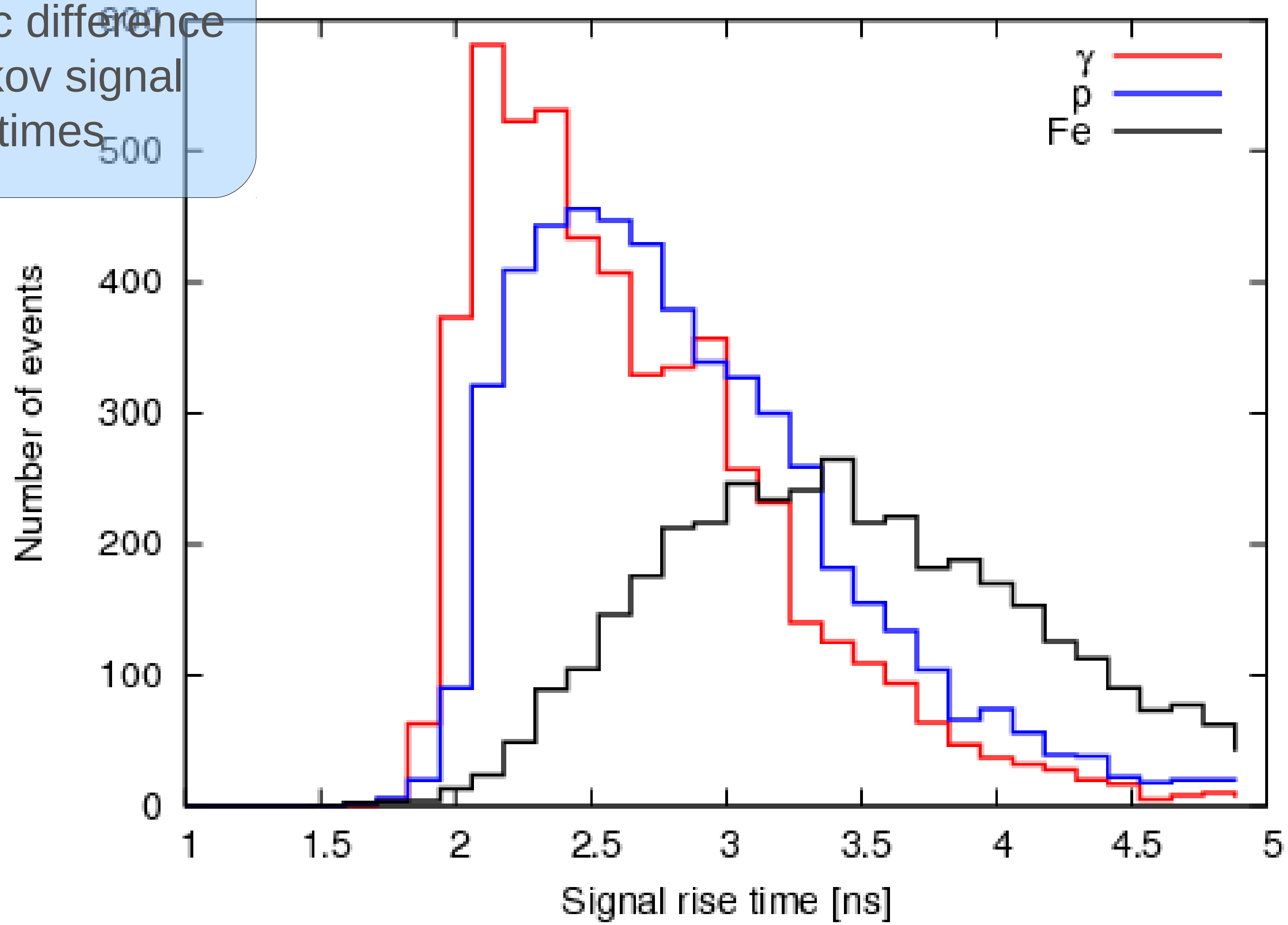
Particle separation (3)

Systematic difference Cherenkov signal rise times



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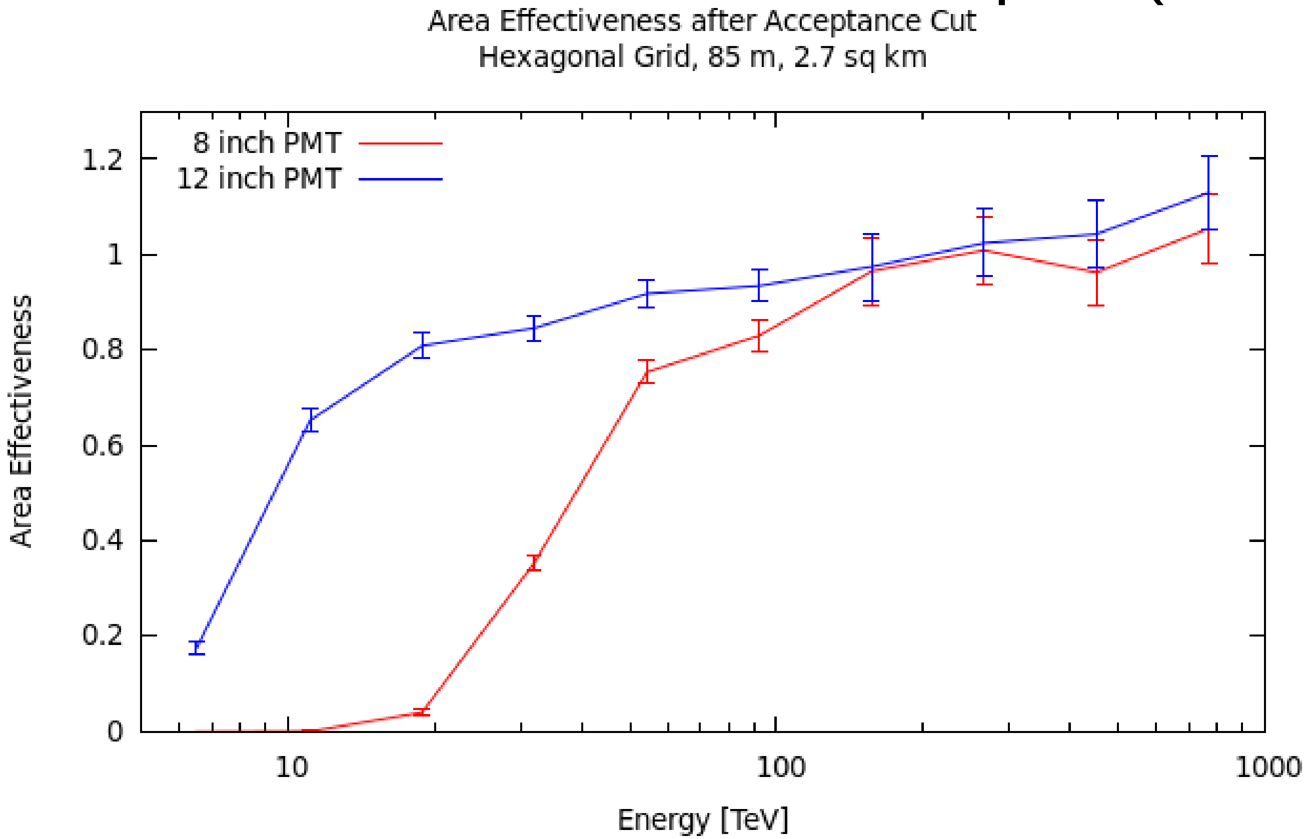
Layout studies

Different altitudes

Different PMT sizes

Combination with other techniques (scintillator, imaging)



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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

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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

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