RF activities at LPSC Grenoble

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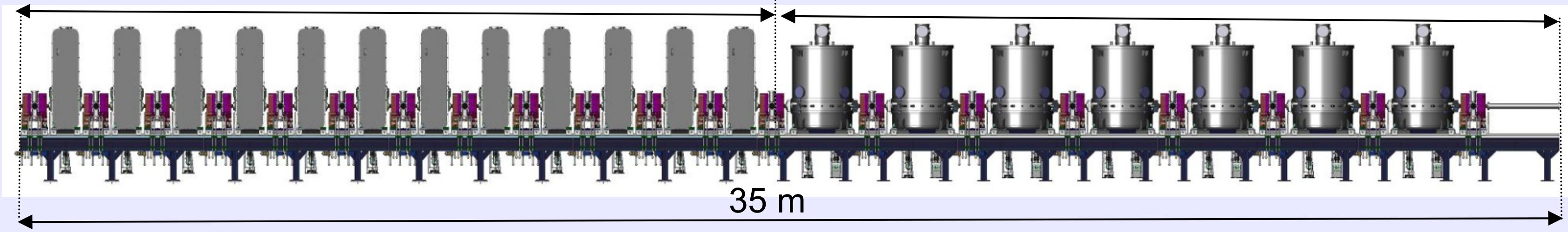
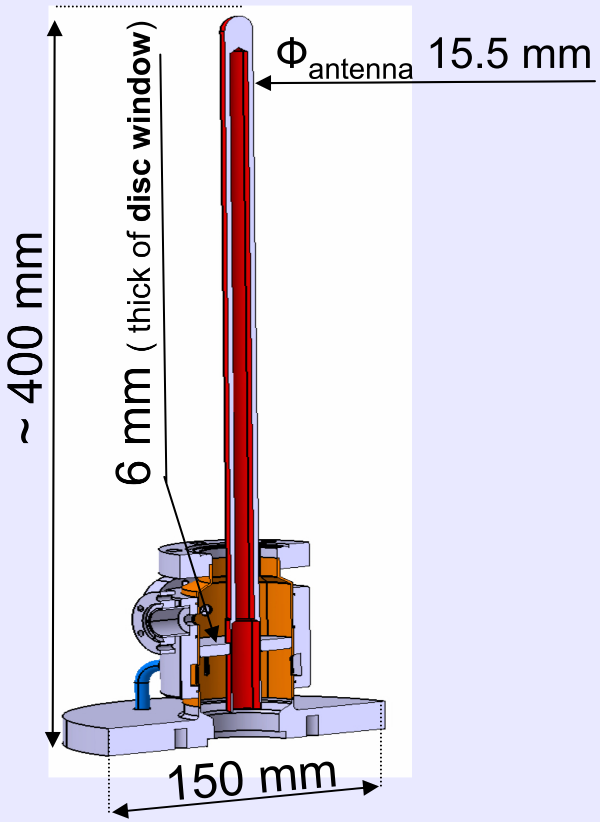
Outline

- Spiral 2 couplers
  - layout & parameters
  - Our learning on
    - Window coating aspects
    - Coupler preparation
- Multipacting state of art for MAX
  - Physical models
  - Multipacting CODES
  - Data
  - Experiments
- Summary

RF Spiral 2 couplers

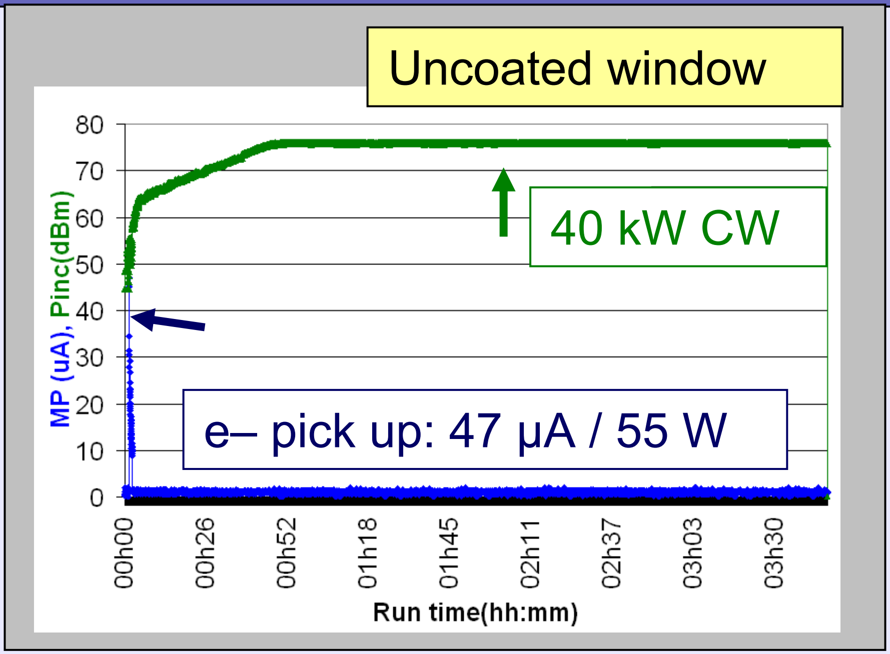




Coupler

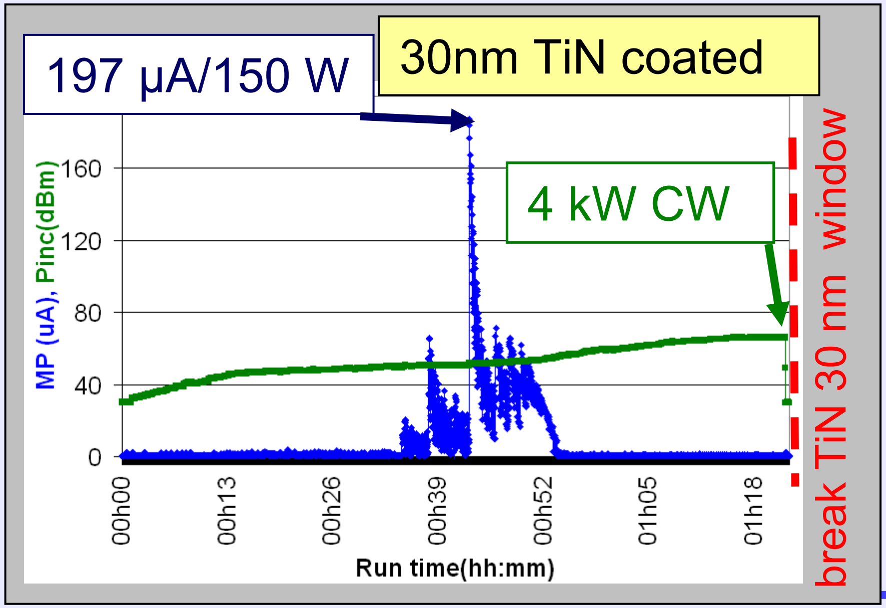
Parameters	Values
Number	26 (12 + 7*2)
Frequency	88.05 MHz
Nominal power*	10 kW CW
Power during test	Up to 40 kW CW
S_{11}	< -25 dB
Thermal load at 4.2 K	< 1 watt
Accepted reflected power	100%
Q_{ext} at nominal current*	1.3 10^6 - 2.4 10^5
**Spiral 2 nominal accelerating gradient*	*6.5 MV/m*
**Spiral 2 nominal current.*	*5 mA deuterons*
Max filed on the tip of the coupler	*E max CMA = 12 MV/m* *E max CMB ~ 11 MV/m*

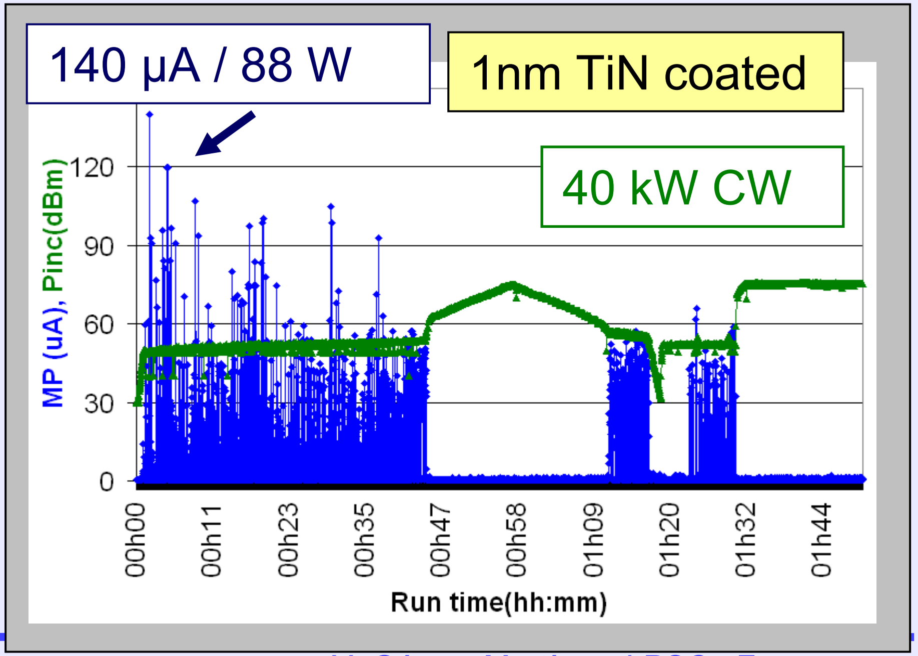
Our learning on coating window aspects



- Although almost no multipactor was observed a TiN coating was tested
- 40 kW CW was reached except for the 30 nm TiN coated window
- A coupler with a 10 nm TiN coated window had a problem during production

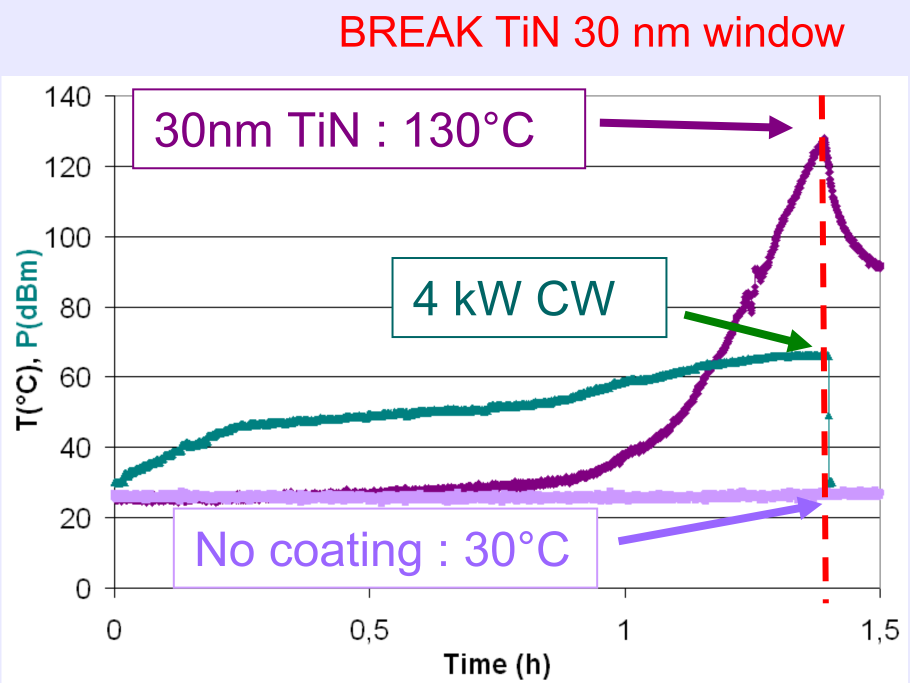
Graphs: Multipactor and power of an uncoated , a 1 nm TiN and 30 nm TiN coated window.





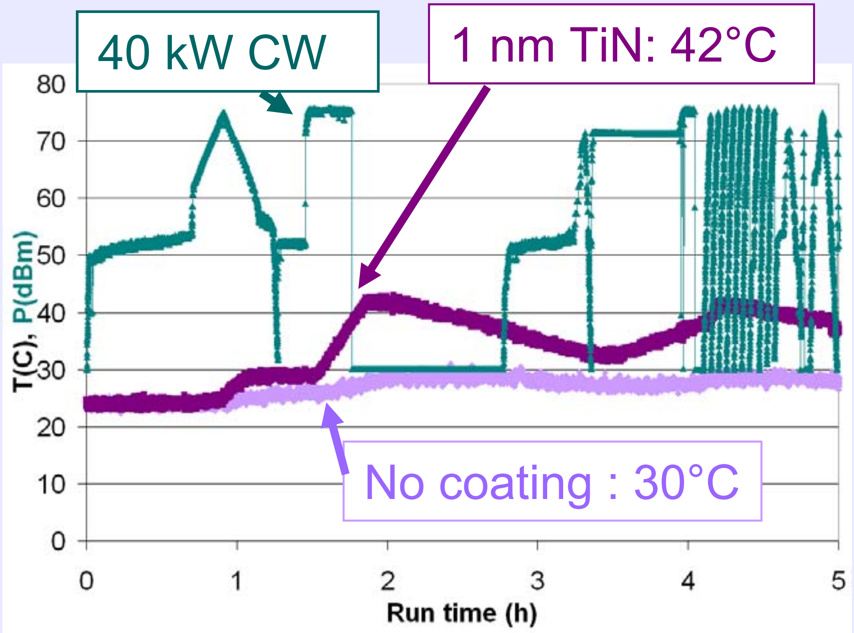
Our learning on coating window aspects

30nm TiN coated window



Temperature and power of an uncoated and a 30 nm TiN coated window

1nm TiN coated window

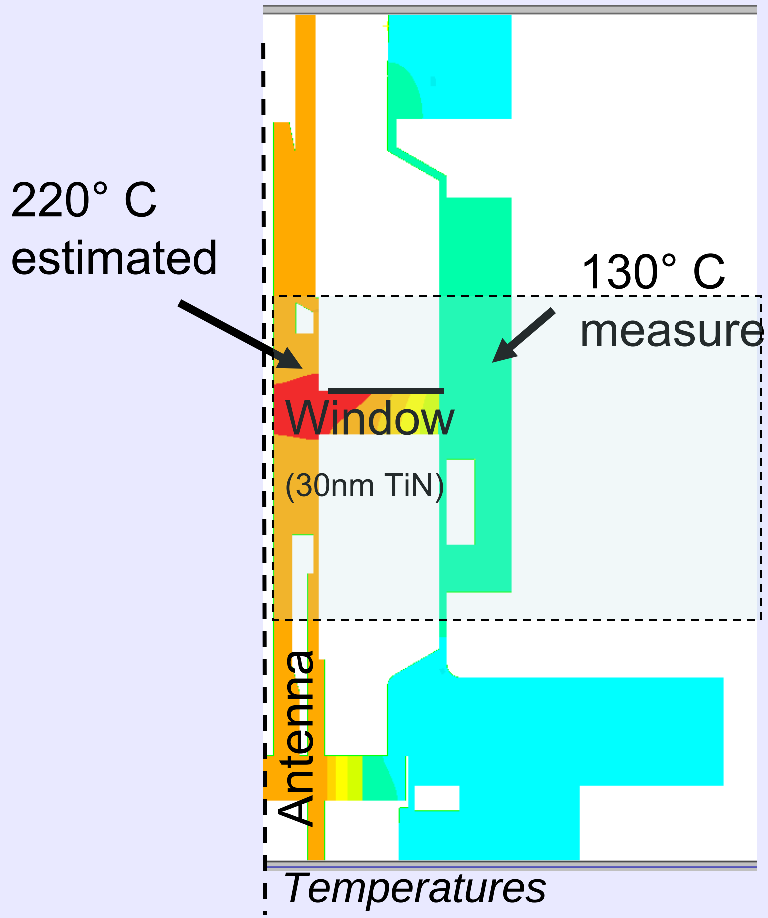


Temperature and power of an uncoated and a 1 nm TiN coated window

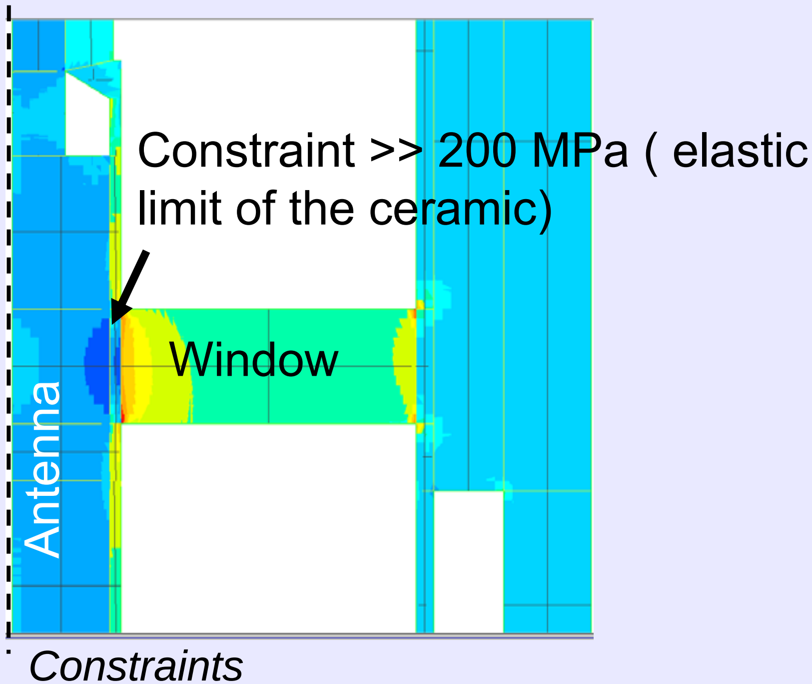
Temperature safety threshold: 40° C.

- **A temperature increase produced by the coating has been observed (normal)**

Our learning on coating window aspects



	Thermal expansion coefficient
Alumina	$7.4\ 10^{-6}\ K^{-1}$
Copper	$1.55\ 10^{-5}\ K^{-1}$



- **This very high constraint led to window's break**

Our learning on coating window aspects

- Measurement of the resistivity of the TiN coating

Thickness	R measure	ρ (Ω cm)	R_{sq} (MΩ/sq)
30 nm	30 kΩ	0,5	~ 0,1
1 nm	200 MΩ	120	~ 1000

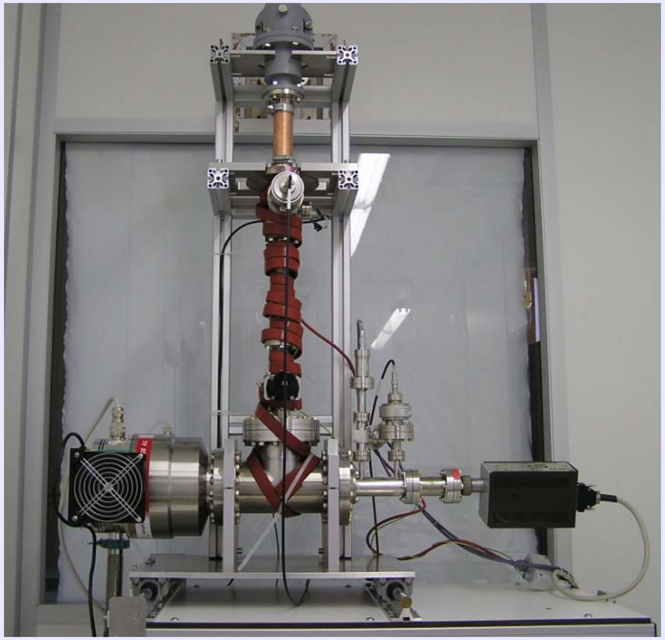
- Rutherfold Backscattering Spectrometry (RBS):

  30 nm TiN [42 % Ti , 50 % N, 8 % O]

Material	ρ (Ω cm)
TiN	$25\ 10^{-6}$
TiO	10^{12} - 25 °C $25\ 10^{4}$ - 600 ° C

Our learning on coupler preparations aspects

- First coupler preparation at LPSC Grenoble :
  - In a clean room ISO 6
  - Ultrasonic bath during 15 min @ 50°C with Ticopur
  - Baking during 60 h @ 200°C and 10^{-2} mbar
  - Baking in situ during 30 h @ 90 °C and around 10^{-8} mbar



Coupler commisioning

AFTER SOME CRYOMODULES
TESTS FAILED
AND IMPORTANT EFFORT
HAVE BEEN MADE
AT THE COUPLER AND AT THE CAVITY
PREPARATION
TO IMPROVE THE CLEANLESS AND
TO IMPROVE THE SURFACE CONDITION

Our learning on coupler preparations aspects

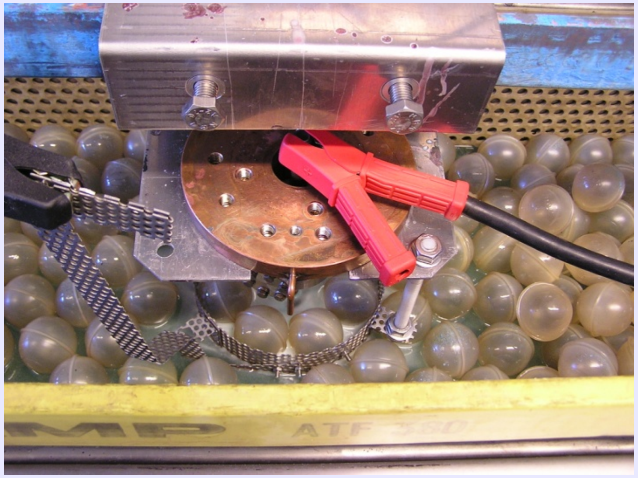
- **To improve the cleanness of the coupler**
  - The coupler is mounted at a ISO 4 hood
  - Test bench is vented with flow-controlled (< 1l/min) N2 filtered alphagaz 2
  - The tip of the antenna is at the bottom all the time (mounted, travel, ..)
  - A counting of the dust of each piece is made (before, while and after mounted)
    - Particles of 0,5 micron : less than 100 particles for 28 liters
    - Particles of 5 microns or more: 0 particle

Our learning on coupler preparations aspects

- ***To improve the surface condition***
  - Electropolishing of the antenna
  - Deoxidation of all metal surfaces (Ac citrique saturated and then the antenne with ac. sulfamide (5g / 1 l))

THESE IMPROVEMENTS MORE OF THE IMPROVEMENTS OF THE CAVITIES LED THAT

THE NEXTS CRYOMODULES TESTED HAVE BEEN A SUCCESS



Electropolishing of the coupler

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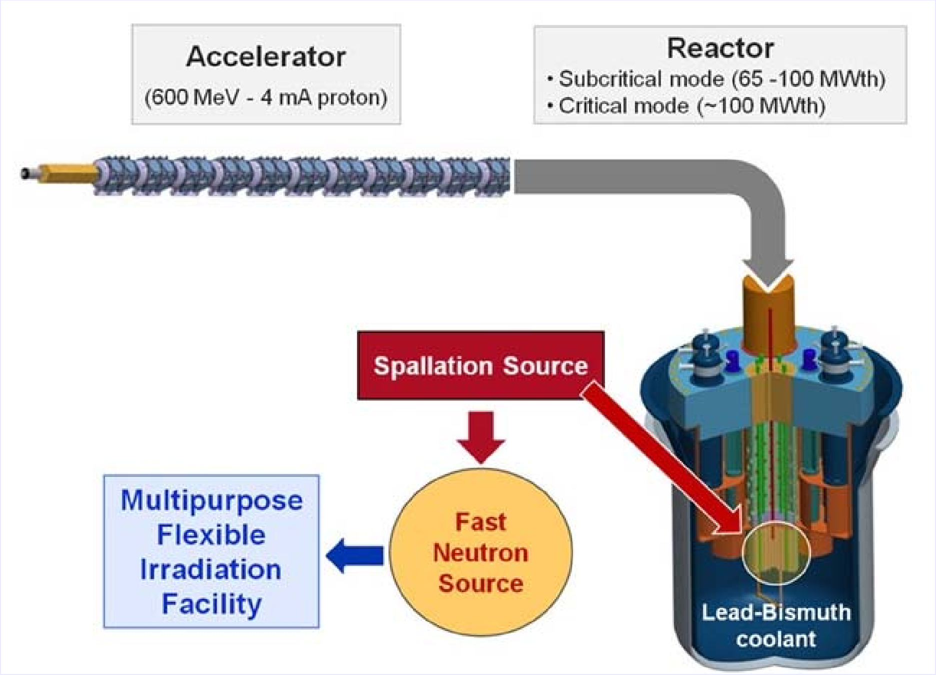
Multipacting state of art for MAX

- MYRRHA Accelerator eXperiment , research & development programme
- Multipurpose hYbrid Research Reactor for High-tech Applications
- Activity/Area: Management of Radioactive Waste: Partitioning and Transmutation

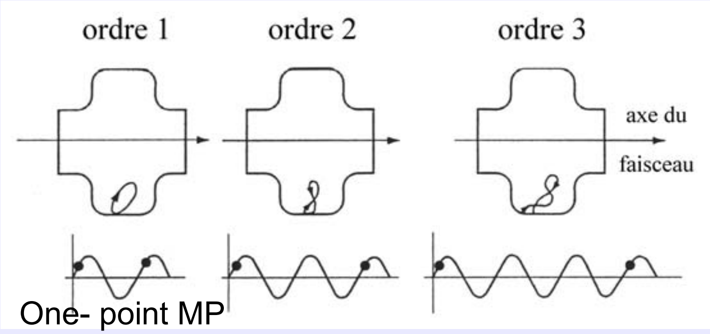


http://myrrha.sckcen.be/

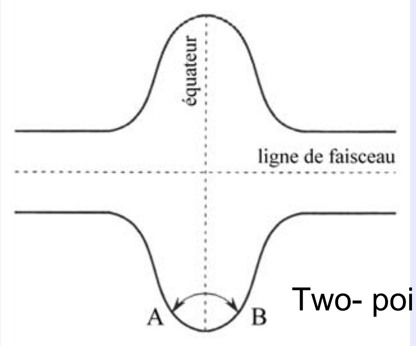
- LPSC: RF study in WP3.1:
  - To establish a state of the art and analysis of the multipactor phenomenon
    - Physical models / Existing and missing tools / Existing and missing data and/or experiments
  - To confront the results to the cavities and couplers developed in WP 3

Multipacting state of art for MAX

- Multipacting (MP) is a phenomenon of resonant electron multiplication encountered in electromagnetic (EM) field region in which a large number of electrons build up an electron avalanche



One- point MP



Two- points MP

- This can lead to power losses and internal surfaces heating and degradation, and produce thermal breakdown in superconducting structures. It can also limit the power coupling/matching between the power source and the RF cavities. A heavy bombing of multipacting electrons may lead to failures in the ceramic windows of high power couplers and to disastrous consequences

- The goal is to determine if a volume (cavity, coupler) present the risk of having multipacting, at which field level and the multipacting trajectory
  - Scaling laws
  - Simple criterion
  - Particle tracking CODE 2D or 3D

Multipacting state of art for MAX / Physical model

- Scaling laws restrict to a coaxial line with a standing wave (Somersalo et al [1] [2])

$$E_{\max} \propto \frac{f^2 d}{n+1}$$

Max E for finding a MP

$$P_{input} \propto \frac{f^4 d^4}{(n+1)^2}$$

P favorable to have a MP

$$P_{1\,point} \propto (fD)^4 Z$$
$$P_{2\,point} \propto (fD)^4 Z^2$$

Power for MP

$$E_{kin} \propto (fD)^2$$

Impact energy of electrons

[1] ' Electron Multipacting in RF Structures' – TESLA Rapport 14 -94, 1994
[2] 'Analysis of Multipacting in Coaxial Lines' PAC95

f : frequency
d : parameter of the size of the line
n : order of the MP f frequency,
D : diameter of the external conductor
Z : impedance of the line

Multipacting state of art for MAX / Physical model

- ‘ Poor man model’ in a RF cavities (R. Parodi et al [3] [4])

$$\frac{f}{n} = \frac{e\mu_0 H}{2\pi m}$$

For potential one-point MP

$$\frac{2f}{2n-1} = \frac{e\mu_0 H}{2\pi m}$$

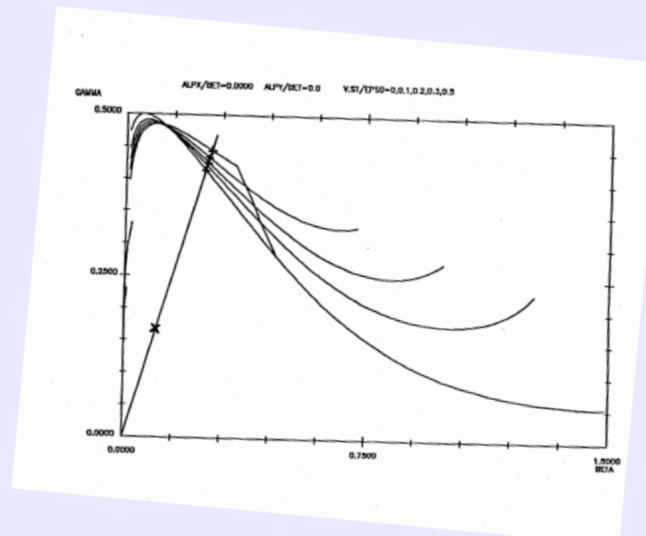
For potential two-point MP

f : frequency
n : order of the MP f frequency,
e : electron charge
***m :* electron mass**
***H :*local magnetic field at the surface**

[3] ‘ An Investigation on the Field Emitted Electrons in Traveling Wave Accelerating Structures’ NIM A. 320 (1992) 1-8.
[4] ‘ Experimental evidence of MP Discharges in Spherical Cavities at 3 GHz ‘ SRF95

Multipacting state of art for MAX / Physical model

- J. Tuckmantel [4] gives a criterion restrict to the case of a point multipacting on local flat surfaces
  - Need the magnetic field $\vec{B}_{z,o,}$ and the electric surface gradient $\frac{\partial \vec{E}_x}{\partial y}$
  - The basic idea: Establish a catalog of all possible field configuration having MP of a predetermined type



- It was intended to complete to the cases of stronger curvature, two point multipacting around an electric field and in edges .

[4] SRF98 : ‘ One Point Multipacting Levels Determined Without Particle Tracking’

Multipacting state of art for MAX / Physical model

- CODES do not give scaling laws (no phenomenology)
- Basic idea: to design the devices, calculate the fields and search for MP

CODES integrate the dynamic equations of the electron in time varying EM fields:

$$\frac{d\vec{v}}{dt} = -\frac{e}{m}\left(1-\left(\frac{v}{c}\right)^2\right)^{\frac{1}{2}}\left(\vec{E}+\vec{v}\,x\,\vec{B}-\frac{1}{c^2}\left(\vec{v}\cdot\vec{E}\right)\vec{v}\right)$$

f fréquency, $\vec{v}$ electron speed, c vacuum light speed, m = mass e, e charge
$\vec{E}$ electric field, $\vec{B}$ magnetic field

- To identify MP, CODES are often based in some functions implemented by the code MULTIPAC (Counter Functions, Enhanced Counter Functions, Distance Functions)

Multipacting state of art for MAX / Codes

- We found the INPUTS of the codes looking the conditions for multipacting:
  - An electron emitted (initial emission angle / initial velocity) for a surfaces (initial sites) is driven by the electromagnetic field (phase of the time – varying EM fields / fields levels / reflection coefficient in coupler case) and returns back after an integer of RF cycles to the same point of the surfaces
  - The impacting electron produces more than one secondary electron (RF- phase, energy of the impacting electron , SEY - secondary emission yield-)
- The tracking of electrons will continue for a specified number of RF cycles

- Most used hypotheses :
  - The field of the emitted electrons is neglected
  - The emission angle of the initial electrons is perpendicular to the boundary
  - The electron initial velocity is constant (ex: 2 eV)

Multipacting state of art for MAX / Codes 2D

CODE	Year	Some features
MULTIPAC v2.1 / RNI (Helsinki)	1994	+ EM field solver included but with a resolution of the mode TM_{onl} only +/- graphical interface but in a old MATLAB no compatible with the new version. - Only three type of geometry (coaxial / coupler / cavity) - Sur Linux +Available freely for research
MUPAC / CEA Saclay	2000	+The geometry and the EM field are imported from SUPERFISH (surface field are smoothed by a higher order interpolation) + Parallel version developed to work on a network PC -Not public

Multipacting state of art for MAX / Codes 2D

CODE	Year	Some features
TWTRAJ / Genoa	1970	+The EM fields are imported from OSCAR2DS (highly accurate solution at he RF surfaces) +/- Runs on personal computers under MS windows
MULTIP / Cornell I		+the EM fields are imported from SUPERLANS or an older version of SUPERFISH v4
MPCALC / ESA		+Available freely

Multipacting state of art for MAX / Codes 3D

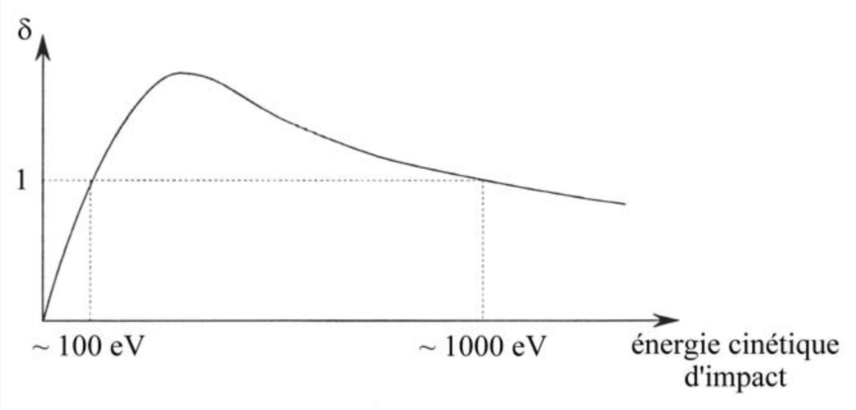
CODE	Year	Some features
TRACK 3P / ACE3P	2012	+ Run at different electrons phases +Run in a network of super computers +Post processing tool: determine the MP order and type, and counter functions to crosscheck the MP barriers -Available for SLAC collaborators
TRAK 3D / UNM Alburquerque		+ EM field solver included -Evaluation and detection of MP must be done by the user - The software is supported is a personal computer
SPARK 3D / Aurorasat		+ the EM fields can be imported from HFSS, CTS and soon COMSOL + You can buy it

Multipacting state of art for MAX / Codes 3D

CODE	Year	Some features
Xing / Cornell II		+ the EM fields are imported from MAFIA
MULTP / russe	2000	+ imported from MAFIA the EM fields + Give the e^- trajectories in real time -Little analyses tools/ hard to know the power to trigger the MP - The software is supported is a personal computer MS Windows - Freely available
MUSICC3D / IPN O	Expected for September	+ the EM fields are imported from HFSS or tetrahedral mesh +Outputs: graphs: load & field, nb of collisions & field, average energy of collisions & max. field, viewing of des trajectoires…

Multipacting state of art for MAX / data

- SEY (δ) depends
  - Energy of the incident electron
  - Surface:
    - the state
      - the air exposition
      - the baking of the surface
      - thickness of the coating (if there is one)
      - temperature (cold regions containing condensed gases which enhanced the surface SEY)
    - cleanliness of the surface



Multipacting state of art for MAX /experiment

- Experiments & theory to define the maximal multipacting values without danger for the devices
- Experiments to measure the SEY
- Experiments & theory to avoid MP
  - Modifying the geometry
  - Imposing an external DC biasing field
  - Coating the surface
    - Specifications
      - Type of coating (Ti, TiN, TiO, CrxOy…)
      - Thickness / properties / composition (% oxygène…) of the coating
    - Methods
      - Evaporation method
      - Sputtering method

Summary

- I did a summary of our experience in the coupler for Spiral 2
  - Technology
  - Process
- Syntheses of the state of art of multipacting on work
  - Codes
  - Need of the expérimental data
- Questions
  - Your opinion about the MP phenomena?
  - Possible collaborations?
    - Modelisation
    - Codes
    - Experimentation