Timing calibration and directional reconstruction for Tunka-HiSCORE

Andrea Porelli for the Tunka-HiSCORE collaboration (DESY)
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 km²
- 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 achieve a sub-ns time resolution
WhiteRabbit timing system

- WR main components

  **WR Master: WR Switch**

  **1Gbit fiber**

  **FMC DIO mezzanine**

  **WR-Node: SPEC card**

  **USB terminal**

  **HiSCORE station 1**

  **HiSCORE station 2**

  **HiSCORE station 3**

  **HiSCORE station 4**

  **HiSCORE station 5**

  **HiSCORE station 6**

  **HiSCORE station 7**

  **HiSCORE station 8**

  **HiSCORE station 9**

  Phase stability < 0.2ns

  Absolute time precision ~ 1ns

  **Early test in 2012/13**

  rms ~0.17ns

  Stability LabTest 50 hrs

  Clock synchronization (long term)
WhiteRabbit/DRS based DAQ system

- 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: $\Delta t = <\text{trg\_time\_data}> - <\text{trg\_time\_MC}> > 0$

- 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
  - 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

Fit results (after trigger time correction)

Run E: 210.8±0.44 75.05±0.14
Run F: 210.8±0.42 75.06±0.21
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

Reconstructed shower parameters:

- **Shower Core:**
  - COG method: weighted average of stations' pulses
- **Direction (theta, phi):**
  - 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)
  - \( t_i = t_i(\theta, \phi, z) + t_0 \)

Fit residuals

\begin{array}{c|c|c|c}
\hline
\text{Entries} & 2620 \\
\text{Mean} & -0.1923 \\
\text{RMS} & 0.5626 \\
\text{Underflow} & 18 \\
\text{Overflow} & 0 \\
\hline
\end{array}

RMS < 0.6ns
HiSCORE-2014: optimization

- 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**

Nhits >= 5
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 HiSCORE-9 prototype
  - EAS-model fit with ~0.6ns rms
  - in progress: optimization for low 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 $\rightarrow$ N-trg $\geq$ 4

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

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

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

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