UT CO_2 COOLING REQUIREMENTS

– Summary –

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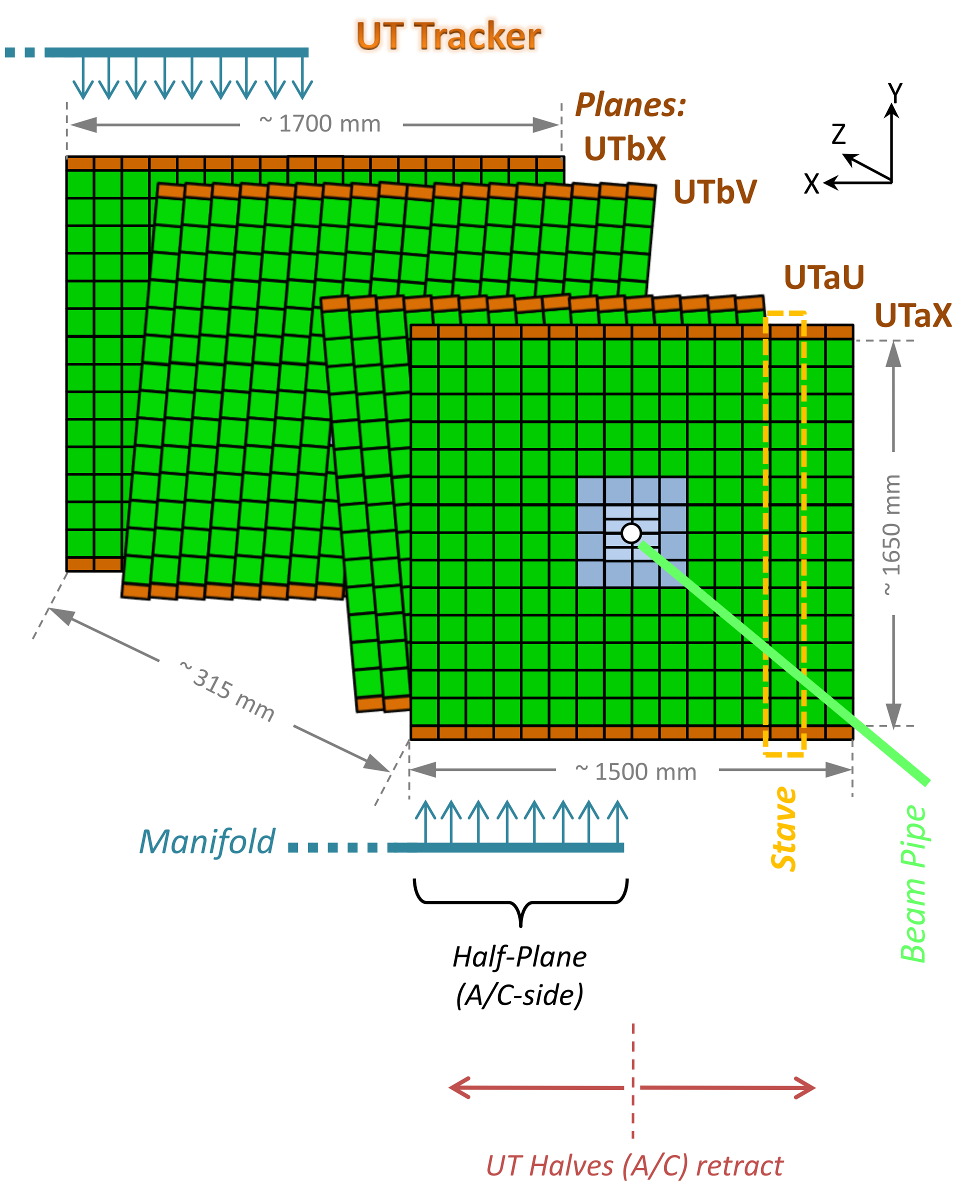
for the UT Tracker Group

UT-Specific Talks Today

08:45 - 09:45	UT evaporator concept and performance *1h0'*	
	Short summary of the requirements document *15'* Speaker: Ray Mountain (Syracuse University (US)) Document	
	Review of the suggested evaporator and manifold designs and results of performance measurements *30'* Speaker: Simone Coelli (Università degli Studi e INFN Milano (IT))	
	Discussion on UT specific points *15'*	
09:45 - 10:15	Coffee break	
10:15 - 11:00	LUCASZ cooling plant for UT assembling and commissioning *45'*	
	Short summary of the requirements for UT assembly and testing *10'* Speakers: Burkhard Schmidt (CERN), Ray Mountain (Syracuse University (US))	
	Conceptual design of the LUKASZ cooling plant *20'* Speaker: Bart Verlaat (CERN)	
	Cost and Schedule for the LUKASZ plant *10'* Speaker: Bart Verlaat (CERN)	
	Discussion on points specfic to the LUKASZ plant *5'*	

Brief Resume of UT Tracker



Relevant Design Points

- Four planes of sensors: XUVX
- Sensors mounted on vertical "staves," integrated mechanical support , 16-18 per plane
- Cooling manifolds bring in CO_2 for each half-plane, individually
- Planes plus Outer Box and Frame (not shown) constructed in two UT halves – designed to retract horizontally from beam pipe

TABLE A. SOME BASIC NUMEROLOGY FOR UT TRACKER.

PLANE			Staves / plane				ASICs / plane				Sensors / plane
PL.	STA.	PRJ.	TOT	A	B	C	TOT	A	B	C	TOT
UTaX	A	X	16	12	2	2	992	672	144	176	228
UTaU	A	U	16	12	2	2	992	672	144	176	228
UTbV	B	V	18	14	2	2	1104	784	144	176	256
UTbX	B	X	18	14	2	2	1104	784	144	176	256
TOTAL / UT :			**68**				**4192**				**968**

** Stave Types A,B,C are enumerated individually here.*

UT Stave Design (1)

Stave Basics

- Main thermal/mechanical element of the UT
- Provides for precise positioning of sensors
- Stiff sandwich structure , mounted vertically
- Integrated with the cooling system
- Three stave types: A,B,C
- Comprised of competing mechanical, thermal and electronic elements

Components of fully-loaded stave

- "Bare" stave: basic innermost structural support / cooling tube
- Data-flex: signal readout / power distribution / control lines
- Module: Sensor / hybrid (w ASIC) / stiffener, mounted on both sides of stave

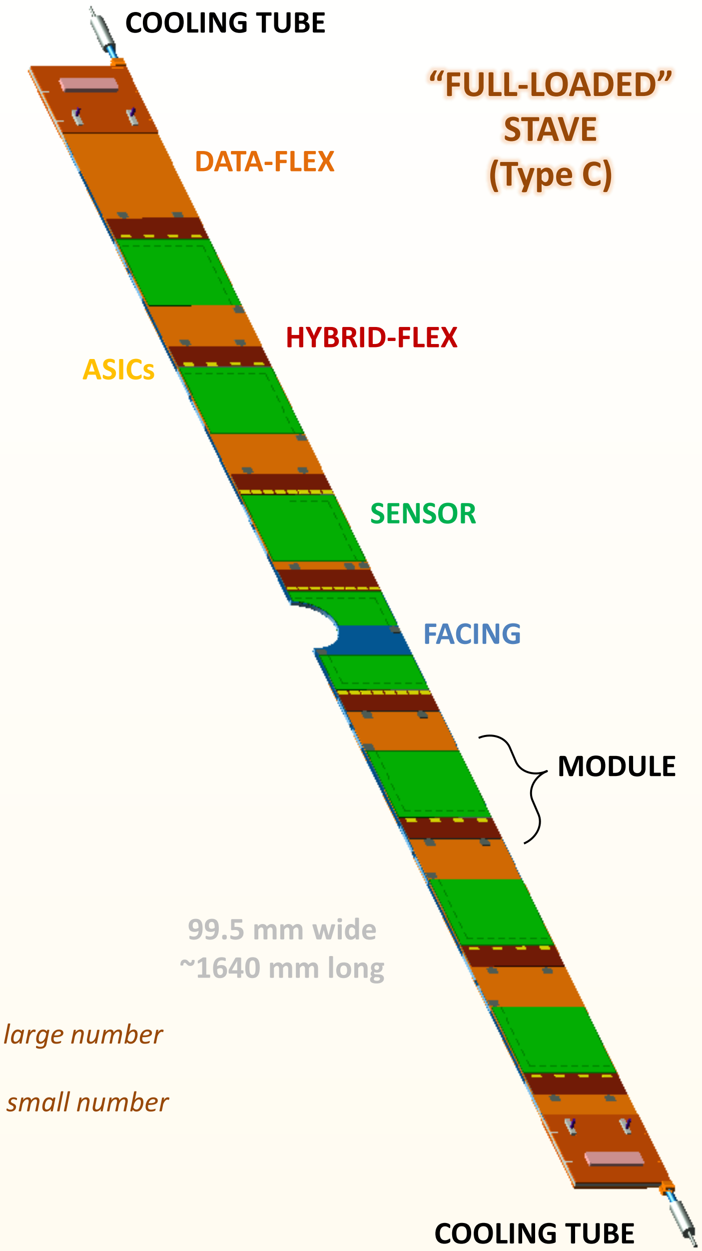
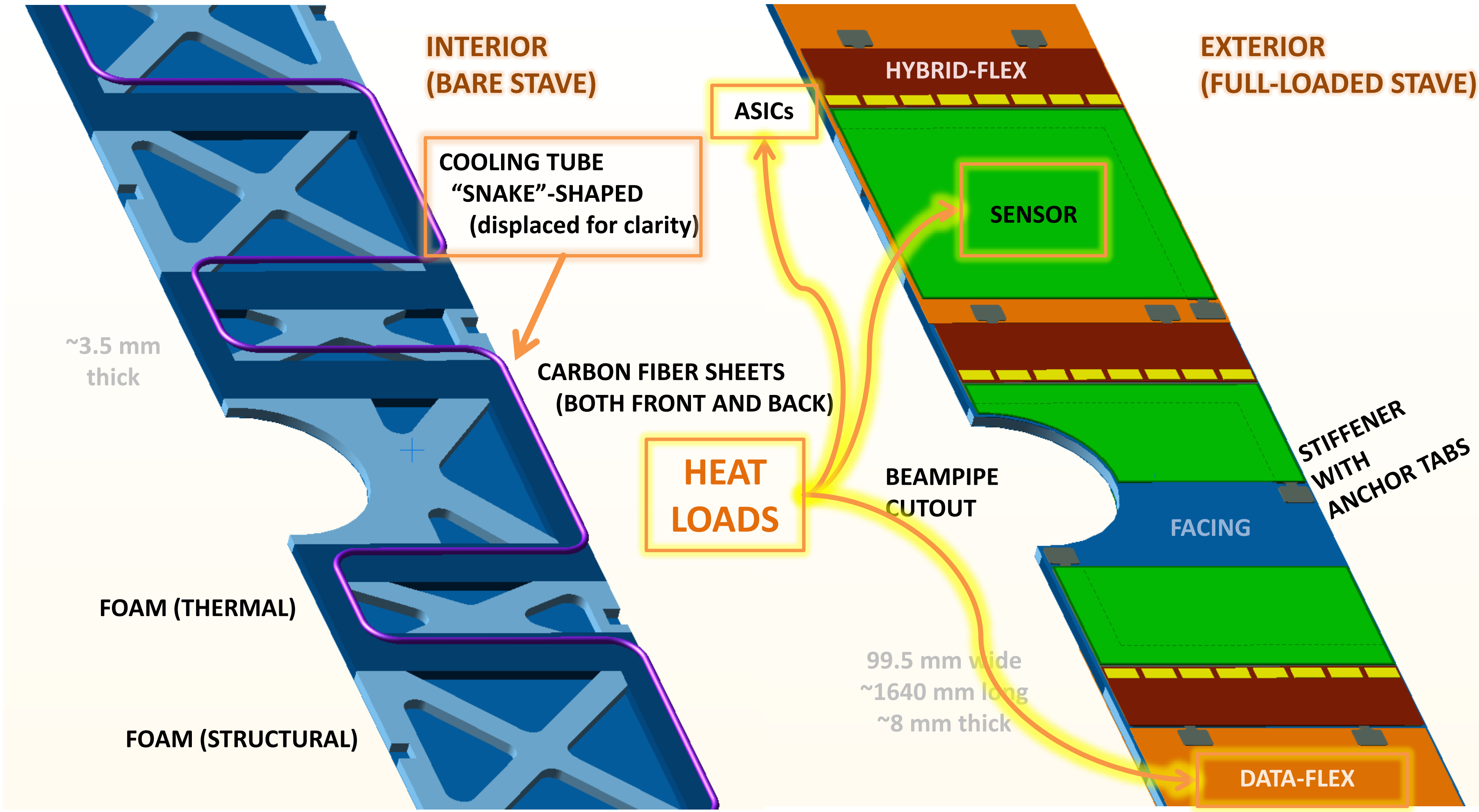


TABLE B. SOME STAVE TYPE NUMEROLOGY.

STAVE TYPE	DESCR.	Number of staves [num]	ASICs / stave [num]	Sensors / stave [num]	Power / stave [W]	
STAVE, Type A	(outer)	52	56	14	47.3	*least power, large number*
STAVE, Type B	(adjacent)	8	72	14	60.8	
STAVE, Type C	(central)	8	88	16	74.3	*most power, small number*
TOTAL / UT :		**68**	**4192**	**968**		

** Power include ASIC, FLEX and SENSOR heat loads.*

UT Stave Design (2)



Bare Stave: CFRP (Carbon Fiber Reinforce Polymer) face sheets epoxied to foam core in sandwich structure with embedded cooling tube, all-epoxy construction

Foams: thermal foam for heat transfer, lightweight structural foam for rigidity of sandwich structure

Cooling Tube: Ti 2.275 mm OD, 135 um wall, "snake" shape, runs under all ASICs and edge of each sensor

Goals: Keep sensors at –5°C or below, uniform ΔT=5°C across sensor, ASICs < 40°C (6 mW/ch, 0.768 W/asic)

General UT Requirements on Cooling System

This section outlines the general functions of the UT cooling system required by the design details and expected operation of the UT Tracker.

The UT cooling scheme must remove the heat from the detector, so as to maintain the sensor operating below the temperature of –5 °C. The choice of evaporation temperature aims to keep the sensor temperature below this temperature during normal running, including after irradiation. The cooling system is expected to be capable of removing at least 5 kW of detector heat load during operation at any temperature. Additional cooling capacity shall be foreseen in order to take heat leaks on the distribution pipes and manifolds into account.

The cooling system is required to:

- Remove all heat produced inside the detector box by sensors, chips and service resistances.
- Maintain the silicon sensors at the appropriate temperatures for the different operating state.
- Allow for continuous operation at adjustable evaporation mean temperature inside the stave tube in the range of –35 °C to ambient temperature, about +15 °C (i.e., above the dew point).
- Not produce ice or condensation anywhere into the detector box and on the external surfaces.
- Comply with CERN safety regulations and LHCb safety.
- Interface to UT and DCS system, DSS systems and interlock system.

The overall design parameters of the UT cooling system are given in Table 1, and the expected environmental parameters are given in Table 2.

Specifics of UT Requirements from Design (1)

1. Temperature difference within a given sensor: Not to exceed ΔT of 5°C

- To limit the sensor deformation due to thermal contraction
- To limit relevant stresses induced on the sensor by cooling
- Controlled by local stave and module design
  - Overall heat transfer between cooling tube and sensor
- This ΔT set for most sensors
  - Worst case sensor T3 on the central staves, with 8 ASICs and directly over the flex: take **ΔT as 10°C** for this, including safety margin

2. Maximum temperature for any sensor: To be maintained below T_max of –5°C

- A functional requirement for sensor operation under the worst conditions: after maximum irradiation, at the end of its life.
- Set to avoid thermal runaway
- Consequences:

T(cooling tube) ≤ T_max(sensor) – ΔT(sensor)
≤ –15°C

T(CO_2) ≤ T(cooling tube) – ΔT(tube wall) – ΔT(conv)
≤ –30°C (with 10°C safety margin)

➔ T_op = –30°C

Specifics of UT Requirements from Design (2)

3. Maximum ASIC temp: Not to exceed T(ASIC) of +40°C

- Electronic readout ASICs should be maintained at the lowest possible temperature compatible with other requirements of the system
- ASICs are the most powerful local heating source in the detector, so this the maximum temp present in the detector
- Meeting other requirements will automatically retain an acceptable ASIC temperature
  - From FEA: expected **T(ASIC) ≤ +5°C**

UT Baseline Heat Loads

TABLE C. BASELINE POWER DISSIPATION BREAKDOWN FOR UT TRACKER.							
PLANE			Power / plane [W]				Power / half-plane [W]
PL.	STA.	PRJ.	TOT	ASIC	FLEX	SENSOR	TOT
UTaX	A	X	840.9	761.9	76.2	2.9	420.5
UTaU	A	U	840.9	761.9	76.2	2.9	420.5
UTbV	B	V	935.9	847.9	84.8	3.2	467.9
UTbX	B	X	935.9	847.9	84.8	3.2	467.9
TOTAL / UT :			**3553.6**	3219.5	321.9	12.2	
			4103.6	*with environmental loads*			
			4924.3	*with 20% margin*			

** Power taken during NORMAL OPERATING MODE.*

ASIC power consumption

- Estimated to be 6 mW/channel, giving 0.768 W/ASIC
- Total = 3220 W/UT
- Major source of heat in UT

FLEX power dissipation

- Estimated as 10% ASIC power (will refine as prototyping continues)
- Total = 322 W/UT

SENSOR self-heating

- Joule heating from increased standing bias current over time due to radiation damage of silicon
- Need to avoid thermal runaway
- Estimated to be small
  - 260 mW/sensor for central sensor
  - Total < 15 W/UT

➔ ***Total Heat Load = 5000 W***

Design Parameters of UT Cooling System

TABLE 1. DESIGN PARAMETERS OF THE UT COOLING SYSTEM			
Property	**Value**	**Units**	**Comments**
GENERAL			
Cooling system	–	–	2-PACL
Cooling power	5000	W	total plus margin (see text and Table 3)
Fluid	CO_2	–	
Fluid filtration	needed	–	accessible, replaceable in technical stop
Emergency redundancy	needed	–	temporary share with VELO system
UPS connection	needed	–	minimal requirement: controls
Maximum design pressure (MDP)	110	bar	max for large volumes (safety valves)
Maximum design pressure (MDP)	130	bar	max for small volumes (burst discs)
Proof test pressure (PTP)	157	bar	test pressure for large volumes
Proof test pressure (PTP)	186	bar	test pressure for small volumes
δT_evap, Stability	0.5	°C	stability at stave (in time)
OPERATIONAL MODES			
T_evap, Normal operation	-30 ± 5	°C	cold, max power 5 kW
T_evap, Partial power operation	-30 ± 5	°C	cold, max power 2.6 kW
T_evap, Maintenance	-30 to +15	°C	cold or warm, max power 1.5 kW
DISTRIBUTION AND MANIFOLD			
Number of individual loops	68	–	one loop per stave
Control of loops	4+4	–	control at each half-plane
Manifold	in BOX	–	local, in UT BOX, connected to loops
Connection to manifold	flexible	–	needs to move with UT as box retracts
CONTROL			
Continuous T_evap control	remotely	–	controlled by 2PACL design
T_evap Set point	see mode	–	mode-dependent, common to all staves
T_evap Monitoring	stave input		at all stave inputs, plus module T readback
Plant to UT signals	as needed	–	will evolve with control design
Safety	several	–	over-pressure valves at strategic points

Operational Modes (1)

TABLE 3. EXPECTED HEAT LOADS DURING VARIOUS OPERATIONAL MODES			
Property	**Value**	**Units**	**Comments**
UT NORMAL OPERATING (DATA-TAKING) MODE		COLD	*T_op = –30°C ± 5°C*
Conditions: Box halves joined+sealed, electronics fully powered, full cooling (normal data-taking mode)			
SALT ASIC power	0.768	W/ASIC	assumption of 6 mW/ch
	761.9	W/plane	for each plane UTAX and UTAU
	847.9	W/plane	for each plane UTBX and UTBV
	3219.5	W/UT	total ASIC heat load
SENSOR self-heating	12.2	W/UT	worst case total, after 50 pb-1
DATA-FLEX power dissipation	321.9	W/UT	est., 10% of power carried
UT BOX load (est. convective, radiative)	500.0	W/UT	est. convective load from environment, assumed minimal, due to box insulation
BEAM-PIPE load (est. convective, radiative)	50.0	W/UT	est. max convective load from beampipe heaters
TOTAL POWER LOAD	**4103.6**	**W/UT**	load for this operational mode
	4924.3	**W/UT**	with 20% margin
	5000.0	**W/UT**	est. max expected with all loads included

NORMAL DATA-TAKING

Operational Modes (2)

UT PARTIAL-POWER (STANDBY) MODE				**COLD** *T_op = –30°C ± 5°C*
***Conditions:* Box halves joined+sealed, electronics on partial power, cooling reduced (sensors kept at –5°C), for electronics testing of digital readout, analog readout, power distribution, and slow control**				
SALT ASIC power		1609.7	W/UT	ON at 10% to 50% power (50% calculated)
SENSOR power	***LIKE DATA-TAKING***	12.2	W/UT	worst case total, after 50 pb-1
DATA-FLEX power	***BUT LESS POWER,***	161.0	W/UT	est., 10% of power carried
UT BOX load	***ELECTRONICS TESTS***	500.0	W/UT	flat est.
BEAM-PIPE load		50.0	W/UT	flat est.
TOTAL POWER LOAD		**2332.9**	**W/UT**	load for this operational mode
		2799.5	**W/UT**	with 20% margin
		3000.0	**W/UT**	est. max expected with all loads included

UT MAINTENANCE (INSTALLATION/COMISSIONING) MODE				**COLD or WARM** *T_op = –30°C to +15°C*
***Conditions:* Box halves retracted+sealed (or retracted+unsealed), electronics and cooling on for one half-plane at a time only, for maintenance/commissioning in pit (not on surface)**				
SALT ASIC power	***CATCH-ALL,***	847.9	W/UT	ON for a half-plane (e.g. UTBX A-side)
SENSOR power	***PARTIAL POWER,***	1.6	W/UT	ON for a half-plane
DATA-FLEX power	***FOR MAINTENANCE***	84.8	W/UT	est., 10% of power carried
UT BOX load		500.0	W/UT	flat est.
BEAM-PIPE load		0.0	W/UT	no load from beam-pipe
TOTAL POWER LOAD		**1434.3**	**W/UT**	load for this operational mode
		1721.1	**W/UT**	with 20% margin
		2000.0	**W/UT**	est. max expected with all loads included

Environment and Safety

8. Environmental Requirements

The detector box needs to have environment control on both the internal volume and the external surfaces, to avoid condensation and icing phenomena, induced by the low temperatures and the presence of water humidity in the air.

The two detector half boxes shall be filled and flushed with nitrogen (or dry air). For safety reason the requirement is that the dew point shall be kept below –60 °C in the box at all times when the detector is run cold. The relevant admissible maximum content of water humidity in the controlled volume is then about 10 ppm (vol).

The Detector boxes shall be designed to be airtight both when: (1) joined and sealed in the nominal position, and (2) retracted and sealed, using temporary covers.

For safety, an over-pressure limiter on the boxes through an material-appropriate bubbler is required.

TABLE 2. ENVIRONMENTAL PARAMETERS RELATED TO THE UT COOLING SYSTEM

Property	Value	Units	Comments
INSIDE UT BOX			
Atmosphere (gas fill)	dry N2, Air	–	dry gas in UT BOX
Temperature, min	-50	°C	coldest possible point (CO_2 return lines)
Dew point, min	-60	°C	safety dew point
OUTSIDE UT BOX			
Atmosphere	Air	–	cavern
Dew point, typ.	14	°C	est., Kaan Vatansever beampipe simulati
Humidity, typ.	55–65	%	
Temperature, typ.	20–25	°C	

9. Safety

The cooling system must meet all relevant EC standards and comply with CERN safety regulations.

In particular:

- The cooling system shall avoid liquids trapped in closed off section, include safety relieve valves where required. **This point is very important.**
- Test pressures in all sections of the cooling system, shall respect engineering standards in compliance with maximum possible fault pressures.
- The distribution system and all on-detector shall be protected from contamination by accessible filter stages.
- The detector box shall be connected to an exhaust bubbler system.
- Controls of the cooling system (plant, distribution, monitoring) need to be connected to UPS in order to retain control during a power cut.

-FIN-