DaimlerChrysler Aerospace
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SPIRE - REF - MHO - 000318

FIRST

Cryostat Study

Update of Instrument Interfaces

Progress Meeting 2, 23. Nov. 1999

AGENDA

1. Introduction
2. Status of Action Items
3. FIRST Optical Bench Design
4. Optical Interfaces
5. Optical Bench Analysis
6. Instrument Harness evaluation status
7. Local Oscillator Unit
8. Input to IID A update
9. AOB

1. Introduction

Main Objectives / Tasks

- Implementation of present FIRST instrument design
- Check of cryostat performance after implementation
- Detail of instrument interfaces

2. Action Item Status

Action Items of Kick-off Meeting (10.09.1999)

Action Item #	Actionee	Subject / Description	Due Date	Status	Reference
01	ESTEC	ESTEC to verify date for PM#2	01.10.1999	closed	SCI-PT/ISI/07119, 27.10.1999
02	PACS	PACS to provide beam envelope at the level of the cryostat aperture as input to the baffle optimisation	01.10.1999	closed	Email, N. Geis, 08.11.1999
03	HIFI	HIFI to provide beam envelope at the level of the cryostat aperture as input to the baffle optimisation	01.10.1999	closed	Email, N. Nhyborn, 03.11.1999
04	HIFI	HIFI to provide update of the cryo-harness list for 15K to 300K	01.10.1999	open	
05	HIFI	HIFI to confirm diameter of LOU windows (30 mm) and distance between the LO-beams of 50 mm	01.10.1999	closed	Verbally in HIFI Meeting, 21.10.1999
06	HIFI	HIFI to provide dimensions and masses of waiveguides between LOU and SVM	01.10.1999	open	
07	HIFI	HIFI to provide a detailed mass breakdown of LOU	01.10.1999	open	

Action Items of Progress Meeting # 1 (20.10.1999)

Action Item #	Actionee	Subject / Description	Due Date	Status	Reference
01	SPIRE	SPIRE to provide updated thermal budget for GSFC detector array	n.a.	closed	During progress meeting by Annex 1 to MoM
02	HIFI/ PACS/ SPIRE	Instrument teams to agree on / base instruments design on: 1. Mounting and dismounting of one instrument can be performed independently of all other ones 2. The mounting interfaces of the optical bench itself shall be accessible during all integration levels (for definition see Annex 3 to MoM of PM#1) 3. Instrument mounting feet shall compensate for thermal displacements between instrument and optical bench	PM#2 23.11.1999	open	
03	SPIRE	SPIRE to update location of SPIRE Filter Box to avoid conflict with optical bench mounting interface	03.11.1999	open	
04	ESTEC	For arrangement of the instruments on the optical bench a clearance requirement of 10 mm between instruments shall be implemeted in the IID-A		open	

Action Items of Progress Meeting # 1 (20.10.1999), cont'd

Action Item #	Actionee	Subject / Description	Due Date	Status	Reference
05	ESTEC	ESTEC to check the design limit loads applicable to the optical bench	05.11.1999	closed	SCI-PT/IFI/07222, 05.11.1999
06	DSS	DSS to define thermal design and interface data required from the instruments to allow update of the thermal mathematical model of the optical bench	26.10.1999	closed	Email, DSS, 27.10.1999
07	HIFI/ PACS/ SPIRE	Instruments to provide design/interface data required by DSS to update the thermal mathematical model of the optical bench (see AI 06 of PM#1)	05.11.1999	closed	Email (HIFI), 15.11.1999; PACS-ME-TN-007, 10.11.1999; Email (SPIRE), 08.11.1999
08	ESTEC	ESTEC to reconsider the nesessity of the presently defined very stringend instrument fixation accuracies (see Annex 6 to MoM)	PM#2 23.11.1999	open	
09	DSS	DSS to sketch necessary harness interface connector arrangement when applying ISO harness technology for FIRST PLM	PM#2 23.11.1999	open	

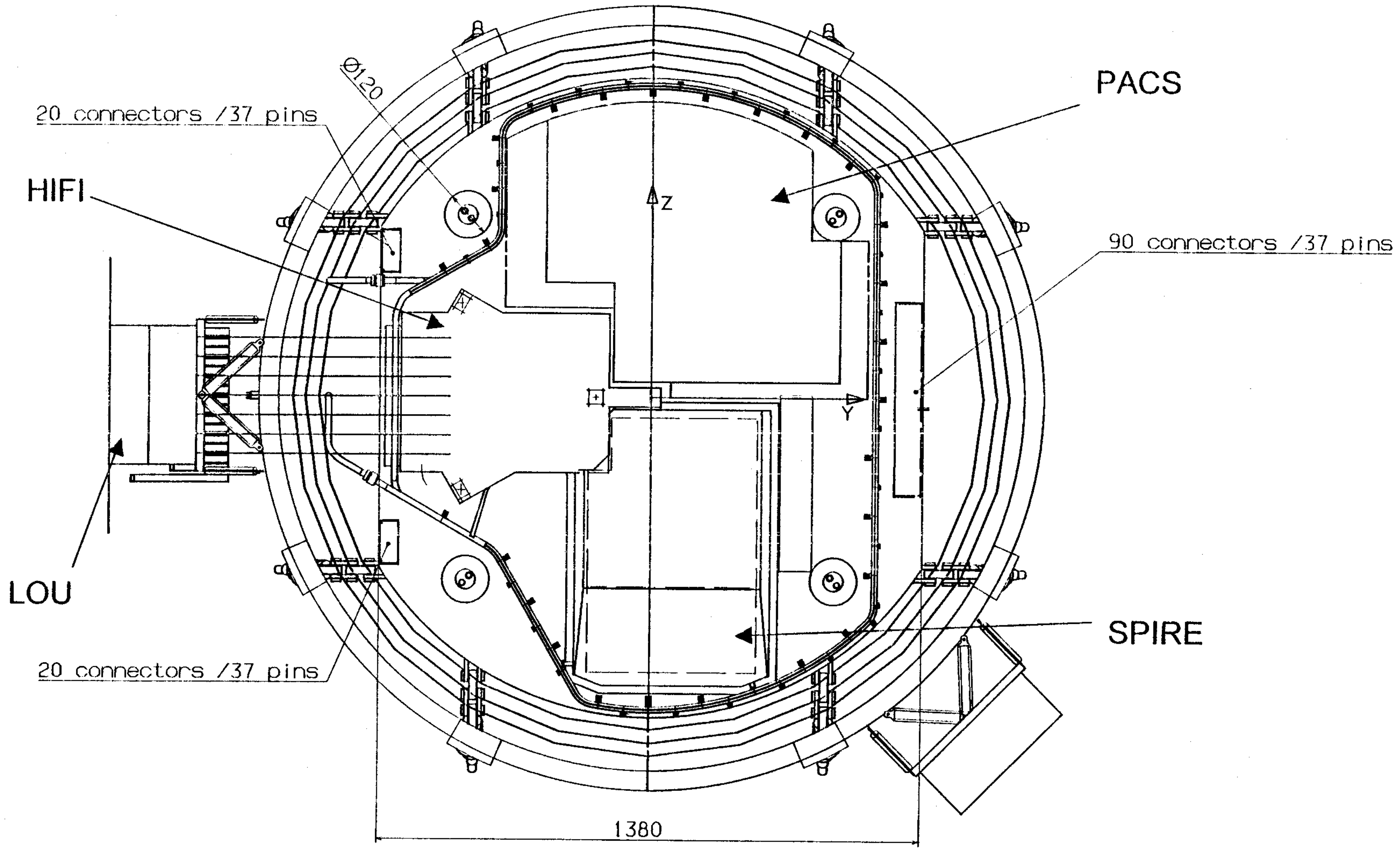
Action Items of Progress Meeting # 1 (20.10.1999), cont‘d

Action Item #	Actionee	Subject / Description	Due Date	Status	Reference
10	DSS	DSS to sketch necessary harness interface connector arrangement required for BAU when applying ISO harness technology for FIRST PLM	PM#2 23.11.1999	open	
11	HIFI	HIFI to define the position of the outlet of the HIFI instrument harness	05.11.1999	open	
12	ESTEC	ESTEC will check what is the sine vibration specification applicable for the instruments on the PLM optical bench and whether the levels can be reduced at higher frequency	05.11.1999	closed	SCI-PT/IFI/07222, 05.11.1999
13	HIFI/ PACS/ SPIRE	Instruments to comment/confirm definition of temperature level-0, level-1 and level-2 applicable to the instruments as defined in PM#1-MoM, page 9/9	PM#2 23.11.1999	open	

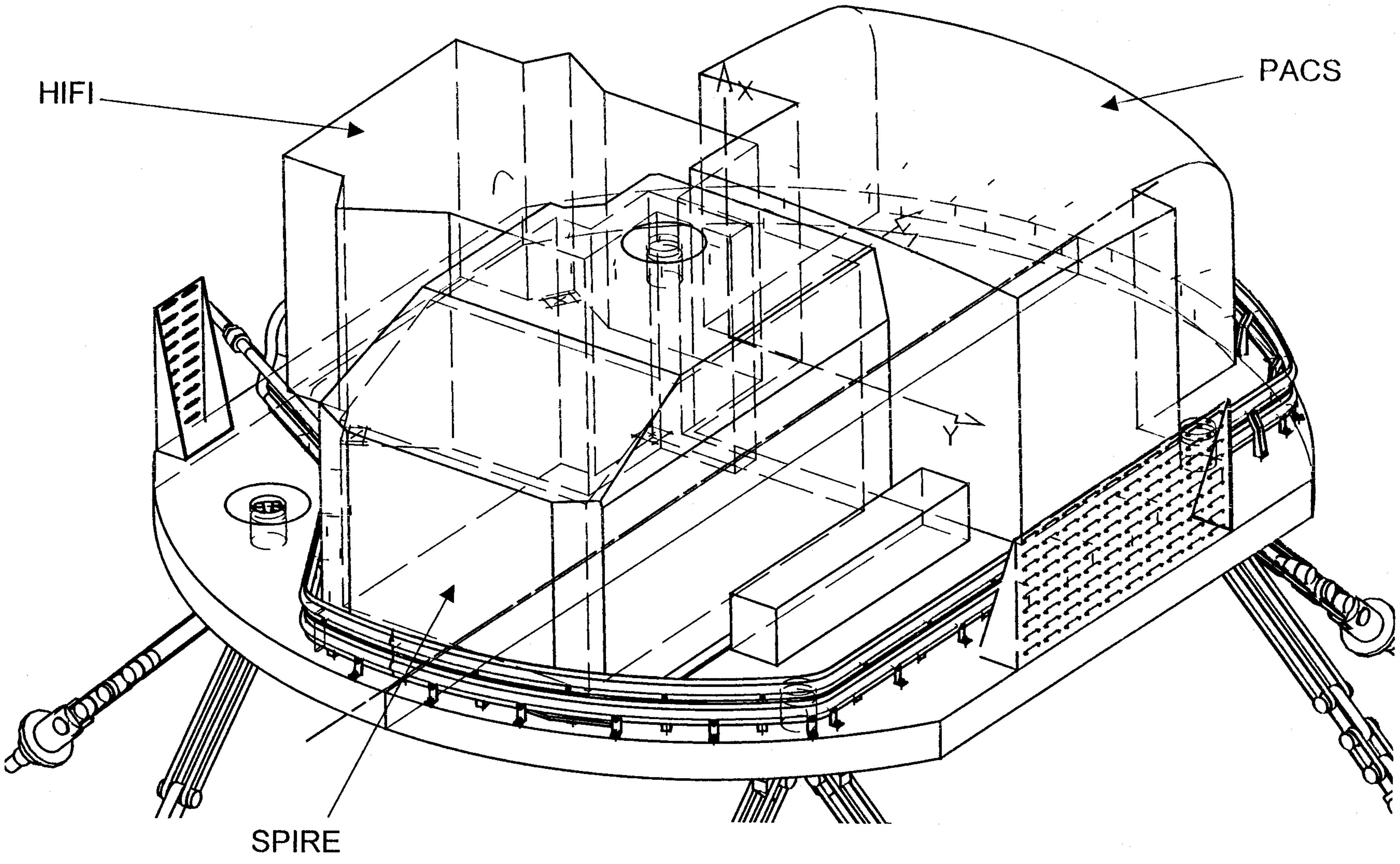
3. FIRST Optical Bench Design

- Arrangement of FPU´s on OB
- Mechanical Interfaces
- Thermal Interfaces (level 0, 1, 2)
- OB connectors, Harness routing
- LO baffle between HIFI and Common Instrument Shield

First Optical Bench Design – Arrangement of FPU's



First Optical Bench Design – Arrangement of FPU's - 3D



First Optical Bench Design – CATIA Layout Status

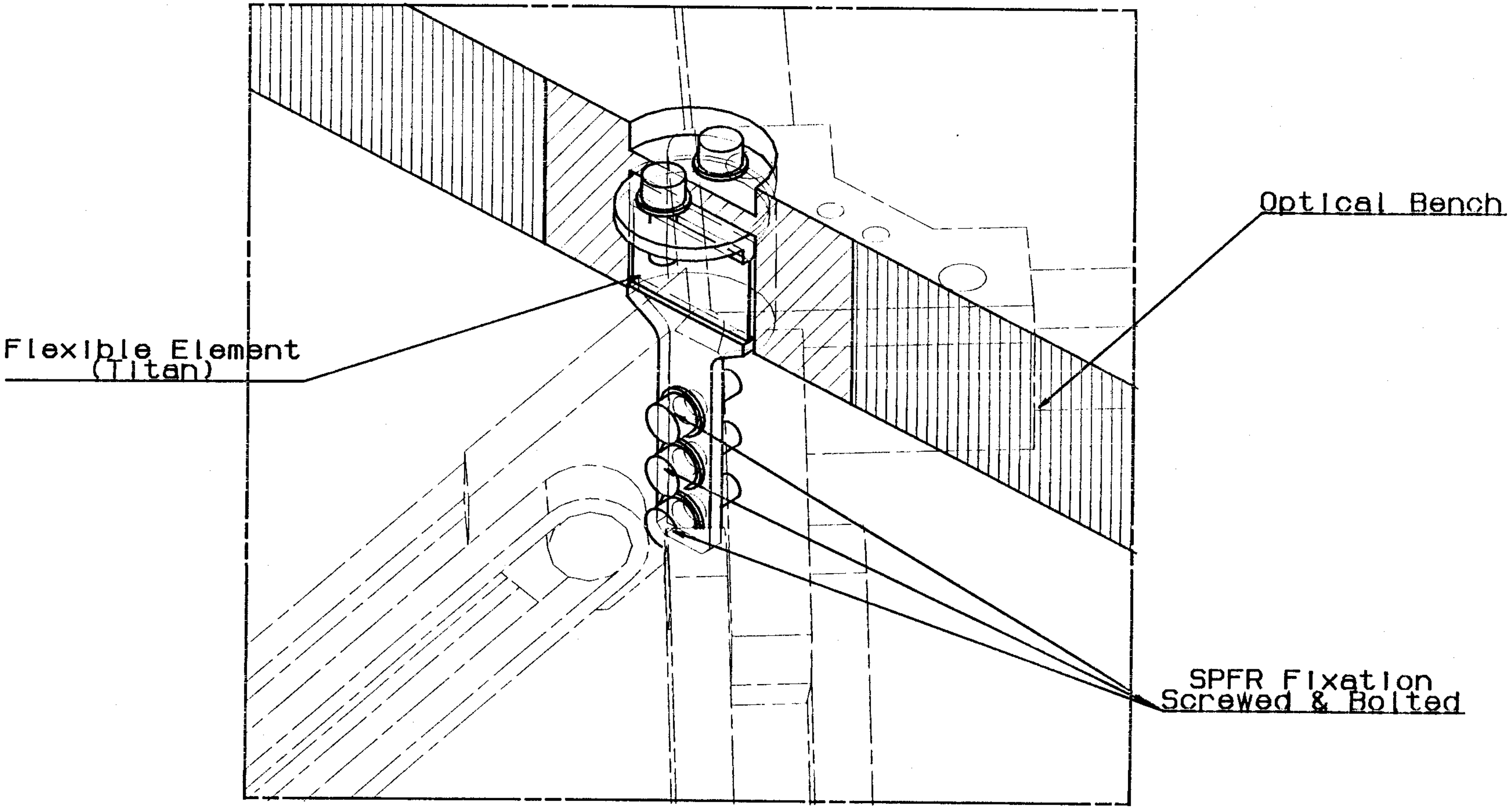
- accessibility to OB fixation points taken into account (dia. 120mm)
- OB enlarged in ± Y direction, thickness kept at 60mm
- heat exchanger below OB deleted
- thermal interface level 1 routed above level 2 on top of the OB
- connector brackets added on ± Y side
- experiment shield adapted
- LOU baffle implemented
- experiment volumes no change since last meeting
- SPIRE JFET Box position open

<u>PACS checked with larger volume:</u>

- enlargement of volume critical in terms of clearance to SPIRE filter box and mounting area between experiments (to be checked in detail)
- no additional activities planned

First Optical Bench Design – Mech. IF to Cryostat

- Previous Design kept – update not included in present study

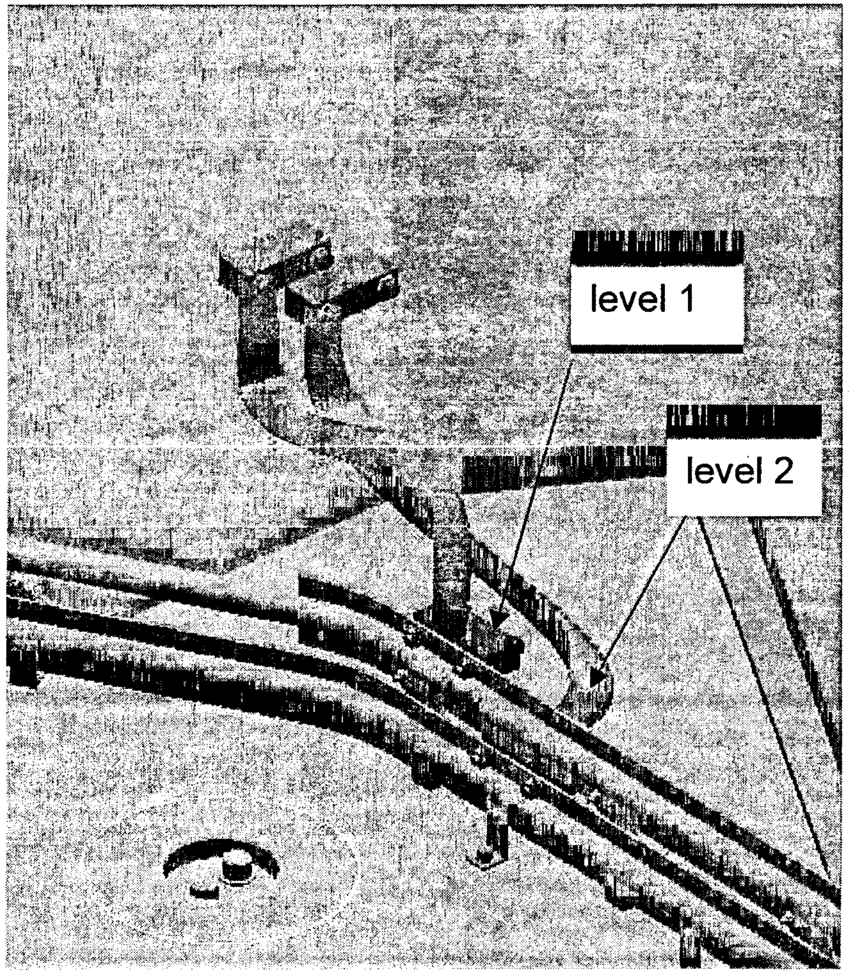


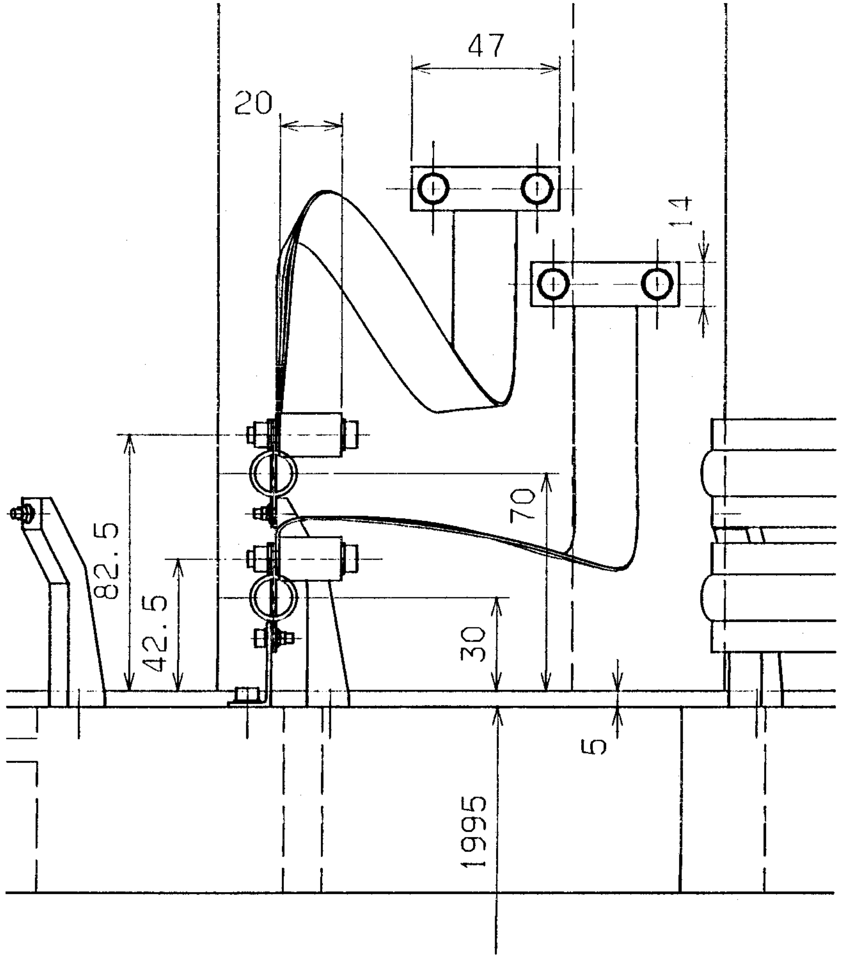
First Optical Bench Design – Mech. IF to Instruments

Summary of last Meeting (see MOM 20.10.99)

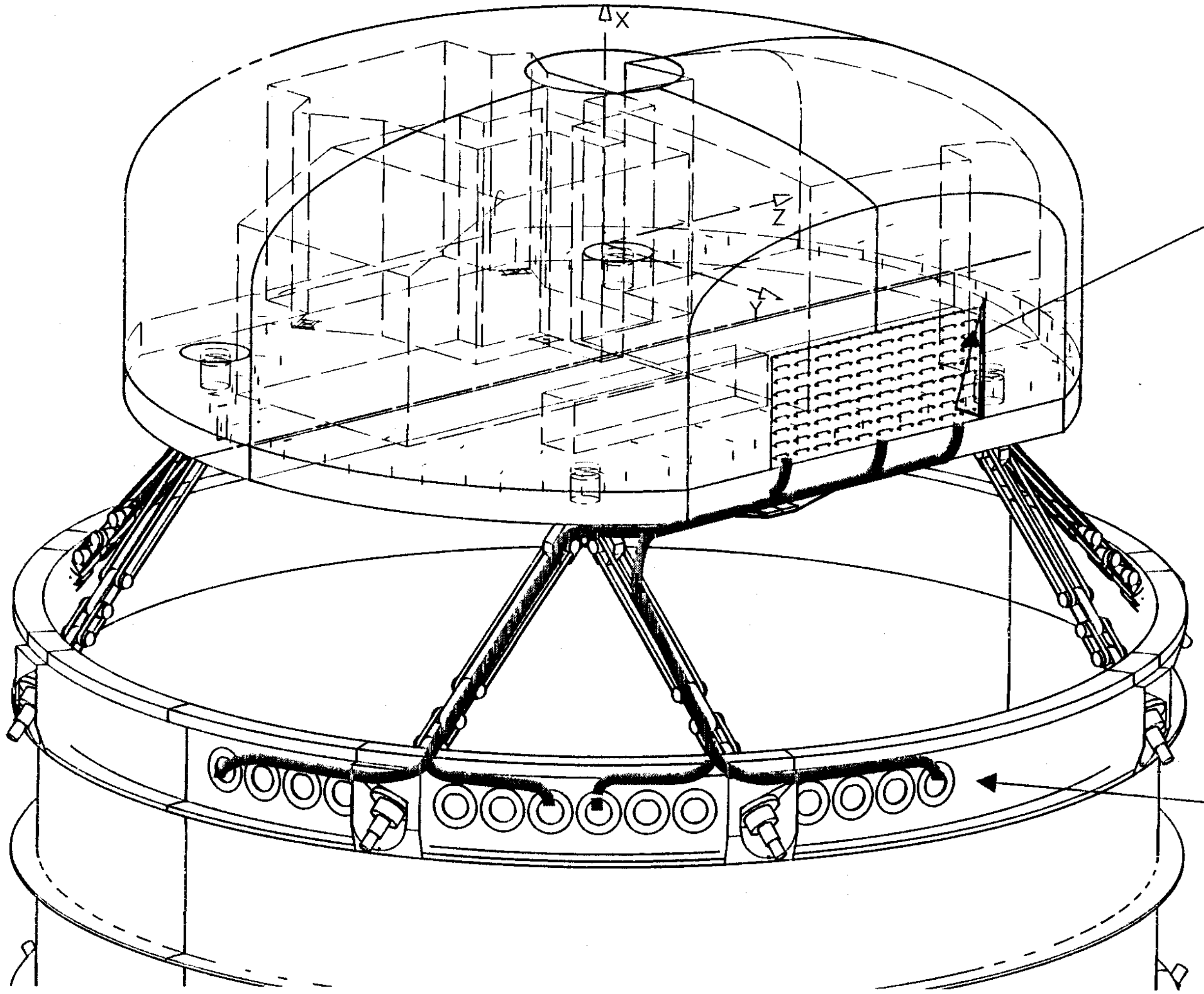
- number of fixations point different for each experiment
  PACS 3, HIFI 3, SPIRE 8
- reference plane STA 2000, one reference hole for each experiment
- fixation holes: Dia. 12H7 location tbd. and 4 screws M6 size around each hole
- all holes on OB are fixed - no provisions for compensation of thermal displacements
- provisions for thermal alignment and thermal displacements shall be done on experiment side

- First Optical Bench Design – Thermal Interfaces (level 0, 1, 2)

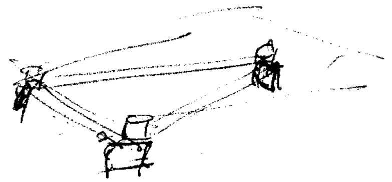




First Optical Bench Design – Harness Routing, Connector Interfaces



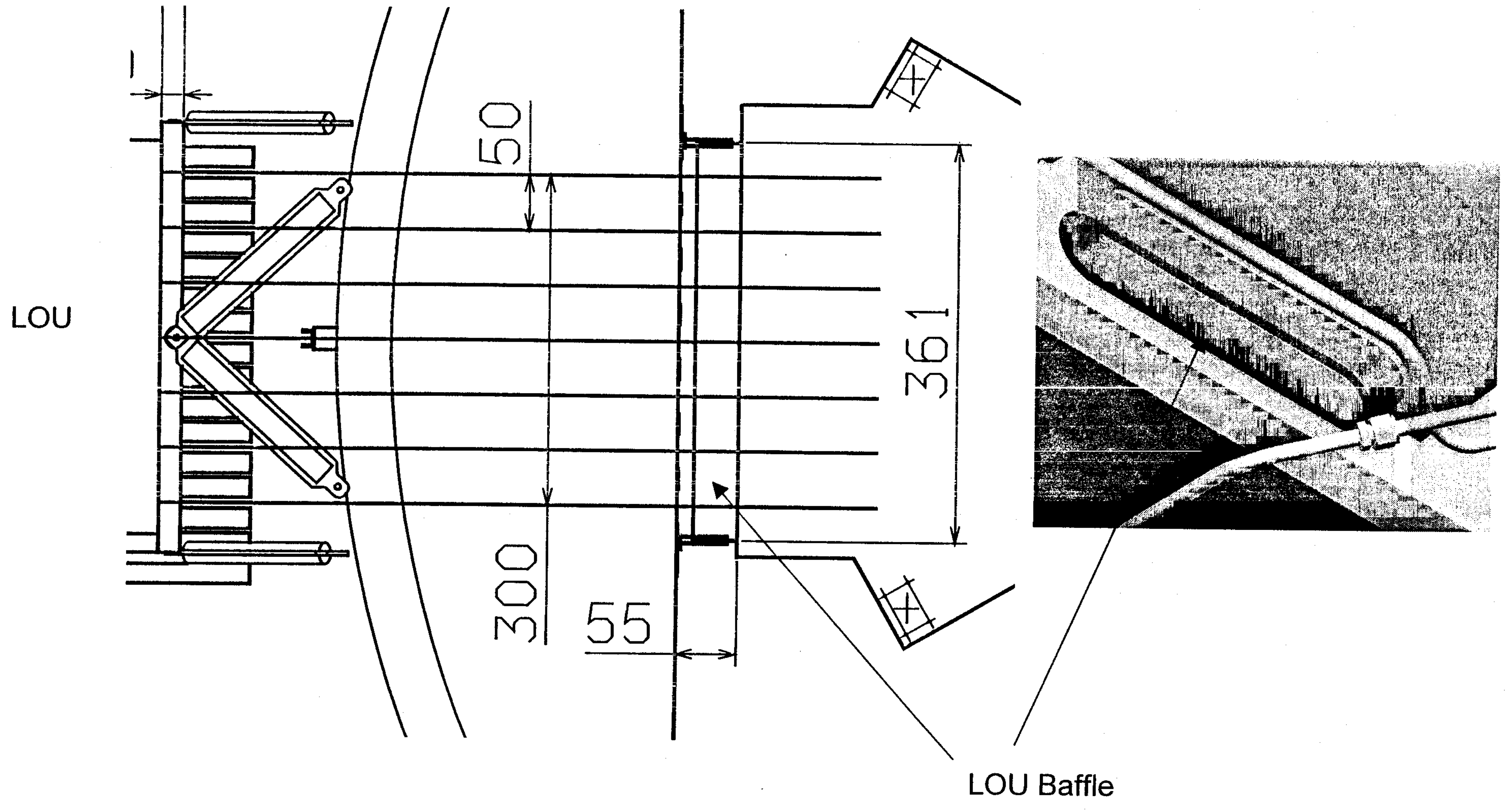
connector bracket
90 x 37 p



principle harness
routing

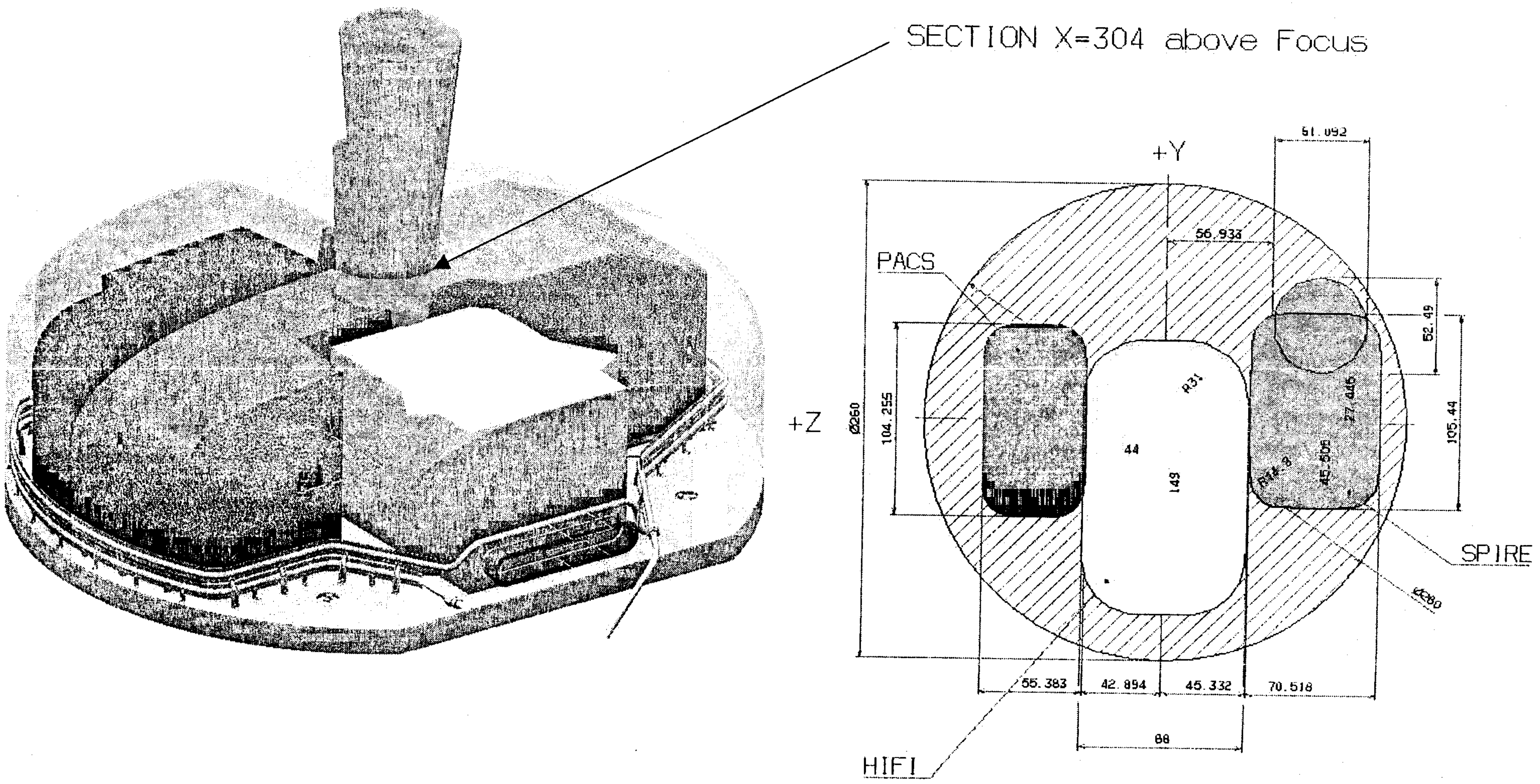
vacuum feedthrough
14 x 100 p in one
quarter

First Optical Bench Design – LOU Baffle



Progress Meeting 2, 23. Nov. 1999

4. Optical Interfaces (Beam Pattern/Baffle Shaping)



5. Optical Bench Analysis

Mechanical Analysis

A structural model of the OB has been established; different configurations of the OB have been analysed

Thermal Analysis

With the inputs from the instruments a thermal model has been build up, first calculations performed;

F I R S T

Optical Bench

Mechanical Analyses

Bernd Gröger RIA54

FIRST I/F Study Progress Meeting 23.11.99

Version	design	total mass	1. eigenfreq.
9	100 mm alu sandwich plate - 96 mm alu core G=283 N/mm^2 e. g. HEXCEL 1/8-5052-.0015-6.1 - 2mm alu face sheets 1mm steel blades (46x29.5mm) alu inserts instruments 156.1 kg sandwich plate + inserts 65.4 kg	247.5 kg	81 Hz
10	60 mm cfc sandwich plate - 58 mm cfc core G=331 N/mm^2 e.g. HEXCEL HFT-G-327-3/16-6.0 - 1mm cfc face sheets quasi isotropic M60 fibers E=120000 N/mm^2 1 mm steel blades (46x29.5mm) cfc inserts instruments 156.1 kg sandwich plate + inserts 25.26 kg	206.7 kg	57 Hz

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Version	design	total mass	1. eigenfreq.
11	60 mm cfc sandwich plate - 56 mm cfc core G= 331 N/mm^2 e.g. HFT-G-327-3/16-6.0 - 2mm cfc face sheets quasi isotropic M60 fibers E = 120000 N/mm^2 1 mm steel blades cfc inserts instruments 156.1 kg sandwich plate + inserts 30.4 kg	211.9 kg	71 Hz
12	70 mm cfc sandwich plate - 66 mm cfc core G = 331 N/mm^2 e.g. HEXCEL HFT-G-327-3/16-6.0 - 2 mm cfc face sheets quasi isotropic M60 fibers e = 120000 N/mm^2 cfc inserts 1mm steel blades instruments 156.1 kg sandwich plate + inserts 33.8 kg	215.3 kg	78.2 Hz

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Version	design	total mass	1. eigenfreq.
13	70 mm cfc sandwich plate - 65 mm cfc core G = 331 N/mm^2 e.g. HEXCEL HFT-G-327-3/16-6.0 2.5 mm cfc face sheets quasi isotropic M60 fibers E = 120000 N/mm^2 1 mm steel blades cfc inserts instruments 156.1 kg sandwich plate + inserts 36.2 kg	217.7 kg	81.0 Hz
14	70 mm cfc sandwich plate - 65 mm cfc core G = 331 N/mm^2 e.g. HEXCEL HFT-G-327-3/16-6.0 - 2.5 mm cfc face sheets quasi isotropic M60 fibers E = 120000 N/mm^2 1 mm cfc blades (E = 120 000 N/mm^2) cfc inserts instruments 156.1 kg sandwich plate + inserts 36.2 kg	217.4 kg	79.3 Hz

Dimensioning Loadcases

Face Sheets

loadcase	min. princ. stress +Z fiber in [N/mm^2]	max. princ. stress -Z fiber in [N/mm^2]	min. princ. stress +Z fiber in [N/mm^2]	max. princ. stress -Z fiber in [N/mm^2]
10 g x + 5g y	-13.0	6.8	-8.8	9.5
10 g x + -5g y	-10.9	5.8	-5.1	10.4
10 g x + 5 g z	-10.5	7.7	-6.2	9.7
10 g x + -5g z	-10.6	8.2	-7.3	10.1

MS

Dimensioning Loadcases
Face Sheets

loadcase	min. princ. stress +Z fiber in [N/mm^2]	max. princ. stress -Z fiber in [N/mm^2]	min. princ. stress +Z fiber in [N/mm^2]	max. princ. stress -Z fiber in [N/mm^2]
-10gx + 5gy	-5.8	10.9	-10.4	5.1
-10gx + -5gy	-6.8	13.9	-9.5	8.8
-10gx + 5gz	-7.7	10.5	-9.7	6.2
-10gx + -5gy	-8.2	10.6	-10.1	7.3

Allowables for quasi isotropic M60 laminate with alpha 0.02 e-6:

pressure: Sig_{ult} = -130 N/mm^2 MOS > 7.6

tensile: Sig_{ult} > 200 N/mm^2 MOS > 11.5

wrinkling: Sig_{wrink} = 480 N/mm^2 MOS > 31

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Quasi static dimensioning loadcases

maximum stress of blades (46x29.5x1mm, E=120000 N/mm^2):

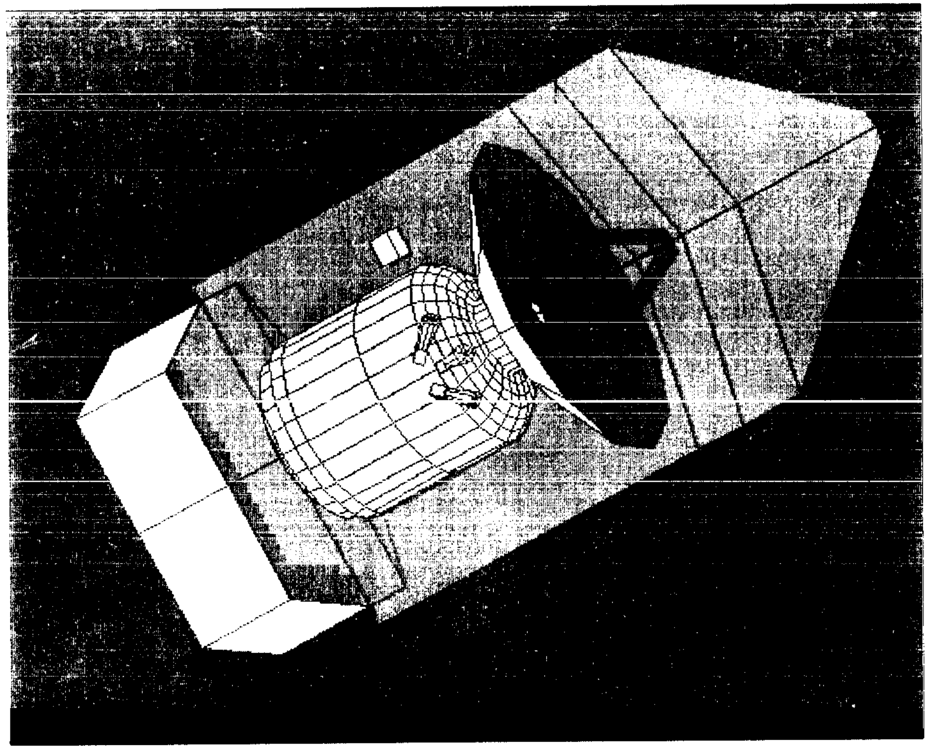
- max. shear 104 N/mm^2
- max. principle stresses 360 N/mm^2
- min. principle stresses -337 N/mm^2
- max. von Mises 353 N/mm^2

for Ti-blades: $MOS_{ult} > 0.8$ $MOS_{shear} > 2.4$

for CFC-blades: ?

ml

Thermal Analysis - Update of Instrument Interfaces

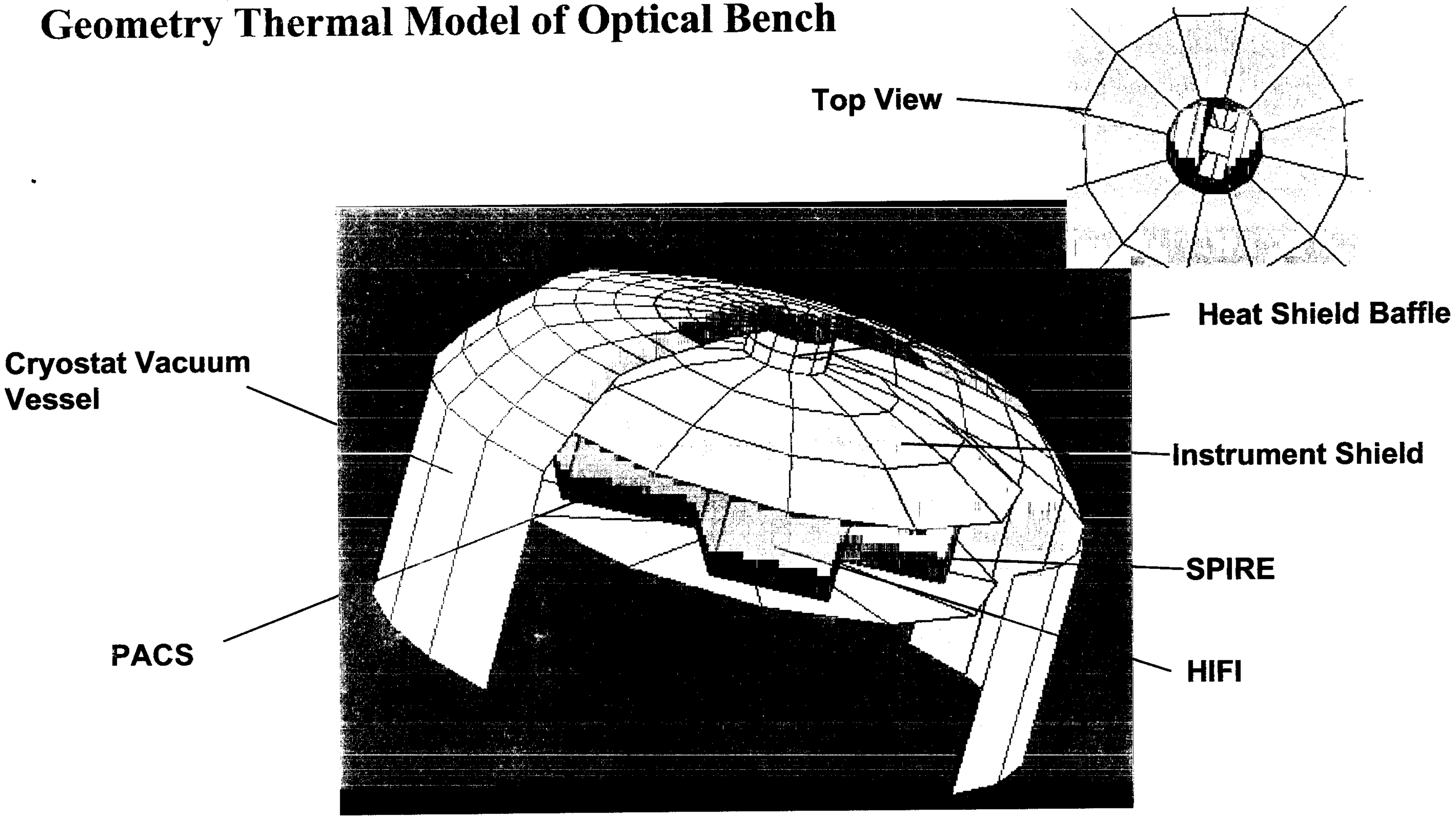


A. Hauser ST41

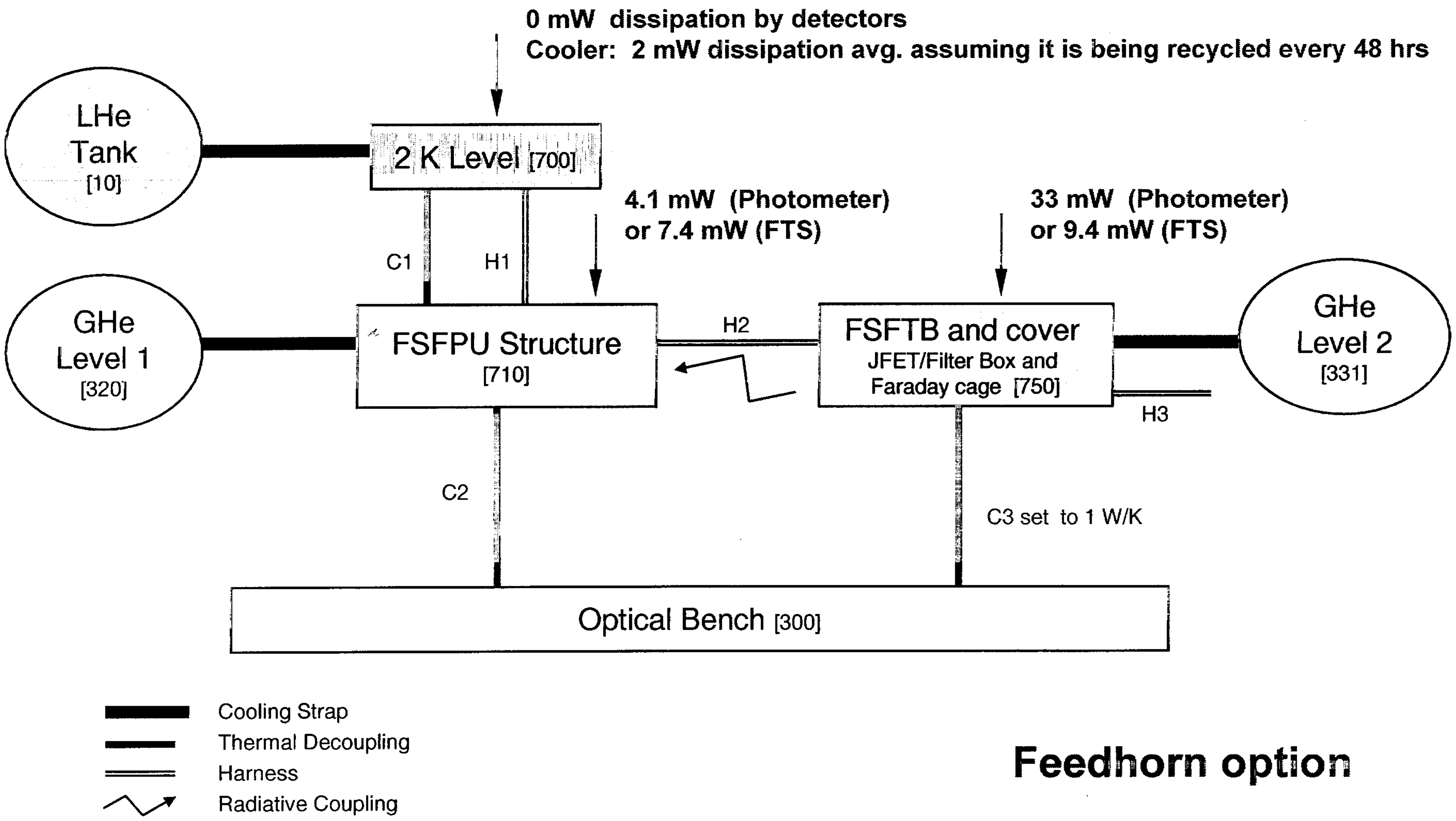
Status of Updated FIRST Thermal Model

- Instruments (PACS, SPIRE, HIFI) included
- Wheel shaped H/X replaced by GHe Level 1
- Instrument I/F to LHe, GHe Level 1 and GHe Level 2 introduced
- Instrument harness updated and disconnected from HS2 and HS3
- Cross section of tank suspension straps increased from 106 mm^2 to 130 mm^2 per strap (tbc)
- Optical Bench support changed from Ti blades to CFRP blades

Geometry Thermal Model of Optical Bench



SPIRE - FPU Thermal Sub Model for FIRST TMM



0 mW dissipation by detectors
Cooler: 2 mW dissipation avg. assuming it is being recycled every 48 hrs

LHe Tank [10]

2 K Level [700]

C1

H1

4.1 mW (Photometer)
or 7.4 mW (FTS)

33 mW (Photometer)
or 9.4 mW (FTS)

GHe Level 1 [320]

FSFPU Structure [710]

H2

FSFTB and cover
JFET/Filter Box and Faraday cage [750]

GHe Level 2 [331]

H3

C2

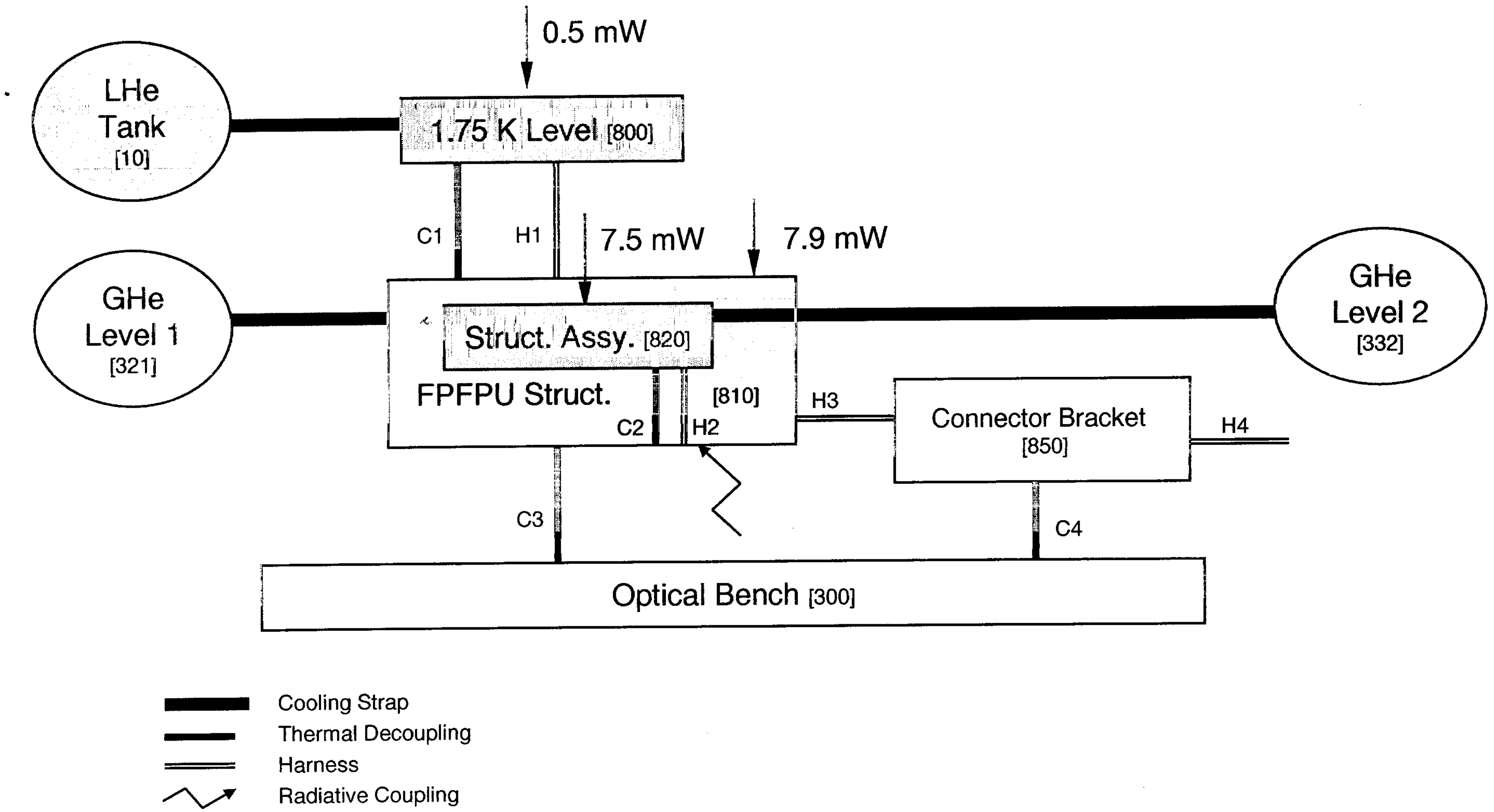
C3 set to 1 W/K

Optical Bench [300]

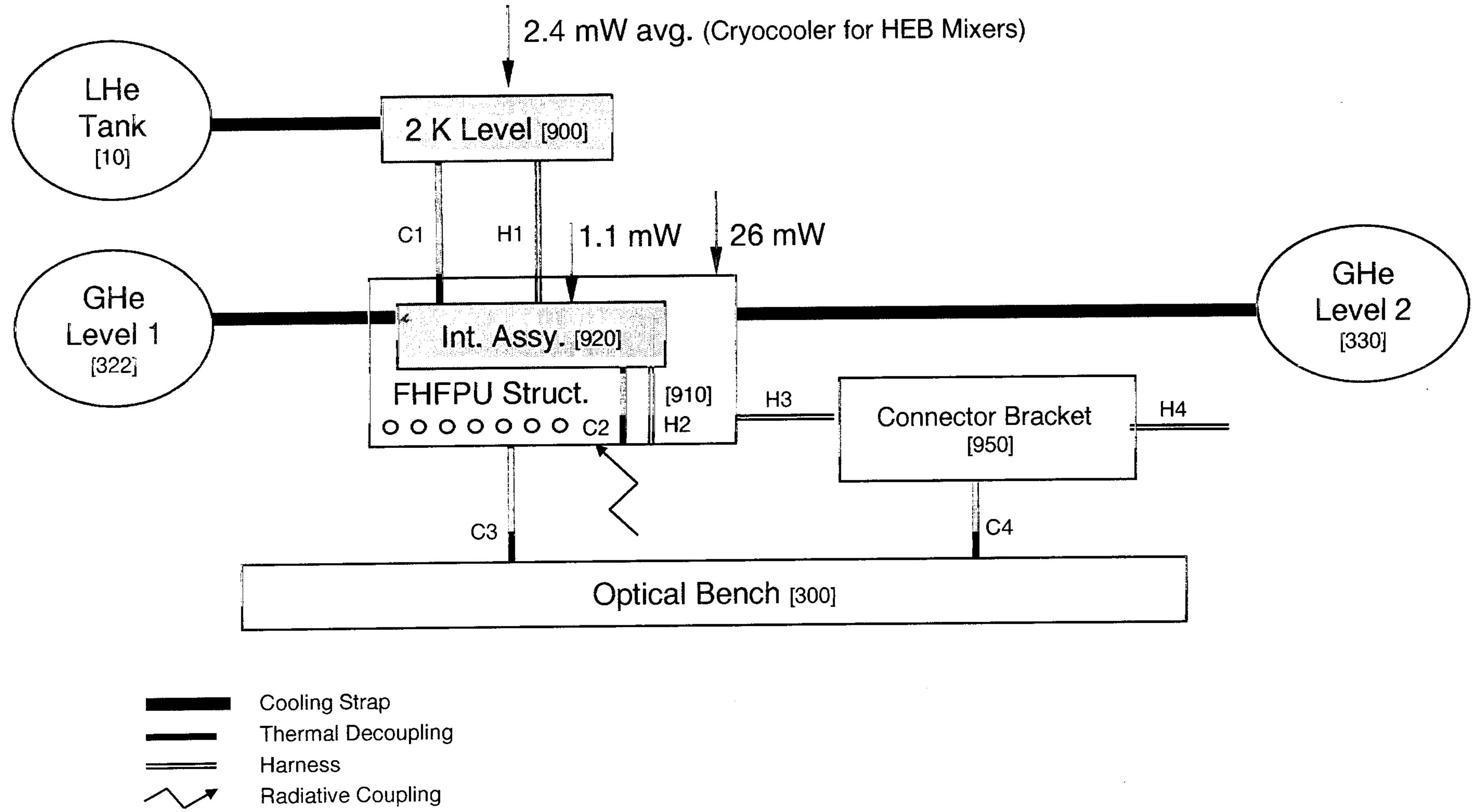
Cooling Strap
Thermal Decoupling
Harness
Radiative Coupling

Feedhorn option

PACS - FPU Thermal Sub Model for FIRST TMM



HIFI - FPU Thermal Sub Model for FIRST TMM



2.4 mW avg. (Cryocooler for HEB Mixers)

LHe Tank [10]

2 K Level [900]

C1

H1

1.1 mW

26 mW

GHe Level 1 [322]

Int. Assy. [920]

FHFPU Struct.

[910]

C2

H2

H3

Connector Bracket [950]

H4

GHe Level 2 [330]

C3

C4

Optical Bench [300]

Cooling Strap
Thermal Decoupling
Harness
Radiative Coupling

Input Data for FIRST TMM Update (1)

Item	Node	Material / Component	Mass	Size	Dissipation		Emiss.	Temp.
					On	Off		
LHe Tank	10							
Spatial Framework	200-213	CFRP struts						
Optical Bench	300	CFRP honeycomb panel (tbc)	40 kg	D=1.63m,H=70mm,2.5mm skins			1.0	
		4 CFRP blades (tbc)		cross sect.: 4x46mm^2, l=30mm				
Instrument Shield	310	Al cover		thickness: 0.8 mm			0.05	
GHe Ventline Level 1	320-322	Al tube	0.5 kg	D=14 mm, d=12 mm				
		CFRP brackets		cross sect.: 52mm^2, l= 57.5 mm				
GHe Ventline Level 2	330-332	Al tube	0.5 kg	D=14 mm, d=12 mm				
		CFRP brackets		cross sect.: 40mm^2, l= 17.5 mm				
Heat Shield Baffles	1050 2050 3050			260 mm diameter			0.78	
SPIRE 2K Level	700	thermally equivalent to Al	7.0 kg		2 mW	2 mW		
		3 Stainless steel blades (mech. supp.)		cross sect.: 60 mm^2, l=0.03m				
		Harness to FSFPU		SPIRE H1, see next table	negligible	0		
		Cooling strap to LHe tank [a]		cross sect.: (20x3)mm, l=0.4m				
SPIRE FSFPU	710	Al casing/structure	23.5 kg	simplified box: 690x410x410mm	4.1/7.4mW [b]	[b]	0.2	
		4 CFRP blades (mech. supp.)		cross sect.: 400 mm^2, l=0.04m				
		Harness to FSFTB		SPIRE H2, see next table	negligible	0		
		Cooling strap to GHe ventline Level-1 [a]		cross sect.: (20x1)mm, l=0.3m				
SPIRE FSFTB & Cov.	750	JFET/ Filter Box (Al)	2.5 kg	simplified box: 300x100x100mm	33/9.4 mW [b]	[b]	0.2	
		Faraday Cage (Al)	1.0 kg					
		Thermal Coupl. to OB (tbd)						
		Harness to shield 1	kg	SPIRE H3, see next table	0.26 mW			
		Cooling strap to GHe ventline Level-2 [a]		cross sect.: (20x1)mm, l=0.3m				
PACS 2K level	800	thermally equivalent to Al	6 kg		0.5 mW			
		6 Kevlar struts (mech. supp.)		cross sect.: 240mm^2, l=60mm				
		50 Kapton supports		cross sect.: 96mm^2, l= 5mm				
		Harness to FPFPU		PACS H1, see next table				
		Cooling strap to LHe tank		cross sect.: (20x1)mm, l=0.4m				

Input Data for FIRST TMM Update (2)

PACS FPFPU	810	thermally equivalent to Al 6 CFRP struts to OB Harness to PACS connect. bracket Cooling strap to GHe ventline Level-1 [a]	50 kg	simplified box: 690x410x410mm Apertures with filters: 0.002 m^2 cross sect.: 2460mm^2, l=420 mm PACS H3, see next table cross sect.: (20x1)mm, l=0.3 m	7.9 mW 5.62mW	0	0.05 0.1	
PACS Struct. Assy.	820	thermally equivalent to Cu 6 Kevlar struts (mech.supp. to FPFPU) Harness to FPFPU Cooling strap to GHe ventline Level-2 [a]	1 kg	cross sect.: 22mm^2, l= 20mm PACS H2, see next table cross sect.: (20x1)mm, l=0.3m	7.5 mW 5mW	0		
PACS connector bracket	850	harness to shield 1	1.5 kg	PACS H4, see next table	8.81 mW	0		
HIFI 2K level	900	thermally equivalent to Cu Vespel support & harness Cooling strap to LHe tank [a]	0.26 kg	1.1 mW/K cross sect.: (20x3)mm, l=0.4m	2.4 mW	2.4mW		
HIFI FHFPU	910	Al casing/structure Harness to HIFI connector bracket Cooling strap to GHe ventline Level-2 [a]	50 kg	box: 400x310x372mm* 0.009 m^2 Apertures (LO port) 0.005 m^2 Aperture (M3 at +Y) HIFI H3, see next table cross sect.: (20x1)mm, l=0.3m	26 mW		0.05 1.0 1.0	
HIFI Internal Assy	920	Al structure Vespel support & harness Cooling strap to GHe ventline Level-1 [a]	1 kg	0.55 mW/K cross sect.: (20x1)mm, l=0.3m	1.1 mW			
HIFI connector bracket	950	harness to shield 1		HIFI H4, see next table PTFE, l=1.2m	11.4 mW	0		

a) Cu 99.99 as baseline material, Al99.999 as option

b) Photometer / FTS for Feed Horn Option

Note: Instrument internal harness w/o margin. All other harness with 20% margin (cross section and dissipation)

Summary of Harness Data for FIRST TMM Update

Harness	Length	Dissipation	Stainl. St.	Brass	CuBe	PTFE	Kapton	Remark
	m	mW	mm^2	mm^2	mm^2	mm^2	mm^2	
SPIRE H1	0.15	~0	6.72				106	
SPIRE H2	0.15	~0	6.72				106	
SPIRE H3	1.2	0.26	18.5	8.78		222		
PACS H1	0.3 0.005	8µW ~0	0.064 0.58			0.17		
PACS H2	0.5	0.5		0.4		2		
PACS H3	0.3	5.62	27.5	4.08		262		
PACS H4	1.2	8.81	27.5	4.08		262		
HIFI H1			1.1 mW/K @ 3.0 K including mechanical supports					
HIFI H2			0.55 mW/K @ 9.5 K including mechanical supports					
HIFI H3	0.3	2.85	15.2	0.54	0.34	58.7		L=0.3 m assumed
HIFI H4	1.2	11.4	15.2	0.54	0.34	58.7		
CVV–HS1 X2	0.25	1.41	53.7	13.4	0.98	542.3		

Note: 20% Margin (cross section and dissipation) included for X2 and all H3 and H4

Preliminary Results and Next Steps

- Lower Optical Bench temperature using CFRP blade coupling to spatial framework
- Level 1 Temperature: 3.1 K - 4.1 K
- Level 2 Temperature: 6.2 K - 9.1 K
- Lifetime reduced to about 4.5 years

Next Steps:

- Update of cross sections of tank suspension and Optical Bench fixation, if necessary
- Implementation of BAU and update of LOU
- Transient analysis:
  SPIRE on → SPIRE off, PACS on → PACS off, HIFI on → HIFI off, SPIRE on

6. Instrument Harness evaluation status

Requirements for Harness OB-Bracket to CVV feedthroughs:

SPIRE:

number of connections (Horn Option): 1116 +180 conductors, with 77 +39 shields
cross-sections (GSFC): 18.5 mm^2 SST, 8.8 mm^2 brass, 222 mm^2teflon (incl.marg.)
ohmic dissipation 0.22 mW/m (incl. margin)

PACS:

number of connections : 686 conductors with 34 shields
cross-sections: 27.5 mm^2 SST, 4.1 mm^2 brass, 261 mm^2 teflon (incl. margin)
ohmic dissipation 7.34 mW/m (incl. margin)

HIFI:

number of connections : 554 conductors with 9 shields
cross-sections: 15.2 mm^2 SST, 0.54 mm^2 brass, 0.34 mm^2 BeCu , 58.7 mm^2 teflon (incl. margin); ohmic dissipation: 9.5 mW/m (incl. margin)

- All instruments have connector brackets on OB (see chapter OB design)
- Routing via OB lower side, to SFWK and via the tank straps to the vacuum connectors
- Wires of instruments distributed to tank straps which are closest
- Required number of connectors on OB and CVV possible to accomodate
- Wires only thermally coupled to shield 1
- Spire-Harness is considered most critical w.r.t number of connections
- Harness length from SPIRE connector bracket to vacuum feedthroughs between 870 and 1400 mm
- About 1200 wires have to be routed via two tank suspension for SPIRE to BAU (46 bundles diameter 2.2 mm with 26 wires each)

Open point:

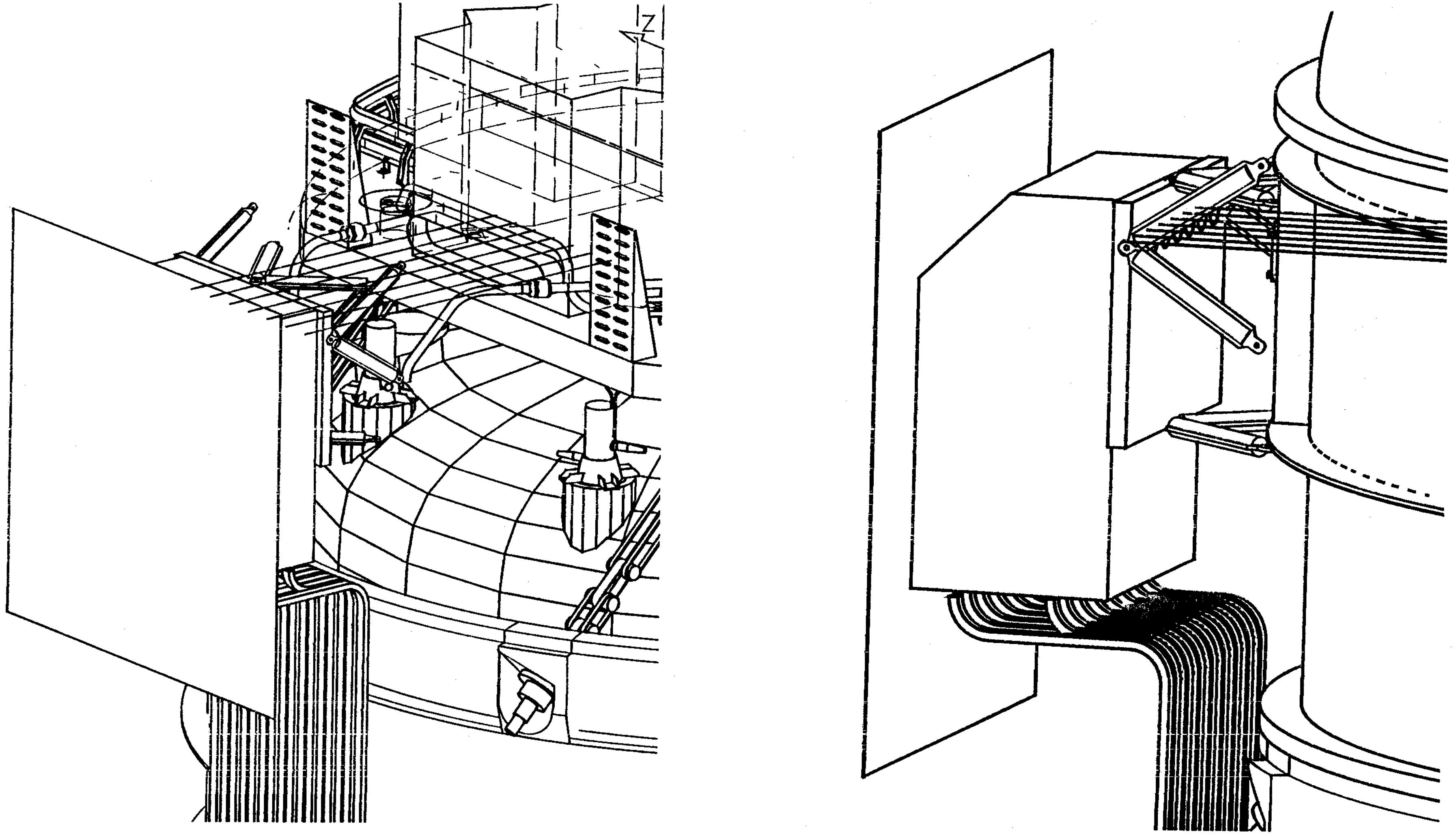
- Vacuum feedthrough technology w.r.t ISO

7. Local Oscillator Unit

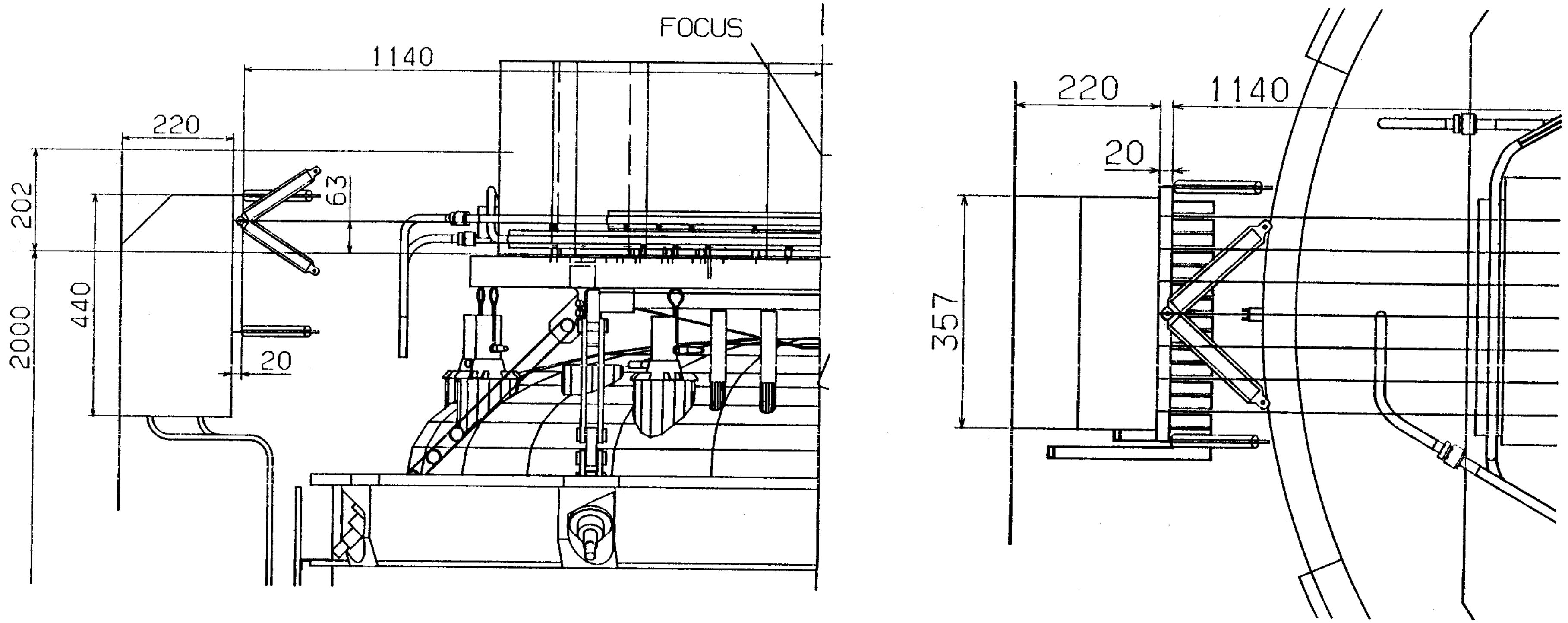
Updated LO requirements (tbc):

Mass	13 kg + radiator mass (?)
Dimension (x, z, y)	440 x 357 x 220 mm
Dissipation	1 W multiplier, 6 & 12 W amplifier
Temperature (goal)	120 K multiplier, 200K amplifier
Temperature stability	?
Alignment w.r.t FPU	±0.8 mm, ± 70 mm, ±0.8mm, ± 0.027°, ± 0.38°, ± 0.027°
Align. stability w.r.t FPU / 100s	±0.08mm, ± 0.002mm, ± 0.08mm, ± 0.003°, ±0.04°, ± 0.003°,
Window diameter	Free inner diameter 30 mm, distance 50mm
Transmission	≥ 90% for each window and filter
Radiator area	2 x 0.25 m²
Waveguides to SVM	tbd

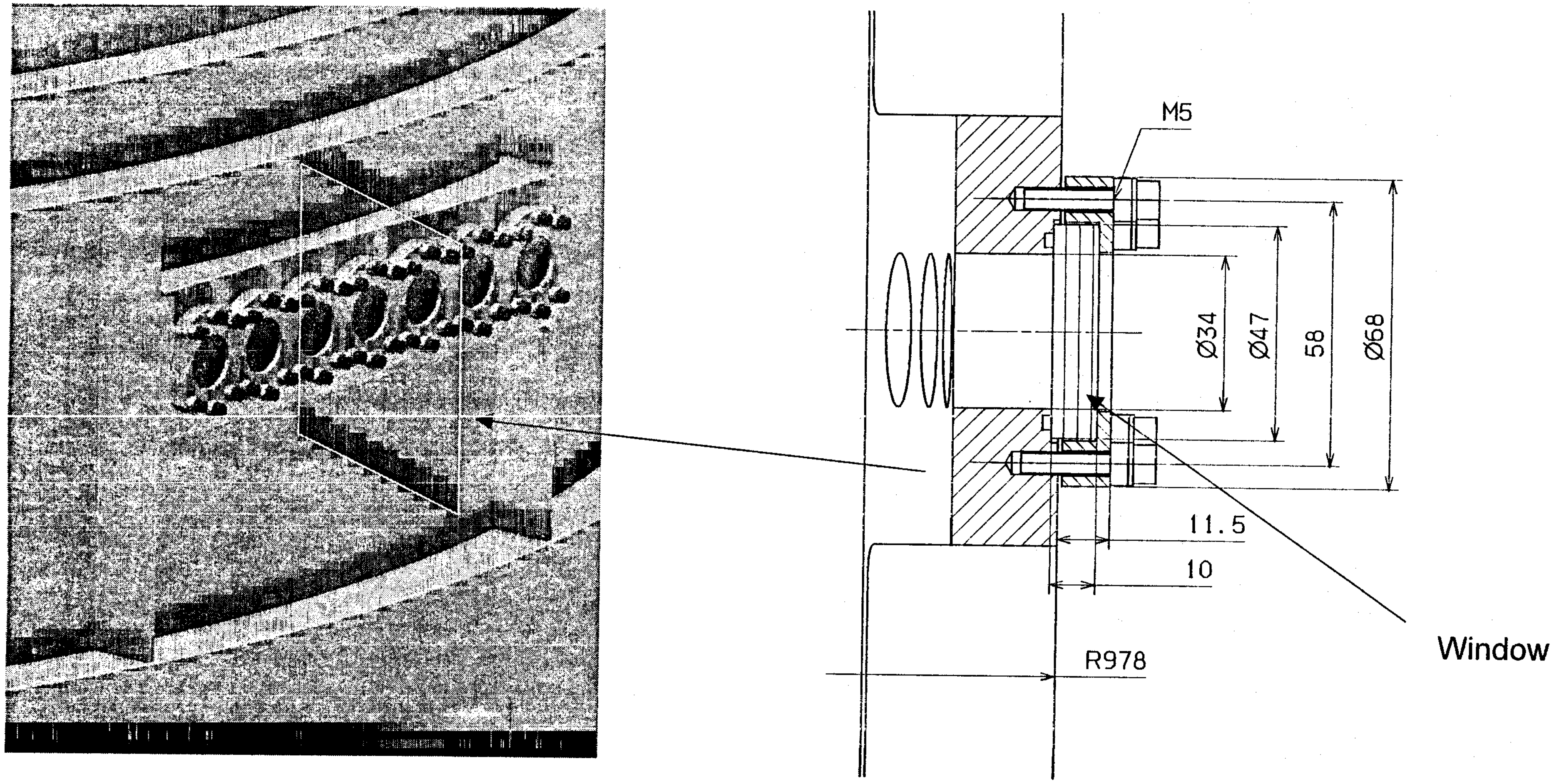
Local Oscillator Unit – Installation Layout



Local Oscillator Unit – Installation Layout



Local Oscillator Unit – Design Concept Optical Windows



LOU Optical Channel

Basic requirements

- outer window has to withstand atmospheric pressure
- One heat filter per channel at cryostat shields
- transmission > 90% per window and per heat filter

LOU Optical Channel

Possibility 1

- **one quartz window** in outer cryostat vessel (about 80K in orbit) and **another quartz window** at one inner shield (30K in orbit)
- use of poly-ethylene anti-reflection coatings on quartz
- inner quartz window with heat filter
- usable diameter = 30 mm
- windows are wedged and tilted by 2° (according to FIRST IID, PT-HIFI-02125)

Possibility 2

- **one quartz window** in outer cryostate vessel (about 80K in orbit) plus **one mesh filter*** on the inner side (30K in orbit)
- use of poly-ethylene anti-reflection coatings on quartz window
- mesh filter as a heat filter
- usable diameter = 30 mm
- quartz window and mesh filter are tilted by 2° , quartz window is wedged (according to FIRST IID, PT-HIFI-02125)

* technique by Peter Ade, Queen Mary and Westfield College, London

LOU Optical Channel

Estimation of window + heat filter transmissions (channel 7)

	Possibility 1	**Possibility 2**
	2 quartz windows	quartz window + mesh filter
Window in cryostat outer vessel	88%	88%
Heat filter	88%	95%
Total	**77%**	**83%**

Remark: informations about mesh filters from Peter Ade

LOU Optical Window

Transmission of window in outer cryostat vessel

quartz window with polyproplene anti-reflection coating

Channel	lower frequency (GHz)	upper frequency (GHz)	required minimum transmission (tbc)	achievable minimum transmission (tbc)
1	480	636	90%	90%
2	640	792	90%	91%
3	792	948	90%	91%
4	960	1120	90%	91%
5	1104	1273	90%	91%
6a	1408	1584	90%	89%
6b	1704	1896	90%	89%
7	2400	2700	90%	88%

Temperature: 80 K

Remark: achievable minimum transmissions tbc by manufacturer!

LOU Optical Window

Transmission budget of window in outer cryostat vessel

quartz window with polyproplene anti-reflection coating

	Channel	**1**	**2**	**3**	**4**	**5**	**6**	**7**
1	transmission loss of quartz window	2%	2%	2%	2%	2%	3%	5%
2	theoretical losses at edges of λ/4 coating	2%	1%	1%	1%	1%	2%	1%
3	-not ideal coating material -change of refractive index over band -change of refractive index (ambient versus 80 K) total	2%	2%	2%	2%	2%	2%	2%
4	manufacturing uncertainty	2%	2%	2%	2%	2%	2%	2%
5	degradation during life-time	2%	2%	2%	2%	2%	2%	2%
	total loss of transmission	**10%**	**9%**	**9%**	**9%**	**9%**	**11%**	**12%**

Temperature: 80 K

LOU Optical Window

Crystal-quartz - Transmission

In literature the following measurement values for the transmission of 6 mm quartz at 2700 GHz

have been found:(quartz is a bire-fringent material):

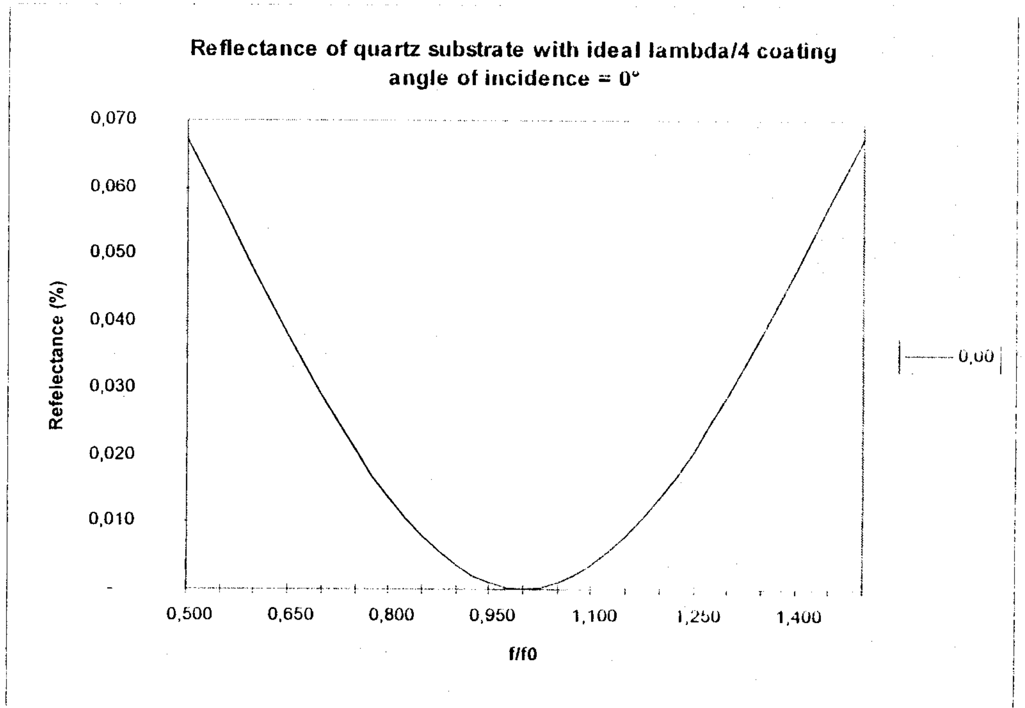
temperature	T (ordinary direction)	T (extra-ordinary)
at 300 K	0.6	0.89
at 10 K	0.985	0.999

Measurements between different literature sources show differences.

No measurements for 80 K have been found yet.

LOU Optical Window

Anti-reflection coatings

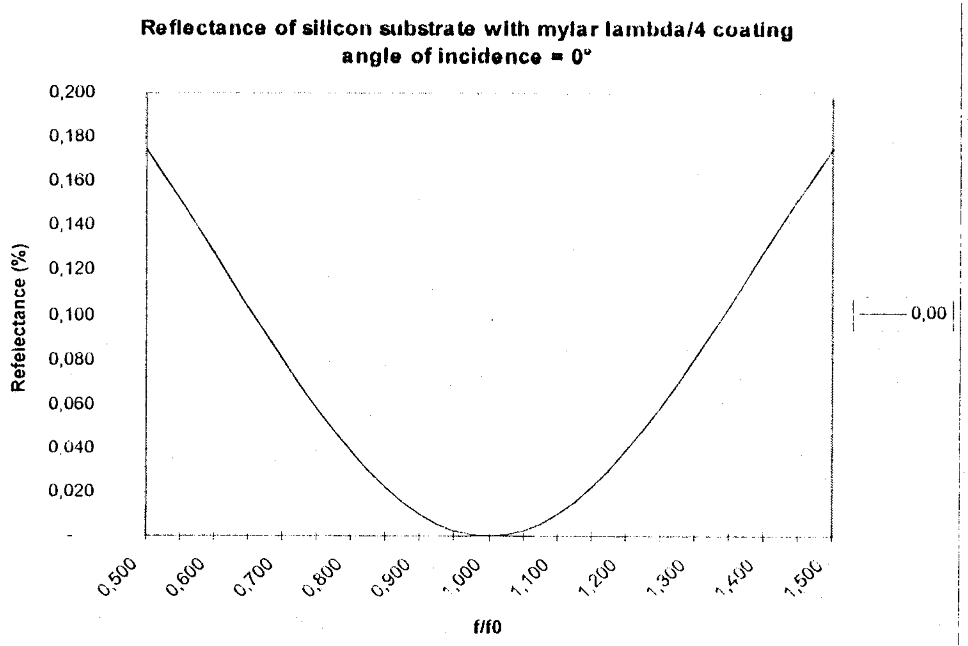


The reflectance of a single $\lambda/4$ anti-reflection layer on a quartz surface ($n = 2.1$) with ideal refractive index ($n = 1.45$) as a function of fre-quency divided by center frequency.
Candidate coating materials: polyethylene ($n = 1.52$), polypropylene ($n = 1.49$) or teflon ($n = 1.44$).

LOU Optical Window

Anti-reflection coatings

Example: Mylar on silicon substrate


Reflectance of silicon substrate with mylar lambda/4 coating
angle of incidence = 0°

The reflectance of a single $\lambda/4$ anti-reflection layer of Mylar ($n = 1.85$) on a silicon substrate ($n = 3.4$) as a function of frequency divided by center frequency.

LOU Optical Window

Anti-reflection coatings

The following materials are candidates for AR-coatings:

- paraffine (n = 1.40)
- teflon (n = 1.44)
- TPX (n = 1.47)
- Polyethylene (n = 1.52)
- Polypropylene (n = 1.49)
- Polystyrene (n = 1.60)
- Parylene (n = 1.63)
- Mylar (n = 1.85)

The coating must be mechanically and optically qualified for operating temperatures

FPUs to CVV Integration and Alignment Sequence

- Integration of the **3 FPUs on Optical Bench (OB)** and Alignment to OB reference cube.

- Integration of OB into CVV (w/o upper dome) and **coarse alignment of OB to CVV**.

- Mounting of CVV upper dome and **fine alignment of OB/HIFI wrt**
  - **the 7 LOU-windows** - using LOU/HIFI alignment channels - and
  - the CVV reference cube (when closed, cover window required)

- **Integration of LOU** on lateral CVV framework and alignment to HIFI - using LOU/HIFI alignment channels

- **Alignment check in cold cond**itions using cover window and LOU/HIFI alignment channels

LOU to HIFI Alignment

The following considerations are made to:

1.) establish the achievable instrument alignment budget (driver: LOU to HIFI alignment accuracy)

2.) derive the requirement on the optically free LOU-windows size based on the requirement to guarantee an optically free 30mm diameter for the LOU beams in operating conditions

Allowed tolerances of LOU to HIFI alignment:

Xrot	Yrot	Zrot	Xpos	Ypos:	Zpos
± 0.027deg	± 0.38deg	± 0.027deg	± 0.8mm	± 70mm (uncritical)	± 0.8mm

Contributions to alignment budget:

1. Alignment accuracy of HIFI to LOU-windows (through LOU-alignment windows)
2. Alignment accuracy of LOU to HIFI (through the LOU-alignment windows)
3. Structural deviations (ISO experience)

Alignment accuracy of HIFI to LOU- windows

(Rotations are measured by autocollimating theodolite to the normals on the 2 LOU-alignment windows, located left and right of the 7 LOU-IR windows. Positions are measured relative to reticles on the same windows).

Xrot and Zrot uncertainties:

1	unknown deviation of HIFI cube normal from nominal position (TBC by HIFI)	± 0.001deg)*	
2	unknown deviation of LOU-alignment window normal from nom. pos.	± 0.001deg	
3	measurement uncertainty on HIFI cube	± 0.001deg	
4	measurement uncertainty onLOU-alignment window normal	± 0.001deg	
5	HIFI adjustment resolution	± 0.001deg	
	Total rot uncertainty 2 to 5 (worst case)	**± 0.004deg**	
	Xrot, Zrot: ± 0.004deg correspond to a **linear error** at LOU-window position of		**± 0.02 mm**
	Yrot calculated from position uncertainty beneath (± 0.5mm on 300mm)	± 0.1deg	

Xpos and Zpos uncertainties:

1	unknown deviation of HIFI marks from nominal position (TBC by HIFI)	± 0.1mm)*
2	unknown deviation of LOU-alignment window marks from nom.pos.	± 0.1mm
3	measurement uncertainty on HIFI marks	± 0.1mm
4	measurement uncertainty on LOU-alignment window marks	± 0.1mm
5	manufacturing tolerances of window positions to each other	± 0.1mm
6	HIFI adjustment resolution	± 0.1mm
	Total pos uncertainty 2 to 6 (worst case)	**± 0.5mm**

)* not considered on LOU to LOU- window Alignment Budget

Ypos: uncritical

Alignment accuracy of LOU to HIFI

(Sequence: LOU is adjusted to HIFI through the LOU-alignment windows. Afterwards LOU alignment to LOU-alignment windows is checked).

Xrot and Zrot uncertainties:

1	unknown deviation of LOU cube normal from nominal position (TBC by HIFI)	± 0.001deg)**	
2	unknown deviation of HIFI cube normal from nominal position (TBC by HIFI)	± 0.001deg)*)**	
3	measurement uncertainty on LOU cube	± 0.001deg	
4	measurement uncertainty on HIFI cube	± 0.001deg	
5	LOU adjustment resolution	± 0.001deg	
	Total rot uncertainty (LOU to LOU-windows) 1, 3, 4, 5 (worst case):	**± 0.004deg**	
	Total rot uncertainty (LOU to HIFI) 3, 4, 5 (worst case):	**± 0.003deg**	
	Xrot, Zrot: ± 0.003deg correspond to **a linear error** at LOU window position of		**± 0.02mm**
	Yrot calculated from position uncertainty beneath (± 0.4mm on 300mm) ~	± 0.1deg	

Xpos and Zpos uncertainties:

1	unknown deviation of LOU marks from nominal position (TBC by HIFI)	± 0.1mm)**
2	unknown deviation of HIFI marks from nominal position (TBC by HIFI)	± 0.1mm)*)**
3	measurement uncertainty on LOU marks:	± 0.1mm
4	measurement uncertainty on HIFI marks:	± 0.1mm
5	LOU adjustment resolution:	± 0.1mm
	Total pos uncertainty (LOU to LOU-windows) 1, 3, 4, 5 (worst case):	**± 0.4mm**
	Total pos uncertainty (LOU to HIFI) 3, 4, 5 (worst case):	**± 0.3mm**

)* not considered on LOU to LOU-IR window Alignment Budget)** not considered on LOU to HIFI Alignment Budget

Ypos is uncritical

Structural experience from ISO

No	ITEM	Rot.	Pos.
1	Expected **rotational** ground to orbit transition effect on LOU (Zrot only)	+ 0.015deg)*	
2	Settling effects derived from TV test (Xrot, Yrot, Zrot)	0.02deg	
	Sum: 1 + 2 (worst case) (Zrot only) Sum: 1 + 2 (worst case) (Xrot, Yrot)	± 0.035deg)** ± 0.02 deg	^ 0.2 mm ^ 0.12mm
3	Expected **position** ground to orbit transition effect on LOU (assessment)		0.2 mm)*
4	Uncertainty of shrinking effect of vacuum vessel		± 0.2 mm)***
	Total position uncertainty (worst case) (Zrot) **Total position uncertainty (worst case) (Xrot, Yrot)**		**± 0.6 mm** **± 0.52 mm**

)* due to in orbit change of: 1.) outer CVV temperature and straps pretension, 2.) gravity, 3.) atmospheric pressure (can be compensated to some extent by precompensation)

)** leads to a **linear offset** at the LOU windows of **0.2mm** (~330mm distance) [for determination of the required LOU window diameters the linear LOU beam offset (translation value) is the crucial figure!]

)***shrinking effect of Al for the expected ΔT: 0.004 (4 ‰) is known with an accuracy of 5%; assumed length: 900mm; shrinking consequently: 3,6mm; shrinking uncertainty: 5% of 3,6mm = 0.2mm

Alignment Budgets

LOU to HIFI

Allowed tolerances of LOU to HIFI alignment					
Xrot	Yrot	**Zrot**	**Xpos**	Ypos:	**Zpos**
±0.027deg	±0.38deg	**±0.027deg)***	**± 0.8mm**	±70mm (uncritical)	**± 0.8mm**
Calculated accuracy of LOU to HIFI alignment					
±0.003deg	±0.1deg	±0.003deg	±0.32mm		±0.32mm
Structural uncertainty					
±0.02deg	±0.02deg	±0.02deg)*	±0.52mm	±0.52mm	±0.4mm)**

)* precompensation of 0.015 deg applied **)** precompensation of 0.2 mm applied**

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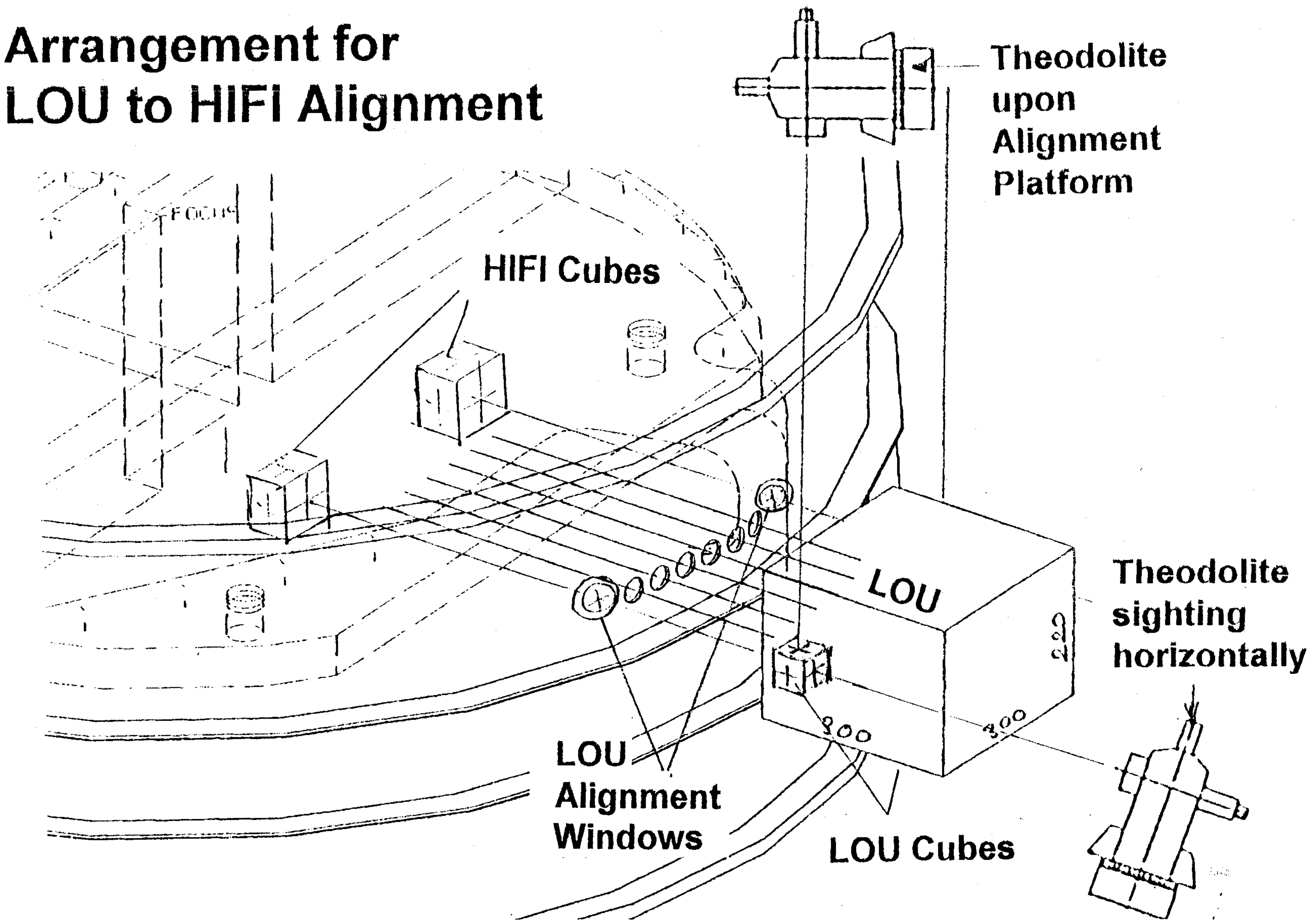
Size of LOU windows

Worst case position uncertainties of LOU Beams to LOU windows (Xpos, Zpos) are derived to obtain the really needed free LOU-IR-windows diameters on the basis of a free 30mm diameter for the LOU beams taking into account possible alignment errors and structural uncertainties.

1	**HIFI alignment to LOU-alignment windows on CVV**	
	* worst case position error of HIFI to LOU-windows is:	**± 0.5 mm**
	* contribution of HIFI rotation error to LOU-windows is:	**± 0.02mm**
2	**LOU to HIFI alignment**	
	* worst case position error of LOU to HIFI is:	**± 0.4 mm**
	* contribution of LOU rotation error of LOU to HIFI is:	**± 0.02mm**
3	**Uncertainty derived from ISO structural experience**	**± 0.6 mm**
4	**Shift of LOU Beam due to LOU-IR-window tilt (3°))***	**± 0.16 mm**
	Total uncertainty (worst case)	**± 1.7 mm**
	Total uncertainty (worst case) inclusive margin	**± 2 mm**
	To guarantee a free LOU-window diameter of 30mm at operational conditions, the actually needed **LOU-window size** has to be increased in diameter by 4 mm	**34 mm**

)* Quartz window 6mm thick, 3deg tilt, $n = 2.1$ for far IR ($v=\varepsilon*d*(n-1)/n$) (can be precompensated!)

4. Arrangement for LOU to HIFI Alignment



LO waveguides:

- Have to be elastic to compensate
  - differential movement between LO and CVV and between CVV and SVM during vibration
  - different thermal expansion between waveguides and CVV, SVM
- Minimum heatinput to CVV (shall be < 0.1 W) by using suited materials (e.g. SST or CFRP) and insulating from CVV

Next steps:

- Mechanical analyses of LO support
- Thermal Analyses of LO (taking into account TMM of B. Collaudin)

8. Input to IID A update (proposal)

- Mounting, Dismounting of all instruments shall be independant from each other
- The mounting interfaces areas of the OB (diameter 120 mm) shall be accessible at all integration levels (i.e. not covered by instruments)
- No forces due to thermal expansions of instruments shall be applied to the optical bench

9. AOB