Magnet and related technologies workshop for industry and CERN experts,
7-8 June 2006

Material development issues

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Outline

1. Evolution of materials and manufacturing technologies, core of future developments

2. Examples from present projects (LHC) and future developments (CMS conductor, CLIC)

    a) End covers and beam screens of the LHC magnets
    b) Toward an improved high strength, high RRR CMS conductor
    c) Bimetals for CLIC

⇒ Developments through

Selection, specification, definition or design of materials
Extensive use of frontier technologies (near net shaping, HIP-assisted diffusion or explosion bonding…)

3. Conclusions

LHC DIPOLE : STANDARD CROSS-SECTION

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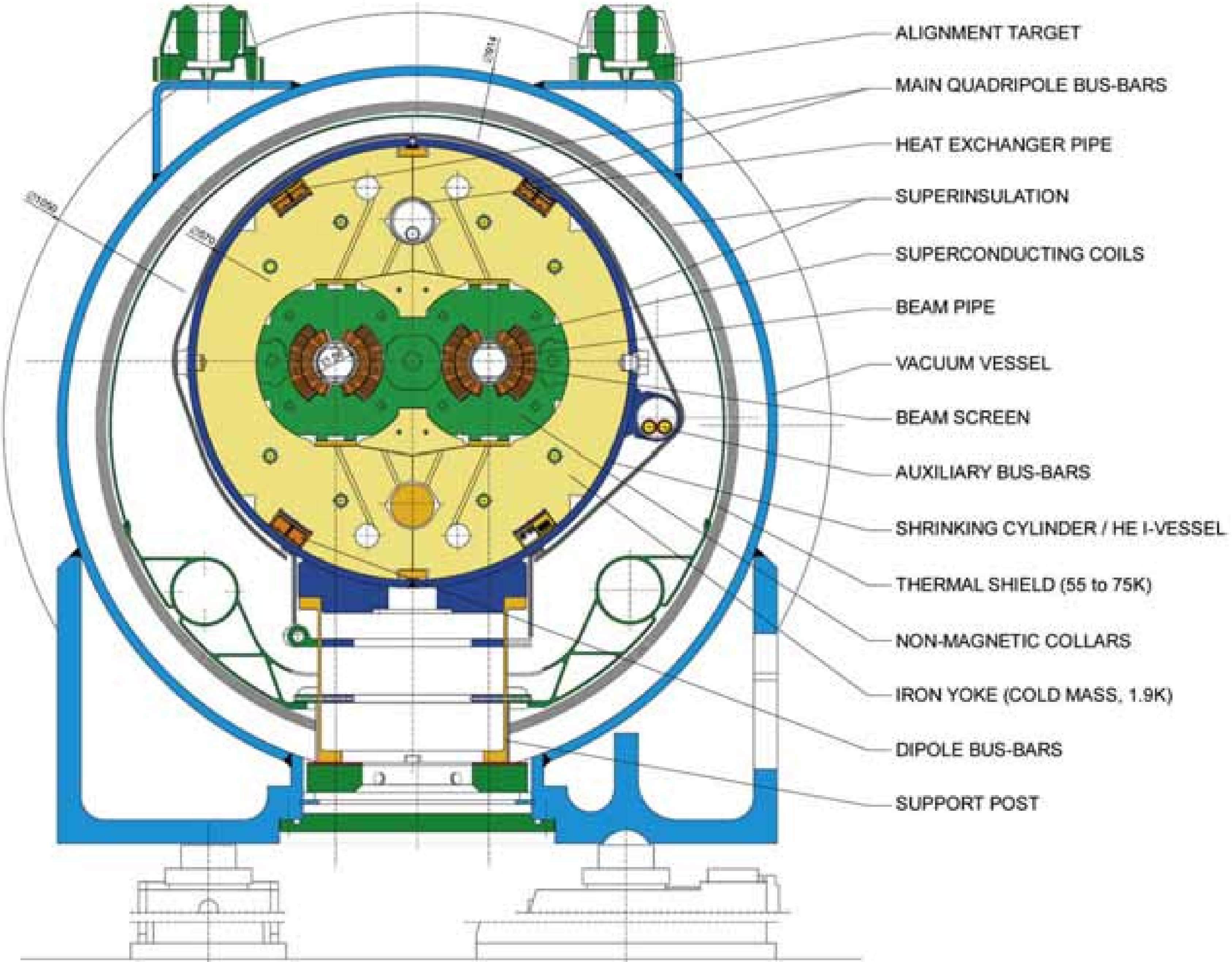


ALIGNMENT TARGET

MAIN QUADRIPOLE BUS-BARS

HEAT EXCHANGER PIPE

SUPERINSULATION

SUPERCONDUCTING COILS

BEAM PIPE

VACUUM VESSEL

BEAM SCREEN

AUXILIARY BUS-BARS

SHRINKING CYLINDER / HE I-VESSEL

THERMAL SHIELD (55 to 75K)

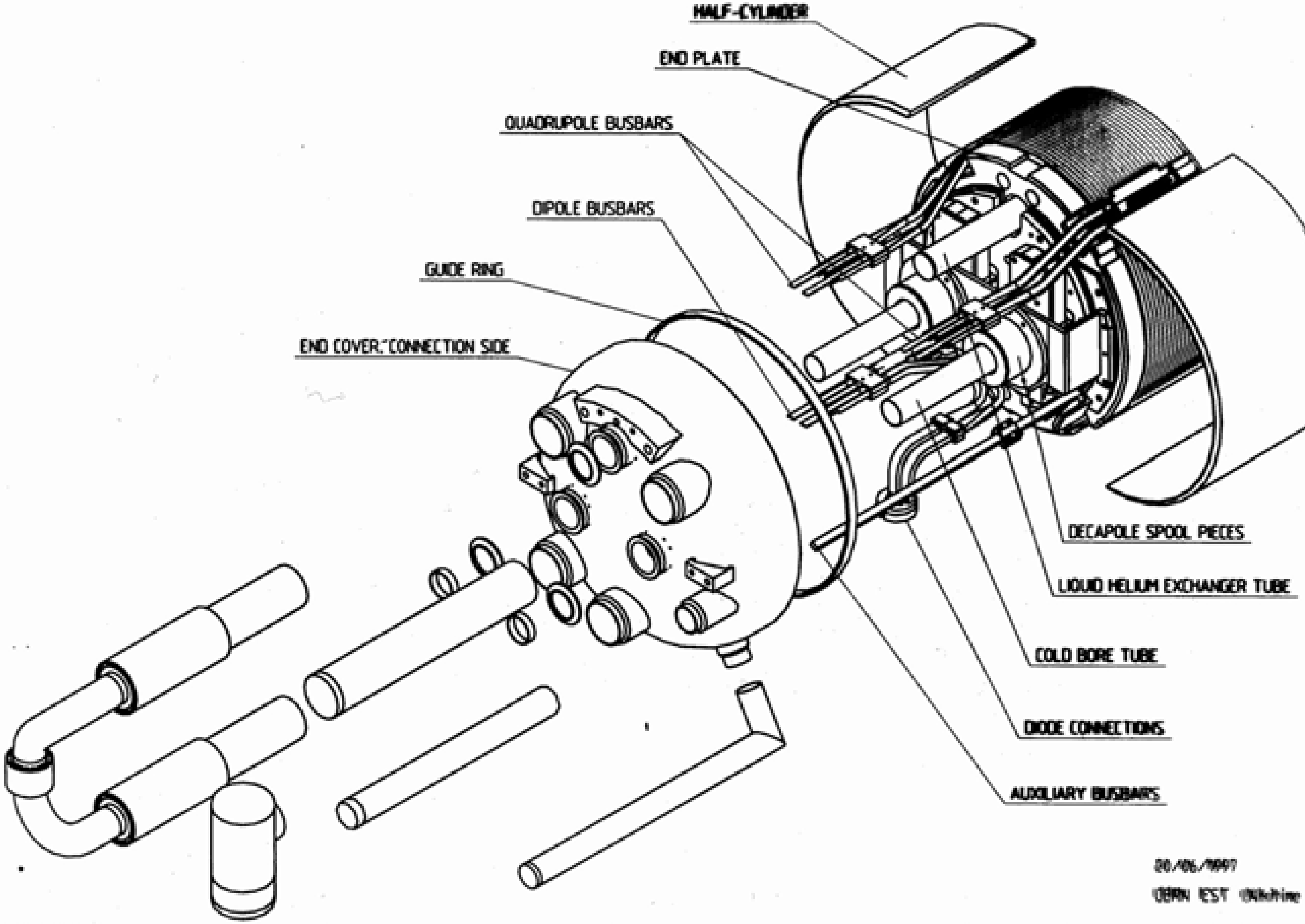
NON-MAGNETIC COLLARS

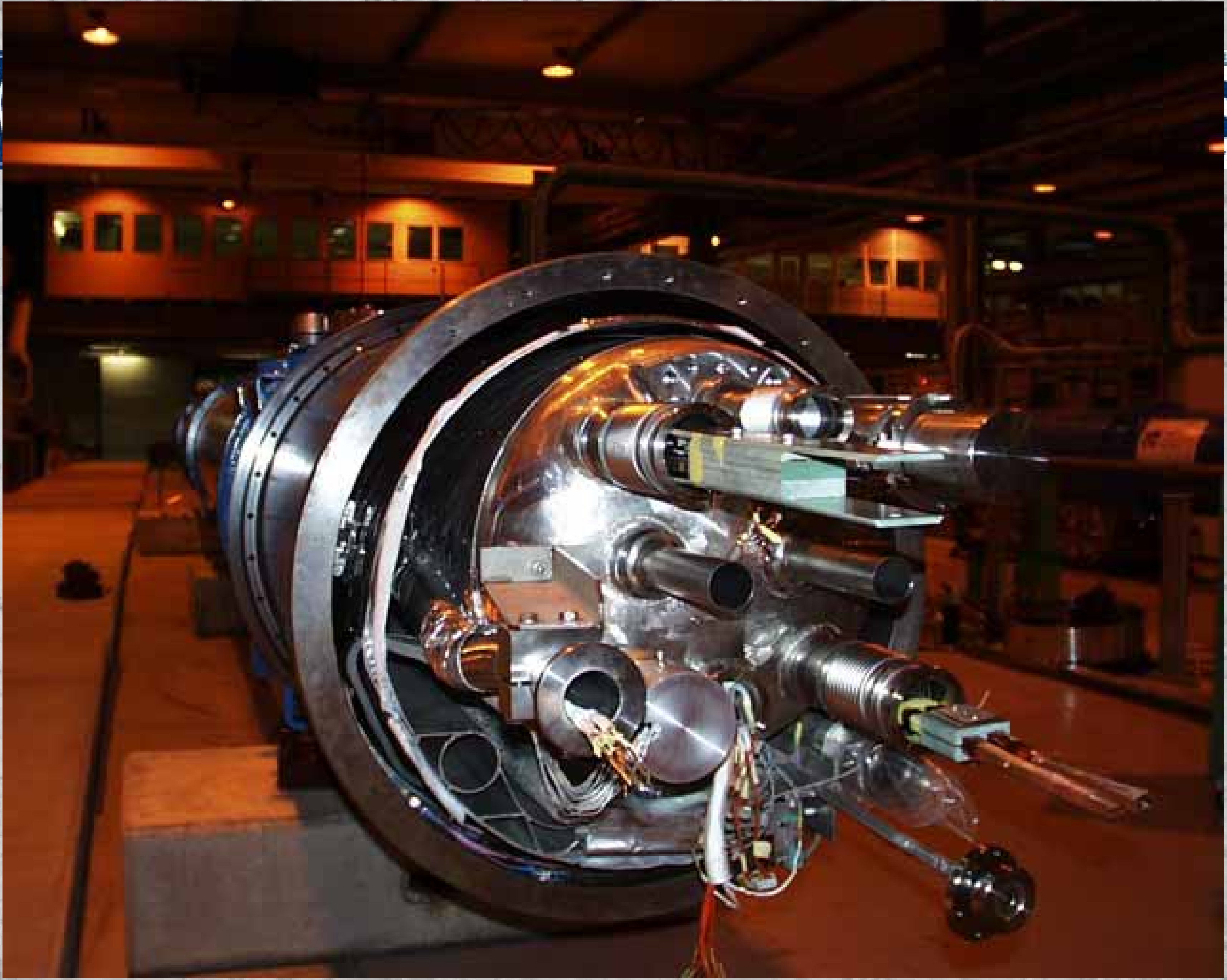
IRON YOKE (COLD MASS, 1.9K)

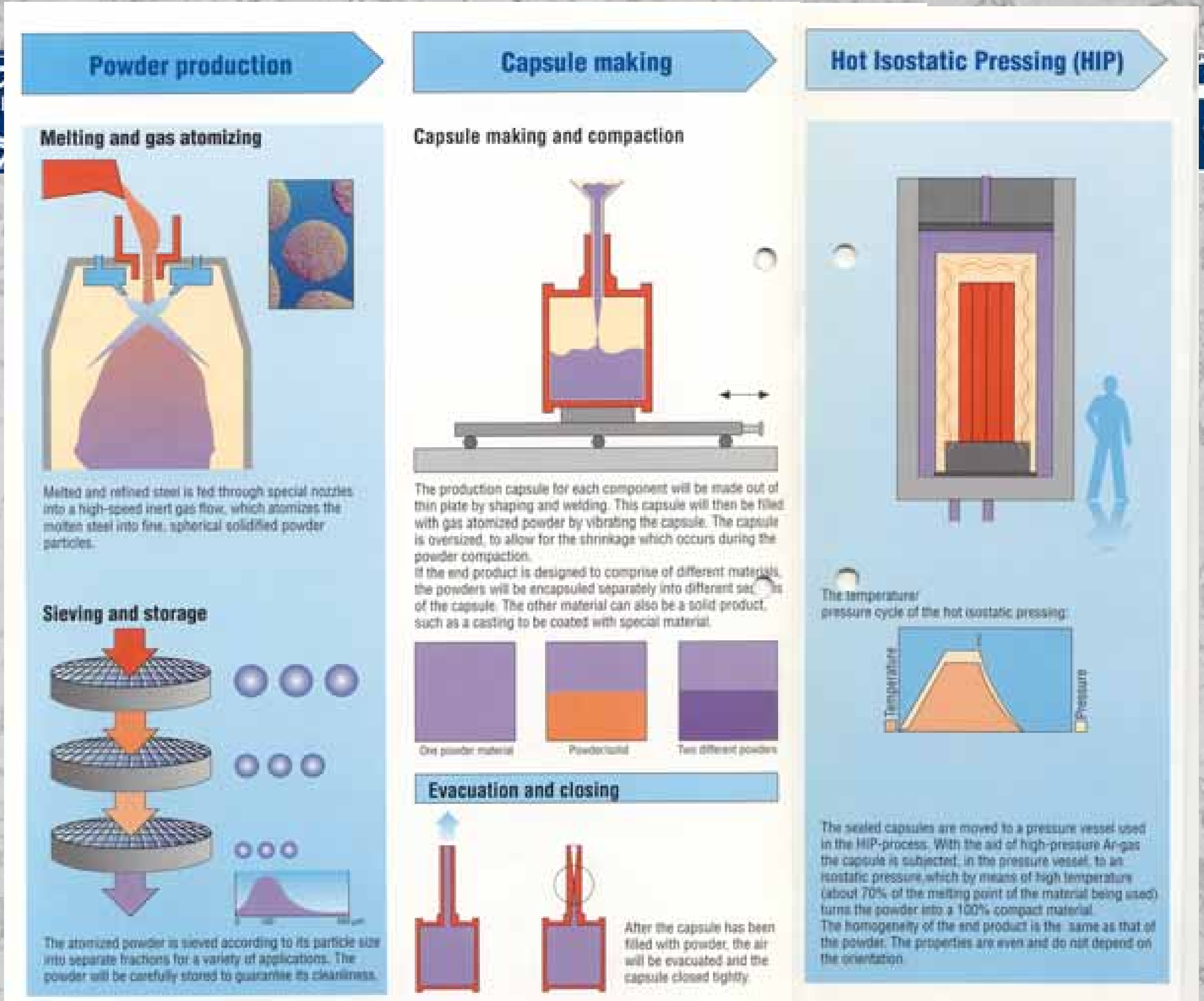
DIPOLE BUS-BARS

SUPPORT POST

END COVER AND DIPOLE. CONNECTION SIDE







Powder production

Melting and gas atomizing

Melted and refined steel is fed through special nozzles into a high-speed inert gas flow, which atomizes the molten steel into fine, spherical solidified powder particles.

Sieving and storage

The atomized powder is sieved according to its particle size into separate fractions for a variety of applications. The powder will be carefully stored to guarantee its cleanliness.

Capsule making

Capsule making and compaction

The production capsule for each component will be made out of thin plate by shaping and welding. This capsule will then be filled with gas atomized powder by vibrating the capsule. The capsule is oversized, to allow for the shrinkage which occurs during the powder compaction.
If the end product is designed to comprise of different materials, the powders will be encapsuled separately into different sec[illegible] of the capsule. The other material can also be a solid product, such as a casting to be coated with special material.

Evacuation and closing

After the capsule has been filled with powder, the air will be evacuated and the capsule closed tightly.

Hot Isostatic Pressing (HIP)

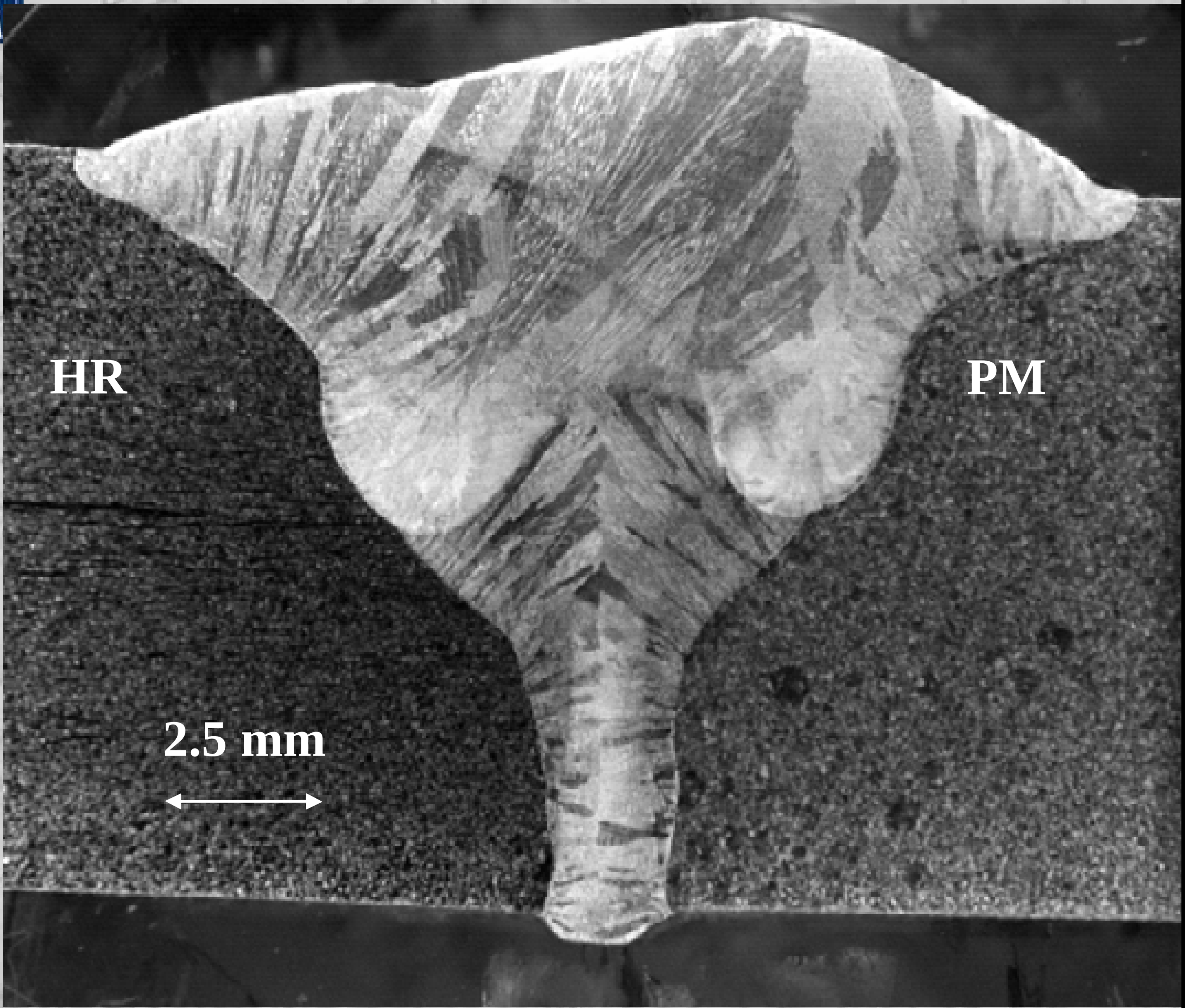
The temperature
pressure cycle of the hot isostatic pressing:

The sealed capsules are moved to a pressure vessel used in the HIP-process. With the aid of high-pressure Ar-gas the capsule is subjected, in the pressure vessel, to an isostatic pressure which by means of high temperature (about 70% of the melting point of the material being used) turns the powder into a 100% compact material.
The homogeneity of the end product is the same as that of the powder. The properties are even and do not depend on the orientation.

HIPed AISI 316LN end covers for CERN LHC project (courtesy of Metso)

After capsule removal by pickling and heat treatment, before machining

PM 316LN, circular MIG weld



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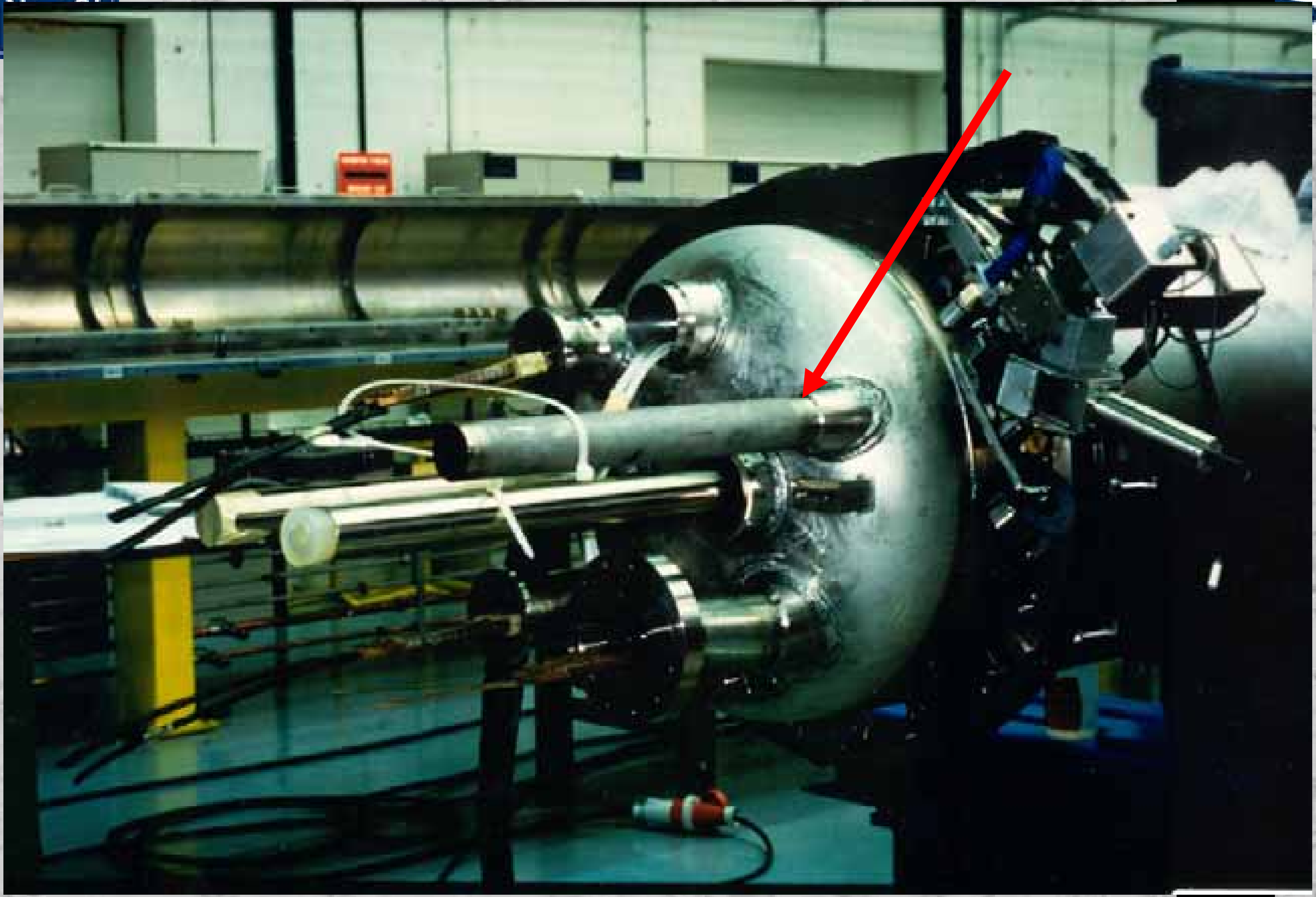
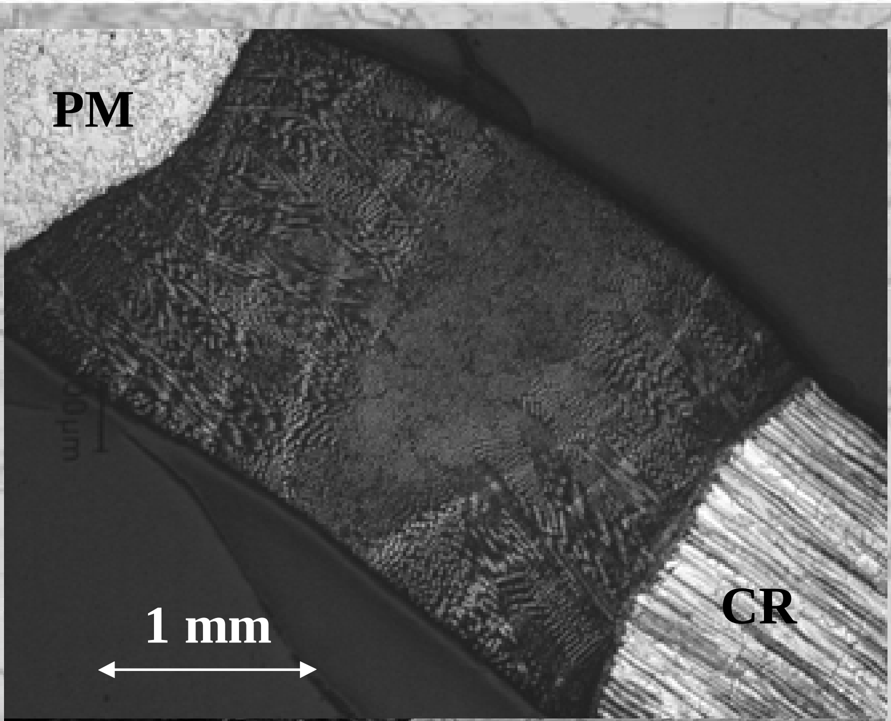
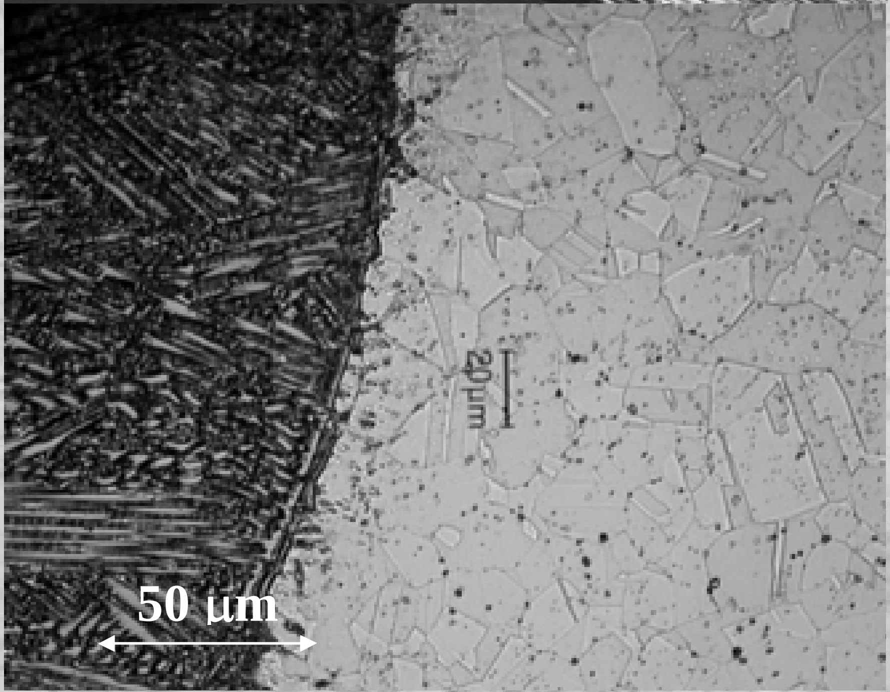
316LN, orbital TIG weld



PM 316LN, orbital TIG weld





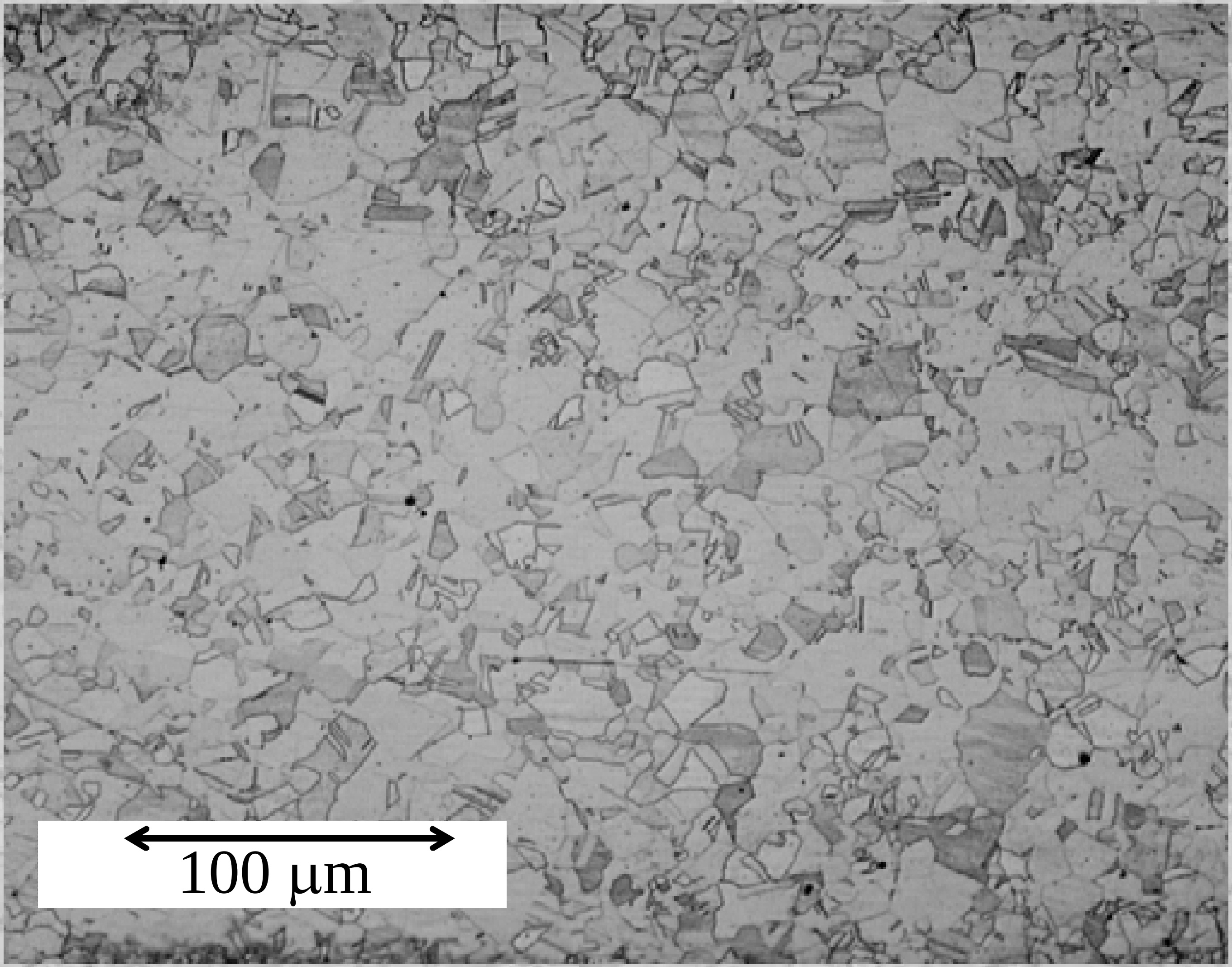
Welding details :			
Travel speed:	1.5E-02m/s	Arc length:	1.5E-03m
Peak current:	68 A	Tip angle	45°
Base current:	32 A	Gas flux and flow rate:	
Peak time:	0.2 s	Shielding:	Ar, 1/6 l/s
Base time:	0.2 s	Backing:	Ar, 1/12 l/s

HIPed PM 316LN		Metso	CERN Specification	
		H 6277	*Min.*	*Max.*
Composition (w%)	C	**0.017**		0.030
	Si	**0.59**		1.00
	Mn	**0.71**		2.00
	S	**0.005**		0.015
	P	**0.012**		0.040
	Ni	**13.07**	12.00	14.00
	Cr	**16.98**	16.00	18.00
	Mo	**2.53**	2.00	3.00
	O	**0.011**		
	N	**0.185**	0.15	0.20

Typical Oxygen levels

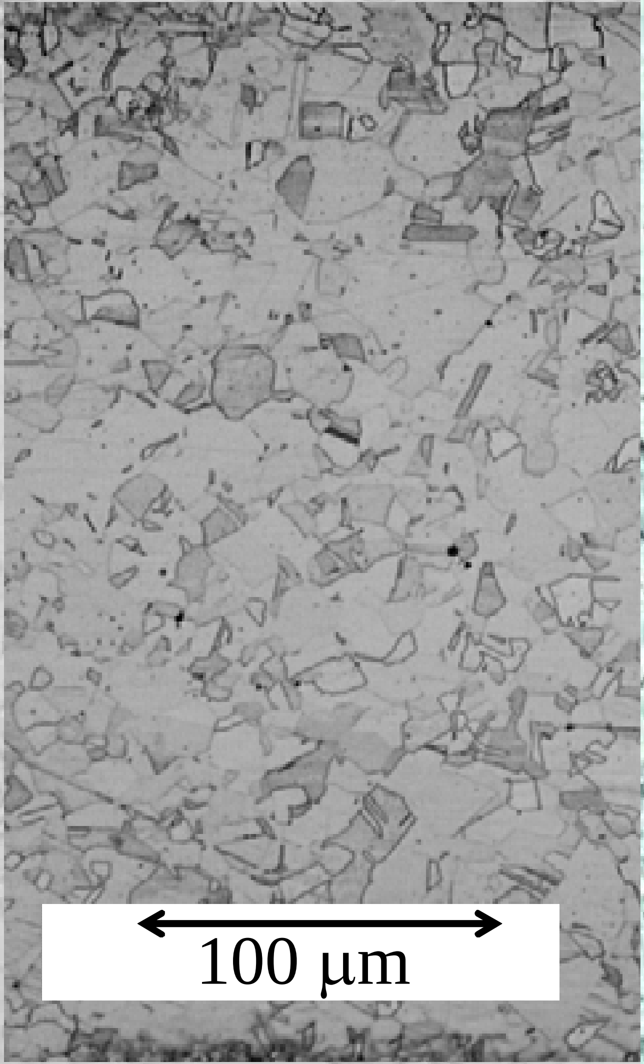
in 316LN:	Couturier et al. (1998)	**200 ppm**
	Dellis et al. (1996)	**195 ppm**
in 304L:	Appa Rao and Kumar. (1997)	**400 ppm**
in aust. SS	Zou and Grinder (1982)	**300 to 4500 ppm**
in 304L	Dunkley (1981)	**1200 to 7800 ppm**

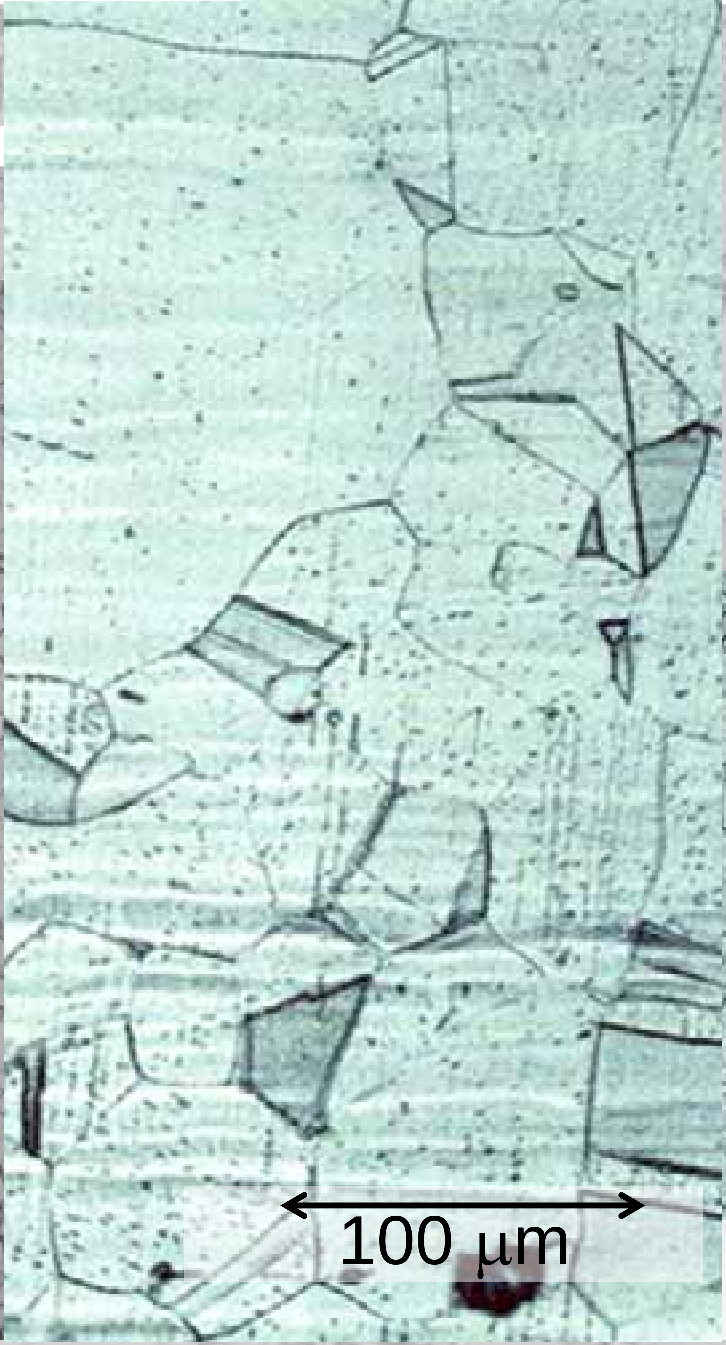
Microstructure



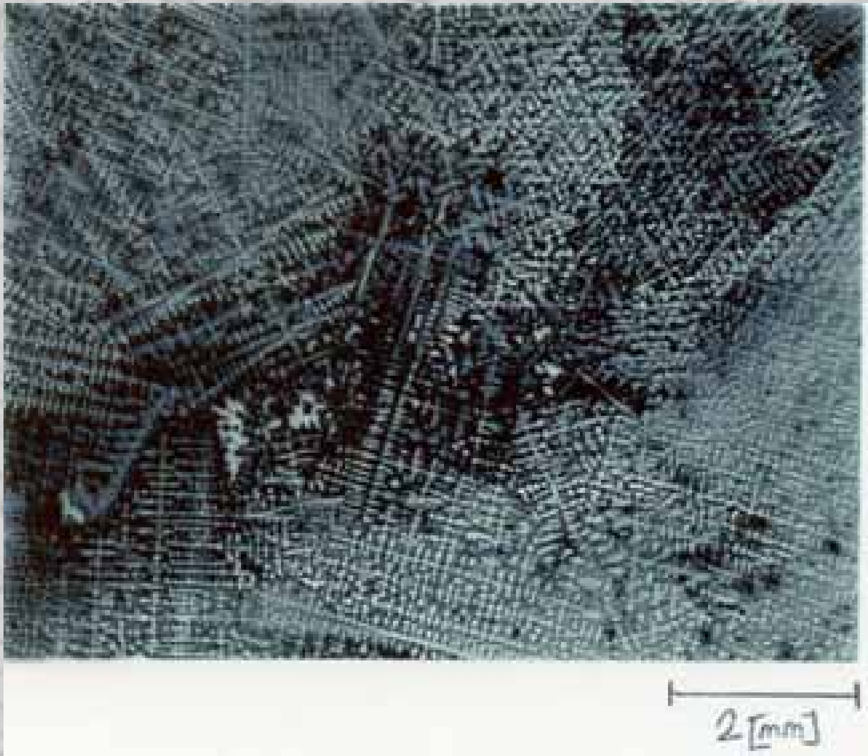
PM 316 LN – Metso, Grain size according to ASTM E112: N° 6 to 7

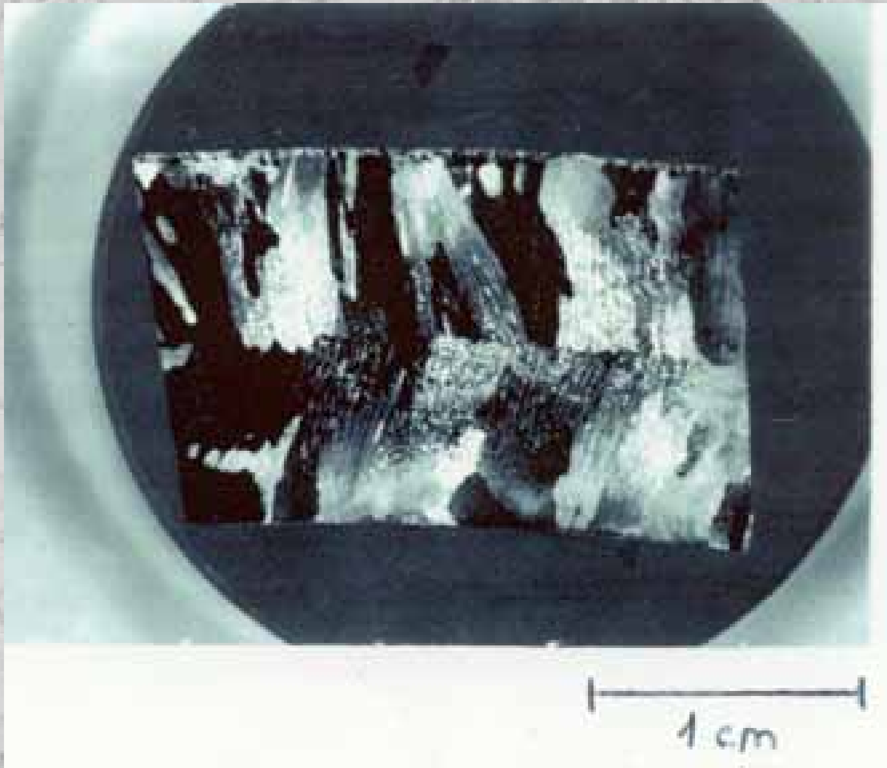
Microstr 1:





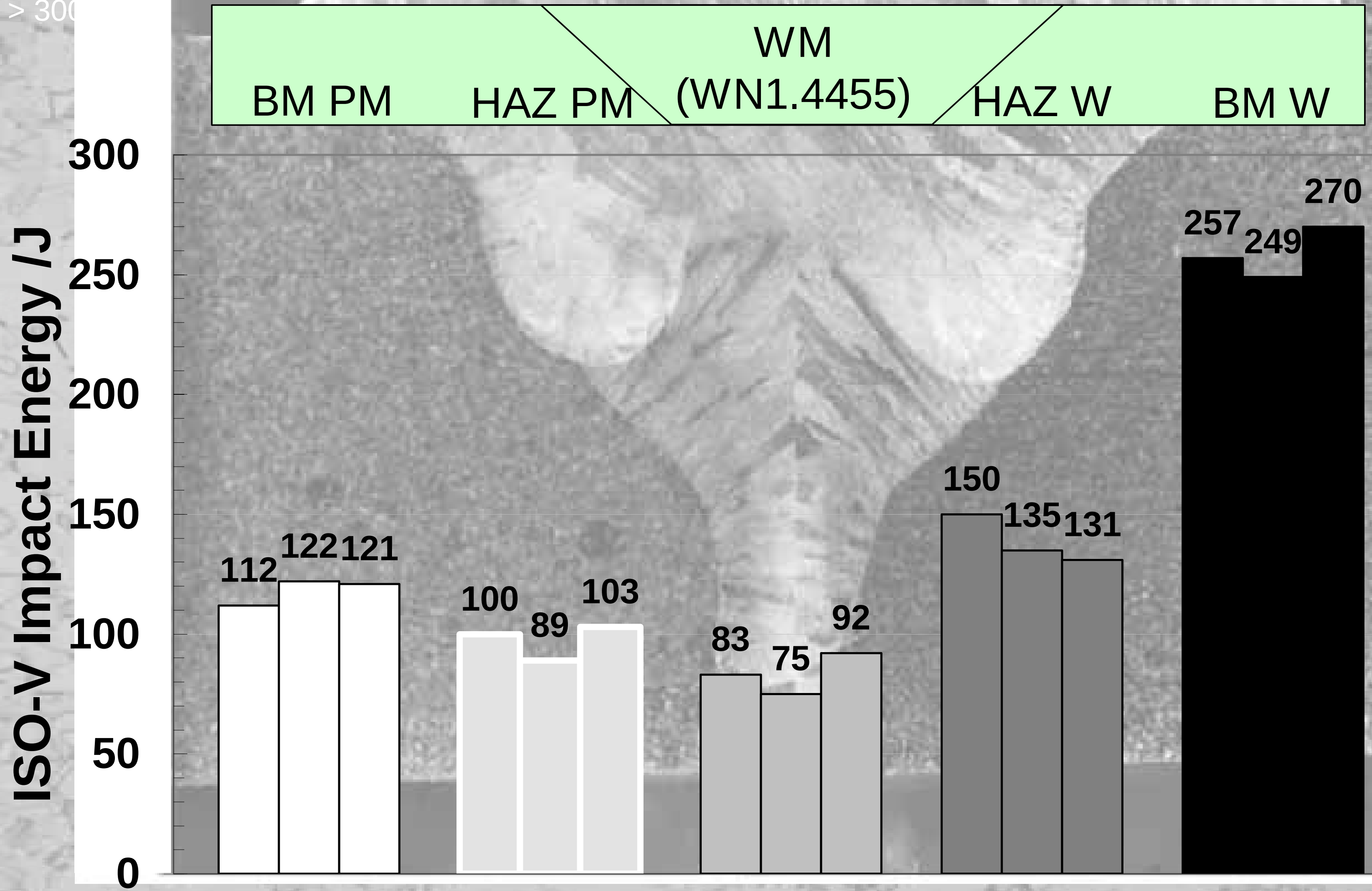
Microstructure, comparison 2: cast





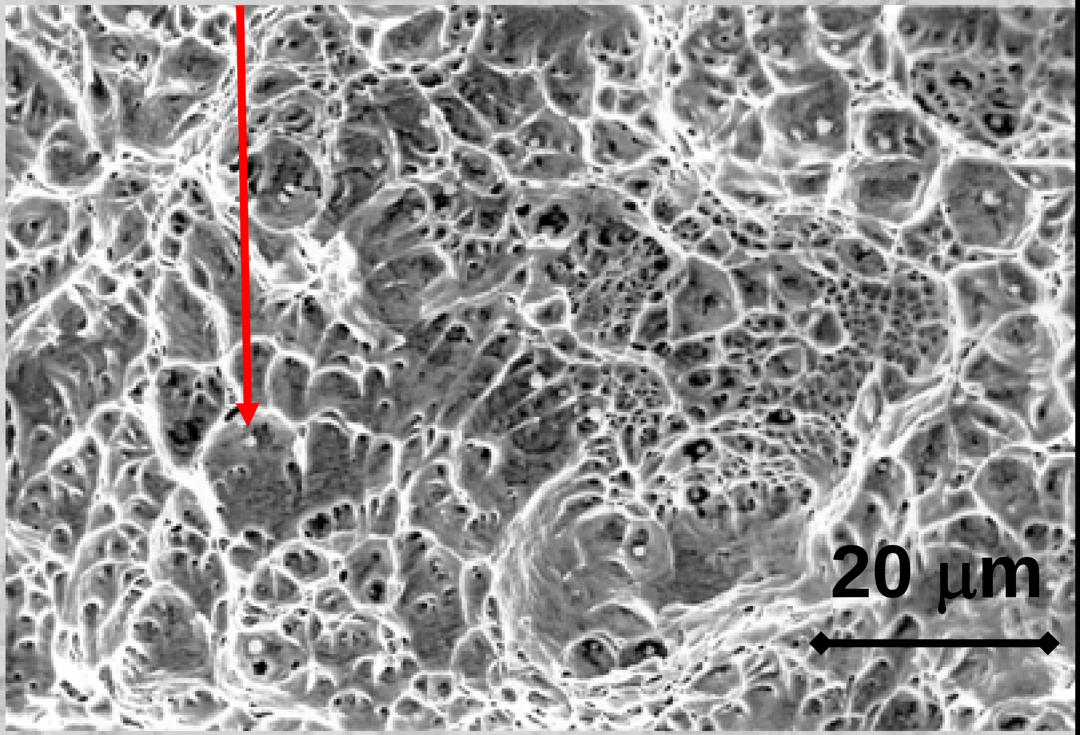
ISO-V impact energy at 4.2 K

> 30



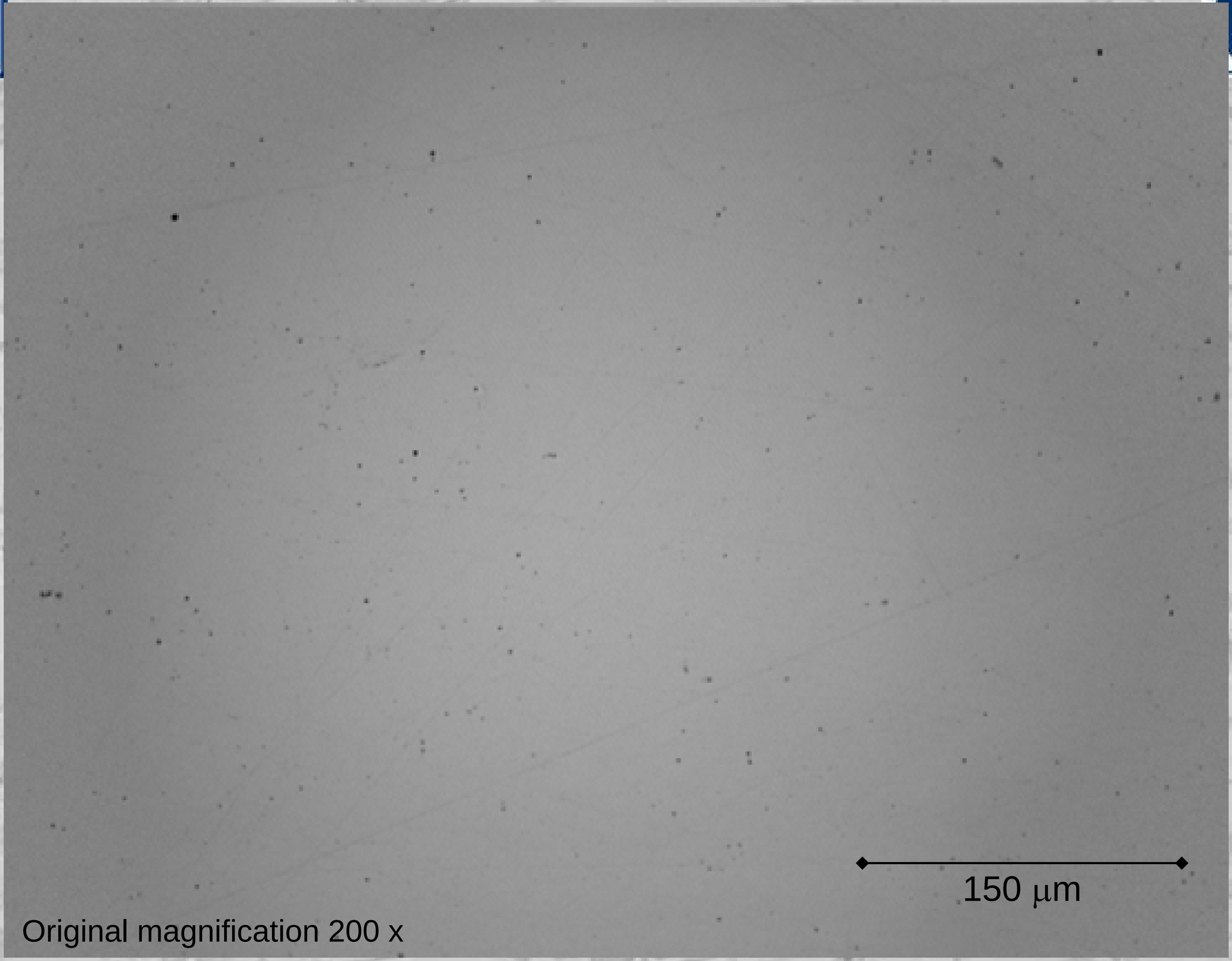
Fractographic analysis

Oxides within dimples



Localized ductility (Couturier 99)

Inclusions



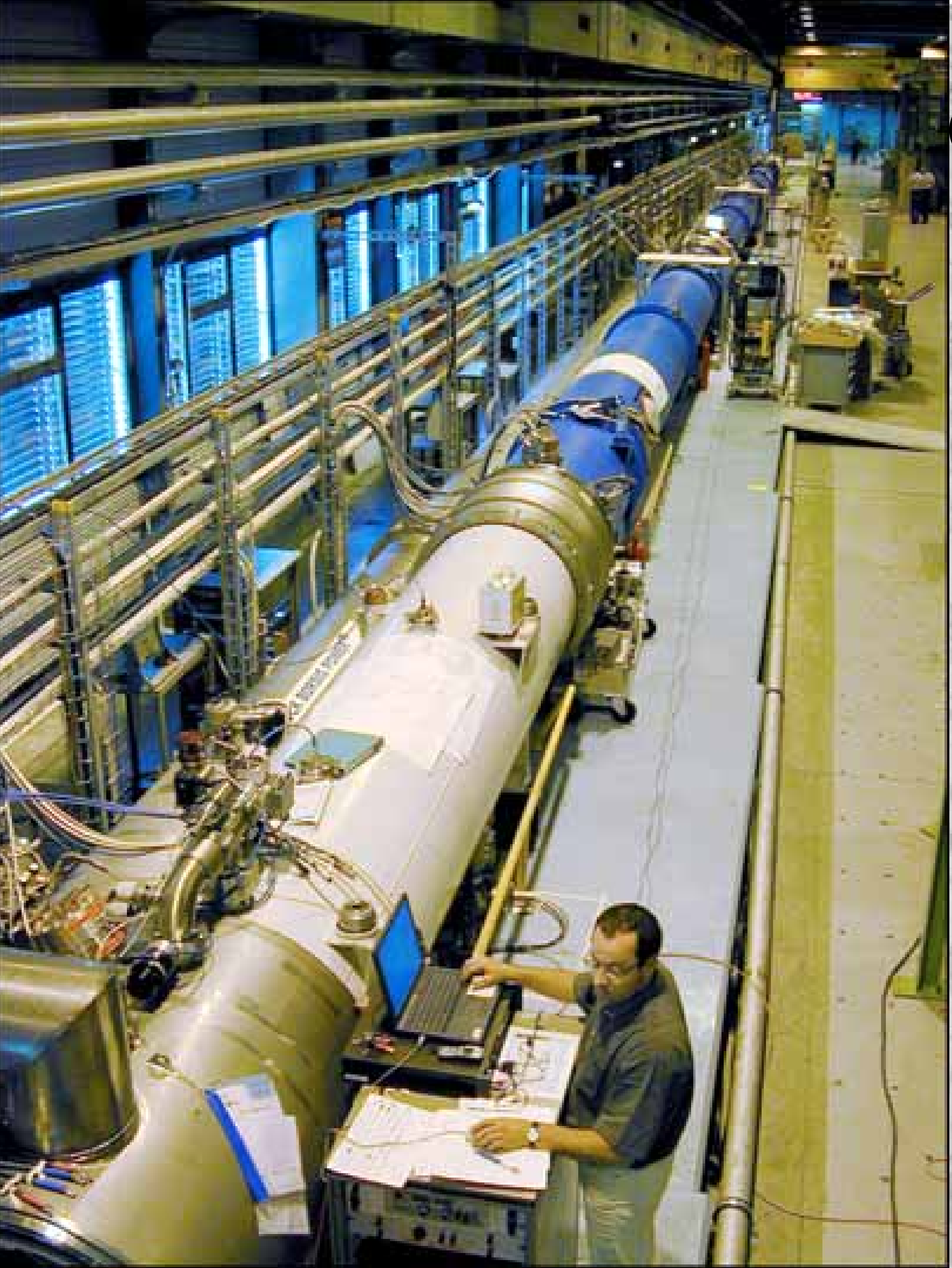
Mainly globular-type

Magnet end covers

Compared advantages of possible fabrication techniques

	welded	*closed die forged*	*cast*	*PM*
Microstructure	-	++	-	++
Tensile properties	+	+	-	++
Impact toughness at 4.2 K	+	++	+	+
Near net shaping	++	--	+	++
Reliability, NDT	--	++	--	++
Competitiviness, small series (tools)	+	--	+	+
Competitiviness, large series (tools)	+	+	+	+

ons



- Two dipole magnets equipped with PM covers operated for several years in the “string”
- Price competitive

LHC DIPOLE : STANDARD CROSS-SECTION

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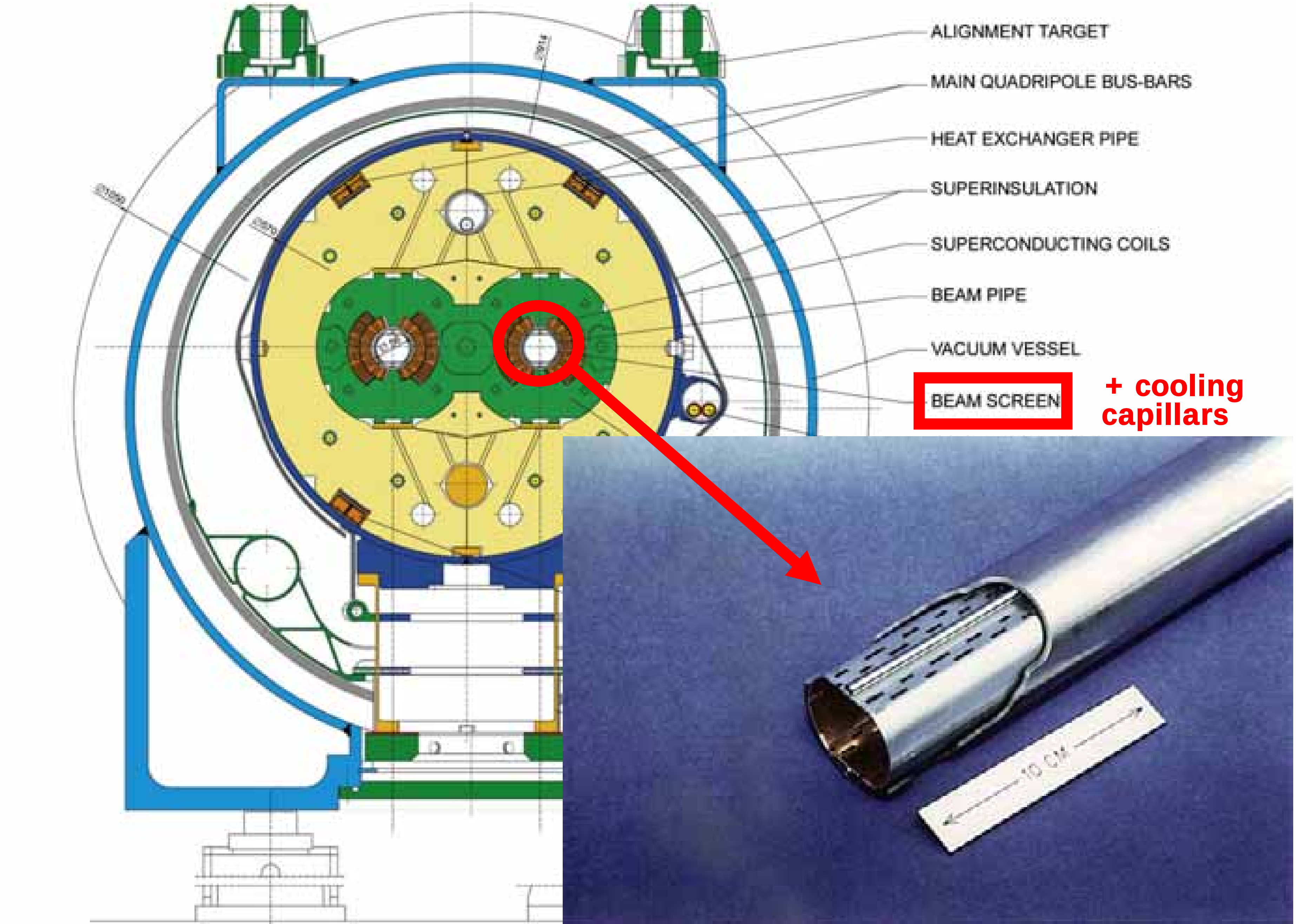

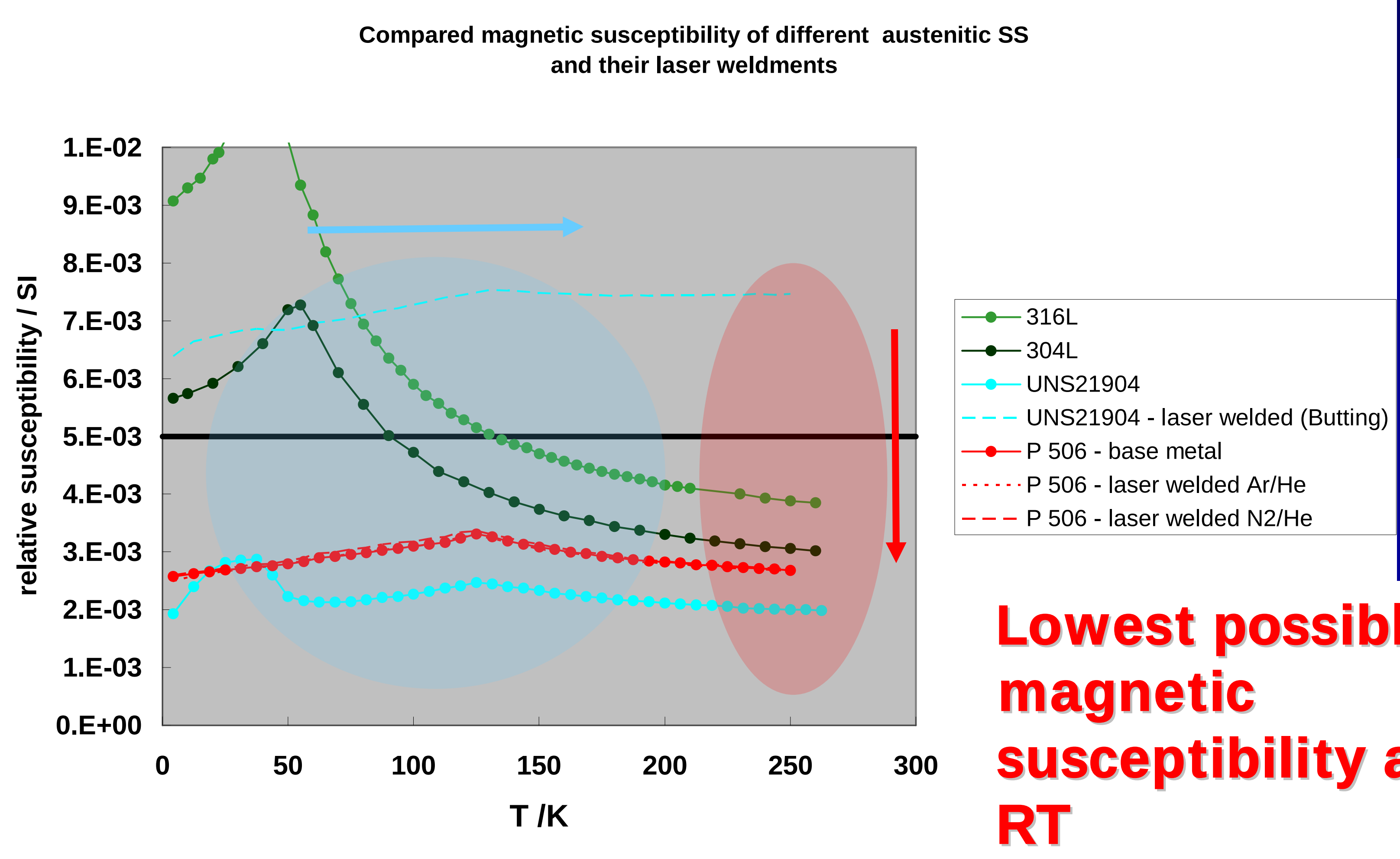

Lowest possible magnetic susceptibility at RT

Highest possible temperature of antiferromagnetic transition

Toward an Improved High Strength, High RRR CMS Conductor

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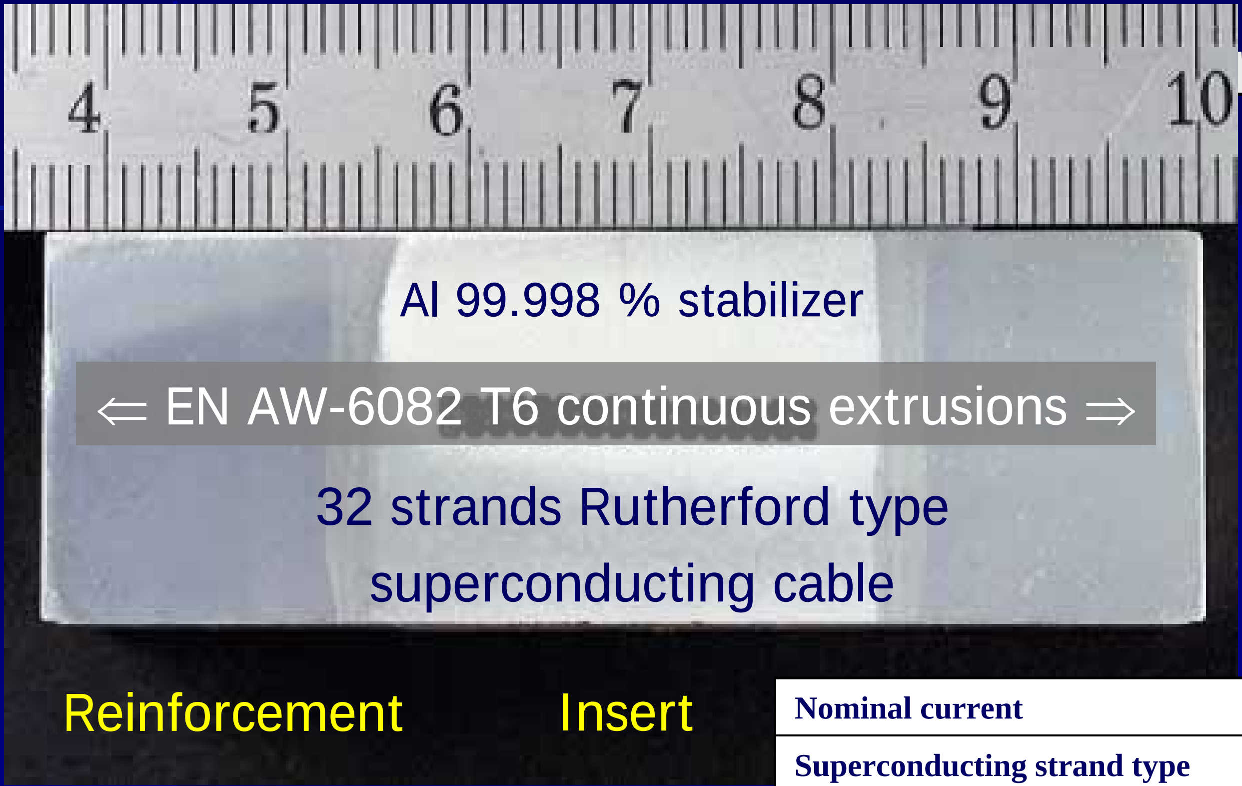


Al 99.998 % stabilizer

⇐ EN AW-6082 T6 continuous extrusions ⇒

32 strands Rutherford type superconducting cable

Reinforcement

Insert

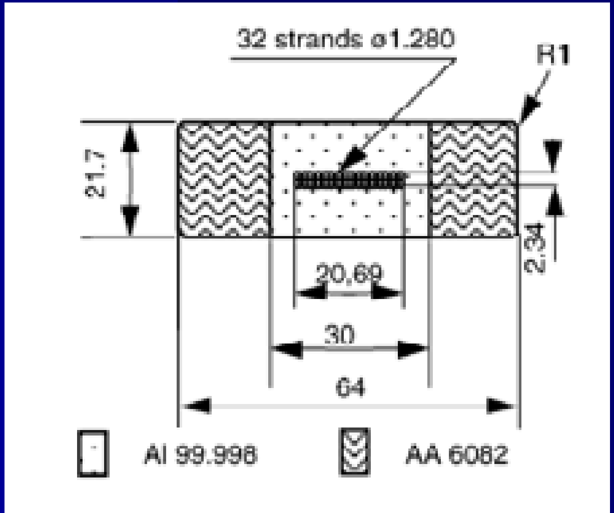


Fig. 1. Cross-section of the conductor

Nominal current	**20 kA**
Superconducting strand type	**NbTi- Cu stabilized**
Strand Cu/SC ratio	**1.1**
Number of strands	**32**
Strand diameter	**1.28 mm**
Rutherford cable cross section	**20.68 mm x 2.34 mm**
Insert cross section	**30 mm x 21.6 mm**
High Purity Aluminum stabilizer	**Al 99.998 %**
RRR aluminum at 0 T, annealed	**> 1500**
Reinforcement material	**EN AW-6082**
Conductor cross section	**64 mm x 21.6 mm**
Quantity produced	**21 lengths x 2600 m**

Toward an improved conductor, material selection

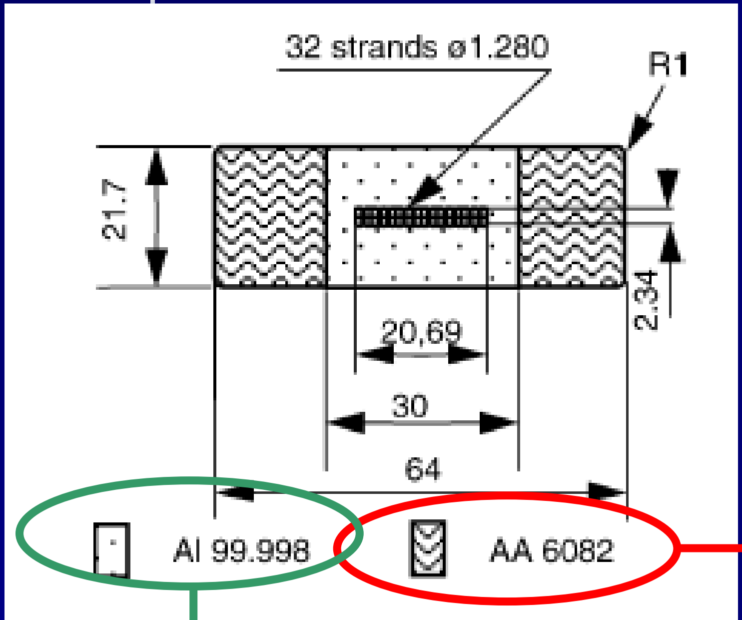


Fig. 1. Cross-section of the conductor.

Replace by:

- a higher strength Al-alloy
- extrudable
- weldable
- compatible with a cryogenic application
- maintaining high ductility and strength at 4.2 K
- even after a curing cycle

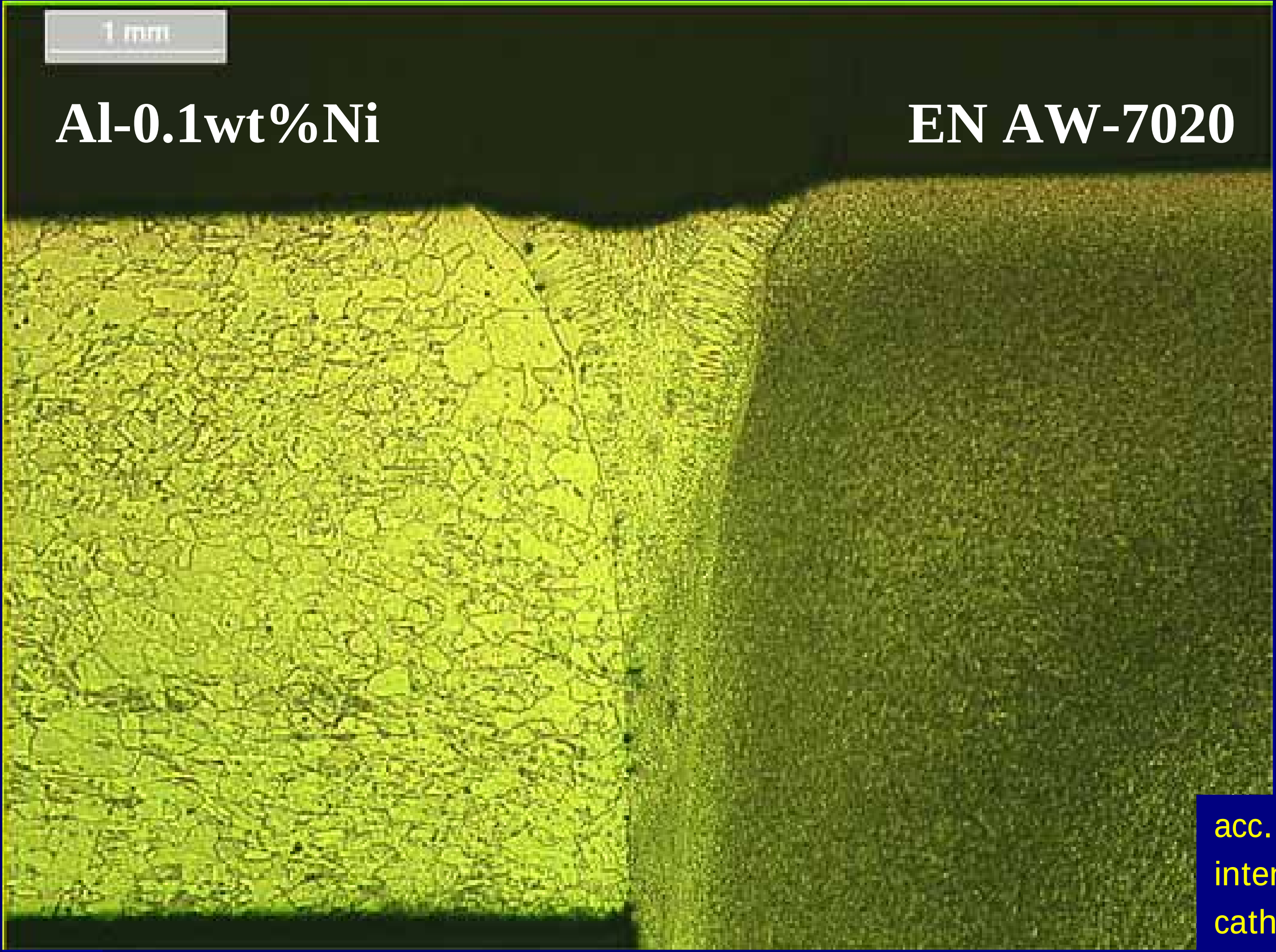
Replace by:

- cold drawn Al-0.1wt%Ni alloy
- developed for the ATLAS thin solenoid superconductor (A. Yamamoto et al., Development towards Ultra-thin Superconducting Solenoid Magnet for High Energy Particle Detectors, Nuclear Physics B (Proc. Suppl.) 78 (1999), pp.565-570)
- enhanced mechanical strength
- without excessive degradation in RRR compared to pure Al

Four roll shaping process (courtesy of Outokumpu / IT)

Toward an improved conductor,

weldability



acc. /kV =120
intensity /mA =9.26
cath. curr /A =1.35
working distance /mm =150
adv. speed /mm·s^{-1} =16.7
X,Y scanning

Comparison of properties,

basis for a comparison of 4.2 K properties