

# Power Test of a 325 MHz Hybrid for Fermilab Proton Driver

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# Outline

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- **RF System for Front Linac of Proton Driver**
- **325 MHz IQ Modulator**
- **Hybrid**
- **High Power Test**

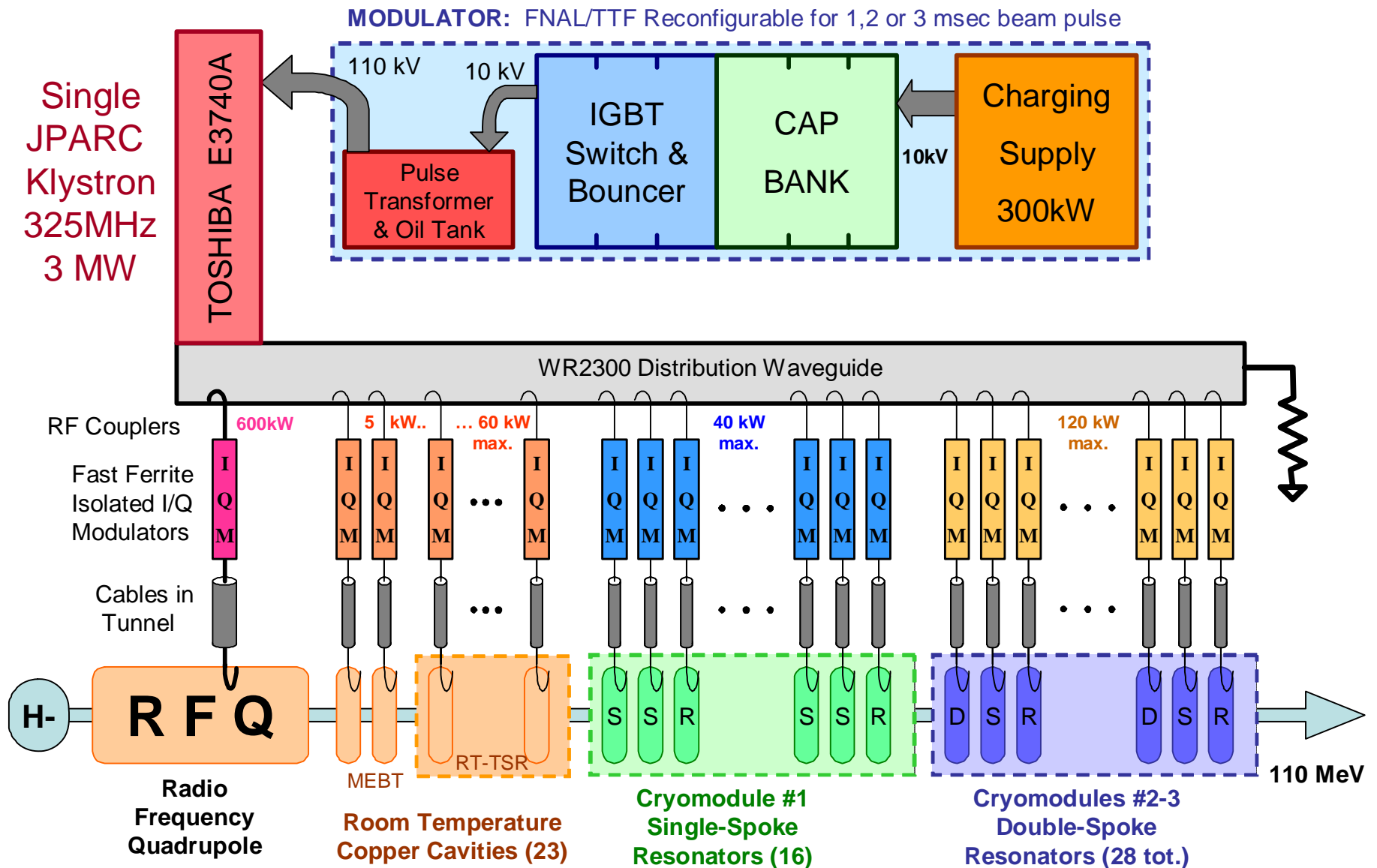
# Front Linac of Proton Driver

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- **The entire front-end linac up to 110 MeV is powered by a single 3 MW klystron.**
- **RF power is carried by a single WR 2300 waveguide alongside the beam line and partially extracted by a waveguide-coax coupler at the location of each RF structure.**
- **IQ modulators are used to control phase and amplitude of the input power for each RF structure.**

# 325 MHz RF System



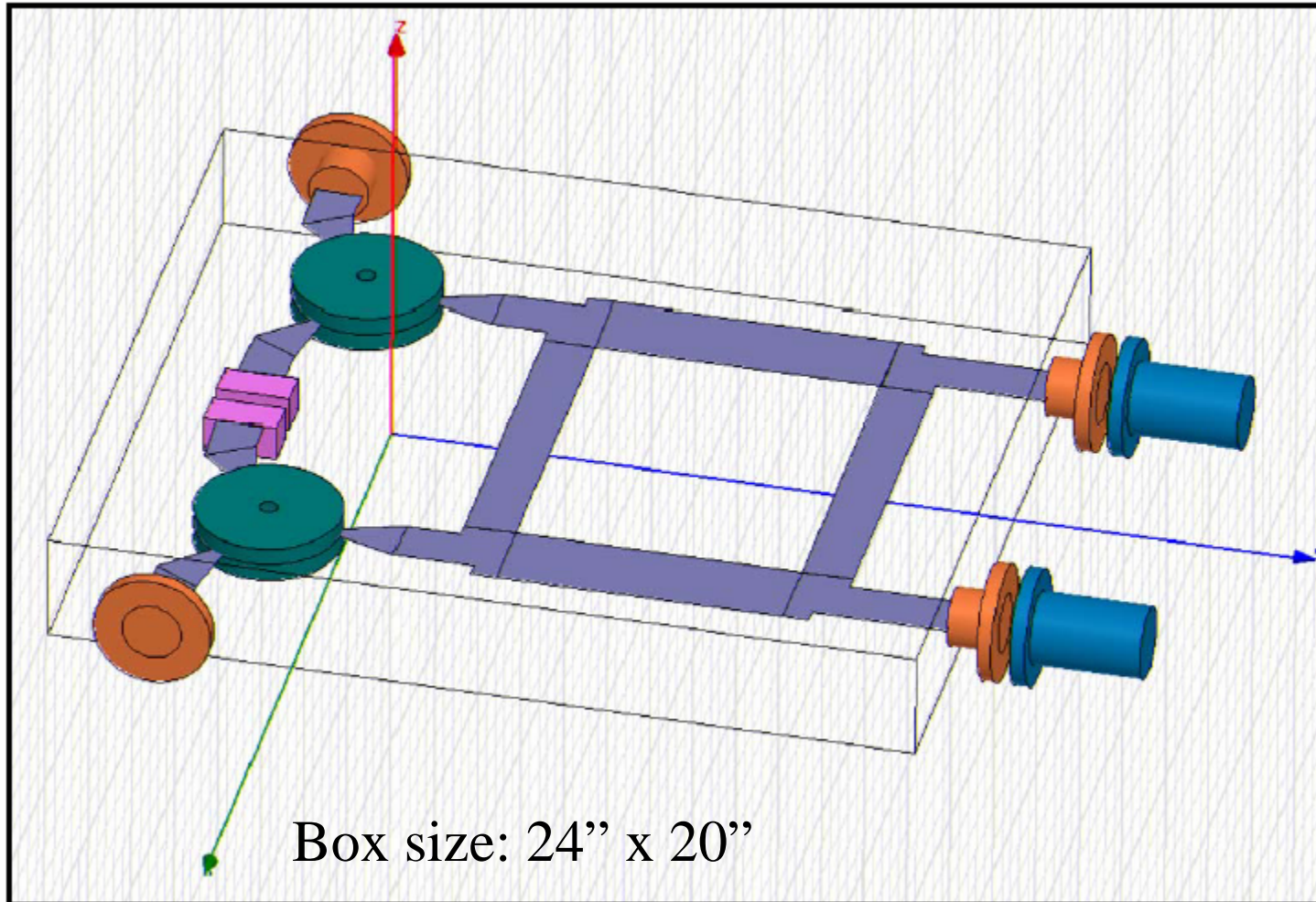
# IQ Modulator R&D

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- **Design and make individual circulator, hybrid and fast ferrite phase shifter.**
- **Power test them separately and modify design if necessary.**
- **Integrate and power test.**

# I/Q modulator box (stripline structure)



# Hybrid

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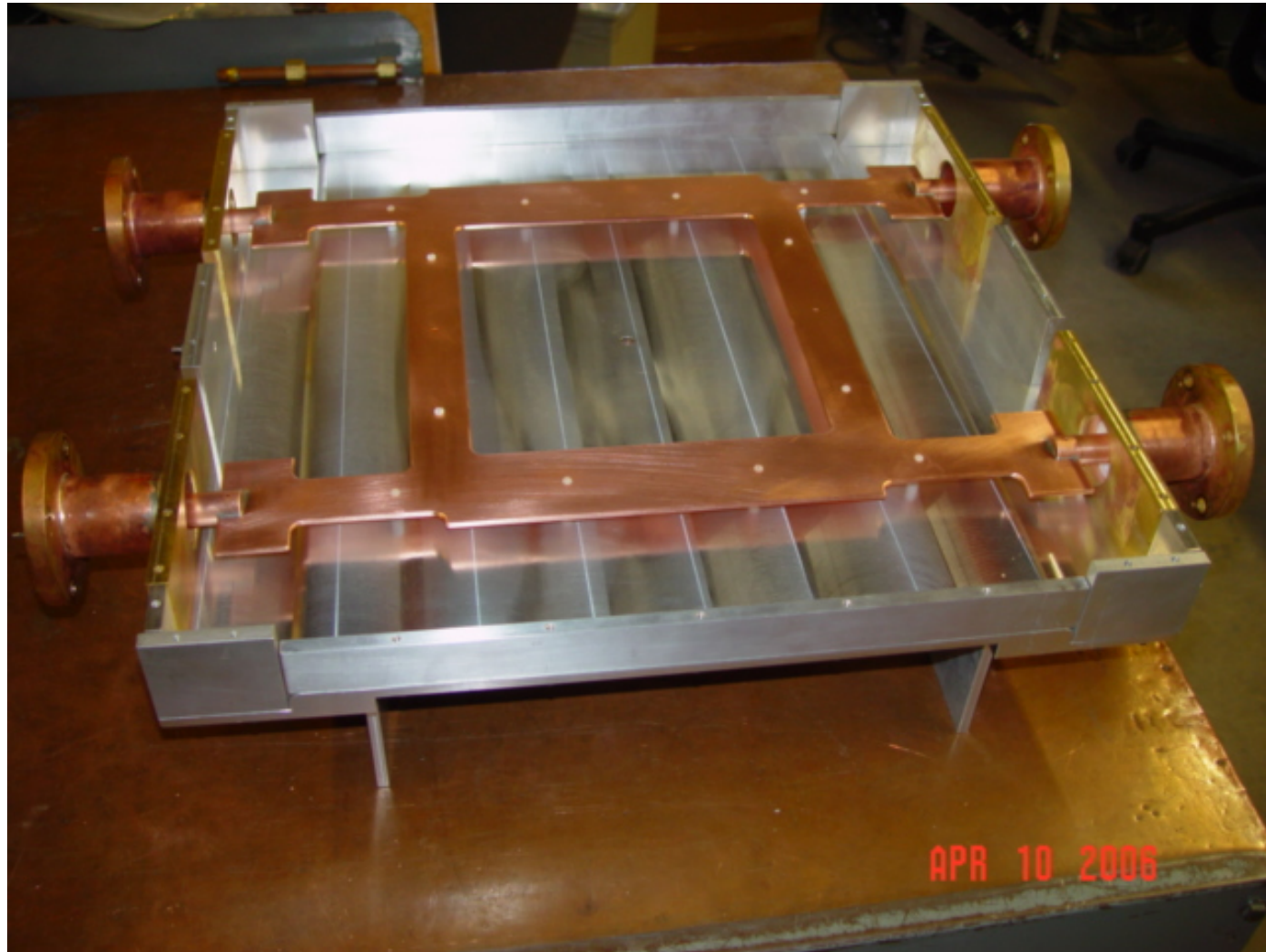
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- **A quadrature branch line coupler made of copper sheet with thickness of 0.125”**
- **A matching section at end of each arm for transition of suspended striplines to 1 5/8” coaxial line ports**
- **Easy fabrication – low cost**
- **Center Frequency: 325 MHz**
- **Bandwidth: ~60 MHz**

# Hybrid (open box, after power test)

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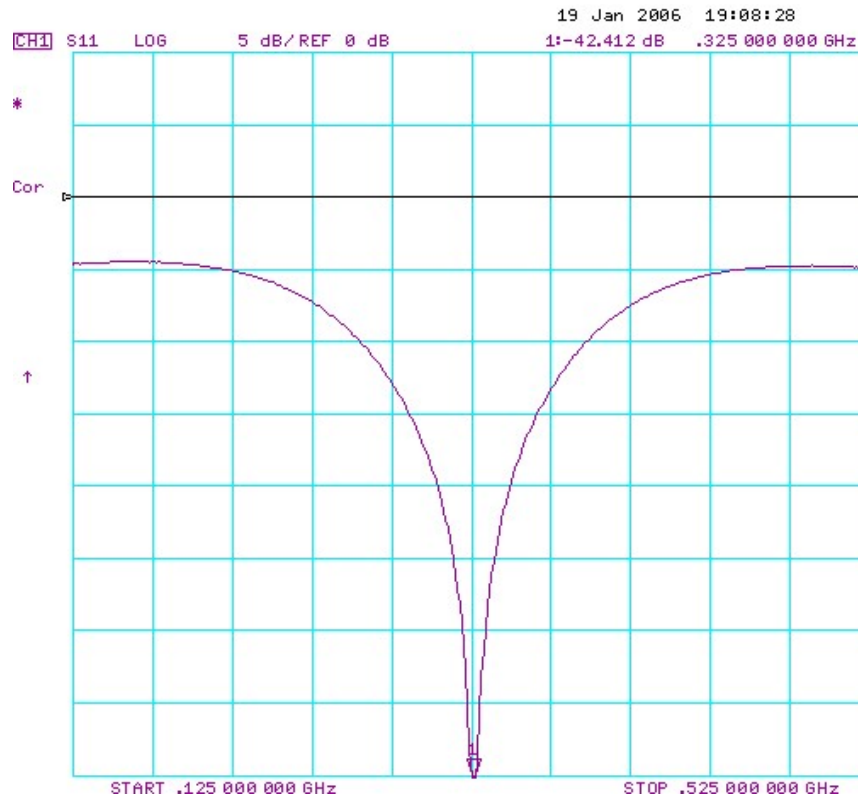
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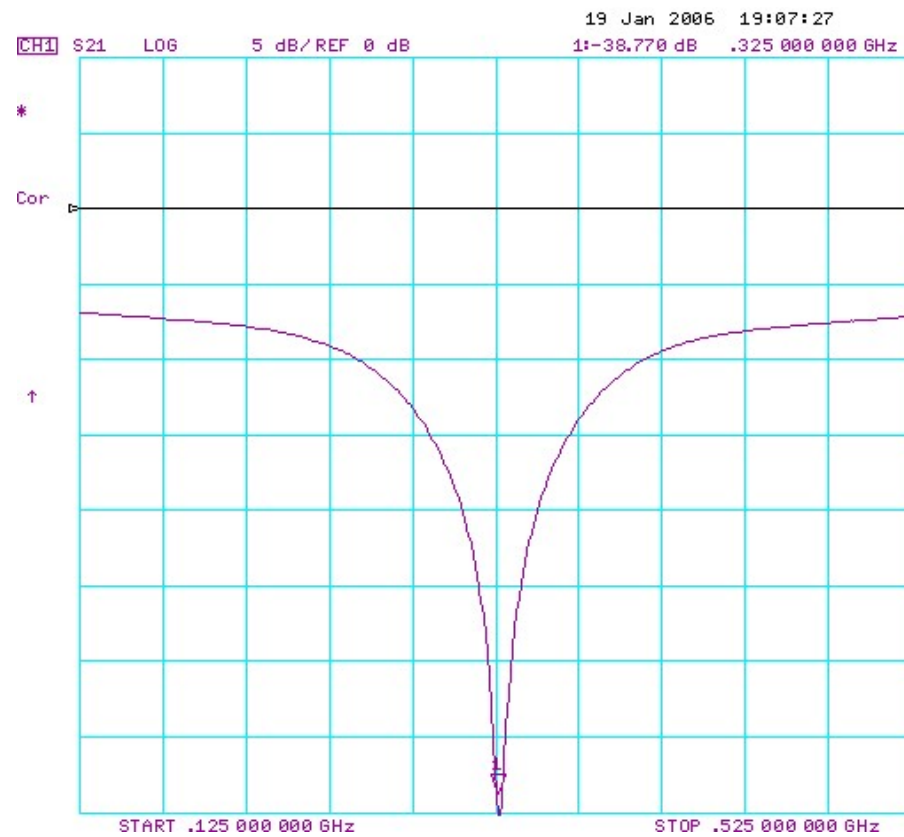
# Measured S parameter

- Reflection at each port:  $< -39$  db



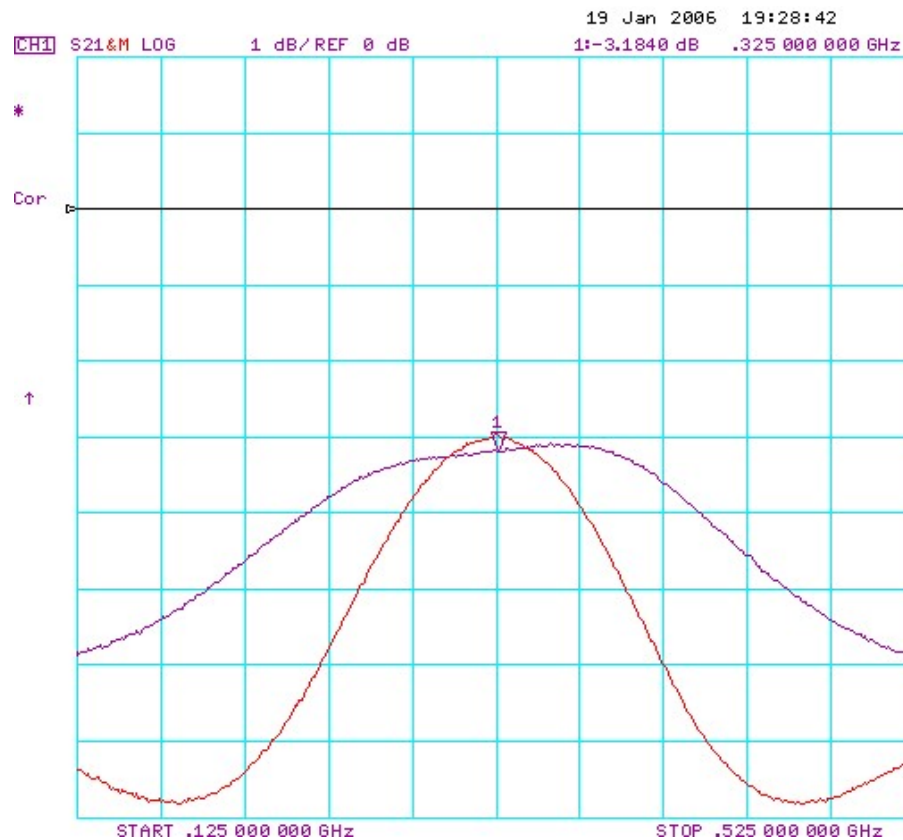
# Measured S parameter

- Isolation:  $< -38.7$  db



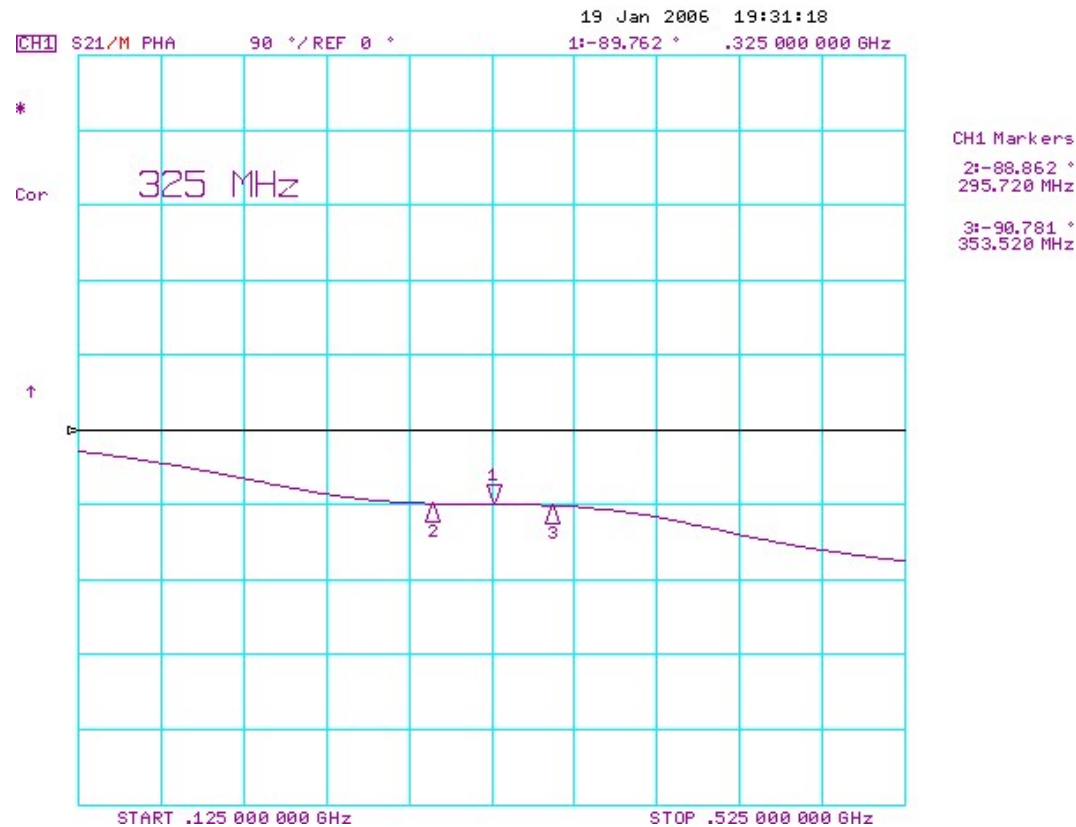
# Measured S parameter

- Amplitude at port 2 and 3: -2.99/-3.18 db



# Measured S parameter

- Phase difference between port 2 and 3: 89.7 deg



# High Power Test

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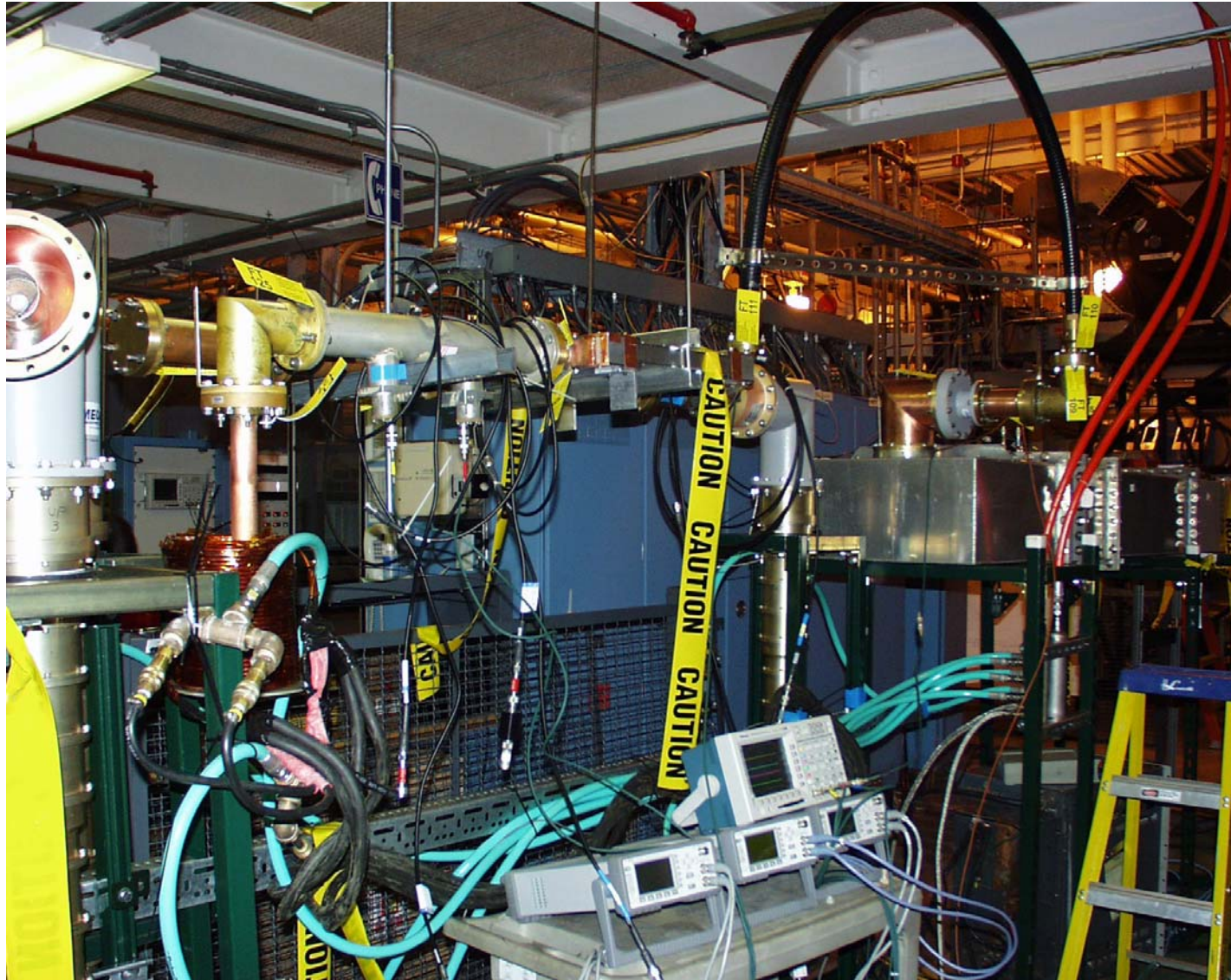
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- **Collaboration of FNAL and APS RF Group**
- **1.3 MW CW Klystron configured in pulsed mode.**
- **Pulse length: 4 ms, 1 Hz repetition rate.**
- **Frequency: 352 MHz.**
- **Two Conditions:**
  - Under matched condition: all three ports are terminated with 200 kW loads.
  - Under reflected condition: port #2 is shorted through a ferrite phase shifter, port #3 is shorted without phase shifter, port #4 is terminated with a 200 kW load.

# Test Setup (matched condition)



# Test Setup (reflected condition)



# High Power Test

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- **Test Procedure**

- Test started at 10 kW. RF power is increased in 10 kW increments until breakdown of a component.
- Dwelling time at each power level: ~ 10 minutes.
- At each power level, ferrite phase shifter was adjusted to several fixed value while amplitude and phase of output power was measured (under reflected condition).

- **Breakdown Detection**

Optical arc detector, reflected RF signal, audible sound caused by arcing.



# High Power Test

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- **Test Results**

- Under matched condition:

- Test stopped at 120 kW due to arcing within a connector of 1 5/8” heliax cable.

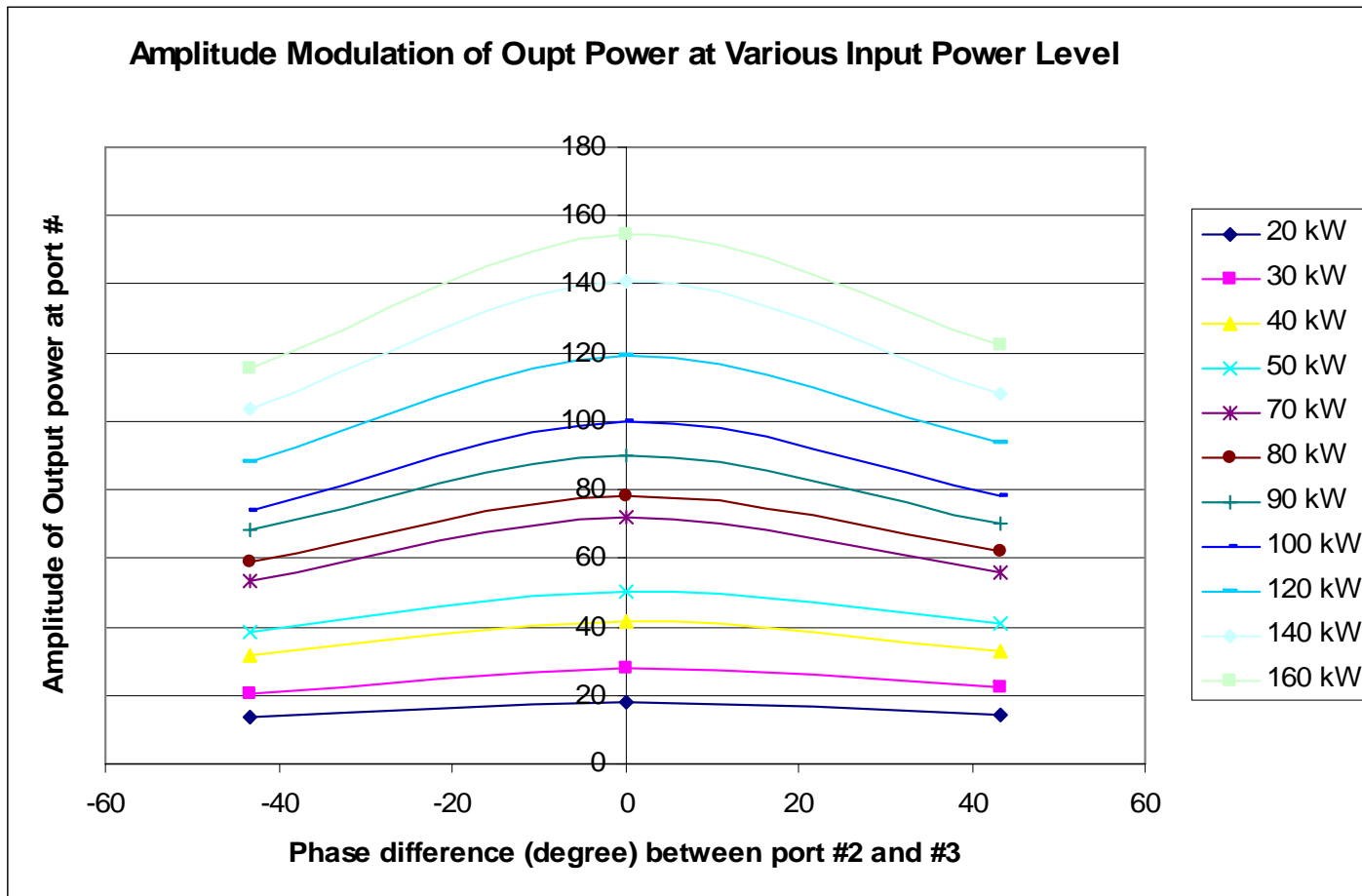
- After repairing the connector, skipped rest of test (under matched condition) and go to next stage.

- Under reflected condition:

- Test stopped at 170 kW due to arcing within phase shifter.

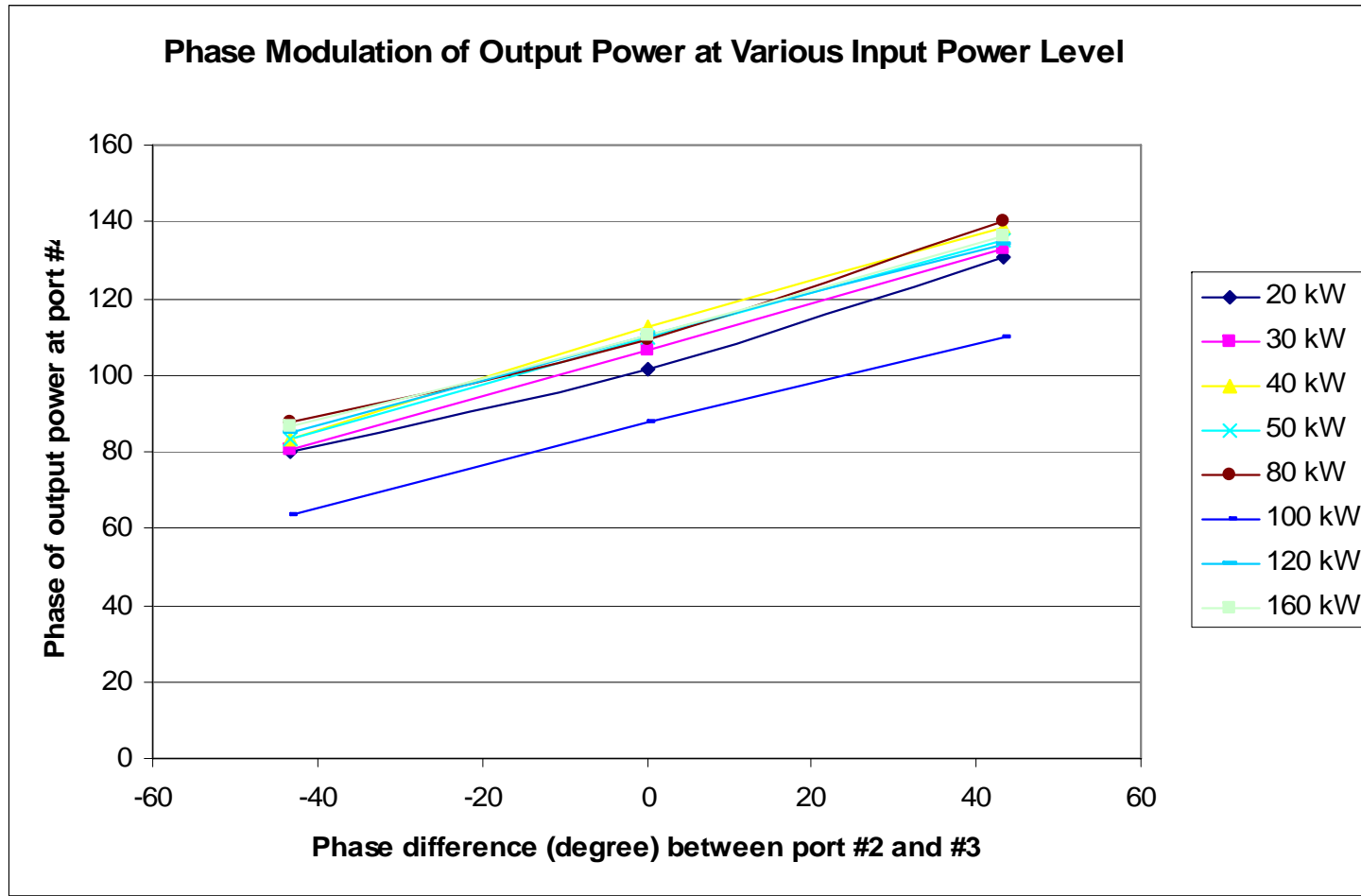
# High Power Test

- Test Results



# High Power Test

- **Test Results**



# Conclusion

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- **The hybrid was tested under full reflection condition up to 170 kW input power without failure. Except for RFQ, power handling capability of this hybrid exceeds operating power level required for all other RF structures in front linac.**
- **Joined hybrid and phase shifter worked as an IQ modulator: control amplitude and phase of output power.**

# ACKNOWLEDGEMENTS

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