Wrocław University
of Science and Technology

WUST involvement to FCC feasibility study

Jaroslaw Polinski, Maciej Chorowski, Pawel Duda, Valentina Venturi

XXVII Cracow EPIPHANY Conference on Future of Particle Physics, Polish FCC day
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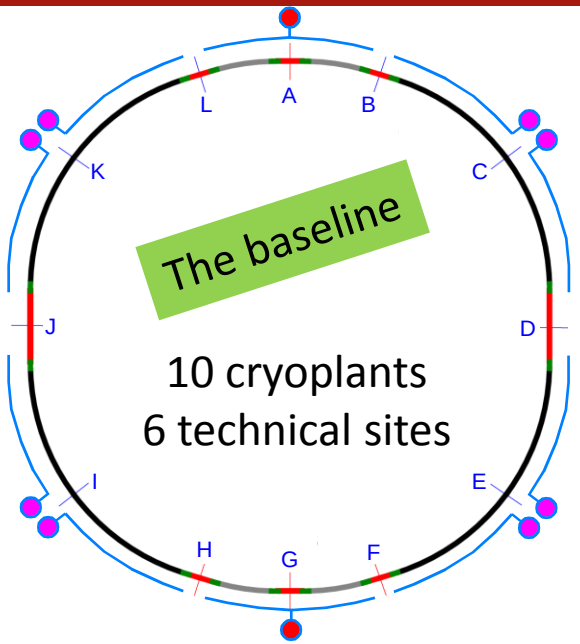
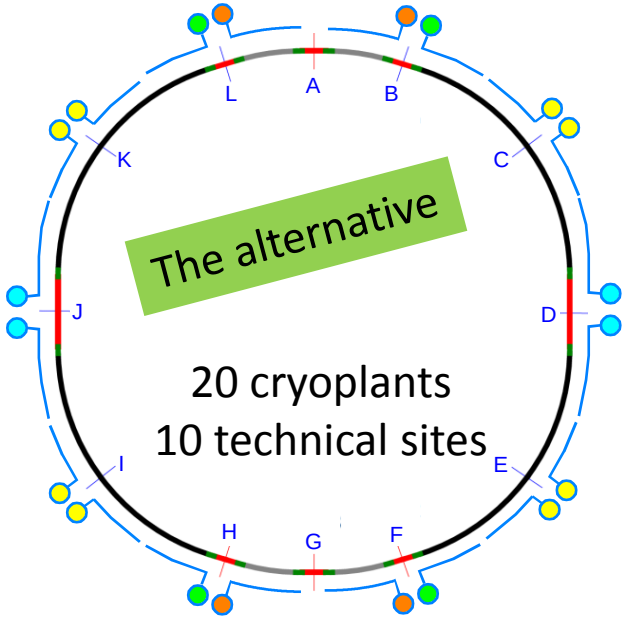
Contents

- Study of the design options for straight sections of the FCC cryogenic lines (2015-2016)
- Thermodynamic optimisation of the FCC thermal insulaion system (PhD thesis 2015-2019)

Cryogenic architecture of the FCC

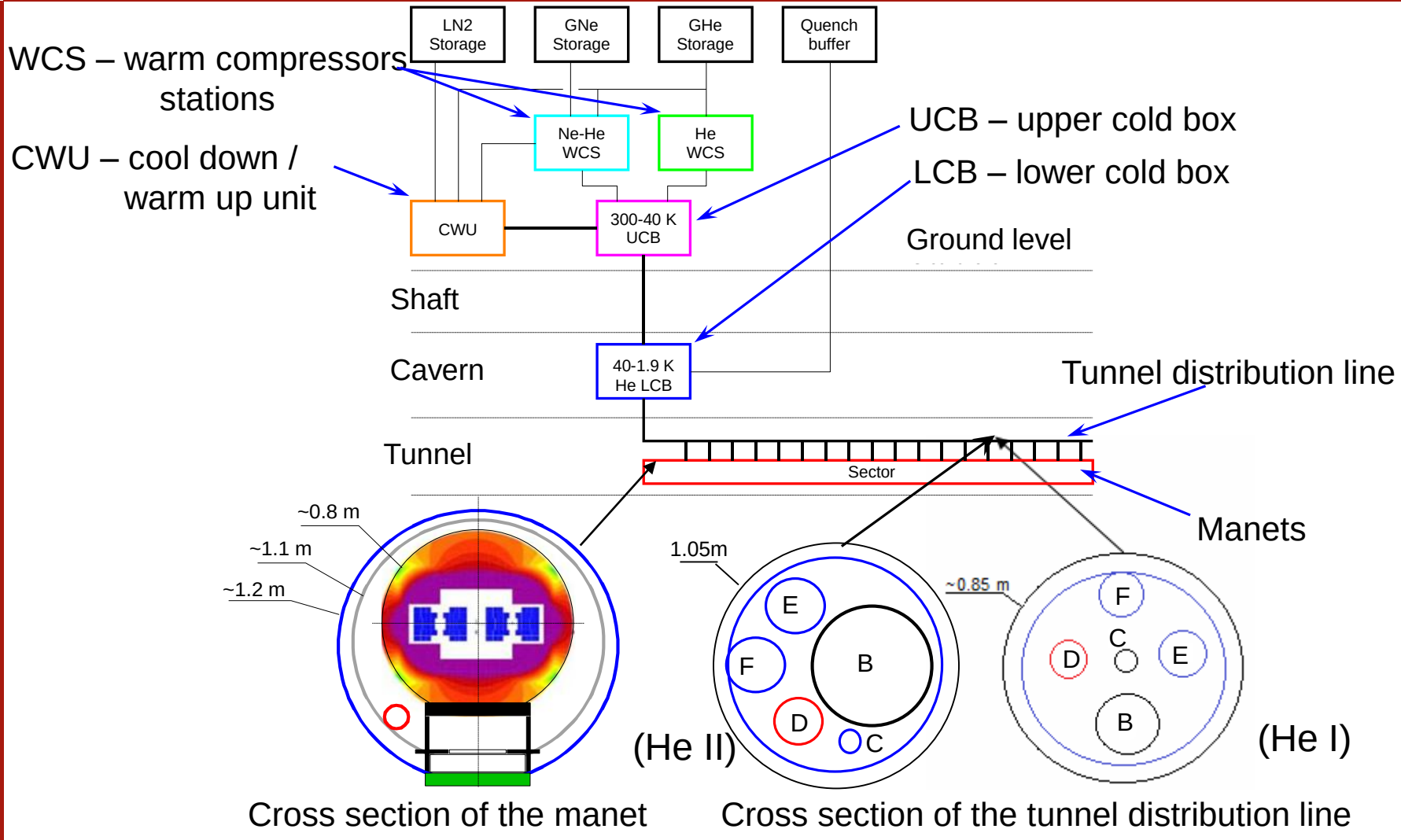


Cryoplant	L Arc+DS km	L distribution km
	2 x 4 = 8	2 x 4.7 = 9.4
	8.4	8.4

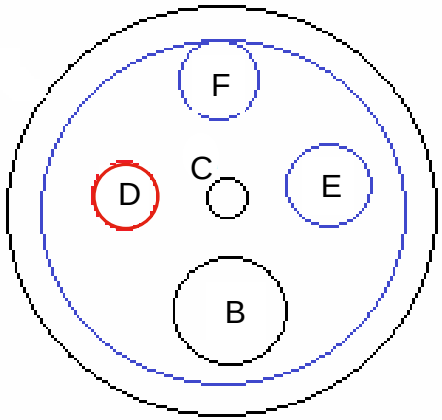


Cryoplant	L Arc+DS km	L distribution km
	4	4.7
	4.4	5.1
	4	4
	4.4	6.5

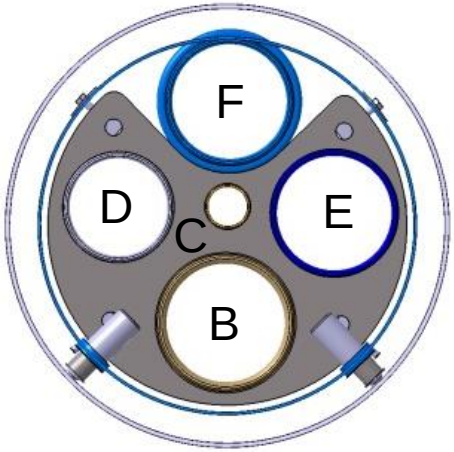
FCC Cryogenic system



Specification of the process pipes of tunnel distribution line of FCC



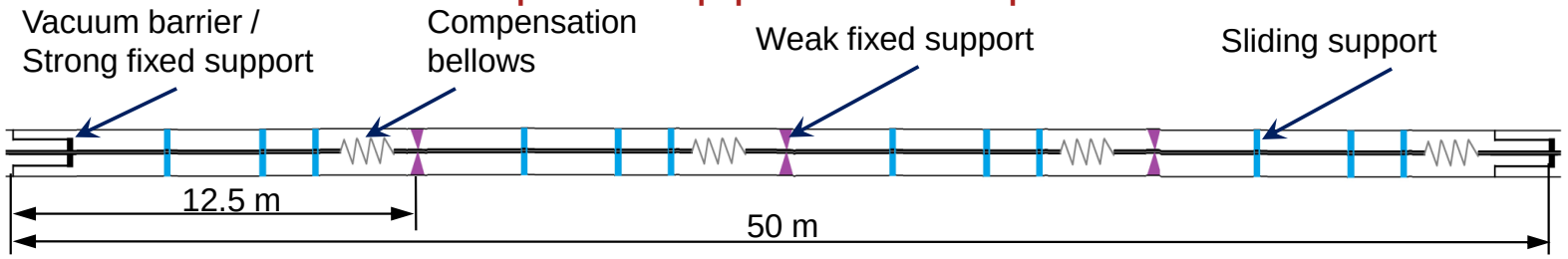
(He I)



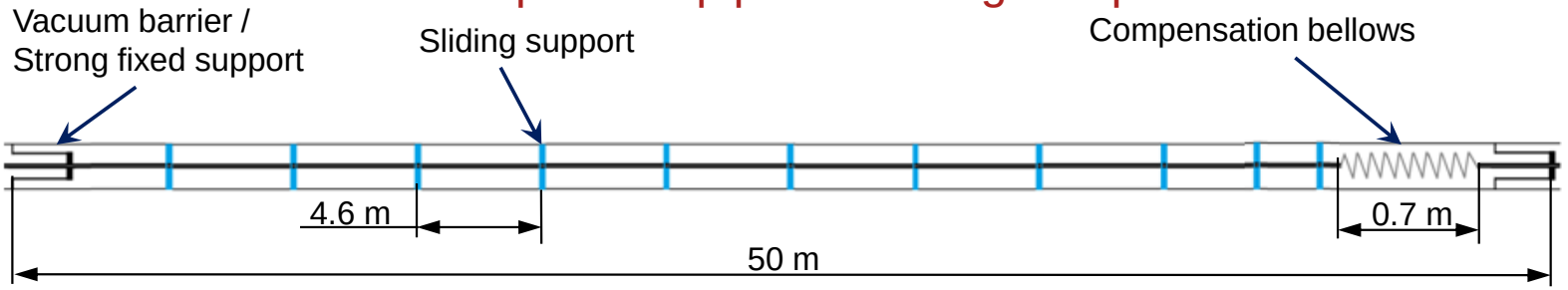
Header	Function	DN mm	Nom. T K	Nom. P_N bar	Design P_D bar	Test P_T bar
Header B	Pumping line	250	4	0.5	4	6
Header C	SHe supply	80	4.6	3	20	29
Header D	Quench line and current lead He supply	200	40	1.3	20	29
Header E	Thermal shield and beam screen He supply	240	40	20 (50)	20 (50)	29 (71.5)
Header F	Thermal shield and beam screen He return	240	60	15 (45)	20 (50)	29 (71.5)
Vacuum jacket	Insulation vaccum enclosure	850	300	0	0 -1.05	1.5

All schemes transfer line analysed in the study

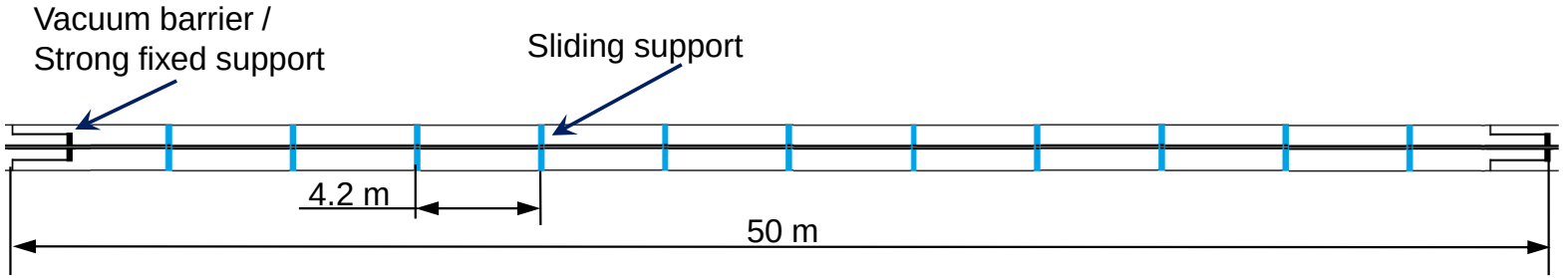
Standard stainless steel process pipes and compensation bellows



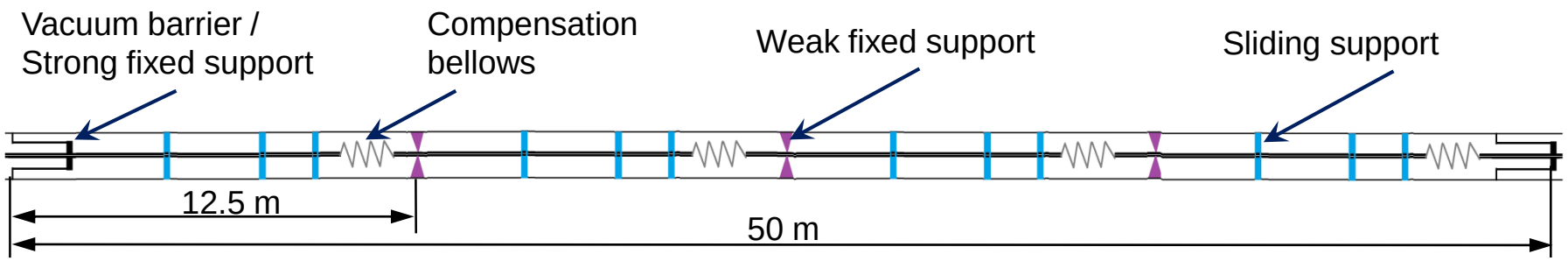
Standard stainless steel process pipes and long compensation bellows

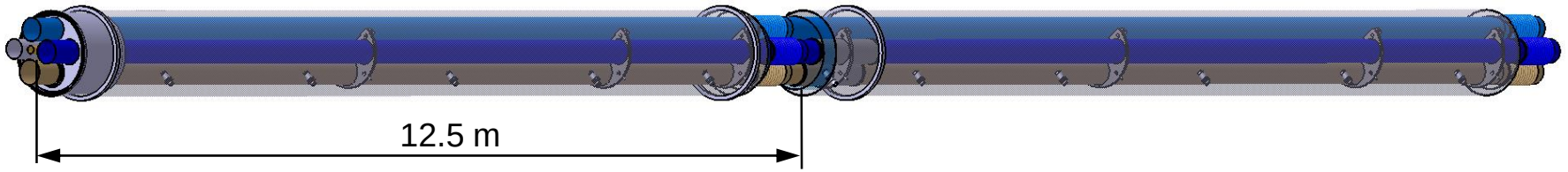


Transfer line with INVAR process pipes



Scheme of the transfer line with stainless steel process pipes and compensation bellows





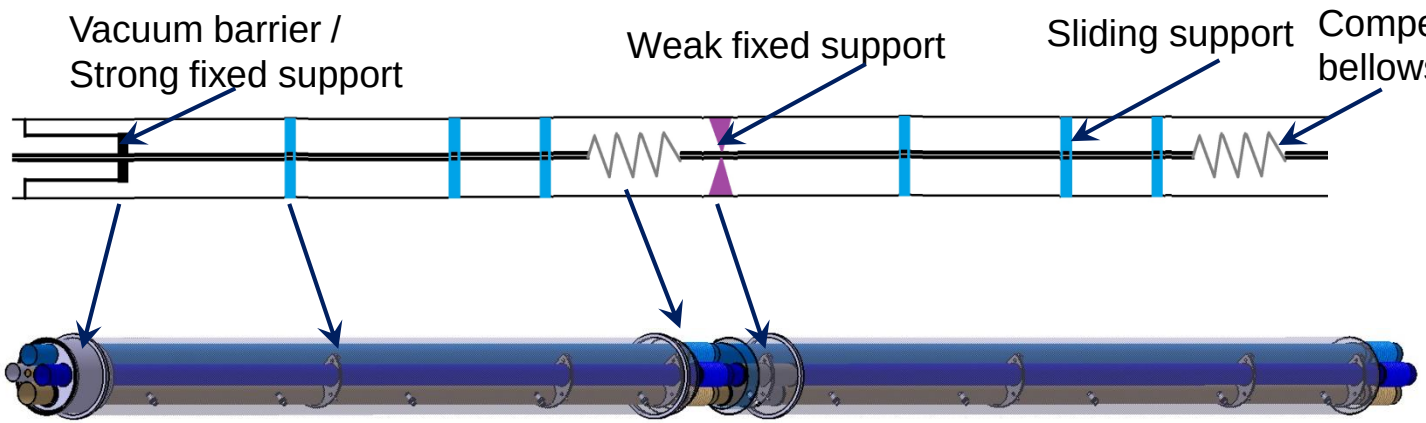
Use of standard stainless steel process pipes and compensation bellows

Parameters of bellows | Parameters of process pipes | Determination of forces

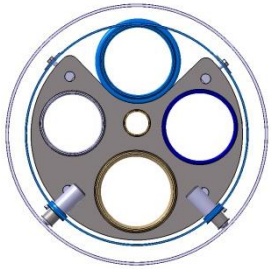
	2δ	A	c_δ	c_α	c_λ	Nom. P	Design P	Test P	ΔL	Prestr.	F_P	$F_{\Delta L}$	F_{NP}	F_{test29}	$F_{test71.5}$
	mm	cm2	N/mm	N/deg	N/mm	bar	bar	bar	mm	mm	kN	kN	kN	kN	kN
DN80	42	92.5	222	5.7	227	3	20	28.6	37.5	20	-2.8	3.9	1.1	-26	-26
DN200	52	443	428	53	1722	1.3	20	28.6	37.5	20	-5.8	7.5	1.7	-127	-127
DN240F	79	679	390	74	1245	20 (50)	20 (50)	28.6 (71.5)	37.5	20	-135.8	6.8	-129.0	-194	-485,5
DN240R	79	679	390	74	1245	15 (45)	20 (50)	28.6 (71.5)	37.5	20	-101.9	6.8	-95.0	-194	-485,5
DN250	79	695	370	78	1350	0.5	4	5.72	37.5	20	-3.5	6.5	3.0	-40	-40

Σ 581 kN Σ 1163 kN !

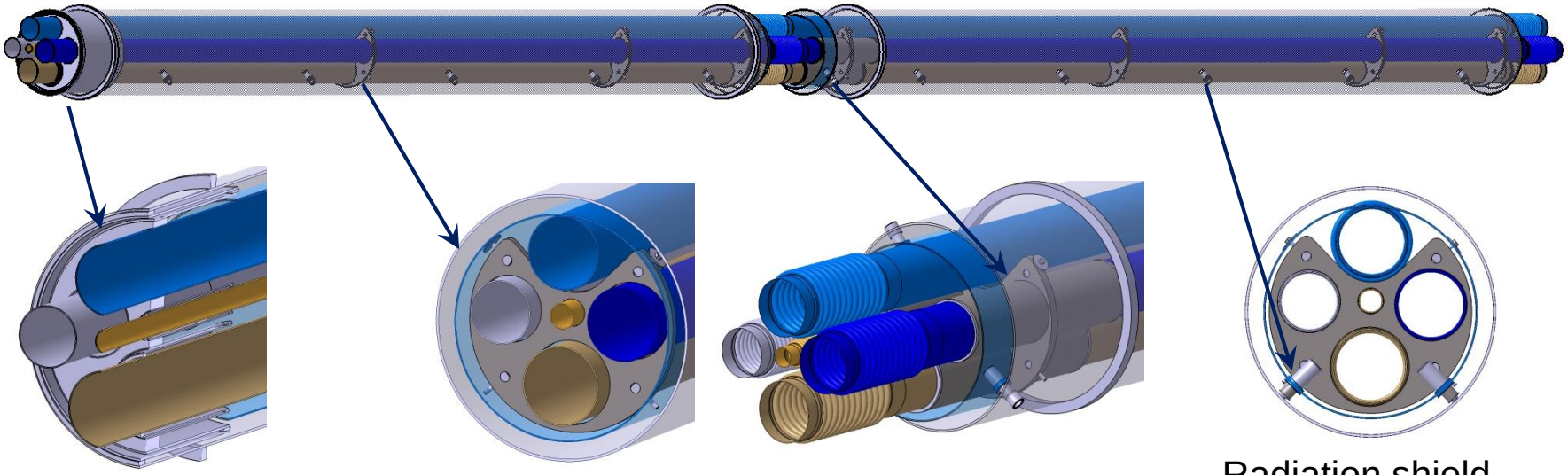
The proposal of design



Cross section



Use of standard stainless steel process pipes and compensation bellows



Vacuum barrier x 2

Sliding support x 12

Weak fixed support x 3

Radiation shield sliding support x 20

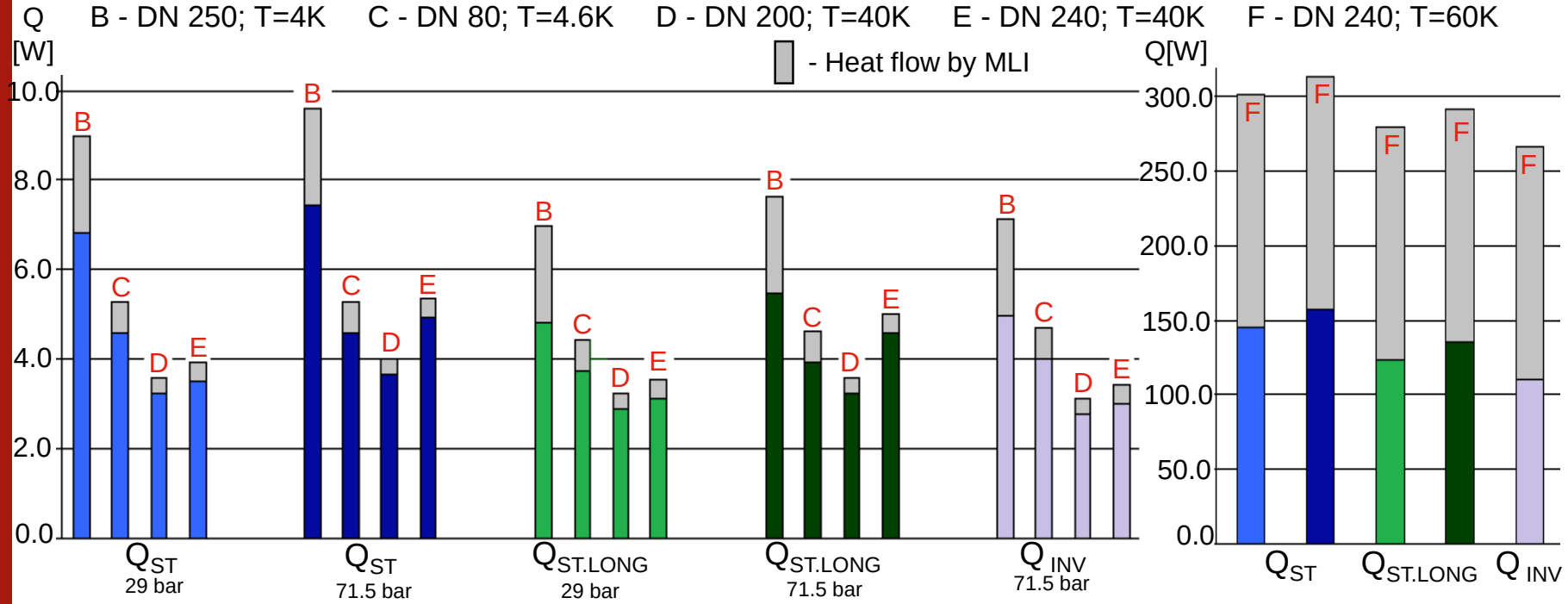
	$Q_{VB\ 29bar}$ W	$Q_{VB\ 71.5bar}$ W	Q_{SS} W	Q_{WFS} W
DN80	0.2	0.3	0.33	0.07
DN200	1.28	1.45	0.03	0.1
DN240 F	1.41	2.13	0.03	0.1
DN240 R	33.71	39.65	-0.63	7.9
DN250	1.21	1.53	0.24	0.5

	Q_{RSSS} W
DN240 R	3.1

Comparison of heat fluxes and the supports structures

Comparison of design parameters

	Number of VB	Number of WFS	Number of SS	Number of SSRS	Number of welds	Number of bellows
Steel standard	2	3	12	20	80	20
Steel long	2	0	10	20	50	4
INVAR	2	0	11	20	25	0



Impact of invar used of cumulative failure rates

Probabilities of defect occurrence (failure rates) of the most common process pipes defects

Stainless steel		
Defect	Failure rate	Source
FR_1 Cold weld rupture	$2.53 \cdot 10^{-7}$ $m^{-1} \cdot year^{-1}$	1
FR_2 Cold pipe leakage	$4.61 \cdot 10^{-6}$ $m^{-1} \cdot year^{-1}$	2
FR_3 Cold pipe rupture	$4.54 \cdot 10^{-7}$ $m^{-1} \cdot year^{-1}$	2
FR_4 Cold bellows rupture	$8.76 \cdot 10^{-5}$ $year^{-1}$	3

INVAR	
Defect	Failure rate
FR_1 Cold weld rupture	$5.06 \cdot 10^{-7}$ $m^{-1} \cdot year^{-1}$
FR_2 Cold pipe leakage	$4.61 \cdot 10^{-6}$ $m^{-1} \cdot year^{-1}$
FR_3 Cold pipe rupture	$4.54 \cdot 10^{-7}$ $m^{-1} \cdot year^{-1}$

Calculation of cumulative failure rate CFR

$CFR_1 = FR_1 \cdot L_W$ L_W - length of welds
$CFR_2 = FR_2 \cdot L_P$ L_W - length of pipe
$CFR_3 = FR_3 \cdot L_P$
$CFR_4 = FR_4 \cdot n$ n - the number of bellows

1. Cadwallader L.C.. Cryogenic System Operating Review for Fusion Application. Idaho National Engineering Laboratory. USA. 1992
2. Failure Frequency Guidance. Process Equipment Leak Frequency Data for Use in QRA. http://www.dnv.com/services/software/products/phast_safeti/safeti/leak_frequency_guidance.asp
3. Cadwallader L. Vacuum Bellows. Vacuum Piping. Cryogenic Break and Copper Joint Failure Rate Estimates for ITER Design Use. Idaho National Laboratory. USA. 2010

Compare of cumulative failure rates

Cumulative failure rate for stainless steel process pipes and compensation bellows

	Circuit of pipe	Length of pipe	Number of welds	Length of welds	Number of bellows	CFR_1	CFR_2	CFR_3	CFR_4	CFR
	m	m	-	m	-	1/yer	1/yer	1/yer	1/yer	1/yer
DN80	0.279	50	16	4.5	4.0	2.3E-06	2.3E-04	2.3E-05	3.5E-04	6.1E-04
DN200	0.688	50	16	11.0	4.0	5.6E-06	2.3E-04	2.3E-05	3.5E-04	6.1E-04
DN240F	0.804	50	16	12.9	4.0	6.5E-06	2.3E-04	2.3E-05	3.5E-04	6.1E-04
DN240R	0.804	50	16	12.9	4.0	6.5E-06	2.3E-04	2.3E-05	3.5E-04	6.1E-04
DN250	0.858	50	16	13.7	4.0	6.9E-06	2.3E-04	2.3E-05	3.5E-04	6.1E-04

Σ 3.0E-3/year

Cumulative failure rate for stainless steel process pipes and long compensation bellows

	Circuit of pipe	Length of pipe	Number of welds	Length of welds	Number of bellows	CFR_1	CFR_2	CFR_3	CFR_4	CFR
	m	m	-	m	-	1/yer	1/yer	1/yer	1/yer	1/yer
DN80	0.279	50	10	2.8	1.0	1.41E-06	2.3E-04	2.3E-05	8.76E-05	3.4E-04
DN200	0.688	50	10	6.9	1.0	3.48E-06	2.3E-04	2.3E-05	8.76E-05	3.4E-04
DN240F	0.804	50	10	8.0	1.0	4.07E-06	2.3E-04	2.3E-05	8.76E-05	3.4E-04
DN240R	0.804	50	10	8.0	1.0	4.07E-06	2.3E-04	2.3E-05	8.76E-05	3.4E-04
DN250	0.858	50	10	8.6	1.0	4.34E-06	2.3E-04	2.3E-05	8.76E-05	3.5E-04

Σ 1.7E-3/year

Impact of invar used of cumulative failure rates

Calculation of cumulative failure rate for INVAR process pipes

	Circuit of pipe	Length of pipe	Number of welds	Length of welds	CFR_1	CFR_2	CFR_3	CFR
	m	m	-	m	1/yer	1/yer	1/yer	1/yer
DN80	0.279	50	5	1.40	7.1E-07	2.3E-04	2.3E-05	2.5E-04
DN200	0.688	50	5	3.44	1.7E-06	2.3E-04	2.3E-05	2.5E-04
DN240F	0.804	50	5	4.02	2.0E-06	2.3E-04	2.3E-05	2.6E-04
DN240R	0.804	50	5	4.02	2.0E-06	2.3E-04	2.3E-05	2.6E-04
DN250	0.858	50	5	4.29	2.2E-06	2.3E-04	2.3E-05	2.6E-04

Σ 1.3E-3/year

Summary

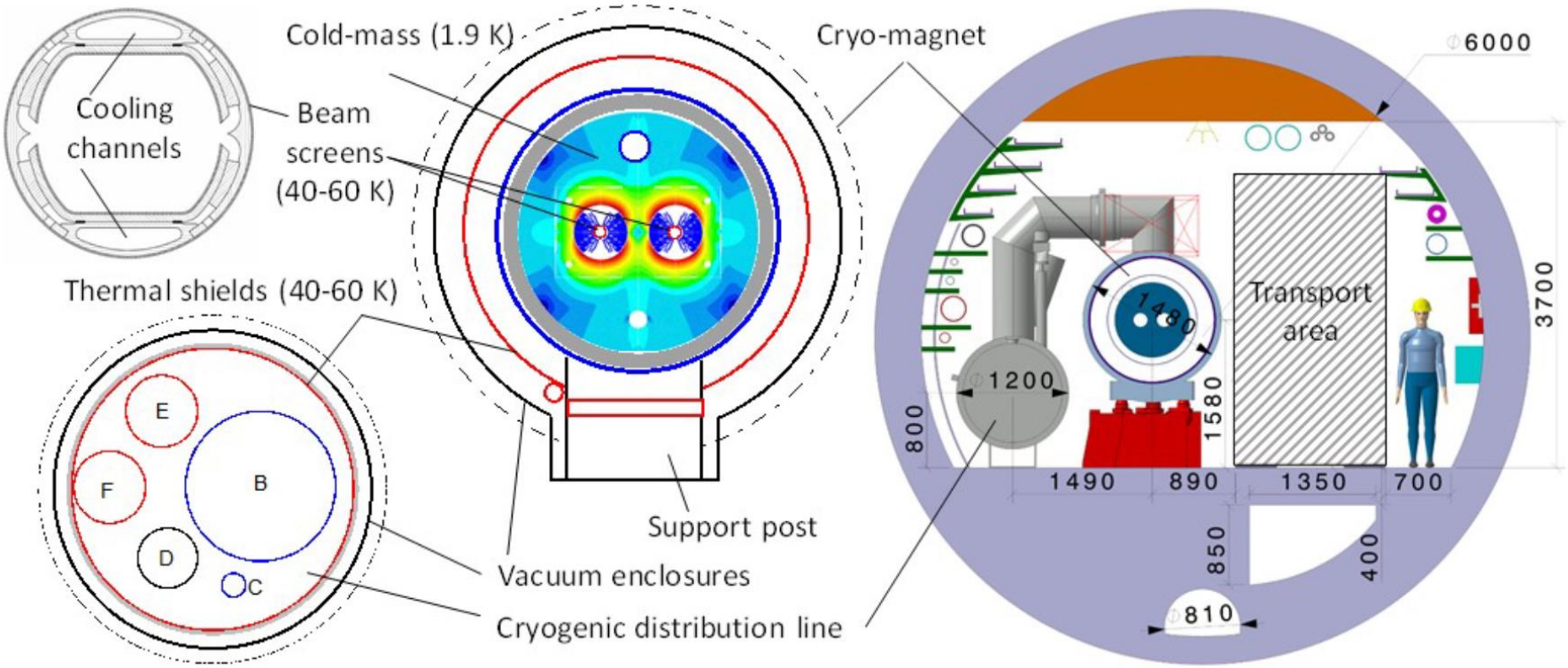
INVAR	Stainless steel
• Less types and numbers of supports • Lower heat fluxes • No compensation bellows • Lower numbers of welds • Lower forces on the vacuum barriers • Lower probability of failure	• Conventional design • A well-known method of welding • Pipes are commonly available

Using of invar process pipes seems to be very attractive alternative for FCC

Contents

- Study of the design options for straight sections of the FCC cryogenic lines (2015-2016)
- Thermodynamic optimisation of the FCC thermal insulaion system (PhD thesis 2015-2019)

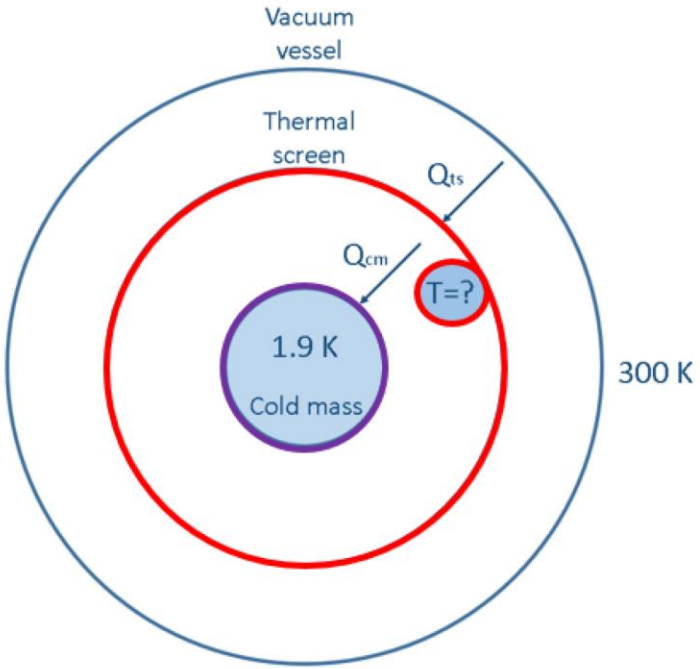
FCC Thermal insulation system

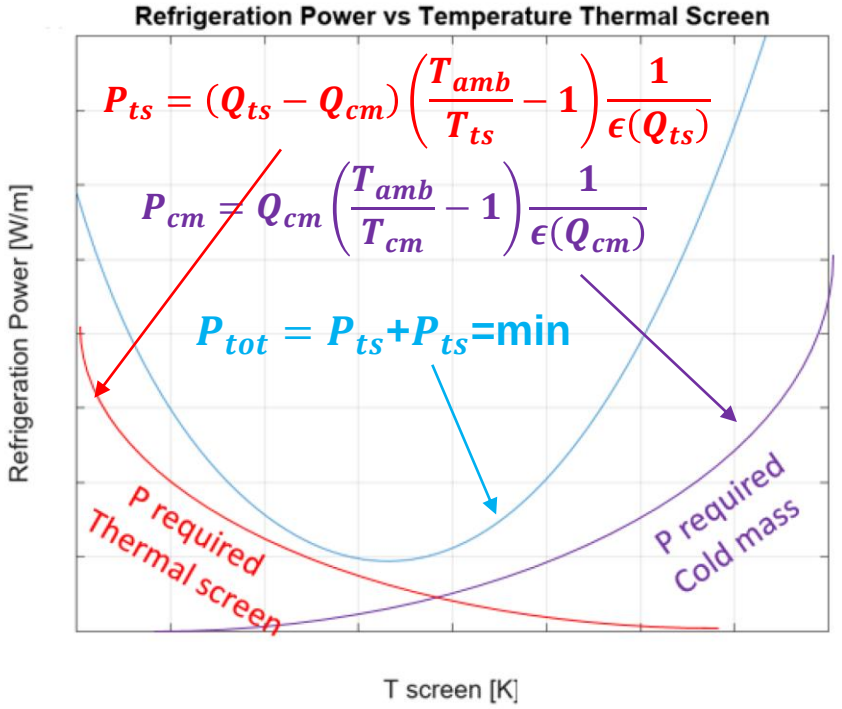


FCC – Cryogenic Heat Loads

Property	HERA	TEVATRON	LHC	FCC
Centre-of-mass energy	0.95 TeV	2 TeV	14 TeV	100 TeV
Circumference	6.3 km	6.5 km	27 km	100 km
Static heat loads (including distribution)	2.24 W/m @ 40 - 80 K	2.15 W/m @ 85 - 90 K	5.5 W/m @ 50 - 75 K	9.3 W/m @ 57 - 61 K
	0.17 W/m @ 4.4 K	0.14 W/m @ 4.6 K	0.085 W/m @ 4.6 - 20 K	–
	–	–	0.28 W/m @ 1.9 K	0.84 W/m @ 1.9 K
Dynamic heat loads	0.14 W/m @ 4.4 K	0.11 W/m @ 4.6 K	0.7 W/m @ 4.6 - 20 K	62.2 W/m @ 40 - 57 K
	–	–	0.15 W/m @ 1.9 K	0.8 W/m @ 1.9 K
Minimal required cooling power (Carnot)	0.19 MW	0.14 MW	2.88 MW	60.42 MW
Ratio of minimal required cooling powers to extract dynamic heat loads and to extract static heat loads	0.46	0.50	0.60	2.95

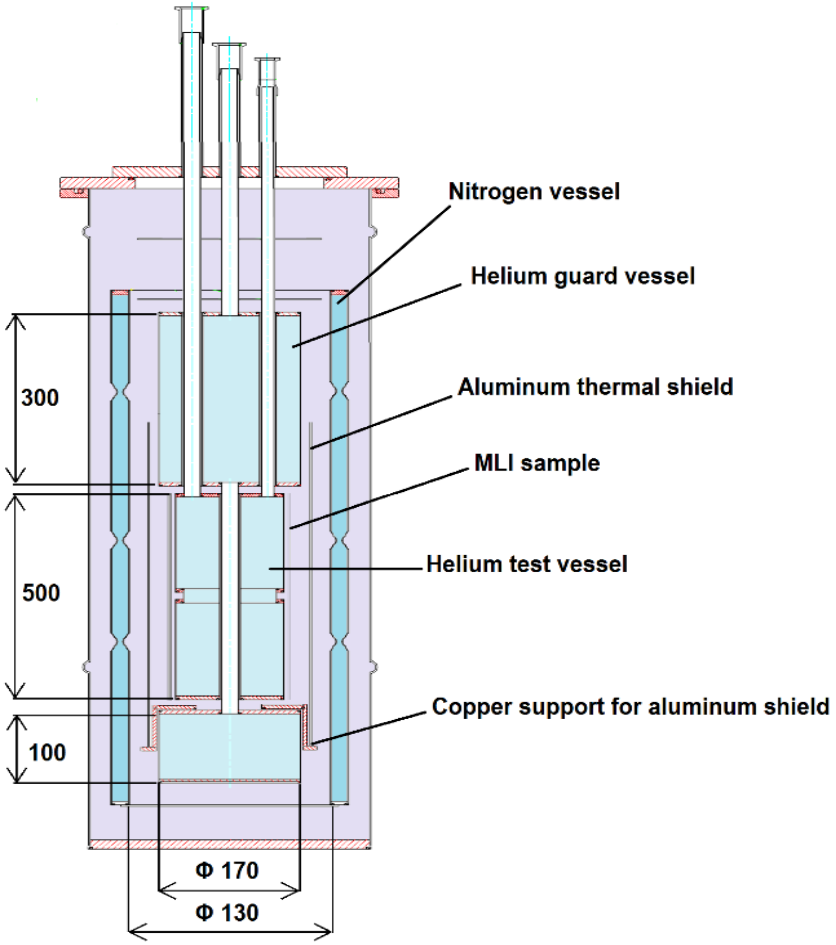
Thermal insulation system optimization





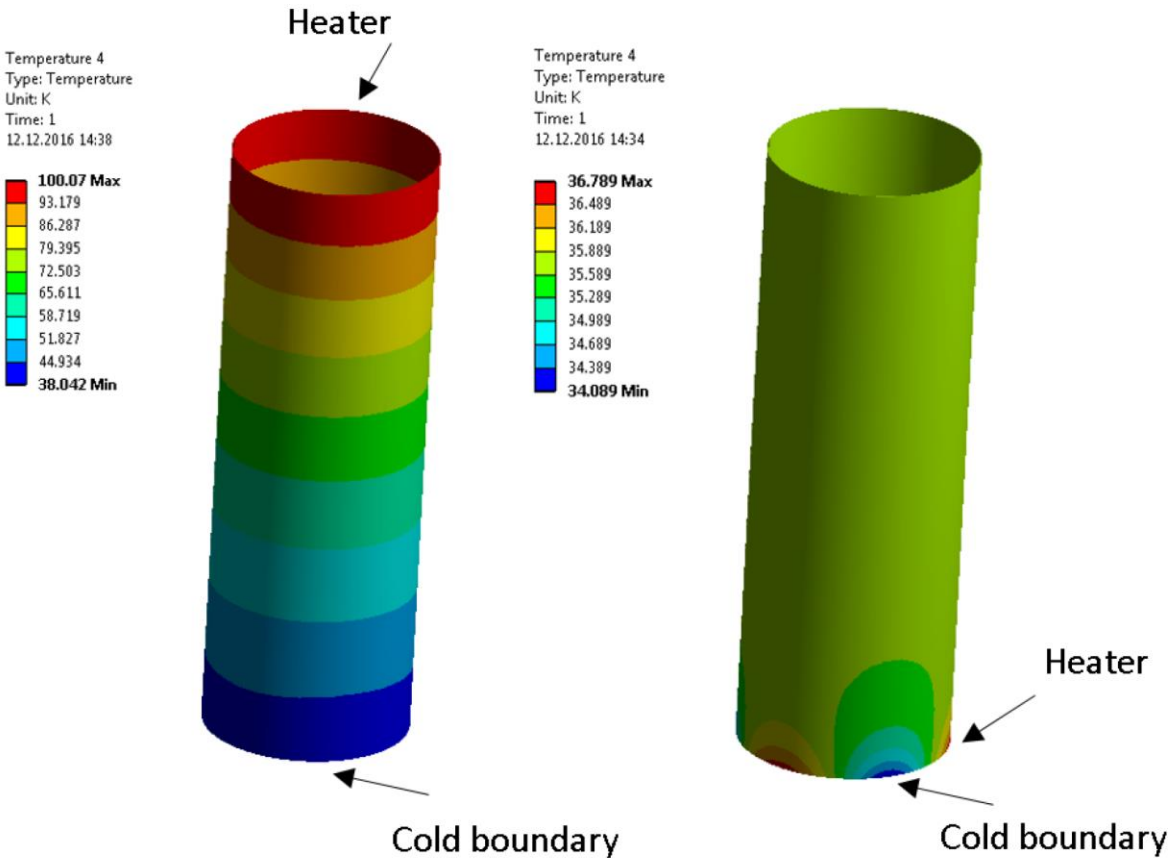
- Radiation heat transfer is mostly T_H depended
- Experimental data of MLI heat transfer for T_H=300 K and T_H=77K are well available
- No experimental data available of MLI heat transfer for T_H = 20 ÷ 70K

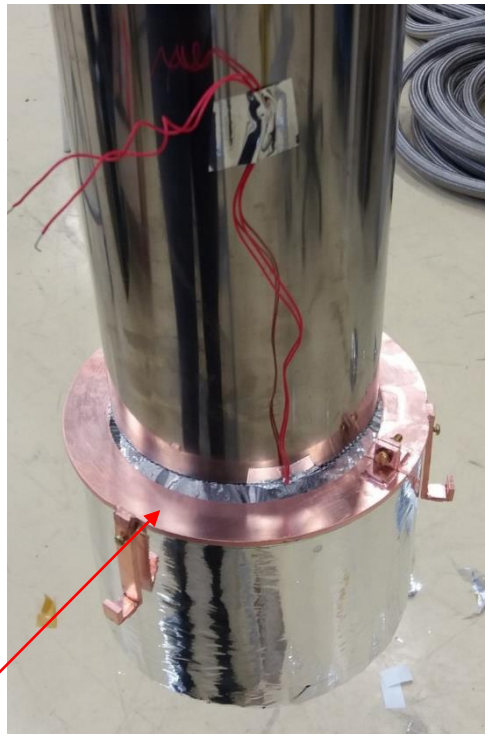
Experimental set-up



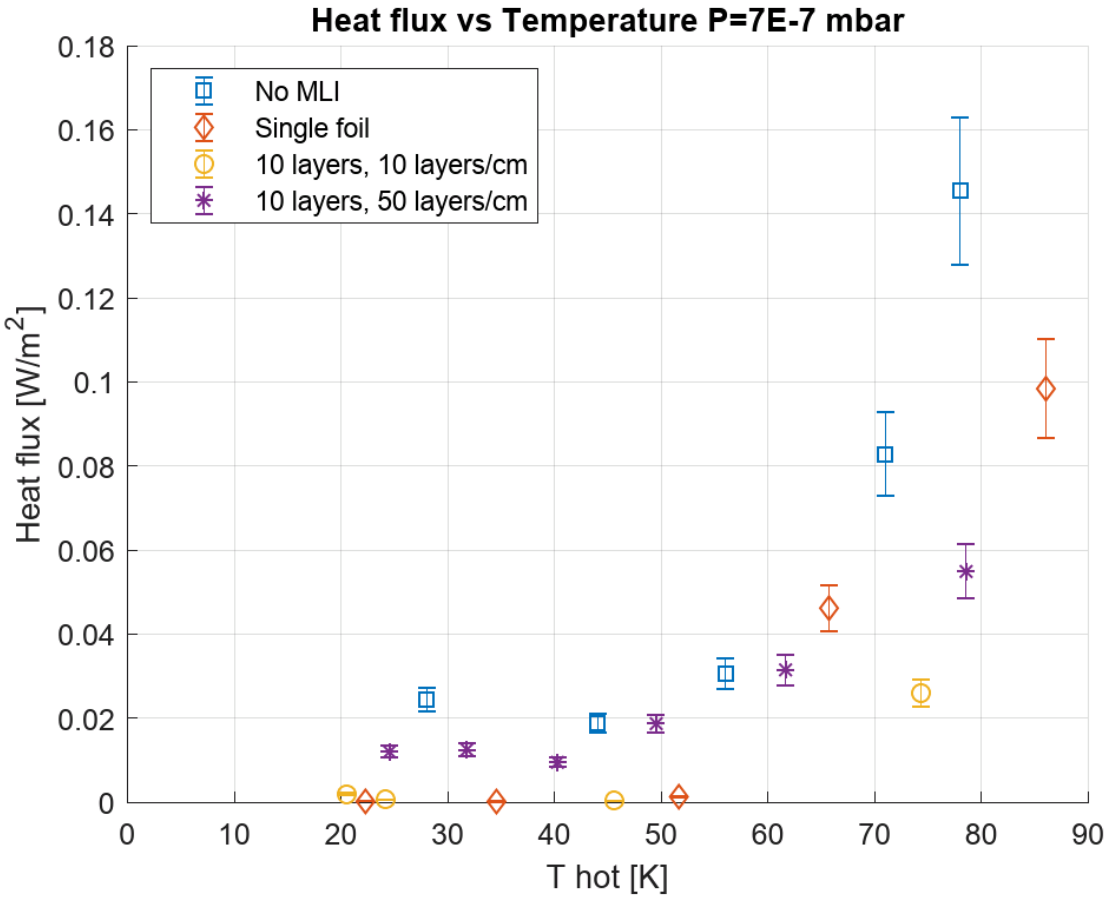
Experimental set-up – Aluminum Thermal Shield

T_H regulation in range 20 ÷ 100 K

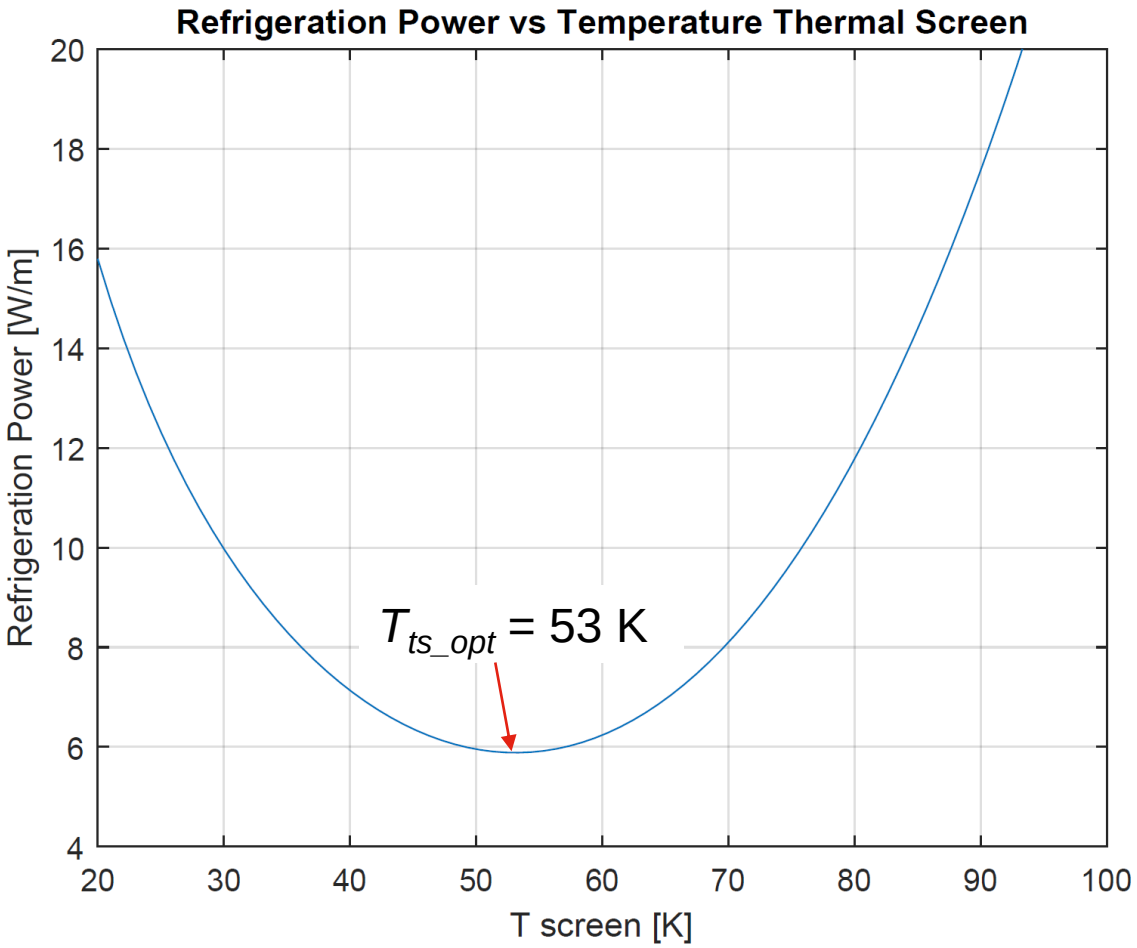
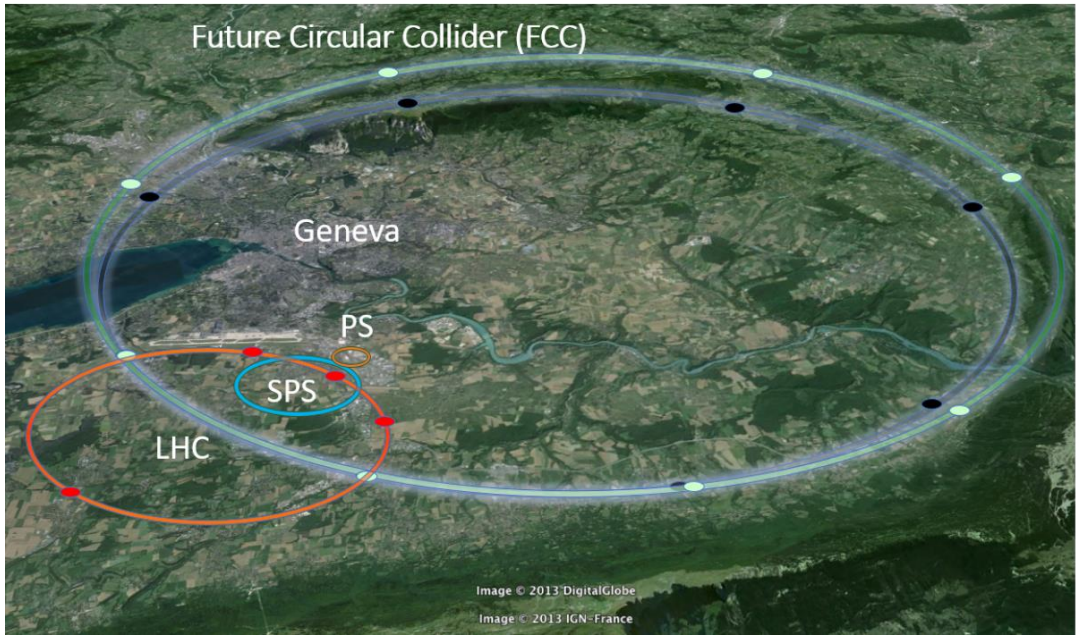




Experiment results



Optimal temperature of the Thermal Shield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