Collimation R&D and developments

Stefano Redaelli, BE-ABP, on behalf of WP5

Acknowledgements: BE/ABP, BE/BI, EN/STI, EN/MME, …

6th HL-LHC Collaboration Meeting
14-16 November 2016
Paris, Espace St. Martin

Introduction — scope of collimation upgrade

- Increased beam stored energy: 362MJ → 700MJ at 7 TeV

  Collimation cleaning *versus quench limits of superconducting magnets.*
  Machine protection constraints from ***beam tail*** *population*
  (7 MJ above 3 sigmas even for perfect Gaussian tails!).

- Larger bunch intensity (Ib=2.2x10^{11}p) in smaller emittance (2.0 µm)

  Collimation impedance *versus beam stability.*
  Collimator robustness *against regular and abnormal beam losses*
  at injection as well as top energy.

- Larger p-p luminosity (1.0 x 10^{34}cm^{-2}s^{-1} → 5.0-7.5 x 10^{34}cm^{-2}s^{-1})

  Need to improve the ***collimation*** *of* ***physics debris****.*

  Overall upgrade of the ***collimation layouts*** *in the insertion regions.*

- Much smaller β^* in the collision points (55 cm → 15 cm)

  Cleaning and protection of high-luminosity insertions and physics background.

- Operational efficiency is a must for HL-LHC!

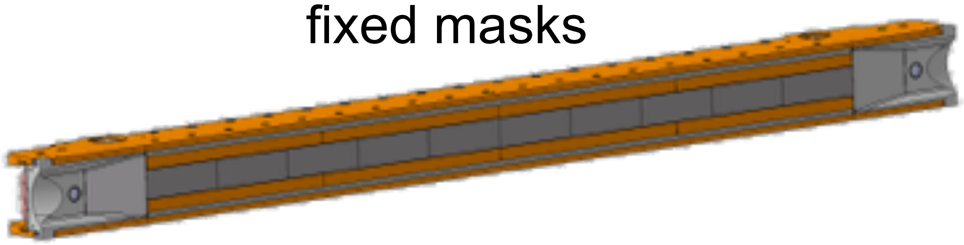
  Reliability of high precision devices in high radiation environment; alignment.

- Upgraded ion performance (6 x 10^{27}cm^{-2}s^{-1}, i.e. 6 x nominal)

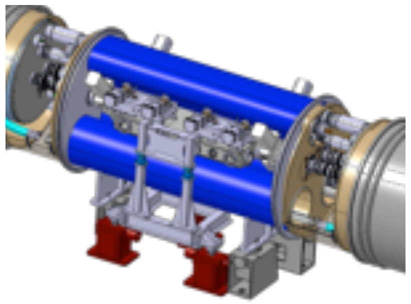
Table of contents

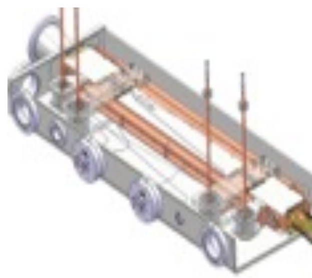
Collimation upgrade baseline

Completely new layouts
Novel materials: TCTs in CuCD
IR1+IR5, <u>per beam</u>:
- 4 tertiary collimators
- 3 physics debris collimators
- fixed masks

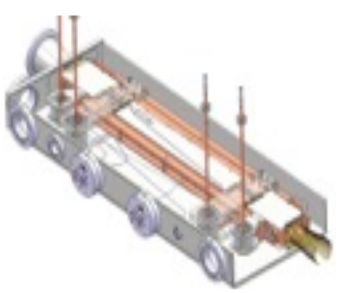


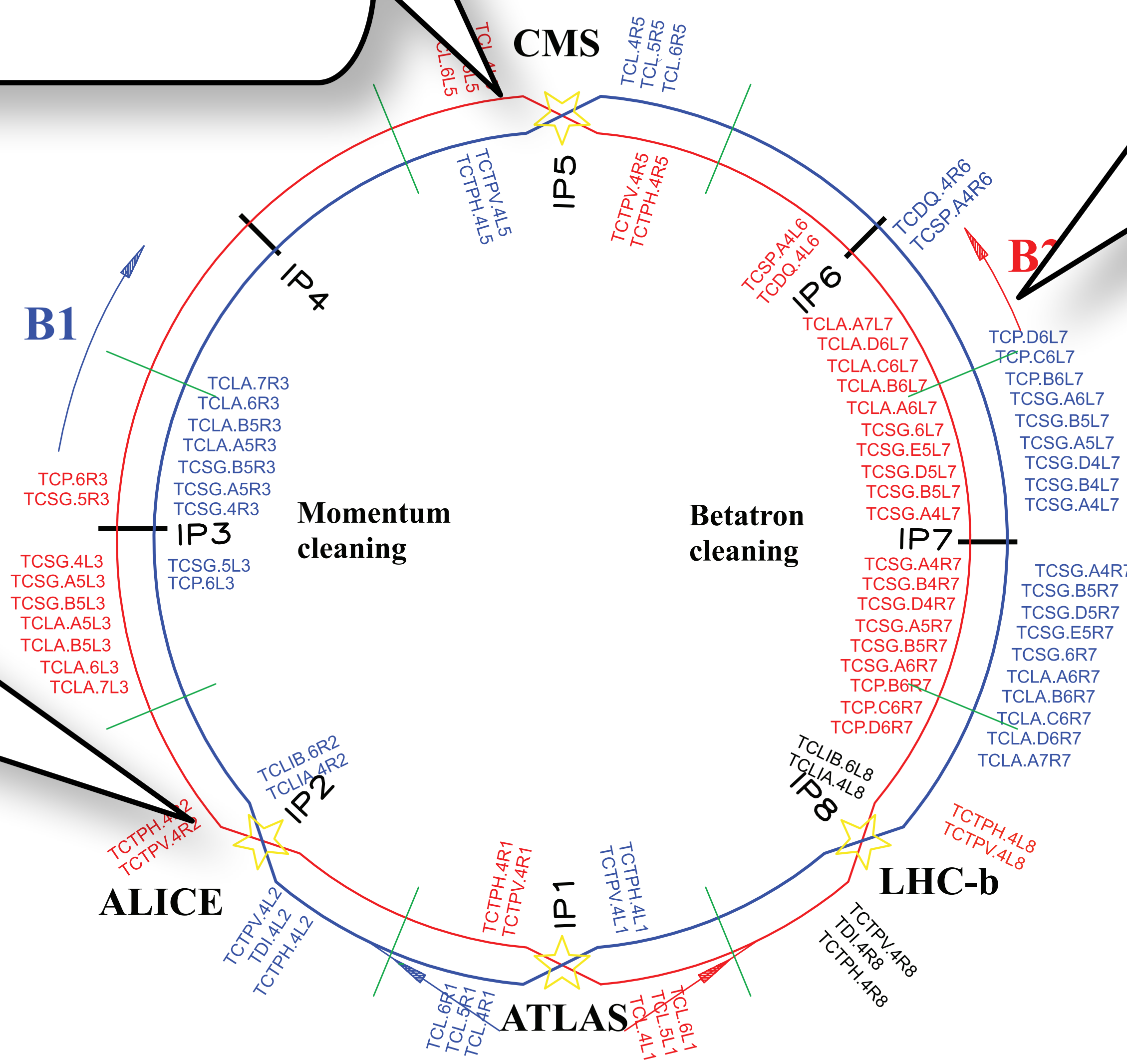
Cleaning: DS coll. + 11T dipoles, 1 unit per beam



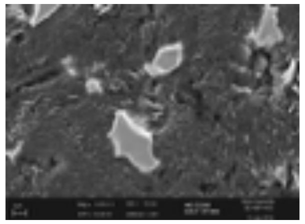


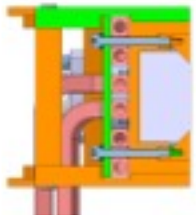
Ion physics debris: DS collimation

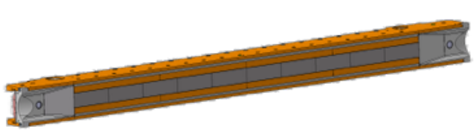




Low-impedance, high robustness secondary collimators: coated MoGr







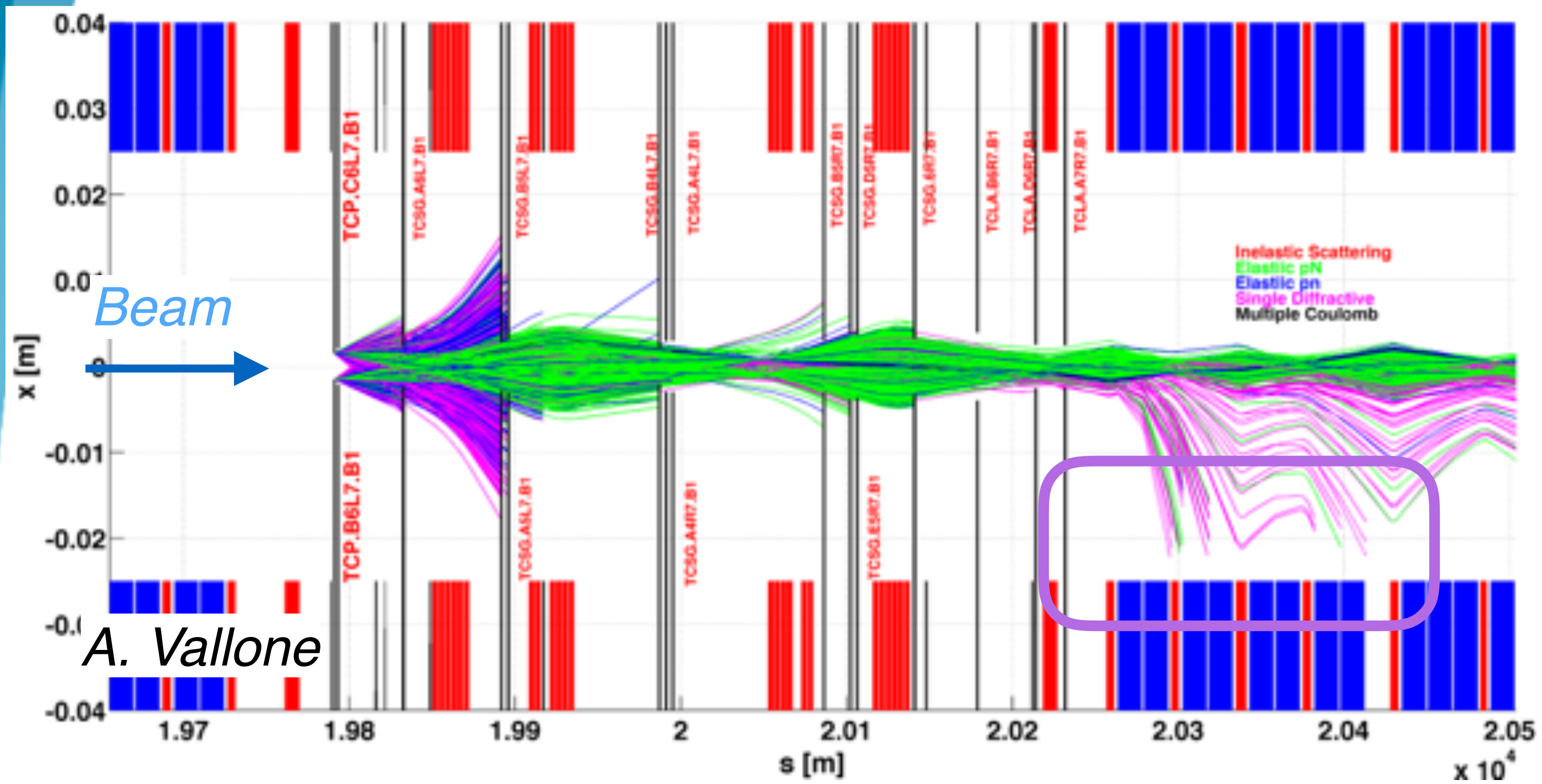
Recent baseline changes

- Recap.: important changes occurred in March 2015:
  - *No dispersion suppressor (DS) collimation in IR1/5 for proton beams.*
  - *Reduced number of units of low-impedance collimators: 30 ↦ 22.*
  - *No upgrade of tertiary collimators in IR2/8.*
- DS collimation **around IR2** <u>without</u> 11T dipole for Run III
  - *Shift location of losses with bumps such that they can be caught by a TCLD collimator in the connection cryostat, without need for dipoles.*
  - *Ion debris cleaning mitigated by local orbit bumps in IR1/5.*
  - *Decision follows successful operation in 2015 that <u>demonstrated</u> bumps.*
- DS collimation **around IR7** <u>with</u> 11T dipole: reduced to 2 units.
  - *To be installed in LS2, when first 11T dipoles will be available (4 dipoles).*
- Re-scoped production plans for tertiary collimators and physics debris collimators in IR1/5, no change of layouts
  - *Studying how to recuperate 8 collimators from the pool of existing devices*

Focus here on motivation for changes of DS collimation plans.

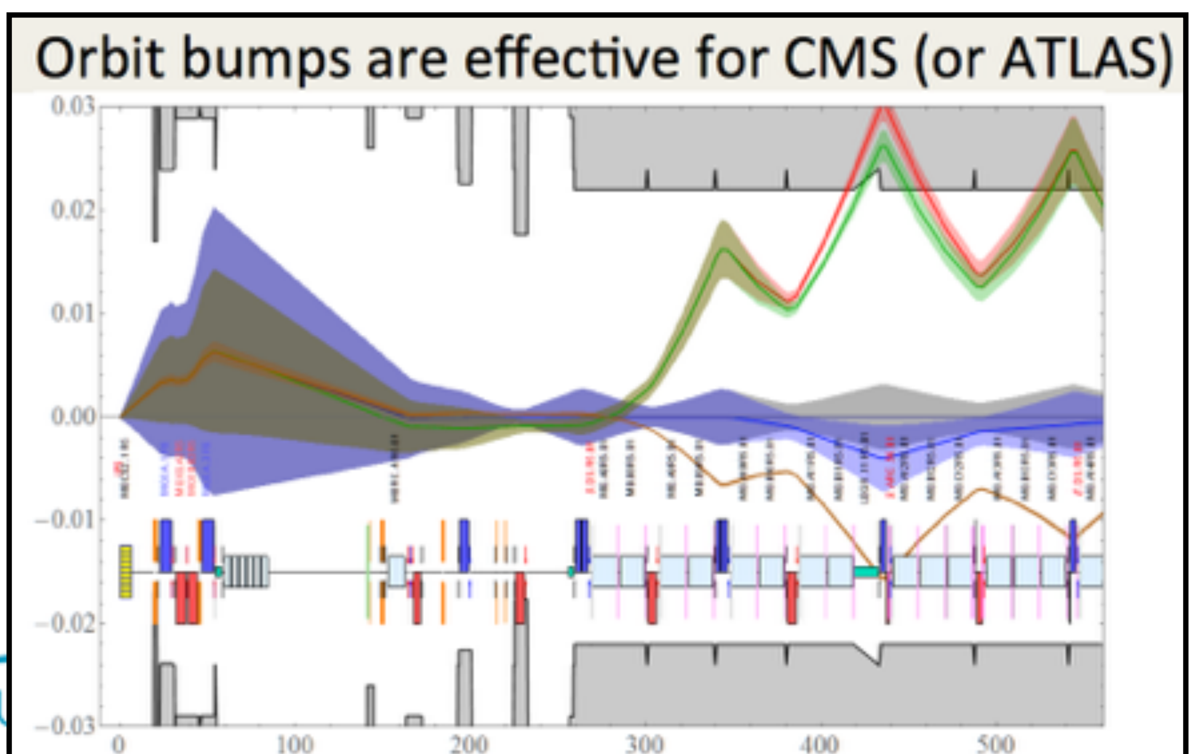
Quench tests in 2016

"Collimation quench test"



Controlled beam losses: halo particles driven unstable are intercepted by the primary collimators and disposed by the IR7 system, as for ***operational losses***. Controlled increase of losses until quench occurs.

"BFPP quench test" (BFPP = Bound-Free Pair Production)



Steer secondary beams generated by the Pb-Pb collision in magnets, at maximum luminosity.
Followed up by J. Jowett et al.

Quench tests done for the first time at energies close to design.

Summary of quench test results

Performed 3 controlled quench tests in 2015

"Collimation quench test" : with proton (6.5TeV) and Pb ion beam (6.37 Z TeV)
"Luminosity quench test" : steer the collision products into DS magnet;
losses dominated by BFPP (bound-free pair production) beam.

First successful quenches of dispersion suppressor dipoles!

Clearly, we quenched at lower losses than expected for the given energy.

Scaling to 7 TeV and simulations (transport + energy deposition) entail uncertainties.

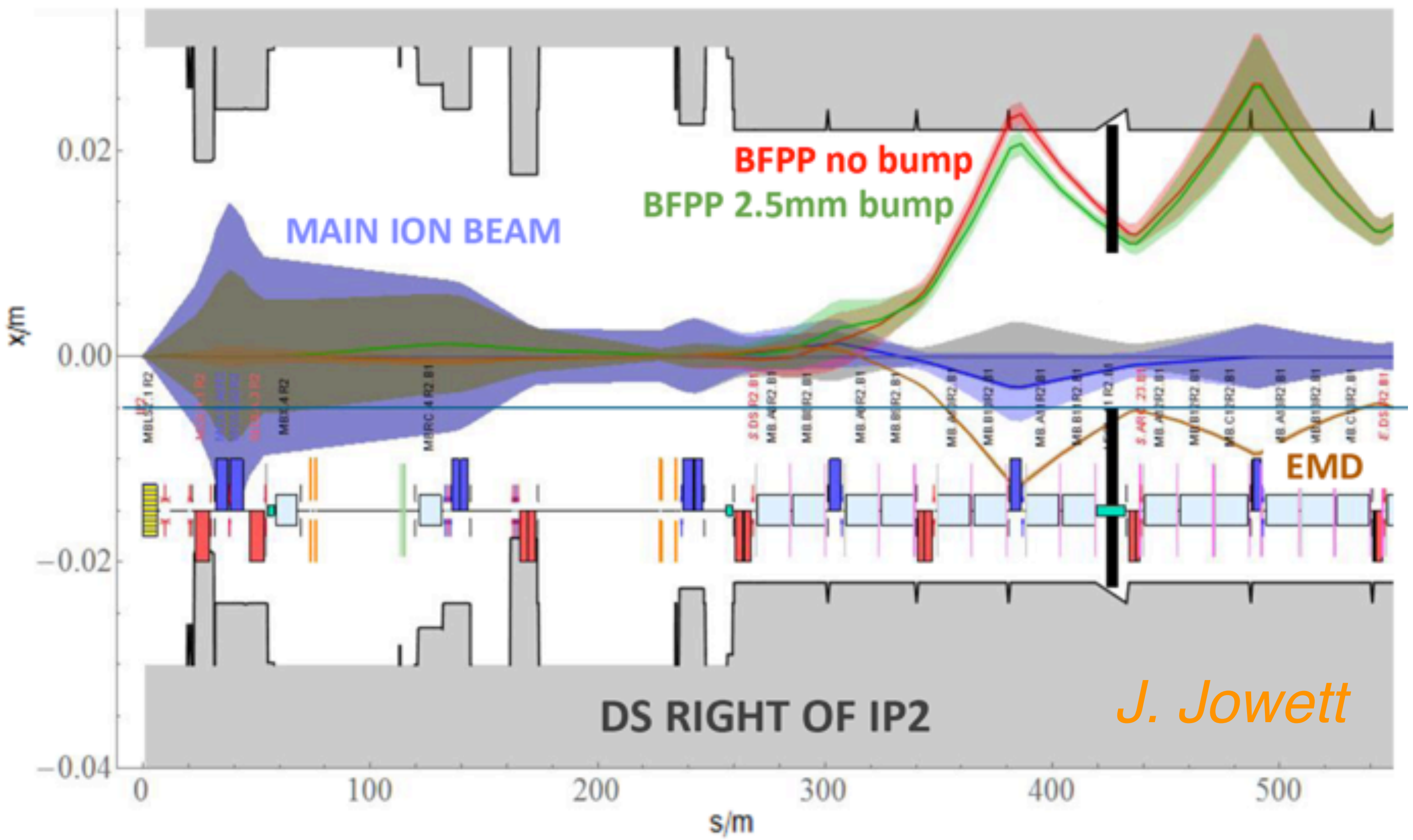
	Beam	Beam energy [Z TeV]	Beam loss [kW]	Losses in coil* [mW/cm^3]	Quench	
IR7	protons	6.50	~ 600	15-20	**NO**	
IR7	Pb ions	6.37	~ 15	~25-30	**YES**	
IR5	Pb ions	6.37	0.053+	**~ 15**	**YES**	*Steady*

** See L. Skordis at Collimation WG, 31/10/2016 and C. Bahamonde, this meeting*
+ Energy carried by th

Crucial ingredient to decide on baseline change: IR2 without 11T dipoles, bring forward IR7 installation.

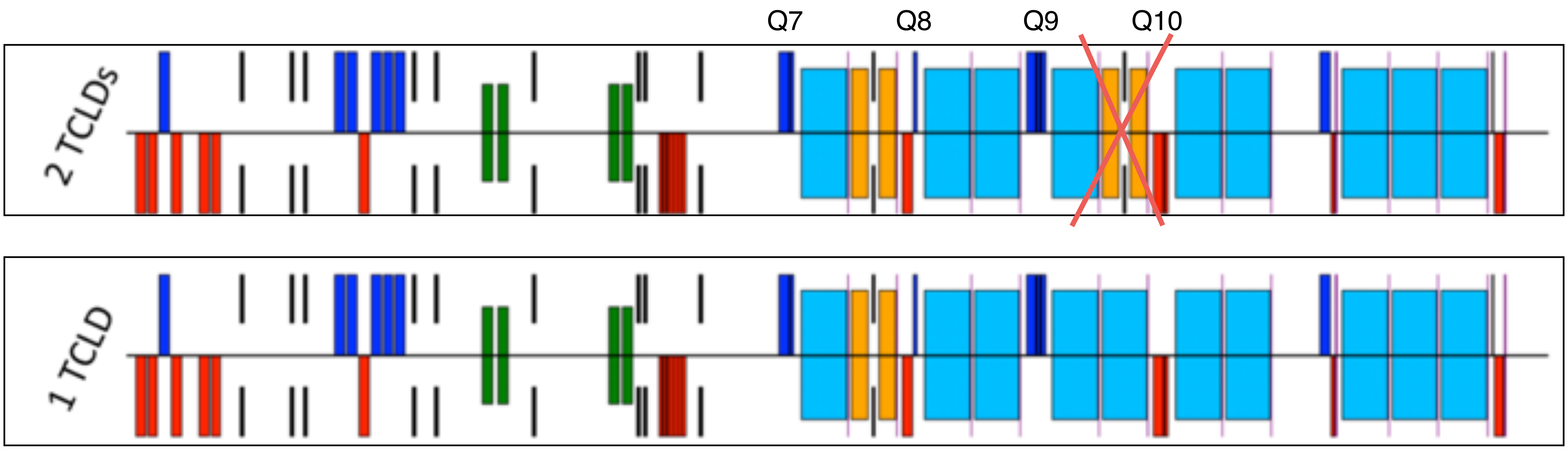
New layouts around IR2

- Taken out of baseline 11T dipoles in the DS around IR2
  Confirmed by operations with bump in ion run 2015!
  ↦ *New baseline: TCLD collimators without dipoles in LS2.*
  ↦ *We believe that this has no risk of performance limitations.*
- No implications on the TCLD collimator production, need new design of cryo by-pass (WP11).



New layouts around IR7

- Taken out of baseline the second cryo units in cell 10 of the IR7 DS
  - ↦ *New baseline: 1 unit in cell 8 only. Planned for LS2, for ion upgrade*
  - ↦ *Detailed studies of performance reach still ongoing.*
- WP5: reduced TCLD units by 2 collimators + 1 spare.
- Have to be ready for LS2: with IR2, total of 5 units + 1 prototype.
- Need to re-study optimised positions for the layout with 1 unit only.
- Note: 11T dipole technology will be at hand — can still add a unit if Run IV performance shows that we need it.

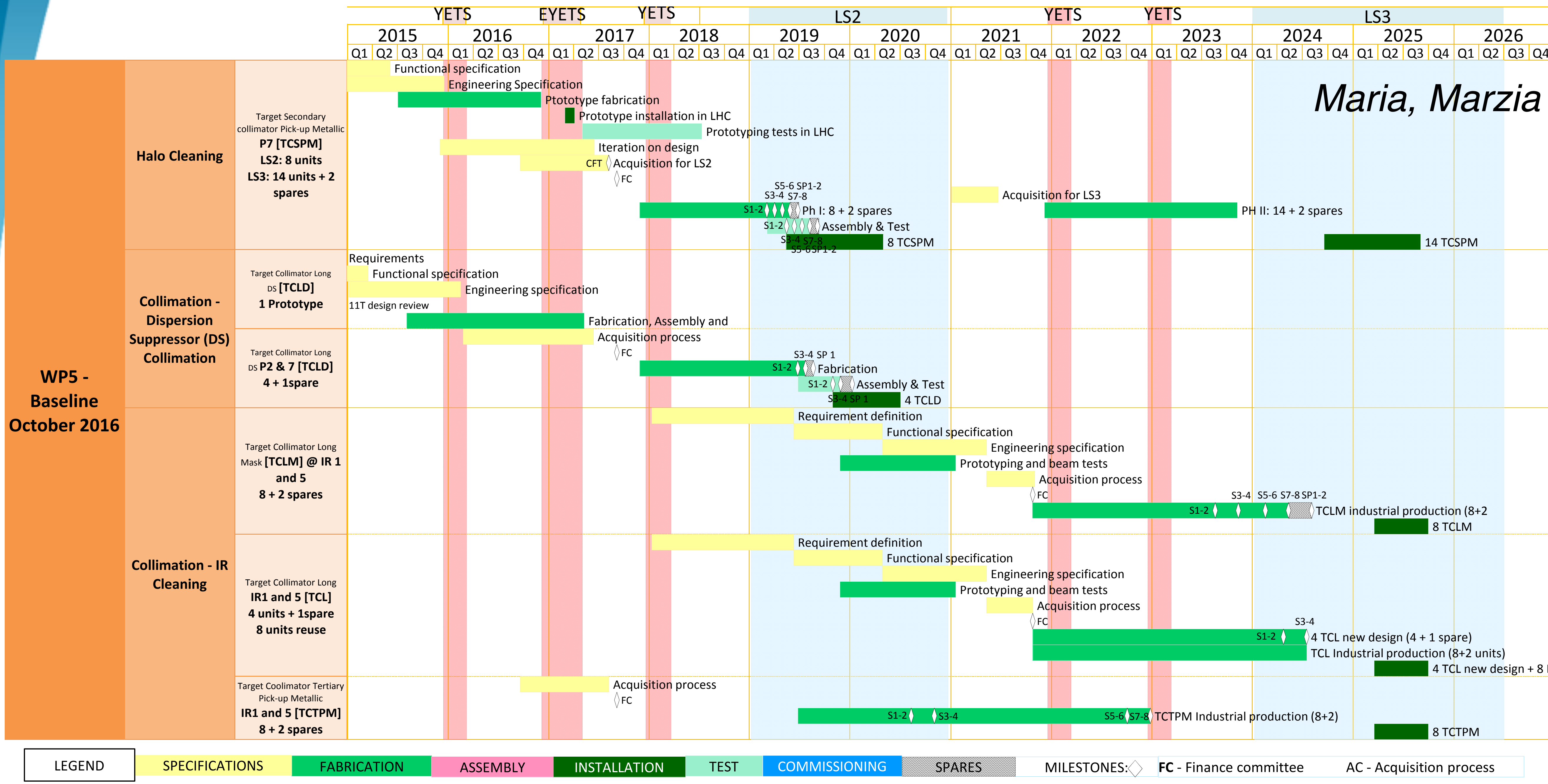


Updated production tables

- DS cleaning
- Low-impedance
- IR collimation
- Consolidated primary and secondaries
- Consolidated IR collimation
- New MQW layouts

		Mar. 2015		Feb. 2016		Jun. 2016	
Type	**IR**	**LS2**	**LS3**	**LS2**	**LS3**	**LS2**	**LS3**
TCLD	IP2	2		2		2	
	IP7		4	2	2	2	
	IP1						
	IP5						
TCSPM	IP3						
	IP7	8	14	8	14	8	14
TCTPM	IP1		6		6		4
	IP5		6		6		4
TCTPX	IP1		2		2		2
	IP5		2		2		2
TCL	IP1/5		8		8		4
TCLX	IP1/5		4		4		4
TCLM	IP1/5		8		8		12
TOTAL - HL		**10**	**54**	**12**	**52**	**12**	**42**
TCPP	IP3	2			2		2
	IP7	6		4	2	4	2
TCSP	IP3		8		8		8
	IP7						
TCTPM	IP1/5	4		4		4	
	IP2		4		4		4
	IP8		4		4		4
TCAP	IP7	2		2		2	
TOTAL - CONS		**14**	**16**	**10**	**20**	**10**	**20**

WP5 schedule

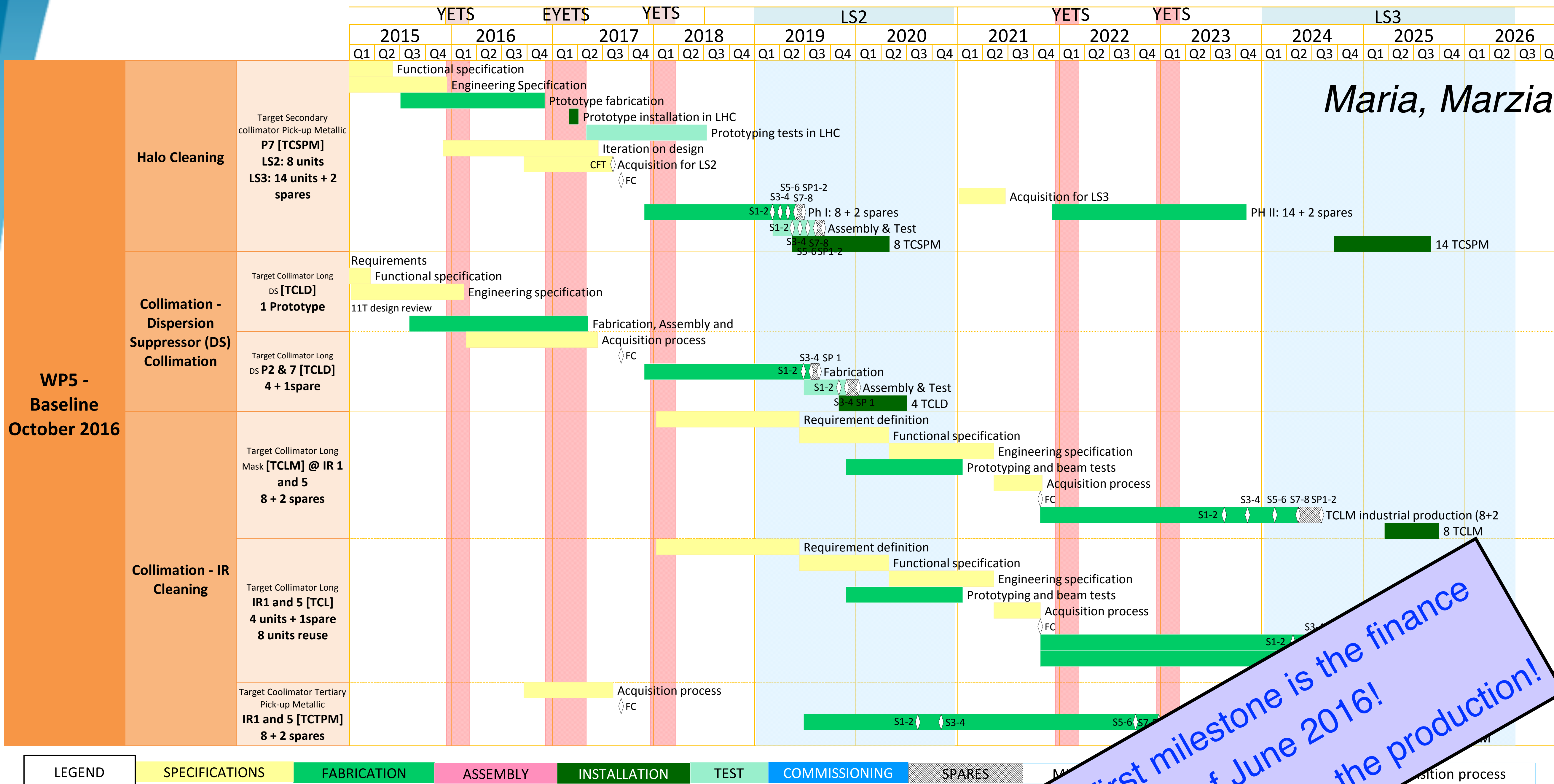


Main activities:

LS2 TCLD collimators around IR2/7
staged deployment of low-impedance solutions

LS3 Full deployment of low-impedance solutions
Complete re-design of IR1/5

WP5 schedule



Challenging – first milestone is the finance committee of June 2016!
Thanks to EN/STI that follows the production!

Main activities:

LS2 TCLD collimator ... staged deployme... ...edance solutions

LS3 Full deployment o... ...pedance solutions

Complete re-design of IR1/5

Table of contents

R&D and developments

- Various important accelerator physics studies: simulations and measurements

  Understand performance limitations and possible improvements (quench limits, aperture, beta reach, …)*
  Study new techniques for halo controls — see yesterday's session
  Beam tests for feedback to design (material choices, loss scenarios…)

- Continued the novel material development — we are building a full prototype or installation in the LHC

  Close to a complete qualification, without and with beam
  Beam impedance measurements in 2017 with a full-scale prototype.

- Very good recent technical developments towards deployment of crystals in accelerators

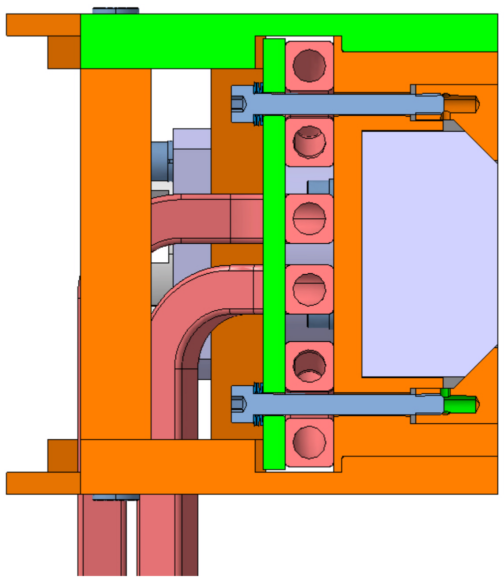
  Some of the key technology in the process of being demonstrated
  Preparing an installation on B2.

- Improved design of hollow e-lens for LHC (synergy with BI)

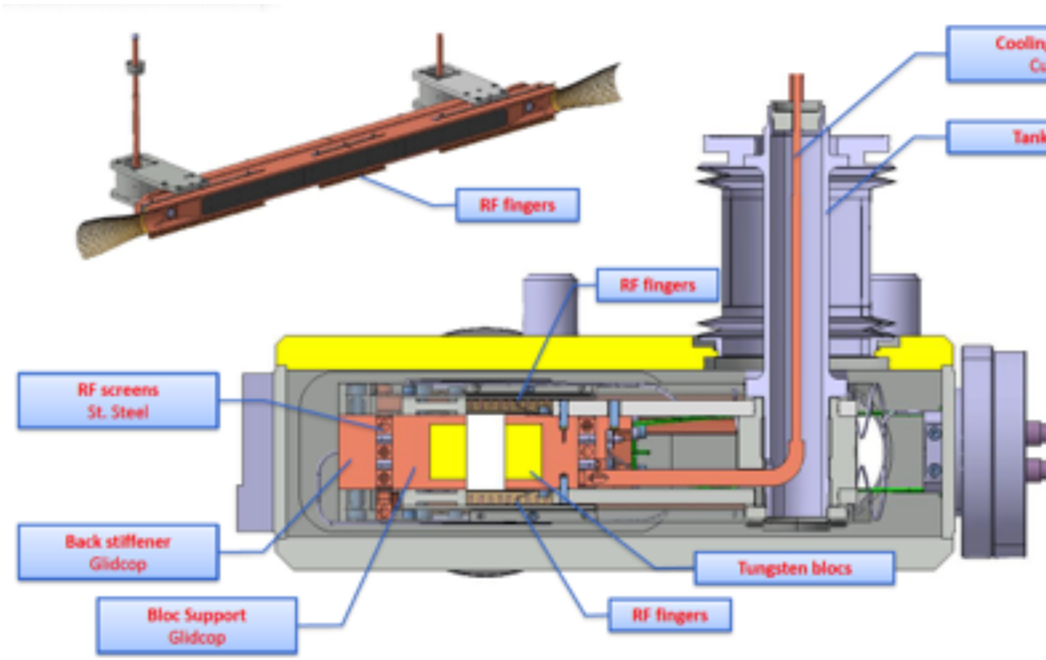
Many thanks to all people involved from various teams and external collaborators!

New collimator designs

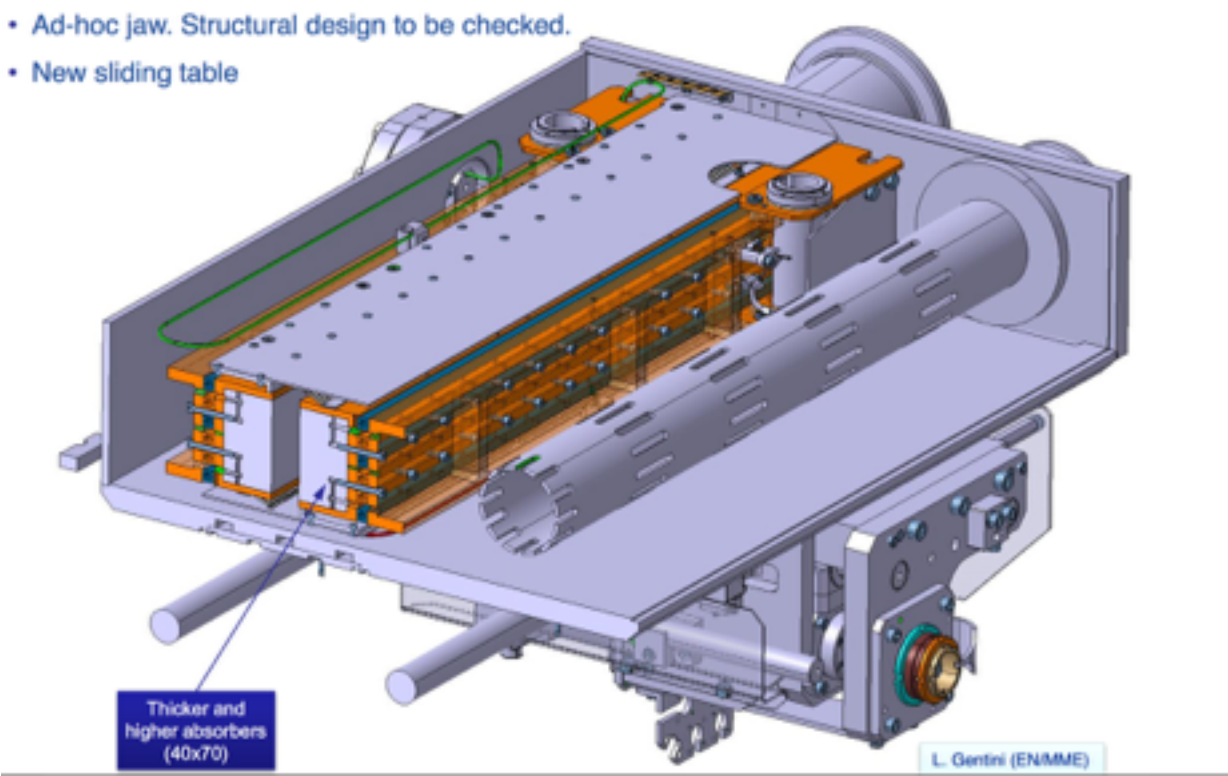
New secondary collimator jaw



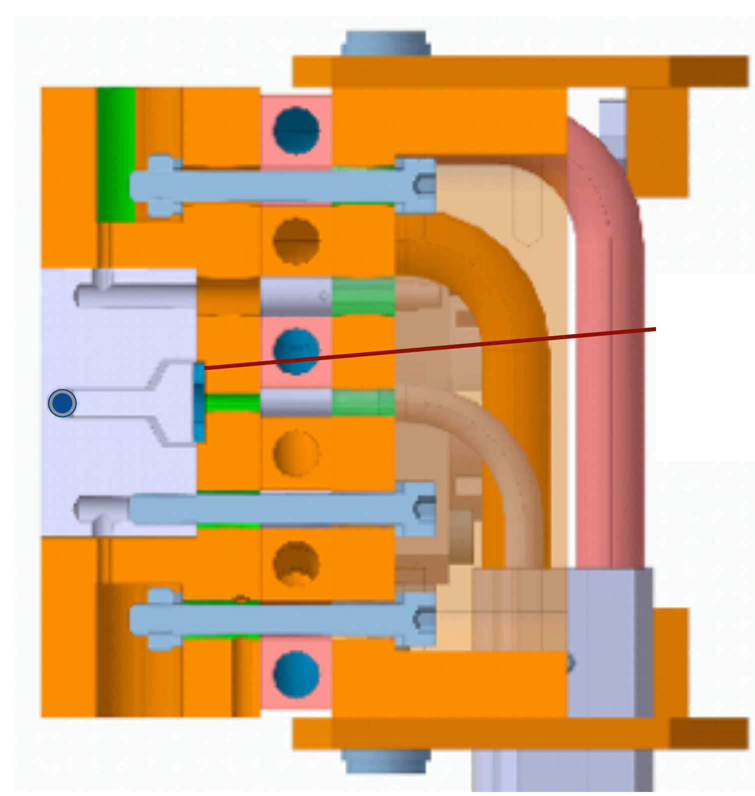
TCLD for DS



TCTX/TCLX for TAXN/D2 regions



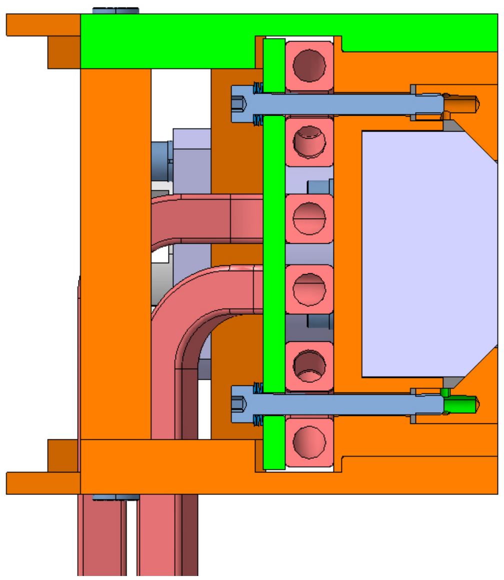
TCTPW for beam-beam compensation studies



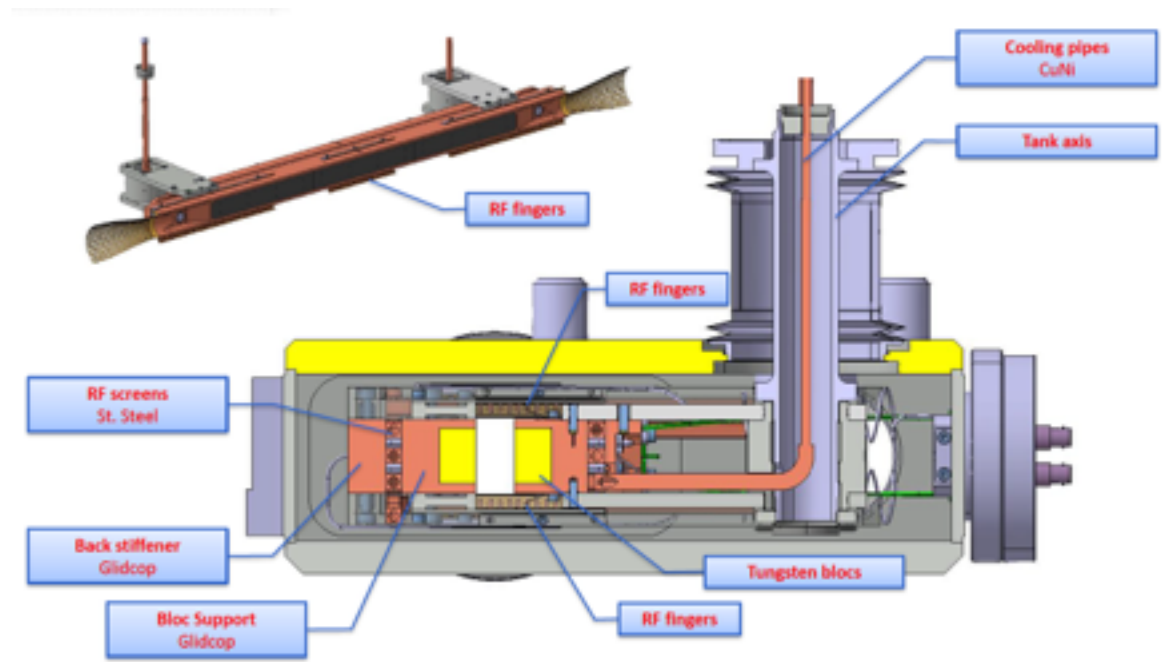
Tertiary collimator with embedded wire for LRBB MDs

New collimator designs

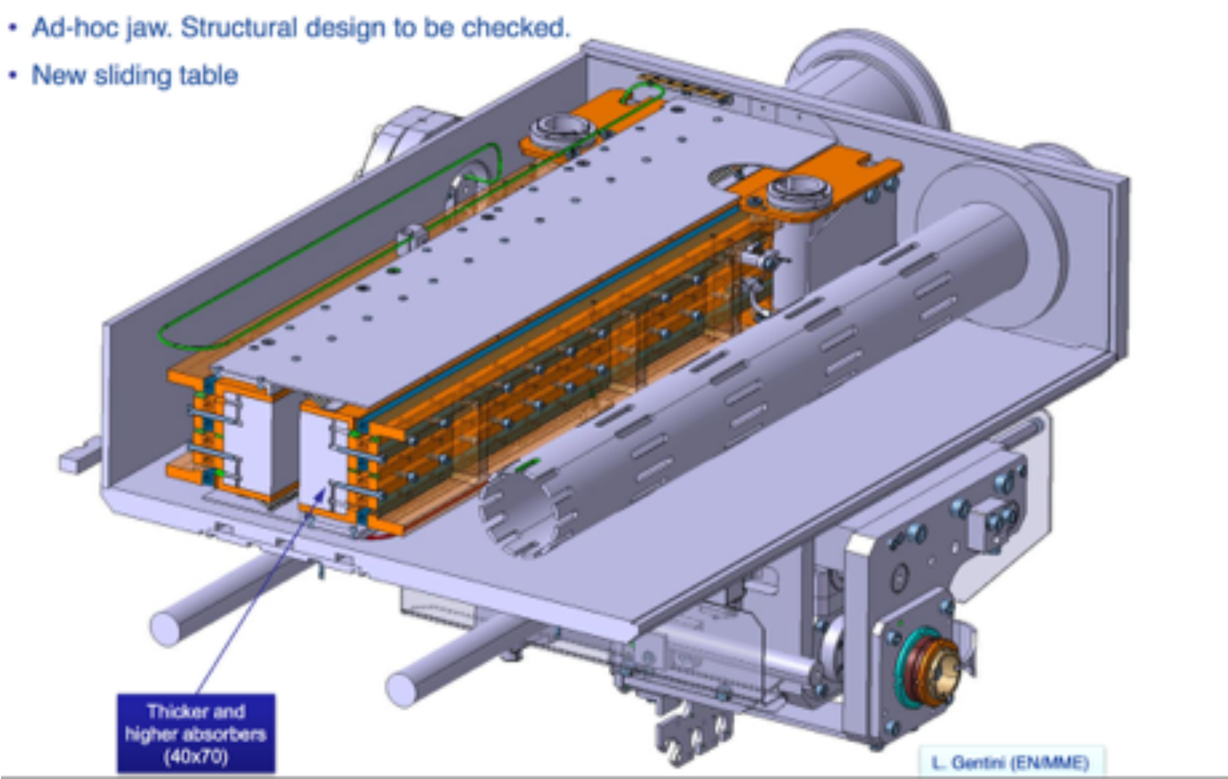
New secondary collimator jaw



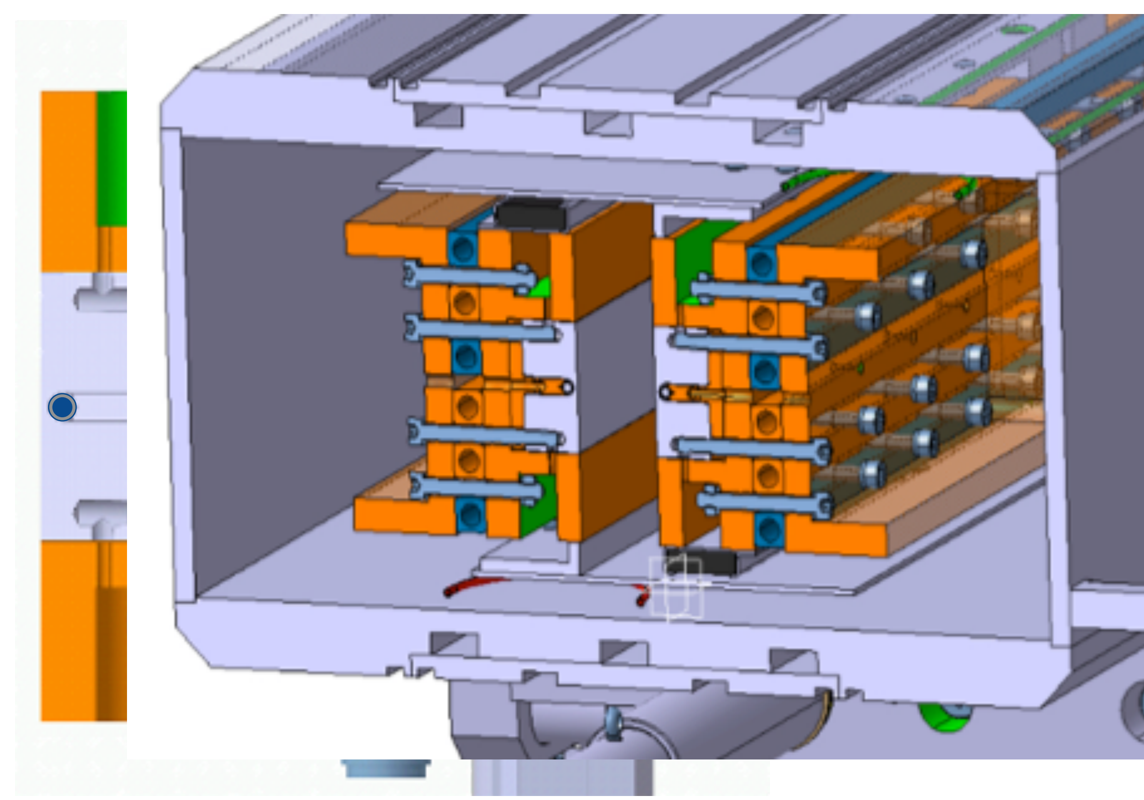
TCLD for DS



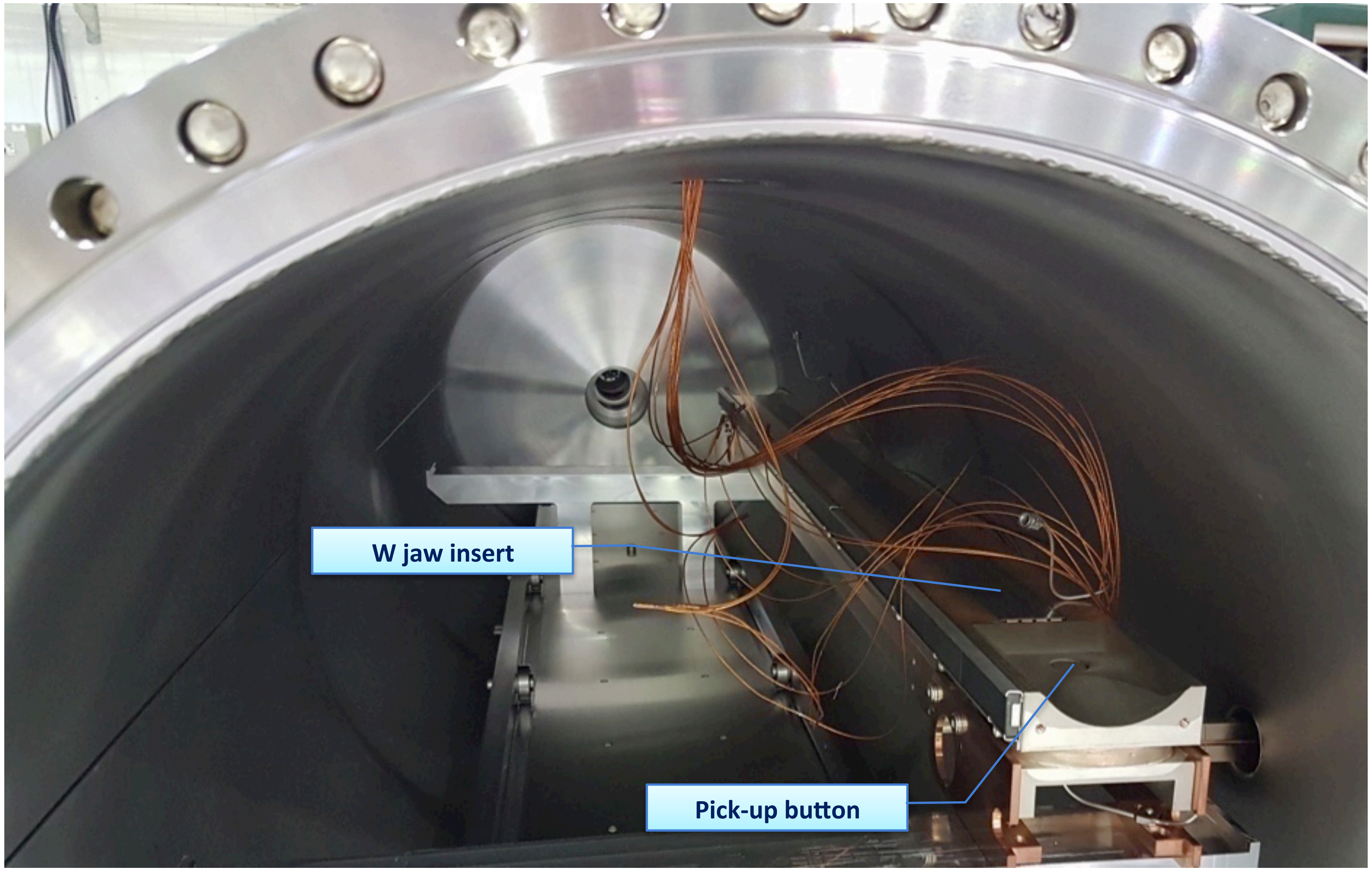
TCTX/TCLX for TAXN/D2 regions



TCTPW for beam-beam compensation studies



Recent news from production — TCTPW



Presented yesterday by A. Rossi

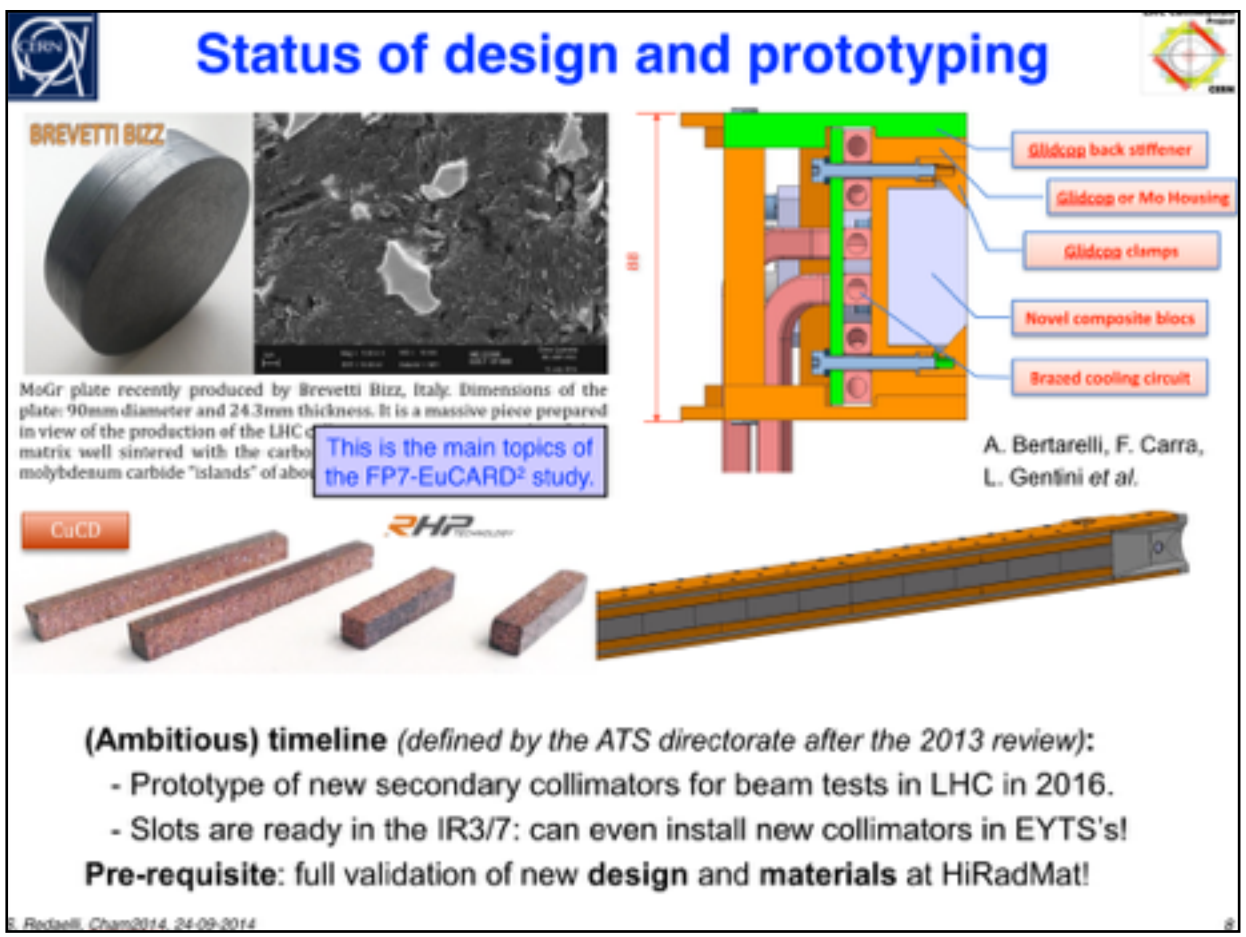
Acknowledgements: EN/STI, EN/MME, BE/BI

- Prototype jaw being tested — ok.
- 2 TCTPW collimators already at CERN, being prepared for the installation in IR5 during the Christmas stop.
- Other two units at CERN in first week of Dec. (IR1: 2017)

Low-impedance secondary collimators (TCSPM)

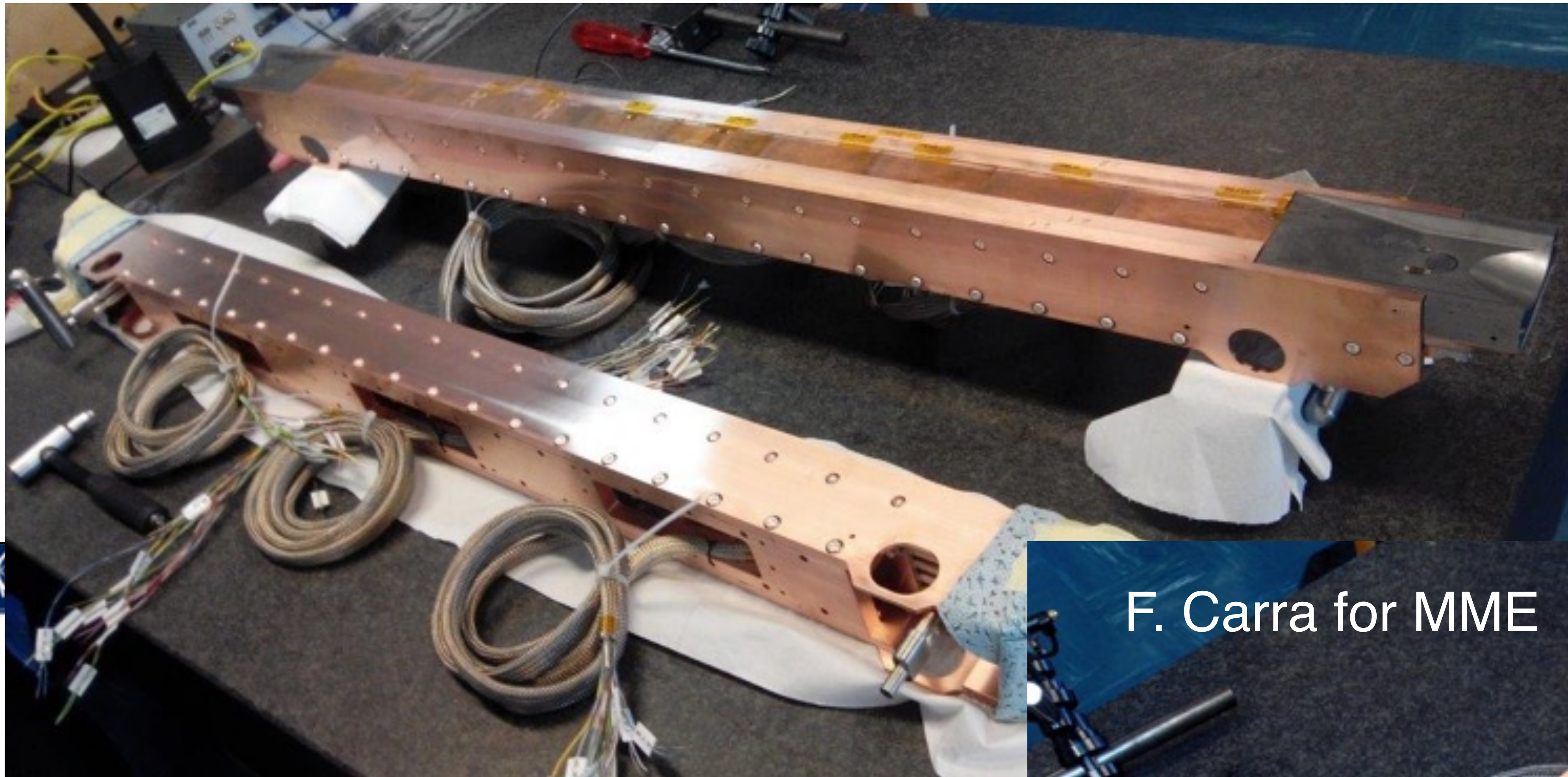
Recent milestones:

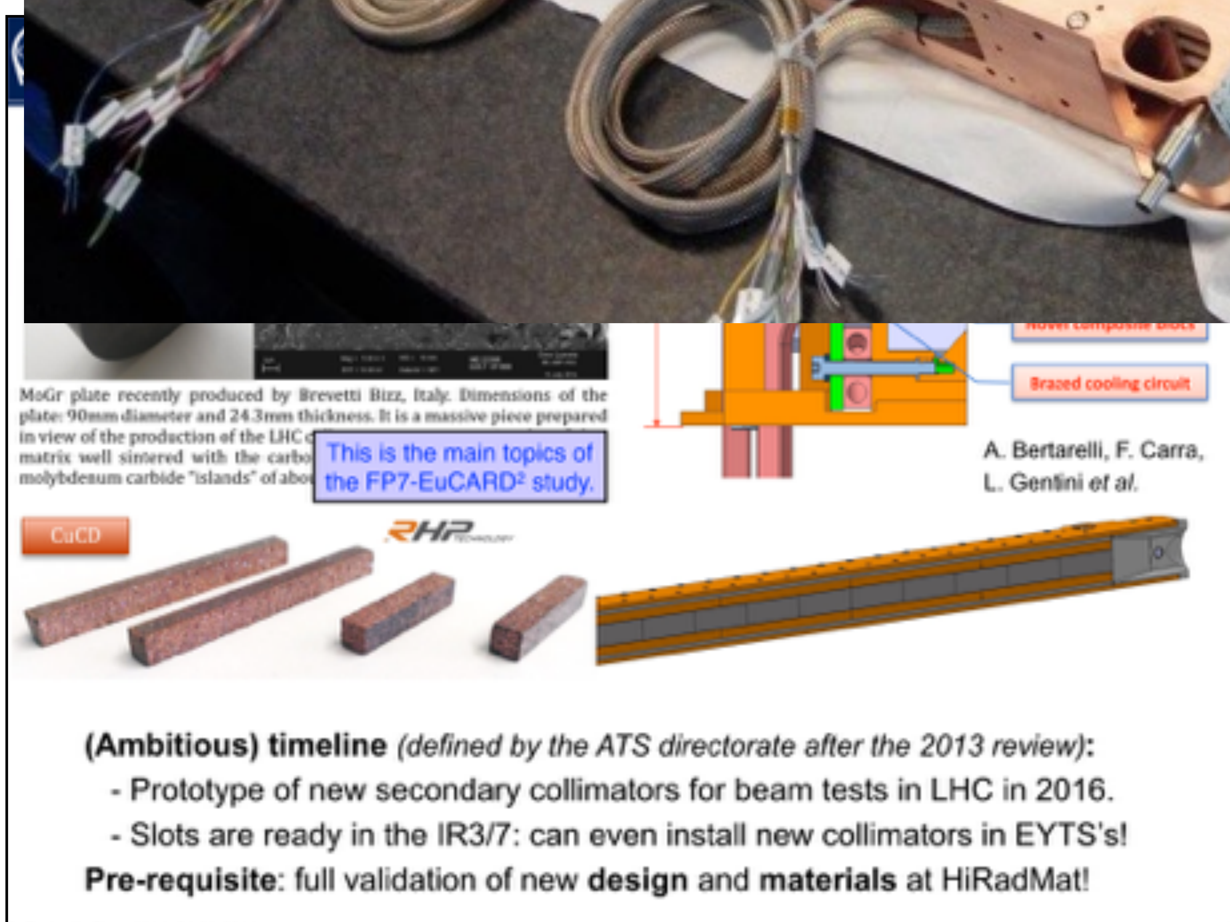
- New full jaws for HRM tests in 2015
- Final iteration on material grades (2016)
- Full prototype for installation and beam tests in the LHC
- (Preliminary) validation of radiation hardness (summer 2016)

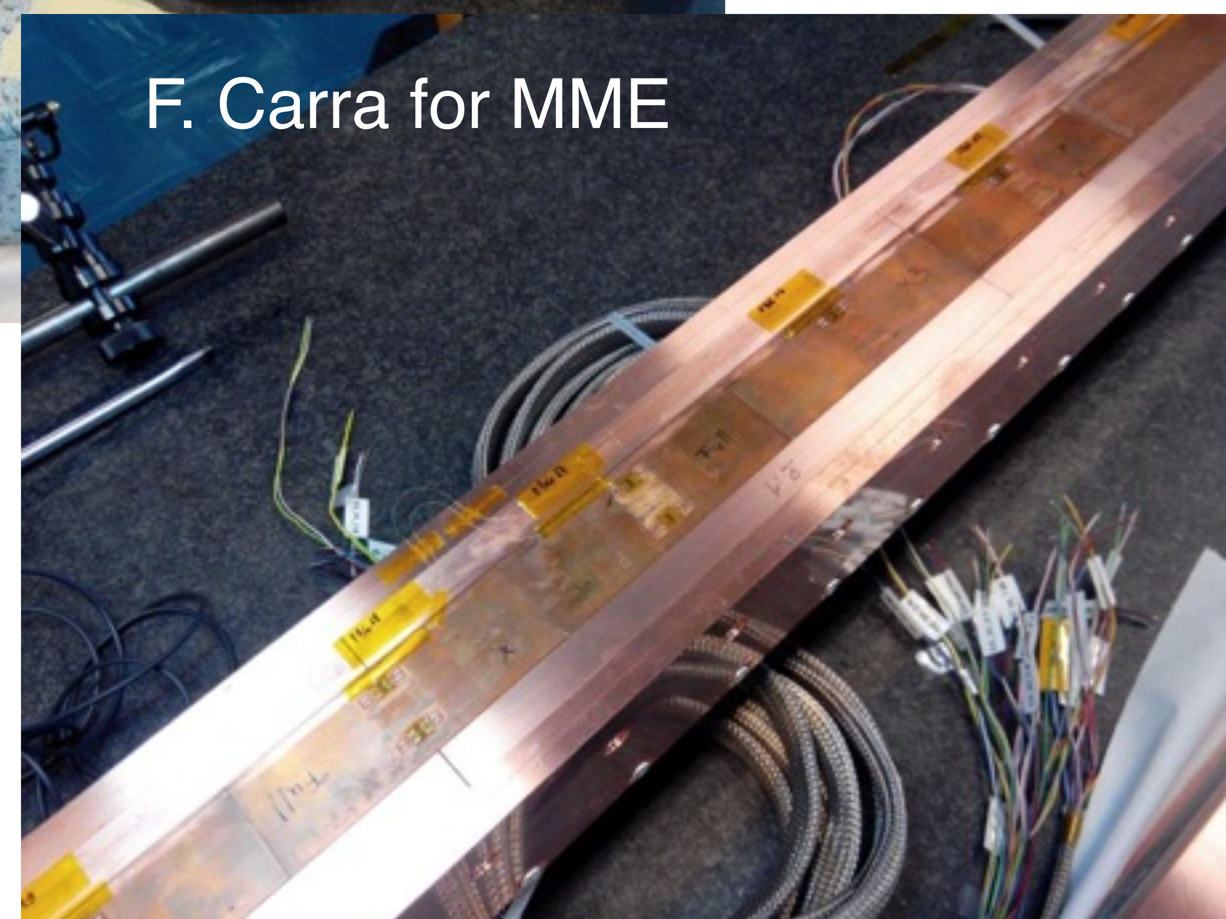


Low-impedance secondary collimators (TCSPM)

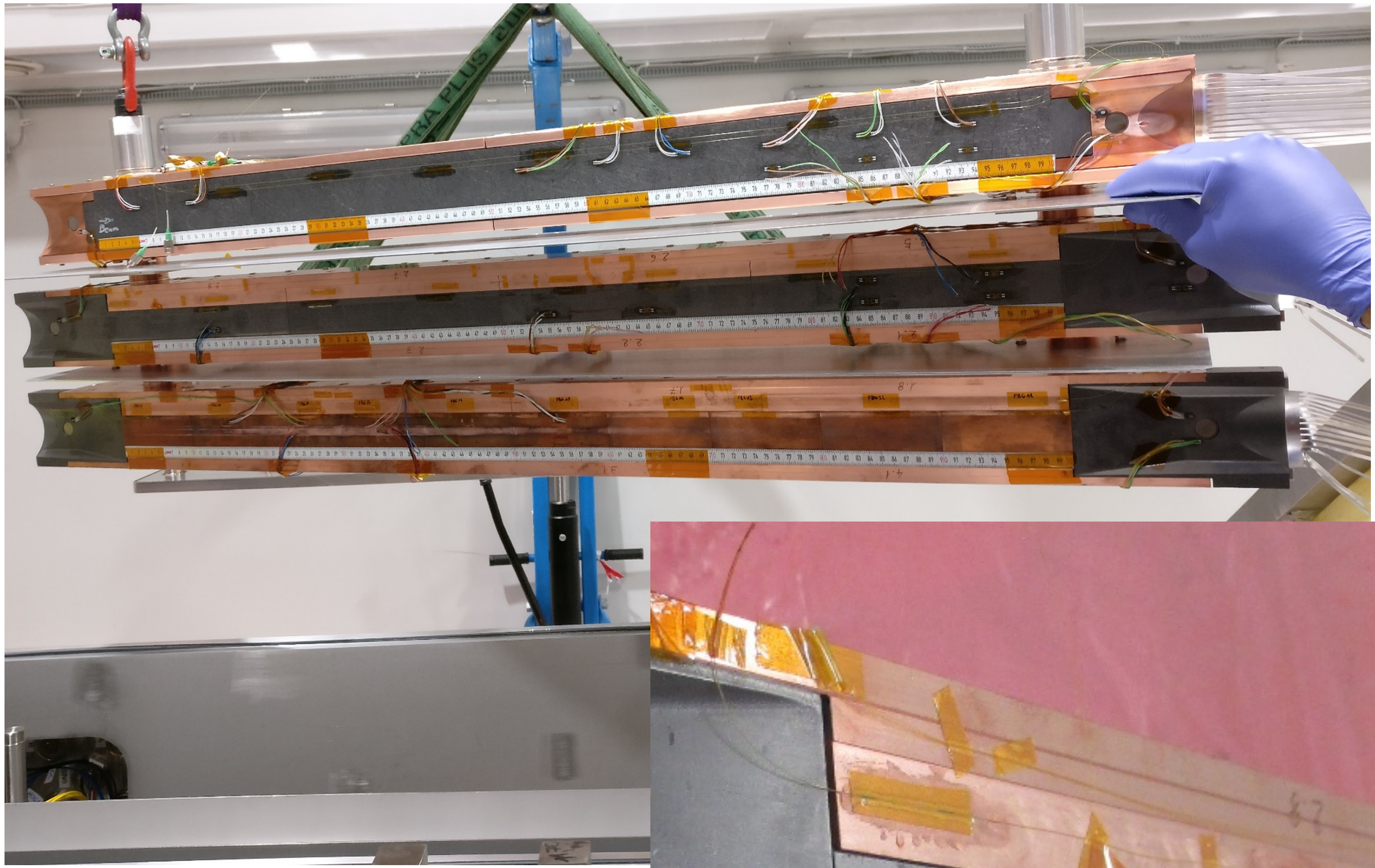
e LHC
nmer 2016)

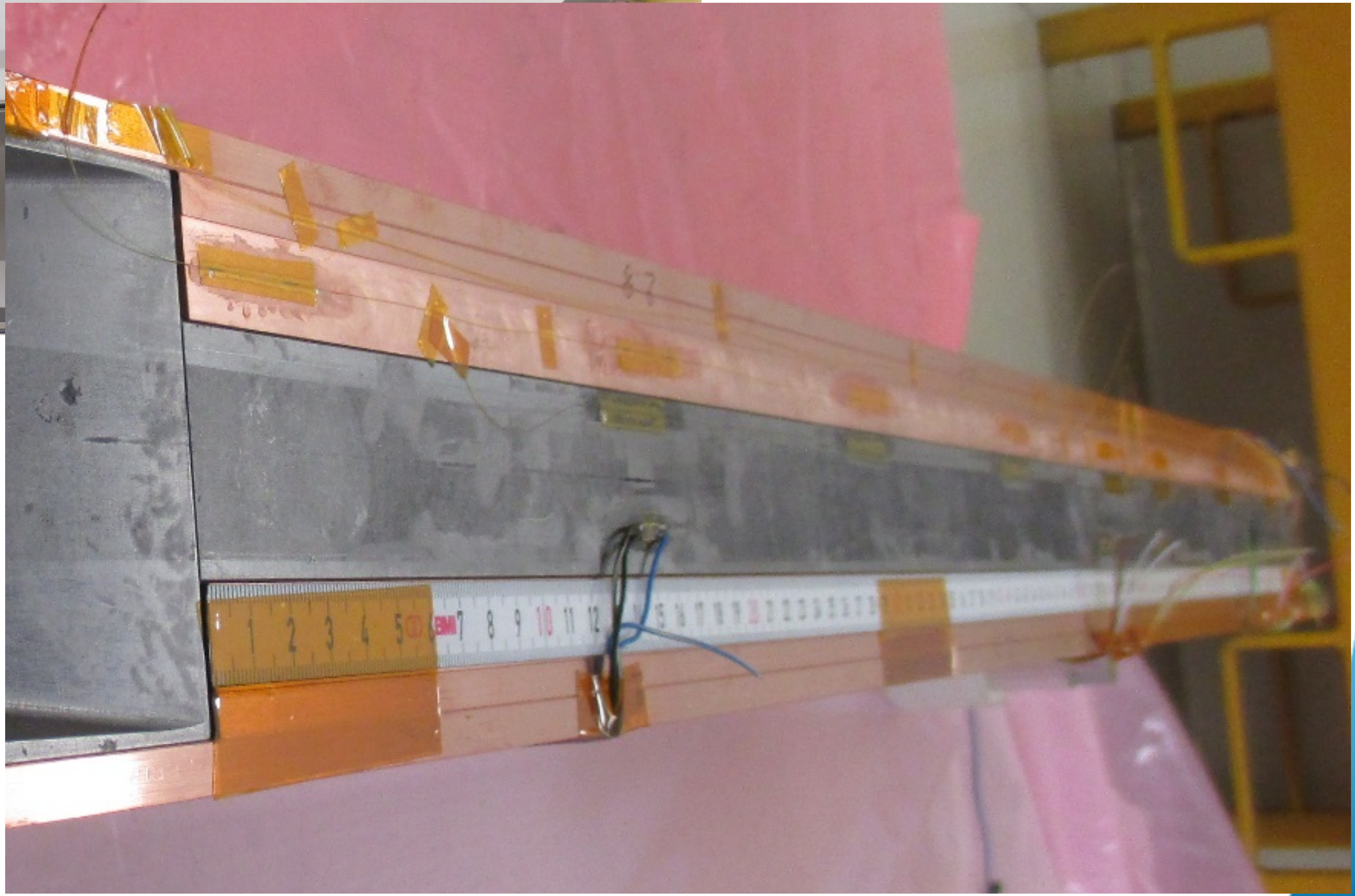






HiRadMat results

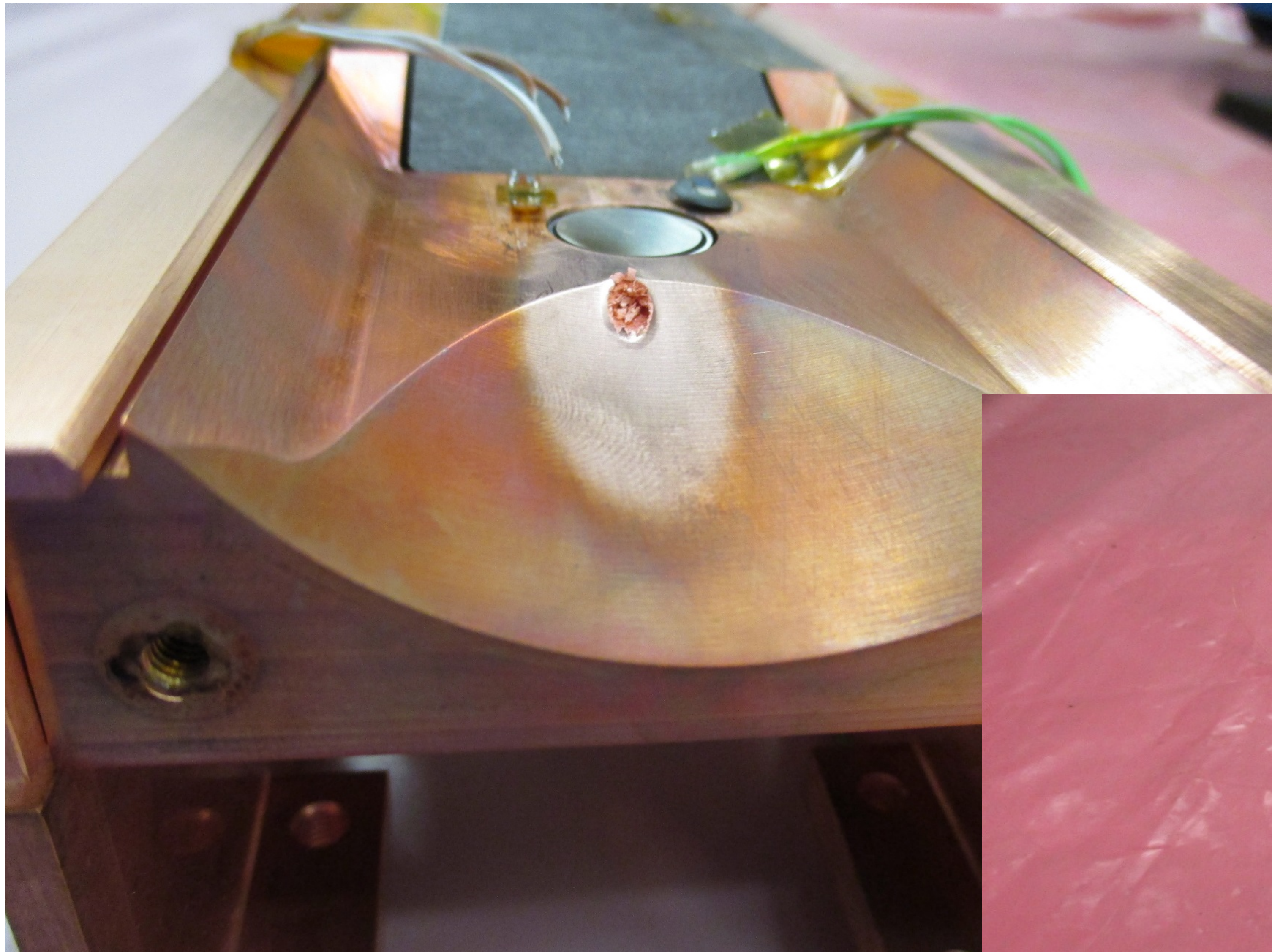




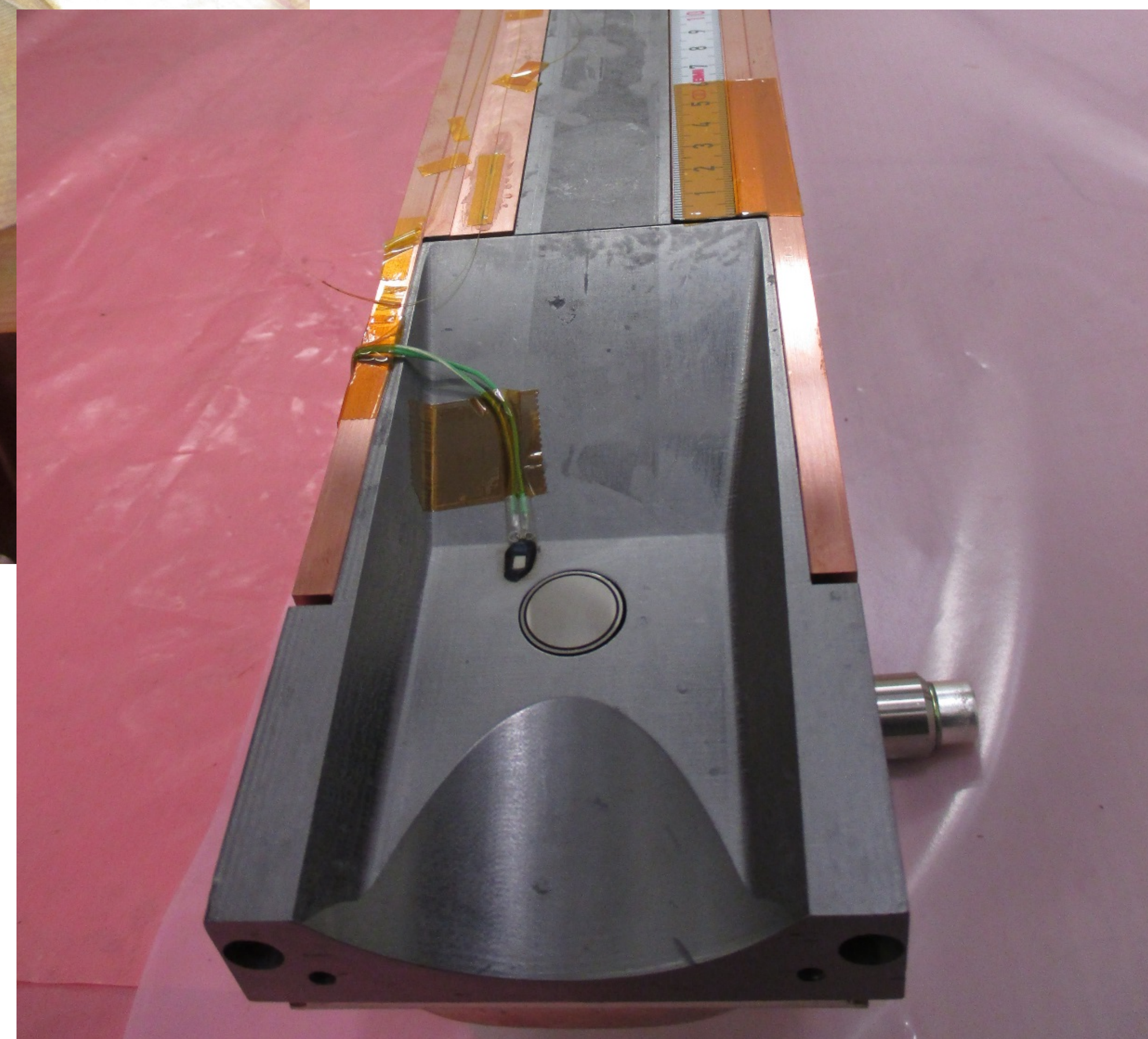
Tank opened last week.

Confirmed preliminary observations that MoGr and CuCD jaws could withstand the (respective) design failure!

Improved tapering

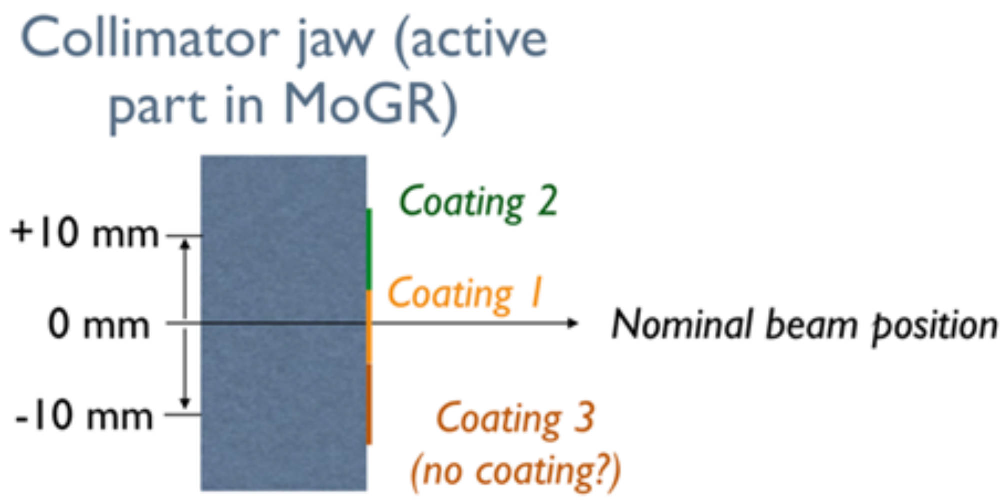


Present design got damaged (as expected from simulations)



Much improved robustness with MoGR tapering

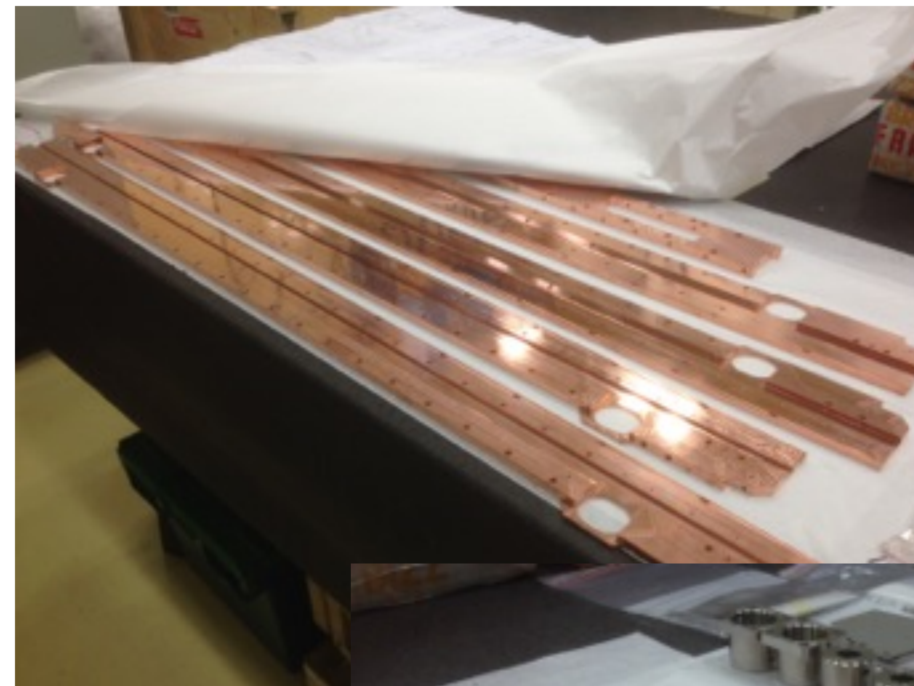
Low-impedance prototype status

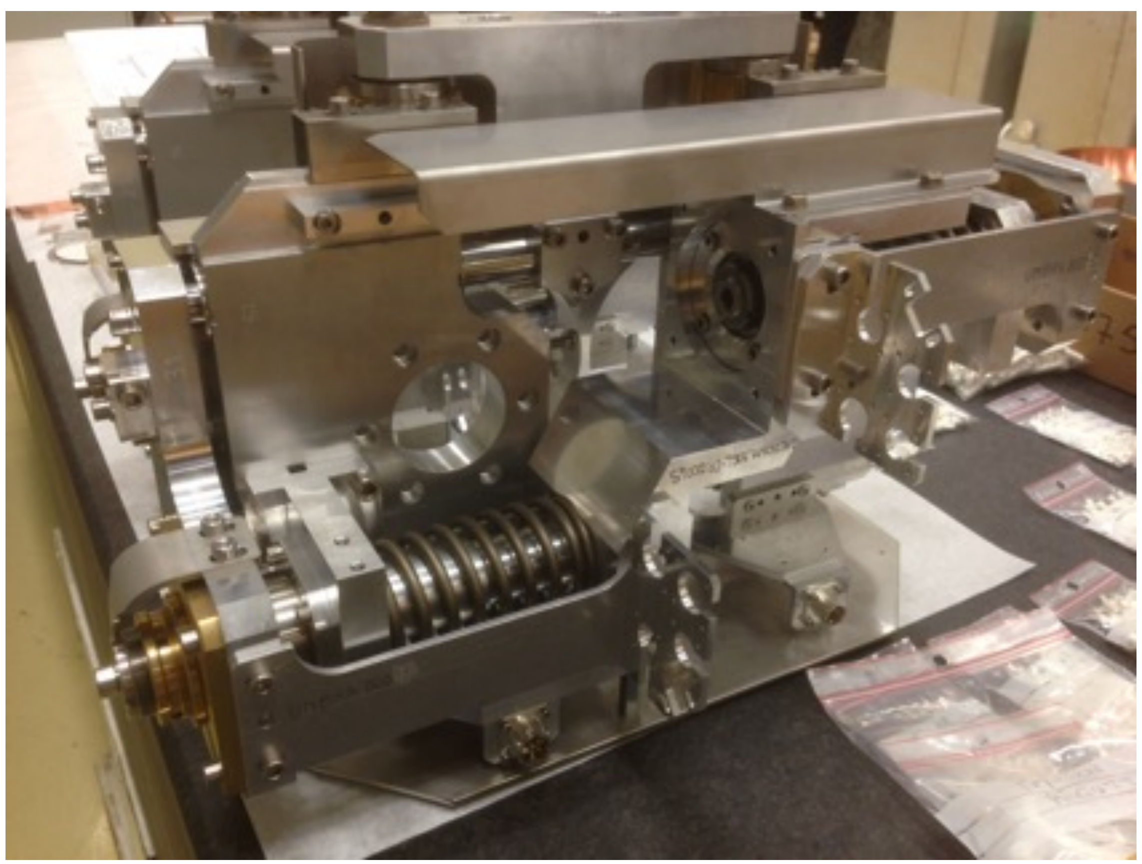


Three-stripes of different coating (MoGr, Mo, ceramic) to test 3 different surface resistivity values with beam (impedance measurements).

Low-impedance prototype status

Three-stripes of different coating (MoGr, Mo, ceramic) to test 3 different surface resistivity values with beam (impedance measurements).

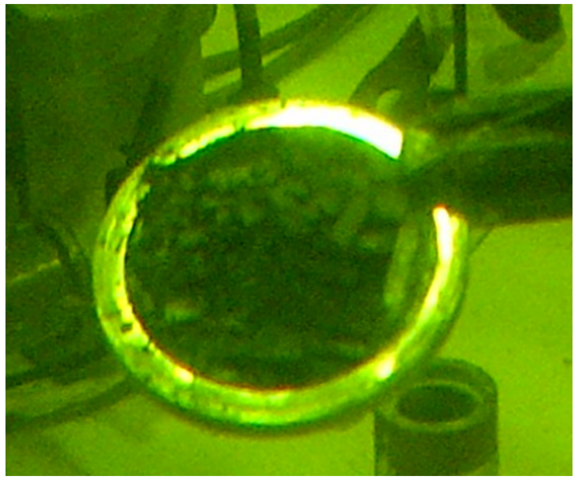




A. Bertarelli for MME team

Recently some concerns with brazing, but on track for installation (MME deliver it to STI by Mid-Jan)

Results from irradiation studies



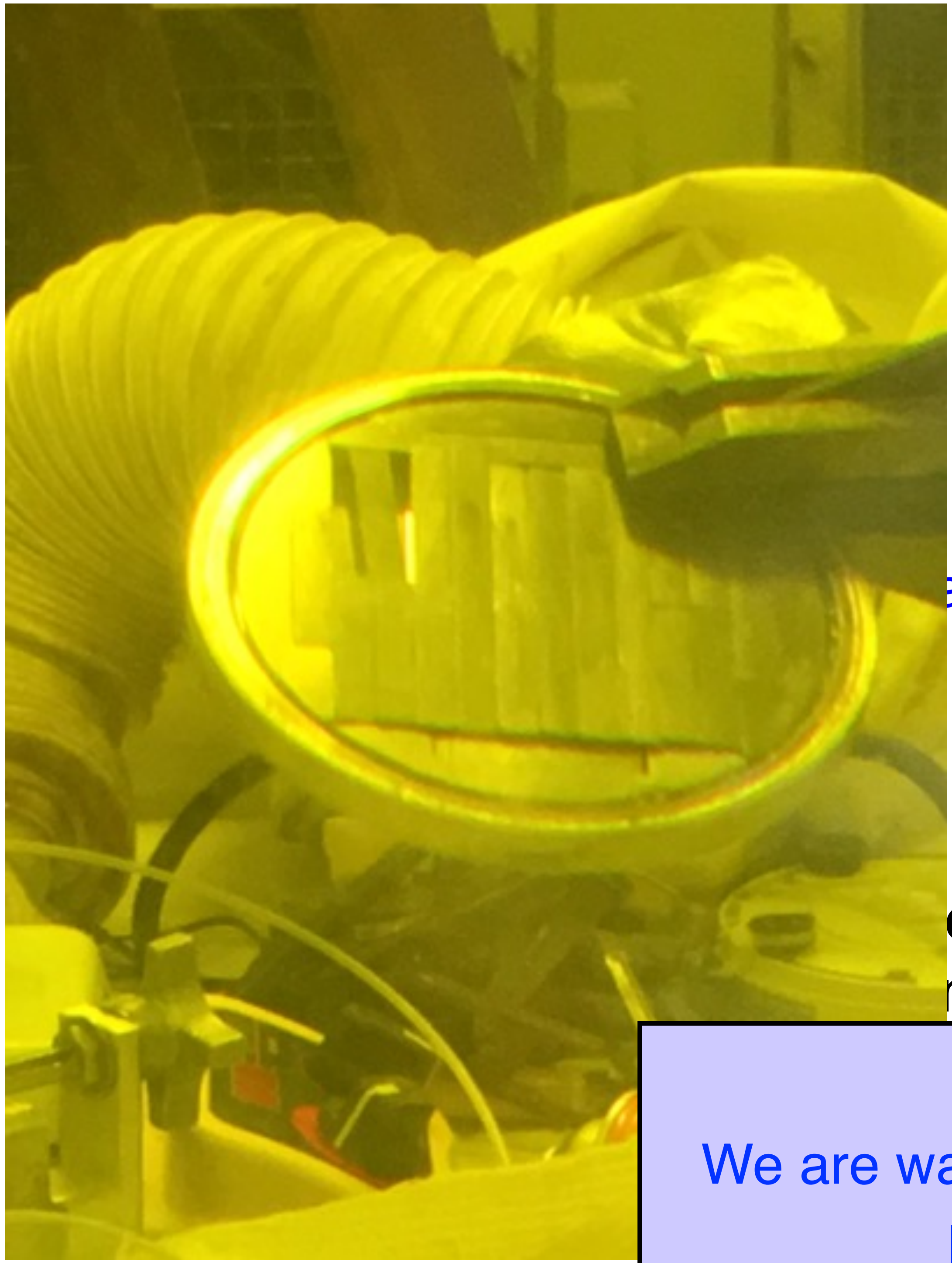
State of Mo-GR after 1.1 10^{21} p/cm^2 FLUENCE !!!!

N. Simos at US-LARP meeting

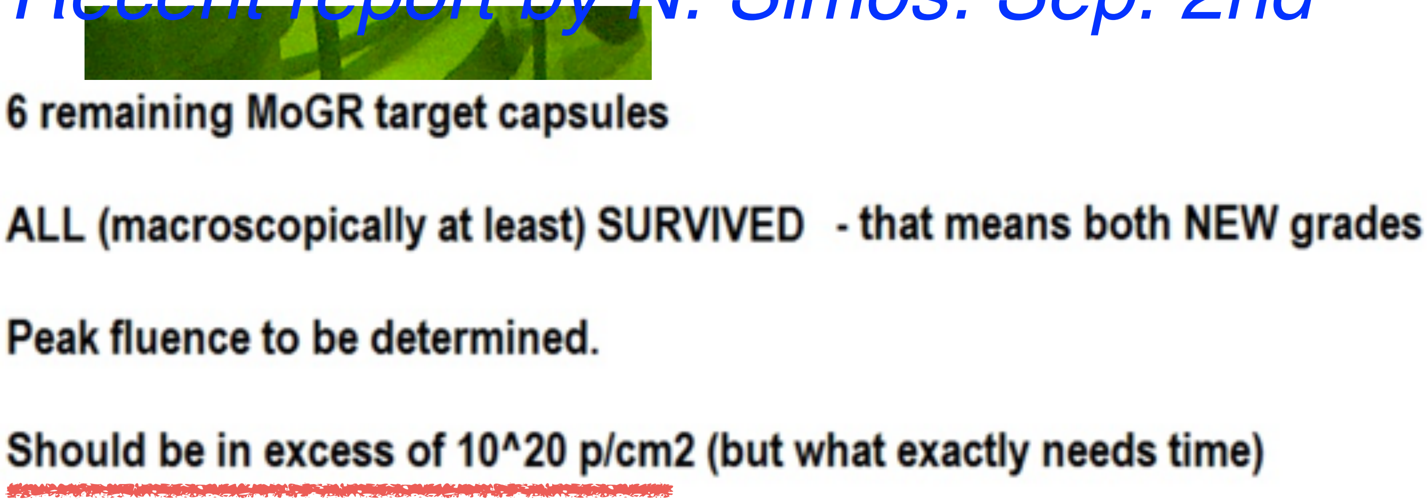
Very high doses at BNL: some MoGR samples broke!

Launching another set of measurements with latest MoGR grades and more optimised beam parameters.

Results from irradiation studies



Recent report by N. Simos: Sep. 2nd



after 1.1 10^{21} p/cm^2 FLUENCE !!!!

N. Simos at US-LARP meeting

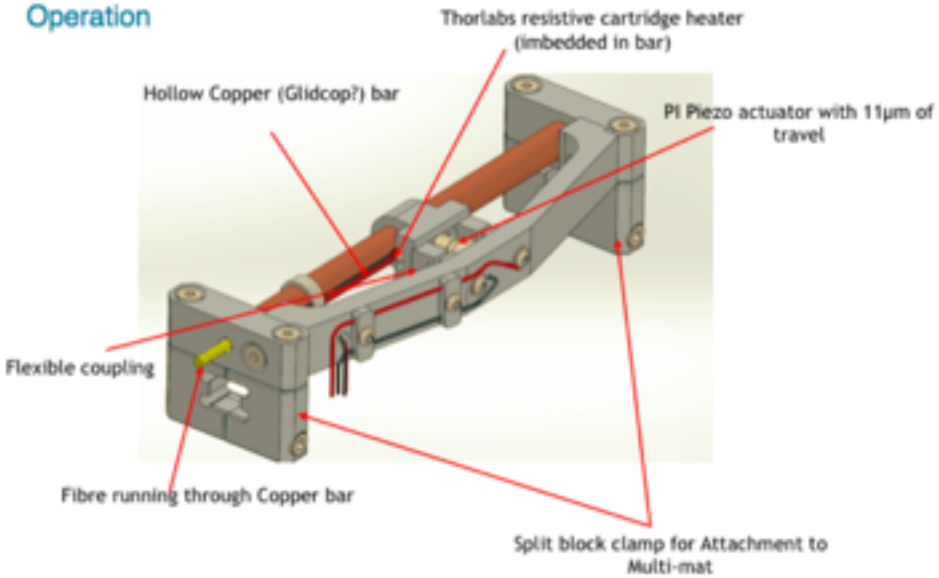
es at BNL: some MoGR
mples broke!

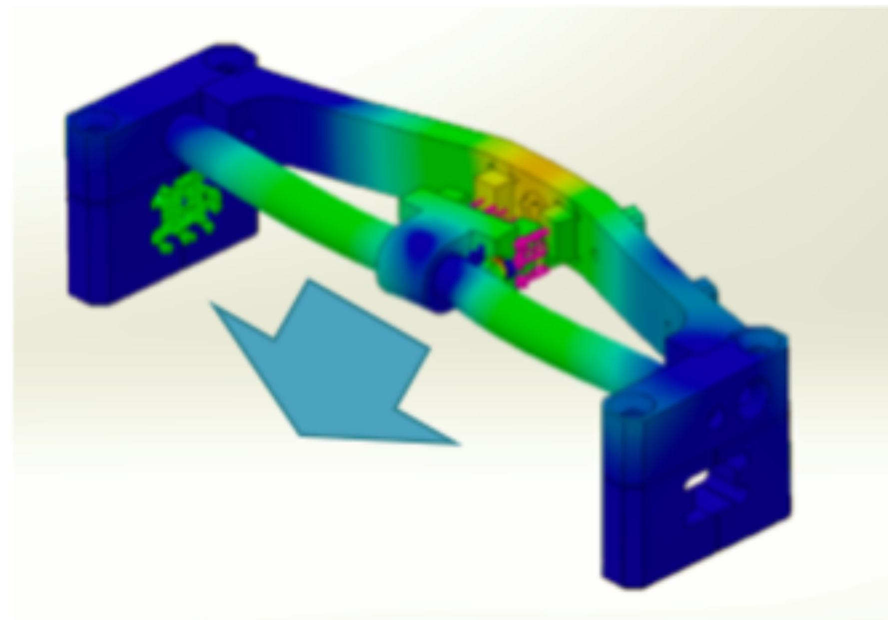
Excellent result!
We are waiting for more news — present inspections are limited by HIGH RESIDUAL DOSES.
Plan to collect relevant results before launching production.

Advanced concept of dynamic jaw control

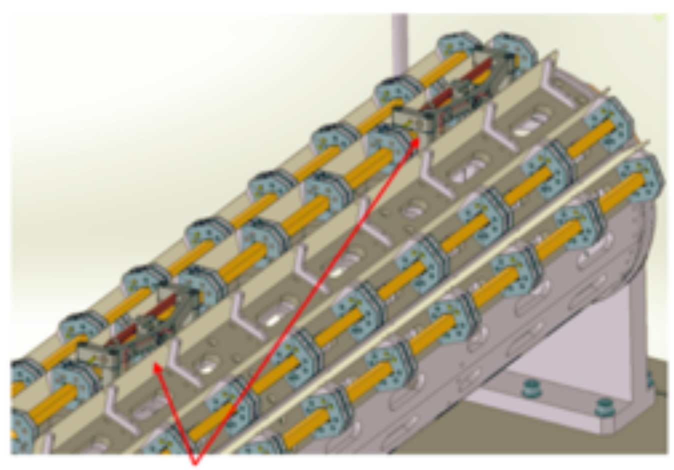
Test rig

Operation





To be installed in Multimat - at least 2 examples, front and back. Run in 2017



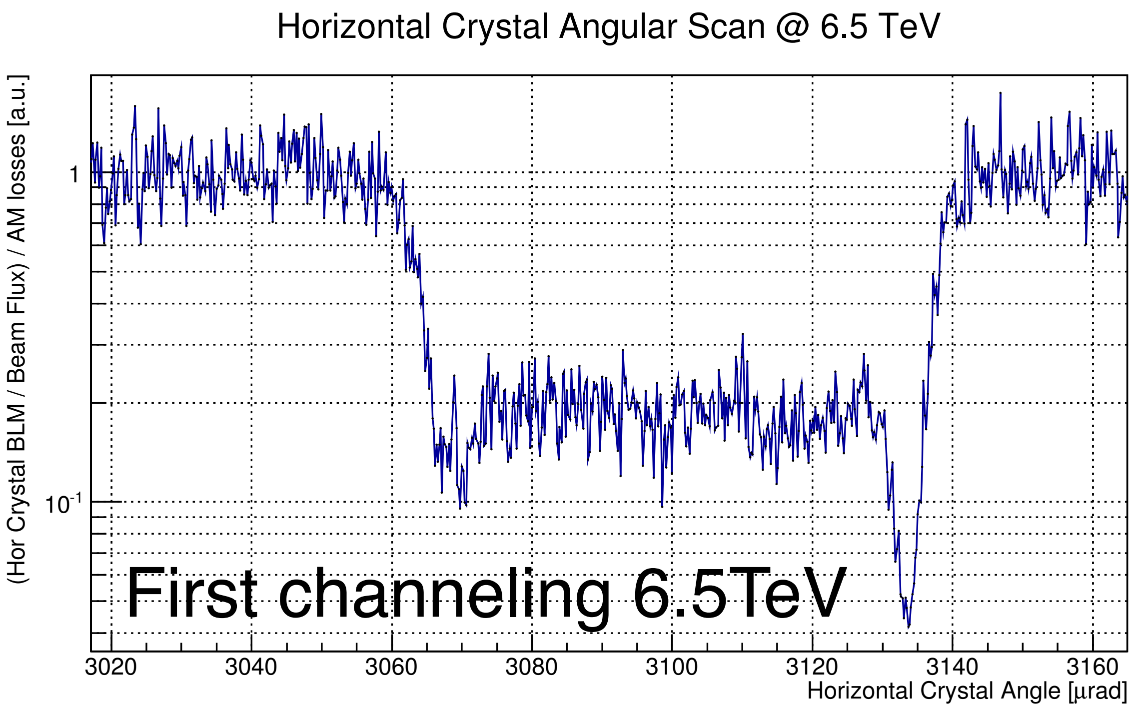
Prototype installation in our next HiRadMat test, plan to build a full scale demonstrator within the HL-UL framework.
Synergy to future projects, probably too ambitious for HL collimator production lines.

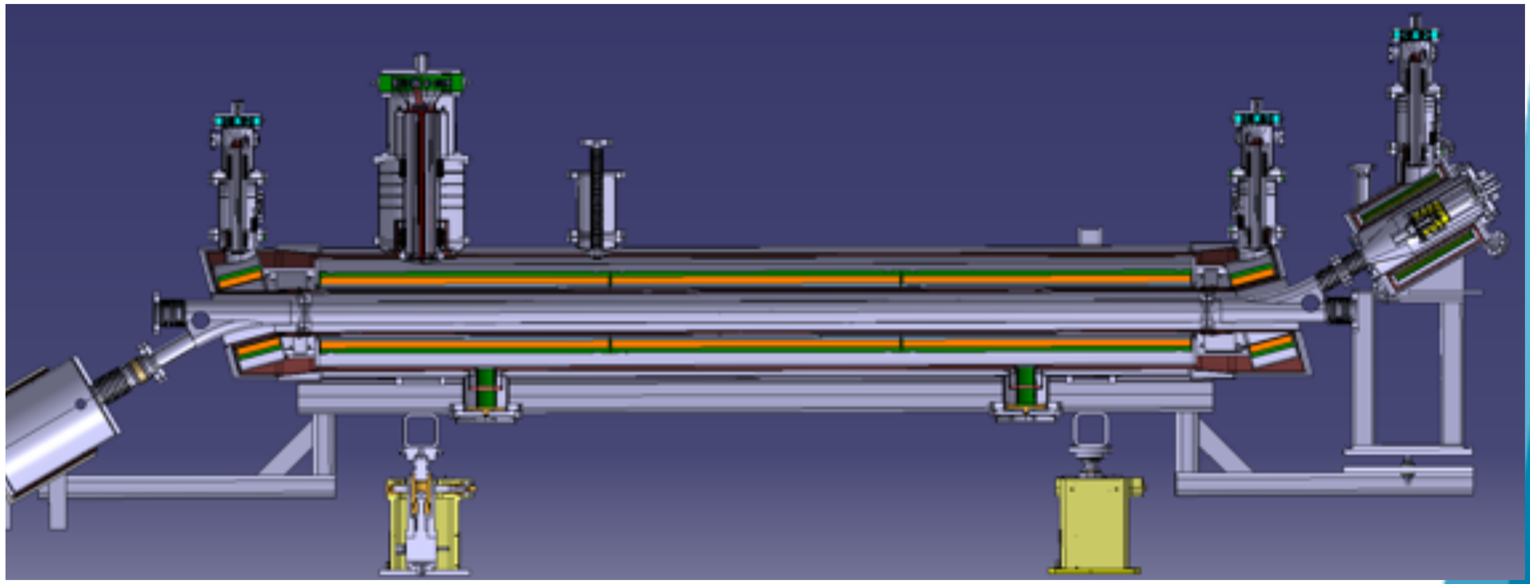
R. Barlow, S. Fletcher for HUD team

Table of contents

Advanced collimation studies

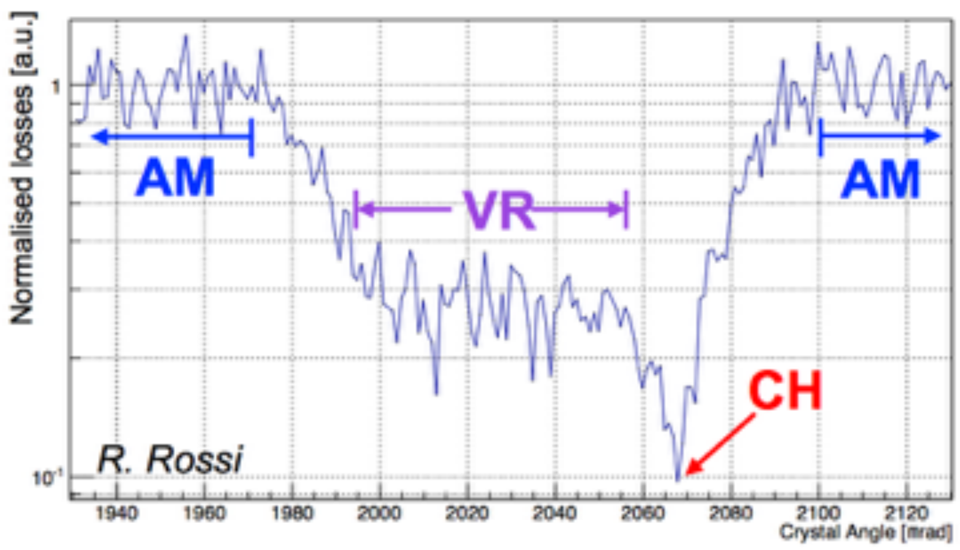
- Good results from **crystal collimation** studies
  - *Goals: improve **ion cleaning performance***
  - *First observation of channeling at 6.5TeV (proton), and 450Z GeV (Pb ions).*
  - *Crystal collimation cleaning measured this year!*
- Studies and developments for active halo control
  - *Recent **project review** on HEL: acknowledged the need for active halo controls at the HL-LHC and fully recommended to deploy HELs.*
  - *We are in the process of assessing the addition of HELs to the baseline (exploring external collaborations, detailed budget estimates).*
  - *Aim at a technical review in 6-8 months.*



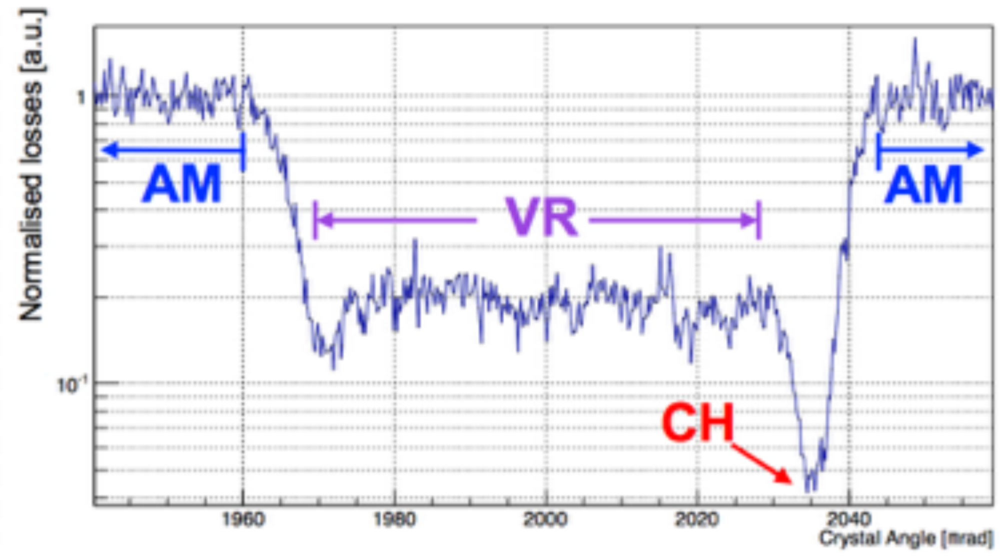


Crystal collimation results

Angular scan at 450 GeV

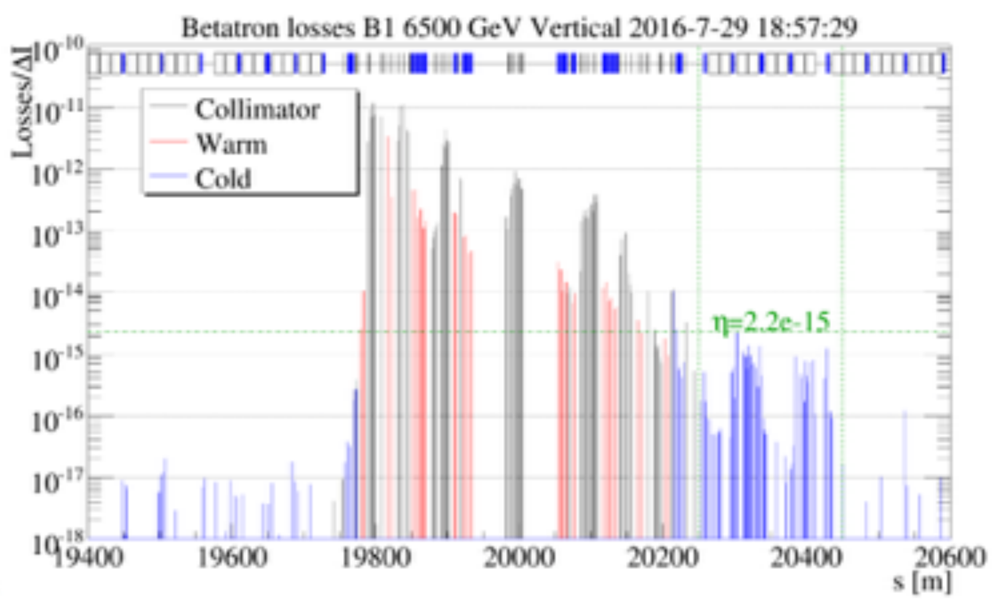


Angular scan at 6500 GeV

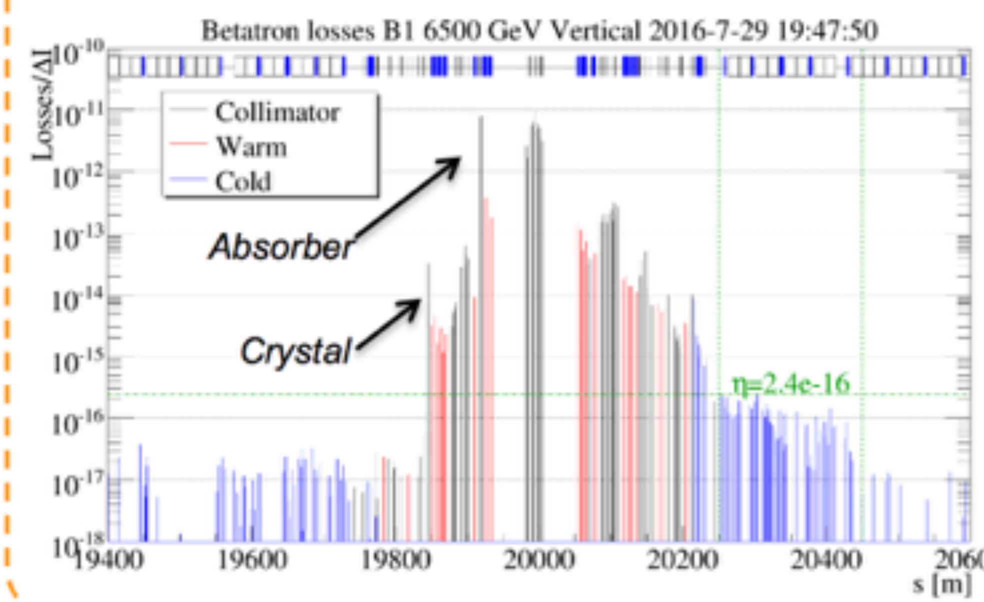


Low-intensity beam tests: gain factor ~10 in cleaning at 6.5TeV

Standard collimation



Crystal collimation

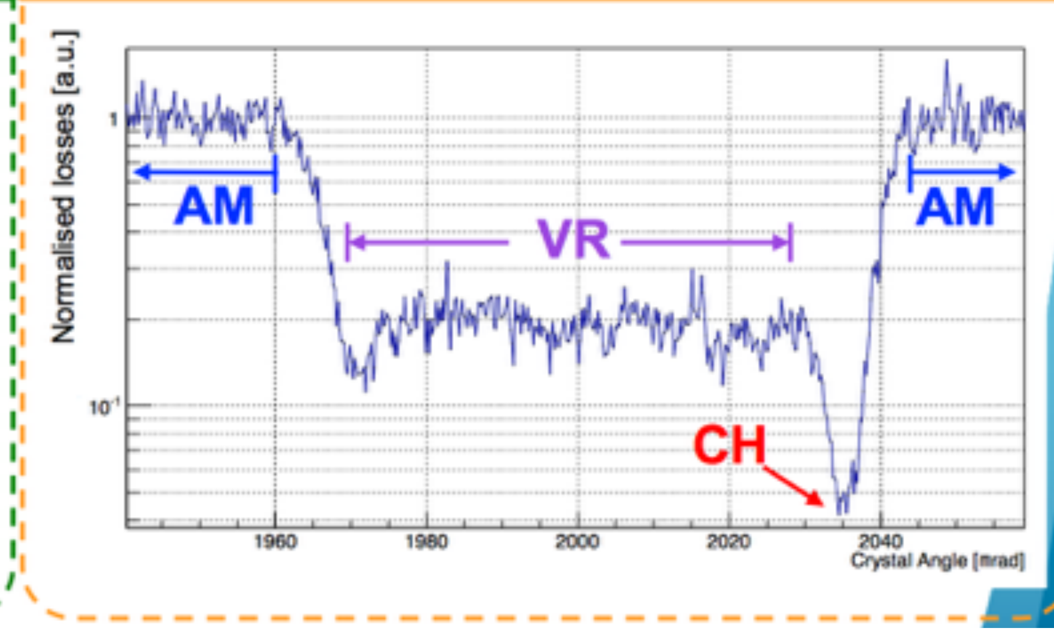


See talk by D. Mirarchi

Crystal collimation results

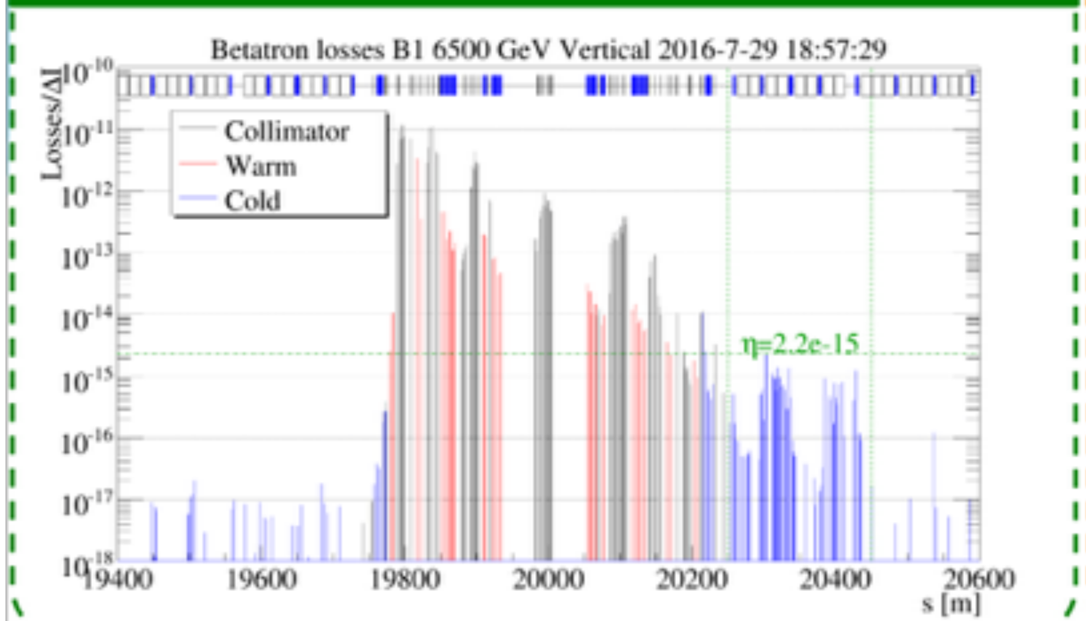
Angular scan at 450 GeV

Angular scan at 6500 GeV

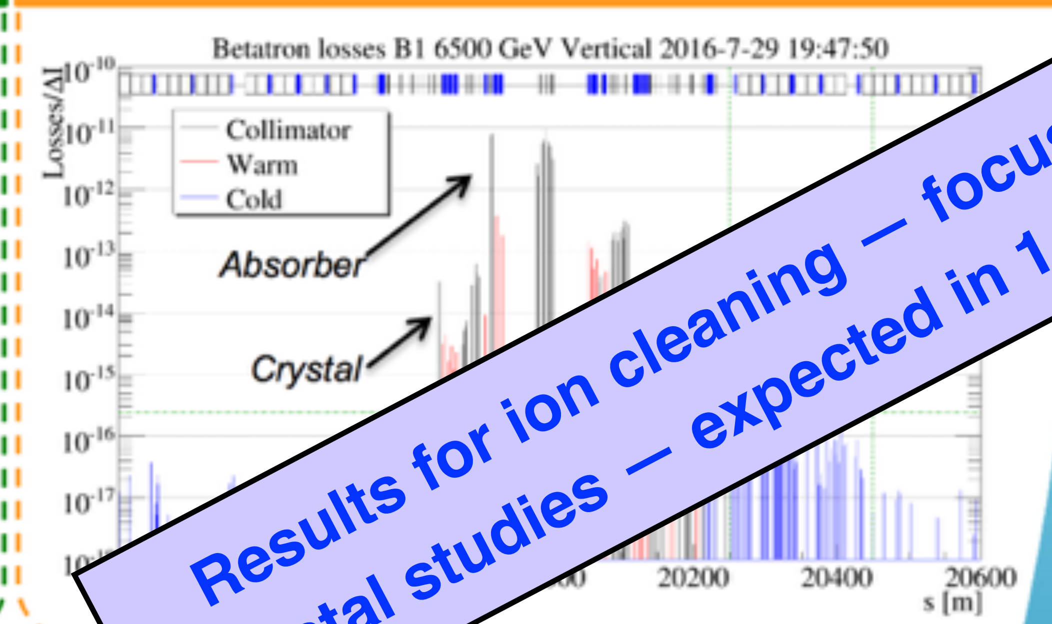


Low-intensity beam tests: gain factor ~10 in cleaning at 6.5TeV

Standard collimation



Crystal collimation

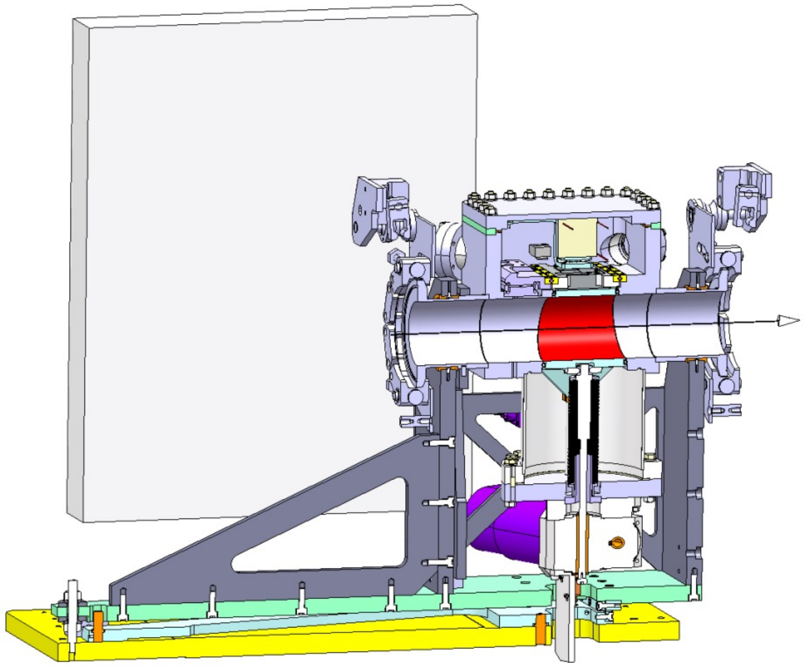


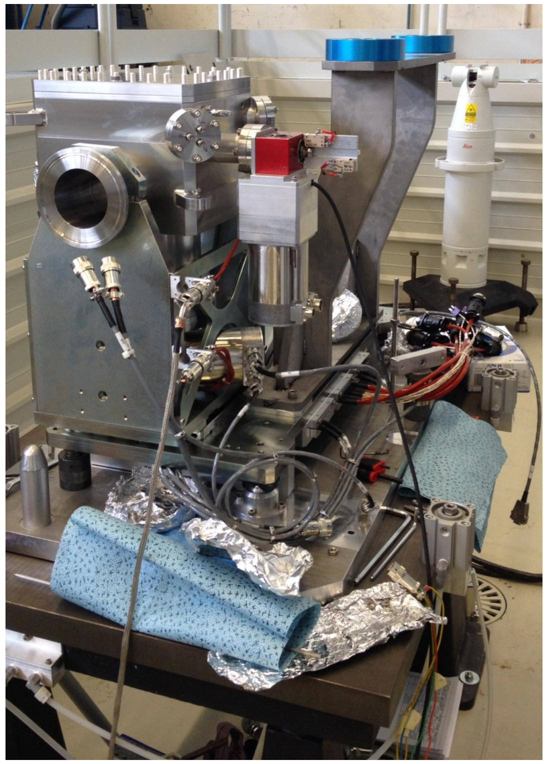
Results for ion cleaning – focus of crystal studies – expected in 1 week!

See talk by D. Mirarchi

Controls R&D and development for crystals

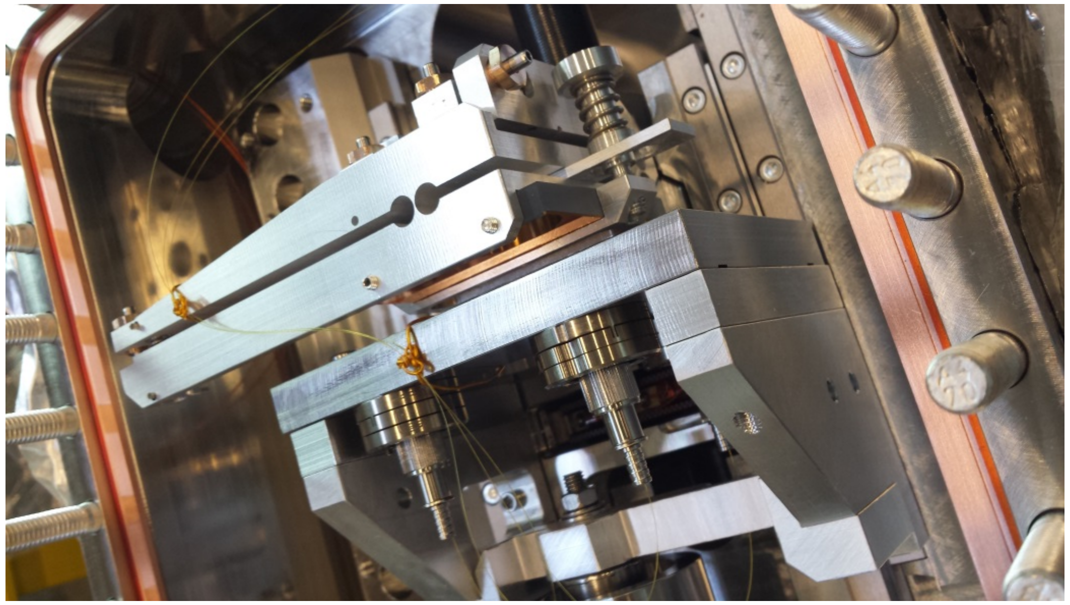
Challenge: angular control belo 1 micro-rad in static and dynamic conditions





Two goniometers installed on B1 in LS2; two more will be installed on B2 in 2017. Developed a control technique based on **interferometer to stabilise angle**. Pioneer technology for accelerators.

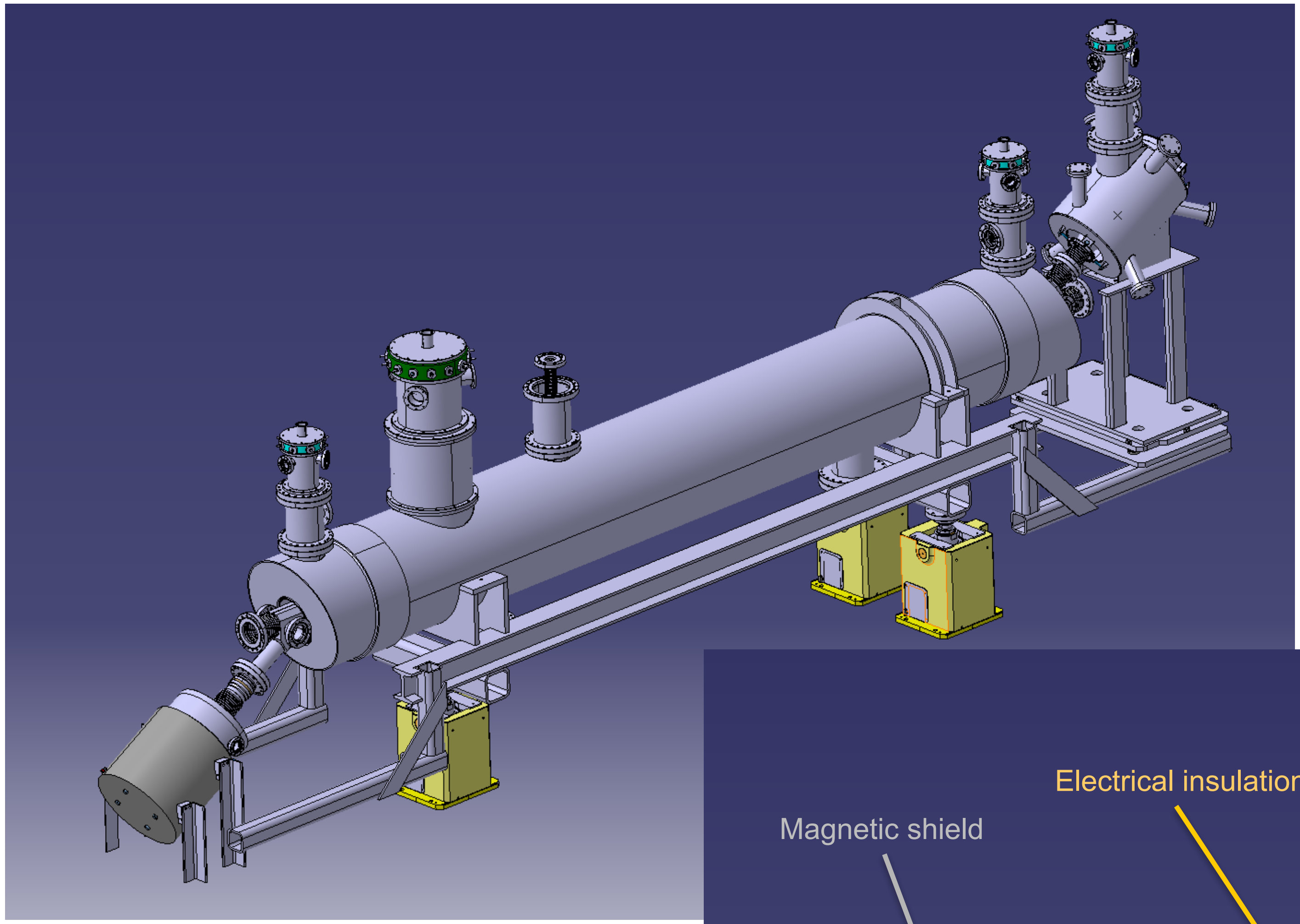
A. Masi for the STI controls team



Piezo rotational stage controlled in closed loop using the Attocube FPS3010 interferometric measurement system based on 3 linear axes +/- 5 nrad accuracy

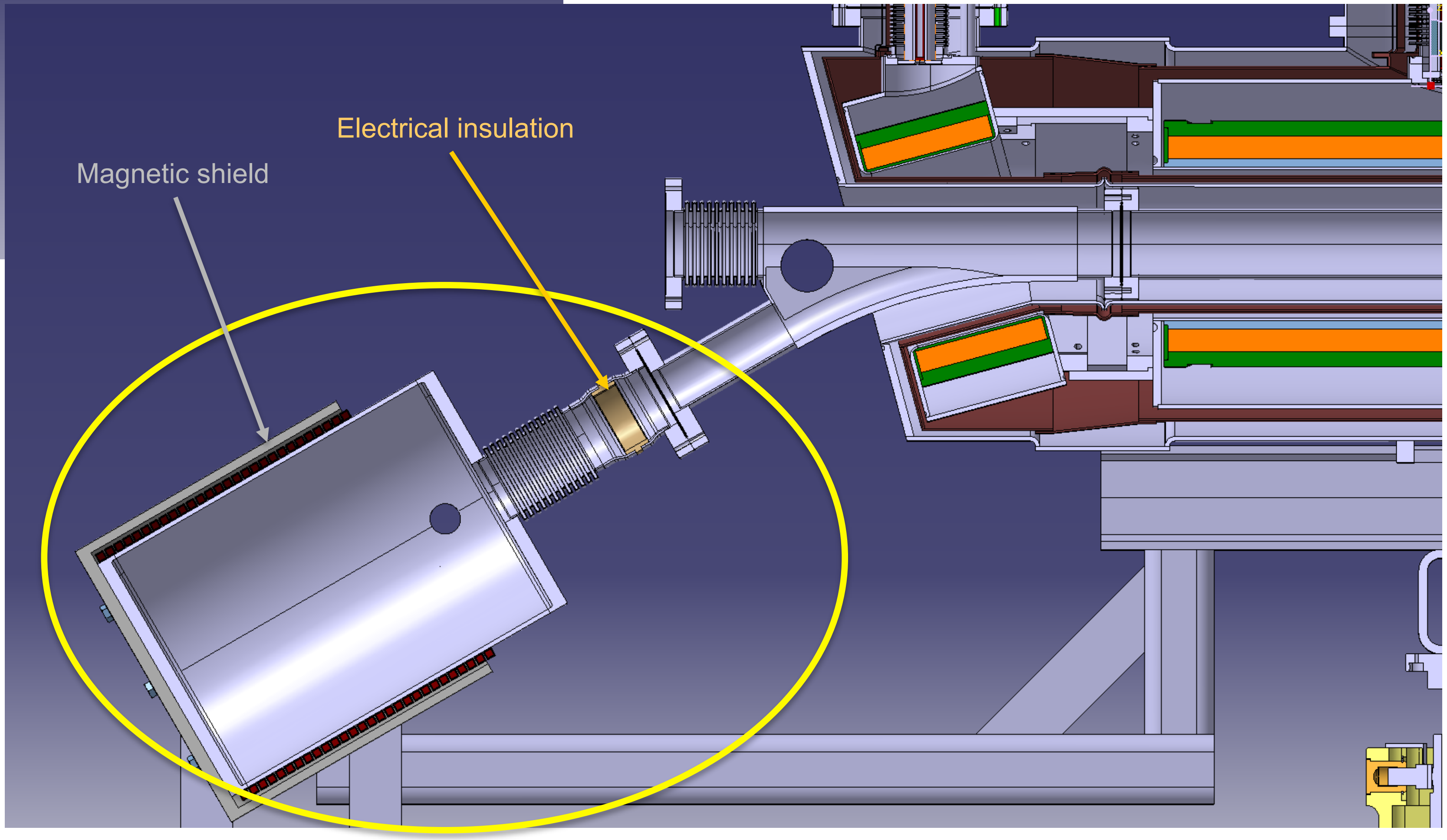
1. Reliably achieved channeling at 6.5TeV (critical angle = 2.5 urad)
2. Very promising first attempt at maintain channeling during the ramp (MD 2 weeks ago, analysis ongoing).

Hollow e-lens design



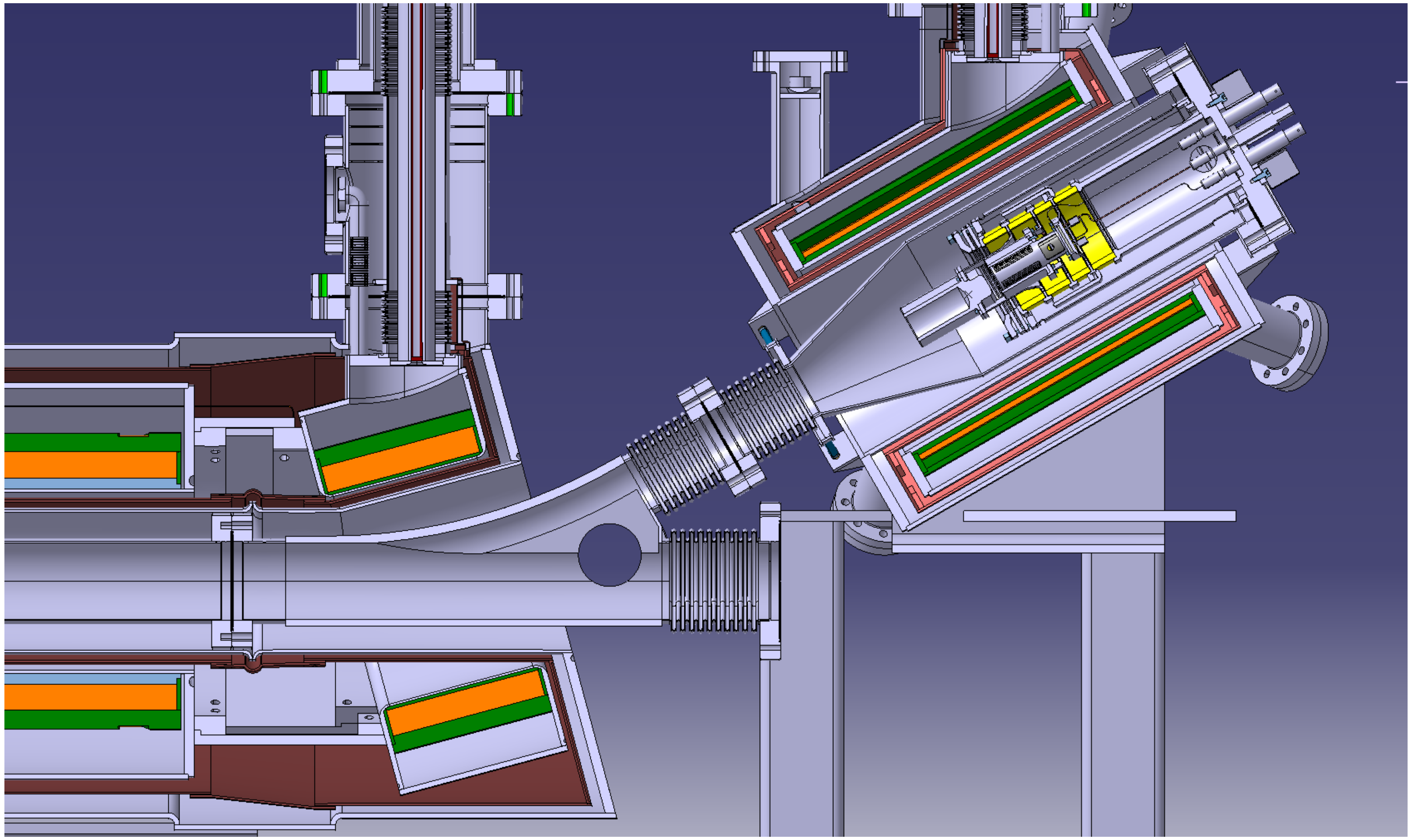
Technical design of hollow e-lens for the HL-LHC is well advanced! All key components have been addressed.

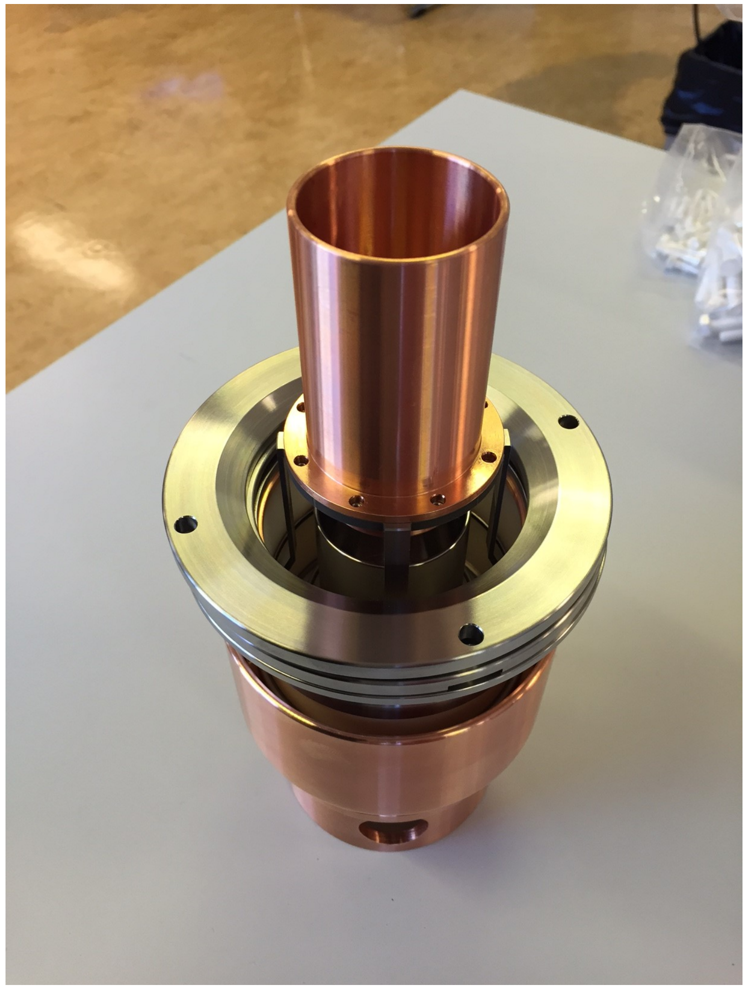
Timeline: implementation of two lenses in LS3!



D. Perini

Electron gun



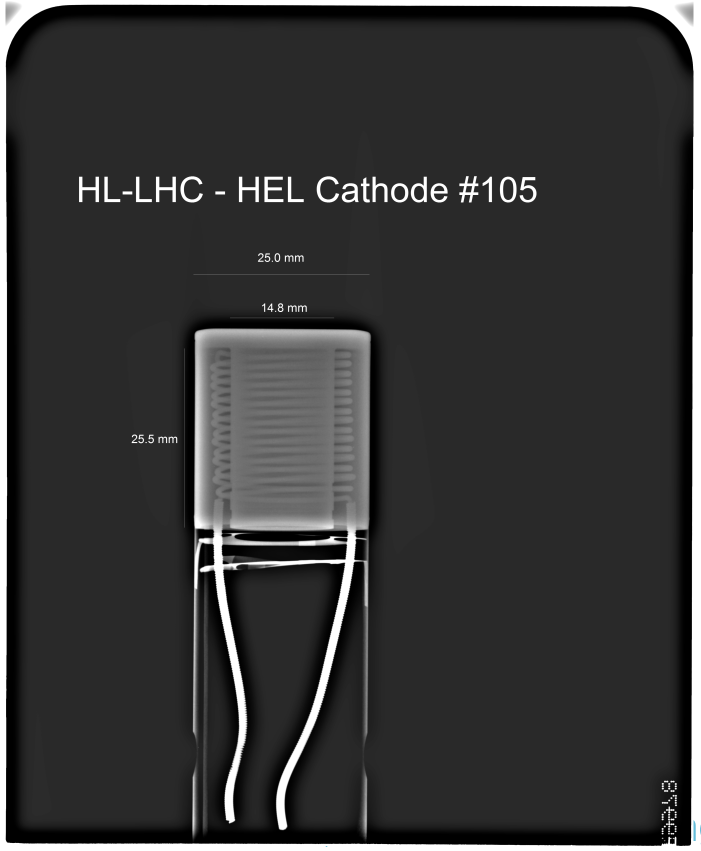


A gun has been produced at CERN EN-MME work shop – Starting point were the drawings received from FNAL. A few modifications were added to have the possibility of using it both in Europe and USA.

Beam tests at FNAL could not start yet because of a short shutdown. Start of tests should be imminent.
Considering also beam tests at RHIC.

Cathode developments

- Present gun used cathodes developed commercially
  - experienced issues/delays with a single producer in USA
- In synergy with the studies in BE/BI on higher-current cathodes, we are following up a cathode development program:
  - exploring other producers
  - testing a broader range of (claimed) currents
  - new development with Italian company to reproduce results of state-of-the-art from industry
- Status on e-beam design/simulations: see A.Rossi talk



Conclusions

- Reviewed the status of the collimation activities within HL-LHC
  - Recent changes of baseline were presented, and impact on LS2/LS3 preparation discussed.
- The collimation upgrade baseline is solid, and we believe that it can fulfil the HL-LHC requirement (with reasonable risks)
  - LS2: final implementation of dispersion suppressor collimation; first stage of IR7 collimation impedance reduction.
  - LS3: completed IR7 collimation impedance reduction; new collimation layouts in the high-luminosity IRs.
- Production of new collimators is feasible, with tight LS2 schedule
  - Well advanced with company qualification and market surveys.
- Important progress on other collimation concepts.
  - Shown results on crystal collimation and halo control.
- Next step: possible iteration on baseline to include hollow e-lenses, following the outcome of a recent international review
  - This possibility is being assessed.
- Thanks again to all them involved, within and outside CERN.