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The HiSCORE Detector

HAP Topic 4 Workshop Jan. 24-25th 2013

Rayk Nachtigall

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Karlsruhe January 25th 2013

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Overview

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- Physics motivation

- The HiSCORE detector

- Signal processing

- Physics potentials in γ-ray astronomy

- Current state and plans

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HiSCORE

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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 km^2

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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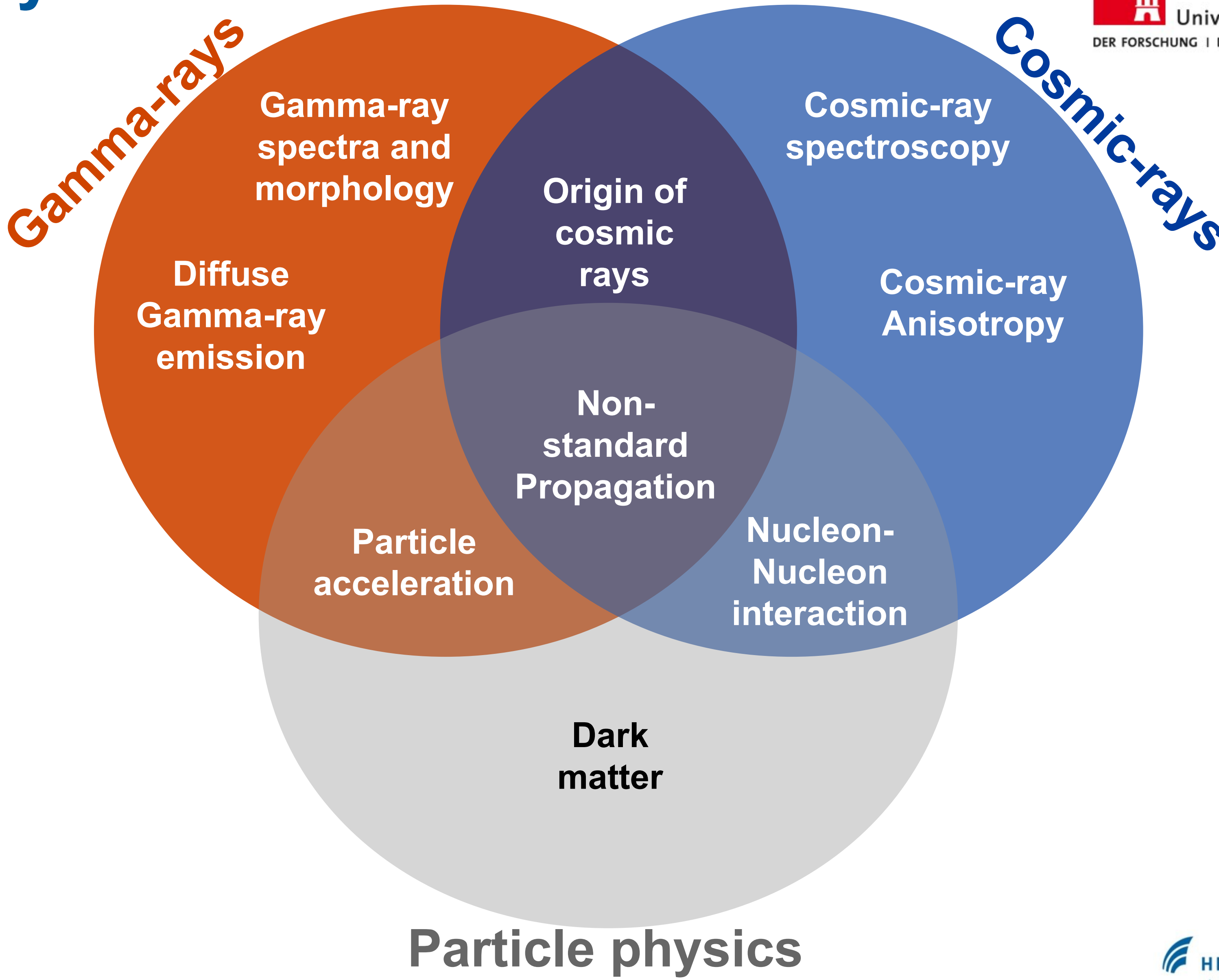
Physics motivations

Physics motivations



Cosmic rays

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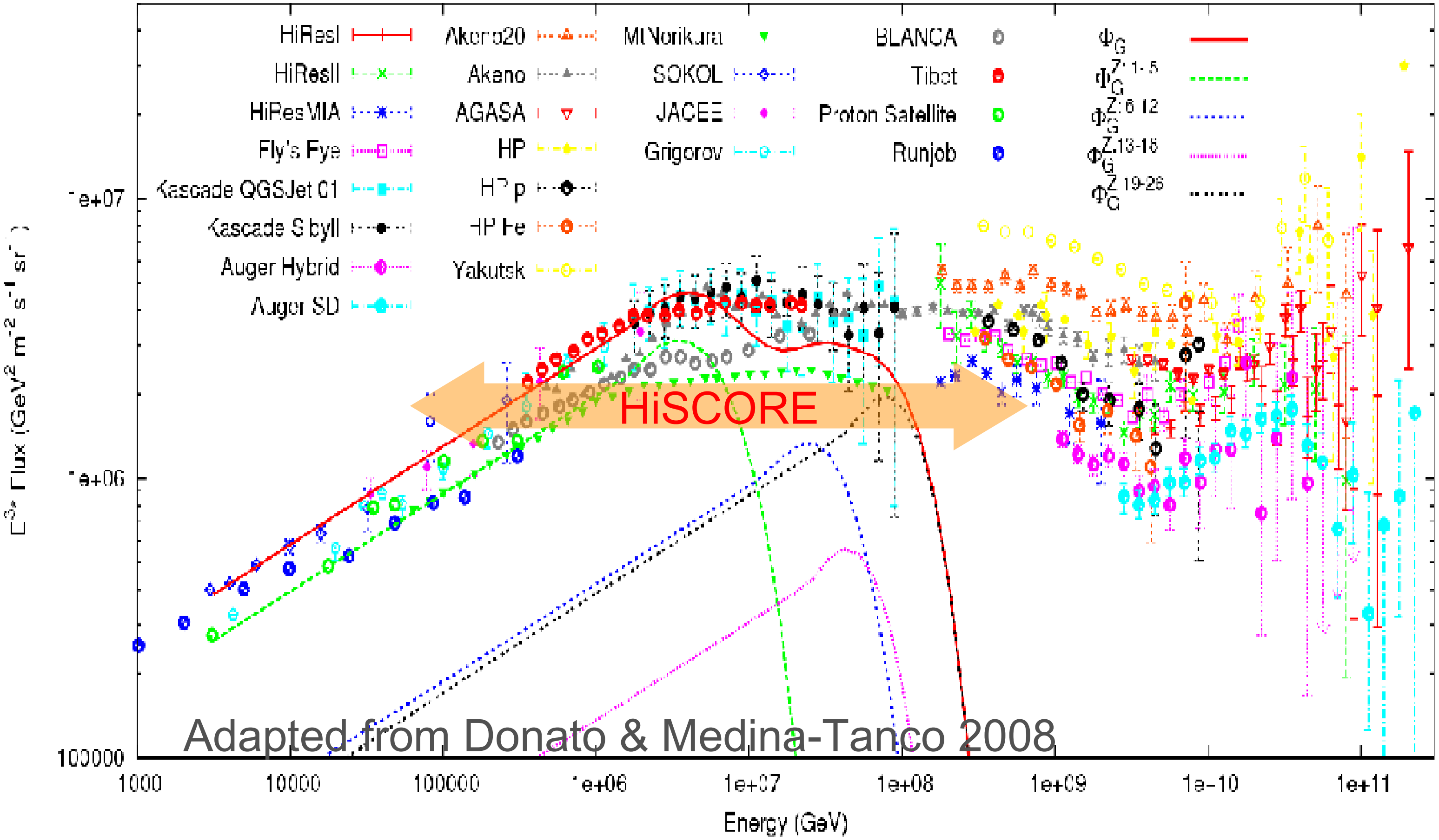

Spectrum&composition in transition range
Galactic / extragalactic origin

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Tevatron sky

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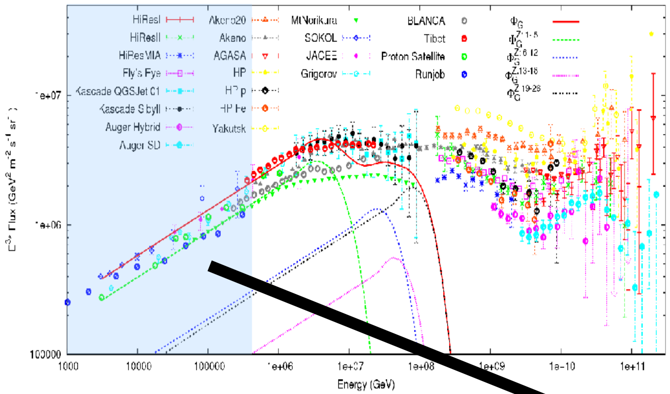

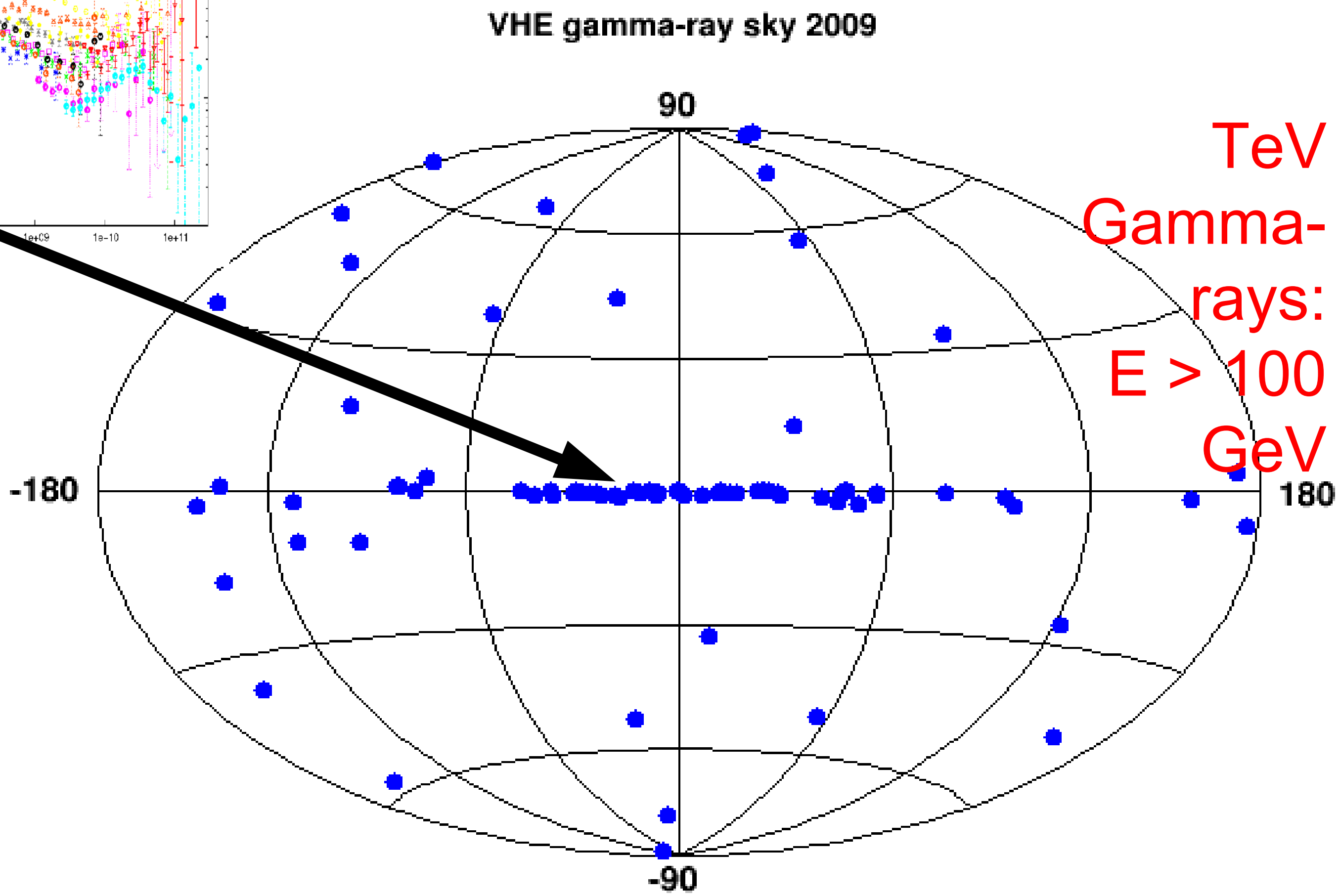

TeV Gamma-rays: E > 100 GeV

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Pevatron sky

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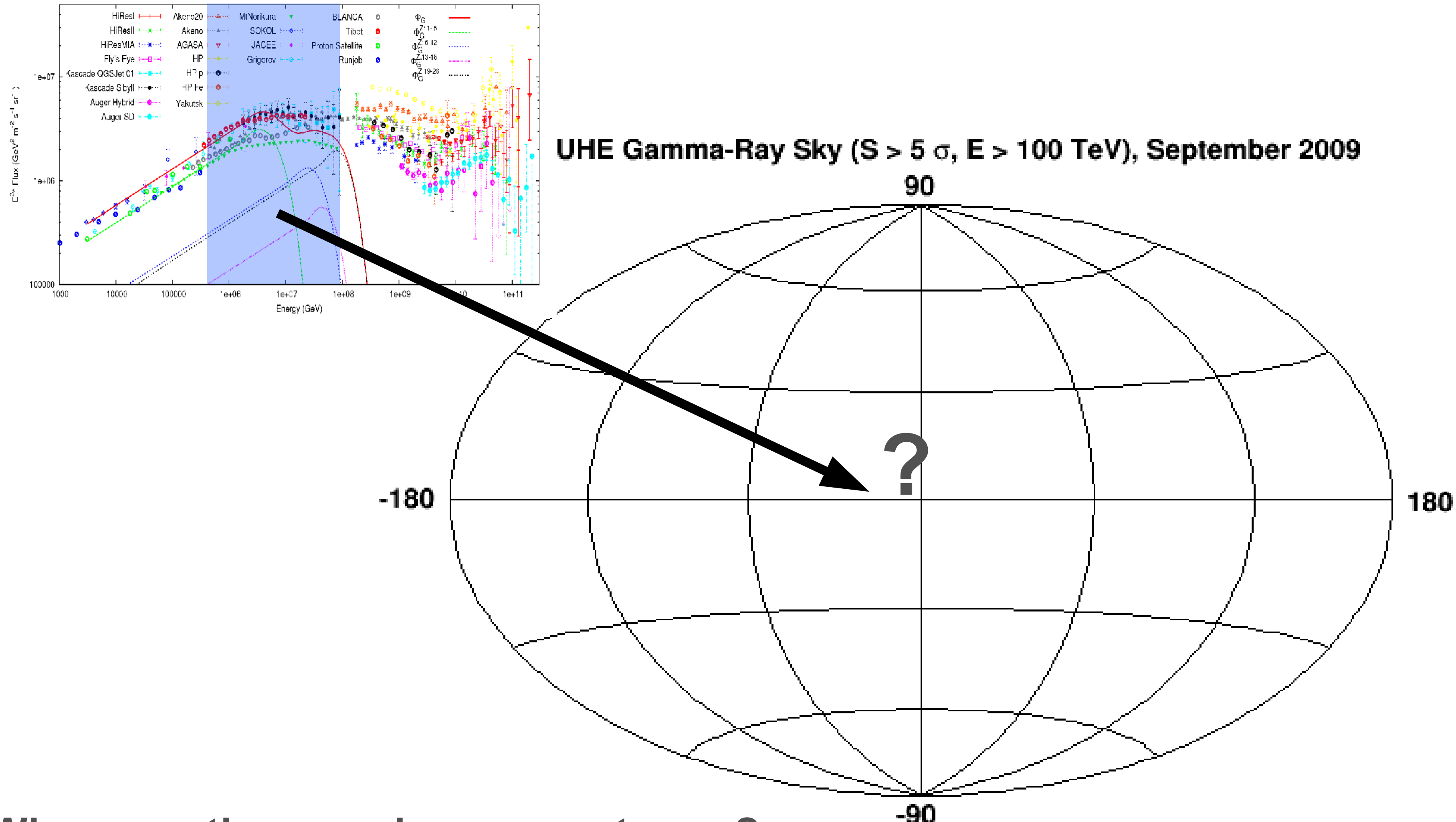

Where are the cosmic ray pevatrons ?

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Accessing the pevatron sky: large area

The HiSCORE detector

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The HiSCORE detector

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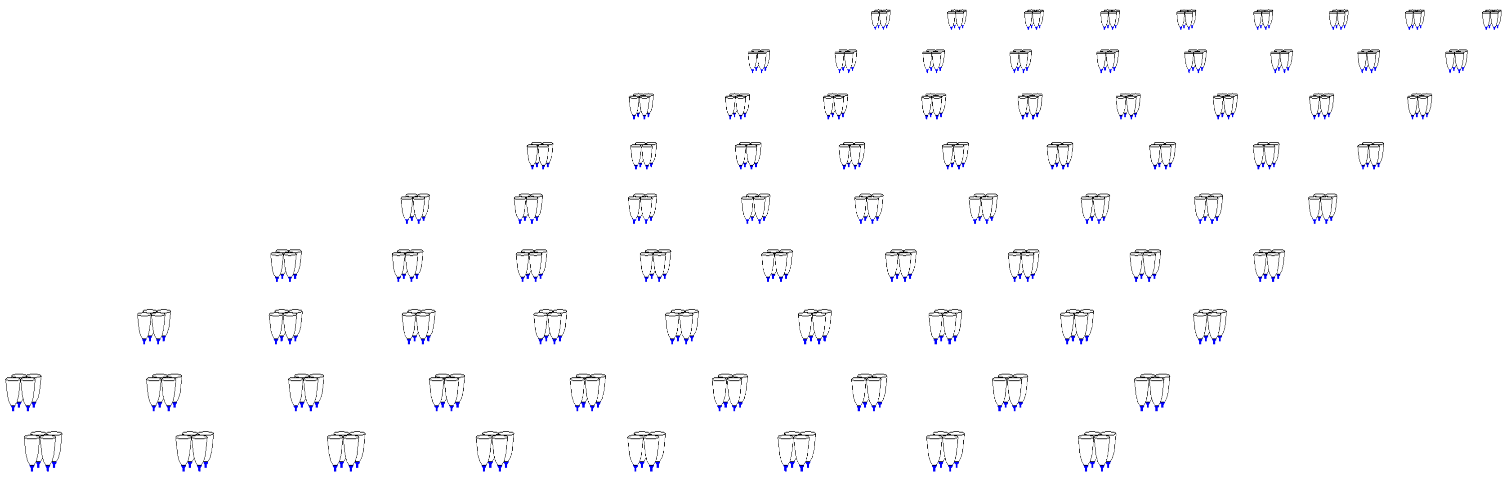
How to achieve large effective area ?

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

Picture: Serge Brunier

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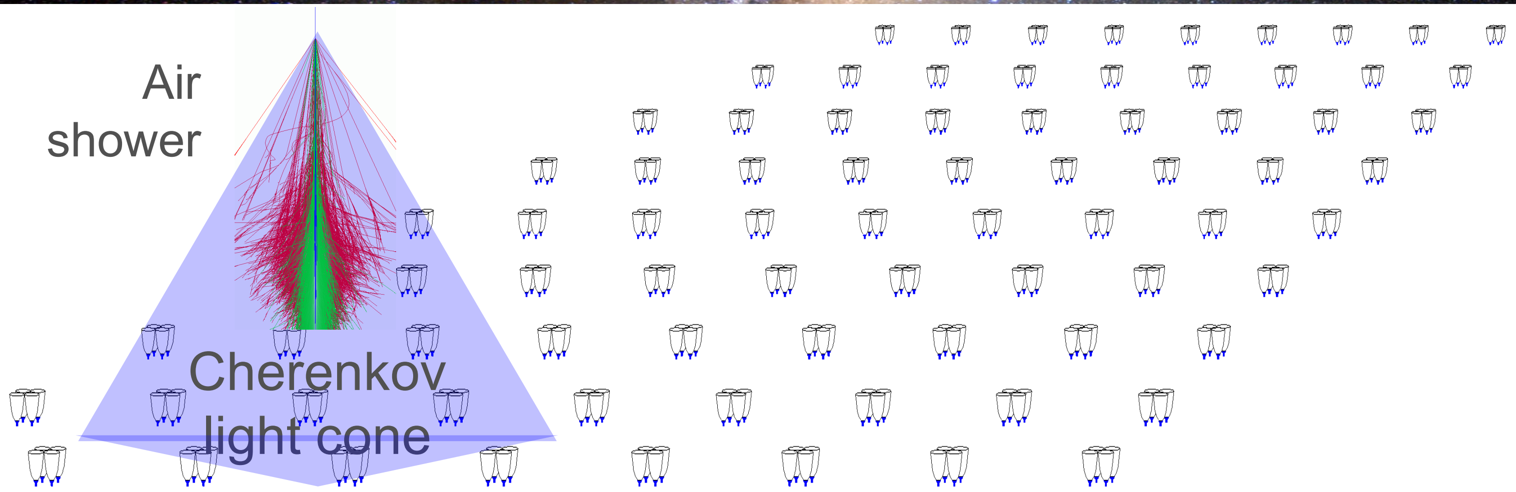
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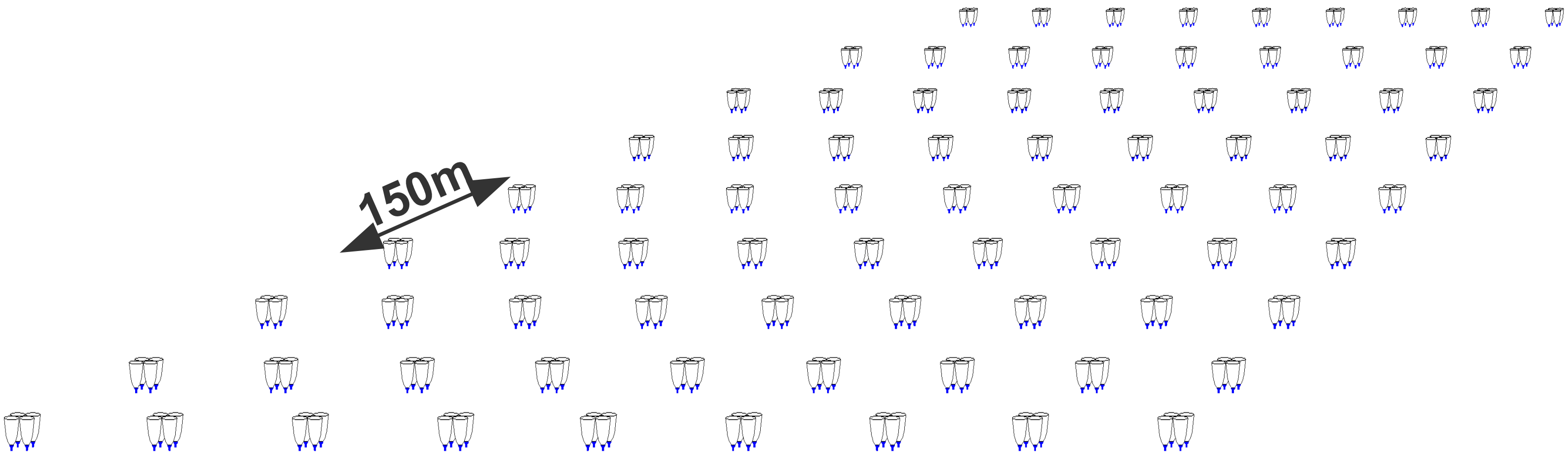

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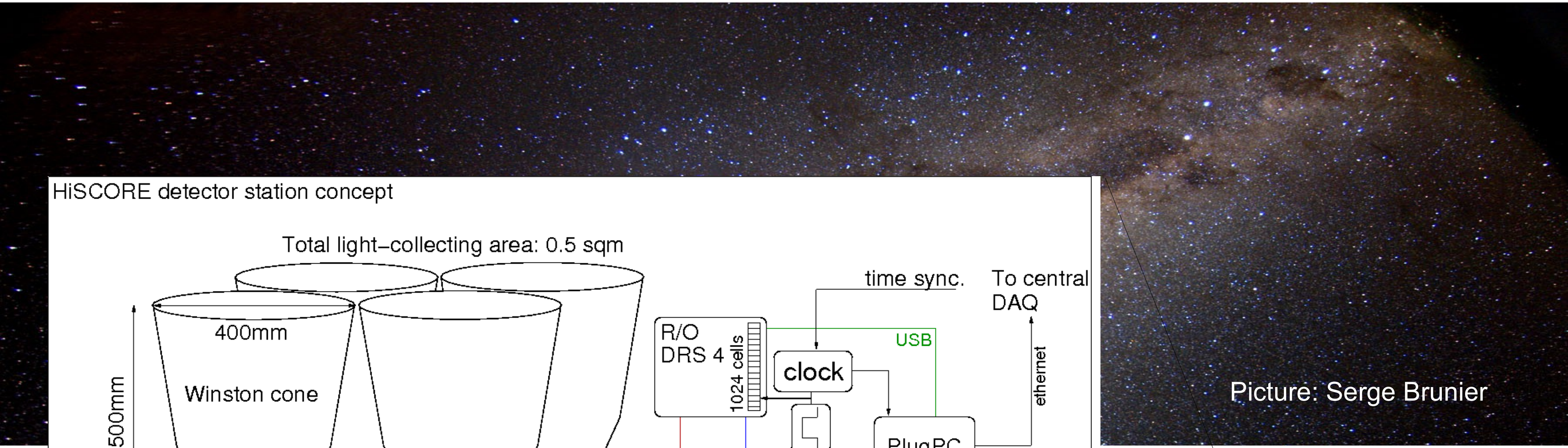

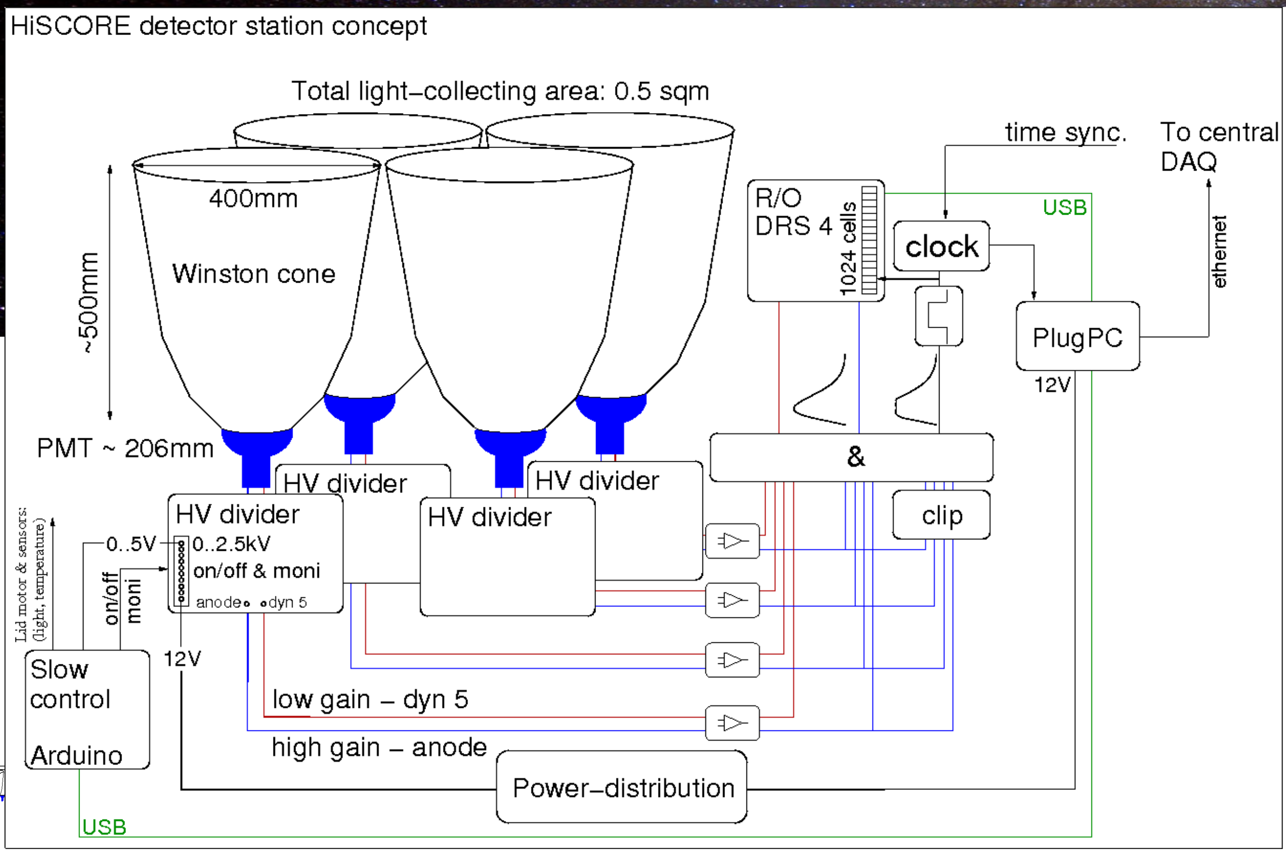

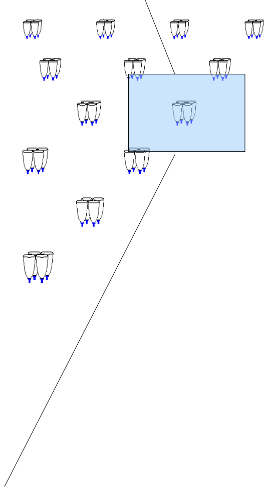

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The HiSCORE detector

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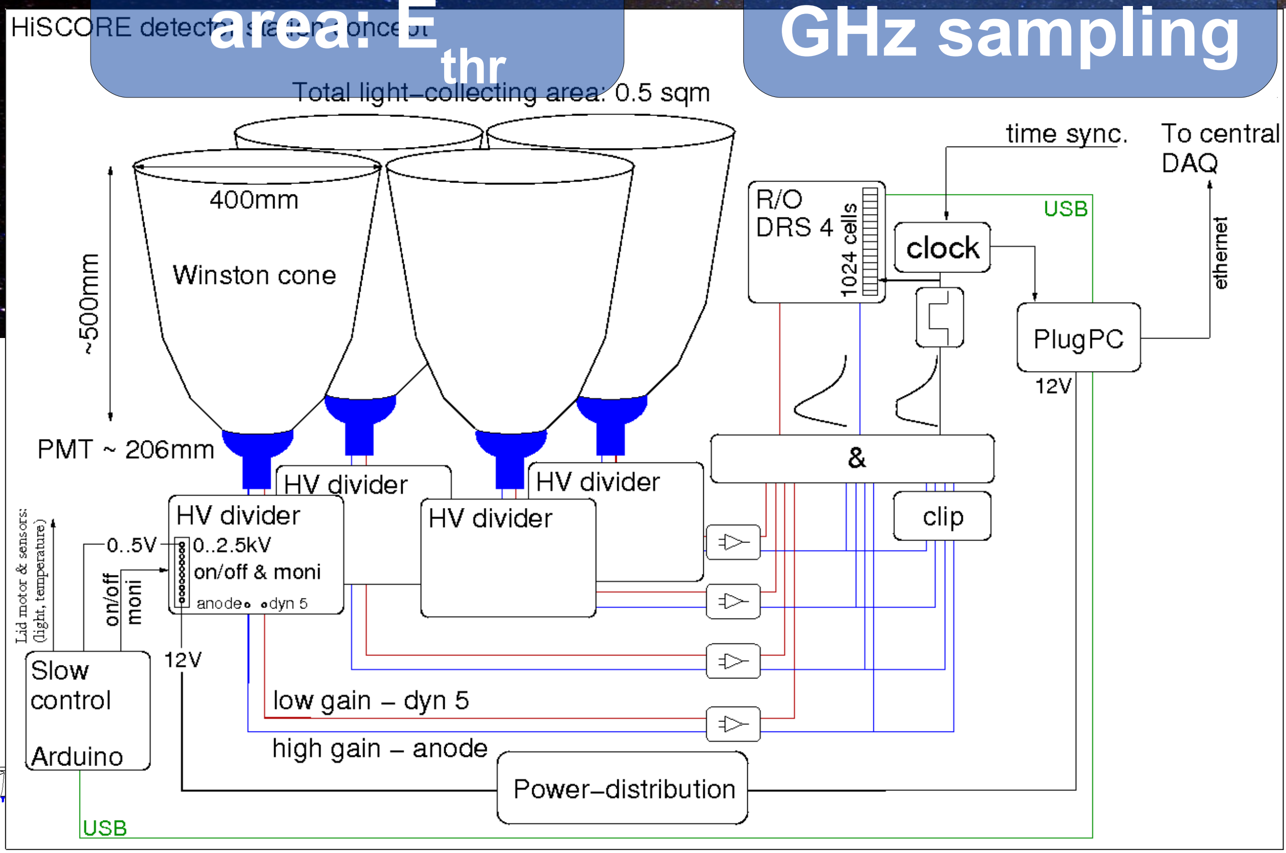
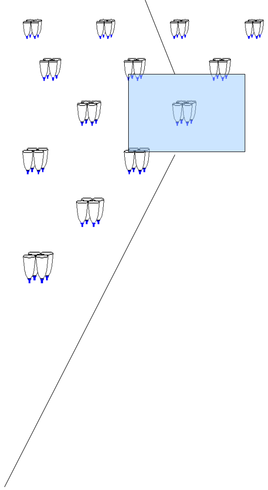
0.5 m² station area: E_{thr}

Readout: GHz sampling

1ns time synch.



Picture: Serge Brunier



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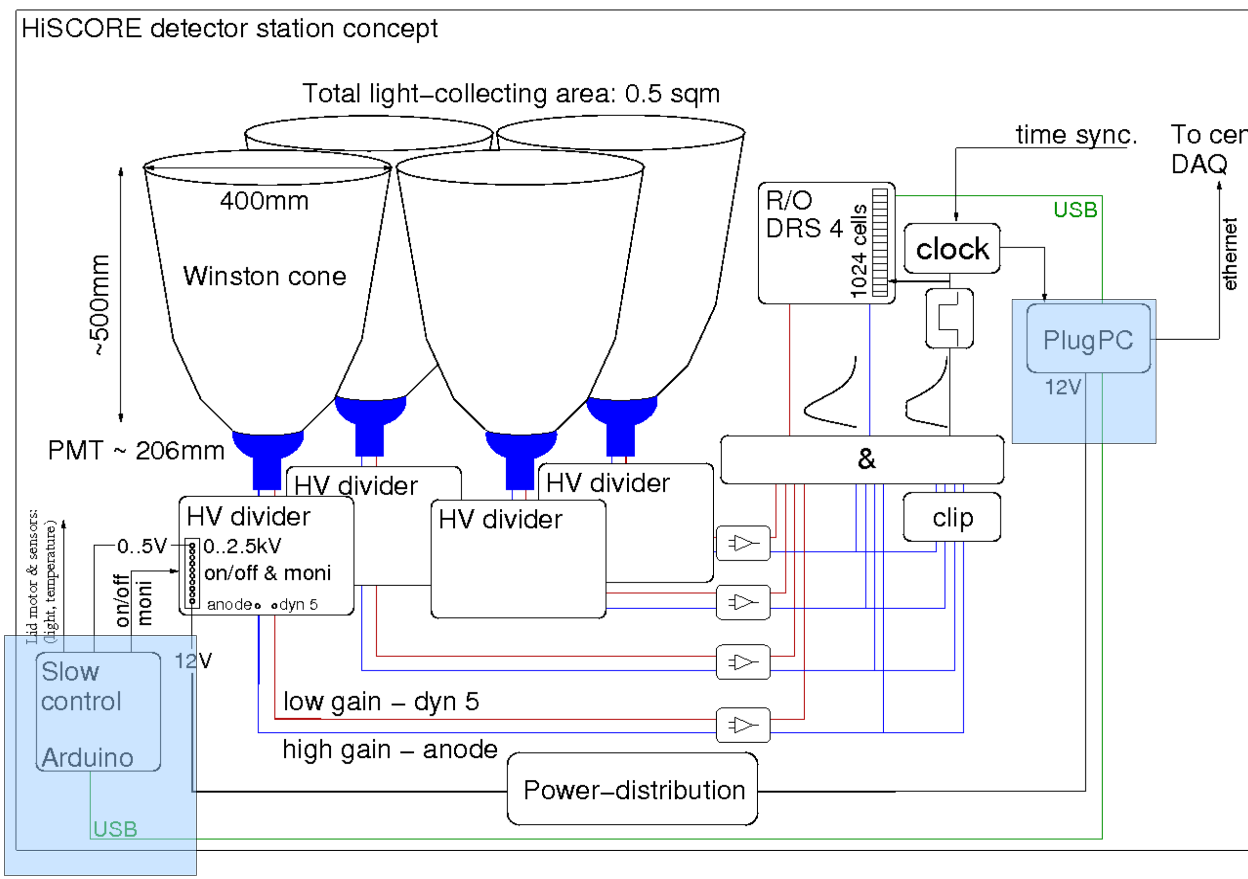

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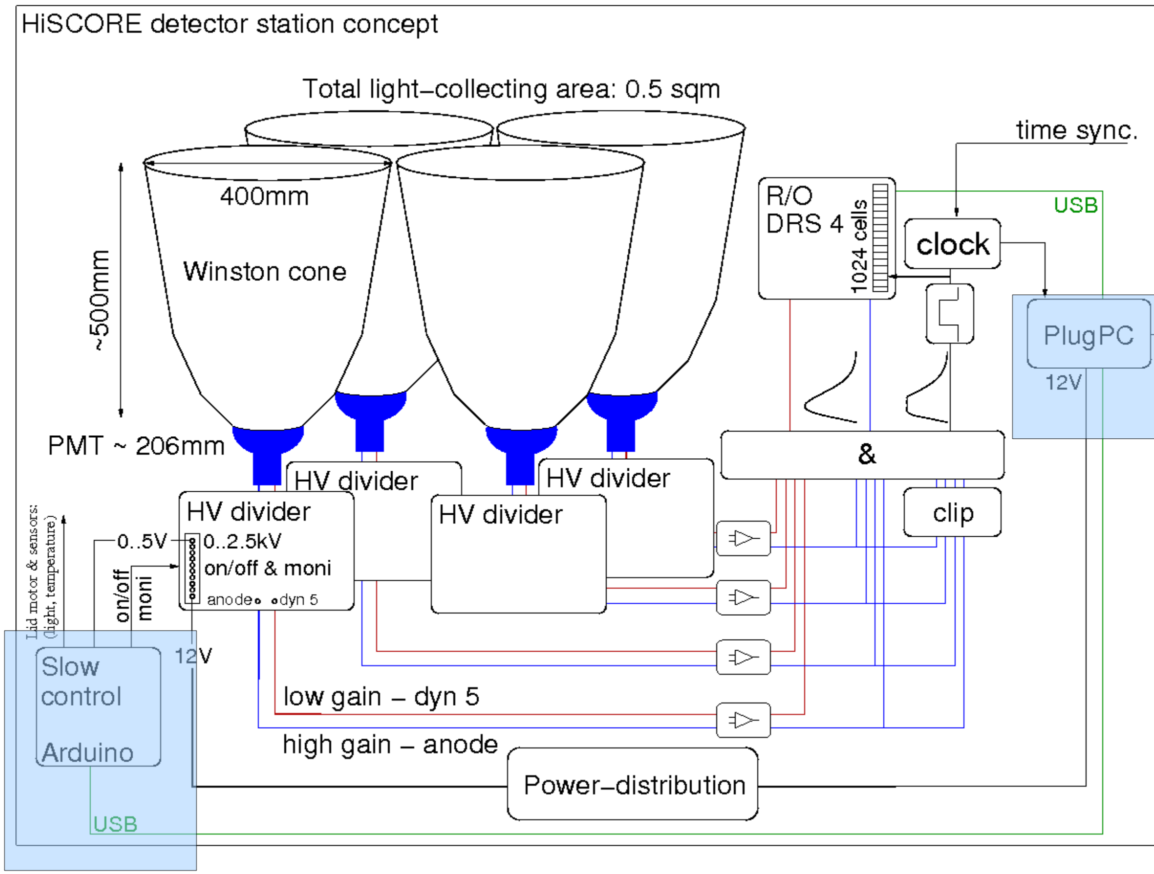

Station Control

slow control with
Arduino MEGA 2562

DAQ interface & station
PC GuruPlug

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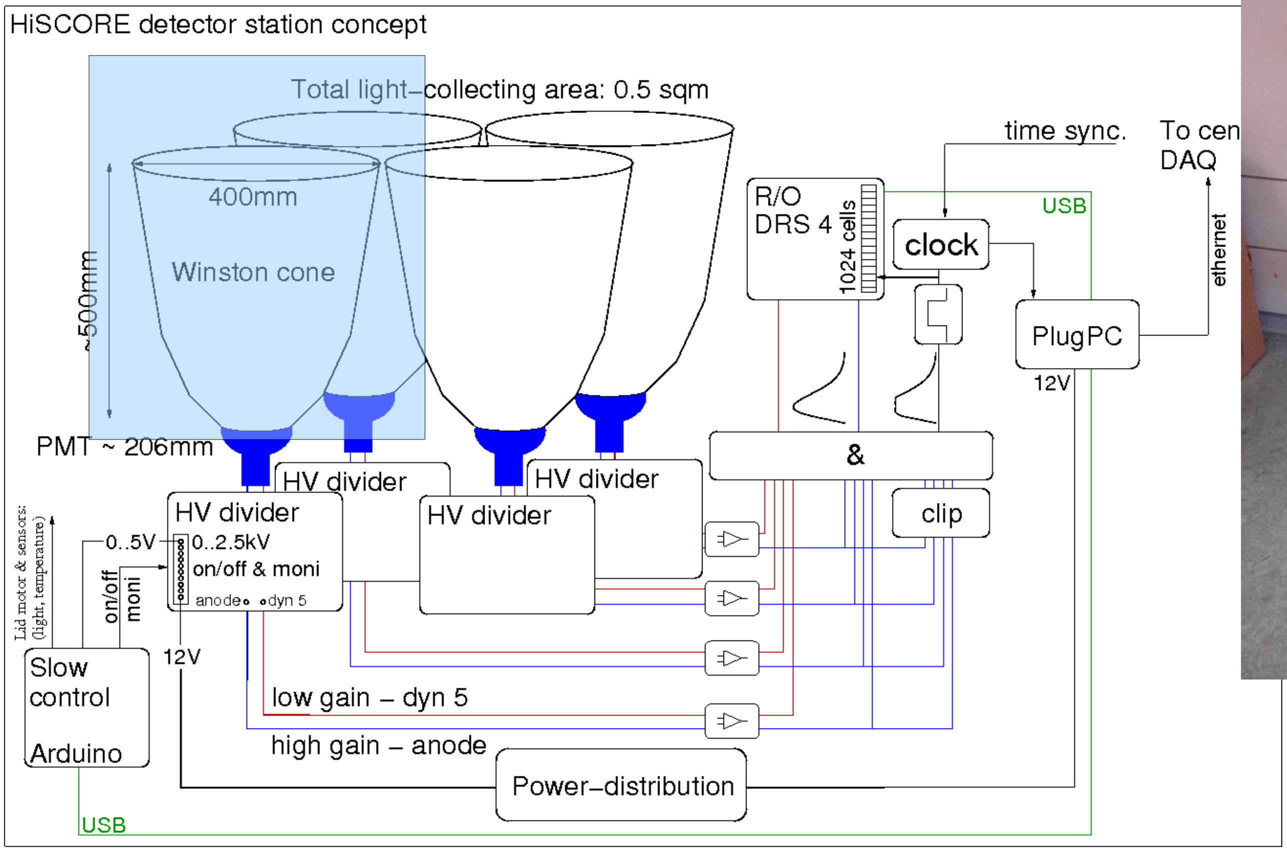
The HiSCORE detector



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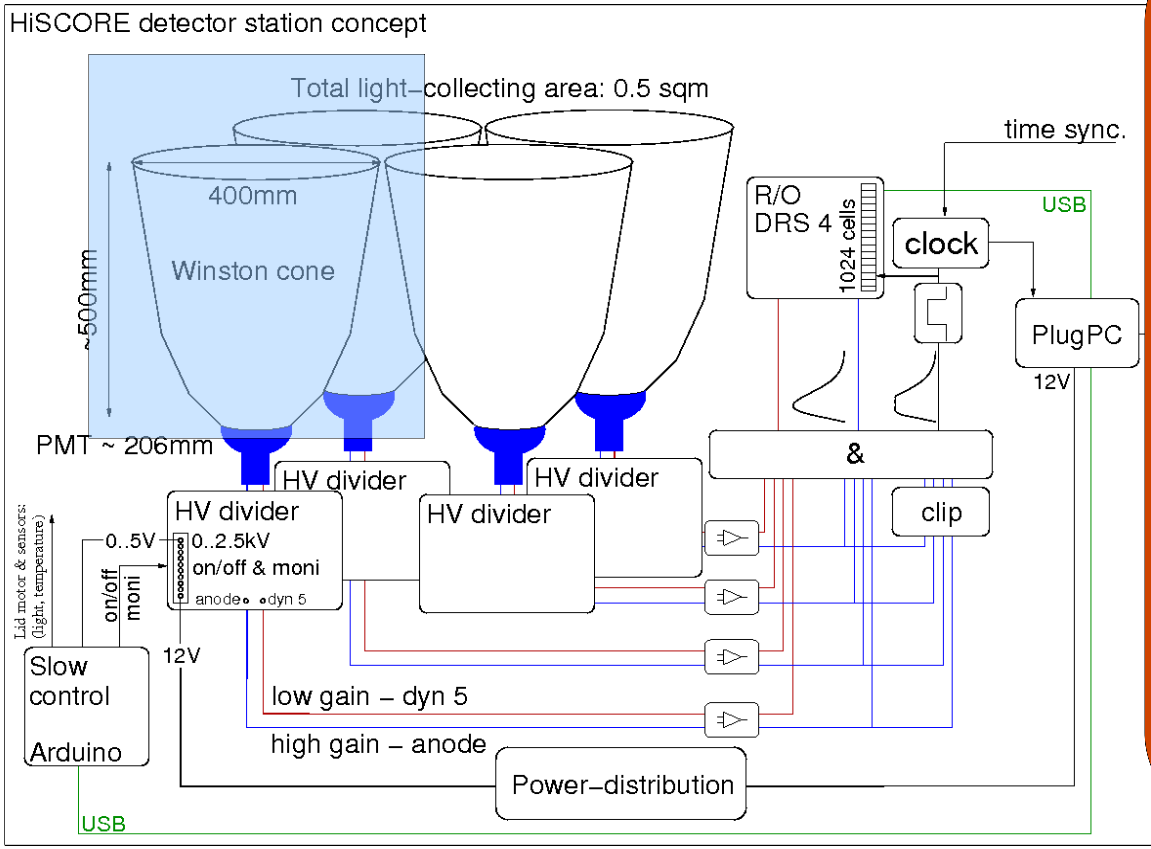

Winston Cone

10 segments of ALANOD 4300 UP

increase light collecting area 4x

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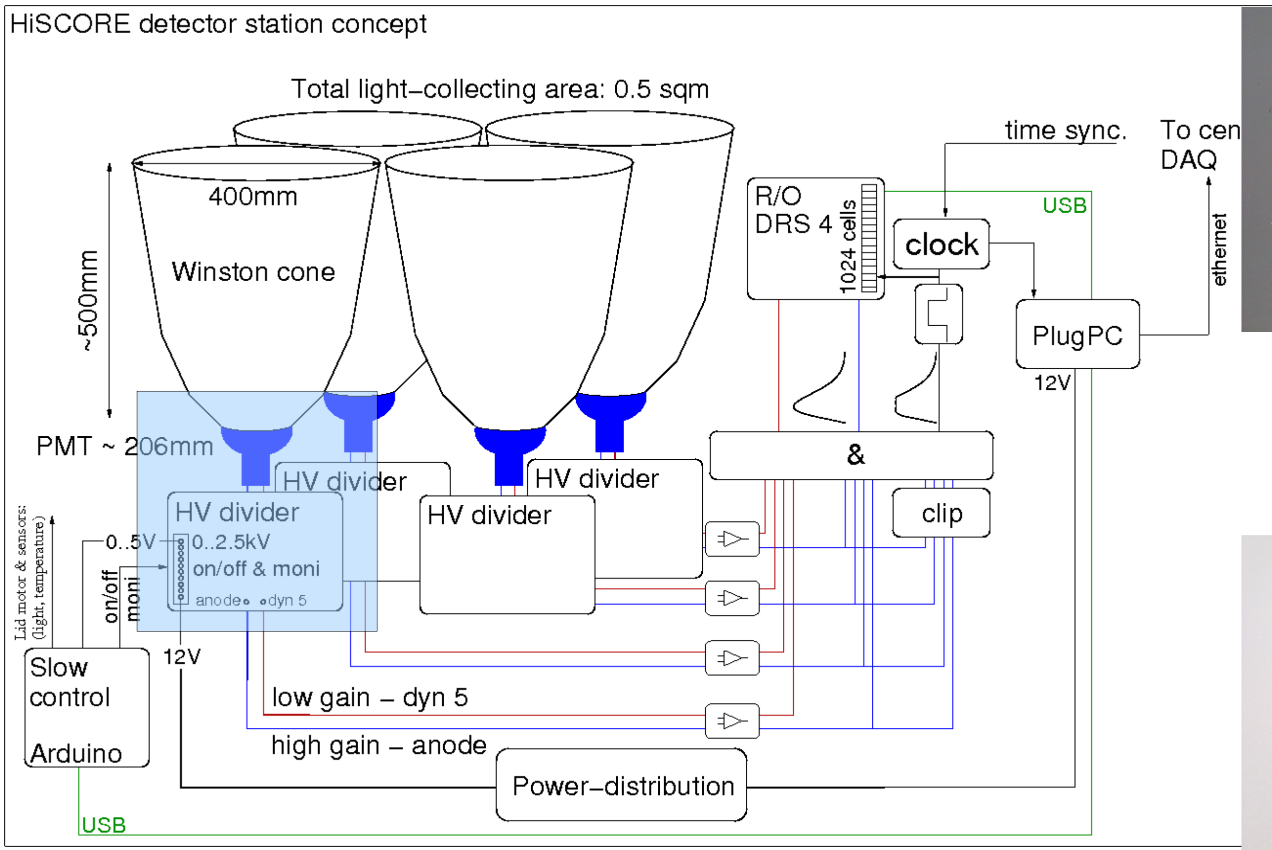
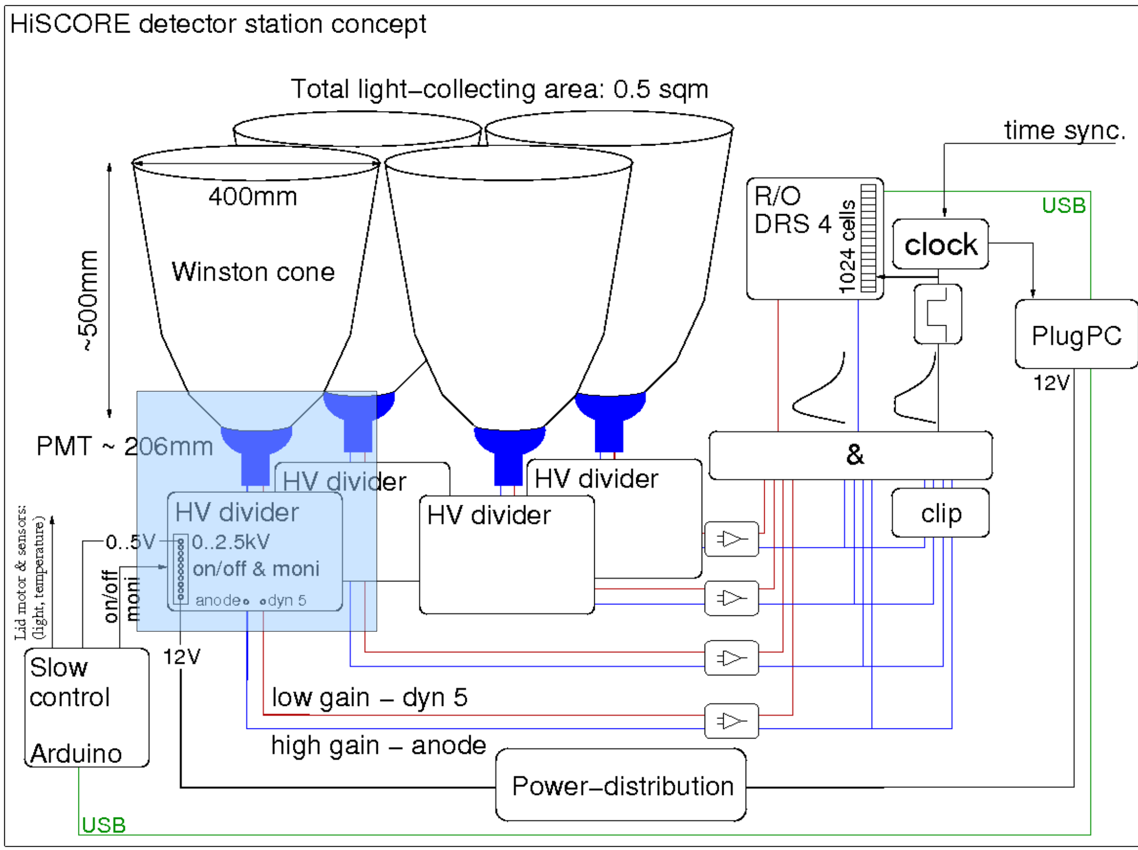


The HiSCORE detector



ET 9352KB

8” PMT with 6 stages

nominal gain 10^4 @ 1.4kV

PHQ9352

divider base with on board HV generation

readout of anode & 5^{th} dynode

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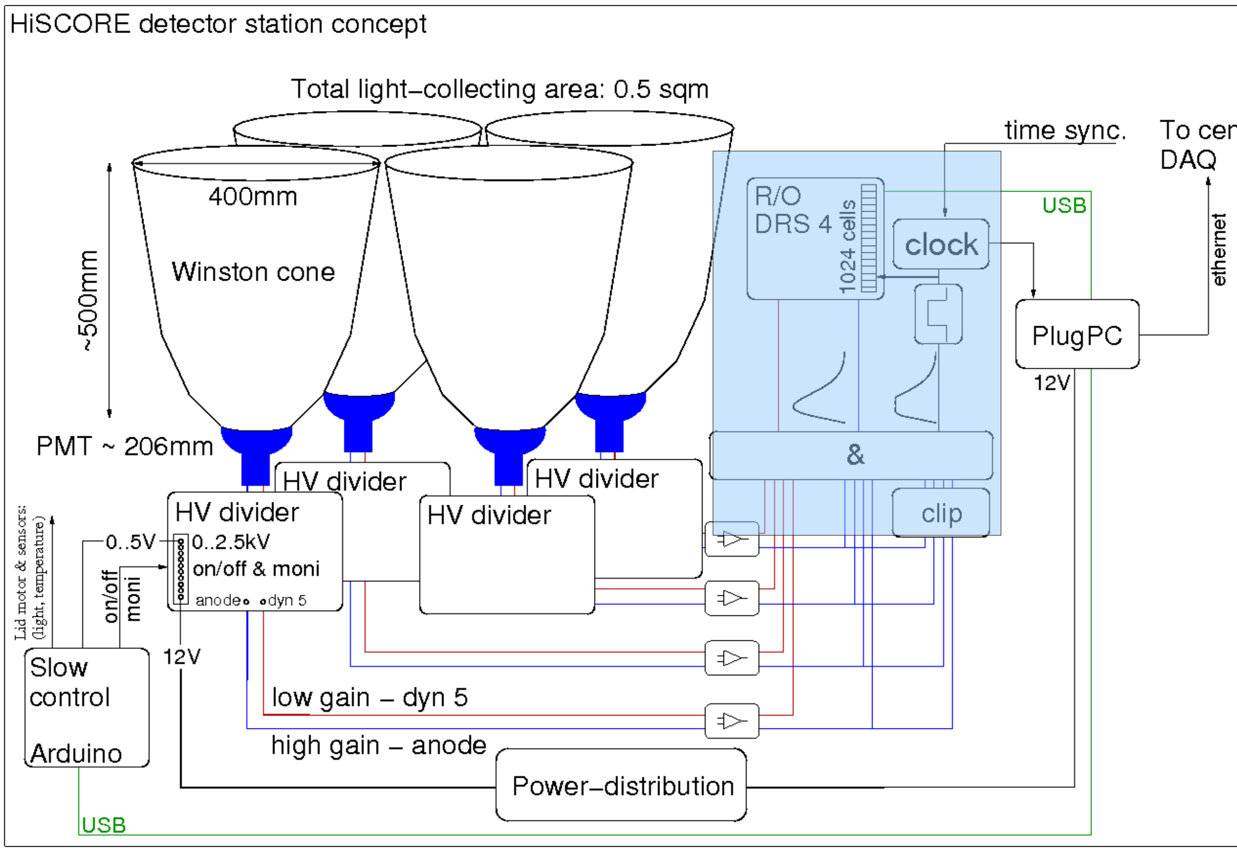
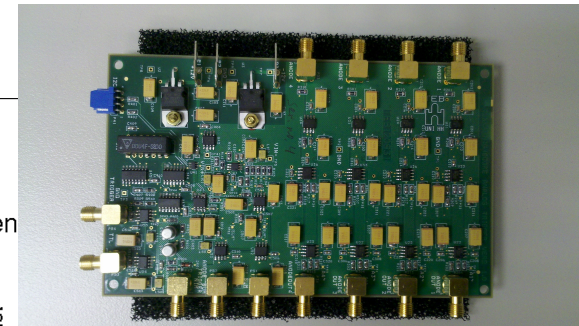
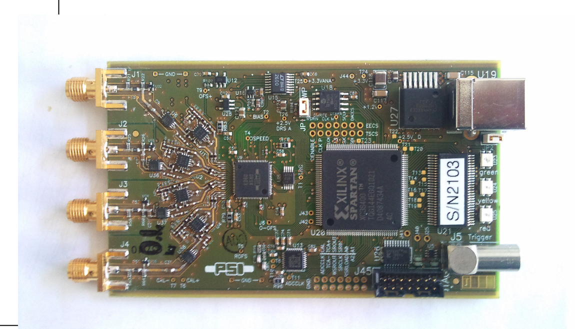
The HiSCORE detector







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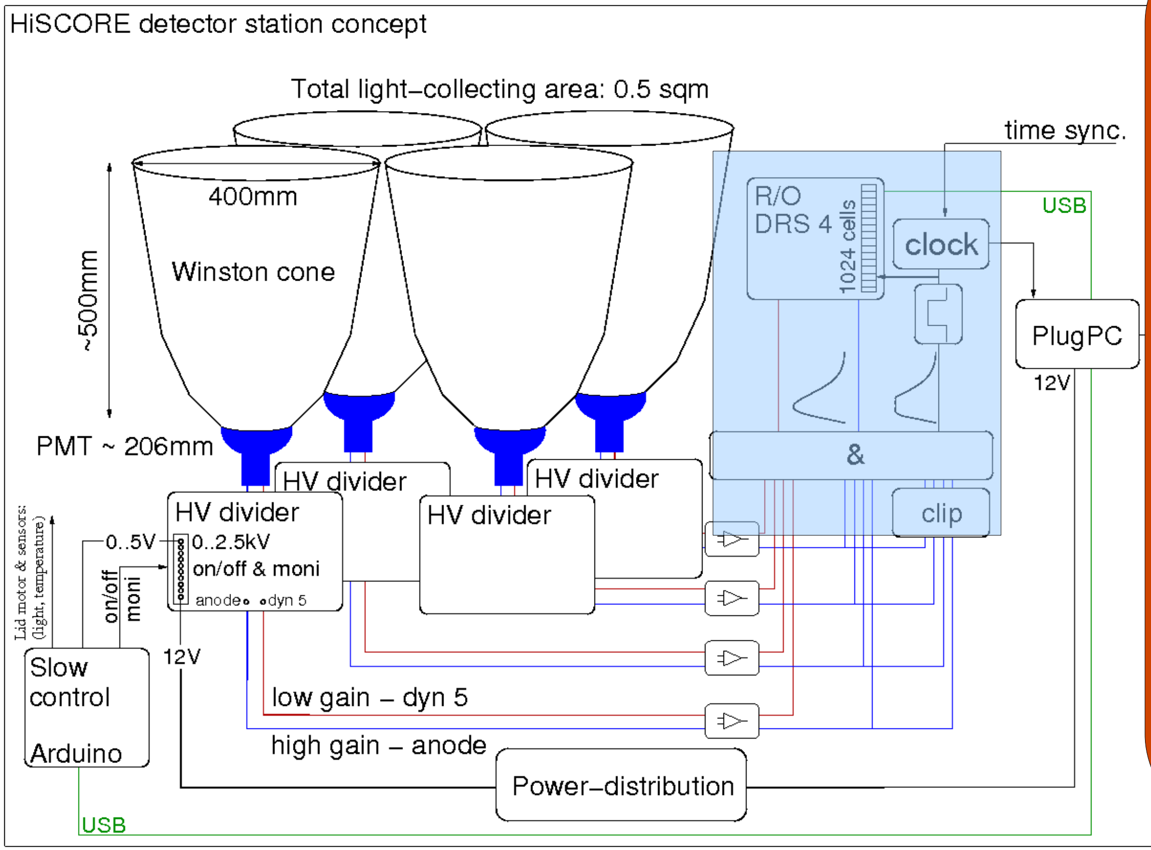

Readout

trigger board with clipped-sum-trigger

DRS4 based sampling

1 GS/s sampling

currently Evaluation Board V3

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Further component alternatives & developments

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MSU

- trigger boards (DRS4 based in prep.)
- PMT & divider bases

ISU

- box mechanics

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Signal Processing

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Signal Processing

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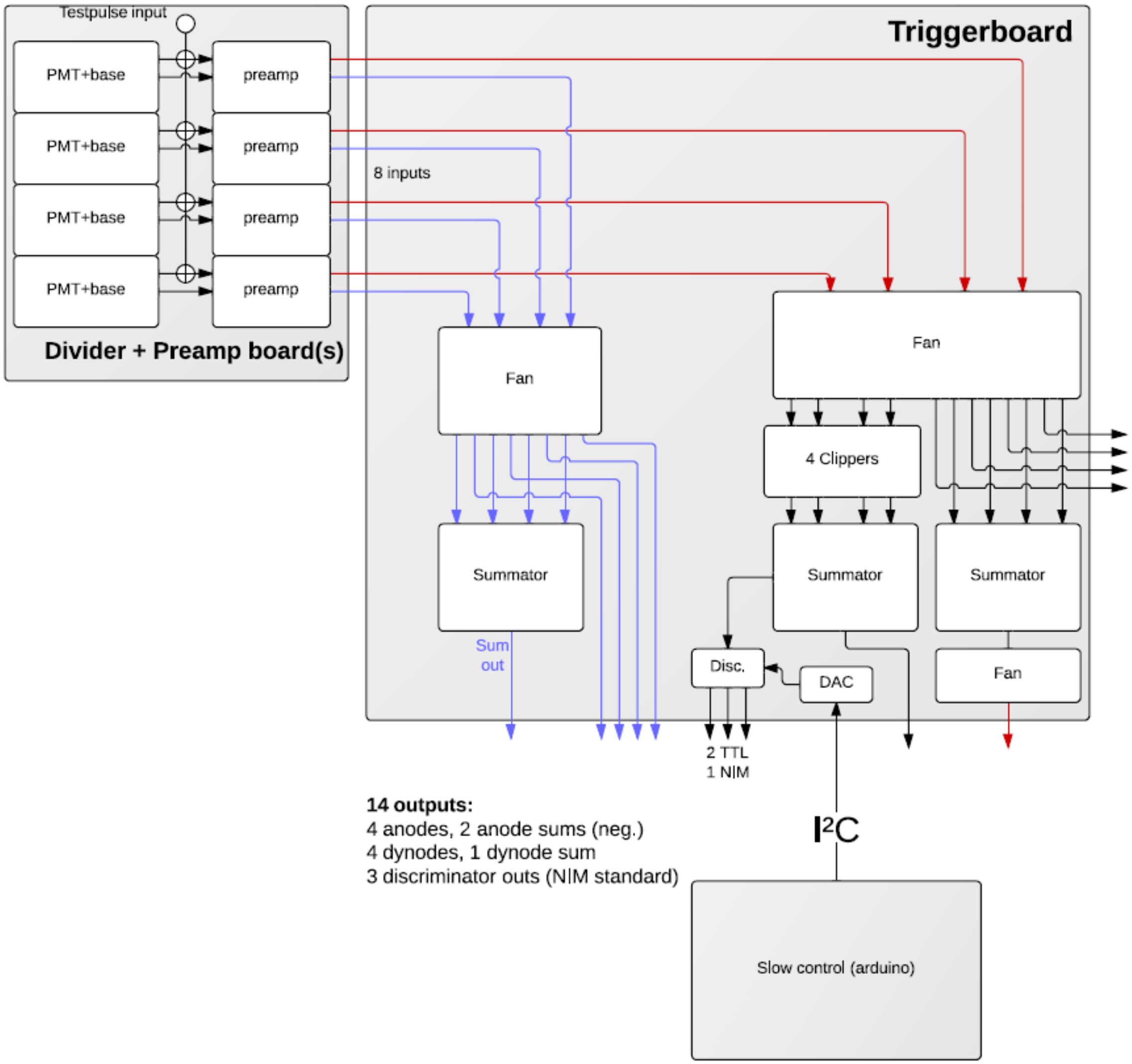

14 outputs:
4 anodes, 2 anode sums (neg.)
4 dynodes, 1 dynode sum
3 discriminator outs (NIM standard)

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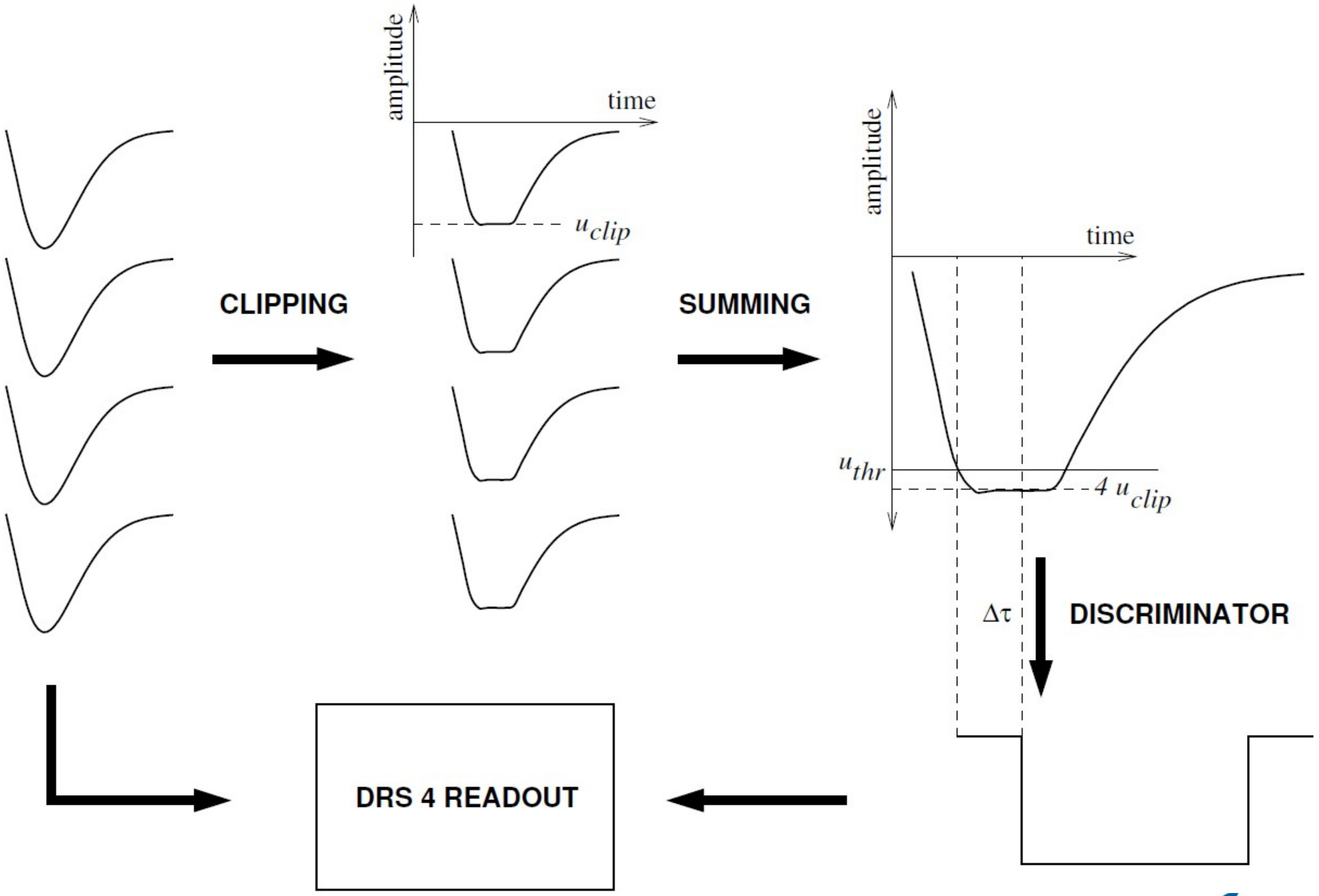
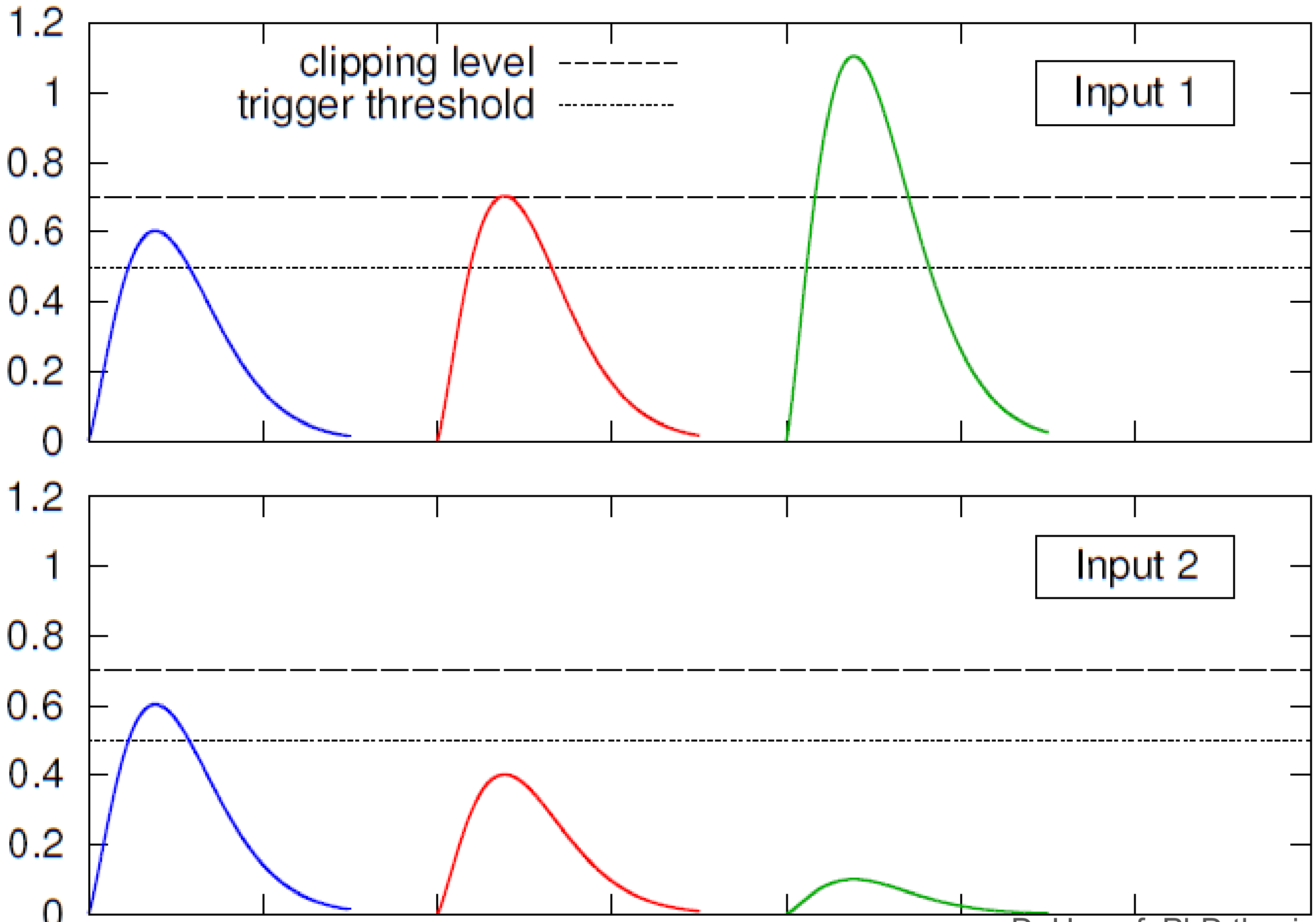
Signal Processing



Signal Processing



D. Hampf, PhD thesis

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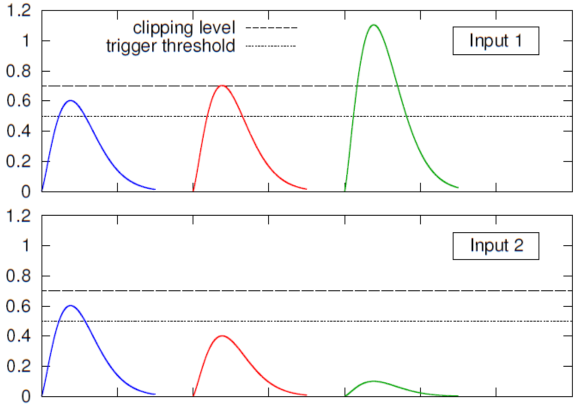

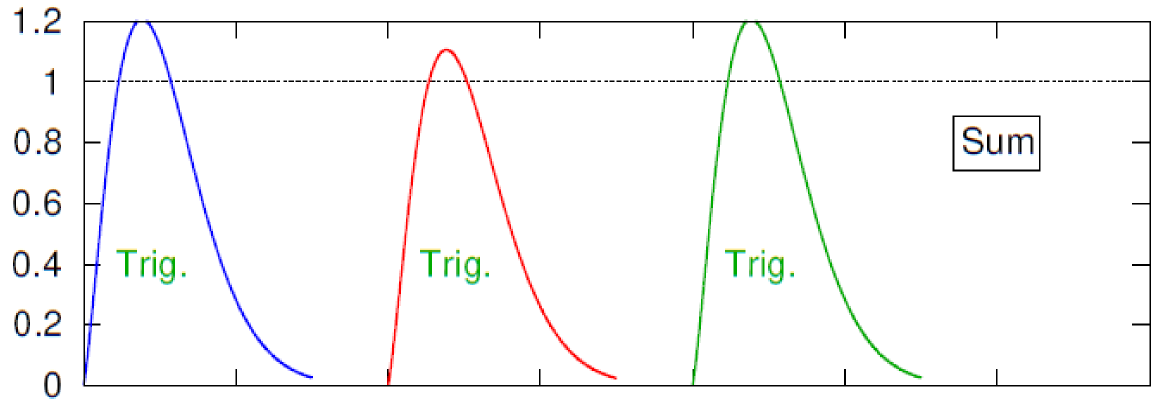

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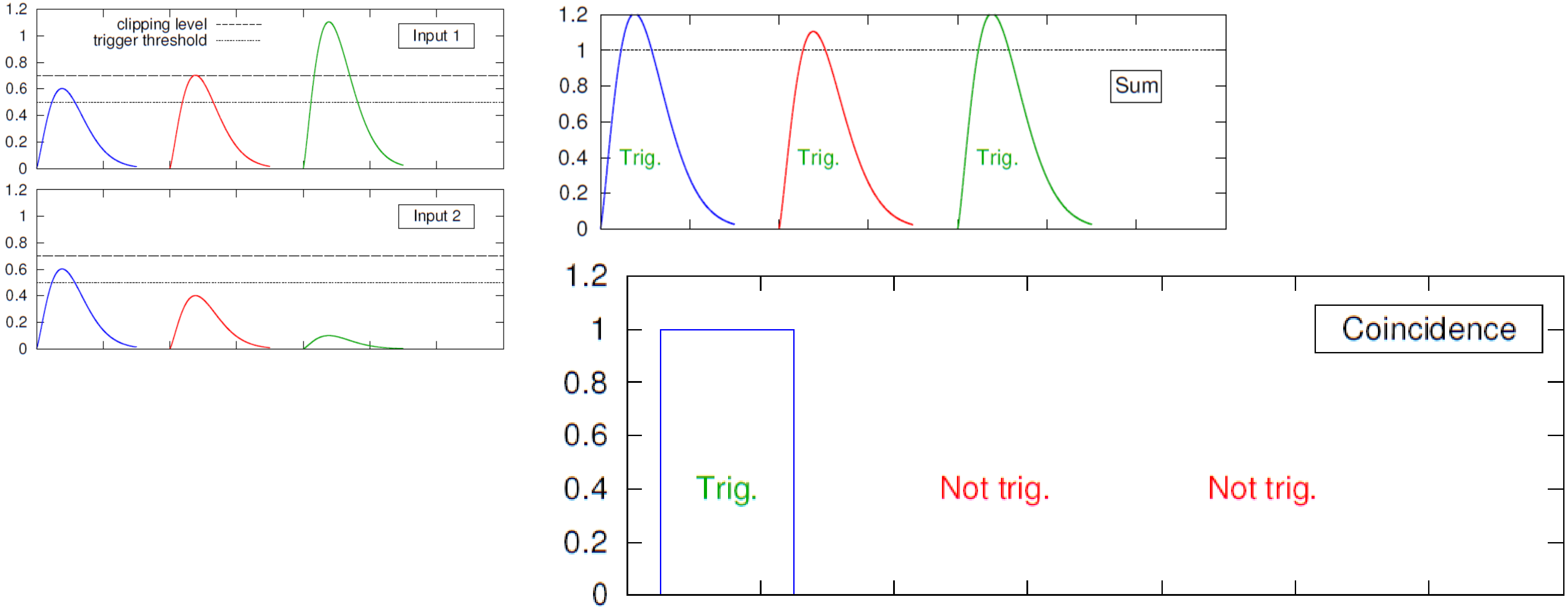

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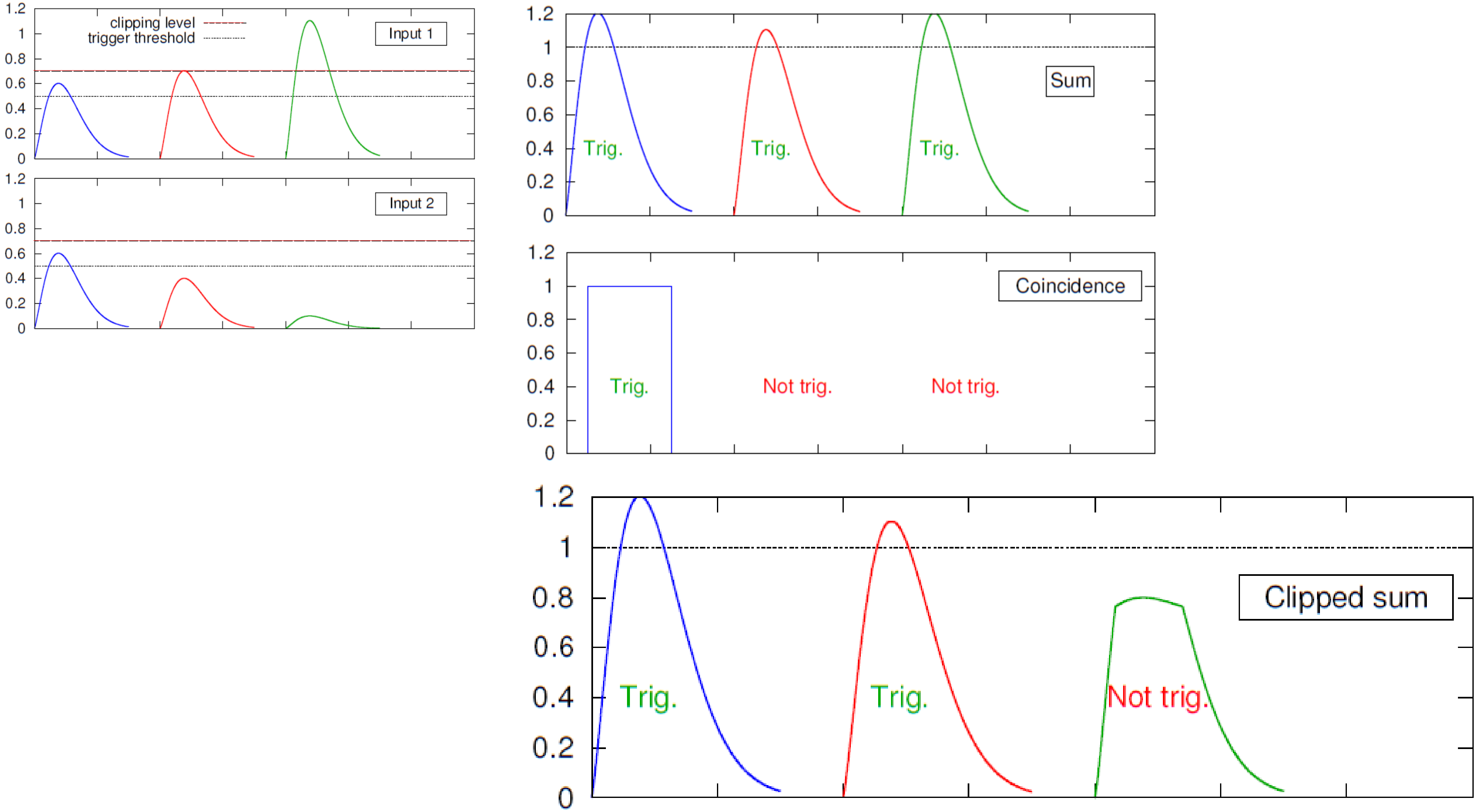

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Physics potential of HiSCORE

(gamma-ray astronomy)

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Opening the Pevatron range

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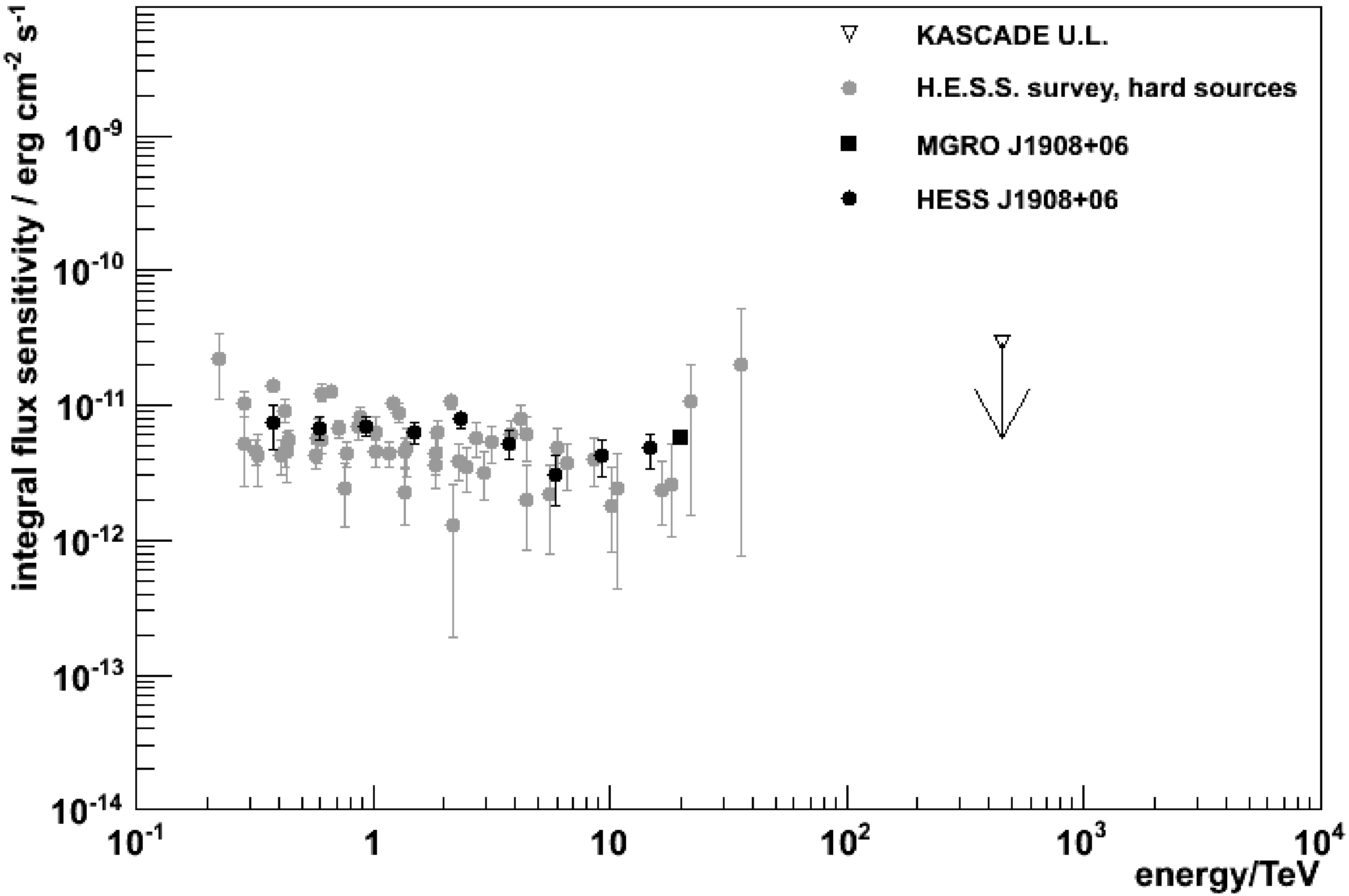

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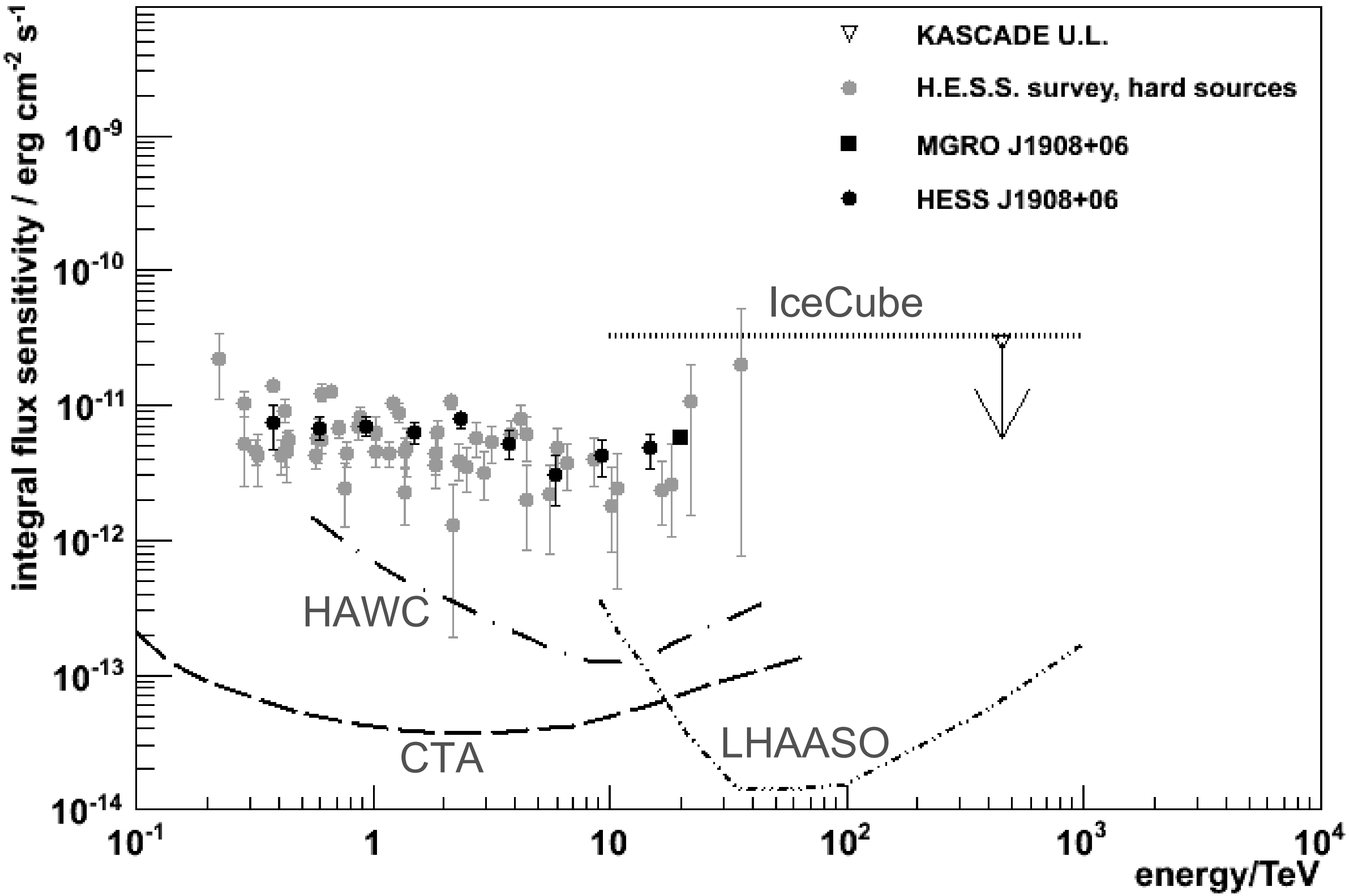

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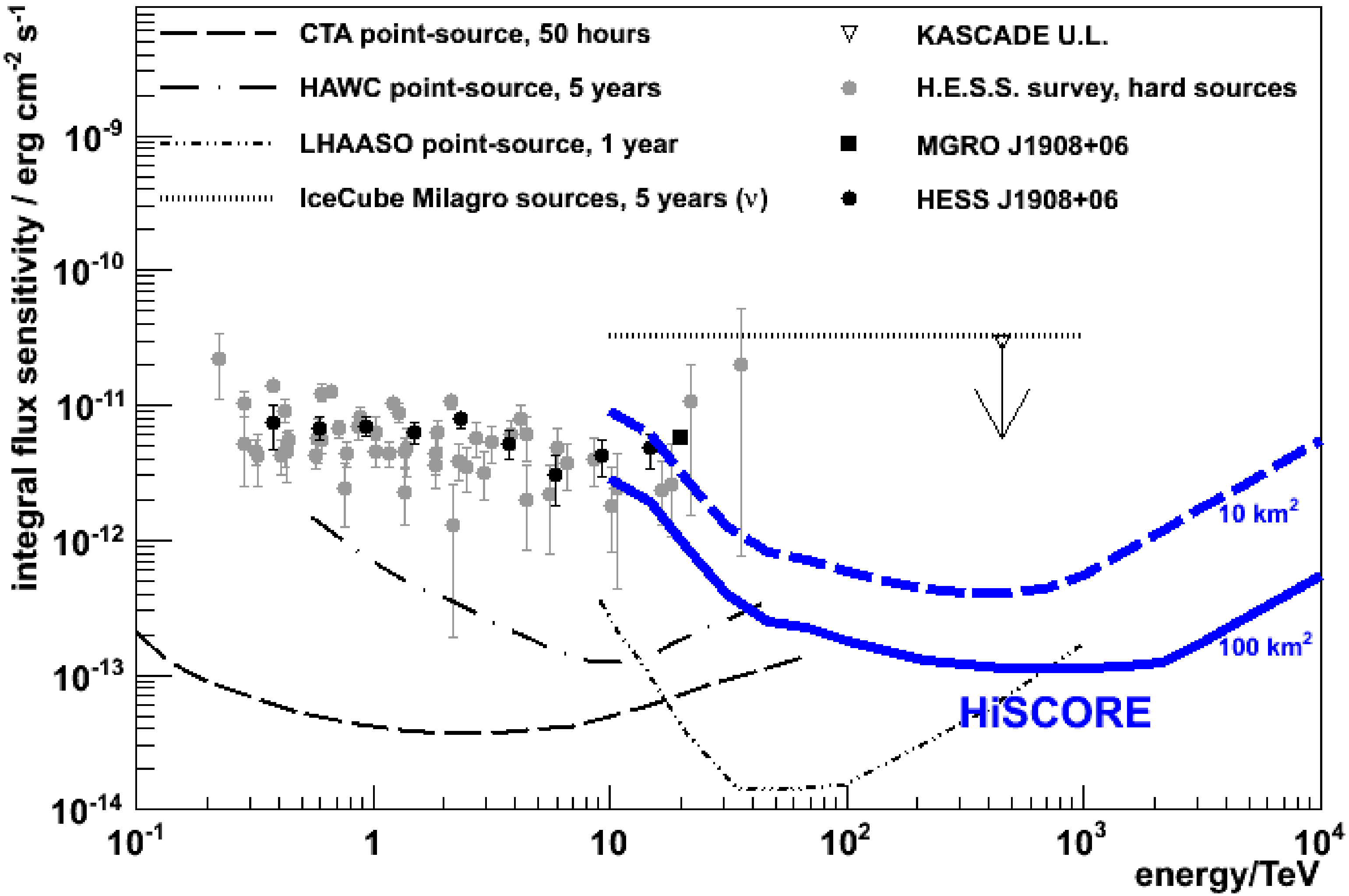

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HiSCORE current status and plans

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Helmholtz Russia Joint Research Group HRJRG

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- U. Hamburg
- KIT
- Desy Zeuthen
- INR Moscow
- MSU Moscow
- ISU Irkutsk

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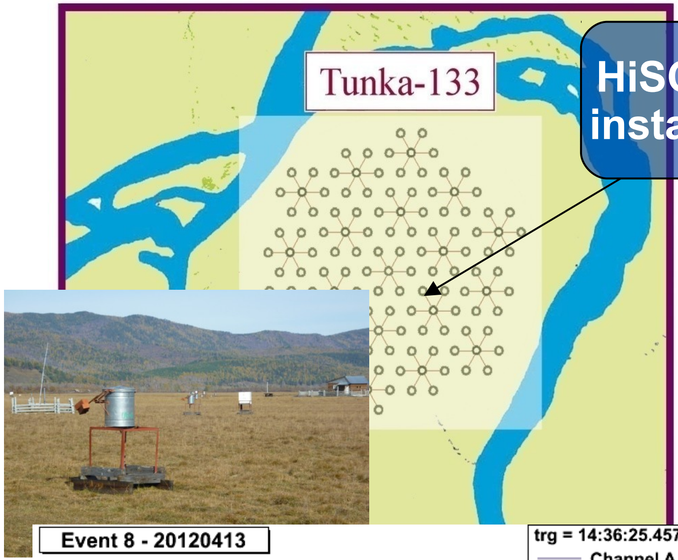
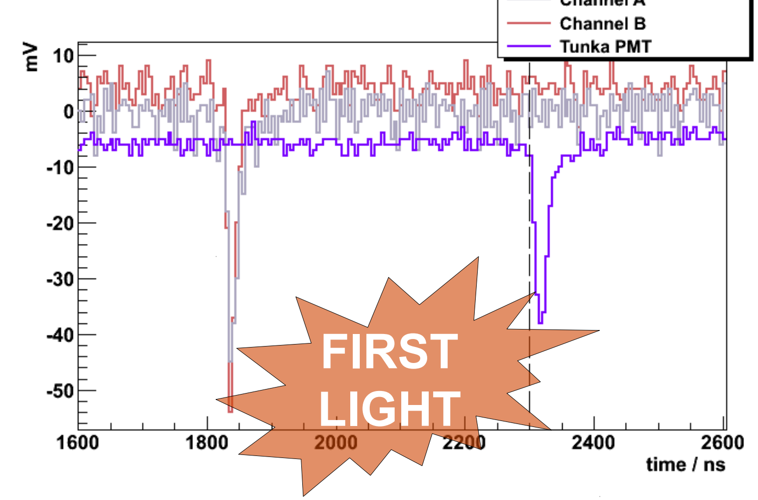
First HiSCORE prototype deployed





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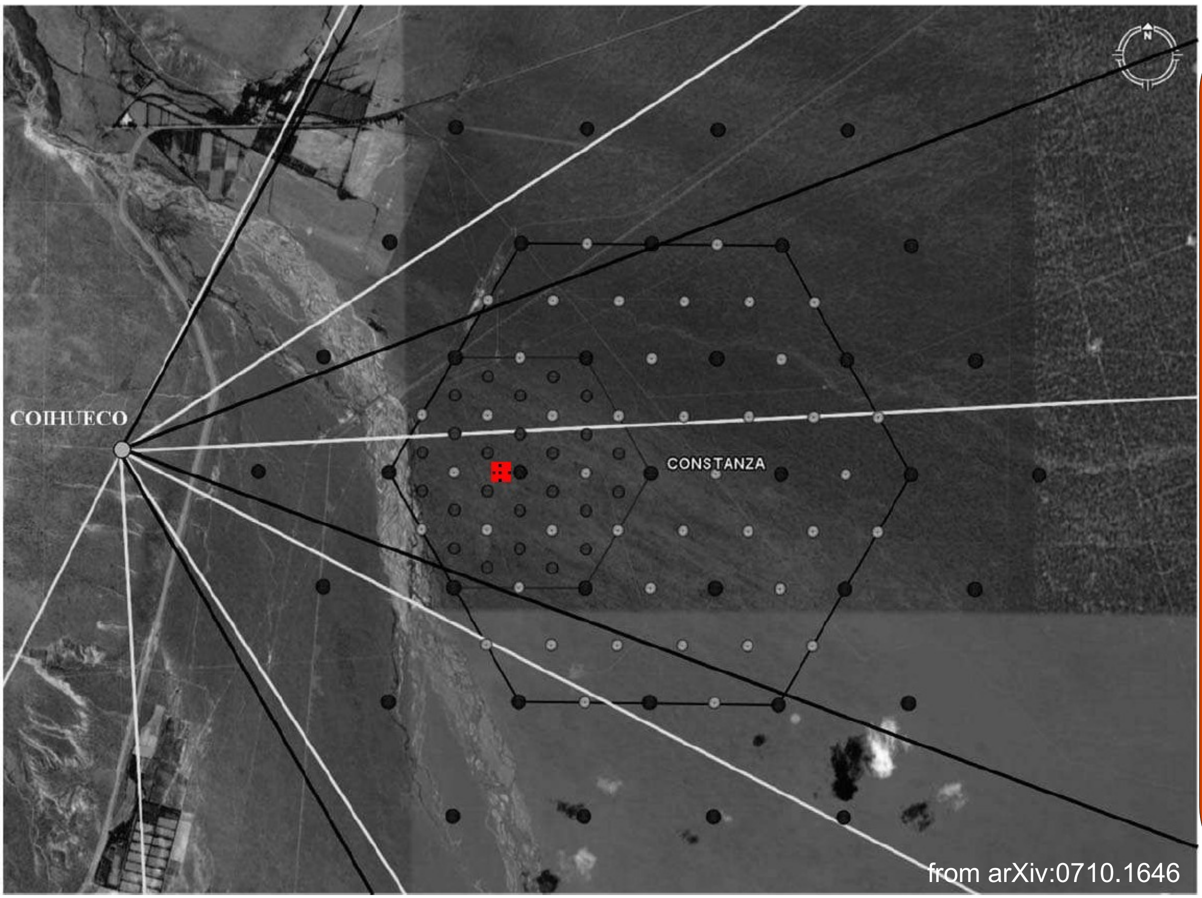
Helmholtz Alliance for Astroparticle Physics
HiSCORE @ PAO



- letter of intent written, waiting for decision
- small array (5 stations)
- synergy with infill SD and FD
- expected 10 cross events per day

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Summary & outlook

HiSCORE goals:

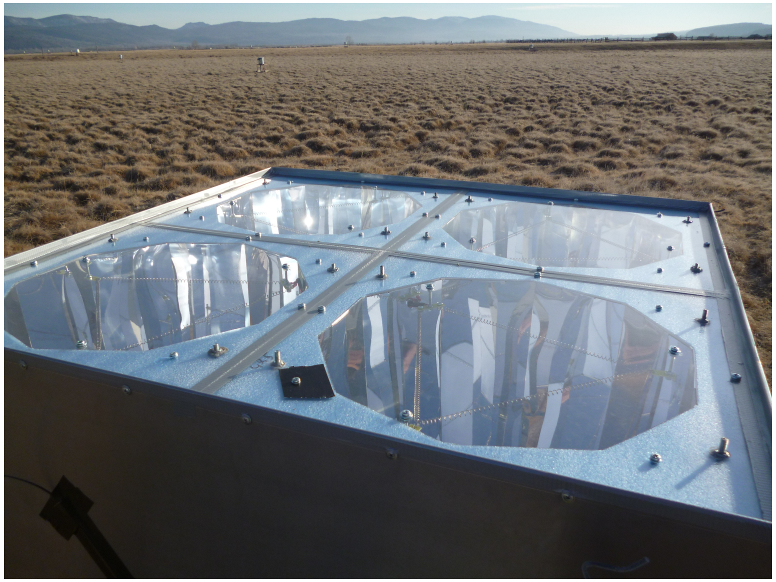
- Ultra-high energy gamma-ray observation window
- Cosmic ray physics from 100 TeV to 1 EeV
- Particle physics beyond LHC energy range

Activities:

- 3 stations since April 2012
- small array @ PAO 2013/14

Engineering array (1 km²), HiSCORE-EA:

- Start 2013
- Potential for 1st physics results



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Thank you!

Backup slides

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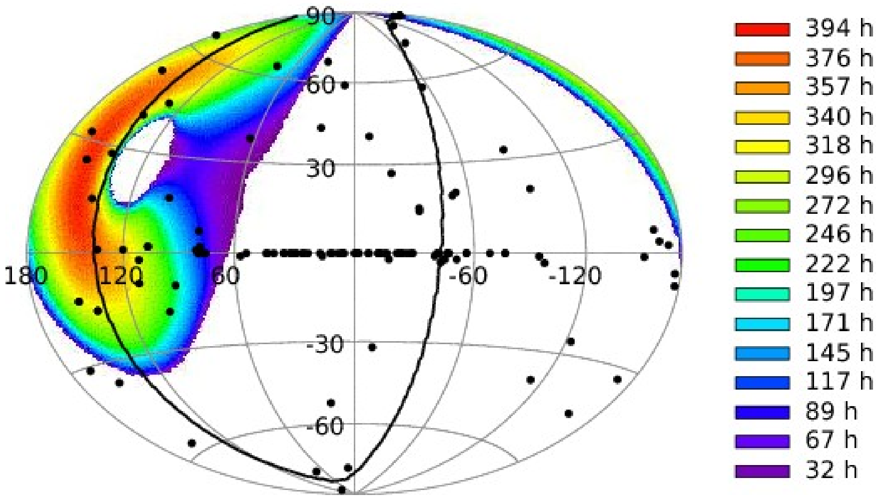
Tunka site exposure map



Tunka site exposure map

Field of view: π steradian

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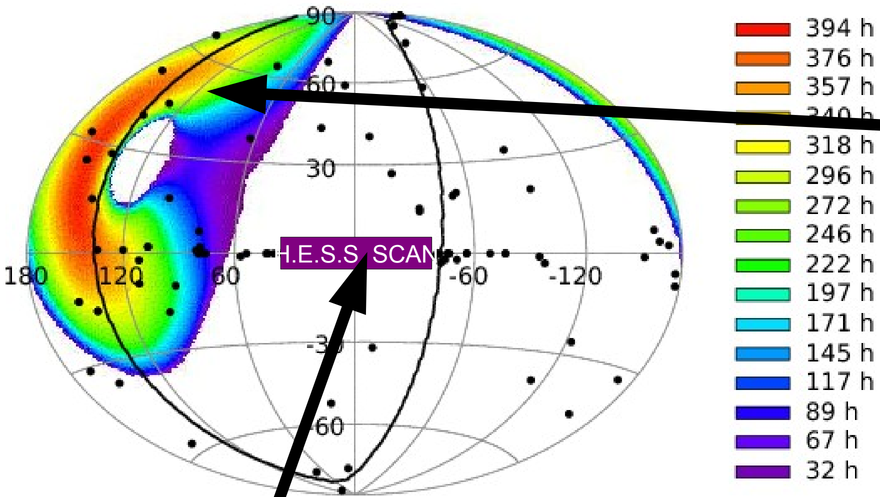
Tunka site exposure map



HiSCORE scan normal mode

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

Tunka site exposure map

Field of view: π steradian

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Tunka site exposure map

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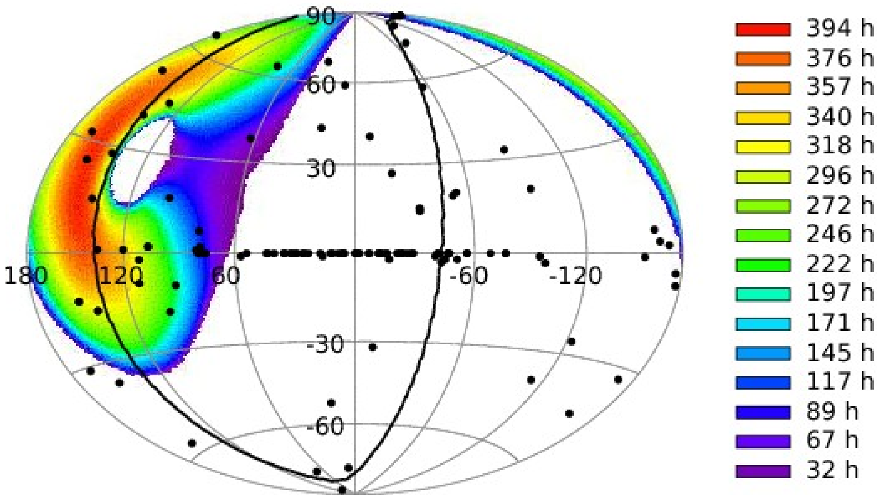

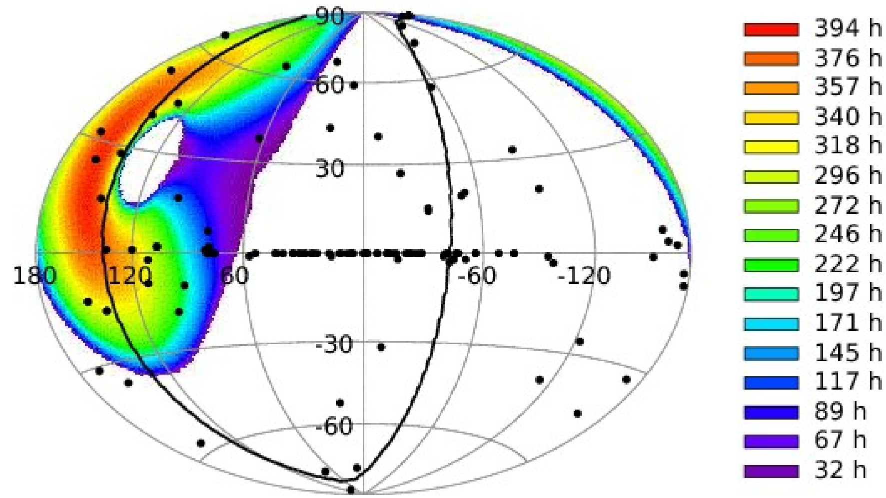

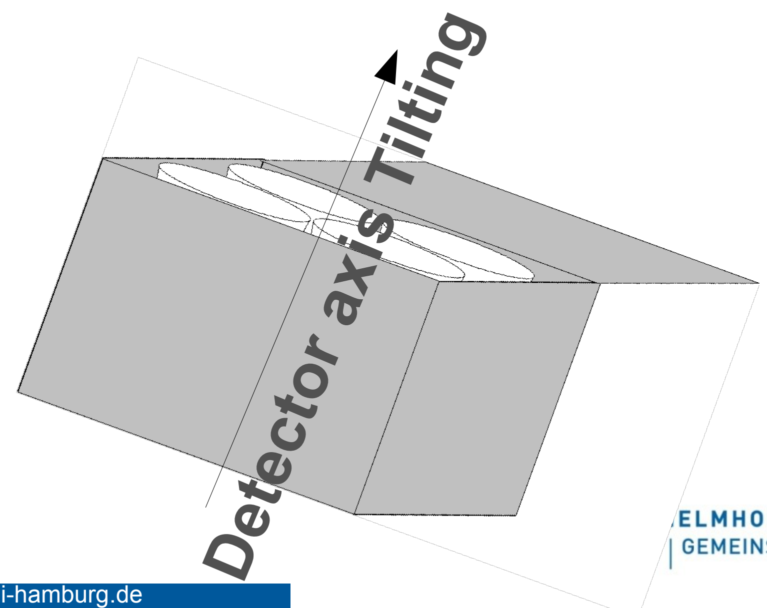

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Tunka site exposure map

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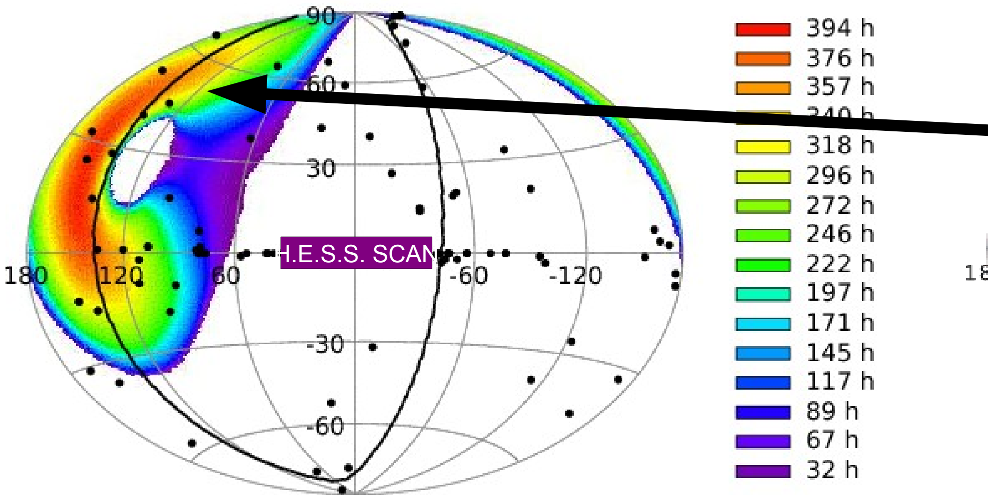

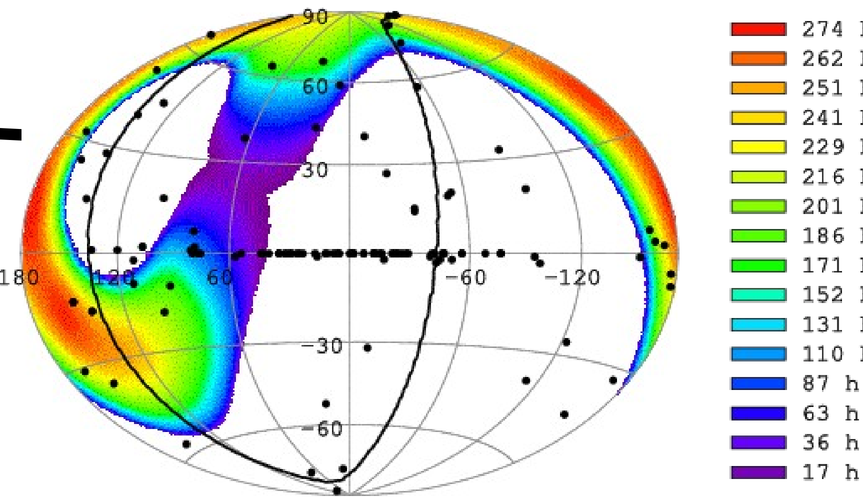

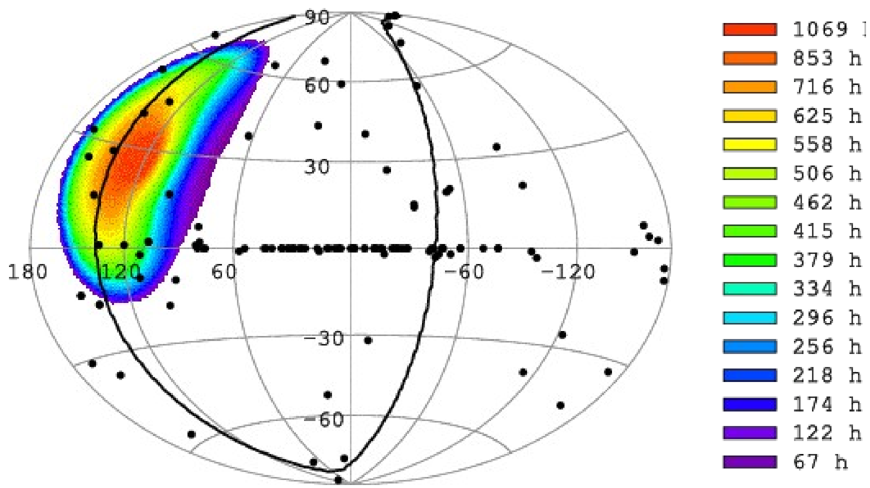

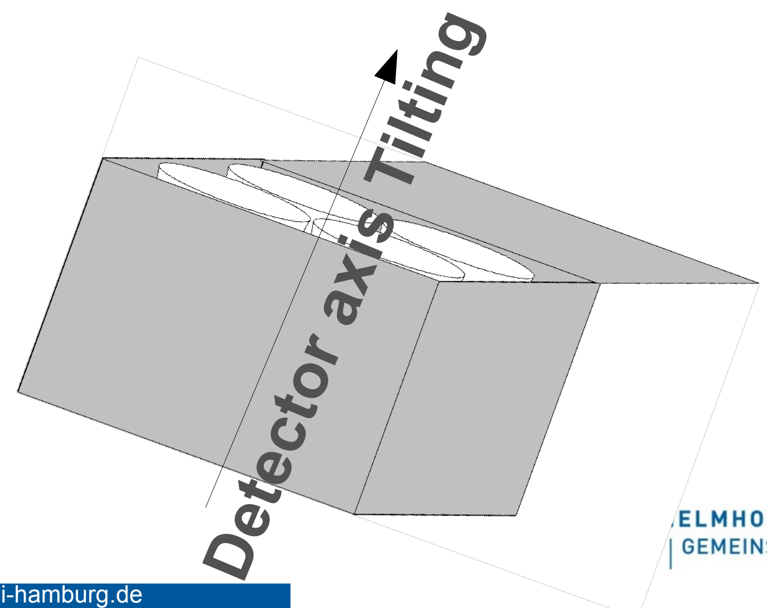

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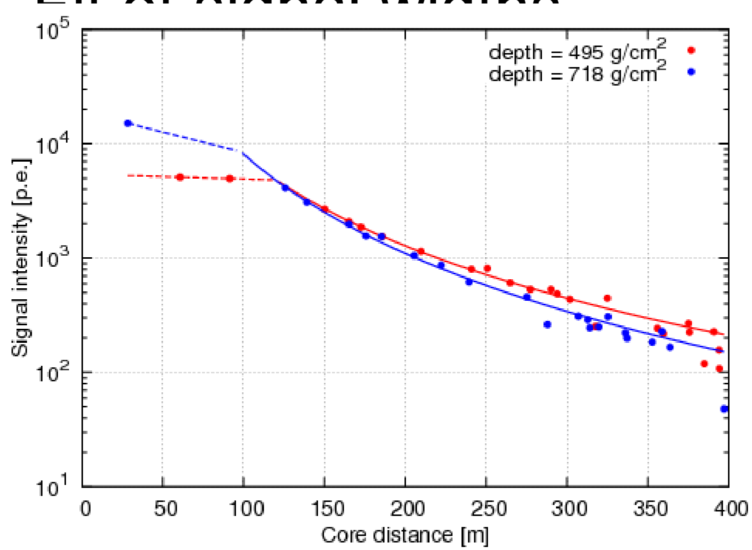
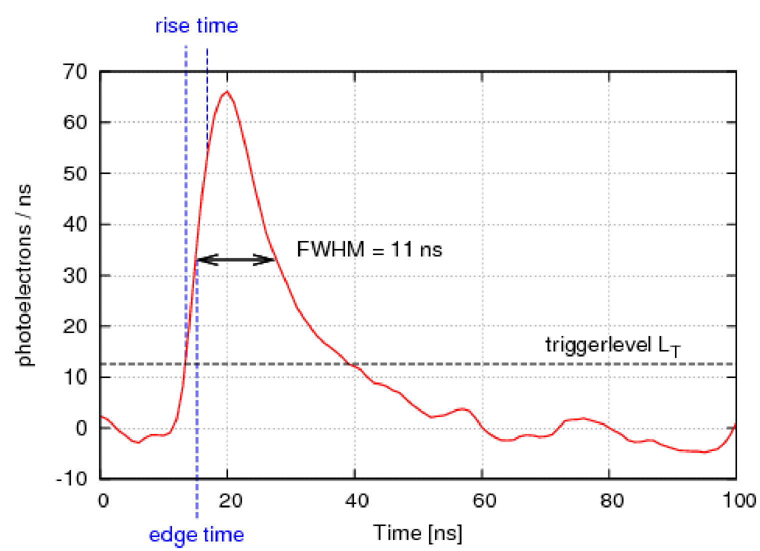
Reconstruction

- 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

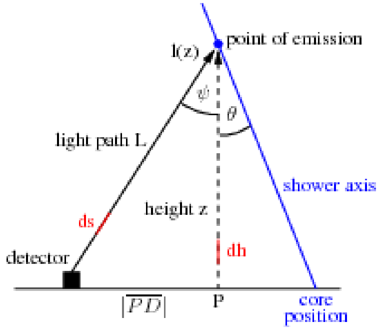




Direction reconstruction

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

Parametrization of time-delay *dt* at detector position



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

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

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

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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

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

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

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

Zenith angle

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Direction reconstruction

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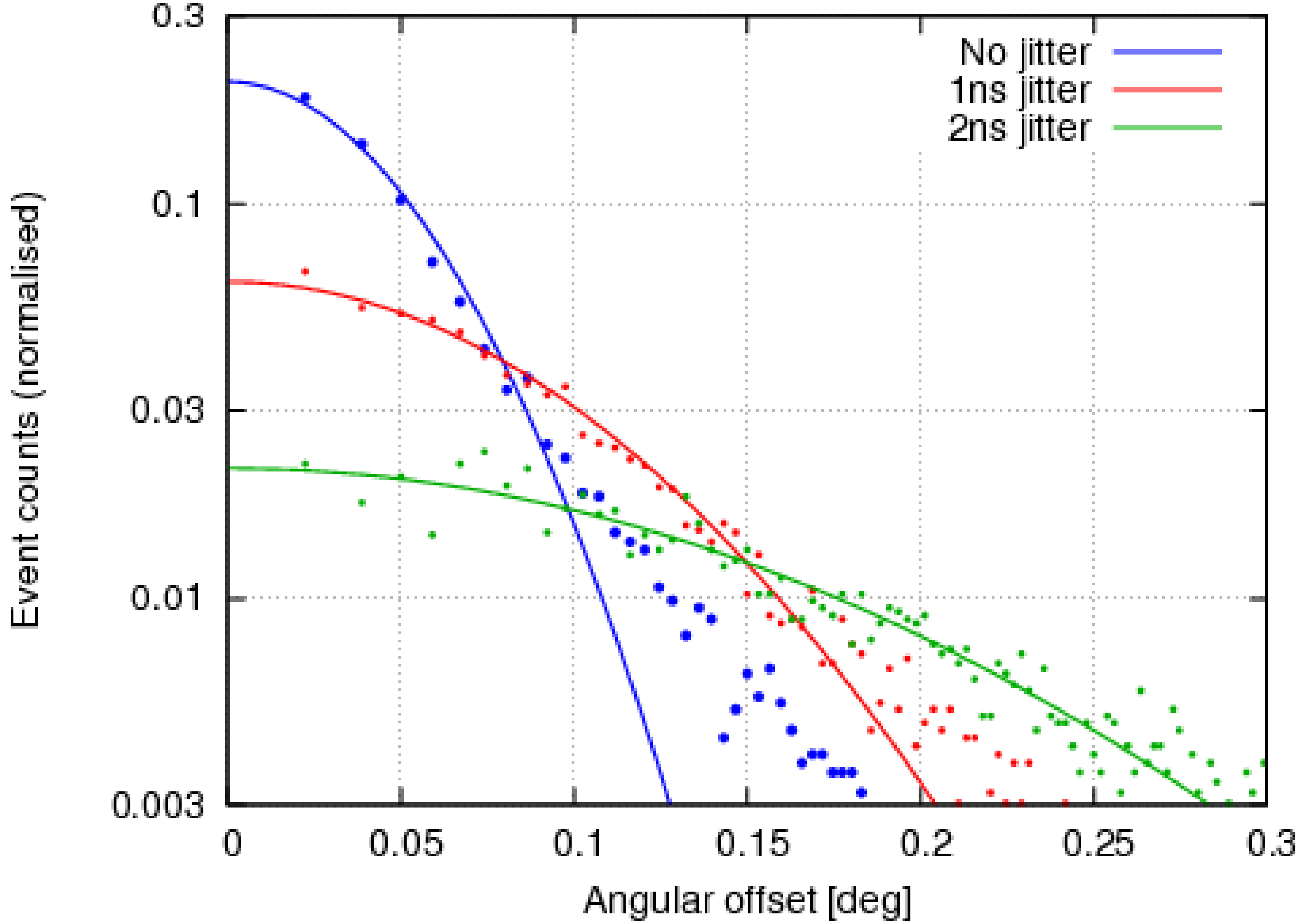

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Energy reconstruction

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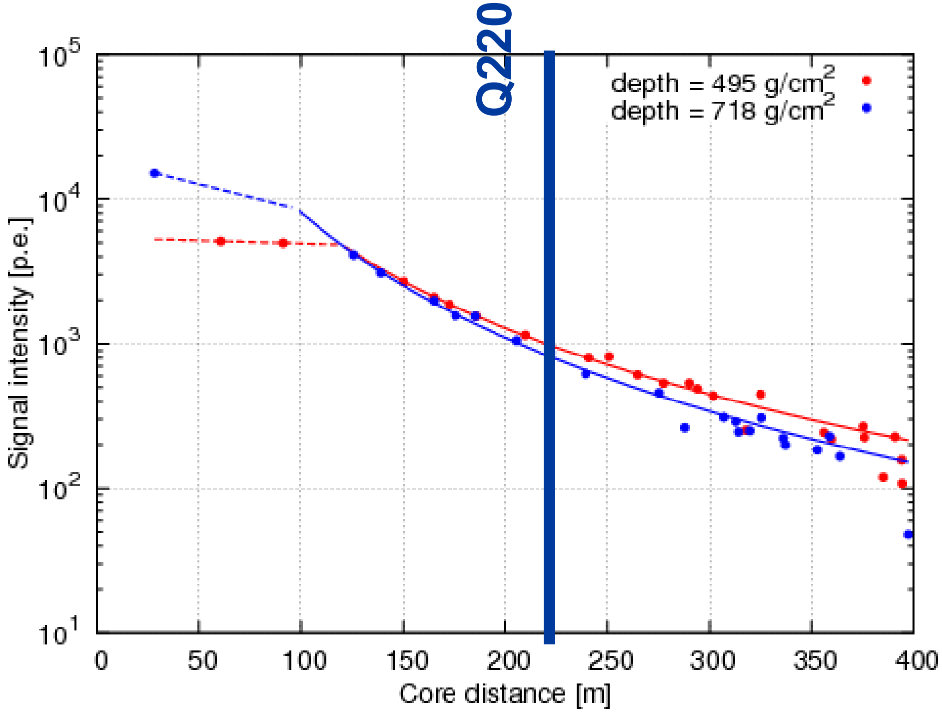
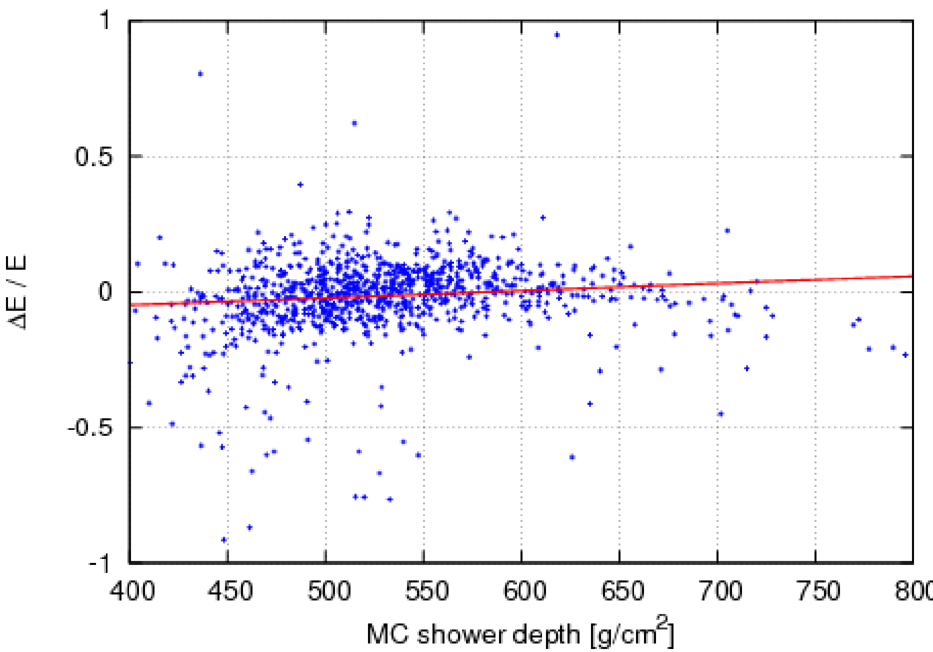
Particle energy: **Q220 = Value of LDF at 220m**





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Energy reconstruction

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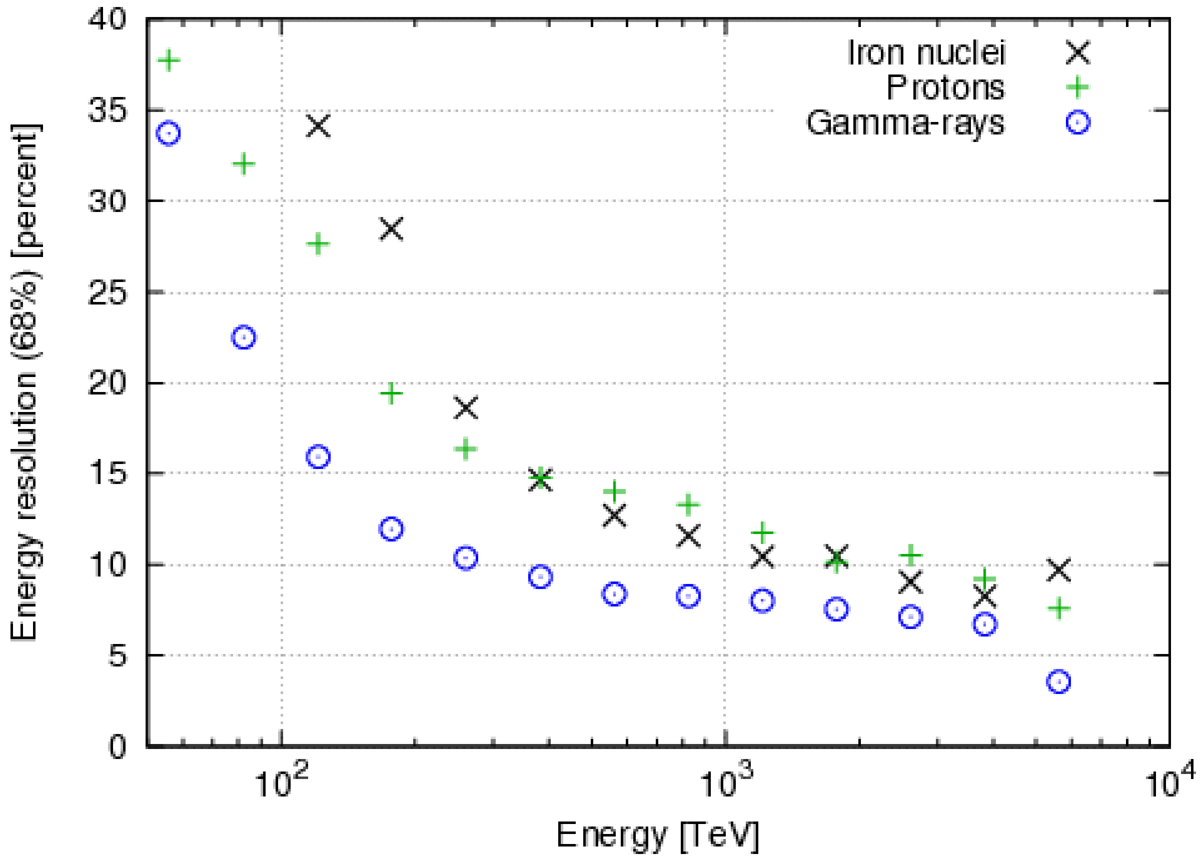
Particle energy: **Q220 = Value of LDF at 220m**



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Cosmic rays

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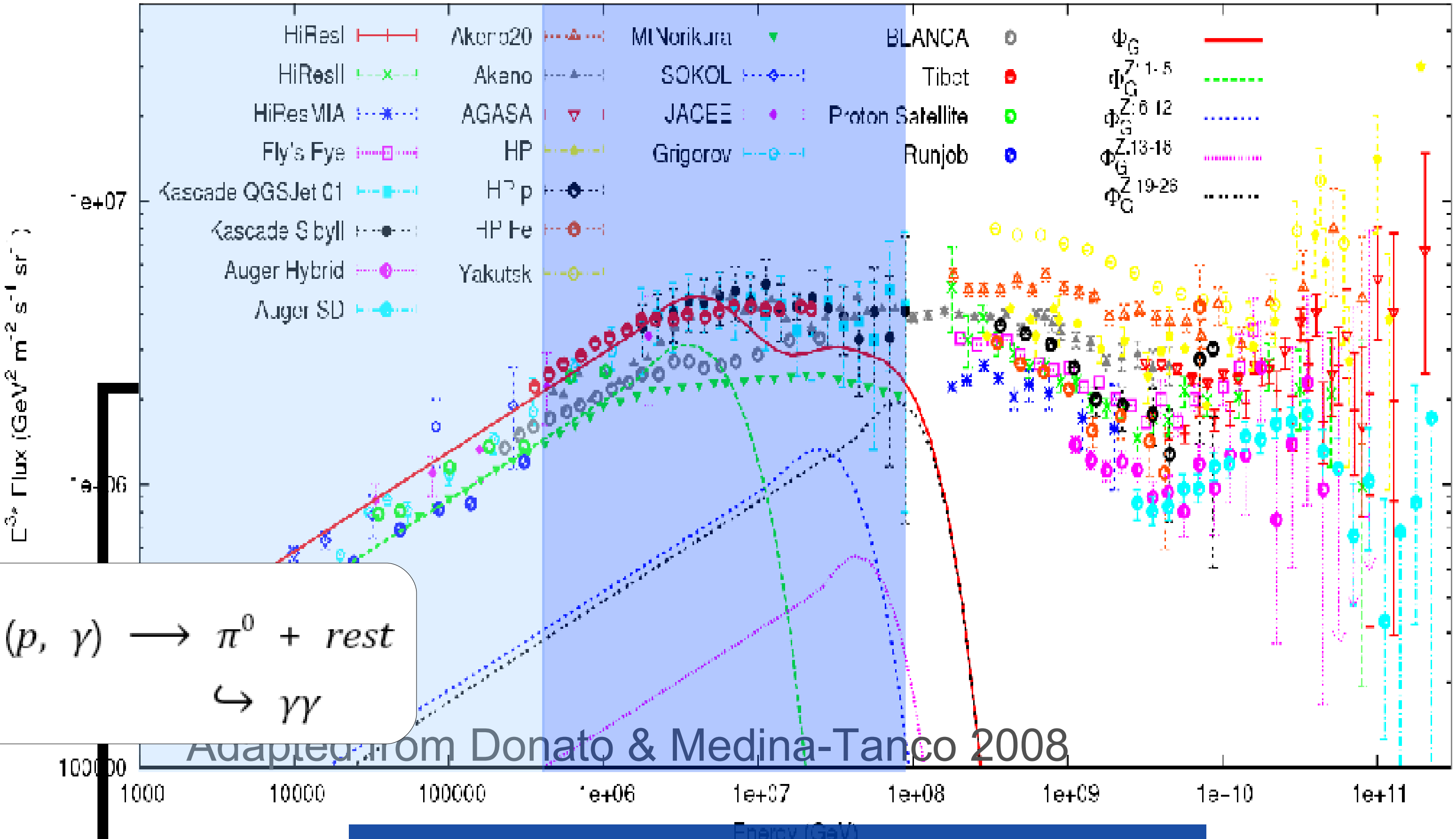

$$p\ (p,\ \gamma) \longrightarrow \pi^0 + rest$$
$$\hookrightarrow \gamma\gamma$$

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

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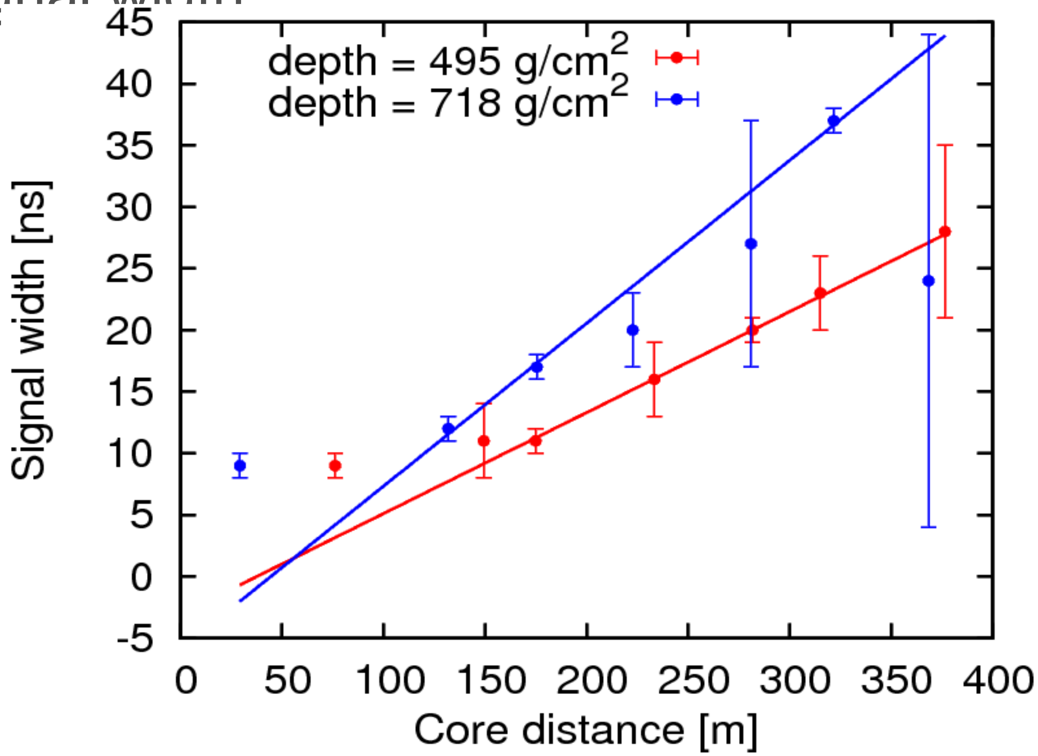
Shower depth reconstruction

Time model method: one free parameter in arrival time model

LDF method: Depth from LDF slope, Q50/Q220

Width method: Depth from signal width



Shower depth

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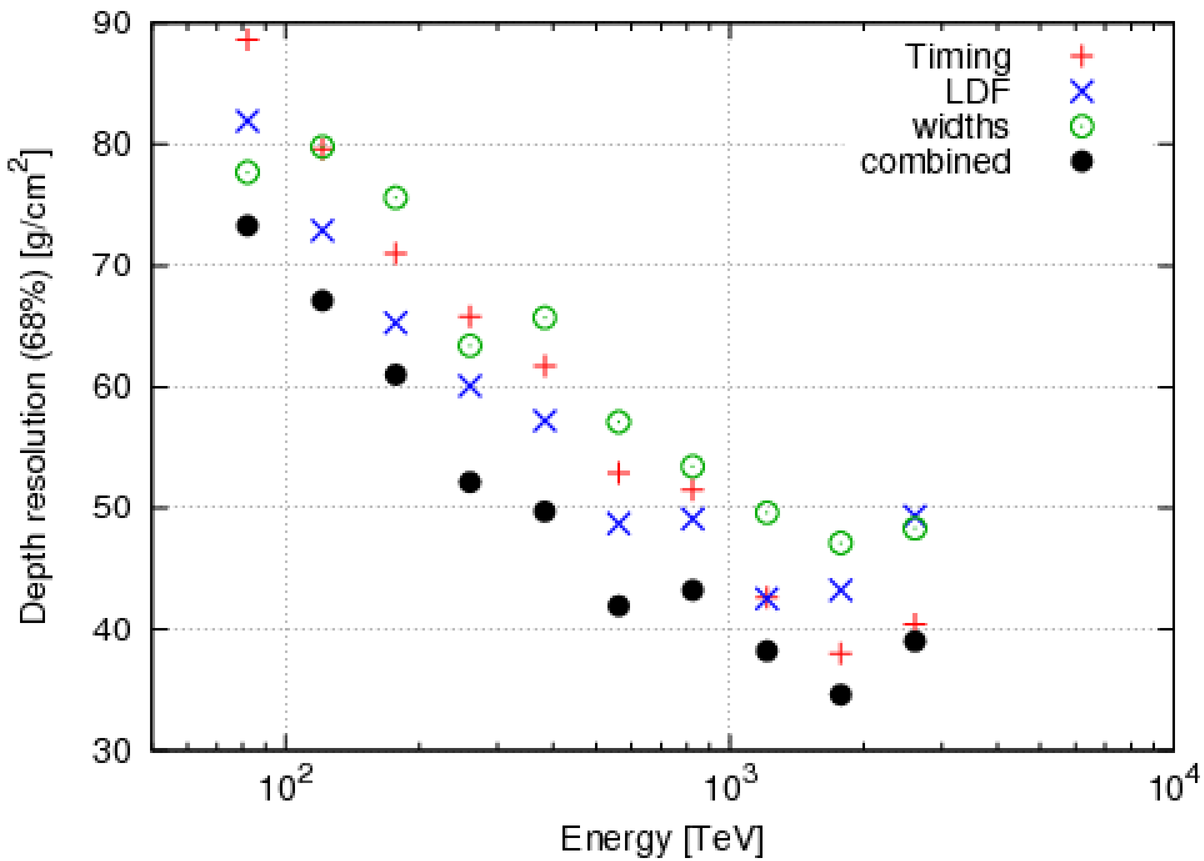
Depth of shower maximum



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Shower depth bias

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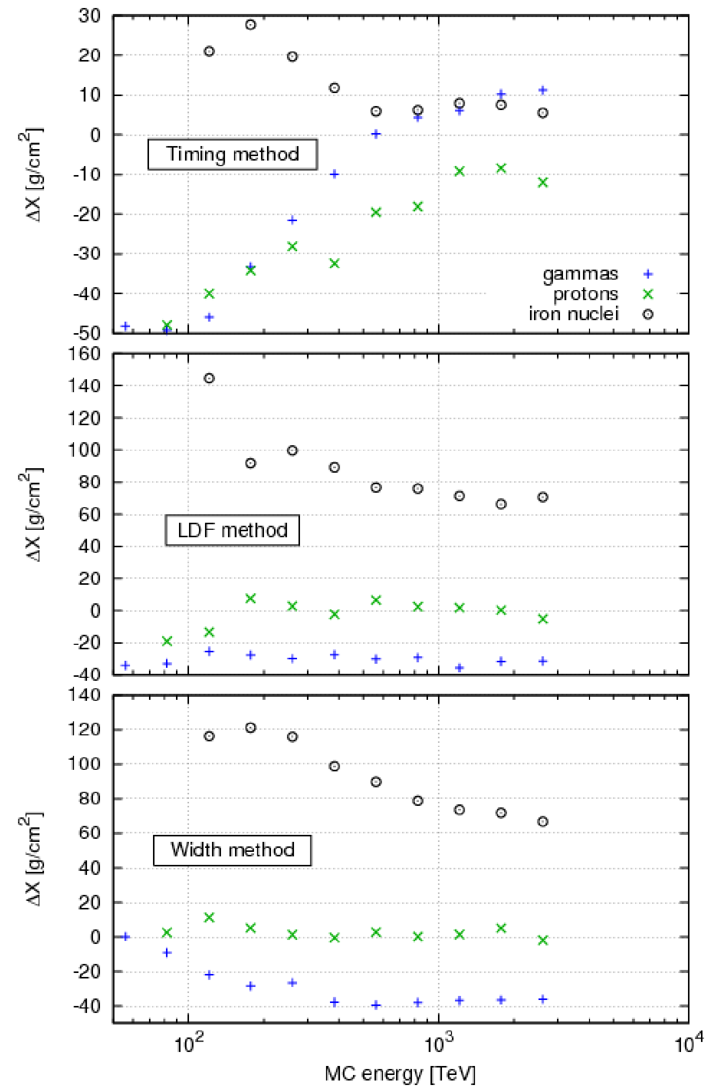

Systematic bias

- 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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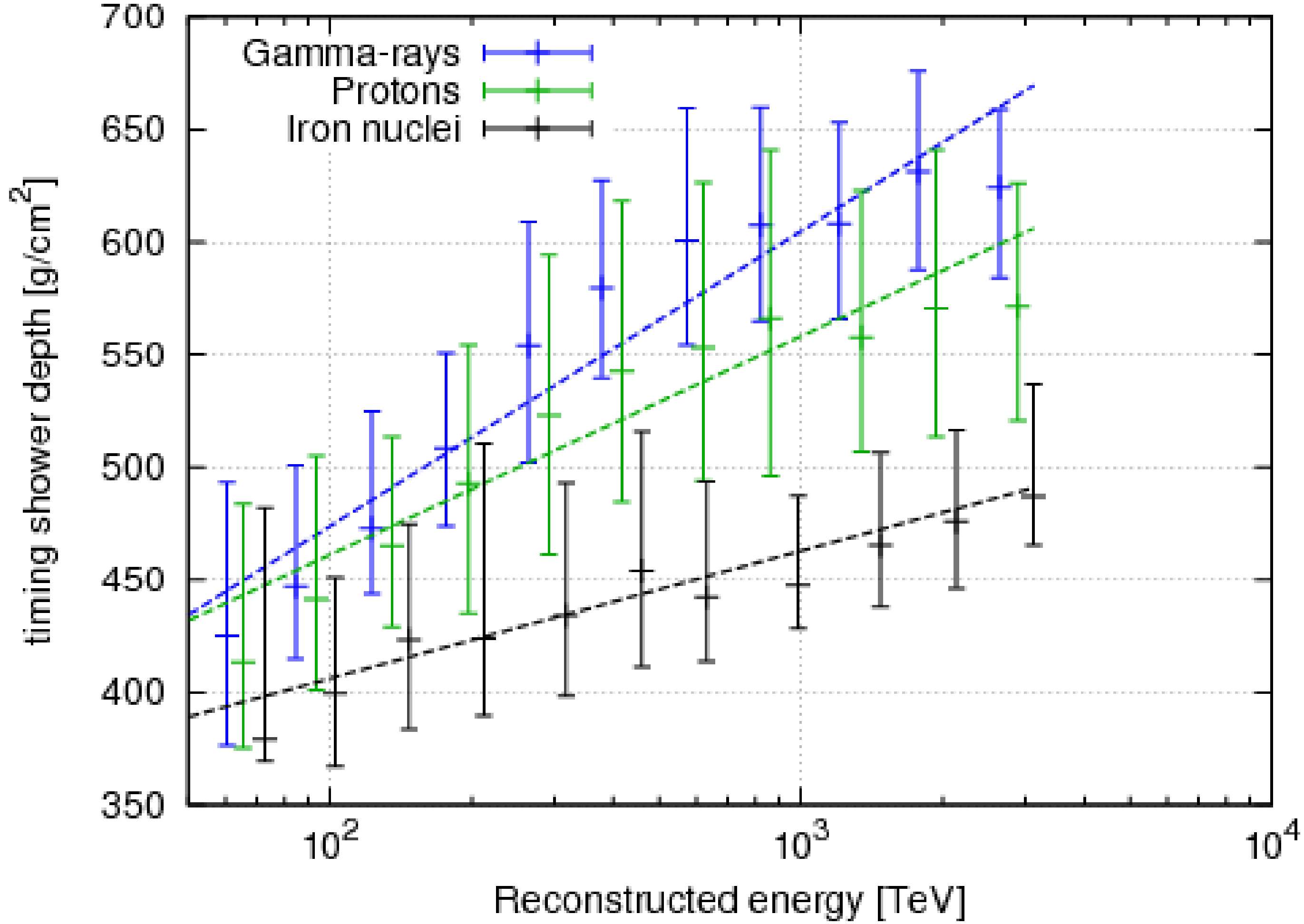

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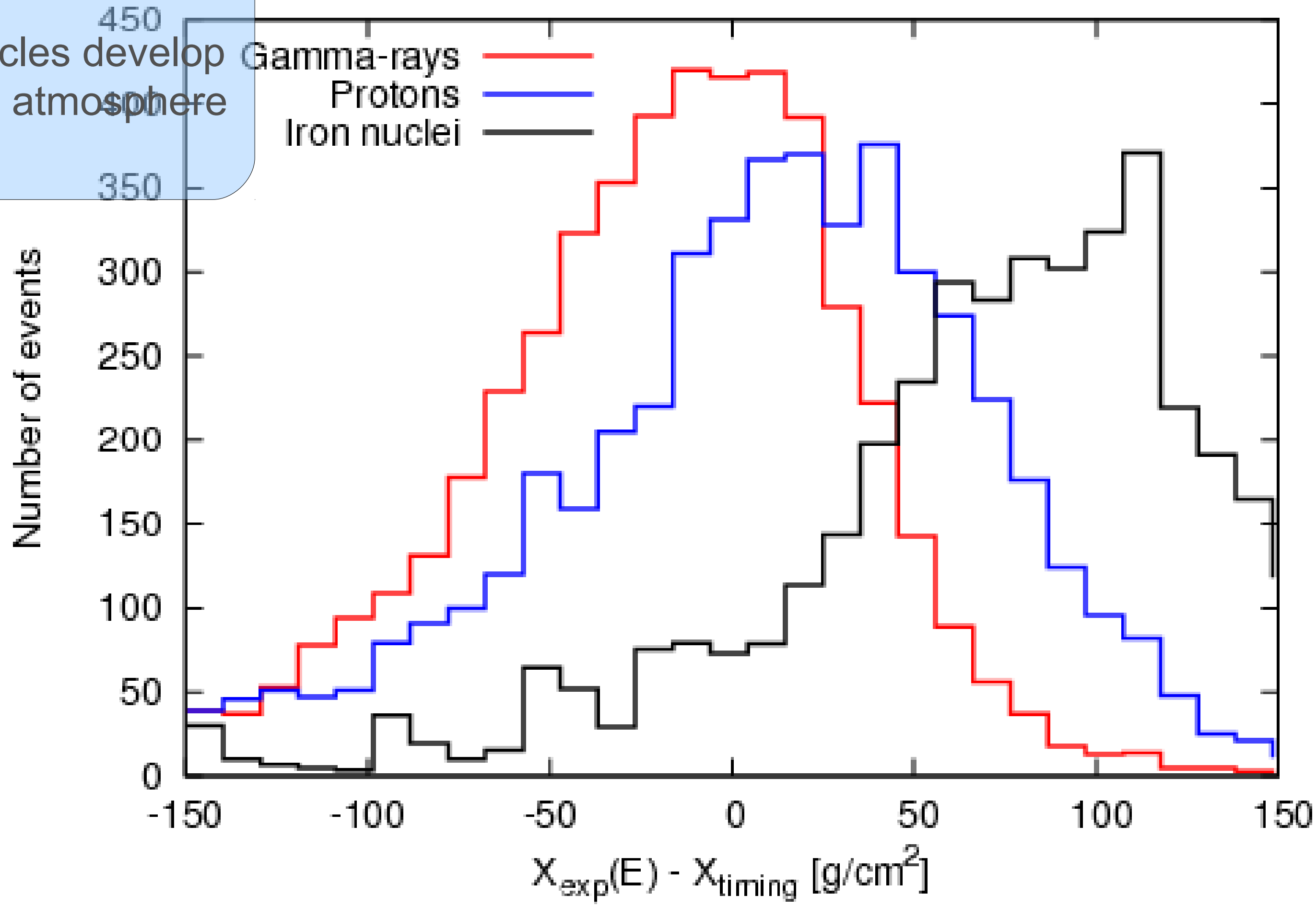
Particle separation (1)

Lighter particles develop
Higher up in atmosphere



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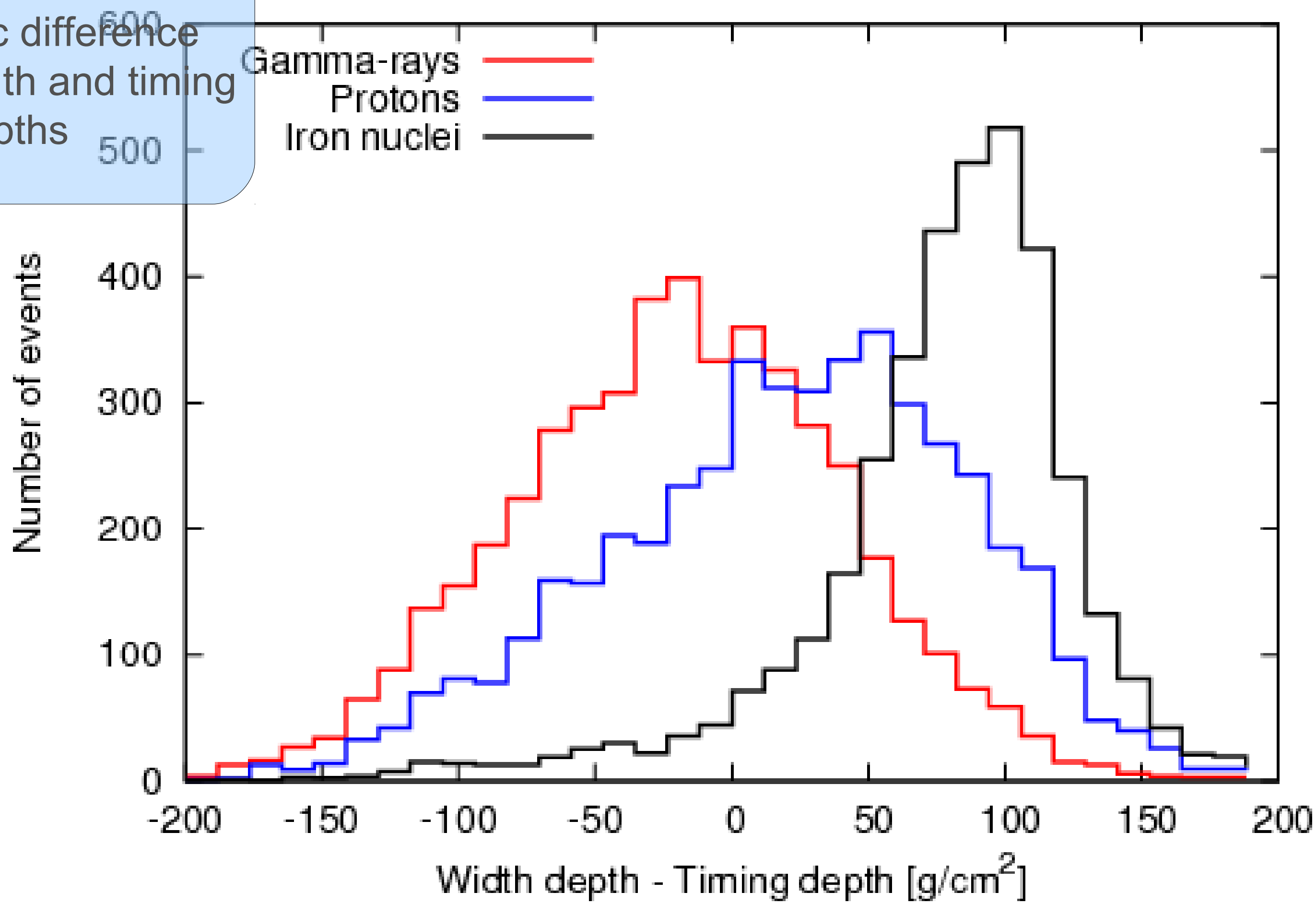
Particle separation (2)

Systematic difference
Between width and timing
Depths



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Particle separation (3)

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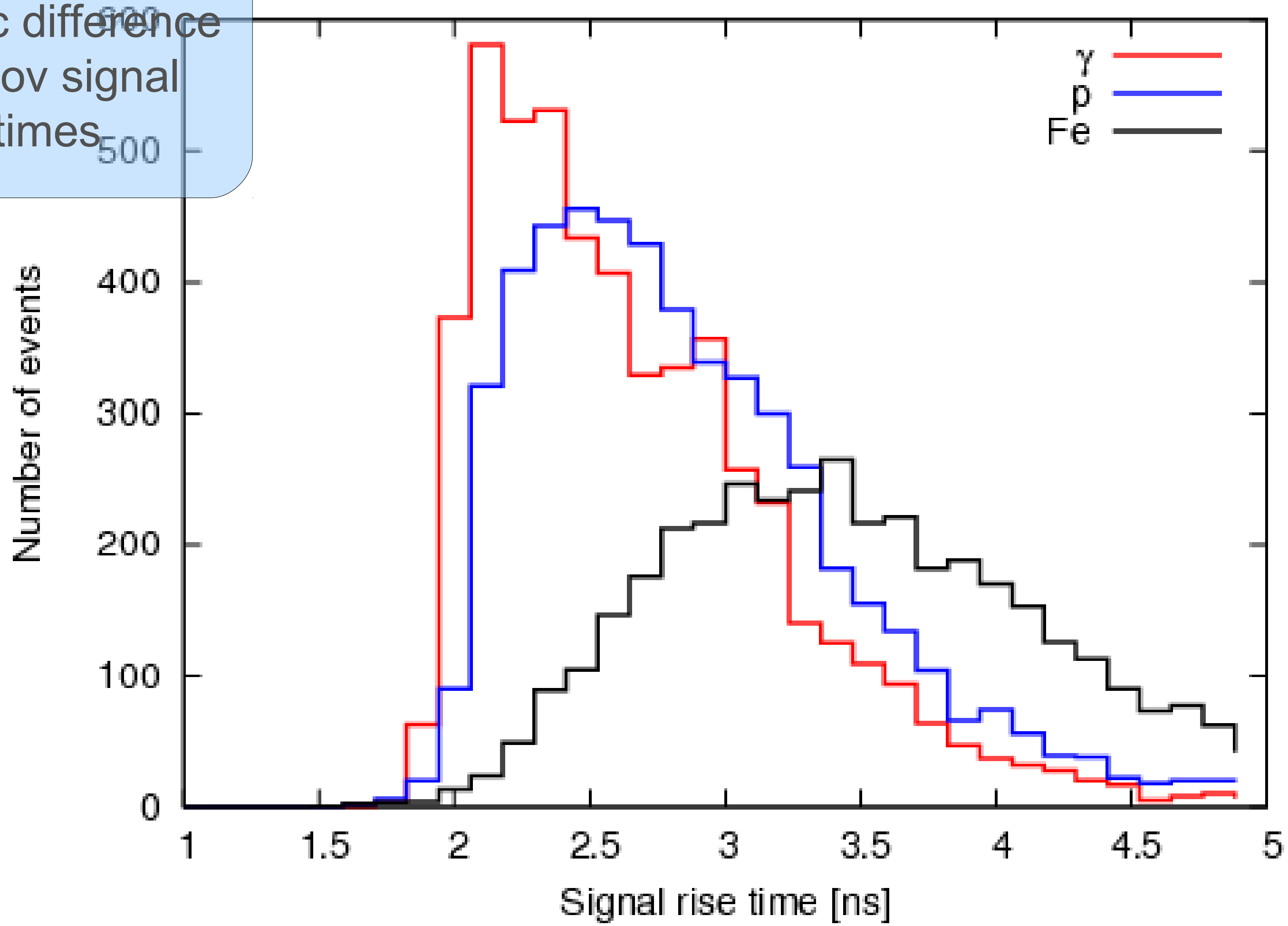
Systematic difference Cherenkov signal rise times



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The HiSCORE detector

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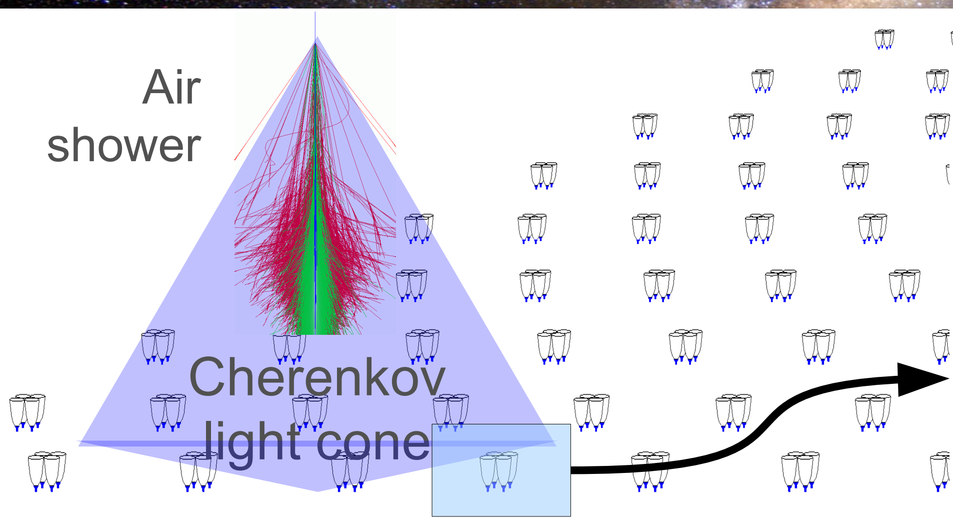
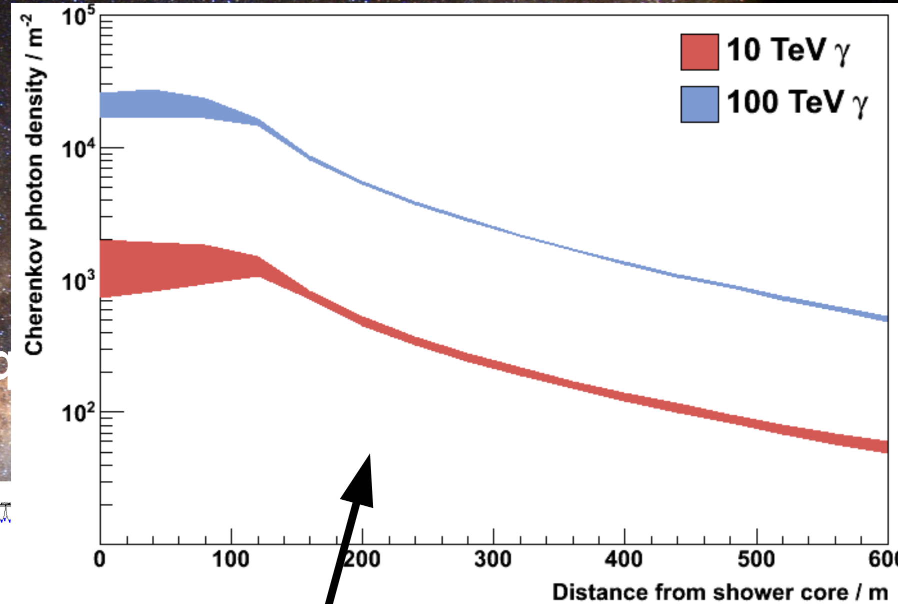
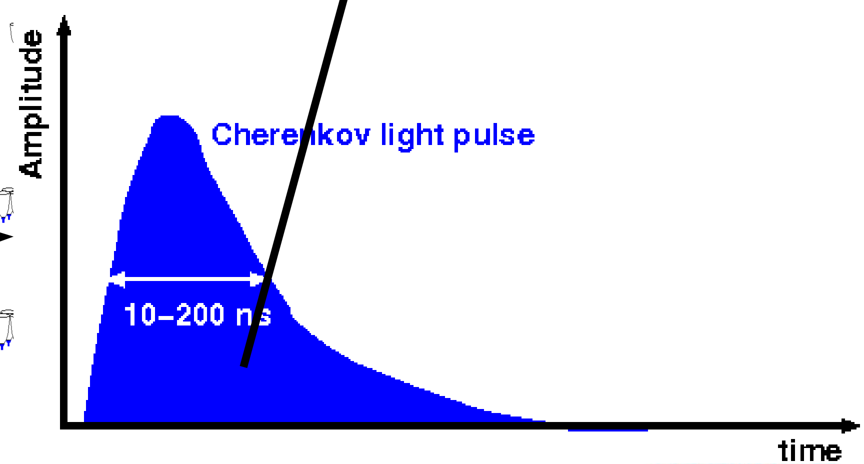
How to achieve large effective area ?

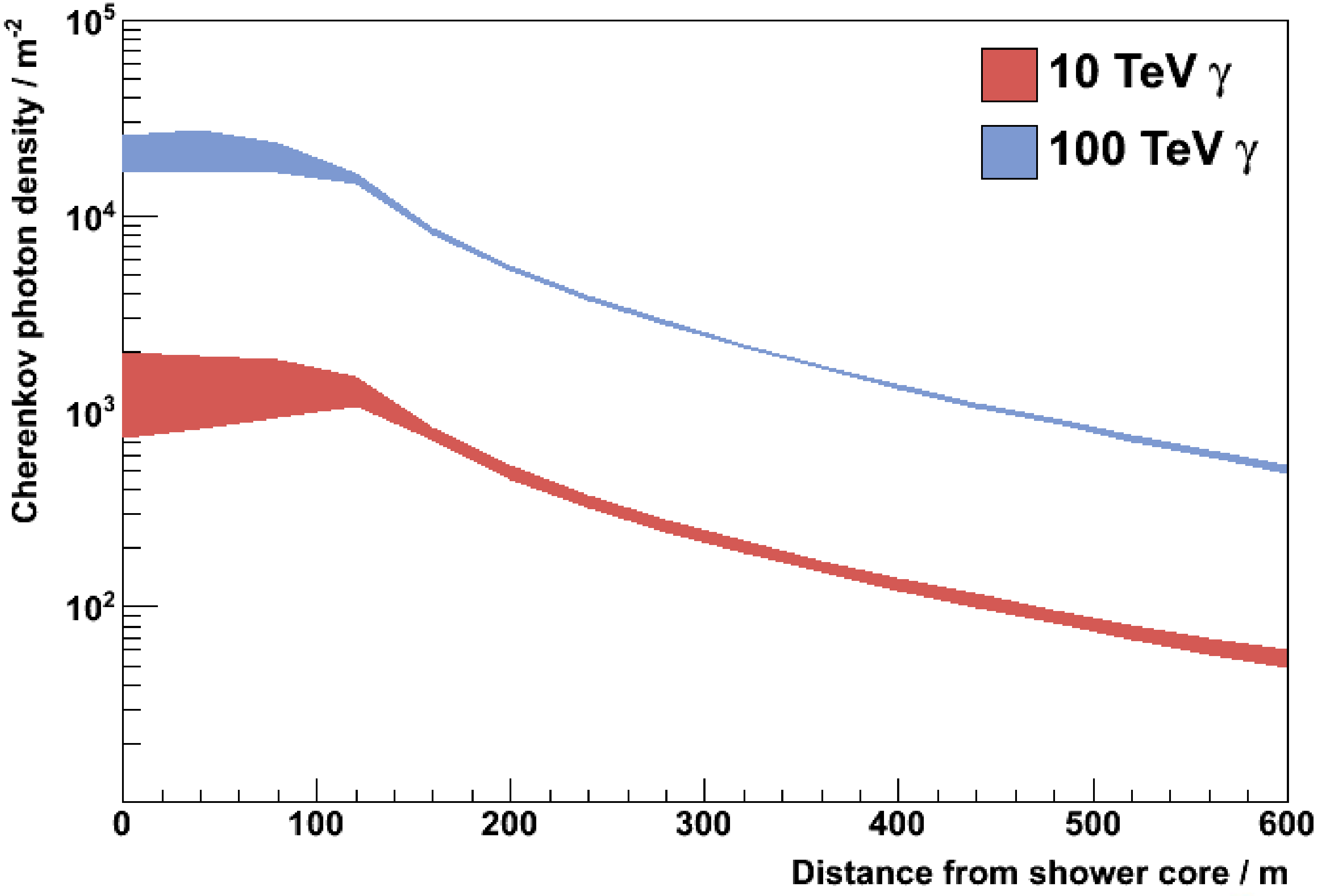
- **Imaging air Cherenkov telescopes:**
  O(1000) channels / km²
- **Non-imaging air Cherenkov technic**
  O(100) channels / km²



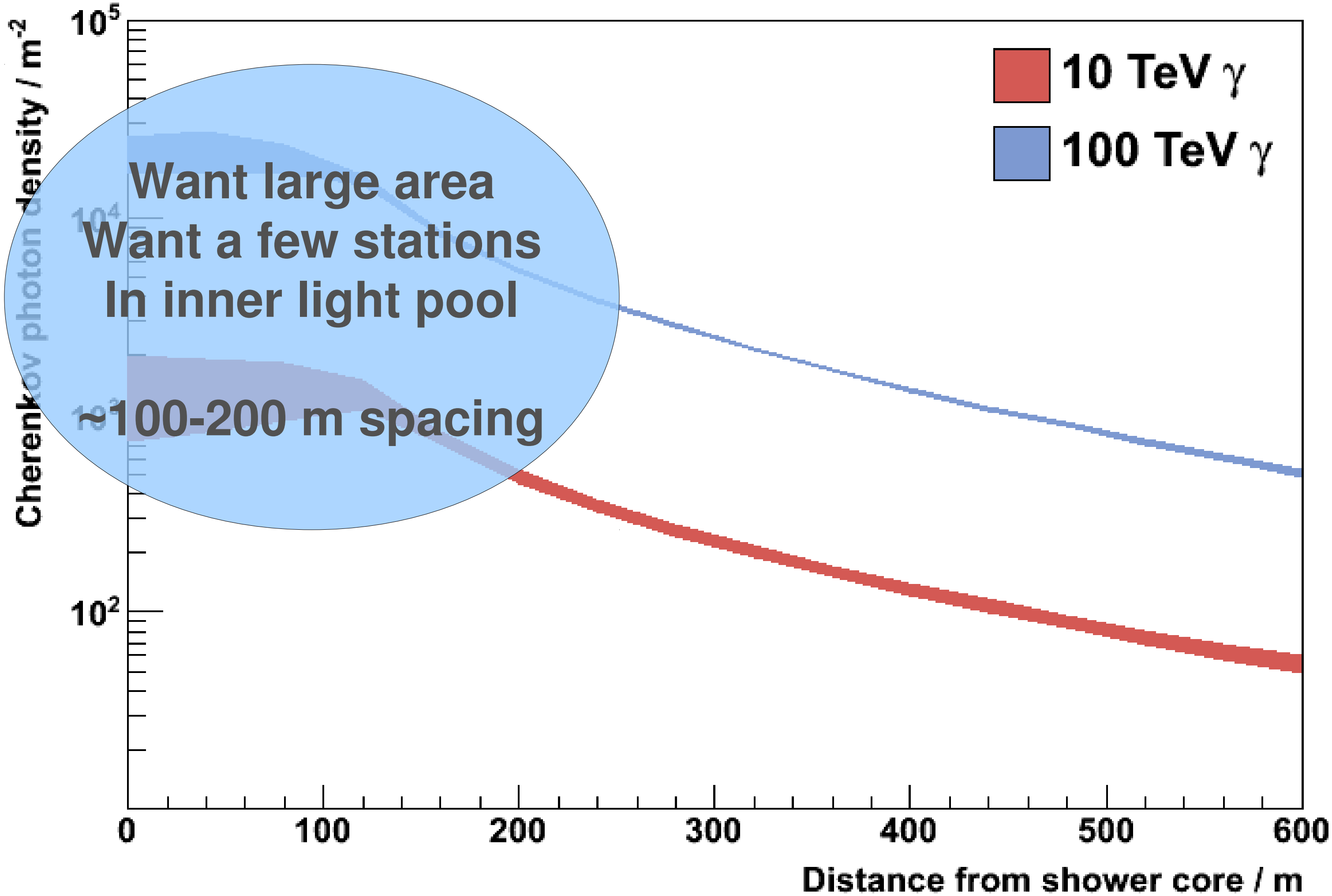




Lateral Cherenkov Photon Distribution



Lateral Cherenkov Photon Distribution



Lateral Cherenkov Photon Distribution

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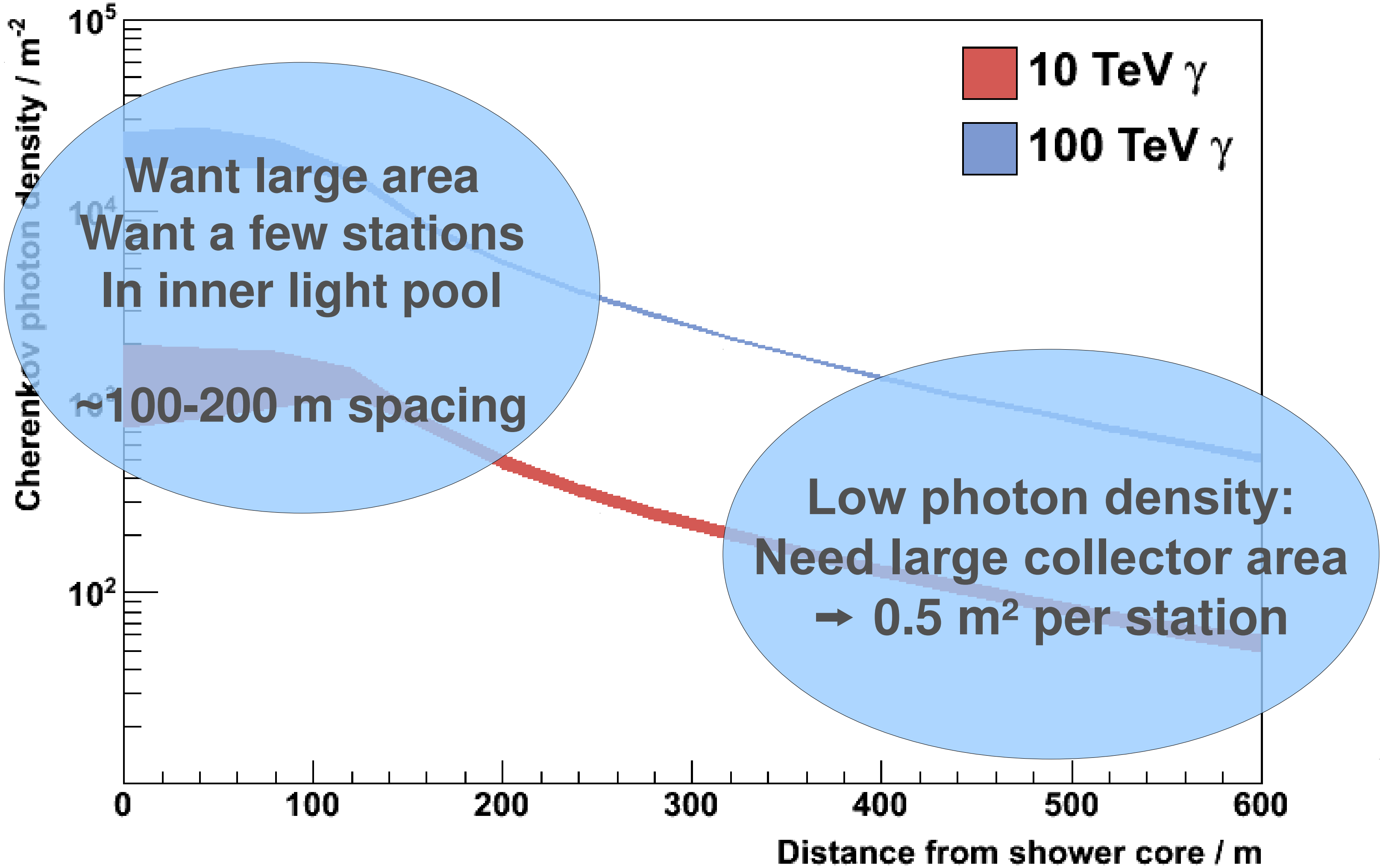

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HRJRG-303
Helmholtz Russia Joint Research Group

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

04/2012 – 04/2015

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

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Helmholtz Russia Joint Research Group HRJRG

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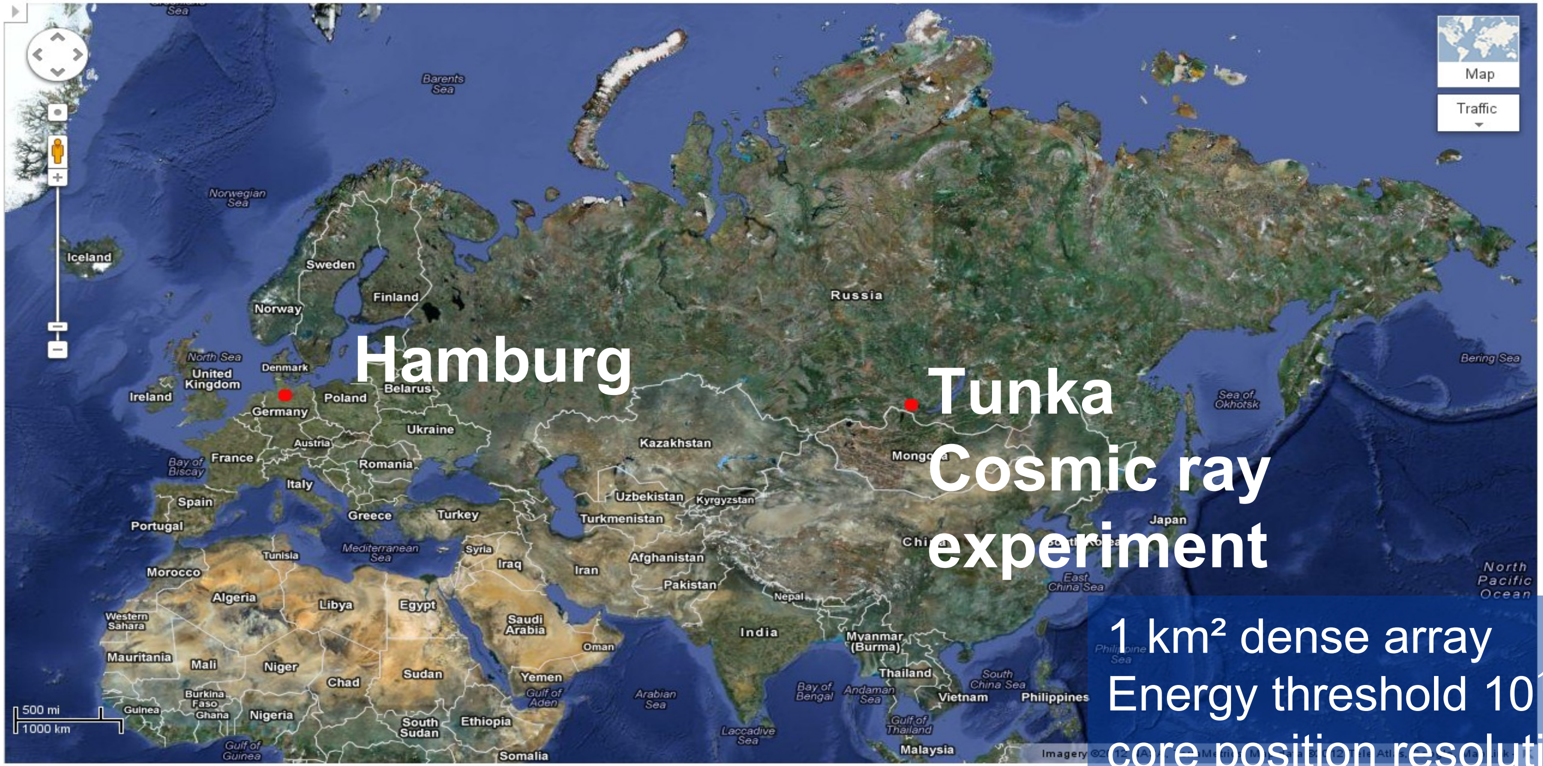

1 km² dense array

Energy threshold 10^{15} eV

core position resolution ~ 10 m

energy resolution ~ 15%

X_{max} resolution< 25 $g \cdot cm^{-2}$

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