HiSCORE
M. Tluczykont for the HiSCORE Collaboration
Astroteilchenphysik in Deutschland
Zeuthen, 09/2012


Sky above Tunka valley
Taiga
Frozen Irkut river
Irkut river

HiSCORE Detector
RX J1713
H.E.S.S. gamma-rays
HiSCORE

The Hundred* i Square-km Cosmic ORigin Explorer

**Cosmic-rays:** $100 \text{ TeV} < E_{CR} < 1 \text{ EeV}$

**Gamma-rays:** $E_{\gamma} > 10 \text{ TeV}$, 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:** $\sim 0.6 \text{ sr}$

http://wwwiexp.desy.de/groups/astroparticle/score/
http://tunka-hrjrg.desy.de/
http://de.wikipedia.org/wiki/HiSCORE
Why do we need a large area?

Energetic events are rare.
Physics motivations
Physics motivations

Gamma-rays
- Gamma-ray spectra and morphology
- Diffuse Gamma-ray emission
- Particle acceleration

Cosmic-rays
- Origin of cosmic rays
- Cosmic-ray spectroscopy
- Cosmic-ray Anisotropy
- Nucleon-Nucleon interaction

Particle physics
- Dark matter

Non-standard Propagation
Cosmic rays

Adapted from Donato & Medina-Tanco 2008

Spectrum & composition in transition range
Galactic / extragalactic origin
Cosmic ray origin

Adapted from Donato & Medina-Tanco 2008

Gammas from Galactic Cosmic rays:

\[ E_\gamma \sim E_{\text{CR}} / 10 \]
Tevatron sky

VHE gamma-ray sky 2009

TeV Cosmic rays
Eγ > 100 GeV
Pevatron sky

Where are the cosmic ray pevatrons?

TeV Cosmic rays $E_{\gamma} > 100$ TeV
The Pevatron energy range

- KASCADE U.L.
- H.E.S.S. survey, hard sources
- MGRO J1908+06
- HESS J1908+06

$E^2 dN/dE / \text{erg cm}^{-2} \text{ s}^{-1}$

$10^{-14}$
$10^{-13}$
$10^{-12}$
$10^{-11}$
$10^{-10}$
$10^{-9}$

$10^{-1}$
$1$
$10$
$10^2$
$10^3$
$10^4$

energy/TeV

$E^2 dN/dE$ vs. energy/TeV graph with data points from different sources.
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
Accessing the pevatron sky: large area

The HiSCORE detector
The HiSCORE detector

How to achieve large effective area?

- Imaging air Cherenkov telescopes: $O(1000)$ channels / km²
- Non-imaging air Cherenkov technique: $O(100)$ channels / km²
The HiSCORE detector

How to achieve large effective area?

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

Picture: Serge Brunier
The HiSCORE detector

How to achieve large effective area?

- Imaging air Cherenkov telescopes: $O(1000)$ channels / km²
- Non-imaging air Cherenkov technique: $O(100)$ channels / km²
The HiSCORE detector

Picture: Serge Brunier
The HiSCORE detector
The HiSCORE detector

- >0.5 m² station area: $E_{\text{thr}}$
- Readout: GHz sampling
- <1ns time synch.
Physics potential of HiSCORE

(gamma-ray astronomy)
Opening the Pevatron range

\[ E^2 dN/dE \text{ / erg cm}^{-2}\text{ s}^{-1} \]

- KASCADE U.L.
- H.E.S.S. survey, hard sources
- MGRO J1908+06
- HESS J1908+06
Opening the Pevatron range

![Graph showing data points and error bars for different energy values and corresponding fluxes. Labels include KASCADE U.L., H.E.S.S. survey, hard sources, MGRO J1908+06, and HESS J1908+06. The graph plots energy (in TeV) on the x-axis and the flux (in erg cm^{-2} s^{-1}) on the y-axis. The data points are distributed across a range of energies, with KASCADE U.L. showing a sharp peak at low energies, and the H.E.S.S. survey, hard sources, MGRO J1908+06, and HESS J1908+06 showing a more scattered distribution. The graph also includes a dashed line labeled CTA, which appears to represent a theoretical or extrapolated curve.]}
Opening the Pevatron range

$E^2dN/dE / \text{erg cm}^{-2} \text{s}^{-1}$

$10^{-9}$

$10^{-10}$

$10^{-11}$

$10^{-12}$

$10^{-13}$

$10^{-14}$

$10^{-1}$

$10^1$

$10^2$

$10^3$

$10^4$

energy/TeV

HiSCORE

KASCADE U.L.

H.E.S.S. survey, hard sources

MGRO J1908+06

HESS J1908+06

$10 \text{ km}^2$

$100 \text{ km}^2$
Opening the Pevatron range
Potential HiSCORE detections

- MGRO J1908+06
- H.E.S.S.
- Tycho supernova remnant (Veritas)
- HiSCORE, 10 km², 1 year
- HiSCORE, 100 km², 5 years

$E^2 dN/dE / \text{erg cm}^{-2} \text{s}^{-1}$

Energy/TeV: $10^{-14}$ to $10^{-10}$
Tunka site exposure map

Field of view: \( \pi \) steradian
Tunka site exposure map

Field of view: $\pi$ steradian

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

HiSCORE scan, 1 year

394 h
376 h
357 h
340 h
318 h
296 h
272 h
246 h
222 h
197 h
171 h
145 h
117 h
89 h
67 h
32 h
HiSCORE current status and plans
Tunka valley

Hamburg

Tunka Cosmic ray experiment

1 km² dense array
Energy threshold $10^{15}$ eV
core position resolution ~ 10 m
energy resolution ~ 15%
$X_{\text{max}}$ resolution < 25 g cm$^{-2}$
Measurements of Gamma Rays and Cosmic Rays in the Tunka-Valley in Siberia by innovative new technologies

Low energy (GeV / TeV / PeV):

HRJRG-303:
- Resolve open questions of cosmic rays
- With innovative methods

Cherenkov

Radio

High energy (PeV - EeV):

HiSCORE

Tunka-Rex

Cherenkov light cone
HiSCORE prototype @ Tunka

First HiSCORE Prototype
April 2012
HiSCORE prototype @ Tunka

S. Epimakhov
Time synchronization

WhiteRabbit: PTP over synchronous ethernet

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

\[\text{rms} \sim 0.17\text{ns}\]

![T-synchronization graph](image)

Stability LabTest 50 hrs

R. Wischnewski
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
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?
HiSCORE / HRJRG-303

M. Brückner², N. Budnev⁵, M. Büker¹, O. Chvalaev⁵, A. Dyachok⁵, U. Einhaus¹, S. Epimakhov¹, O. Gress⁵, D. Hampf¹, D. Horns¹, A. Ivanova⁵, E. Konstantinov⁵, E. Korosteleva³, M. Kunnas¹, L. Kuzmichev³, B. K. Lubsandorzhiev⁴, N. B. Lubsandorzhiev⁴, R. Mirkazov⁵, R. Nachtigall¹, A. Pakhorukov⁵, V. Poleschuk⁵, V. Prosin³, G.I. Rubtsov⁴, G.P. Rowell⁶, P.S. Satunin⁴, Yu. Semeney⁵, C. Spiering², L. Sveshnikova³, M. Tluczykont¹, R. Wischnewski², A. Zagorodnikov⁵

¹Institute for Experimental physics, University of Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany
²DESY, Platanenallee 6, 15738 Zeuthen, Germany
³Skobeltsyn institute for Nuclear Physics, Lomonosov Moscow State University, 1 Leninskie gory, 119991 Moscow, Russia
⁴Institute for Nuclear Research of the Russian Academy of Sciences 60th October Anniversary st., 7a, 117312, Moscow, Russia
⁵Institute of Applied Physics ISU, Irkutsk, Russia
⁶University of Adelaide 5005, School of Chemistry & Physics, Australia
Opening the Pevatron range

- HAWC point-source, 5 years
- LHAASO point-source, 1 year
- IceCube Milagro sources, 5 years (ν)
- CTA point-source, 50 hours
- KASCADE U.L.
- H.E.S.S. survey, hard sources
- MGRO J1908+06
- HESS J1908+06

integral flux sensitivity / erg cm⁻² s⁻¹

10⁻¹¹

10⁻¹²

10⁻¹³

10⁻¹⁴

10⁻¹

1

10

10²

10³

10⁴

energy/TeV

HiSCORE

10 km²

100 km²
Backup slides
Lateral Cherenkov Photon Distribution

![Graph showing lateral Cherenkov photon distribution with distance from shower core]

- **10 TeV γ**
- **100 TeV γ**

Cherenkov photon density / m²

Distance from shower core / m
Lateral Cherenkov Photon Distribution

- Want large area
- Want a few stations
- In inner light pool
- ~100-200 m spacing
Lateral Cherenkov Photon Distribution

Want large area
Want a few stations
In inner light pool

〜100-200 m spacing

Low photon density:
Need large collector area
→ 0.5 m² per station
Tunka site exposure map

- 394 h
- 376 h
- 357 h
- 340 h
- 318 h
- 296 h
- 272 h
- 246 h
- 222 h
- 197 h
- 171 h
- 145 h
- 117 h
- 89 h
- 67 h
- 32 h

Detector axis Tilting
Tunka site exposure map
Simulation & Reconstruction
Simulation & reconstruction

CORSIKA + IACT

*.iact

sim_score
iact-package
Full detector sim

*.ascii
*.root

reco_score
Reconstruction

HiSCORE event display
500 TeV gamma-ray Simulation

Intensity [p.e.] 1912
Peakt ime [ns] 526
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

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

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

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

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

Parametrization of time-delay \( dt \) at detector position

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

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

\[
\delta = \phi + \text{atan2}\left((x_{Det} - x_{core}), (y_{Det} - y_{core})\right)
\]
Reconstruction

Direction: photon arrival time model
Energy: Value of LDF @ 220 m
Particle type: Shower depth and Signal rise-time
Direction reconstruction

![Graph showing event counts (normalised) vs. angular offset (deg) for different jitter conditions: No jitter, 1ns jitter, 2ns jitter.](image)
Energy reconstruction

Particle energy: $Q_{220} =$ Value of LDF at 220m
Energy reconstruction

Particle energy: $Q_{220} = \text{Value of LDF at 220m}$
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

![Graph showing depth of shower maximum vs energy]
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

![Graph showing the separation of Gamma-rays, Protons, and Iron nuclei based on reconstructed energy.](image)
Particle separation (1)

Lighter particles develop higher up in the atmosphere.
Particle separation (2)

Systematic difference Between width and timing Depths

- Gamma-rays
- Protons
- Iron nuclei

Number of events vs. Width depth - Timing depth [g/cm²]
Particle separation (3)

Systematic difference
Cherenkov signal rise times
Layout studies

Different altitudes

Different PMT sizes

Combination with other techniques (scintillator, imaging)
HRJRG-303
Helmholtz Russia Joint Research Group


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)
References

