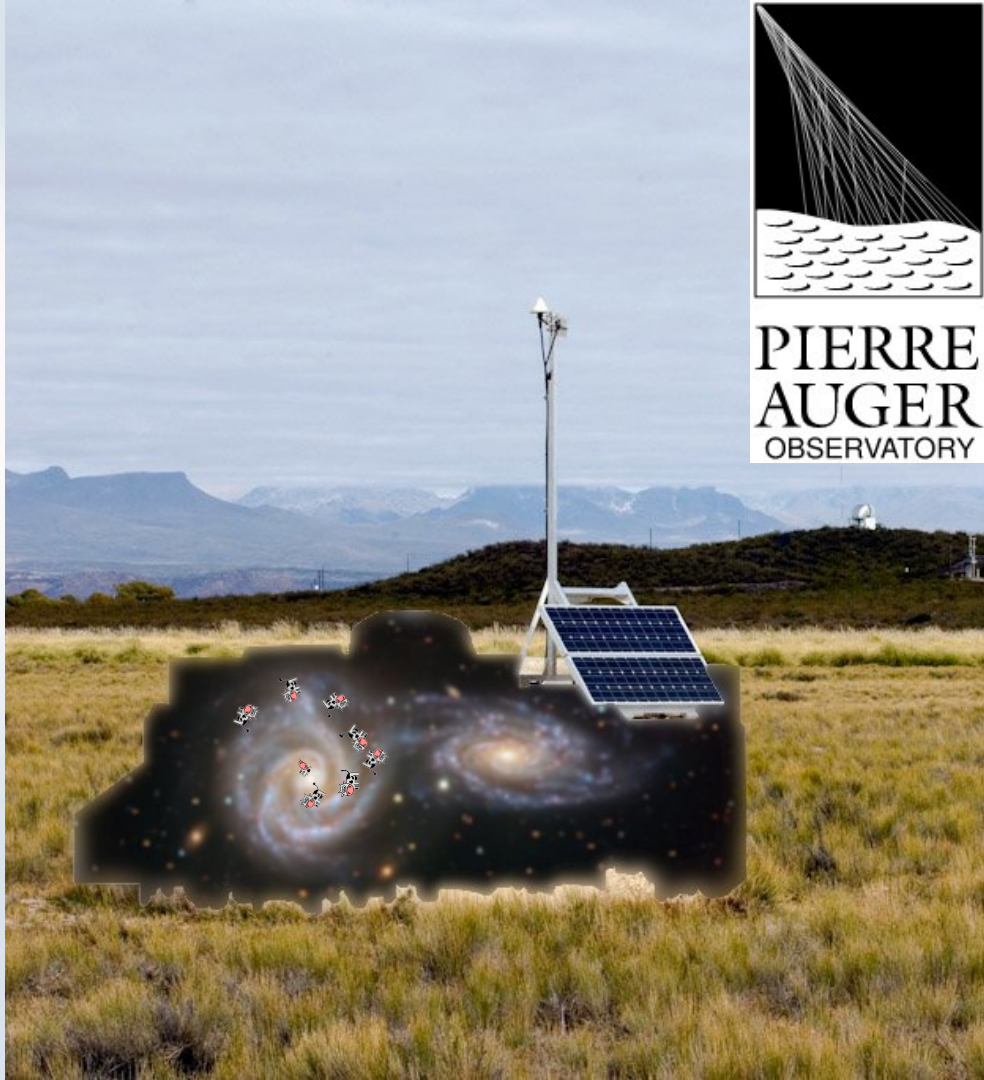
Improving the photon sensitivity of the Pierre Auger Observatory with the AugerPrime Radio Detector

Jannis Pawlowsky
on behalf of the Pierre Auger Collaboration

13 June 2024

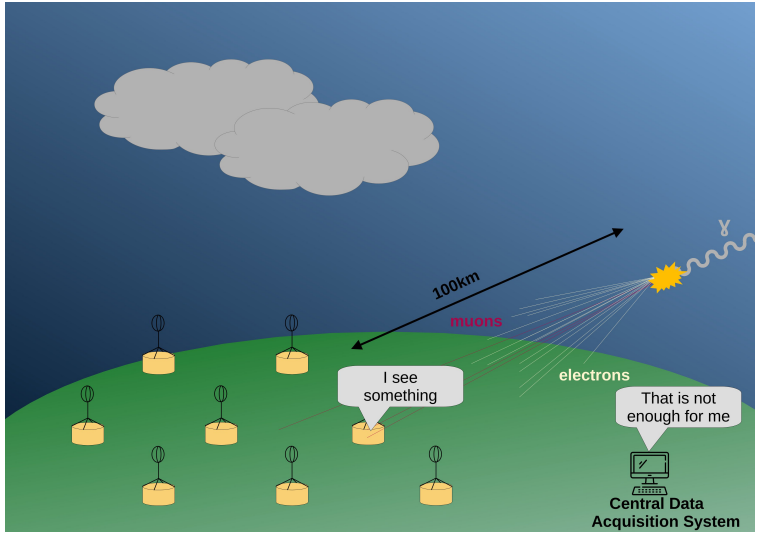
BERGISCHE
UNIVERSITÄT
WUPPERTAL



Neccessity of a radio trigger at Auger

Inclined photon air showers

- **Muon content too low for particle triggers**
- **Electromagnetic particles absorbed in the atmosphere**
- **Atmosphere (almost) transparent for radio emission in the 30-80 MHz range**



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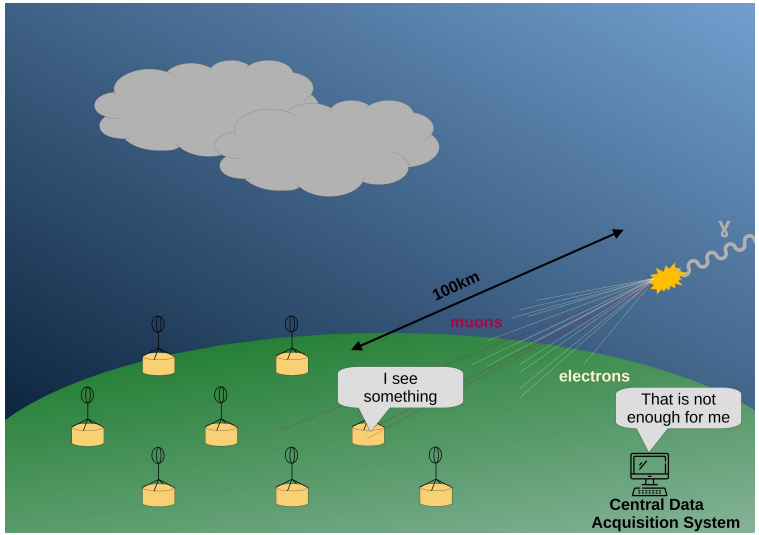

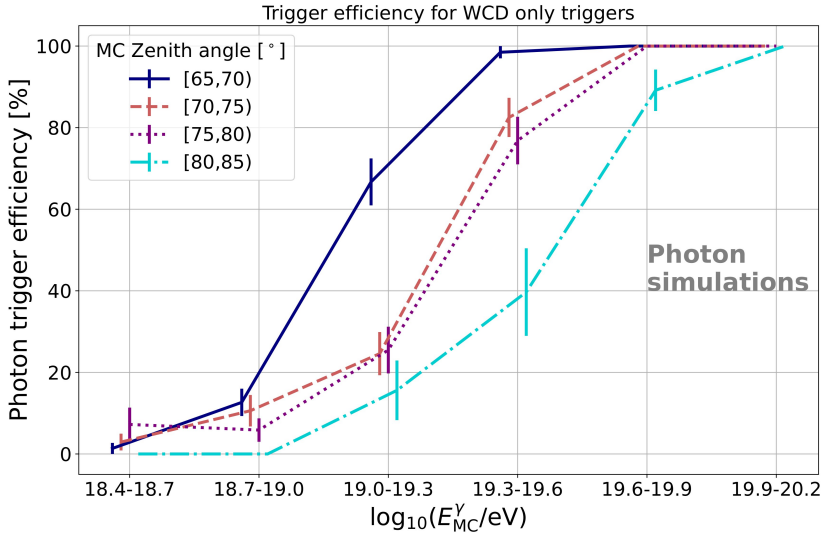

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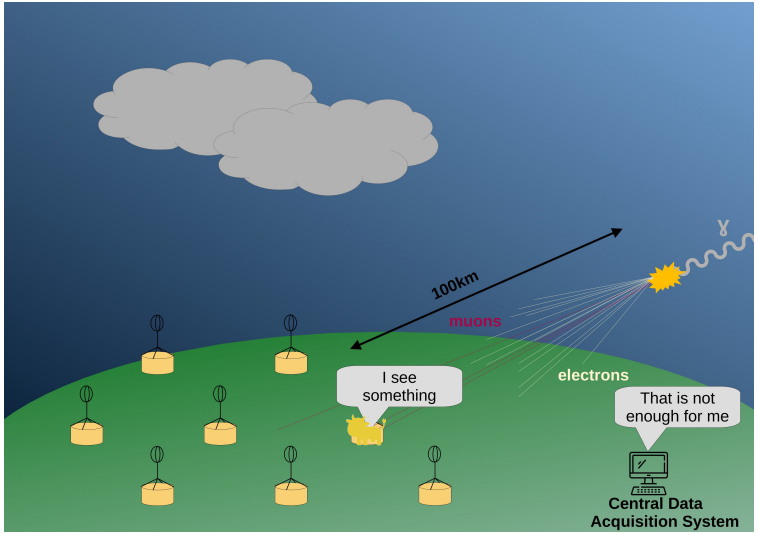
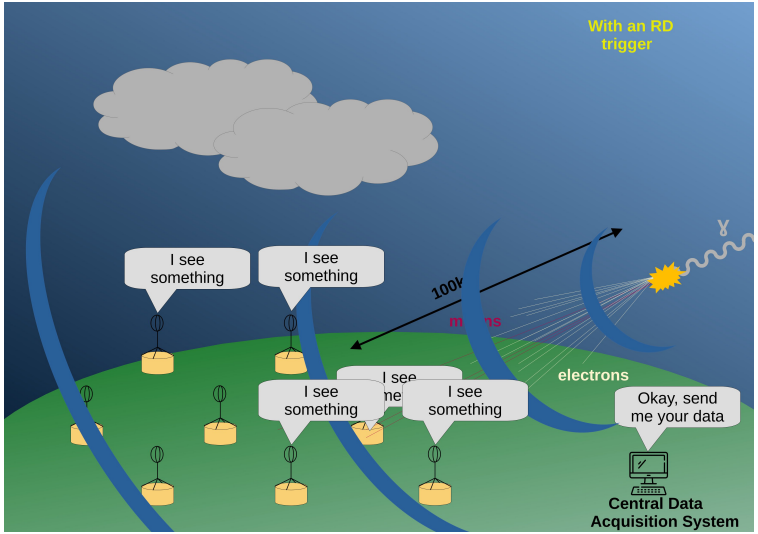




Benefit of radio detection of inclined photons

High discrimination power anticipated:

- Trigger high-energy showers without particle signal
- Clear indication for neutral primary

Direct access to photon energy:

- 98 % of energy feeds the electromagnetic component
- Particle detectors underestimate energy

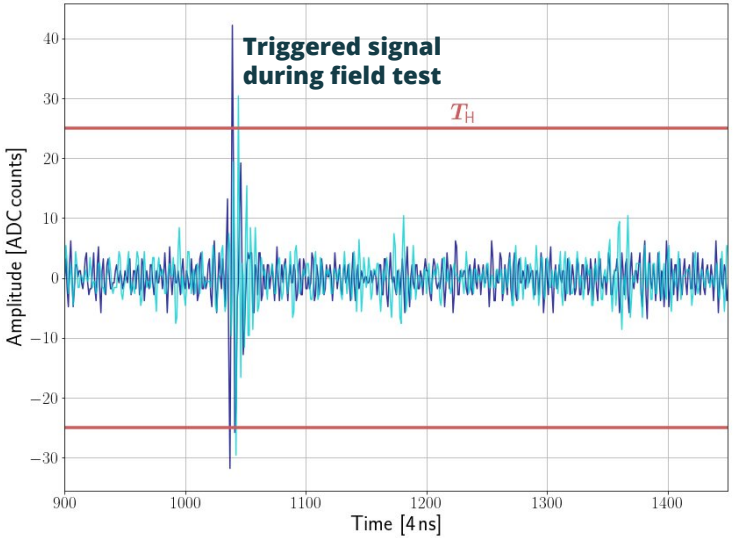
Deepness of shower:

- Vertical photons often with maximum below ground

Designed trigger

Trigger threshold T_H

Classic threshold trigger with added vetoing mechanism



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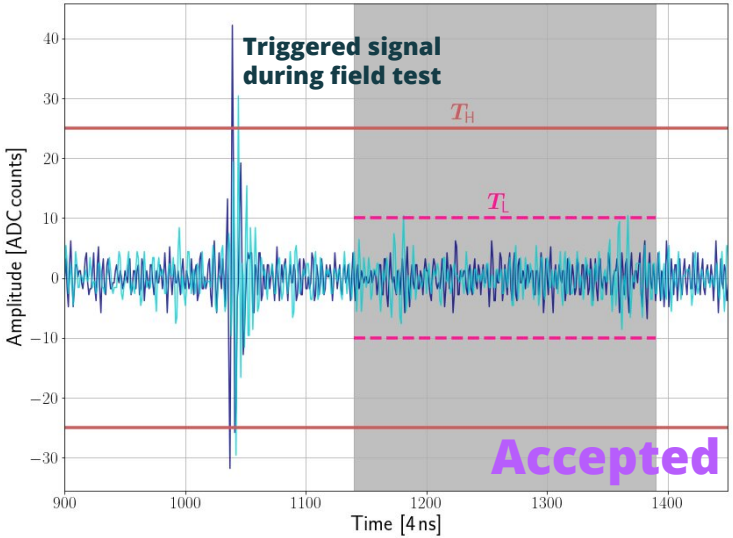

Count how many times a second threshold after the signal is exceeded

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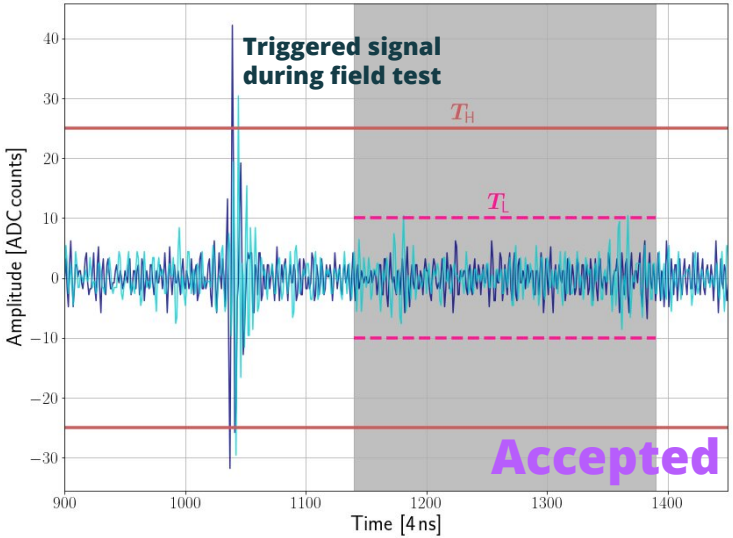
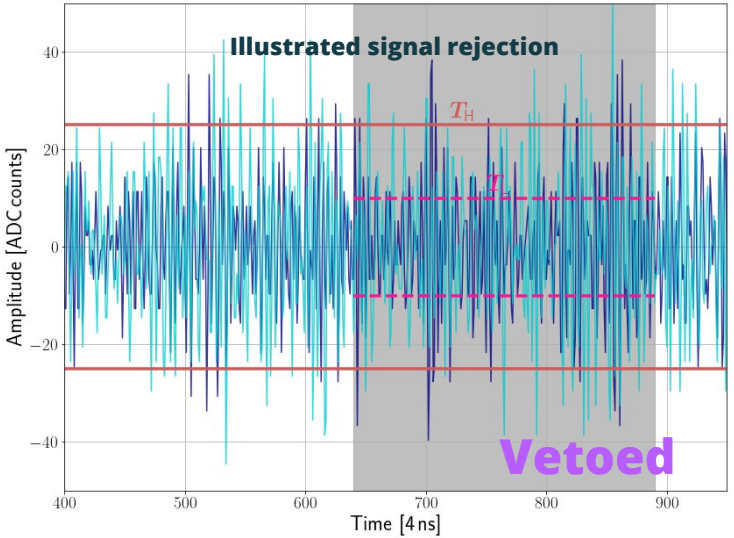
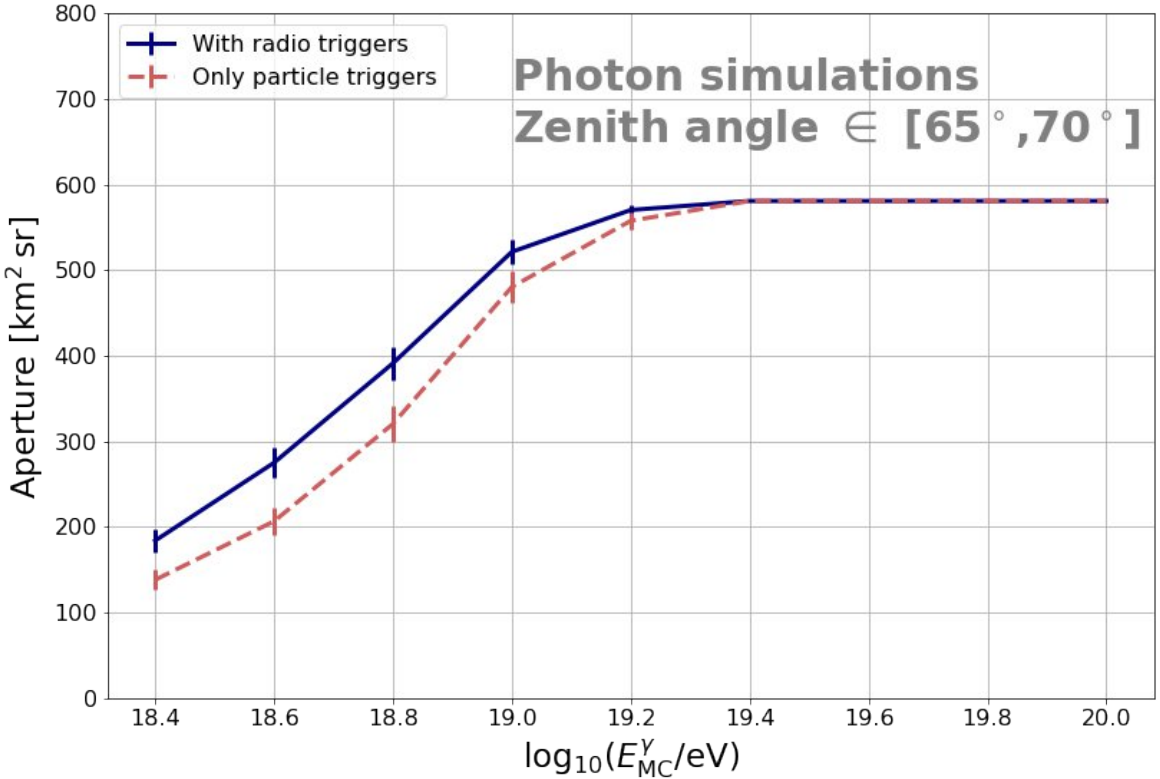




Count how many times a second threshold after the signal is exceeded

Second threshold too often exceeded - vetoed

Gain in aperture



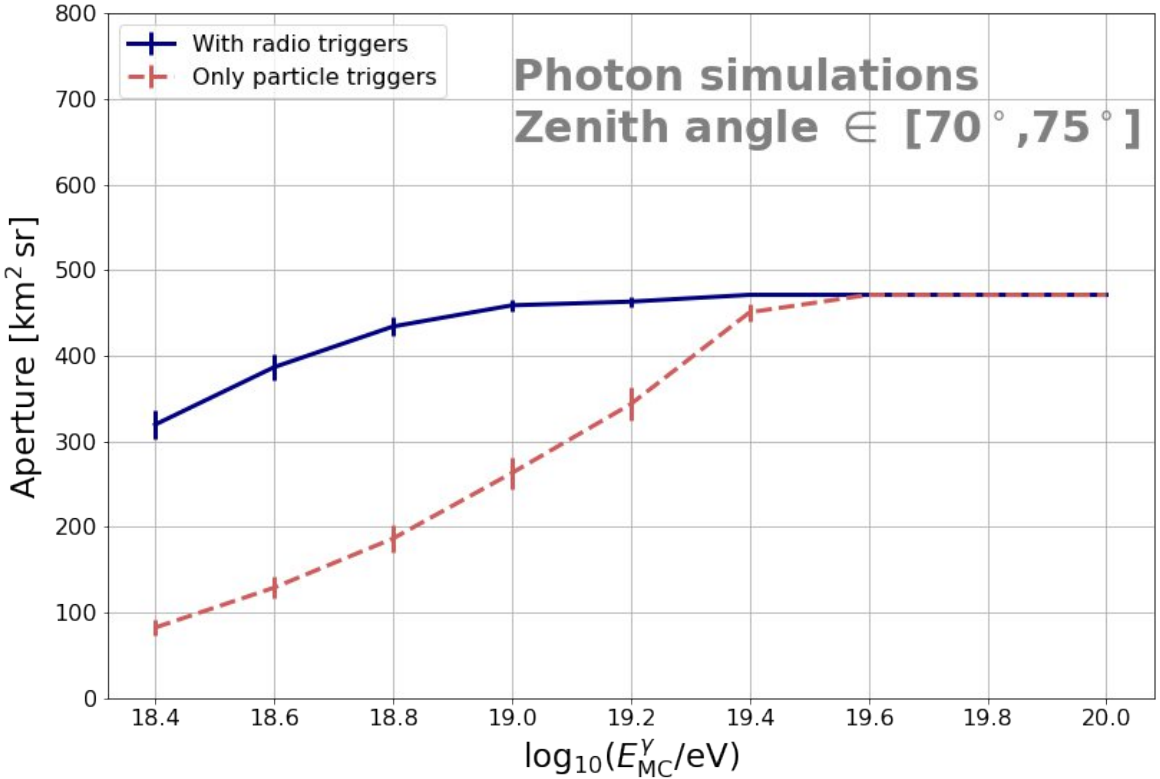
Simulation studies:

Treat radio trigger equivalent to existing particle triggers

Increasing zenith angle

Increasing relative gain due to radio trigger

Gain in aperture



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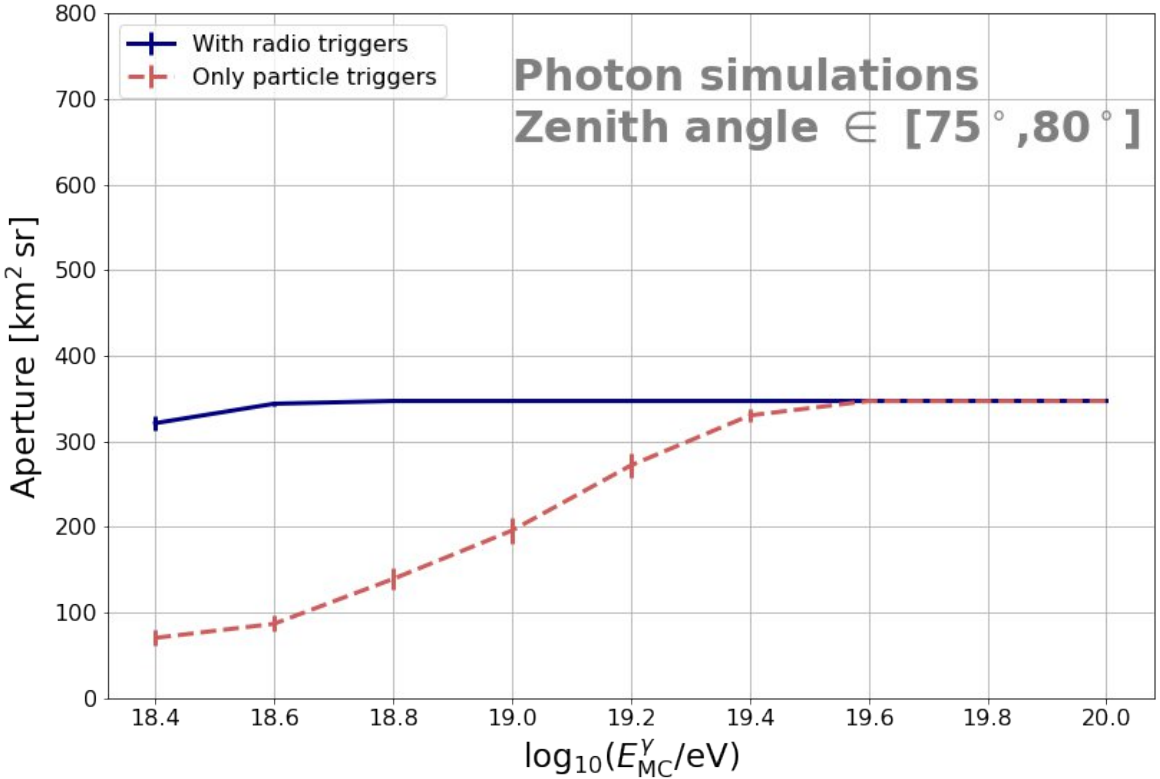

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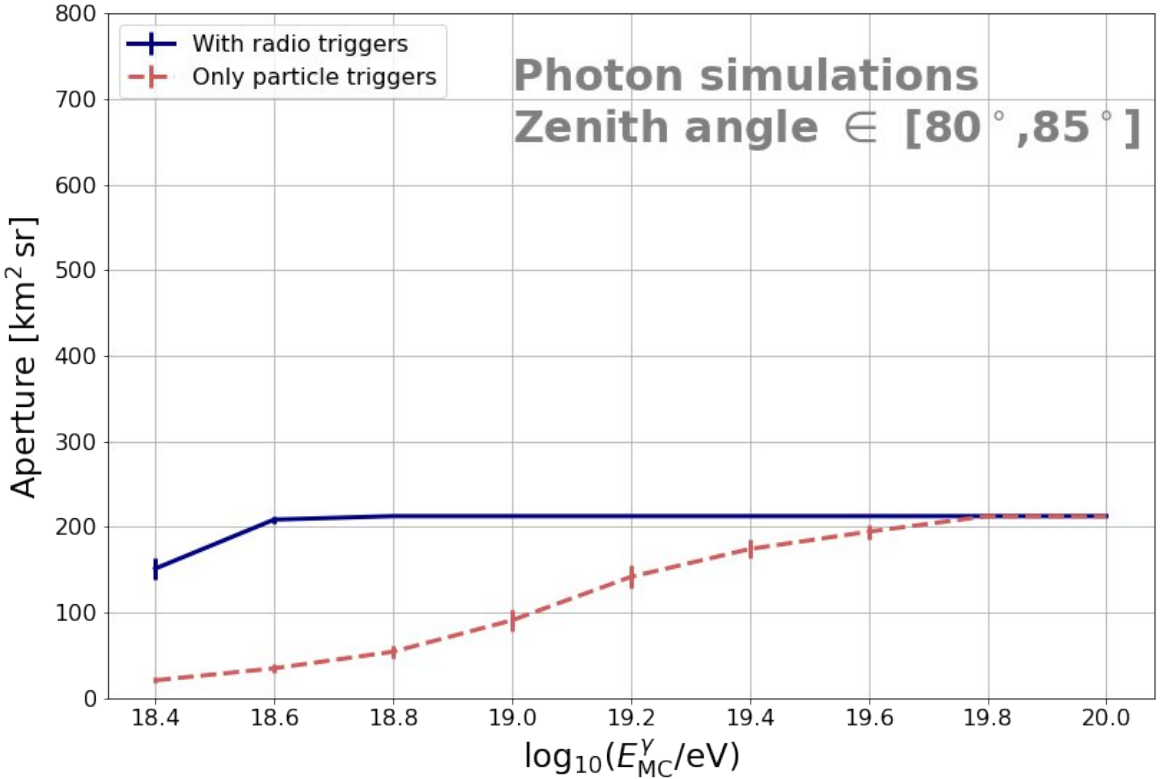

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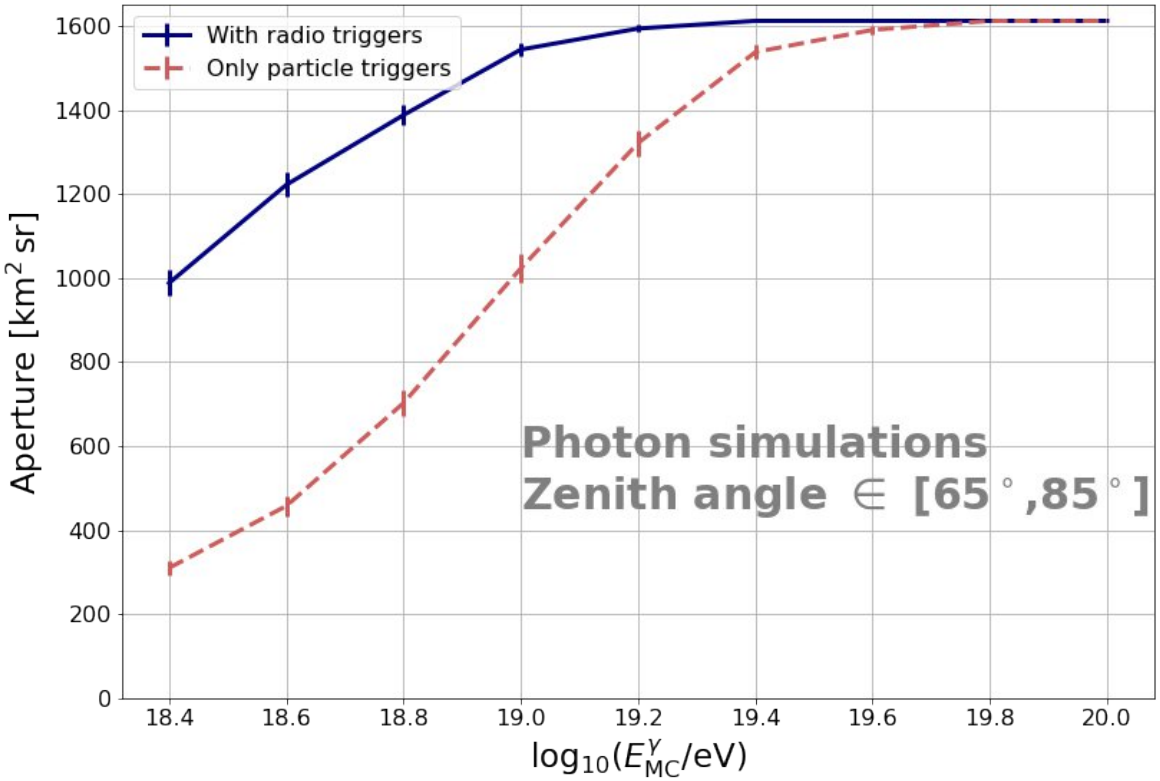

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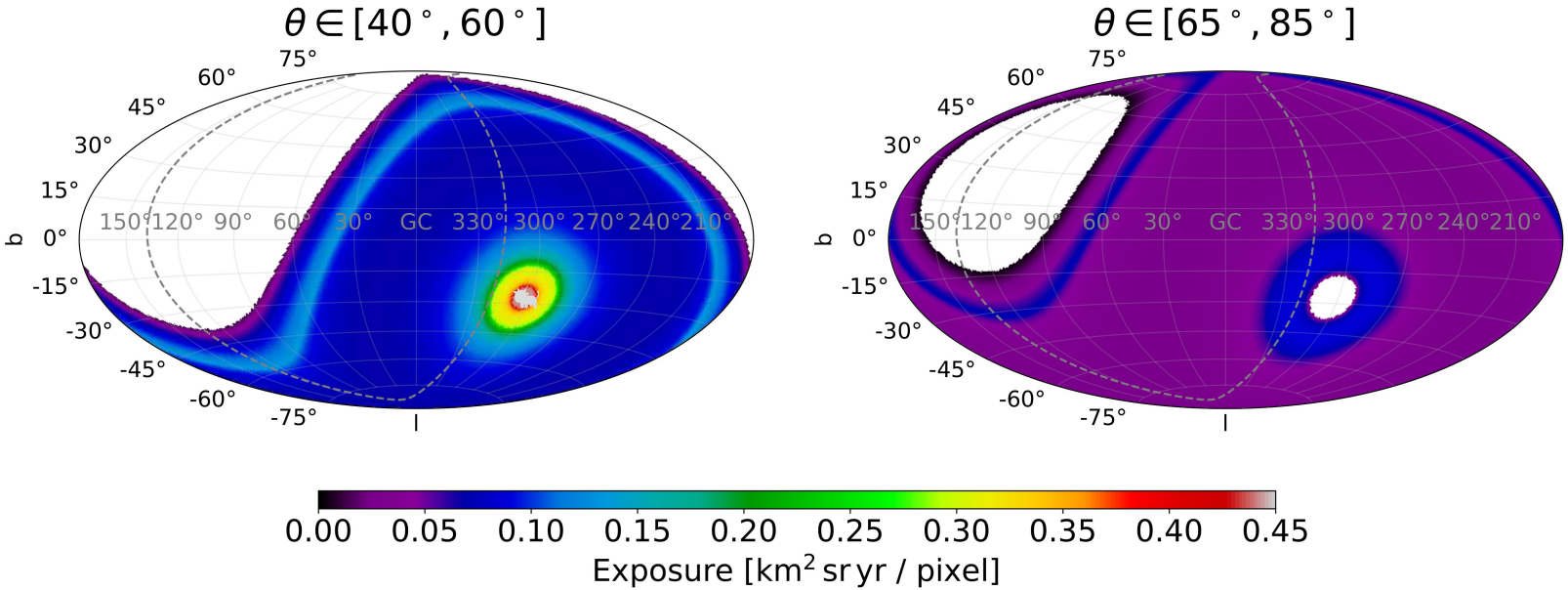
Increasing relative gain due to radio trigger

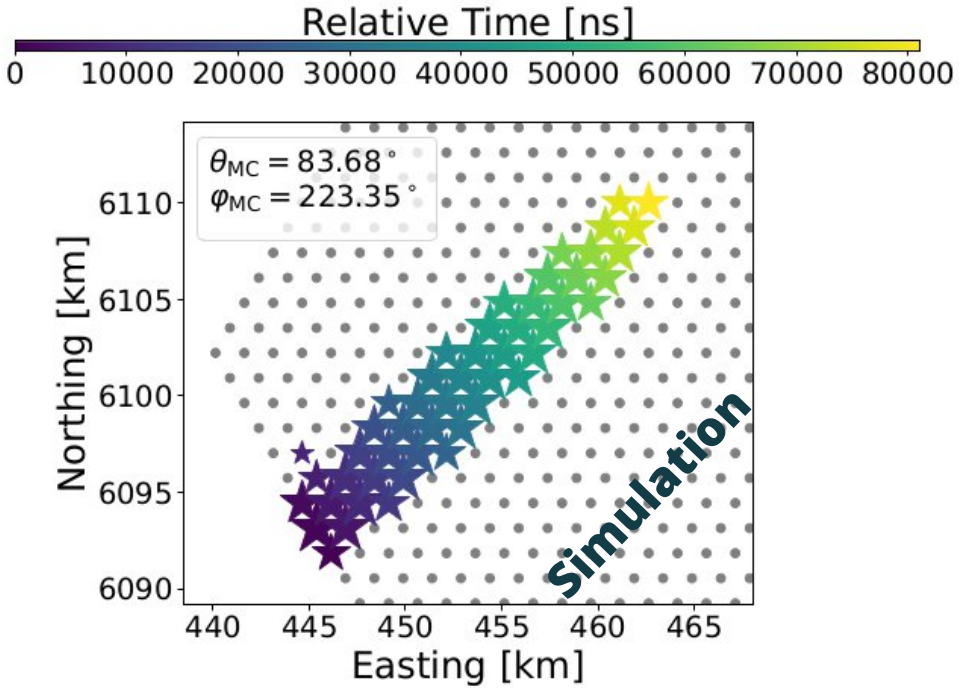
In sum: up to x4 times more aperture at low energies

Sky coverage

Not only gain in aperture, but also sky coverage increases



Simulated photon event



Simulated photon events:

Events with

- **Large footprint**
- **Large station signals**
- **High reconstruction probability**
- **Not read-out without radio trigger**

Realization of the trigger

Is the implementation (radio trigger equivalent to existing particle triggers) feasible?

Bandwidth limitation  **Noise situation**

(20 year old system,1200 bits/s station bandwidth)

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~43 days to download all 3 LOTR movies

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Allowed radio rates:

Average station trigger rate: < 1 Hz

Read-out rate: ~1-2 / station / day
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No burst of triggers/read-outs allowed

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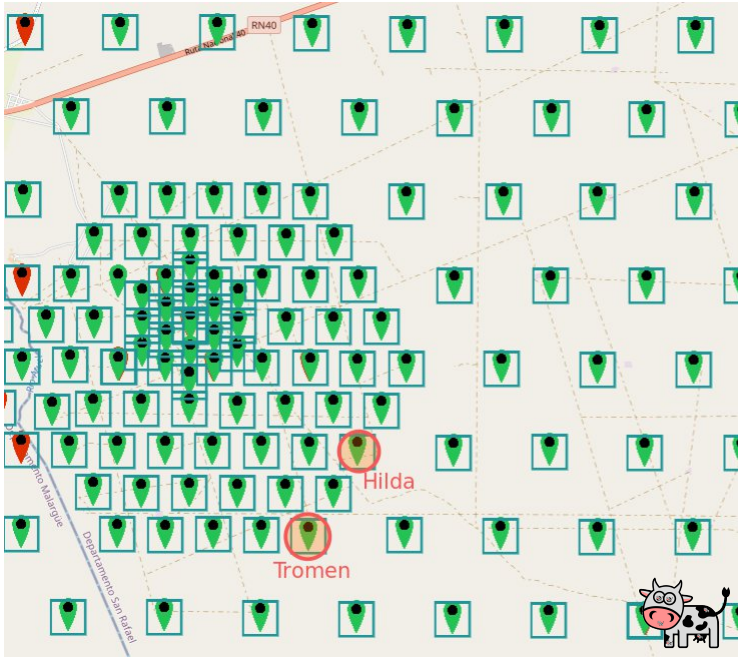
Field test

Test implementation with two stations

No “pure” radio read-outs, at least 3 stations required for read-out

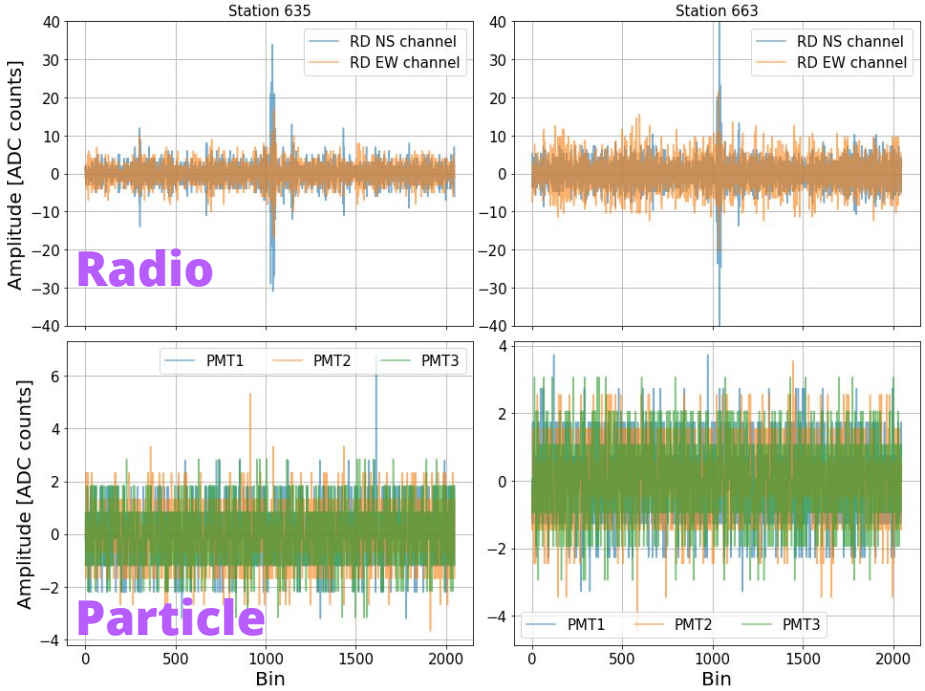


Goals:

- **Prove trigger is working**
- **Show read-out rate is acceptable**

Trigger working?

Triggers are read-out in case of (random) coincidence with particle trigger of third station



Air shower-like signals triggered

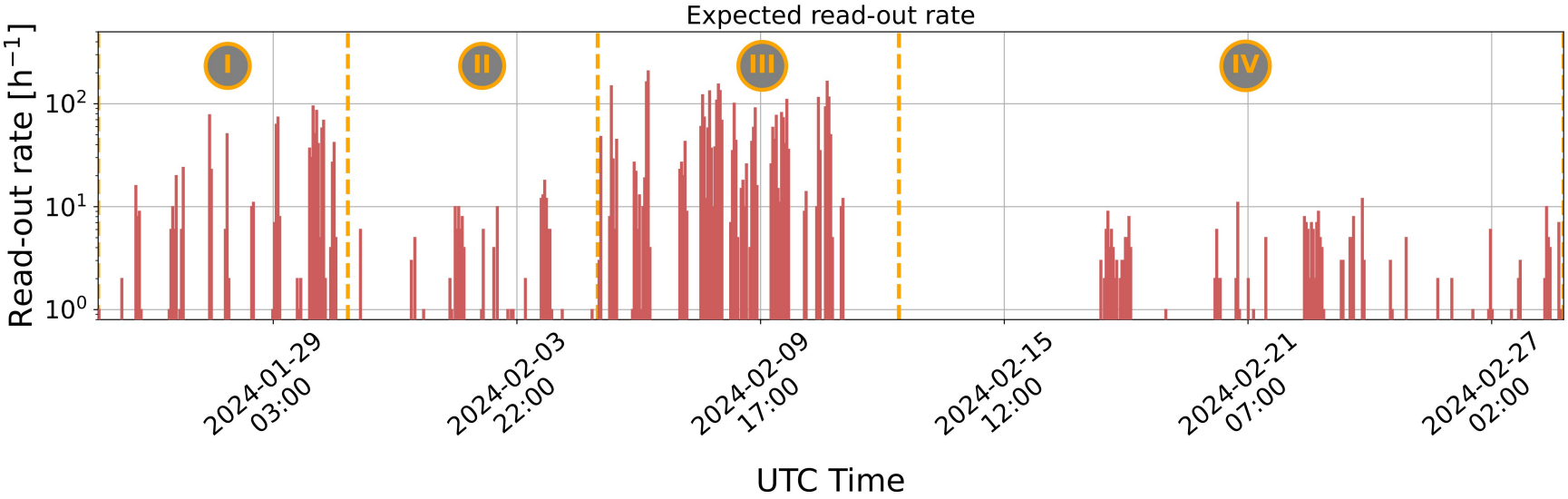
No particle signal visible

Read-out rate acceptable?

Tested different settings of trigger (I-IV)

Analyse coincidence of radio triggers. Assume: signals reach third station (read-out)

Up to now: no suitable setting found to be compatible with strict bandwidth limitations



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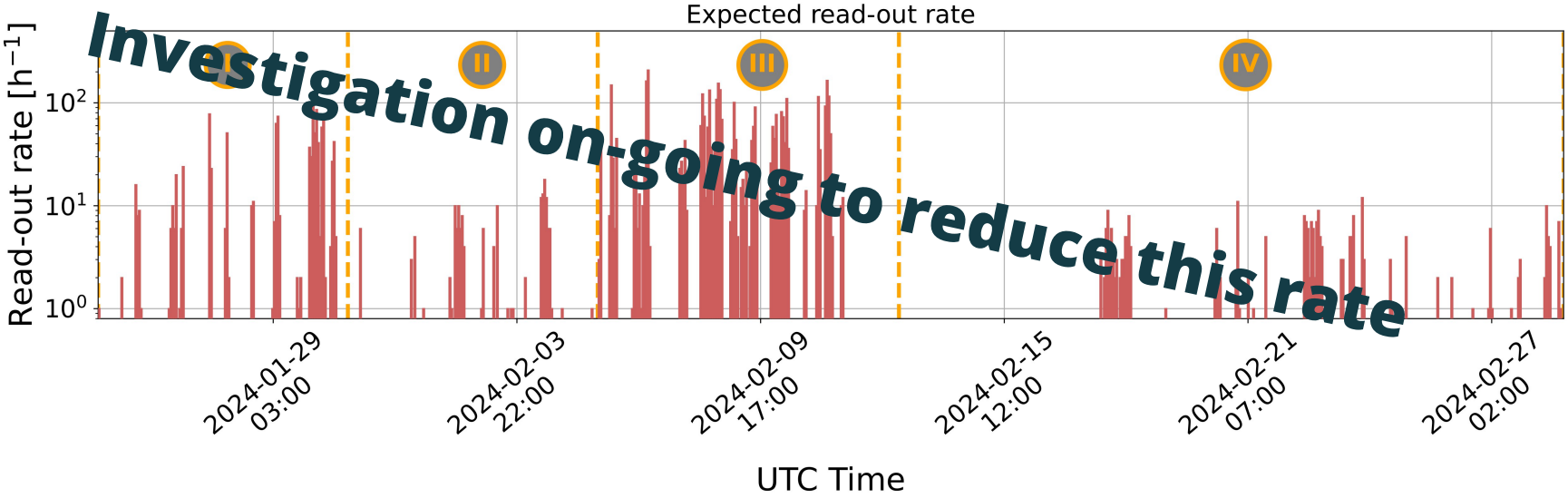

Approaches to reduce read-out rate

Change triggering algorithm:

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- **More advanced trigger designs suitable?**

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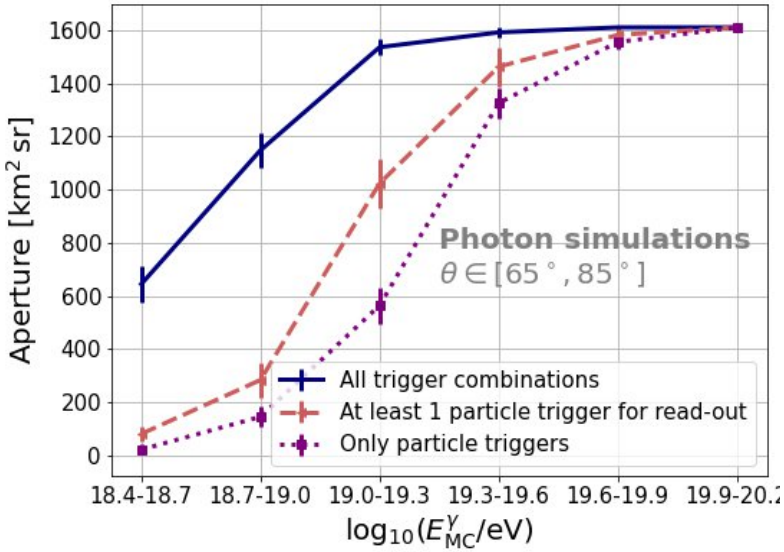
Request particle triggers for read-out

+ **Good at limiting noise read-outs (no correlation of radio and particle noise)**
– **Reduces trigger efficiency**

Intermediate solution?



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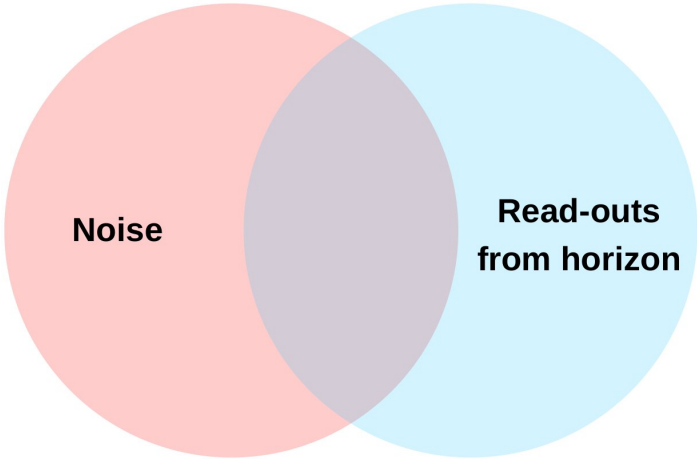
Reject pure radio events from horizon

- Radio noise mostly from horizon
Horizon read-outs mostly noise



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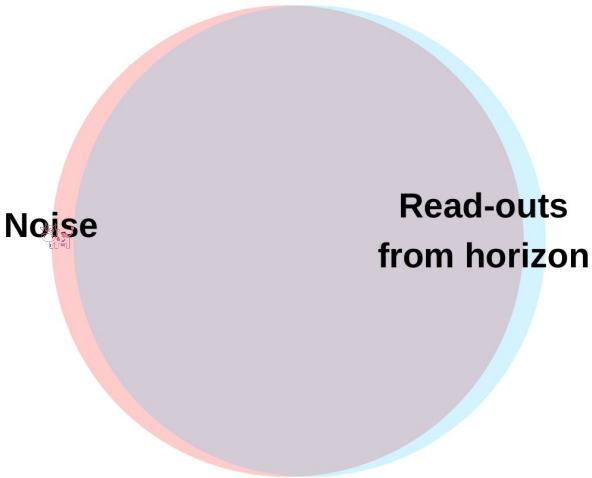


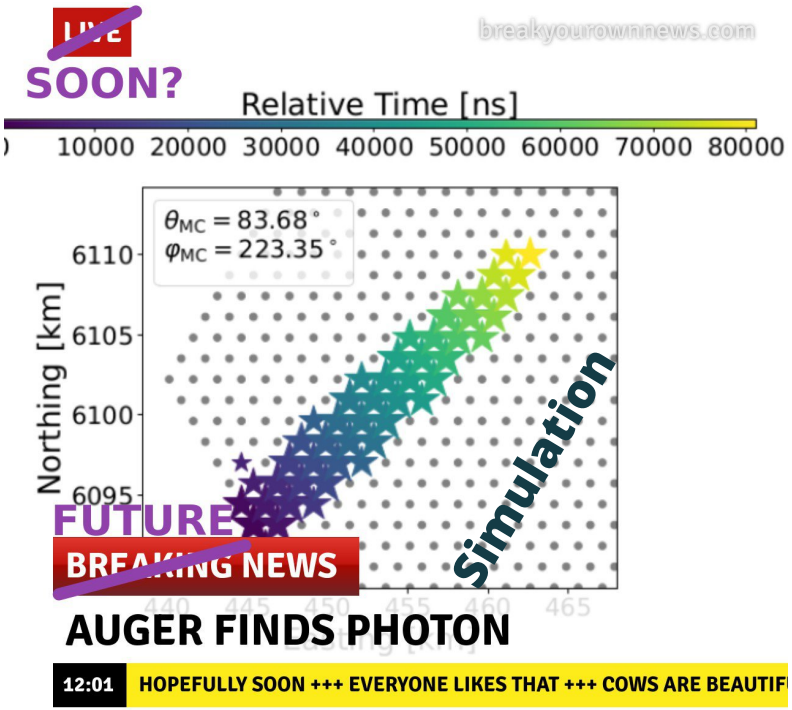
Reject pure radio events from horizon

- Radio noise mostly from horizon
Horizon read-outs mostly noise

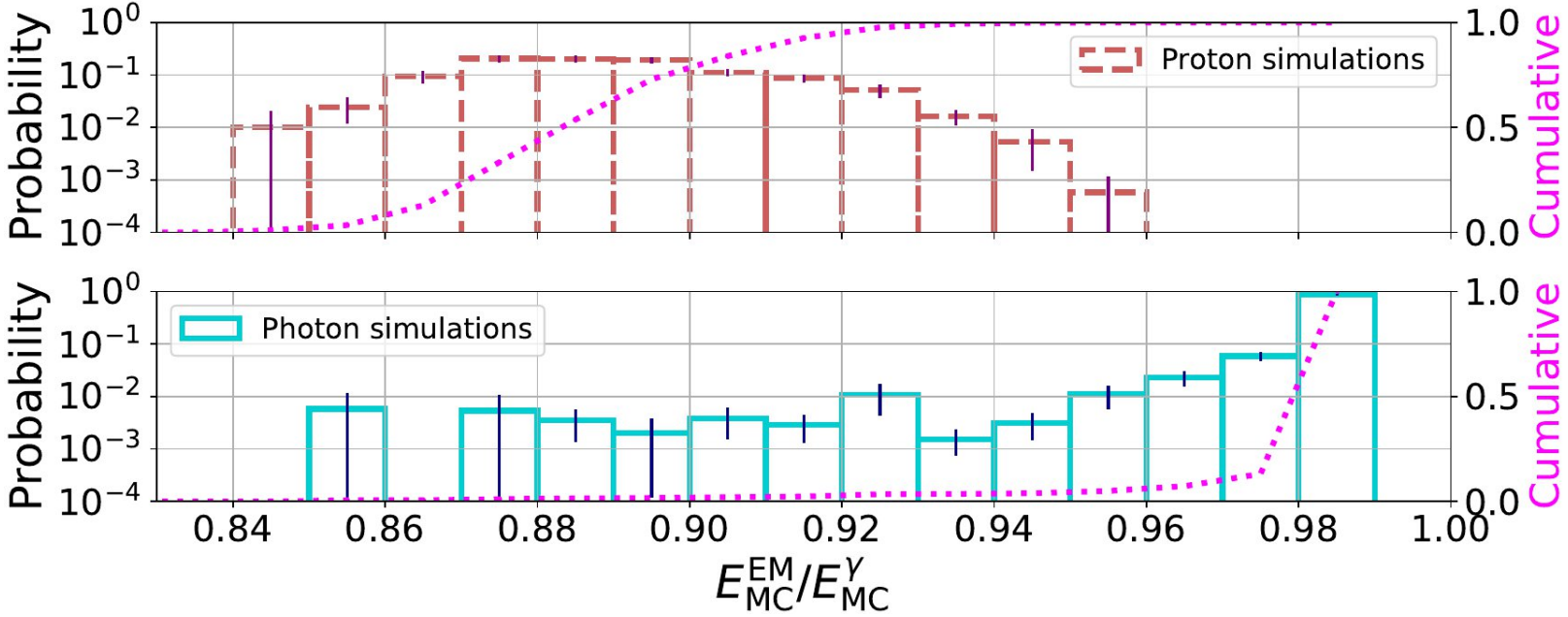
Summary

- **Radio trigger designed, tested and validated**
- **Simulations: significant improvement in photon trigger efficiency for ideal scenario**
- **Field test shows proof of princple, but work still to be done**
- **Limitation due to bandwidth: optimal and feasible implementation under discussion**

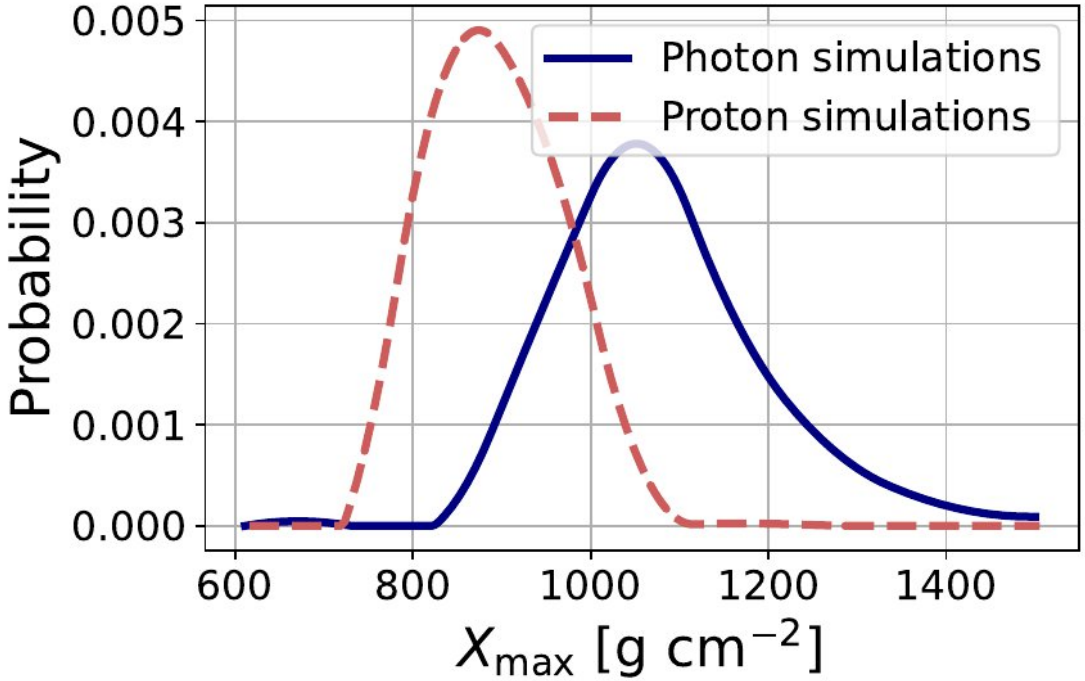
Stay tuned!



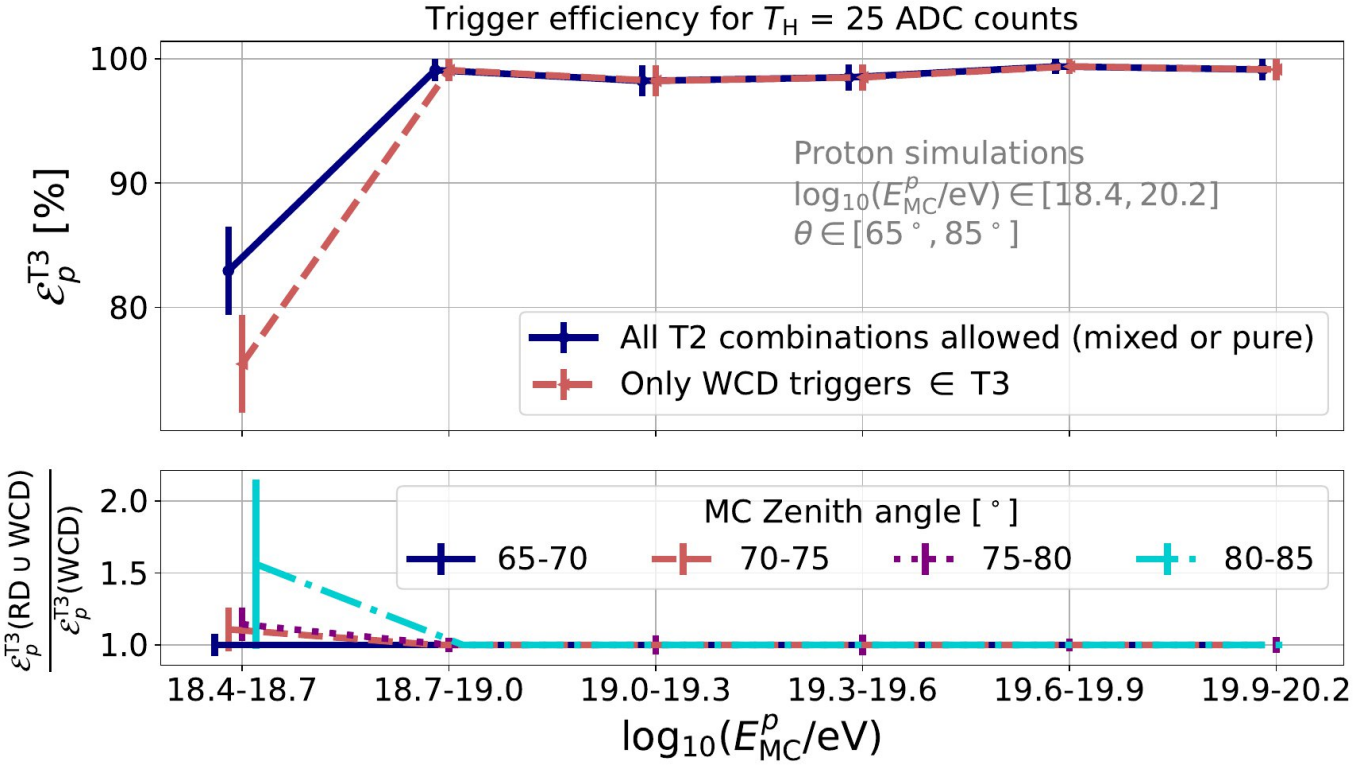
Simulations: EM fraction



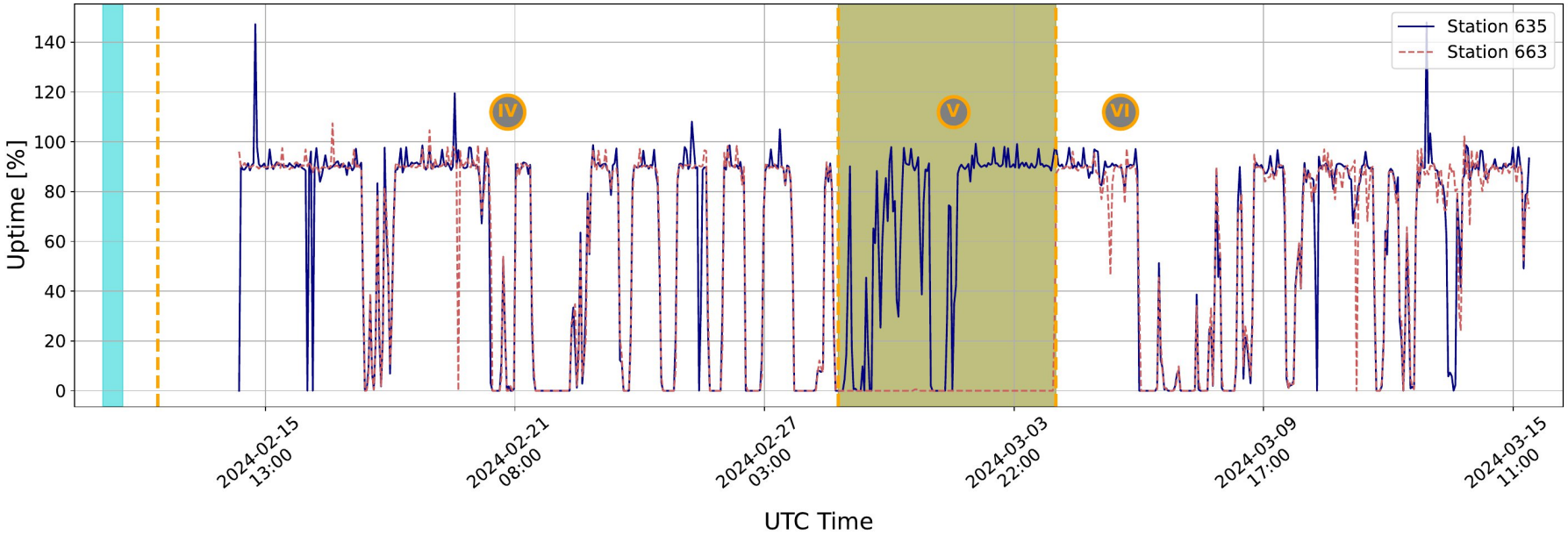
Simulations: Shower depth



Simulations: Trigger efficiency for protons

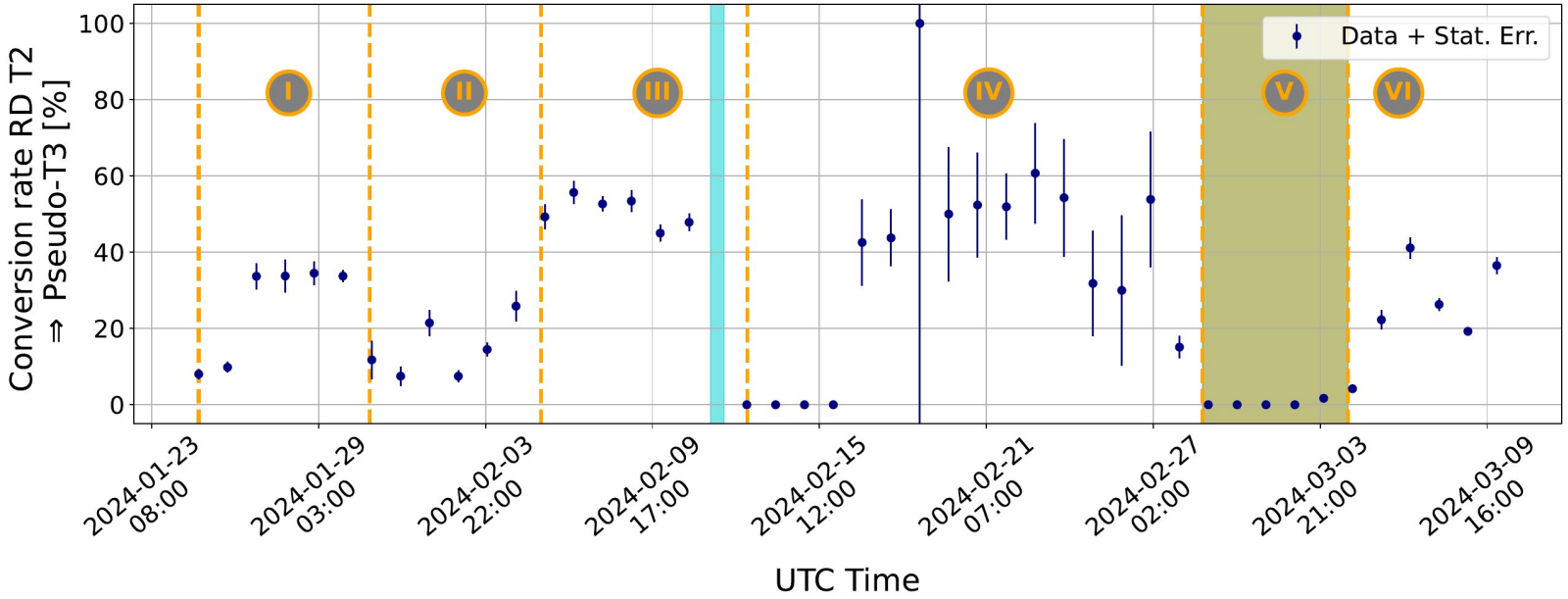


Field test: Dead-time due to limiting trigger rate



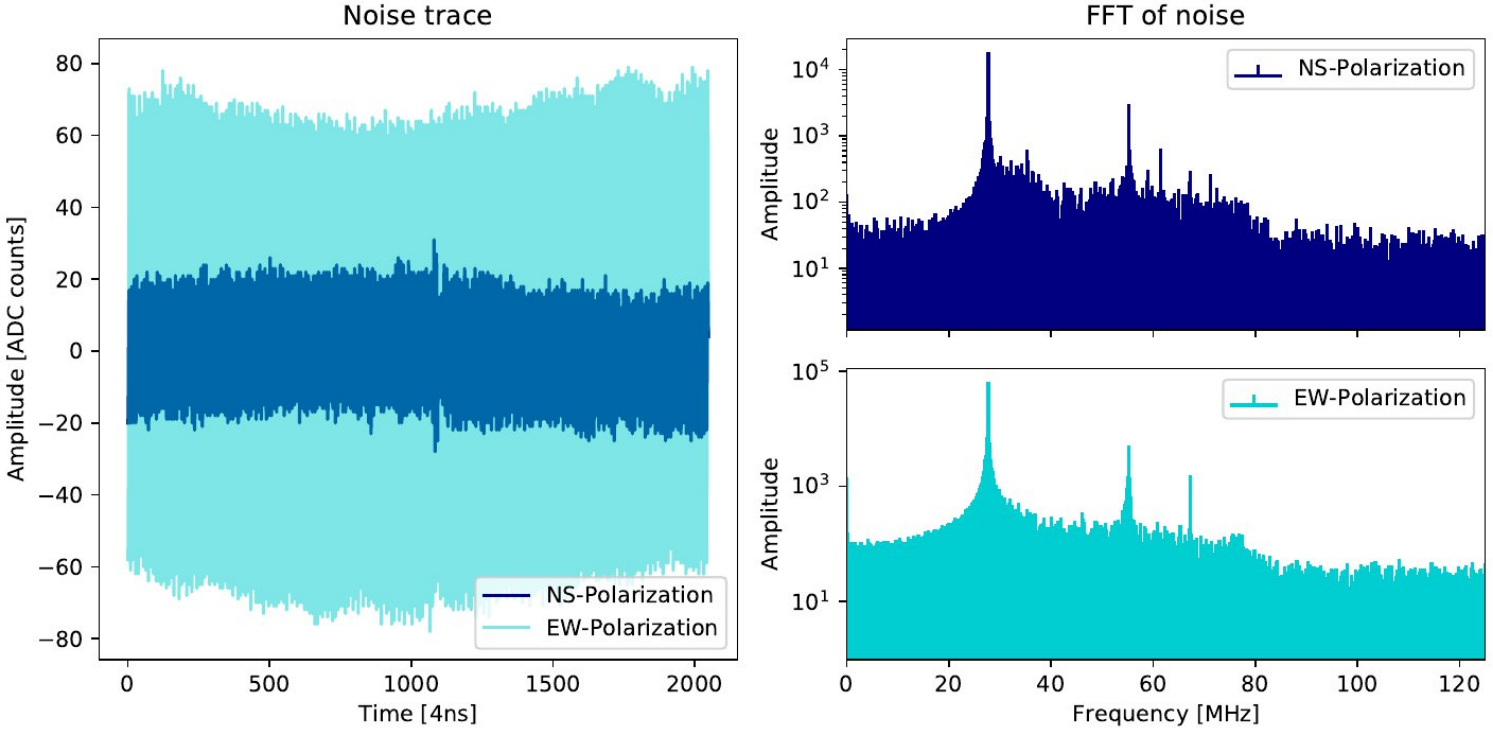
Up-time very noise dependent. Between 50 % and 80 % at one of the worst position in the array

Field test: Conversion rate of triggers

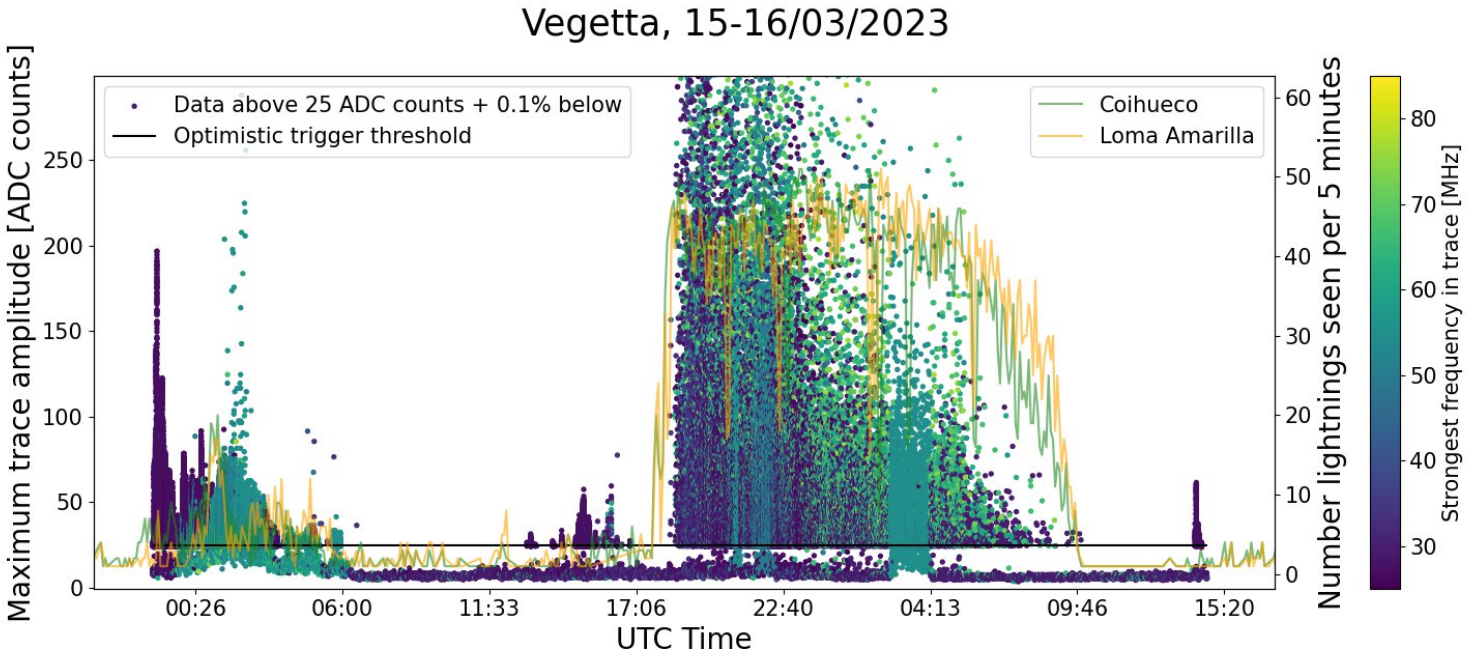


Conversion from station trigger to read-out ~ 10,000 times higher for radio than for particle triggers

Noise data: Mono-frequent noise

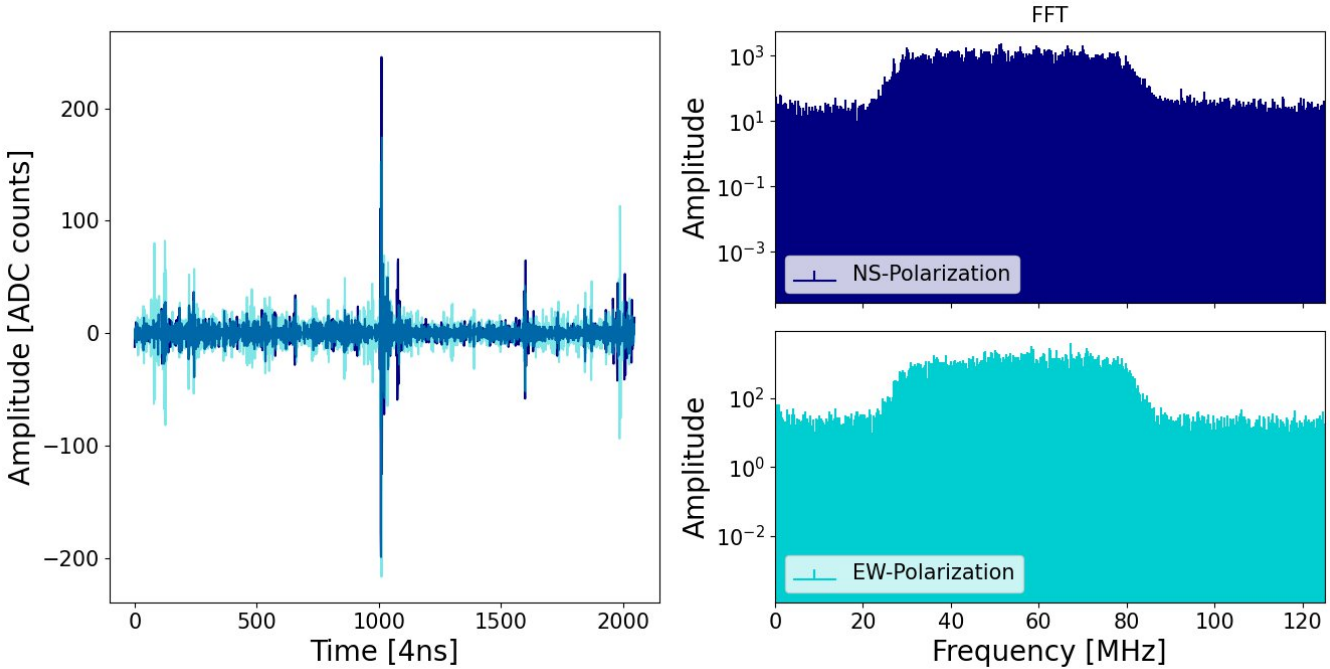


Noise data: Effect of lightning



Noise data: read-out via USB-stick with 100 Hz, by chance during lightning

Noise data: Lightning trace



Lightning traces hard to discriminate with simple algorithms