HL-LHC (High Luminosity LHC)

Technical needs

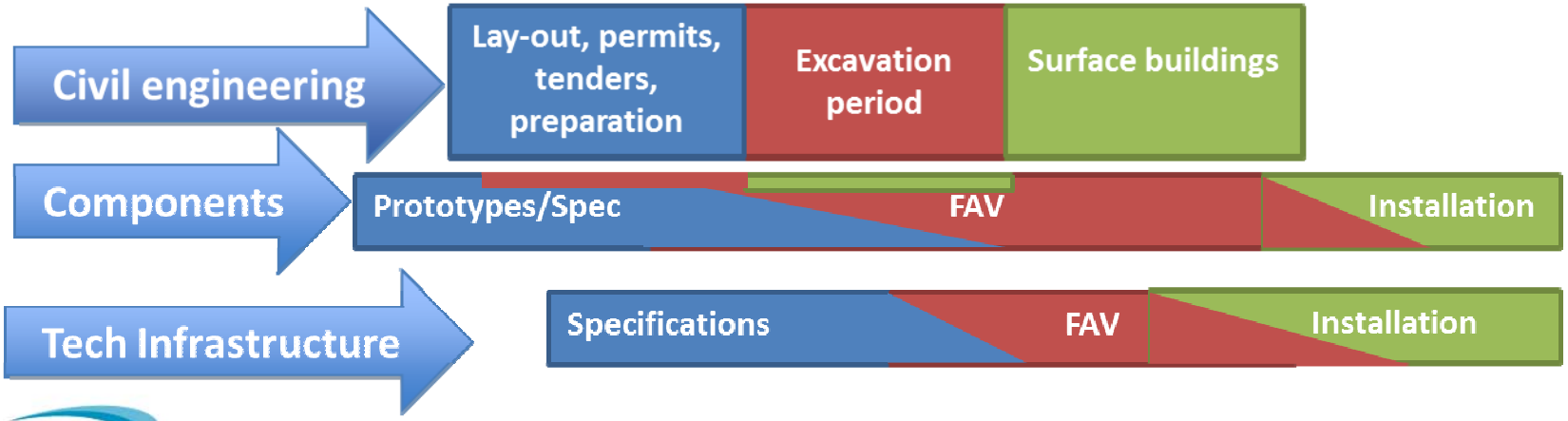
Isabel Bejar Alonso - CERN
HL-LHC Configuration, Quality & Resources Officer
On behalf of the HL-LHC Project team

TOBB İkiz Kuleler, ANKARA, 14th April 2016

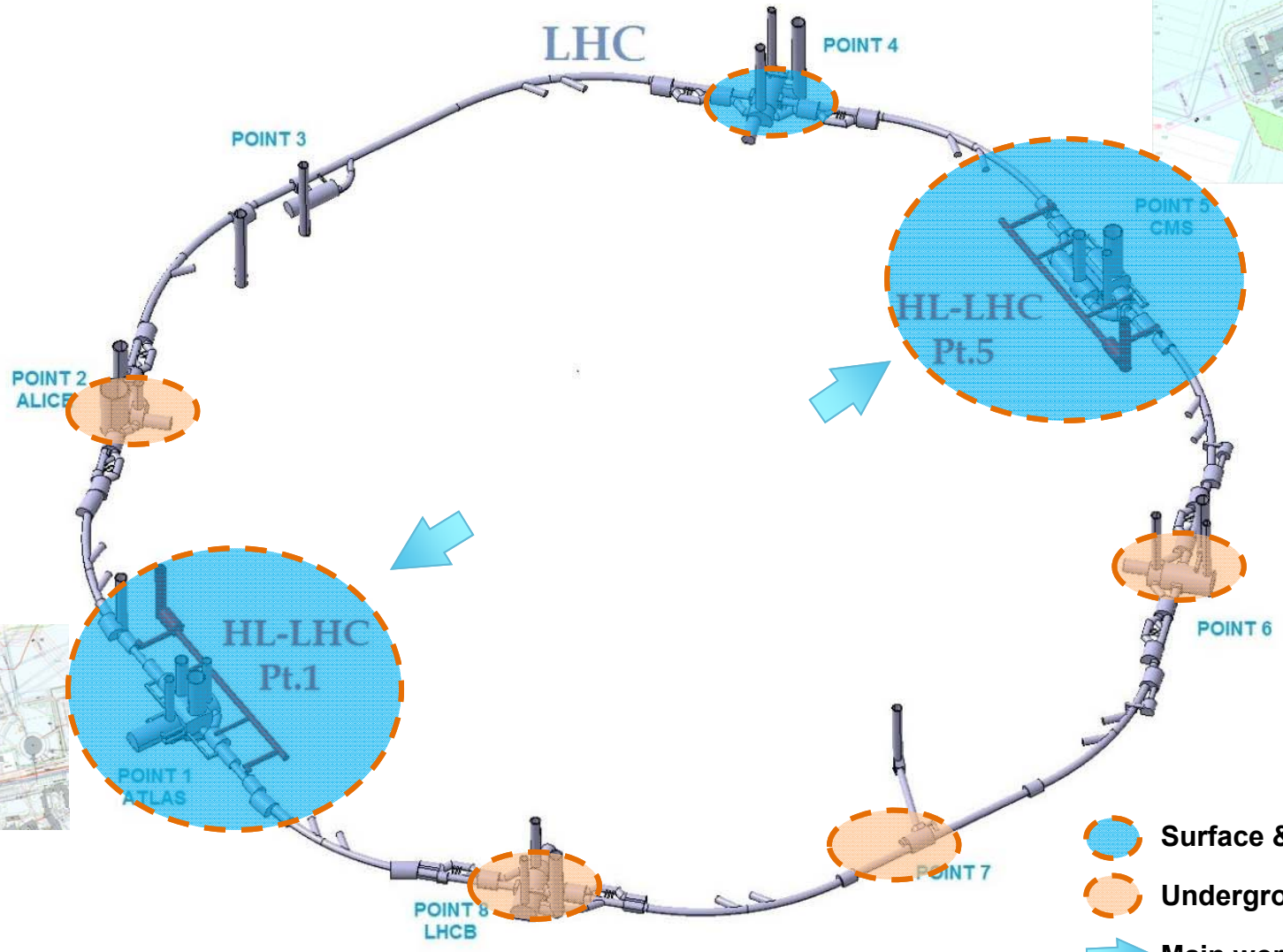
The HL-LHC Project

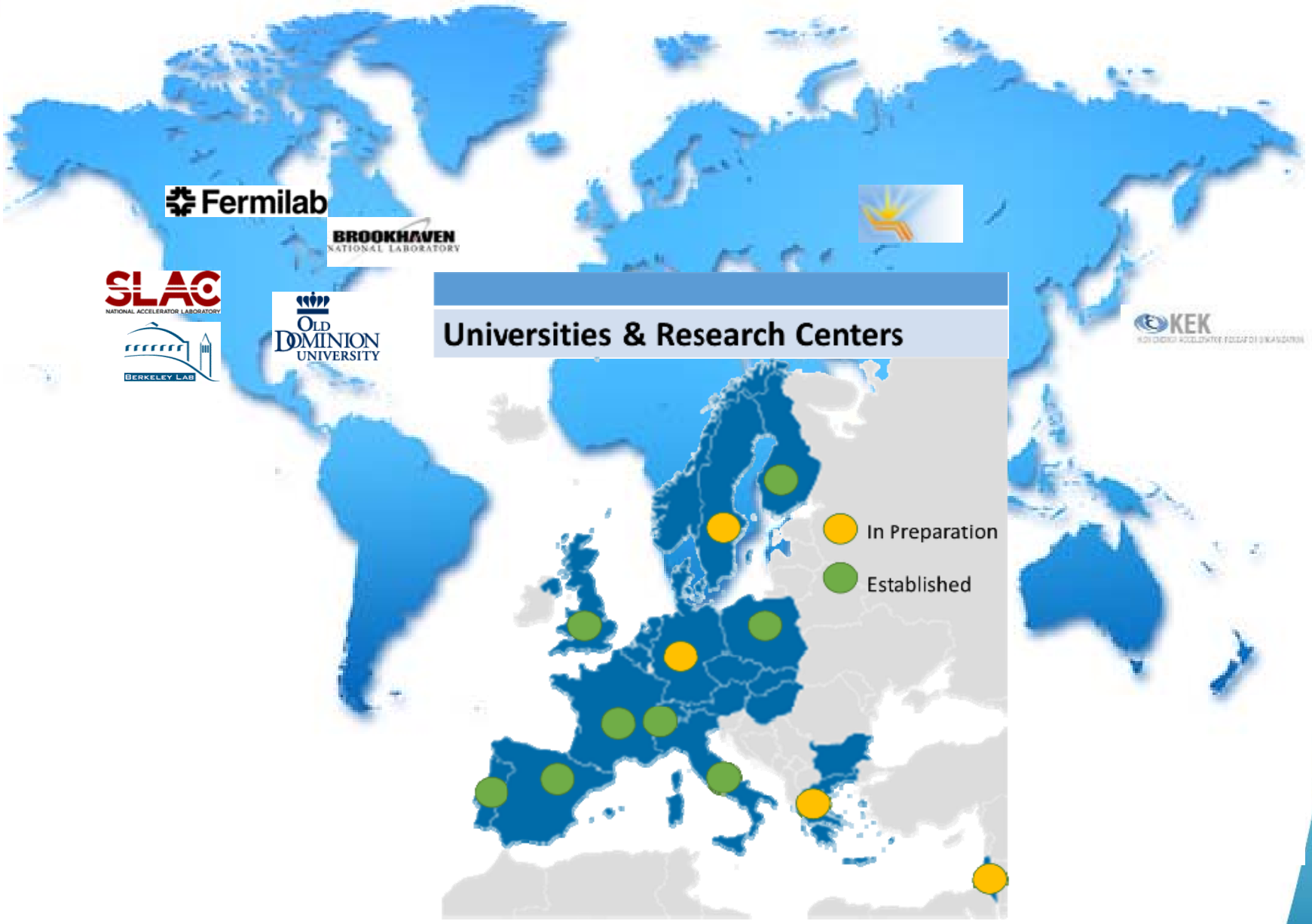
When, where, by whom?

LHC / HL-LHC Plan



Many points around the ring




Fermilab
BROOKHAVEN NATIONAL LABORATORY
SLAC NATIONAL ACCELERATOR LABORATORY
BERKELEY LAB
OLD DOMINION UNIVERSITY
KEK
Universities & Research Centers
In Preparation
Established

HL-LHC needs your industry

- The industry will have a crucial role and will be heavily involved within the HL-LHC Project since it will be the main source to provide the technologies and equipment that are required to successfully achieve the goals of this upgrade of the LHC.
- The HL-LHC will collaborate with many types of industries and businesses to pursue its goals. Knowledge and technology to be developed during the HL-LHC project will make a lasting impact on society

We have to find the right industrial partners all around our member states on time and having the best added value

HL-LHC needs your industry

Our work axis

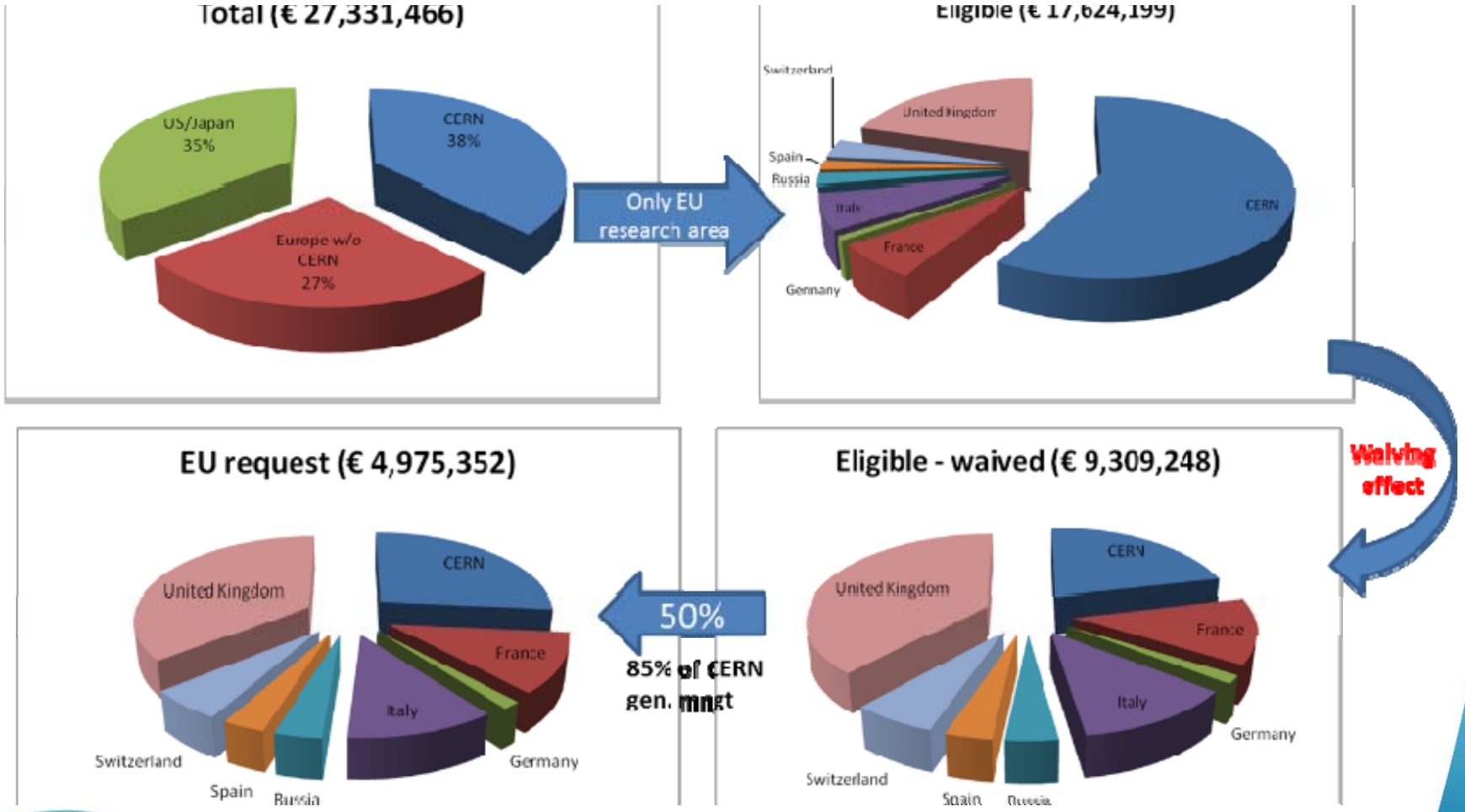
Provide you timely information of what we require and for when

Clear list of what we will need, their main characteristics and when the tendering process will start with easy access to the documents

Industry

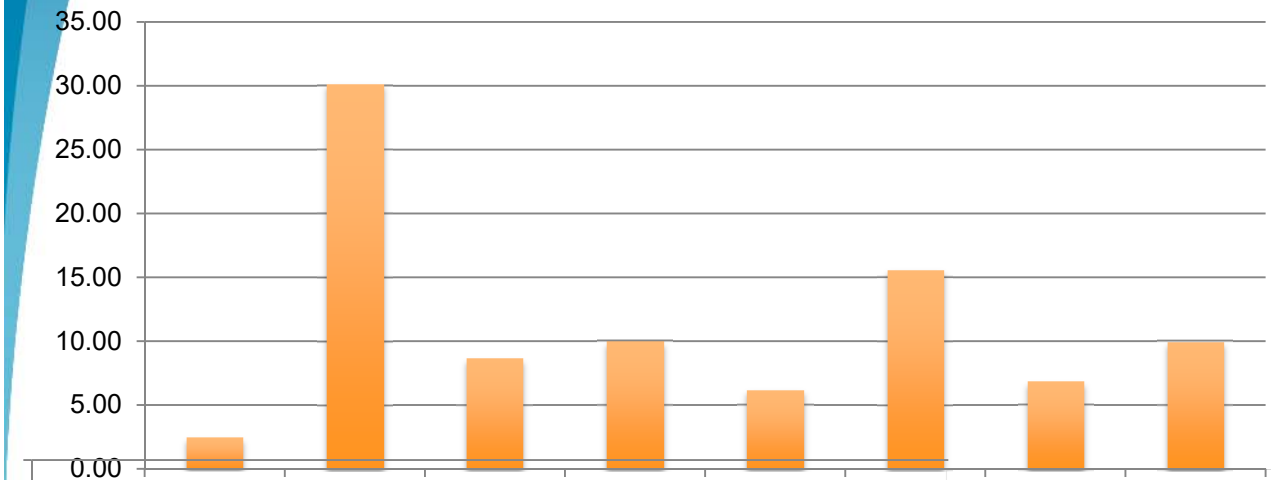
Procurement from HILUMI to HL-LHC

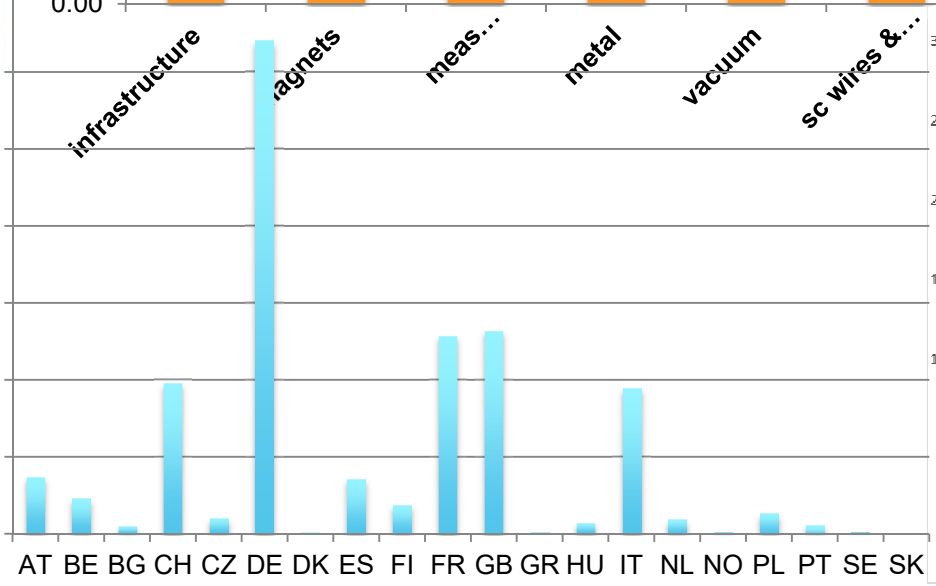
HILUMI FP7


Total (€ 27,331,466)
US/Japan 35%
CERN 38%
Europe w/o CERN 27%
Only EU research area
Eligible (€ 17,624,199)
Switzerland
United Kingdom
Spain
Russia
Italy
France
Germany
CERN
Waiving effect
Eligible - waived (€ 9,309,248)
CERN
United Kingdom
France
Italy
Germany
Switzerland
Spain
50%
85% of CERN gen. mngt
EU request (€ 4,975,352)
CERN
United Kingdom
France
Italy
Switzerland
Spain
Germany

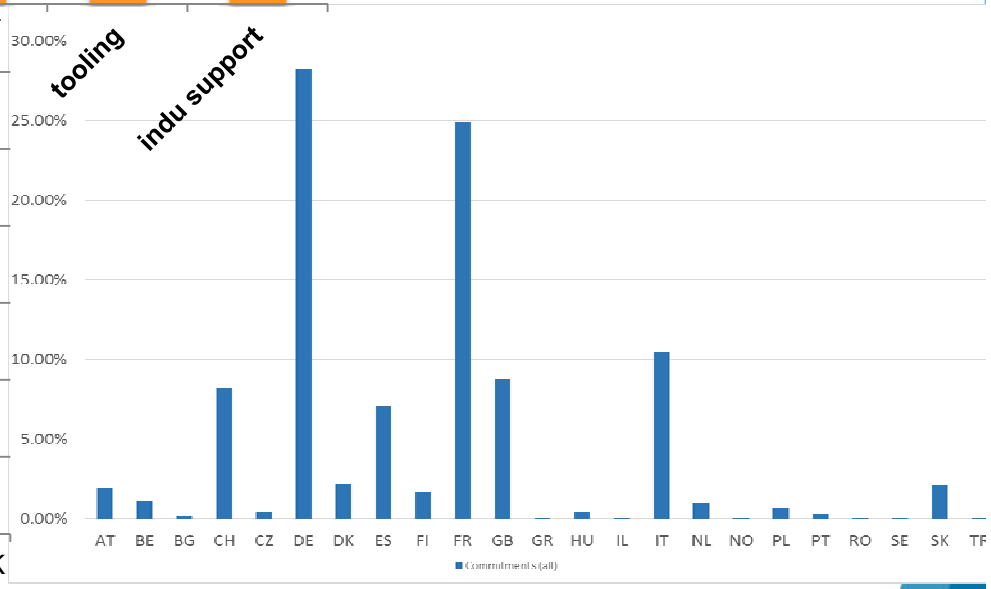
HILUMI Procurement

Hi-Lumi procurement sector allocation, %

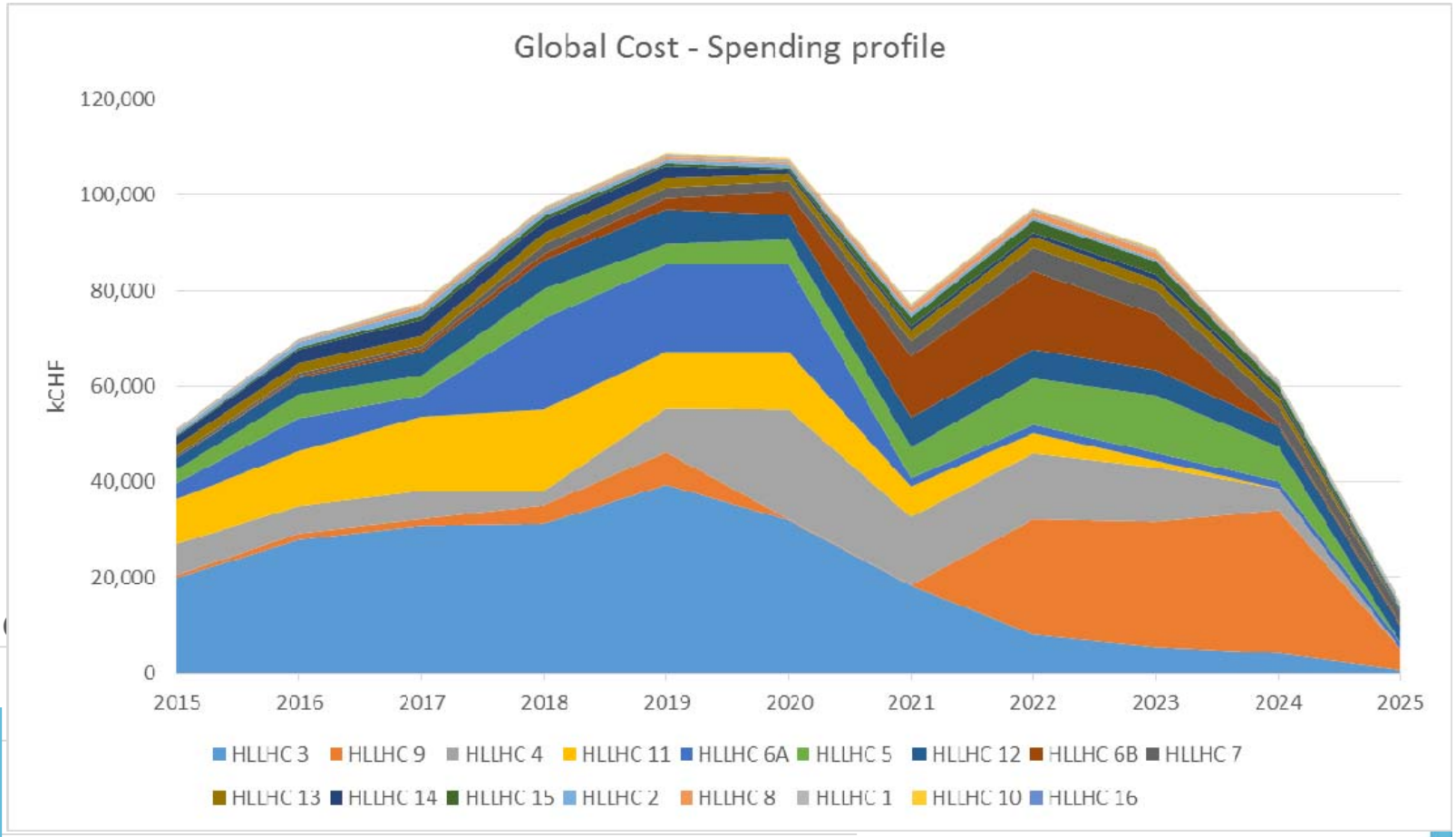


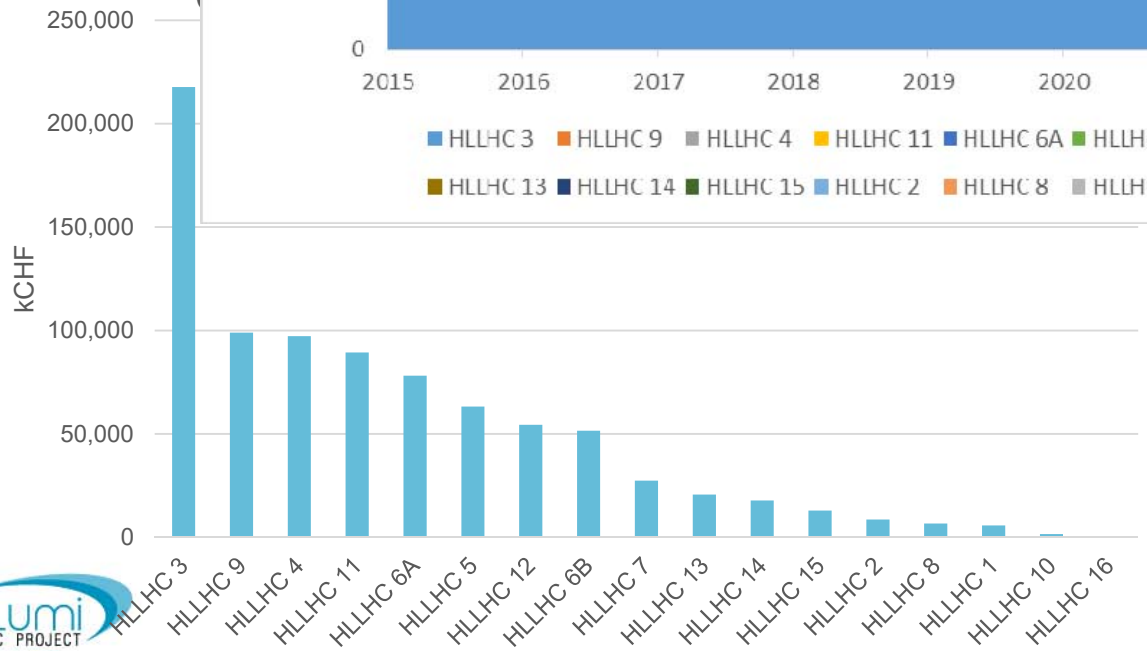


2012 - 2014



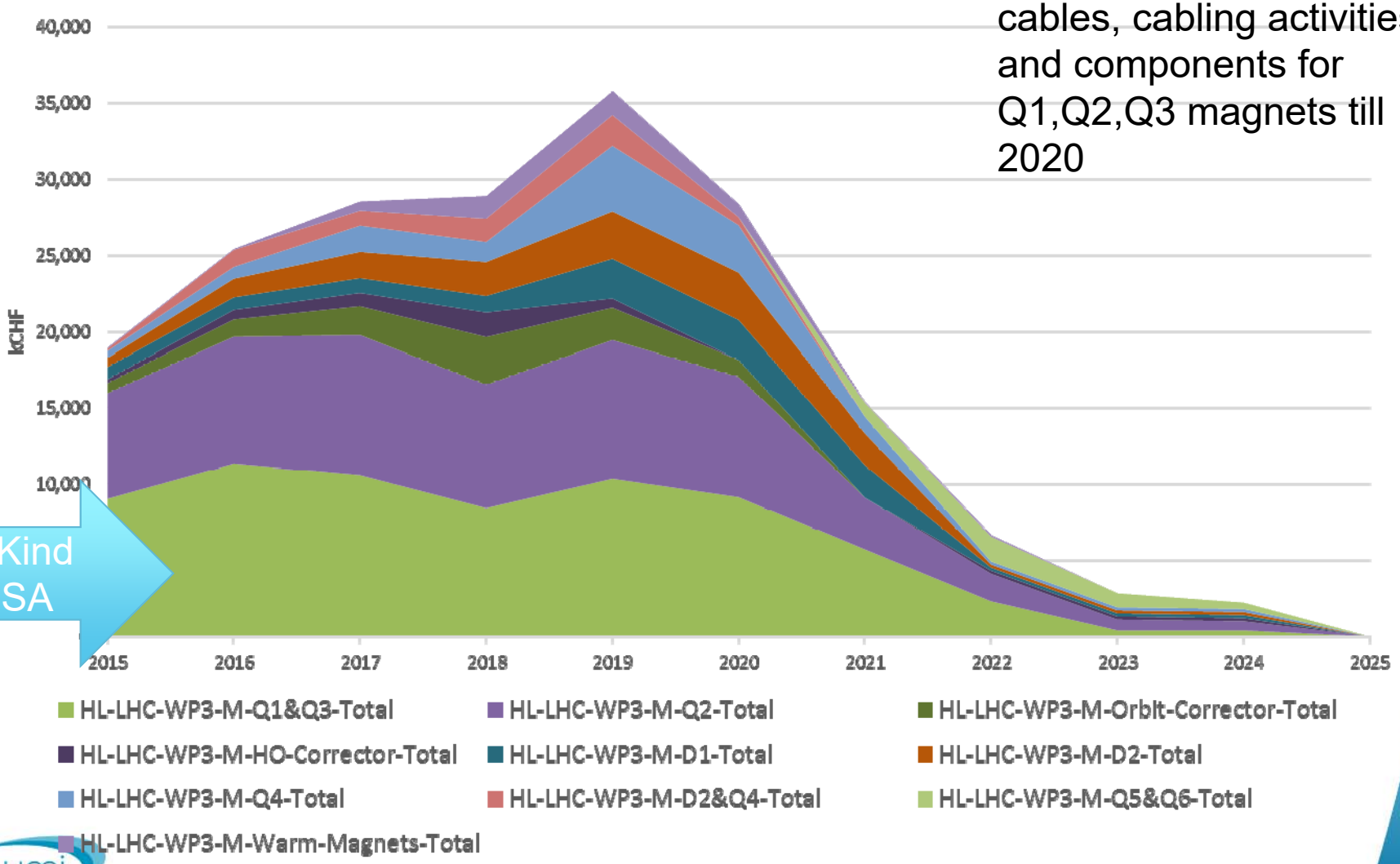
2012 - 2015


Global Cost - Spending profile
120,000
100,000
80,000
60,000
40,000
20,000
0
kCHF
2015
2016
2017
2018
2019
2020
2021
2022
2023
2024
2025
HLLHC 3
HLLHC 9
HLLHC 4
HLLHC 11
HLLHC 6A
HLLHC 5
HLLHC 12
HLLHC 6B
HLLHC 7
HLLHC 13
HLLHC 14
HLLHC 15
HLLHC 2
HLLHC 8
HLLHC 1
HLLHC 10
HLLHC 16


250,000
200,000
150,000
100,000
50,000
0
kCHF
HLLHC 3
HLLHC 9
HLLHC 4
HLLHC 11
HLLHC 6A
HLLHC 5
HLLHC 12
HLLHC 6B
HLLHC 7
HLLHC 13
HLLHC 14
HLLHC 15
HLLHC 2
HLLHC 8
HLLHC 1
HLLHC 10
HLLHC 16

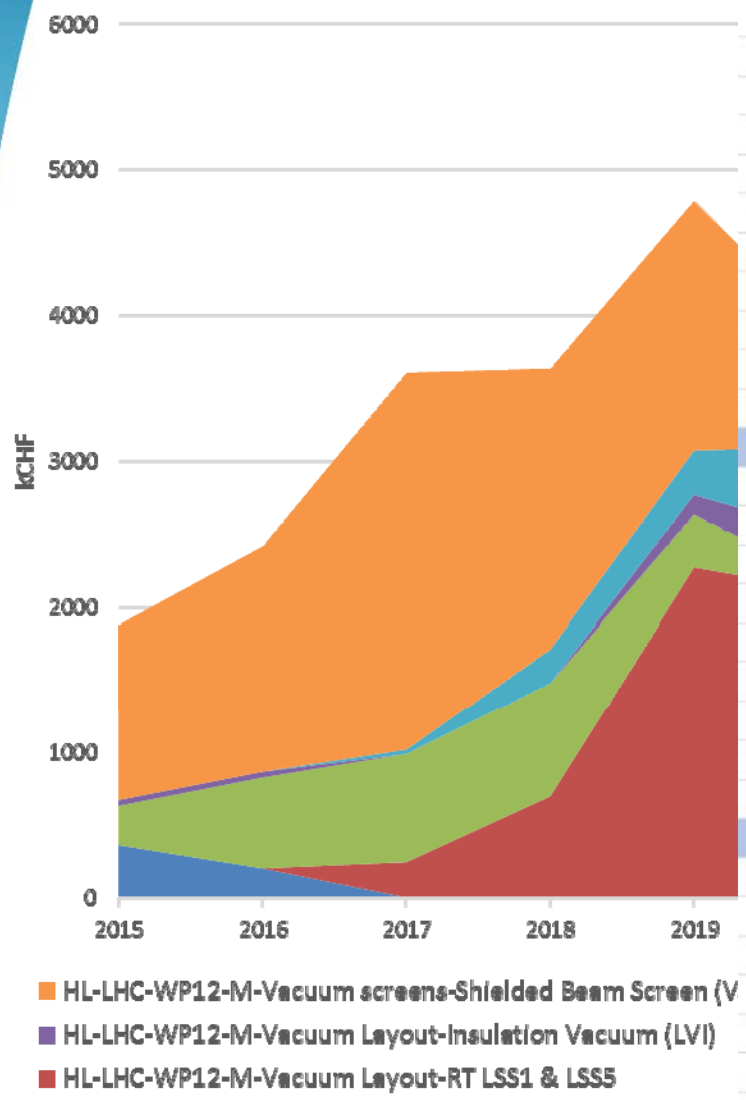
HL-LHC – IR Magnets

WP03 : most spending in GOODS, purchase of cables, cabling activities and components for Q1,Q2,Q3 magnets till 2020



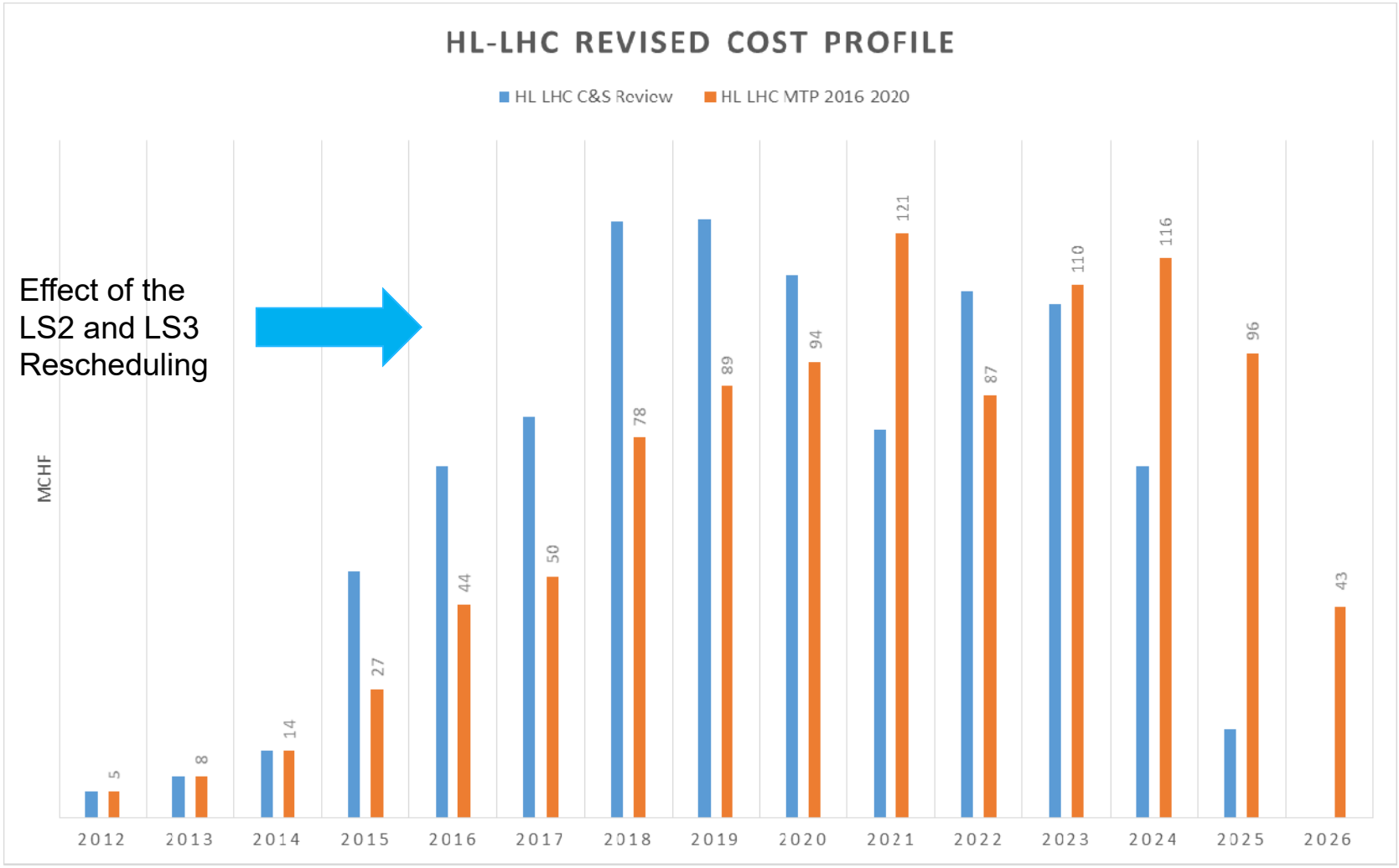
In Kind USA

HL-L

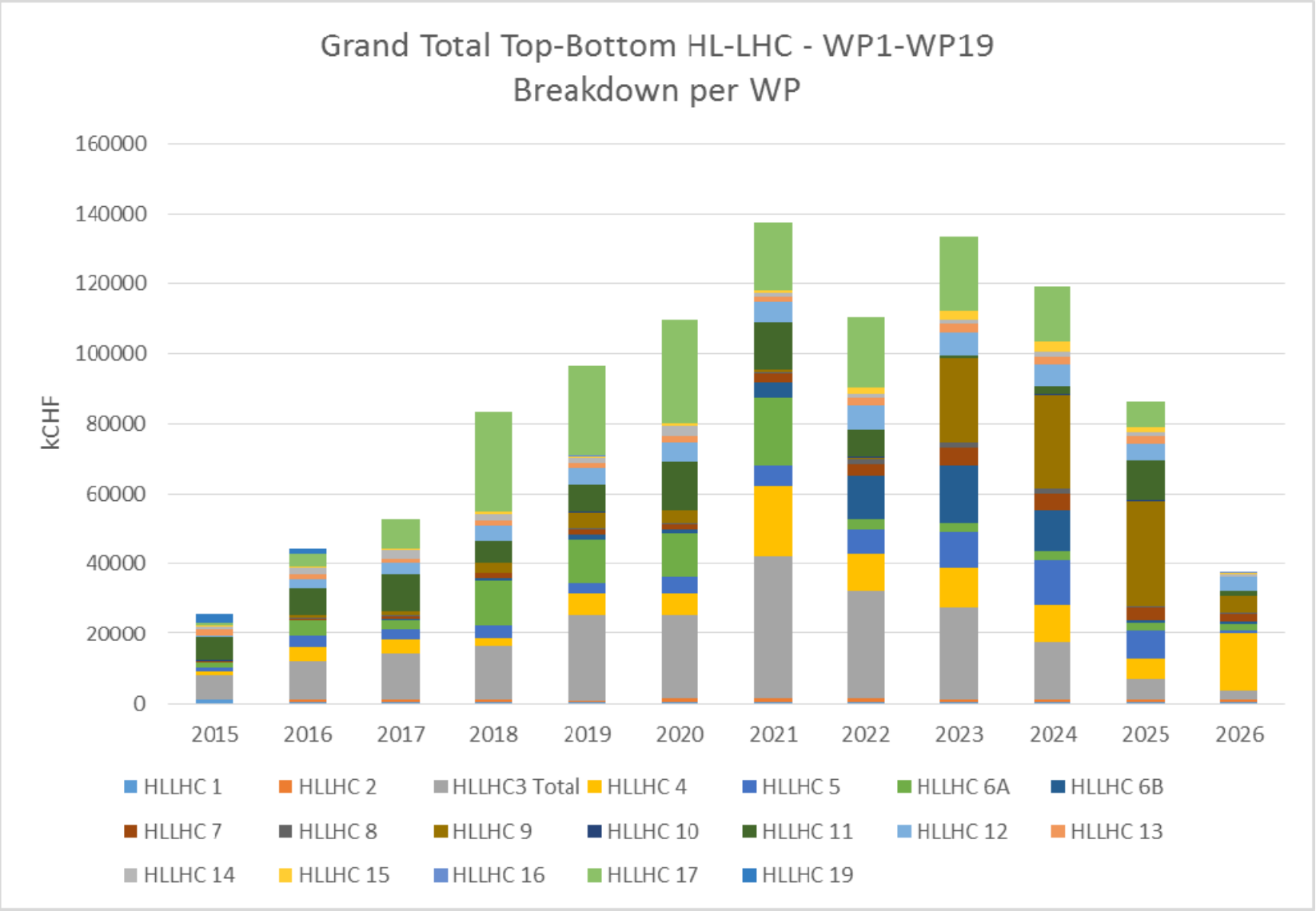


WP12: Beam Vacuum	**Wed 01/01/14**
HL-LHC Shielded Beam Screen @P1 and P5	**Wed 01/01/14**
Acquisition process	**Tue 30/06/15**
tungsten (c>750)	Tue 15/12/15
Titane and supporting system (c<200)	Tue 14/06/16
Thermal link (c<200)	Tue 14/06/16
BS strip (cat 200<c<750)	Tue 30/06/15
BS colamination (cat 200<c<750)	Tue 15/12/15
BS punching, forming & welding (c>750)	Tue 15/12/15
cooling pipe (C<200)	Tue 14/06/16
CB (200<c<750)	Tue 15/12/15
PIM (cat c<200)	Tue 30/06/15
interconnect (beam vacuum+cooling) (200<c<750)	Tue 10/01/17
CWT (c<200)	Tue 14/11/17
Tooling BS horizontal coating -----> 500 (C<200)	Tue 14/06/16
HL-LHC (non shielded) Beam Screen	**Wed 01/01/14**
Acquisition process	**Tue 30/06/15**
BS strip (200<c<750)	Tue 30/06/15
BS colamination (200<c<750)	Tue 14/06/16
BS punching, forming & welding (200<c<750)	Tue 30/05/17
cooling pipe (C<200)	Tue 14/06/16
BS tube (c<200)	Tue 14/06/16
CB (c<200)	Tue 14/06/16
CWT (200<c<750)	Tue 23/01/18
Tooling BS coating (shared at 50 %) (c<200)	Tue 14/06/16
HL-LHC Beam Vacuum Layout in LSS1 & LSS5	**Wed 01/01/14**
Acquisition process	**Wed 11/01/17**
supports (200<c<750)	Tue 04/04/17
chambers (50% LSS) (c>750)	Wed 11/01/17
VM (c>750)	Wed 11/01/17
gauges (VGR, VGP,VGI) (200<c<750)	Tue 04/04/17
gauges (VGI) (c<200)	Tue 27/06/17
sector valves (c>750)	Wed 11/01/17
roughing valves (c<200)	Tue 27/06/17
VPI pumps (1 VPI tous les 14 m across all the ring) (c>750)	Wed 11/01/17
NEG cartridges (excluding ALARA 3 and 7 i.e. CONS 50 %) (c<200)	Tue 27/06/17
bakeout (jackets, cable, thermocouple) (200<c<750)	Tue 04/04/17

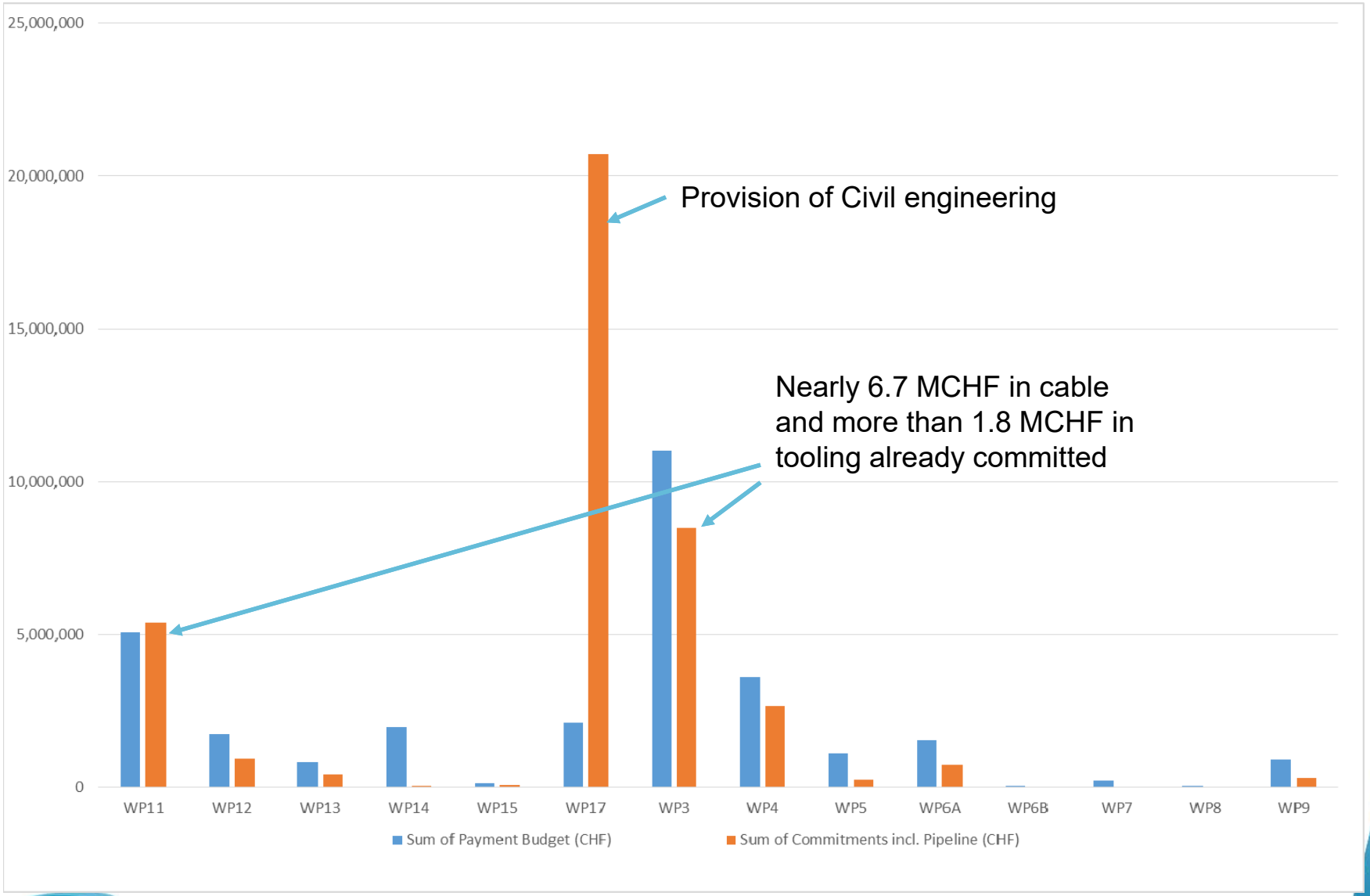
How much we will spend in the next years



On what we will spend this money



… and on 2016

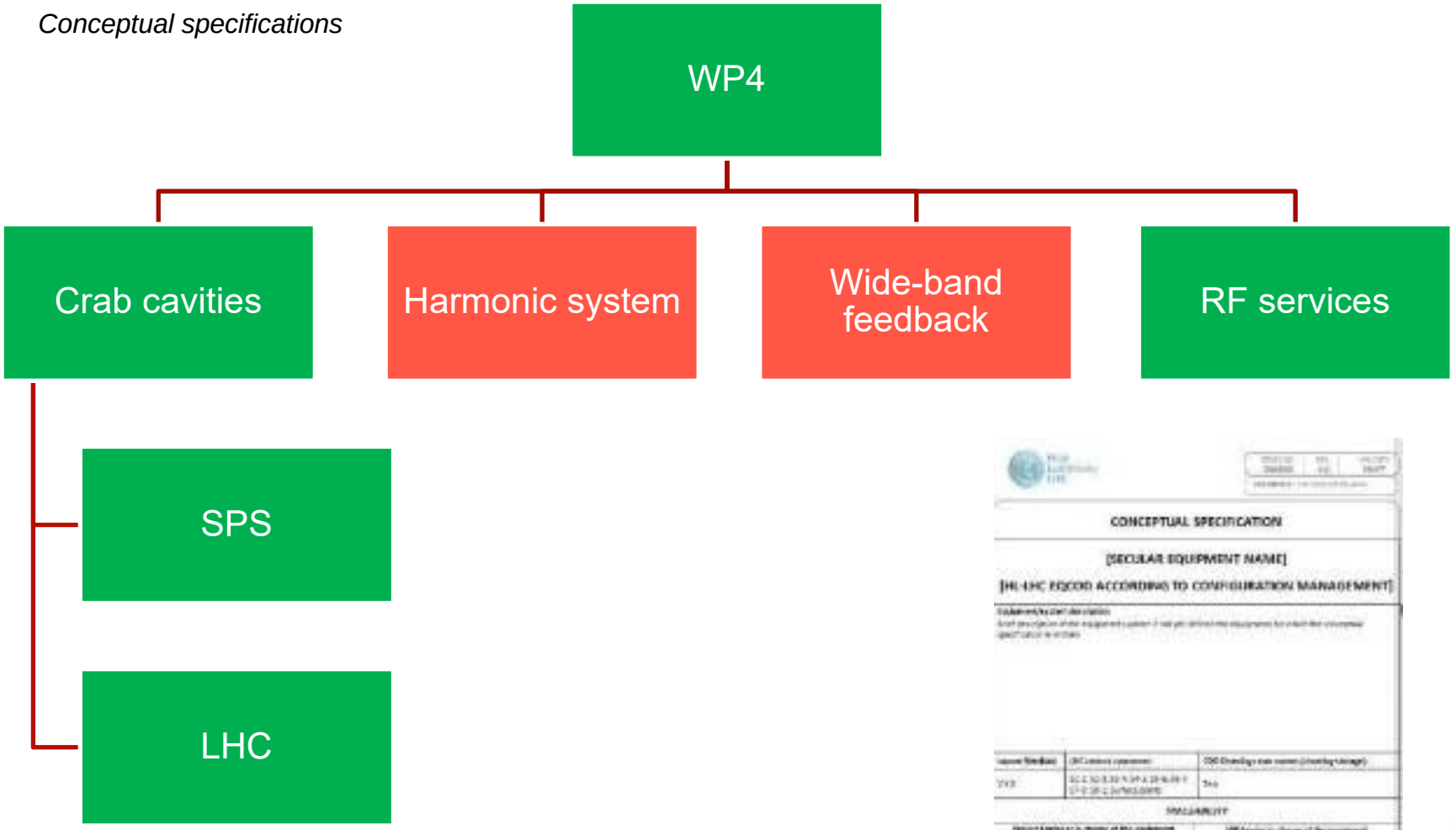

25,000,000
20,000,000
15,000,000
10,000,000
5,000,000
0
Provision of Civil engineering
Nearly 6.7 MCHF in cable and more than 1.8 MCHF in tooling already committed
WP11
WP12
WP13
WP14
WP15
WP17
WP3
WP4
WP5
WP6A
WP6B
WP7
WP8
WP9
Sum of Payment Budget (CHF)
Sum of Commitments incl. Pipeline (CHF)

Industry

Make or buy process.

Ex. WP4 Crab Cavities and RF systems

Conceptual specifications



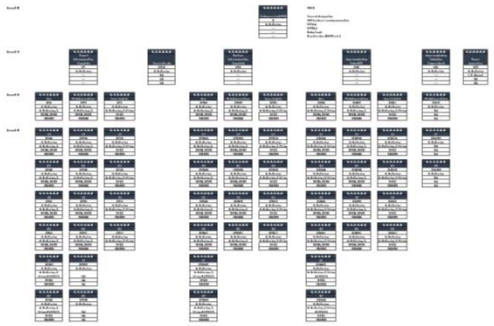
CONCEPTUAL SPECIFICATION

[SECULAR EQUIPMENT NAME]

[HL-LHC FQCOD ACCORDING TO CONFIGURATION MANAGEMENT]

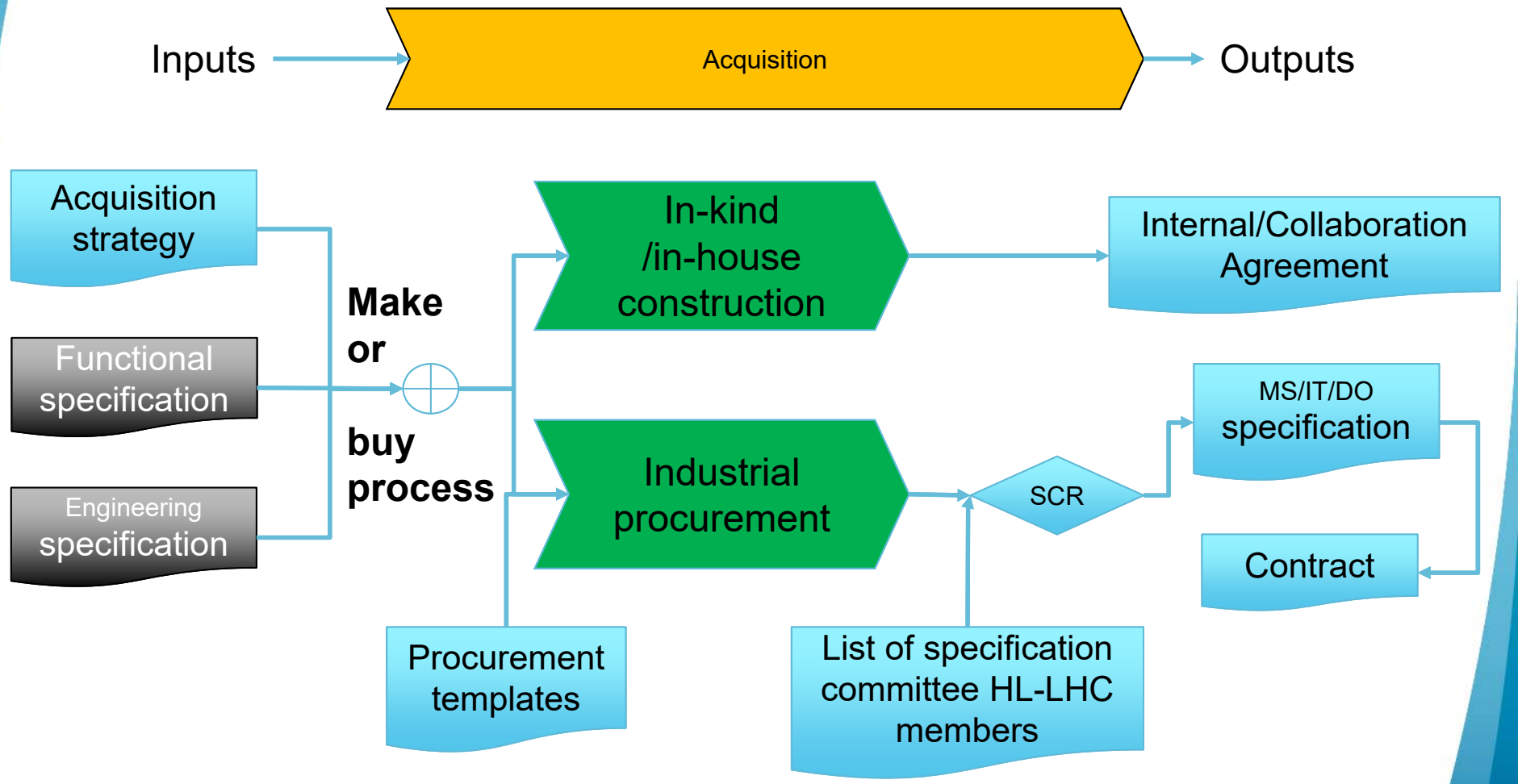
FEASIBILITY

Analysis of the subcomponents



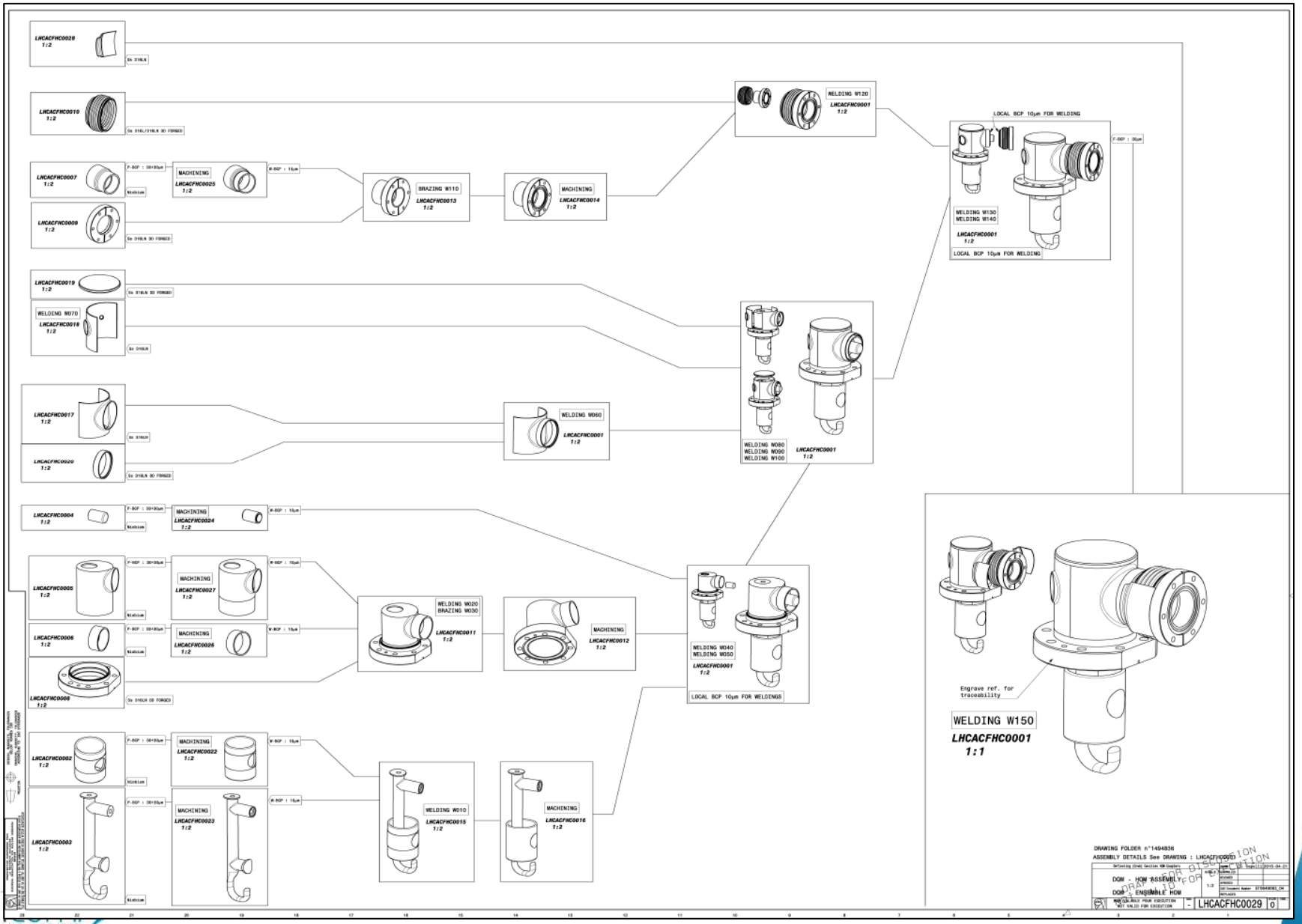
- WP4
  - Crab cavities **(ACF)**
    - LHC (ACF)
    - SPS prototype (idem to LHC)
      - Cryomodule **(ACFGA)**
        - Vacuum vessel **(ACFVT)**
        - External supports (HACF)
        - Cryostat components (ACFAC)
          - *Cryogenic circuits*
          - *Supports*
          - *Thermal shield*
          - *Magnetic shield*
        - Dressed cavities **(ACFDC)**
          - Bare cavities with interfaces **(ACFCA)**
          - Tuning system **(ACFTU)**
          - Helium vessel **(ACFHT)**
          - HOM couplers **(ACFHC)**
        - Instrumentation (ACFIS)
        - Main coupler (ACFMC)
        - Vacuum valves (VVG)
      - RF services (ACFSV)
        - LLRF & Fast Controls (ALL)
        - RF racks (AY)
        - Slow controls (AS)
        - Transmission lines (ACFWG)
        - Pick-ups (APW)

Acquisition process



SCR: Specification Committee Review

Example - HOM Couplers



Make or Buy Plan

PBS Element Life-Cycle

High Luminosity LHC

EDMS NO.	REV.	VALIDITY
1517895	1.1	VALID
ACQUISITION		RESTRICTED

MAKE OR BUY PLAN

PBS Iter	LHC Equipment code	Name	Engineering specificatio	Fabricatior	Assembl	Verificatic	Installatio	Commissioni
4.1.1.1.0.0	ACFGA	SPS Cryomodule	CERN	CERN + New Collaborations	CERN + New Collaborations	CERN + New Collaborations	CERN	CERN + New Collaborations
4.1.1.1.1.0	ACFVT	SPS Vacuum vessel	CERN	CERN + New Contract	CERN	CERN + New Collaborations	CERN	CERN + New Collaborations
4.1.1.1.2.0	HACF	SPS External supports	CERN	CERN + New Contract	CERN	CERN + New Collaborations	CERN	CERN + New Collaborations
4.1.1.1.3.0	ACFAC	SPS Cryostat components	CERN	CERN + New Contract	CERN	CERN + New Collaborations	CERN	CERN + New Collaborations
4.1.1.1.4.0	ACFDC	SPS Dressed cavities	CERN	CERN + New Collaborations	Collaboration US-LARP	CERN + New Collaborations	CERN	CERN + New Collaborations
4.1.1.1.4.1	ACFCA	SPS Bare cavities with interfaces	CERN	Collaboration US-LARP	Collaboration US-LARP	CERN + New Collaborations	CERN	CERN + New Collaborations
4.1.1.1.4.2	ACFTU	SPS Tunning system	CERN	CERN + New Contract	CERN	CE Col		
4.1.1.1.4.3	ACFHT	SPS Helium vessel	CERN	Collaboration US-LARP	Collaboration US-LARP	CE Col		
4.1.1.1.4.4	ACFHC	SPS HOM couplers	CERN	CERN	CERN	CE Col		
4.1.1.1.4.5	Not defined yet	SPS Cold magnetic shield	CERN	Collaboration UK	Collaboration UK	CE Col		
4.1.1.1.5.0	ACFIS	SPS Instrumentation	CERN	CERN + New Contract	CERN	CE Col		
4.1.1.1.6.0	ACFMC	SPS Main coupler	CERN	CERN + New Contract	CERN	CE Col		
4.1.1.1.7.0	VVG	SPS Vacuum valves	CERN	CERN + New Contract	CERN + New Contract	CE Col		

HiLumi HL-LHC PROJECT

What and When

Name	Number of units	Engineering specification	Fabrication	Assembly	Verification
Power Converter [Current 16.5 kA, Voltage 20V, 1 Quadrant]	16	CERN	New procurement contract	New procurement contract	New procurement contract
Power Converter [Current 13 kA, Voltage 18V, 1 Quadrant]	8	CERN	New procurement contract	New procurement contract	New procurement contract
Power Converter [Current 6 kA, Voltage 8V, 1 Quadrant]	16	CERN	New procurement contract	New procurement contract	New procurement contract
Power Converter [Current ±2 kA, Voltage ±10V, 4 Quadrant]	60	CERN	New procurement contract	New procurement contract	New procurement contract
Power Converter [Current ±0.6 kA, Voltage ±10V, 4 Quadrant]	4	CERN	New procurement contract	New procurement contract	New procurement contract
Power Converter [Current ±0.2 kA, Voltage ±10V, 4 Quadrant]	28	CERN	New procurement contract	New procurement contract	New procurement contract
Power Converter [Current ±0.12 kA, Voltage ±10V, 4 Quadrant]	40	CERN	New procurement contract	New procurement contract	New procurement contract
Power Converter [Current 17 kA, Voltage ±18V, 2 Quadrant]	R&D	New collaboration			
Power Converter [Current 13 kA, Voltage ±18V, 2 Quadrant]	R&D	New collaboration			
Power Converter [Current 6 kA, Voltage ±10V, 2 Quadrant]	R&D	New collaboration			

2018

2020 for launching of Fabrication orders

Looking for (short term)

- Collaborations with universities interesting in R&D on 2-quadrant topologies for converters up to 17kA to improve current ramp down (17kA/±18V)
and squeeze time (6kA/±10V) – end 2015
- Potential suppliers from MS - before 2020

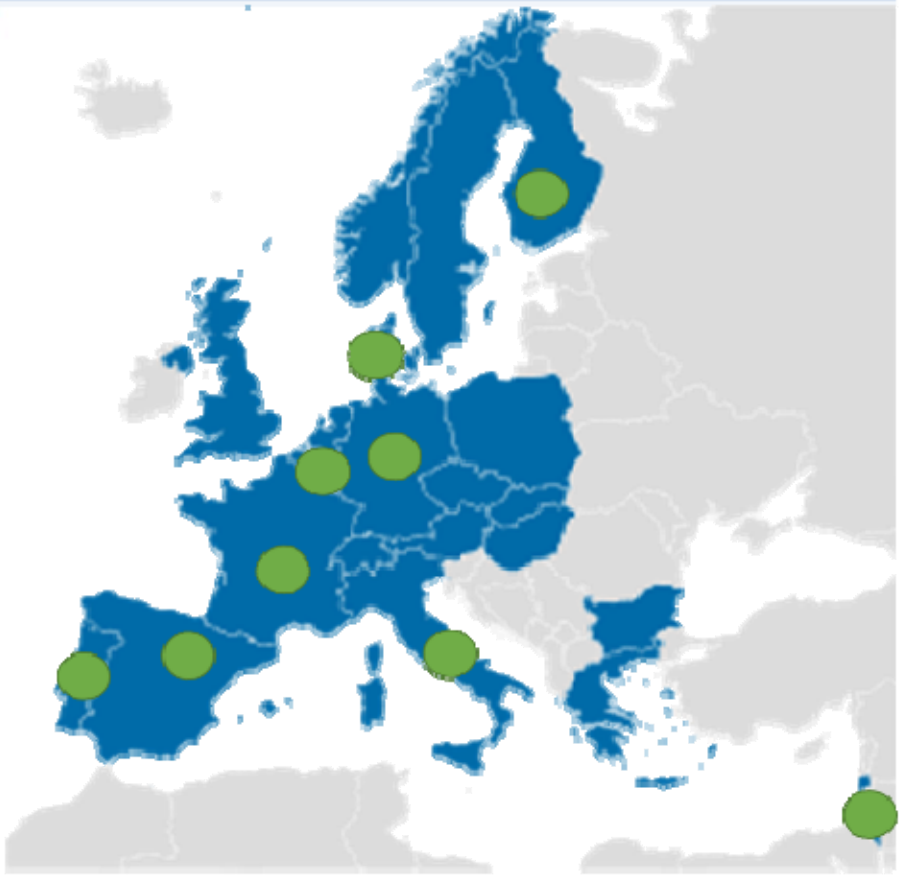
Contacts & more info

HL-LHC_Knowledge_and_Industry@cern.ch
WWW: HL-LHC Knowledge & Industry

Example of procurement lists/suppliers

Domains of Activity

Power Converters



Identification of fields where we need suppliers

Presently identified as potential suppliers

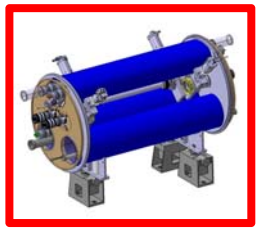
MS	Firm	MS	Firm
AT		HU	
BE	JEMA	IL	TDK-LAMBDA
BG		IT	EEI, OCEM
CH		NL	
CZ		NO	
DE	TRANSTECHNIK, HEINZINGER	PL	
DK	DANFYSIK	PT	EFACEC
ES	JEMA	SK	
FI	KEMPOWER	SE	
FR	SIGMAPH	UK	

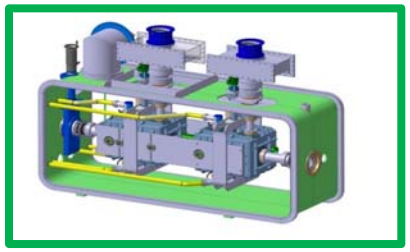
PBS Item #	Name	WP	Required on	Foreseen cost	DR Description	Comments
3.1.0.0.0.0	Q2 Magnets	WP03	2015-05	c>750k	Strand for prototypes OST	
3.1.0.0.0.0	Q2 Magnets	WP03	2015-05	c>750k	Strand for prototypes PIT	
3.2.0.0.0.0	Q1 & Q3 Magnets	WP03	2015-05	c>750k	Strand for prototypes OST	
3.2.0.0.0.0	Q2 Magnets	WP03	2015-05	200k<c<750k	Winding-curing tooling	
3.2.0.0.0.0	Q2 Magnets	WP03	2015-06	200k<c<750k	Tooling: reaction fixture	
3.2.0.0.0.0	Q2 Magnets	WP03	2015-06	200k<c<750k	Tooling: impregnation fixture	
3.2.0.0.0.0	Q2 Magnets	WP03	2015-06	50<c<200k	Short model coil: End-parts (spacers, end-shoe)	
3.2.0.0.0.0	Q2 Magnets	WP03	2015-06	50<c<200k	Prototype coil: Poles and end-shoe extensions	
3.6.0.0.0.0	D2 Magnets	WP03	2015-08	50<c<200k	Manufacturing short model	
11.1.2.0.0.0	Cryo-Magnet assembly for High Field 11 T Dipole - Prototype	WP11	2015-08		Ceramic Binder	EDMS #1513360 - Specification for procurement Material will be also used for series
11.1.2.0.0.0	Cryo-Magnet assembly for High Field 11 T Dipole - Prototype	WP11	2015-08		Cable Insulation	EDMS #1431875 - Specification for procurement Material will be also used for series
3.2.0.0.0.0	Q2 Magnets	WP03	2015-09	50<c<200k	Laminated structure short model	
3.2.0.0.0.0	Q1 & Q3 Magnets	WP03	2015-09	50<c<200k	Laminated structure short model	
3.7.0.0.0.0	Orbit Correctors	WP03	2015-09	c>750k	Strand for correctors	

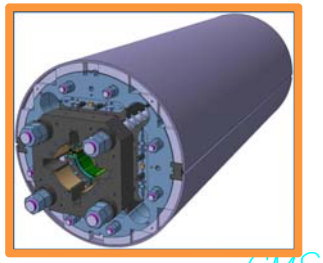
The HL-LHC Project

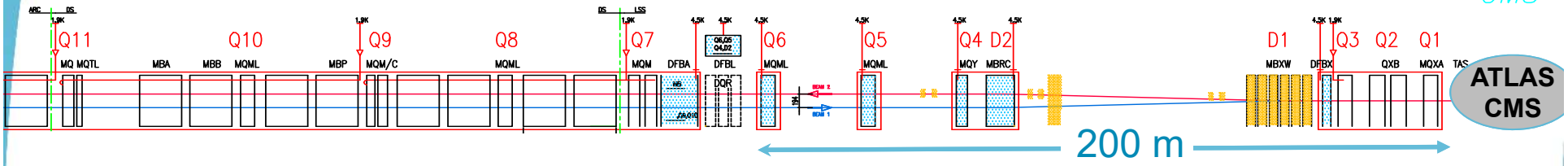
Main components, technical services and infrastructure

The largest HEP accelerator in construction







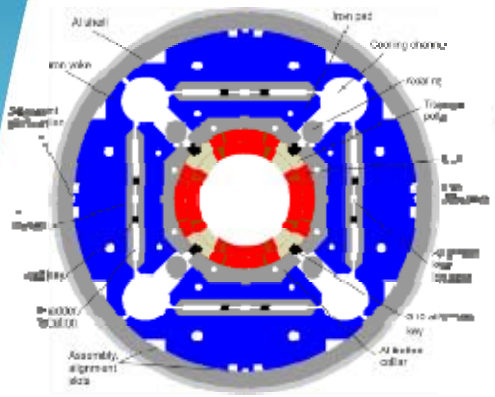


Dispersion Suppressor (DS)	Matching Section (MS)	Interaction Region (ITR)
Modifications 1. In IP2: new DS collimation in c. Cryostat 2. In IP7 new DS collimation with 11 T	**Complete change and new lay-out** 1. TAN 2. D2 3. CC 4. Q4 5. All correctors 6. Q5 7. New MQ in P6 8. New collimators	**Complete change and new lay-out** 1. TAXS 2. Q1-Q2-Q3 3. D1 4. All correctors 5. Heavy shielding (W)

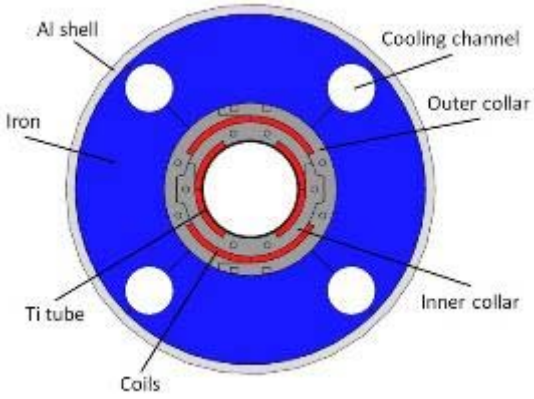
Cryogenics, Protection, Interface, Vacuum, Diagnostics, Inj/Extr… extension of infrastructure

> 1.2 km of LHC

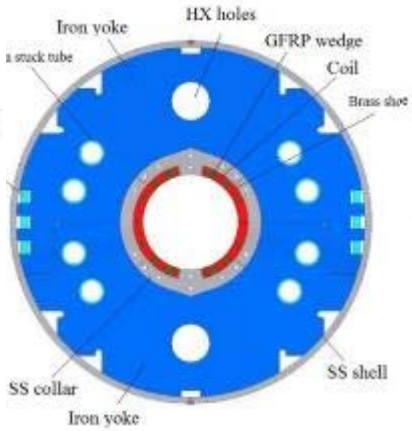
HiLumi LHC magnet zoo



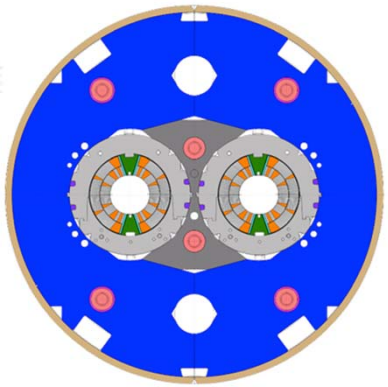
Triplet QXF (LARP and CERN)



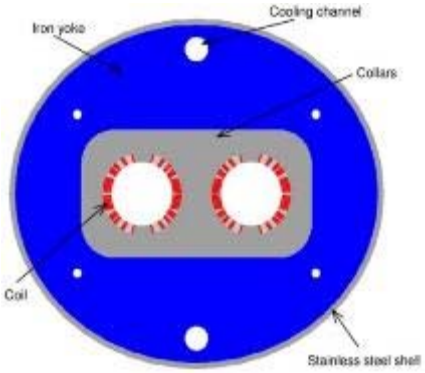
Orbit corrector (CIEMAT)



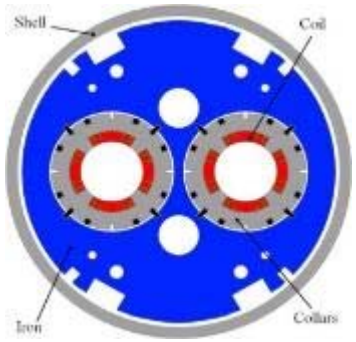
Separation dipole D1 (KEK)



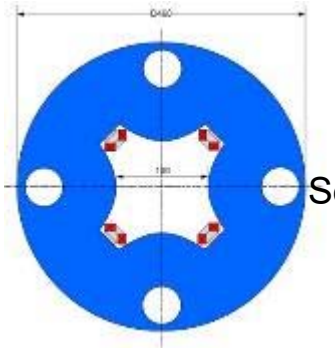
11 T dipole (CERN)



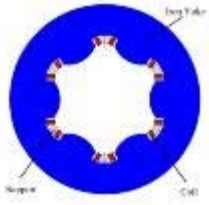
Recombination dipole D2 (INFN design)



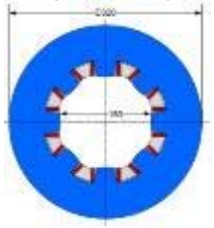
Q4 (CEA)



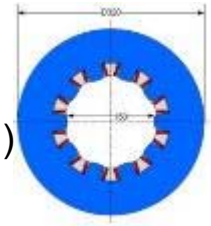
Skew quadrupole (INFN)



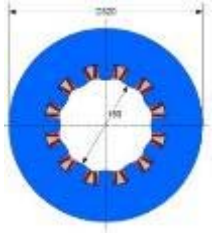
Sextupole (INFN)



Octupole (INFN)



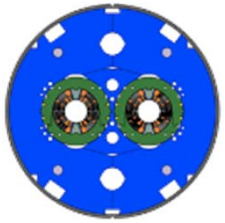
Decapole (INFN)

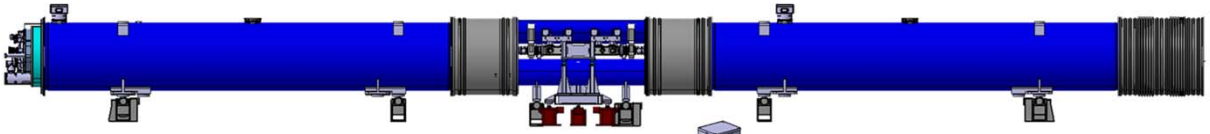


Dodecapole (INFN)

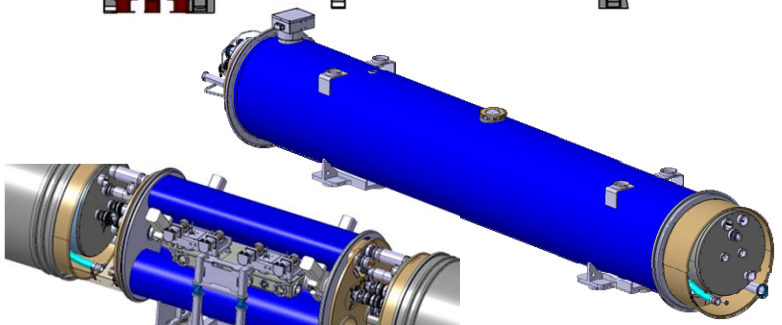
Overall, about 150 magnets are needed

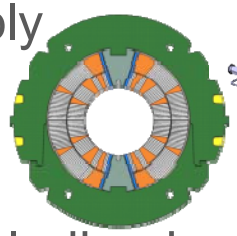
Assembly Breakdown Structure for the 11 T (main elements)

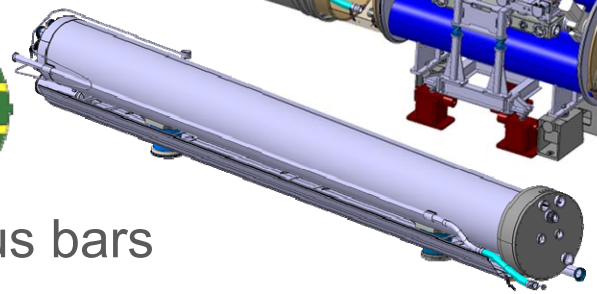


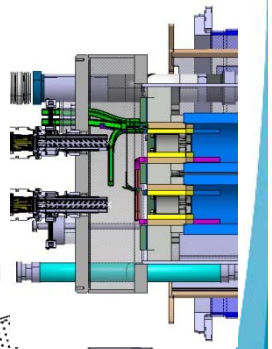


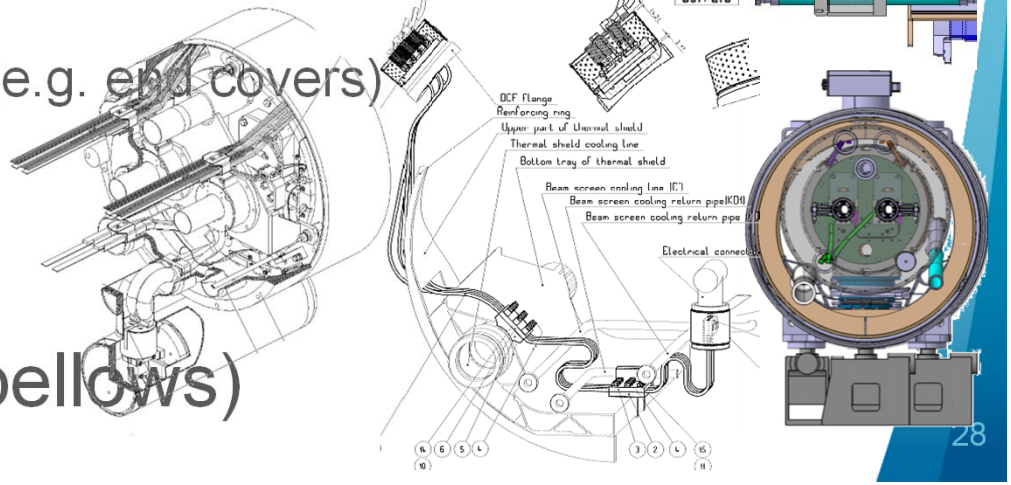
- Cryo-assembly
  - Cryostat, main and by-pass
  - Bus bars for by-pass cryostat
  - Jacks (RT support, cryostat to ground)
  - Cold mass assembly
    - **Coils**
    - Collared coils
    - Active part, including bus bars
    - Ancillaries (e.g. spool pieces 6-poles, N-line, protection diode…)
      and cold mass envelope (e.g. end covers)
  - Cold feet
  - Thermal shield
  - Current leads for trim
- Interconnects (with W-bellows)











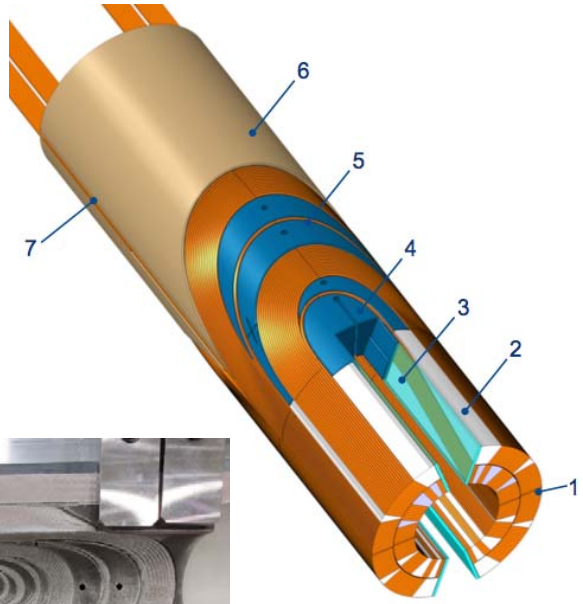
How can industry contribute to magnets for HL-LHC?

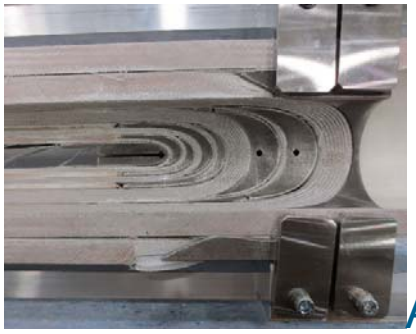
Legend: We are covered | We need more suppliers | We desperately need suppliers

Item #	Description	Raw material	2018	Later	What is challenging
1	Coil keys	AISI 316 L – DIN 1.4435			Machining (accuracy & elasticity)
2	End spacers	SLS – AISI 316 L – DIN 1.4435			3D-metrology, electrical insulation is needed
3	Saddles	Impregnated glass fiber as per IEC/EN 61212-3-1 EP-GC22			5-axes machining, GC22, accuracy
4	Removable pole	TA6V annealed (Ti6Al4V; 3.7165)			Accuracy & material
5	Wedges – precision profiles	Aluminum oxide dispersion strengthened copper (ODS)			Accuracy, material ODS
6	Quench heaters	Polyimide – St.Steel – Copper			Flexible Printed Circuits
7	Collars	YUS-130S (High Mn Steel)			Fine blanking, accuracy
8	Collaring keys	AISI 316 L – DIN 1.4435			Accuracy
9	Yoke laminations & inserts	Low carbon steel			Fine blanking, accuracy
10	Heat exchanger tube	Oxygen Free Cu – UNS C10200			Cu quality
11	Bus bars – hollow bars	Oxygen Free Cu – UNS C10200			Length, Cu quality
12	Lyras	Oxygen Free Cu – UNS C10200			Cu quality
13	Shells	AISI 316 LN – DIN 1.4429			Raw material, thickness, accuracy
14	End covers	AISI 316 LN – DIN 1.4429			Raw material, accuracy

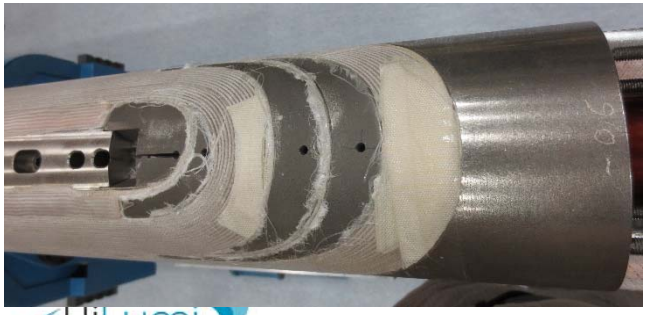
Coil keys – end spacers – saddles

- Can be produced from STP files
- Item 4: coil key, AISI 316 L
- Item 5: Selective Laser Sintering (SLS) end spacer, AISI 316 L, with flex. legs
- Item 6: Saddle, EP-GC22, base material woven glass cloth, matrix epoxy resin

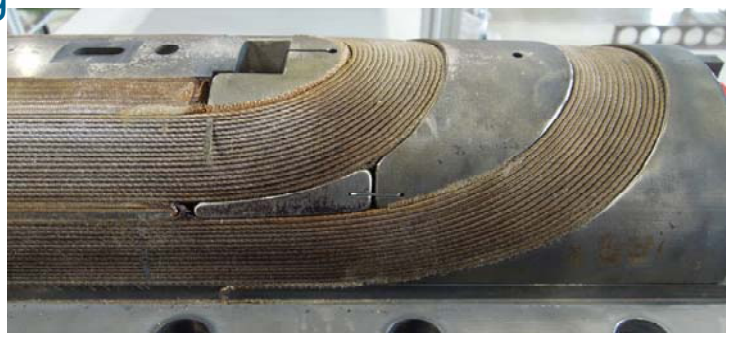




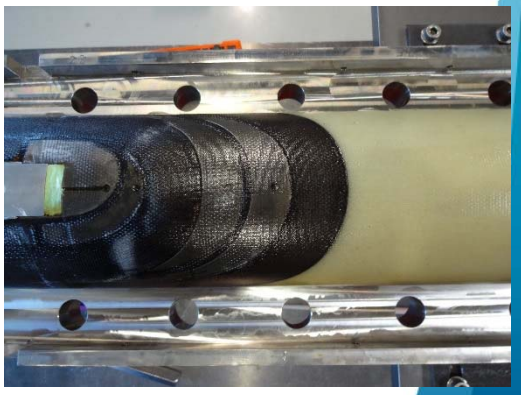
After curing



After reaction

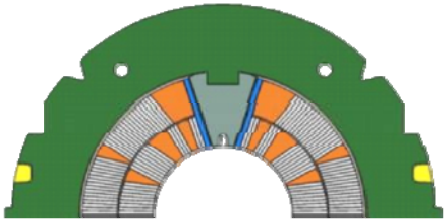


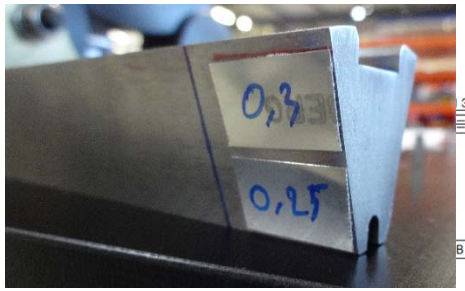
After impregnation

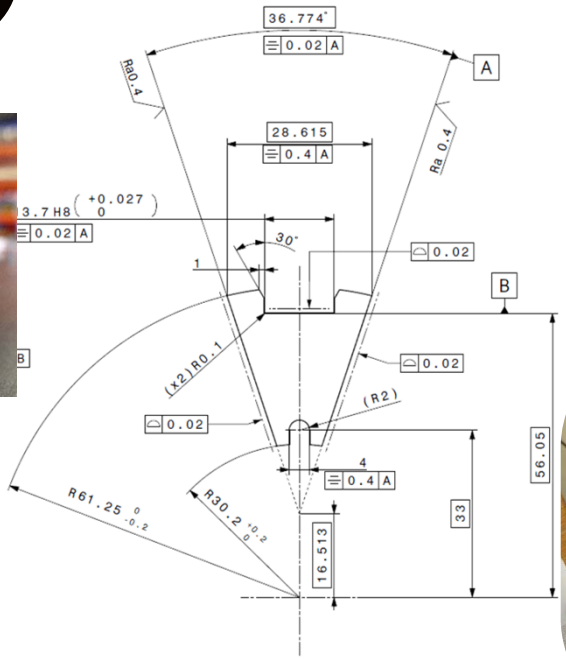


Loading pole – ODS Wedge

- Loading pole, to be made of titanium, 240 mm long

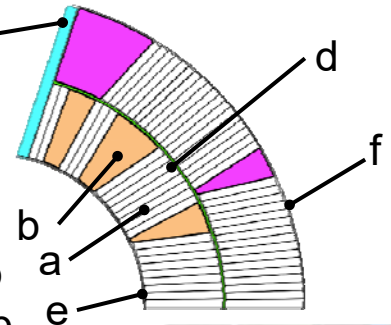


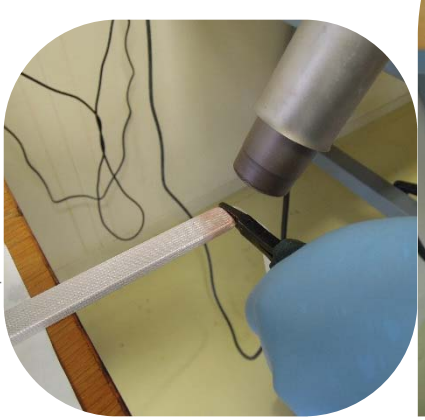


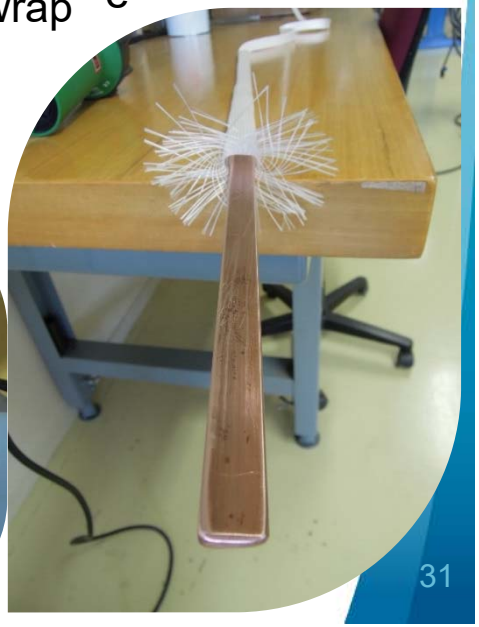


- Wedges, to be made of aluminum **Oxide Dispersion Strengthened** copper, cold drawn in length of 2.6 m

a. Insulated cable
b. Filler Wedge
c. Loading plate
d. Inter-layer
e. Inner ground wrap
f. Outer ground wrap

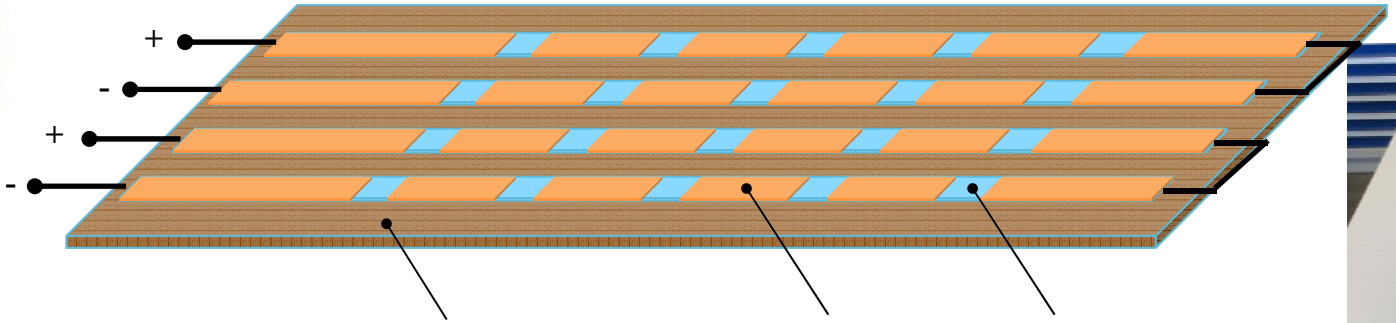


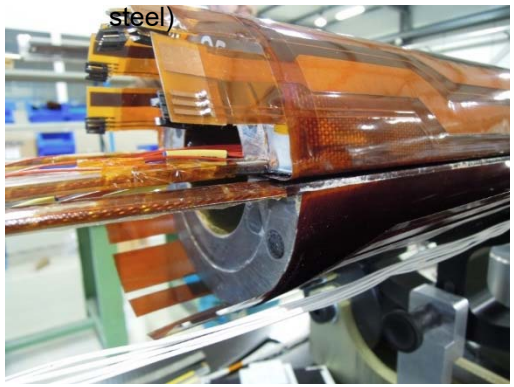


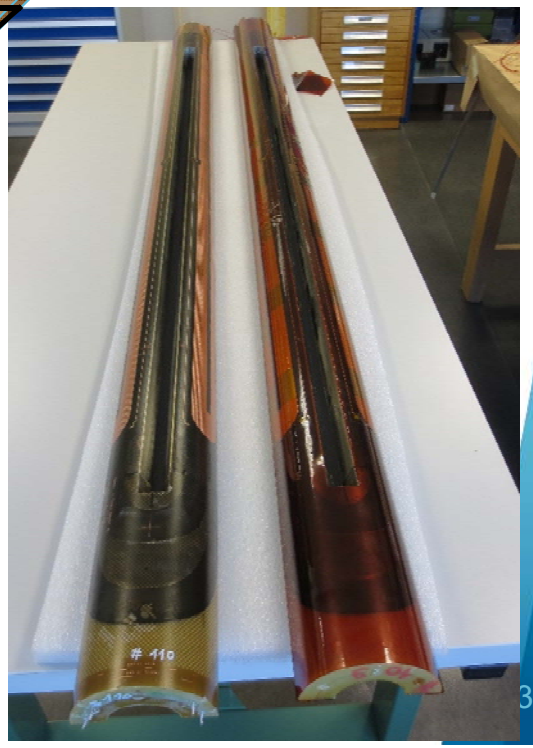


Quench heaters

- Basically a strip of stainless steel of 20 μm running along the coil outer surface
- A thin copper layer of 5 μm (electrolytic deposition) lower the resistance of the strip in between 2 heating areas
- The substrate is a 50 μm polyimide film
- The metallic circuit is encapsulated with a 37.5 μm to 50 μm thick polyimide film as cover layer with an adhesive coating



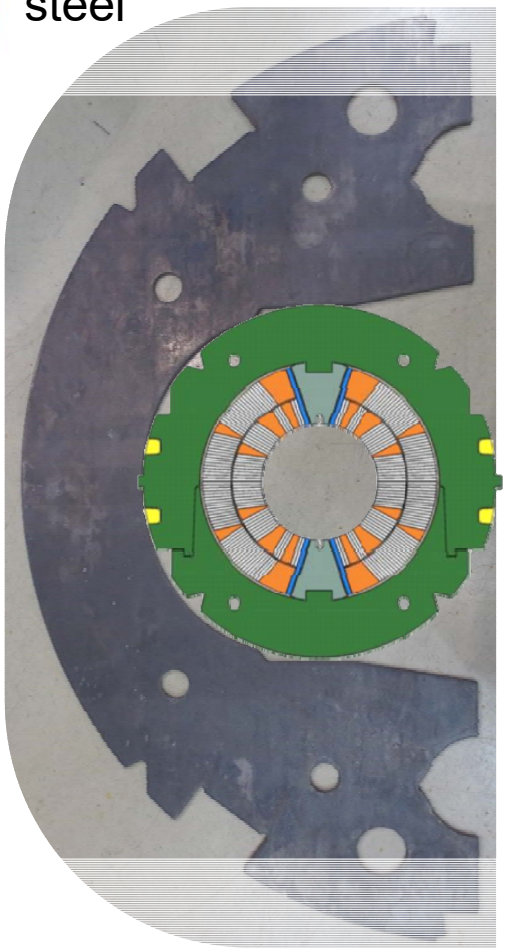


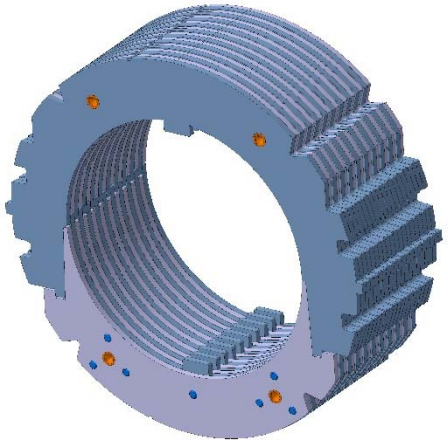


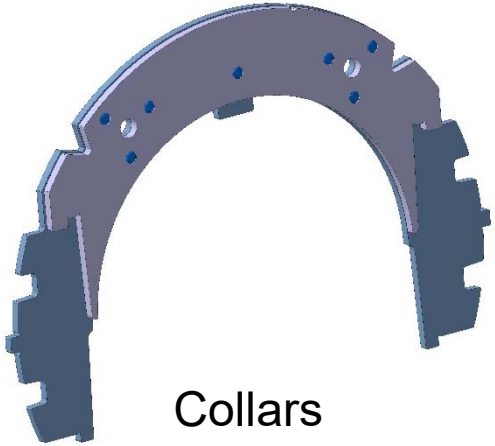
- **Overall length: 5600 mm**
- Width: 160 to 300 mm

Collars – collaring keys – yoke laminations

Yoke laminations: 5.8 mm thick low carbon steel



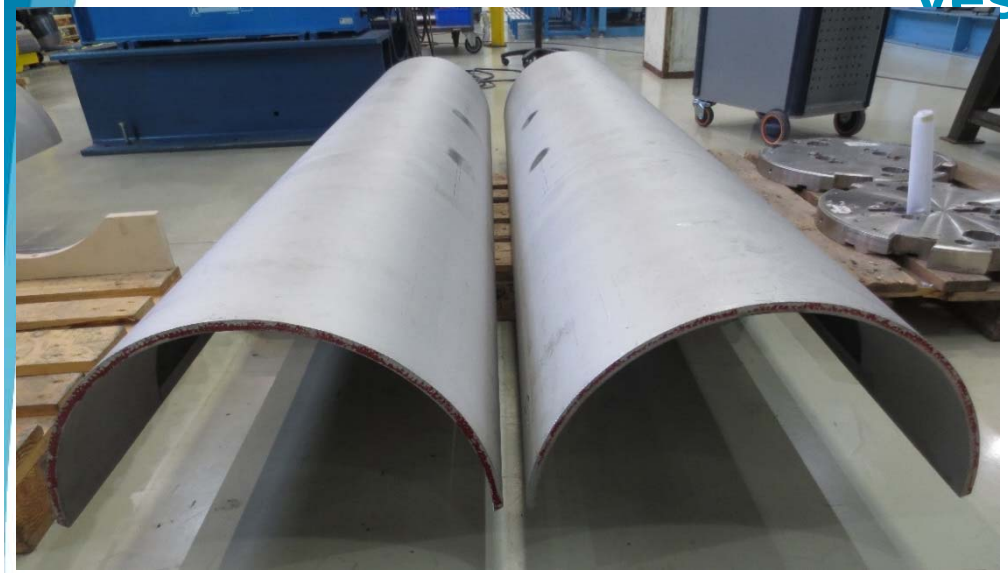




Collars

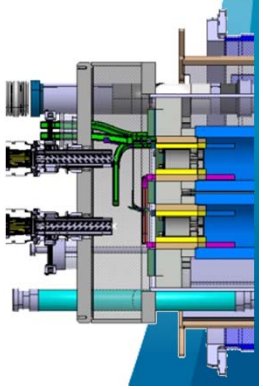
- 3 mm thick high Mn steel
- $\sigma_{0.2}$ > 400 MPa

Shells – end covers, main parts of the He containment vessel

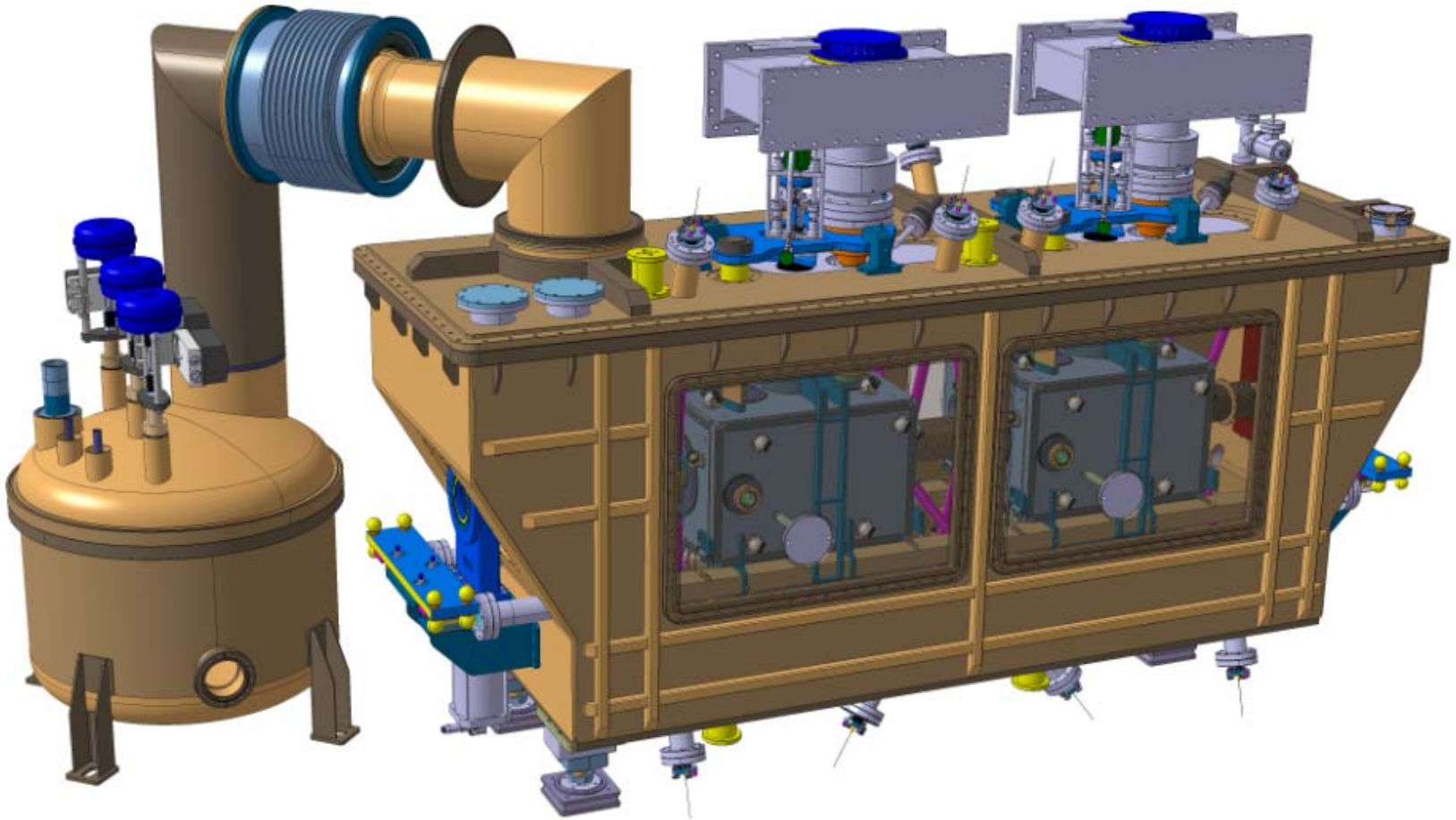


- Material: AISI 316 LN, hot rolled plates formed in folding press
- Thickness: 15 mm
- Tight fit with yoke laminations, i.e. need to be precise
- Leak tightness
- Weldability

- Material: AISI 316 LN
- Powder metallurgy for the dished cover, or welded construction for the flat cover
- Leak tightness
- Weldability

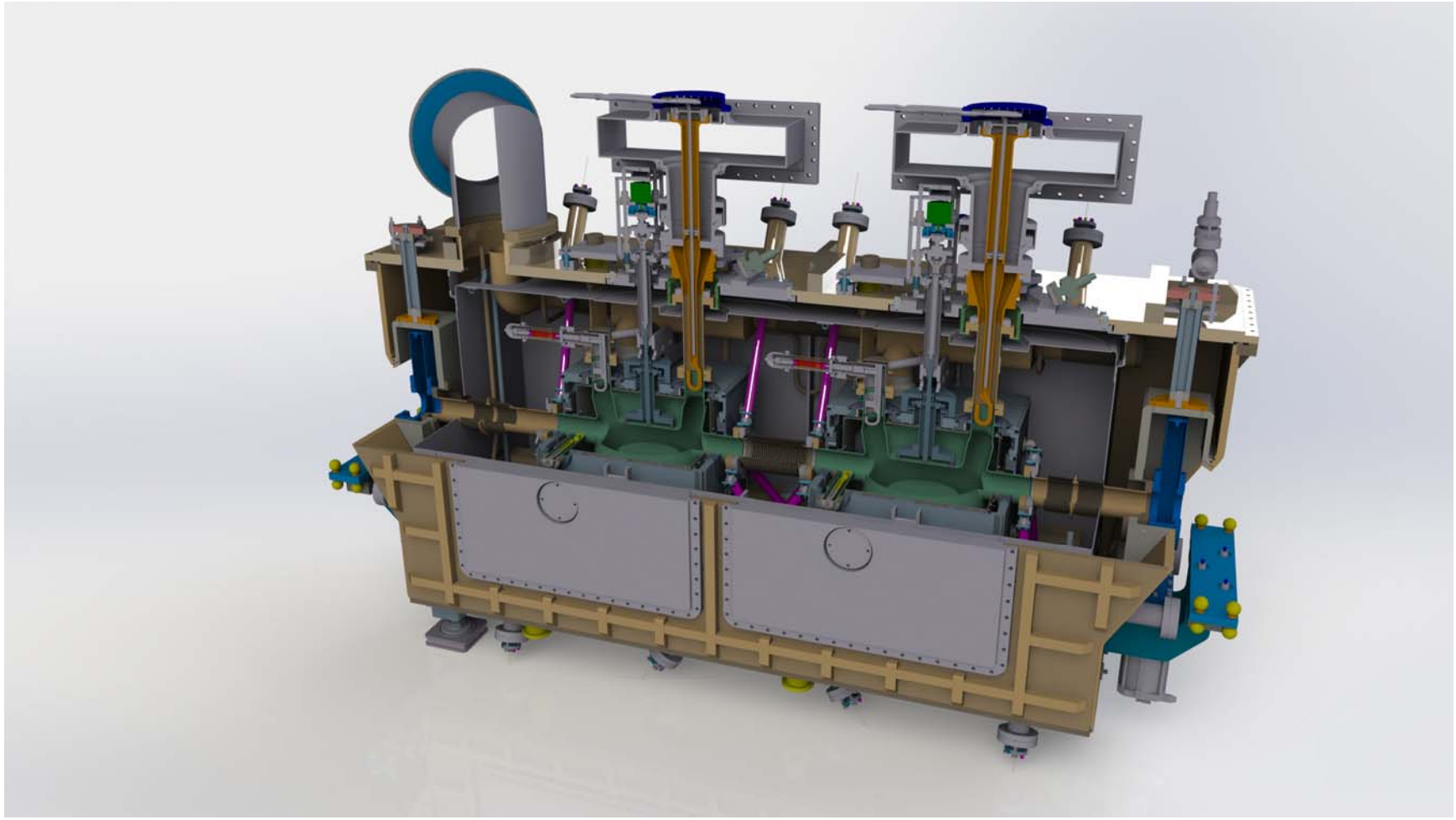


SPS Cryomodule:
Include 2 identical cavities

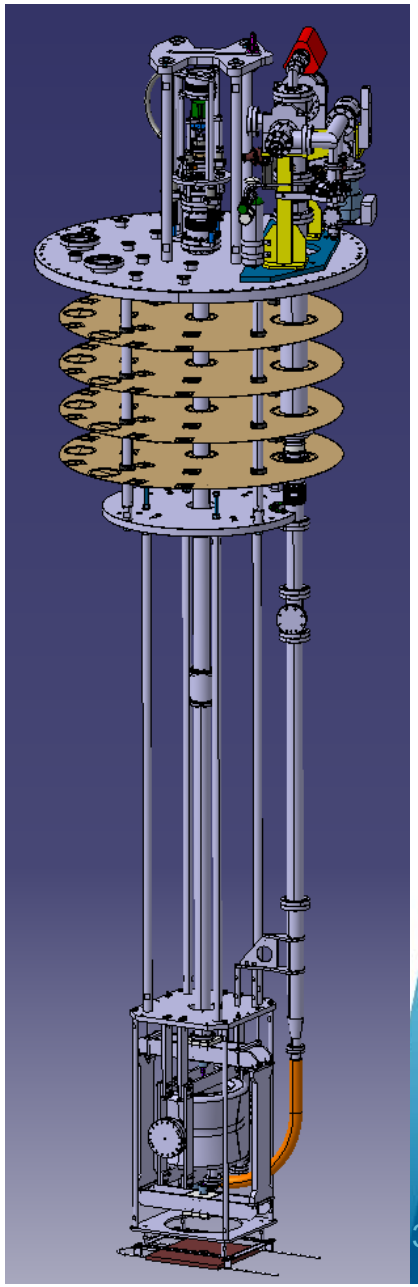


Double Quarter Wave

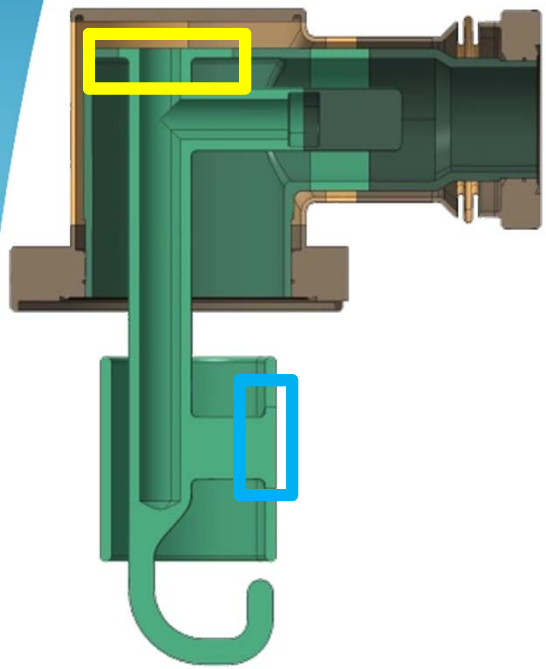
View of the different components

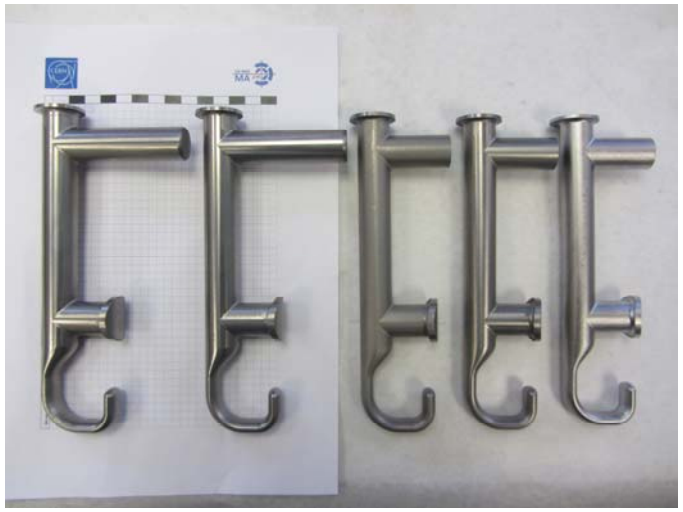


Tuning system



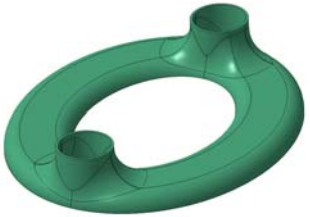
HOM

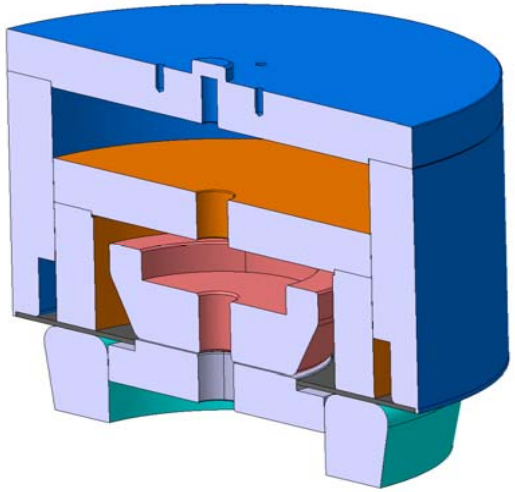


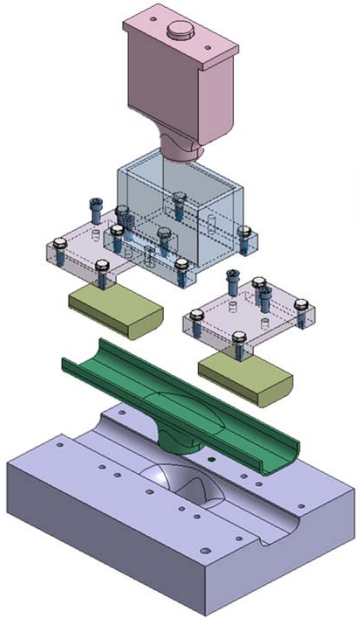


- All pieces produced BCPed & ready for welding
- (caveat: Hook Ring)
- Metrology **OK** (EDMS 1507831)
- Welding qualification ongoing
- NEXT STEP: welding (start beg. April)

Cavity: Shaping – Elliptical Cap





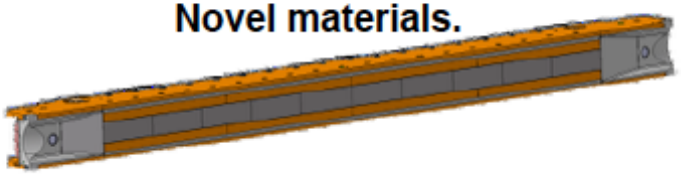


- Promising shaping results in terms of precision and minimum thicknesses
- Machining & Extrusion-shaping tests on Nb ongoing
- Design of elliptical tool ongoing

Collimation system evolving with the Run

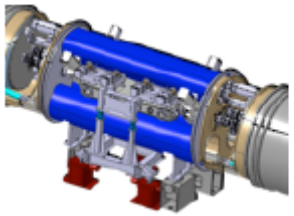
IR1+IR5, per beam:
- 4 tertiary collimators
- 3 physics debris collimators
- fixed masks

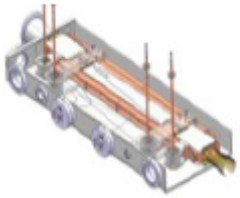
Completely new layouts
Novel materials.



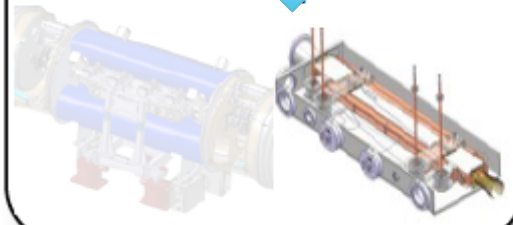
Final decision on installation to be taken based on Run 2 experience

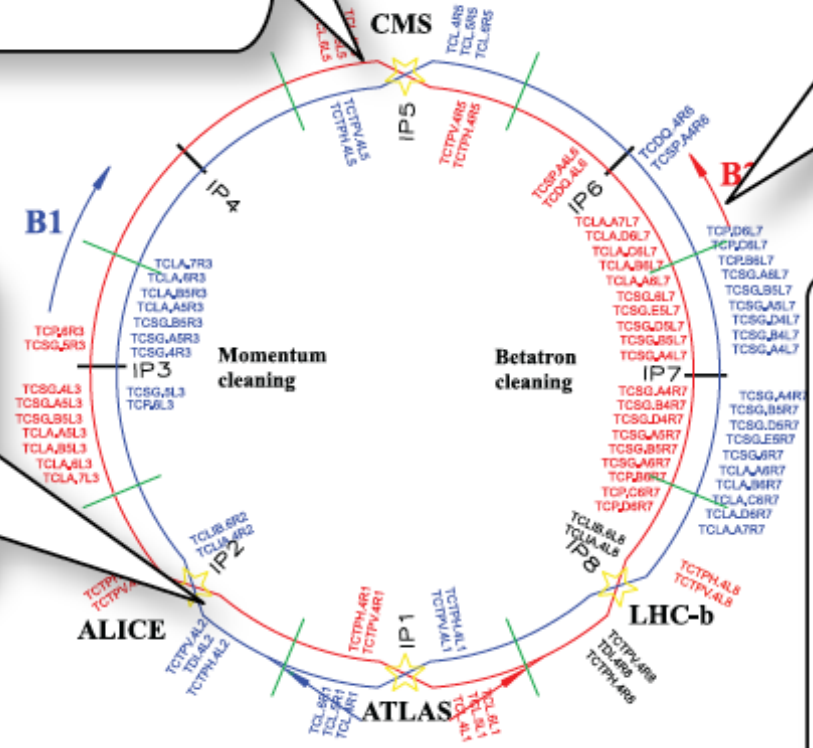
Cleaning: DS coll. + 11T dipoles, 2 units per beam



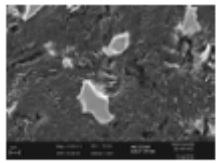


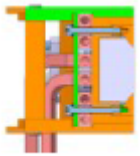
Ion physics debris:
DS coll. + 11T dipoles



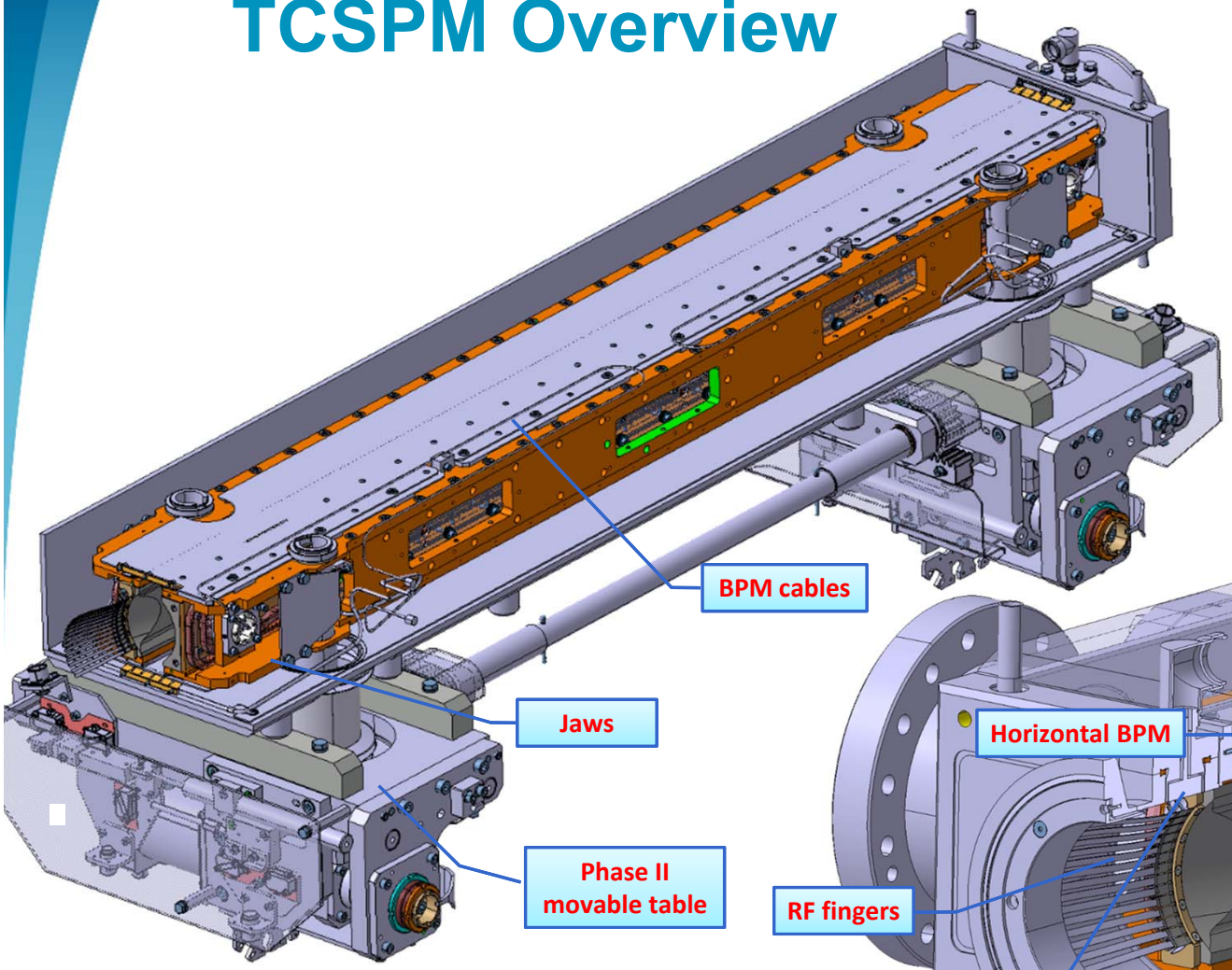


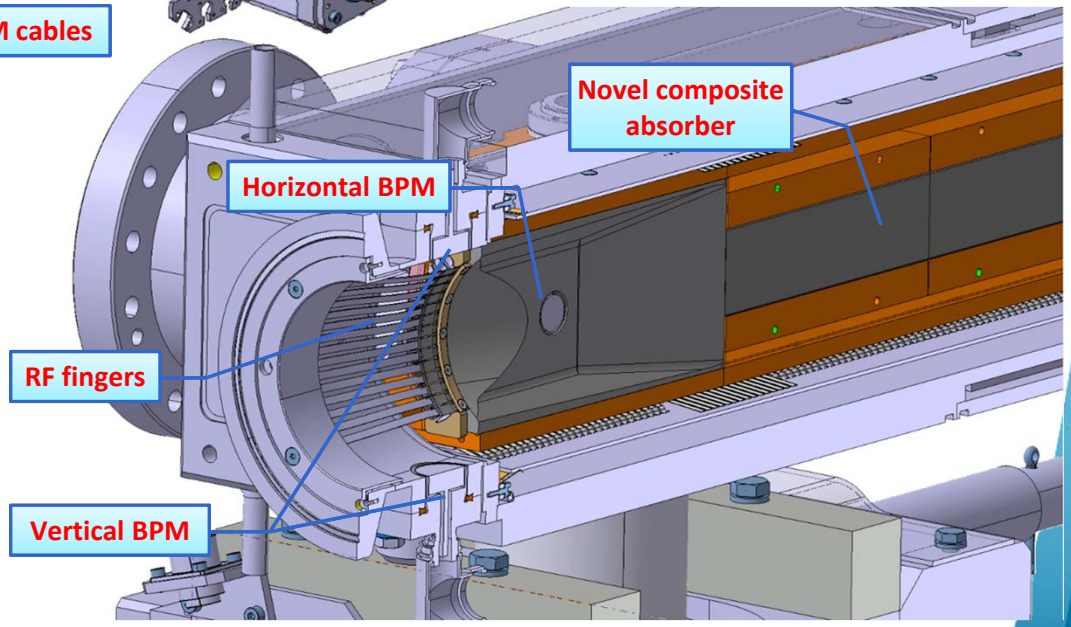
Low-impedance, high robustness secondary collimators





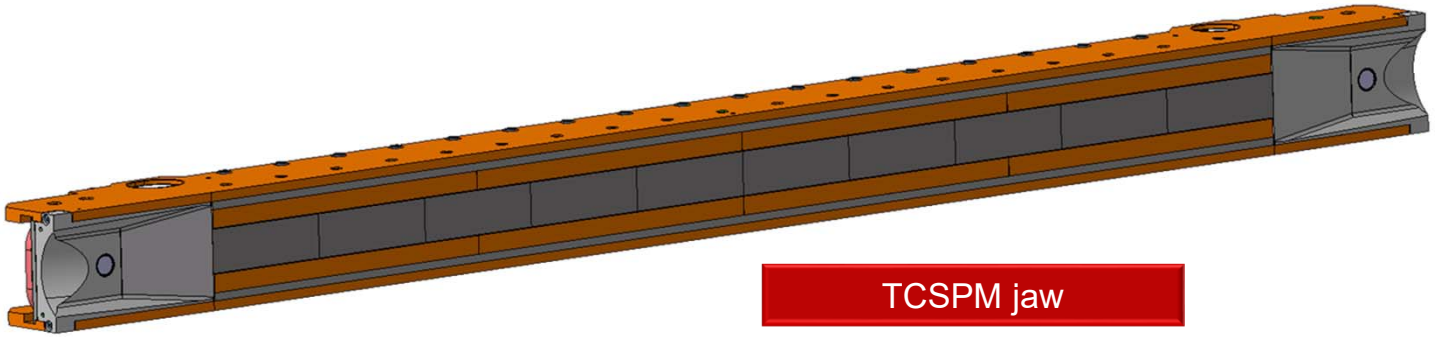
TCSPM Overview



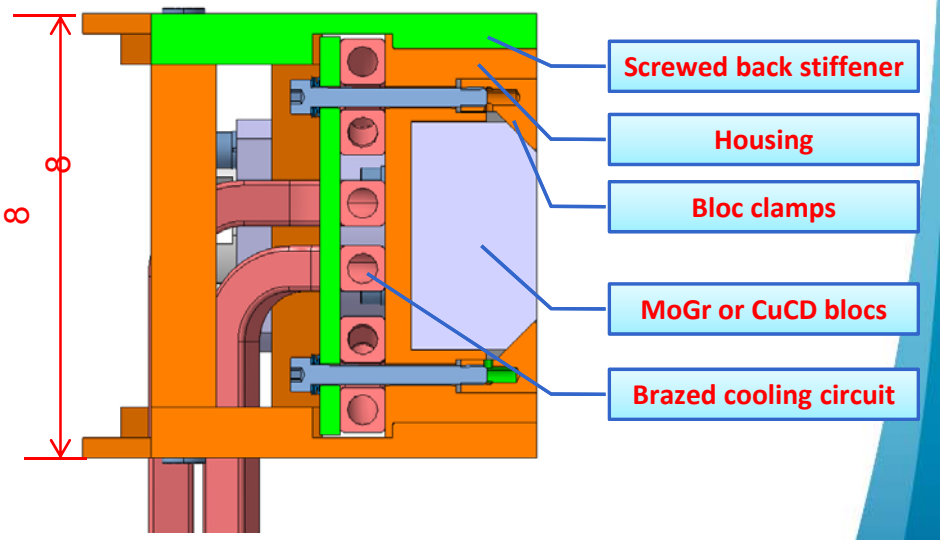


- **Longer** jaws, tapering and vacuum tank
- **Shorter** RF fingers, upstream and downstream flange collars
- **Same flange-to-flange length**
- **BPM vertical buttons** upstream, on top of the **horizontal BPMs** for jaw positioning

TCSPM Jaws

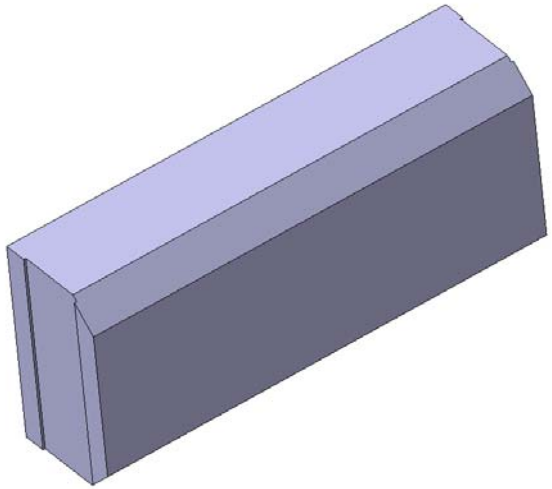


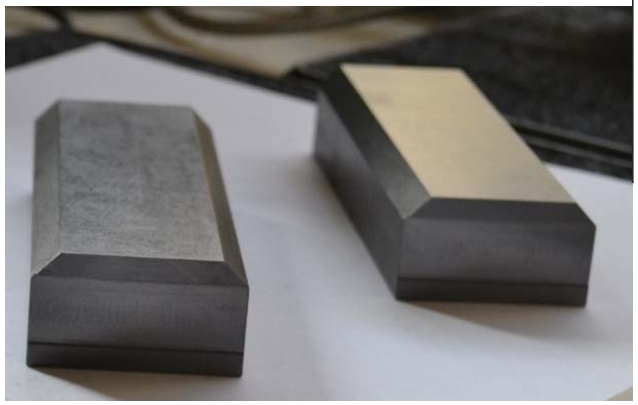
- 1m active jaw made of **8 composite blocs**
- **Clamped solution** to host any block material (avoids stress concentrations and allows sliding between components with different CTE)
- **One-side brazed cooling circuit** (CuNi90-10)
- **Screwed stiffener** to increase the geometrical stability of the jaw
- Housing, stiffeners and clamps in **Glidcop Al-15 LOX**
- Outgassing holes for trapped volumes

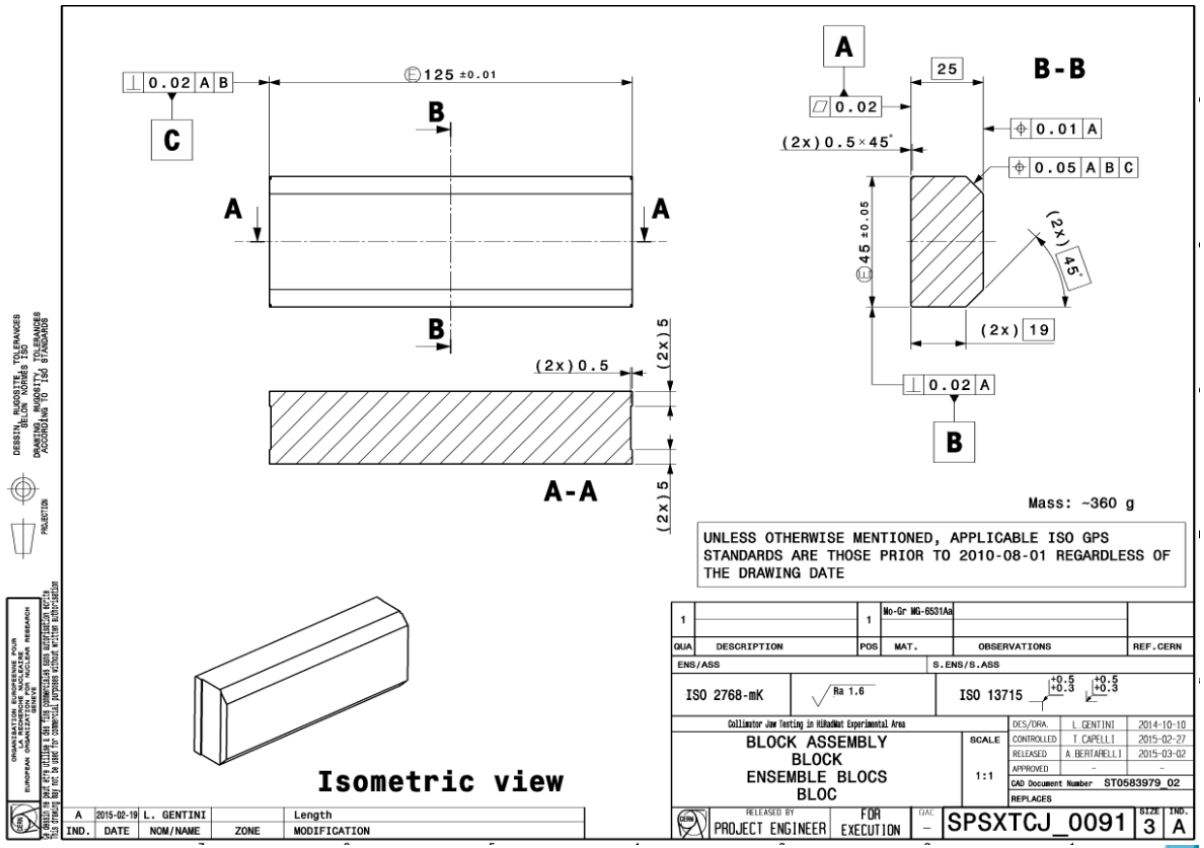


TCSPM Absorber

MoGr blocs

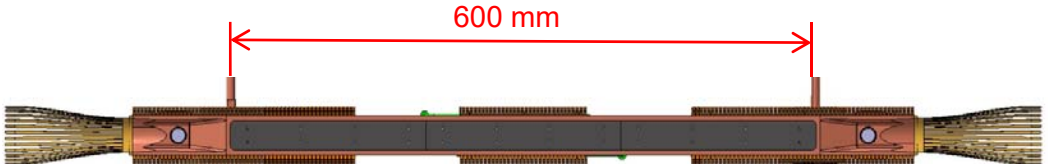






*In case of **copper-diamond**, for manufacturing reasons the bloc length is 100 mm (10 blocs)*

TCLD Overview



General

- Active length **600 mm**
- Brazed cooling circuit
- **Cantilever jaws**

Cooling system

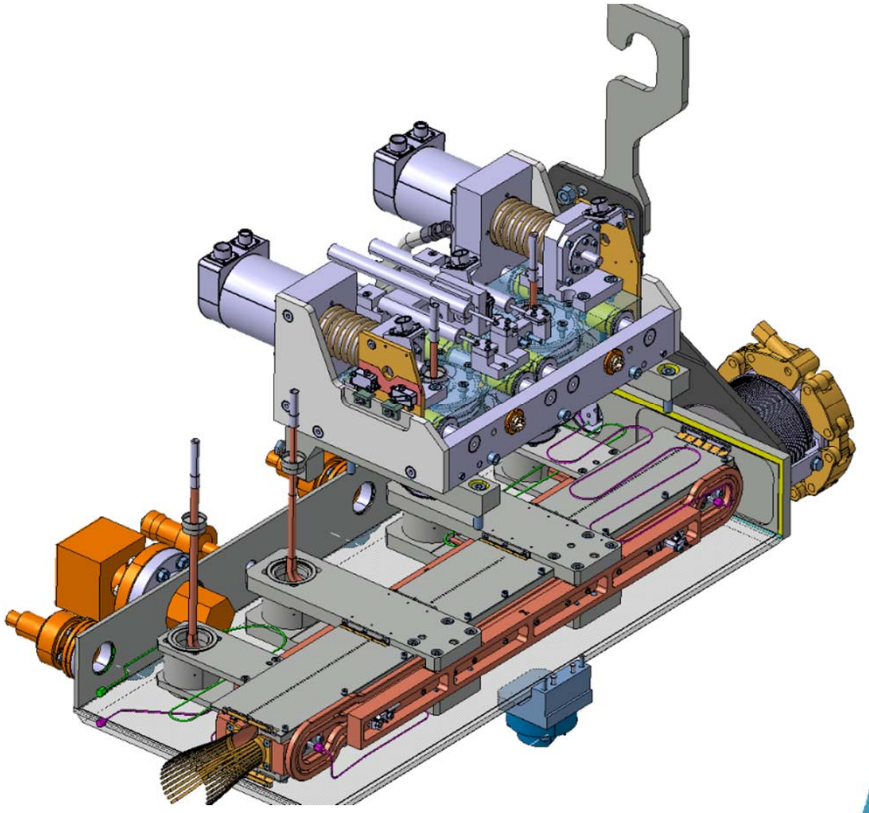
- 1x Square pipes (9 mm edge, CuNi)
- 3x cooling pipes in the central cross-section

Instrumentation

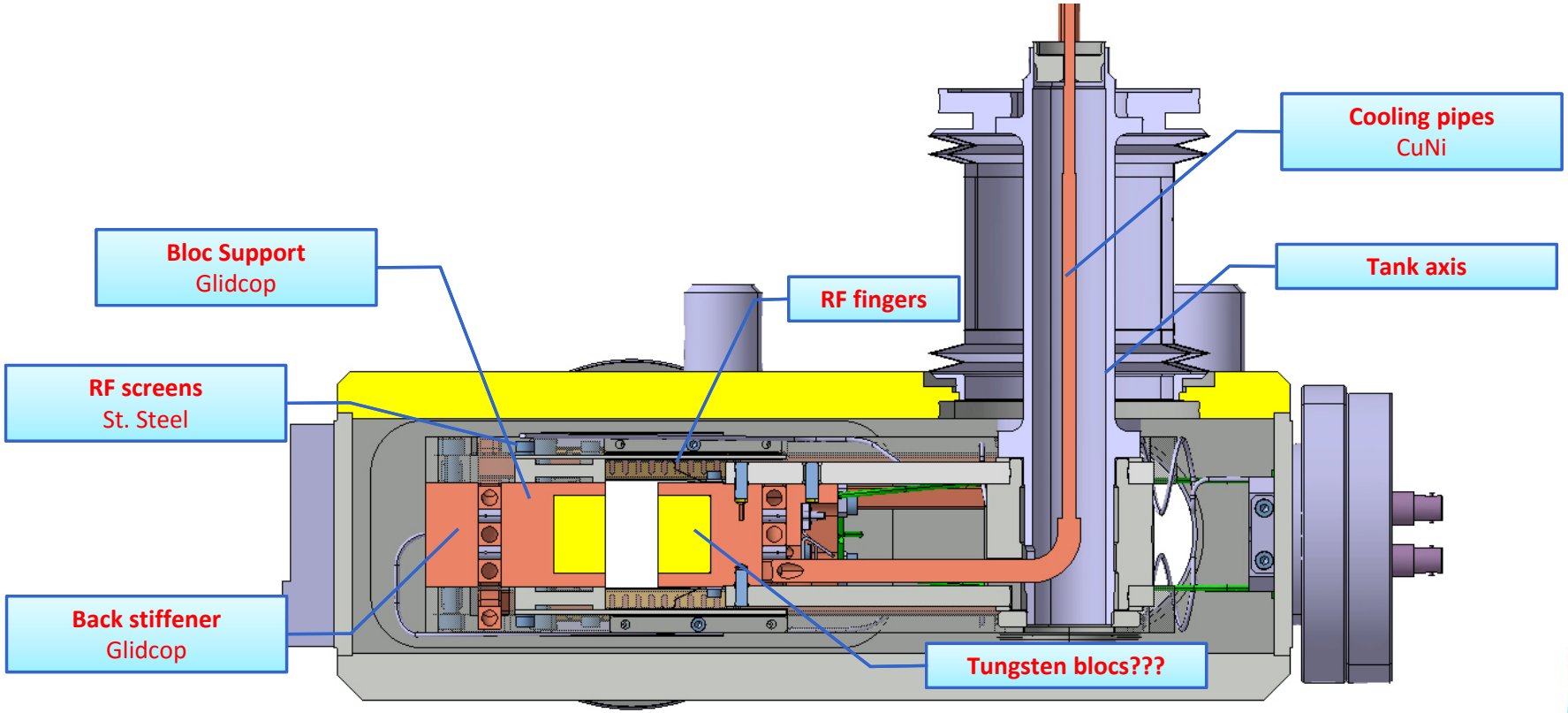
- 2x temperature probes (PT100) each jaw
- 2x Beam Position Monitor each jaw

RF system

- **RF fingers + St. steel screens**



TCLD Jaw



- Absorber baseline is **Inermet180** (tungsten alloy)
- Material for the prototype already ordered
- Waiting from BE/ABP confirmation on the **required robustness**
- Using a high-robustness composite (e.g. CuCD) would require a **different design**
- Metals or alloys such as **Mo, Glidcop and W-La could be a good compromise** (higher robustness than Inermet180, no design change needed)

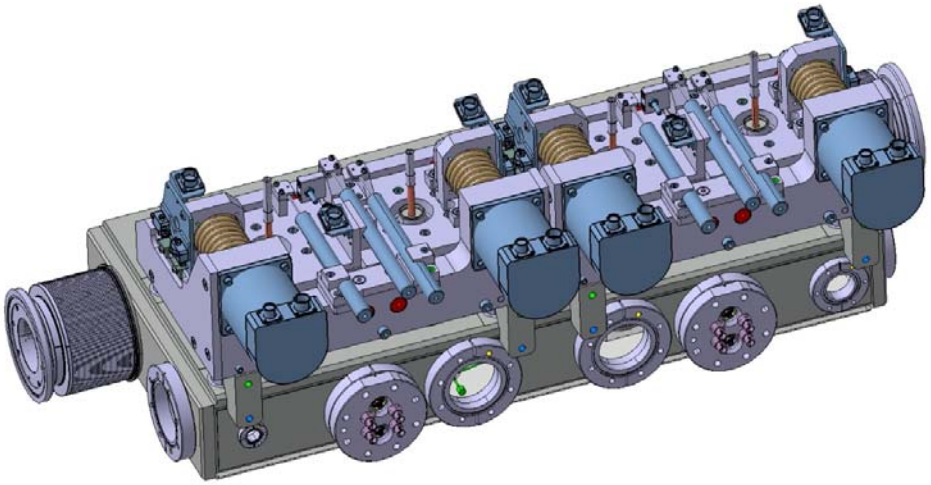
TCLD Actuation System

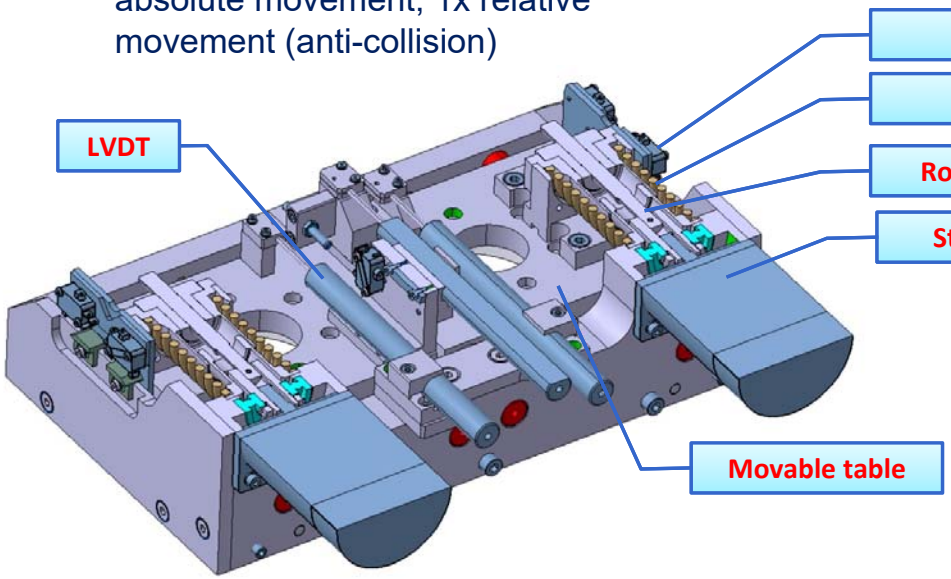
Movement

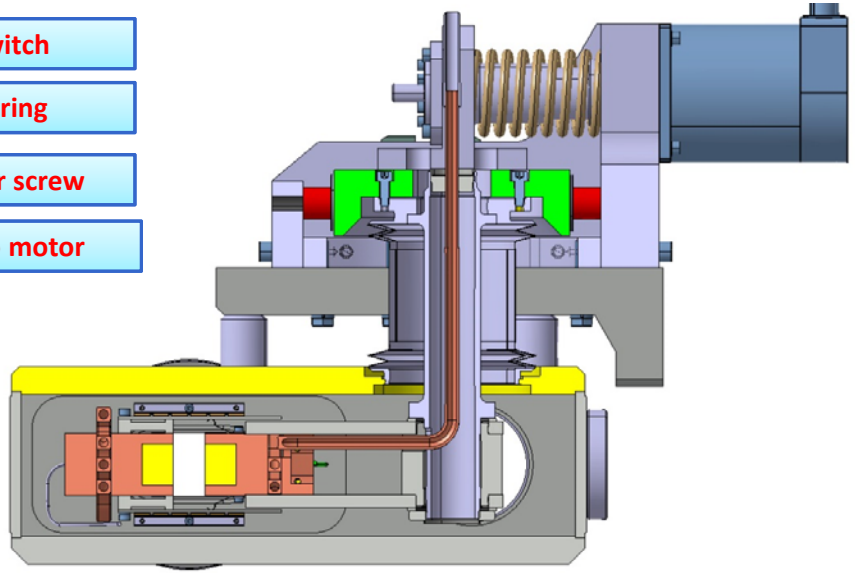
- Two step motors each jaw → Jaw tilting
- Stroke: -5 → 25 mm
- Spring-back: in case of electrical short-cut the jaws must not go in beam direction

Instrumentation

- 3x LVDT each jaw: 2x absolute movement, 1x relative movement (anti-collision)
- 3x switch assemblies each jaw : 2x absolute movement, 1x relative movement (anti-collision)

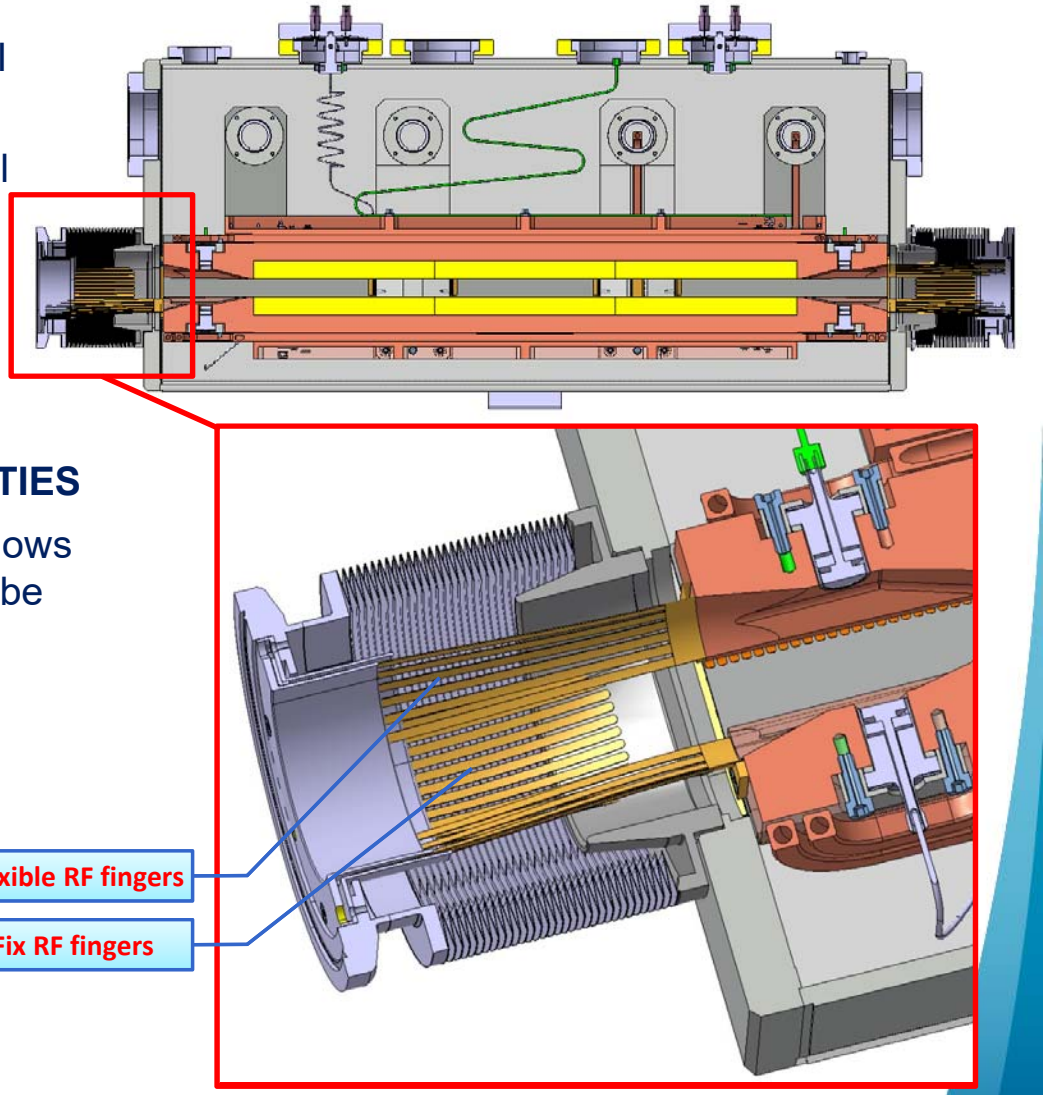






TCLD Tank

- Manufacturing process based on Ph.II tank
- Electron Beam welded Stainless Steel
- No cooling system



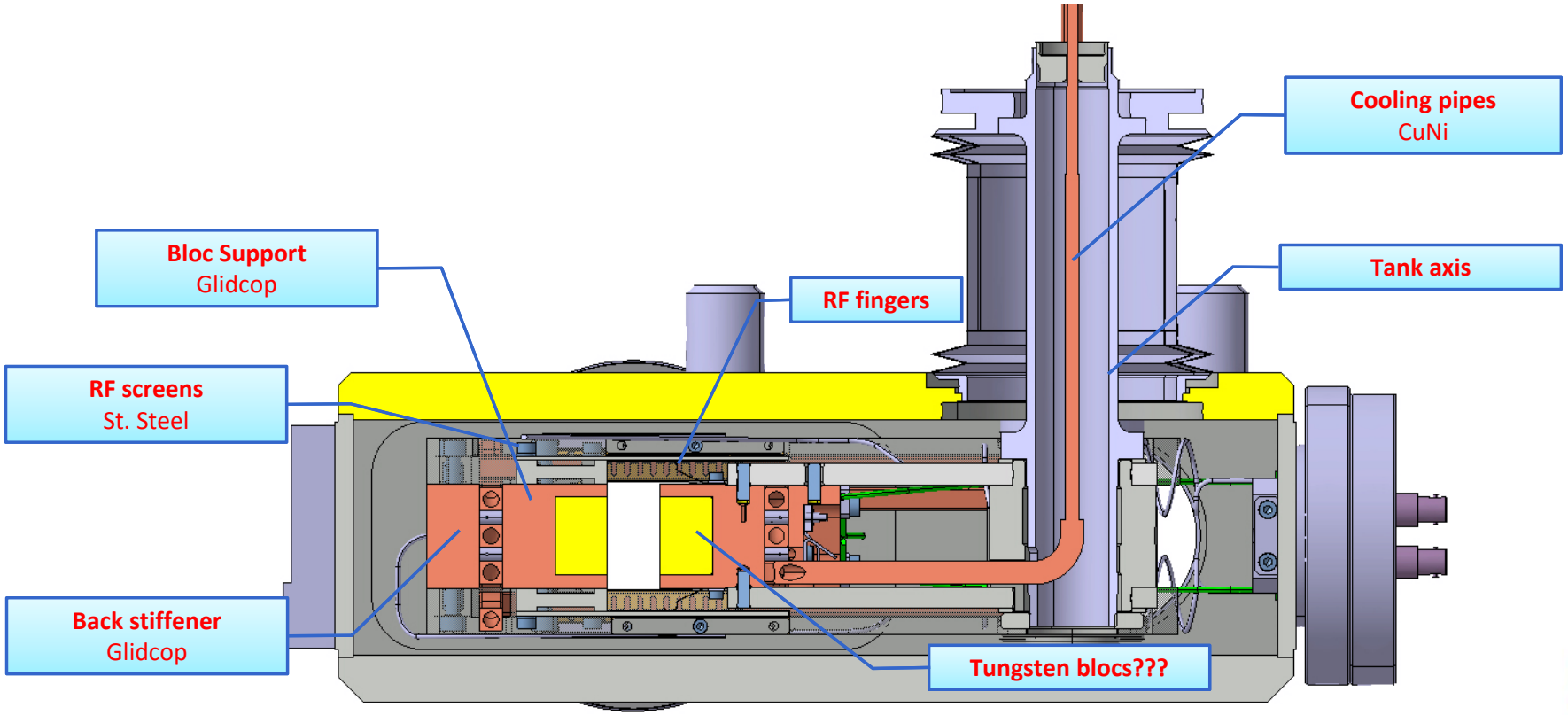
NEW DESIGN OF THE EXTREMITIES

To gain longitudinal space, the bellows after and before the collimator will be integrated into the tank transitions.

Longitudinal stroke: +5; -15 mm

Radial stroke: ±10 mm

TCLD Jaw



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- Using a high-robustness composite (e.g. CuCD) would require a **different design**
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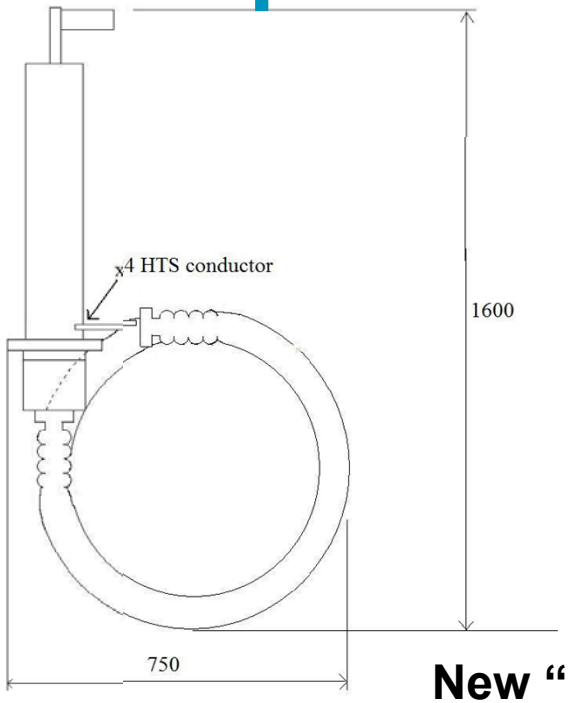
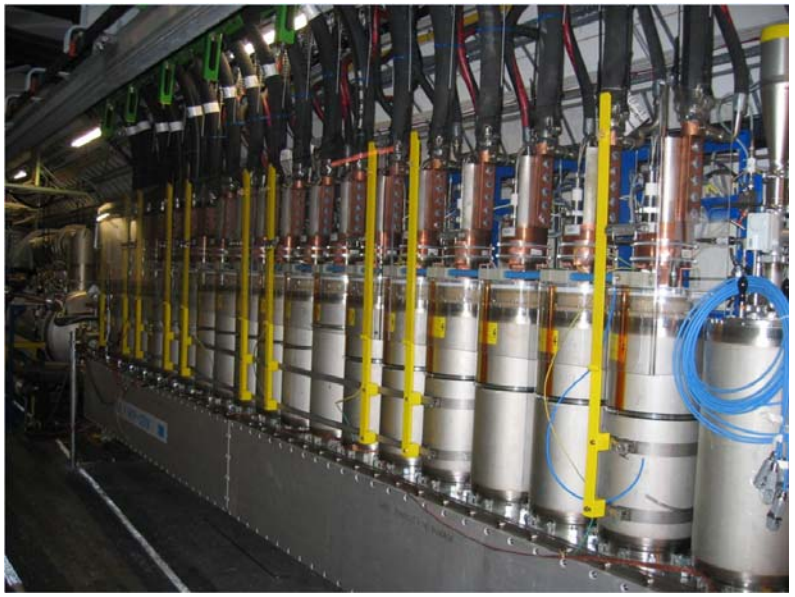
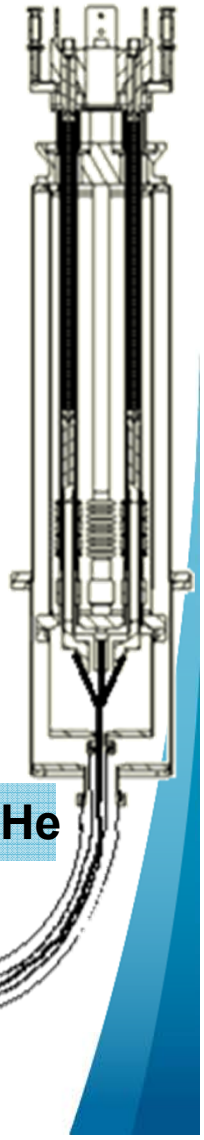
Superconducting link concept

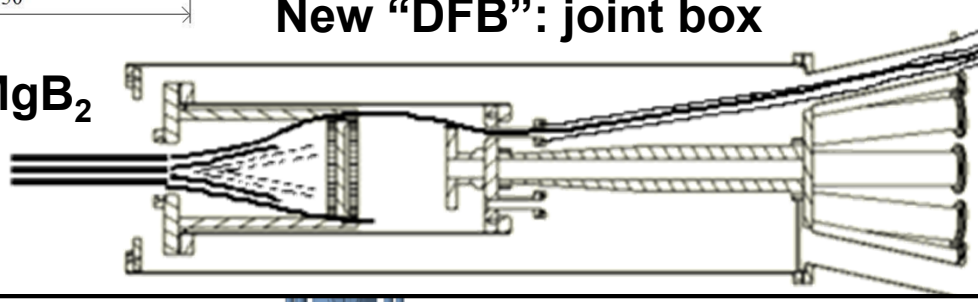






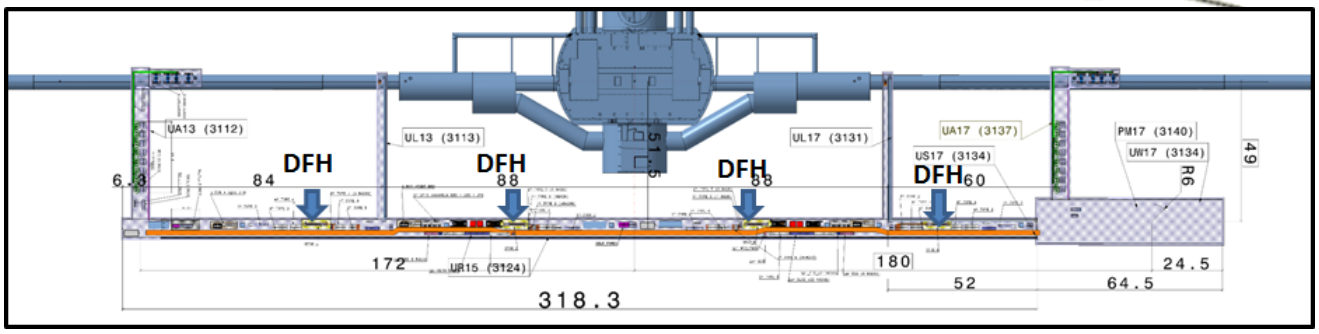
New “DFB”: joint box

MgB_2

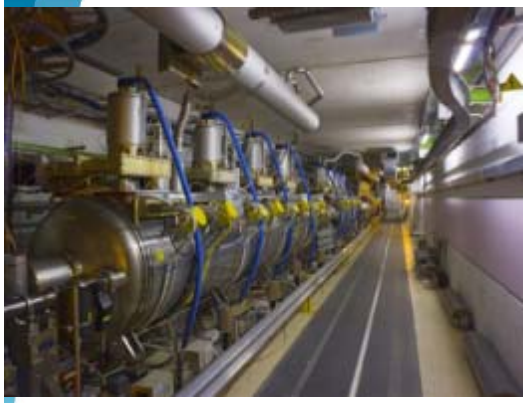


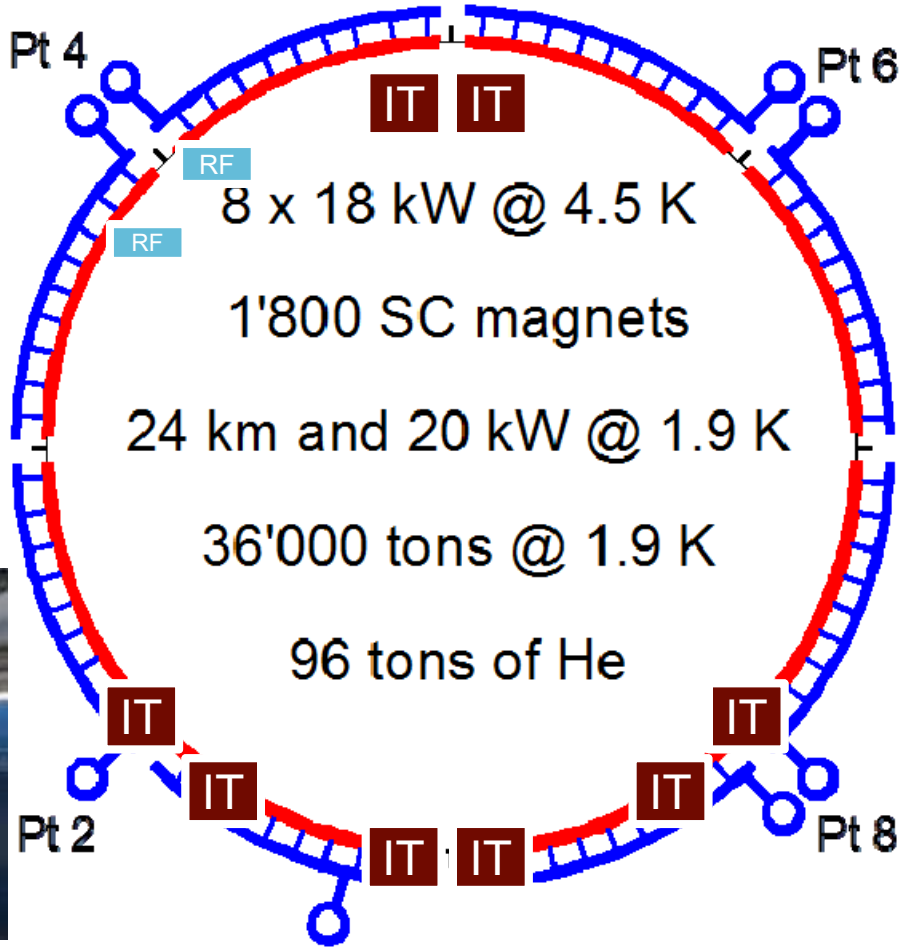
HTS

No LHe



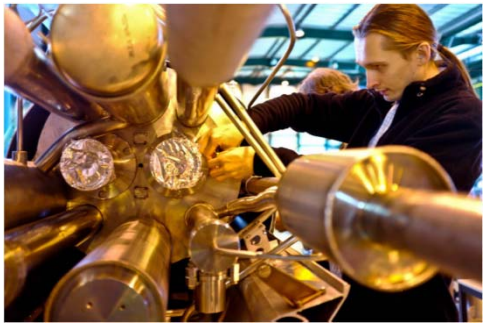
Eliminating Technical bottlenecks

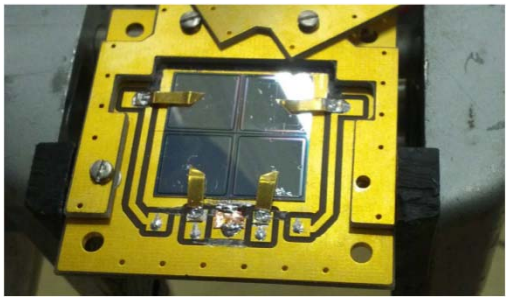


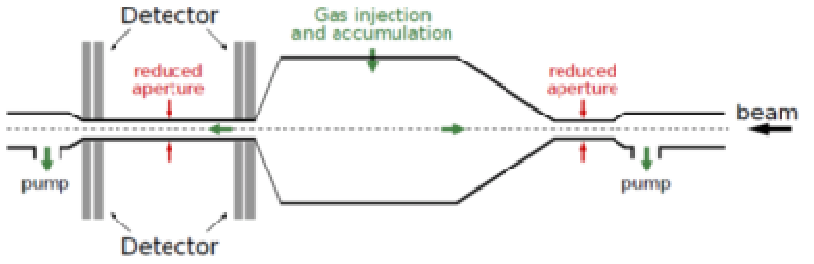


Beam diagnostic improvement

- Cryogenic BLMs & Radiation Hard Electronics
  - Cryogenic BLMs
  - Radiation hard electronics
- Fast WireScanners
- Insertion Region BPMs
  - Cold directional couplers
  - Tungsten shielded cold directional couplers
  - Warm directional couplers
  - High precision electronics for insertion region BPMs
- Luminosity Monitors
- Diagnostics for Crab Cavities
- Upgrade to Synchrotron Light Monitors
  - Upgrade to existing monitor
  - New light source
  - Halo diagnostics
- Beam Gas Vertex Detector
  - Final Implementation
- Long-Range Beam-Beam Compensator
  - Prototype
  - Final Implementation

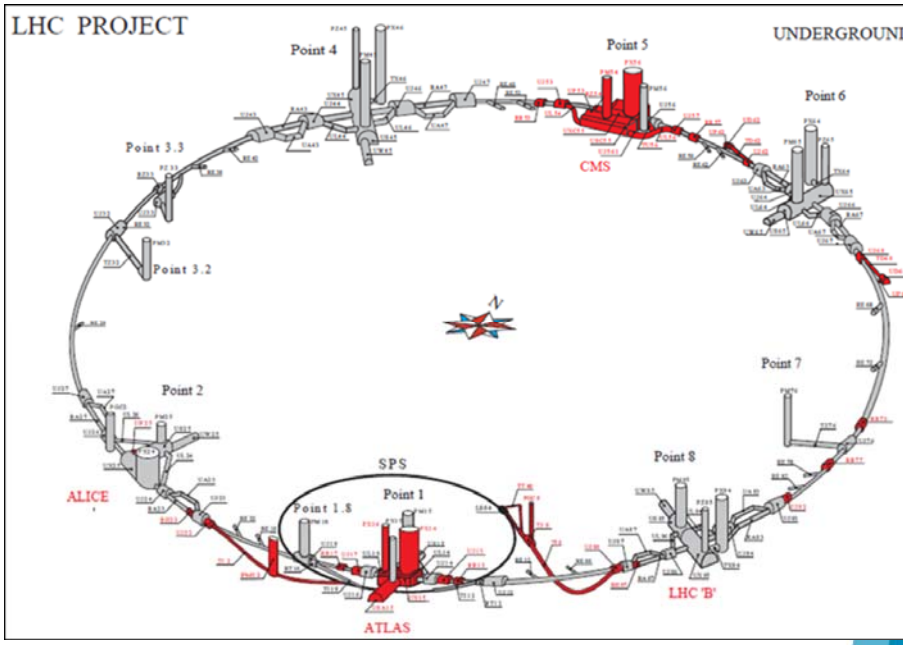




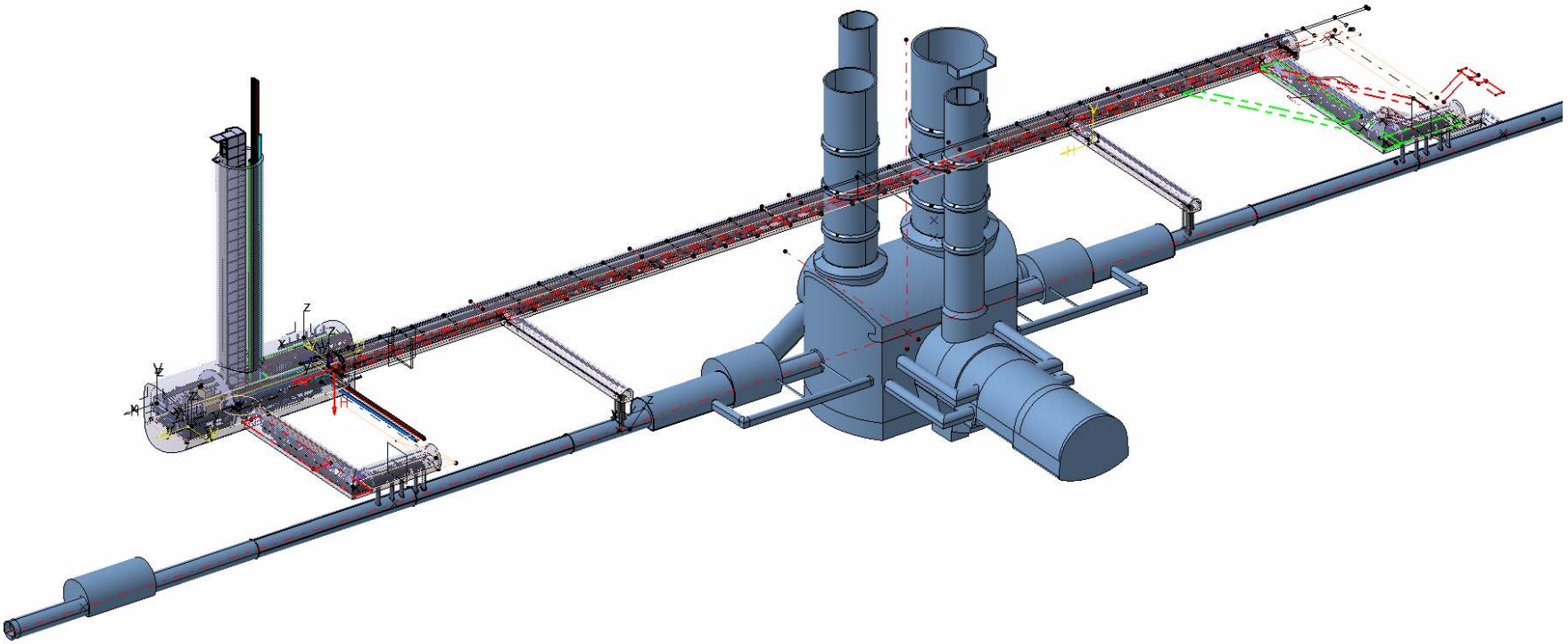


And many other improvements

- **Machine protection:** improved robustness to mis-injected beams, to kickers sparks will be required. The kicker system, collimation and TDI, is the main shield against severe beam induced damage.
- **Quench Protection System** of SC magnets to remake a 20 years old design.
- **Remote manipulation:** the level of activation around 2020 requires development of special equipment to allow replacing/servicing collimators, magnets, vacuum components etc., according to ALARA principle. Remote manipulation, enhanced reality and supervision is the key to minimizing the radiation doses sustained during interventions.
- **Vacuum** …



Point 1 Civil Engineering underground



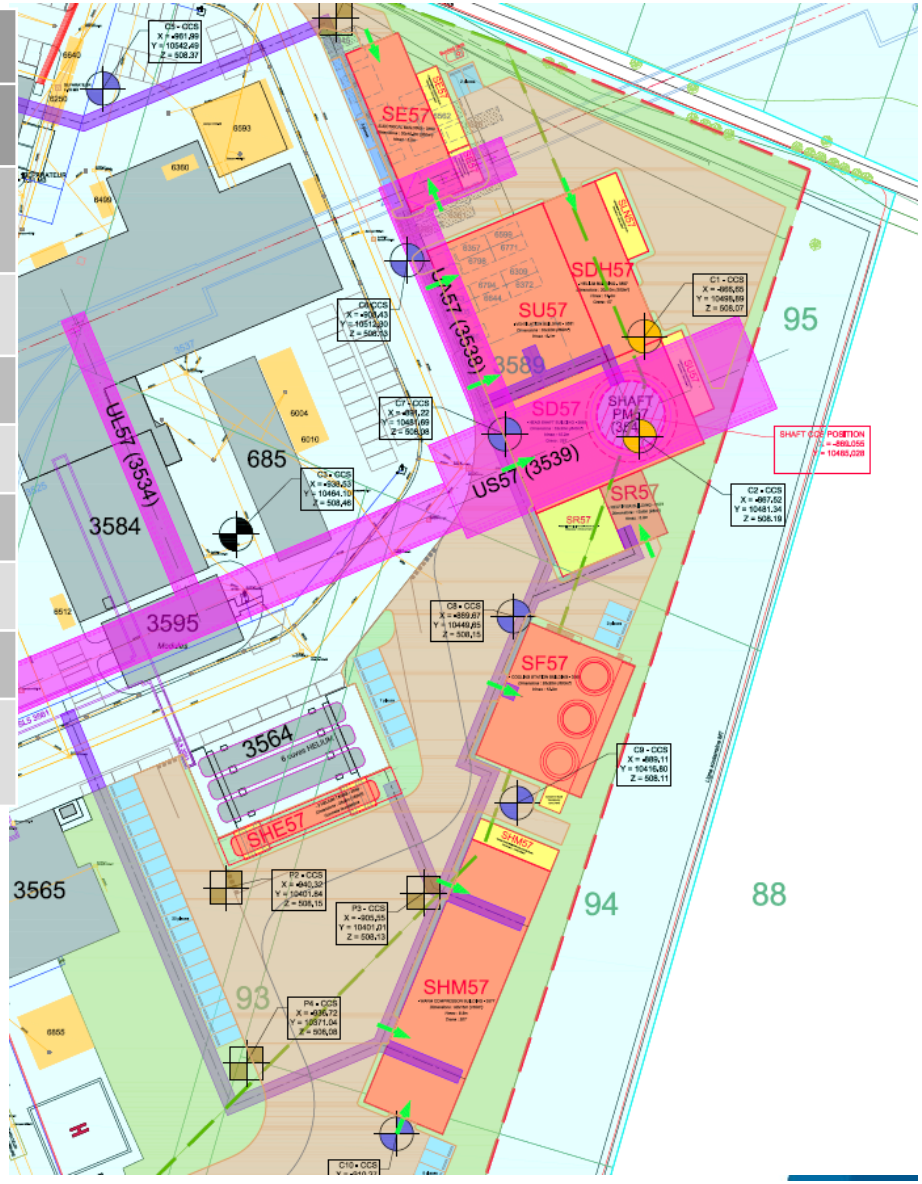
Surface buildings

Description	Sigle	DIMENSIONS (m) H	L	W
Plateforme réservoirs hélium	SHE	5	33	5
Bâtiment ventilation	SU	9	30	22
Bâtiment électrique	SE	3	30	10
Bâtiment tête de puits	SD	15	32	20
Bâtiment compresseurs	SHM	9.5	50	15
Rectifier Building 3175	SR	7	12	8
Tour de refroidissement	SF	12	25	20
Bâtiment déchargement hélium	SDH	14.4	30	10

≈ 3'400 m² new buildings

P1
- Present surface≈ 75'200 m²
- New surface≈ 91'200 m²

P5
- Present surface≈ 42'300 m²
- New surface≈ 55'300 m²



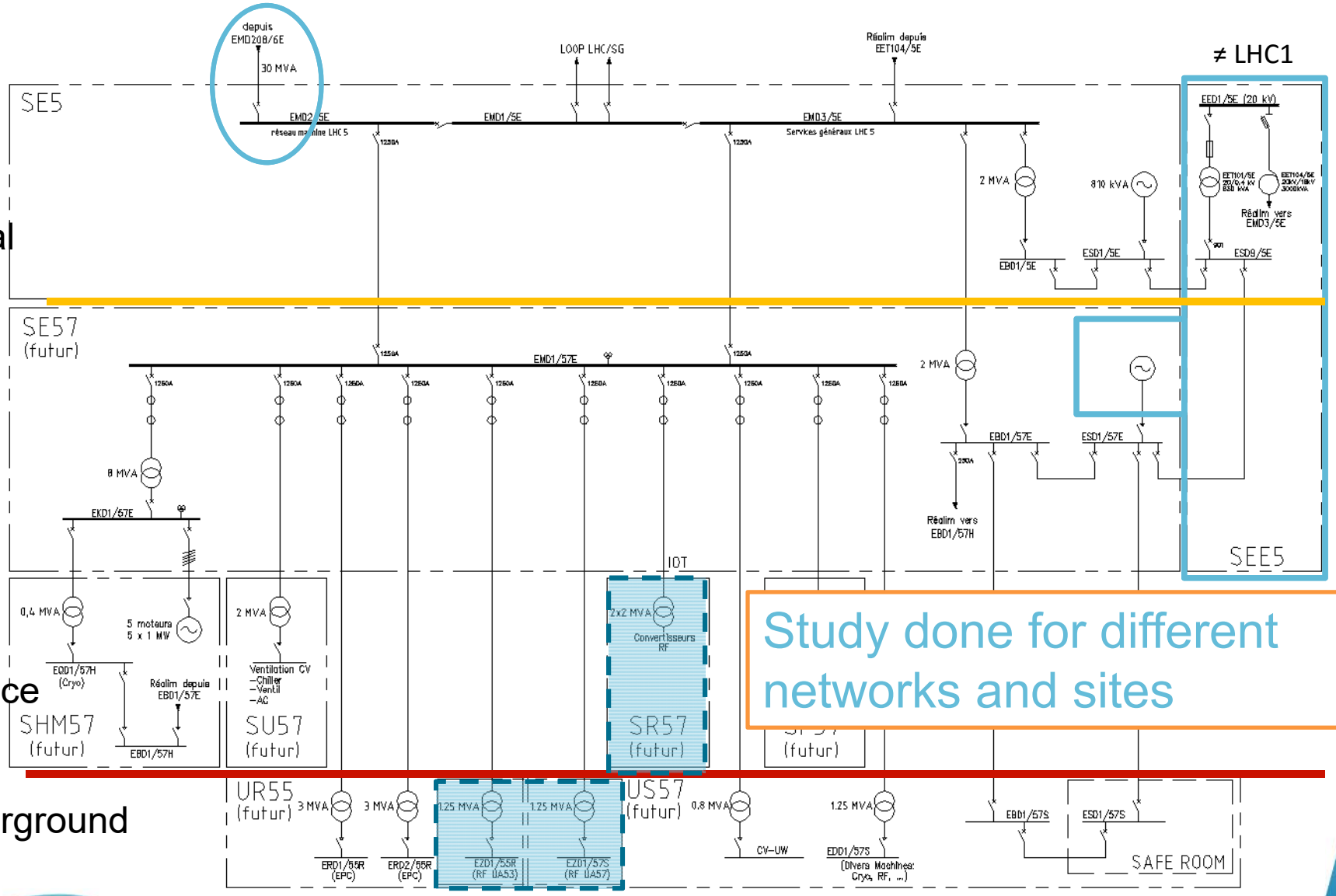
18 kV single-line diagram for LHC5 HL-LHC

Actual

HL-LHC

Surface

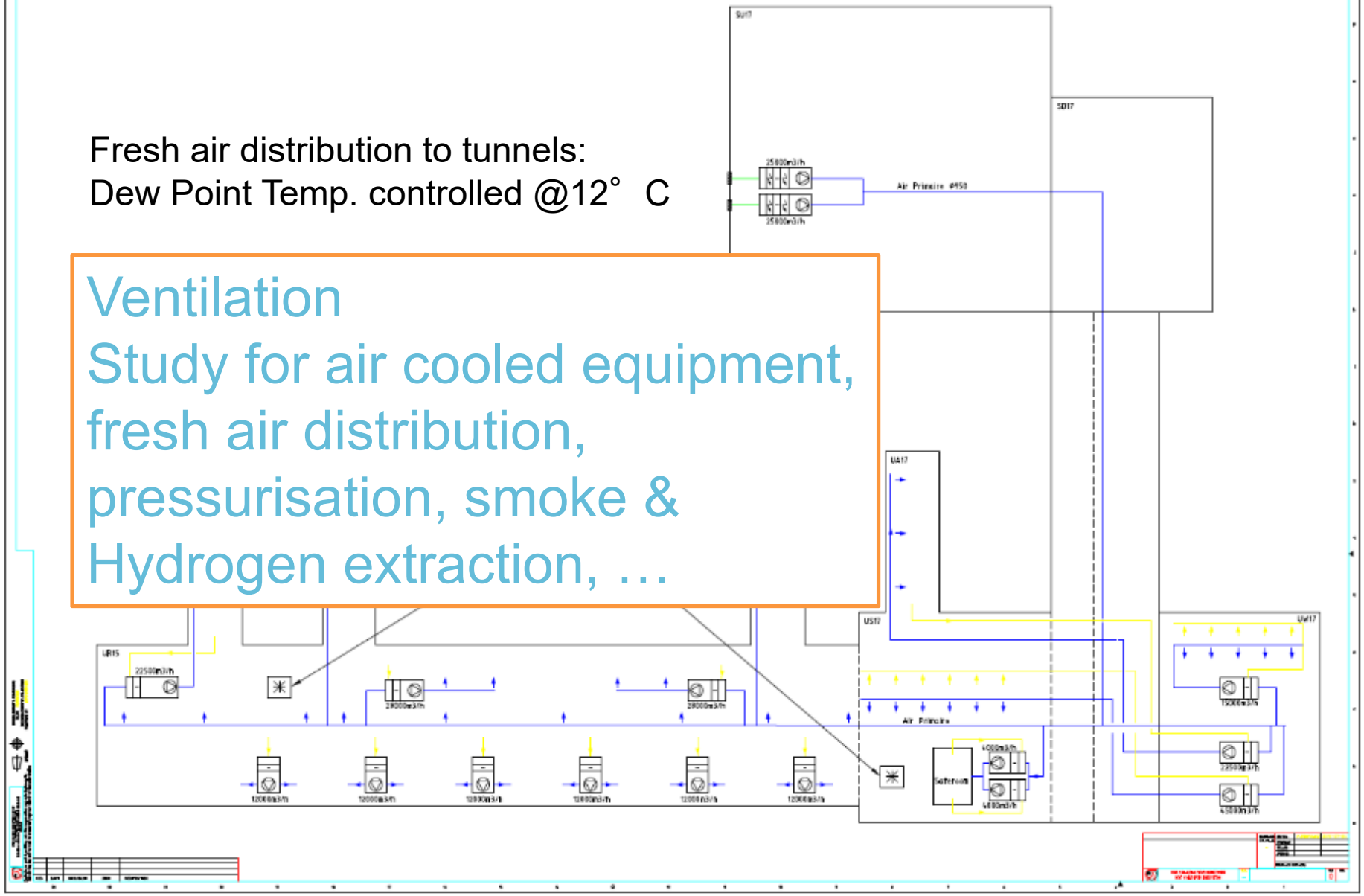
Underground



Study done for different networks and sites

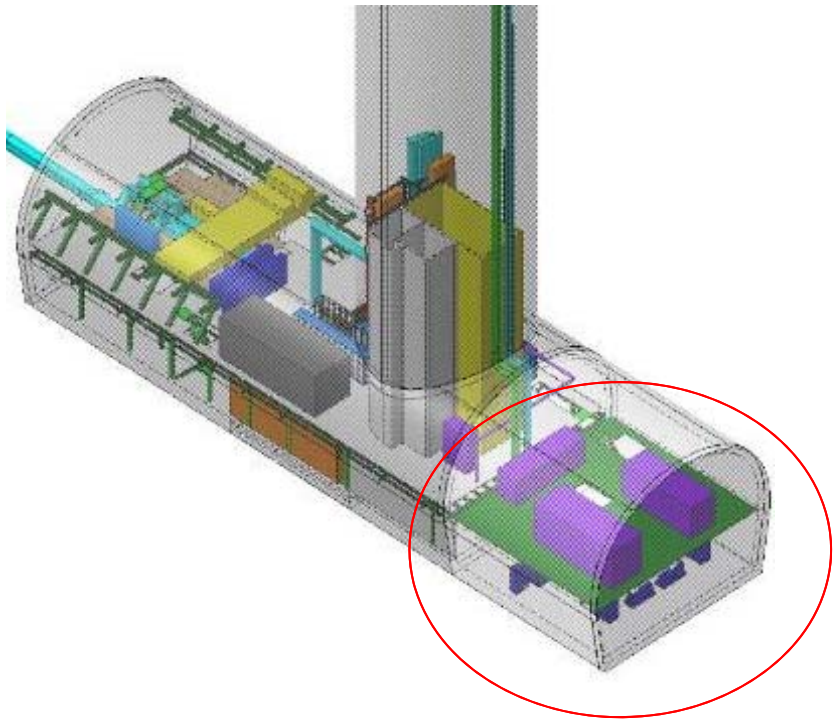
Fresh air distribution to tunnels:
Dew Point Temp. controlled @12° C

Ventilation
Study for air cooled equipment, fresh air distribution, pressurisation, smoke & Hydrogen extraction, …

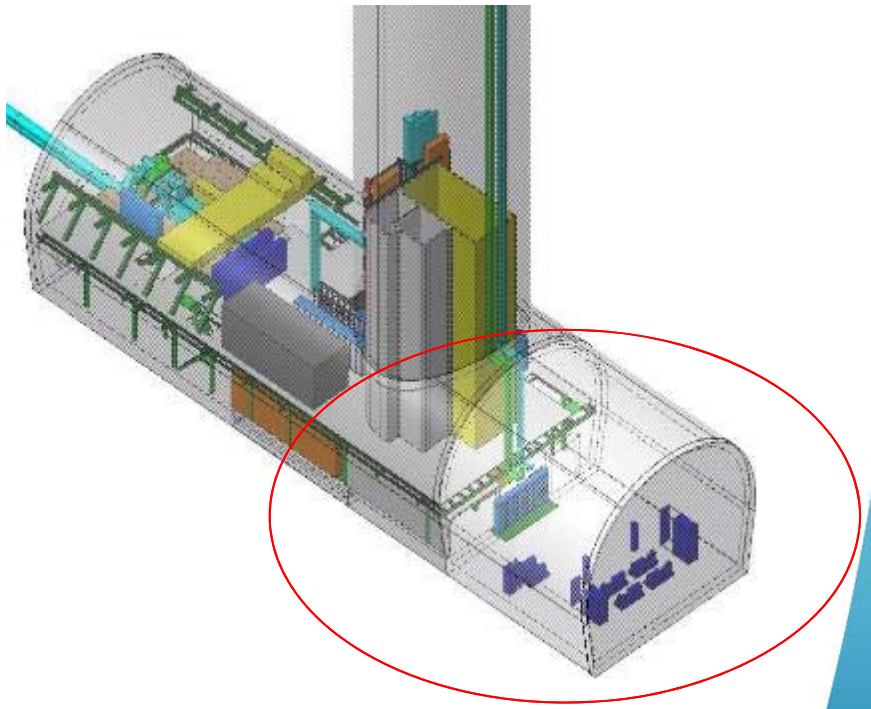


EN-CV equipments integrated in 3D models

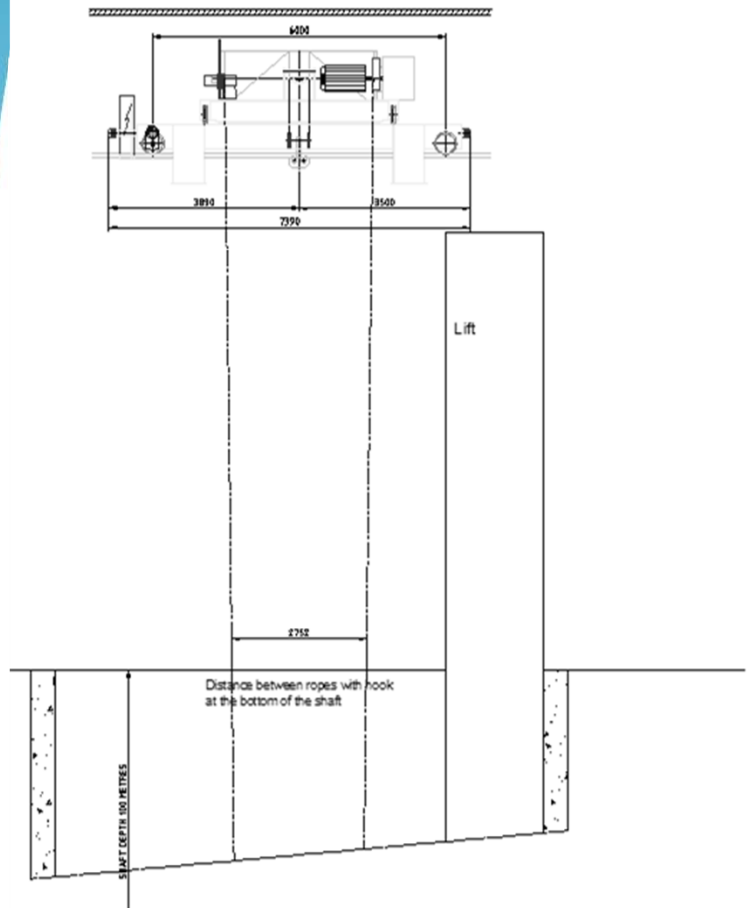
UW ventilation units & distribution

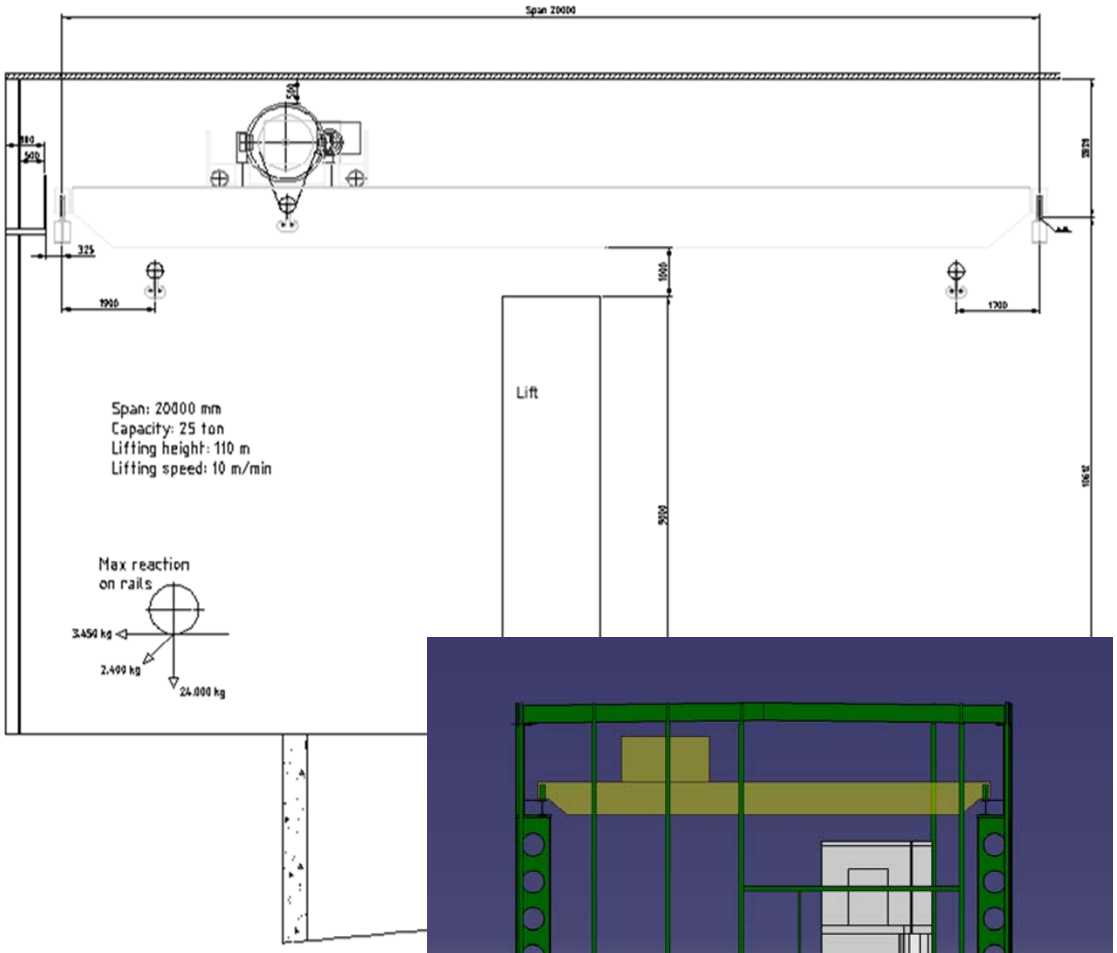


UW cooling station

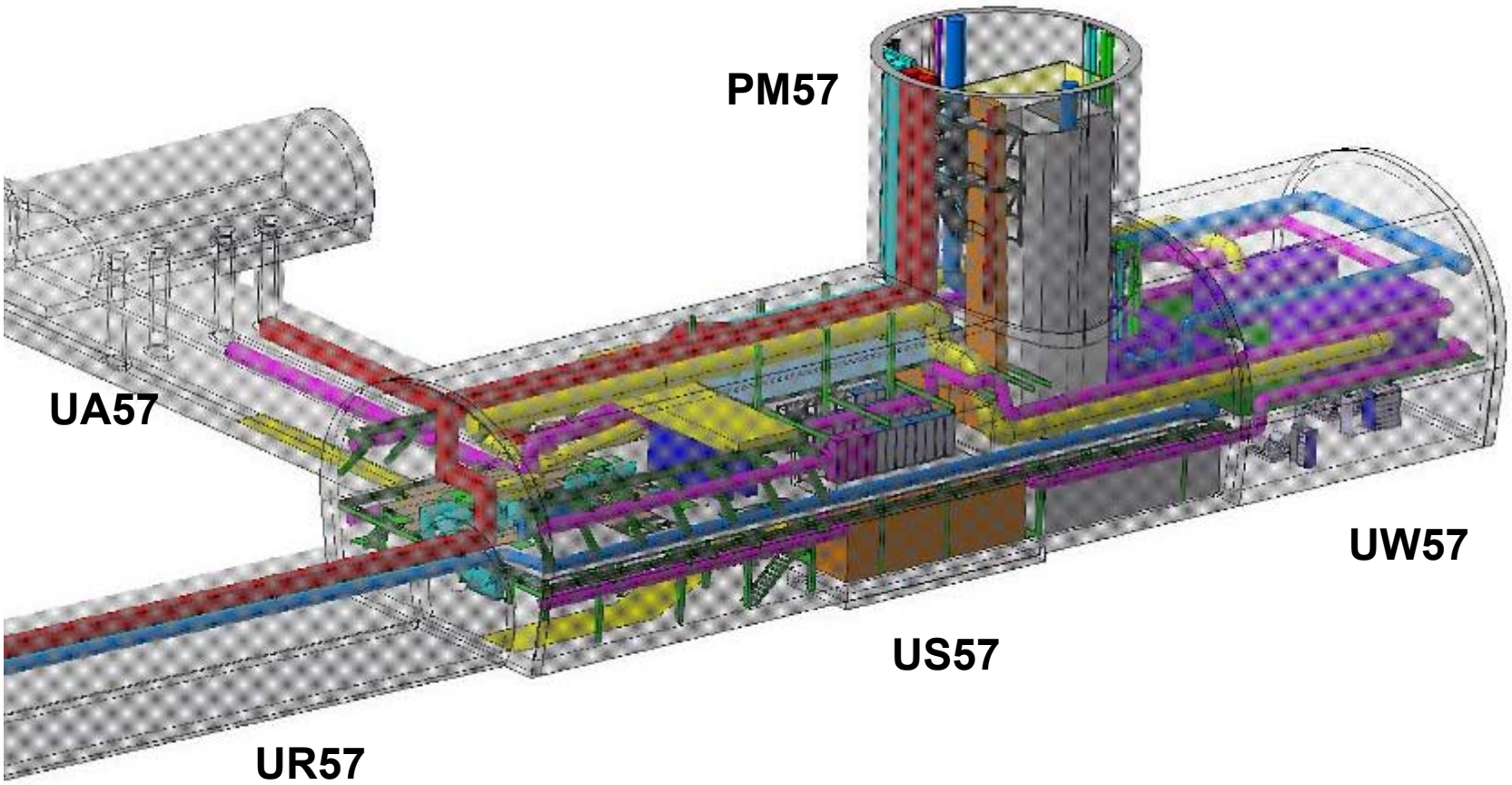


Example of SD17 & SD 57 cranes

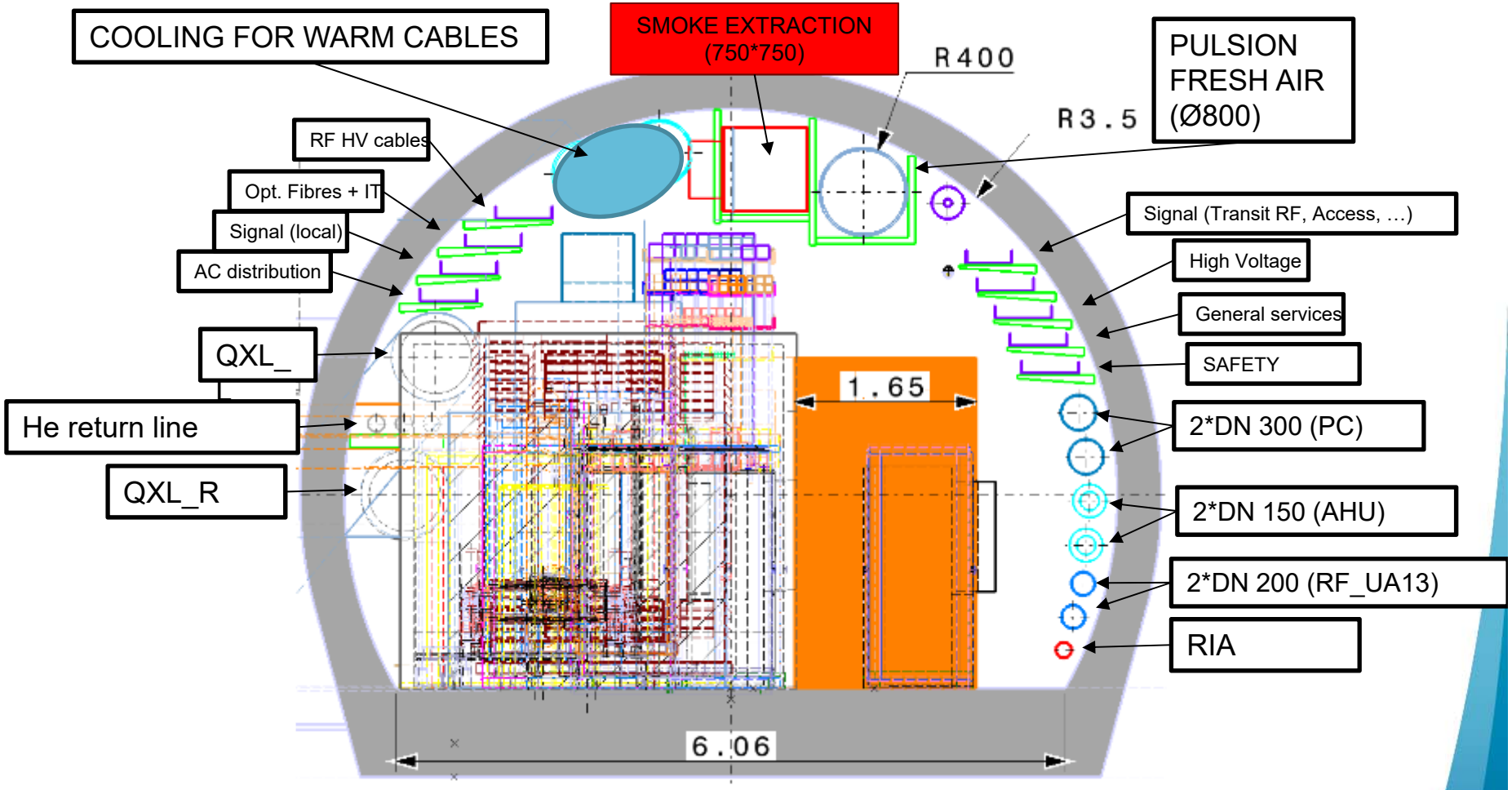




General view



The most busy section



Industry

Tools to communicate and to get informed

Information must be dynamic …

https://project-hl-lhc-industry.web.cern.ch/

Our objective

- The High Luminosity project seeks industrial suppliers and collaborations to start the construction phase and make the High Luminosity upgrade.
- CERN aims at fostering R&D collaborations and knowledge exchange also with SMEs, a perfect opportunity to match their capacity with the requirements of HiLumi.
- Next 4 years there will be intensive prototyping and the production of some of the first series of components.
- Understanding our needs is the first step to tender successfully.
- Understanding your capabilities and the know how that could come from industry is the best way to specify equipment that can be built by industry

HiLumi HL-LHC PROJECT

Ready for the challenge?

Become a CERN supplier to built future accelerators

Visit us on

https://project-hl-lhc-industry.web.cern.ch

Thank you for your attention

Special Thanks to all HL-LHC WP Leaders for their contribution and specially to F, Carra, O. Capatina, P. Fessia, B. Lemoine and F. Savary

Procurement needs now->2018

Some examples

What and When

MAKE OR BUY PLAN

Name	Engineering specification	Fabrication	Assembly	Verification	Installation	Commissioning
SPS Cryomodule	CERN	CERN + New Collaborations	CERN + New Collaborations	CERN + New Collaborations	CERN	CERN + New Collaborations
SPS Vacuum vessel	CERN	CERN + New Contract	CERN	CERN + New Collaborations	CERN	CERN + New Collaborations
SPS External supports	CERN	CERN + New Contract	CERN	CERN + New Collaborations	CERN	CERN + New Collaborations
SPS Cryostat components	CERN	CERN + New Contract	CERN	CERN + New Collaborations	CERN	CERN + New Collaborations
SPS Dressed cavities	CERN	CERN + New Collaborations	Collaboration US-LARP	CERN + New Collaborations	CERN	CERN + New Collaborations
SPS Bare cavities with interfaces	CERN	Collaboration US-LARP	Collaboration US-LARP	CERN + New Collaborations	CERN	CERN + New Collaborations
SPS Tunning system	CERN	CERN + New Contract	CERN	CERN + New Collaborations	CERN	CERN + New Collaborations
SPS Helium vessel	CERN	Collaboration US-LARP	Collaboration US-LARP	CERN + New Collaborations	CERN	CERN + New Collaborations
SPS HOM couplers	CERN	CERN	CERN	CERN + New Collaborations	CERN	CERN + New Collaborations
SPS Cold magnetic shield	CERN	Collaboration UK	Collaboration UK	CERN + New Collaborations	CERN	CERN + New Collaborations
SPS Instrumentation	CERN	CERN + New Contract	CERN	CERN + New Collaborations	CERN	CERN + New Collaborations
SPS Main coupler	CERN	CERN + New Contract	CERN	CERN + New Collaborations	CERN	CERN + New Collaborations
SPS Vacuum valves	CERN	CERN + New Contract	CERN + New Contract	CERN + New Collaborations	CERN	CERN + New Collaborations
LHC Cryomodule	CERN	CERN + New Collaborations	CERN	CERN + New Collaborations	CERN	CERN + New Collaborations
LHC Vacuum vessel	CERN	CERN + New Contract	CERN + New Contract	CERN + New Collaborations	CERN	CERN + New Collaborations
LHC External supports	CERN	CERN + New Contract	CERN + New Contract	CERN + New Collaborations	CERN	CERN + New Collaborations
LHC Cryostat components	CERN	CERN + New Contract	CERN + New Contract	CERN + New Collaborations	CERN	CERN + New Collaborations

2018

MAKE OR BUY PLAN

LHC Dressed cavities	CERN	CERN + New Collaborations	CERN + New Collaborations	CERN + New Collaborations	CERN	CERN + New Collaborations
LHC Bare cavities with interfaces	CERN	CERN + New Collaborations	CERN + New Collaborations	CERN + New Collaborations	CERN	CERN + New Collaborations
LHC Tunning system	CERN	CERN + New Collaborations	CERN + New Collaborations	CERN + New Collaborations	CERN	CERN + New Collaborations
LHC Helium vessel	CERN	CERN + New Collaborations	CERN + New Collaborations	CERN + New Collaborations	CERN	CERN + New Collaborations
LHC HOM couplers	CERN	CERN + New Collaborations	CERN + New Collaborations	CERN + New Collaborations	CERN	CERN + New Collaborations
LHC Cold magnetic shield	CERN	CERN + New Collaborations	CERN + New Collaborations	CERN + New Collaborations	CERN	CERN + New Collaborations
LHC Instrumentation	CERN	CERN + New Contract	CERN	CERN + New Collaborations	CERN	CERN + New Collaborations
LHC Main coupler	CERN	CERN + New Contract	CERN	CERN + New Collaborations	CERN	CERN + New Collaborations
LHC Vacuum valves	CERN	CERN + New Contract	CERN + New Contract	CERN + New Collaborations	CERN	CERN + New Collaborations
LLRF & Fast Controls	CERN	CERN	CERN	CERN + New Collaborations	CERN	CERN + New Collaborations
RF racks	CERN	CERN	CERN	CERN + New Collaborations	CERN	CERN + New Collaborations
Faraday Cages and Ancilliary Equipment	CERN	CERN + New Contract	CERN + New Contract	CERN + New Collaborations	CERN	CERN + New Collaborations
Slow controls	CERN	CERN	CERN	CERN + New Collaborations	CERN	CERN + New Collaborations
Transmission lines	CERN	CERN	CERN	CERN + New Collaborations	CERN	CERN + New Collaborations
Pick-ups	CERN	CERN	CERN	CERN + New Collaborations	CERN	CERN + New Collaborations
Power Amplifiers	CERN	CERN + New Contract	CERN	CERN + New Collaborations	CERN	CERN + New Collaborations
Power Amplifiers	CERN	CERN + New Contract	CERN	CERN + New Collaborations	CERN	CERN + New Collaborations
4 - RF & Crab Cavities - Harmonic system	CERN	CERN	CERN	CERN + New Collaborations	CERN	CERN + New Collaborations
800 MHz	CERN	CERN	CERN	CERN + New Collaborations	CERN	CERN + New Collaborations
200 MHz	CERN	CERN	CERN	CERN + New Collaborations	CERN	CERN + New Collaborations

2018

Looking for (short term)

- Collaborations interesting in R&D on Digital I/Q Demodulators & DSPs, low noise demodulators, Tetrode, IOT & SSPA, flexural guides , machining, forming techniques, E-beam welding and for Nb and NtTi sheets – by 2016
- Potential suppliers from MS on raw materials (Nb and NbTi), machining and forming of raw materials, vacuum valves and RF equipment – before 2016

Contacts & more info

HL-LHC_Knowledge_and_Industry@cern.ch
WWW: HL-LHC Knowledge & Industry

HiLumi HL-LHC PROJECT

What and When

MAKE OR BUY PLAN						
Name	**Engineering specification**	**Fabrication**	**Assembly**	**Verification**	**Installation**	**Commissioning**
Target Collimator Tertiary Pick-up Metallic	CERN	New procurement contract	New procurement contract	New procurement contract	CERN	CERN
Long Collimator IR1&IR5	CERN	New procurement contract	New procurement contract	New procurement contract	CERN	CERN
Target collimator long mask IR1&IR5	CERN	New procurement contract	New procurement contract	New procurement contract	CERN	CERN
Target Collimator Long Dispersion suppressor	CERN	New procurement contract	New procurement contract	New procurement contract	CERN	CERN
Target Seconday Collimator Pick-up Metallic	CERN	New procurement contract	New procurement contract	New procurement contract	CERN	CERN

2018

Looking for (short term)

- Potential suppliers from MS on Raw Materials for Advanced Collimators for Accelerators & manufacturers of Collimators – before 2016

Contacts & more info

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WWW: HL-LHC Knowledge & Industry

What and When – WP6a: Cold Powering

MAKE OR BUY PLAN						
Name	**Engineering specification**	**Fabrication**	**Assembly**	**Verification**	**Installation**	**Commissioning**
Tunnel Interconnection cryostats prototype	CERN	CERN or Industry	CERN	CERN	CERN	CERN
Current Leads prototype	CERN	CERN or Industry	CERN or Industry	CERN	CERN	CERN
Surface cryostats prototype	CERN	CERN or Industry	CERN	CERN	CERN	CERN
Superconducting links prototype	CERN	Industry	CERN	CERN	CERN	CERN
Tunnel Interconnection Cryostats series	CERN	Industry	CERN	CERN	CERN	CERN
Current Leads series	CERN	Industry	Industry	CERN	CERN	CERN
Surface cryostats series	CERN	Industry	CERN	CERN	CERN	CERN
Superconducting links series	CERN	Industry	CERN	CERN	CERN	CERN

2018

Looking for (short term)

- Potential suppliers from MS on cabling of superconducting and semi flexible long cryostats – by 2016

Contacts & more info

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What and When

Name	Number of units	Engineering specification	Fabrication	Assembly	Verification
Power Converter [Current 16.5 kA, Voltage 20V, 1 Quadrant]	16	CERN	New procurement contract	New procurement contract	New procurement contract
Power Converter [Current 13 kA, Voltage 18V, 1 Quadrant]	8	CERN	New procurement contract	New procurement contract	New procurement contract
Power Converter [Current 6 kA, Voltage 8V, 1 Quadrant]	16	CERN	New procurement contract	New procurement contract	New procurement contract
Power Converter [Current ±2 kA, Voltage ±10V, 4 Quadrant]	60	CERN	New procurement contract	New procurement contract	New procurement contract
Power Converter [Current ±0.6 kA, Voltage ±10V, 4 Quadrant]	4	CERN	New procurement contract	New procurement contract	New procurement contract
Power Converter [Current ±0.2 kA, Voltage ±10V, 4 Quadrant]	28	CERN	New procurement contract	New procurement contract	New procurement contract
Power Converter [Current ±0.12 kA, Voltage ±10V, 4 Quadrant]	40	CERN	New procurement contract	New procurement contract	New procurement contract
Power Converter [Current 17 kA, Voltage ±18V, 2 Quadrant]	R&D	New collaboration			
Power Converter [Current 13 kA, Voltage ±18V, 2 Quadrant]	R&D	New collaboration			
Power Converter [Current 6 kA, Voltage ±10V, 2 Quadrant]	R&D	New collaboration			

2018

2020 for launching of Fabrication orders

Looking for (short term)

- Collaborations with universities interesting in R&D on 2-quadrant topologies for converters up to 17kA to improve current ramp down (17kA/±18V) and squeeze time (6kA/±10V) – end 2015
- Potential suppliers from MS – before 2020

Contacts & more info

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What and When

MAKE OR BUY PLAN						
Name	**Engineering specification**	**Fabrication**	**Assembly**	**Verification**	**Installation**	**Commissioning**
Energy extraction system - High DC Switches, By pass Diodes, High power diodes, High Power Resistors, Electronics Controls	CERN + New Collaboration	New procurement contract	New procurement contract	CERN + New Contract	CERN + New Collaboration	CERN + New Collaboration
Beam Interlock System - Electronic Cards and Cabling, Optical Components, and communications	CERN	New procurement contract	New procurement contract	CERN + New Contract	CERN + New Collaboration	CERN
Quench Detection System - Electronic Boards, Cabling, Communications	CERN	New procurement contract	New procurement contract	CERN + New Contract	CERN + New Collaboration	CERN
Power Interlock - PLC (Safety PLCs) and Cabling	CERN	New procurement contract	New procurement contract	CERN + New Contract	CERN + New Collaboration	CERN

2018

Looking for (short term)

- Collaborations with universities interesting in R&D on design and manufacturing of Mechanical High DC Current Switches, Cold By-pass Diodes and Assembly of these Diodes – before 2016
- Potential suppliers from MS – before middle 2017

Contacts & more info

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What and When

MAKE OR BUY PLAN						
Name	**Engineering specification**	**Fabrication**	**Assembly**	**Verification**	**Installation**	**Commissioning**
Neutral Beam Absorber TAXN (ATLAS, CMS)	CERN	CERN + New Collaborations	CERN + New Collaborations	CERN + New Collaborations	CERN + New Collaborations	CERN + New Collaborations
Neutral Beam Absorber TAXN (LHCb)	CERN	CERN + New Collaborations	CERN + New Collaborations	CERN + New Collaborations	CERN + New Collaborations	CERN + New Collaborations
Target Absorber for Insertion region TAXS (ATLAS, CMS)	CERN	CERN + New Collaborations	CERN + New Collaborations	CERN + New Collaborations	CERN + New Collaborations	CERN + New Collaborations
Radiation shielding (ATLAS & CMS)	CERN	CERN + New Collaborations	CERN + New Collaborations	CERN + New Collaborations	CERN + New Collaborations	CERN + New Collaborations

2018

Looking for (short term)

- Collaborations with universities interesting in R&D on design and manufacturing of Neutron absorbers for accelerators – end 2015
- Potential suppliers from MS on machining in situ of radioactive materials – before 2016

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What and When

MAKE OR BUY PLAN

Name	Fabrication	Assembly	Verification	Installation	Commissioning
Q1 & Q3 Magnets					
Model	Collaboration US-LARP	Collaboration US-LARP	Collaboration US-LARP		
Prototype	Collaboration US-LARP	Collaboration US-LARP	Collaboration US-LARP	CERN	Collaboration US-LARP
Series	Collaboration US-LARP	Collaboration US-LARP	Collaboration US-LARP	CERN	CERN
Q2 Magnet					
Model	CERN	CERN	CERN		
Prototype	CERN	CERN	CERN	CERN	CERN
Series	CERN	CERN	CERN	CERN	CERN
Short Orbit Corrector					
Model					
Prototype	Collaboration CIEMAT	Collaboration CIEMAT	CERN		
Series	New procurement contract	New procurement contract	CERN		
Long Orbit Corrector					
Model					
Prototype	Collaboration CIEMAT	Collaboration CIEMAT	CERN		
Series	New procurement contract	New procurement contract	CERN		
High Order Correctors					
Model					
Prototype	Collaboration INFN	Collaboration INFN	Collaboration INFN	CERN	CERN
Series	New procurement contract	New procurement contract	Collaboration INFN	CERN	CERN

2018

MAKE OR BUY PLAN

Name	Fabrication	Assembly	Verification	Installation	Commissioning
D1 Magnet					
Model	Collaboration KEK	Collaboration KEK	Collaboration KEK		
Prototype	New procurement contract	New procurement contract	Collaboration KEK	Collaboration KEK	CERN
Series	New procurement contract	New procurement contract	Collaboration KEK	CERN	CERN
D2 Magnet					
Model	New procurement contract	New procurement contract	Collaboration INFN		
Prototype	New procurement contract	New procurement contract	CERN	CERN	CERN
Series	New procurement contract	New procurement contract	CERN	CERN	CERN
Q4 Magnet					
Model	Collaboration CEA	CERN	Collaboration CEA		
Prototype	New procurement contract	New procurement contract	Collaboration CEA	CERN	CERN
Series	New procurement contract	New procurement contract	Collaboration CEA	CERN	CERN
D2 & Q4 Correctors					
Model					
Prototype	CERN	CERN	CERN		
Series	New procurement contract	New procurement contract	CERN		
Q5 Magnet					
Model					
Prototype					
Series					

2018

Looking for (short term)

- Potential suppliers from MS on Raw Materials Metallic and non-Metallic (Stainless Steel, Cooper, Low Carbon Steel, Fiberglass, Mica, Ceramic Binder), Machining of metallic components, Machining of composite component and Cryostats – before March 2016

Contacts & more info

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What and When

MAKE OR BUY PLAN						
Name	**Engineering specification**	**Fabrication**	**Assembly**	**Verification**	**Installation**	**Commissioning**
Magnet Model Single aperture	CERN	CERN + New suppliers	CERN	CERN		
Magnet Model Double aperture	CERN	CERN + New suppliers	CERN	CERN		
Cryo-Magnet assembly for High Field 11 T Dipole - Prototype	CERN	CERN + New suppliers	CERN	CERN + New suppliers		
Cryo-Magnet assembly for High Field 11 T Dipole - Series	CERN	CERN + New suppliers	CERN	CERN + New suppliers	CERN + New Collaborations	CERN + New Collaborations

2018

Looking for (short term)

- Potential suppliers from MS on Raw Materials Metallic and non-Metallic (Stainless Steel, Cooper, Low Carbon Steel, Fiberglass, Mica, Ceramic Binder), Machining of metallic components, Machining of composite component and Cryostats – before March 2016

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What and When

MAKE OR BUY PLAN						
Name	**Engineering specification**	**Fabrication**	**Assembly**	**Verification**	**Installation**	**Commissioning**
Shielded Beam Screen (VSM)	CERN	New procurement contract	CERN + Industry	CERN + Industry	CERN + Industry	CERN + Industry
Beam Screen non-shielded (VSC)	CERN	New procurement contract	CERN + Industry	CERN + Industry	CERN + Industry	CERN + Industry
In-situ coating of Inner tripplets IT2 & IT8	CERN	CERN	CERN	CERN	CERN + Industry	CERN + Industry
Room temperature vacuum system in LSS1 & LSS5	CERN	CERN + Industry	CERN + Industry	CERN + Industry	CERN + Industry	CERN + Industry
Room temperature vacuum system in LSS4	CERN	CERN + Industry	CERN + Industry	CERN + Industry	CERN + Industry	CERN + Industry
Insulation Vacuum system	CERN	New procurement contract	CERN + Industry	CERN + Industry	CERN + Industry	CERN + Industry
Vacuum system in experimental areas	CERN	CERN + Industry	CERN + Industry	CERN + Industry	CERN + Industry	CERN + Industry

2018

Looking for (short term)

- Collaborations with universities interesting in R&D on Laser Engineered Surface – before 2017
- Potential suppliers from MS on Bake out System, Machining and Assembly of UHV Components, Raw Materials (W alloy, Al alloy, SS…), Beam screens, bellows for UHV, Supports and Vacuum system controllers – before 2018

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What and When

MAKE OR BUY PLAN						
LHC Equipment code	**Engineering specification**	**Fabrication**	**Assembly**	**Verification**	**Installation**	**Commissioning**
Beam diagnostics & instrumentation - BLM - Beam loss monitors	CERN	CERN + New Contract	CERN + New Contract	CERN + New Contract	CERN	CERN
Beam diagnostics & instrumentation - BWSF - Fast wire scanners	CERN	CERN + New Contract	CERN + New Contract	CERN + New Contract	CERN	CERN
Beam diagnostics & instrumentation - BPM - Beam position monitors	CERN	CERN + New Contract	CERN + New Contract	CERN + New Contract	CERN	CERN
Beam diagnostics & instrumentation - BRANQ - Luminosity monitors	CERN	CERN + New Contract	CERN + New Contract	CERN + New Contract	CERN	CERN
Beam diagnostics & instrumentation - BPW - Wide-band pick-ups	CERN	CERN + New Contract	CERN + New Contract	CERN + New Contract	CERN	CERN
Beam diagnostics & instrumentation - BSR - Synchroton light monitors	CERN	CERN + New Contract	CERN + New Contract	CERN + New Contract	CERN	CERN
Beam diagnostics & instrumentation - BGV - Beam Gas Vertex Detector	CERN	CERN + New Contract	CERN + New Contract	CERN + New Contract	CERN	CERN
Beam diagnostics & instrumentation - Long range beam-beam compensator	CERN	CERN + New Contract	CERN + New Contract	CERN + New Contract	CERN	CERN

2018

Looking for (short term)

Qualification of potential suppliers:

- cryogenic cables – before 2017
- UHV RF feedthroughs – before 2017
- Packaged diamond detectors – before 2017

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What and When

MAKE OR BUY PLAN						
Name	**Engineering specification**	**Fabrication**	**Assembly**	**Verification**	**Installation**	**Commissioning**
Beam transfer & kickers - Injection System - Absorber for Injection Segmented	CERN	CERN + New Contract	CERN + New Contract	CERN + New Contract	CERN	CERN
Beam transfer & kickers - Injection System - Collimator for D1 Protection	CERN	CERN + New Contract	CERN + New Contract	CERN + New Contract	CERN	CERN
Beam transfer & kickers - Injection System - Injection kickers	CERN	CERN + New Contract	CERN + New Contract	CERN + New Contract	CERN	CERN
Beam transfer & kickers - Injection System - Beam Instrumentation	CERN	CERN + New Contract	CERN + New Contract	CERN + New Contract	CERN	CERN
Beam transfer & kickers - LHC Beam Dumping System - Collimator for MSD Protection	CERN	CERN + New Contract	CERN + New Contract	CERN + New Contract	CERN	CERN
Beam transfer & kickers - LHC Beam Dumping System - Diluter Dump Kicker	CERN	CERN + New Contract	CERN + New Contract	CERN + New Contract	CERN	CERN
Beam transfer & kickers - LHC Beam Dumping System - Controls	CERN	CERN + New Contract	CERN + New Contract	CERN + New Contract	CERN	CERN

2018

Looking for (short term)

- Potential suppliers from MS on Raw Materials (Glidcop, Graphite, 3D C-C composites), machining of components, Welding (Electro Beam Welding), Brazing, Interferometers, Bake out coating, Vacuum equipment and Water System equipment – before 2017

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