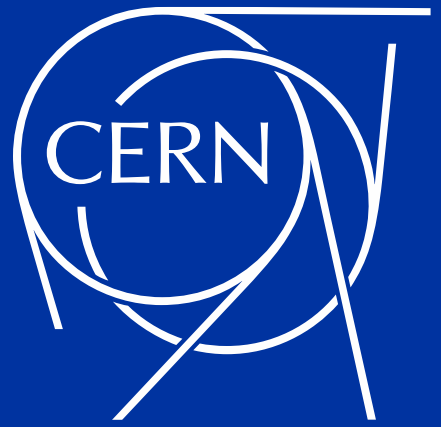


Main vacuum components for accelerators and their supply

Nicolaas Kos TE-VSC-DLM

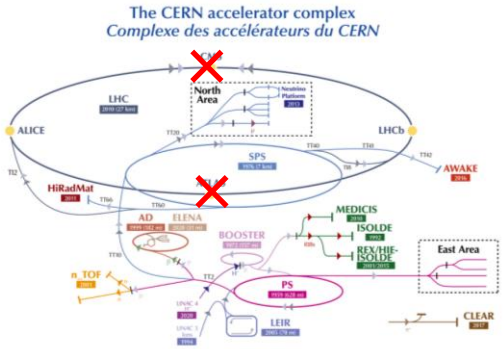
06 October 2023

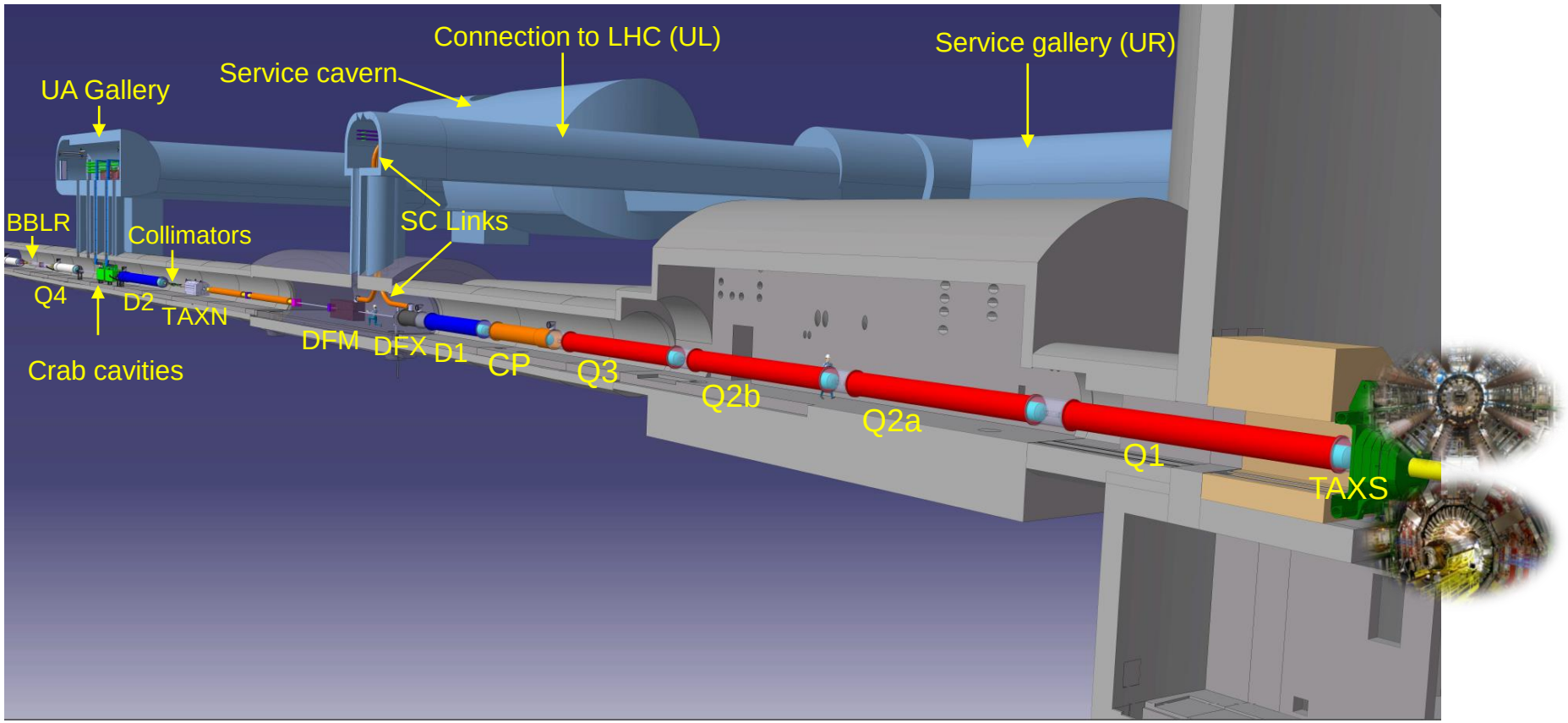
Main vacuum components for accelerators and their supply

Outline:

- ✓ Introduction
- ✓ HL-LHC Cold bores (external supply)
- ✓ HL-LHC Beam screens (mix of in-house manufacturing and external supply
- ✓ Components and materials from the CERN stores
- ✓ Traceability
- ✓ CERN procurement rules
- ✓ Summary

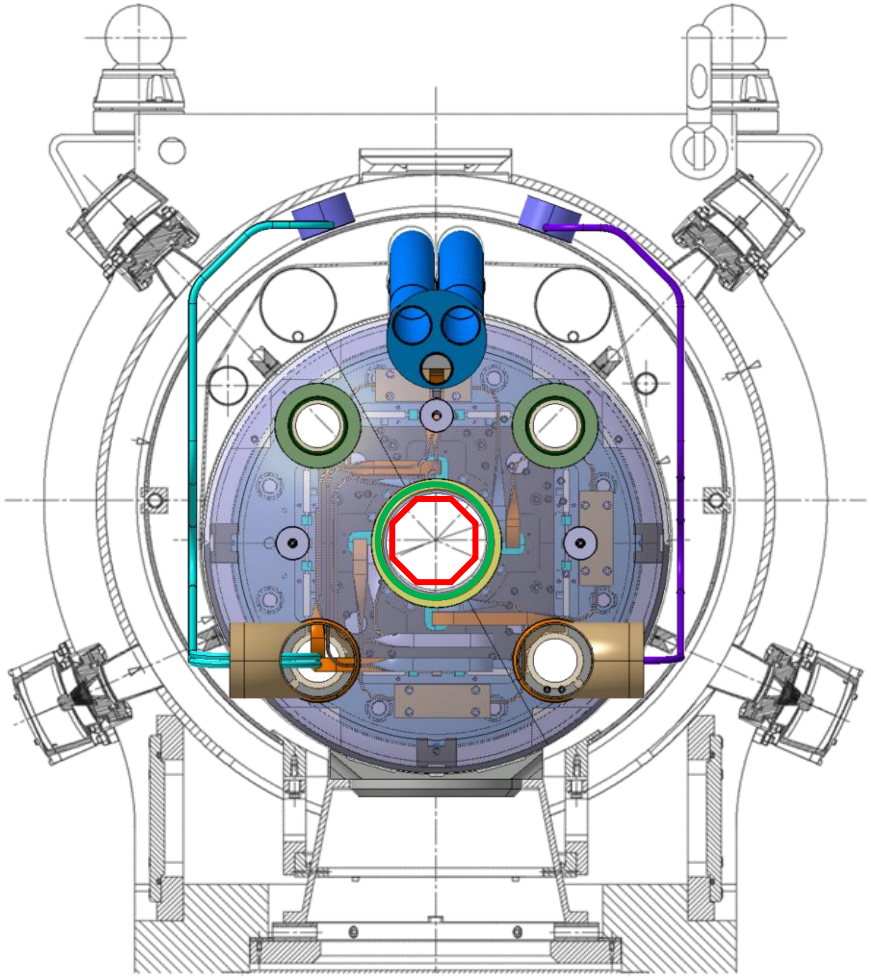
New cryo-magnets around ATLAS and CMS

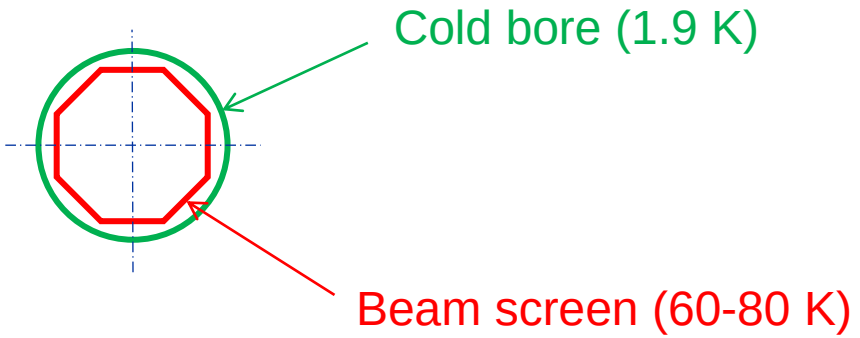




HL-LHC cryo-magnet cross-section

L1

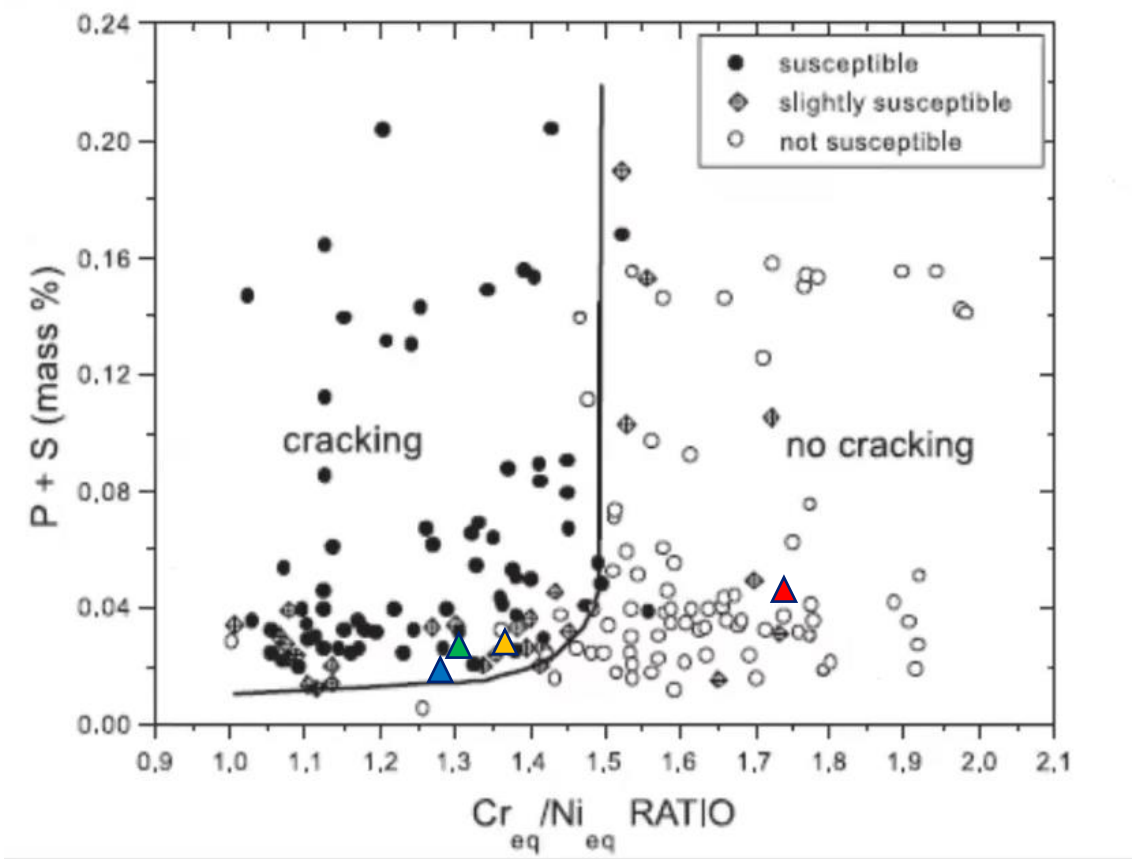




Cold bores – material grade

- 42 tubes (including spares), Ø144.7, lengths up to 10850
- ″CERN specific″ AISI 316LN grade austenitic stainless steel for its low-temperature mechanical properties, low magnetic permeability, weldability and availability.
- Low Co content (≤0.1%) to minimise transmutation of stable natural ^{59}Co into radioactive ^{60}Co during operation.
- Mandatory ESR:
  - Reduce inclusions and ensure leak tightness.
  - Reduce impurity level to avoid cracks during welding (fully austenitic stainless steel is very sensitive to hot cracking).

Austenitic stainless steel - susceptibility to hot cracking



Schaeffler equivalent formulae for Cr_{eq} and Ni_{eq}

$Cr_{eq} = Cr + 1.5Si + 1.37Mo$

$Ni_{eq} = Ni + 0.31Mn + 22C + 14.2N$

via Schaeffler equation - hot cracking:

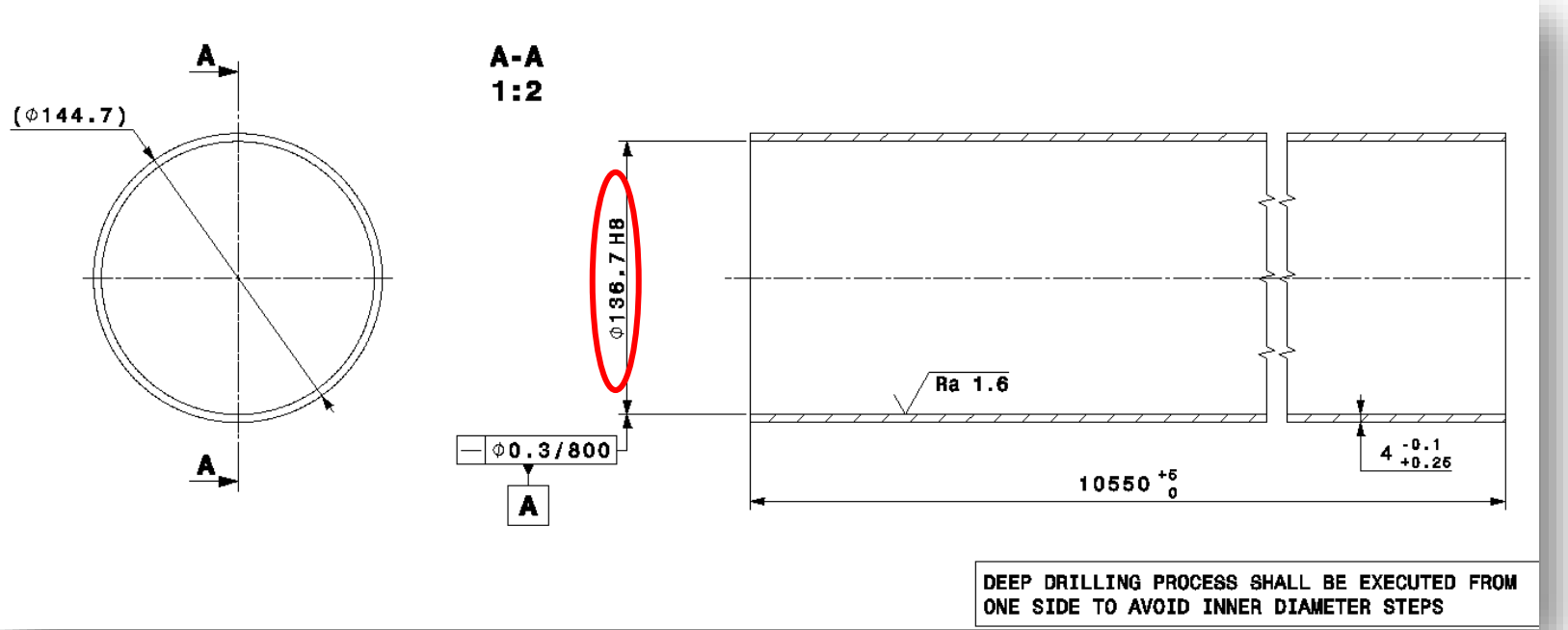
	Cr Eq.	Ni Eq.	Cr/Ni ratio	P+S (mass%)
1.4435 (CERN spec.)	22.3	16.4	1.36	0.028
1.4441 (ISO 5832-1, EN 10088-3)	21.7	17.0	1.27	0.017
1.4429 (CERN spec.)	21.3	16.4	1.30	0.026
1.4404 (EN 10028-7, EN 10088-1)	21.1	12.1	1.74	0.042

Reduced S and P content reduce risk of hot cracking during welding.

Risk of hot cracking when welding “CERN 1.4429” to “off-the-shelf” 1.4404

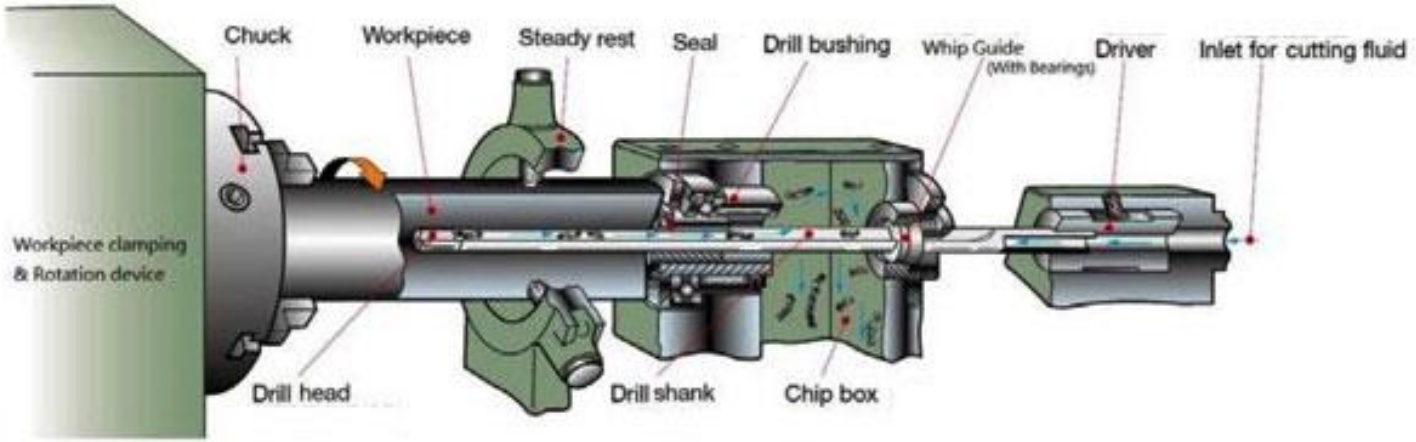
Courtesy Adrià GALLIFA TERRICABRAS and Ignacio AVILÉS SANTILLANA, CERN EN-MME-MM

Production of cold bores (42x)

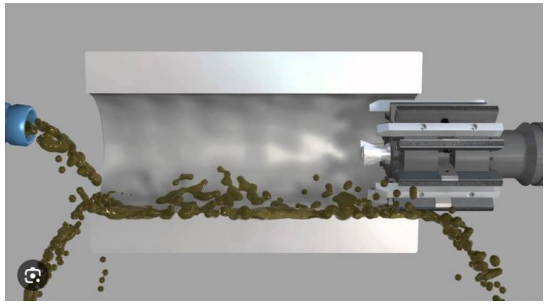


- No longitudinally welded tube to reduce risk of leaks between ultra-high beam vacuum and superfluid helium.
- No seamless tube (diameter and wall thickness tolerances insufficient).
- Produced from forged stainless steel bar Ø160 mm by deep drilling followed by honing.
- 1800 kg of raw material to produce a 150 kg tube.
- Leak testing at CERN because no firm has both deep drilling and high-sensitivity leak testing capabilities. No additional risk because CERN supplied the raw material anyway.
- Geometrical check at the firm and at CERN.
- Systematic full-length endoscopy (following an incident with a groove in one of the cold bores)
- Production in progress (38/42).

Machining of cold bores

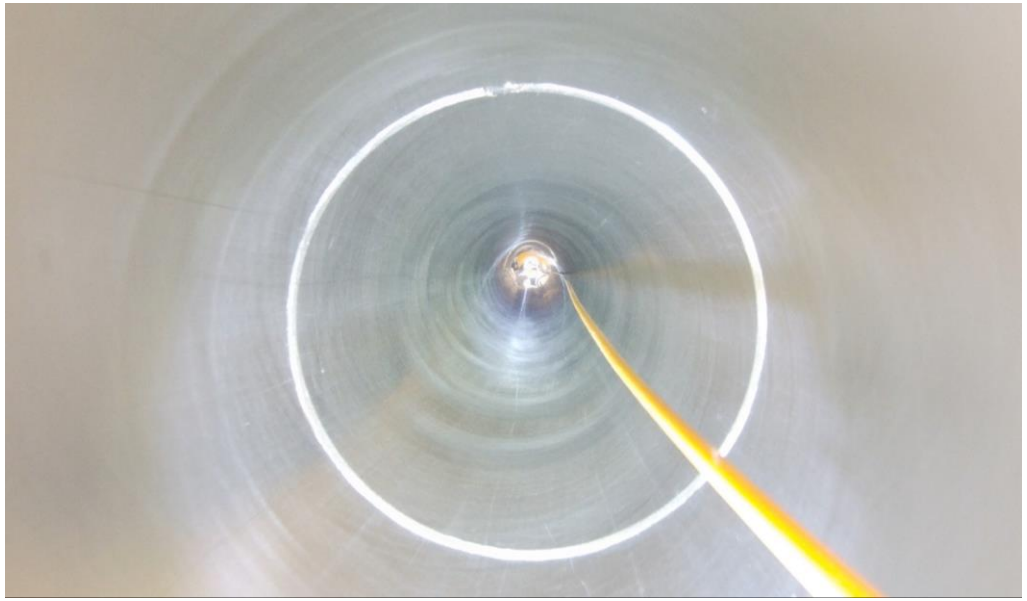


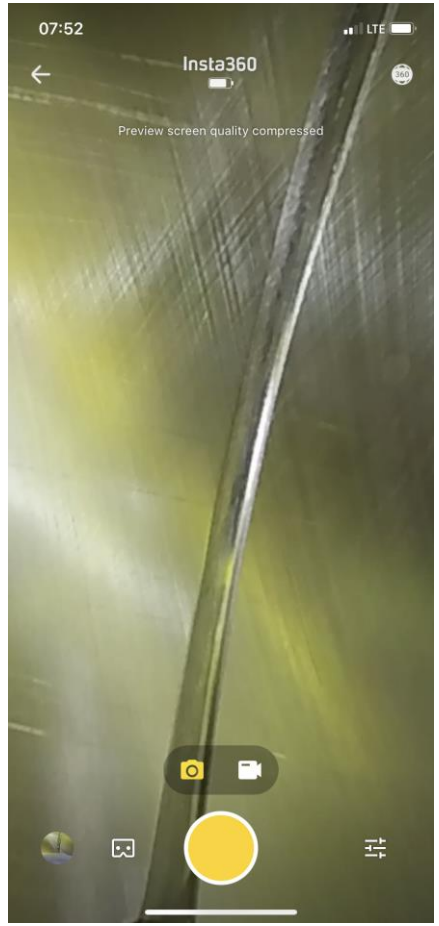
Deep-hole drilling



Honing

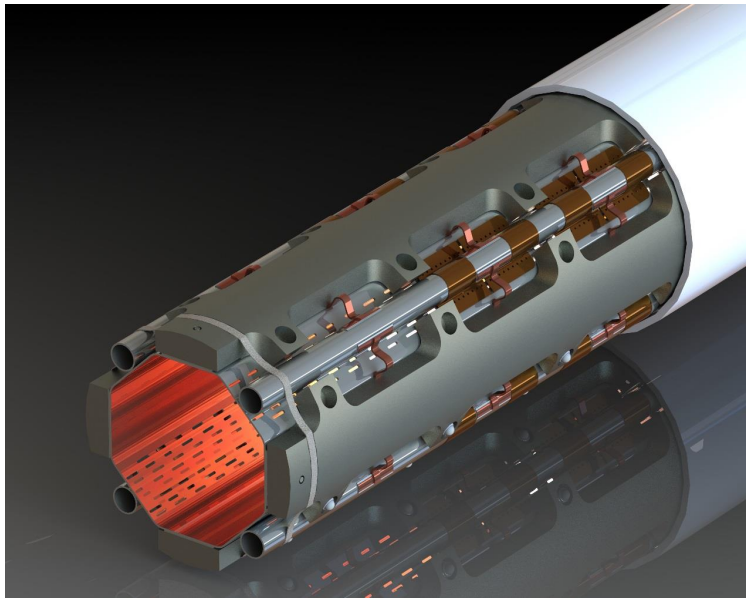
Cold bore production incident





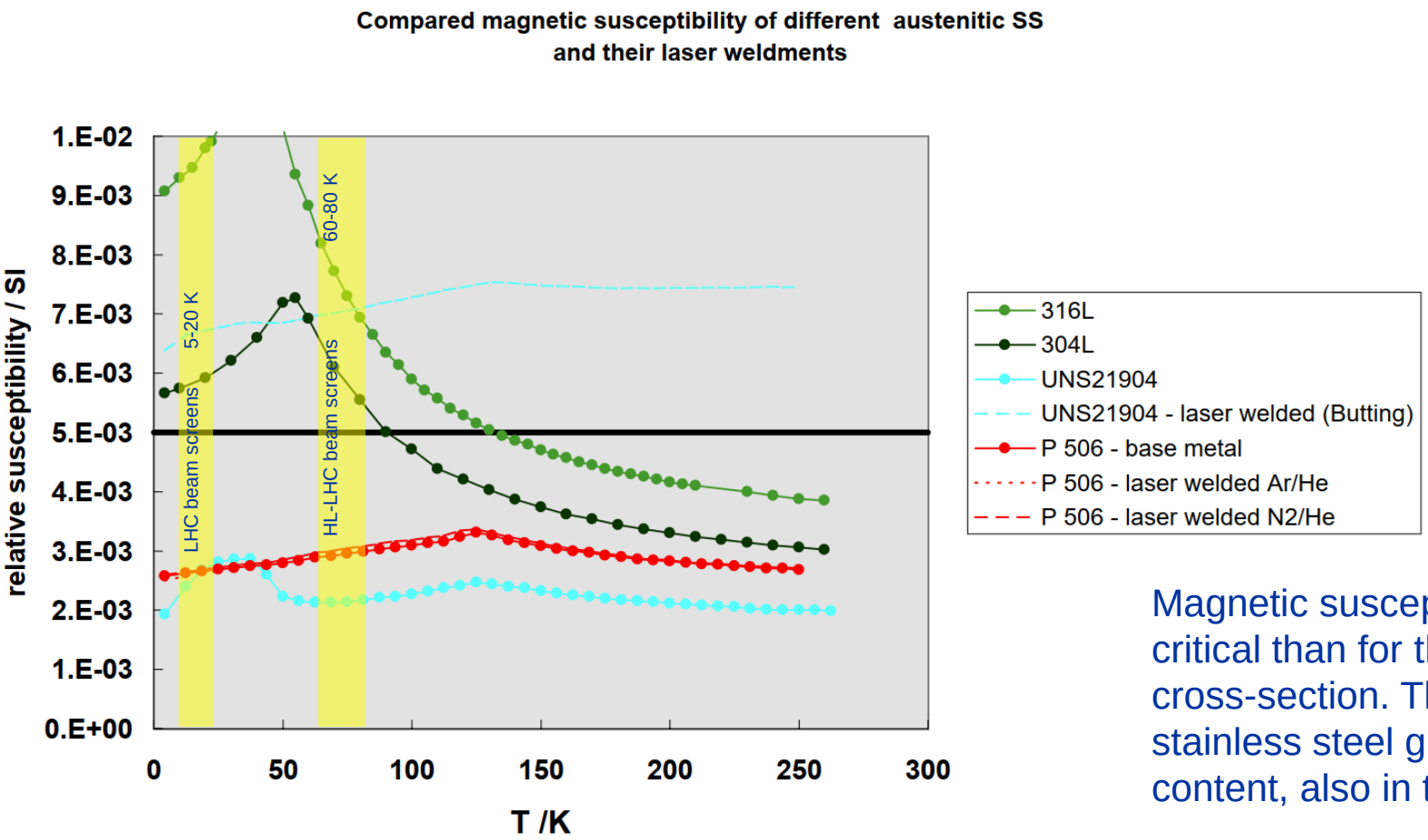
- During testing of a cold mass assembly at Fermilab (US), the test mole got stuck halfway the cold bore.
- Endoscopic inspection revealed a groove in the inner surface of the cold bore.
- During the deep drilling process an unwanted groove has been machined.
- Endoscopic inspection of all tubes already produced revealed two further cases.
- Following the incident, a systematic full-length endoscopy is performed at the firm.
- Three replacement cold bores will have to be machined.

Beam screens



- Interception and evacuation of beam induced heat load.
- OFE copper layer on the inner surface to reduce impedance. Plating by means of co-lamination to obtain a more homogeneous thickness and more reliable adhesion compared to electroplating.
- Austenitic stainless steel backbone to ensure mechanical stability under quench.
- Low impurities to avoid cracks during welding (ESR mandatory)
- Low Co content to minimise transmutation of stable natural ^{59}Co into radioactive ^{60}Co during operation.
- 32 octagonal beam screens (+ spares) in 3 cross-sections and 5 unit-lengths.

Magnetic susceptibility requirement for (HL-)LHC beam screens



Ref.: S. SGOBBA and G. HOCHOERTLER : A New Non-Magnetic Stainless Steel for Very Low Temperature Applications, Proceedings of the International Congress Stainless Steel 1999: Science and Market, Chia Laguna (I), 6-9 June 1999, Vol. 2, p. 391-401

Magnetic susceptibility of the beam screen is more critical than for the cold bore due to the non-circular cross-section. Therefore, a specifically developed stainless steel grade (P506) to ensure zero ferrite content, also in the welds.

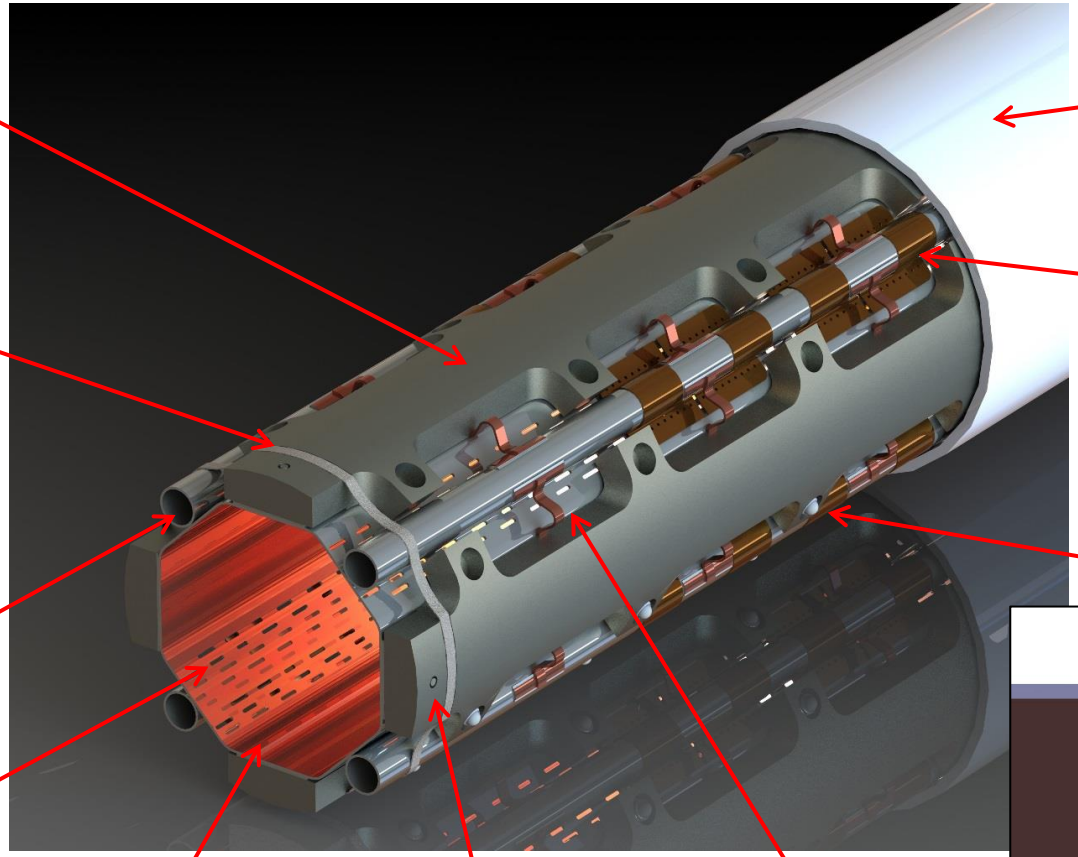
Shielded beam screen components

Tungsten absorbers, flexibly attached to the beam screen.
(Under quench the absorbers push outwards with up to 32 tonnes/m)

Ti6Al4V rings
Formed and welded instead of the initially foreseen additive manufacturing

Seamless P506 cooling tubes Ø10 x 1.
Produced in industry from CERN supplied material and leak tested at CERN.

Punched pumping slots with quasi-random lengths and longitudinal positions

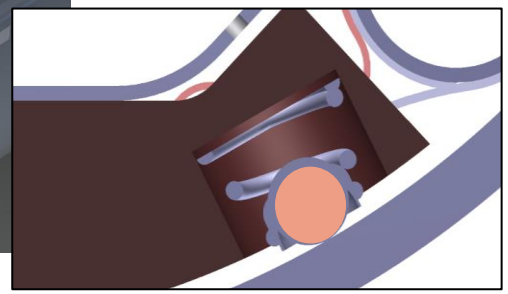


316LN Cold bore

Formed Cu2Be Pumping slot shields

Off-the-shelf !

Ti6Al4V springs + ZrO_2 balls



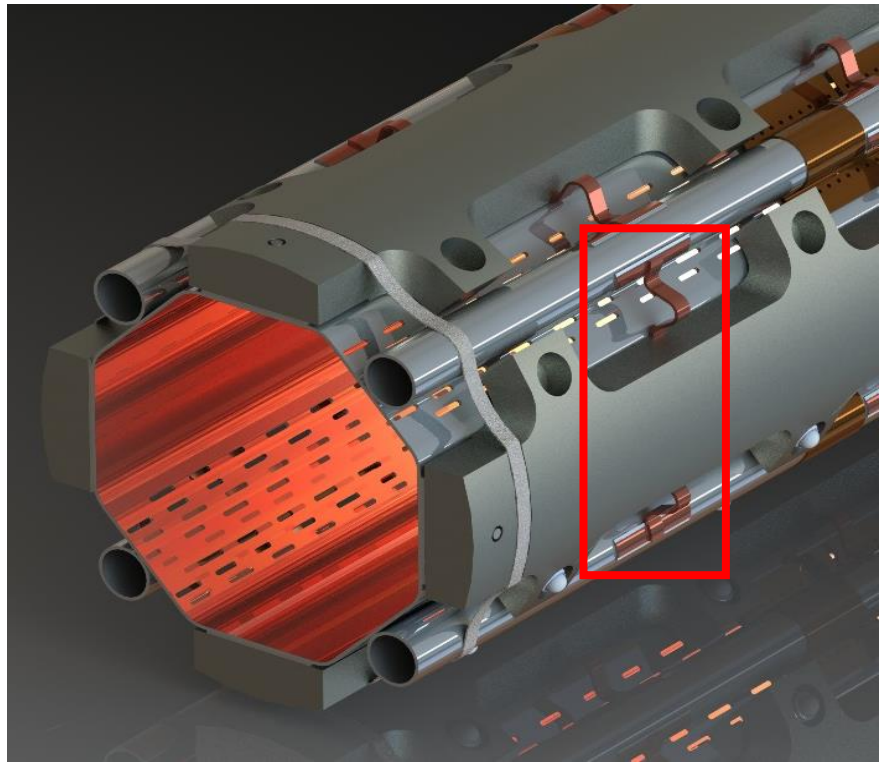
Co-laminated P506 (1 mm) + OFE-Cu (75 µm)

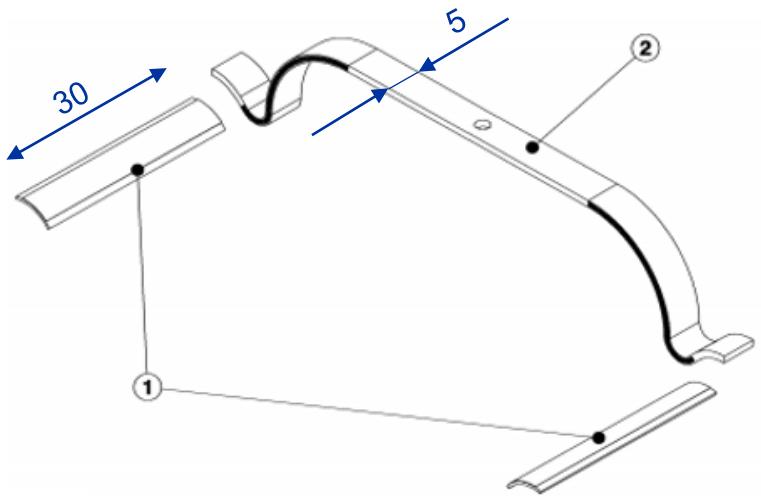
Machined P506 support studs

OFE-Cu Thermal links

Thermal links for HL-LHC beam screens

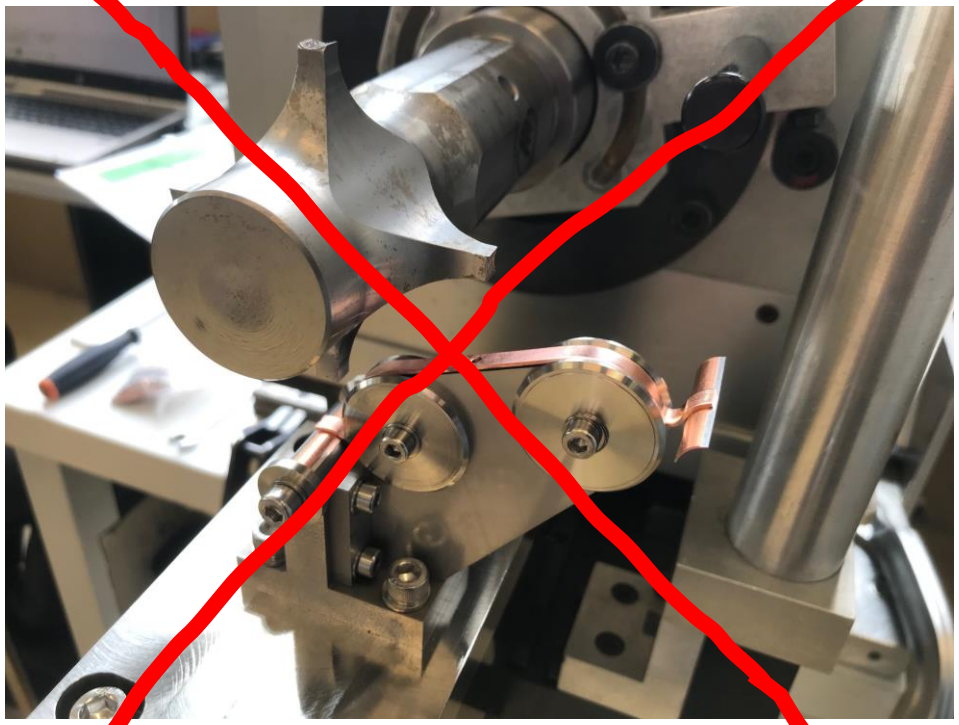
- Price enquiry issued in July 2019 was unsuccessful (one non-compliant offer and one offer 8 times over budget).
- Production of thermal links at CERN (~9500 pieces).



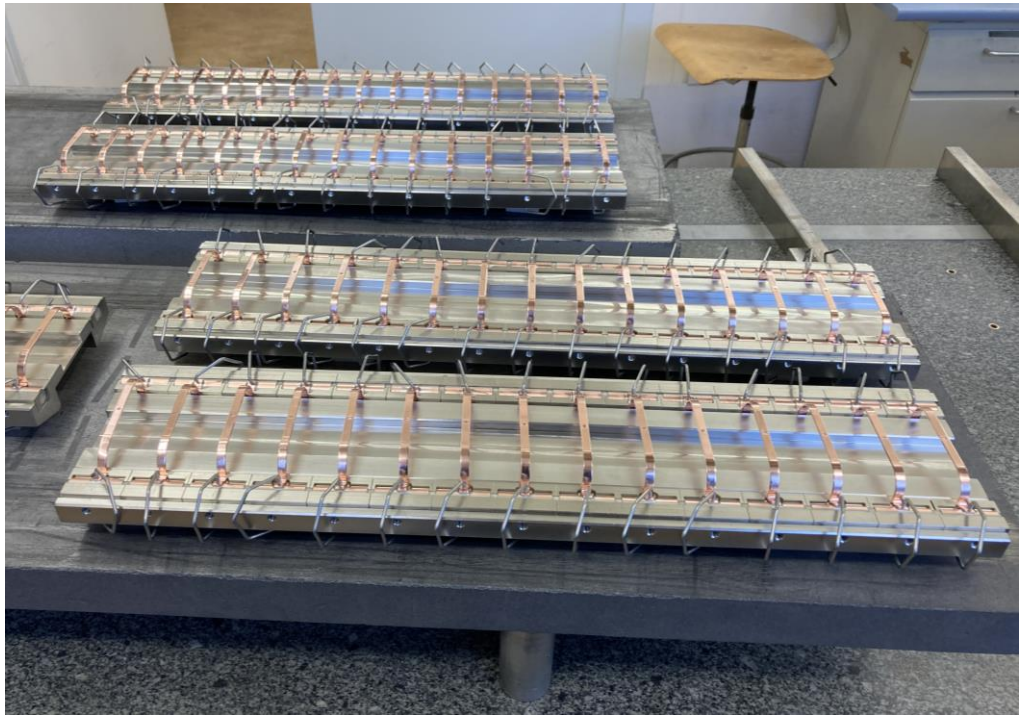


thermal link - 1) Interface plates, 2) Copper strip.

Assembly of thermal links by means of vacuum brazing



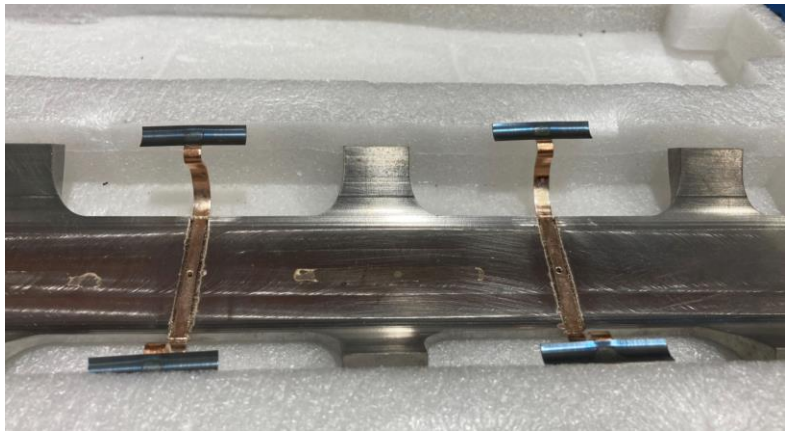
- US welding process developed at CERN.
- Mechanical strength of US weld reduced by a factor 3 following subsequent brazing treatment.

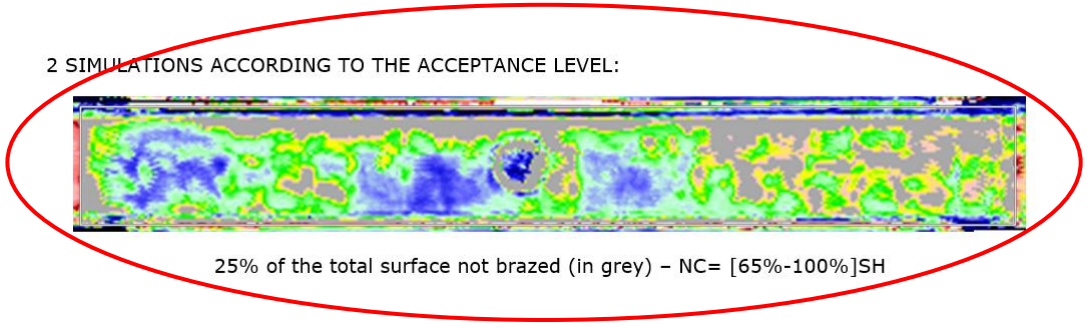


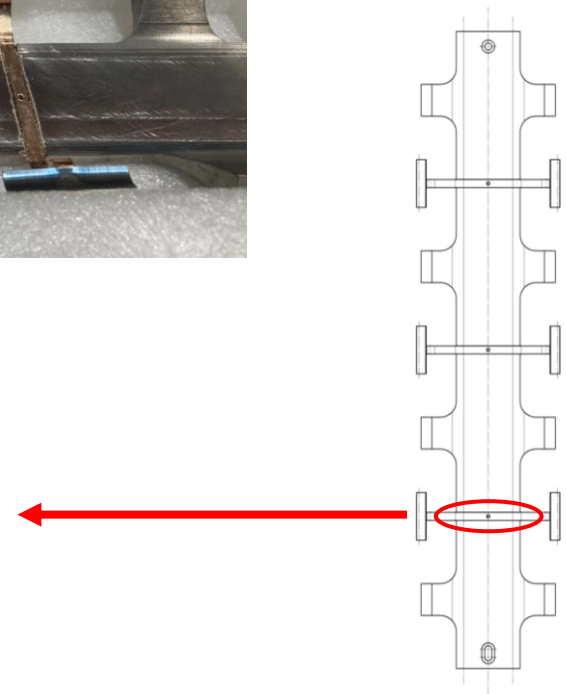
- Assembly by means of brazing with AgCu (790 C).
- Dedicated tooling to position the interface plates.
- Subsequent brazing to W blocks at AgCuIn (750 C).
- Production in progress (8500/9500).

Brazing of thermal links to W blocks

- Brazing of the thermal links to the tungsten absorber blocks was contracted to a UK firm following a competitive tender.
- The contract has been amicably terminated because the firm did not manage to produce acceptable results (blue-coloured oxidation of P506 interface plates, due to insufficient vacuum in combination with a low brazing temperature).
- The brazing process has been internalised at CERN.
- Production is in progress with 15% of the blocks equipped with their brazed thermal links.
- One block per brazing batch is US tested.

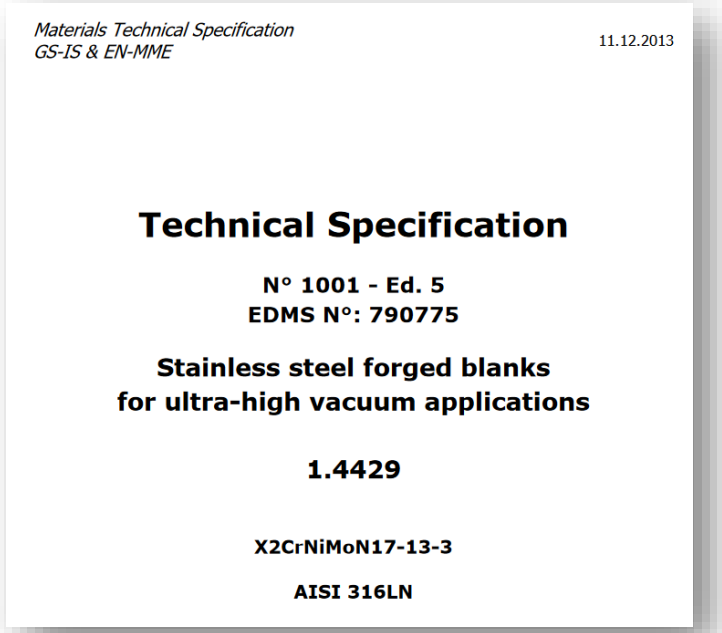






Components and materials from the CERN stores

- Vacuum flanges (ISO-KF, ISO-K and Conflat)
- Multi-directionally forged 316LN blanks for machining of UHV flanges, adaptors, etc.
- Forged 316LN bar
- 304L, 316L and 316LN sheet
- All materials are available with material certificate.
- Technical specifications regularly reviewed/updated by technical sub-committees of the CERN Standardisation Committee.



Materials Technical Specification
GS-IS & EN-MME

11.12.2013

Technical Specification

N° 1001 - Ed. 5
EDMS N°: 790775

Stainless steel forged blanks for ultra-high vacuum applications

1.4429

X2CrNiMoN17-13-3

AISI 316LN

Element	Chemical composition (product analysis) % by mass
Cr	16.00 – 18.50*
Ni	12.00 – 14.00*
C	0.030 max.
Si	1.00 max.
Mn	2.00 max.
Mo	2.00 – 3.00*
N	0.14 – 0.20*
P	0.030 max.*
S	0.010 max.*
Fe	Remainder

* CERN requirement

Special requirements: Cobalt shall be present only as a trace or to a maximum content of 0.10%, including measuring tolerance.

The nitrogen content 0.14% - 0.20% is imperative.

Content of impurity elements (P, S, B) shall reach the lowest achievable level.

Elements not listed in this table shall not be intentionally added to the steel without the agreement of CERN.

Traceability of components

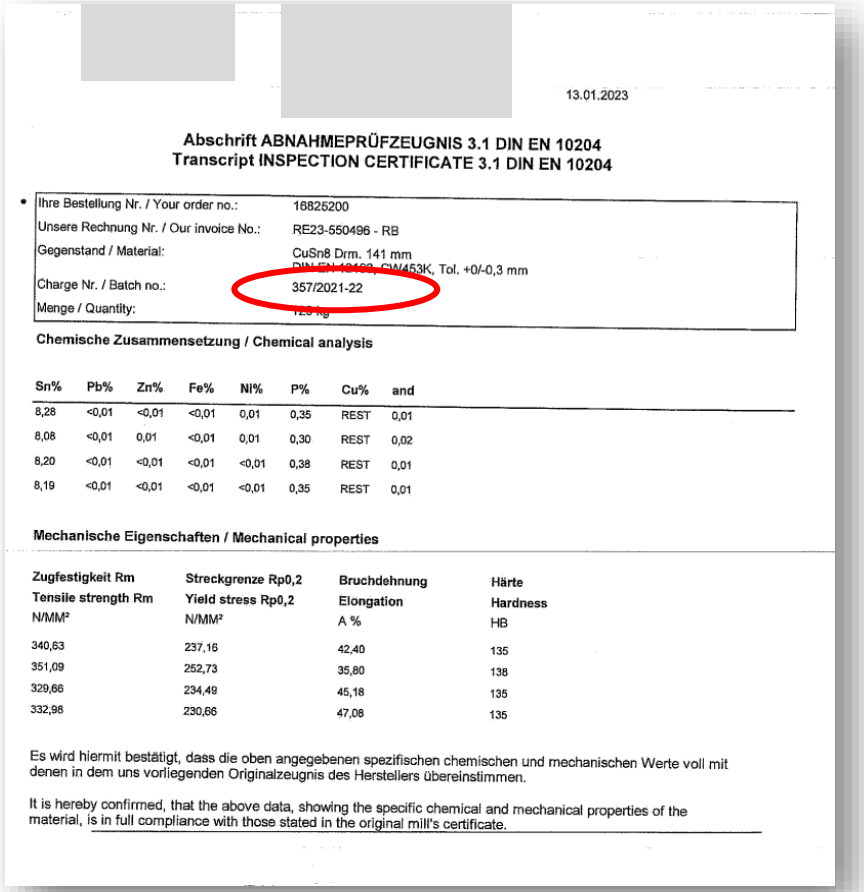
MTF (Manufacturing and Test Folder) is a database used to store all manufacturing data.

Parts can be identified in two ways:

- As an asset with a full part identifier communicated by CERN
  (in case of unique properties per component, e.g. individual leak test or geometrical measurement report)

Traceability of components

- As a batch (properties defined for the batch, rather than per component, e.g. material certificate)



13.01.2023

Abschrift ABNAHMEPRÜFZEUGNIS 3.1 DIN EN 10204
Transcript INSPECTION CERTIFICATE 3.1 DIN EN 10204

Ihre Bestellung Nr. / Your order no.:	16825200
Unsere Rechnung Nr. / Our invoice No.:	RE23-550496 - RB
Gegenstand / Material:	CuSn8 Drm. 141 mm DIN EN 12163, CW453K, Tol. +0/-0,3 mm
Charge Nr. / Batch no.:	357/2021-22
Menge / Quantity:	125 kg

Chemische Zusammensetzung / Chemical analysis

Sn%	Pb%	Zn%	Fe%	Ni%	P%	Cu%	and
8,28	<0,01	<0,01	<0,01	0,01	0,35	REST	0,01
8,08	<0,01	0,01	<0,01	0,01	0,30	REST	0,02
8,20	<0,01	<0,01	<0,01	<0,01	0,38	REST	0,01
8,19	<0,01	<0,01	<0,01	<0,01	0,35	REST	0,01

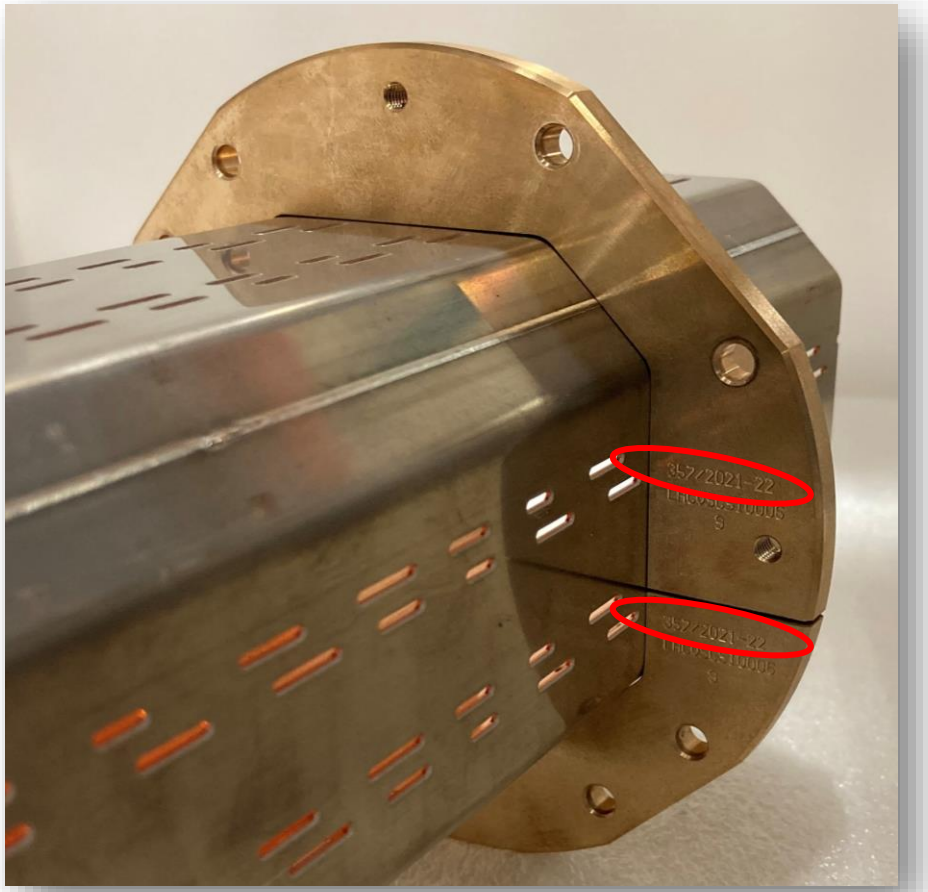
Mechanische Eigenschaften / Mechanical properties

Zugfestigkeit Rm Tensile strength Rm N/MM²	Streckgrenze Rp0,2 Yield stress Rp0,2 N/MM²	Bruchdehnung Elongation A %	Härte Hardness HB
340,63	237,16	42,40	135
351,09	252,73	35,80	138
329,66	234,49	45,18	135
332,98	230,66	47,08	135

Es wird hiermit bestätigt, dass die oben angegebenen spezifischen chemischen und mechanischen Werte voll mit denen in dem uns vorliegenden Originalzeugnis des Herstellers übereinstimmen.

It is hereby confirmed, that the above data, showing the specific chemical and mechanical properties of the material, is in full compliance with those stated in the original mill's certificate.

Material certificate provided by the firm (EN10204 type 3.1)



The firm engraves the component with the agreed material identifier *(example from Denmark).*

Traceability of components

- As a batch (properties defined for the batch, rather than per component, e.g. material certificate)

Raw material provided by CERN
The firm copies the raw material number onto the machined part *(examples from Denmark).*

Summary of CERN purchasing rules

Requests up to 5 kCHF (39’000 DKK)
- 1 written bid by Technical Officer
- Purchase Requisition (DAI)
- Validated by Procurement Officer

Requests between 5 and 10 kCHF (39’000 - 77000 DKK)
- Price enquiry by Technical Officer or Procurement Officer
- Minimum of 3 bids requested
- Purchase Requisition (DAI) made to the lowest compliant bidder

Requests between 10 and 200 kCHF (77’000 – 1’500’000 DKK)
- Technical specification provided by Technical Officer
- Price enquiry made by Procurement Officer (4 weeks)
- 3 to 5 bids requested
- Purchase Requisition (DAI) made to the lowest compliant bidder

Requests between 200 and 750 kCHF (1’500’000 – 5’800’000 DKK)
- Market Survey followed by Invitation to Tender (minimum 6 months)

Requests above 750 kCHF (5’800’000 DKK)
- Market Survey followed by Invitation to Tender
- Finance Committee approval (4 times per year)

Industrial Returns for CERN Member States

For Supply contracts between 01.03.2023 until 29.02.2024

Well Balanced

- Austria
- Estonia*
- France
- Hungary
- Italy
- Lithuania*
- Switzerland
- Turkey*

Poorly Balanced

- Belgium
- Croatia*
- Cyprus*
- Czech Republic
- Finland
- Germany
- Greece
- Latvia*
- Netherlands
- Norway
- Pakistan*
- Poland
- Portugal
- Romania
- Serbia
- Slovak Republic
- Slovenia*
- Spain
- Sweden
- United Kingdom

Very Poorly Balanced

- Bulgaria
- Denmark
- India*
- Israel
- Ukraine*

The **return coefficient** of a Member State is defined as the ratio between that Member State's percentage share of the value of all Supply contracts and that Member State's percentage contribution to the CERN Budget over the same period.

A Member State is defined as **very poorly balanced** if its return coefficient for Supply contracts falls below 0.40, **poorly balanced** if its return coefficient for Supply contracts falls below 1.00 and **well balanced** if it is equal or greater than that value.

The **country of origin** is the country where the supplies (including their components and sub-assemblies) are manufactured or undergo the last major transformation by the contractor or his sub-contractor(s).

Promotion of procurement in (very) poorly balanced member states

- **Limited tendering**
  - Only firms in one or more very poorly balanced member states (and their ILO's) are contacted / invited to tender.

- **Alignment rule (for Invitations to tender >100 kCHF)**
  - If the lowest compliant bid is from a firm in a (very) poorly balanced member state, the firm is awarded the contract.
  - If the lowest compliant bid is from a firm in a well-balanced member state, and the 2nd lowest compliant bid is from a firm in a (very) poorly balanced member state AND within 20% of the lowest compliant bid, the 2nd lowest bidder is invited to align its price with the lowest bid and be awarded the contract.

    Example:

    Lowest compliant bid from a Swiss firm at 200 kCHF.

    2nd lowest compliant bid from a Danish firm at 216 kCHF (Δ=8%).

    If the Danish firm agrees to reduce its price to 200 kCHF, it will be awarded the contract.

Summary

- Many accelerator components have specific requirements (Co-content, magnetic susceptibility, helium leak tightness., etc.). This complicates production ☹ but reduces competition ☺.
- HL-LHC vacuum components are in principle procured from member state firms. If there's no interest, if the price is prohibitive or if the firm is unsuccessful, production is insourced.
- CERN intends to purchase from all its member states and has mechanisms in place to promote this.
- Denmark is currently classed as "very poorly balanced". This is an issue for the Danish delegation to CERN but an advantage for Danish firms.