

Imaging Atmospheric Radio Telescopes

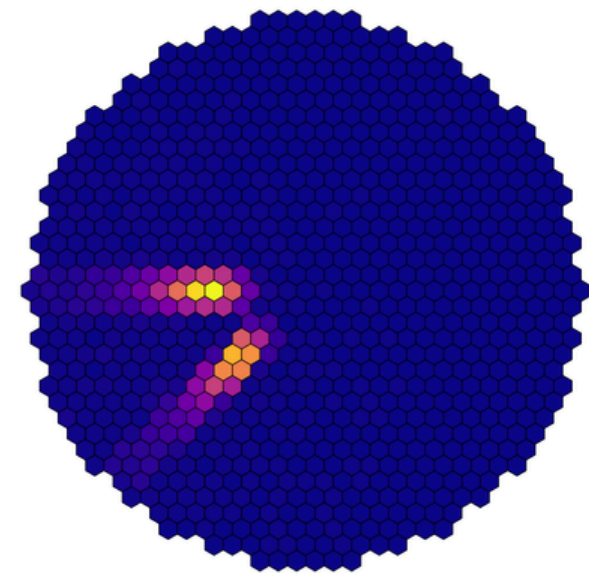
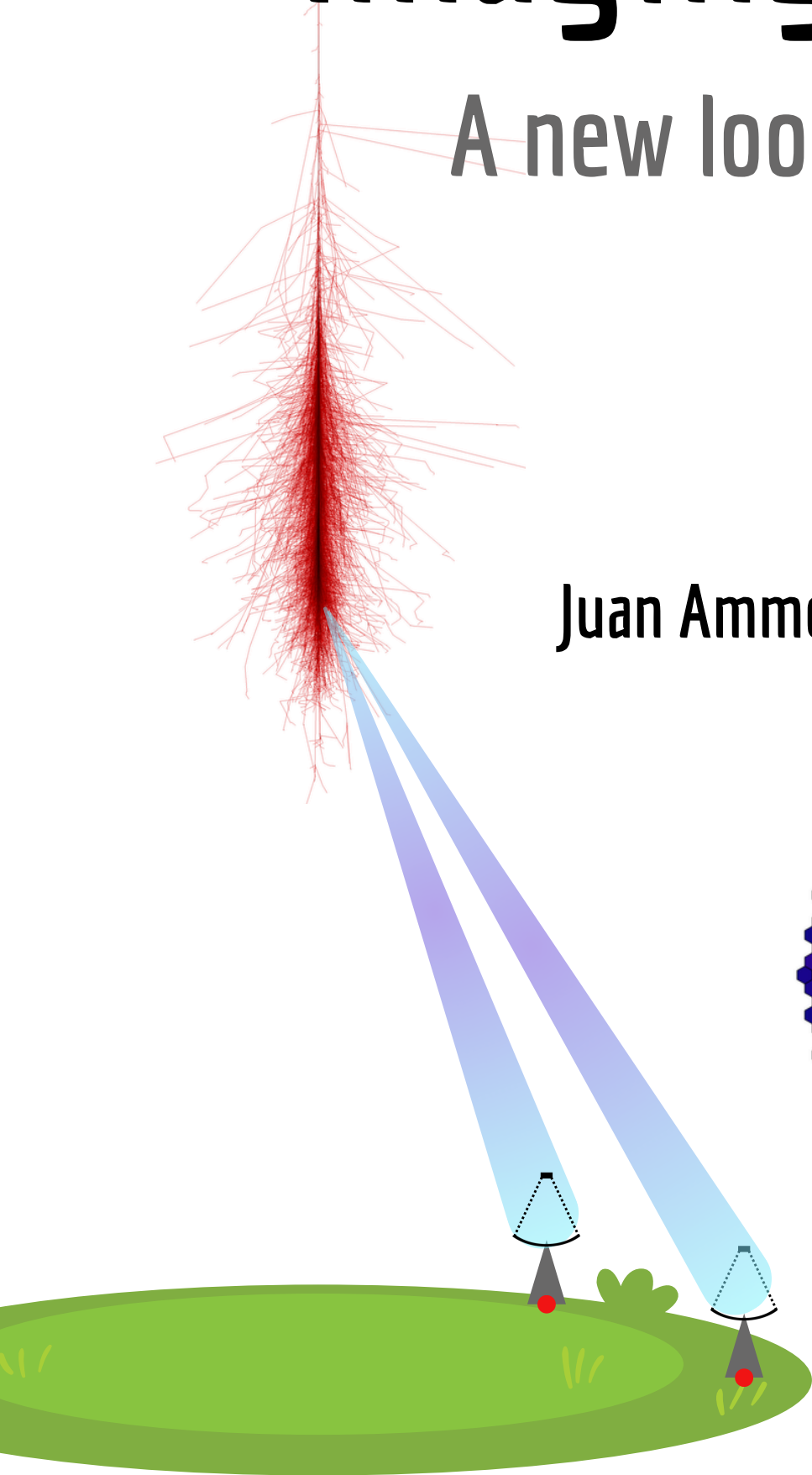
A new look into the radio emission from extensive air showers

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ARENA

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Imaging Atmospheric Cherenkov Telescope

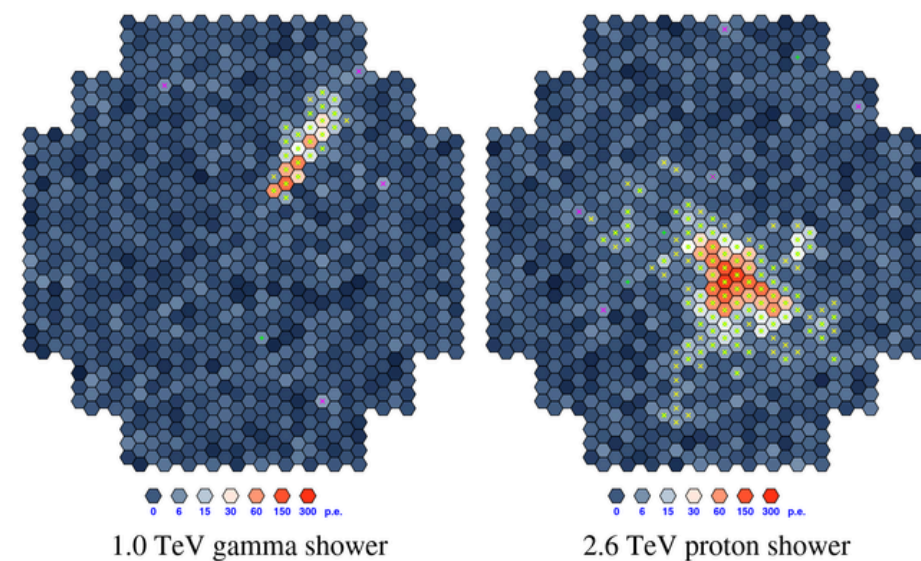
Detect very high energy photons (< 100 TeV) and cosmic rays through the Cherenkov photons that particle showers emit.

High angular resolution: less than 0.1° .

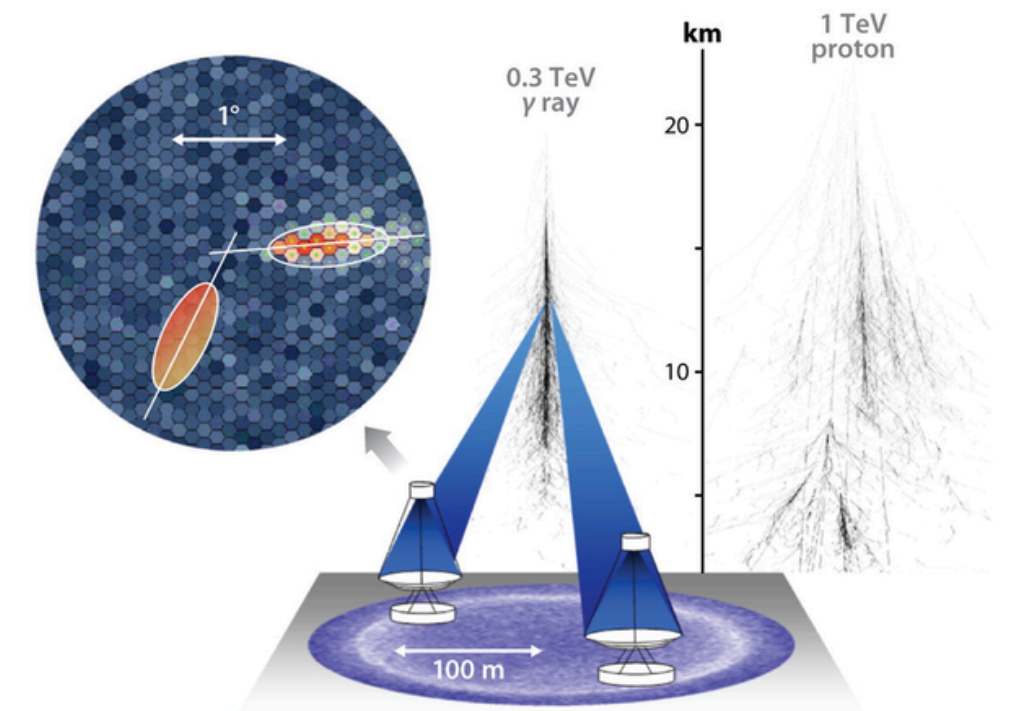
Distinguish photons from cosmic rays through the image: CR more sparse signal than photons (at these energies).


Only operate in dark nights: around an eighth of a year.

Detect the (scattered) Cherenkov photons from the shower.



K. Bernhlor, Exp Astron (2009) 25:173–191



 Hinton JA, Hofmann W. 2009. Annu. Rev. Astron. Astrophys. 47:523–65

**What if ...
we could observe 24/7?**

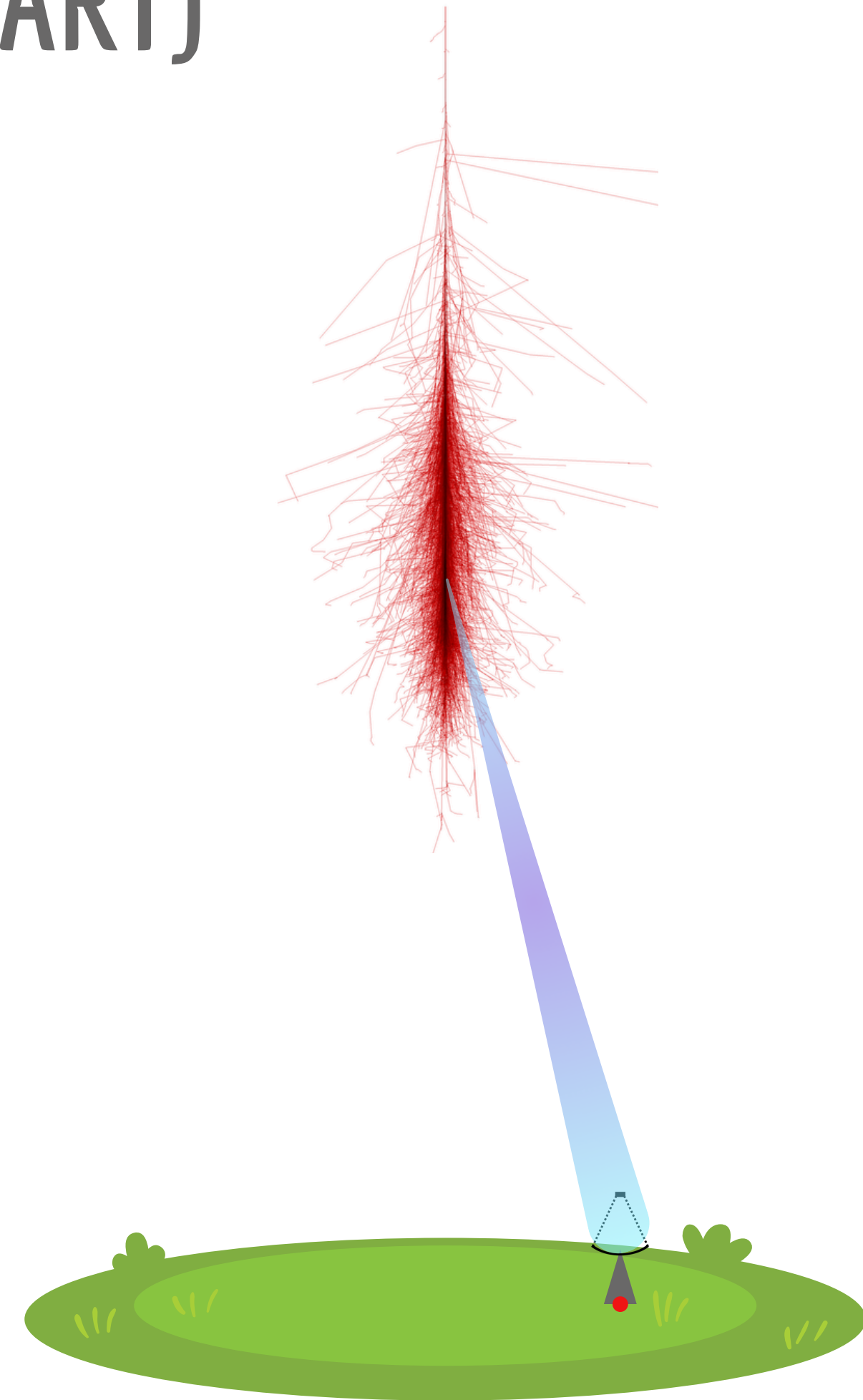
Imaging Atmospheric Radio Telescope (IART)

Have a camera made out of small antennas (GHz regime) instead of pmts.

Observes the coherent radio emission (not scattered) from the shower.

In fair weather conditions it can always operate → 8-fold increase in exposure.

GHz regime implies: low noise background and very beamed emission from the shower.



IART: simulation setup

This presentation is about an ideal case:

- **Ideal reflector**: each pixel of the camera only sees a certain angular space.
- The **observer is point like**, reflector and camera size are not taken into consideration.
- Conceptually imaging radio emission.

This setup showcases the possible radio features one could observe and take advantage of.

Modified ZHAireS version:

- For each antenna a direction and angular size is specified.
- For each track the arrival direction to the antenna is checked:
if $|\text{antenna direction} - \text{arrival direction}| < \text{angular size} \rightarrow$ radio emission of that track is accepted for that antenna.



For full reflector simulation do not miss

Anne Timmermans' talk tomorrow!!

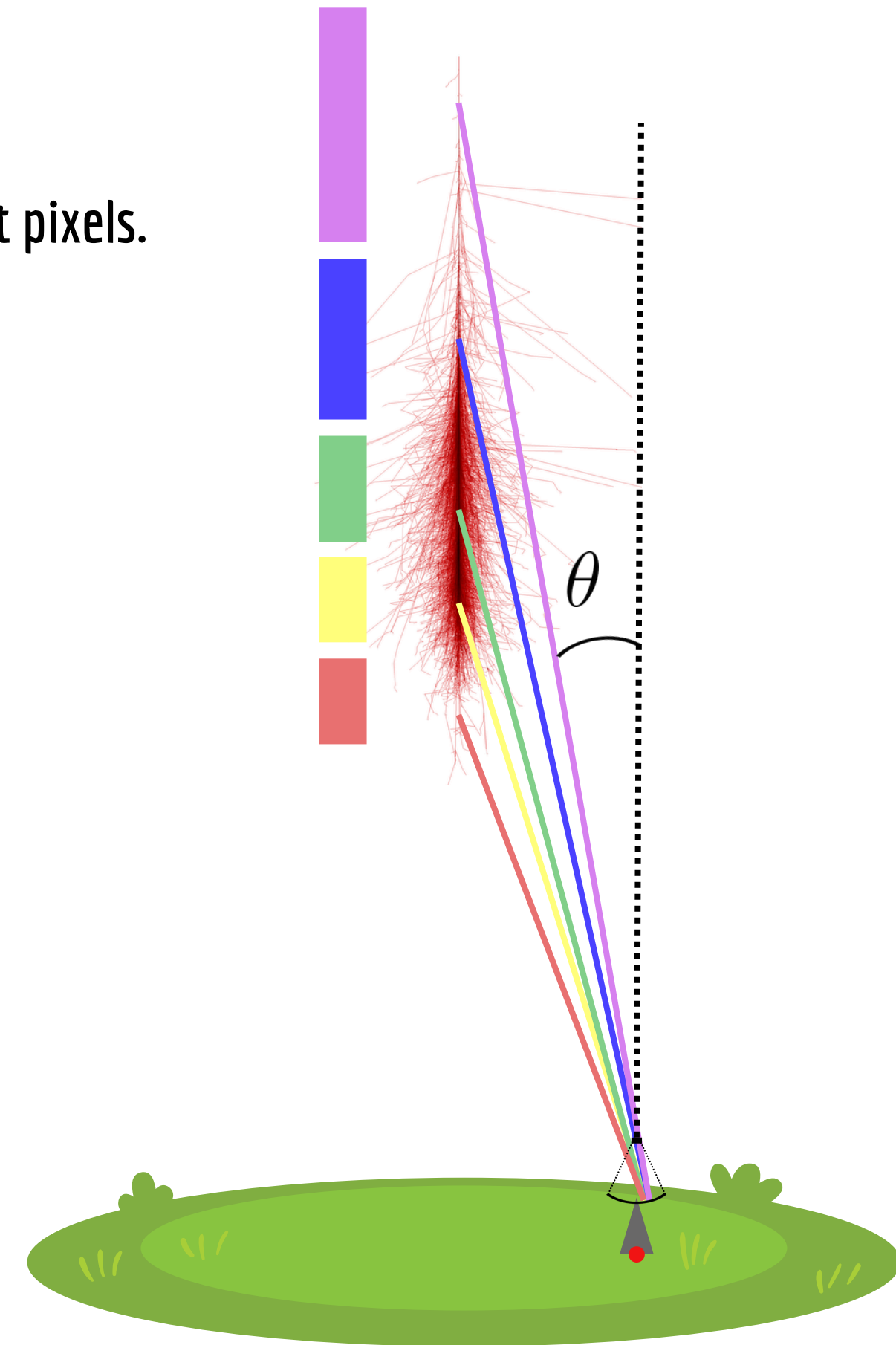
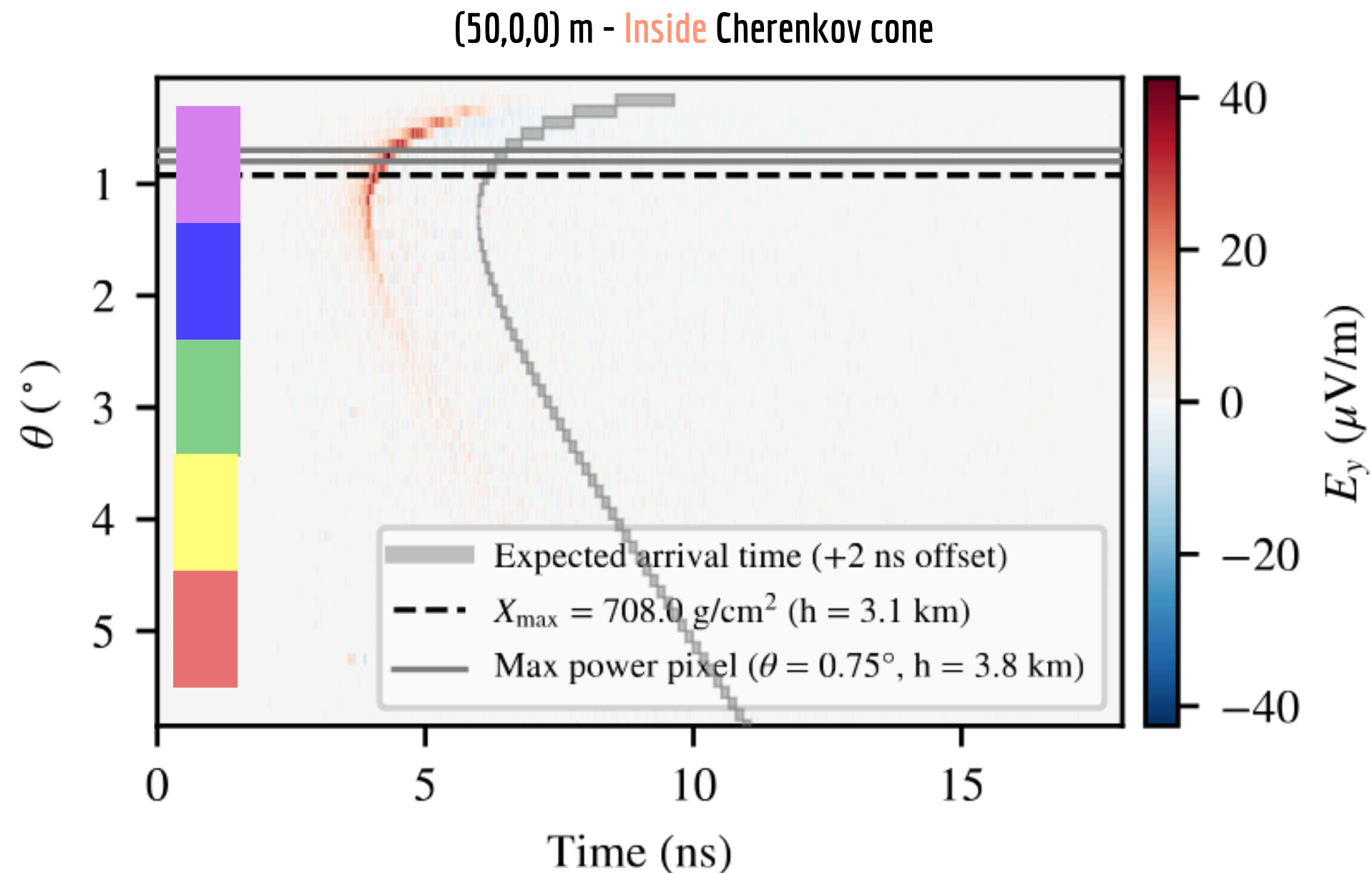
<https://indico.kit.edu/event/5380/contributions/22646/>

IART: 1 dimensional angular discretization

We first focus on a one dimensional “camera”.

We bin in zenith angle \rightarrow different parts of the longitudinal profile contribute to different pixels.

10 PeV vertical proton in a horizontal magnetic field (x) \rightarrow Y-pol: geomagnetic emission.



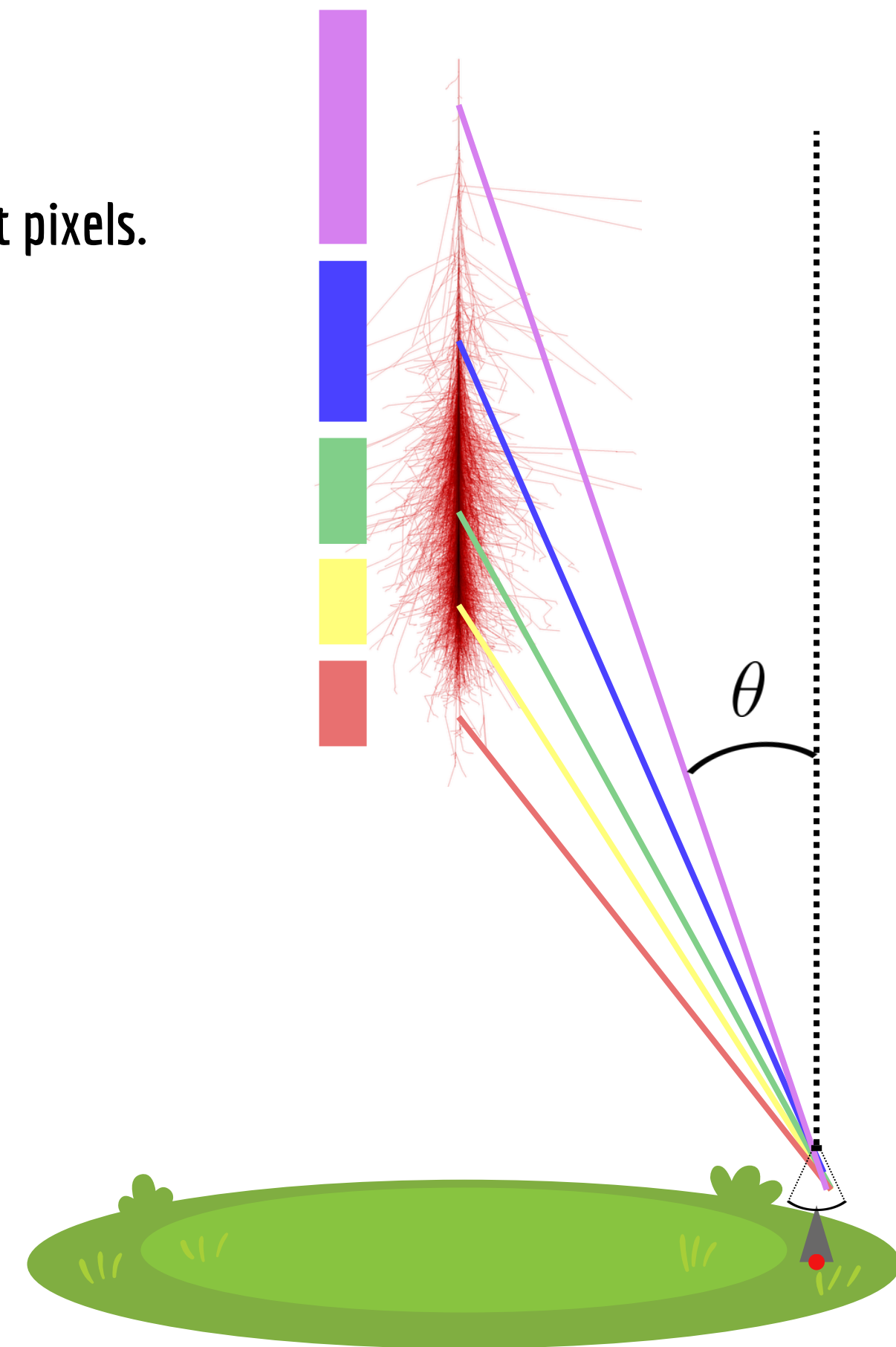
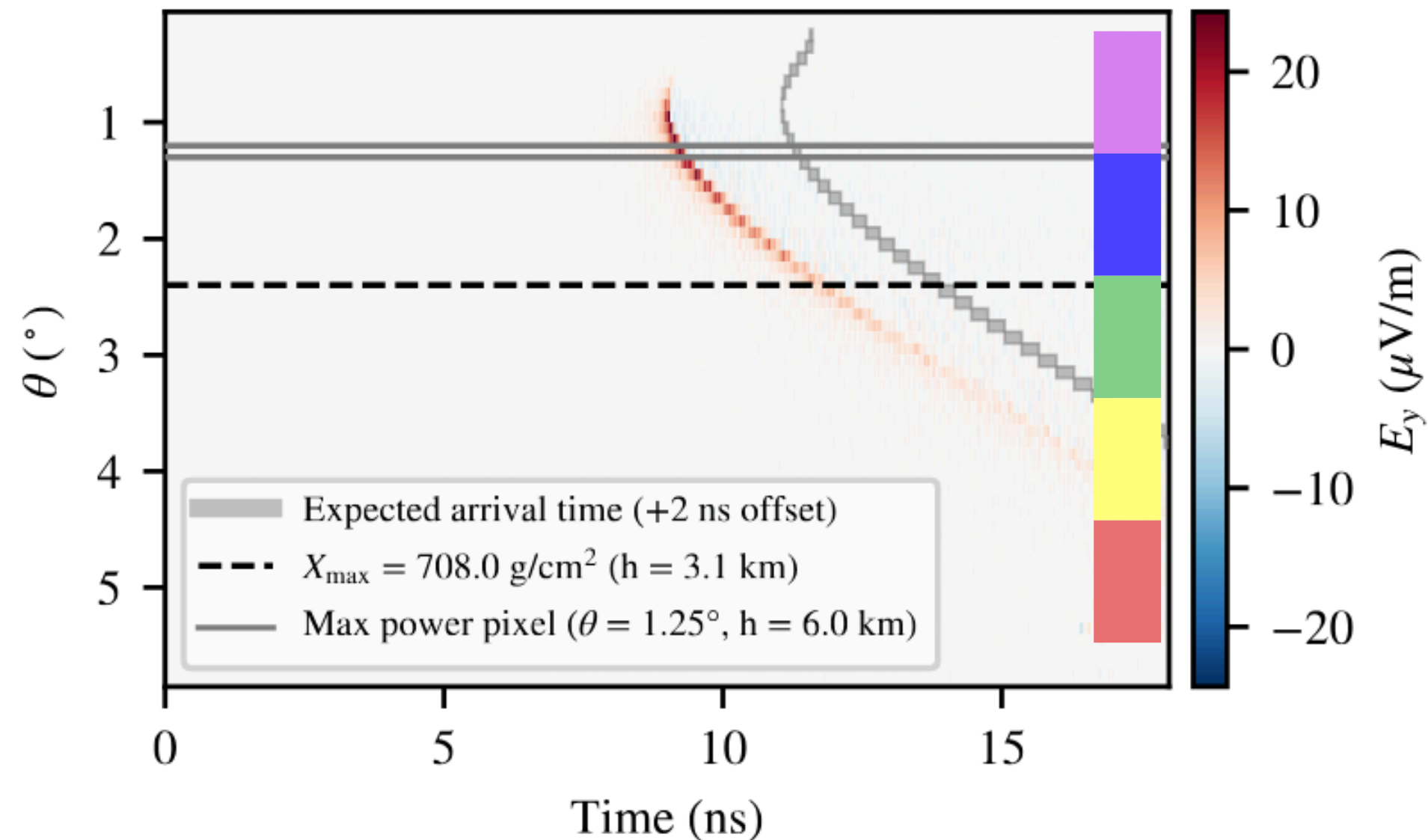
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(100,0,0) m - **Outside** Cherenkov cone



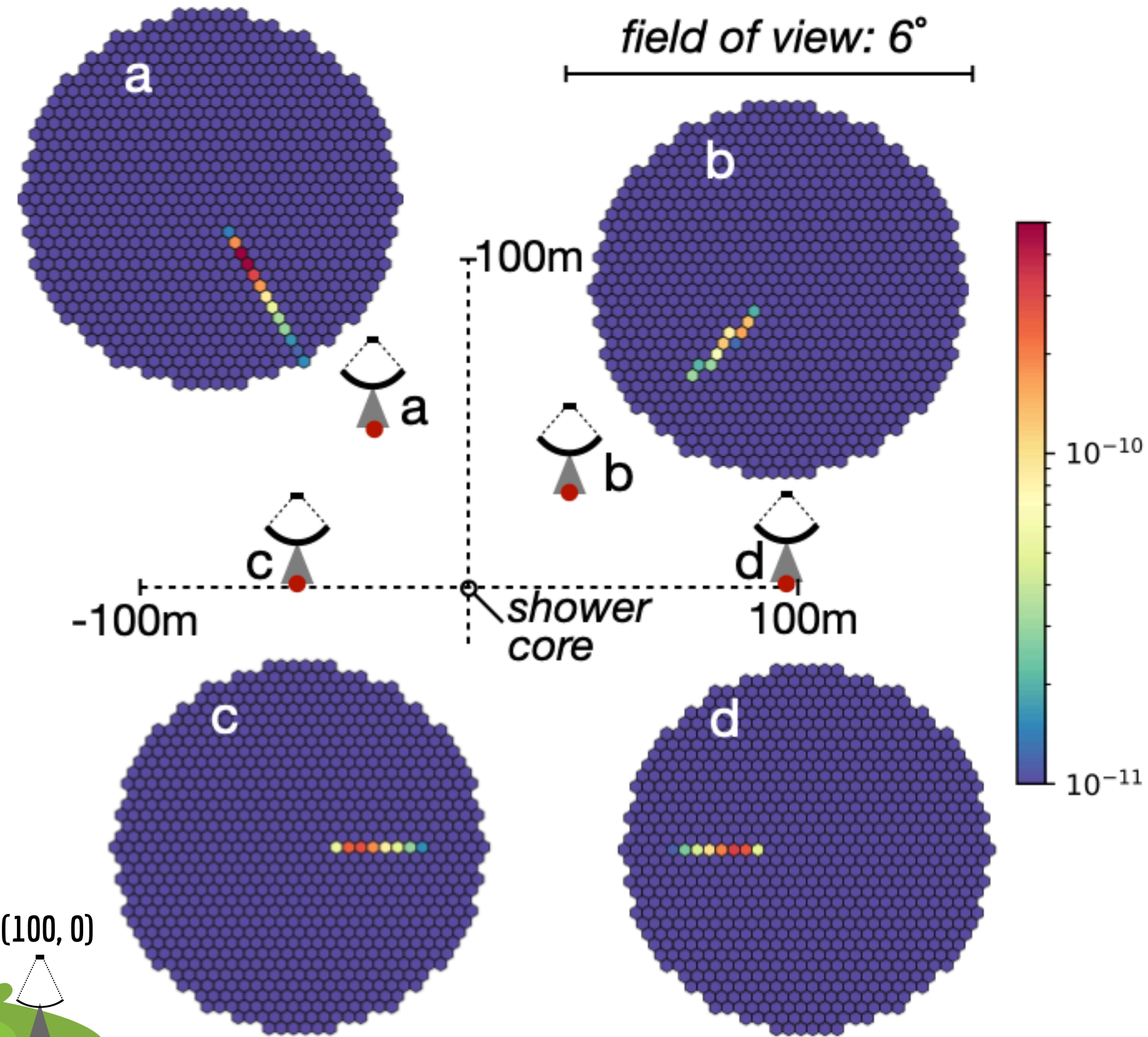
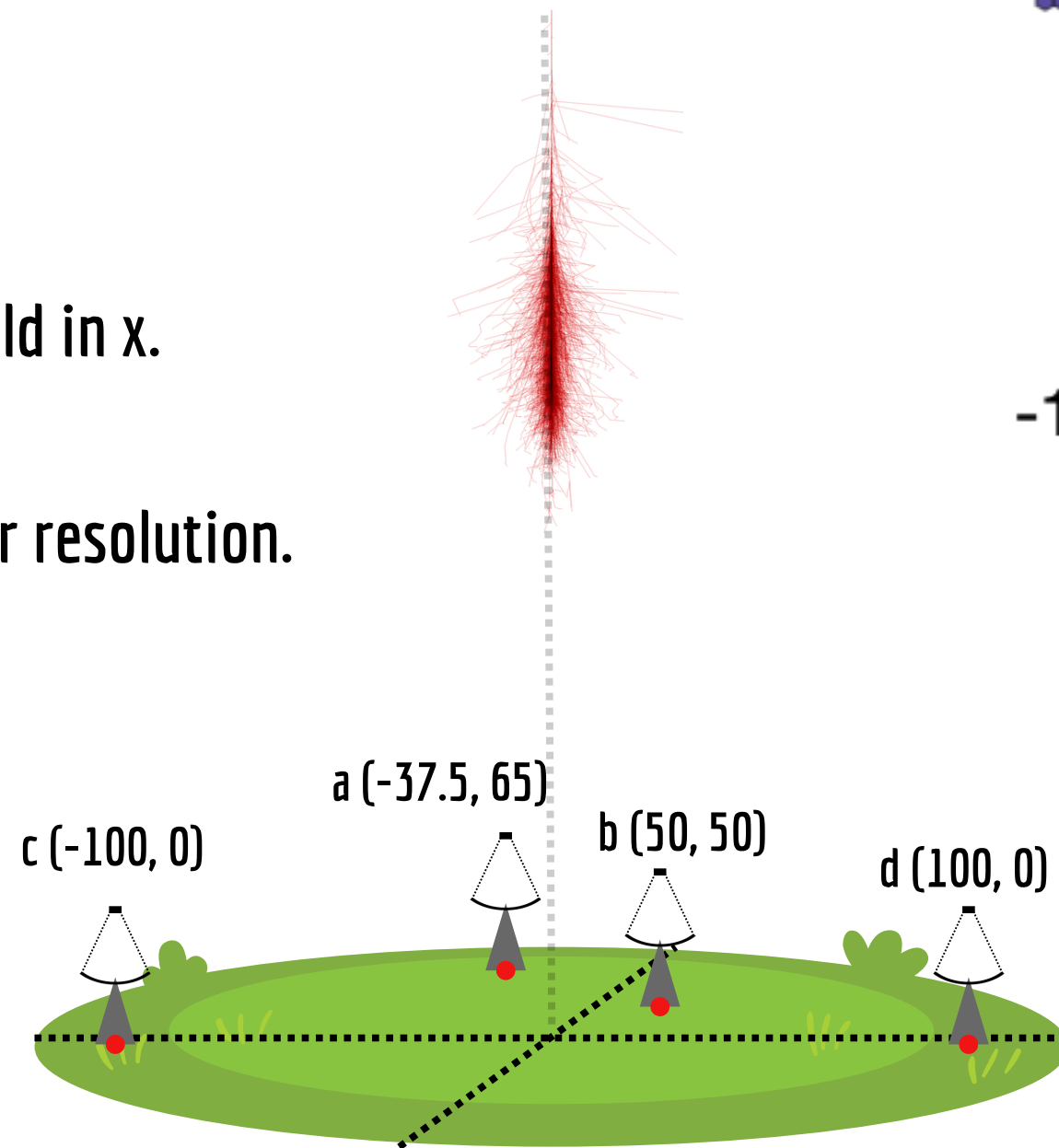
IART: imaging the shower

We now pixelize the angular space in bins of 0.2 degrees.

Same scenario:

- Vertical 10 PeV proton
- Horizontal magnetic field in x.

Potentially very good angular resolution.



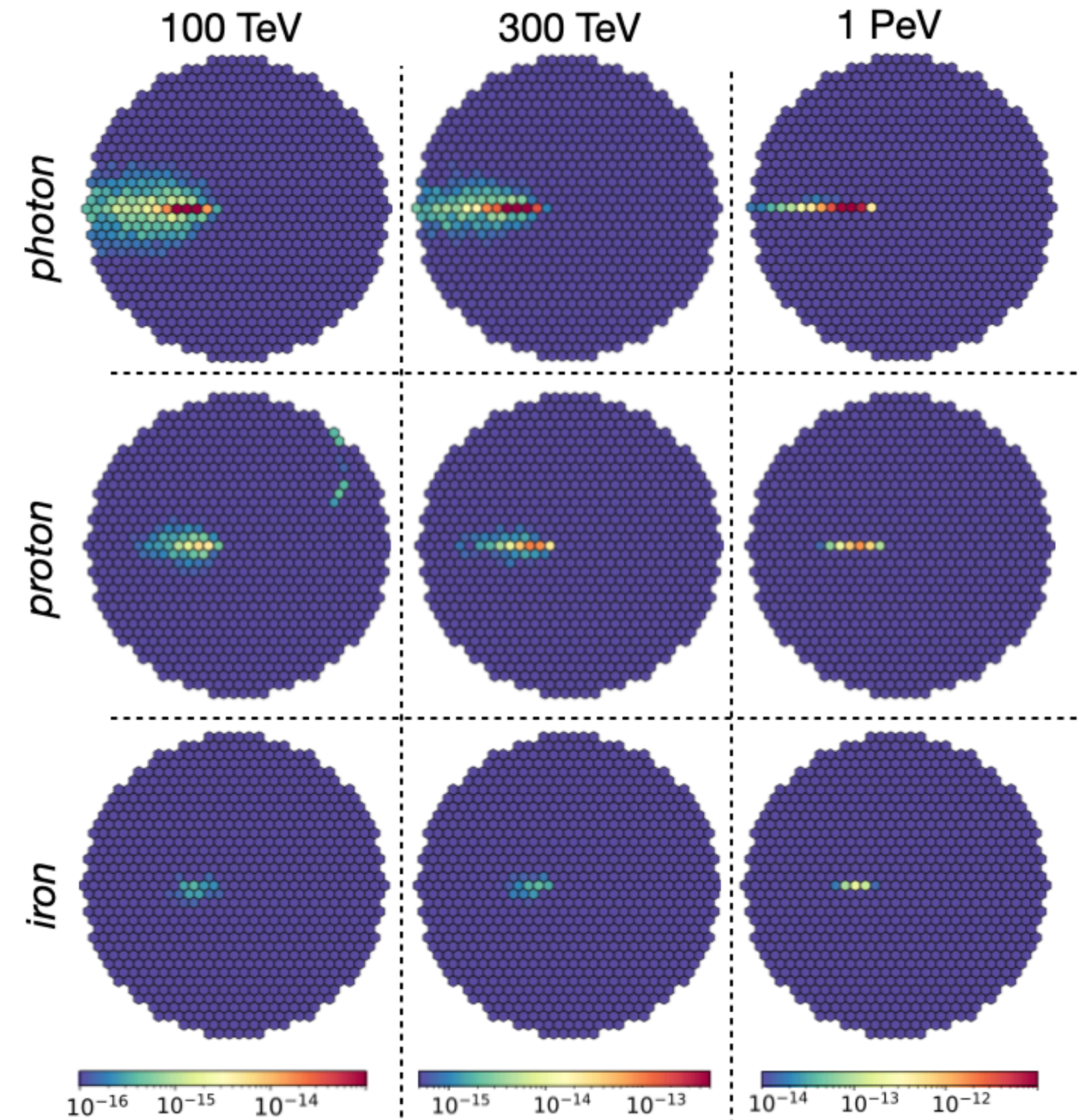
10 PeV proton
Power received between 2-4 GHz for the geomagnetic polarization
($\text{ns V}^2/\text{m}^2$)

IART: imaging different primaries

3 primaries:

- photon
- proton
- iron

The hadronic interactions make the shower more sparse and as a result the radio emission, which leaves a wider imprint in the camera and a loss of intensity.



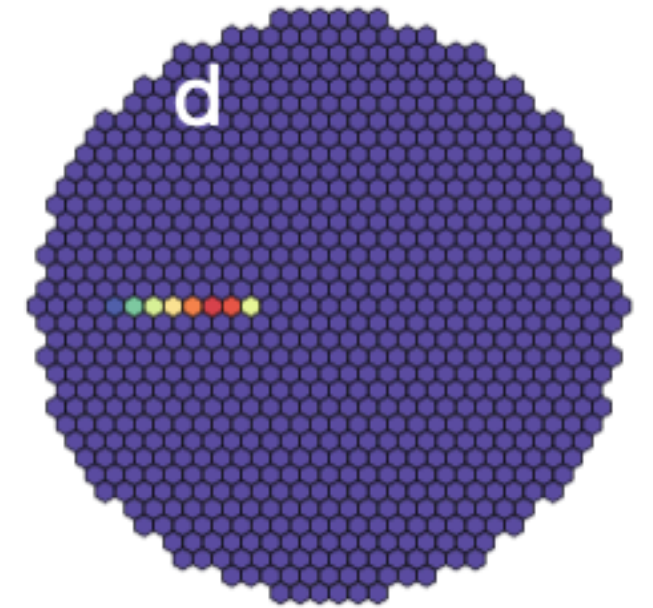
Power received between 2-4 GHz for the geomagnetic polarization
($\text{ns V}^2/\text{m}^2$)

IART: additional emission by imaging

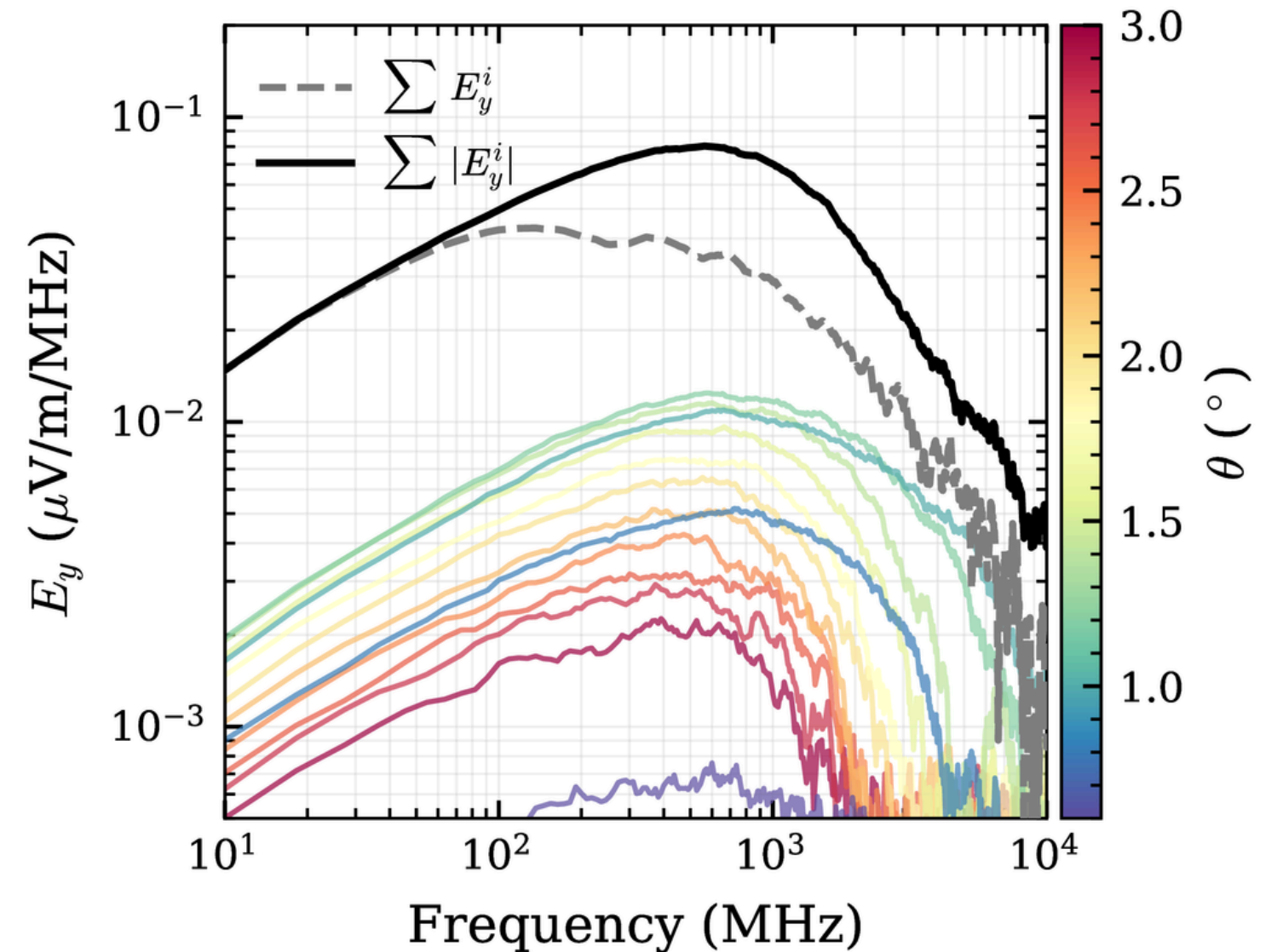
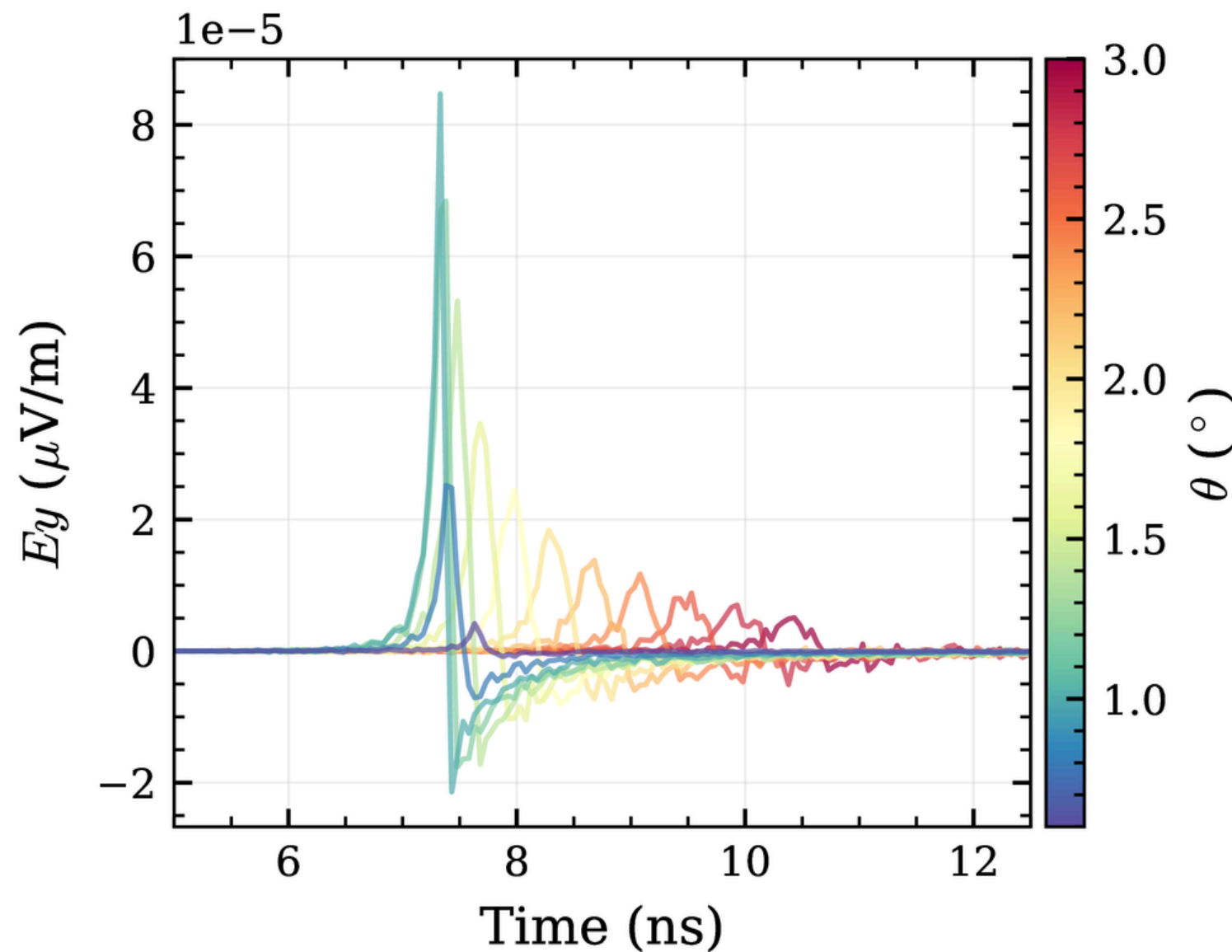
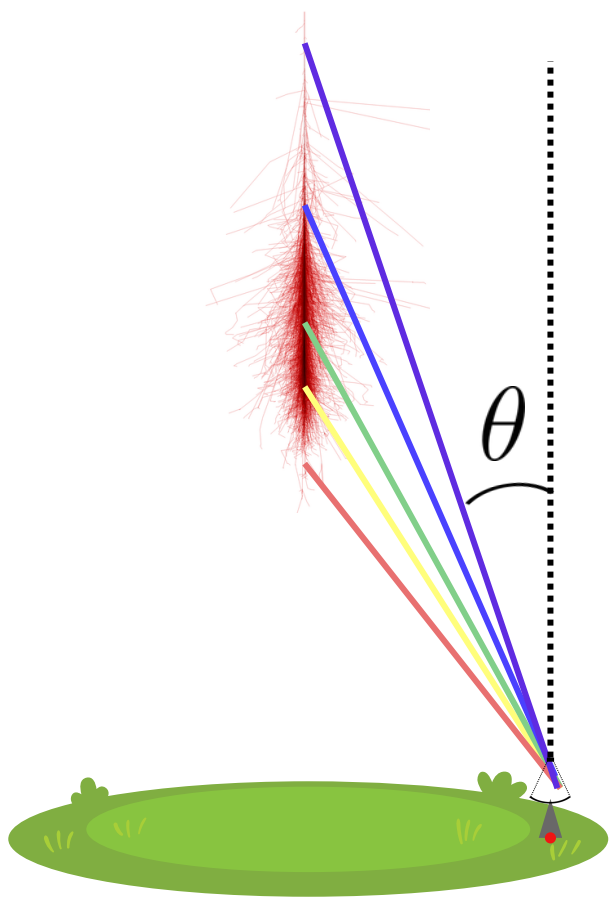
Common antennas sum the contributions from different parts of the shower.

Radio emission from different parts arrives at different times \rightarrow smaller coherence at high frequencies.

By only observing smaller parts of the shower we boost the total high frequency power detected.



(100, 0) m



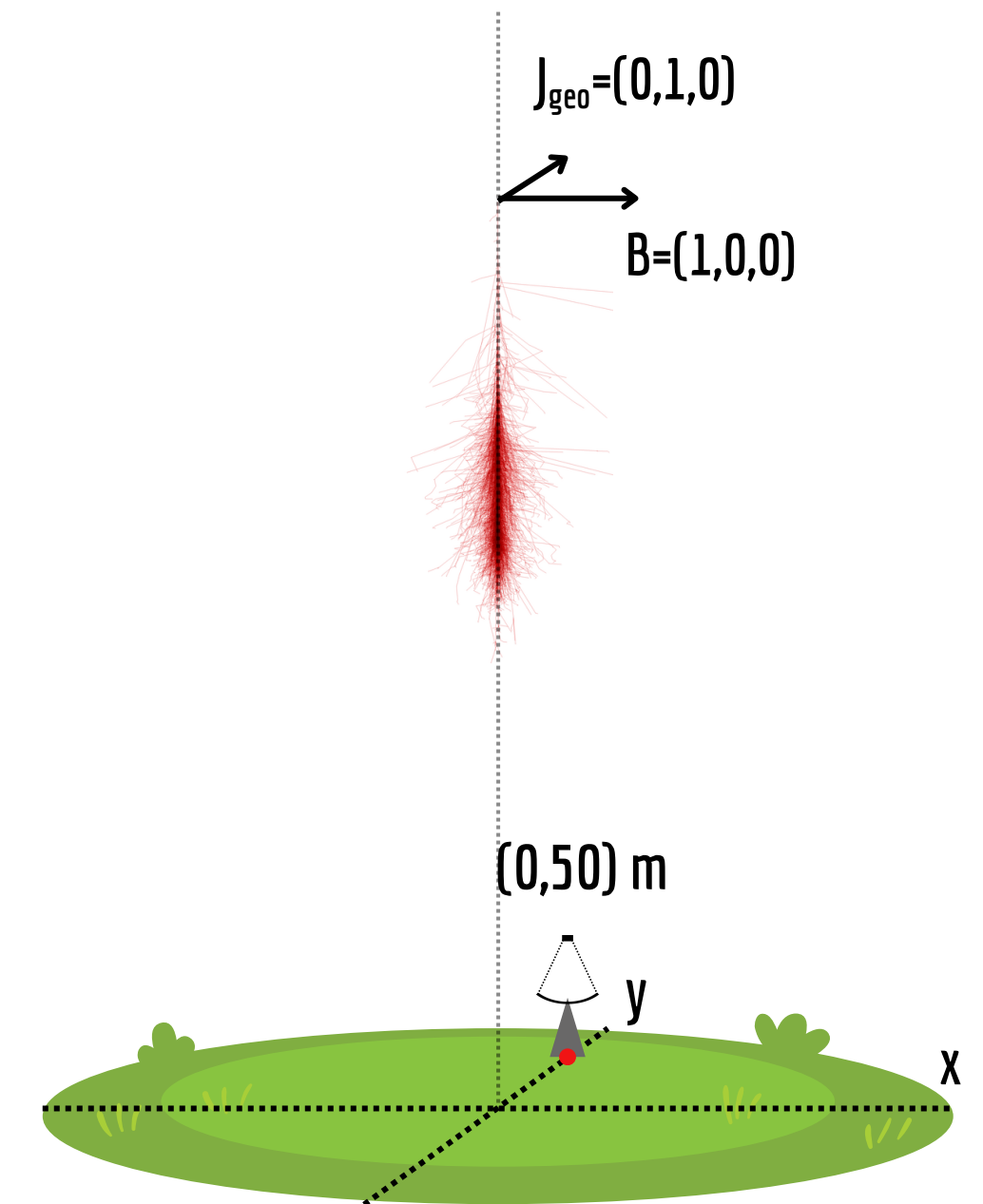
IART: additional emission by imaging

The pixelization also generates a new, subtle, emission.

We now put our camera in the y -axis:

- Vertical shower + B field points to the x -axis \rightarrow y -pol is mainly geomagnetic emission.
- Vertical shower + antenna in the y -axis \rightarrow y -pol also contains the Askaryan emission.

This means that our x -polarization should basically be negligible but..



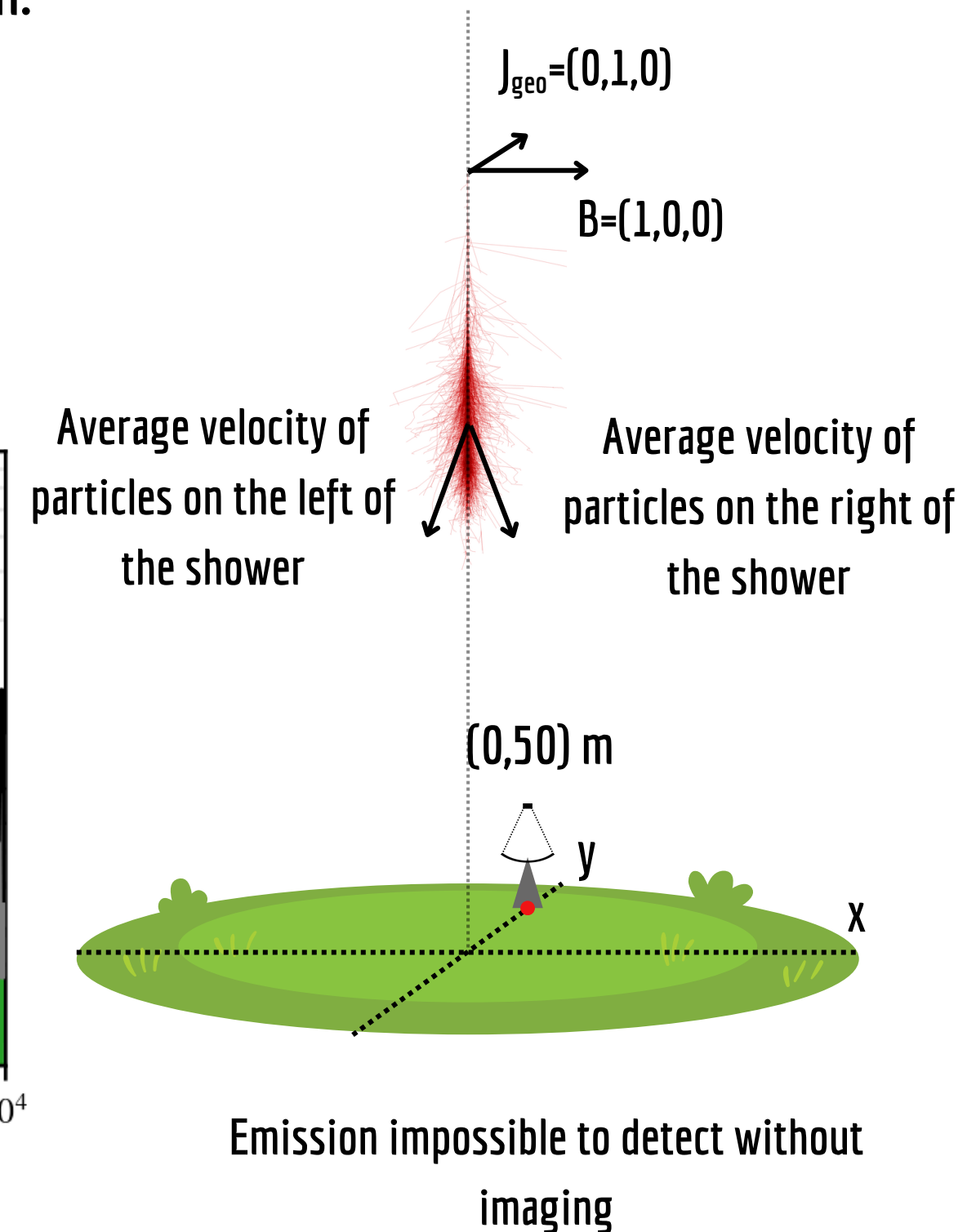
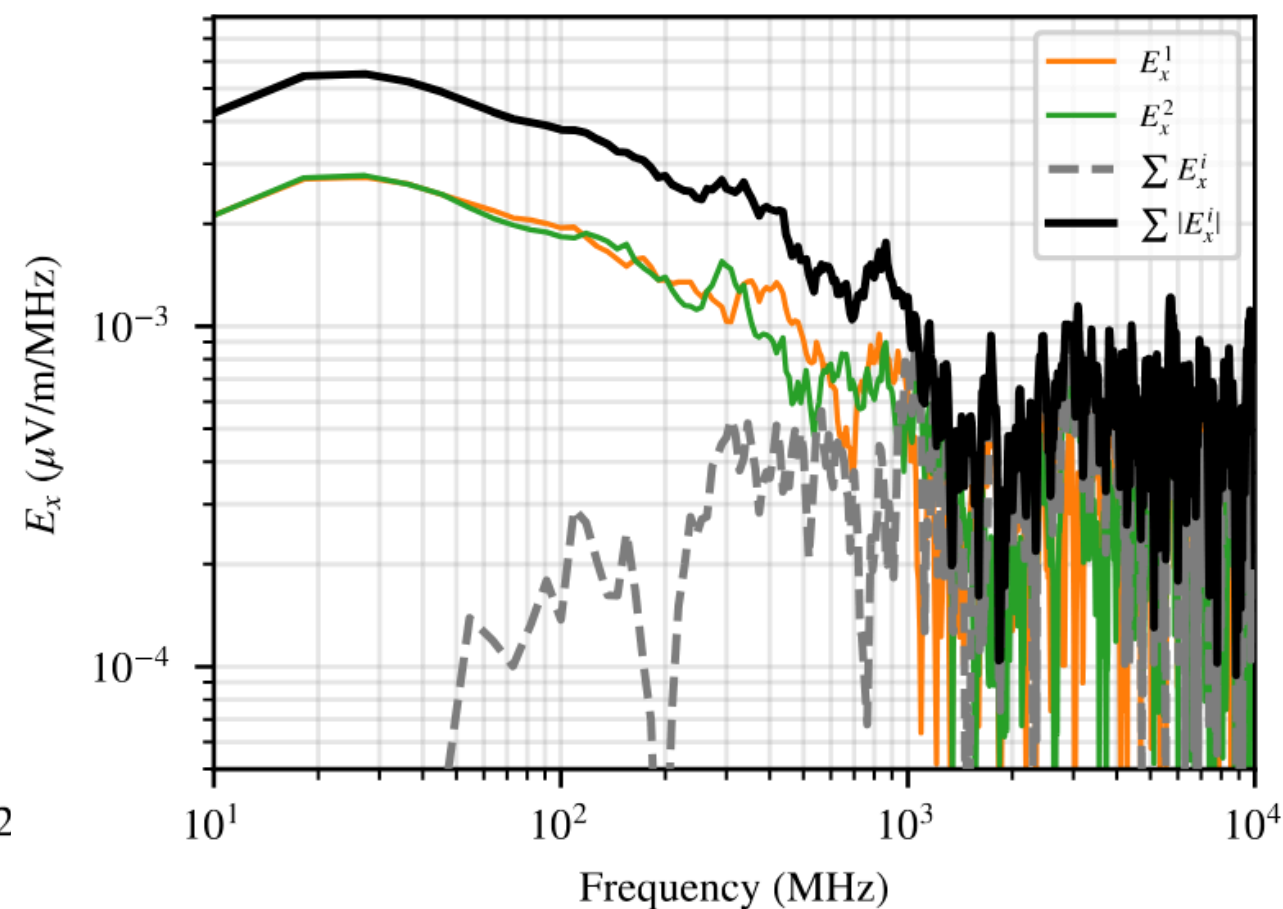
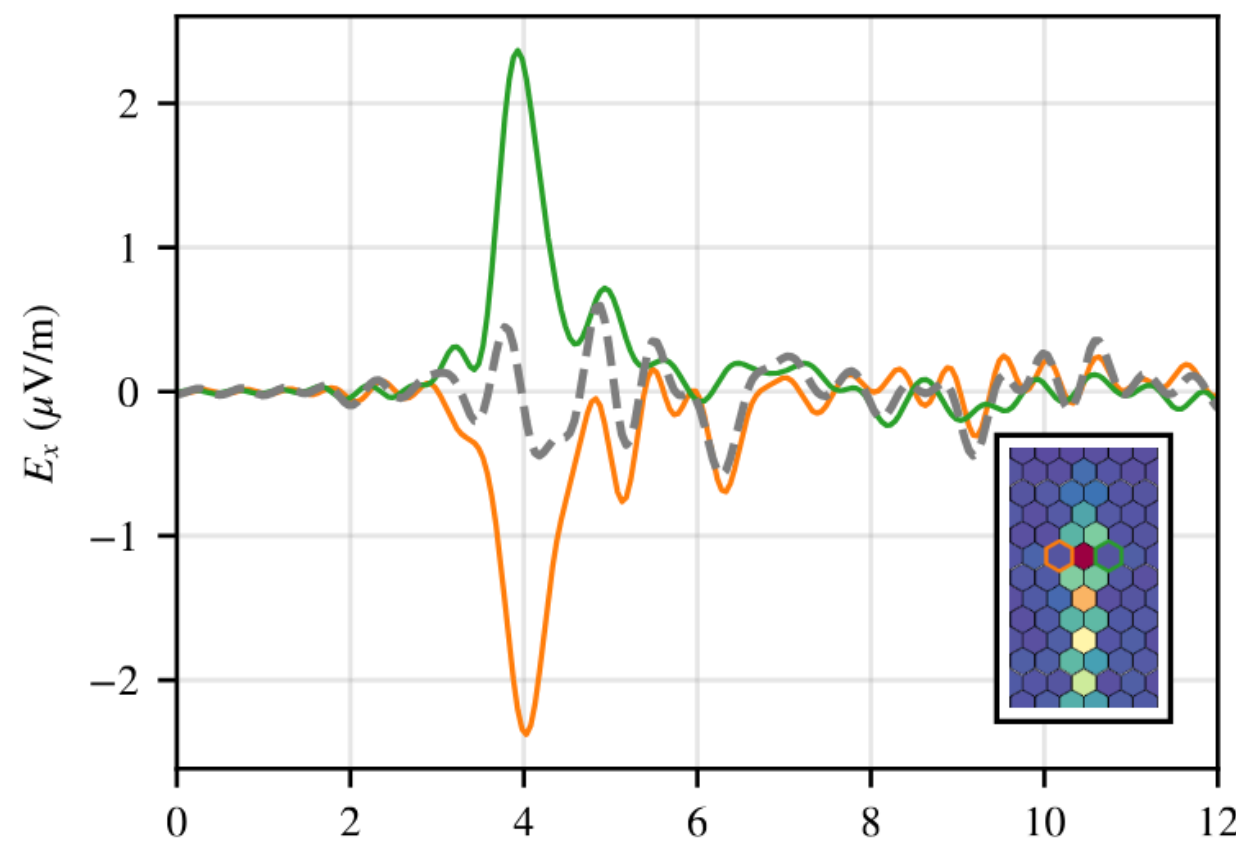
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we do actually see a pulse at low-mid frequencies.



Summary

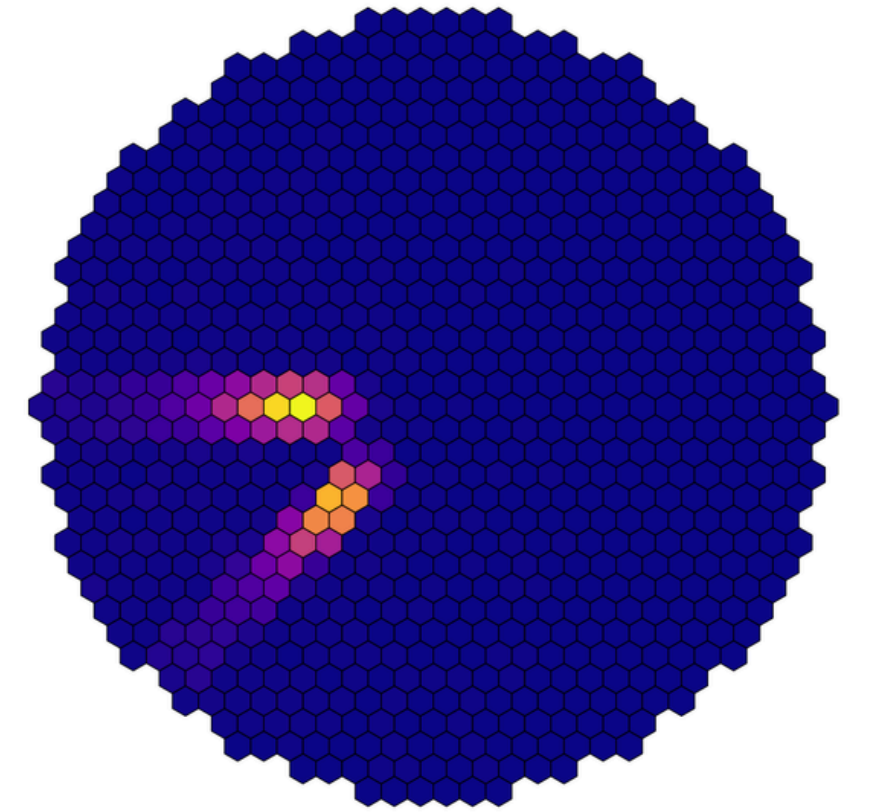
We have successfully simulated an ideal Imaging Atmospheric Radio Telescope.

First results show that a high angular resolution could be achieved.

Mass discrimination could work like in current IACTs but more research is needed.

We have shown that imaging the shower results in an enhanced radio emission, boost of coherence at high frequencies.

New radio emission from the shower observed at low-mid frequencies due to pixelization.



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