HL-LHC Collimator Designs: Status and Outlook

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On behalf of the LHC Collimation Design Team

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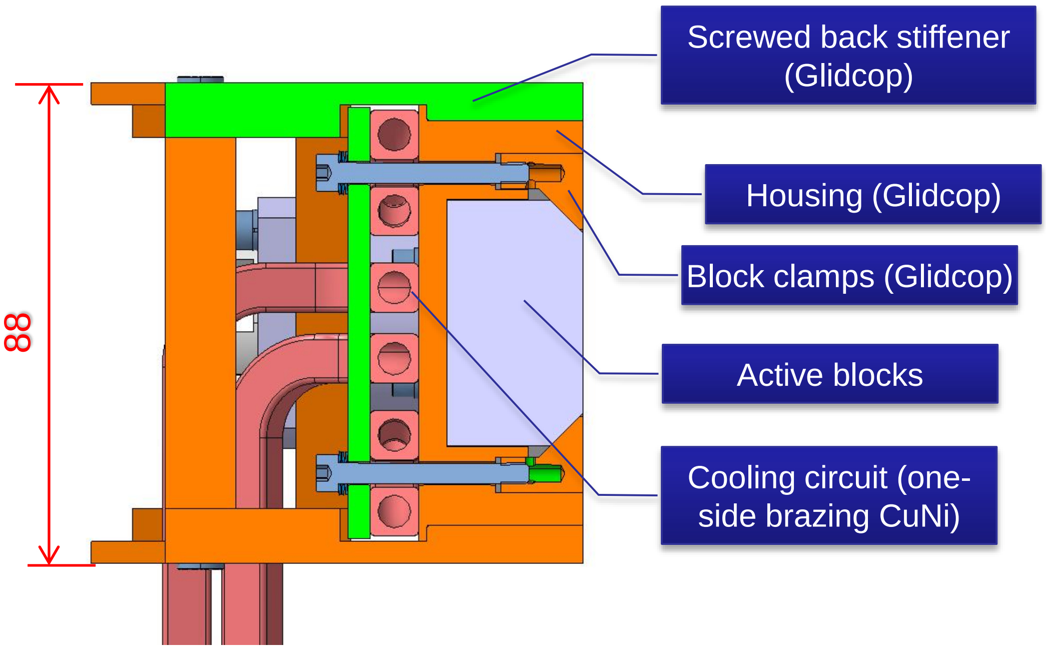
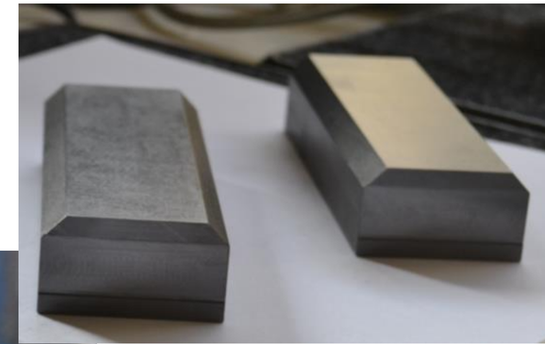
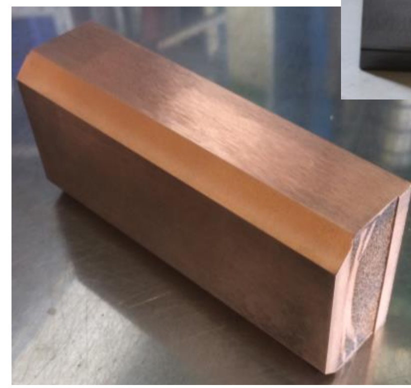
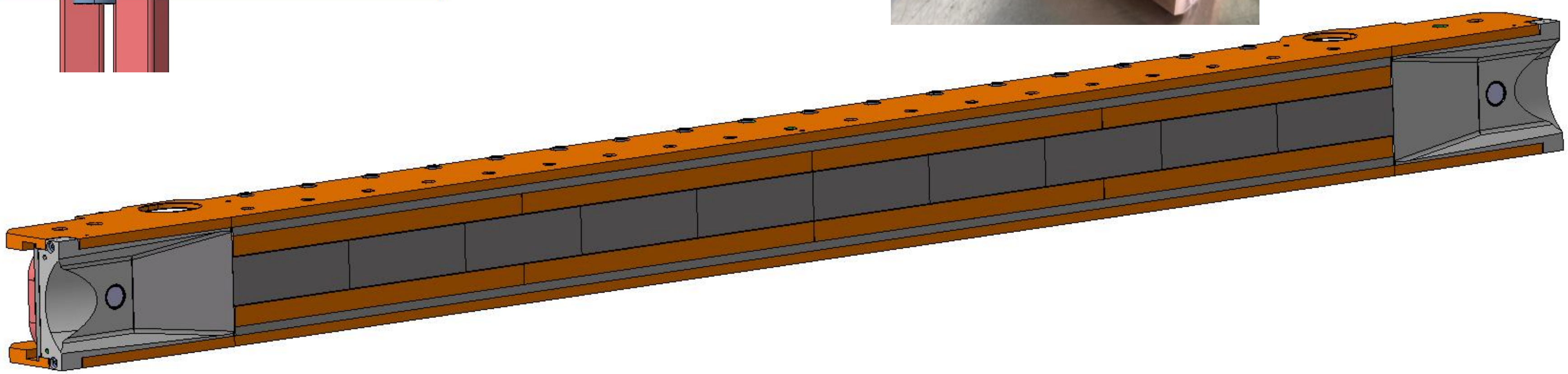
HL-LHC Collimator Baseline Design

- **Modular design** for **HL-LHC Collimators** practically completed. It can be used as a baseline for any collimator with standard dimensions (TCPPM primary, **TCSPM** secondary or TCTPM tertiary).
- The concept allows to install **active blocks** made of (theoretically) any material (e.g. **MoGr** or **CuCD**)



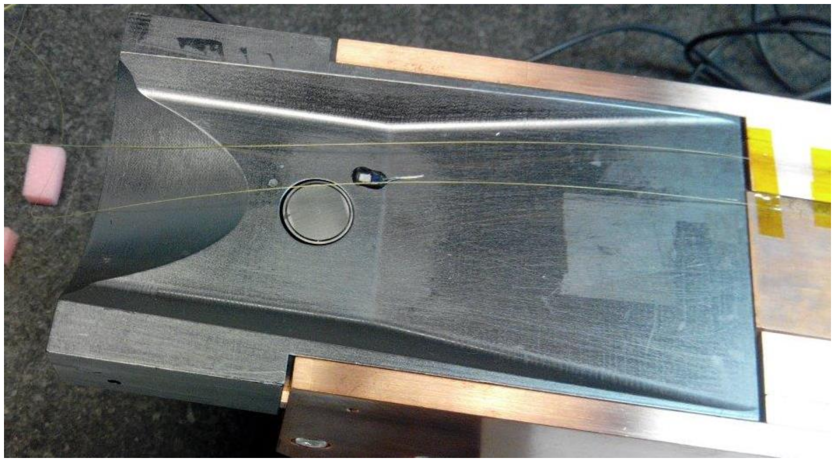




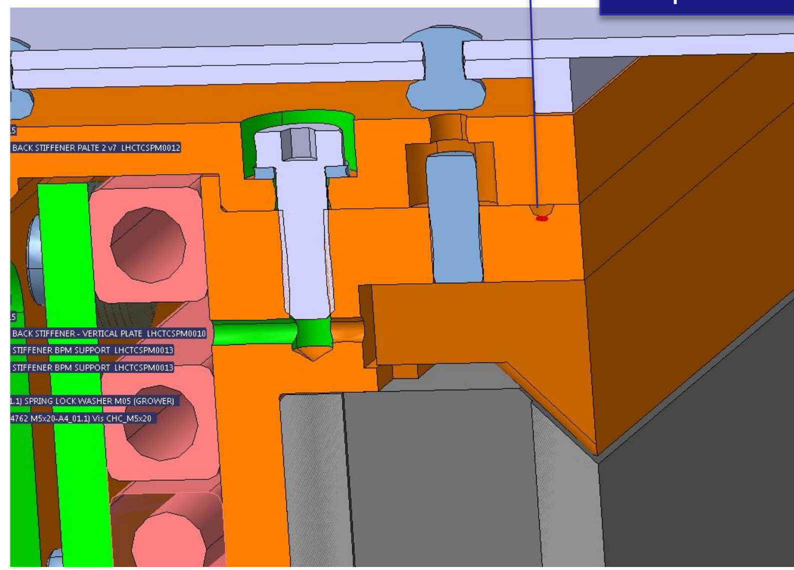


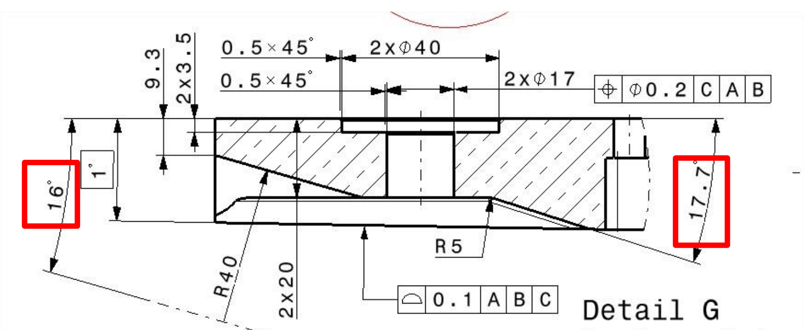
HL-LHC Collimator Baseline Design

- Foreseen embarked diagnostics include BPM pick-ups, Fiber Bragg Grating (FBG) for strain and deformation (pending green-light on glue UHV compatibility), Temperature sensors (glued or clamped).
- **BPM pickup** seat (tapering) lengthened and smoothened to reduce RF perturbations. Material to be chosen to withstand beam impacts (e.g. MoGr)

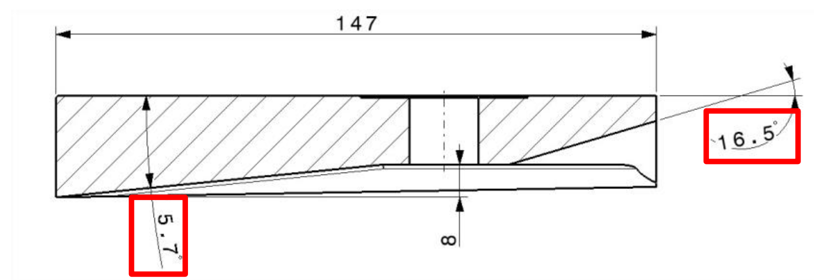


Proposed FBG location





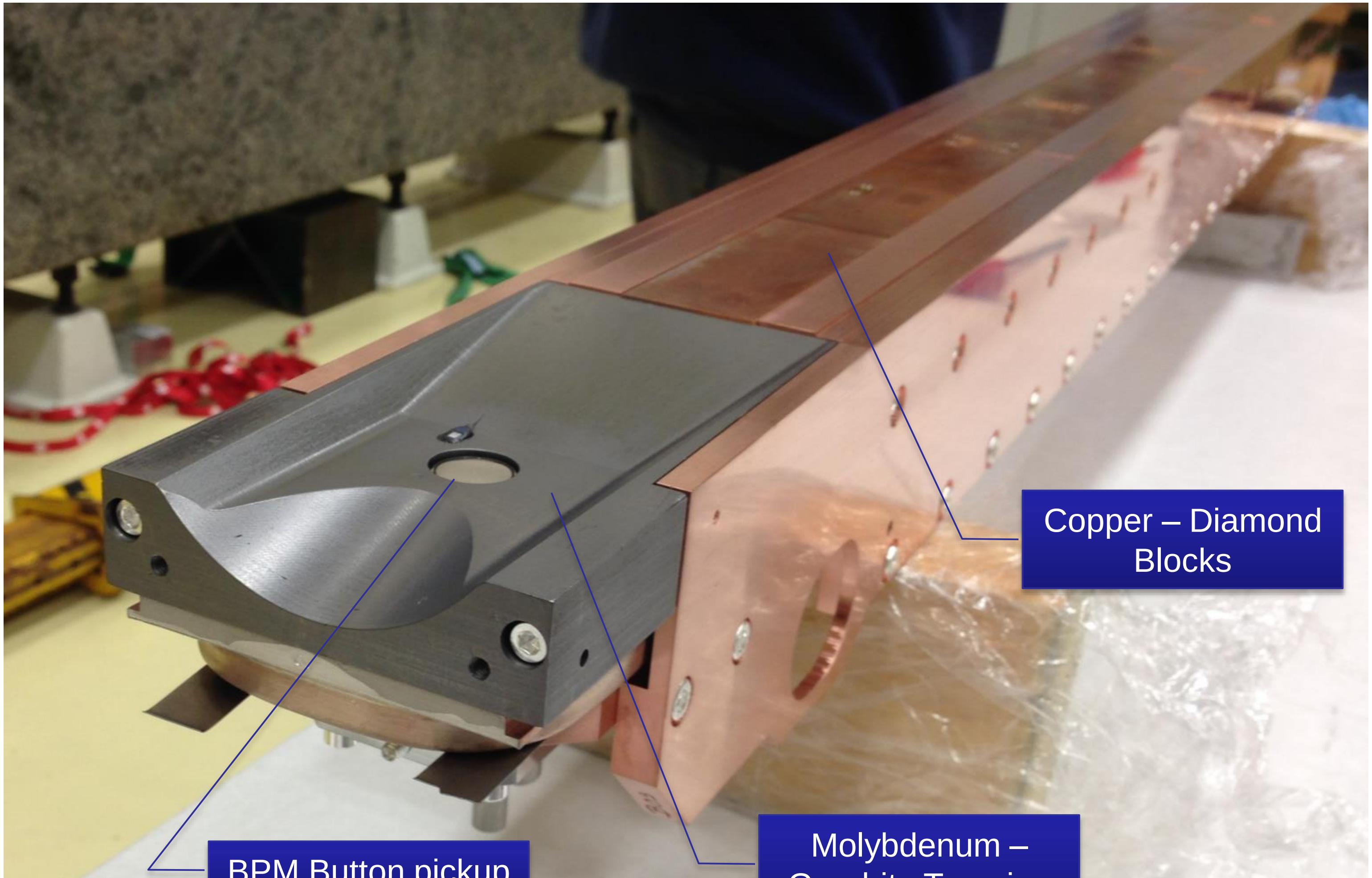
TCSP cross-section



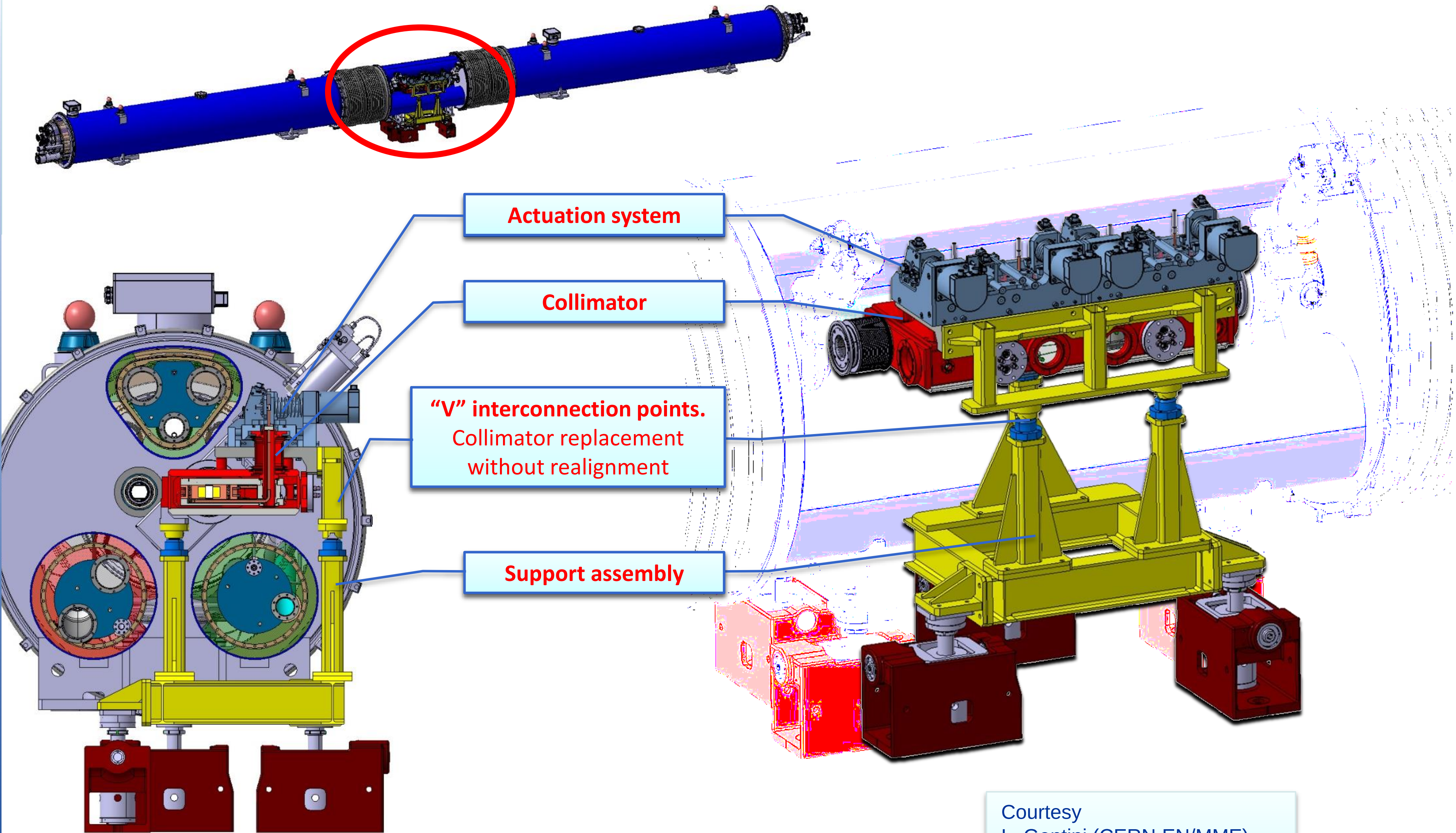
TCSPM cross-section

TCSPM Secondary Collimator

- A full-scale prototype is expected to be manufactured in 2016 by EN/MME for (mainly) impedance tests in the LHC.
- LHC installation foreseen during EYETS 2016 (with possible previous installation in SPS in autumn 2016).



TCLD Dispersion Suppressor Collimator



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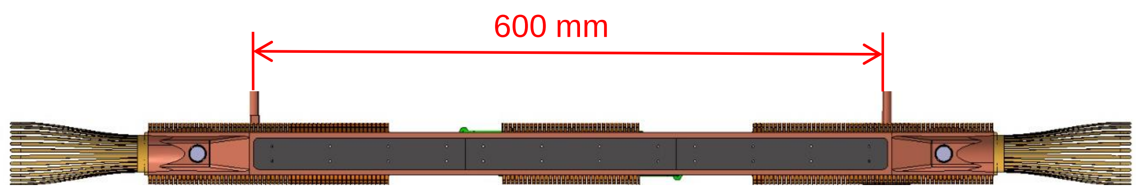
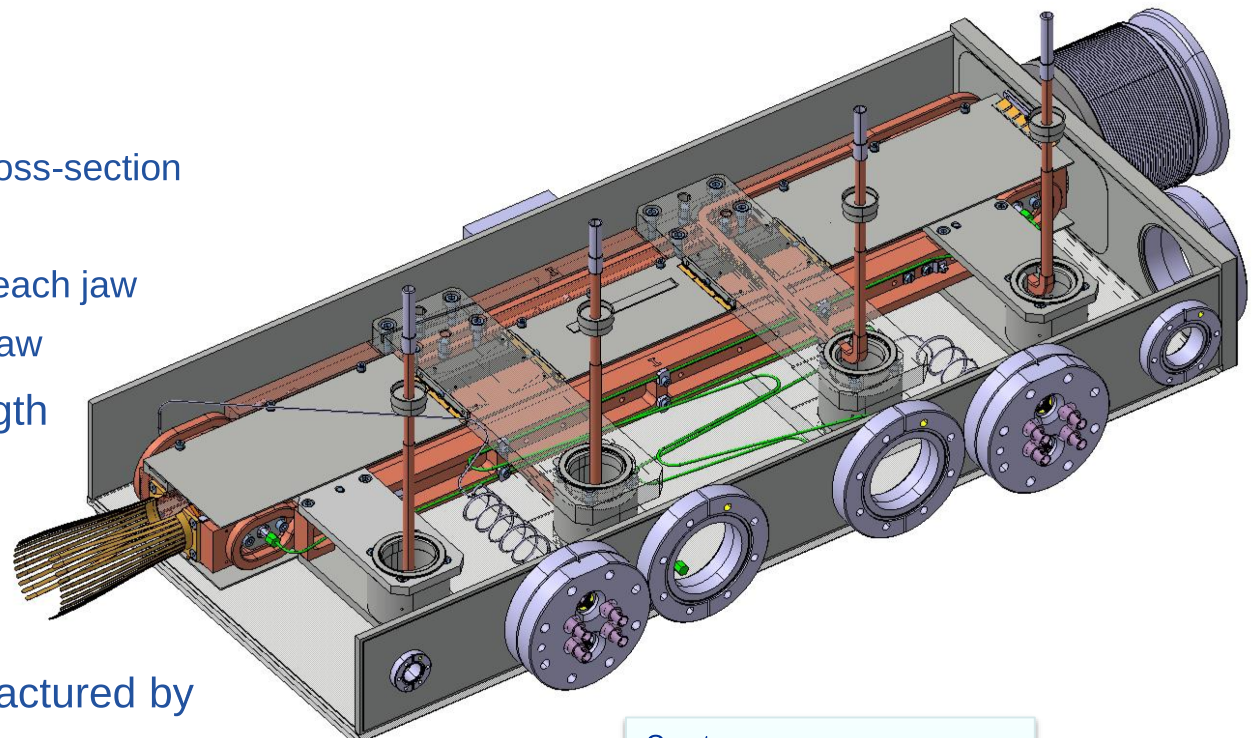
TCLD Dispersion Suppressor Collimator

- General
  - Active length 600 mm
  - Brazed cooling circuit
  - 3x screwed Inermet blocks per jaw (30x20x200 mm)
  - Tapering slopes 10˚ and 15°
  - Cantilever jaws
- Cooling system
  - Square pipes (9 mm, CuNi)
  - 3x cooling pipes in the central cross-section
- Instrumentation
  - 2x temperature probes (PT100) each jaw
  - 2x Beam Position Monitor each jaw
- BPM cables: same electrical length of TCTP with different shape
- RF system
- RF fingers + St. steel screens
- Full-scale prototype to be manufactured by EN/MME by early 2017
- 2 units to be installed at IR2 during LS2





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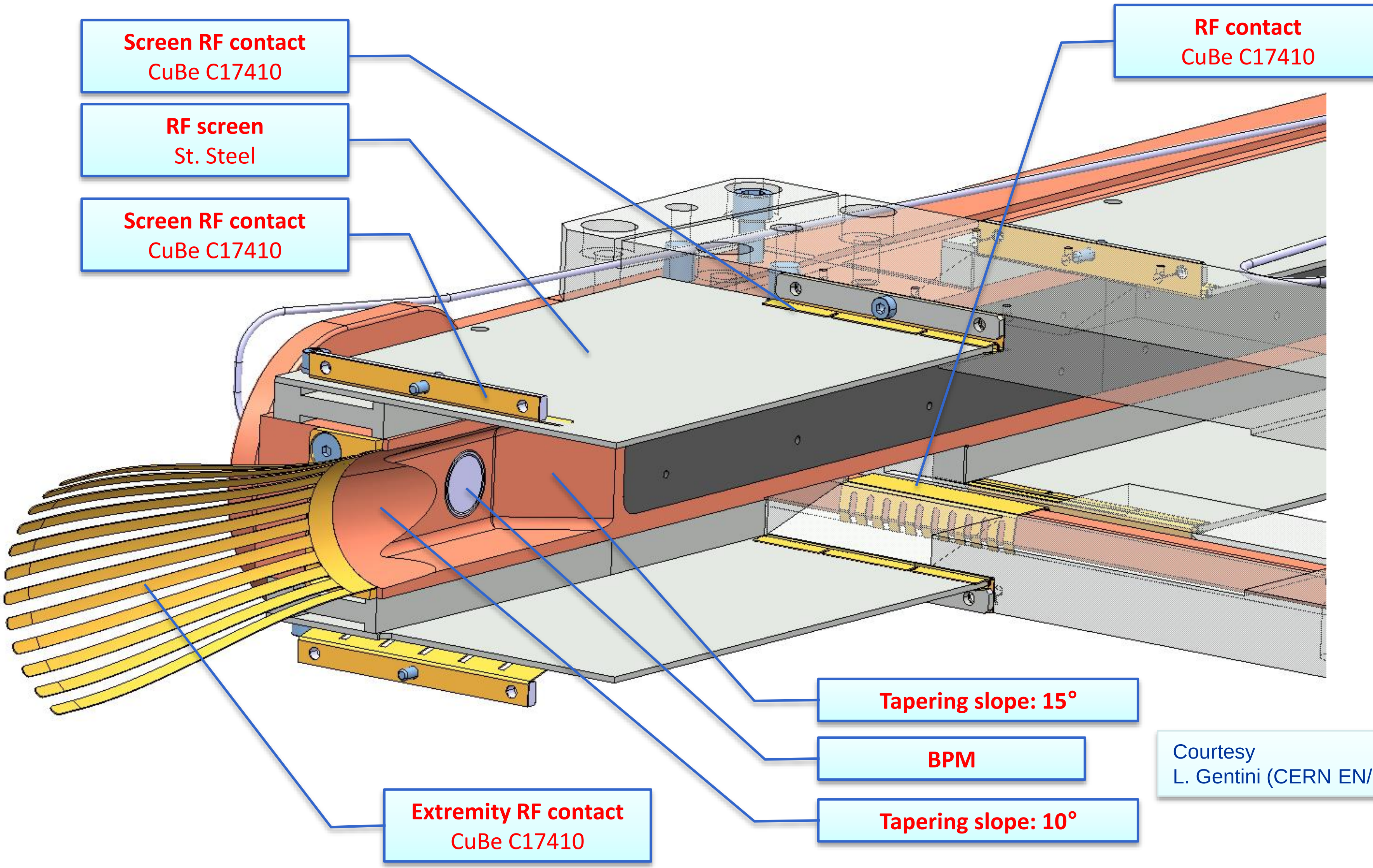
TCLD Dispersion Suppressor Collimator



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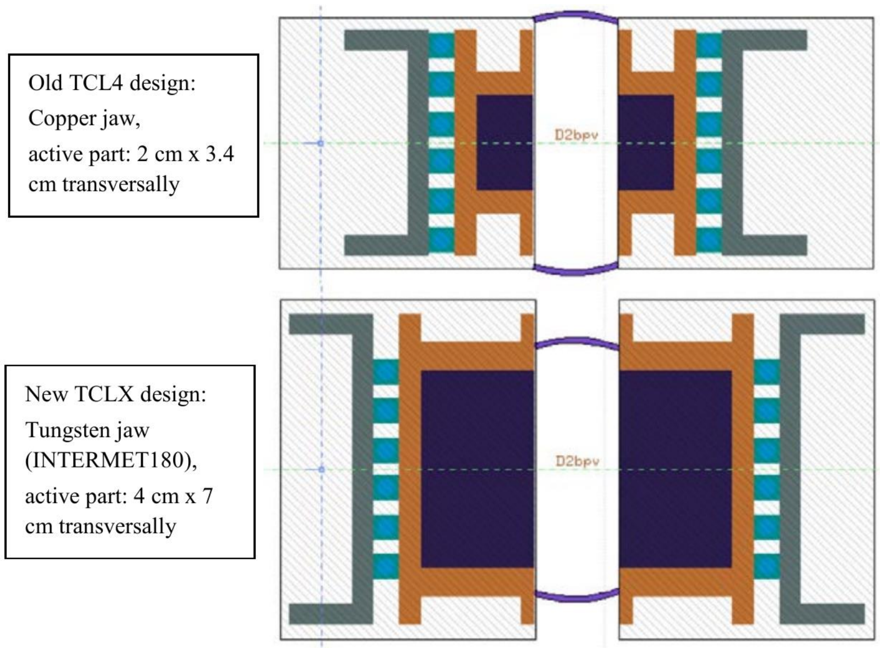
Other Designs

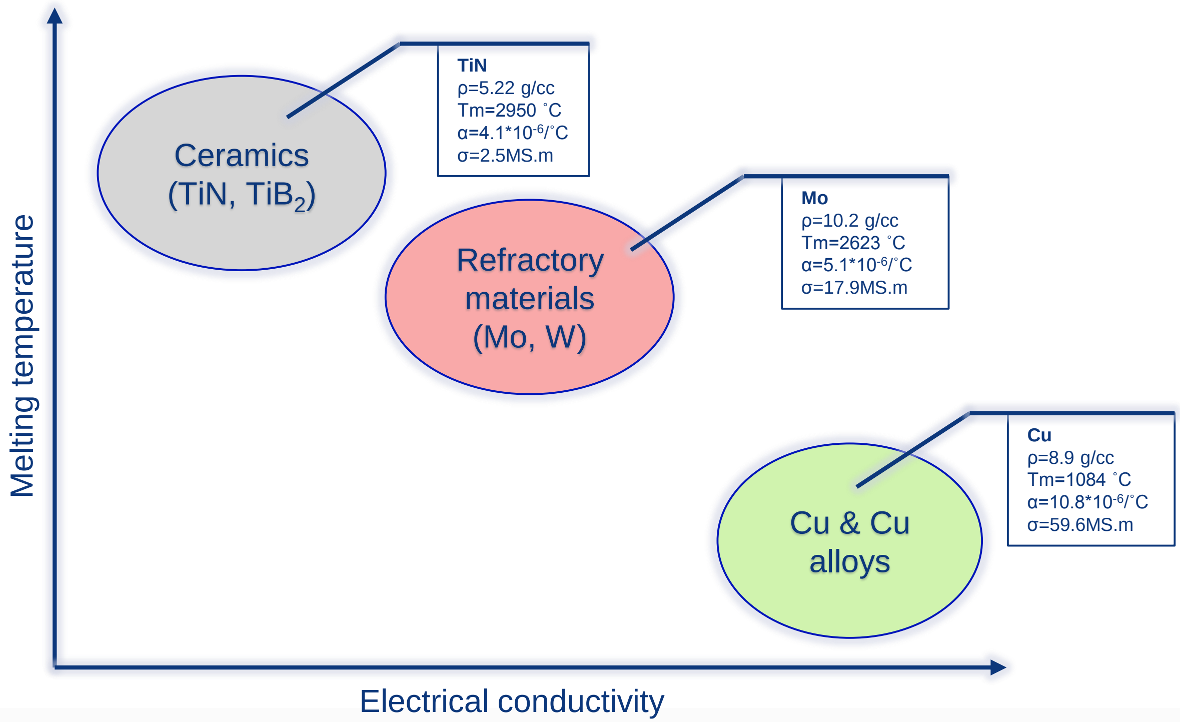
- Other designs to be launched in the near future include:
  - TCLx to be installed in cells 4 of IR1 and IR5 to protect against luminosity debris in HL-LHC, with thicker Inermet jaws (instead of Cu)
  - TCT with increased stroke (40 mm instead of 30 mm) to cope with larger β in IR1 and IR5
  - Additional Passive Absorbers (TCAPx)



Materials and Coatings

- Coatings are a convenient option to reduce collimator RF impedance given the thin region affecting impedance response (less than 10 μm)
- Coatings must combine good robustness with high electrical conductivity
- Properties to be optimized include:
  - Electrical conductivity
  - Melting point
  - Adhesion (chemical bonding)
  - Density
  - CTE
  - Radiation hardness
  - Elastic modulus/strength
  - Feasible process

Three candidates, aimed at exploring the full spectrum of options, currently under study



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Two ceramics promise good compromise between robustness (CTE, density) and electrical conductivity

Electrical conductivity at room temperature			
	MS/m	μΩ.m	μΩ.cm
TiB2	11.1	0.09	9.01
ZrB2	10.3	0.10	9.71
TiSi1.93 monocrystal	7.8	0.13	12.82
Ni2B	7.15	0.14	13.99
TiSi2	5.93	0.17	16.86
α-WC	5.88	0.17	17.01
ZrN0.97	5.55	0.18	18.02
WC	5.22	0.19	19.16
Ni3B	4.76	0.21	21.01
Mo3Si	4.63	0.22	21.60
MoSi2	4.63	0.22	21.60
TaC0.99	4.55	0.22	21.98
β-MoB	4	0.25	25.00
Mo2B5	3.85	0.26	25.97
TiN0.97	2.5	0.40	40.00
Mo2B	2.5	0.40	40.00
α-MoB	2.23	0.45	44.84
MoB2	2.23	0.45	44.84

	MS/m	μΩ.m	μΩ.cm
Mo5Si3	2.18	0.46	45.87
ZrC0.97	2.04	0.49	49.02
Ta2C	2.04	0.49	49.02
MoC	2.04	0.49	49.02
ZrSi	2.03	0.49	49.26
NiB	2	0.50	50.00
Ti5Si3	1.82	0.55	54.95
TiC0.96	1.64	0.61	60.98
TiSi	1.59	0.63	62.89
Mo2C	1.41	0.71	70.92
W2C	1.32	0.76	75.76
ZrSi2	1.32	0.76	75.76
MoGr	≈1	≈1	≈100
SiC	7.70E-04	1.30E+03	1.30E+05
B4C	1.00E-04	1.00E+04	1.00E+06
AlN	1.00E-13	1.00E+13	1.00E+15
α-BN	5.90E-14	1.69E+13	1.69E+15
Si3N4	5.00E-14	2.00E+13	2.00E+15

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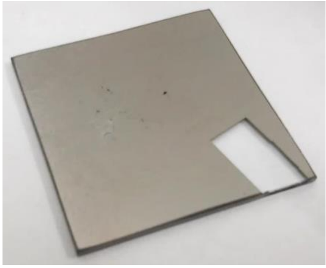
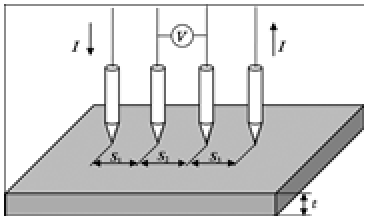
Reference: HANDBOOK OF REFRACTORY COMPOUNDS 1980 G.V. Samsonov (all except MoGr)

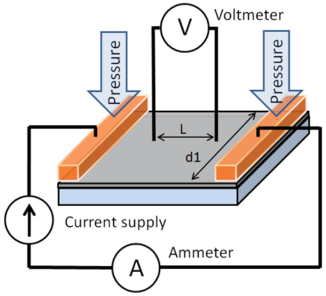
- TiB_2 has been successfully sputtered on different substrates with poor electrical performance
- MoGr, Si and glass have been coated with apparent good adhesion both at CERN and Danish Technology Institute (DTI)
- Measured electrical conductivity of as-coated and annealed samples (0.2-0.6 MSm^{-1}) is consistently below the minimum theoretical of 11.1 MSm^{-1}



4-Point-Probe



Direct method



- So far the effect of thermal annealing on electrical properties of TiB_2 thin films, as discussed by B. Todorovic*, has not been reproduced at CERN
- The reproducibility of the process and its extension to a full collimator have raised questions about its feasibility

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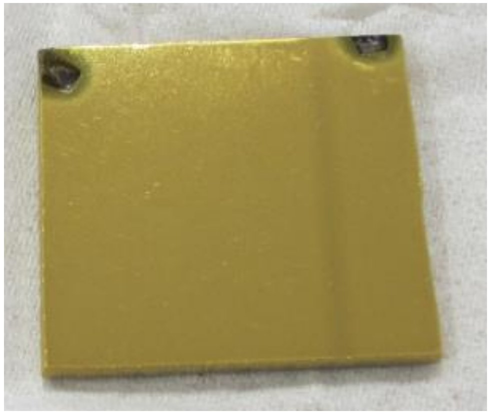
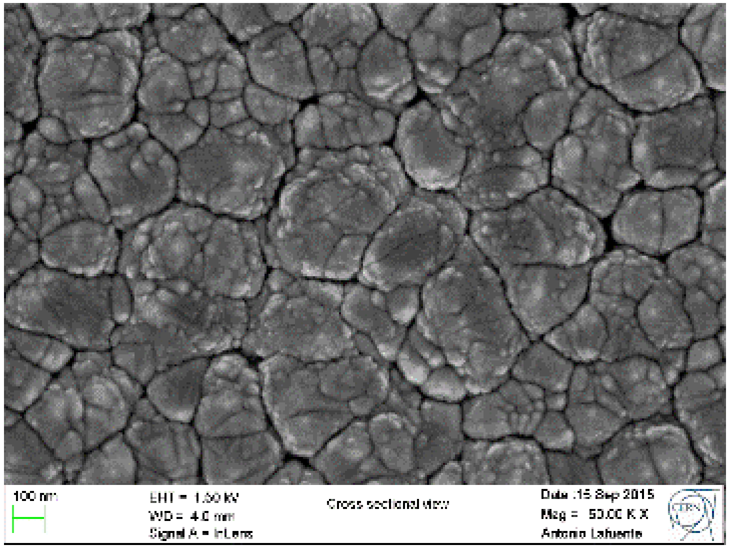
* B. Todorovic, Thin Solid Films 300 (1997) 272-277

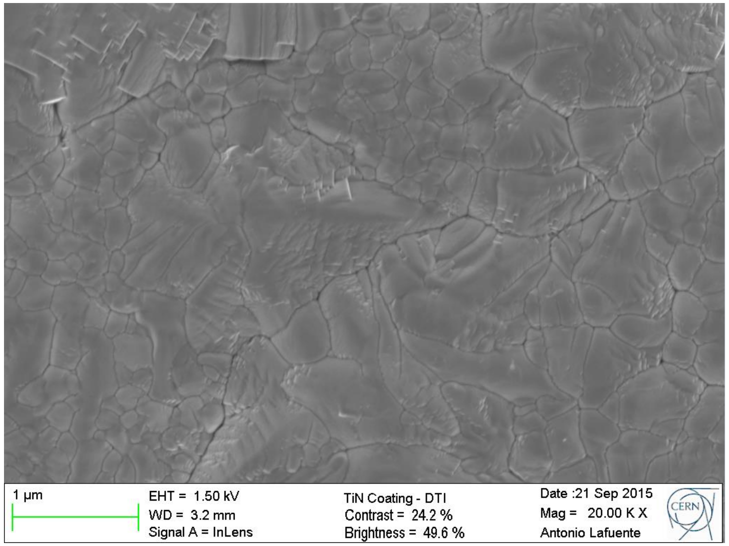
- Trials with TiN have shown a better and more consistent electrical behaviour
- Electrical conductivity of as-coated samples (2 MSm^{-1}) is close to the theoretical value of 2.5 MSm^{-1}
- A comparison between SEM micrographs of both coatings suggests that the more continuous grain structure of the TiN could be the reason behind this



TiB_2



TiN



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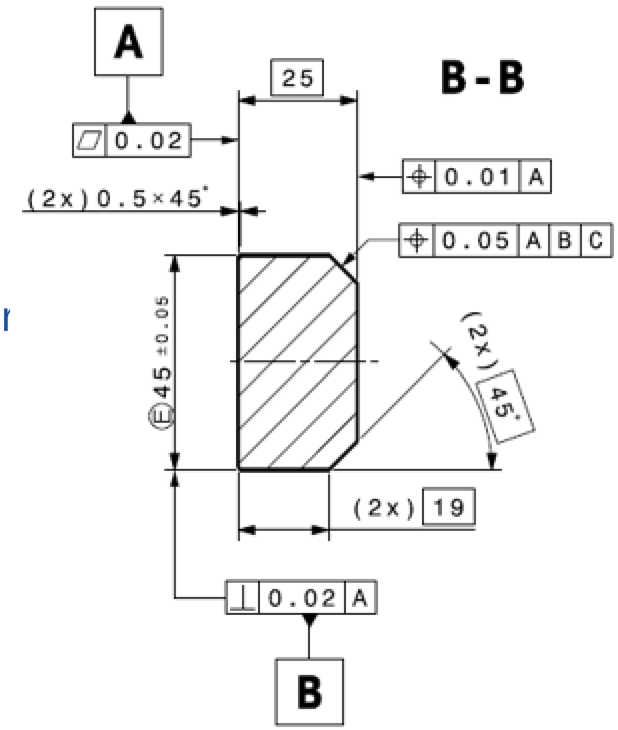
- An extensive characterization campaign for TiN coatings is currently underway
- Three TCSPM blocks, one of graphite, one of CFC and one of MoGR, will be coated with TiN and qualified for their use in the LHC
- The test campaign will study, among other things:
  - ✓ Impact of the coating on tolerance requirements
  - ✓ Coating adherence
  - ✓ Resistance to thermal-shock
  - ✓ Vacuum compatibility and potential effect of surface pr treatments on the previous points



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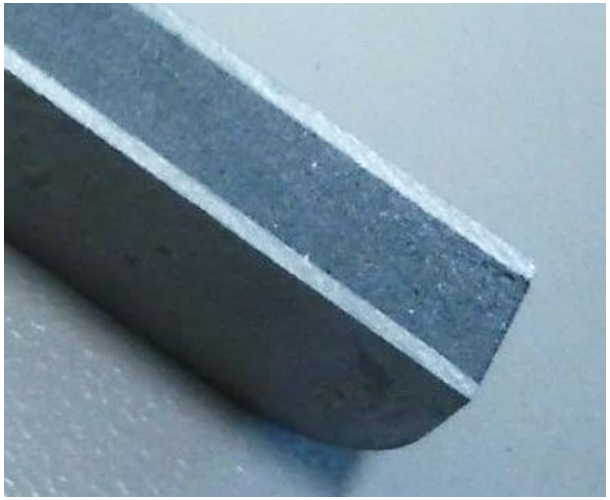
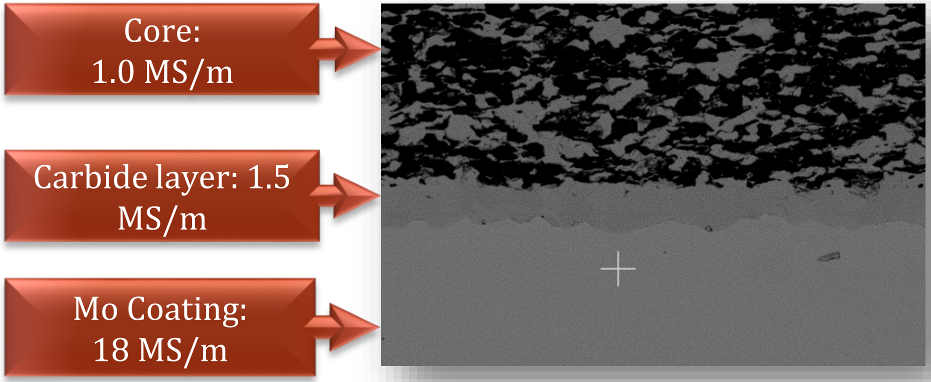
Materials and Coatings

- The idea of using Molybdenum to improve impedance is currently being revisited
- Molybdenum claddings proved to increase electrical conductivity with excellent adhesion





- Cladding large required thicknesses and the presence of a brittle interface resulting from the production route has shifted interest towards Mo sputtered coatings

- First trials scheduled with TE-VCS group for early November

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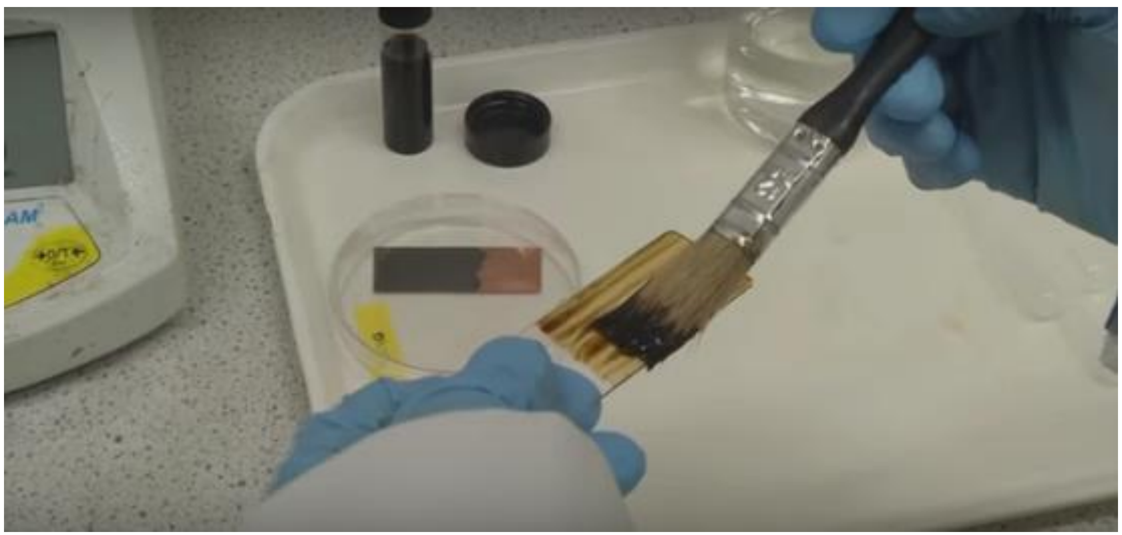
Materials and Coatings

- Graphene coatings could actually represent an exotic solution to the impedance problem
- Manchester University has developed graphene coatings/paints that can be used to improve electrical conductivity of insulating materials
- Conversations are currently under way to try to understand its potential but technology seems to have reached a maturity level that would allow deployment in the very near future



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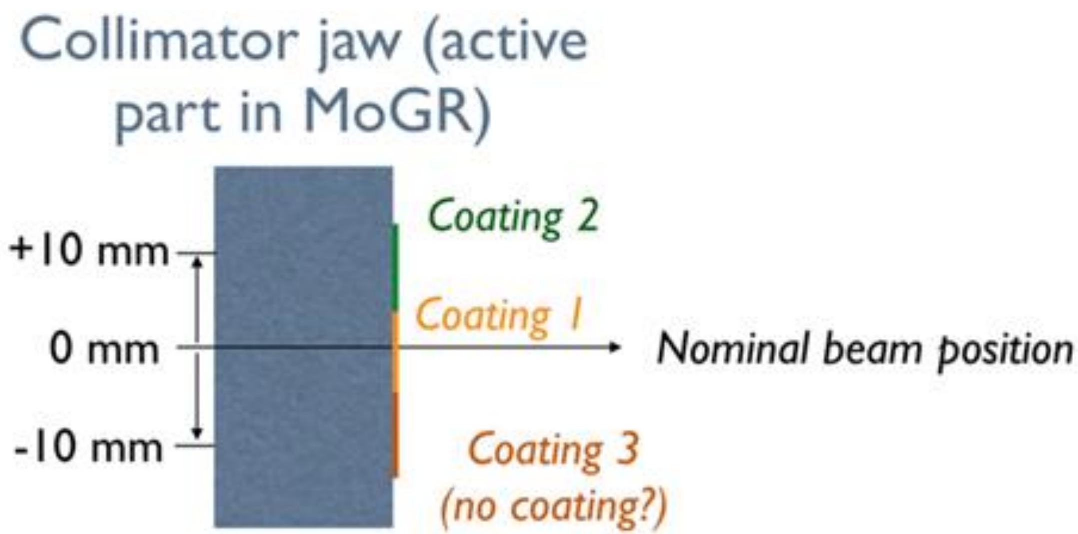
Materials and Coatings

- The transversal mobility of the jaws by +/- 10mm, available to offer a fresh surface to the beam in case of damage, could be used test several coatings (or no coating) in the same jaw.
- This solution should be implemented in the full-scale prototype to be produced in 2016, if on-going EM simulations (BE-ABP) confirm its test effectiveness (cross-talk between different coatings to be avoided)



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Thank you for your attention!

The research leading to these results has received funding from the European Commission under the FP7 Research Infrastructures project EuCARD, Grant Agreement 227579, EuCARD-2 Grant Agreement 312453 and HiLumi Grant Agreement …

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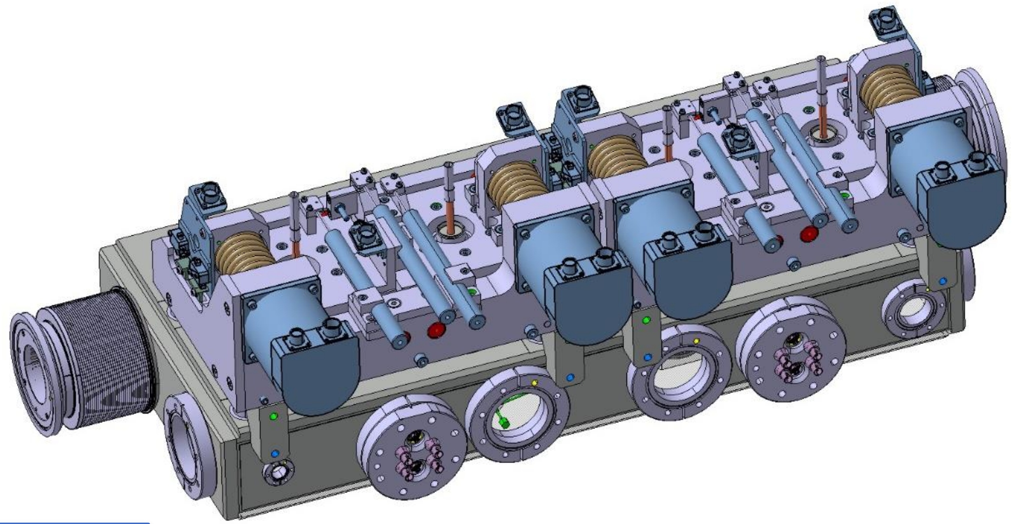
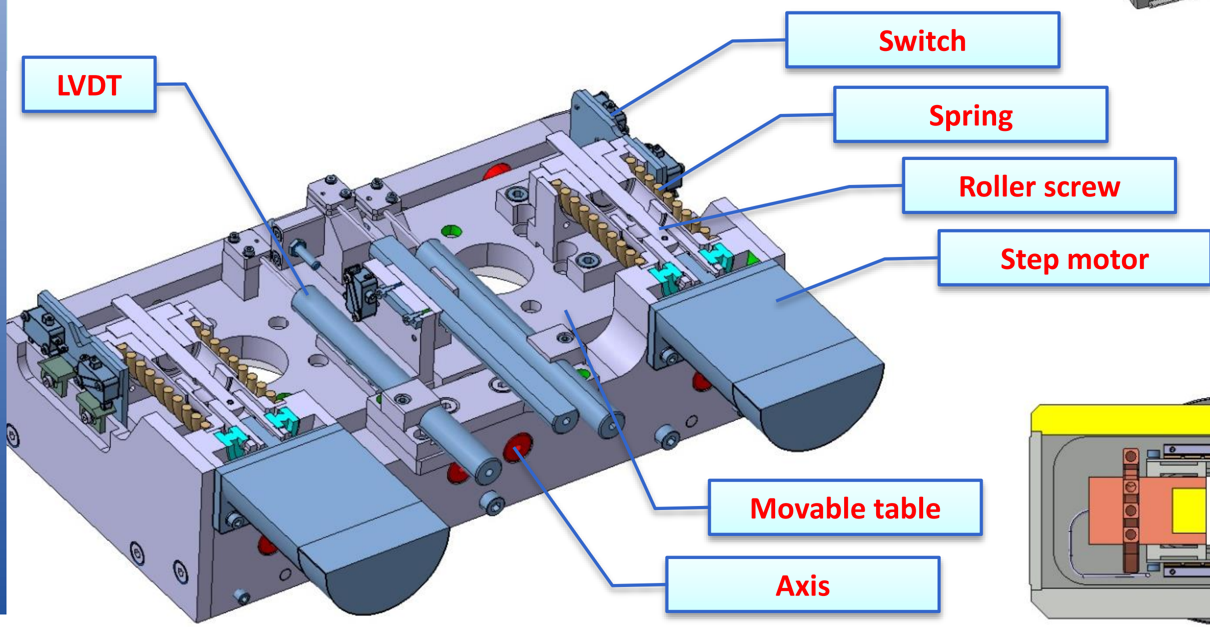
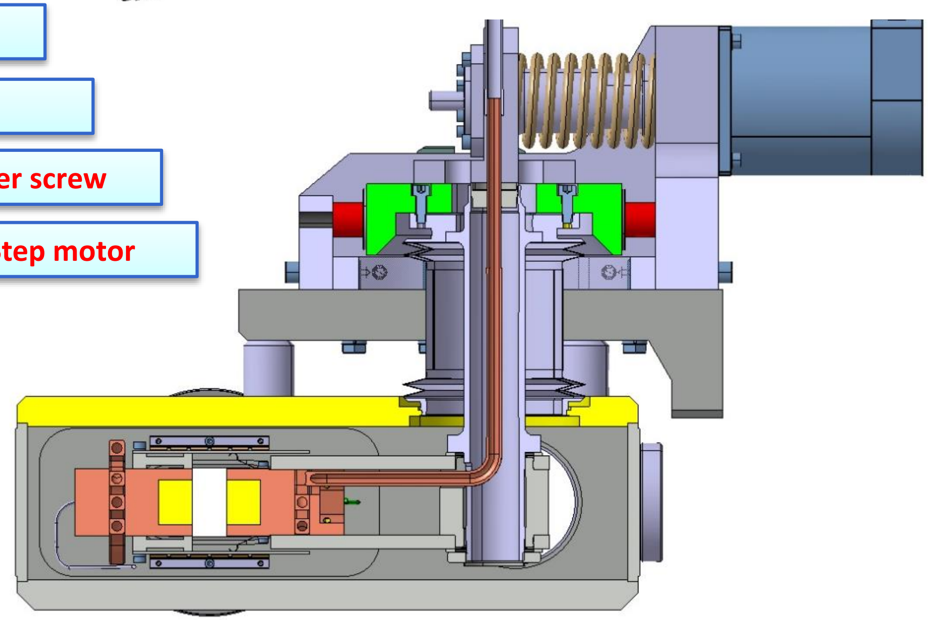
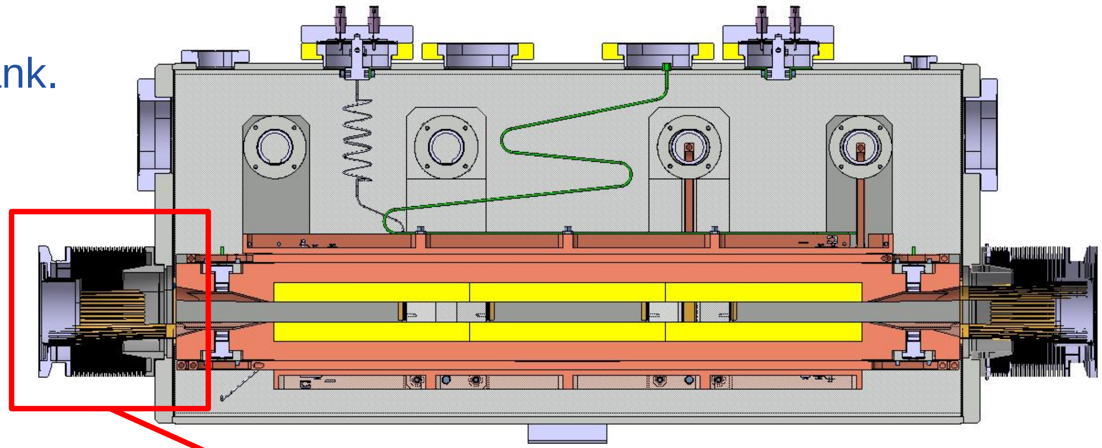
- Movement
- Two step motors each jaw (Jaw tilting)
- Stroke: -5 – 25 mm
- Spring-back: in case of electrical short-cut the jaws must not go in beam direction
- Instrumentation
- 3x LVDT each jaw: 2x absolute movement, 1x relative movement (anti-collision)
- 3x switch assemblies each jaw : 2x absolute movement, 1x relative movement (anti-collision)



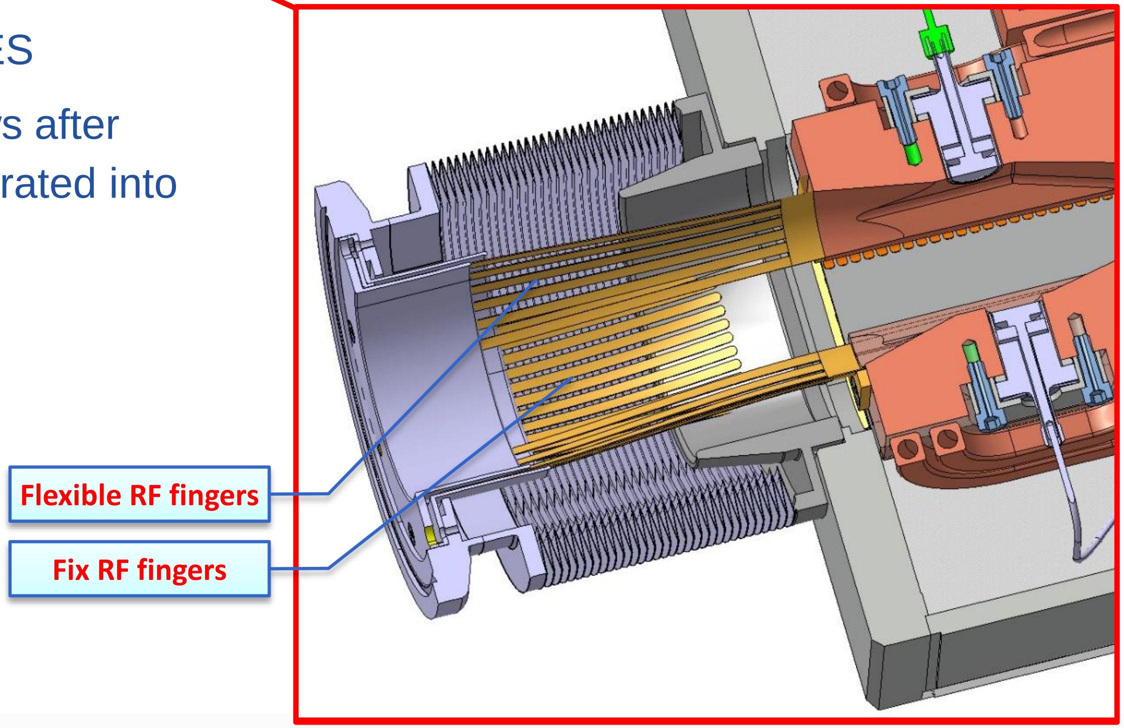




- General
- Manufacturing process based on Ph.II tank. Electron Beam welded Stainless Steel.
- No cooling system



- NEW DESIGN OF THE EXTREMITIES
- To gain longitudinal space, the bellows after and before the collimator will be integrated into the tank transitions.
- Longitudinal stroke: +5; -15 mm
- Radial stroke: ±10 mm



- Vacuum components
- 2x D-500-5 NEXTorr Pumps
  (NEG Ion pump)
- 1x VVFMF DN 40 valve for mobile pumping
- 2x VGPB DN35 Penning pressure gauges
- 1x VGRB DN16 Pirani pressure gauge