

# Reconstruction of coincident SD/RD Events at the Pierre Auger Observatory using the OffLine-Framework

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# Outline

## 1 Motivation

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- 2 An improved SD-Reconstruction

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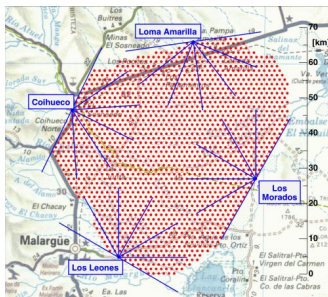
- 1 Motivation
- 2 An improved SD-Reconstruction
- 3 Analysis of self-triggered radio data

# Outline

- 1 Motivation
- 2 An improved SD-Reconstruction
- 3 Analysis of self-triggered radio data
- 4 Outlook & Summary

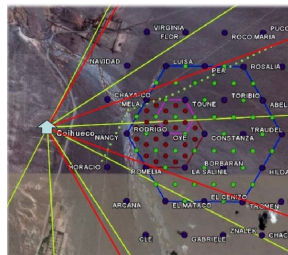
# The Pierre Auger Observatory (PAO)

- Pierre Auger (1938): Existence of extensive air showers (EAS)
- PAO is largest surface detector experiment worldwide with an array of approximately  $3000 \text{ km}^2$
- Sited near the city of Malargüe, Mendoza, Argentina



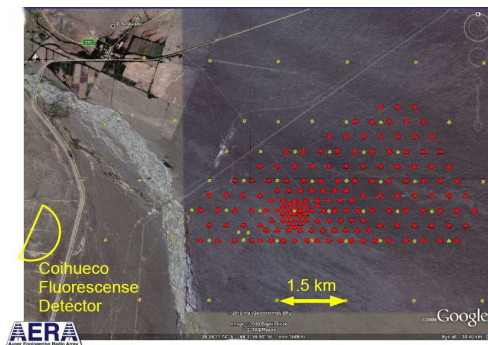
# Surface- & Fluorescence Detectors

- PAO build as Hybrid-Detector
- 1600 Water-Cherenkov-Tanks (SD)
- 4x6 Fluorescence-Telescopes (FD)
- Extensions:
  - AMIGA : **A**uger **M**ouns and **I**nfill for the **G**round **A**rray
  - HEAT : **H**igh **E**levation **A**uger **T**elescopes



# Auger Engineering Radio Array

- 161 autonomous radio detector stations
- 3 stages of deployment (144m, 250m, 433m spacing)
- sited near Coihueco / HEAT and in the infill array



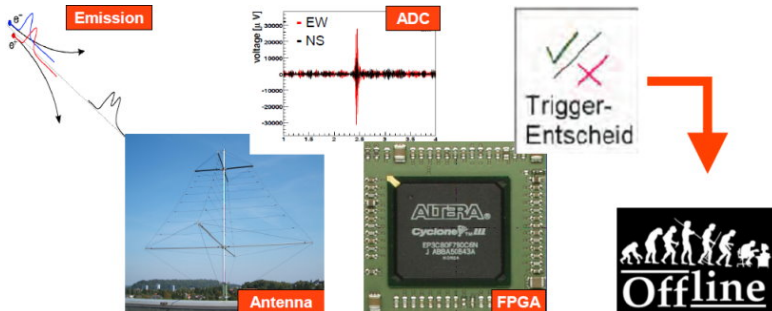


# Antenna & electronics

- Logarithmic Periodic Dipole Antenna : '*Small Black Spider*'
- Low Noise Amplifier
- FPGA-based front-end electronics (digitizer)



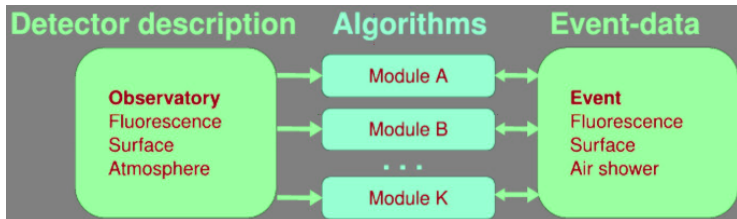
# From EAS to ASCII



- More information on electronics / trigger → Talk: C. Ruehle
- ASCII files from DAQ are fed into OffLine for further analysis

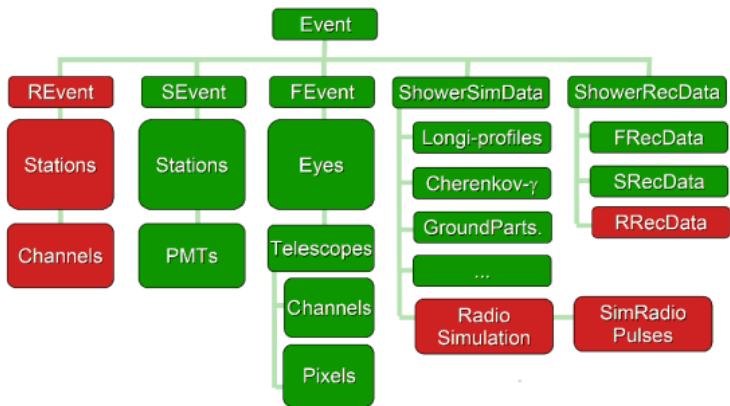
# The Offline-Framework

- Software-Framework for analysis purposes
- Completely modularized for highly flexible applications
- Clear separation between event and detector structure

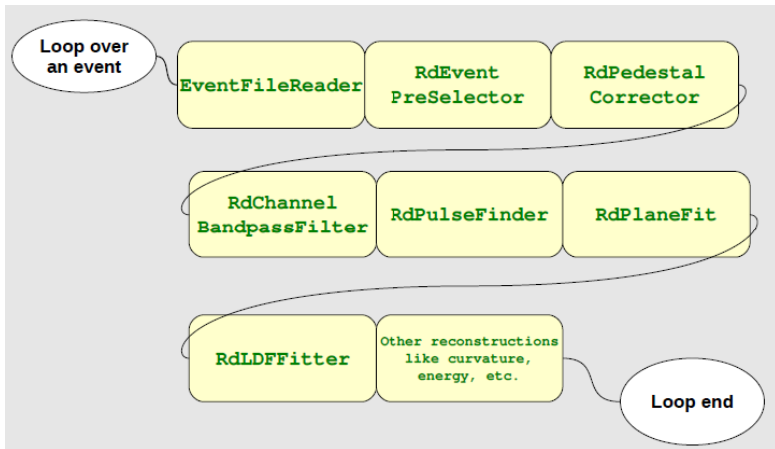


# The Offline-Framework

- Structure of the OffLine-Event class



# Typical module sequence

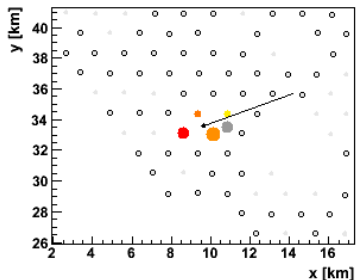


## What we have (and what not) ...

- Three test setups in AERA Phase 1:
    - MAXIMA @ BLS
    - STAR @ BLS
    - RAuger @ CLF
  - MAXIMA data from 2007/2008:
    - Daily check for events with additional SD-Tank 'Olaiá'
    - Check for coincidences in  $\approx 100 \mu\text{s}$  window
    - Found 494 'coincident' events
  - 'Problem': Only done with normal Auger reconstruction
- Need for a corresponding SD-Reconstruction in OffLine for further RD analysis

# SDEventSelector

- Initial point: Tank 'Olaia' not included in standard OffLine-Reconstruction
- Incorporate extensions from Infill-Reconstruction
- Add code for selecting events by list of requested stations



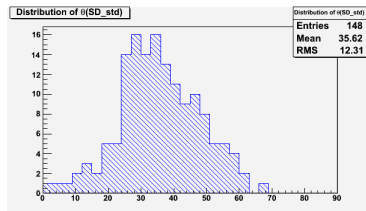
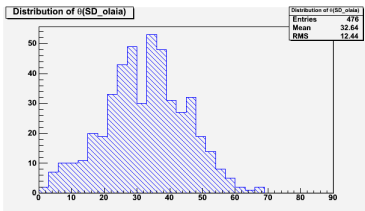
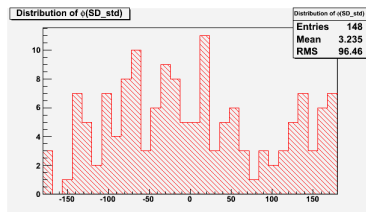
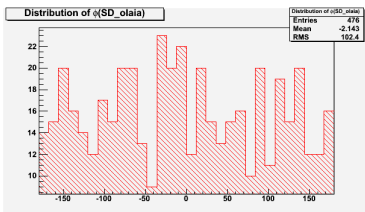
## CoinData494

- Run Observer-Reconstruction for CoinData time period
  - apply some (Non)-'Quality' cuts
  - Standard reconstructions yields 148 of 494 events
  - Olaia reconstruction yields 476 of 494 events
- Only 31 % of the total events reconstructed without Olaia
- missing 18 events identified as shower, but not reconstructable due to alignment of hit tanks



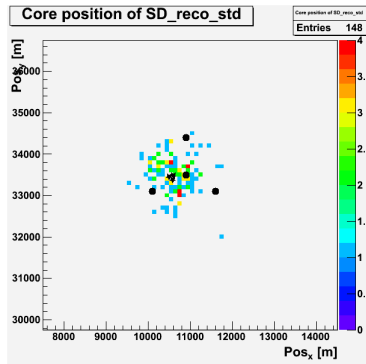
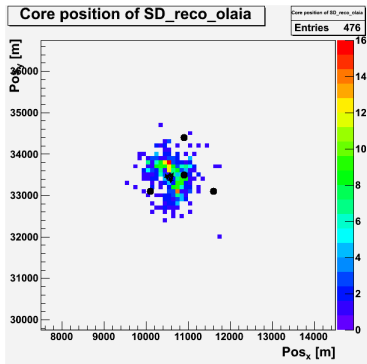
## CoinData494

- Angular distribution ( $\phi$  (top) and  $\theta$  (bottom))

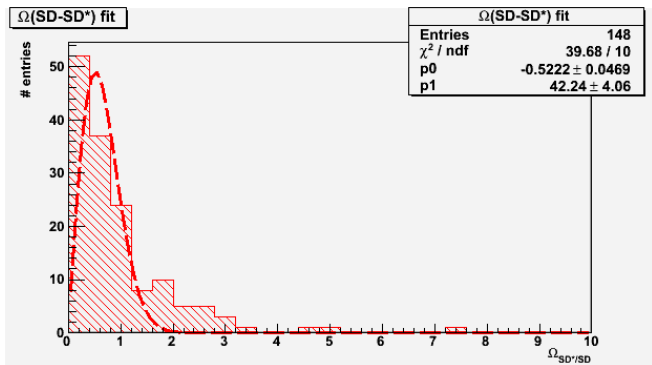


## CoinData494

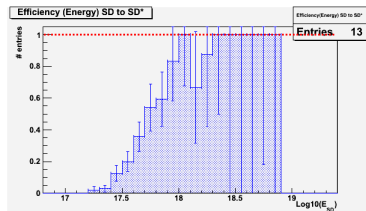
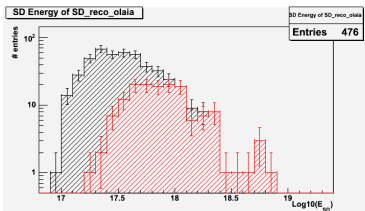
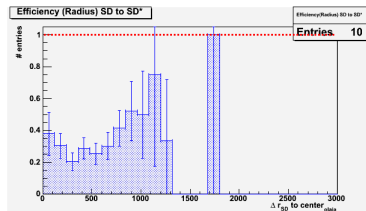
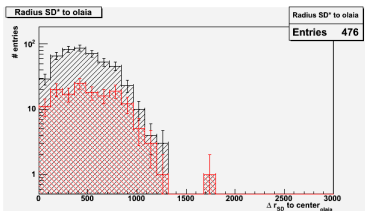
- Core position (● = *Tank*, \* = *Antenna*)



- Angular resolution  $< 2^\circ$

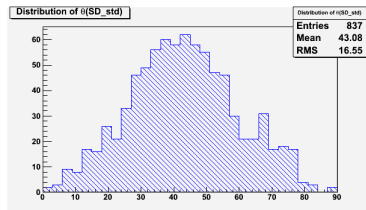
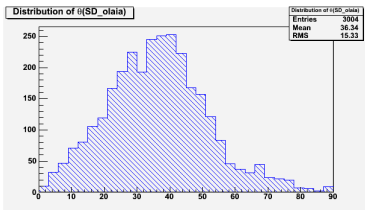
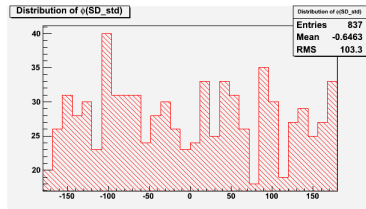
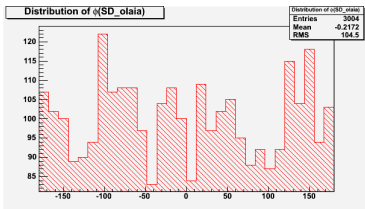


- Angular efficiency for radial distance and energy



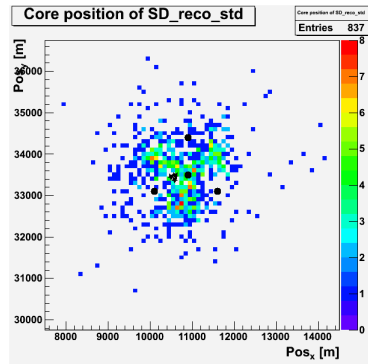
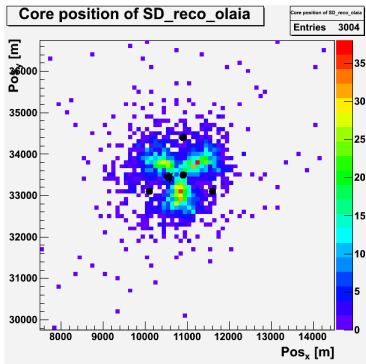
## FullCoinTime

- Angular distribution ( $\phi$  (top) and  $\theta$  (bottom))

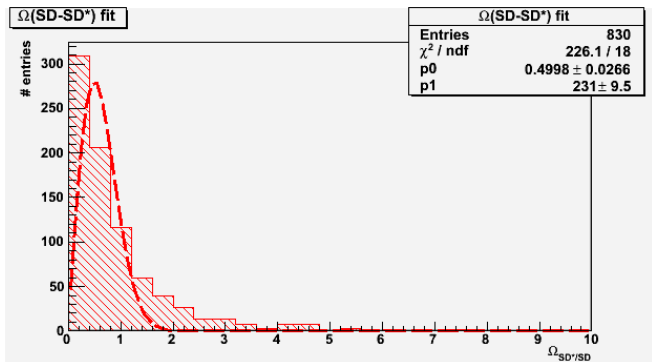


## FullCoinTime

- Core position (● = *Tank*, \* = *Antenna*)

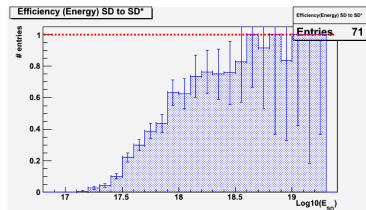
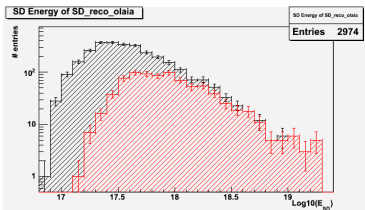
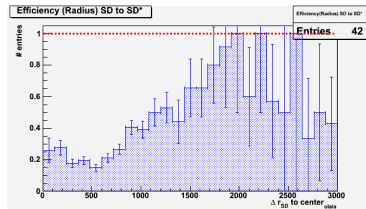
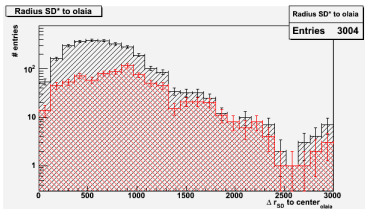


- Angular resolution  $< 2^\circ$



## FullCoinTime

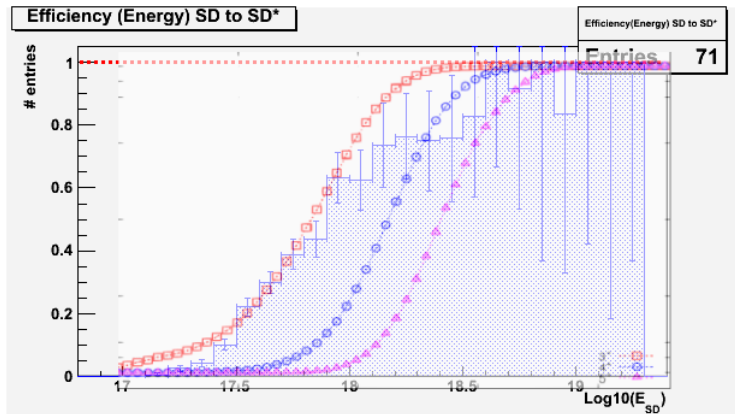
- Angular efficiency for radial distance and energy





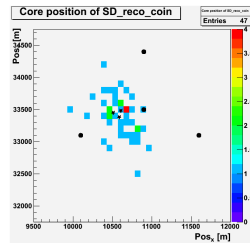
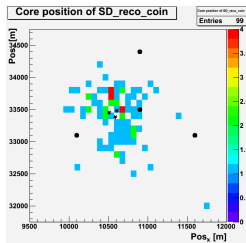
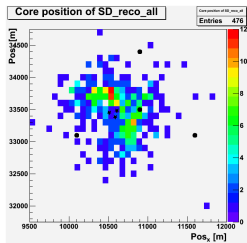
## FullCoinTime

- Cross-check: Efficiency  $\approx$  Auger acceptance



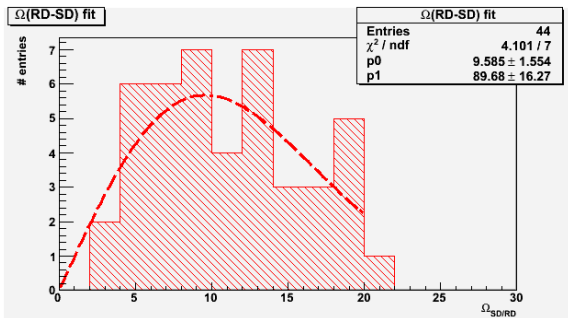
## CoinData494

- Compare SD\*-reconstruction with RD-reconstruction for available parameters
- Core Position for SD, RD( $\text{SNR}^2 = 16$ ) and RD( $\text{SNR}^2 = 25$ )



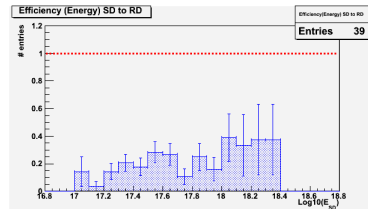
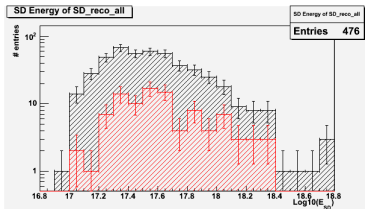
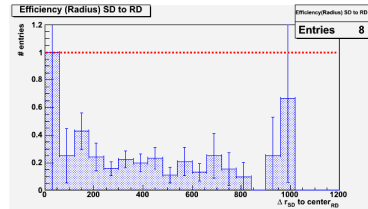
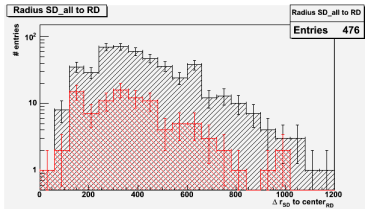
## CoinData494

- Angular resolution  $\approx 10^\circ$
- Sounds huge, but remember 150m baseline of antenna layout
- No big change with increasing SNR



## CoinData494

- Angular efficiency for radial distance and energy

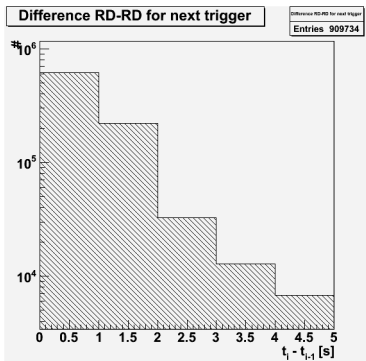
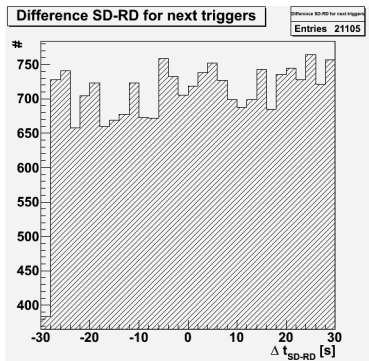


# STAR data

- Even more important is analysis of the newer radio data
  - Search for coincidences between STAR and SD\*
  - Check for GPS-time differences
  - Noise studies
  - Favoured arrival directions
  - influence of different SNR

# STAR raw data

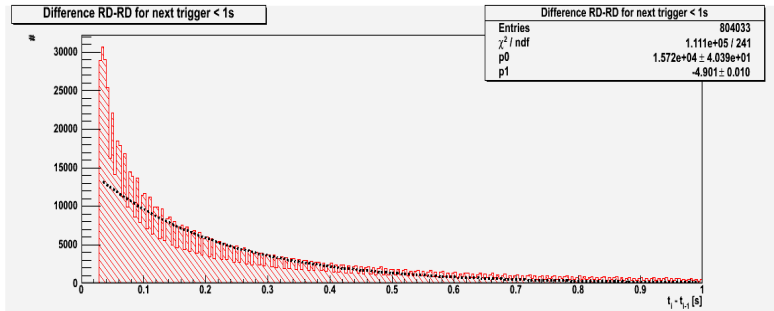
- Difference to next trigger for SD/RD and RD/RD



- No clue for time offset between SD and RD due to many RD events for one SD event

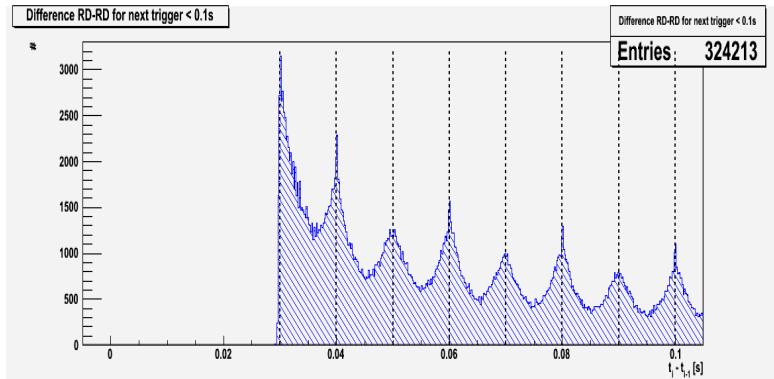
# STAR raw data

- Difference to next trigger for RD/RD for  $\Delta t < 1s$
- Exponential drop-off, sin-structure on top?!



# STAR raw data

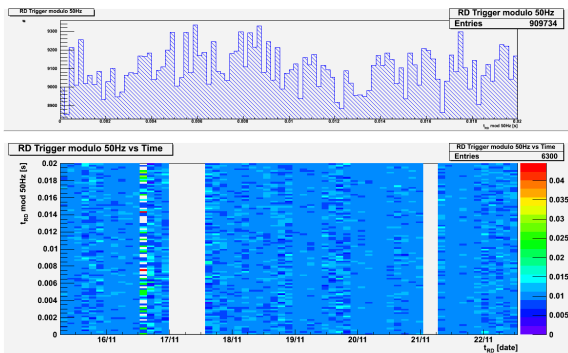
- Difference to next trigger for RD/RD for  $\Delta t < 0.1s$
- 50 Hz power line clearly visible





## STAR raw data

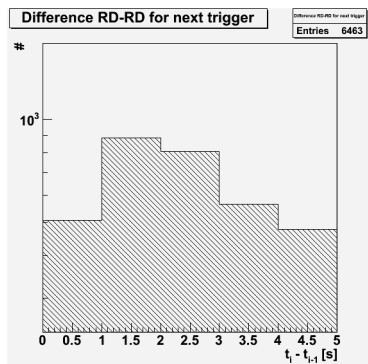
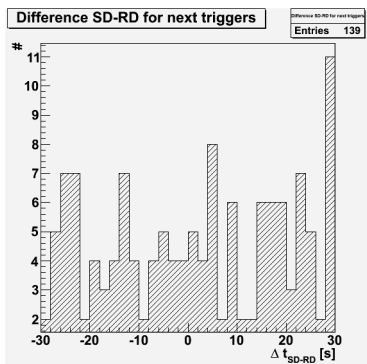
- $t \bmod 50 \text{ Hz}$  (Phase ? )



- unfortunately no sign for (time-dependent) phase

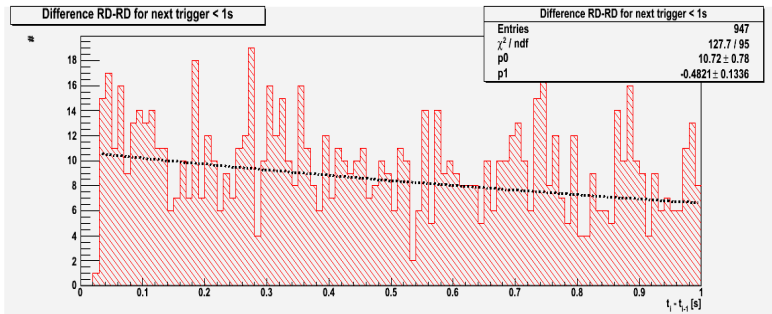
# STAR reconstructed data

- Difference to next trigger for SD/RD and RD/RD



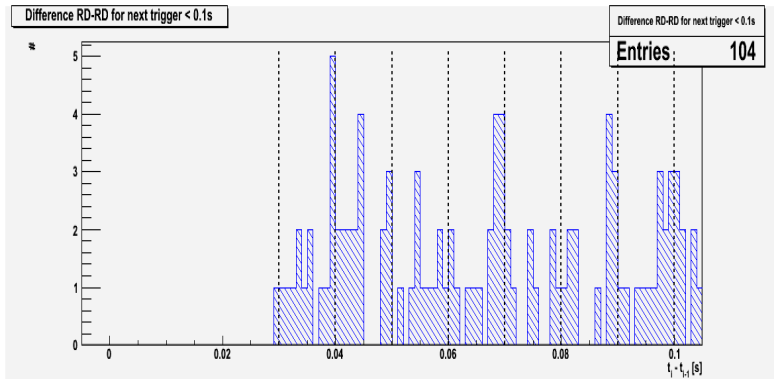
# STAR reconstructed data

- Difference to next trigger for RD/RD for  $\Delta t < 1s$



# STAR reconstructed data

- Difference to next trigger for RD/RD for  $\Delta t < 0.1s$
- Are there still power line events? → ongoing!



# Pull the trigger..!

- AERA will run in self-trigger mode
- 'Framework' almost clear, but parameters not fixed yet
- need larger 'database' of real pulses for further pulse shape analysis
- try to filter out the possible coincident events for additional hints on trigger parametrization
  
- influence of SNR? azimuthal arrival direction?

# Summary

- AERA is in build-up phase and will deliver first data soon
- RD-Offline is ready for this
- Final goal will be a **RD/SD(/FD) Hybrid-Reconstruction**
  
- SD-Reconstruction has been adapted to include Olaia
- Without Olaia only 35% of the coincident events reconstructed
- Angular residuals  $< 2^\circ \rightarrow$  no change in accuracy, but in statistics
  
- Coincidence search in STAR data ongoing
- Exclusion of e.g. power line events not as easy as 'hoped'
- further investigations of parameters (SNR, angles, ...)

T H A N K S !