Multipacting at LPSC

FCCee SRF IN2P3 collaboration

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Summarized

- Experimental facilities
- Way of simulations
- Projects
  - Before 2018:
    - MAX ‘ Myrrha Accelerator eXperiment research & development programme’
    - SPIRAL 2 : 'Système de Production d'Ions RadioActifs en Ligne de 2ème génération'
  - After 2018
    - MYRRHA : 'Multi-purpose hYbrid Research Reactor for High-tech Applications'
    - Project ‘Multipactor’ (internal R&D IN2P3) : on going

Experimental facilities : Multipacting test bench

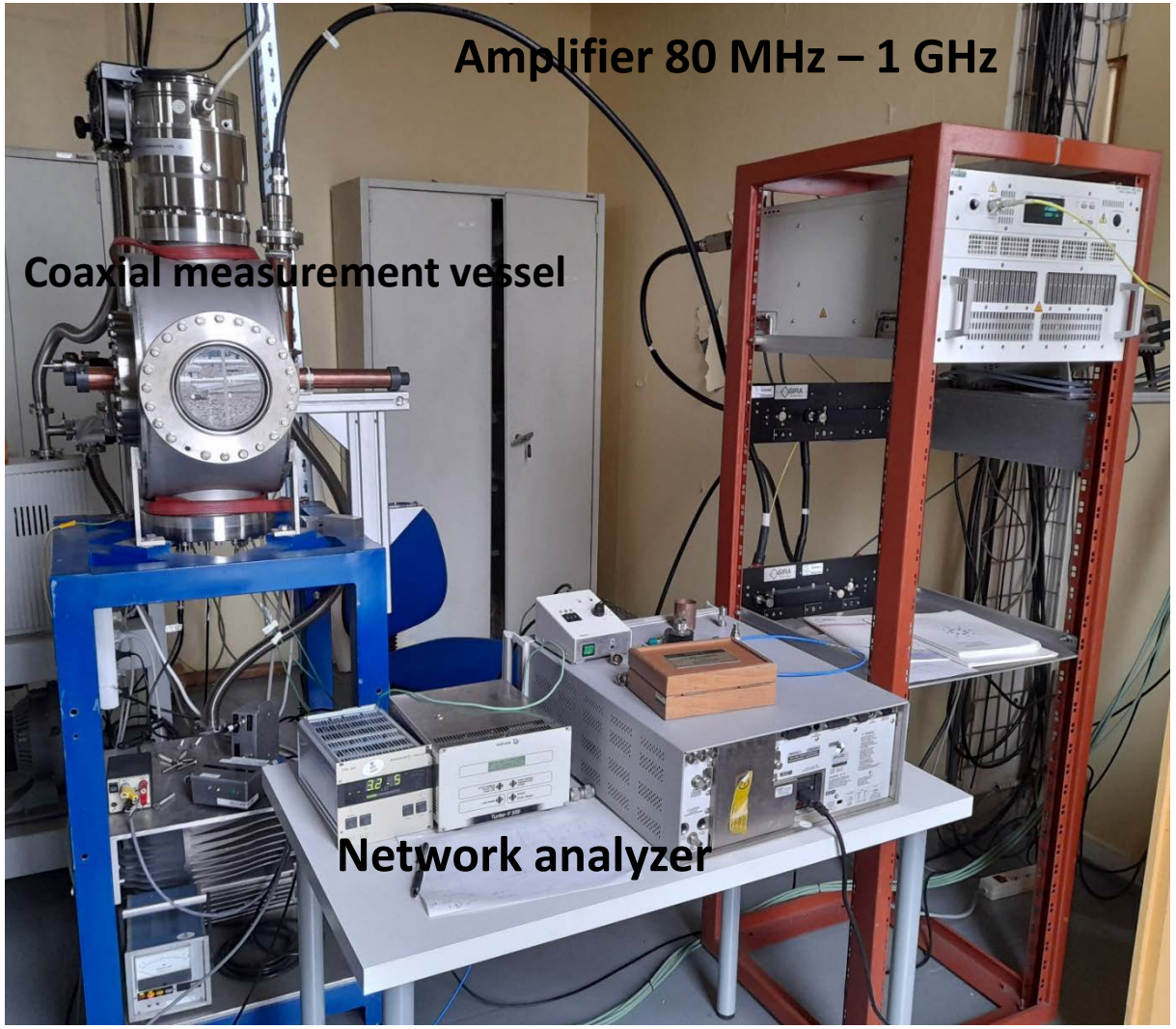
The accelerator group at LPSC has developed an experimental set-up dedicated to multipactor phenomenon study.
The test bench is composed of :

- **RF devices :** Network analyzer, amplifier 80 MHz – 1GHz @ 400 W garanteed…
- **Coaxial measurement vessel :** Coaxial line (ϕ_{ext} : 38.8 mm / ϕ_{int} : 16.87 mm) which allowed us to observe multipactor up to 180 MHz.

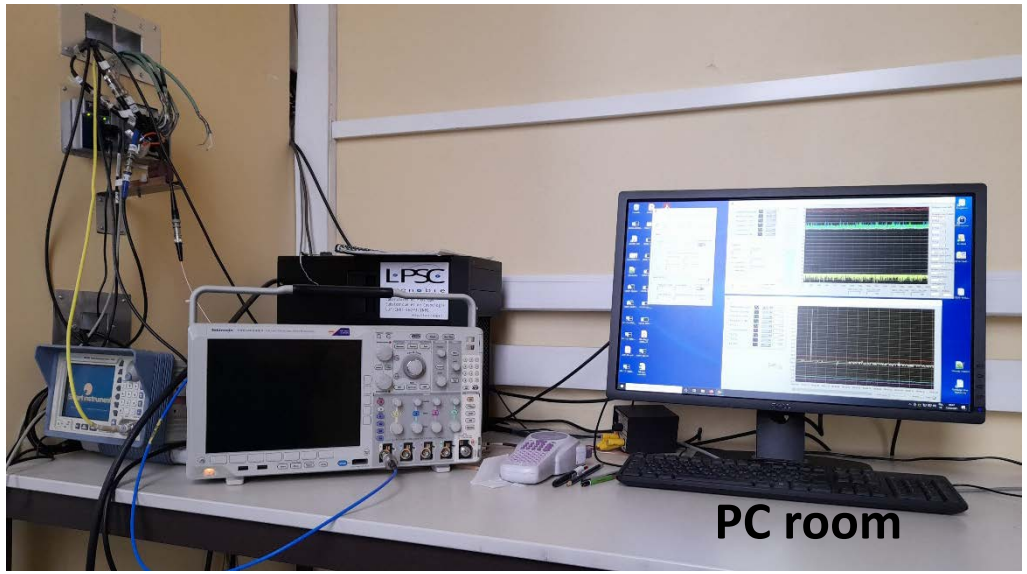
  In progress: Validation up to 1 GHz with resonant configuration
- **Diagnostics** : Power and pressure measurements, electron pick-up with a polarized antenna + 45V thermocouples, RGA.

  Under study for implementation: Measurement of electron energy, arc detector, voltage probe.
- **Data acquisition and setup automation**: Handled by a LabVIEW software running on a standard PC
- **Clean room:** ISO 7 with ultrasonic bath, vacuum oven, demineralized water, …

Experimental facilities

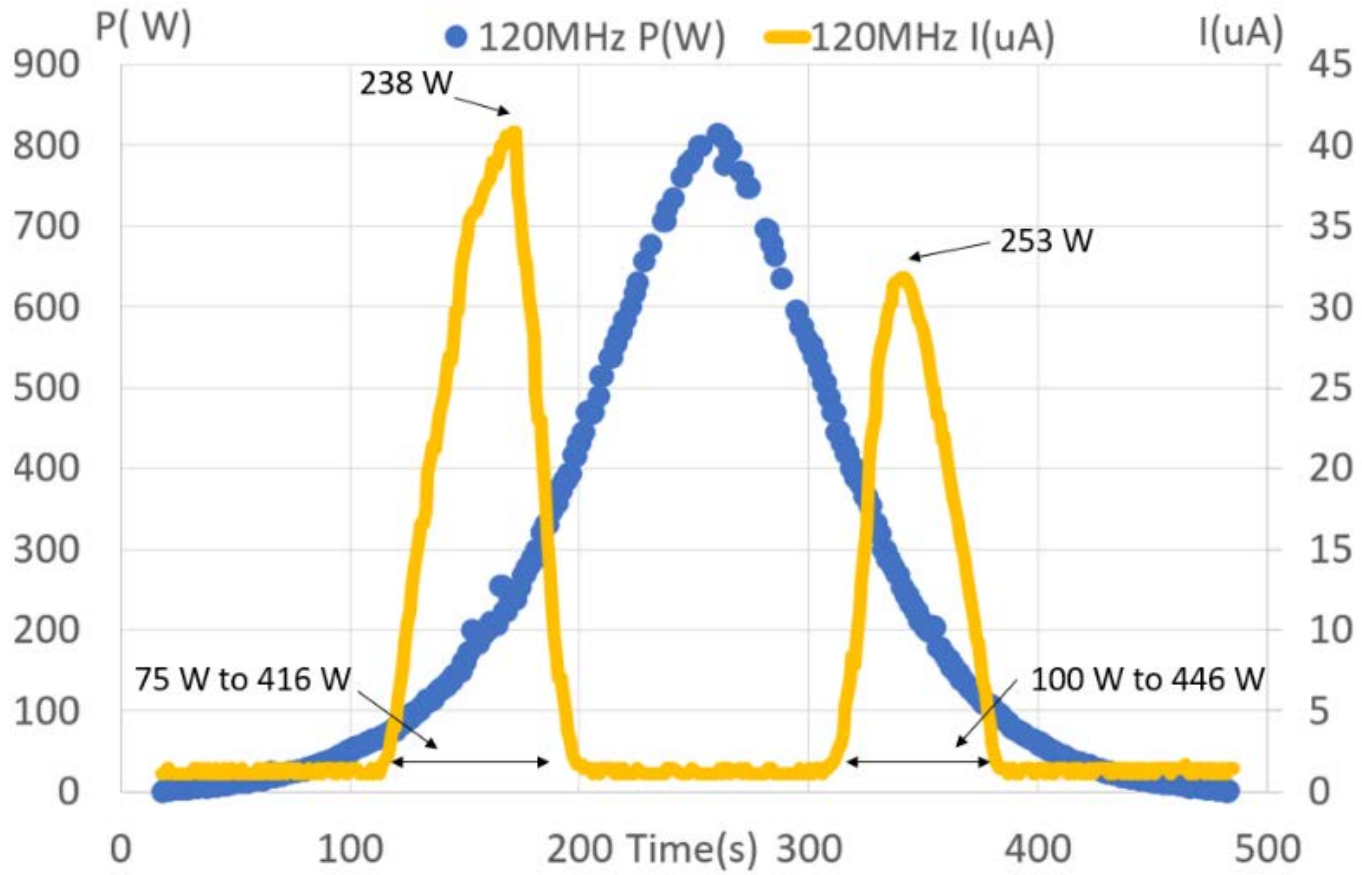


Test bench dedicated to multipactor studies



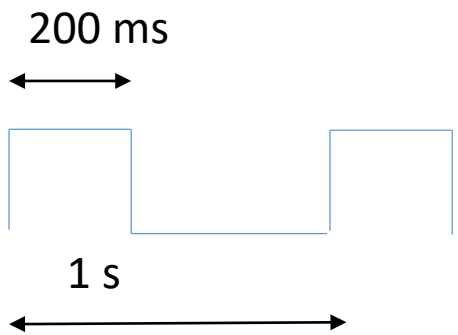
Experimental facilities

Monitoring measurements *(One measurement per second, maximum values recorded)*

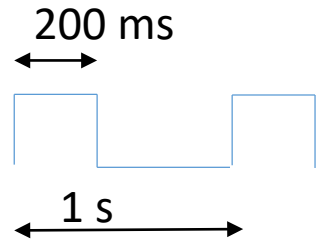


Power et multipacting measurement in pulse mode at 120 MHz

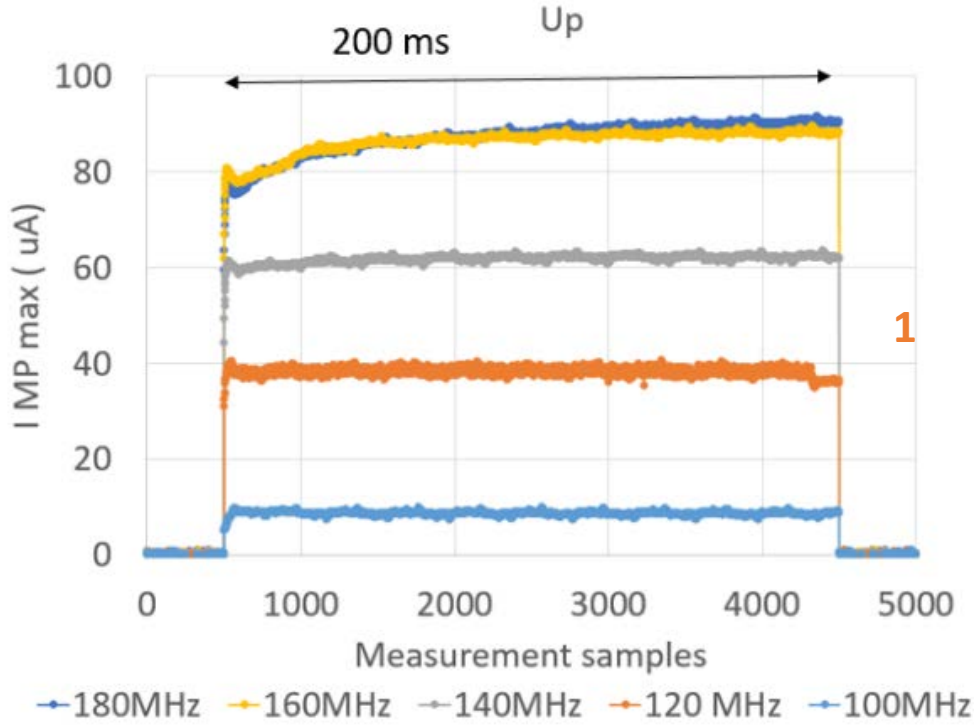
Consecutive rise and fall power ramp in pulse mode:

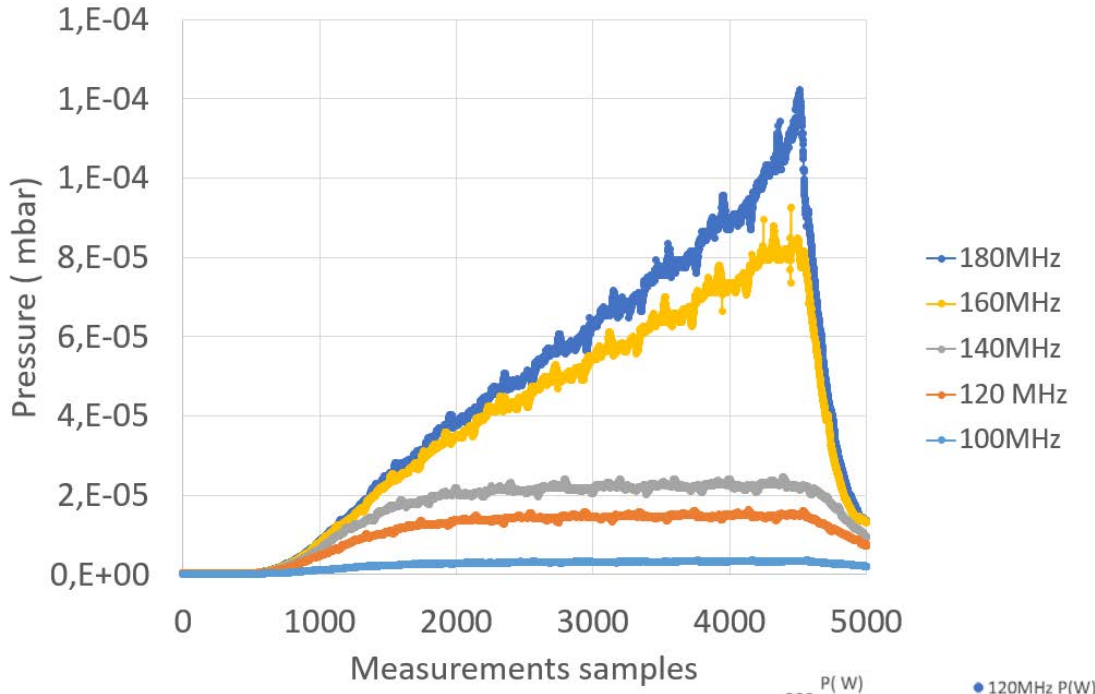


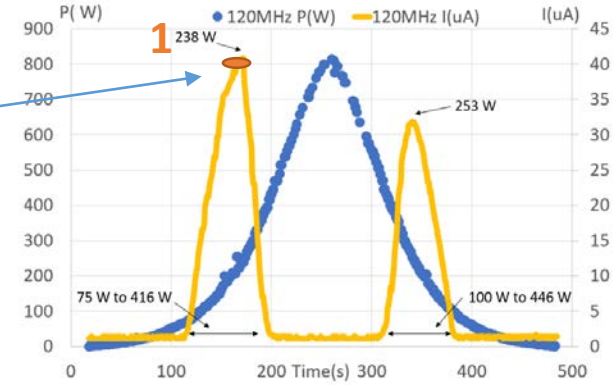
Experimental facilities



Snapshots (20 kS/s – 4000 samples @ 200 ms)

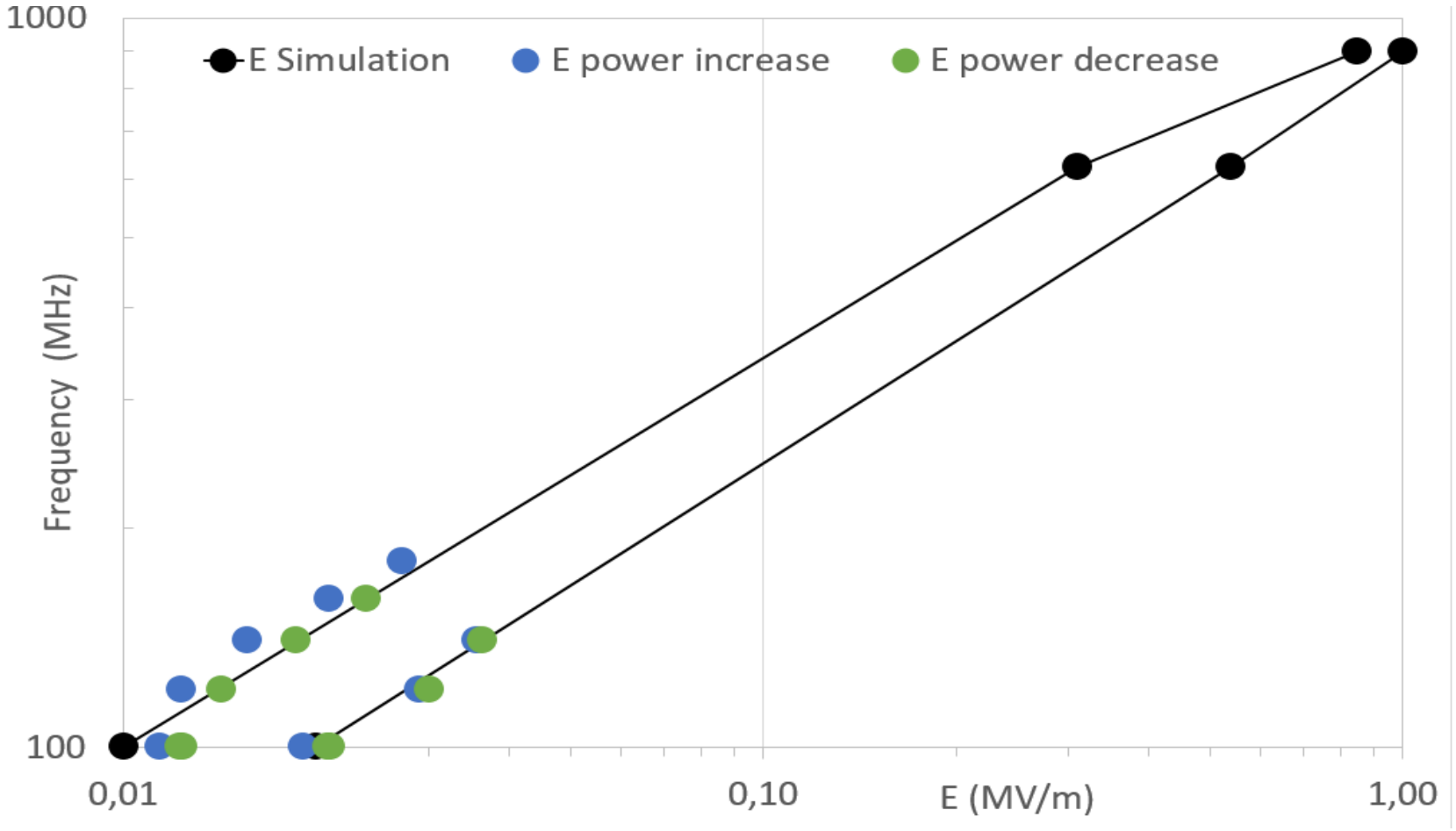






*A snapshots of a waveforms at maximum multipactor current at point **1** when the power is increased at 100, 120, 140,160 and180 MHz.*

Test bench measurement and simulation correlated



Comparaison of the electrical field range where multipacting has been measured and the simulation results (HFSS /MUSICC3D@IJC Lab).

Ways of simulation

- Electromagnetism : **HFSS**, **CST**.
- Multipactor : **SPARK3D** (@ CST), **MUSICC3D** (@IJCLab), **Multipaction** 3D(@HFSS), **MULTIPAC 1D** (@Helsinki University of Technology).
- Other : Mathematica, …

Projects

Project	Aprox date	Study	Simulation codes
MULTIPAC	In progress	Multipacting phenomenon	**SPARK3D and MUSICC3D**
MYRRHA	2018 (studies end)	RF coupleur 80 kW CW@352,2 MHz	HFSS and MUSICC3D
SPIRAL2	2017 (RF conditionning end)	RF coupleur (without multipacting studies) 20 kW CW@88 MHz	HFSS
MAX	2015 (studies end)	Cavity multipacting 13 MV/m@704,4 MHz	MULTIPAC
MAX	2015 (studies end)	Coupler multipacting 70 kW CW@704,4 MHz	MULTIPAC

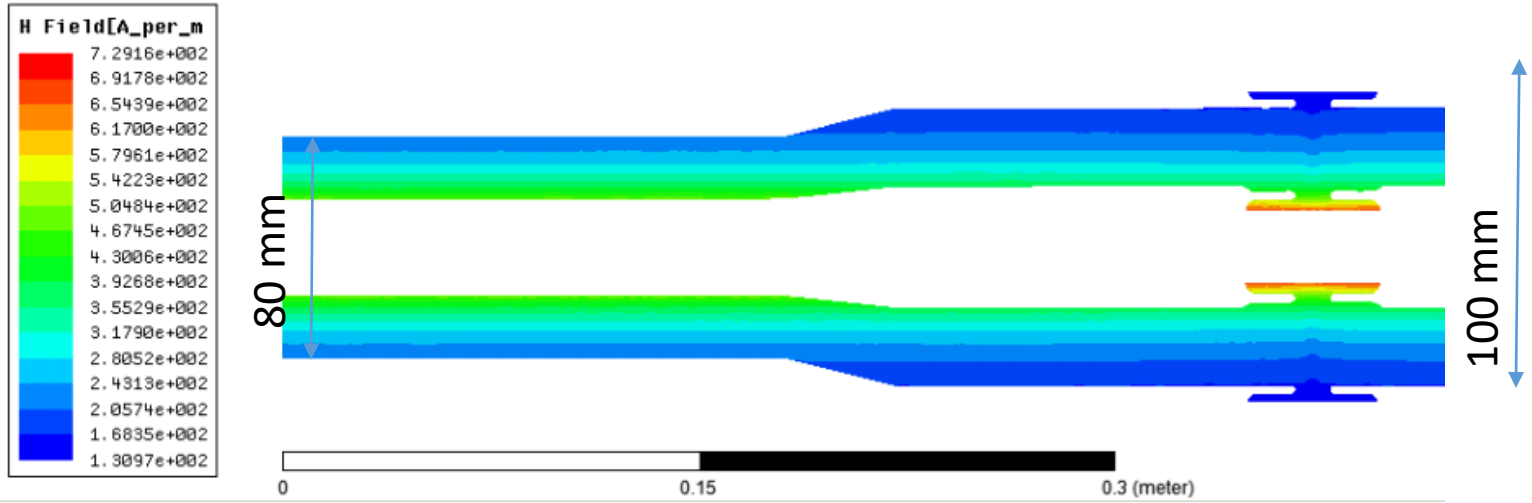
MAX ‘ Myrrha Accelerator eXperiment research & development programme’
SPIRAL 2 : 'Système de Production d'Ions RadioActifs en Ligne de 2ème génération'
MYRRHA : 'Multi-purpose hYbrid Research Reactor for High-tech Applications'
Project ‘Multipactor’ (internal R&D IN2P3)

Projects : MAX

- Multipactor study of the MAX cavity with MULTIPAC

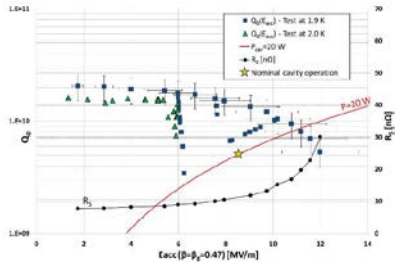
Frequency (mode $TM_{010-\pi}$)	704.4 MHz
β_g	0.47
(r/Q)	80 Ω
E_{acc_max}	13 MV/m
E_{peak} / E_{acc}	3.57
B_{peak} / E_{acc}	5.88 mT / (MV/m)

- Multipactor study of the MAX RF coupler de MAX with MULTIPAC
  - 70 kW CW @ 704.4 MHz

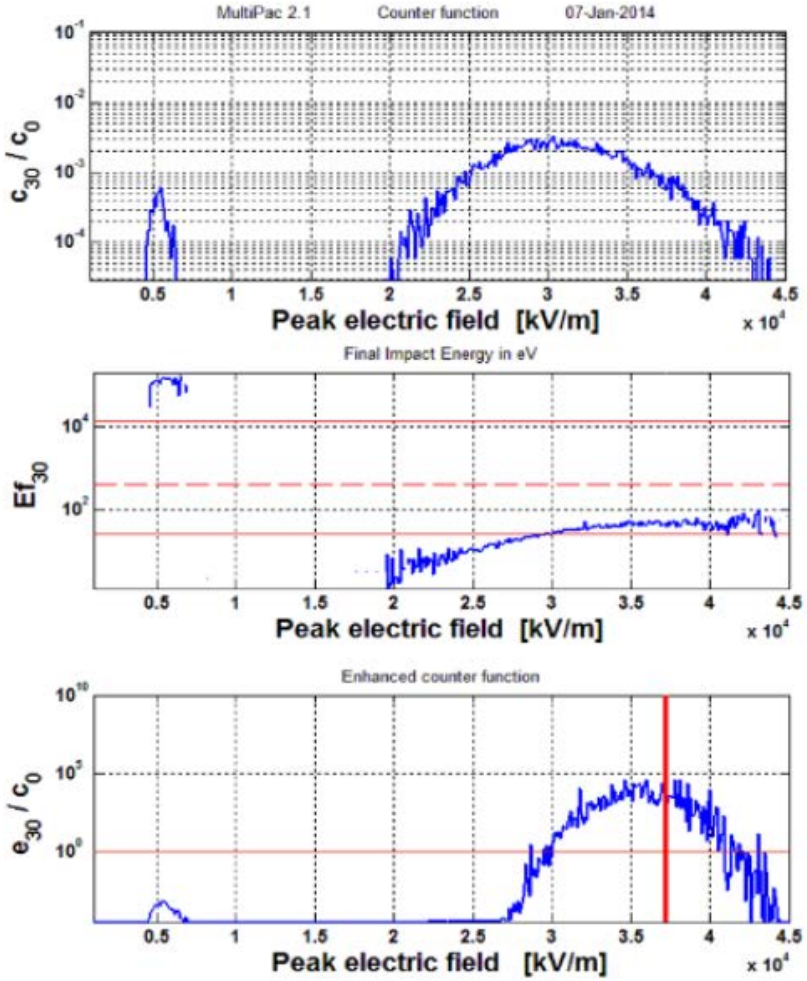


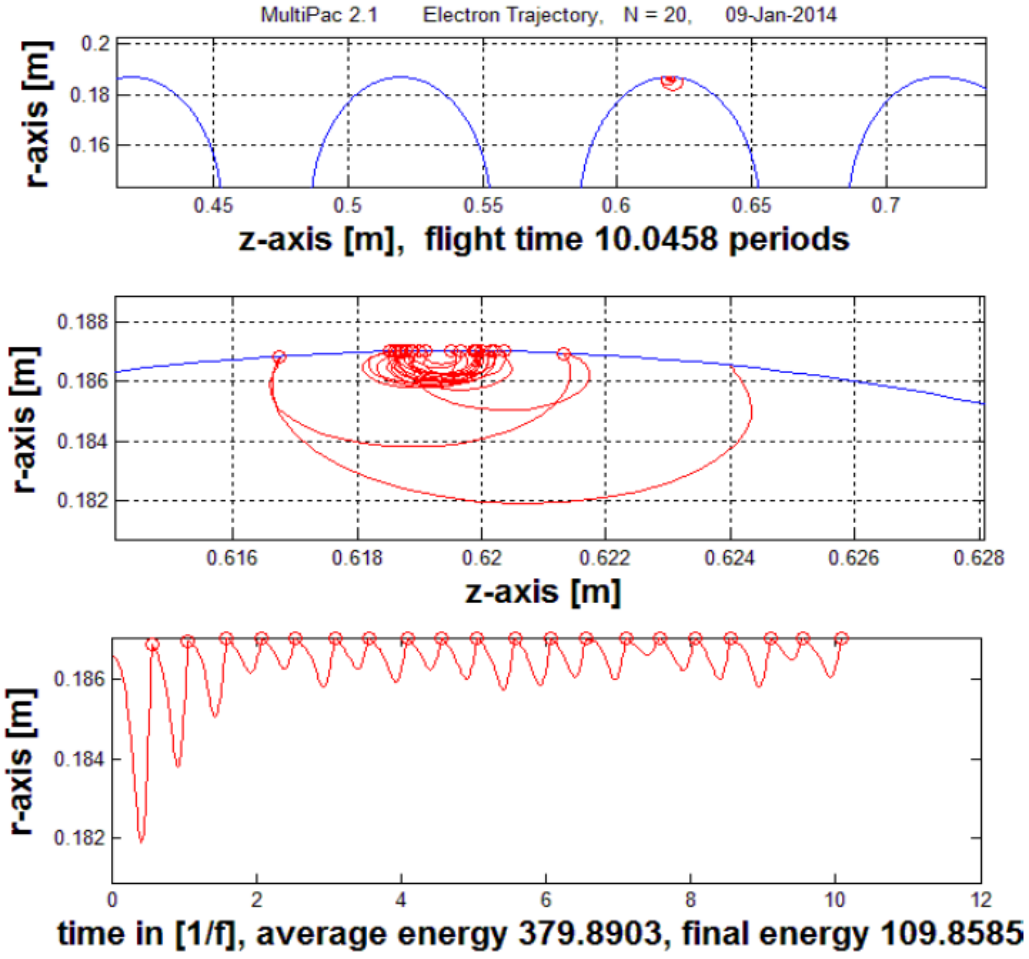
Y. Gómez Martínez et al., State of art of the multipactor phenomenon for the MAX project, 2015

MAX cavity: MULTIPAC results



- Multipactor 2 points in the equator of the cavity between 30 MV/m < Epeak < 41 MV/m





MAX coupler: MULTIPAC results

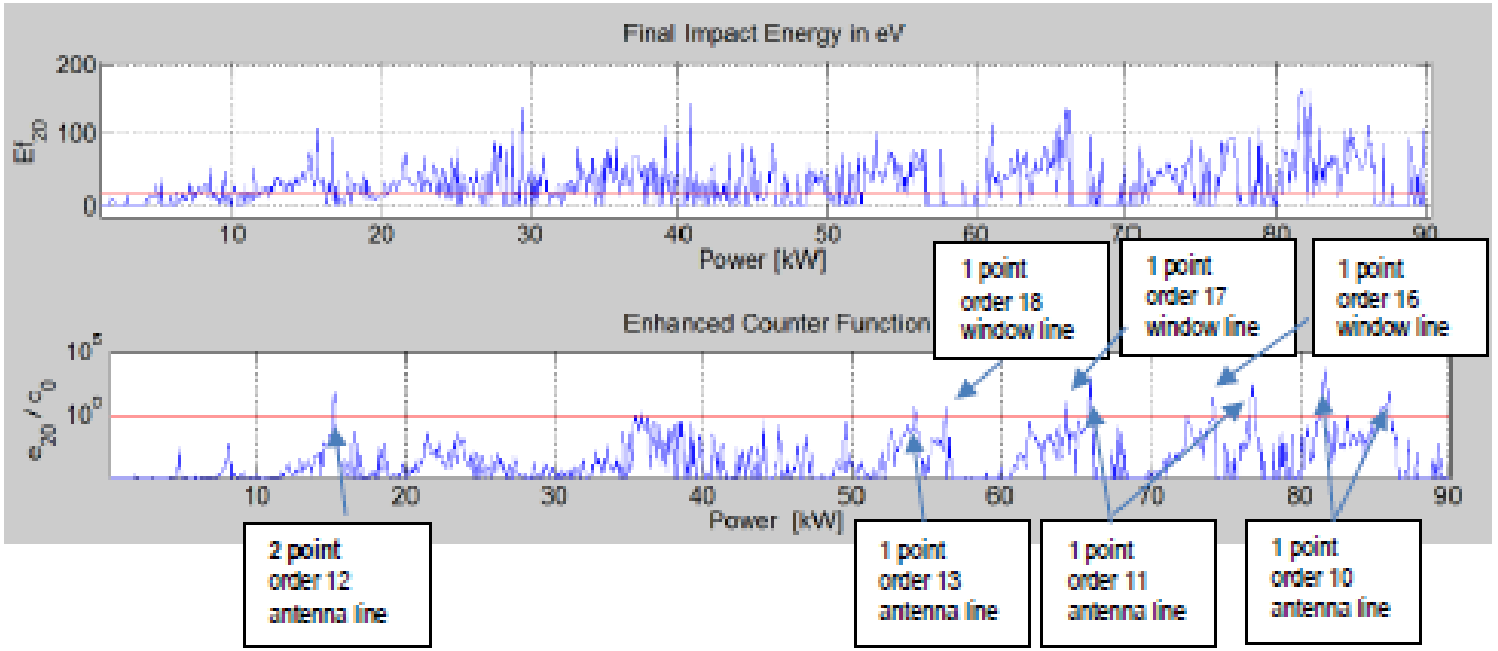


Figure 15: The final impact energy (eV) on the top and the enhanced electron counter at the bottom in the travelling wave case. Orders and type of multipacting are indicated.

- Multipac results correlated with measurements:

Table 4: Comparison of the input power (kW) for MP of the MAX coupler up to 70 kW in the case of a travelling wave.

Measurements	MULTIPAC	Scaling laws
-	15 kW (2 point; order 12; antenna line)	
Region 1 between 50 and 56 kW: At 50 kW MP peak At 54 kW MP peak At 56 kW MP peak	*Region 1 between 52 and 56 kW:* 54 kW (1 point; order 13; antenna line) 56 kW (1 point; order 18; window line)	MP order higher than 8 not available in figure 2 and 3
Region 2: Around 68 kW	*Region 2:* 64.5 kW (1 point; order 17; window line) 66 kW (1 point; order 17; antenna line	

Projects : SPIRAL 2 couplers

- Coupleur for both cavity LINAC
- Design and RF conditionning of the 28 RF couplers
- 20 kW CW @ 88 MHz

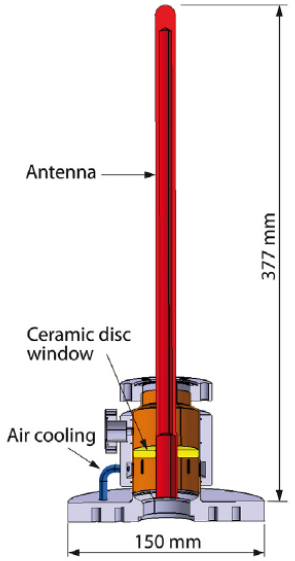


Fig. 1. 3D drawing of the RF coupler.

Fig. 2. Filtered N_2 blowing during the assembly of the coupler.

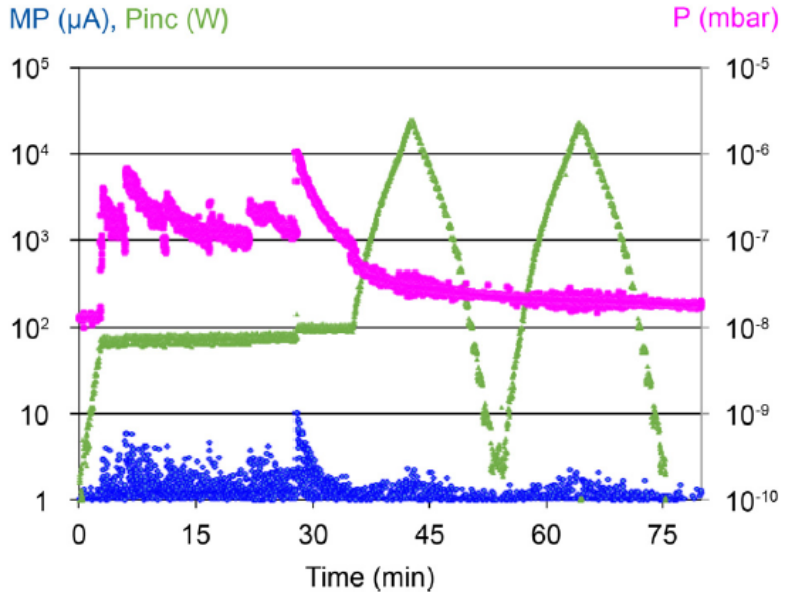


Fig. 3. Typical response to the power conditioning of coupler N29. Displayed are multipacting current (MP), incident RF power (P_{inc}) and pressure (P) versus time.

- Study by simulation of the multipactor carried out by our colleagues from CEA Saclay, then the IJC Lab

Final results of power conditioning of SPIRAL 2 couplers, Y. Gómez Martínez et al., Nucl. Instrum. Meth. A 870 (2017) 37-42

Projects : MYRRHA RF couplers

Paramètre	Valeur théorie
Frequency (MHz)	352.2 MHz
Percentage of the maximum reflected power (%)	100%
Maximum power certification coupler OP(kW) $P_{nominal}$ (kW)	80 kW CW* 8 kW**
Minimum coefficient of reflection(dB)	< -30 dB
Q_{ext} optimal (à froid)	$2.2\ 10^6$
Int. diameter of outer conductor for cavity connection(mm)	56 mm

*56 kW 'Fault Tolerance'
** 14 kW 'Fault Tolerance'

- Three coupler design with the corresponding multipactor studies (Somersalo and MUSICC3D) made for the final choice.

Y. Gómez Martínez et al., MYRRHA 80 kW RF COUPLER DESIGN, IPAC 2019, Melbourne, Australie, may 2019.

MYRRHA coupler: Somersalo study

$$MP_{1\ point\ ordre\ 1} \propto \frac{(f\ D)^4\ Z}{4}$$

$$MP_{2\ point\ ordre\ 1} \propto \frac{(f\ D)^4\ Z^2}{4}$$

f : frequency – 352,2 MHz

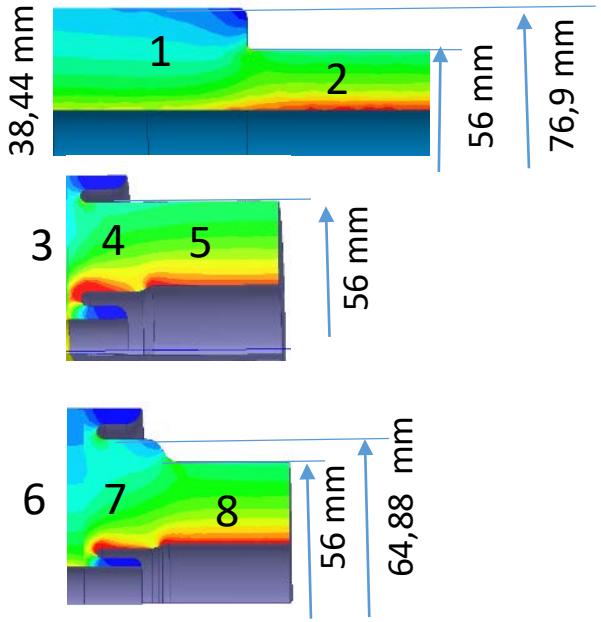
D : diameter of the outer conductor

Z : impedance characteristic of the line

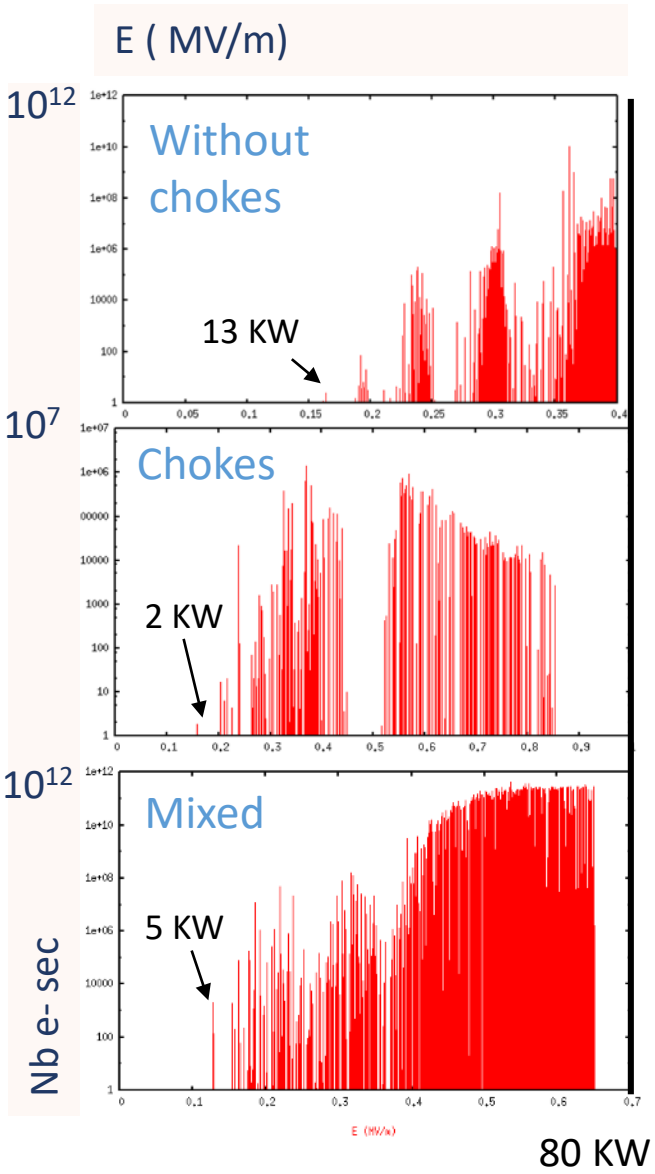
$$Z = \frac{1}{2\pi}\sqrt{\frac{\mu}{\varepsilon}}\ Ln\left(\frac{R_{ext}}{R_{int}}\right)$$

Power where there is multipactor order 1:

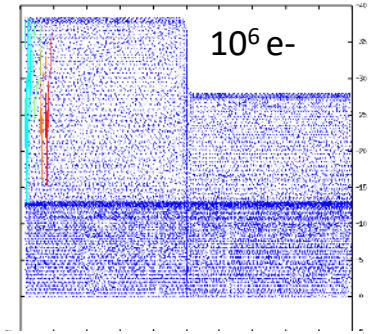
Version	Paramètres	MP 1 point	MP 2 point
With chokes	(1c) D = 76,88 mm; Z = 64,6 Ohm	61,1 kW	3 MW
	(2) D = 56 mm; Z = 45,6 Ohm	**12 kW**	430 kW
Without chokes	*(3) D = 66,2 mm; Z = 103,4*	*53 kW*	*4 MW*
	(4) D = 56 mm; Z = 59,7	*15,9 kW*	*740 kW*
	(5) D = 56 mm; Z = 50	**13,3 kW**	517 kW
Mixed	*(6) D = 76,88 mm; Z = 97,2*	*92 kW*	*6 MW*
	(7) D = 64,88 mm; Z = 63,8	*30,6 kW*	*1 MW*
	(8) D = 56 mm; Z = 50	**13,3 kW**	517 kW



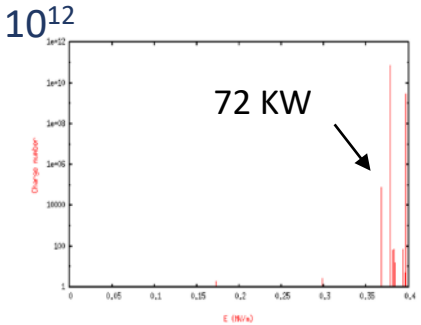
MYRRHA coupler : MUSICC3D



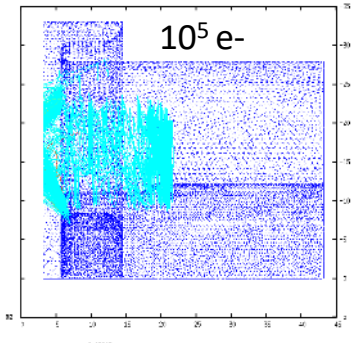
Multipactor trajectories

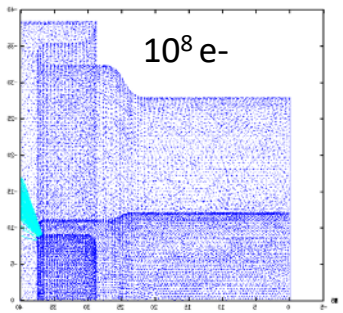


Without the window



$n_{coté\ céramique} = 100$
Maximal number of impacts max





Multipactor with the window

Internal IN2P3 Project: Multipac

- Project on going
- IN2P3 laboratories involveds: LPSC, IJC Lab, SIMaP
- Goal :
  - Improve the test bench dedicated to multipactor studies.
  - Mastering the phenomenon and applying this knowledge to particle accelerators
  - Explore Anti-Multipacting Surface Engineering Processes for Accelerators
- Support:
  - IN2P3 (with project allocations dotations au projet)
  - The CNRS (via the inter-institute call for projects 80Primes: EPISAMA project)
  - the Carnot Energies Institute of the Future (NITALD project).

Y. Gómez Martínez et al, 'First measurements on multipactor study', IPAC2021, Campinas, SP, Bresil.