RF test benches for electron cloud studies

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1. The Traveling Wave multiwire chamber

1.1. Introduction: the TW chamber and the need of a Ring Resonator

1.2. Improvements on the original TW chamber

1.3. Coupler requirements

1.4. Calculation and design of strip-line type coupler circuit

1.5. The final Ring Resonator

1.6. Conclusions and outlook

2. The Standing Wave single conductor coaxial chamber

2.1. Introduction: Why a Standing Wave coaxial chamber?

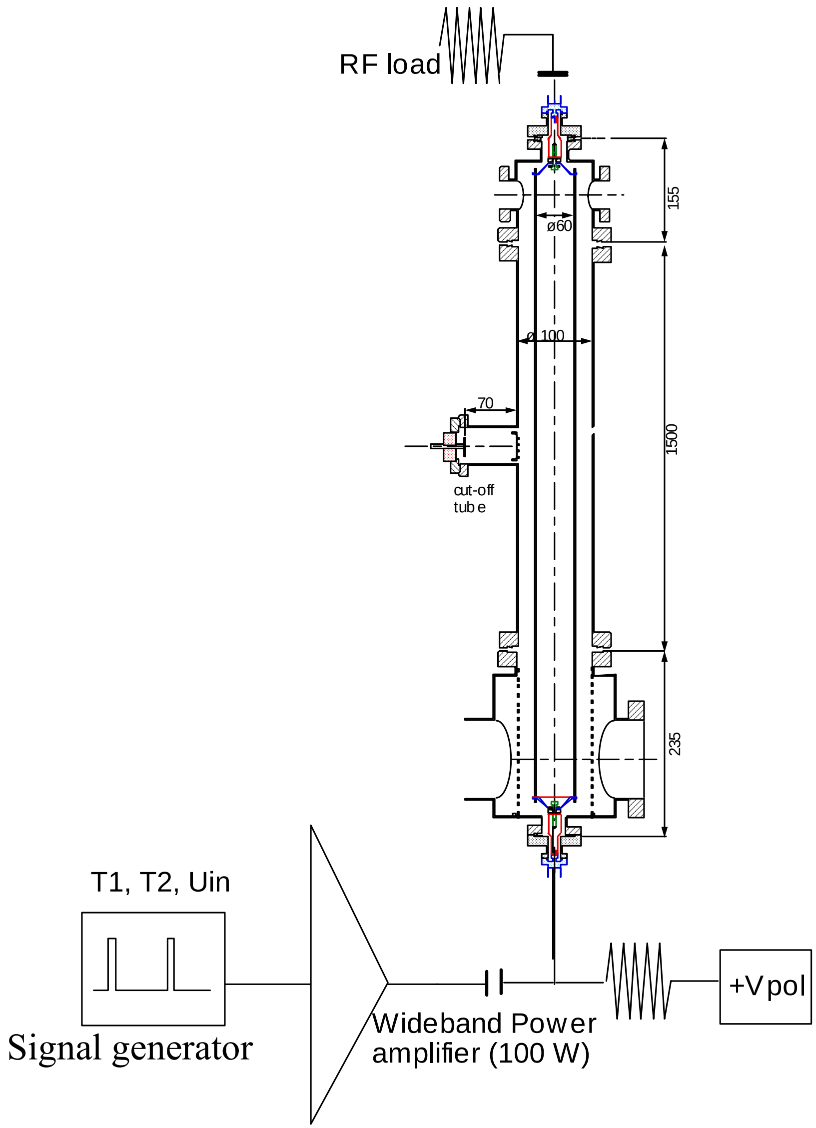
2.2. Experimental set-up

2.3. Multipacting in a resonant TEM structure

2.4. Scrubbing effect in samples and for the total chamber

2.5. Conclusions and outlook

1.1. Introduction: the TW chamber



- Short pulses travel along 6 inner wires simulating the proton bunches and producing multipacting in the chamber.

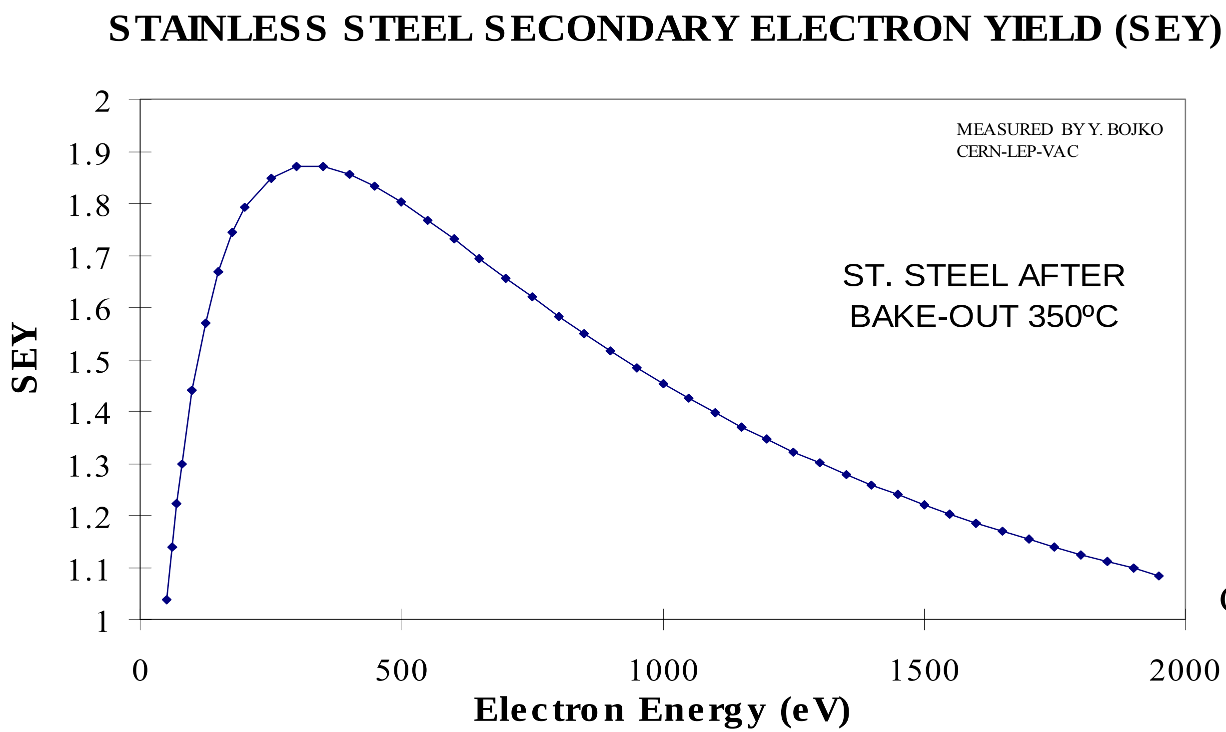
- The pulses are dumped in a load placed at the end of the vacuum chamber.

- Lay-out voltage limited by the wideband 100 W power amplifier:

$$V_{pk\text{-}pk_{MAX}} \sim 150V \Rightarrow E_{electron\_MAX} \sim 75eV$$

(for stainless steel)

Multipacting limits in Secondary Emission Yield:

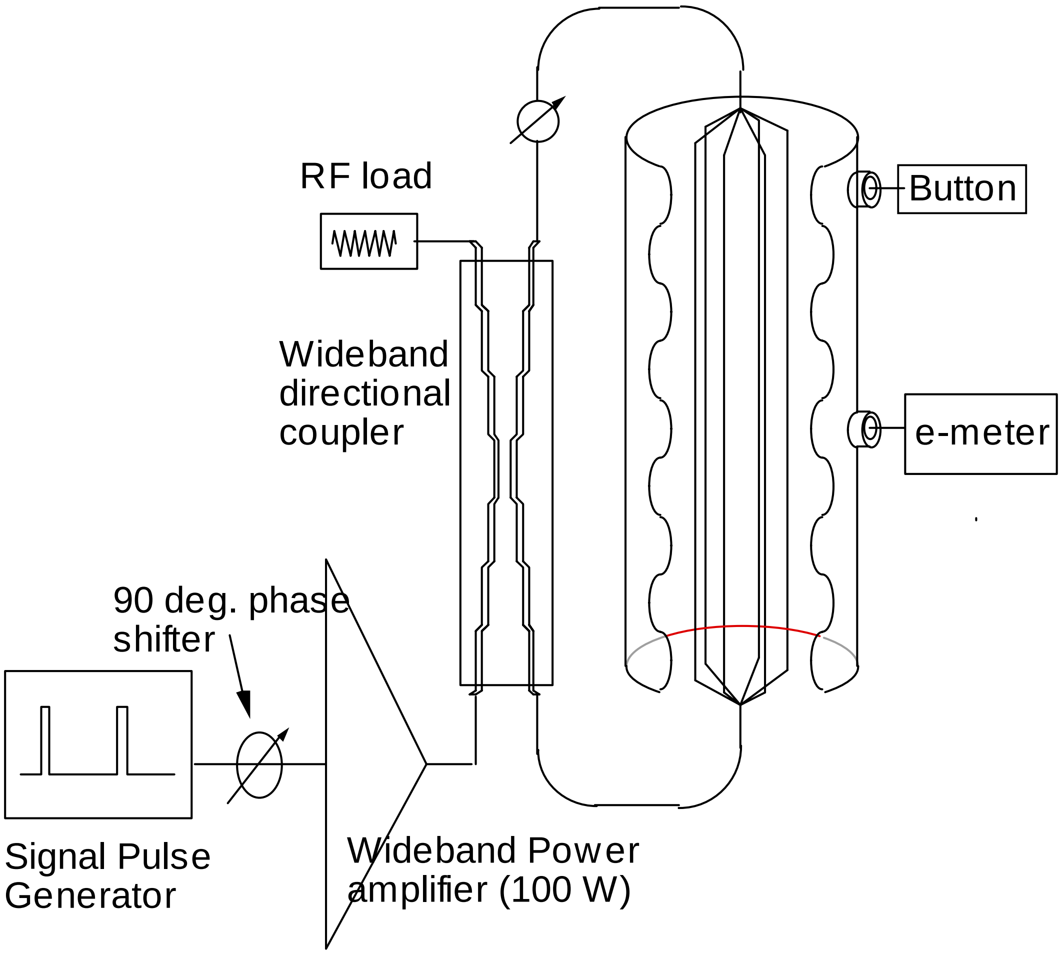


Courtesy of N.Hilleret

- Before bombardment, E_e=75eV ➔ SEY~1.6
- After bombardment, SEY(E_e=75eV) < 1.3 ➔ no multipacting!

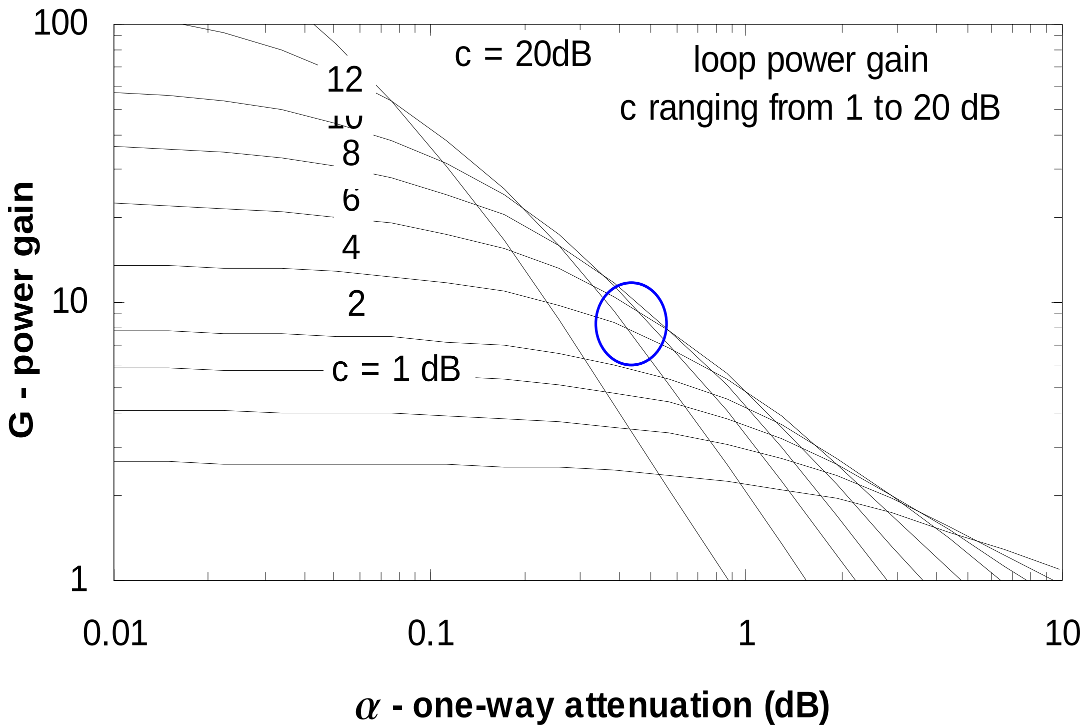
GOAL: E_e for LHC: 250 eV ➔ new lay-out for increasing V in a factor ~**3-4**.

Ring Resonator (RR) principle



- The pulsed power is not dumped into the load, but re-circulated again inside the chamber by using a directional coupler.

Motivation for the RR: loop power Gain



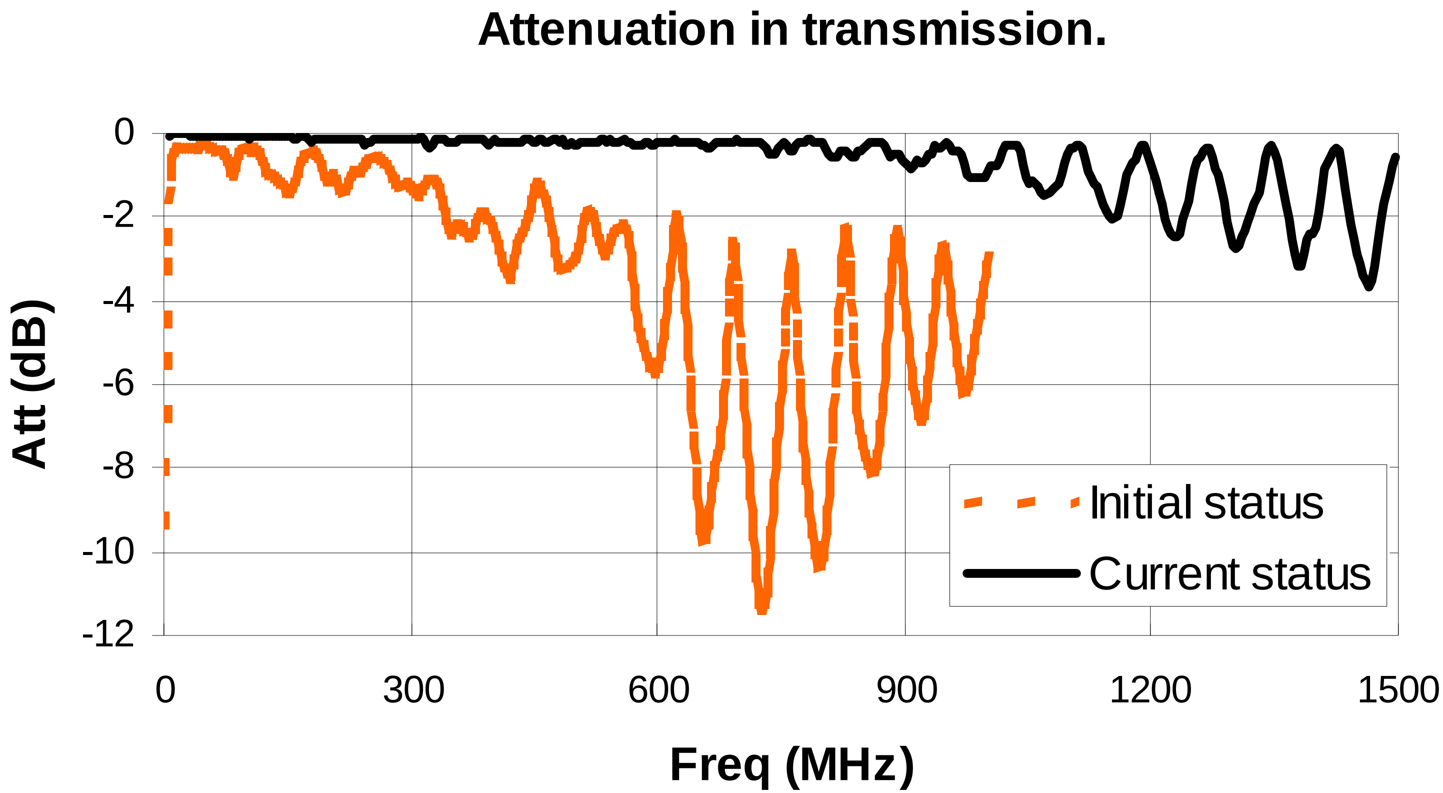
$$G = \left[\frac{c}{1 - 10^{-\alpha/20} \sqrt{1 - c^2}} \right]^2$$

c = coupling factor (dB)
α = set-up attenuation
G = total power Gain

REFERENCE:
Microwave filters, impedance-matching networks, and coupling structures.
G.L.Matthaei, L/ Young, E.M.T.Jones

α~0.6 dB
c~10 dB } ➔ G_{power}~8 dB (voltage factor~2.5).

1.2. Original TW chamber requirements



- Total losses along the RR must be < 1 dB (according to plot before)
- Finally, $|\alpha|_{chamber}$ < 0.3 dB up to 600 MHz (after improvements)

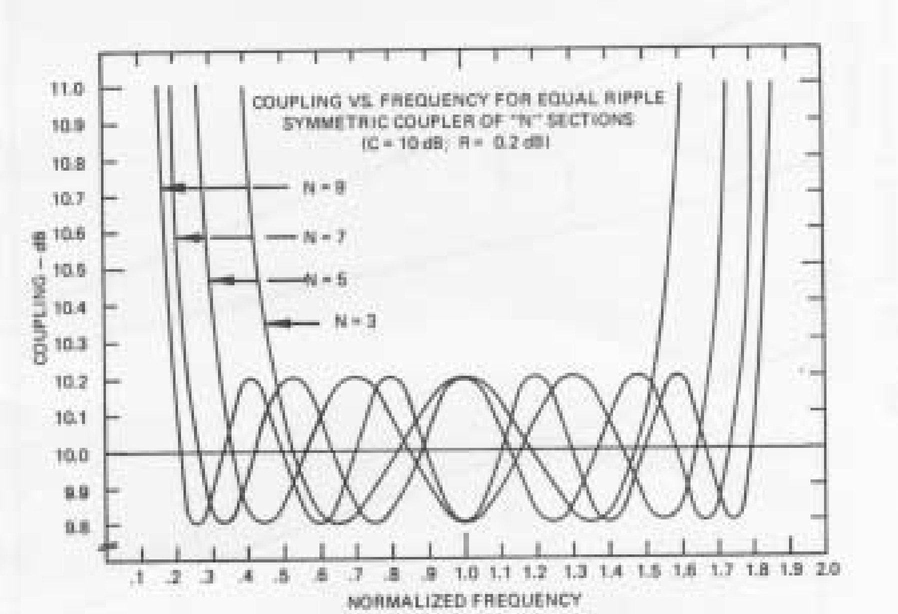
1.3. Coupler requirements

G_{power}=8 dB
Bandwidth: 20-600 MHz

Coupling factor c=10 dB

DC isolation up to 1 KV

Very low transmission losses at each arm (0.2-0.3) dB



Examples for multiple section $\lambda/4$ strip-line coupler characteristics

REFERENCE: **Strip-line circuit design,** Harlan Howe, JR

- SOLUTION: $\lambda/4$ symmetric 9 sections coupler!

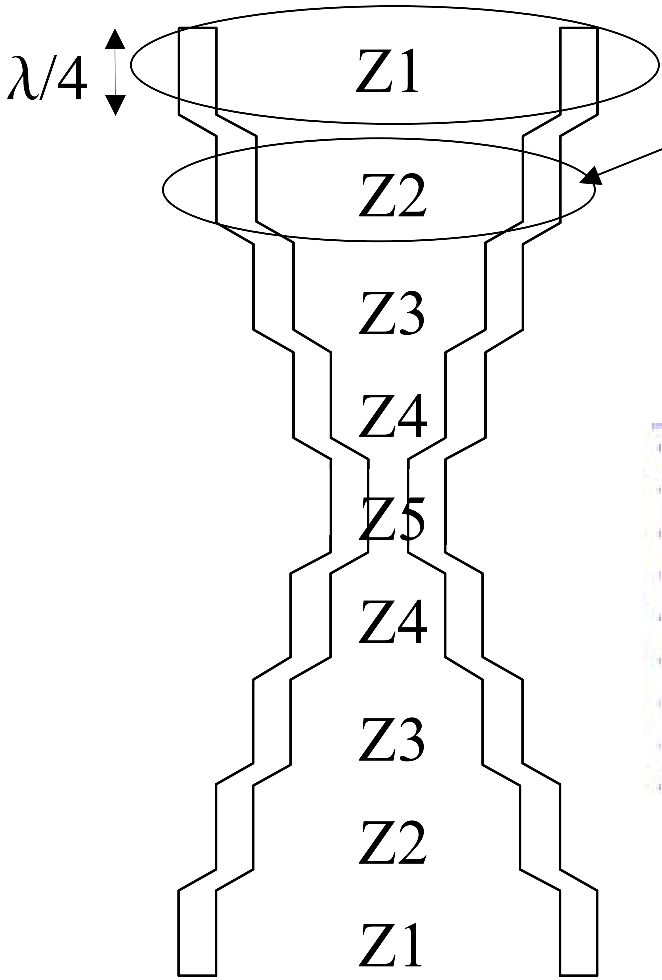
In our design, the relative Bandwidth=18, ripple= ±1 dB
Since f_{center}=300 MHz ➔ $\lambda/4$ = 25 cm ➔ total coupler length = 2.25 m!

Reasons for the choice of the presently used coupler layout

- Not easy to find on the market a coupler with such a characteristics: c=10 dB, BW=2 decades, standing about 1 kV between the strip-lines and to ground
- Not a printed version because metallic losses increase due to the presence of a dielectric (increase of current density)
- Shielding box not bigger than roughly 10x10 cm in cross section: limit due to propagation of wave-guide modes (cut-off around 1 GHz)

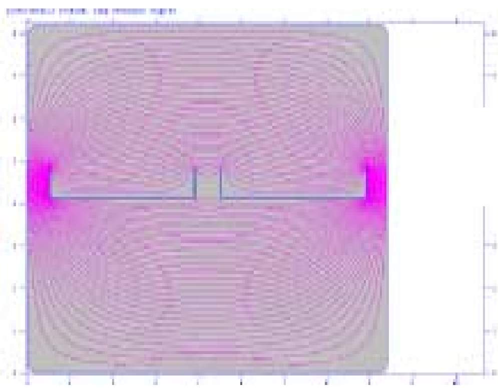
•That's why we decided to build it ourselves!!

1.4. Calculation and design of strip-line circuit



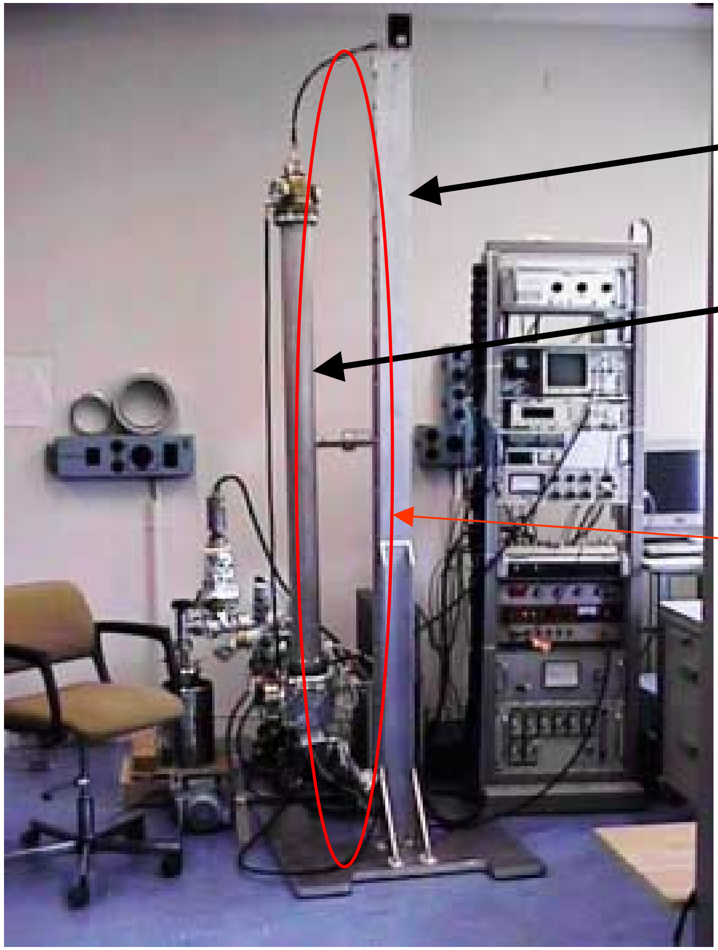
Each section has to be designed according to tabulated impedance values in odd and even mode.

- Design was done by ***SuperFish*** (2-d Electrostatic computer code)



- The design was tested and measured for each section in a test bench (50 cm long) using VNA.

1.5. The final Ring Resonator



coupler

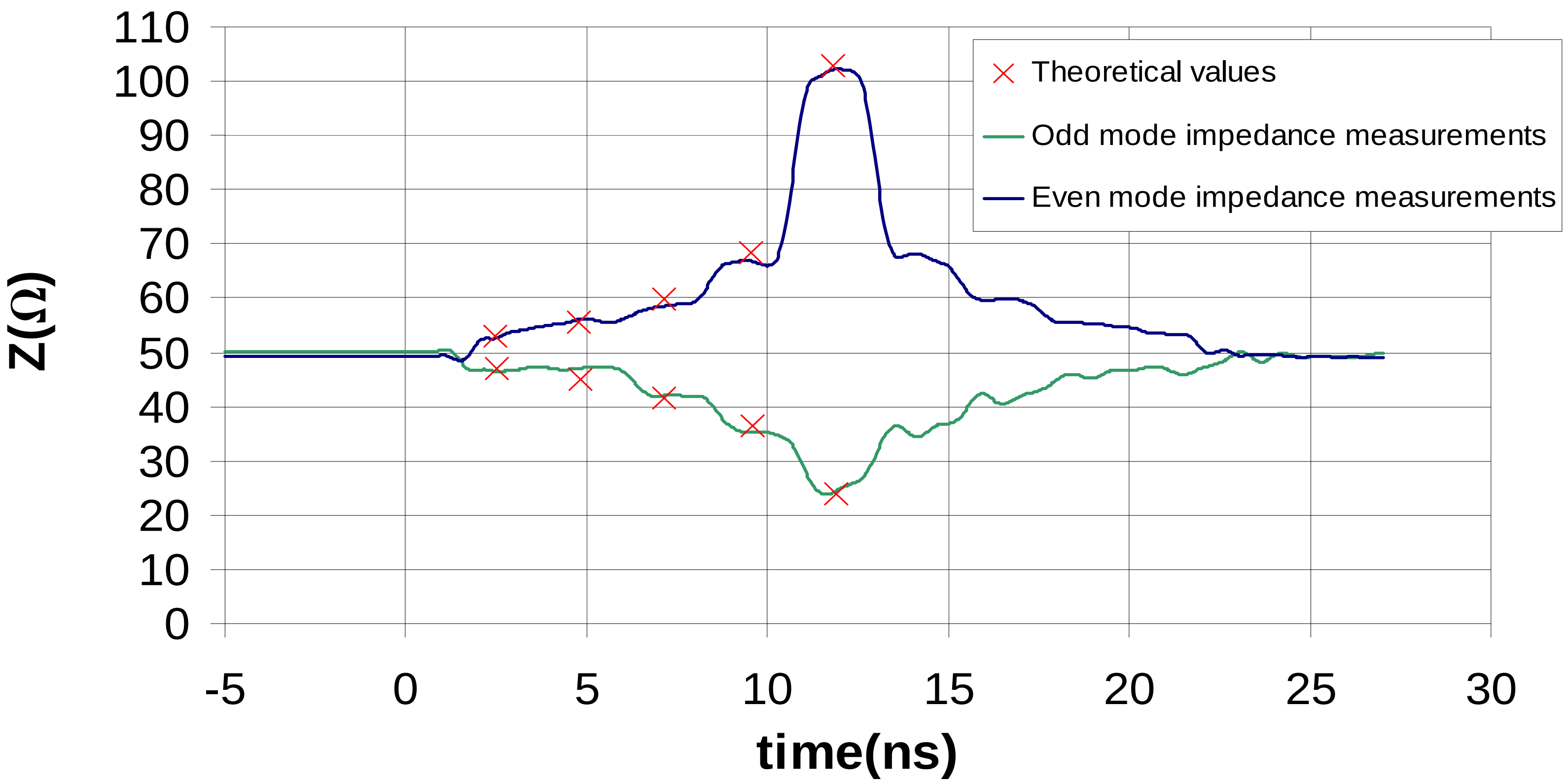
multiwire chamber

Ring Resonator

and… does it really work?

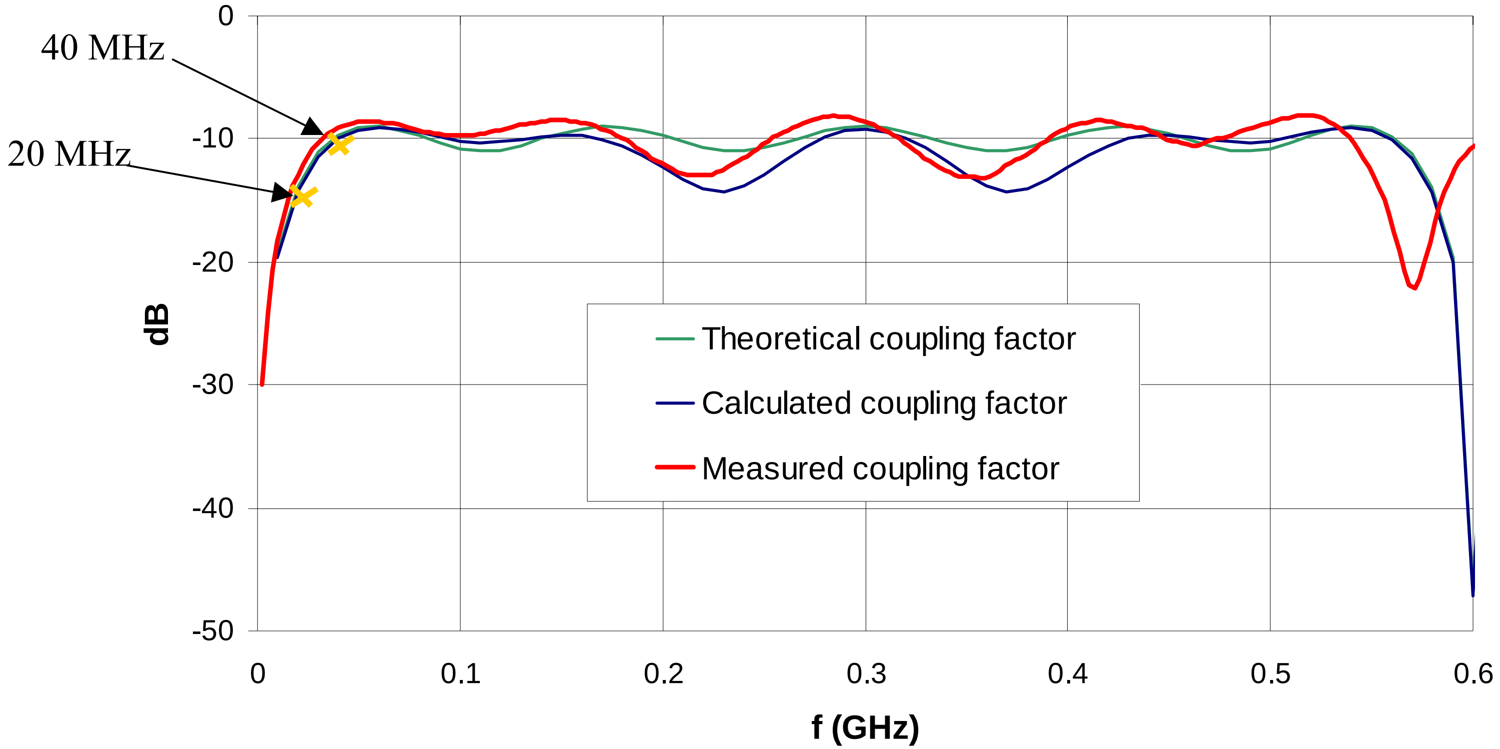
Main coupler characteristics:

Odd and Even mode impedances



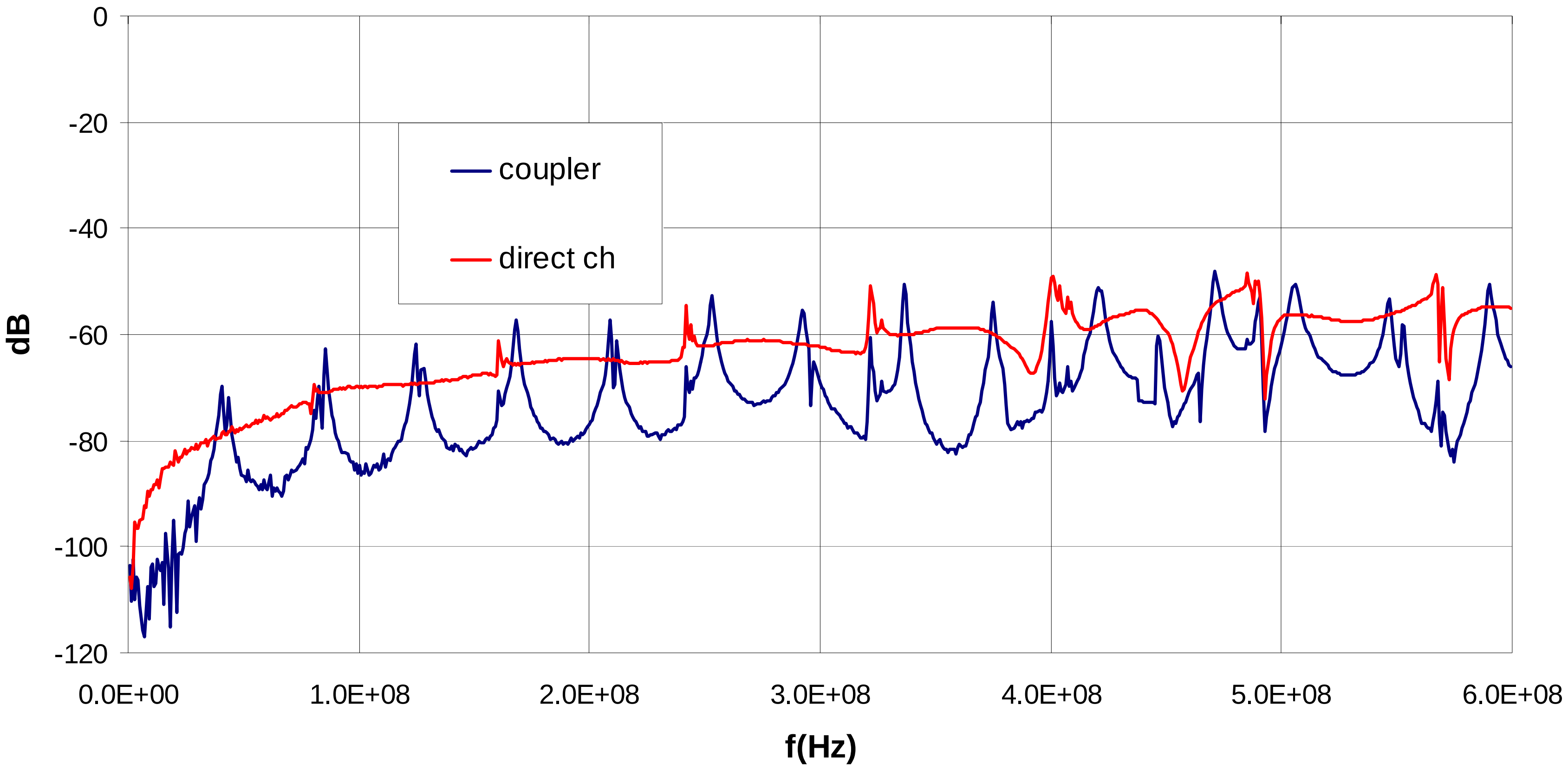
Main coupler characteristics:

coupling factor



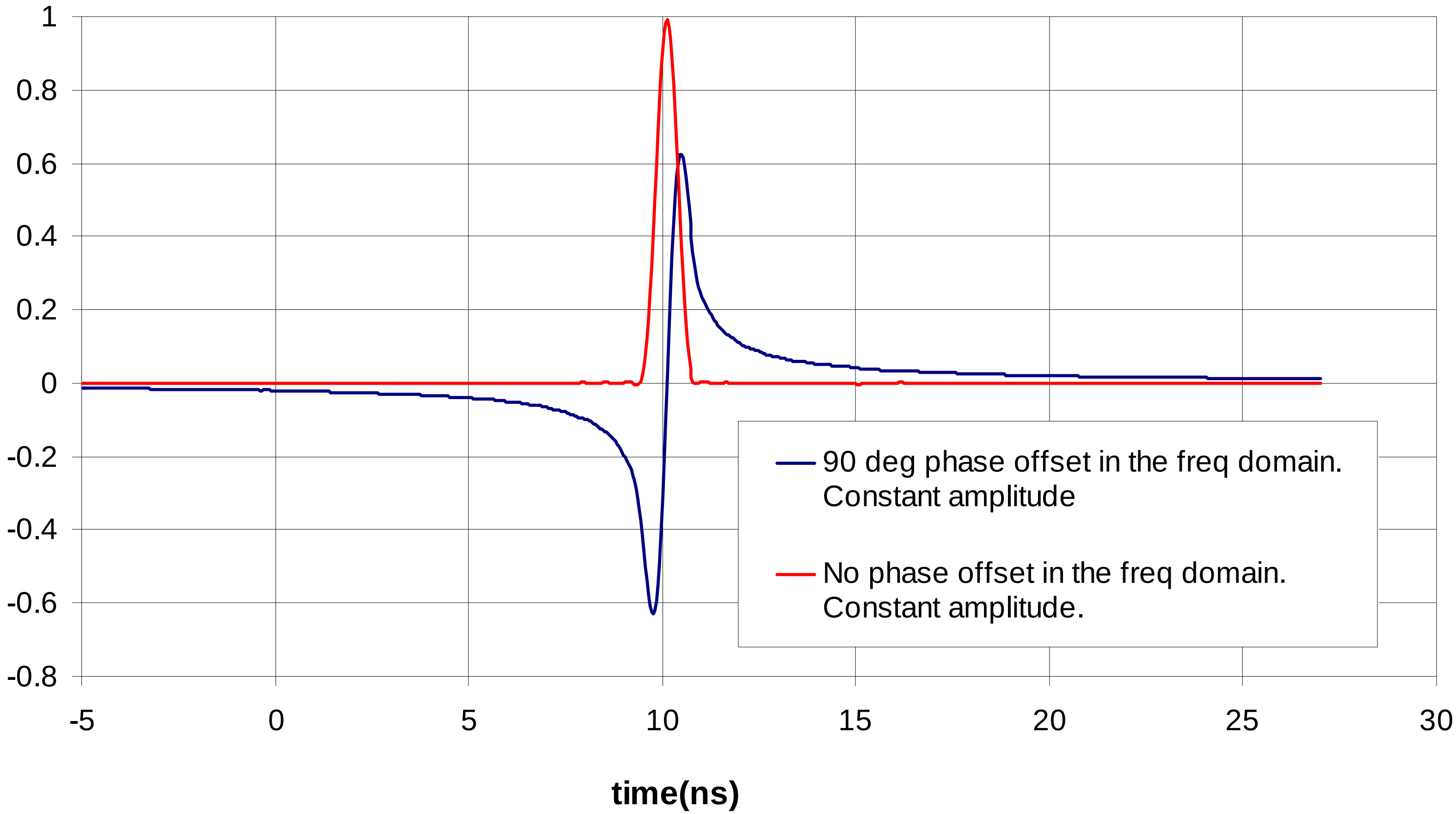
* Thanks to C. Deibele for having carried out numerical calculations for the coupler parameters.

Ring Resonator power enhancement:



- Every 40 MHz (LHC beams), the minimum increase is 6 dB

Phase offset



- Better use of the amplifier power limiting characteristics by applying a 90 deg phase shifter: bipolar to polar Gaussian pulse gives a gain of ~ 3 dB

1.6. Conclusions and outlook

- Preliminary tests conclude that the coupler (in fact, the Ring Resonator) works reasonably well
- Expected increase of the Traveling Wave voltage by about a factor of 3: 2 (= 6 dB measured) from the coupler, 1.5 from the phase shifter and amplifier limitations properties.
- The difference in electron energy (Ee):

original set-up: E_e=75 eV

current set-up: E_e=225 eV

- Modeling and scaling of 2-point type multipacting (as produced in accelerators)
- Characterize of scrubbing effect for different surface coatings or treatments

The second RF test bench:

2. The Standing Wave single conductor coaxial chamber

2.1. Introduction: Why a Standing Wave coaxial chamber?

2.2. Experimental set-up

2.3. Multipacting in a resonant structure

2.4. Scrubbing effect for a chamber and for samples

2.5. Conclusions and outlook

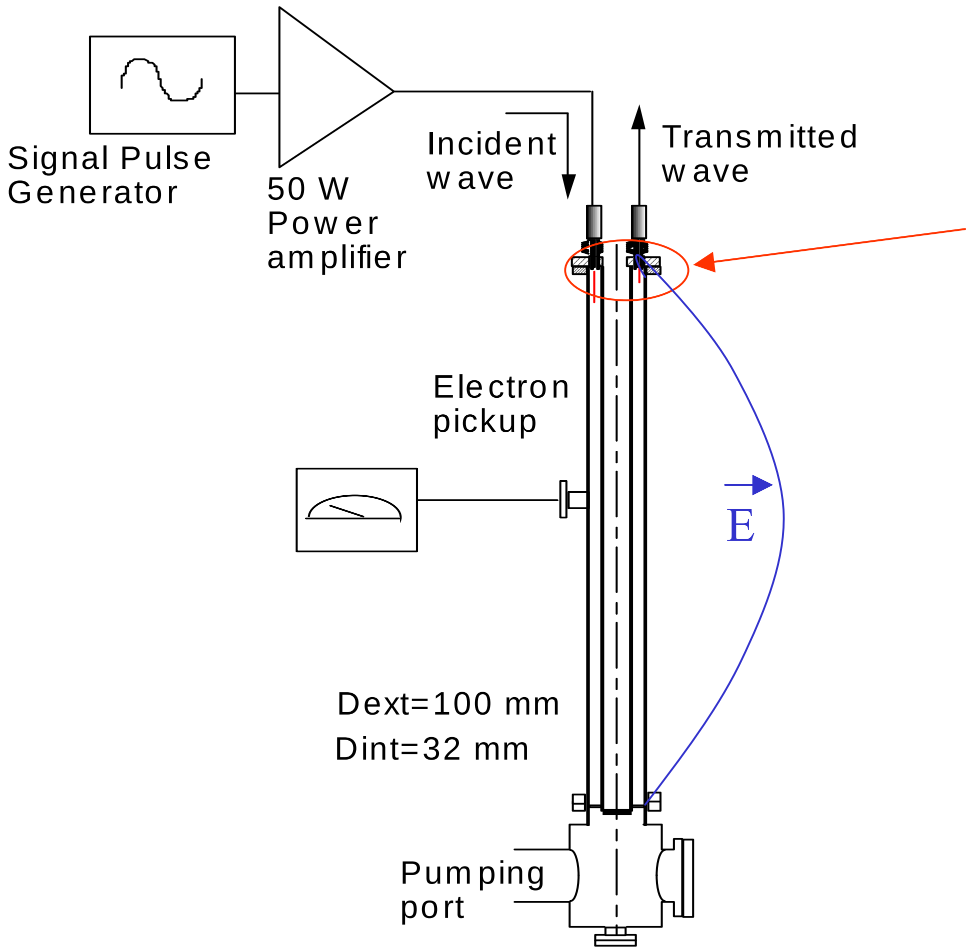
2.1. Why a Standing Waves coaxial chamber?

- High electric fields are easily obtained by using standing waves with the limited power available
- High surface electron bombardment dose
- Scrubbing effect for different surface treatments in a whole chamber (not just on a sample) is suitable

But…

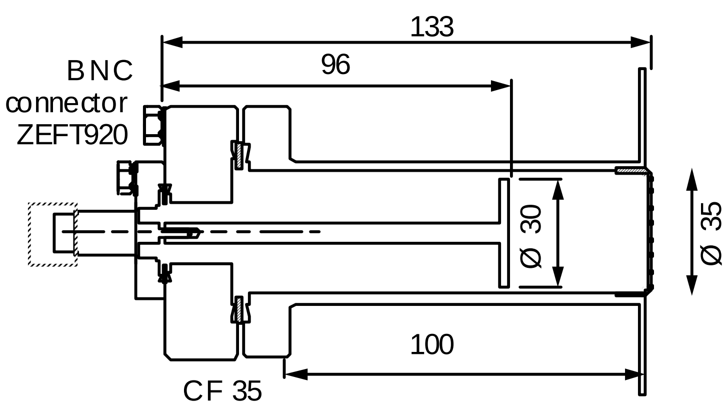
- Sinusoidal fields ➔ multipacting is one-point type, not like in particle accelerators

2.2. Experimental set-up

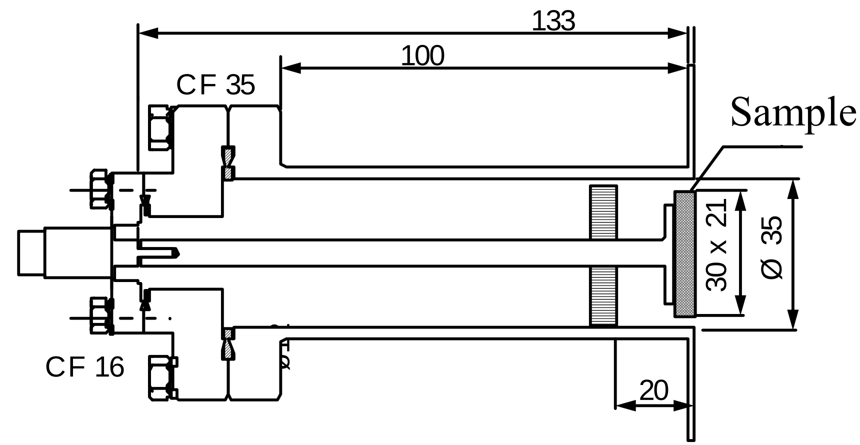


- Coaxial TEM line shorted at each end
- RF Power inferred via a adjustable magnetic coupler
- $\lambda/2$ configuration in TEM mode: $\vec{E}_{max}$ always in the center and perpendicular to wall surface
- Bombardment dose measured by integrating the electron current in the pick-up
- The set-up allows testing multipacting in samples.

Samples testing



Electron pick-up with grid.



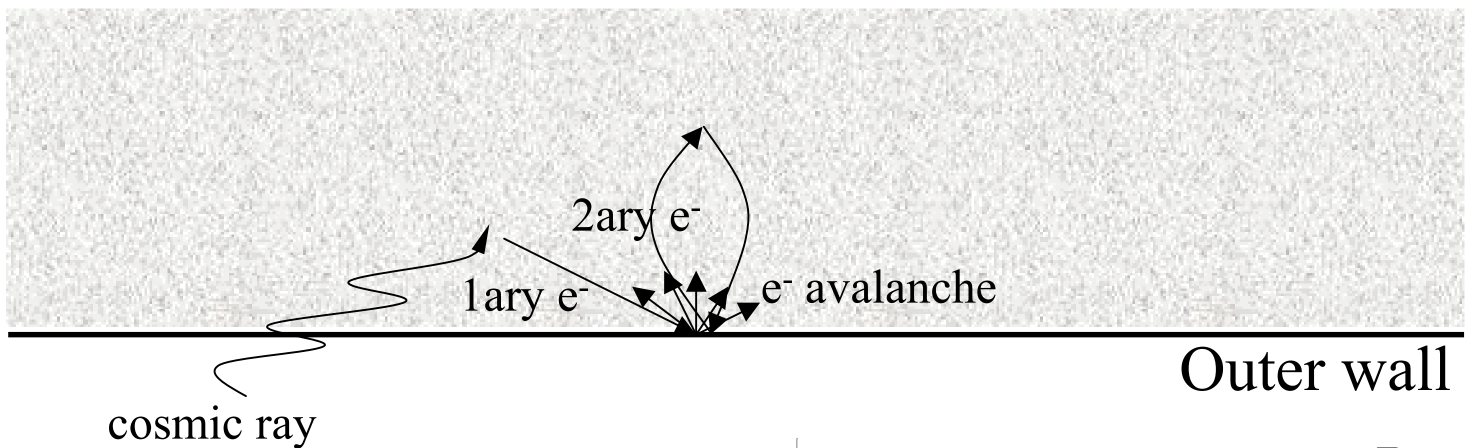
Pick-up sample holder.

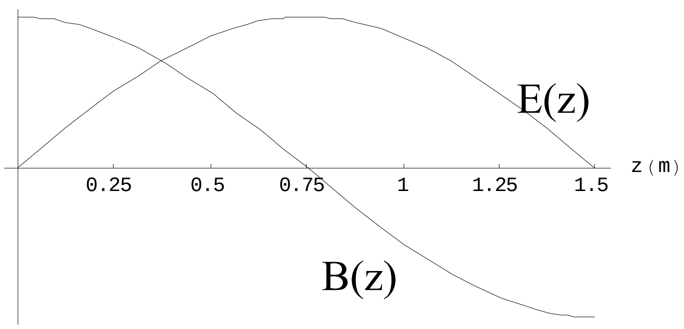
- Since |E| is always maximum in the center of the chamber, by placing a sample glued to the pick-up we can trigger multipacting in the sample, if the multipacting level for the sample is lower than the one for the stainless steel.

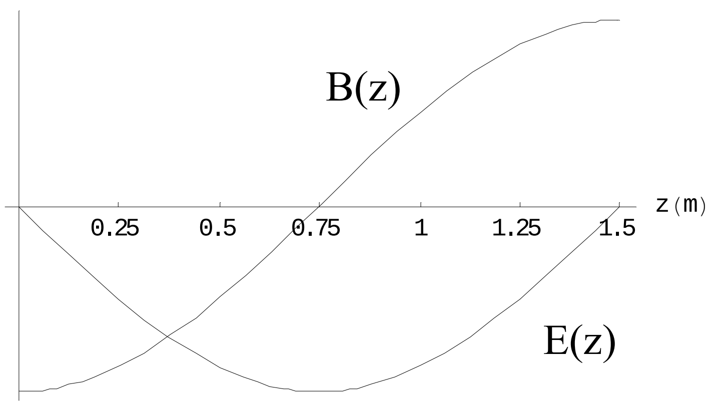
- Ferrite and amorphous carbon (a-C) has been tested in this set-up.

2.3. Multipacting in a Resonant TEM structure

One point type multipacting:



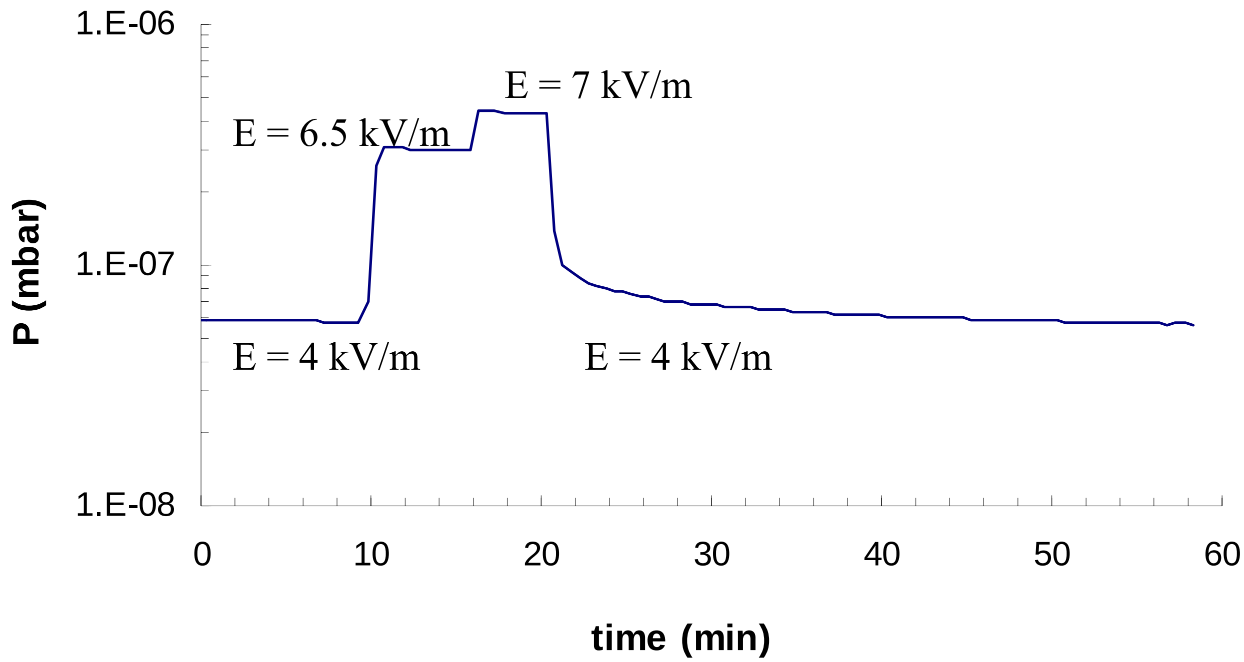




Multipacting takes place when |E| is high enough to produce the e^- avalanche

Multipacting signatures (1)

- Pressure increase during multipacting

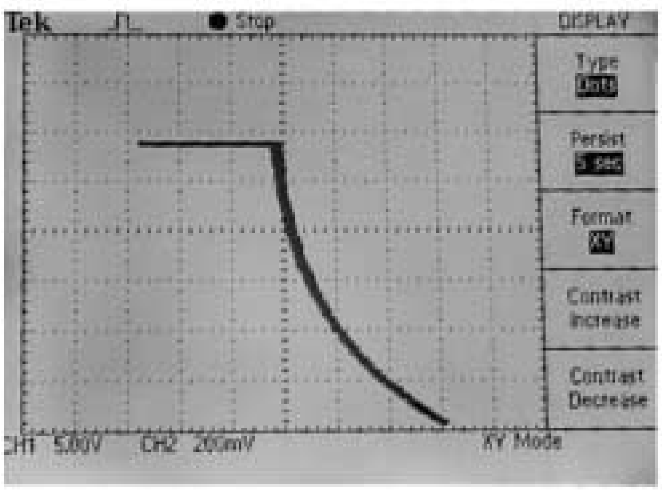


P evolution during multipacting for stainless steel

- Multipacting level is defined as the minimum electric field |E| to trigger multipacting. For stainless steel, multipacting level before bombardment is set in 5.8 kV/m.

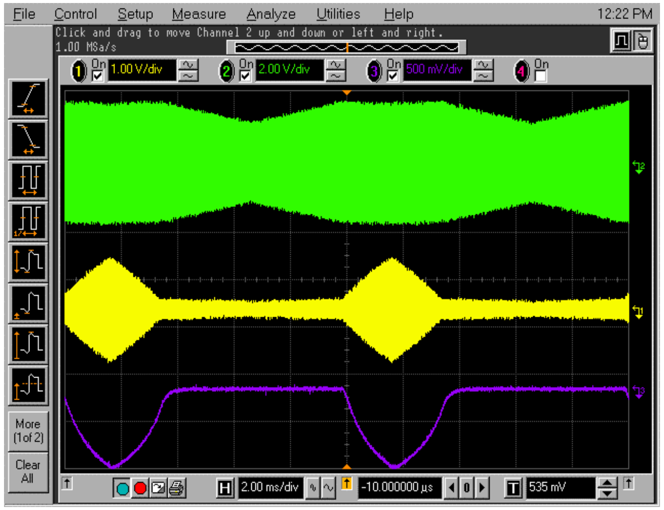
Multipacting signatures (2)

Data taken modulating |E| amplitude around the multipacting level.



- Electron current (I_e):

No I_e is detected before multipacting level. When multipacting level is exceeded, I_e increases with |E|.



- Cavity detuning:

1) Transmitted wave level off

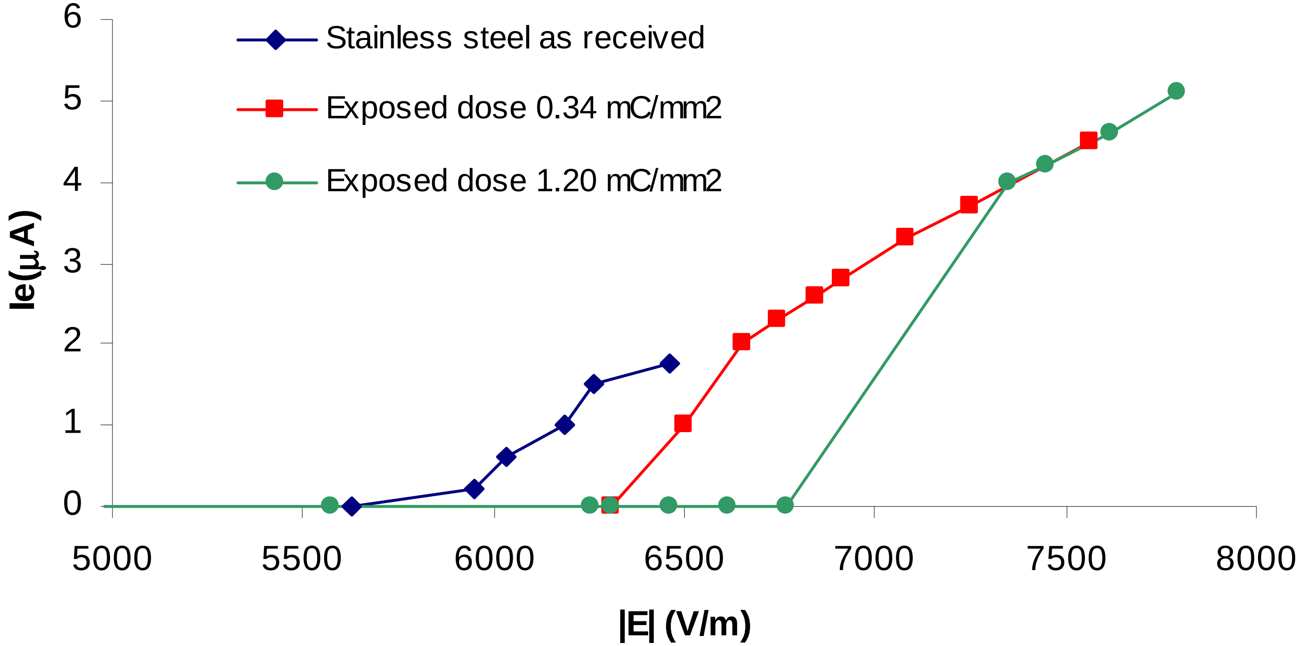
2) Reflected wave increase

3) Electron current detected

- Electron cloud detunes the cavity!

2.4. Scrubbing effect (1)

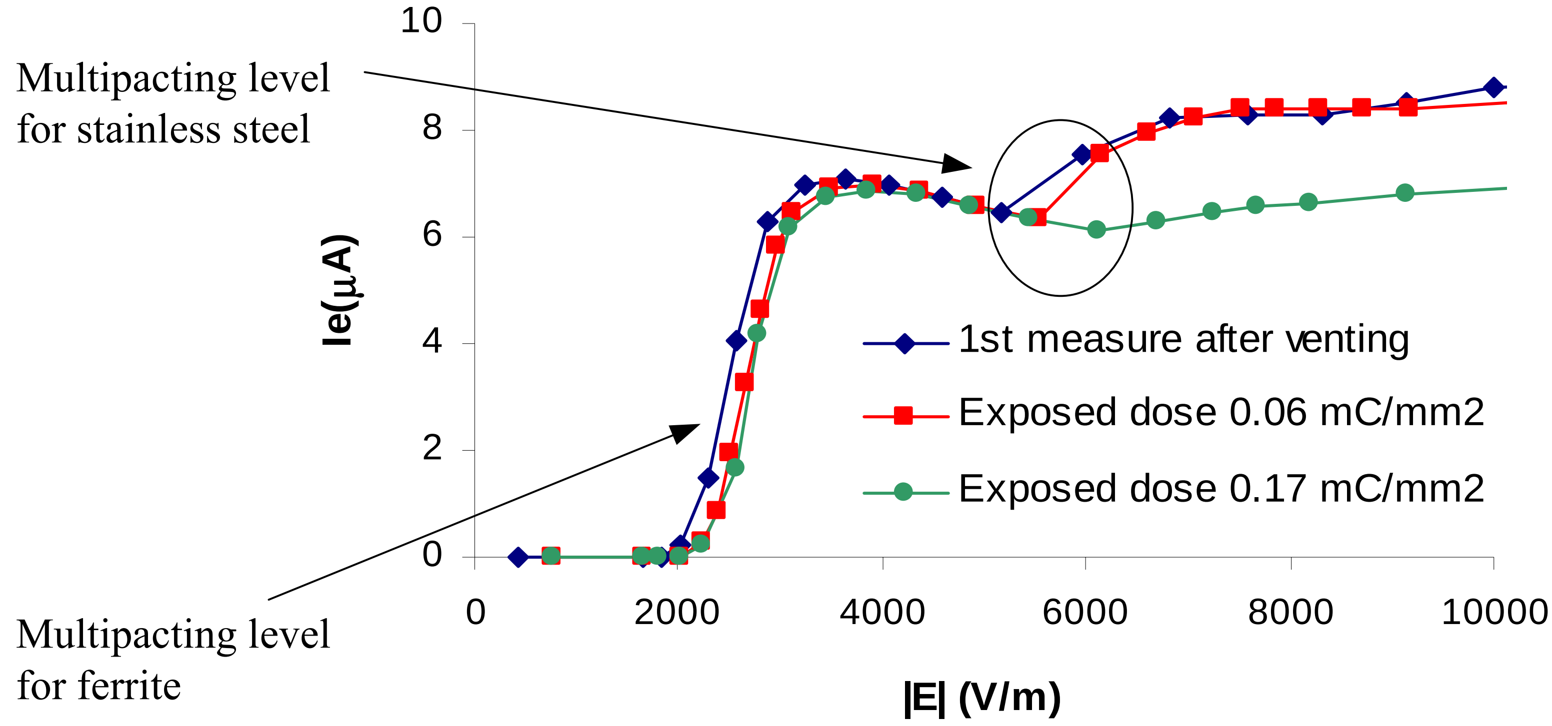
•Scrubbing effect for a stainless steel chamber



➢ Multipacting level increases with the exposed dose

2.4. Scrubbing effect (2)

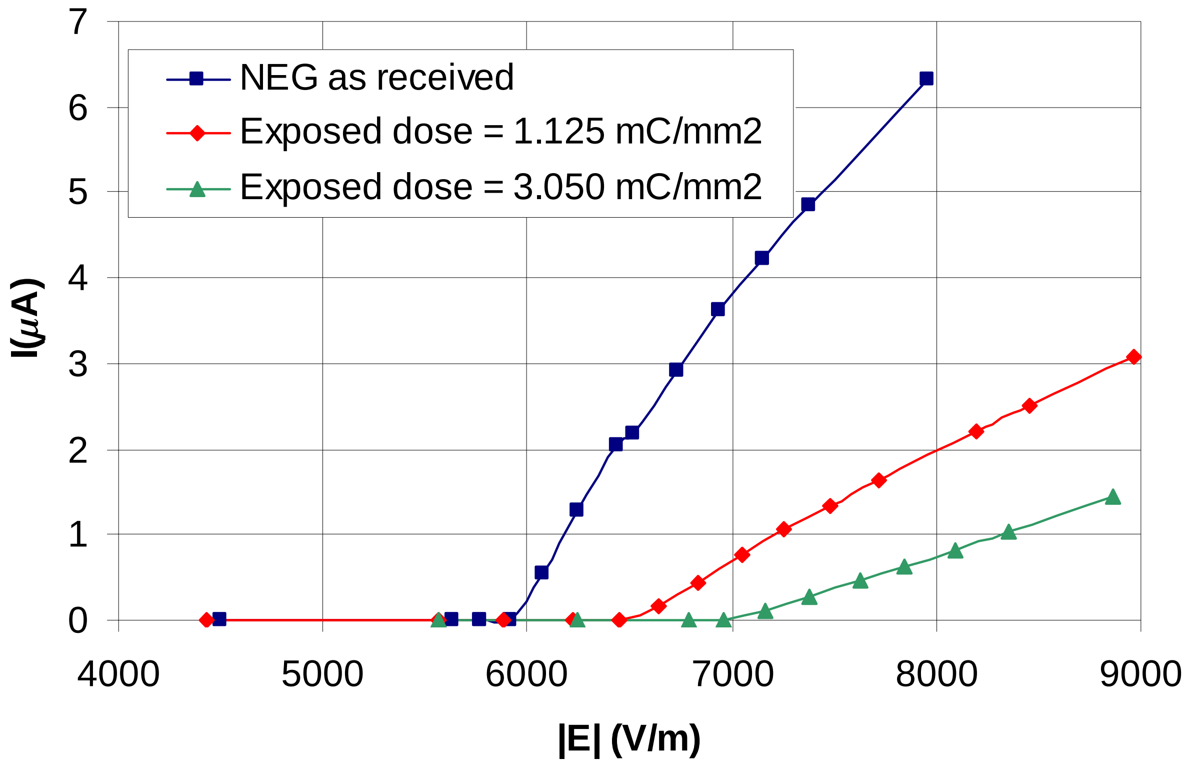
•Scrubbing effect for a ferrite sample



➢ Multipacting is first produced in the center of the chamber (where the ferrite sample is placed) and then in the other parts (stainless steel).

2.4. Scrubbing effect (3)

Scrubbing effect for a NEG coating before activation

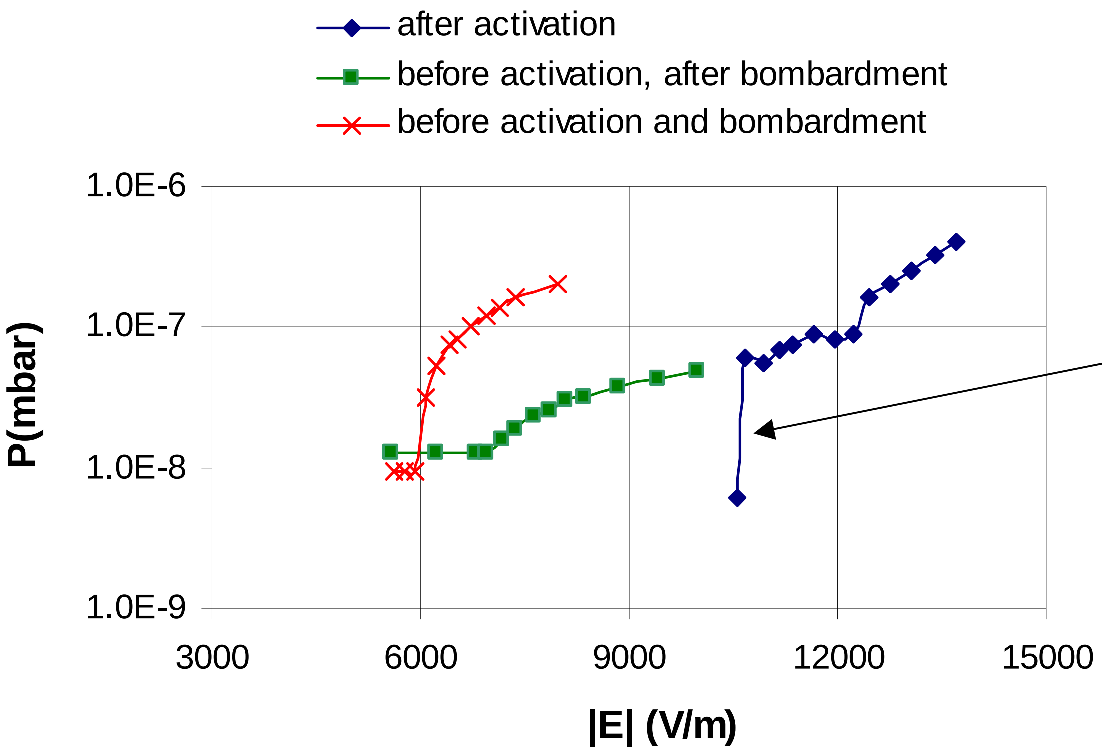


NEG= Non Evaporable Getter
NEG thickness film: 1 μm

- Scrubbing effect is remarkable even before activation

NEG after activation

- No I_e is detected, no changes in Reflected Wave, no changes in Transmitted Wave… but P increases.



Increase of P at 10.6 kV/m, roughly twice the m.l. for stainless steel; or 5 times for ferrite.

2.5. Conclusions…

Suitable set-up to study scrubbing effect not only for samples, but also for surface coatings or treatments.

Space charge due to electron cloud detunes the cavity

For a NEG coating, preliminary results show no evidences for electron presence after activation, but P increases.

and Outlook

Details study of NEG coating behavior

Determine the E_e both with computer code (collaboration with G.Rumolo) and measurements

Measure rise time for electron cloud build-up

Test for other surface treatments: TiN and ArGD