Construction of a 704 MHz prototypical cryomodule for the EUROTRANS ADS proton linear accelerator

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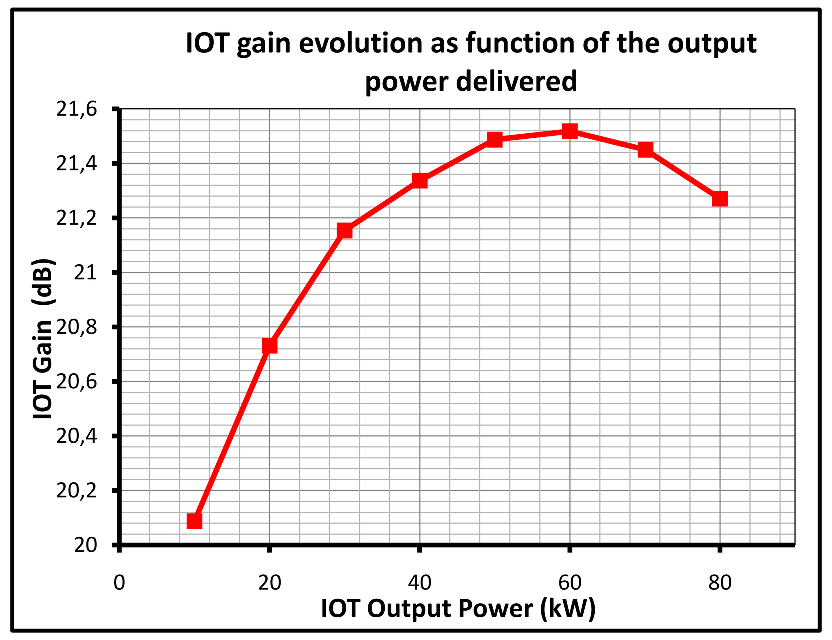
Overview : Accelerator Driven system (ADS) are being considered for their potential use in the transmutation of nuclear waste. Such a device typically requires a 600MeV to 1GeV accelerator delivering a beam of few mA intensity. Because of the induced thermal stress to the subcritical core, the high-power proton LINAC will have to fulfill stringent reliability requirements, with less than a dozen of unwanted beam trips per year.

One working package of the EUROTRANS project is dedicated to the design, realization and tests of a prototypical cryomodule, operating at 2K , for the LINAC high energy section. About 70 elliptical cavities (β = 0.47 & β = 0.65) will compose this accelerator section. A full scale Cryomodule with a beta 0.47 TRASCO cavity and its cold tunning system will be tested at IPNO, early 2010. Experiment aims to evaluate the cavity performances (Nominal field expected *Eacc=8.5 MV/m*) but above all the Cryomodule reliability to fulfill ADS stringent requirements.

700 MHz RF source

- A CW 80 kW Thales Electron devices IOT (Induced Output Tube) is power supplied by a 40kV- 4A DC Brucker generator and driven by a 1KW Brucker RF-amplifier.
- At 704 MHz, the IOT provides 80 kW in CW with a power gain of 21.2 dB.



Experimental setup for IOT tests at IPNO.

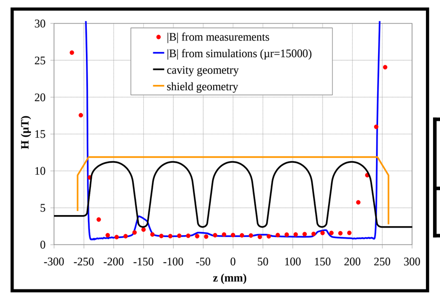
Cavity & tunning system

- The 5 cells β = 0.47 Z501 TRASCO cavity, developped by INFN/LASA Milano, will be used for the full scale cryomodule experiment.
- Cavity tuned to its nominal frequency 704.4 MHz.

Electromagnetic Parameters
SUPERFISH calculation

Parameter	Value
Design Frequency	704.4 MHz
Geometrical β	0.47
Iris Radius	40 mm
Cell to cell coupling	1.34%
R/Q	160 Ω
G	150 Ω
E_{peak}/E_{acc}	3.58
B_{peak}/E_{acc}	5.88 mT/(MV/m)

- The magnetic shield made of Cryoperm10® is include inside the cavity cryogenic vessel.



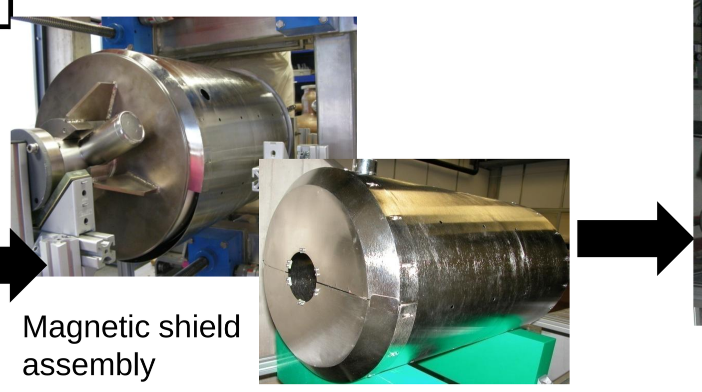
	<H> (µT)	Rs (nΩ)
Simulated value (μ_r = 15000)	3.35	8.44
Measured case	3.70	9.33

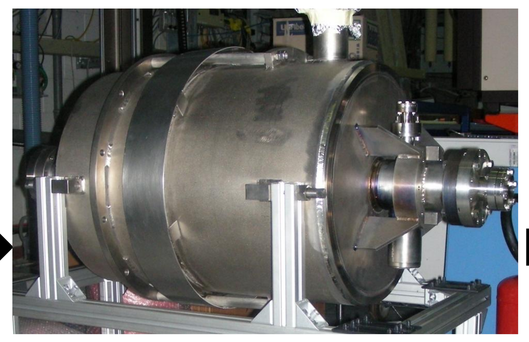
Shield performance measurements :→ **Rs allows $Q_0 > 5.10^9$**

- To match the resonnance frequency, the cavity will be equipped of a blade tuner system coupled with fast piezoelectric actuators.

- Vessel assembly


Naked TRASCO Cavity


Magnetic shield assembly


Cavity + Shield integrated in the Helium Tank which is welded.

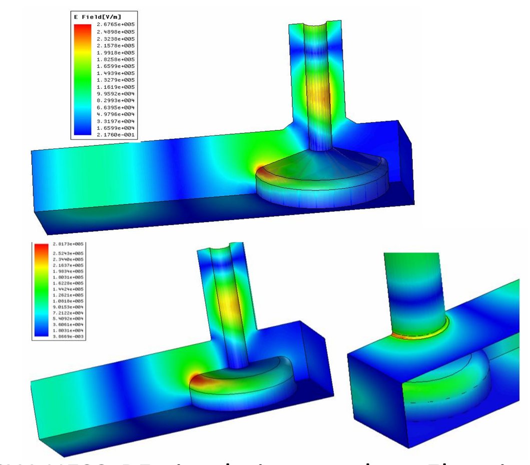
The tunning system is then set up arround the tank.

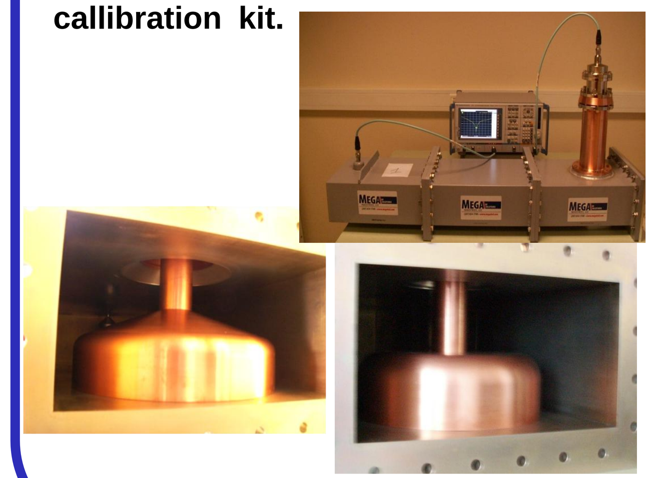
Doorknob transitions

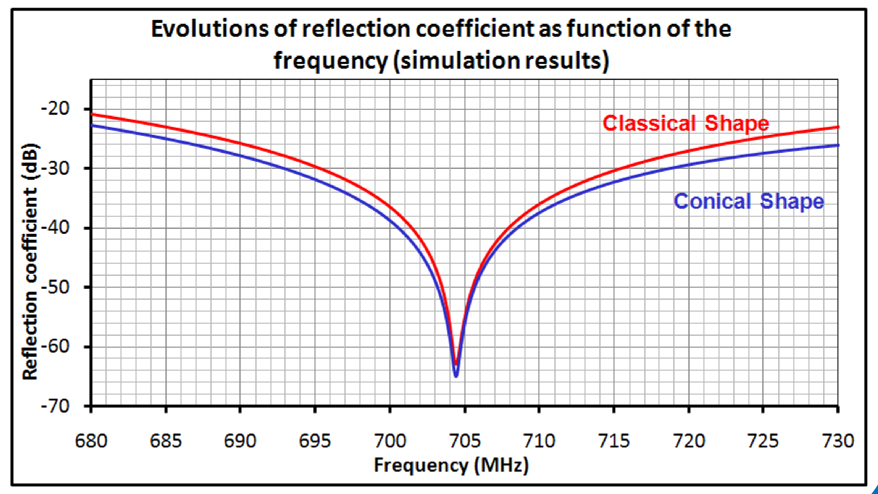
Two different doorknob transitions were designed and manufactured.

	Classical Shape	Conical Shape
S_{11} expected, at 704 MHz	- 61 dB	- 65 dB
S_{21} expected, at 704 MHz	-0.005 dB	-0.09 dB
S_{11} measured, at 704 MHz	-35 dB *	-23 dB *
S_{21} measured , at 704 MHz	-0.01 dB *	-0.04 dB *
Bandwith at -30 dB (simulation)	20 MHz	26 MHz
Number of tunned parameters	4	7

*** First low power measurements results were done by using a type N-WR1150 transition and a type coax-N transition. Those results need to confirm by using a WR1150 callibration kit.**


CW HFSS RF simulation results : Electric field distribution in both transitions.

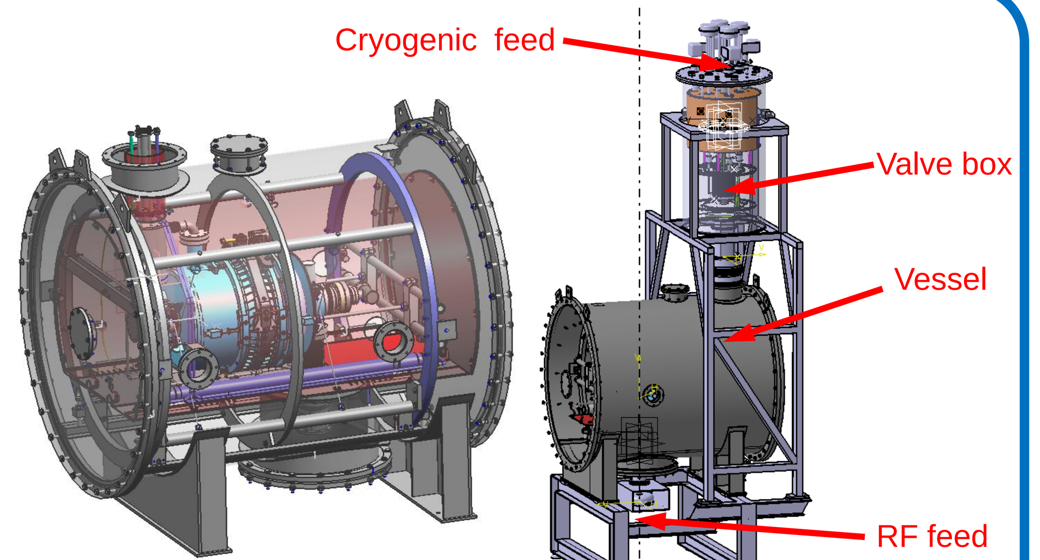

Doorknob transitions at IPNO.



The Cryomodule

- The cryomodule was designed to operate at 2K for a nominal accelerating gradient of 8.5 MV/m.
- Expected Static losses:
  _ 1.2 W @ 2K.
  _ 41 W @ 77K.

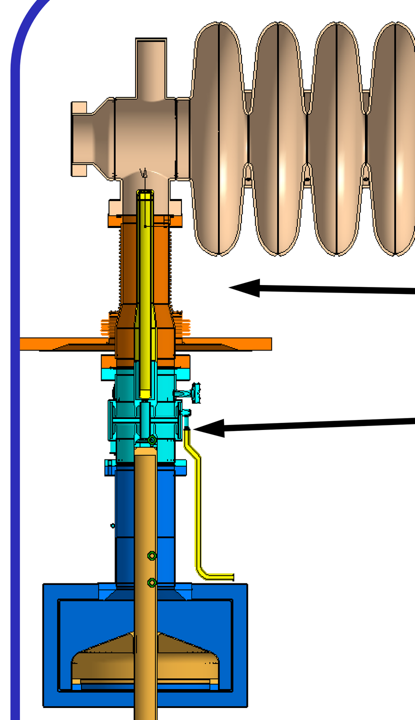
=> The module fabrication is in progress.



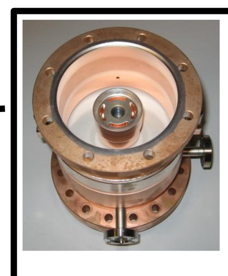
the Trasco cavity in the Space frame.
The whole cryomodule.

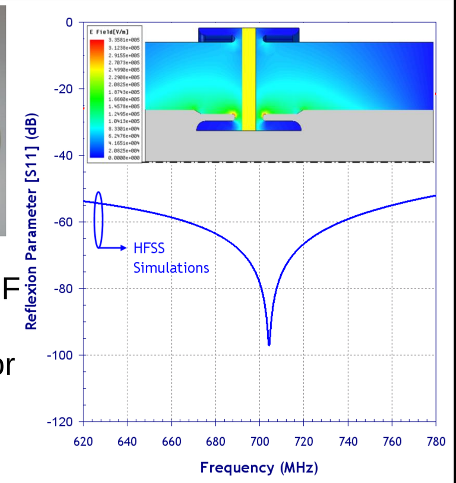
Power coupler Design

- 2 Power Couplers were manufactured by the French company SCT (Tarbes).
- A TiN deposit was applied on the ceramics windows in order to minimize multipacting.

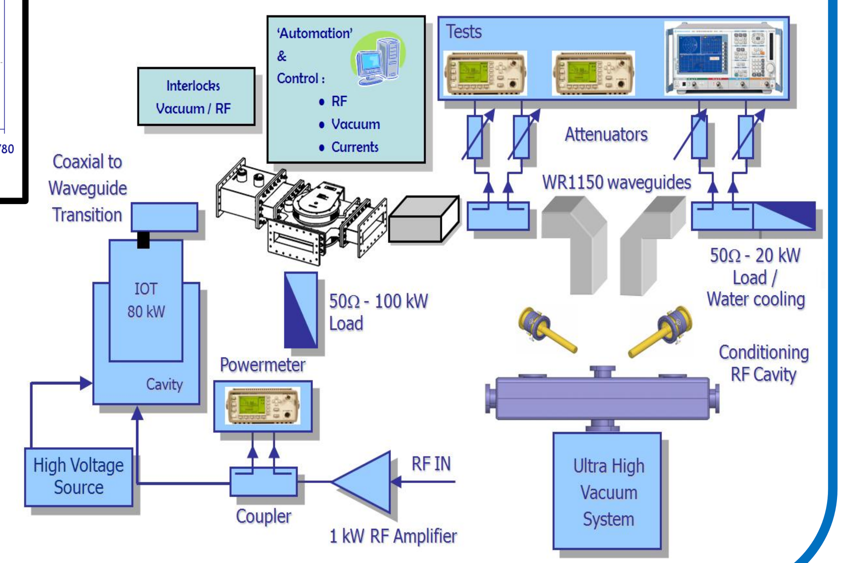

Mechanical Design of the complete power coupler, connected to the Cavity and the Doorknob transition.


Heat exchangers at IPNO. Designed to allow the temperature transition from 300K to 2K.

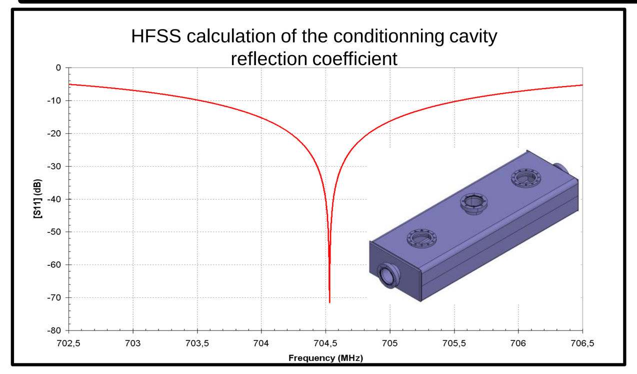

Results of RF simulations carried out for the windows design.



- The test bench is ready to be set up, and the experiment control system program, including interlocks definition, is implemented.



- Fabrication of the conditionning cavity in progress.



Experiments, Perspectives & Goals

<u>Experimental Schedule</u> :

1st Tests : Low power measurements with the cavity insisde the cryomodule

Critical coupling. Measurements of Q_0, Microphonics, Lorentz Factor, Bath pressure influences.

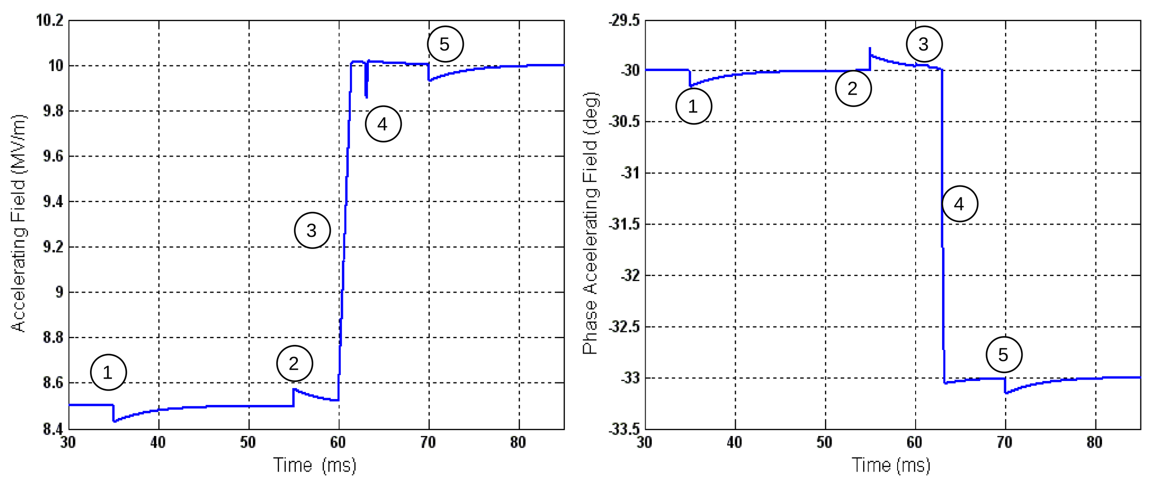
2nd Tests : High power Tests

_ The cavity is coupled via the power coupler (Q_{ext}= 10^7).
_ Performance evalution of the the digital LLRF I/Q feedback loop coupled with the tunning system.
_ Reliability tests :
- **Long time experiment (more than 24 hours) to evaluate possible failures.**
- **Define a process for fast fault-recovery scenario, update the cavity parameters with short beam stop, in less than 100ms.**

1st experiment forseen for March 2010.

- The cavity set points are updated to compensate the failure of an other accelerating device of the LINAC.
- Cavity and its Feedback Loop system simulated in the MATLAB Simulink Environment.
- Set point can be updated in 10 ms :
  _ 15% Field increase
  _ 3 degrees phase change

Simulations results for a fast cavity set points update



Main Simulations Parameters			
Frequency	704.4 MHz	Beam current I0	10 mA
(r/Q)	160 Ω	Synchronous phase	-30°
Coupling Q_L	~1.10^7	Sampling Time	1 µs
Static Lorentz Coef.	-10 Hz/(MV/m)²	Loop Delay	2 µs
Accelerating Field	8.5 MV/m	Source Power (IOT)	80 kW max
Accelerating gap	0.5 m	IOT Average Gain	20 dB
Mechanical constant	1 ms	IOT gain & phase non linear variations as function of output power are taken into account.	
Tunning system response time	10 ms		
Microphonics amplitude	10 Hz Max.	Loop corrector gain	120
Microphonics frequency	600 Hz Max.	Corrector integration time	400µs

1- Beam Loading due to beam injection. (t = 35 ms)
2- Failure of an other cavity detected, beam switched-off. (t =55 ms)
3- Field set point update. (t =60 ms)
4- phase set point update. (t =58 ms)
5- Beam switched-on again. (t =70 ms)

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