8TH ADVANCED BEAM DYNAMICS MINI-WORKSHOP ON
ICFA Two-Stream Instabilities
In Particle Accelerators and Storage Rings

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A TW multi-wire chamber experimental set-up to simulate bunch induced multipacting

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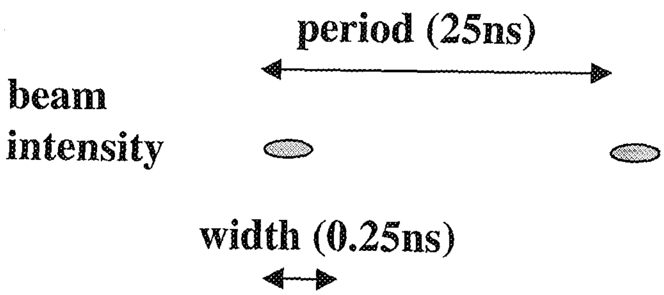
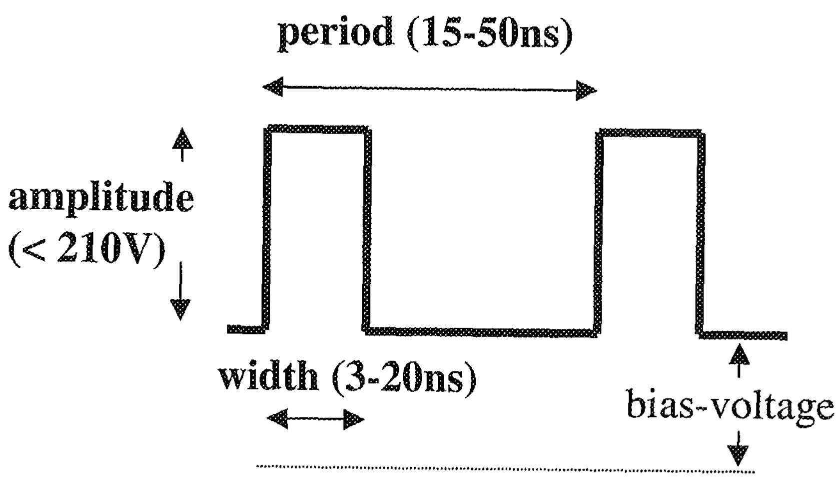
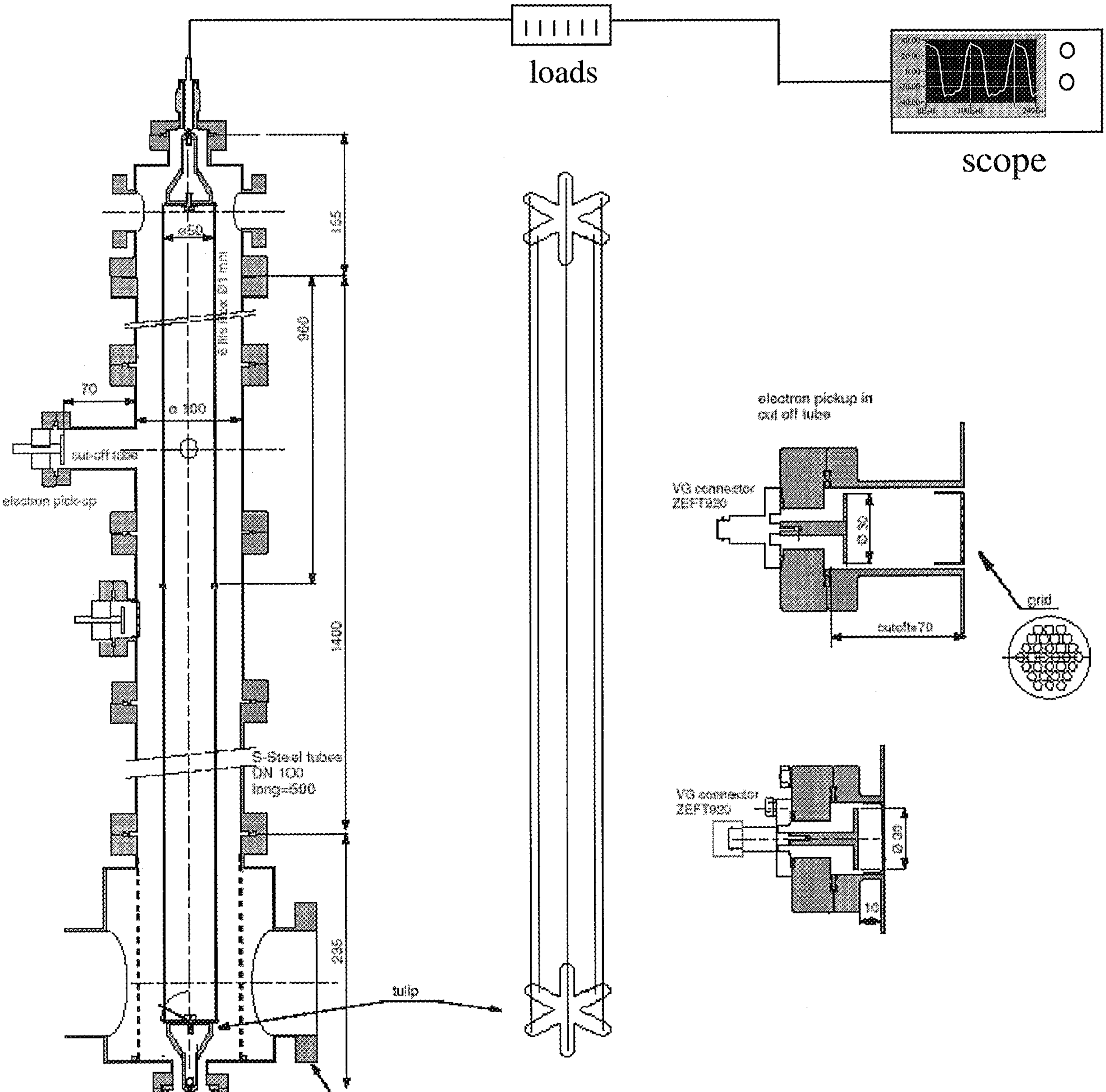
Simulating the proton beam

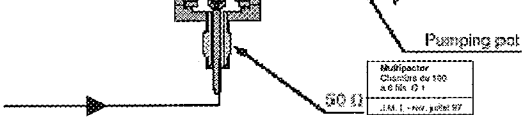


RF pulse parameters (ISR)



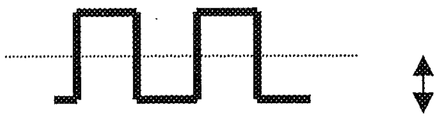
TW chamber experimental setup





from Amplifier

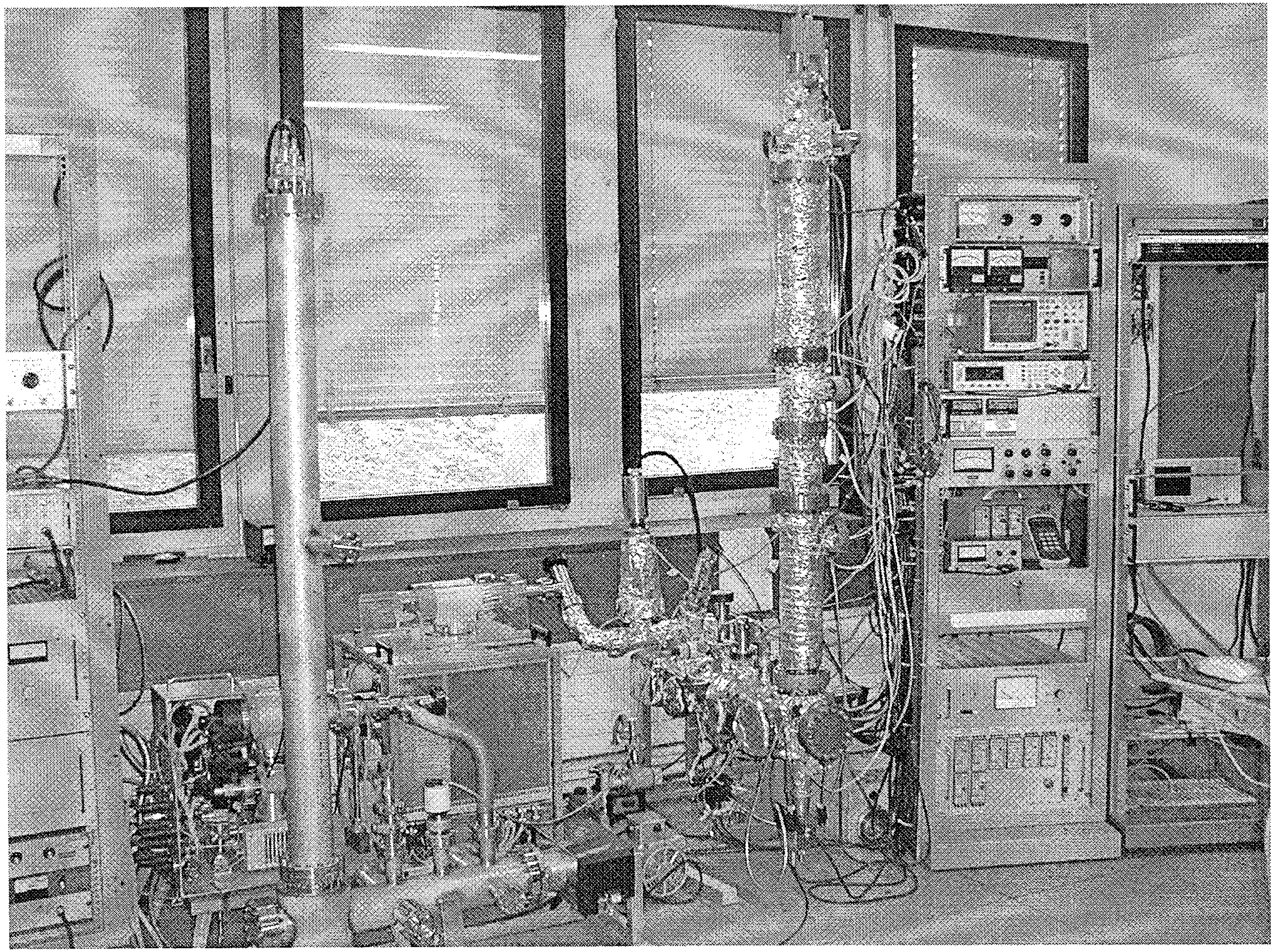
- Pressure rapidly increases
- Current at the pick-up



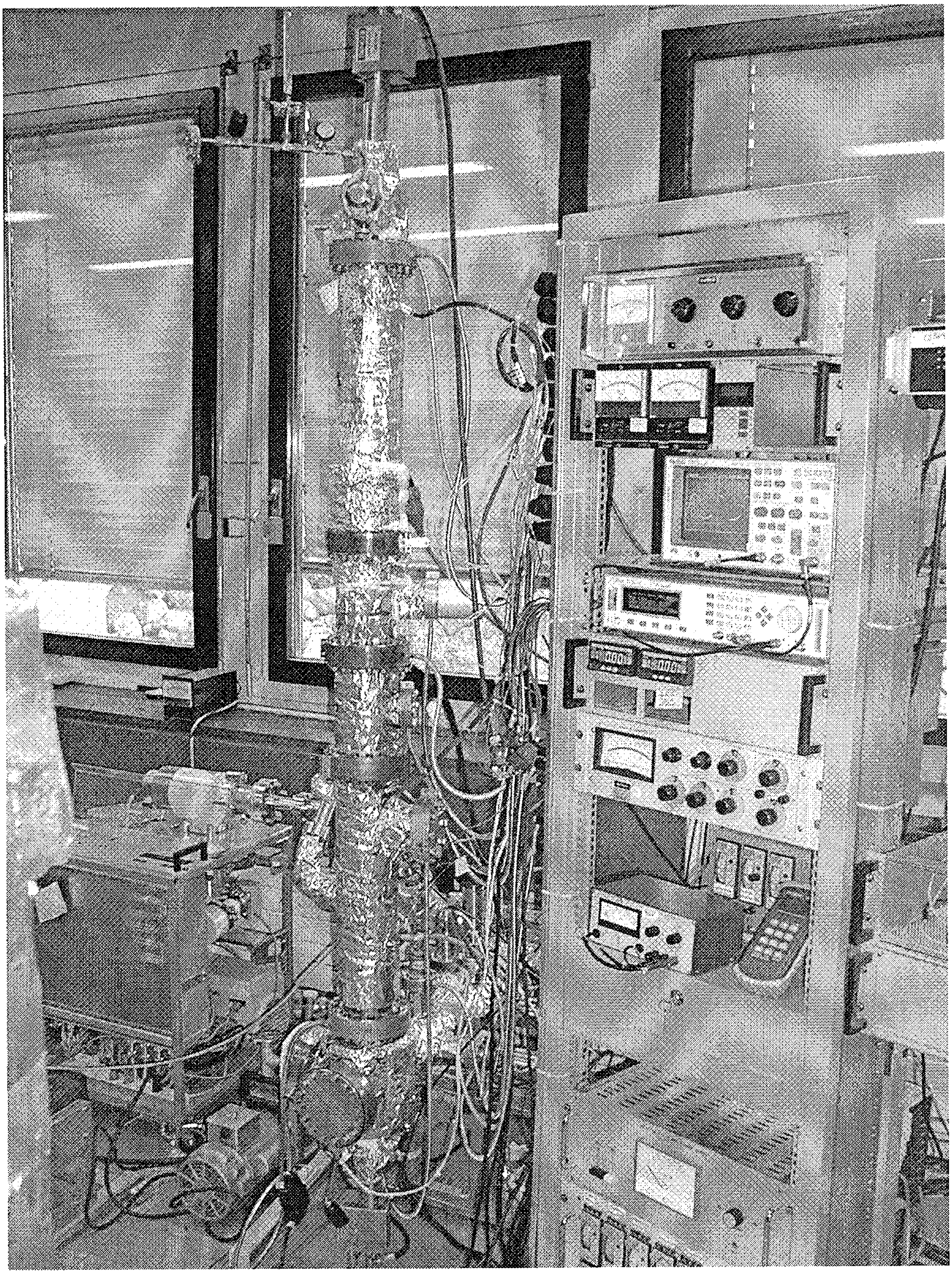
Multipacting depends strongly on the RF pulse parameters

Beam-induced multipacting tests for LHC

100 MHz resonant cavity and TW multi-wire chamber



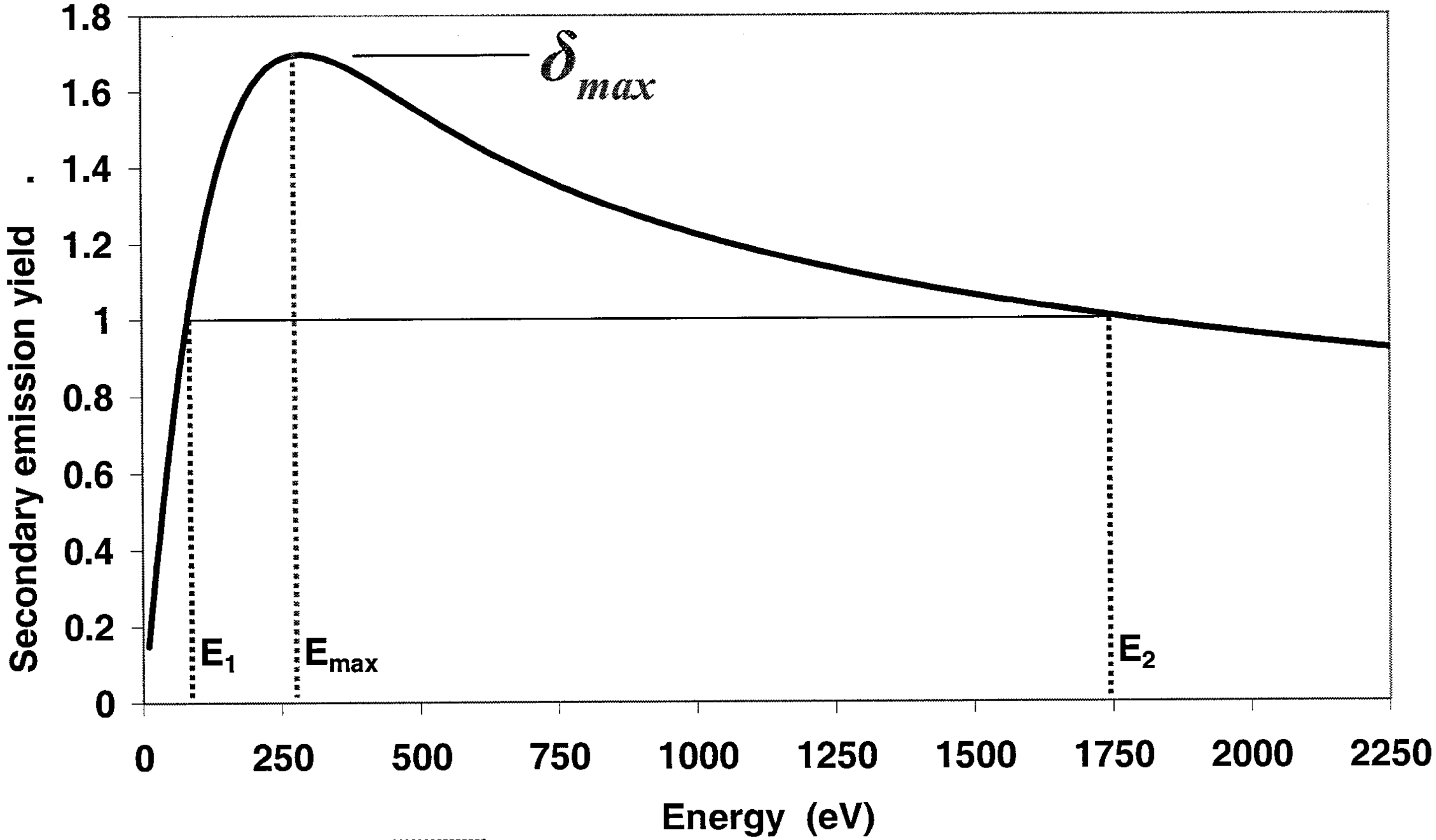
Beam-induced multipacting tests for LHC TW multi-wire chamber



Analytical expression for Secondary emission yield [H.Seiler, J.Appl.Phys. 54 (11), (1983)]

$$\delta(E,\theta) = \delta_{max}\, 1.11\left(\frac{E}{E_{max}}\right)^{-0.35} \frac{\left(1 - e^{-2.3\left(\frac{E}{E_{max}}\right)^{1.35}}\right)}{\cos\theta} = \delta_{max} \frac{h(E/E_0)}{\cos\theta}$$

with θ the angle of incidence to the surface normal



Simulation code [CERN 1997, F. Zimmermann, O. Bruning]:

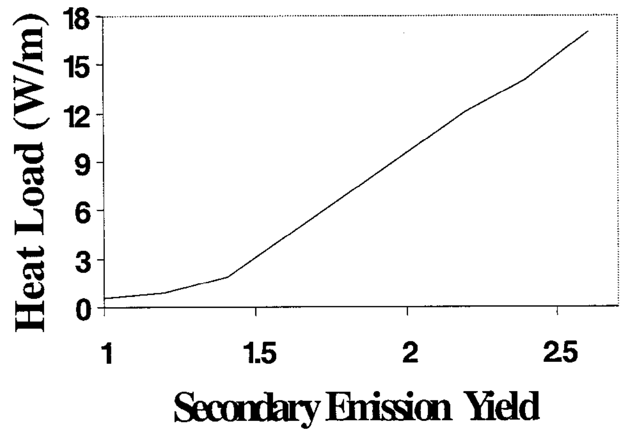
Electron cloud in the LHC:

- Heat load on the cold bore (dipole sections, cryogenic system tolerate 0.5 W/m) multipacting → 0.2W/m
- Space charge + energy coupling between electrons and protons
- Fast pressure increase, (*due to electron stimulated desorption,* ESD)

may cause ultimately the ***loss*** of the proton beam (*300ms*).

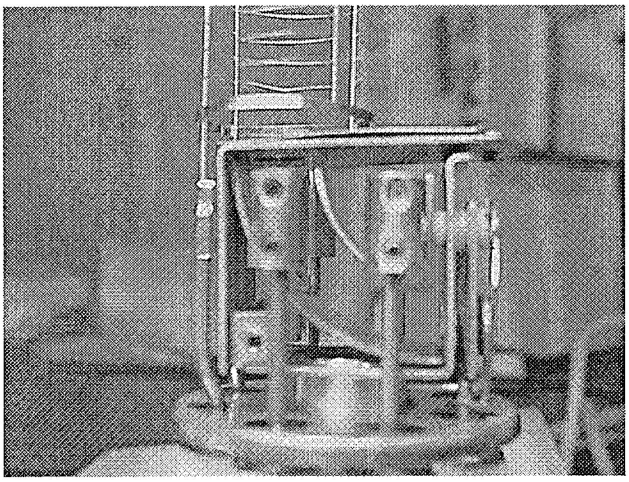
• *at nominal LHC proton beam parameters*

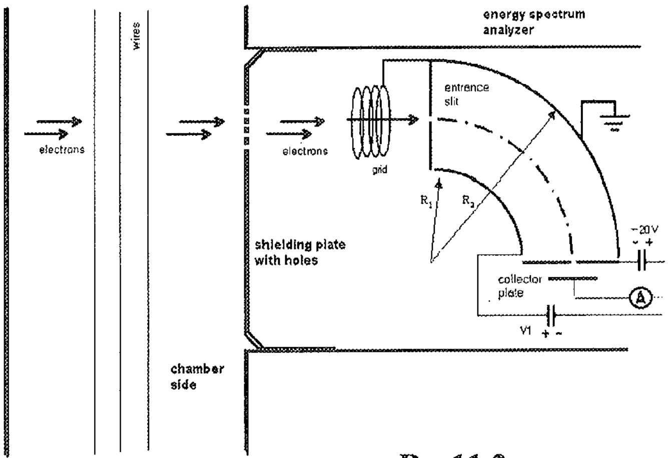
$$\delta_{max} < \delta_{crit}=1.4$$



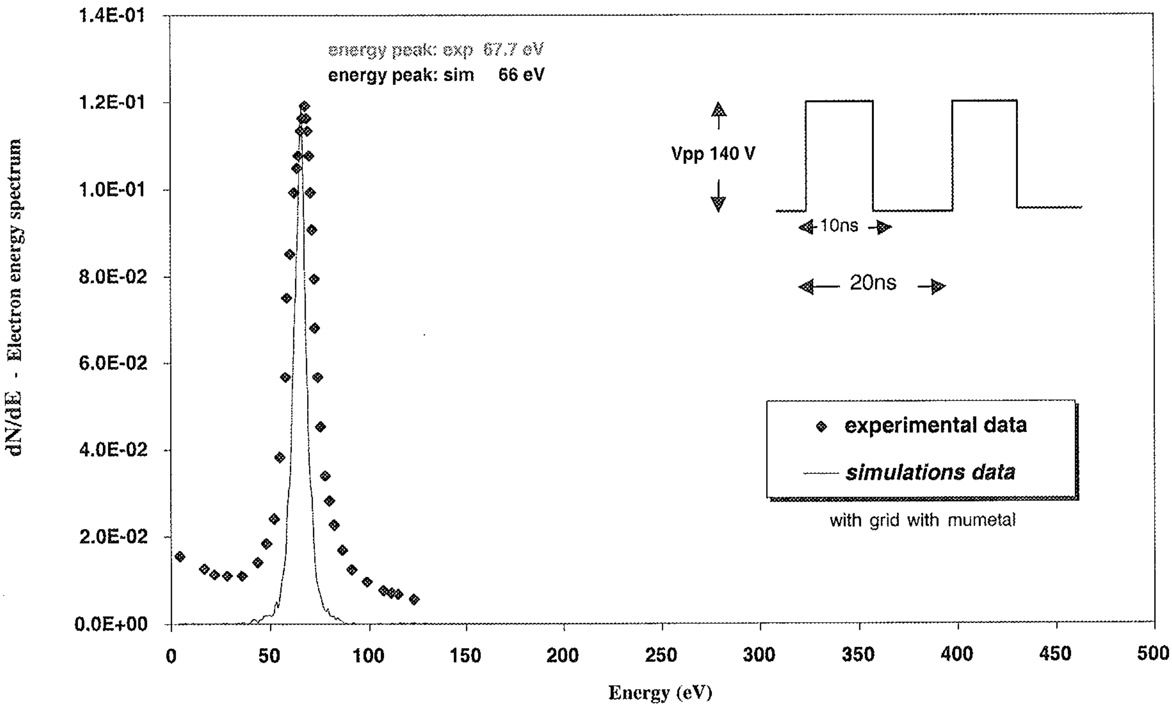
Electron energy spectrum in the TW multi-wire chamber

- **Energy distribution of the electron hitting the vacuum chamber during multipacting**

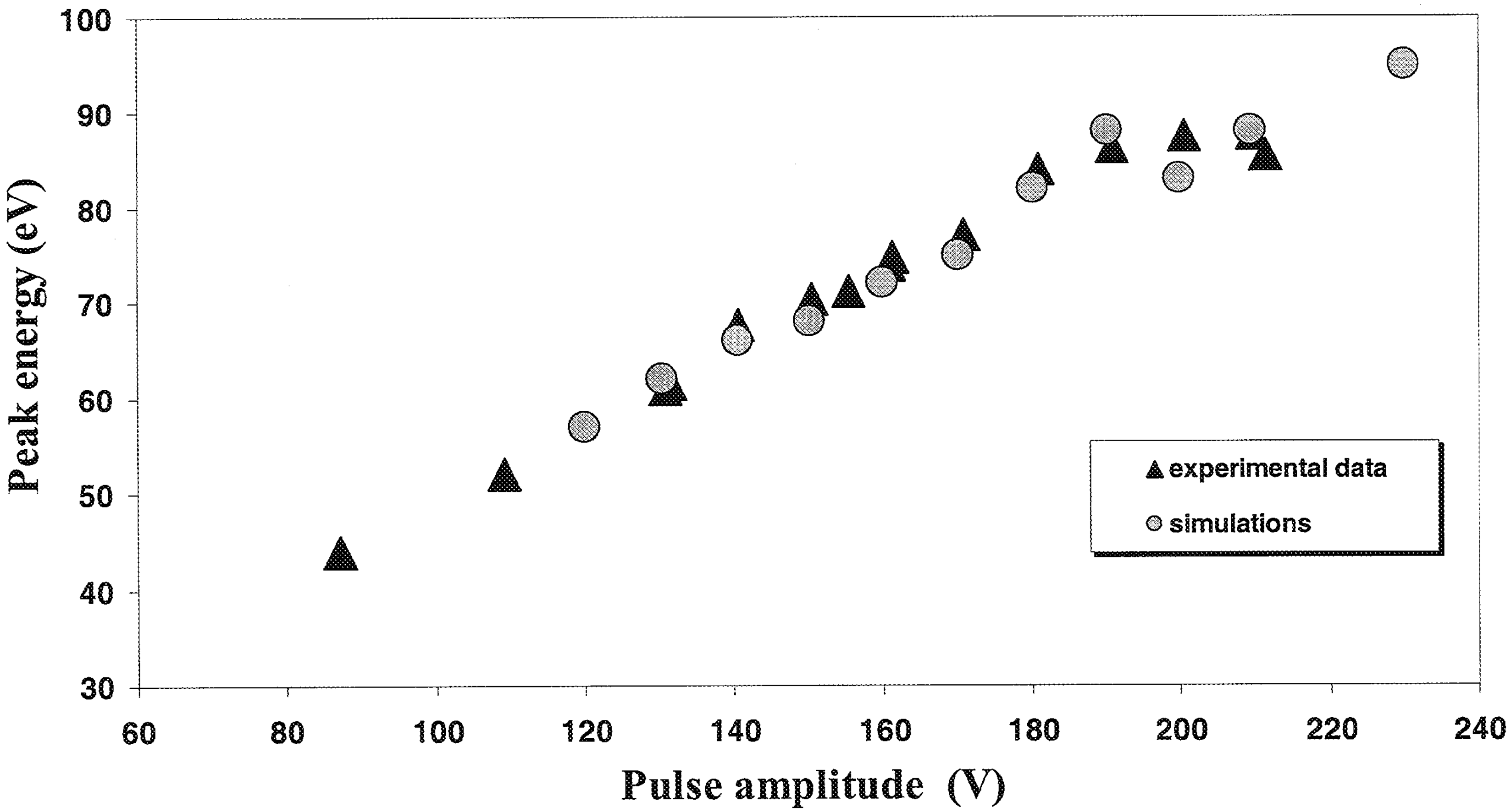




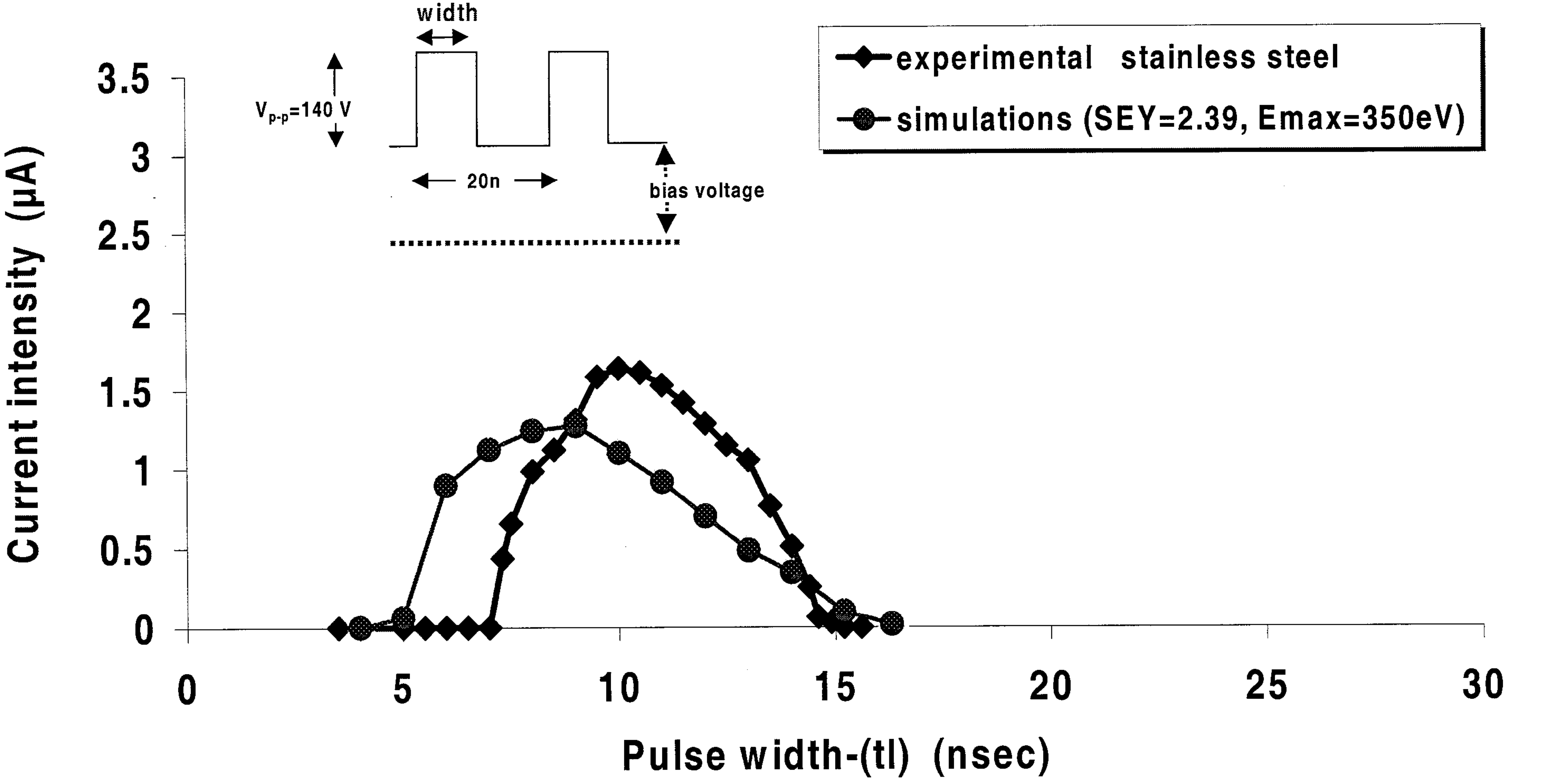
R_1=11.2mm
R_2=18.7mm
slits=0.2mm



Electron energy corresponding to the peak of the spectrum as a function of the pulse amplitude



Multipacting as a function of the RF pulse width



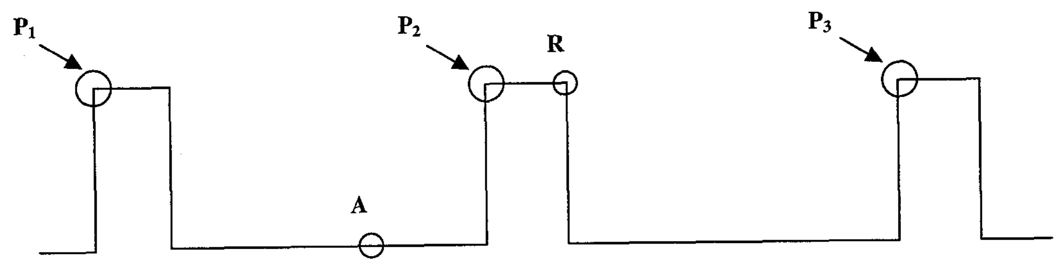
Single particle model for multipacting in the TW chamber

Multipacting conditions:

- the electron hit the surface in synchronism with the RF pulse (kinematic condition)

$$\overline{E} = \frac{1}{2e} m_e \left(\frac{2R_0}{T}\right)^2$$

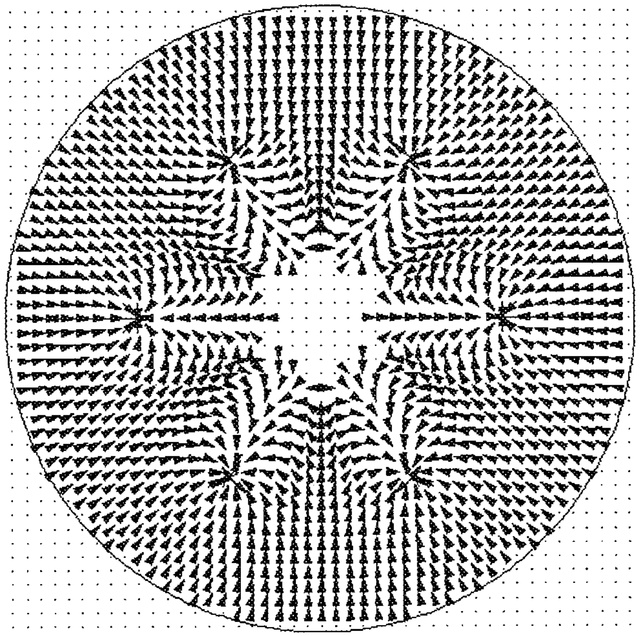
- secondary electron yield $\delta(E) > 1$ if: $E_{imp} \geq 39eV$ (energy condition)



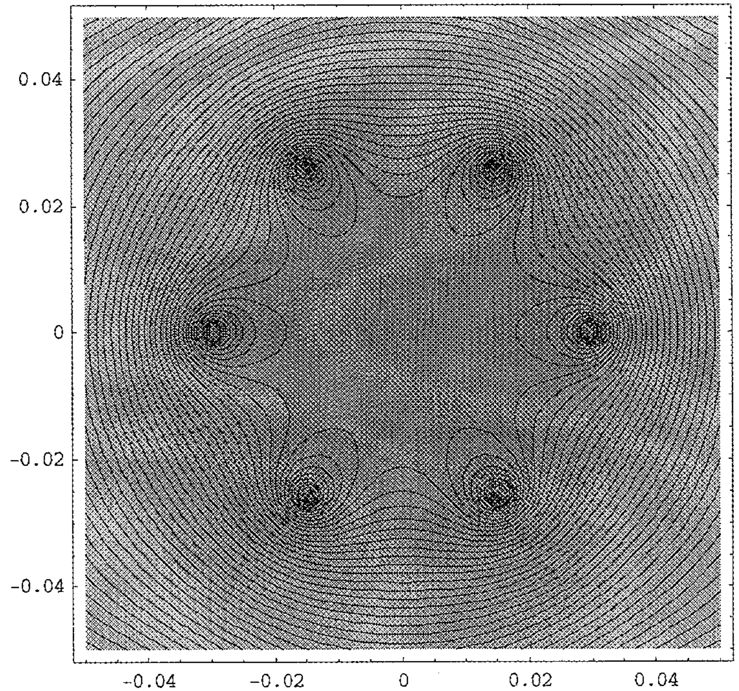
Single particle model for multipacting in the TW multi-wire chamber

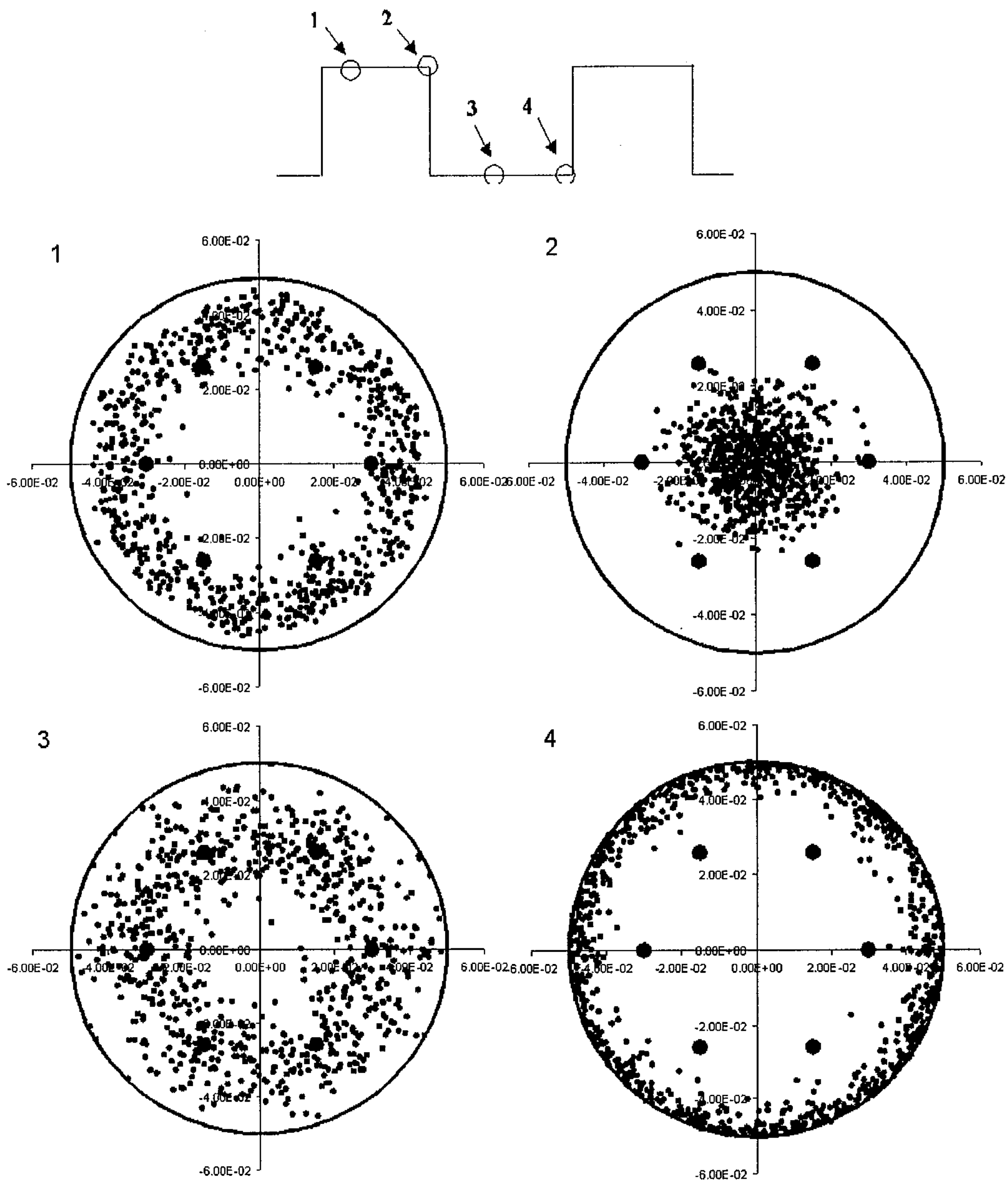
Electric field: $$\vec{E} = \sum_{n=1,6} \left(\vec{a}_n \frac{1}{r_n} - \vec{a}'_n \frac{1}{r'_n} \right) \frac{u(t)}{5.4}$$

Field lines in the multi-wire chamber



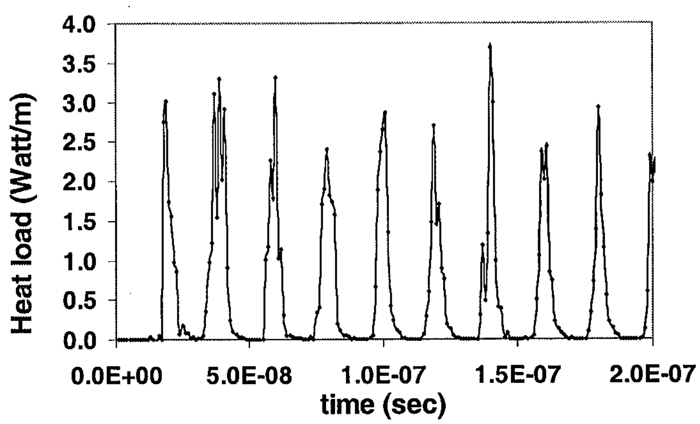
Equipotentials lines





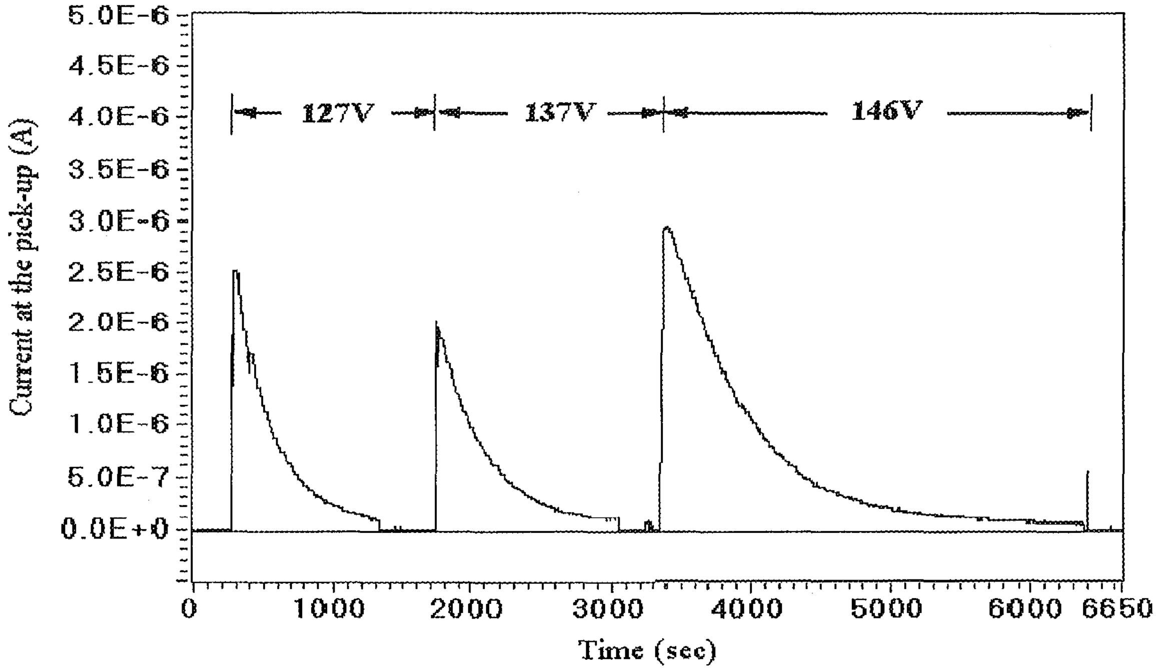
from simulations

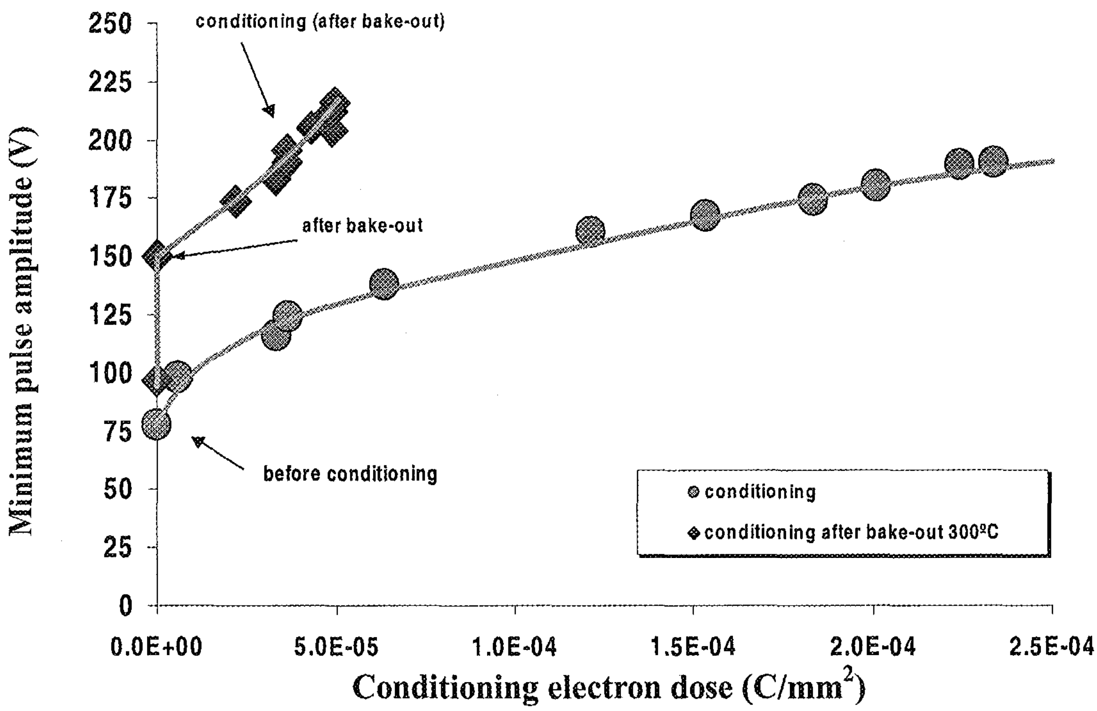
Heat load on the surface vs time



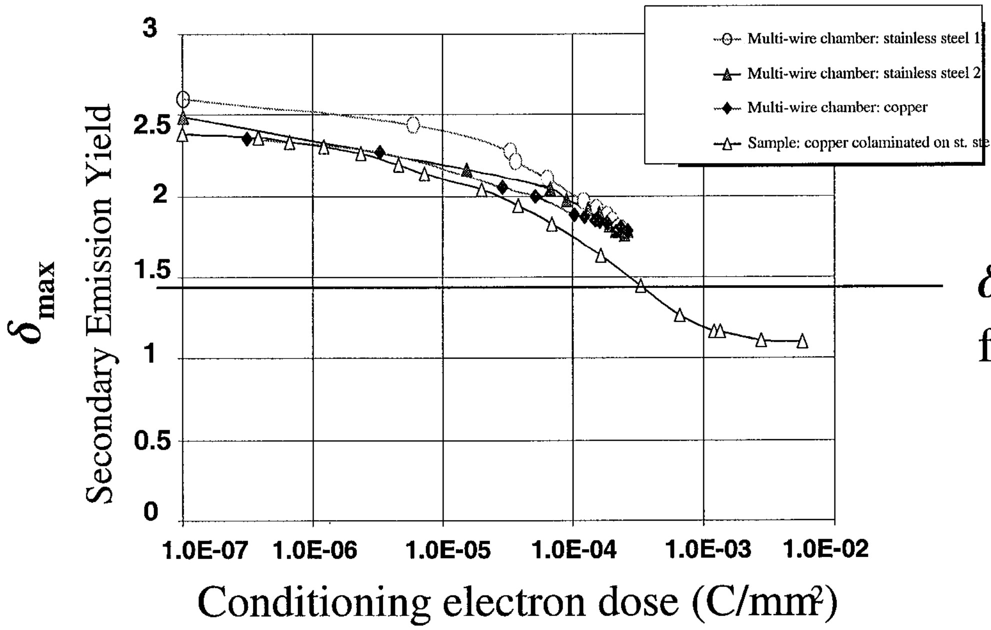
Remedies against the electron cloud build-up

• Electron *conditioning* or *scrubbing*





Reduction of the secondary electron yield as a function of the electron dose



From simulations $\delta_{crit} \approx$ **1.4** for **LHC**

- if $\delta_{max} \geq \delta_{crit}$ ⟶ **divergence** of the electron-cloud
- if $\delta_{max} < \delta_{crit}$ ⟶ **exponential decrease** of the electron-cloud

Estimation scrubbing time for the LHC (dipole sections):

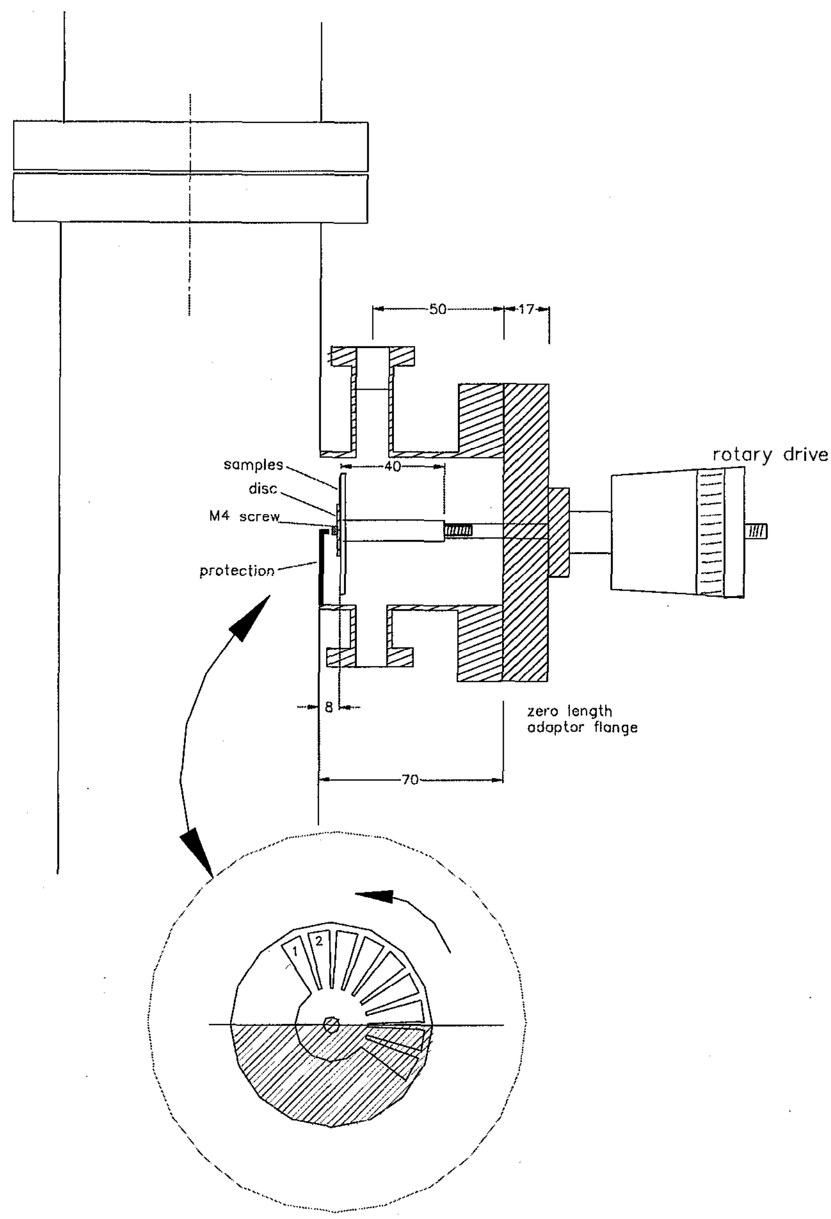
- maximum heat load (0.2W/m): $D = \dfrac{W_{max}}{<E> f} \approx 8 \cdot 10^{-9} \dfrac{C}{mm^2 s}$

  scrubbing time $\approx$ **55** *h* (18) ⟶ (ESD, beam instabilities)

- first year operation LHC 1/10 to 1/5 nominal beam current photoelectrons only (commisioning period):

  scrubbing time > **6000** *h* (2200) $D' = \int_0^{t'} \dfrac{eR\gamma \dot{\Gamma}(t)}{2\pi r_p} dt$

Auger electron spectroscopy of samples exposed to multipacting



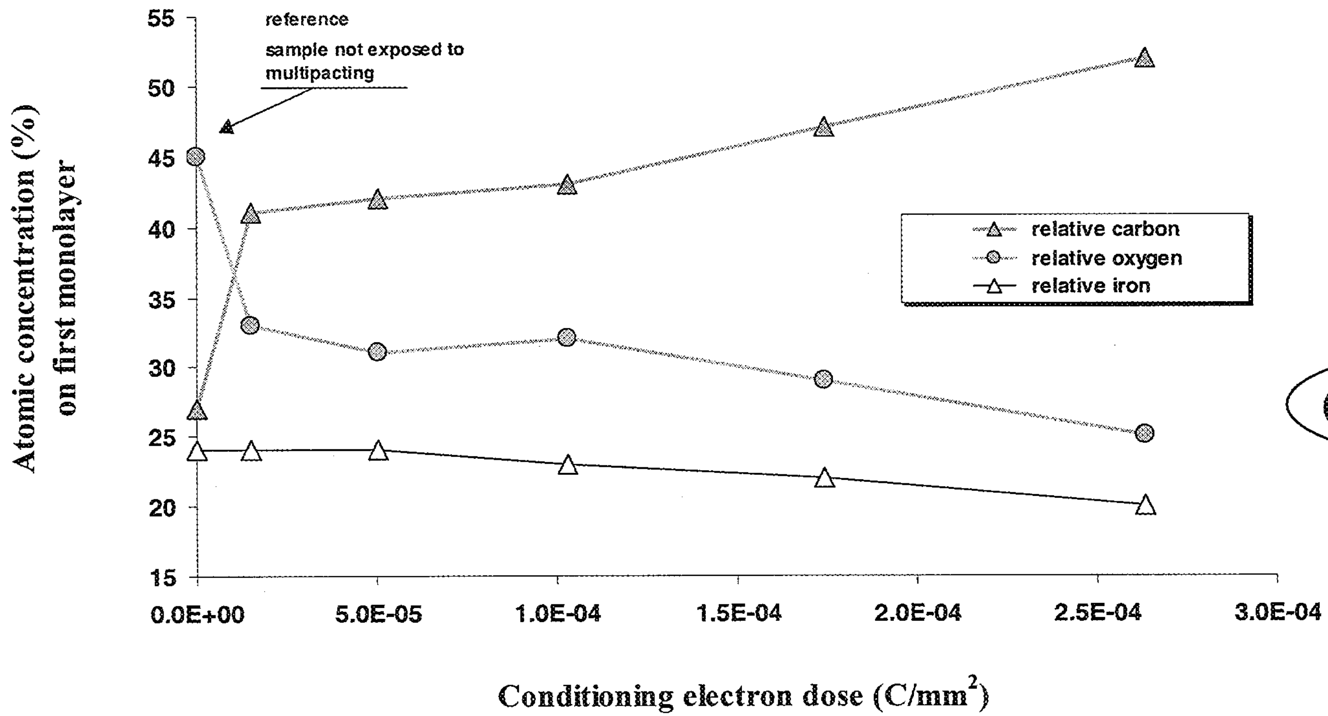
Auger surface analysis:
prospect of the measurament

CERN – European Laboratory for Particle Physics

LHC / Vacuum

M. Pivi

Auger electron spectroscopy of samples exposed to conditioning



$0.5 < \delta_{carbon} < 1$

(effect directly related to the fabrication carbonaceous tips and wires by EBID)

SEY decreases during electron bombardment due to TWO simultaneous effects:

- **the removal of contaminants from the surface responsible of a high SEY**
- **the formation of a carbon layer on the surface, with a SEY < 1**

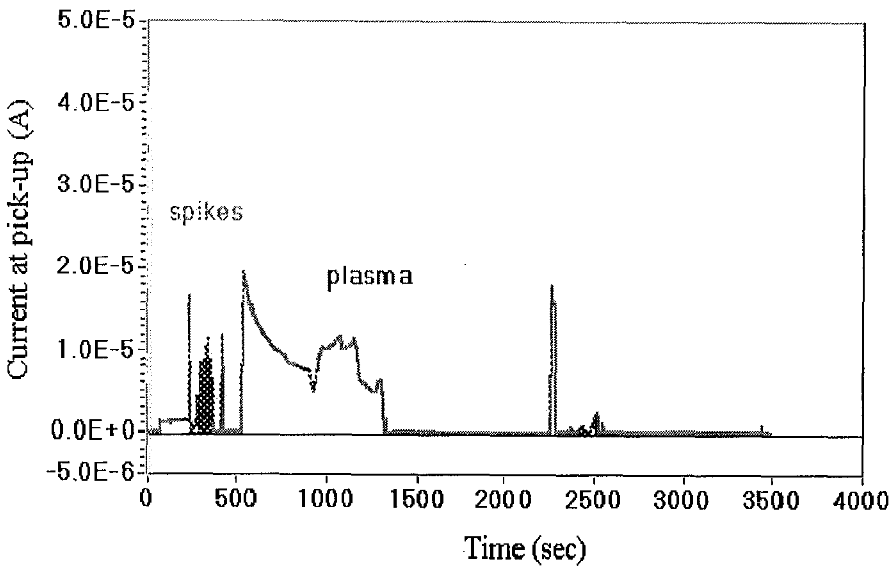
- severe problem: recontamination when venting to atmospheric pressure the system

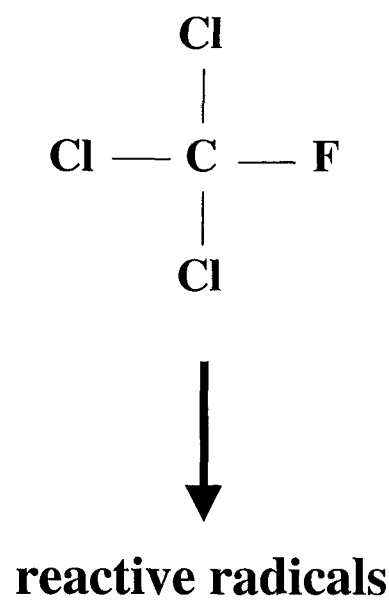
  (or during stand-by periods under vacuum)

Freon (CCl_3F) plasma conditioning

- **Freon11 injection during multipacting novel plasma RF discharge → surface treatment**
- **after few minutes multipacting disappears**

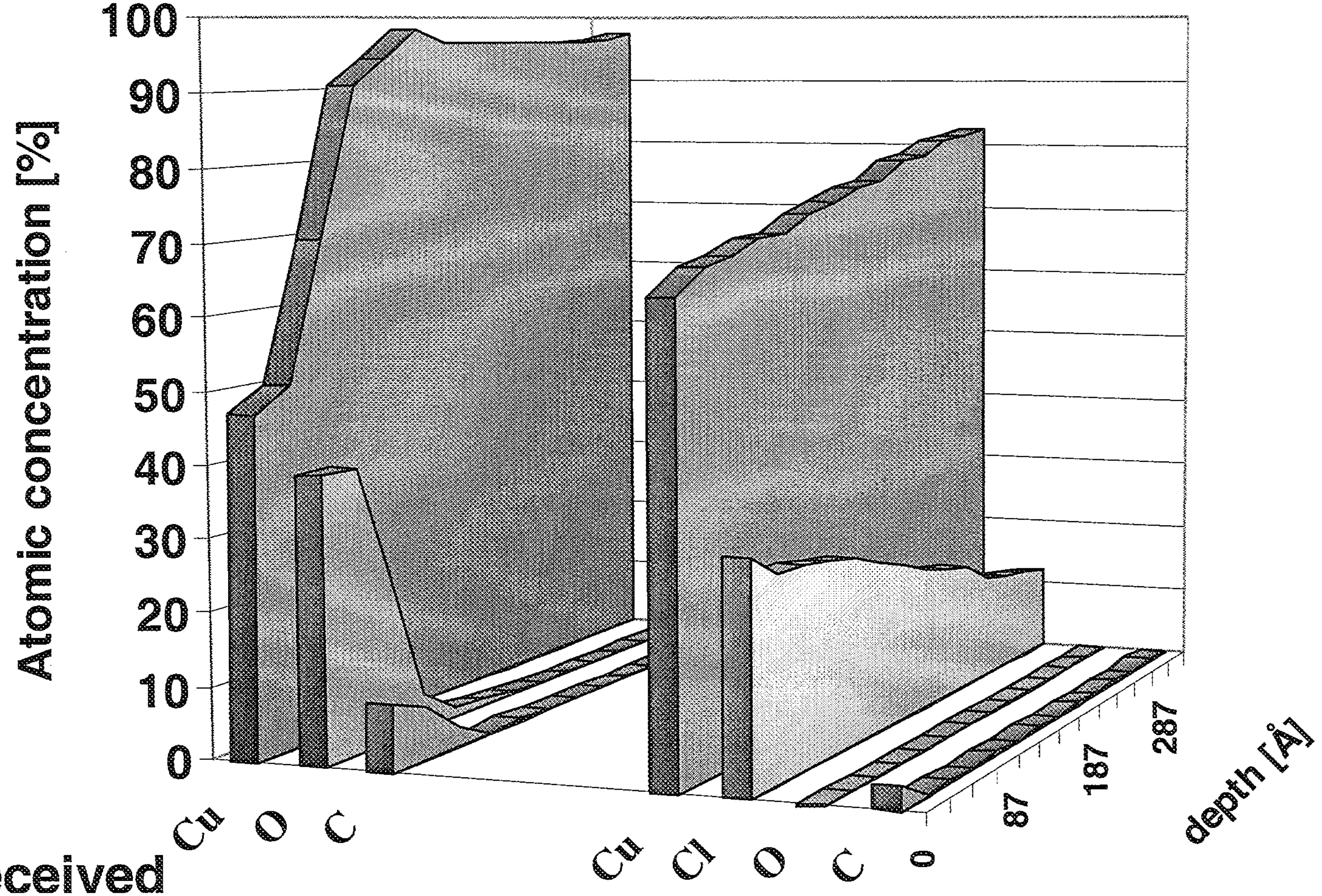
Pick-up current during freon injection





- **following long exposure to atmospheric pressure, multipacting still low → memory effect**
- **argon not effective**

Auger analysis of OFHC Cu sample*
before and after Freon11 plasma conditioning

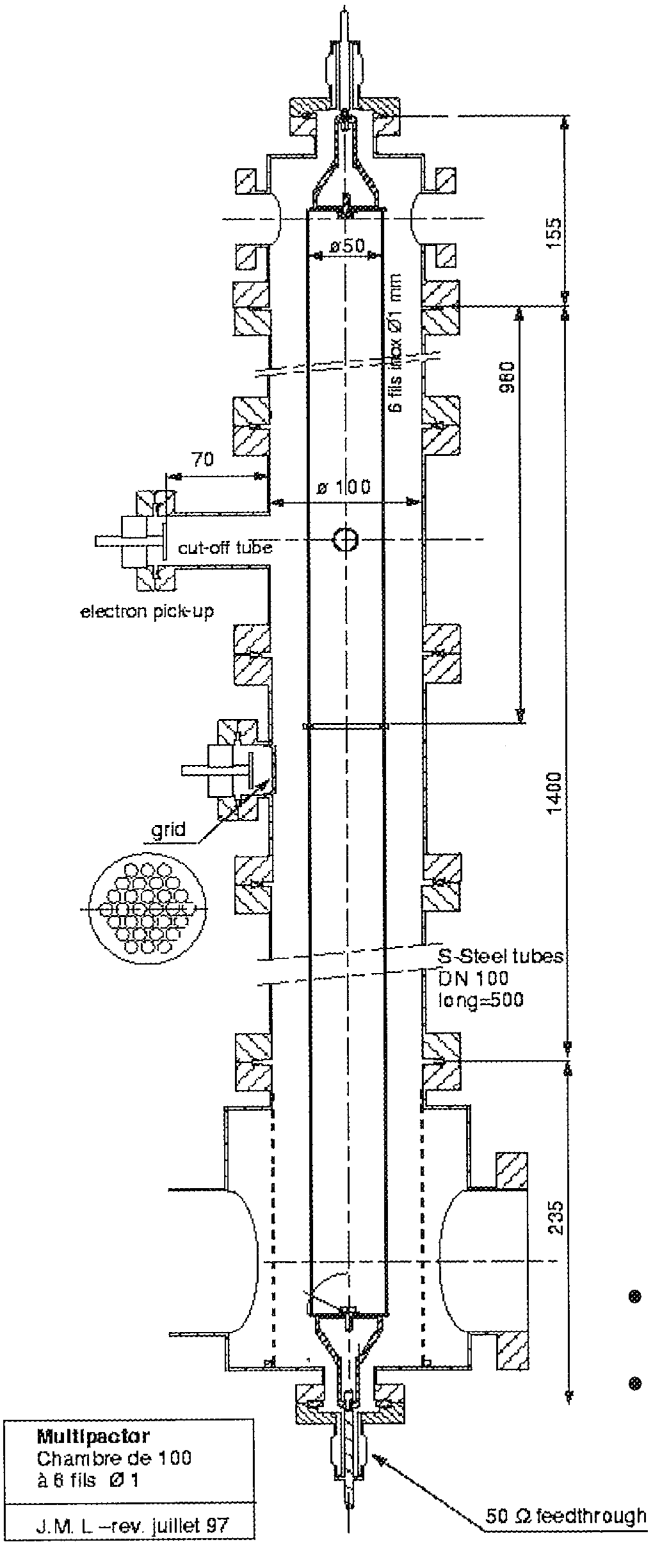


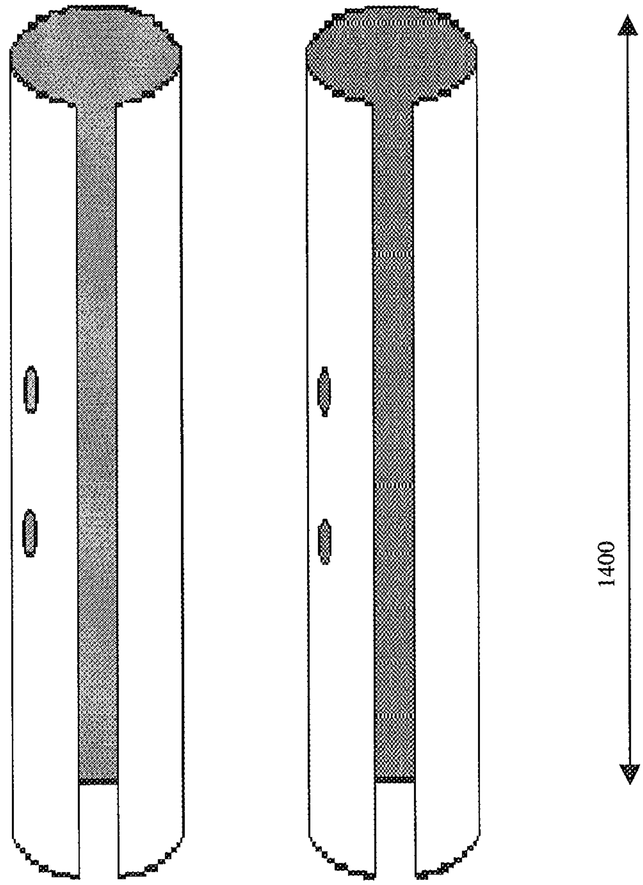
as received

after freon conditioning

*chemically cleaned

Multipacting studies with different surface materials: *Cu* and *TiZrV*





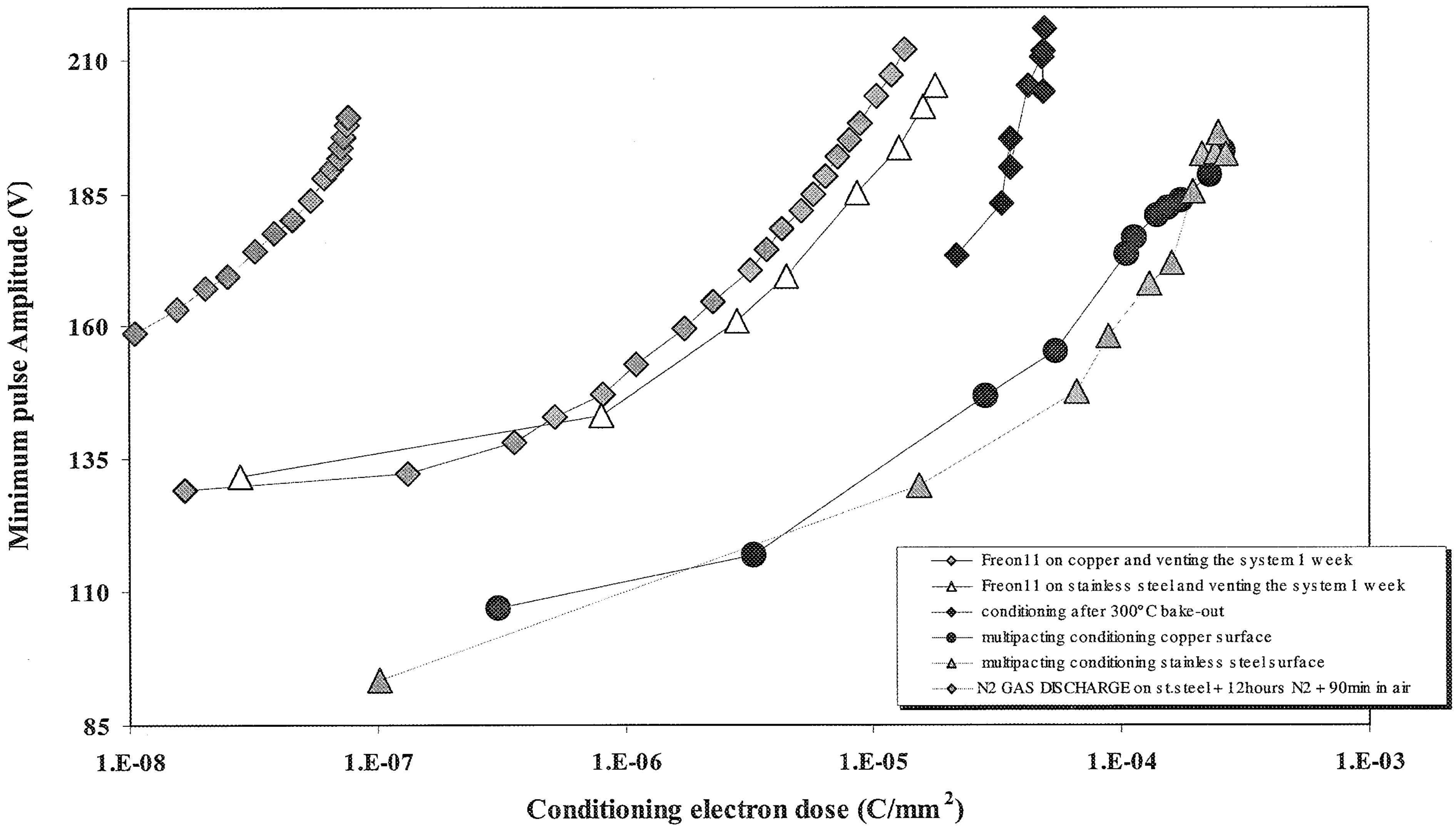
Copper

- conditioning
- Freon plasma

TiZrV sputtered on Stainless Steel 316L N

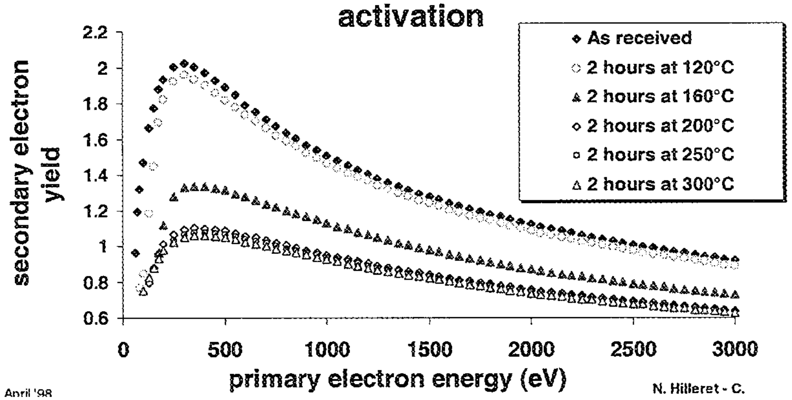
- NEG activation

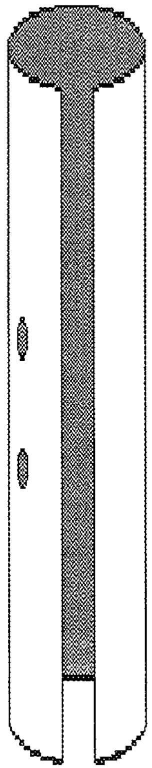
Multipacting conditioning methods



TiZrV-coating (NEG) activation to suppress multipacting

SEY of NEG TiZrV on Cu, as received and after 120°C, 160°C, 200°C, 250°C and 300°C activation



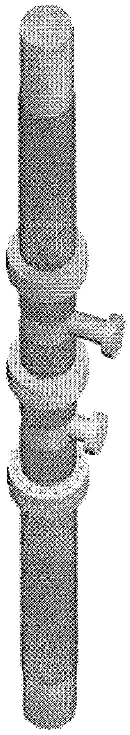


TiZrV-coated sheet introduced in the TW chamber

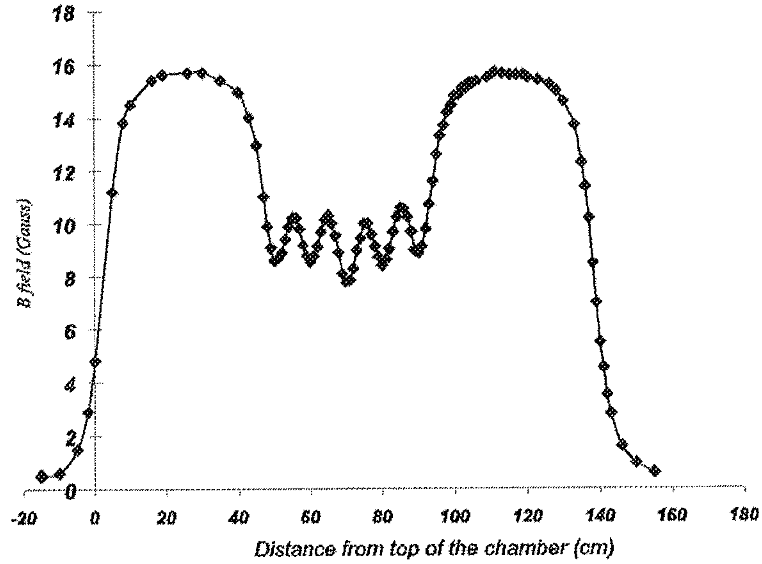
- **150°C bake-out*** still multipacting
- **180 °C ⟶ multipacting no longer present**
- after **250 °C** bake-out and then **venting** 1 week to air the system, still **no** multipacting
- after venting 1 month to air the system multipacting is present but with very low intensity

***12 hours**

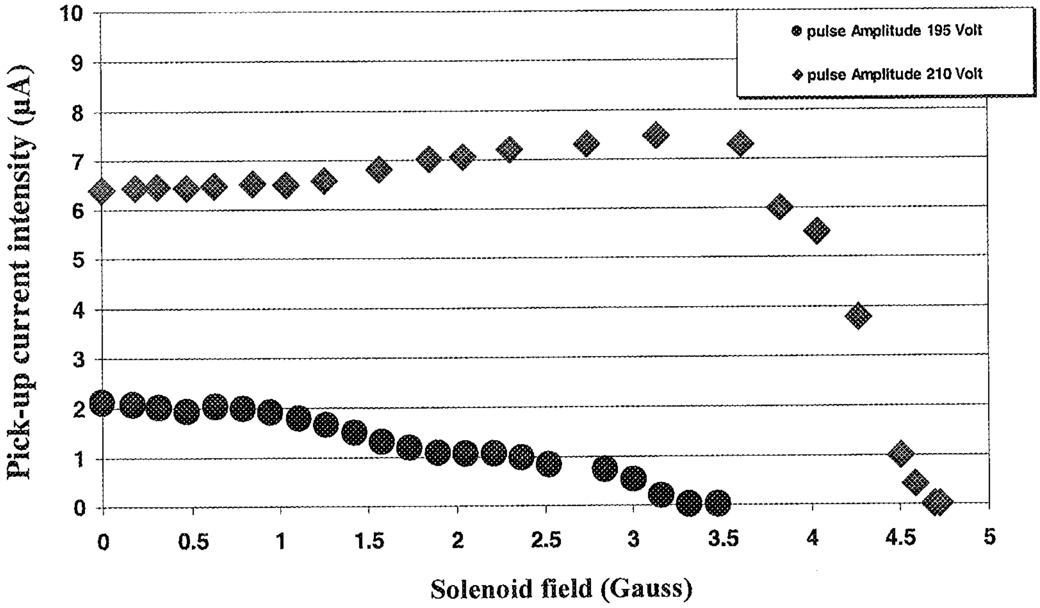
Suppression of multipacting with a solenoid magnetic field



Magnetic field on axis per Ampere of current



Multipacting intensity as a function of the solenoid magnetic field



Conclusions

TW multi-wire chamber

- experimentally determined the dependence of multipacting on the RF pulse parameters, pulse amplitude period and width (simulating the proton beam parameters)
- studied and built an electron energy analyzer and measured electron energy spectrum during multipacting
- performed simulations with the LHC multipacting computer code, adpted, which are in qualitative agreement with the experimental results
- studied a model for multipacting: agreement with experimental result

Conditioning (*Scrubbing*)

- measured multipacting conditioning in the TW chamber, estimated δ_{crit} , estimated the reduction of the SEY with the electron dose and the scrubbing-time for LHC (≈**6000*h*** *comm. period* - **55*h*** *thresh.*)
- studied the electron bombardment effect: Auger analysis of samples exposed to multipacting: formation of a carbon layer with low SEY

Remedies against the electron cloud build-up

- experimented a novel plasma RF discharge treatment using Freon11, is a promising way to suppress multipacting (*copper*)

  More studies are necessary, in particular to:

  - **Confirm the effect with other experiments**
  - **estimate the optimal freon working pressure**
  - **test freon on the 100 MHz resonant cavity, (and at low temperatures)**
  - **verify the recontamination time after venting the system in air, etc....[1]**

- Auger studies of samples exposed to the freon plasma (two different effects on copper and stainless steel)

- activated TiZrV-coating in the TW chamber
  ⟶ multipacting absent, quite permanent effect

- suppressed multipacting with a solenoid magnetic field - 5 Gauss, estimation for LHC (> 15 Gauss)

- analyzed bake-out of the system (desorption)

Future plans

during next *Machine Develepment* sessions in the **SPS**

- Gas discharge treatment N_2, Freon11, TiN
- solenoid magnetic field
- TiZrV-coating activation

Involved in multipacting in the LHC at Cern:
LHC Vacuum group: I. Collins, O. Grobner, N. Hilleret, J-M. Laurent, M. Pivi
SL/AP: F. Ruggiero, O. Bruning, F. Zimmermann
SL/OP: G. Arduini, K. Cornelis
PS: F. Caspers, M. Morvillo

http://wwwslap.cern.ch/collective/electron-cloud/electron-cloud.html

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