Report on ET2 (HHFW)Research

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NSTX Research Forum

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PPPL

Princeton NJ

Goals of HHFW Phase 1 Research

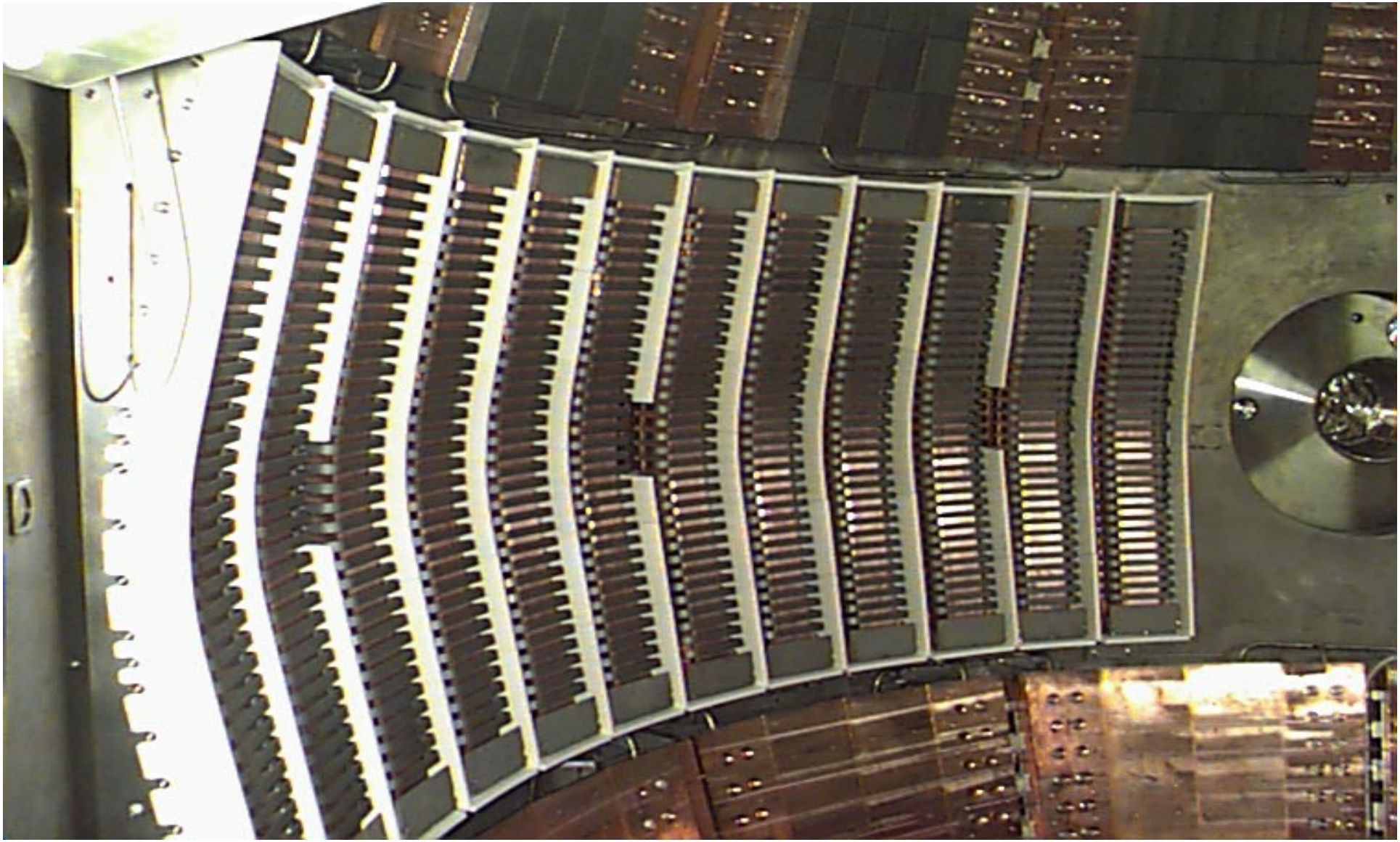
1 Understand the operation of the HHFW Antenna System

2 Understand where the HHFW power goes

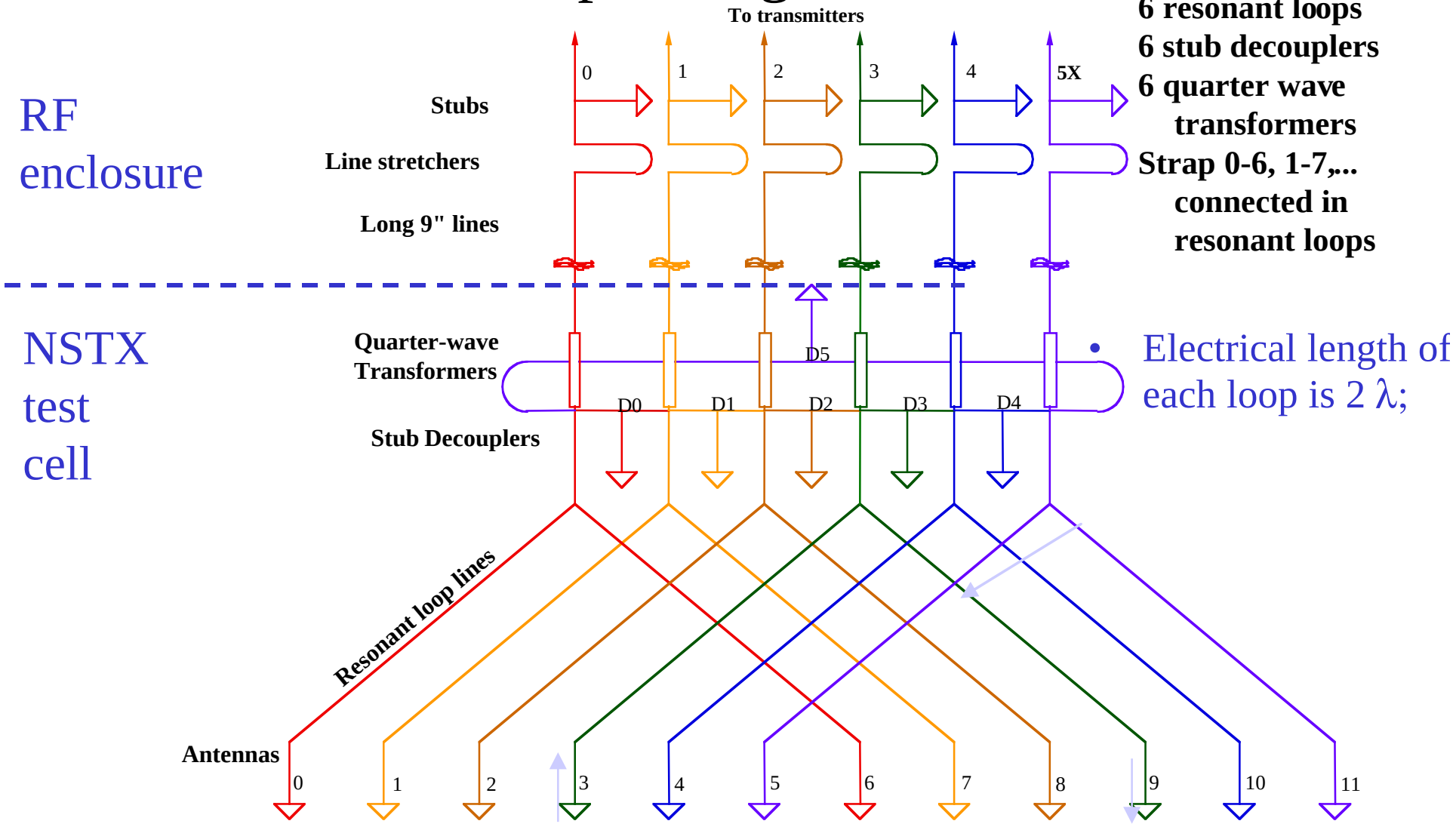
3 Be prepared to begin CD Experiments

- We have a good start on goal 1
- We also have data on goal 2
- Goal 3 will be explored this summer/fall

HHFW Antenna Installed



Each transmitter drives pair of antennas in resonant loop configuration

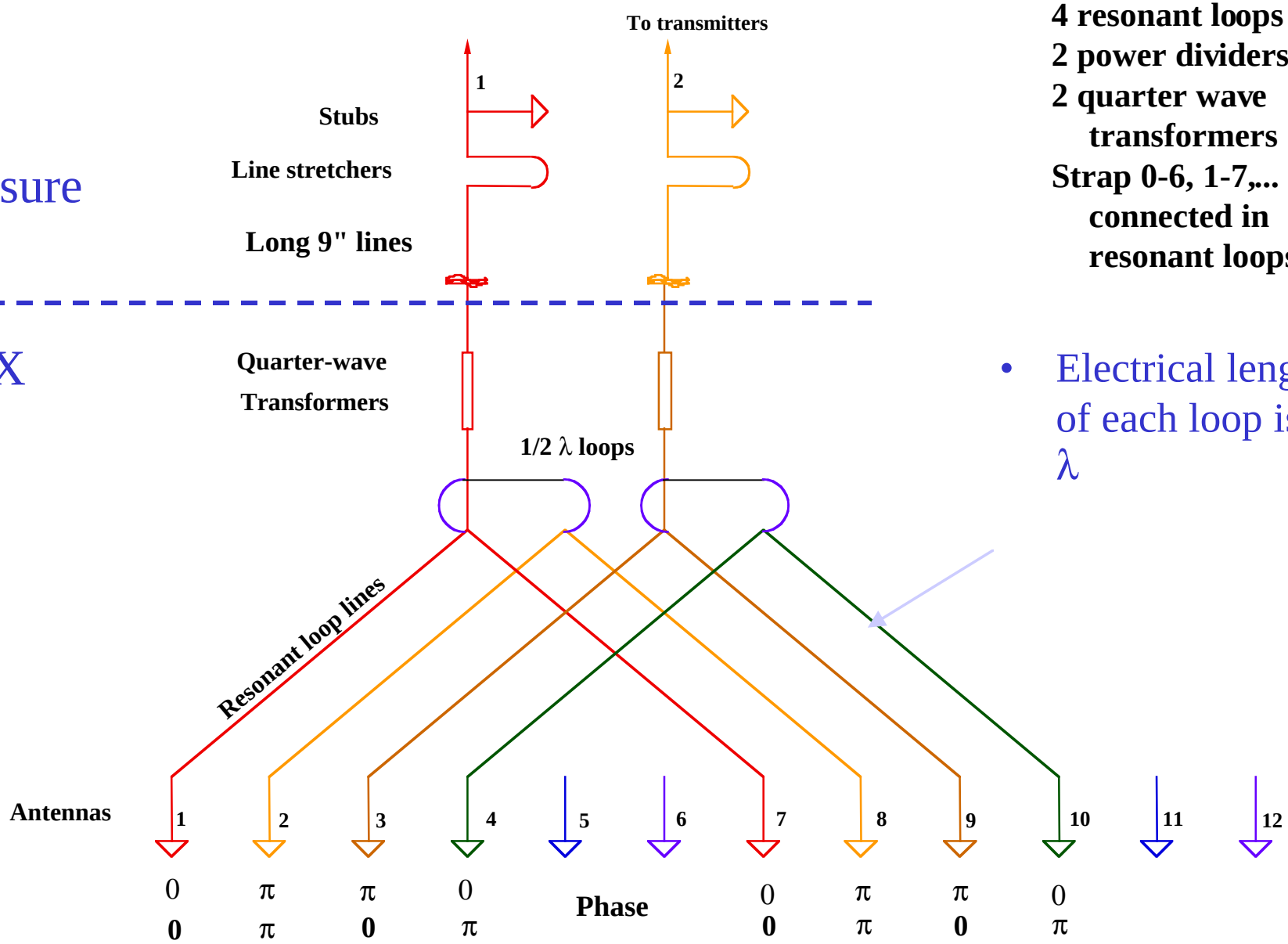


Preliminary setup with two transmitters and eight antennas

8 current straps
4 resonant loops
2 power dividers
2 quarter wave transformers
Strap 0-6, 1-7,... connected in resonant loops

RF enclosure

NSTX test cell



- Electrical length of each loop is 2 λ

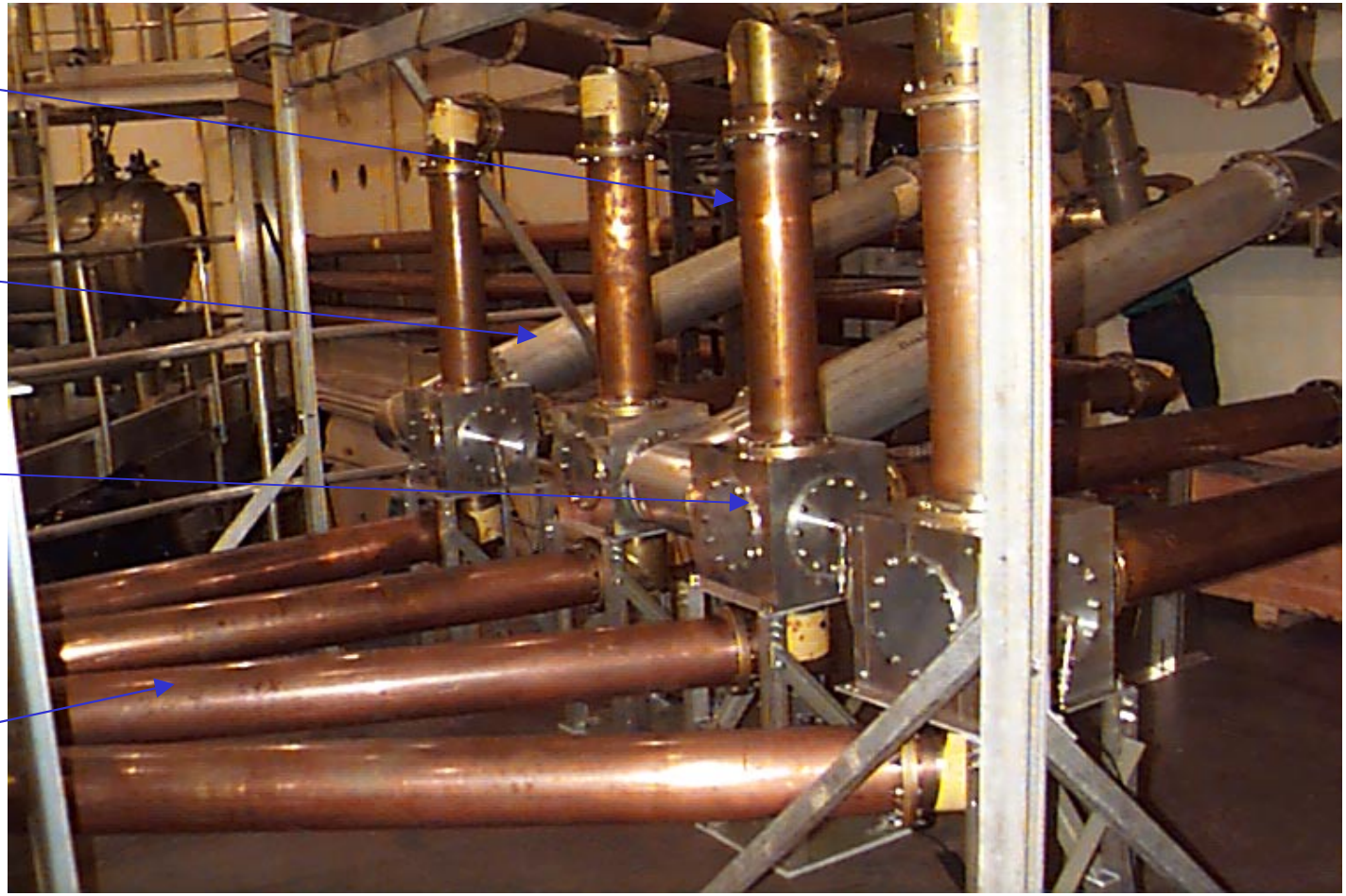
POWER FEED AND SPLITTING ARRANGEMENT

Upper Loops
7-10

1/4 Wave
XFMR and
Feed line

5 Way Cubes

Lower Loops
1-4



ET2 Run Summary

- 1 XMP brought system into operation - 2 days
  - 11/11, 12
    - Up to 400 kW short pulse (0.03 s) with 1 transmitter and 4 antenna straps
- 1 XP explored coupling and preliminary heating - 6 days
  - 12/9, 10
    - Removed $\lambda/4$ transformers -loading as measured in piggy back mode was too high
    - Power up to 660 kW (0.03 s) with 2 transmitters and 8 antenna straps
    - Loading studies - density scan, gap scan
    - $0–\pi–\pi–0$ phasing ($k_{||} \sim 7\ m^{-1}$)
  - 12/14, 15
    - Power to 1 MW (0.07 s)
    - Phasing changed to $0–\pi–0–\pi$ ($k_{||} \sim 14\ m^{-1}$)
    - Plasma position varied
  - 1/10, 11
    - Power to 2 MW (0.04 s) 1.6 MW (0.07 s)
    - AM power for heating studies - 100 Hz square wave up to 1.6 MW for (0.1 s)
    - Both antenna phasings applied

Goals of Phase 1 Research as Expressed at last years Forum and Status

- Bring system into operation
  - **Partial System used during this run**
  - **8 of 12 antenna elements**
  - **2 of six transmitters**
  - **All antenna diagnostic signals**
  - **Two fixed phasings available -** $0–\pi–\pi–0$ **and** $0–\pi–0–\pi$
  - **2 MW power goal met**
  - **Voltage is not a limitation**

    - PLASMA LOADING HIGHER THAN EXPECTED REQUIRING REMOVAL of $\lambda/4$ TRANSFORMERS

Goals and Status

- Establish Baseline Properties of Antenna Array
  - Vacuum condition to 20 kV 0.5 s
  - ☞ **Achieved 25 kV 0.3 s**

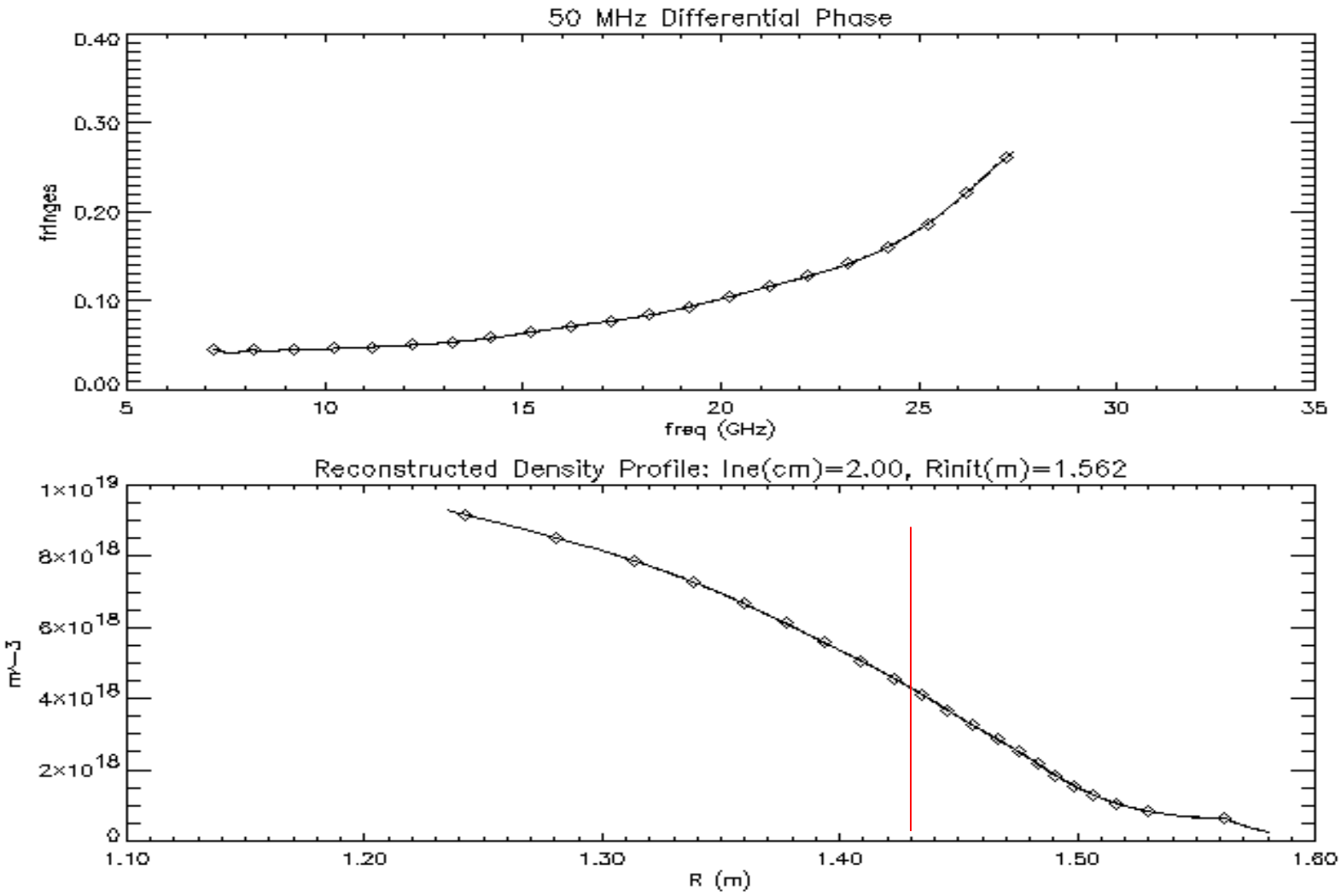
    Vacuum conditioning was easy and fast and did not determine antenna performance in plasma. It was helpful in recovering from other operation quickly

  - Measure electrical properties of antenna (L,M,R) as a function of plasma density, edge location, shape, power, and phase and compare with theory
  - ☞ **Have data for these analyses and have begun work**

    Density profiles seem broader than expected, little dependence with power observed. Only small change with phase observed. Larger changes seen with configuration

  - Define parameters for full power operation
    Vacuum Voltage limit not an obstacle
    Plasma conditioning and MHD events more important

Edge Density profile as measured by ORNL Reflectometer

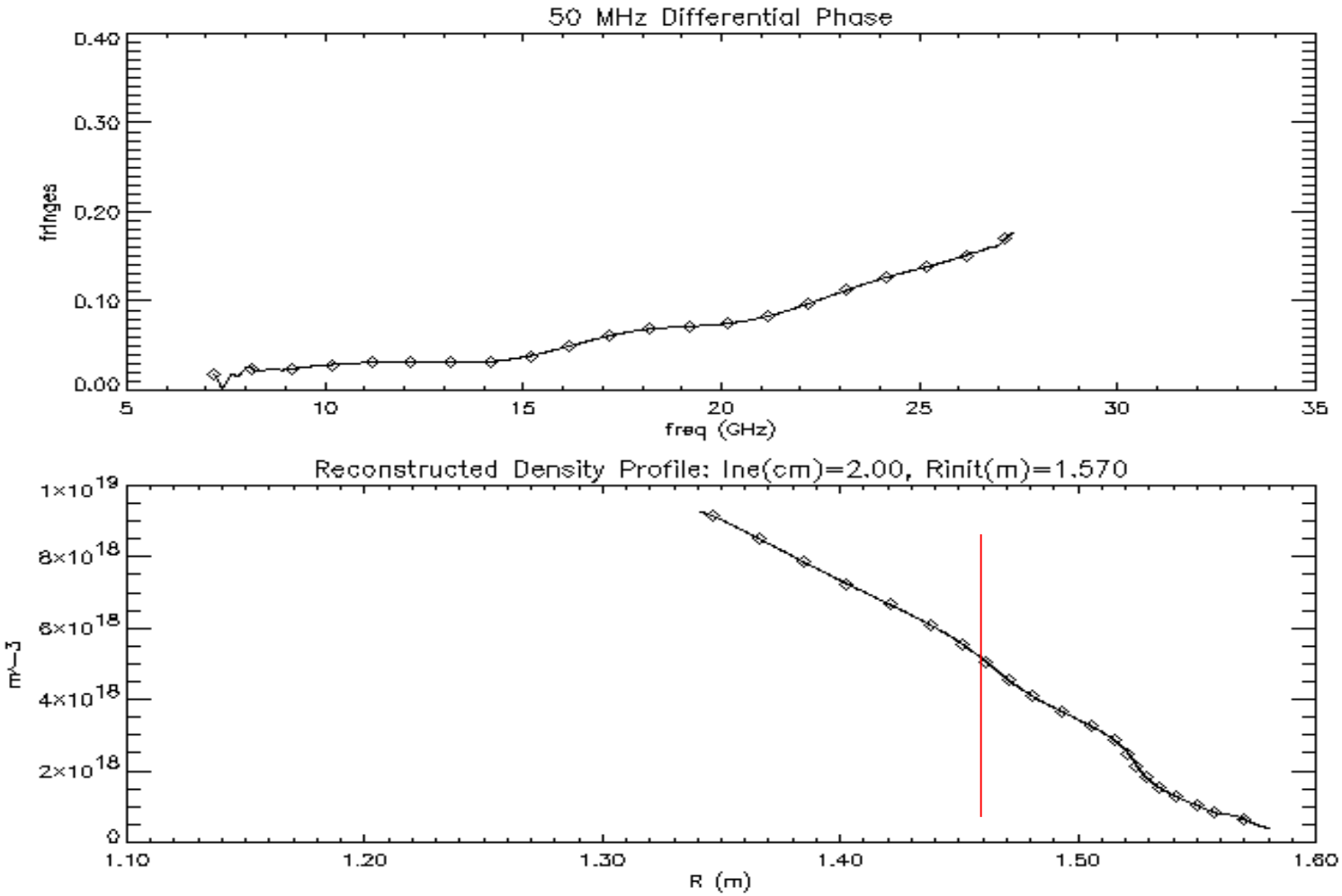


101544

R=11 Ω

t= 160 ms

Edge Density profile as measured by ORNL Reflectometer

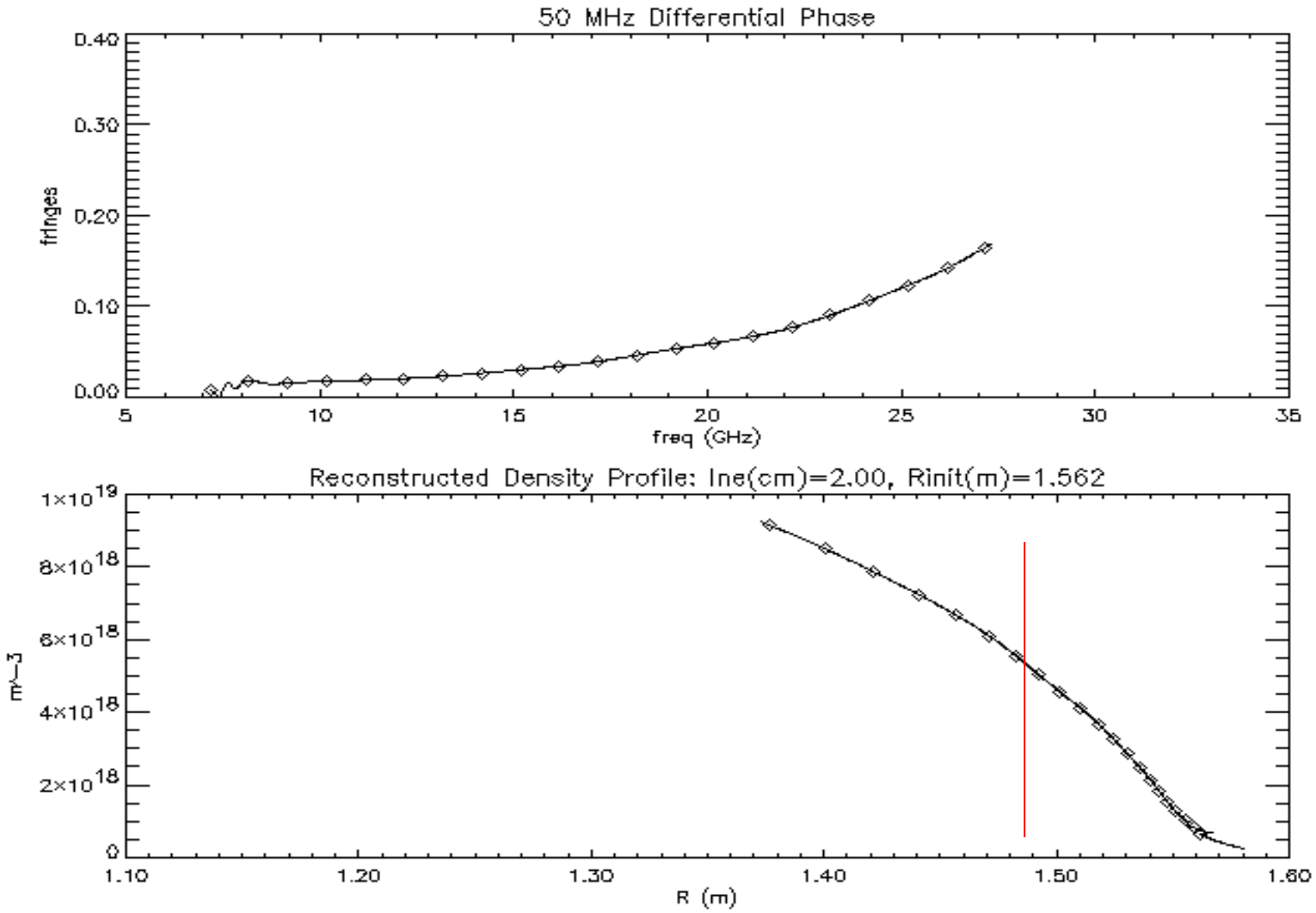


R= 17 Ω

101544

t = 175 ms

Edge Density profile as measured by ORNL Reflectometer

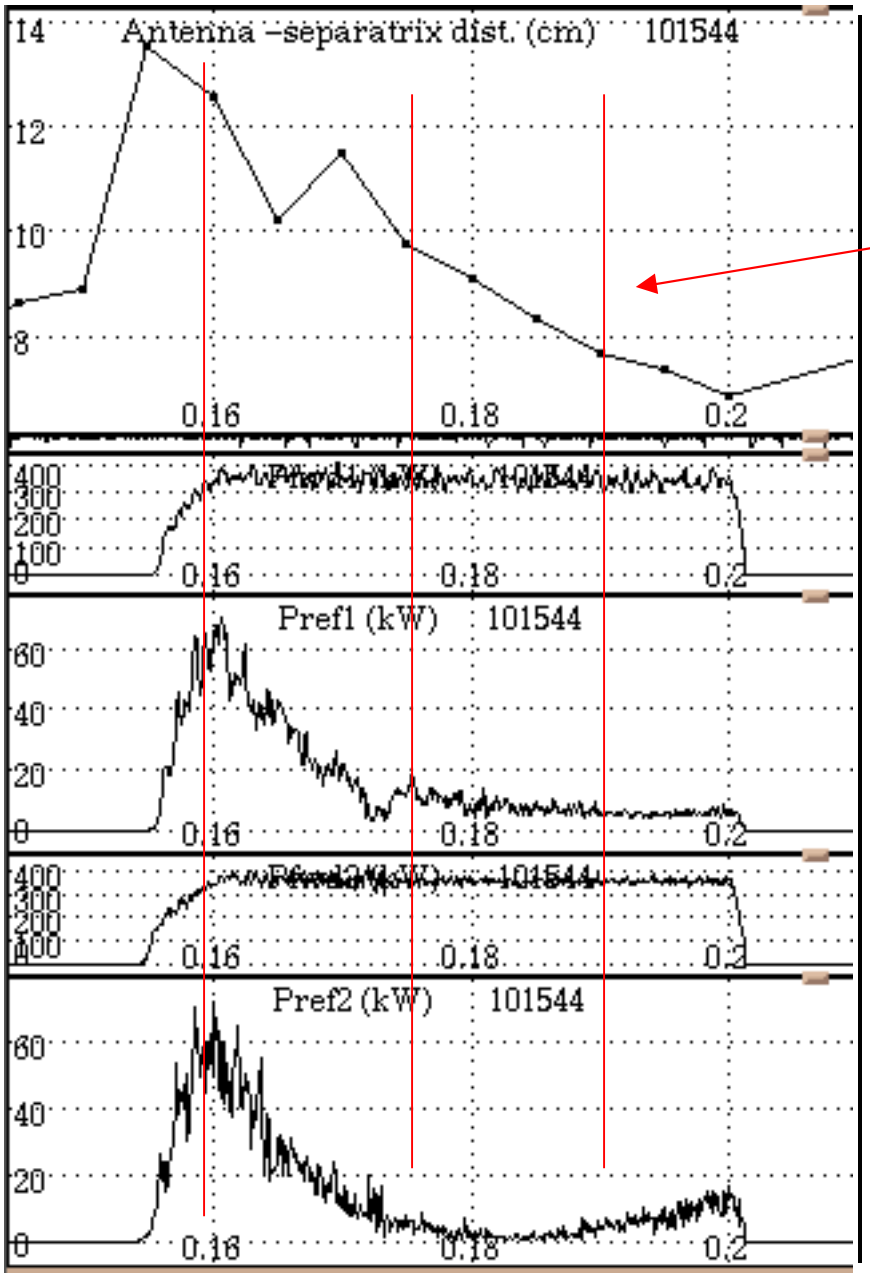


R= 23 Ω

t = 190 ms

101544

Loading
Calculation
0-p-0-p phasing



Times of
ne profiles

Time (s)

Goals and Status (cont.)

- Power Goals
  - 2 MW half way through Phase 1 ☞**Achieved**
  - 4 MW at end of Phase 1

    Requires some improvement in power handling with plasma and plasma response to power

    Antenna- plasma interaction continued to improve with time

- Edge Physics
  - Characterize rf power flow in scrape-off

  ☞ **TV Camera showed little interaction on antenna**

  ☞ **Have edge density profiles (needs analysis)**

  More work needed to see if power flowing to divertor region

  Edge probe etc.

Goals and Status (cont.)

- Heating
  - Quantify heating efficiency using magnetics

☞ **More difficult to quantify than anticipated but still under analysis**

  - Determine location of heating using USXR

☞ **On modulated shots, heating observed for r/a ≤ 0.4 with 0–π–0–π phasing but not 0–π–π–0**

☞ **Theory would predict this for low target temperature**

☞ **Given density and target temperature profiles we can try to model this**

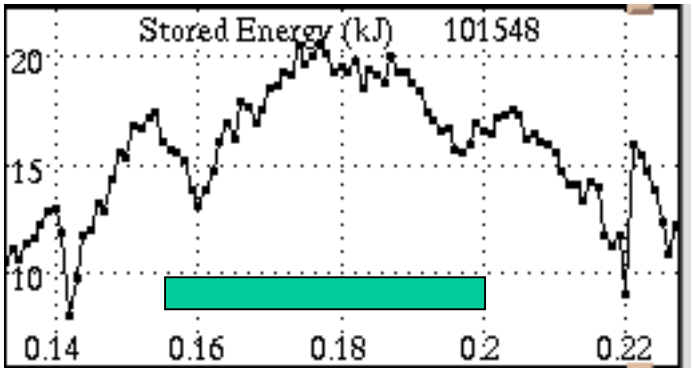
⇨**Absolute calibration needs new diodes**

Determine if ion absorption present

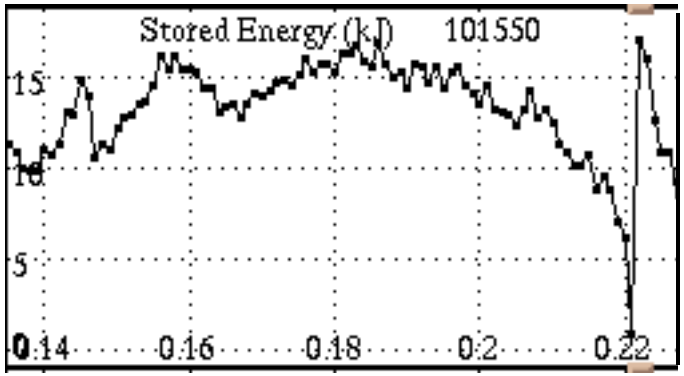
☞ **No diagnostic available yet - low apparent temperatures should not yield ion heating**

First signs of heating observed for 0–π–0–π phasing

900 kW rf



No rf



USXR data for HHFW experiments

- Three diode arrays with different filters

Filter	Energy range	Estimated spectral content	Position on NSTX
Ti 03 µm	E > 0.1 keV	C V, C VI lines E ≈ 0.35 keV + metallic (Cu) lines E ≈ 1.1 keV	Horizontal down
Be 10 µm	E > 0.7 keV	Metallic lines E ≈ 1.1 keV	Horizontal up
Be 100 µm	E > 1.4 keV	Continuum	Top

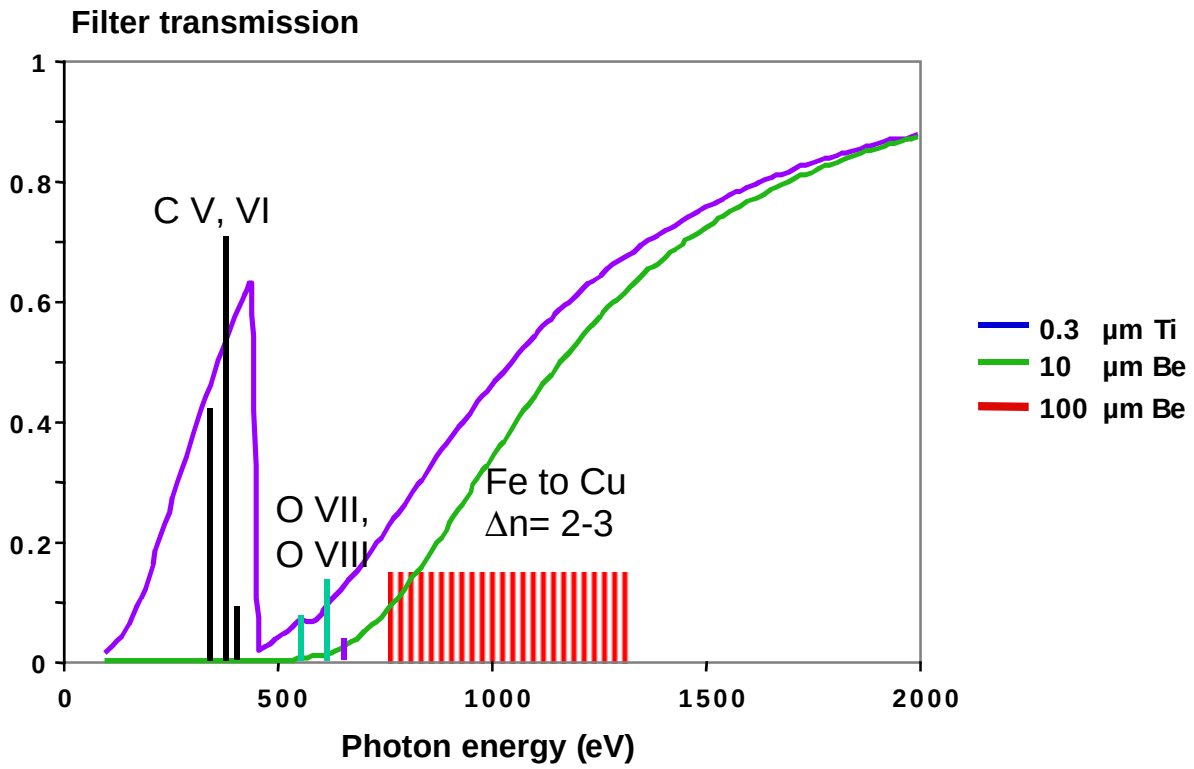
- T_e sensitive ratios:

  Be 100 / Be 10 ≈ continuum / metallic lines

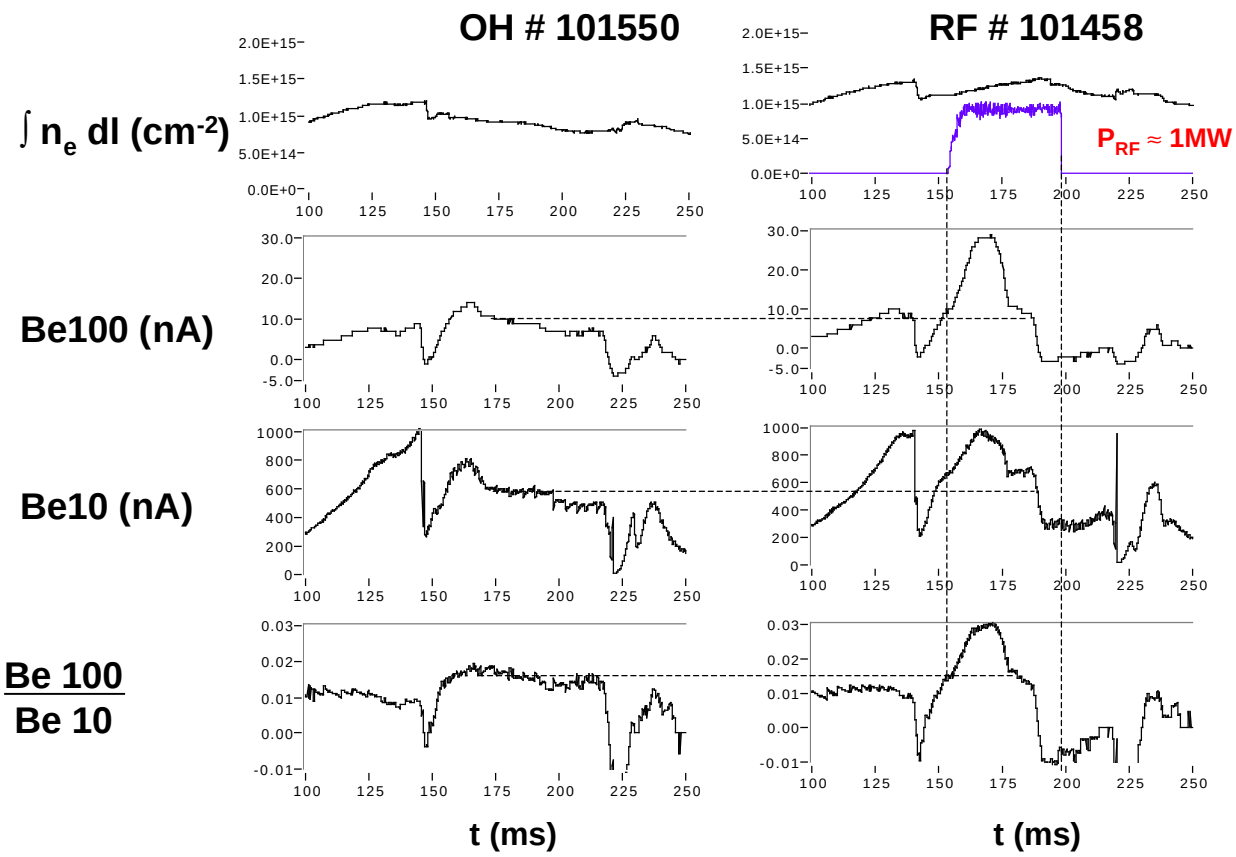
  Be 10 / (Ti 03 - Be 10) ≈ metallic lines / carbon lines

- Impurity injection effects assessed in RF modulation experiment

Spectral response of USXR arrays

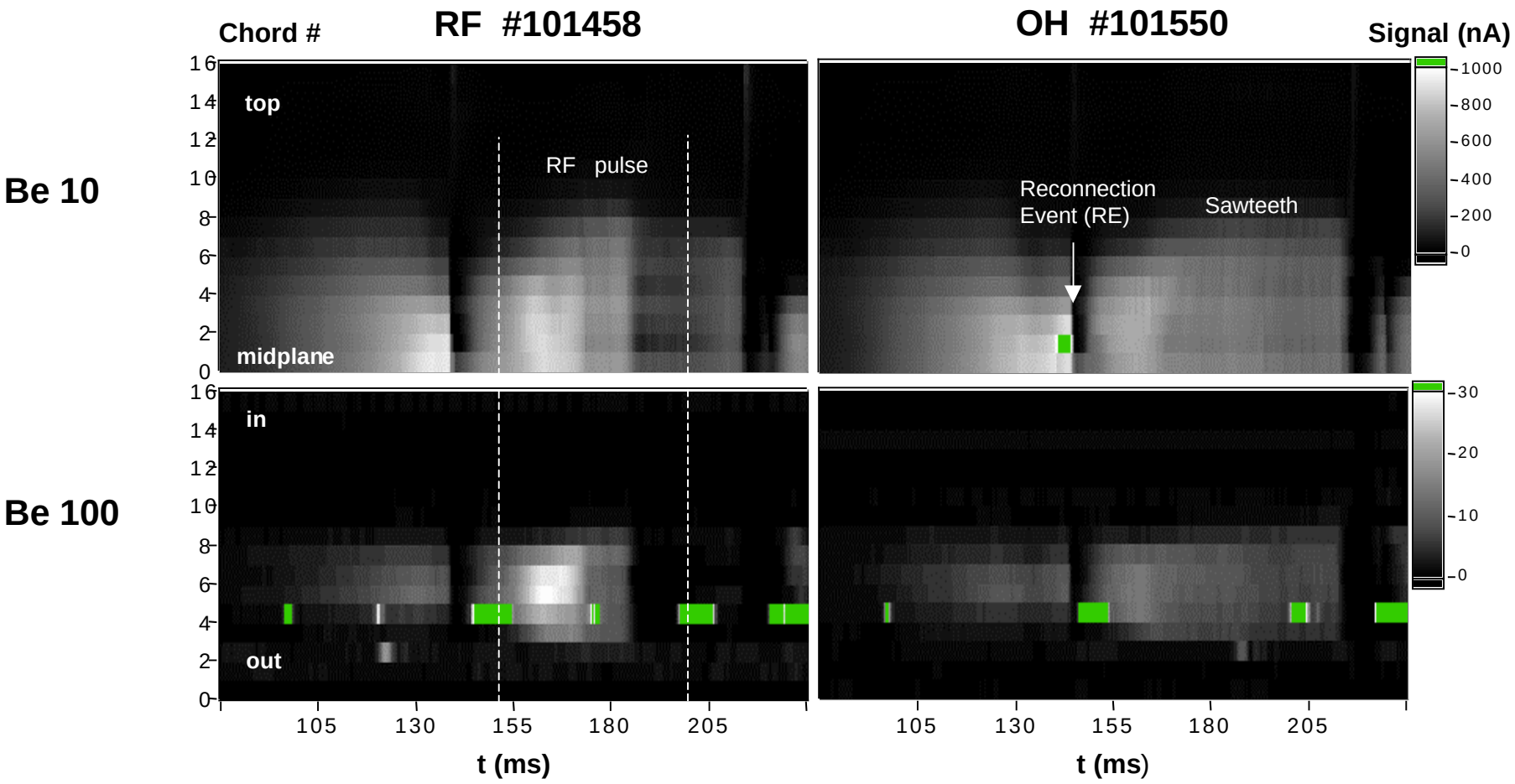


Central chord signals and ratio in OH and RF shots



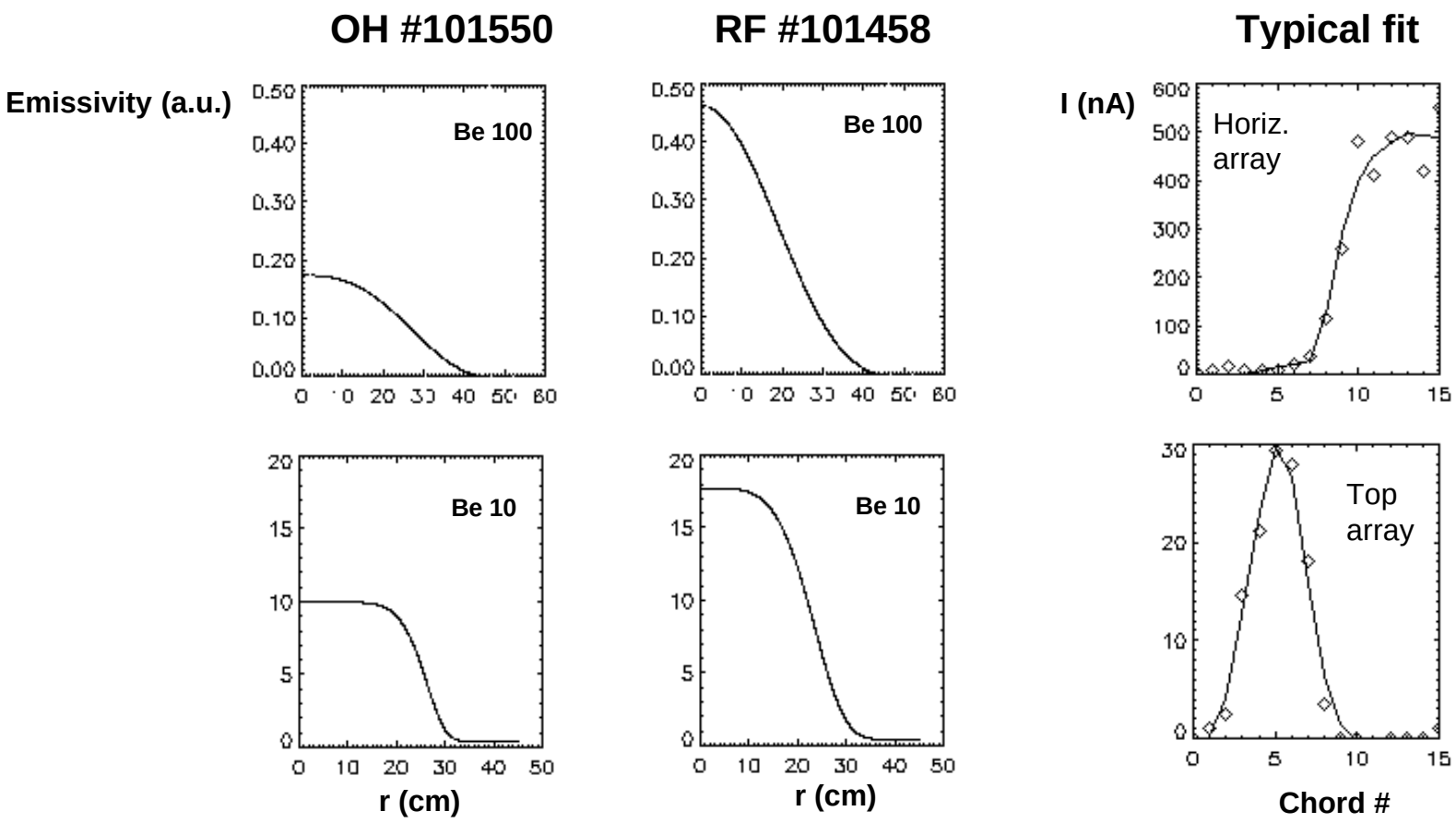
- 60 % increase in Be 100 / Be 10 during first half of RF pulse
- Minor density increase
- Sudden emission drop before the pulse end

Evolution of the emission profiles



- Both mid and high energy signals peak during RF
- Emission drop at t≈ 182 ms occurs simultaneous in all chords (mild RE ?)

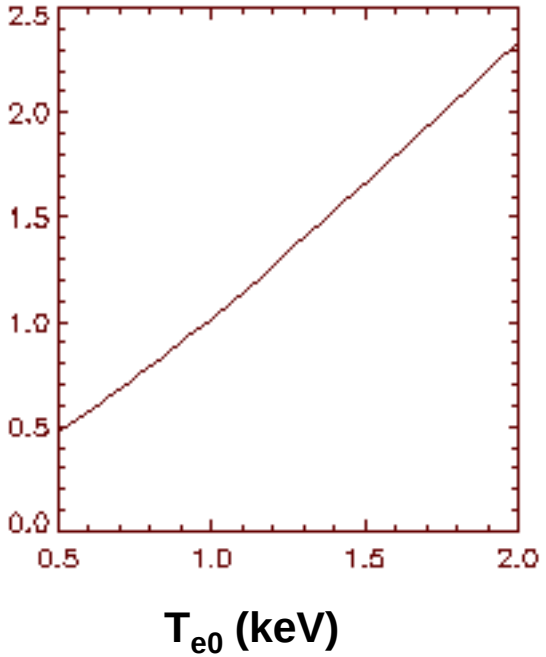
Reconstructed emissivity profiles at t ≈ 170 ms



- Strong peaking of high energy emission during RF
- 150 % increase in Be 100 / Be 10 emissivity ratio on axis

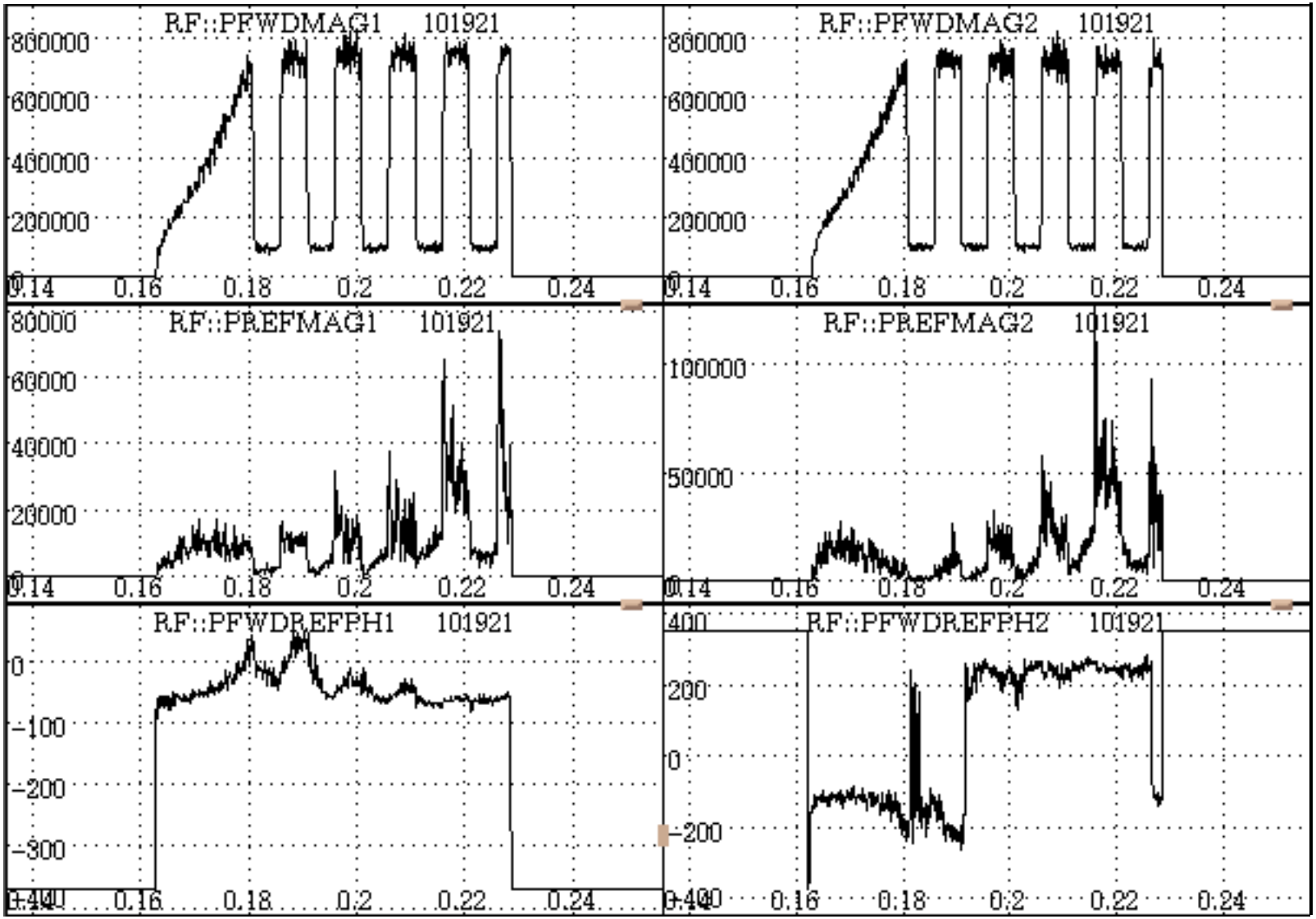
Possible estimate of T_{e0} increase

$\frac{\text{Be 100 / Be 10 } (T_{e0})}{\text{Be 100 / Be 10 (1 keV)}}$



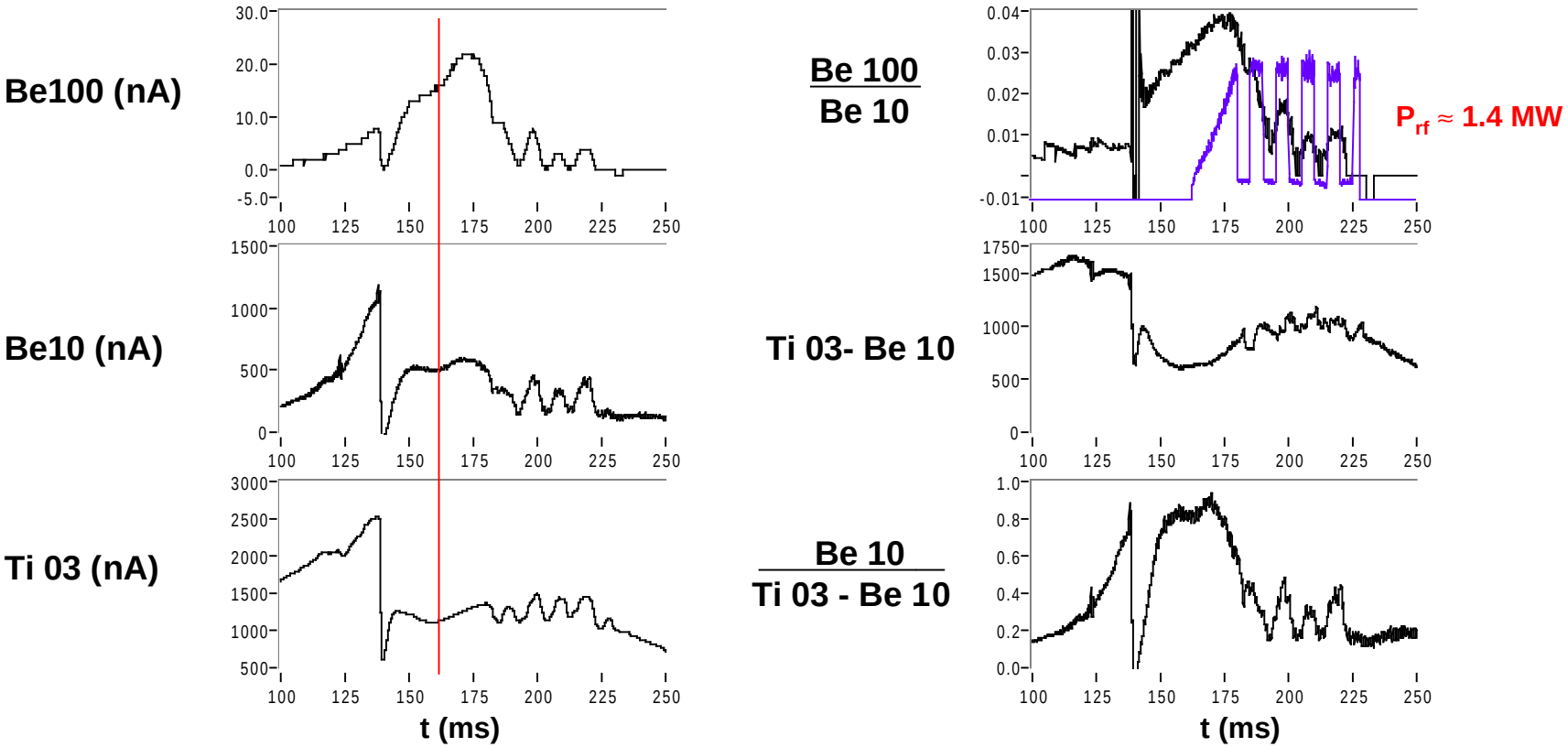
- Rough calculation of line integrated Be 100 / Be 10 ratio in C+Cu plasma
- Observed 60 % ratio increase may indicate up to 50 % T_{e0} increase

Amplitude Modulated Power Waveforms for Heating Study

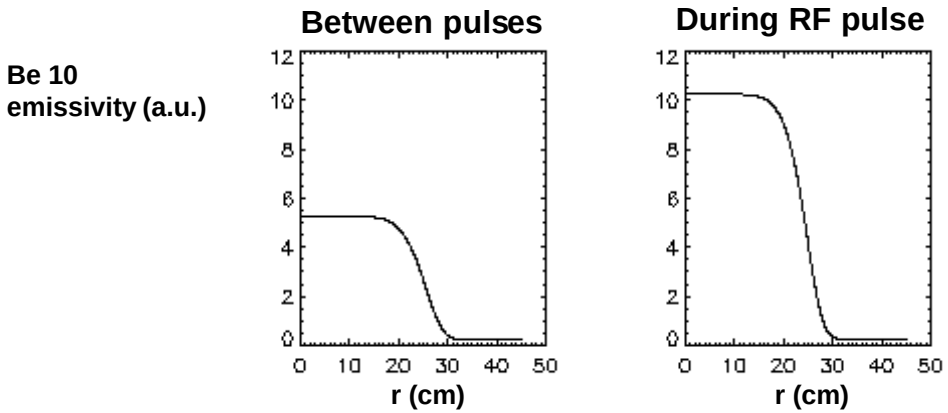


Phasing 0–π–0–π

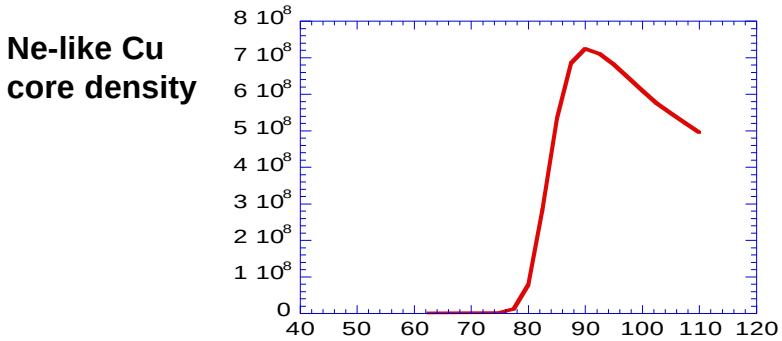
RF modulated shot # 101921 (0-π, 0-π phasing)



- Strong increases in both the high-to-mid and mid-to-low energy ratios synchronous with the RF pulses suggest again core heating
- Slow ratio decay after 175 ms seen also without RF during the day



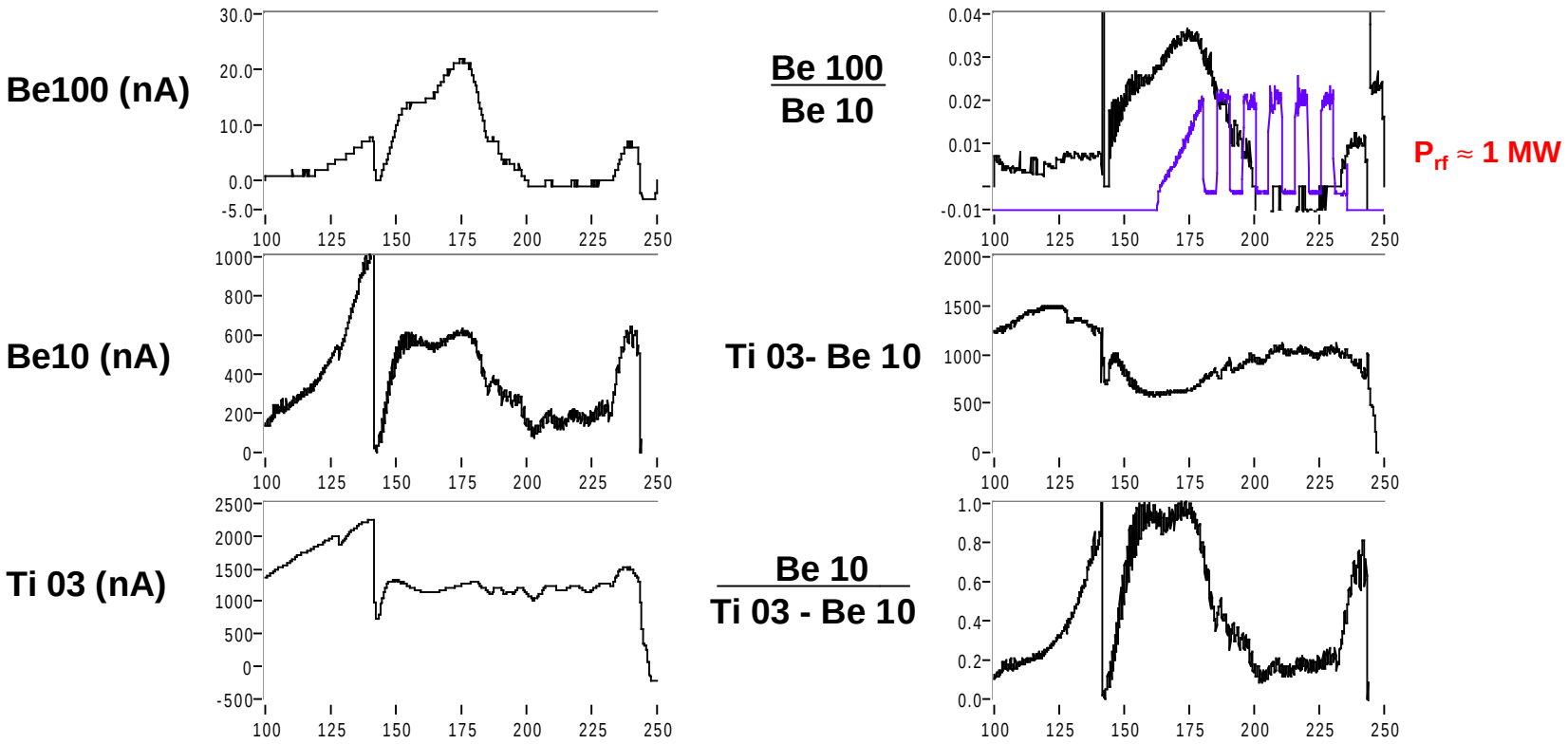
- Emission increase localized inside r/a < 0.4



MIST simulation of Cu injection in T_{e0} =1 keV, N_{e0}= 10^{13} cm^{-3} plasma
D= 8 m^2/s

- Time scales for impurity effects much longer than those observed

RF modulated shot # 101933 (0–π–π–0 phasing)



- Significantly weaker modulation seen in 0–π–π–0 phasing shot
- Too poor statistics for a definite conclusion

Remaining Phase I Research

- Complete HHFW system hookup

Issues:

  - **Do large values of antenna loading require a change in configuration ?**
  - **Make phase control operational**

- Complete Heating study
  - **Heating at higher density, temperature**
  - **Raise power to max**

Issues:

  - **Why does heating sometimes disappear?**
  - **MHD? Radiated Power?**
  - **Role of ion heating**

HHFW Summary

- Successful start of HHFW campaign
- 2 MW power milestone met
- Large data base of loading data acquired
  - **Edge density profiles will allow quantitative analysis**
  - **Loading resistance larger than expected**
- Heating observed under some conditions
  - **Centrally peaked electron heating ($r/a \leq 0.4$)**
  - **Only for slowest phase velocity**
  - **MHD or radiated power may terminate heating**