GERDA TG4 - Cryogenic Vessel

Status Report

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GERDA Collaboration Meeting at Dubna
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Outline

(Semi-)Final Layout of Copper Cryostat

FMECA , HAZOP and PID

‘Basissicherheits-Konzept’ and Cryostat

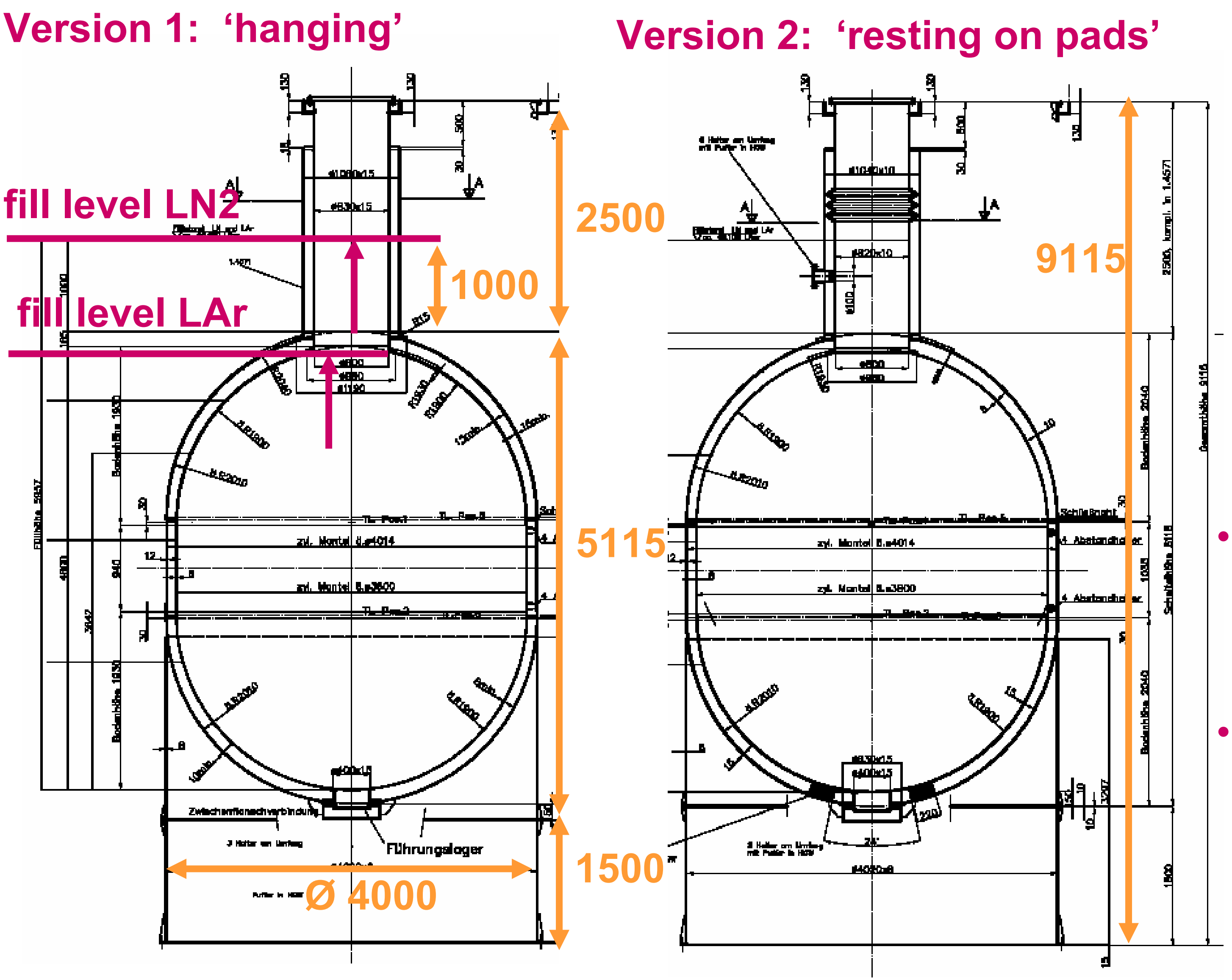
Cu-Cu and Cu-SS Welding Tests

Manifold and its Access

Next Steps

Conclusions

Optimized Cryostat Layout



- length of neck increased
  ► 1m add. LN2
- 2 piece skirt
  ► less height for transport & installation

FMECA, HAZOP & PID for Cryostat

METHODS FOR SAFETY ANALYSIS

FMECA = Failure Mode, Effects and Criticality Analysis
identifies and offers solution to potential problems
(uses severity and probability of events – yields 'risk' matrix)

HAZOP = Hazard and Operability analysis
identifies possible deviations from normal operation, and
ensures that adequate safeguards are available to prevent accidents
(uses primary - 'process conditions' like 'flow', 'pressure' – and
secondary – 'special adjectives' like 'more', 'less', 'no' - KEYWORDS)

PID = Piping and Instrumentation Diagram

INPUT : New cryostat drawings and Technical Proposal

Apr 21 : Preparatory meeting (LNGS-MPI-HD) at Milano
Apr 25 : Order awarded to Air Liquide (AL)
Apr 28 : Kick-off meeting at Sassenage (AL, MPI-HD)
May07 : Intermediate meeting at CERN (AL, LNGS, MPI-HD)
Jul 05 : Final meeting at LNGS (example for very efficient interaction)

FMECA – Severity Classes

SEVERITY

Si = Initial severity (without safety barriers)
Sr = Residual severity

SEVERITY CLASS	BODILY INJURY (SAFETY)	ENVIRONMENTAL DAMAGE (ENVIRONMENT)	DAMAGE TO EQUIPMENT OR PRODUCTION (PRODUCTION)
0	**No bodily injury**	**No damage** to the environment	**No damage** to equipment or production
1	**Minor injury** with no lasting effect	**Moderate damage with no durable effect** (temporary exceed of regulatory limits or products spilled on site temporary)	**Damage to small and medium-sized equipment, or a brief loss of production** (several hours)
2	**Serious injury** (localized accident, resulting in serious consequences on people working in the area affected by the feared event)	**Serious damage but may be corrected** (a localized accident causing serious ecological damage to the environment, but which may be quickly treated and eliminated)	**Damage to large equipment or loss of production** (several days)
3	**Potential victim**	**Serious and durable damage** (accident causing serious and durable damage around the site)	**Damage to very large items of equipment or extended loss of production** (several weeks to months)
4	**Major accident with potentiality of several victims**	**Ecological catastrophe**	**Massive destruction of facilities** or **total loss of production** (permanent shut-down)

FMECA – Occurrency Classes

OCCURRENCE CLASSES

Fi = Initial frequency (without safety barriers)
Fr = Residual frequency

OCCURRENCE CLASS	CLASS NAME	PROBABILITY OF OCCURRENCE / YEAR
0	Unlikely	$P \leq 10^{-6}$
1	Very rare	$10^{-6} < P \leq 10^{-5}$
2	Rare	$10^{-5} < P \leq 10^{-3}$
3	Possible	$10^{-3} < P \leq 10^{-1}$
4	Frequent	$P > 10^{-1}$

FMECA – Criticality Matrix

CRITICALITY MATRIX

Ci = Initial Criticality
Cr = Residual Criticality

	Severity				
	0	1	2	3	4
4	04	14	24	34	44
3	03	13	23	33	43
2	02	12	22	32	42
1	01	11	21	31	41
0	00	10	20	30	40

Unacceptable risk area.

Area for which studies to minimize risk must be conducted.

Low level risk area

FMECA – Sample Results

9 of 20 columns – 10 of 52 lines

Item	#	Function	Performance constraint	Equipment	Characteristics	Failure mode	Causes	Effects
1	PF1	To maintain a requested amount (95% +/- tolerance) of LN2 or Lar	constant level (95%)	Level gauge High		Indicates a level lower than the real one	- Signal drift, gauge failure - Presence of operator in lab room	- Overflow - Degradation of equipmer structure due to Cryogenic temperature - Anoxia
2				Level gauge Low		Indicates a level high than the real one	- Signal drift, gauge failure	- Underfilling - Measurement noise
3				Filling line+valves		get clogged	Air through leakage Air during depoting	- Underfilling - Measurement noise
4				Vent line		get clogged	Ice inside vent line RD or SRV fail to work Operator mistake	Shells rupture
5				Regulation system		- does not open the valve when low level setpoint is reached - does not close the valve when high level is reached	PLC fails	Overflow or underfilling Measurement noise
6	CF1	To shield the detectors against external radioactivity	background index of 10-3 cts/(keV.kg.y)	Cryostat		do not achieve activity less than maximum value	Construction material properties Material is not properly shielded	Measurement noise
7				Vent line		allows ambient radioactivity inside the cryostat	Line is not properly shielded	Measurement noise
8	CF2	To be insulated against thermal losses	no more than 0,2% cryogenic liquid loss per day.	same equipments as function CF4	see CF4	see CF4	see CF4	see CF4
9			maintain a vacuum below 10-4 mbar between inner and outer shells	vacuum pump		diffuses oil	If power supply stops, pump oil can migrate	vacuum loss
10				vacuum pump		fails to work	Permanent pumping	vacuum loss

Function constraint device failure mode causes effects

FMECA - Sample Results

cnt'd columns 9 to 20

Si Pi Si.Pi

Sr,Pr

Item	#		Effects	Effect on	Si	Pi	S+P	Ci	Detection/ Protection	Actions/ Remarks	Sr	Pr	S+P	Cr
1	PF1	To mair (95% +,	- Overflow - Degradation of equipment or structure due to Cryogenic temperature - Anoxia	S	3	3	6	33	- Redundancy with another gauge - Oxygen detector in space above cryostat with alarm/flashing light to restrict entry in the lab room above the cryostat		3	1	4	31
2			- Underfilling - Measurement noise	P	1	2	3	12	- Redundancy with another gauge		1	1	2	11
3			- Underfilling - Measurement noise	P	1	2	3	12			1	2	3	12
4			Shells rupture	S	4	1	5	41	- Regular maintenance check - Double vent line - Check vent line diameter		4	0	4	40
5			Overflow or underfilling Measurement noise	S	3	3	6	33	- Redundant PLC - Check SIL level of PLC - Hard wired interlock on relays for safety - UPS - Oxygen detector in space above cryostat with alarm/flashing light to restrict entry in the lab room above the cryostat		3	1	4	31
6	CF1	To shiel externa	Measurement noise	P	4	3	7	43	- Check the radiopurity of raw material, all equipments - Check contamination level of manufacturing processes		4	1	5	41
7			Measurement noise	P	4	3	7	43	- Check the radiopurity of raw material, all equipments - Check contamination level of manufacturing processes - Add a cold trap to prevent back scattering		4	1	5	41
8	CF2	To be ir losses	see CF4											
9			vacuum loss	P	2	3	5	23	- Back up on power supply (see HAZOP : interlock on FV011 in case of power supply failure) - Check valve inside the pump - Add a cold trap or use a dry pump	Pump fails more often than power supply	2	1	3	21
10			vacuum loss	P	2	2	4	22	- Vacuum gauge to be connected to alarm (information to SCADA) - Redundancy with another pump		2	1	3	21

effects

detection / protection

actions

Sr Pr

effect on Safety / Production

Hazard and Operability Analysis

PRIMARY KEYWORDS

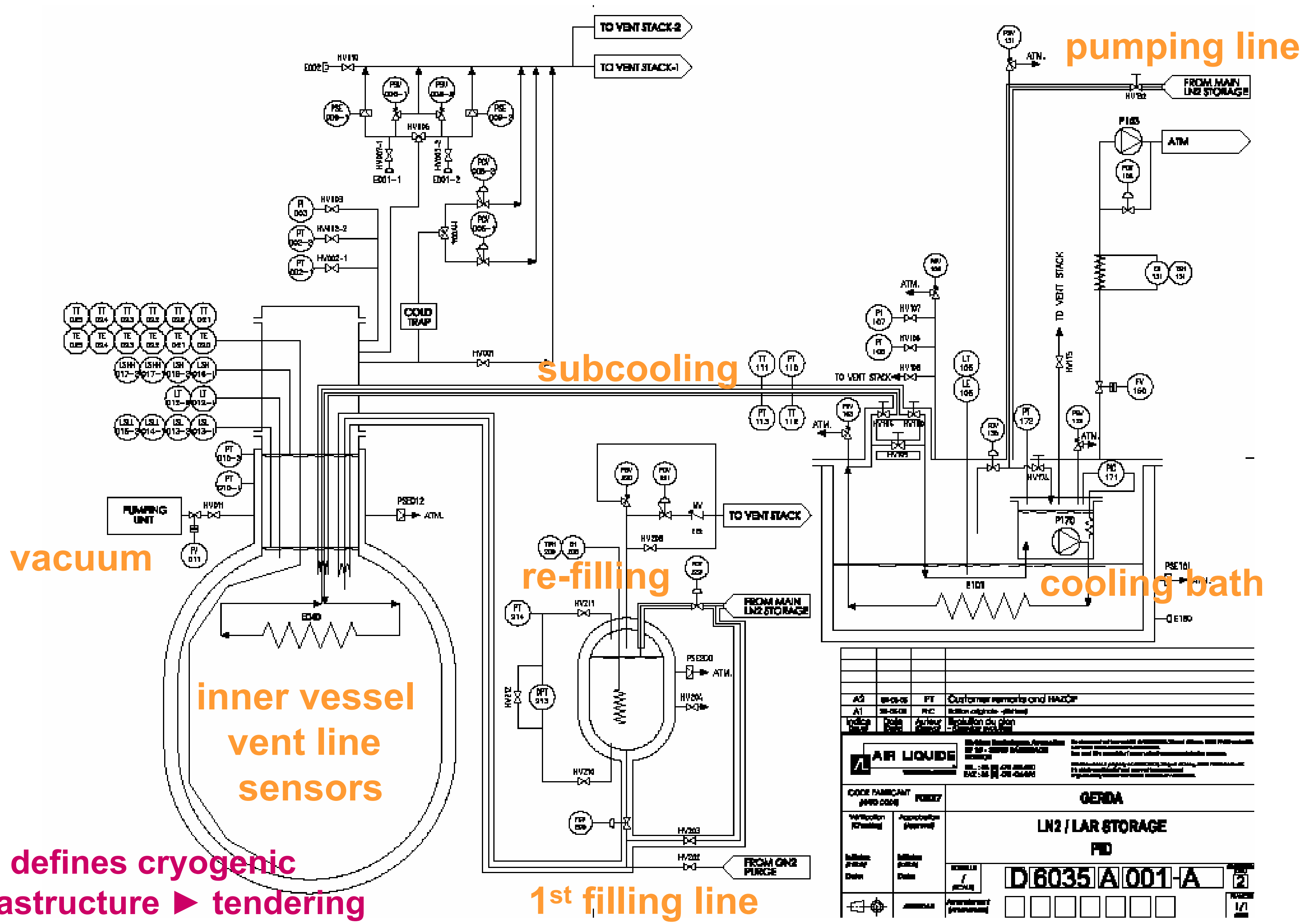
Word	Meaning
Flow	Physical Parameter
Pressure	Physical Parameter
Temperature	Physical Parameter
Composition	Chimical Parameter
Level	Physical Parameter
Viscosity	Physical Parameter
Oil Utilities	Operability Parameter
N2 Utilities	Operability Parameter
Air Utilities	Operability Parameter
Water Utilities	Operability Parameter
Electric Utilities	Operability Parameter
Vent	Operability Parameter
Purge	Operability Parameter
Maintain	Operability Parameter
Start-up	Operability Parameter
Shutdown	Operability Parameter

SECONDARY KEYWORDS

Word	Meaning
No	The design intent does not occur (e.g. Flow/No), or the operational aspect is not achievable (Isolate/No)
Less	A quantitative decrease in the design intent occurs (e.g. Pressure/Less)
More	A quantitative increase in the design intent occurs (e.g. Temperature/More)
Reverse	The opposite of the design intent occurs (e.g. Flow/Reverse)
Also	The design intent is completely fulfilled, but in addition some other related activity occurs (e.g. Flow/Also indicating contamination in a product stream, or Level/Also meaning material in a tank or vessel which should not be there)
Other	The activity occurs, but not in the way intended (e.g. Flow/Other could indicate a leak or product flowing where it should not, or Composition/Other might suggest unexpected proportions in a feedstock)
Fluctuation	The design intention is achieved only part of the time (e.g. an air-lock in a pipeline might result in Flow/Fluctuation)
Early	Usually used when studying sequential operations, this would indicate that a step is started at the wrong time or done out of sequence
Late	As for Early

applied to 7 nodes of PID

Piping and Instrumentation Diagram with 7 Nodes



NB: defines cryogenic infrastructure ► tendering

HAZOP sample result for 'Vacuum Node'

Table n° : 1 PID Reference : D-6035-A001-A1 Table revisi

Node: **Vacuum node** Da

Intention: Maintain a pressure below 10-4 mbar

Description: Assumption of active continuous pumping

N°	PRIMARY KEYWORDS	SECONDARY KEYWORDS	DEVIATION	CAUSE	CONSEQUENCE	SAFEGUARDS	ACTION	PERSON IN CHARGE
1	Composition	Other	Other Composition	Extraction of MLI	Damage on pump Pressure too high	Good MLI installation practices Slow purge cycles Protect the MLI from pump main streamline Pump protection High pressure setpoint on PT010		
2	Flow	No	No Flow	FV011 fail to open	Pressure too high	High pressure setpoint on PT010		
3	Flow	No	No Flow	HV011 closed	Pressure too high	High pressure setpoint on PT010		
4	Flow	No	No Flow	Pump fails to work Loss of power supply	Air or oil contamination of double containment Pressure too high	High pressure setpoint on PT010 If pump is not functionning interlock on FV011shut down Cold trap to prevent oil from going inside double containment To use dry pump To backup power supply		
5	Flow	No	No Flow	Vacuum line choked with MLI	no pressure decrease	High pressure setpoint on PT010		
6	Pressure	other	other Pressure	PT010 failure	No vacuum control	Redundant sensor for PT010		
7	Pressure	More	More Pressure	see no flow				
8	Pressure	More	More Pressure	inner shell leak	Vacuum loss	High pressure setpoint on PT010 PSE012		
9	Pressure	More	More Pressure	outer shell leak	Vacuum loss	High pressure setpoint on PT010 PSE012		
10	Pressure	More	More Pressure	Fittings lose leaktightness with time (PT, PSE) FV011 and HV011 external leaks	Small and slow pressure increase	Gasket material choice High pressure setpoint on PT010	Check gasket material Periodical check of leaktightness	
11	Pressure	More	More Pressure	PSE012 breaks (due to external action)	Pressure too high	Mechanical protection around PSE012	To design mechanical protection	
12	Pressure	Fluctuation	Fluctuation Pressure	Outgassing gases and moisture from inside components (MLI)	Small vacuum variation	Permanent pumping At start-up : purge cycles by pumping/dilution with GN2		

Results of Preliminary Safety Discussion

FMECA and HAZOP analysis show GERDA cryostat system to be safe if constructed 'correctly' ; NEVERTHELESS, concerns by LNGS safety experts (need of 3rd shell or extra wall):

- Is cryostat really a double-wall container?

  we see / argue : YES !

- Is probability for rupture of one shell low enough for underground use?

  application of 'Basissicherheits-Konzept' for cryostat layout & construction
  ► reduces probability for single shell rupture to $<10^{-7}$ per year

In consequence, the maximum credible failure will be a loss of the isolation vacuum.

Cryostat & Basissicherheits-Konzept

..... introduced for pressurized components of German nuclear power plants in order to yield negligible (10^{-7} / a) failure probability, in particular for shell rupture:

- use of materials of premium quality – i.e. high ductility
- use of very conservative limits for yield strength
- prevention of stress peaks by optimized design
- optimized construction and quality inspection technologies
- knowledge / analysis of possible failure events
- operational control of all relevant components and systems

Application to our cryostat, i.e. pressure vessel made out of **copper**:

- Design such that yield strength Rp is less than 10 N/mm²
  ► this is Rp value of **soft** copper down-scaled by safety factor of 5
  (see next picture for resulting wall thicknesses)
- follow in construction and quality control all rules of Basissicherheits-Konzept – certification supplied by TÜV Nord.

FEM Analysis for Inner Vessel V1 + Basissicherheit

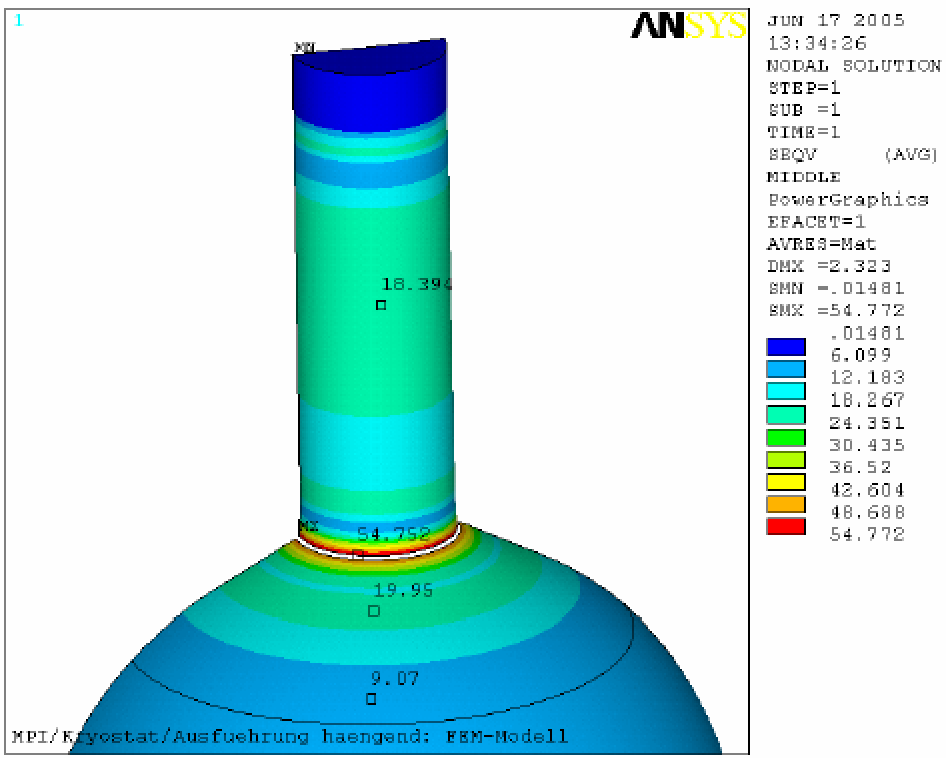
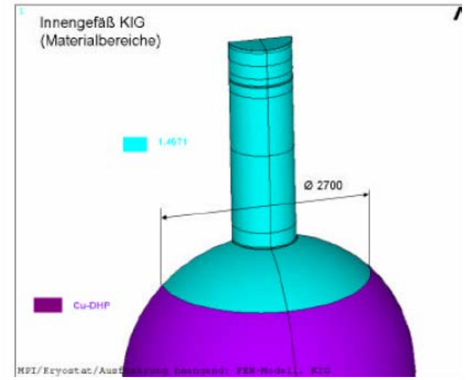


Bild 6: Spannungen oberer Bereich



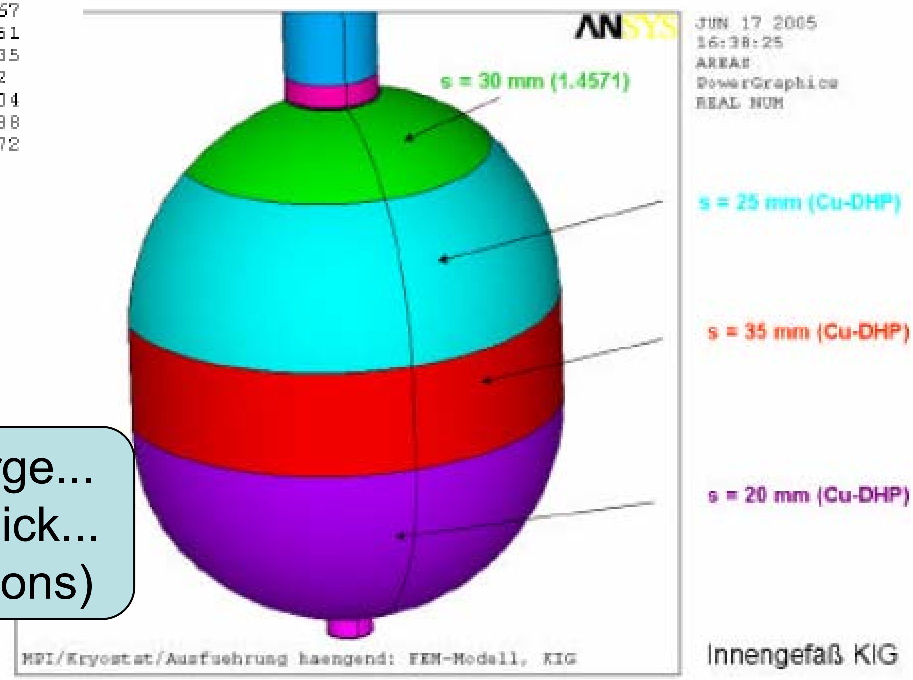


Bild 3: Materialdicken mittlerer Bereich

ss segment too large...
copper shell too thick...
(cost, weight > 40tons)

Version 1 feasible ! - But
Version 2 to be preferred !!

Electron-Beam Welding Tests

Order awarded	Feb 28	
Schedule for deliveries	Mar 24	
	due	delivered
NOSV-Cu – NOSV-Cu (SS)	Apr 22	May 05
DHP-Cu -- DHP-Cu (SS)	May 04	Jun 27
Certification by SLV Halle		
Hemispherical part from 2 segments	Jun 06	?

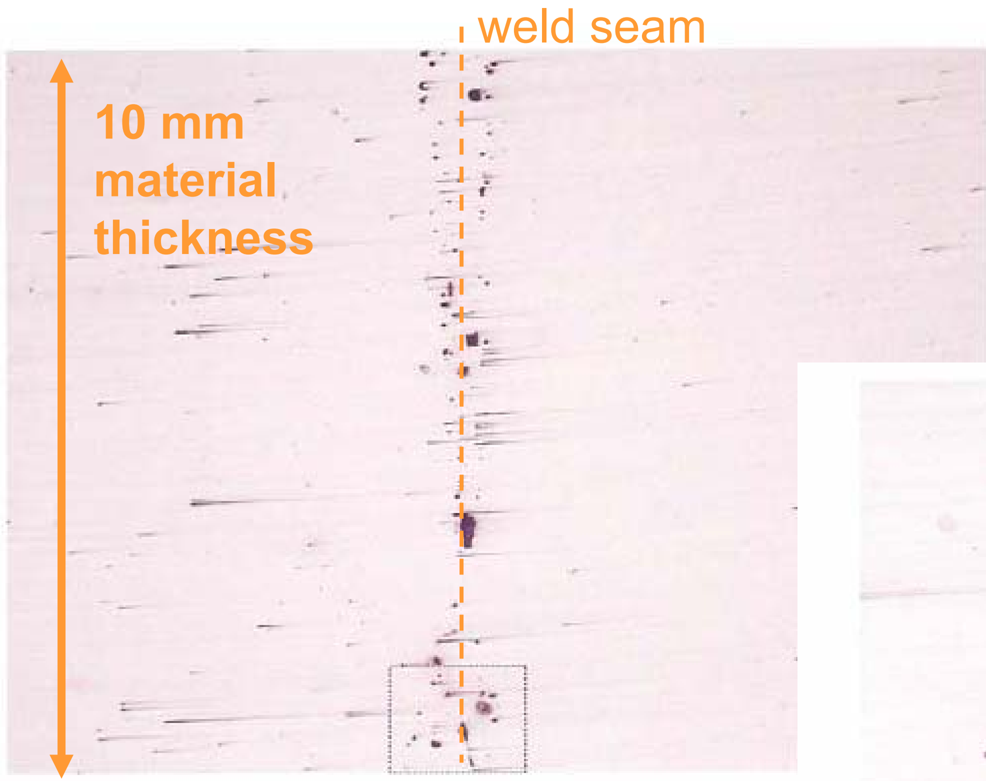
(example for strong delays)

Preliminary results :

X-ray test of NOSV-NOSV (SS) weld — 'Bindefehler' along weld seam: porosities clearly visible in polished and etched microsections

Meeting (Jun 7) with experts at CERN: only > OFE copper < can be reasonably well welded with an electron beam!

Porosities along Weld Seam



Fehlerbereich bei 16-facher Vergrößerung

NOSV-NOSV copper e-beam weld

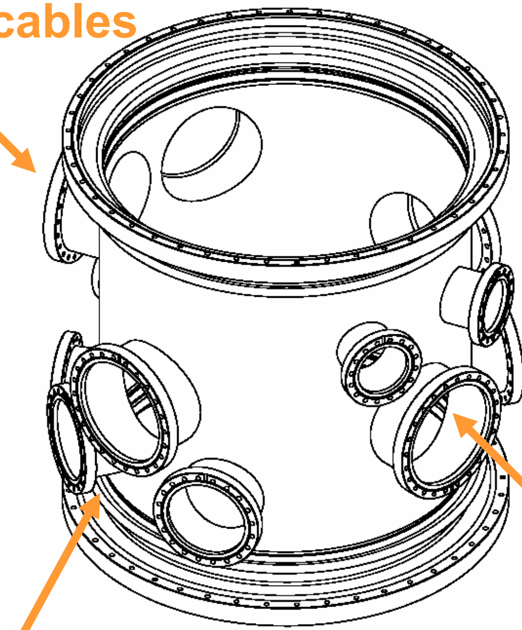
Fehlerbereich bei 100-facher Vergrößerung

result not acceptable!
Reason:
welding technique ?
NOSV material !

DHP-DHP copper welds better ?

Manifold

for cables



for cryogenics

for handling

to be modified:

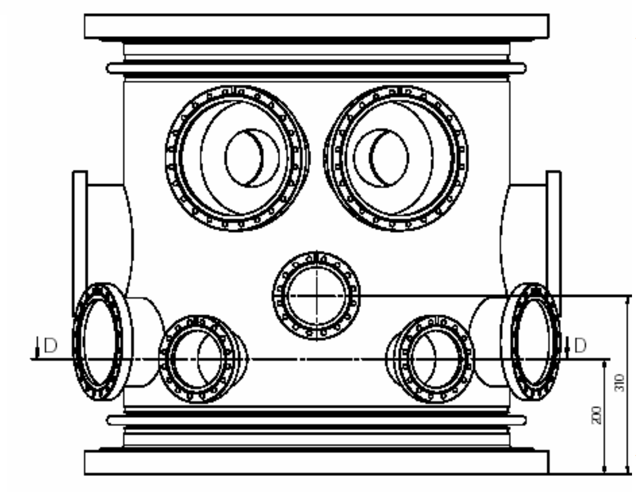
2 separate pieces

top : h = 300 mm , for cable feed-thrus - Mu

+ 2 x 100 mm for bellows

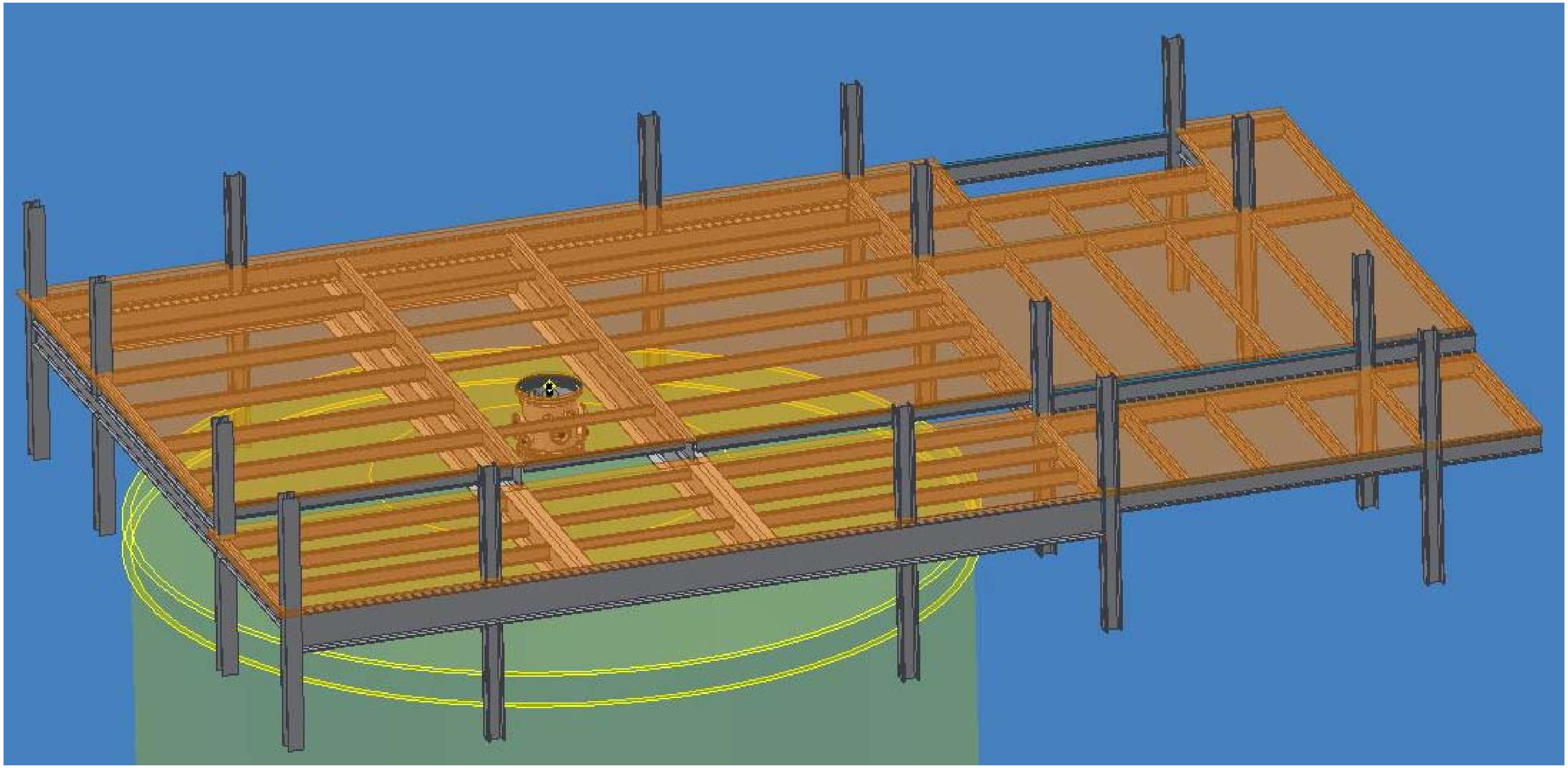
bot : h = 500 mm, for cryogenics - HD

dia 800



800

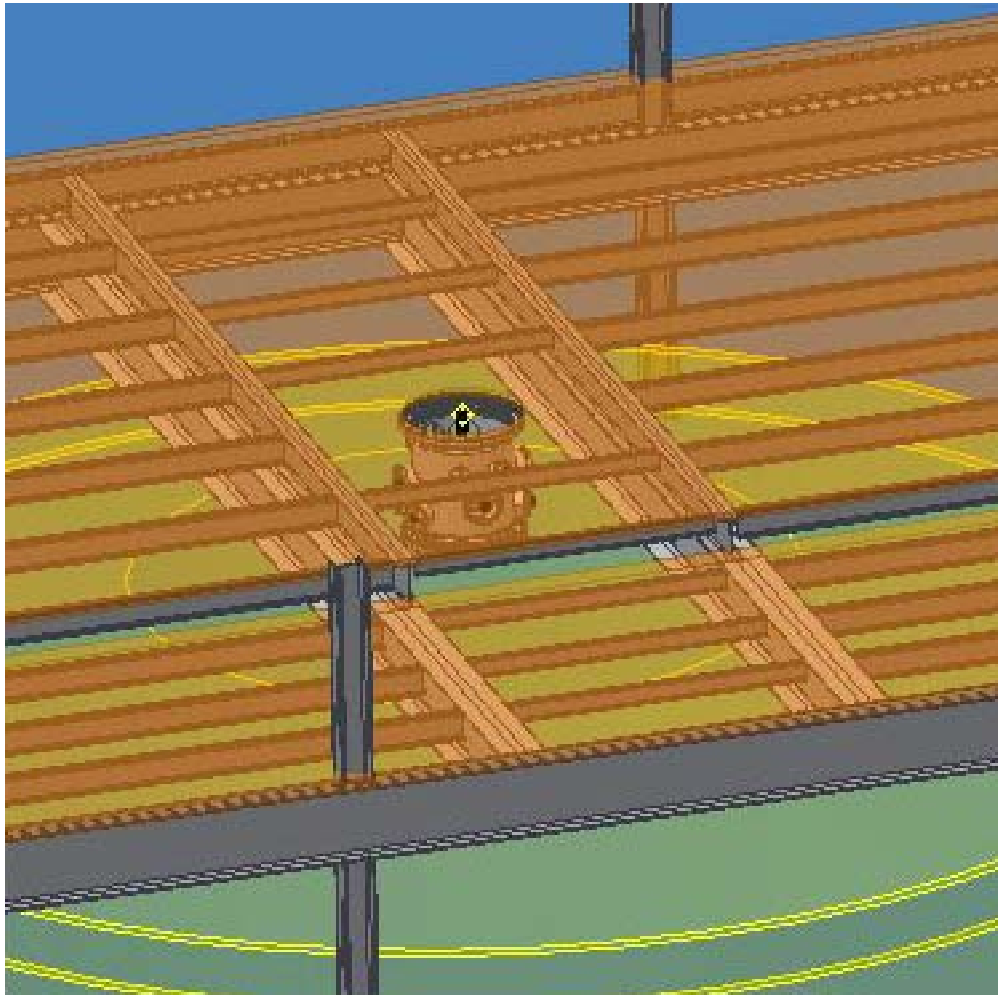
Manifold and Platform



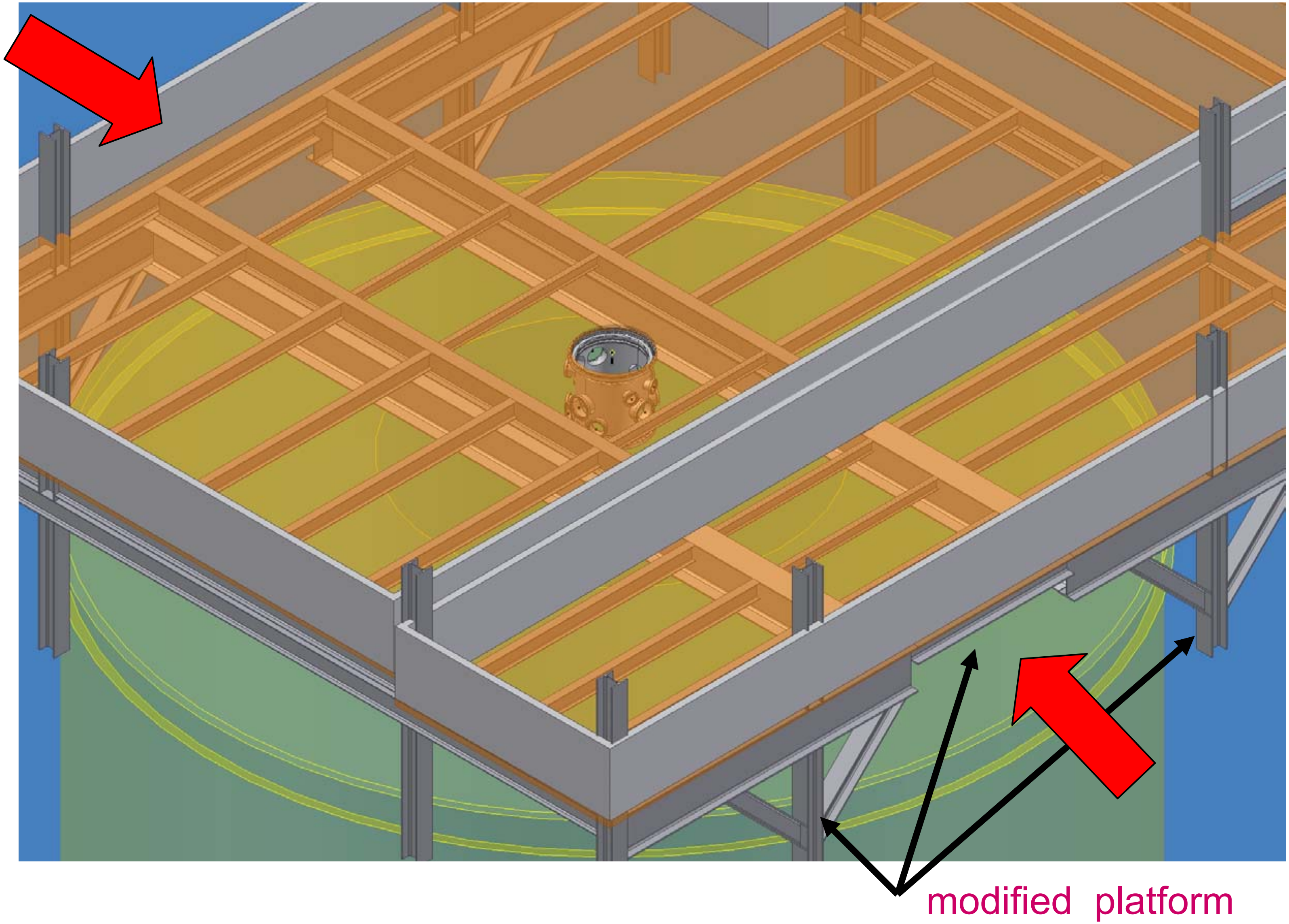
3D drawing deduced by MPI-Mu engineers from drawing Piante050405.dwg
(sizes of various beams to be verified)

Big thanks to K.Ackermann and S.Mayer !

No Access to Manifold !



Modified Platform: Access to Manifold Possible!



Next Steps

- Jul Final FMECA, HAZOP, PID review
  Final design for vessel
- Aug Safety Report
  Start of certification of welding procedures
- Sep Safety review by LNGS
- Tender for/order cryogenic infrastructure
- Study of how to install cryostat within water vessel
- Oct acquire copper material (OFE material fast available)
- rolling of copper bars (will be fast)
- ? pressing of segments (duration not yet clear)
- precision water cutting of segments
- cleaning of segments (procedure not yet defined)
- EB-welding of half-shells
- assembly of superinsulation (verify radiopurity of ALL components)
- assembly of cryostat and final EB-welds
- cleaning of vessel (procedure not yet defined)
- vacuum tests
- cryogenic tests
- ? 06 Shipment of cryostat to LNGS

Conclusions

- Geometry and standard design of copper cryostat finalized
- FMECA, HAZARD, and PID almost done
- Dimensions and construction procedures will be determined by Basissicherheits-Konzept in collaboration with TÜV Nord
  ► single shell rupture probability < 10^{-7} / year
- Welding tests in progress, slow progress
  DHP copper may be replaced by OFE copper
  (more expensive, but less radioactive)
- Interface (e.g. manifold, platform) problems addressed
- Open issues: corrosion, shields within cryostat (see, however, Igor's talk)
  welding certificates, certificates required by Basissicherheit
- Orders for vessel and cryogenic infrastructure in October possible
  if LNGS approves safety concept in-time.