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RADIO SIMULATIONS UPDATE

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University of Delaware[1] ○ Pennsylvania State University[2]

UNIVERSITY OF DELAWARE
BARTOL RESEARCH INSTITUTE

PennState

PBR COLLABORATION MEETING, JUNE 5TH 2025

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SIMULATION SOFTWARE

CORSIKA ⟷ **AireS**

analogous to

Simulation of extensive air showers initiated
by high energy cosmic ray particles

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SIMULATION SOFTWARE

CORSIKA <-- analogous to --> **AireS**

CORSIKA includes **CoREAS**

AireS extends to **ZHAireS**

Simulation of extensive air showers initiated by high energy cosmic ray particles

CoREAS <-- analogous to --> **ZHAireS**

Code extension from respective parent software to allow for radio emission of the showers.

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SIMULATION SOFTWARE

CORSIKA <-- analogous to --> **AireS**

CORSIKA includes **CoREAS**

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Simulation of extensive air showers initiated by high energy cosmic ray particles

CoREAS <-- analogous to --> **ZHAireS**

ZHAireS extends to **RASPASS**

Code extension from respective parent software to allow for radio emission of the showers.

ZHAireS-RASPASS (Aires Special Primary for Atmospheric Skimming Showers). Standalone version of ZHAireS that accommodates simulations of diverse shower geometries, including downward-going, upward-going, Earth-skimming, and atmosphere-skimming showers.

JCAP01(2025)112

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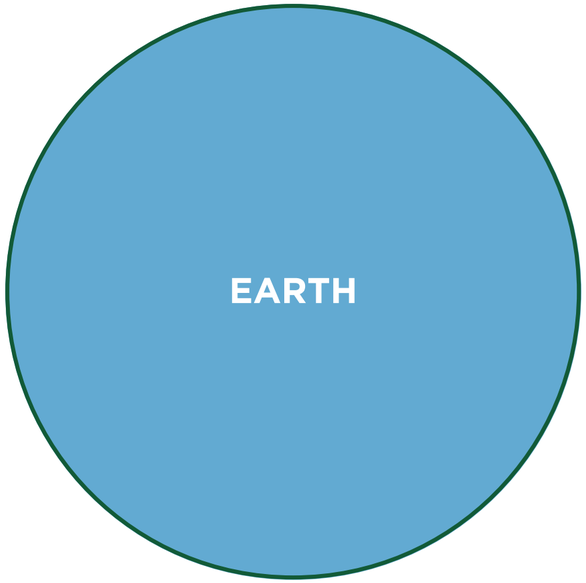
GEOMETRY



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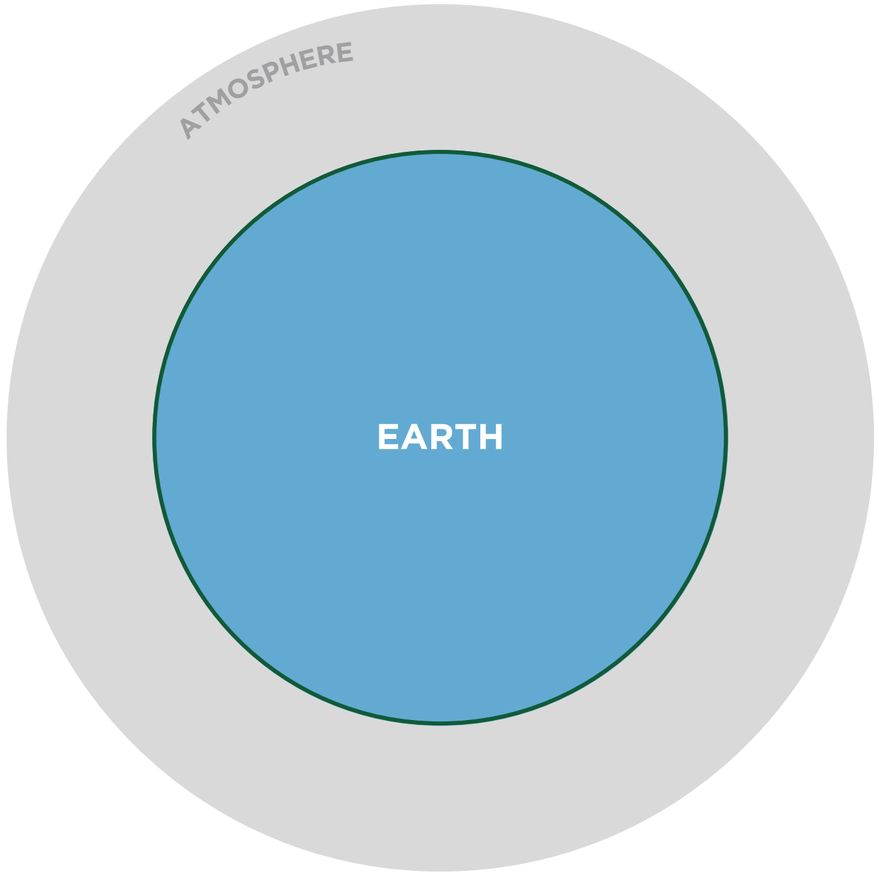

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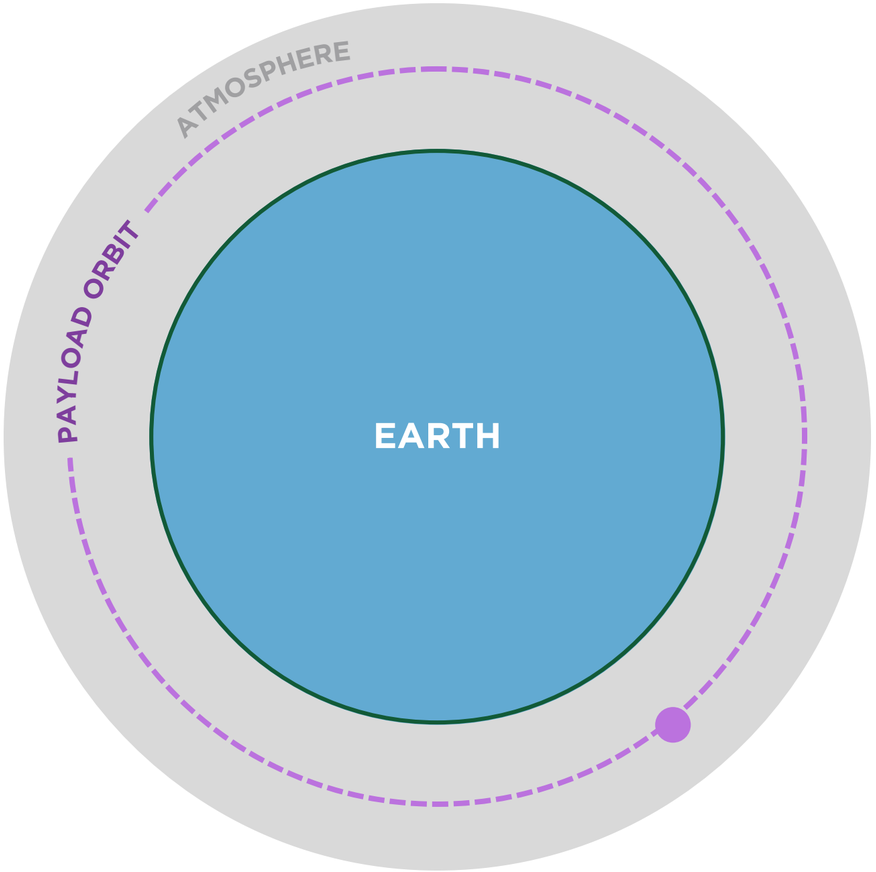

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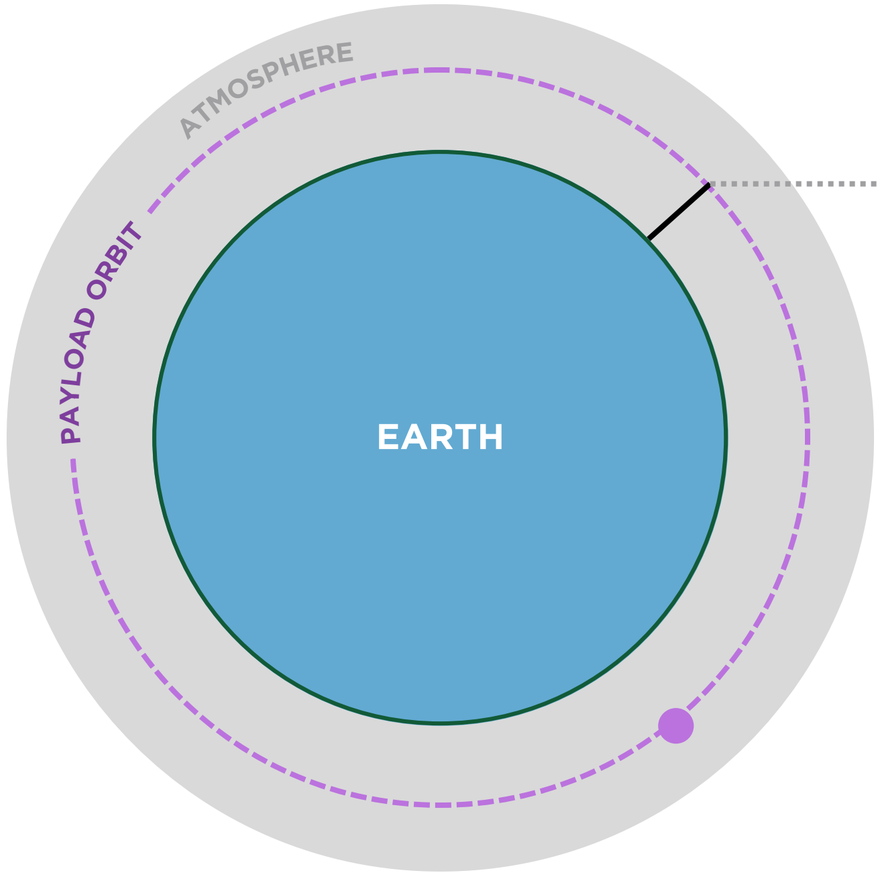

Payload Altitude (RASPASSHEIGHT) - 36 km a.s.l

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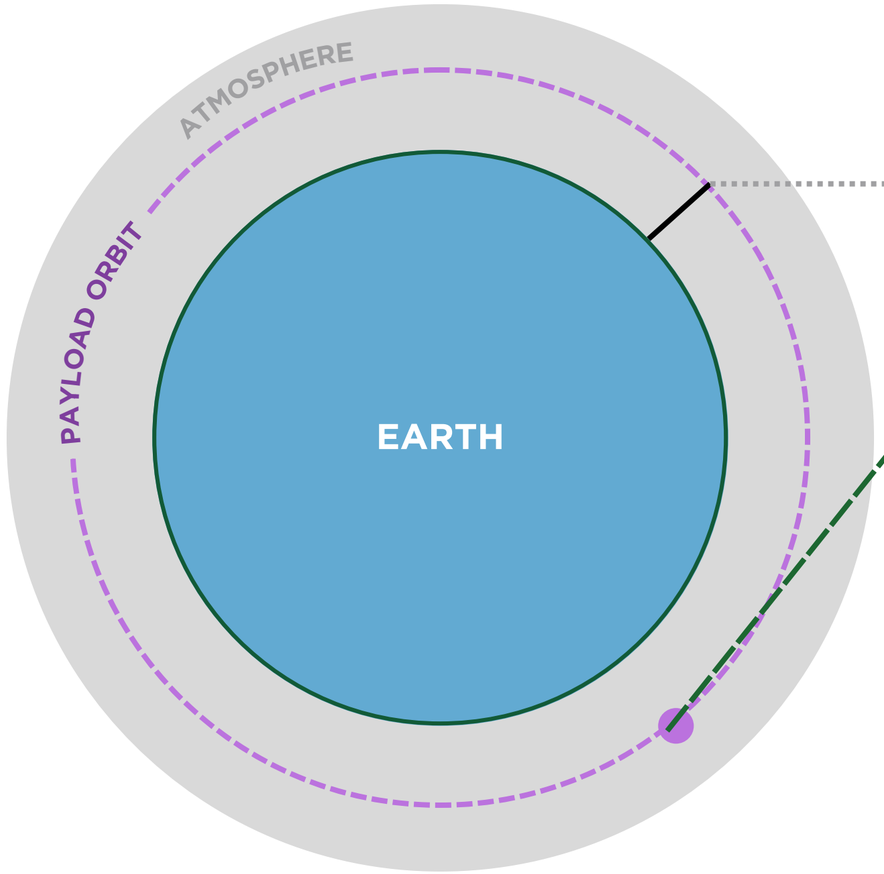
GEOMETRY



Payload Altitude (RASPASSHEIGHT) - 33 km a.s.l

Atmosphere-skimming Cosmic Ray Shower

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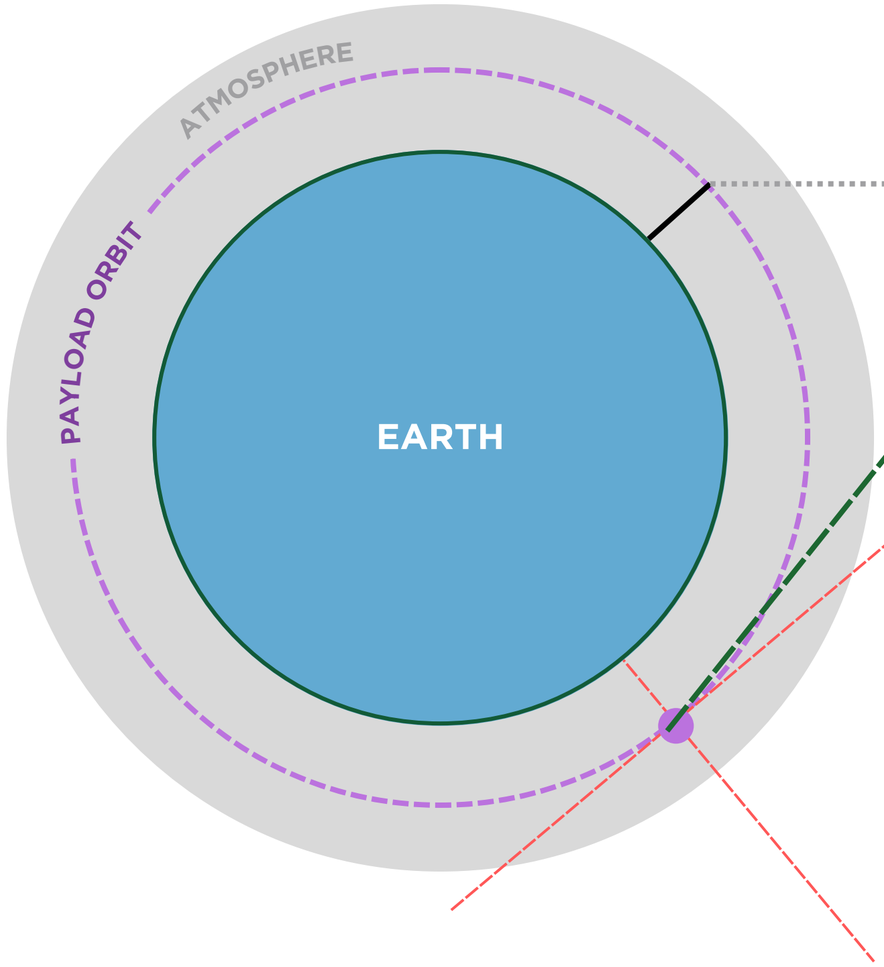
GEOMETRY



Payload Altitude (RASPASSHEIGHT) - 33 km a.s.l

Atmosphere-skimming Cosmic Ray Shower

Local frame of reference

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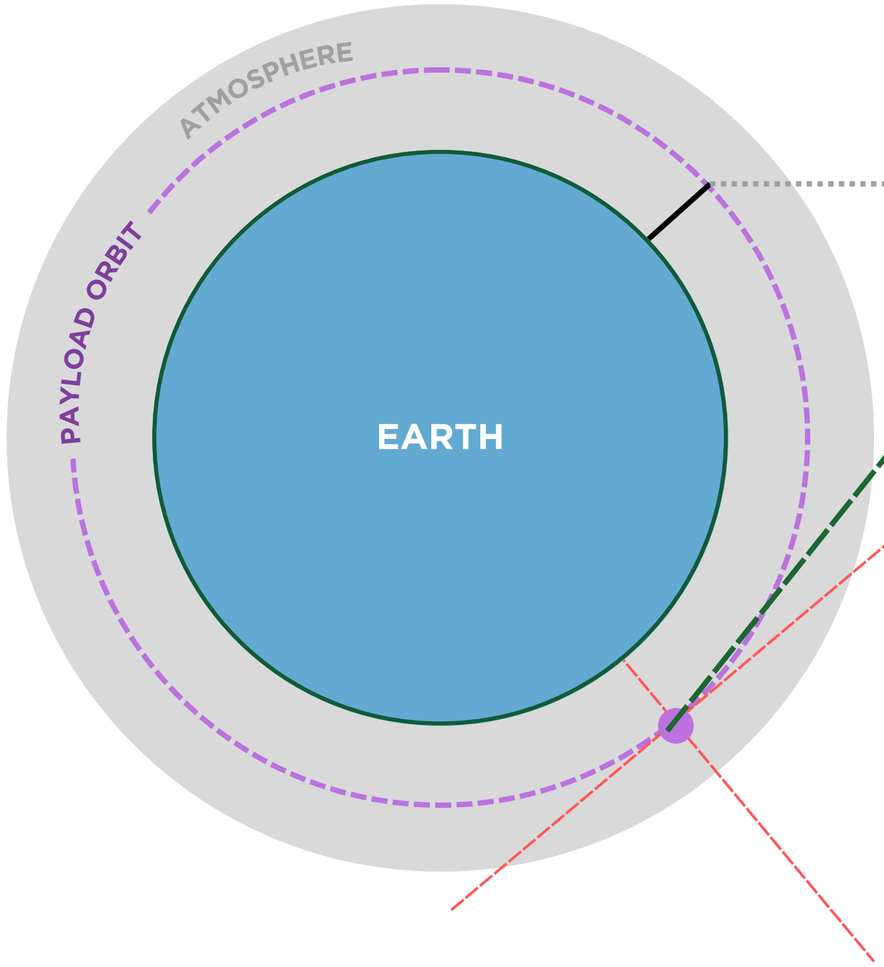
GEOMETRY



Payload Altitude (RASPASSHEIGHT) - 33 km a.s.l

Atmosphere-skimming Cosmic Ray Shower
aka High-Altitude Horizontal Air showers (HAHA)

Local frame of reference

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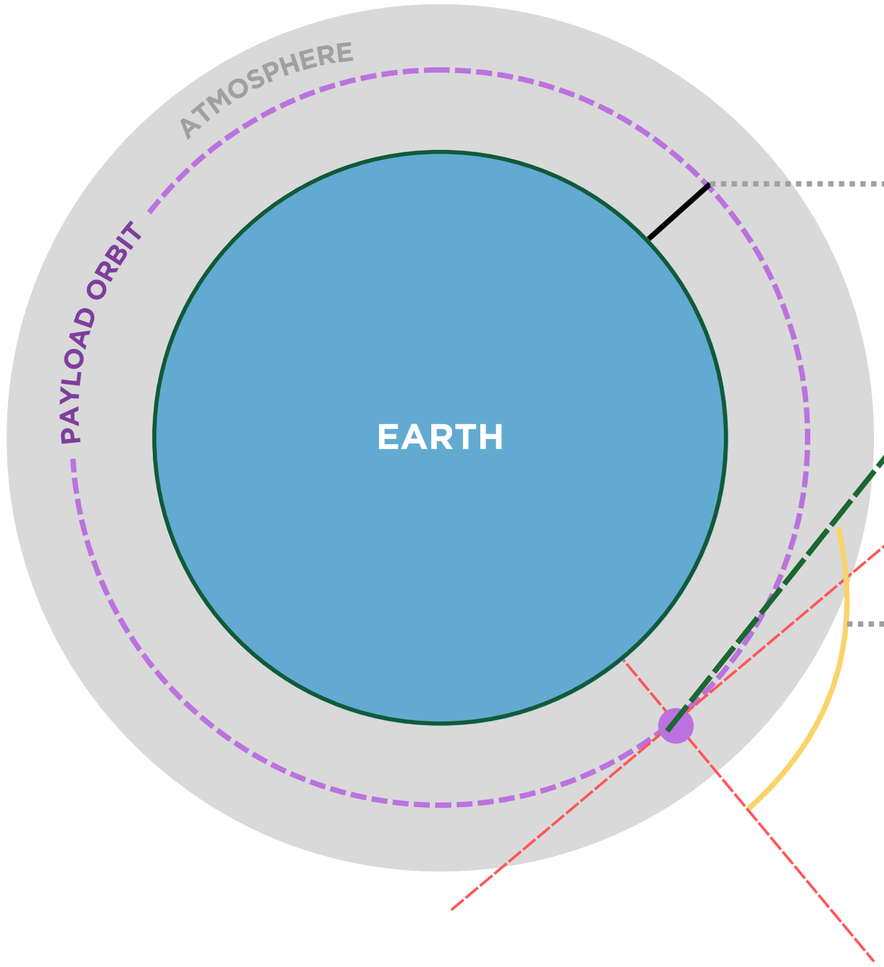
GEOMETRY



Payload Altitude (RASPASSHEIGHT) - 33 km a.s.l

Atmosphere-skimming Cosmic Ray Shower
aka High-Altitude Horizontal Air showers (HAHA)

Local frame of reference

Zenith angle (PrimaryZenith) - less than ~96°

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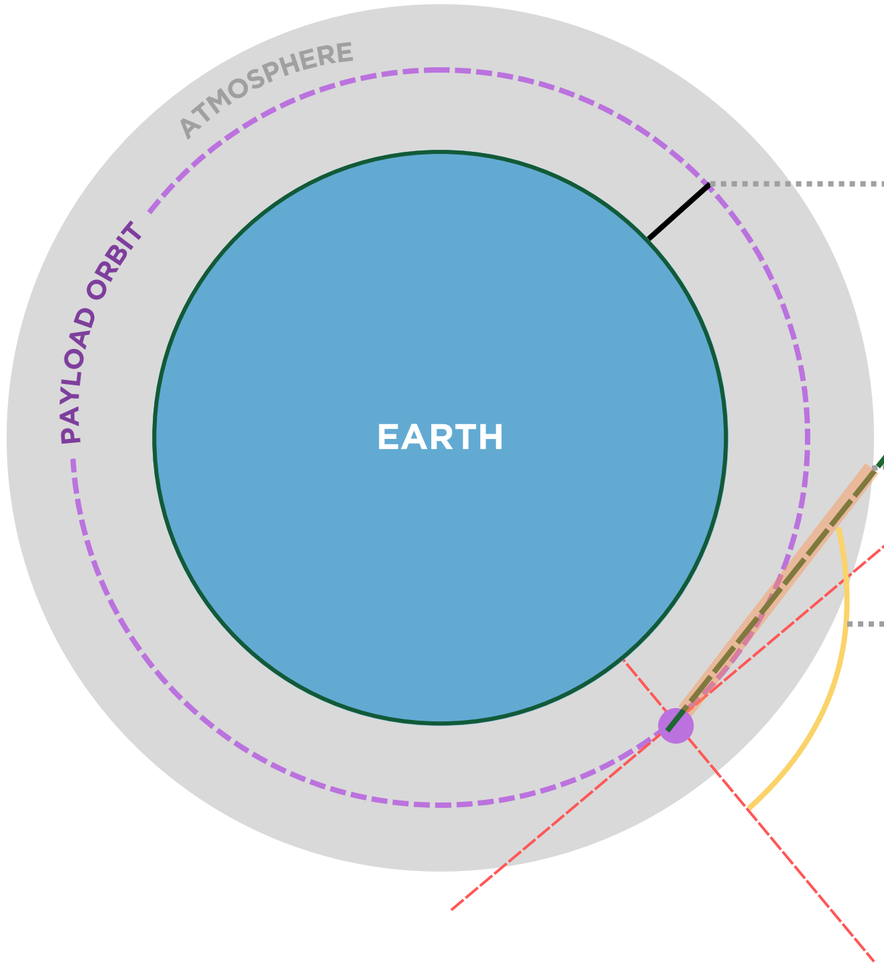
GEOMETRY



Payload Altitude (RASPASSHEIGHT) - 33 km a.s.l

Atmosphere-skimming Cosmic Ray Shower
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RASPASSDistance

Local frame of reference

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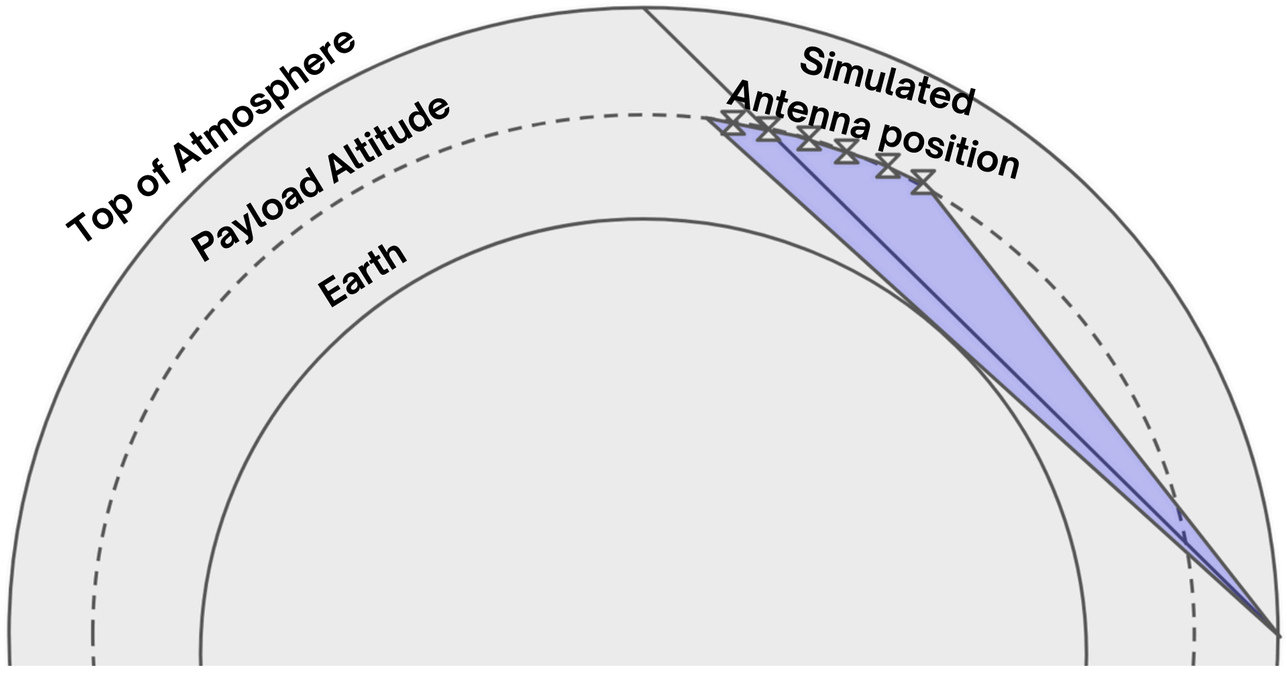
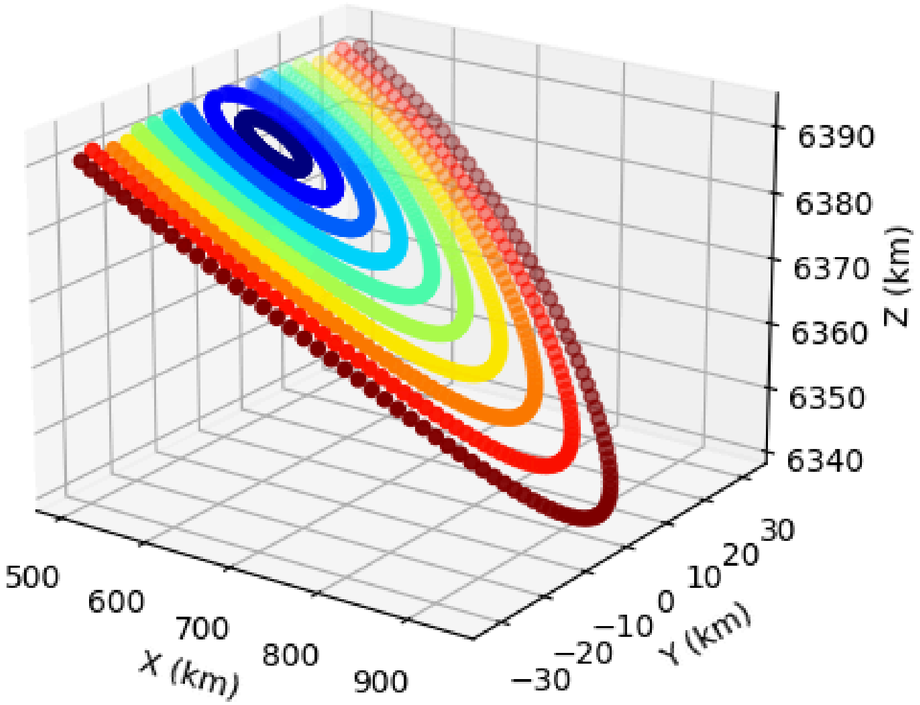
ANTENNA PLACEMENT

- Geometry of antenna positions is nontrivial and is accounted for:





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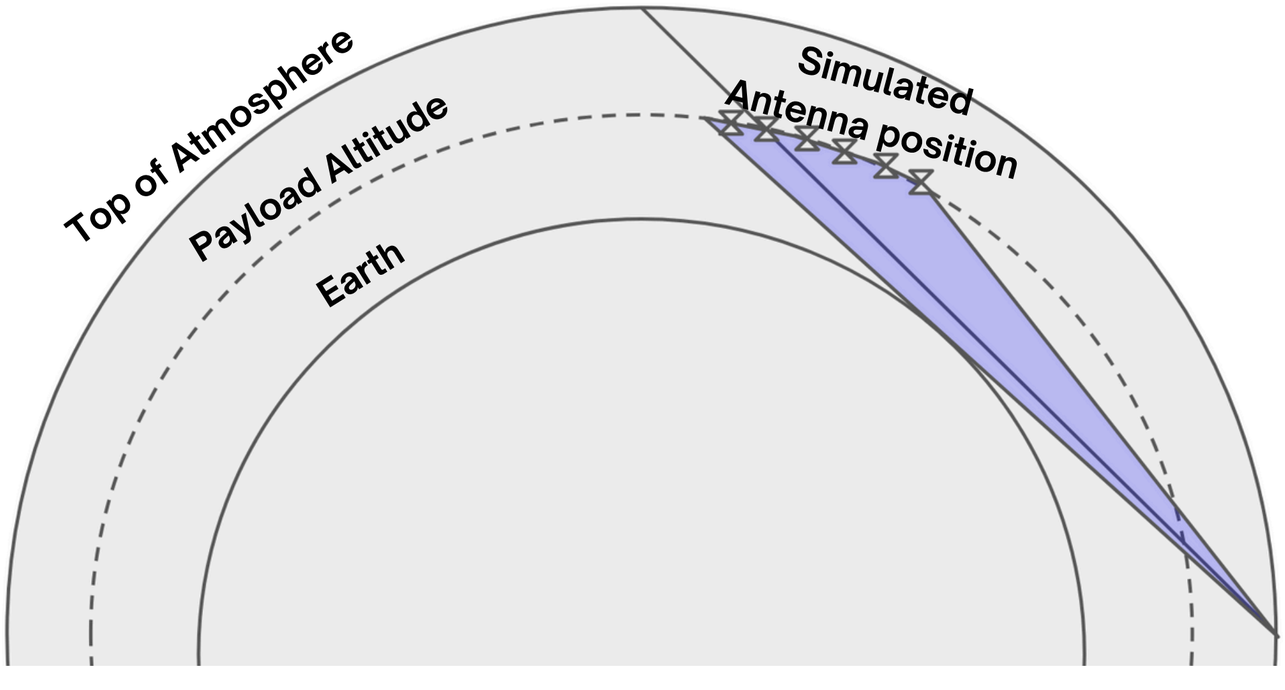
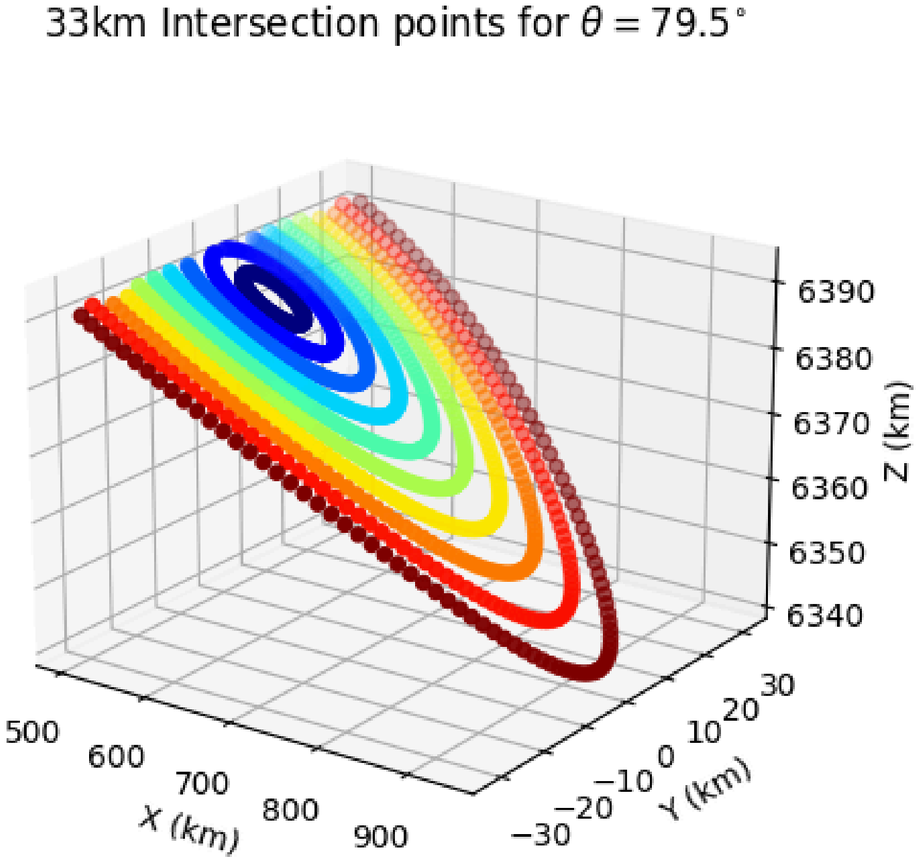
ANTENNA PLACEMENT

- Geometry of antenna positions is nontrivial and is accounted for:
  - Intersection of cone about shower axis with payload altitude





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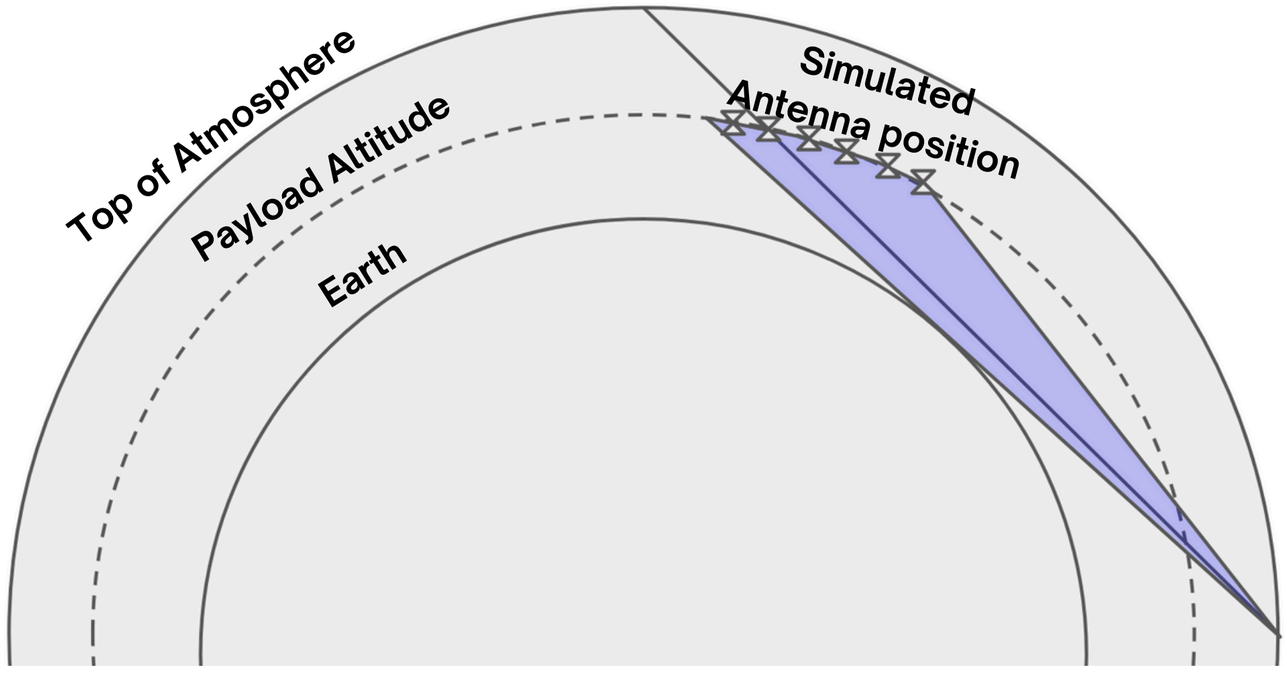
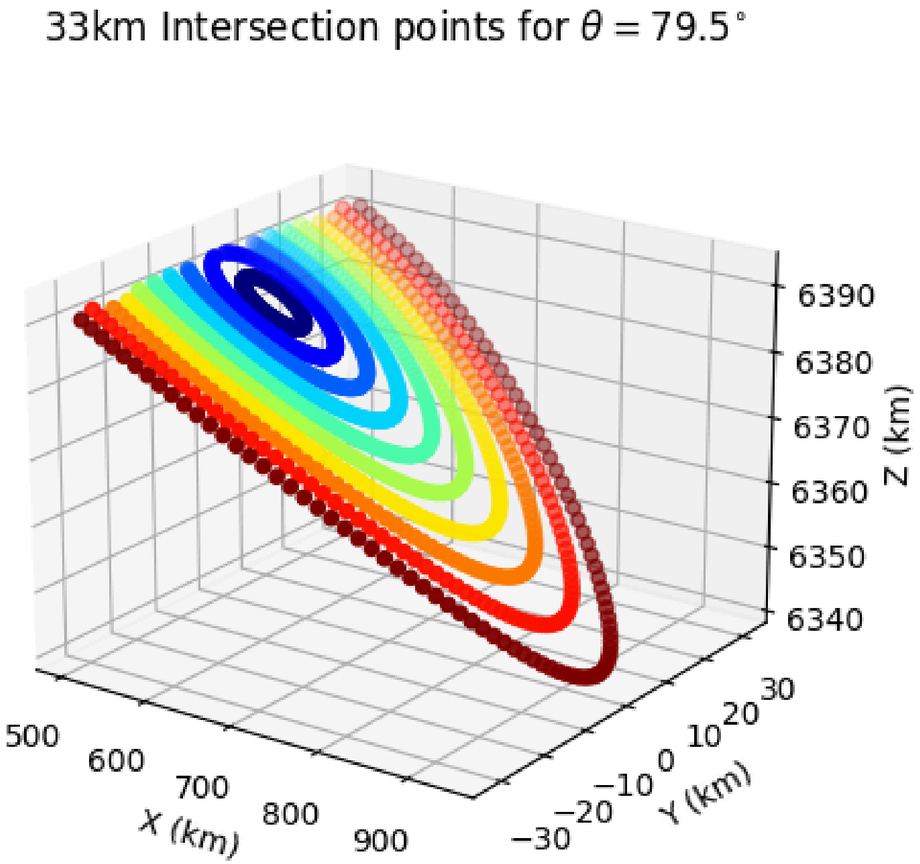
  - Intersection of cone about shower axis with payload altitude
  - Earth shadowing effects (paths which cannot reach payload) taken into account





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- Geometry of antenna positions is nontrivial and is accounted for:
  - Intersection of cone about shower axis with payload altitude
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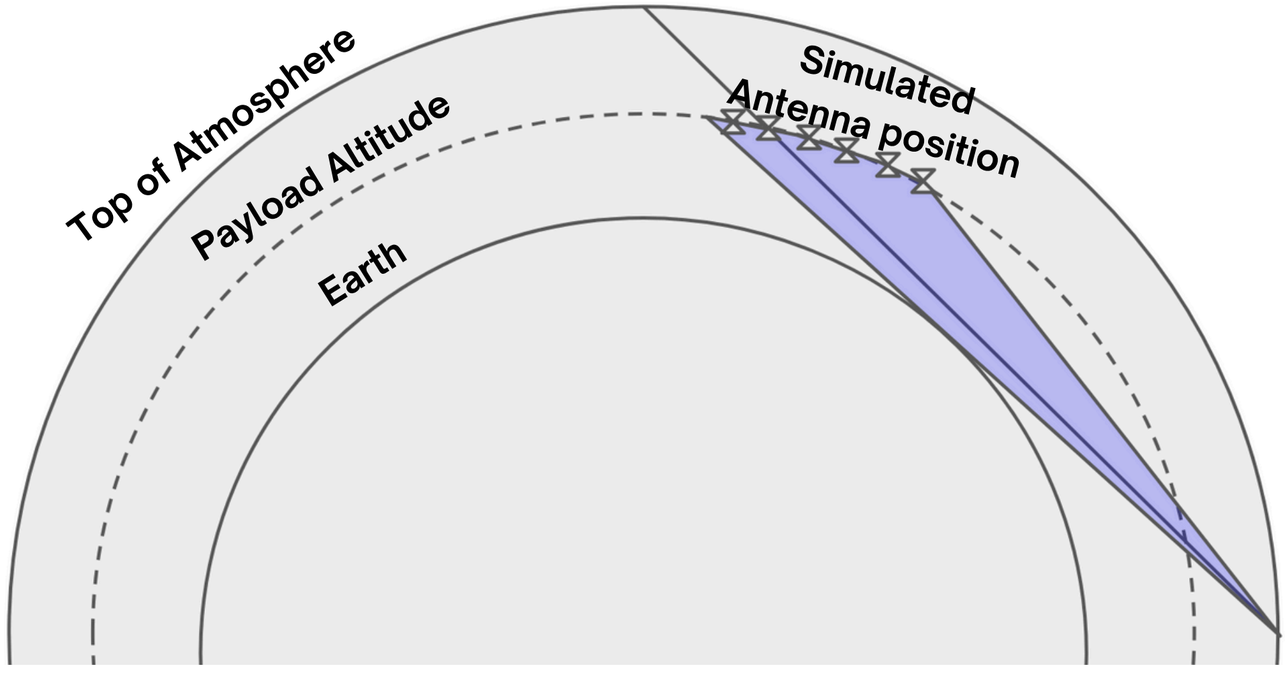
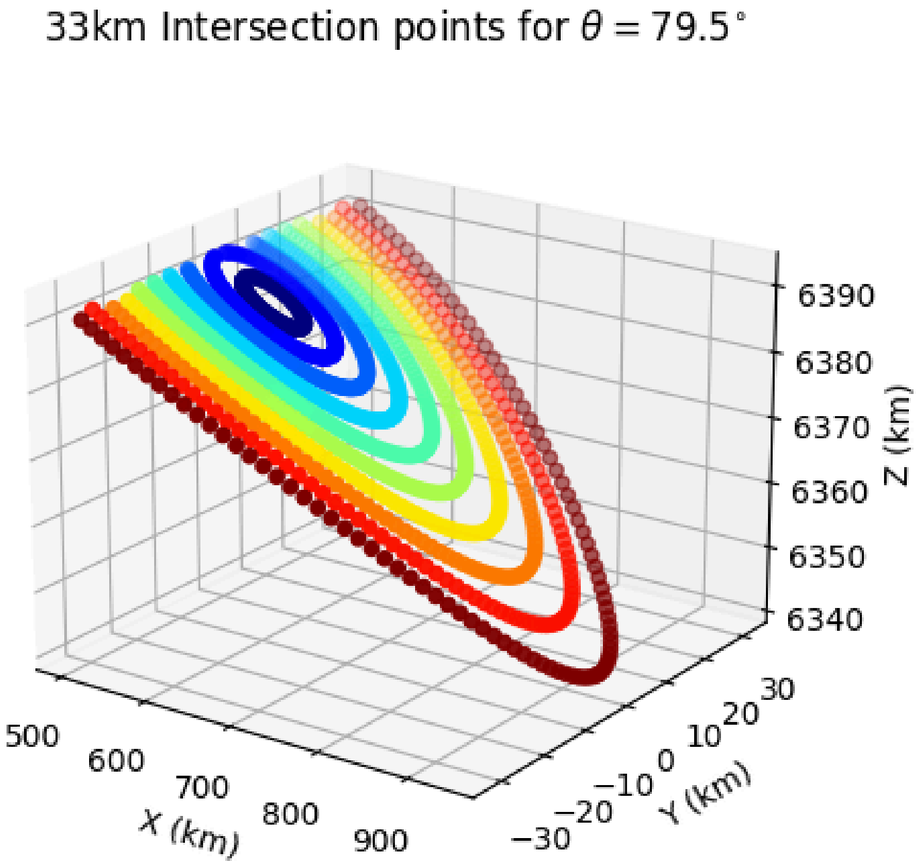
- Above horizontal showers captured





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RUNNING SIMULATIONS

- Running on the University of Delaware’s cluster: Caviness

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- Cores used: 33

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- **Total run time for a single shower with pseudo-parallelization: 1 hour 10 minutes***

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*Thus, with the resources available, we can run in the order of 50-100 showers daily

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RUNNING SIMULATIONS

- Running on the University of Delaware's cluster: Caviness
- Cores used: 33
- **Total run time for a single shower with pseudo-parallelization: 1 hour 10 minutes***
- Parameter set up:
  - **Primary particle: Proton, Electron**
  - Energy of primary: 1000 PeV
  - **Zenith: 93° (Atmosphere-skimming)**
  - Azimuth: 0
  - RASPASSHeight: 36000.00
  - RASPASSDistance: 1367862.44
  - Geomagnetic Field: 51.683e3 nT, -90.0°, 0.0°
  - Thinning factor: 1e-5
  - TimeDomainBin 0.1 ns

*Thus, with the resources available, we can run in the order of 50-100 showers daily

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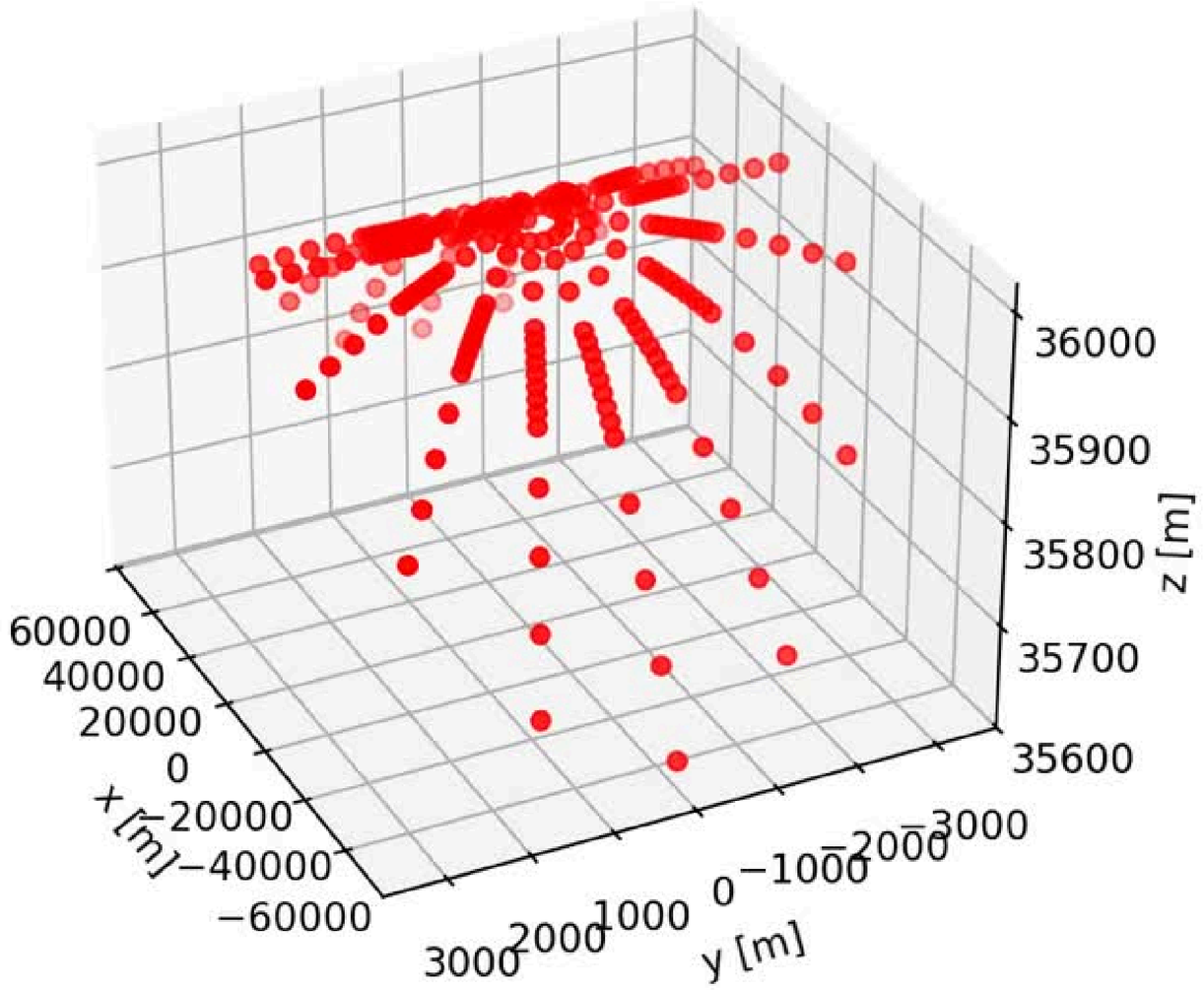
SAMPLE SIMULATIONS



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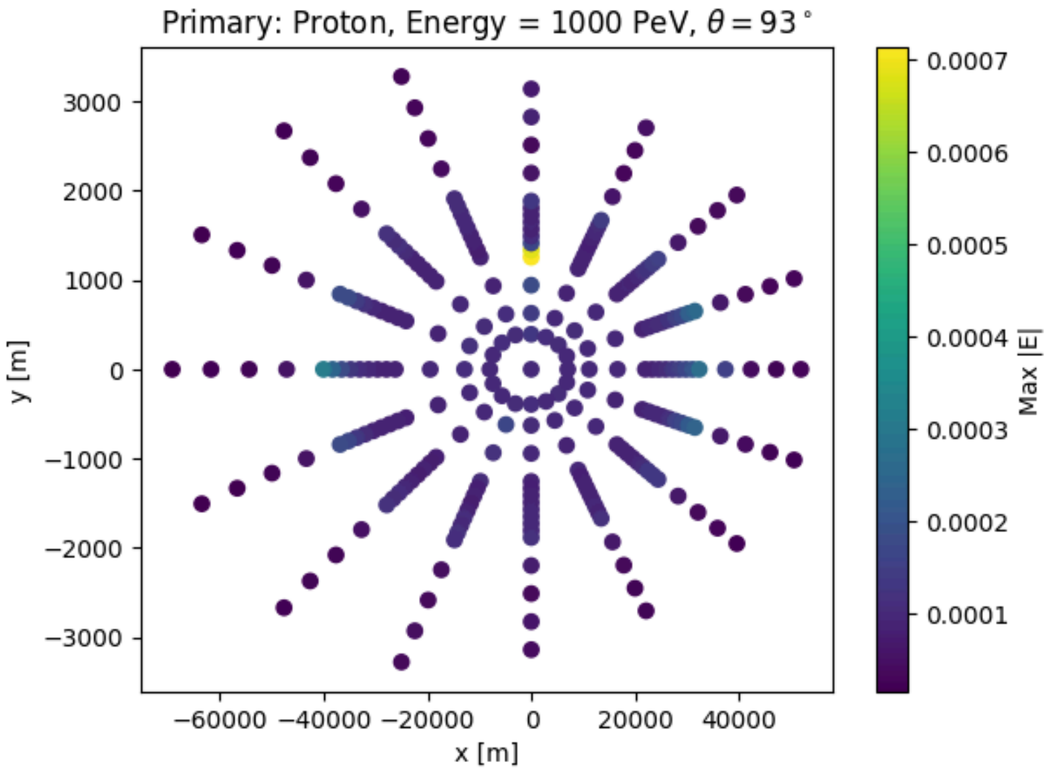
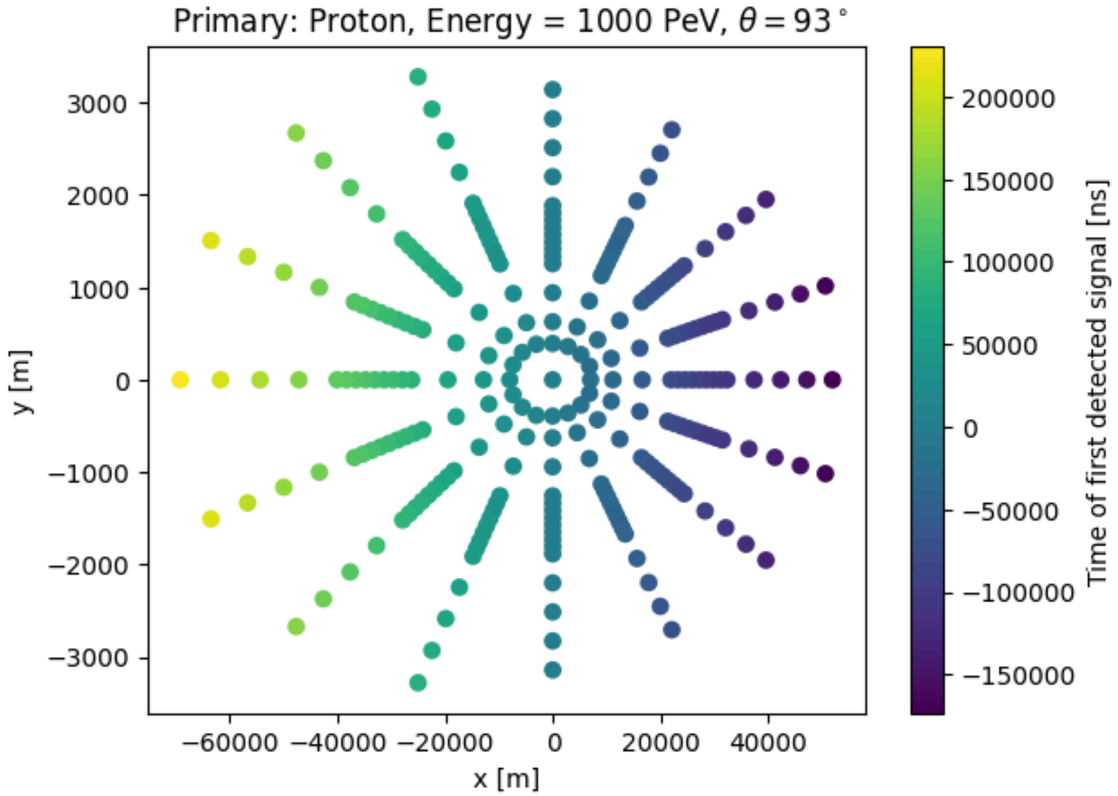
SAMPLE SIMULATIONS

2D PROTON INTENSITY



ARRIVAL TIMING



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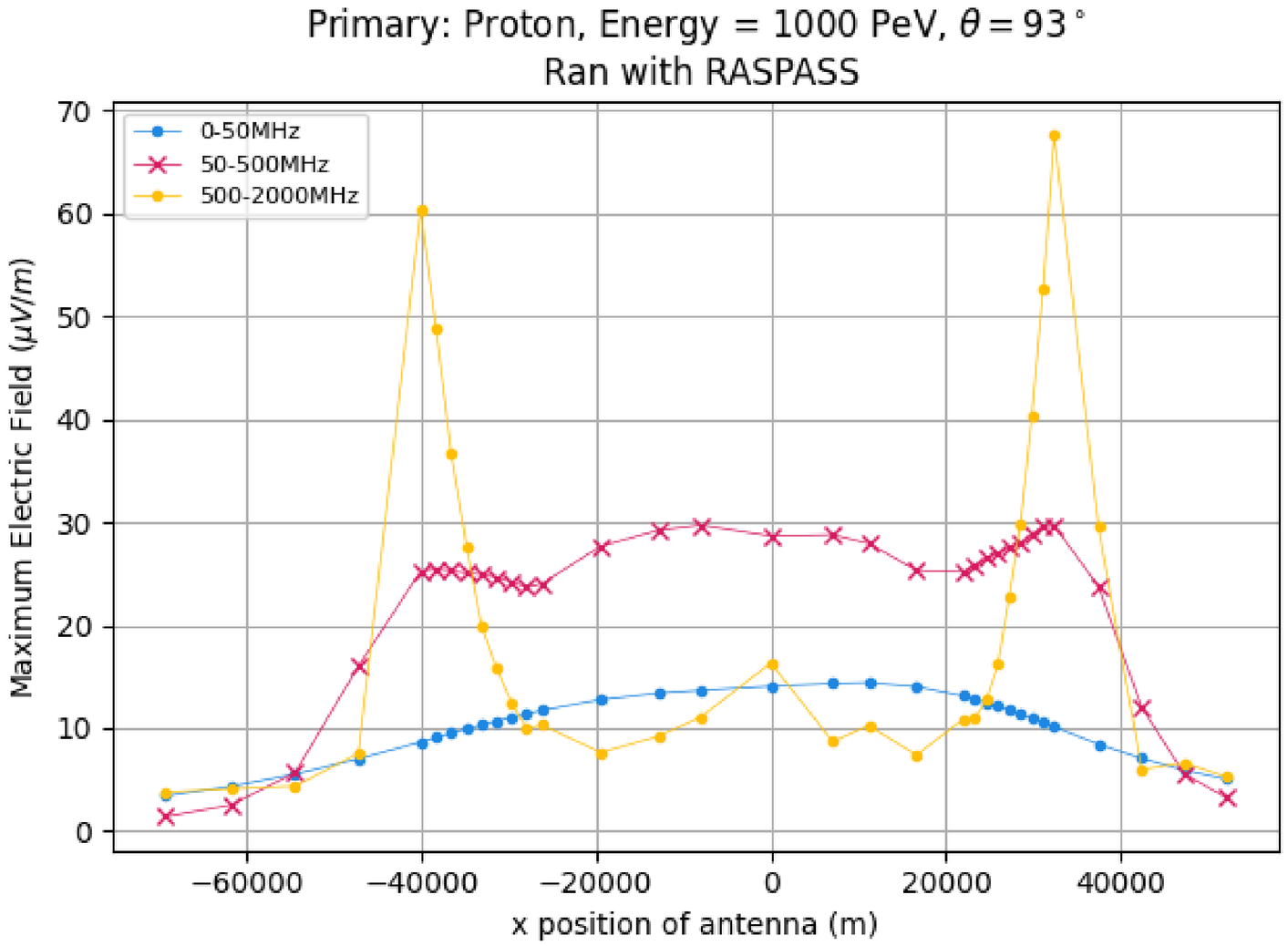

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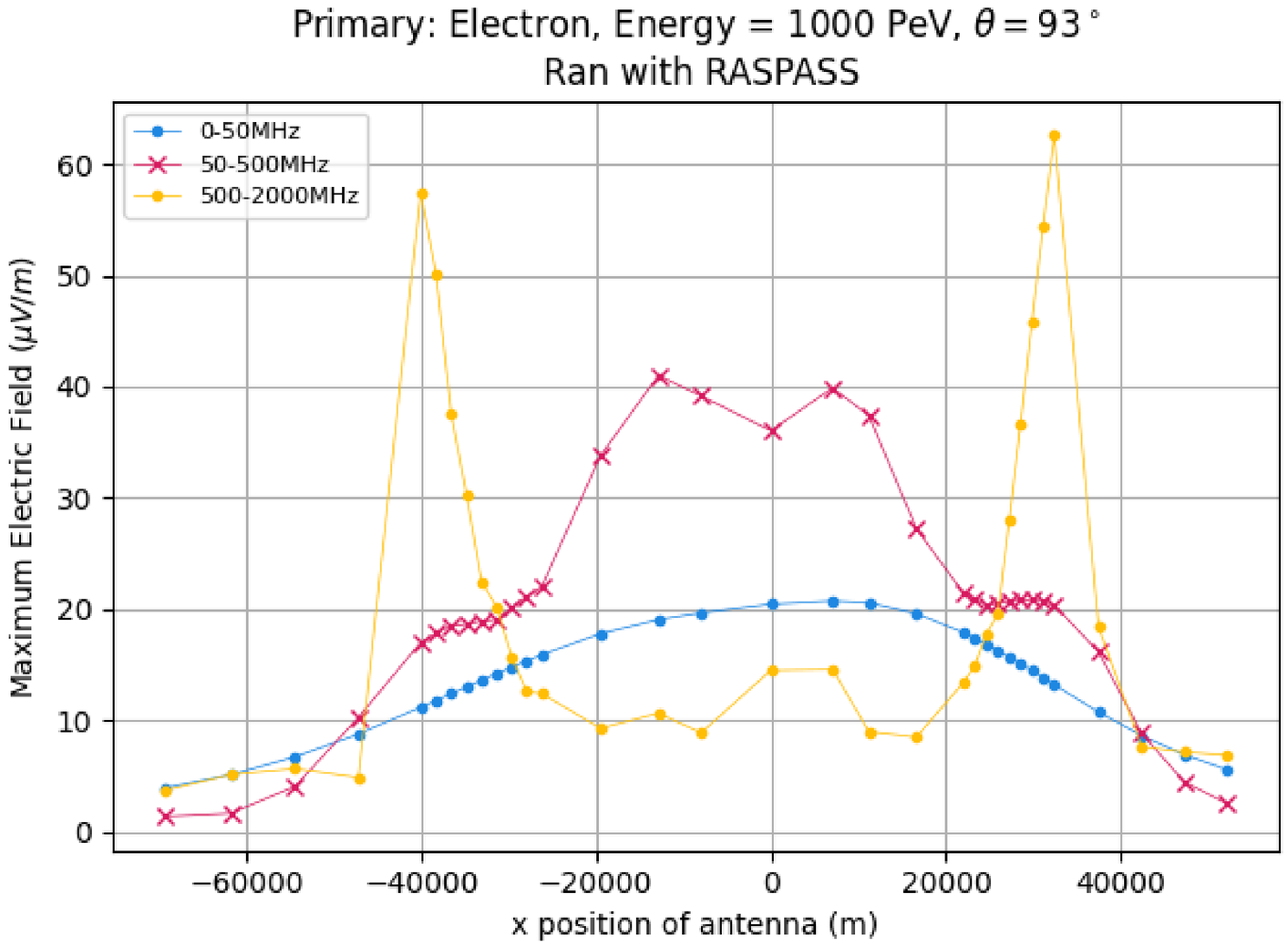

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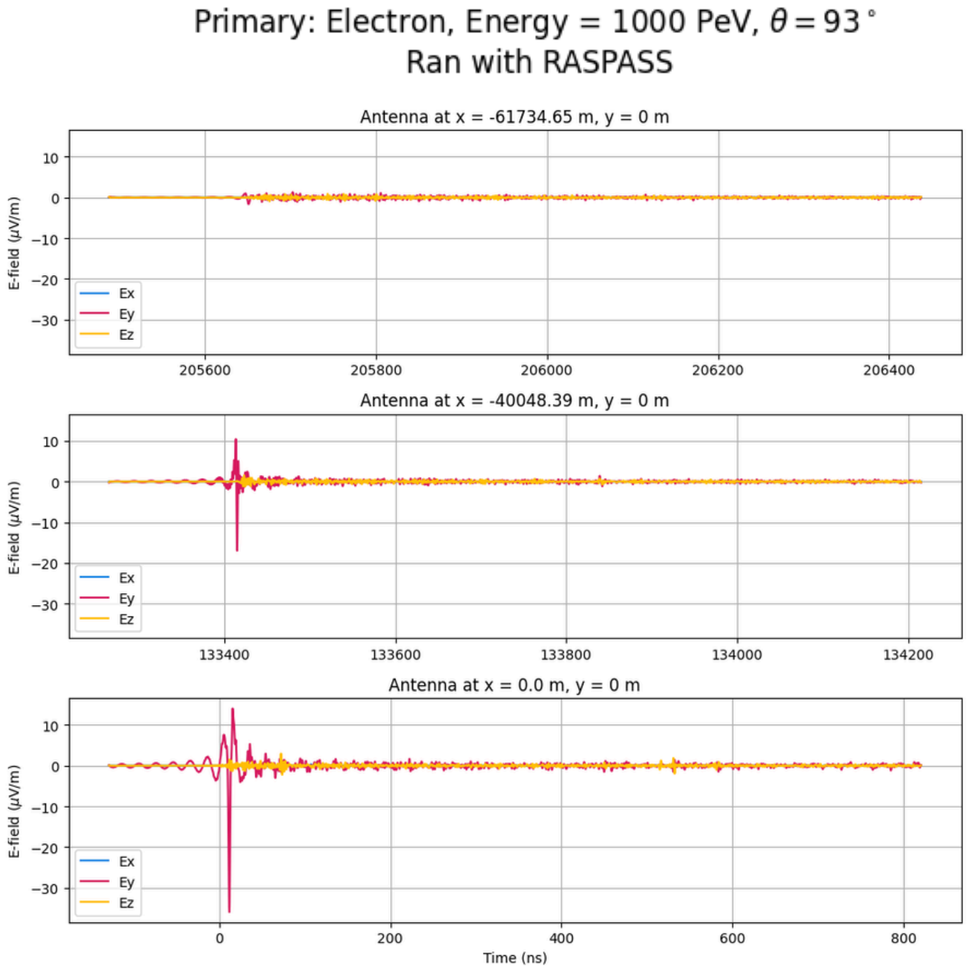
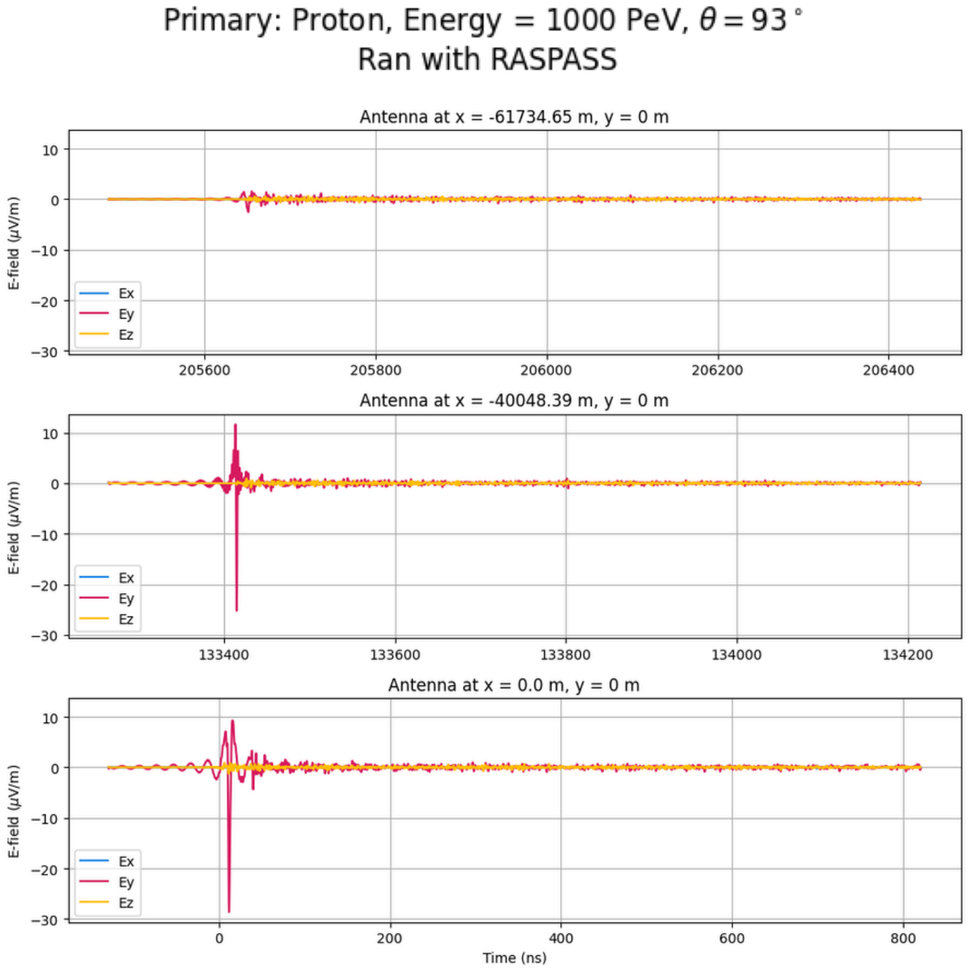


outside the ring

on the ring

inside the ring



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NEXT STEPS

- Simulate showers using the updated script for antenna placement (denser antenna pattern)

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  We expect to have a robust set in a couple of weeks

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  We expect to have a robust set in a couple of weeks
- Add electronic response (e.g. Offline) to simulations
- Get a background for the simulations: ideally (once available) measured background from PUEO + measurements of our antennas + DAQ at a quiet location

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SUMMARY

- Currently using **RASPASS** for simulations, we will perform comparison study for atmosphere-skimming (zenith 90-96) showers with CORSIKA v7

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- Currently using **RASPASS** for simulations, we will perform comparison study for atmosphere-skimming (zenith 90-96) showers with CORSIKA v7

- There is a **script for antenna positioning** that accounts for the geometry of HAHAs and Earth-shadowing effects that will be implemented next for the dataset of simulations

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SUMMARY

- Currently using **RASPASS** for simulations, we will perform comparison study for atmosphere-skimming (zenith 90-96) showers with CORSIKA v7
- There is a **script for antenna positioning** that accounts for the geometry of HAHAs and Earth-shadowing effects that will be implemented next for the dataset of simulations
- We are capable of **running a full shower simulation in about an hour** and produce about 50-100 showers per day.

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BACKUP SLIDES

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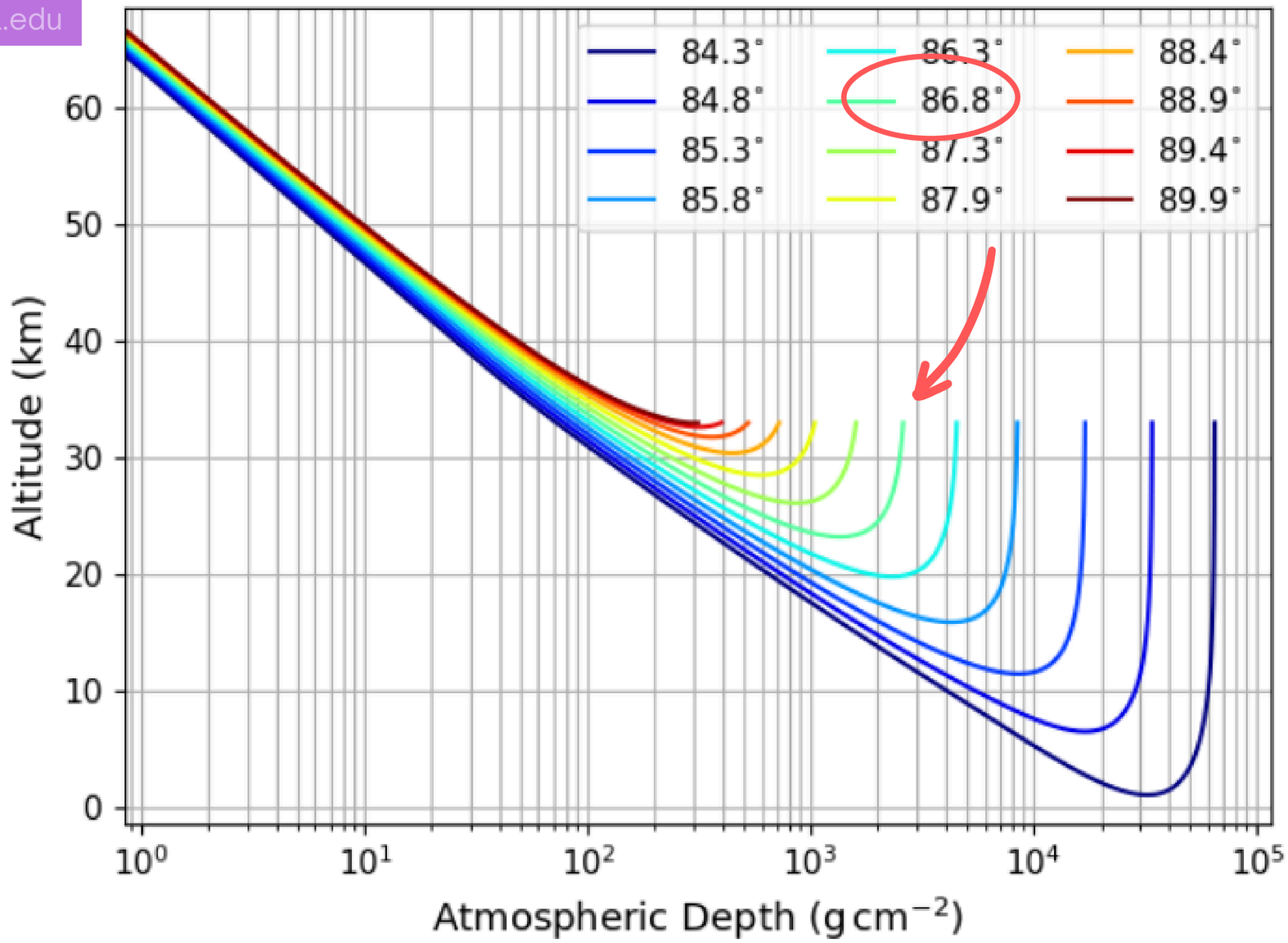

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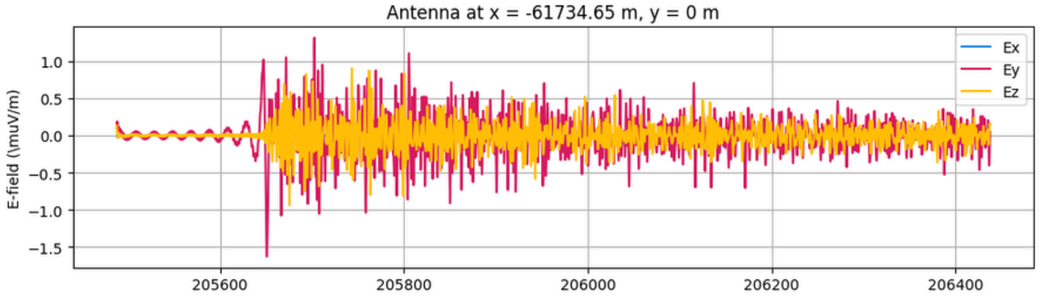
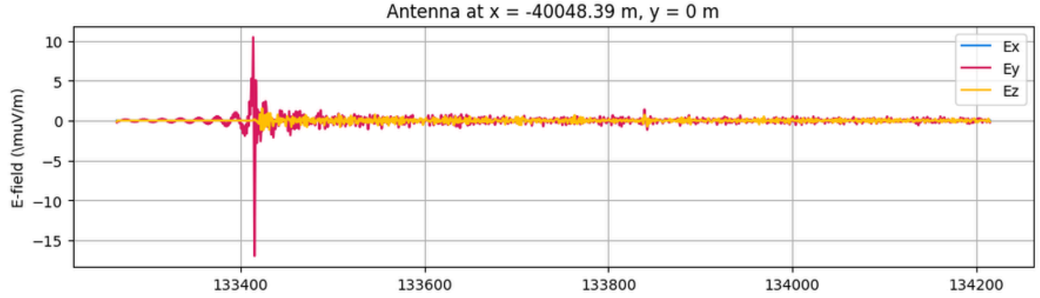
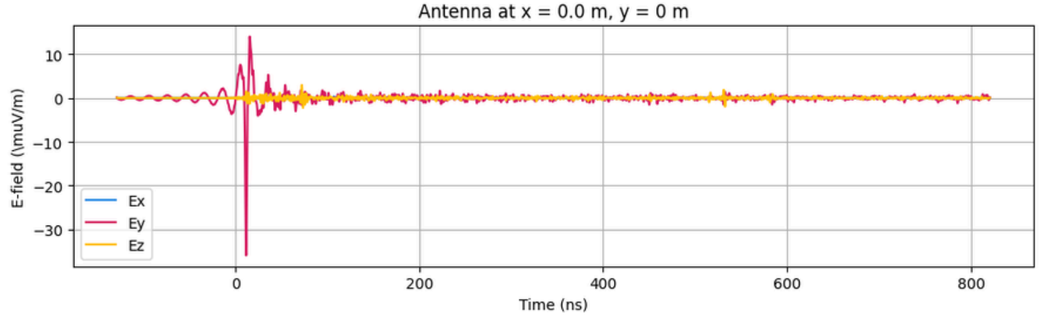
Primary: Electron, Energy = 1000 PeV, $\theta = 93^\circ$
Ran with RASPASS



outside the ring

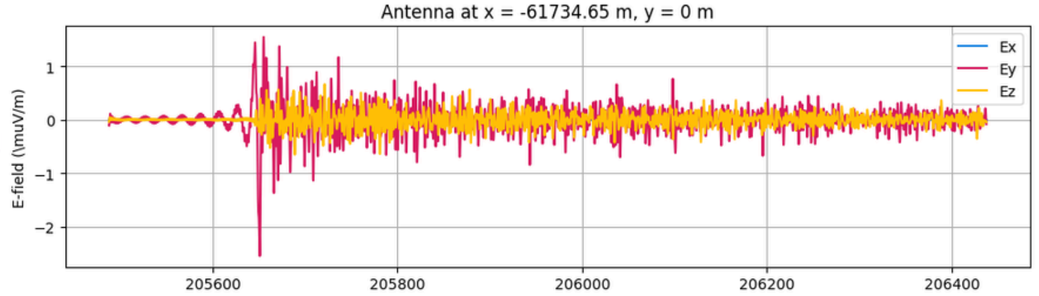


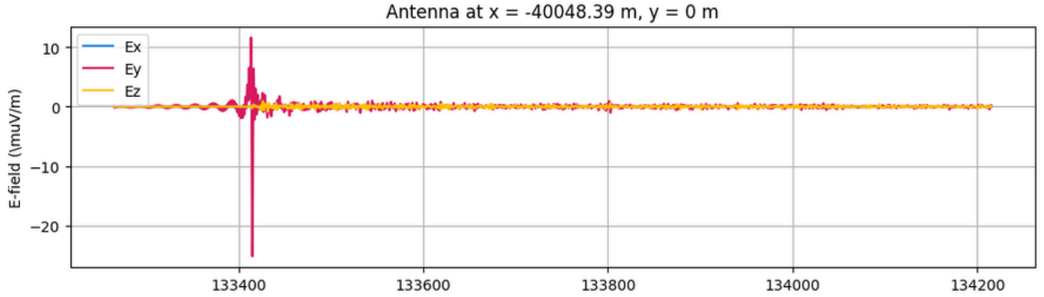
on the ring

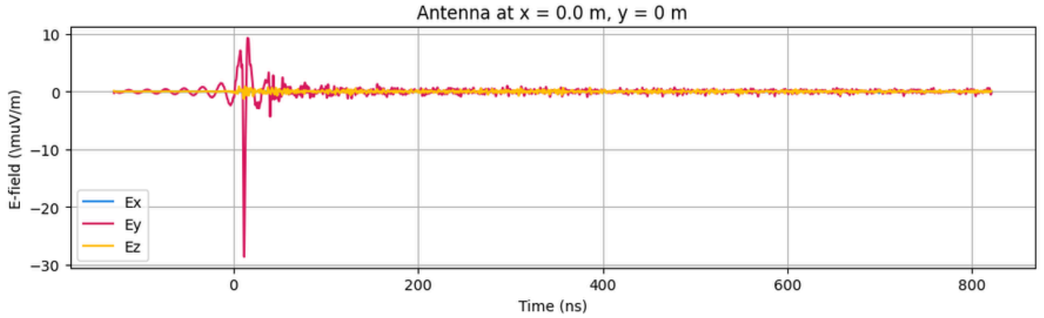


inside the ring

Primary: Proton, Energy = 1000 PeV, $\theta = 93^\circ$
Ran with RASPASS







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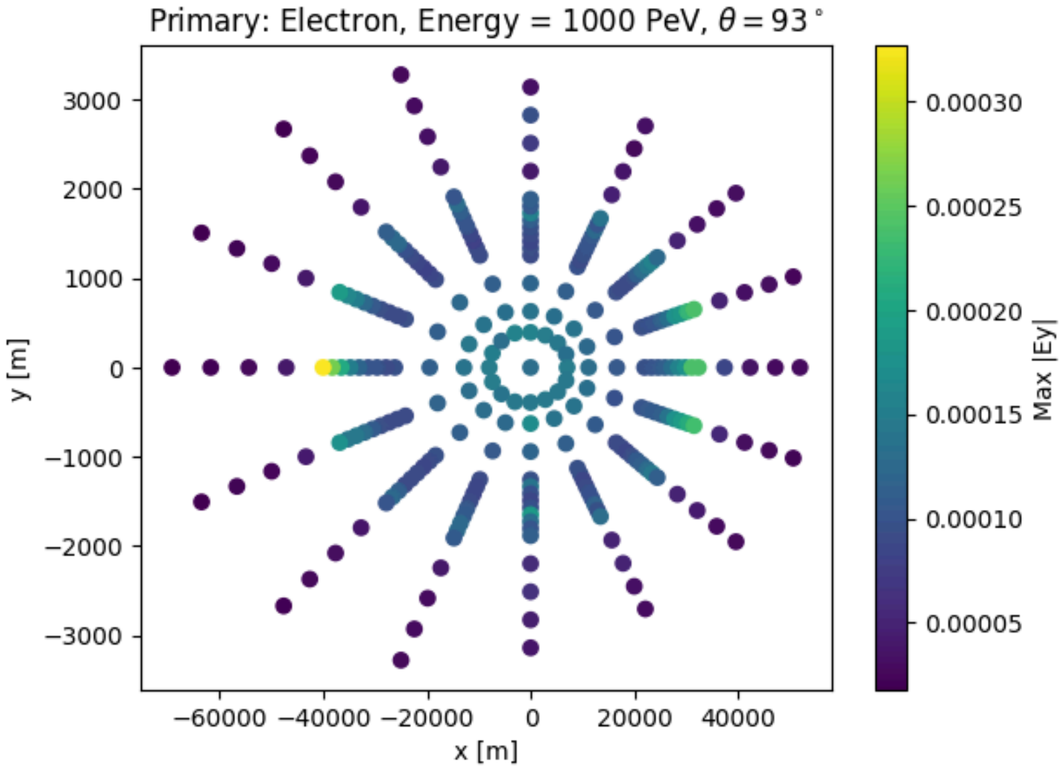
2D ELECTRON INTENSITY



ARRIVAL TIMING