Summit S11/S12 measurements

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1. **S12&S11 set-up and data-taking, S12 results.**
2. **Curtis: S11 data analysis and results coming.**
3. **Possible follow-up for 2026**

June 2, 2025

Science goals:

S11: n(z) from $f_{ant}(z)$; $l = (2m+1)\lambda/2$ gives nodal resonances

1. Can we improve on 2024 n(f1(z)) measurement?
2. Can we extract refractive index profile n(f2(z)) from second resonance?
3. Is $z > -20$ m structure real (if so, what are implications for propagation of Askaryan from in-ice uhecr)?
4. Is -79 $m > z > -84$ m structure real?

S12/S21:

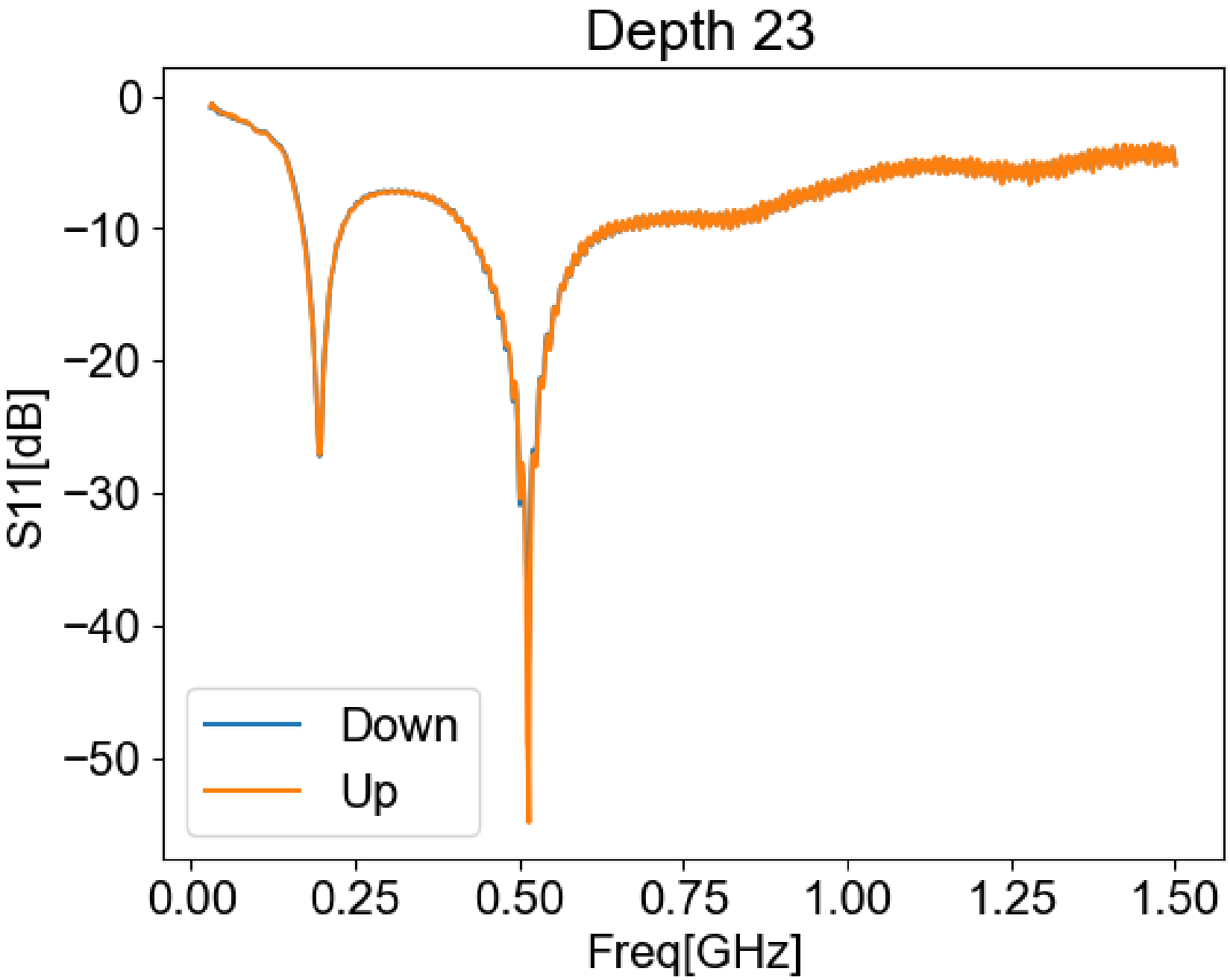
1) how does signal originating in firn propagate (in-ice uhecr)?

2) can we extract n(z) from S12/S21 phase?

3) published SPICE$\rightarrow$ARA data: As signal propagation becomes increasingly horizontal:

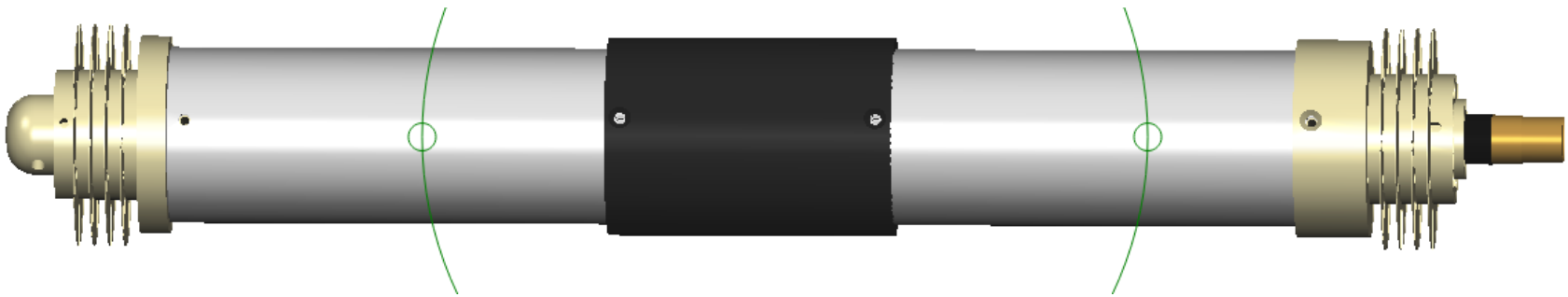
- $A_{HoI} : A_{VPoI} \rightarrow 0.8$
- spectral shift to lower frequencies
- Signals sensitive to small vertical displacements ($\sim$10 cm)
- Oddities in surface pulsing (Matthew's analysis)

⇓ v. ⇑: Clear elucidation of f2 (Curtis, next week)



Systematic Concerns

- bends in coaxial cable?
- VNA droop @-25 C?
- At throat of Saltzman hole, d=21 cm; unknown depth at which d=9.7 cm?
- Effects of multiple connectors? (should be calibrated out, but...)
- Snow accumulation in centralizer brushes with time?



Top of hole

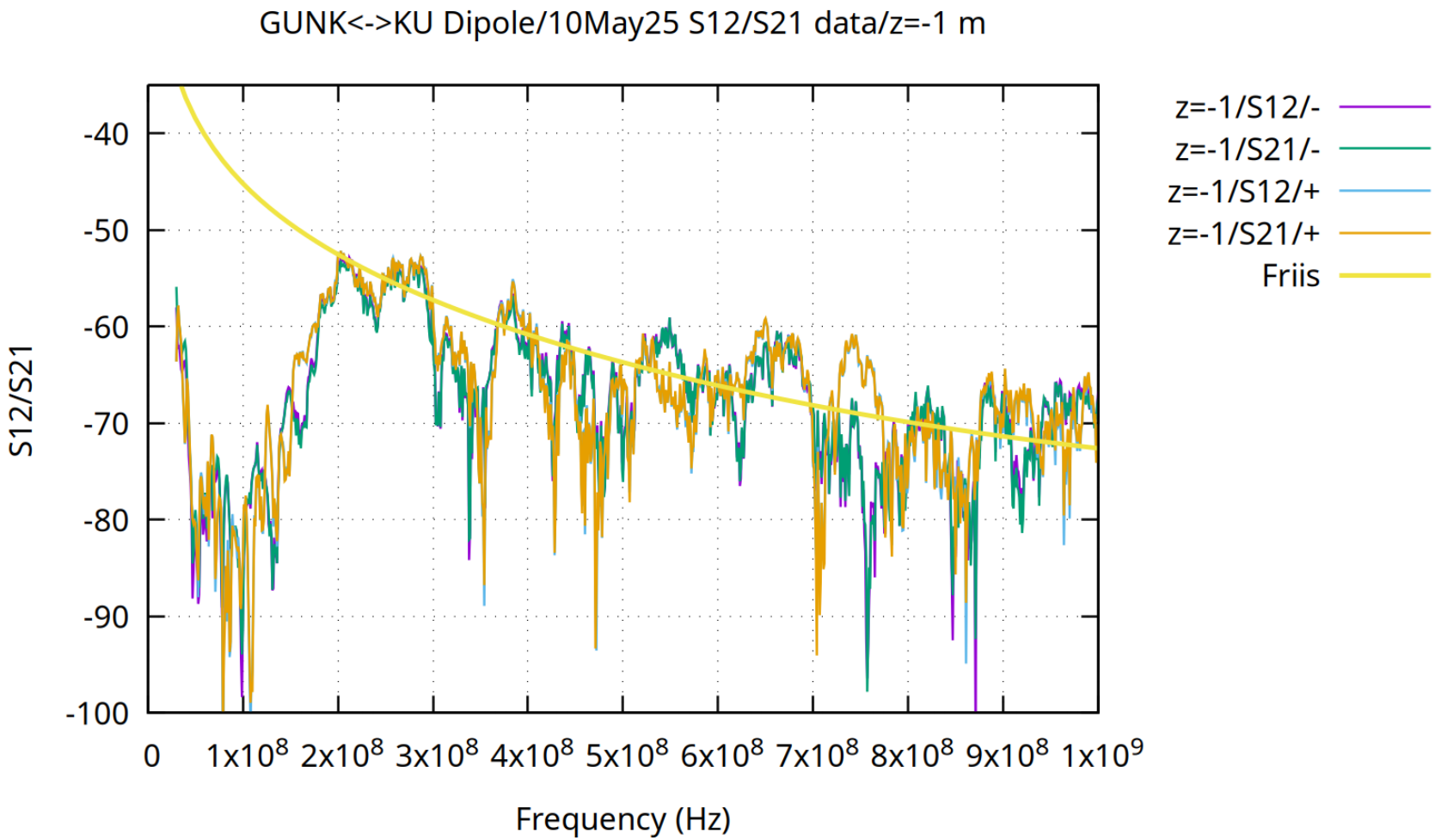
Parameters of S12/S21 Data-taking

- FieldFox VNA port 1→30 m LMR-600→GUNK dipole antenna→Saltzman hole
- FieldFox VNA port 2→80 m LMR-600→KU dipole antenna→DISC
- (unfortunately, second KU dipole confiscated at KCI airport)
  - N9913B 'standard operating range' -10→55 C; our operation at -31 C (-45 C wind chill);
  - cloth sleeve (modified gaitor) + hand-warmers to warm unit
  - Cable was marked with tape at 1 meter intervals; depths are approximate (probably to 10 cm)
  - Measurements taken both ↓ and ↑ for consistency check

NB: 1. VNA sweeps S12, then S21; as we were hand-holding (lifting/lowering) antennas, not entirely stationary.
2. DISC data thru casing
3. S11 & S22 data to check S12/S21 measurements
4. My recollection: VNA@P_{max} (9 dBm)/MM: lower P_{out}

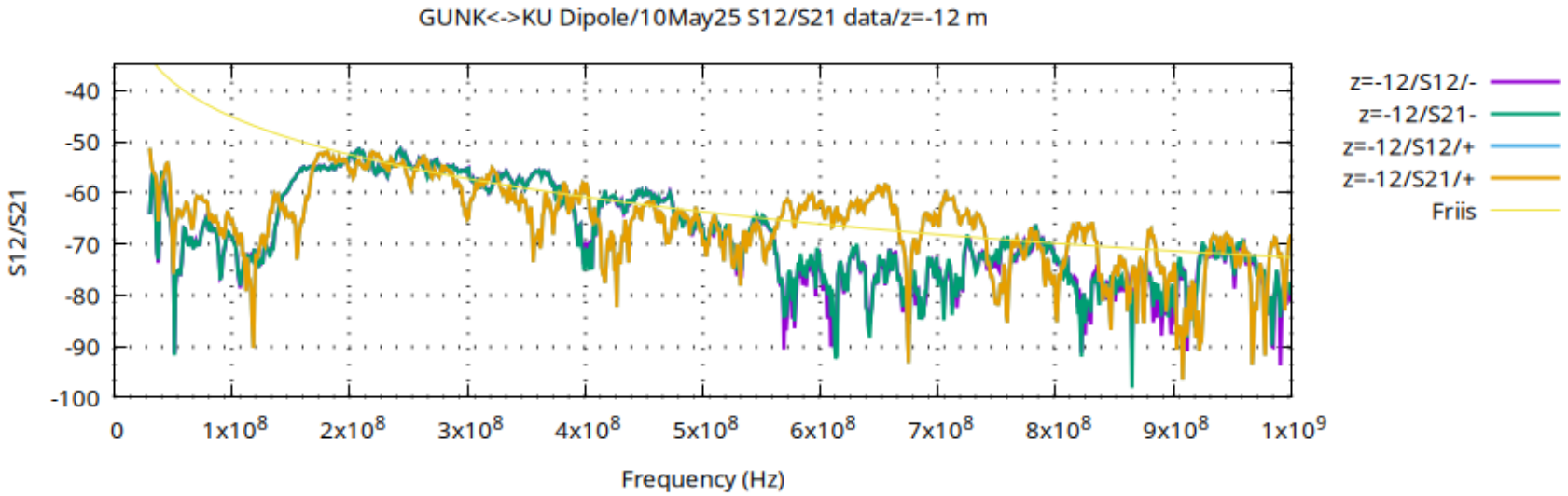
z=-1 m (shadow zone): S12/S21 Data

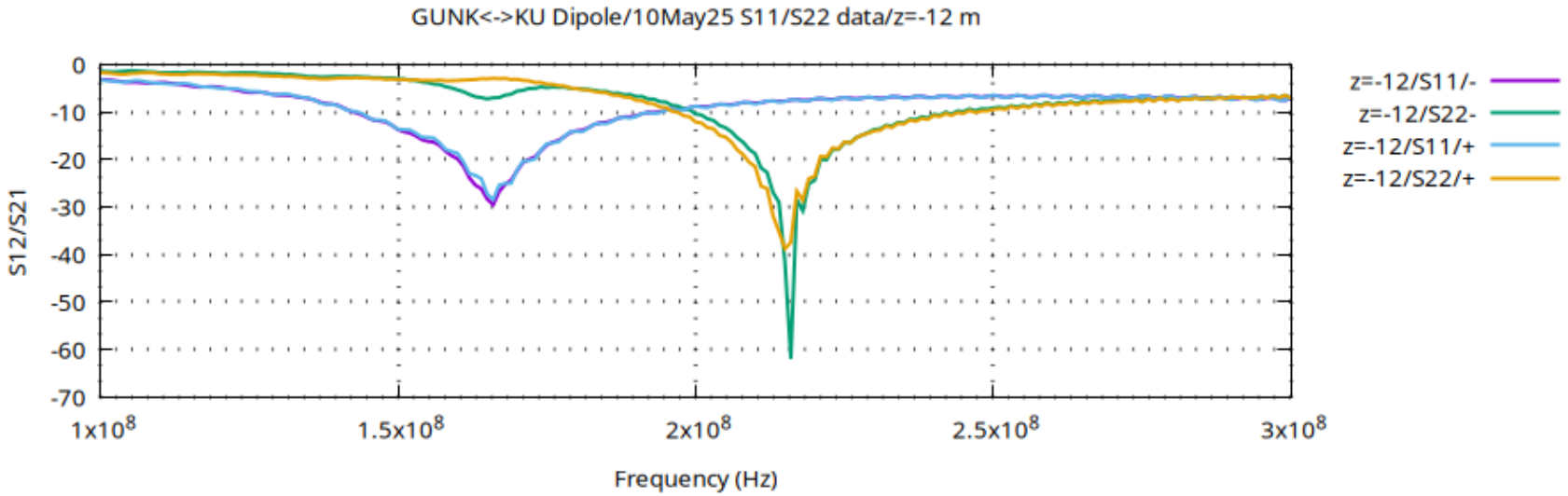
Good msrmnt: S12==S21 && ↑=↓ (within depth errors)
shadowed, but agrees with Friis??



z=-12 m (unshadowed)

Slight offset (<10 cm) in vertical location of GUNK (↑ v. ↓), based on S22

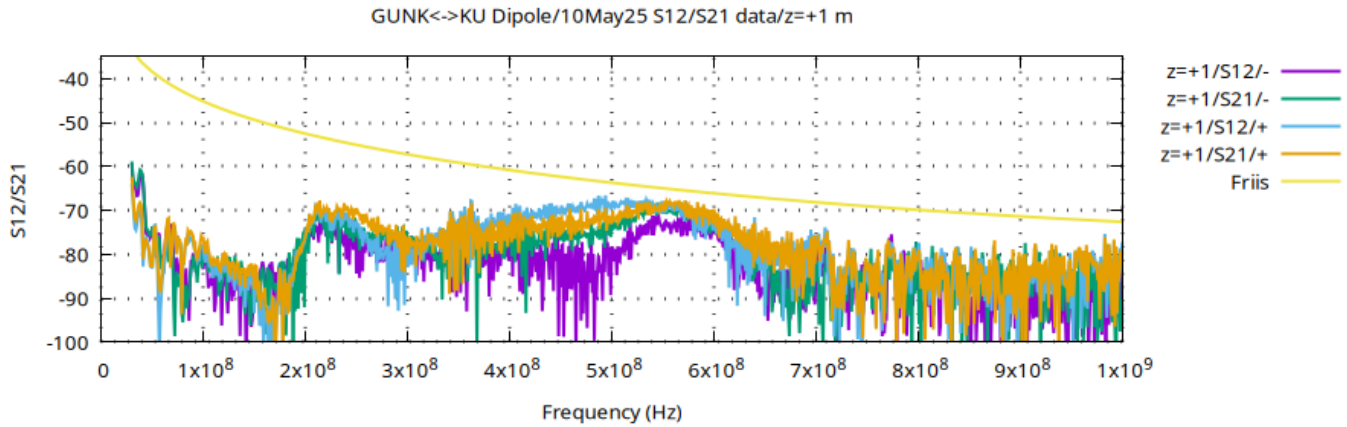


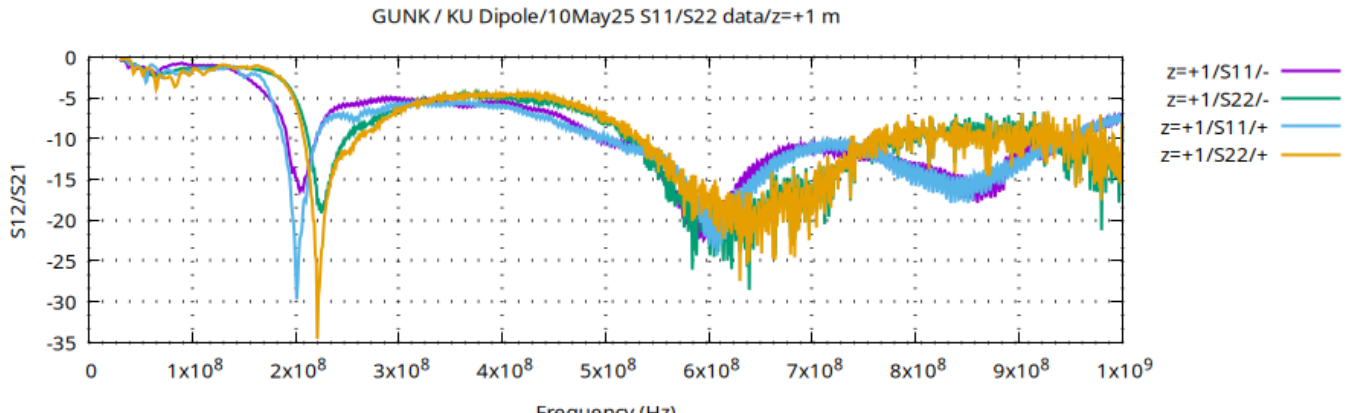


z=+1 m

1. Signal power 100-300 MHz suppressed relative to other traces
2. Only trace to show strong ripples (df$\sim$2.5 MHz)

Lowest S12 of all traces$\Rightarrow$destructive interference b/w D/R?, BUT not observed for z=-1 m, nor 8/21 LPDA surface S12 (phase shift across Fresnel zone should suppress interference due to surface inversion)



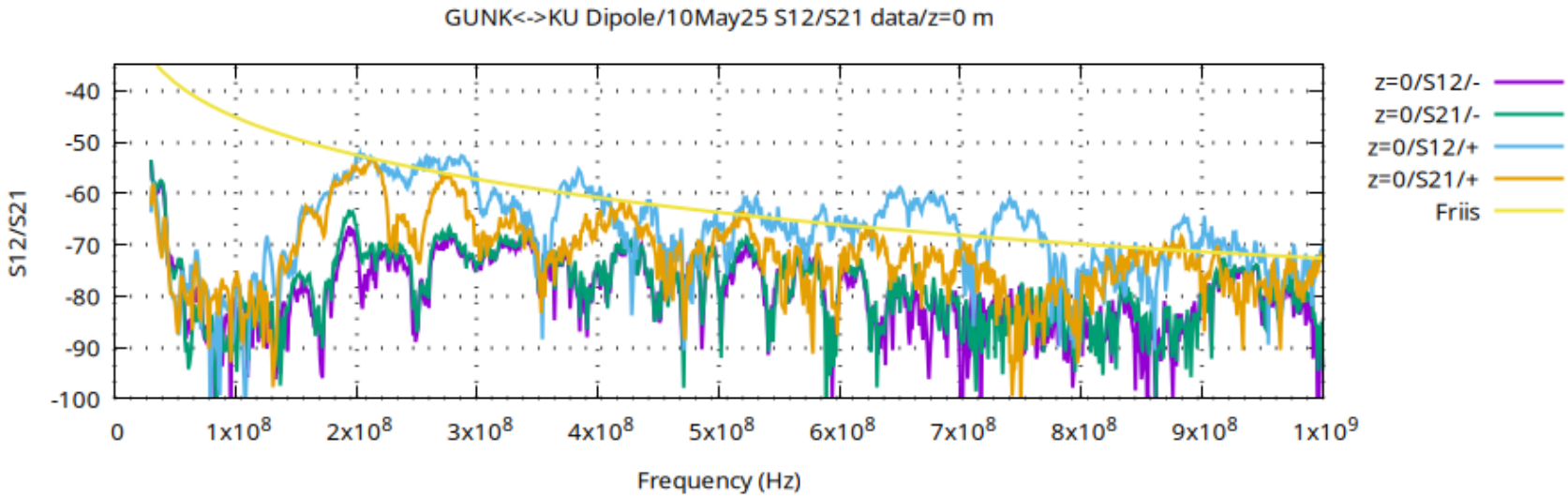


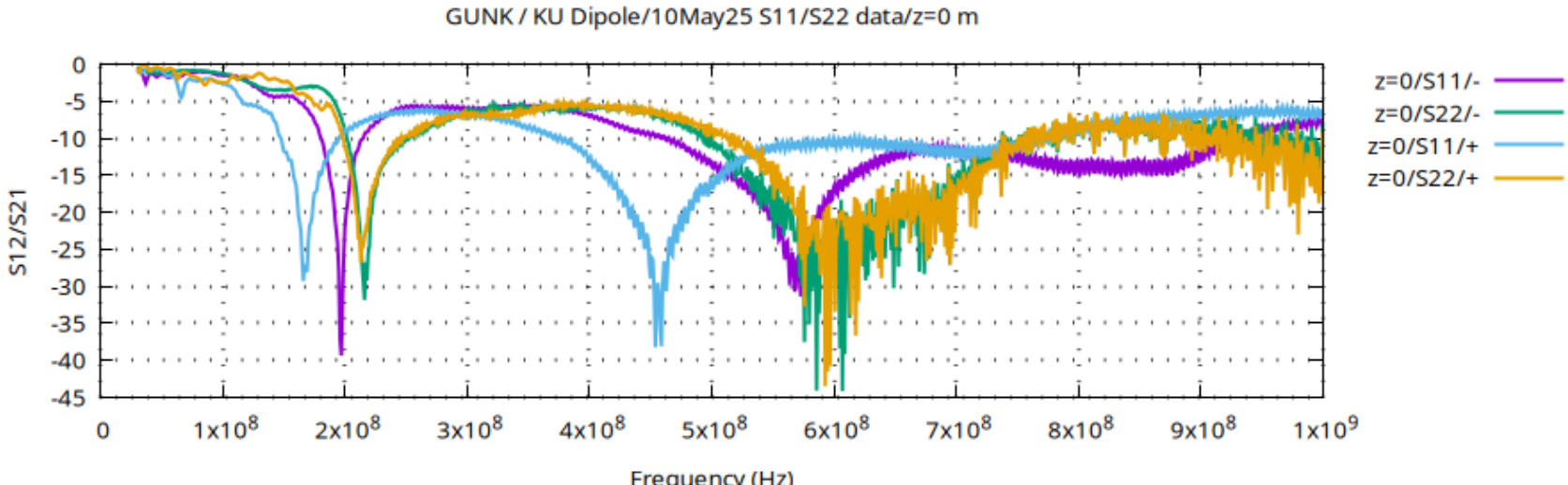
z=0 m: ↑∼15 dB >↓; S21↑ loses power beyond 200 MHz

(Only sweep with such a large difference b/w ↑ / ↓)

No clear indication of surface wave propagation (E(r)∝1/r)

From S11⇒clear offset b/w ↑/↓ vertical positioning

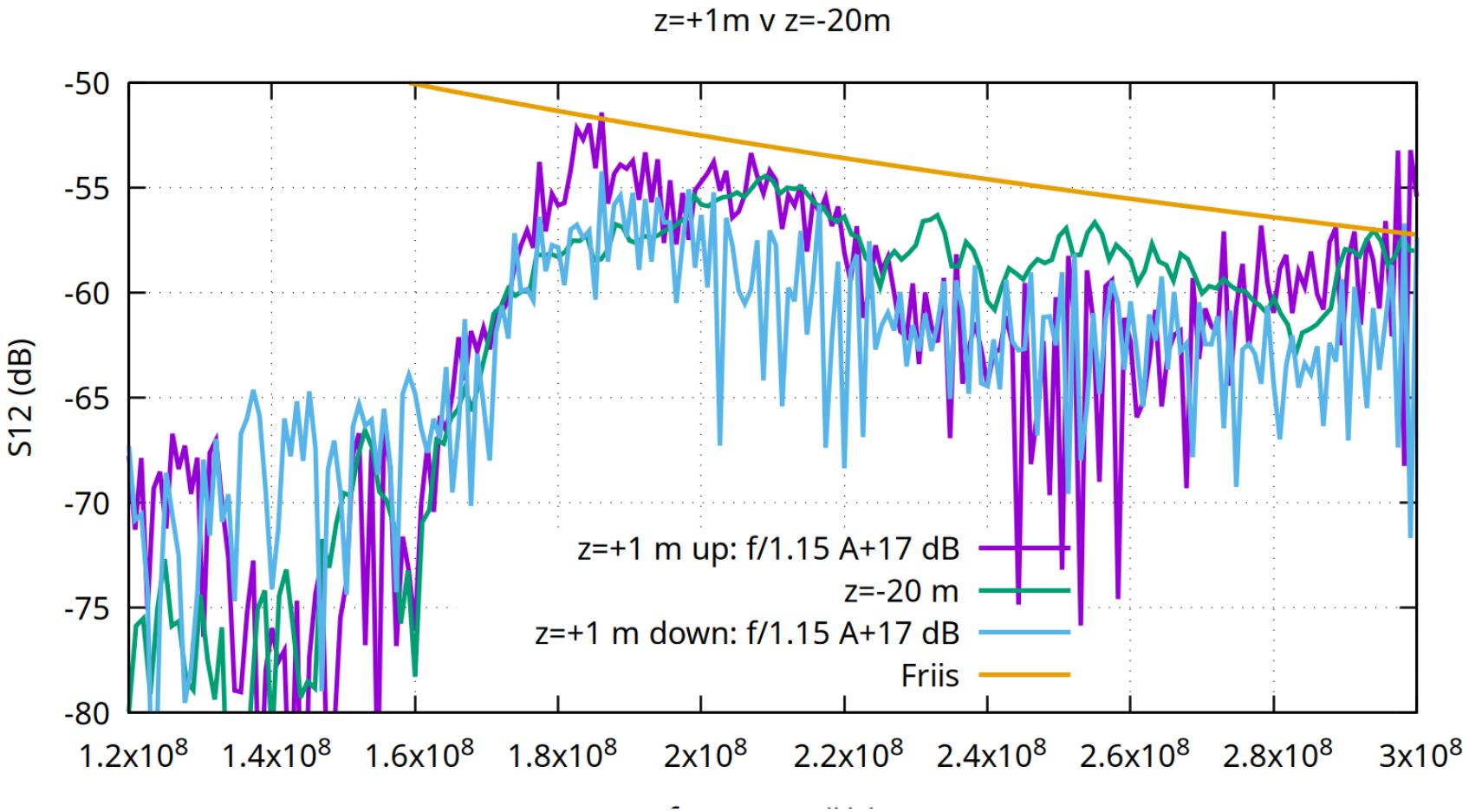




$z < -11$m: S12=S21, BUT $\downarrow \neq \uparrow$

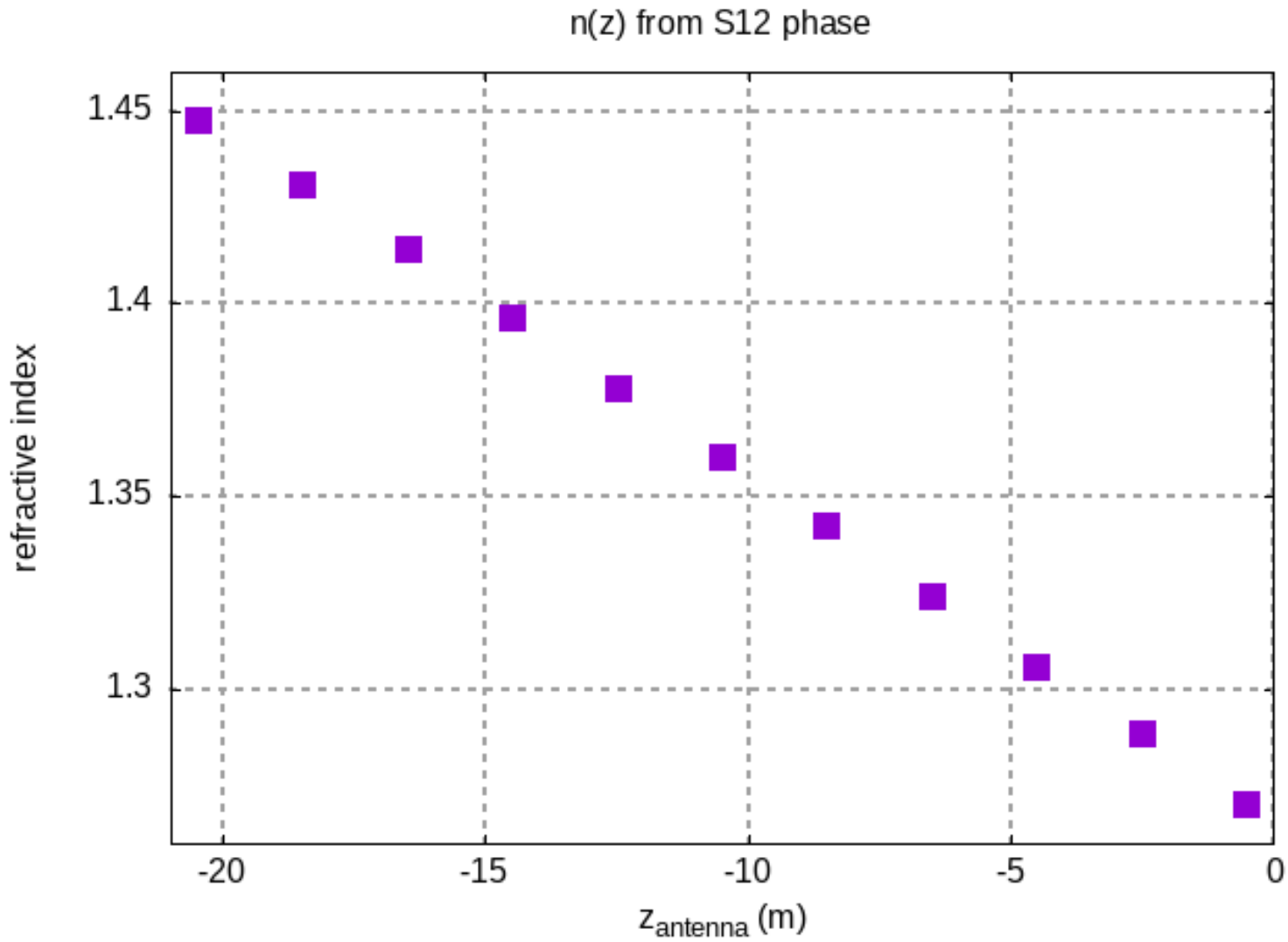
- variation b/w $\uparrow\downarrow \sim$ 5 dB
- In such cases, $S12_{\downarrow} > S12_{\uparrow}$
- Two interpretations:
  - VNA was beginning to fail at low temperature, but:
    - did not see this on bench
    - If so, then shape of $\uparrow$=shape of $\downarrow$ (not obviously the case)
  - differences of a few cm can significantly impact horizontal propagation through the firn
  - If this is a Huygens effect, then shapes should diverge more at higher frequencies (studying now)
  - (aside: observed that meter-scale depth differences significantly impacted RICE shadow zone propagation)

z=+1 m v z=-20 m: Check migration of S11(n)



n(z) from S12 phase?

Map $\Delta\phi$ to Δn, BUT need to select m(2π) wrap-around!

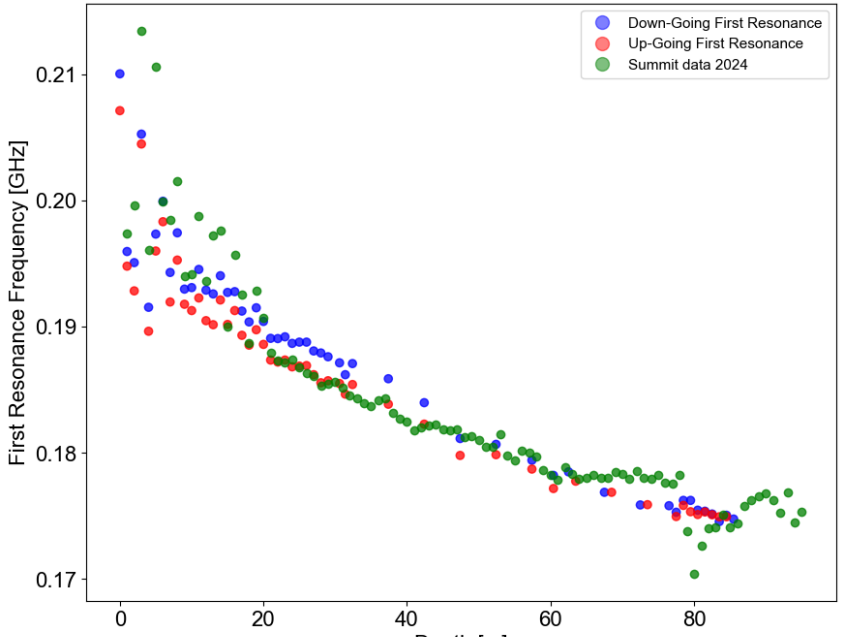


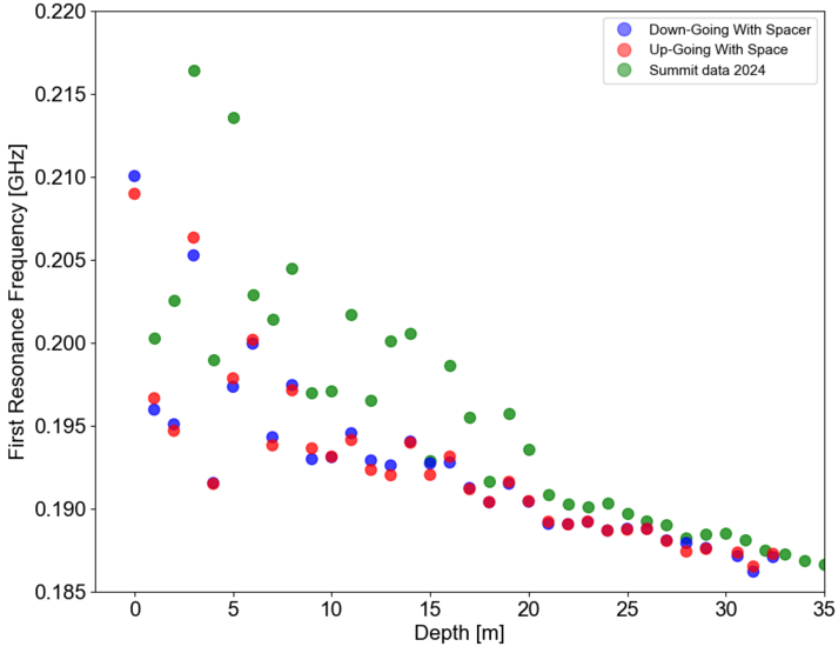
Comments and Future Work

- In S12/S21 measurements, no evident shadow zone transition (maybe not surprising, since L_{α}^{shadow} $\sim$500 m)
- $\Rightarrow$Should be in-ice CR signals emanating from shadow zone, with larger geometric aperture than non-shadowed!
- 2026+ S12/S21 work: 3$\times$20-30 m deep holes w/ Kovacs drill (Eric has one + one currently at KU)
  - Set VNA max points (1600), limit BW 150-500 MHz to better map out $\phi(S12/S21)$ $\Rightarrow$n(z) from phase only!
    - Over-constrained system, since large # frequencies
  - Current data too sparse to unwrap ϕ
  - Take data in firn with finer step size (20 cm?)
  - Working at higher outside temperature
  - In addition to co-lower, explore range of elevation angles.
- Store $Re(Z)$ and $Im(Z)$ rather than $\mathcal{R}$

IMHO, still need rno-g SPICE-like pulsing; GISP-2? 2026: return to DISC (to be re-cased in July), and try to (finally) scope hole

top: Raw data/bottom: zoom shallow





2024 v 2025 parameters of S11 data-taking

	2024	2025
N_{avg}	1	16
cable	120-m LMR-400	30-m LMR-600
		+ 2×30-m LDF4-50A
drop	GV530	lower by hand
σ_z	1 cm	10 cm
P_{out}	-15 dBm	0 dBm
T	-8 C	-25 C
Sweep	0→1 GHz	0→1 GHz
z_{min}	-100 m	-85.5 m
runs	no spacers	run A/B w/o and with spacers
data	drop→100 m/dz++→0 m	A: dz-1→z=-25 m; &↑
		B: dz-1→-32 m; dz-5 m→-77 m
		dz-77→-85.5 m; &↑