ESS elliptical cavities and cryomodules

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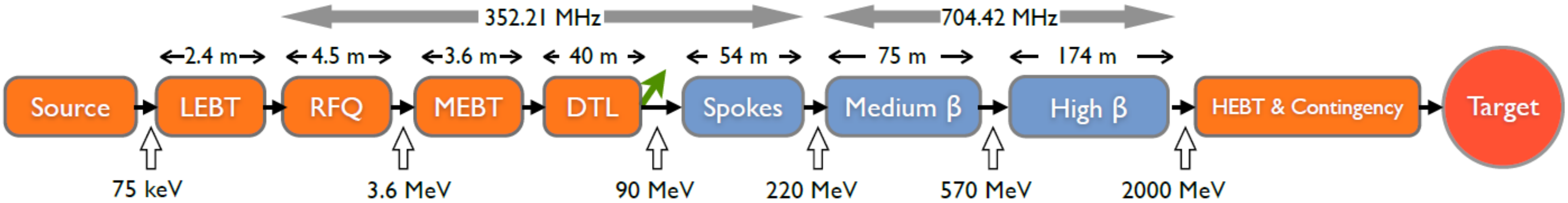
On behalf of the cryomodule technical demonstrator team

The European Spallation Source linac

Beam power (MW)	5
beam current (mA)	62.5
Linac energy (GeV)	2
Beam pulse length (ms)	2.86
Repetition rate (Hz)	14

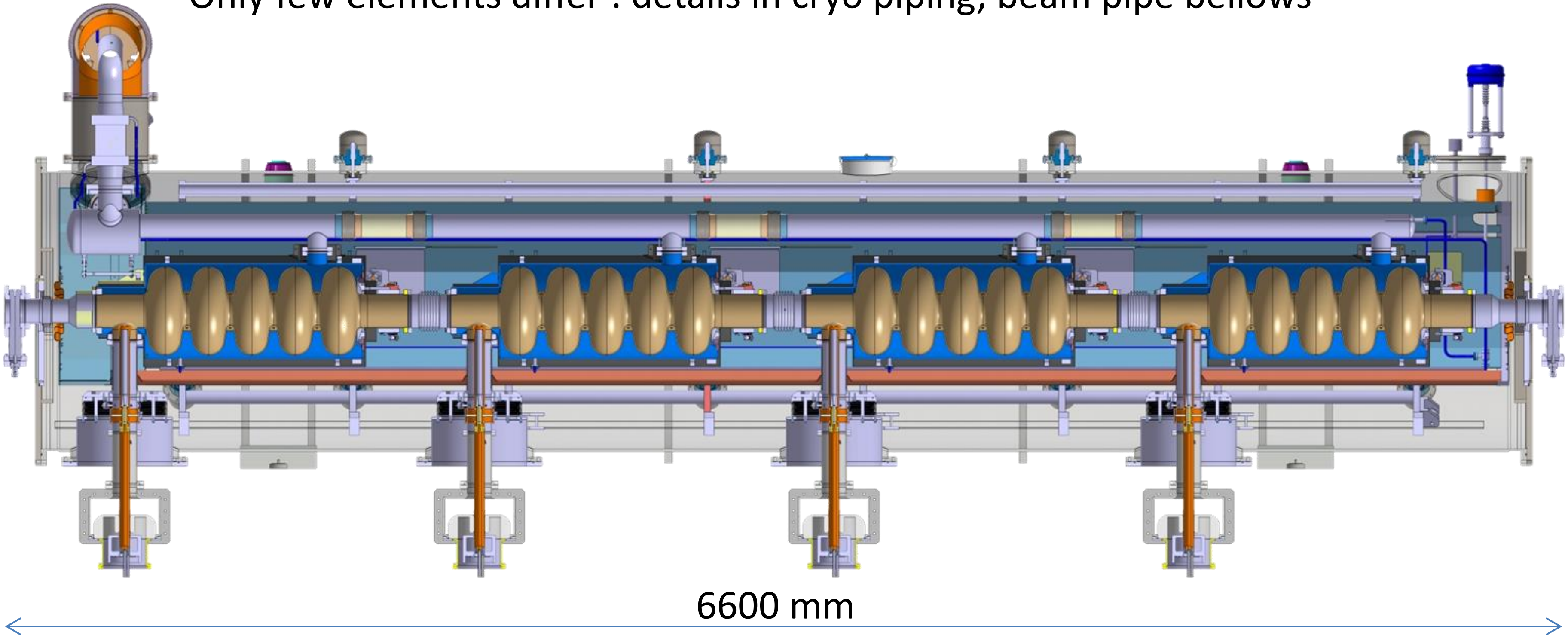


Segmented, superconducting linac, with RT focusing elements

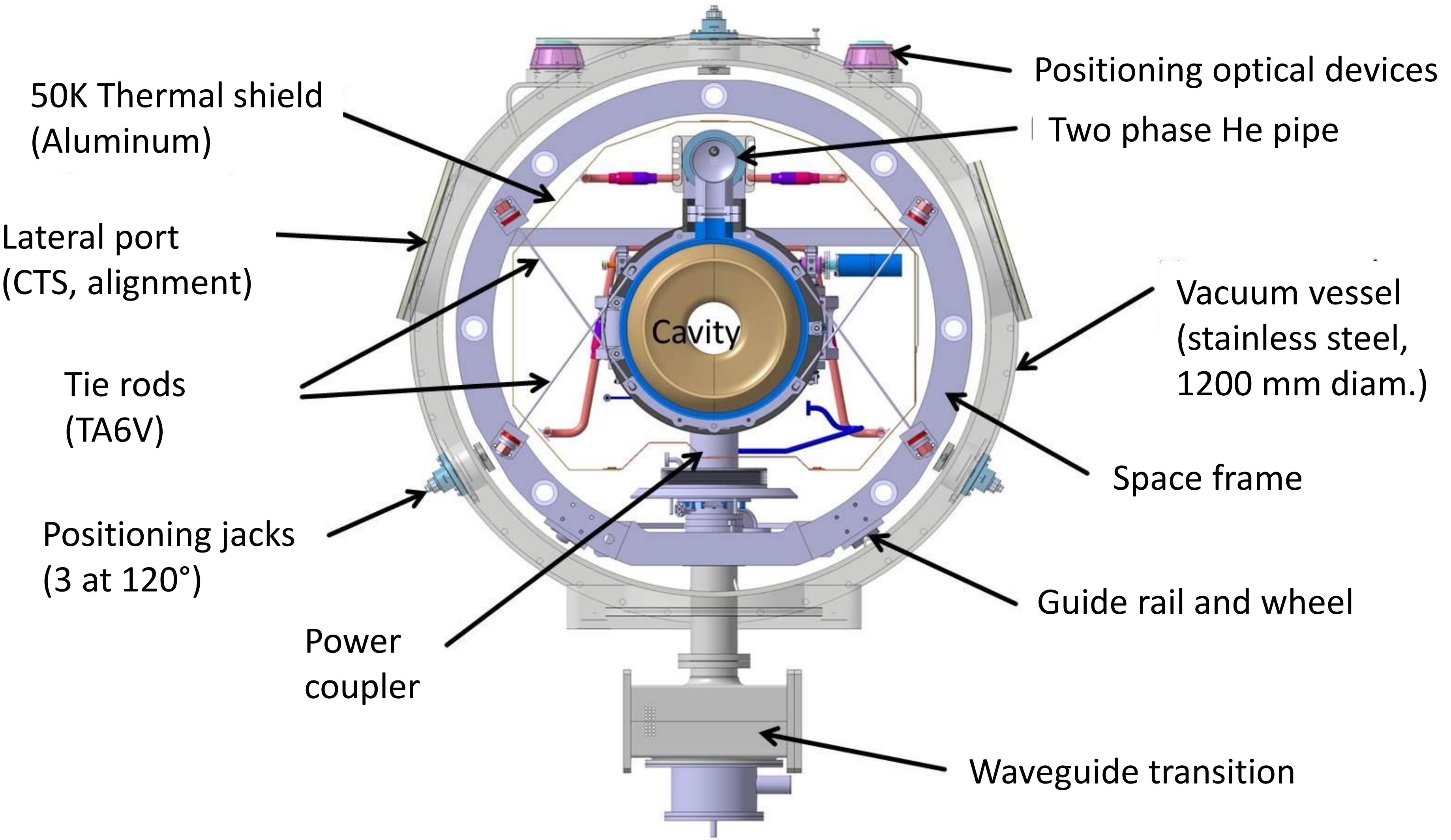
	Num. of CMs	Num. of cavities
Spoke	13	26
6-cell medium β	9	36
5-cell high β	21	84

4-cavity cryomodules

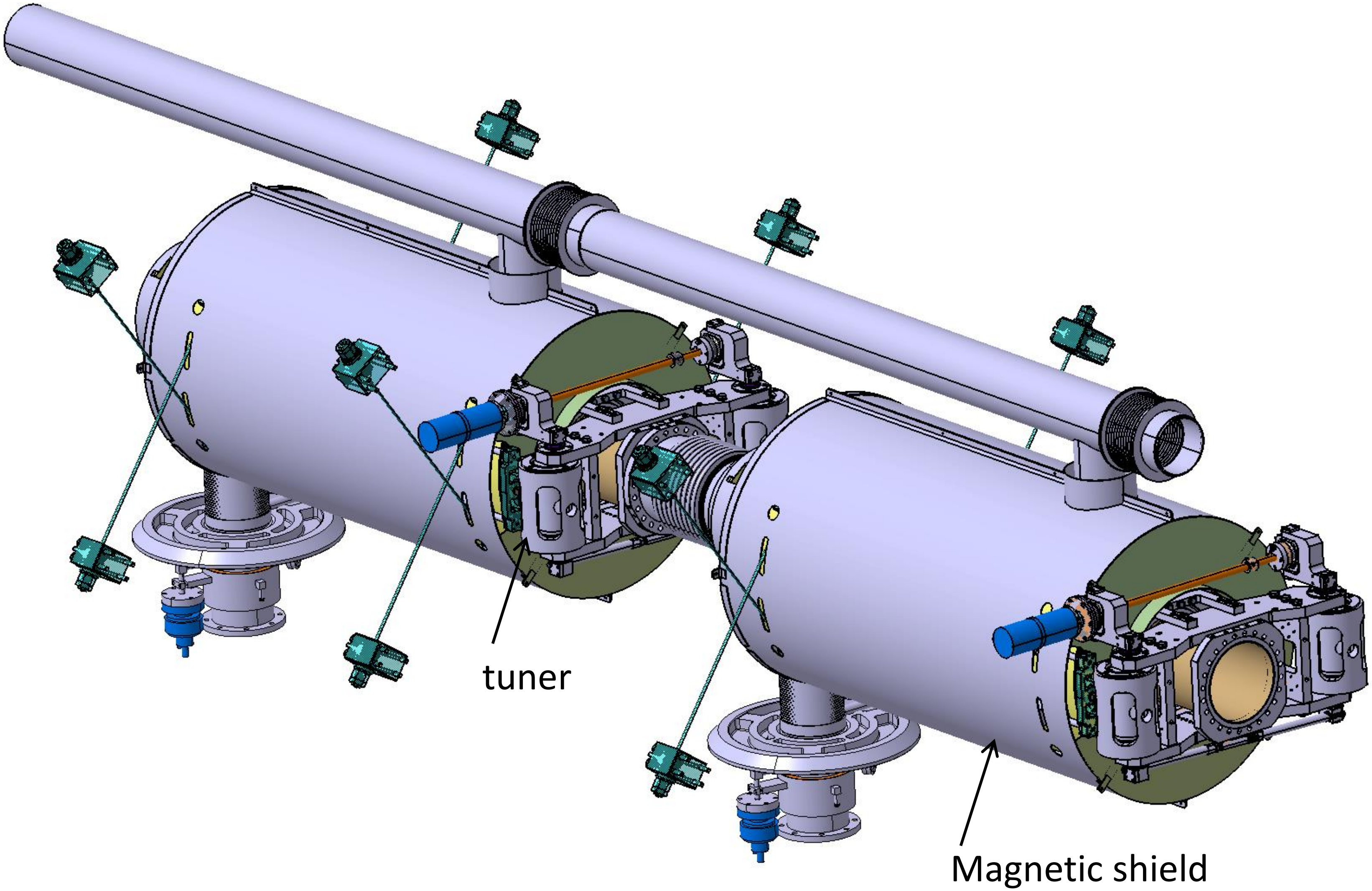
- Similarity with SNS in size and purpose : reuse the same concepts
- Common design for medium and high beta
  - made sensible thanks to the small length difference between 6-cell medium and 5-cell high beta cavities
  - Main components are identical : vaccum vessels, thermal shield, supports, alignment system, etc.
  - Only few elements differ : details in cryo piping, beam pipe bellows



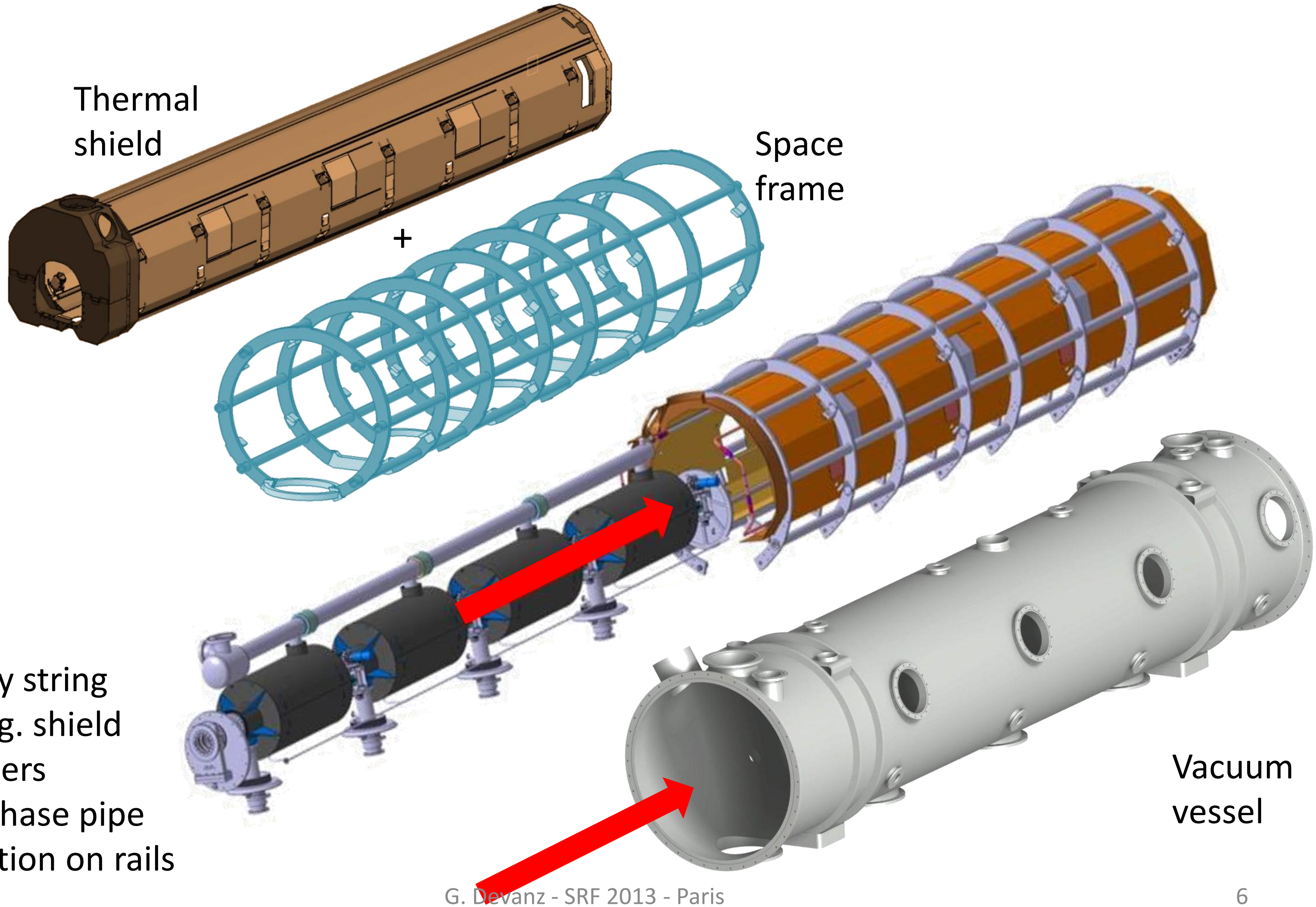
CM cross-section



Cavity package

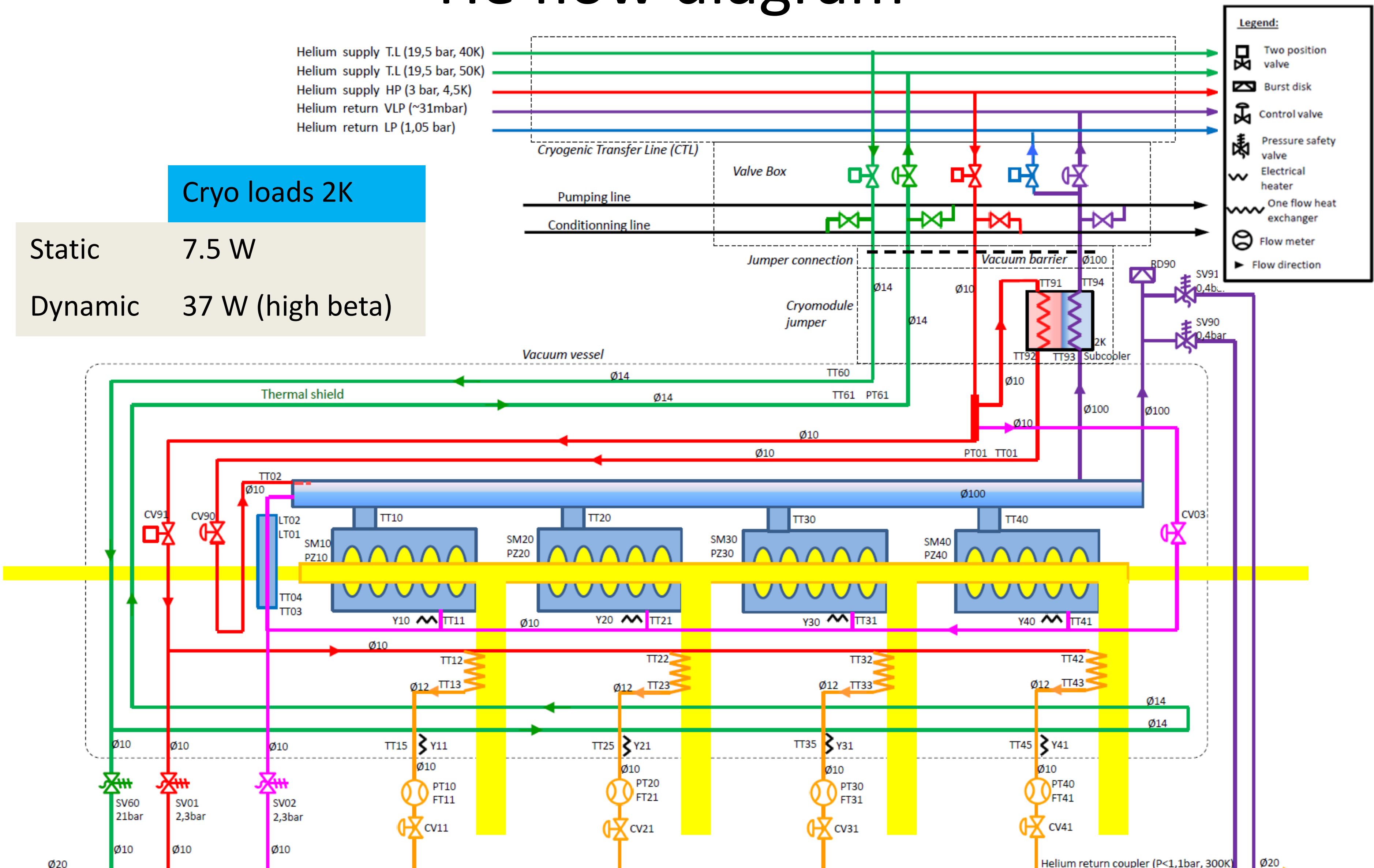


Component insertion order



He flow diagram

Cryo loads 2K	
Static	7.5 W
Dynamic	37 W (high beta)



Elliptical cavities RF parameters

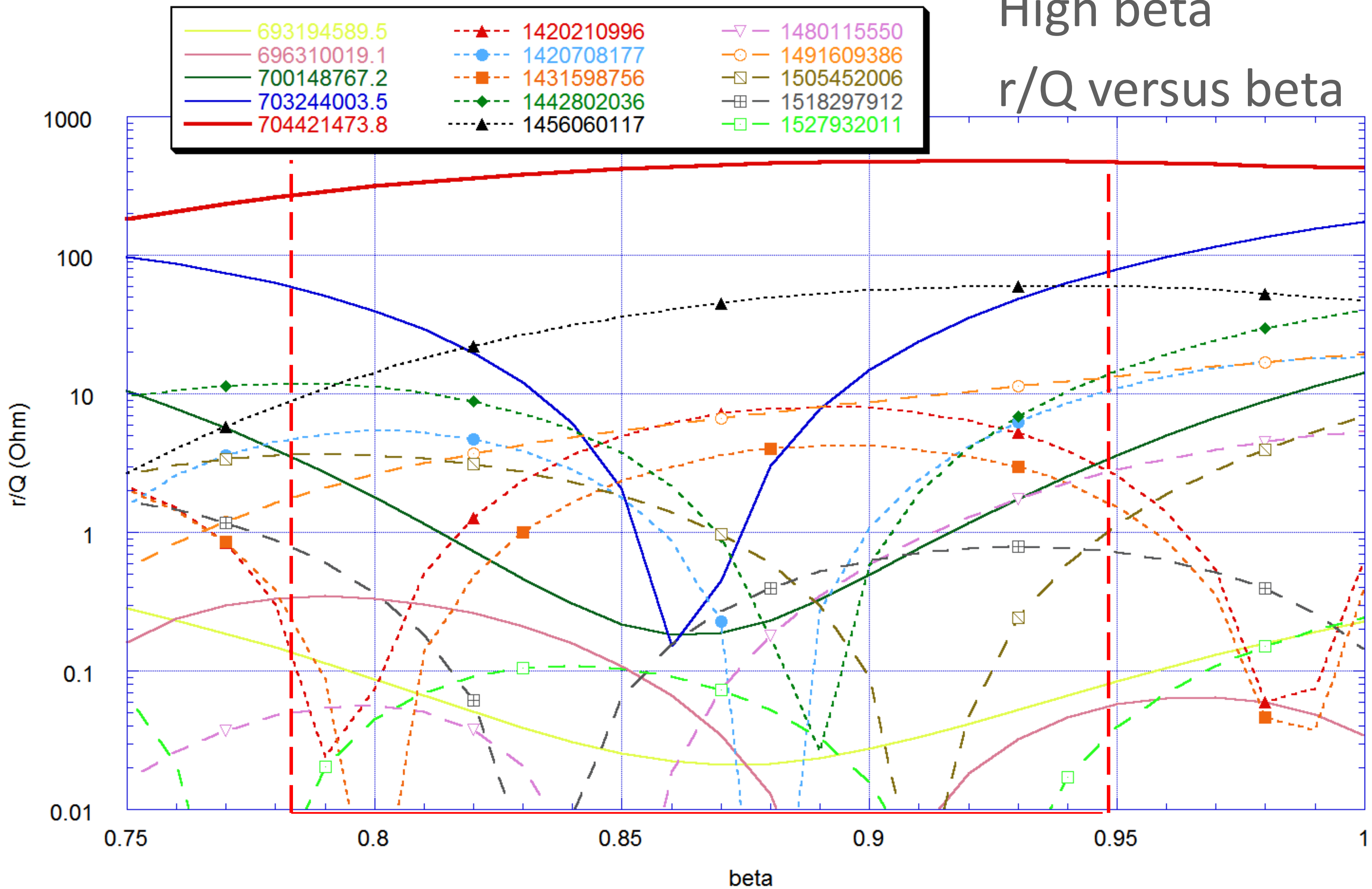
	Medium	High
Geometrical beta	0.67	0.86
Frequency (MHz)	704.42	
Number of cells	6	5
Operating temperature (K)	2	
Maximum surface field in operation (MV/m)	44	44
Nominal Accelerating gradient (MV/m)	< 16.7	< 19.9
Q_0 at nominal gradient	> 5e9	
Q_{ext}	$7.5\ 10^5$	$7.6\ 10^5$

	Medium	High
Iris diameter (mm)	94	120
Cell to cell coupling k (%)	1.22	1.8
π and $5\pi/6$ (or $4\pi/5$) mode separation (MHz)	0.54	1.2
E_{pk}/E_{acc}	2.36	2.2
B_{pk}/E_{acc} (mT/(MV/m))	4.79	4.3
Maximum. r/Q (Ω)	394	477
Optimum β	0.705	0.92
G (Ω)	196.63	241

Longitudinal HOM below cut-off

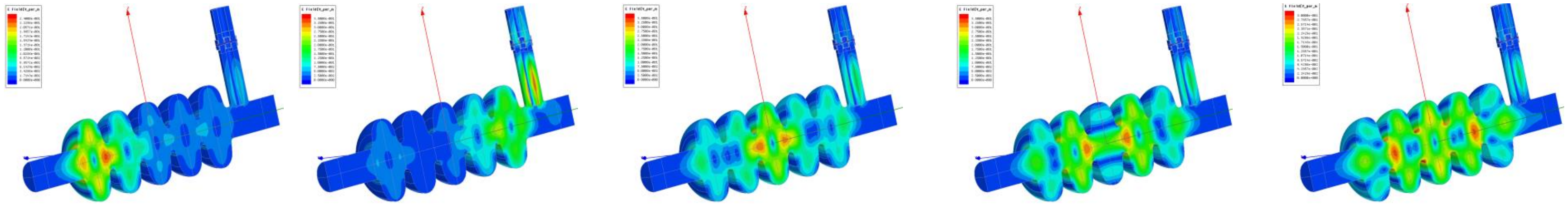
High beta

r/Q versus beta



High beta has 2 L-bands below cutoff

HOM damping by NC parts



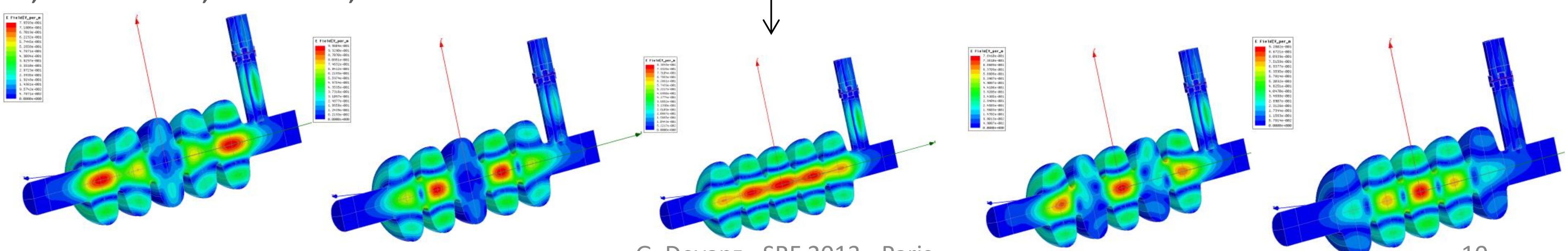
Freq	Q	Max. r/Q
1,420314E+09	1,58E+05	8
1,421856E+09	4,30E+03	17
1,431672E+09	3,22E+04	4
1,442845E+09	3,30E+04	29
1,456038E+09	4,41E+04	60

First longitudinal HOM band
Maximum QL 1.6e5

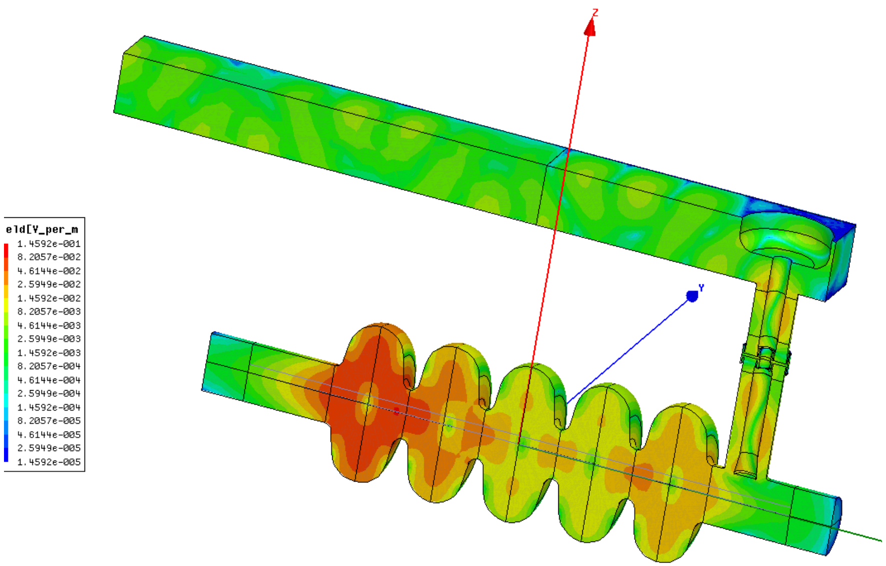
Freq	Q	Max. r/Q
1,480140E+09	1,98E+04	5
1,491491E+09	1,33E+04	17
1,505236E+09	1,40E+04	4
1,518154E+09	1,87E+04	4
1,527895E+09	4,57E+04	0,2

Second longitudinal HOM band
Maximum QL 4.6e4

- Mostly damped by the FPC antenna
- But optimistic case because of matched termination



HOM damping - More realistic coupler modeling



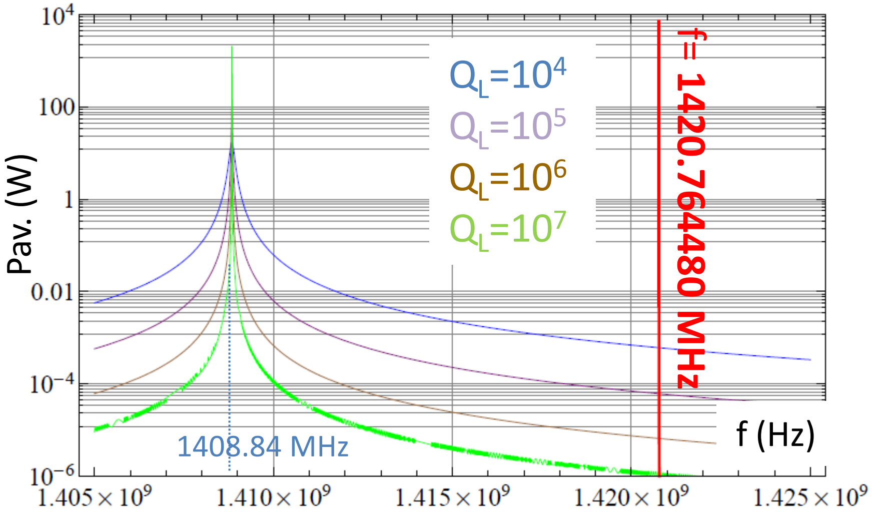
Electric field amplitude (logscale) – 1420 MHz

F (MHz)	Matched termination	Doorknob + WG
1 420 300	1.58e5	4.06E+05
1 421 018	4.30e3	2.38E+04
1 431 633	3.22e4	6.36E+05
1 442 796	3.30e4	1.27E+06
1 456 101	4.41e4	5.05E+05
1 480 038	1.98e4	1.29E+05
1 491 485	1.33e4	2.03E+05
1 505 199	1.40e4	4.99E+05
1 518 257	1.87e4	1.94E+05
1 527 899	4.57e4	6.08E+05

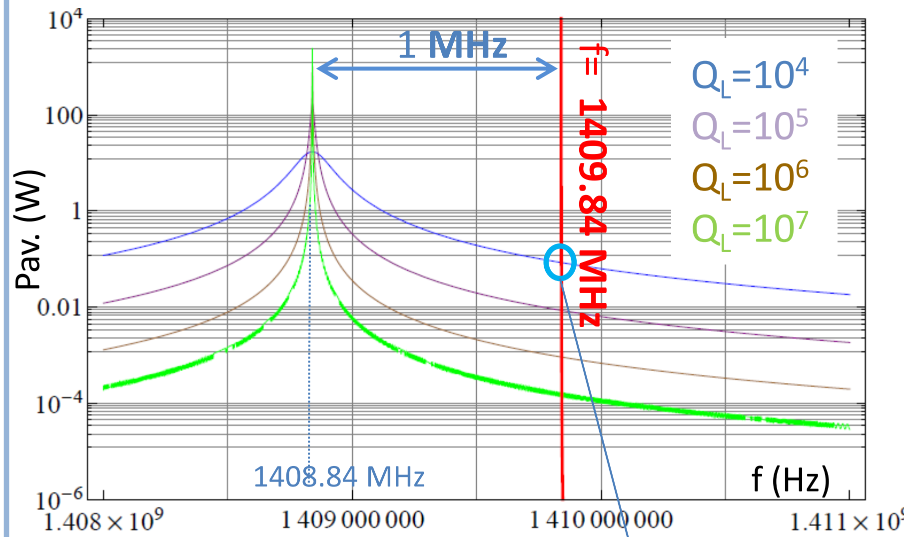
Still, the transmission characteristics of the high power waveguide network are unknown. (Here, the rectangular WG is terminated by a lossy short.)

Power deposited on the non-propagating longitudinal modes

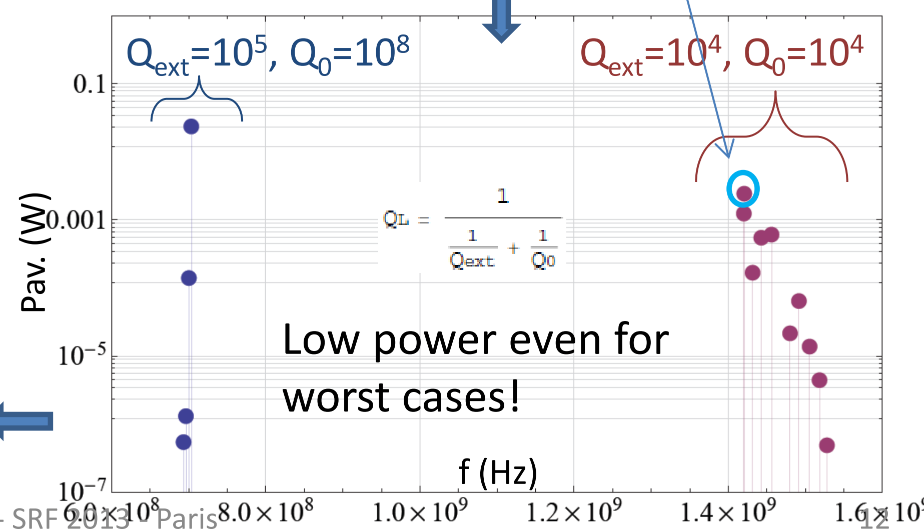
Most dangerous mode : 2nd mode of the 1st HOM L-band at f= 1420.764480 MHz



What would happen if this mode was at 1 MHz from the beam line ?



Very important : distance between mode and beam harmonics

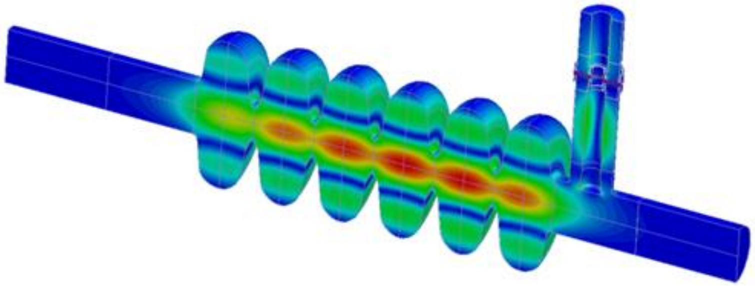


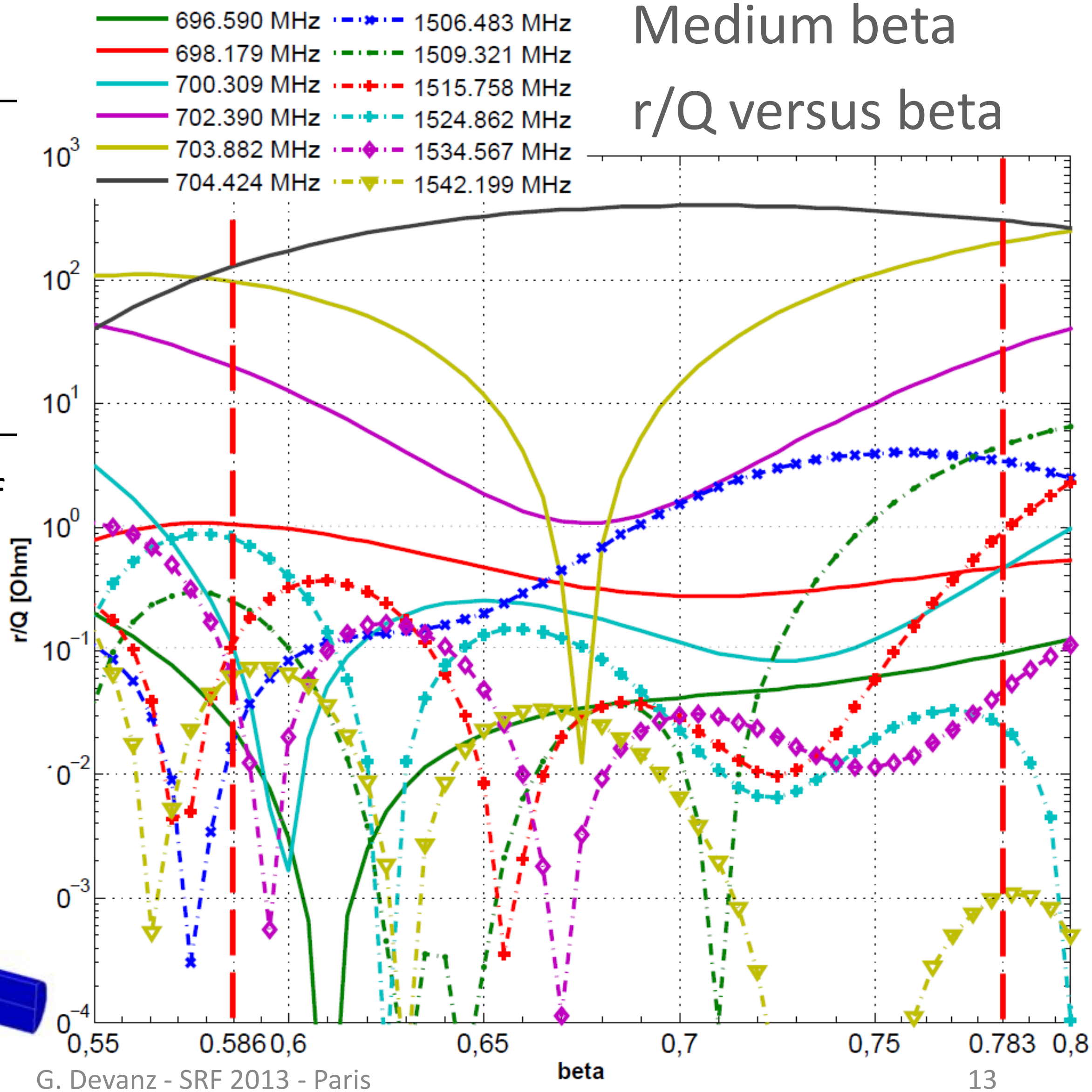
Conclusion: If longitudinal HOMs are more than 1MHz away from beam harmonics:
- no extra damping is necessary
- more damping is harmful

Medium beta HOMs

Frequency (MHz)	r/Q (Ohm)	QL estimate
1506.48	0.444	13000
1509.32	0.0021	7000
1515.76	0.0020	5000
1524.86	0.127	3000
1534.57	0.0001	2000
1542.20	0.0032	3000

High beta has 1 L-band below cutoff



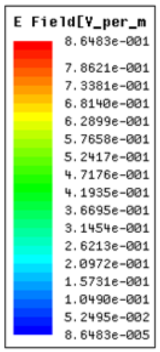


Medium beta

r/Q versus beta

Medium beta HOMs

- Above cut-off : full module simulation is required to estimate r/Qs and damping
- Cryomodule end tubes can help damping the HOMs at higher temperature



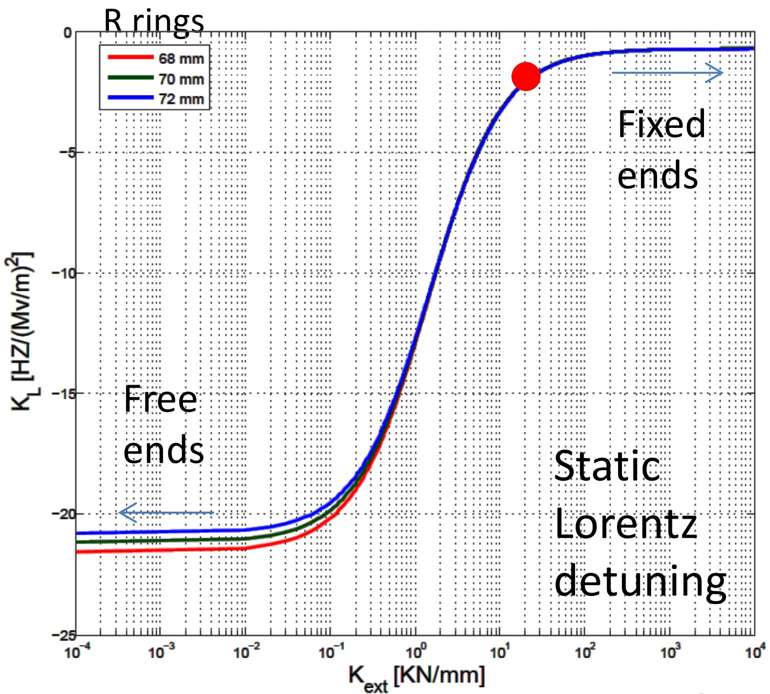
pipe diameter (mm)	Cut-off frequencies (GHz)	
	TE11	TM01
100 (warm section)	**1.7595**	**2.2988**
140	**1.2568**	**1.6420**

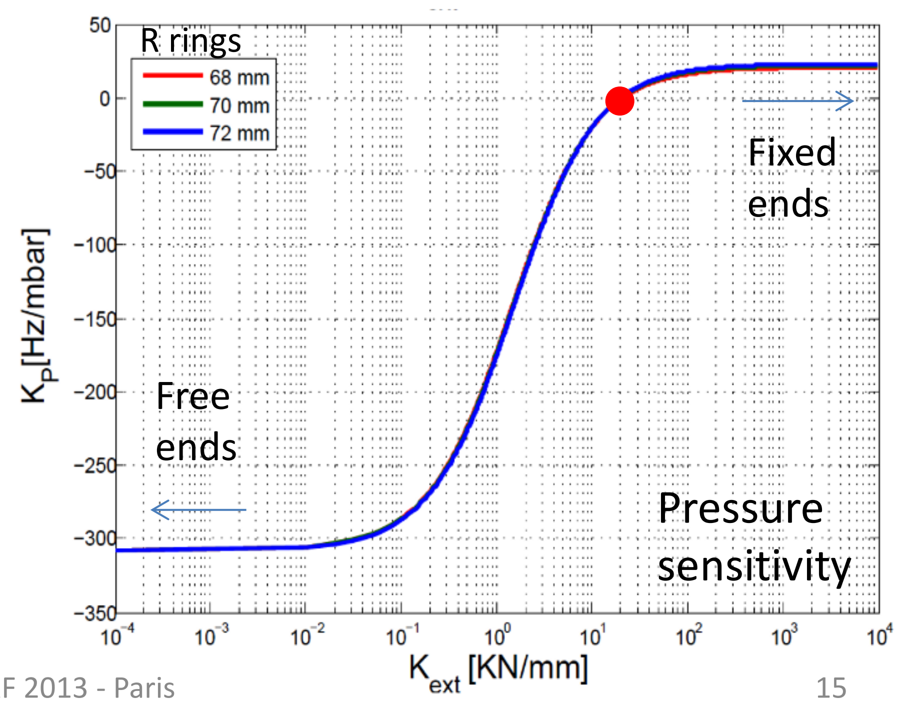
Example : mode of 2nd longitudinal band is a cryomodule mode

Work in progress…

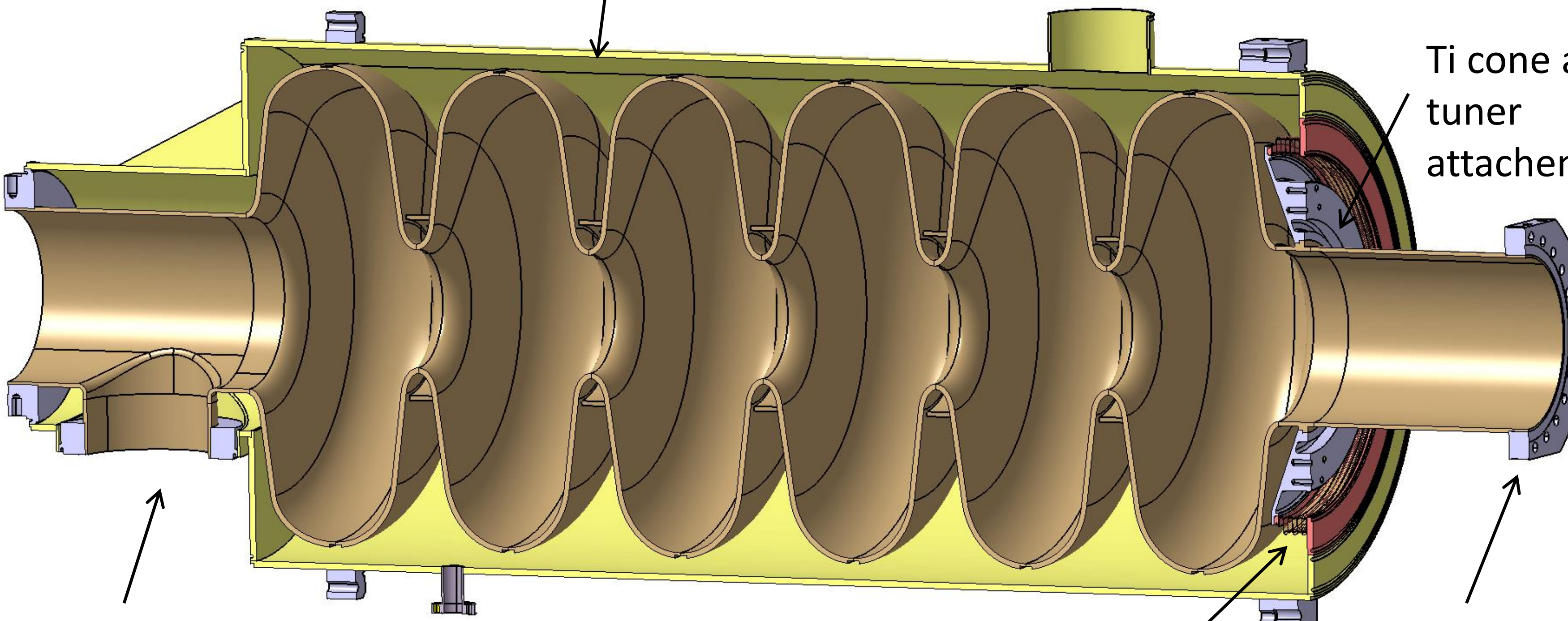
Medium beta RF/Mechanical parameters

Cavity wall thickness (mm)	4
Tuning sensitivity (kHz/mm)	217
Stiffness (kN/mm)	1.47
K_L static Lorentz coefficient (Hz/(MV/m)²) (fixed ends)	-0.71
K_L static Lorentz coefficient (Hz/(MV/m)²)	-21.1
K_L static Lorentz coefficient (Hz/(MV/m)²) for Kext=21 kN/mm (●)	-2.06
Max. relative pressure (bar) in He vessel at 300K keeping V.M. stress in cavity wall < 40 MPa (fixed ends, pressure test case)	2.2
Max. Von Mises stress (MPa) in cavity wall with 1.5 bar in helium vessel	28





Cavity components



Most of the elements are identical for medium and high beta

High beta prototype cavity

High beta prototype

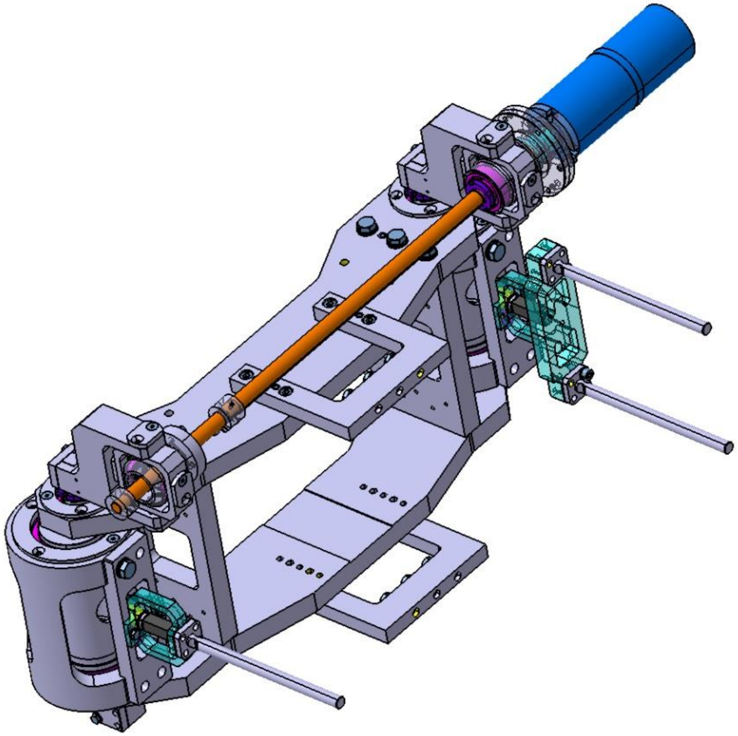
Delivered last week

Coupler side

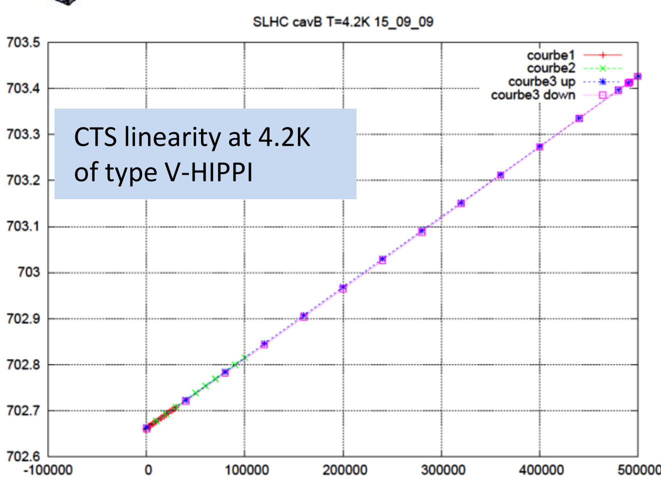
Tuner side

Extra « HOM » ports for RF measurements on the prototypes

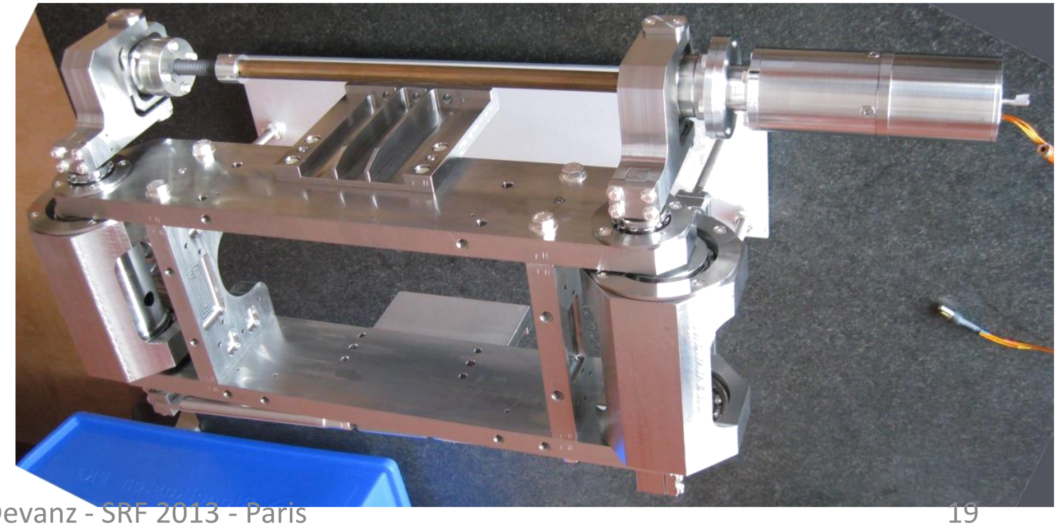
Cold tuning system



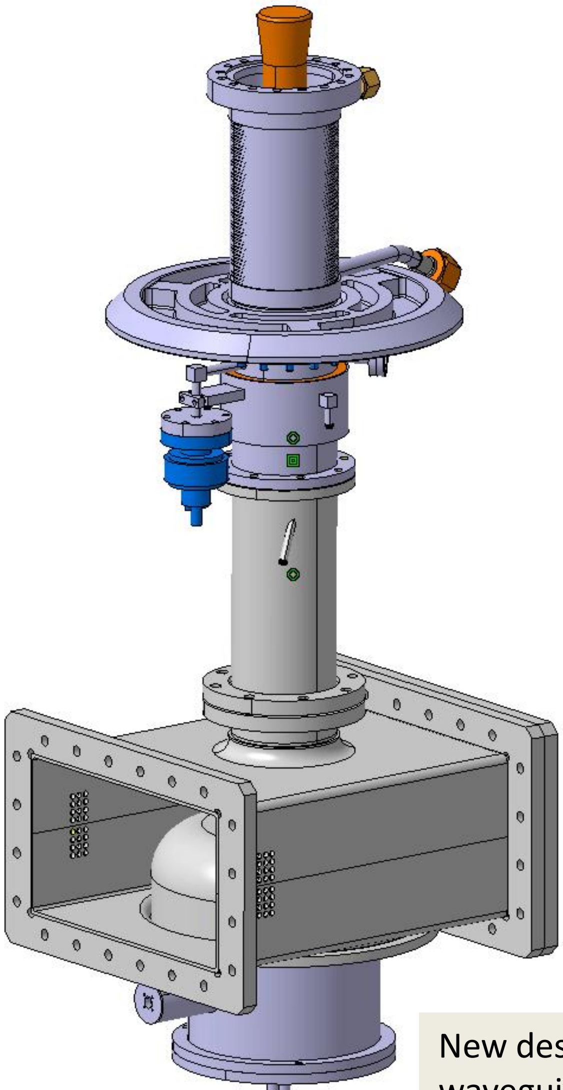
- Saclay V type adapted for ESS cavities
- +/- 3 mm range
- 1+1 piezo
- Cold motor and planetary gearbox (1/100e)
- Piezo support has a stiffness 10 times higher than the cavity ⇨ piezo preload at 2K is independant of the cavity springback force



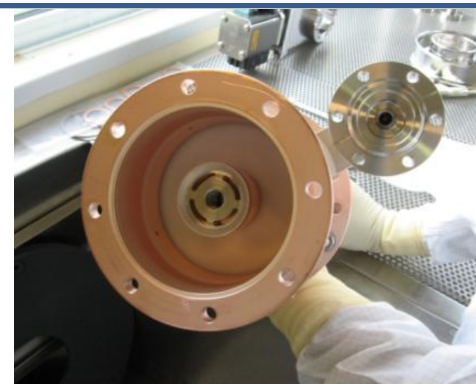
Type V for SPL beta = 1 5-cell prototype



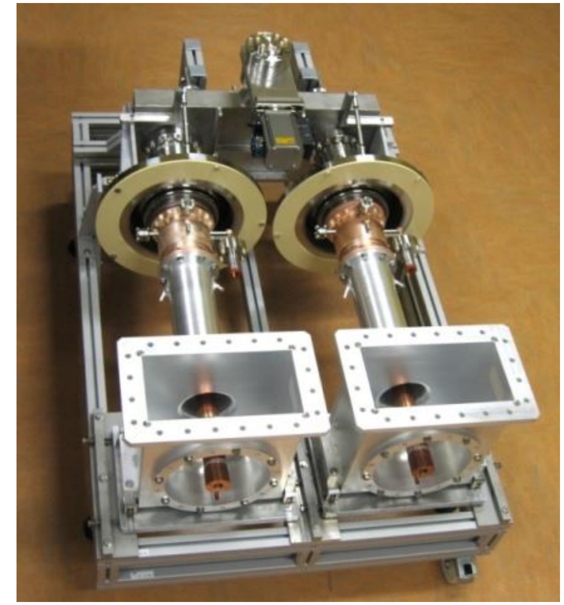
Fundamental power coupler

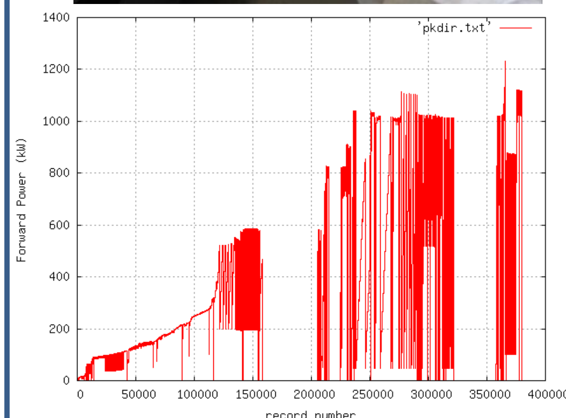


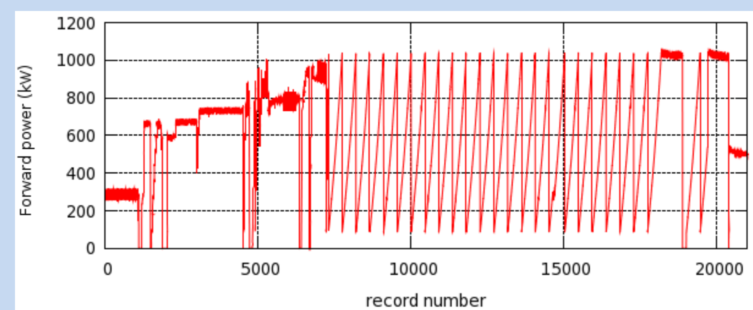
New design of the doorknob waveguide transition including a HV bias capacitor with RF trap



HIPPI power coupler (KEK-type window) tested to 1.2 MW, 10% Duty factor at Saclay





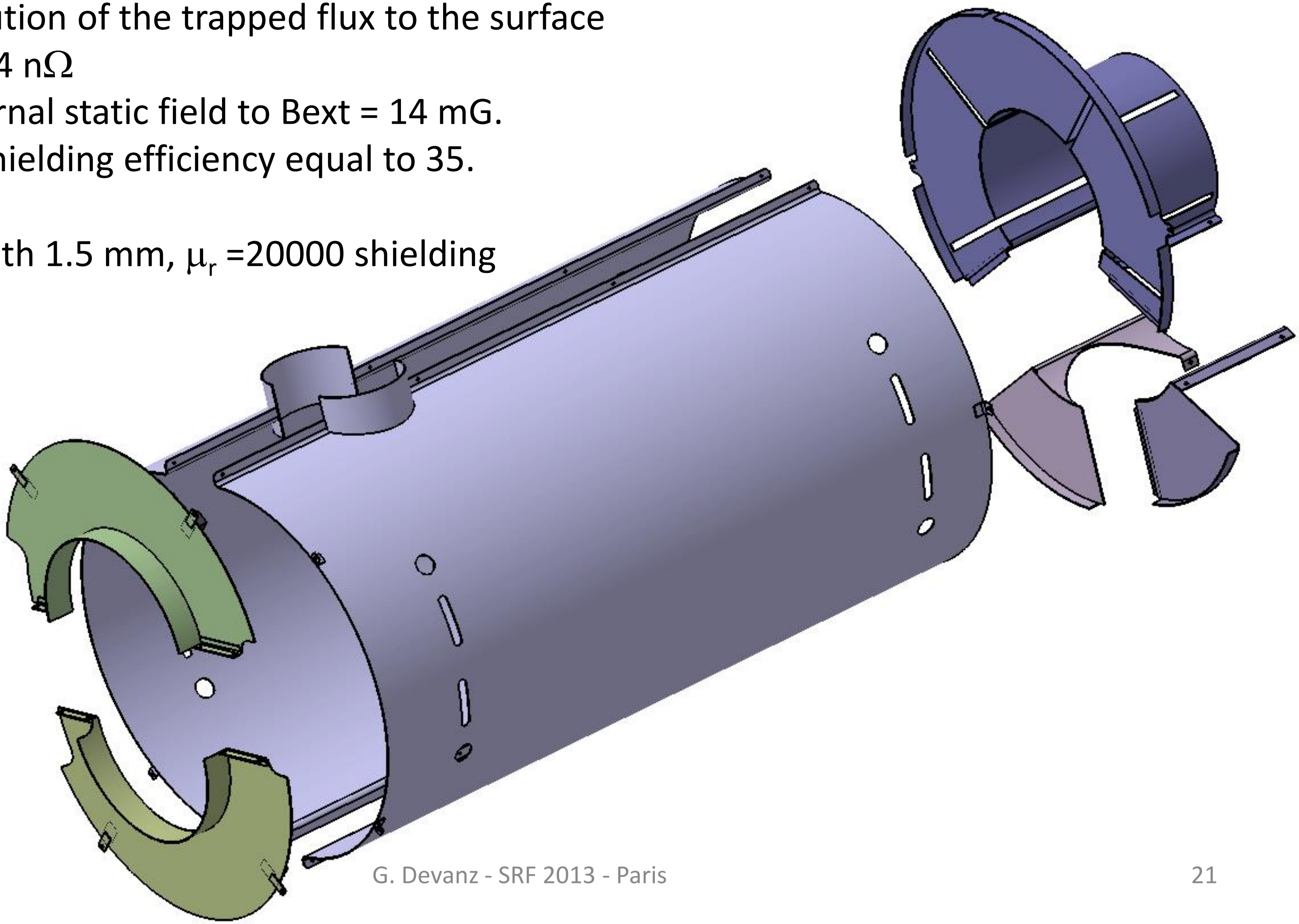


Test of the HIPPI power coupler on the HIPPI cavity at 1.8 K, full reflection

Magnetic shield

Limit contribution of the trapped flux to the surface resistance to 4 nΩ
limit the external static field to Bext = 14 mG.
→ required shielding efficiency equal to 35.

Achievable with 1.5 mm, μ_r =20000 shielding material



Outlook

- Design of most cryomodule components well advanced
- Phase of medium beta cavity package procurement
- Development of cavity preparation has started with a very similar SPL beta=1 5-cell cavity

- A new clean room is under construction at Saclay for SPIRAL2 and ESS first cryomodules assembly
- The medium beta cryomodule will be then and tested at Saclay

704.42 MHz 5-cell Beta=1
in Saclay Vertical. EP