The Wall Current Transformer
A new sensor for bunch-by-bunch intensity measurements in the LHC

Michal Krupa[1,2], Marek Gasior[1]

[1]CERN Beam Instrumentation Group, Geneva, Switzerland
[2]Lodz University of Technology, Lodz, Poland

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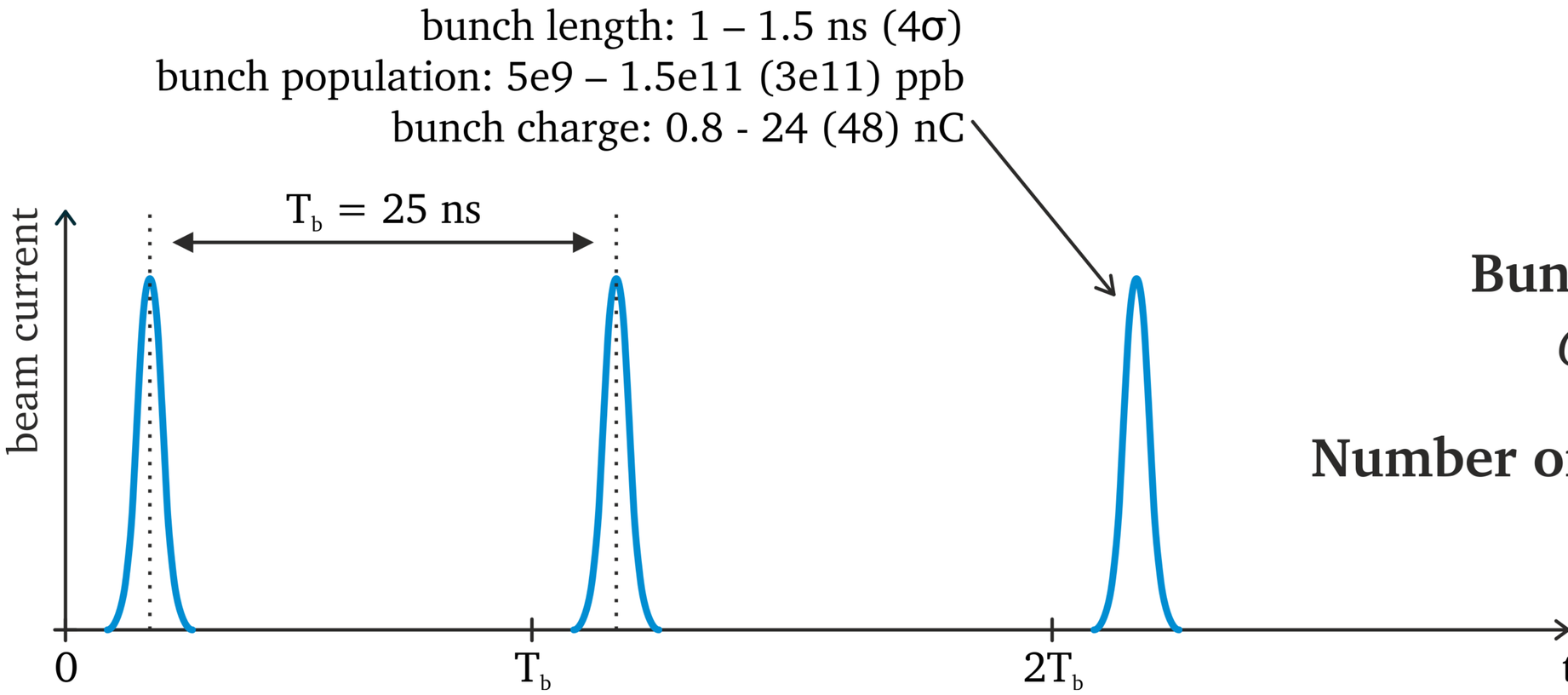
Outline

- Bunch current measurements in the LHC
- WCT principle of operation
- LHC implementation
- Laboratory measurements
- Beam measurements
- Conclusions

LHC bunch current measurements



Bunch charge:

$Q_B = \int i_B(t)\,dt$

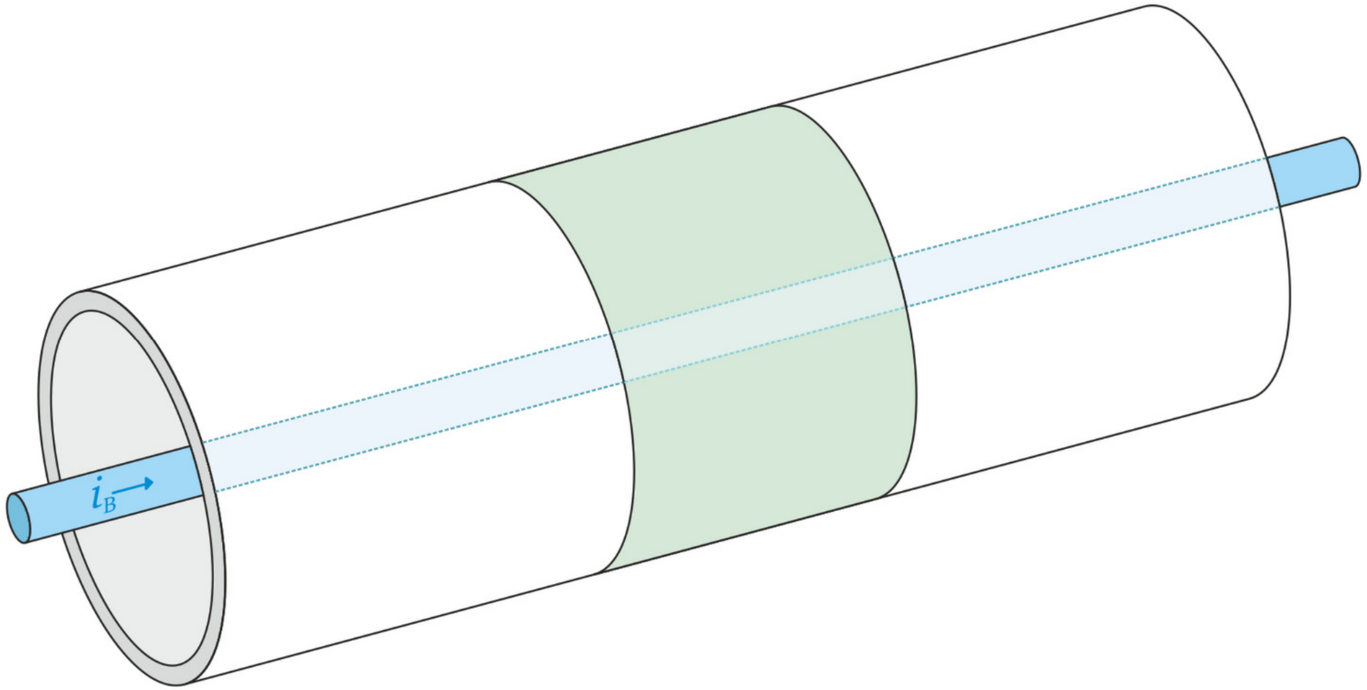
Number of particles:

$N = Q_B / e$

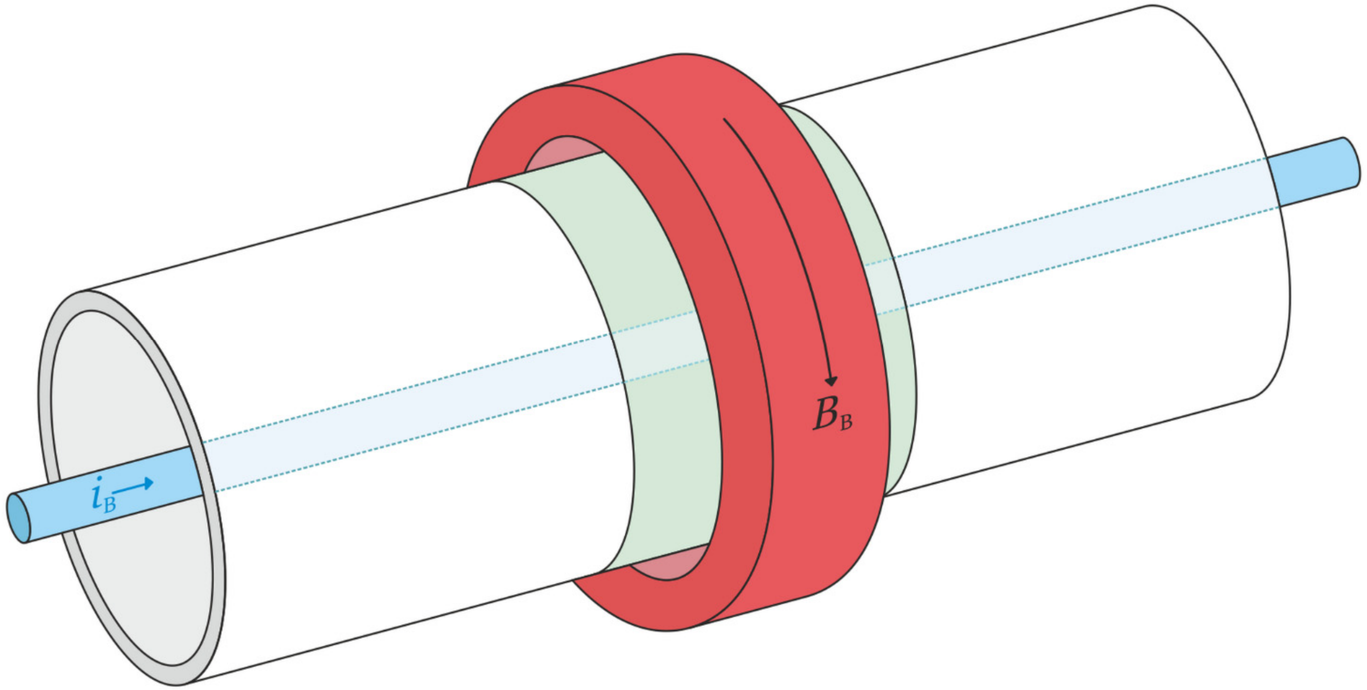
LHC bunch current measurements

- **LHC Run 1 (2008-2012):** 4 Fast Beam Current Transformers (FBCT) bunch position sensitivity
- **LS1 (2013-2014):** Design of new monitors for absolute bunch-by-bunch intensity measurements.
  Two developments in parallel:
  - Integrating Current Transformer (ICT) in collaboration with the industry
  - Wall Current Transformer (WCT) by the CERN BI Group
- **2015:** FBCT + ICT, FBCT + WCT
- **2016:** 3 WCTs + ICT
- **2017+:** 4 WCTs

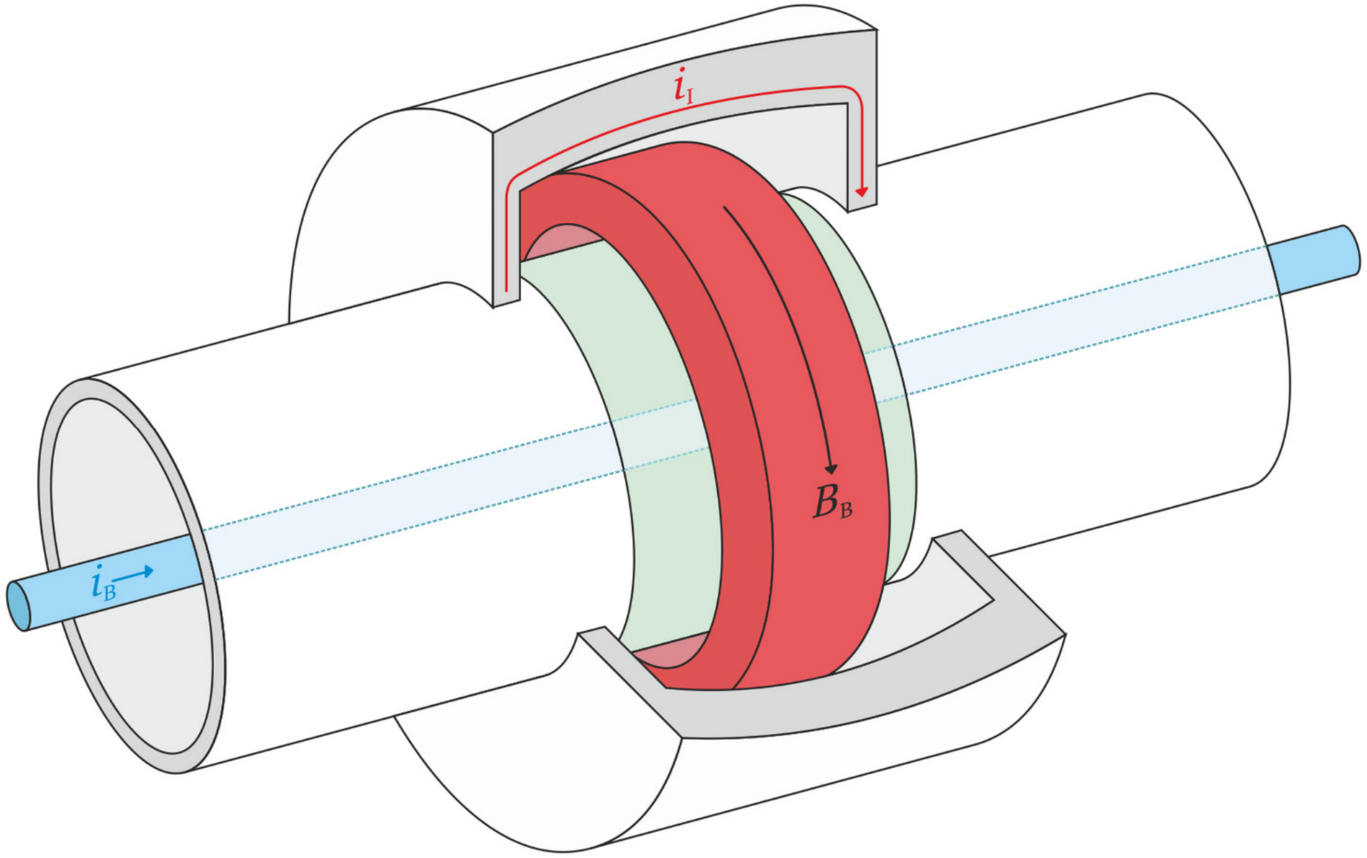
FBCT recap



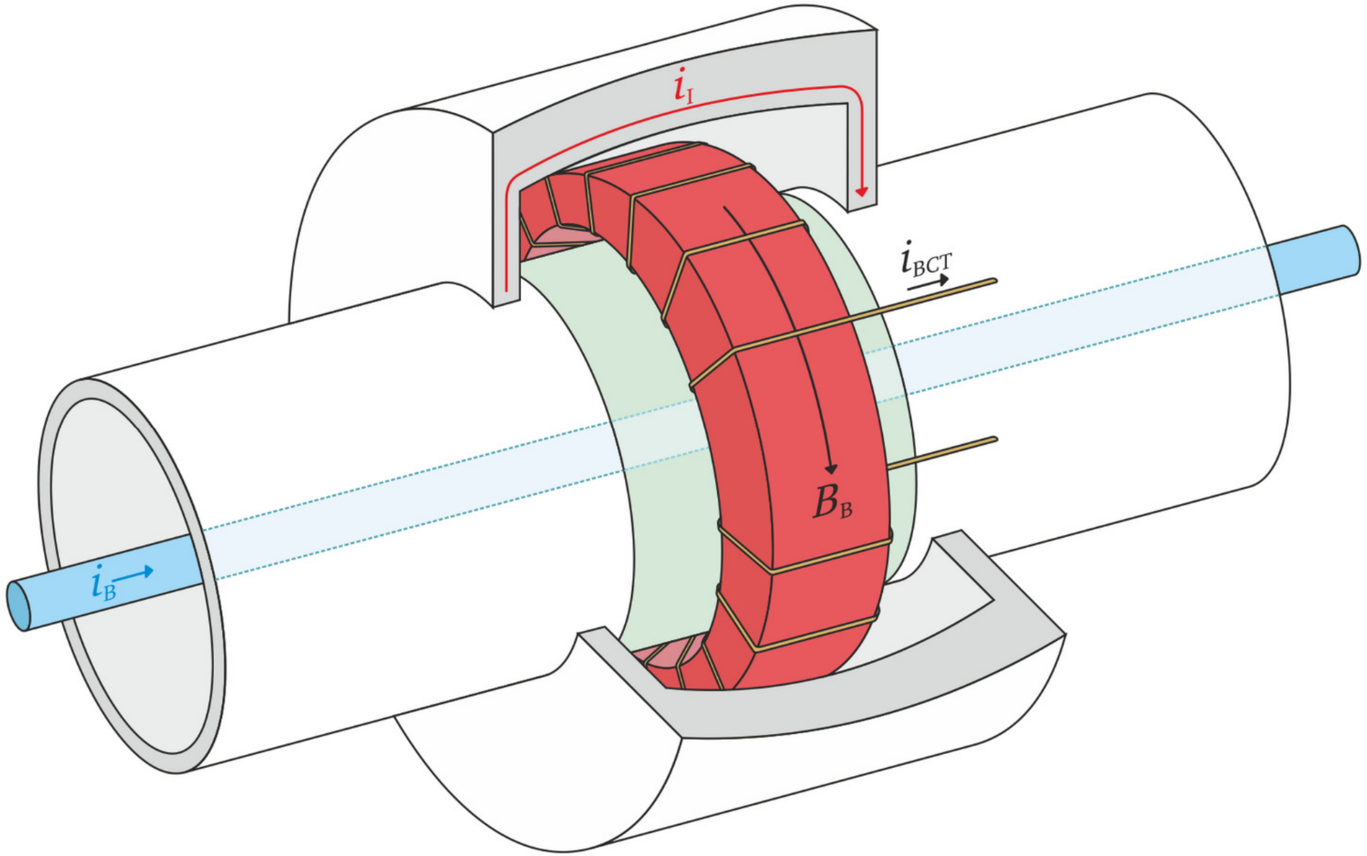
FBCT recap



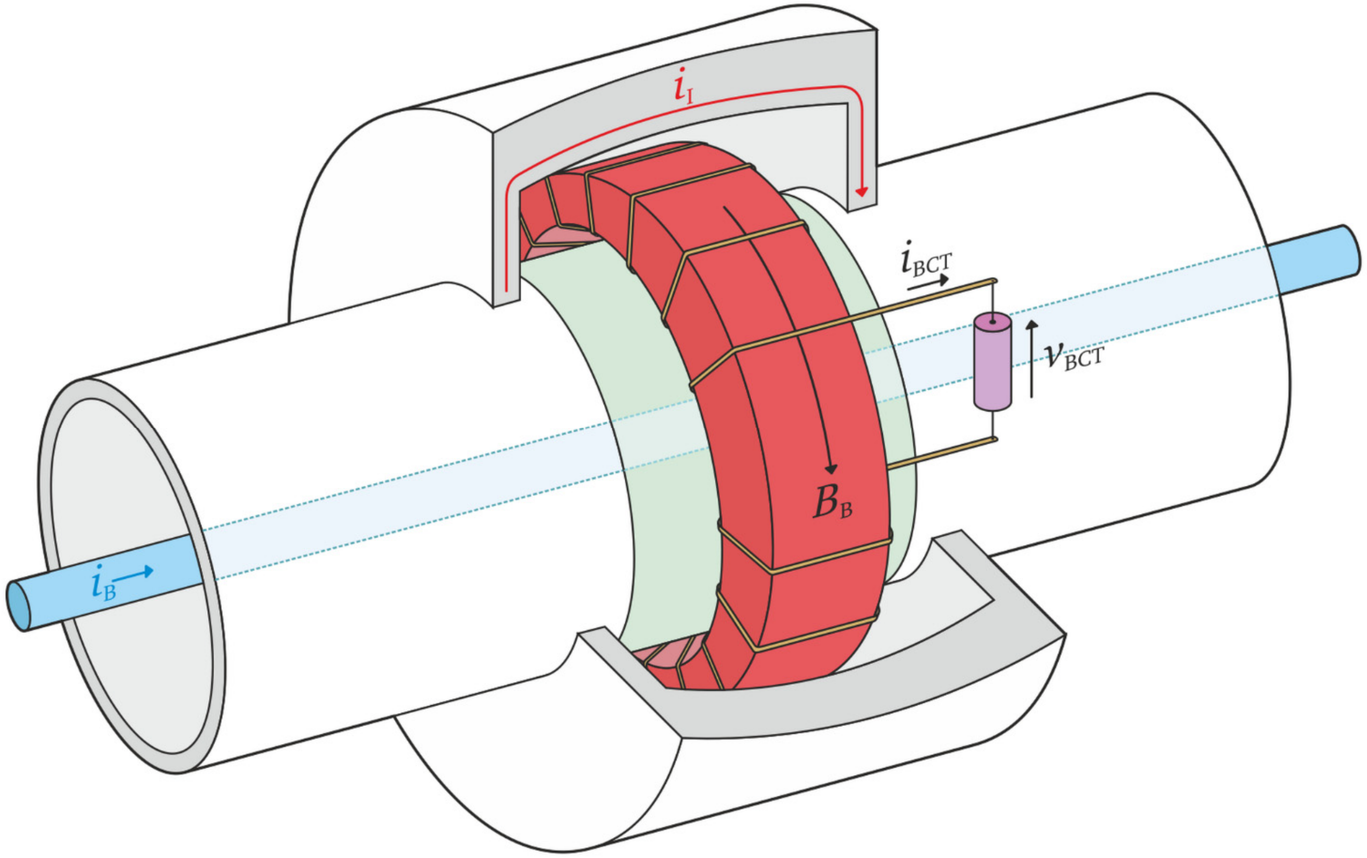
FBCT recap



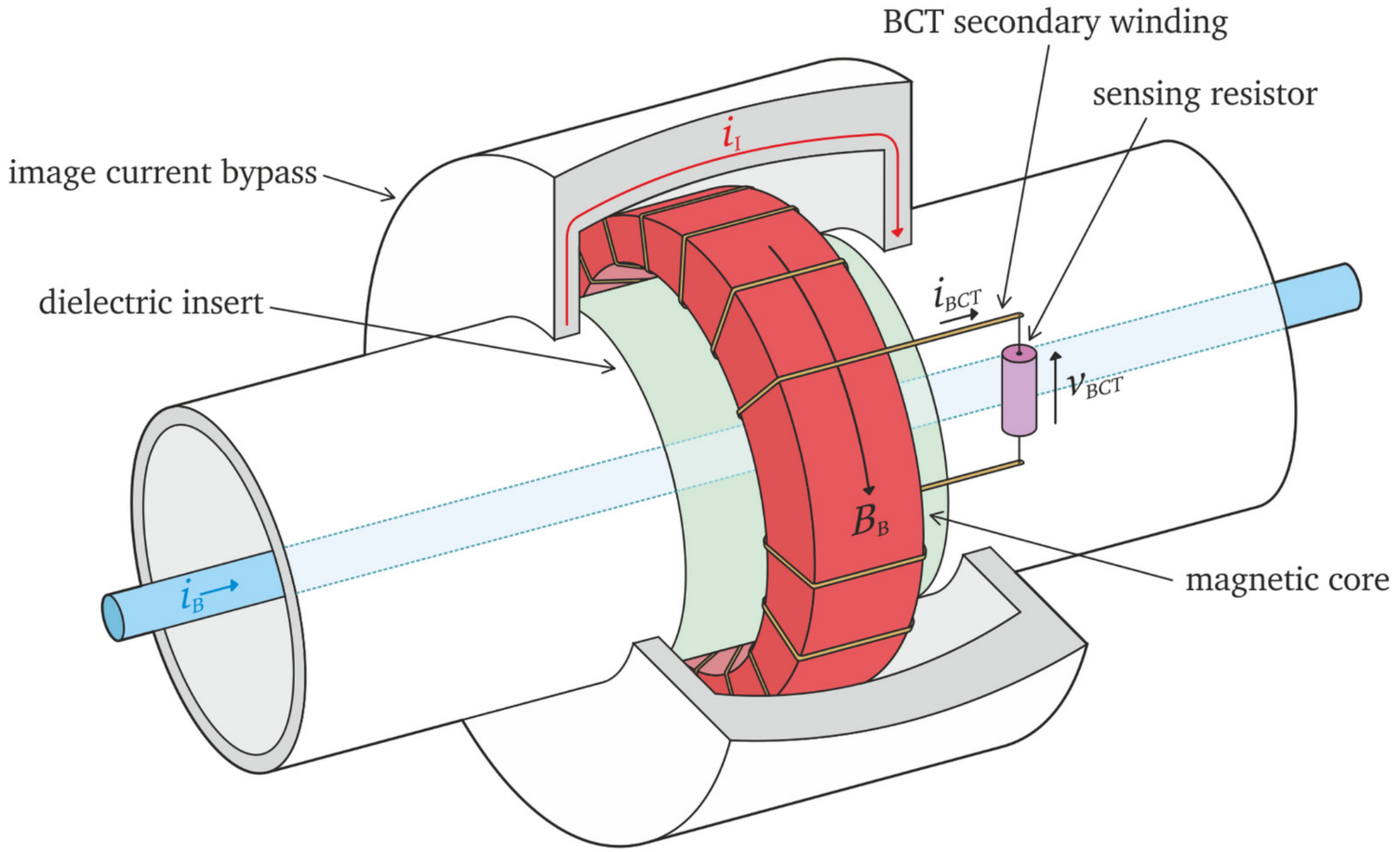
FBCT recap



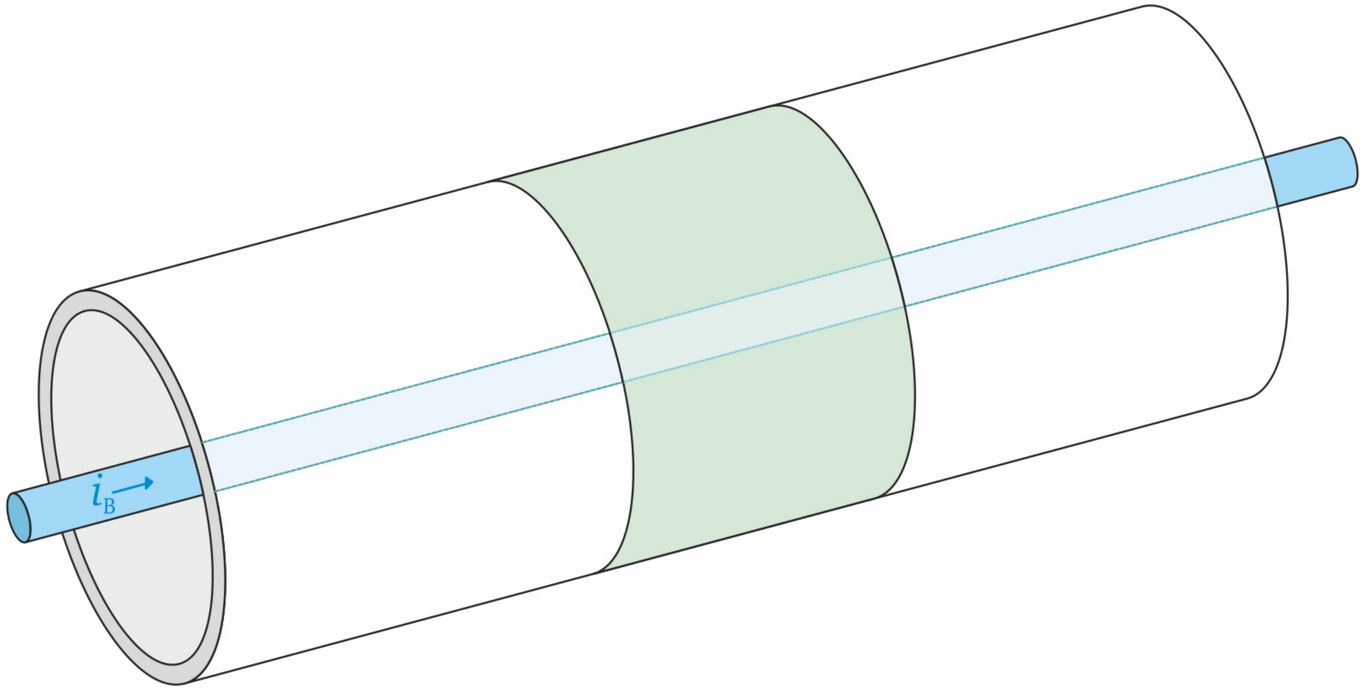
FBCT recap



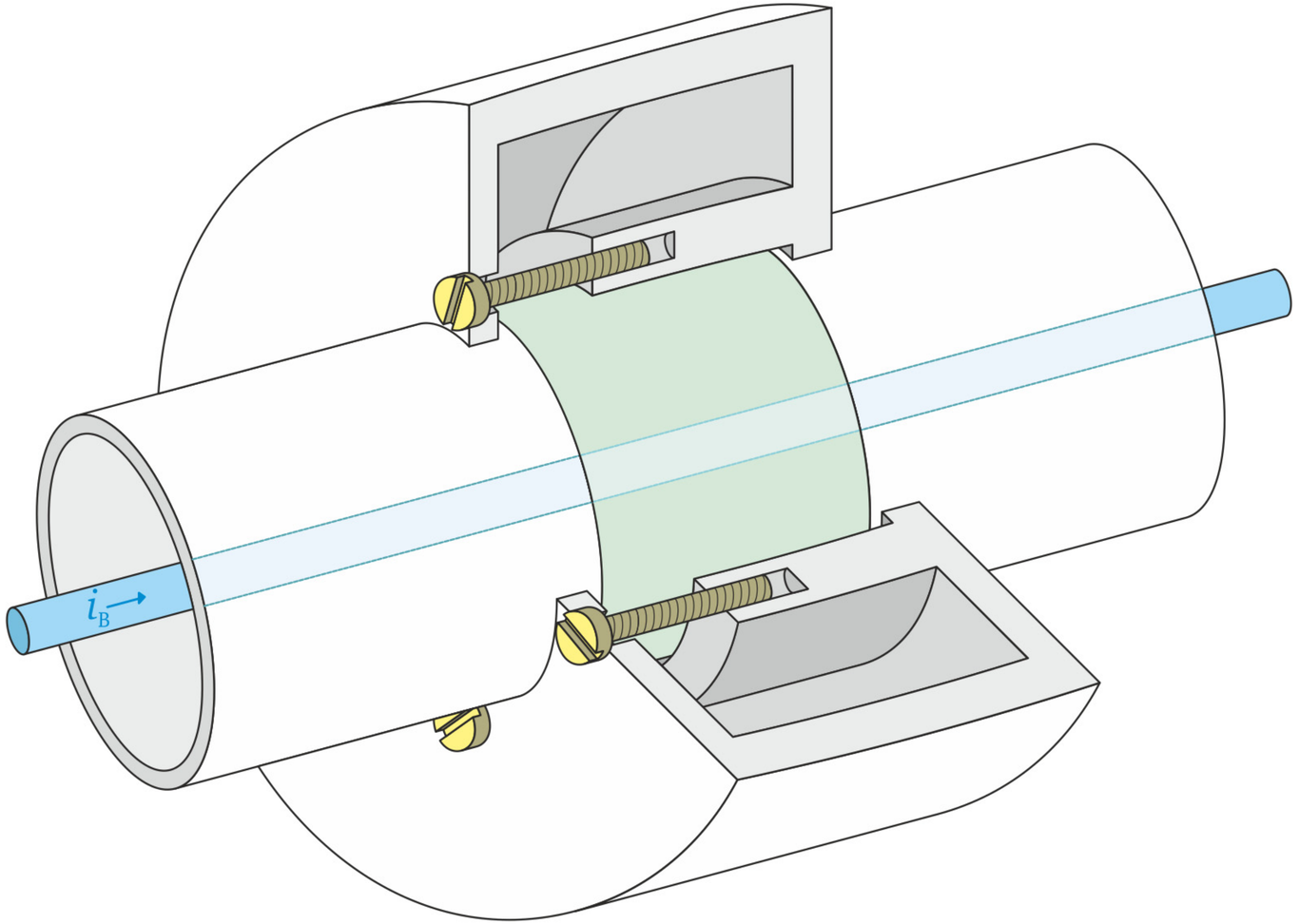
FBCT recap


BCT secondary winding
sensing resistor
image current bypass
dielectric insert
i_I
i_{BCT}
v_{BCT}
B_B
i_B
magnetic core

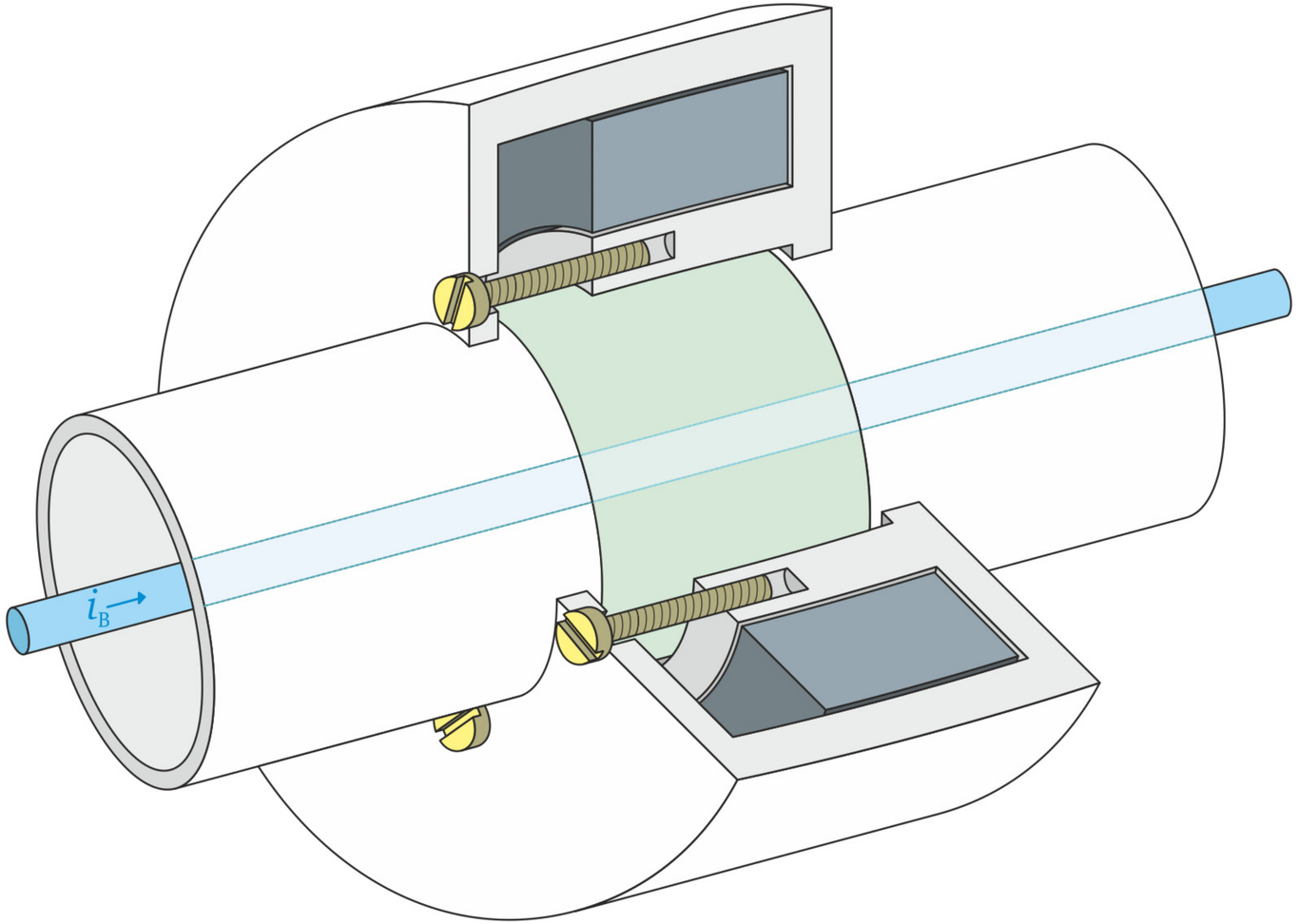
WCT principle of operation



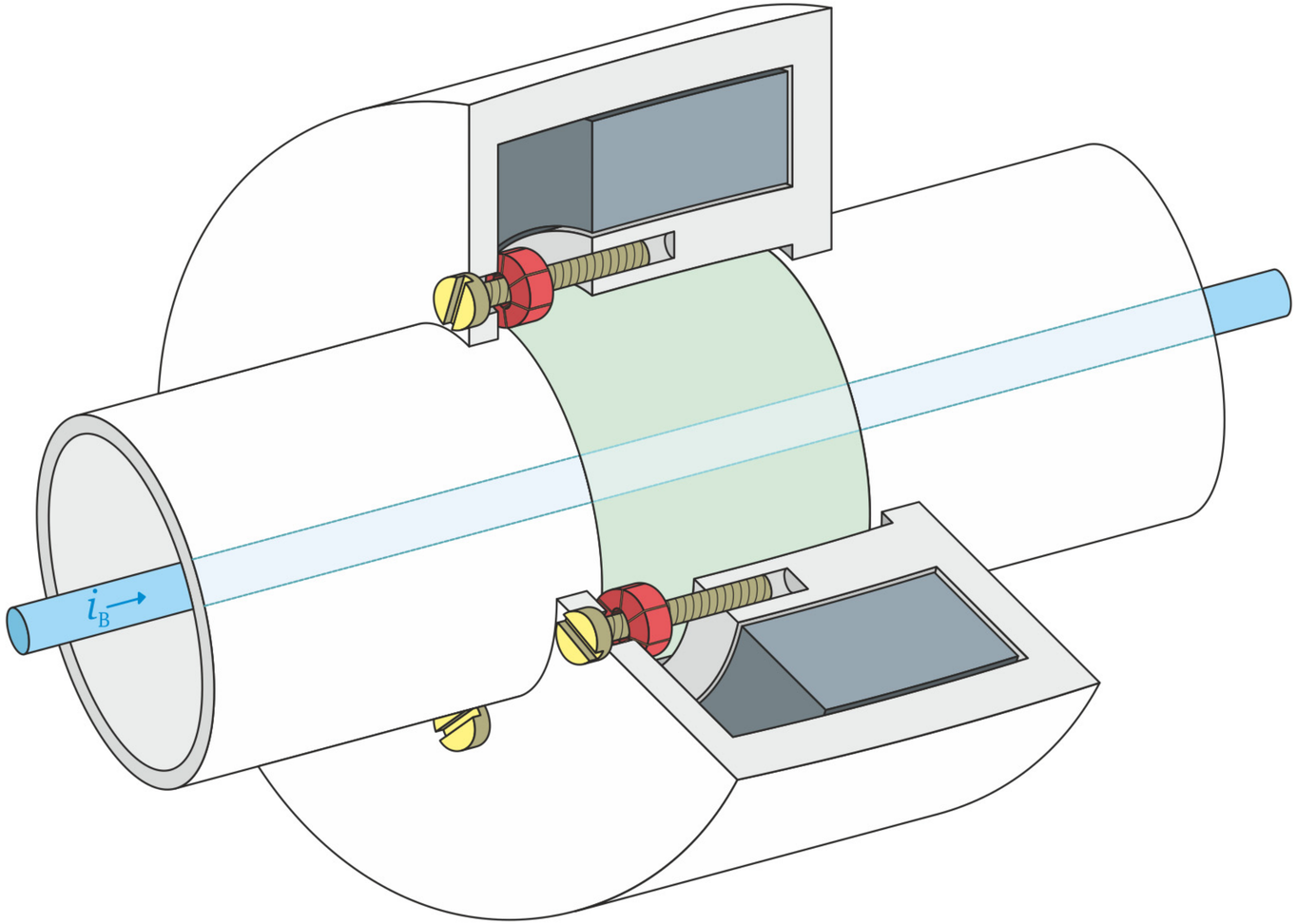
WCT principle of operation



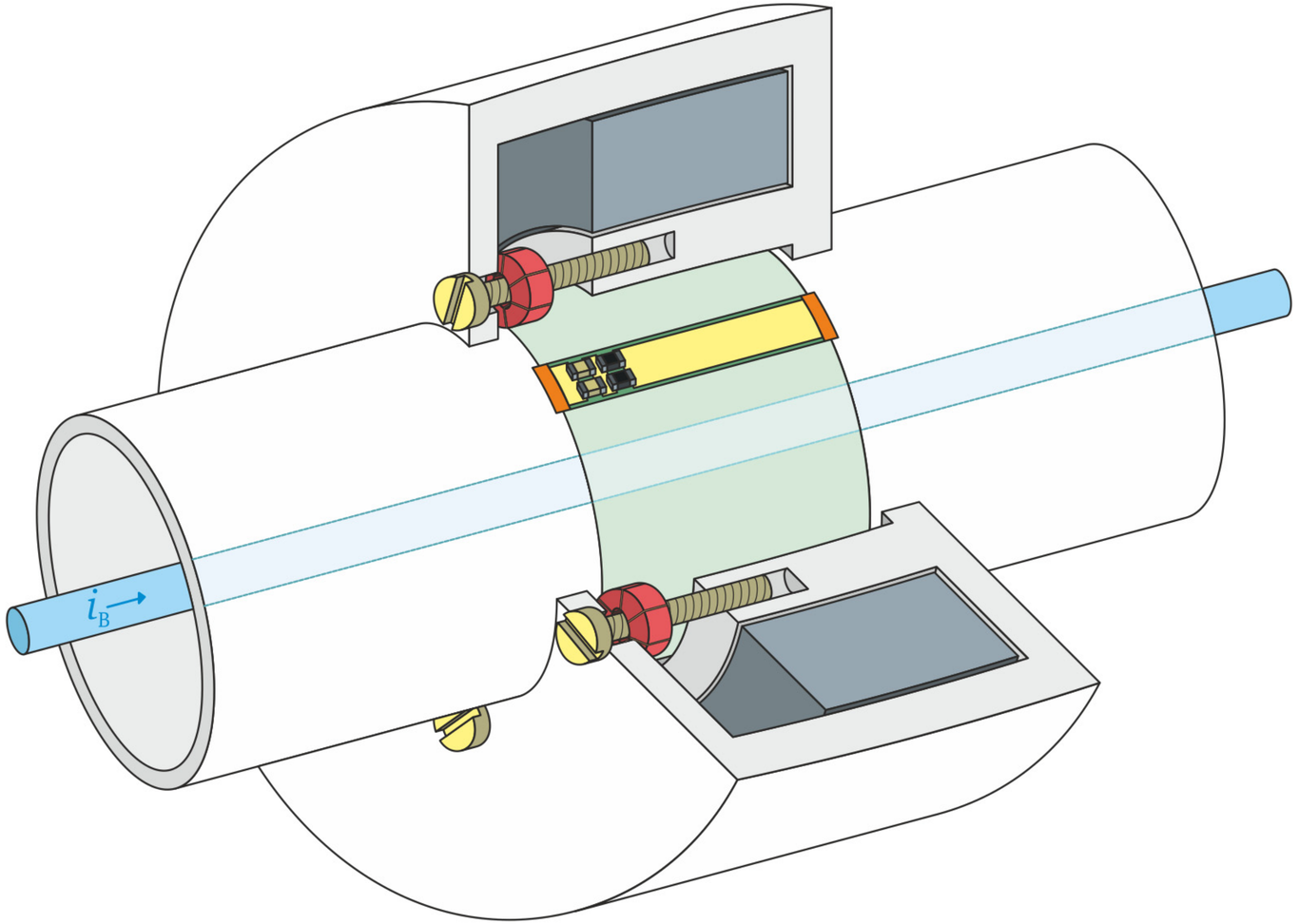
WCT principle of operation



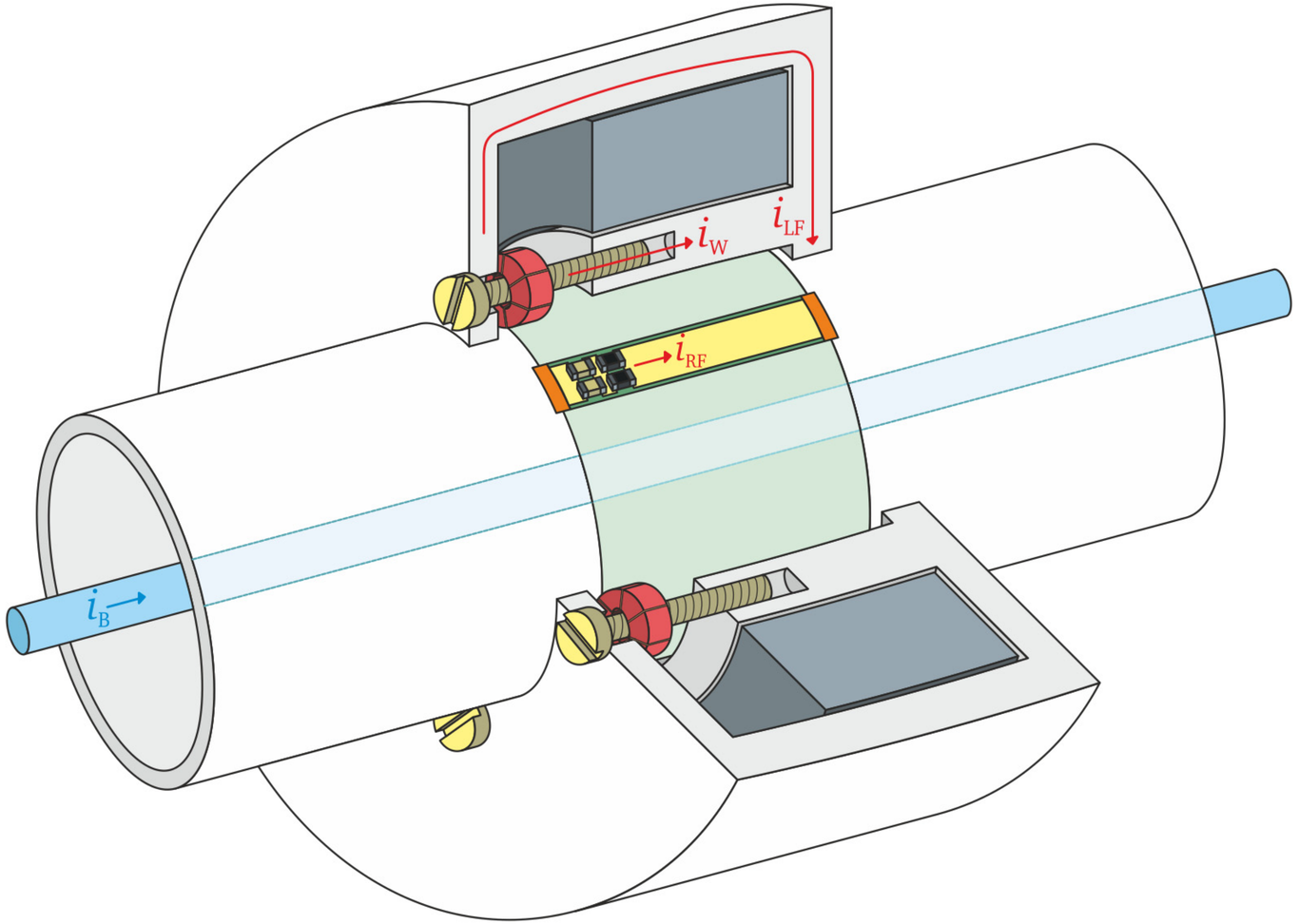
WCT principle of operation



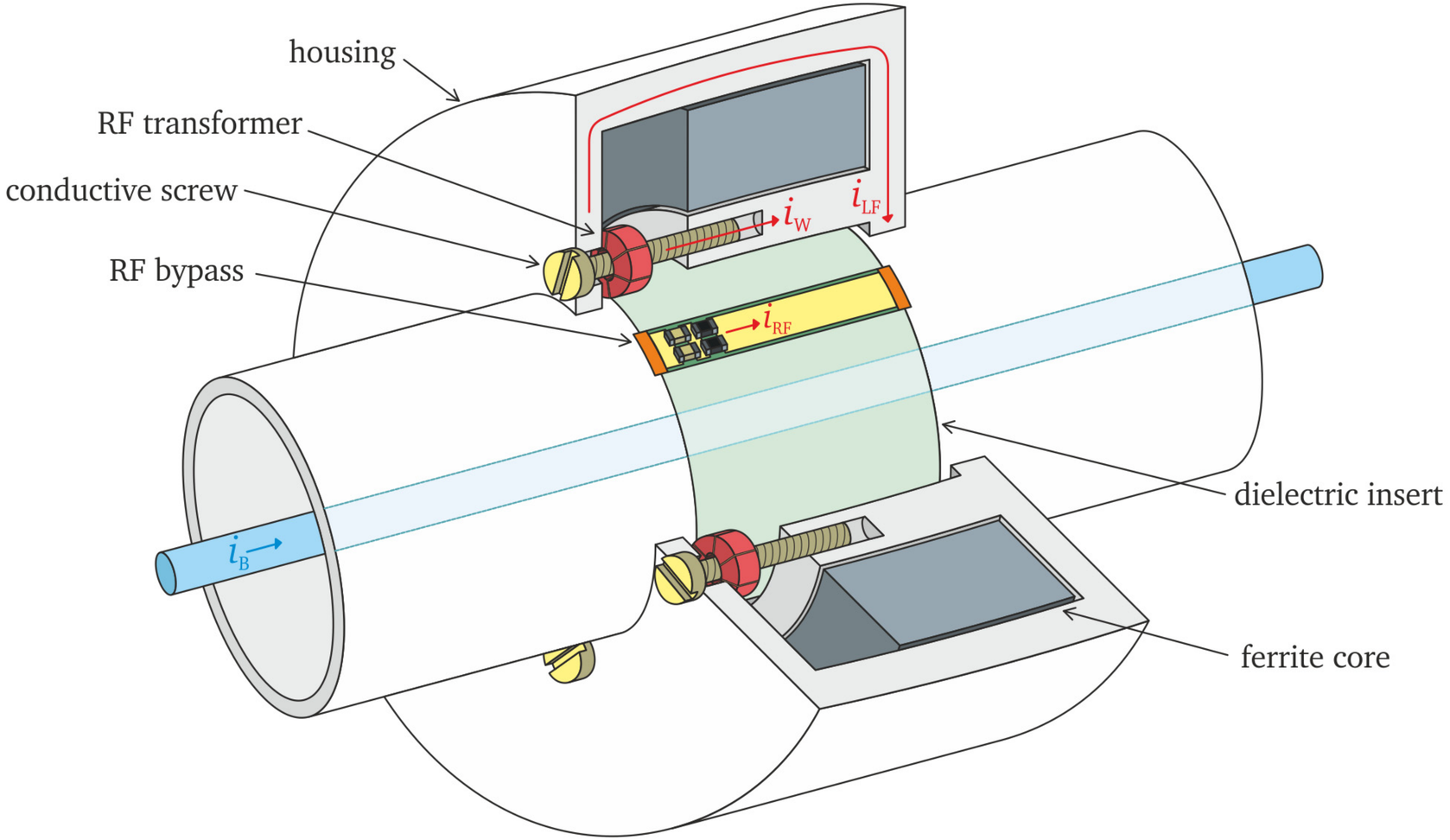
WCT principle of operation



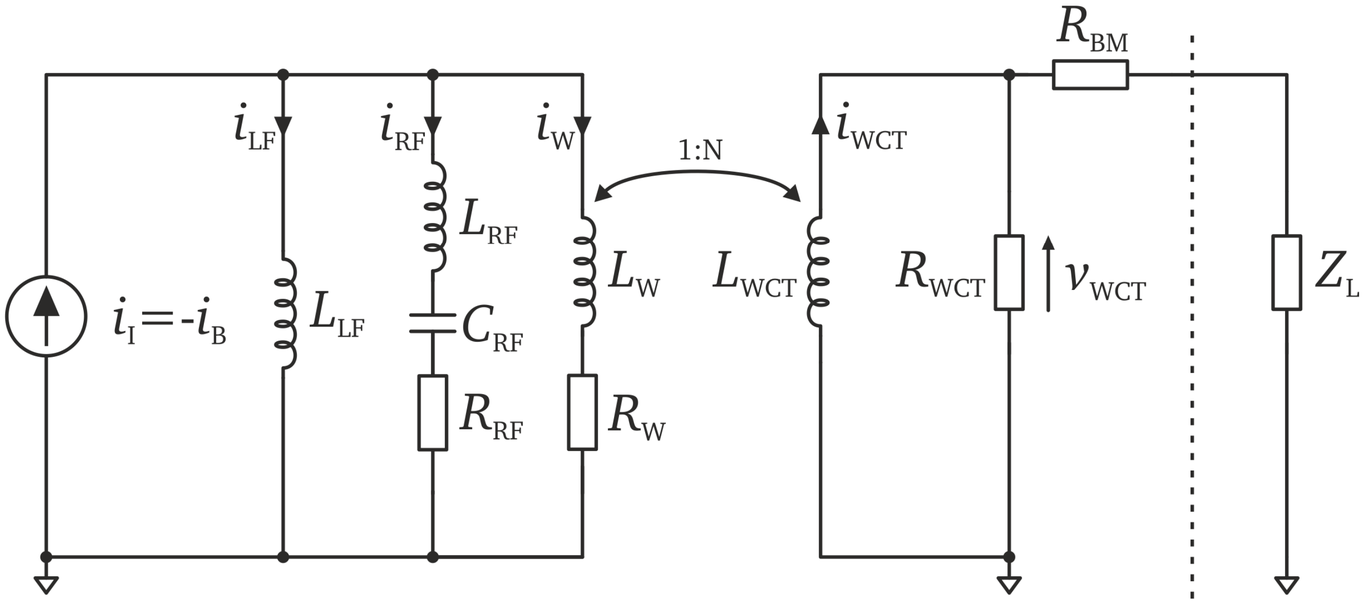
WCT principle of operation

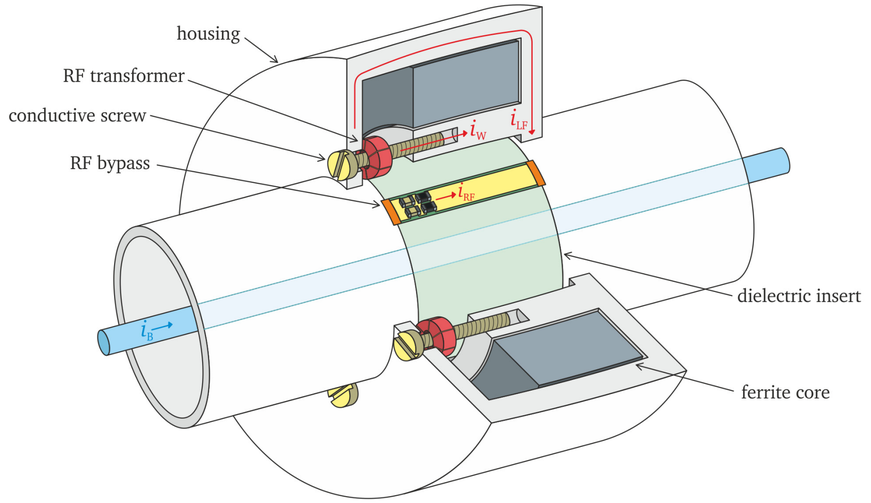


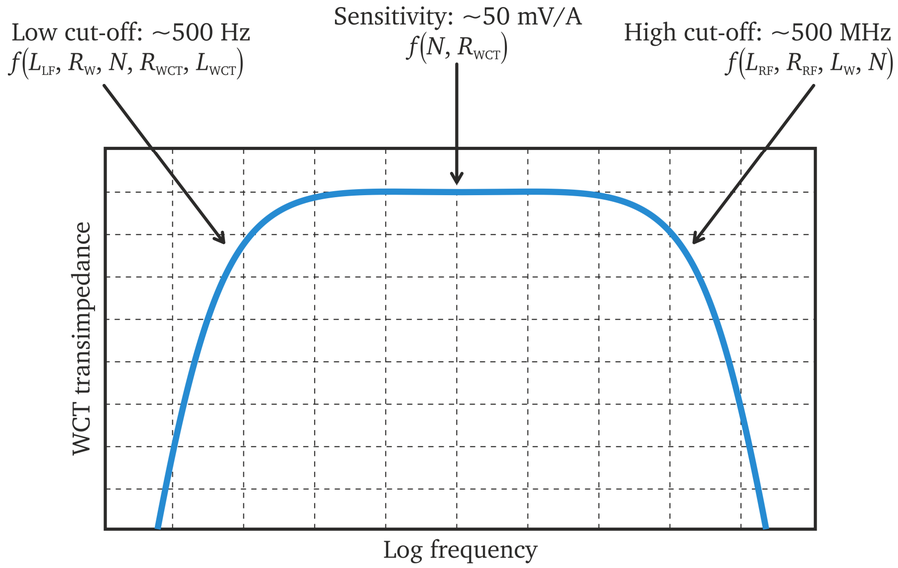
WCT principle of operation



WCT principle of operation



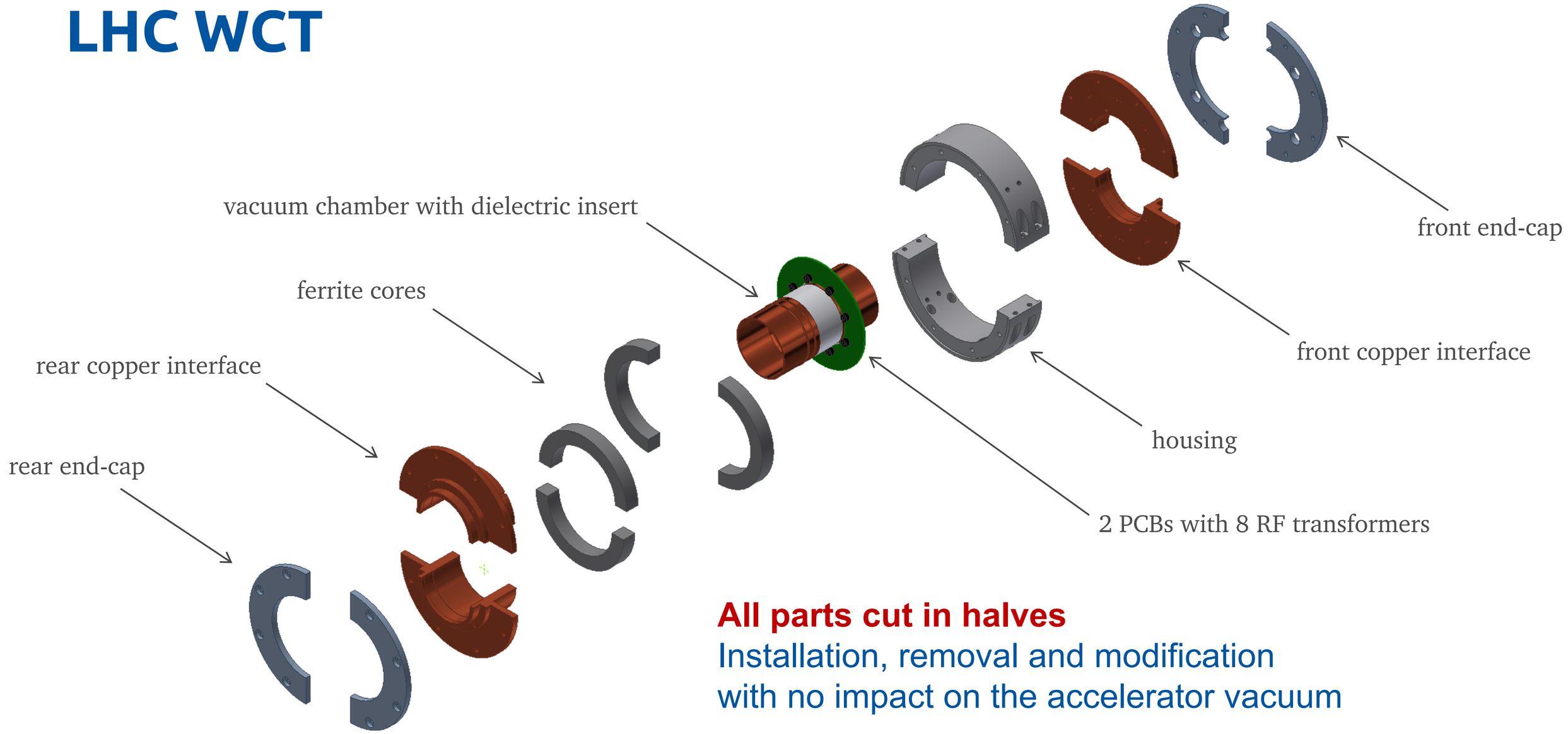




For the LHC implementation:

L_{LF} ~ 10 µH	L_{RF} ~ 0.1 nH	L_{WCT} ~ 1 mH
L_W ~ 1 nH	C_{RF} ~ 50 nF	R_{WCT} ~ 5 Ω
R_W ~ 50 mΩ	R_{RF} ~ 1 Ω	N ~ 10

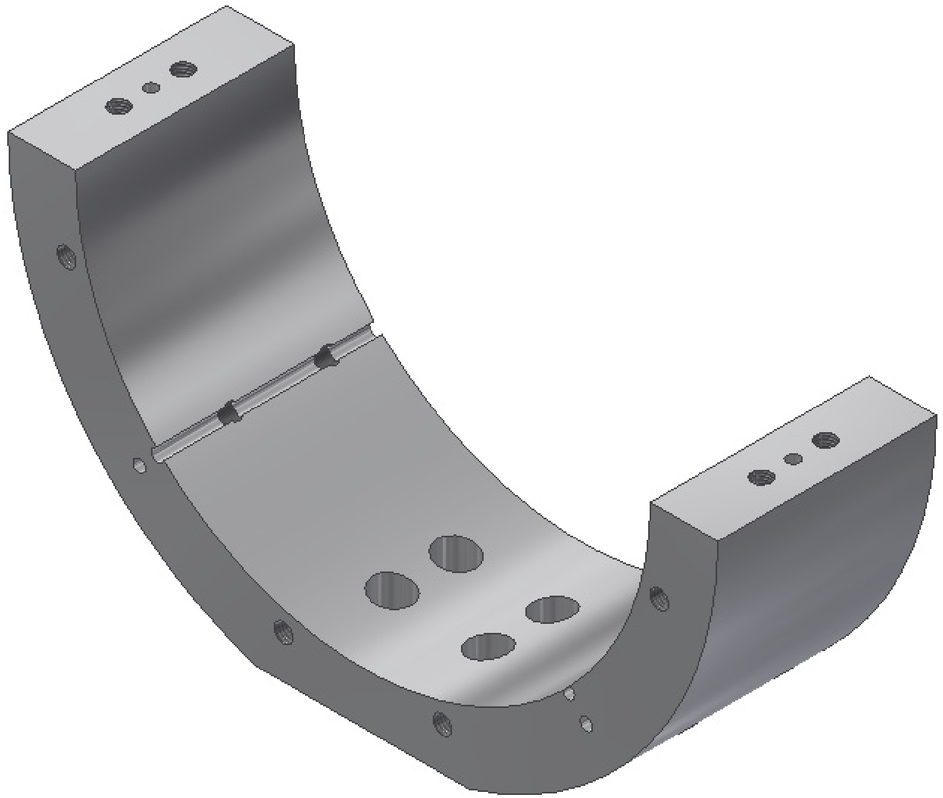
LHC WCT



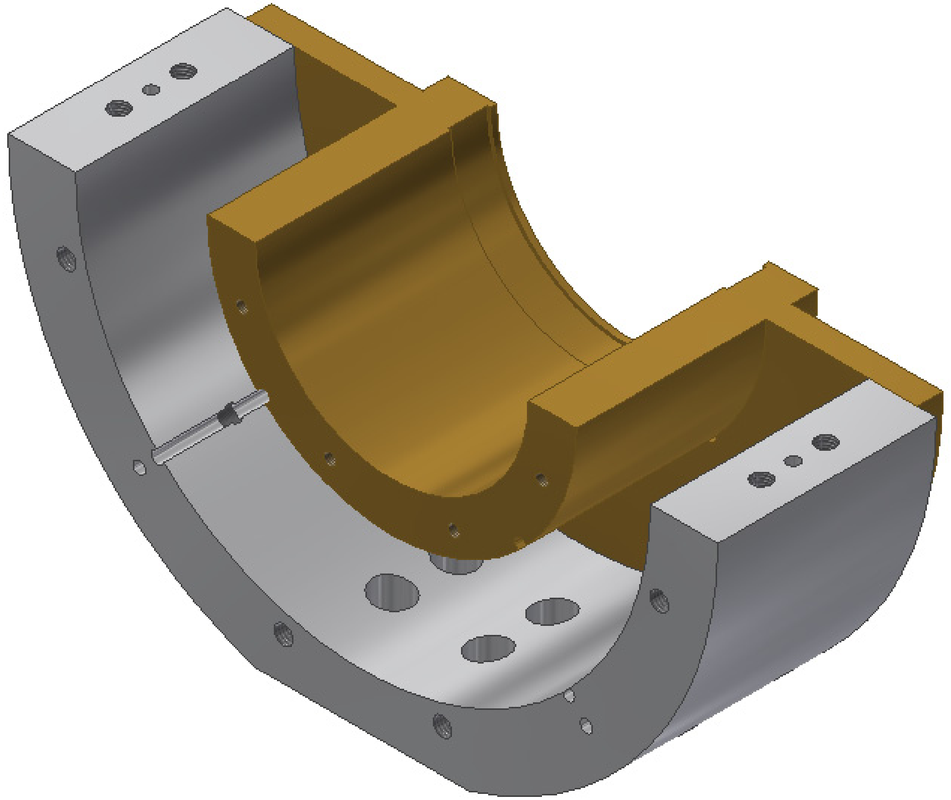
All parts cut in halves

Installation, removal and modification with no impact on the accelerator vacuum

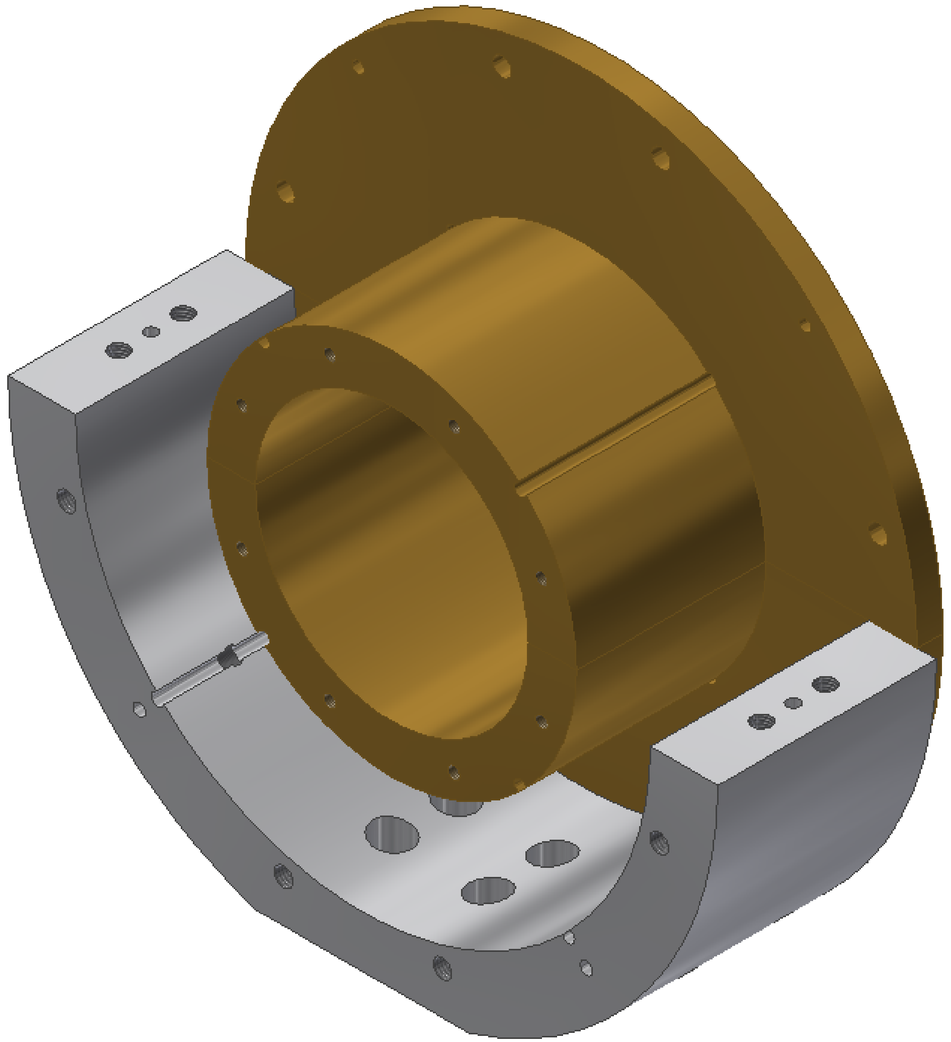
LHC WCT



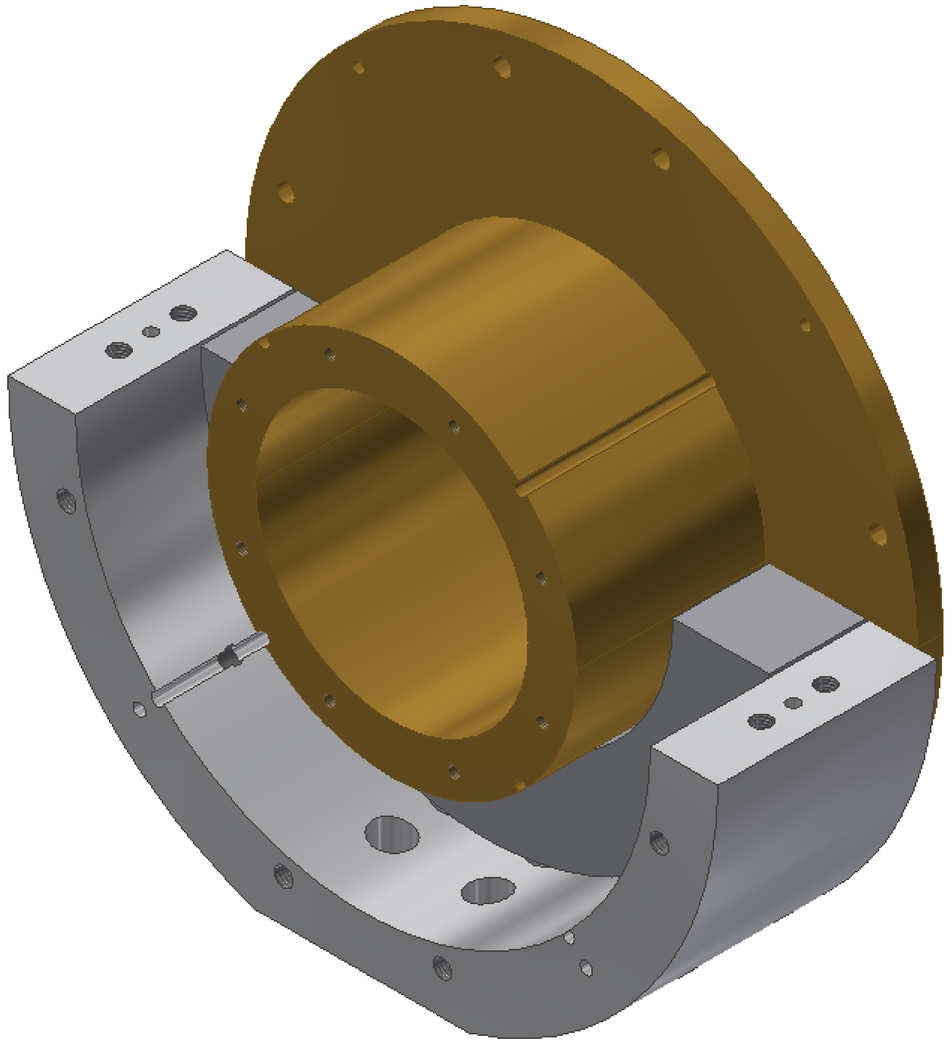
LHC WCT



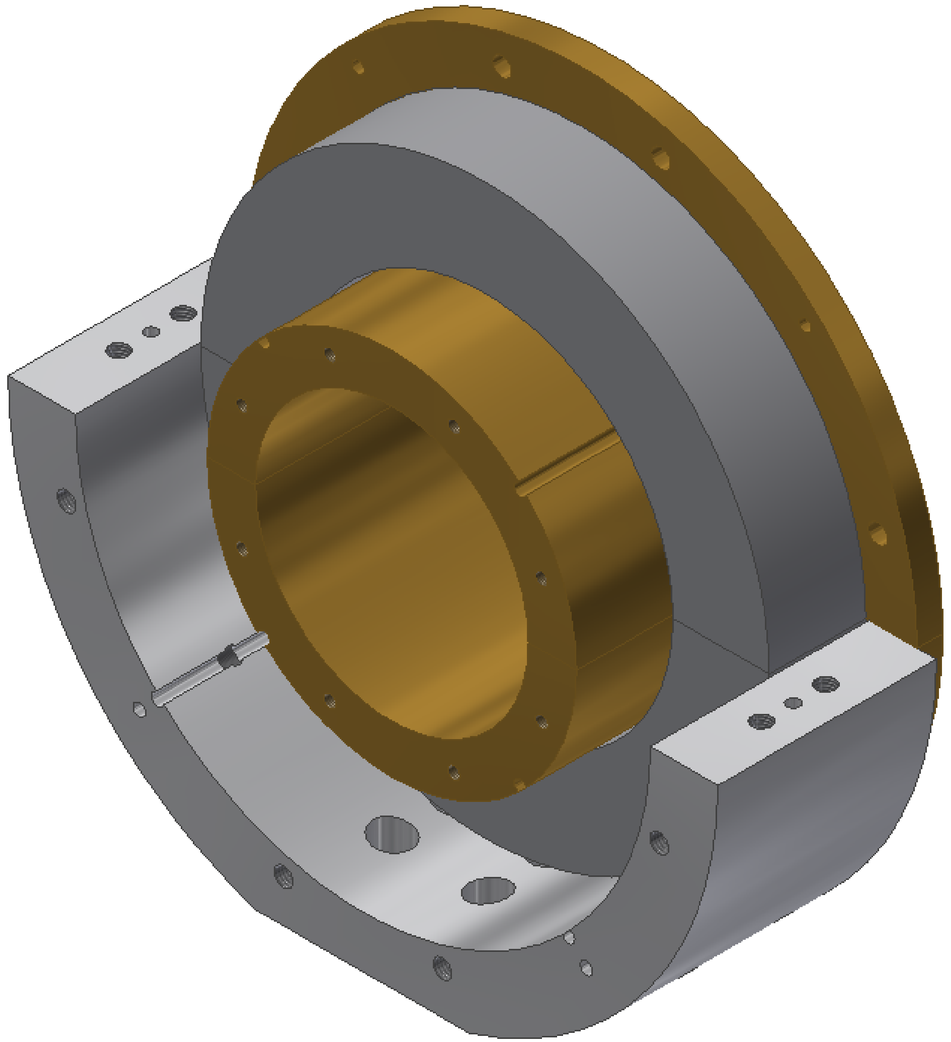
LHC WCT



LHC WCT



LHC WCT



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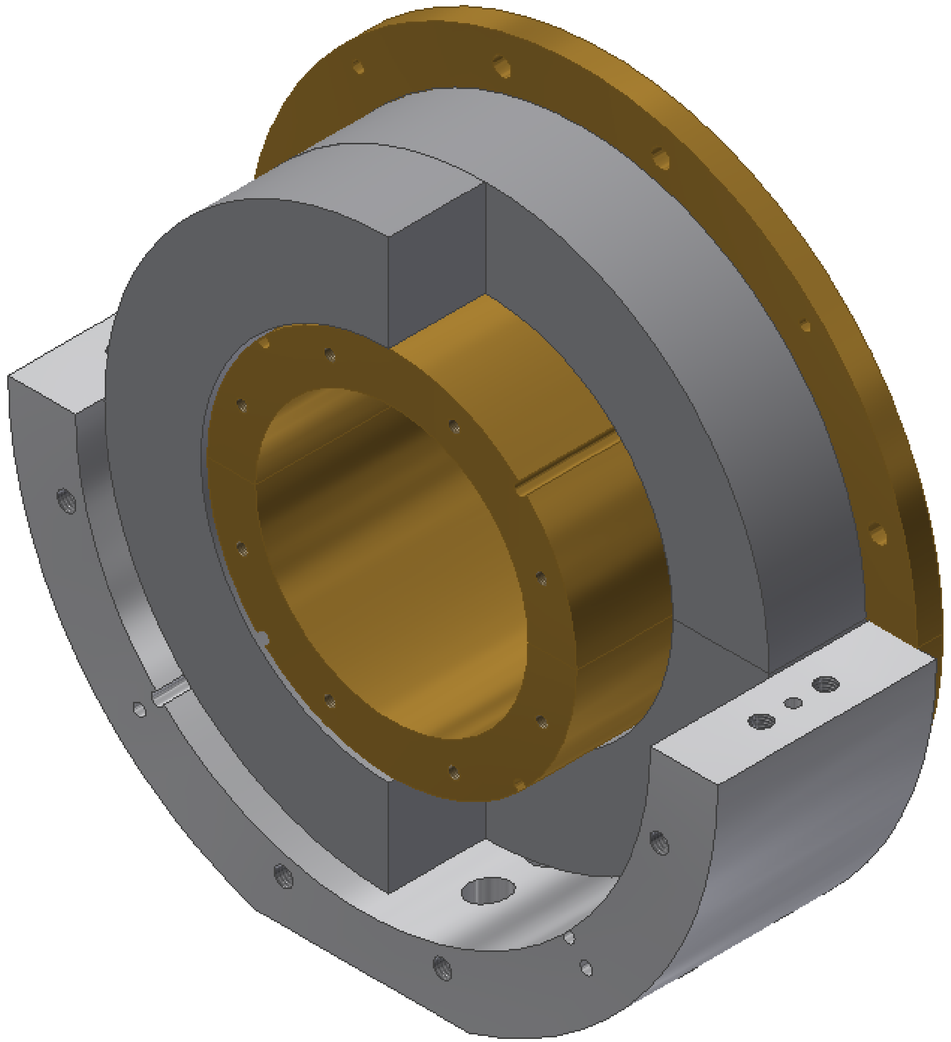
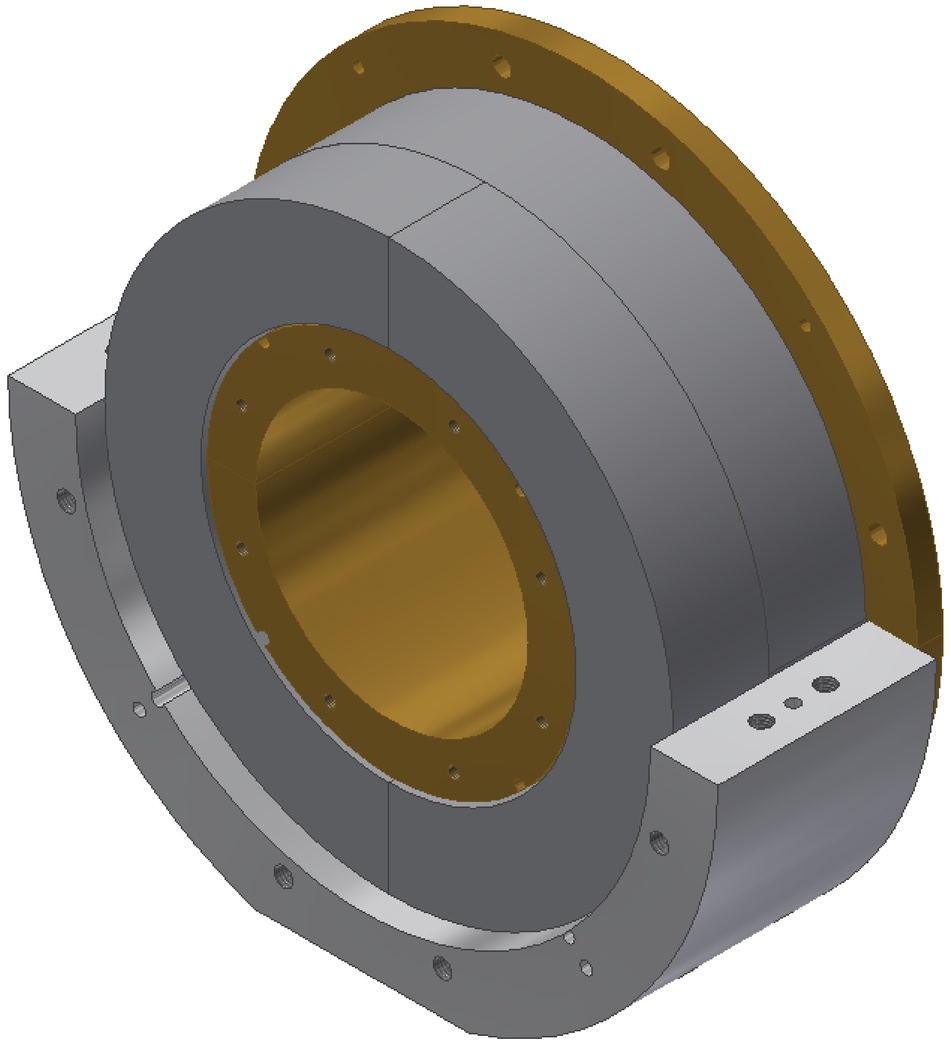


LHC WCT



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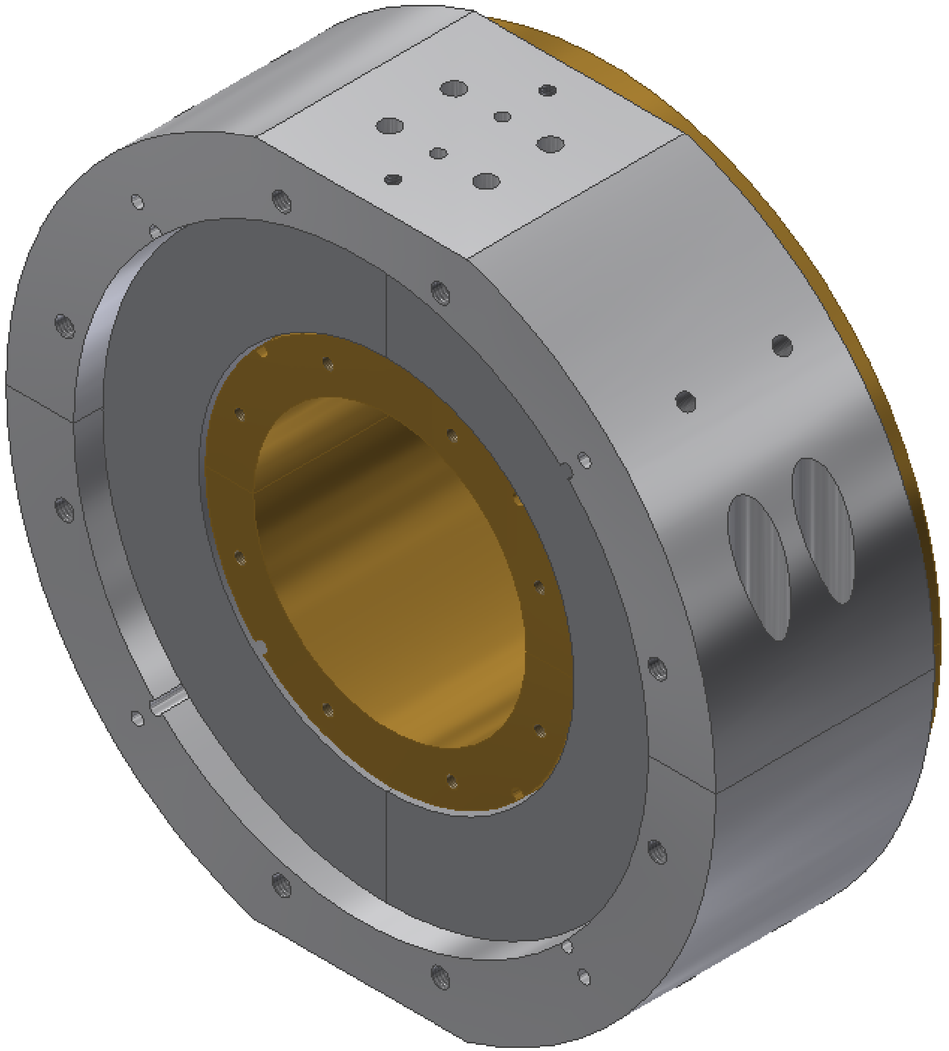

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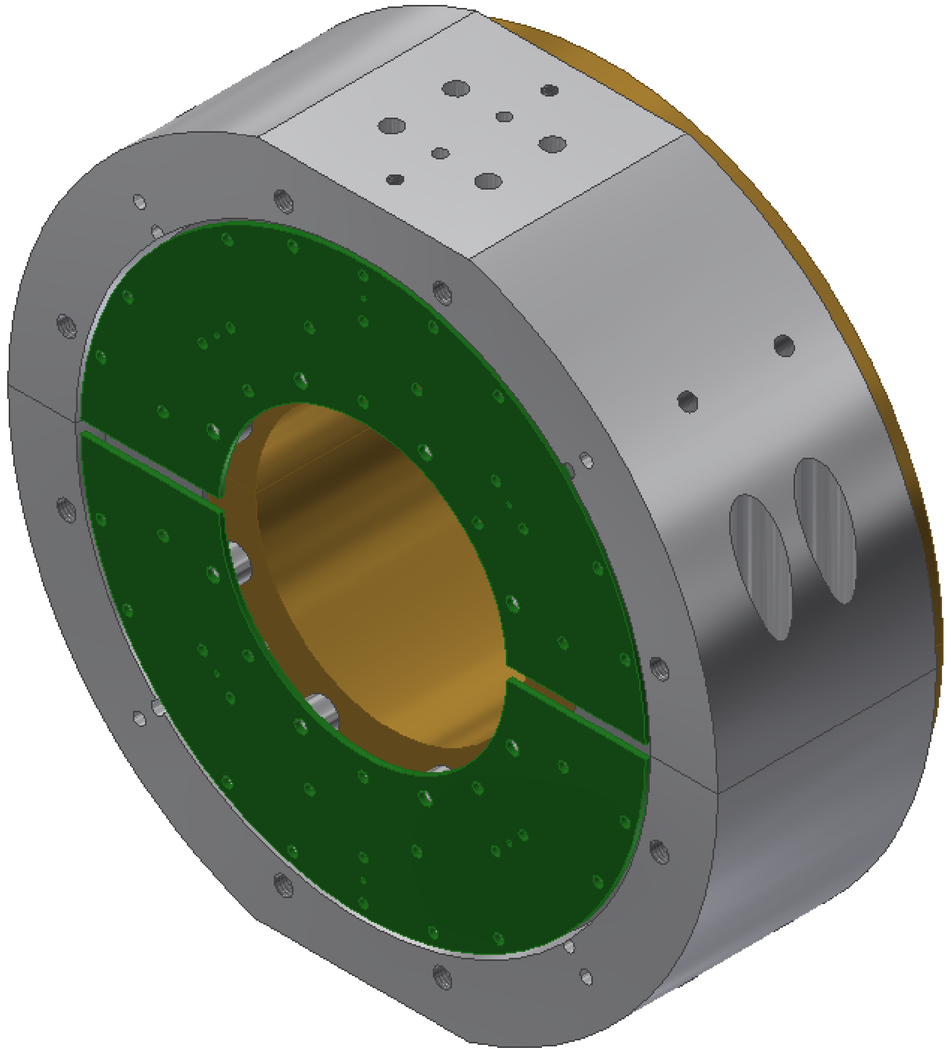

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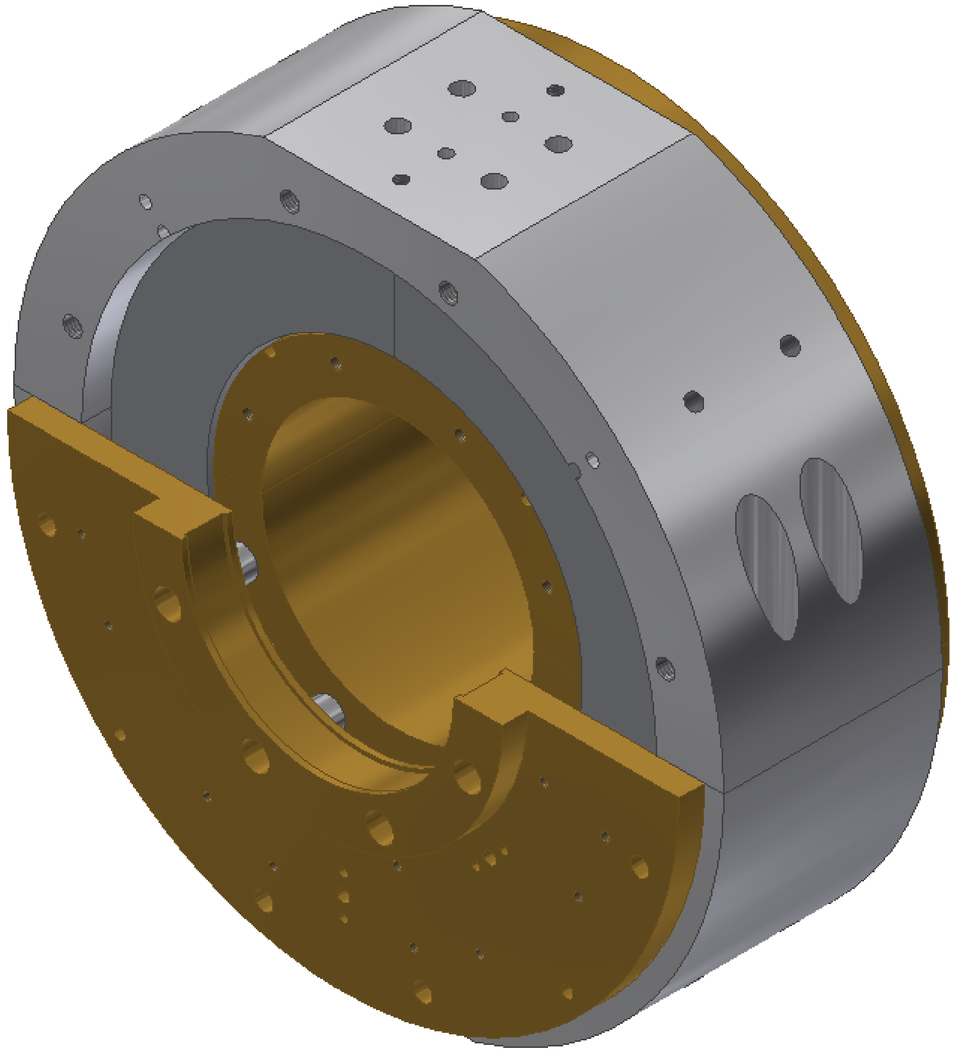

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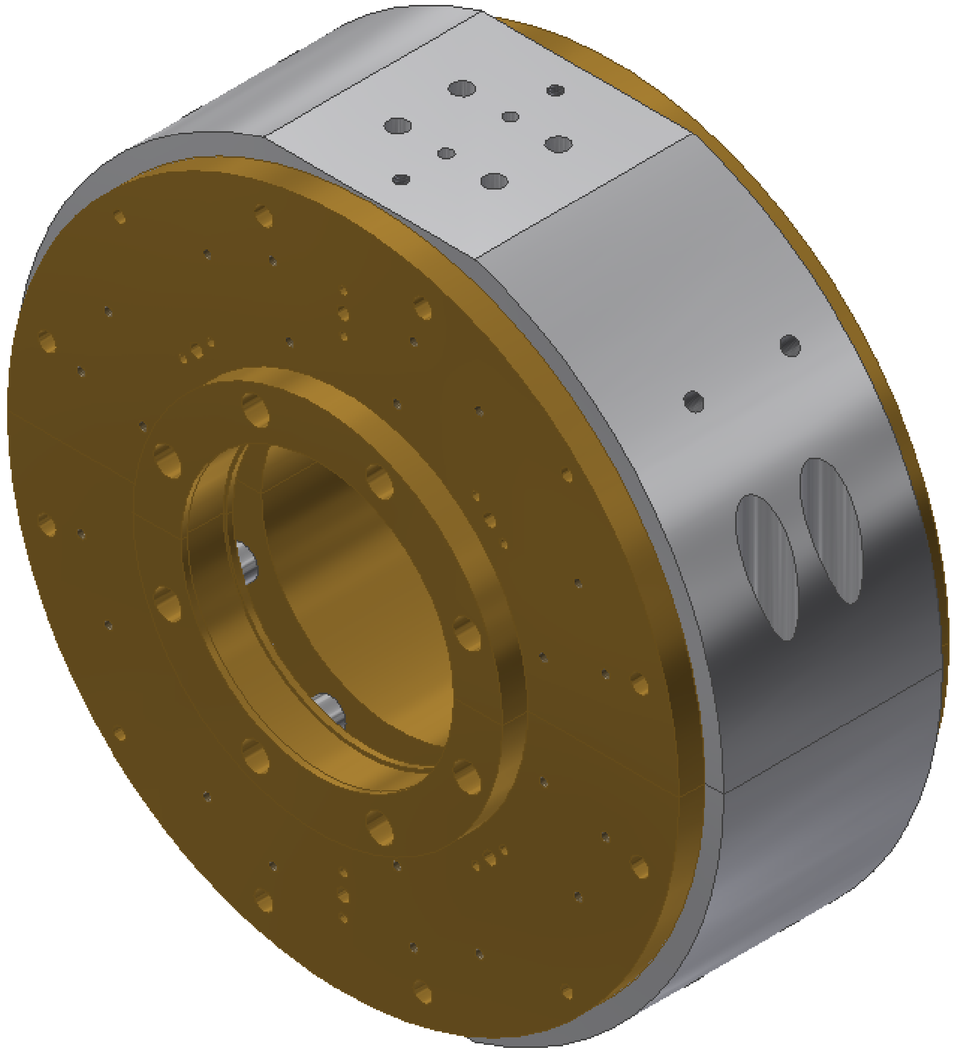

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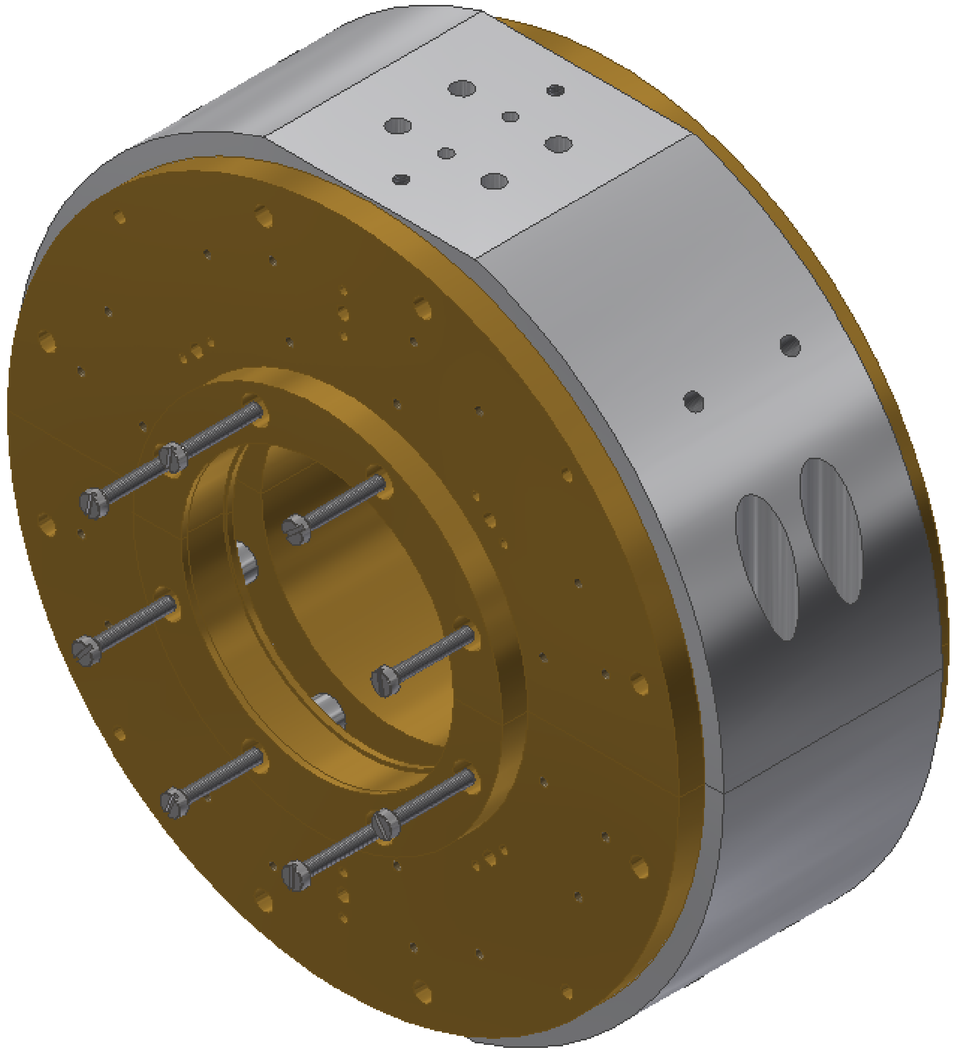

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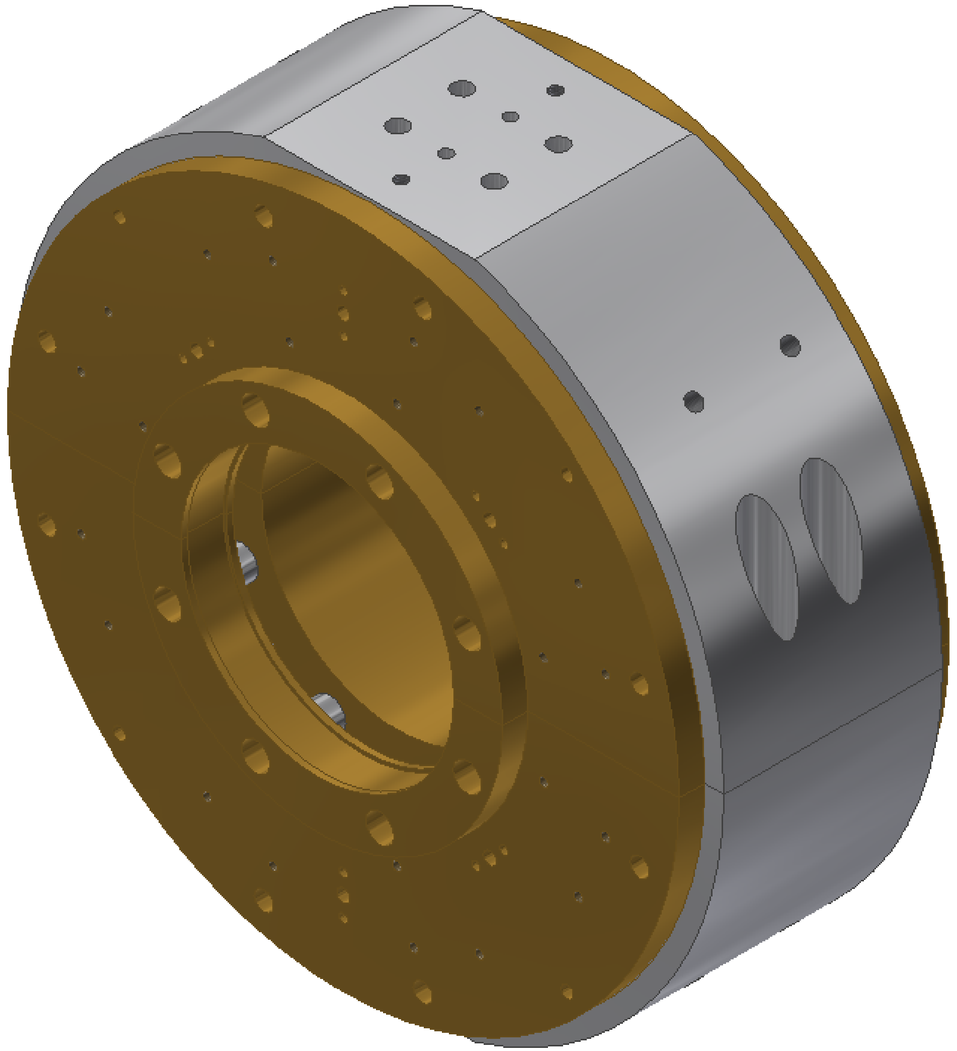

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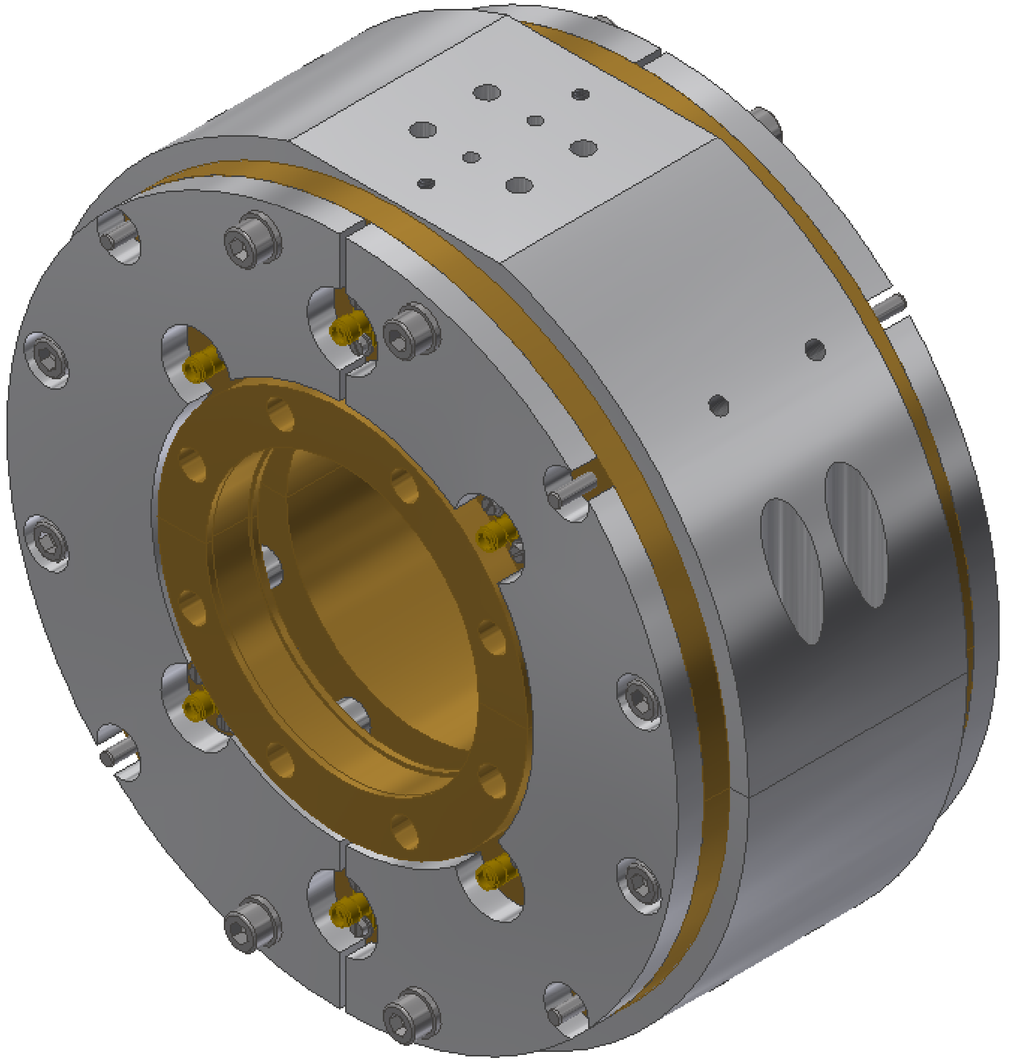
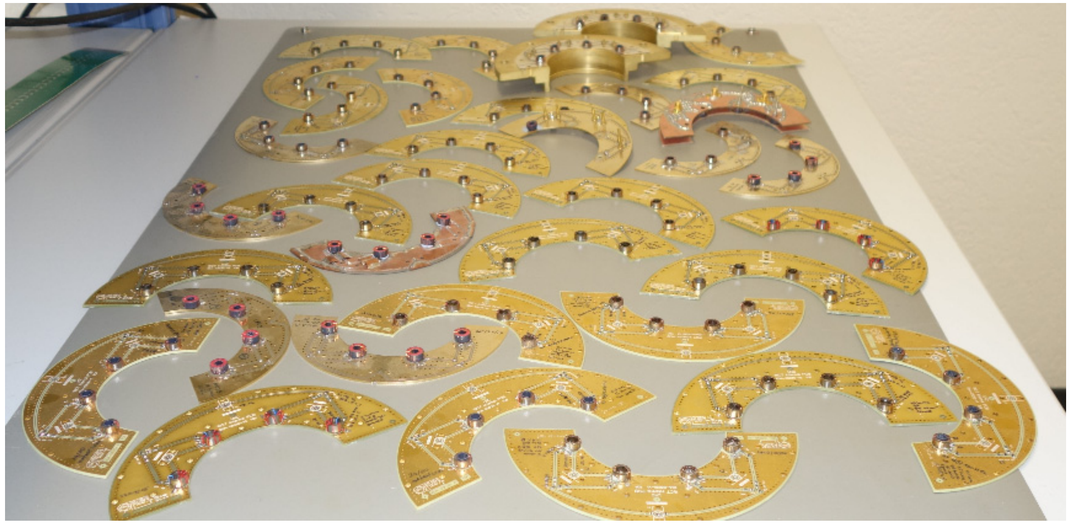
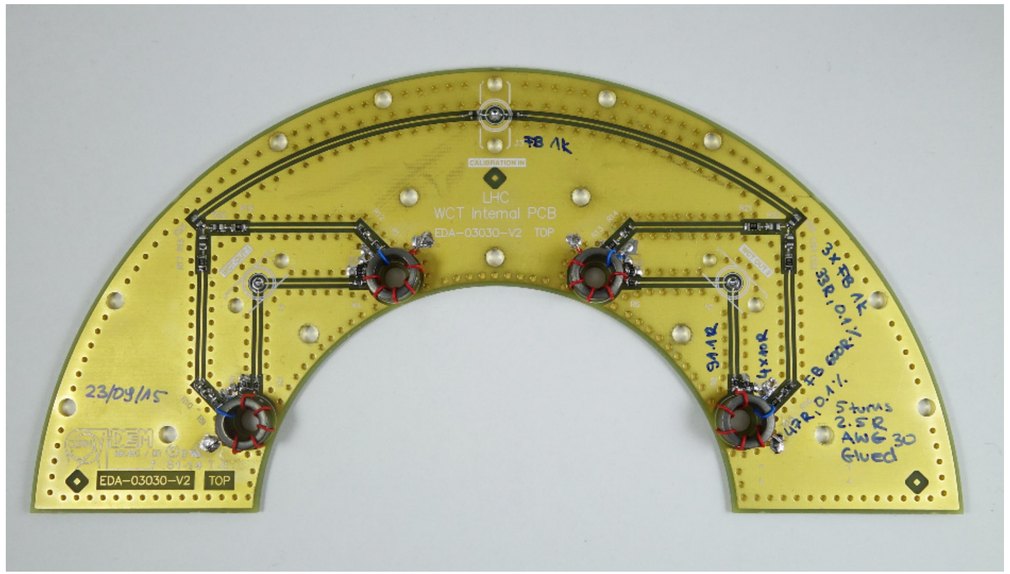


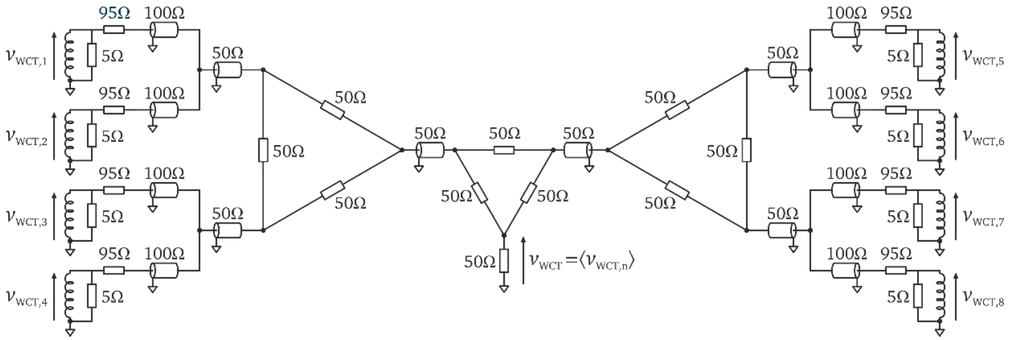
LHC WCT

Off the shelf cores
Vacuumschmelze cores with
slight manual modifications



LHC WCT



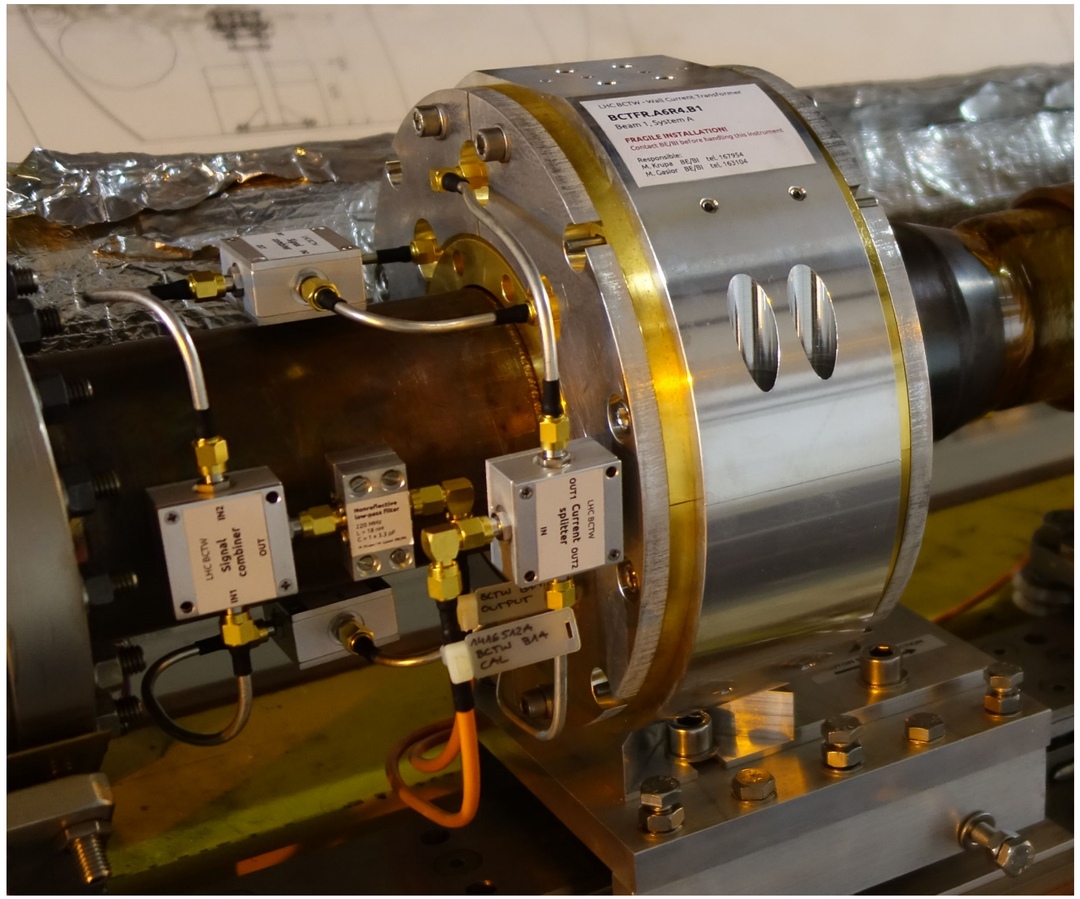


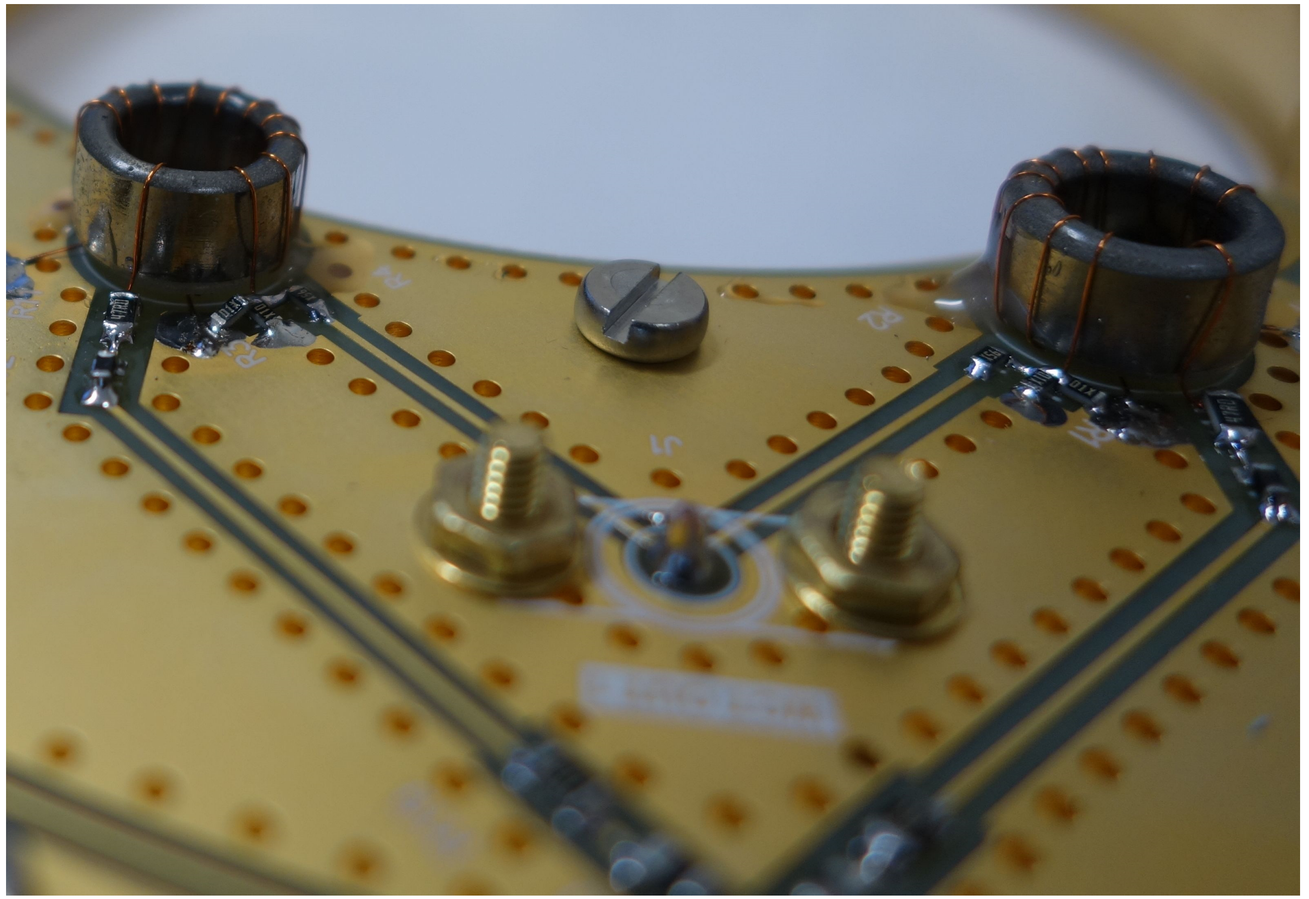
Signal winding:
- few turns
- low impedance
- averaging two nearest transformers on the PCB

Calibration winding:
- single turn for calibration with current
- low resistance at low frequencies (minimising power dissipation)
- high impedance at high frequencies (decoupling from beam)

Signal addition:
the four outputs are passively summed (averaged) outside, but close to, the monitor

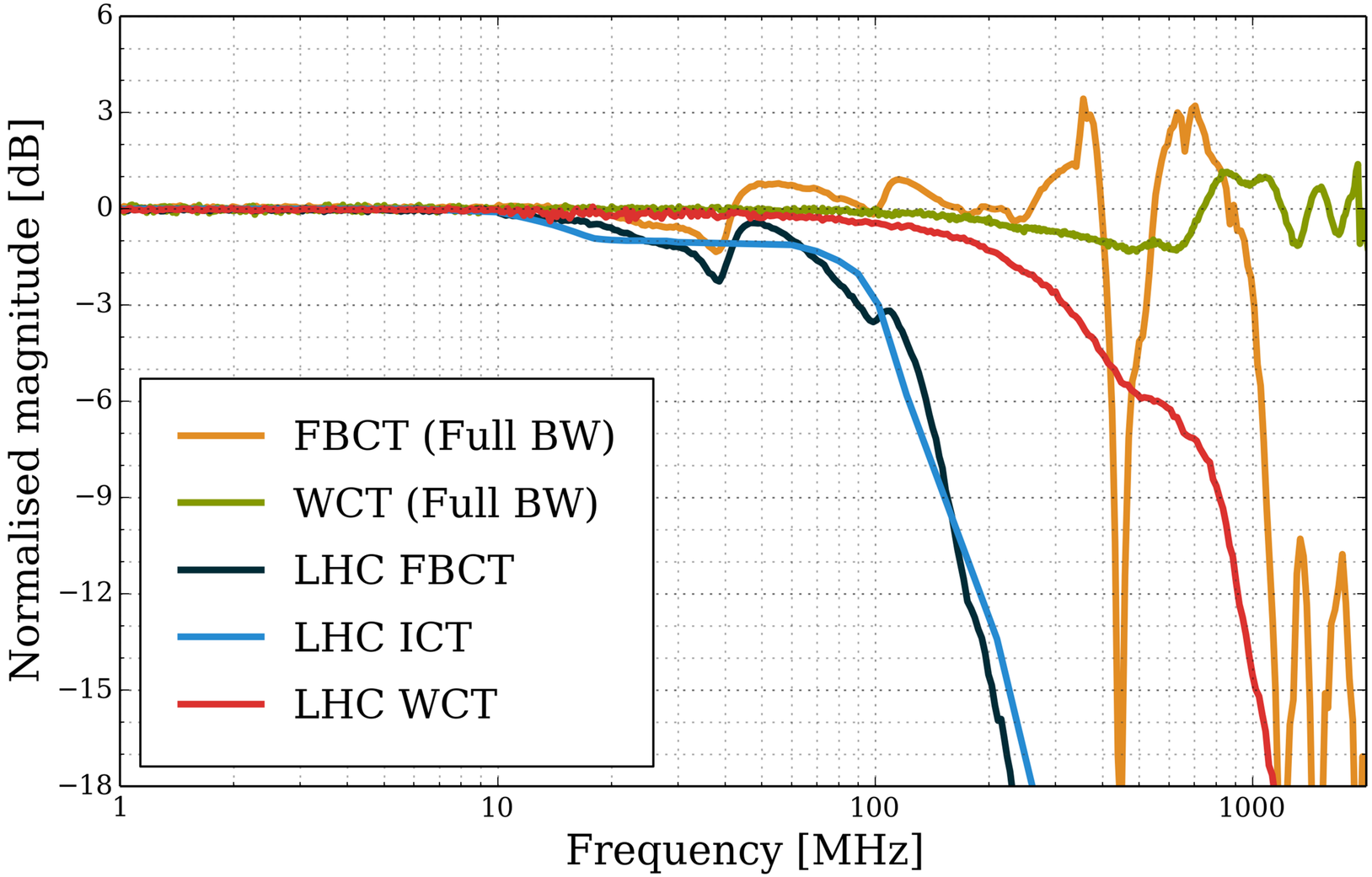
LHC WCT





Design launched: 01/10/2013 First installation in the LHC: 02/03/2015

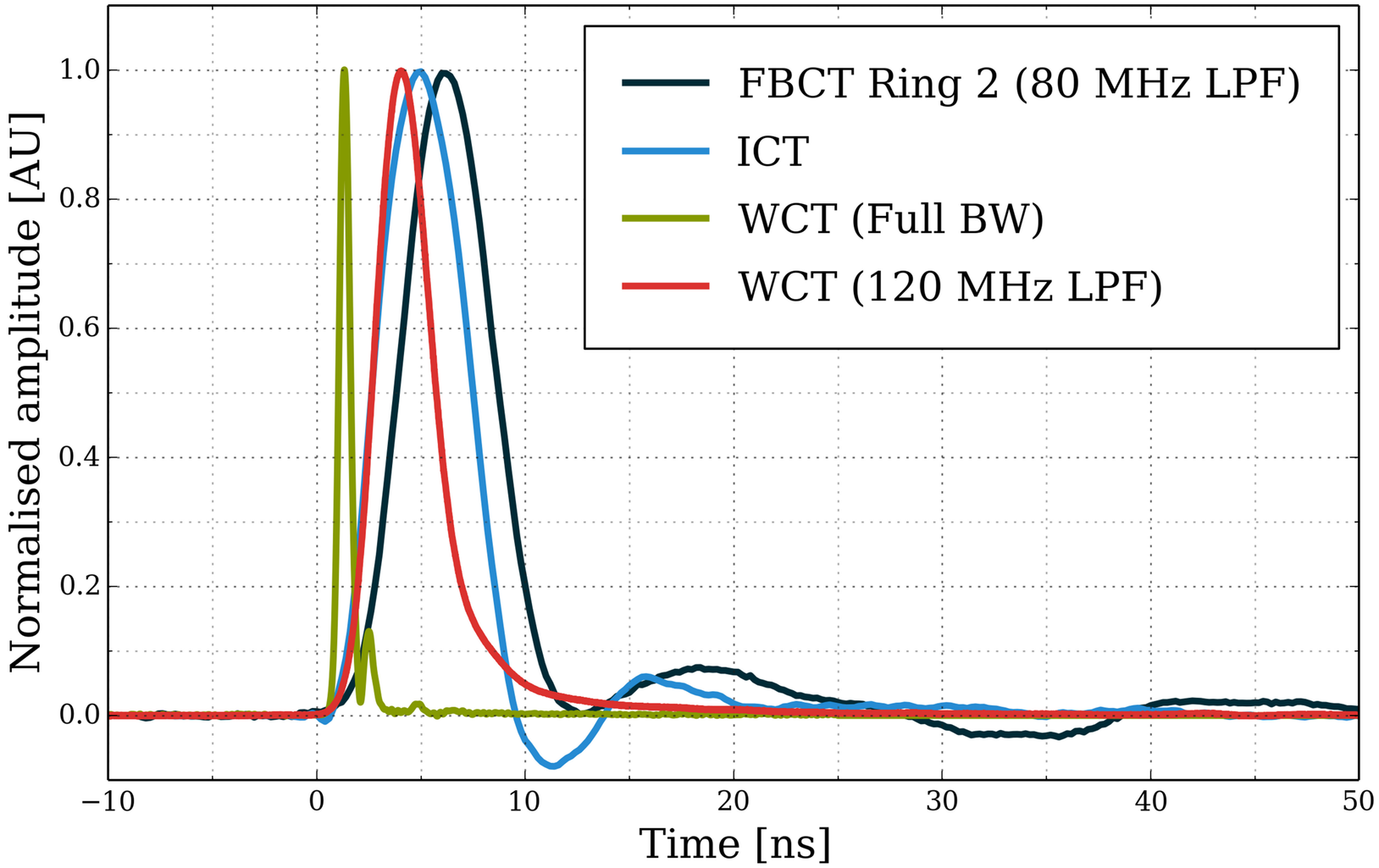
Bandwidth measured in the laboratory



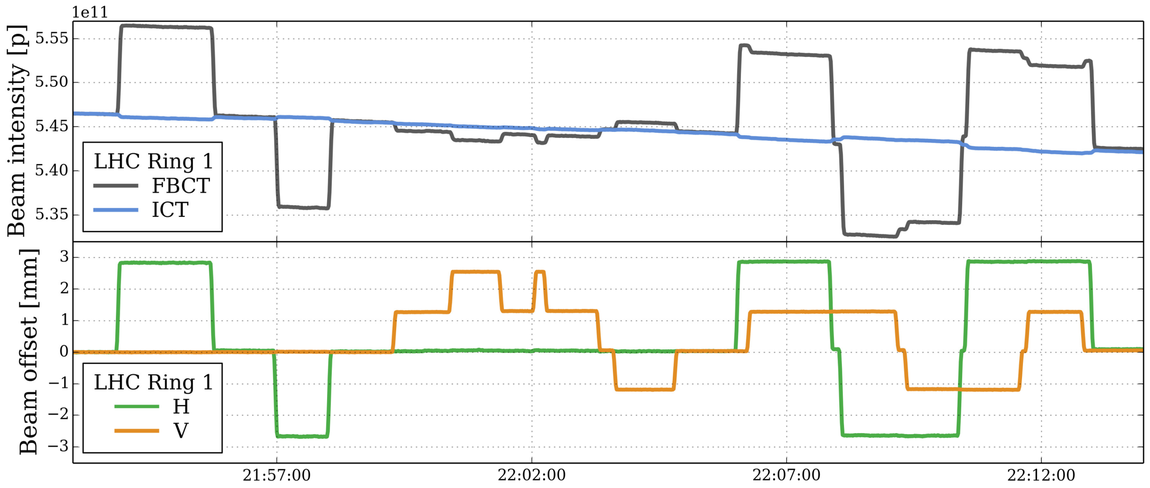
Sensitivity:
LHC WCT: 62.5 mV/A
LHC ICT: ~ 20 dB more signal

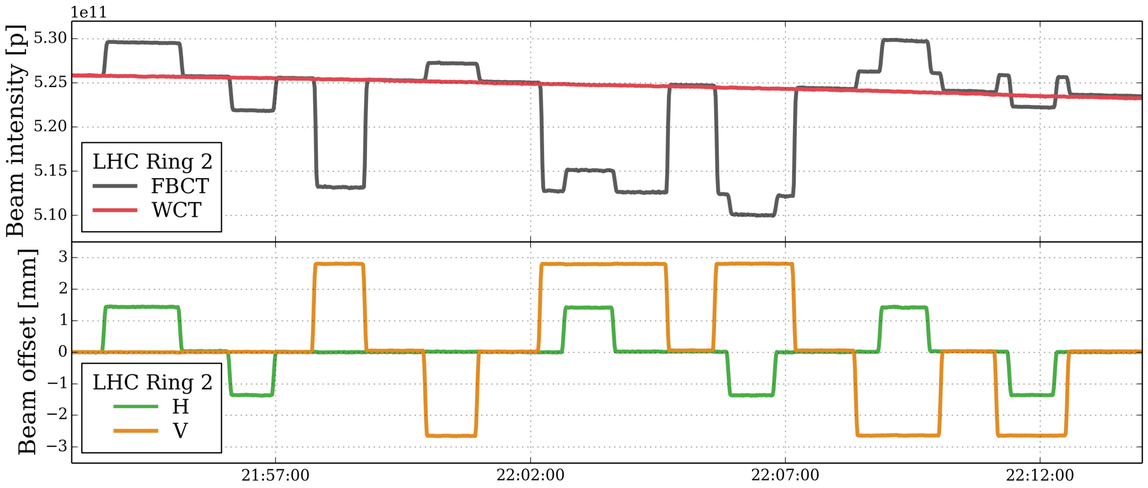
Low cut-off frequency:
< 1 kHz for all sensors

Time response to a nominal LHC bunch



Beam position sensitivity measured with beam

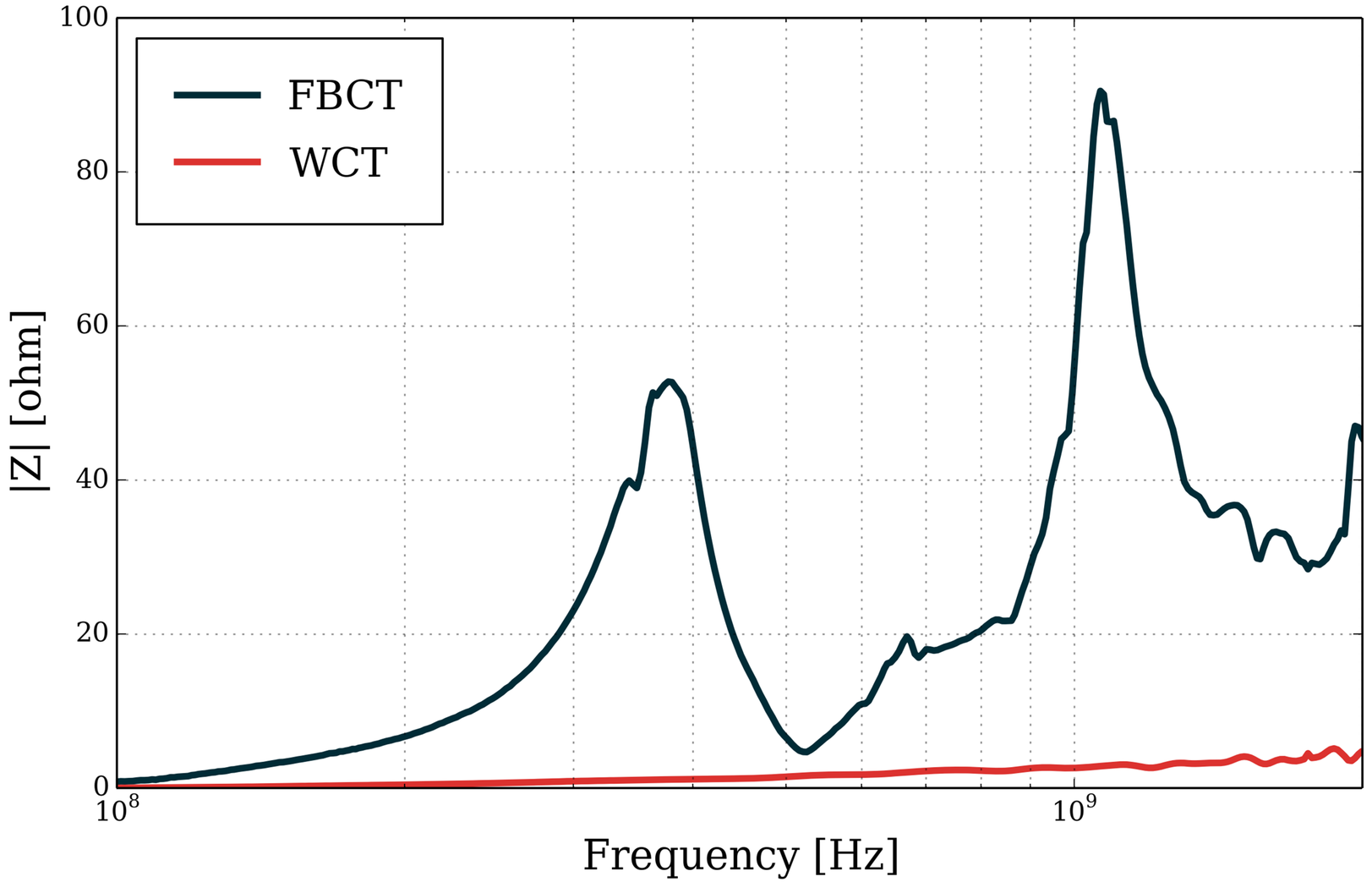




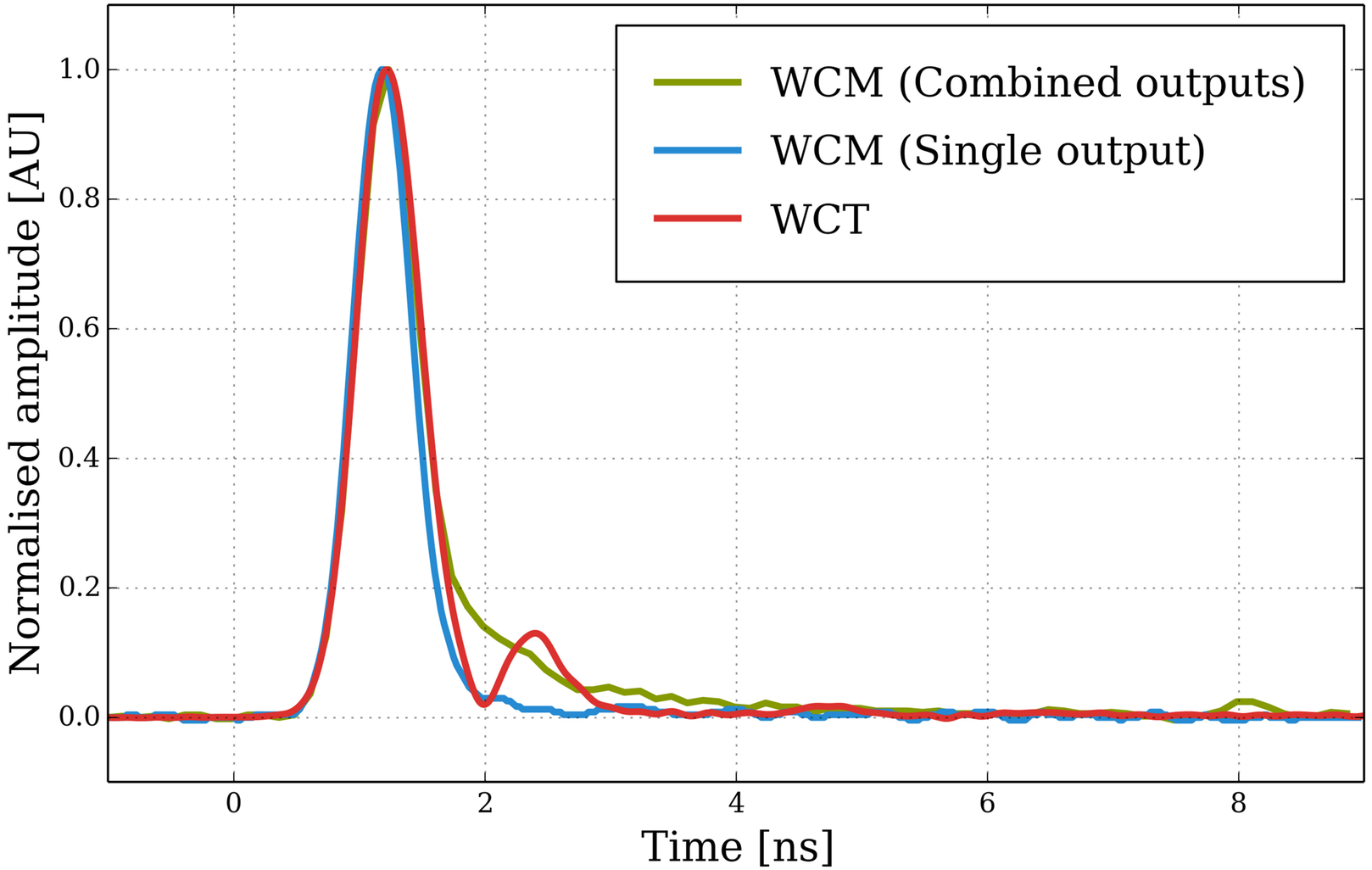
Beam position sensitivity in %·mm^{-1}

Axis	FBCT R1	FBCT R2	ICT	WCT
Horizontal	0.65	0.51	0.02	< 0.005
Vertical	0.14	0.82	0.01	< 0.005

Impedance measured in the laboratory



Full BW time response to a nominal LHC bunch



WCM (Combined outputs):
The operational LHC WCM

WCM (Single output):
The LHC WCM used for specialised longitudinal diagnostics

Conclusions

- New bunch-by-bunch intensity monitor for the LHC
- Designed to not require vacuum intervention
- Designed for absolute calibration with current
- Optimised for nanosecond bunches spaced by 25 ns
- 400 MHz bandwidth limited by external filters
- Smaller output signals than the ICT / FBCT
- No measurable beam position sensitivity
- Low longitudinal impedance
- Encouraging first longitudinal measurements

Thank you for your attention!
Questions?

Acknowledgements:
S. Aguilera, S. Bart-Pedersen, D. Belohrad, N. Chritin, J.J. Gras, J. Kral, T. Lefevre, T. Levens, A. Napieralski, L. Soby