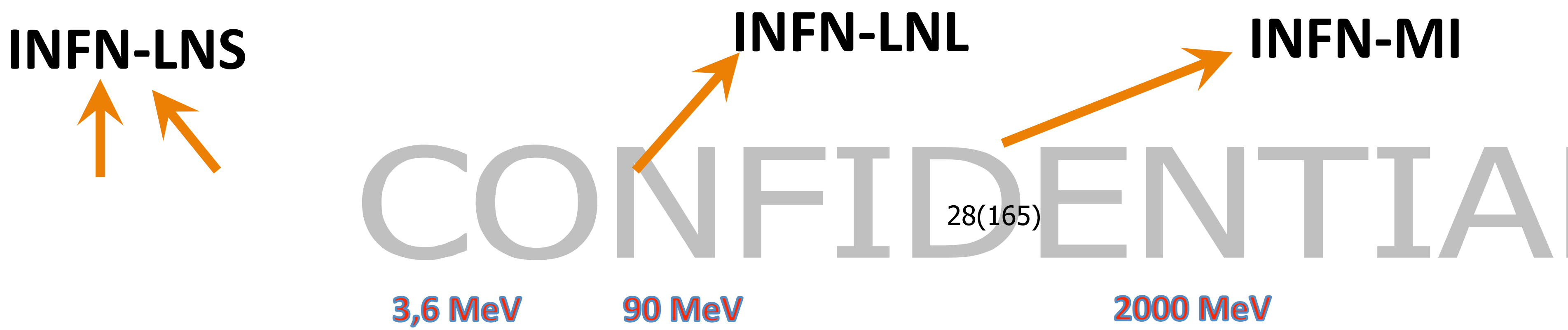
Il contributo in-kind dell' INFN

S. Gammino

INFN contribution to the European Spallation Source



INFN is in charge of the management of the WP3-Normal Conducting Linac

1. **Ion Source & LEBT (INFN-Laboratori Nazionali del Sud, Italy),**
2. **RFQ (CEA-IRFU, France),**
3. **MEBT (ESS Bilbao, Spain)**
4. **Drift Tube Linac (INFN-Laboratori Nazionali di Legnaro, Italy)**

Other INFN groups are involved in the in-kind contribution to ESS:

5. **Milan (expertise about superconducting elliptical cavities for WP5):** INFN is also involved in the design and construction of prototypes of SC elliptical cavities (Milan-Lasa) and it is agreed that will be charged for the construction of medium beta section, once that the in-kind contract will be signed
   → **know-how for ESS construction, industrial background for series construction**
6. **LNL for ICS + LNS,LNL&Milan for support to commissioning**

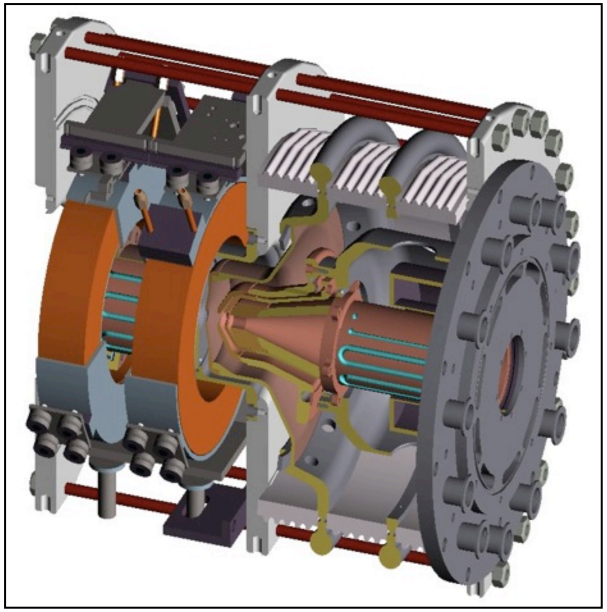
ESS - The INFN contribution

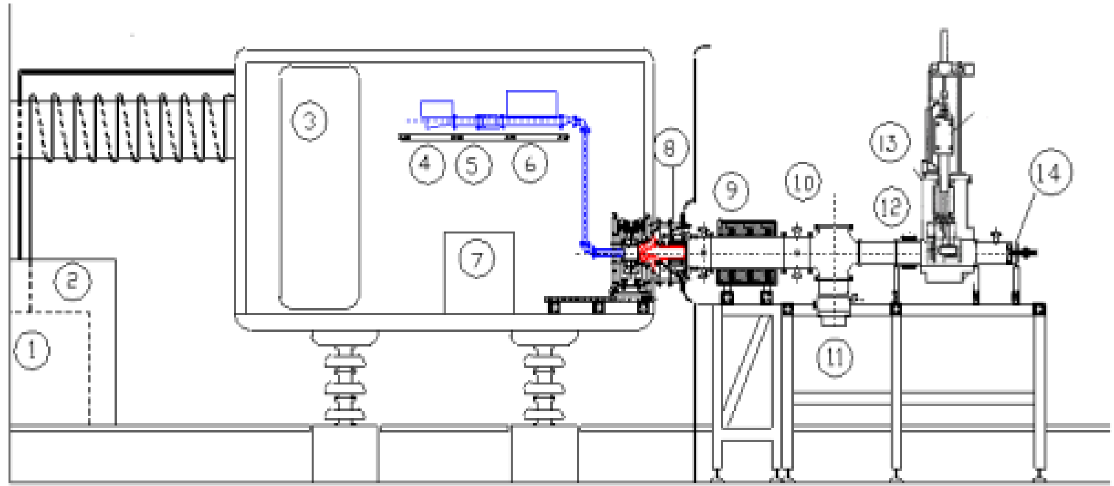
The involvement of INFN in the Accelerator Design Update (and similarly of CEA and IN2P3 from France) it **is a natural consequence of the R&D efforts done at INFN in the frame of the TRASCO-ADS research programme** (a study for a high power proton accelerator for the radioactive waste transmutation), along with **the daughter programmes NTA-HPPA at national level** and through different EU programmes aimed to the design of components for high power proton accelerators:

- studies done for the production **of intense beam of proton with small emittance figure**s and high reliability/stability;
- the R&D for the following parts of the **low energy high power accelerator**;
- the development of **high performance superconducting cavities**

are particularly useful for the ESS project.

TRIPS (TRasco Intense Proton Source)





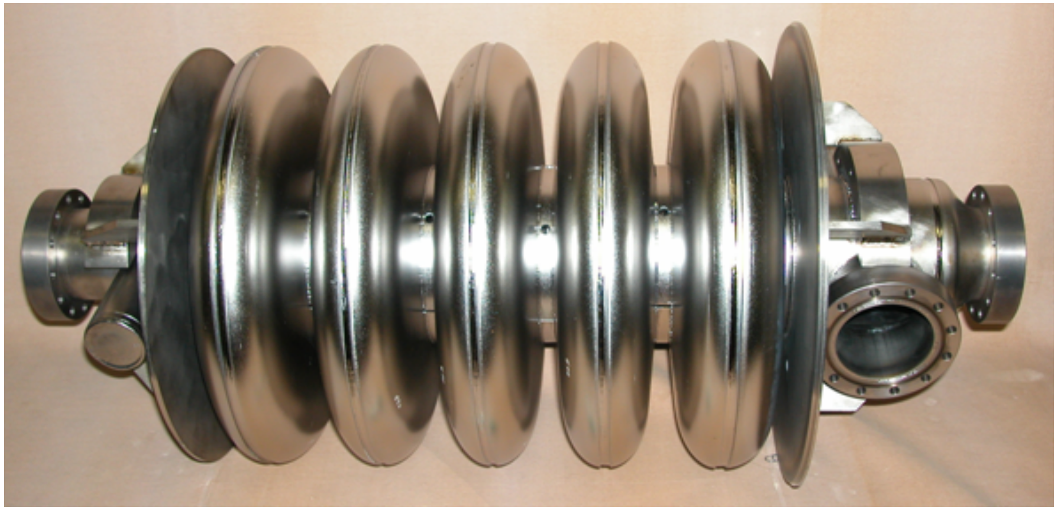
A layout of the whole set-up at INFN-LNS:
1- Demineralizer; 2- 120 kV insulating transformer; 3- 19" Rack for the power supplies and for the remote control system; 4- Magnetron and circulator; 5- Directional coupler; 6 – Automatic Tuning Unit; 7- Gas Box; 8- DCCT 1; 9- Solenoid; 10 – Four sector ring; 11- Turbomolecular pump; 12- DCCT 2; 13- EMU ; 14- Beam stop.

Proton beam current:
35 mA dc
Beam Energy:
80 keV
Beam emittance:
$\varepsilon_{RMS} \leq 0.2\,\pi$ ***mm mrad***
Reliability:
close to 100%

PS-ESS is based on TRIPS experience
MANY INNOVATIONS

INFN-Milan: involvement in the CARE-HIPPI

- In the framework of the 6FP of EU → ESGARD
- Valuable INFN-Mi contribution: cavities already available for TRASCO were extended to pulsed and high-power operations;



- **TRASCO cavity β=0.47 for protons @ 90-200 MeV**
- **Successful tests up to 17 MV/m (designed for 8.5 MV/m)**

Comments on new requirements

- The updated design has relaxed requirements on the high energy part, while charging the most part of criticalities on the front-end, i.e. for components under INFN responsibility: a lower cost of accelerating cavities is possible with **lower energy BUT larger current**.

- Moreover, a very low beam current ripple is requested, with stringent constraints on Twiss parameters.

- Moreover, the possibility to produce beam variable from 10% to 100% of the maximum is requested.

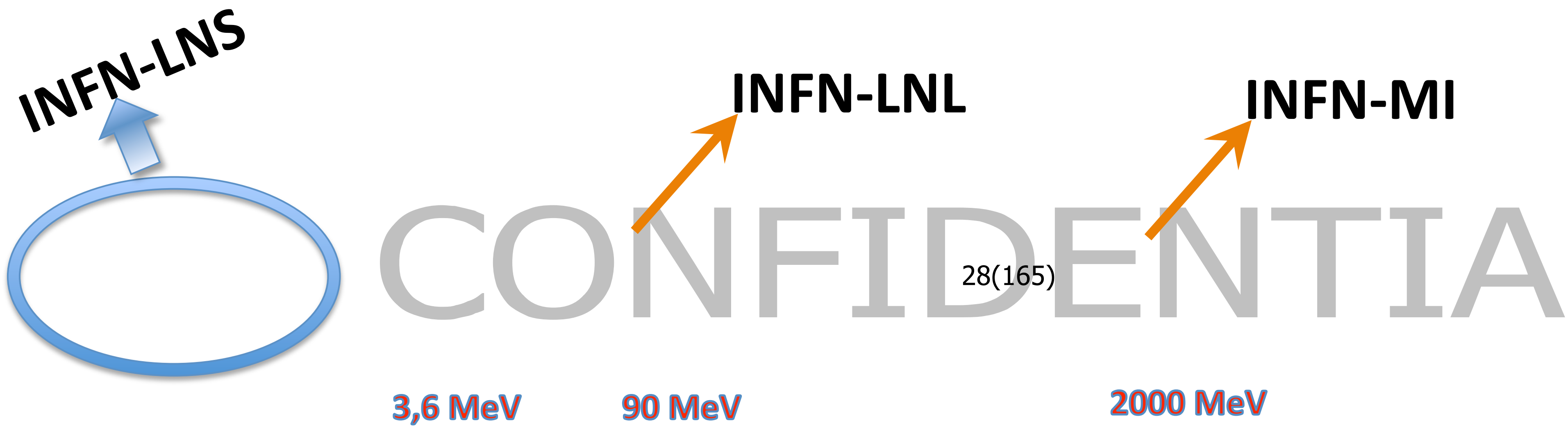
Comments on new Requirements

- **Maximum proton beam current at the target: 62.5 mA**
  (>90 mA of source's output current)
- Pulse during neutron production: 2.86 ms
- Beam Stability: ±2.5% (I,ε) - Beam emittance 0.25 π mm mrad
- New RFQ input Twiss parameters;
- **The peak beam current to be able to be varied from 6.3 mA to 62.5 mA with** a maximum step size of 6.3 mA and with a precision of 1.6 mA.

Huge impact of Mechanical design and beam dynamics in the low energy part

INFN Contribution 1

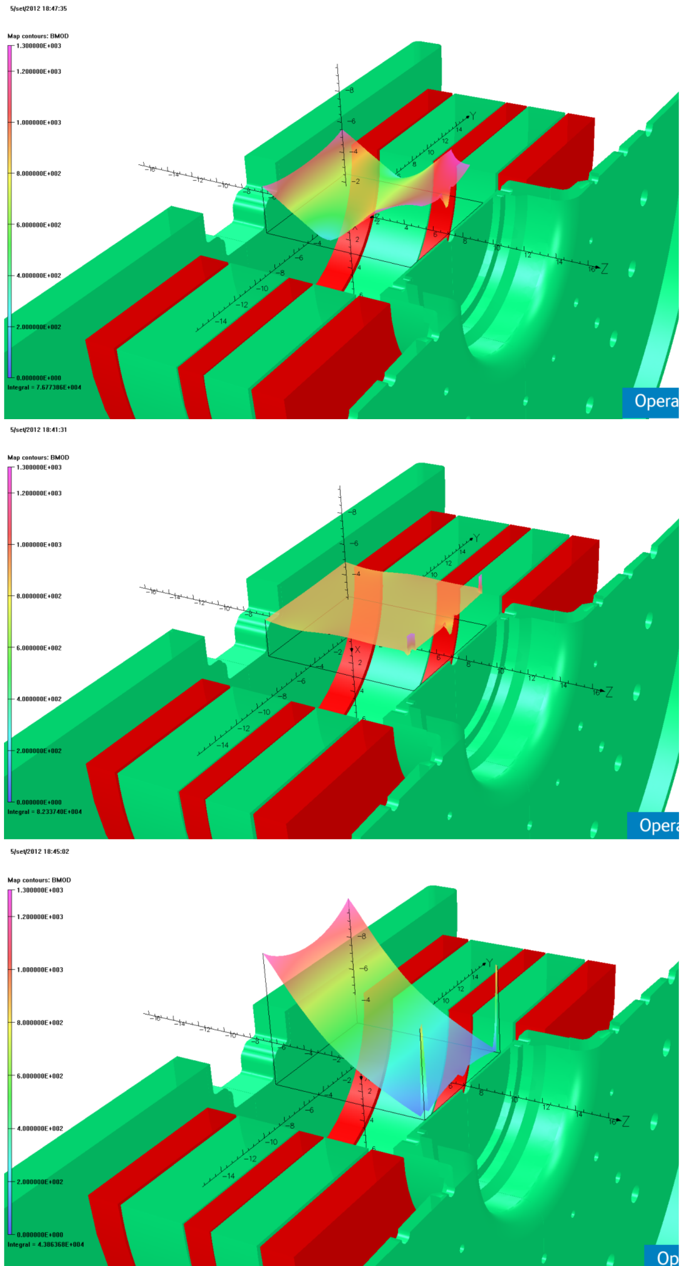
- **Proton source**

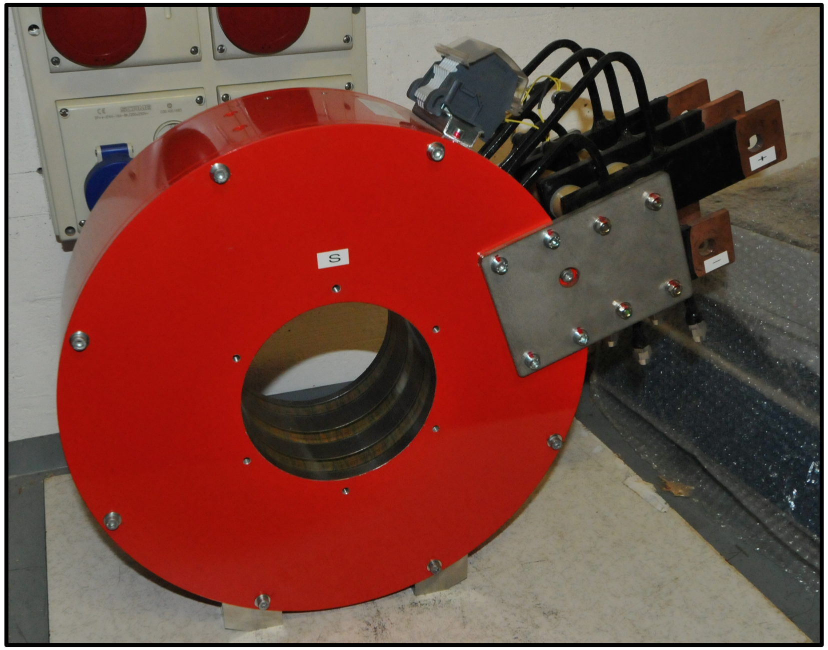


The ESS Proton Source prototype

- From R&D activities on plasma based compact sources to the PS-ESS design;
- Searching a **balance between innovative solutions and robust design**;
- **Flexibility required for the magnetic field and RF system**;

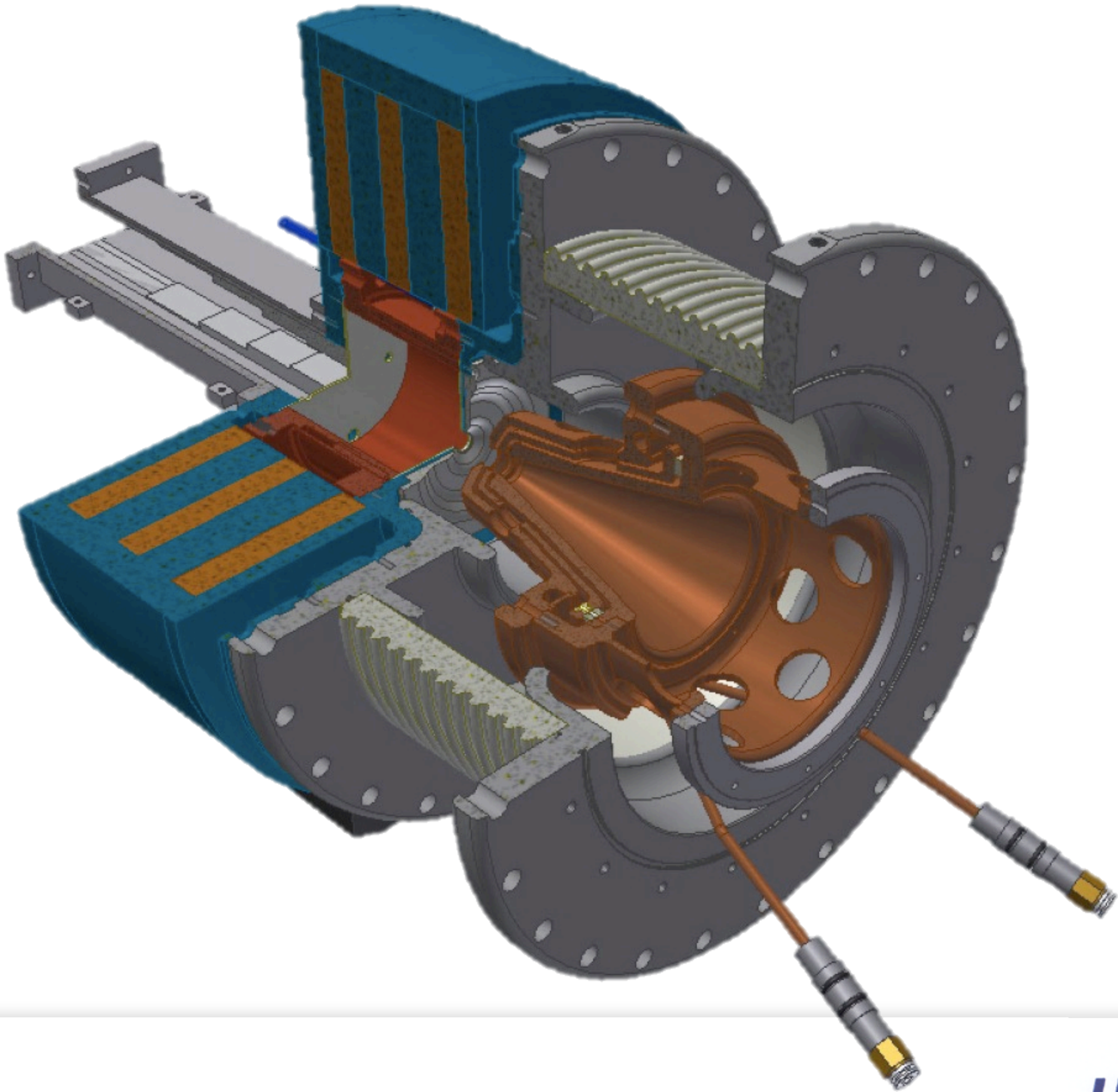
The PS-ESS very flexible magnetic system





- Magnet manufactured by Sigma-phi
- Magnetic system **already delivered at LNS**
- **Ready for installation!**

The Proton Source for ESS



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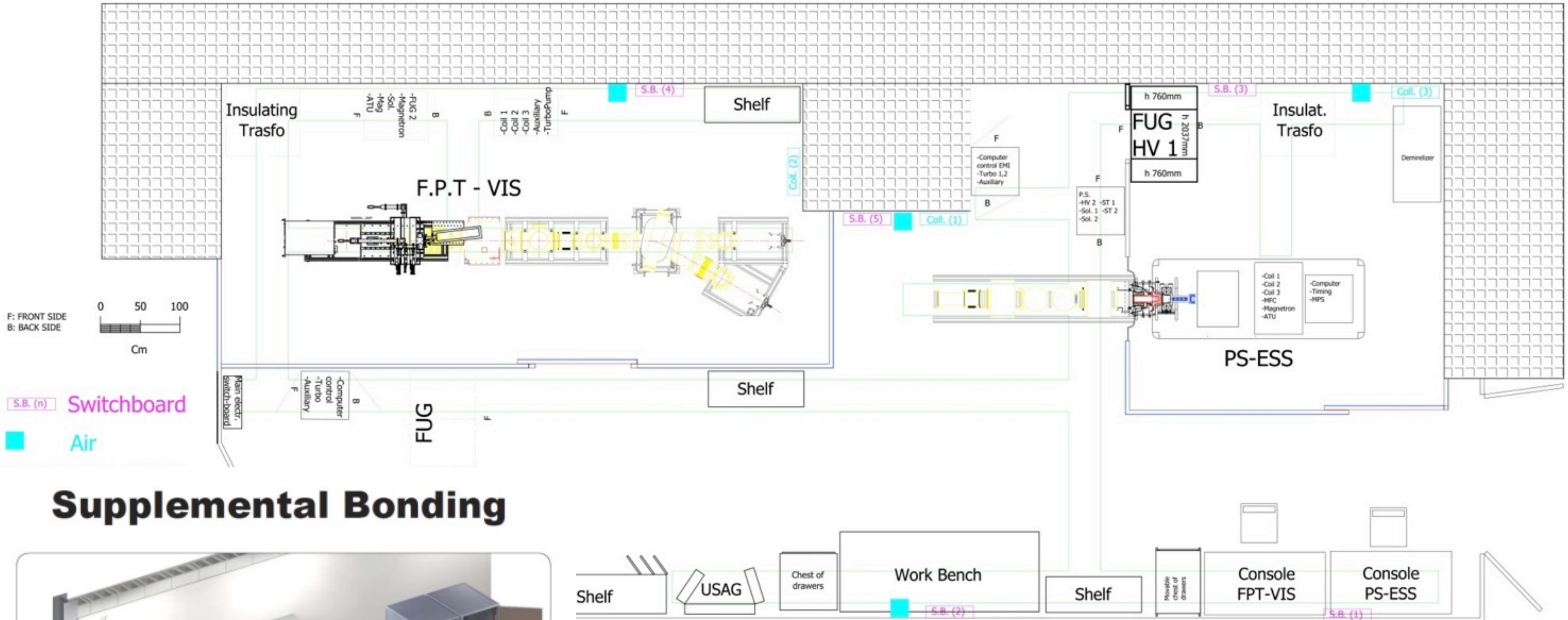
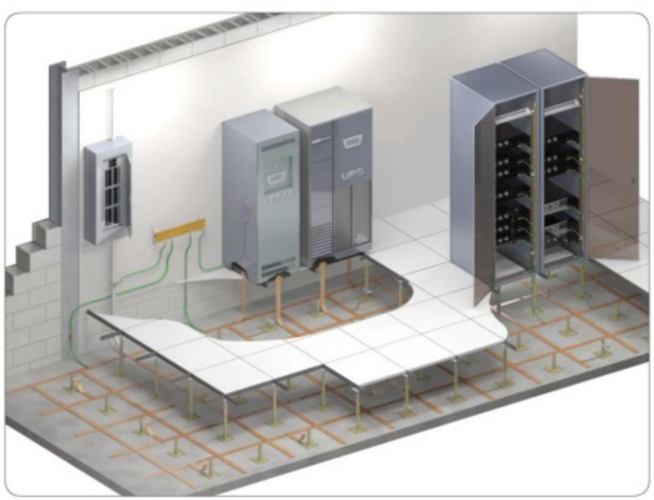
Ion Source & LEBT: ESS test area at LNS



Supplemental Bonding



High Frequency Bonding for H.V. sparks

A careful preparation of the site has just been completed, with particular attention to grounding to minimize the effects of sparks

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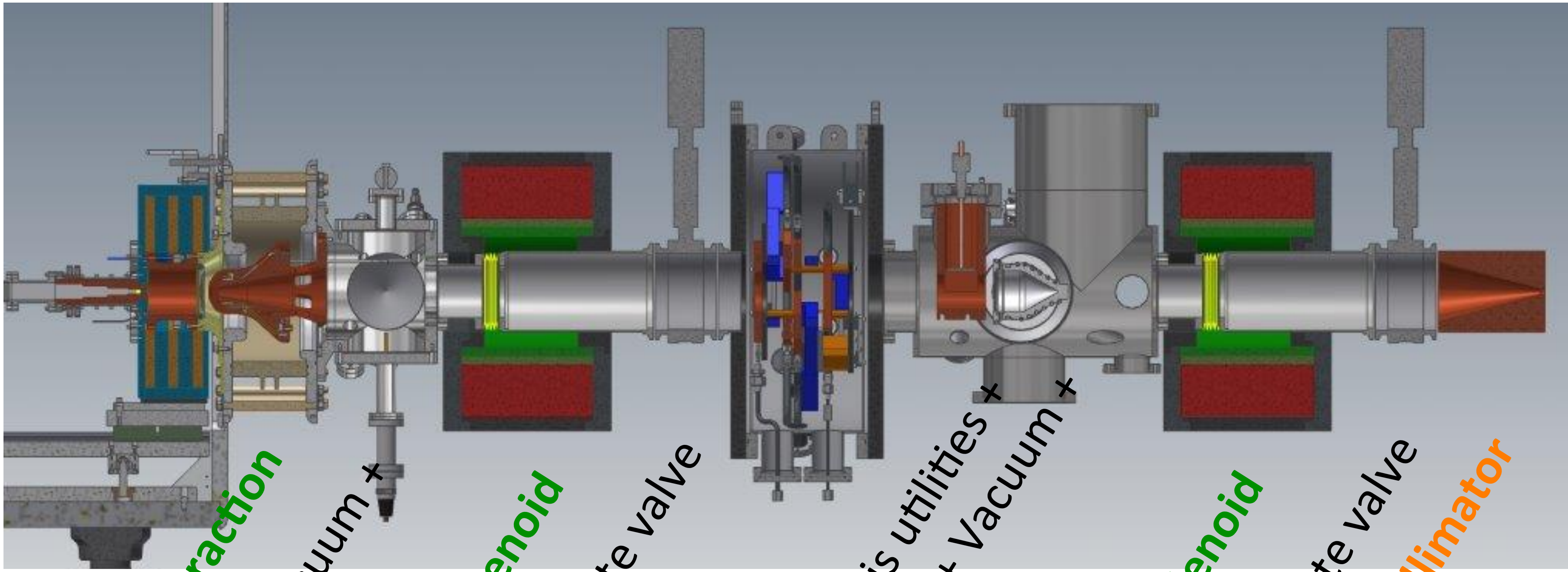
LEBT Layout

INFN

2654 mm from plasma electrode to LEBT collimator



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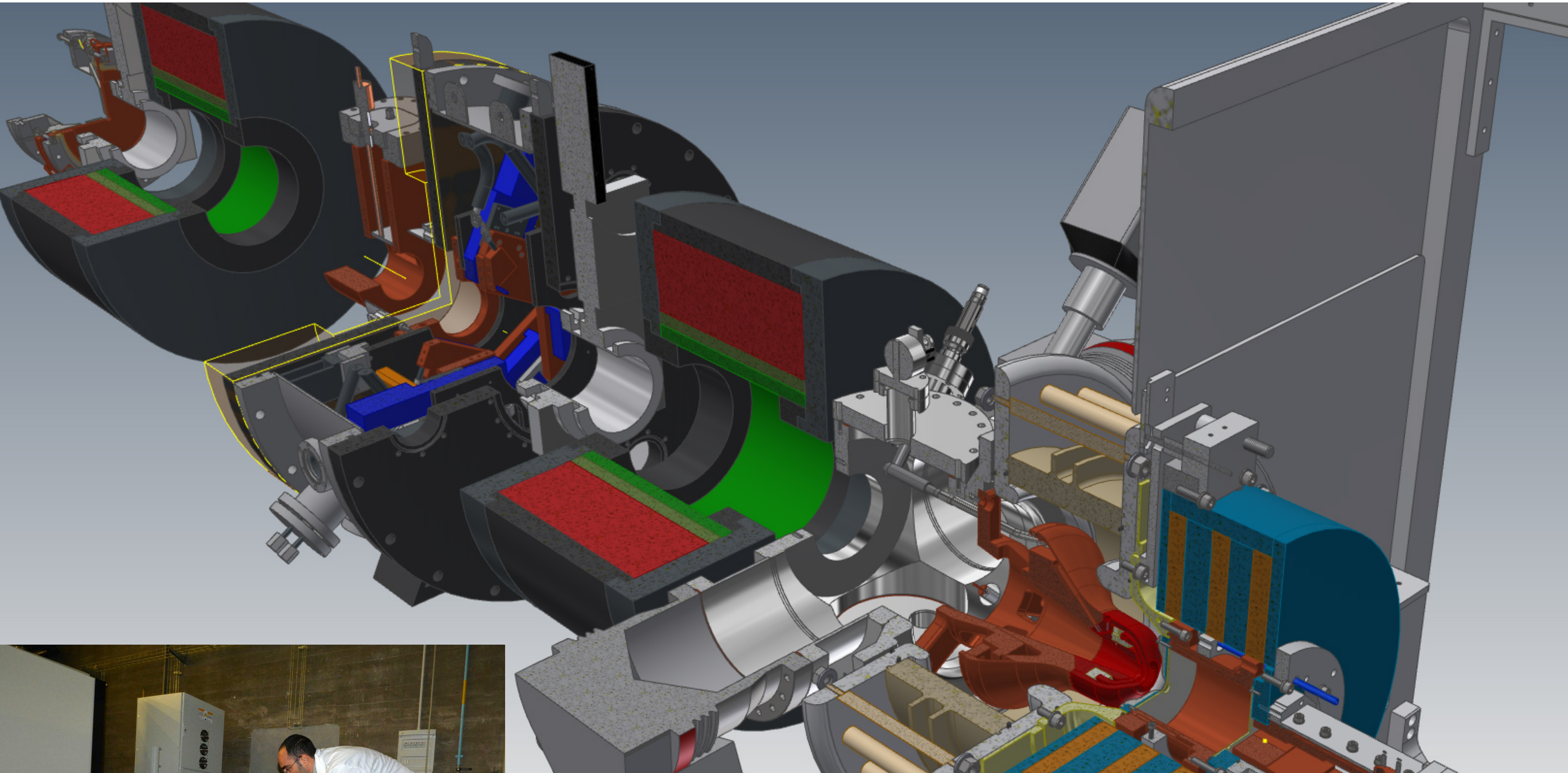
PS-ESS and LEBT layout



Status and open items

Sites

• LNS site	Complete except for interlocks
• ESS-Lund site	in progress, interaction supp. by Lead Engineer

Proton source (PS-ESS) and accelerator column

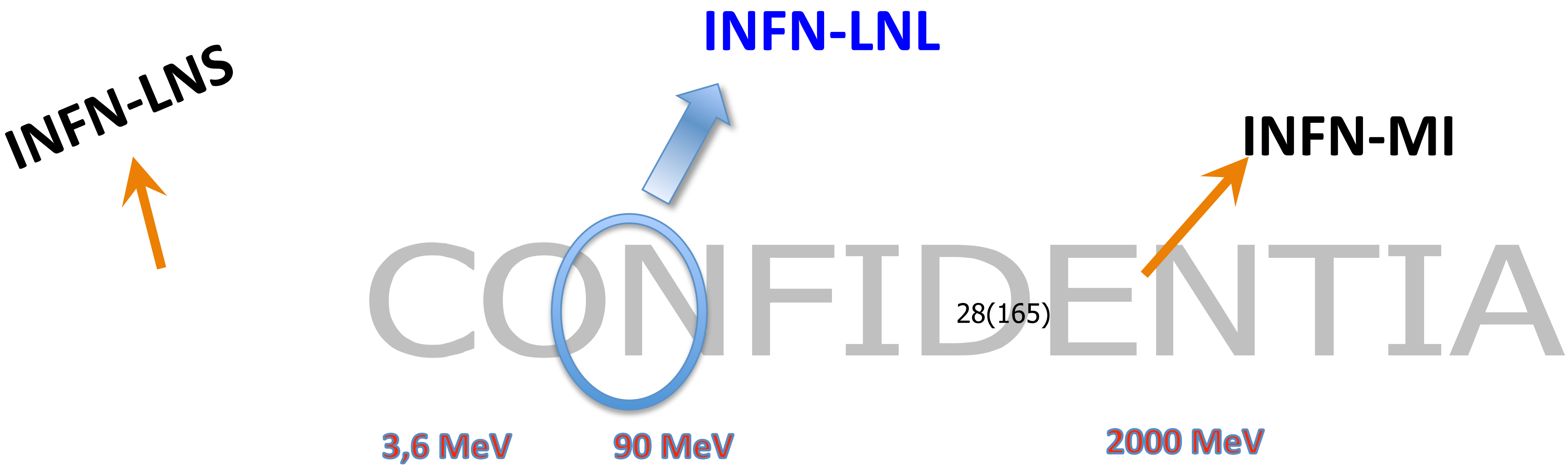
• HV platform	To be ordered, short delivery time
• Power supplies (High current, High voltage)	Delivered
• Microwaves equipment	Ordered
• Magnetic system	Delivered
• Plasma chamber	Ordered
• Mechanical integration and LEBT	already defined
• Extraction system	Ordered

Interfaces

• MPS	definition in progress
• Control interface	definition in progress

INFN Contribution 2

- **Drift Tube Linac**



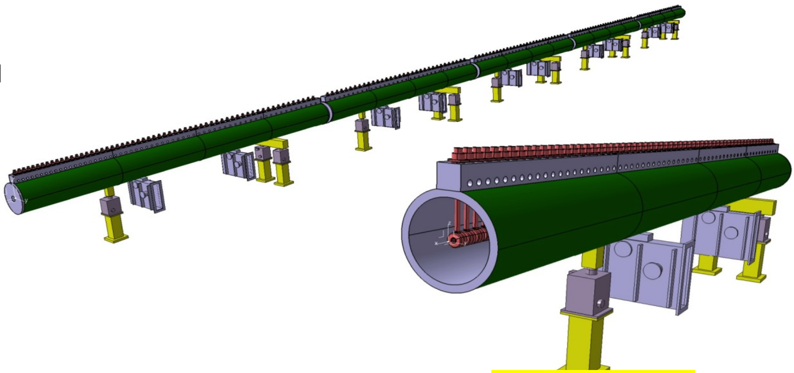
Technical performances (SoW)

- The DTL (Drift Tube Linac) cavity is constituted of 20 modules, assembled in 5 tanks, composed of 4modules each for a total length of approximately 40 m.

- This profile describes the life cycle phases of the DTL regardless of the responsibilities assigned to contributors of this Scope of Works.

1. DTL design
2. Manufacturing of test of components
3. Assembly, low power test and tuning of each tank.
4. Transport and Installation in the ESS tunnel in Lund
5. Check out and RF conditioning to full power
6. Beam commissioning in two steps, beam dump after tank 1 and tank 5
7. Operation with the other Accelerator components (and neutron production target).

- This scope of work describes the points from 1. to 6.



First tank

CERN-INFN prototype

DTL Input Constraints

- Input Energy equal to **3.62** MeV.
- Final energy > 88 MeV in 5 tanks
- Tank length < 8 m
- Current = **62.5** mA.
- Power 2.2 MW per tank, including margin=1.25 on MDTfish computation.
- Input RMS Emittance: Trans. / Long. = **0.28/0.39** mm mrad (**0.15** π deg MeV).

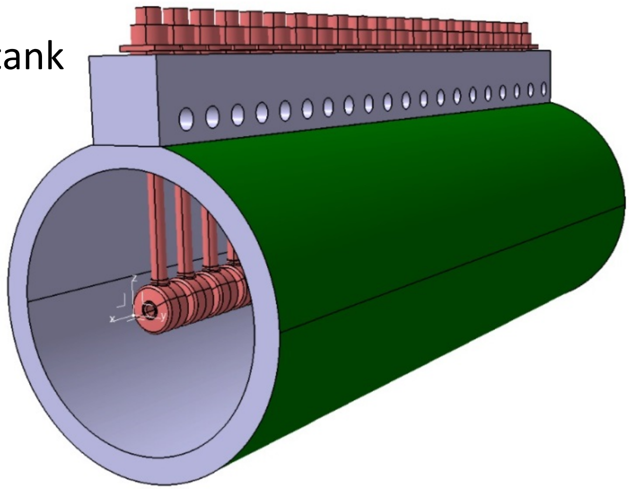
ESS DTL properties:
design parameters fixed

Tank	1	2	3	4	5
Cells	61	34	29	26	23
E_0 [MV/m]	3.00	3.16	3.07	3.04	3.13
E_{max}/E_k	1.55	1.55	1.55	1.55	1.55
ϕ_s [deg]	-35,-25.5	-25.5	-25.5	-25.5	-25.5
L_{Tank} [m]	7.62	7.09	7.58	7.85	7.69
R_{Bore} [mm]	10	11	11	12	12
L_{PMQ} [mm]	50	80	80	80	80
Tun. Range [MHz]	±0.5	±0.5	±0.5	±0.5	±0.5
Q0/1.25	42512	44455	44344	43894	43415
Optimum β	2.01	2.03	2.01	1.91	1.84
Beam Det [kHz]	+2.3	+2.0	+2.0	+1.8	+1.8
P_{cu} [kW] (no margin)	870	862	872	901	952
E_{out} [MeV]	21.29	39.11	56.81	73.83	89.91
P_{TOT} [kW]	2192	2191	2196	2189	2195

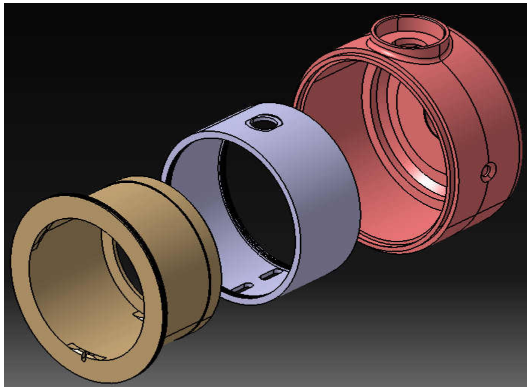
Mechanical Design

GIRDER (EN AW5083 Al alloy)
Precise positioning of the DT stem axis in steel bushing SLAVE

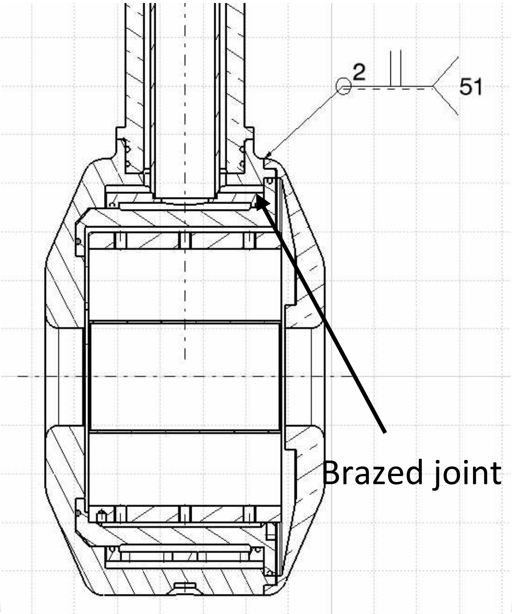
Helicoflex
Vacuum tightness at stem/tank interface

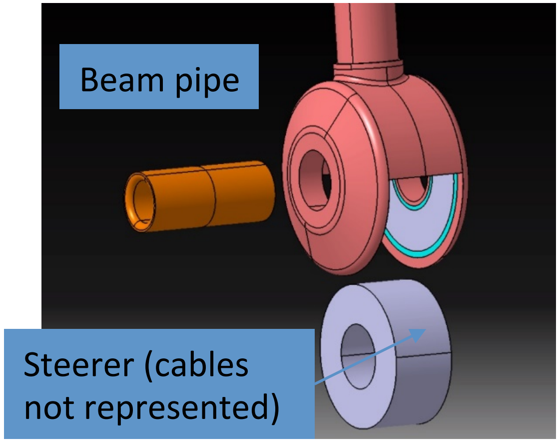


TANK (304L stainless steel)
internal Cu plating on finished surface internal Cu plating on finished surface (Ra 0,8) high stiffness support MASTER

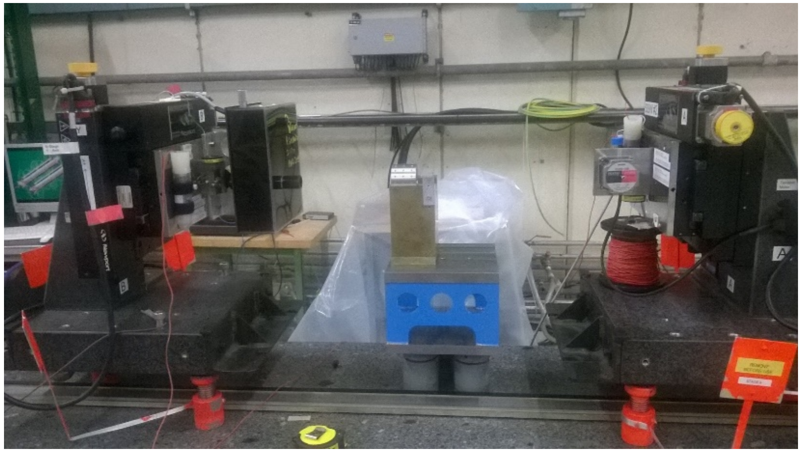


Rough sleeve 316LN | Sep. cylinder 304L | Rough DT body CuC2-OFE





Prototypes: PMQ designed, machined and assembled by INFN. Tested at CERN



	Measured	Estimated Uncertainty	Unit
SSW	2.869	0.003	Tm/m
		1Â·10^{-3}	-
ROTATING COIL	2.866	0.005	Tm/m
		1.7Â·10^{-3}	-

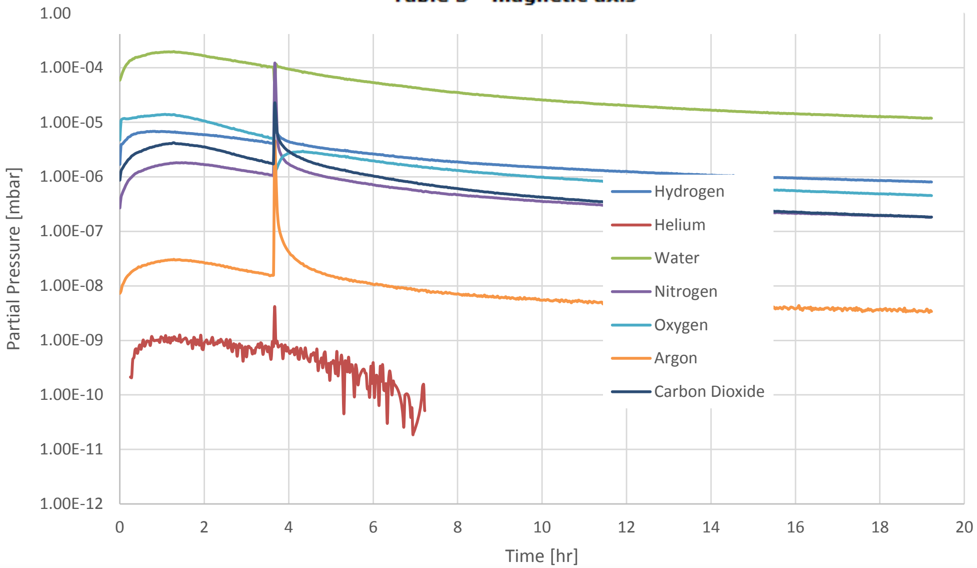
Table 3 - integrated gradient measurement

	SSW	Estimated Uncertainty	Tolerance	Rotating coil	Estimated Uncertainty	Unit	Pass
X	-0.007	0.003	0.100	-0.009	0.003	mm	OK
Y	0.000	0.003	0.100	-0.002	0.003	mm	OK

Table 5 - magnetic axis

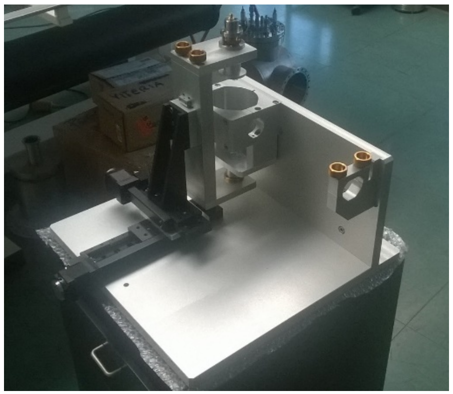
Vacuum test

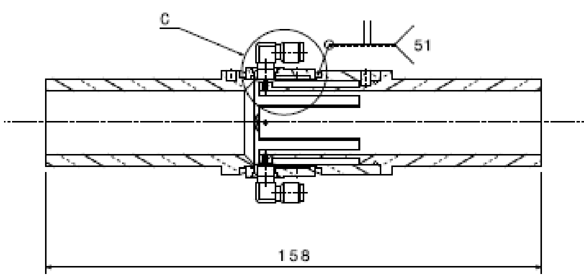
- final pressure similar to the background value.
- Larger amount of H2O, H2, O2, C02 These cannot be determined if they are from the AISI frame or from the PMs.



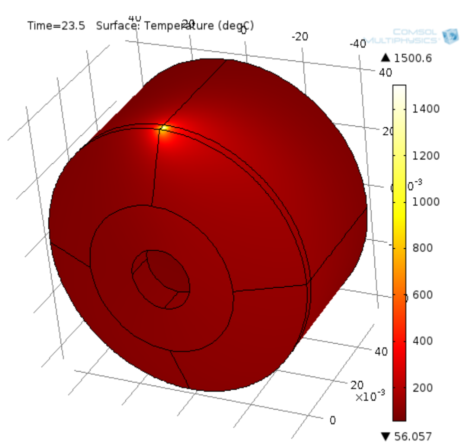
Prototypes: BPM and EBW test

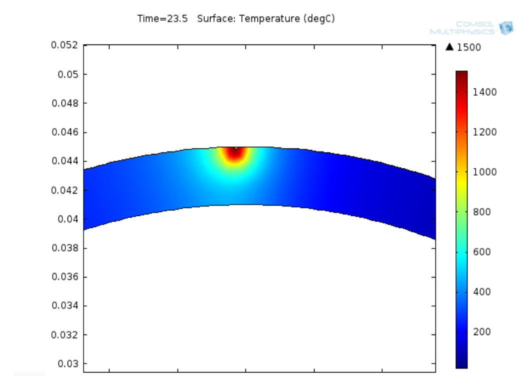
- BPM: strip-line already brazed, waiting for coaxial feed-trough from USA
- Mapper at LNL





- EBW on Brazing possible weak point (T ebw > 1100°C, Tbrazing =850 °C)
- Simulation shows non problem (Power_EBW=1800 W, v=12mm/s, spot volume=1mm^3, brazed point < 650°C)
- Order placed at Zanon for test on brazed DT





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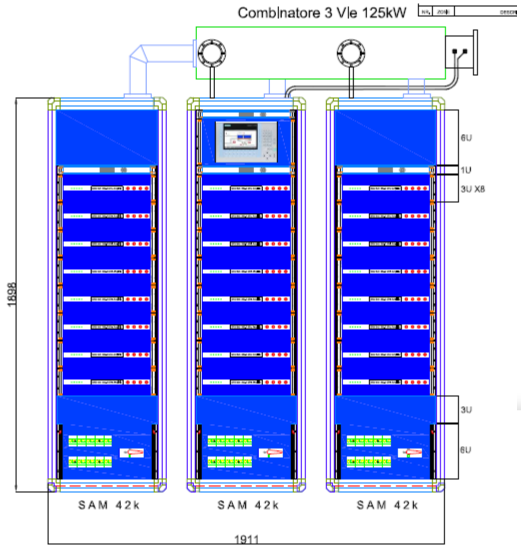
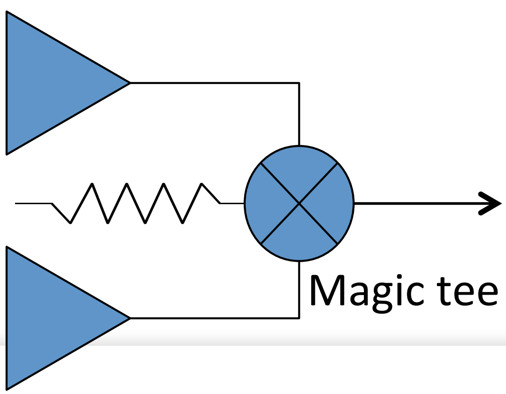
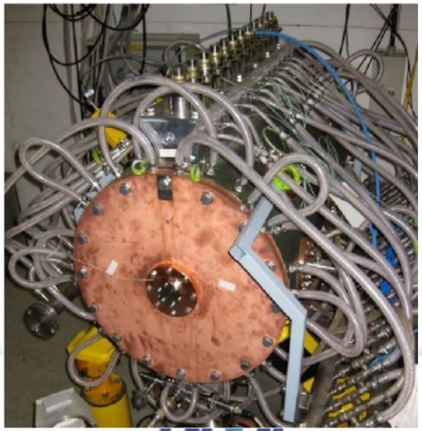
High Power test @ LNL

- 2 solid state amplifiers 125 kW-CW each, 352 MHz.
- Control system developed for multiple coupler feeding.
- Waveguides and circulator at LNL.
- **IFMIF high power test stand now ready will be readapted.**
- High power DTL prototype from Linac4-CERN (peak power 180 kW, 10% duty cycle, E0=3.3MV/m) agreement KN2155/KT/BE/160L between CERN and INFN-LNL
- 3 drift tubes will be replaced by ESS drift tubes containing instrumentation + 1movable tuner for frequency control.
- **Ready for test in summer 2015**







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In-kind contribution

- **The DTL structure**

1. **Tanks (n=5)**
   i. Module cylinder 20
   ii. Girder 20
2. **Drift tubes** 60+33+28+25+22=168 (four kinds, with PMQ n=89, steerers n=30, BPM n=15, empty n=39)
3. **RF Components**
   1. Couplers 10
   2. Pick up 9x5=45
   3. Tuners fixed 115, movable 10?
   4. Post couplers 123
4. **Beam Components**
   1. PMQ 31(L=50mm)+58(L=80mm)
   2. Steerers 6x5=30
   3. BPM 3x5=15
5. **Vacuum components** (10 manifolds)
6. **End plates and 4 intertanks**
   1. End covers 10, with PMQ 5, with beam current monitor 5
   2. **N=4 intertanks**
7. **Support and alignment**
   1. N=5 isostatic support
   2. N=2 alignment support

In-kind contribution (2)

- **The Ancillary Systems**
  - **Cooling system**
    - 1 skid with temperature stabilization.
    - Tubes from skids to tank: mounted by ESS. Provided by LNL?
  - **Vacuum system**
    - Manifold designed and provided by LNL
    - valves, gauges, pumps defined by ESS (vacuum handbook). Provided by ESS or LNL?
  - **Local control system** (provided by LNL but in a different WP?):
    - water temperature controls
    - Vacuum control and interlock
    - Temperature monitors?
    - Arc detector for RF windows. Provided by LNL, controlled by LLRF (outcome warmlinac meeting @ LNL)
  - RF Cables? t.b.d.
  - Assembly
  - Installation and commissioning? t.b.d.

Preliminary Schedule

- **2014: conceptual design**
- **Early 2015: completion of prototyping phase**
- **2015: technical design phase, detailed drawings, tender for rough material**

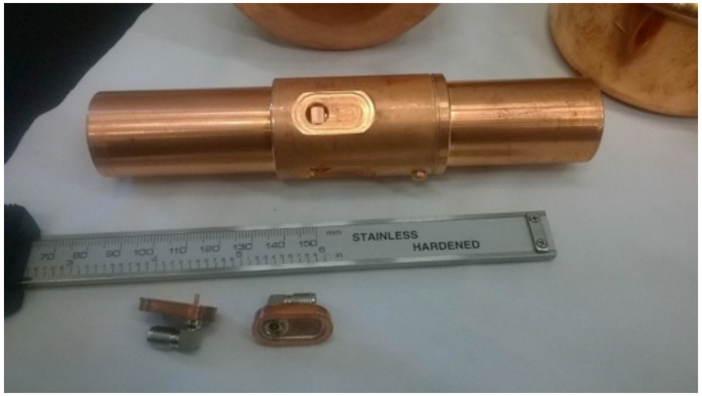
- **2016-2017: construction**
- **2017-2019: assembly and tuning**

- **2017-2018:**
  - installation and conditioning in the tunnel.
  - beam commissioning of the 5 DTLs

Prototyping

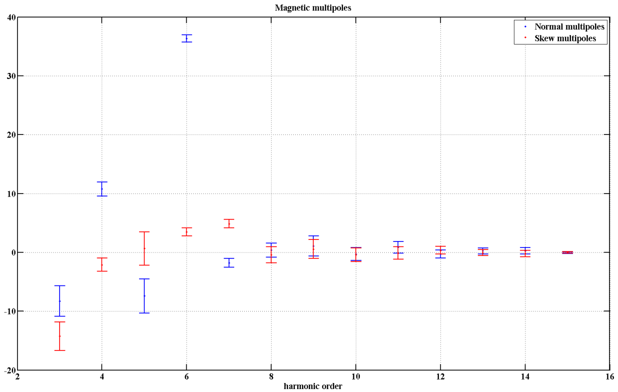
Test of Cu-plating on Stainless steel Stem order to be placed. It will make them more rigid compared and will allow for a larger bore for the BPM and corrector cables.

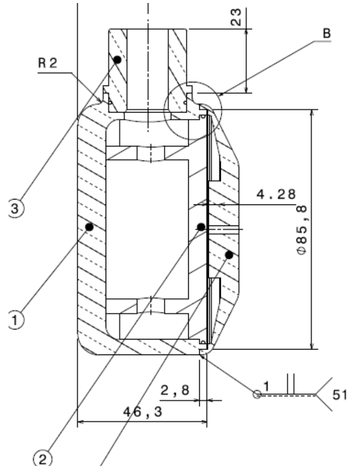
BPM: feedthrough to be welded on the BPM stripline



EBW on Brazing: DT brazed and EB-welded. **Vacuum test ok**. Next step: section and micrography

PMQ fully tested





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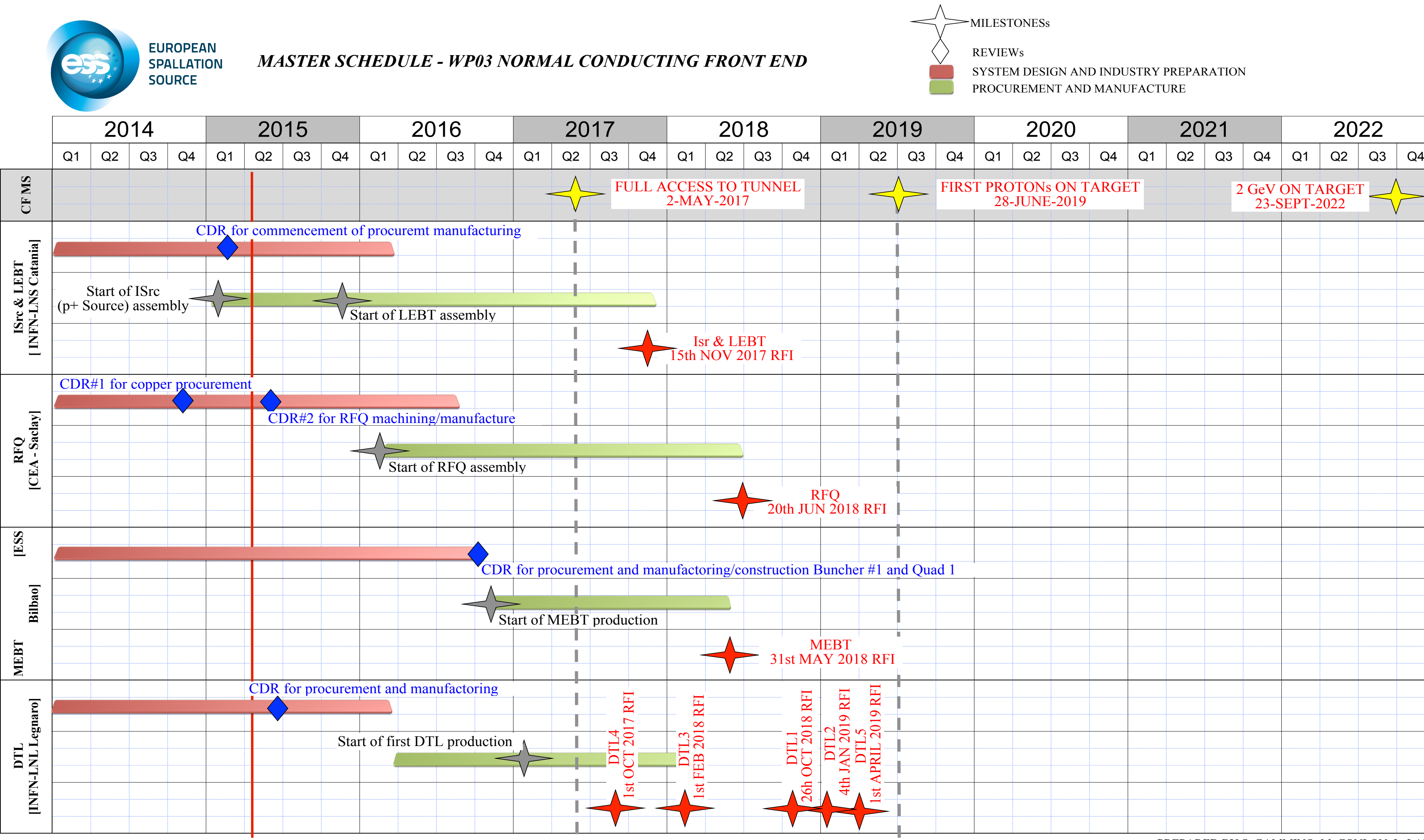
WP03 Master Schedule

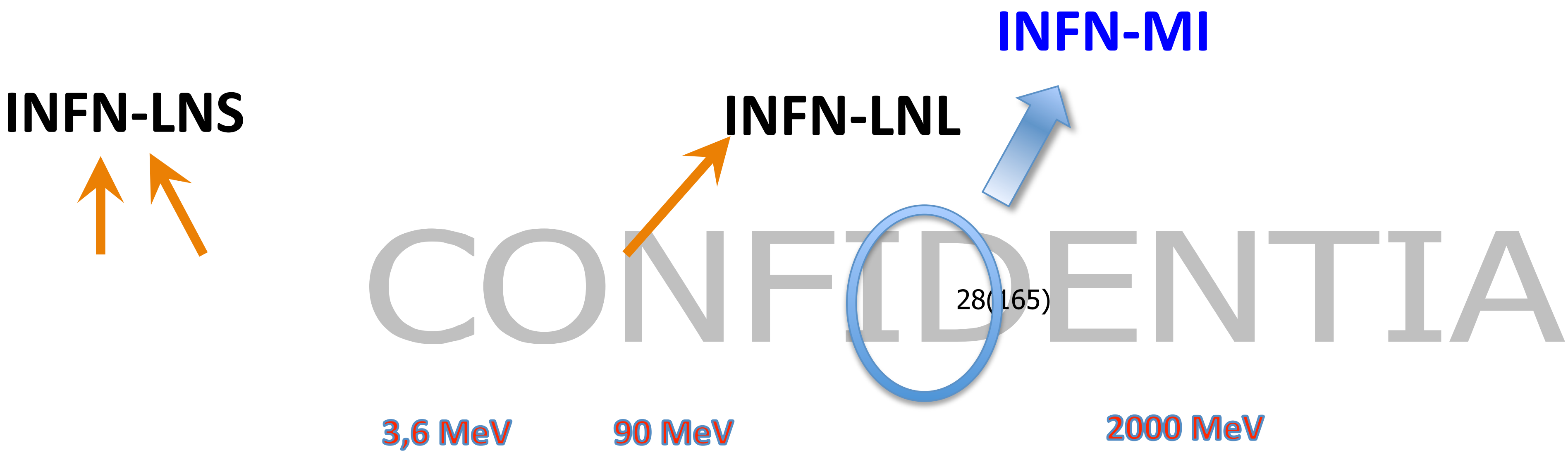


DATA EXTRACTED BY P6 PLANNING - MARCH 2015

PREPARED BY S. GAMMINO, M. CONLON, L. LARI
CHECKED BY J. WEISEND
APPROVED BY M. LINDROOS

INFN Contribution 3

- **Medium β−cavities**

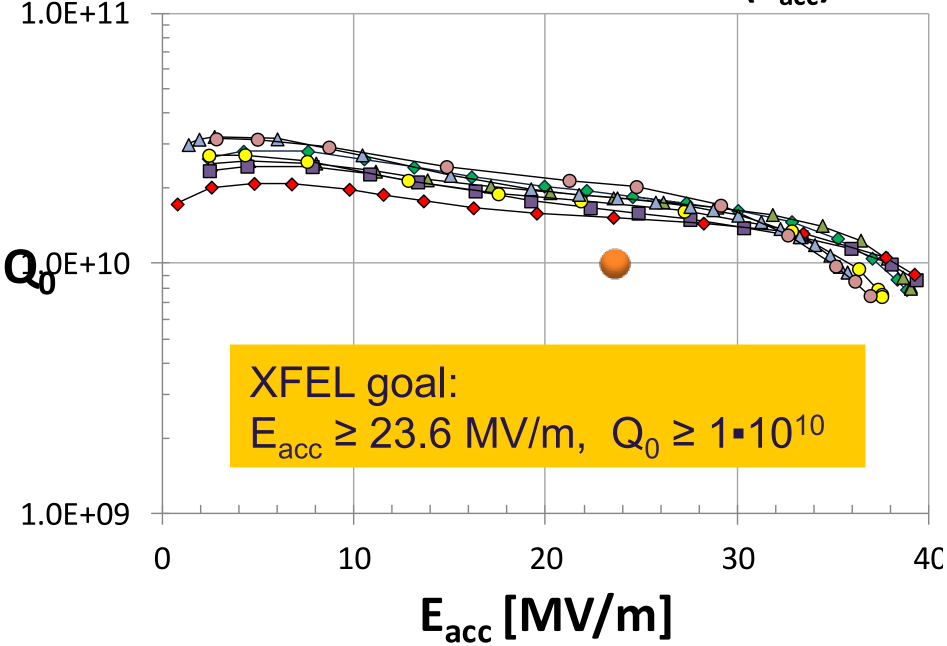


INFN – Milano contribution to ESS

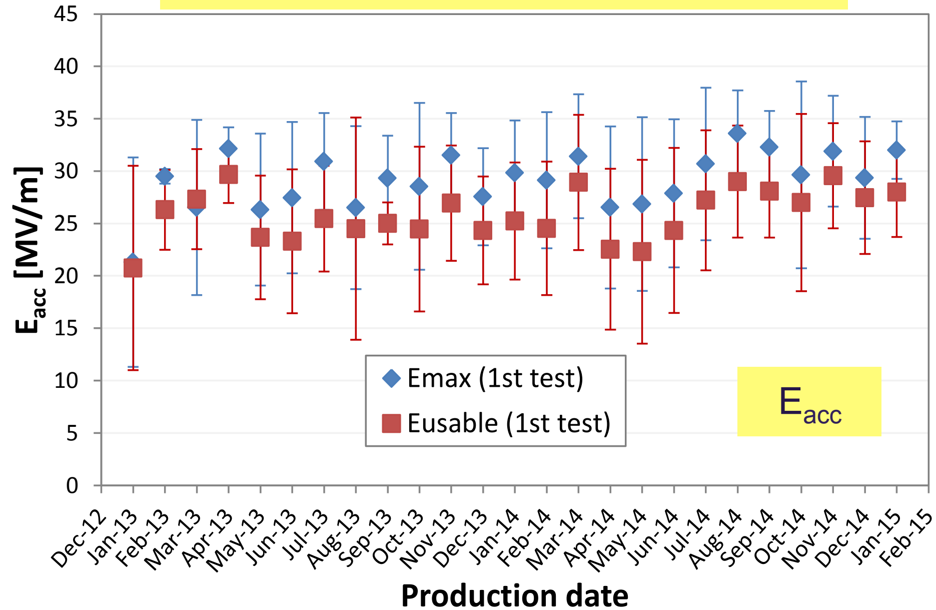
- Up to the end of 2014 INFN-Mi involved in XFEL;
- Expression of interest for in-kind contribution to ESS of medium-β cavities;
- Well consolidated expertise + good connection with industries for series production

XFEL 1.3 GHz SC cavities: Cavities Performances (EZ)

EZ Best Performances Cavities (E_{acc})



1st test of cavities (as rrived from EZ)



- Re-treatment typically due to field emission
- Cavities “cured” mainly by HPR (done both at DESY and at the Company)

Average **maximum** gradient	before re-treatment: (29.1 ± 5.9) MV/m
	after re-treatment: **(32.0 ±3.8) MV/m**
Average **usable** gradient	before re-treatment: (25.8 ± 6.1) MV/m
	after re-treatment: **(29.0 ±3.6) MV/m**

Medium Beta Cavities Technical performances

INFN Medium Beta Cavities Technical Performances

Requirements	Medium beta
Frequency (MHz)	704.42
Geometric beta	0.67
Nominal Accelerating Gradient (MV/m)	16.7
Epk (MV/m)	< 50
Cell coupling k(%)	≥ 1.5
RF peak power (kW)	1100
Q ext	$7.5\ 10^{5}$
Q0 at nominal gradient	$> 5\ 10^{9}$

INFN in-kind contribution to ESS: elliptical SC cavities

Deliverable no.	Deliverable
1	Medium beta pre-series cavity, vertically tested at LASA
2	High beta pre-series cavity, vertically tested at LASA
From 3 To 38 (# 36)	Superconducting RF cavity for the **medium beta section** of the linac, equipped of **all the necessary ancillaries** (helium tank, flanges, vacuum valve, frame, RF antenna and pickup), **tested vertically** and delivered at the cryomodule assembling facility.

Two **spare cavities** could be foreseen during the series production (**constituting Deliverable nos. 39-40**).

INFN in-kind contribution to ESS: medium beta elliptical SC cavities

List of technical documentation to be provided for each cavity

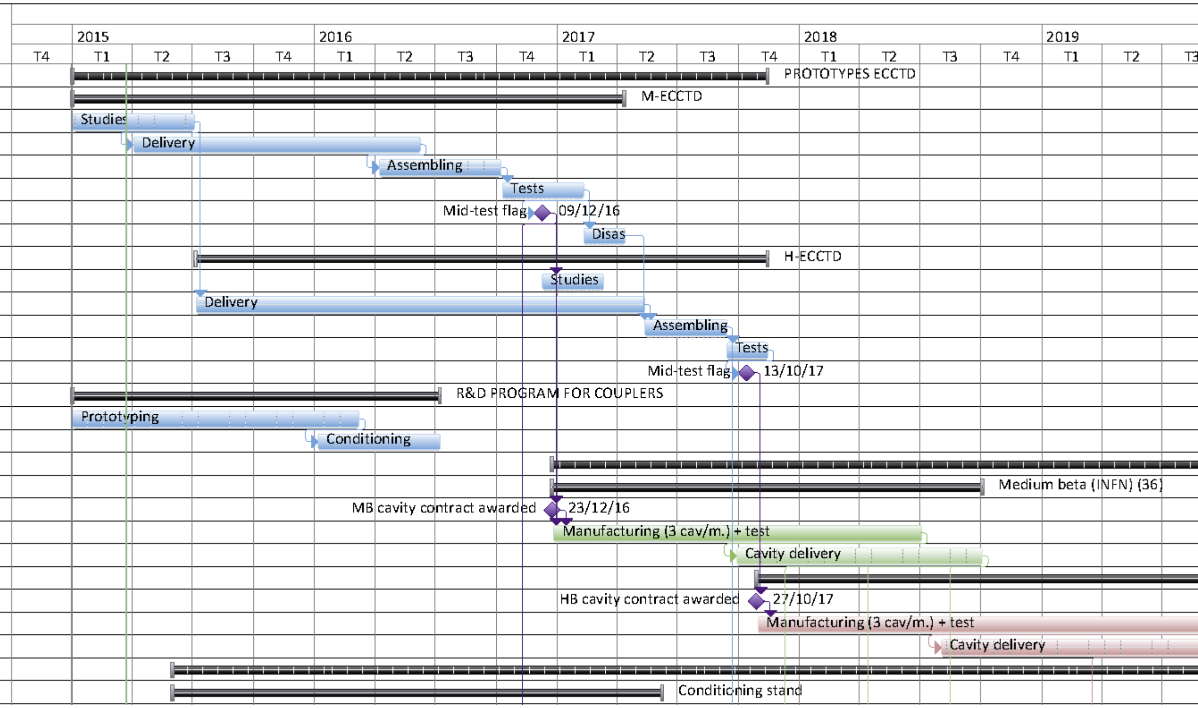
	Document
1	**Fabrication drawings** for the series cavities.
2	**Complete fabrication documentation package**, including documentation for product compliance according to the possibly needed **certifications**.
3	**Complete processing information** of the cavities, during the preparation of the functional surfaces for RF testing (etching, HPR, clean room operations, assembly, etc.)
4	**Report of the vertical tests.**

Medium Beta Cavities Major Procurements

Revised scheduling proposed

CMS_WP5_TAC11_150401.mpp

N°		Mode Tâche	N° hiérarchique	Nom de la tâche	Durée	Début
1			1	**PROTOTYPES ECCTD**	**34 ms**	**Jeu 01/01/15**
2			1.1	M-ECCTD	27 ms	Jeu 01/01/15
3			1.1.1	Studies	6 ms	Jeu 01/01/15
4			1.1.2	Delivery	14 ms	Ven 03/04/15
5			1.1.3	Assembling	6 ms	Jeu 07/04/16
6			1.1.4	Tests	4 ms	Lun 10/10/16
7			1.1.5	Mid-test flag	0 ms	Ven 09/12/16
8			1.1.6	Disassembly	2 ms	Jeu 09/02/17
9			1.2	H-ECCTD	28 ms	Lun 06/07/15
10			1.2.1	Studies	3 ms	Ven 09/12/16
11			1.2.2	Delivery	22 ms	Lun 06/07/15
12			1.2.3	Assembling	4 ms	Ven 12/05/17
13			1.2.4	Tests	2 ms	Mer 13/09/17
14			1.2.5	Mid-test flag	0 ms	Ven 13/10/17
15			2	**R&D PROGRAM FOR COUPLERS**	**18 ms**	**Jeu 01/01/15**
16			2.1	Prototyping	14 ms	Jeu 01/01/15
17			2.2	Conditioning	6 ms	Mer 06/01/16
18			3	**CAVITIES**	**49 ms**	**Ven 23/12/16**
19			3.1	Medium beta (INFN) (36)	21 ms	Ven 23/12/16
20			3.1.1	MB cavity contract awarded	0 ms	Ven 23/12/16
21			3.1.2	Manufacturing (3 cav/m.) + test	18 ms	Lun 26/12/16
22			3.1.3	Cavity delivery	12 ms	Jeu 28/09/17
23			3.2	High beta (STFC) (84)	39 ms	Ven 27/10/17
24			3.2.1	HB cavity contract awarded	0 ms	Ven 27/10/17
25			3.2.2	Manufacturing (3 cav/m.) + test	36 ms	Lun 30/10/17
26			3.2.3	Cavity delivery	30 ms	Jeu 02/08/18
27			4	**COUPLERS**	**64 ms**	**Lun 01/06/15**
28			4.1	Conditioning stand	24 ms	Lun 01/06/15



First 4 series cavities delivered by end 2017

In-kind contribution

- Some preliminary work, for about 6M€ (a great part from INFN) has been carried out in the frame of Accelerator Design Update and the contract for this phase was concluded in Dec.2014 with the acceptance of ESS-AB of these pre-construction contributions as in-kind.
- The IK contribution related to Isrc & LEBT, DTL and WP3 management is well defined
- The IK contribution related to medium beta superc. cavities has been recently agreed and the details of integration in cryomodules will be defined soon.
- The amount of contribution related to ICS and to the support to commissioning has been estimated by INFN but not yet defined in details
- The amount of INFN contributions should account to about 33 M€
- As the conditions for the signature of in-kind contract are not yet mature, a preliminary set of “Heads of Agreement” are going to be signed.
- IK contract preparation is under way.

Thank your for the kind attention