TAIGA-HiSCORE -

Gamma Astronomy beyond 30 TeV

Ralf Wischnewski, DESY-Zeuthen
for the TAIGA-Collaboration

Workshop on a Wide-FOV Southern hemisphere TeV gamma ray observatory, Puebla, 11.11.2016

TAIGA :

Tunka Advanced Instrument for CR and Gamma Astronomy

A multi-component CR- and Gamma-Project

In the Tunka-Valley/Siberia

TAIGA, see also:
https://indico.desy.de/conferenceDisplay.py?confId=14253

The collaboration

Russia

ISU, Irkutsk
MSU, Moscow
MEPhI, Moscow
INR, Moscow
JINR, Dubna
IZMIRAN, Troitsk/Moscow
Budker INP, Novosibirsk
NSUniv, Novosibirsk
IPSM, Ulan Ude

Germany

Hamburg Univ.
DESY, Zeuthen
MPI, Munich

Italy

Torino, INFN

Romania

ISS, Bucharest

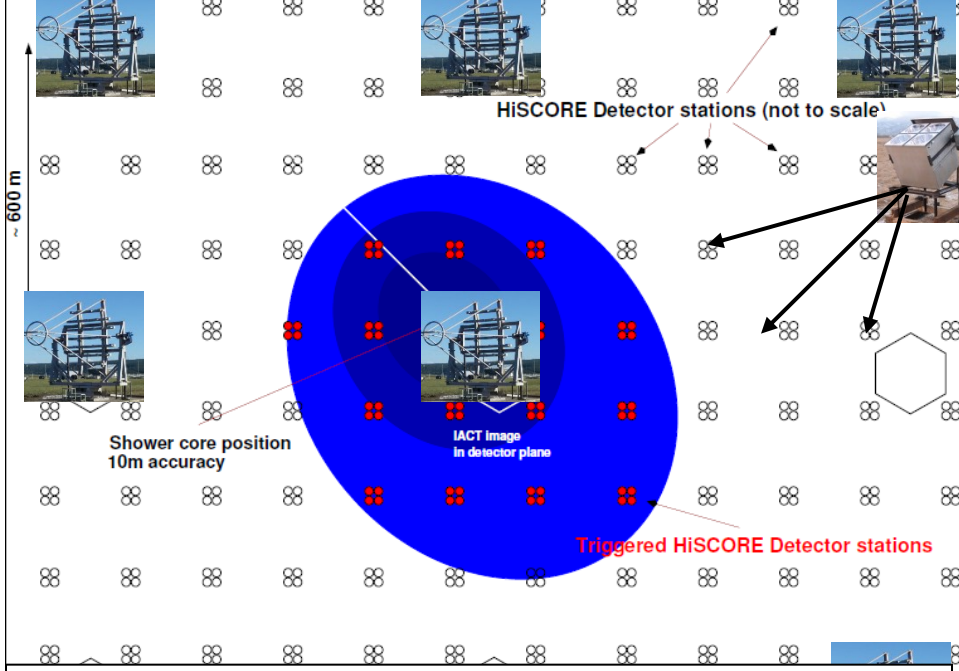



TAIGA – Executive Summary

Concept: **Combine Imaging & Non-Imaging Techniques**

- **HiSCORE: 1 km² array of wide angle non-imaging Cherenkov detectors**
- **IACTs: 4m dish/ FoV 9.3°/ 543pix at large IACT distances 0.8-1.2km**

proof of principle



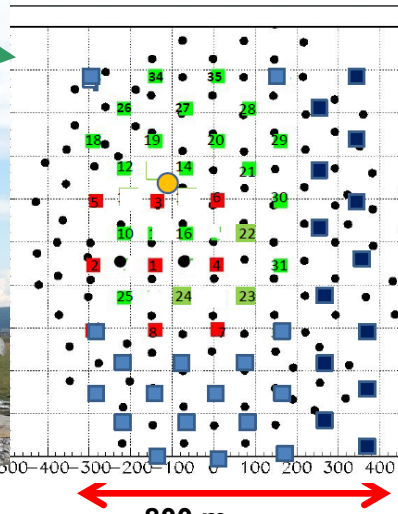
HiSCORE: Shower reconstruction by timing (core, direction,E)

IACT: γ-Hadron separation by shower image

- **HiSCORE 28-station array 0.25km²**
  - Analysis of 2015/16 data: Crab at >50 TeV ?
  - First „source“: ISS - LIDAR (1mJ/ 14m spot)

58-stations in 2017: 0.60 km²

- **1st IACT**
  - in commissioning fall 2016: TelStructure + Camera

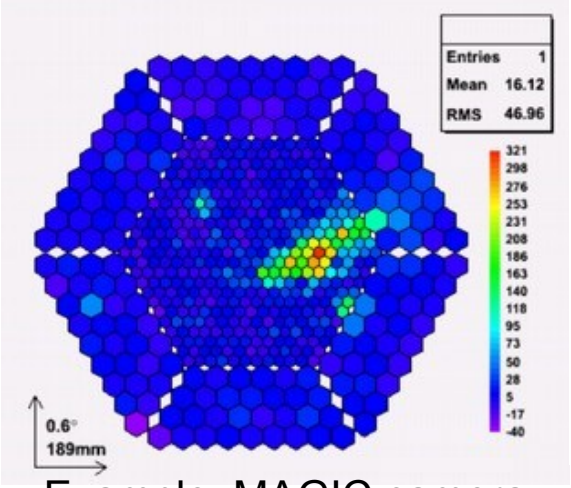


HiSCORE Timing Array

High Sensitivity Cosmic ORigin Explorer

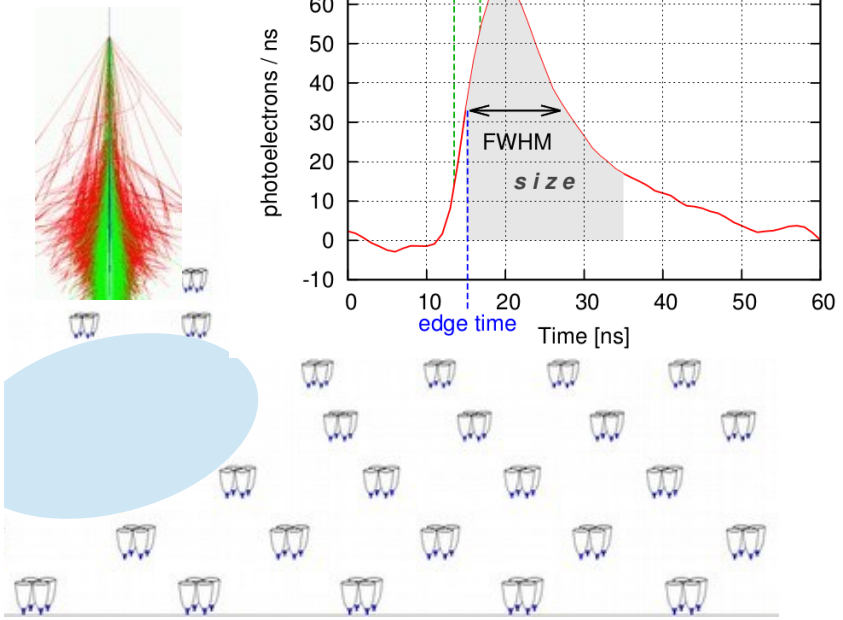
Air Cherenkov: Imaging and Timing

Imaging Telescope Arrays



Example: MAGIC camera image

Timing Arrays (non-imaging)

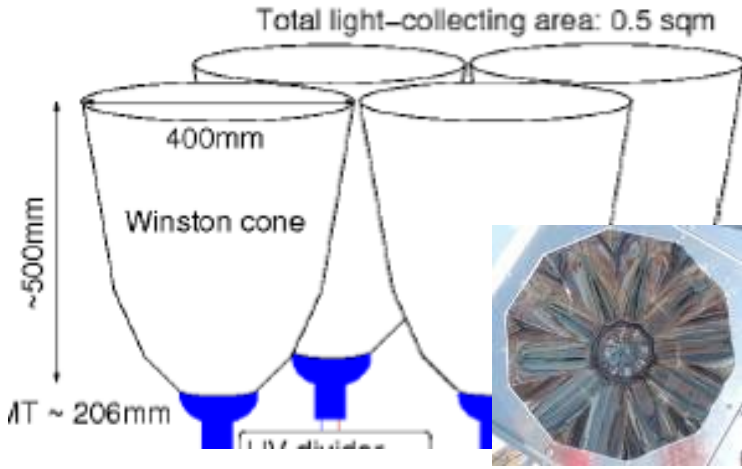


A possible compromise between IACT+Timing:
See “Famous” (T.Bretz,today) or ASGARD concept .
With pixelized timing sttaions
→ Lower Eth, larger FOV (see backup slides)

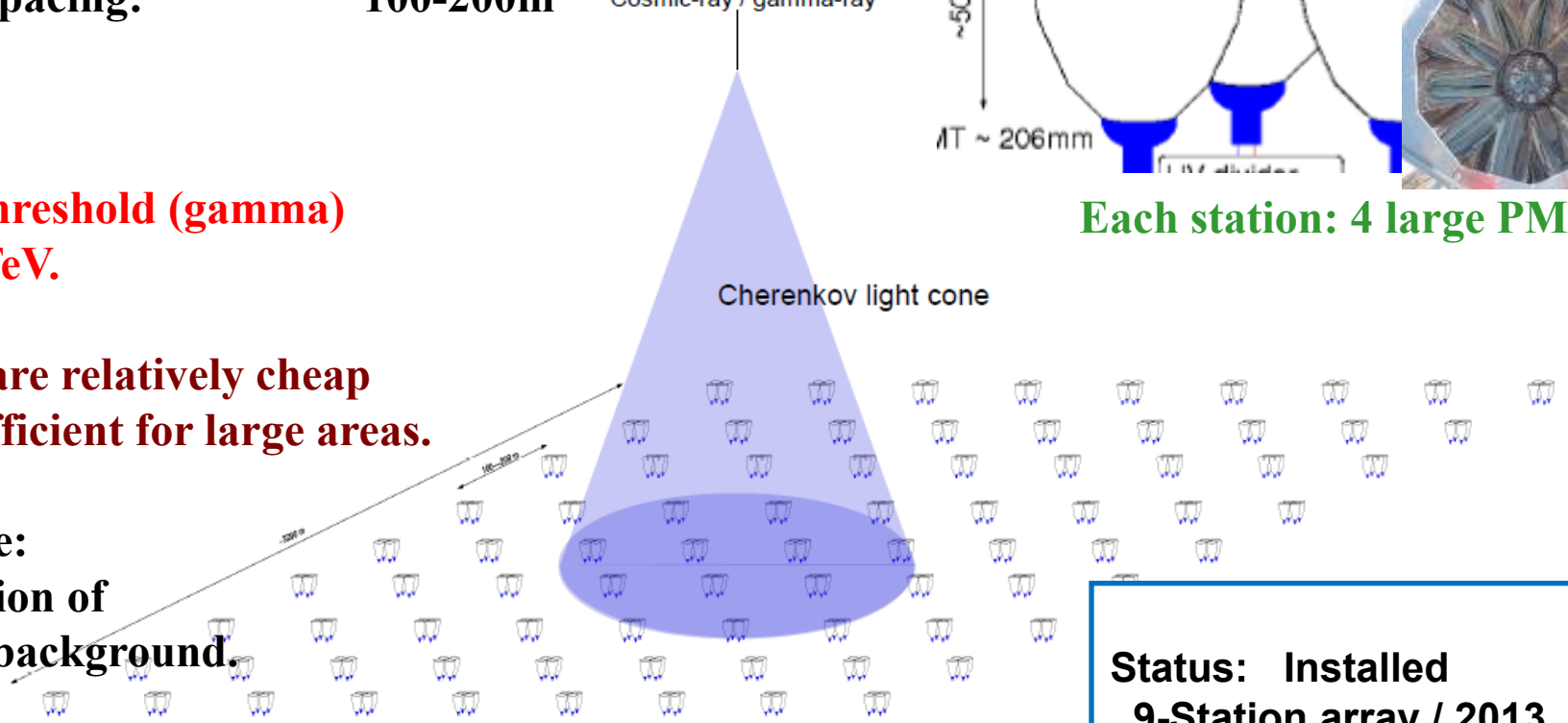
TAIGA - HiSCORE : Concept

(High Sensitivity Cosmic ORigin Explorer)

Non-imaging Air Cherenkov Array
Angular resolution : ~ 0.1 deg
Large Field of view (FOV): ~ 0.6 sr
Area: 0.25 km² ⟹ 5 km²
Station spacing: 100-200m



Each station: 4 large PMTs



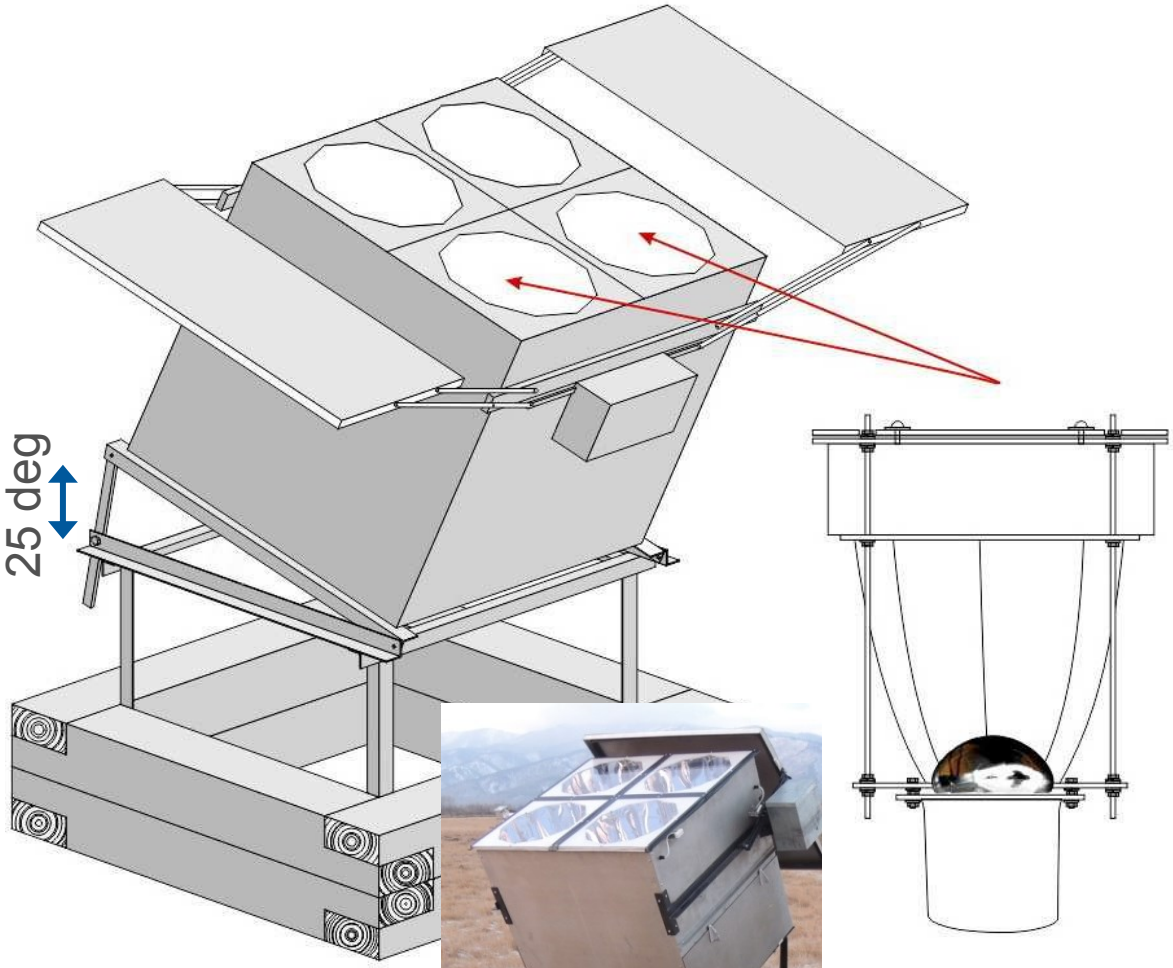
Energy threshold (gamma)
Eγ > 30 TeV.

Stations are relatively cheap
→ cost-efficient for large areas.

Challenge:
Suppression of
of CRay background.

Status: Installed
9-Station array / 2013
28-Station array / 2014

The HiSCORE Station



- Four 8" PMTs
- Winston cones, collection area 0.5m²
- FoV ~0.6 sr
- Southward “tilting”

DAQ :

- GHz readout
  - custom DRS4-FEB
- sub-ns array-wide time synchronization (hybrid)
  - custom fiber system
  - WhiteRabbit

(see talk tomorrow)

Upgrade

13 new stations
in 2017

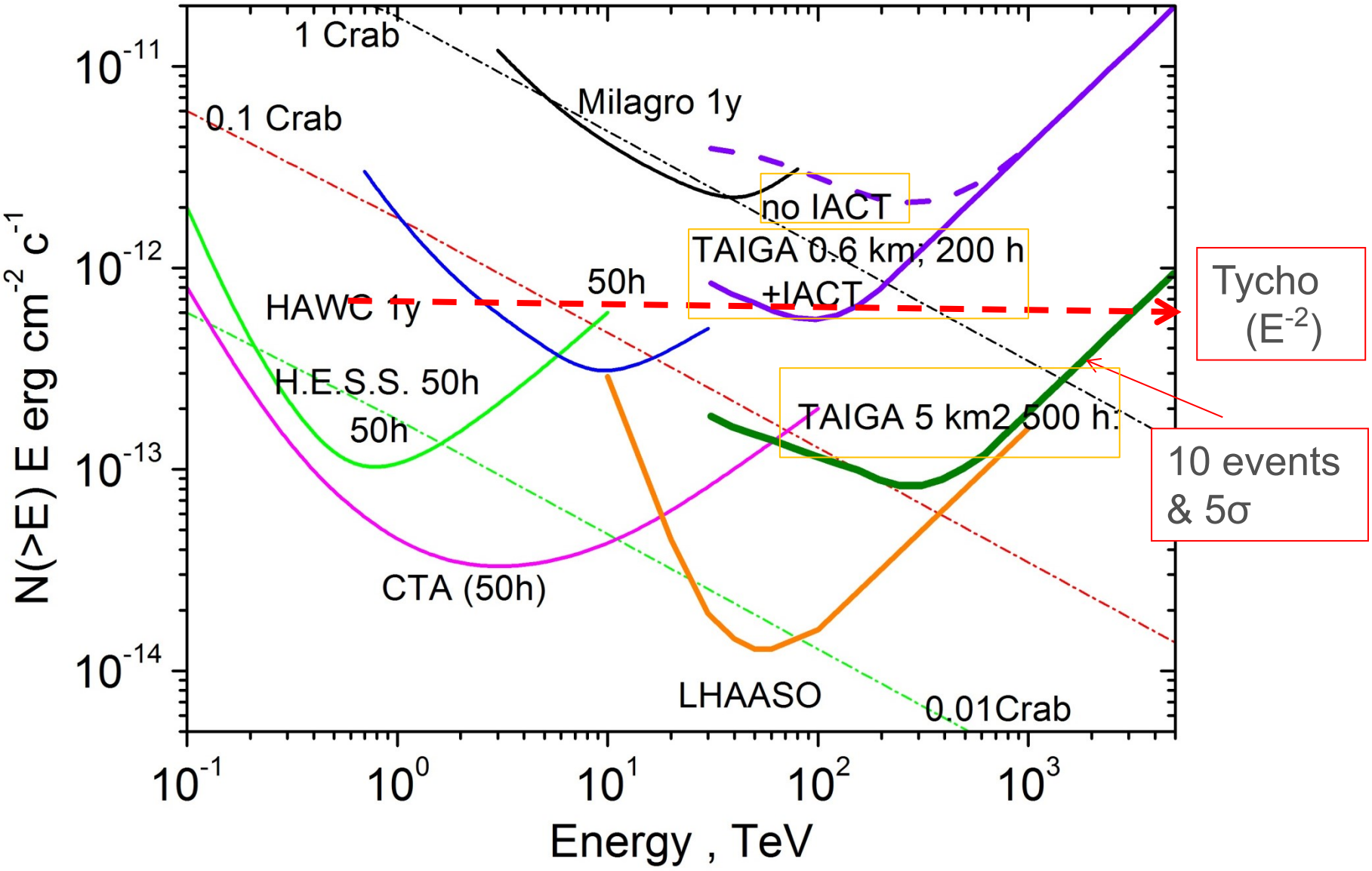
17 new stations
in 2017

Fall 2017:
58 Stations
on A=0.6 km²

Since 2014: 28 Stations, 0.25 km²

N

Integral Sensitivity to point sources

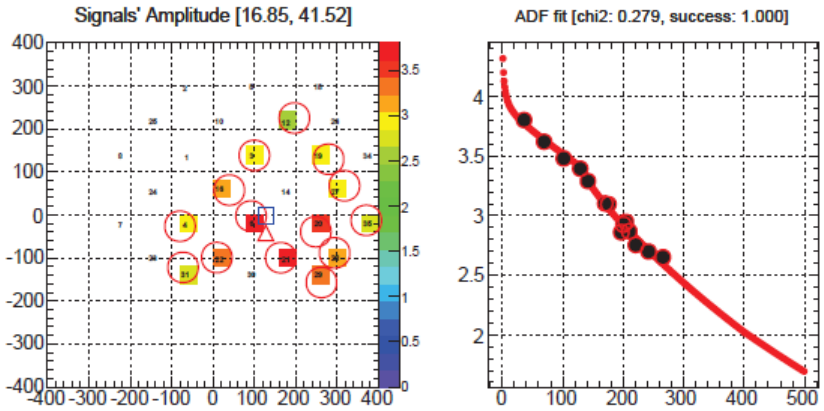


HiSCORE

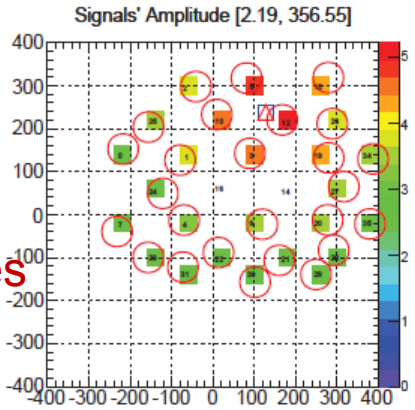
Comparison of Monte Carlo simulation to Real Data (2015/16)

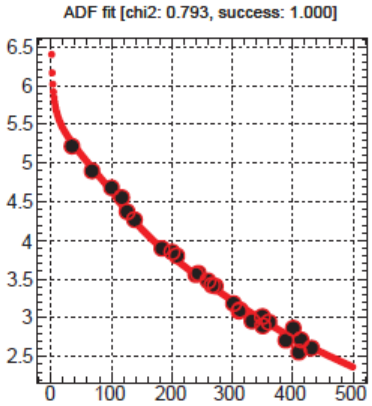
Event reconstruction

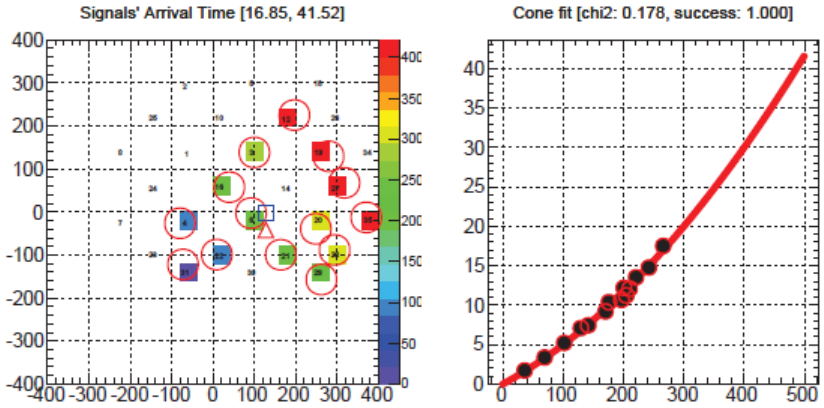
Two example events:
Amplitude vs. R, Time vs. R



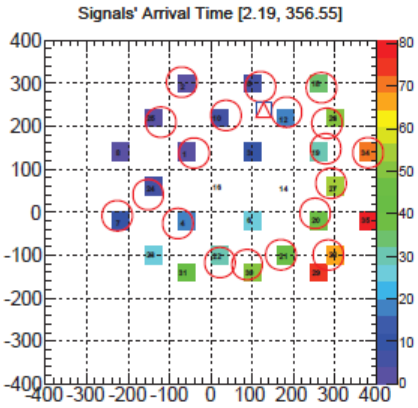
Core :
Amplitudes
+ Fit

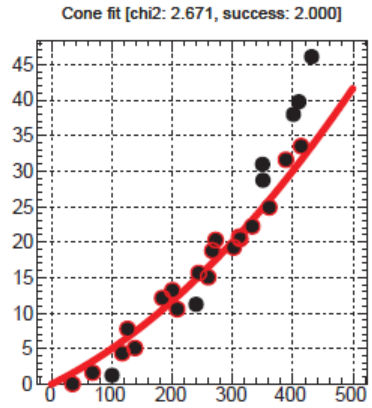






Direction
Times
+ Fit

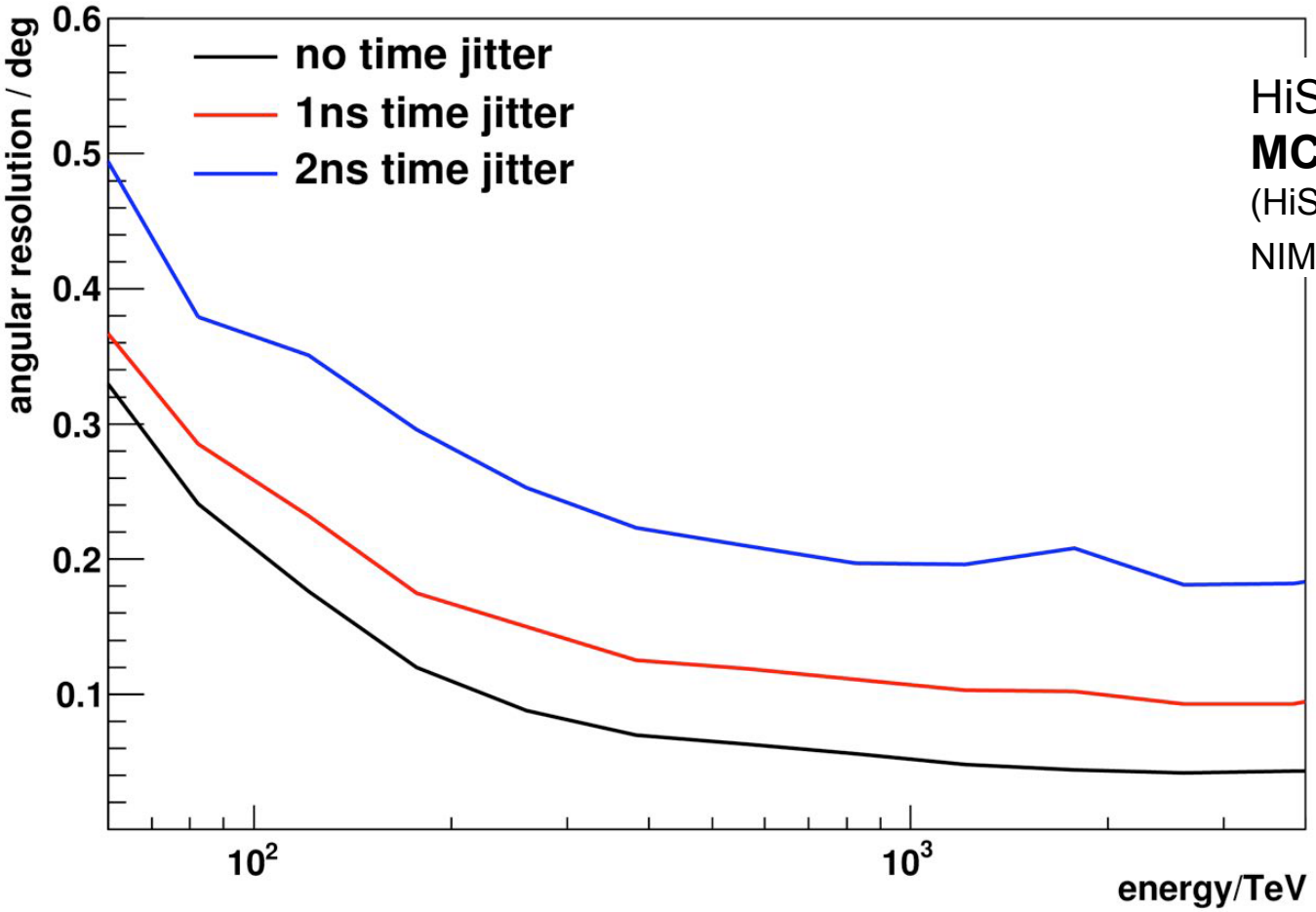




Stations=14/14/14

Stations=26/26/19 (Trg/A/T)

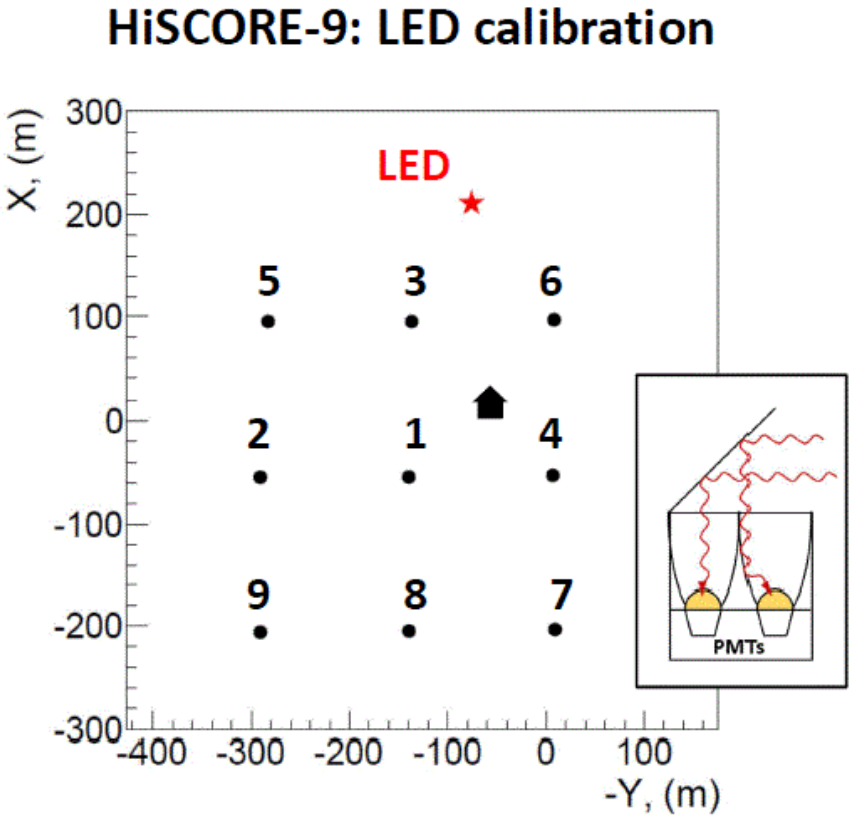
Precision Pointing: needs nsec-timing

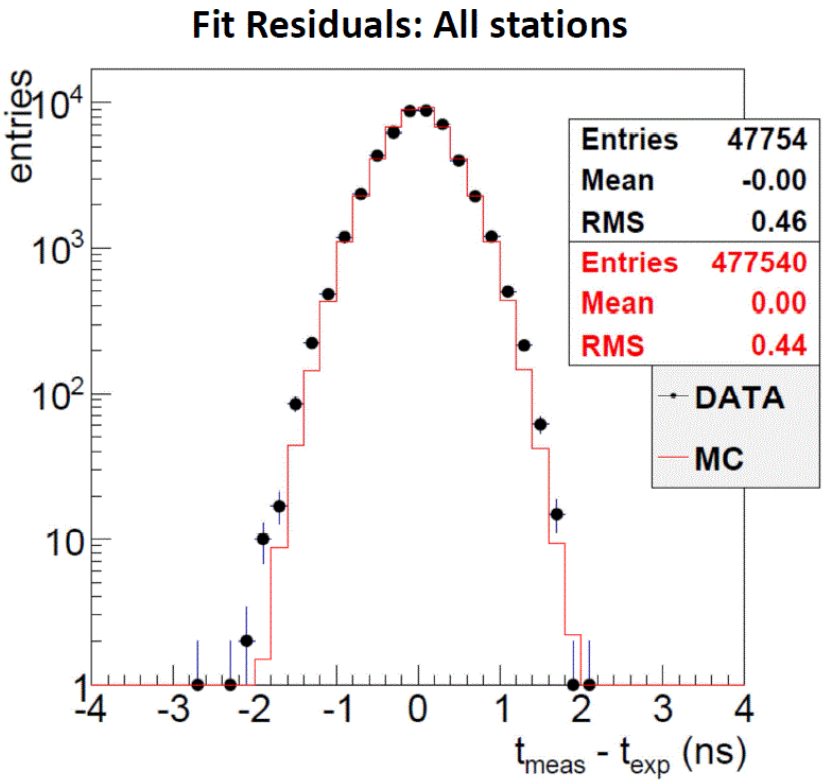


HiSCORE
MC simulation
(HiSCORE-10 simulation, NIMPA.712..137H)

Crucial. Relative time-synchronization in the array: <1ns

Time calibration





HiSCORE-9 (2013): External ns-LED source

2 independent timing systems yield comparable accuracies (<0.5 ns).

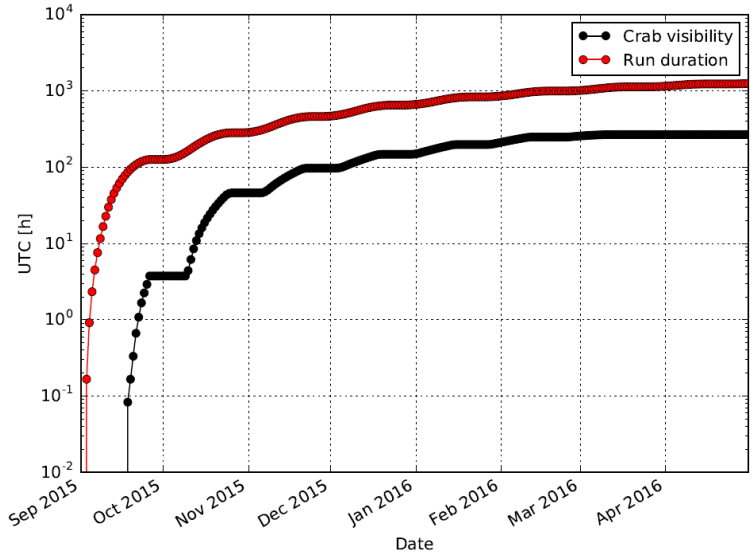
HiSCORE-28 (2014/2016):

A single DAQ, with hybrid timing system system

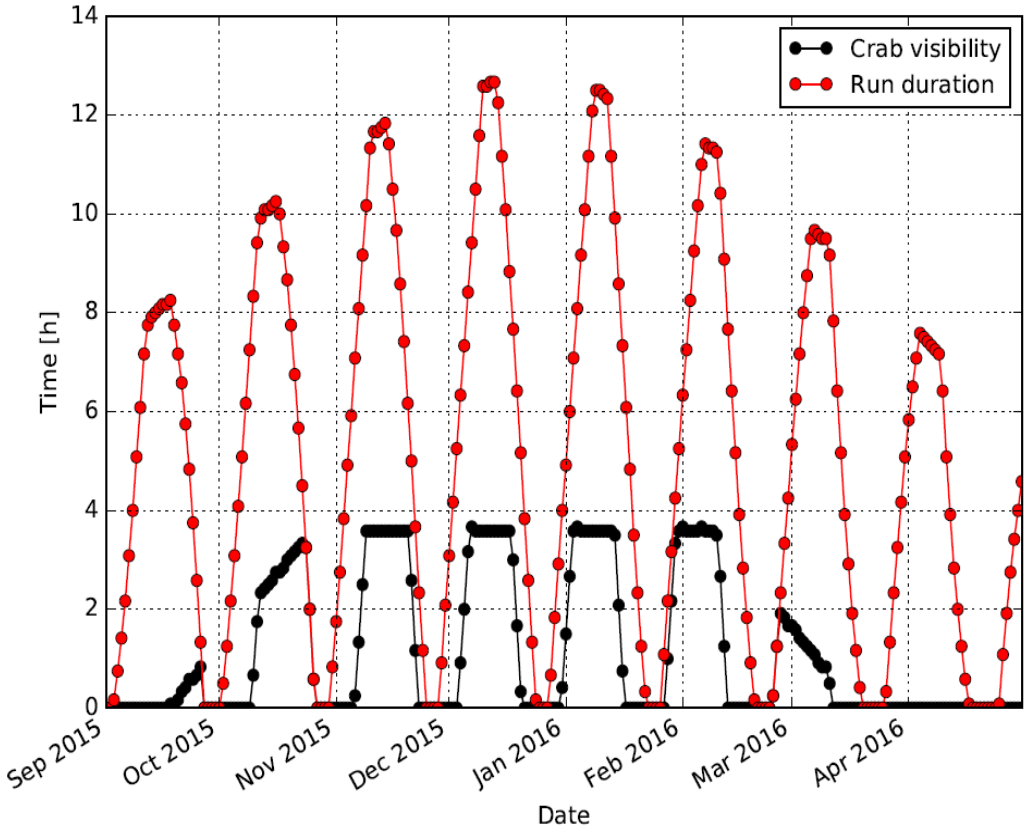
Crab Nebula: visibility at Tunka / TAIGA

- Crab as standard candle .
- Simulated crab visibility at TUNKA site for season 2015/16
- Observation time
  maximal: 265 hr (psi<25°)
  good weather: ~120 hr (expected)
- Obtained: ~60 hr of good runs

Integrated obs. time



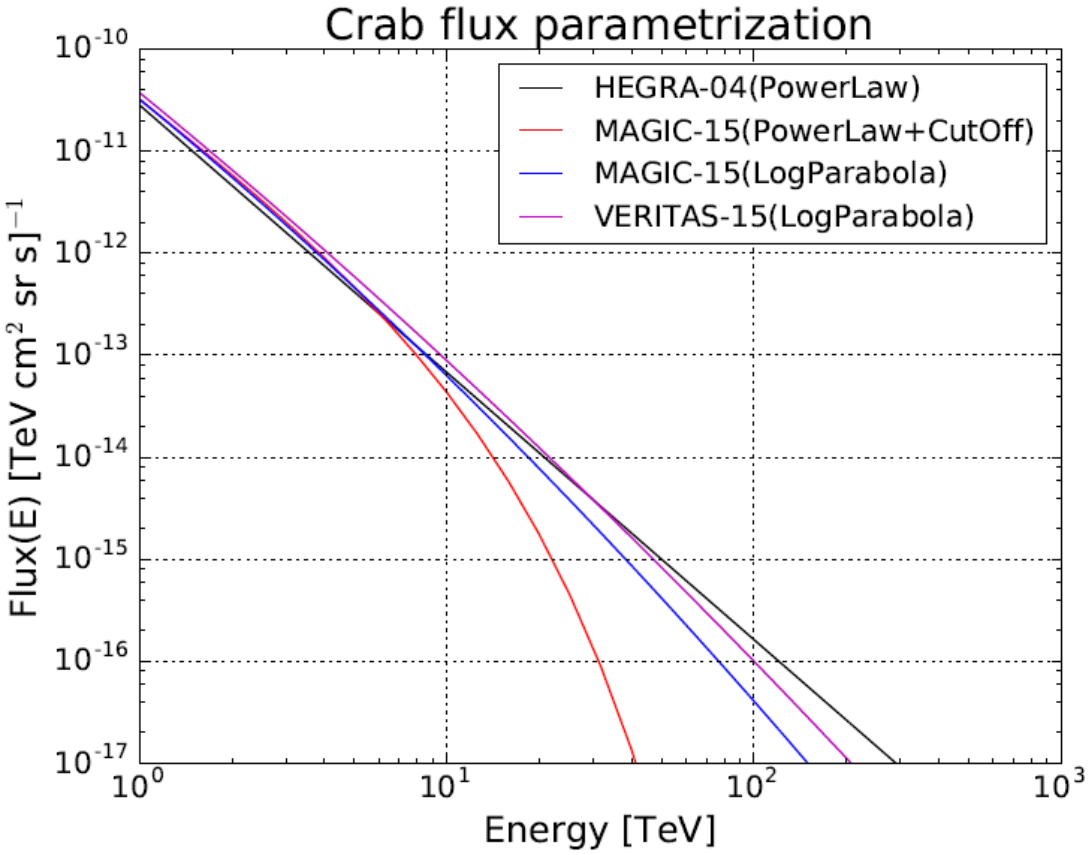
Daily obs. time



Crab: spectra from IACTs

- MAGIC, HEGRA, VERITAS, H.E.S.S. parametrizations used to estimate the signal
- Small statistics at >40TeV

->Predictions uncertain for >10TeV



- Total Number of Crab events depends on energy threshold (trigger, analysis)

E_th	Heg / Ver / Mag
40 TeV	28 – 12 evts
60 TeV	15 - 4 evts
80 TeV	12 - 2 evts
(for 60 hr)	

→ Crucial: reduction of energy threshold

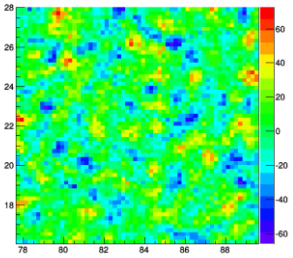
Remarks on Crab Nebula data from commissioning season

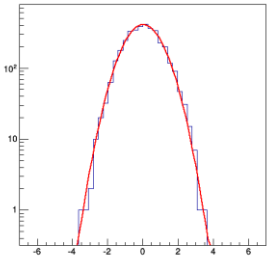
- 60 hr good weather exposure on Crab Nebula 2015/16
- $>10^4$ events within 3 deg of Crab Nebula
- A (very) preliminary analysis gives O(20) events.
  (with large BG, not significant; details not yet public)

  → As expected with 0.25 km² prototype sensitivity
  → Analysis not yet optimized
  → Improve pointing / core-reconstruction for low energy events; reject low multiplicity mis-reconstructed out-trigger , …

- Potential for future improvement
  - Array size → 0.6 km²
  - Reduce E-threshold
  - Hybrid: HiSCORE + IACT

Example: BG-excess skymap (blinded) in Crab region. Significance distribution in FoV





HiSCORE's first source:

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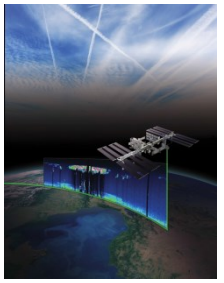


A few mysterious short episodes were found in the 2015/16 data analysis (Oct-April):

- **For about 1 second ~2000 events are triggered vs. 15 Hz normal CR trigger rate.**

- **Is that X-talk, spikes, hardware failures,… ??**
  Typical analysis decision: "rare, *additional background*". → Skip and ignore.

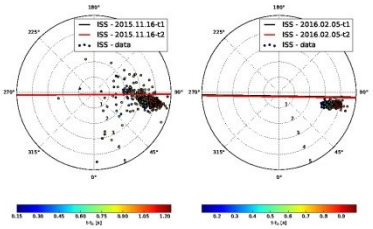
However:

- **Reconstructing these events, they all**
  - **-- fit with high quality**
  - **-- have all similar directions**

- **Each event is of only few nsec duration**
- **Time pattern strikingly different from CR or gamma shower, resemble rather a "plane wave"**

- **Events move over the sky within 1 sec**
- **For all episodes: point to same sky direction**

- **Derives from a 4.00 kHz source rate**



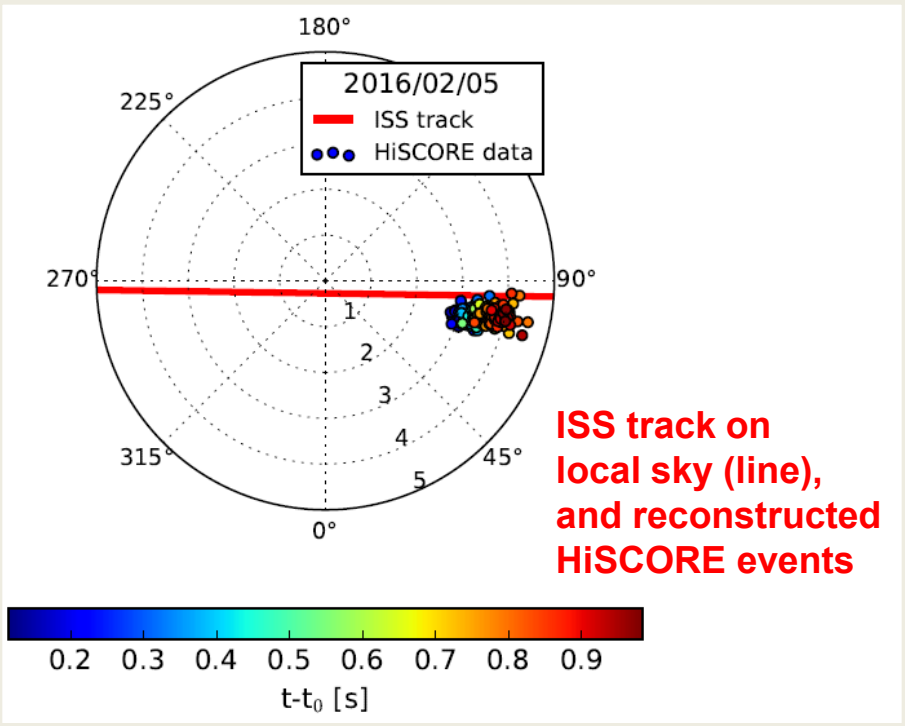
(prelim)

HiSCORE's first source: ISS - Laser flashes with 10ns 1mJ

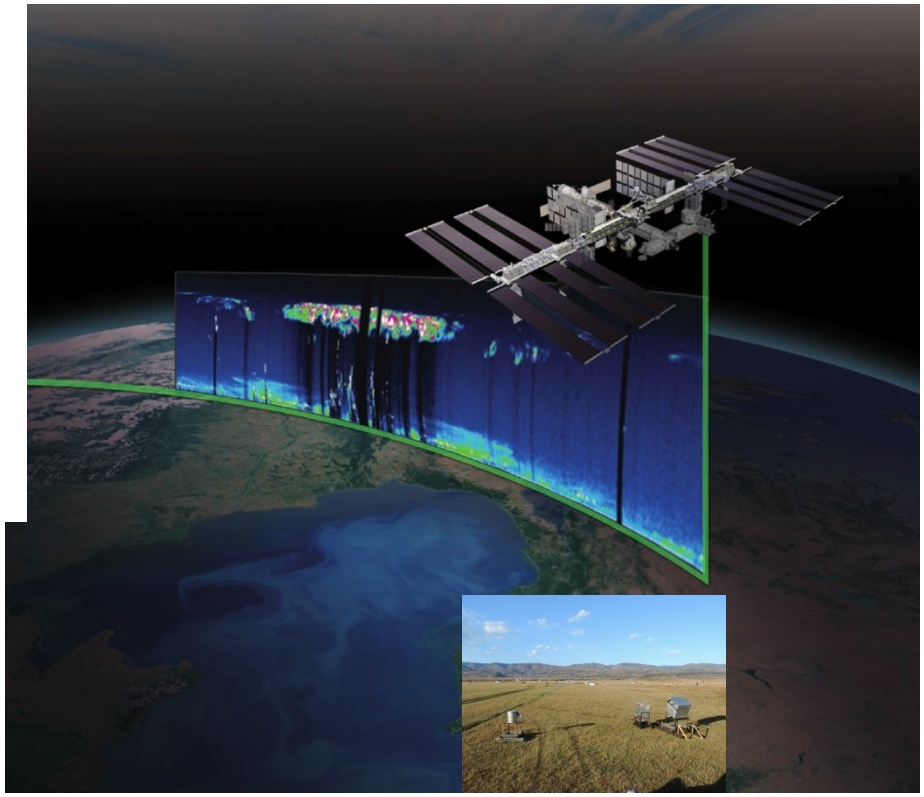
HiSCORE's first source: ISS - Laser flashes with 10ns 1mJ

- **The CATS Lidar on ISS at 410km a.s.l.**
  - **10^{13} photons/m^2 532nm in a 14m spot**
  - **4 kHz repetition rate at 7km/s ISS speed**
  - **observed at large distance of o(km)**
  - **2000 trig vs. 15 Hz BG → "500 σ"**

- **Serendipitous discovery:**
  3 times in 2015/16 for ~1 second
- **Next occurrence predicted, and verified two weeks after**



ISS track on local sky (line), and reconstructed HiSCORE events



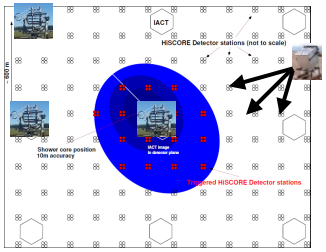
Adapted from CATS

- **Excellent HiSCORE calibration source**
  - **flat timing profile**
  - **precision pointing**

- **Further Interest :**
  - **useful for IACTs (HESS, MAGIC, CTA…) ?**
  - **LIDAR physics: opens forward scattering**

Summary

- TAIGA combines Imaging and Non-Imaging techniques
  → HiSCORE & IACTs



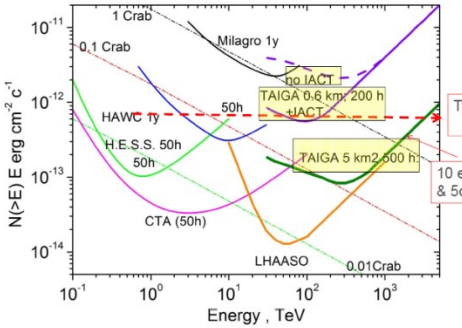
- Complementary to CTA
  - energy scale beyond CTA, low cost experiment

- HiSCORE
  - Double size next year 0.6 km2

- 1st IACT
  - now in commissioning DC/FOV 9.4º/ 540pix / 4.6m

Summary (2)

- TAIGA – HiSCORE aims at γ-astronomy at >30TeV with a 5km^2 Hybrid Array:
  - 500 Timing stations & 10-16 IACTs
  - sensitivity 10^{-13} erg cm^{-2} s^{-1} (500hr)
- Prototype in 2017
  - 58 stations + 1st IACT on 0.6km^2
  - sensitivity 10^{-12} erg cm^{-2} s^{-1} (200hr)

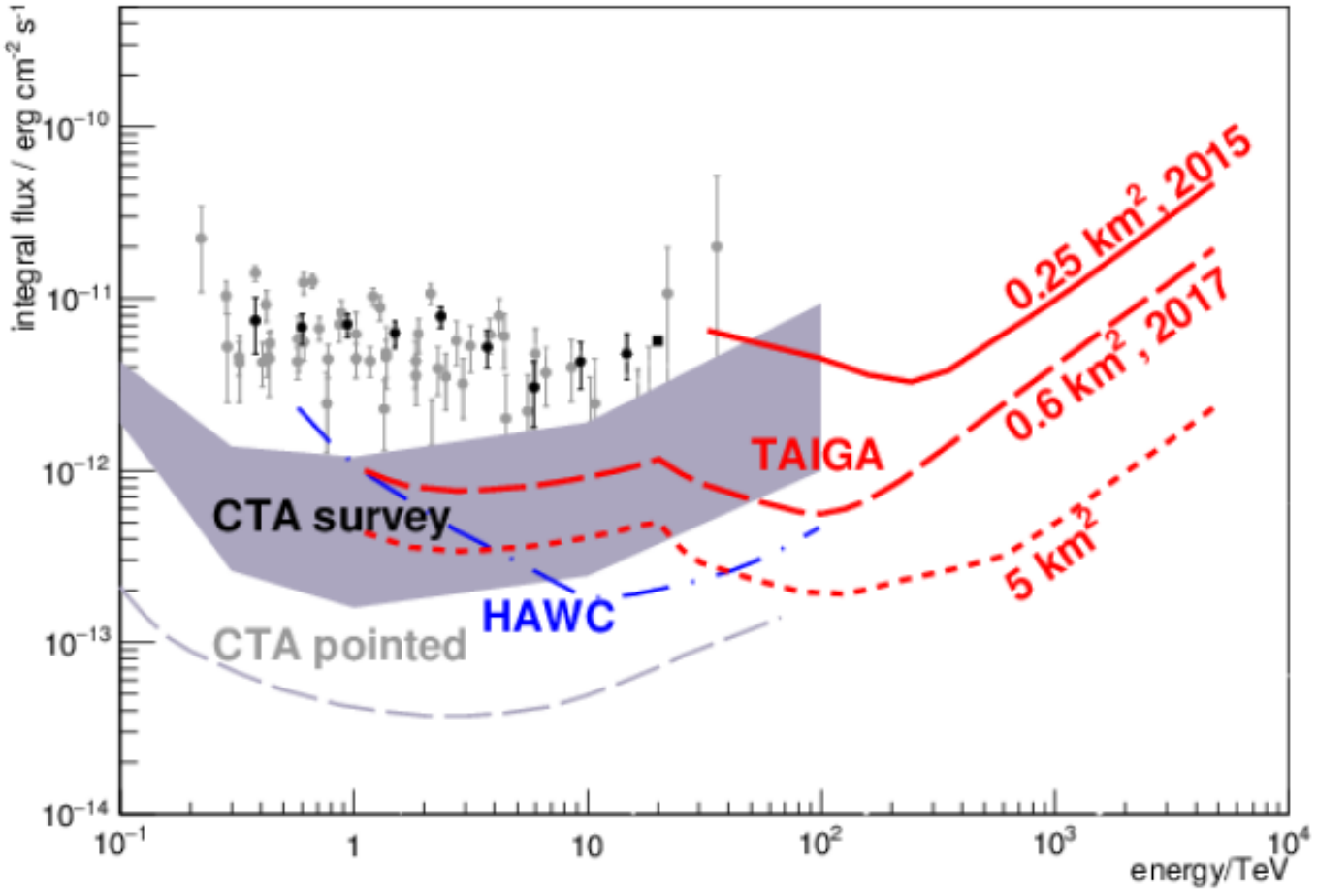


- HiSCORE-28 prototype: analyzing first data season 2015/16
  - Data-analysis, calibration in good shape; improvements expected
  - Gamma threshold is 50-70TeV; aiming to reach 30 TeV
  - Crab signal in reach w/ HiS-58
  - ISS as moving laser point-source discovered
    - excellent HiSCORE calibration source, also for IACTs
    - Opens forward scattering for LIDAR

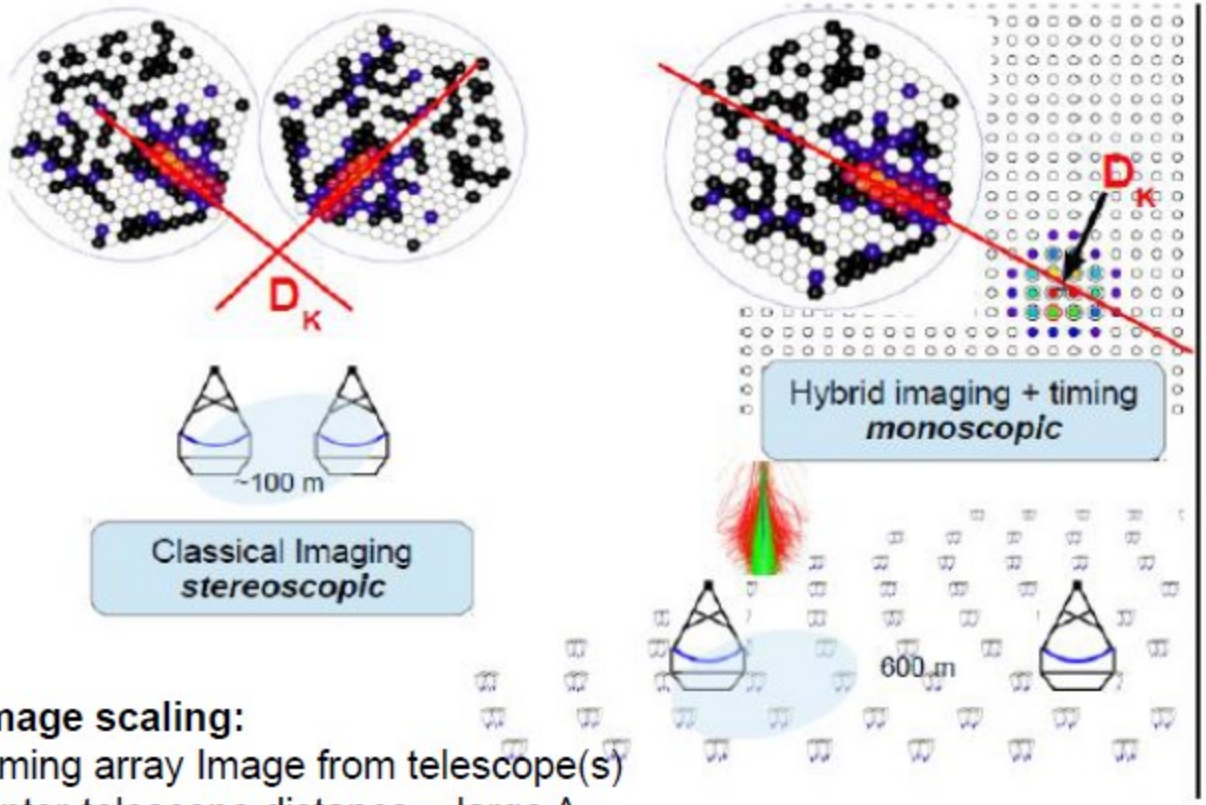
Thank you.

Backup Slides

Integral Sensitivity to point sources



Hybrid approach to hadron rejection

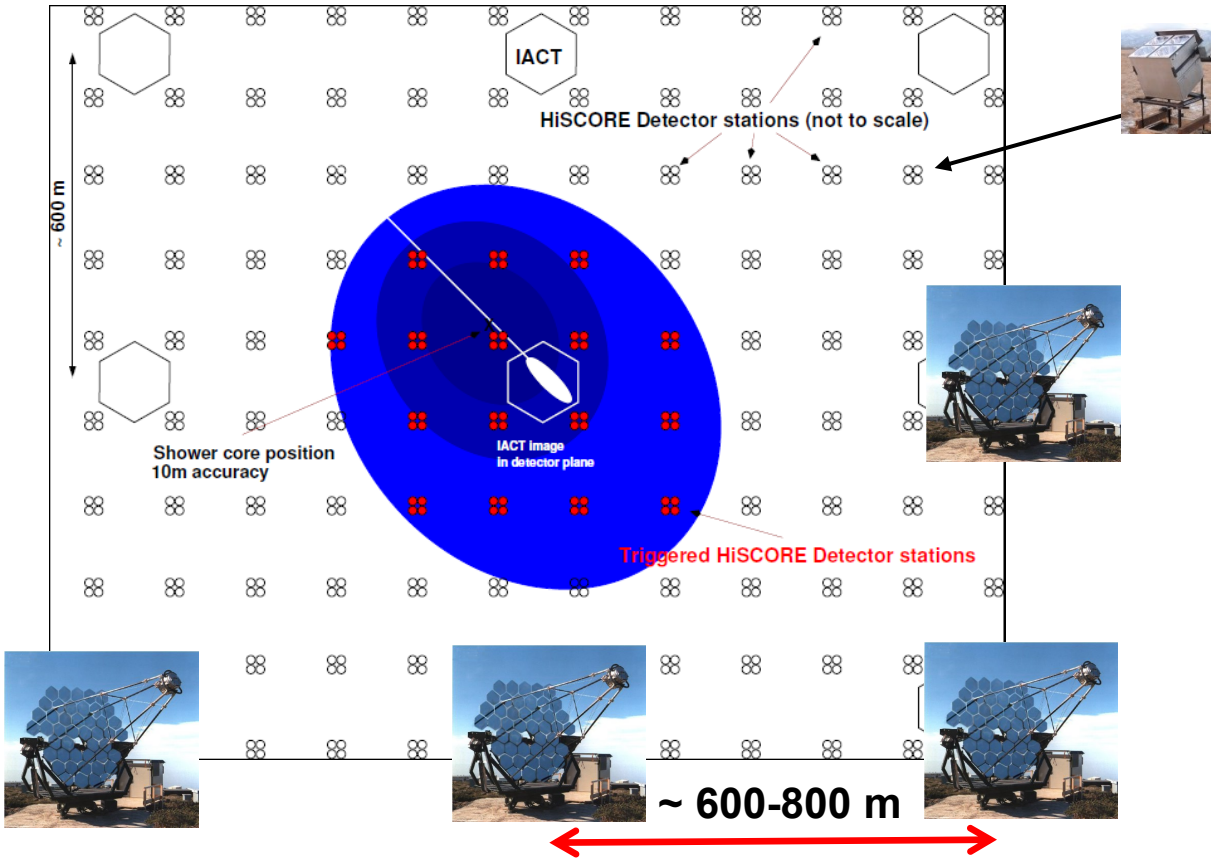


Hybrid Image scaling:

D_K from timing array Image from telescope(s)

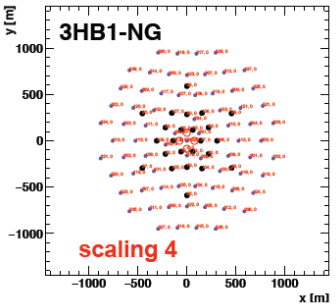
1) large inter-telescope distance = large A_{eff},
2) scaled width separation parameter

TAIGA Concept: combine HiSCORE & IACT



HiSCORE: Shower reconstruction by timing (core, direction,E)

IACT: Gamma-Hadron separation by shower image



CTA: SSTs at <~300m

(Bonus slides)

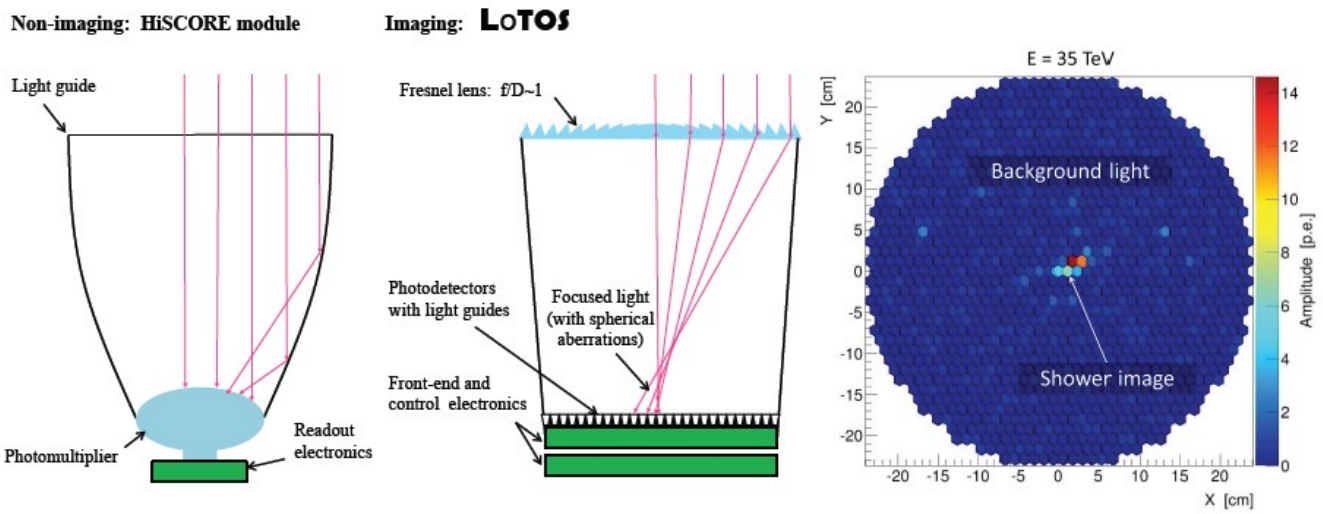
ASGaRD – A novel all-sky gamma-ray detector with minimal imaging.

- Compromise between Imaging and “timing-only”
- M.Shayduk – ICRC2015 paper / ERC-H2020 proposal
- A new instrument for the >10 TeV domain.Two new ideas:

1. LoTOS – LowThreshold Optical station

   50 deg FoV, imaging by Fresnel Lens + SiPMMatrix

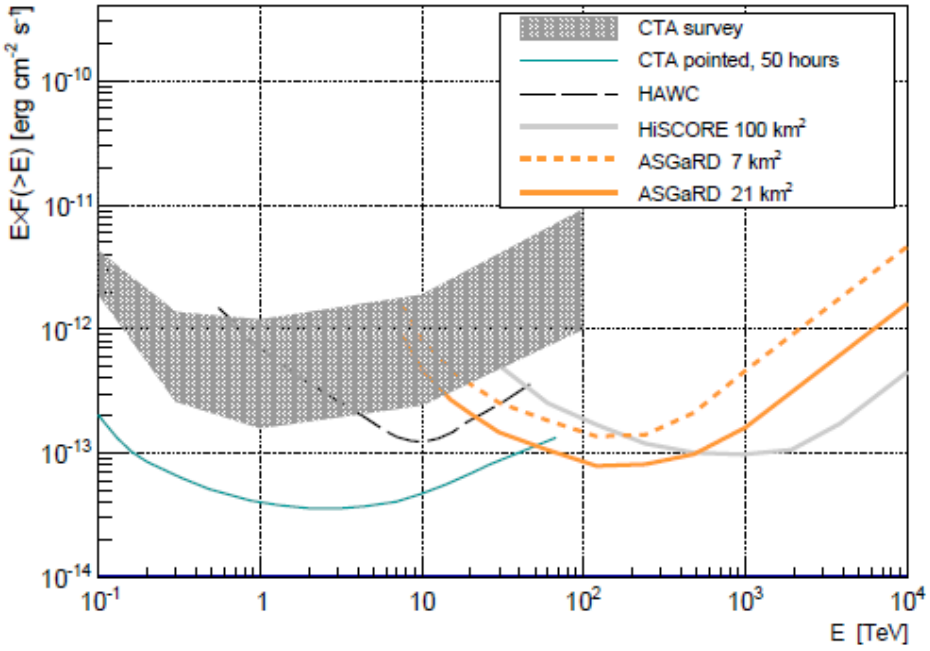
   → Improves the HiSCORE concept: avoid NSB integration



ASGaRD – A novel all-sky gamma-ray detector with minimal imaging (2)

2. LiBROS – LongBuffer Readout System
   - Elegant, deadtime-free Camera-Readout + trigger system
   - Image: nsec-timing (trigger path) + 65MHz Fadc charge R/O
   - Allows “array-trigger” up to >100usec latency
   - Usable for CTA-cameras, and most other DAQ+Trigger
   - Cheap

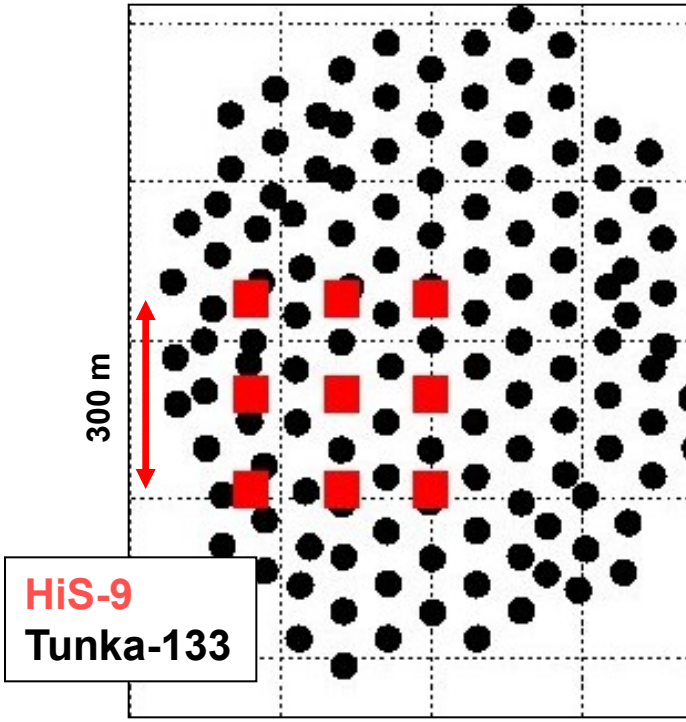
- Sensitivities for ASGaRD
  A= 7 km^2 / 21 km^2
- Build 5 prototypes / 2 yrs.



HiSCORE Milestone:
9-station prototype array - 2013

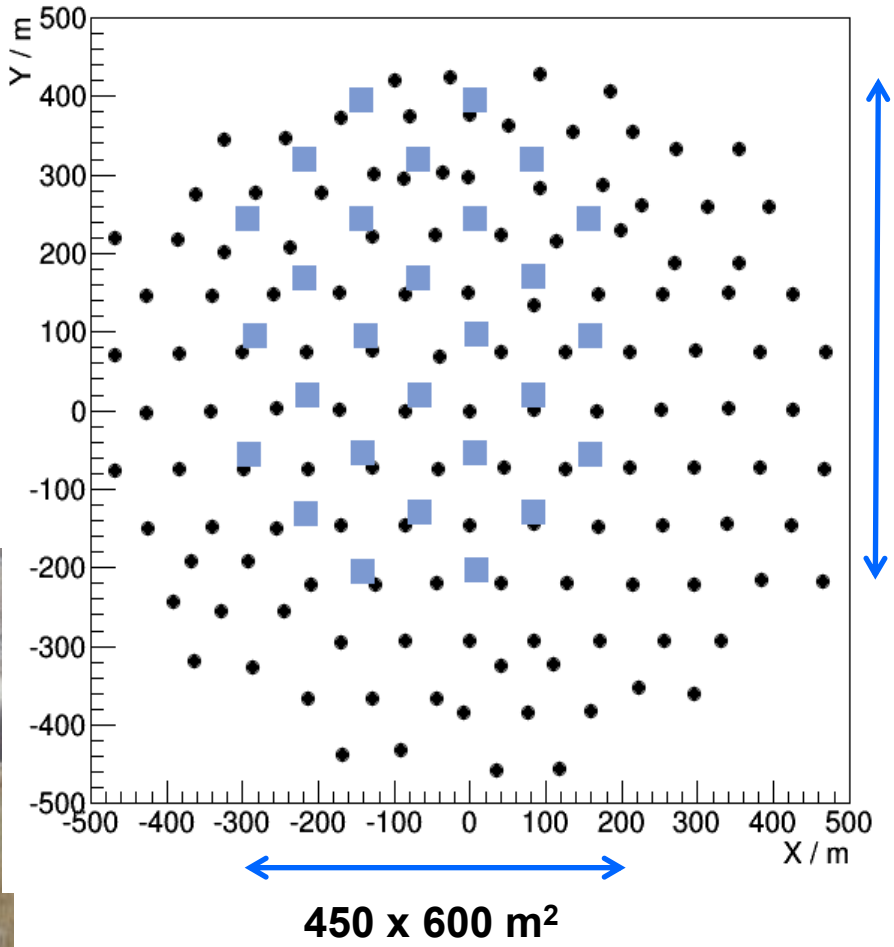
- Work started fall 2011
- 9 stations on a 300m x 300m grid: 0.1 km^2
- Per Station: 4 PMT (R5912 8") + Winston Cone
- Routine operation: Oct.-April
- Full nsec-Timing, 2GHz R/O, ADQ-prototypes

➔ Reconstruction: core, direction, energy,..



HiSCORE Milestone : 28 station array - 2014

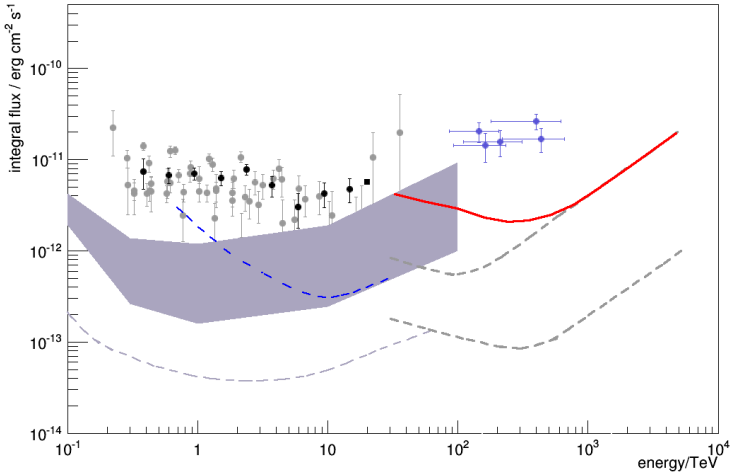
- 0.25 km^2
- spacing 100-150m
- Installed: fall 2014; full operation since 2015
- Tilting mode – 25° south to increase sky coverage
- Threshold: few 10 TeV.

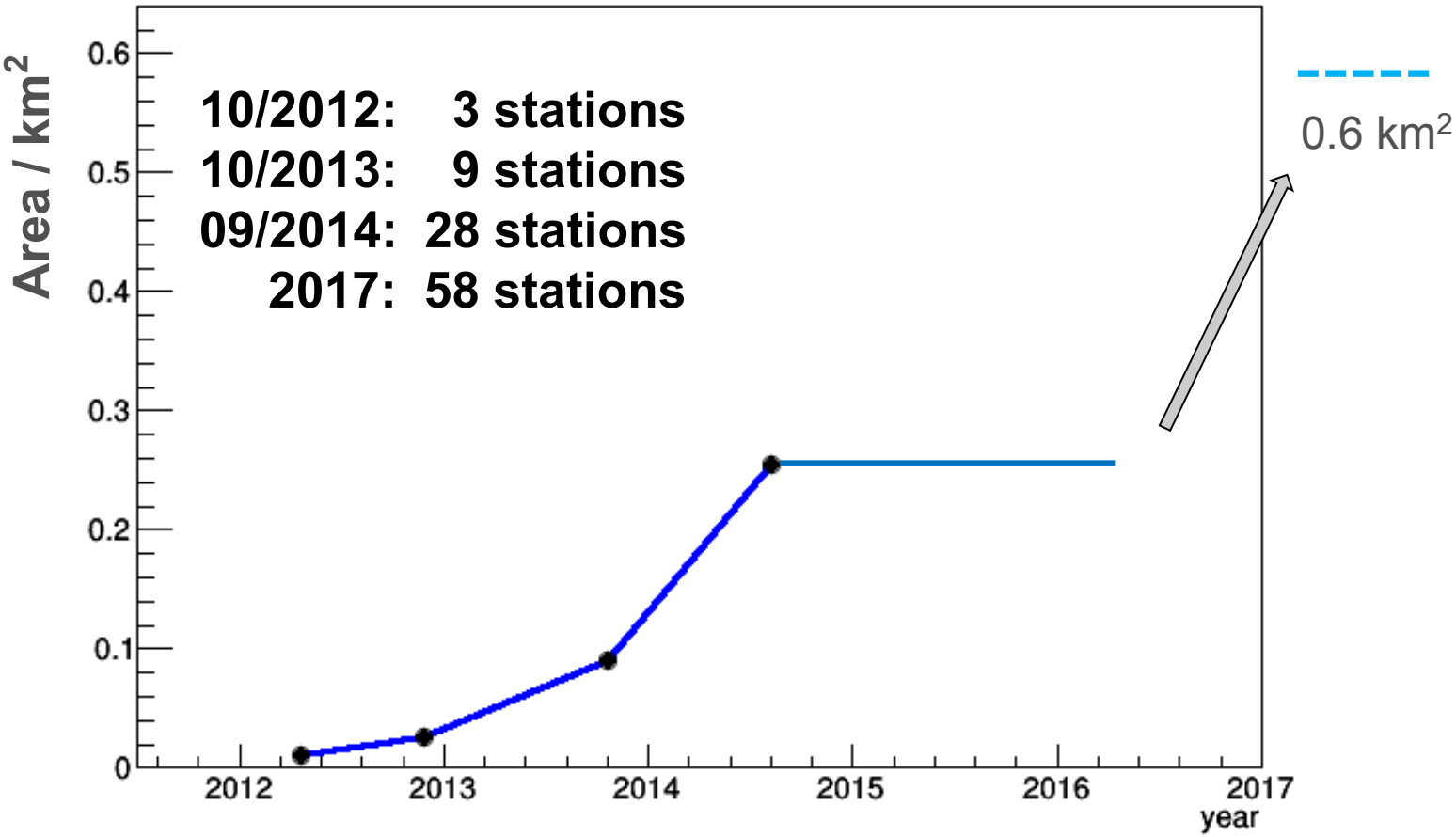


450 x 600 m^2

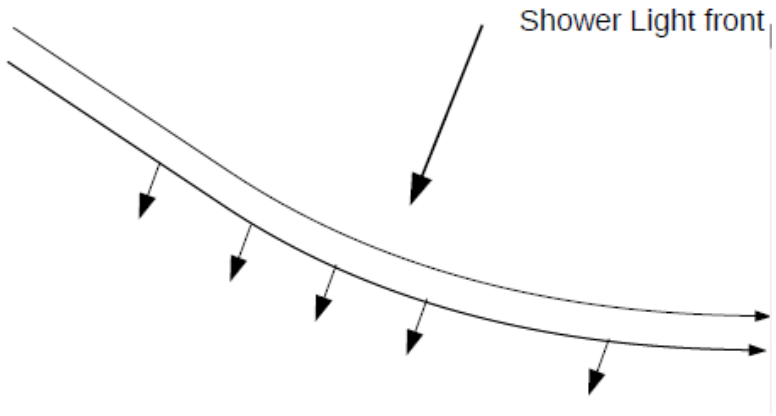
HiSCORE timing stations
Tunka 133 stations

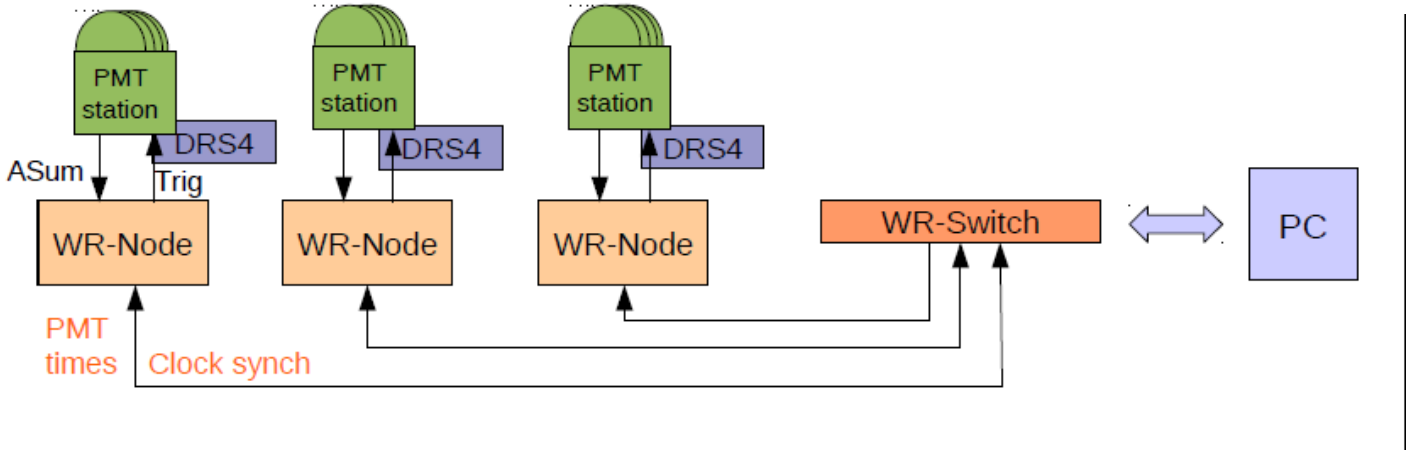
Evolution of effective area





HiS-9: Reconstructing Cosmic Ray Showers





Note: An astonishingly simple DAQ-setup to measure ns-pulse pat

Expectation for the 5 km^2 TAIGA array (short list)

Source	RA [deg]	Dec [deg]	Flux at 1 TeV [10^{-12}cm^{-2} s^{-1}TeV^{-1}] slope Γ	Flux at 35 TeV [10^{-17}cm^{-2}s^{-1}TeV^{-1}] (from Milagro)	Obs.Time per year (incl. 50% weather)	Number of events per season (E> 30 TeV)
Tycho SNR (J0025+641)	6.359	64.13	0.17 ±0.05 Γ=1.95 ±0.5		**236h**	~**200** **2.5σ – HiSCORE only** **12σ – TAIGA**
Crab	83.6329	22.0145	32.6 ±.9.0 Γ=2.6 ±0.3	162.6 ±9.4	**110h**	**~1000**
SNR IC443 (MAGIC J0616+225)	94.1792	22.5300	0.58 ±0.12 Γ=3.1 ±0.30	28.8 ±9.5	**112h**	**10**+ (from MAGIC) **200 (** from Milagro)
Gemingа MGRO C3 PSR	98.50	17.76		37.7 ±10.7	**102h**	**400**
M82 (Starburst Galaxy)	148.7	69.7	0.25 ±0.12 Γ=2.5 ±0.6±0.2		**325h**	**50**
Mkn 421 (BL, z=0.031, var.)	166.114	38.2088	50-200 Γ=2.0-2.6		**140h**	**20 – 1000 ?**
SNR 106.6+2.7 (J2229.0+6114)	337.26	61.34	1.42 ±0.33 ±0.41 Γ=2.29 ±0.33 ±0.30	70.9 ±10.8	**167h**	**400** (from VERITAS **700** (from Milagro)
Cas A (SNR)	350.853	58.8154	1.26 ±0.18 Γ=2.61 ±0.24±0.2		**177h**	**100**
CTA_1 (SNR,PWN)	1.5	72.8	1.3 Γ=2.3		**266 h**	**500**