

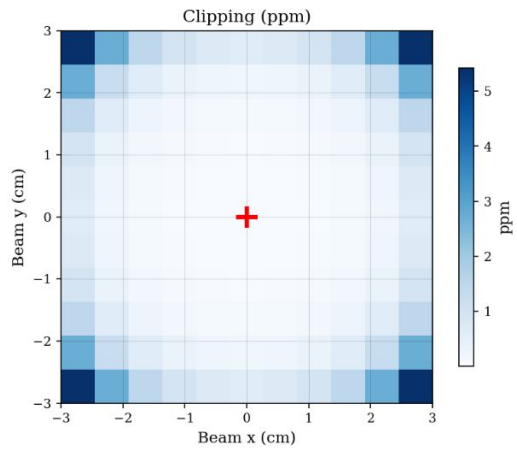
# Update

## Beam Position Optimization Algorithm

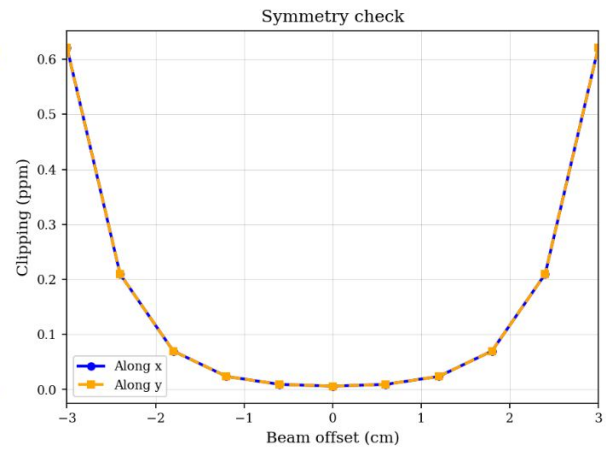
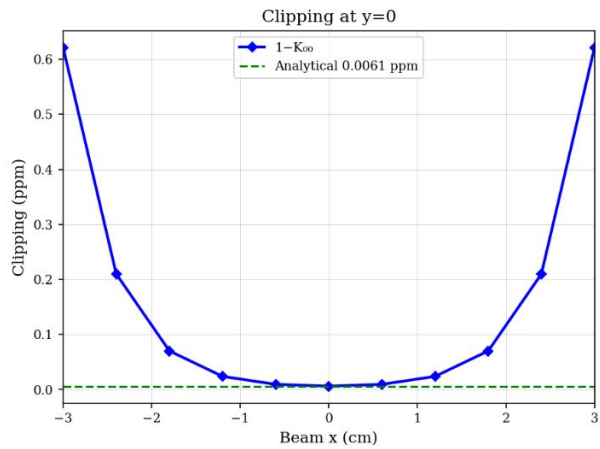
04/16/2024

(Happy National High 5 day)





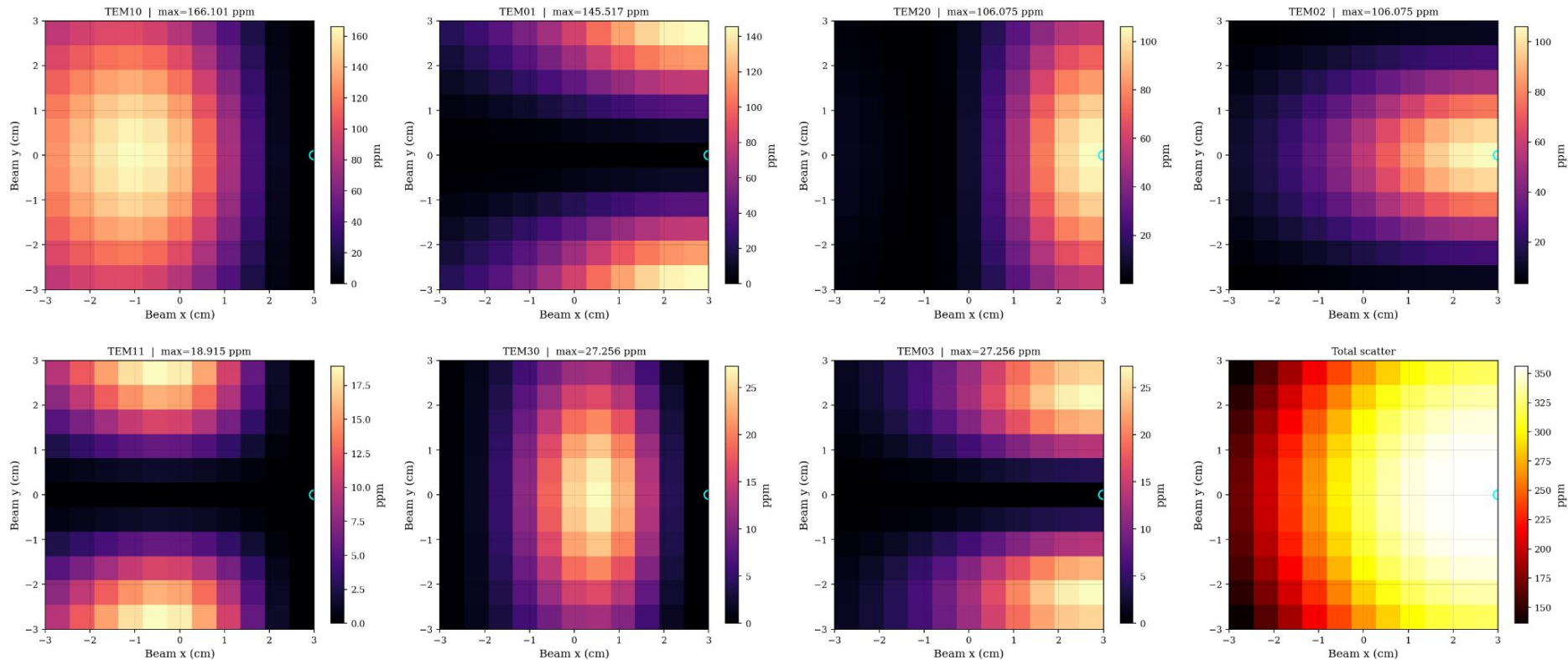
## STEP 1a: Single-Bounce Clipping [1 - K<sub>∞</sub>]





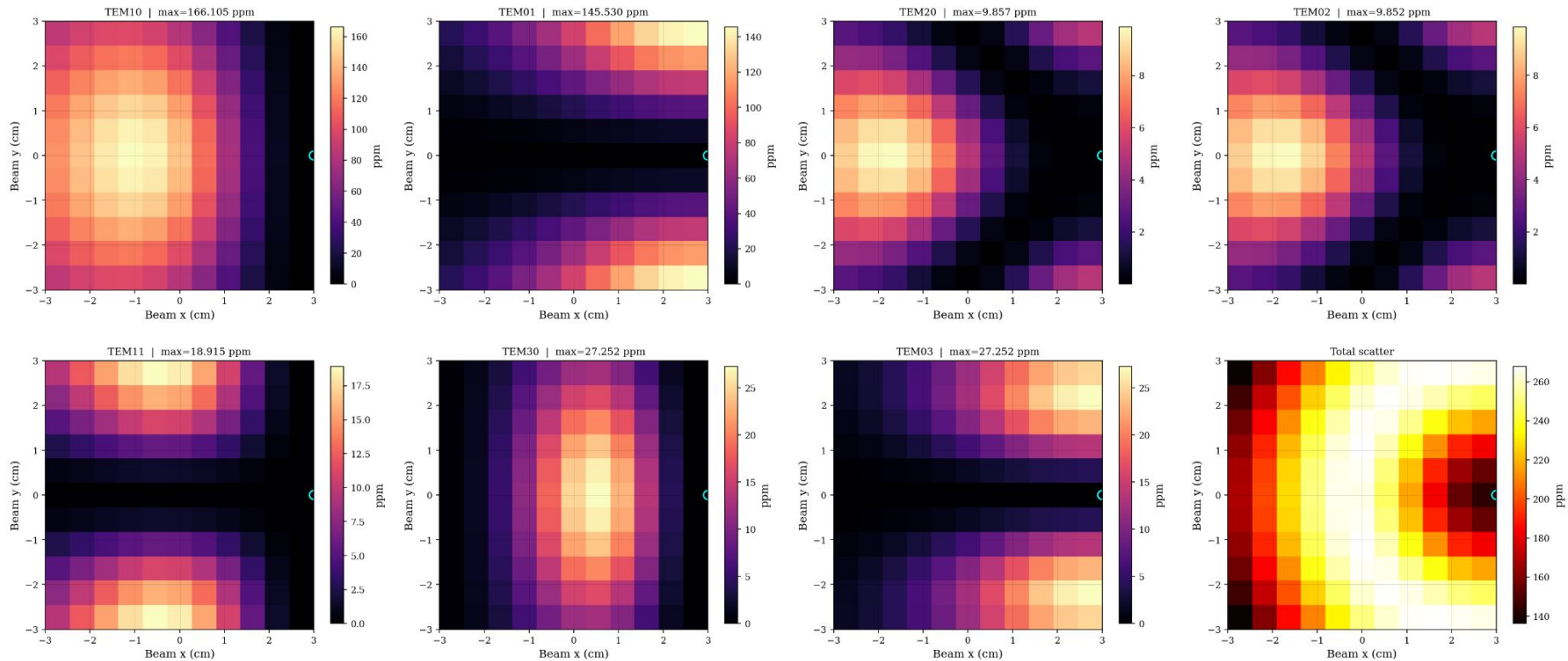
TEM10 max = 166 ppm, TEM20 = 106 ppm → huge losses; total ~350 ppm

Per-Mode Scatter Heat Maps — No TCS



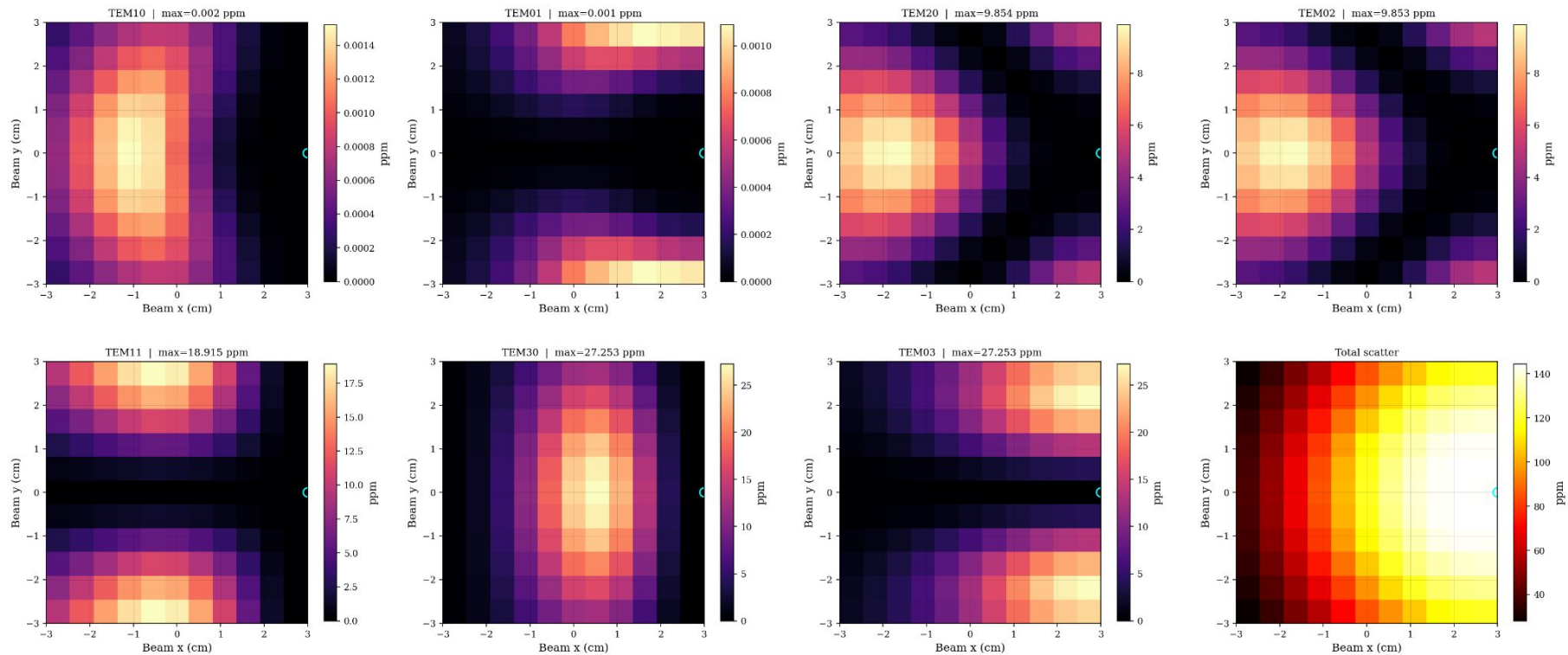
TEM20 drops from 106 → 9.9 ppm; TEM10 unchanged; total ~260 ppm

Per-Mode Scatter Heat Maps — Ring Heater



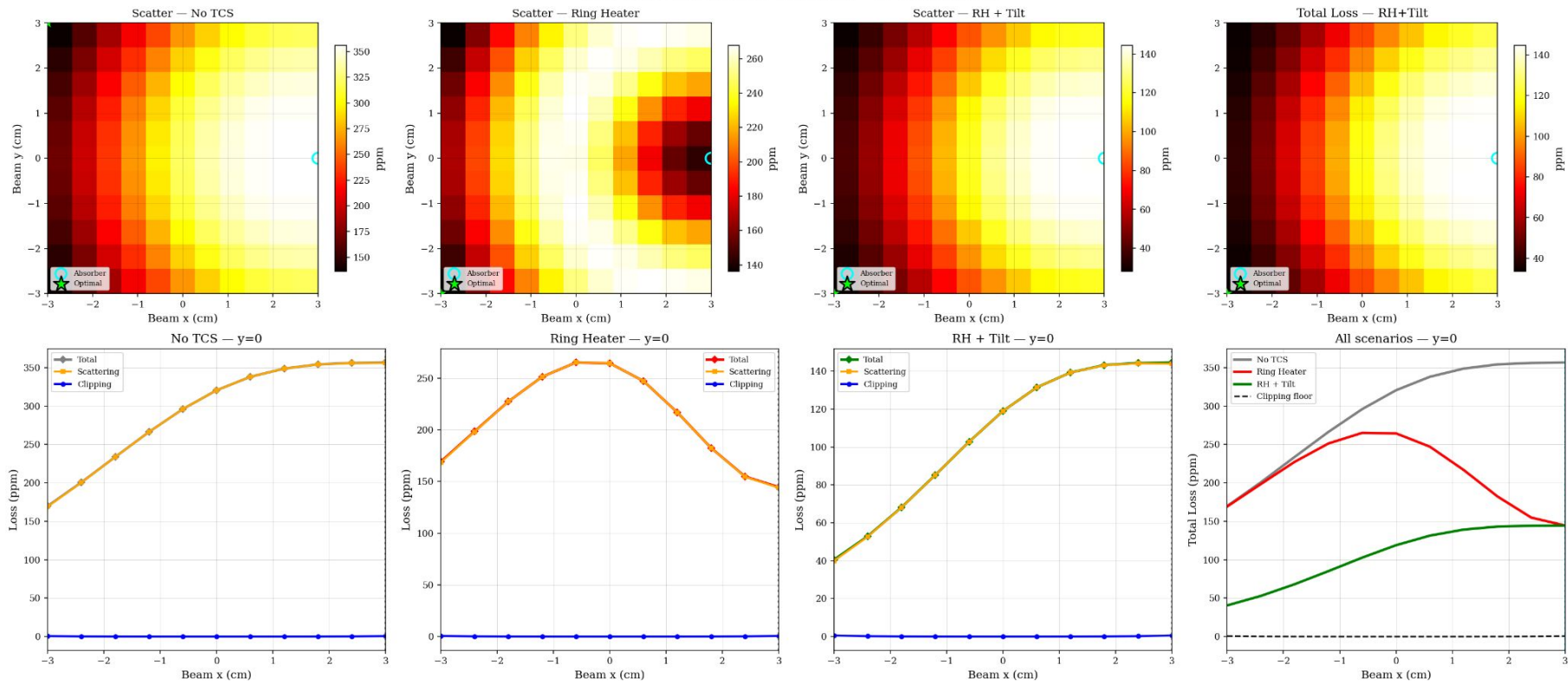
TEM10 drops to 0.002 ppm, TEM20 still ~9.9 ppm; total drops to ~140 ppm

Per-Mode Scatter Heat Maps — RH + Tilt



TCS improvement map shows RH+Tilt saves ~20–60 ppm/bounce over most of the mirror

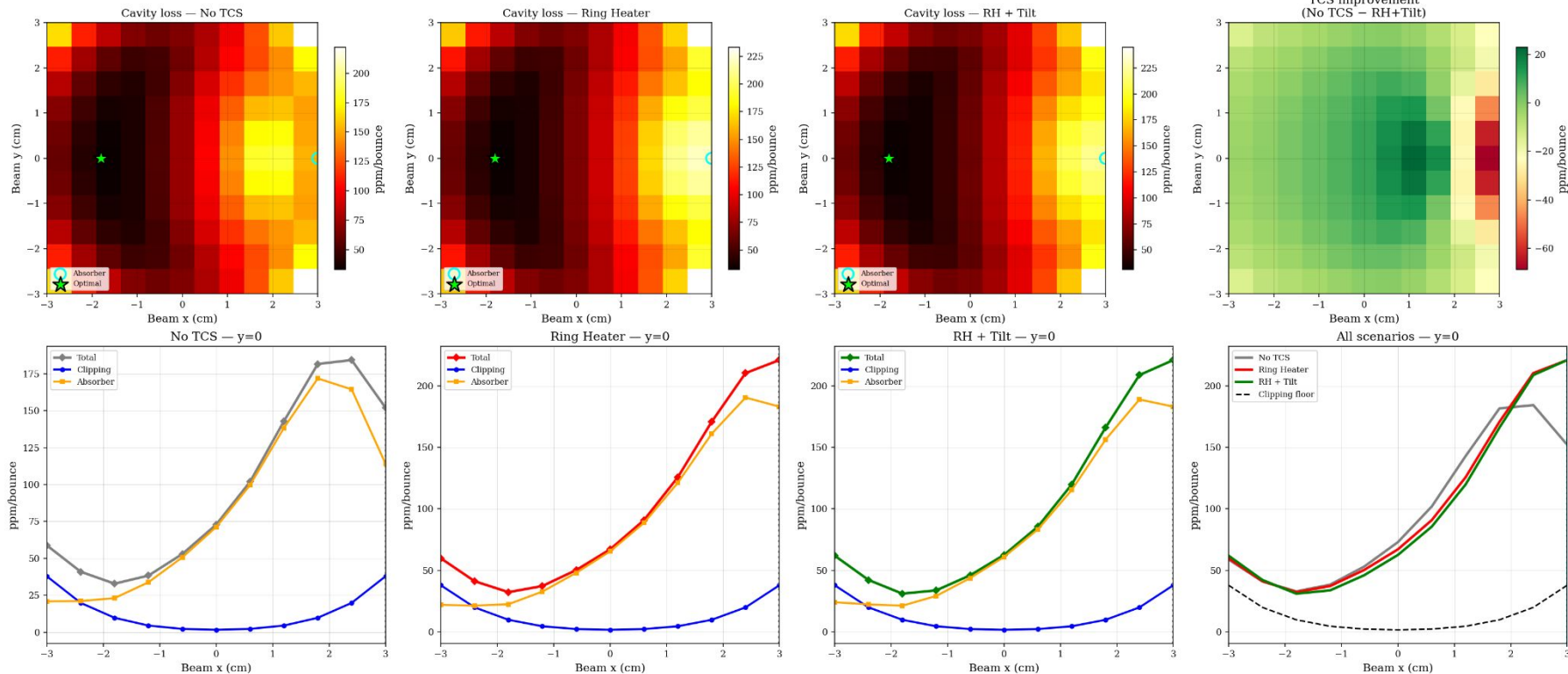
### STEP 1b/c: Single-Bounce Scattering — all TCS scenarios



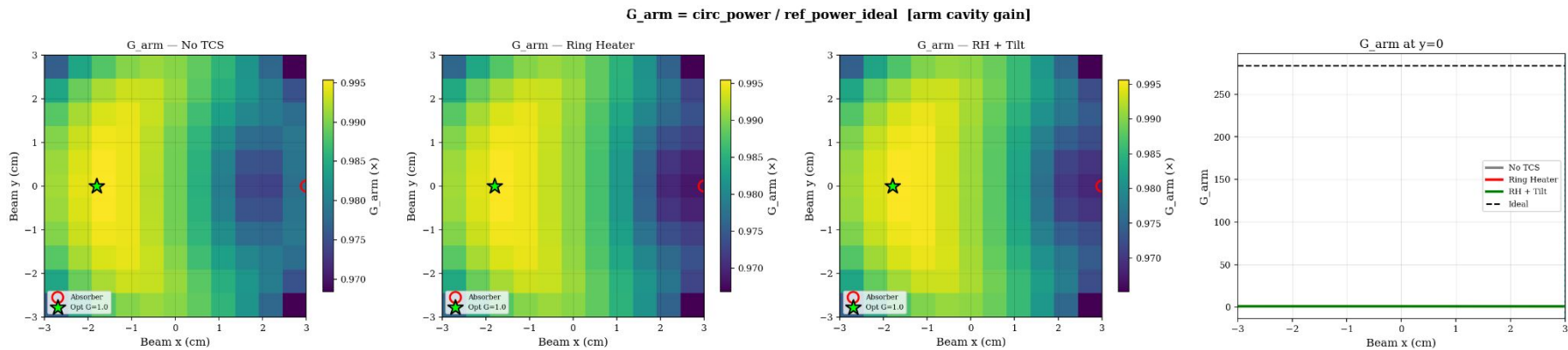
The **arm cavity optical gain** for each beam position is  $G_{\text{arm}} = \text{circ\_power} / \text{ref\_power\_ideal}$ , where ref computed with no surface map, no aperture.

Maximizing  $G_{\text{arm}}$  is equivalent to minimizing loss : maximize(circ, [ETM.phi]) # find resonance

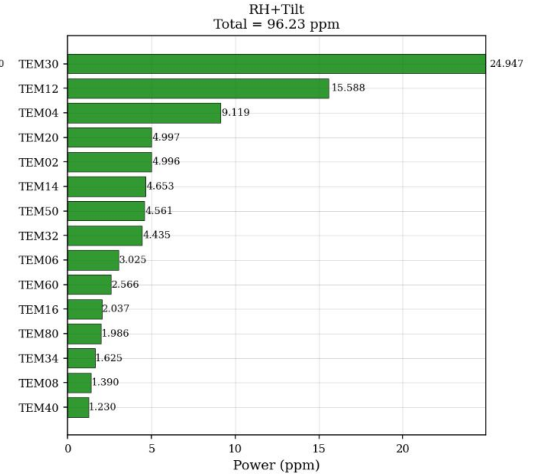
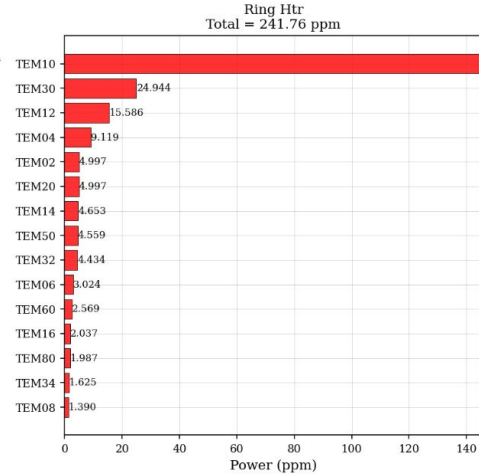
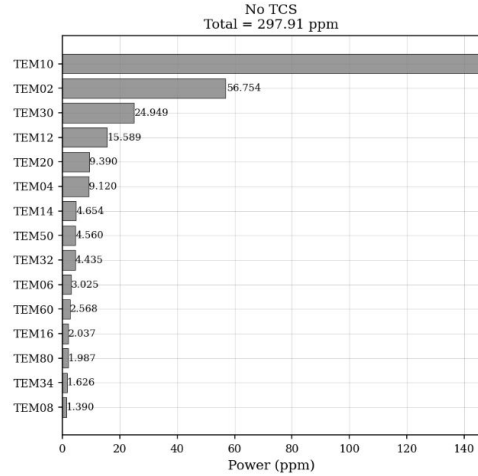
### STEP 2: Cavity Loss (maxtem=10) — per-bounce



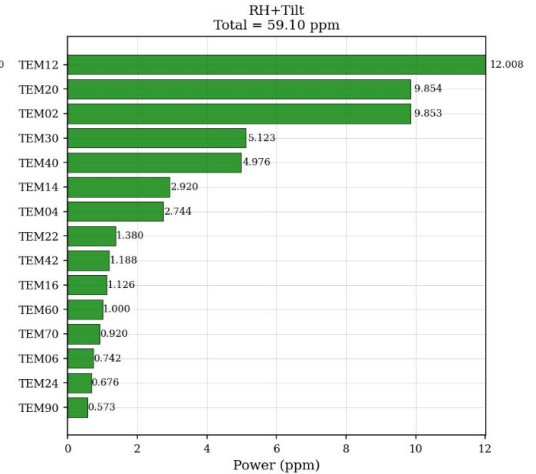
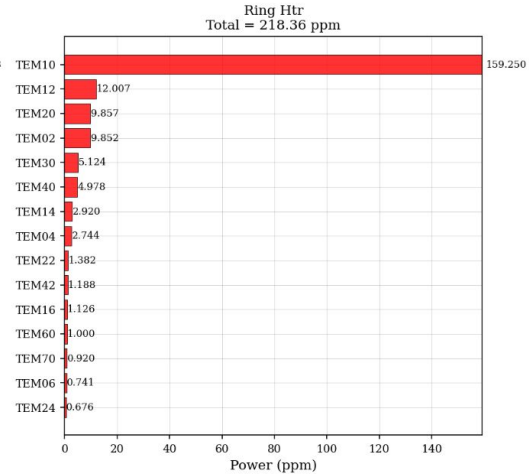
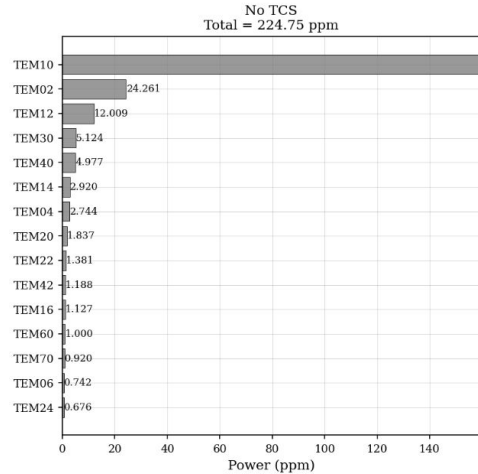
The 4th panel ( $G_{\text{arm}}$  at  $y=0$  line plot) shows all three TCS scenarios collapse near  $G_{\text{arm}} \sim 0$  in the linear scale — meaning they're all close to ideal but with small differences only visible in the heat maps

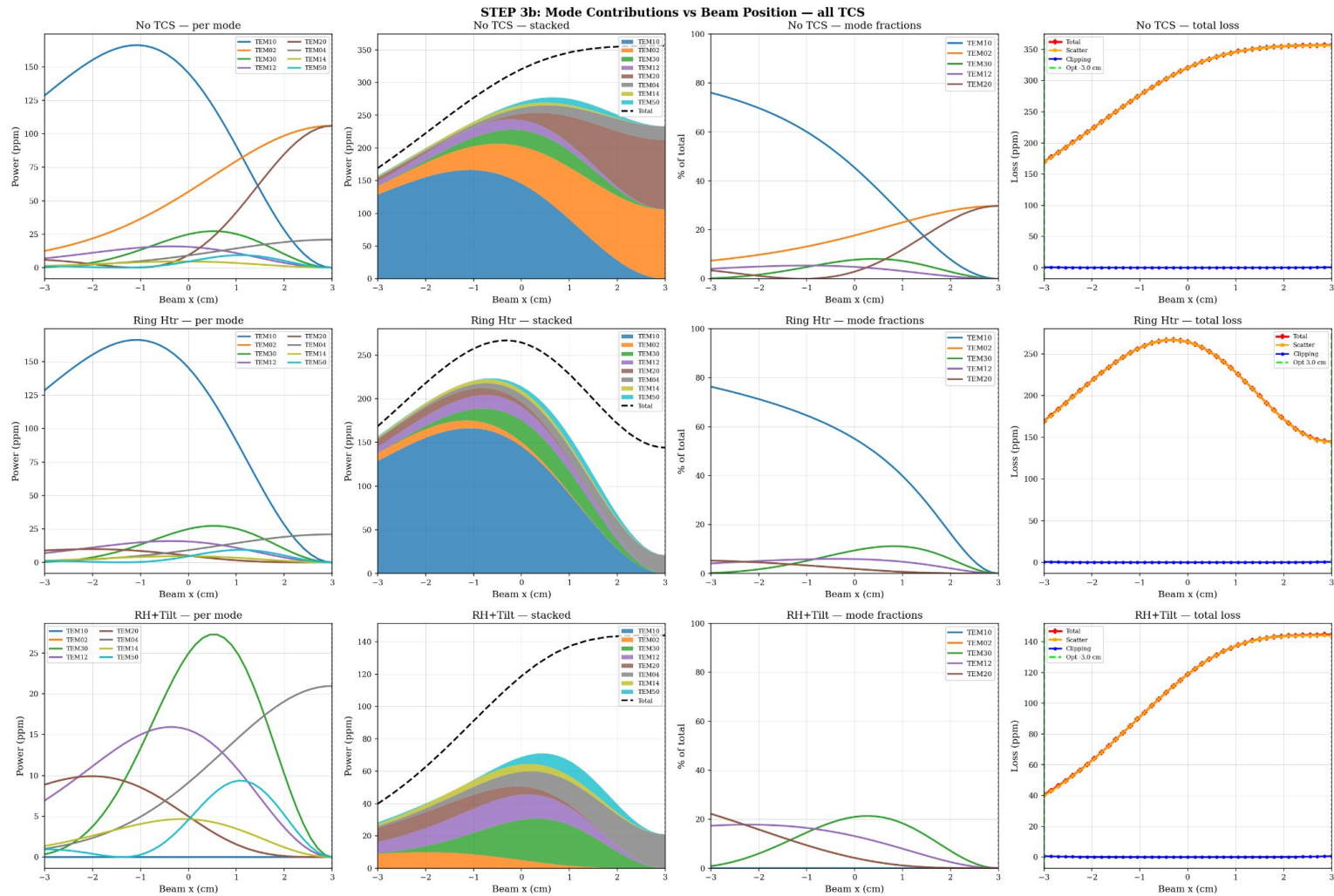


### HOM Decomposition — Centered (0,0)



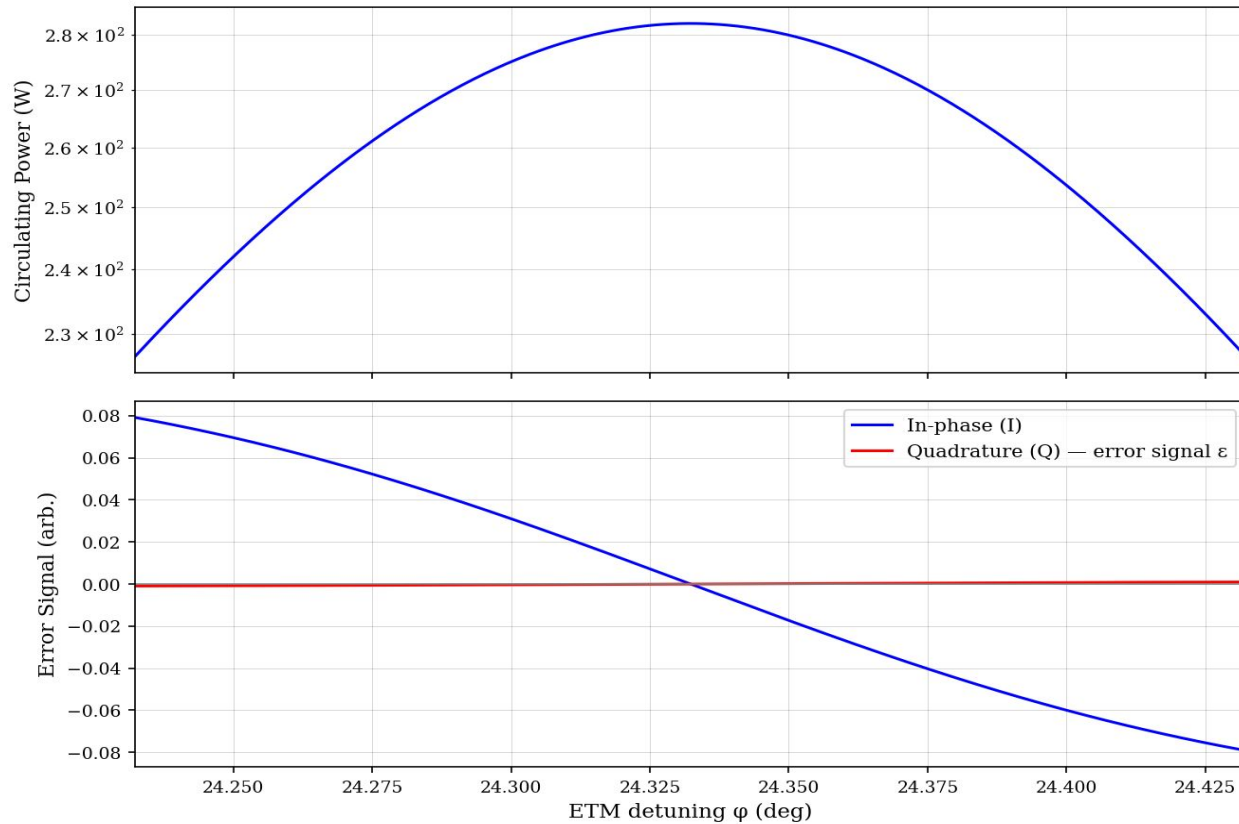
### HOM Decomposition — Optimal RH+Tilt (-1.8, 0) cm





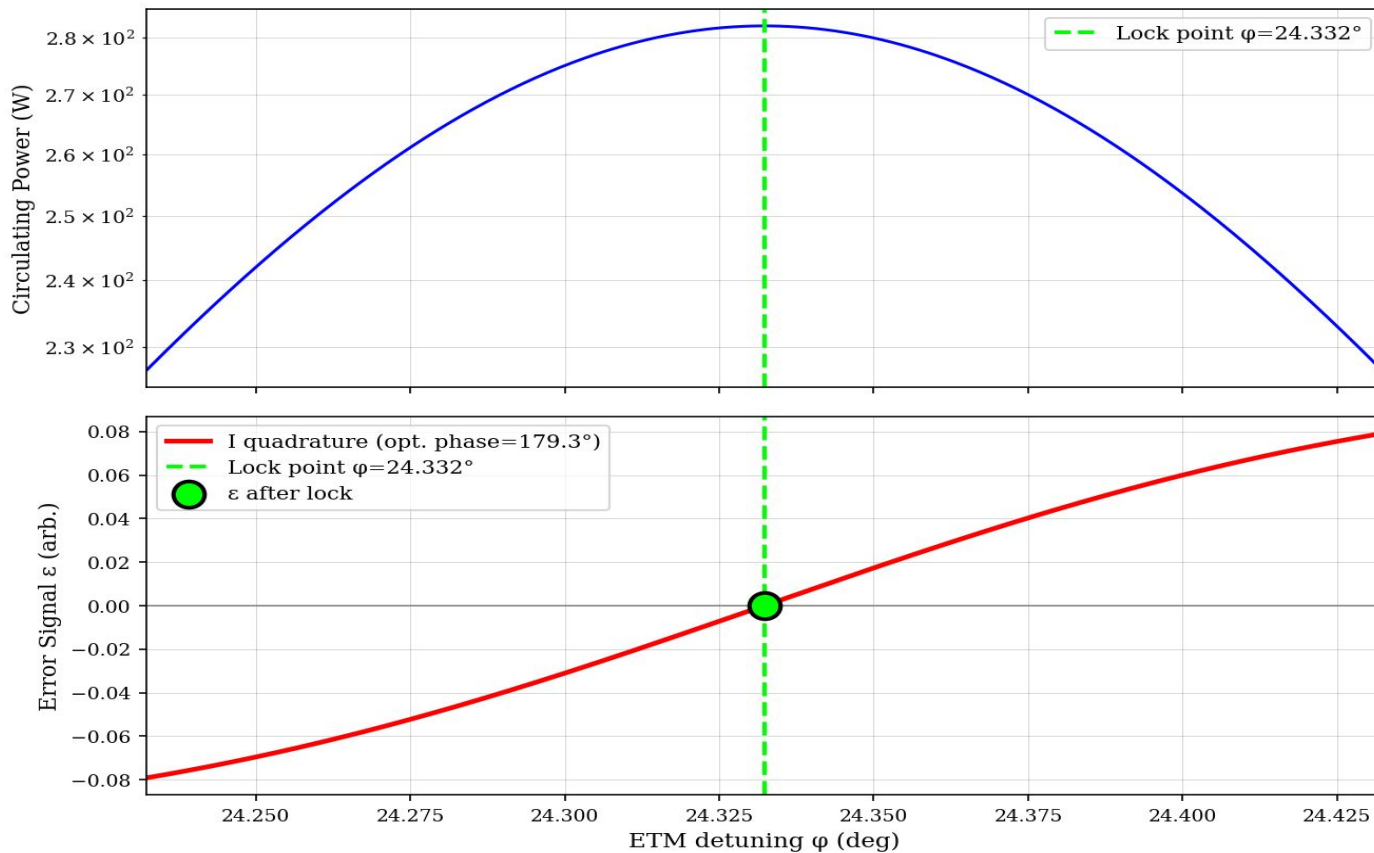
finding the resonance and diagnoses the error signal shape

### PDH Locking — Scan ETM.phi



proving the feedback loop actually locks the cavity exactly there.

### PDH Locking – Optimal Phase + Lock Verification



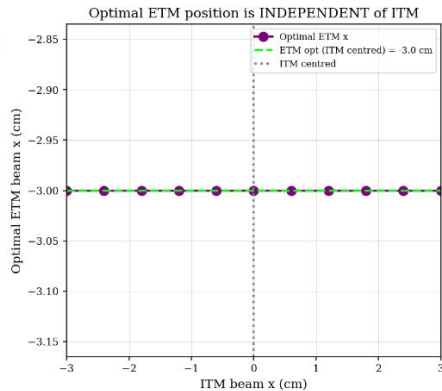
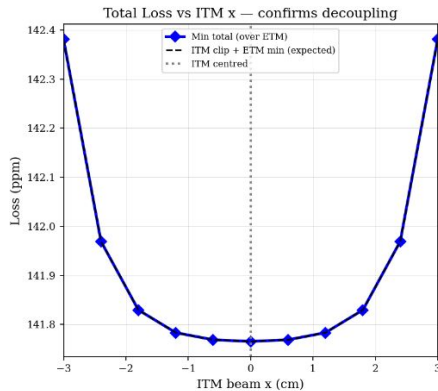
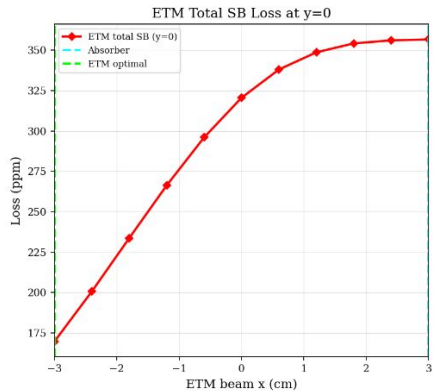
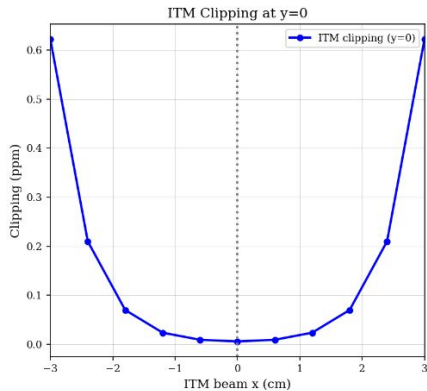
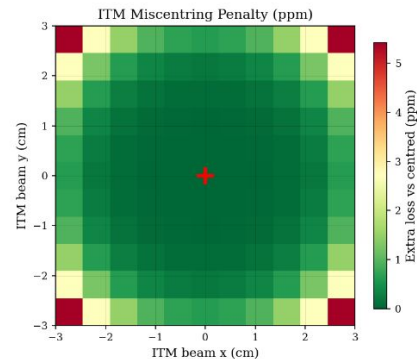
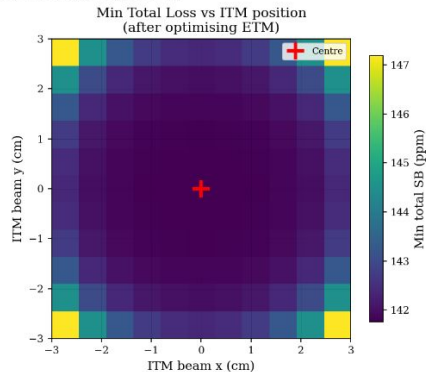
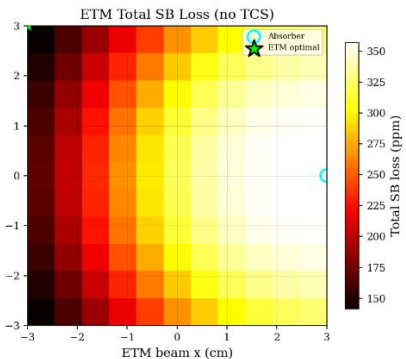
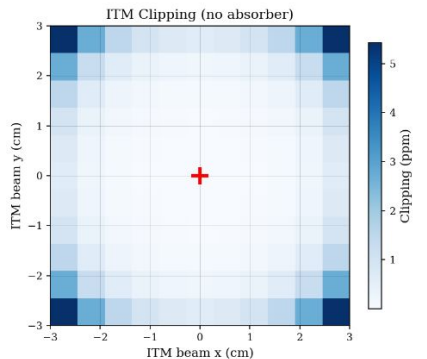
**The full 4-dimensional search over both ITM and ETM beam positions simultaneously.** ITM and ETM fully decoupled; If the ITM and ETM are truly decoupled, the optimal ETM position should be IDENTICAL regardless of where the ITM beam is.

(0,2):For each ITM position, the best achievable total loss (with ETM optimised). For each ITM position, the ETM is independently optimized. The resulting minimum loss is nearly **flat** across all ITM positions

(0,3):Extra loss added by moving the ITM beam away from center.

The purple dots (optimal ETM x for each ITM position) form a **perfectly flat horizontal line** at  $x_{\text{ETM}} = -3.0$  cm regardless of where the ITM beam is.

4D Single-Bounce Search: total\_SB(x\_ITM, y\_ITM; x\_ETM, y\_ETM)



# Next Step

- ❑ Developing a coupled cavity system where we effectively add an SRC onto ITM, and we will do the same analysis for the ITM then, as well as for the ETM with the coupled cavity present. (Arm+SRC)
- ❑ Implementing TCS in my code from PRL as laser beam moves around