# Drift Tube Linac

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# Status

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- The CDR took place 22-23 June 2015, giving the green line to material procurement and construction (after completion of last prototypes).
- The technical annex of the in-kind contribution contract is being finalized in these weeks.
  - The DTL (Drift Tube Linac) cavity is constituted of 20 modules, assembled in 5 tanks, composed of 4 modules 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 and 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 4
7. Operation with the other Accelerator components (and neutron production target).

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

Rough material for tank 4 mod 3, 403 L forged

# DTL organization in INFN

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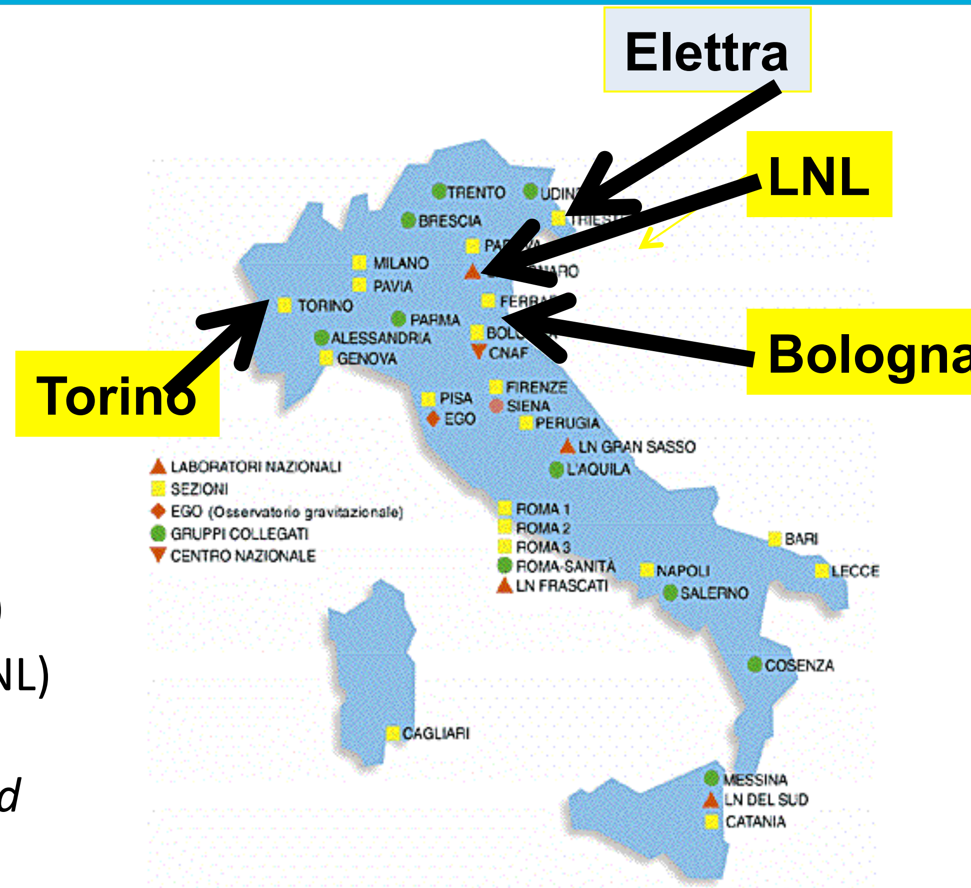
- Andrea Pisent (WU coordinator, LNL)
- Francesco Grespan (deputy coordinator, LNL)
- Paolo Mereu (Mechanics design, Torino)
- Michele Comunian (Beam dynamics, LNL)
- Carlo Roncolato (Vacuum system and brazing, LNL)
- Enrico Fagotti (Accelerator Physics and cooling system, LNL)
- Marco Poggi (Beam instrumentation, LNL)
- Mauro Giacchini (Local Control System, LNL)
- *Collaboration with Elettra (Trieste) for the dipole steering magnets and PS design and prototyping, Davide Castronovo and Roberto Visentini*



# DTL design

# DTL Input Constraints (after the design update in 2013)

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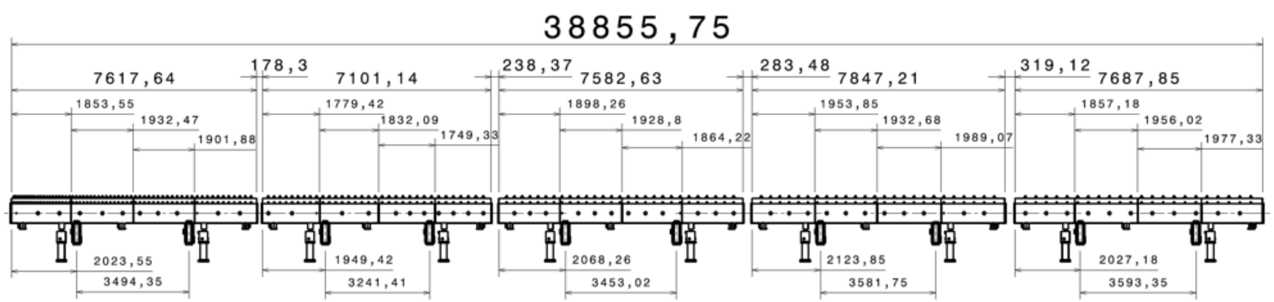
| Requirement | Target value | Comment |
|---|---|---|
| Particle type | H+ | H- are possible |
| Input energy | 3.62 MeV | +- 50 keV |
| Output energy | 90 MeV | |
| Input current | 62.5 mA | Peak, (2.86 ms long with a repetition rate of 14 Hz) |
| Input emittance | 0.28 mm mrad | Transverse RMS normalized |
| | 0.15 deg MeV | Longitudinal RMS |
| Emittance increase in the DTL | <10% | Design |
| Beam losses | <1 W/m | Above 30 MeV |
| RF frequency | 352.21 MHz | |
| Duty cycle | <6% | |
| Peak surface field | <29 MV/m | 1.6 Ekp |
| RF power per tank | <2.2 MW | Peak, dissipated+beam load, including |
| Module length | <2 m | Design constraint |
| Focusing structure | FODO | Empty tubes for Electro Magnetic Dipoles (EMDs) and Beam Position Monitors (BPMs) to implement beam corrective schemes |
| PMQ field | <62 T/m | |

# DTL design



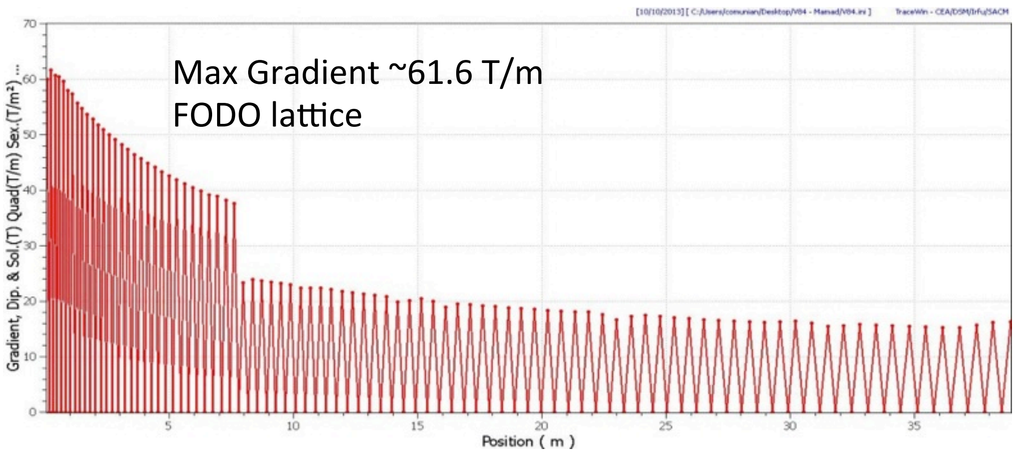
| Tank | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Cells | 61 | 34 | 29 | 26 | 23 |
| $E_0$ [MV/m] | 3.00 | 3.16 | 3.07 | 3.04 | 3.13 |
| $E_{max}/E_k$ | 1.55 | 1.55 | 1.55 | 1.55 | 1.55 |
| $\phi_s$ [deg] | -35,-25.5 | -25.5 | -25.5 | -25.5 | -25.5 |
| $L_{Tank}$ [m] | 7.62 | 7.09 | 7.58 | 7.85 | 7.69 |
| $R_{Bore}$ [mm] | 10 | 11 | 11 | 12 | 12 |
| $L_{PMQ}$ [mm] | 50 | 80 | 80 | 80 | 80 |
| Tun. Range [MHz] | ±.1. | ±1. | ±1. | ±1. | ±1. |
| 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 |

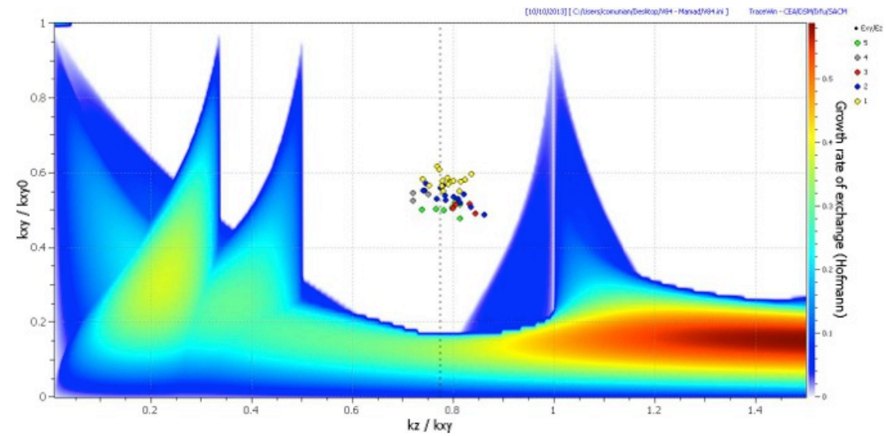


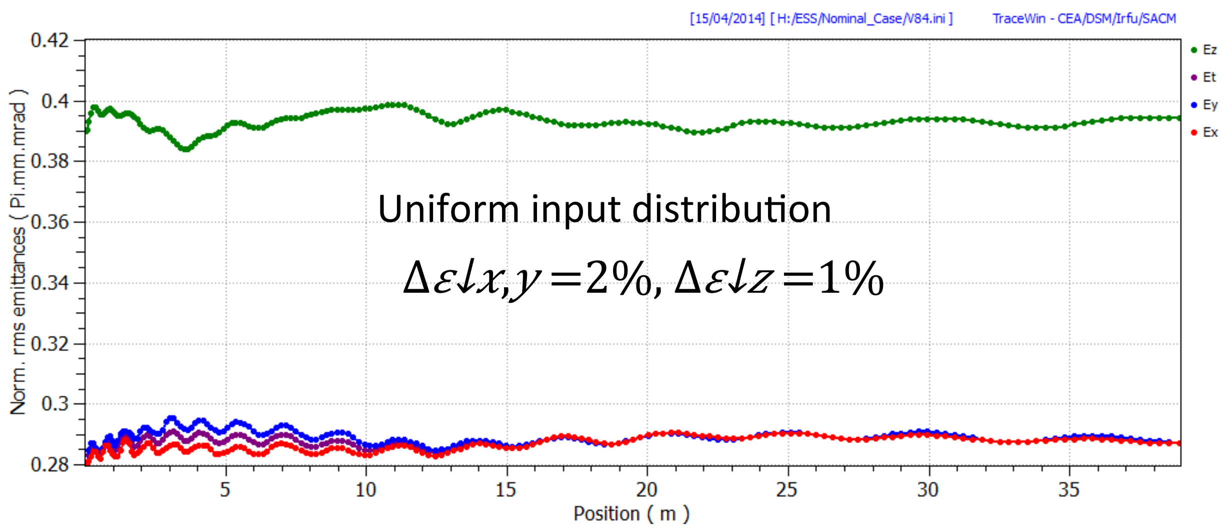
# DTL design MAIN CHOICES

- Beam dynamics
  - FODO cell PMQ focusing, internal BPM and steering dipoles for orbit correction, space for additional beam instrumentation in the inter-tank transitions.
  - With this architecture the beam dynamics is very smooth, with short focusing period, to fulfill the emittance increase requirement.
  - Reliable and resistant respect to construction errors
  - Conservative parameters, very large longitudinal and transverse acceptance, equipartitioning.
- Resonator
  - Homogeneous accelerating field (no field ramping)
  - Tuning with movable plungers, independent temperature setting for each tank.
- Mechanical design
  - CERN linac4 design is acknowledged as basis (agreement KF 1807/BF/Linac4)
  - DT design was deeply modified, to house the cabling for BPMs and Steerers:
  - copper plated stainless steel stems (brazing and e-beam welding used).
  - After the CDR the tank structure has been deeply modified.

# Beam dynamics



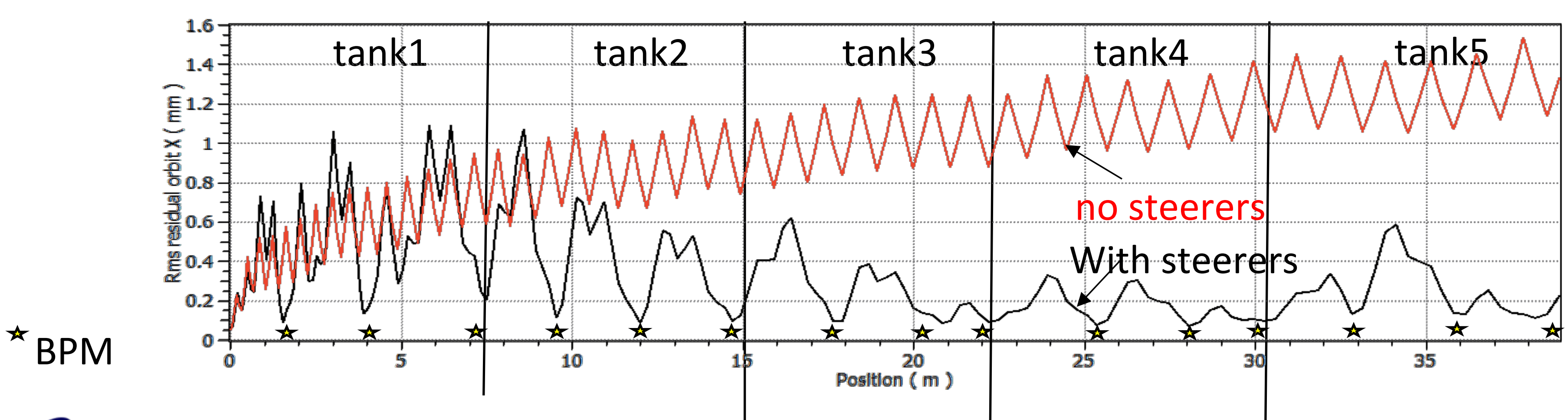



# Nominal errors

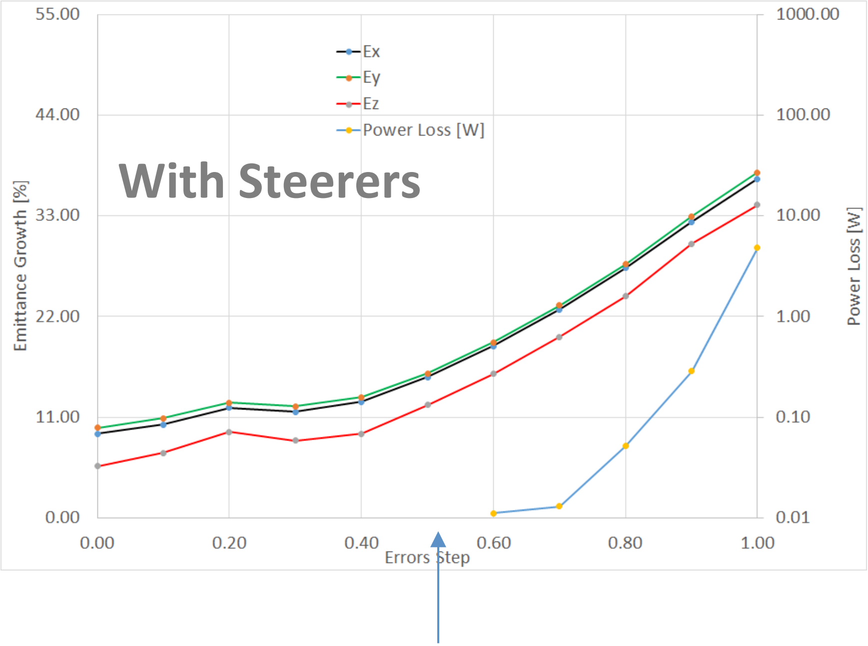
| Nominal set of Tolerances, so called “nominal errors” | | |
|---|---|---|
| DTL Errors | Name | Values |
| PMQ position | δx, δy | ±0.1mm |
| PMQ rotation | ϕx, ϕy, ϕz | ±1 deg, ±0.2 deg |
| PMQ gradient | ΔG/G | ±1 %, |
| PMQ ageing | ΔG/G | -5 %, |
| PMQ multipole contents | | ±1 %, |
| E0 field flatness | $\Delta E_0/E_0$ | ±2 %, |
| Synchronous phase | $\delta\phi_{synch}$ | ±2 deg, |
| Klystron RF phase and amplitude | $\Delta E_{kly}/E_{kly}$; $\phi_{kly}$ | ±1 %,<br>±2 deg, |
| Tank to tank position | $X_{tank}, Y_{tank}$ | ±0.1mm, |
| BPM precision | $X_{bpm}, Y_{bpm}$ | ±0.1mm, |
| Max Steeres strength | Sx,Sy | ±16mT*m |

r.m.s. beam center displacement for sets 1000 error cases, with and without steerers (M. Comunian)



# Average values of Emittance and Losses

Steerers improve losses of 1 order of magnitude, emittance improves of 10%

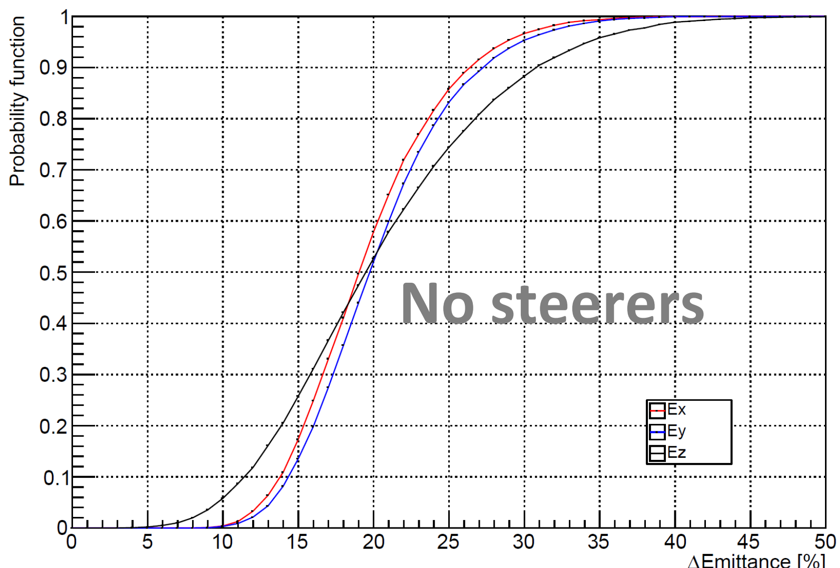




Nominal error amplitude

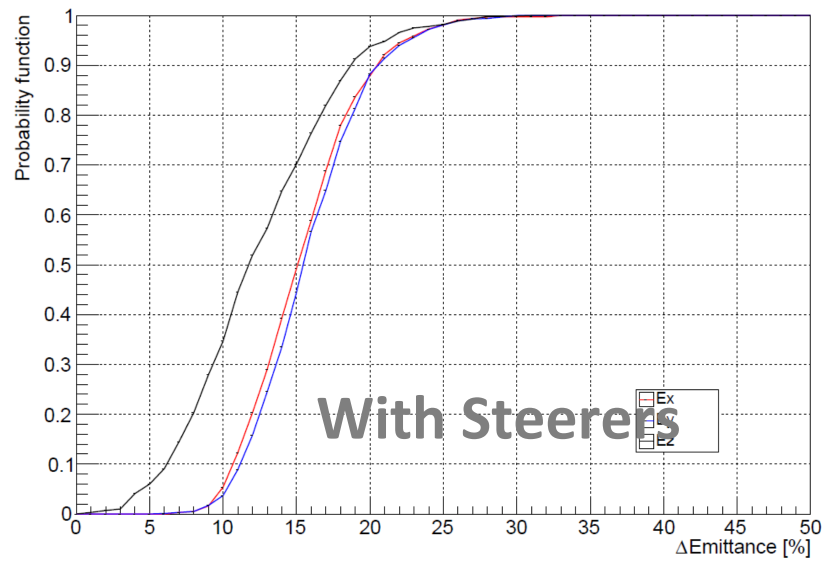
Nominal error amplitude

# Probability function of emittance growth with uniform errors dist.

For ΔE < 20% improvement from 60% to 90% of the cases
For ΔE < 30% improvement from 90% to 99% of the cases




“nominal errors”
100 000 Macro Particles Gaussian (3σ) dist. 10000 statistical runs.
Max power lost=5098 Watts; average=0.86 Watts;
Power Lost (99.9%)=206 W

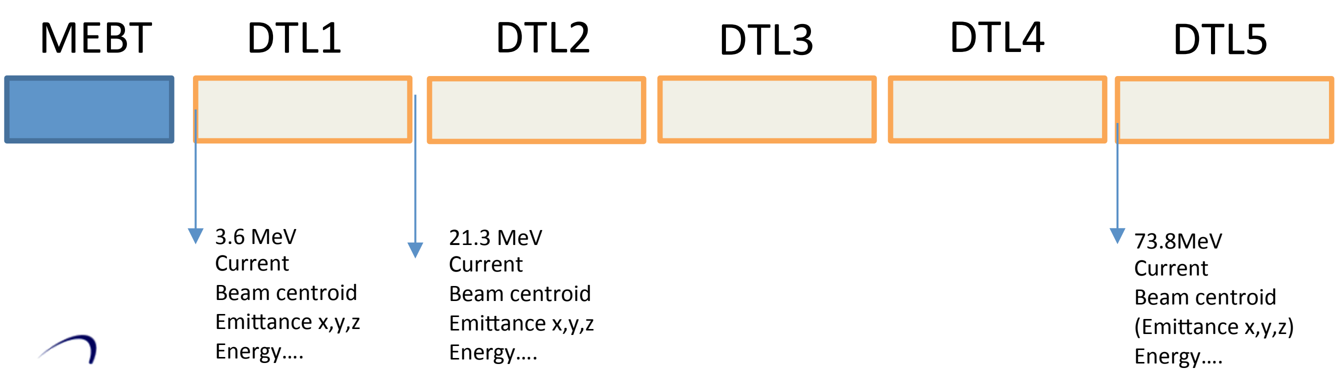



“nominal errors”
100 000 Macro Particles Gaussian (3σ) dist. 1000 statistical runs.
**Using Steerers and BPM**.
Max power lost=0 Watts;

Possible further optimization of the BPM and steerer positioning within 1st June 2016 (in collaboration with ESS beam dynamics group)

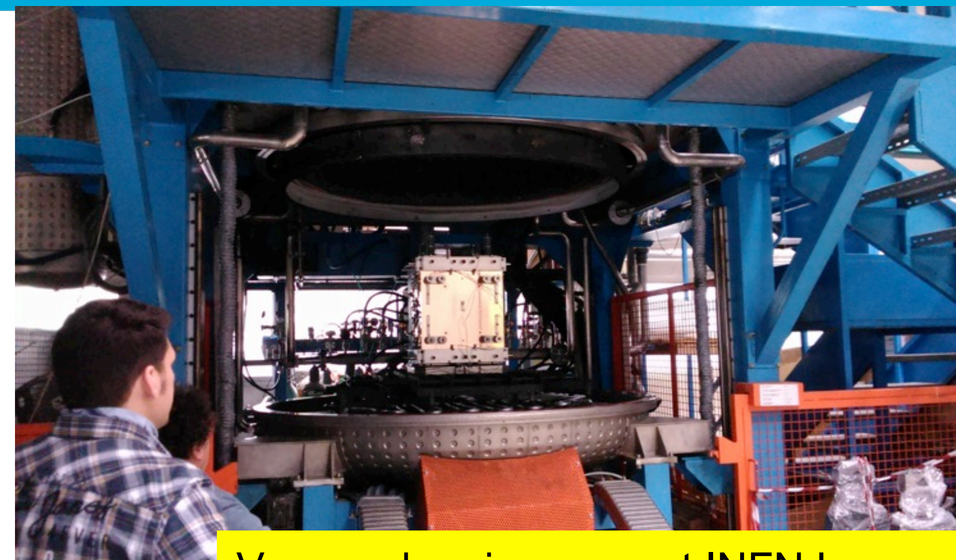
# General Commissioning strategy

- The DTL tanks will be produced and conditioned in the tunnel (in the order 4, 3, 1, 2, 5). The duty cycle to achieve is at least 7%.
- Conditioning of tank 4 is the high power test of the structure (RF design, cooling water stabilization, tuning with movable tuners, RF restart, computer control…..)
- Prerequisite of beam commissioning is the full characterization of the MEBT beam characteristics.
- The beam commissioning will be in two steps, after tank1 and after tank4. After tank 5 performances assessed together with the spoke section.
- The INFN proposal is to use a dedicated temporary **diagnostic plate** in the three locations (together with BPMs in the DT and **inter-tank diagnostics**).



# DTL Selected technologies

- Key mechanical technologies
  - High precision machining
  - Qualification of small parts, (DT) by CMM and large pieces (tank) (laser tracker, arm..)
  - E-beam welding (Zanon, CERN….)
  - Vacuum brazing (in house and Cinel)
  - Copper-plating of large tanks (two possible providers,
    CERN and GSI)



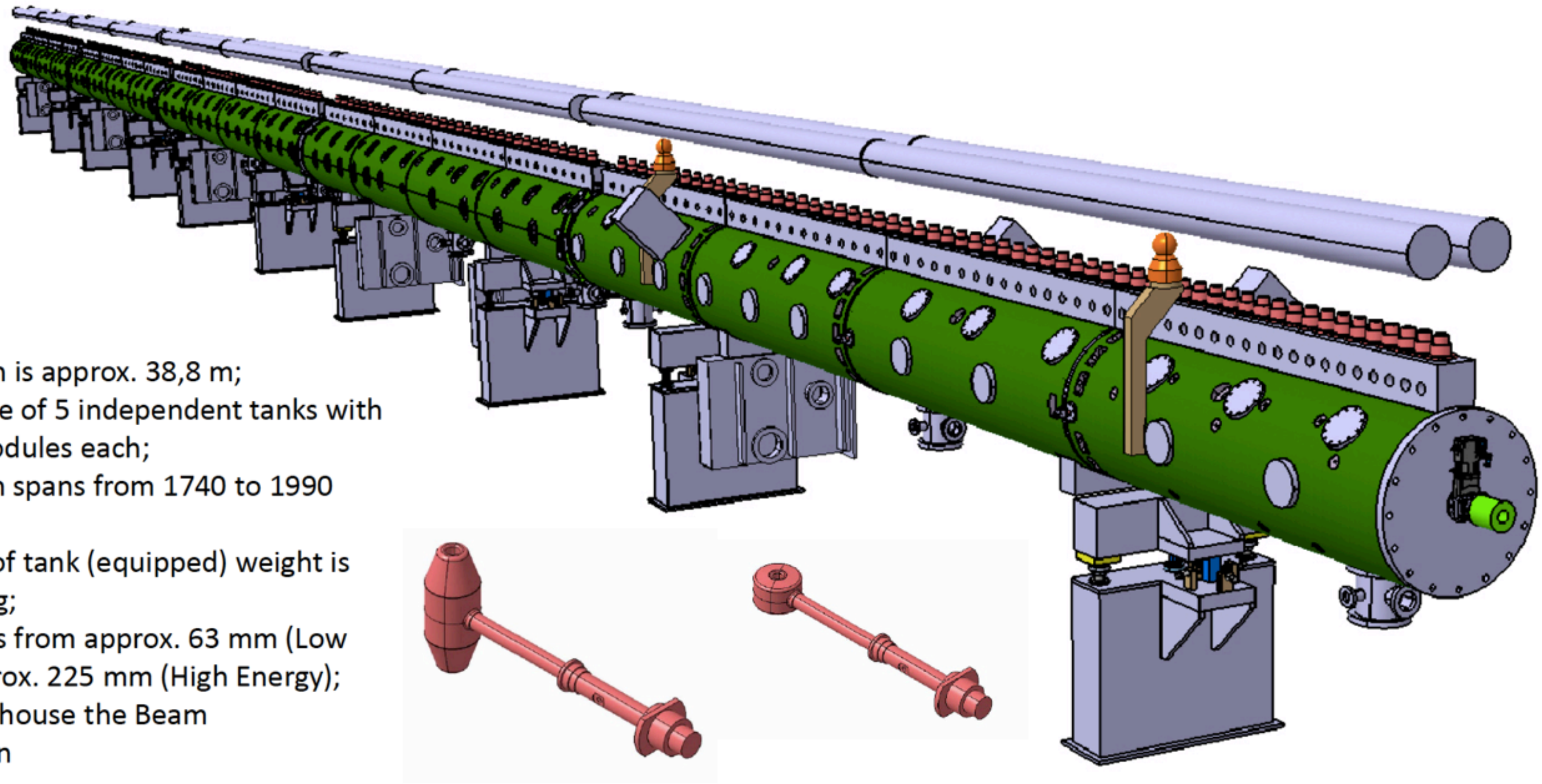
Vacuum brazing oven at INFN Legnaro

- Construction procedure
  - Construction of drift tubes and tanks with base in LNL, assembly at ESS Lund.
  - **A dedicated laboratory (DTLW) in Lund is necessary since beginning 2017 (with reference schedule)**

CMM machine at INFN Padova

# Mechanics design

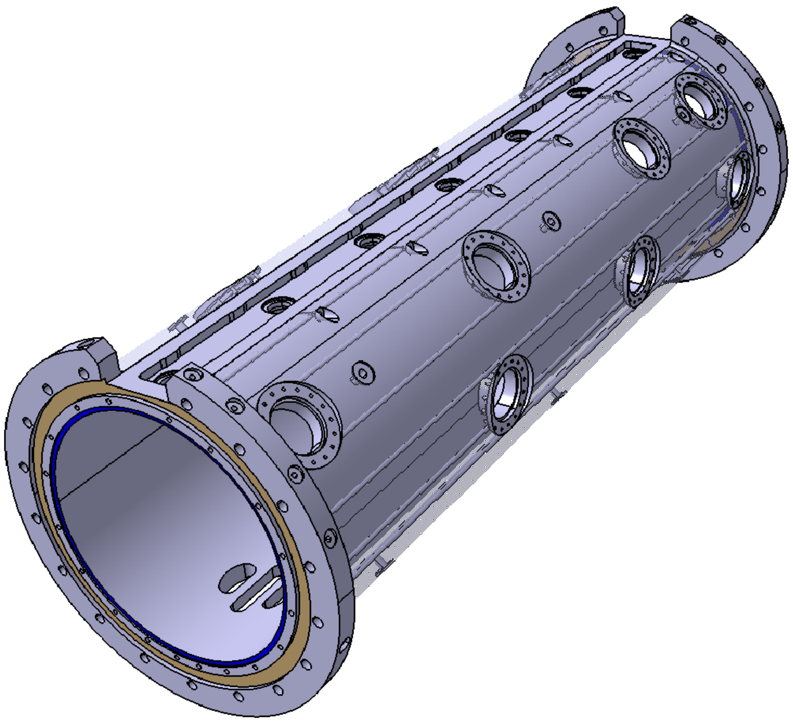
## General characteristics and design criteria of the DTL

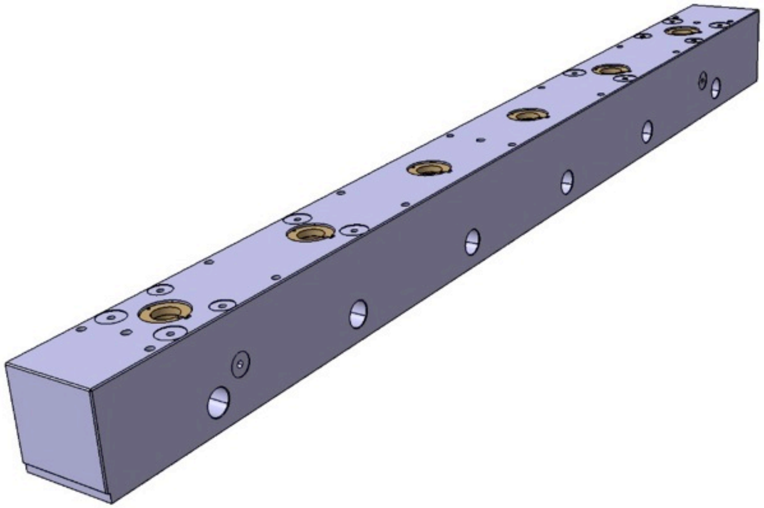


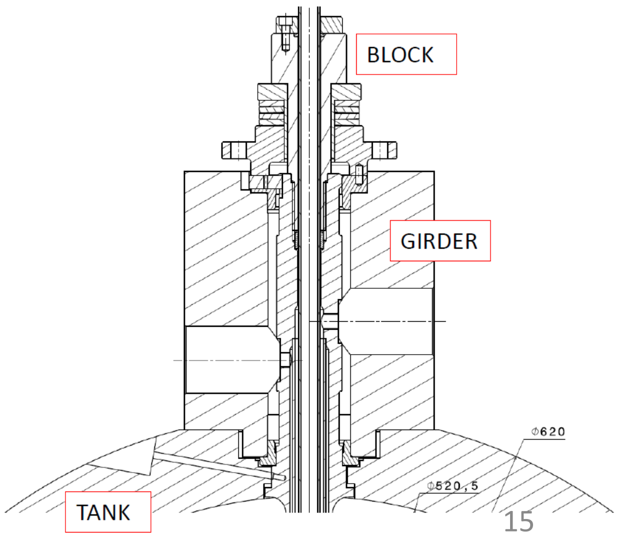
- DTL total length is approx. 38,8 m;
- The DTL is made of 5 independent tanks with 4 segments/modules each;
- Segment length spans from 1740 to 1990 mm;
- Each segment of tank (equipped) weight is approx. 1700 kg;
- DT length spans from approx. 63 mm (Low Energy) to approx. 225 mm (High Energy);
- 4 Intertanks to house the Beam instrumentation

# The tank and the girder

- The precision of the PMQ positioning (0.1 mm) is guaranteed by the stiffness of the tank, the precision of the girder and of the various mechanical couplings.

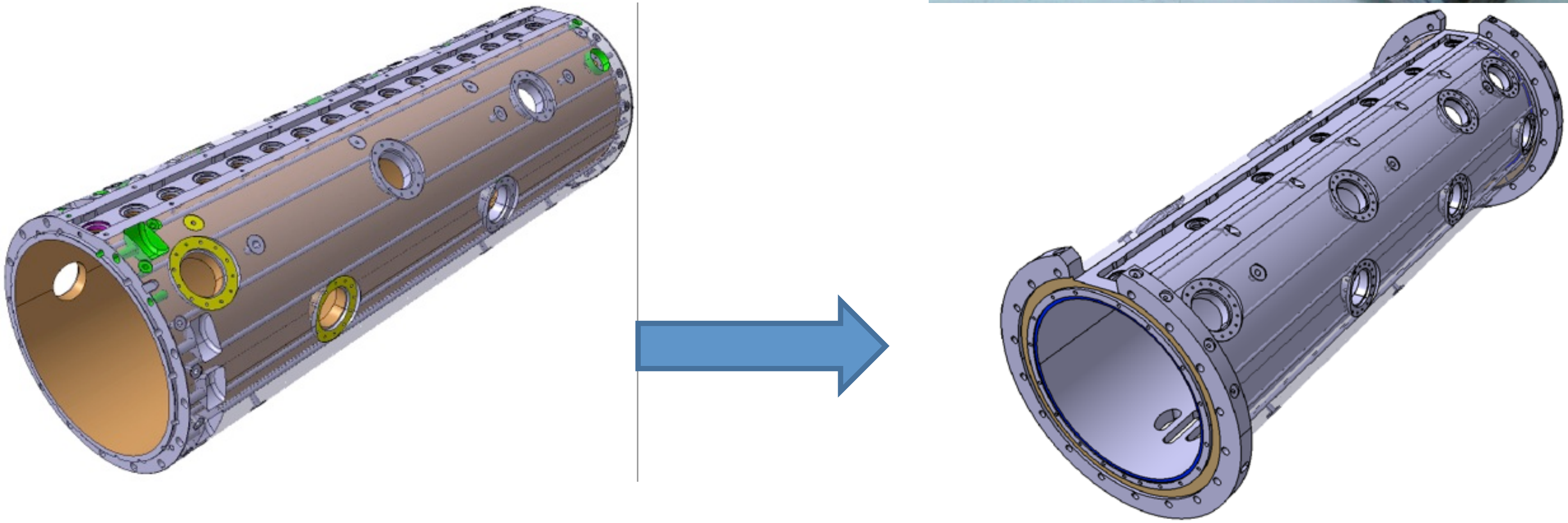


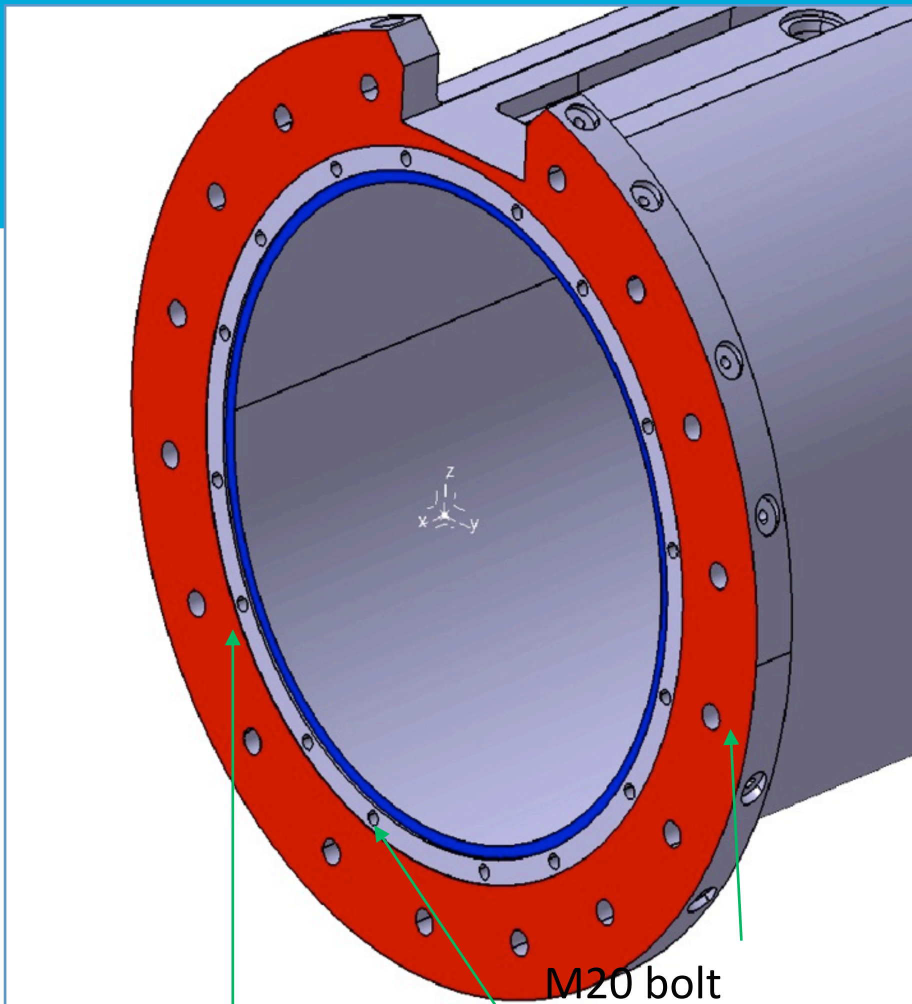




# After the CDR new design of head flanges

– New design of the head flanges of modules to easy the reproducible positioning and the assembly of modules. (spring metallic joints as we are using for IFMIF RFQ)

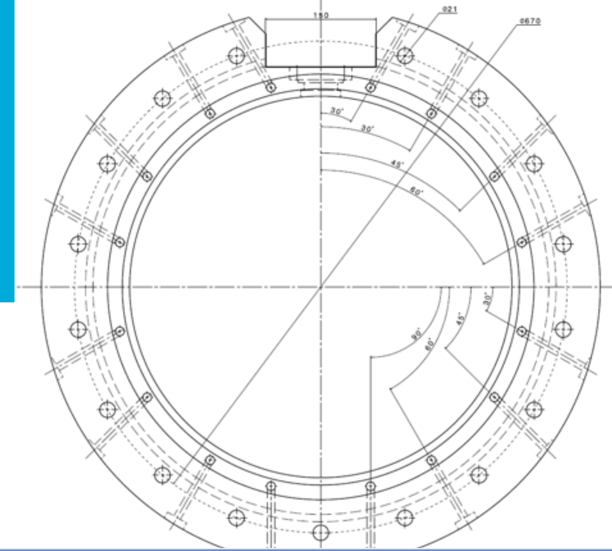


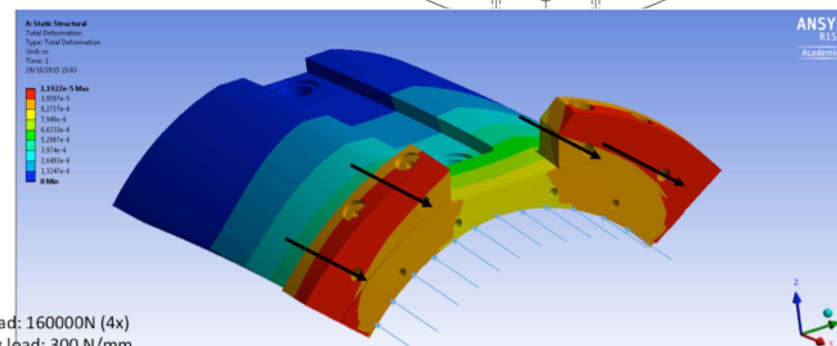


M20 bolt

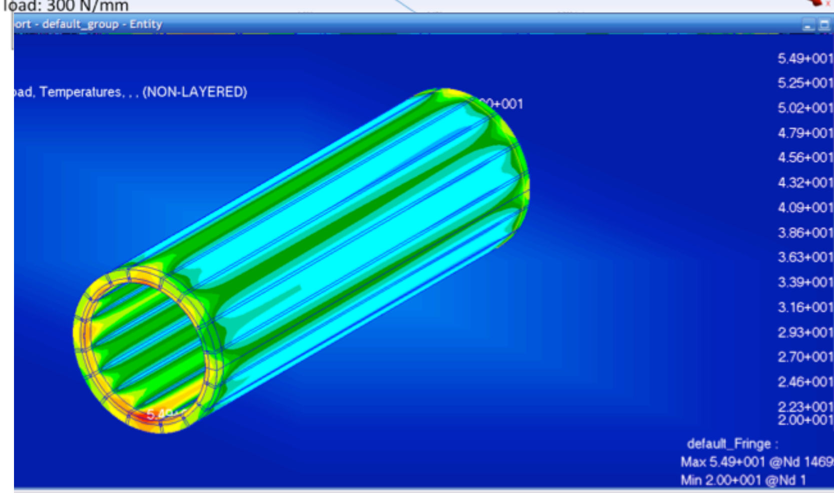
Vacuum seal

Water distribution holes






Bolt load: 160000N (4x)
Sealing load: 300 N/mm



# Alignment and assembly of IFMIF RFQ super modules, metallic spring gaskets

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# Drift tube design

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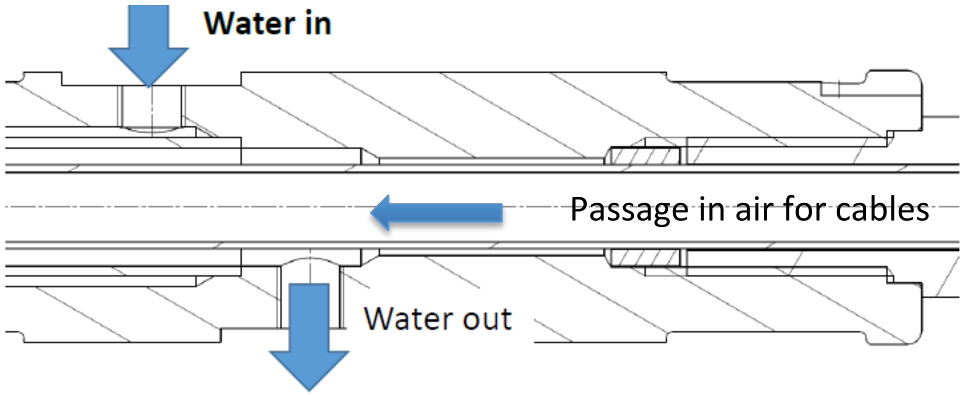
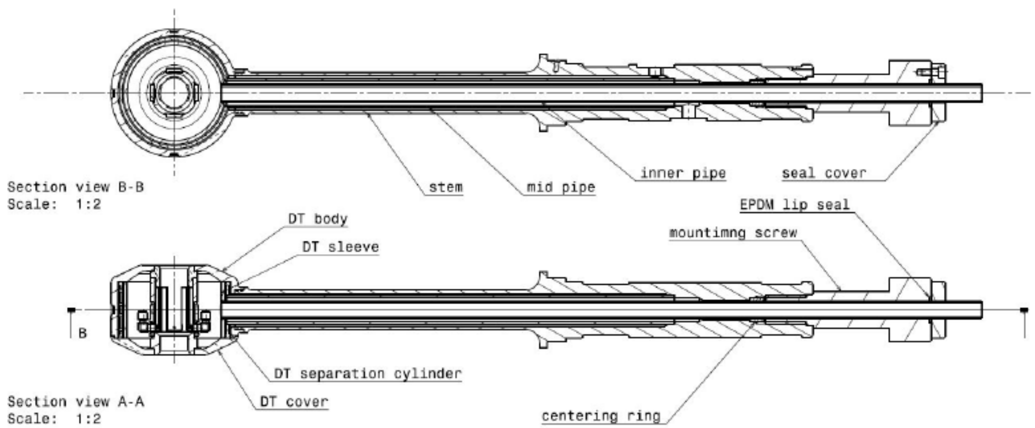
The design of the DTs is derived from the LINAC4 design:

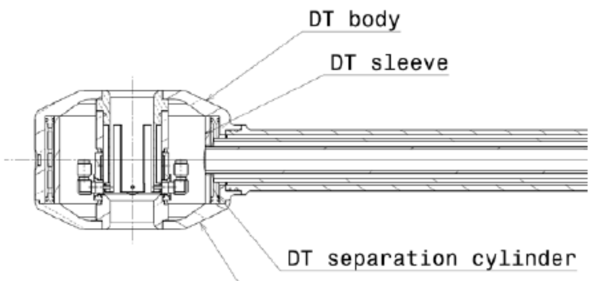
- Stem and DT
- Water distribution system for the DTs;
- Sleeve and separation cylinder in the water flow inside the DT body
- Integration and alignment of the DTs with the tank/girder system;
- Machining of the reference surfaces on the DTs for the coupling with the bushings in the girder;
- Final circular EBW sealing of the DTs (body and cover interface);
- Integration of the PMQs inside the DTs.

Major modifications from LINAC4:

- Vacuum brazing;
- Stainless steel stem with copper deposition;
- Integration of steerers and BPMs in the DTs



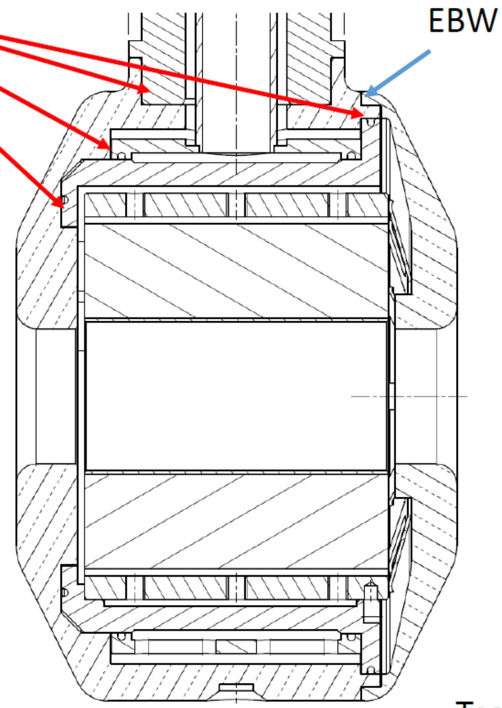



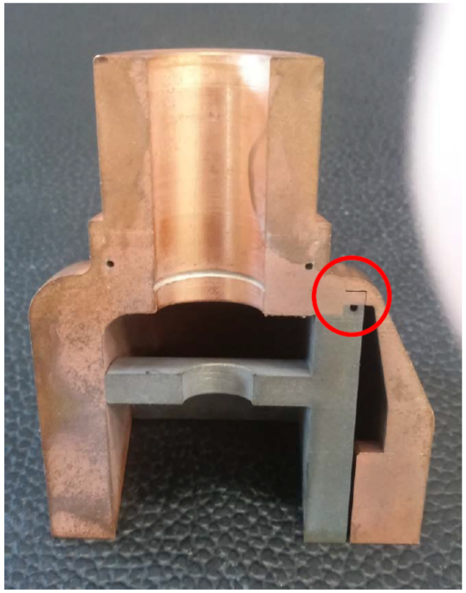



# DT Brazing and e-beam welding

## Vacuum brazing vs. EBW in the production of the DTs

The vacuum brazing technique is a very well known and widely used technology in INFN-LNL, where a lot of expertise has been reached during RFQ IFMIF production with very good/excellent results in terms of maintaining the geometrical tolerances of the brazed components.
Vacuum brazing has therefore been used instead of some EBWs of the LINAC4 design

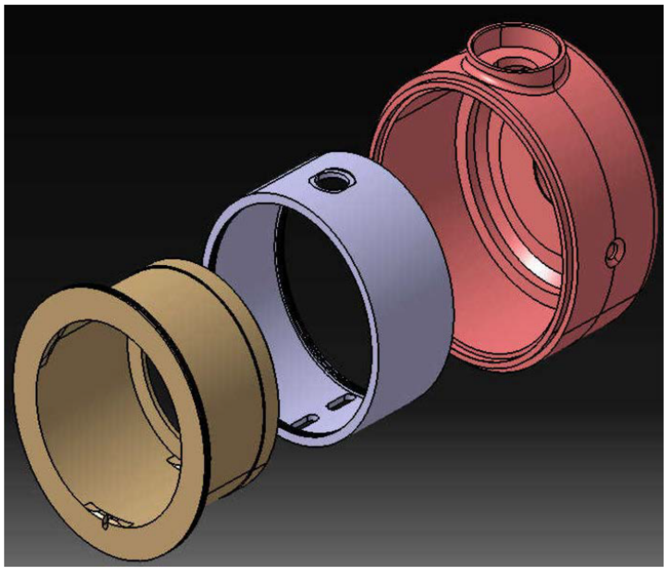


Test of the EBW sealing of the DT cover to check the vacuum tightness of the brazed joint

# Permanent quadrupole DT design

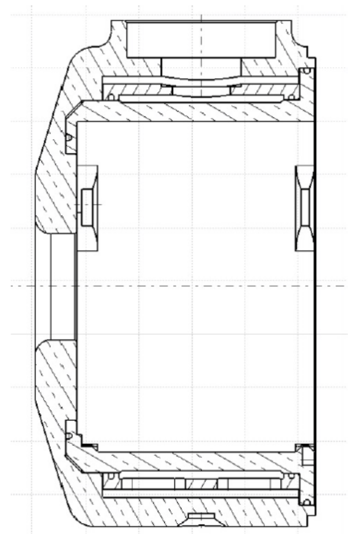




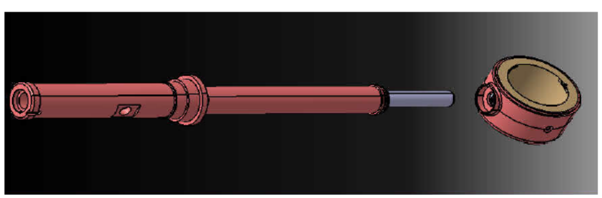
Rough sleeve 316L

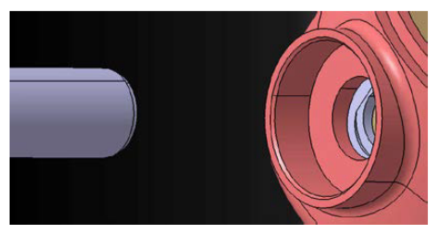
Sep. cylinder 304L

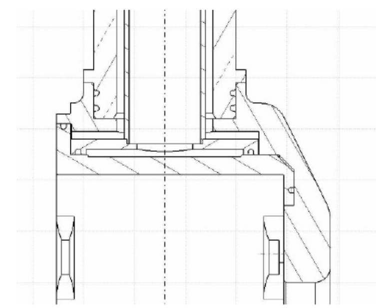
Rough DT body CuC2-OFE



The PMD DT is assembled in a two-step brazing procedure:
Step 1: brazing of the DT body with the internal components (sleeve, separation cylinder);
Step 2: brazing of the stem and internal pipe with the DT body;
After each brazing step a vacuum leak test is carried out





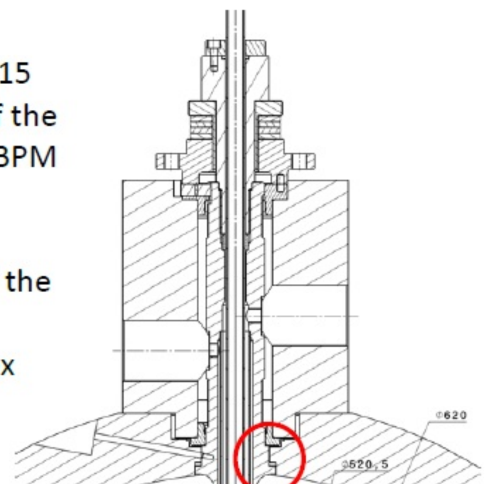


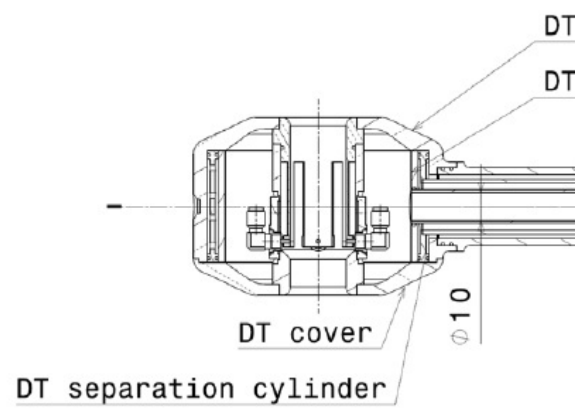
# Stainless steel stems

In red: regions to be protected from the Cu-plating

Main reasons for the steel stem design

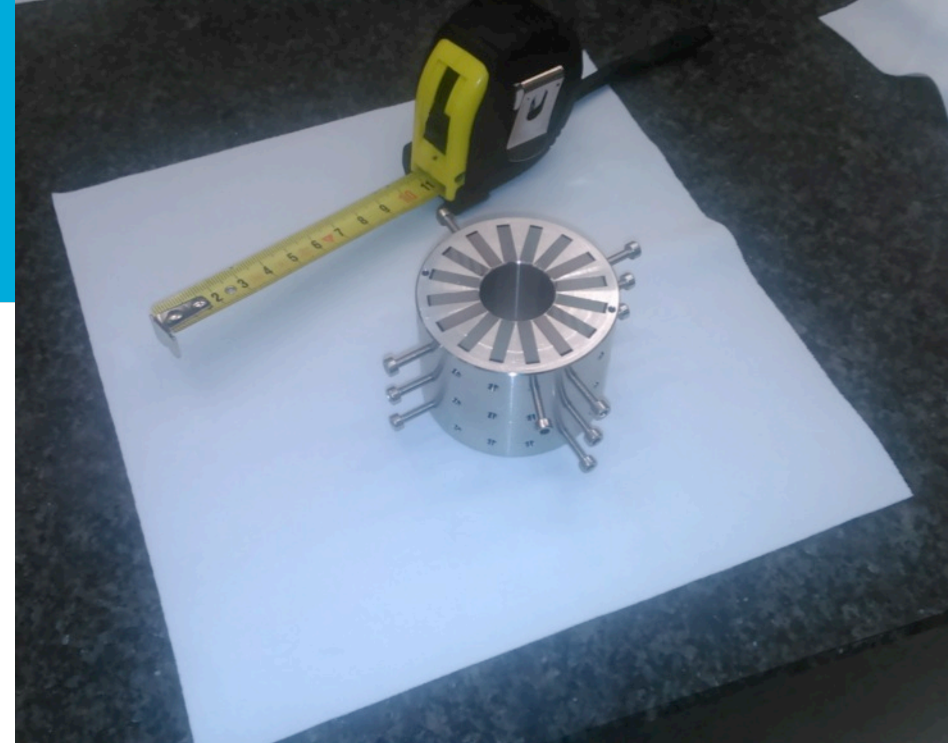
- To increase the inner space (from diameter 15 mm of the Cu version to diameter 23 mm of the steel version ) for the passage of cables for BPM and steerer with same mechanical characteristics;
- To avoid the annealing of the copper during the brazing;
- To have steel/steel surfaces for the helicoflex sealing between stem and tank





# PMQ

## (permanent magnet quadrupole)



### Rare earth block specifications (Sm2Co17):

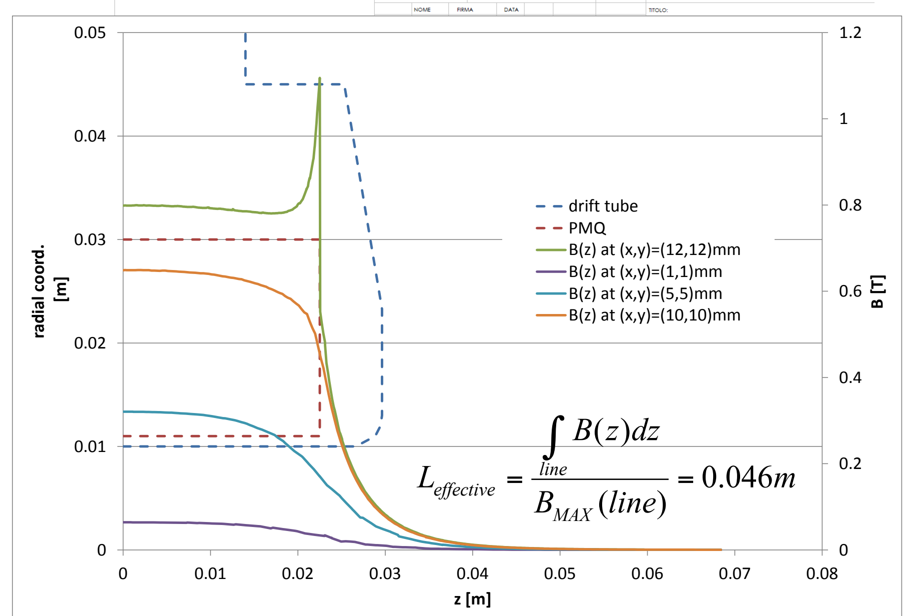
- Error Br < 3%
- Error an Angle < 2deg
- Dimension tolerances < 0.05mm – 0.1mm
- Br=1.1 T → **Simulated Gradient=65 T/m**

### Assembly specifications:

- Housing Material - Stainless Steel (316LN)
- Outgassing rate per magnet below 4.10-6mbar l s-1
- Gradient integral error (rms) -+ 0.5 %
- Magnetic versus geometric axis: < 0.1 mm
- Harmonic content at 10 mm radius: Bn/B2 for n=3,4,...10: < 0.01
- Roll: 1 mrad

### Goal:

- define assembly criticalities
- verify feasibility of specifications
- define magnetic measurement bench and procedure
- tunability of PMQ
- Company qualification



# Prototypes: PMQ

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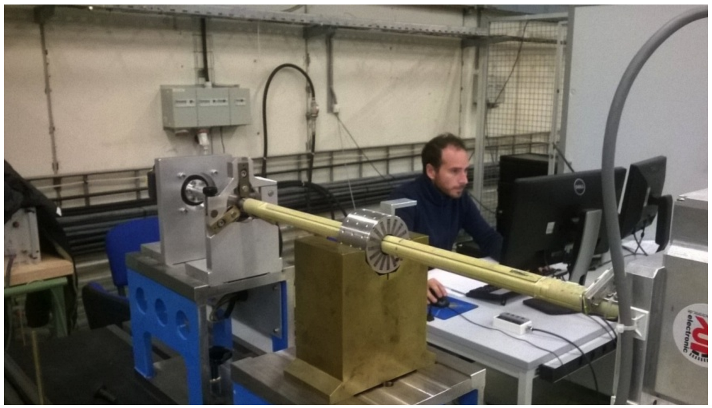
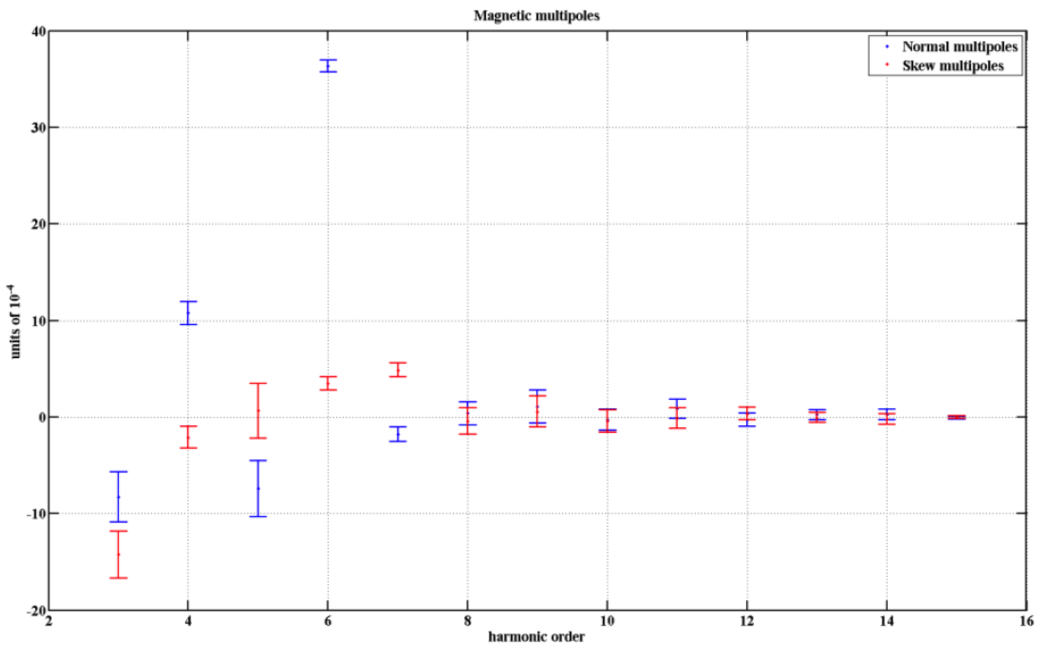


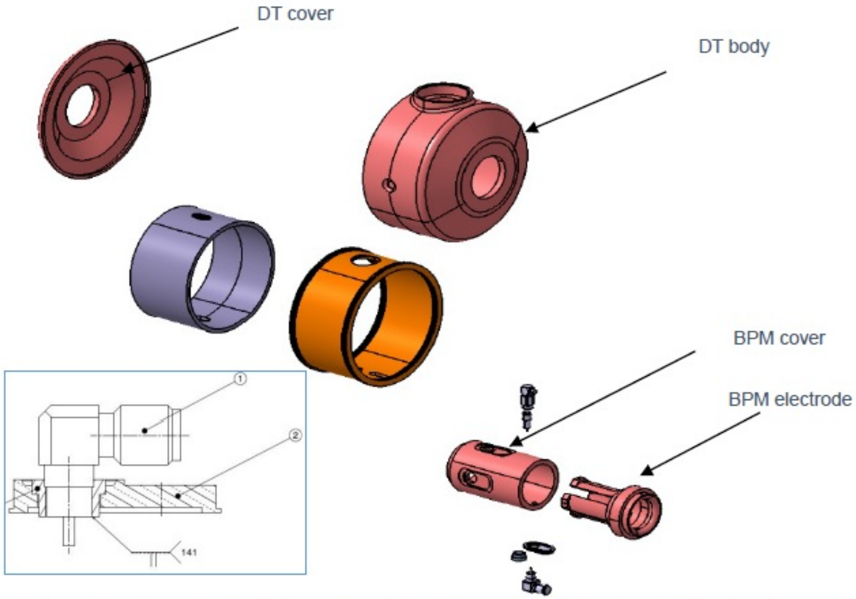
The PMQ prototype built and assembled at INFN-Torino has been measured with a rotating coil at CERN

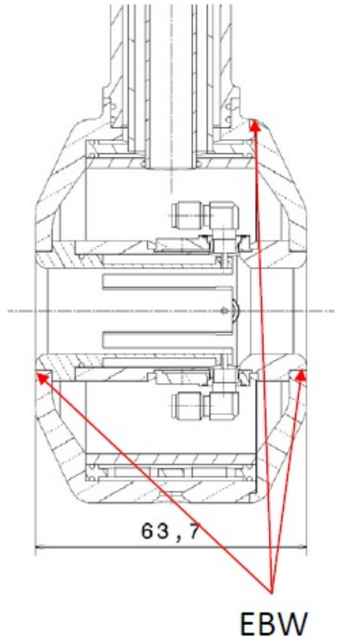
The integrated gradient is 63.7 T/m and the harmonic content is lower than 1% at 7.5 mm radius



# Beam Position Monitor DT design

## Beam Position Monitor DT design

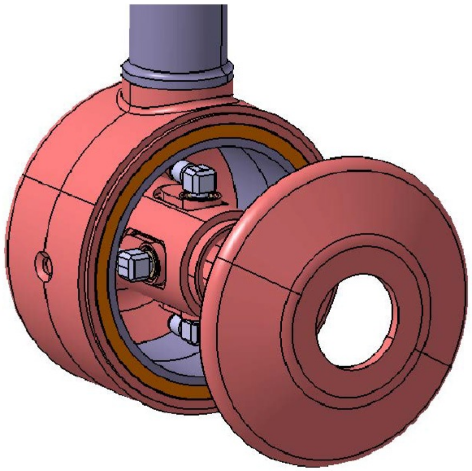


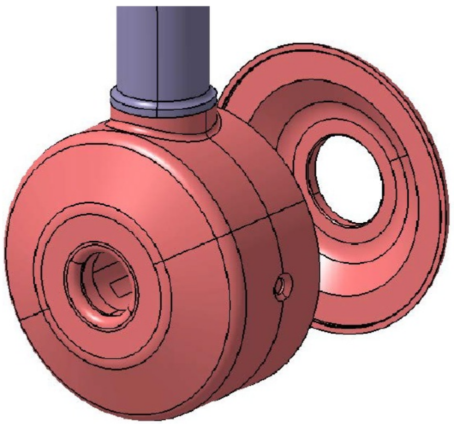

The production of the BPM DT is a combination of Vacuum Brazing and EBW steps:

- Brazing of the **steel** collar of the feedthrough on the **copper** oval support;
- TIG welding of the feedthrough on the steel collar;
- Brazing of the two components of the BPM (cover, electrode);
- EBW of the assembled KAMAN feedthrough on the BPM cover housing;
- Machining of the radius and final length of the BPM;
- EBW of the machined BPM on the DT body
- EBW of the cover of the DT on the DT body and on the BPM

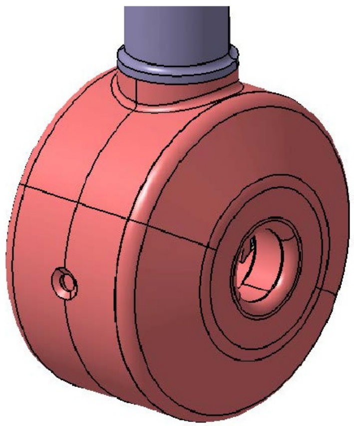
# BPM drift tube assembly



The BMP is inserted in the DT body (the BPM cables are pulled through the inner pipe up to the end of the stem



The BMP is EB welded on the DT body in the Central area

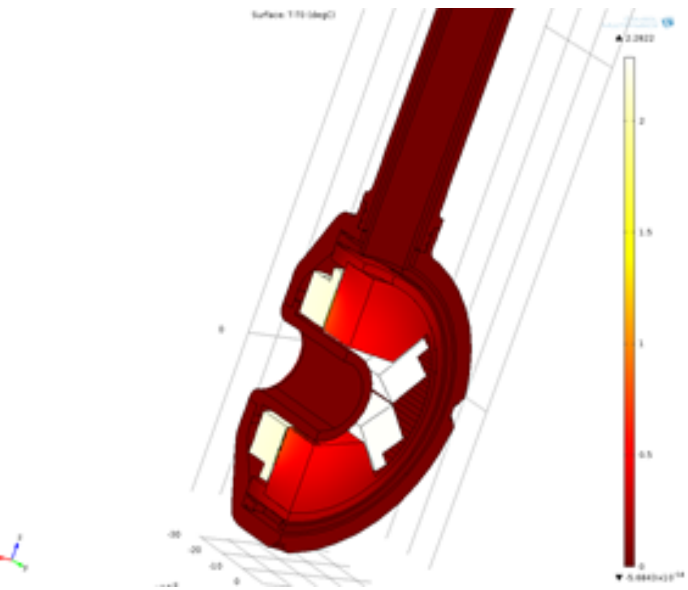


The BMP DT is sealed with last EB weld between the DT body, the DT cover and the BPM on the DT cover

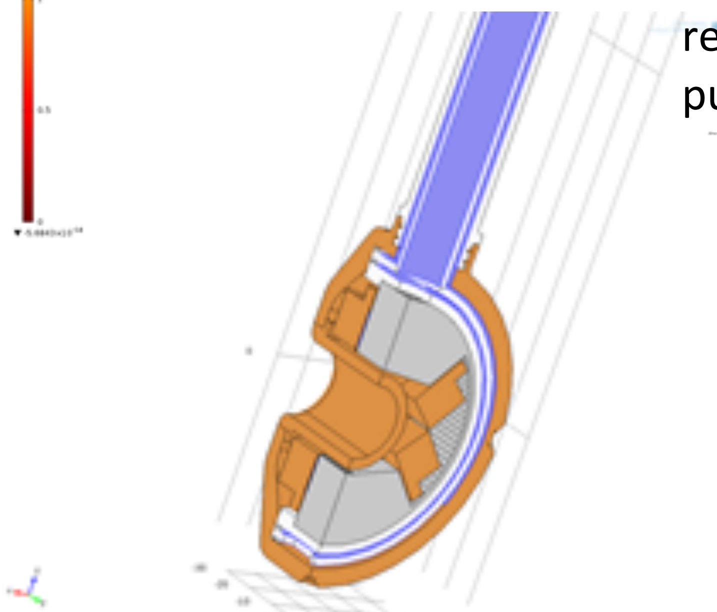
The DT with the BPM is calibrated on the calibration bench and the references of the DT body and on the stem are machined

# New steerer design, flexible cable and same DT design





Conductor (including insulation) 4x1.8 mm (sez. 6.837 mm2) and 20 turns each, Ic =20A determines IntBy =16.5 Gm.
The average current is reduced to 1 A/$mm^2$ by pulsing.




Design by *Davide Castronovo, Sincrotrone Trieste*

# Schedule

EUROPEAN SPALLATION SOURCE

- The detailed schedule, very aggressive, is being optimized.
- In the production sequence
  - Tank 4 test on line of RF characteristics
  - Tank 3
  - Tank 1 (beam tests up to tank 1)
  - Tank 2 (beam tests up to tank 4)
  - Tank 5
- The DTL lab in Lund should be ready to start DTL module assembly beginning of 2017
- The completion of tank assembly and transfer to the tunnel in middle 2019

# Production sequence

1. Forged cylinders production, tank machining, copper plating. Girder and other components, CMM and vacuum tests…
2. Production of the beam components (PMQ, BPM, dipole steerers)
3. Production of vacuum, support and inter-tank components
4. DT Brazed  structure production (with cooling circuit tested)
5. Integration of the beam component in the DT
6. E-beam welding sealing, final tests on DTs
7. Assembly of the module (2 m), installation and alignment of the DTs
8. Assembly of the tank (4 modules), alignment, machining of the adaptation rings for relative position, tuning, tuners, ports, vacuum test,…
9. Installation and alignment of the tanks in the tunnel, installation of the intertank plates
10. Installation of vacuum, cooling, RF couplers….

NOTE 1-6 al INFN site, 7-8 DTL workshop at Lund, 9-10 in the tunnel

# Optimization of the schedule

- Optimization of the critical path schedule (tanks and girders production):
  - SS Forged material: the first tube has been ordered in December ‘15. The procedure to procure the entire amount (20 tubes) ASAP (approval by INFN board of directors (CD) in May ‘16)
  - Tank machining in two procurements (2+3 tanks): CD of May ‘16 and December ‘16.
  - Transportation from maching premises to electroplating to DTLW at RATs module by module (at least 40x1500 km 2 tons transportation).
- MoU with GSI about copper plating needs to be signed June ‘16
- Very optimistic compression of procedure time in various steps of procurement procedure.
- No contingency at all for any technical problem (in the production or in the availability of the infrastructures).

# RFI dates and associated risk transfer to ESS.ERIC (in-kind contract not yet signed)

- Start date: [Signing date]
  - RFI date tank #4: 2017-10-20
  - RFI date tank #3: 2018-02-22
  - RFI date tank #1: 2018-06-01
  - RFI date tank #2: 2018-10-01
  - RFI date tank #5: 2019-02-01
- End date, transfer of ownership: [date]
- To be added in section 4:
  - To be in line with the ambitious time schedule, INFN was forced to reduce the duration of the purchasing and quality assurance phases. **This increases the level of risk of the risk portfolio, both in terms of time, cost and technical performance, which are transferred to ESS-ERIC.**
- To be added in section 5:
  - 5.X Risks management
  - A risks management process is performed at INFN at the work package level for the WU scope of Work. Thus, it will include risks impacting technical requirements, performances, design, time schedule, costs.
  - Concerning the DTL WU, specific risks register linked to the ambitious schedule is provided in annex -XX-. The consequences, the mitigation or the corrective actions, as well as the impact on INFN of the corresponding risks are under ESS responsibility both in term of performances and costs.

- Thank you for your attention