Design, Development and Manufacturing Experiences for Sirius Button BPM

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On behalf of Materials, Vacuum and Mechanical Projects Group

CNPEM
Brazilian Center for Research in Energy and Materials

LNLS sirius
Brazilian Synchrotron Light Laboratory

Outline

- Sirius Overview
- Developments
  - Electromagnetic Analysis
  - Button/ceramics/housing brazing
  - Housing-to-body insulation (flange or welding)
  - Wake Heating Analysis
- Quality Control
- Production

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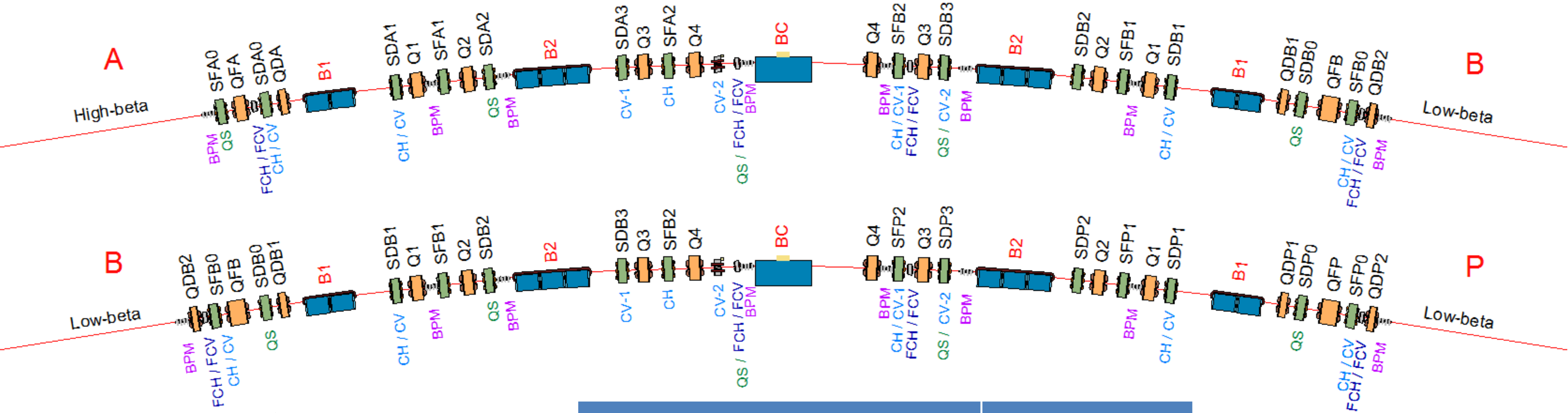
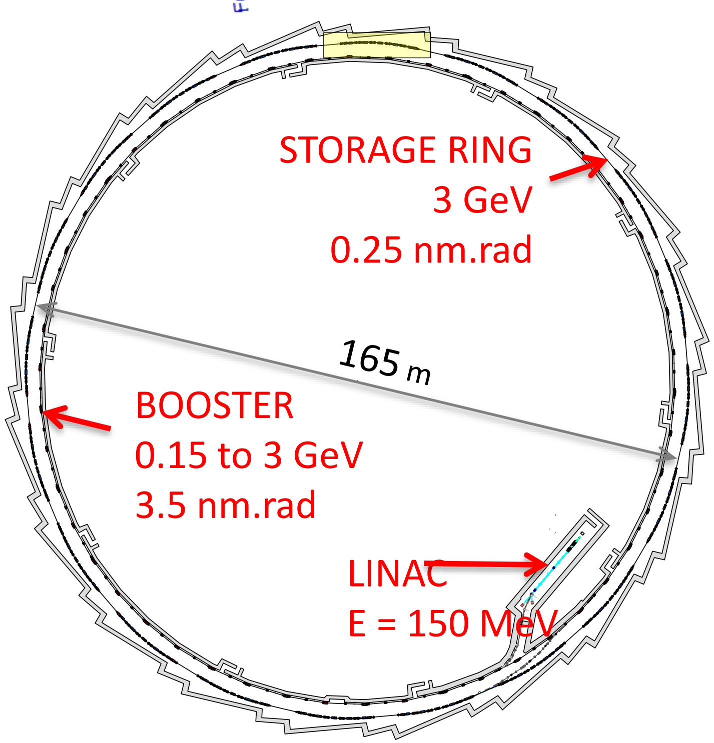
Sirius Main Parameters

A superperiod is composed of one high-beta and 3 low beta sections: A-B-P-B



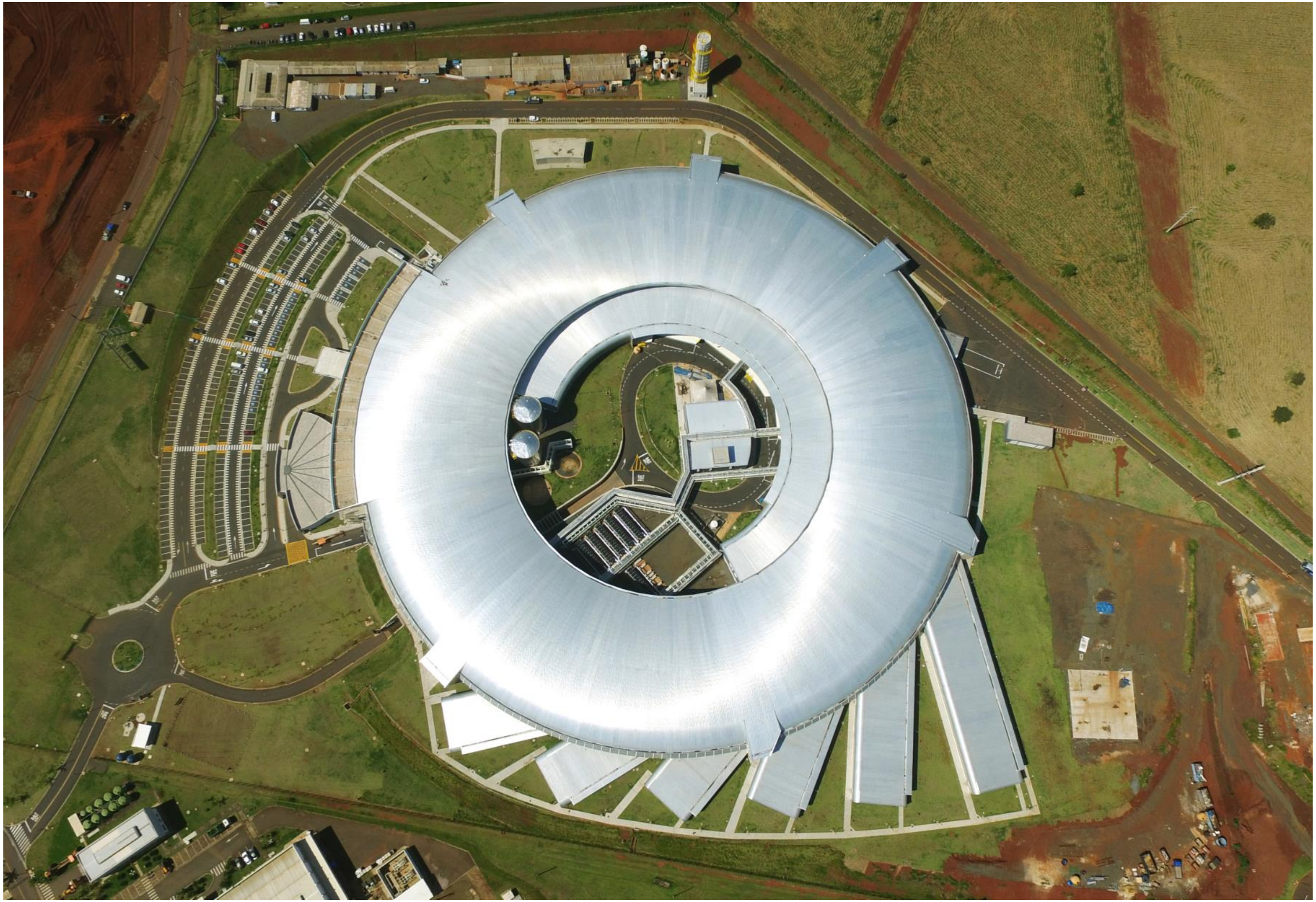


Storage Ring Parameter	Value
e^--Beam energy	**3.0 GeV**
Circumference	**518.4 m**
Lattice	20 x 5BA
Hor. emittance (bare lattice)	**0.25 nm.rad**
Hor. emittance (with undulators)	**0.15 nm.rad**
Betatron tunes (H/V)	49.11 / 14.17
Natural chrom. (H/V)	-119.0 / -81.2
Energy spread (rms)	0.85×10^{-3}
Energy loss/turn (dipoles)	473 keV
Damping times (H/V/L) [ms]	16.9 / 22.0 / 12.9
Nominal beam current (top up)	**350 mA**

8 BPMs / arc
160 BPMs in total

Sirius – March 2019

Sirius – March 2019



Installation

150 MeV LINAC commissioned in May 2018

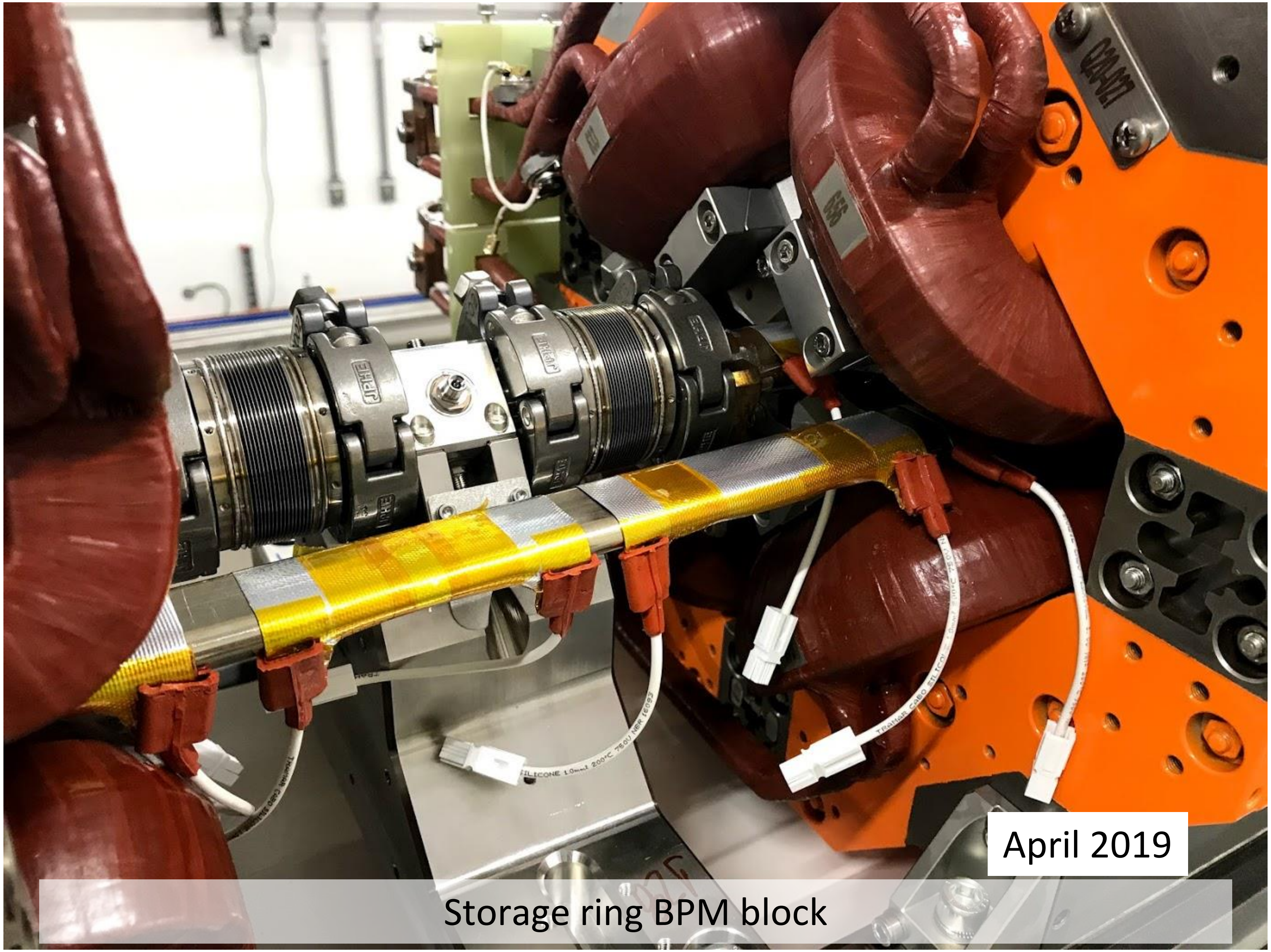
Installation

Booster cavity in place and e⁻beam at 10^{-8} mbar

Installation

First (and only) storage ring arc fully assembled, under NEG activation

Installation



Storage ring BPM block

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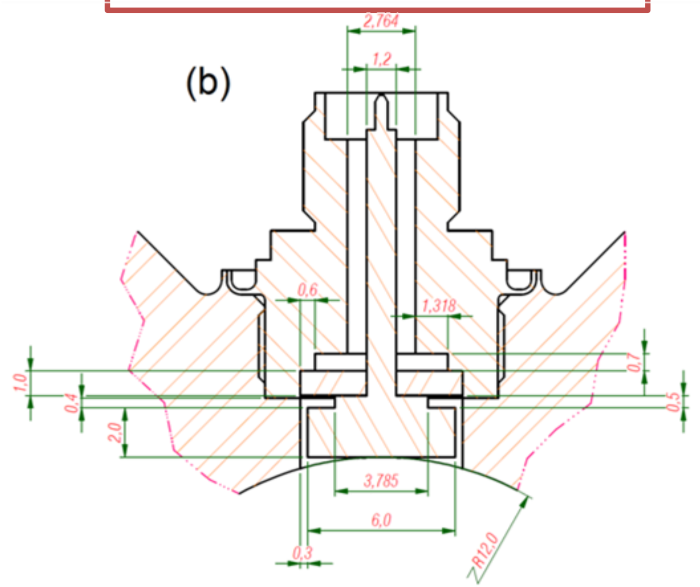
BPM – Best 3 Candidates

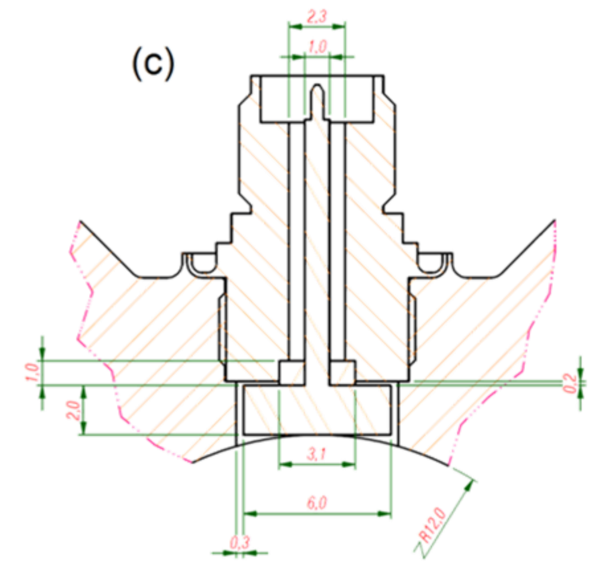
Step-Shaped BPM Button

Based on the geometry style implemented at ALBA.



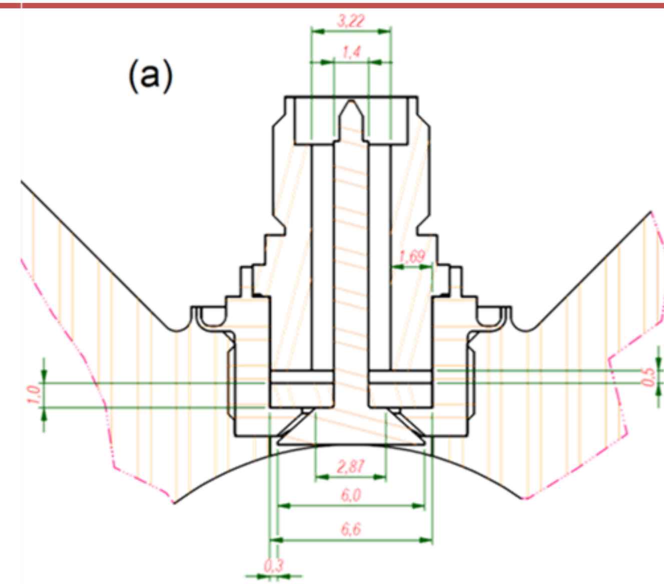
Flat BPM Button

Reduced ceramics dimensions to decrease wakelosses.



Bell-Shaped BPM Button

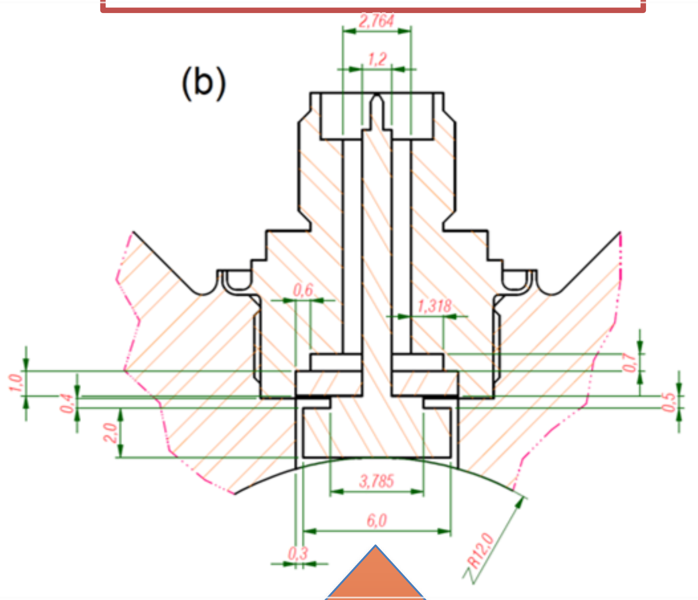
Conical profile shifts the HOMs to higher frequencies and hide the ceramics from the beam.

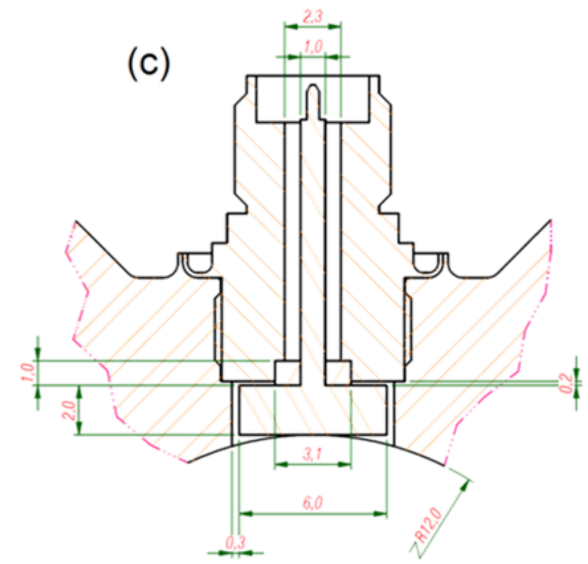


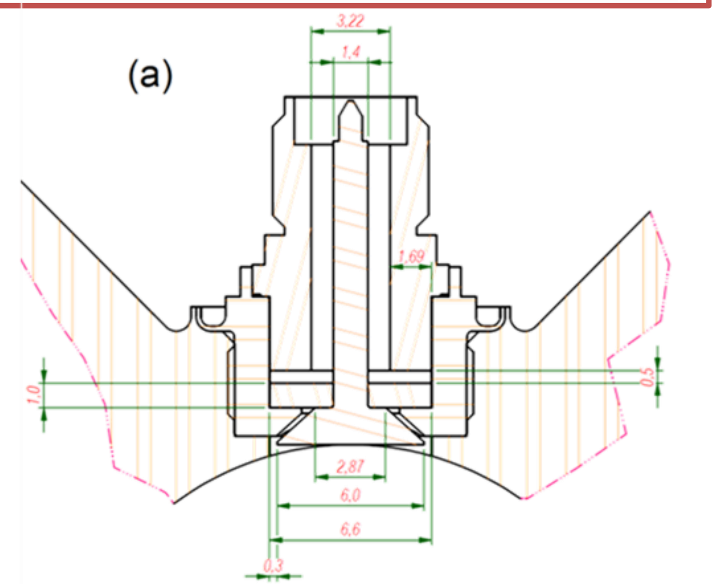
From electromagnetic (wakefield) simulations, wakelosses are calculated

BPM – Best 3 Candidates

Step-Shaped BPM Button	Flat BPM Button	Bell-Shaped BPM Button
Based on the geometry style implemented at ALBA.	Reduced ceramics dimensions to decrease wakelosses.	Conical profile shifts the HOMs to higher frequencies and hide the ceramics from the beam.







Input power

From electromagnetic (wakefield) simulations, wakelosses are calculated

BPM – Best 3 Candidates

Step-Shaped BPM Button

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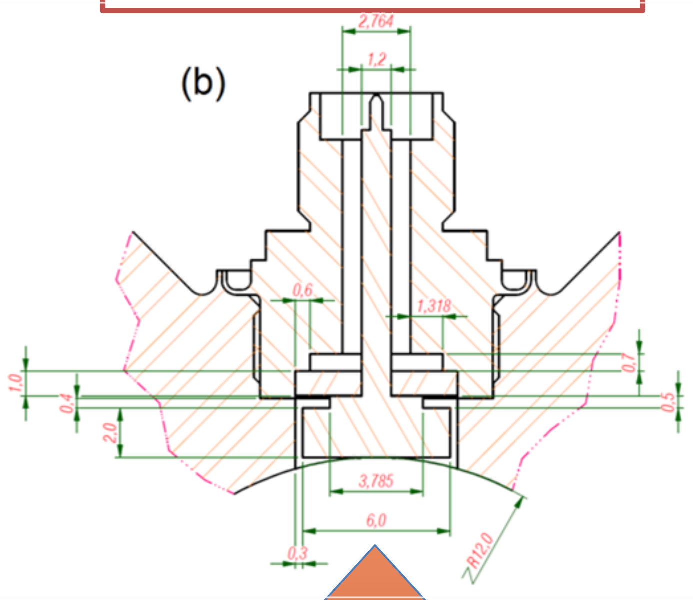
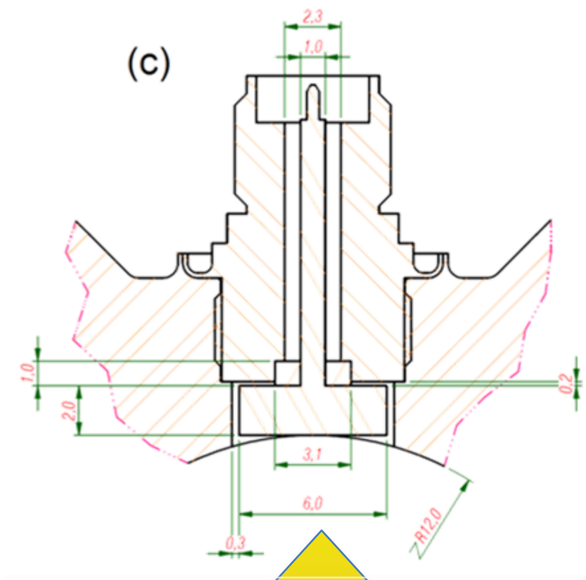


Input power

Flat BPM Button

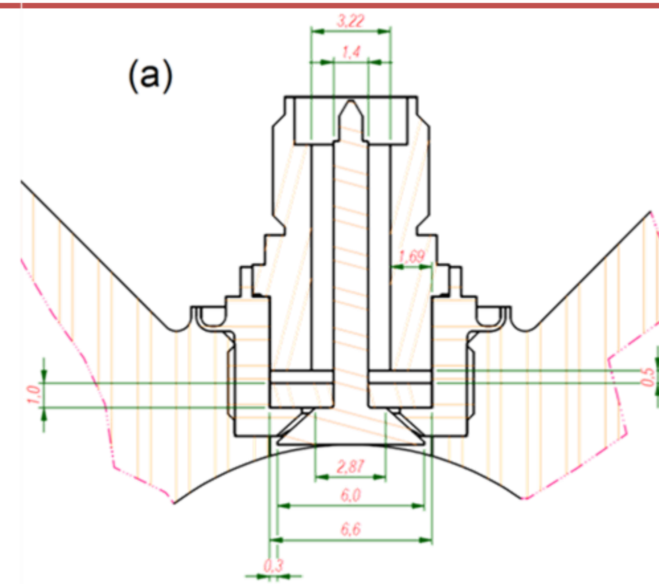
Reduced ceramics dimensions to decrease wakelosses.



37% reduction

Bell-Shaped BPM Button

Conical profile shifts the HOMs to higher frequencies and hide the ceramics from the beam.



From electromagnetic (wakefield) simulations, wakelosses are calculated

BPM – Best 3 Candidates

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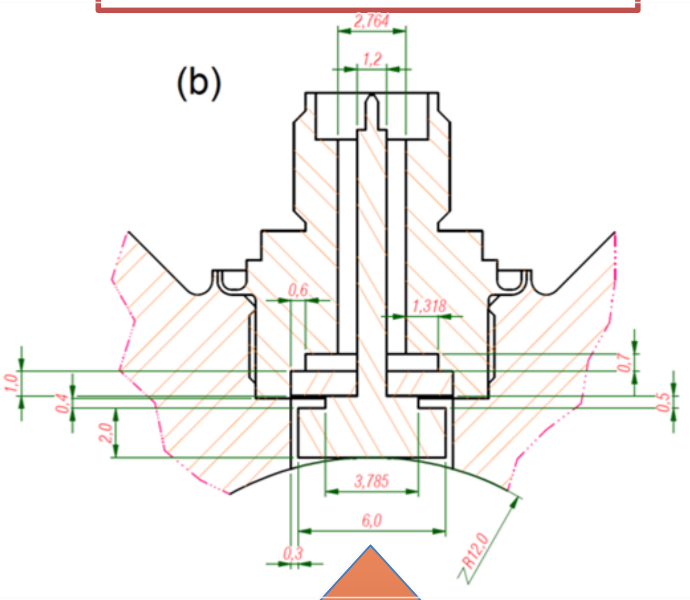

Input power

Flat BPM Button

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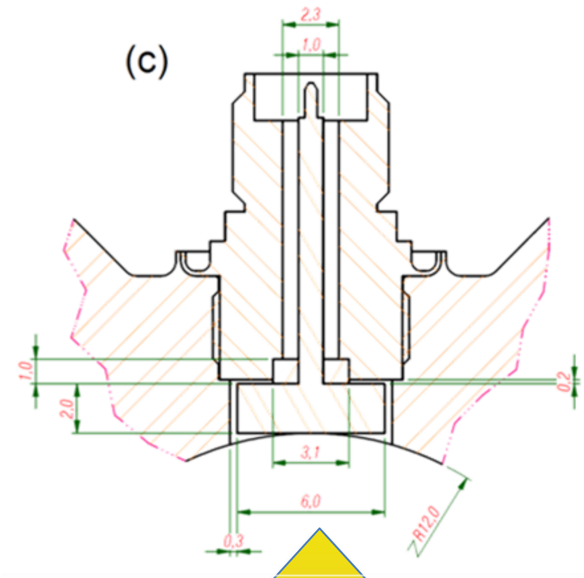

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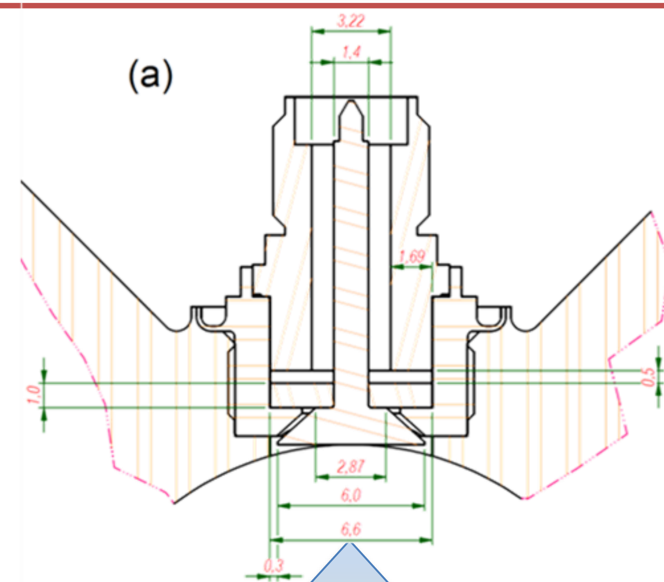
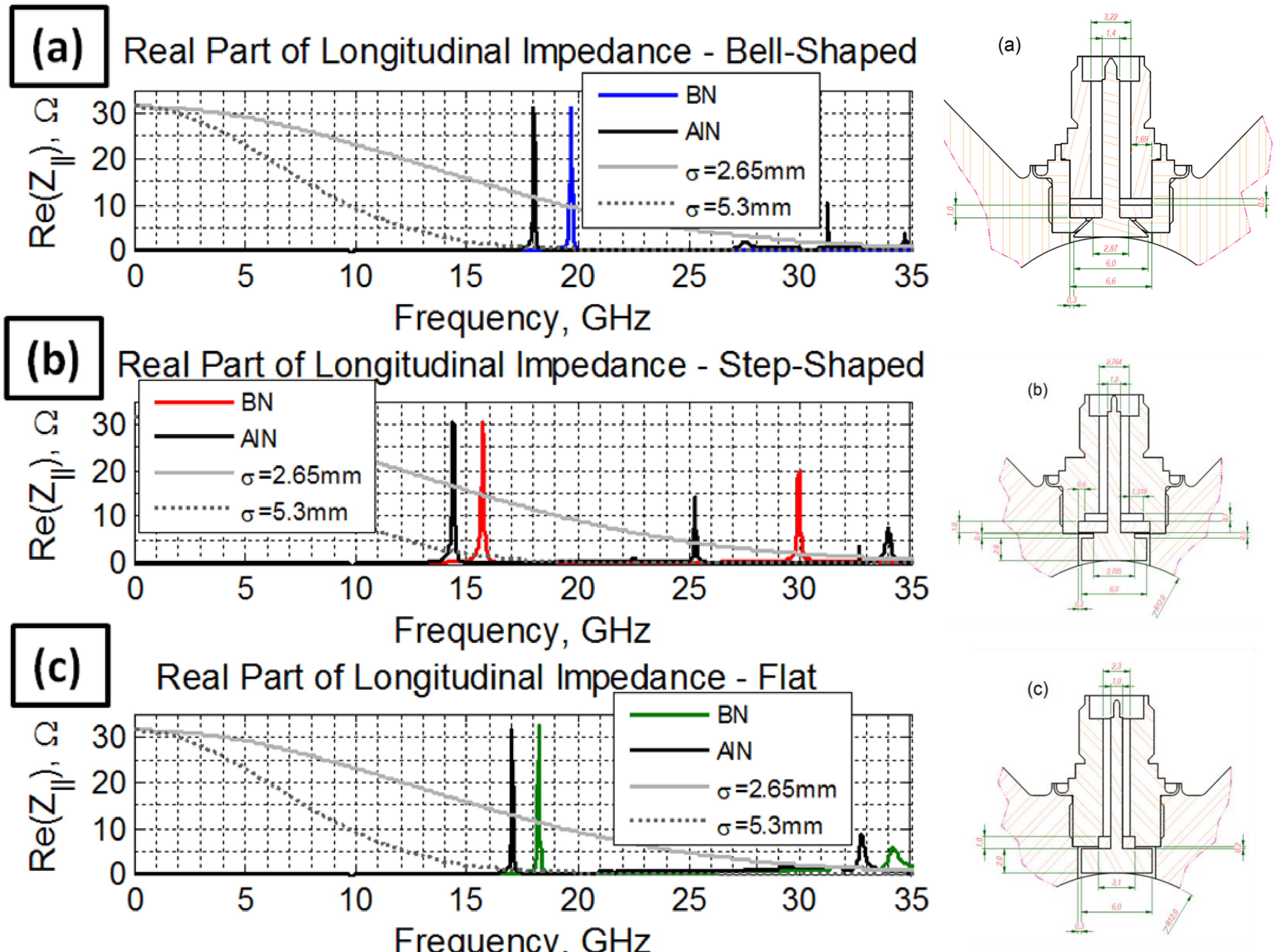
Conical profile shifts the HOMs to higher frequencies and hide the ceramics from the beam.



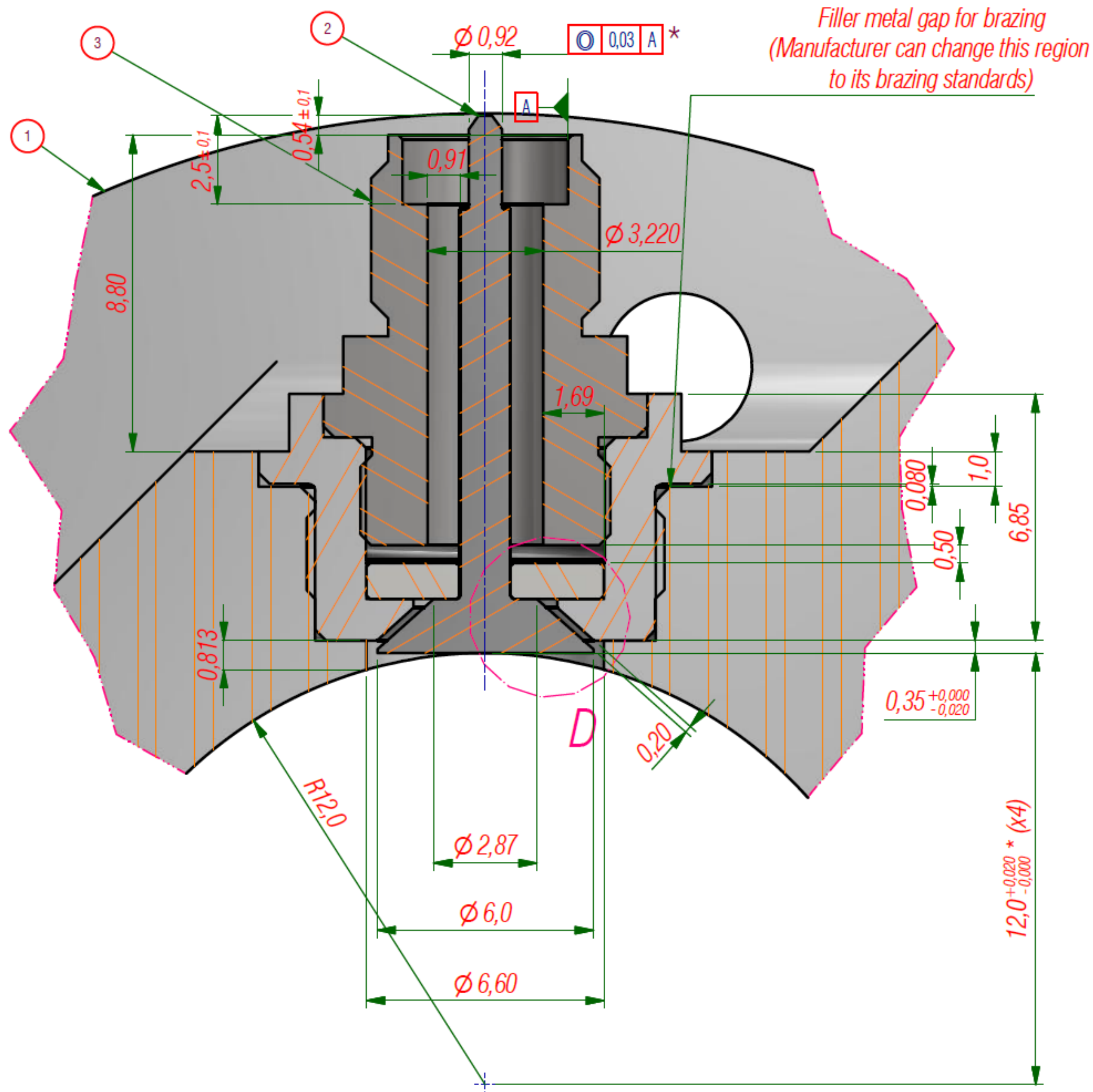
50% reduction

From electromagnetic (wakefield) simulations, wakelosses are calculated

BPM – 3 Candidates Performance

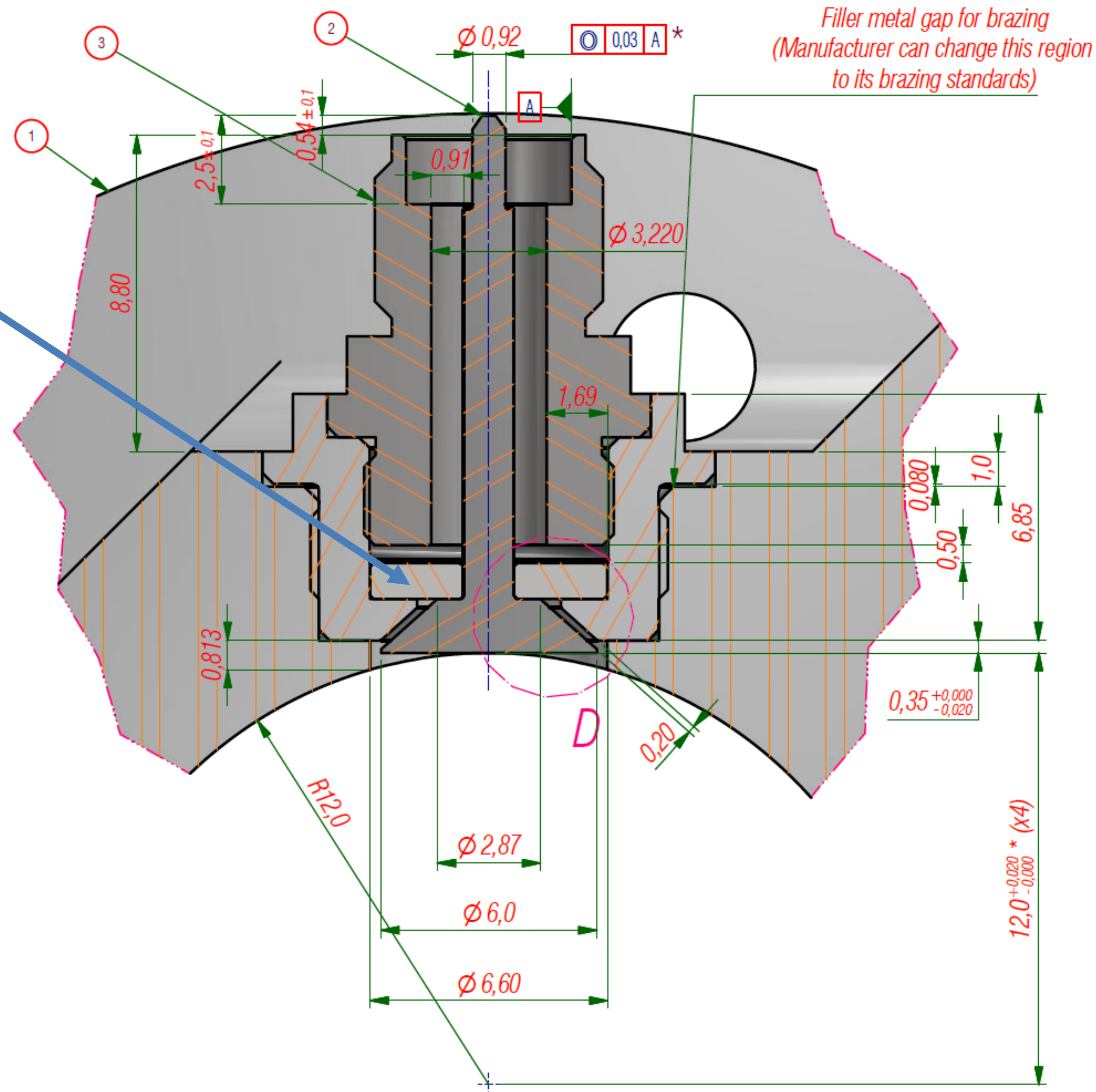


Mechanical Concepts



Mechanical Concepts

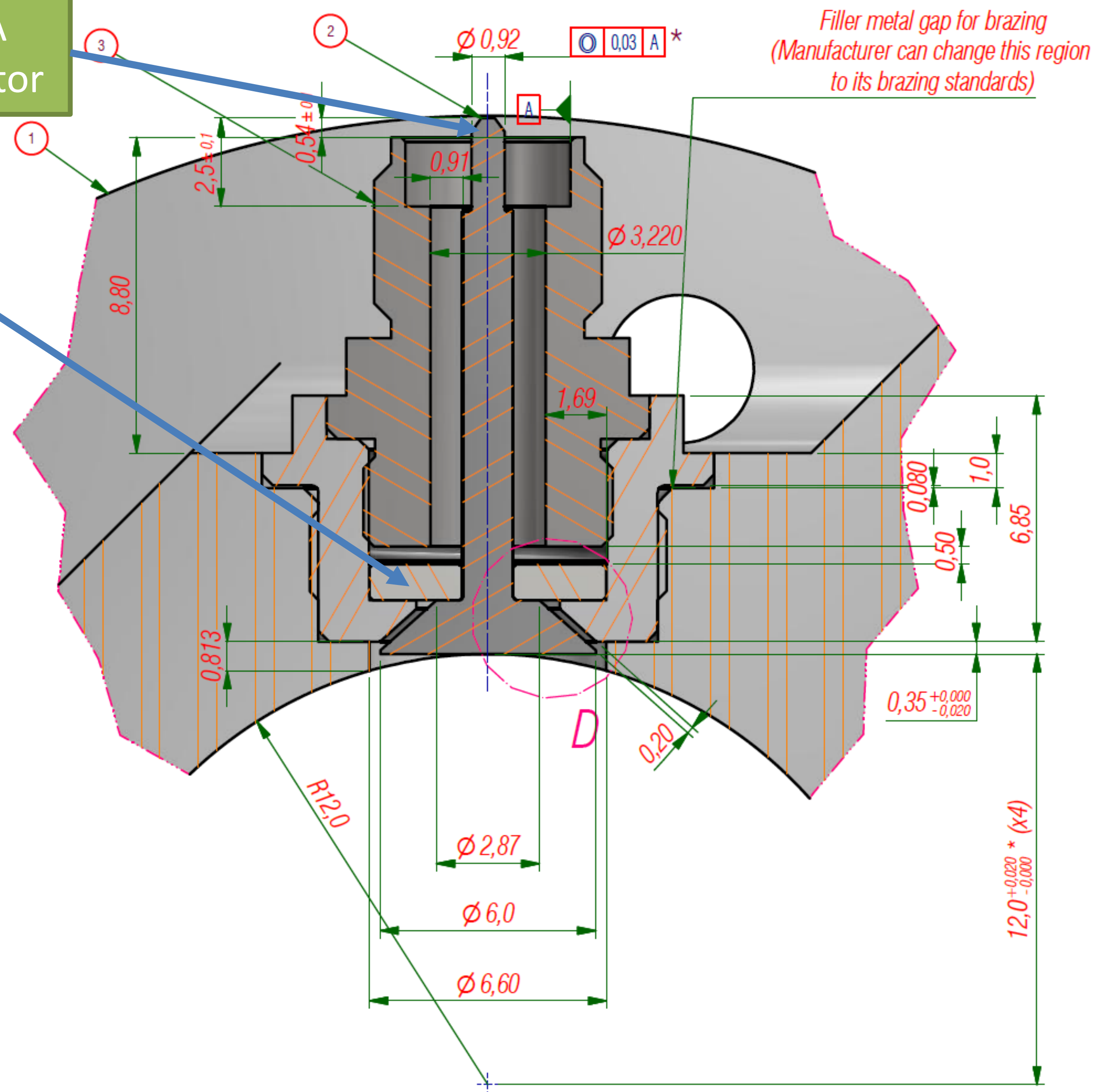
Brazed Al_2O_3 insulator, 1 mm thickness



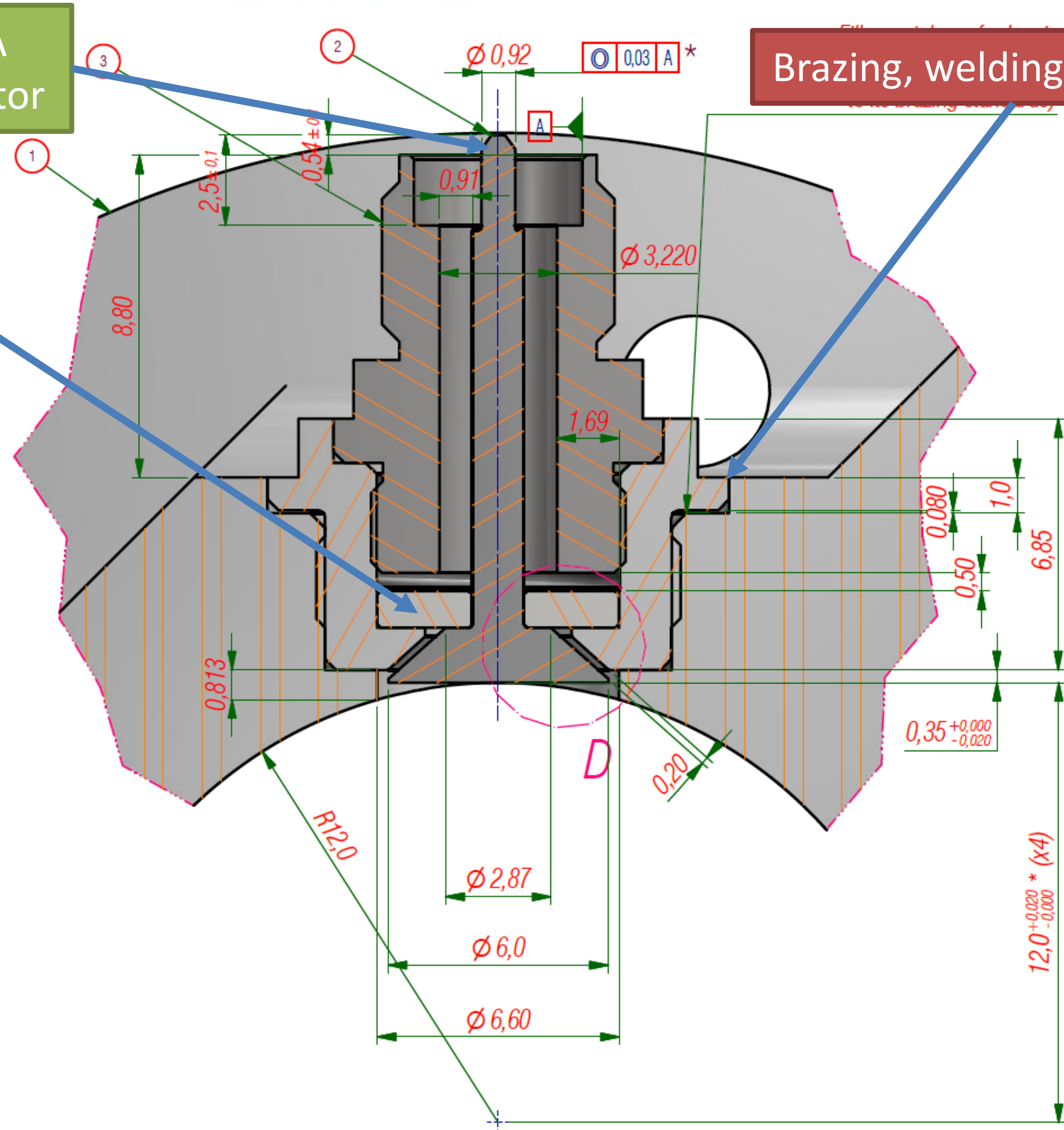
Mechanical Concepts

RP-SMA connector

Brazed Al_2O_3 insulator, 1 mm thickness



Mechanical Concepts



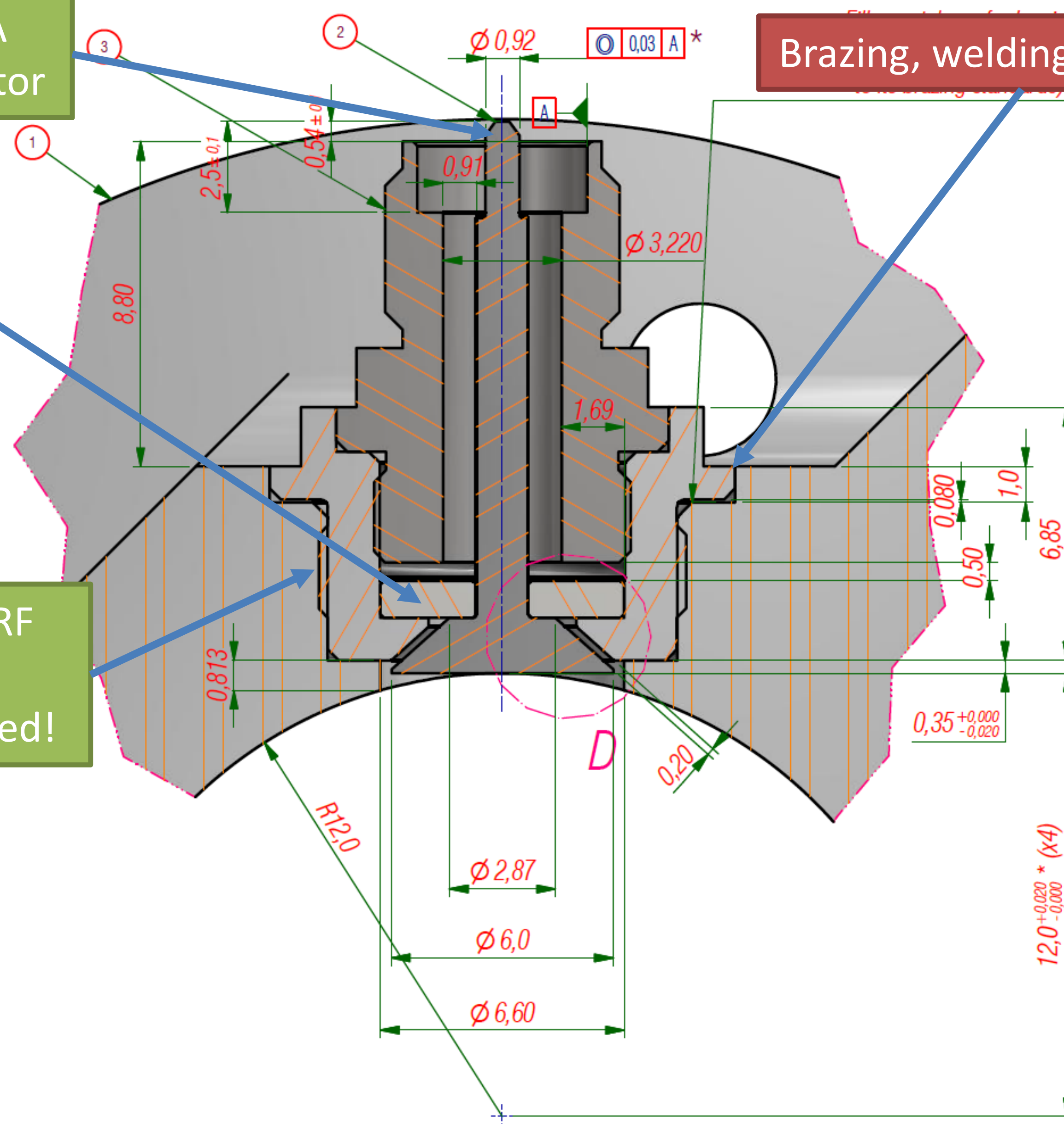
Mechanical Concepts

RP-SMA connector

Brazing, welding or flange?

Brazed Al_2O_3 insulator, 1 mm thickness

Threads: thermal contact, RF shielding and fixation. 4 outgassing channels included!



Mechanical Concepts

RP-SMA connector

Brazed Al_2O_3 insulator, 1 mm thickness

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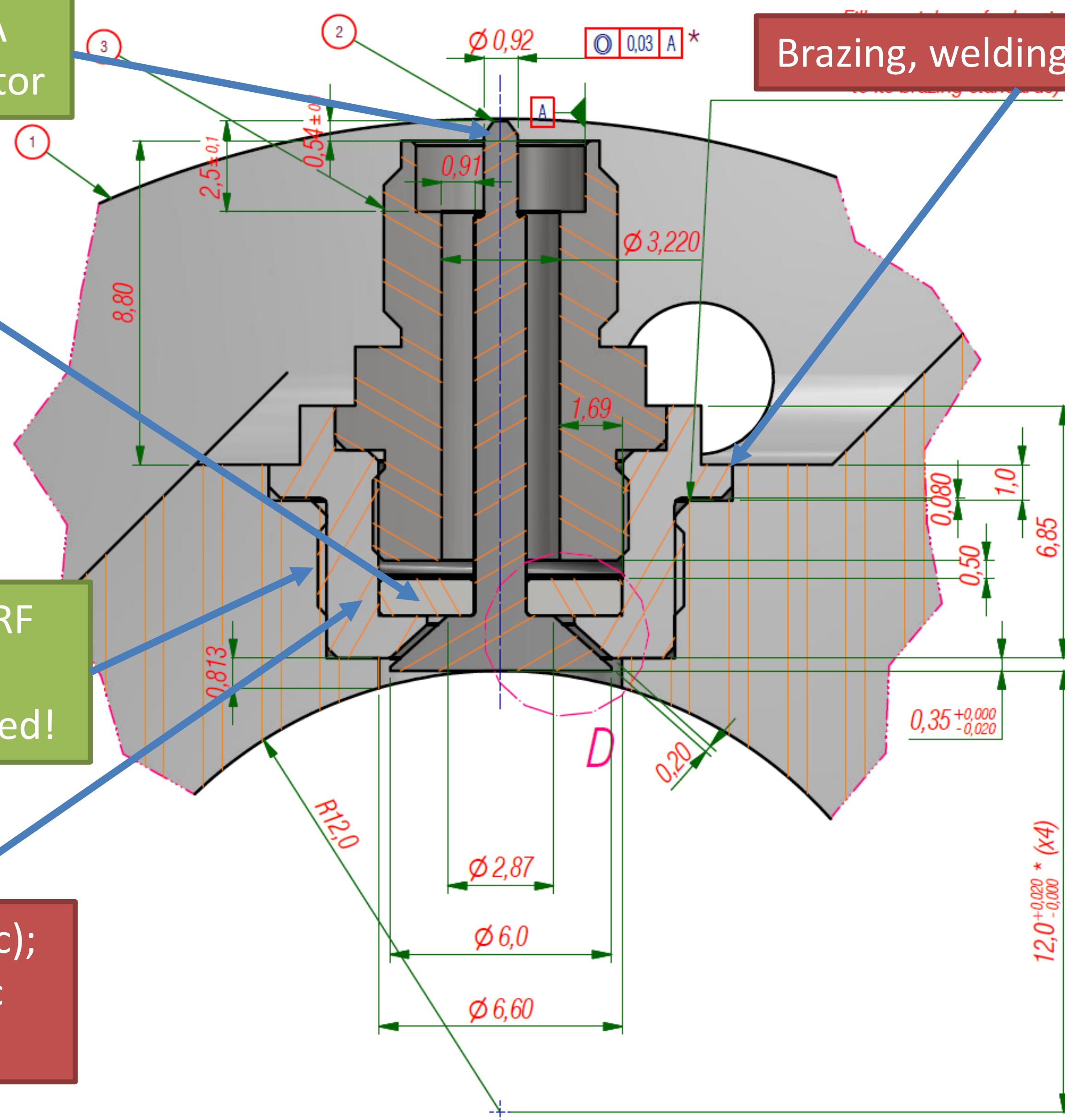
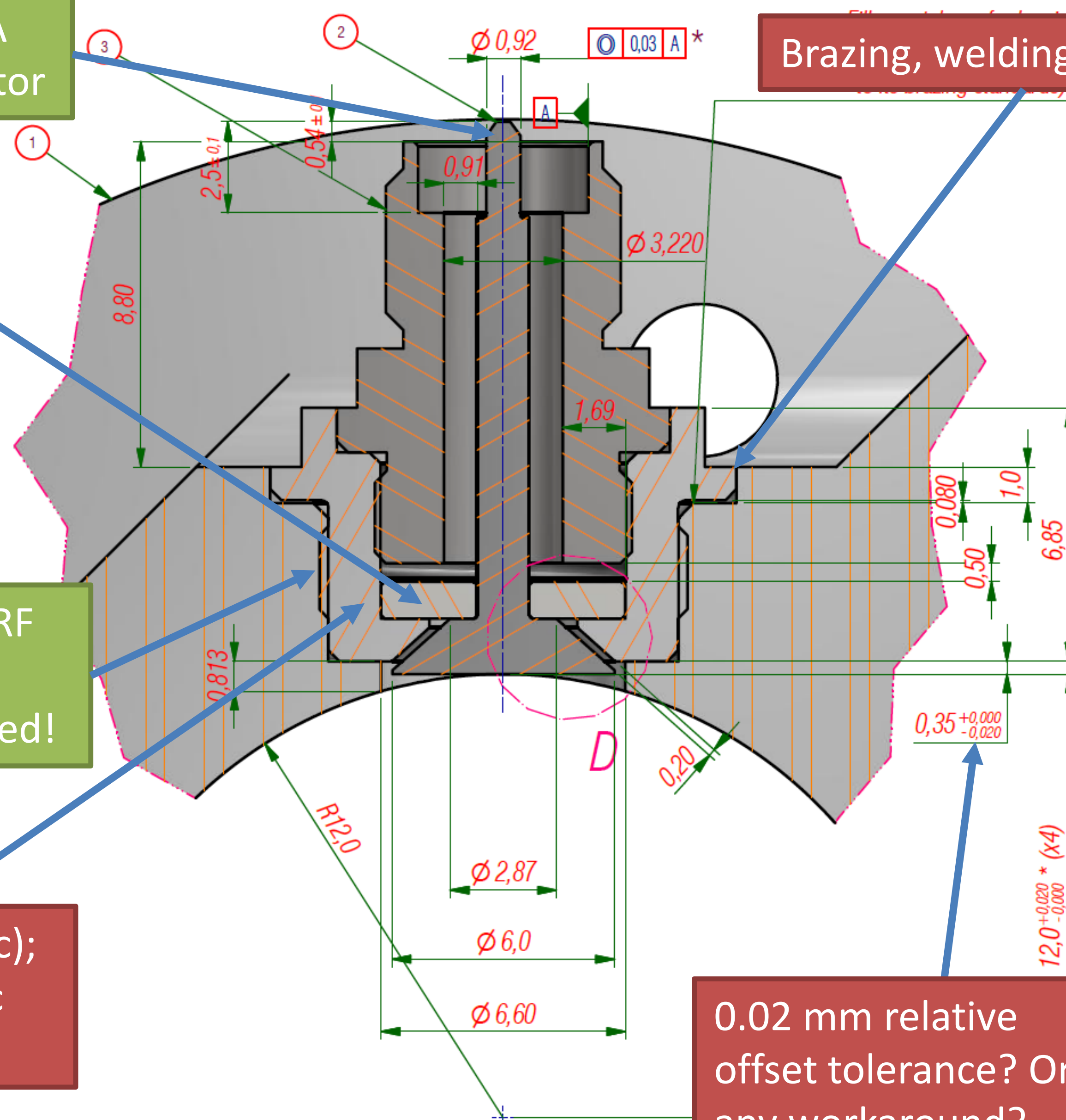
Kovar housing (magnetic); Ti alloy as non-magnetic alternative metal.

Brazing, welding or flange?



Mechanical Concepts



RP-SMA connector

Brazing, welding or flange?

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Kovar housing (magnetic); Ti alloy as non-magnetic alternative metal.

0.02 mm relative offset tolerance? Or any workaround?

Mechanical Concepts

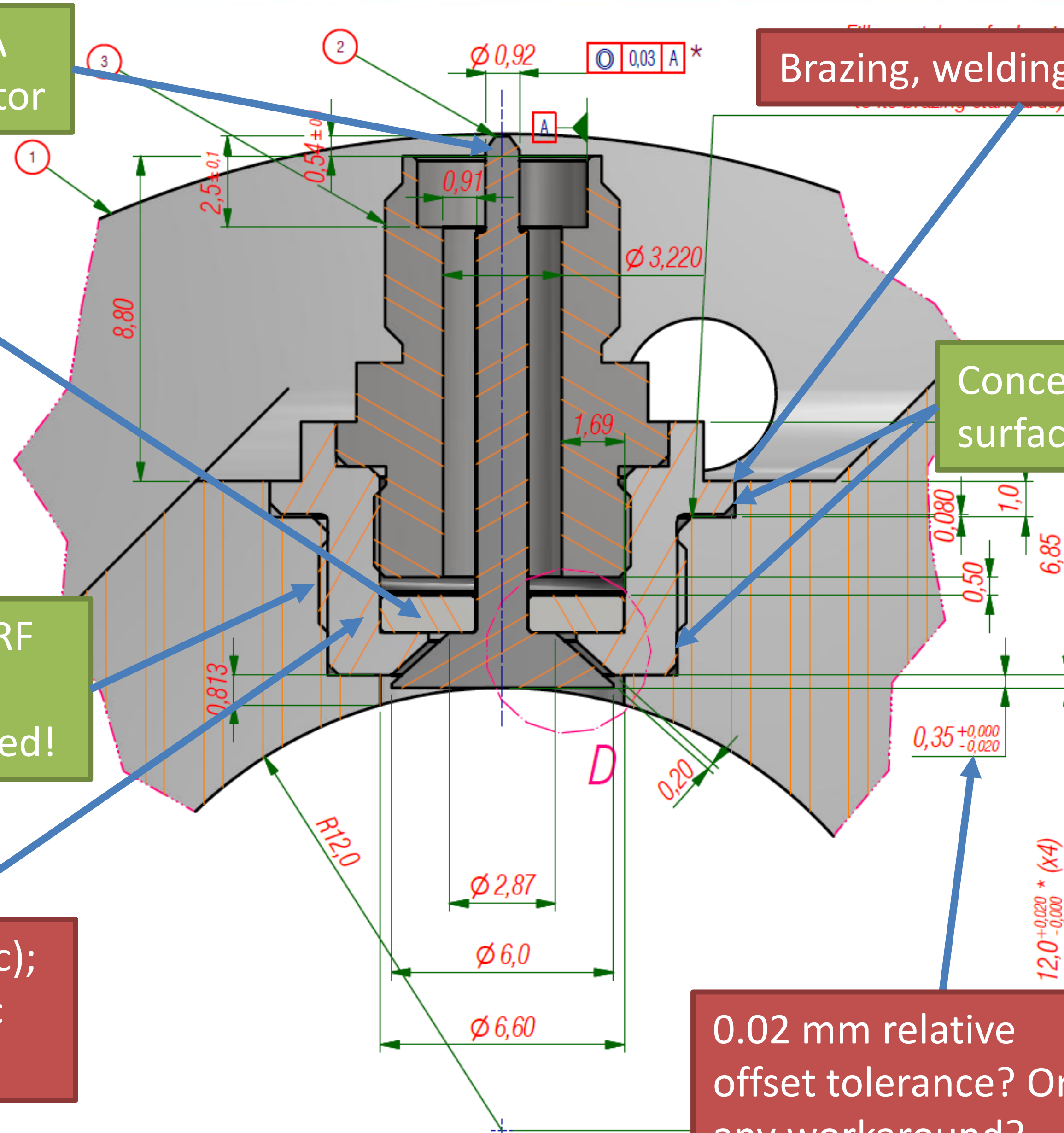
RP-SMA connector

Brazing, welding or flange?

Brazed Al_2O_3 insulator, 1 mm thickness

Concentricity reference surfaces

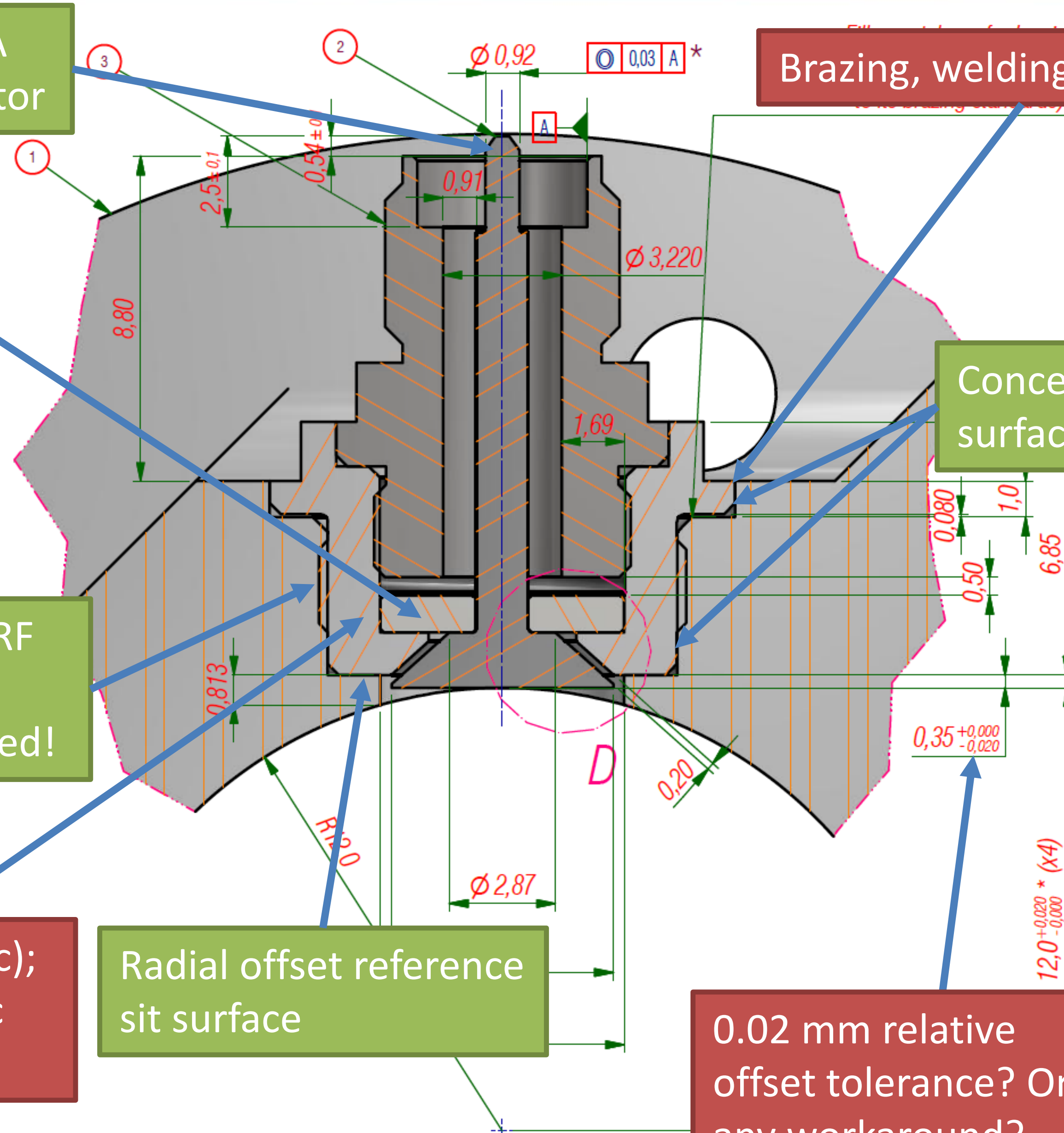
Threads: thermal contact, RF shielding and fixation. 4 outgassing channels included!



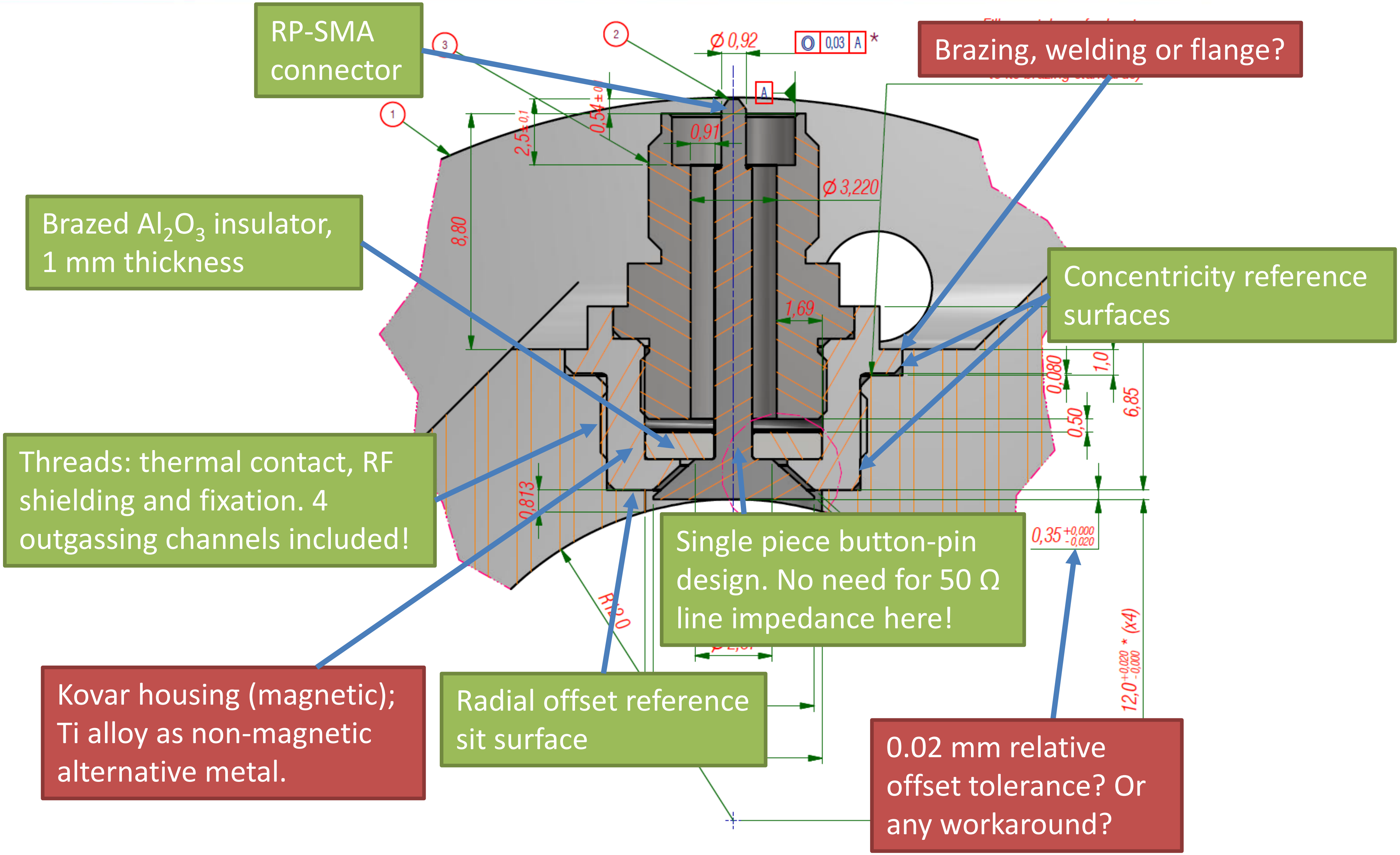
Kovar housing (magnetic); Ti alloy as non-magnetic alternative metal.

0.02 mm relative offset tolerance? Or any workaround?

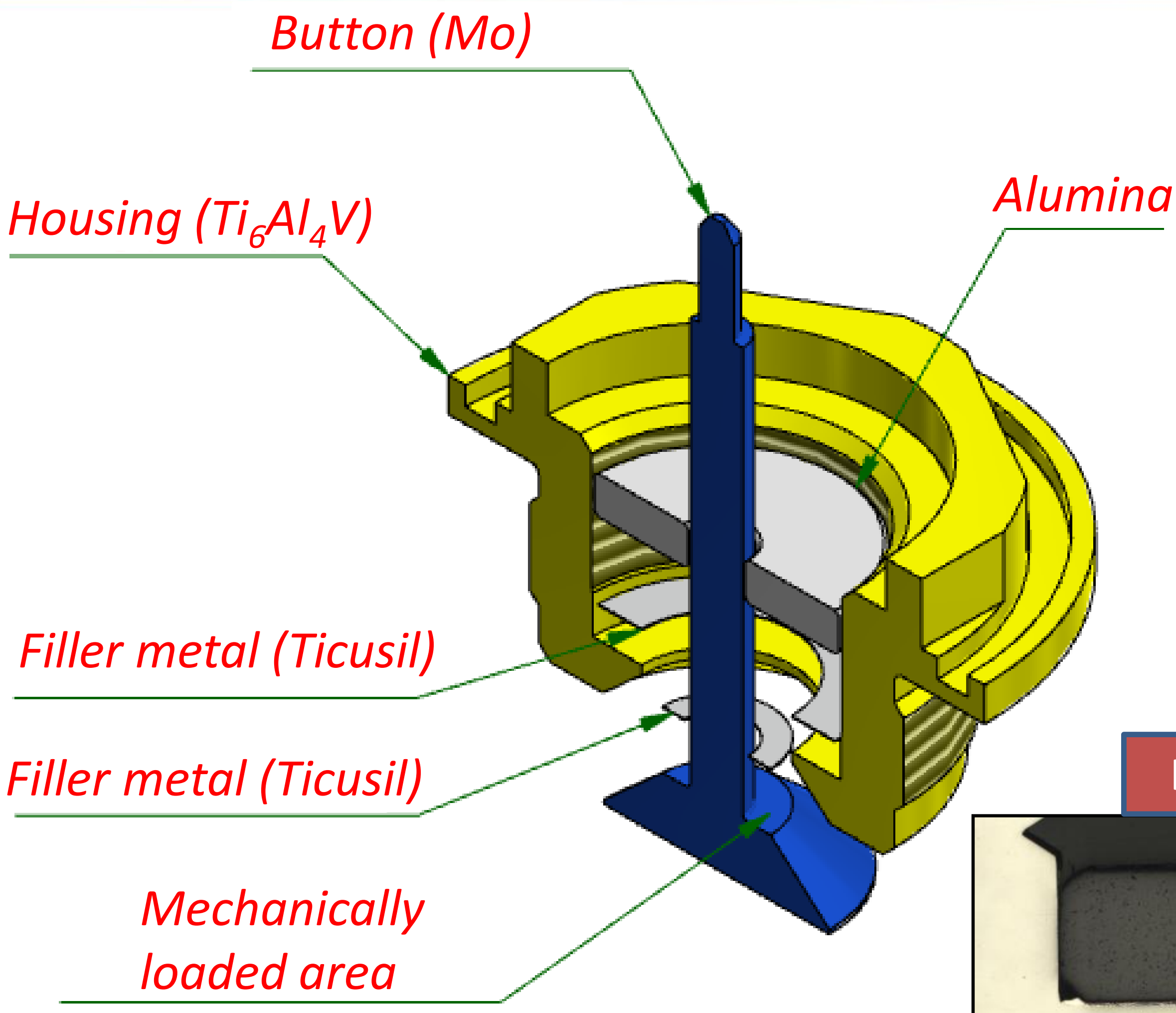
Mechanical Concepts



Mechanical Concepts

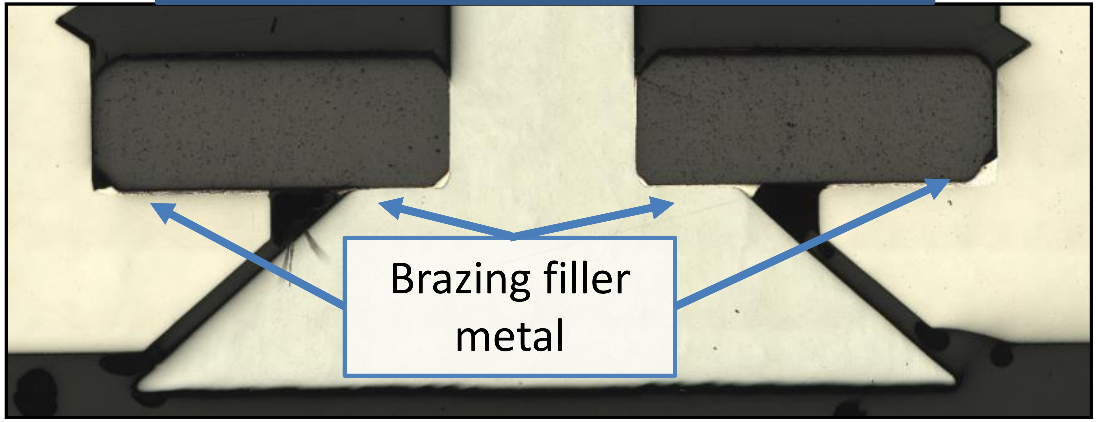


Brazing

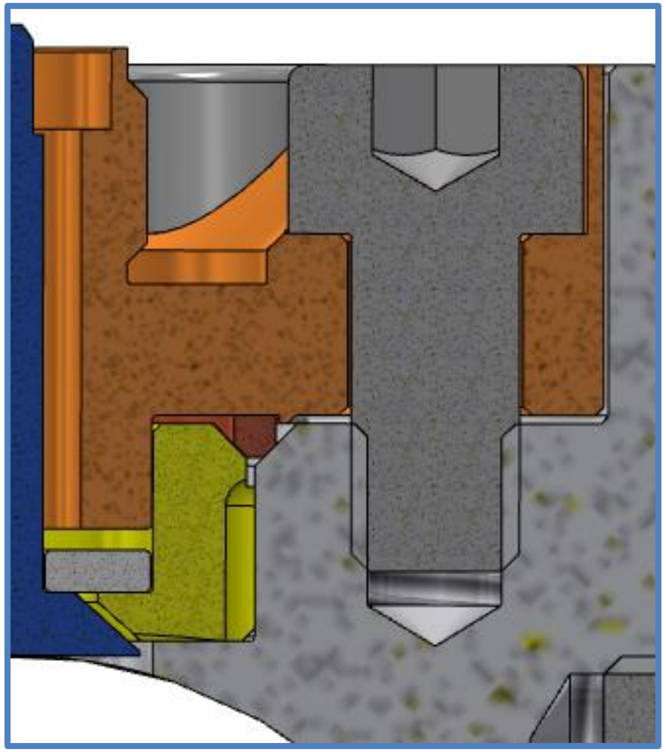
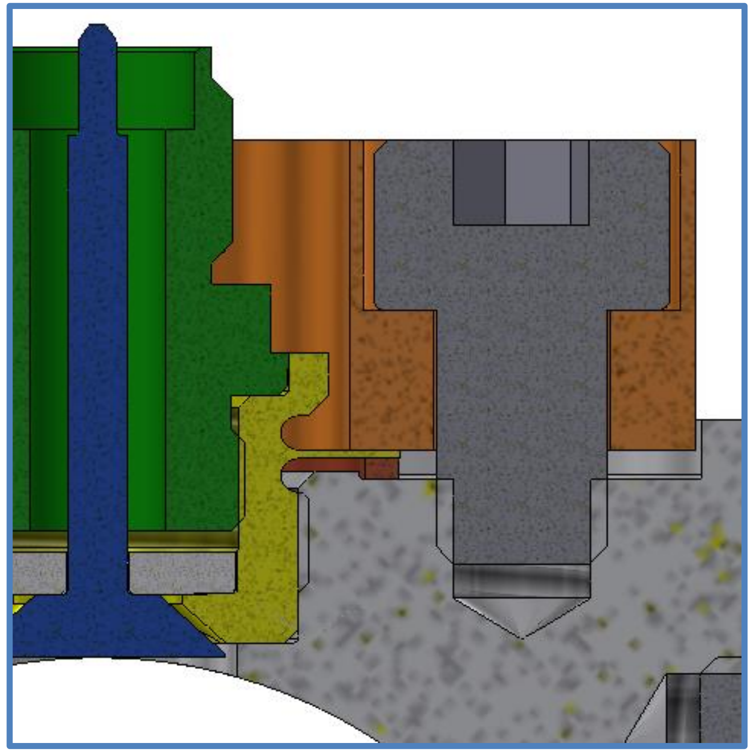
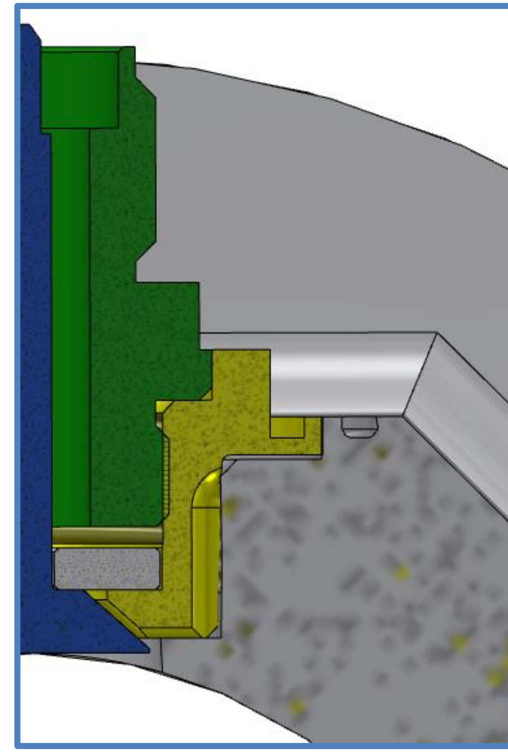


Development has started in parallel with housing-to-body insulation

In-house prototype metallography



Housing-to-body insulation

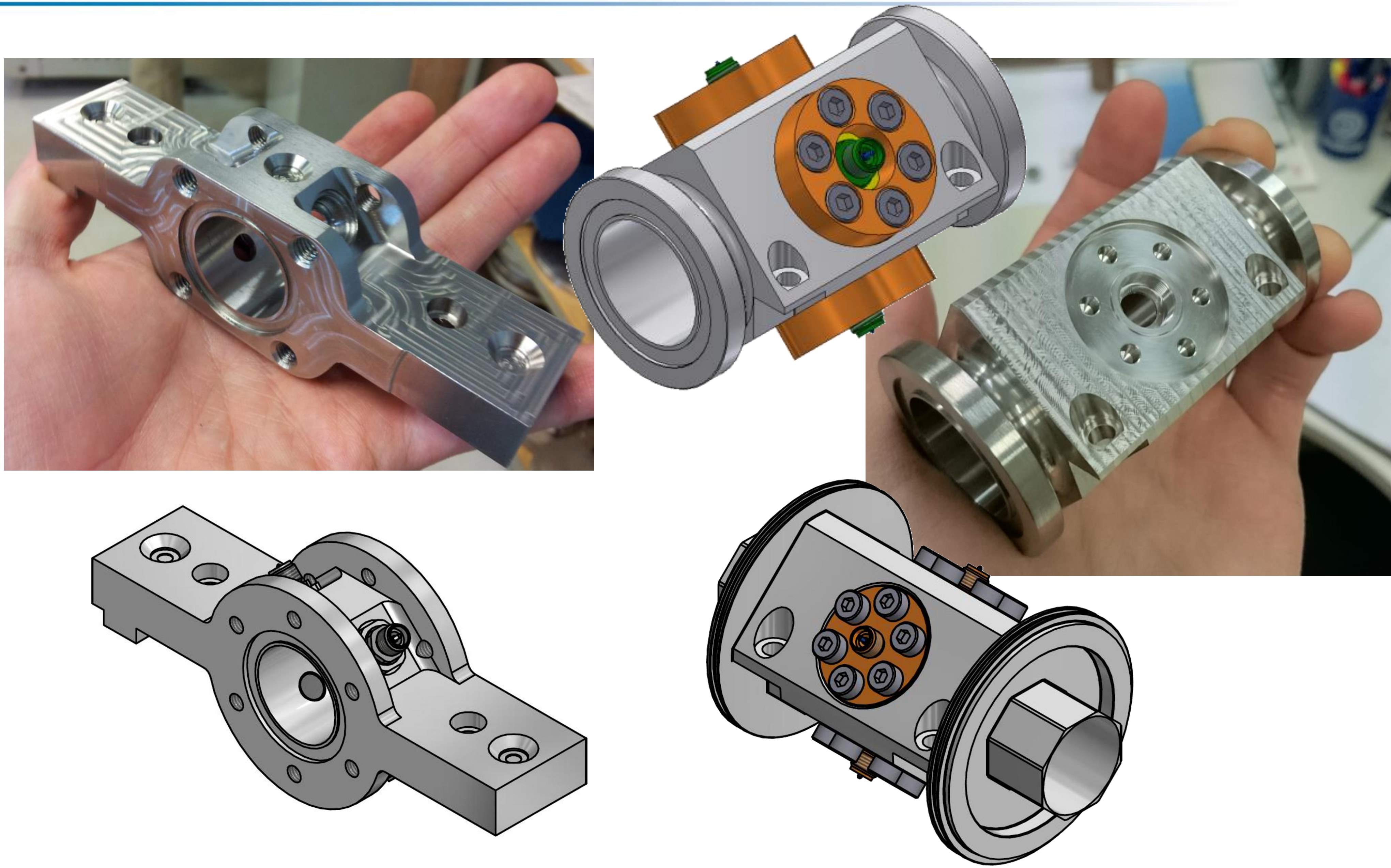
Chamfer-type Flange	Flap-type Flange	Welded
		

Chamfer-type Flange
- Unthreaded housing;
- Requires housing and body with same CTE (otherwise leaks during baking);
- Risk of misaligning the outer SMA conector.

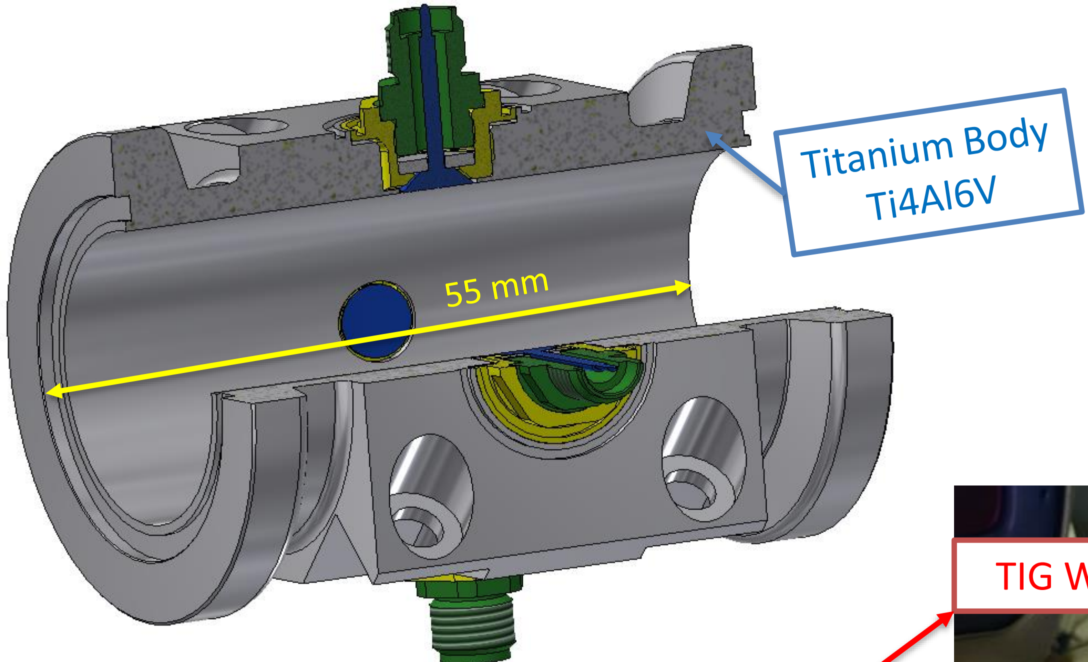
Flap-type Flange
- Proposed solution for chamfer-type flange “problems”;
- Flange (copper-colored piece) bends for stronger tighteninghs.

Welded
- Fastest assembly;
- Materials choice restriction for proper welding;
- Failure in welding compromises the entire BPM.

Project Evolution and Alternatives

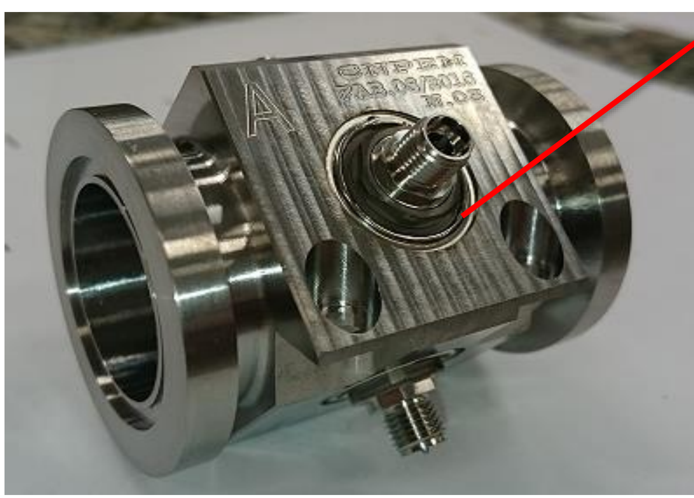


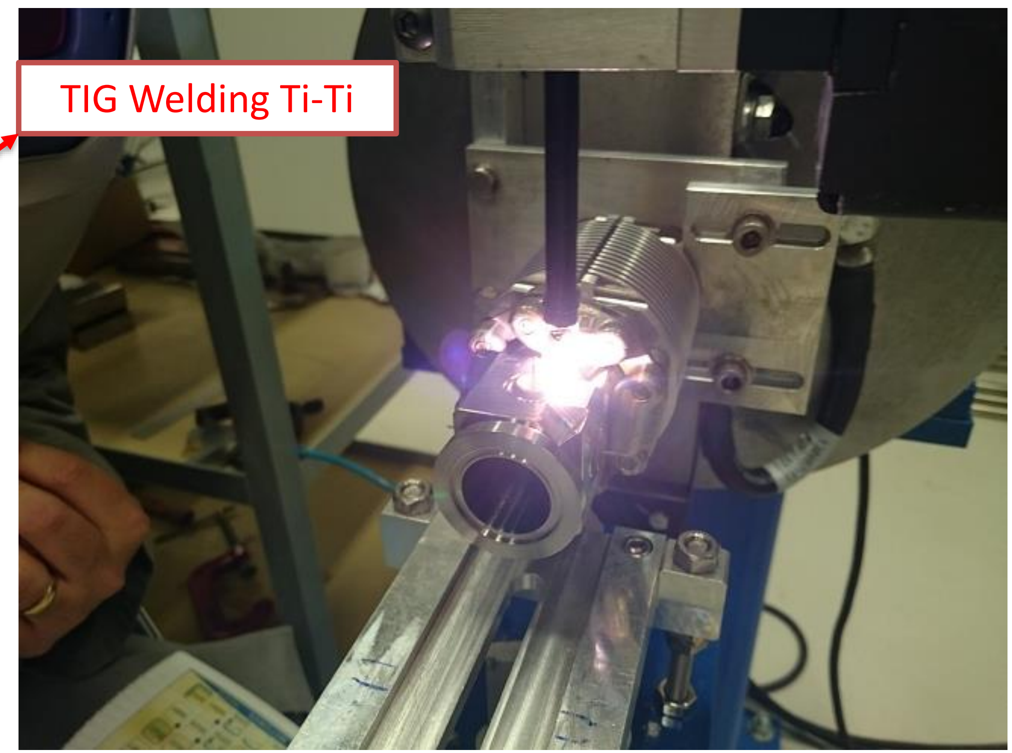
Final Design



Motivations

- Ti-Ti welding
- More compact design
- Electrical center deviation





With geometries and materials defined,

WE CAN NOW ANALYZE THE WAKE HEATING EFFECTS

Wake Heating Analysis

ANALYSIS AND COUNTERMEASURES OF WAKEFIELD HEAT LOSSES FOR SIRIUS

H. O. C. Duarte*, T. M. Rocha, F. H. de Sá, L. Liu, S. R. Marques
Brazilian Synchrotron Light Laboratory (LNLS), Campinas, Brazil

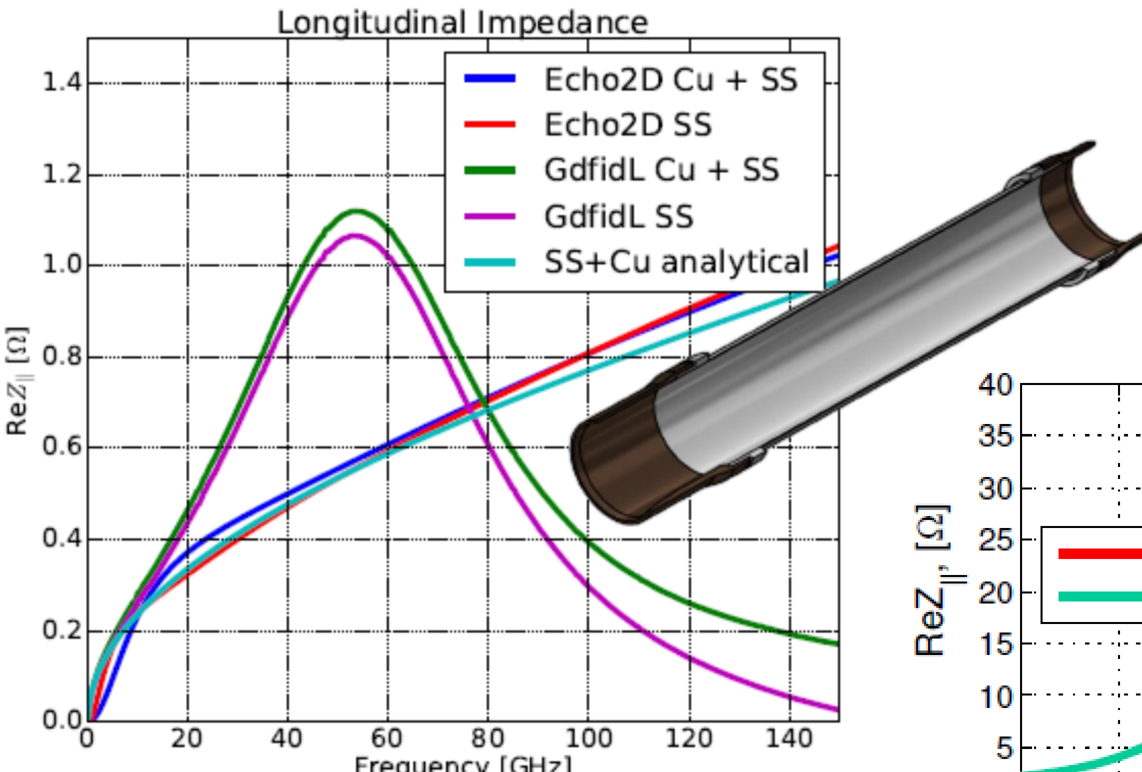


Figure 1: Real part of the longitudinal impedance of fast corrector chamber: comparison between ECHO2D, GdfidL – with and without copper pipe terminations – and theory.

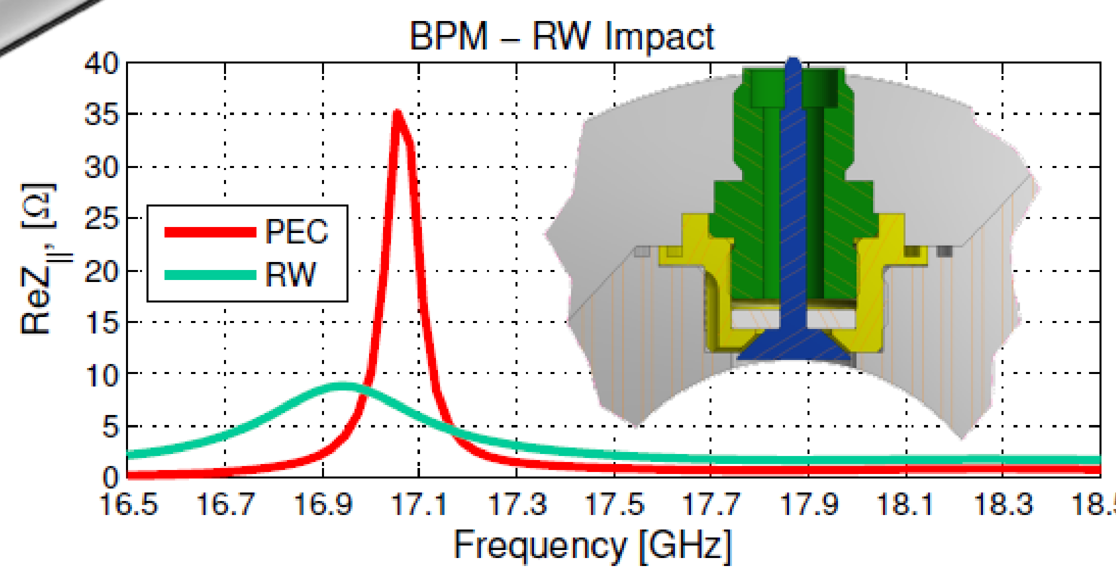
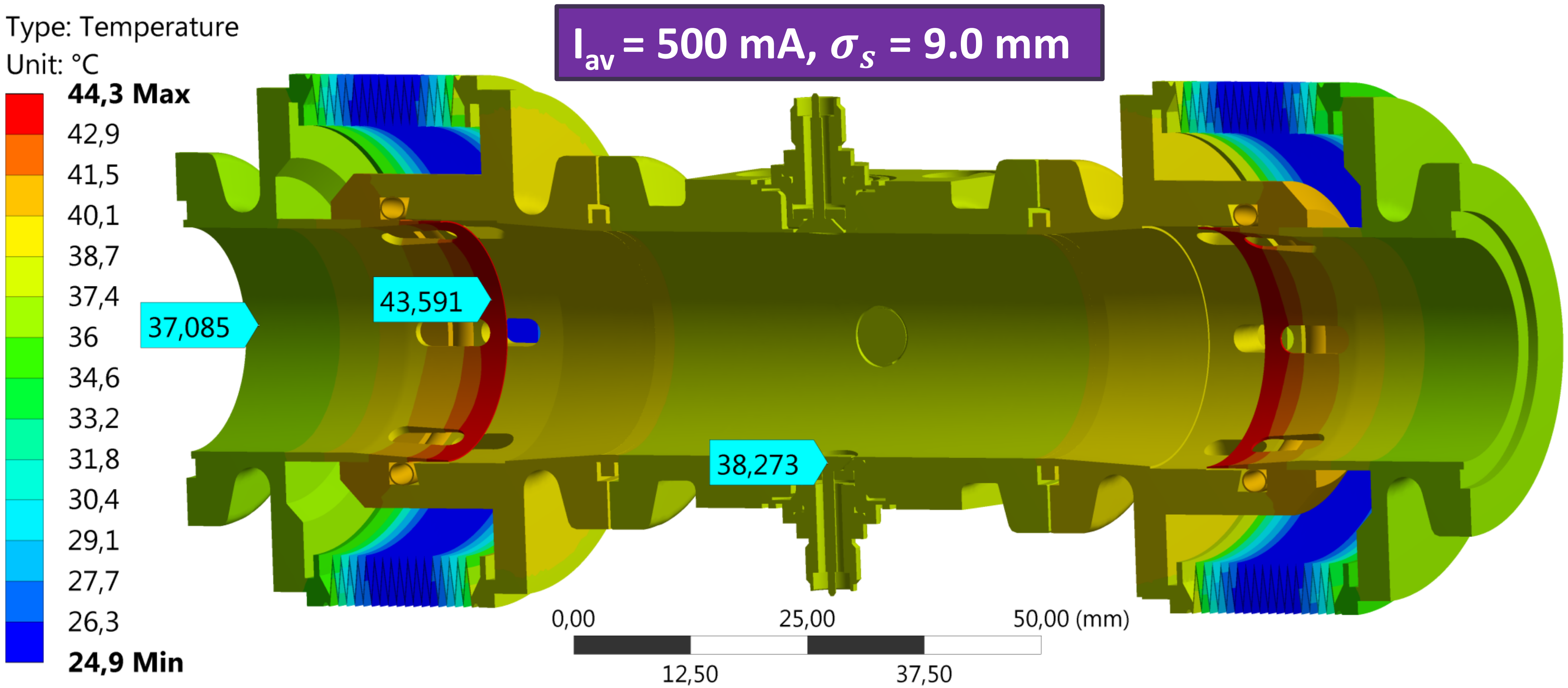


Figure 2: Effect of RW BC on BPM Button HOM.

BPM Wake Heating Analysis

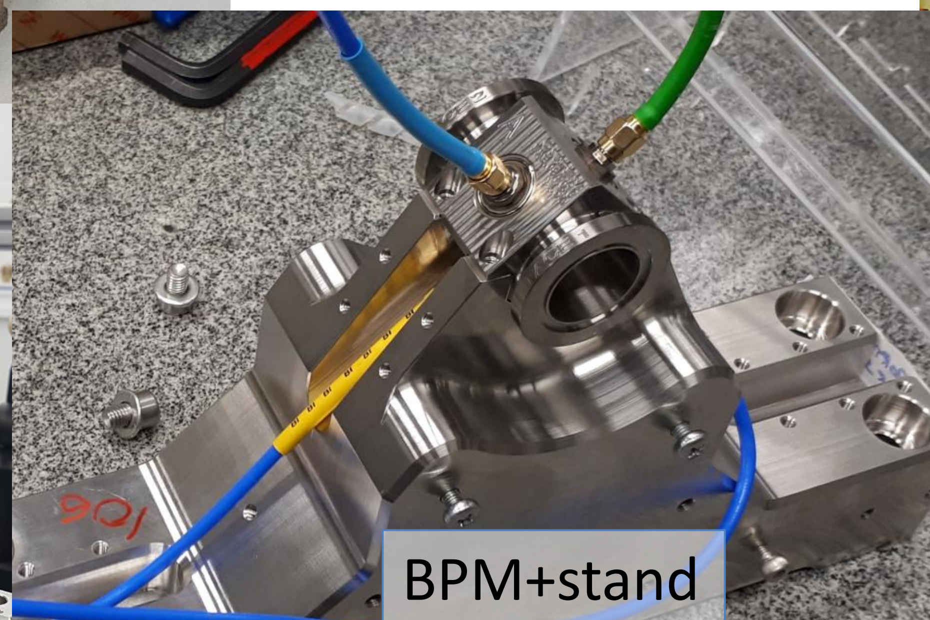
GdfidL impedance BCs (separate pieces) + ANSYS

Mo button, Alumina ceramics, Ti_6Al_4V BPM housing and body, SS bellows

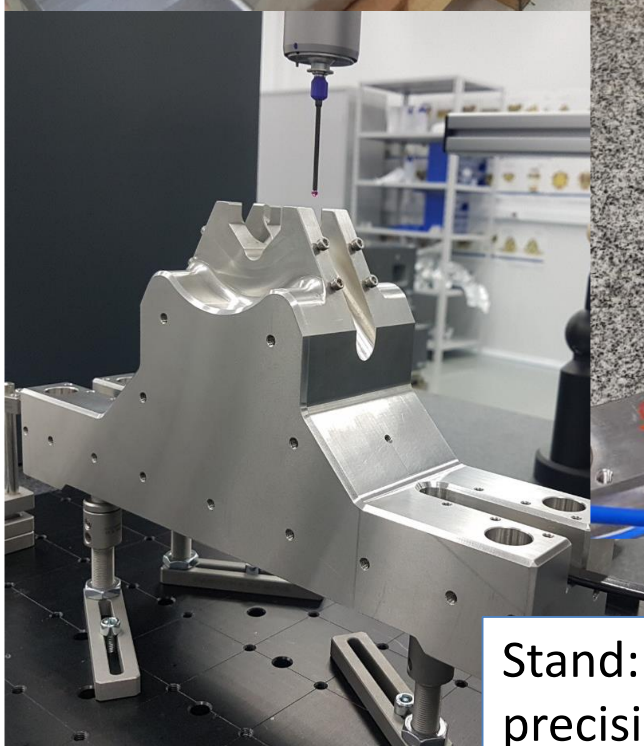


BPM Stand + Full Prototype

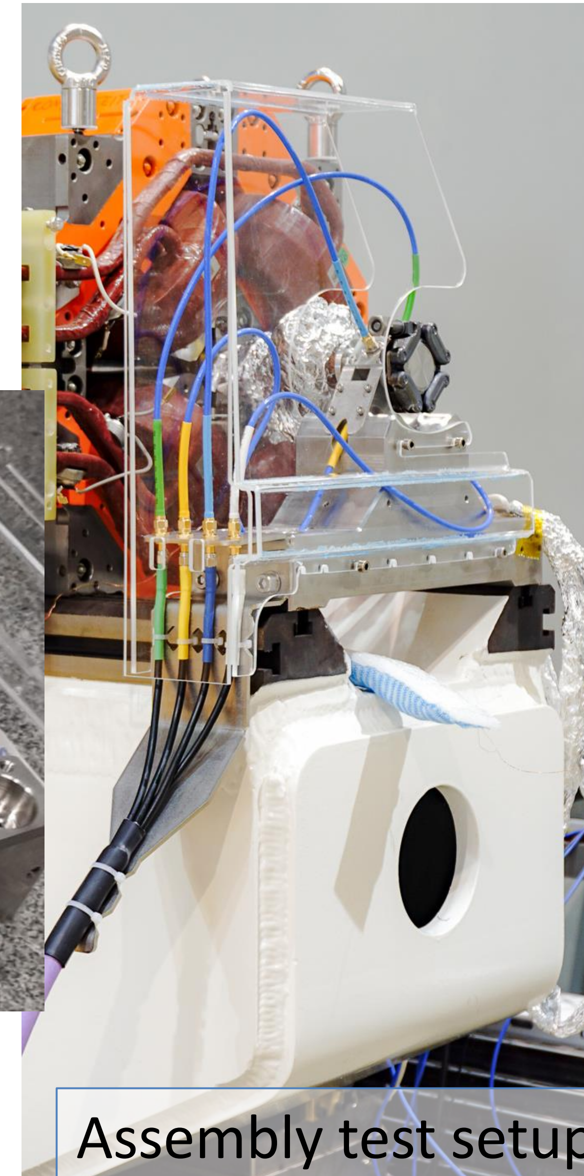
Stand: cast steel batch



BPM+stand

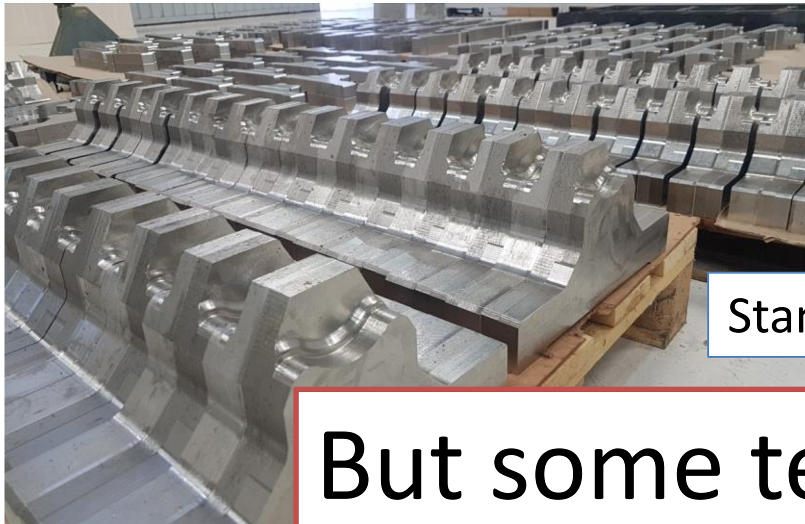


Stand: inspection measurement after precision machining



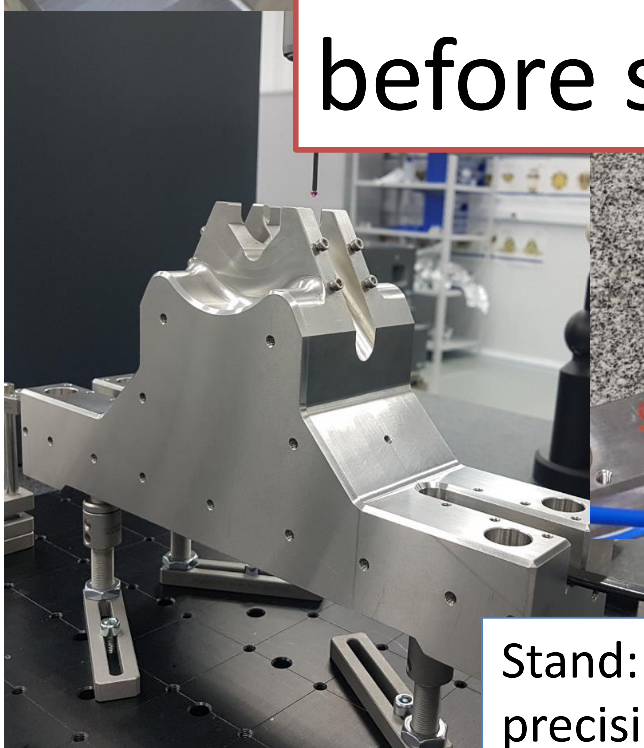
Assembly test setup

BPM Stand + Full Prototype



Stand: cast steel batch

But some tests were needed before safely arriving here



Stand: inspection measurement after precision machining

BPM+stand

Assembly test setup

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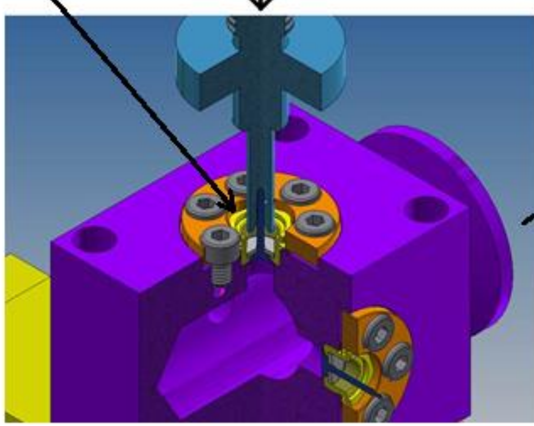
HOW STRONG ARE THE FEEDTHROUGHS?

Crash Test Setup

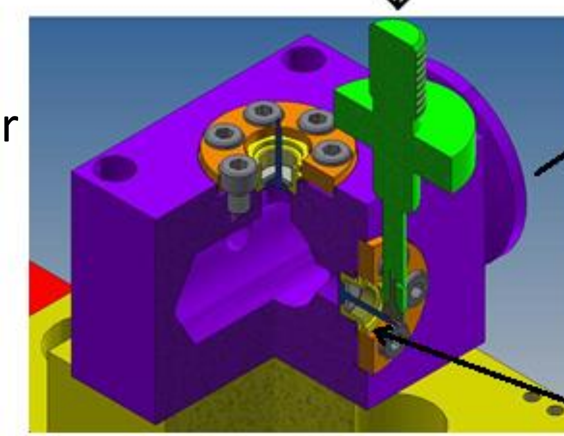
Incident helium flux

Load



Leak detector

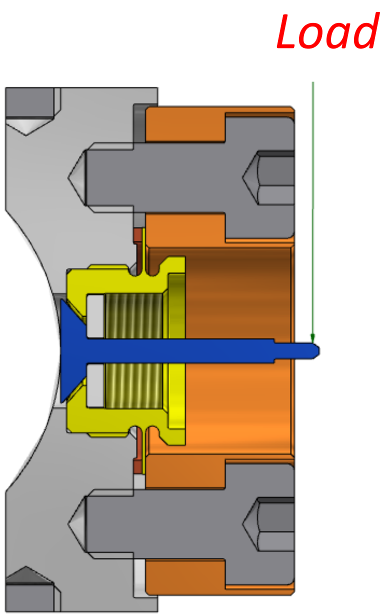
Load



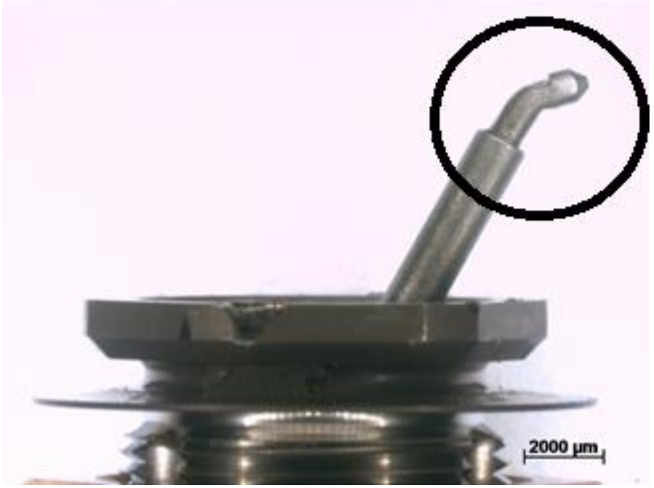
Leak detector

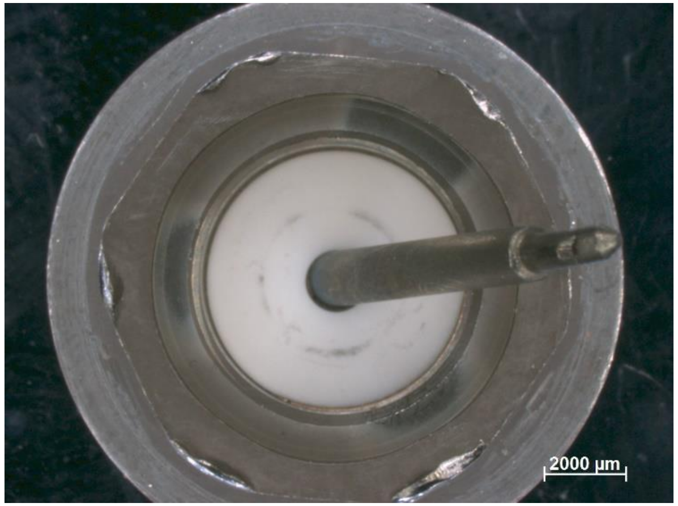
Incident helium flux

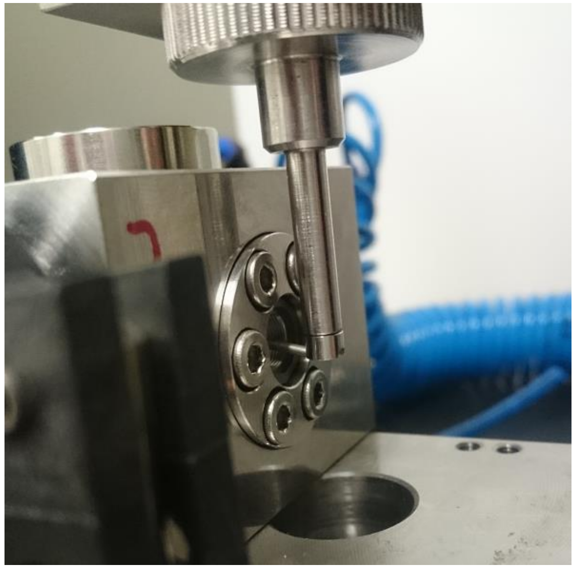
Crash test: shear load



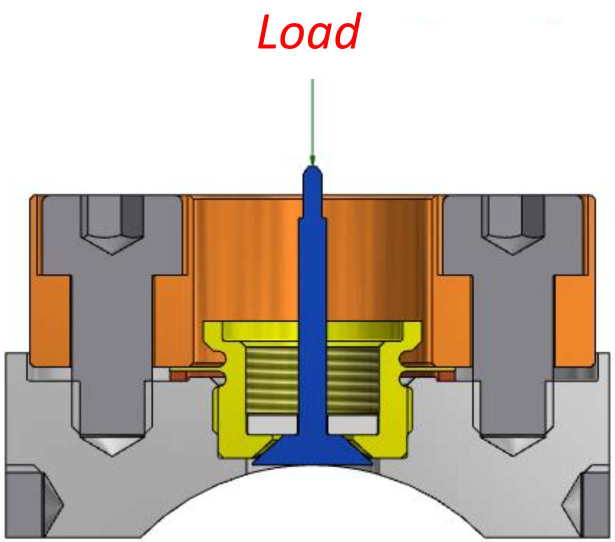
No button has leaked

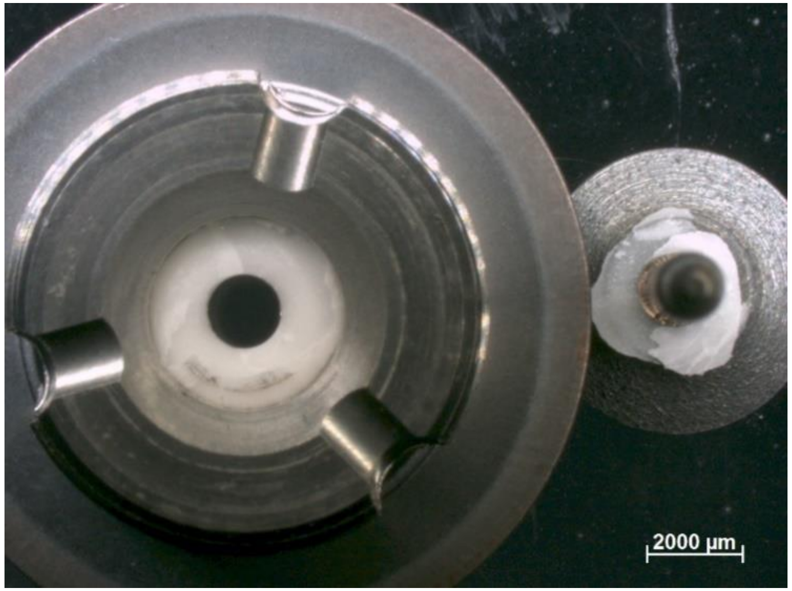


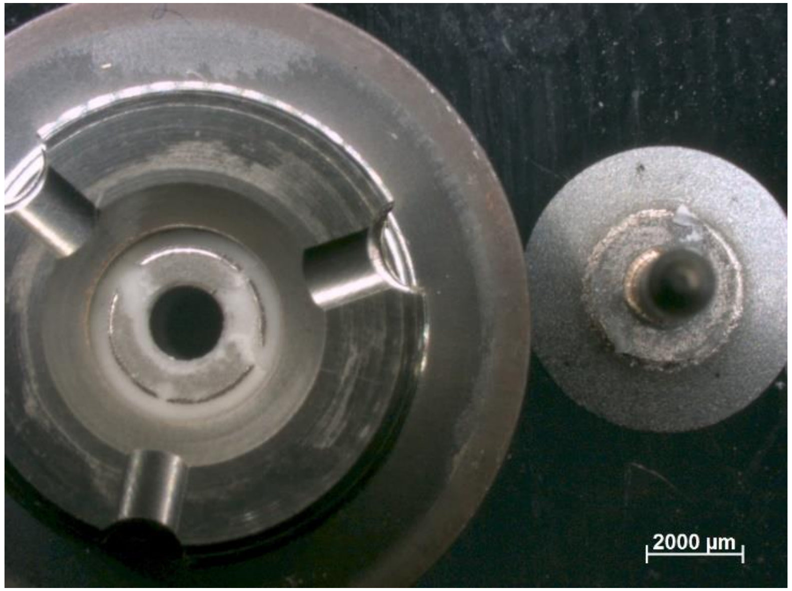




Crash test: axial load

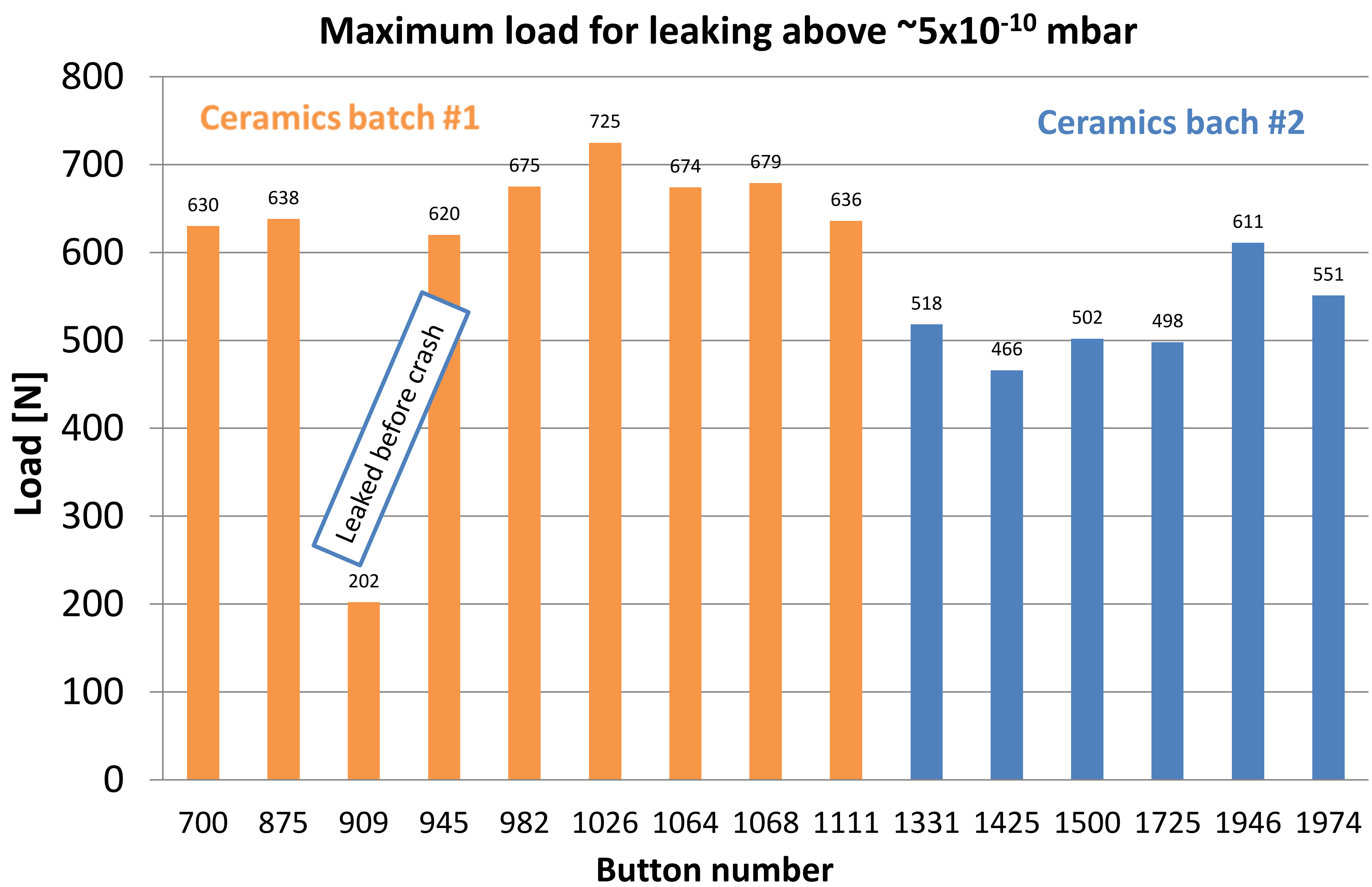






All 15 (except one) leaked right before crash

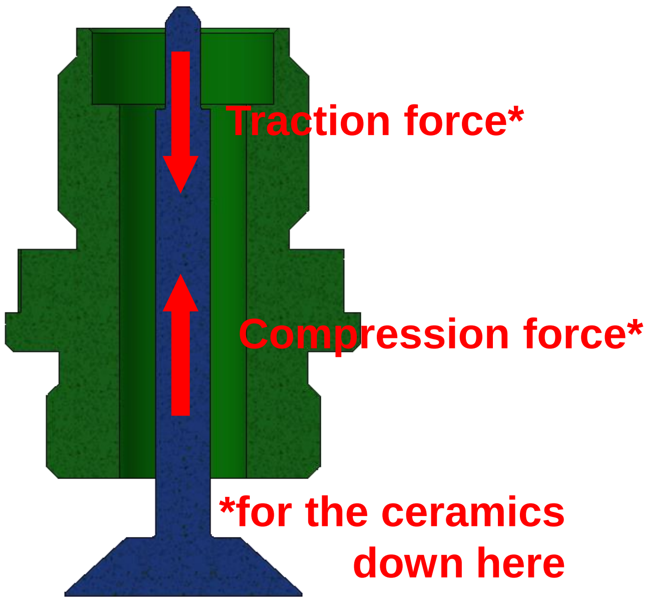
Crash test: axial load

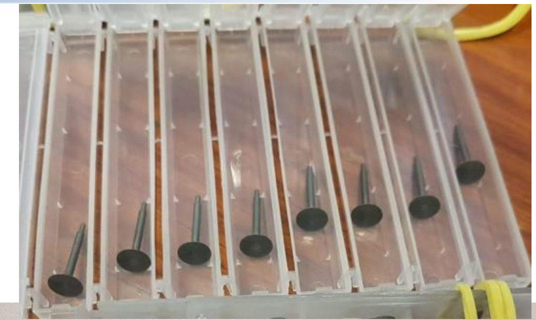


Ok, the feedthroughs seem strong...

BUT WHAT LOAD THEY WILL COMMONLY FACE?

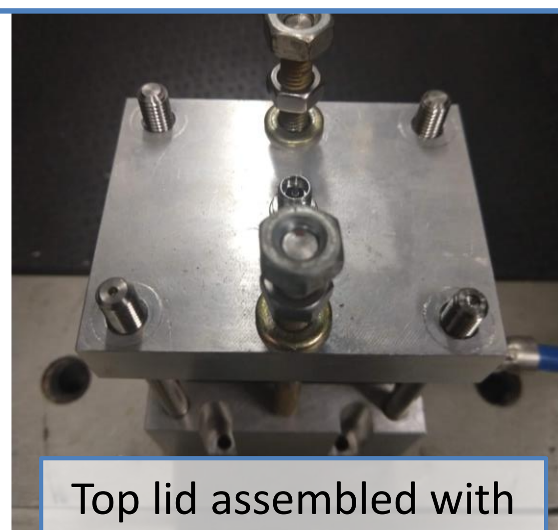
Measuring Loads from SMA Connections



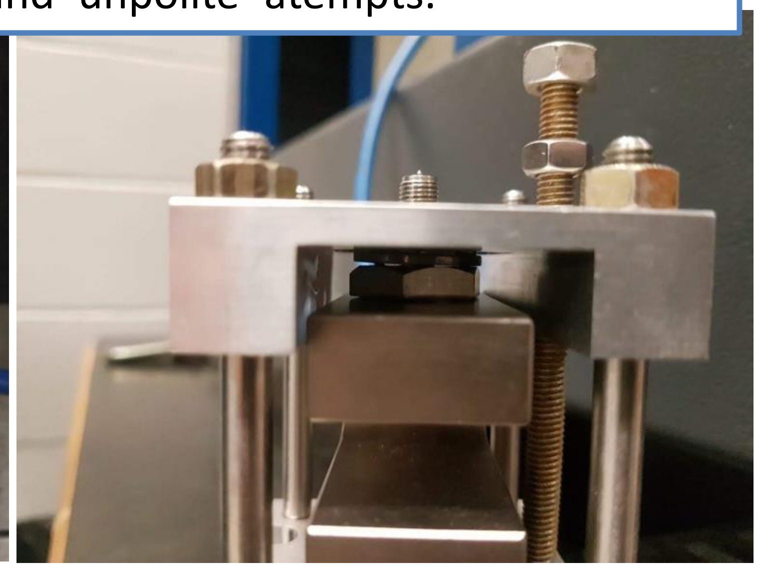


Tests performed with 6 buttons. For each:
- Conector was tightened once with maximum hand torque;
- Conector was tightened 3x with nominal torque (0.9 N.m);
- Several insertion angles and ‘unpolite’ atempts.

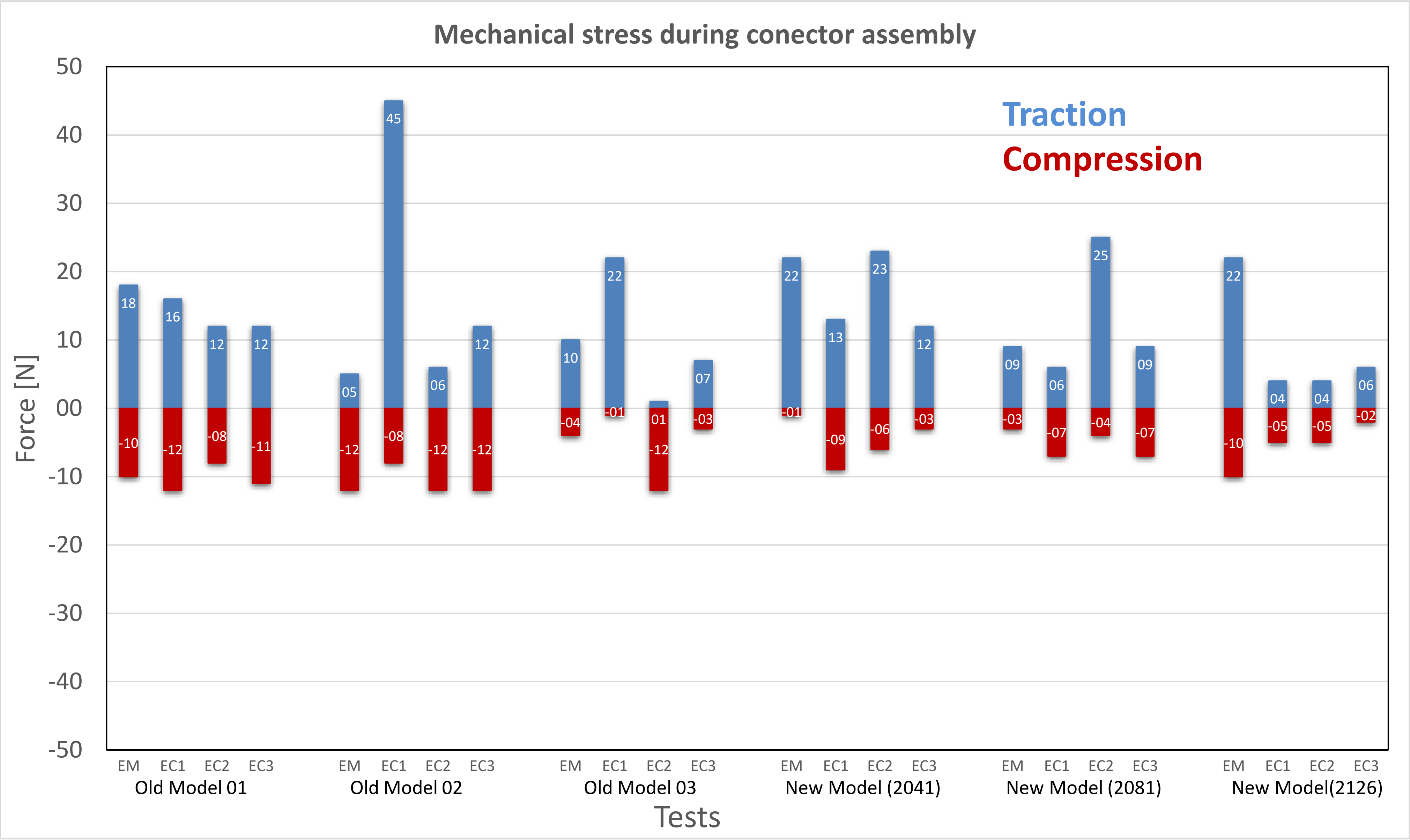
Button locked over load cell



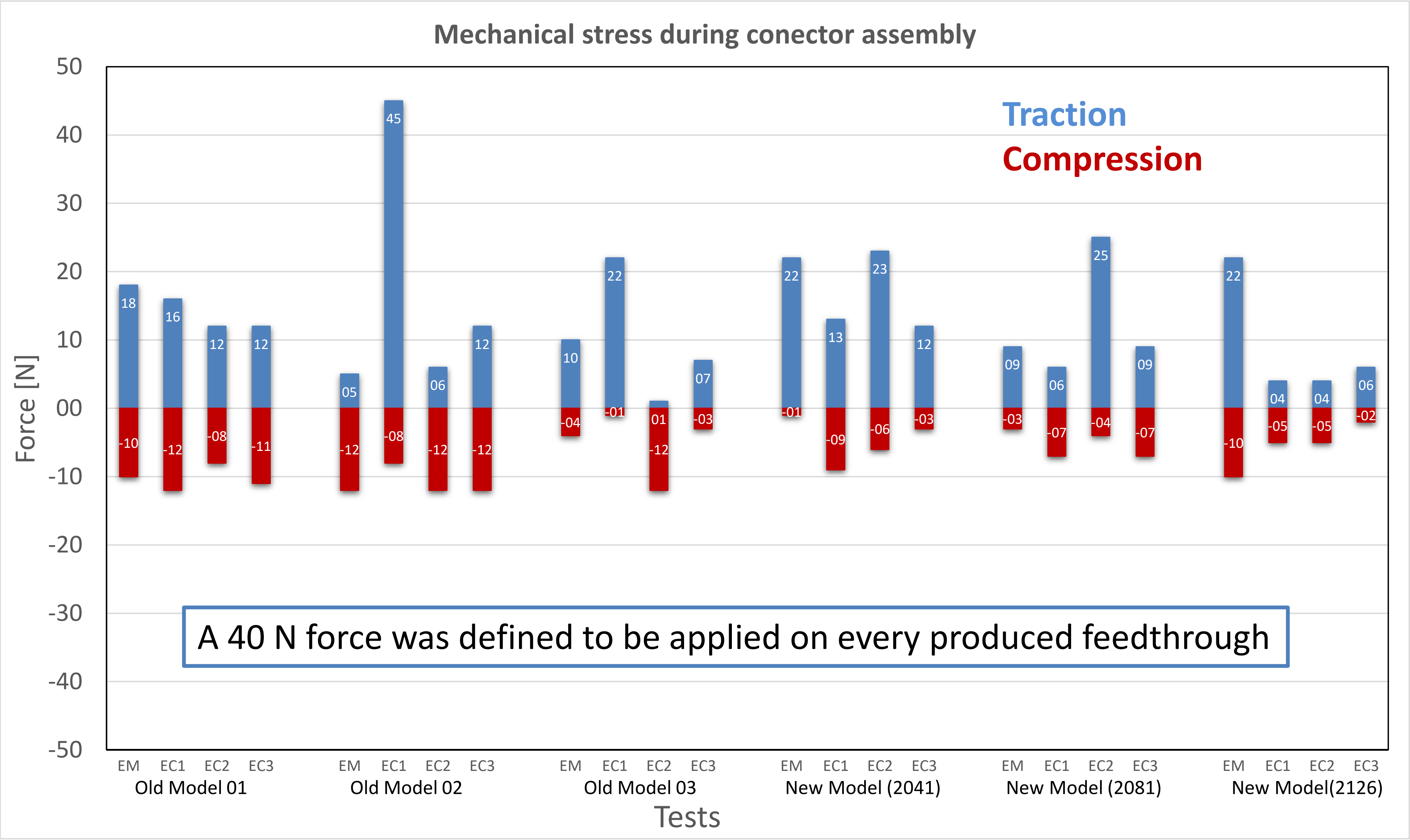
Top lid assembled with outer SMA connector



Measurement Results

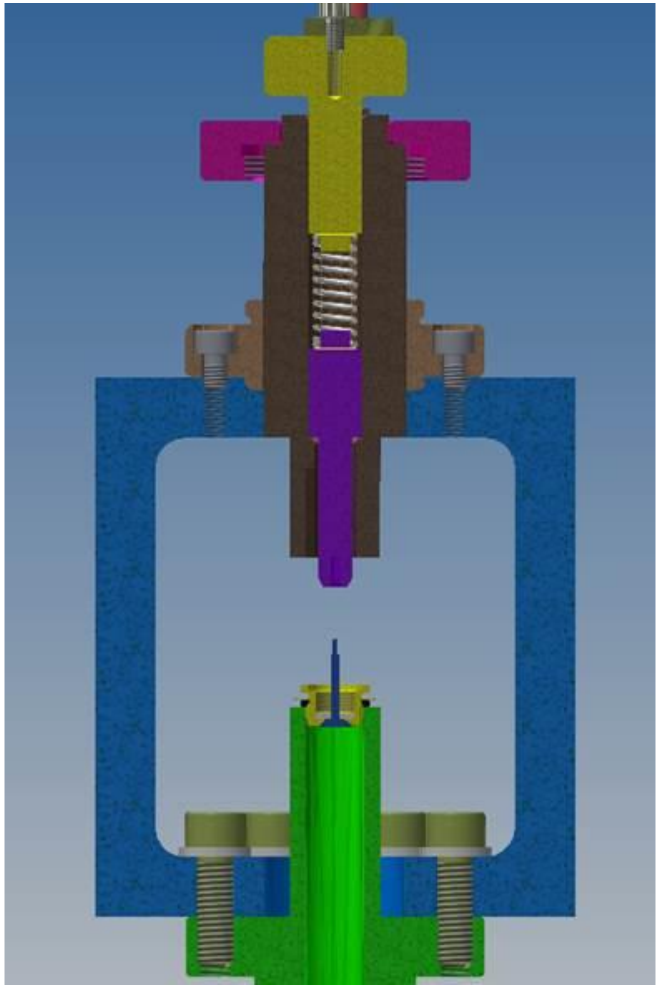


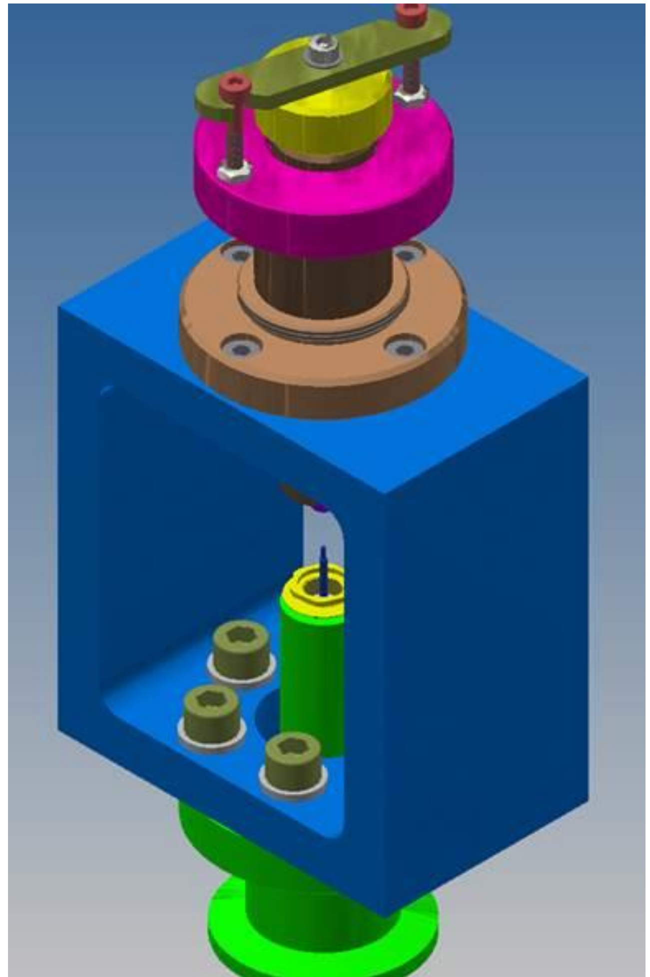
Measurement Results



Mechanical Quality Control Setup

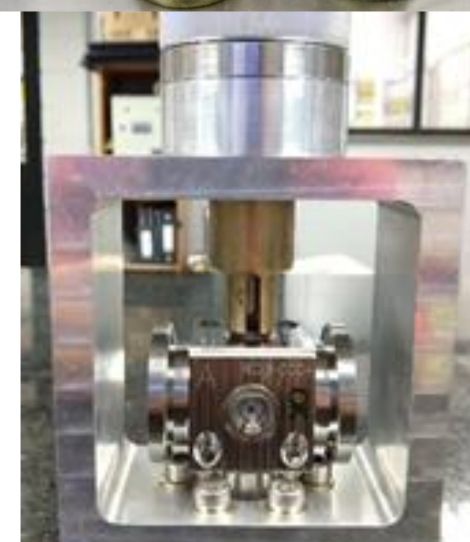
Test device mechanical design





Leak detector attached here

Force on separate feedthrough w/ leak detection



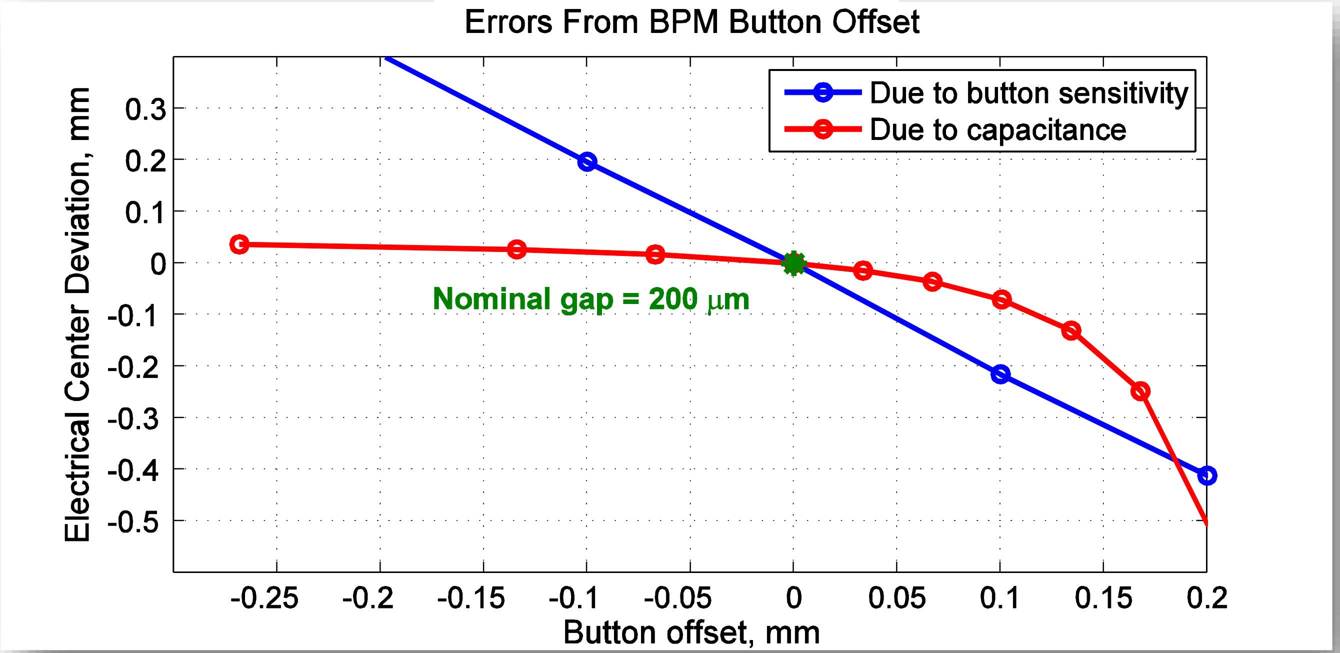
Force on welded feedthrough w/o leak detection

Lot of mechanics/vacuum quality control by now...

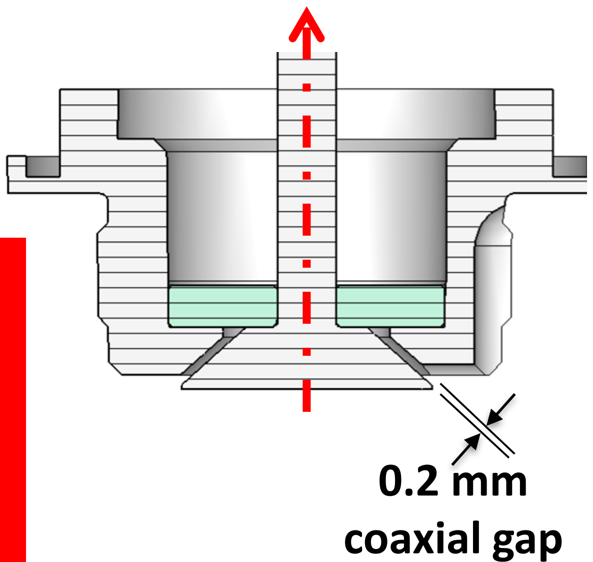
WHAT ABOUT CAPACITANTE AND BPM ELECTRICAL CENTER?

Button offset & gap tolerances

For a single button!



@ 500 MHz,
k = 10 mm



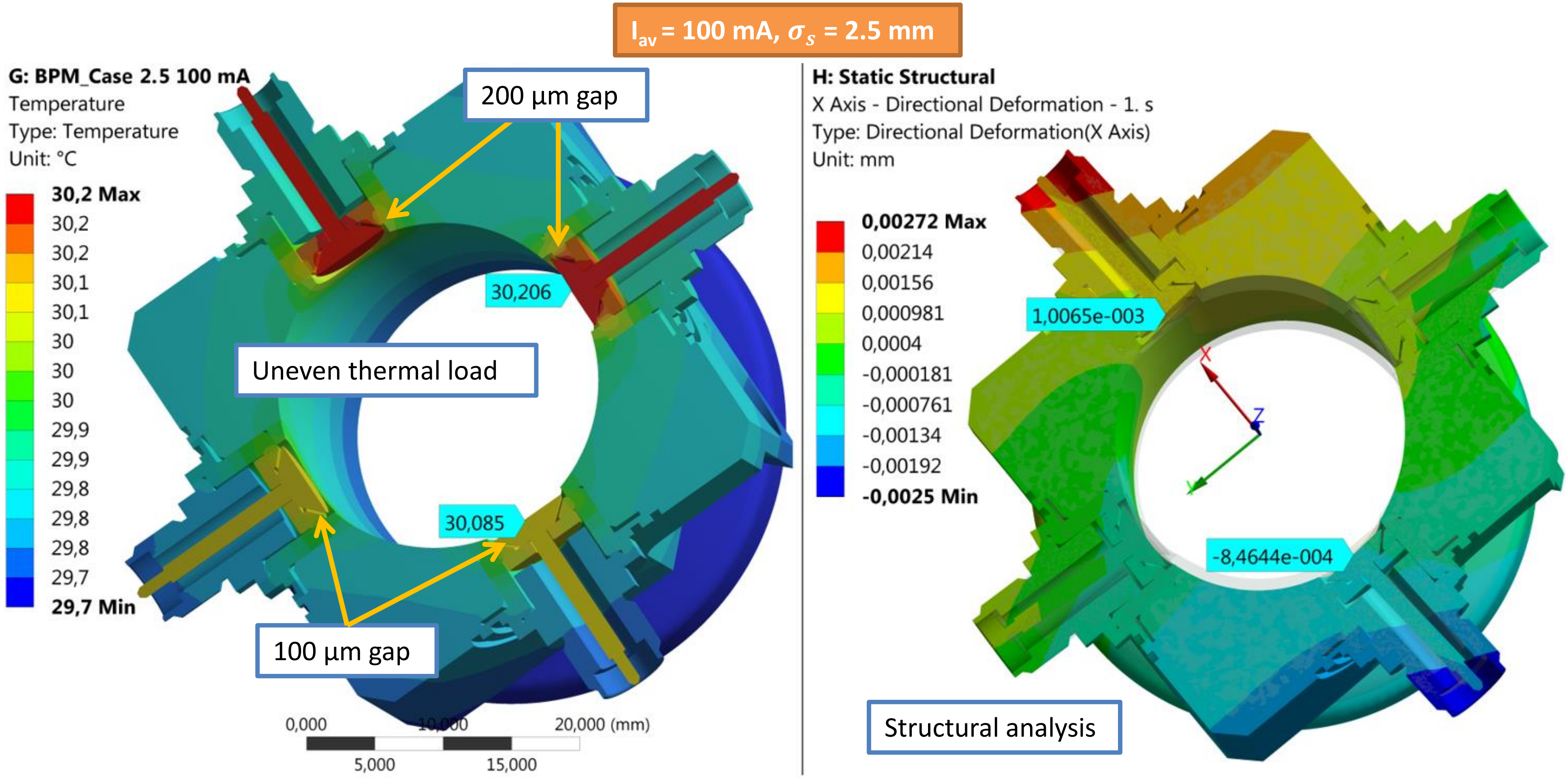
From the output power spectrum of wakefield simulations (keeping a constant gap value)

$$|Z_b(\omega)| = \frac{R_0}{2\,b\,c}\,\frac{\omega\, r^2}{\sqrt{1+(\omega\, R_0\, C_b)^2}}$$

DAΦNE BROAD-BAND BUTTON ELECTRODES

F. Marcellini, M. Serio, M. Zobov

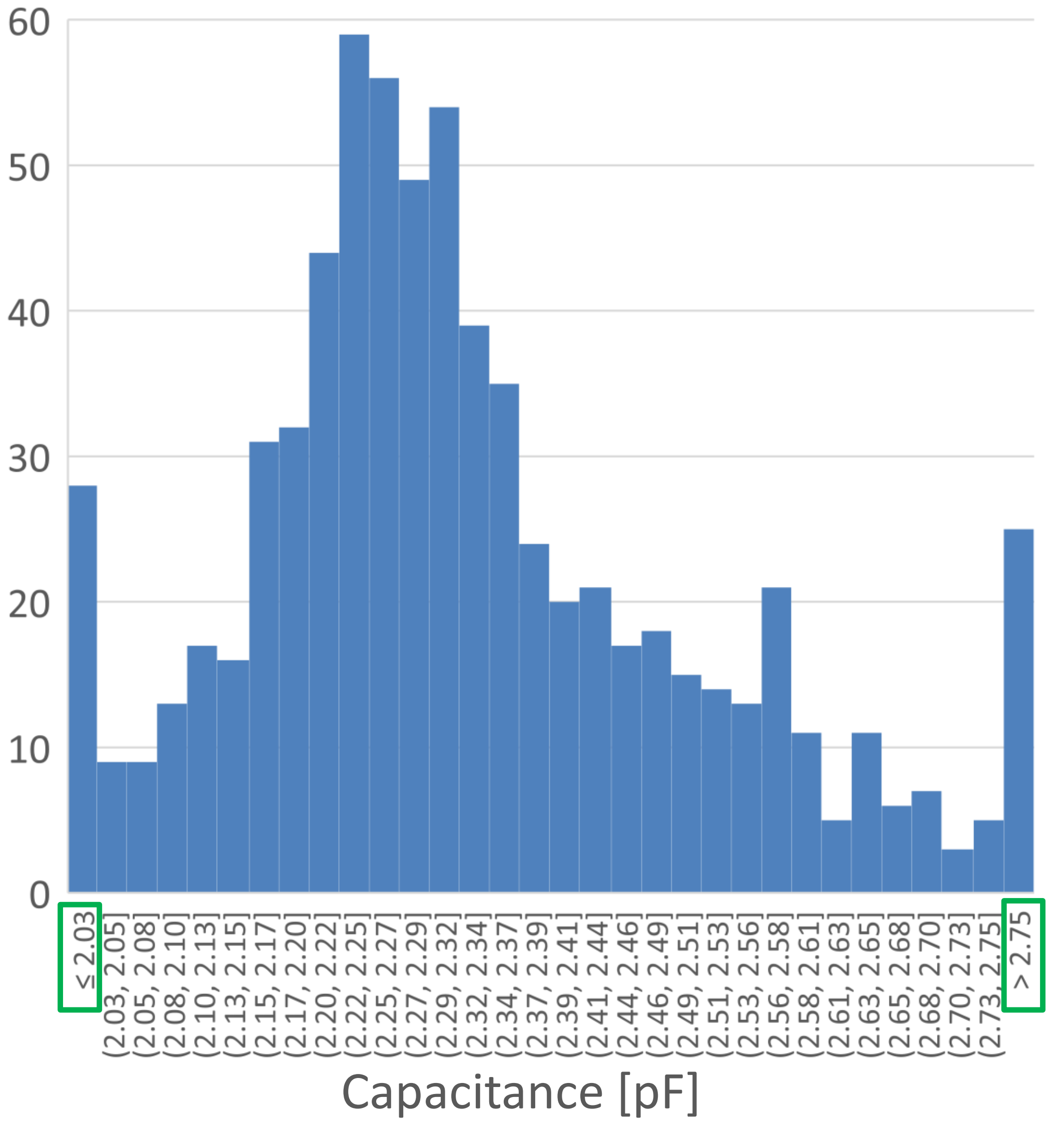
BPM Deformation



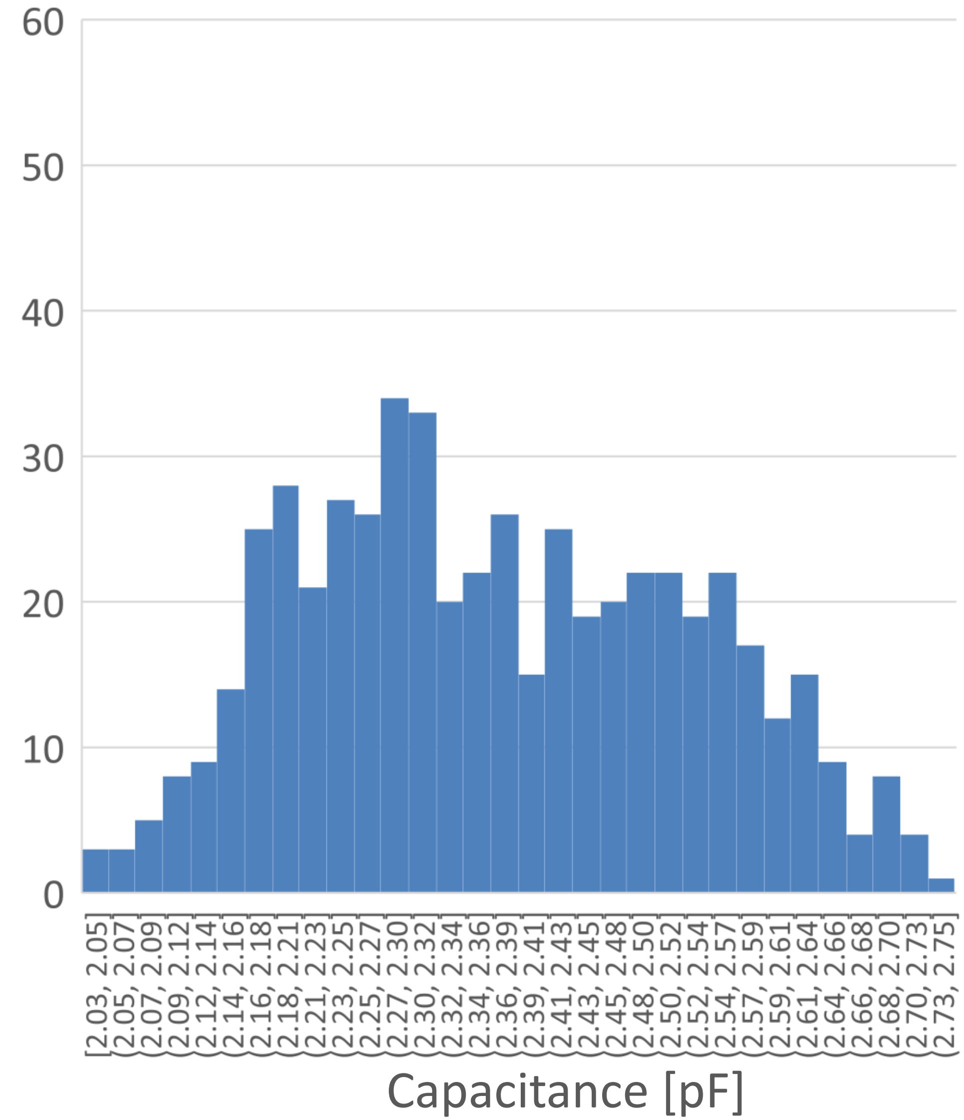
150 nm relative vertical offset: **300 nm BPM electrical center deviation** (from studies of electrical deviation). Since Sirius requires **sub-hundred nanometer stability**, sorting the buttons by similar gap size (or, close capacitance values) is required

Buton Capacitance Measurement

Capacitance measurement histogram – First batch (727 buttons) @ 2017



Capacitance measurement histogram – Second batch (538 buttons) @ 2018



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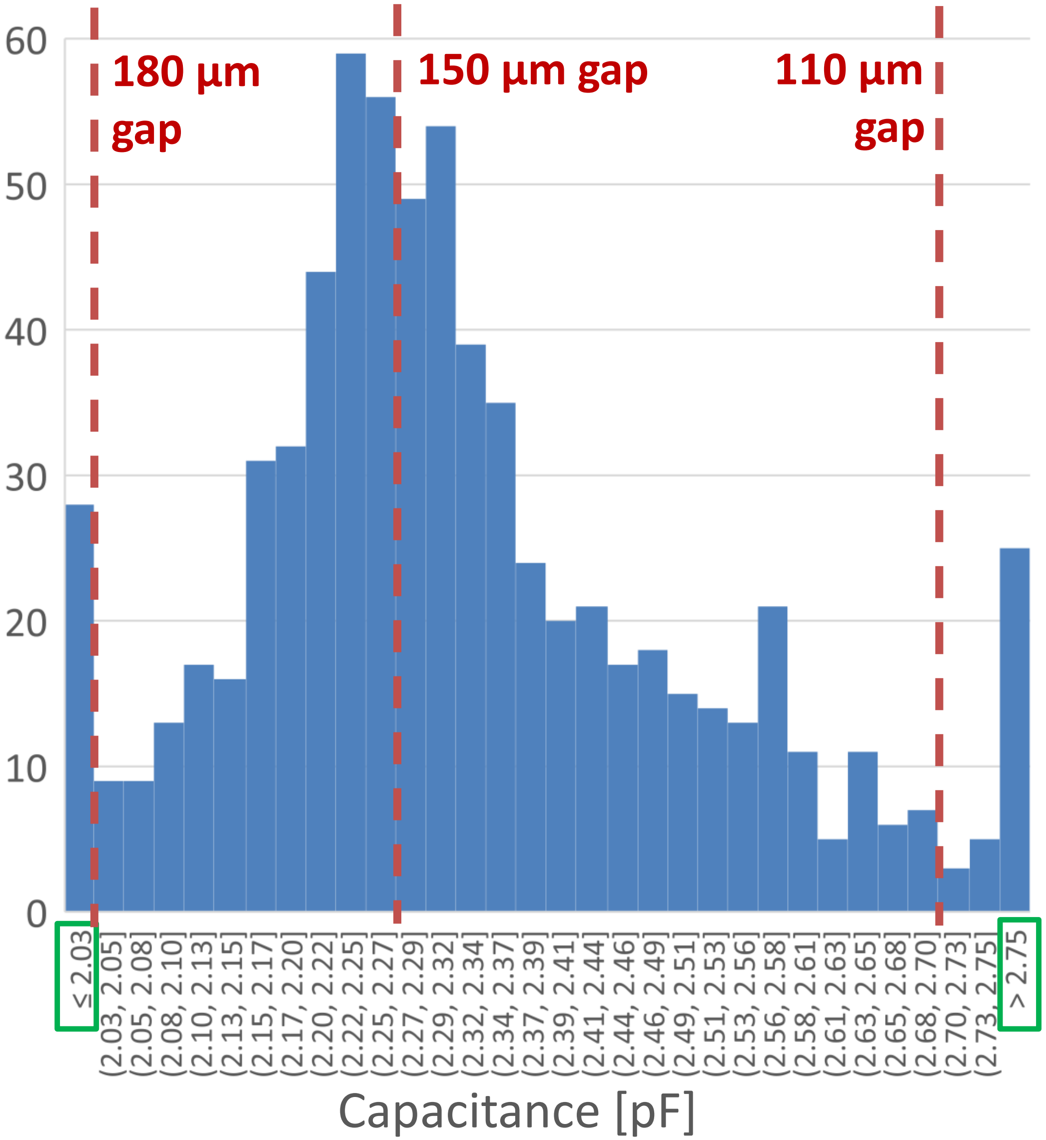

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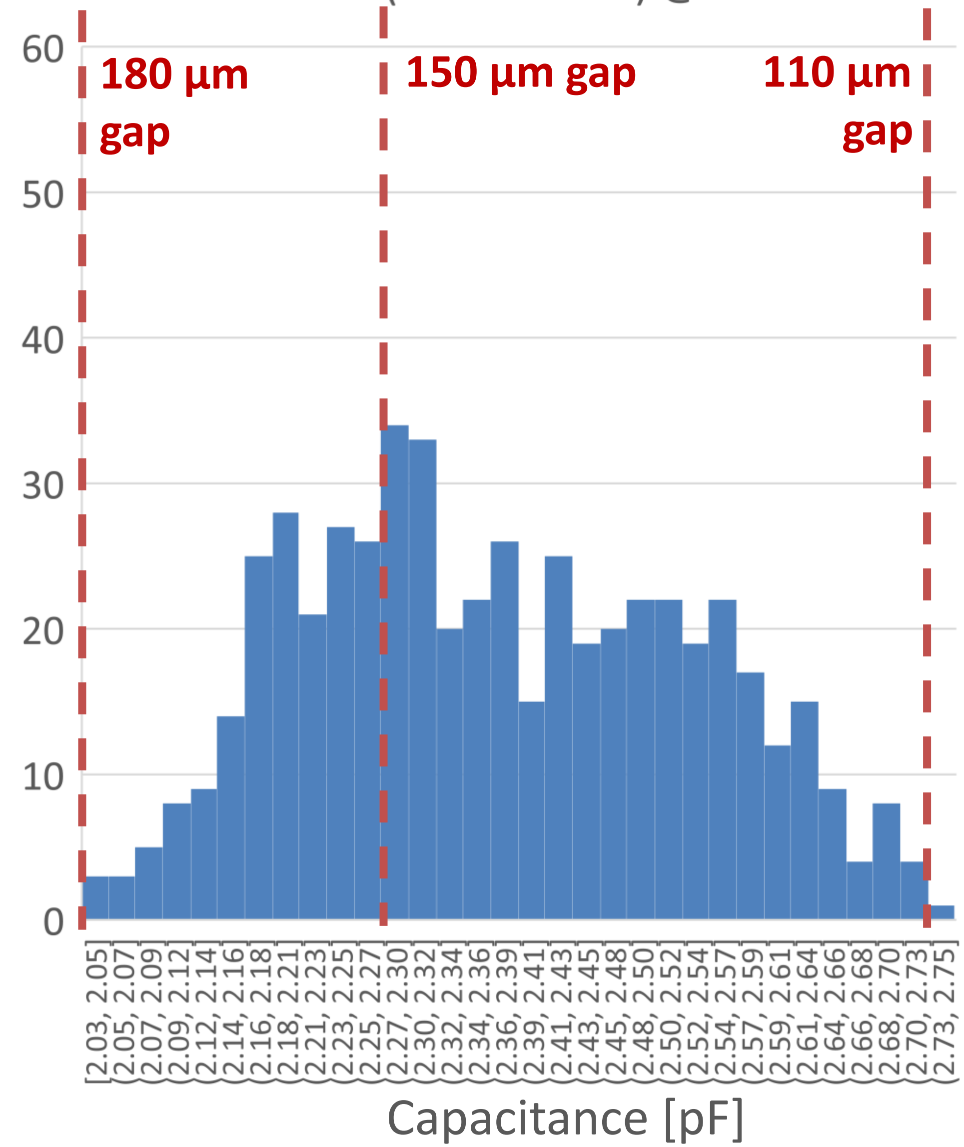
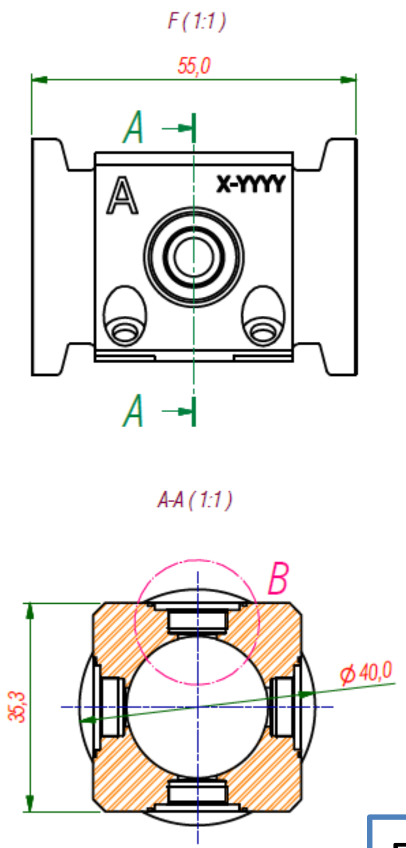
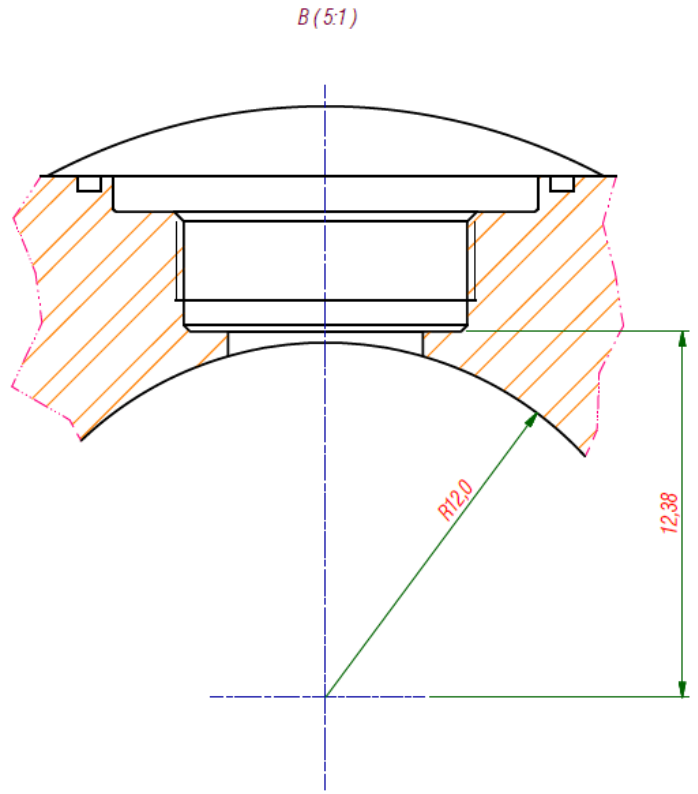
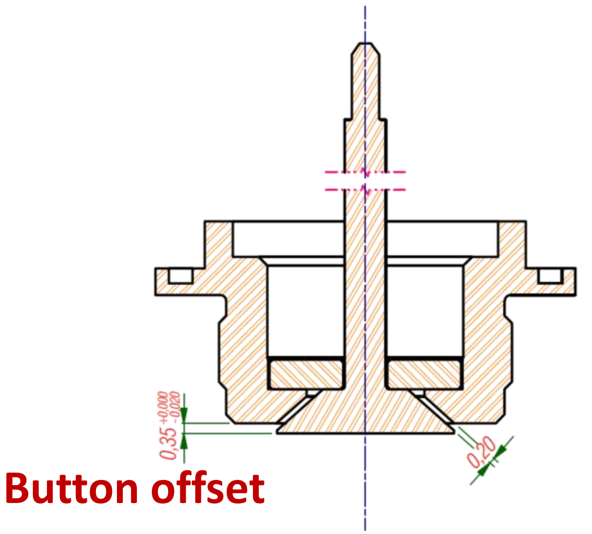


Button sorting







Each BPM was assembled with 4 feedthroughs with:

- Similar capacitance (< 1%) – hence similar gap sizes;
- Complementary housing seat and button offset – so the buttons face the same distante from BPM center .

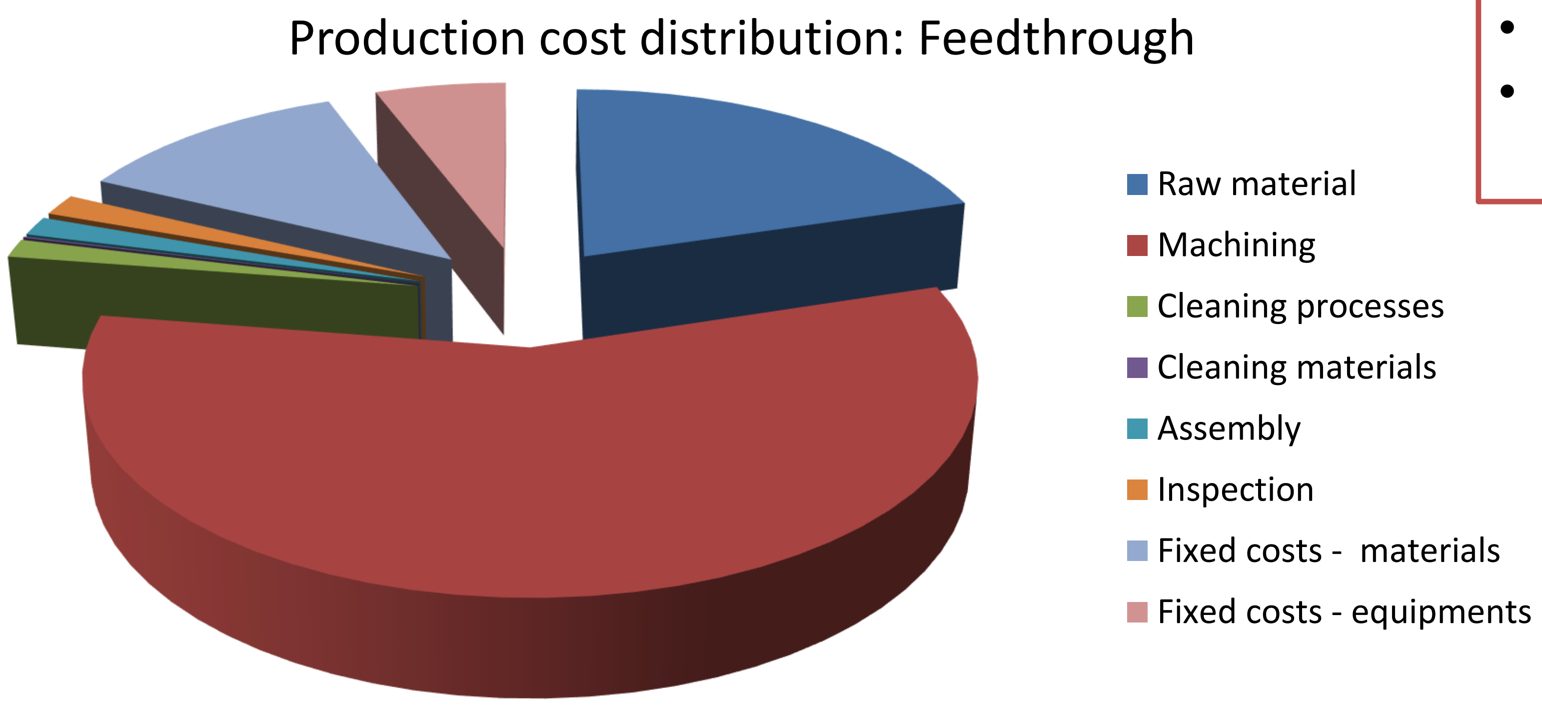
Outline

- Sirius Overview
- Developments
  - Electromagnetic Analysis
  - Button/ceramics/housing brazing
  - Housing-to-body insulation (flange or welding)
  - Wake Heating Analysis
- Quality Control
- Production

Production Statistics: Feedthrough

Unitary value: €232 + 5% losses

Losses include:
- Short-circuit
- Leak
- Microcracks
- Intermediate value shunt resistance

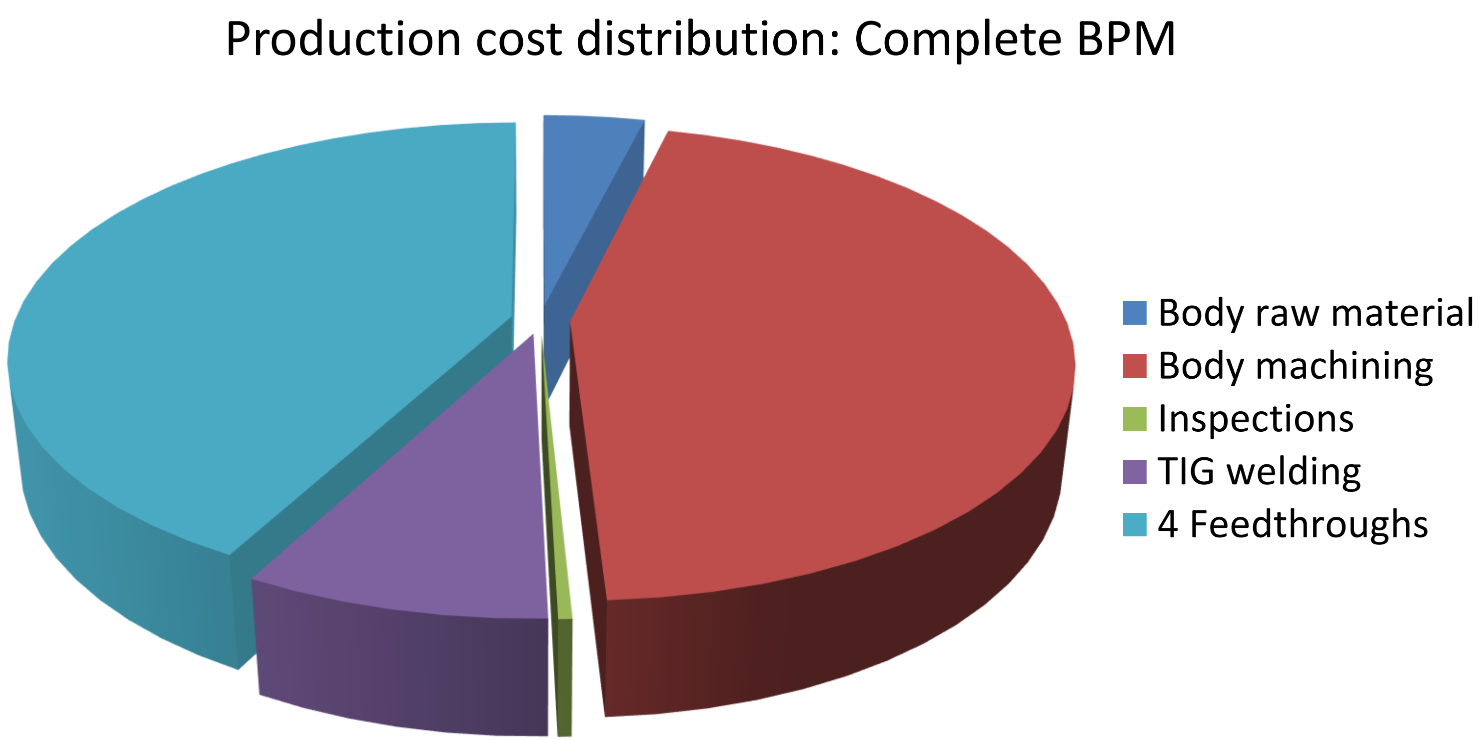


Production Statistics: Complete BPM

Unitary value: €2200 + 20% losses

Losses include:

- Leak after welding
- Microcracks while/after welding
- Leak after traction test
- Microcracks after traction test



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- We are open for colaborations ☺

Thank you!