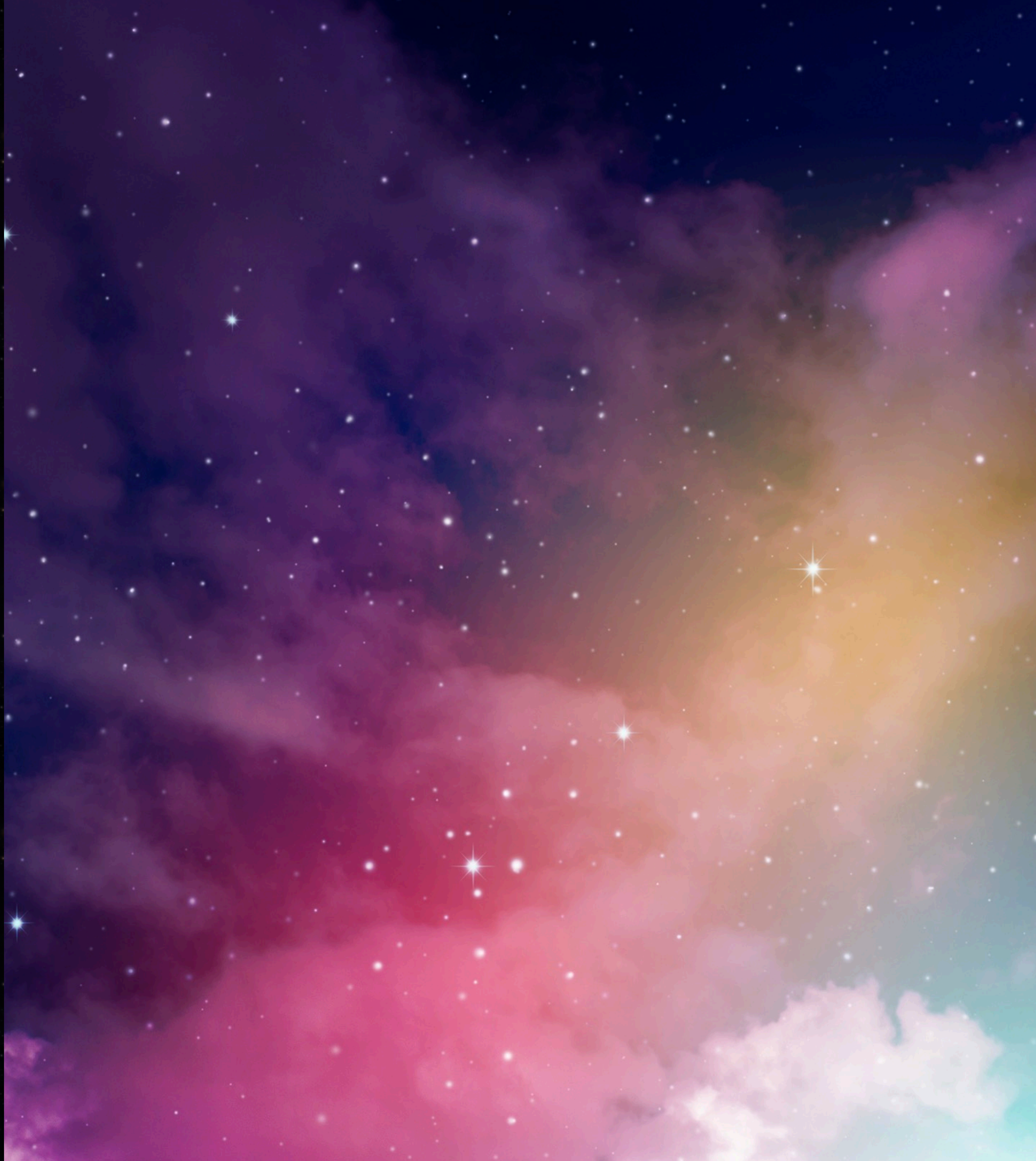
Towards an Autonomous Trigger for the Detection of Air-Shower Radio Emission

Jelena Köhler
Lukas Gülzow, Tim Huege, Markus Roth,
Marvin Gottowik, Olivier Martineau, Pablo Correa, Kumiko Kotera, Marion Guelfand

DPG Spring Meeting 2024
March 5th 2024

Physics Background: Cosmic Ray Air Showers

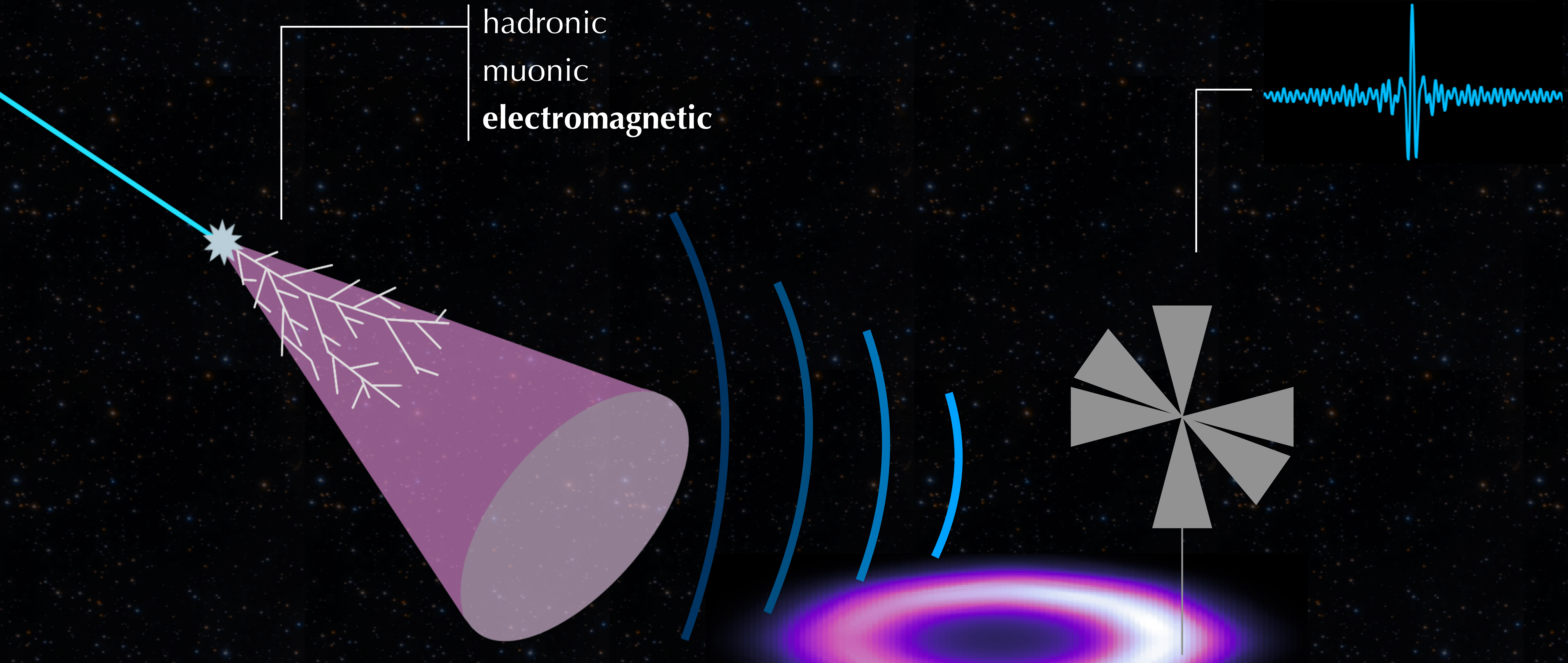


Extensive Air Showers

https://bigthink.com/starts-with-a-bang/speed-limit-below-speed-of-light/

jelena.koehler@kit.edu

Radio Emission of Air Showers

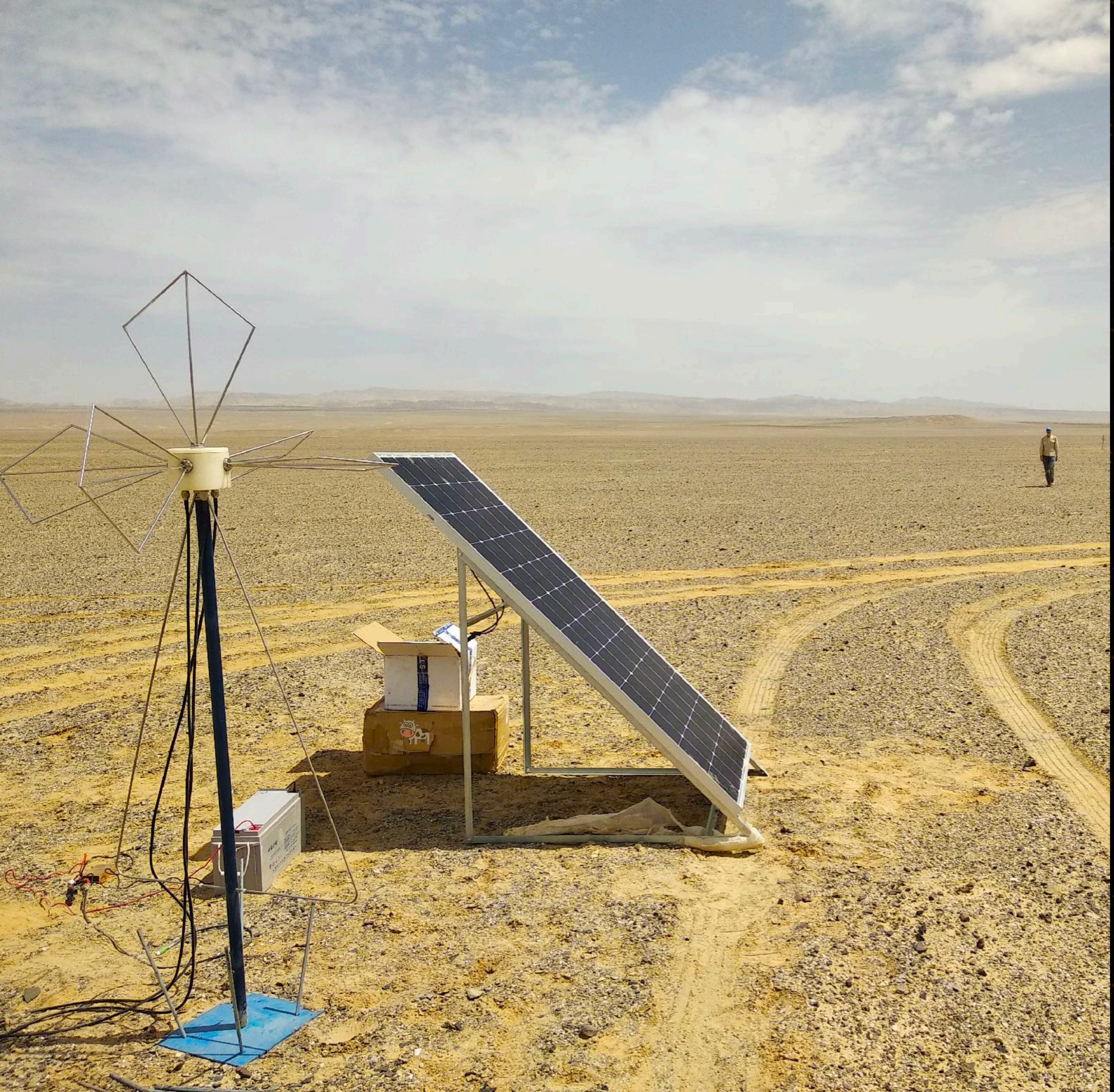


hadronic

muonic

electromagnetic

GRAND
Giant Radio Array for Neutrino Detection



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Giant Radio Array for Neutrino Detection

- ⋆ CR and ν detection
- ⋆ pure radio experiment
- ⋆ combined detection area of 200 000 km^2
- ⋆ frequency band 50-200 MHz

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Site Status

GRAND@Auger

GRAND@Nançay

GP13 → GP80

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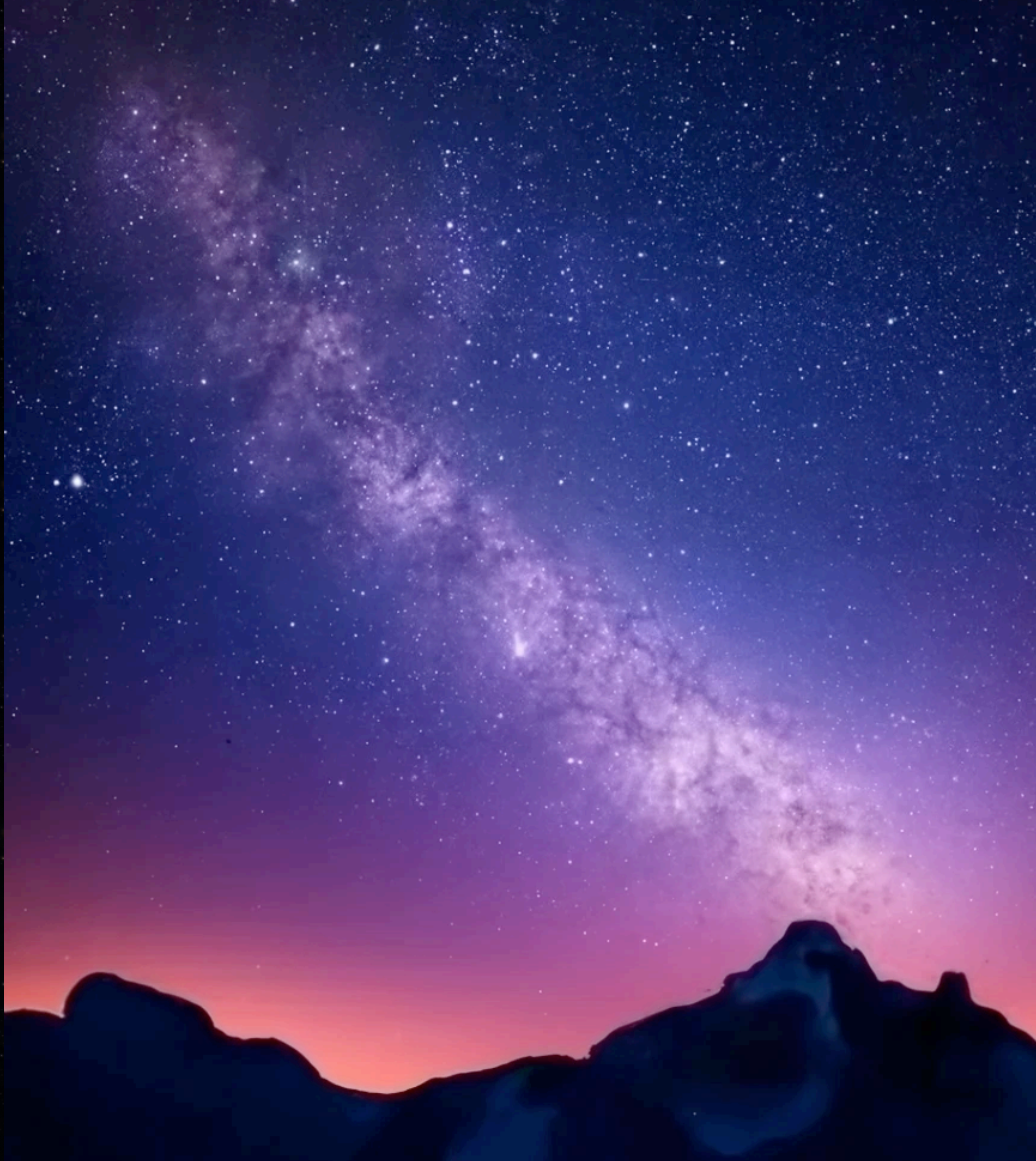
Developing an Autonomous Radio Trigger



Developing an Autonomous Radio Trigger

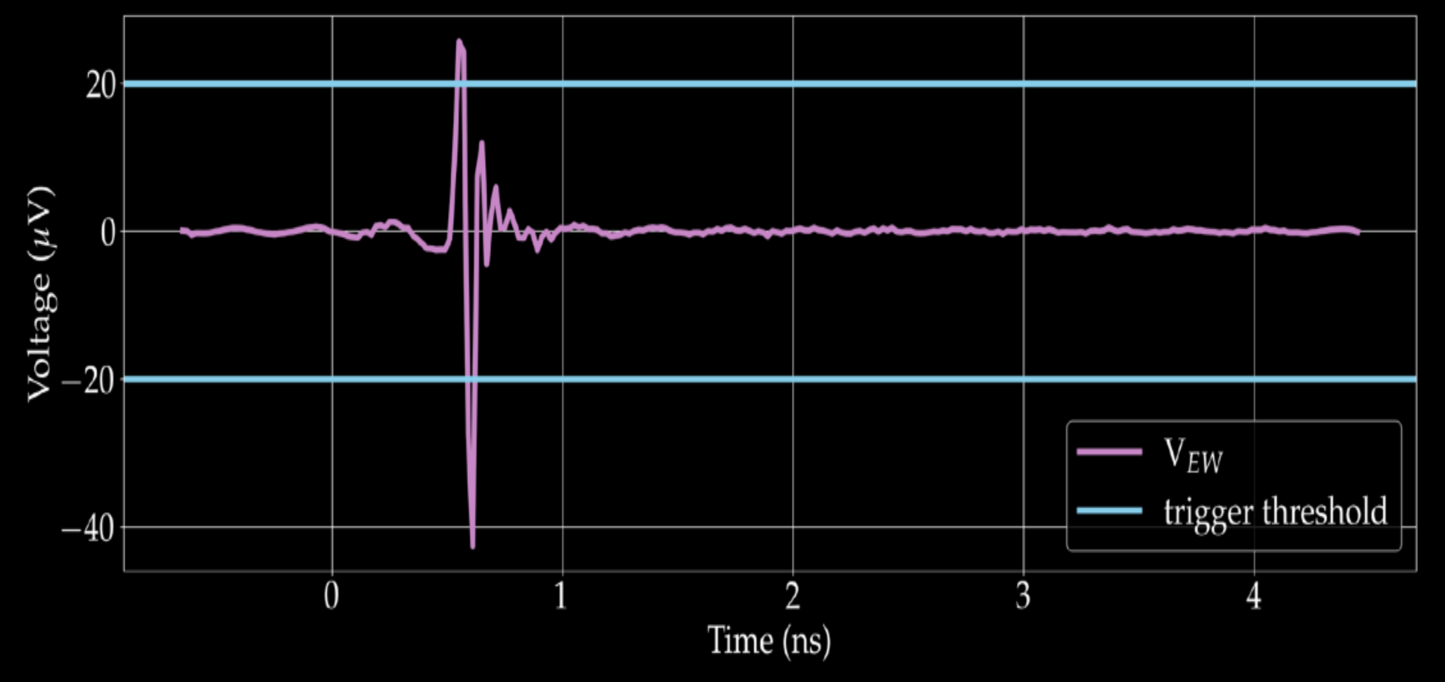
Multi-Level Trigger Systems

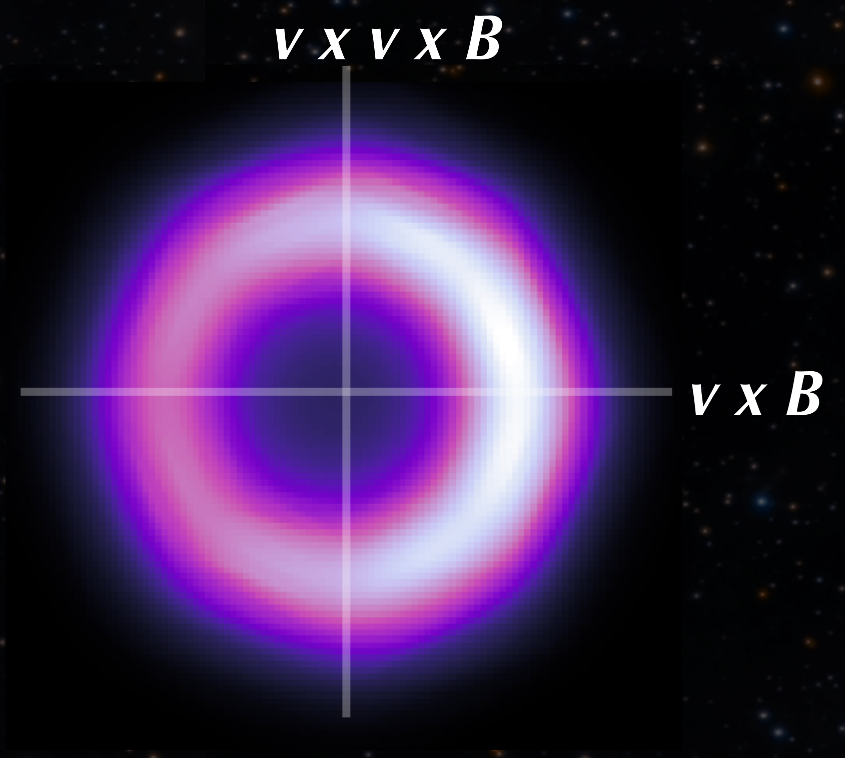
- ★ **step 0:** hardware trigger
- ★ **step 1:** antenna level

- evaluate **individual antennas**

- ★ **step 2:** detector level

- evaluate **array of antennas**





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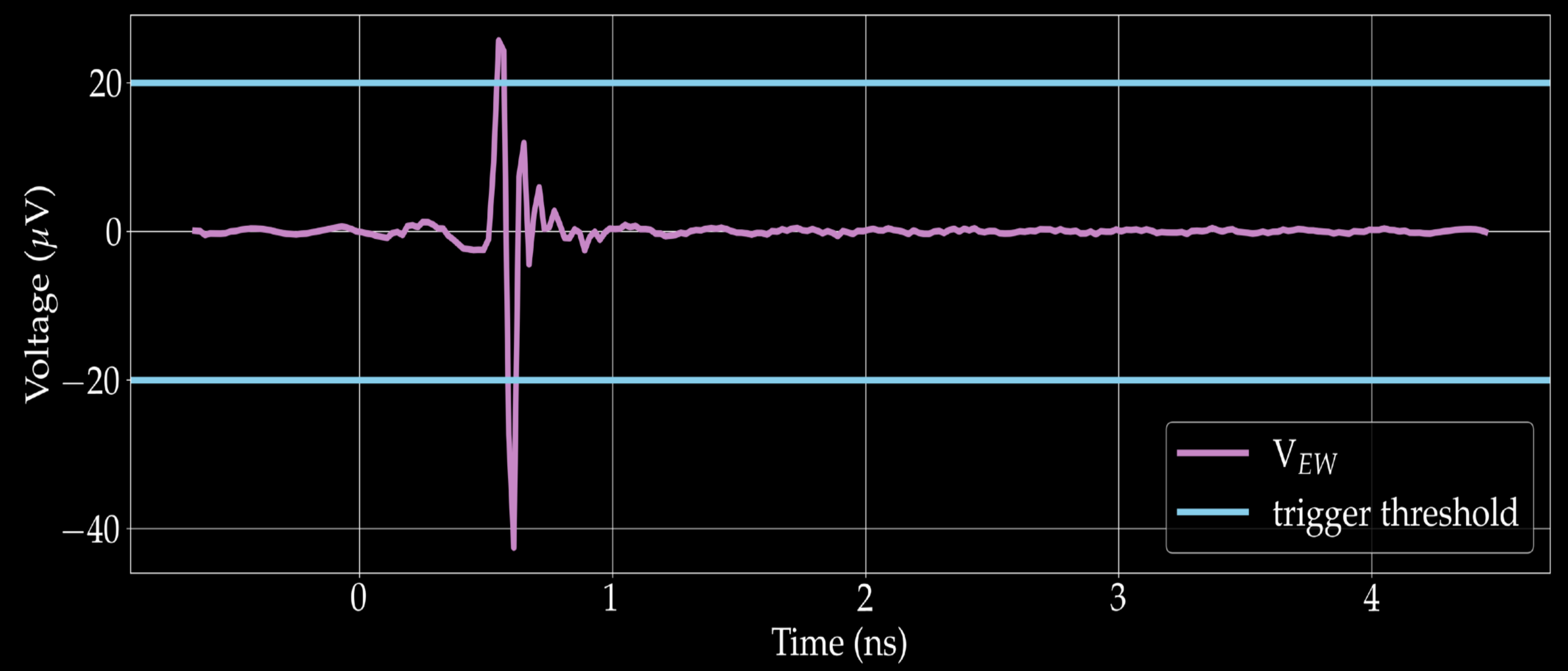
antenna level

Antenna Level Trigger

keep the classic methods

for each antenna



basic threshold trigger & template fitting

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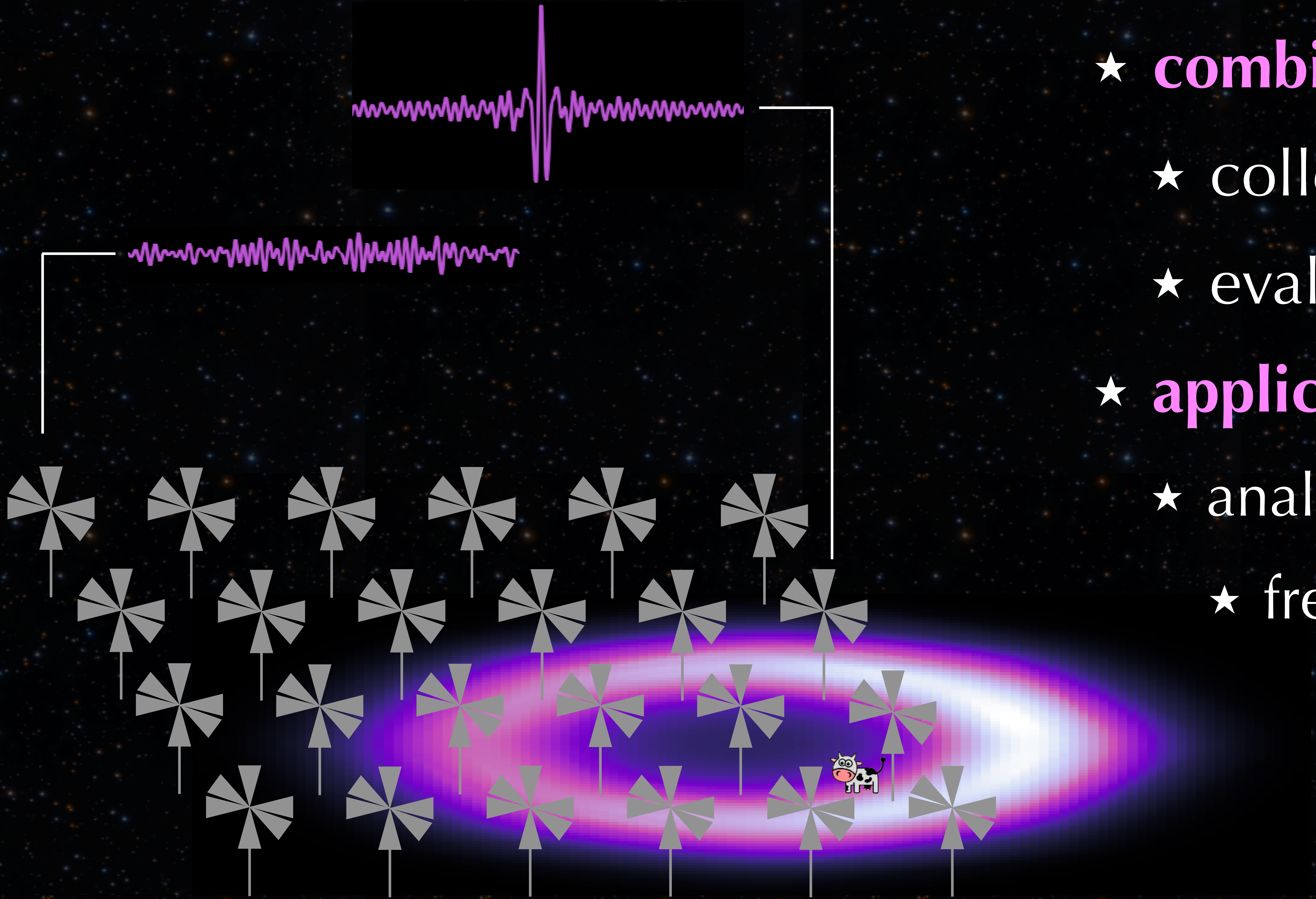
detector level

Event Level Trigger

add the new methods



- ⋆ **combine antenna level info**
  - ⋆ collect data from triggered antennas
  - ⋆ evaluate distribution & signal arrival times
- ⋆ **application**
  - ⋆ analyze **radio emission patterns**
    - ⋆ frequencies, energies, fluence, etc.

jelena.koehler@kit.edu

Event Level Trigger Methods

Event Level Trigger Method

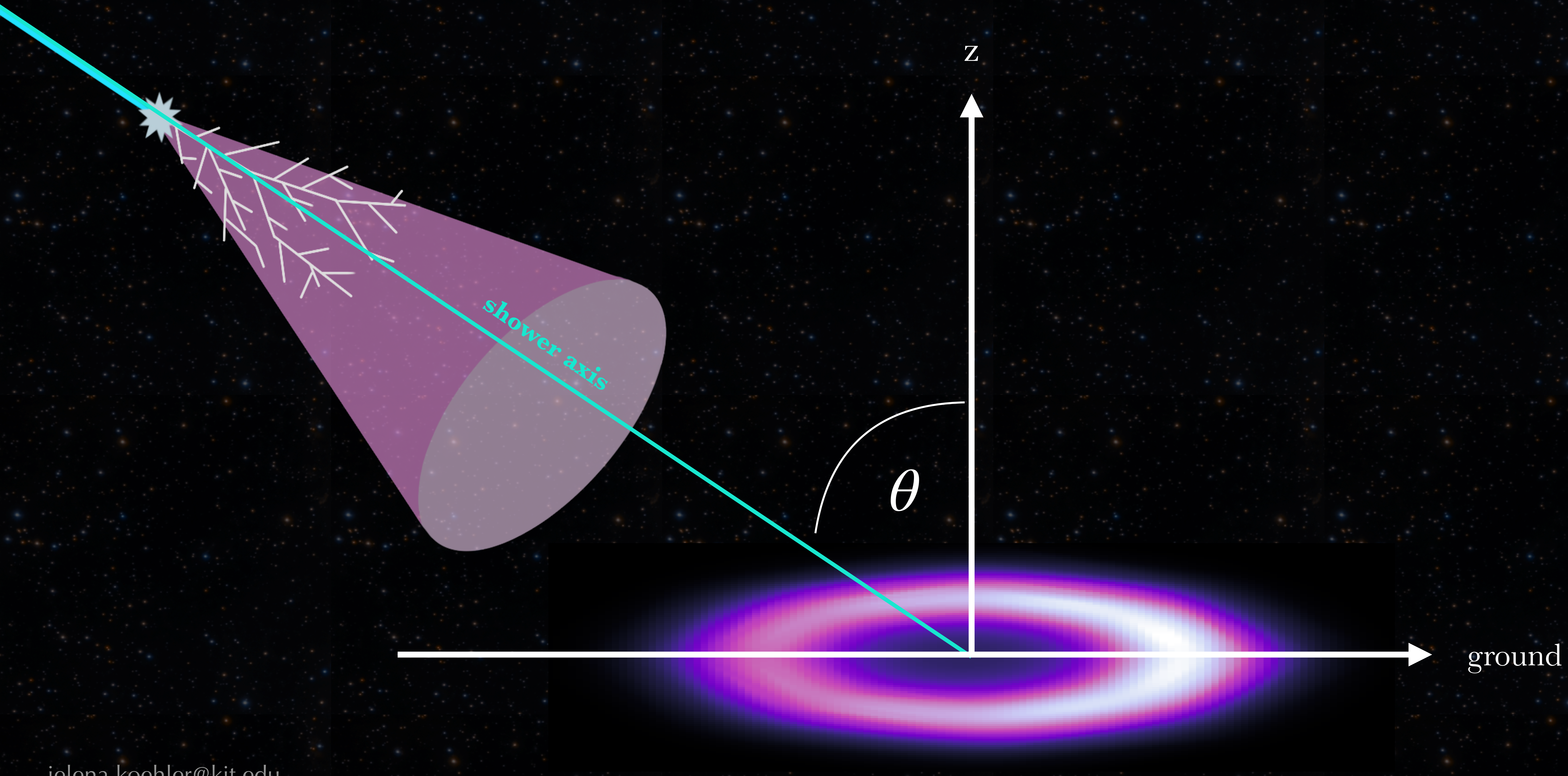
Do the reconstructed parameters match theoretical expectations?

- **trigger conditions:**
    - reconstructed **zenith angle** matches computed zenith angle
    - reconstructed **azimuth angle** matches computed azimuth angle
    - **signal arrival time distribution** matches theoretical expectations
- **real-life application:**
    - **template database** derived from simulations to approximate expected parameters in real time

jelena.koehler@kit.edu

Air Shower Parameters for Reconstruction

Zenith Angle


z
shower axis
θ
ground

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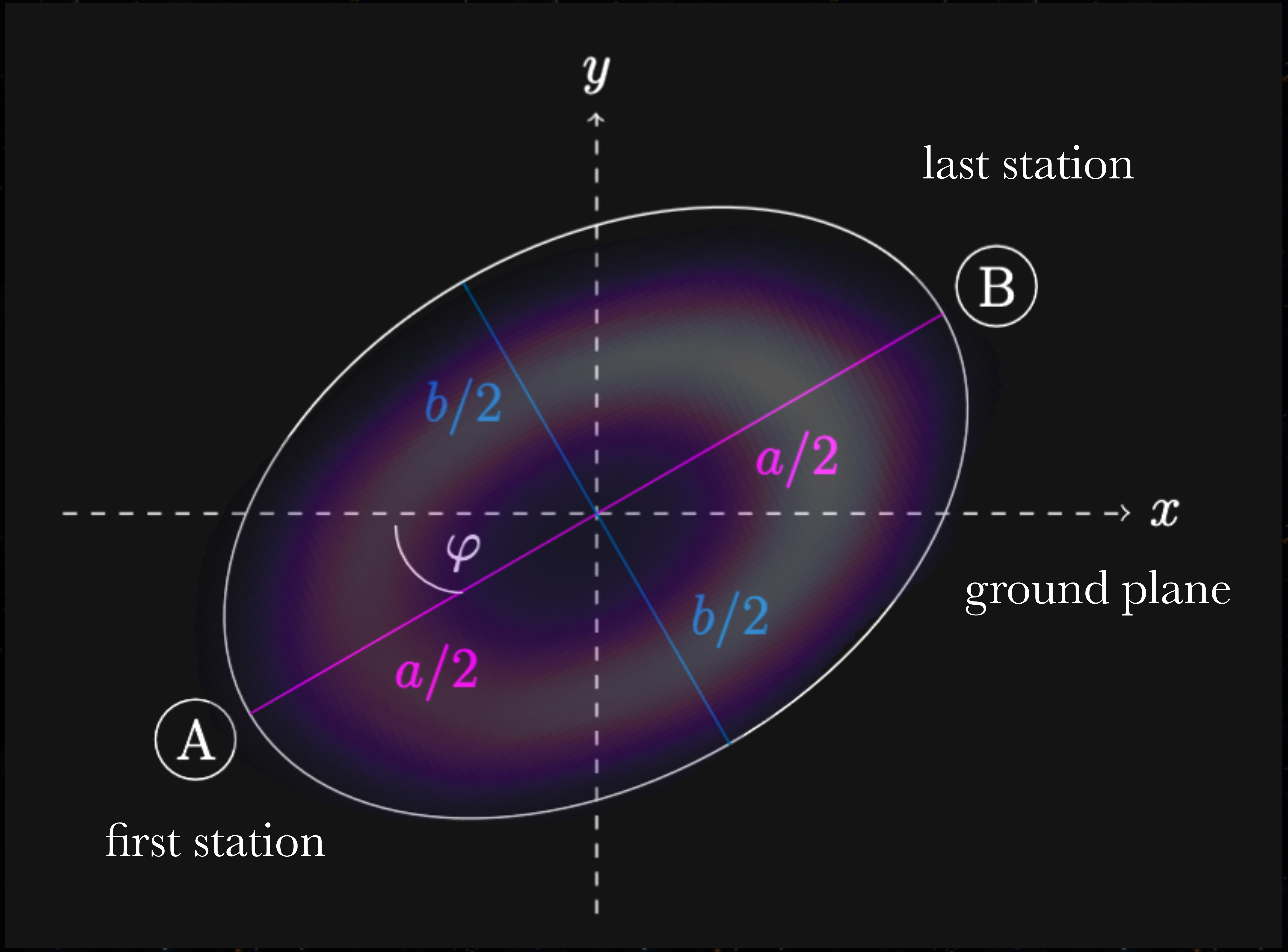
Air Shower Parameters for Reconstruction

Azimuth Angle


y
last station
B
b/2
a/2
x
φ
ground plane
b/2
a/2
A
first station

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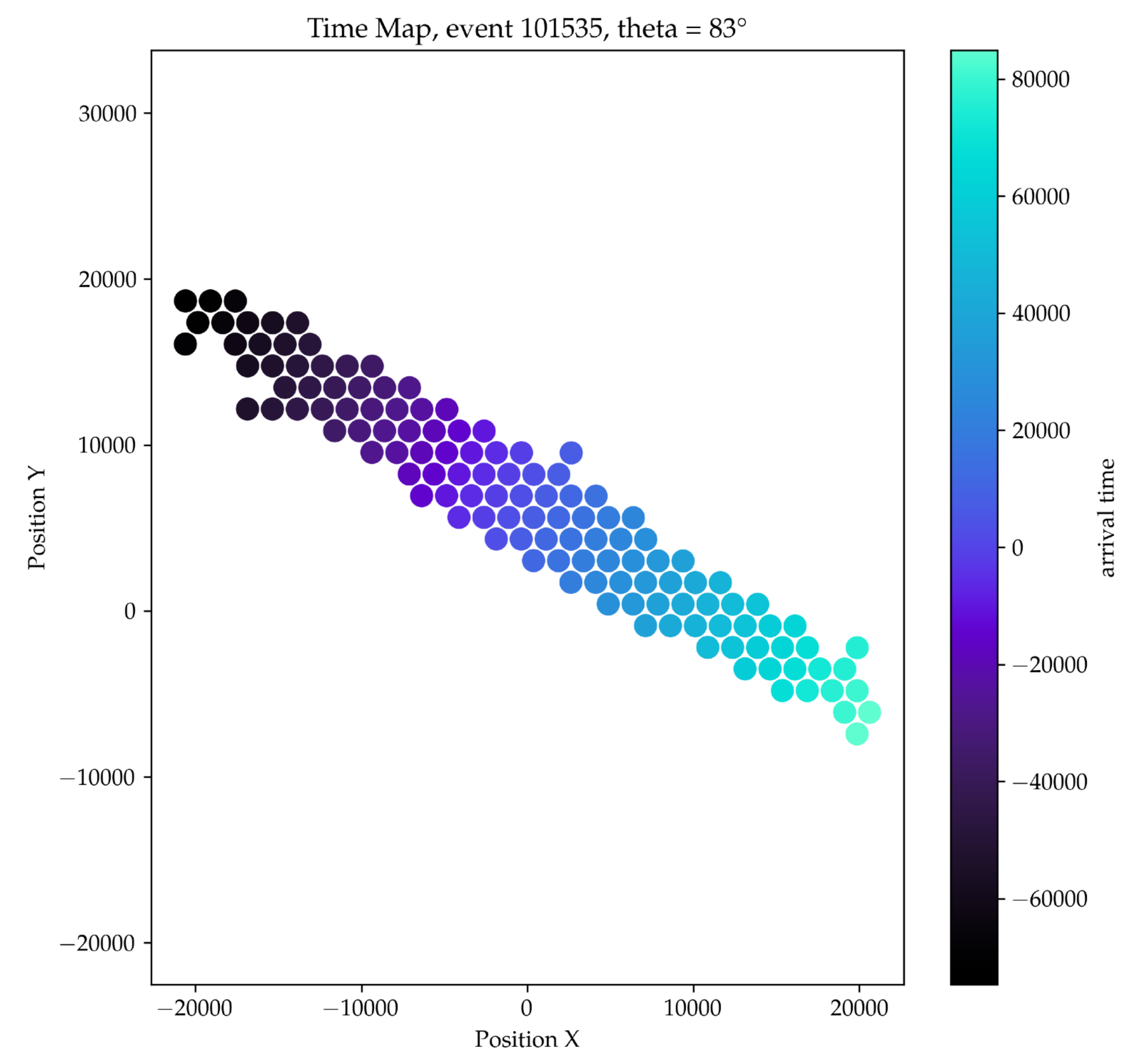
Air Shower Parameters for Reconstruction

Signal Arrival Times



jelena.koehler@kit.edu

Summary

- autonomous radio triggers make cost-effective experiments at **large scales** possible
- an **event-level trigger** enhances the classic methods with detailed understanding of radio emission

Outlook

- **improve & validate** two-level trigger method in the next months using simulations & measurements

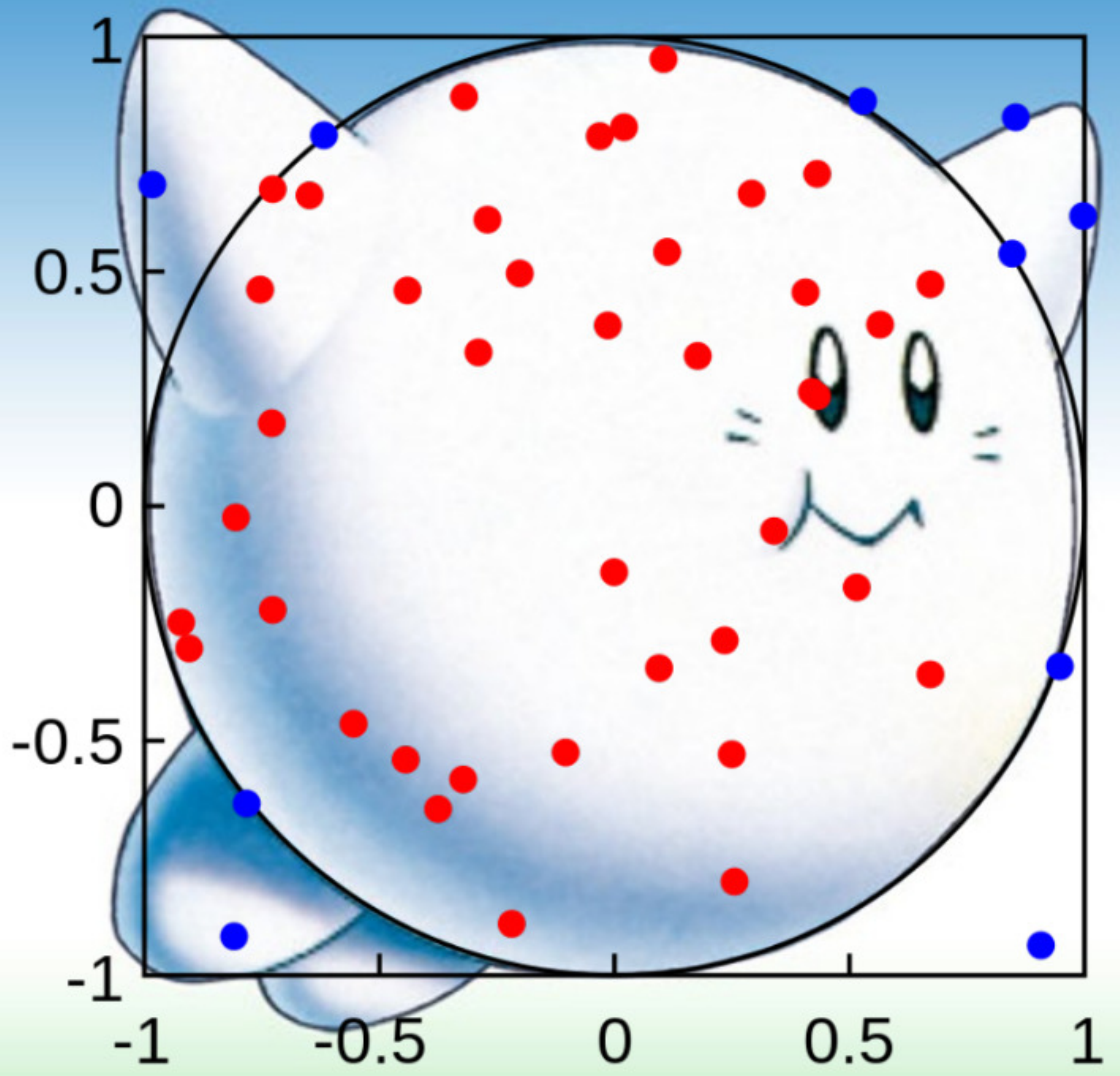
jelena.koehler@kit.edu

KIT

Karlsruher Institut für Technologie

Backup

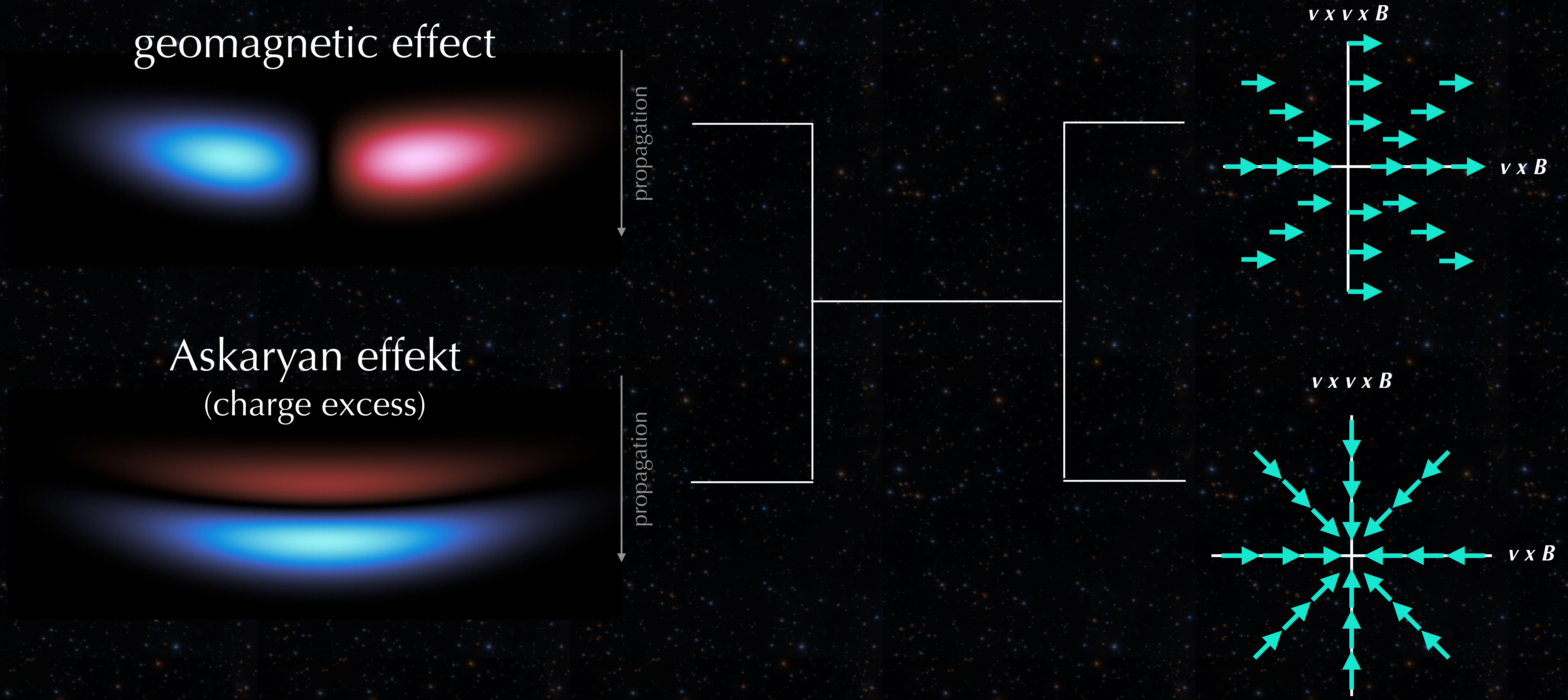
jelena.koehler@kit.edu



MONTE KIRBY'S DREAM LAND

Key Elements for New Trigger Methods

Understanding Radio Emission Patterns



geomagnetic effect

Askaryan effekt
(charge excess)

propagation
propagation
v x v x B
v x B
v x v x B
v x B

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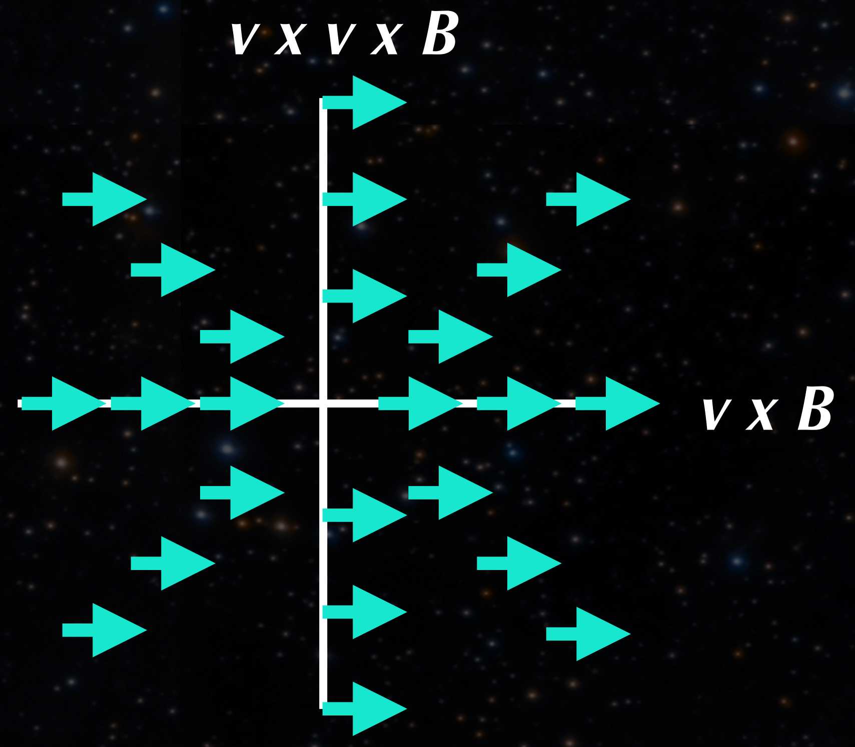
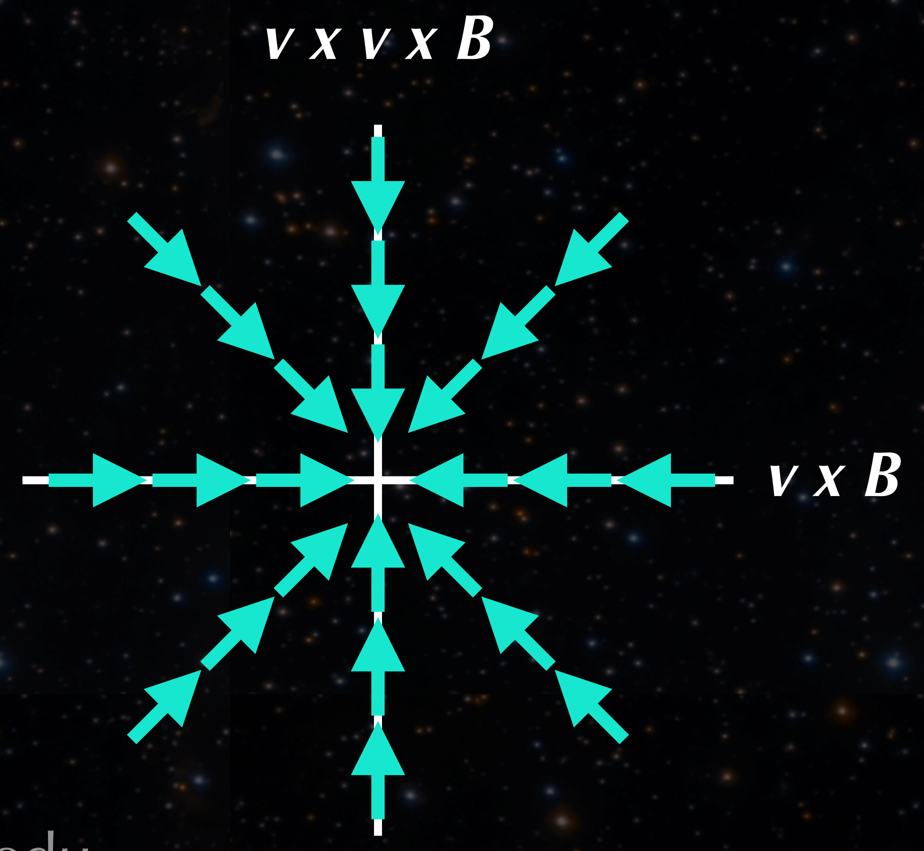
Key Elements for New Trigger Methods

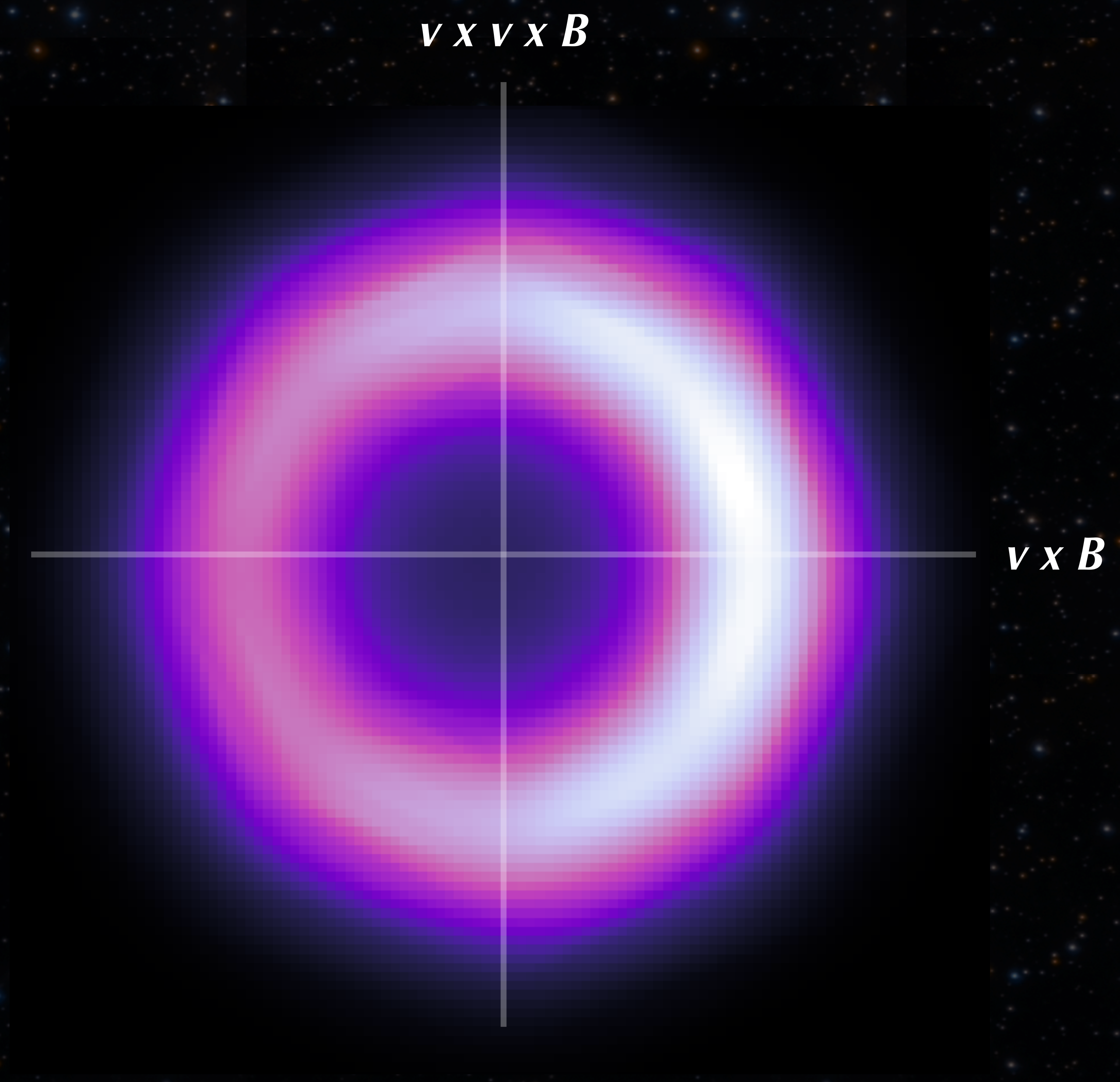
Understanding Radio Emission Patterns

geomagnetic effect



Askaryan effect
(charge excess)





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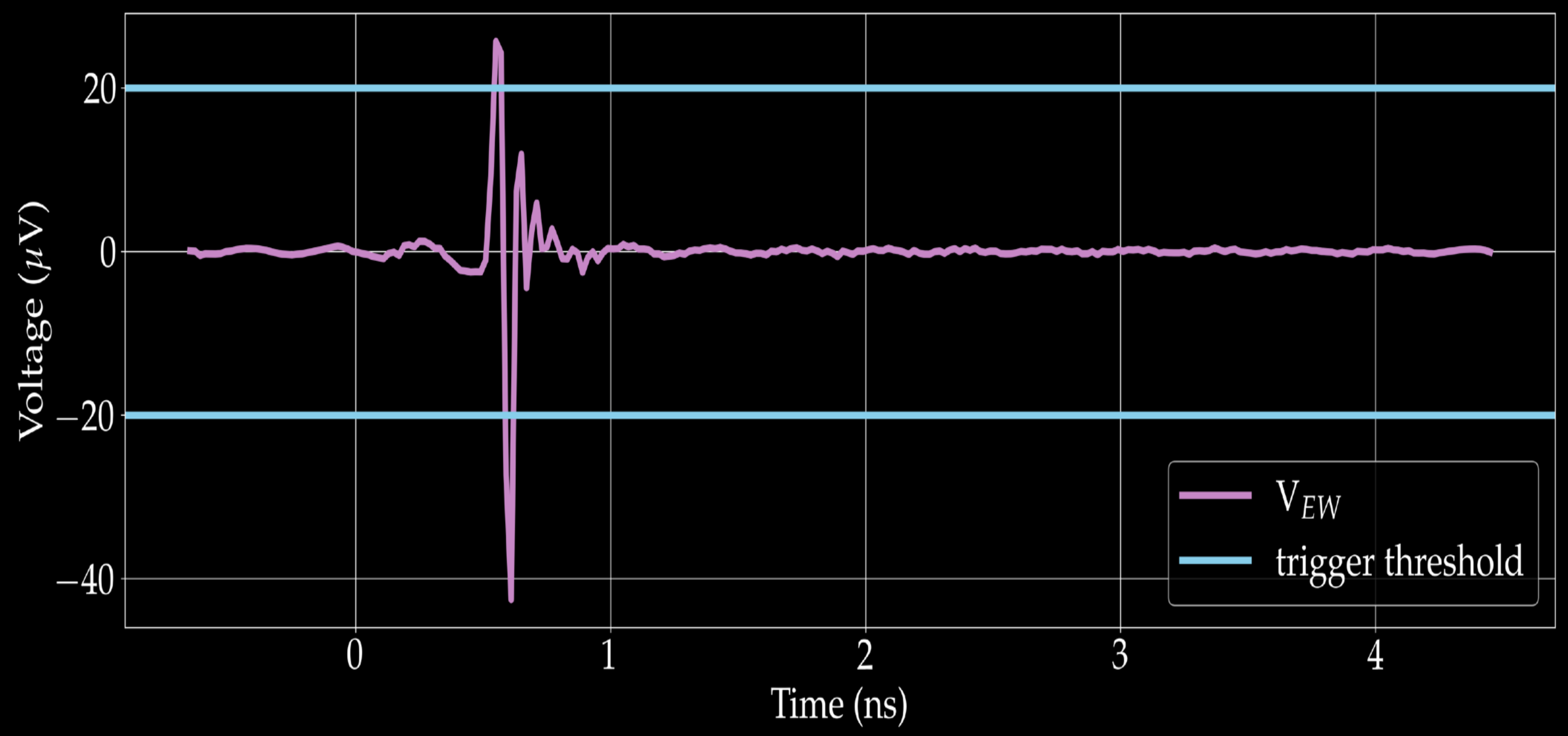
The Need for New Trigger Methods

Common Trigger Methods

- **basic signal characteristics**
  - analyze basic shape of radio signals (width, amplitude, etc.)
- **temporal coincidence**
  - detect signals in different antennas that coincide in time
- **hybrid detection**
  - correlate radio signals with other detection methods



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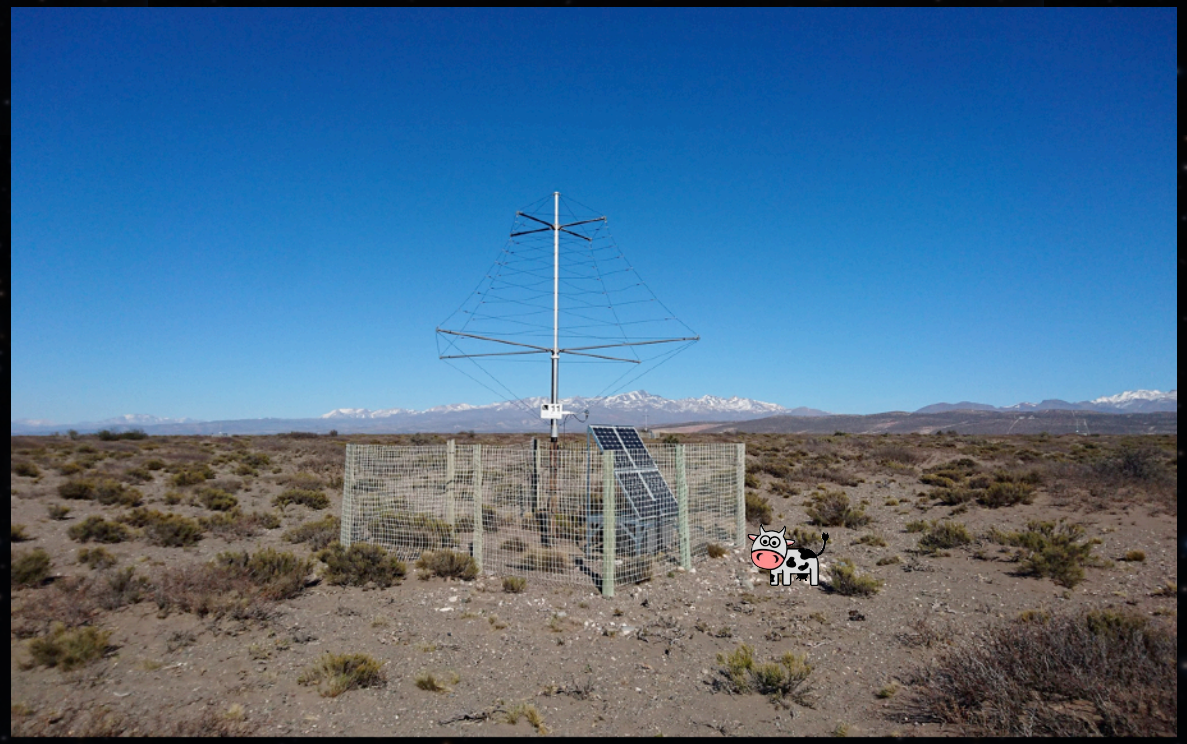
Limitations of Typical Radio Triggers

- ★ **strengths**

good performance for **very quiet regions**



effective in **small arrays** and in combination with **other detector types**

- ★ **challenges**

do not work for **noisier regions**

struggle to scale for **large arrays**

jelena.koehler@kit.edu

The Key to Larger Experiments

- advantages of radio
  - **cost-effective**: pure radio experiments are budget-friendly
  - **scalability**: easily expandable for large arrays
- challenges of radio
  - **current trigger limitations**: existing triggers fall short for large experiments
- room for improvement
  - existing radio triggers do not apply the **understanding of radio** that we have

jelena.koehler@kit.edu

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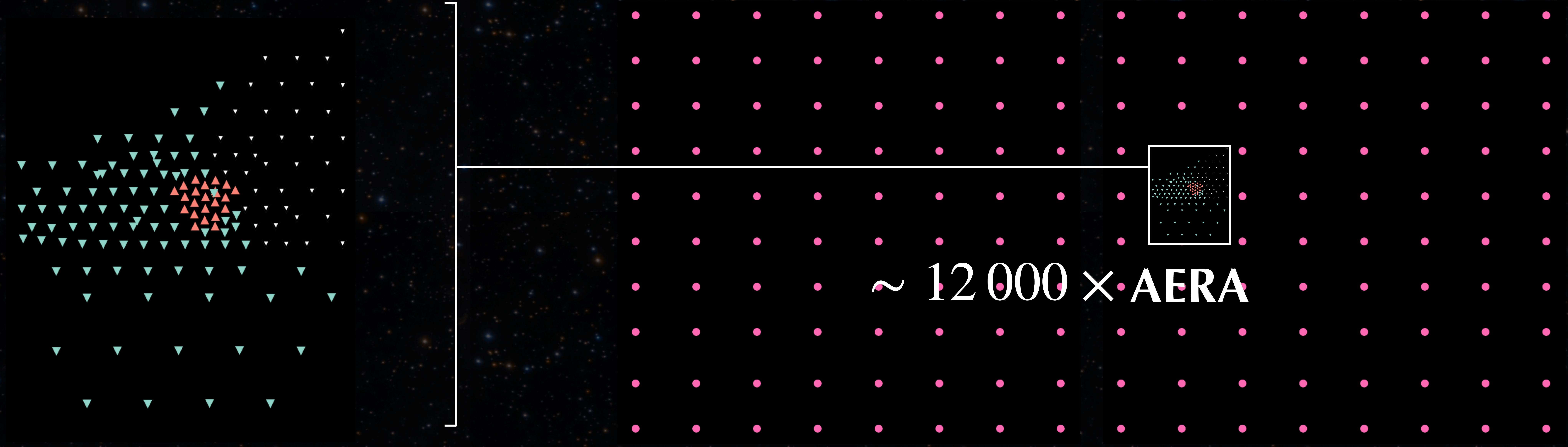
Scale in Comparison to Auger's AERA



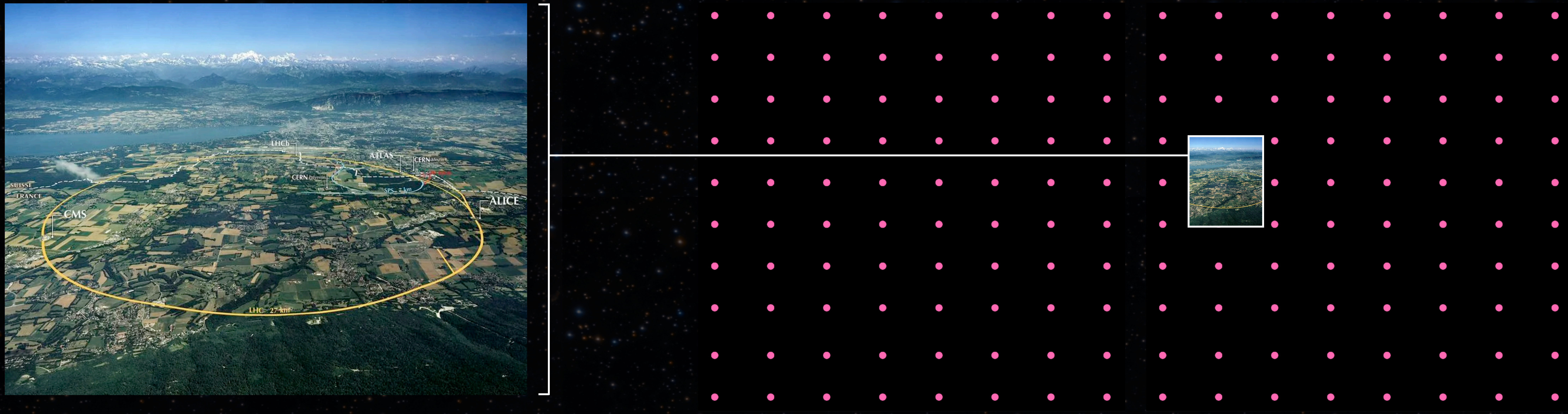
AERA
17 km^2

GRAND
200 000 km^2

jelena.petereit@kit.edu

GRAND

Scale in Comparison to LHC


LHCb
ATLAS
CERN
CERN
SUISSE
FRANCE
CMS
ALICE
SPS 7 km
LHC 27 km

LHC

27 km

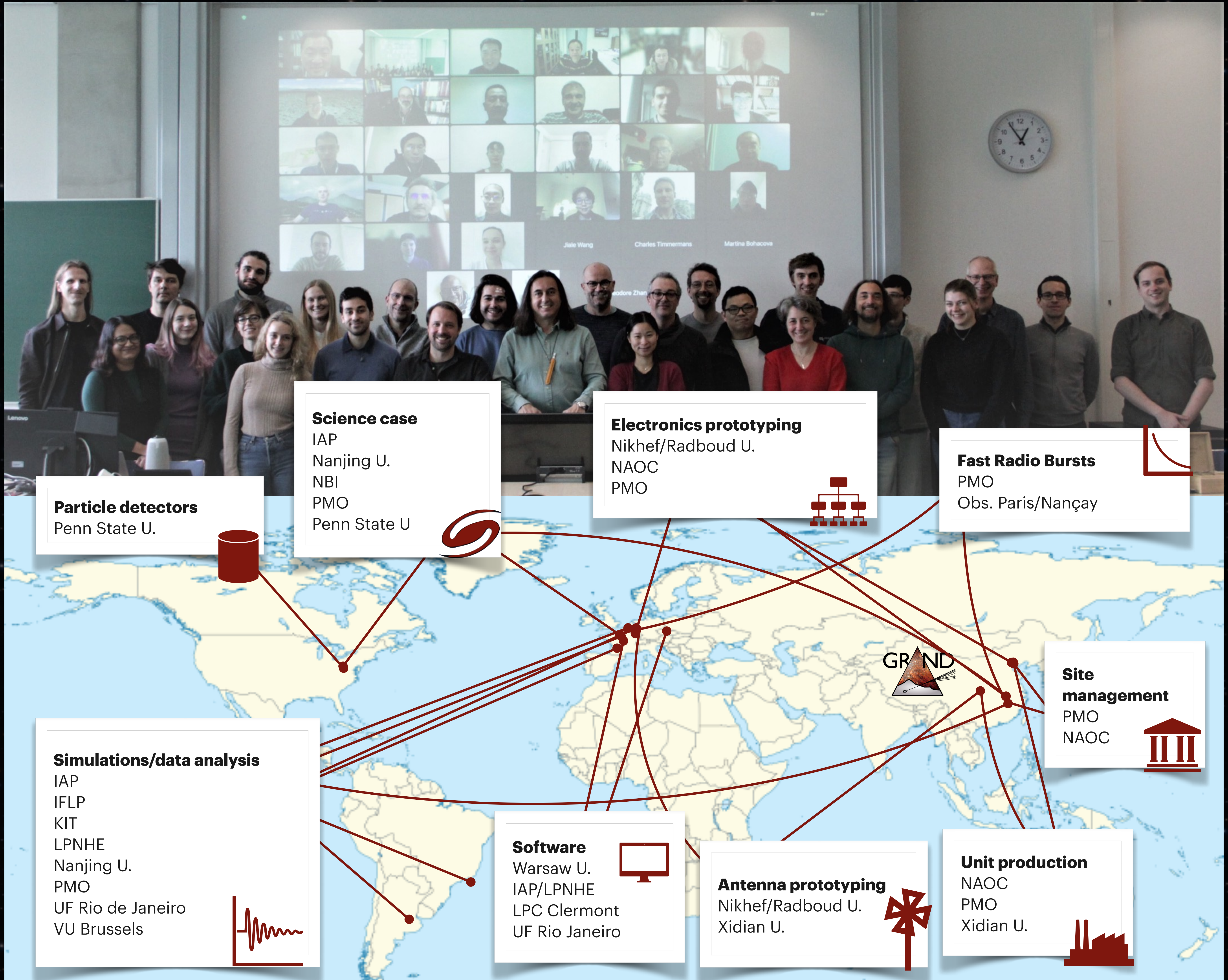
GRAND

~450×450 km

jelena.petereit@kit.edu

GRAND Today

93 collaborators from 12 countries



Particle detectors
Penn State U.

Science case
IAP
Nanjing U.
NBI
PMO
Penn State U

Electronics prototyping
Nikhef/Radboud U.
NAOC
PMO

Fast Radio Bursts
PMO
Obs. Paris/Nançay

Site management
PMO
NAOC

Simulations/data analysis
IAP
IFLP
KIT
LPNHE
Nanjing U.
PMO
UF Rio de Janeiro
VU Brussels

Software
Warsaw U.
IAP/LPNHE
LPC Clermont
UF Rio Janeiro

Antenna prototyping
Nikhef/Radboud U.
Xidian U.

Unit production
NAOC
PMO
Xidian U.

jelena.petereit@kit.edu