A macroscopic radar scatter model for the RADAR ECHO TELESCOPE

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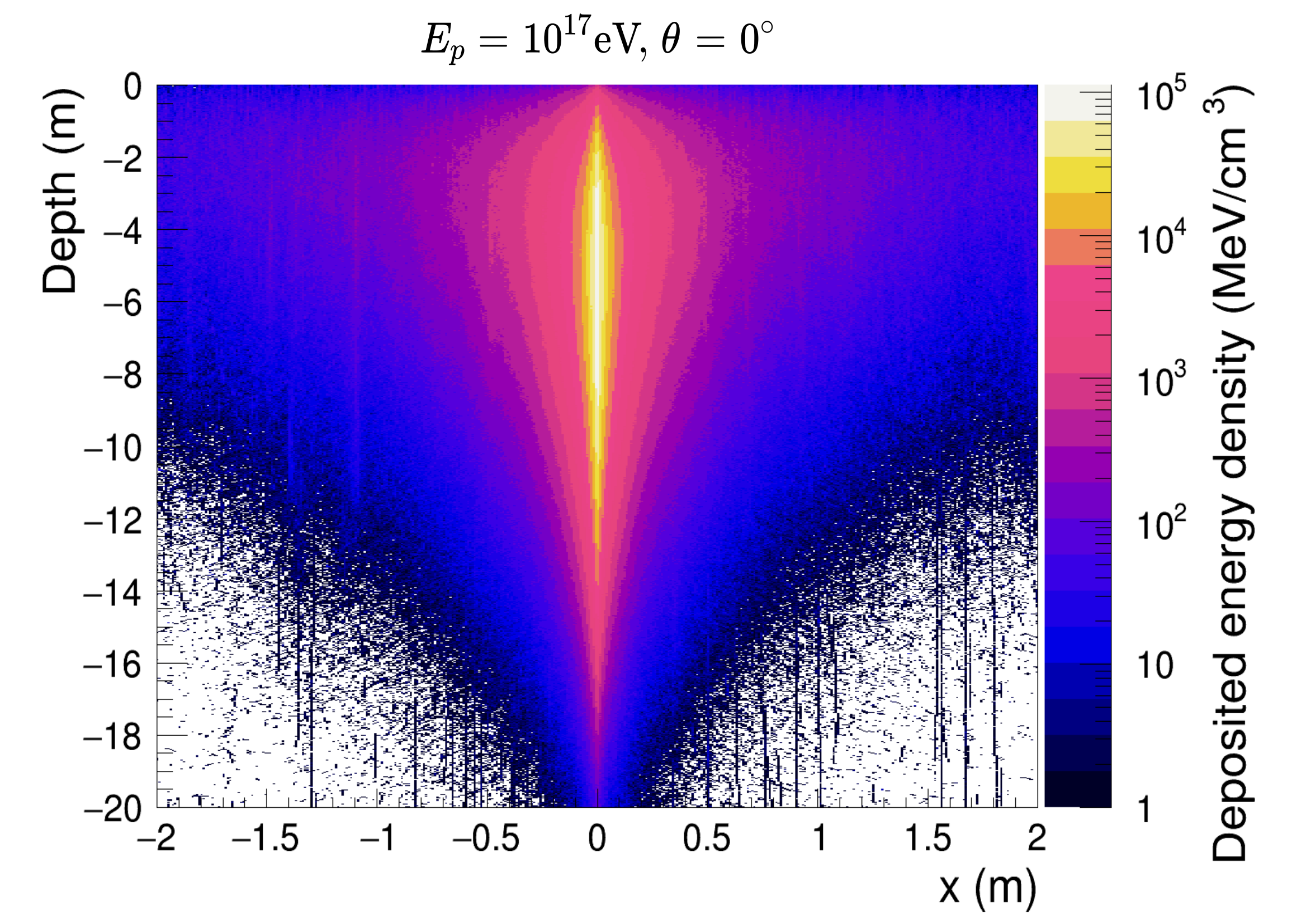
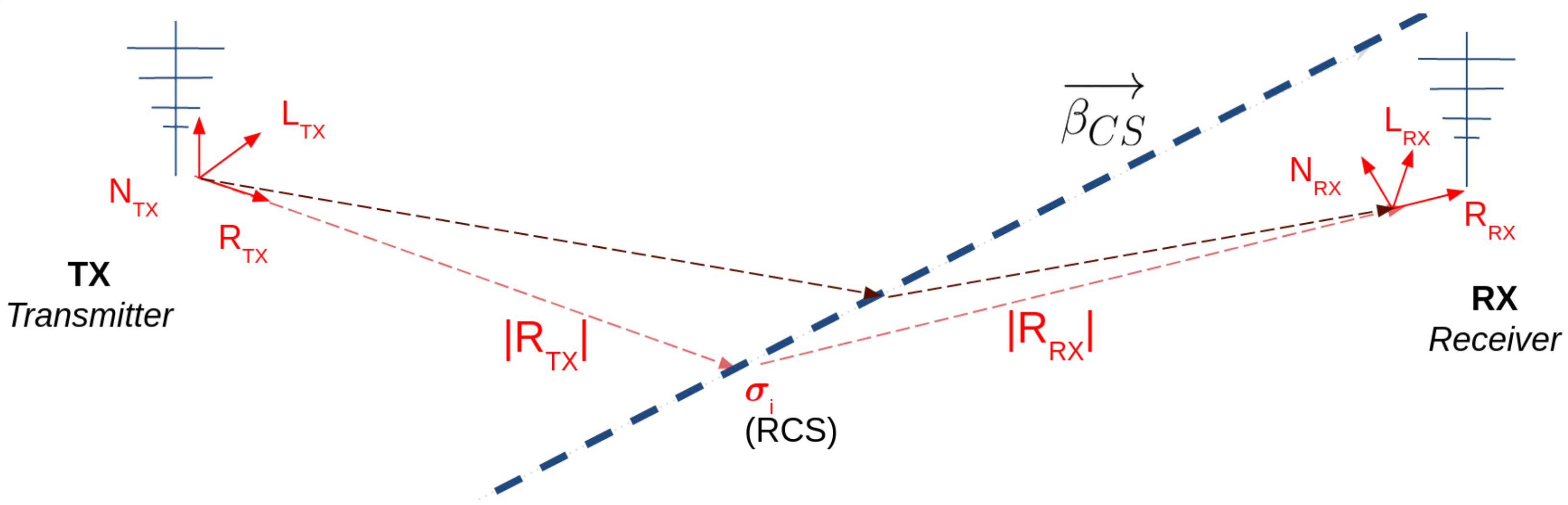
Motivation



- A particle cascade that develops in ice will leave a dense trail of ionised electrons around its core: $n_{e,\,core} = 3.5 \cdot 10^3 E_p\,[\mathrm{GeV}]\,\frac{e^-}{cm^3}$
- The ionised electron plasma should be capable of freely scattering radio waves, making the radar detection of the shower core possible.
- The relativistic propagation of the cascade, the collisional dampening with the ice and the short lifetime - $\tau_e \simeq O(10)$ ns - of the free electrons makes the radar scatter problem not trivial.

The Model: MacroScatter

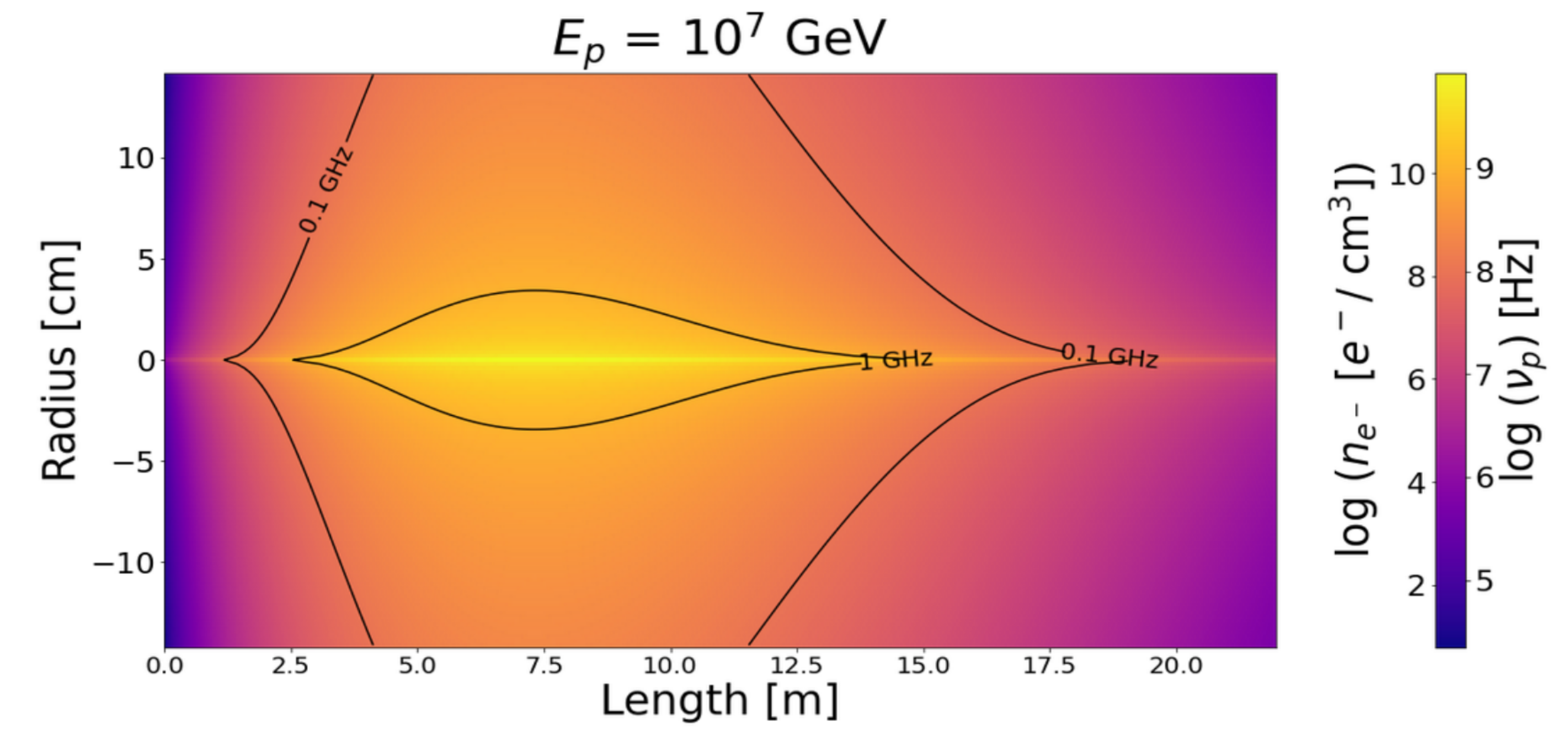
- MacroScatter is a new semi-analytic model that computes the returned power and radar cross section of a bistatic radar scatter from an in-ice particle cascade.
- The elongated shape of the cascade core allows us to model it like a line of deposits of charges. The elements of the line act as independent, coherent scatterers, and the signal at the receiver is the sum of their contibutions.
- The cascade's small, radial dimension is integrated along the line of sight from the transmitter, so each scatterer captures all the relevant physics in its radar cross section.



$$P_{RX} \propto |\vec{E}_{RX}(R,t)|^2 = |\sum_{i=1}^{N} E_{sc,i}(R_i,t) * e^{i(kR_i - \omega t|_{RX} + \psi_i)}|^2$$

The particle cascade

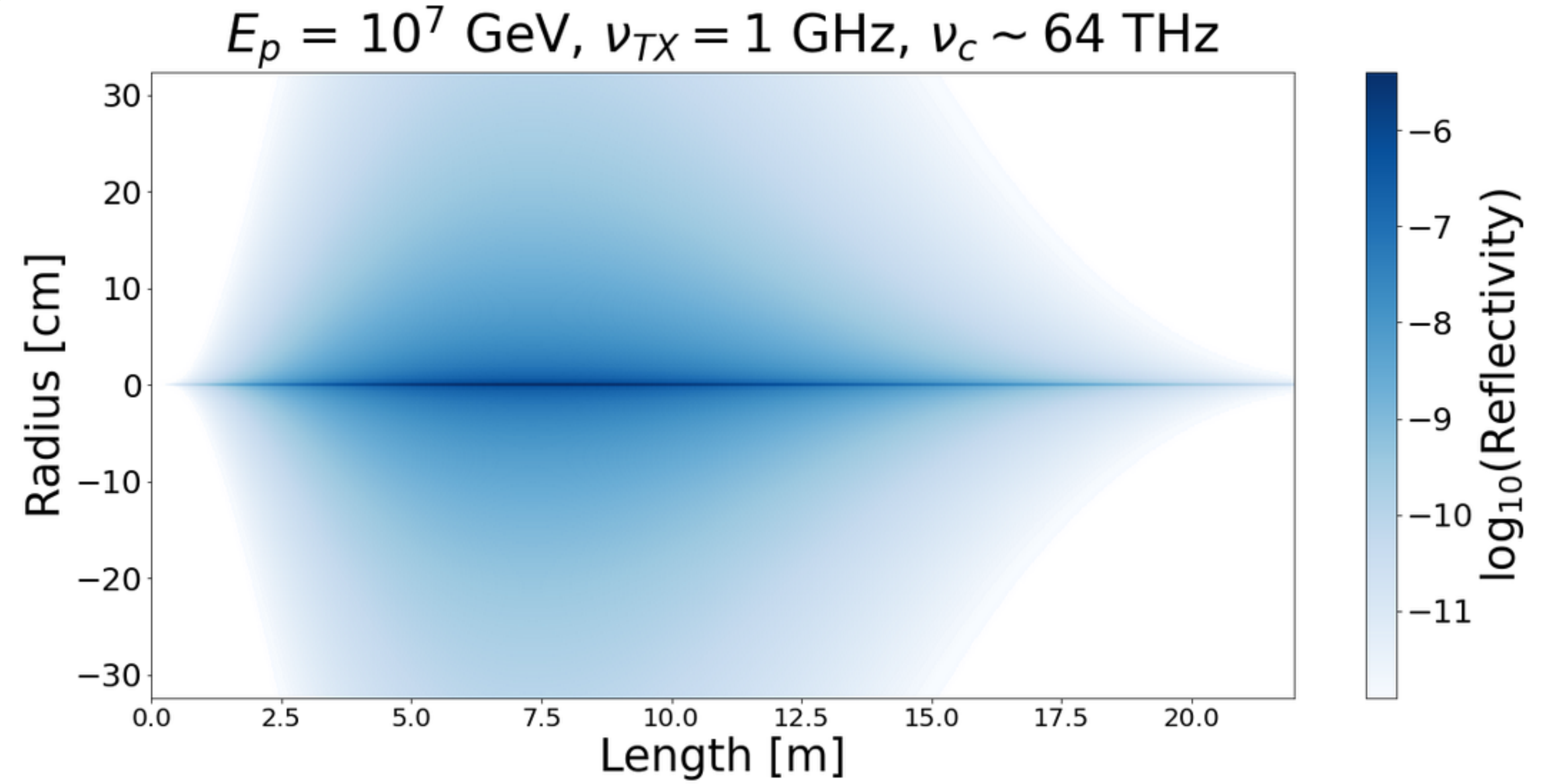
Charge distribution



Using the dispersion relation for cold, collisinal plasmas

- NKG parametrisation, adapted to ice: $$n_e = \frac{1}{V}\int_L N_e(l, E_p)dl \int_R w(r, r_{moliere} = 7\mathrm{cm})dr$$
- Plasma frequency: $\nu_{plasma}\,[Hz] = 8980\sqrt{n_e\,\left[\frac{e^-}{\mathrm{cm}^3}\right]}$
- Reflectivity: $\rho = f(\nu_{TX}, \nu_{plasma}, \nu_{collisions})$

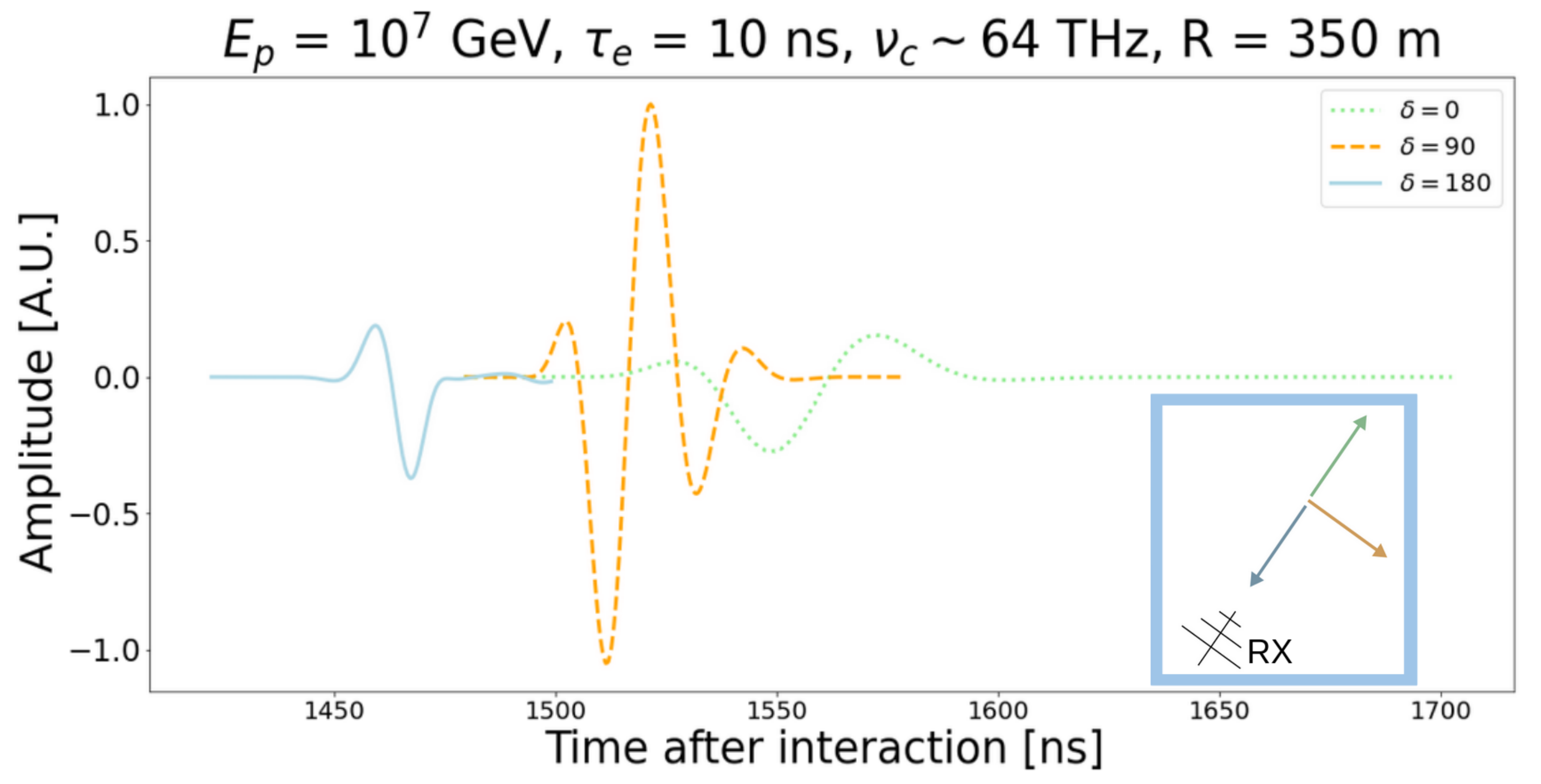
Shower Reflectivity



- Given that $\tau_{collisions} \simeq 10^{-13}\ s = 10^4\ \tau_e$, energy is conserved during the scatter ($P_{reflected} = -P_{absorbed}$). This is consistent with a complete picture of the scatter from the single electron approximation to the coherent scatter of the plasma bulk via the reflectivity.

The Expected Signal

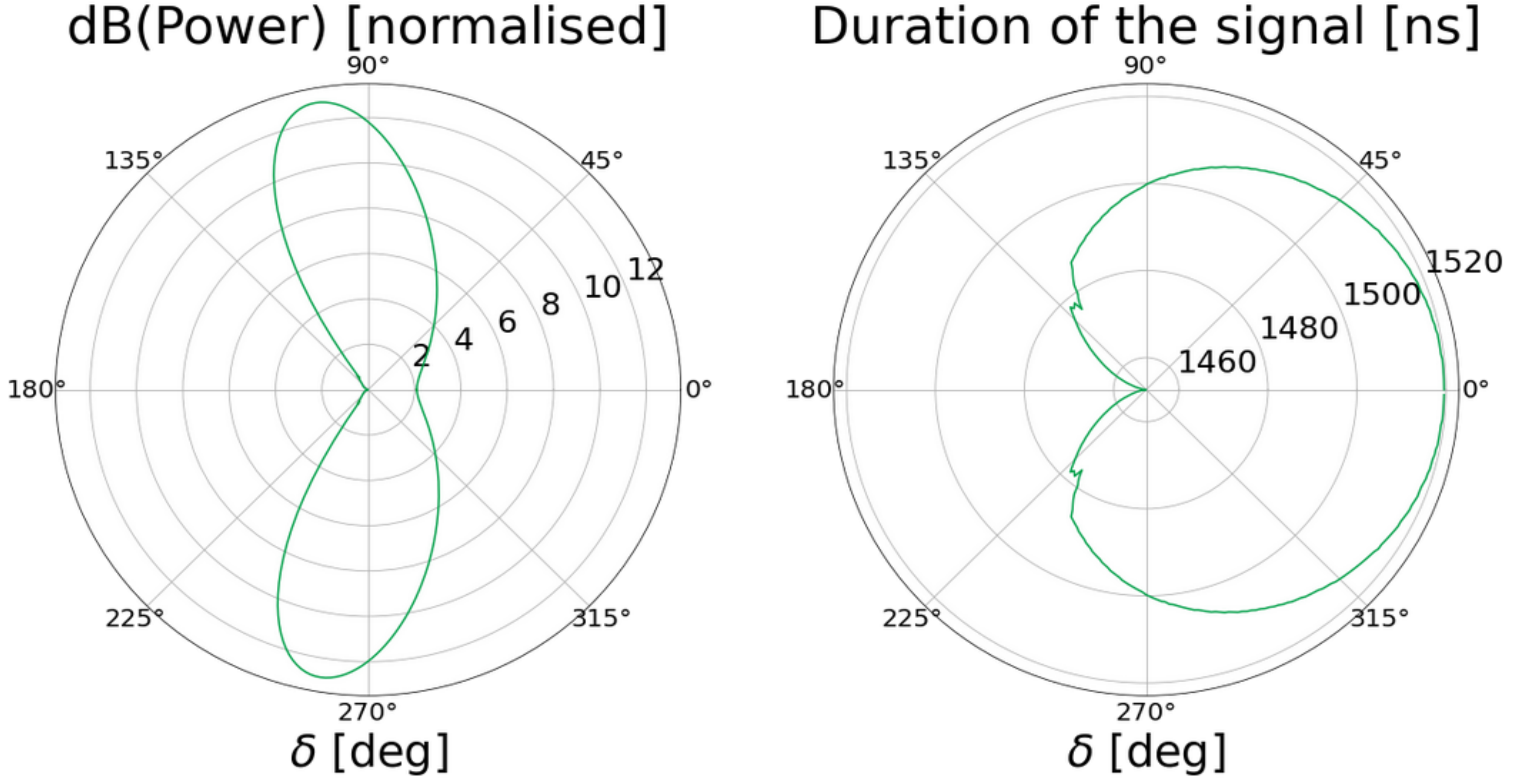
MacroScatter Waveforms



- The properties of the scattered signal depend on the geometry of the scatter. This provides multiple handles with useful information for reconstruction.

Exploring the whole phase space in the plane of the receiver

Global parameters



- We can already notice unique signal modulation effects from the relativistic scatter akin to Cherenkov radiation or Doppler effects.
- A good understanding and modelling of the in-ice radar scatter is required in order to archieve a succesful event reconstruction.