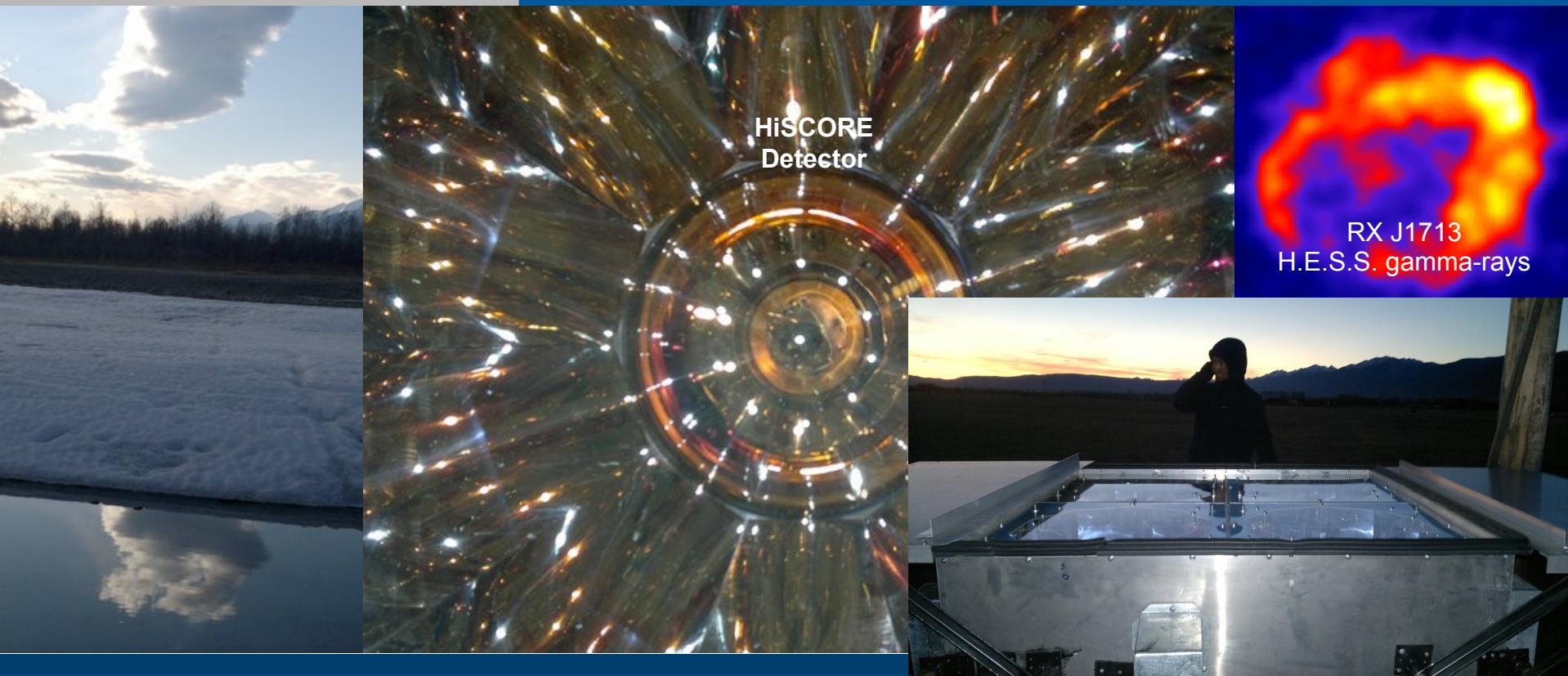


... more logos ...



Universität Hamburg
DER FORSCHUNG | DER LEHRE | DER BILDUNG



Status of the HiSCORE project

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

The HiSCORE concept

Status of the 9-station Tunka-HiSCORE array

Status of the PAO-HiSCORE prototype array

Future plans

The HiSCORE concept

The Hundred*i Square-km Cosmic ORigin Explorer

Concept: non-imaging air Cherenkov technique

Large area: up to few 100 km²

Large Field of view: ~ 0.6 sr

Sky-coverage: $> \pi$ sr 200 h / year

2014: Astroparticle Physics, in press, 2014arXiv1403.5688T

2013NIMPA.712..137H, arXiv:1302.3957

2011AdSpR..48.1935T, astro-ph/1108.5880

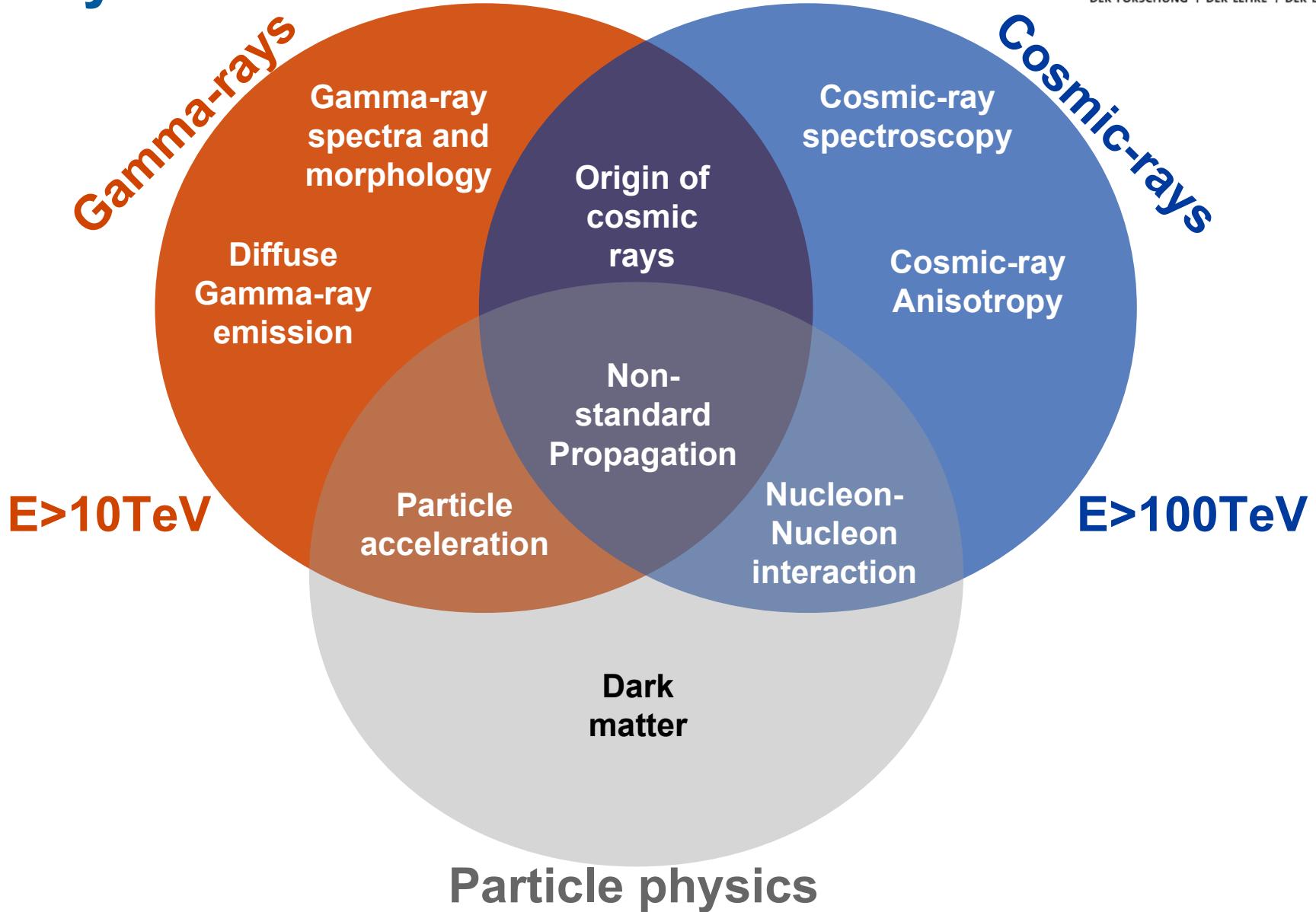
<http://wwwiexp.desy.de/groups/astroparticle/score/>

<http://tunka-hrjrg.desy.de/>

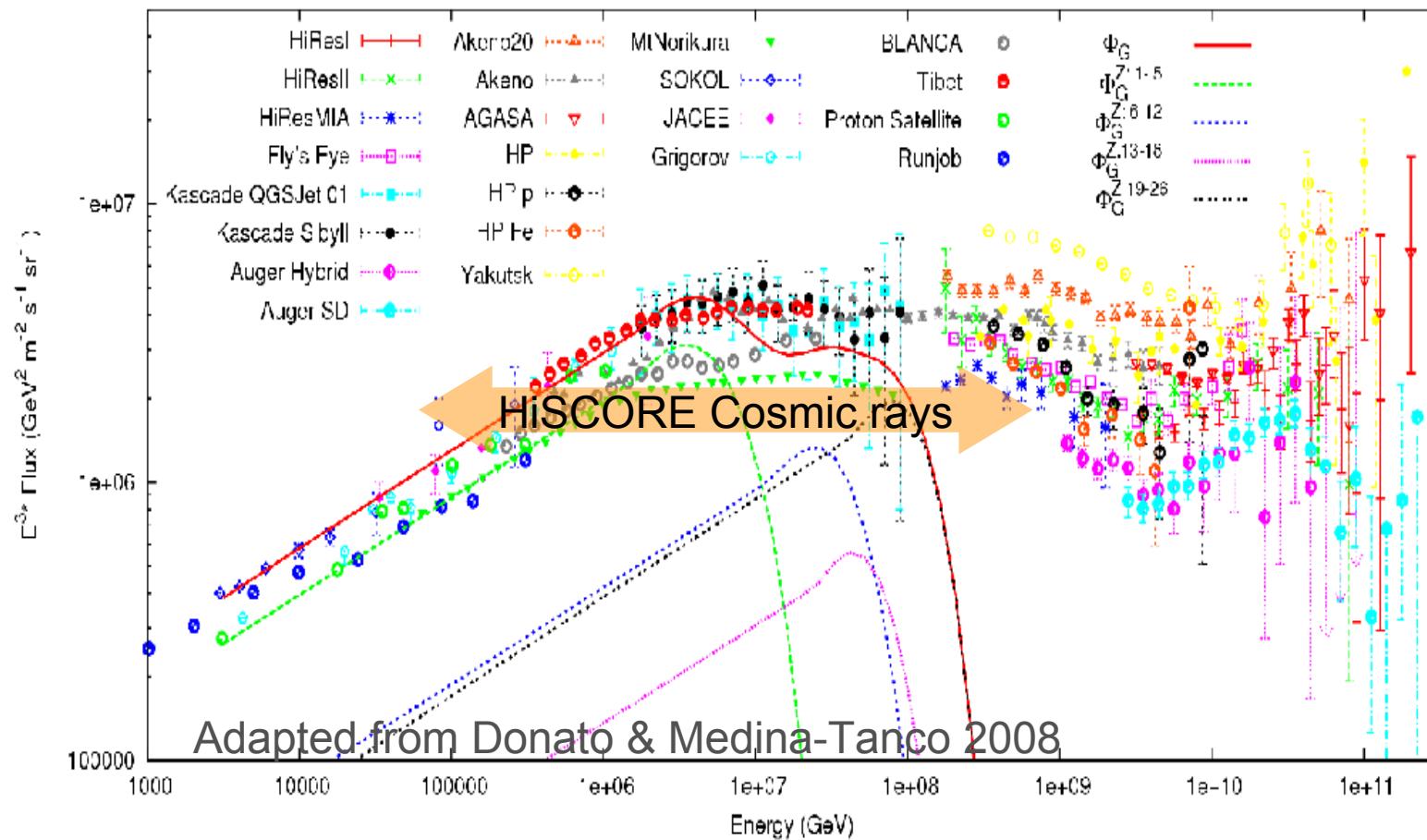
<http://de.wikipedia.org/wiki/HiSCORE>

Physics motivations

Physics motivations

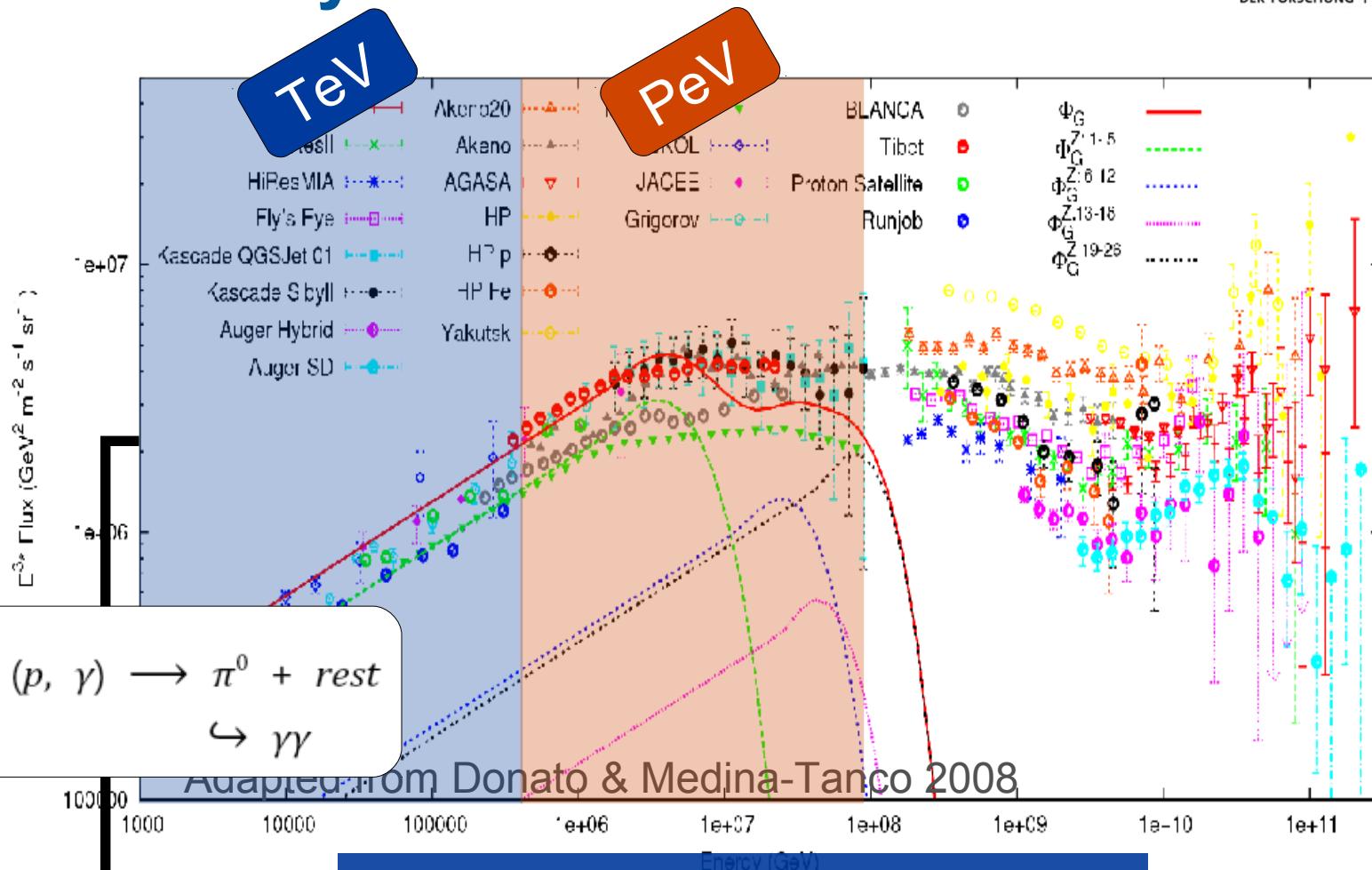


Cosmic rays



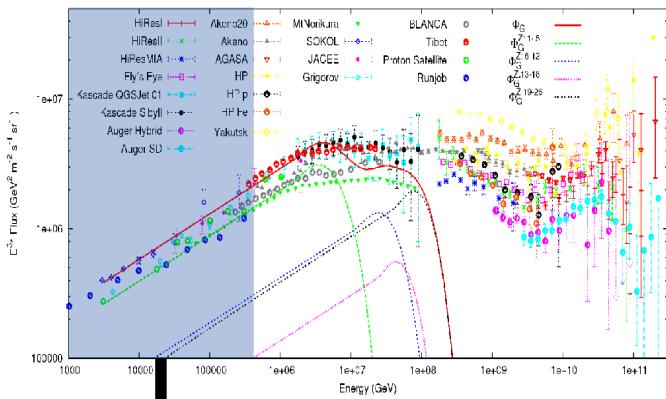
Spectrum & composition
in transition range
Galactic / extragalactic origin

Cosmic rays

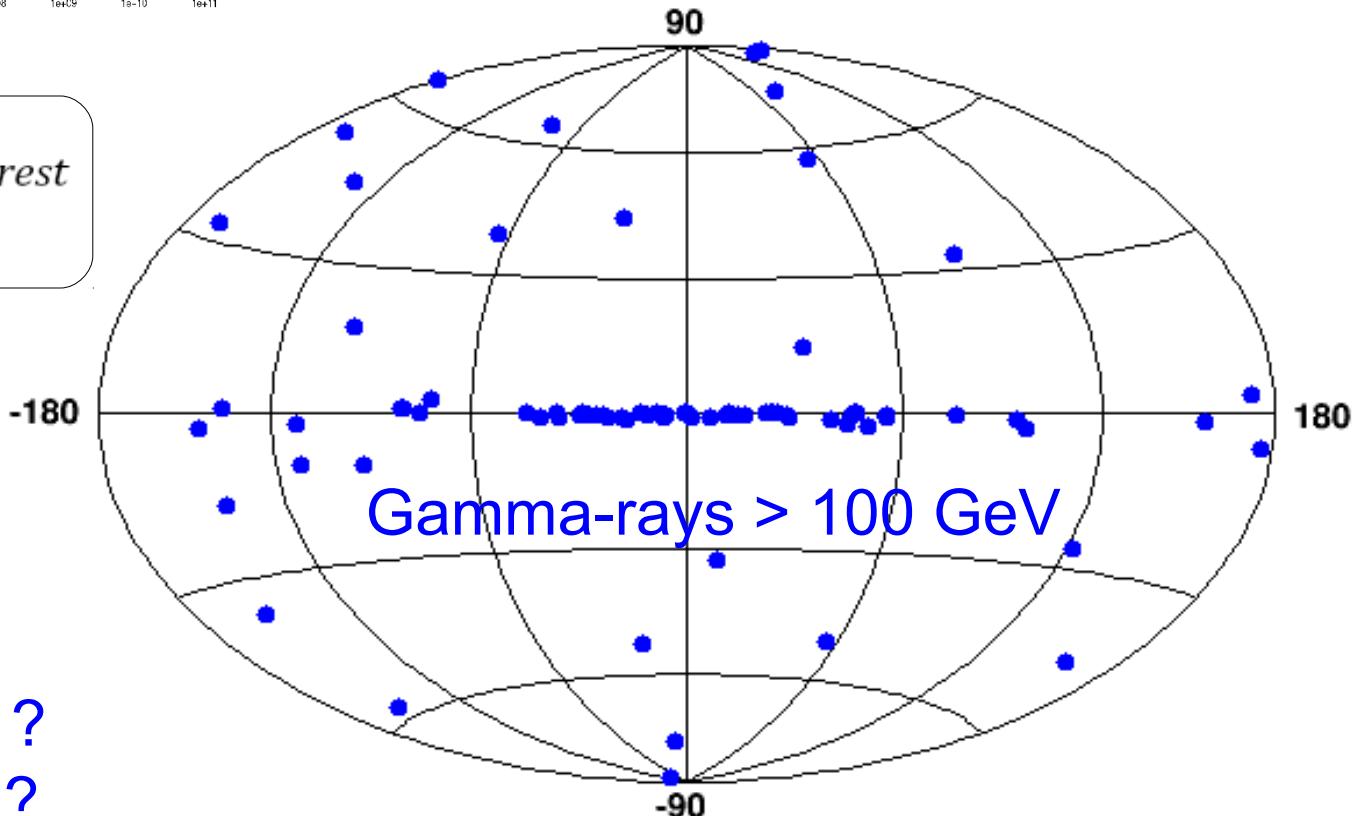
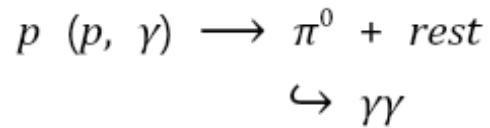


Gammas from Galactic Cosmic rays:
 $E_\gamma \sim E_{\text{CR}}/10$

Tevatron sky

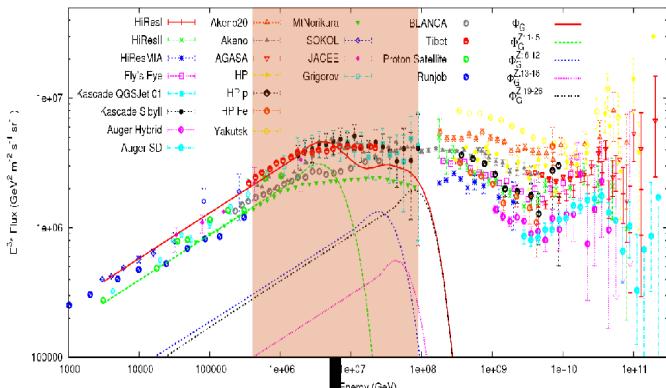


VHE gamma-ray sky 2009

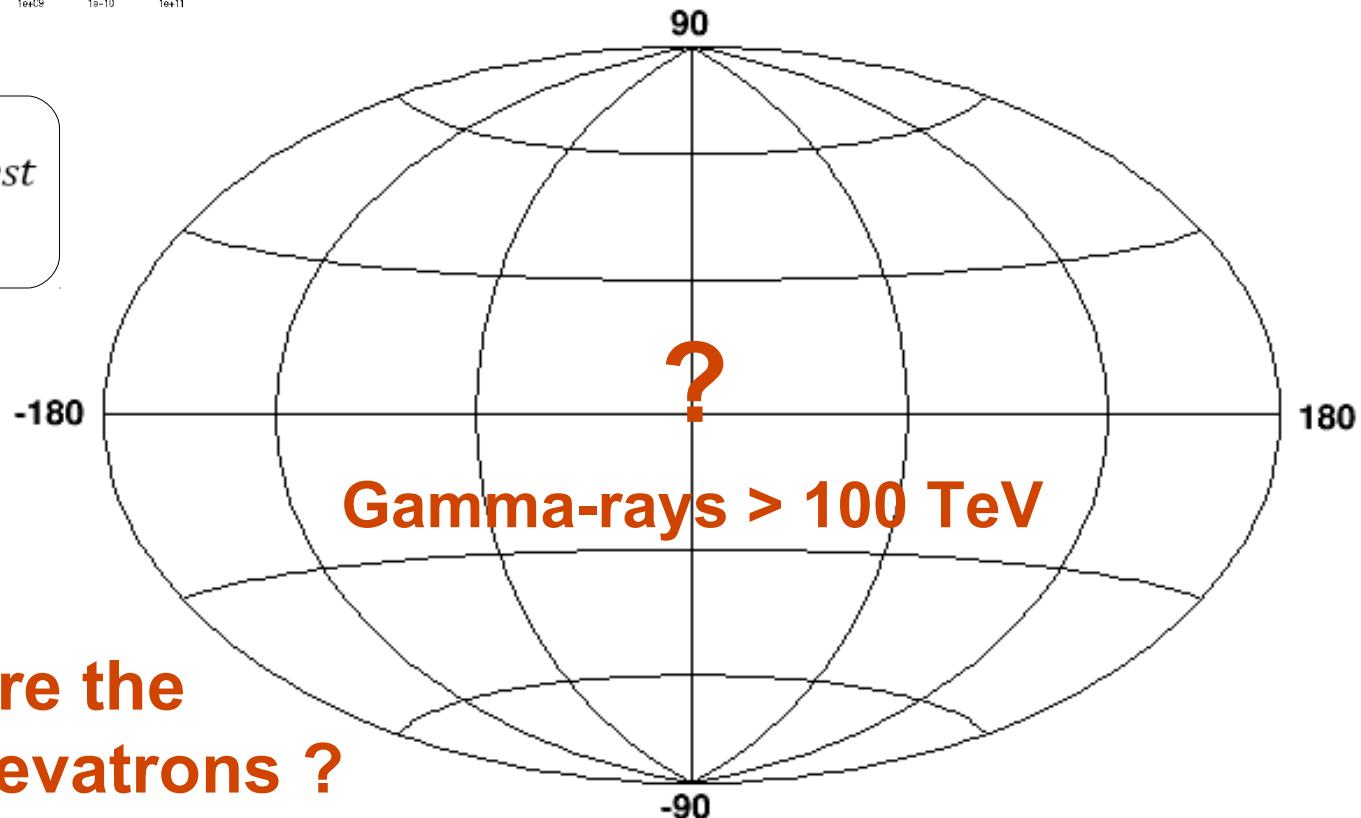
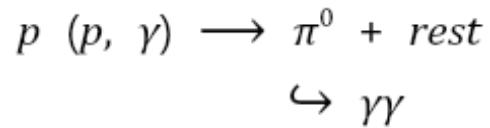


Hadronic ?
Leptonic ?

Pevatron sky

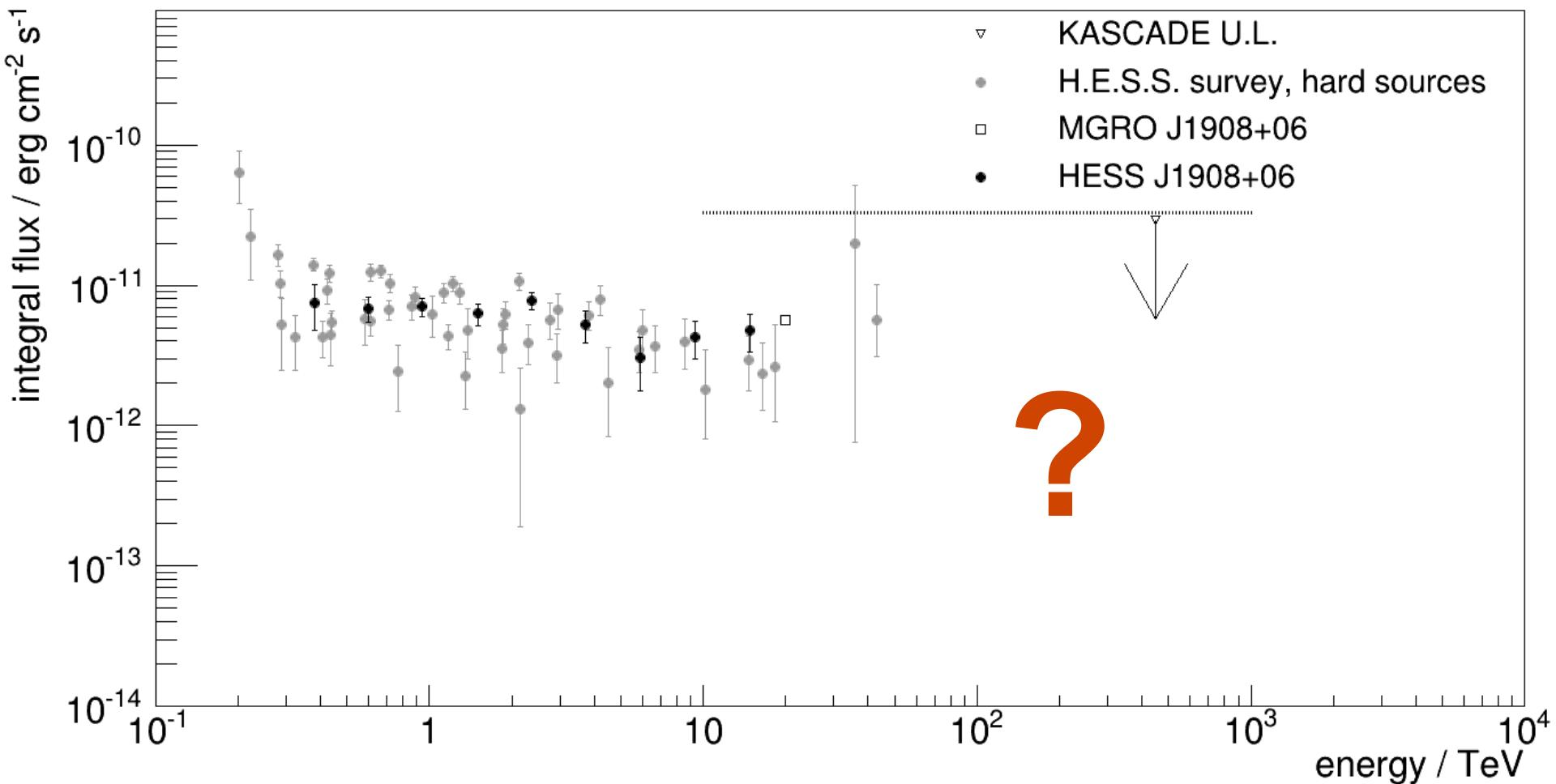


UHE Gamma-Ray Sky ($S > 5\sigma$, $E > 100 \text{ TeV}$), September 2009



**Where are the
cosmic ray pevatrons ?**

The Pevatron energy range



Accessing the pevatron sky: large area

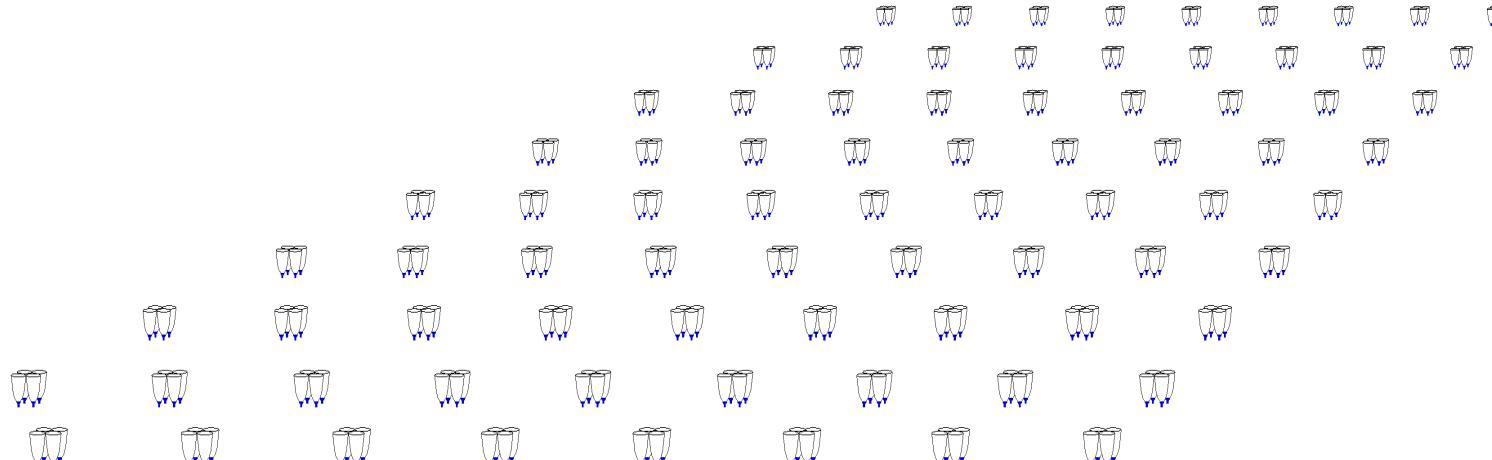
The HiSCORE detector

The HiSCORE concept

Picture: Serge Brunier

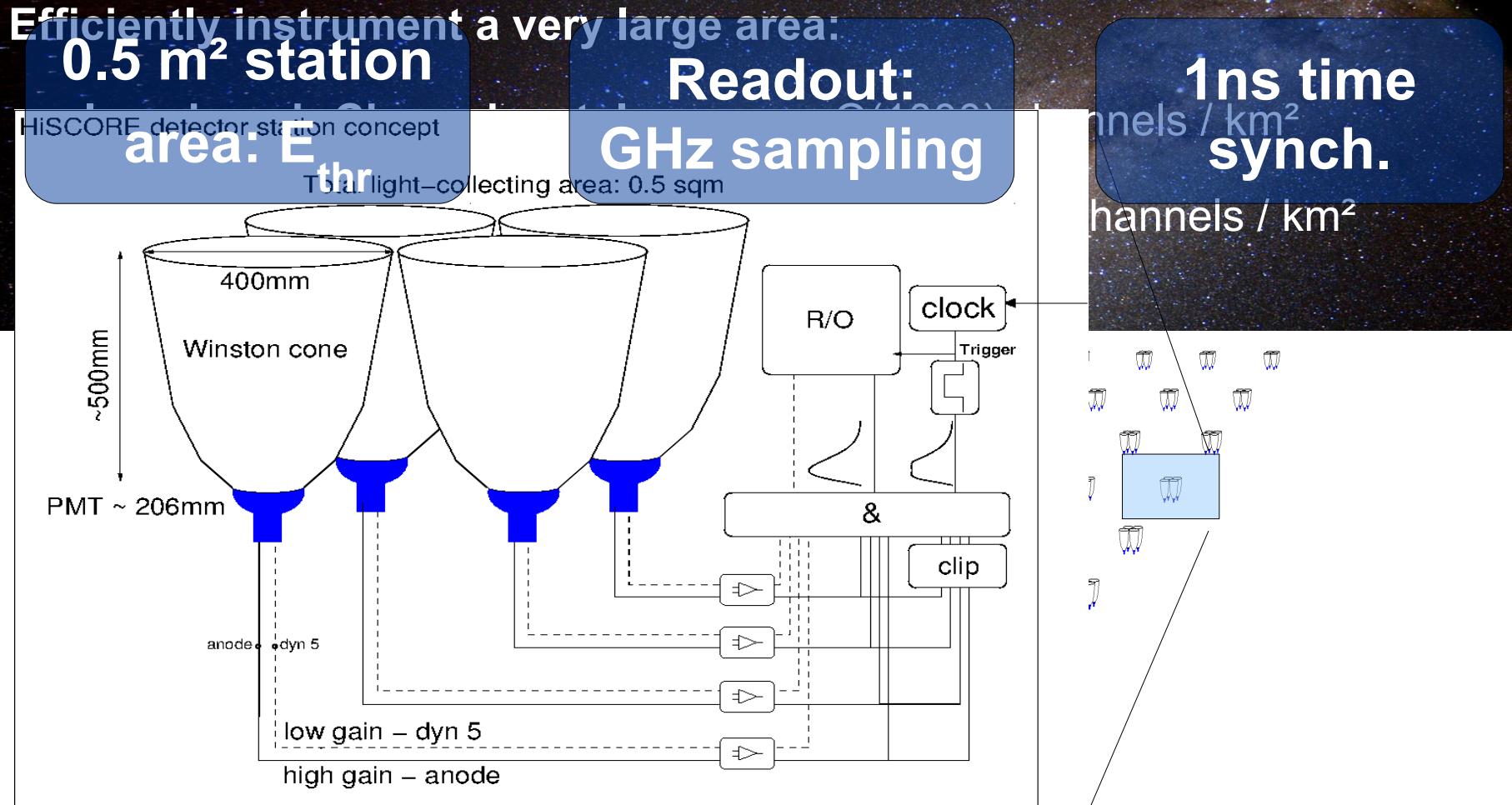
Efficiently instrument a very large area:

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



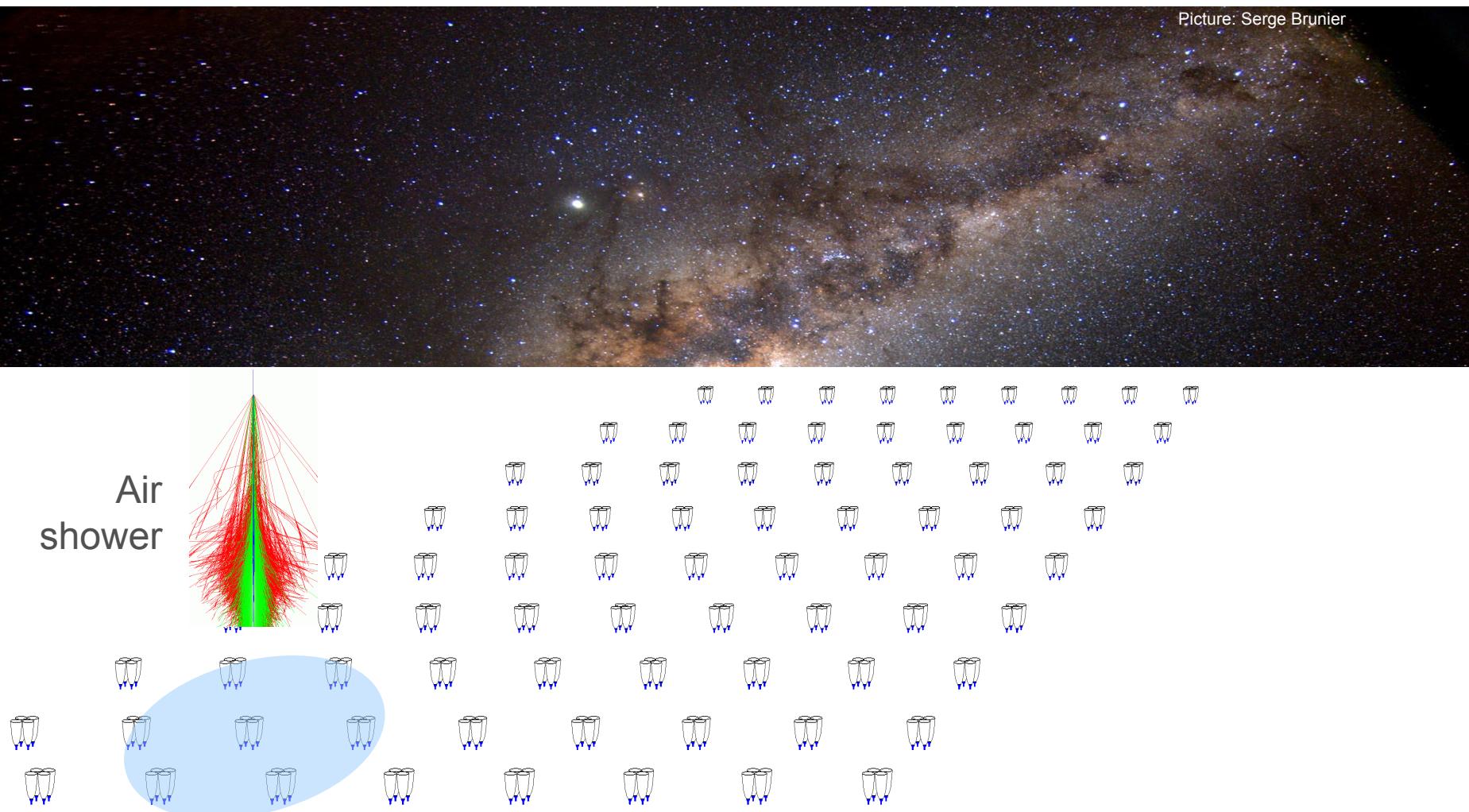
The HiSCORE concept

Picture: Serge Brunier



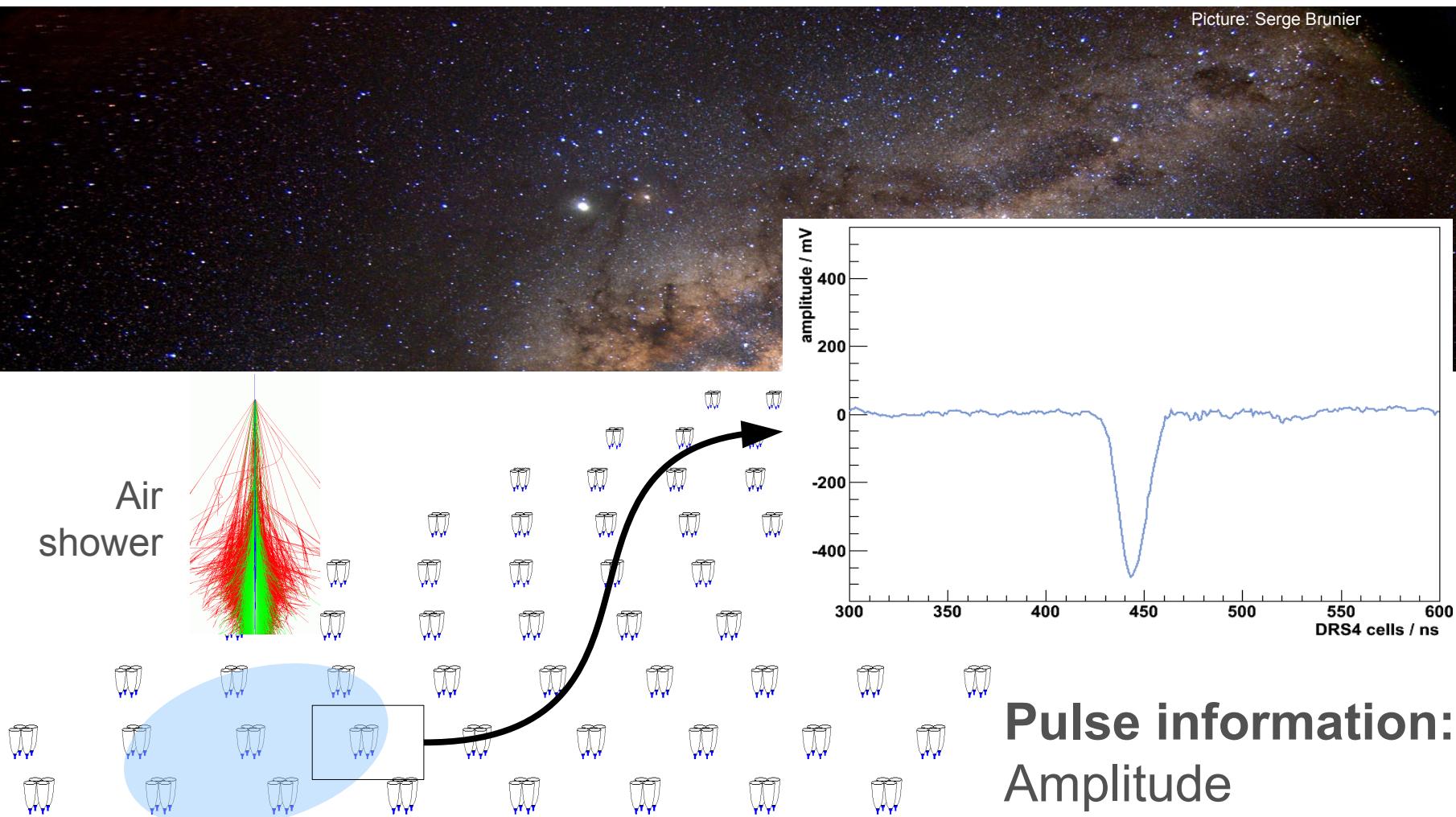
The HiSCORE concept

Picture: Serge Brunier



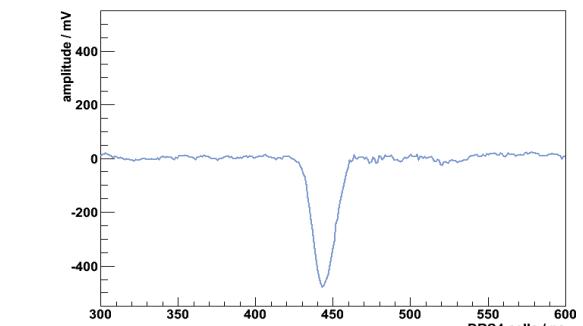
The HiSCORE concept

Picture: Serge Brunier

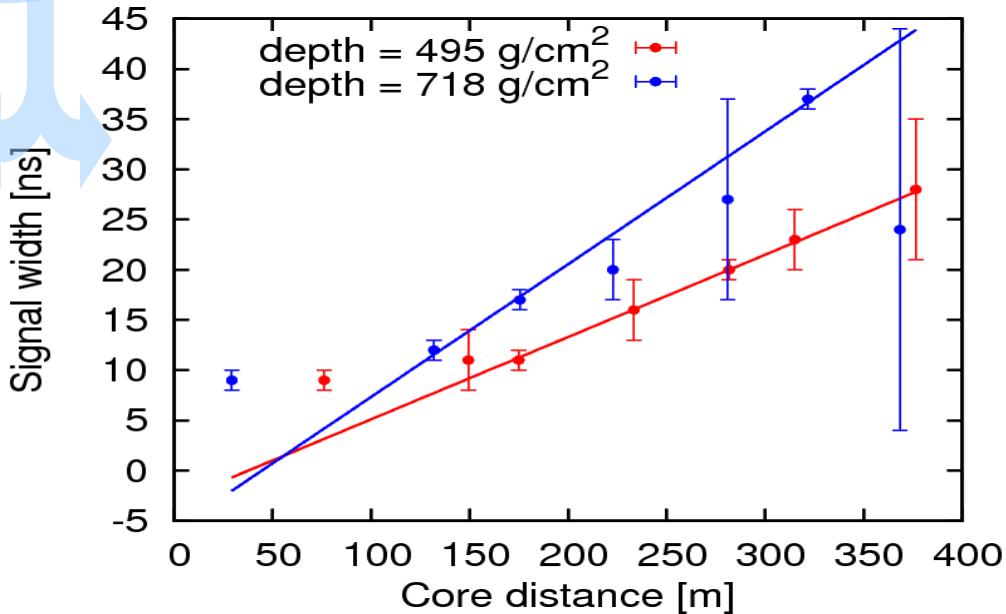
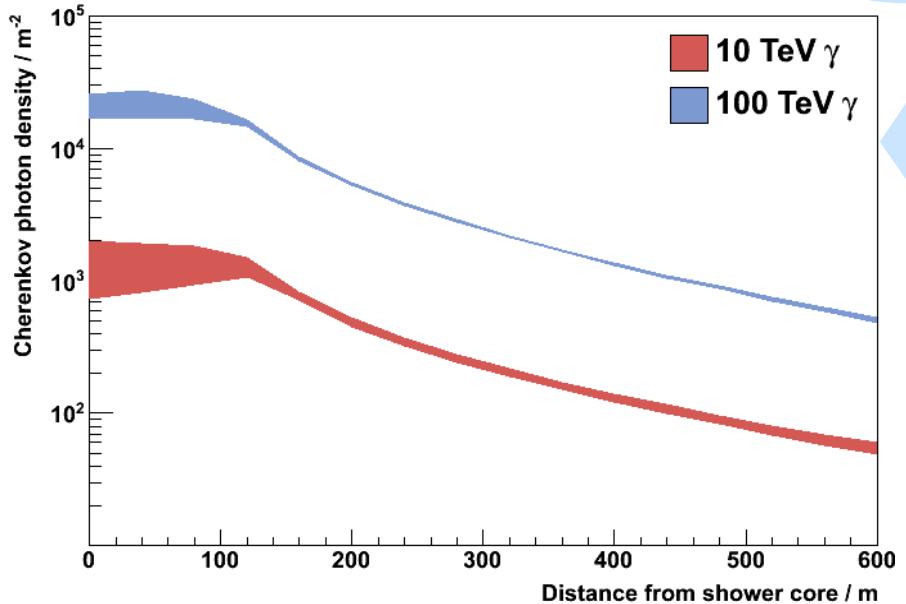
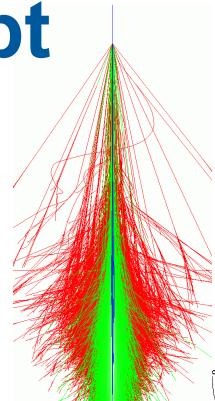


Pulse information:
Amplitude
Time (half-rise-)
Time width

The HiSCORE concept



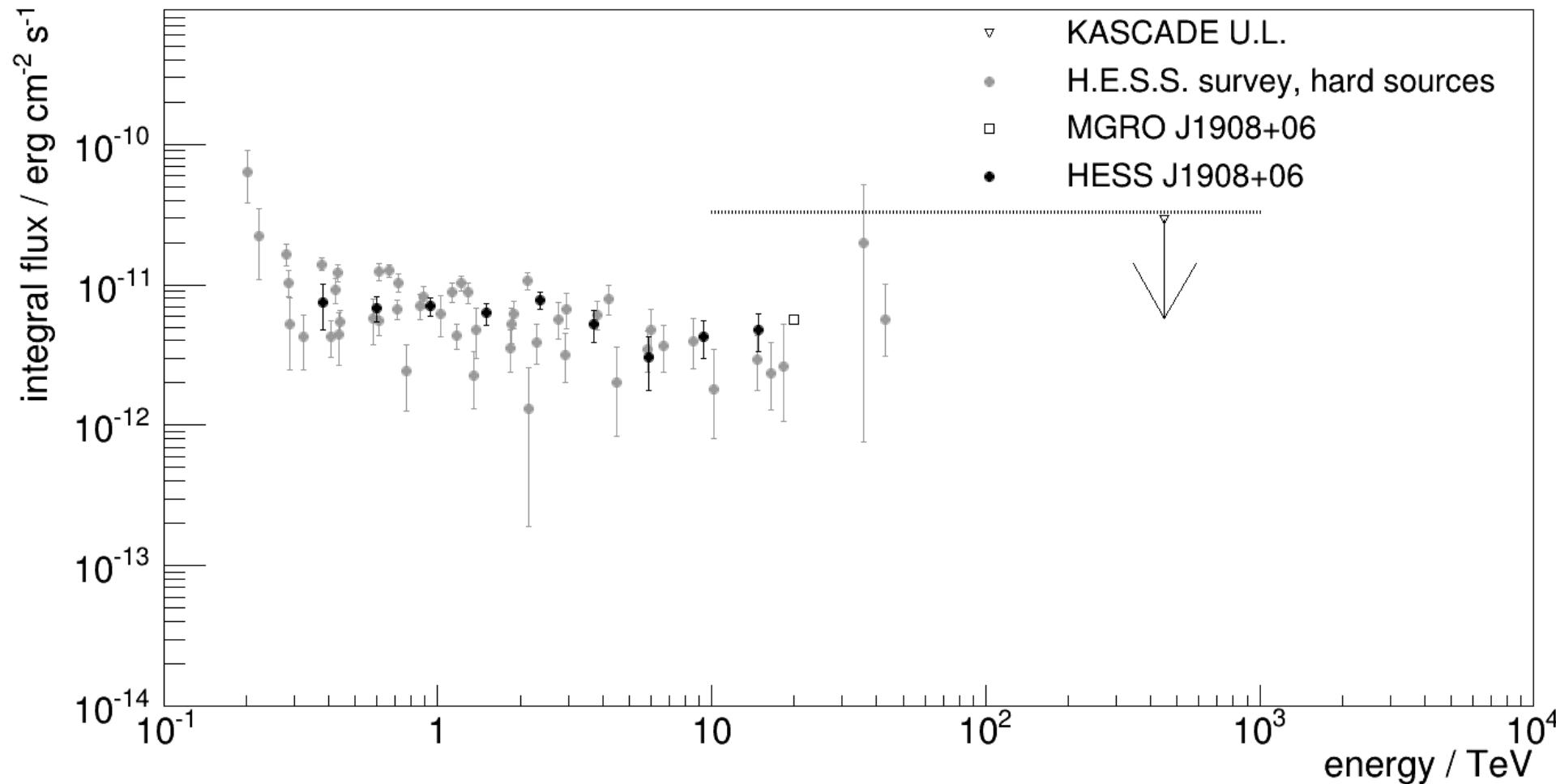
Air shower



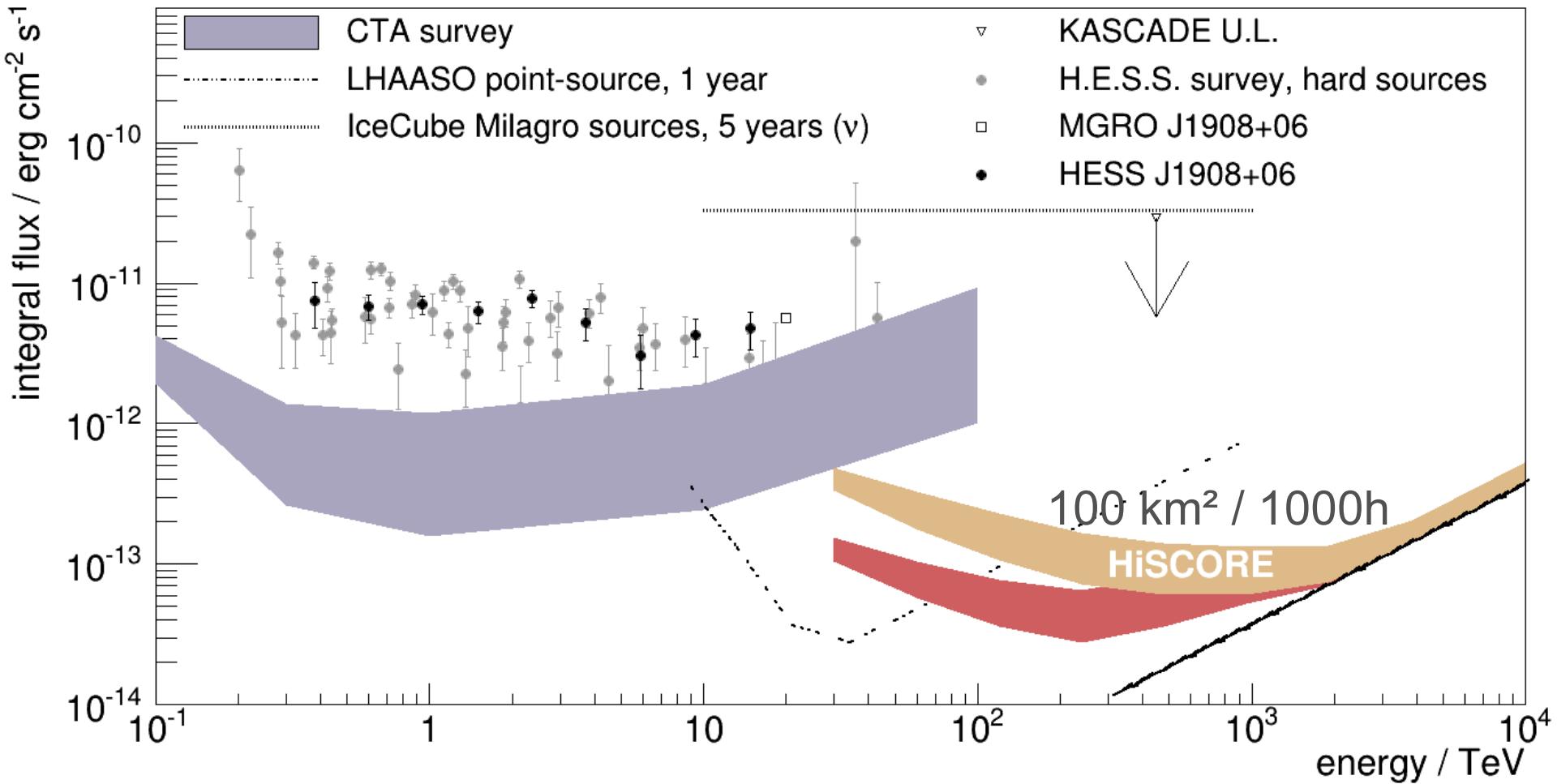
Physics potential of HiSCORE

(gamma-ray astronomy)

Opening the Pevatron range



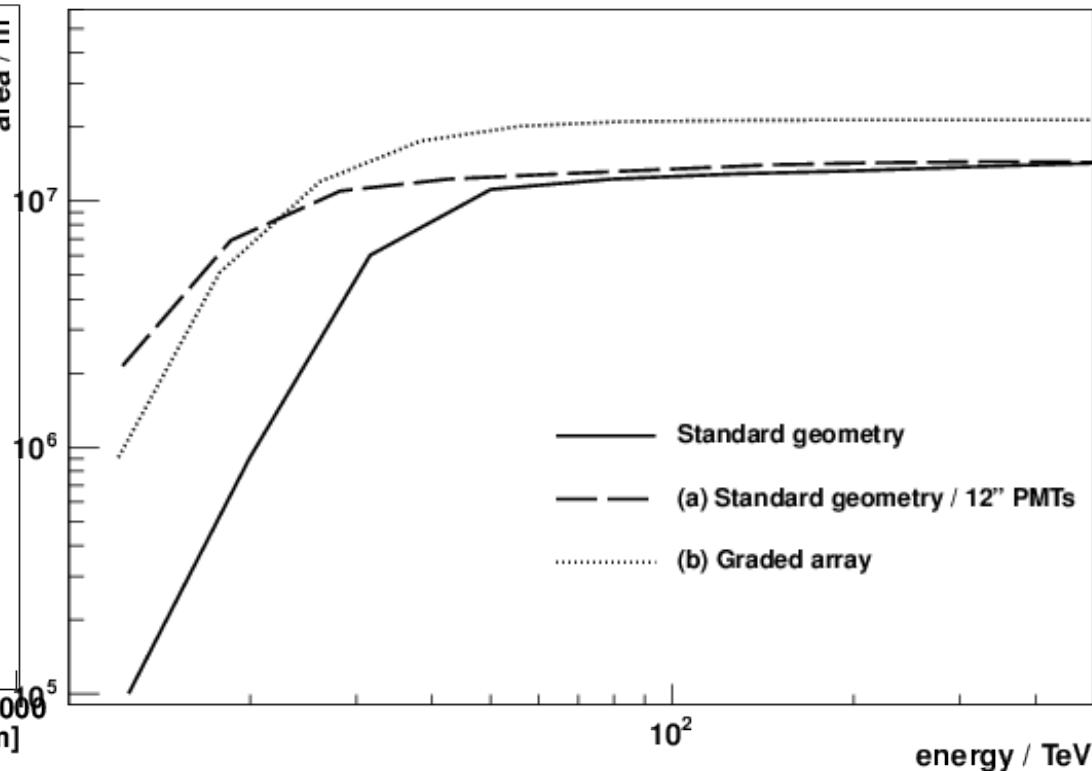
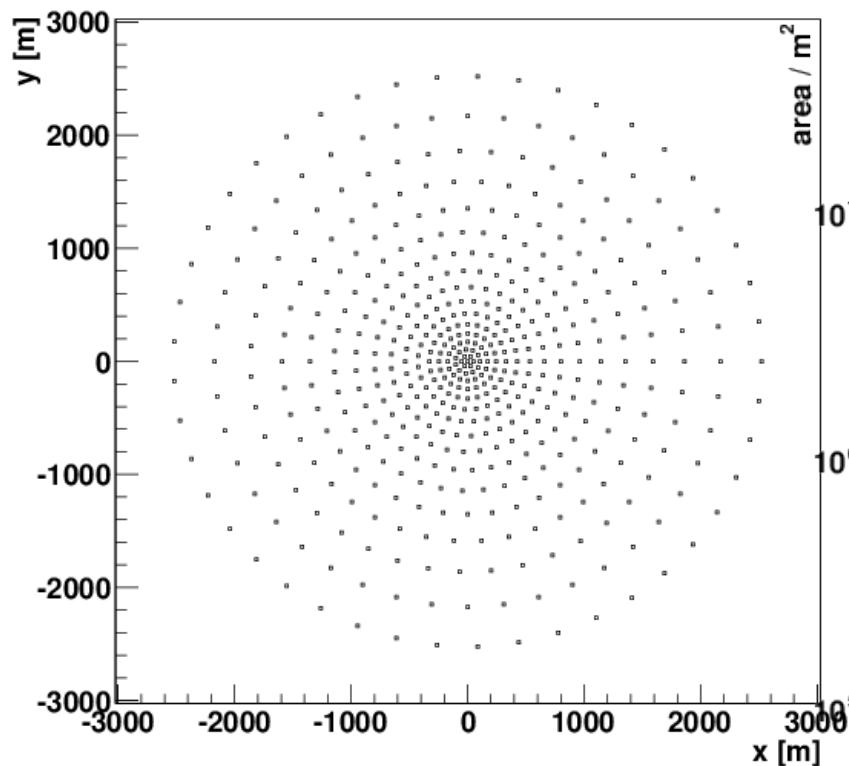
Opening the Pevatron range



Array Optimization

Simulation studies:

- Large PMTs (12")
- Graded array layout



The Tunka-HiSCORE project

The first realization of the HiSCORE concept

Tunka-HiSCORE



M. Brückner³, N. Budnev⁵, O. Chvalaev⁵, A. Dyachok⁵,
S. Epimakhov¹, O. Gress⁵, D. Hampf¹, D. Horns¹,
A. Ivanova⁵, S. Kiruhin⁵, E. Konstantinov⁵, E. Korosteleva⁴, M. Kunnas¹,
L. Kuzmichev⁴, B. Lubsandorzhiev⁶,
N.B. Lubsandorzhiev⁴, R. Mirgazov⁵,
R. Monkhoev⁵, R. Nachtigall¹, A. Pakhorukov⁵, V. Poleschuk⁵,
A. Porelli², V. Prosin⁴, G.I. Rubtsov⁶,
M. Rüger^{2,3} P.S. Satunin⁶, Yu. Semeney⁵, D. Spitschan¹,
L. Sveshnikova⁴, M. Tluczykont¹,
R. Wischnewski², A. Zagorodnikov⁵

February 17, 2014

Germany:
Universität Hamburg
Humboldt Universität
DESY

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

2 : DESY, Platanenallee 6, 15738 Zeuthen, Germany

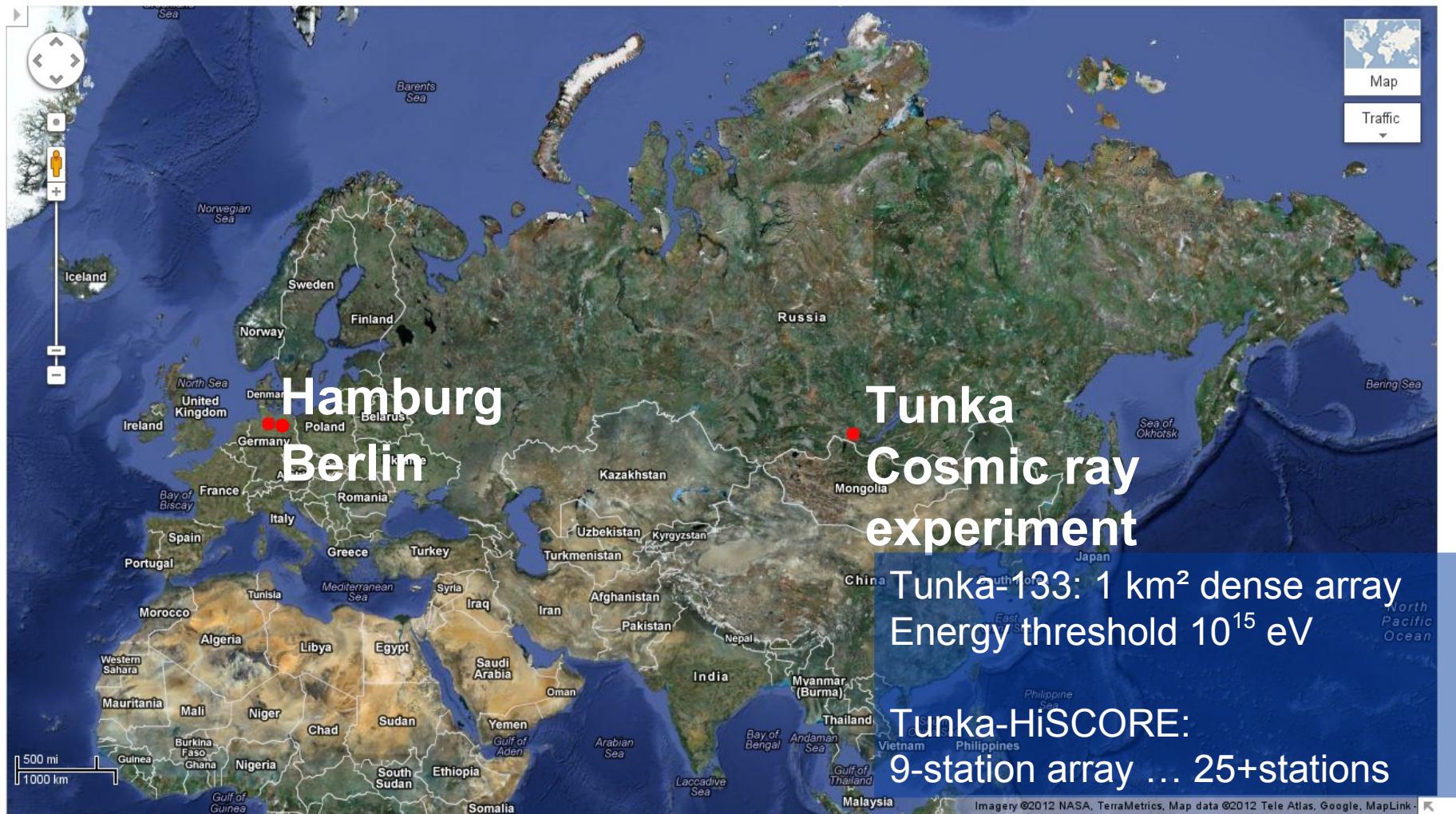
3 : Institute for Computer Science, Humboldt-University Berlin, Rudower Chaussee 25,
12489 Berlin, Germany

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



Status

1st light prototype 2012

3-station array 2012/13

9-station array since October 2013



Prototype-array:

- 9 stations, 300m X 300m
- 150m inter-station distance
- 4 channels (PMT+Cone)
- 2 parallel DAQ systems
- Energy threshold: <30 TeV

Future:

- Projected E_{thr} : 10 TeV
graded array and clipping



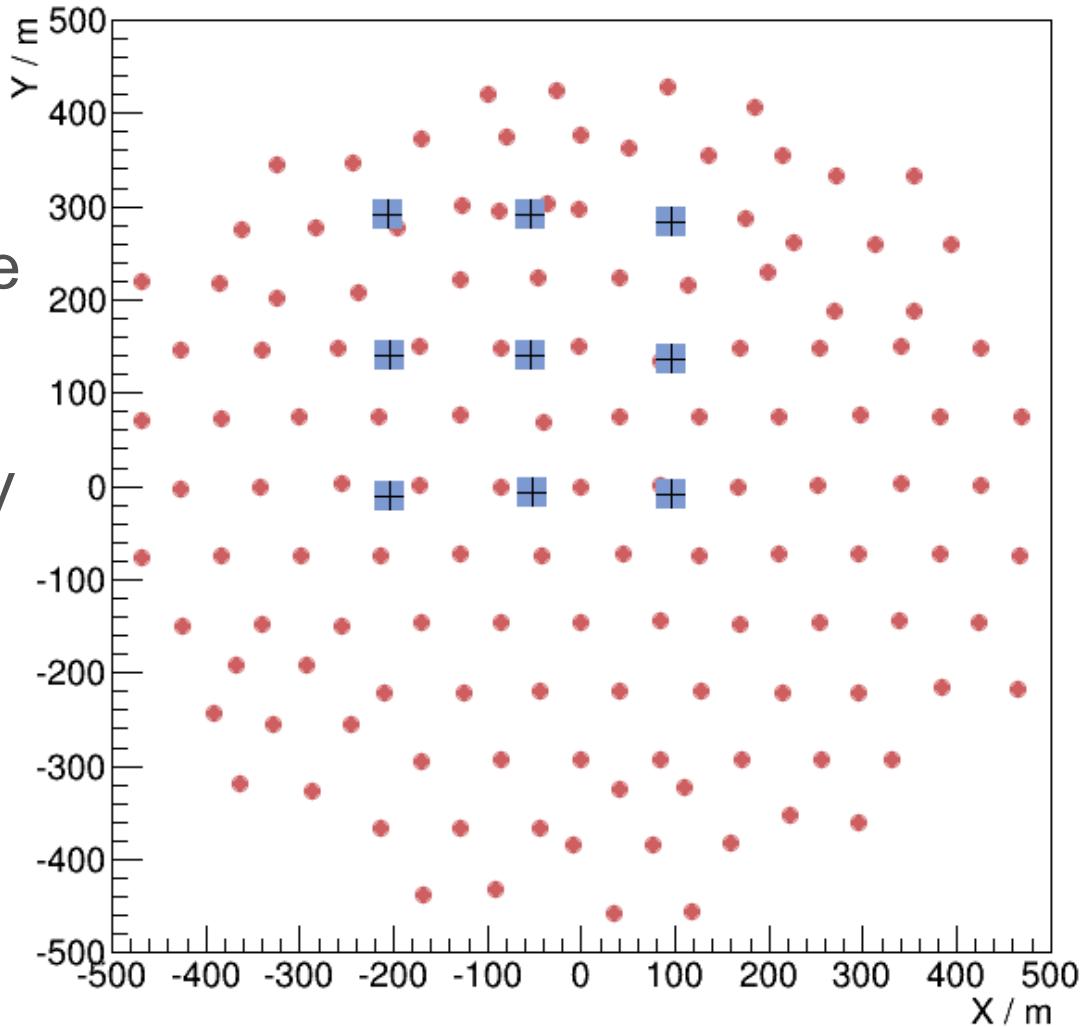
Status

Prototype-array:

- 9 stations, 300m X 300m
- 150m inter-station distance
- 4 channels (PMT+Cone)
- 2 parallel DAQ systems
- Energy threshold: <30 TeV

Future:

- Projected E_{thr} : 10 TeV
graded array and clipping



Status

Optical station



Electronic box



More pictures ?

Detector components

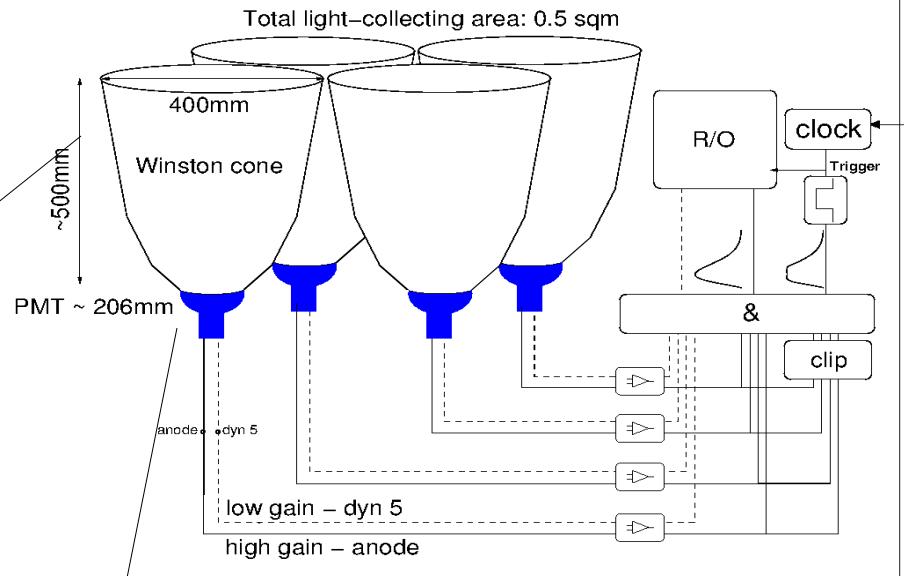
Detector components



Alanod 4300UP reflective sheets



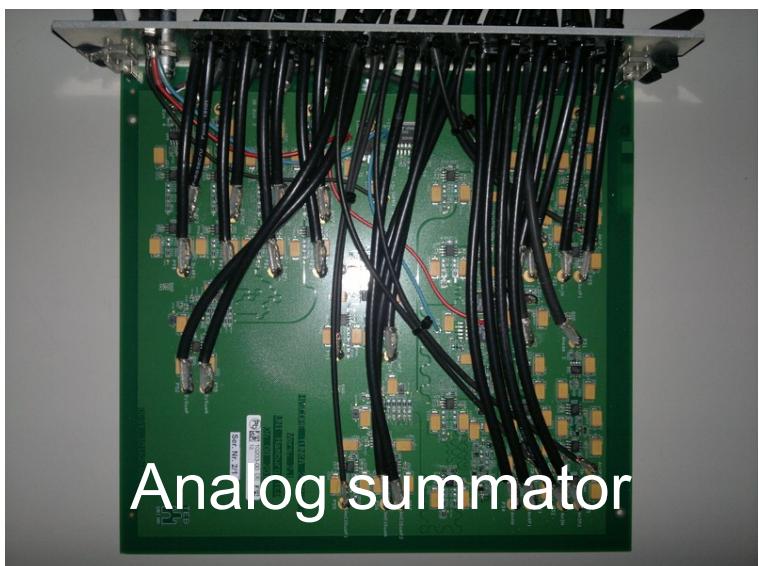
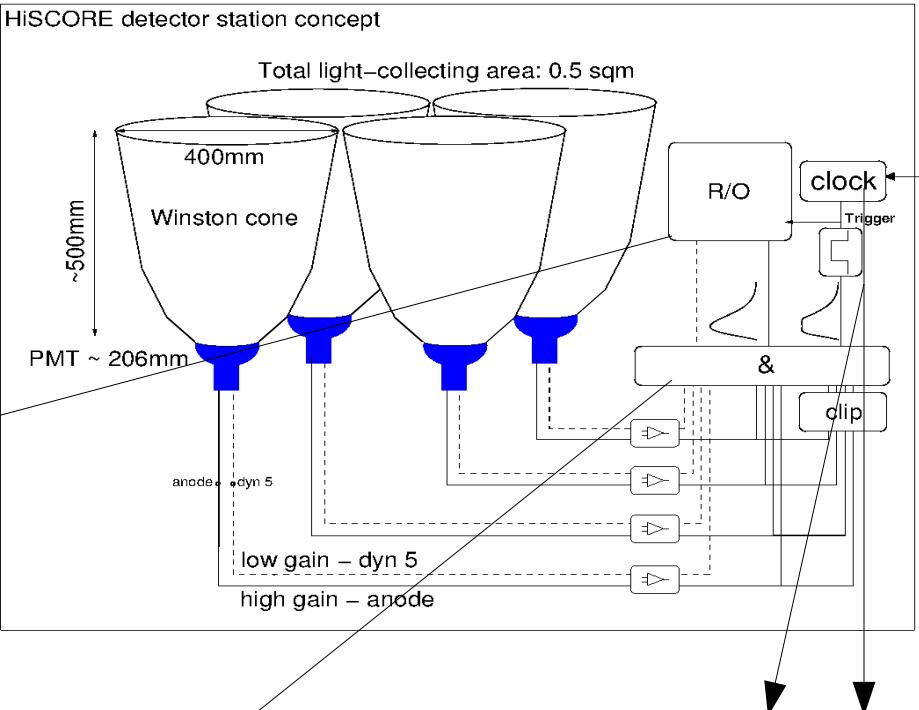
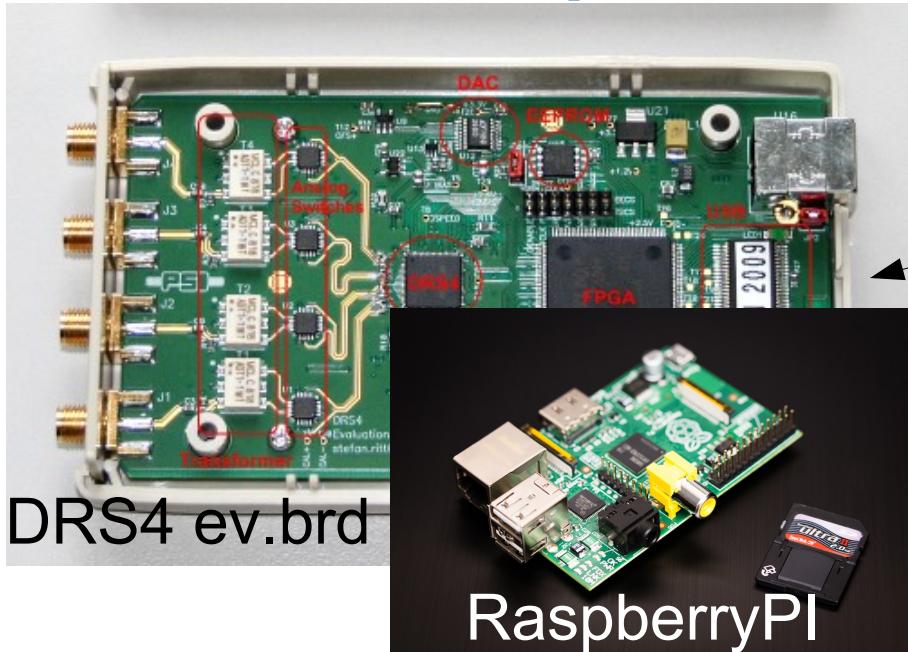
HiSCORE detector station concept



8" PMTs (Hamamatsu & ElectronTubes)



Detector components



System (Talk by A. Porelli)

Onboard FPGA : triggering

More pictures on detector components

Slow control system ?

PMT base ?

MSU readout board ?

9-station array DAQ

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

Analog sum trigger: $\sum_{i=1..4} a_i > A_{thr}$

Plan: clipped sum trigger (reduction of noise)

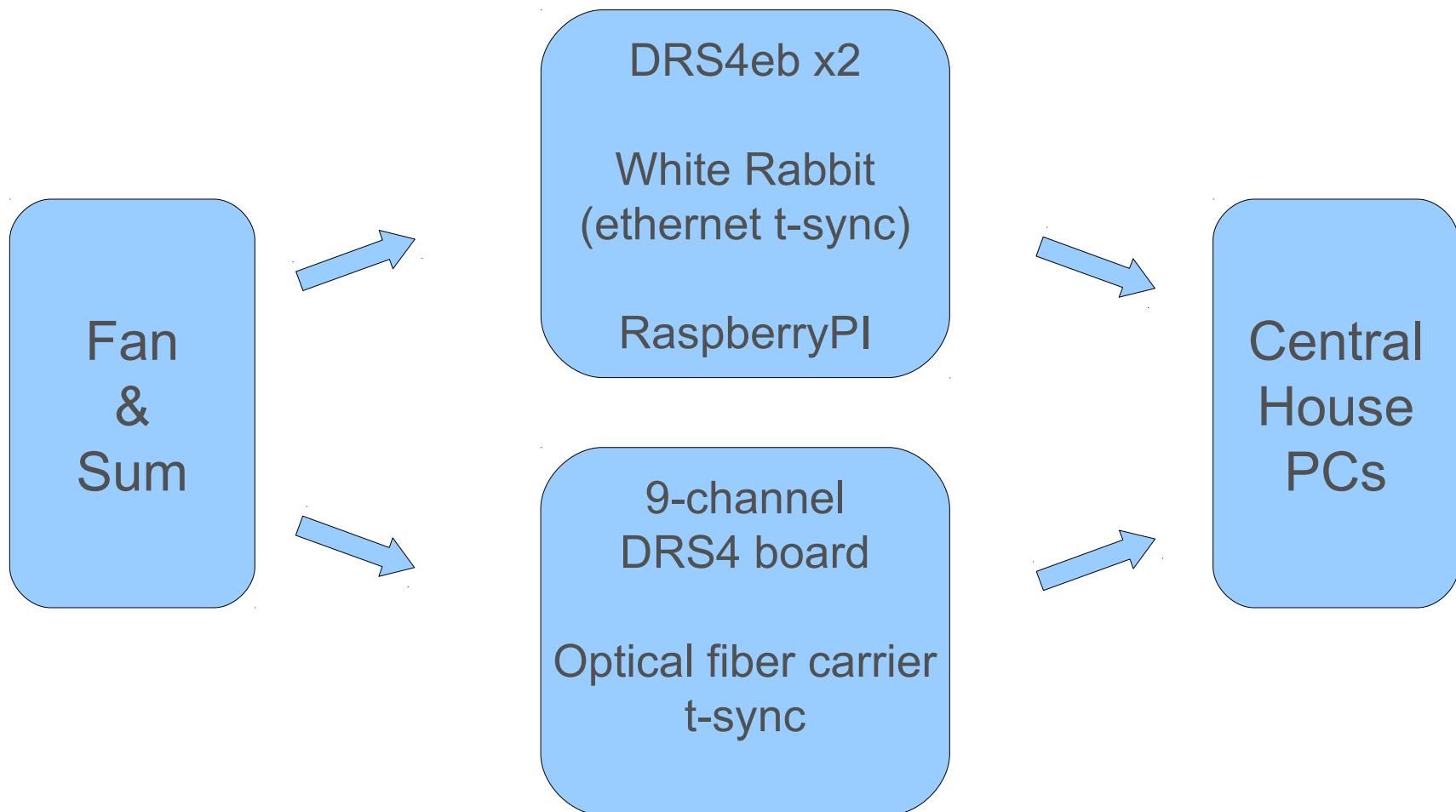
2 independent DRS4-based DAQ systems

- DRS4 custom board + t-sync system
- DRS4 evaluation board + WhiteRabbit sub-ns time- synchronization

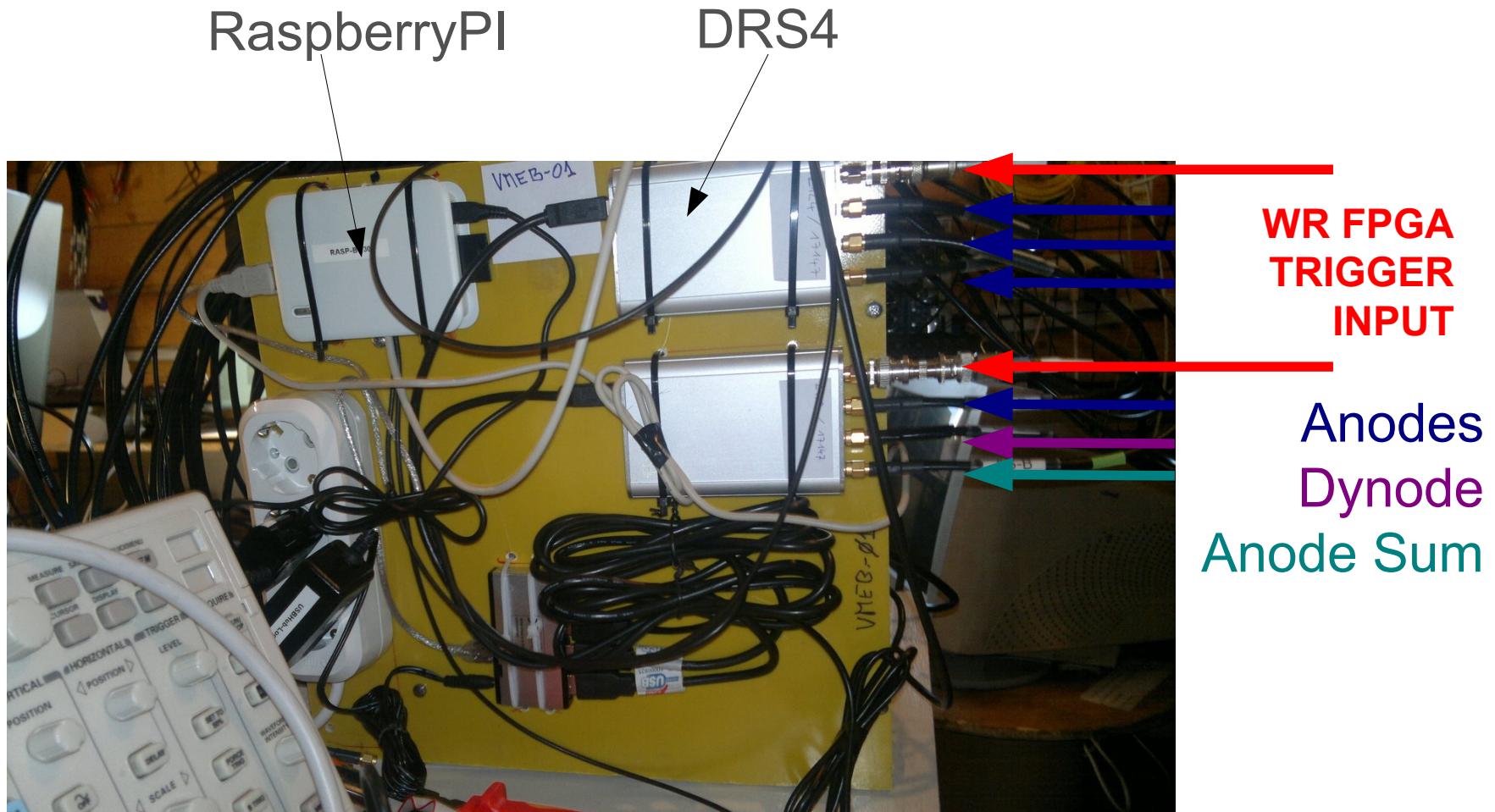
Low threshold
trigger

GHz sampling and
sub-ns precision !

9-station array DAQ Systems



DRS4eb DAQ



DRS4 9-channel DAQ

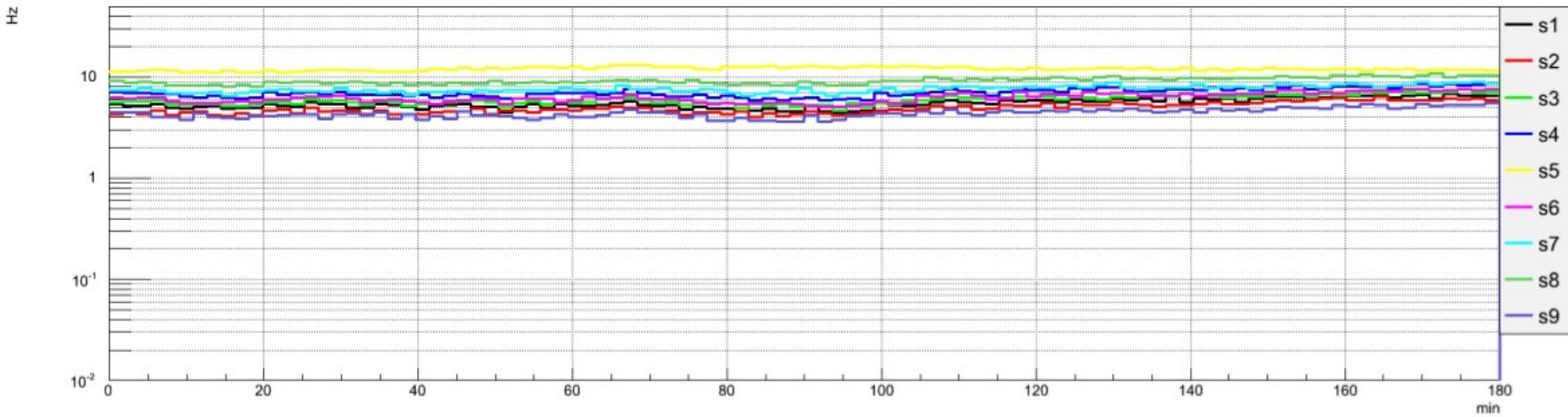
Pictures of MSU-DAQ ?

Some conceptual ideas of MSU-DAQ ?

Data quality

Operation since 10/2013

Daily data quality checks (rate stability, Amplitude spectra, time difference distributions, ...)



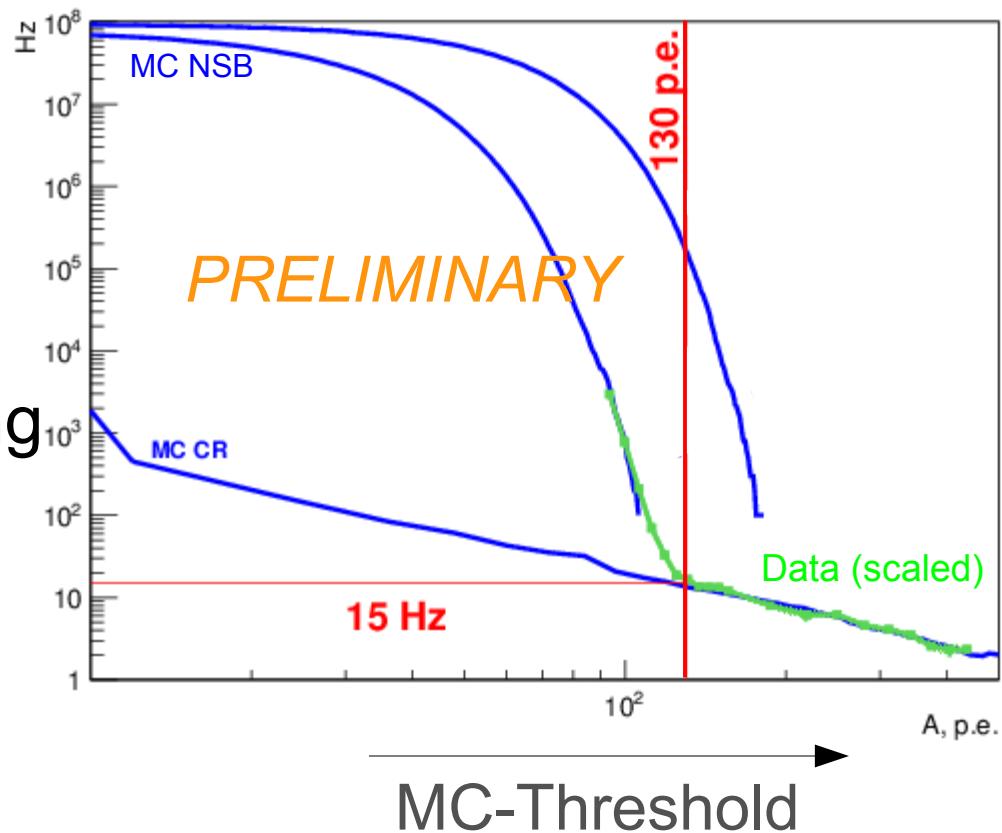
Pulses

Differential amplitude distributions

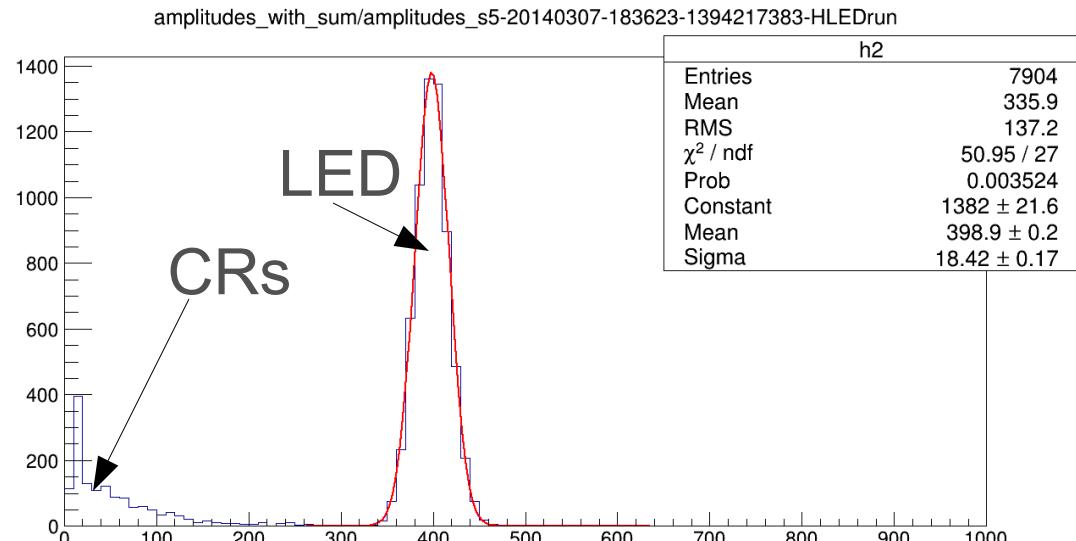
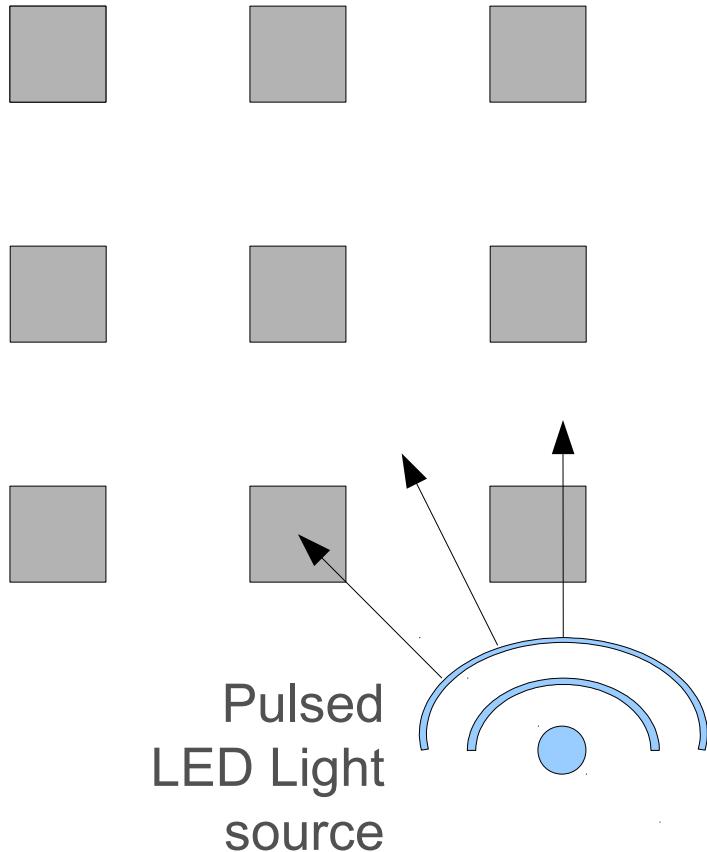
Raw data

Trigger rate vs. threshold

- Cosmic ray branch
- noise wall
- Simulation attempt p.e./mV Scaling



Timing verification



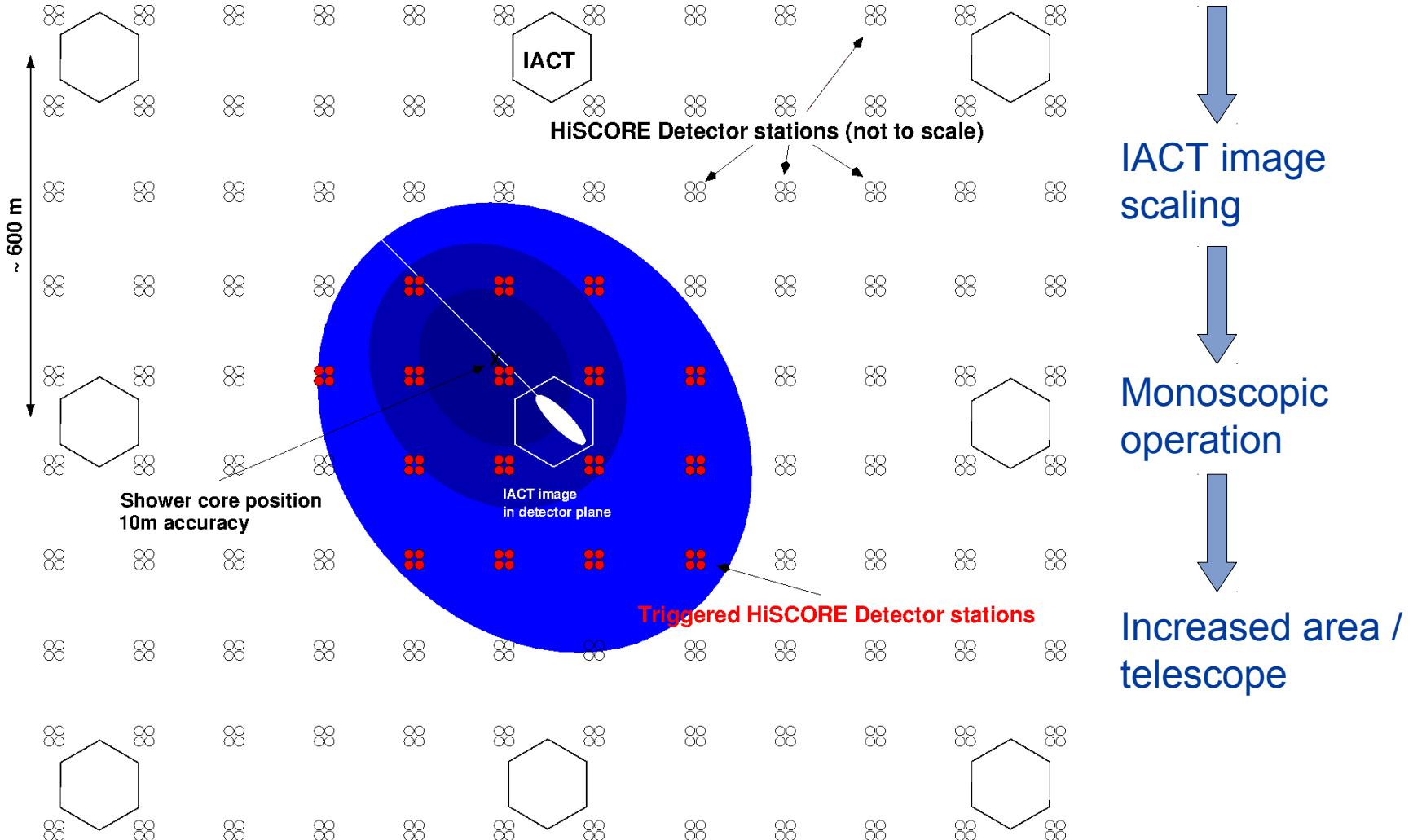
Spherical wave fit:
Residuals $\rightarrow dt \sim 0.6 \text{ ns}$

Combining HiSCORE with telescopes

Non-imaging and imaging hybrid detection

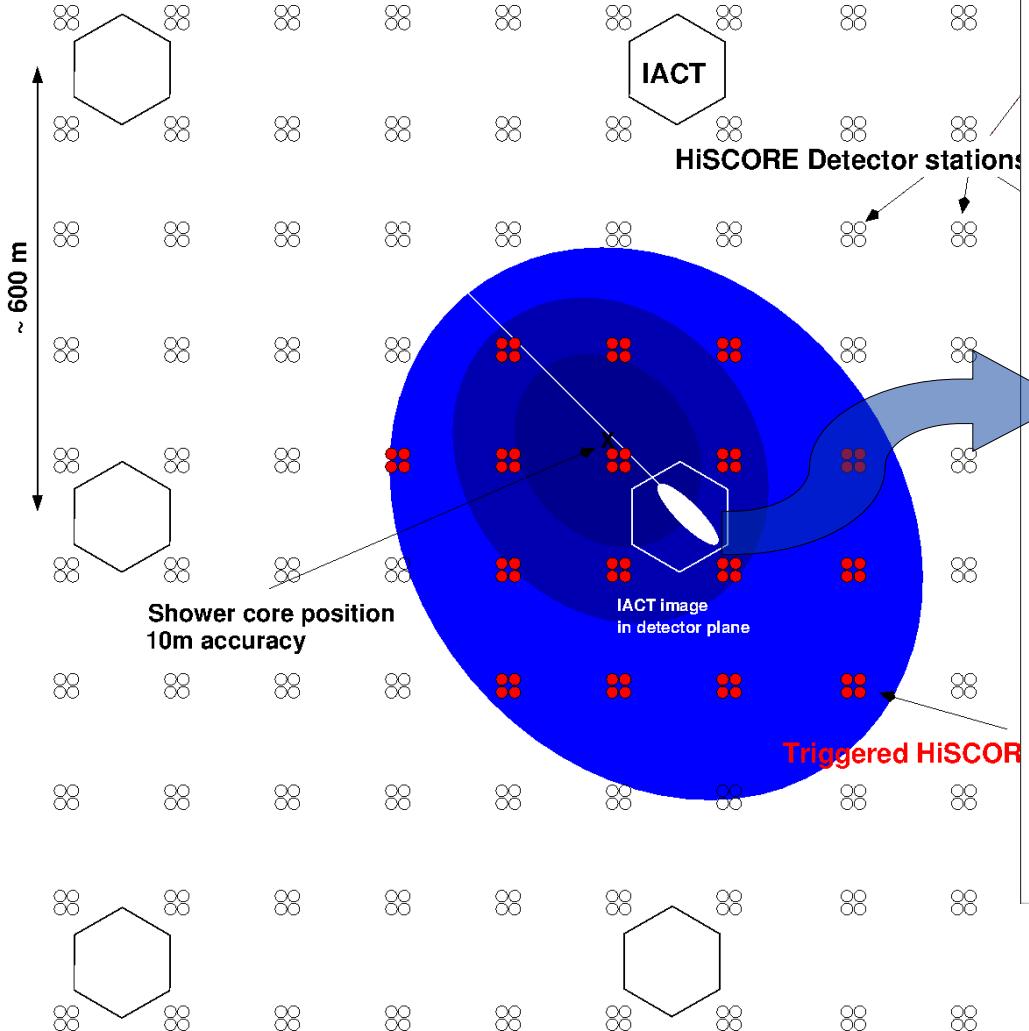
HiSCORE + IACTs

Important reconstruction parameter: Shower core position

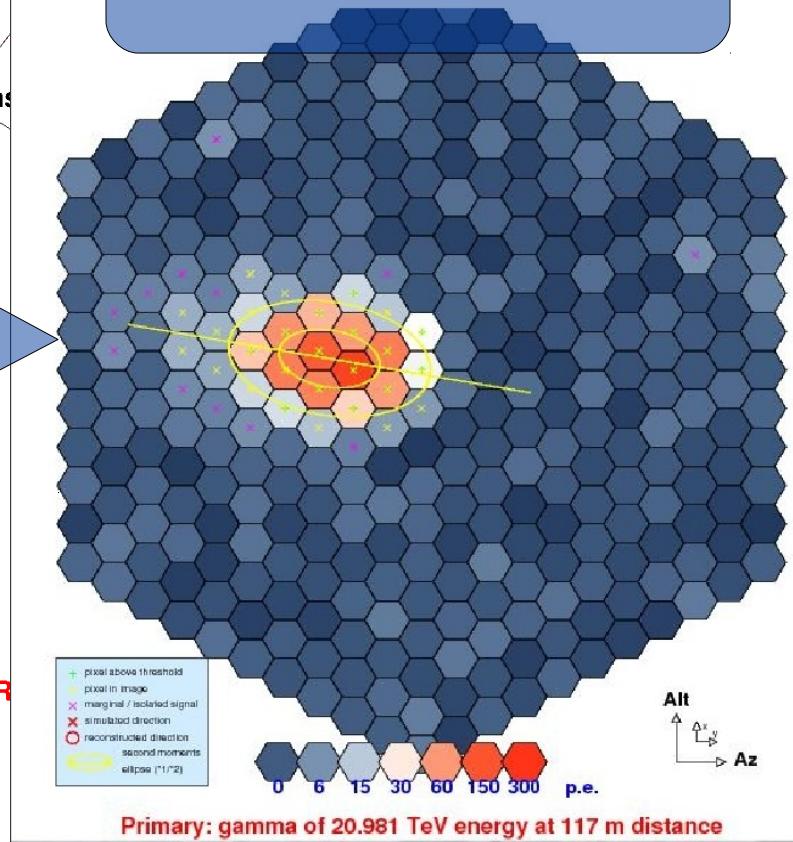


HiSCORE + IACTs

Important reconstruction parameter: Shower core position



Simulation underway



Simulation: sim_telarray + sim_score

Preliminary results:

- Improves gamma-hadron separation
- Increases total area covered by telescopes+stations

Summary & outlook TAIGA

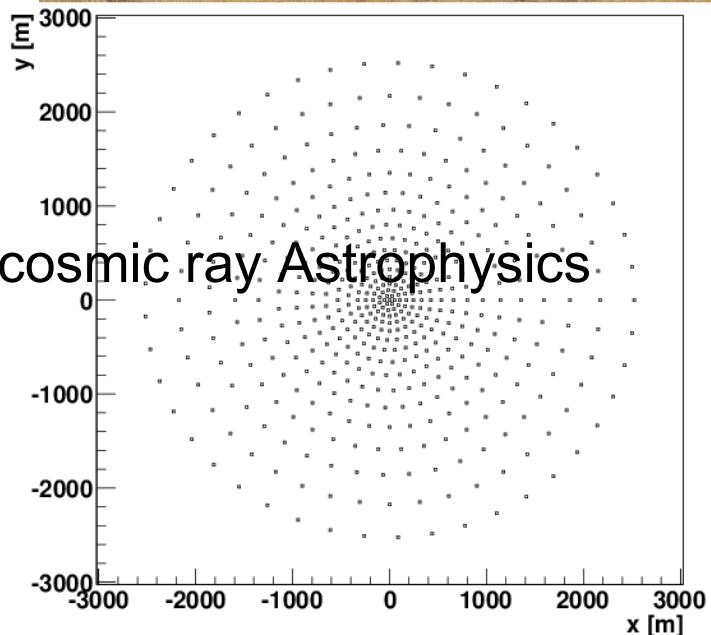
Tunka-HiSCORE 9-Station array:

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



TAIGA, 2014+

- 1 km² engineering array
- HiSCORE + imaging telescopes
- Expect 1st physics results
- Tunka Area International Gamma-ray and cosmic ray Astrophysics

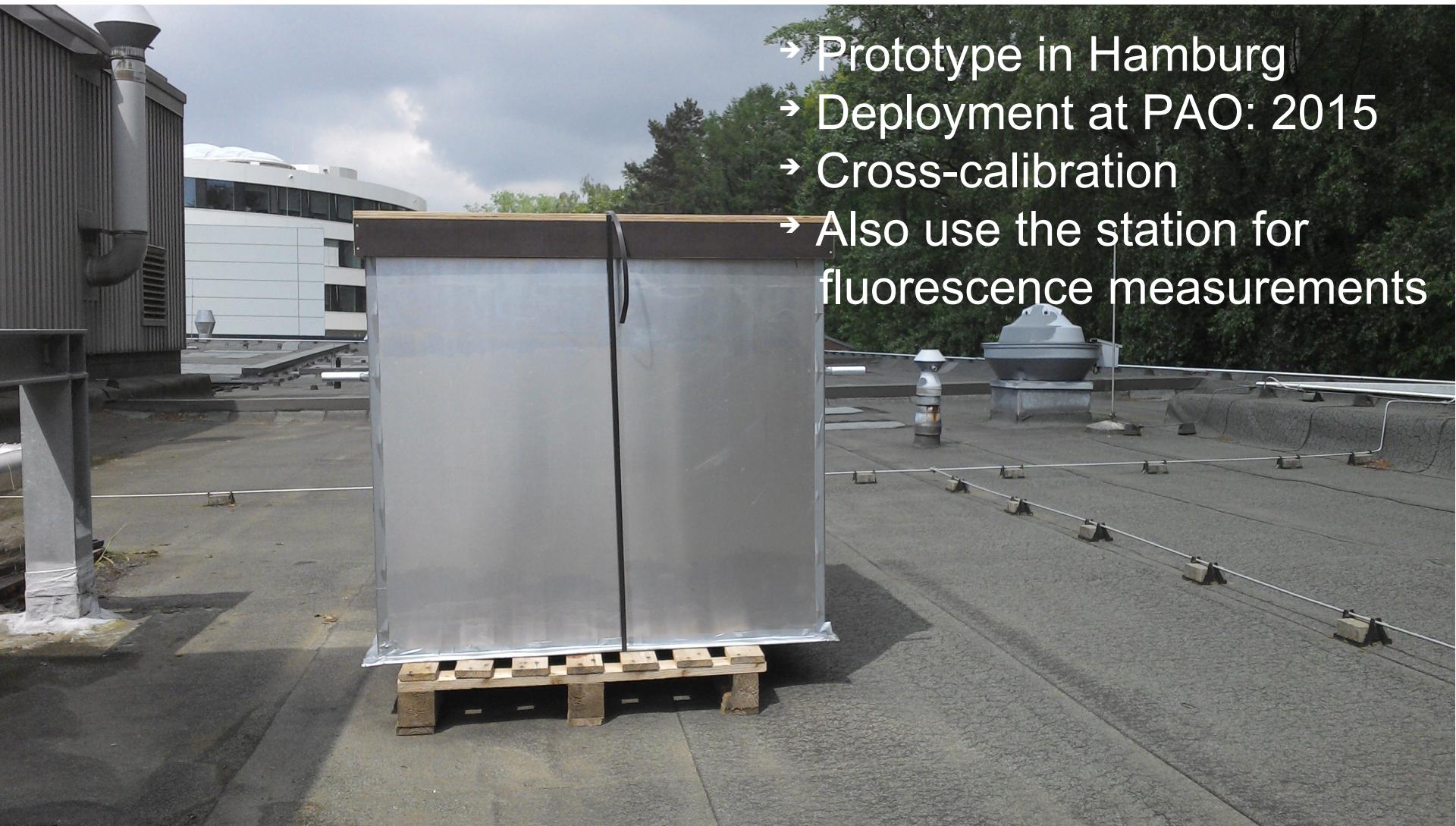


HiSCORE @ PAO

- Prototypes planned for deployment 2015

Outlook 2: HiSCORE at Pierre Auger Observatory

- Prototype in Hamburg
- Deployment at PAO: 2015
- Cross-calibration
- Also use the station for fluorescence measurements



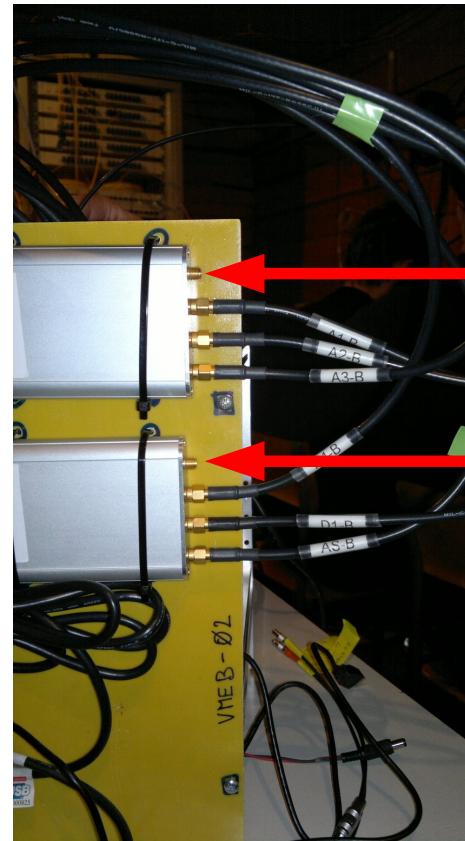
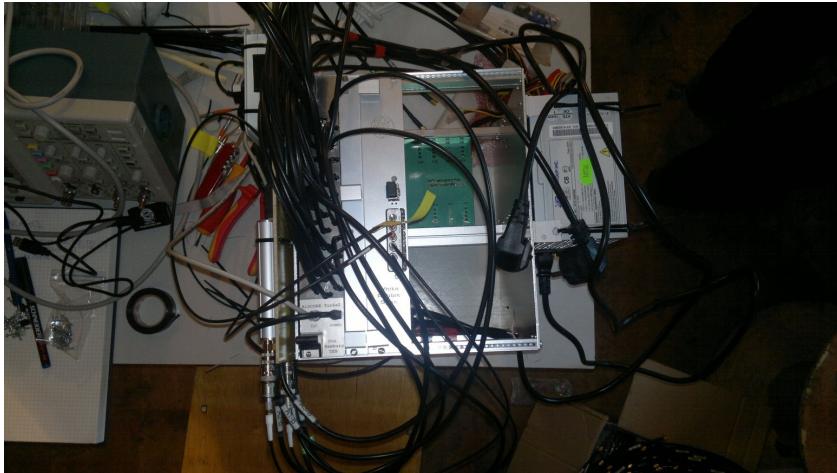
Outlook 2: HiSCORE at Pierre Auger Observatory

Possibly some principle sketch on
fluorescence with HiSCORE stations

(maybe input from Paolo)

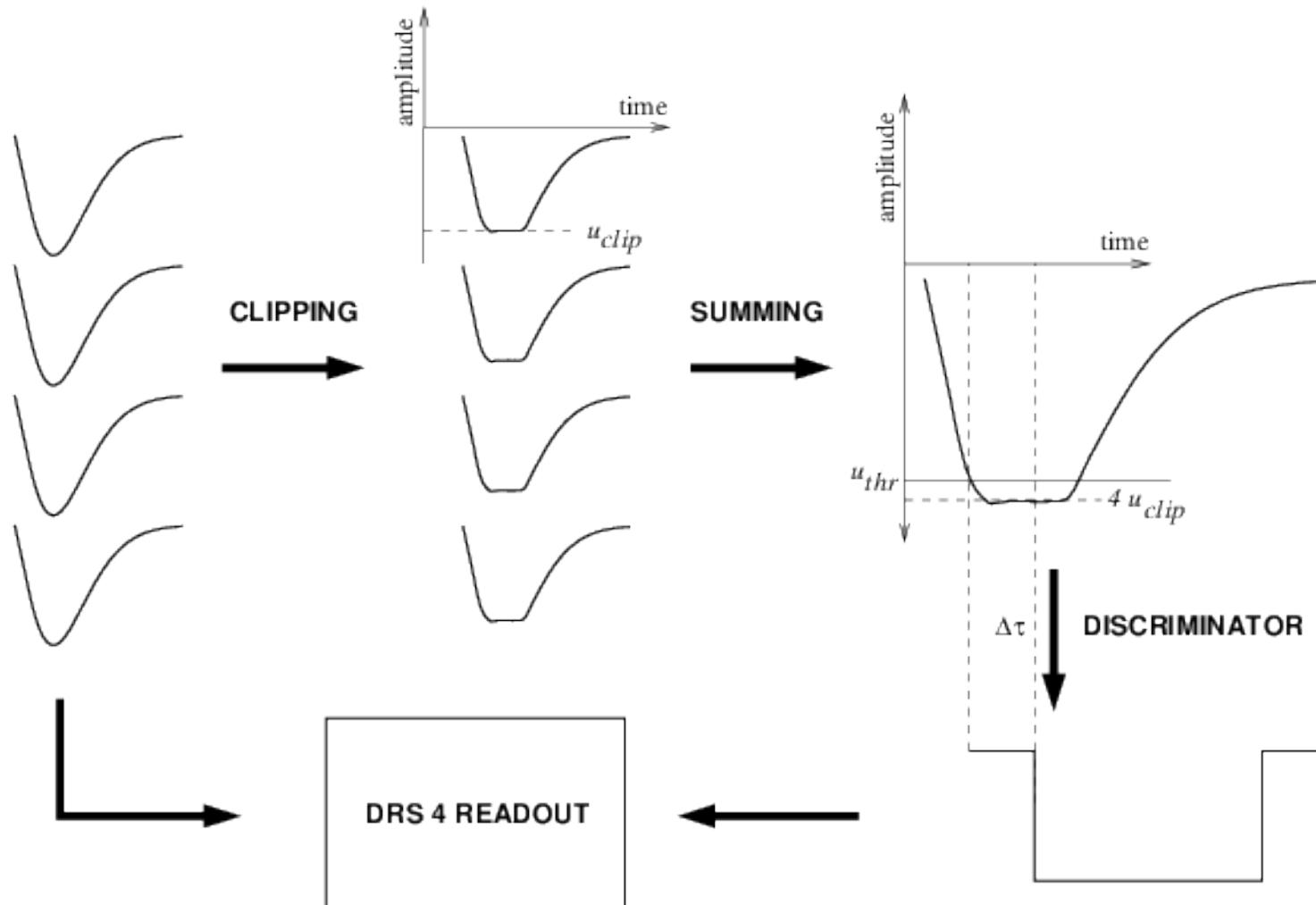
Backup slides

Status



**WR FPGA
TRIGGER
INPUT**

Trigger



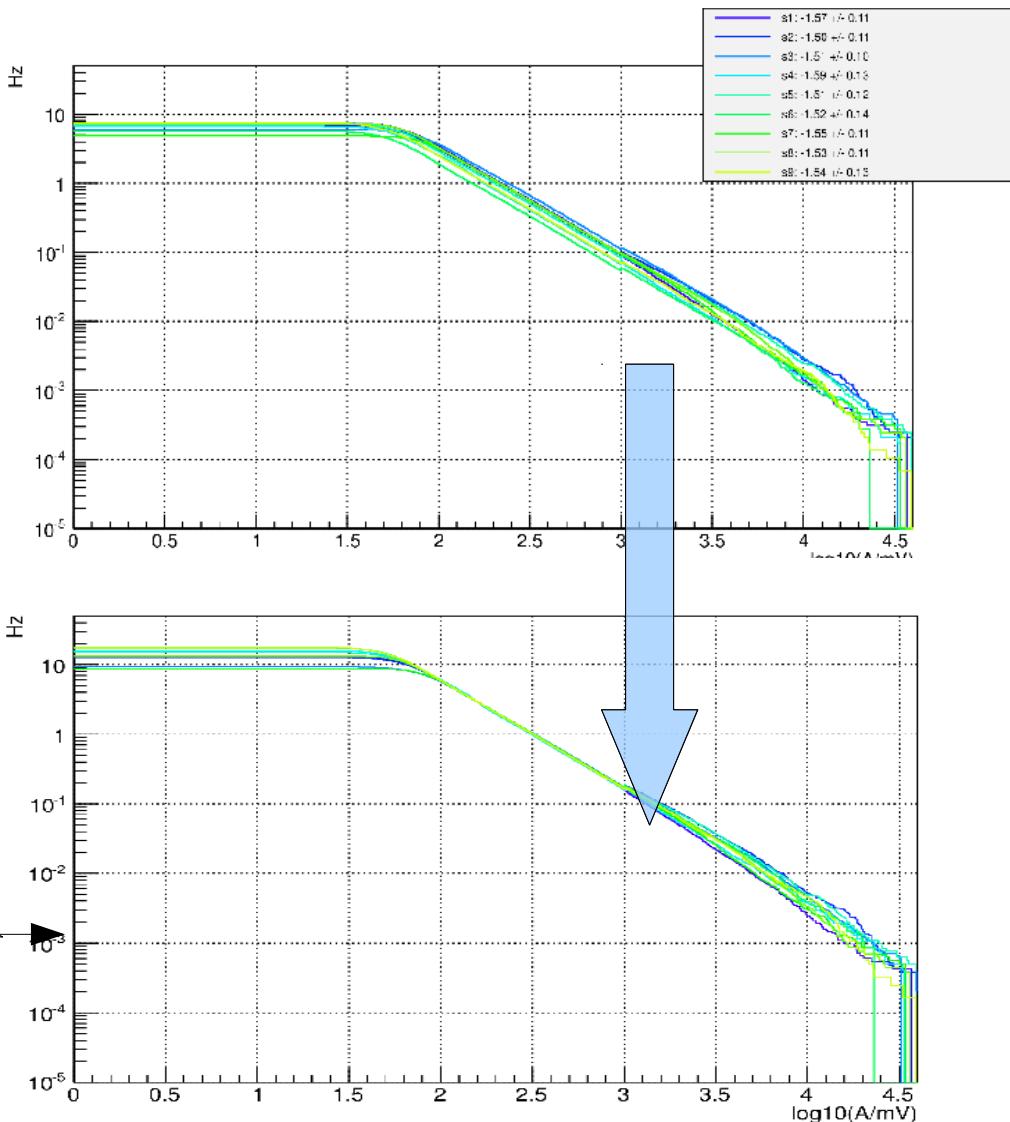
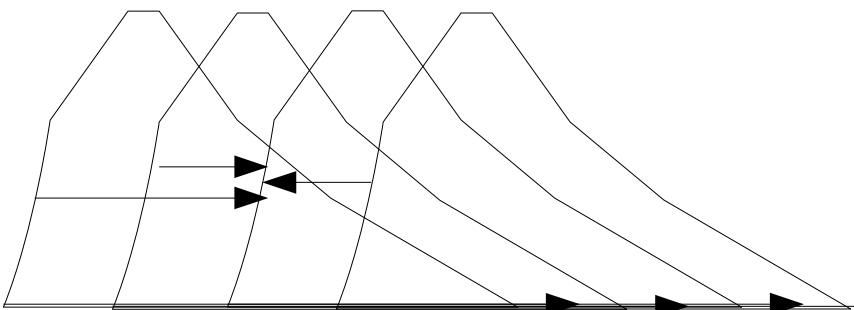
Amplitude calibration

LED runs: conv. factor

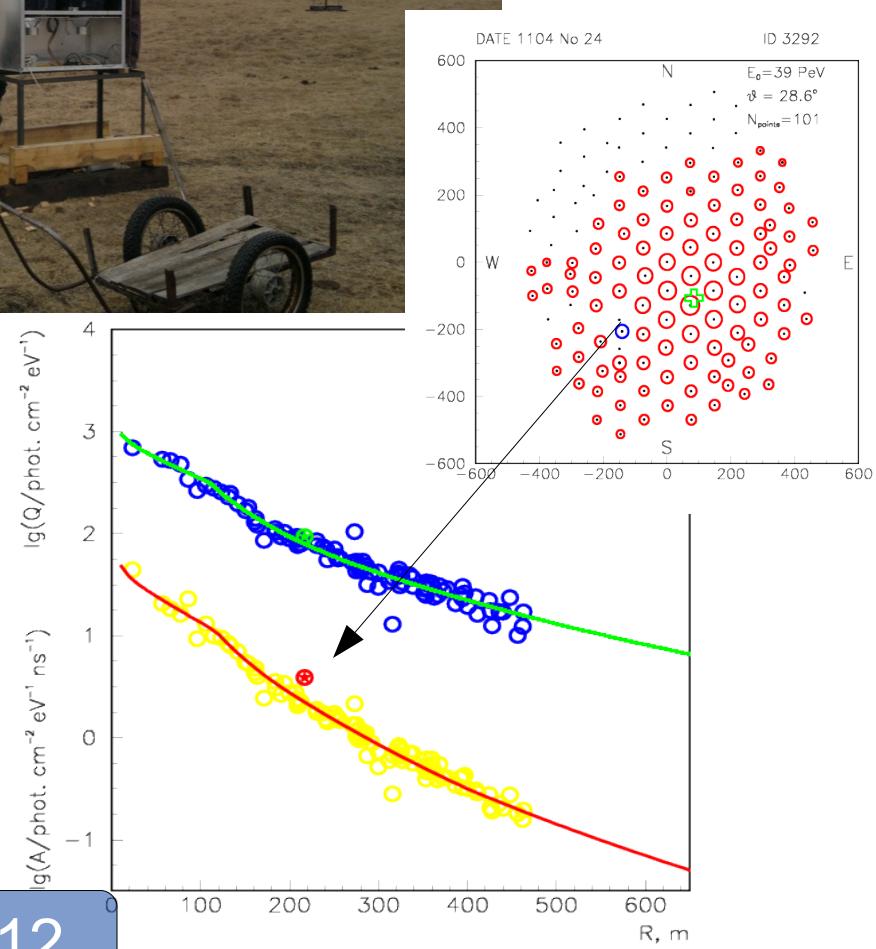
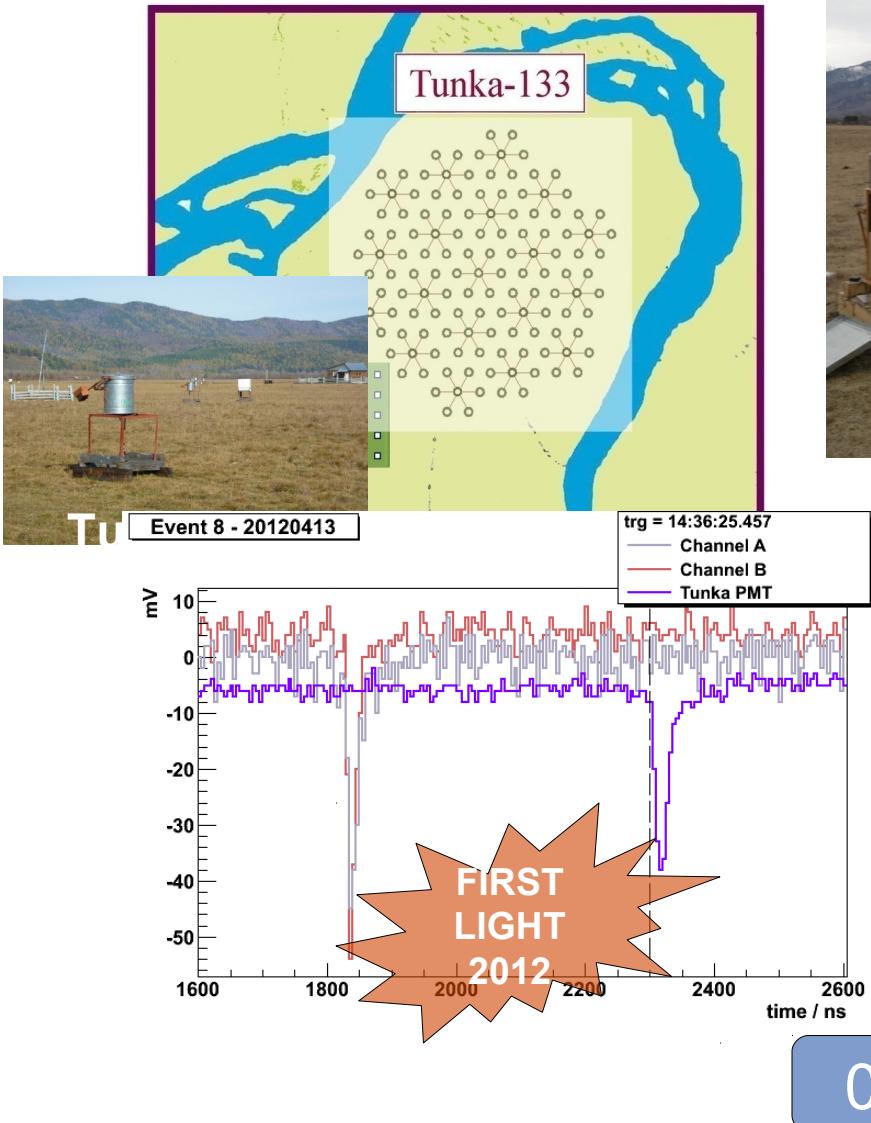
$$\langle C \rangle \sim 1.5 \text{ p.e./mV}$$

Amp. scale shifting:

- In time
- mV scale



First HiSCORE prototypes deployed

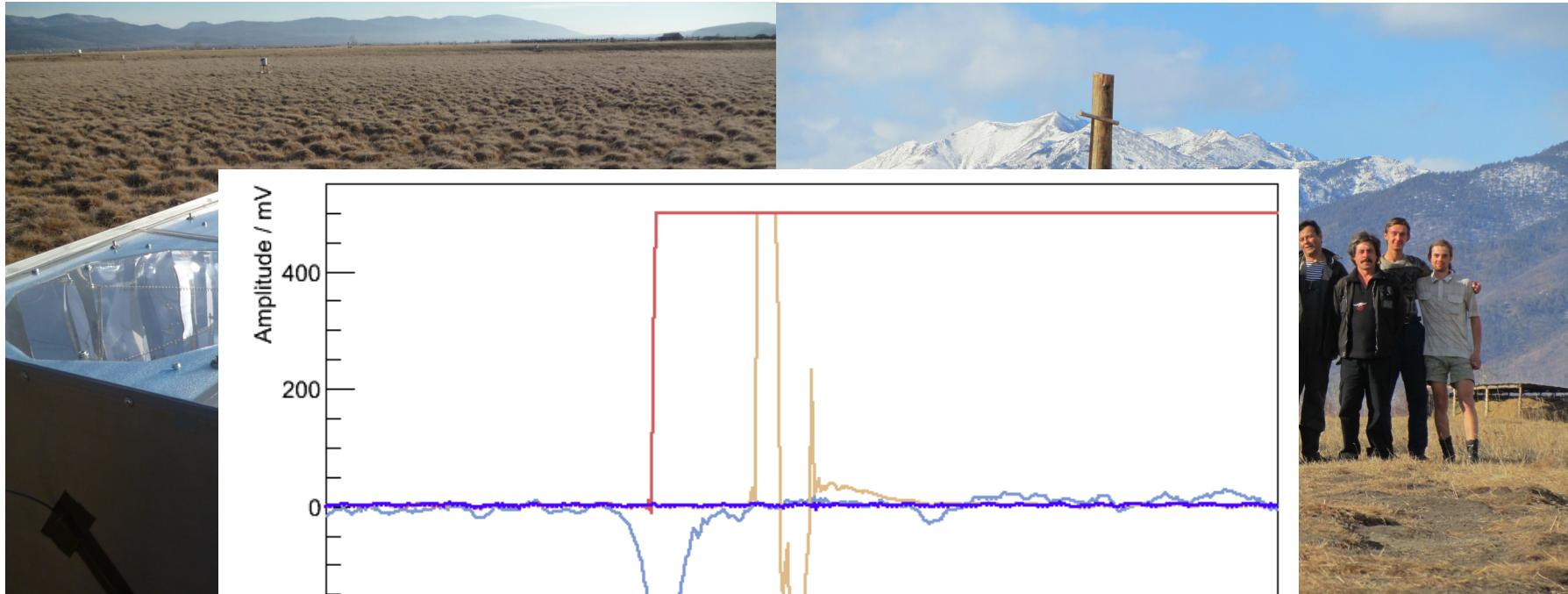


3 Station array 10/2012 – 04/2013



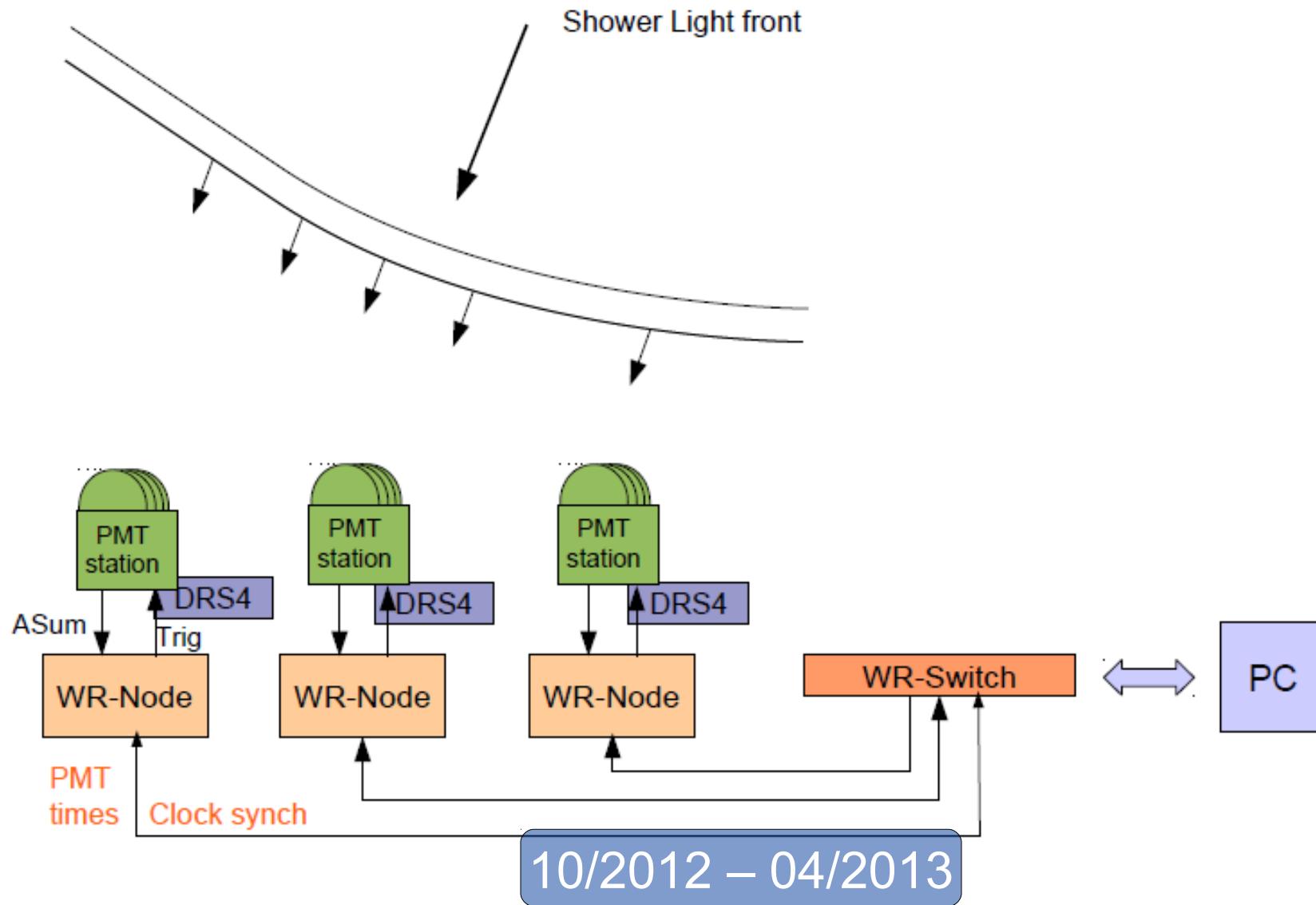
10/2012 – 04/2013

3 Station array 10/2012 – 04/2013

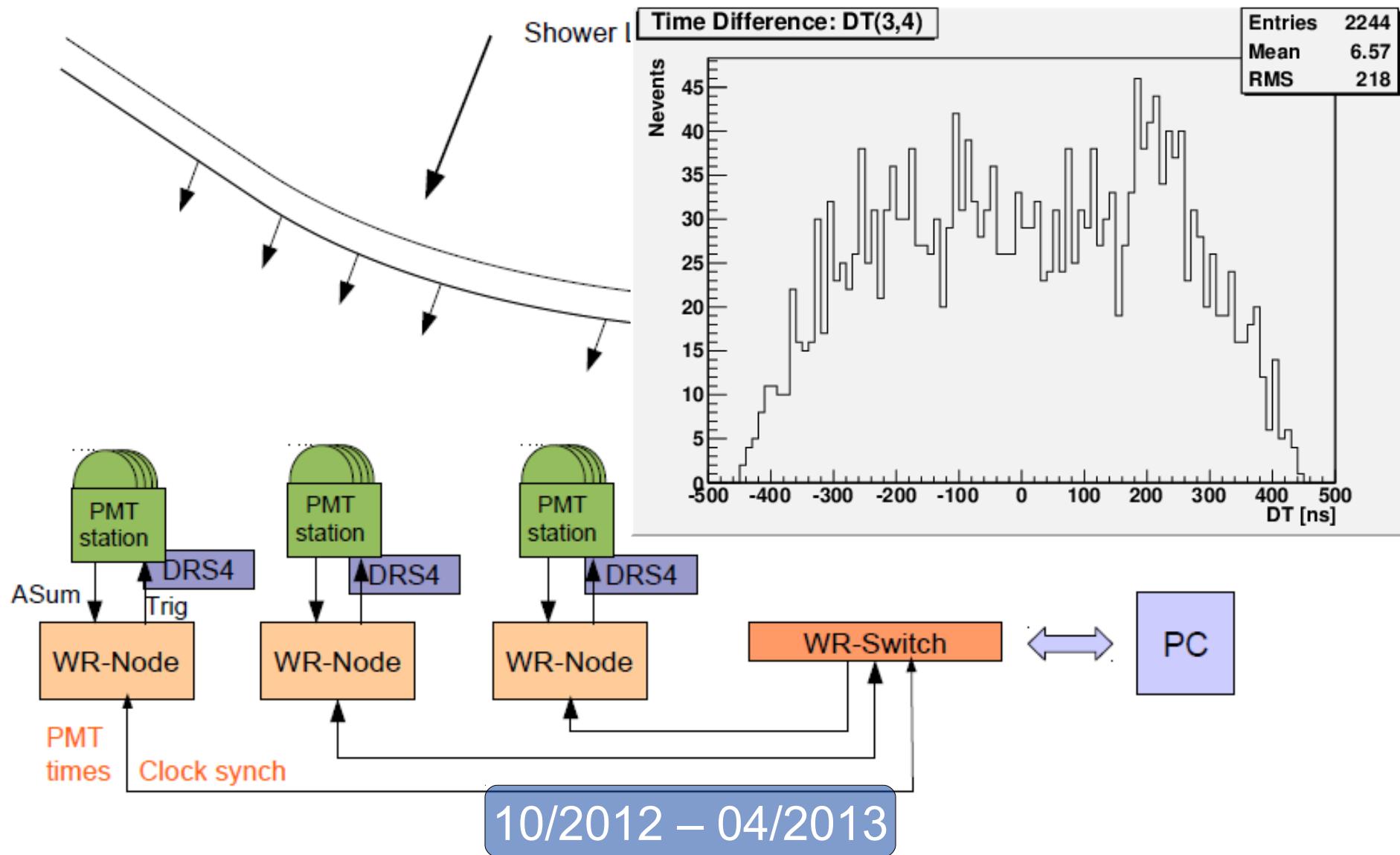


10/2012 – 04/2013

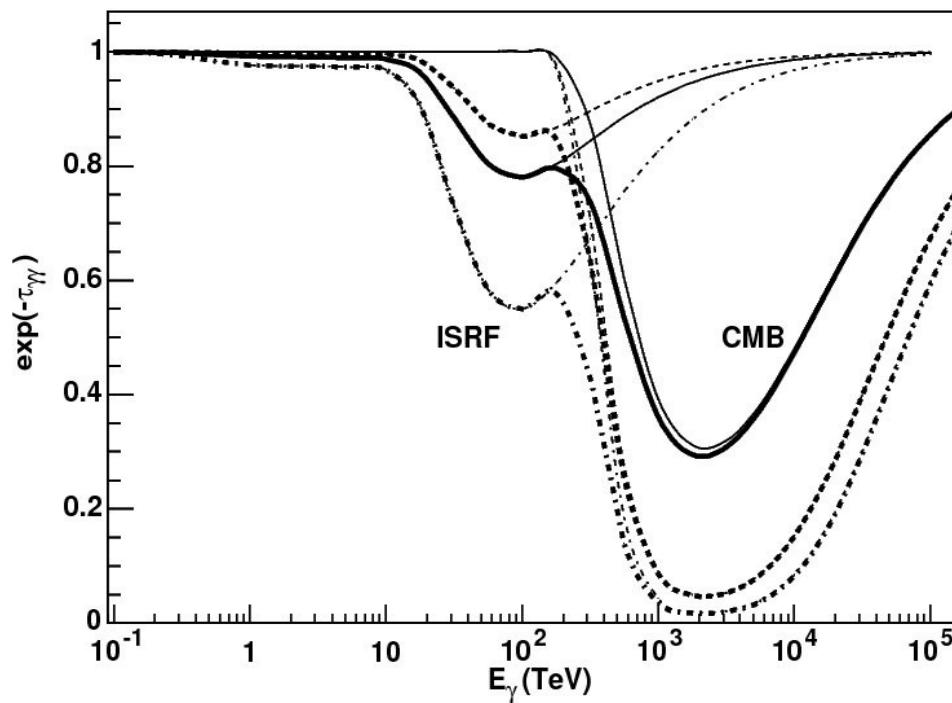
3 Station array 10/2012 – 04/2013



3 Station array 10/2012 – 04/2013



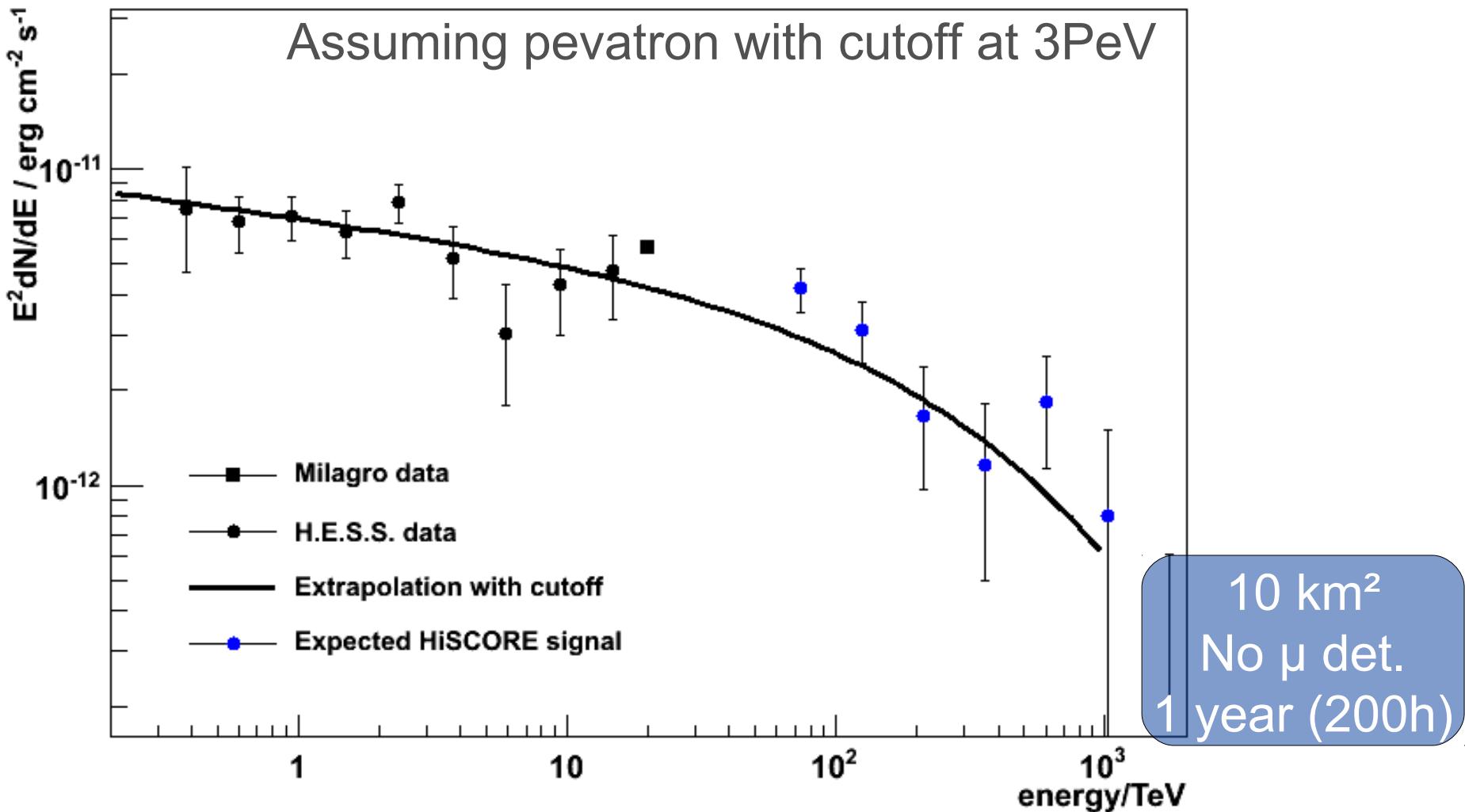
Absorption



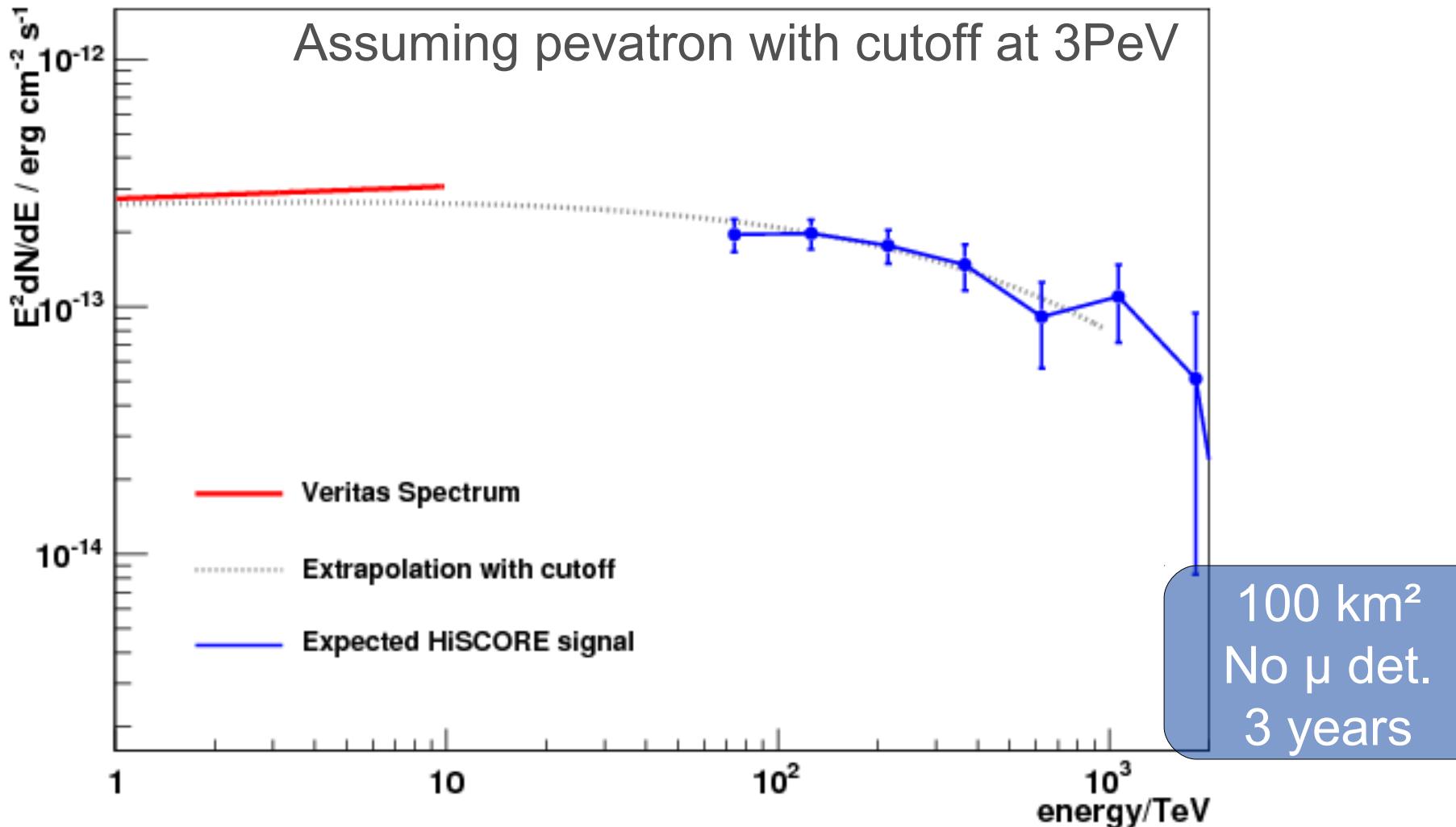
Absorption of gamma-rays by e+e- pair production with low energy photons (Moskalenko et al. 2006):

- Interstellar radiation field
- Cosmic Microwave Background

MGRO J1908+06



Tycho Supernova remnant



Absorption

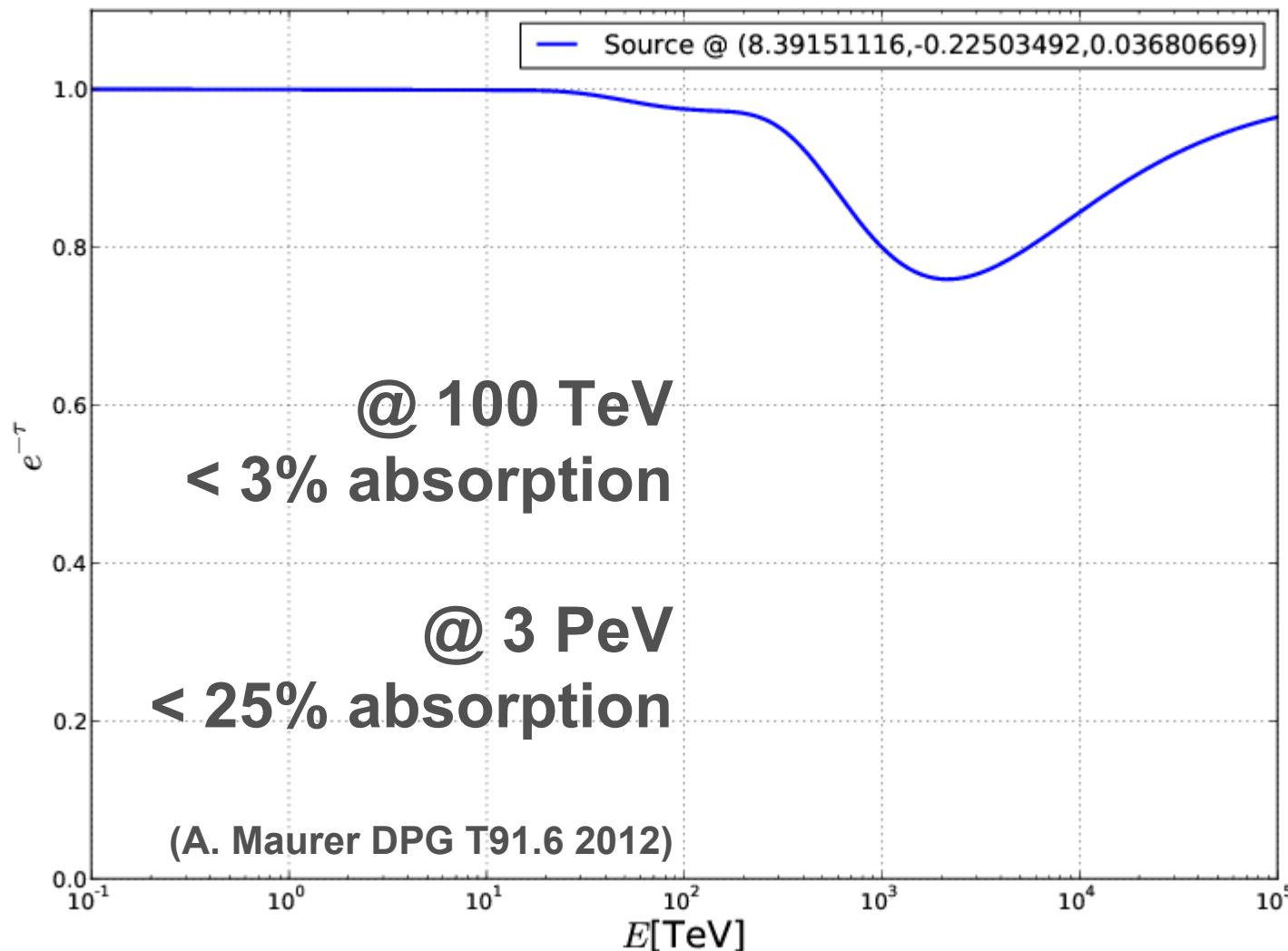
Galaxy: 100TeV-PeV: e+e-pair production with low-E photons

- **Interstellar radiation field**
- **Cosmic Microwave Background**

(e.g. Moskalenko et al. 2006)

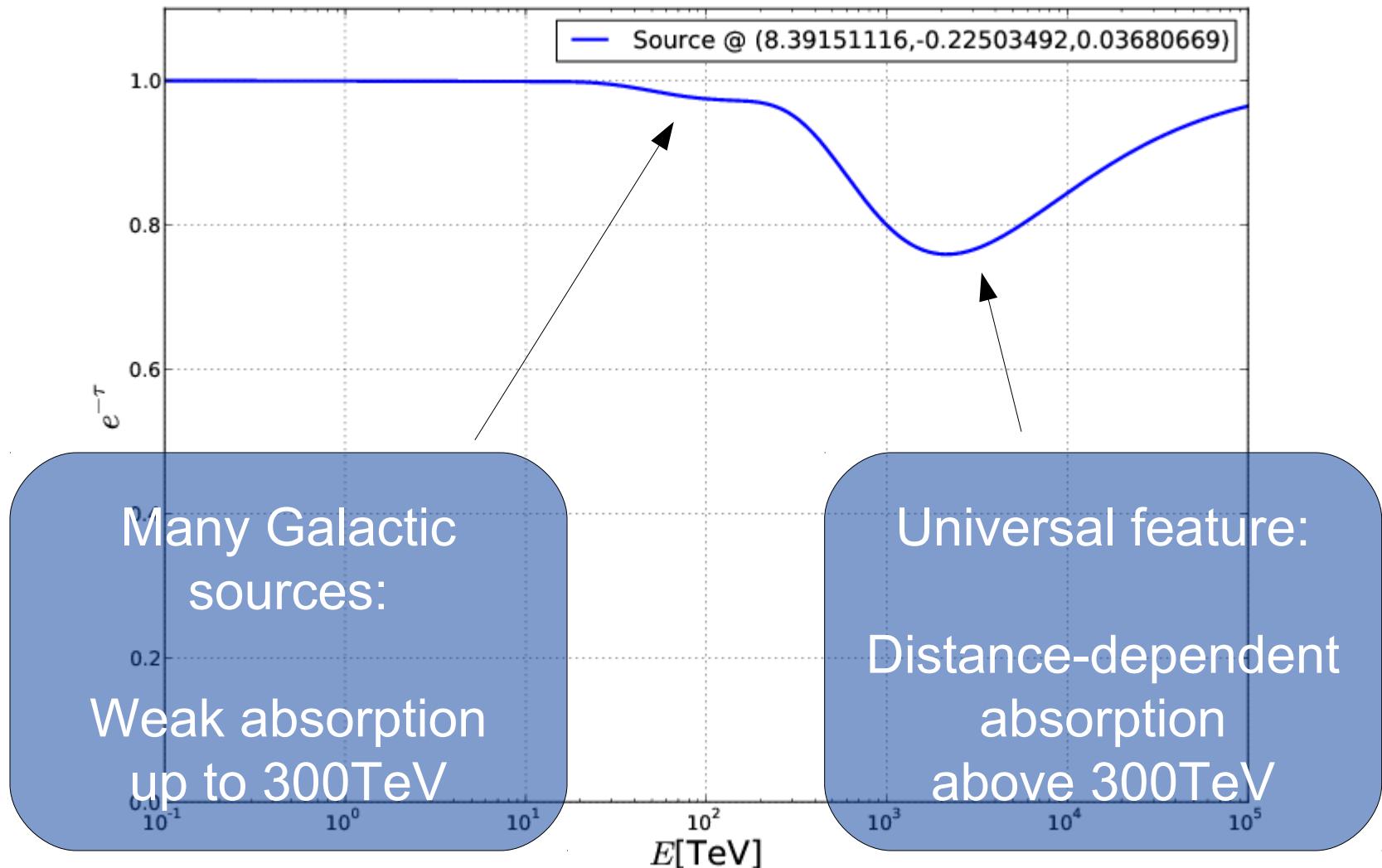
Absorption

MGRO J2031

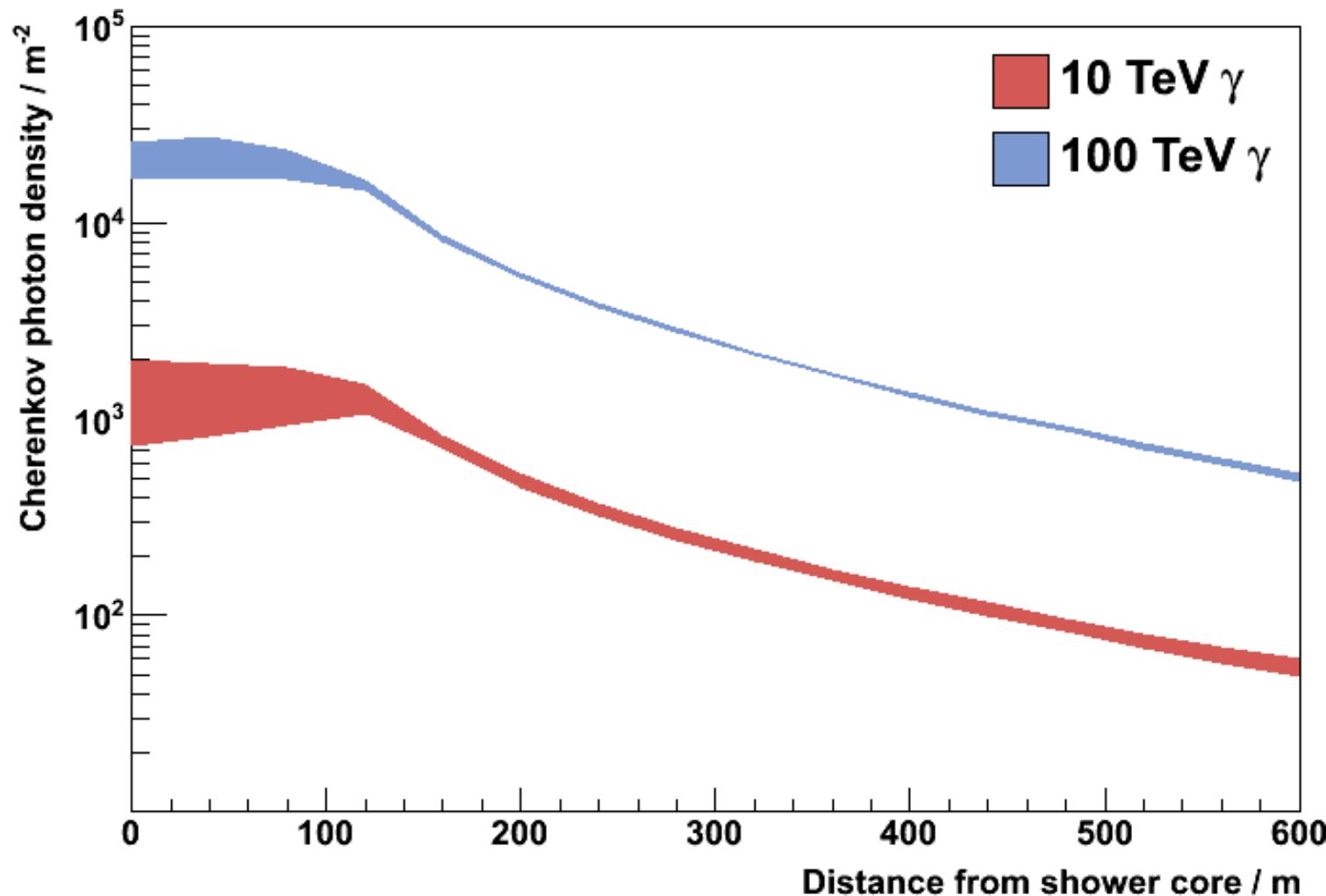


Absorption

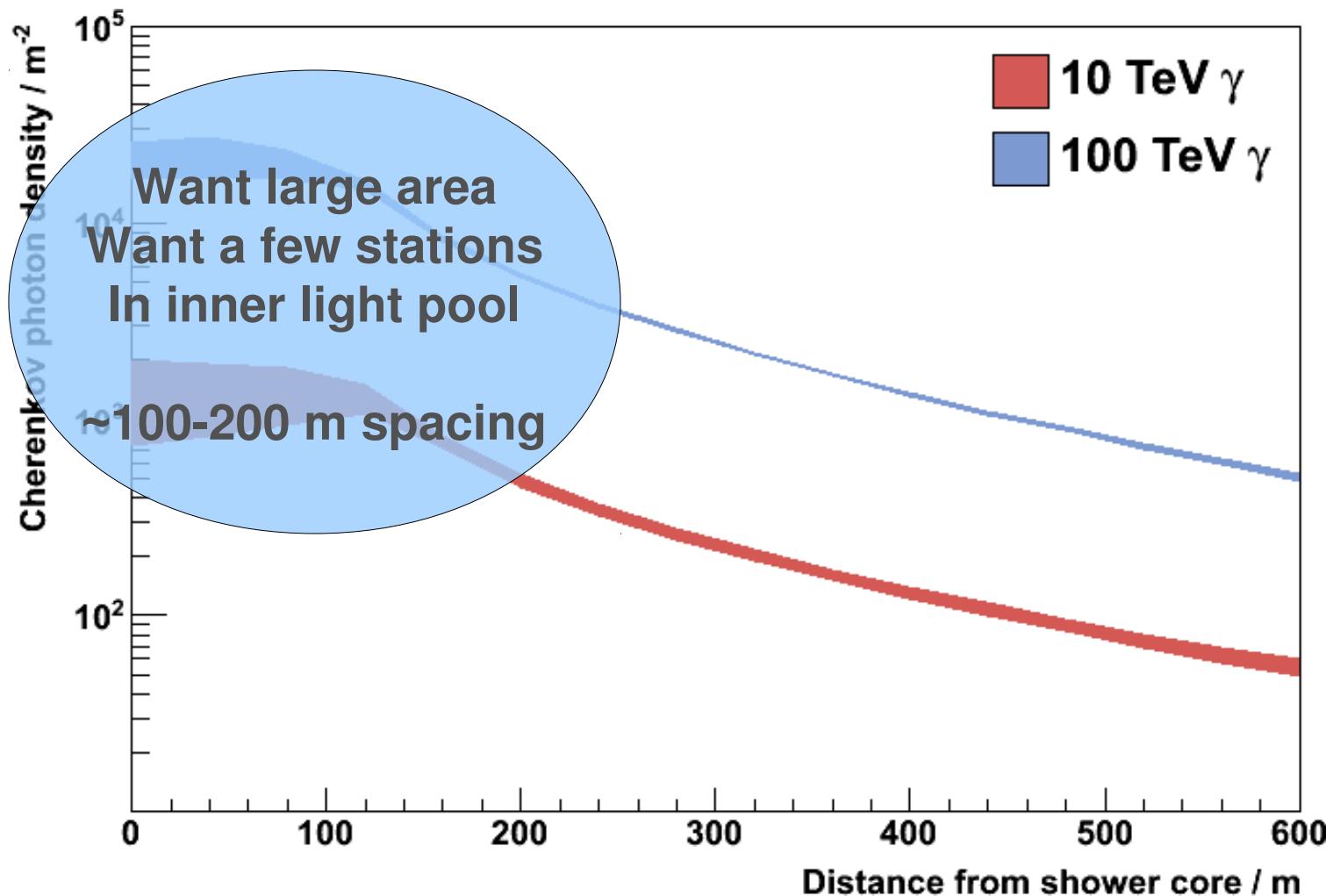
MGRO J2031



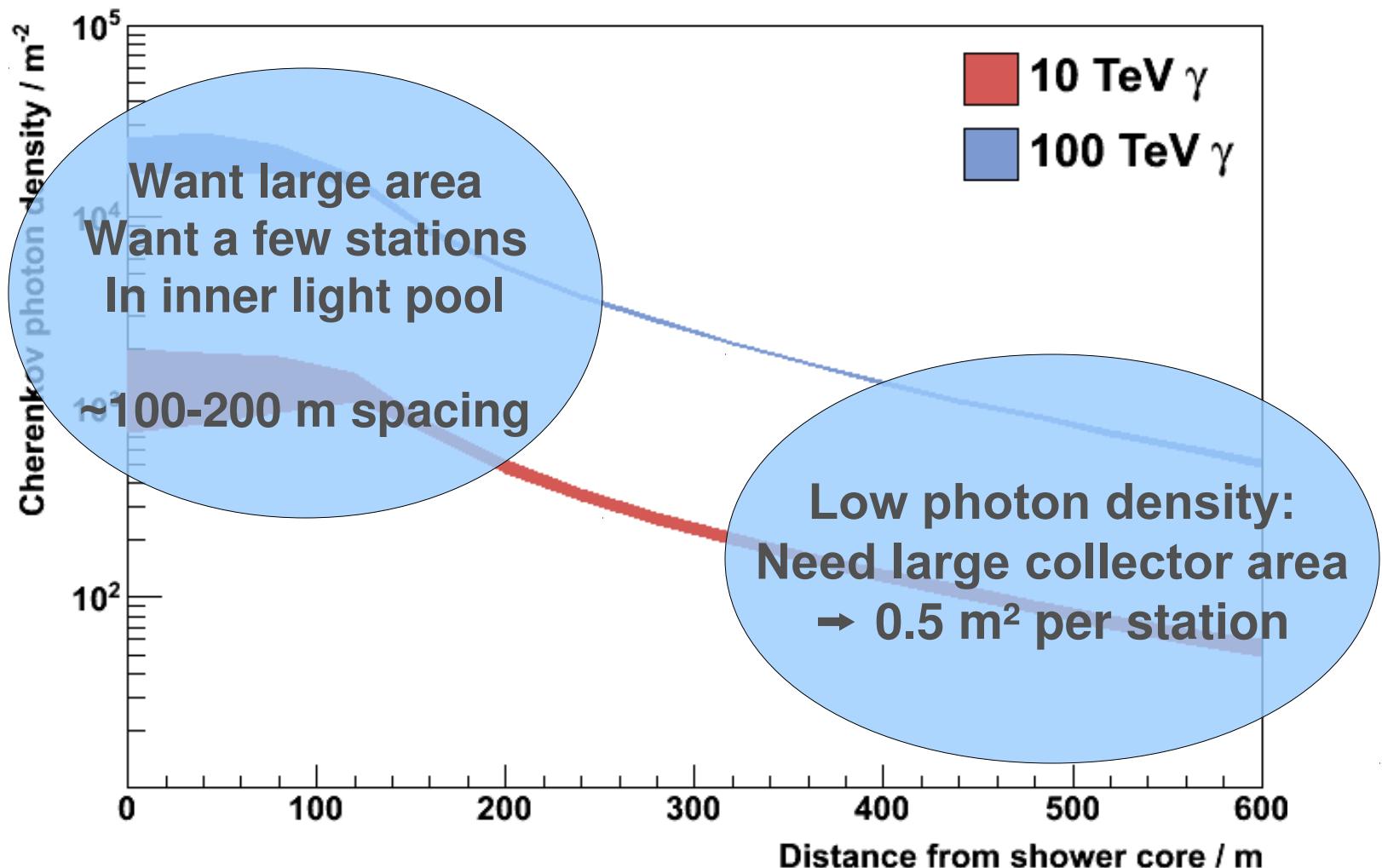
Lateral Cherenkov Photon Distribution



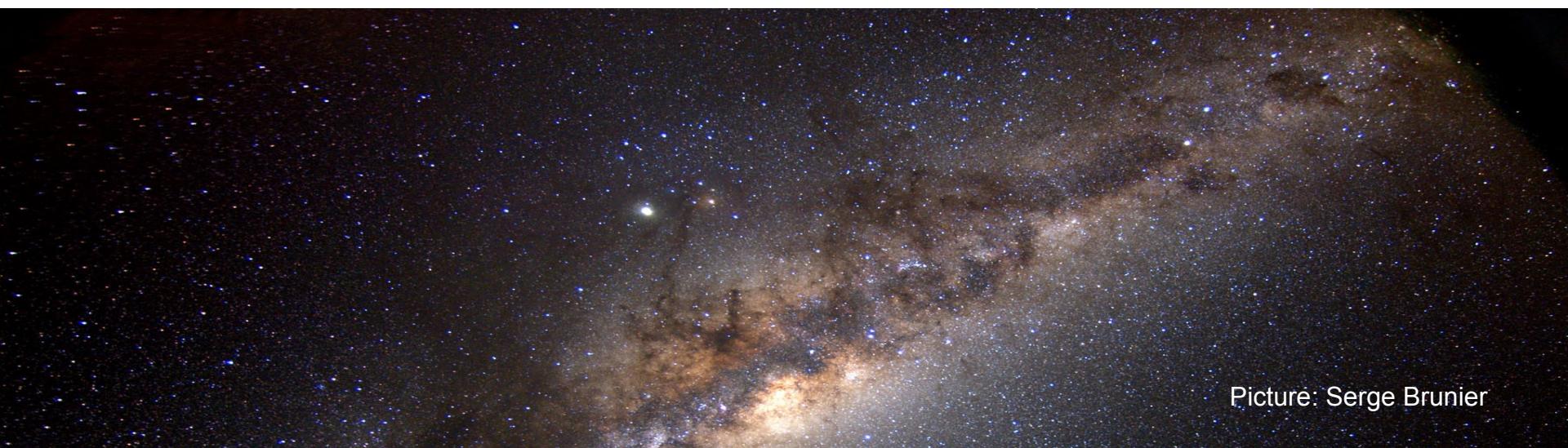
Lateral Cherenkov Photon Distribution



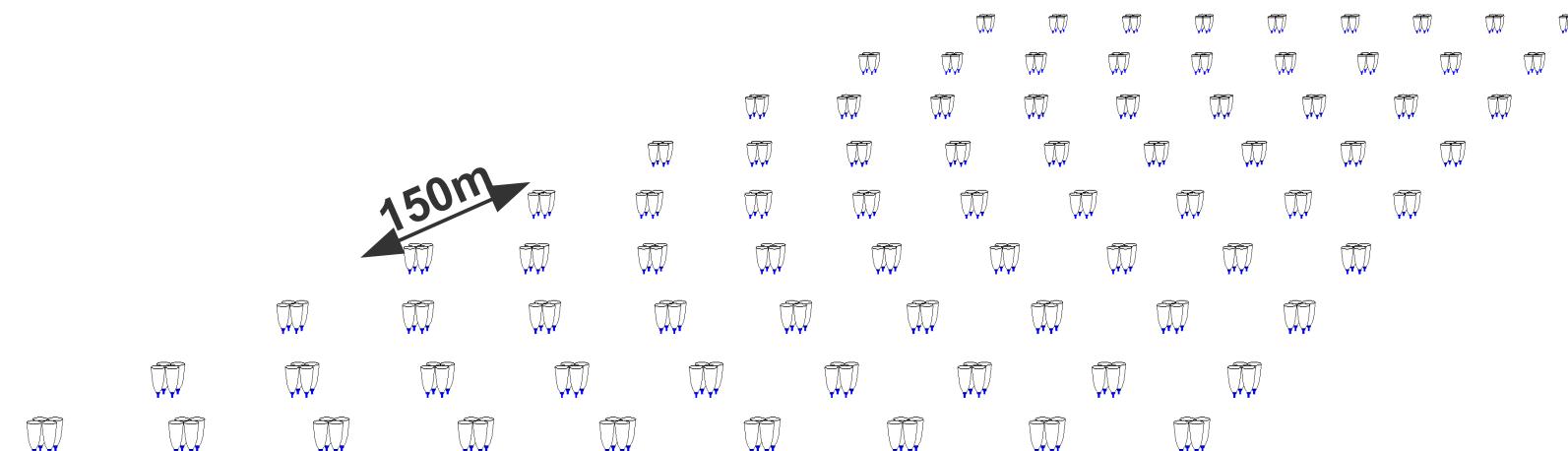
Lateral Cherenkov Photon Distribution



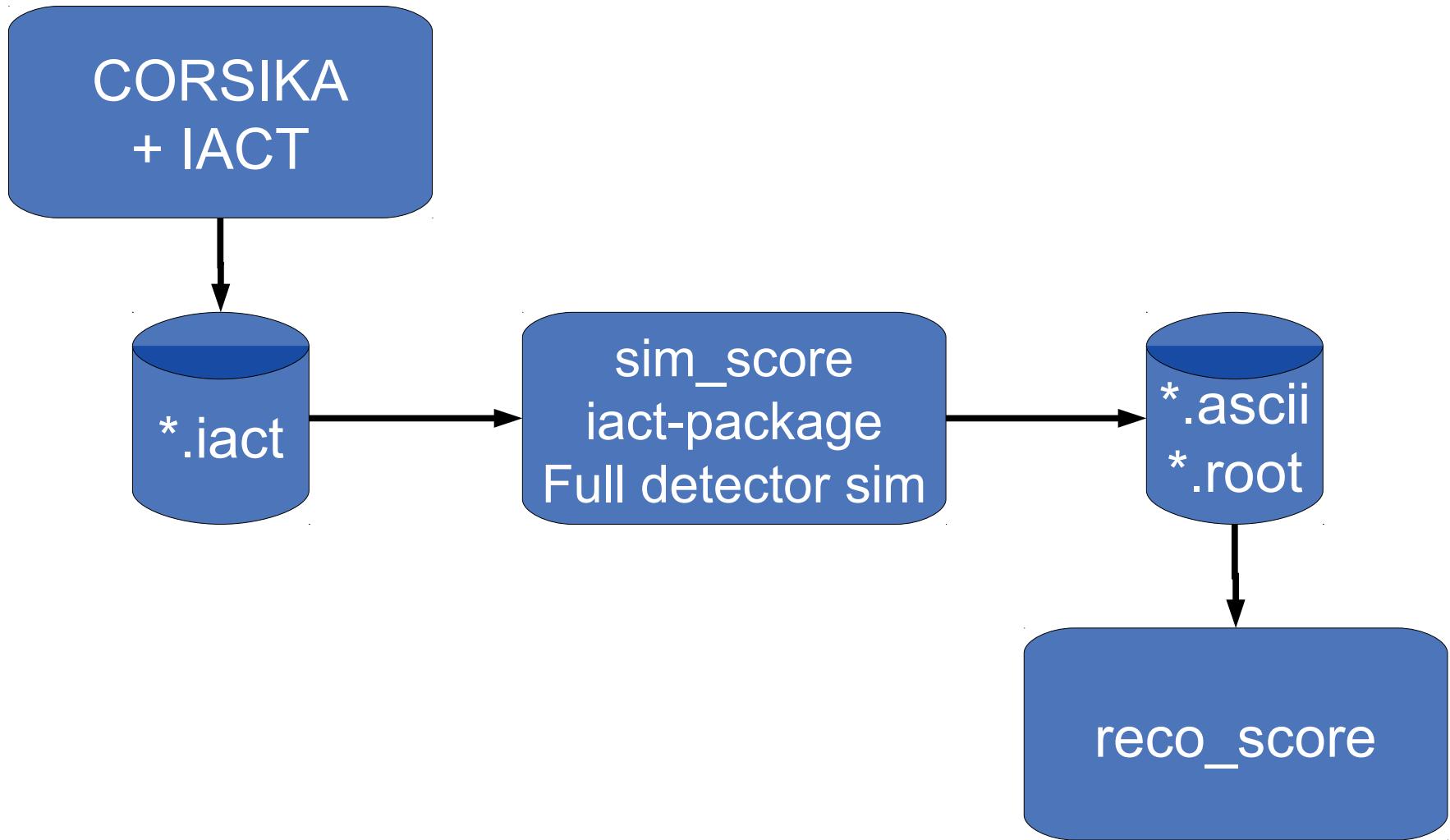
The HiSCORE detector



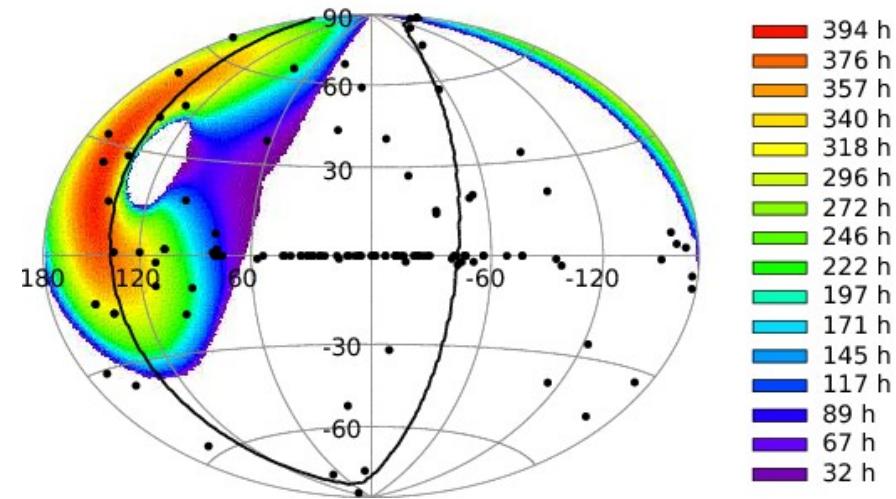
Picture: Serge Brunier



Simulation & reconstruction



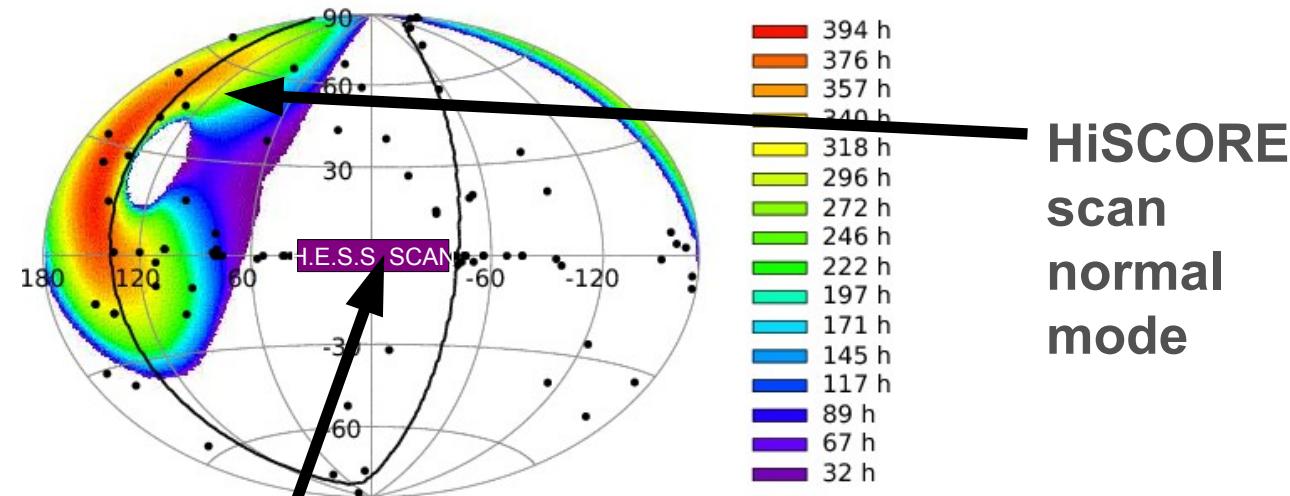
Tunka site exposure map



Tunka site exposure map

Field of view: π steradian

Tunka site exposure map



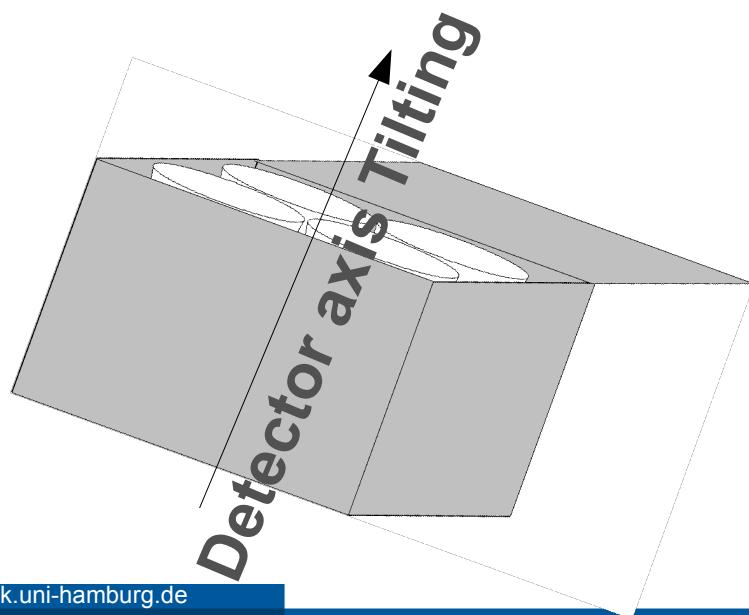
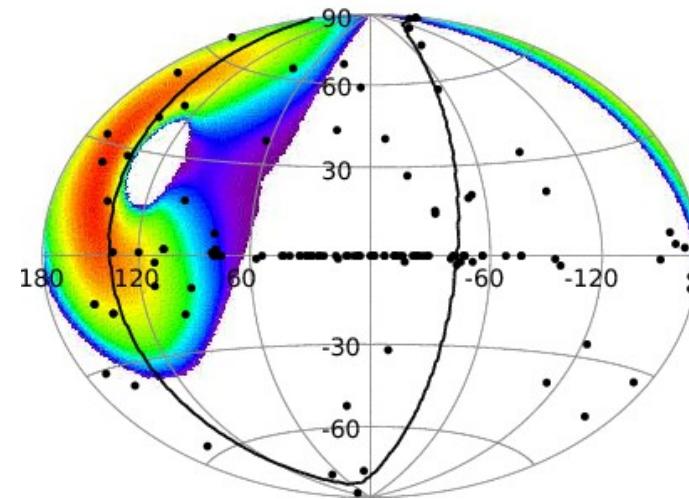
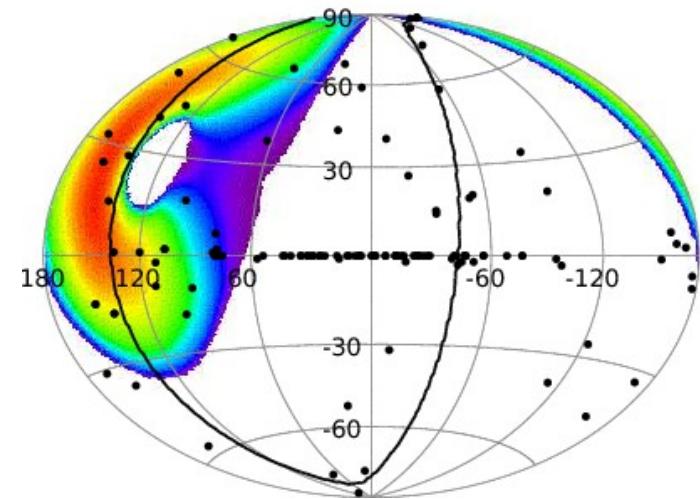
First H.E.S.S.
Galactic plane
scan

HiSCORE
scan
normal
mode

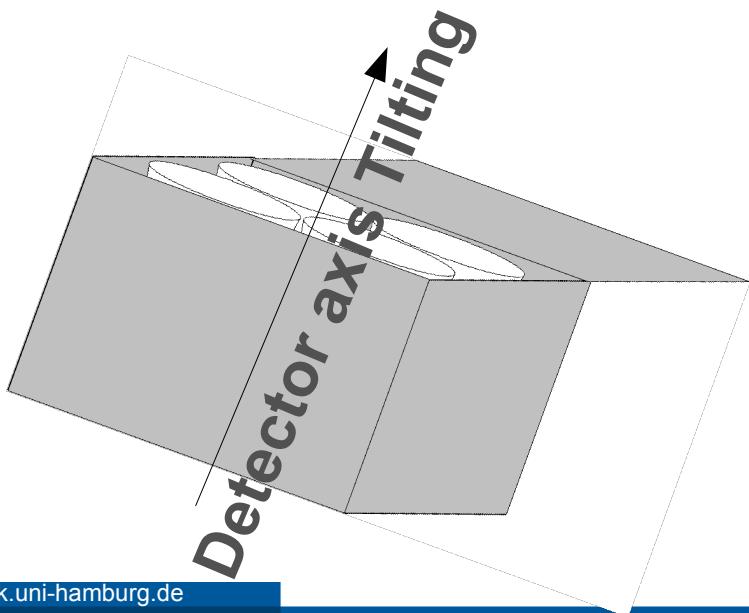
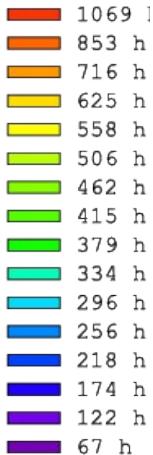
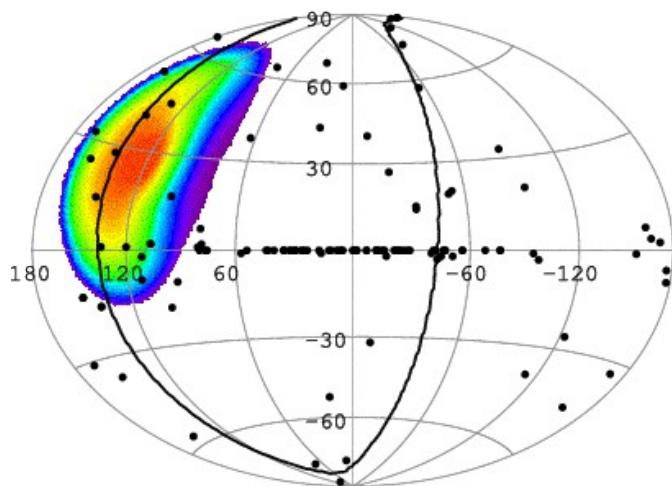
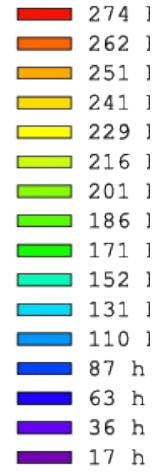
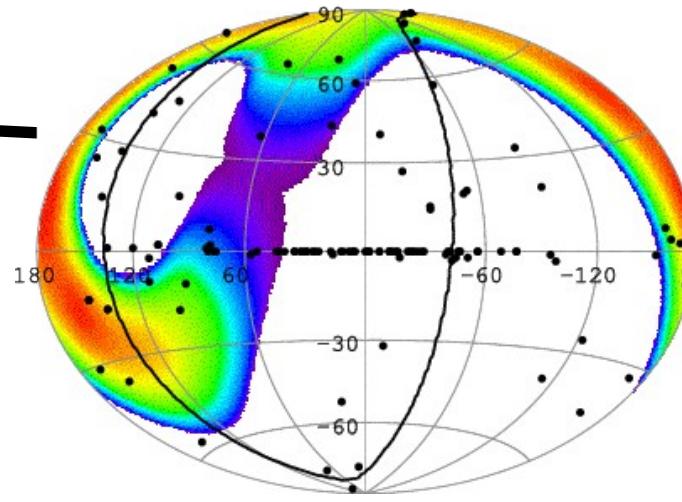
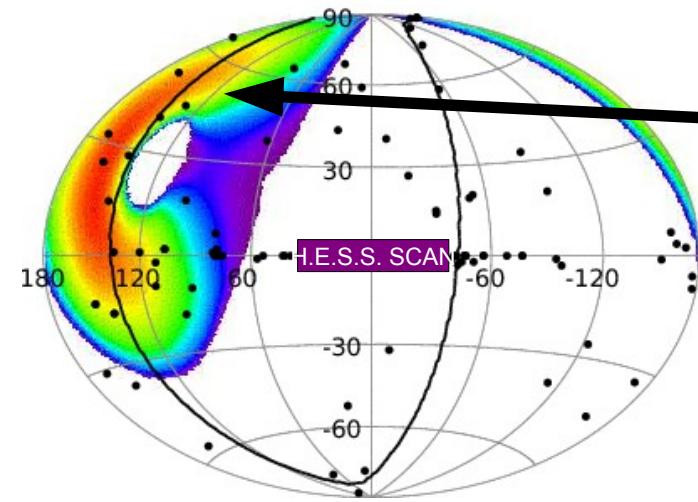
Tunka site exposure map

Field of view: π steradian

Tunka site exposure map



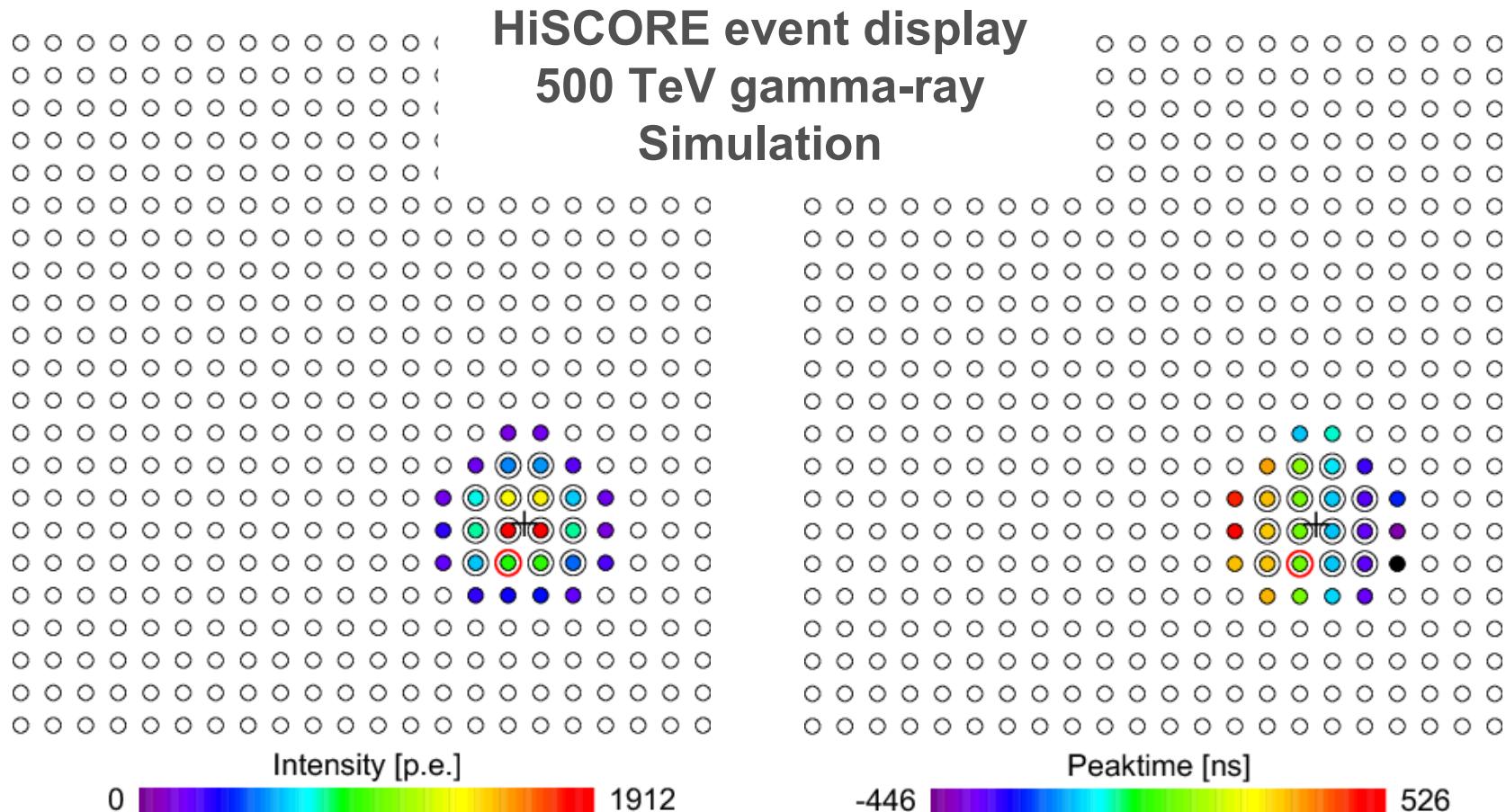
Tunka site exposure map



Simulation & Reconstruction

Reconstruction

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

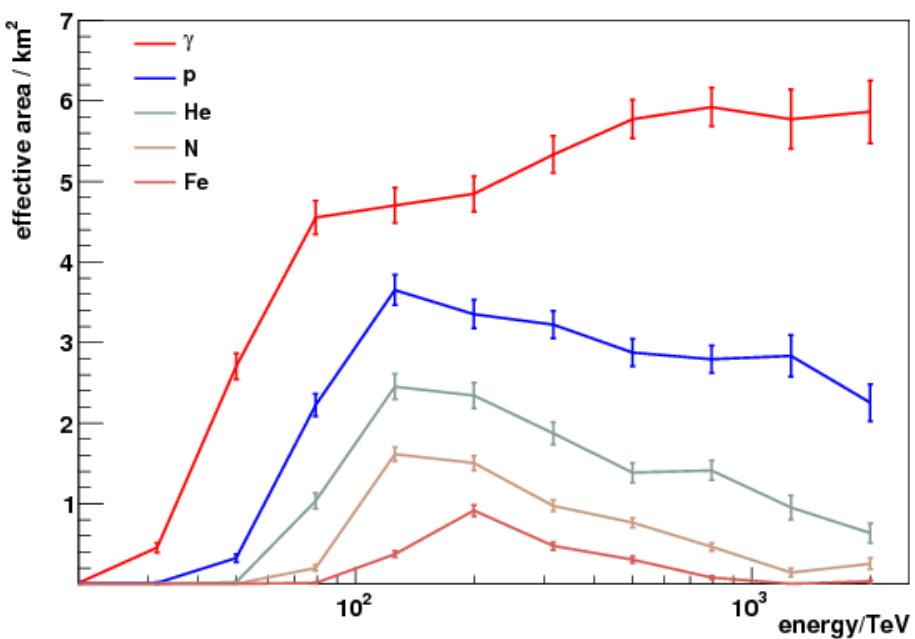
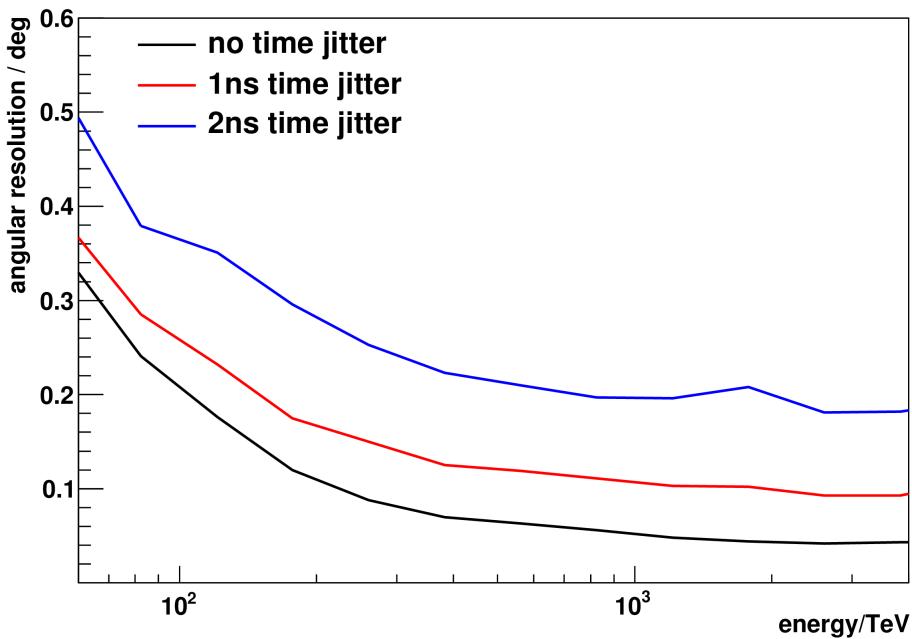


Reconstruction

Direction: photon arrival time model

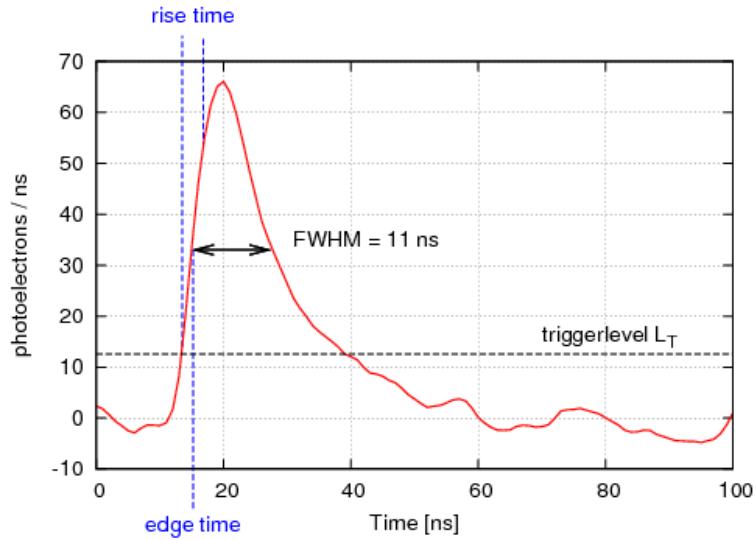
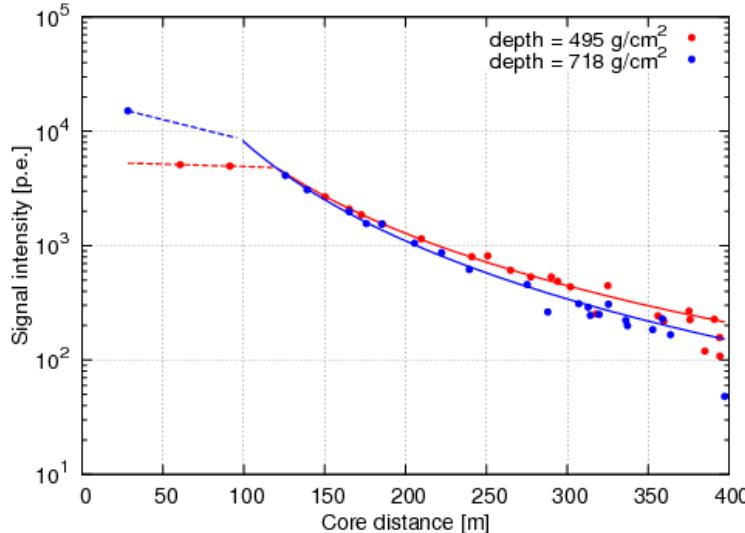
Energy: Value of LDF @ 220 m

Particle type: Shower depth and Signal rise-time



Reconstruction

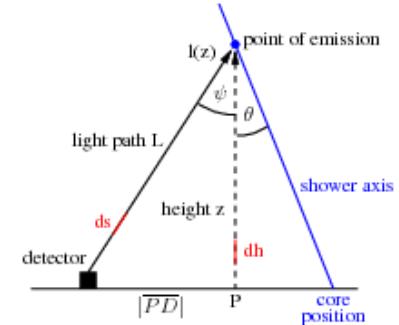
- Extract PMT signal parameters
- Preliminary shower core position (cog)
- Preliminary direction (time plane fit)
- Improved core position:
light distribution function (LDF) fitting
- Improved direction: arrival time model
- Fit of signal widths



Direction reconstruction

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

Parametrization of time-delay dt at detector position



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

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

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

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

Shower height in km

Slope of atmospheric refractive index

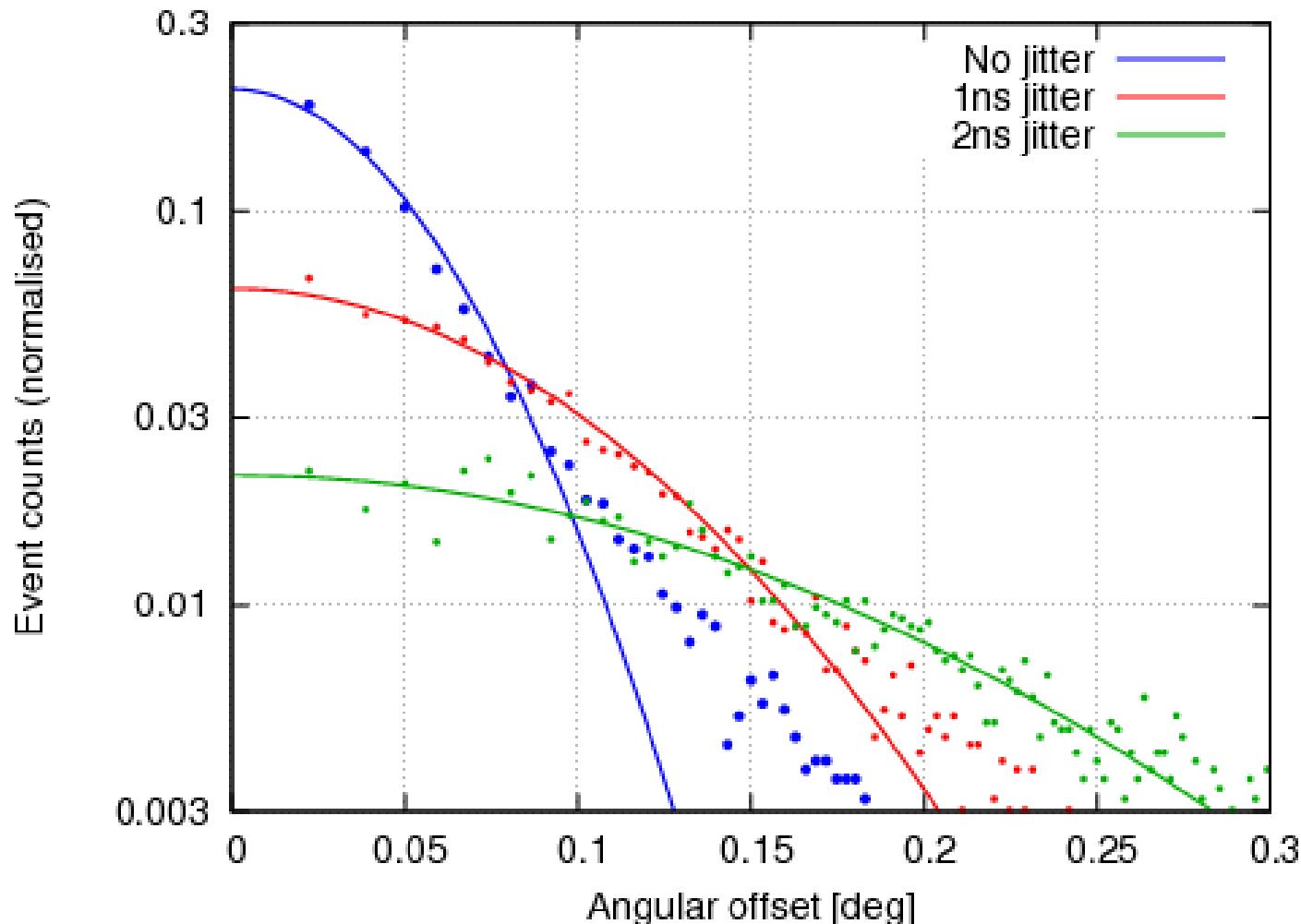
$$dt(k, z) = \frac{1}{c} \left(\sqrt{k} - \frac{z}{\cos(\theta)} + \frac{8.0}{z} \sqrt{k} \eta_0 \left(1 - \exp \left(\frac{-z}{8.0} \right) \right) \right)$$

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

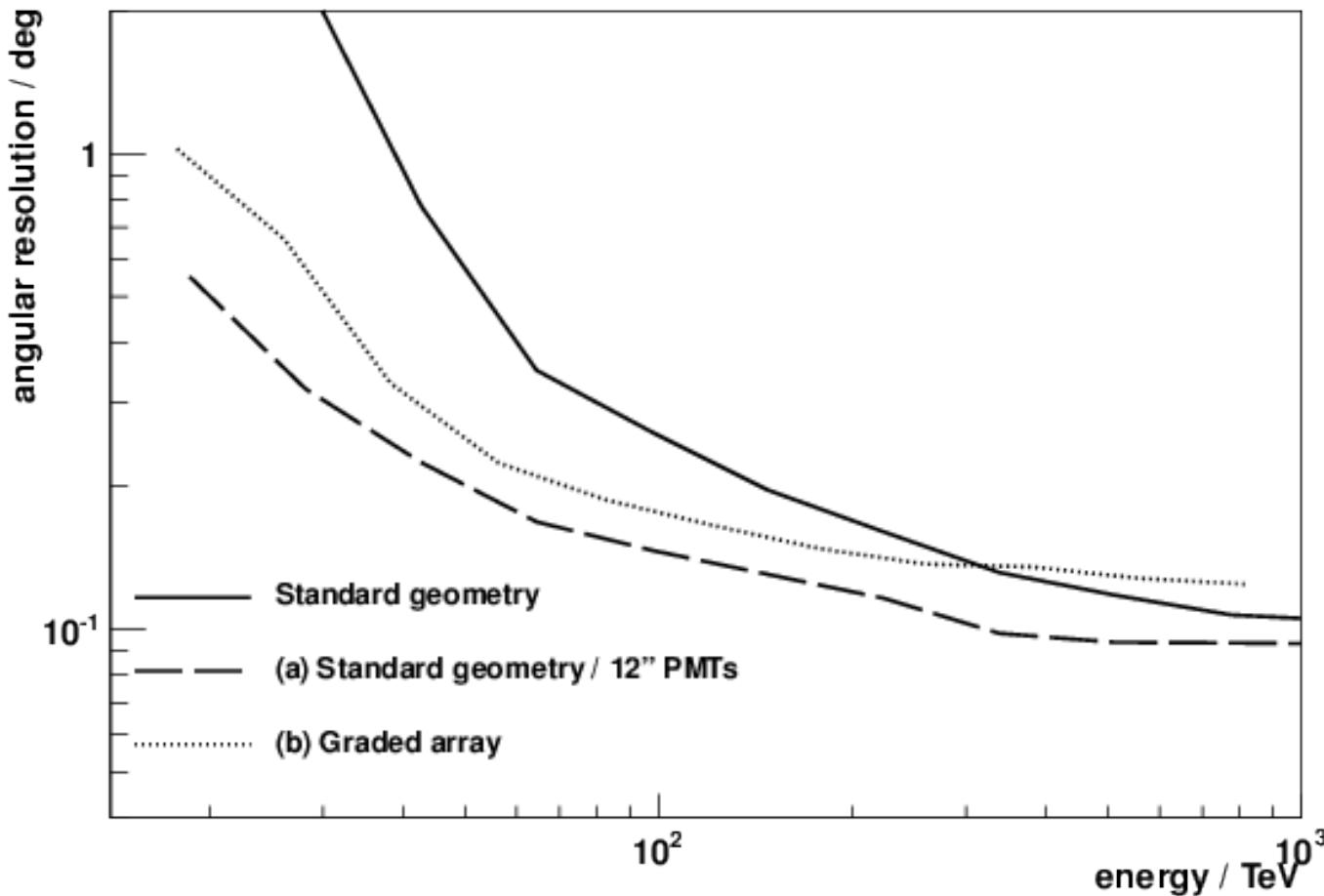
$$\delta = \phi + \text{atan2}((x_{\text{Det}} - x_{\text{core}}), (y_{\text{Det}} - y_{\text{core}}))$$

Zenith angle

Direction reconstruction

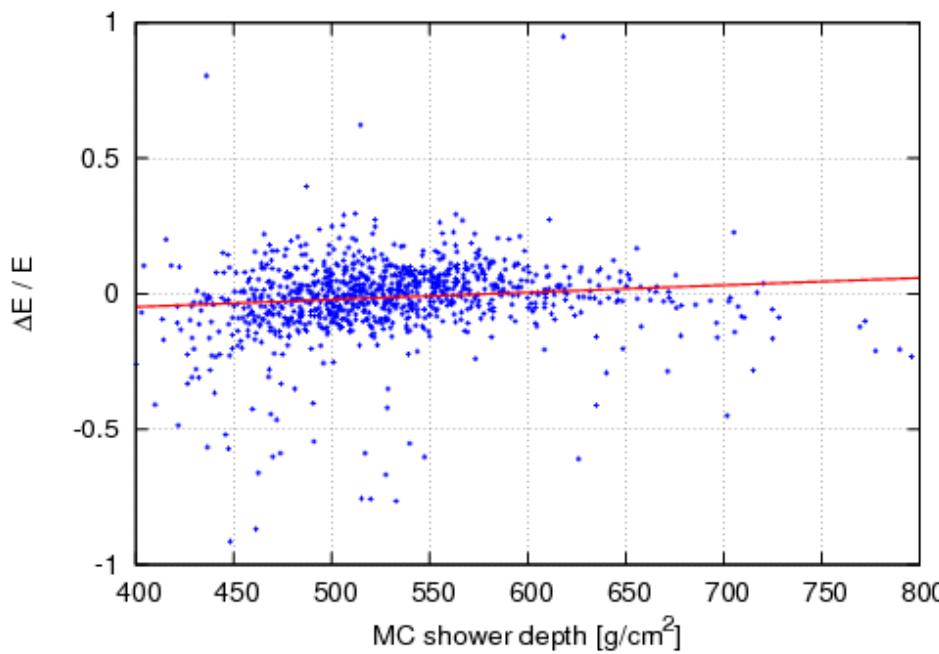
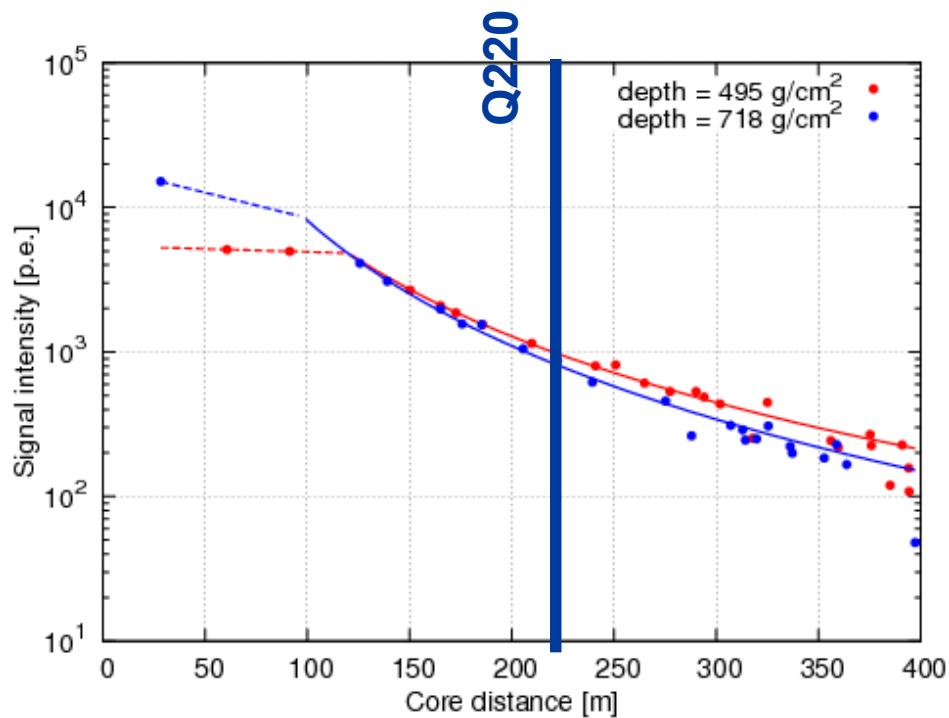


Angular resolution of alternative layouts



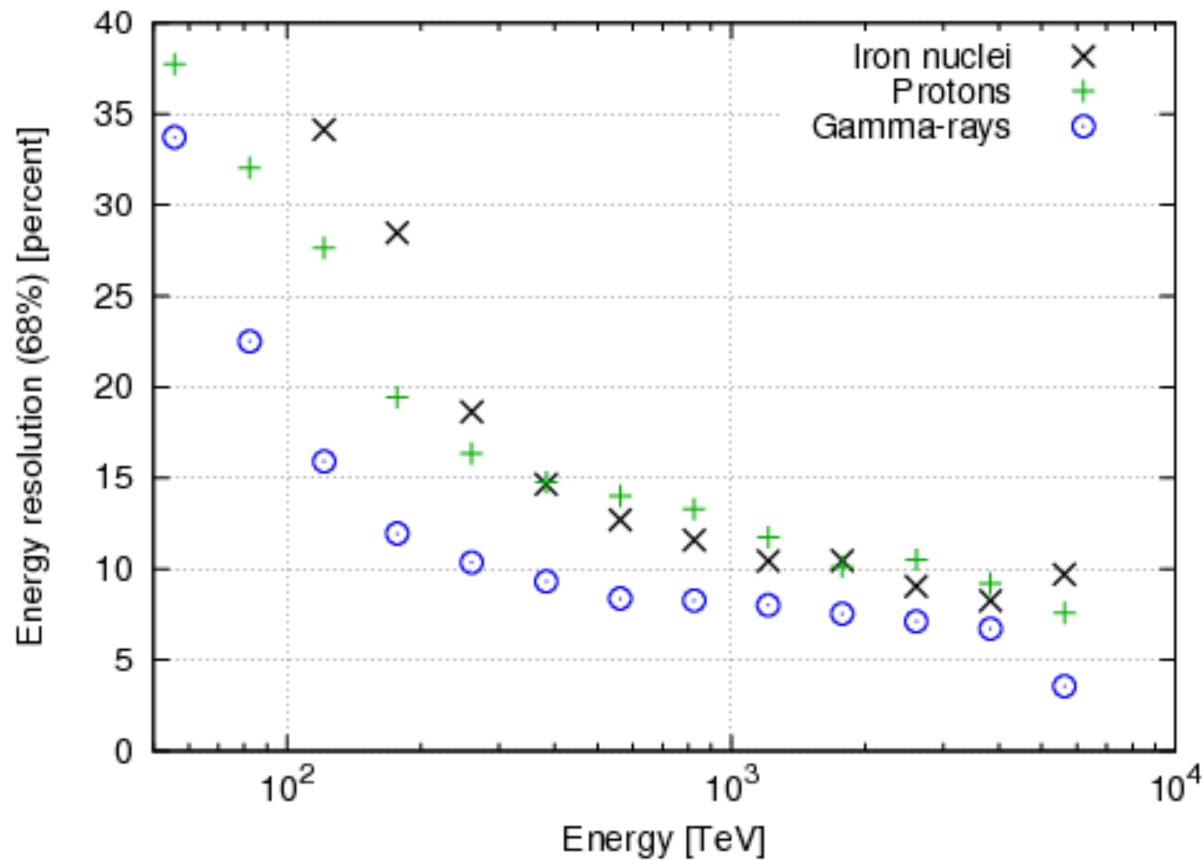
Energy reconstruction

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



Energy reconstruction

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

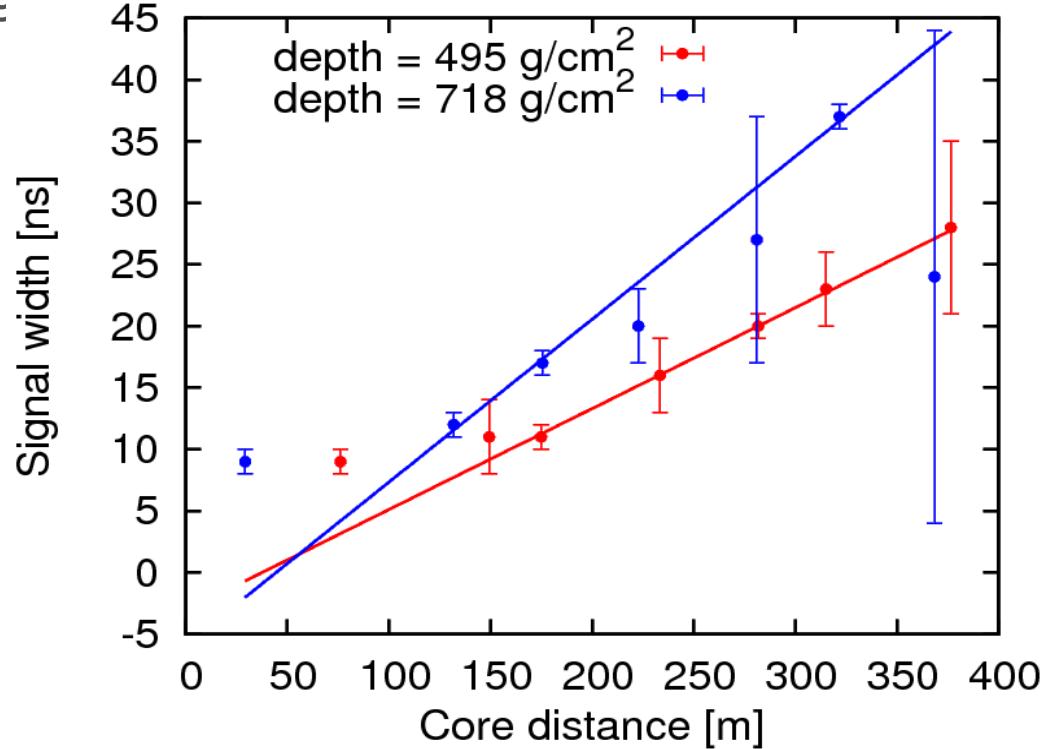


Shower depth reconstruction

Time model method: one free parameter in arrival time model

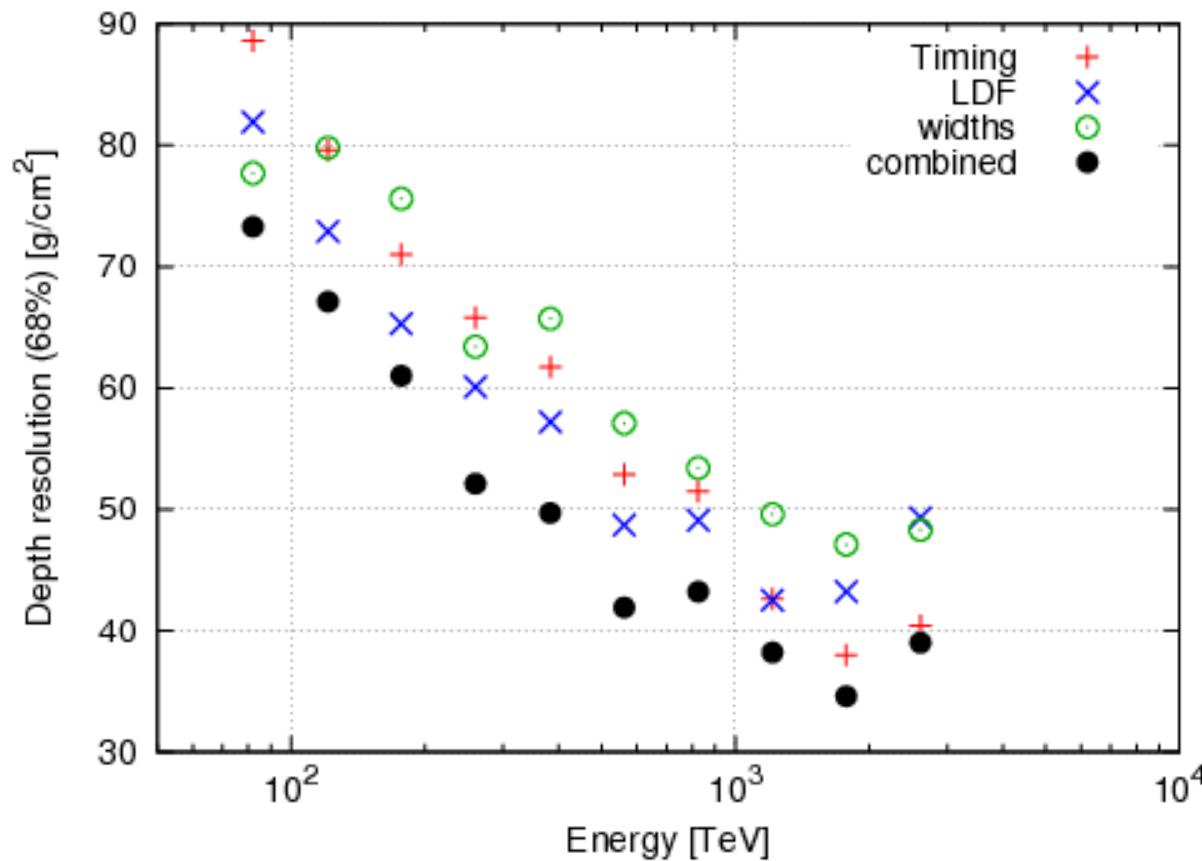
LDF method: Depth from LDF slope, Q50/Q220

Width method: Depth from signal width



Shower depth

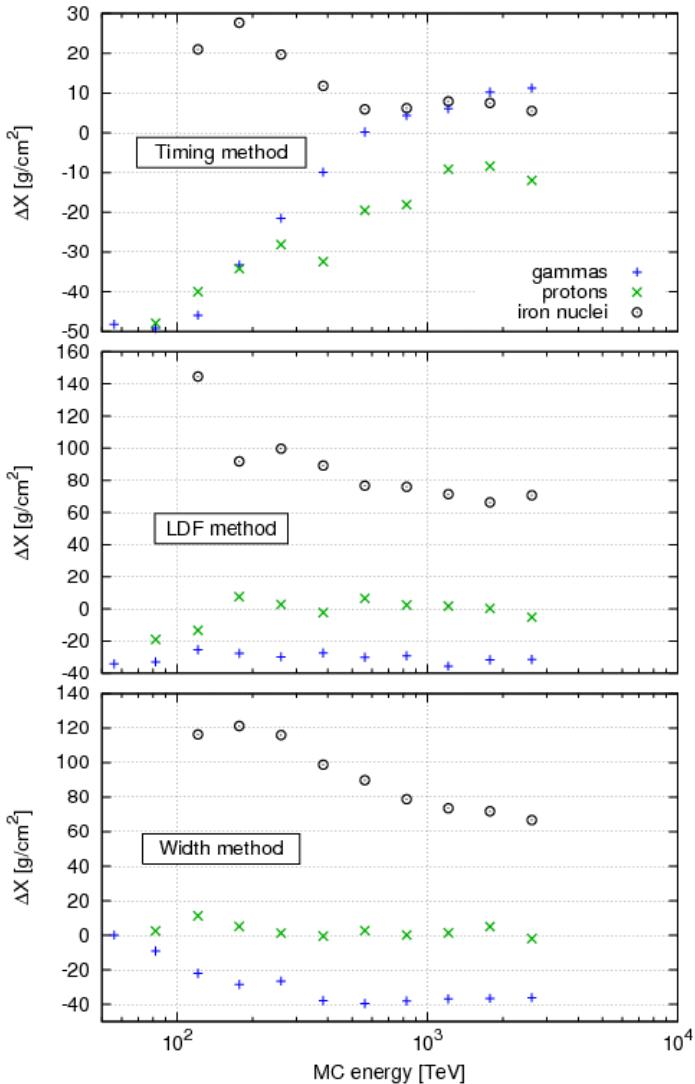
Depth of shower maximum



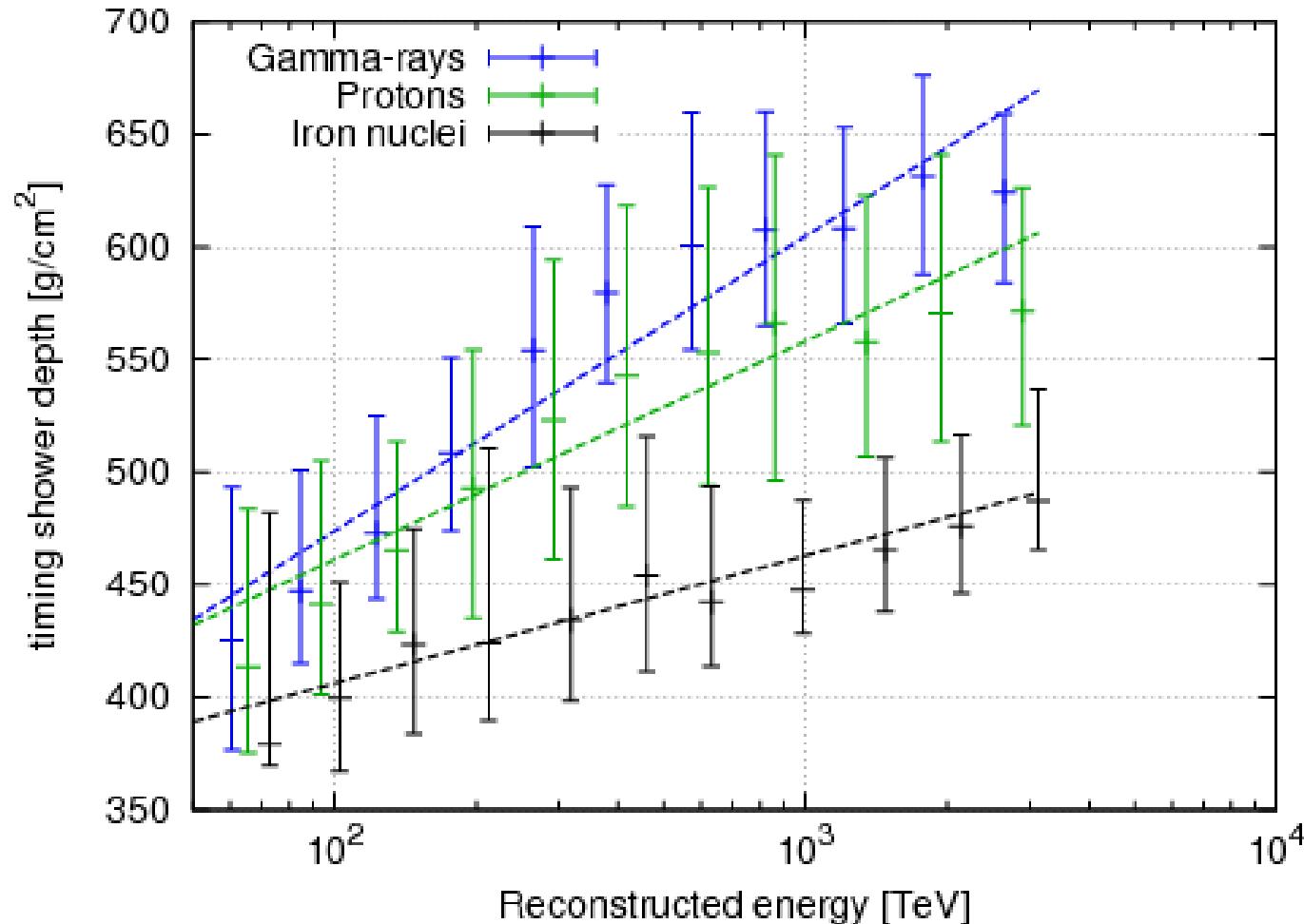
Shower depth bias

Systematic bias

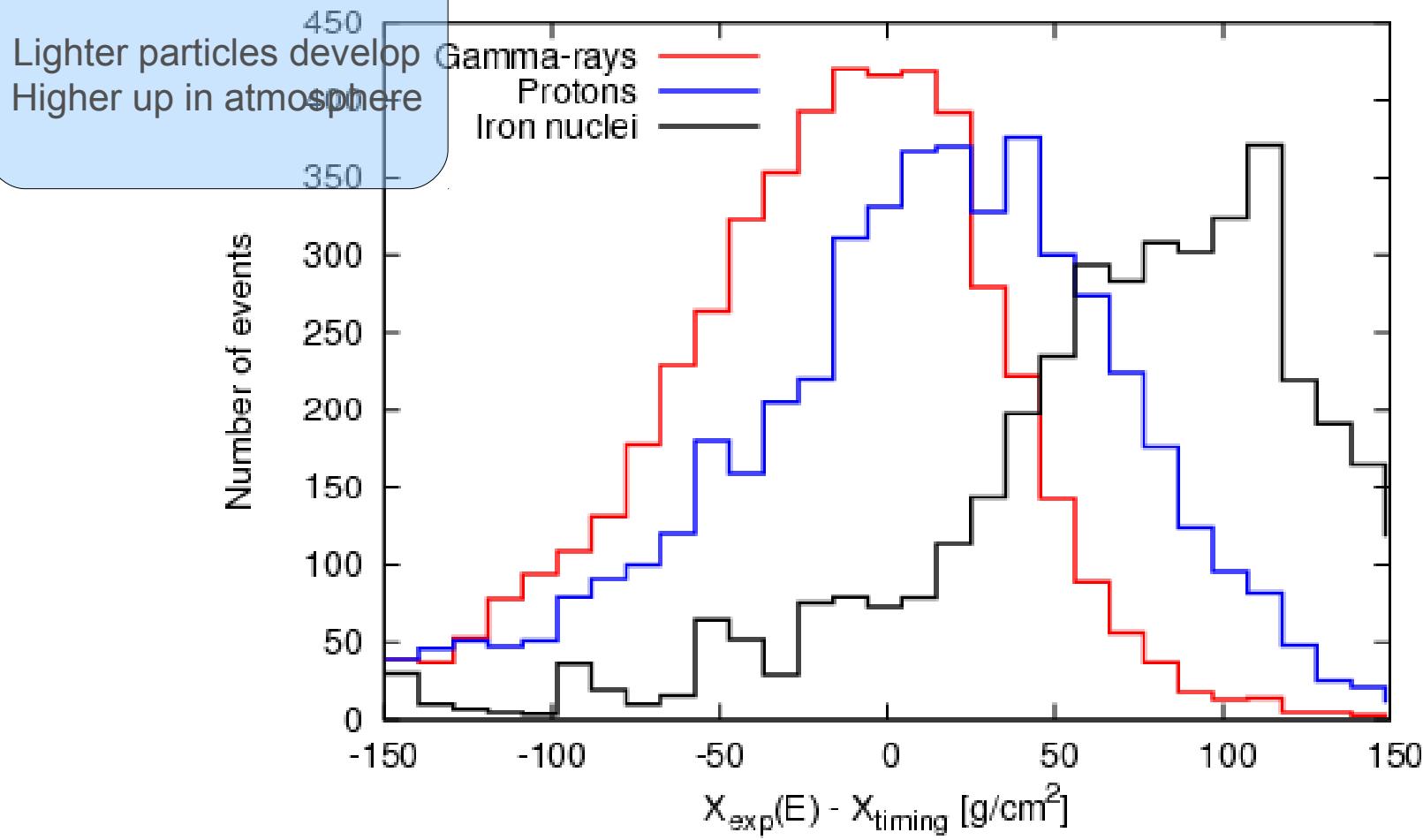
- LDF & widths : sensitive to whole shower
Large overestimation for heavy particles
(long tails)
- Timing : sensitive to specific point
(edge time)
Small overestimation for heavy particles



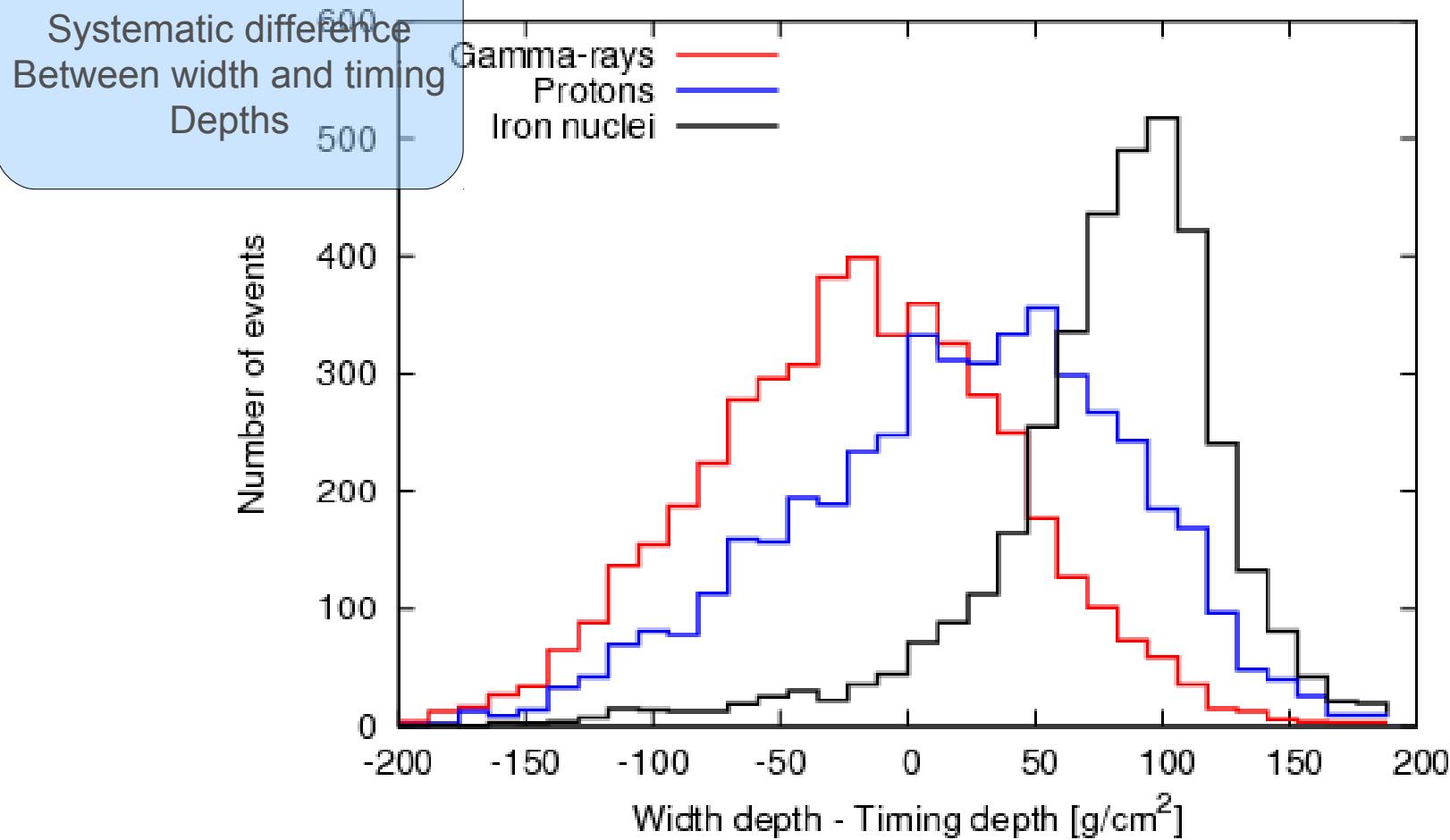
Particle separation



Particle separation (1)

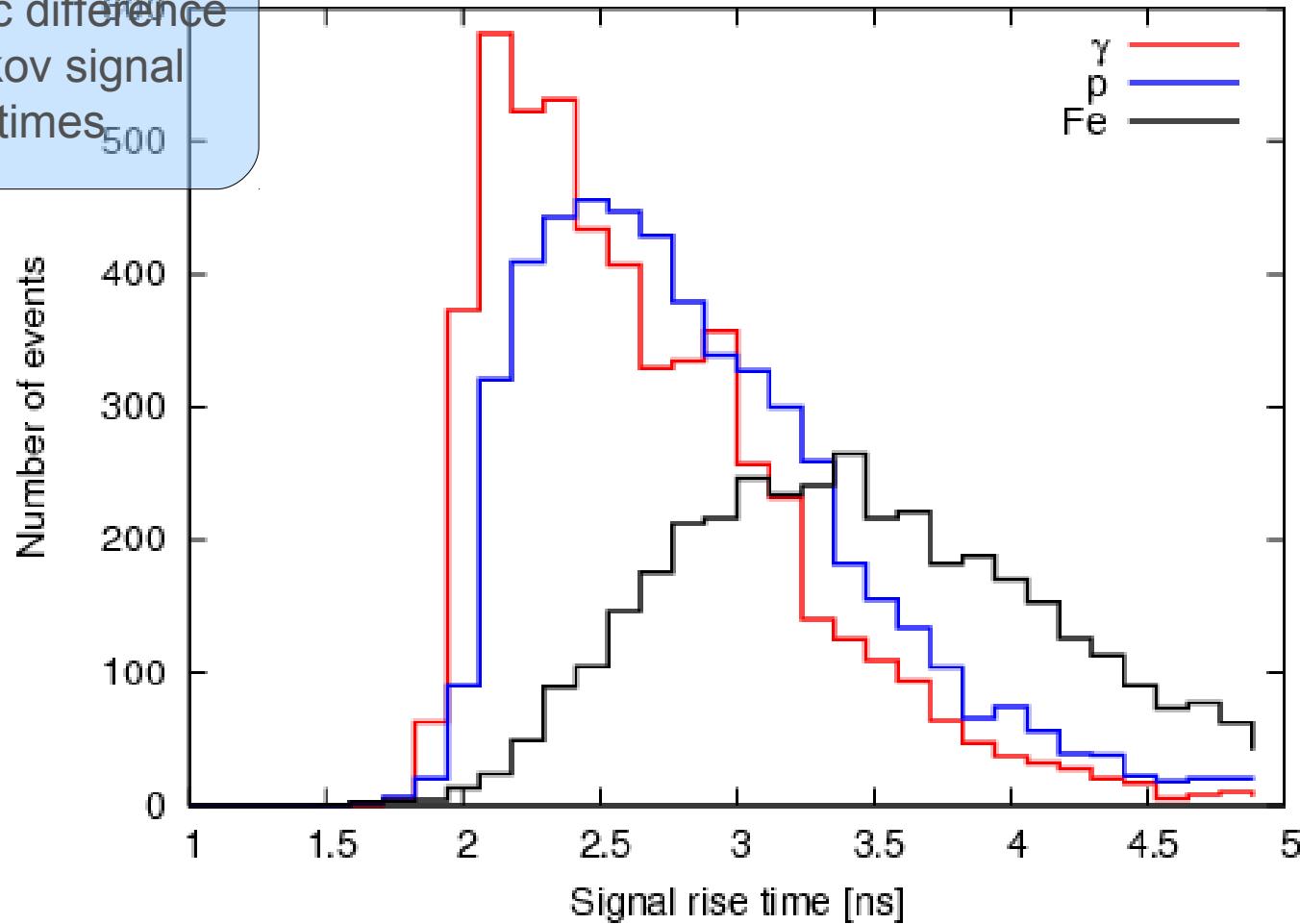


Particle separation (2)



Particle separation (3)

Systematic difference
Cherenkov signal
rise times





“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**