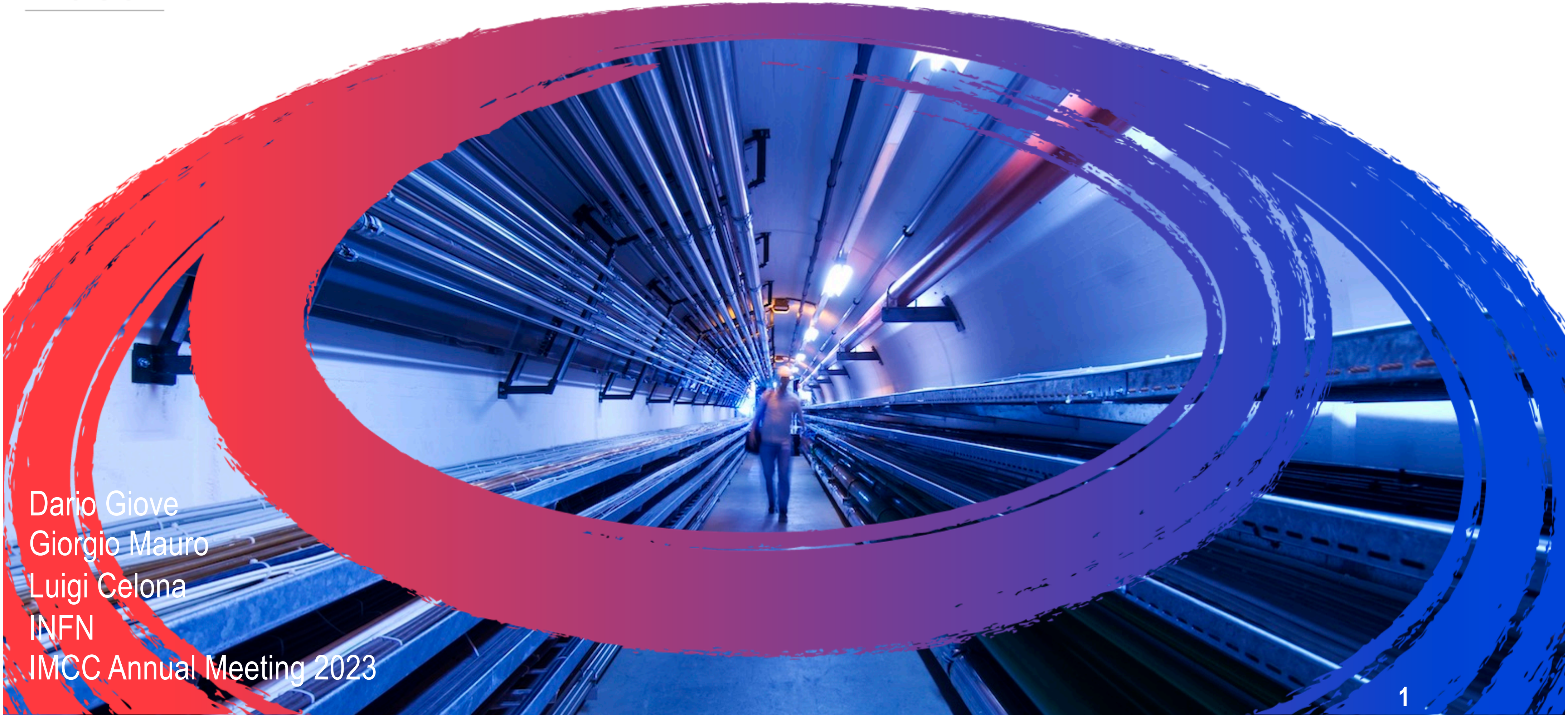
Test Stand Plans INFN



Dario Giove
Giorgio Mauro
Luigi Celona
INFN
IMCC Annual Meeting 2023

General Reference

Objectives

- The RF cavities for the cooling channel of the MuCol project require a medium/high electric field (nominally 28-30 MV/m) in high magnetic fields (13-15 T)
- This call for a deep understanding of the breakdown phenomena in NC RF cavities taking into account the influence of the magnetic field
- The subject is complicated by the wide range of conditions foreseen in the design and by the inherent difficulties of designing experimental test stands

Kilpatrick's criterion:

an empirical voltage threshold for vacuum sparking

THE REVIEW OF SCIENTIFIC INSTRUMENTS VOLUME 28, NUMBER 10 OCTOBER, 1957

Criterion for Vacuum Sparking Designed to Include Both rf and dc*

W. D. KILPATRICK
Radiation Laboratory, University of California, Berkeley, California
(Received May 31, 1957)

An empirical relation is presented that describes a boundary between no vacuum sparking and possible vacuum sparking. Metal electrodes and rf or dc voltages are used. The criterion applies to a range of surface gradient, voltage, gap, and frequency that extends over several orders of magnitude. Current due to field emission is considered necessary for sparking, but—in addition—energetic ions are required to initiate a cascade process that increases the emitted currents to the point of sparking.

- Based on the idea that breakdown happens when regular Field Emission is enhanced by a cascade of secondary electrons ejected from the surface by ion bombardment.
- Useful for DC and AC voltages

Kilpatrick frequency dependance

RF BREAKDOWN STUDIES IN COPPER ELECTRON LINAC STRUCTURES

J. W. Wang and G. A. Loew
Stanford Linear Accelerator Center
Stanford University, Stanford, California 94305

1989

An expression for the breakdown threshold was obtained empirically from early experimental data gathered in the 1950's:

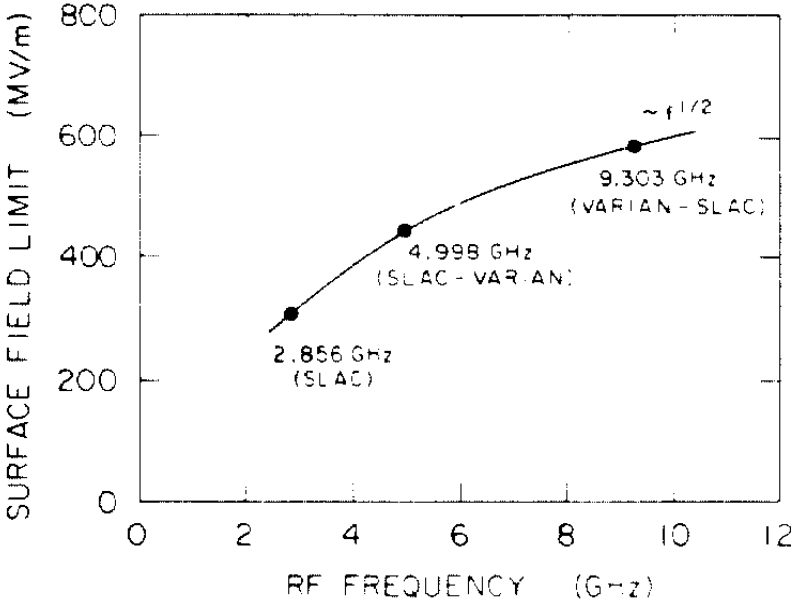
$$Ee^{-4.25/E} = 24.4 \cdot [f(GHz)]^{\frac{1}{2}} \; MV/m$$

The expression was reformulated by T. J. Boyd[*] in 1982 as:

$$f = 1.64 \cdot E(MV/m)^2 \cdot e^{-8.5/E(MV/m)} \; MHz$$

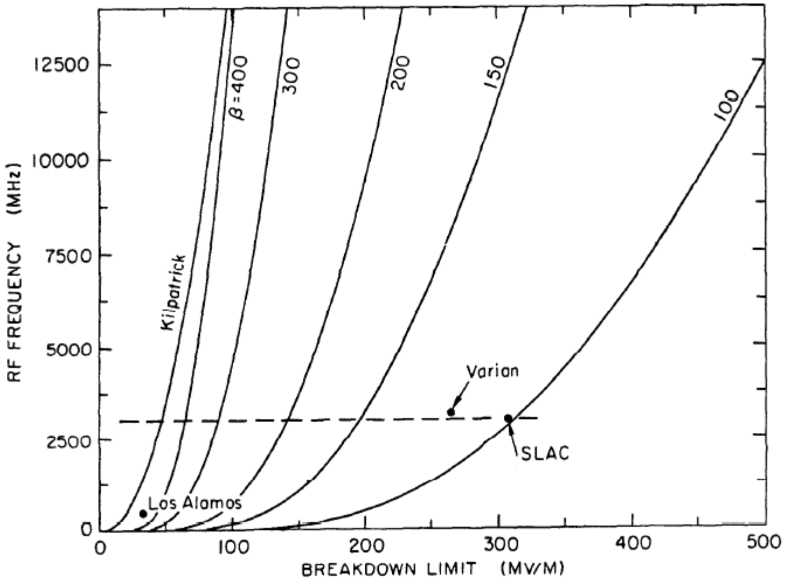
➔ The threshold voltage varies as the square root of the applied frequency.

➔ Kilpatrick already pointed out in this paper that the threshold could be slightly raised by processing the electrode surfaces.



Kilpatrick frequency dependance

Year	*Author*	*Quantity*	*Characteristics*
1963	Nicolaev	90 MV/m peak surface	~11 Kilp., 23.6 MHz
1979	Williams (Los Alamos)	50 MV/m peak surface	~1.6 Kilp., 100 μs pulse, 425 MHz
1984	Tanabe (Varian)	150 MV/m acc. field 300 MV/m peak surface	~6 Kilp., 4.5 μs pulses in S-band, "half" single cavity
1985	Loew, Wang (SLAC)	150 MV/m acc. field 300 MV/m peak surface	~6 Kilp., 2.5 μs pulses in S-band, SW 2π/3 mode linac
1986	Tanabe, Loew, Wang	445 MV/m peak surface	~7 Kilp., 5 GHz, single cavity
1986	Tanabe, Loew, Wang	572 MV/m peak surface	~7 Kilp., 9.3 GHz, single cavity
1994	SLAC/CERN	150 MV/m acc. gradient	130 ns pulse length at 30 GHz, small iris structure
2002	CLIC	130 MV/m acc.gradient	15 ns, operated without breakdowns



RF cavities for muon cooling

Challenges:

- High Gradient
- High magnetic field
- High radiation
- Technology far from been common

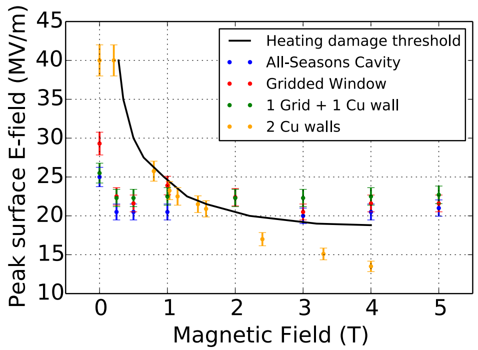


Figure 3: Peak surface electric field vs. external, applied B-field for cavity configurations described above. The black line indicates the threshold for surface fracture from beamlet heating, as discussed in [4].

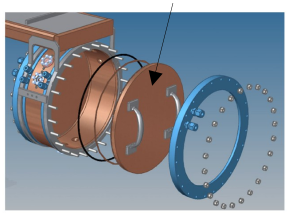
RF BREAKDOWN OF 805 MHZ CAVITIES IN STRONG MAGNETIC FIELDS*

D. Bowring, A. Kochemirovskiy, M. Leonova, A. Moretti, M. Palmer, D. Peterson, K. Yonehara, FNAL, Batavia, IL 60150, USA
B. Freemire, P. Lane, Y. Torun, IIT, Chicago, IL 60616, USA
D. Stratakis, BNL, Upton, NY 11973, USA
A. Haase, SLAC, Menlo Park, CA 94025, USA

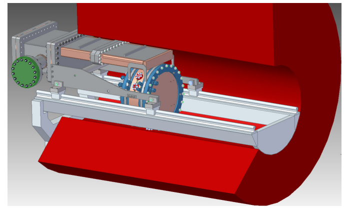
Bowring et al, PRAB 23 072001, 2020

Material	B-field (T)	E-field (MV/m)
Cu	0	24.4 ± 0.7
Cu	3	12.9 ± 0.4
Be	0	41.1 ± 2.1
Be	3	$> 49.8 \pm 2.5$

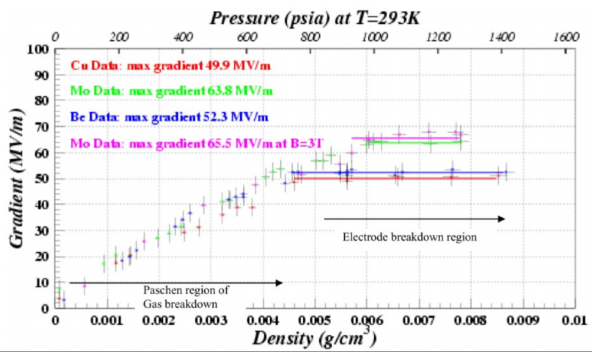
Changeable Cu/Be walls

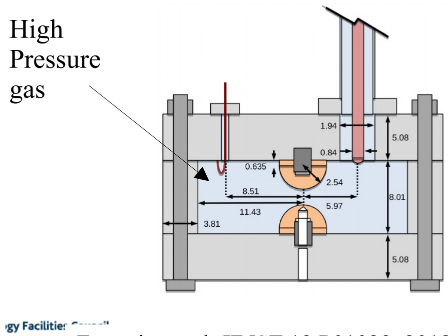


Freq. 804 MHz



Operation of normal-conducting rf cavities in multi-Tesla magnetic fields for muon ionization cooling: A feasibility demonstration





Freemire et al, JINST 13 P01029, 2018

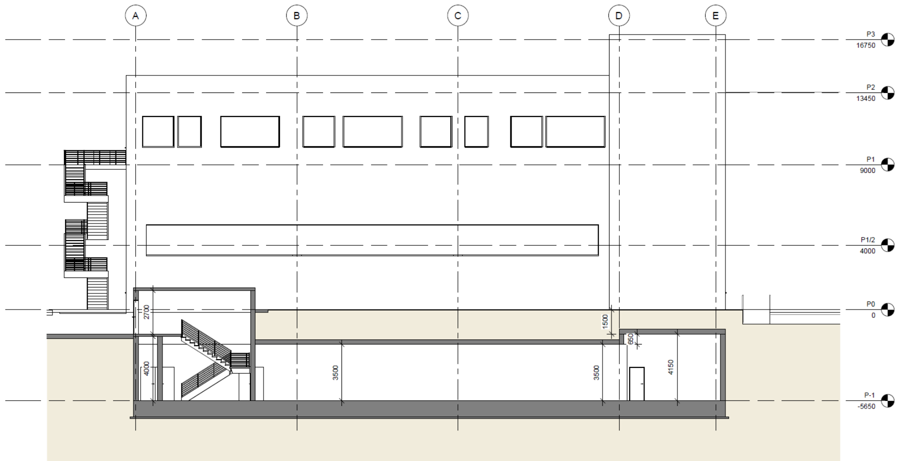
Freq. 800 MHz

Dario Giove

The LASA laboratory today …

Dario Giove

...and the LASA Lab in 2025



The new building has been funded within the frame of the PNRR program named IRIS and thanks to a remarkable financing by INFN of 2 Meuro.

The building will host two laboratories:

- Superconducting Magnet Laboratory (SML)
- Advanced Accelerators Test Facility (AATF)

Finanziato dall'Unione europea NextGenerationEU
Ministero dell'Università e della Ricerca
Italiadomani PIANO NAZIONALE DI RIPRESA E RESILIENZA

New laboratory infrastructure

A new liquefier is going to be ordered in these days and it will be operative within 20 months

Muon Collider related Test Stand Proposals

We are in an advanced phase of design related to a couple of tests stands:

- A DC HV test stand with pulsed capabilities embedded in 1 T magnetic field
- A high power (10 MW) S band RF test stand to power a 2856 MHz RF cavity installed in the bore of a SC magnet.

The DC Test Stand may be installed immediately in the existing experimental area @ LASA. We are discussing the design of the pulsed power supply with S. Calatroni (CERN) and the people of his group.

The S band RF test stand may be installed in the AATF in the new building, taking advantage of all the infrastructures we will have at that time and adding a RF power equipment.

DC based experimental test stand

Why we are proposing to carry out tests in a DC based environment ?

- **Simple setup with respect to a RF based one**
- **Tests faster and more flexible**
- **Study on materials and surface treatments**
- **Additional input for further RF based experimental campaigns**
- **Field levels of the order of 100 MV/m (over max. 1 mm gp)**
- **Energy similar to the one involved in RF**
- **UHV conditions**
- **BD initial phenomena very similar**

We already have a possible setup (magnet @ 1 T with a 120 mm bore and HV power supplies, radiation detectors, experience on data and image acquisition and competence in material treatments)

1. study of innovative materials to create electrodes to be tested with a high DC static field in the presence of a magnetic field of at least 1 T or higher
2. study of surface finishing, coating and cleaning techniques for the above materials
3. DC high static field test in the presence of a magnetic field of at least 1 T or higher

A 3 GHz Proposal for a LASA Test Facility

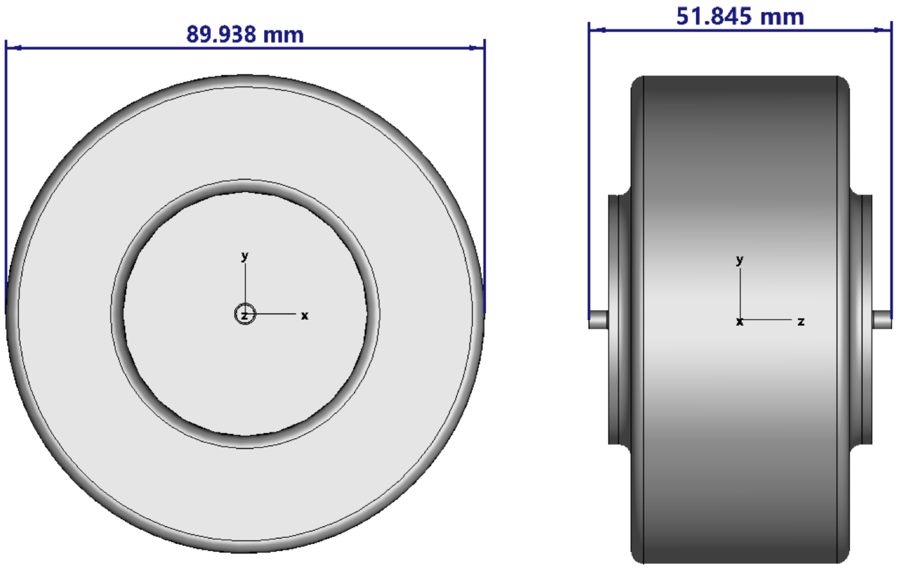
MuCol

INFN
Istituto Nazionale di Fisica Nucleare

Rationale of a proposal of a high power RF Test Facility at LASA

- availability of a modern infrastructure with the space and the possibility to test both SC magnets and RF cavities (bunker structure, liquid helium liquefier, electrical power available) may allow to start experimental activities in late 2025
- the proposal for a frequency different from the one in discussion for the whole RF chain of the cooling channel takes into account the following aspects:
  1. a well known relation exists to correlate the maximum electric field achievable wrt to the frequency of operation and pulse length
  2. reduction in costs related to the SC magnets (going from 704 MHz to 3 GHz may result in a reduction of cost of the order of 2 Meuro over 5 Meuro)
  3. reduction in costs for the machining of the cavities due to the smaller size at 3 GHz (80 mm in diameter with respect to 320 mm just for the cavity, then we have to take into account at least 50 mm of circular corona for cooling, etc.)
  4. the cost of a 5-10 MW modulator+Klystron may be considered affordable (600-700 Keuro) and it may be delivered in 12 months upon the receipt of a order
  5. a complete design of a 3 GHz cavity and related coupler (compatible with the SC magnet) is already available

A 3 GHz Proposal for a LASA based Test Facility



The simulated models consist of a vacuum volume with finite conductivity (copper) boundary condition

Operational frequency: f_0 = 2.856 GHz

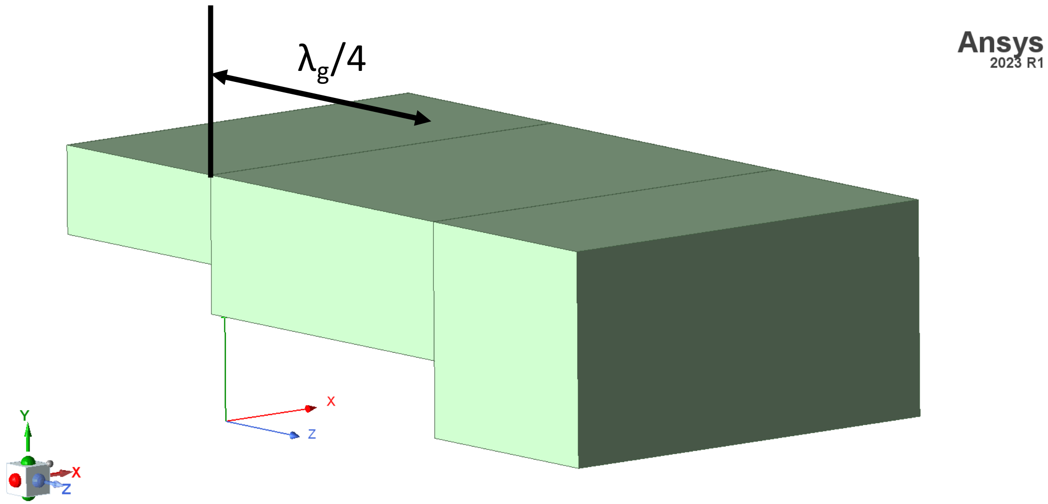
Unloaded quality factor: $Q_0 = \frac{\omega_0 U}{P_{Cu}} = 16590$

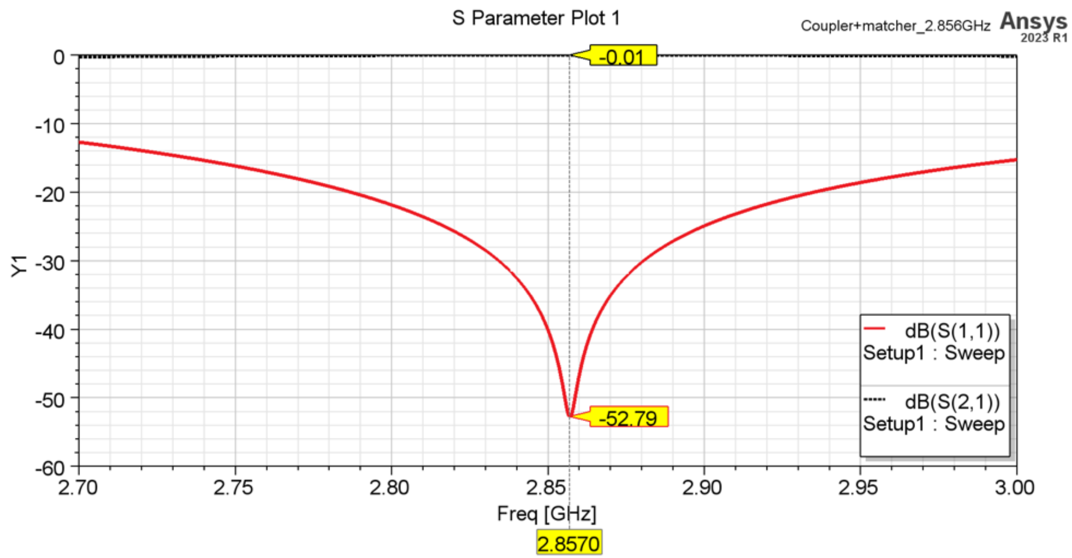
NOTE: $Q_0 \propto \frac{1}{1+\frac{R_{cav}}{L_{cav}}}$: increasing the cavity length increases Q_0 values. For the considered study $L_{cav} \approx \frac{\beta\lambda}{2}$, with β = 1.

A 3 GHz Proposal for a LASA based Test Facility

- Simple coupler with standard WR229 input.
- A single $\lambda_g/4$ central section is employed in order to improve the matching between the first and last wg sections.

Coupler vacuum model + copper b. c.





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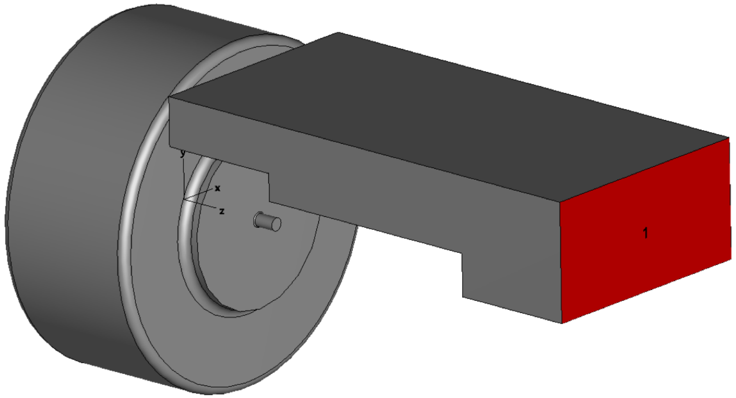
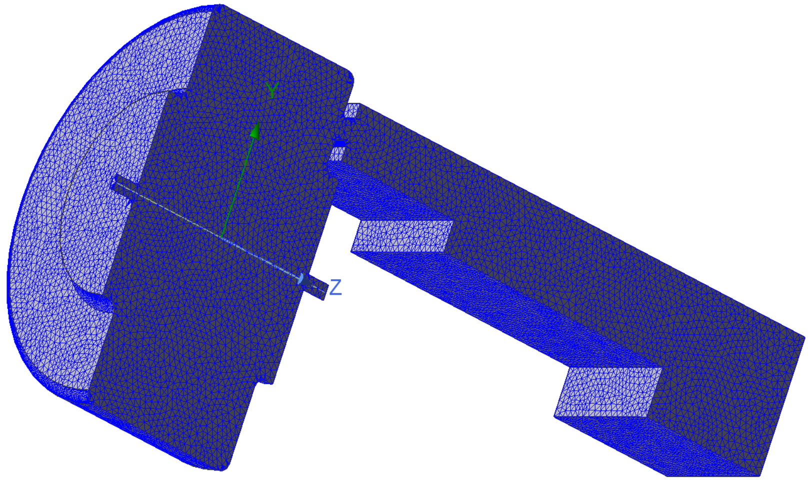
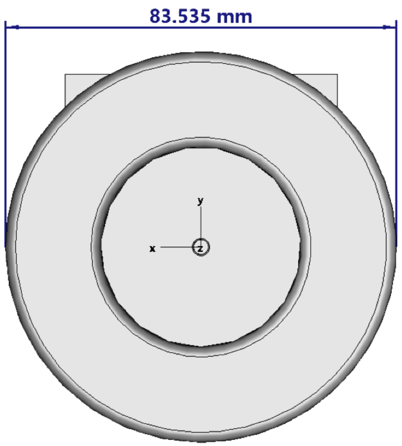
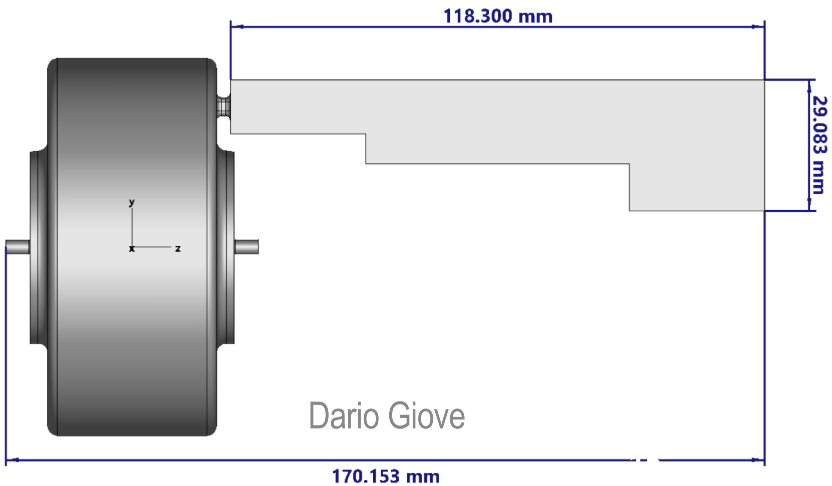
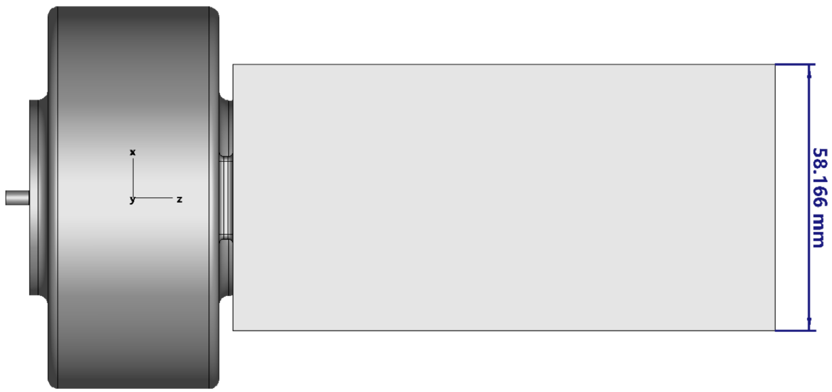


Cavity and coupler are magnetically coupled through a slot.









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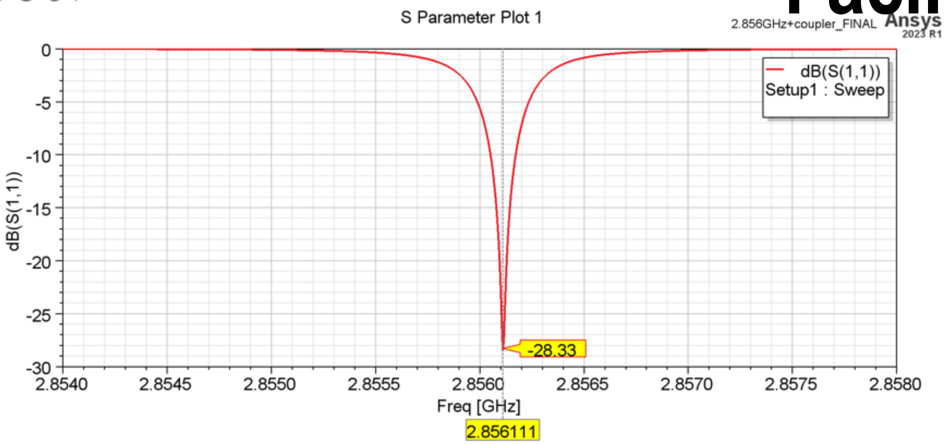
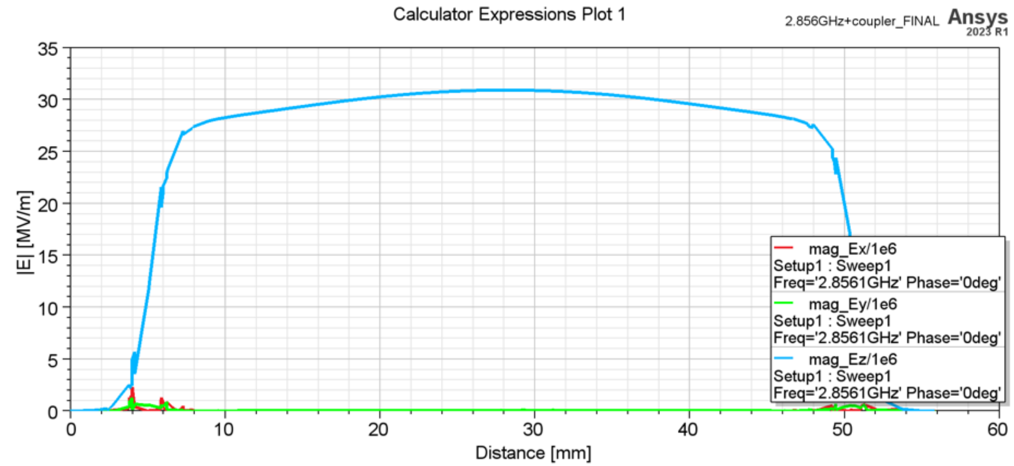
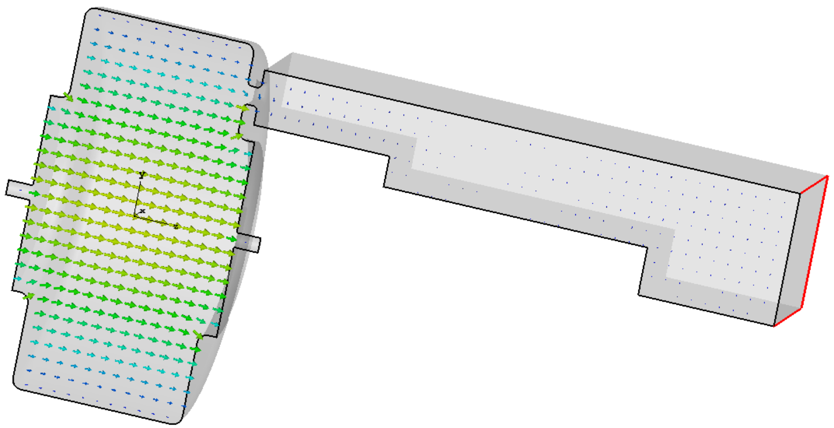
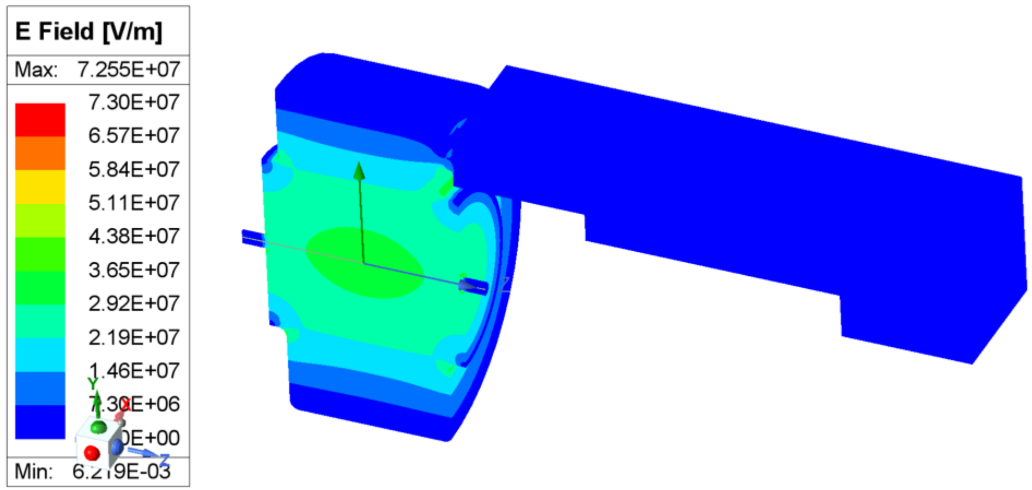
A 3 GHz Proposal for a LASA based Test Facility









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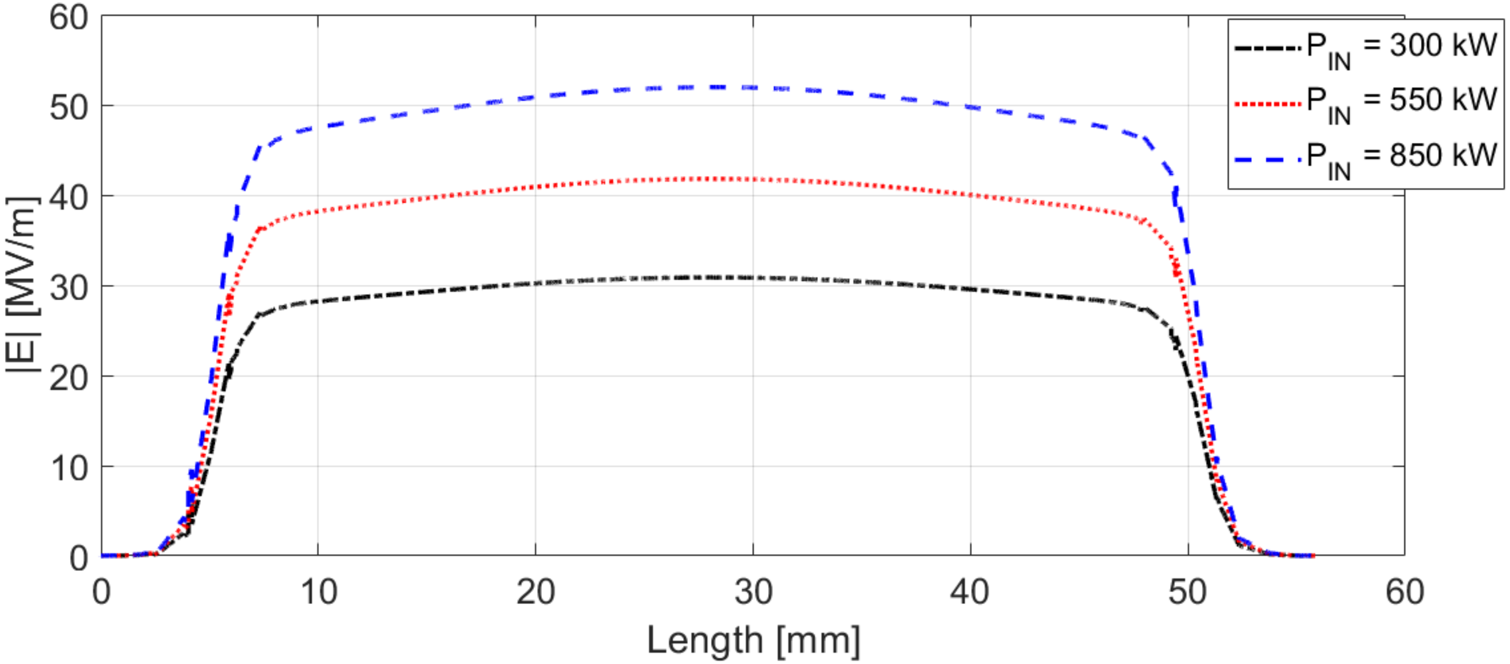
A 3 GHz Proposal for a LASA based Test Facility



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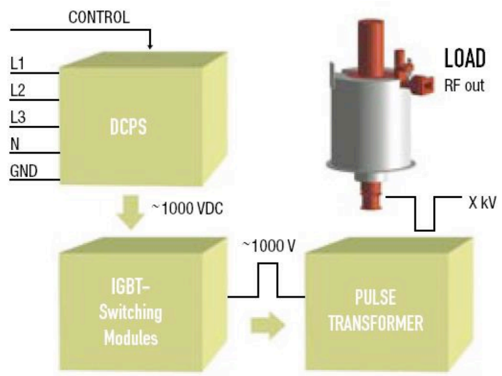
Scandinova and Canon Power Plant

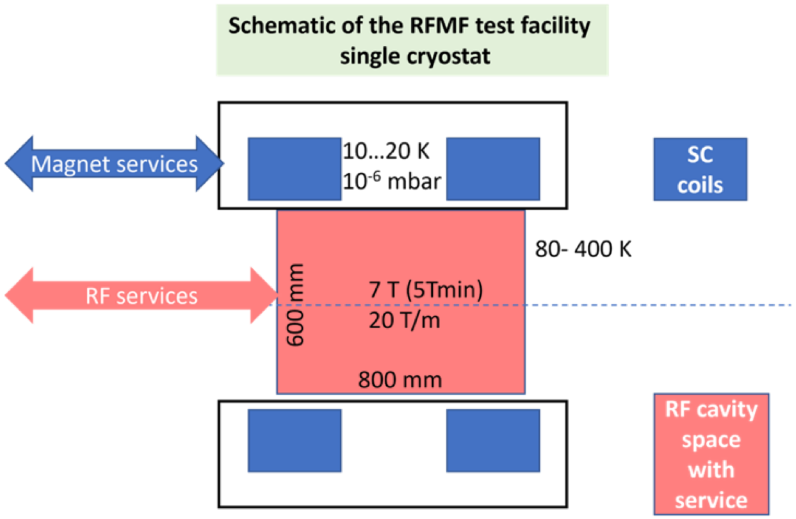


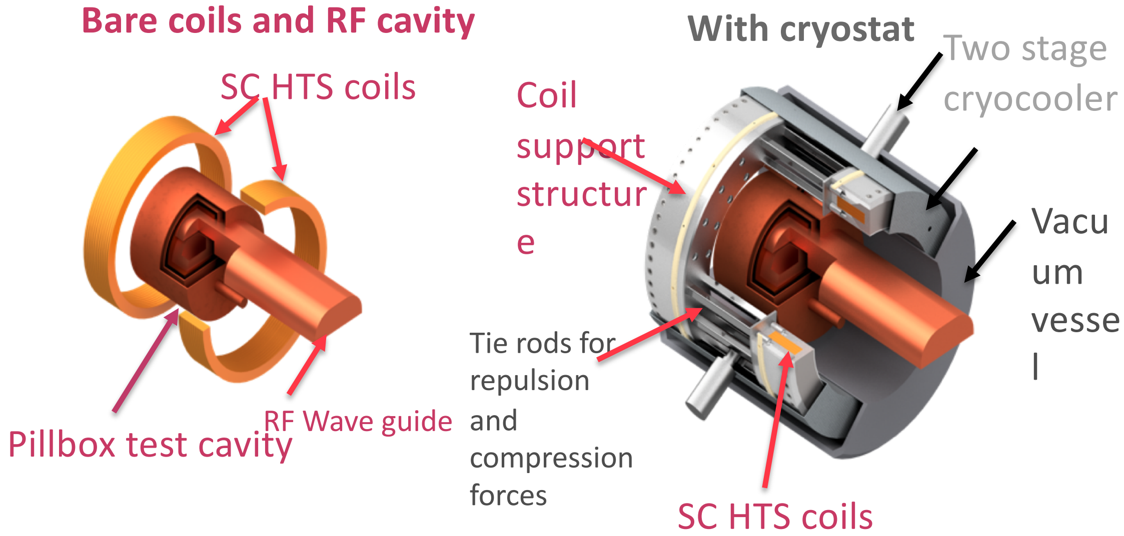
		Unit	Range/Value	Notes
RF Output	RF-frequency	MHz	2998.5	
	RF-peak power	MW	10	
	RF-average power	kW	10	
	RF-pulse length (top)	µs	0.5 - 4.0	See above figure.
Modulator Output	Modulator peak power	MW	23.1	
	Modulator average power	kW	31.8	
	Voltage range	kV	0 - 175	See above figure.
	Current range	A	0 - 132	See above figure.
	PRF range	Hz	0 - 250	Subject to max. average power.
	Top flatness (dV)	+/-%	1.0	Deviation from constant voltage within the top of the pulse length.
	Pulse to Pulse stability rms (max)	ppm	75	
	Rate of rise	kV/µs	< 158	Measured at 50% of Peak voltage.
	Rate of fall	kV/µs	< 156	Measured at 50% of Peak voltage.
	Trig delay	µs	~1.2	See above figure.
	Pulse to Pulse time jitter	ns	<±4	Total
	Pulse width time jitter	ns	<±8	Total
Filament Output	Max voltage	VDC	20.0	According to klystron data sheet.
	Max current	ADC	18.0	According to klystron data sheet.
	Current regulation stability	%	<1%	

5MW K100, PRF 100Hz and pulse length 2-3us, equipped with Canon E3779,B

Price of the order of 500-700 kEuro (+ taxes)

RF Cavity tested within a SC magnet





In the 3 GHz option the bore diameter may be reduced to 350-400 mm

Courtesy of L. Rossi

Thanks !!!