Ultra High Frequency Radiation from Inclined Extensive Air Showers

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Summary

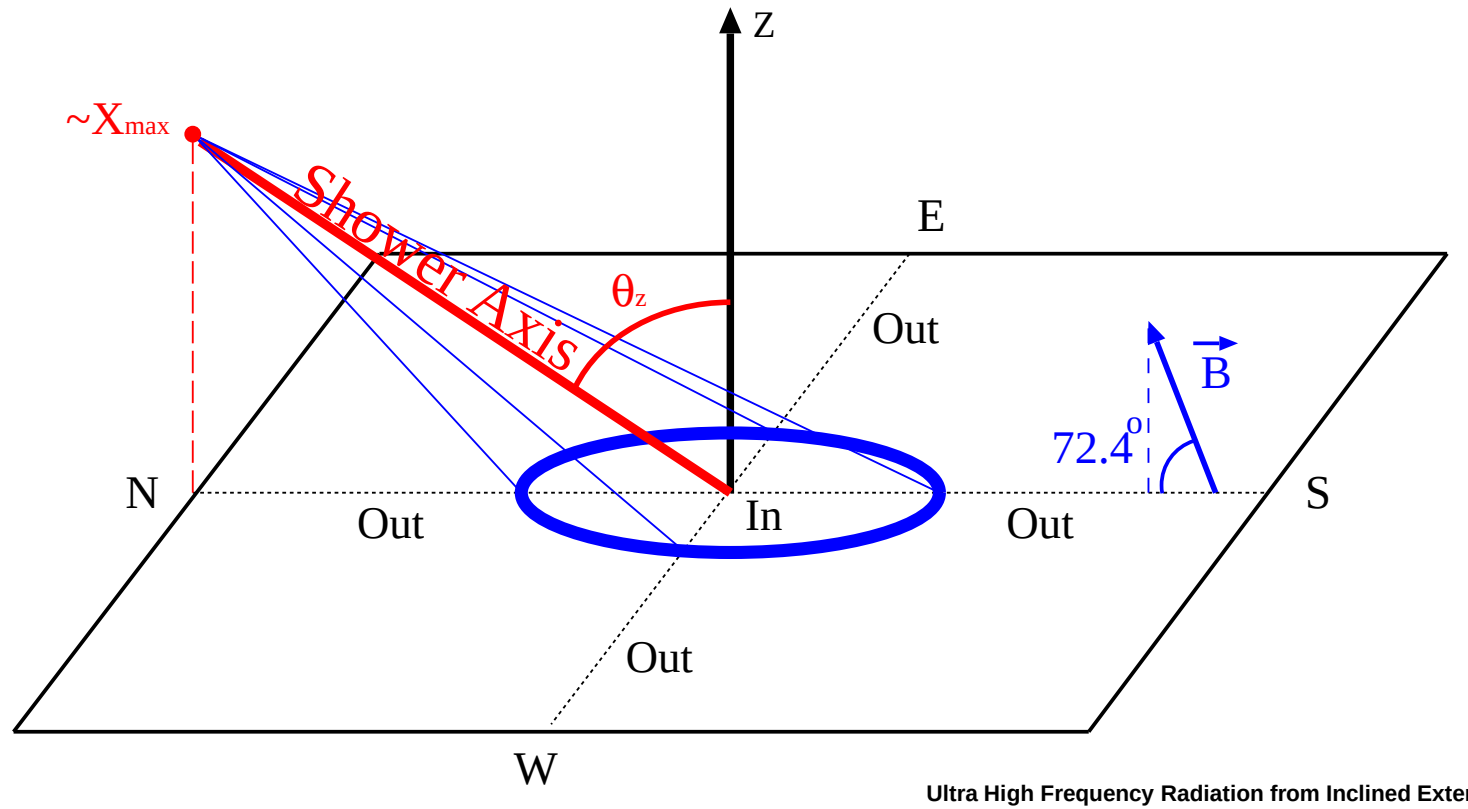
- ZHAires Simulations of inclined showers
- Fourier Spectrum extends to the GHz range
  - Geomagnetic and Askaryam mechanisms
  - No molecular Bremsstrahlung
  - Fits well to an exponential
  - Compatible with ANITA observations
- Elliptical ring like “GHz illuminated” region on the ground
  - Intersection of Cherenkov cone centered around X_{max}
  - Width depends on observed frequency
  - Only regions very close to shower axis contribute
  - LDF measurements can be used to obtain X_{max}

The ZHAireS code

- ZHAireS (ZHS + Aires): Simulation of radio emission in air showers (Also works in dense media)
  (AstropaPhys, **35**,325, 2012)
- Full shower simulation using Aires
- Radio emission calculation based on ZHS algorithms
  (Zas, Halzen, Stanev, Phys.Rev.D V**45**, 362 (1992) and Phys.Rev.D81:123009,2010)
  - First principles (Maxwell) - No emission model presuposed.
    Geomagnetic, Askaryan, etc... all included (but no molecular bremmstrahlung)
  - Frequency- and Time-domain calculations of vector potential $\vec{A}$ and electric field $\vec{E}$
- Takes into account varying refractive index n(h)

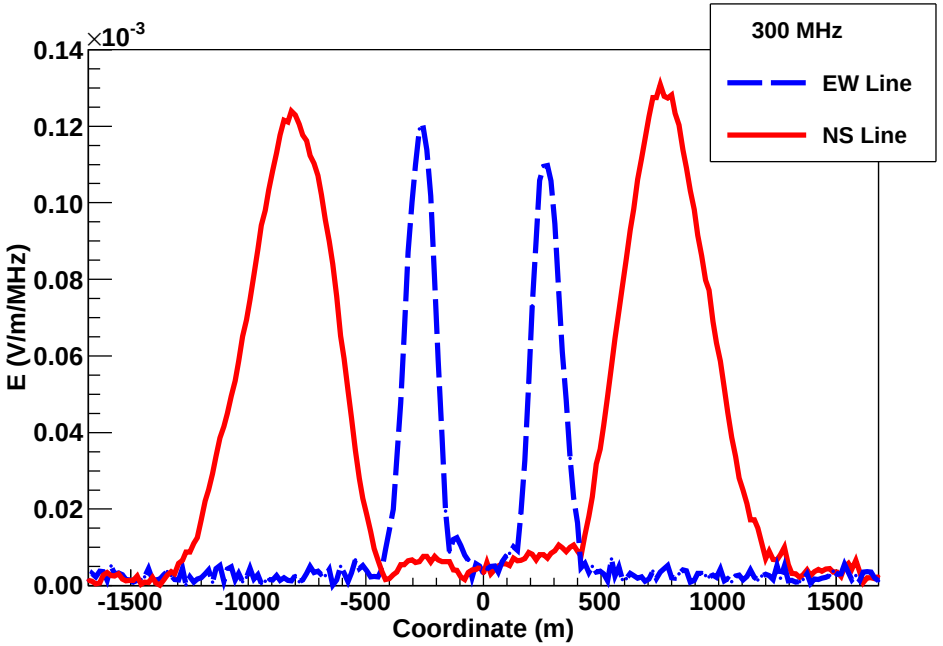
Shower geometry

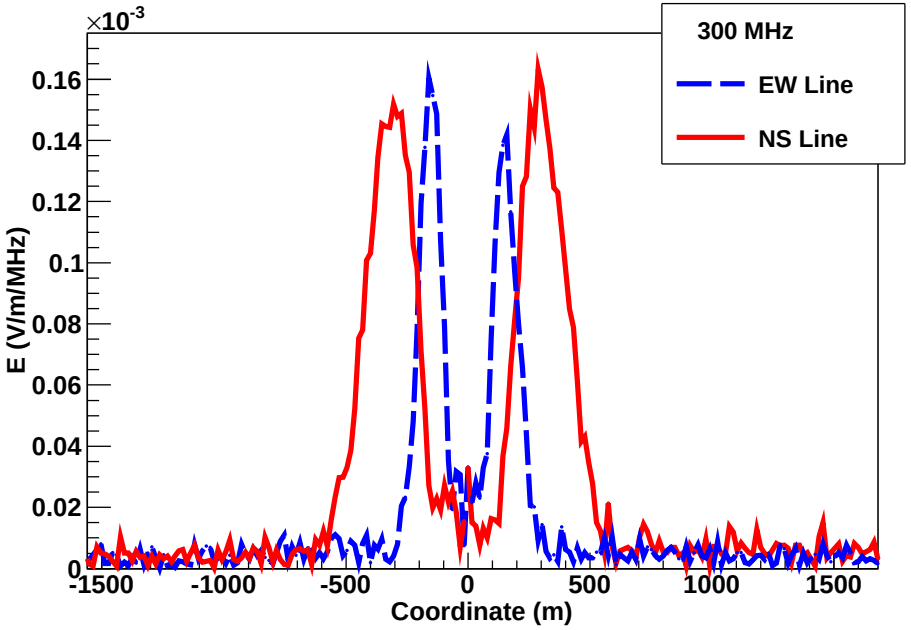
- Antennas placed along the E-W and N-S lines
- Ground at 2800 m a.s.l., $|\vec{B}| = 55\mu T$, decl. $0°$ and incl. $-72.4°$
- Elliptical ring like region defined by a Cherenkov cone centered at X_{max}

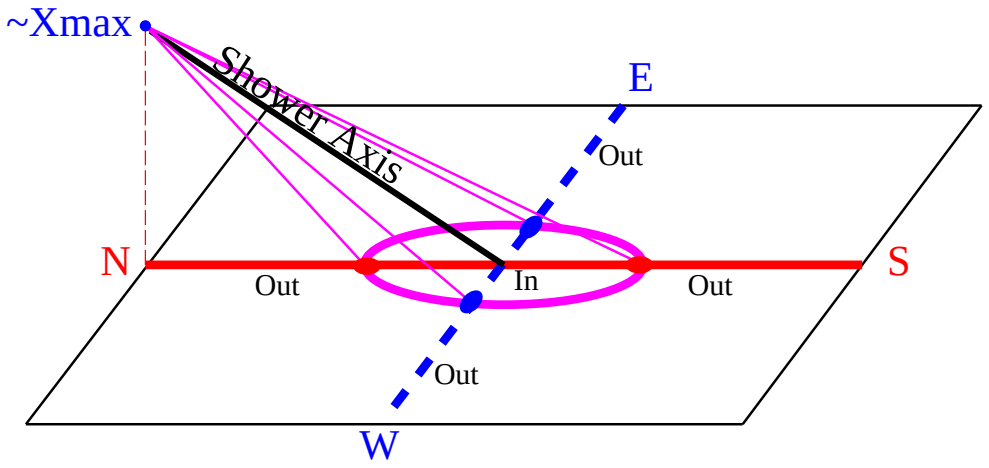


Elliptical ring: Maximum UHF signal

70° 60°

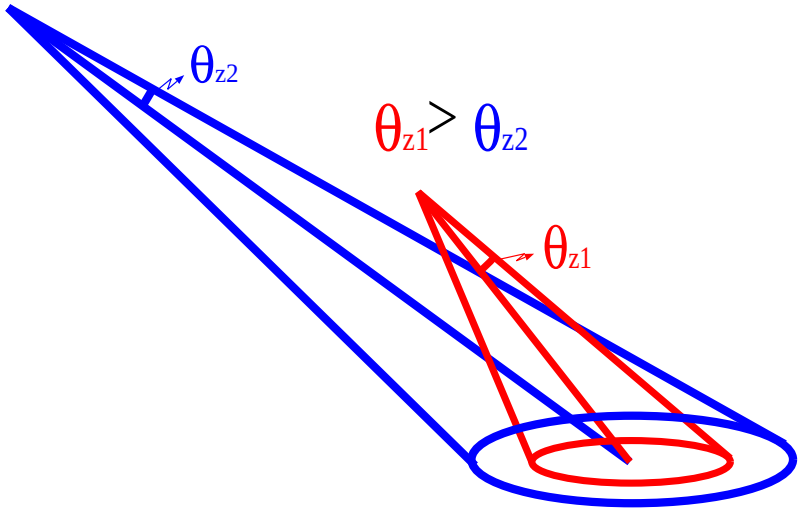


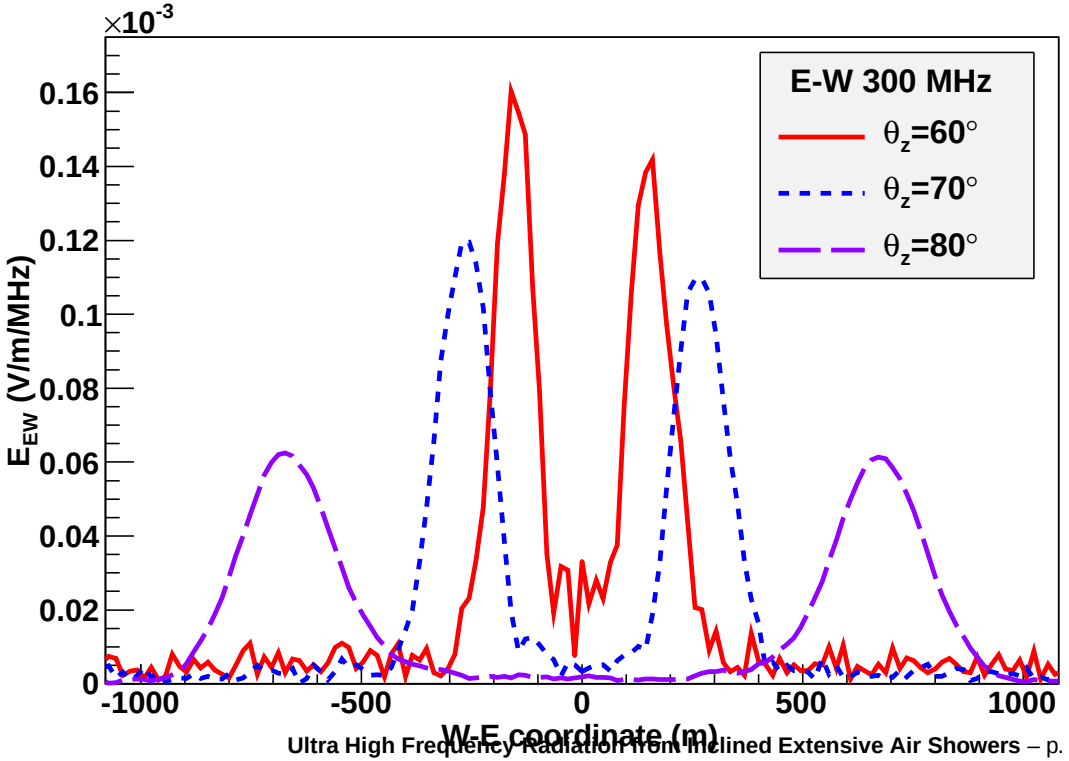




Ring dependence on θ_Z

- X_{max} altitude increases with θ_Z
  - Distance from X_{max} to core on the ground greatly increases with θ_Z
- Cherenkov angle θ_C slightly decreases with altitude
  - Cone opening angle slightly decreases with θ_Z
- Net effect: Elliptical ring size increases with θ_Z

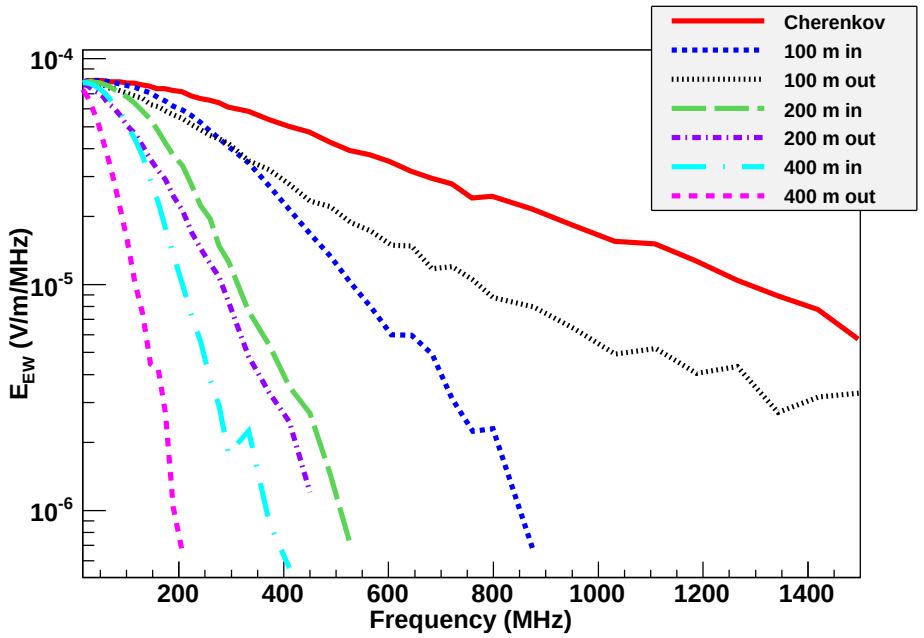




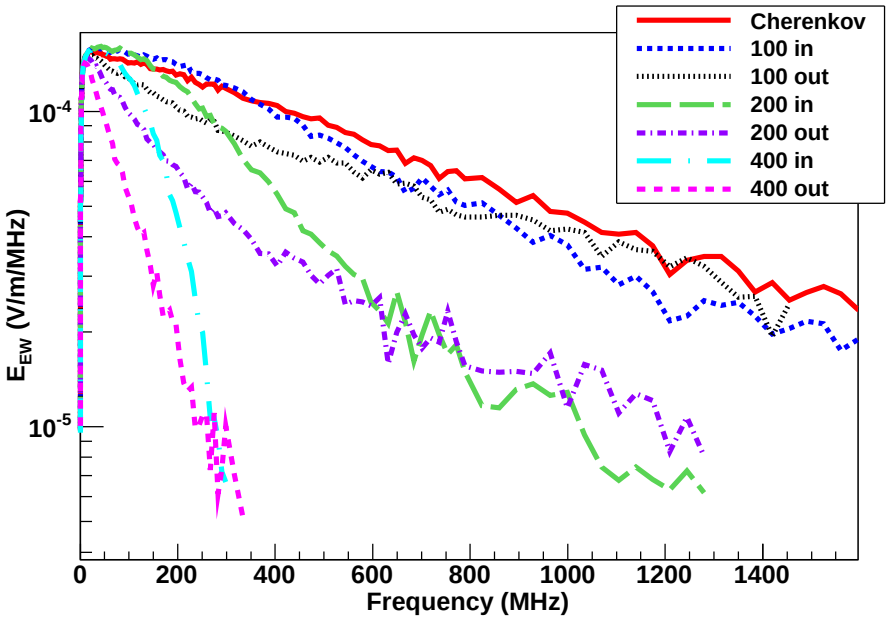
Spectrum

- Exponential falloff behaviour
- Falloff increases as we move away from the Cherenkov ring
- Slope at the Cherenkov ring has no strong zenithal angle dependence in the range $60 < \theta_Z < 80$

80° E-W line (W of core)

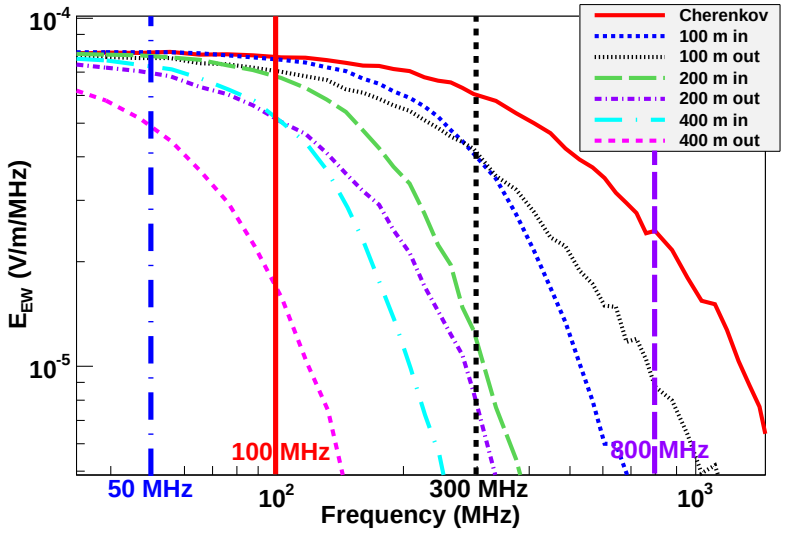


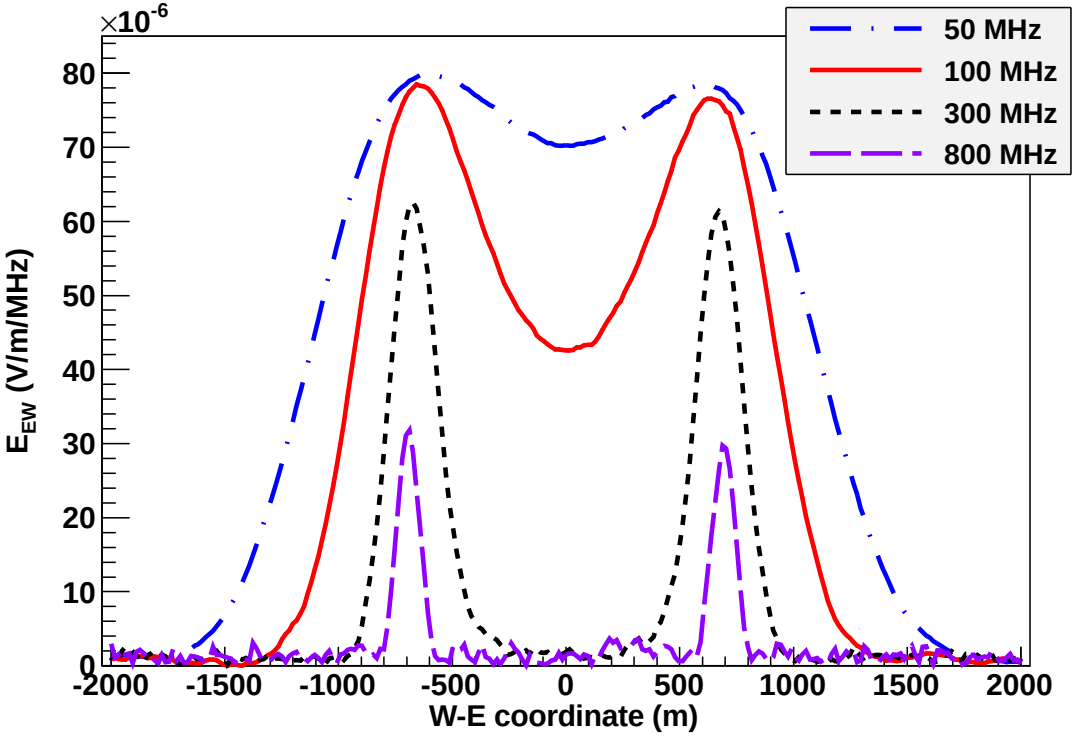
70° N-S line (N of core)



"Illuminated" area dependence on frequency

- Antennas further away from the ring have significant signal at lower frequencies
- Illuminated region widens as observed frequency decreases





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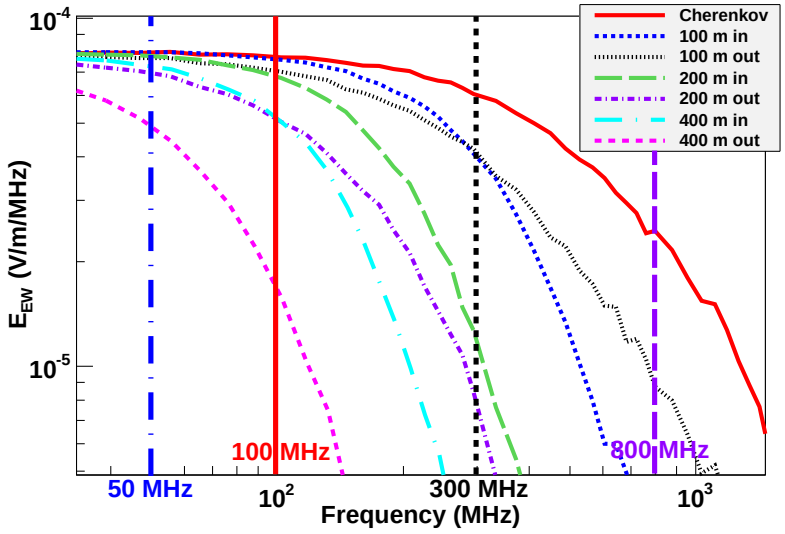
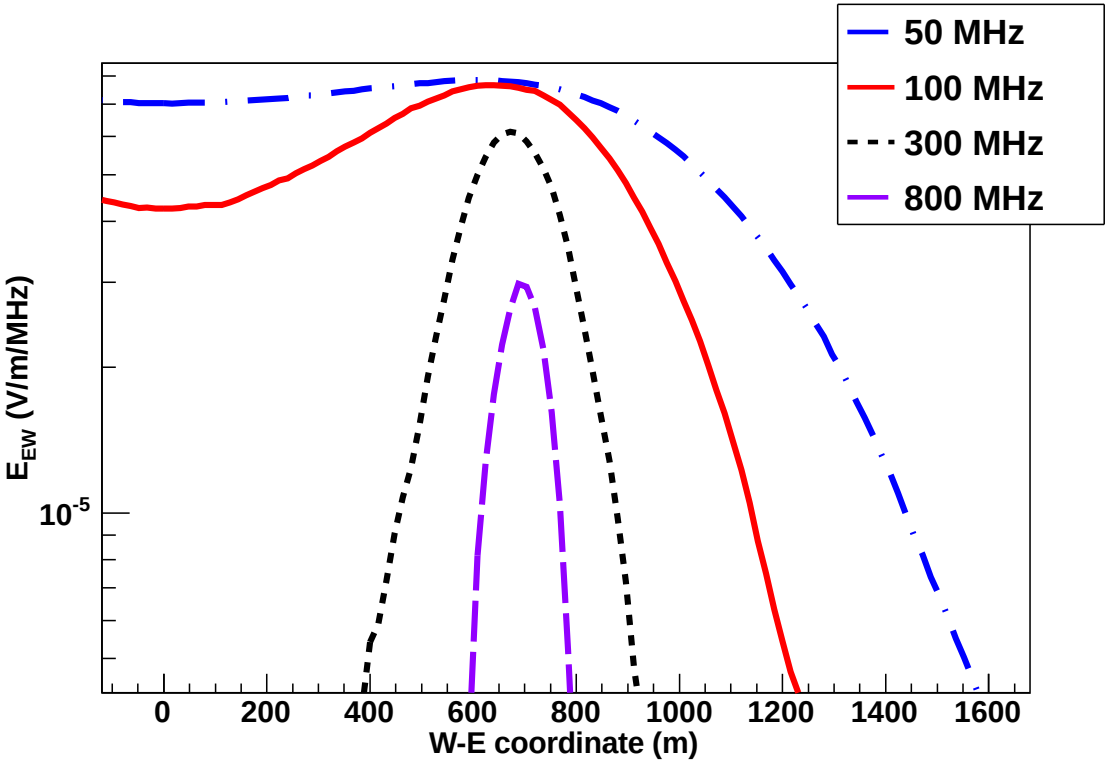
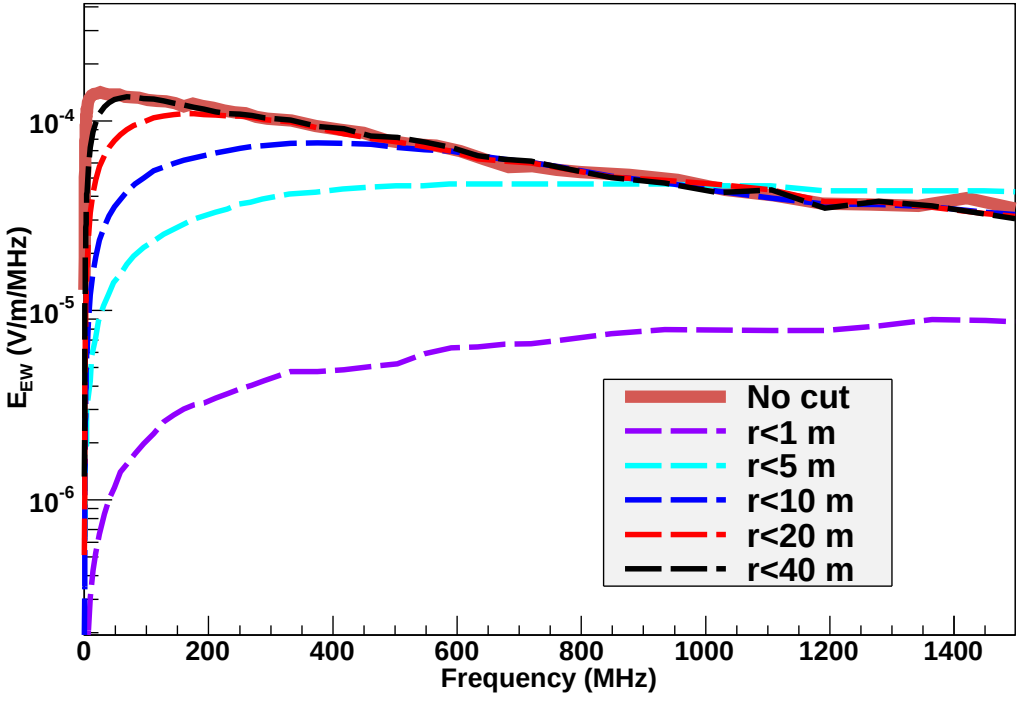
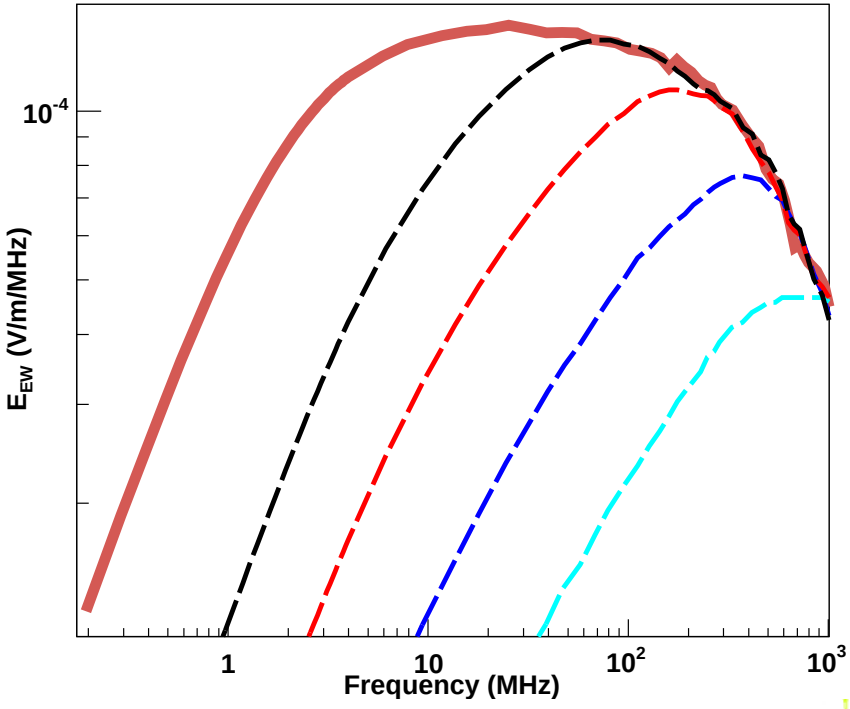




UHF emission comes from the axis

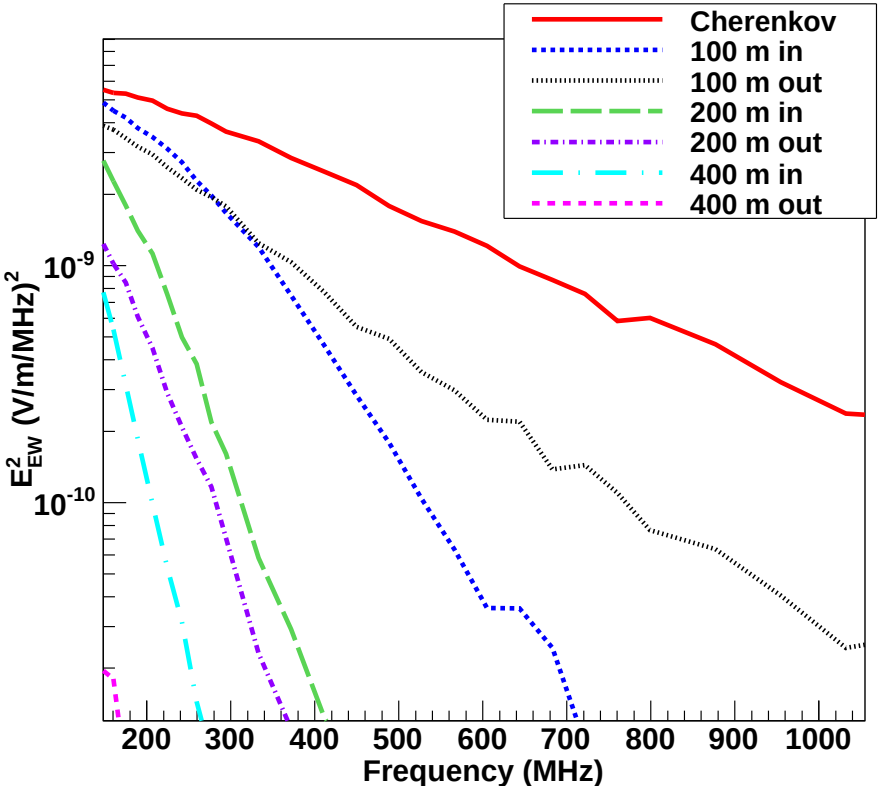
- High frequency components comes from shower axis
- Simulation with cuts in distance r from the shower axis
  - Spectrum virtually unchanged above:
    200 MHz for r<20 m, 500 MHz for r<10 m and 900 MHz for r<5 m
  - Low frequencies: Regions further away from the shower axis are important

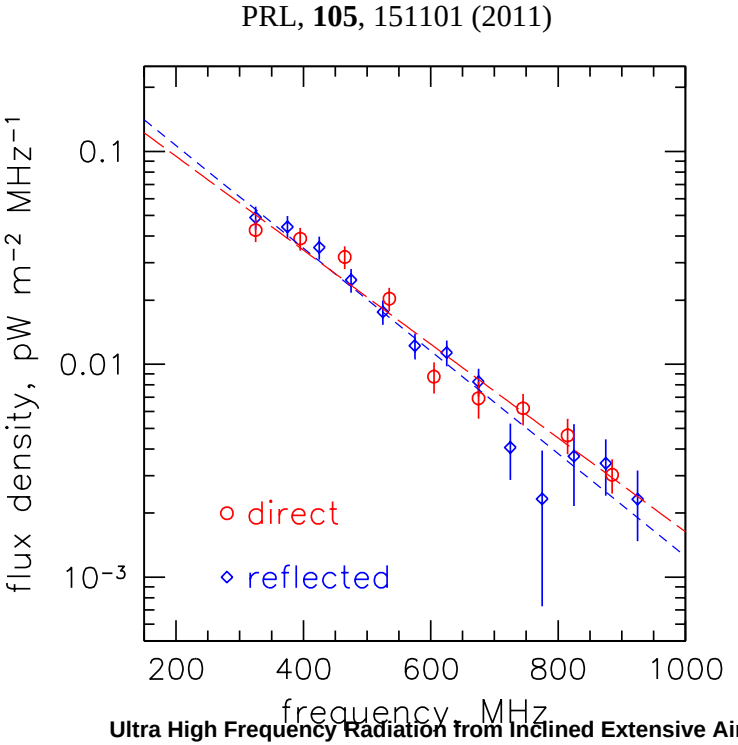




ANITA observation of exponential spectrum

- Exponential falloff
  - ANITA reflected:$\sim$180 MHz
  - ZHAireS: $\sim$ 260 MHz at Ring, $\sim$170 MHz 100m out, $\sim$85 MHz 100 m in
- ANITA trigger: Coincidence in several frequency bands
  - Detection bias $\Rightarrow$ Effective cut in spectral slope
  - Anita can only observe reflections close to the Cherenkov Ring





Questions?