Status of SC cavity development (SPL WG2 report)

W. Weingarten

Outline of talk 1/2

- Participants to cavity WG activity
- Cavity geometry

Fabrication of Nb and Cu SPL cavities and required tools , Towards the final design of the beta=1 cavity, Towards Common Interfaces, RF parameters for the BNL and CEA cavities, β=1 cavity-parameters, Discussion on the RF parameters for the SPL cavities - CEA vs. BNL II, beta = 0.65 design features, SCRF Research at JAI@RHUL - intra-cavity coupling in short cryomodule

- Mechanical and material issues spec's Nb sheets , Towards the acquisition of niobium: mechanical calculations
- Power coupler (cf. also Ed Ciapala's presentation)
- HOM issues

SPL - HOM Qload - coupled S-parameter calculations, Beam tube damping estimationsfor SPL cavity, Beam tube damping estimations for SPL cavity, cont'd , Longitudinal HOM power estimationsfor pulsed beams, Damping Considerations for coax type couplers , Qext-limits, transition section and damping

- Magnetic shielding
- Update parameter list SPLparameterList
- Electropolishing (EP) status at CERN
- (Safety issues CERN safety requirments for pressure vessels)
- Concluding remark

Outline of talk 2/2
references

Presented material is based on the following sources:

Meetings related to cavity activity since last (3rd) collaboration meeting on 11 -13 Nov. 2009:

- 5 cavity WG meetings

http://indico.cern.ch/categoryDisplay.py?categId=2722

- 21 Jan 2010, RF needs for SPL SC cavity tests

http://indico.cern.ch/conferenceTimeTable.py?confId=80891#20100121

- 16 - 17 March 2010, Review of SPL RF power couplers

http://indico.cern.ch/conferenceTimeTable.py?confId=86123#20100317

- 1st Annual RFTech meeting

https://indico.desy.de/getFile.py/access?contribId=7&sessionId=1&resId=0&materialId=slides&confId=2831

Participants to cavity WG activity

- **CERN, Geneva,**
  - BE-RF (clean room assembly, low and high power RF tests, inspection, RF power coupler)
  - TE-CRG (cryogenics SM18)
  - TE-VSC (surface preparation: chemical and electro-polishing, high pressure water rinsing)
  - EN-MME (manufacture of $\beta = 1$ cavities and He tank)
- **CEA - Saclay**, France (design and fabrication of β = 1 cavity, 5 helium vessels, 9 tuners, test bench availability 8 RF power couplers)
- **CNRS - IPN Orsay**, France (design, fabrication and test of β = 0.65 cavity equipped with a titanium helium reservoir)
- **TEMF University of Darmstadt**, Germany (el-mag. simulations: interaction of power coupler with beam)
- **University of Rostock**, Germany (el-mag. simulations of HOM antenna coupler design)
- **BNL, Upton N.Y.**, USA (manufacture of β = 1 cavity)
- **TRIUMF, Vancouver**, Canada (manufacture of β = 1 cavity)
- **Royal Holloway, University of London**, John Adams Institute for Accelerator Science, U.K. (room temperature RF measurements on cavity models

Ofelia Capatina / CERN-EN-MME

Cavity geometry 1/5
design considerations

- Maximum allowed pressure for cavity beta =1 and beta =0.65 design

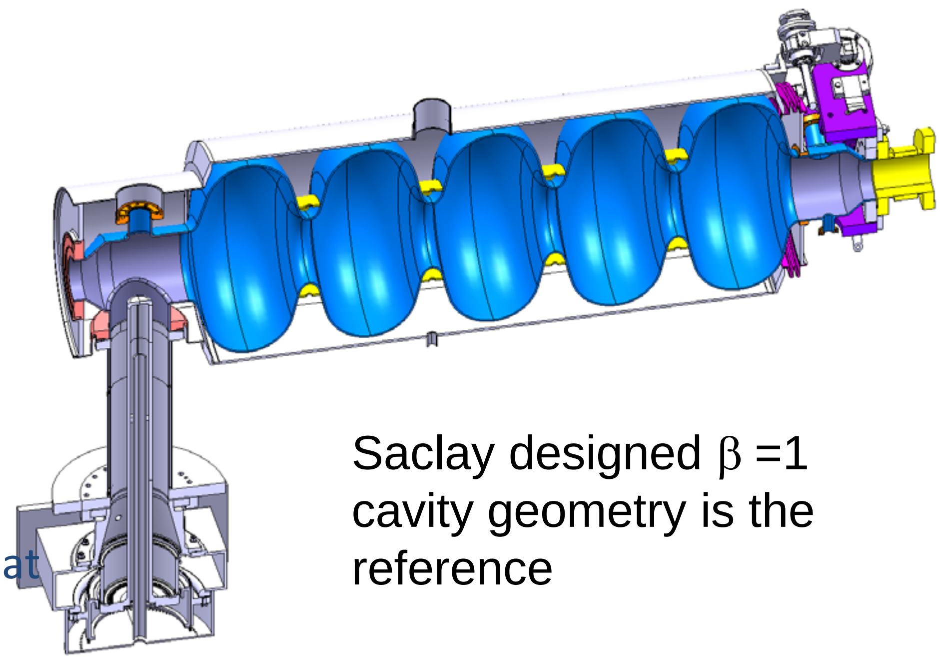
  Max pressure at 300 K :   1.5 bars

  Max pressure at 2K: 2 bars

- Beta=1 cavity

  Position of HOM ports

  - opposite to power coupler (ease of manufacture)
  - Vertical upwards for possible future cooling considerations => the Power coupler will be downwards
  - The other HOM port will be positioned at 60 deg / vertical
  - The pick-up port downwards



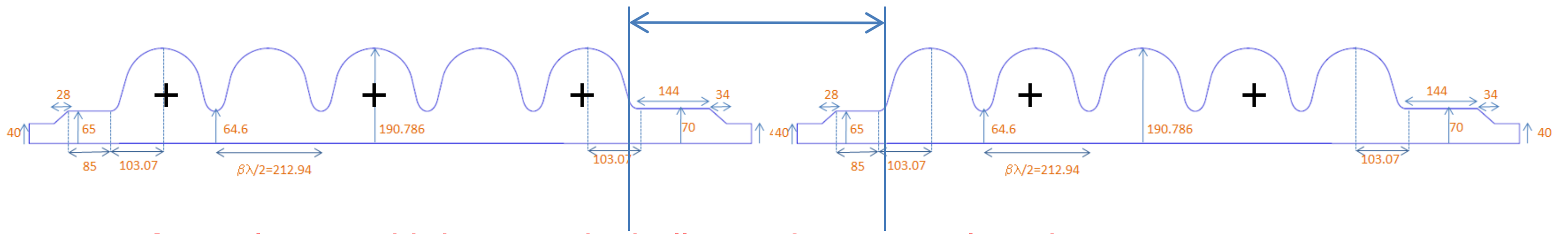
Saclay designed β =1 cavity geometry is the reference

- Beta=0.65 cavity
  - same end cavities as for beta=1 and to modify the inner design

Cavity geometry 2/5
phase relation between string of several cavities (π - mode)

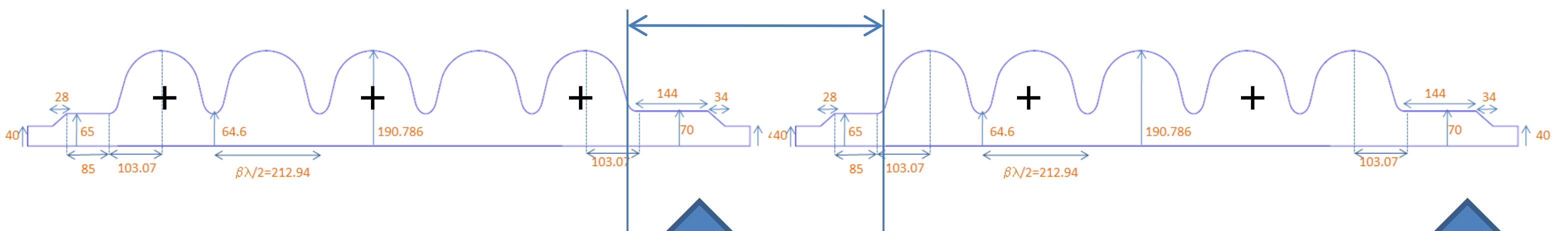
present layout with inter-cavity bellows of **100 mm** length

$2.05 \cdot \lambda/2$



proposed new layout with inter-cavity bellows of **89.4 mm** length

$2 \cdot \lambda/2$



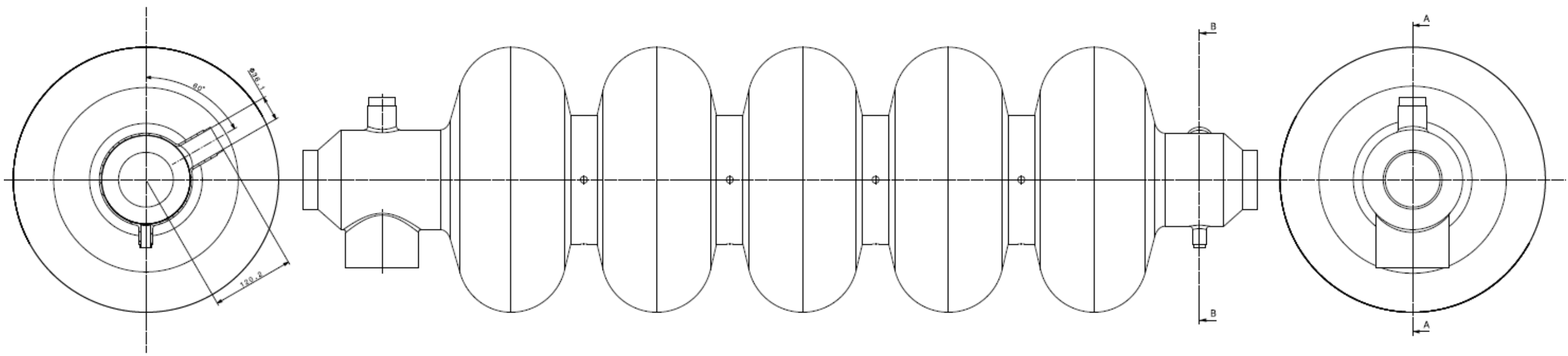
RF power coupler
phase = -180°

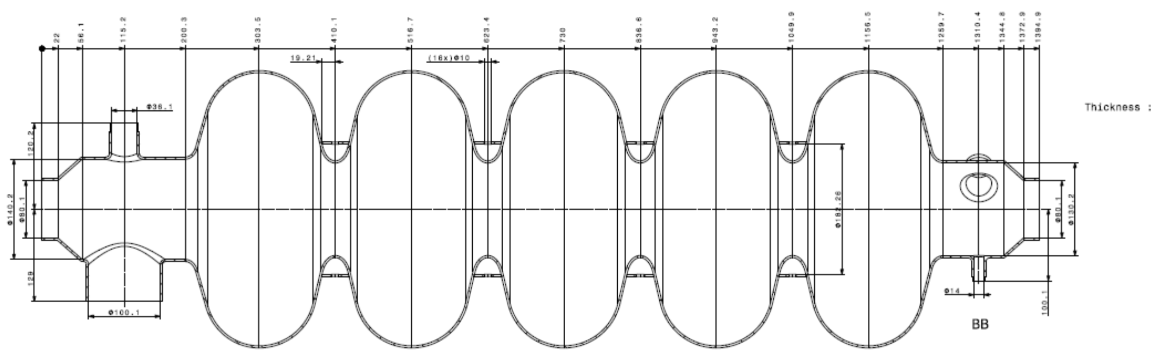
RF power coupler
reference phase = 0°

RF power coupler
phase = 180°

Ofelia Capatina
Said Atieh / CERN-EN-MME

Cavity geometry 3/5

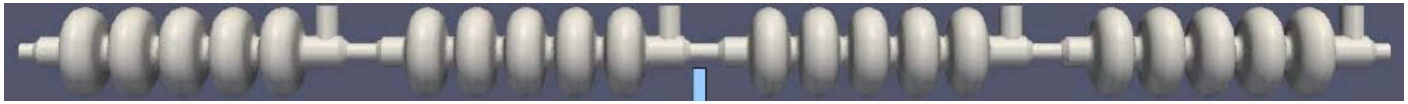




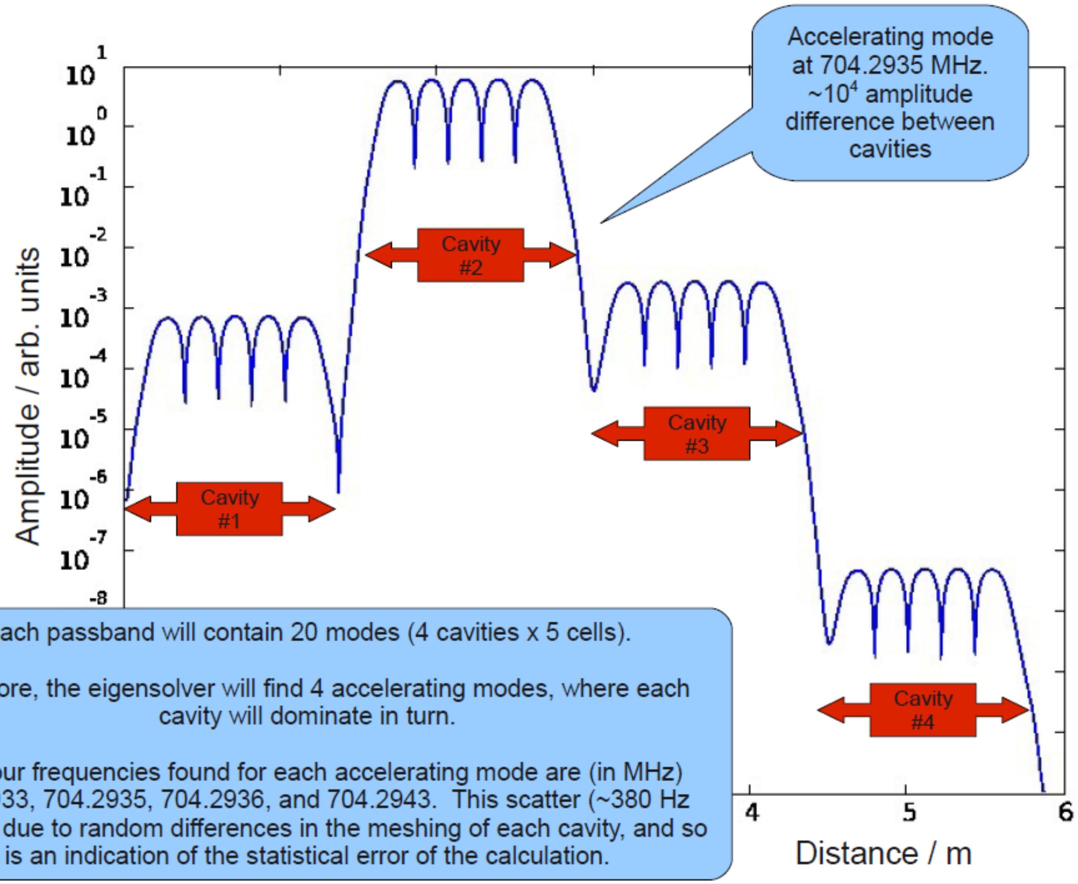
Geometry of He tank, magnetic shielding and position of power coupler flanges still to be finalized

Steven Molloy / Royal Holloway
University of London

Cavity geometry 4/5
inter-cavity coupling in string of 4 cavities



Eigenmodes exist in **all** cavities

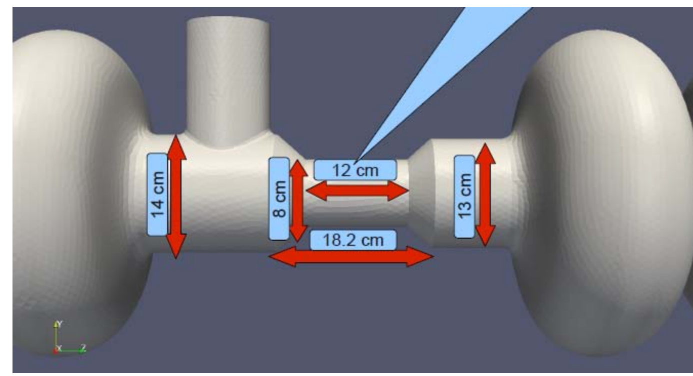


Each passband will contain 20 modes (4 cavities x 5 cells).

Therefore, the eigensolver will find 4 accelerating modes, where each cavity will dominate in turn.

The four frequencies found for each accelerating mode are (in MHz) 704.2933, 704.2935, 704.2936, and 704.2943. This scatter (~380 Hz RMS) is due to random differences in the meshing of each cavity, and so is an indication of the statistical error of the calculation.

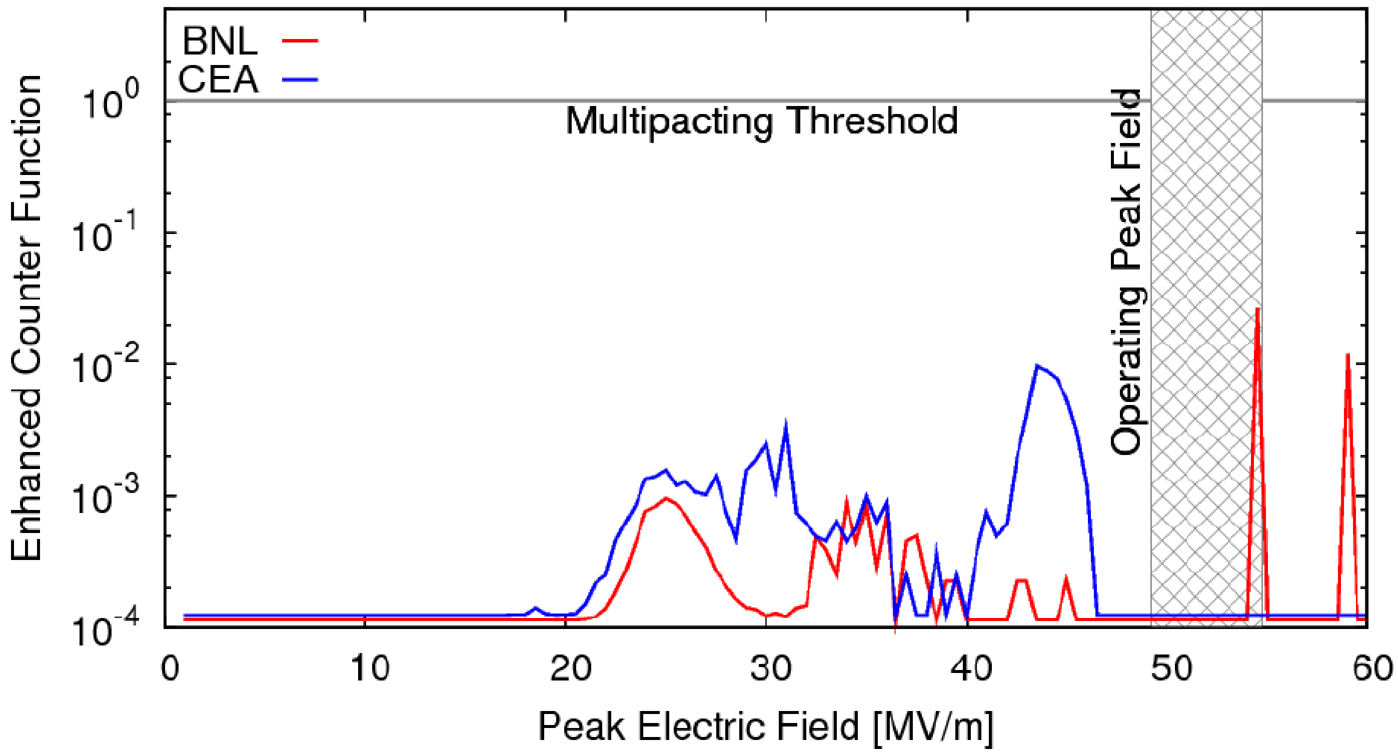
Not the nominal SPL geometry.



Cavity geometry 5/5
study of multipacting in end groups

Rama Calaga/ BNL

MULTIPACTING BNL & CEA END GROUPS



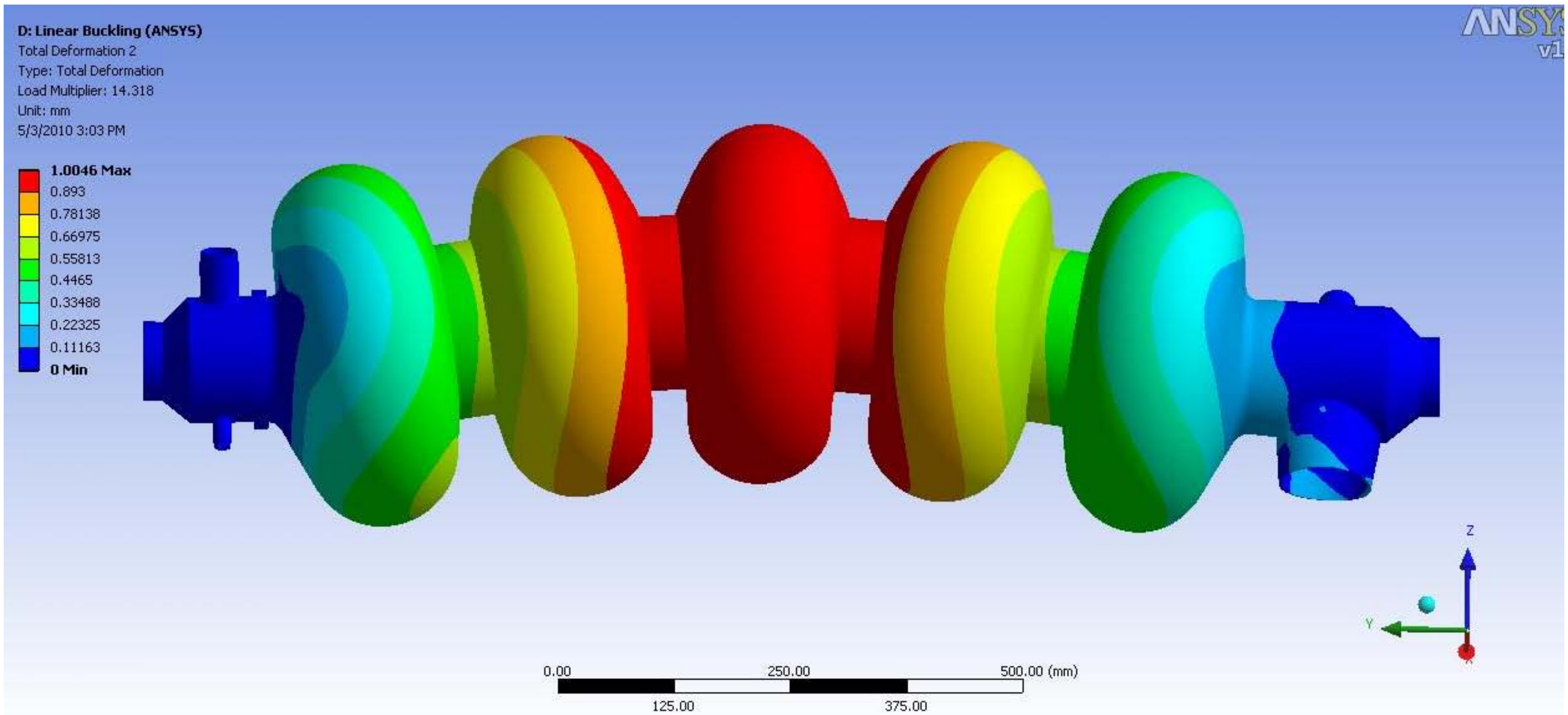
Number of secondary electrons surviving after 20 impacts normalized to the secondary yield of Nb

Mechanical and material issues 1/2
$\beta = 1$ cavity buckling calculations

Ofelia Capatina / CERN-EN-MME

Cavity with **2.5 mm thickness** (worst case); boundary conditions fixed-fixed (best case); external pressure loading:

1st buckling mode (security factor of 14 with respect to the p=2bars loading)



Mechanical and material issues 2/2

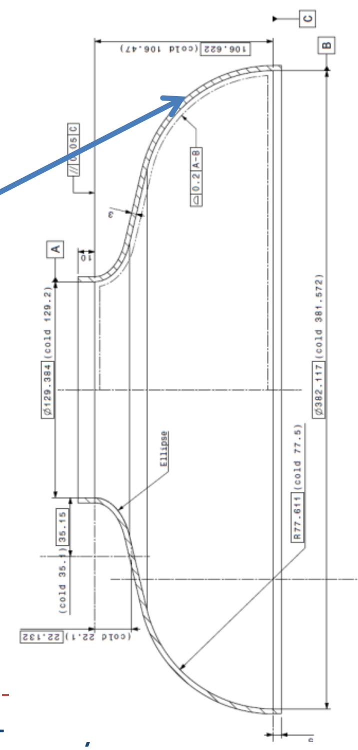
- Technical specification of Nb sheets OK
  - Including chemical composition, structure (grain size), mechanical properties, homogeneity and surface quality, tests carried out by the manufacturer
  - Start thickness of Nb sheets defined as 3.5 mm[1]

c.f. S. Adieh's presentation to cavity WG:

[spec's Nb sheets]

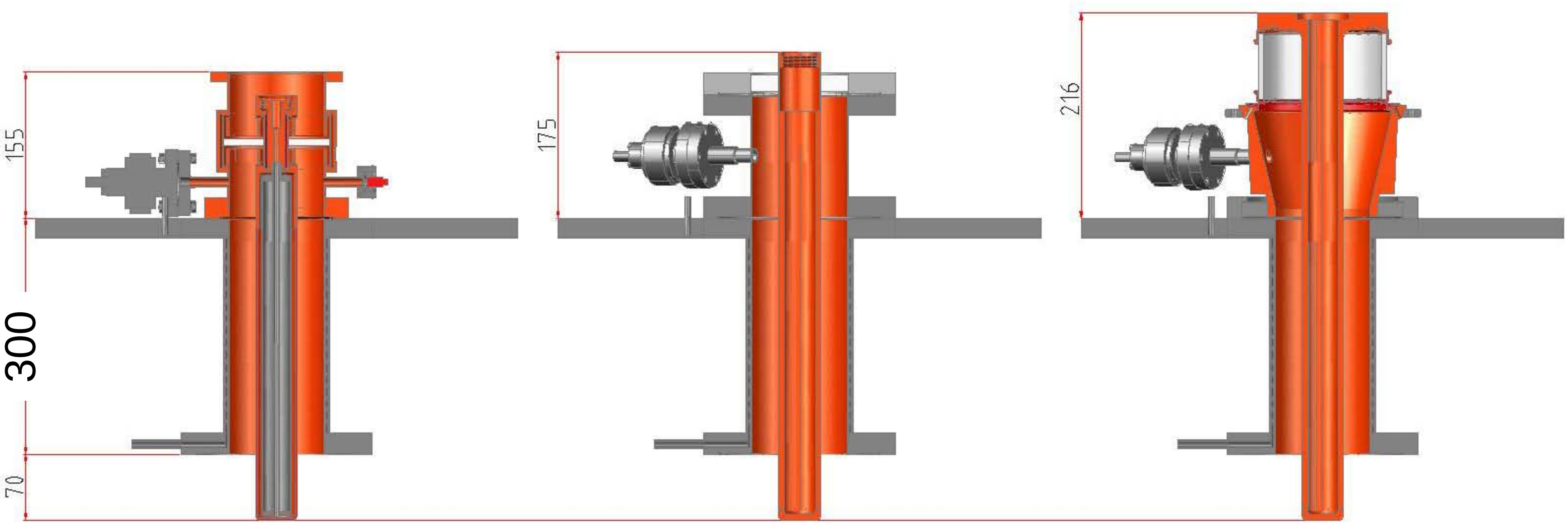
1

spinning thickness loss	- 0.6 mm
thickness tolerances	- 0.1 mm
chemical etching and EP	- 0.2 mm
optimised start thickness	is 3.5 mm



Eric Montesinos / CERN-BE-RF

Power coupler 1/2
three possible remaining designs



SPL-CEA HIPPI coaxial disk water cooled window

SPL-SPS coaxial disk air cooled window

SPL-LHC cylindrical air cooled window

All use the same double walled tube

All use the same vacuum gauge, electron monitor and arc detector

We have designed them to be compatible without modifying the cryomodule

Power coupler 2/2
Decisions after March 2010 Coupler Review

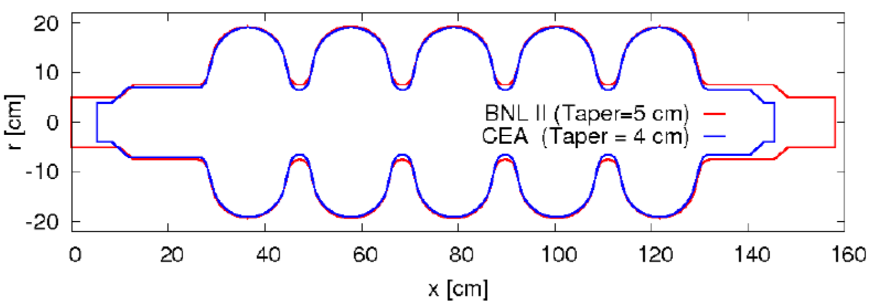
- A single window coupler
- A fixed coupler ($Q_{ext} = 1.25 \times 10^6$)
- With a Double Walled Tube
- Mounted in clean room with its double walled tube horizontally in only one operation
- With its final position vertically below the cavity (regarding HOM, cryo-module integration, pollution, etc… requirements)
- With a HV DC biasing capacitor
- Air cooled

HOM issues 1/6
do we have the optimum design of cavity and end groups?

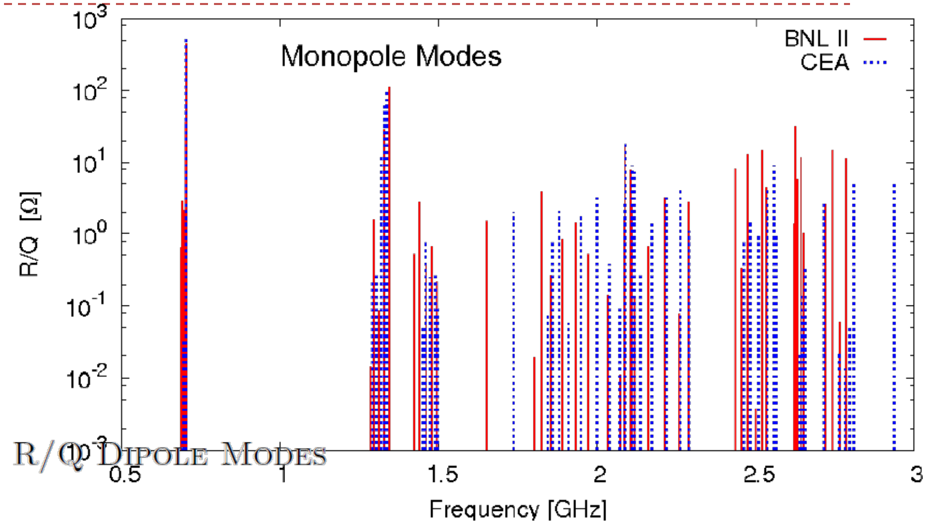
Rama Calaga/ BNL

Fundamental Mode

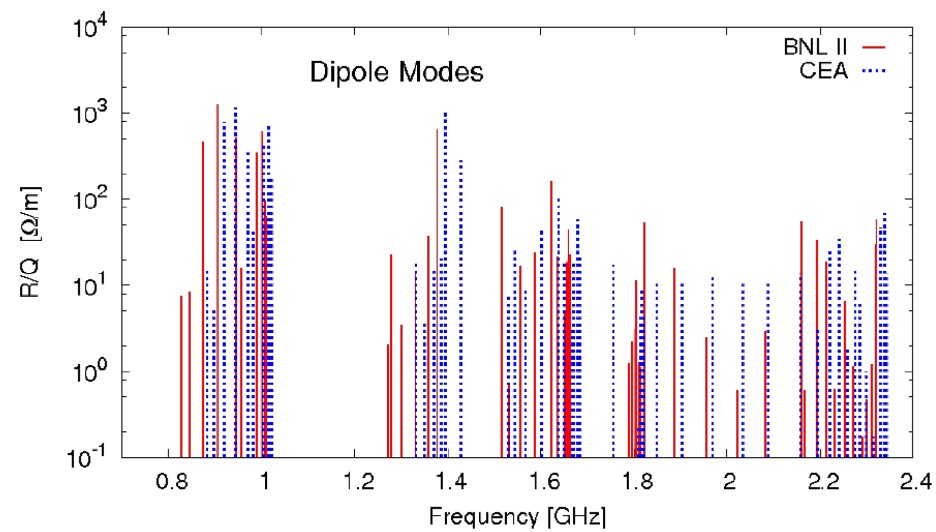
Parameter	BNL II	CEA	% Diff
Frequency	704	704	
Epk/Ea	2.18	2.04	-6.4 %
Bpk/Ea	4.48	4.30	-4.0%
R/Q	504	555	+9.2%
Kcc	3 %	-	



R/Q Monopole Modes



R/Q Dipole Modes



HOM issues 2/6

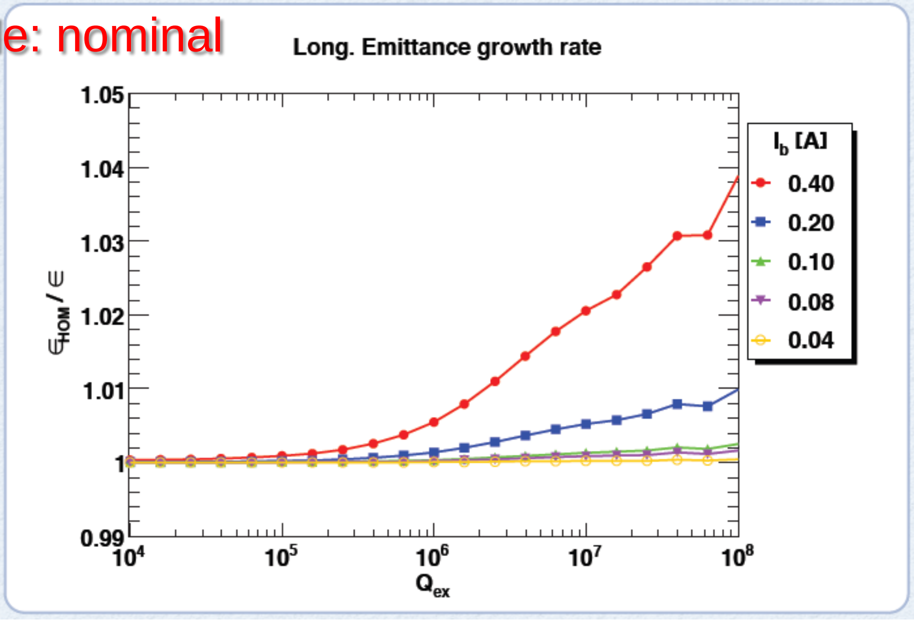
Marcel Schuh / CERN-BE-RF

what Q do we need wrt beam break up simulations under various conditions for whole linac?

Q_{ex} limits based on beam dynamic simulations

Simulated cases: nominal, RF errors, chopped beams, fundamental pass-band modes

Example: nominal



- one HOM with max R/Q in each cavity present.

Overall conclusion:

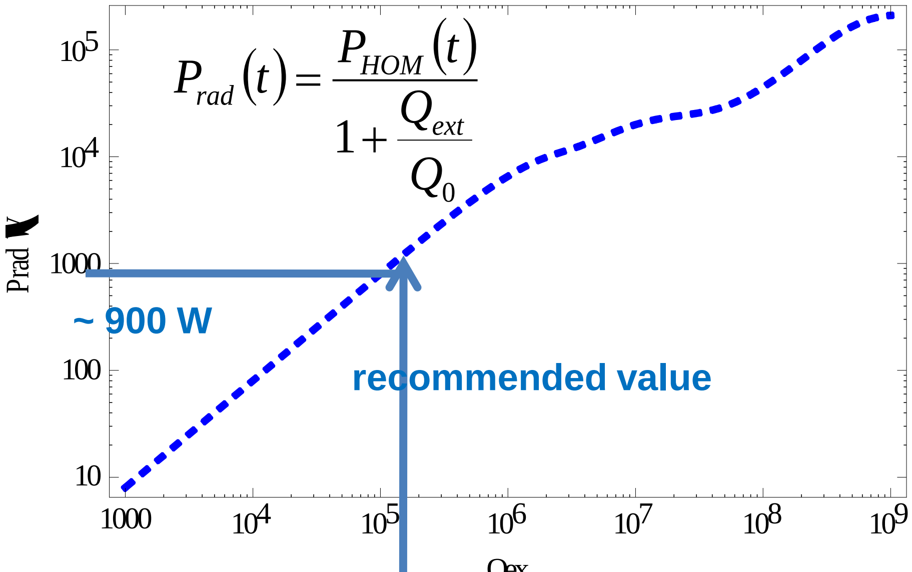
To be on the save side and keep all operation options open a $Q_{ex} = 10^5$ is recommended!

HOM issues 3/6
what is the longitudinal HOM power for pulsed beams to be dumped into the HOM load/cavity?

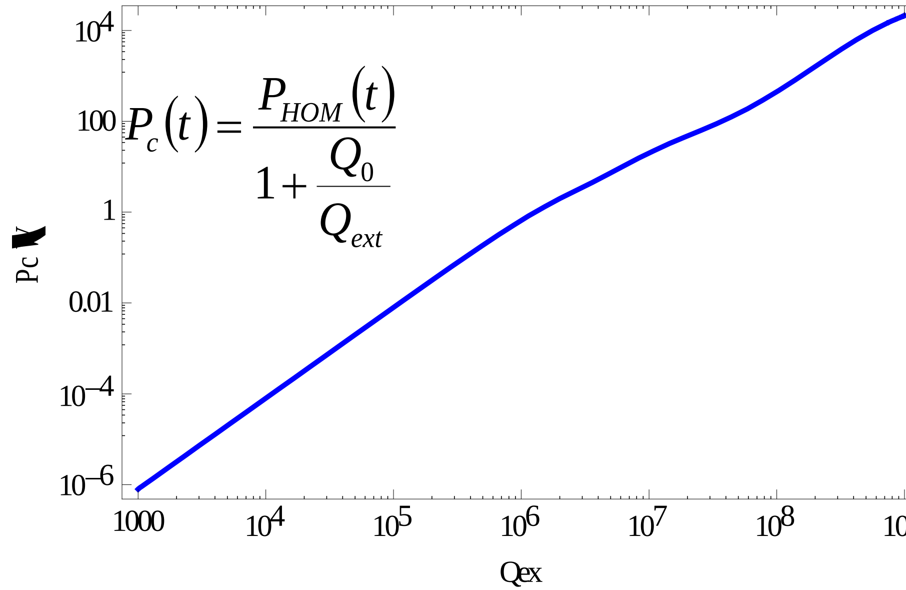
f (HOM) precisely on beam spectral line

I = 40 mA; pulse length 1 ms, *R/Q* = 100 Ω ; rep. rate 50 Hz; ***f*** $\boldsymbol{f_{HOM}}$ **= 2.1 GHz**; $Q_0 = 10^{10}$

radiated power to HOM load



dissipated power in cavity



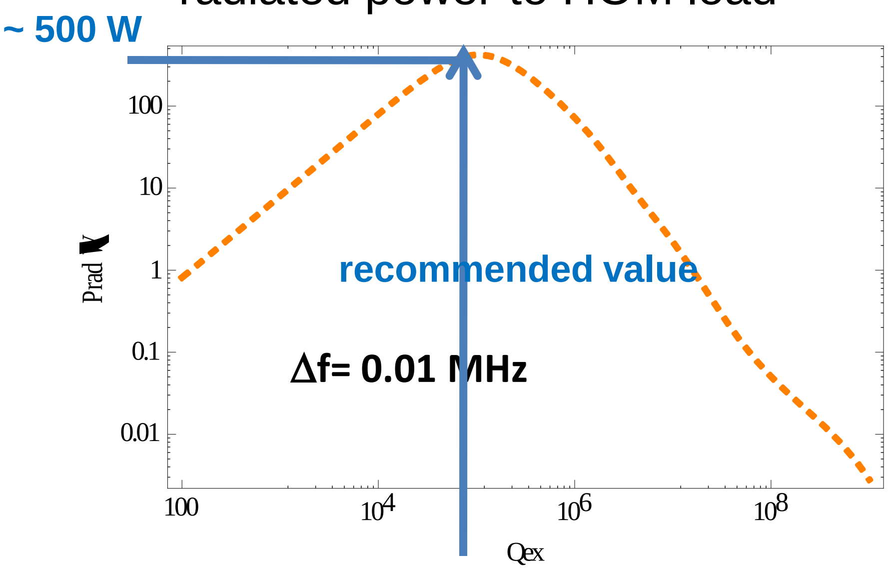
The main beam Fourier components (n·352 MHz) contribute significantly to the HOM power, the 50 Hz Fourier component, however, only marginally; to reduce the HOM power below 100 W, **the Q-value of the HOM must be *Q* < 10^4**

HOM issues 4/6
what is the longitudinal HOM power for pulsed beams to be dumped into the HOM load/cavity?

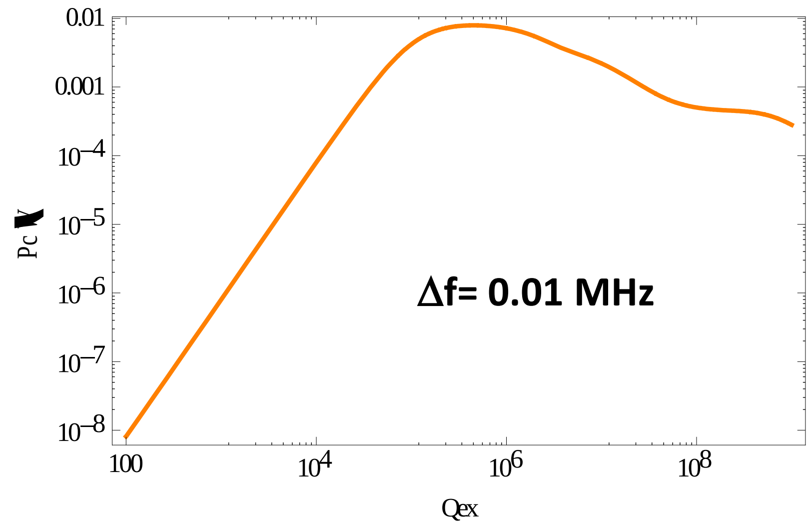
f (HOM) off beam spectral line

I = 40 mA; pulse length 1 ms, R/Q = 100 Ω ; rep. rate 50 Hz; $\boldsymbol{f_{HOM}}$ **= 2.1 GHz**; $Q_0 = 10^{10}$

radiated power to HOM load



dissipated power in cavity



Avoiding the main beam Fourier components by the HOM frequencies within 10 kHz reduces the HOM power significantly, with a tendency to become even smaller for larger Q-values ($\boldsymbol{P < 1}$ **W @** $\boldsymbol{Q > 10^7}$)

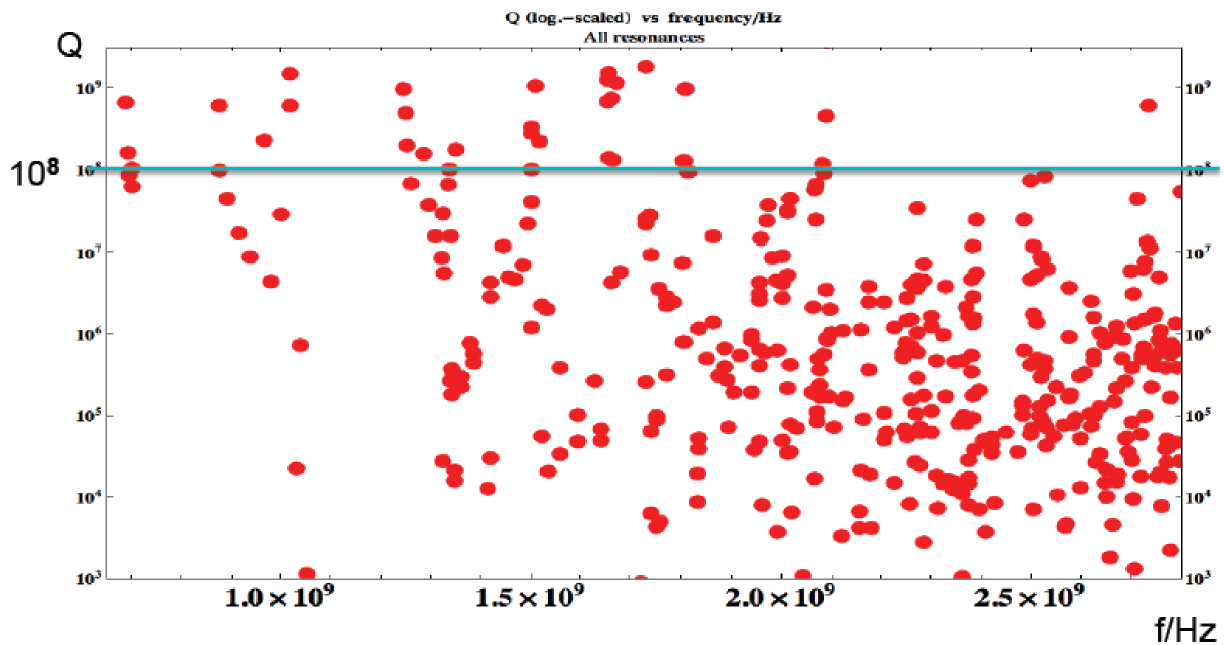
(this statement is presently under debate for a beam with charge jitter)

HOM issues 5/6
is sufficient damping by coaxial antenna possible?

Hans-Walter Glock/Uni Rostock

H.-W. Glock; : K. Rothemund; U. van Rienen. CSC – A System for Coupled S-Parameter Calculations, TESLA-Report 2001-25

Q-value spectrum for 0 mm antenna depth:



by far to heavy loading of fundamental mode => ...

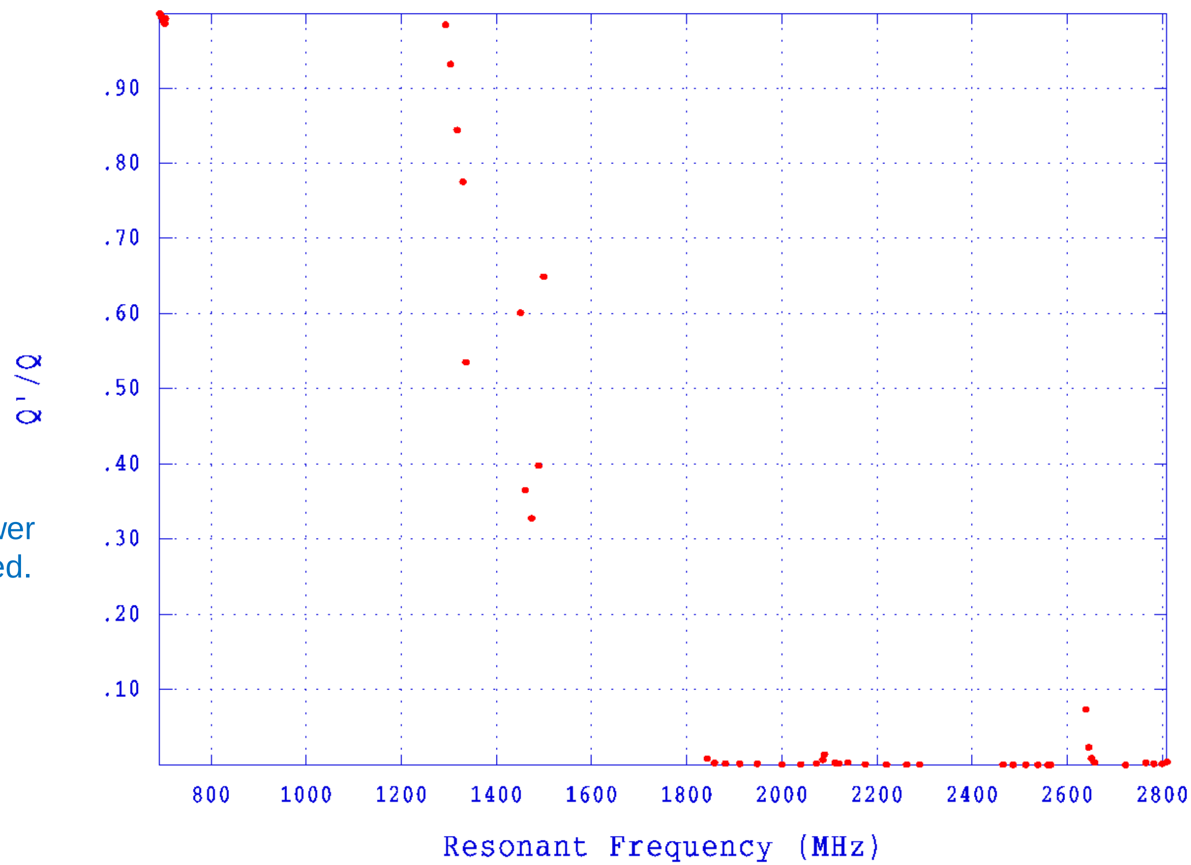
... the main message remains:

Pick-ups without fundamental mode filters will not be able both to preserve fundamental mode Q and damp all HOMs sufficiently.

Confirmed by Wolfgang Weingarten's 2D computations using beam pipe dampers.

Karol Kriska/University of Toronto
and summer student at CERN

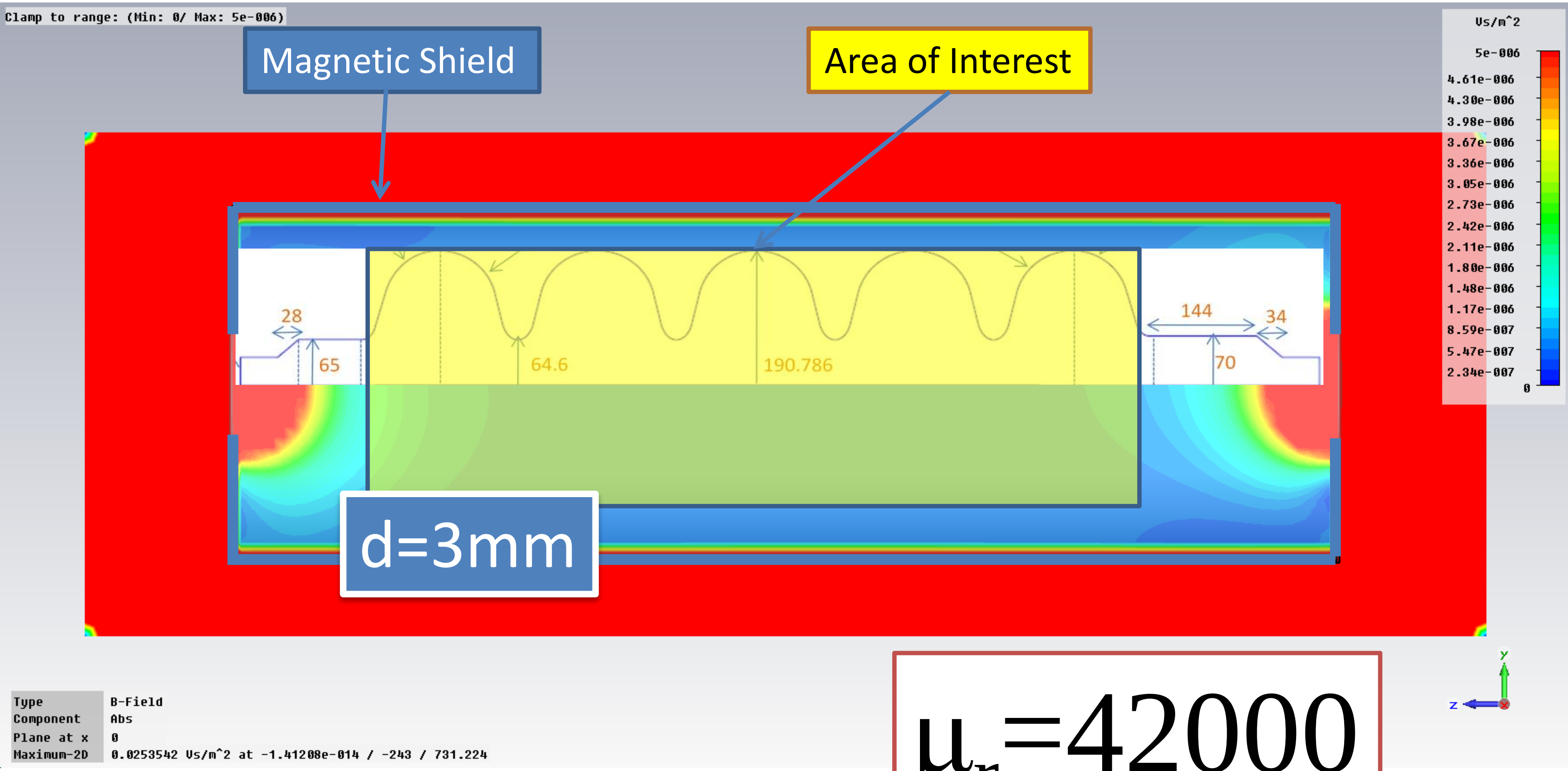
HOM issues 6/6
do stainless steel bellows provide sufficient damping?



Damping action of power coupler not yet included.

Ratio of Q-values between making the bellows superconducting and made out of stainless steel.

Magnetic shielding 1/2



$\mu_r = 42000$

Tobias.Junginger@quasar-group.org

Magnetic shielding 2/2 conclusions

- μ_r = 42.000 needed for the whole temperature range for 3 mm sheet
- End caps are necessary
- A gap of a few millimeters between end caps and cylinder can be tolerated
- Holes lead to higher field values than 1µT in spots of approximately their size

My recommendations:

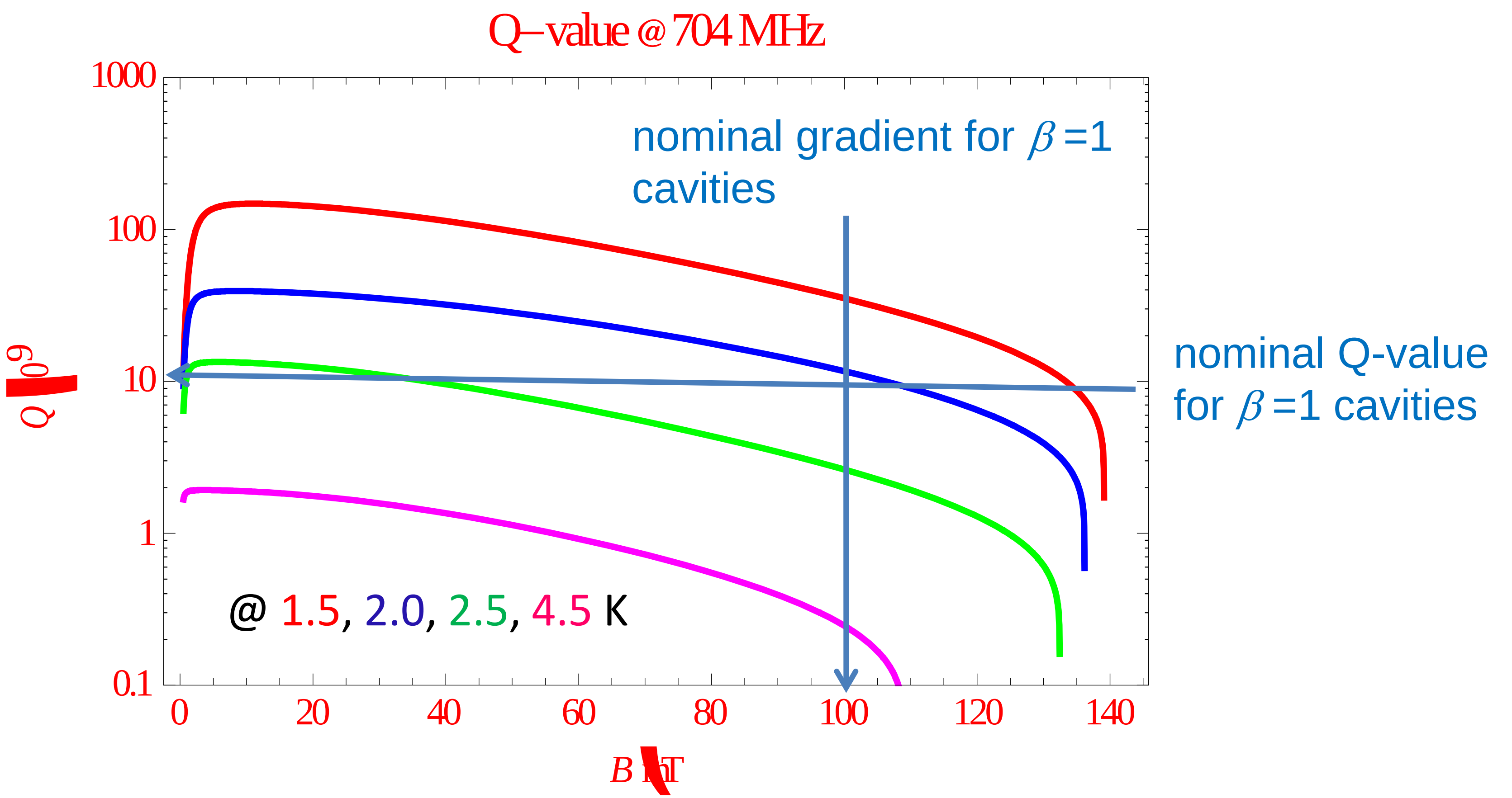
- External Shield of Cryoperm (3 mm)
- As close as possible to the helium tank
- Annealing of tubes and end caps

Tobias.Junginger@quasar-group.org

Update Parameter list 1/2
what Q-value may we expect?

Plot was obtained by a fit from “world” data @ 600 MHz < f < 800 MHz

Based on paper: http://accelconf.web.cern.ch/AccelConf/srf2009/papers/tuppo052.pdf



Update Parameter list 2/2

https://twiki.cern.ch/twiki/bin/view/SPL/SPLparameterList

Cryo design parameters (assuming 40 mA/0.4 ms beam pulse as nominal, 20 mA/0.8 ms beam pulse as ultimate)

Parameter	Unit	low-beta	high-beta
		nominal/ultimate	
Cavity bath temperature	[K]	2.0	2.0
Beam loss	[W/m]	1.0	1.0
Static loss along cryo-modules at 2 K	[W/m]	?	?
Static loss at 5-280 K	[W/m]	?	?
Accelerating gradient	[MV/m]	19.3	25
Quality factor Q	[10^9]	6/3	10/5
R/Q value	[Ω]	290	570
Cryogenic duty cycle	[%]	4.09/8.17	4.11/8.22
Coupler loss at 2.0 K	[W]	<0.2/0.2	<0.2/0.2
HOM loss at 2.0 K in cavity	[W]	<1/<3	<1/<3
HOM coupler loss at 2.0 K (per coupler)	[W]	<0.2 /0.2	<0.2/0.2
HOM & Coupler loss 5-280 K	[g/s]	0.05	0.05
Tunnel slope	[%]	1.7%	1.7%
Magnet operating temperature	[K]	ambient	ambient
No. of cavities		60	200
No. of cryostats		20	25
Cavities per cryostat		3	4/8
Dynamic heat load p. cavity	[W]	4.2/13.4	5.1/16.2

Updated values in red

EP status at CERN 1/3
pipework and acid tank

Leonel Marques Antunes Ferreira
Sergio Calatroni/CERN-TE-VSC

Ready to be installed in the safety cabinet foreseen for the treatment

EP status at CERN 2/3
walk-in booth

Leonel Marques Antunes Ferreira
Sergio Calatroni/CERN-TE-VSC

Separated environment with dedicated air washer for safety

All cabling and services connections have been performed

EP status at CERN 3/3 tentative planning

Leonel Marques Antunes Ferreira
Sergio Calatroni/CERN-TE-VSC

- Setup completed by mid-2010 (major hardware, excluding EP cathode)
- Simulation work of EP process is ongoing (with the Elsyca[1] software)
- A cathode suitable for EP of $\beta = 1$ cavities should be designed and manufactured by end-2010

[1]Simulation software for calculation and optimisation of potential, current density, deposit thickness distributions in electrochemical reactors

Concluding remarks 1/2

- The reference **mechanical design** of cavity + He-tank + magn. shielding tank is mainly based on the Saclay work
  - some minor features of the He tank and related integration issues for the tuner and power coupler still to be finalized [1] as well as the integration of the magn. shielding;
  - the Nb sheets specification is defined (call for tender in preparation)
- The **power coupler** will be a coaxial 50 Ω line of single window type and a double wall gHe cooled outer conductor and air-cooled inner conductor;
  - distance of flange to beam axis to be defined[1]
- **Beam breakup studies** stipulate the HOMs to be damped to an equivalent $Q < 10^5$

[1] preparatory meeting foreseen on Thursday 1st July, 16h00, meeting room SAM-ASK lower floor of Grand Hotel

Concluding remarks 2/2

- Pros and cons of alternate designs of the end group with regard to the deposited **HOM power** were discussed; no follow up possible (by now) due to time constraints
  - At the recommended $Q = 10^5$, the beam deposited power into the HOMs can achieve ~ 1 kW
  - Cures to reduce the beam deposited power consist in
    - avoiding the beam Fourier components by at least 10 kHz with a Q-value $Q > 10^7$ or
    - damping the HOMs to below $Q = 10^4$
  - The previous idea (HOM workshop) of damping the HOMs by a normal conducting (nc) beam tubes and additional coaxial antennas (without filter) does not survive;

    however, damping by nc beam tubes turns out to be efficient above 1800 MHz (the damping action of the power coupler not yet included!)
  - **Hence if we want to damp the HOMs equivalently to a Q-value of 10^5 or even more, we should envisage notch filter type HOM couplers**
- A reference design of the **magnetic shielding** exists
- The **cavity** and **cryogenic parameter** list was updated
- The build-up of the CERN **EP installation** is progressing