Dealing with multipacting in coaxial fundamental power couplers

Mircea Stirbet

Jefferson Laboratory

Multipacting currents absorb RF energy and can produce breakdown in high power components as couplers, windows, high order mode absorbers, cavities.

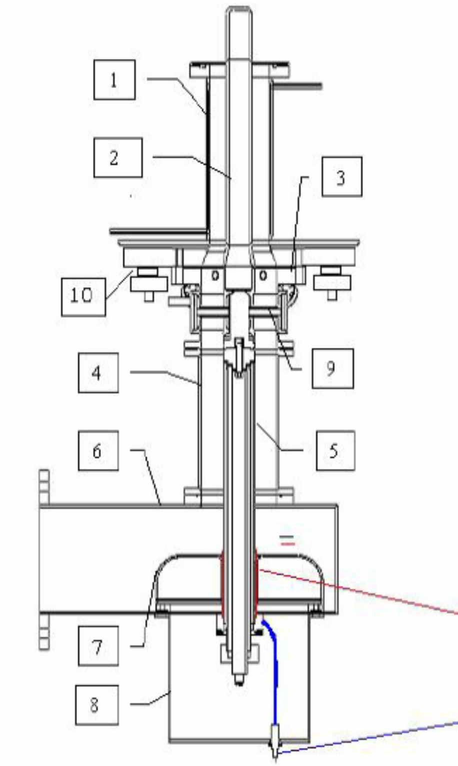
Conditions for multipacting in simulation:

- Emitted electrons have to return to the initial point
- The energy of the impacting electrons must be sufficient to produce more than one secondary electrons.
- Number of secondary electrons depends on the impact energy.

Aim of these simulations:

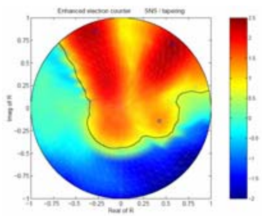
- To find the multipacting levels.
- To locate and identify multipacting processes.
- To predict the suppressing DC bias voltage.

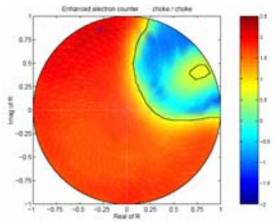
Simulations for the SNS Fundamental power couplers

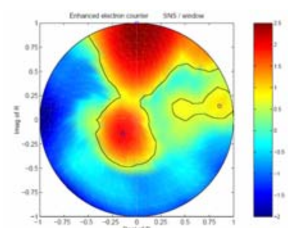


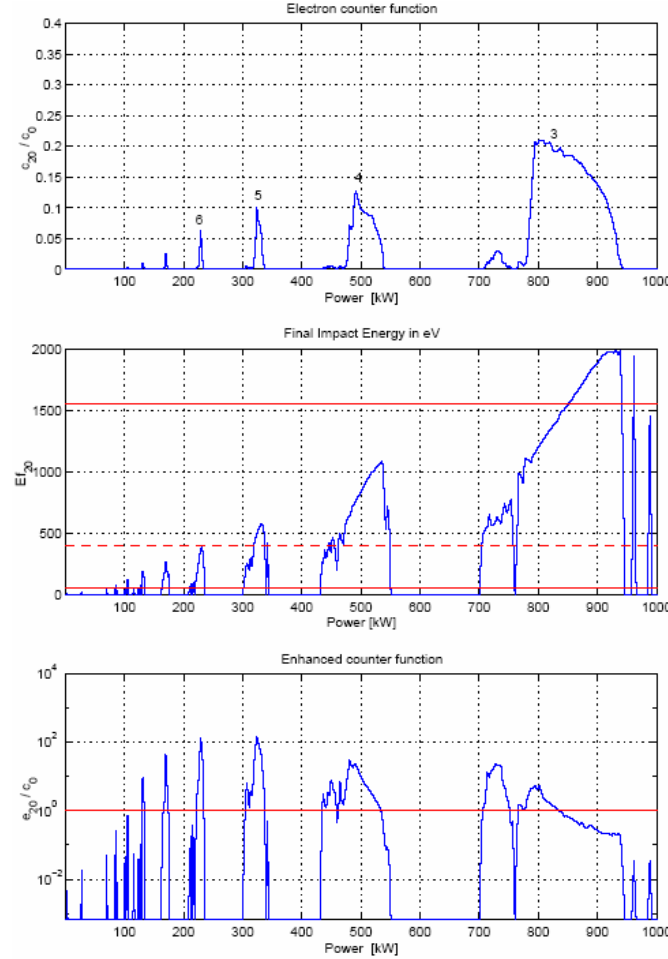
1 – Outer Conductor
2 – Inner Conductor
3 – Window Assembly
4 – Outer Extension
5 – Inner Extension
6 – Waveguide
7 – Doorknob
8 – Waveguide Cover
9 – Ceramic Window
10 – Vacuum Gauge

Predicted multipacting events in all vacuum and RF exposed components. Recommend to use at least -1.9 kV for dc bias









Multipacting in coaxial line

FWD input: max 550 kW pulsed, 1.3 ms 60 Hz at 805 MHz

Average power: 48 kW

E. Somersalo et al. University of Helsinki, Finland

Experience with FPCs for the SNS project

At the design stage we took care to address: modeling (RF, multipacting, Qext), material issues (type, surface finish, coatings), mechanical (tolerances), RF (losses, multipacting), thermal aspects (cryo heat load), instrumentation (vacuum gauges, electron pick up antenna, sapphire windows for arc detector, capacitor for DC bias, temperature and cooling agent flow sensors, tooling, **SAFETY** issues

Implement and use adequate procedures for:

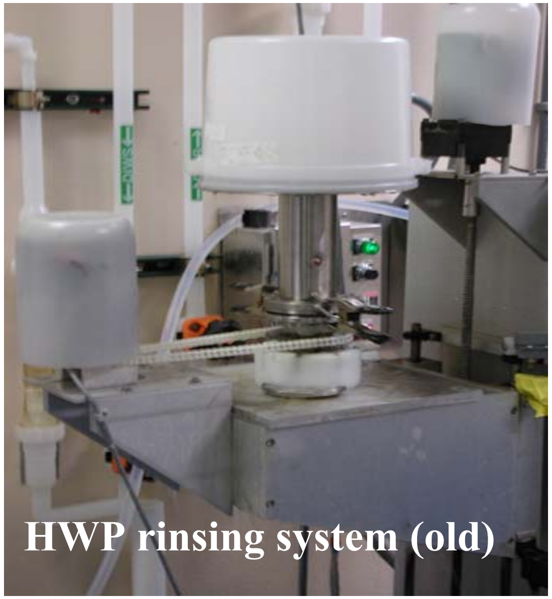
- Cleaning HWP rinsing of UHV coupler components
- Firing under vacuum (for annealing at 800 C, for blister test at 300 C after Cu plating)
- Clean room assemble and clean room tooling
- Baking under vacuum at 200 C for 24 Hours
- RF conditioning as a function of vacuum. Dedicated electronic racks with different interlocks. RF vacuum feedback loop integrated in system.
- Storage under nitrogen after RF conditioning and high power RF testing
- Clean room assemble on cavity
- RF conditioning as a function of vacuum on cryomodule
- For safe operation, apply DC bias in machine operation (with beam)

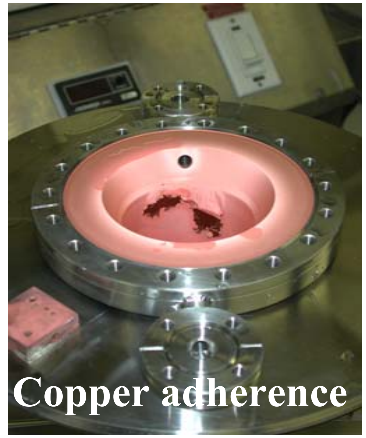
Expectations for the SNS FPCs: RF FWD pulsed 550 kW 1.3 ms 60 Hz

Tested on room temperature test stand: FWD TW mode 750 kW 1 ms 60 Hz and in SW mode up to FWD 600 kW 1 ms 60 Hz

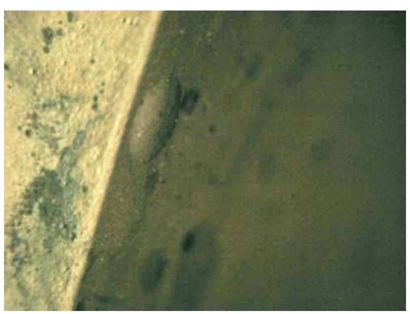
Tested on cold cavity: up to 450 kW 1 ms 60 Hz (cavity field limitation)

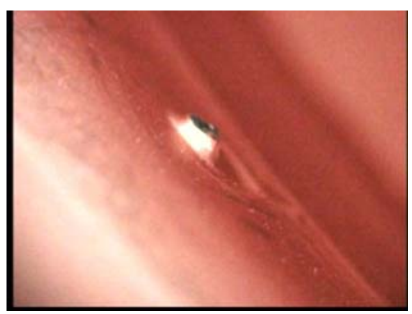
Copper plating issues on outer conductors


HWP rinsing system (old)


Copper adherence


Firing under vacuum (blister test)





Copper plating issues: oxidization, inclusions, blisters

Clean room assemble and vacuum leak checks

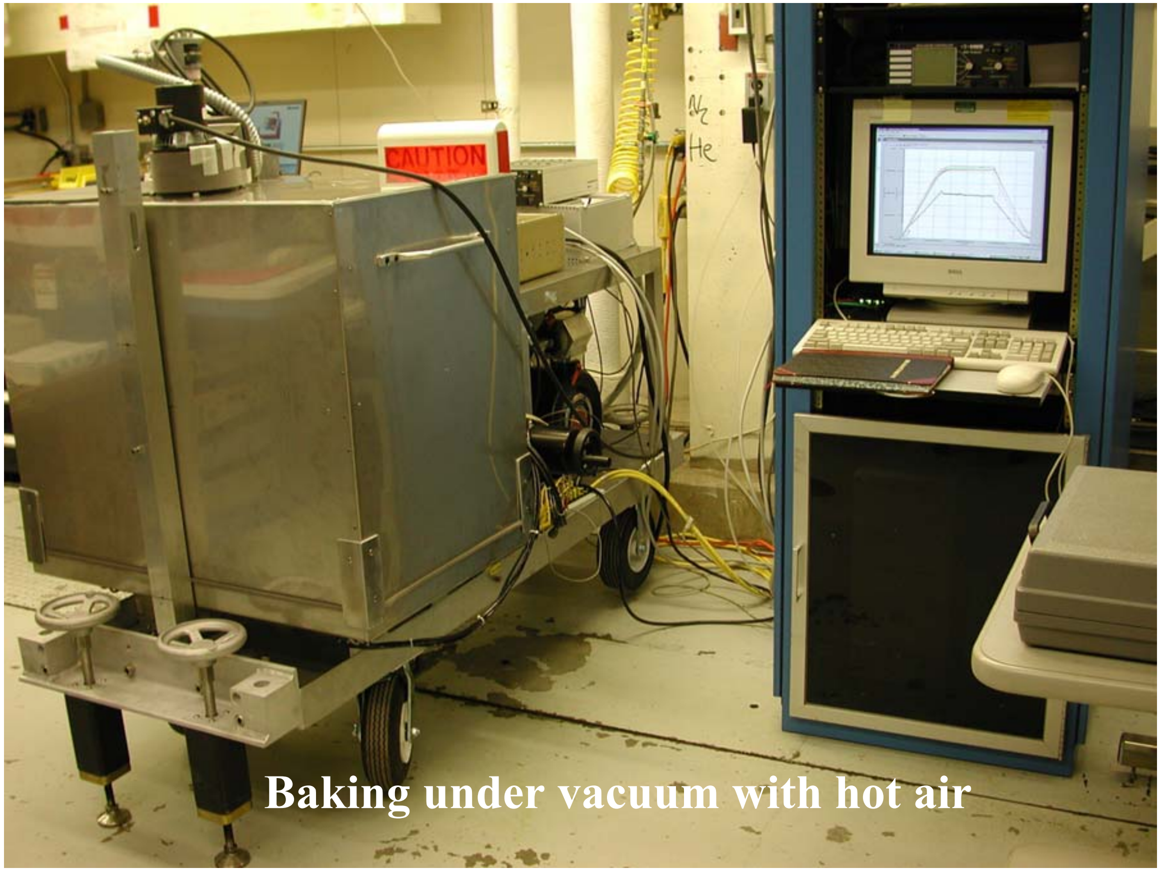

Cleaning OC in US bath


Vacuum leak checks

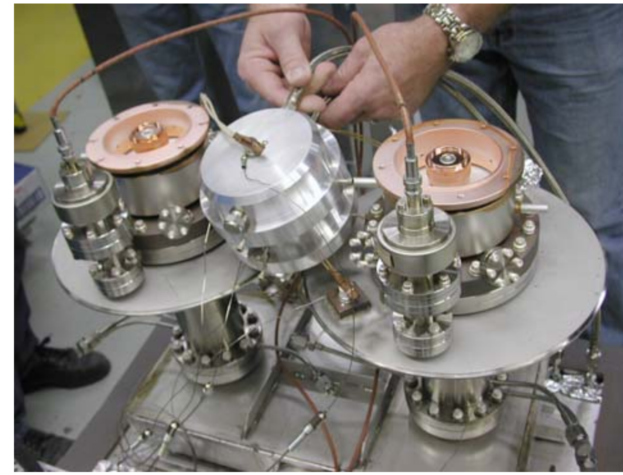

FPC assemble on a cavity

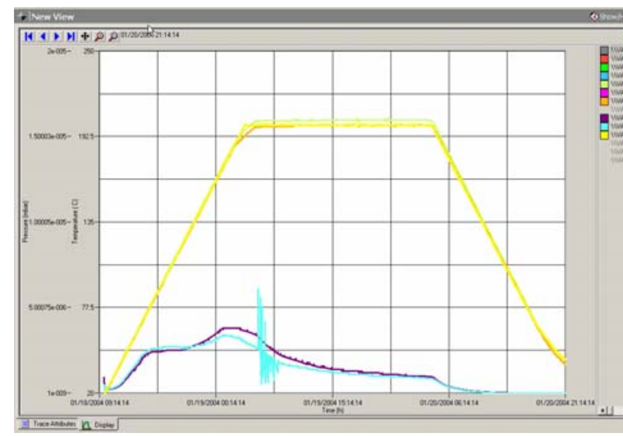

Cleanroom FPC assemble on connecting waveguide

Baking FPCs



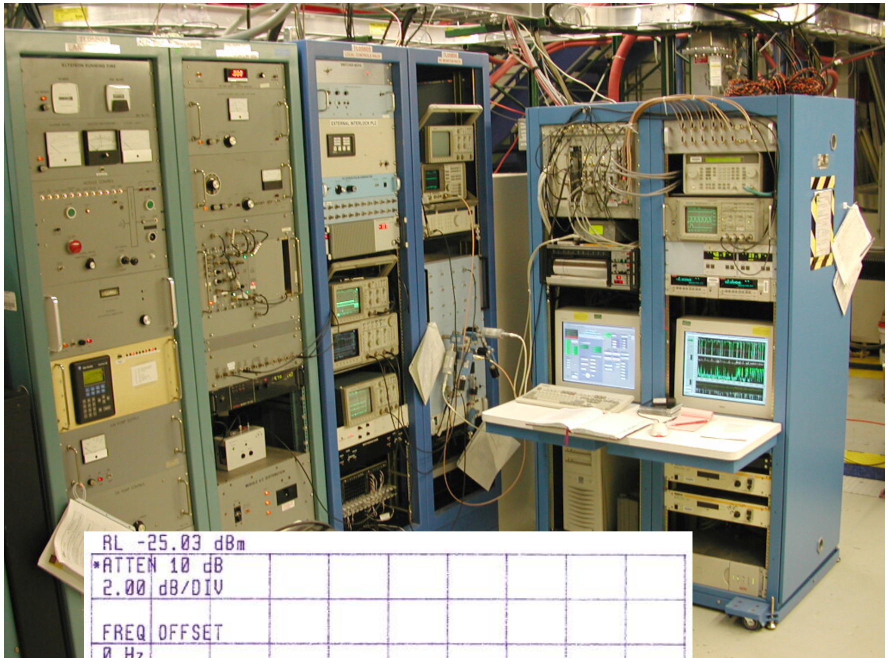
Baking under vacuum with hot air

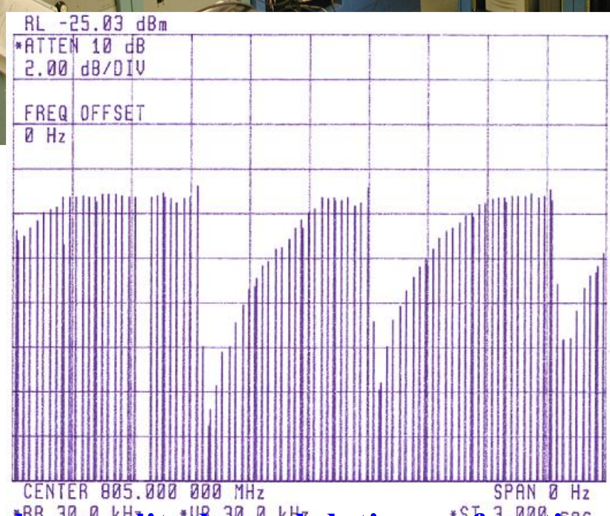




Temperatures and vacuum during bake

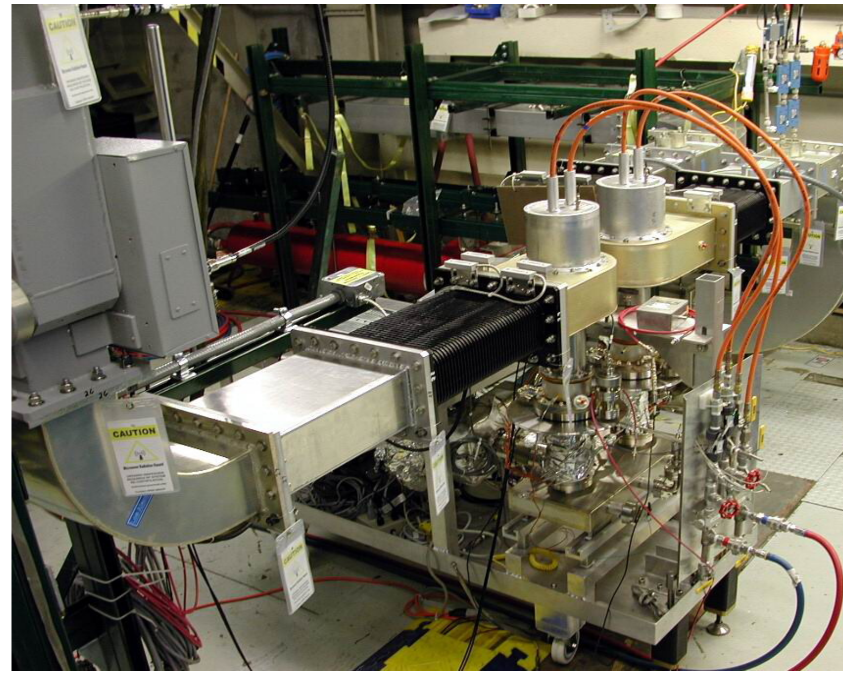
RF conditioning and high power RF tests





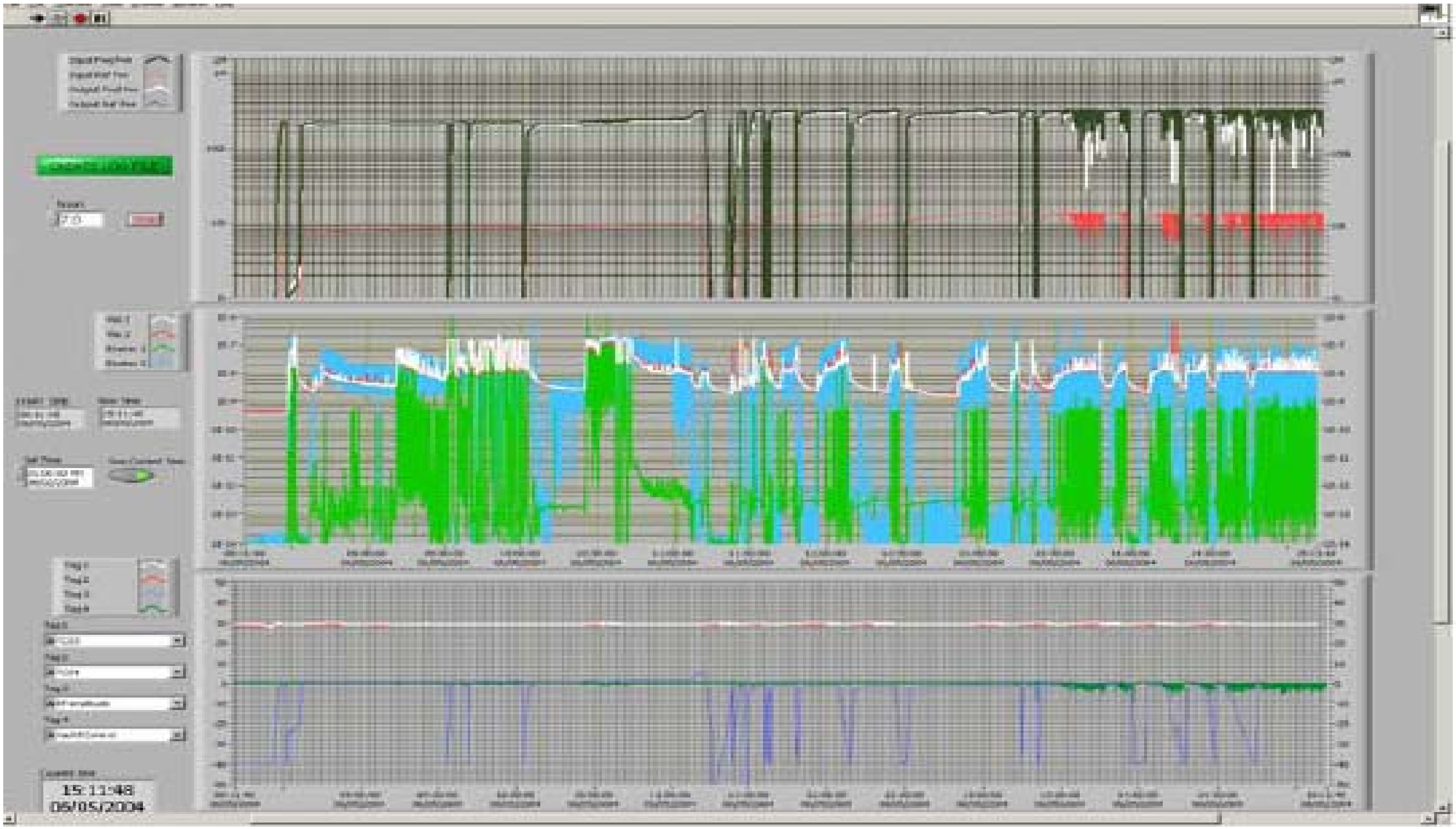
RF pulse amplitude modulation as function of vacuum

JLAB's Electronic racks and test stand.
Setup for operation in TW mode.



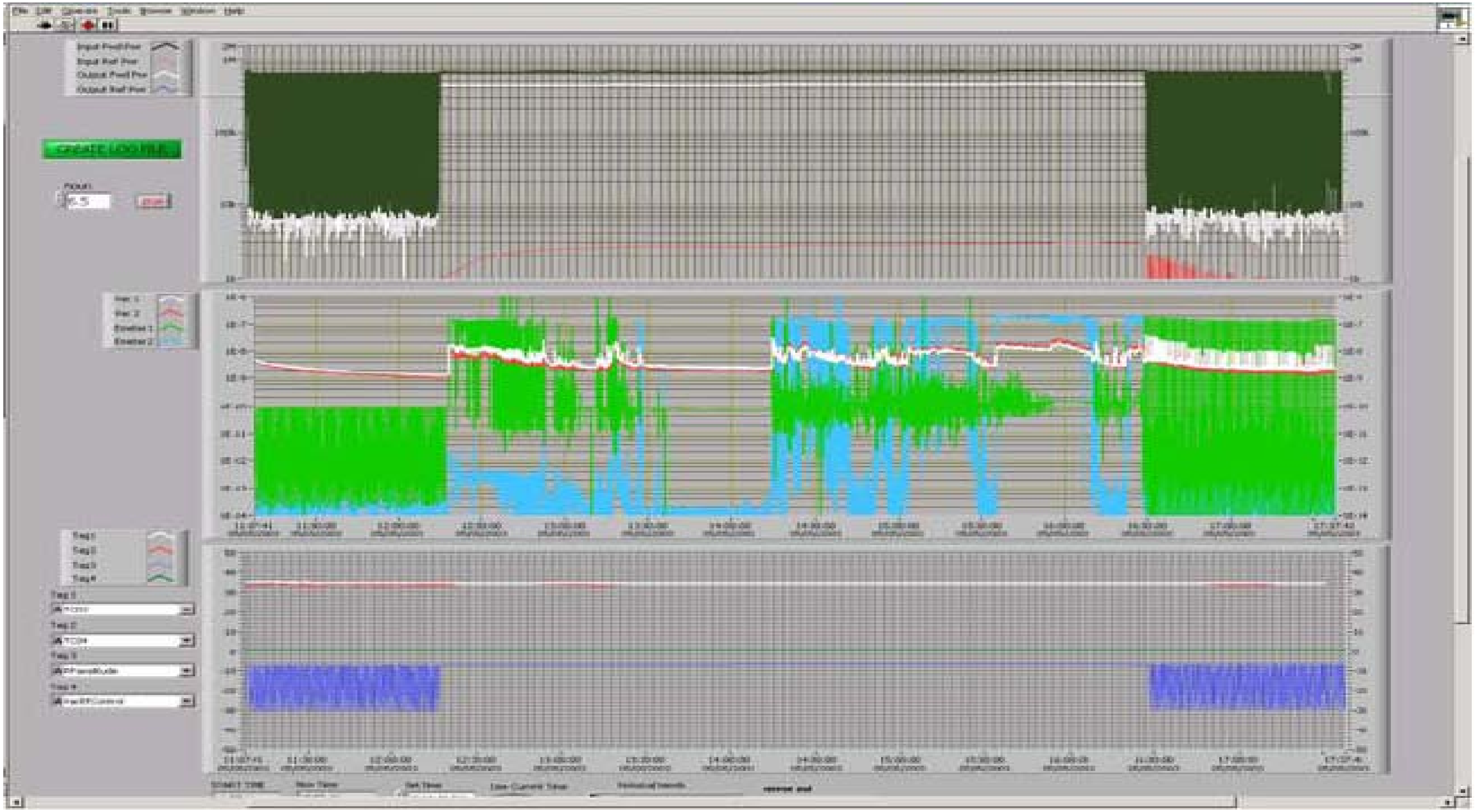
Tests performed in TW and SW modes, at LANL – on prototypes, JLAB and SNS ORNL on production couplers

RF conditioning and high power RF tests



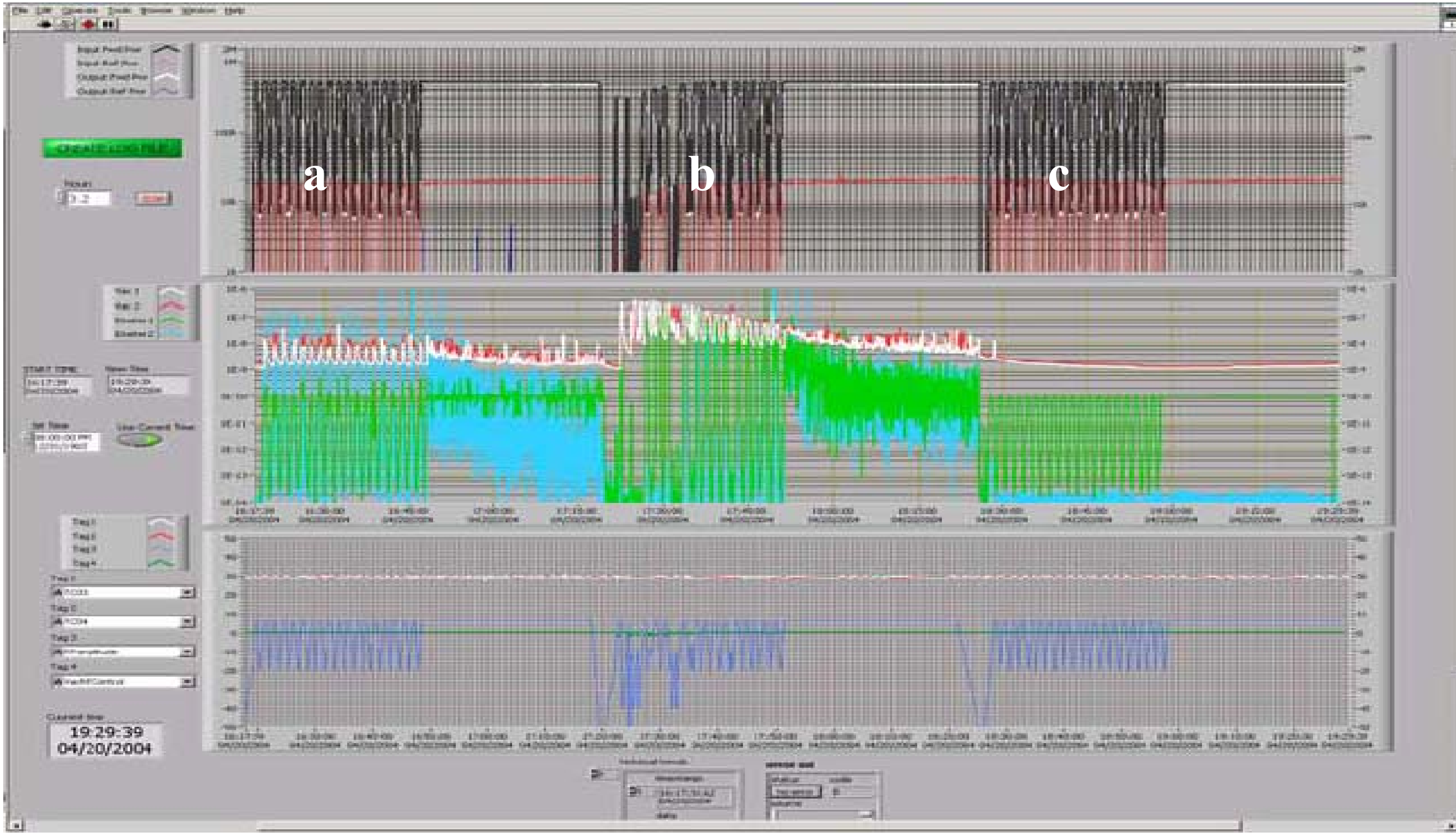
Vacuum and electron activity at the beginning of RF conditioning in TW mode

RF conditioning and high power RF tests cont 2



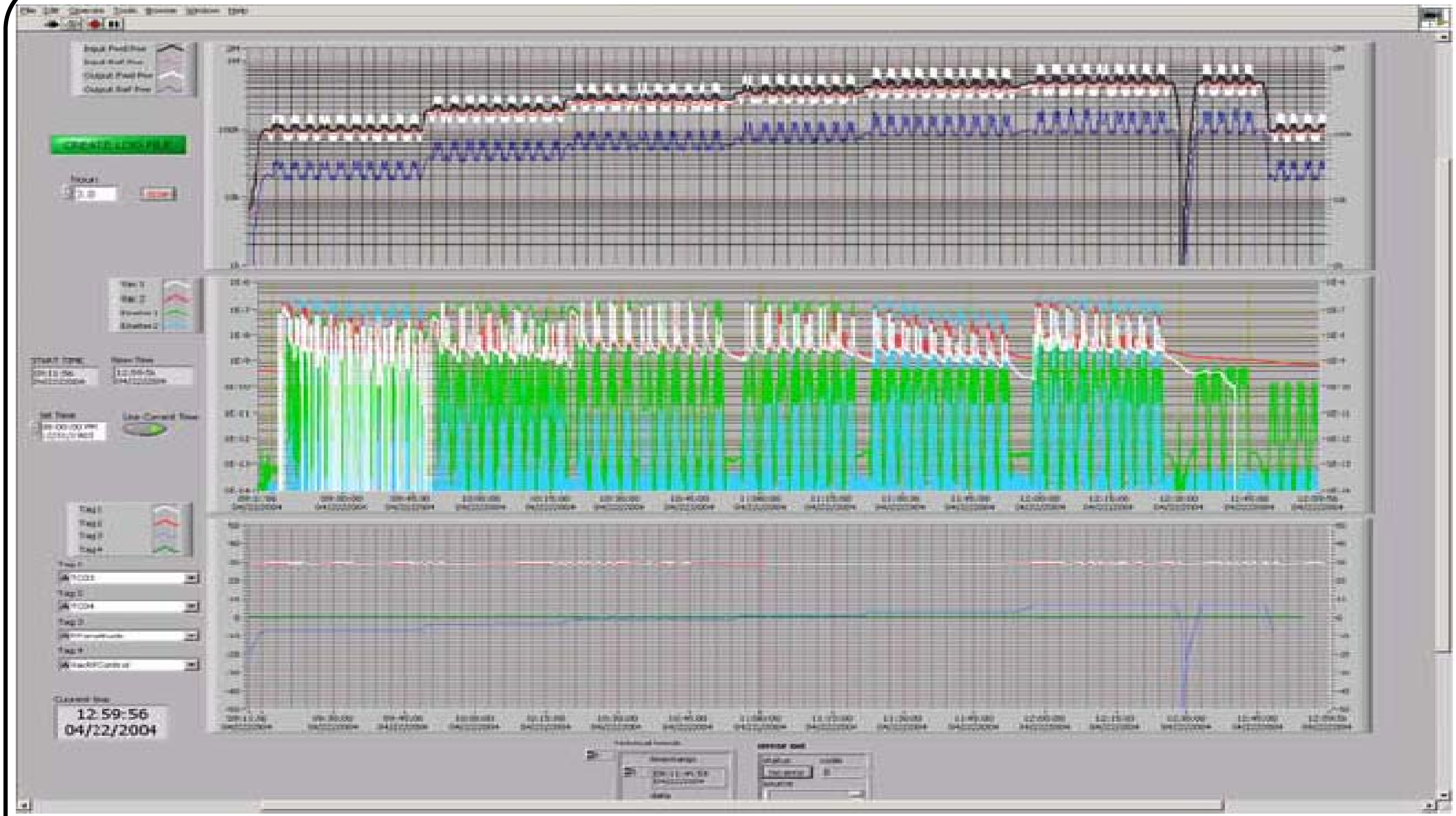
Deconditionig during high power RF tests

RF conditioning and high power RF tests cont.3



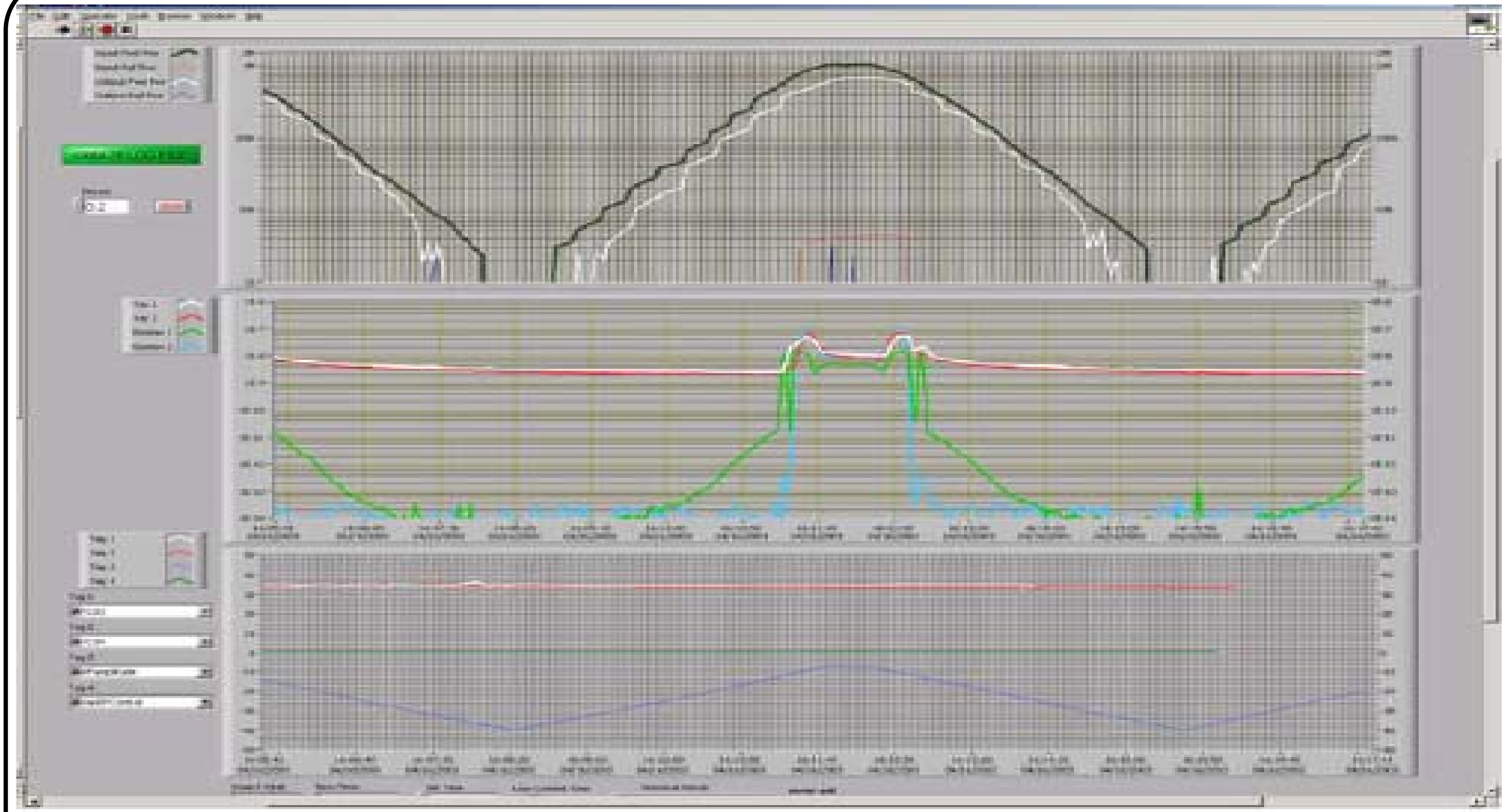
DC bias test: a) No dc bias ; b) -2.5 kV c) +2.5 kV

RF conditioning and high power RF tests cont. 4



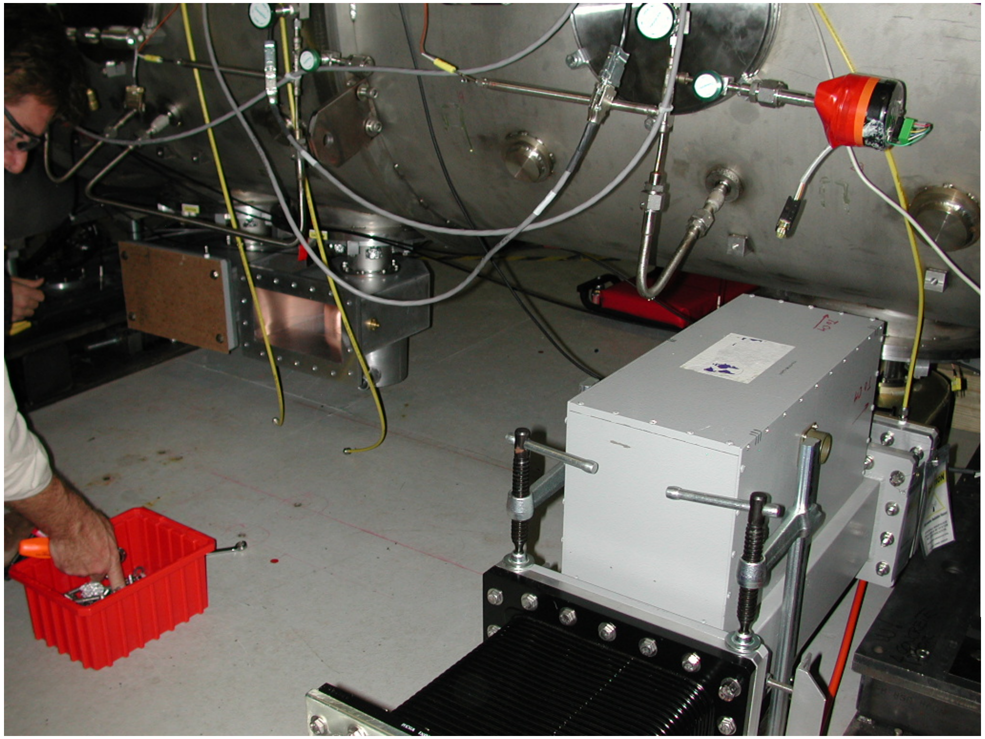
Vacuum and electron activity in SW mode up to FWD 600 kW

Multipacting events during high power RF tests

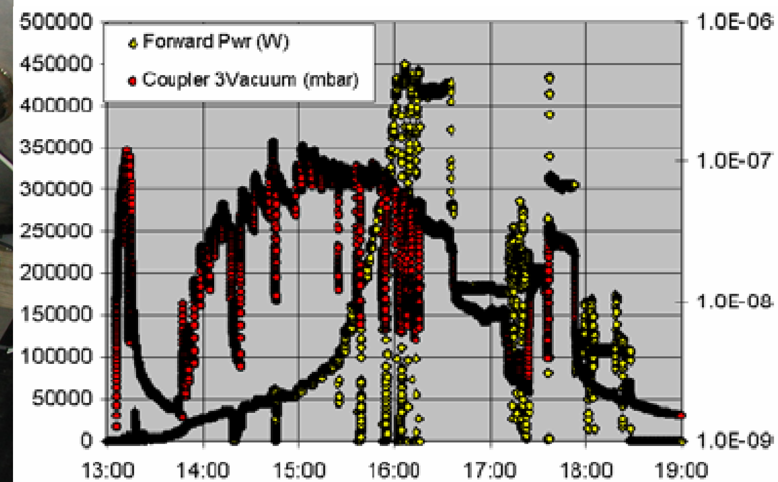


Multipacting at 600 – 700 kW while cycling 1 kW – 1 MW CP1 10 nA CP2 100 nA, ~2 10-7 mbar

Conditioning SNS Couplers on cryomodule



SNS FPCs on a cryomodule in CMTF at JLAB



Vacuum activity during SNS FPC conditioning on cryomodule

Summary

Multipacting simulations can predict:

- Some multipacting levels in coaxial lines

- Shifting the multipacting bands to higher RF power levels as a function of coaxial impedance (50 Ω, 60 Ω is multipacting free?, 75 Ω)

- Effective DC bias values (and polarity) to control multipacting levels

Multipacting simulations don’t predict:

-Time evolution of multipacting events

- Deconditioning

- RF memory

Efficient methods to deal with multipacting in coaxial couplers are available.

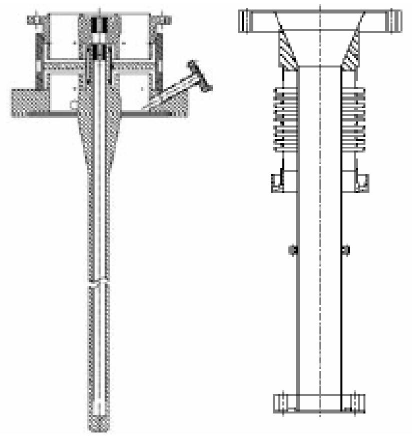
Once multipacting events are understood and properly controlled, should be considered as an efficient tool in conditioning components exposed simultaneously to high power RF and ultra high vacuum

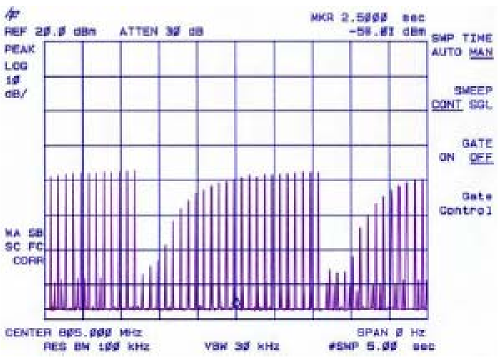
Making the FPCs for the SNS project was a demanding job. Support was needed and was generously granted in different laboratories: JLAB, LANL and SNS-ORNL. In time, several tens of persons were involved.

Looking forward for the good news: machine operation with beam, I want to thank everybody concerned and to mention here one name:

Katherine Wilson.

Experience with fundamental power couplers for RIA project



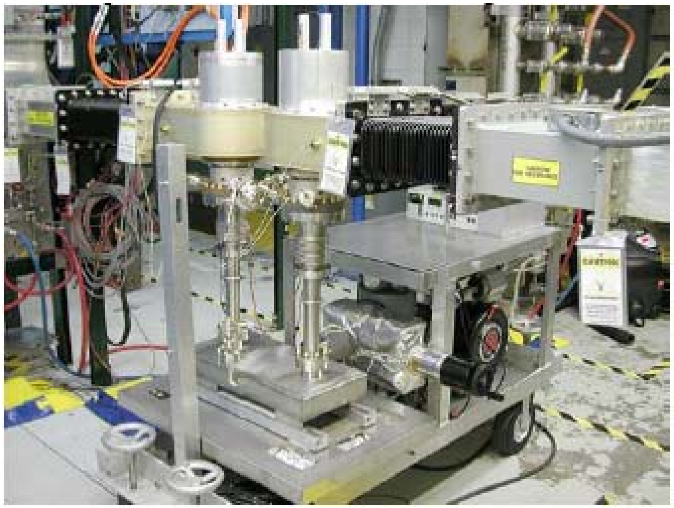


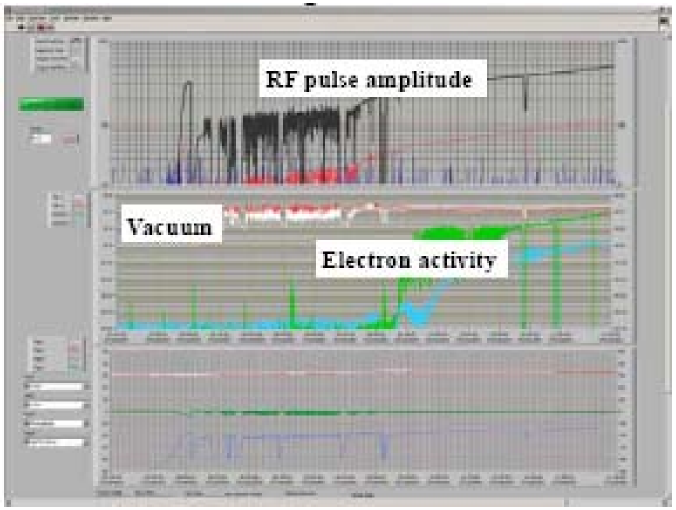
In operation couplers should be able to sustain FWD CW mode 10 kW at 805 MHz

Tested in TW mode up to 200 kW 1ms 60 Hz, average power 9 - 12 kW.

No hard multipacting, **no dc bias**

RF conditioning memory, after 2 weeks under vacuum the RF power could be ramped directly to 200 kW (outgassing 2 10-8 mbar, eec 100 nA)





http://www1.jlab.org/ul/Publications/documents/ACF20F.pdf

Dealing with multipacting on LEP2 main power couplers

When operated in LEP, the power couplers showed erratic vacuum outbursts. To avoid such catastrophic occurrences, a) the control of klystron power has been made much faster, b) the RF power dissipations and heating in window area minimized and c) control the multipactor (resonant avalanche discharge) in the coaxial part of the coupler

(D. Boussard, RF Hardware Status, Chamonix, 1994)

Coupler's geometry: (Changing from 50 to **75 Ohm coaxial line**, trying couplers with eccentric antennae)

- Outer conductor surface (grooving, special treatments like discharge in Ar atmosphere, ion implantation)
- **Stainless steel massive block with smooth surface for outer conductors.** Grooved surface inconclusive.
- **Ceramic coating with TiN**.
- **Outgassing control (firing, improved cooling, copper plating)**

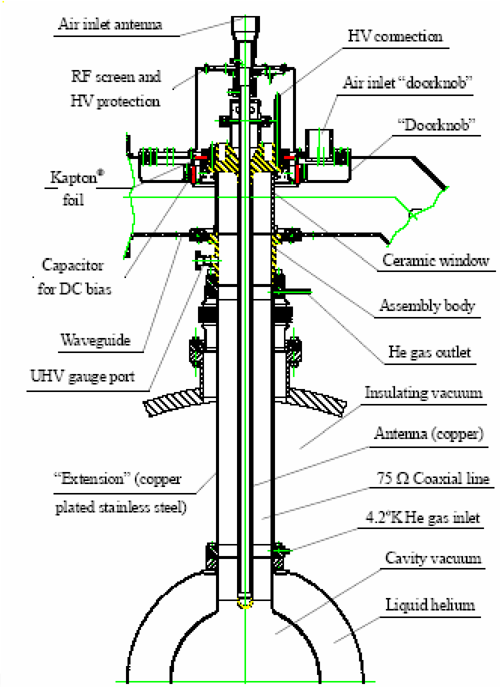
Instrumentation:

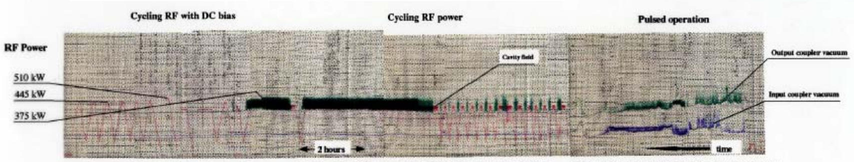
- **fast vacuum gauges, electron pickups, vacuum RF feedback controllers, dc bias**
- **Copper plating:**
  - Electrochemical methods
  - **Sputtering**
  - Coating the outer conductors with NEG getters

- **Wet cleaning and assemble in clean room (dry cleaning was performed on several couplers)**

- **Baking**
- **RF conditioning as function of vacuum on room temperature test stands**
- **Multipacting control (**perturbation with permanent magnets, **second frequency, dc bias)**
- **Storage under nitrogen after RF qualification under vacuum**
- **RF conditioning as a function of vacuum on the cryomodule**
- **DC bias protection in machine operation**

Experience with fundamental power couplers for LEP2





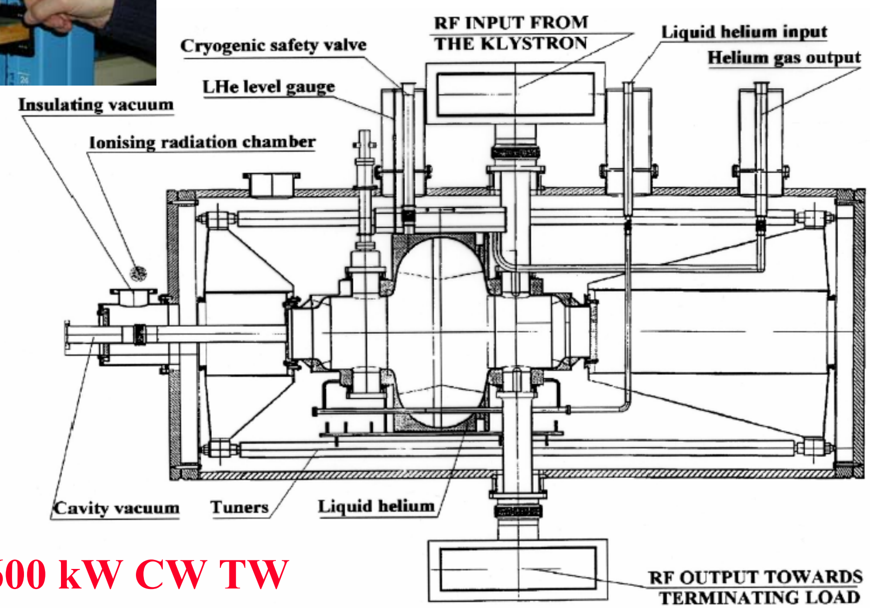
Crossing the 375 kW multipactor level with a DC bias of 2.5 kV.

Cycling the RF power (controlled by computer and an analog feedback loop, adjusting the RF power as function of the vacuum) with vacuum spikes at 375 kW

RF pulsing 15 ms / 50 ms. For the first hours with very strong vacuum activity.

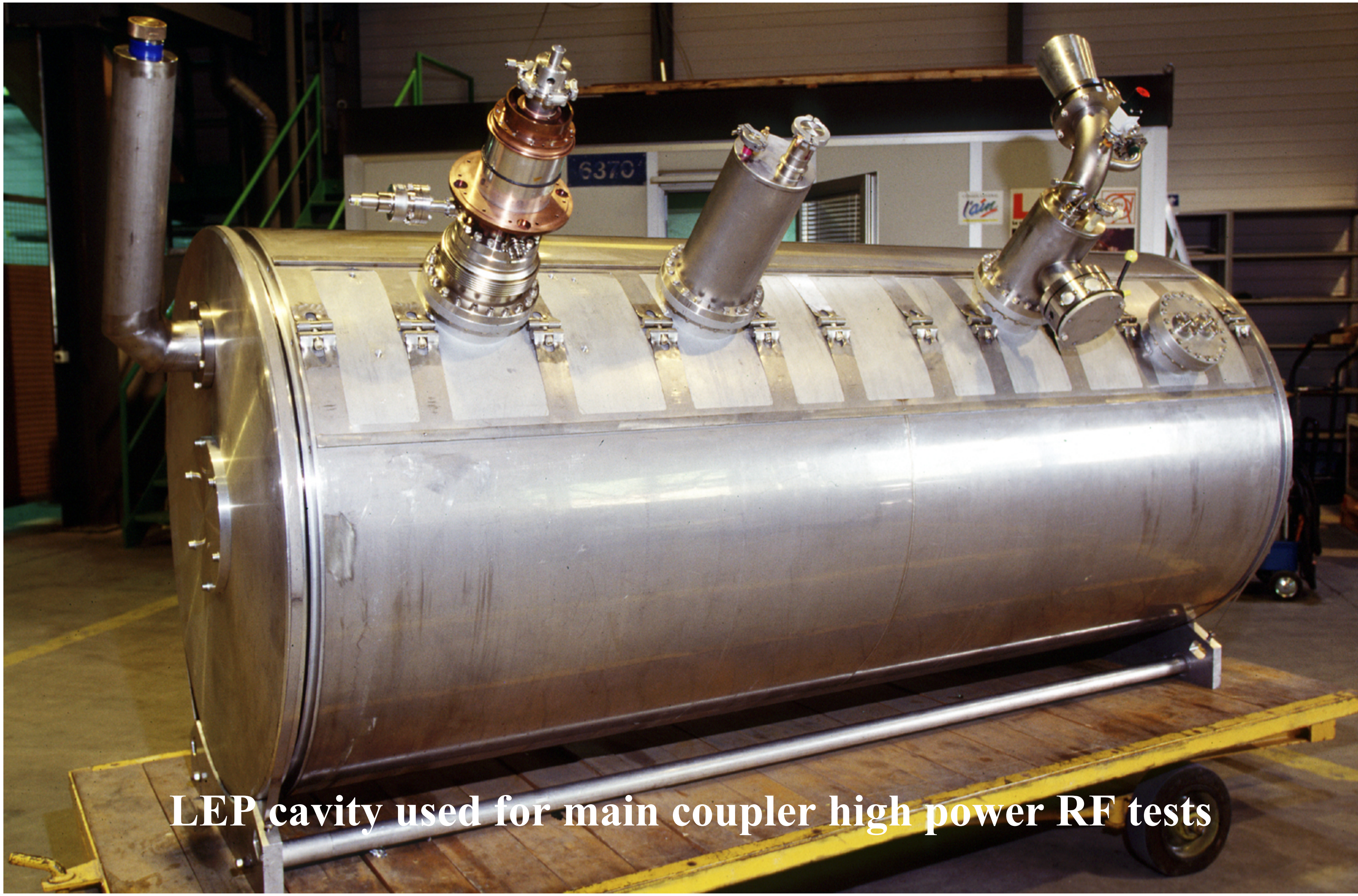
565 kW CW test

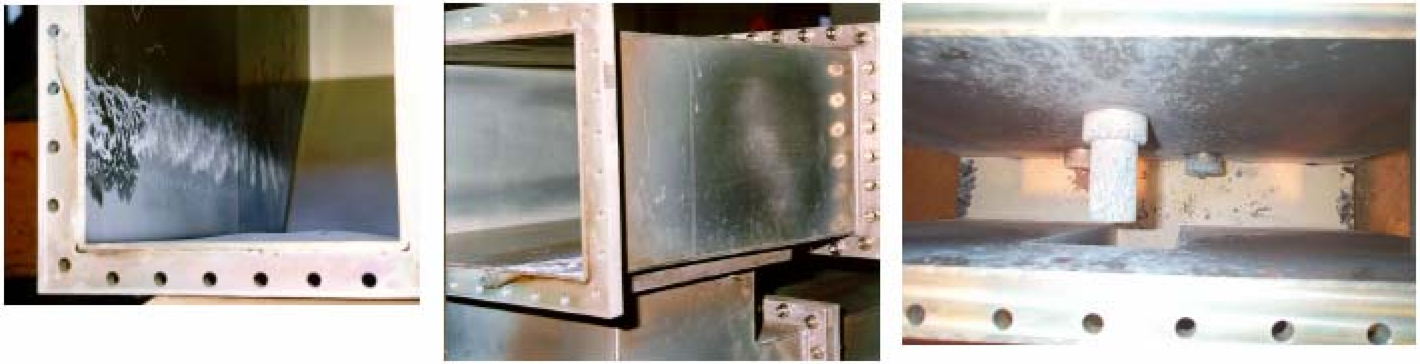
48 hour long-term test at 445



600 kW CW TW

LEP test cavity



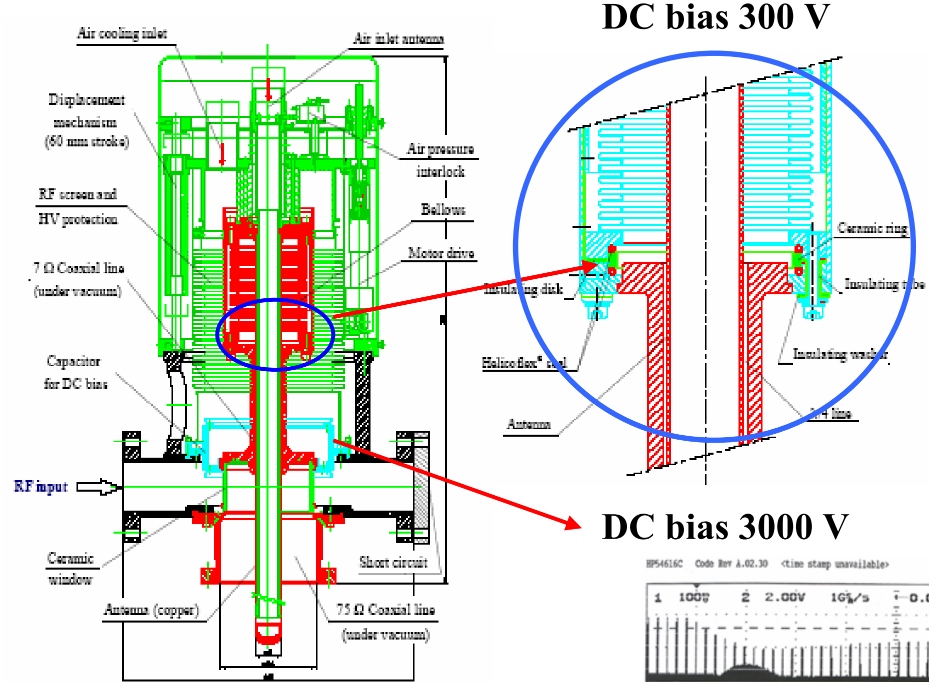


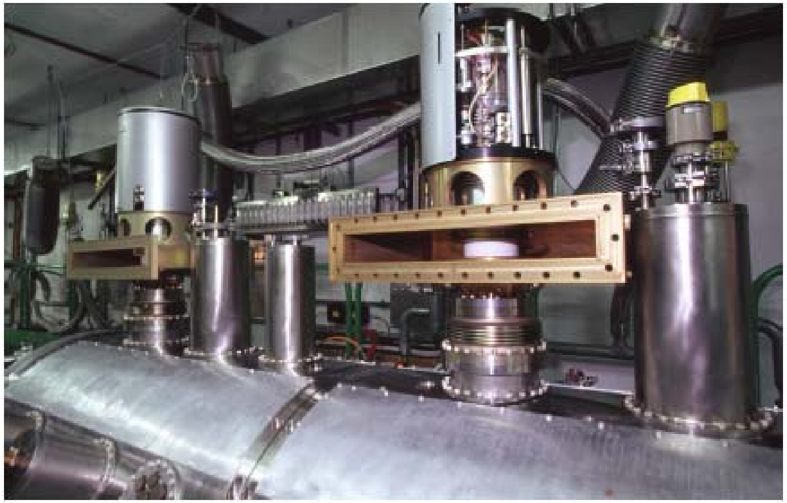
High energy operation of LEP leaves its marks…

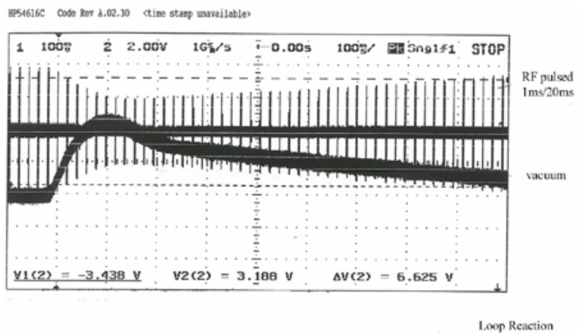
But not on the main power couplers. None has failed from the 288 installed.

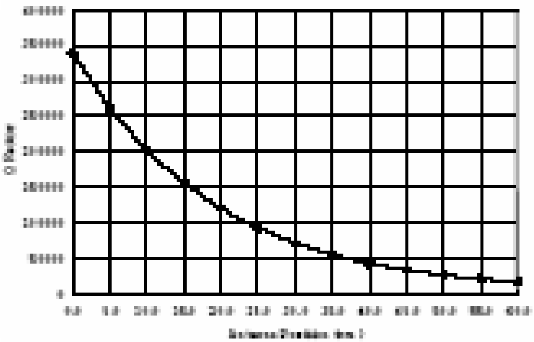
LEP2000 modules

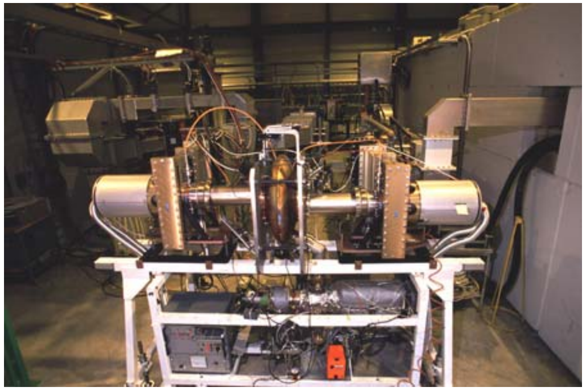
Experience with variable power couplers for LHC











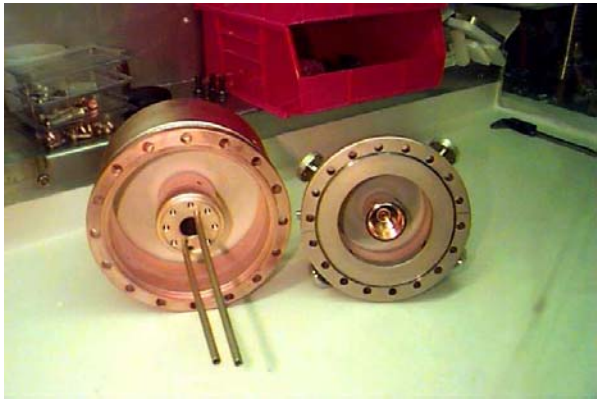
Will operate at: **FWD CW 120 kW and pulsed 180 kW, 32 kW delivered to the beam**

On room temperature test stand: FWD CW 500 kW, pulsed 2 MW 50 ms pulse at 10% duty

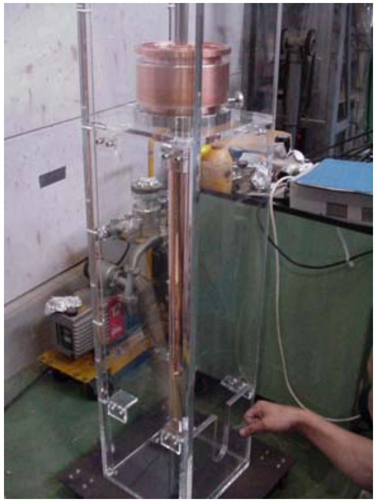
On cold cavity tested up to FWD CW 300 kW, Qext variation 2 order of magnitude under

http://documents.cern.ch/archive/electronic/cern/preprints/sl/sl-99-074.pdf

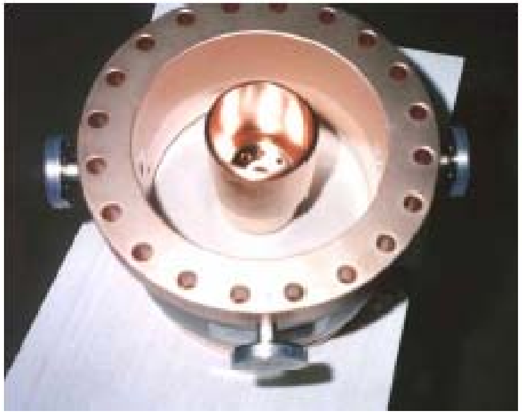
Coaxial power couplers with planar ceramic



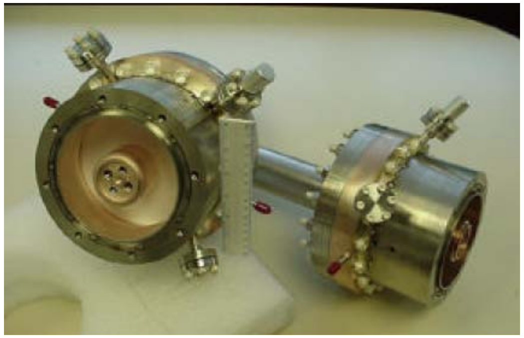
Toshiba 500 & 805 MHz windows



500 MHz window assembly



972 MHz window



805 MHz CPI window assembly

RIA 805 MHz window assembly

Plan to use similar windows:

- 200 MHz for MICE project

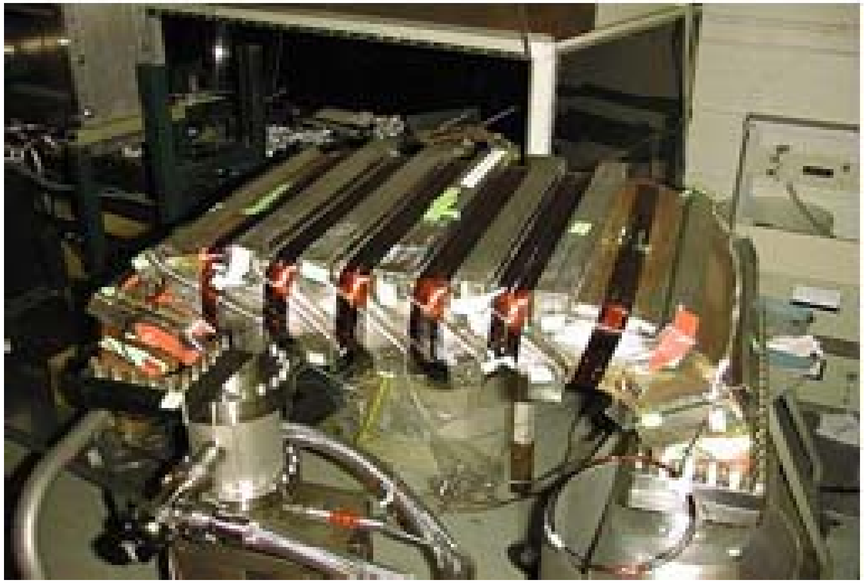
- 400 MHz for RFQ cavities

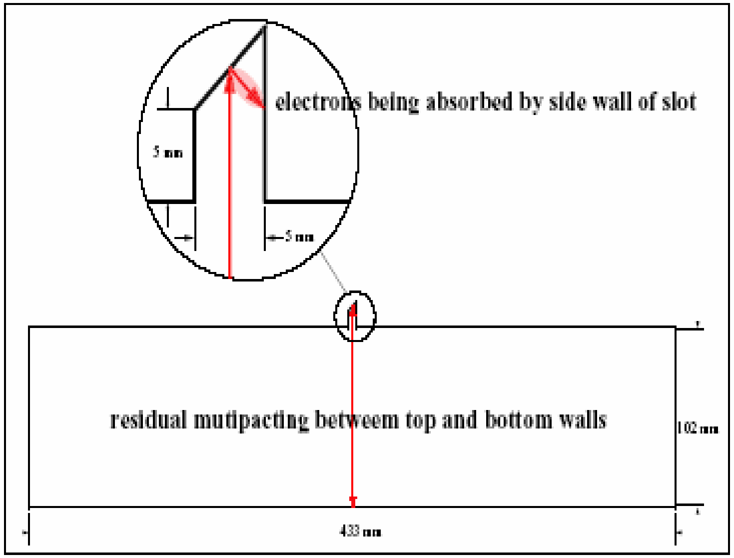
- 703 MHz BNL project

- 750 MHz AES injector

- 750 MHz 1 A CM

Multipacting control in waveguide couplers





Solenoid coils on a reduce height waveguide to suppress multipacting (field ~30 Gauss)

Suppressing multipacting by a slot 5x10 mm 2 – 7 %reduction

Geng et al. 1999 - 2003