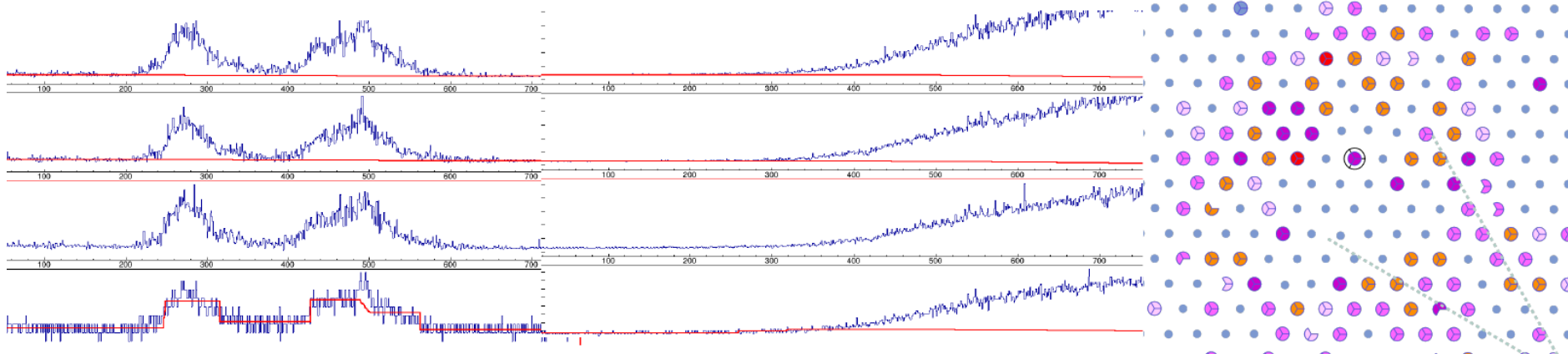# Exploiting the Trigger Information of the Pierre Auger Observatory
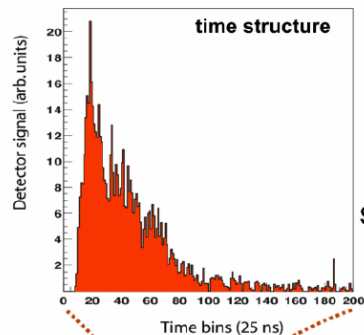
Martin Schimassek
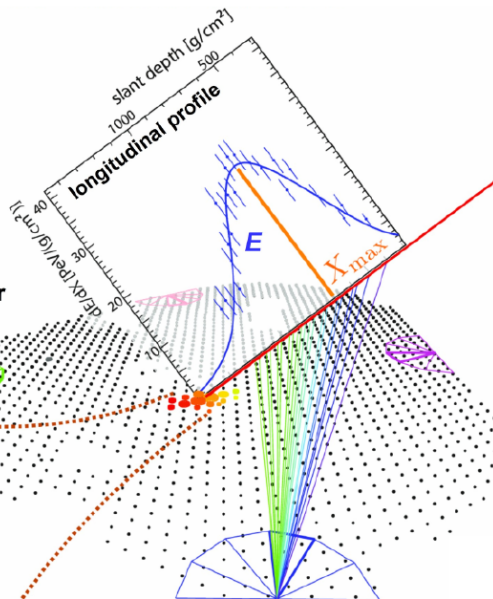
The (usual) Measurements

time structure

Surface Detector
~100% duty cylce

$S_{1000} \propto E$

S_{1000}

lateral distribution

longitudinal profile

E

X_{max}
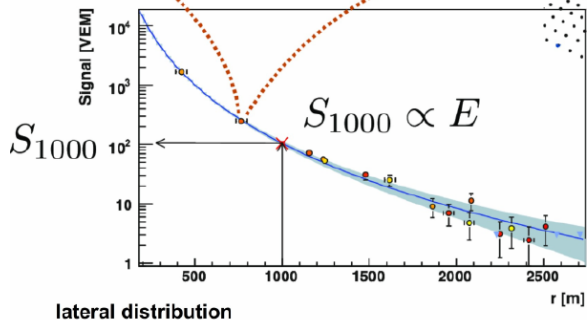
Fluorescence Detector
~15% duty cylce
(cloudless nights, low moon fractio

Phys. Rev. D 102, 062005 (2020)

Observed Excess Map - E > 39 Eev

Astrophysical Journal Letters, 853:L29

Science 357, 1266–1270 (2017)
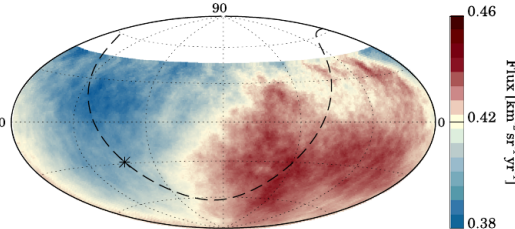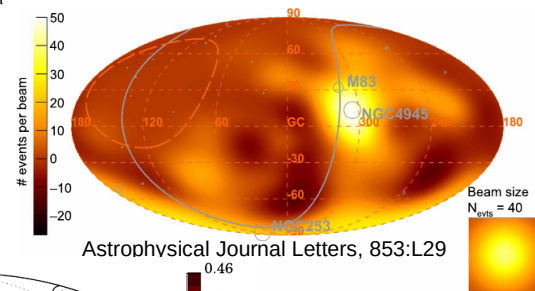
How does data taking work?
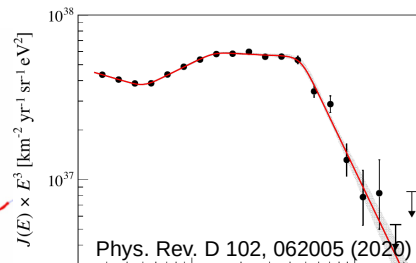
UNSAM
UNIVERSIDAD NACIONAL DE SAN MARTÍN

KIT
Karlsruhe Institute of Technology

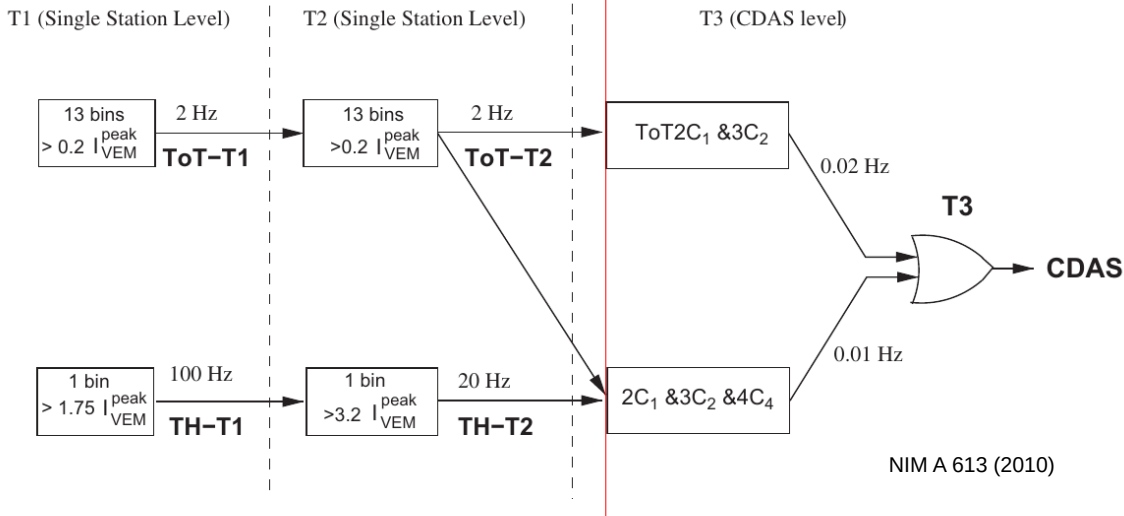SD-station:
independent operation
forms **local triggers**
+ calibration /
monitoring information

Comms:
 backbone between FDs
 SD: WLAN with stations
 1200 b/s uplink per station

CDAS:
 receive and store data
 internet connection
 **from array triggers and request data**

Local Triggers

SD-station:
independent operation
forms **local triggers**
+ calibration /
monitoring information

T1 (Single Station Level)   T2 (Single Station Level)   T3 (CDAS level)

13 bins $> 0.2\, I_{VEM}^{peak}$ **ToT−T1** — 2 Hz →

13 bins $> 0.2\, I_{VEM}^{peak}$ **ToT−T2** — 2 Hz →

$ToT2C_1\, \&3C_2$ — 0.02 Hz →

T3
CDAS

1 bin $> 1.75\, I_{VEM}^{peak}$ **TH−T1** — 100 Hz →

1 bin $> 3.2\, I_{VEM}^{peak}$ **TH−T2** — 20 Hz →

$2C_1\, \&3C_2\, \&4C_4$ — 0.01 Hz →
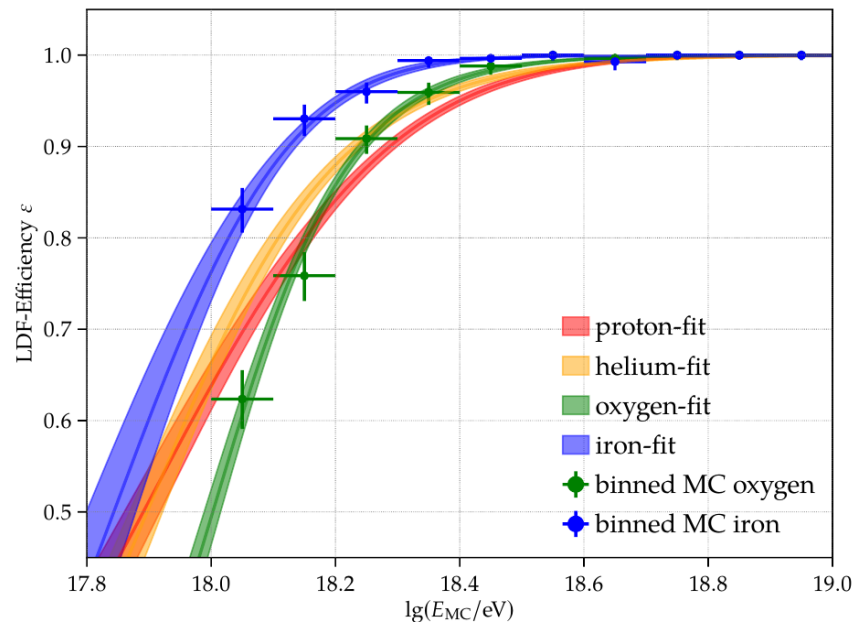
NIM A 613 (2010)

Two (main) triggers:
 - single bin trigger
 - time-over threshold
 - since 2013: a deconvoluted ToT + MoPS (pos. steps)

How efficient is the trigger?

NIM A 613 (2010)
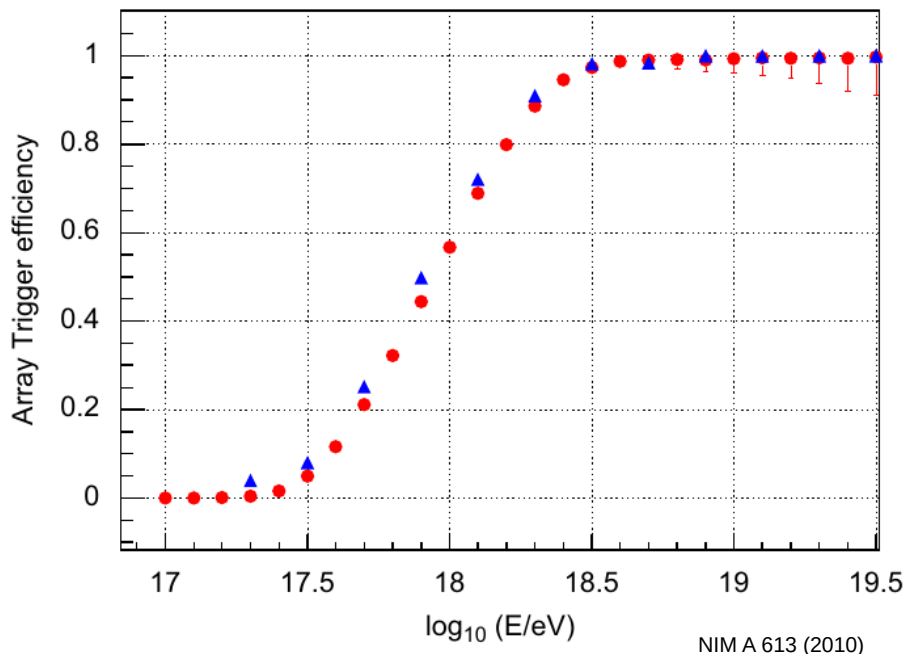
estimated from hybrids and SD


check with Monte-Carlo

New Data – What changed?

- We save all T2 triggers at CDAS (starting 01/2016)

- about 360 GB / month

- 'usual' SD data: about 17 GB / month

- contains (station Id, µs, trigger type) only


```
/12/t2dump_2020_12_01_*
515M Jan 11  2021 /lsdf/auger/tmp/T2Dump/2020/12/t2dump_2020_12_01_00h00.dat.bz2
514M Jan 11  2021 /lsdf/auger/tmp/T2Dump/2020/12/t2dump_2020_12_01_01h00.dat.bz2
513M Jan 11  2021 /lsdf/auger/tmp/T2Dump/2020/12/t2dump_2020_12_01_02h00.dat.bz2
514M Jan 11  2021 /lsdf/auger/tmp/T2Dump/2020/12/t2dump_2020_12_01_03h00.dat.bz2
513M Jan 11  2021 /lsdf/auger/tmp/T2Dump/2020/12/t2dump_2020_12_01_04h00.dat.bz2
513M Jan 11  2021 /lsdf/auger/tmp/T2Dump/2020/12/t2dump_2020_12_01_05h00.dat.bz2
513M Jan 11  2021 /lsdf/auger/tmp/T2Dump/2020/12/t2dump_2020_12_01_06h00.dat.bz2
513M Jan 11  2021 /lsdf/auger/tmp/T2Dump/2020/12/t2dump_2020_12_01_07h00.dat.bz2
```
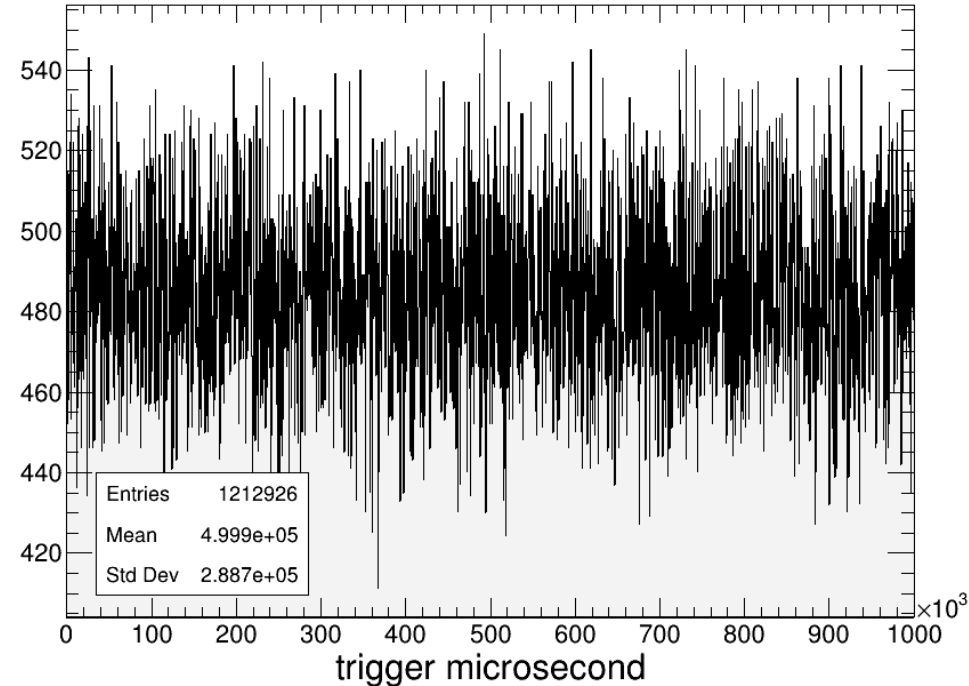
Special Events

- coincident events from nuclei split by solar photons

- prediction by Gerasimova & Zatsepin (JETP 11 (1960) 899)

- very challenging:
  - low flux
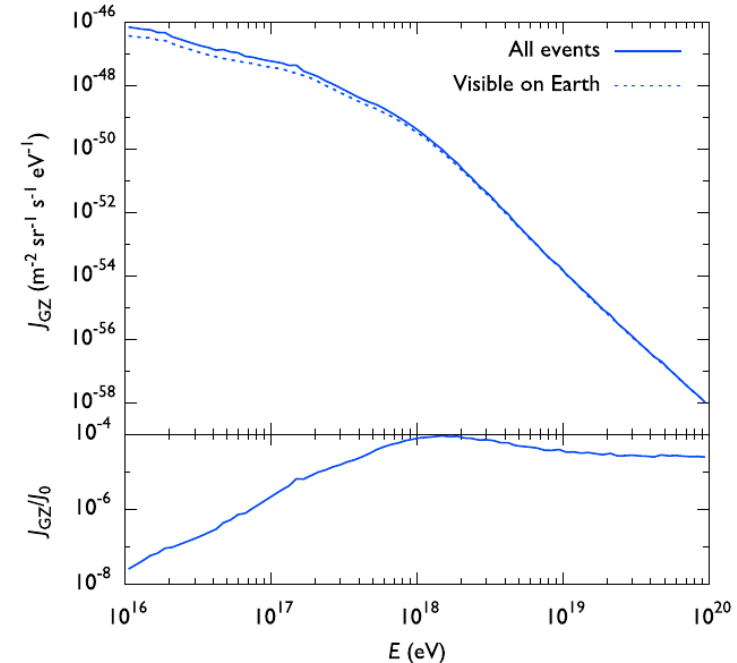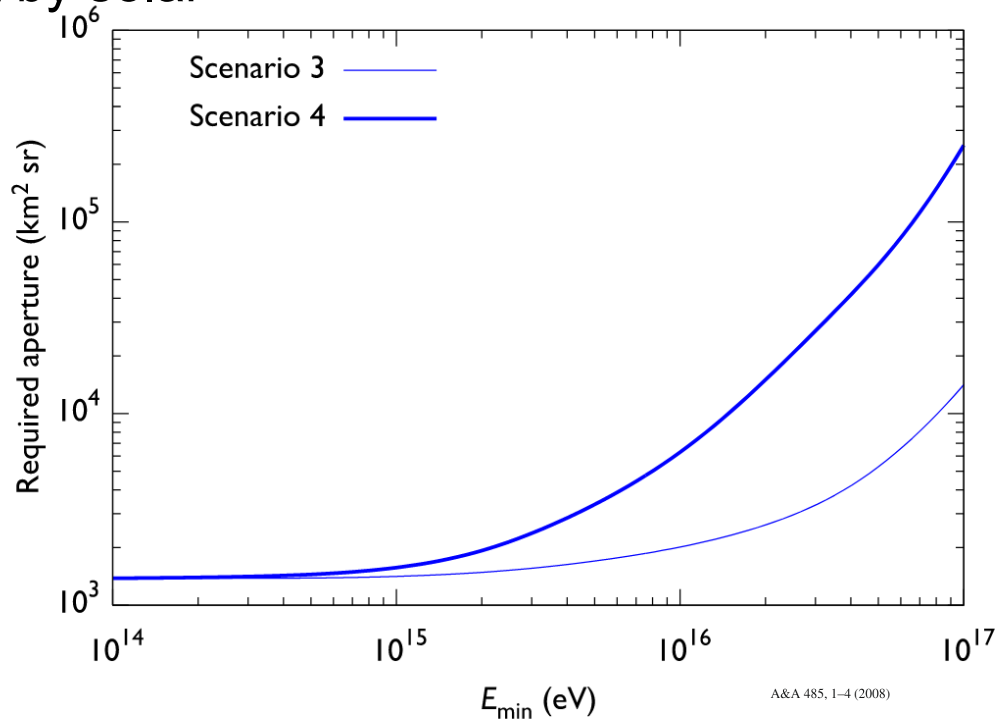

A&A 485, 1–4 (2008)

Special Events

- coincident events from nuclei split by solar photons

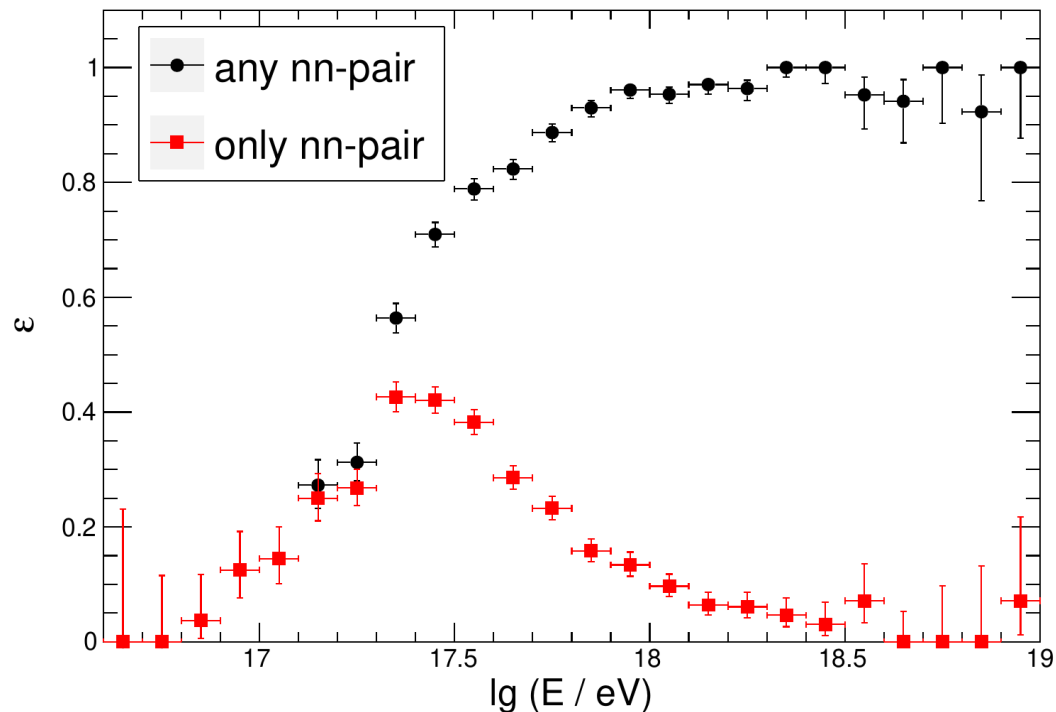- prediction by G & Z (JETP 11 (1960) 899)

- very challenging:
  - low flux
  - very low threshold required

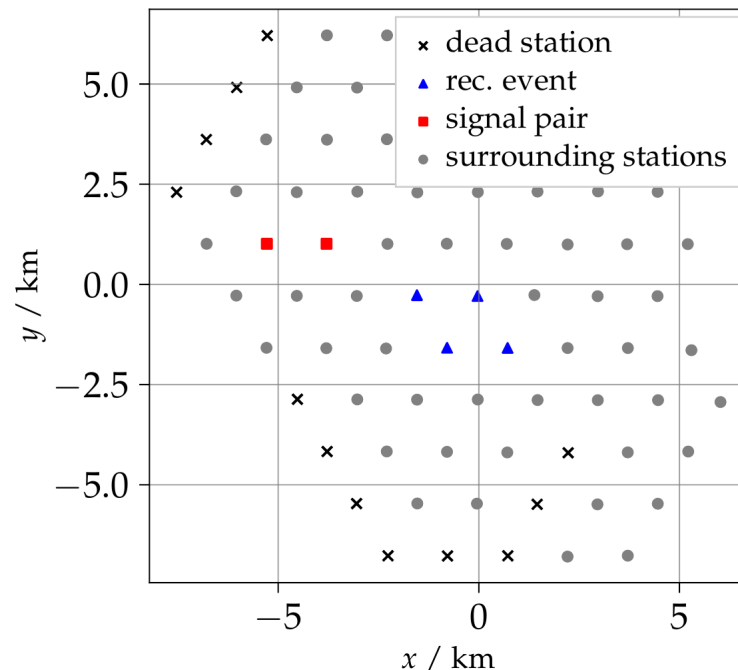A&A 485, 1–4 (2008)

(Low) Energy Frontier

- Using pairs of triggers from nearest neighbor stations?

- use hybrid measurements of showers (FD) as input sample

- we reach one decade lower in energy

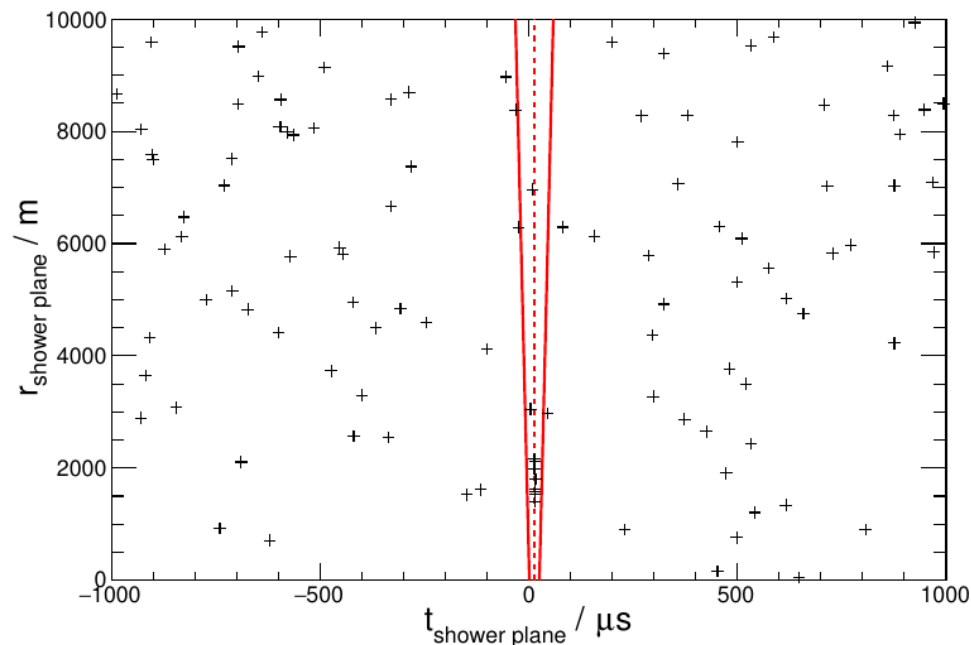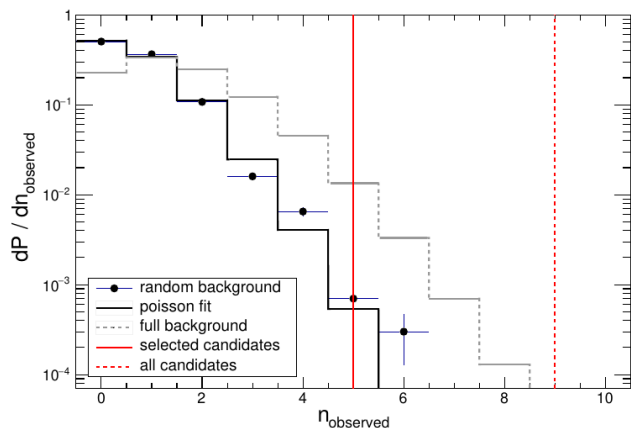Institute of Experimental Particle Physics (ETP)

Search for GZ-events

- lower threshold by using trigger pairs + reconst. event

- use the reconstructed direction to calculate distance in shower-plane

- use recon. events with lg (E / eV) > 17.5 to go as low in energy as possible

Search for GZ-events

- search window at t ~ 0

- get background from random t

02.11.2021   Martin Schimassek – Trigger System at Auger   Institute of Experimental Particle Physics (ETP)
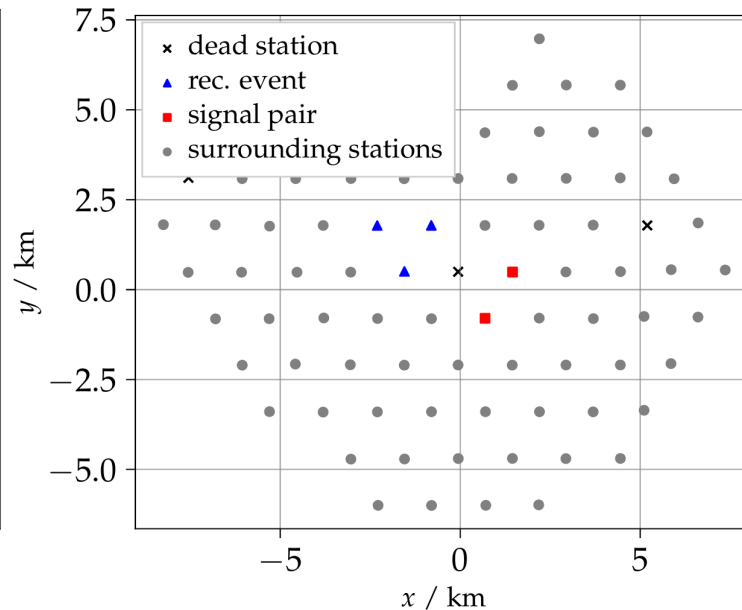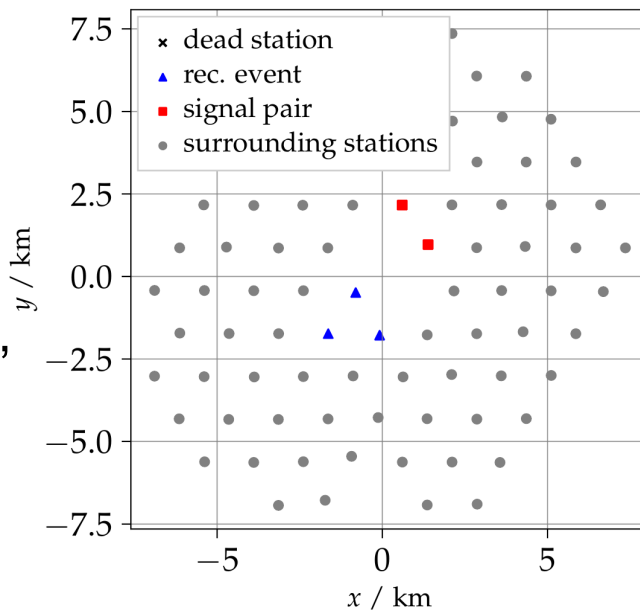
Selected Candidates?

- dead stations

- holes

- remove 4 out of 9 'candidates'

Full Background?

- split events due to dead-time of stations
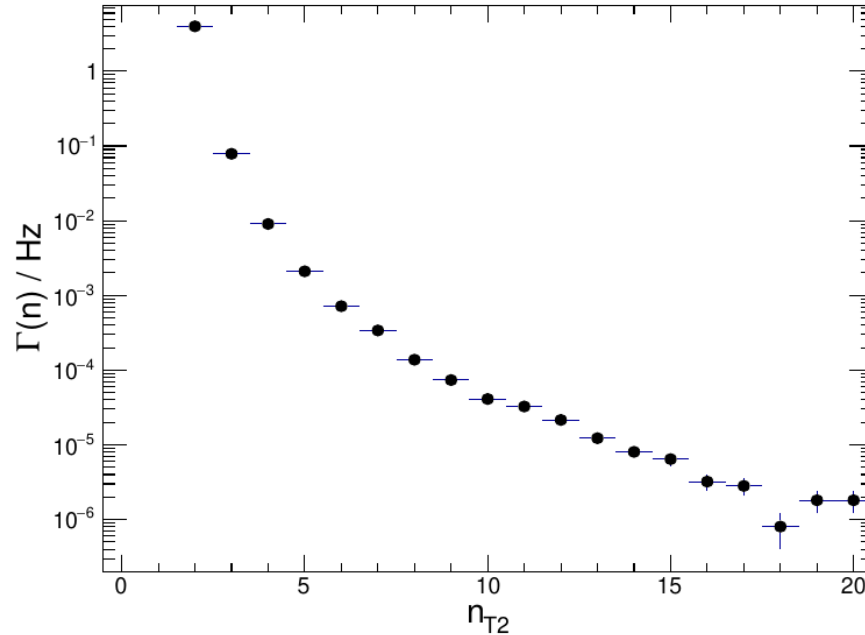
- calculate as

$$\Gamma_{\mathrm{dead}} \approx \Gamma(n \geq 6)\gamma_{\mathrm{geo}}p(\mathrm{dead})$$

- result:

$$\Gamma_{\mathrm{dead}} = 6.8 \times 10^{-9}\,\mathrm{Hz}$$
$$N(\mathrm{dead}) \doteq 0.84$$

$$N_{\mathrm{obs}} = 5 | N_{\mathrm{bg}} = 1.50 \qquad \rightarrow 2.2\sigma$$
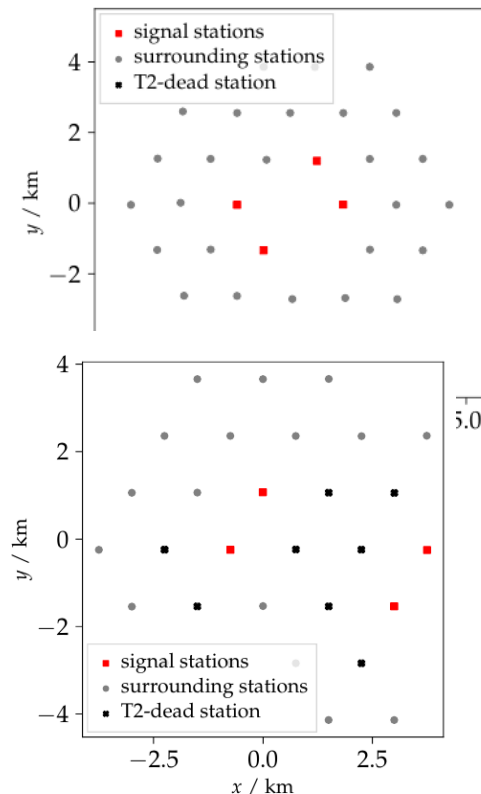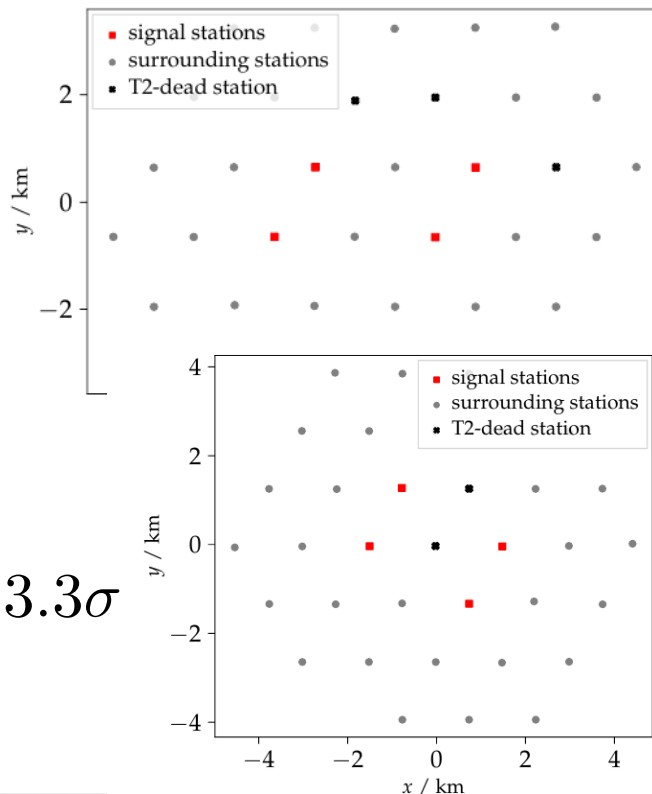
Extension to pairs only

- similar approach

- more influence of background

- result:

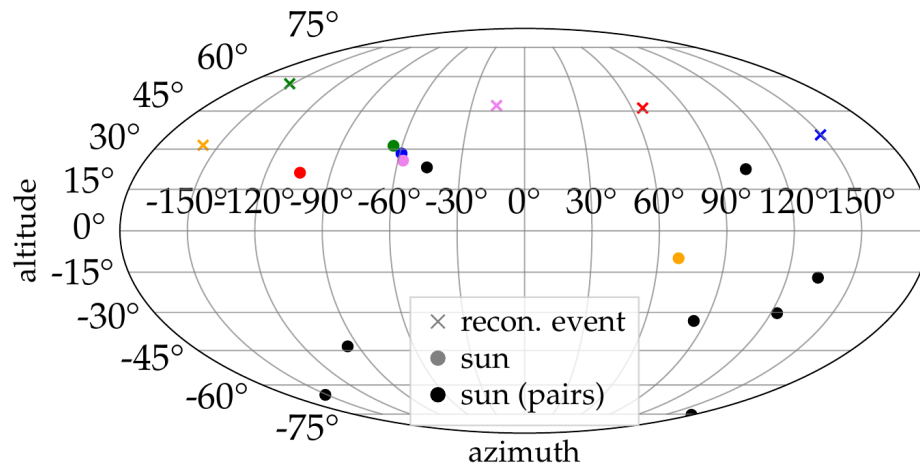$$N_{\mathrm{obs}} = 8 | N_{\mathrm{bg}} = 1.77 \rightarrow 3.3\sigma$$

Combined Results

- minor indications of excess

- statistics too low to give clear answer

- curios:
6 / 8 pair-candidates happen during night

4 / 5 event+pair candidates during day

Summary

- the SD-triggers of the Auger Observatory are fully recorded now and we can use them to search for exotic events

- we have weak indications of GZ-like events

- search for GZ-events not pointless because background low

- extension to more exotic signatures yield null-results → limits

- other topics not covered here for lack of time:
 exotic SD-events, correlation of CR and lightning, Scaler

Institute of Experimental Particle Physics (ETP)

Even Lower?

- How many low energy showers are picked up by a station?

- Can we use them to correlate low-energy events with ...

  - lightning strikes? (initiation problem)

  - each other (GZ events, exotics? c.f. CREDO)

- How to select them using the available information?

Even Lower?

- Using doublets we can find 'real' events depending on the trigger type

- special algorithm in the station: tagging 'wide' signal → even flag

- event rate: 0.7 Hz with a background of 20.5 Hz
  → no clean sample available
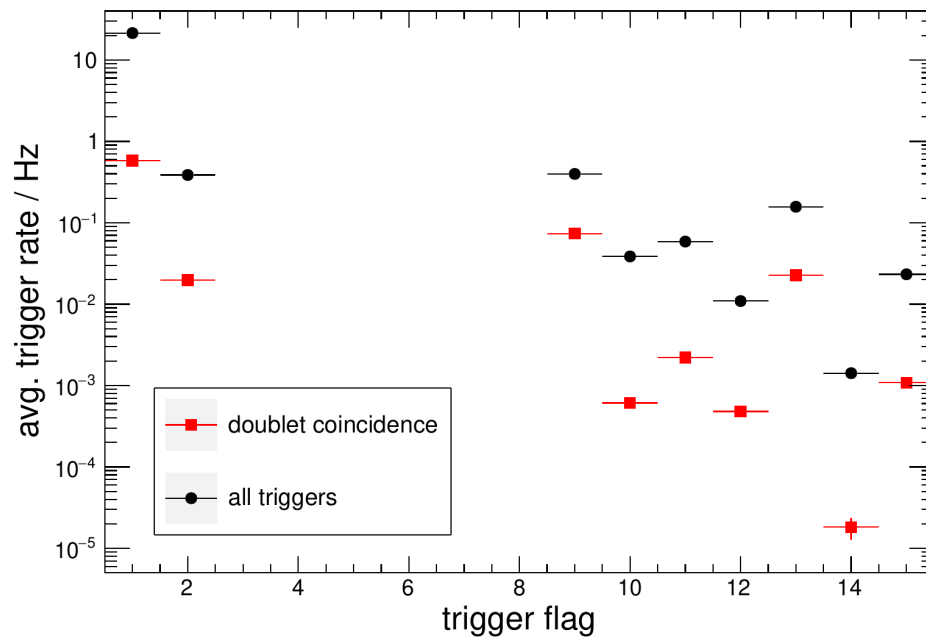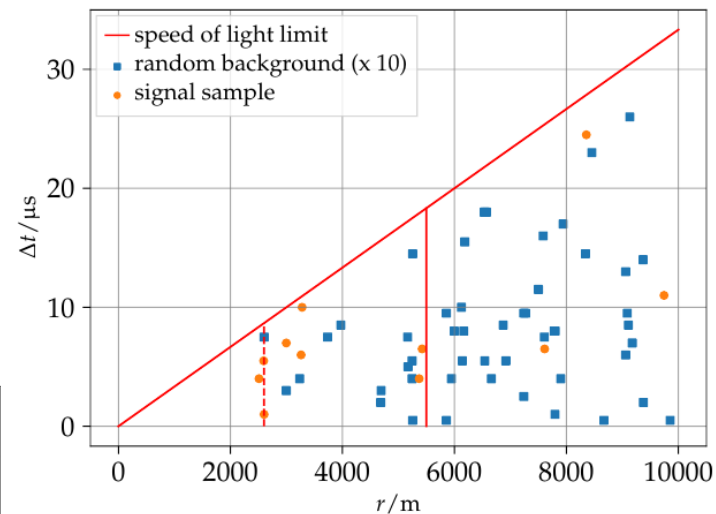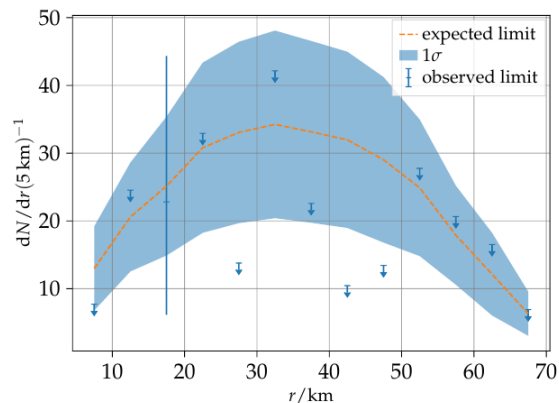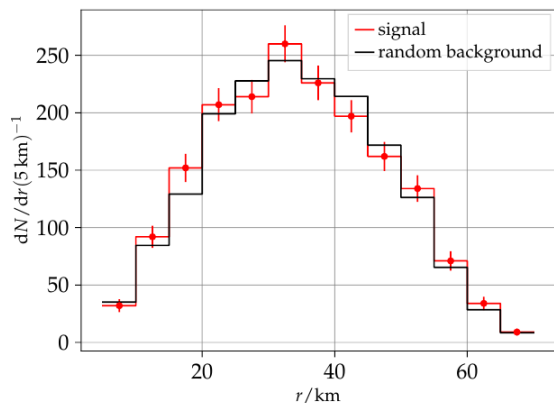
Exotic signatures

- using all stations to create plane fronts (on two months)

- use Hough-transform + DBScan

- background from scrambling data

- computationally expensive:
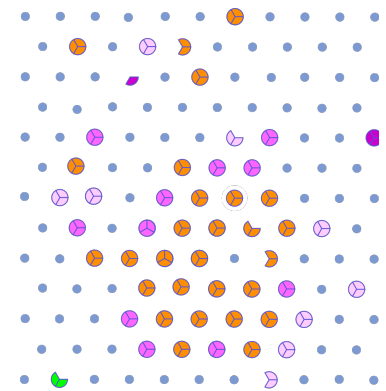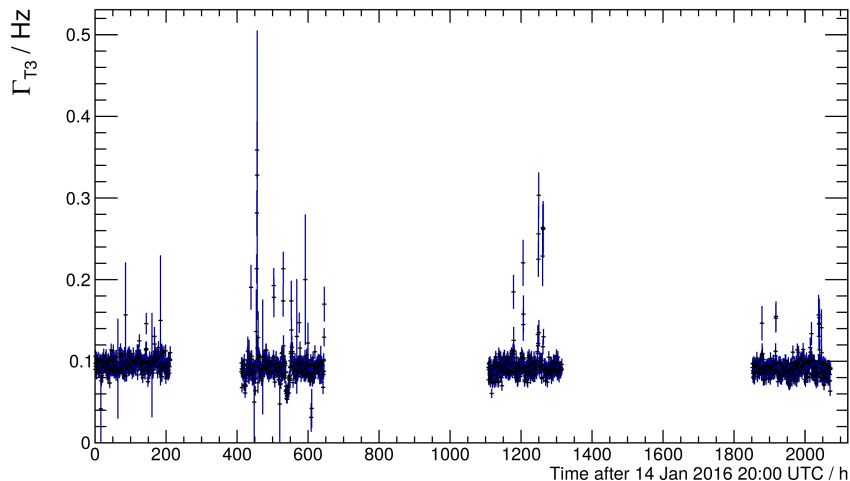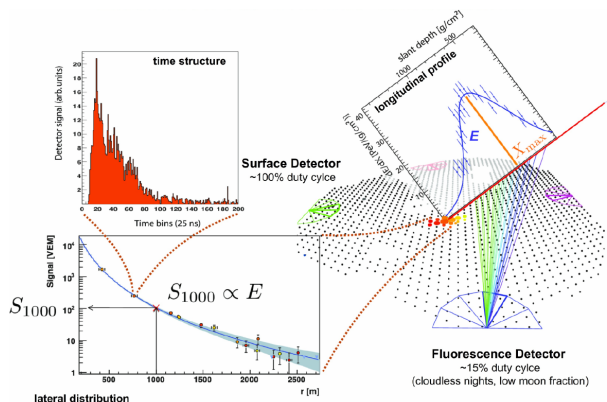 1h of data → (1 + 15bg) x 40 min cpu time
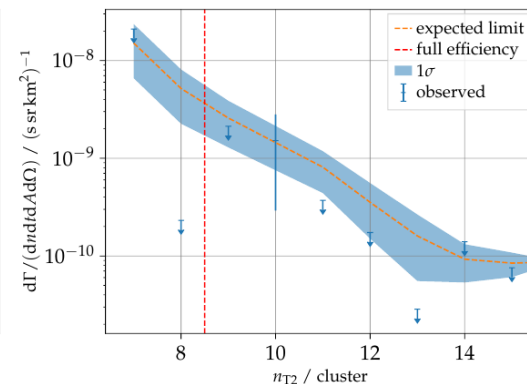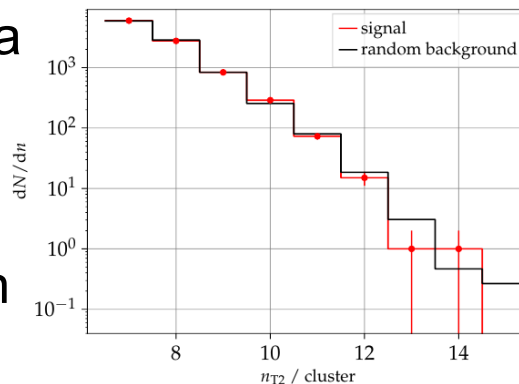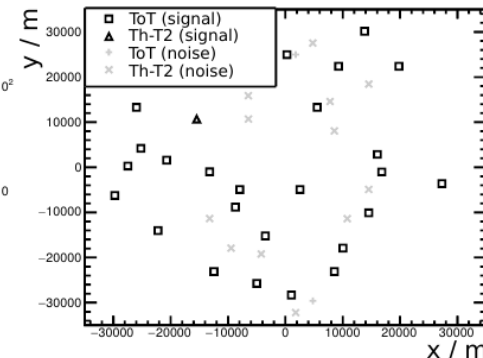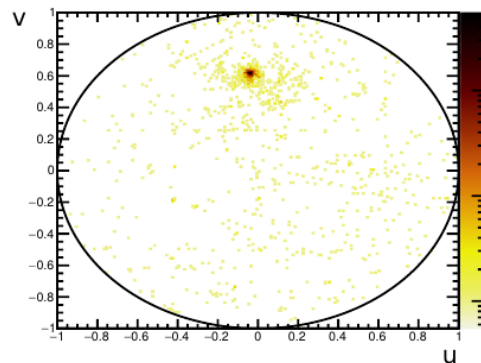
Pairs

- detailed geometric selection necessary
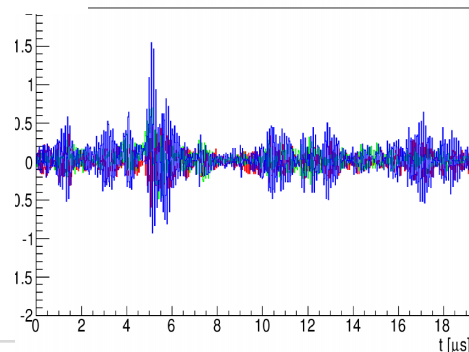- limits for other geometries than close-by events

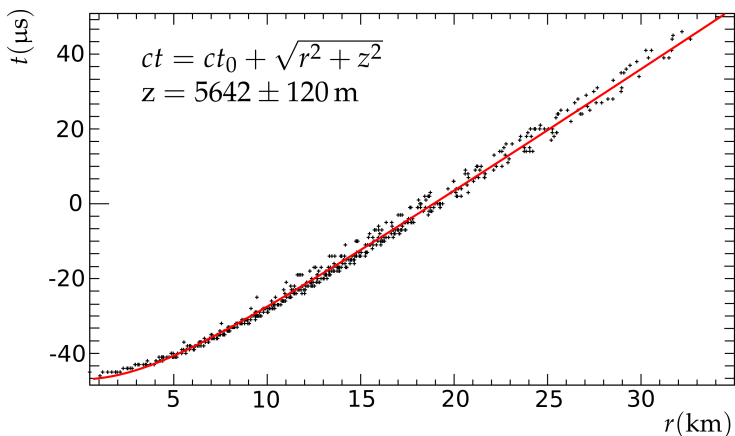# Limits – Special Conditions?

Cosmic Rays:
~0.05 Hz across the whole SD

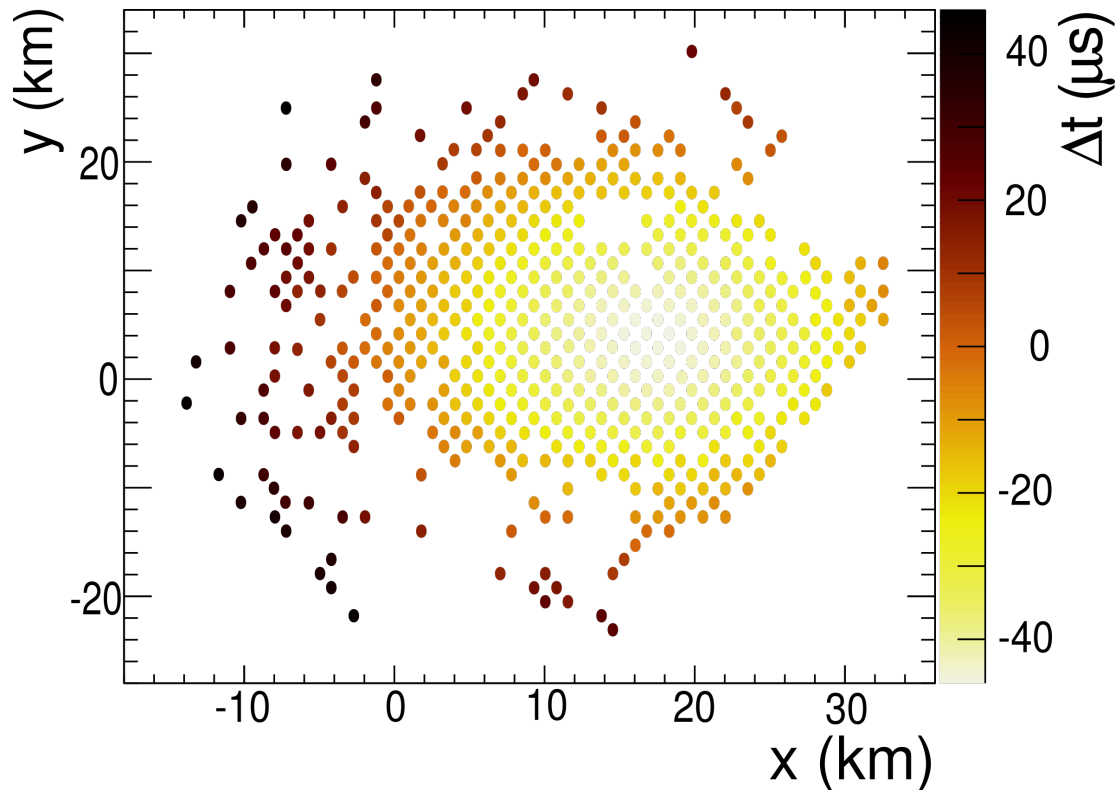mostly 3/4 station events

Thunderstorms:
high rates of events

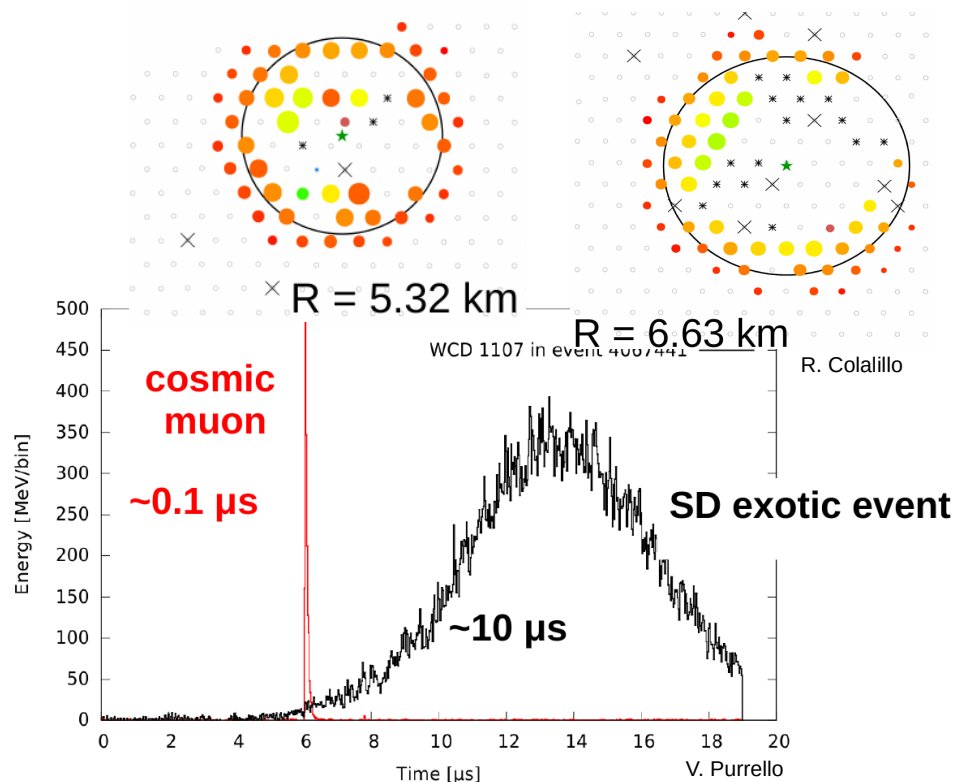large 'circular' footprints

HF-noise in traces

Big Events?

$$ct = ct_0 + \sqrt{r^2 + z^2}$$
$$z = 5642 \pm 120 \, \text{m}$$

Some events reach ~1000 stations

scales of 50 x 50 km²

# Limits – 'SD-Rings'

- very large signals
  - often longer than the recorded trace

- footprints variable but typically large and round
  - in some events hole in the centre
  - some completely filled

- some indications of repeated events

R = 5.32 km

R = 6.63 km

WCD 1107 in event 4007441

R. Colalillo

cosmic muon

~0.1 µs

SD exotic event

~10 µs

Energy [MeV/bin]

Time [µs]

V. Purrello

Are those real signals?

- different channels agree
  - cables with different orientation and length should have different pick-up, if it's only RF-noise

- all PMTs agree

  - different cables not symmetric

- large signals from particles within thunderstorms

  - TA has downwards TGFs (DOI: 10.1029/2019JD031940), these are similar, but not the same
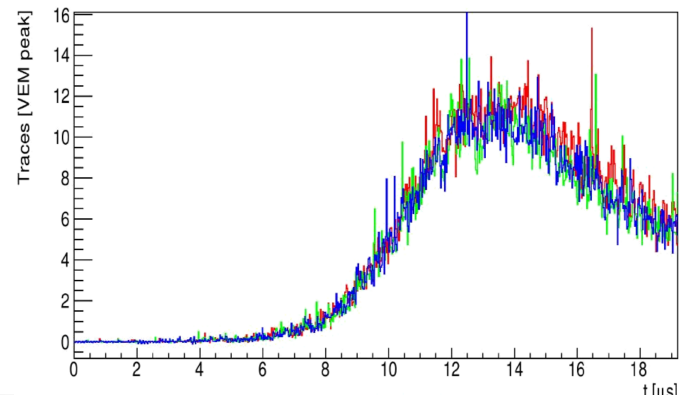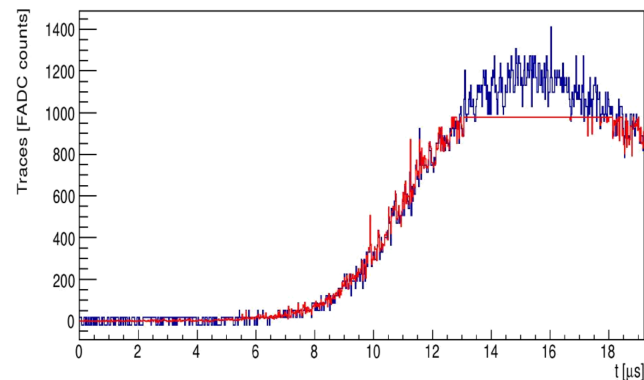
Current Limitations

- example event that has such signals

- DAQ optimised for UHE-CRs
  - event rate of about 0.05 Hz
  - about 4 triggers per CR event
  - ~1000 triggers for these events

- lightning strikes lead to many triggers

Institute of Experimental Particle Physics (ETP)
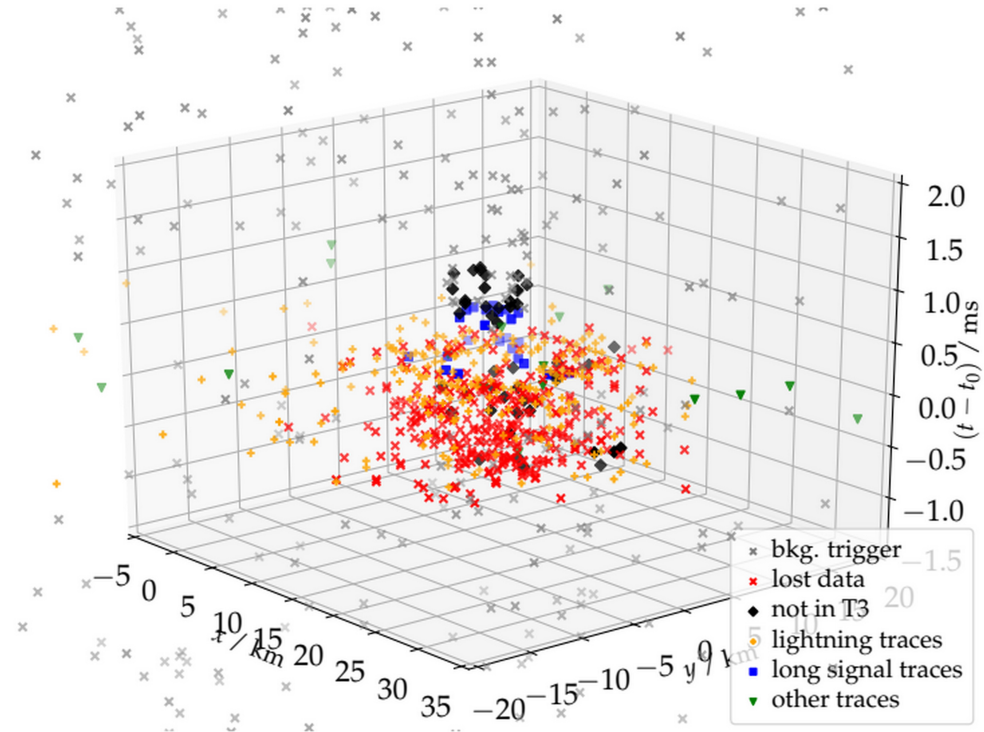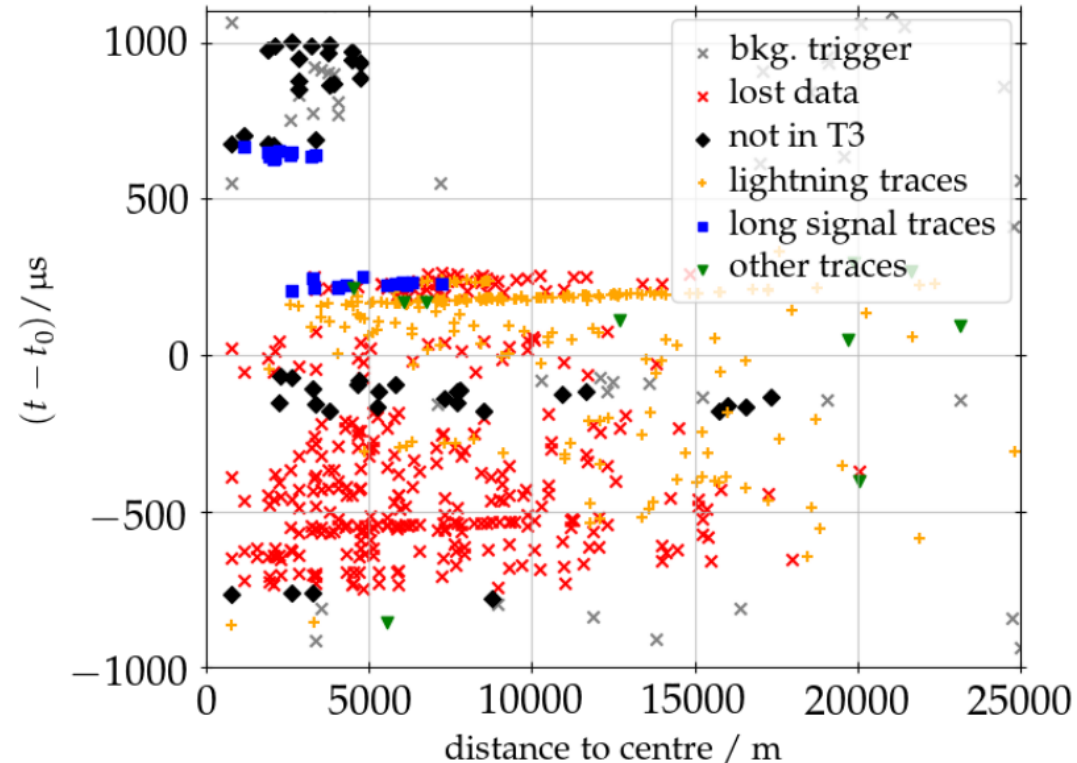
Current Limitations

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  - ~1000 triggers for these events

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Current Limitations

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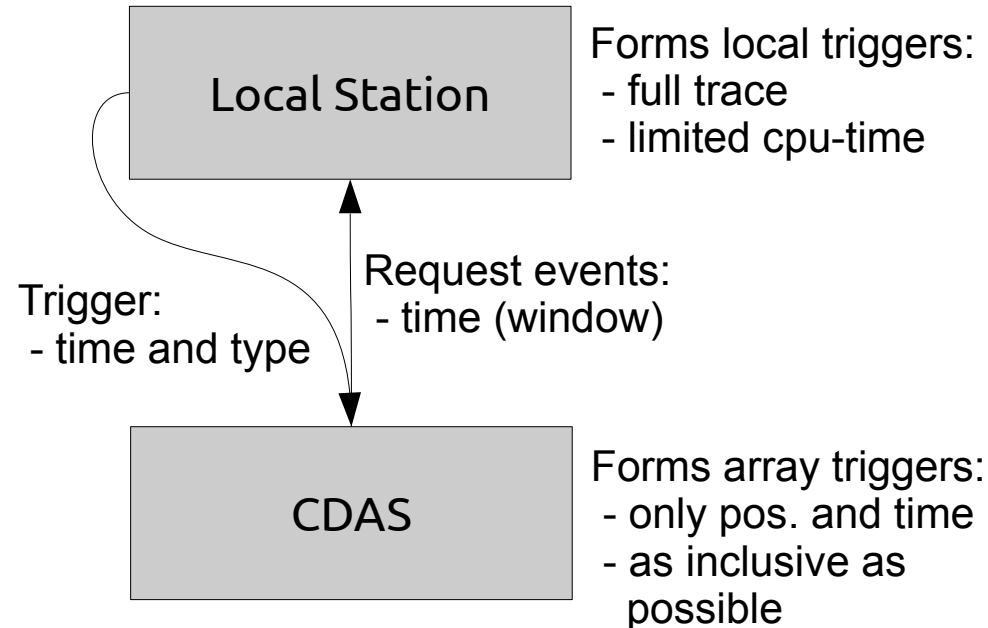SAN MARTÍN

KIT
Karlsruhe Institute of Technology

- example event that has such signals

- DAQ optimised for UHE-CRs

- lightning strikes lead to many triggers

- later events lost due to memory limitations of (old) hardware
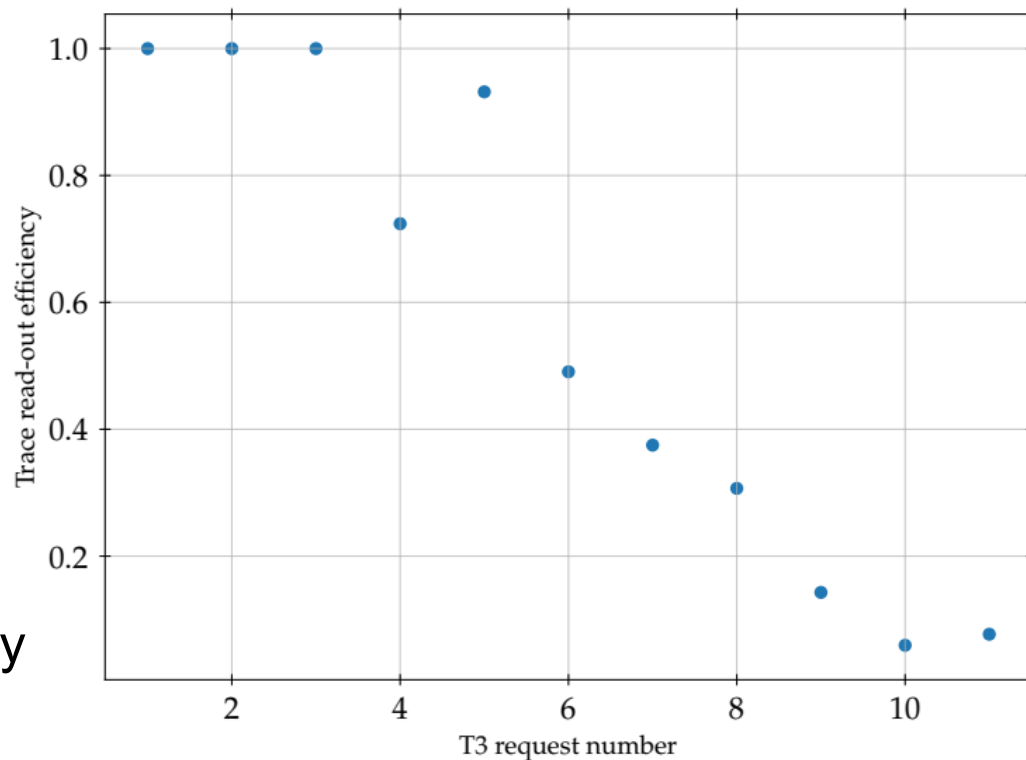
Improvement possible?

- trace not available for read-out decision

- station is limited in computations
  - AugerPrime upgraded electronics can help here

- yes/no information about special signals can in principle be passed through to CDAS

Local Station — Forms local triggers:
- full trace
- limited cpu-time

Trigger:
- time and type

Request events:
- time (window)

CDAS — Forms array triggers:
- only pos. and time
- as inclusive as possible
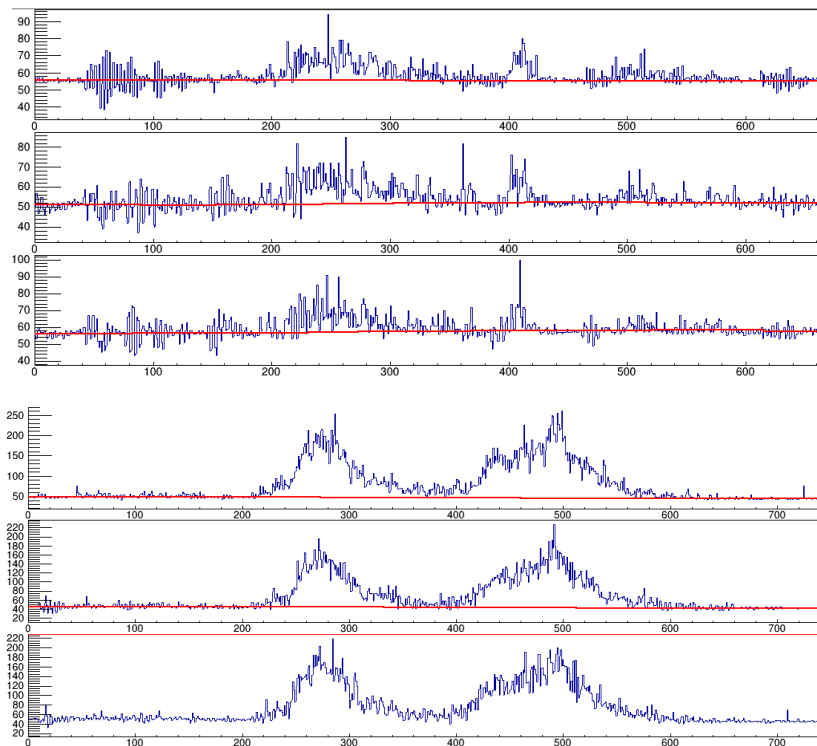
Tagging interesting signals

- design and test an algorithm to run on the station

- what is actually interesting?

  - very large and long signals

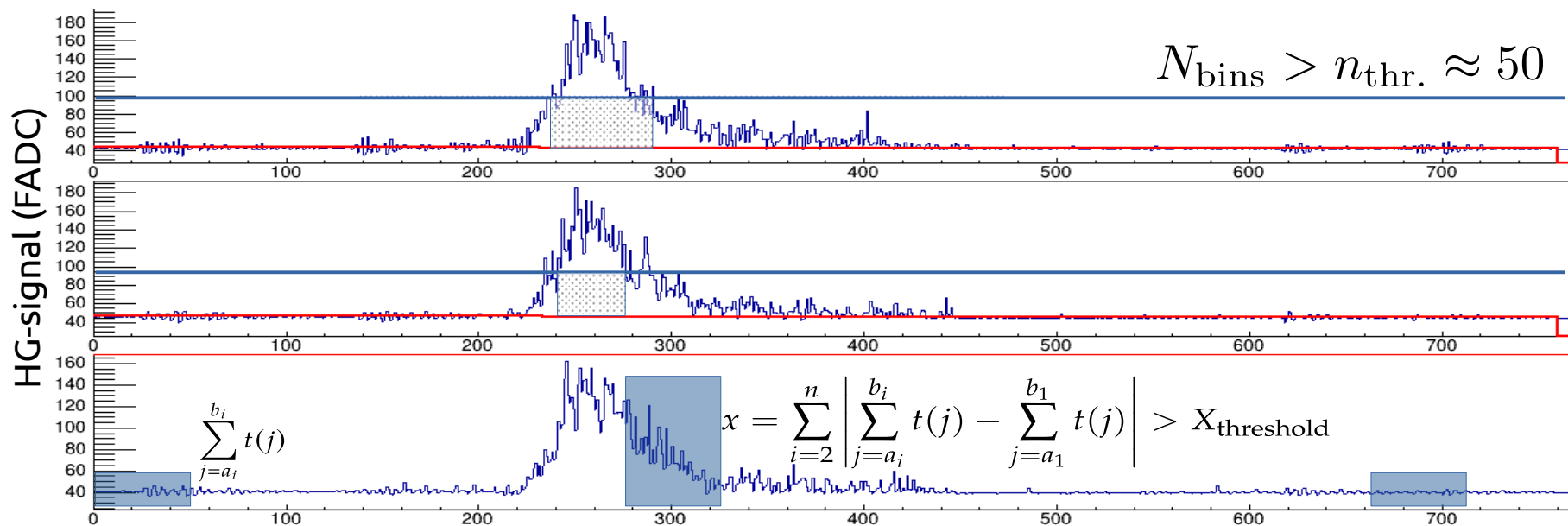 - those of similar events but at smaller amplitude
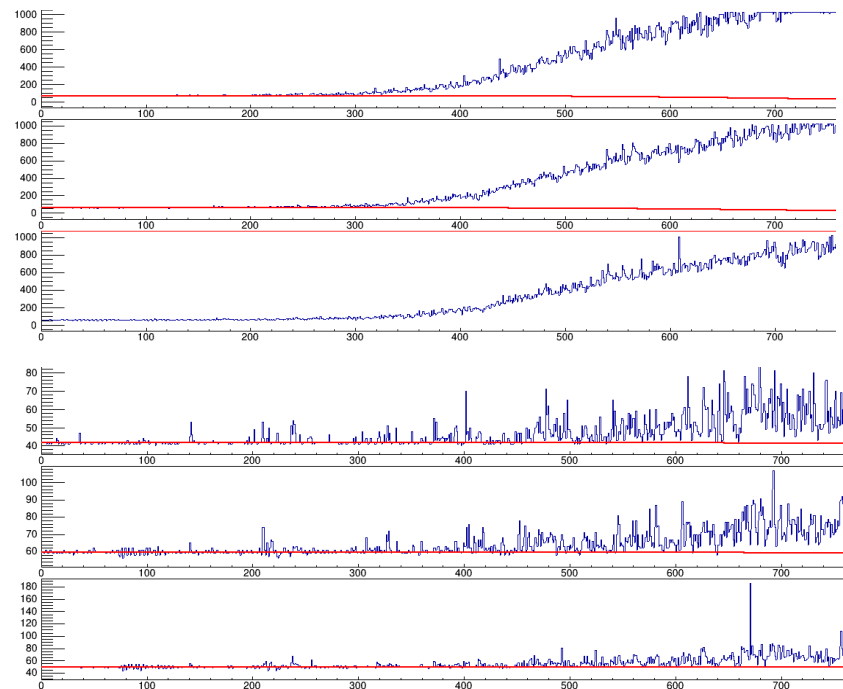
Tagging interesting signals

- design and test an algorithm to run on the station

- what is actually interesting?
  - very big and long signals
  - those of similar events but at smaller amplitude
  - mixed with lightning noise?
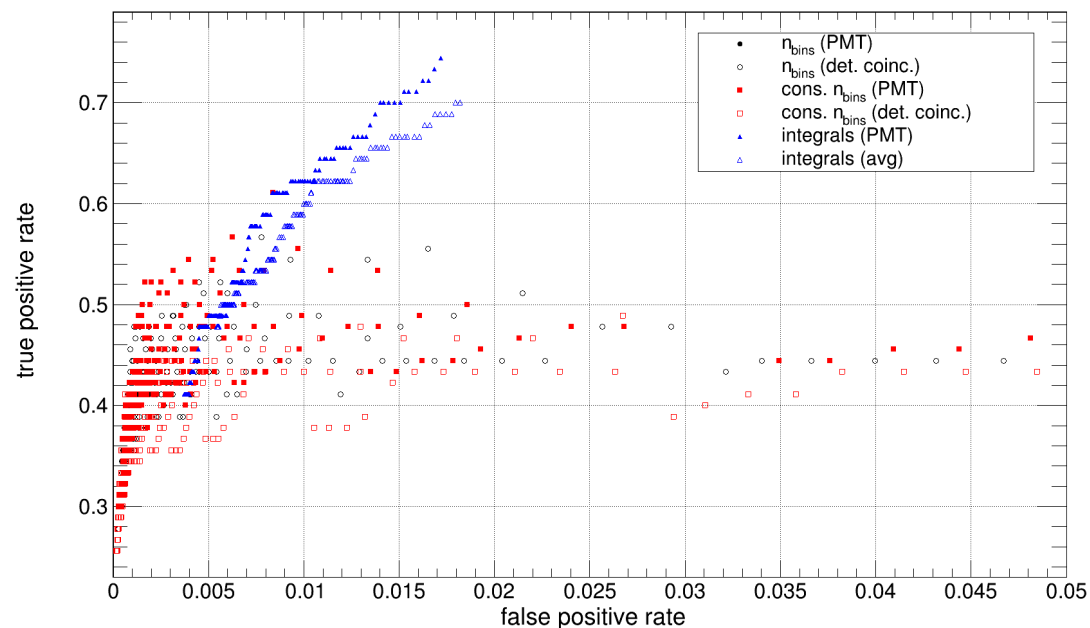 - more exotic signatures?

- all we can tag!

Tested Algorithms

$$N_{\text{bins}} > n_{\text{thr.}} \approx 50$$

HG-signal (FADC)

$$\sum_{j=a_i}^{b_i} t(j)$$

$$x = \sum_{i=2}^{n} \left| \sum_{j=a_i}^{b_i} t(j) - \sum_{j=a_1}^{b_1} t(j) \right| > X_{\text{threshold}}$$
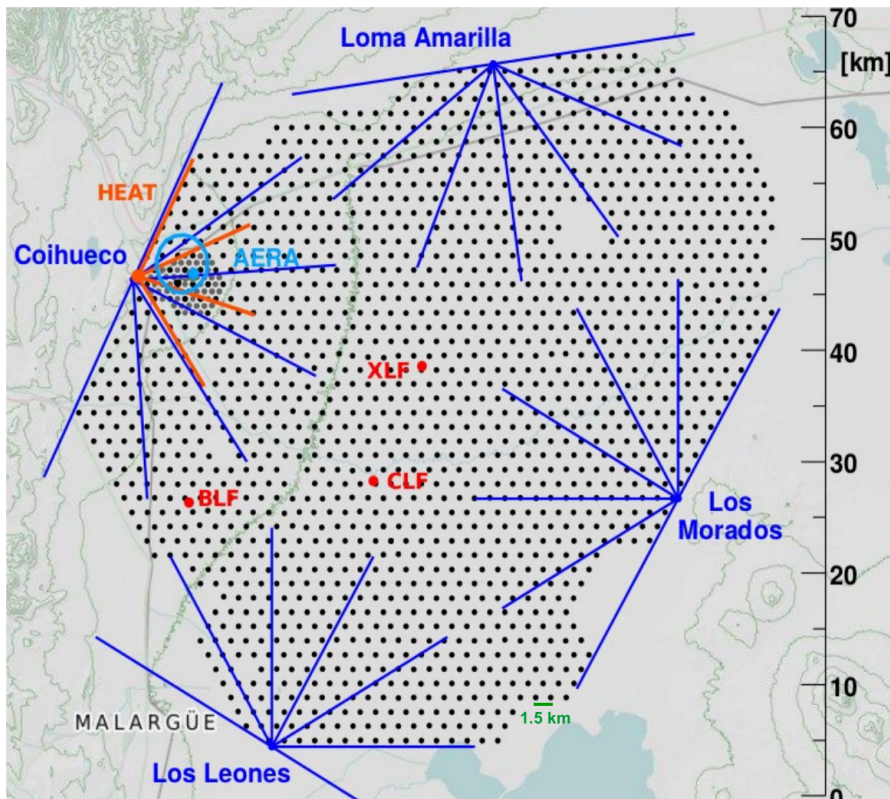
Tested Algorithms

- evaluation: fix false positives to < 2 in test sample

- differences of algorithms
  - comparable performance
  - differences reflected in overall false positives

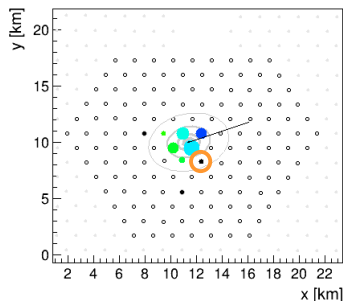- we can achieve ~75% efficiency

The Pierre Auger Observatory

for photos used here, see Auger Flickr: https://www.flickr.com/photos/134252569@N07/
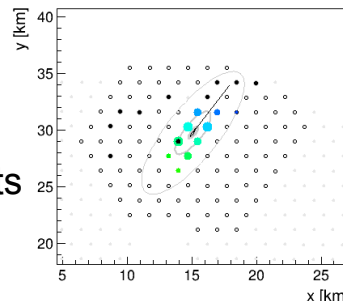
Local Triggers

ToT:
- 'for EM-part'
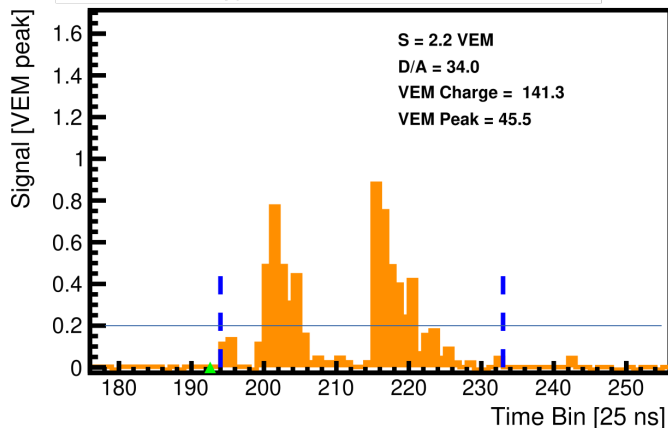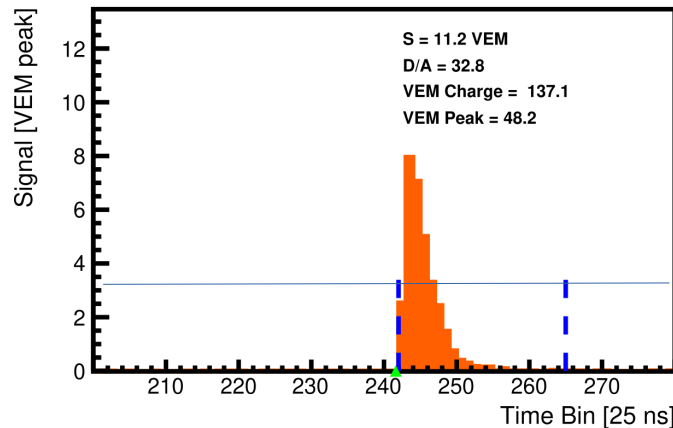- further from core (time dispersion)

Th:
- 'for muons'
- good for inclined events

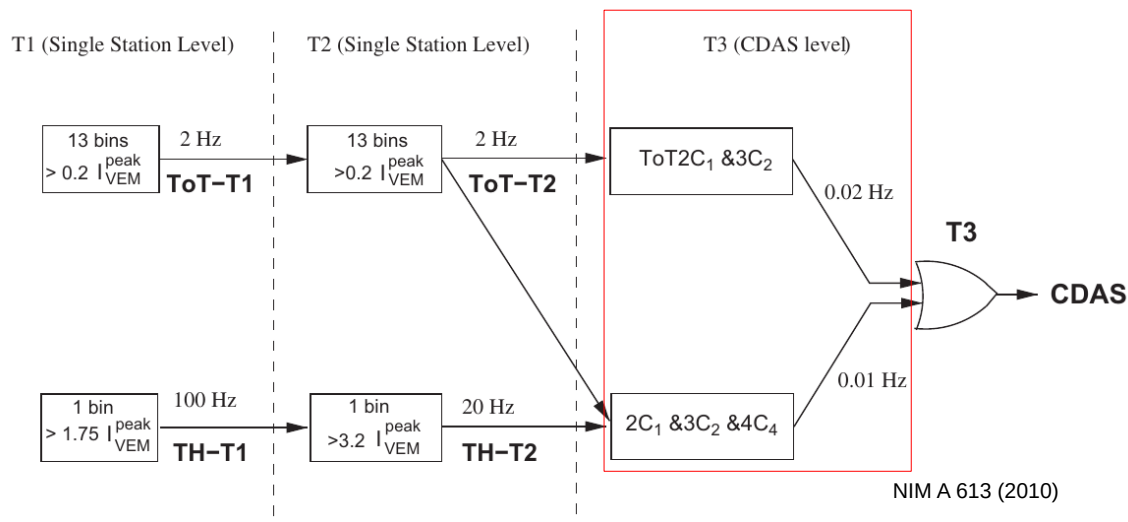SD-station: independent operation forms **local triggers** + calibration / monitoring information

Lumpy Jr (1804), PMT 1 at 2008m

S = 2.2 VEM
D/A = 34.0
VEM Charge = 141.3
VEM Peak = 45.5

Bernard (1143), PMT 1 at 661m

S = 11.2 VEM
D/A = 32.8
VEM Charge = 137.1
VEM Peak = 48.2

Central Trigger

T1 (Single Station Level) | T2 (Single Station Level) | T3 (CDAS level)

13 bins $> 0.2\ I_{VEM}^{peak}$ **ToT–T1** → 2 Hz → 13 bins $>0.2\ I_{VEM}^{peak}$ **ToT–T2** → 2 Hz → $ToT2C_1\ \&3C_2$ → 0.02 Hz

1 bin $> 1.75\ I_{VEM}^{peak}$ **TH–T1** → 100 Hz → 1 bin $>3.2\ I_{VEM}^{peak}$ **TH–T2** → 20 Hz → $2C_1\ \&3C_2\ \&4C_4$ → 0.01 Hz

T3 → **CDAS**

NIM A 613 (2010)

Array Trigger:
- combination of spatial and temporal coincidence conditions
- two modes: ToT only + all triggers

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CDAS:
receive and store data
internet connection
from array triggers and request data

Central Trigger – Spatial Selection
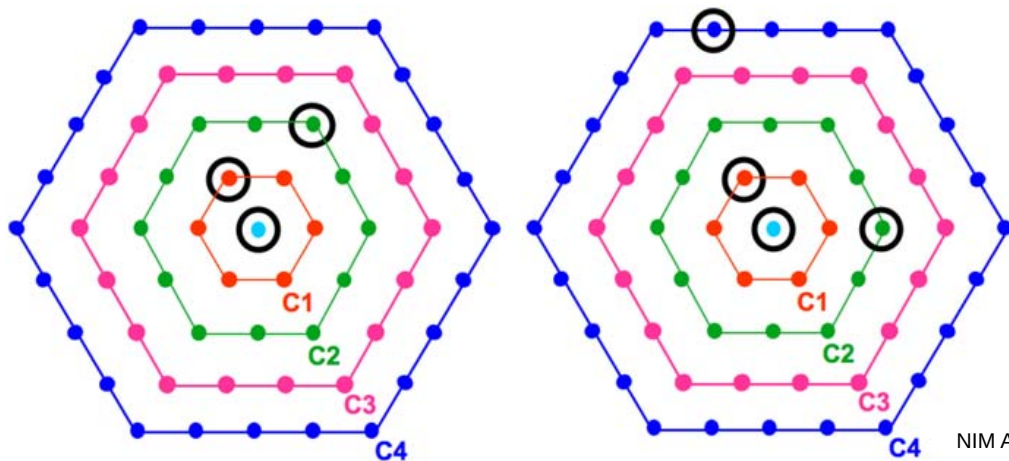
Two Modes:
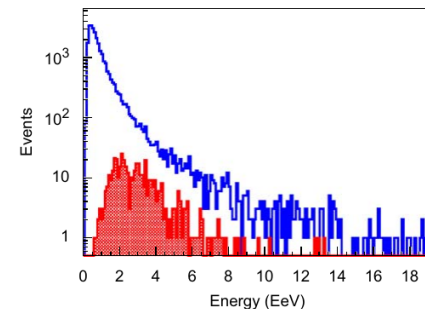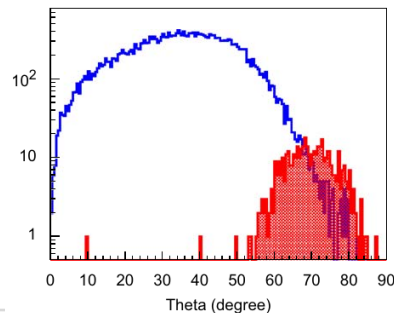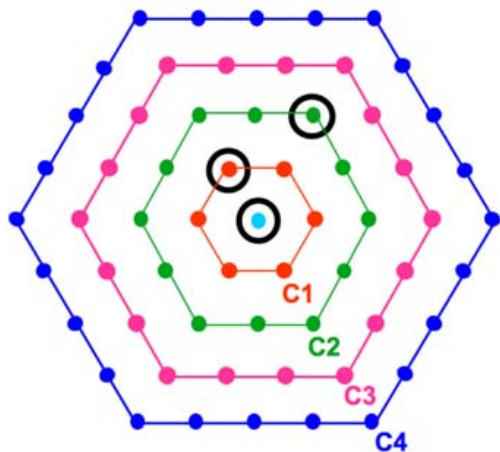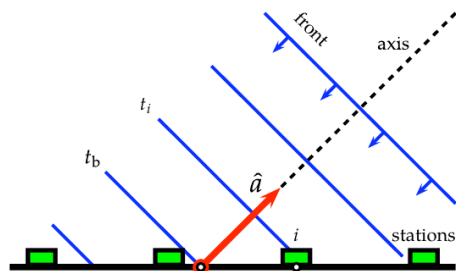- vertical showers (ToTs): '2C1&3C2'
- inclined showers (Ths mostly): '2C1&3C2&4C4'

Central Trigger – Temporal Selection

NIM A 613 (2010)

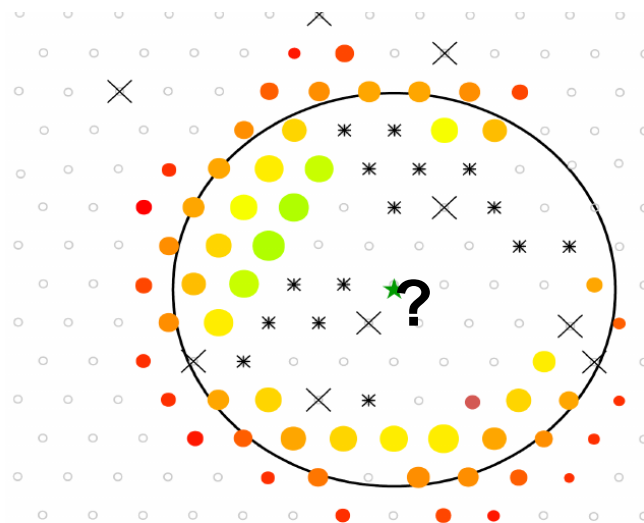$$c\Delta t \approx \sin(\theta) \cdot r$$

$$\Delta t = (t_{Trigger} - t_{GPS}) / ns$$
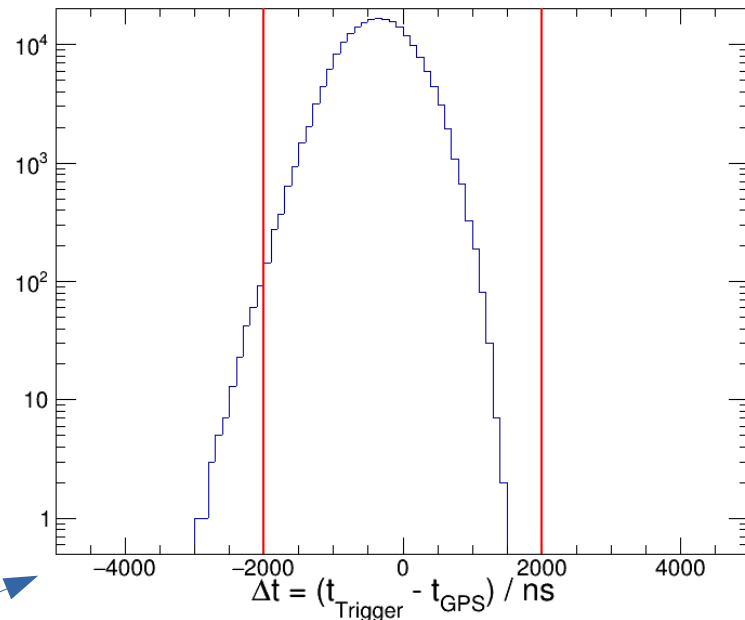
Two Modes:
- Request: $\Delta t < (3 + 5C_n)\,\mu s$

time jitter

Limits – 'SD-Rings'?

- footprints variable but typically large and round
  - in some events hole in the centre
  - some completely filled
- is the hole a 'trigger' effect?
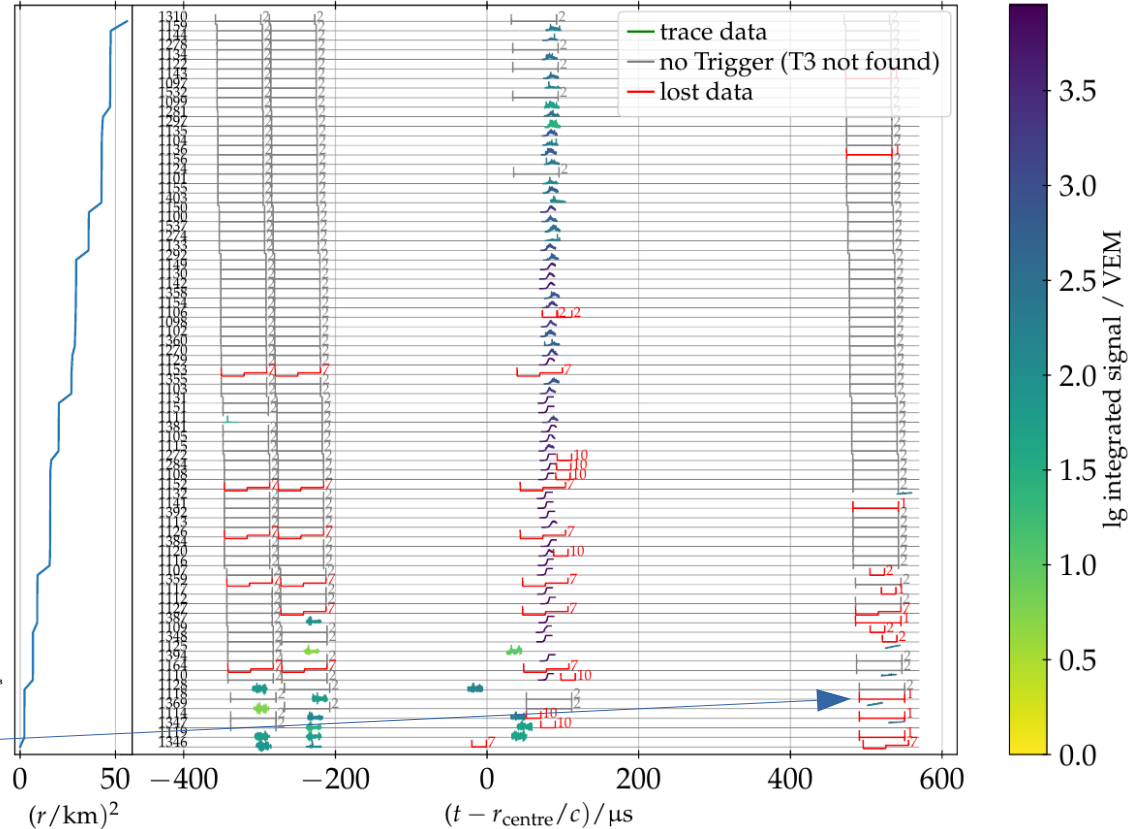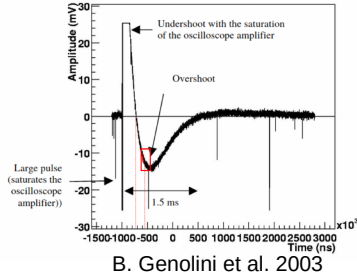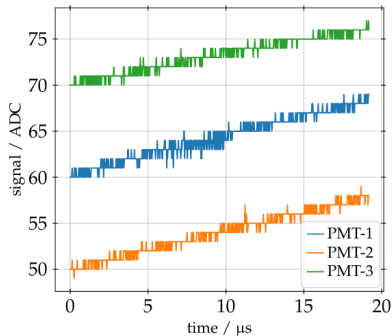 - make use of new data to find out!

$R = 6.63 \text{ km}$

Ring or disk?

- situation complex,
  - many events
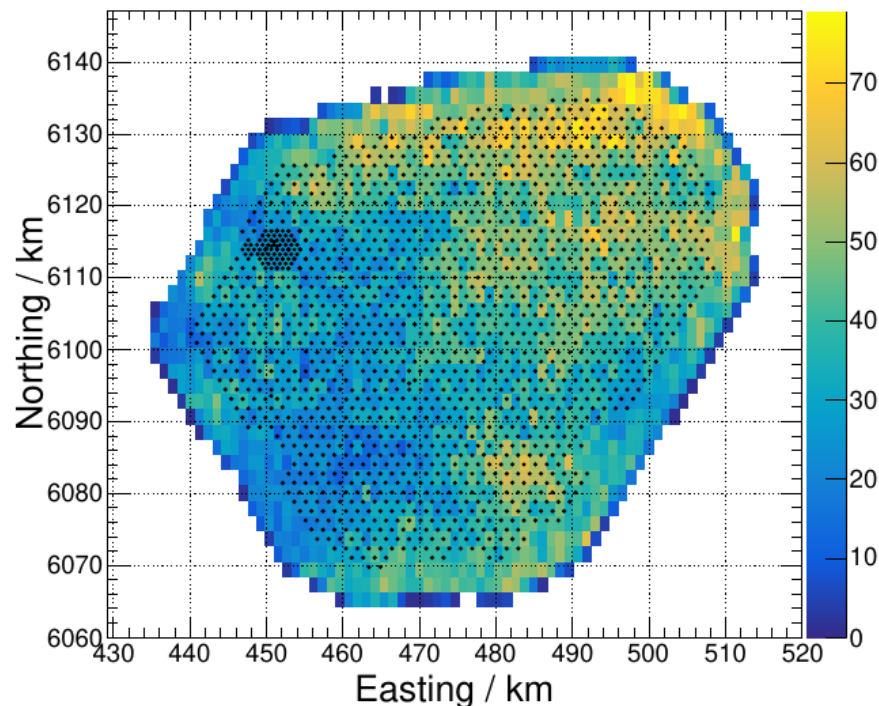 - lost data
  - overshoots

- overshoot → filled!

B. Genolini et al. 2003

Lightning Initiation – Teaser

- Data from GLD-360
  commercial lightning detection
  network:
  https://www.vaisala.com/en/products/systems/lightning/gld360

- select strikes within the SD-array
  (d < 5 km)

- search for correlations of SD-triggers
 with the lightning strike

Lightning Initiation – Teaser

- the lightning strike itself is clearly visible

- precision of location about 5 km

- timing: sigma of about 5 µs

- need to take this RF-induced background into account
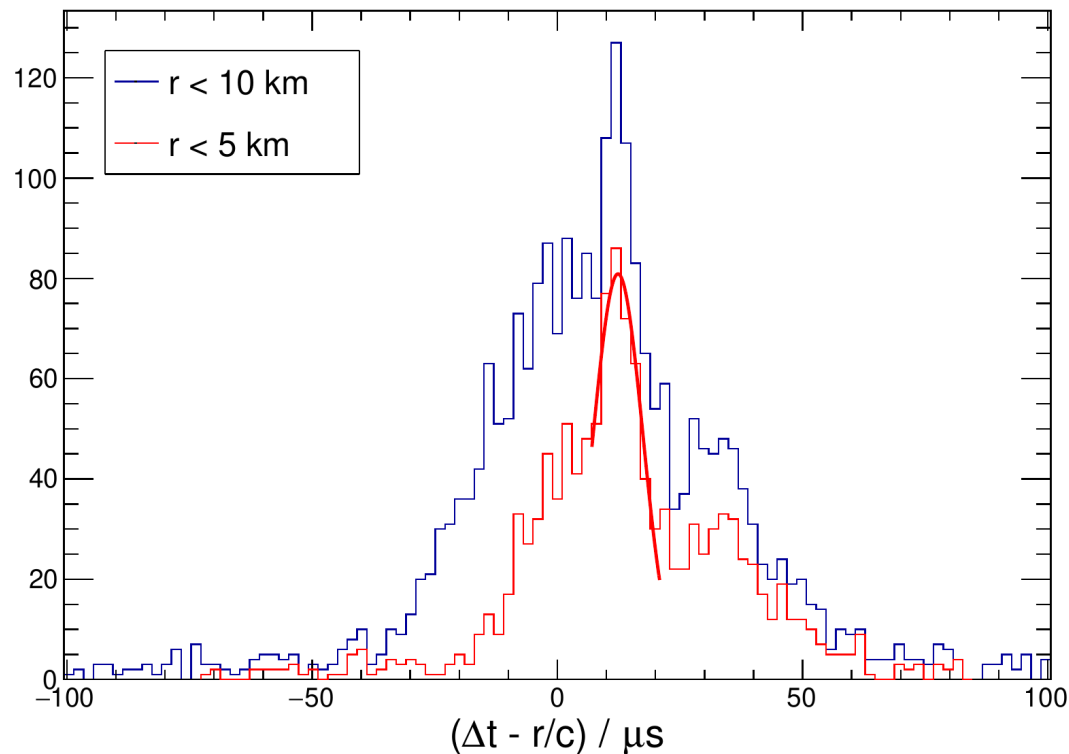
Lightning Initiation – Teaser

- using a test-sample of two months (Nov + Dec 2016)

- influence of RF-events clearly visible (-500… 500 ms)

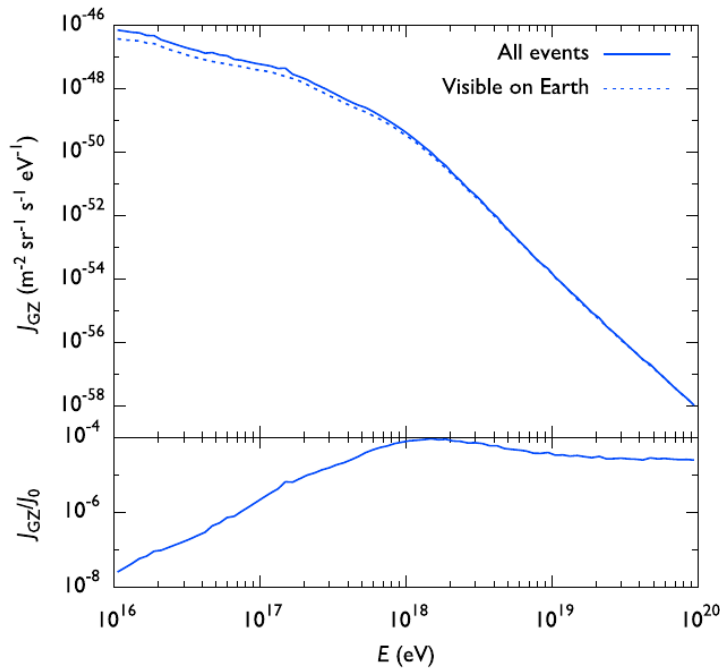- try to use 'wide' flags to select non-lightning events
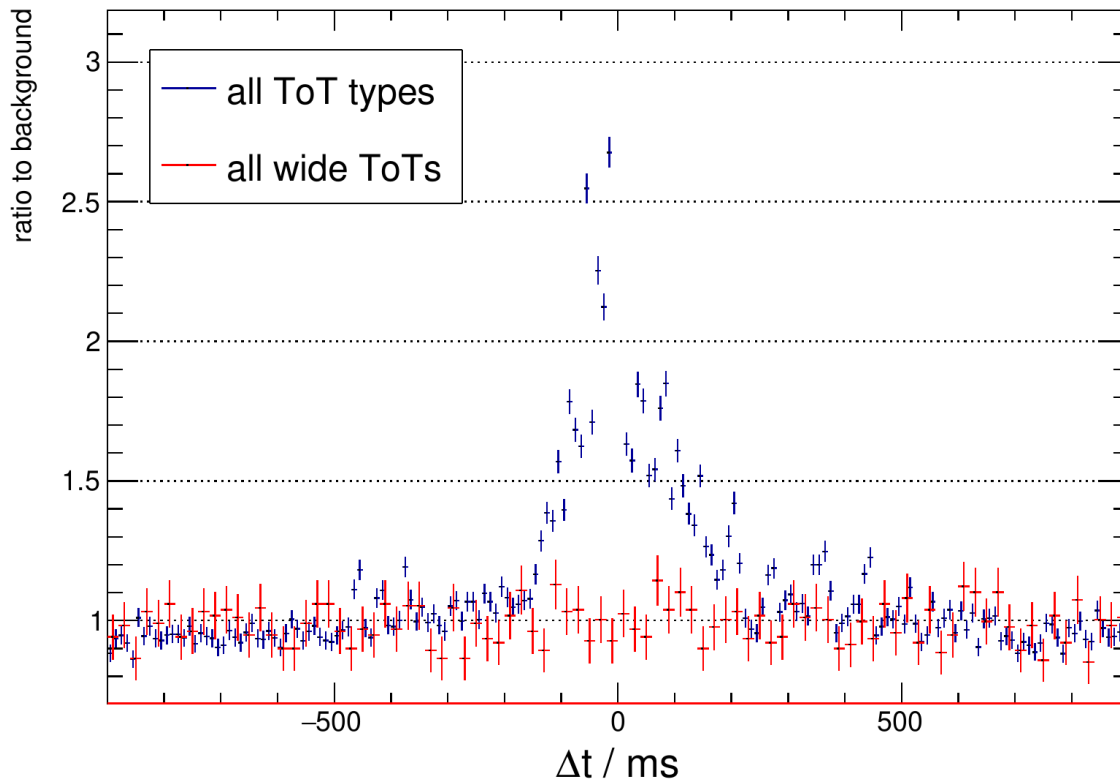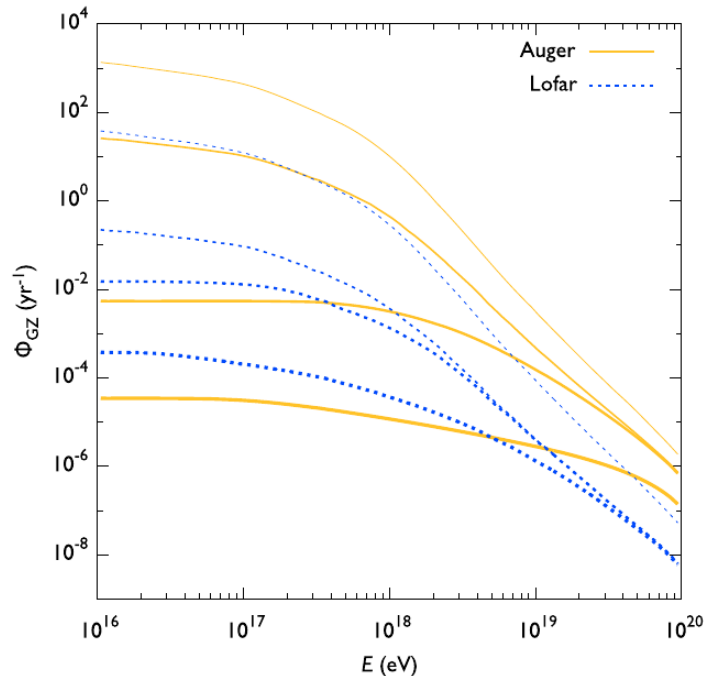
Prospects – GZ-Effect

- nuclei split by photon in solar radiation field

- magnetic fields lead to separation
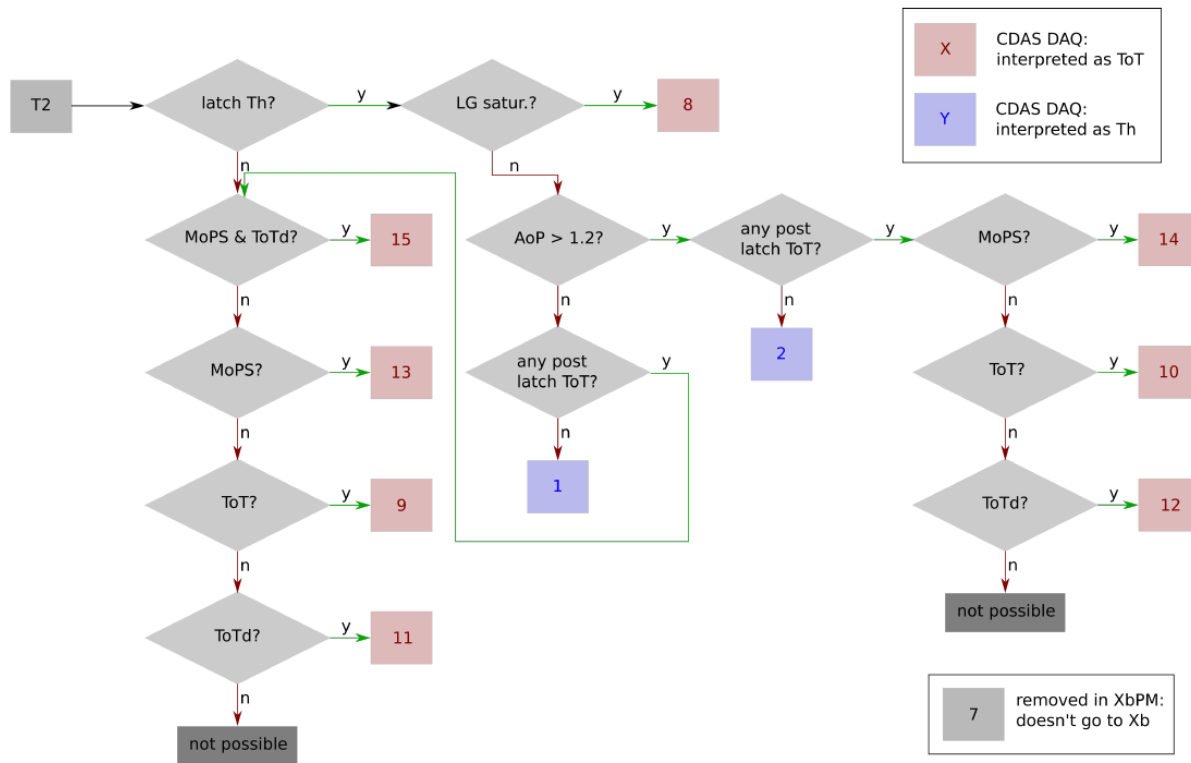
- direct proof of A > 1

A&A 485, 1–4 (2008)

A&A 485, 1–4 (2008)

Trigger Flags

■ important interface: CDAS interprets flag

- 7 < flag: ToT

- 7 > flag: Th

Rings: Event Complexity

- complex time evolution

- also here overshoots

- many lost traces