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HIISI, New 18 GHz ECRIS for The JYFL Accelerator Laboratory

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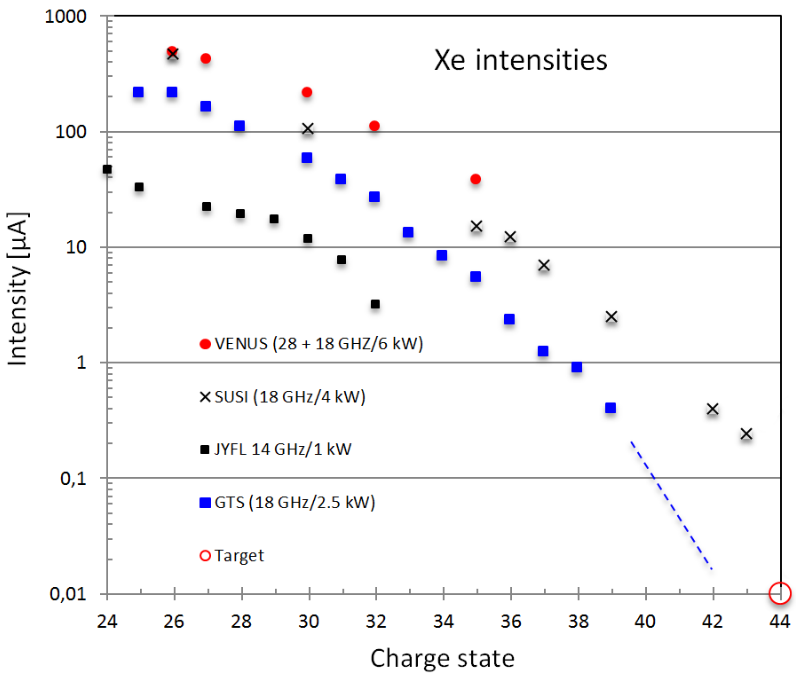
Presentation outline

- Requirements for the new ion source
- Design goals for magnetic field
- Solenoid field
- Refridgerated hexapole and plasma chamber design
- Schedule

New ECRIS for the JYFL Accelerator Laboratory

Academy of Finland granted funding for a new 18 GHz ECRIS HIISI (Heavy Ion Ion Source Injector). Source has to provide adequate ion beam intensities for the nuclear physics program and applications at the Accelerator Laboratory.



- Nuclear physics: $\times 10$ intensity at medium charge states (Ar^{8+}, Xe^{26+}, energy > 5 MeV/u)
- Radiation effects facility: Ion beam cocktail energy increased from current 9.3 MeV/u to 15 MeV/u (Xe^{44+} required)

- SUSI can meet the requirements for example
- Construction costs of fully superconducting ECRIS greatly exceeds available funding

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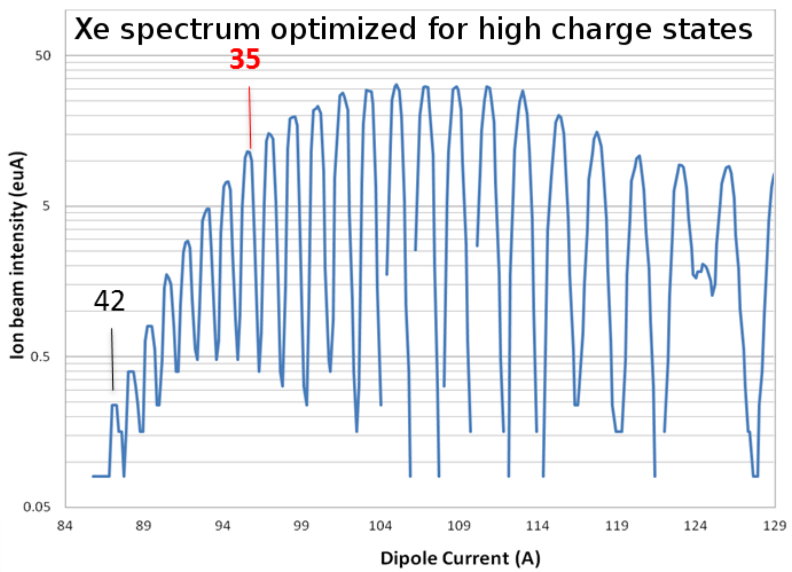
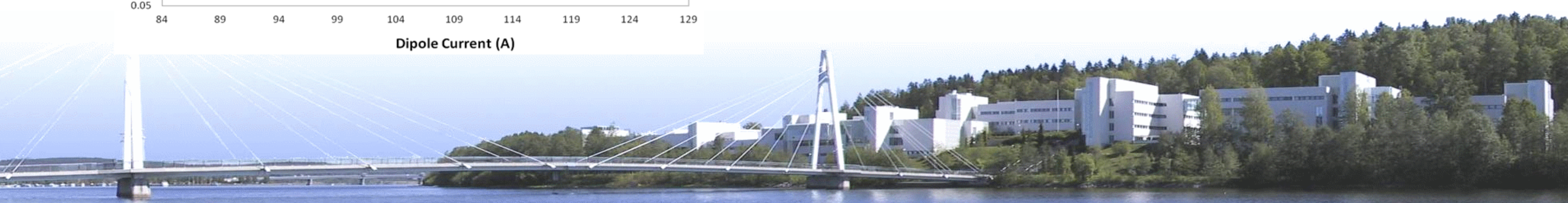
Magnetic field of SUSI at 18 GHz operation mode

Element	Charge	I (euA)	Power (kW)	Brad (T)	Binj (T)	Bmin (T)	Bext (T)	gradB Inj (T/m)	gradB Ext (T/m)	Plasma (mm)
129Xe	26	504	3.8	1.04	2.63	0.48	1.29	5.1	5.1	119
129Xe	27	385	3.9	1.08	2.68	0.51	1.29	4.7	4.9	112
129Xe	**35**	**16**	**3.2**	**1.36**	**2.82**	**0.46**	**1.56**	**6.6**	**5.9**	**115**
40Ar	11	780	3.6	1.06	2.52	0.42	1.21	6.8	5.7	144
40Ar	12	730	3.8	1.06	2.55	0.43	1.19	6.8	5.6	142
40Ar	**14**	**308**	**3.9**	**1.23**	**2.69**	**0.48**	**1.37**	**5.9**	**5.1**	**118**
209Bi	30	306	3.9	1.36	2.84	0.52	1.52	5.4	5.0	100
84Kr	18	380	2.7	1.18	2.56	0.47	1.27	5.4	5.1	126



Xe^{44+} achievable at needed intensities

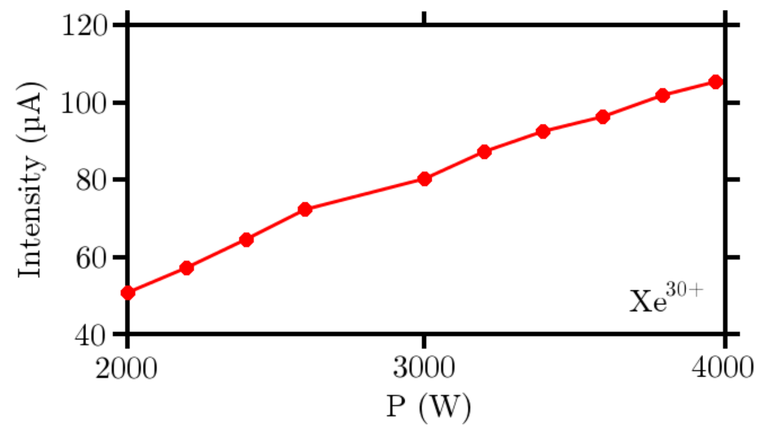


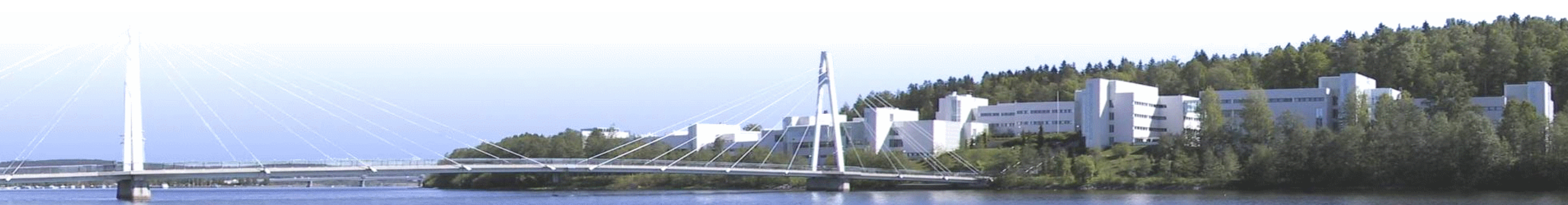
Design goals

Design idea: trying to reach SUSI magnetic field parameters with normally conducting solenoid and permanent magnet technology.

Also:

- Microwave power of 4 kW or higher (no saturation seen)
- Resonance length of 115–145 mm
- Plasma chamber diameter of 100 mm





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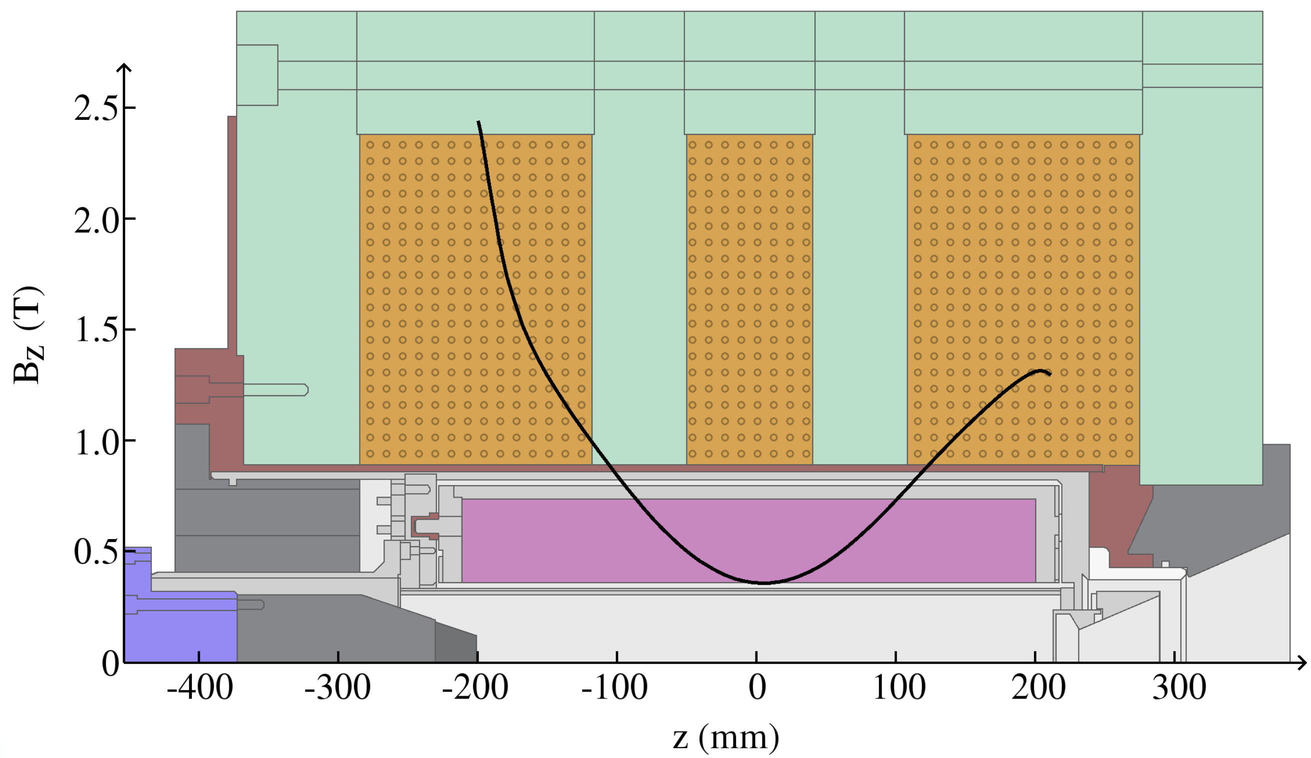
Solenoid field design

- Injection and extraction coils: 7 double wound, double pancakes (20 turns)
- Middle coil: 3 double wound, double pancakes (20 turns)
- Power consumption 120–220 kW at 18 GHz mode, 100 kW at 14 GHz



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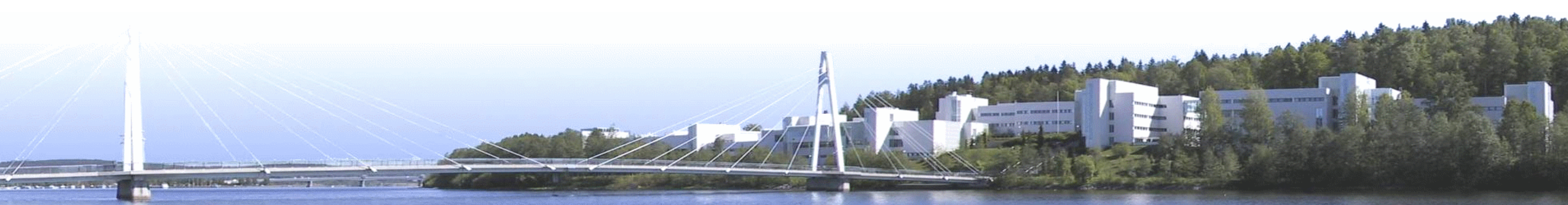
Solenoid field design

Total P (kW)	Iinj / Pinj (A / kW)	Iext / Pext (A / kW)	Imid / Pmid (A / kW)	Binj (T)	Bext (T)	Bmin (T)	gradB Inj (T/m)	gradB Ext (T/m)	Plasma (mm)
HIISI:									
216	1050 / 101	1050 / 101	600 / 14	2.51	1.52	0.43 (66 %)	6.3	6.3	132
158	1000 / 92	820 / 62	300 / 3.6	2.47	1.33	0.42 (65 %)	6.1	6.1	143
137	1000 / 92	680 / 43	210 / 1.8	2.48	1.18	0.41 (64 %)	6.2	5.5	157
139	900 / 75	820 / 62	250 / 2.5	2.36	1.33	0.40 (62 %)	6.2	5.8	151
120	800 / 59	820 / 62	125 / 0.6	2.22	1.34	0.40 (62 %)	5.6	6.2	154
SUSI:									
Xe35+				2.82	1.56	0.46	6.6	5.9	115
Ar12+				2.55	1.19	0.43	6.8	5.6	142

Solenoid field configuration of SUSI can be met as well as possible.

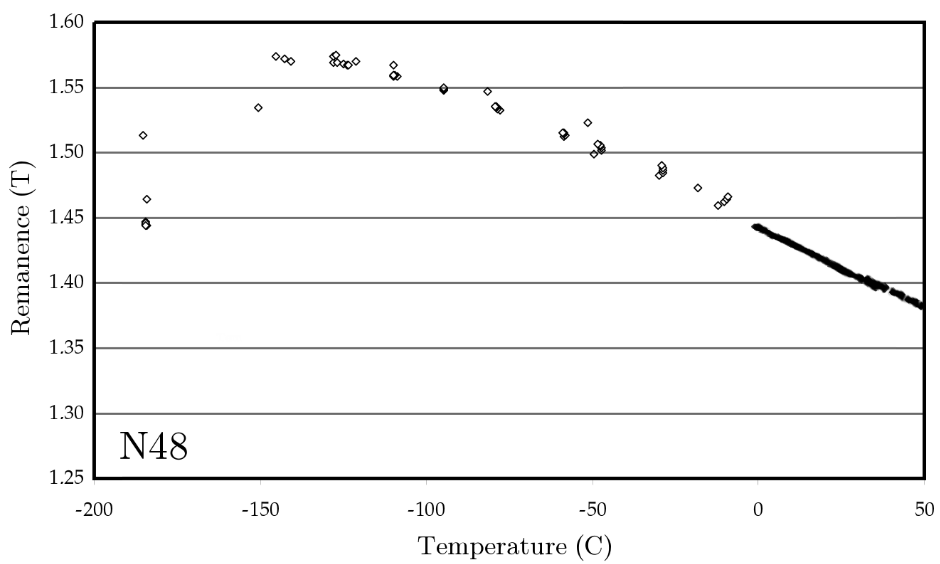


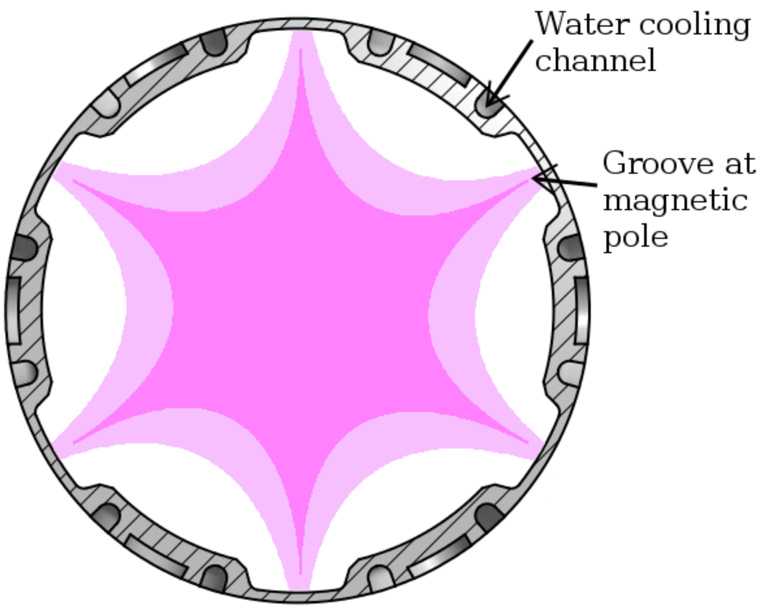
Hexapole field

It is difficult to reach required 1.36 T radial field using permanent magnets.

Methods to boost the field:

1. Minimize distance between magnet and plasma at the pole
2. Cool the magnets (5 % in B_r going from 20°C to -10°C)



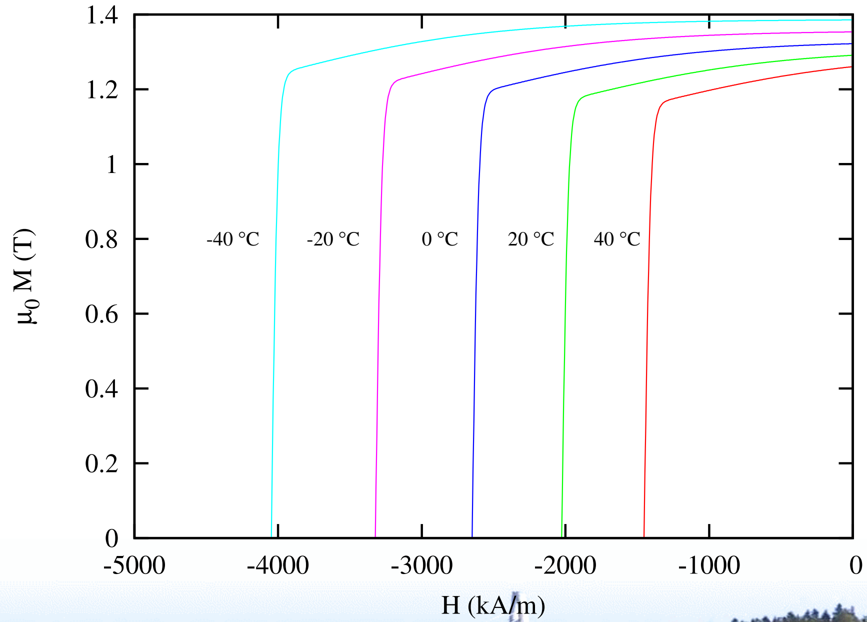


Hexapole field

Permanent magnet grade N40UH was chosen for the first hexapole

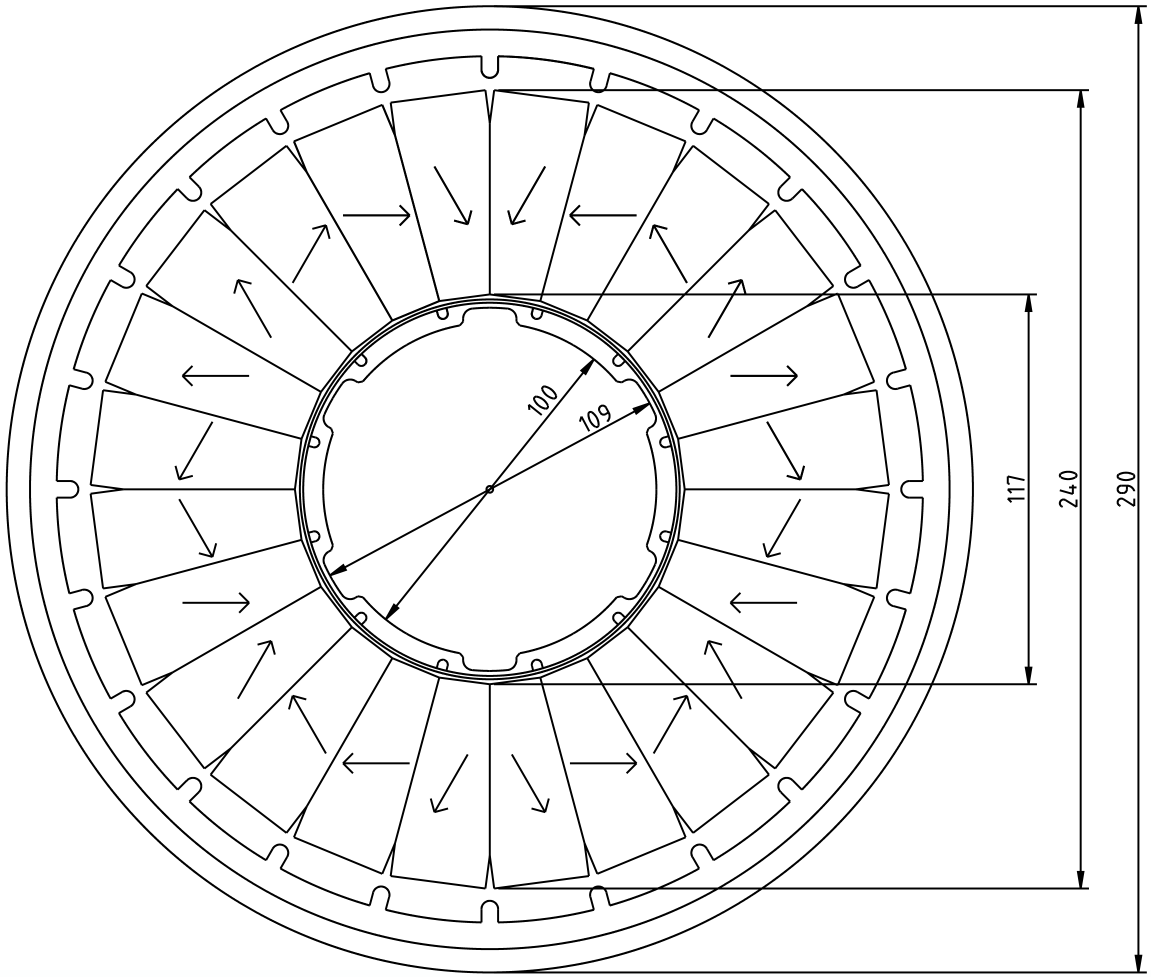
N40UH	$\mathbf{B_r = 1.29\ T}$	$\mathbf{H_c = 1990\ kA/m}$
N42SH	$B_r = 1.32$ T	$H_c = 1600$ kA/m
N48H	$B_r = 1.42$ T	$H_c = 1350$ kA/m

H-field analysis shows magnets are exposed to 1800 kA/m, ok at 20°C

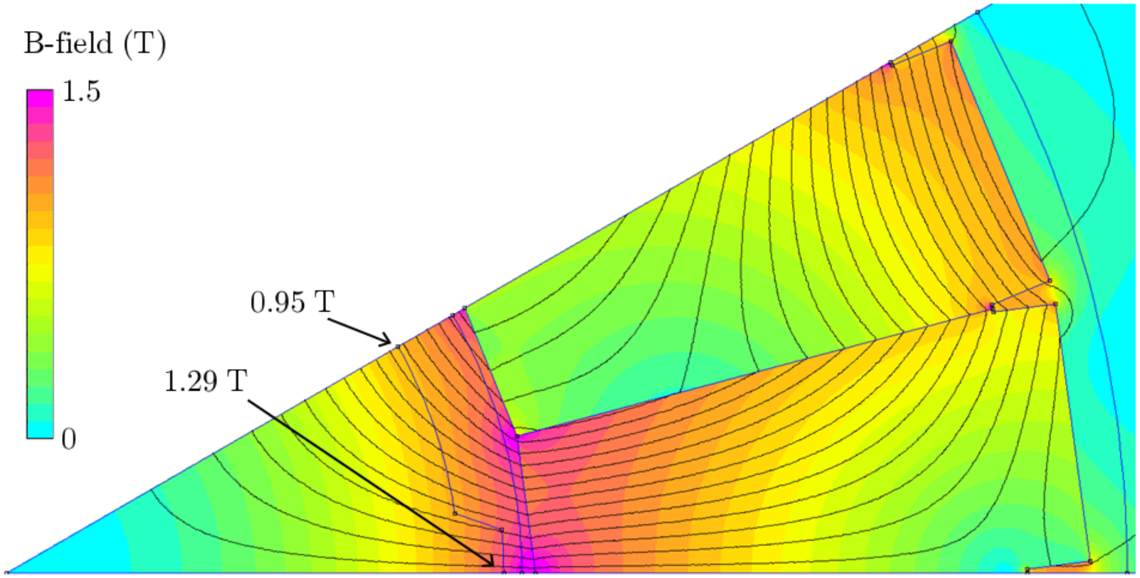


Hexapole design

24-segment offset Halbach



Hexapole magnetic field



Distance (mm)	Description	B 20°C (T)	B -10°C (T)	B using N48H -10°C / -30°C (T)
3	1 mm gap + 2 mm wall	1.29	1.33	1.46 / 1.49
3.5	1.5 mm gap + 2 mm wall	1.27	1.30	1.44 / 1.47
4	**1.5 mm gap + 2.5 mm wall**	**1.24**	**1.28**	**1.41 / 1.44**
4.5	1.5 mm gap + 3 mm wall	1.22	1.26	1.38 / 1.41
5	1.5 mm gap + 3.5 mm wall	1.20	1.23	1.36 / 1.38

36-segment Halbach for further improvement?

Roadmap for hexapole development

Hexapole #1 — N40UH

- Being designed, will not reach 1.36 T
- Will be used to develop and verify techniques needed for refridgeration
- Works with high confidence even at 20°C
- Provides a backup for hexapole #2

Hexapole #2 — N48H?

- Future development
- Aims to $B_{\text{pole}} > 1.36$ T
- Dependent on reliable refridgeration system

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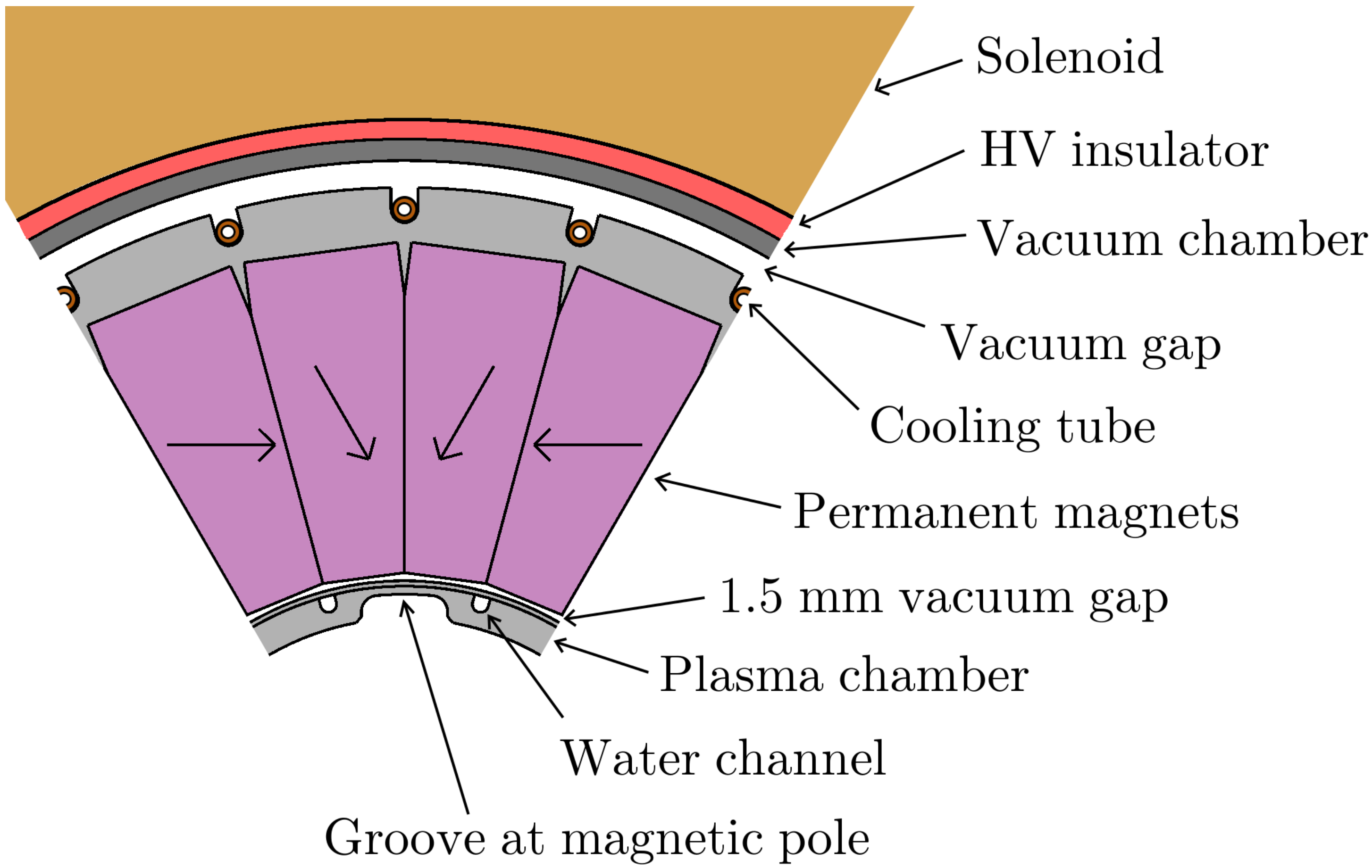
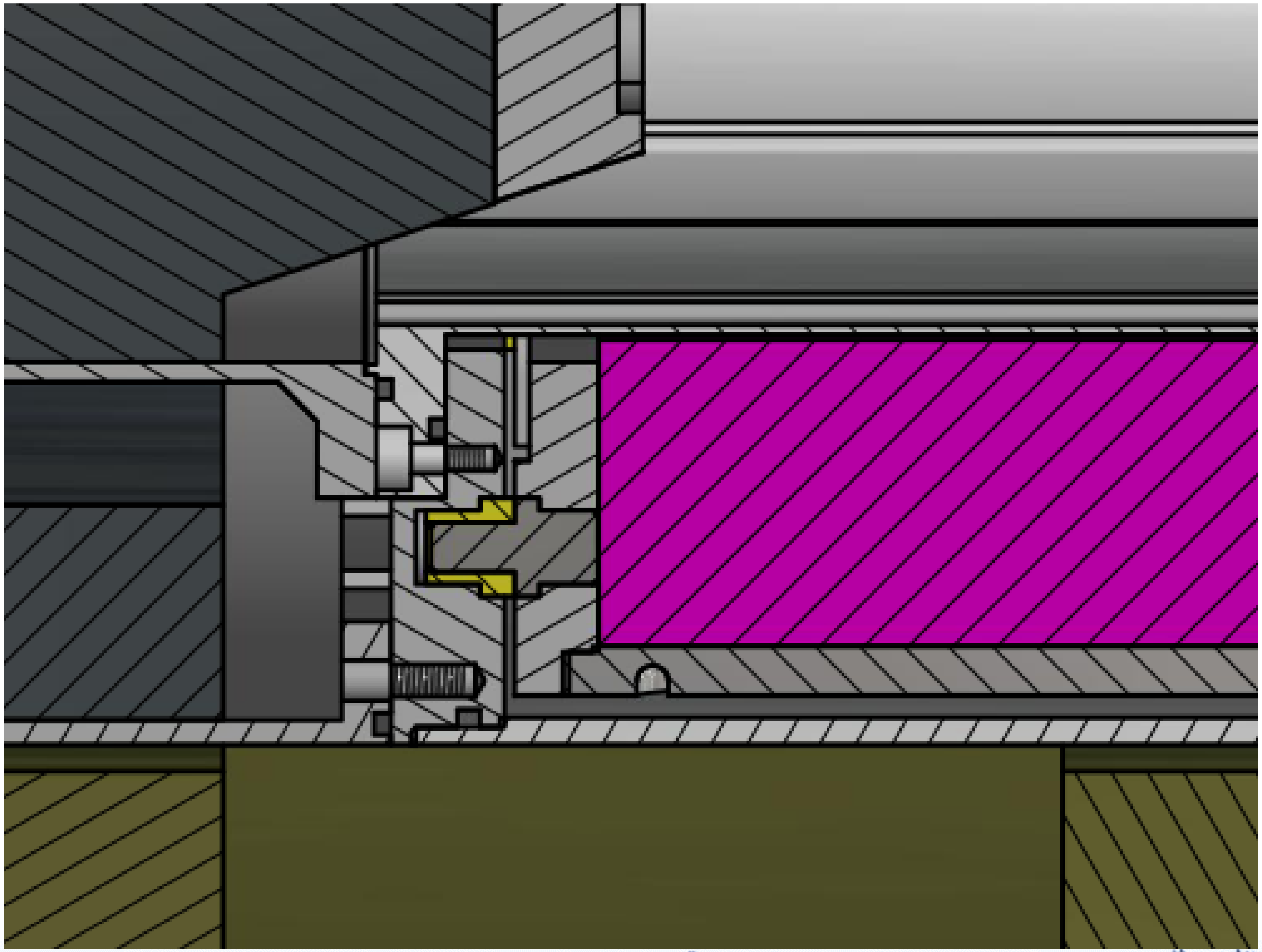
Cross section



Hexapole supports

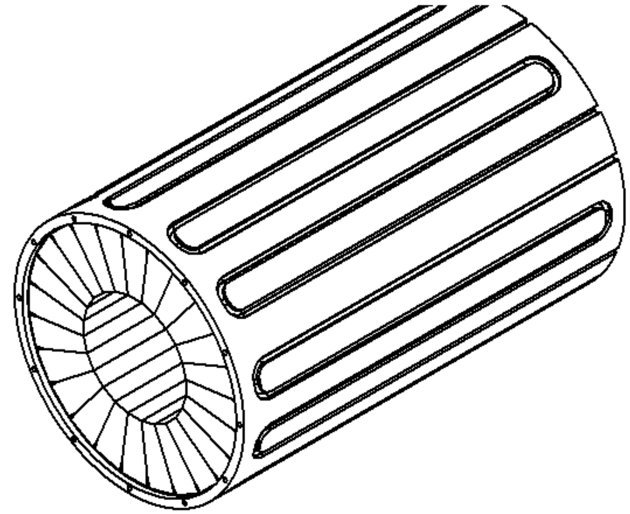
Only 12 PEEK-insulated rods are holding hexapole in place

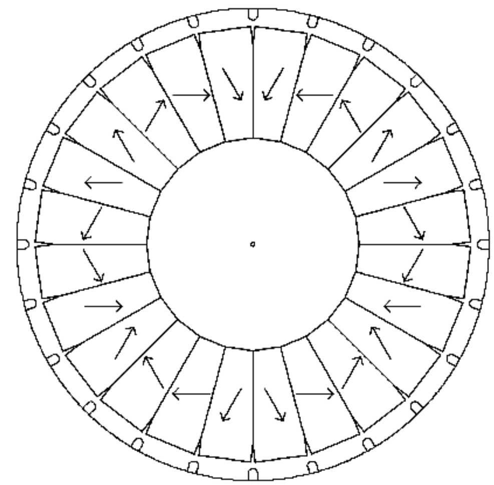


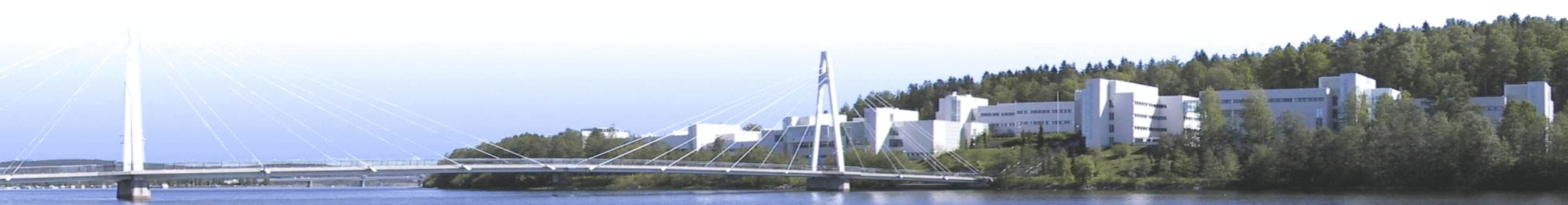
Challenges with cooling

- Thermal contact between sleeve and magnets
  $\rightarrow$ thermally conducting paste
- Heat expansion:
  - NdFeB: $\alpha_{\|} = 6 \cdot 10^{-6}$/K,
  - NdFeB: $\alpha_{\perp} = -2 \cdot 10^{-6}$/K
  - Aluminium: $\alpha = 23 \cdot 10^{-6}$/K
- Simple model $\rightarrow$ ok down to $-20°$C
- In reality?
- Thermal cycling is a risk

Development needed!







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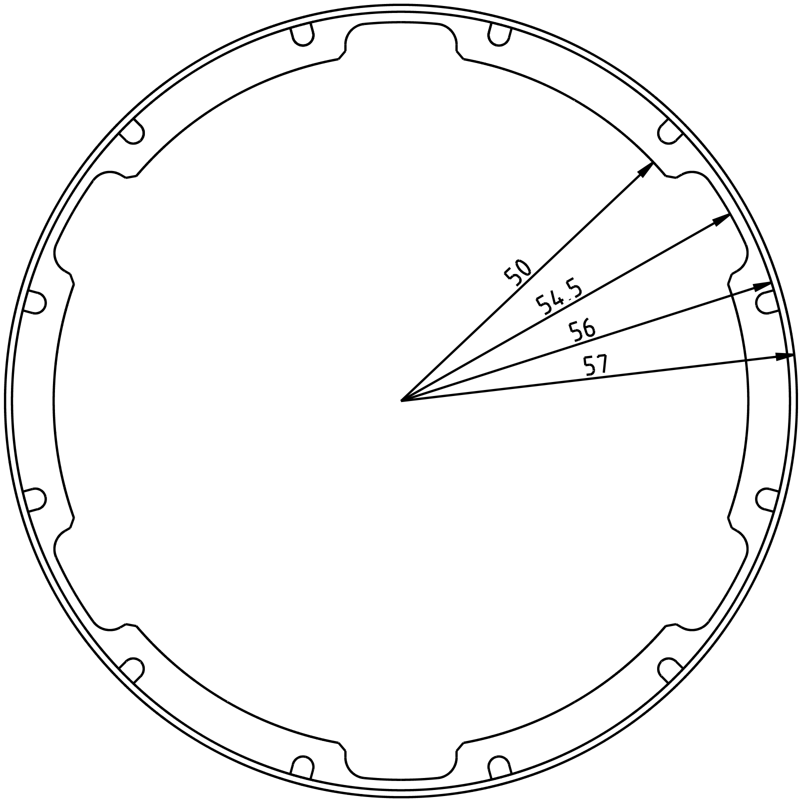
Plasma chamber

Mechanical structure

- Plasma chamber is constructed from two concentric aluminium cylinders shrink fitted together
- Cooling channels and pole grooves are machined to the inner one
- Ends are welded together



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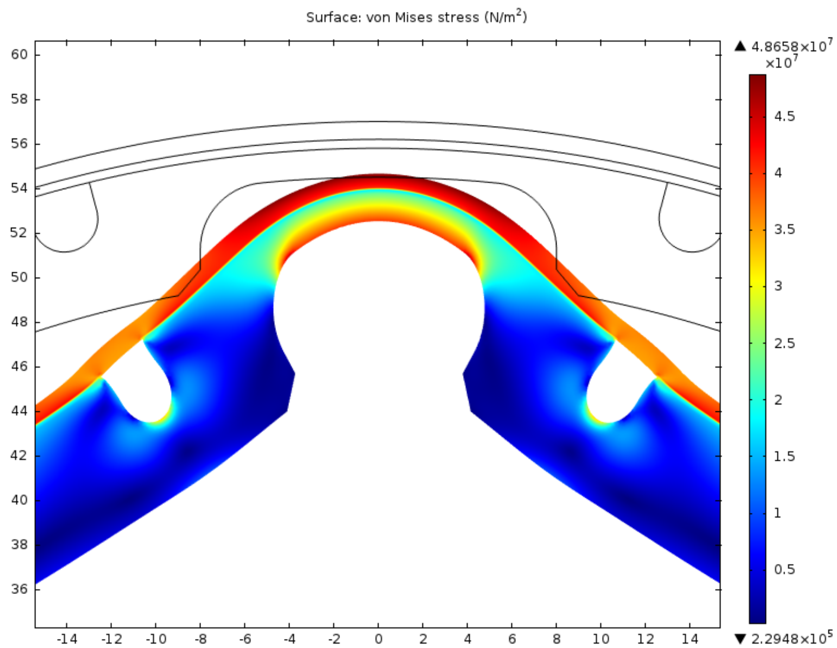
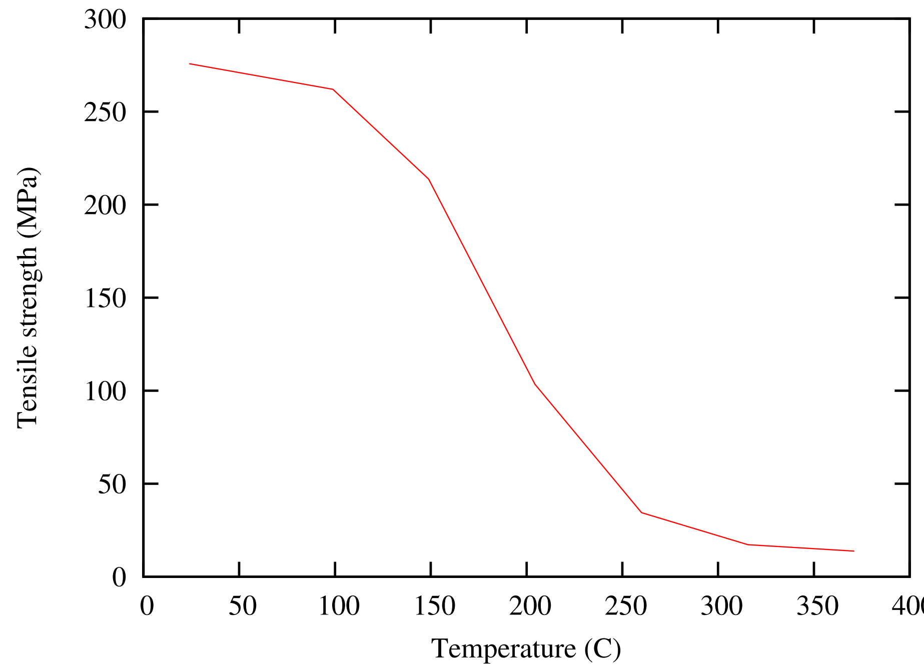
Structure stresses

Shrink fit by 0.06 mm overlap in diameter causes 50 MPa stresses





At 400 K (130°C) there is still plenty of safety margin

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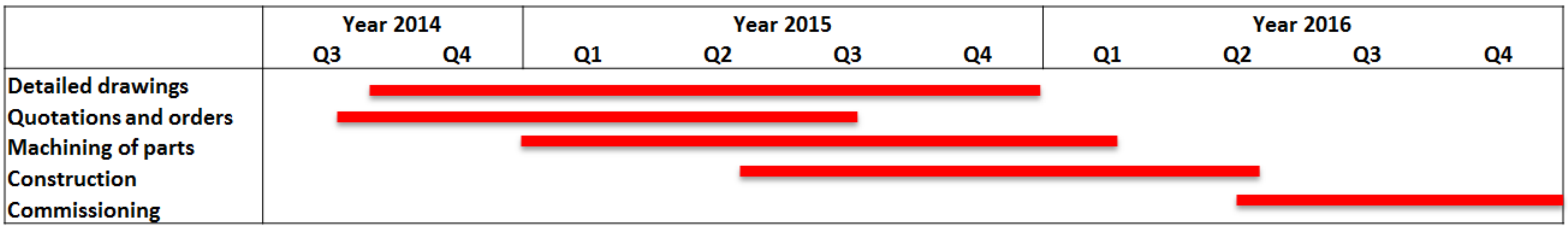
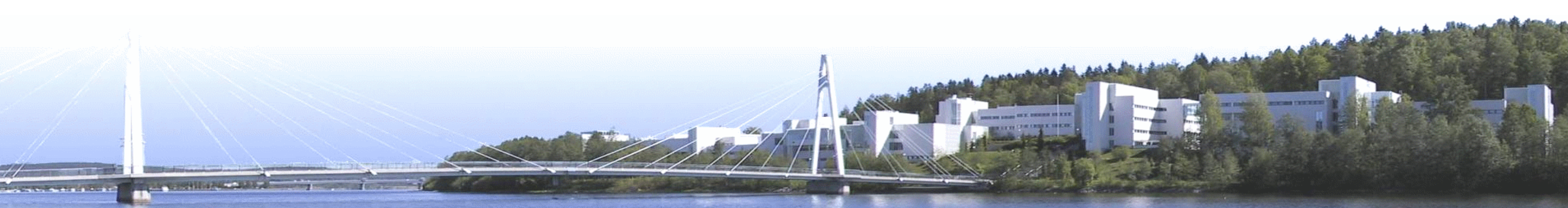
Schedule for HIISI project

Project is on schedule



Expecting first beams in late 2016.



Thank you for your attention!