LS3 Collimators: Design and Technical Choices

F. Carra on behalf of WP5.2, with additional inputs from many other WPs and colleagues

Special thanks to C. Accettura, L. Gentini, F.-X. Nuiry for material

12th HL-LHC Collaboration Meeting
Uppsala, Sweden
20 September 2022

Outline

- LS3 collimators production
- General design considerations
- Design of housing-to-cooling interface
- Main technical choices for each collimator family
- Collimators optimization studies
- Summary of main calculations
- Conclusions

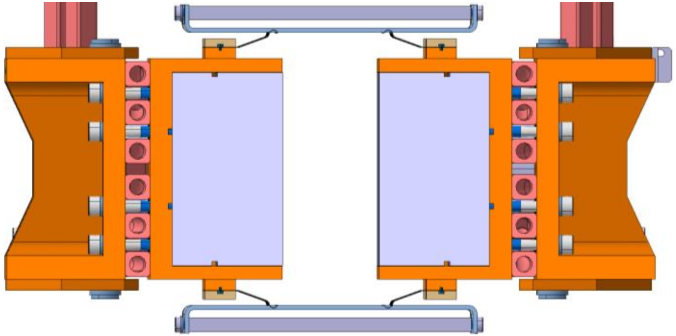
Production of LS3 collimators

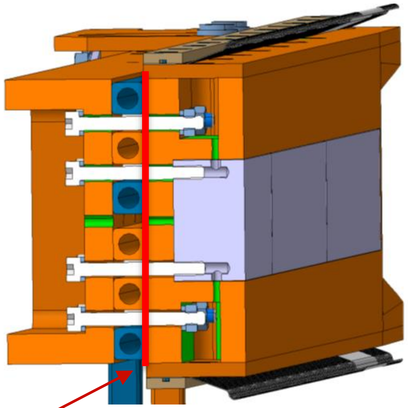
- LS3 collimator production summarized in EDMS document: LHC-TC-ER-0006 v.1

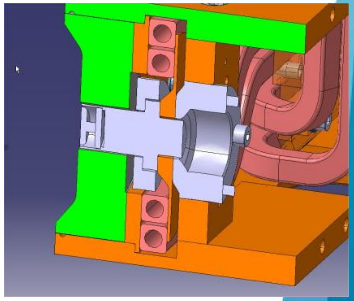
Collimator Description	Names	LS2 installation				LS3 installation				Design
		Operational	Total Series Production	Spares	CERN Protos	Operational	Total series Production	Spares	CERN Protos	
Tertiary collimators	TCTPXH	-	-	-	-	4	4*	1	1	LHCTCTPXH_0001
	TCTPXV	-	-	-	-	4	5	1	-	LHCTCTPXV_0001
	TCTPM	-	-	-	-	4	5	1	-	TCSPM Design
	(TCTP)	-	-	-	-	4 (re-used)	-	-	-	LHCTCTP_0001
Physics debris collimators	TCLP	-	-	-	-	4	5	1	-	TCSPM design
	TCLPX	-	-	-	-	4	5	2	1	LHCTCLPX__0001
	(TCTP)	-	-	-	-	4 (re-used)	-	-	-	LHCTCTP_0001
Physics debris collimator Masks	TCLM	-	-	-	-	4 TCLM4 8 TCLM5/6	15	3	-	LHCTCLM_0001 and LHCTCLM_0002
DS collimators	TCLD	2 (point 2)	5	2	1	2 (point 7)?	-	-	-	LHCTCLDA0001
Low-Impedance secondary collimators	TCSPM	8	10	2	1	10 (point7)	12	2	-	LHCTCSPM0160

General design considerations

- Collimators to be installed during LS3 are **newly designed**. Even TCSPM, TCTPM, TCLP, which are based on the LS2 design, are made of **updated materials**.
- All LS3 collimators:
  - Feature **RF fingers and no ferrite**
  - Host **in-jaw BPMs** for fast alignment
  - Require **EB welding** and **vacuum brazing** technologies.
- However, in most of them, the **critical housing / cooling circuit brazing interface is replaced by a bolted interface**
- Brazing still needed in every collimator to achieve **vacuum tightness between cooling pipes and tank**







Housing / cooling circuit interface

Design of housing-to-cooling interface

From: EDMS 2595082

What about these 5 collimator families? **Can we replace brazed jaws with bolted ones?**

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	TCTPXV	-	-	-	-	4	5	1	-	LHCTCTPXV_0001
	TCTPM	-	-	-	-	4	5	1	-	TCSPM Design
	(TCTP)	-	-	-	-	4 (re-used)	-	-	-	LHCTCTP_0001
Physics debris collimators	TCLP	-	-	-	-	4	5	1	-	TCSPM design
	TCLPX	-	-	-	-	4	5	2	1	LHCTCLPX__0001
	(TCTP)	-	-	-	-	4 (re-used)		-	-	LHCTCTP_0001
Physics debris collimator Masks	TCLM	-	-	-	-	4 TCLM4 8 TCLM5/6	~~15~~	3	-	LHCTCLM_0001 and LHCTCLM_0002
DS collimators	TCLD	2 (point 2)	5	2	1	2 (point 7)?	-	-	-	LHCTCLDA0001
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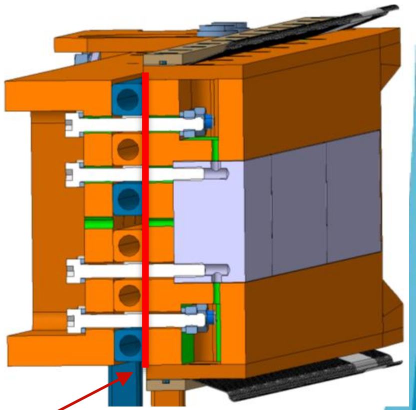

Housing / cooling circuit interface

Jaw brazing needed: most loaded jaws ~ 10 kW, **brazed jaws T~120°C and δ~50μm** for 1h BLT (see *F. Carra, "TCSPM Compatibility with HL-LHC Slow Loss Scenarios for CFC and MoGr jaws", 2nd Special Colusm on Material and Design Readiness for LS2 productions*)

Steady-state power loads breakdown

Collimator Description	Names	Power loads contributors on most loaded jaw [W]				Total power loss on most loaded jaw (steady-state) [W]
		p-p collision debris [1]	Beam halo (1h BLT) [2]	Beam-gas [3]	Resistive impedance [4]	
Tertiary collimators	TCTPXH*	25	< 1	<< 1	6	~ 30
	TCTPXV	16	< 1	<< 1	5	~ 20
	TCTPM*	< 1	< 1	<< 1	17	~ 20
Physics debris collimators	TCLP5	130	~ 0	~ 0	9	~ 140
	TCLP6	55	~ 0	~ 0	21	~ 75
	TCLPX	230	~ 0	~ 0	4	~ 235

References:

1. M. Sabaté-Gilarte, *"HL-LHC beam-halo background at CMS"*, LBS#114.
2. R. Bruce et al., *"Functional specification for TCL* Collimators", EDMS* 2276600, *Table 5.*
3. M. Sabaté-Gilarte, *"HL-LHC background simulations with FLUKA"*, LBS#112.
4. N. Mounet, *"RF power on tertiary collimators"*, *8th August WP5.2 Technical Meeting. – note that loads presented there are for collimator, they have been divided by 2 here.*

*** Values given for IT180,**

When do we need to braze a jaw?

Examples of jaw solutions

Joining Solution	Jaw type	1h BLT losses on most loaded jaw [W]	Maximum peak temperature [°C]	Maximum beam-induced sagitta [um]
Brazed jaws	HL-LHC TCSPM (MoGr) [1]	9400	127	55
	HL-LHC TCSP (CFC) [1]	2000	43	60
Bolted jaws	TCTP [2]	420	40	50
	TCLPX [3]	230	34	15

Also subjected to power losses increased by 5 times during accidental 0.2h BLT scenario

Loads not changing from 1h to 0.2h BLT

Collimator Description	Names	Total power loss on most loaded jaw (steady-state) [W]
Tertiary collimators	TCTPXH*	~ 30
	TCTPXV	~ 20
	TCTPM*	~ 20
Physics debris collimators	TCLP5	~ 140
	TCLP6	~ 75
	TCLPX	~ 235

References:

1. F. Carra, *"TCSPM Compatibility with HL-LHC Slow Loss Scenarios for CFC and MoGr jaws"*, *2nd Special Colusm on Material and Design Readiness for LS2 productions*)
2. F. Carra, *"Summary of calculations performed on TCTP collimators"*, *EDMS n. 1212639*.
3. R. Key Sanchez, *"TCLPX collimator jaw: Thermomechanical response under collision debris load"*, *EDMS n. 2318440*.

When do we need to braze a jaw?

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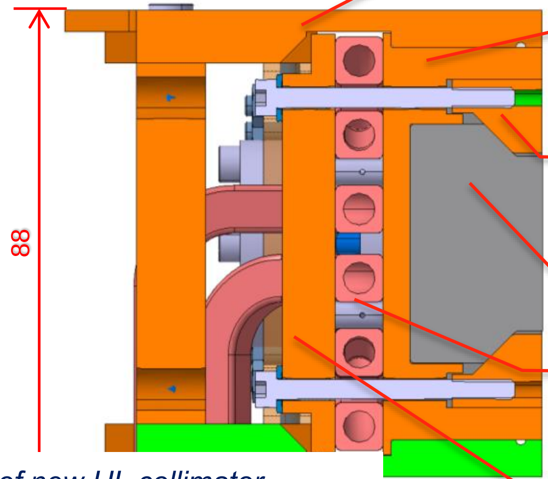
	TCLP6	~ 75
	TCLPX	~ 235

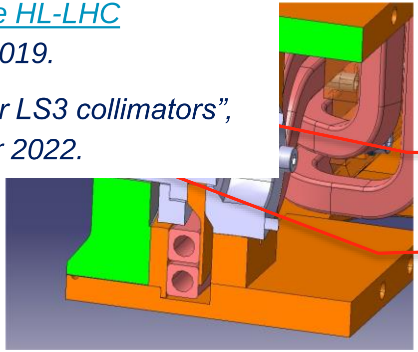
- The acceptability of a bolted solution depends on the jaw design and material, however, the **upper limit validated so far for a bolted solution is in the order of ~400 W / jaw** steady state.
- **Bolted TCLPX** (230 W total jaw load) already verified by ad-hoc ANSYS calculation
- **TCTPXH, TCTPXV, TCTPM** have total losses lower than 40 W → we can consider the bolted solution validated without need of additional ANSYS calculations
- **TCLP** also seems on the safe side for a bolted jaw (~130 W), **however, a dedicated ANSYS calculation, if a FLUKA energy density map is available, could be useful to re-assure us on the validity of the bolted solution**

Main technical choices: TCSPM

- **Brazed jaw**
- **Metallic jaw is in Glidcop**, CuCrZr cannot be used because of brazing
- **Cu-coated graphite absorbers, graphite taperings** (better RF impedance alternative for taperings are MoGr and Cu-coated graphite, under evaluation)
- Absorber 33x25 mm^2
- Stroke -5/+30 mm
- In-tank BPM: Yes
- FRAS: No



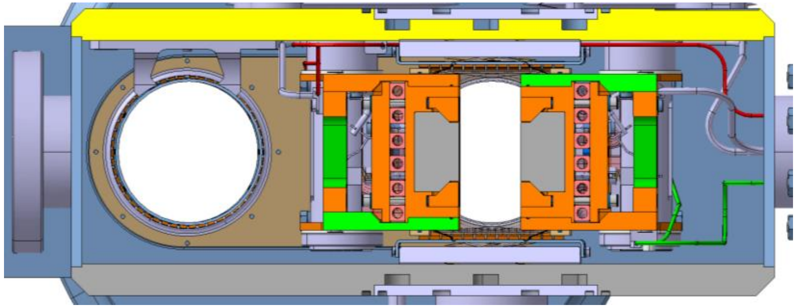
- *A. Bertarelli, " Performance of new HL collimator designs", International Review of the HL-LHC Collimation System, 12th February 2019.*
- *F.-X. Nuiry, "Jaw materials option for LS3 collimators", 162nd HL-LHC TCC, 14th September 2022.*

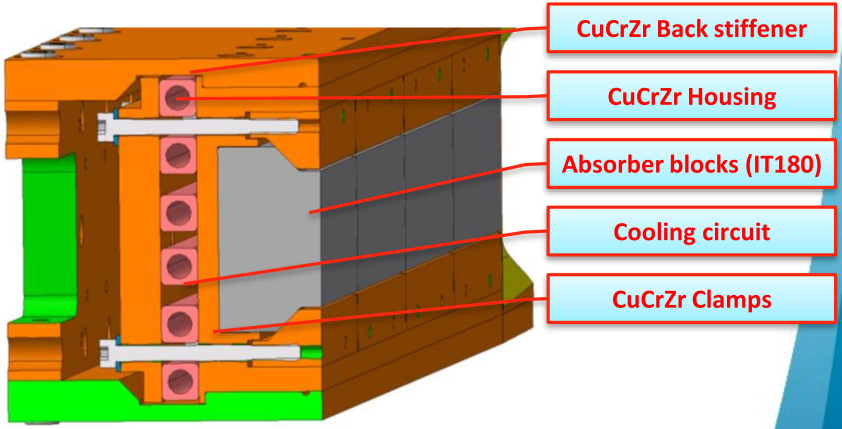


- *Nota bene:* graphitic TCSPM collimator has never been calculated in operational conditions (1h and 0.2h BLT) → **waiting for SixTrack + Fluka calculations**

Main technical choices: TCTPXH

- **2-in-1**
- **Bolted jaw**
- **Metallic jaw is in CuCrZr**
- **Inermet180 absorbers, CuCrZr taperings**
- Absorber 33x25 mm^2
- Stroke -5/+35 mm
- In-tank BPM: No
- FRAS: Yes
- 2nd beam chamber: NEG coated

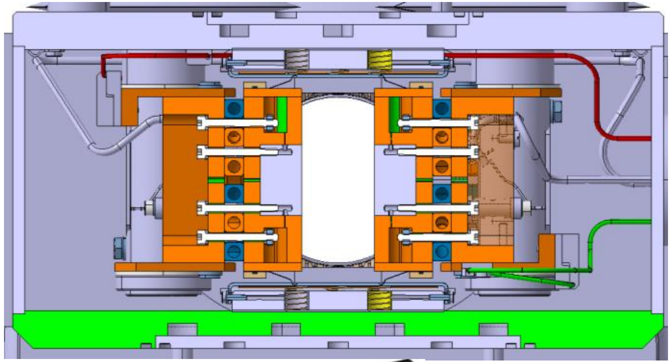


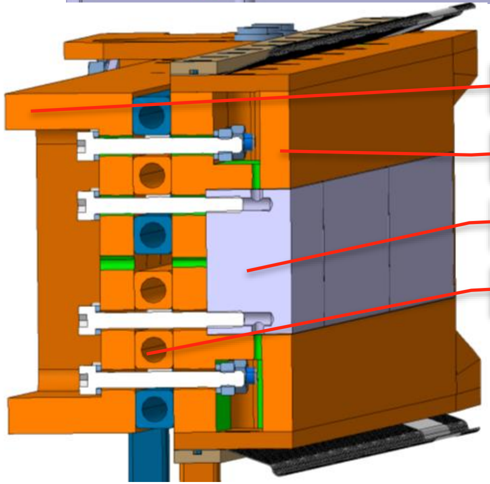


- *L. Gentini, "Status of new IR collimator design", IR Collimators Review, 4th March 2020.*
- *F.-X. Nuiry, "Jaw materials option for LS3 collimators", 162nd HL-LHC TCC, 14th September 2022.*

Main technical choices: TCTPXV

- Design similar to TCTP, except for **RF fingers vs ferrite**
- **Bolted jaw**
- **Metallic jaw is in CuCrZr**
- **Inermet180 absorbers, CuCrZr taperings**
- Absorber 34x20 mm^2
- Stroke -5/+42 mm
- In-tank BPM: No
- FRAS: Yes

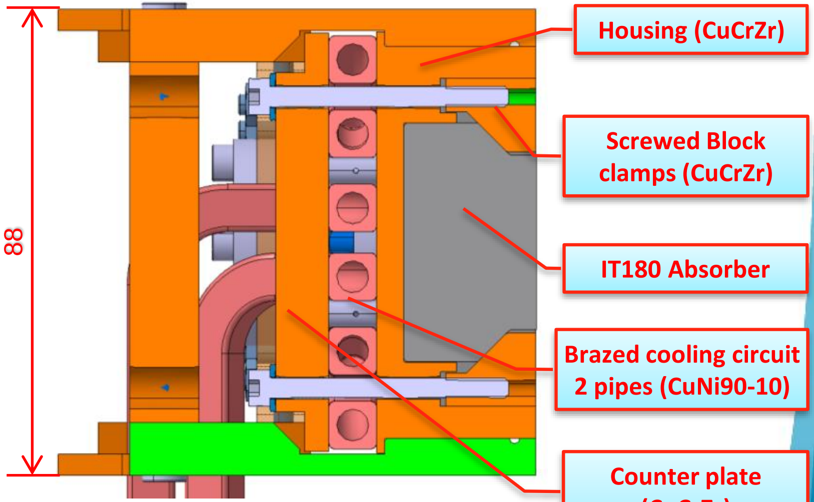


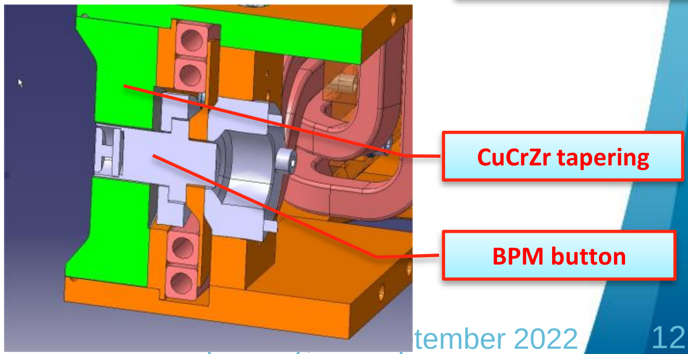


- *L. Gentini, "Status of new IR collimator design", IR Collimators Review, 4th March 2020.*
- *F.-X. Nuiry, "Jaw materials option for LS3 collimators", 162nd HL-LHC TCC, 14th September 2022.*

Main technical choices: TCTPM and TCLP

- **Bolted jaw**
- **Metallic jaw is in CuCrZr**
- **Inermet180 absorbers, CuCrZr taperings**
- Absorber 33x25 mm^2
- Stroke -5/+30
- In-tank BPM: Yes
- FRAS: No

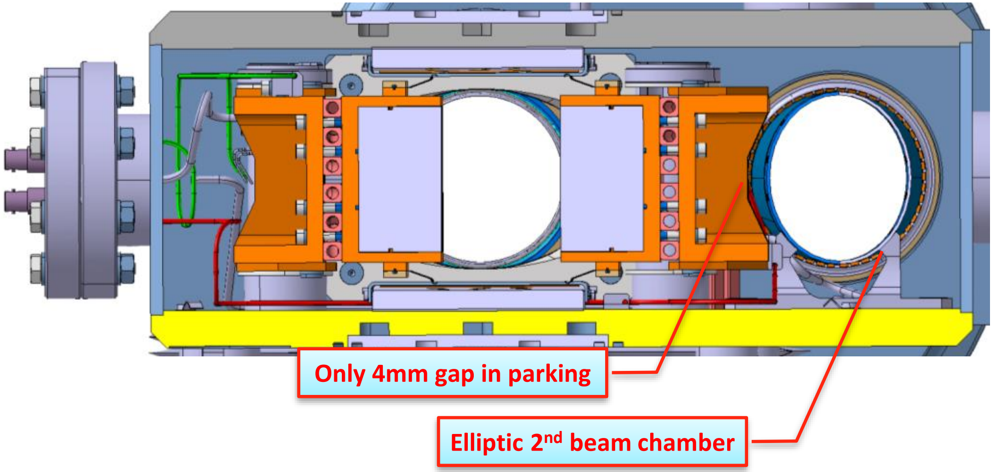


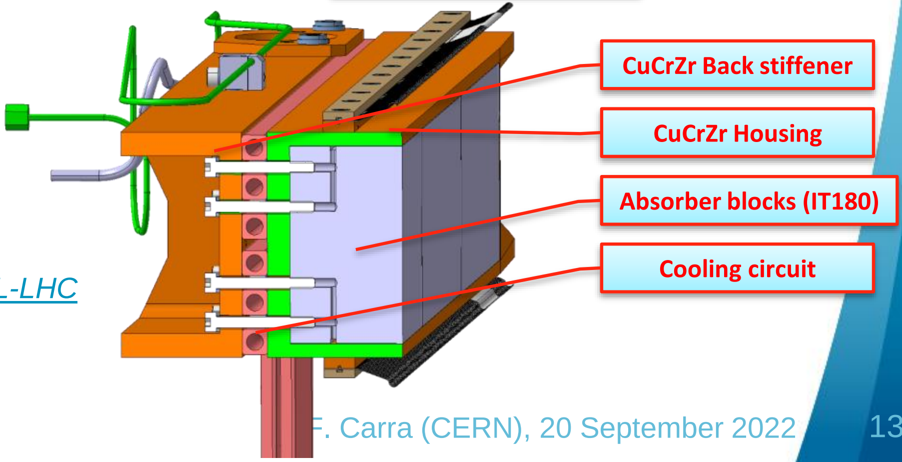


- *F.-X. Nuiry, “Jaw materials option for LS3 collimators”, [162nd HL-LHC TCC], 14th September 2022.*

Main technical choices: TCLPX

- **2-in-1**
- **Bolted jaw**
- **Metallic jaw is in CuCrZr**
- **Inermet180 absorbers, CuCrZr taperings**
- Absorber 70x40 mm^2
- Stroke -5/+40 mm
- In-tank BPM: No
- FRAS: Yes

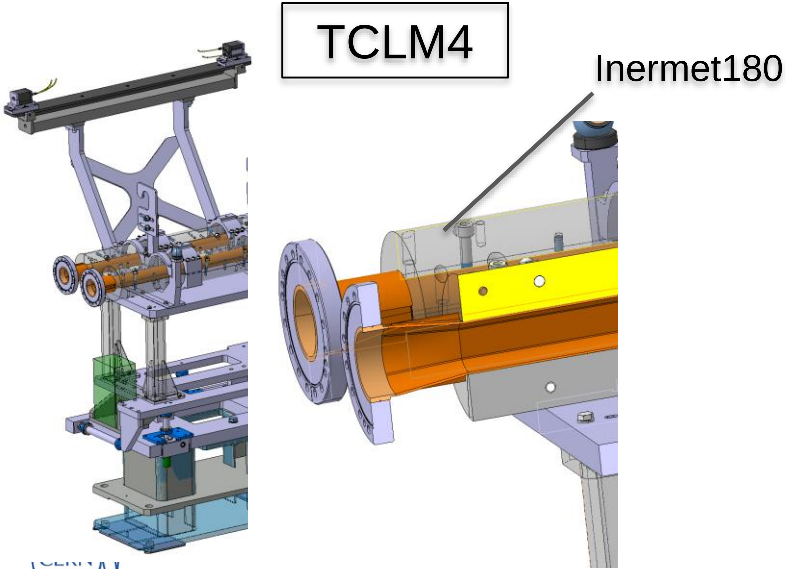


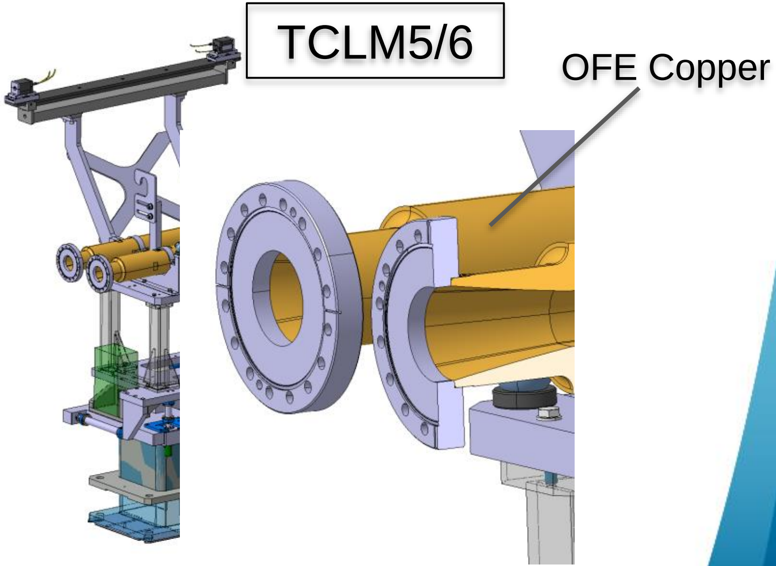


- *L. Gentini, "Status of new IR collimator design", IR Collimators Review, 4th March 2020.*
- *F.-X. Nuiry, "Jaw materials option for LS3 collimators", 162nd HL-LHC TCC, 14th September 2022.*

Main technical choices: TCLM

- Fixed beam intercepting-device with aperture shape matching the beam screen of the downstream dipole, needed in front of the MS magnets Q4, Q5 and Q6
- 15 TCLMs
  - 5x TCLM4 → W shield
  - 10x TCLM5/6 → Cu shield

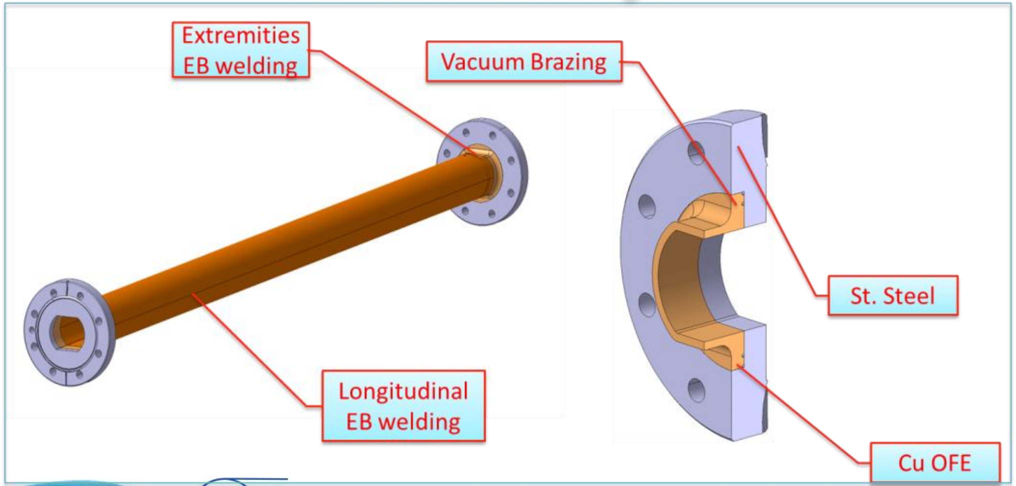




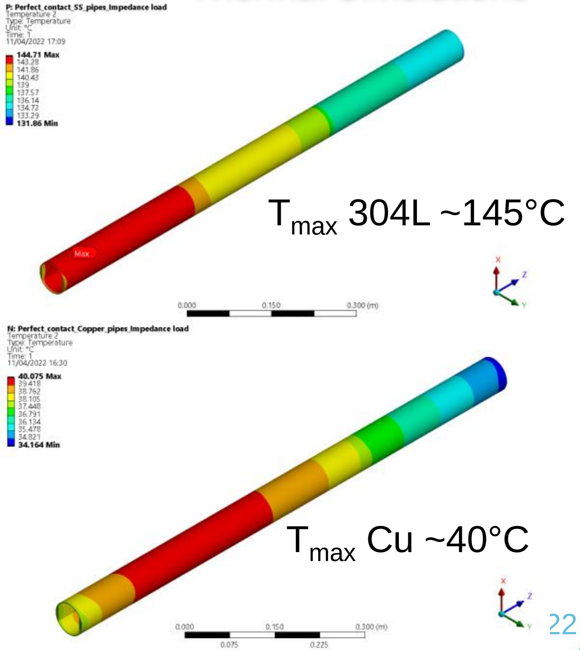
Main technical choices: TCLM

- **Diverse fabrication technologies** involved and **tight tolerances** to ensure the magnet protection → ongoing studies with WP2 and WP10 to optimize the design and reduce costs
- **Stainless steel chamber evaluated**, would have allowed to eliminate the brazing process → thermal simulation showed that is not compatible, because of significant increase of outgassing due to the high generated temperatures (T_{max} ~150°C)

Fabrication technologies

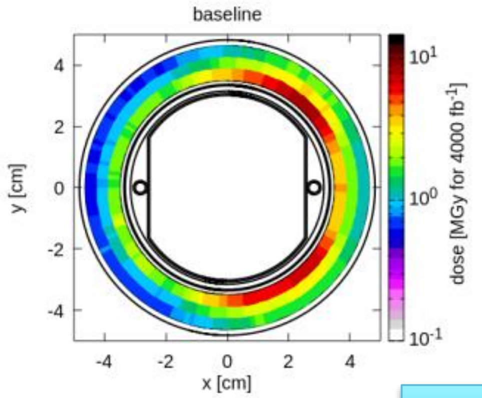


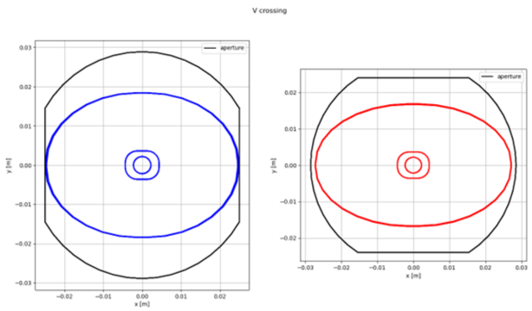
Thermal Simulations



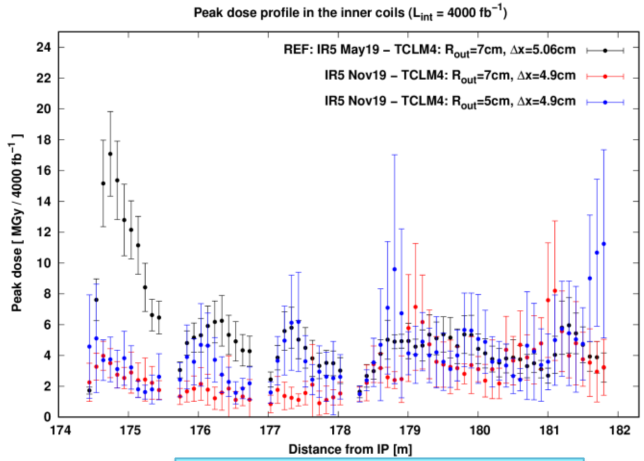
Main technical choices: TCLM

- **FLUKA studies allowed material saving up to 80% of total cost for IT180 for TCLM4**
  - Incoming beam absorber can be replaced by Cu
  - External radius of mask can be safely reduced from 7 to 5 cm
- WP2 & WP10 studies led to a better understanding the **criticalities in terms of beam aperture and magnet protection**, which will allow reviewing the chamber dimensions and better define (possibly relax) the machining tolerances.





Courtesy of M. Sabate and R. De Maria



Courtesy of M. Sabate

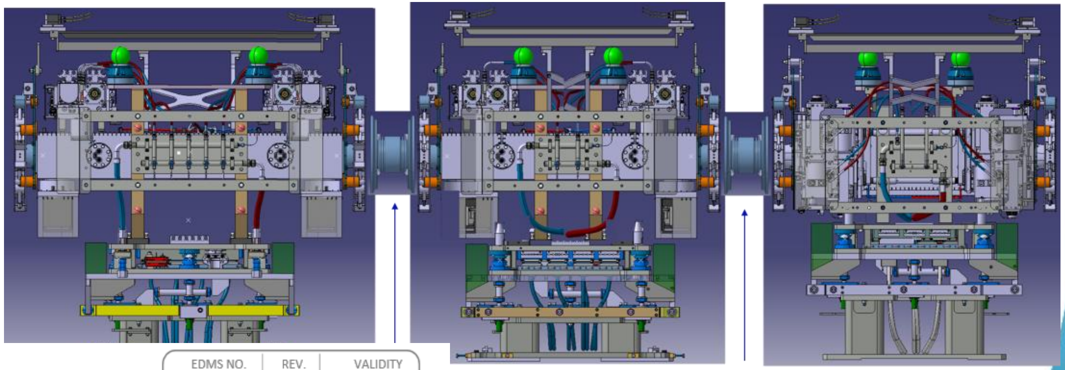
Collimator’s Design optimization studies

- Space between X series collimators is small
- Hydro-formed bellows welded to the vacuum vessel. In case of leak:
  - ~3 weeks of machine down time
  - Collimator cannot be re-used
- Study on collimator’s shortening & Review on HL-LHC collimation system
- Less jaw deflection / better impedance / simpler manufacturing / lower thermal loads…

Cost ~400 kCHF
Delay ~ 6 months

Not implemented

- Try implementing switches
- Bellow attachement modifications



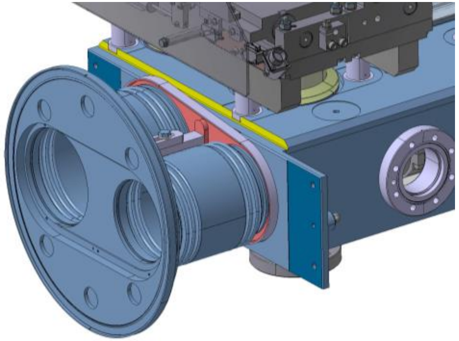
EDMS NO.	REV.	VALIDITY
2709514	1	RELEASED

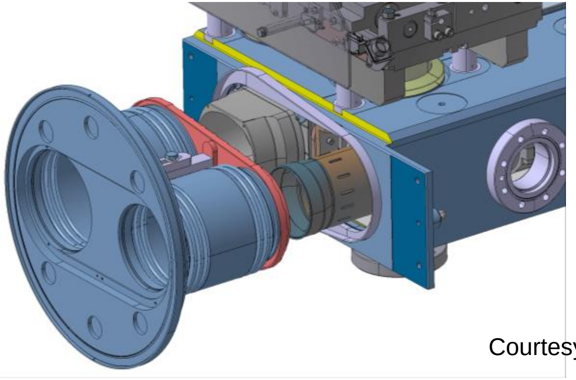
REFERENCE : NOT REQUIRED

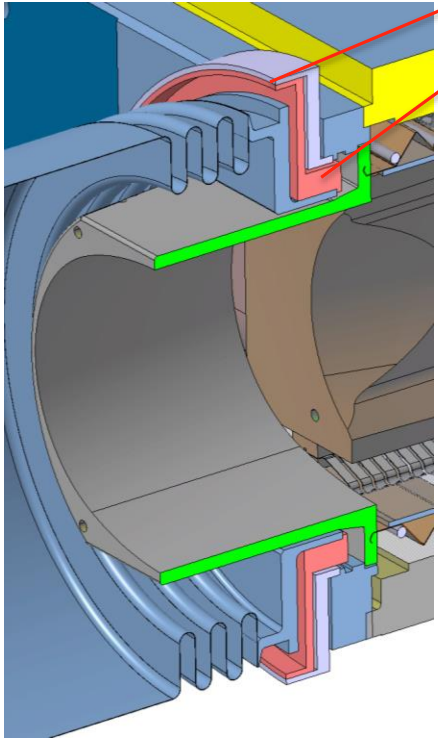
HL-LHC WP5

Discussion about optimisation of jaw lengths for IR collimators
Meeting Minutes

Collimator's Design optimization studies: Re-usable collimator







Courtesy: L. Gentini

- In case of bellow's leak:
→ Possibility to repair the collimator (Depending on activation)

- Solution for the prototype (because production was launched)

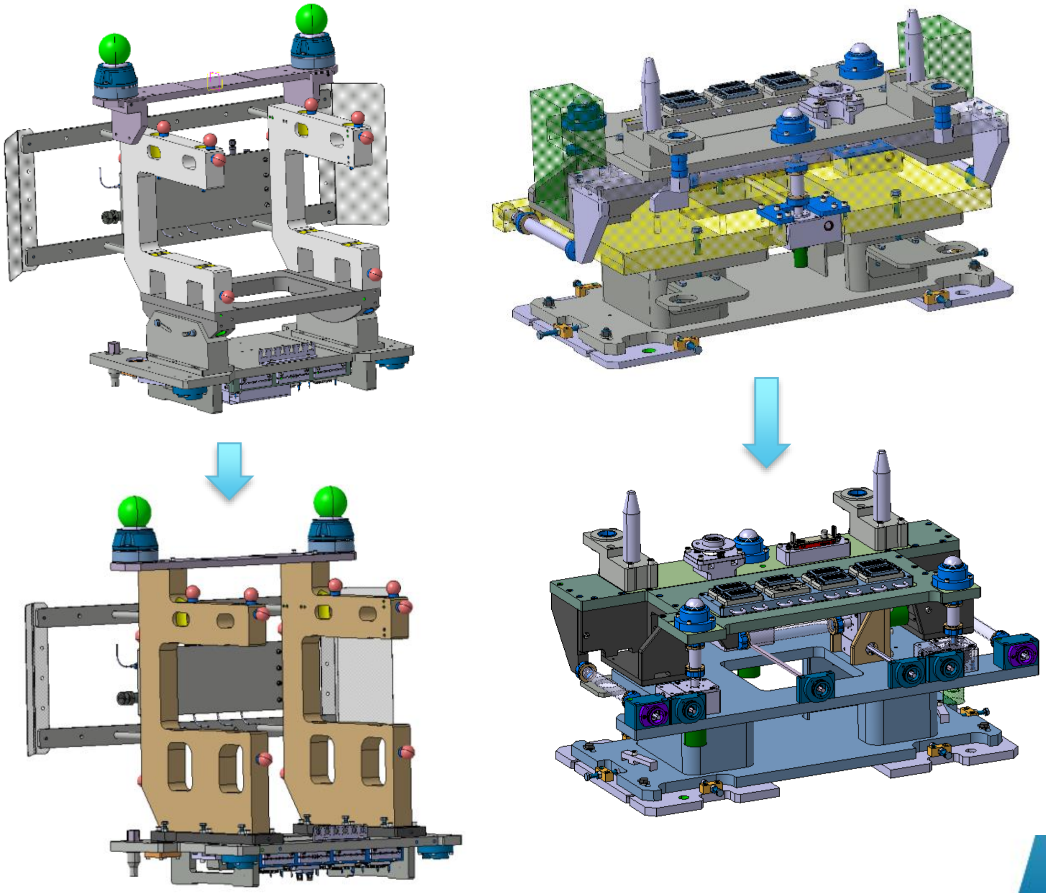
- Optimized solution (less welds) to be implemented for the series

Collimator's Design optimization studies: Support and adjustment platform

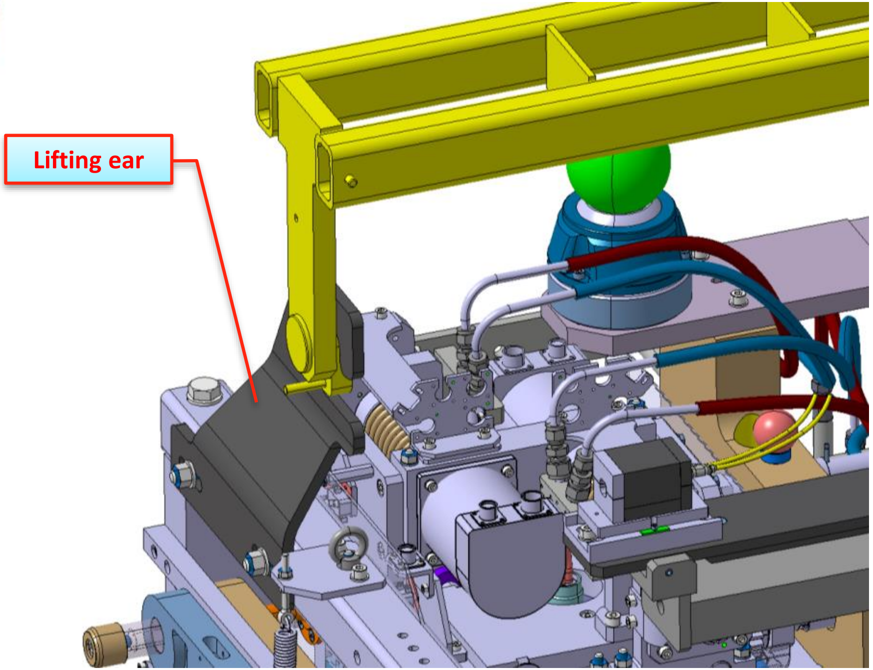
WP5.2 collaboration with WP15.4

Technical simplification and costs reduction:

- Longitudinal axis addition
- Rotation removal
- Improvement of the rigidity (alignment of components)



Collimator's Design optimization studies: Lifting hooks updates



Courtesy: L. Gentini

- Dedicated lifting hooks
- Re-use of existing spreader beams
- Structural validation completed *(I. Tabian, Finite Element Analysis of the updated lifting support for the TCLPX Collimator, EDMS n. 2721306)*

Summary of LS3 collimators main calculations

RF FINGERS

- A. Lafuente, “Engineering evaluation of TCSPM RF contact fingers”, EDMS 1721985.
- R. Key, “Engineering evaluation of the RF Extremity fingers for TCLPX/TCTPXH/TCTPXV collimators”, EDMS 2356208.
- R. Key, “Engineering evaluation of the RF Longitudinal fingers for TCLPX/TCTPXH/TCTPXV collimators”, EDMS 2356210.

JAWS

- F. Carra, “Slow losses on TCSPM collimator”, EDMS 1862278.
- F. Carra, “Response of TCSPM when used as crystal absorber”, EDMS 2596402.
- F. Carra, “TCSPM scraping scenario & BLM thresholds”, EDMS 2596407.
- C. Fichera, “Numerical simulation of the brazing process on LHC collimator jaws”, EDMS 1889123.
- F. Corrales, “Study and optimization of thermally-induced deformation of HL-LHC Secondary Collimators”, EDMS 2012377.
- R. Key, “TCLPX collimator jaw: Thermomechanical response under collision debris load”, EDMS 2318440.

BPMs

- M. Pasquali, “Thermal analysis of the BPMs embarked in HL-LHC collimators”, EDMS 1886273.
- M. Pasquali, “Experimental and numerical studies of the BPMs embarked in the HL-LHC collimators”, EDMS 1886533.
- L. Bianchi, “BPM cables for TCLPX, TCTPXV and TCTPXH: Finite Element Analysis”, EDMS 2215957 .

Summary of LS3 collimators main calculations

BERCEAUX & SUPPORTS

- R. Key, "Calculation of the TCLPX cradle", EDMS 2430481.
- C. Accettura, "Structural verification of modified support leg of TCLPX/TCTPXH collimators", EDMS 2752559.
- C. Accettura, "Structural validation of the new verticalized UAP support for X series collimators", EDMS 2778123.

TANK

- A. Jaradat, "Upper plate deformation of the TCLPX", EDMS 2218125.
- M. Holko, "Finite Element Analysis of the TCLPX Collimator Transport and Handling", EDMS 2518285.
- I. Tabian, "Finite Element Analysis of the updated lifting support for the TCLPX Collimator ", EDMS 2721306.
- C. Accettura, "Thermal analysis of TCLPX and TCTPXH vacuum tank with a downscaled cooling circuit", EDMS 2616208.

MECHANICAL TABLE

- A. Jaradat, "Structural analysis of moving shafts for the TCLPX collimator", EDMS 2215957.

MASKS

- C. Accettura, "Thermal simulation of TCLMs", WP 5.2 Technical Meeting, 13th April 2022.

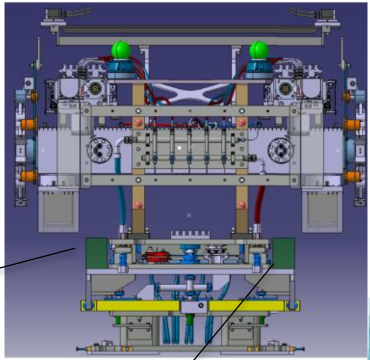
Conclusions

- **36 collimators and 15 masks** must be produced during the LS3, in addition to **2 prototypes** currently under building in-house.
- On top of the significant quantity, one main challenge is given by the **number of different collimator types and designs**.
- Ahead of prototyping, many **in-depth design studies and advanced computations** have been performed to ensure an optimal collimator operation, improving the robustness of particular aspects.
- Design efforts and analyses were also done in order to simplify some technical solution, with the objective of **cost & time savings**.
- Although all aspects appear well defined, a few **outstanding engineering studies** might be very useful for a formal validation of the performance of:
  - **Cu-coated graphite TCSPM** (1h and 0.2h beam lifetime)
  - **Inermet180 TCLP5** (steady state operation under debris thermal loads)

Thanks for your attention!

Backup slides

Collimator's Design Updates: Plug in studies for Ion pumps

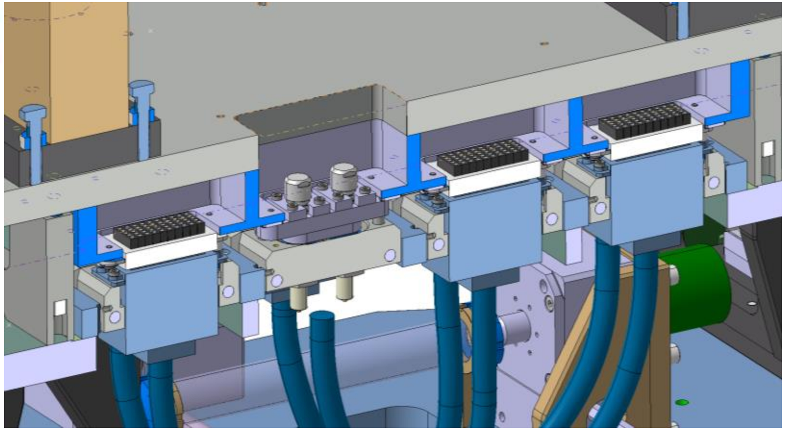


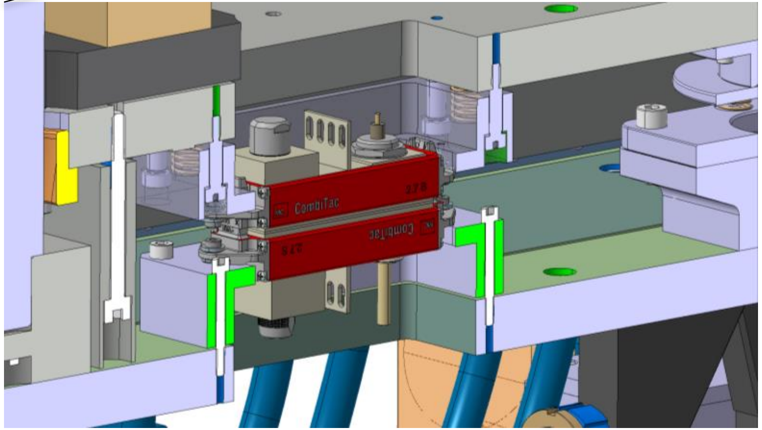
Integration in the Hypertac

- New Hypertac automatic plug-in design done with 8x connector slots.
- One slot is dedicated to the high voltage Fischer connectors with special housings.

Dedicated plug-in connector

Tentative to integrate a standard combitac connector.





Courtesy: L. Gentini

Some cables (copper cables of WPS sensors) cannot be connected through the Hypertac requiring manual intervention from the survey team.

WP5.2 collaboration with WP12