Status of the SPL cryo-module development

(report from WG3)

V.Parma,
CERN, TE-MSC

Outline

- Reminder of the frame of WG3
- Cryomodule Specification meeting (19 th September last)
- Recent advances:
- Summary and outlook

Short cryo-module: Goal & Motivation

Goal:

- Design and construct a ½-lenght cryo-module for 4 β=1 cavities

Motivation:

- Test-bench for RF testing on a multi-cavity assembly driven by a single or multiple RF source(s)
- Enable RF testing of cavities in horizontal position, housed in their helium tanks, tuned, and powered by machine-type RF couplers
- Validate by testing critical components like RF couplers, tuners, HOM couplers in their real operating environment

Cryo-module-related goals:

- Validation of design
  - Innovative supporting of cavities via the RF couplers
- Learning of the critical assembly phases:
  - handling of long string of cavities with complete RF coupler
  - alignment/assembly in the cryostat
- Validation through operational experience:
  - Cool-down/warm-up transients and thermal mechanics
  - Gas-cooled RF coupler double-wall tube
  - Alignment/position stability of cavities
  - Cryogenic operation (He filling, level control, etc.)

Working group (WG3)

System/Activity	Responsible/member	Lab
Machine architecture	F.Gerigk	CERN
WG3 coordination	V.Parma	CERN
Cryo-module conceptual design	V.Parma. Team: N.Bourcey, P.Coelho, O.Capatina, D.Caparros, Th.Renaglia, A.Vande Craen	CERN
Cryo-module detailed design & Integration CNRS	P.Duthil (P.Duchesne) + CNRS Team	CNRS/IN2P3-Orsay
Cryostat assembly tooling	P.Duthil (P.Duchesne)	CNRS/IN2P3-Orsay
WG 2 activity (RF cavities/He vessel/tuner, RF coupler)	W.Weingarten/S.Chel/O.Capatina/ E.Montesinos	CERN, CEA-Saclay
Vacuum systems	S.Calatroni	CERN
Cryogenics	U.Wagner	CERN
Survey and alignment	D.Missiaen	CERN

Main contributions for short cryo-module

Institute	Supply
CEA – Saclay (F)	1. Design of **β=1 cavities** (EuCARD task 10.2.2) 2. Design & construction of **4 helium vessels for β=1 cavities** (French in-kind contribution) 3. Supply of **4 (+4) tuners** (French in-kind contribution) 4. Testing of RF couplers
CNRS - IPN – Orsay (F)	1. Design and construction of **prototype cryomodule cryostat** (French in-kind contribution) 2. Design & construction of **cryostat assembly tools** (French in-kind contribution)
Stony Brook/BNL/AES team	*(Under DOE grant)* 1. Designing, building and testing of **1 β=1 SPL cavity**.
CERN	**1. 4 (+4) β=1 cavities**
CERN	**1. 4 (+5) RF couplers**

Goal of the cryomodule spec meeting

(CERN 19th September 2010)

- Identify and address still outstanding cryo-module design specification issues
- Address the specific requirements related to the test program of the short cryomodule at CERN (for ex. : windows for in-situ intervention, need for diagnostics instrumentation, etc.).
- Converge towards a technical specification to allow the continuation of the engineering of the short cryo-module, or identify road-maps to settle outstanding issues.
- Engineering Specification in preparation at CERN (end 2010)

20 participants from: CEA-Saclay, CNRS-IPN, JLAB, SNS, FNAL, ESSS and CERN

http://indico.cern.ch/conferenceDisplay.py?confId=108640

Cavity alignment requirements

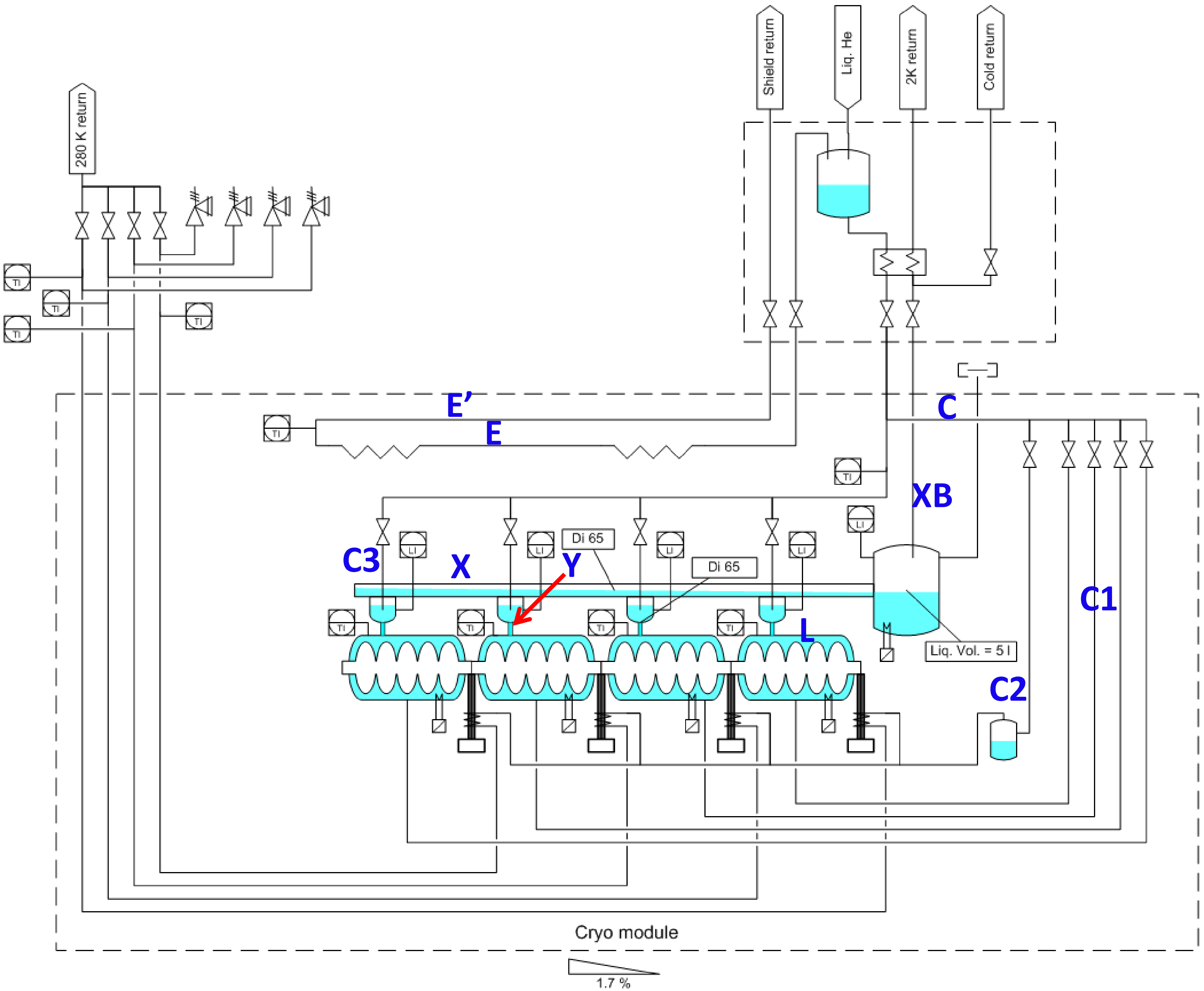
Transversal position specification

BUDGET OF TOLERANCE			
Step	**Sub-step**	**Tolerances (3σ)**	**Total envelopes**
Cryo-module assembly	Cavity and He vessel assembly	*± 0.1 mm*	Positioning of the cavity w.r.t. external referential **± 0.5 mm**
	Supporting system assembly	*± 0.2 mm*	
	Vacuum vessel construction	*± 0.2 mm*	
Transport and handling (± 0.5 g any direction)	N.A.	*± 0.1 mm*	Reproducibility/Stability of the cavity position w.r.t. external referential **± 0.3 mm**
Testing/operation	Vacuum pumping	*± 0.2 mm*	
	Cool-down		
	RF tests		
	Warm-up		
	Thermal cycles		

Construction precision

Long-term stability

Cryogenic Scheme

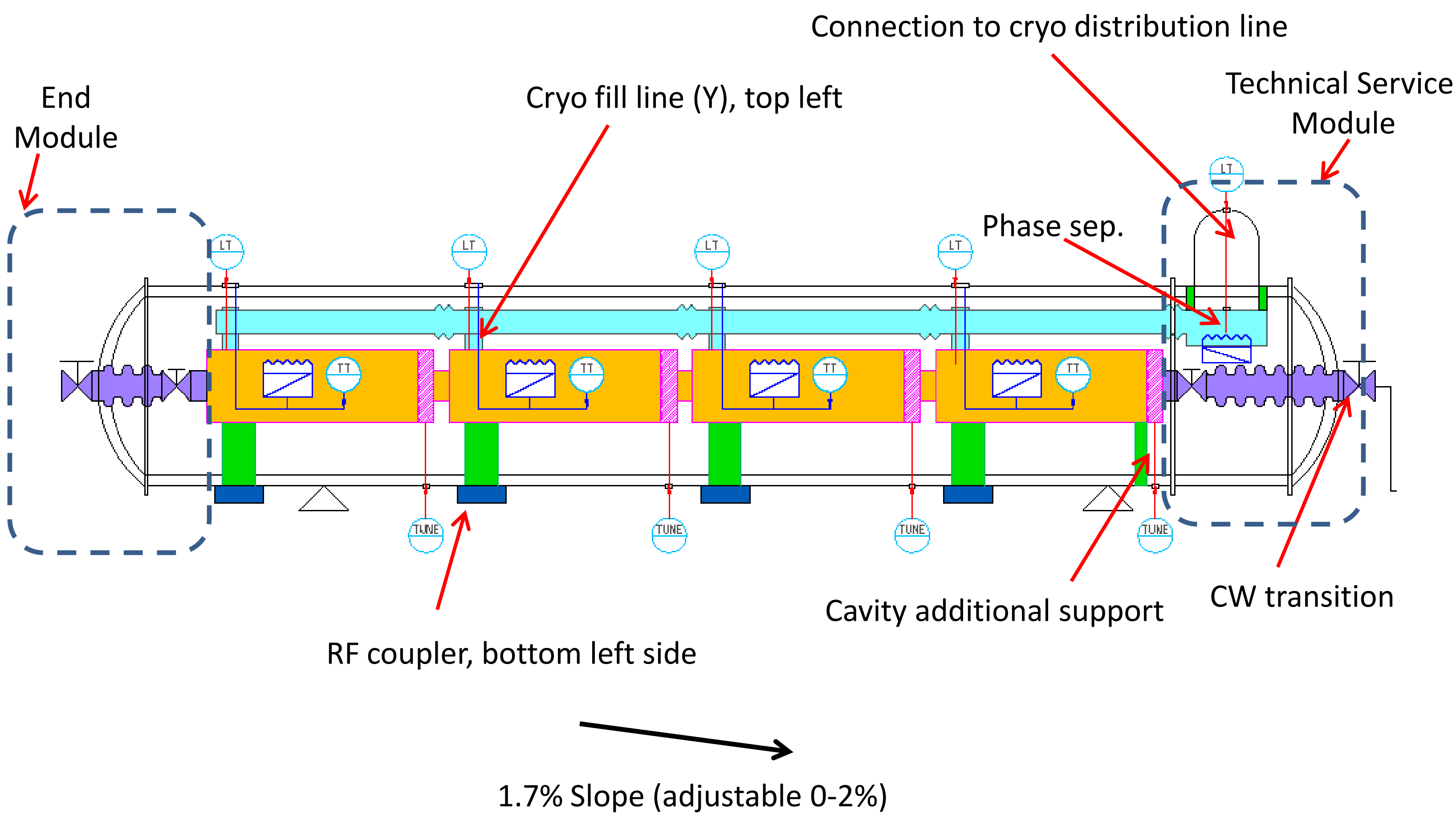


Pipe sizes and T, p operating conditions

Line	Description	Pipe Size (ID,mm)	Normal operating pressure [MPa]	Normal operating temperature [T]	Cool-down/warm-up pressure [MPa]	Cool-down/warm-up temperature [K]	T range [K]	Maximum operating pressure [MPa]	Design pressure [MPa]	Test pressure [MPa]	Comment
L	Cavity helium enclosure	400	0.0031	2	0.13 @ 293K 0.2 @ 2K	293-2	2-293	0.15 @ 293K 0.2 @ 2K	TBD	TBD	
X	Bi-phase pipe	100	0.0031	2	0.13 @ 293K 0.2 @ 2K	293-2	2-293	0.15 @ 293K 0.2 @ 2K	TBD	TBD	
Y	Cavity top connection	80	0.0031	2	0.13 @ 293K 0.2 @ 2K	293-2	2-293	0.15 @ 293K 0.2 @ 2K	TBD	TBD	
XB	Pumping line	100	0.0031	2	0.13 @ 293K 0.2 @ 2K	293-2	2-293	0.15 @ 293K 0.2 @ 2K	TBD	TBD	
E	Thermal shield supply	40 (TBD)	2.0	50-75 (20-40 on test stand?)	2.0	293-50	50-293	2.0	2.0		Heat intercept
E'	Thermal shield return	15 (TBD)	2.0	50-75 (20-40 on test stand?)	2.0	293-50	50-293				Return only
W	Cryostat vacuum vessel	1000 (TBD)	vacuum	293	vacuum	293	237-293	O.P. 0.1	I.P. 0.15	N.A.	
C1	Cavity filling	4	0.1	4.5	0.1	293-4.5	4.5-293				Liquid supply
C2	Coupler cooling	15 (TBD)	0.1	4.5-293	0.1	293-4.5	4.5-293				Gaseous supply
C3	Cavity top supply	6	0.1	2	0.1	293-4.5	2-293				Liquid supply

...a few figures still to be settled

Short cryomodule: layout sketch



Cavity Supporting System

Transversal position specification

BUDGET OF TOLERANCE			
Step	**Sub-step**	**Tolerances (3σ)**	**Total envelopes**
Cryo-module assembly	Cavity and He vessel assembly	*± 0.1 mm*	Positioning of the cavity w.r.t. beam axis **± 0.5 mm**
	Supporting system assembly	*± 0.2 mm*	
	Vacuum vessel construction	*± 0.2 mm*	
Transport and handling (± 0.5 g any direction)	N.A.	*± 0.1 mm*	Stability of the cavity w.r.t. beam axis **± 0.3 mm**
Testing/operation	Vacuum pumping	*± 0.2 mm*	
	Cool-down		
	RF tests		
	Warm-up		
	Thermal cycles		

Construction precision

Long-term stability

2 K Heat Loads (per β=1 cavity)

Operating condition	**Value**	
Beam current/pulse lenght	**40 mA/0.4 ms beam pulse**	**20 mA/0.8 ms beam pulse**
cryo duty cycle	4.11%	8.22%
quality factor	10×10^{9}	5×10^{9}
accelerating field	25 MV/m	25 MV/m

Source of Heat Load	**Heat Load @ 2K**	
Beam current/pulse lenght	**40 mA/0.4 ms beam pulse**	**20 mA/0.8 ms beam pulse**
dynamic heat load per cavity	5.1 W	20.4 W
static losses	<1 W (tbc)	<1 W (tbc)
power coupler loss at 2 K	<0.2 W	<0.2 W
HOM loss in cavity at 2 K	<1	<3 W
HOM coupler loss at 2 K (per coupl.)	<0.2 W	<0.2 W
beam loss	1 W	
Total @ 2 K	**8.5 W**	**25.8 W**

Issues identified and work in progress

Functional/Design requirements:

- Magnetic shielding: 2 level of shielding proposed
  - 1st shield @ cryo T. cryo-perm or other (A4K?). Active cooling? (No, answer today). Interesting solution of Spiral 2 cryo-module (A4K, active cooling)
  - 2nd shield @ RT: remagnetisation of low carbon steel?; mu-metal shield?
- “fast” cool-down (Q desease mitigation): 100 K/h as a goal (though not a specif requirement yet; vertical tests will tell)
- inter-cavity bellows: no active cooling, but T measurement for monitoring

Issues identified and work in progress

Interfaces/operational functionalities:

- Cryostat windows requested for in-situ maintenance (for prototype only) → will need large windows!
  - access to tuners (motors, piezos)
  - access to HOM ports (there are 2)
- Connection to cryo distribution line. Confirmed:
  - Welded solution for connection to the cryo distribution line
  - Flexibility on connection to allow tilt change (0-2%)
- Cryo distribution line in SM18. Supply of 50K helium for thermal shield. Outstanding:
  - This needs an additional distribution line in SM18 or heating of existing supply line.
  - T, p, and He flow rates requiremnts in work
- Clarify warm-up transients and means (heater boil-off of helium, insulation vac.degradation?)
- Cryogenics with and without slope (ESSS specific)
  - Adjustable slope foreseen (0-2%)
  - Redundant cryogenic equipment → simple to complex control possible
  - He liquid connection between cavities (hydrostatic head link) could be added if retained necessary

Issues identified and work in progress

Instrumentation requested for cavity testing:

- He pressure gauge
- lHe level sensors (redundancy)
- temperature-sensors at strategic points (bellows, magnetic shield, HOM couplers, power coupler
- 8 HOM couplers with (broadband) feedthrus and RF cables to room temperature loads (rated 100 W) sufficiently thermally anchored
- pressure gauges for cavity vacuum (outside cryostat) and insulation vacuum
- 4 heaters inside He tank (among others used for measurement of Q-value)

Issues identified and work in progress

Instrumentation for cryogenics/cryo-module purpose:

- Alignment Monitoring System: choice pending
  - On-line monitoring movements and vibrations of the Cold Mass (CM) during cool down and steady state operation
  - Requires referentials on helium vessel

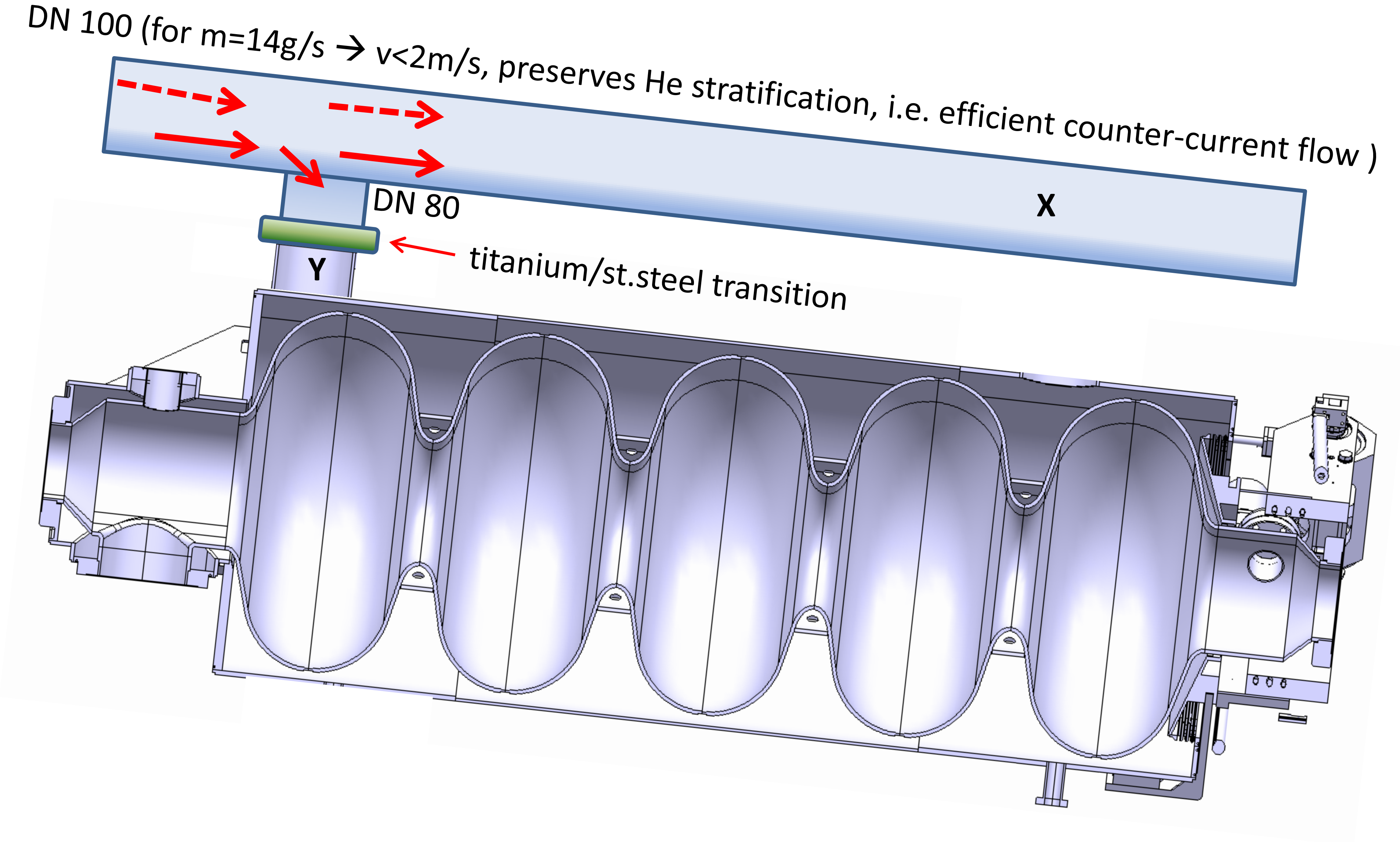
- Measurements of HL (static/dynamic) @ 2K
  - Pressure gauge measurement in 2K circuit → leak-tight feed-thru
  - He flow-meter would be useful
  - T gauge in He bath (not strictly necessay) but would be useful

- Cryogenic operation instrumentation:
  - 25 W electrical heaters in helium bath: 1 per cavity, 1 in Phase Separator
  - He level gauge: 1 per cavity, 1 in Phase Separator → needs to be in He bath so needs leak-tight feedthru
  - T gauge: 1per cavity (could be outside He vessel)

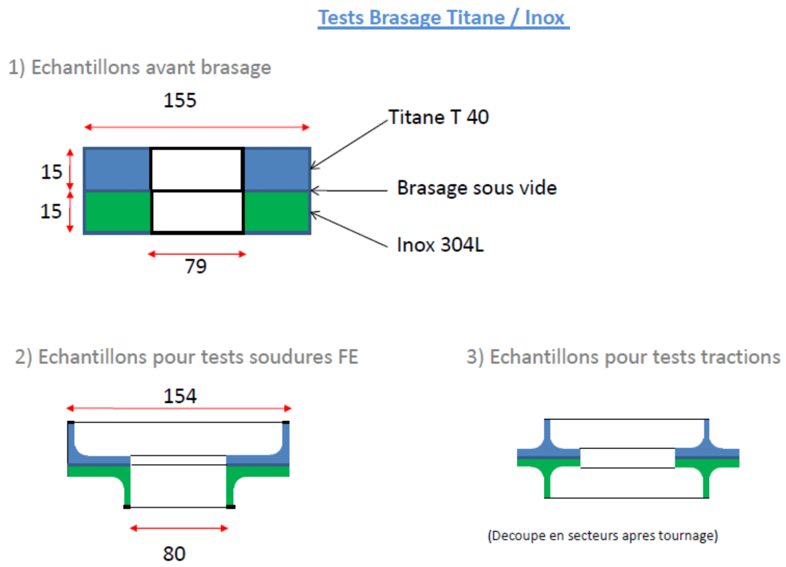
- Temperature mapping of cryostat cold components: T gauges (in insulation vacuum)
  - RF coupler double-walled tube (several locations)
  - Tuner mechanical parts (normally badly thermalised, slow transients)
  - Thermal shielding temperature mapping
  - …I estimate about 75-100 T gauges! → wires/routing/feed-through flanges

We cannot avoid 2K bath instrumenation (P and level gauges) → leak-tight feedthrough needed

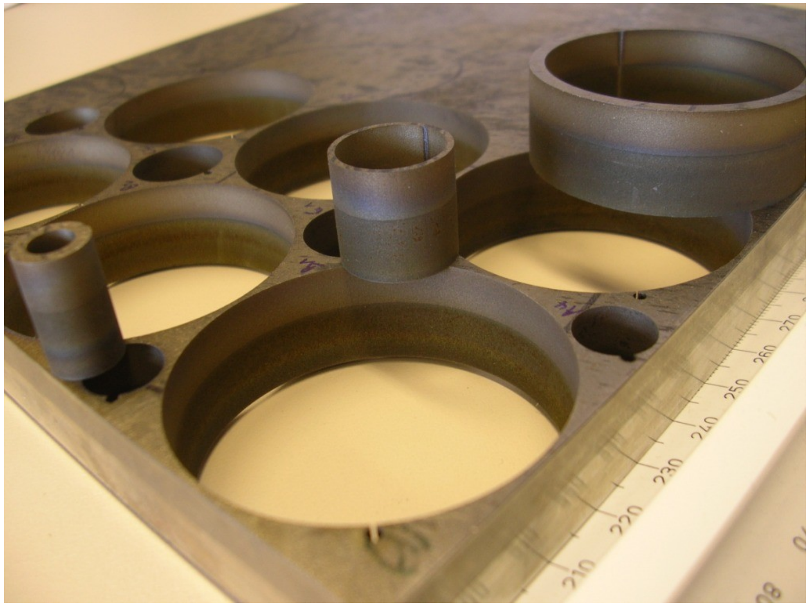
Lines X (st.steel) and Y (Ti): transitions



Brazed and bi-metallic samples



Brazing samples, (S.Mathot, EN/MME)



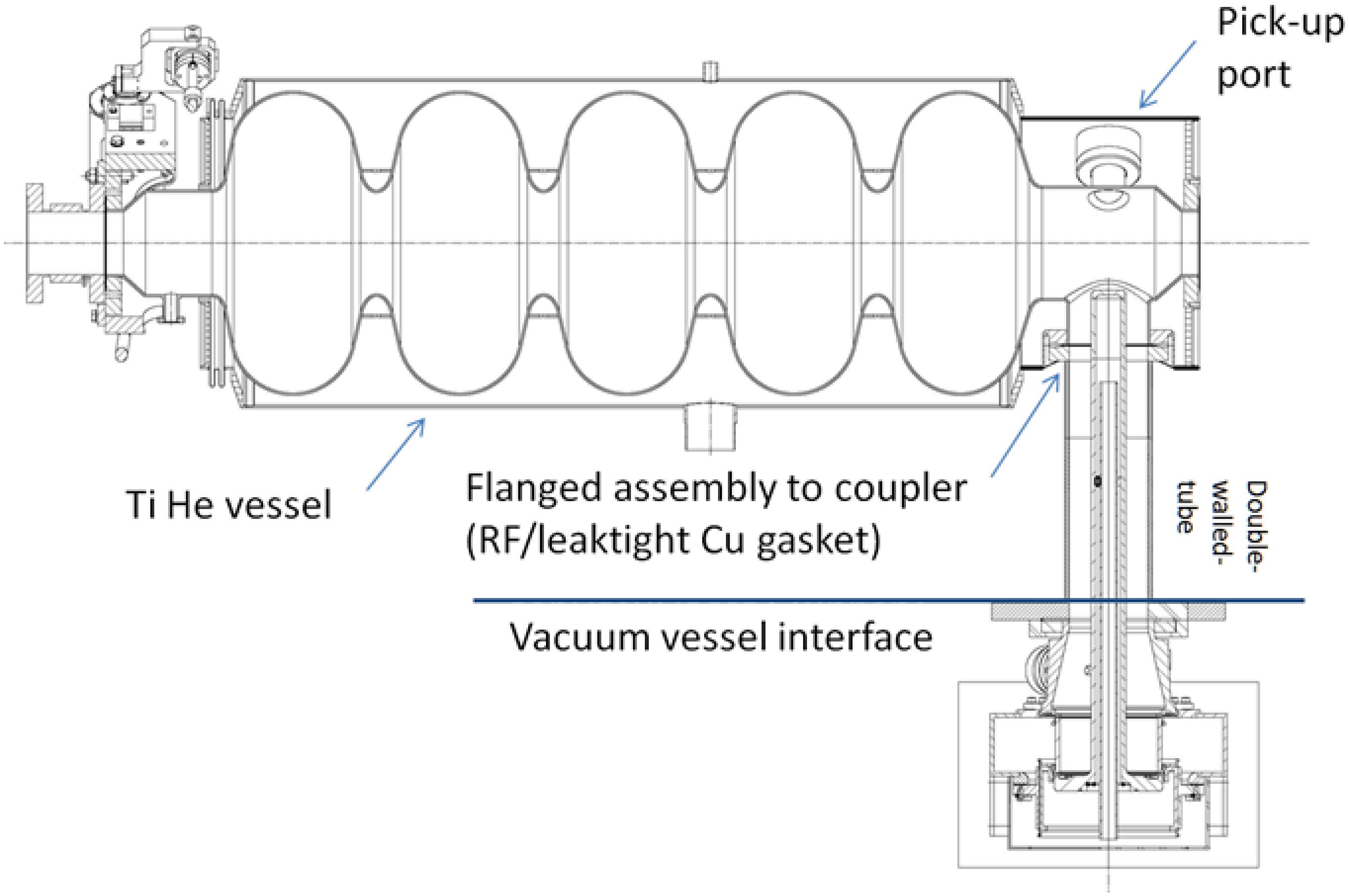
Tube samples from explosion bonding (PMI, Minsk/Bielorussia)

Qualification tests:

- Mechanical properties (tensile, shear)
- Leak tests @ RT, @ LN2 T: passed
- Leak tests @ superfluid: **Today's breaking news** from the Cryolab: **2 samples tested: 10^{-12} mbar/l/s**

Helicoflex solution remains a proven back-up solution

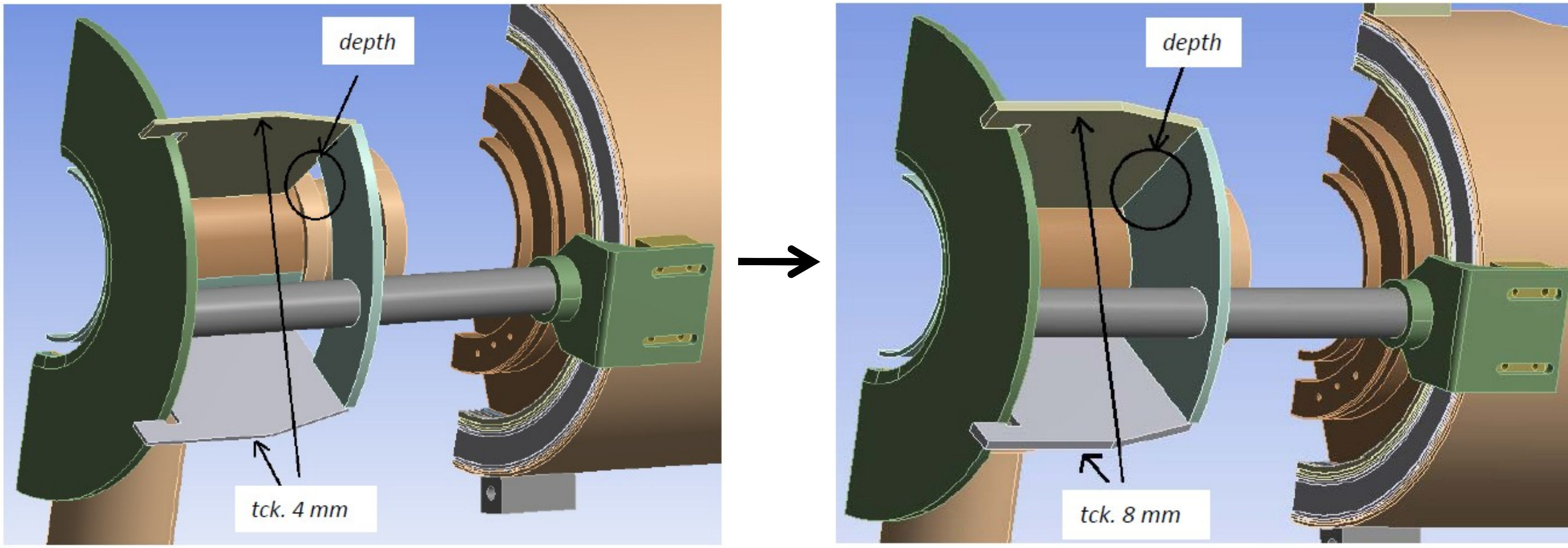
Supporting system



- Mechanical/leak test mock-up in preparation at CERN to confirm “2-in-1” concept

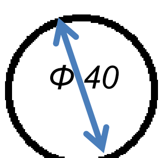
4. Inter-cavity sliding support

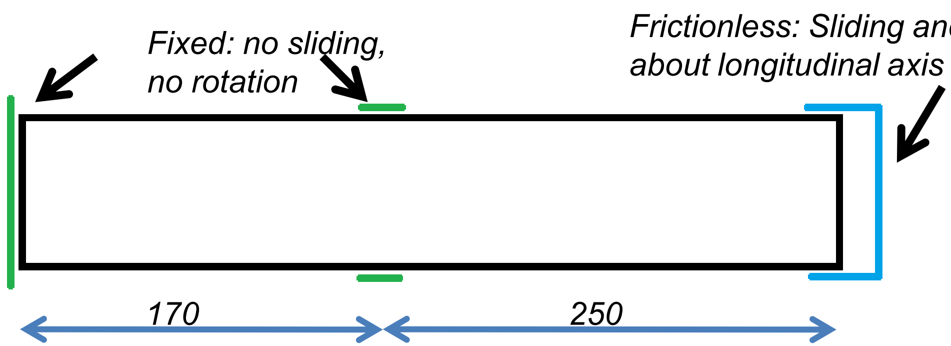
Size of stiffeners increased for better results:



Inter cavity support's stiffness:

2 x





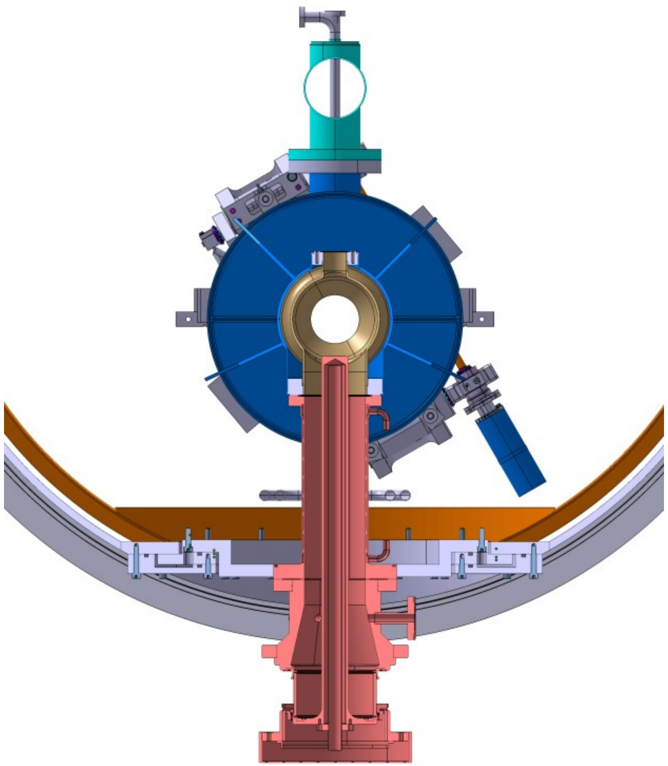
E= 193 Gpa

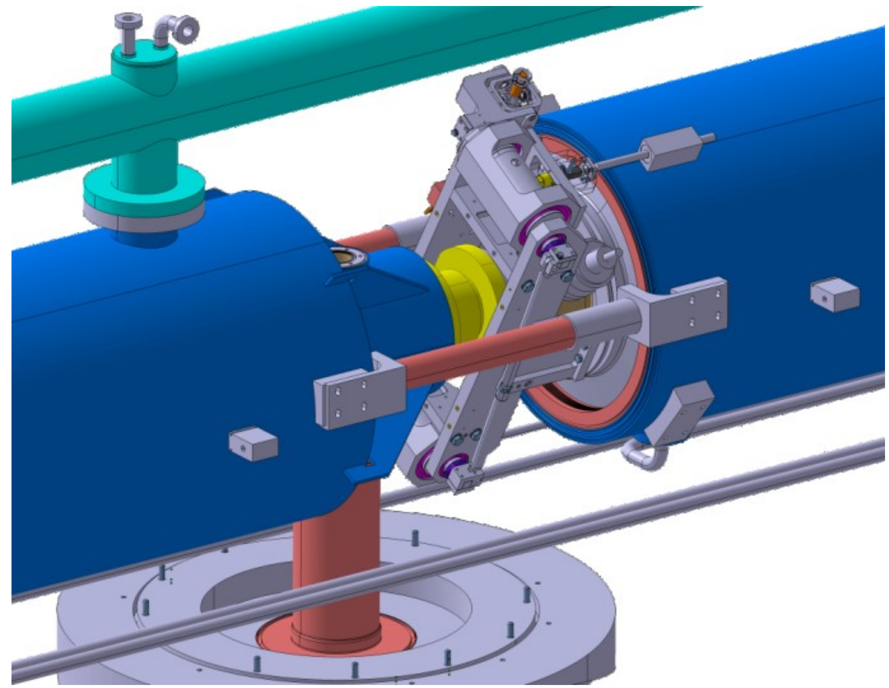
ν = *0.31*

P.Coelho, CERN

Cryostat – Cavity Support system

- **Based on :**
  - Coupler bi-tube supporting
  - Cavities inter-connections

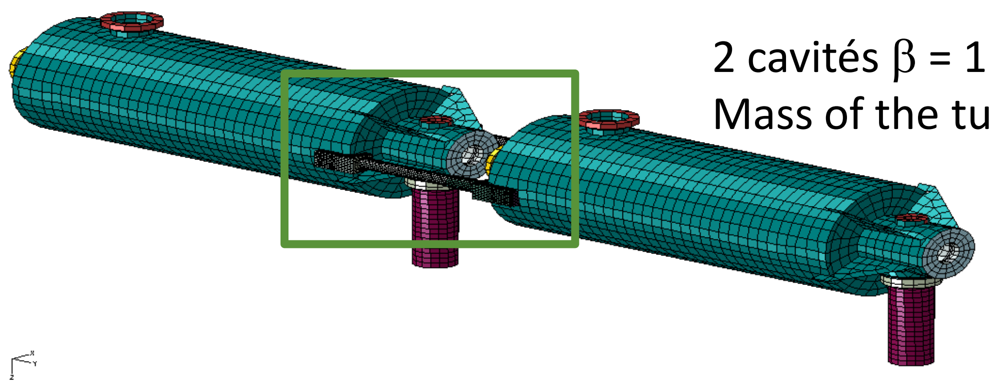




P.Duthil, CNRS-IPN

Cryostat – Cavity Support system – Cavities inter-connection

Preliminary concept 2

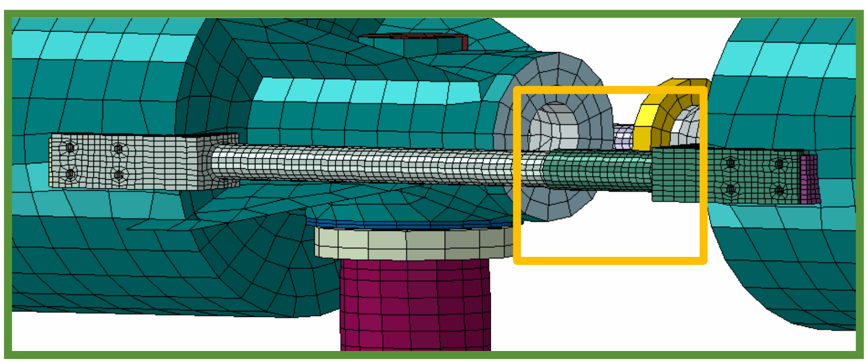


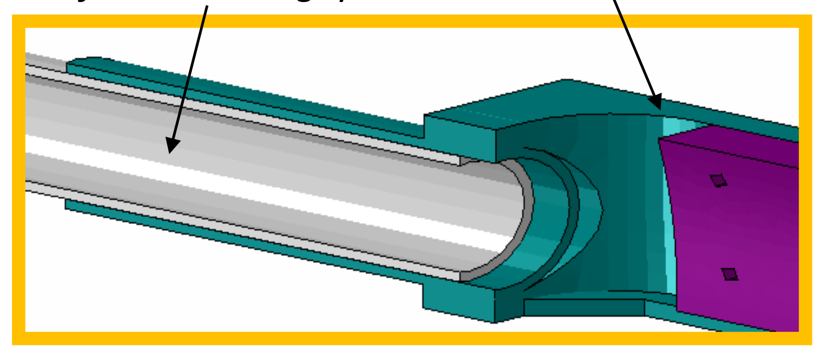
2 cavités β = 1 fixed at the bottom of their couplers
Mass of the tuner is taken into account

Possibility of adding 2 chocks for the y and z alignment procedure

Assumptions :
Stainless steel tubes (∅ext = 40mm ; e=3mm) and support
Titanium He tank

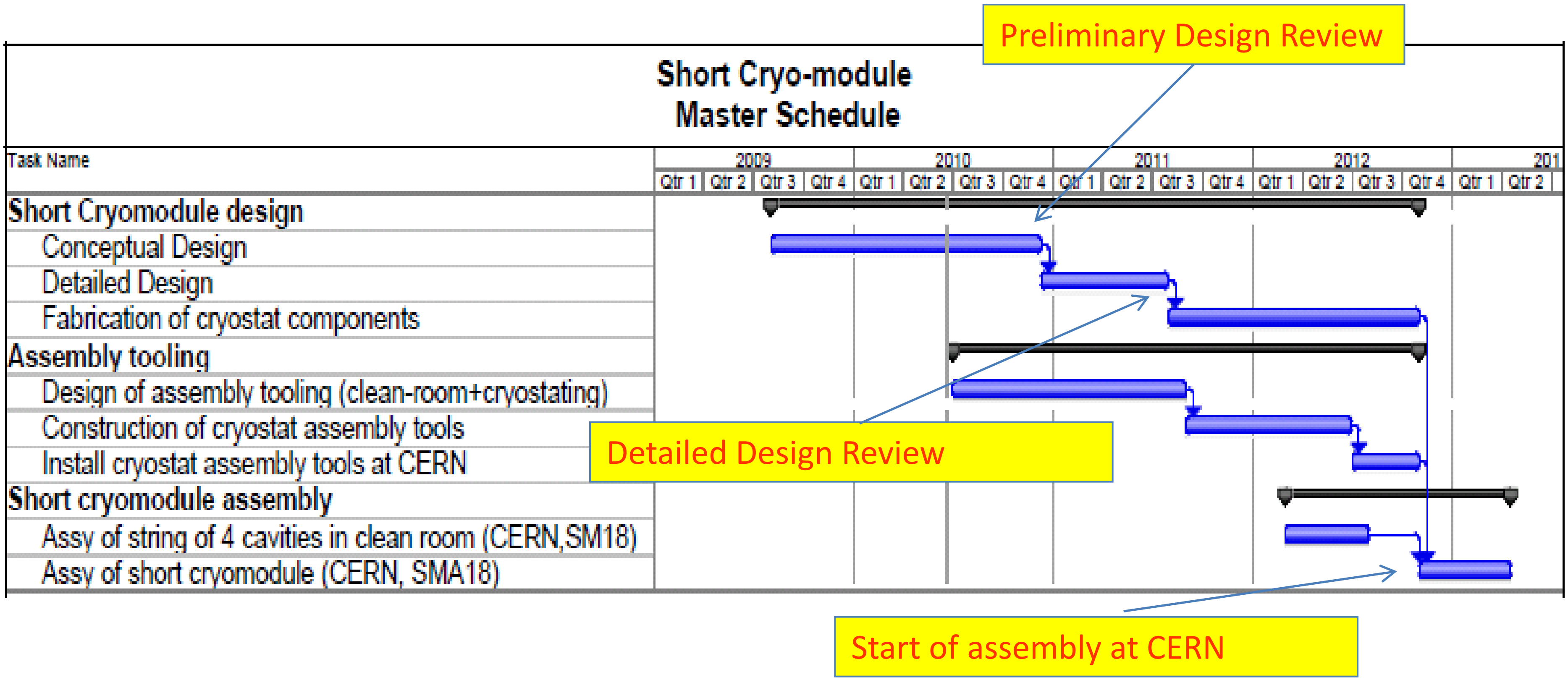
Sliding without friction - No gap



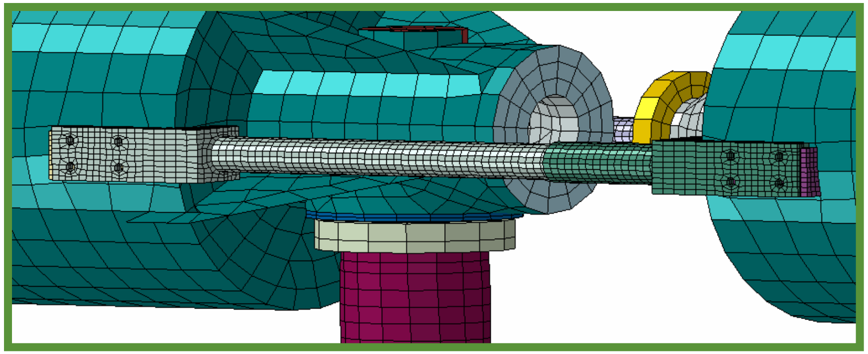


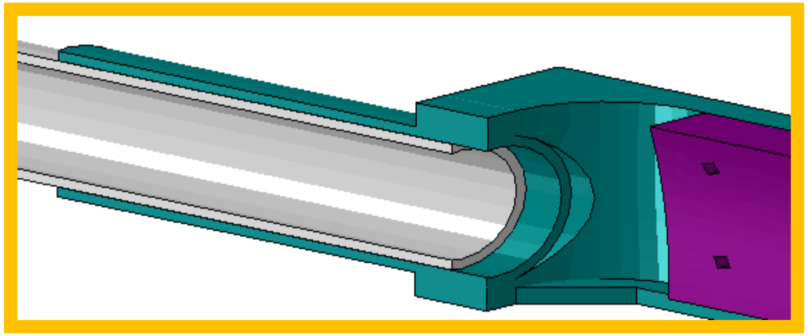
P.Duthil, CNRS-IPN

Master Schedule



Inter-cavity support





- Concept needs to evolve to an engineering solution:
  - Thermal transients, differential thermal contractions
  - Sliding solutions:
    - Engineering (sliding, rolling, hinged...)
    - Materials
    - Surface treatments (tribology @ cryo T under vacuum)

ESS cryomodule requirements

- Welcome to ESS in WG3
- Too early to see specific requirements
- Input expected for the SPL Short Cryomodule Engineering Specification

Summary and outlook

- Most of cryo-module requirements are now settled
- Test-specific requirements (windows, instrumentation) well advanced
- Conceptual choices made (cavity supporting, cryogenic scheme,…)
- Still needing conceptual design work: magnetic shielding, thermal shield
- 2 Vacuum vessel concepts compared:
  - Tube-type, large diameter (radial space constraint from cavity/tuner)→ preferred solution
  - U type ESSS, construction complexity (=cost)
- Assembly tooling concepts in progress (depend on vacuum vessel type)
- Supporting system (inter-cavity support): detailed design starts now by CNRS
- Mock-up for testing supporting solution in preparation at CERN
- Ti-st.steel transitions: options under study
- Engineering Specification of the Short Cryo-module in preparation (end 2010)
- Preliminary design review will take place in February/March 2011
- Detailed design review September 2011
- Procurement of cryostat components in 3rd QTR 2011
- Schedule very tight!

Thank you
for your attention!

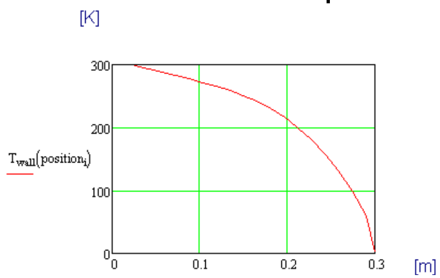
Spare slides

Actively cooled RF coupler tube

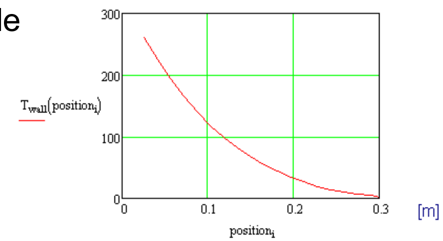
SPL coupler double walled tube, active cooling to limit static heat loads

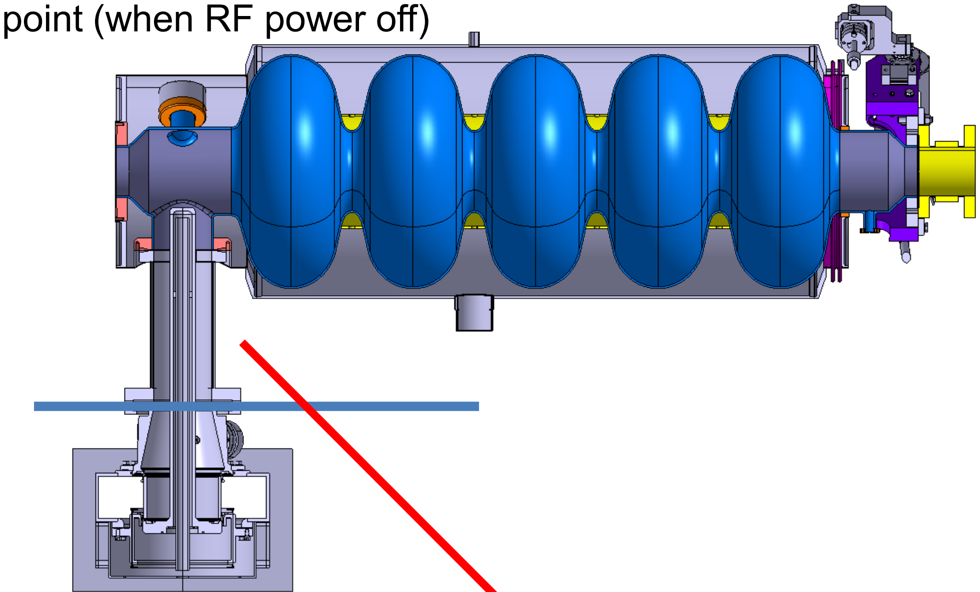
- Connected at one end to cavity at 2K, other end at RT (vessel)
- Requires elec. Heater to keep T > dew point (when RF power off)

No cooling T profile
→ 21W to 2K

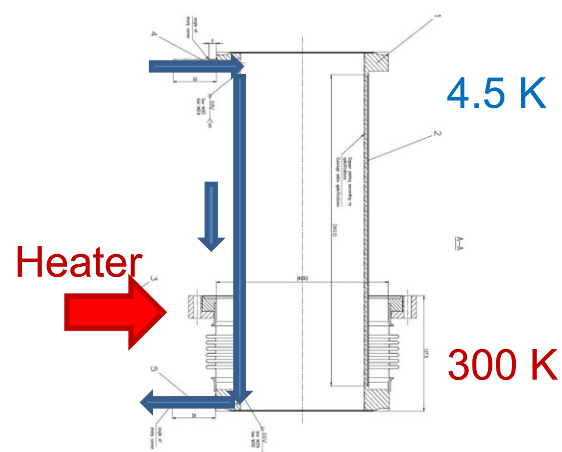


Cooling (42 mg/sec) T profile
→ 0.1 W to 2K





Massflow mgram/sec	21		23		28		35		42	
Power	ON	OFF	ON	OFF	ON	OFF	ON	OFF	ON	OFF
Temp. gas out	286 K	277 K	283 K	273 K	271 K	242 K	255 K	205 K	232 K	180 K
Q thermal load to 2K	2.4 W	0.1 W	1.7 W	0.1 W	0.4 W	0.1 W	0.1 W	0.1 W	0.1 W	0.1 W
Q heater	19 W	32 W	21 W	34 W	29 W	38 W	39 W	41 W	46 W	44 W
ΔL	0.1 mm (0.63-0.53)mm				0.05 mm (0.66-0.61)		~ 0 mm (0.67-0.67)			

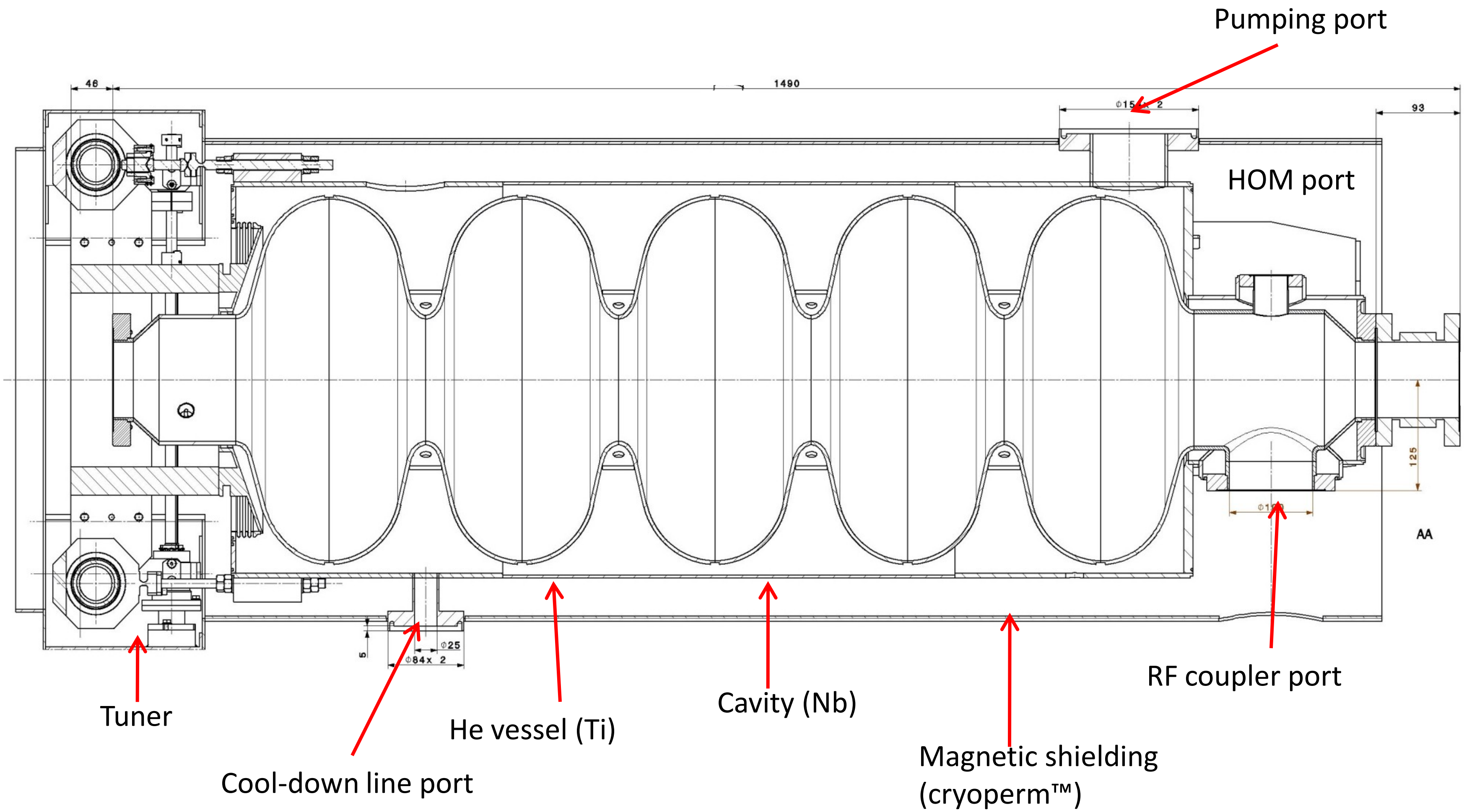


→ Yields a certain degree of position uncertainty (<0.1 mm?)

(O.Capatina, Th.Renaglia)

Helium gas cooling the double wall

Cavity/He vessel/tuner



Includes specific features for cryo-module integration (inter-cavity supports, cryogenic feeds, magnetic shielding …)

Not latest design!

Coupler position: top or bottom...?