LHC Collimation Review 2013
May 30th-31st, 2013
CERN, Geneva, Switzerland

LHC Collimation Upgrade plans

Stefano Redaelli on behalf of the
Collimation Project, HL-LHC-WP5, EuCARD, US-LARP teams

The HiLumi LHC Design Study is included in the High Luminosity LHC project and is partly funded by the European Commission within the Framework Programme 7 Capacities Specific Programme, Grant Agreement 284404.

Review team photo

Outline

- ☑ Scope of collimation upgrades
- ☑ Upgrade strategy and timeline
- ☑ Selection of topics
- ☑ Advanced concepts
- ☑ Conclusions

Scope of collimation upgrades

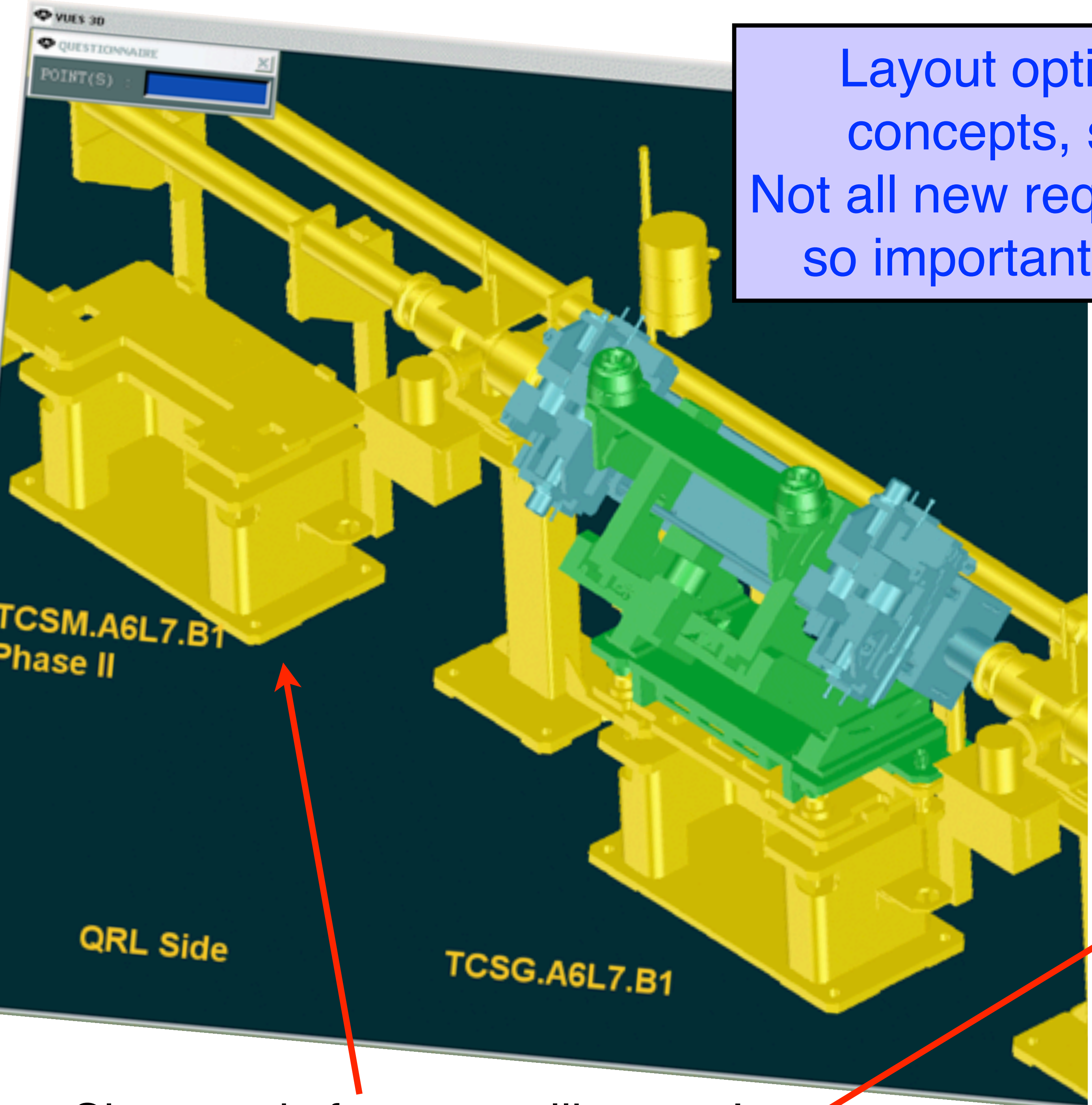
- ☑ Improve the **cleaning performance** — ➛ This review
  - *System limitations: dispersion suppressors (DS's)*
  - *Advanced concepts for halo scraping and diffusion control; crystal collimation.*
- ☑ Improve cleaning of **physics debris** — ➛ My talk yesterday
- ☑ Improve **impedance** and **robustness**
  - *State-of-the-art new material and new designs for secondary collimator jaws*
  - *Improved robustness at critical locations (like TCTs)*
- ☑ Improve **operational** efficiency / machine protection aspects
  - ***Better beta* reach**, faster collimator alignment;*
  - *More flexibility for machine configurations (experimental regions).*

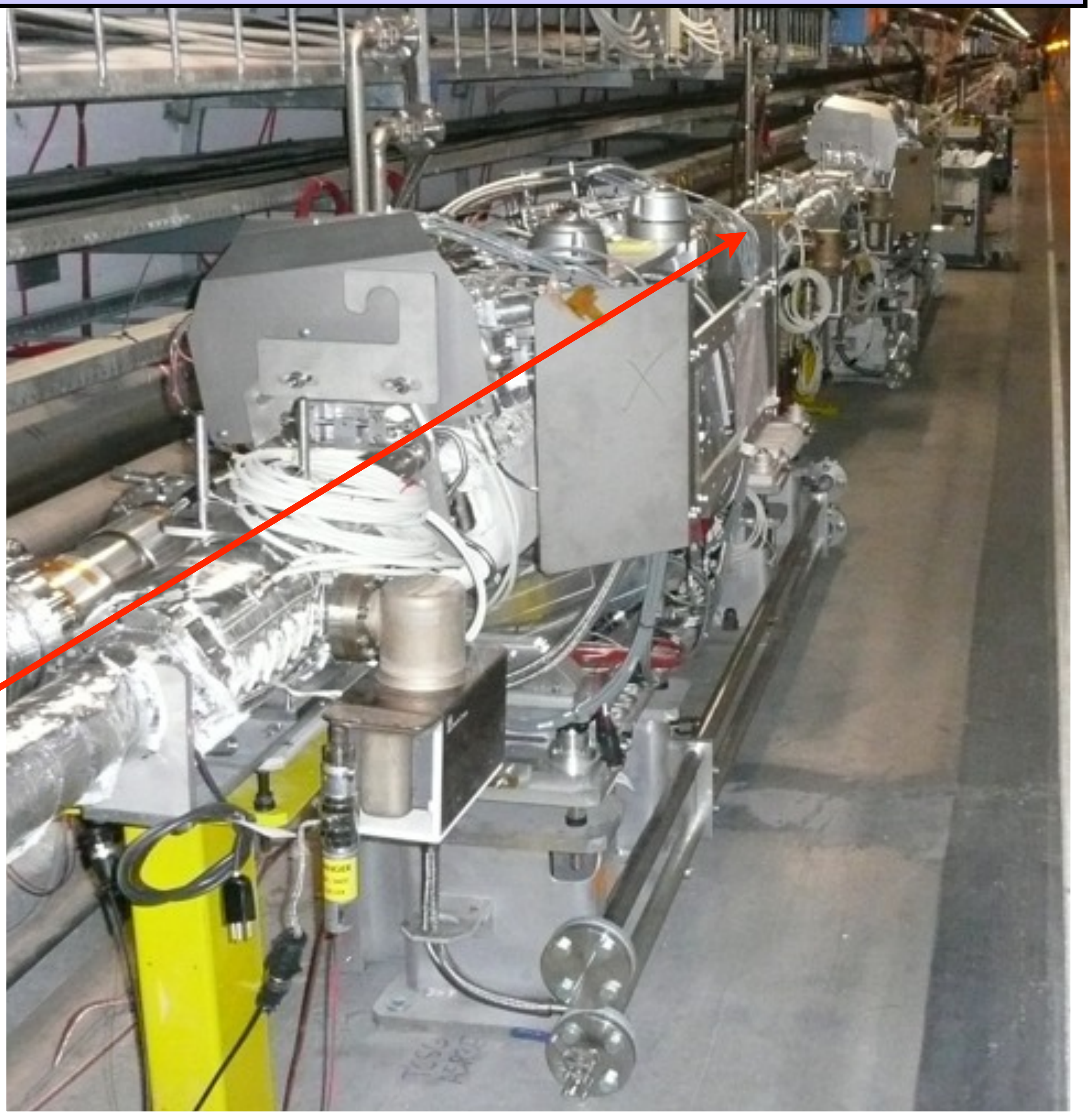
  ➛ My talk yesterday
- ☑ Improve protection of the **warm magnets** in cleaning IRs.
- ☑ Be ready to replace **collimators** if they brake or age — ➛ R. Losito's talk
  - *The hardware is designed for 10 y lifetime*
- ☑ Achieve **remote handling** in high radiation environment — ➛ R. Losito's talk
  - *Quick collimator replacement in hottest LHC locations*
- ☑ **New layouts** in experimental regions for **HL-LHC**
  - *Re-think IR1/5 collimation for new optics options/constrains*
- ☑ New injection / dum

Here, address mainly hardware aspects. Important ongoing simulation efforts (e.g. HiLumi-WP5) not covered.

The layout is optimized for upgrades

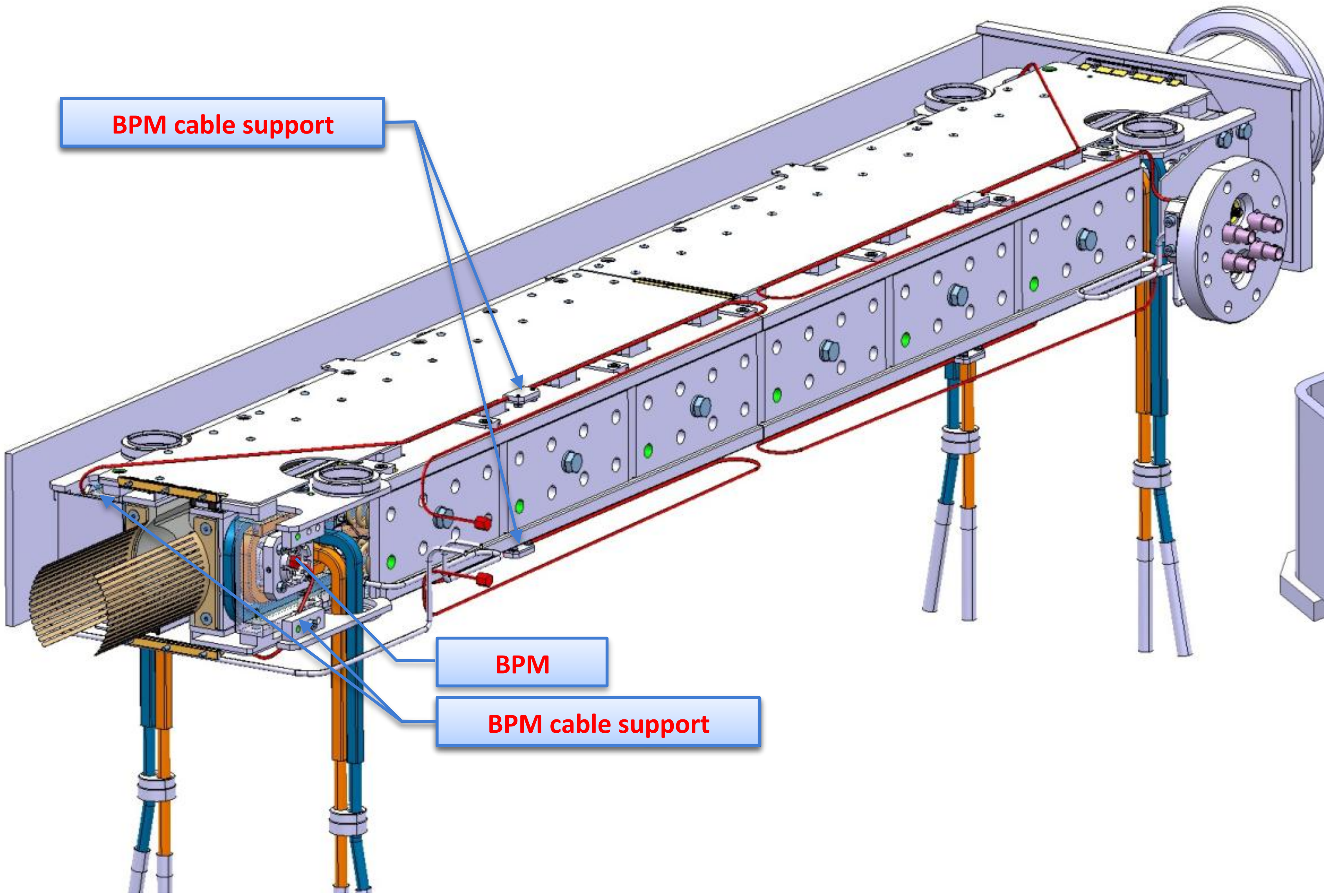
Layout optimized for some upgraded (quick plug-in concepts, slots for new TCSGs). Thanks to Ralph!
Not all new requirements are covered by the existing slots, so important changes are needed for major upgrades.



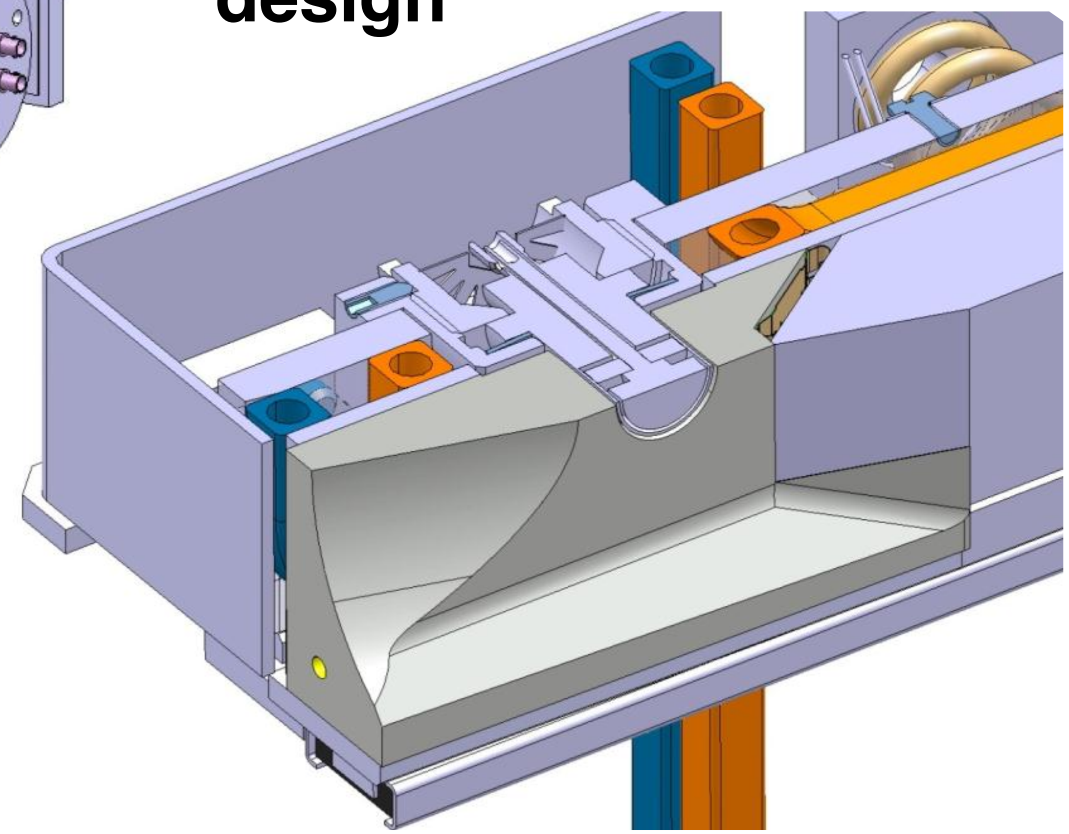


Slots ready for new collimators!
Can install and test new designs/ materials in IR3/7 without impact on the present system.
Installation in short tech. stops.

Baseline for future collimators



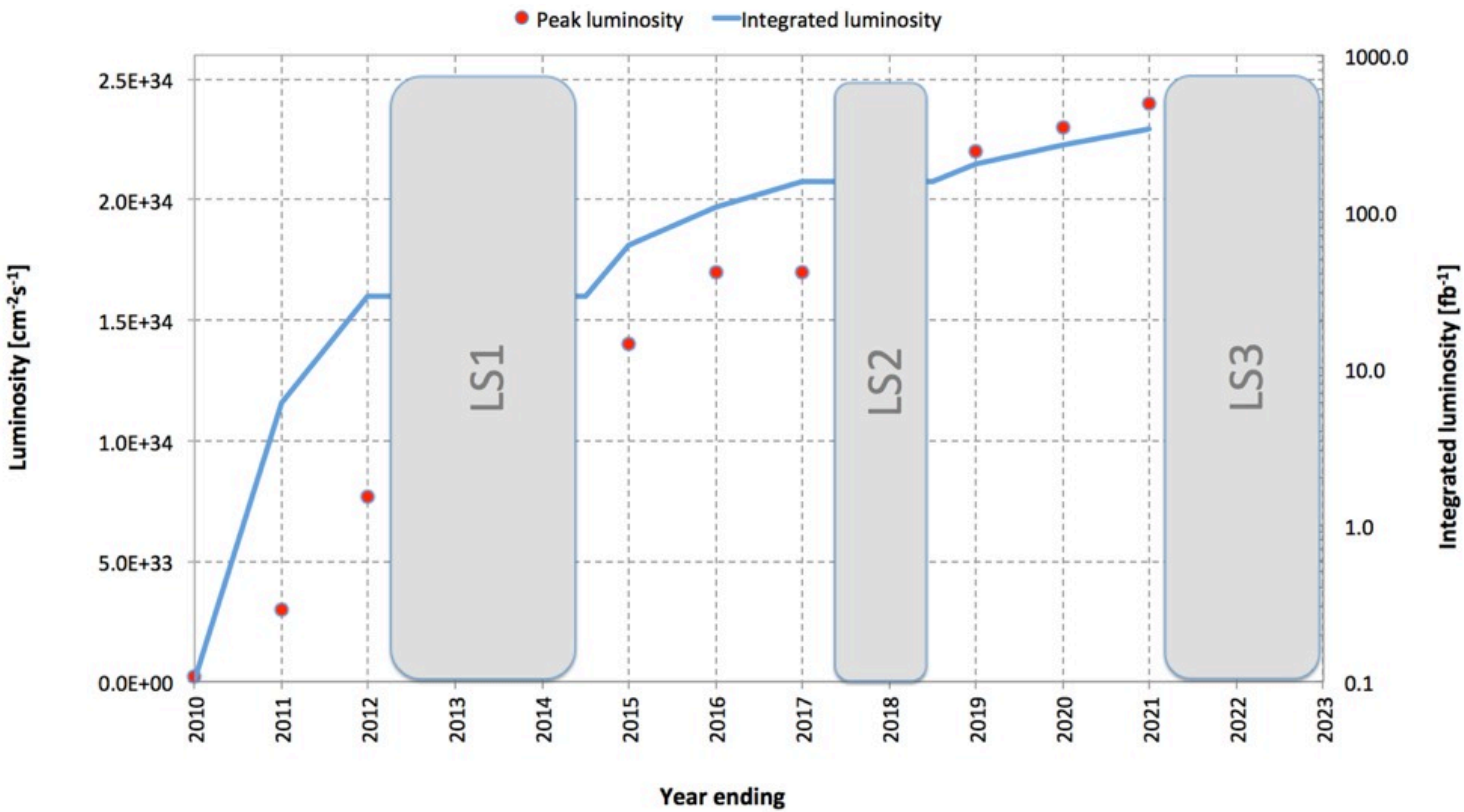
BPM collimator design



Courtesy of A. Dallocchio for the MME team

- New BPM features + various design improvements.
- Expect a lot from this design ➛ consider this as baseline for new collimators.
  Ideally, would like to have BPMs in all collimators.
  In practice, we will try to replace critical ones first.
- The BPMs require new cabling - major concern now for the LHC!
- Design details against impedance can be optimized further *(see N. Mounet's talk)*

Recap. of timeline towards HL-LHC



Major changes of the collimation system must be synchronized with LS's.
But important improvements can also take place in short stops
(E.x.: add some TCL, or replace critical TCT's in short stops).

Overall strategy and timeline (i)

Shutdowns 2010-11 and 2011-12

- New IR2 layout for improved ALICE data taking.
- Software for faster and more robust collimator alignment.
- Improved protection strategy (β^* limits).
- Improved controls HW: OP efficiency against downtimes from radiation.

LS1 (LHC energy to ~ nominal)

- **BPM-integrated design** in experimental and dump regions (16 TCT, 2 TCSG)
  → **Faster** alignment in the IP's, **smaller β^***, improved **machine protection.**
- **New passive absorbers in IP3** (longer lifetime of warm magnets).
- Updated layout of **physics debris absorption** (new TCL layout in IR1/5).
- Improved collimation vacuum layout in IR8.
- Replacement of electronics components to improve redundancy.
- Update the **air duct** in the betatron cleaning insertion.
- Replace 1 primary collimator that presented abnormal heating.

Overall strategy and timeline (ii)

LS2 (double LHC luminosity)

- Possible first upgrade of experimental regions: **DS collimators**.
- Additional collimators equipped with **BPMs** (faster alignment, better protection).
- **Improved design** and **new materials** (less impedance, more robustness).
    - Considering to upgrade the TCSG's in IR7 for impedance reduction
    - More robust TCT at selected locations
- Possible implementation of **hollow e-lens** as beam scraper.
- Investigate collimator HW **aging** / lifetime.
- Remote handling (partly).

LS3 (HL-LHC)

- Re-design of **collimator layout** in the experiments regions.

  (DS collimators + additional local protection for ATS optics).
- Complete **DS collimation** in all the required IRs.
- New collimator materials to **replace collimators** that have aged. BPM design.
- Fully remote handling in radiation environment.
- New concepts for improved cleaning (crystal, hollow e-lens) - if needed.
- . . .

Outline

- Scope of collimation upgrades
- Upgrade strategy and timeline
- **Selection of topics**
  - **Materials studies**
  - **New designs**
- Advanced concepts
- Conclusions

Recap.: Robustness vs. impedance

- "Staged approach" to the LHC collimation challenges:
  - *Initial system based on CFC jaw: robustness at the expenses of impedance and cleaning. Considered appropriate for the LHC startup.*
  - *CFC primary and secondary collimators must withstand basic failure scenarios.*
- Operation experience at β* limits showed the importance of **TCT robustness**!
  - *Significant operational overhead to make sure that TCTs are protected.*

- **Failure scenarios** are being re-evaluated based on the 2010-13 experience
  - *See discussions at recent machine protection workshop. Many new ideas on the table.*
- Complex parameter space for **beam instability** matters: see talk by N. Mounet
  - *Interplay between impedance, damper performance, machine settings (Q', octupoles), beam-beam, operational scenarios (collisions, squeeze, ...)*
  - *There will be a workshop on that after summer.*

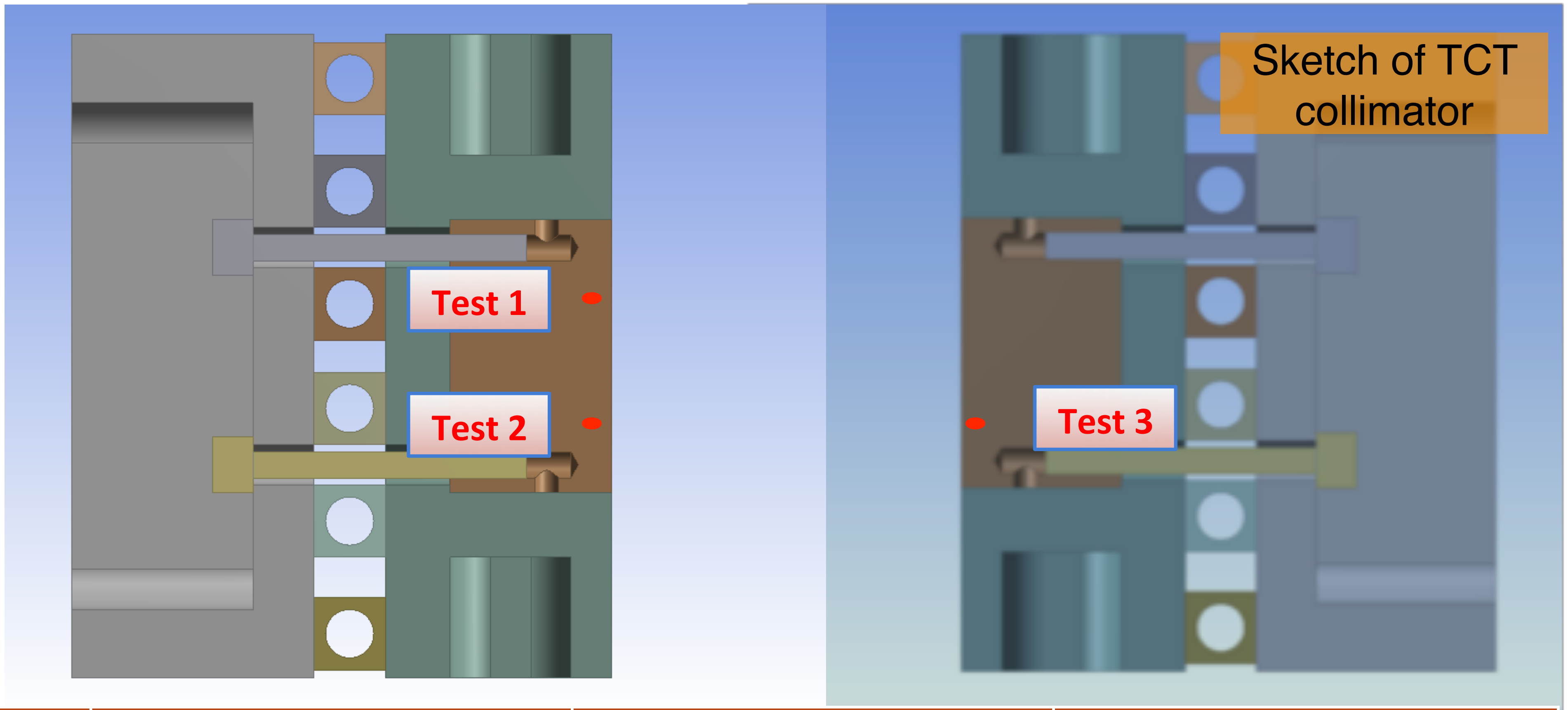
- Our goal:

  Can we find an ideal material with low impedance and high robustness?
  Immediate applications: improve IR7 impedance and TCT robustness.
- Rich program to understand the **material changes** with **high radiation doses**!
  - *Parallel programs at Kurchatov, BNL. Hopefully also at GSI (ions) within EuCARD2*
  - *Experimental evidence as well as theoretical understanding are crucial!*

Collimator robustness at HRM

- Beam energy: **440 GeV**
- Impact depth: **2mm**
- Jaws half-gap: **14 mm**

A. Bertarelli, *et al*



	Test 1	Test 2	Test 3
Goal	**Beam impact equivalent to 1 LHC bunch @ 7TeV**	**Identify onset of plastic damage**	**Induce severe damage on the collimator jaw**
Impact location	Left jaw, up (+10 mm)	Left jaw, down (-8.3 mm)	Right jaw, down (-8.3 mm)
Pulse intensity [p]	3.36×10^{12}	1.04×10^{12}	9.34×10^{12}
Number of bunches	24	6	72
Bunch spacing [ns]	50	50	50
Beam size [σ_x - σ_y mm]	0.53 x 0.36	0.53 x 0.36	0.53 x 0.36

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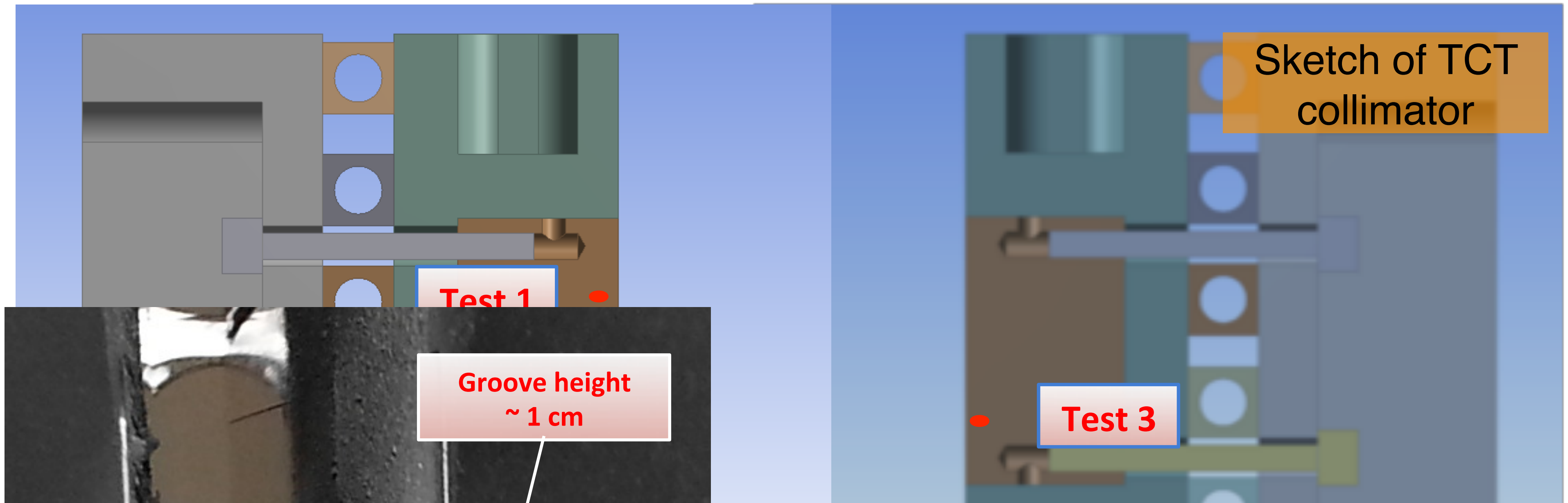

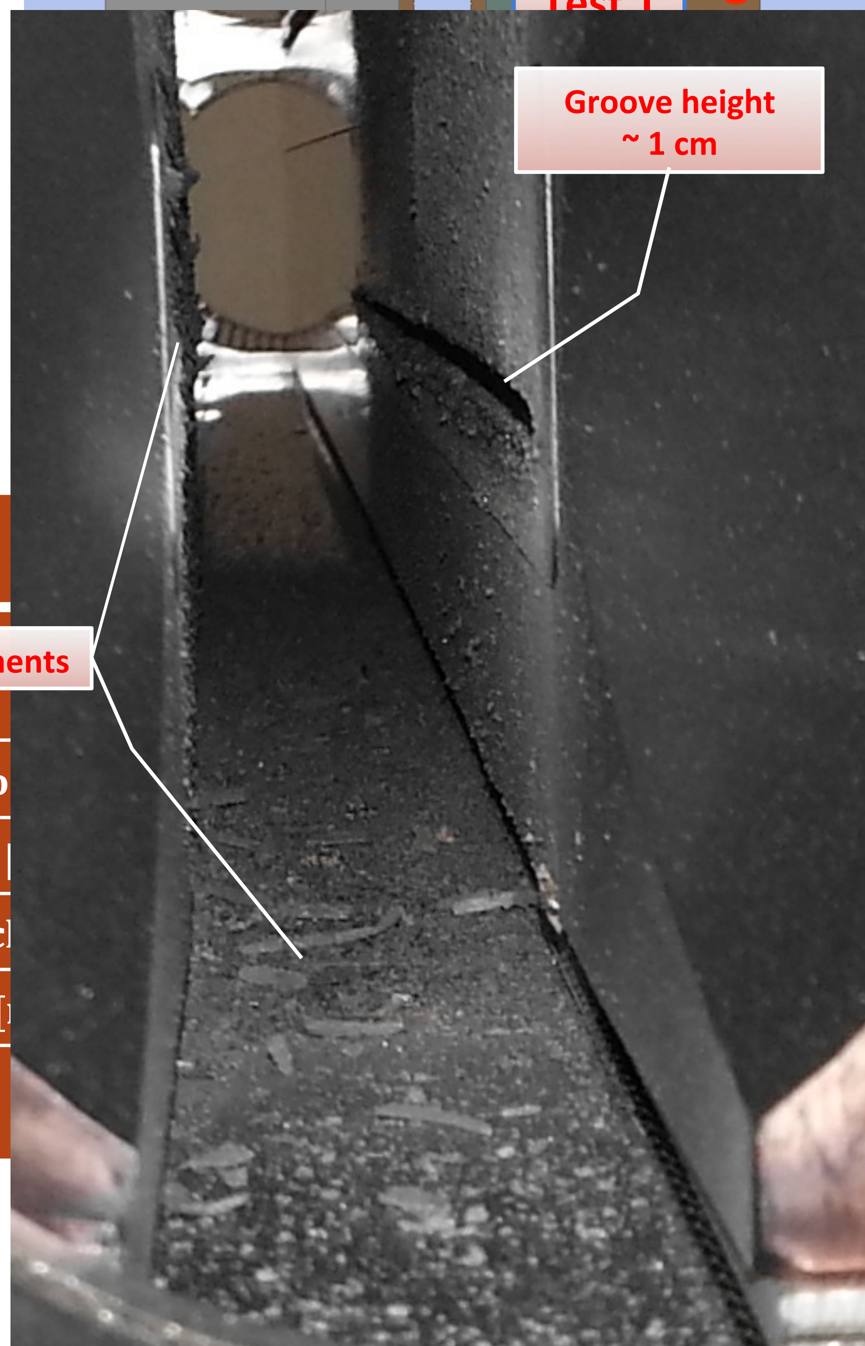

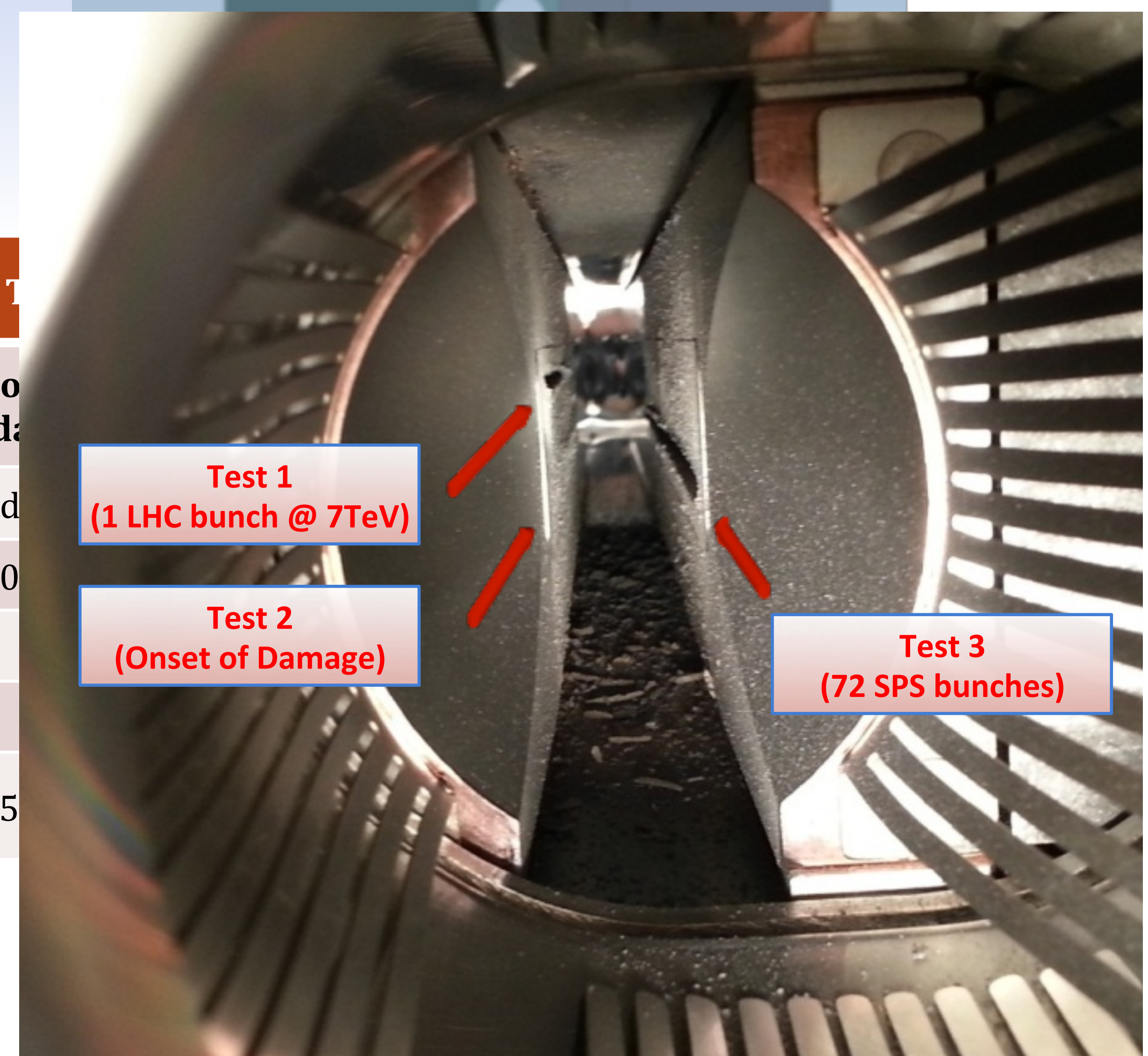

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Impact locatio	aw, d
Pulse intensity		1.0
Number of bunc	
Bunch spacing [	
Beam size [σ_x - σ_y mm]	0.5

12

Updated robustness limits

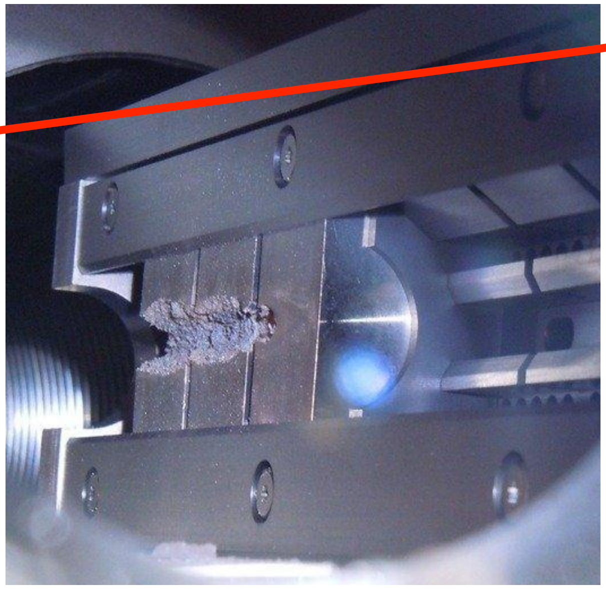
- New damage limits proposed in line with updated accident scenarios (Annecy ‘13):
  - **Onset of plastic damage : $5x10^9$ p**
  - **Limit for fragment ejection: $2x10^{10}$ p**
  - **Limit of for 5^{th} axis compensation (with fragment ejection): $1x10^{11}$ p**

Challenge for the collimator commissioning at 7 TeV that required a few nominal bunches for collision and orbit setup! Need follow up!

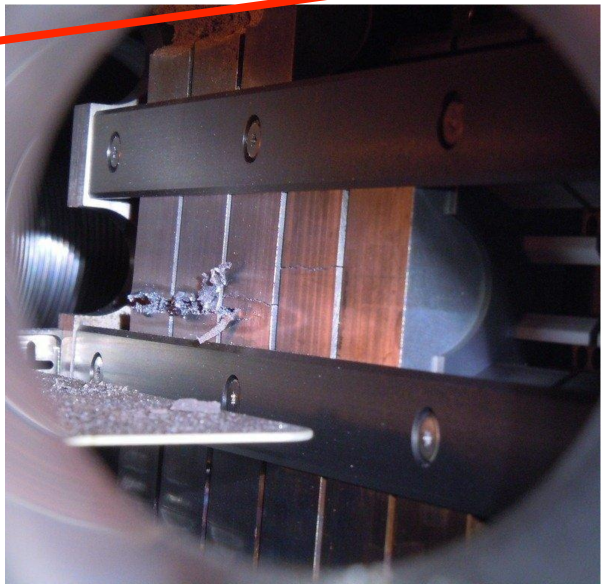
Studied alternative materials for future collimator jaws!

Investigating Mo-coated Mo-G!

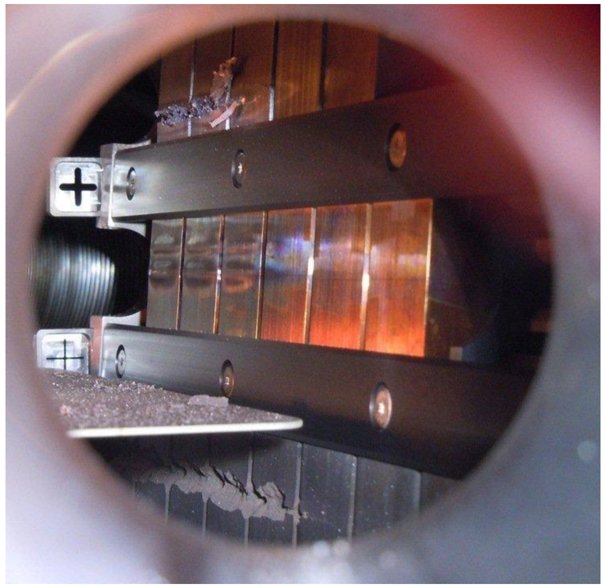
A. Bertarelli:
MP workshop 2013
Recent ATS seminar



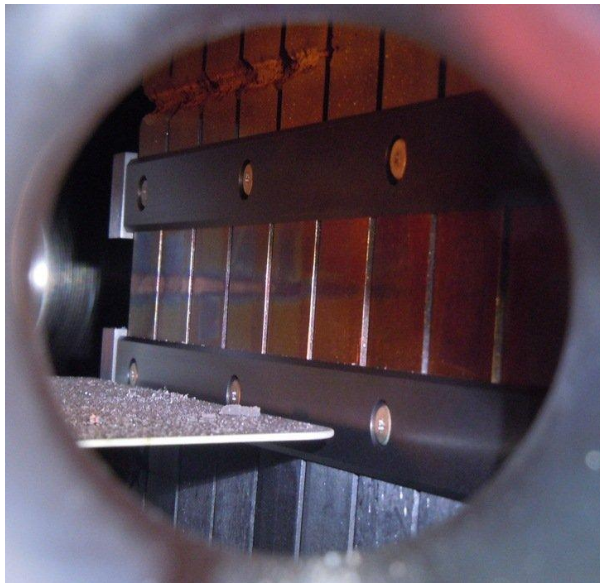
Inermet 180, 72 bunches



Molybdenum, 72 & 144 bunches



Glidcop, 72 bunches (2 x)



Copper-Diamond 144 bunches

Molybdenum-Copper-Diamond 144 bunches

Molybdenum-Graphite (3 grades) 144 bunches

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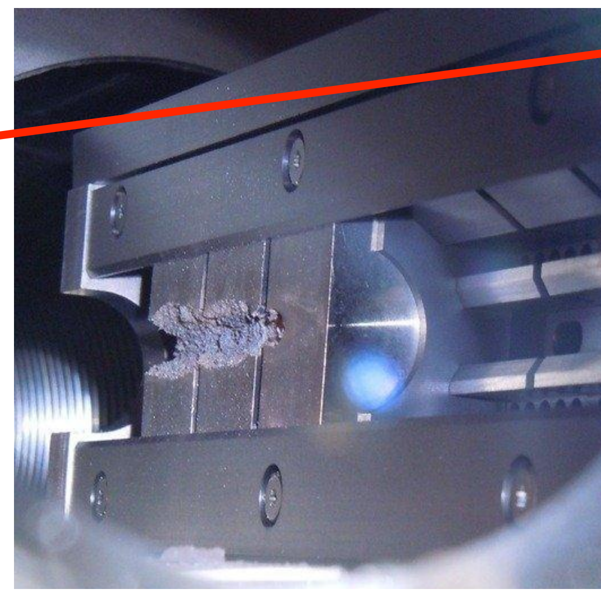

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Copper-Diamond
144 bunches

Molybdenum-Copper-Diamond
144 bunches

Molybdenum-Graphite (3 grades)
144 bunches

Dedicated working group chaired by A. Dallocchio started to come up with an executive summary of HRM results.

In addition to fast loss scenarios, it is important to address the issue of material property changes in case of **high radiation doses**.

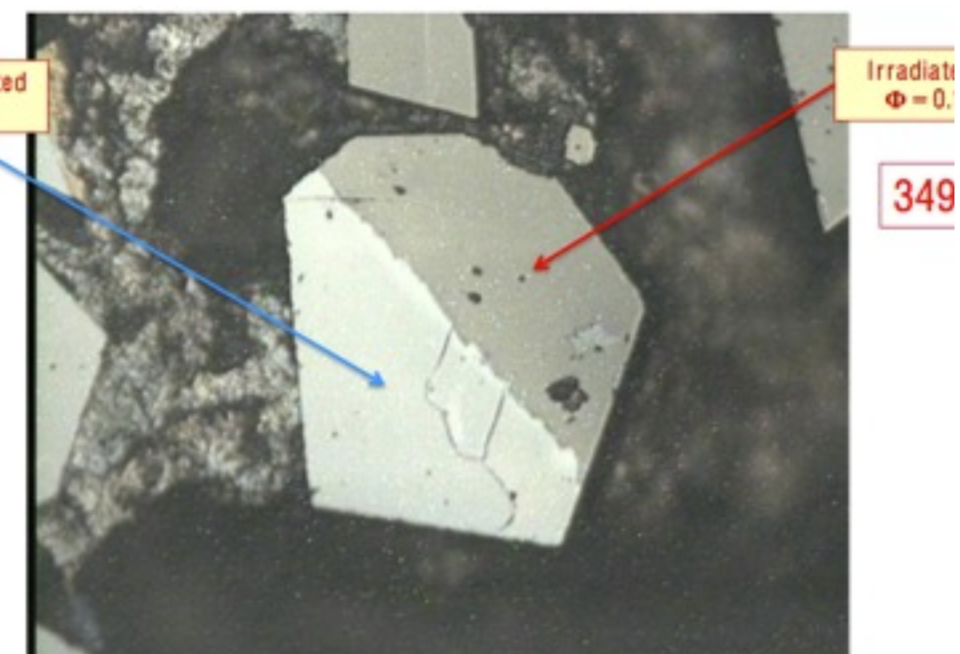
Material properties under high doses

Fast loss studies at HRM address robustness against failure scenario, with impact on β* reach.

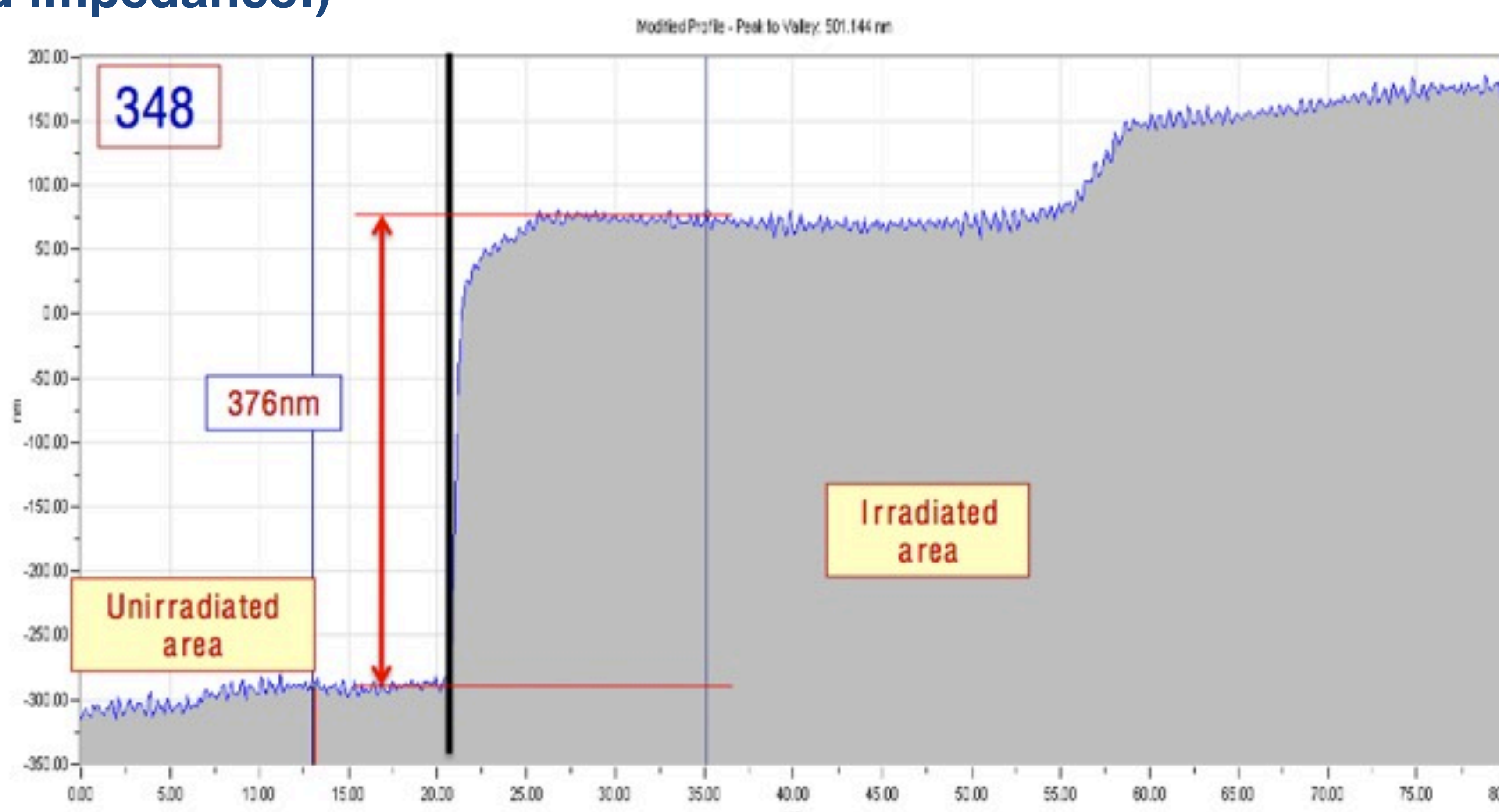
We work with **high priority** on understanding the **material behaviour** under high irradiation doses! Collaboration with Russia (Kurchatov) and USA (BNL within LARP): testing a panel of **6 new materials**.

Thanks a lot to the US-LARP friends for supporting this new study proposed in 2012! Supported also by EuCARD + EuCARD2.

Key issues: Variation of dimensions (swelling)
Change of thermo-mechanical properties (increased impedance!)



A. Ryazanov, Kurchatov



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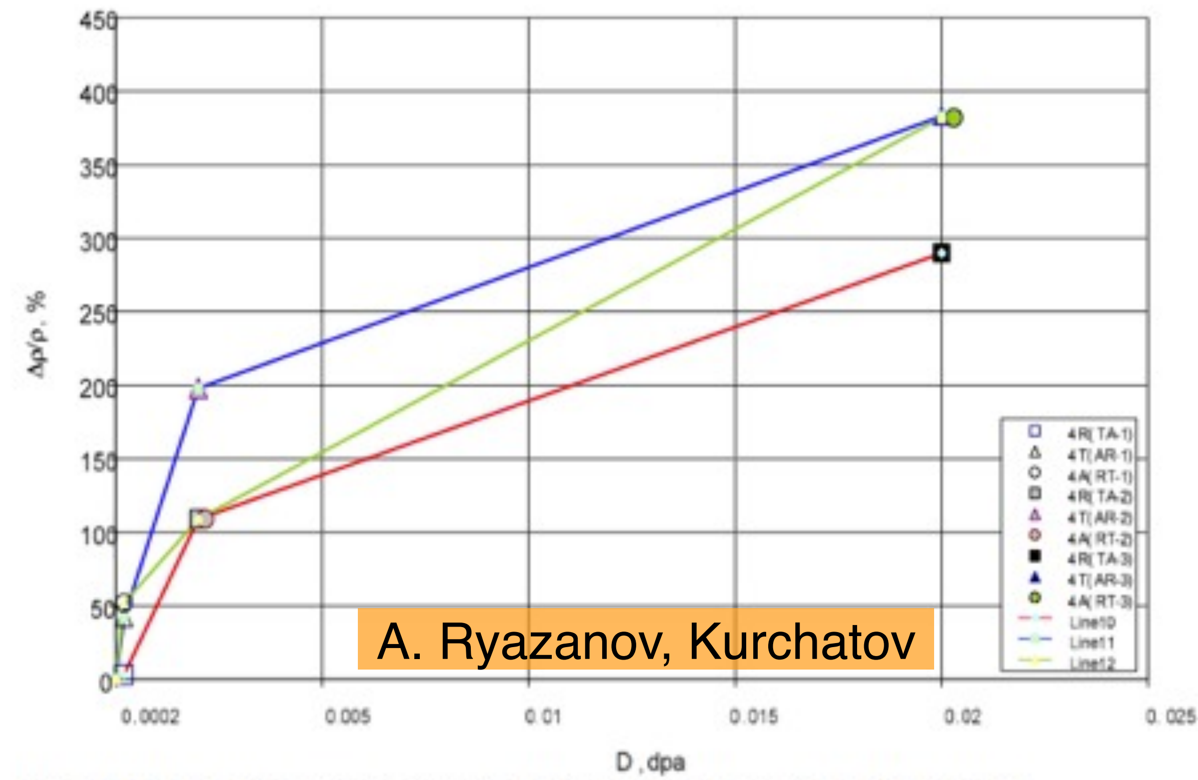
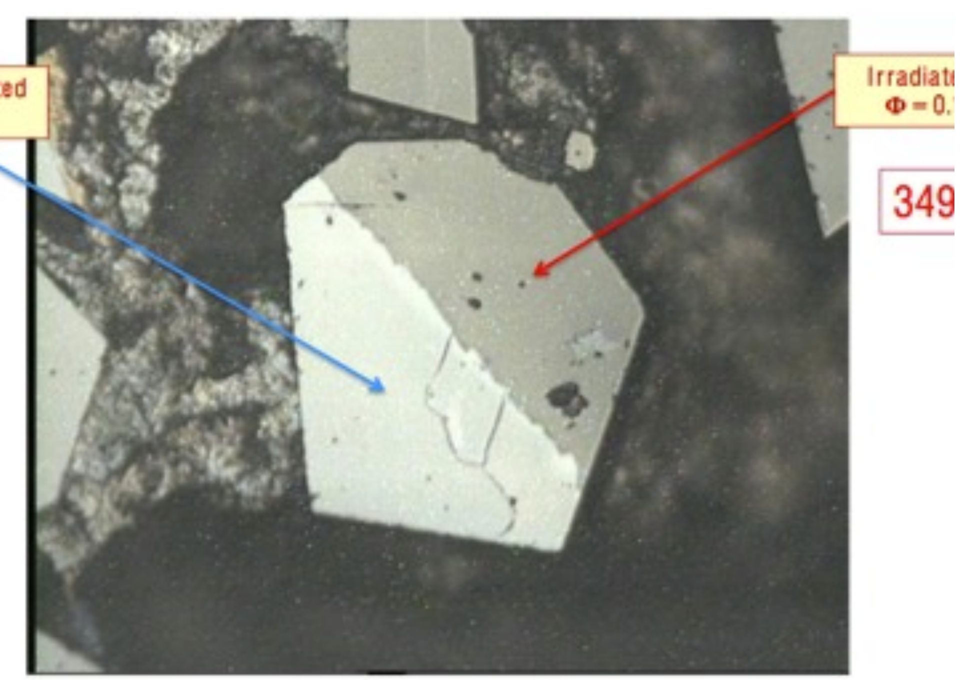


Fig. 50. The relative change in resistivity of samples for AC-150 material depending on the doses.



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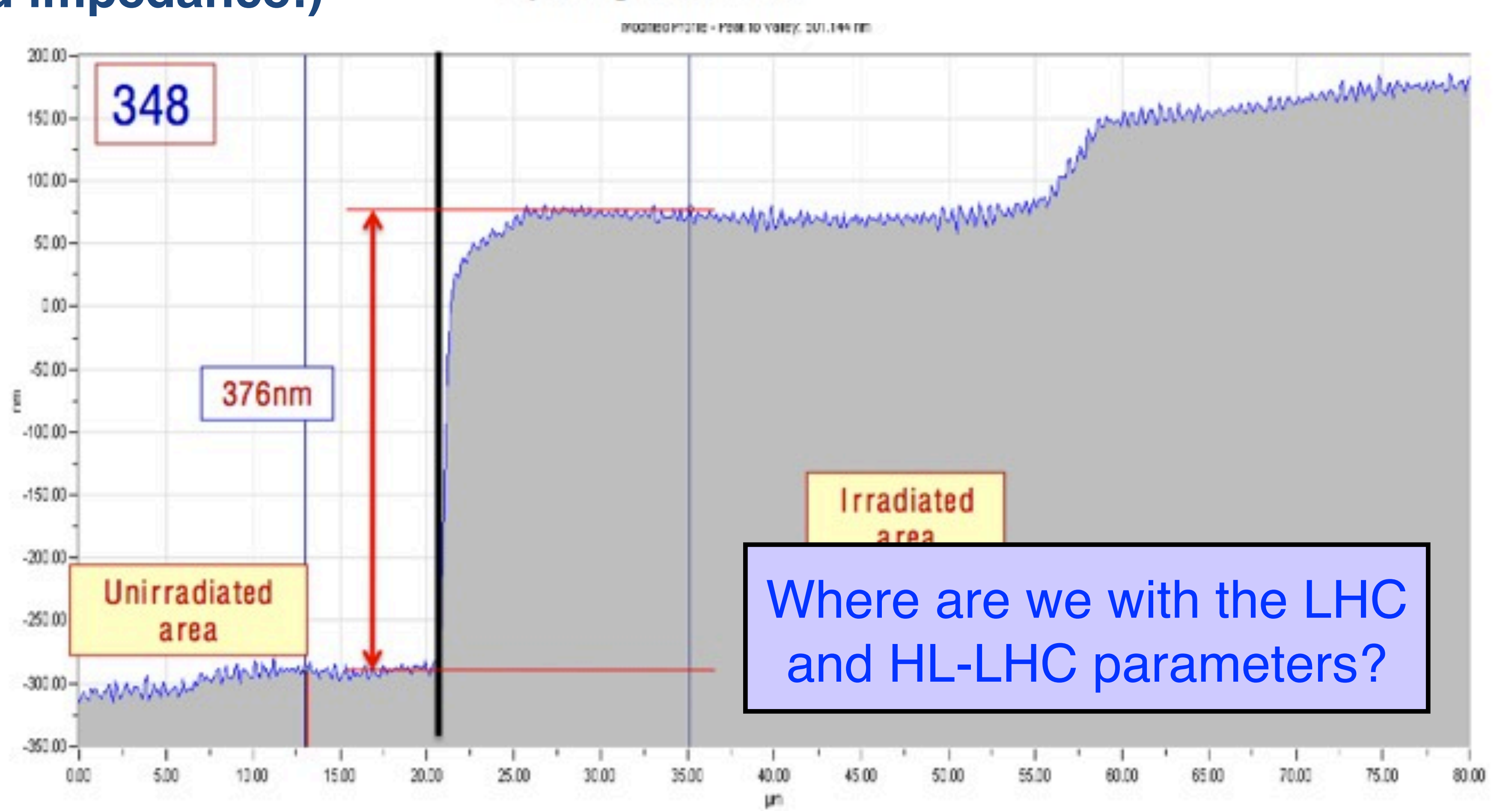


Where are we with the LHC and HL-LHC parameters?

Overview of ongoing studies

Proposal of **BNL** study brought forward at the CM18 a Fermilab (Apr. 2012).

Approved by US-LARP: endorsement at the Frascati meeting in Nov. (basic program and goals definition).

Complements and extends important studies ongoing at **Kurchatov**.

Goals of Irradiation in BNL

- Assess degradation of physical and mechanical properties of selected materials (Molybdenum, Glidcop, CuCD, MoGRCF) as a function of *dpa* (up to 1.0).
- Key physical and mechanical properties to be monitored :
  - Stress Strain behavior up to failure (Tensile Tests on metals, Flexural Tests on composites)
  - Thermal Conductivity
  - Thermal Expansion Coefficient (CTE) and swelling
  - Electrical Conductivity
  - Possible damage recovery after thermal annealing

l to expected *dpa* level in LHC at nominal/ultimate ons

indicator to compare different irradiation

Nicola Mariani – EN-MME 5

Radiation Hardness Studies

- Radiation Hardness is a key requirement.
- Benefit from complementary studies in two research centers with different irradiation parameters, different materials and approaches
- Results Benchmarking

Ongoing Characterization Program in RRC-Kurchatov Institute (Moscow) to assess the radiation damage on:
- CuCD
- MoCuCD
- MoGRCF (ex SiC)

Features:
- Irradiation with protons and carbon ions at **35 MeV and 80 MeV** respectively
- Direct water cooling and T~100°C
- Thermo-physical and mechanical characterization at different fluencies (10^{16}, 10^{17}, 10^{18} p/cm^2)
- Theoretical studies of damage formation

Proposal for Characterization Program in Brookhaven National Laboratory (New York) to assess the radiation damage on:
- Molybdenum
- Glidcop
- CuCD
- MoGRCF

Features:
- Irradiation with proton beam at **200 MeV**
- Indirect water cooling and T~100°C (samples encapsulated with **inert gas**)
- Thermo-physical and mechanical characterization for fluence **up to 10^{20} p/cm^2**
- Possibility to irradiate with **neutrons**

Experimental measurements must be complemented by a good understanding (theoretical/ simulations) on where we are with the LHC / HL-LHC regime (EuCARD2).

SLAC RC collimator design

The LARP Rotatable Collimator Prototype Candidate for a Phase II Secondary Collimator

LARP

Two jaw collimator made of Glidcop

- Rotate jaw after 1MJoule beam abort failure accident occurs

Each jaw is a cylinder with an embedded brazed cooling coil

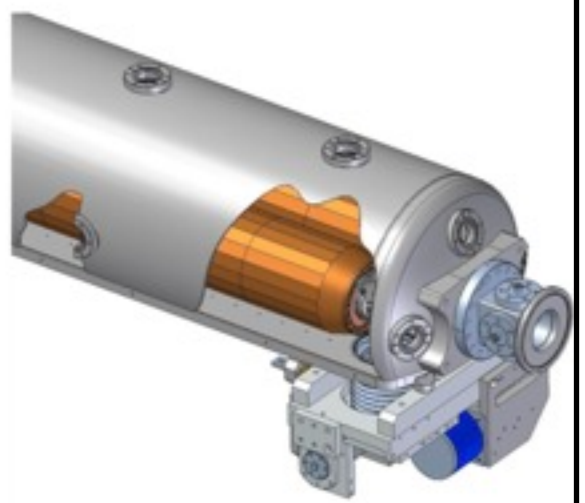
- No vacuum-water braze; 12kW/jaw cooling; minimal thermal distortion
- Maximum radius cylinder possible given beam pipe separation
- BPMs integrated on ends of tank

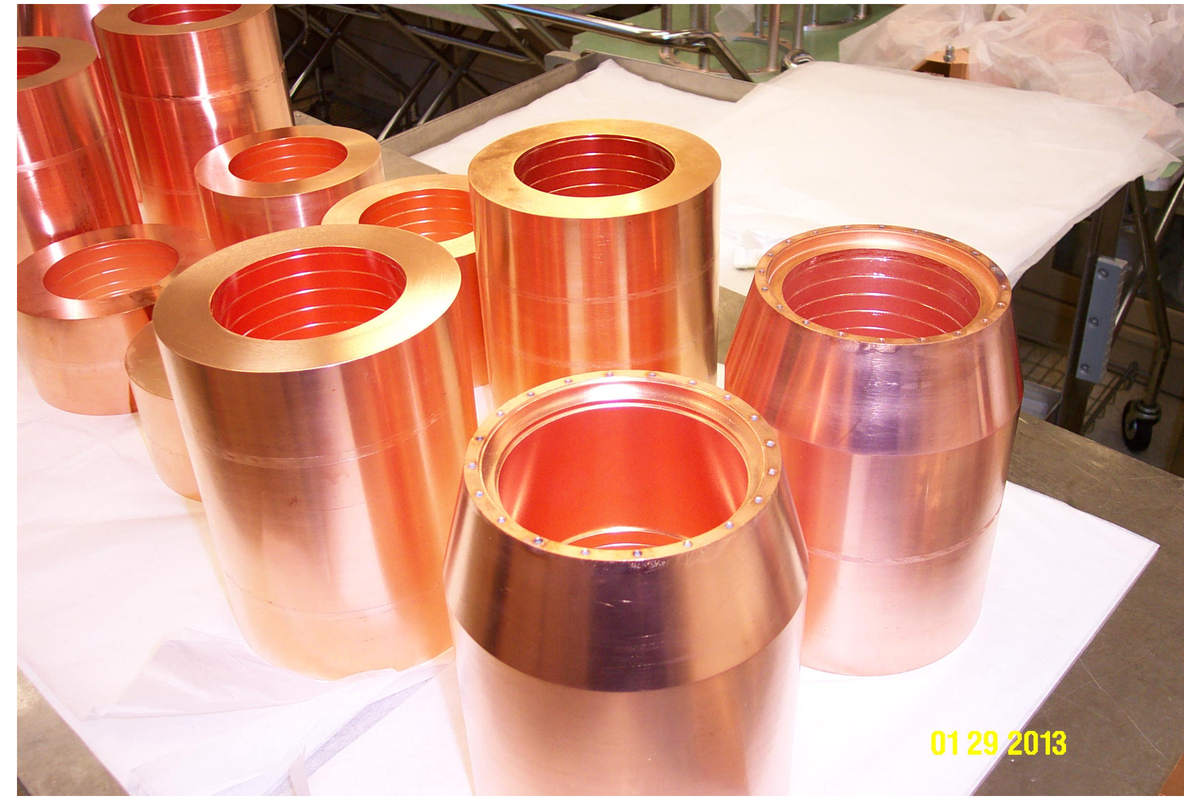
Advantages:

- Not exotic material
- High Z for better collimation efficiency & more debris absorption
- Low resistance for better impedance
- Elemental for high radiation resistance

Disadvantages:

- Glidcop WILL be damaged in asynchronous beam abort



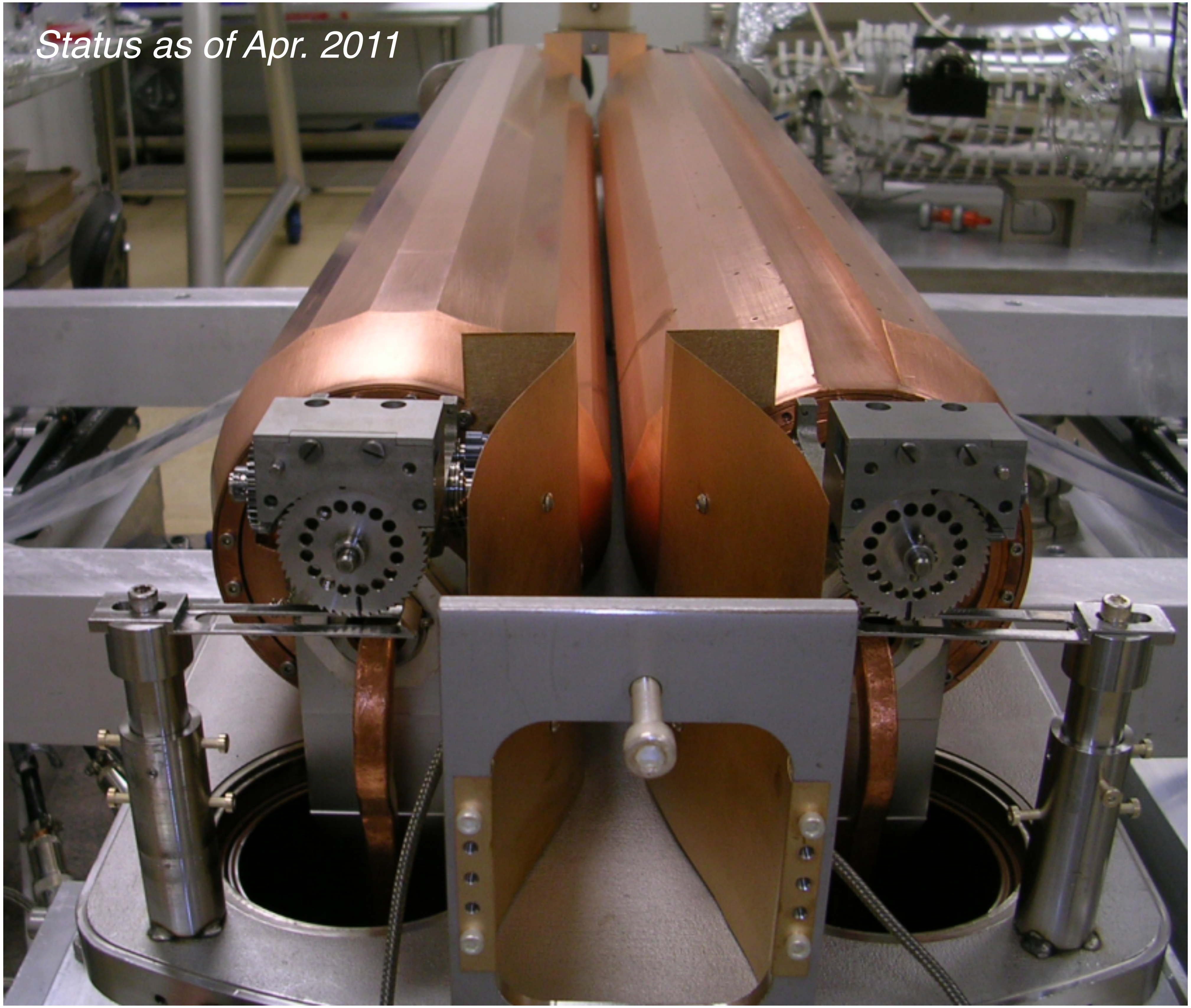


Jaw 3 mounted with rotation bearings in bearing housing onto jaw supports

Retesting of rotation drive system to begin 3 June 2013

- Nice concept. Might be reconsider it in light of the recent material tests and updated safe limits?
- Cannot be considered as candidate until fully validated by beam tests (HRM, SPS?)
- A beam test strategy will be established as soon as we have the chance to test it at CERN!
- One drawback: not easy to integrated BPM concept. Other ideas under investigation.

Recent summary by Tom M.



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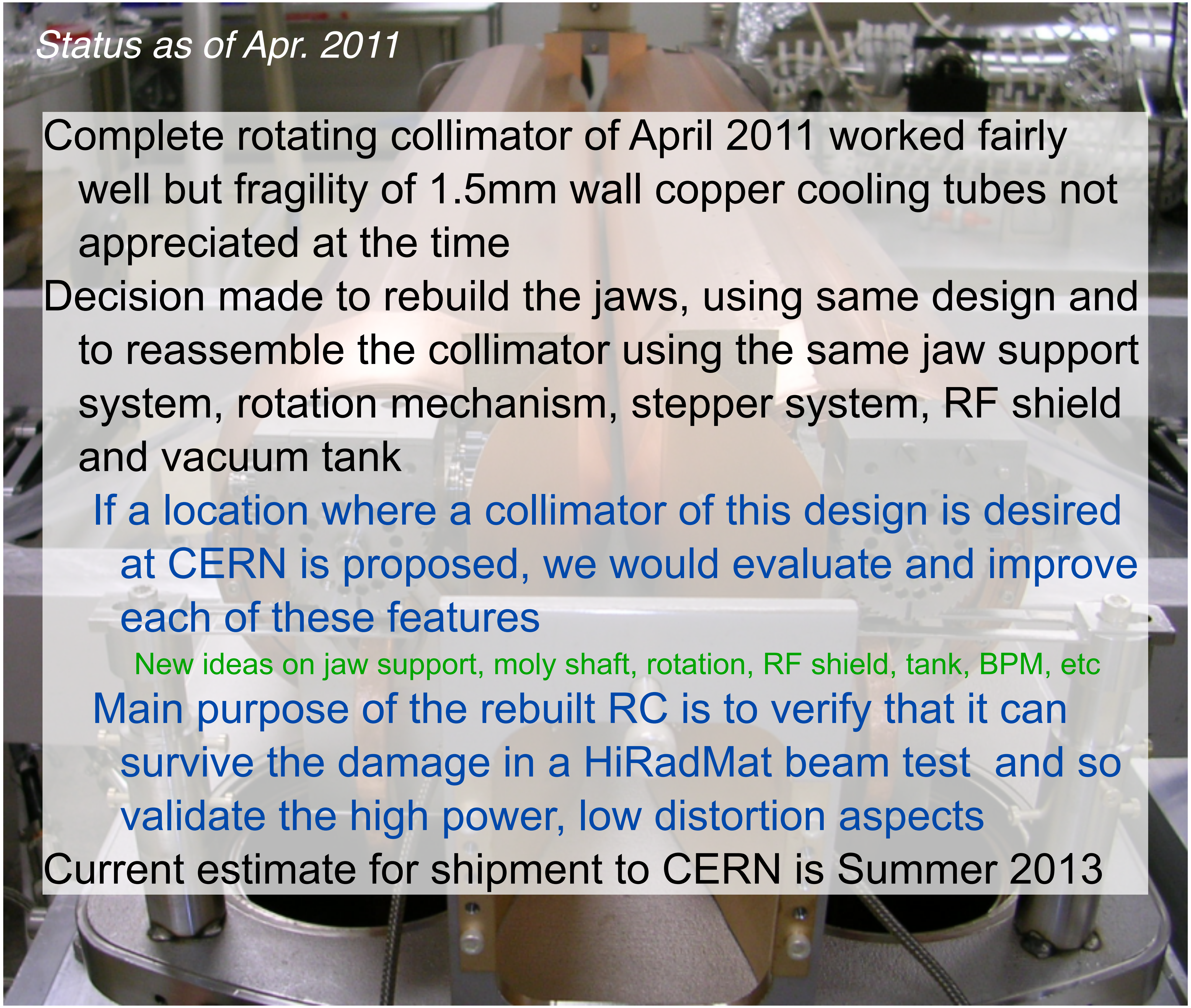

Status as of Apr. 2011

- Complete rotating collimator of April 2011 worked fairly well but fragility of 1.5mm wall copper cooling tubes not appreciated at the time
- Decision made to rebuild the jaws, using same design and to reassemble the collimator using the same jaw support system, rotation mechanism, stepper system, RF shield and vacuum tank
  - If a location where a collimator of this design is desired at CERN is proposed, we would evaluate and improve each of these features
    - New ideas on jaw support, moly shaft, rotation, RF shield, tank, BPM, etc
  - Main purpose of the rebuilt RC is to verify that it can survive the damage in a HiRadMat beam test and so validate the high power, low distortion aspects
- Current estimate for shipment to CERN is Summer 2013

Outline

- ☑ Scope of collimation upgrades
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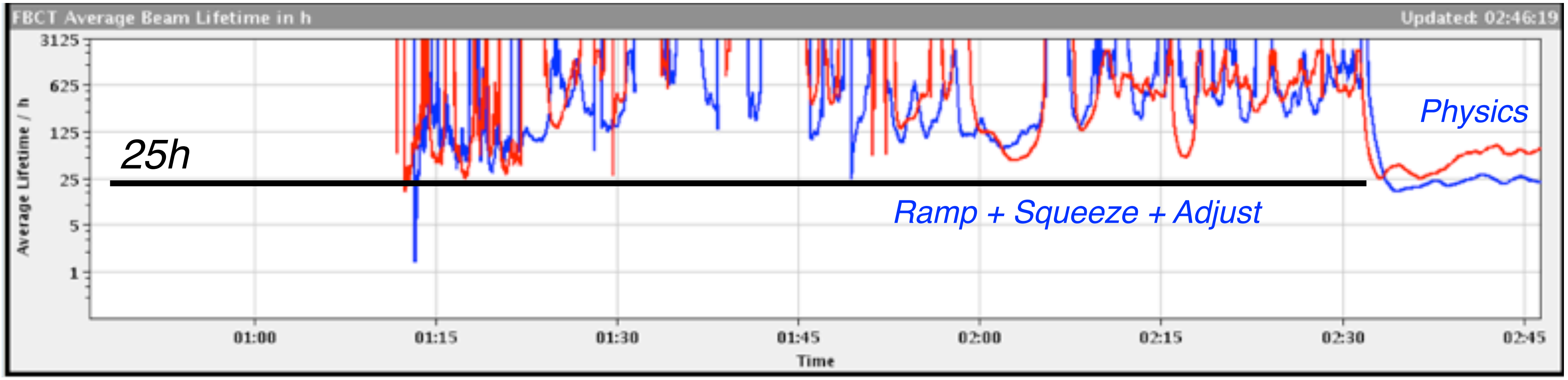
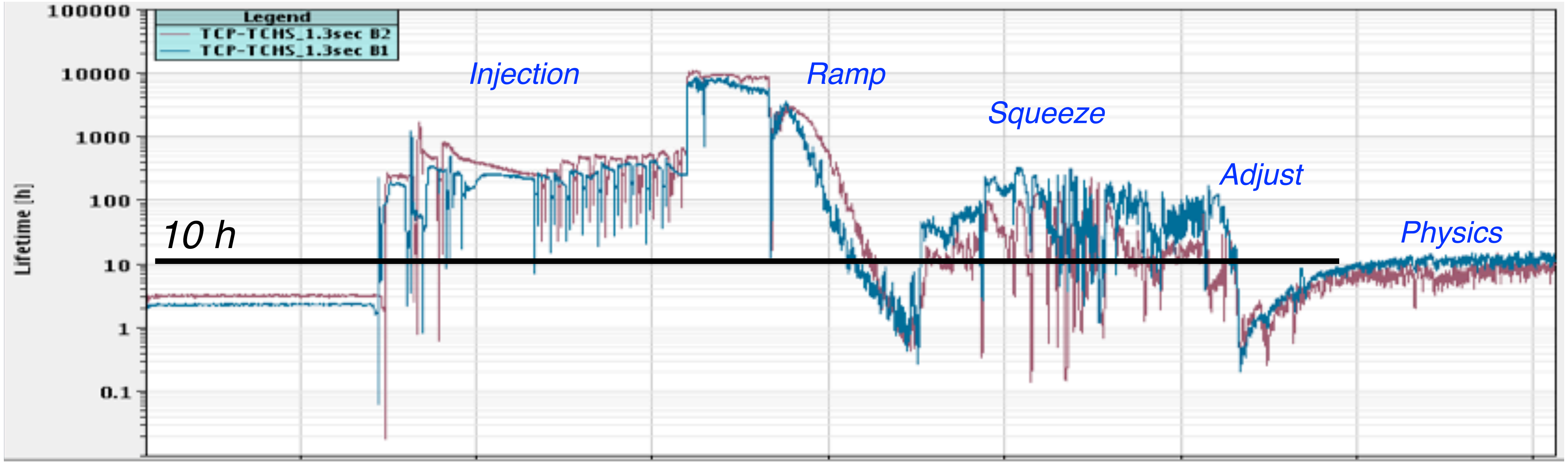
- ☑ Selection of topics
- ☑ **Advanced concepts**
  - **- Halo scraping**
  - **- Crystal collimation**
- ☑ Conclusions

Lifetime and losses during OP cycle

Couple of illustrative examples taken randomly from the LHC elogbook...





Issue after LS1 at higher energies? *(Depends obviously on latest quench results)*.

Losses during cycles could be greatly improved with **halo control mechanisms**: hollow e-lens, tune modulation, narrow-band damper excitation are being studied!

Organized a review in Nov. 2012 where these aspects were discussed.

Interplay with proposed DS collimation option need to be studies in more detail...

Our strategy

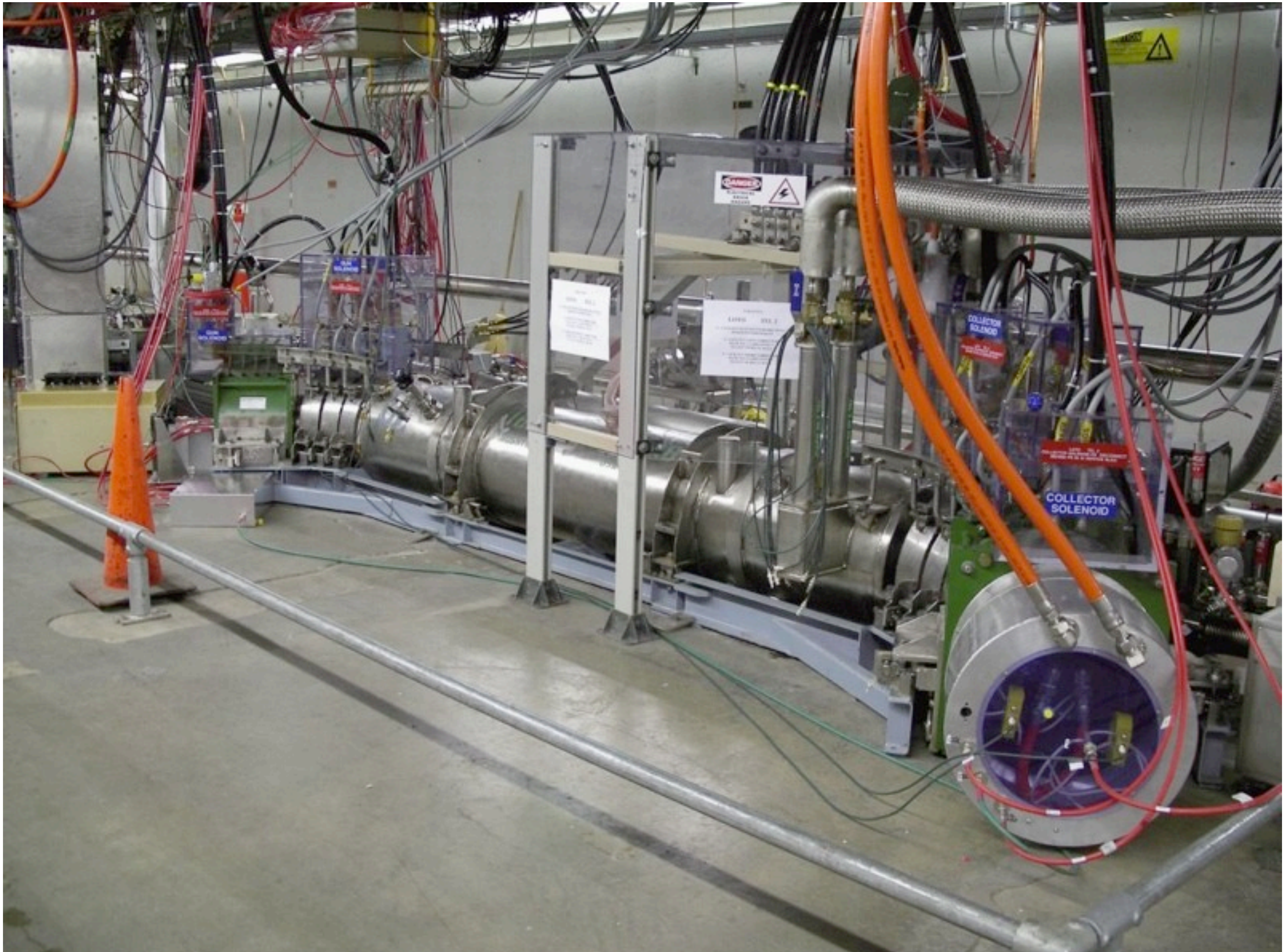
We decided that the **halo control and scraping studies** should be followed up for the LHC and HL-LHC. Hollow lens is a strong candidate but **alternative solutions** to must be addressed to tackle potential problems after LS1.

Within the given constraints for LS1 and due to the major implications to install the Tevatron hardware, we decided not to use the FNAL HW at CERN.

The CERN management fully supports the studies on hollow e-lens and strongly recommends to **focus the presently available resources** towards the **preparation** of a possible **production of 2 hollow e-lens for the LHC**.

- **Design** of a device optimized for the LHC at 7 TeV (improve integration into the LHC infrastructure and improve instrumentation).
- Actively **participate** to beam tests worldwide on this topic.
  Specifically, CERN endorses the setup of hollow e-beam tests in RHIC.
- Start building **competence at CERN** on the hollow e-beam hardware (collimation, BE-BI, EN-MME).
- Work with very high priority on **improving the halo diagnostic** at the LHC.

Recent timeline for hollow e-lens study



Recent timeline for hollow e-lens study

Timeline for the definition of a **CERN strategy** for the usage of TEL2.

- **CERN review in Nov. 2012**

  Brought up comprehensively technical aspects for installation in LHC or SPS.

- **HiLumi annual meeting in Frascati, end of Nov. 2012**

  CERN iterated the strong interest to pursue this option for HL-LHC.
  Promised a response to US-LARP request on TEL2 usage by spring 2013.

- **Jan. 2013**

  CERN internal executive
  strategy base on the tech

- **April 8th**

  Presentation to HL-LHC t

- **April 2013**

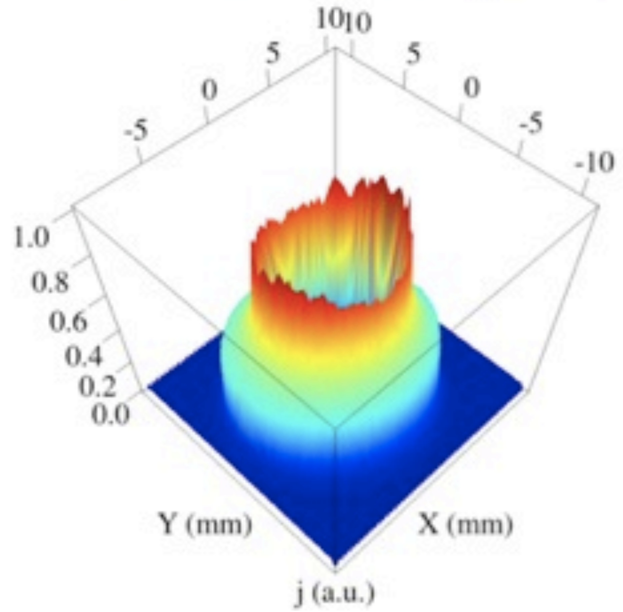
  Present CERN strategy to US-LARP CM20 to steer their contribution.

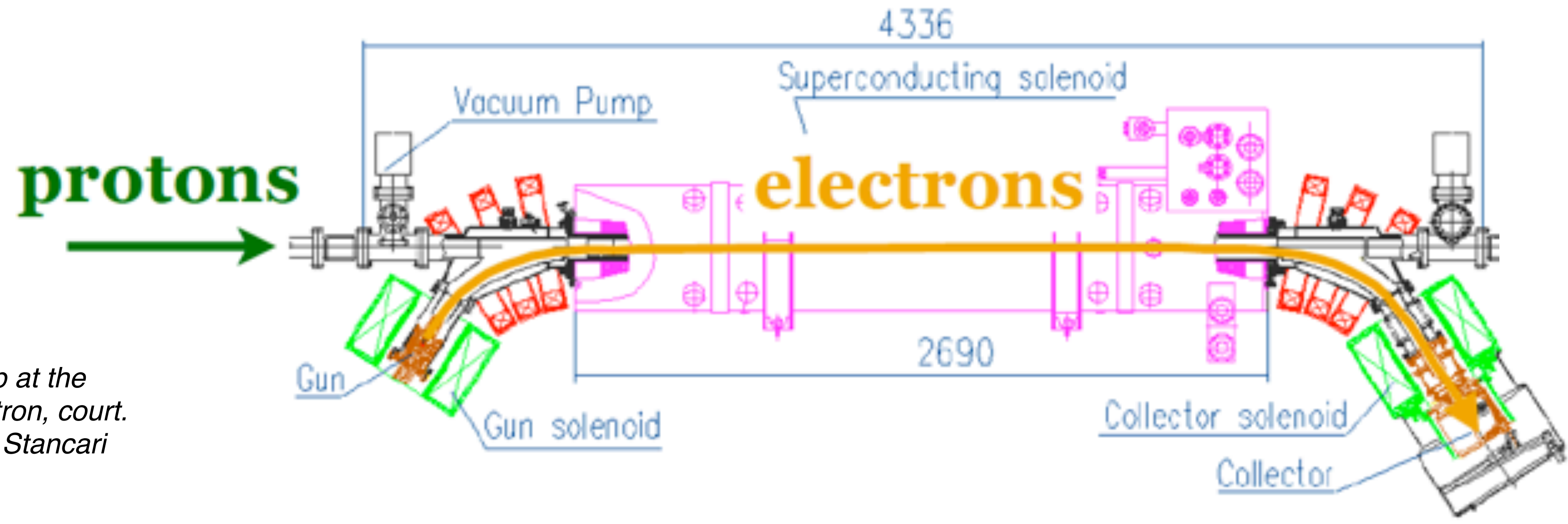
- **May onwards**

  Preparation of project structure at CERN to follow up development (Collimation project, BE-BI, EN-MME)

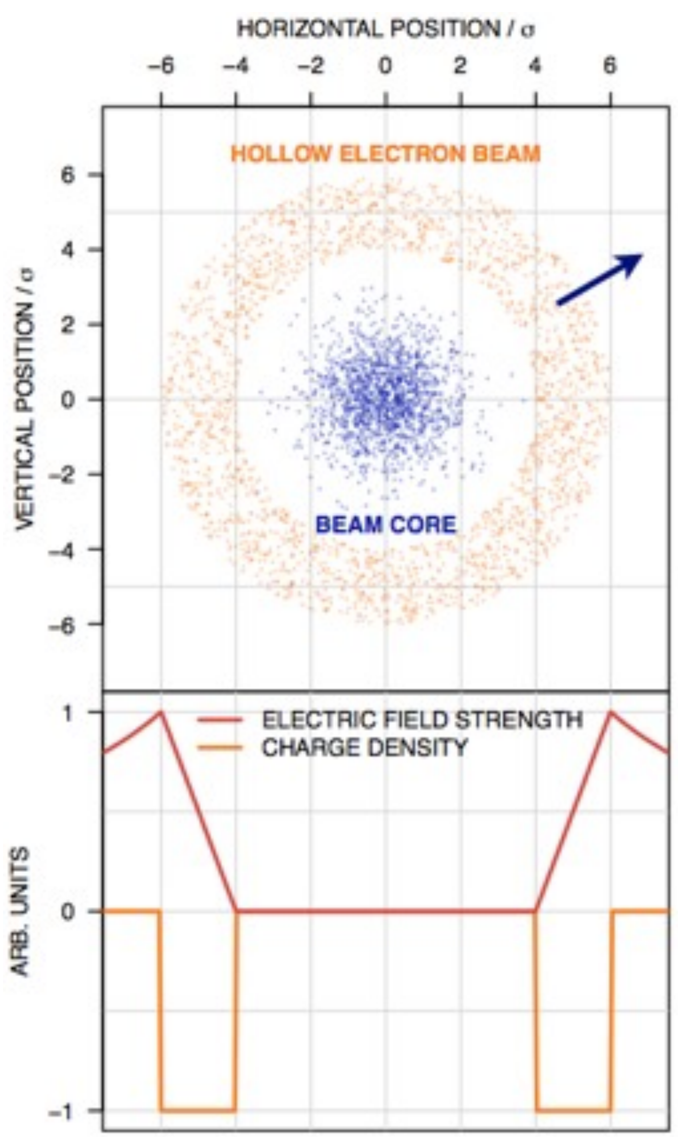
Crucial contribution from US-LARP team at FNAL (G. Stancari, S. Valishev, V. Previtali):
- Provided solid experimental data from Tevatron;
- Now working on a conceptual design for LHC;
- Recently started simulation work on alternative methods (tune modulation).

Basic hollow e-lens concepts





Setup at the Tevatron, court. of G. Stancari

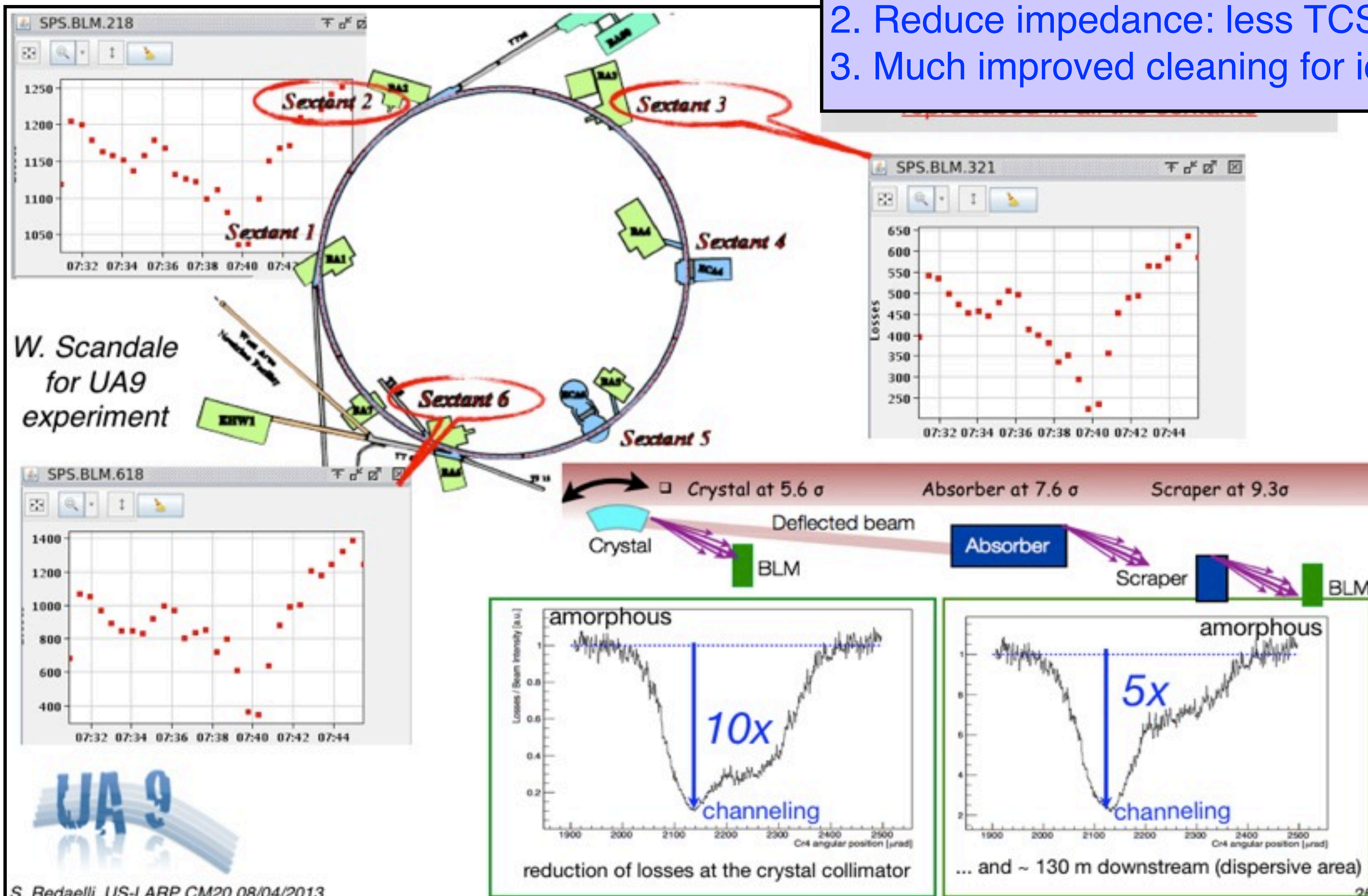


- **A hollow electron beam** runs parallel to the proton beam
  - *- Halo particles see a field that depends on (A_x,A_y) plane*
  - *- Beam core not affected!*
- Adjusting the e-beam parameter, one can **control diffusion speed** of particles in the area that overlaps to e-beam.
  - *- Drives halo particles unstable by enhancing (even small) non-linearities of the machine.*
- Particles excited are selected by their transverse amplitude.
  - *- Completely orthogonal to tune space.*
- This is an ideal scraper that is **robust** by definition.
- Conceptual **integration** in the LHC collimation system:
  - *- The halo absorption is done by the standard collimators.*
  - *- Hollow beam radius smaller than primary collimator aperture.*
- Complex beam dynamics required beam data validation.
- **Need to study to what extent can relax the DS limitations.**

LHC crystal collimation studies

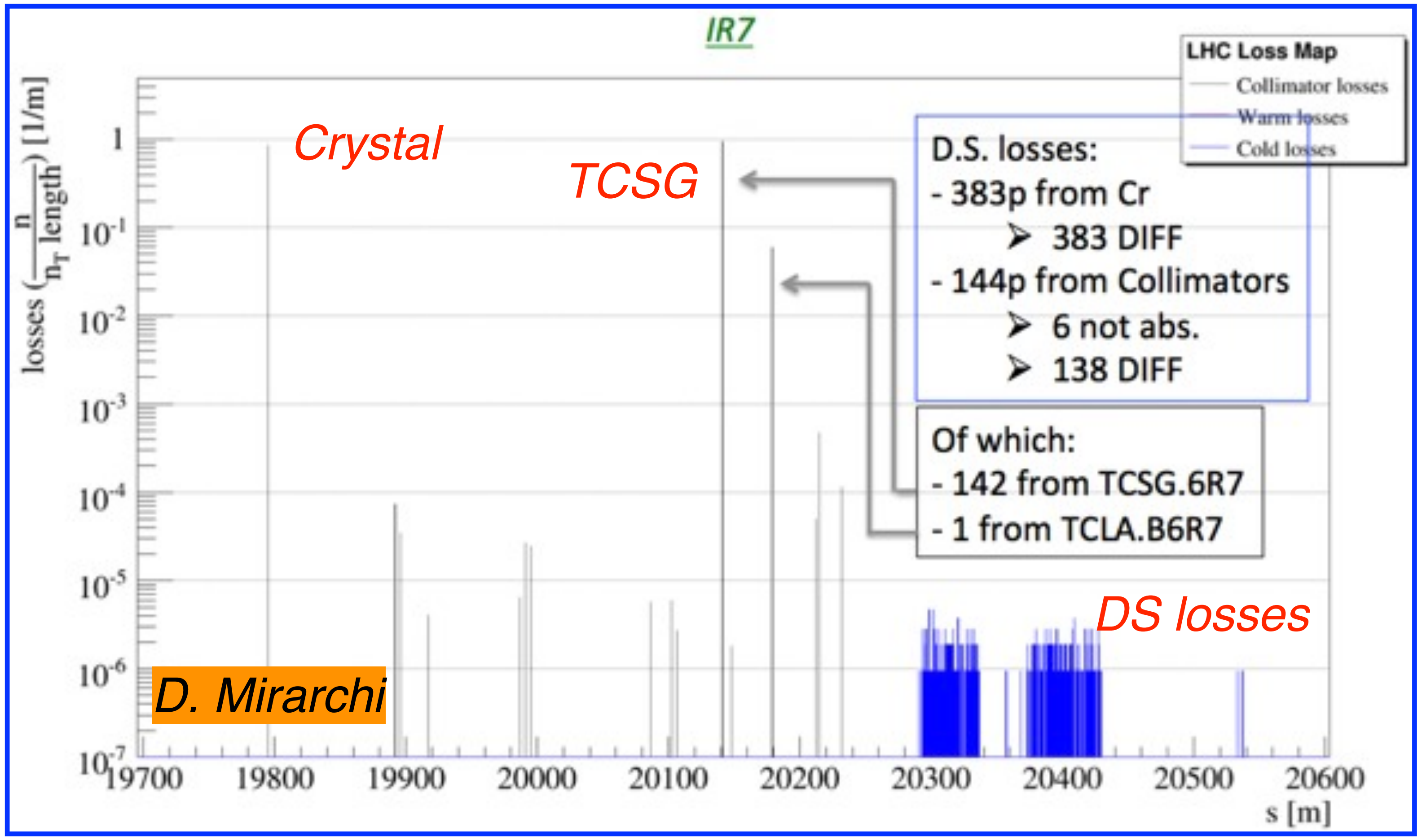
UA9 collaboration: interesting beam tests at the SPS since first operation in 2009.

Promises of crystal collimations:
1. Improved DS cleaning in channeling
2. Reduce impedance: less TCSGs' larger gaps
3. Much improved cleaning for ion beams.



*Slide presented at the CM18; More details at Frascati (**D. Mirarchi**)*

Plans for tests at the LHC



Simulations confirm the potential benefit on cleaning (improvements achieved with much reduce impedance).

SPS tests within UA9 did not address specific concerns for the LHC: continuous channeling needed in dynamics conditions (ramp, squeeze, ...).

Scope of LHC tests: low-intensity studies!

Outstanding concerns for machine protection and handling of ~1MW losses will have to be addressed.

Potential for ion cleaning to be addressed.

***Status for the LHC studies**:*

- *Following the endorsement of the LHCC (Sep. 2011), the installation into the LHC was accepted by the CERN directorate.*
- *Request of works for the crystal experiment (minimum change based on the installation or one or two goniometers re-using collimator cabling) was approved and is presently in the LS1 work planning.*
- *The official go-ahead can only come after the approval of an Engineering Change Request (ECR) with the detailed layout change, which we are working on*
- *It looks feasible to have a minimum setup for crystal collimation tests after LS1!*

Conclusions

- Introduced the present upgrade strategy for the LHC collimation.
  Focus on what is ongoing on top of the DS collimation concept.
  Very partial overview in the short given time...
- Important focus: future collimator materials.
  - Building up a panel of candidate materials and designs to address the various - often conflicting - challenged.
  - Basing our choices on the operational experience and on dedicated beam tests.
  - Optimistically, we could be ready for actions in LS2 if needed.
- Extended material studies cover **fast failures** and **high doses**
- More **advanced collimation concepts** are being addressed!
  - We believe that hollow e-lenses would be very useful for HL-LHC, considering alternatives for implementation until LS2+.
  - Exploring crystal collimation option.
- Though not in your mandate, we clearly appreciate your advice/support on the presented studies.
- Acknowledge the support of HiLumi, EuCARD, Kurchatov, US-LARP...