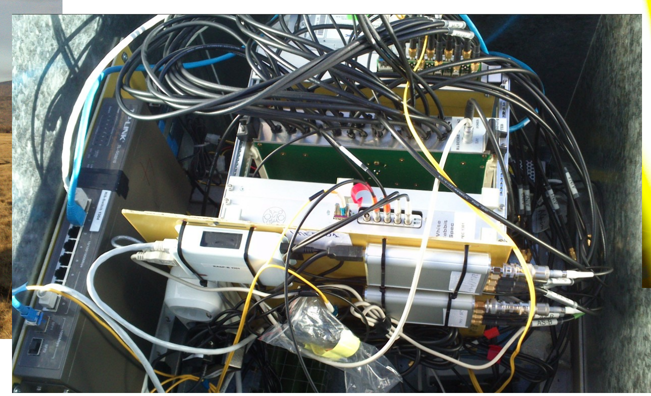
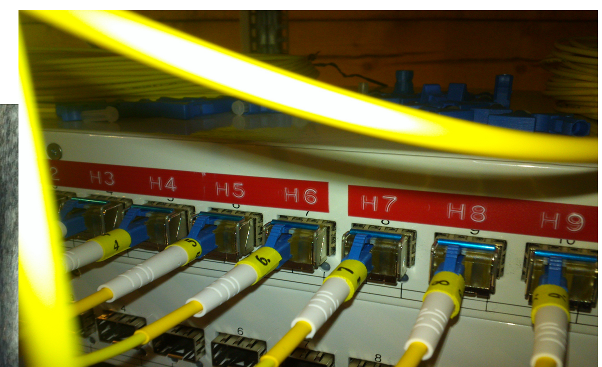
24th European Cosmic Ray Symposium

Timing calibration and directional reconstruction for Tunka-HiSCORE

Andrea Porelli for the Tunka-HiSCORE collaboration (DESY)



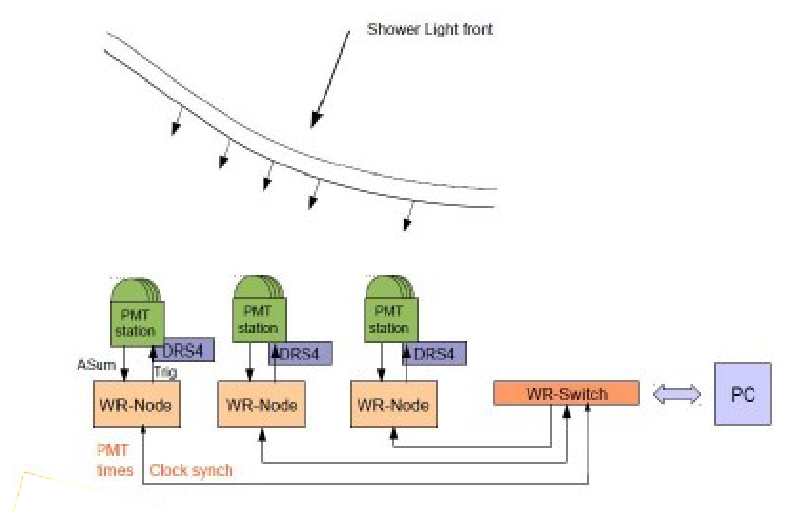


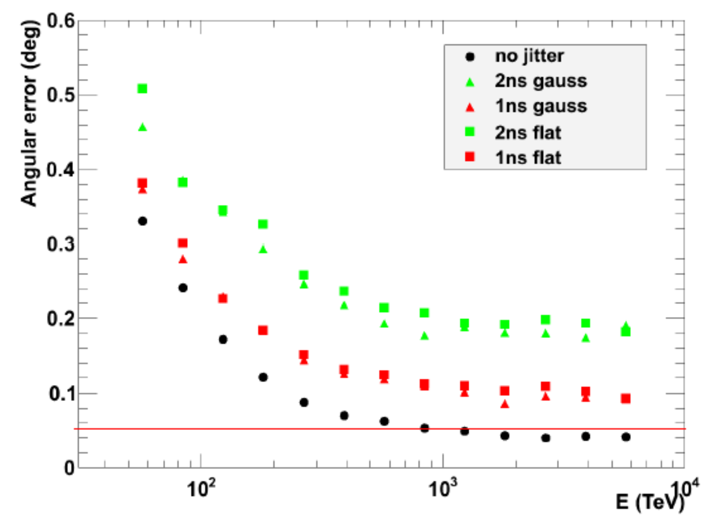
outline

- HiSCORE: Time synchronization and angular resolution
- DAQ system with WhiteRabbit timing
- Time calibration with LED source
- HiSCORE-9 prototype EAS reconstruction
- Array layout optimization for HiS-2014
- Summary

Time synchronization

- Tunka-HiSCORE:
  "see N.Budnev (previous talk), and M.Tluczykont (plenary)"
  - Ground array detector
  - Stations spacing ~150m over 1-100 km^2
  - nsec-time resolution between stations needed for optimal EAS-pointing
- MC simulations:
  - angular resolution degrades for >1nsec time resolution



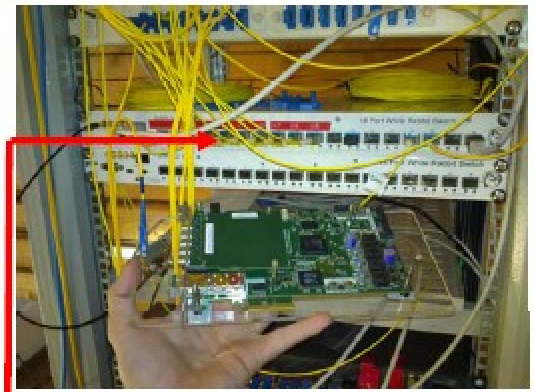


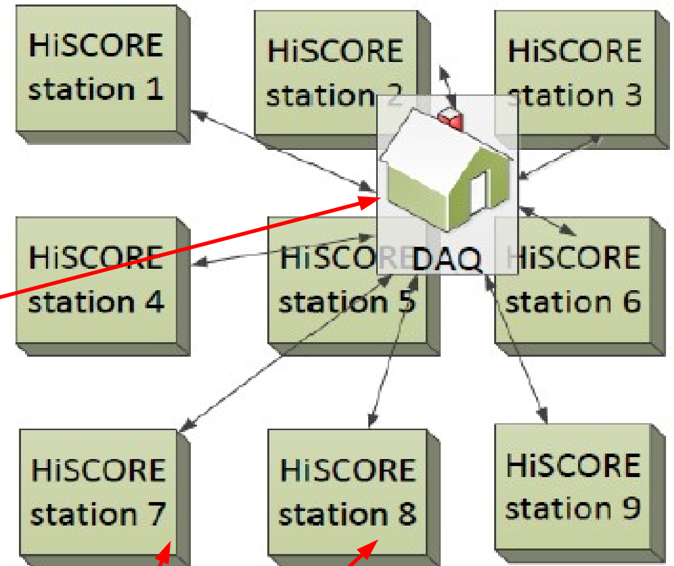
A distributed DAQ system for the HiSCORE detector based on the WhiteRabbit (WR) timing system has been developed in order to achive a sub-ns time resolution

WhiteRabbit timing system

- **WR main components**

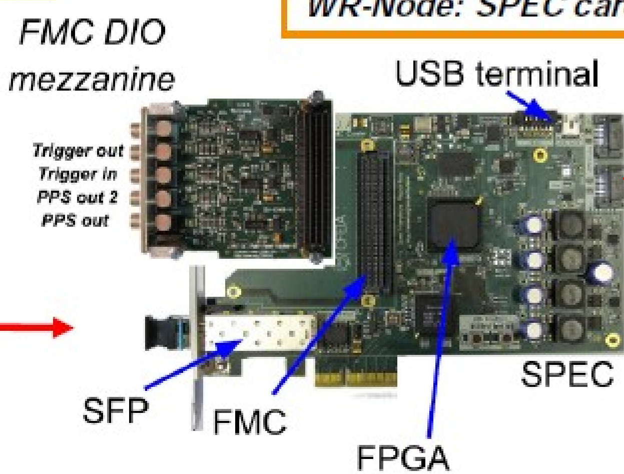
WR Master: WR Switch

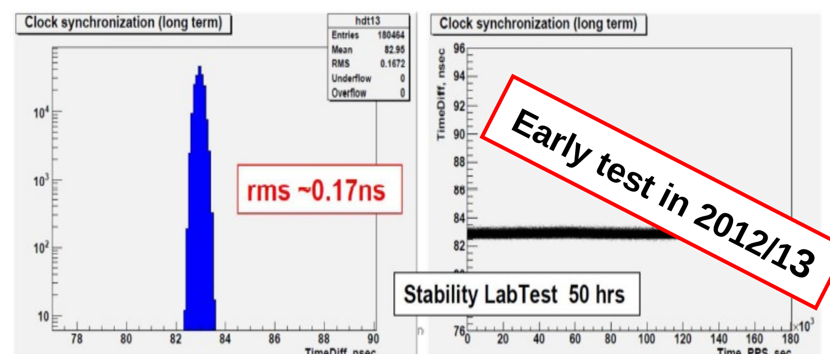




1Gbit fiber

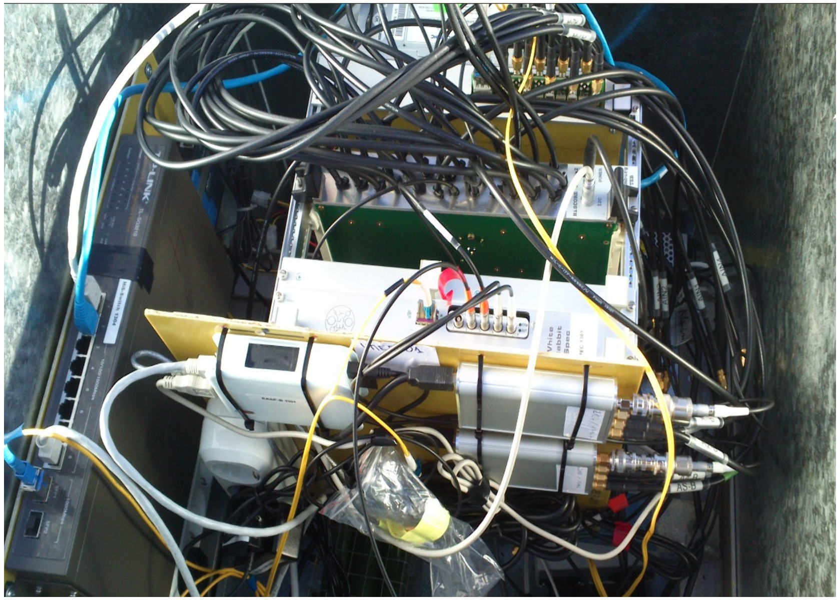
WR-Node: SPEC card

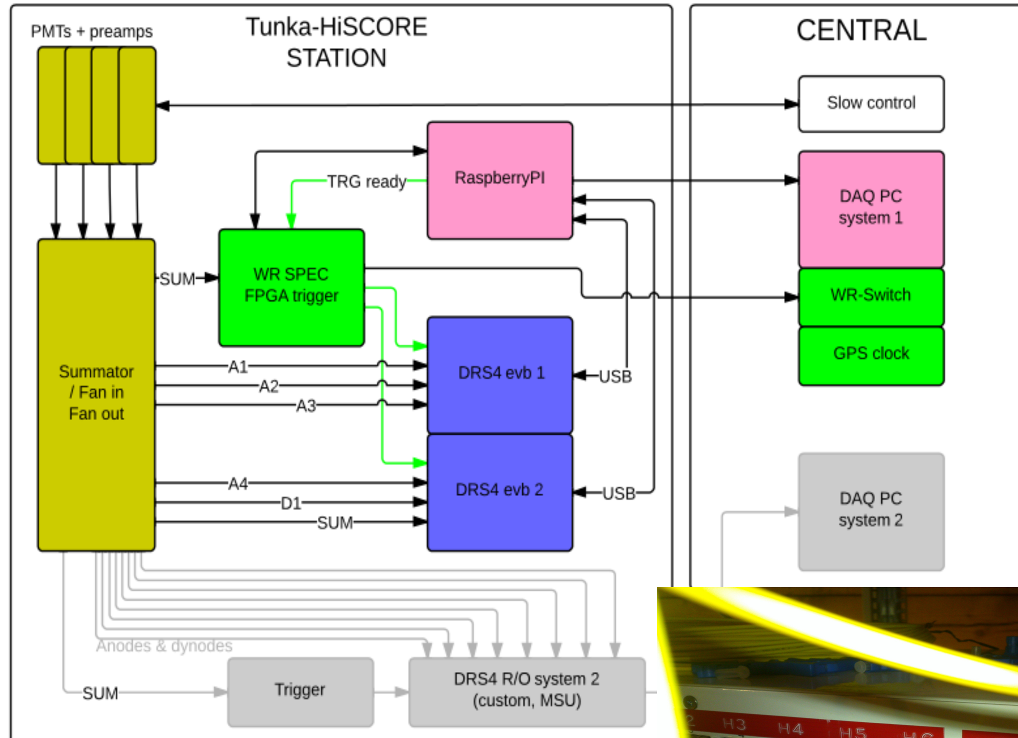


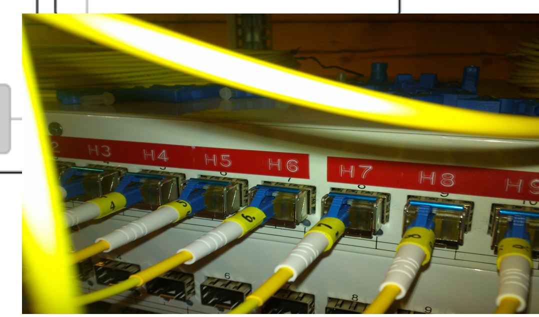


Phase stability < 0.2ns
Absolute time precision ~ 1ns

WhiteRabbit/DRS based DAQ system







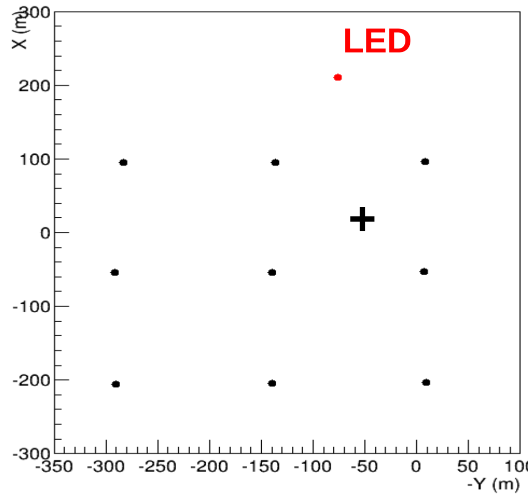
(WR Swithc)

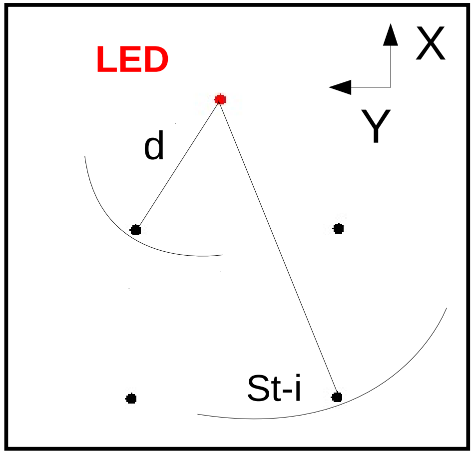
- **PMTs + Summator: signal**
  - 4 Anodes Sum (AS)
- **WR SPEC FPGA:**
  - trigger on the AS (9ns above the threshold)
- **RaspberryPI**: Connected to SPEC and DRS4 boards
  - When SPEC triggers: DRS4 start recording
  - When DRS4 recording is finished: ready flag sent to SPEC to trigger next event
  - Send data to the DAQ center
- **WR Switch:** synchronize all the array stations trigger time

Array time calibration

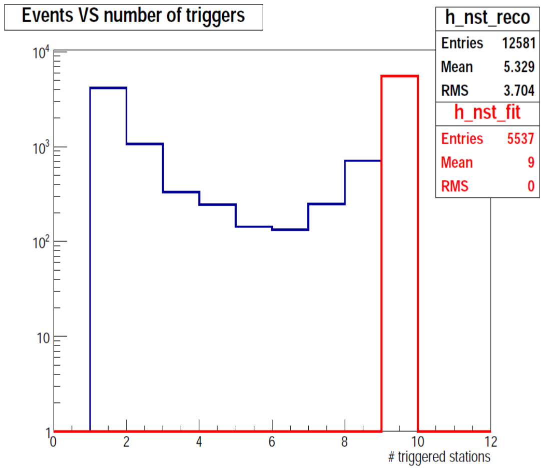
A test with a bright/wide-angle LED light source ~200m outside the array has been performed to check:

- single station performances
- Full array event reconstruction quality





- Setup:
  - LED light source (~6Hz) on the ground
  - 45° inclined mirrors on top of the stations
  -
- Data analysis:
  - only array events with all the 9 stations triggered are used
  - Constant/fixed threshold is used
  - only time information from WR timing system are used

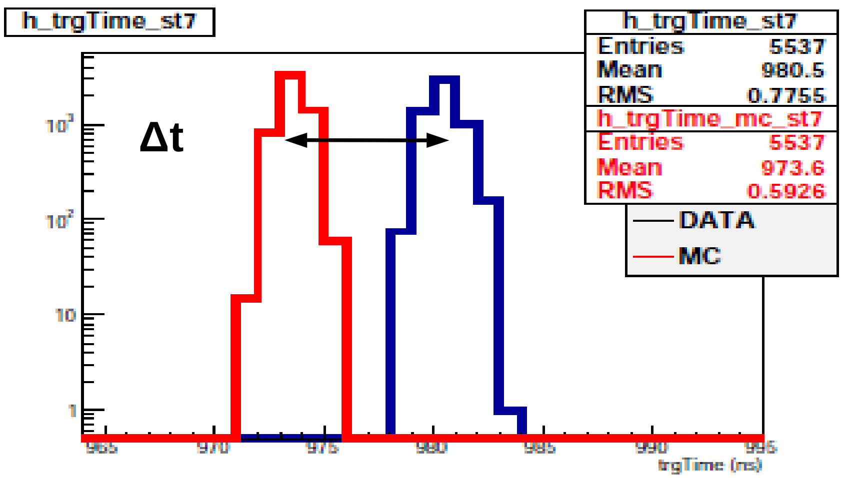


- Use a ToyMC simulation to simulate the expected behaviour of the array to compare with the data results:
  - Spherical model for light propagation
  - Time jitter with gaussian distribution (sigma = .5 ns)
  - Discretization to 1ns precision (WR)

Array time calibration

- Absolute station time delay: for each station we compare the distributions for the measured (Data) and expected (MC) relative trigger time (with respect station 3, the closest station to the LED source)

- we get: Δt = <trg_time_data> - <trg_time_MC> > 0



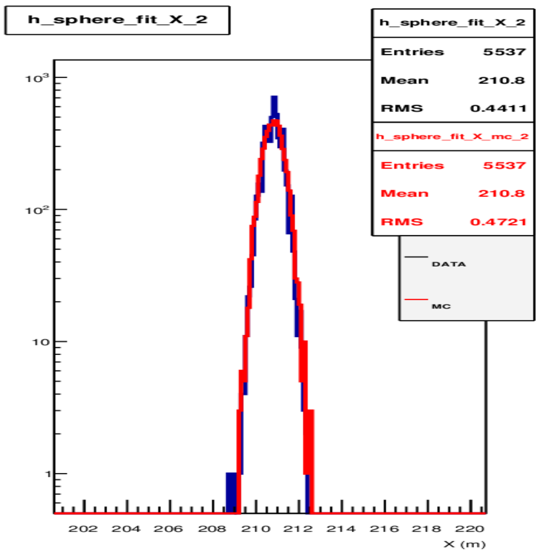
Δt	s1	s2	s3	s4	s5	s6	s7	s8	s9
run E	3,40	10,23	0,00	1,44	1,02	0,98	6,31	3,82	2,86
run F	3,28	9,80	0,00	2,08	-0,04	1,06	6,59	3,97	2,92
Mean (E-F)	3,34	10,02	0,00	1,76	0,49	1,02	6,45	3,90	2,89

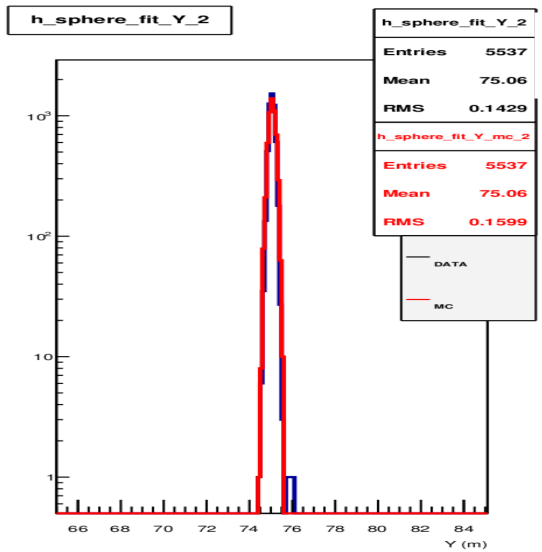
- This station time delay:
  - is due to different factors (PMTs amplification, electronics, cables,…..)
  - affects the LED source position reconstruction.

- Need to correct the single station trigger time to perform a correct event reconstruction (LED position)

Array time calibration

- Event reconstruction precision: the LED position is reconstructed by fitting the 9 stations relative trigger times (corrected) with a spherical model for the light propagation





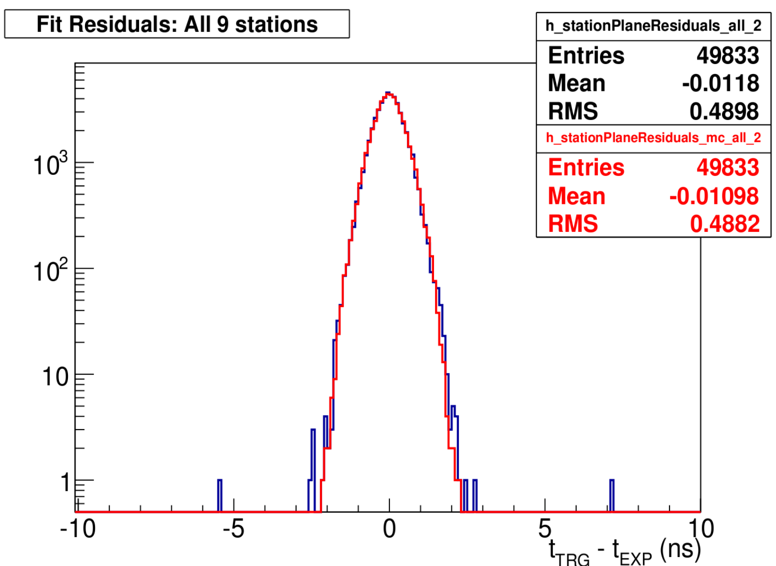
LED nominal (E,F) 210.83+-0.5 75.05+-0.5

Fit results (after trigger time correction)

	x	y
run E	210.8+-0.44	75.05+-0.14
run F	210.8+-0.42	75.06+-0.21

- The error on the LED position is < 1m

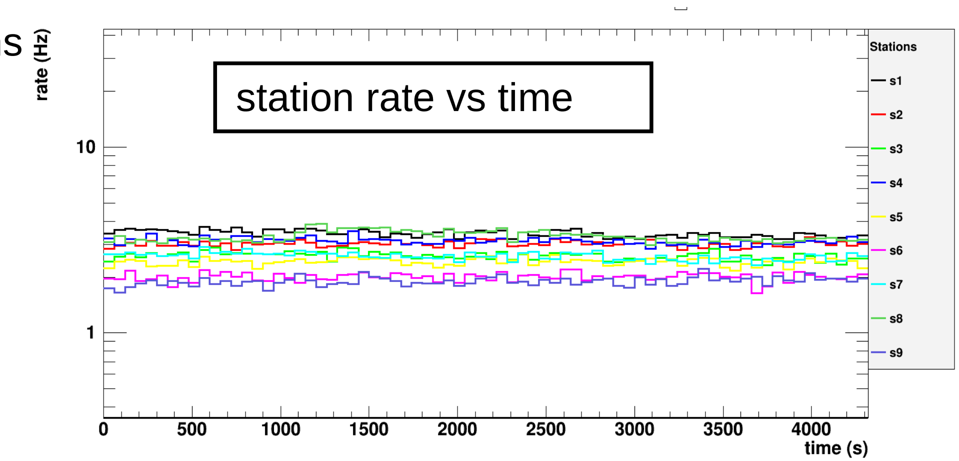
- The RMS of the fit residuals distribution gives the average time resolution/fluctuation for the trigger time (9-station fit)
  - RMS < 0.5ns



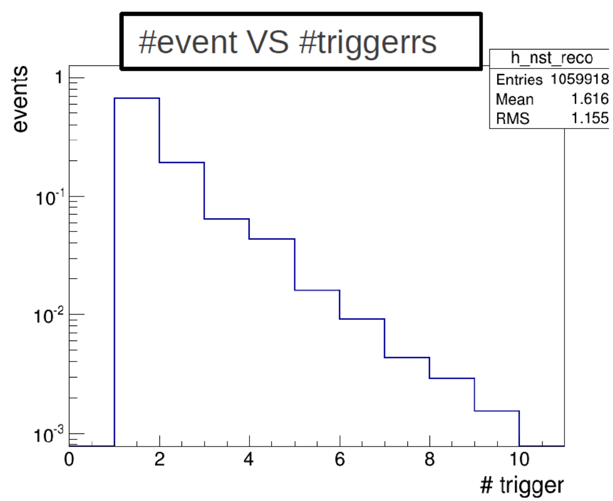
HiSCORE-9 data reconstruction

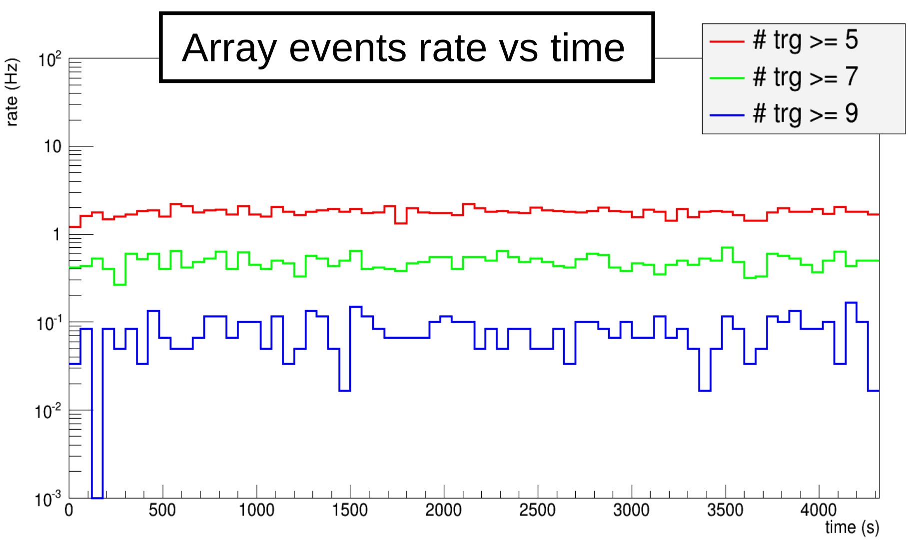
First reconstruction of the EAS events collected with the HiSCORE-9 prototype

- Data set: 12 runs from the same period of calibration runs
  - ~ 40h of data taking



- Array event building:
  - merge stations triggered in a time window of 1.5µs
  - Time information: WR trigger time
- Time calibration obtained from calibration runs
- Preliminary amplitude correction factor from mV to phe
- Selection: events with 9 station hit

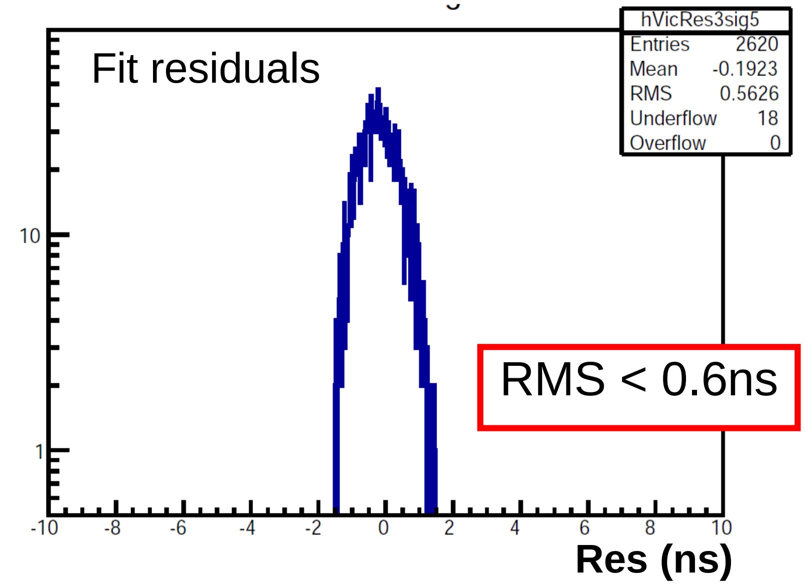


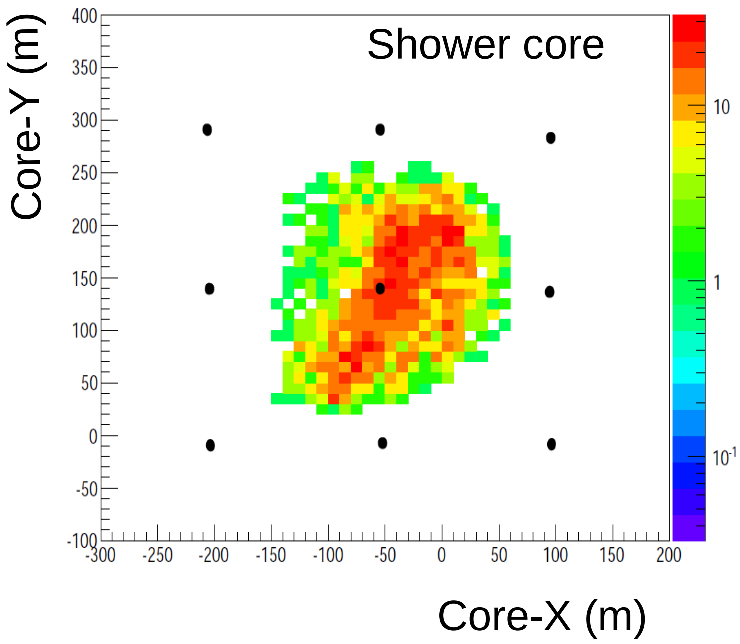


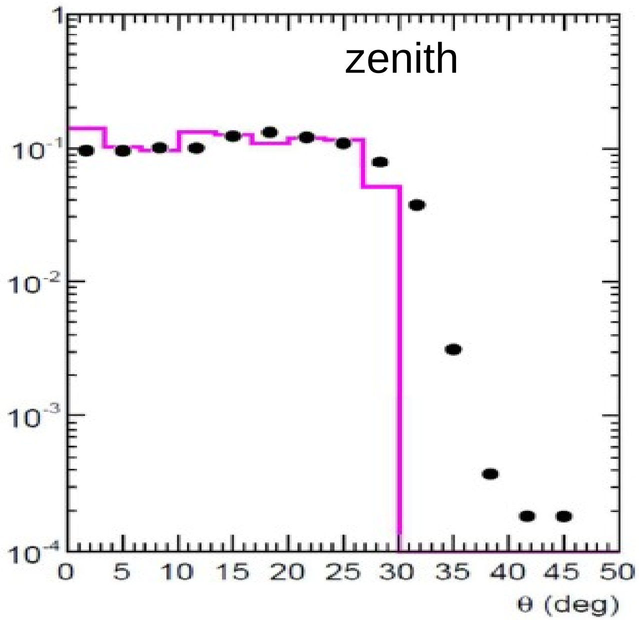
HiSCORE-9 data reconstruction

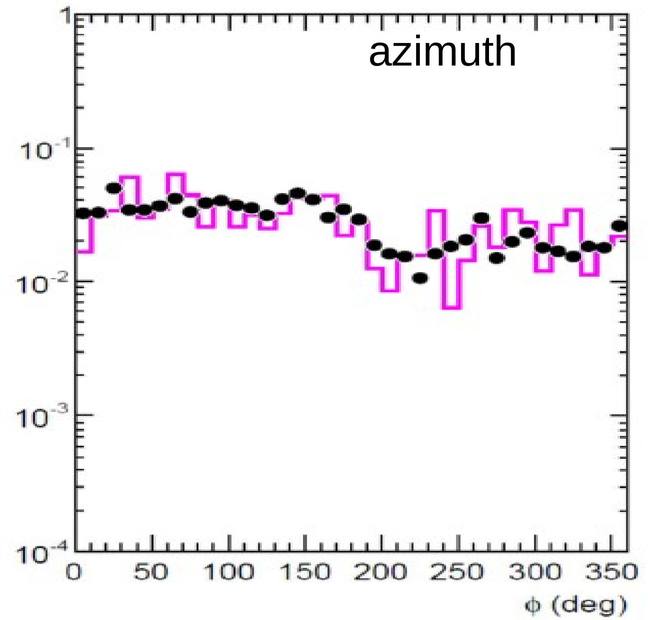
Recontructed shower parameters:

- Shower Core:
  - COG methond: weighted average of stations' pulses
- Direction (theta, phy):
  - Direction reconstruction algorithm based on a parametrization of arrival time at detector position (model fit adapted from Stamatescu et al. 2011, D.Hampf PhD thesis, 2012)
  - $t_i = t_i\,(\theta, \varphi, z) + t_0$





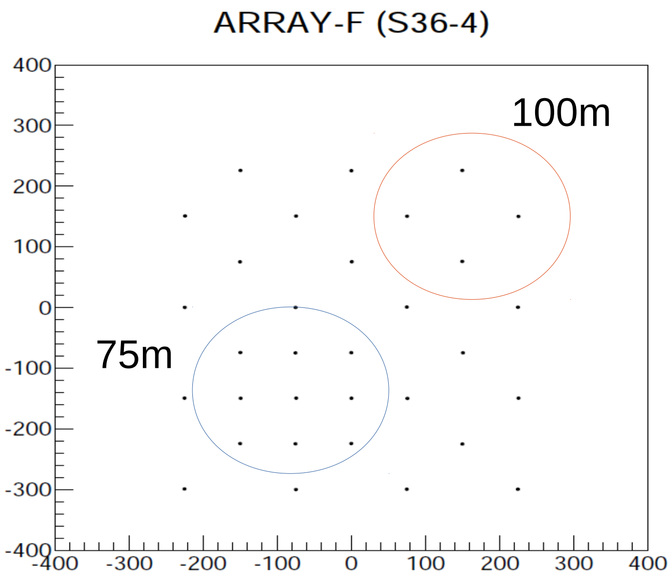




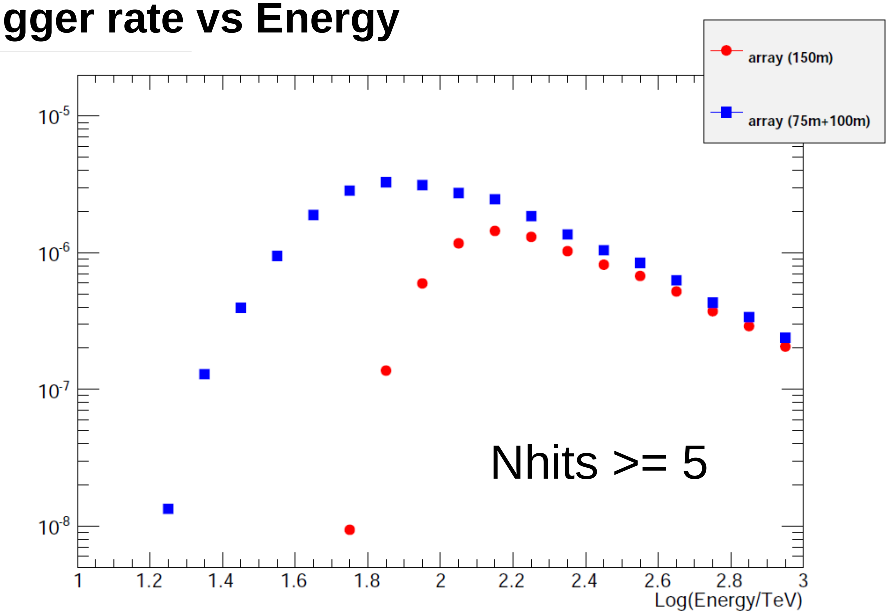
HiSCORE-2014: optimziation

- Array layout optimization: Tunka HiSCORE-2014
  - 25 new station will be deployed (fall 2014)
  - Hybrid array layouts: 100m and 75m inter-stations distance

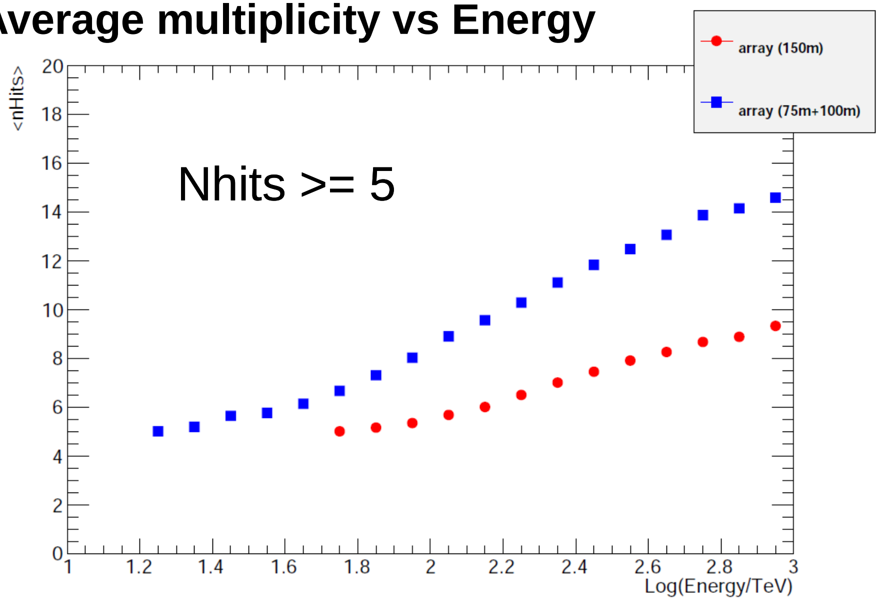
    7 different layouts simulated (example: ARRAY-F)
  - Aim: minimal threshold for sources detection (Crab)



Trigger rate vs Energy



Average multiplicity vs Energy



summary

- HiSCORE 9-station prototype array operates since Oct.2013
  - a dedicated DAQ to study the WhiteRabbit system for nsec-timing (first field setup)

- Time calibration
  - extract station calibration for EAS-reconstruction
  - timing precision ~0.5ns (fit residual)

- EAS reconstruction with HiSOCRE-9 prototype
  - EAS-model fit with ~0.6ns rms
  - in progress: optimization for lwo energy events (low multiplicities)

- HiSCORE-2014 array optimization
  - hybrid setup (graded array): denser inner array
  - to lower threshold for source detection (~20TeV)

THANK YOU

Back up slides

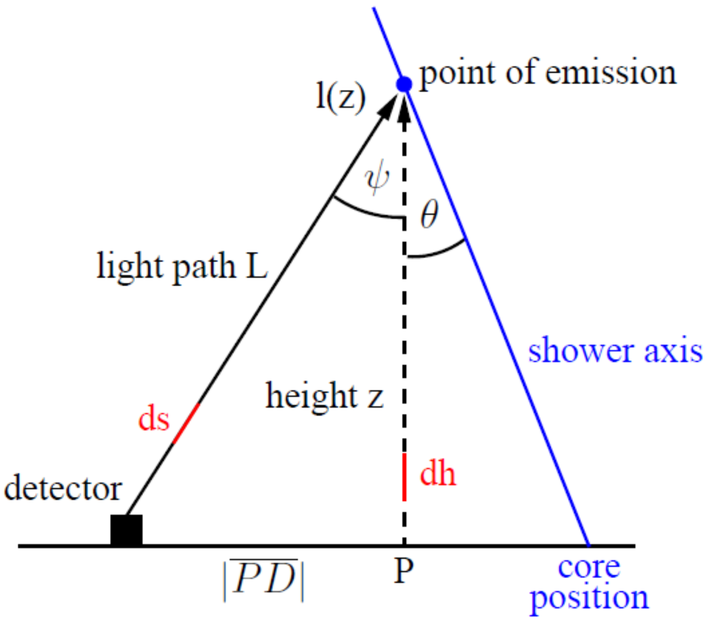
Direction reconstruction model

- (model fit adapted from V.Stamatescu et al. 2011) [D.Hampf reco_score]
  - $t_i = t(\theta,\varphi,z) + t_0$
  - 4 parameters → N-trg ≥ 4

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

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

$$\delta = \varphi + atan2\big((x_{DET} - x_{CORE}),(y_{DET} - y_{CORE})\big)$$



  - Integration along the light path L (ds = c dt)