Overview of the HL-LHC BPMs

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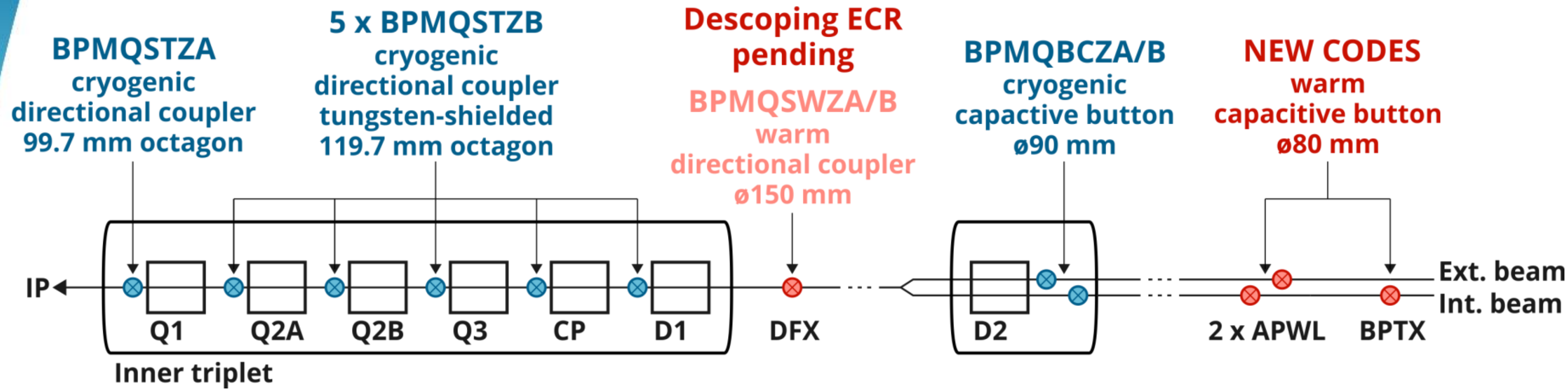
HL-LHC BPM Design Review – 18/11/2020

New HL-LHC BPMs

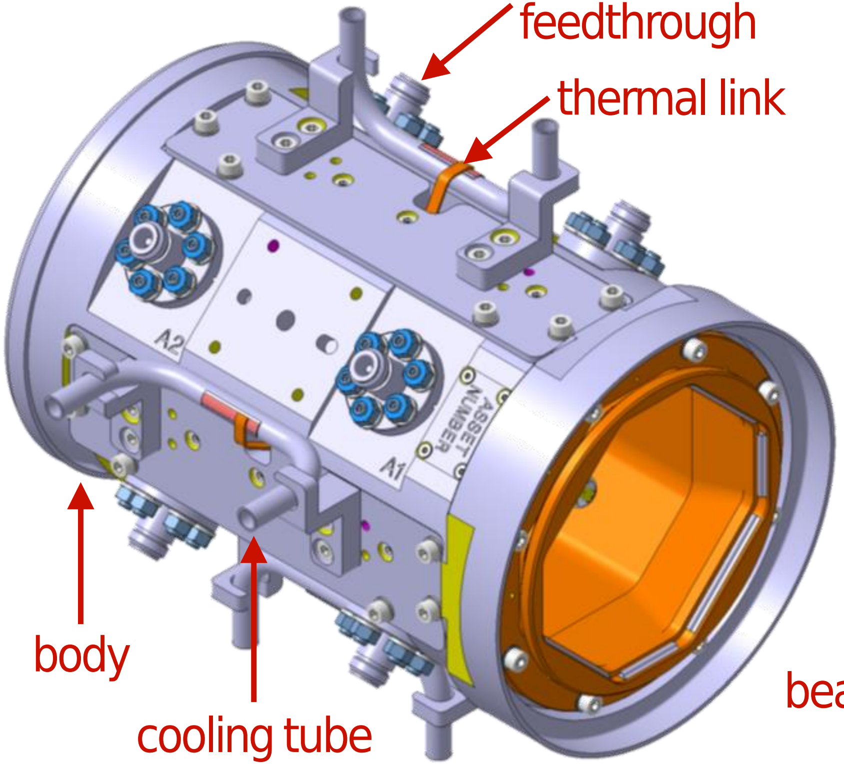


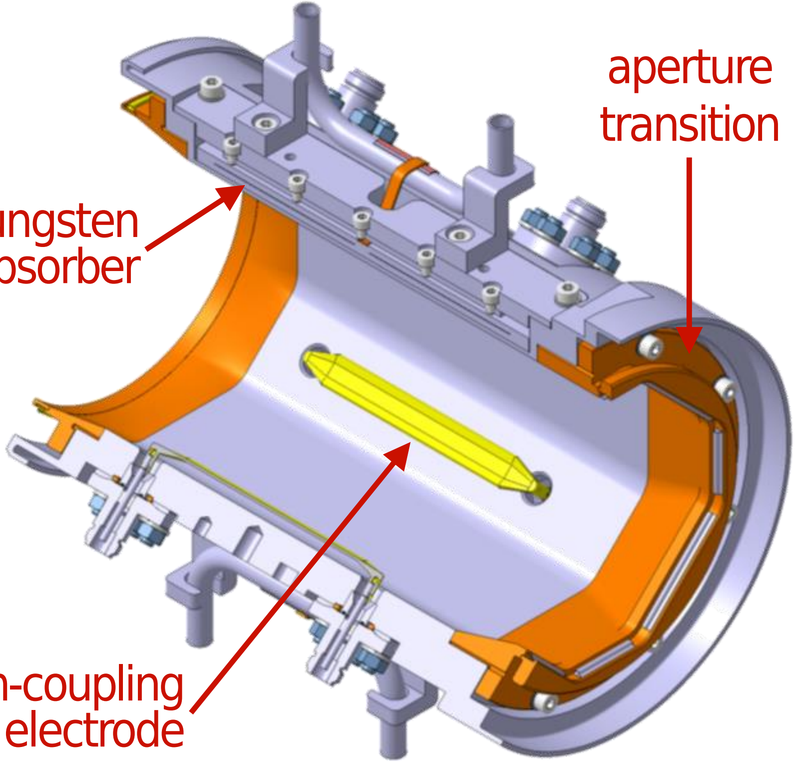
	BPMQSTZA (A Type)	BPMQSTZB (B type)	BPMQSWZA/B	BPMQBCZA/B (D2 type)	APWL	BPTX	TOTAL
Series	4	20	4	8	8	4	44
Spares	2	2	2	2	2	1	9
Prototypes	2	2	2	2		1	7

HL-LHC BPMs (IR – Q6)

Code	Location	Distance from IP [m]	Aperture [mm]	Warm or cold	Stripline or button	Tungsten shielding	Electrode orientation	Bunch crossing timing [ns]	New or existing
BPMQSTZA	Q1 (IP side)	21.871	Octagonal 101.7 / 99.7	Cold	Stripline	No	0° / 90°	3.92	New
BPMQSTZB	Q2A (IP side)	33.108	Octagonal 112.7 / 119.7	Cold	Stripline	Yes	45° / 135°	3.92	New
BPMQSTZB	Q2B (IP side)	43.893	Octagonal 112.7 / 119.7	Cold	Stripline	Yes	45° / 135°	6.82	New
BPMQSTZB	Q3 (IP side)	54.679	Octagonal 112.7 / 119.7	Cold	Stripline	Yes	45° / 135°	9.72	New
BPMQSTZB	CP (IP side)	65.770	Octagonal 112.7 / 119.7	Cold	Stripline	Yes	45° / 135°	10.52	New
BPMQSTZB	D1 (IP side)	73.723	Octagonal 112.7 / 119.7	Cold	Stripline	Yes	45° / 135°	7.36	New
BPMQBCZA BPMQBCZB	D2 (arc side)	151.848	Round Ø 90	Cold	Button	No	0° / 90°	N/A	New
2 x APWL	Between crabs and Q4	163.532 (not final)	Round Ø 80	Warm	Button	No	0° / 90°	N/A	New (based on BPMWI)
BPTX	Between crabs and Q4	165.945 (not final)	Round Ø 80	Warm	Button	No	0° / 90°	N/A	New (based on BPMWI)
2 x BPMYA	Q4 (arc side)	182.727	Round Ø 61	Cold	Button	No	0° / 90°	N/A	Existing
BPM BPMR	Q5 (IP / arc side)	203.845 210.135	Round Ø 49	Cold	Button	No	0° / 90°	N/A	Existing

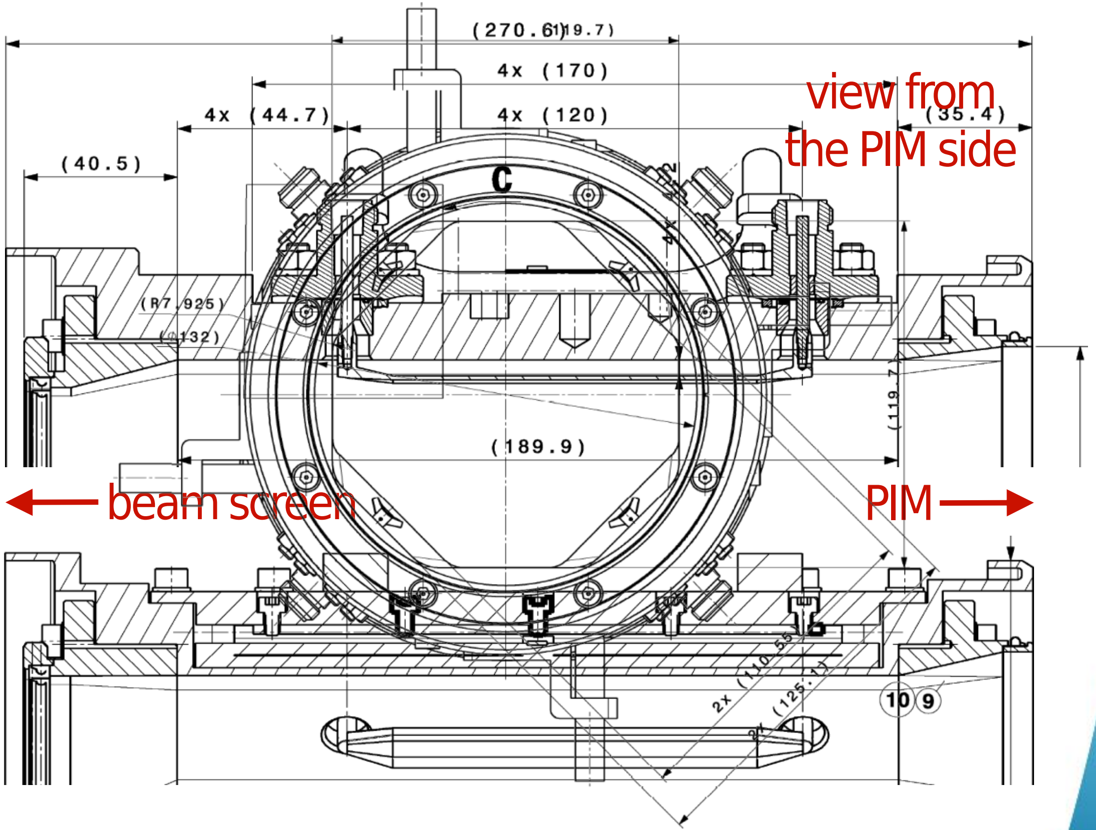
Q2A-D1 BPM – B type (BPMQSTZB)





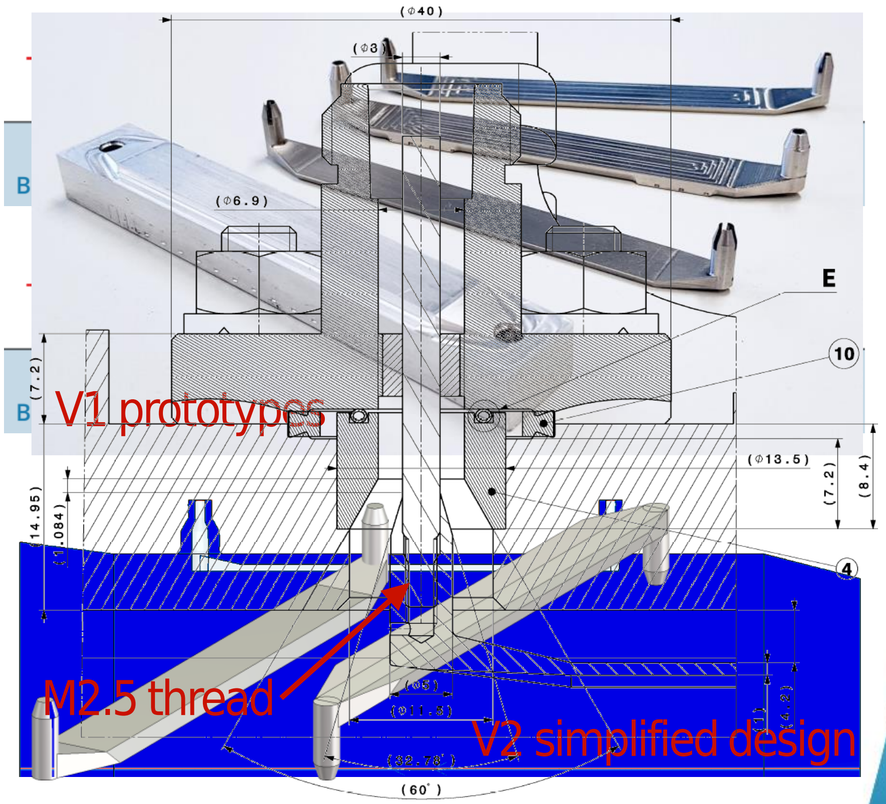
B type - aperture

- Octagonal aperture
  - 119.7 at H and V (same as BS)
  - 125.1 at ±45º ("hidden" electrode)
- Aperture-adapting transition on each side of the BPM
- Transition angle < 15º to avoid impedance problems



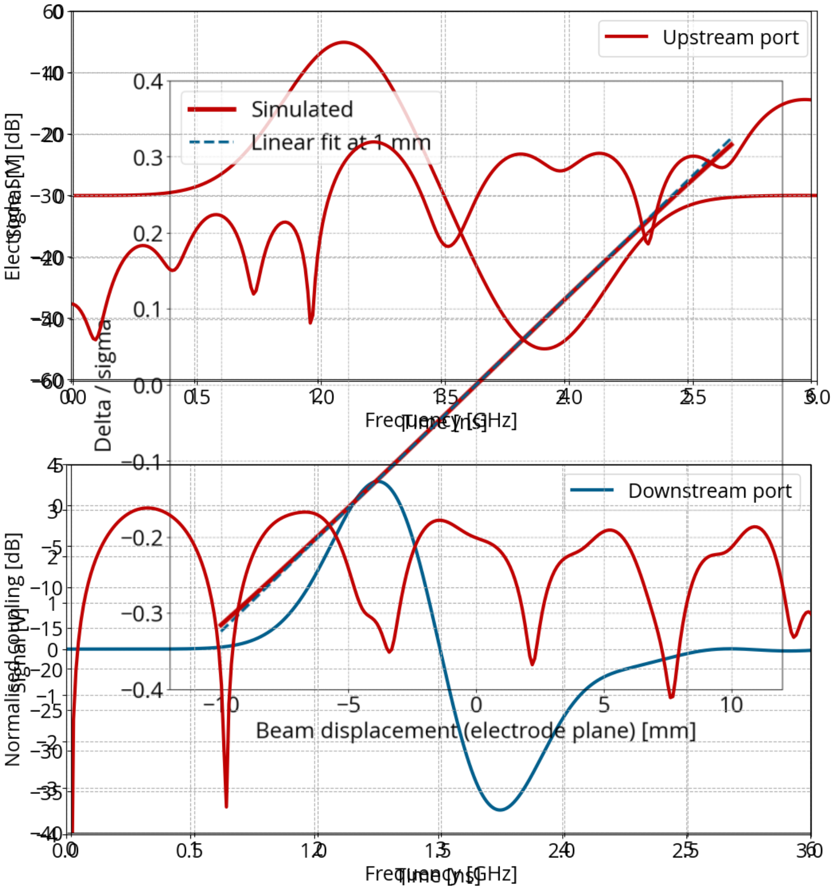
B type – directional coupler

- IT BPMs see both counter-rotating beams
- In a good directional coupler a signal is seen mostly at the upstream ports
  - Optimal performance reached with electromagnetic simulations
- Electrode length > ¼ bunch length
  - For 1.2 ns → > 90 mm
- Improved by installing the BPMs far from the long-range bunch crossing locations
- **Electrode design decisions:**
  - 120 mm long (same as in the LHC)
  - Made of a single piece of 316LN steel (same as the body)
  - Gap to body adjustment by turning the FT: ±1 mm, 75 µm resolution



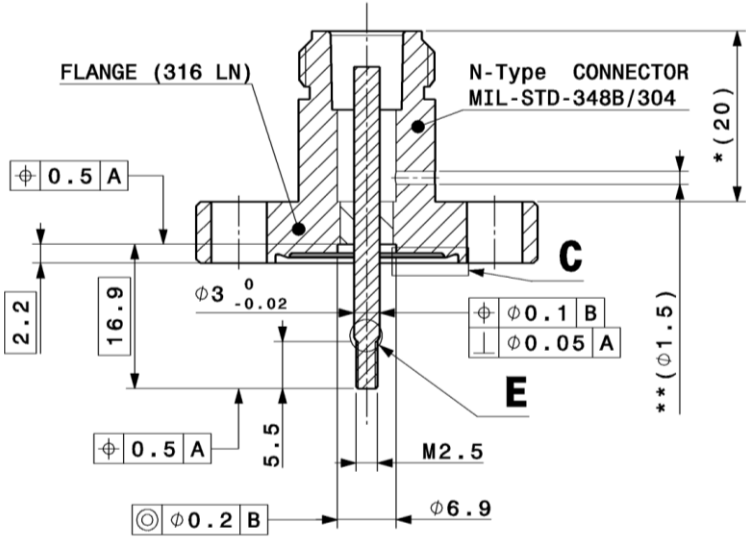
B type – beam position measurements

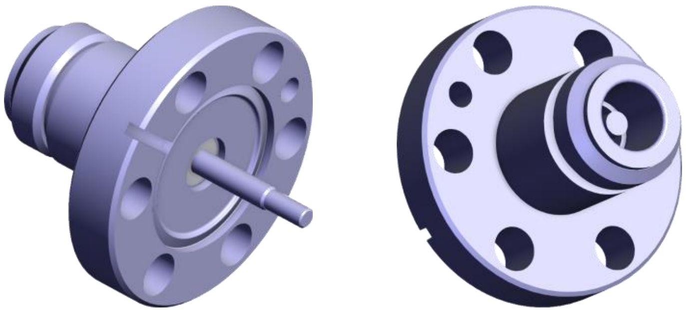
- Single electrode bunch current sensitivity: 50 V peak for a 1e11 1 ns bunch
- Single electrode beam position sensitivity: 0.28 dB/mm
- Δ/Σ sensitivity for 1 mm displacement: 0.032
- Broadband directivity: 24.3 dB
- Electrode S11: -25 dB @2.2 GHz
- Centre frequency of the 1st lobe: 625 MHz



B type – RF coaxial feedthrough

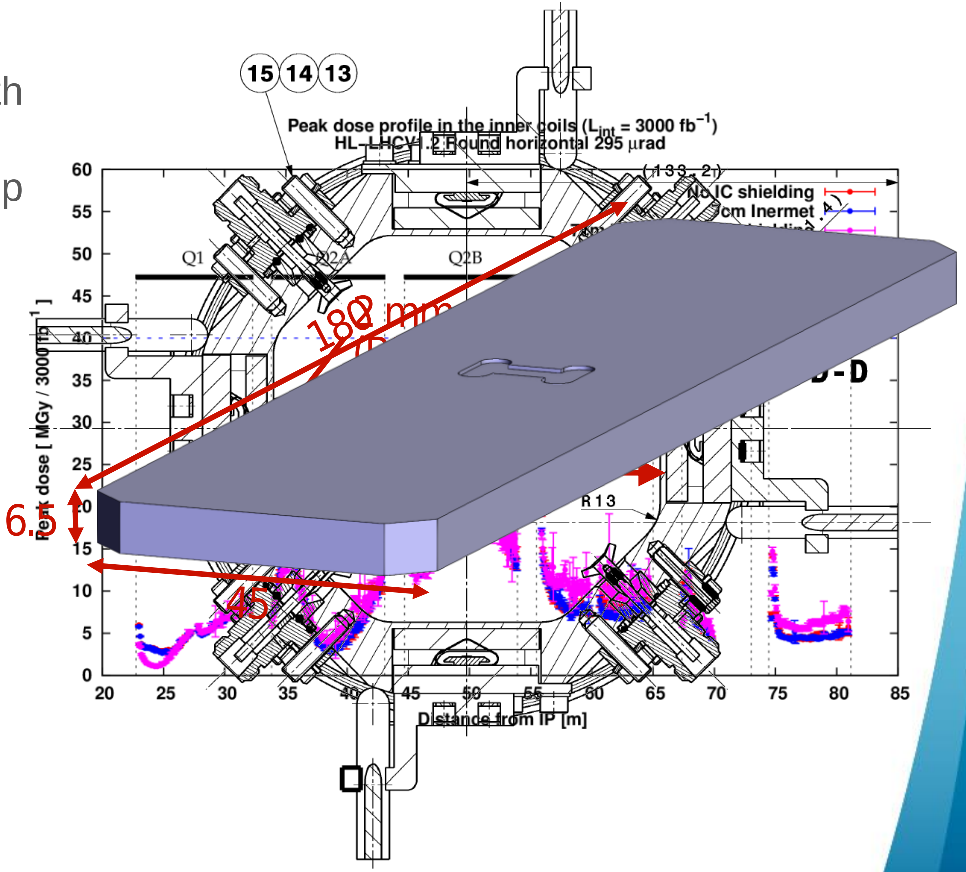
- Custom-made commercial component
- Multiple important functions:
  - RF transmission: 50 Ω optimisation
  - UHV barrier: only some dielectrics
  - Mechanical support for the electrode: ~25 g between two feedthroughs
- All functionalities will be tested during component qualification
  - RF measurements
  - Vacuum tests (warm and cold)
  - Mechanical tests (warm and cold, 4 x load, pin bending, vibrations)
- Potential suppliers identified and contacted, procurement ongoing





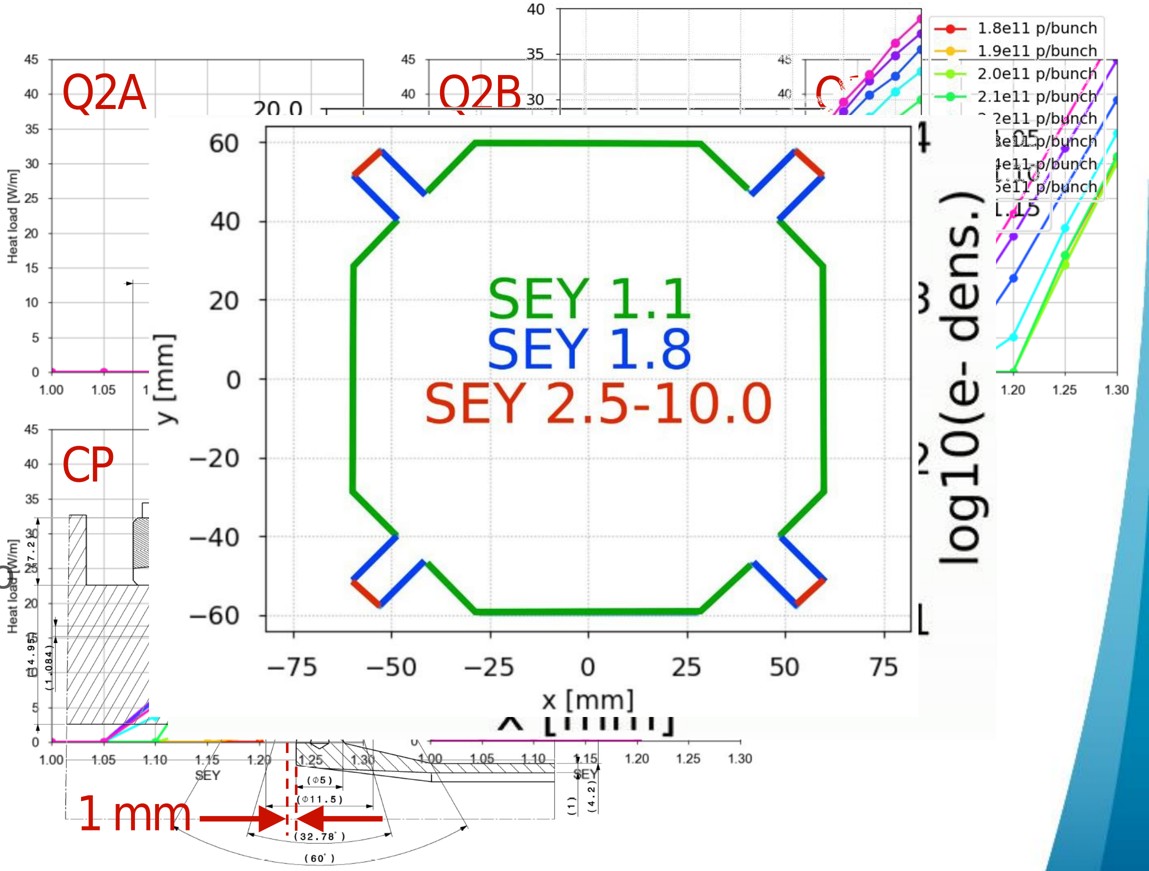
B type – tungsten shielding

- Summary of WP10 simulations:
  - Peak dose at Q2B reduced by ~30% with a tungsten-shielded BPM
  - BPM absorbers might be displaced by up to 2 mm radially w.r.t. the BS ones
  - Up to 2.12 W deposited on a tungsten absorber, up to 2.5 W on the body
- **Design decisions:**
  - All B type BPMs include tungsten shielding (fewer BPM types)
  - Electrodes installed at ±45º
  - Tungsten displaced by 1 mm radially (extra wall thickness)
  - Absorbers 180 mm long, > 6 mm thick
  - Absorbers include a slot for brazing



B type – electron cloud

- WP2 simulations: each BPM, various SEY, various intensities
- With SEY ≤ 1.1 only the CP BPM suffers from e-cloud for intensities > 2.1e11
  - Max values: 1.65 W body, 40 mW each electrode
- Up to 20 mW on each exposed piece of FT ceramic – coating might be possible if needed
- Difficult for WP2 to simulate coated body and uncoated electrodes – recommendation to coat body and electrodes
- **Design decisions:**
  - Coat body + aperture transitions (SEY = 1.1)
  - Coat electrodes (SEY = 1.0)



B type - impedance

- Previous model simulated in 2019
  - Eff. transverse impedance: < 10 kΩ/m (HL-LHC: 20 MΩ/m)
  - Eff. longitudinal impedance: < 4 μΩ (HL-LHC: 96 mΩ)
- New model (new electrode, aperture transitions) provided to IWG for verification – no significant deterioration expected
  - WP13 electromagnetic simulations do not show any concerning impedance effects
- Resistive wall model heat load: 100 mW
- **Design decisions:**
  - Coat beam-facing side of the BPM body with 100 μm copper (RRR = 100) – impedance reduction + thermalisation

B type – summary of heat loads

		Heat load [W]															
		Collision debris									Electron cloud			Imped.	Signals	Total	He temp [K]
IR	BPM	Body	Absorbers V+	Absorbers H+	Absorbers V-	Absorbers H-	Electrodes V+	Electrodes H+	Electrodes V-	Electrodes H-	Body	Electrode (each)	FT (each)	Body	Cable (each)		
1	Q1	0	0	0	0	0	0	0	0	0	0	0	0	**0.1**	**0.01**	0.180	60.0
1	Q2A	0	0	0	0	0	0	0	0	0	0	0	**0.020**	**0.1**	**0.01**	0.340	63.3
1	Q2B	1.2	0.28	0.27	0.30	0.83	0.003	0.003	0.003	0.003	0	0	0.018	**0.1**	**0.01**	3.216	66.6
1	Q3	2.0	0.20	0.23	0.22	0.81	0.006	0.006	0.007	0.007	0	0	0.018	**0.1**	**0.01**	3.810	70.0
1	CP	1.3	0.40	0.17	0.46	0.51	0.004	0.004	0.004	0.004	**1.65**	**0.04**	**0.020**	**0.1**	**0.01**	5.006	73.3
1	D1	1.3	0.37	0.15	0.34	0.21	0.005	0.005	0.005	0.005	0	0	**0.020**	**0.1**	**0.01**	2.730	76.6
5	Q1	0	0	0	0	0	0	0	0	0	0	0	0	**0.1**	**0.01**	0.180	60.0
5	Q2A	0	0	0	0	0	0	0	0	0	0	0	**0.020**	**0.1**	**0.01**	0.340	63.3
5	Q2B	1.3	0.26	0.45	0.61	0.49	0.006	0.004	0.003	0.004	0	0	0.018	**0.1**	**0.01**	3.451	66.6
5	Q3	**2.5**	0.20	0.45	0.45	0.41	0.007	**0.010**	**0.010**	0.007	0	0	0.018	**0.1**	**0.01**	4.368	70.0
5	CP	1.9	0.29	0.25	**2.12**	0.26	0.005	0.005	0.005	0.005	**1.65**	**0.04**	**0.020**	**0.1**	**0.01**	**6.990**	73.3
5	D1	1.8	0.20	0.17	1.21	0.18	0.007	0.007	0.006	0.007	0	0	**0.020**	**0.1**	**0.01**	3.927	76.6

B type – studied heat loads

- 3 out of 12 BPMs were chosen for thermal simulations
  - Largest total heat load
  - Largest heat load into a single tungsten absorber
  - Largest heat load into the BPM body
- Active cooling of tungsten absorbers (radiativ d out before)
- E-cloud contribution to CP (1.65 W) and D1 (0 W) were mistakenly swapped
  - Noticed only when preparing these slides, simulations will be repeated

Simulated values

	Case 1 (IR5 D1) Largest total	Case 2 (IR5 CP) Largest tungsten	Case 3 (IR5 Q3) Largest body
Body (full volume) [W]:	1.8	1.9	2.5
Body (inner copper layer) [W]:	**1.75** ~~(0.1)~~	**0.1** ~~(1.75)~~	0.1
Tungsten (full volume) [W]:	1 x 1.2, 3 x 0.2	1 x 2.12, 3 x 0.3	4 x 0.45
Electrodes (each, full volume) [W]:	0.015	0.015	0.015
FT ceramic (each, full volume) [W]:	0.02	0.02	0.02
Helium temperature [K]:	77	74	70

True values

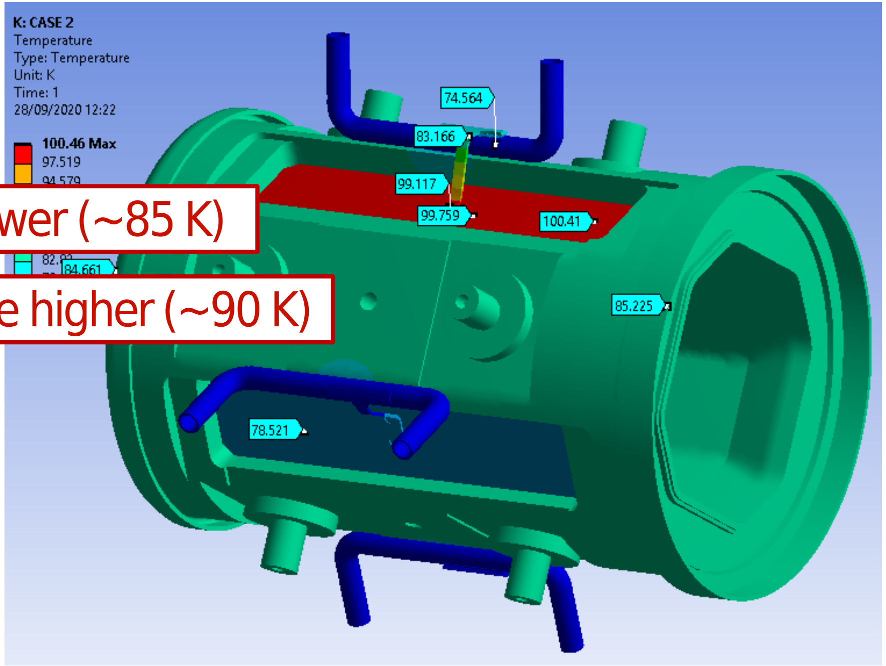
B type – thermal simualtions

- BPM cooling deemed sufficient
  - 4 cooling pipes welded to body
  - Tungsten cooled via thermal links
  - 100 μm OF Cu coating
- Other BPMs can be simulated if
- Thermomechanical simulations planned

will be lower (~85 K)

will be higher (~90 K)

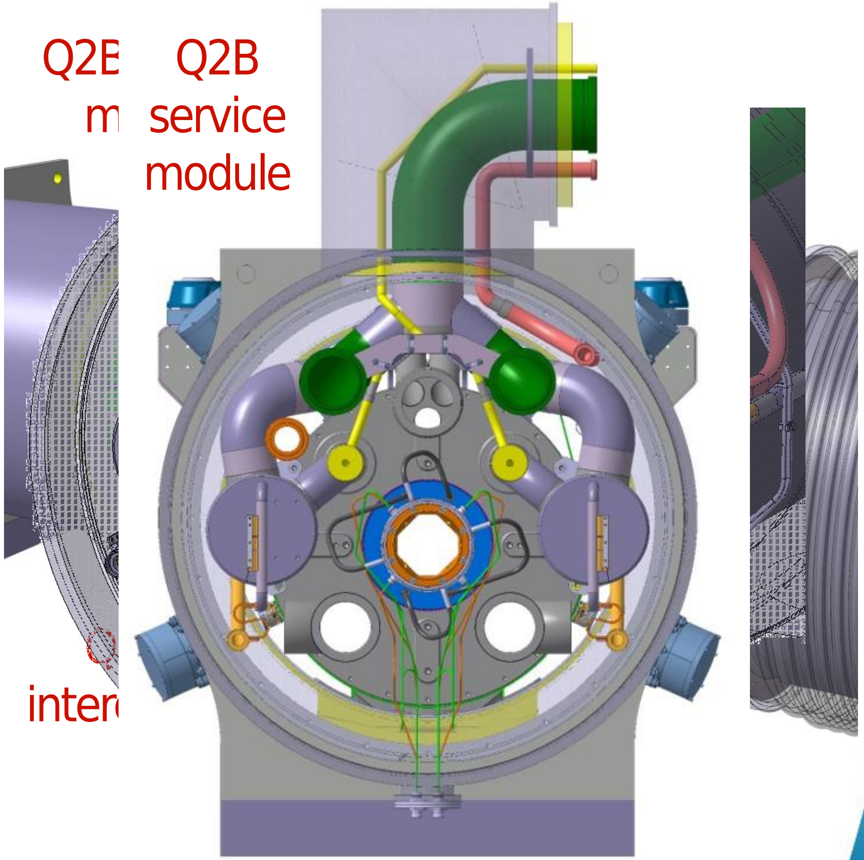
	Case 1 IR5 D1	Case 2 IR5 CP	Case 3 IR5 Q3
Body, external (max) [K]:	89.4	85.2	83.2
Body, internal (max) [K]:	89.3	85.1	83
Single tungsten (max) [K]:	89.2	100.4	76.3



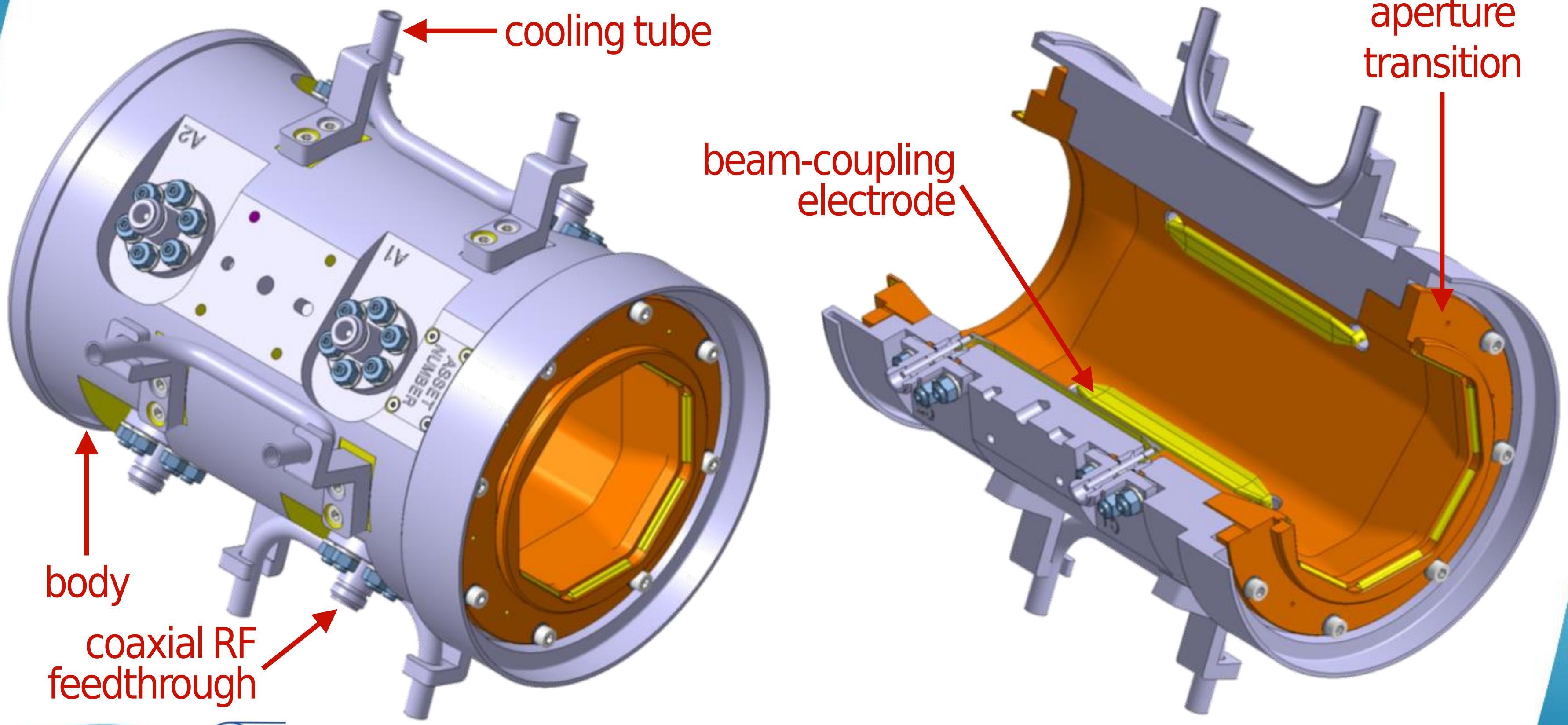
Case 2 – BPM inner surface

B type – integration

- Very challenging integration and installation – work ongoing by WP3, WP12 and WP13
- Responsibility share agreed in a memorandum (EDMS 2105453)
- BPM cryogenic cables (same length for all BPMs) routed to flanges installed on the bottom of the service module
  - Clearance to the tunnel floor: 721 mm (IR1), 541 mm (IR5)
  - Detailed cable routing not yet frozen but no showstoppers identified or foreseen

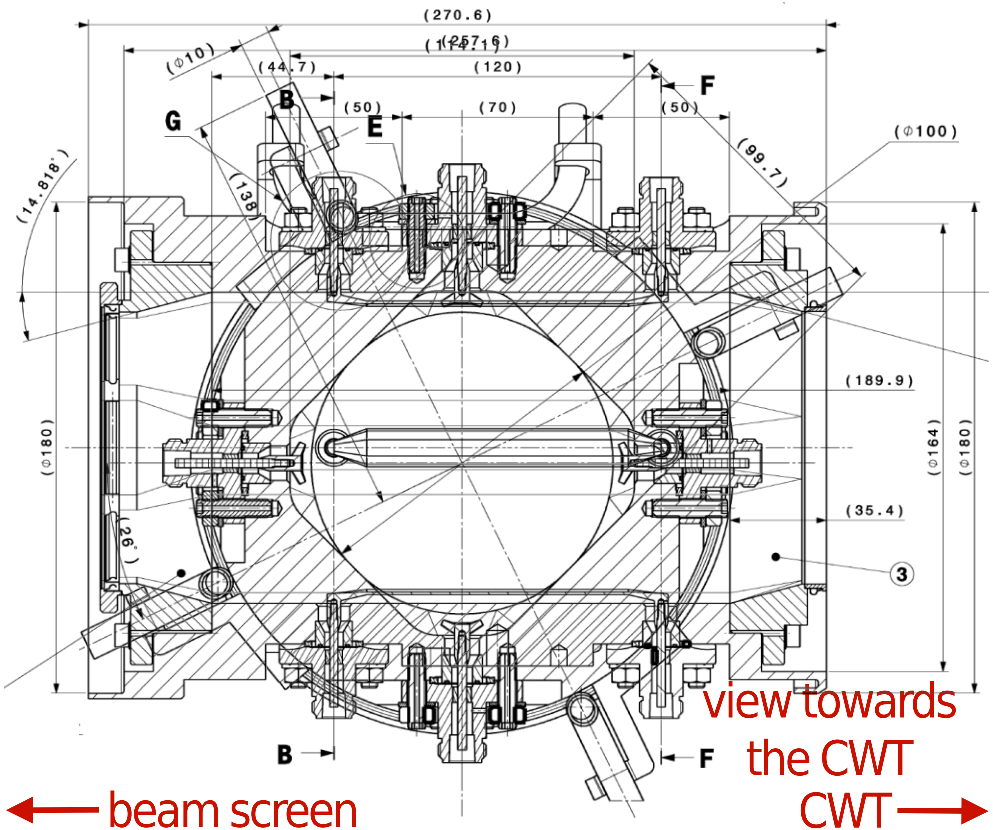


Q1 BPM – A type (BPMQSTZA)



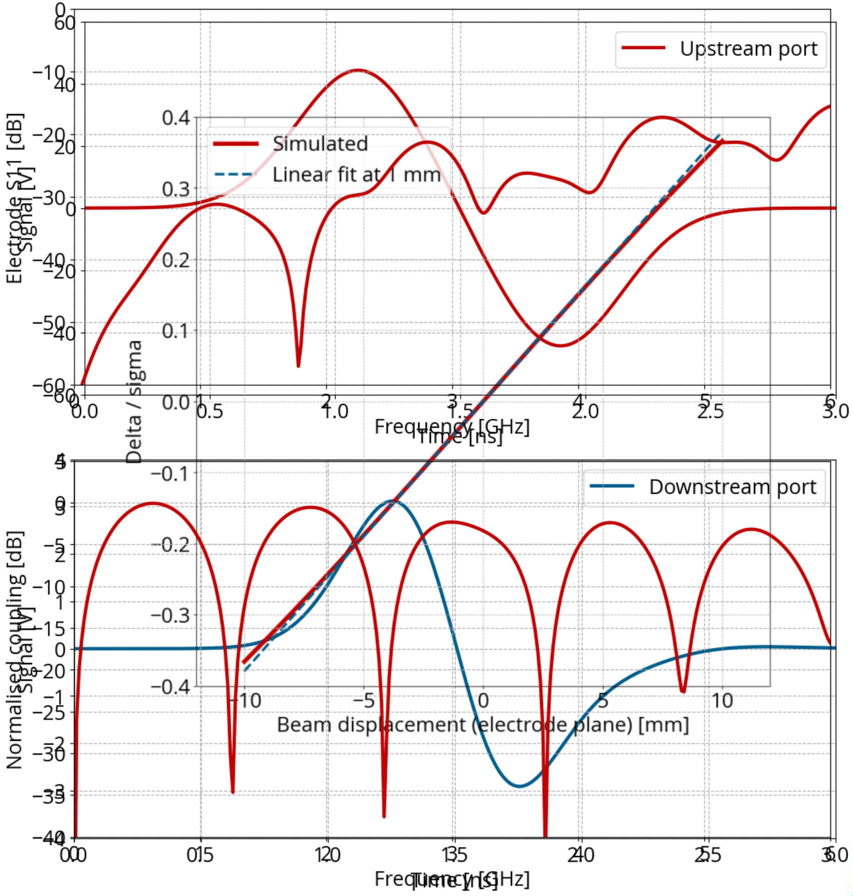
A type – aperture

- Octagonal aperture
  - 114.1 at H and V ("hidden" electrode)
  - 99.7 at ±45º (same as BS)
- Aperture-adapting transition on each side of the BPM
- Transition angle < 15º to avoid impedance problems



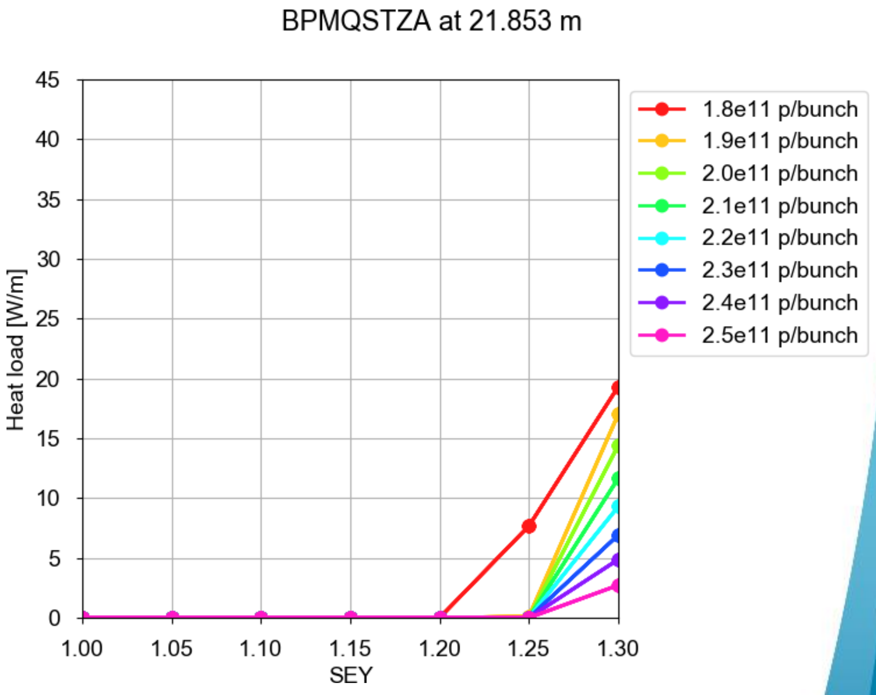
A type – beam position measurements

- Single electrode bunch current sensitivity: 45 V peak for a 1e11 1 ns bunch
- Single electrode beam position sensitivity: 0.33 dB/mm
- Δ/Σ sensitivity for 1 mm displacement: 0.038
- Broadband directivity: 24.6 dB
- Electrode S11: -25 dB @2.5 GHz
- Centre frequency of the 1st lobe: 625 MHz



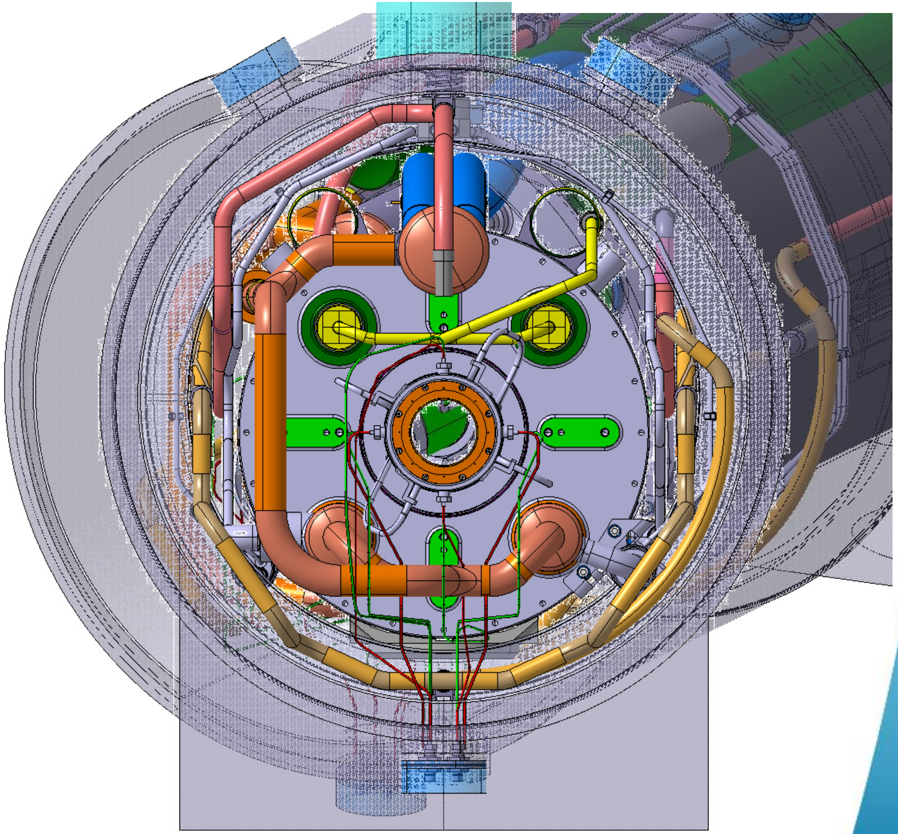
A type – simplified B type

- WP10: no need for tungsten shielding at the Q1 BPM
  - Electrodes installed at 0º and 90º
- WP2: no e-cloud if SEY < 1.25
  - aC coating at SEY=1.1 (as B type)
- Impedance: model provided to IWG
- Heat load: no collision debris, no electron cloud, coldest helium
  - Total heat load of 180 mW
  - Cooling with 4 tubes (as B type)
  - No problems foreseen

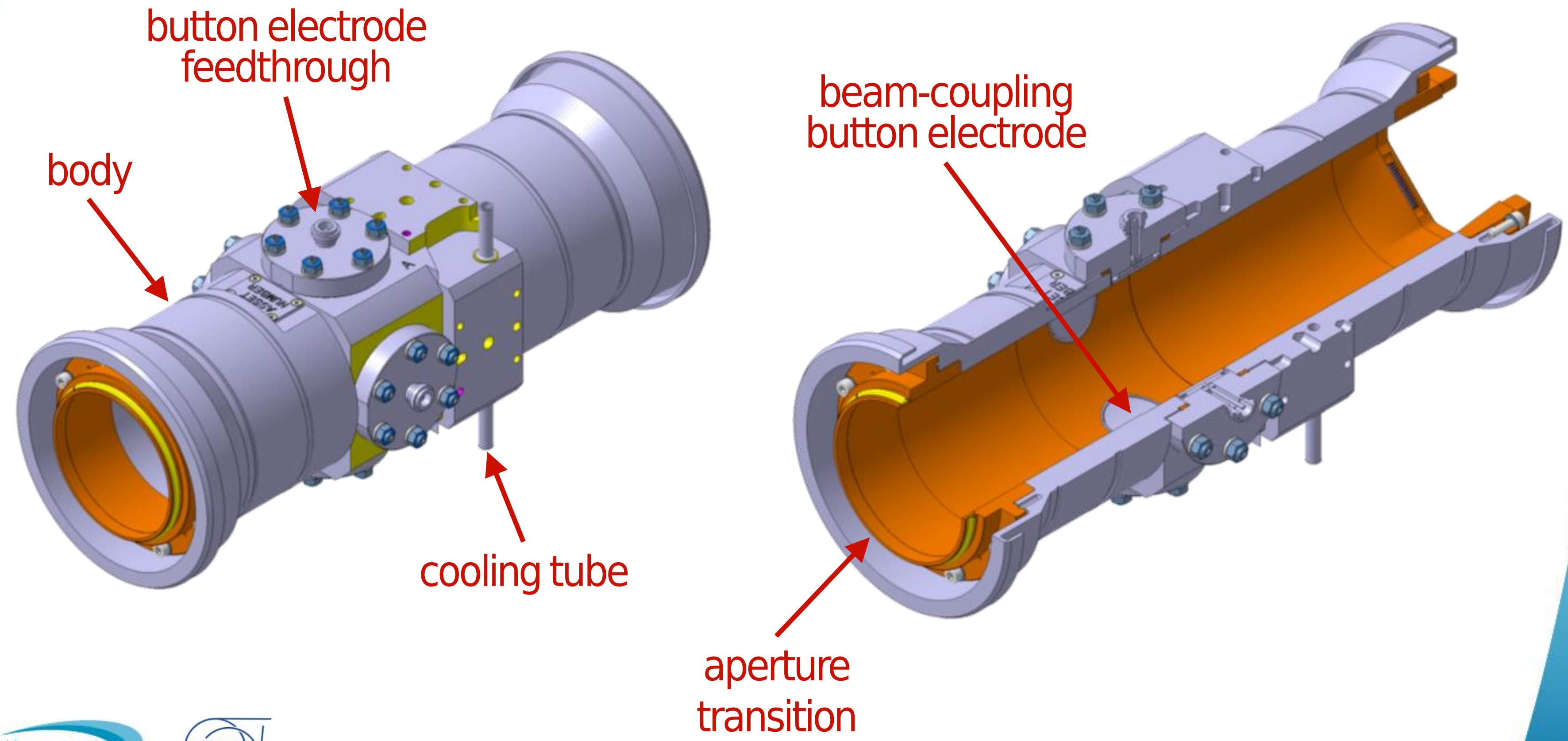


A type - integration

- Very challenging integration and installation – work ongoing by WP3, WP12 and WP13
- Responsibility share agreed in a memorandum (EDMS 2105453)
- BPM cryogenic cables (same length as for the B type) routed to flanges installed on the bottom of the service module
  - Clearance to the tunnel floor: 721 mm (IR1), 541 mm (IR5)
  - Detailed cable routing not yet frozen but no showstoppers identified or foreseen

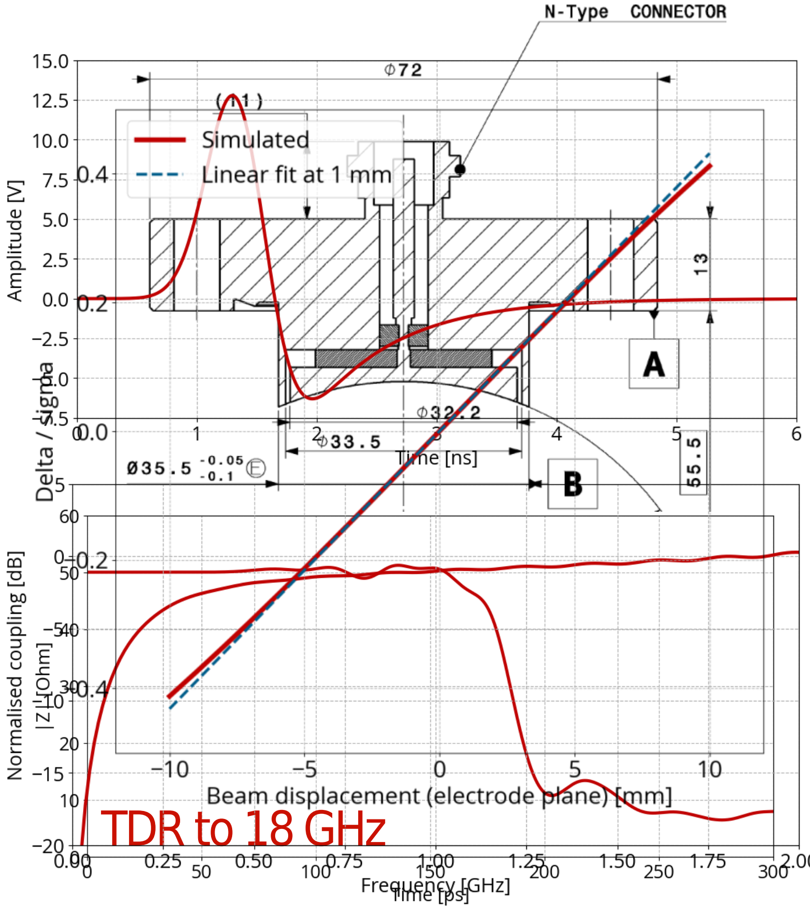


D2 BPM (BPMQBCZA/B)



D2 BPM – beam position measurements

- Electrostatic button electrodes: Ø32.2 mm, 0.65 mm gap, 15 pF
- Optimised for 50 Ω impedance
- Single electrode bunch current sensitivity: 12.5 V peak for a 1e11 1 ns bunch
- Low cut-off frequency: 212 MHz
- Single electrode beam position sensitivity: 0.38 dB/mm
- Δ/Σ sensitivity for 1 mm displacement: 0.043

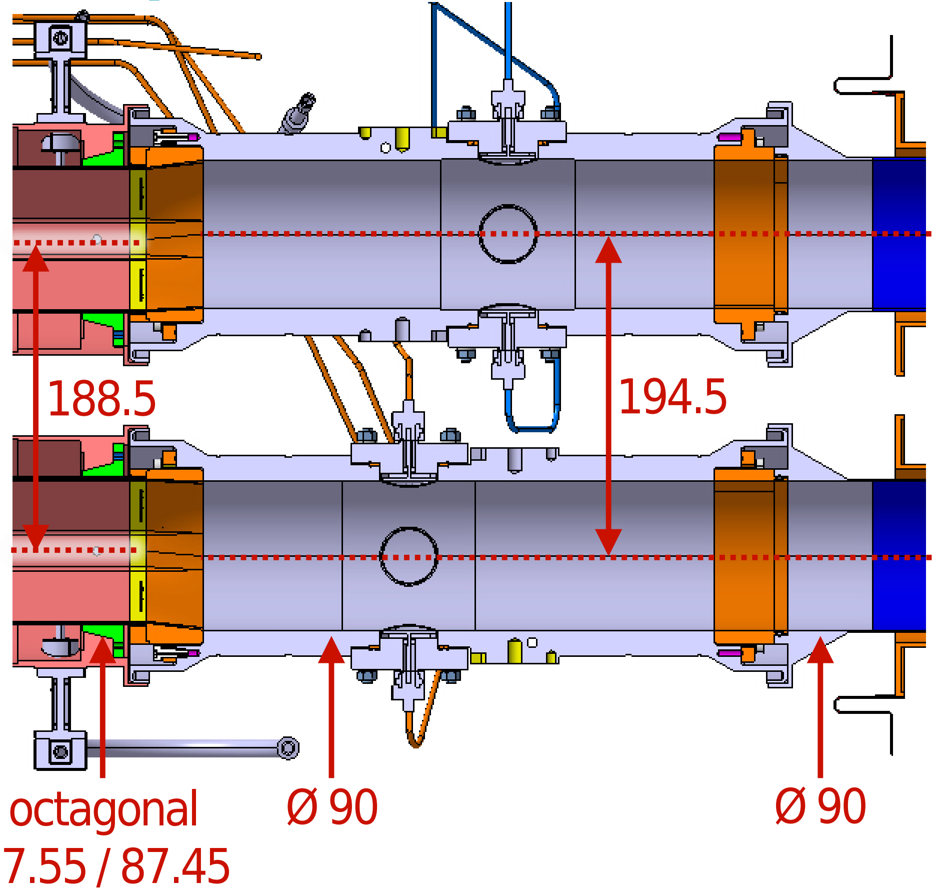


D2 BPM – electron cloud and impedance

- No dedicated e-cloud simulations for the D2 BPMs
  - Only metal surfaces visible to the beam
  - WP2 recommends to aC coat the body and electrodes
- No impedance issues foreseen
  - Design very similar to the ~800 existing LHC BPMs
  - Updated models provided to IWG for verification
  - Resistive wall model heat load 100 mW
- **Design decisions:**
  - Coat the BPM body with 100 μm copper (RRR = 100) for impedance reduction + thermalisation
  - Coat body + aperture transitions + electrodes with aC

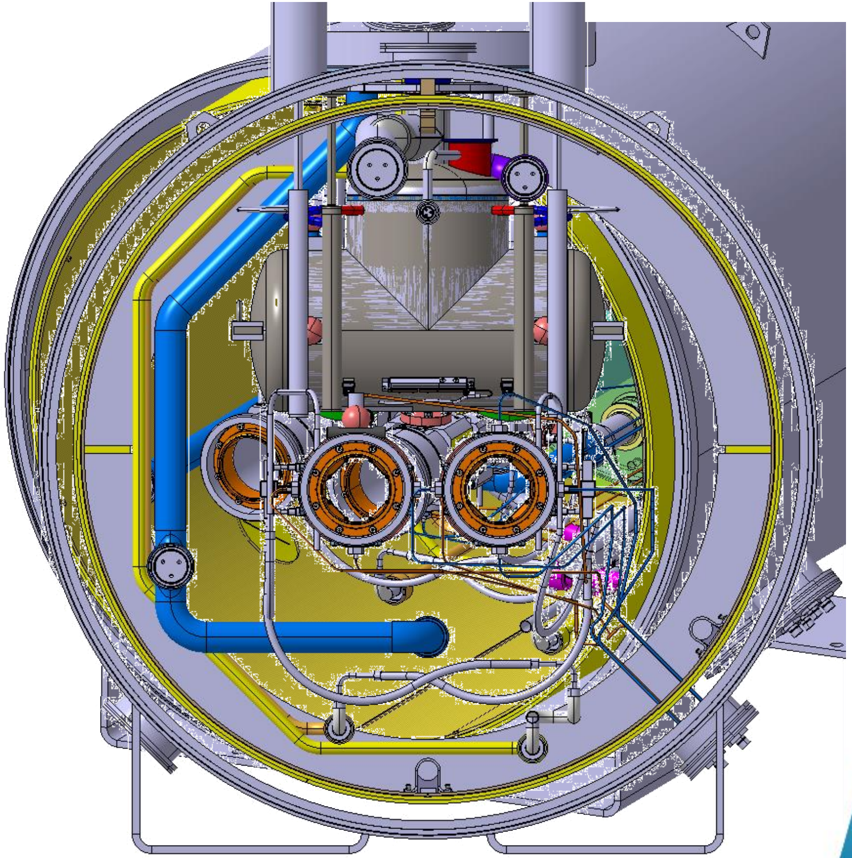
D2 BPM - two top assemblies

- Connectors of both BPMs must be staggered to gain space for cable installation
- Aperture transitions are different on the BS side (octagonal-round, eccentric) and on the CWT side (round-round, concentric)
- **Design decisions:**
  - BPM body is “reversible”
  - All sub-parts are the same
  - Two various top assemblies



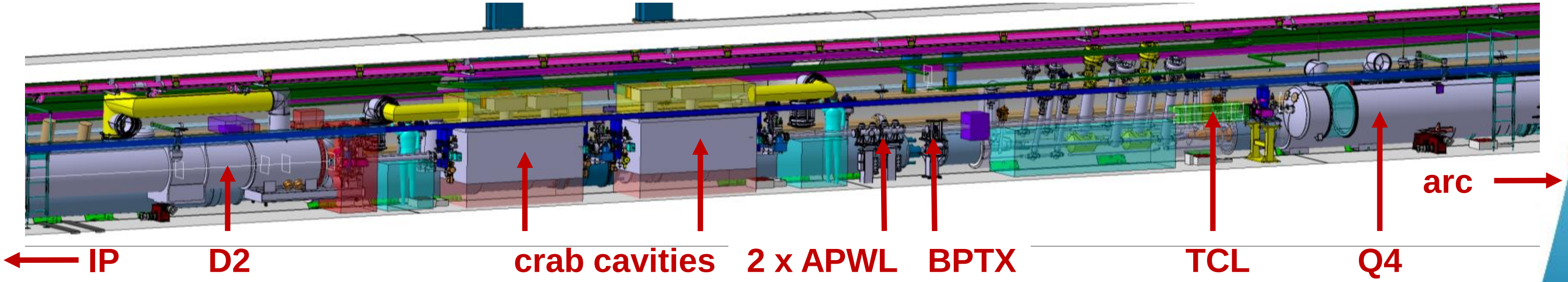
D2 BPM - integration

- Challenging integration and installation – work ongoing by WP3, WP12 and WP13
- Responsibility share agreed in a memorandum (EDMS 2105453)
- BPM cryogenic cables (same length for all) routed to flanges installed on a side of the QQS
  - Possibility of routing to the bottom of the QQS studied and ruled out due to inaccessibility
  - Cables routed always to the passage side of the QQS
  - Detailed cable routing not yet frozen but no showstoppers identified or foreseen



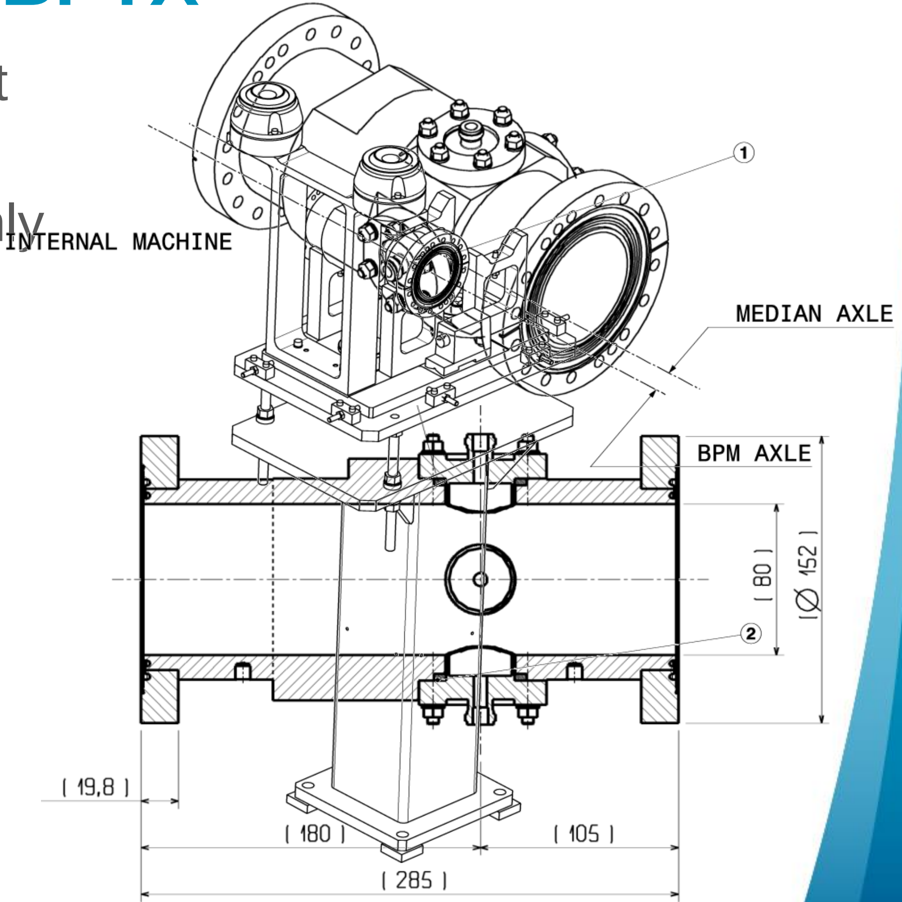
BPTX & APWL

- First non-cryogenic pick-ups in HL-LHC LSS 1/5:
  - 2 x APWL (one per beam): owned by WP4, used for CC diagnostics
  - BPTX (only for the beam heading towards the IP) – owned by WP13, used for timing the experiments
- WP4 and WP13 decided that a BPTX-like pick-up can replace APWLs
  - Technical agreement reached recently
  - Responsibility share remains to be formally agreed



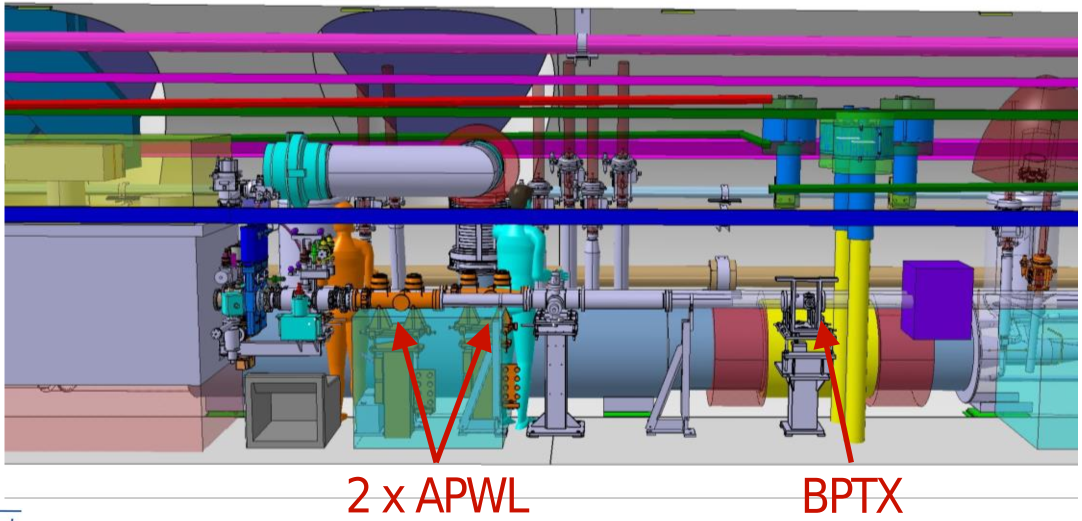
HL-LHC BPTX

- LHC BPTX has 60 mm aperture but ≥80 mm needed for HL-LHC
  - Aperture large enough to align only once at installation
- HL-LHC BPTX to be based on a slightly modified BPMWI design:
  - Conflat seals, new button design
  - New signal combiners
  - Reuse the supports if possible
- To be added to the BINP contract
- ECR in preparation



BPTX & APWL - integration

- Longitudinal positions discussed recently with WP15
  - APWLs as close to the CC as reasonable
  - BPTX farther away to minimize the risk of accidental damage
- Integration uses models of the LHC monitors
  - Updated models and supports to be given to WP15 when available
- Discussions with EN/EL ongoing on minimizing the BPTX cables length



Functional specifications

- Functional specification for the cryogenic directional couplers BPMQSTZA (A type) and BPMQSTZB (B type) recently circulated: EDMS 2394486
  - EDMS and review comments will be addressed in the new version
- Functional specification for the cryogenic buttons BPMQBCZA/B (D2 type) in preparation – lighter than A and B type
  - To be circulated in Q1 2021
  - Review comments will be addressed
- Functional specification for BPTX and APWL will be prepared after the ECR is approved
  - To be circulated not before Q3 2021
  - Review comments will be addressed

Summary

- 3D designs of A type, B type and D2 BPMs are ready for releasing manufacturing drawings for pre-series production preparation
  - Various simulations done or ongoing by relevant WPs
  - Integration and interfaces checked using 3D models
  - A type and B type electrode model to be updated
  - Designs not yet frozen but no further major changes planned
- BPTX / APWL design not stared yet but will be mostly a copy-paste of an existing BPMWI design with minor modifications
  - Needed-by dates for warm BPMs much more relaxed
- The rest of the review will focus only on the cryogenic BPMs
  - WP13 goal for the review is to approve launching the pre-series production phase at CERN main workshop

Thank you for your attention

Special thanks for the input and discussions: N. Biancacci, F. Carra, F. Cerutti, N. Chritin, A. Demougeot, D. Duarte Ramos, M. Gonzalez de la Aleja, J. Hansen, G. Iadarola, N. Kos, A. Kurtulus, S. Pereira, M. Sabate Gilarte, B. Salvant, G. Skripka, J. Swieszek, A. Vande Craen