Q studies for the higher power 1.5 GHz couplers for BESSY VSR

Emmy Sharples
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Outline

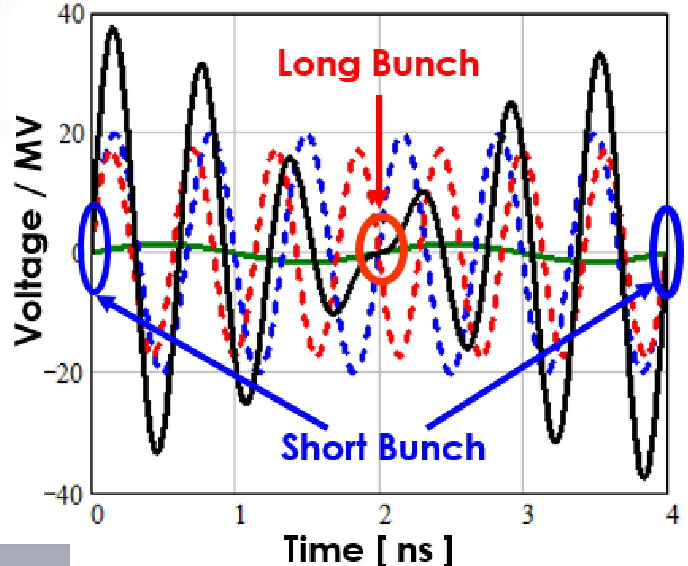
- BESSY VSR coupler a brief intro
  - VSR requirements
  - Finalised coupler design
- Q studies
  - Q range limits
  - Determining the optimal Q range for stable operation
- Tolerance studies
  - Module stresses and the coupler port
  - Displacement studies
- Outlook

BESSY VSR Requirements

BESSY VSR
Variable pulse length **S**torage **R**ing

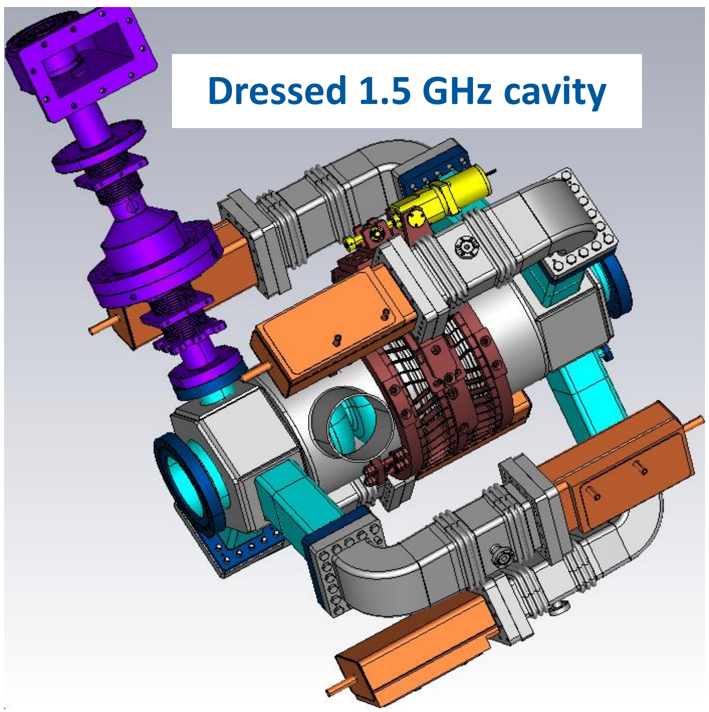
→ Upgrading the existing ring with SRF 1.5 GHz and 1.75 GHz SRF cavities

→ RF beating allows for simultaneously long and short bunches



Initial parameters as laid out in the TDS for BESSY VSR VSR

Parameter	Value
Central Freq (f_c)	1.498 GHz
Power level	16 kW CW
Q_{ext} range	$6x10^6$ to $6x10^7$
Q_{loaded}	$5x10^7$
S_{11} @f_c	≤-30 dB
S_{11} @f_c ± 5MHz	≤-20 dB



Dressed 1.5 GHz cavity

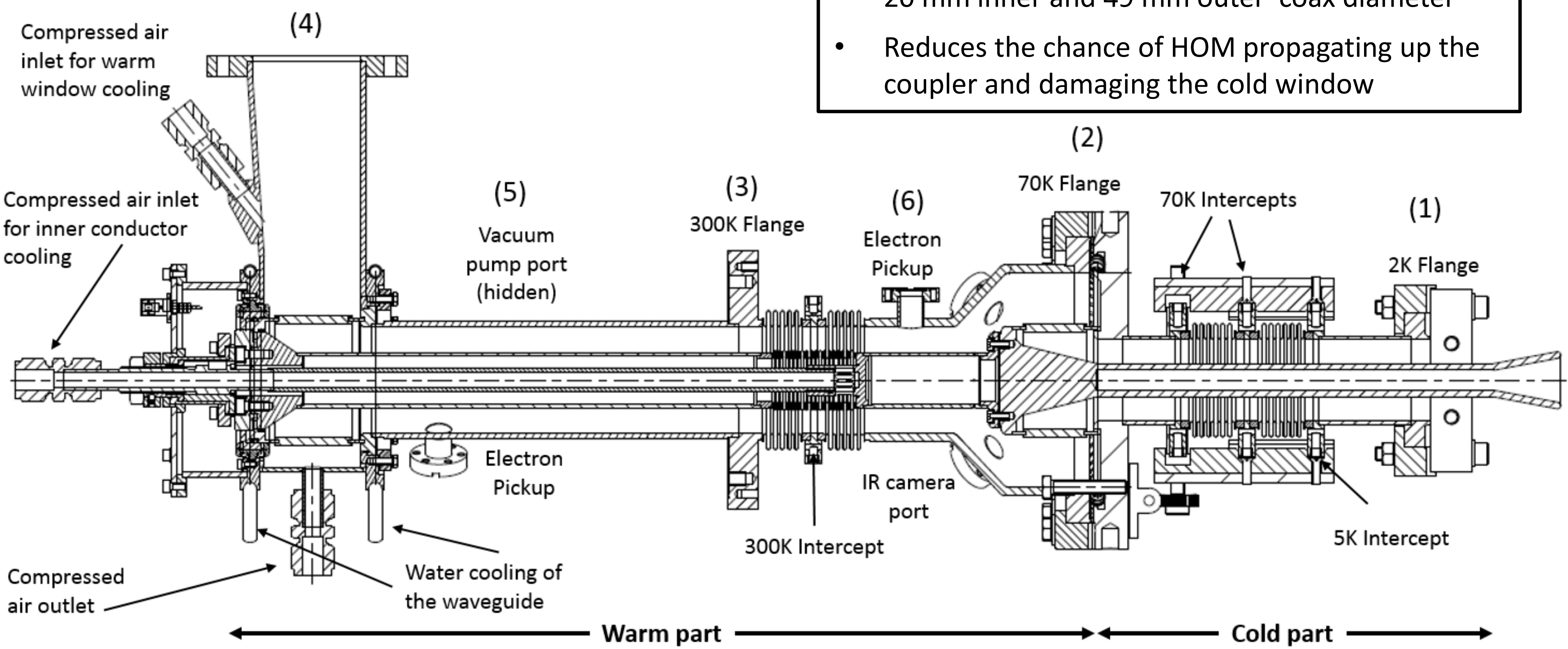
Fundamental coupler design

Adjustable coaxial coupler based on Cornell cERL injector coupler: Lower coupling level and lower power but higher frequency

Unique challenges of VSR

- Complex cavity design → Higher order mode propagation
- High power, high fields, small scale → heating issues
- Smaller scales → Mechanical challenges
- Module integration → dimensional constraints
- High gradients and SRF → Field emission + multipacting must be avoided

Final design



Small cold coax dimensions

- 20 mm inner and 49 mm outer coax diameter
- Reduces the chance of HOM propagating up the coupler and damaging the cold window

DC Bias system

- Kapton foil capacitor located around the waveguide to coax transition.
- Reduce the chance of multipacting

Warm coax dimensions

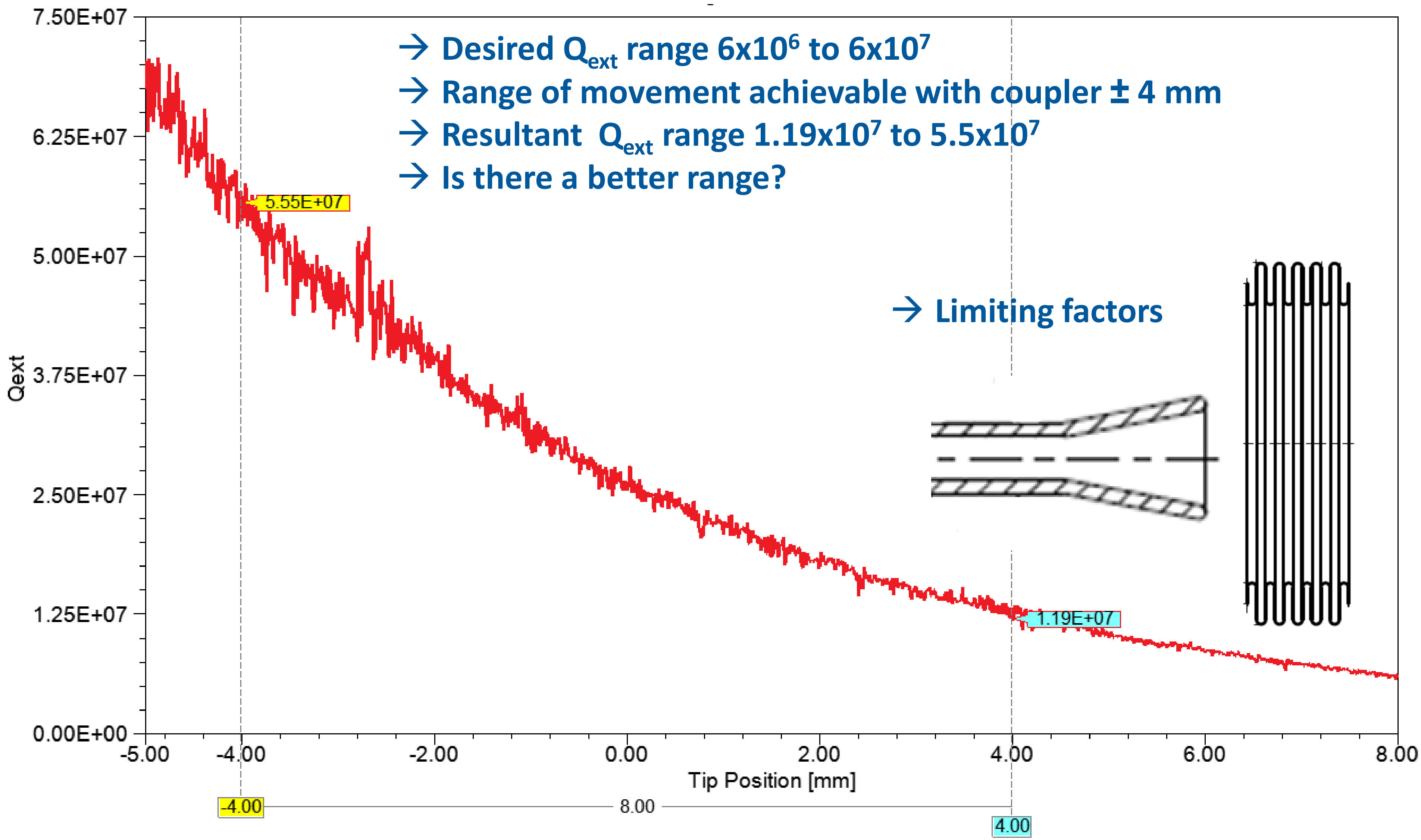
- 33mm inner and 64 mm outer coax diameter
- Increased diameter to allow for better cooling of the inner conductor.

Tip design

- Simple conical shape to fit with the required coupling
- Hollow to reduce the weight and the stress on the cold window.
- Open to allow for cleaning

Q limitations

- → Desired Q_{ext} range $6x10^6$ to $6x10^7$
- → Range of movement achievable with coupler ± 4 mm
- → Resultant Q_{ext} range $1.19x10^7$ to $5.5x10^7$
- → Is there a better range?
- → Limiting factors



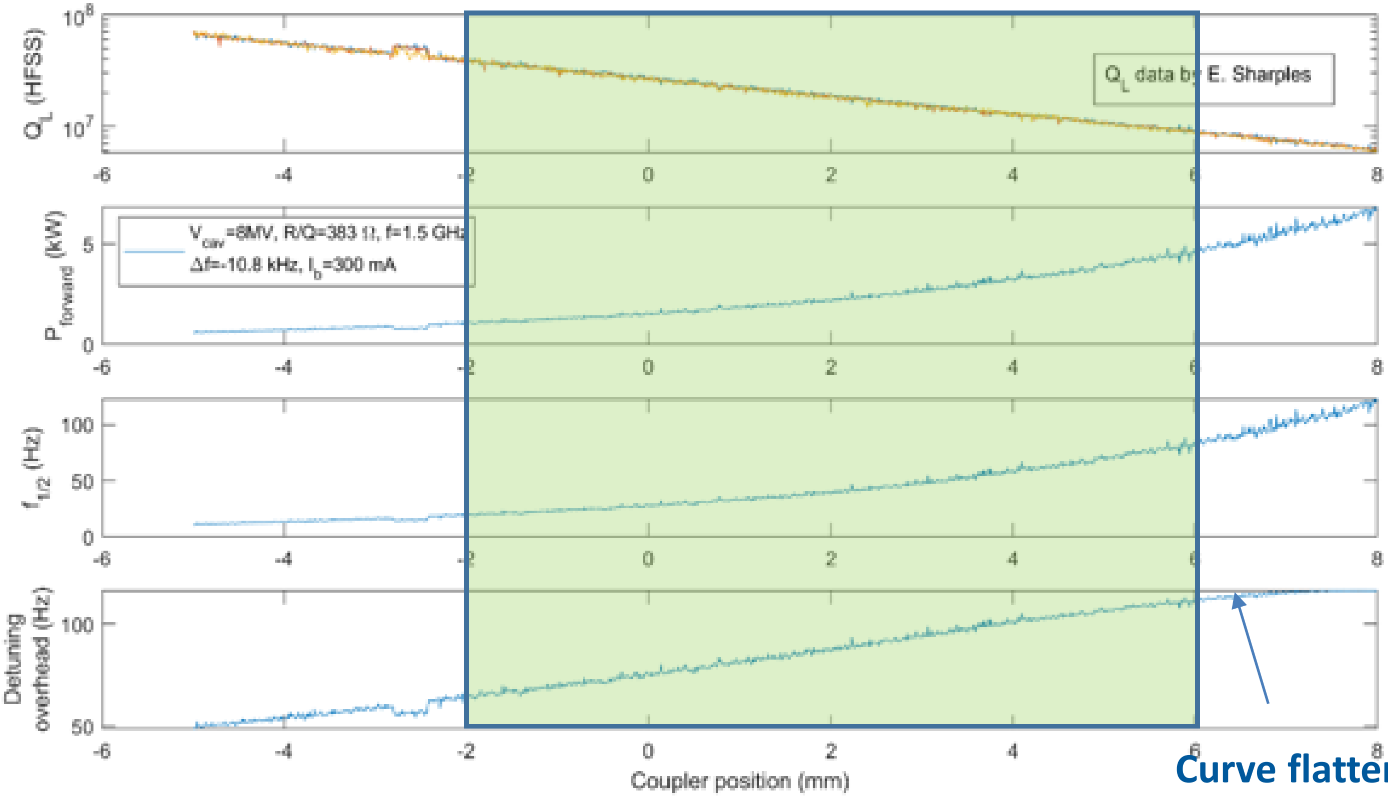
Optimal Q range

→ **Aim for Q for stable operation: Achieve as much tuning overhead as possible while maintaining acceptable average power level**

$$P_\mathrm{f} \approx \frac{V_\mathrm{cav}^2}{\frac{R}{Q}Q_\mathrm{L}}\frac{1}{4}\left\{\underbrace{\left(1+\frac{\frac{R}{Q}Q_\mathrm{L}I_\mathrm{b0}}{V_\mathrm{cav}}\cos\phi_\mathrm{acc}\right)^2}_{\text{resistive}}+\underbrace{\left(\frac{\Delta f}{f_{1/2}}+\frac{\frac{R}{Q}Q_\mathrm{L}I_\mathrm{b0}}{V_\mathrm{cav}}\sin\phi_\mathrm{acc}\right)^2}_{\text{reactive}}\right\}$$

=1 Compensated by proper tuning

Parameters:
l_{acc}=4*0.1m, f=1.5 GHz
R/Q= 383 W
V_{cav}= 8 MV, i.e. E_{acc}=20 MV/m
P_{max} at coupler 13 kW



Chosen range:
-2 to +6 mm of original coupler range:
$3.9\cdot10^7 \le Q_L \le 9.1\cdot10^6$
→ 250 ≤b_c ≤1100

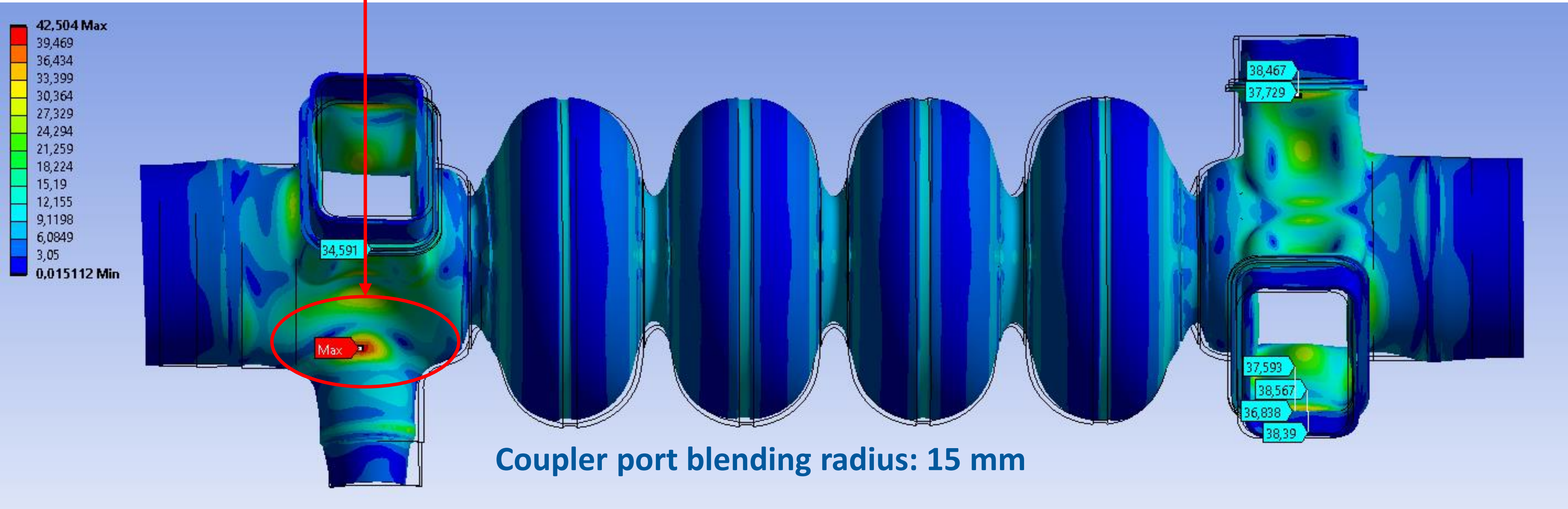
Curve flattens here

Courtesy of A. Neumann

Mitigation of mechanical stress

When cavity @ max pressure peak stress @ coupler port is 42 MPa
Stress > yield strength of Nb → deformation

Stress limits for the warm cavity			
Pressure	**Operation**	**Yield strength – Nb 38 MPa after baking**	**Safety factor**
1.5 bara	Warmup/ cool down	22 MPa	1.7
3.5 bara (max)	Safety valve	38 MPa	1.0



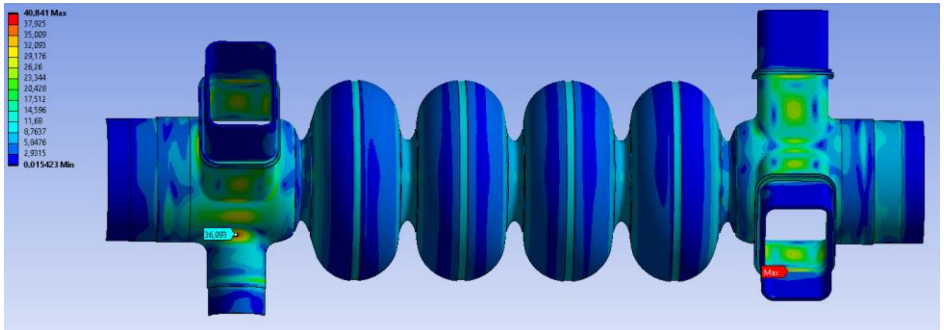
Coupler port blending radius: 15 mm

- **Increasing radius in critical region reduces the peak stress**
- **Space limitations → cannot apply a larger radius in the full region.**
- **<u>Solutions:</u> a variable radius, with a fixed R15 mm in horizontal plane (wrt installation orientation) and increased value in peak stress region.**

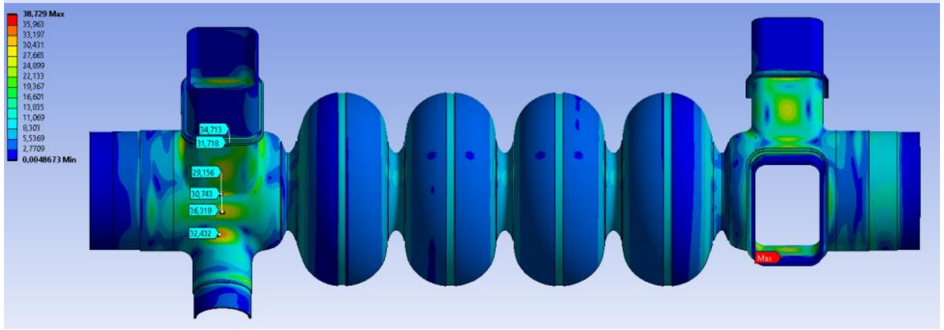
Courtesy of Nora Wunderer

Mitigation of mechanical stress

Blend rad	Stress (MPa)	Q_{ext} @ -4mm	Q_{ext} @ 4mm	Span	$Q_{ext}=3.86\times10^7$	$Q_{ext}=9.16\times10^6$	tip length change
15 mm	42	3.86×10^7	9.16×10^6	2.94×10^7	-4 mm	4 mm	0
20 mm	36	3.17×10^7	8.01×10^6	2.37×10^7	-4.2 mm	3.8 mm	-0.2 mm
25 mm	32.5	3.1×10^7	7.42×10^6	2.36×10^7	-5.2 mm	2.8 mm	-1.2 mm
30 mm	30	3.13×10^7	7.19×10^6	2.41×10^7	-5.5 mm	2.5 mm	-1.5 mm

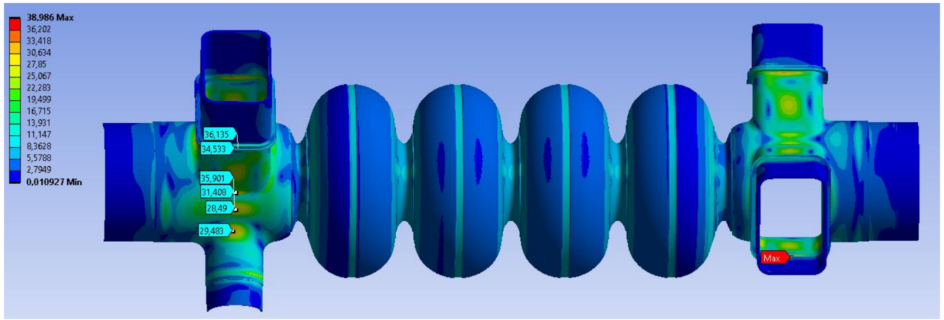


Blending radius 20 mm
Stress: 36 MPa



Blending radius 25 mm
Stress: 32.5 MPa

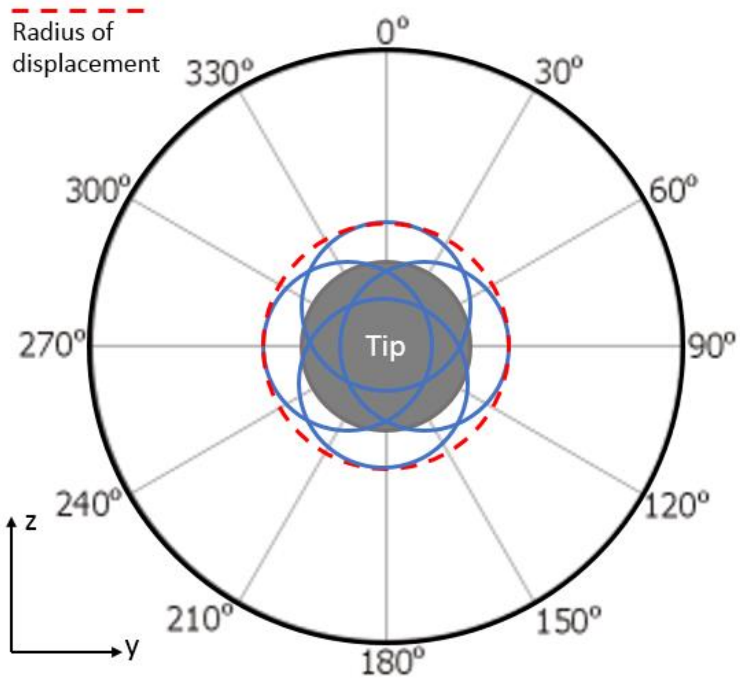
Best option: lower stress, shorter tip, good coupling range

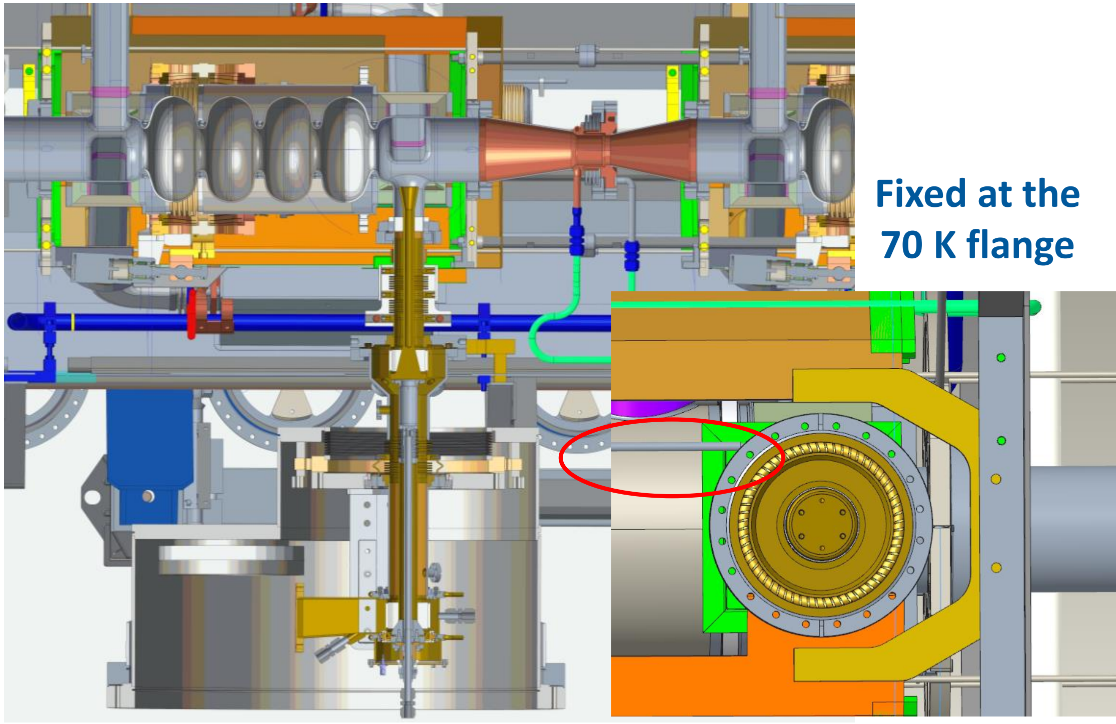


Blending radius 30 mm
Stress: 30 MPa

Courtesy of Nora Wunderer

Displacement analysis





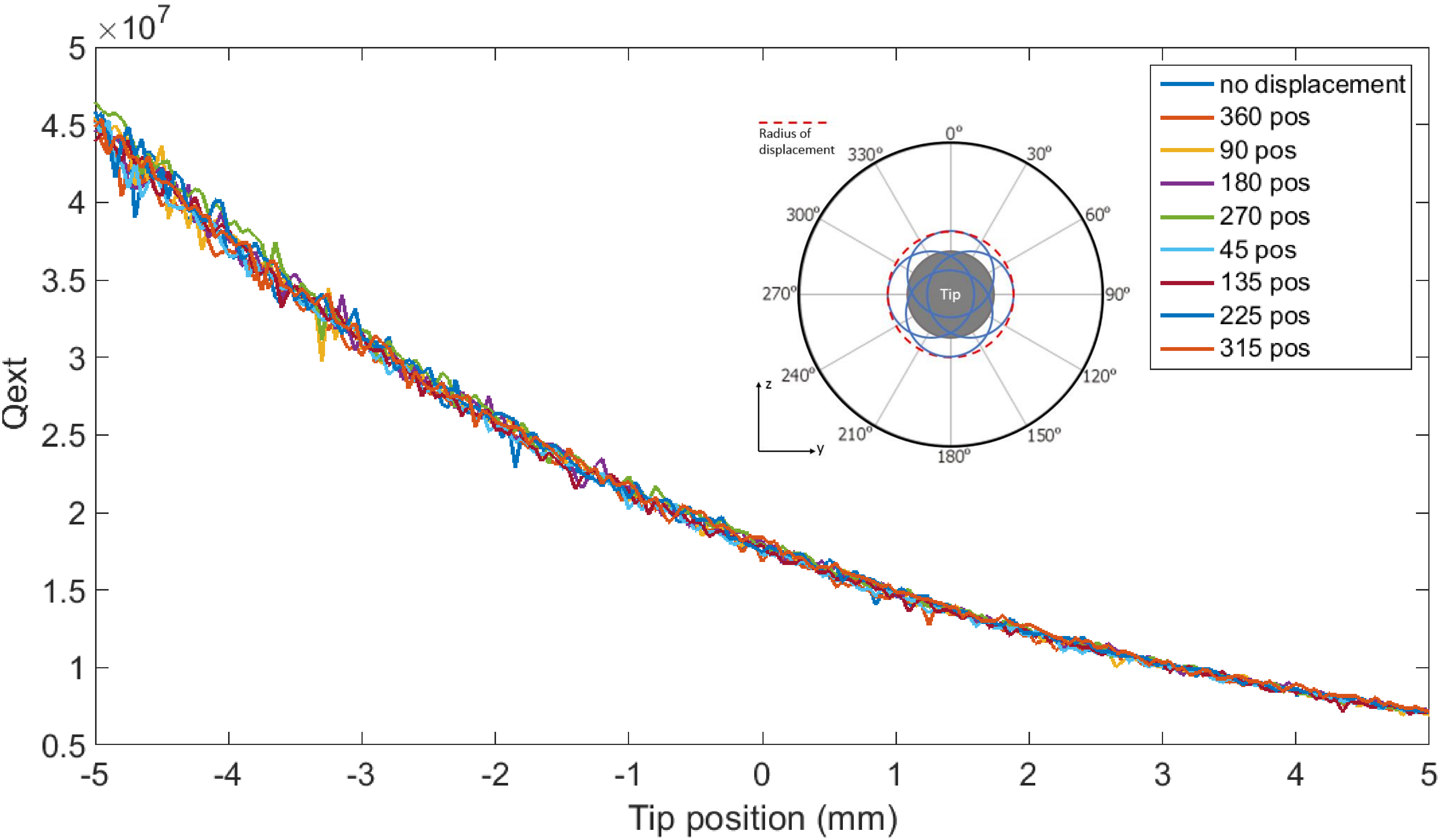
Fixed at the 70 K flange

The coupler is a fixed point within the module.
→ during cooldown, displacement of the coupler tip can be expected.

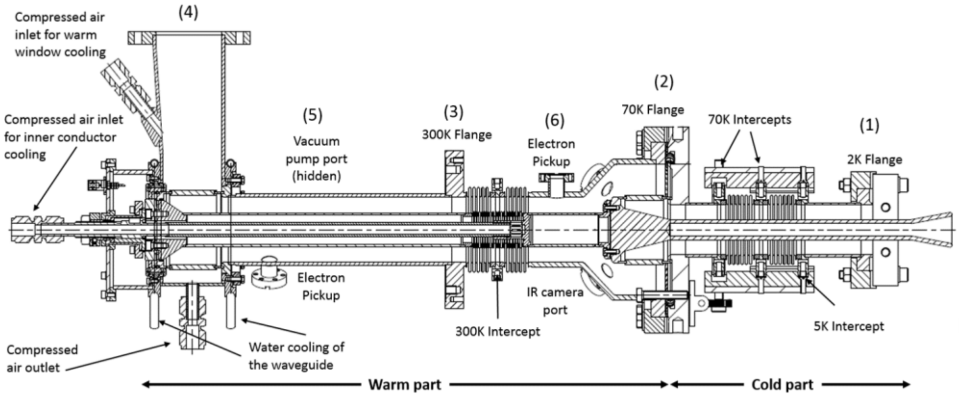
y (mm)	z (mm)	Radial °	E_{ext} @ -4 mm	E_{ext} @ 4 mm	% diff @ -4 mm	% diff @ 4 mm
0	0	-	3.66×10^7	8.26×10^6	0%	0%
0.56	0.56	45	3.79×10^7	8.61×10^6	-3.49%	-4.15%
0.8	0	90	3.75×10^7	8.61×10^6	-2.43%	-4.15 %
0.56	-0.56	135	3.82×10^7	8.36×10^6	-4.28%	-1.2%
0	-0.8	180	3.68×10^7	8.62×10^6	-0.54%	-4.27%
-0.56	-0.56	225	3.66×10^7	8.51×10^6	0%	-2.98%
-0.8	0	270	3.78×10^7	8.51×10^6	-3.23%	-2.98%
-0.56	0.56	315	3.78×10^7	8.93×10^6	-3.23%	-7.8%
0.8	0	360	3.75×10^7	8.61×10^6	-2.43%	-4.15%

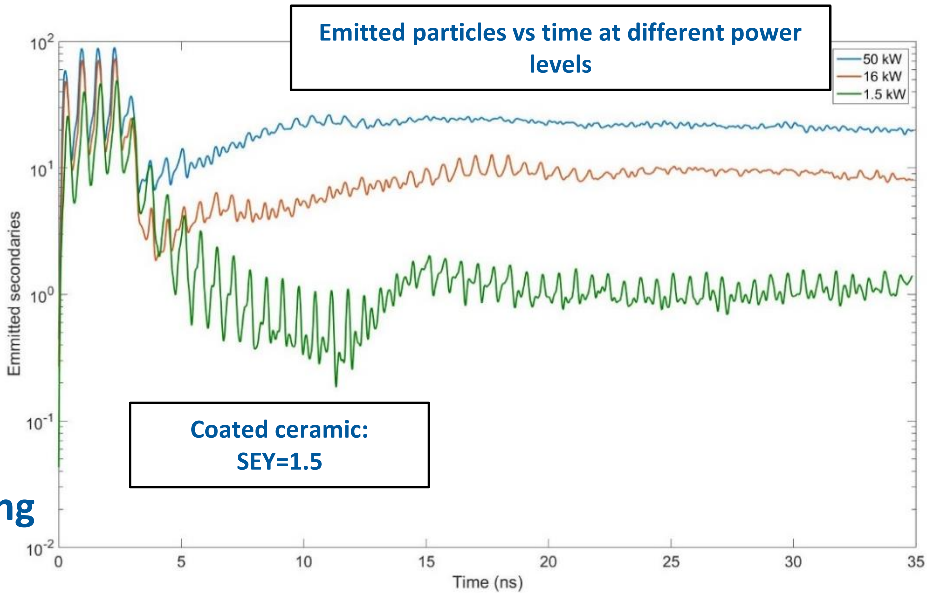
Displacement analysis

→ **Minimal change < 5% in Q for all displacements**
→ **Further studies to see how the fields are affected are required**

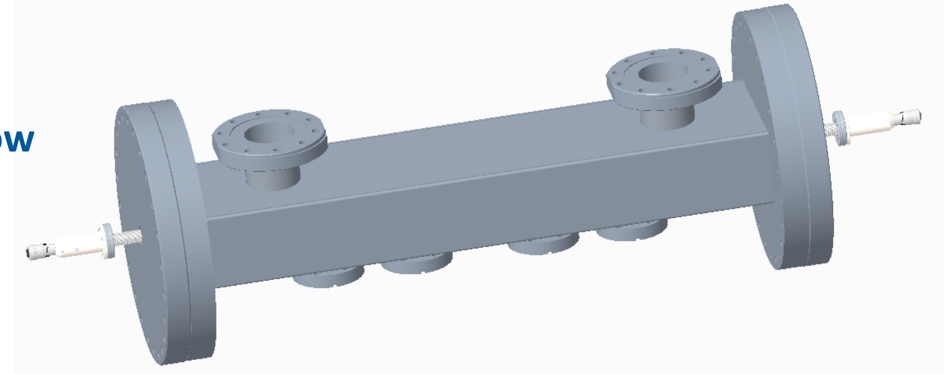


Outlook





- Design finalised
- Multipacting studies performed and no multipacting found
- Further field studies required for tolerance and blending studies
- Thermal concerns still present around warm bellow but solution being sought
- Testbox development almost complete



Current coupler status: Tender awarded, kick off meeting scheduled for the next month

Prototype Delivery: Expected November 2020

Series delivery: Expected August 2021

Thank you for your attention

Any Questions?

2nd Workshop on Operating SRF Systems Reliably in a "Dirty" Machine

November 10th - 12th, 2020
Helmholtz Institute
Mainz, Germany

https://indico.him.uni-mainz.de/event/63/

dirtySRF@uni-mainz.de

TOPICS:

- Controlling contamination of SRF cavities during accelerator operation
- Elimination of accelerator contamination
- Experience in long term operation and degradation
- Gas targets at the experimental sites: possible issues and safety measures for SRF installations

Local organizing committee:

Florian Hug
Miriam Jäger
Thorsten Kürzeder
Tanja Schwerdt
Timo Stengler

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Operating SRF in A dirty machine: Workshop 2