20th US-LARP Collaboration Meeting - CM20
April 8th-10th, 2013
Embassy Suites - Napa Valley, CA, USA

LHC Collimation Project Status

Stefano Redaelli, CERN, BE-ABP
for the Collimation Project and HL-LHC-WP5 teams

CERN

SEVENTH FRAMEWORK PROGRAMME

High Luminosity LHC

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.

LHC Collimation Project CERN

Introduction

- **Baseline collimation upgrade strategy for LS1 defined in 2011**
  - *Decided to postpone major changes in the dispersion suppressors (DSs)*
  - *Other important upgrades will take place in LS1:* ***Collimators with BPM design***
- **The good performance at 4 TeV (up to 140 MJ!) confirmed this strategy, but uncertainties remain for the extrapolations to 7 TeV**
  - *Need to review cleaning, lifetime assumptions, quench limits, impedance...*
- **The possible needs for local collimation in the dispersion suppressor have steered the development of the 11 T dipoles**
  - *Important progress - see magnet talks.* ***Can we get them in LS2 if needed?***
  - *What do we need to decide now to be ready to take a decision in 2015?*
- **External collimation review is being organized: 30-31/05/2013**
  - *Scope: present the baseline on collimation upgrades on mid and long term: (1) Full beam intensity and luminosity; (2) x2 design; (3) HL-LHC.*
  - *Mandate: advice on 11 T dipole strategy until post-LS1 operation, for actions in LS2.*
- **Other important studies for collimation upgrades are ongoing, within and outside CERN, to ensure readiness for HL-LHC era!**

Outline

- Introduction
- Collimation up to 140 MJ
- News on upgrade studies
- Conclusions

(Some) collimation people

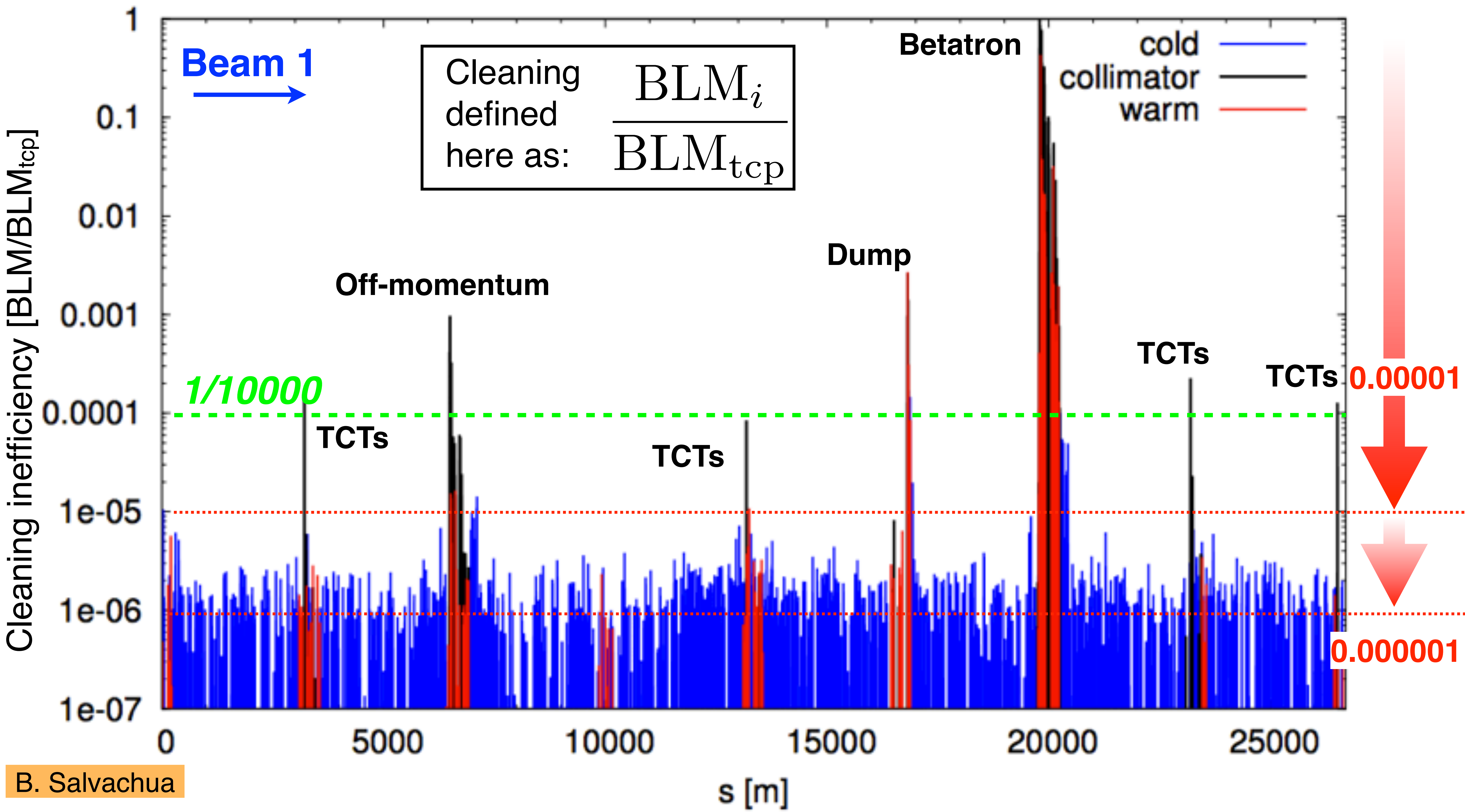
Contributions for this talk

B. Salvachua (2012-13 performance)
R. Bruce (post-LS1 performance)
G. Stancari, A. Valishev, W. Fisher (hollow e-lens)
N. Simos, A. Bertarelli, N. Mariani, L. Lari (BNL radiation tests)
A. Bertarelli *et al.* (collimator material studies)
M. Sapinski (non-collimation quench tests)
W. Scandale, D. Mirarchi (crystal studies)
O. Bruning, L. Rossi, H. Schmickler (overall strategy within HL-LHC)

Core collimation team in the LHC accelerator physics group:
R. Bruce, M. Cauchi, D. Deboy, L. Lari, D. Mirarchi, E. Quaranta, M. Salvachua, A. Rossi, A. Marsili, G. Valentino.
Members who left recently: R. Assmann, D. Wollmann.

Acknowledgements: OP team, ADT team and many others.

Collimation cleaning at 4 TeV (β^*=60cm)

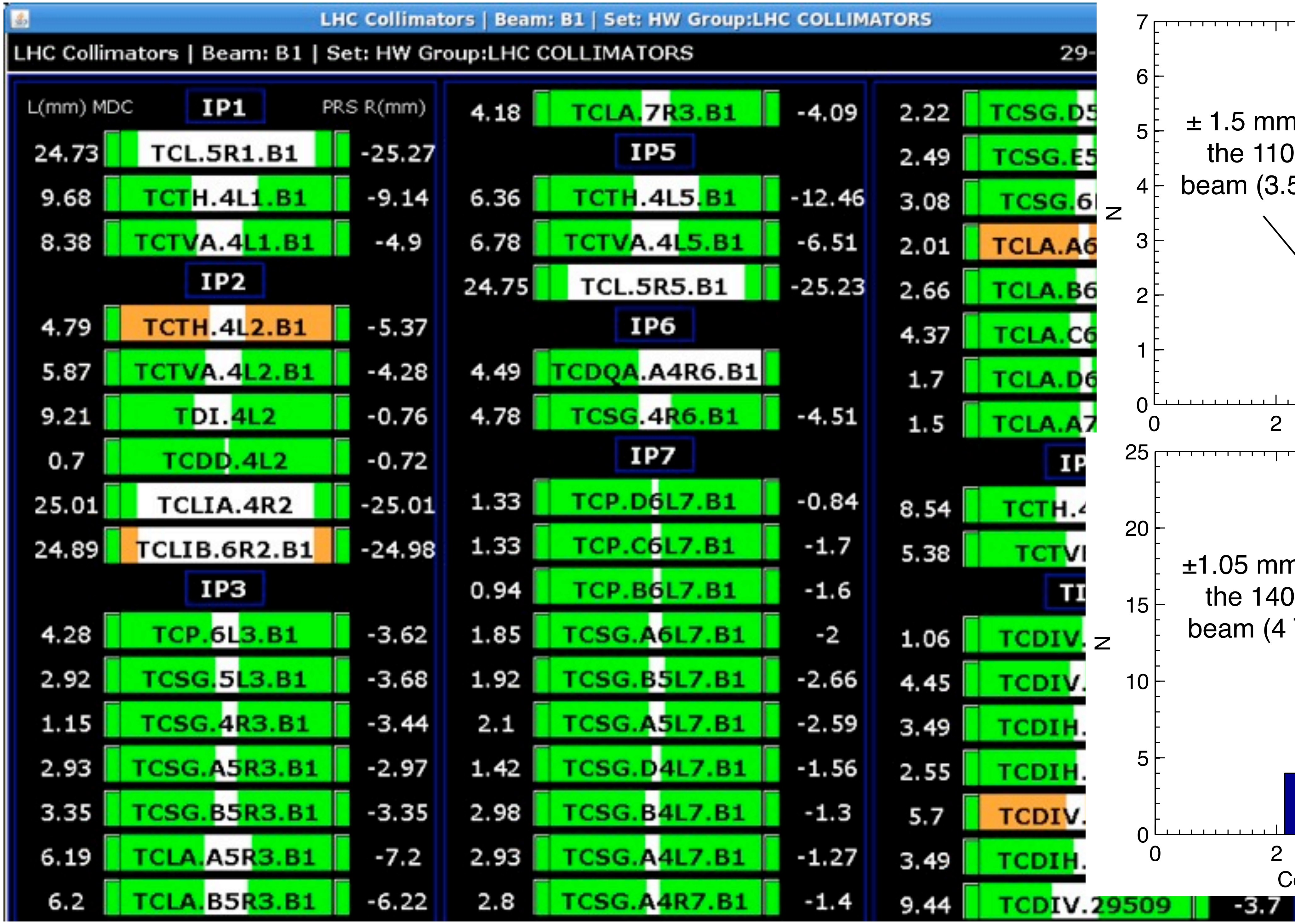


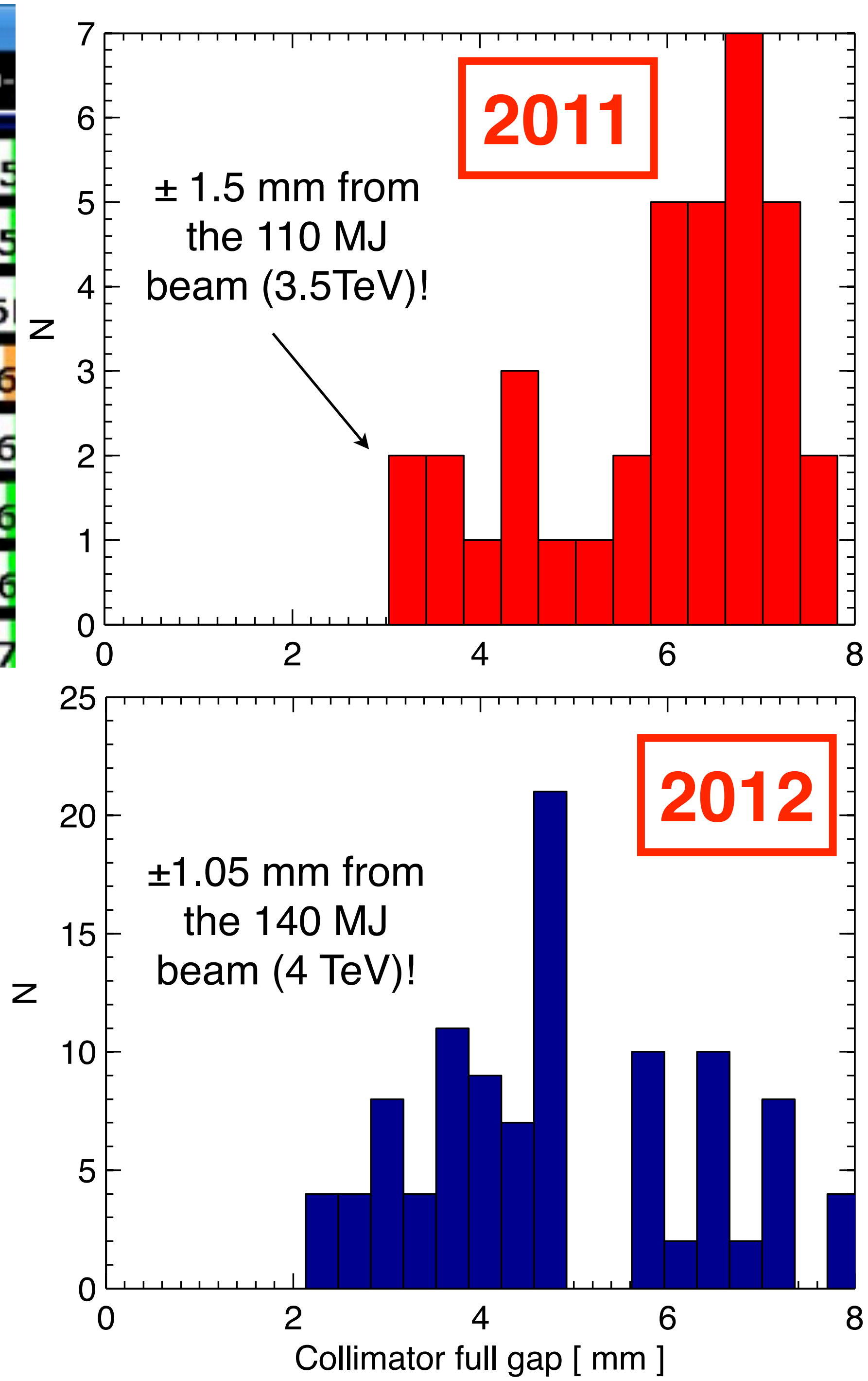
B. Salvachua

2012-13: “tight” collim
60

Highest COLD loss location: efficiency of > 99.99% !
Most of the ring actually > 99.999%

How “tight” tight settings are?

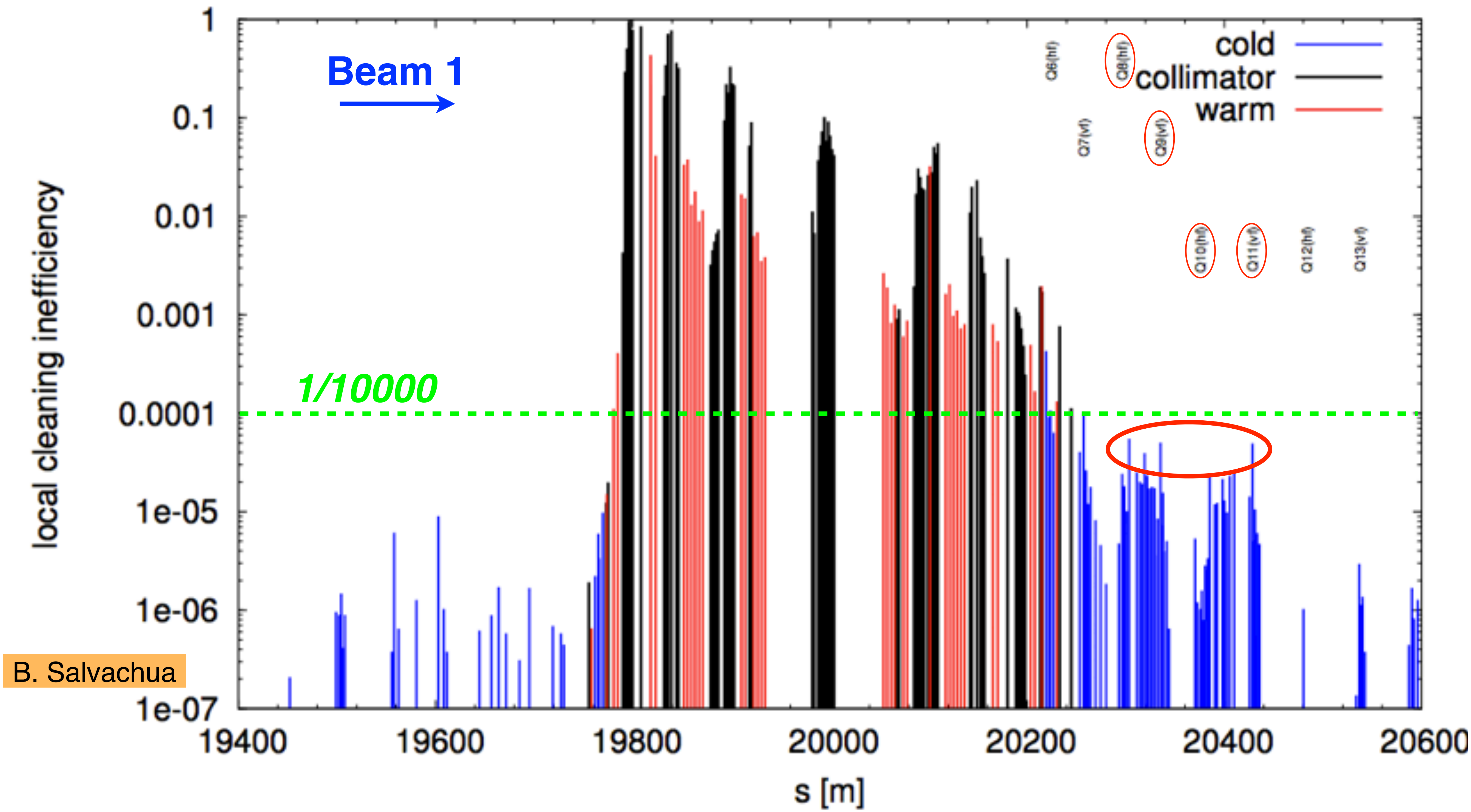




“Tight” collimator settings in the betatron cleaning (IR7):

- Primary collimator gaps are the nominal as at 7 TeV!
- Secondary collimator retracted by 2 sigmas (σ_{4TeV}).
- Tertiary collimators at 9 sigma for a β^* of 60 cm!

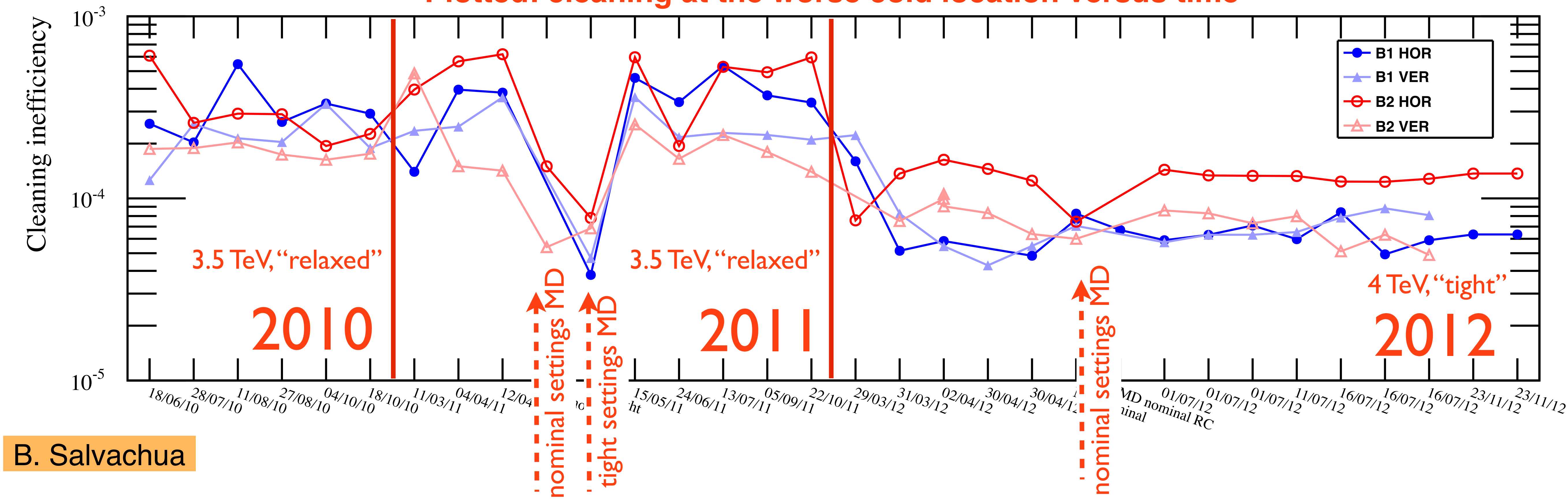
Loss maps in IR7



Critical locations (both beams): losses in the dispersion suppressor magnets Q7-Q11, from single diffractive interactions at the primary collimators.

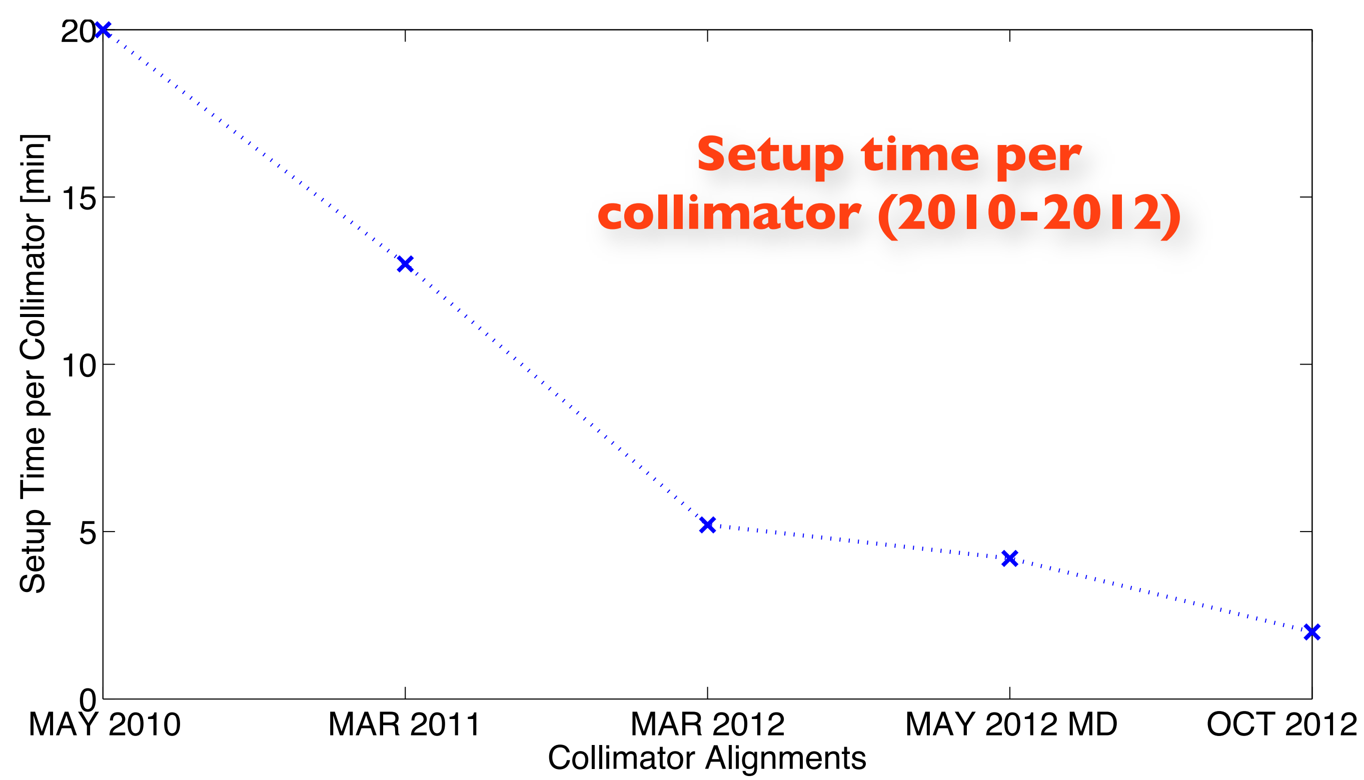
Stability of cleaning in 2010-12

Plotted: cleaning at the worse cold location versus time



B. Salvachua

- **Excellent stability** of cleaning performance observed!
- Achieved with **only 1 alignment per year** in IR3/6/7 (2x30 collimators).
- New alignments are only repeated for **new physics configurations** *(it remains crucial to be efficient!)*



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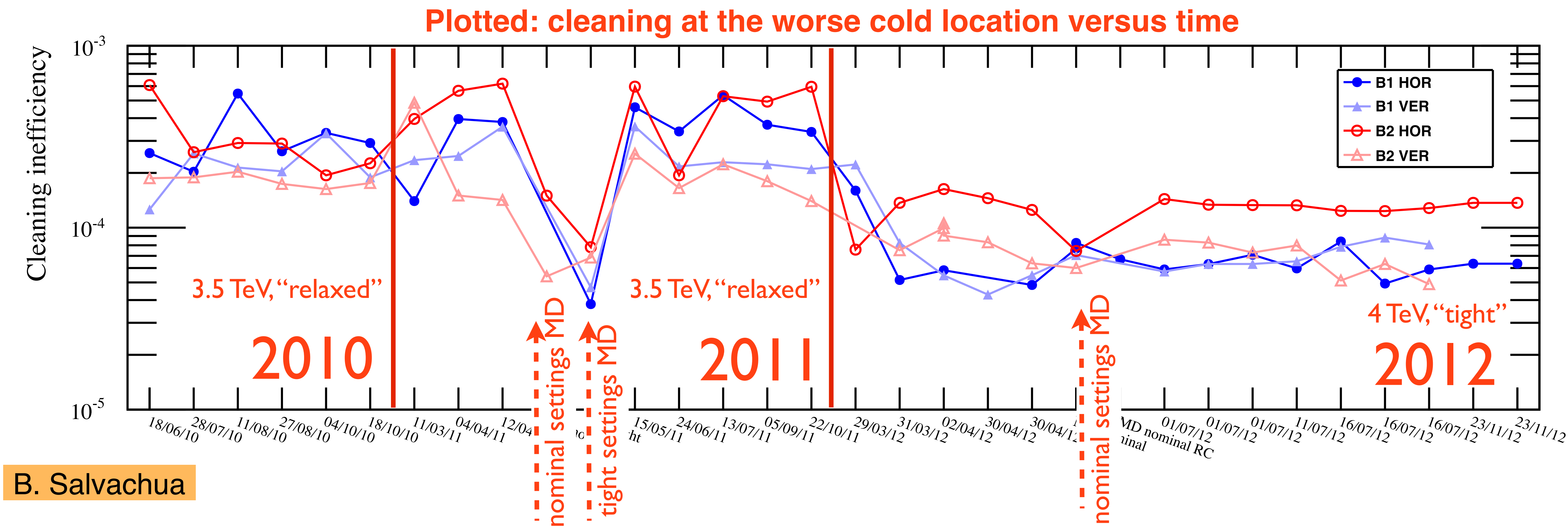

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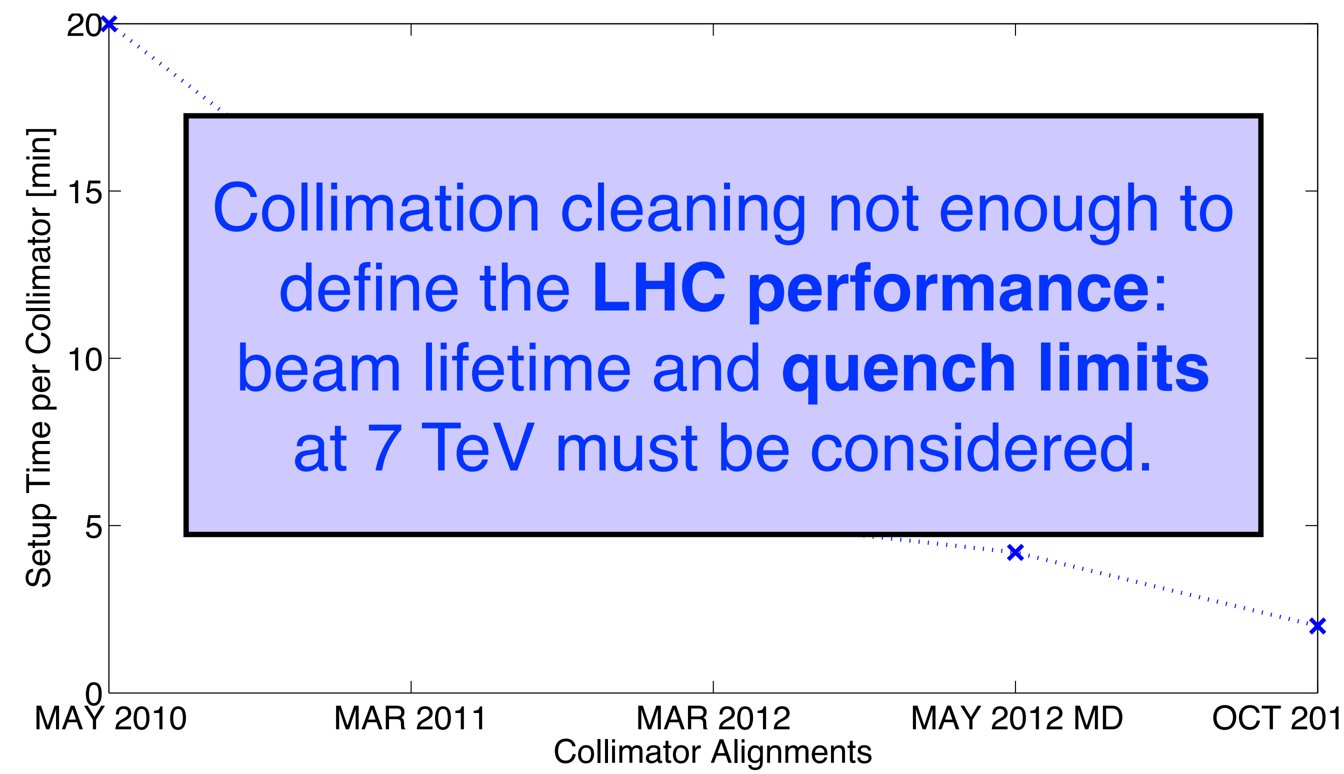


Collimation cleaning not enough to define the **LHC performance**: beam lifetime and **quench limits** at 7 TeV must be considered.

LHC quench tests with beam

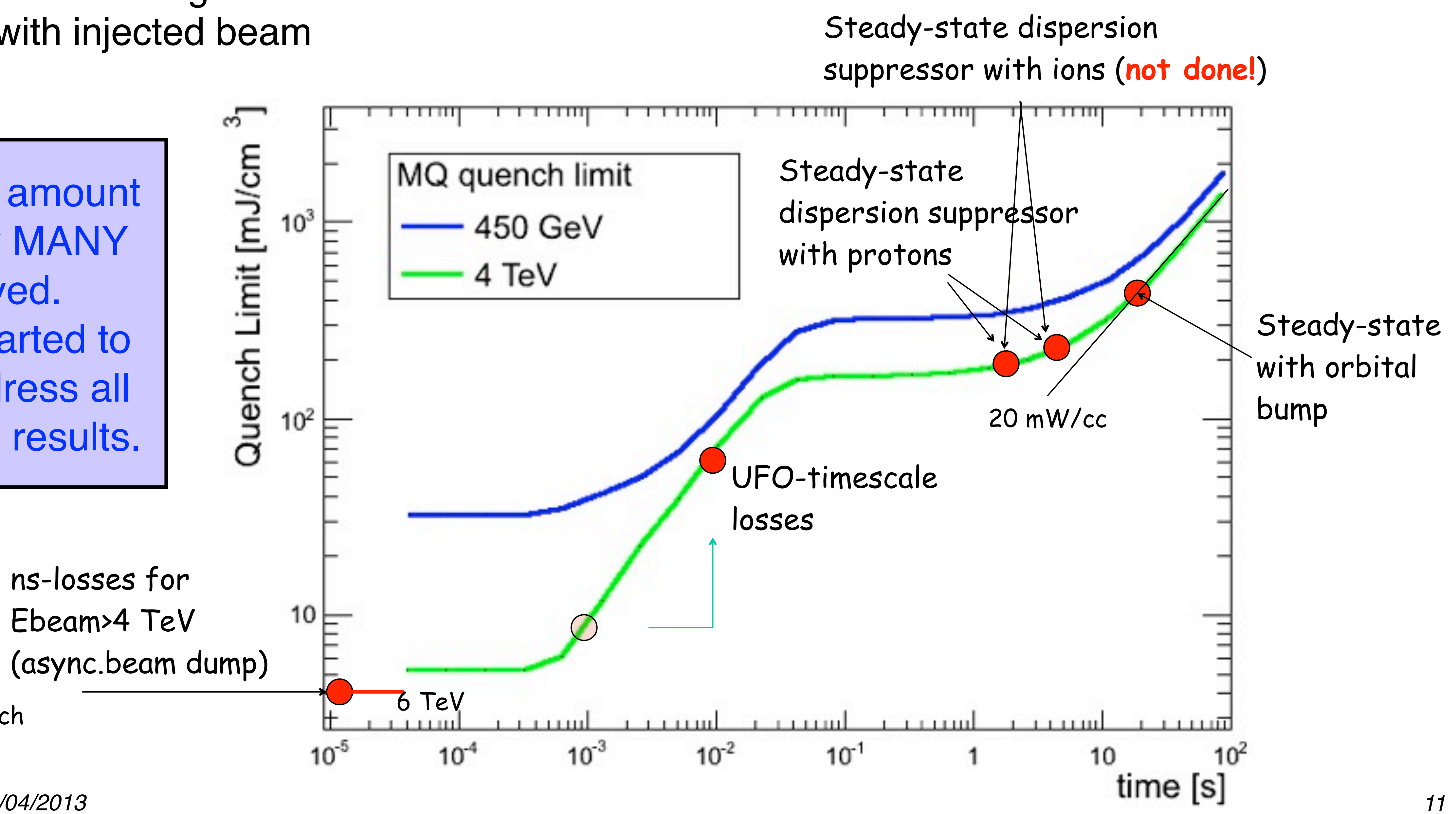
Recap. on the LHC beam loss monitoring system:

- *Beam losses are monitored over 12 "running sums" (RS), from 40μs (1/2 turn) to 80s.*
- *Independent thresholds for each RS to protect the machine from ultra-fast to steady-state losses.*

Five quench tests were proposed at the end of the 2012-13 run to probe different time scales:

- Collimator test with protons
- *Collimator test with ions (not done due to unavailability of ion beams)*
- Orbital bumps
- Fast losses on UFO range
- Single-pass with injected beam

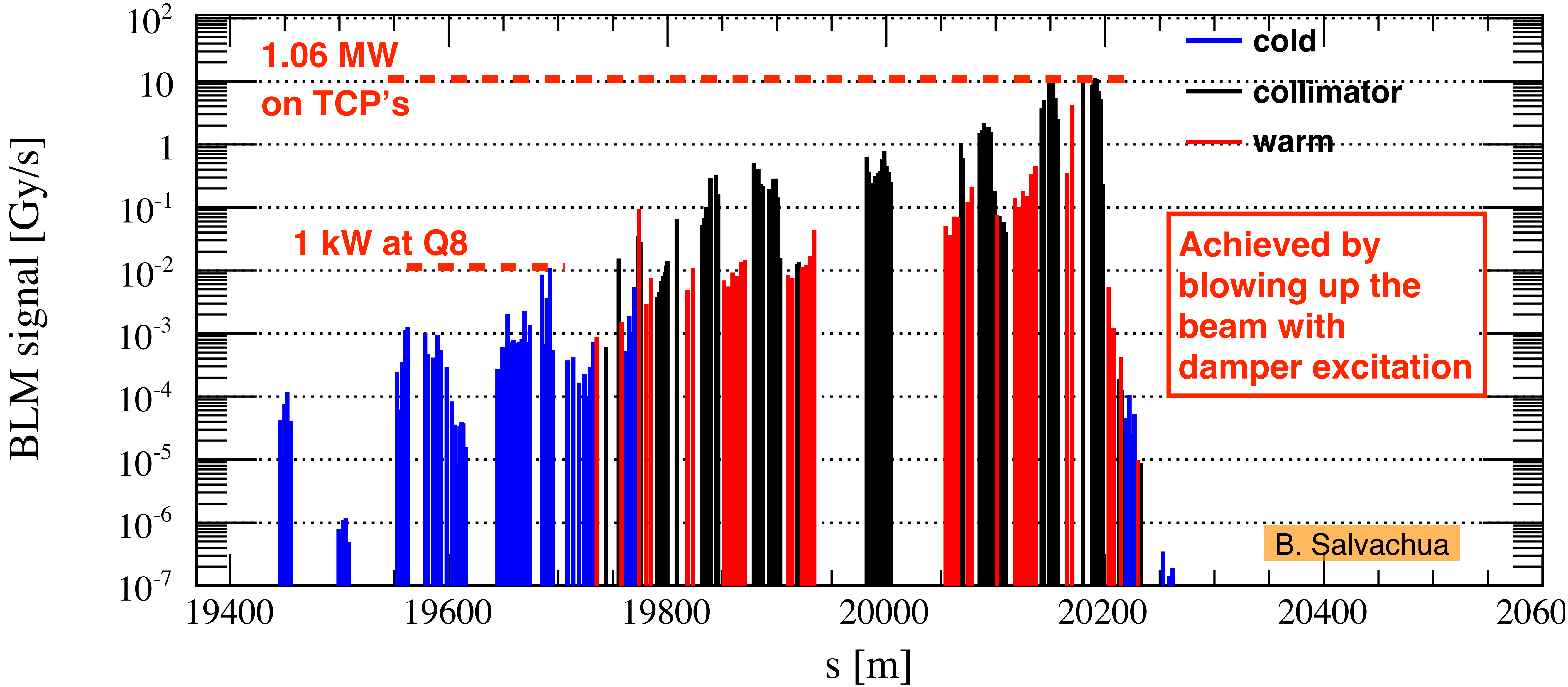
Truly impressive amount of work done by MANY teams involved. Dedicate WG started to consistently address all the experimental results.



M. Sapinski for the Quench Strategy Working Group

Collimator proton quench tests

Preliminary analysis of beam tests done on 14/02/2013



Controlled beam excitation over several seconds: **Peak losses > 1MW on TCP!**
Worsened cleaning by relaxing collimator settings ("very relaxed").
Achieved 2 to 5 times the assumed quench limit at 4.0 TeV **without quenching**!
(2011: only achieved ~65% of 3.5 TeV limit.)

Collimator proton quench tests

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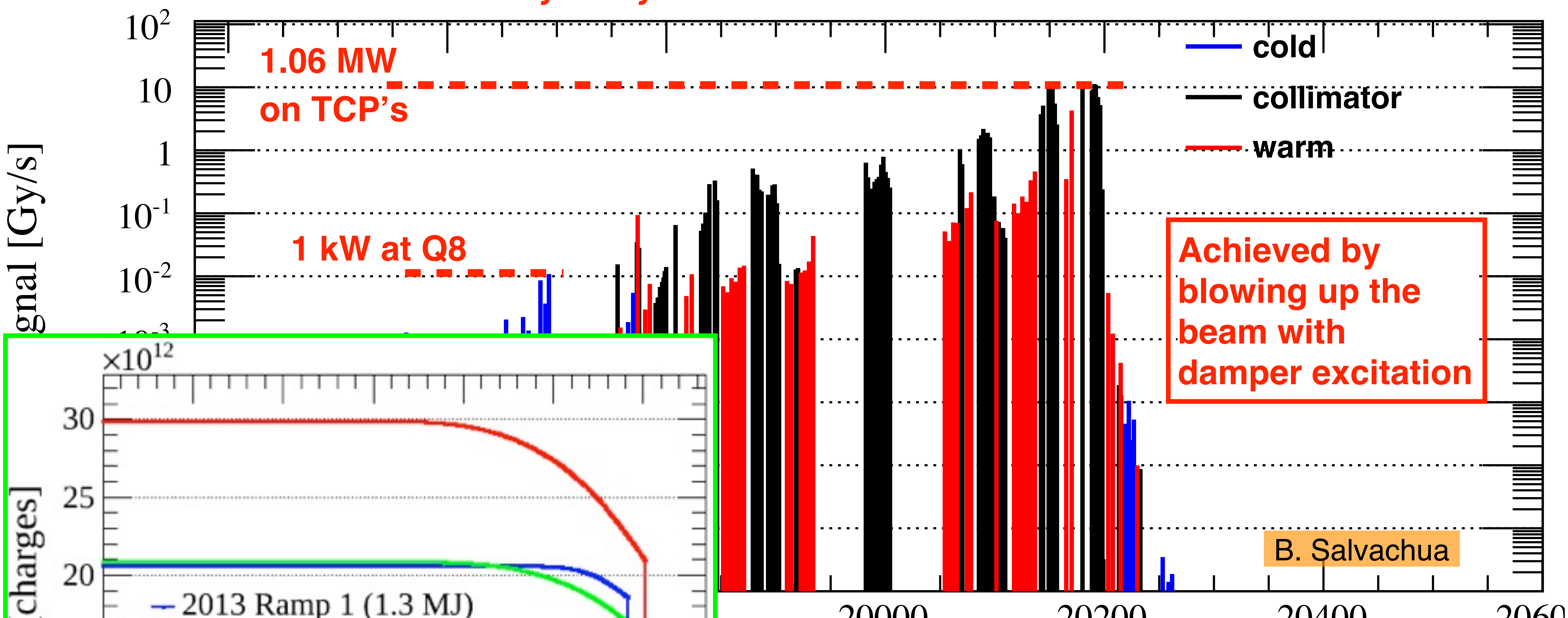

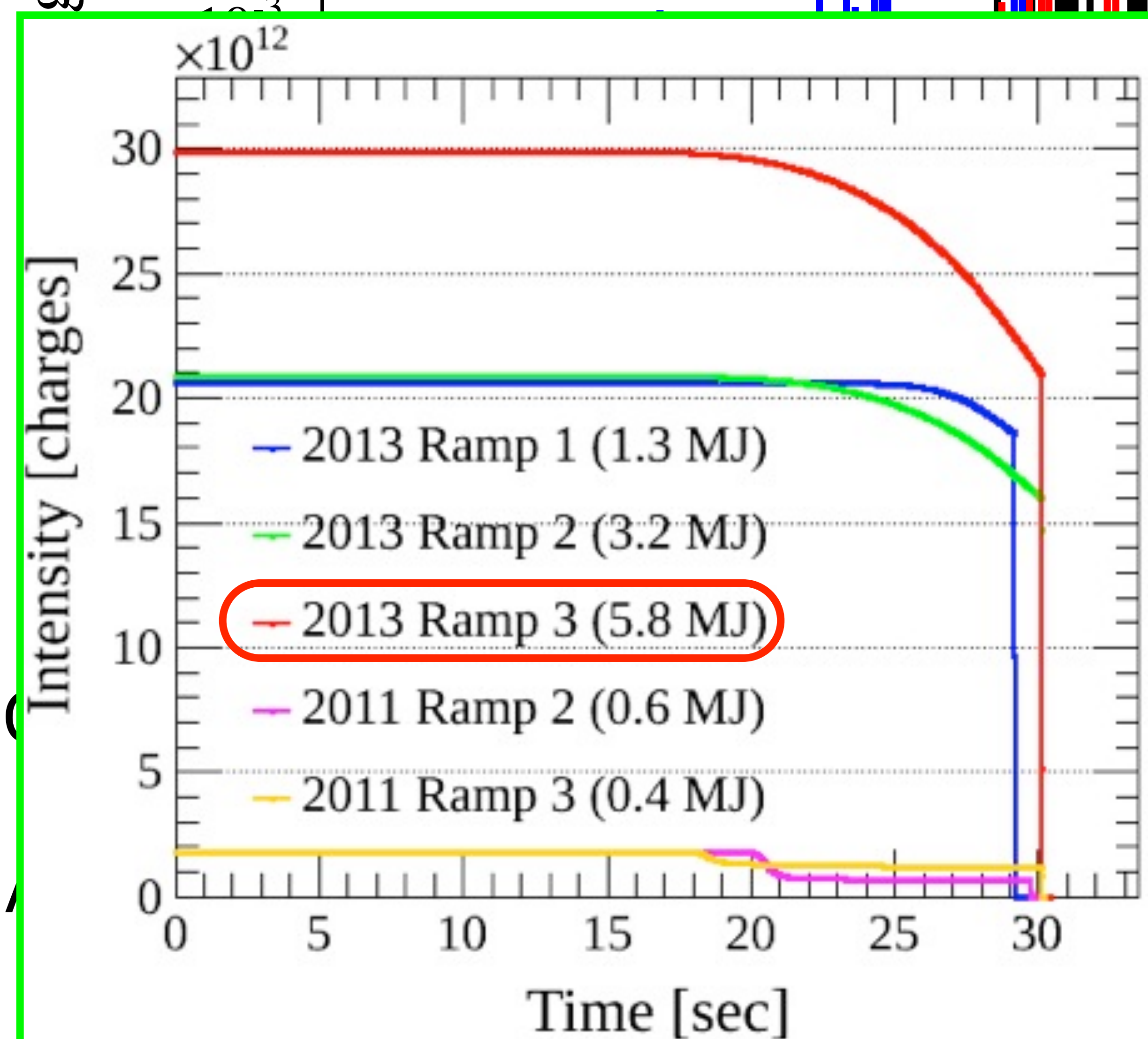

…ral seconds: **Peak losses > 1MW on TCP!**
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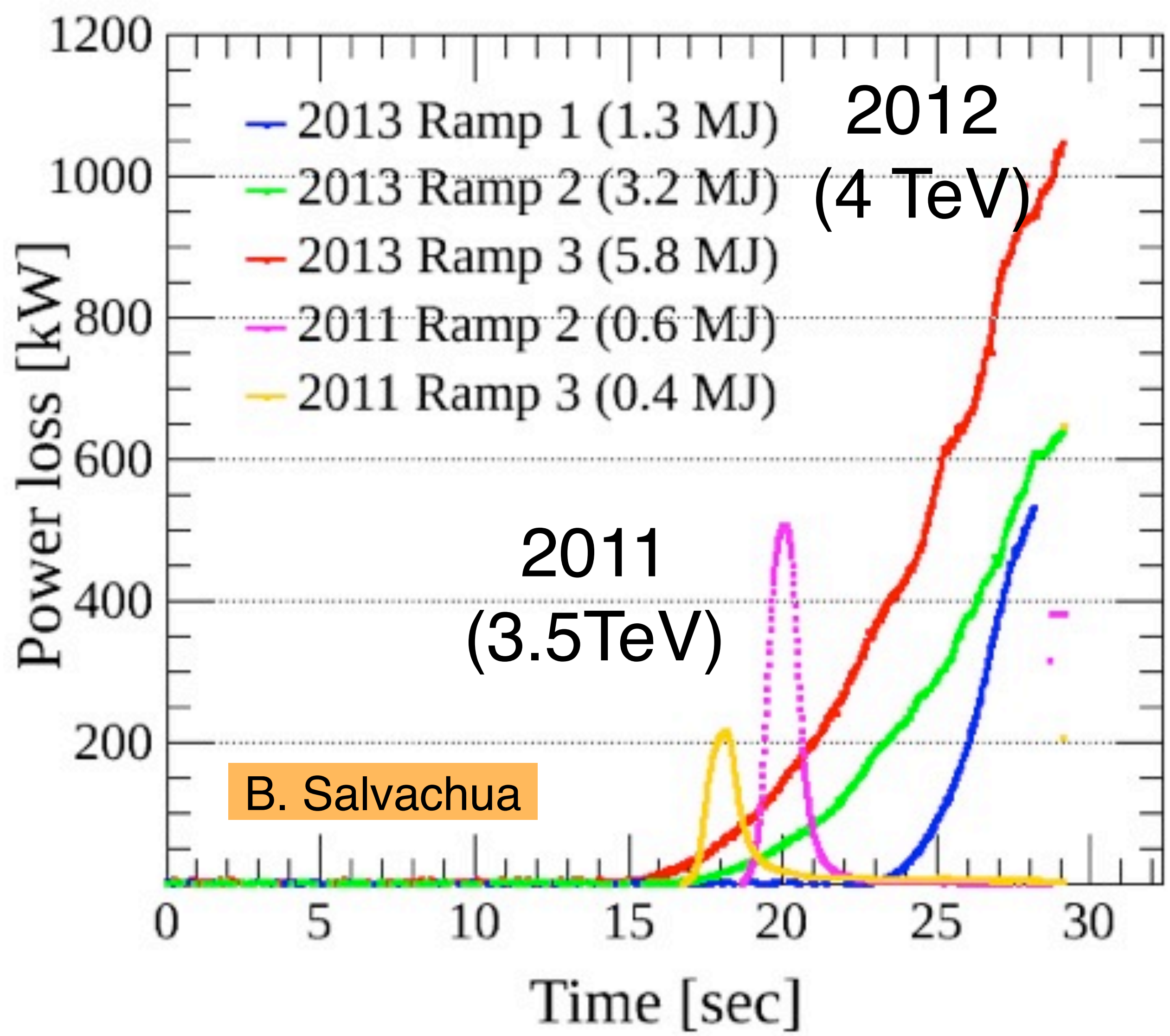
…uench limit at 4.0 TeV **without quenching**!
…ed ~65% of 3.5 TeV limit.)

Achieved losses vs quench limit



New method to excite controlled blow-up with the transverse damper (ADT): could probes "steady" losses between 1.3s and 5.2s!

Achieved loss rate a **factor 2-5** larger than the assumed quench limits!

Remark: We have seen this type of losses during 2012! Collimator BLMs are set to dump beams in case of losses > 200kW)!

Ramp 3: ~1MW	**RS09 = 1.3 s**			**RS10 = 5.2 s**		
	BLM Measurement [Gy/]	Assumed Quench Limit [Gy/s]	**Ratio BLM to Quench Limit**	BLM Measurement [Gy/]	Assumed Quench Limit [Gy/s]	**Ratio BLM to Quench Limit**
BLMQI.08L7.B2I10_MQ	1.08E-02	4.65E-03	**2.3**	8.42E-03	1.67E-03	**5.1**
BLMQI.08L7.B2I20_MQ	3.81E-03	6.40E-03	**0.6**	2.87E-03	2.29E-03	**1.3**

Ongoing work for review

Minimum (assumed) beam lifetime

Quench limit of SC magnets

LHC total intensity reach from collimation

$$N_{\text{tot}} = \frac{\tau R_q}{\tilde{\eta}_c}$$

Collimation cleaning at limiting cold location

(Some) items being addressed:

- **Tracking + energy deposition** simulations of quench test conditions.
  - *Understand in detail the energy deposited in SC coils.*
- Refined beam lifetime analysis and dump statistics.
- **Ion cleaning**: effect of cryo collimator of DS in IR2 (no more details here).
  - *Efficiency of DS collimator in IR2 and parametric study (length, material).*
  - *Review IR7 performance reach in light of new quench tests.*
- **LHC impedance limitations**: trade off between settings, instabilities and beta*.

Tentative agenda of collimation review

Dates frozen: **30-31 May 2013**

- **Introduction to present collimation system**
- **Sources of performance limitation:**
  - *Lifetime and cleaning efficiency*
  - *Quench margin from beam measurements (with energy deposition studies)*
  - *Quench form magnet studies*
  - *Impedance*
- **Estimated performance reach (including beta star)**
- **DS collimation (in collision points and cleaning insertions):**
  - *11 T dipole status: what do we need to be ready in LS2*
  - *Scenarii for heat loads (protons and ions)*
  - *Technology choice and integration issues*
- **HL-LHC challenges for collimation:**
  Cleaning with ATS optics and needs for DS collimation in LS3
- **Perspective of hollow lens**
- **Status of Crystal**
- **New collimator materials (impedance vs robustness)**
- **Lifetime of collimator hardware and radiation handling**
- **Wrap-up and outline a consistent strategy for LS2 and LS3**

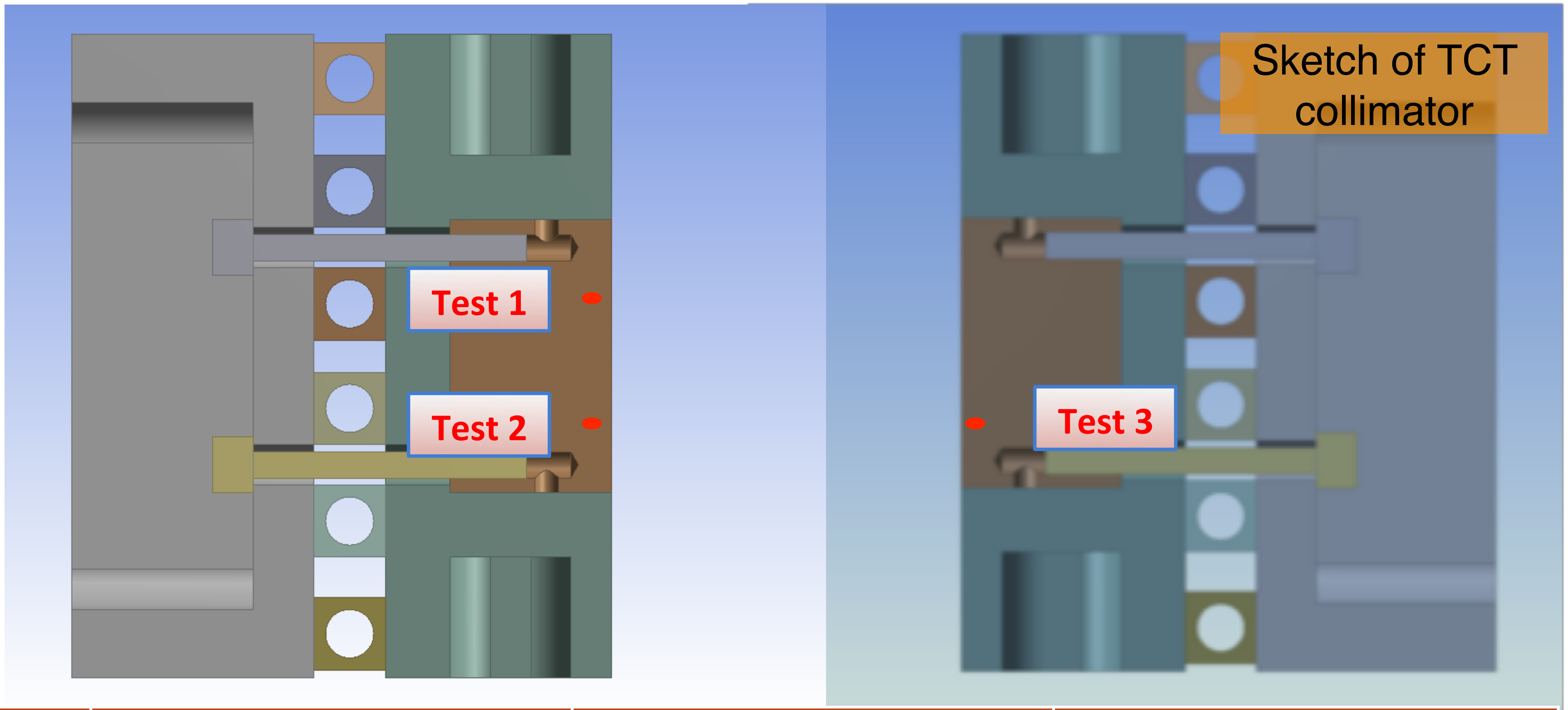
Outline

- Introduction
- Collimation up to 140 MJ
- **News on upgrade studies**
- Conclusions

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

Address by beam tests the robustness of the TCT (critical for β* reach). Complementary dedicated material tests to find "ideal" collimator materials.

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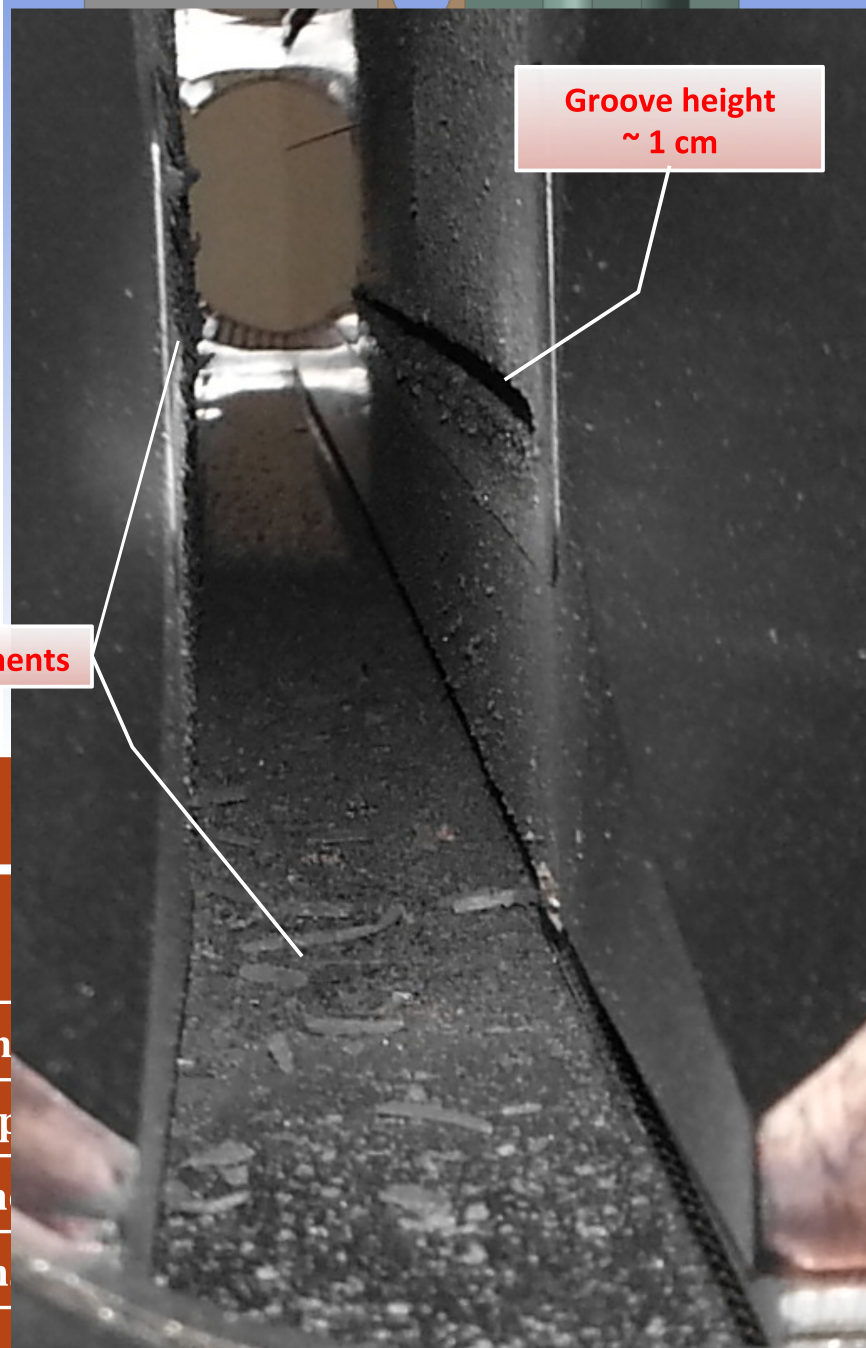
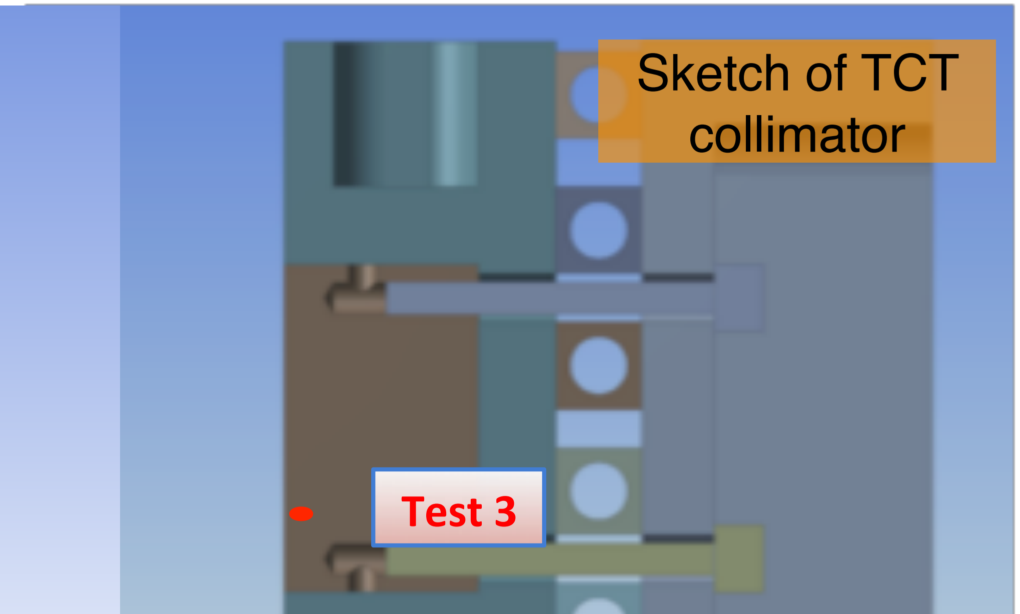
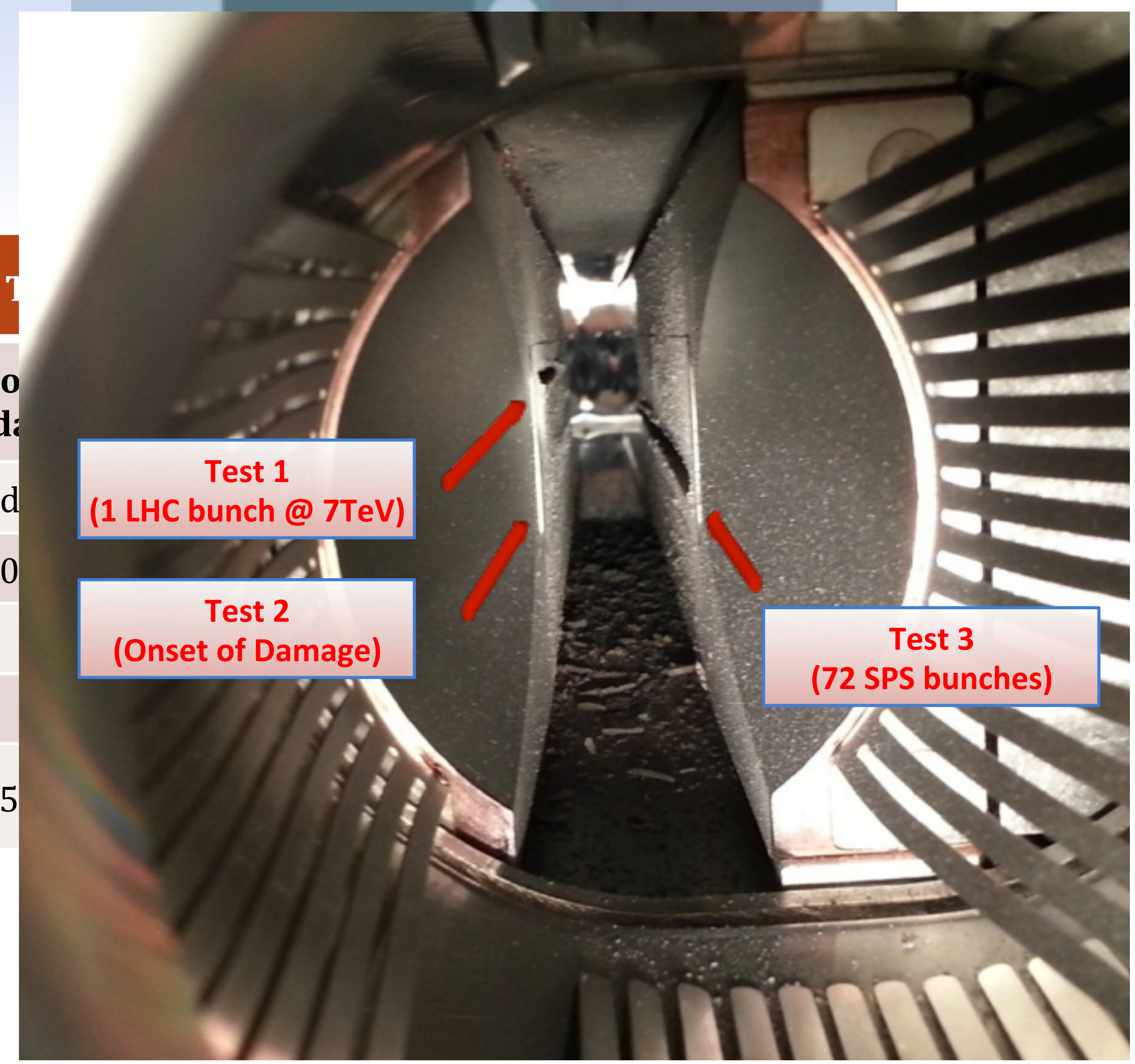




			T
Goal			ify o da
Impact location			w, d
Pulse intensity [p			1.0
Number of bunch			
Bunch spacing [n			
Beam size [σ_x - σ_y mm]	0.53 x 0.36	12	0.5

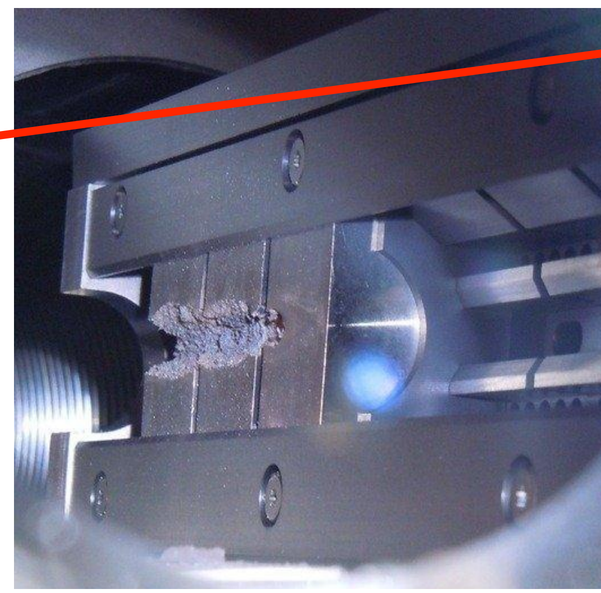


Address by beam tests the robustness of the TCT (critical for β* reach). Complementary dedicated material tests to find "ideal" collimator materials.

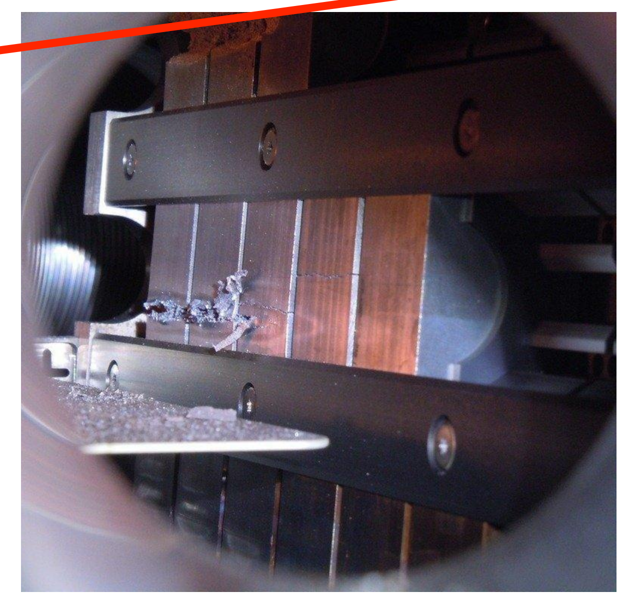
Updated robustness limits

- 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**

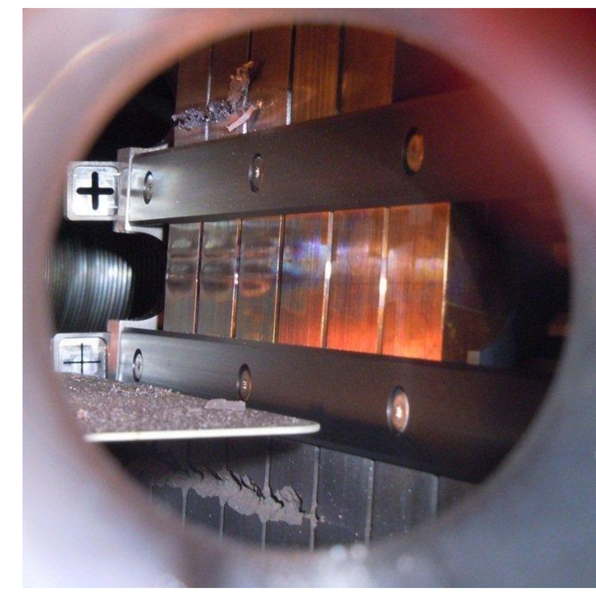
Challenge for the collimator commissioning at 7 TeV that required a few nominal bunches for collision and orbit setup! Need follow up!



Inermet 180, 72 bunches



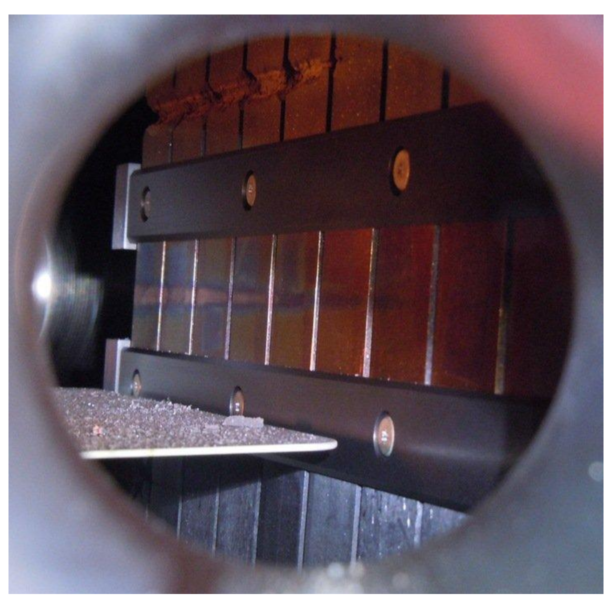
Molybdenum, 72 & 144 bunches



Glidcop, 72 bunches (2 x)

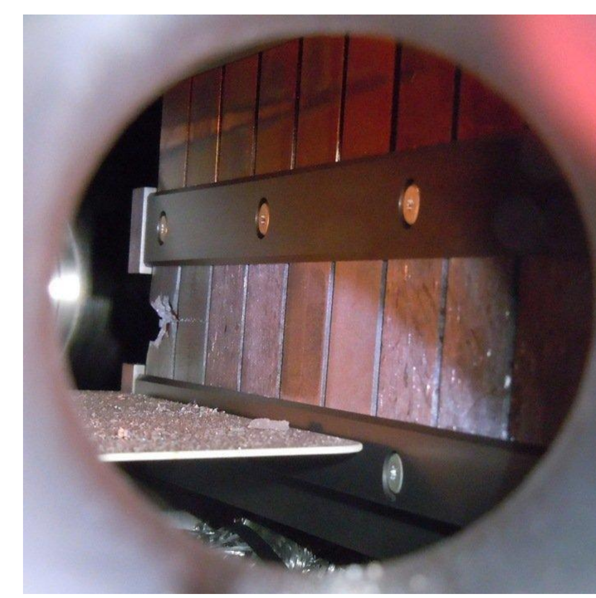
Studied alternative materials for future collimator jaws!

A. Bertarelli:
MP workshop 2013
Recent ATS seminar



Copper-Diamond
144 bunches

Molybdenum-Copper-Diamond
144 bunches



Molybdenum-Graphite (3 grades)
144 bunches

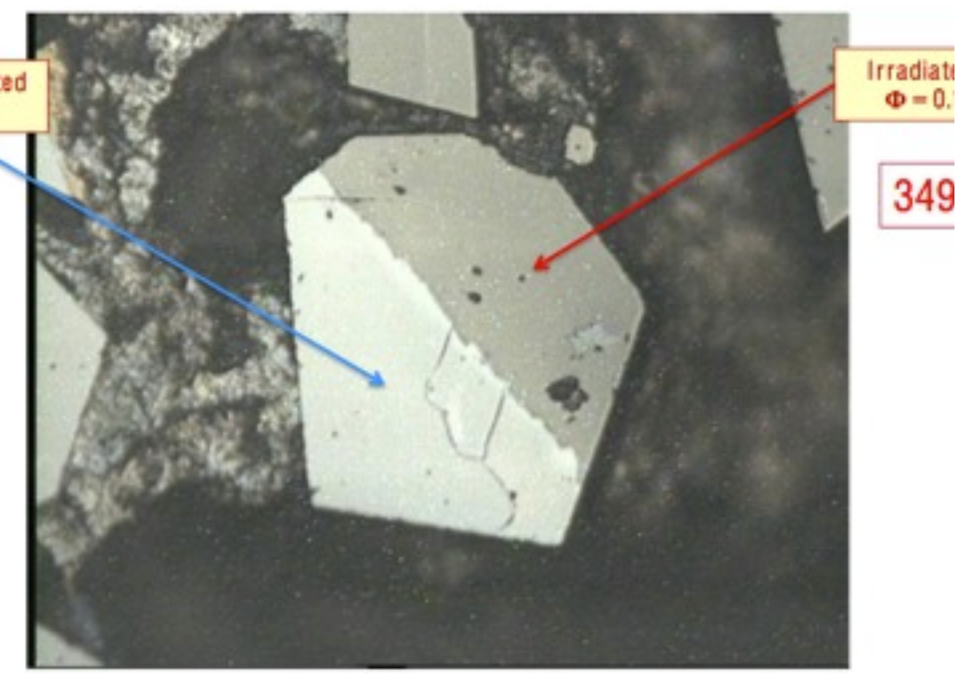
Material properties under high doses

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

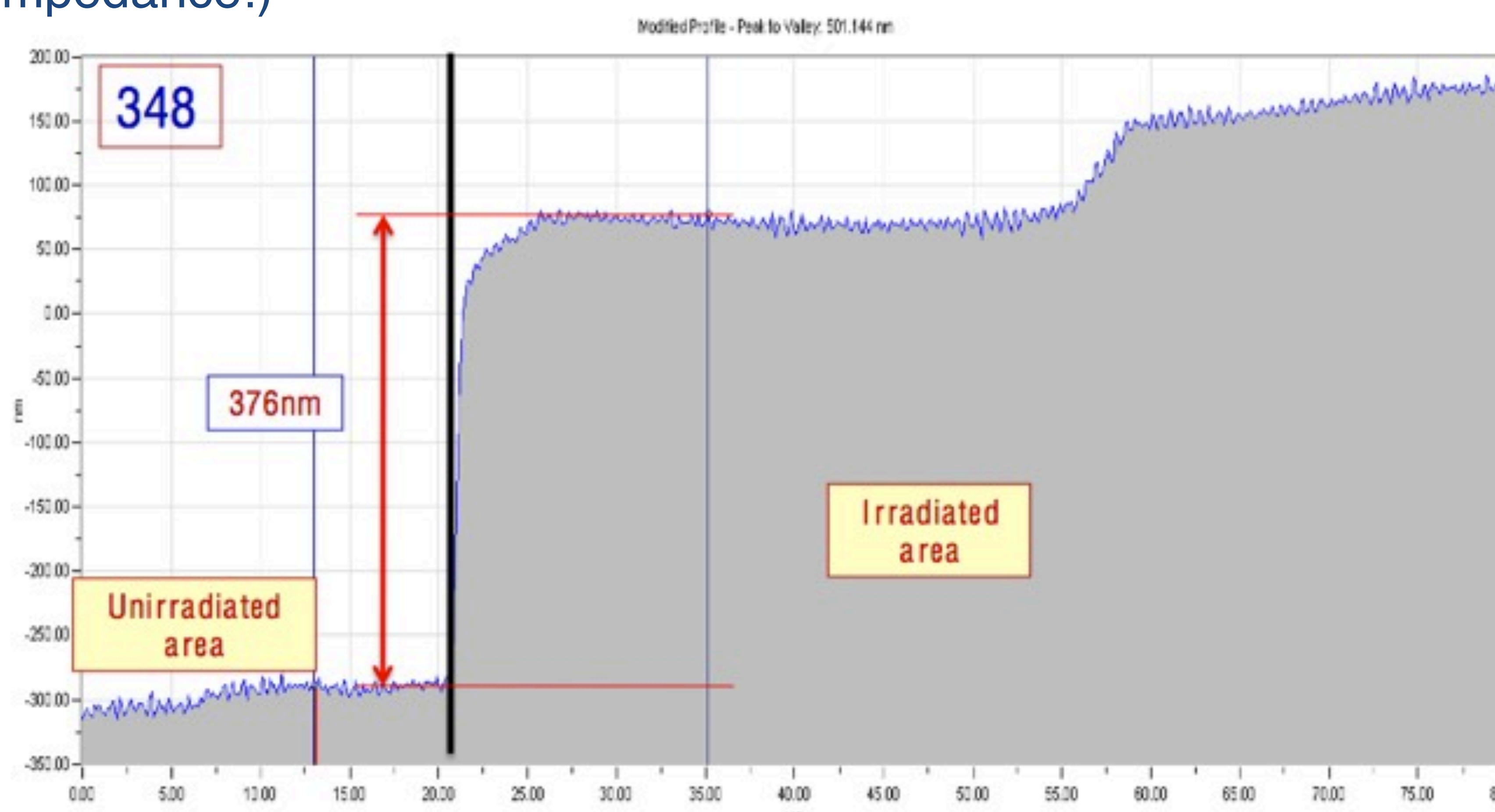
We work with high priority on understanding the **material behaviour** under high irradiation doses! Collaboration with Russia (Kurchatov) and USA (BNL within LARP): testing a panel of **6 new materials**.

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

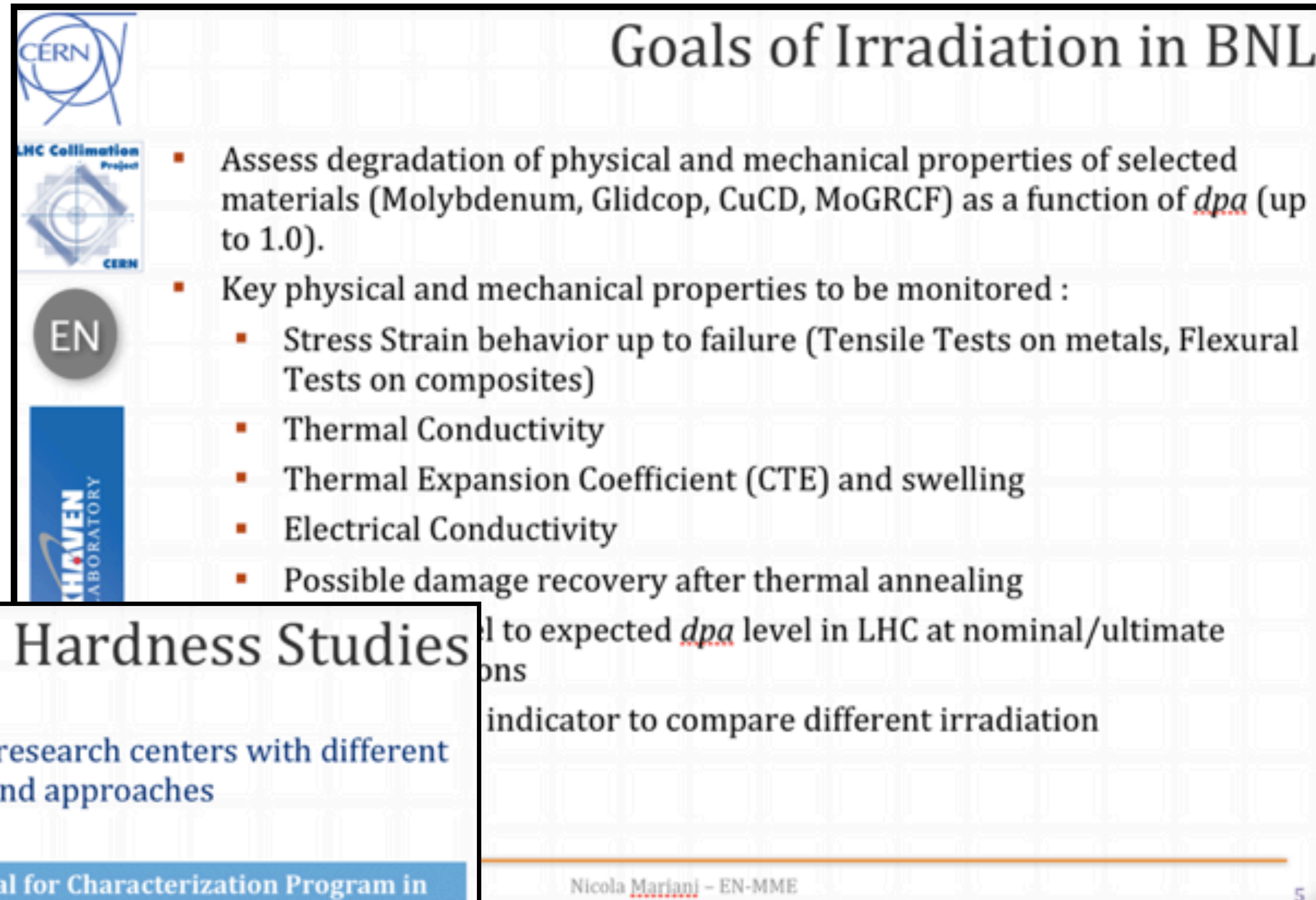


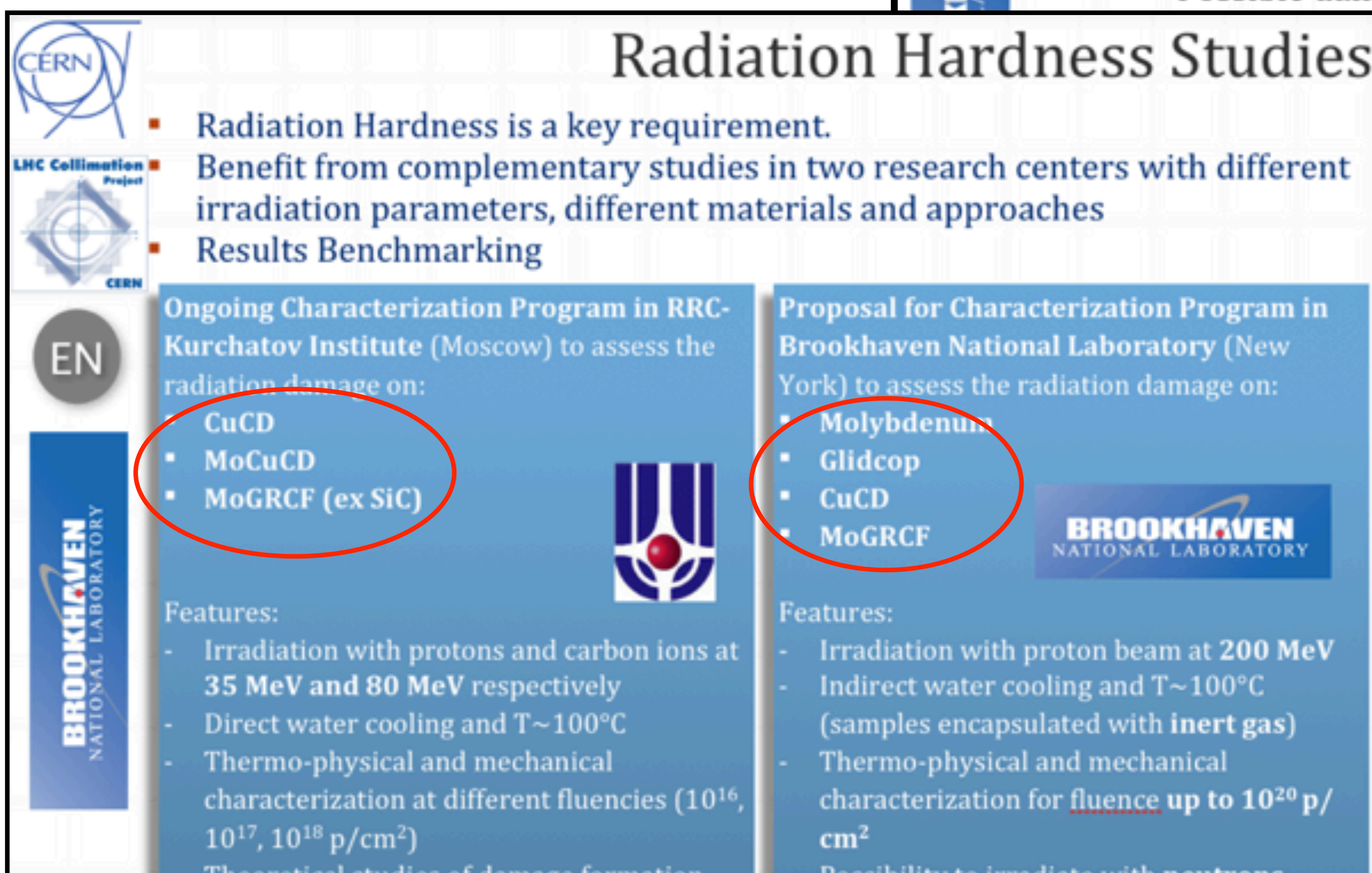
New material studies at BNL

Proposal brought forward at the CM18 a Fermilab (Apr. 2012).

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

Complements and extends important studies ongoing at Kurchatov.





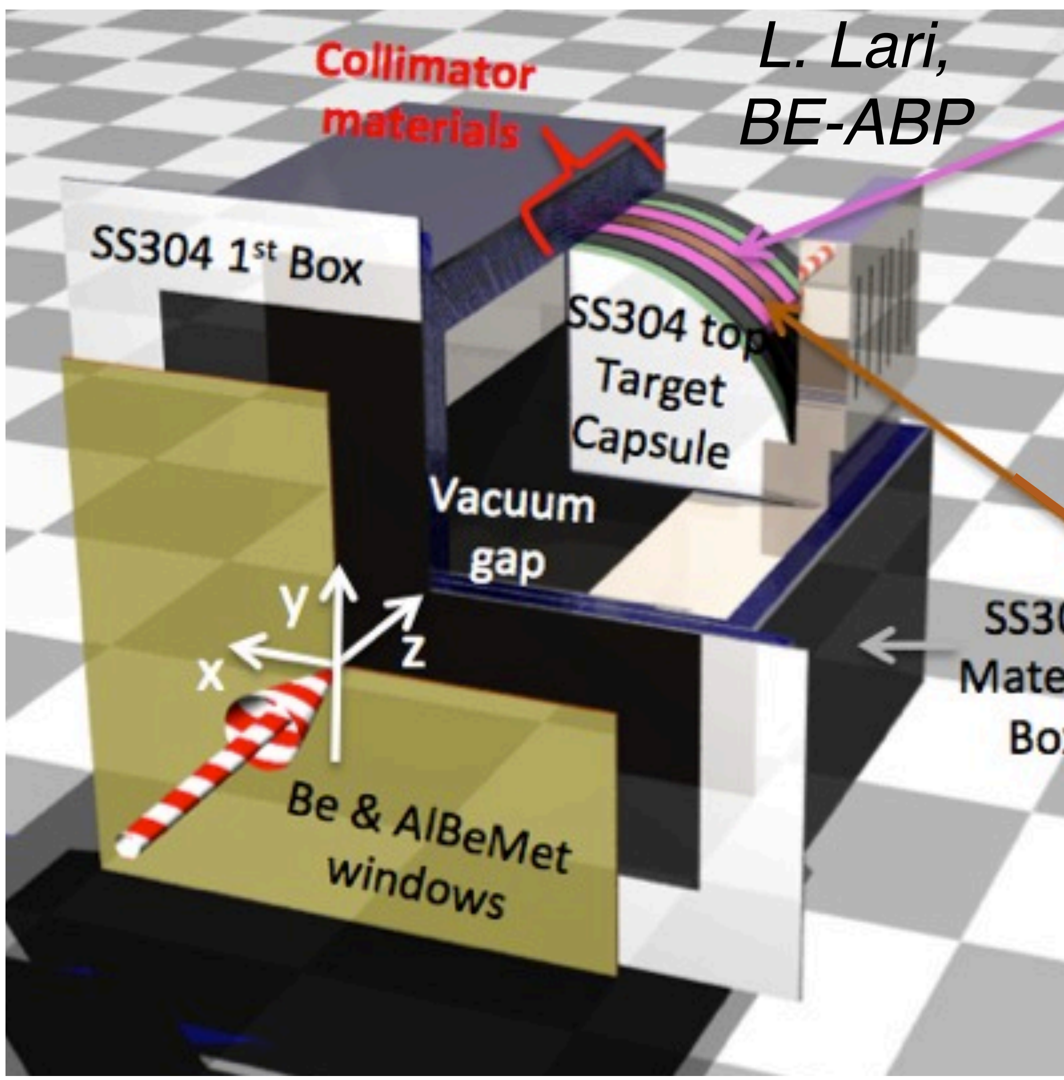
Not possible to give many details here - just brief status.

Status of BNL irradiation tests

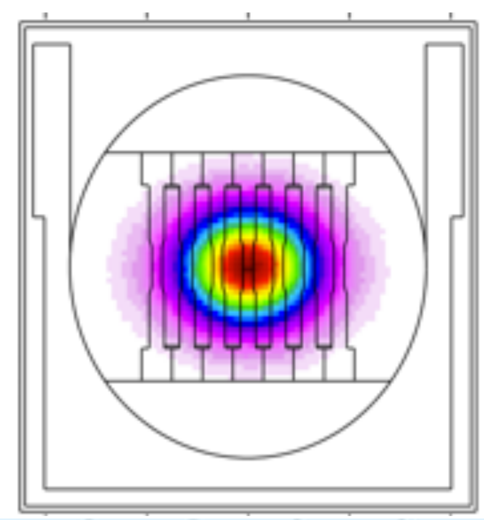
Following the US-LARP support announced at the Frascati meeting in Nov., much progress has been made:

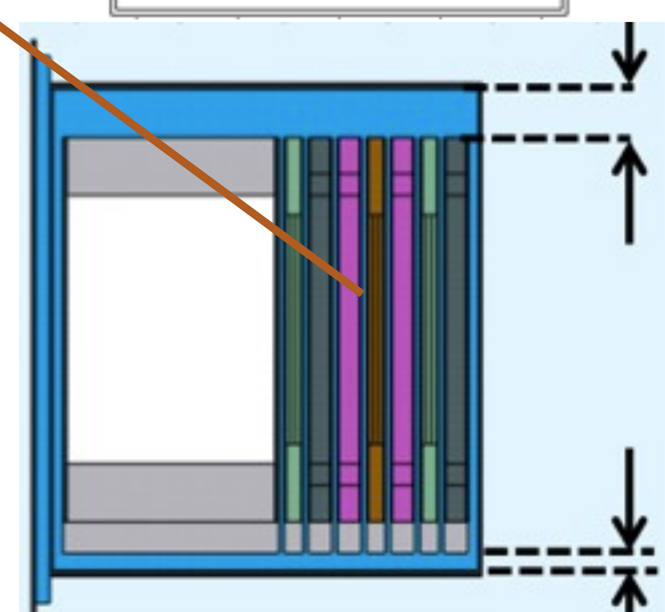
- Defined materials and optimum sample shapes.
- Ordered new materials; soon to be shipped to BNL.
- Energy deposition and structural analysis.
- Presentation to the safety committee at BNL
  Experiment Safety Review meeting of 27/03/2013

We are expecting that the tests will take place during this year's RHIC run!

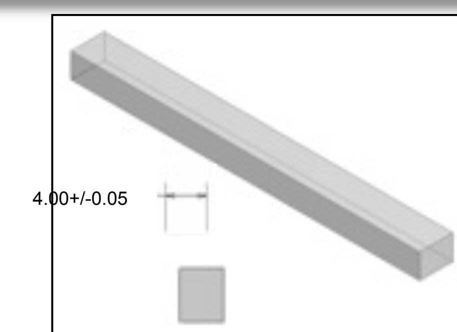


L. Lari, BE-ABP



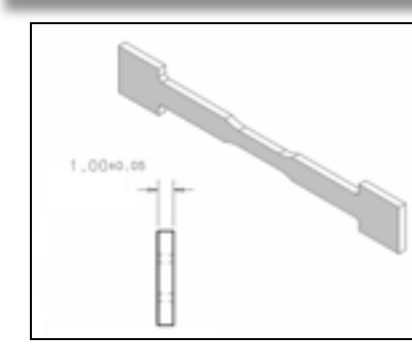


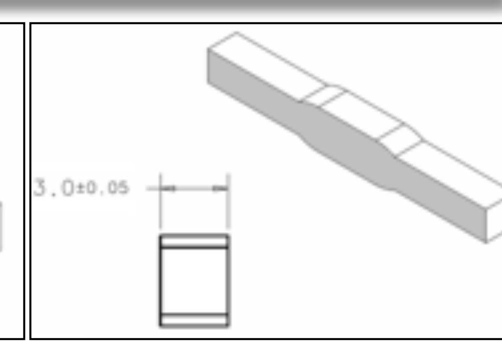
Composite materials samples:
CuCD + MoGRCF



Parallelepiped shape for all tests

Metallic materials samples:
Molybdenum + Glidcop





Tensile tests | Other

N. Mariani, EN-MME

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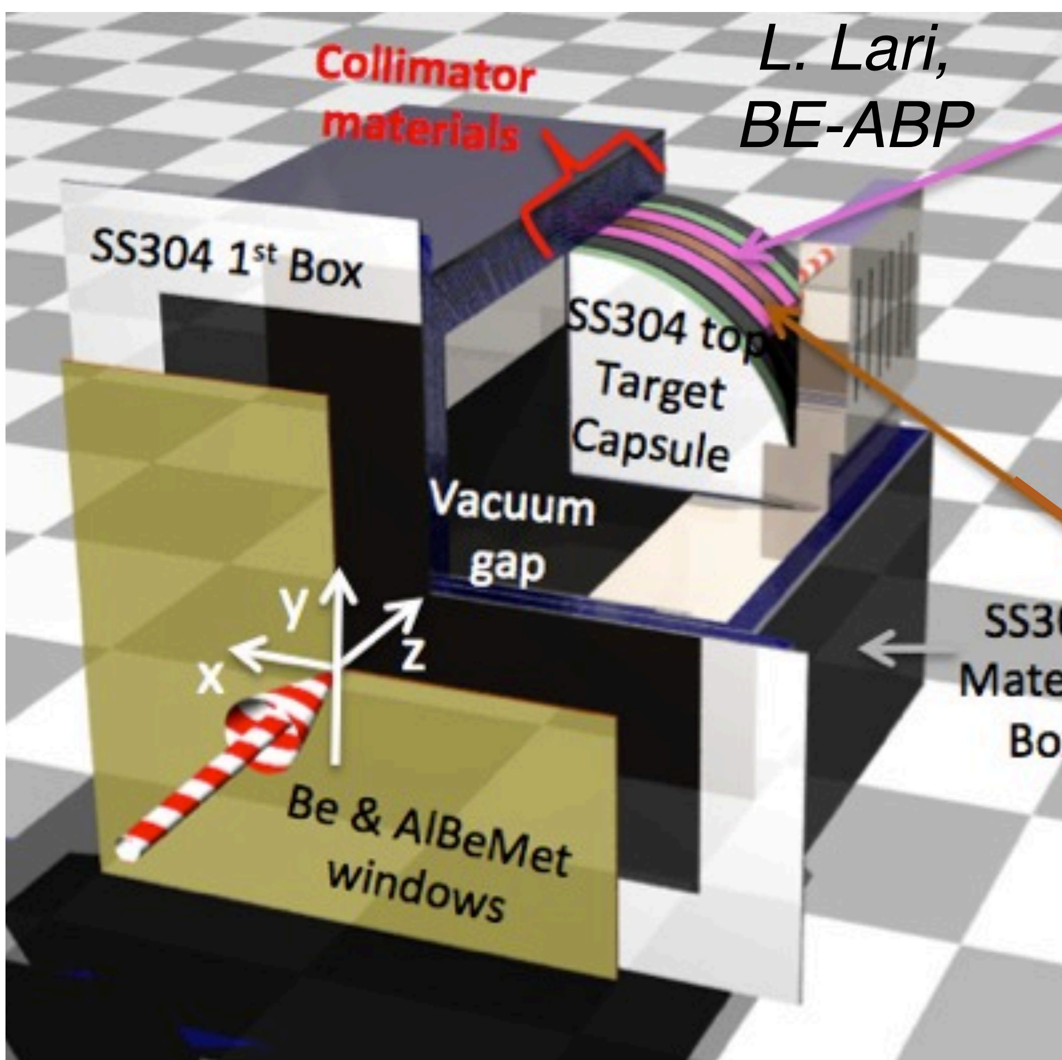
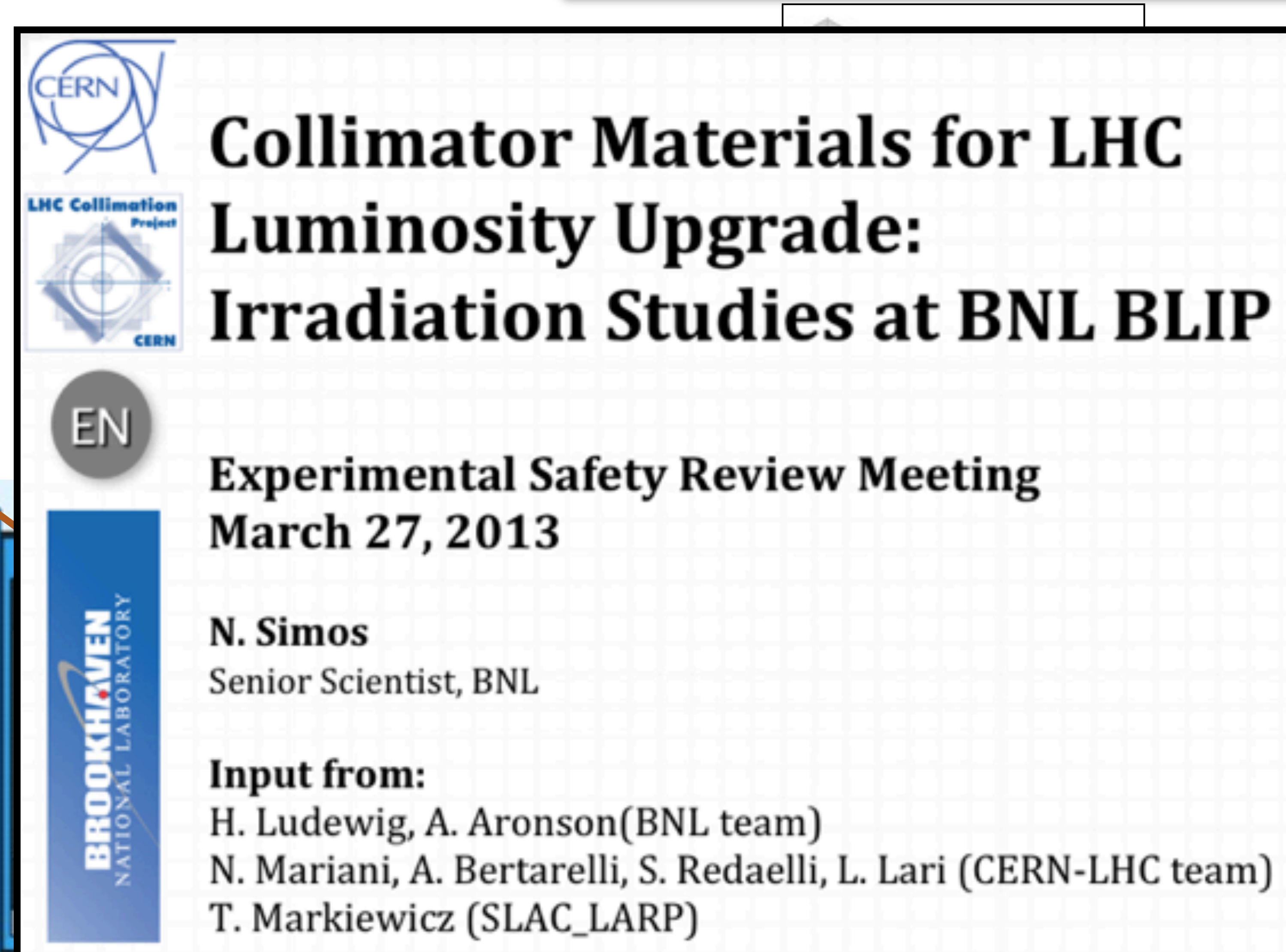




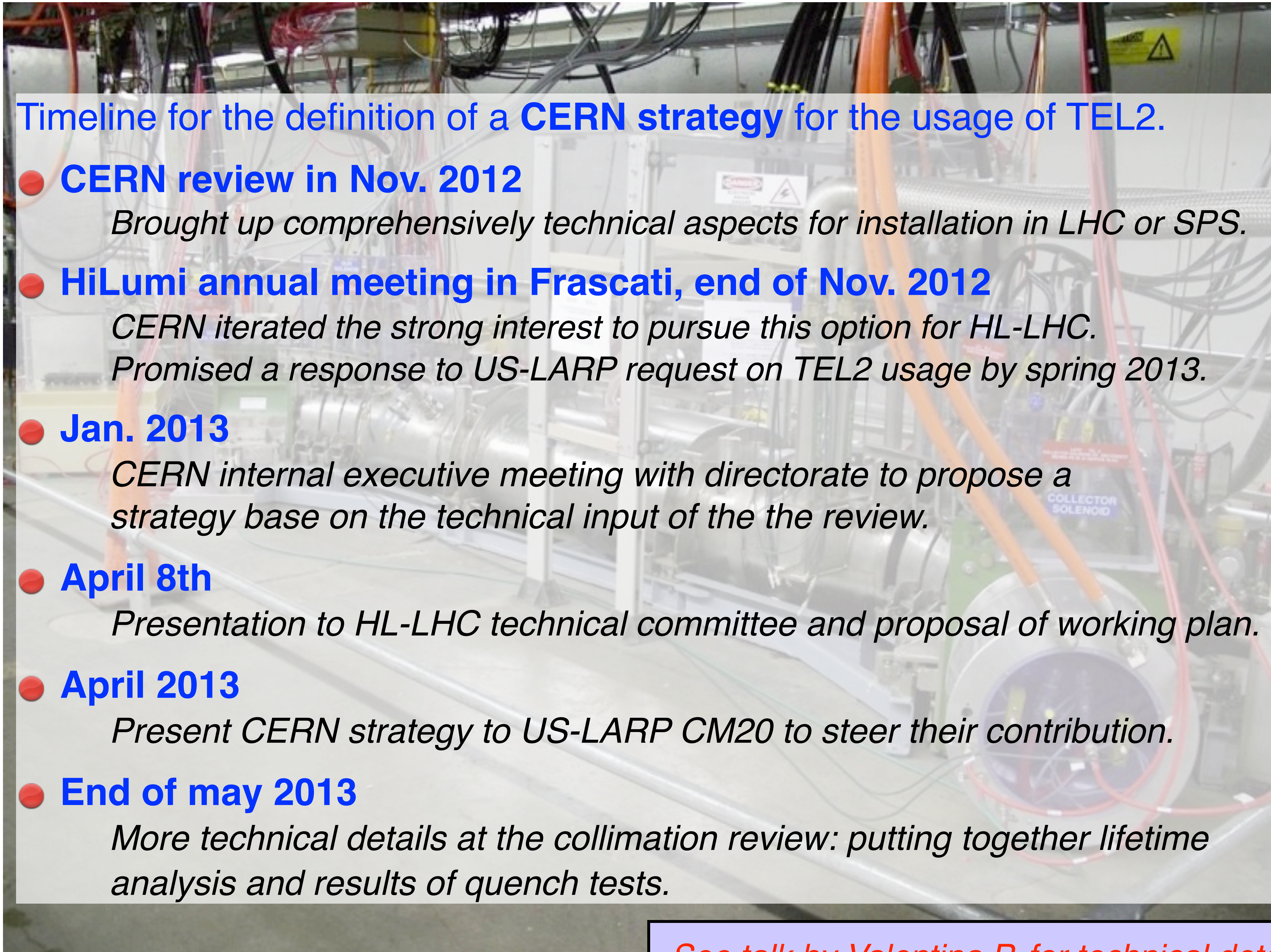
Collimator Materials for LHC Luminosity Upgrade: Irradiation Studies at BNL BLIP

Experimental Safety Review Meeting
March 27, 2013

N. Simos
Senior Scientist, BNL

Input from:
H. Ludewig, A. Aronson(BNL team)
N. Mariani, A. Bertarelli, S. Redaelli, L. Lari (CERN-LHC team)
T. Markiewicz (SLAC_LARP)

Tevatron hollow e-lens for the LHC



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 meeting with directorate to propose a strategy base on the technical input of the the review.
- **April 8th**
  Presentation to HL-LHC technical committee and proposal of working plan.
- **April 2013**
  Present CERN strategy to US-LARP CM20 to steer their contribution.
- **End of may 2013**
  More technical details at the collimation review: putting together lifetime analysis and results of quench tests.

See talk by Valentina P. for technical details

Hollow e-lens review outcome

- Very positive outcome for the review: a lot of **support/interest within CERN** for this topic! This message was passed on to LARP at Frascati's meeting in Nov.
- There are **very convincing indications** that the LHC could profit from the scraping functionality. The excellent Tevatron results indicate that **hollow e-beams** could provide this functionality *(Do we really need new tests?)*
- But **cannot** state now that without scraping the LHC performance will be limited!
  - *The final answer must wait until the first operational experience at ~7 TeV*
- The **upgraded "TEL2" hardware** is **appropriate** for the LHC and for beam tests at the SPS. **However**, the required time for an **implementation** in the LHC is **4-5 months** (driven by cryogenics works in IP4). *SPS estimates to be finalized.*
- 1 technical concern: effect on beam core emittance from hollow e-beam "edge".
- **Alternative methods** for active beam scraping must be studied with **high priority**. Presently, lacking alternatives solidly proved by beam tests.
  - *If there are problems in 2015, the available single device will not help*
  - *Several options on the table: narrow damper excitation (see Wolfgang H. talk); tune modulation by rippling quadrupole currents; beam wire compensators; scraping with TCP's.*
- **Strong** message on the need to improve **halo diagnostics!** *See Gianluigi's A. talk.*

CERN strategy

Taking into account the present financial situation and the manpower commitment to the LS1 activities, CERN cannot decide now on the installation of the available Tevatron hardware in the SPS or the LHC.

This also takes into account that firm indications of LHC critical performance limitations without scraping, can only become apparent after some operational experience at energies near to 7 TeV.

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.
- Continue working on **alternative methods** for halo scraping.
- Work with very high priority on **improving the halo diagnostic** at the LHC.

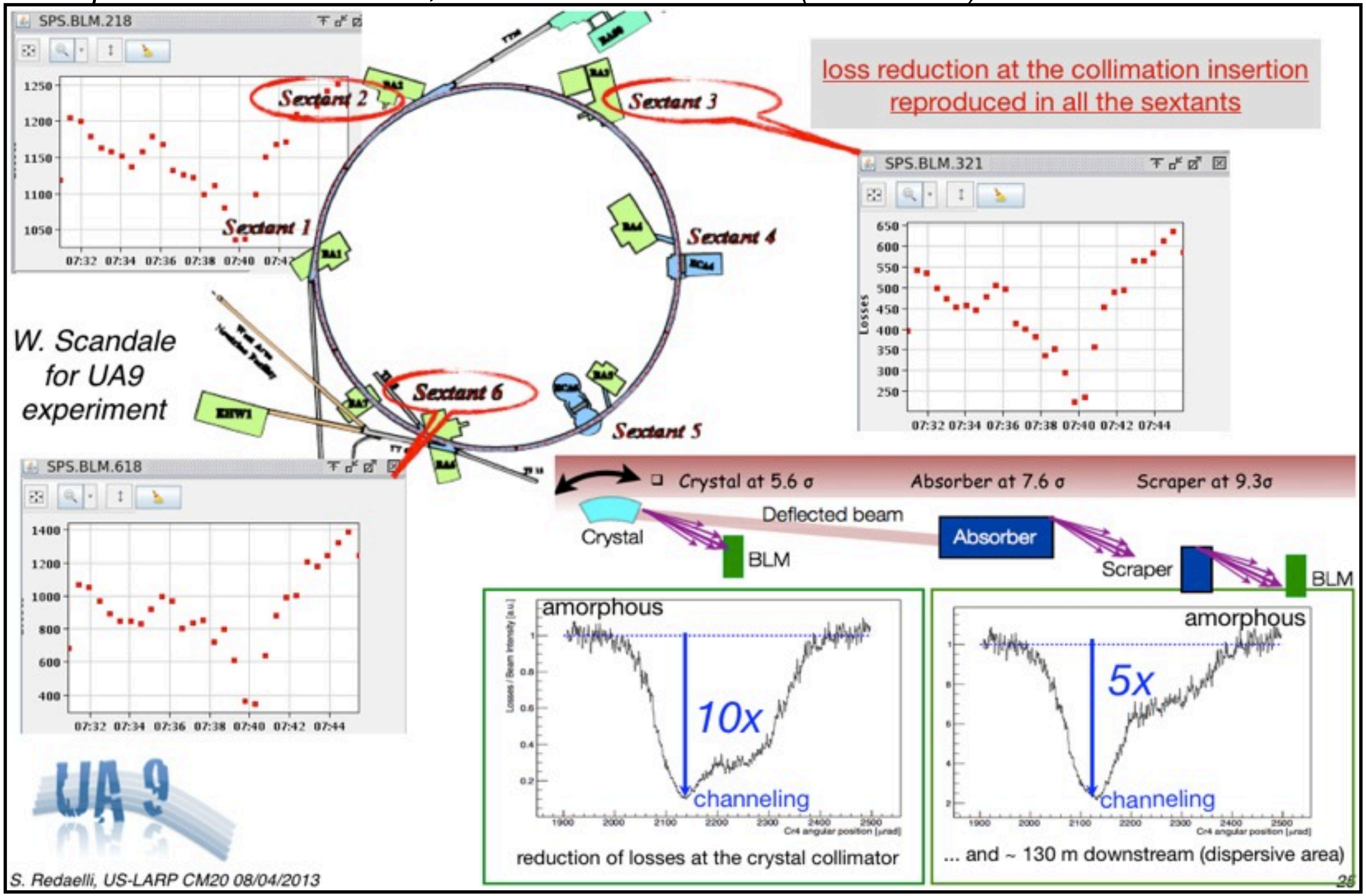
Synergies with US-LARP

(Based on discussions with G. Stancari, A. Valishev, W. Fisher, H. Schmickler, et al.)

- FNAL is interested to work on an **optimum conceptual design** for the LHC:
  - *Time structure of beam; Improved instrumentation; Improved impedance; Better integration in LHC cryo system; reduced impedance.*
  - *First specifications in the next 6 months, to be followed by detailed design.*
  - *Continue measurements to characterize new gun for the LHC parameters.*
- At CERN, we established links to achieve a design report by the end of 2014
  - *Main links from collimation (S. Redaelli), instrumentation (R. Jones) and engineering design team (F. Bertinelli) to follow up a detailed design.*
- FNAL is interested to continue simulation and theoretical works for hollow e-lens as well as for **alternative methods**!
  - *First priority: model the effect of hollow beam "edges" on beam core emittance.*
  - *Continue joint effort on diffusion measurement and modelling.*
  - *Study alternative methods: effect on beam tails/core from tune modulation.*
- CERN link from collimation aspects for alternative scraping: R. Bruce
  - *ADT narrow-band excitation -> see talk tomorrow by W. Höfle.*
- We would like profit from the RHIC e-lens setup to make more beam tests
  - *Interest from RHIC side to work on that - see talk by Wolfram F.*
  - *Tests are subject to their successful commissioning for the RHIC p run!*
  - *Possibility to change the gun to get hollow beams (limited resources needed).*
  - *Primary goal: verify with beam effect on beam core from beam "edge".*
- The EPFL in Lausanne (L. Rivkin) is interested in participating to this study!

LHC crystal collimation studies

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



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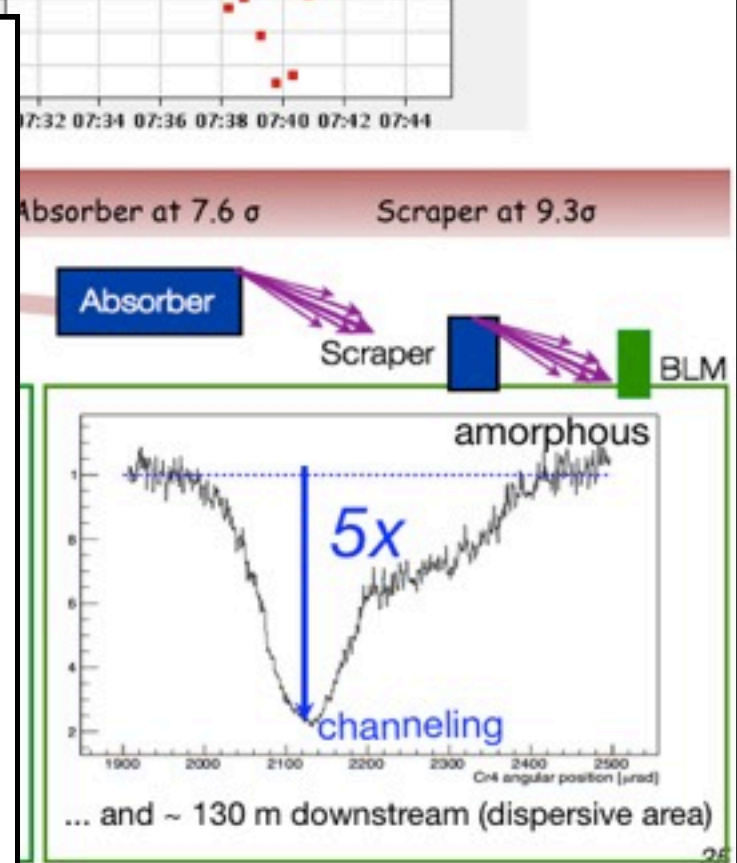
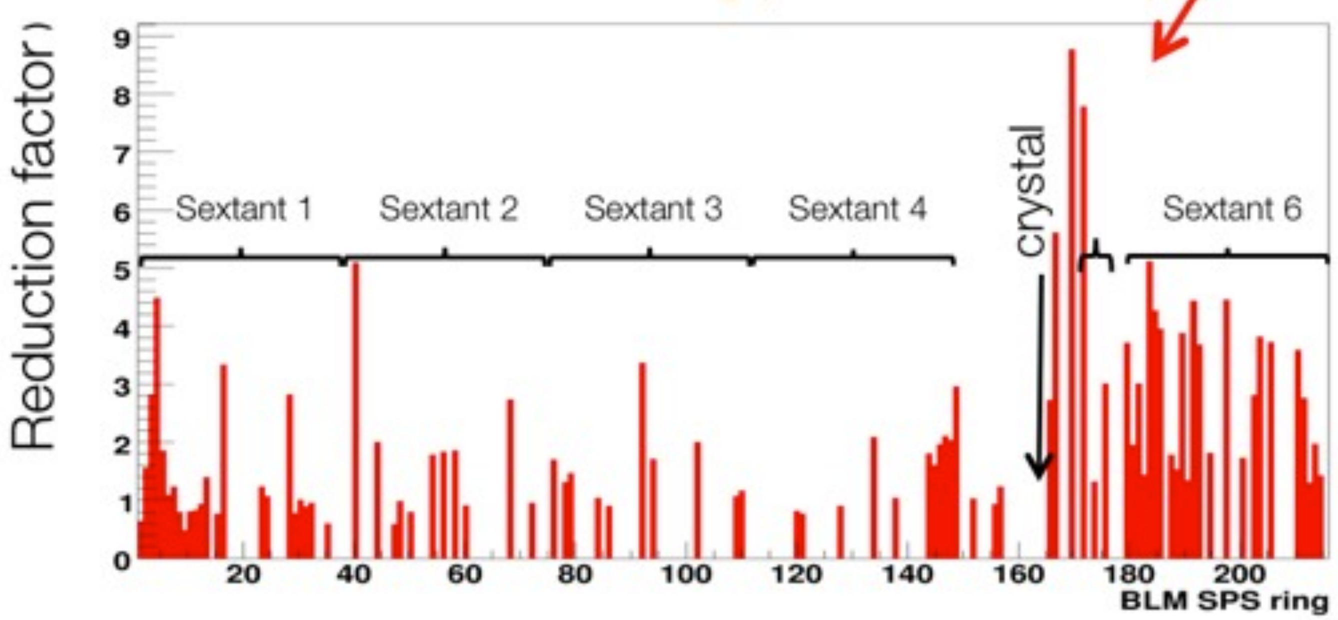


New measurements in 2012:

- *Cleaning around the ring with higher beam intensities.*
- *More detailed measurements for proton and ions*

❑ Loss map measurement in 2012:

- total intensity: 3.3 x 10^{13}, 4 x 72 bunches with 25 ns spacing
- Loss reduction in the entire ring (in the reliable BLMs)



LHC crystal collimation studies

Slide presented at the CM18; More details at Frasca

W. Scandale

New measurements in 2012:

- *Cleaning around the ring with higher beam inte*
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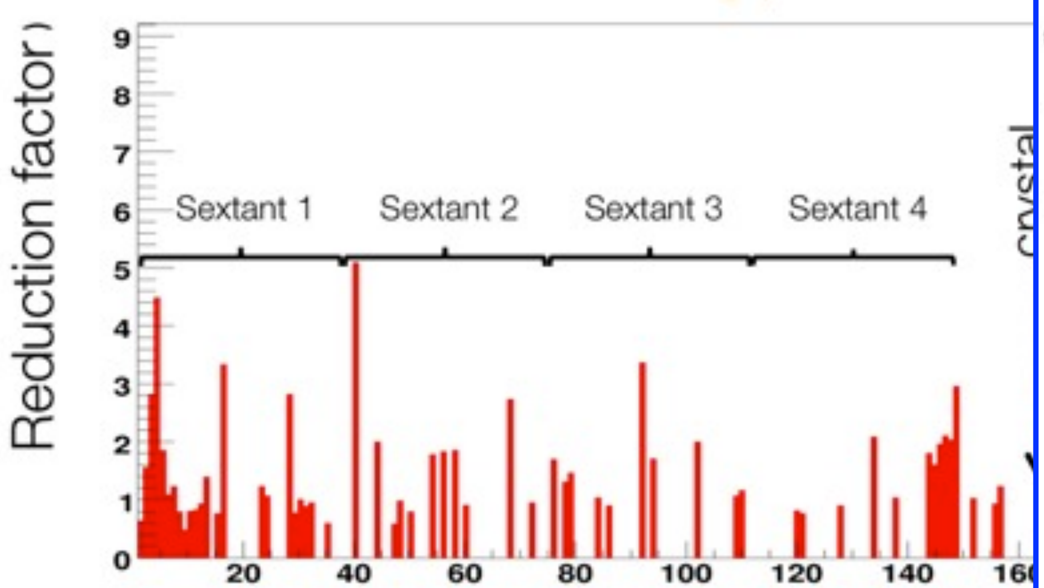
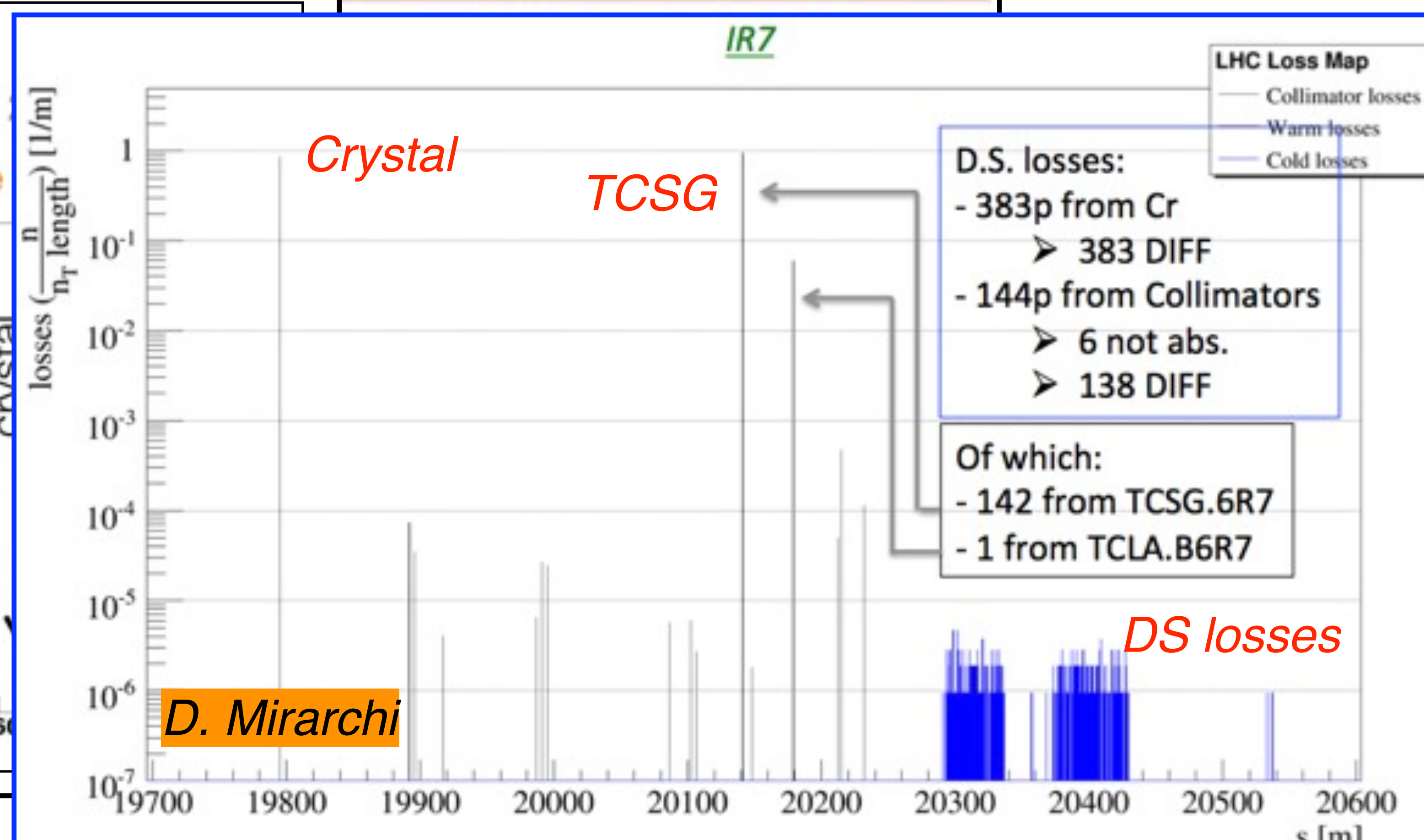


Status for the LHC studies:

- *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 was approved and is presently in the LS1 work plan.*
- *Working on detailed LHC layouts - plan to circulate soon an Engineering Change request for approval.*
- *Realistic to have a minimum setup (crystals only, no dedicated additional instrumentation).*

Need to discuss here if there is interest from US-LARP in participating into this effort!

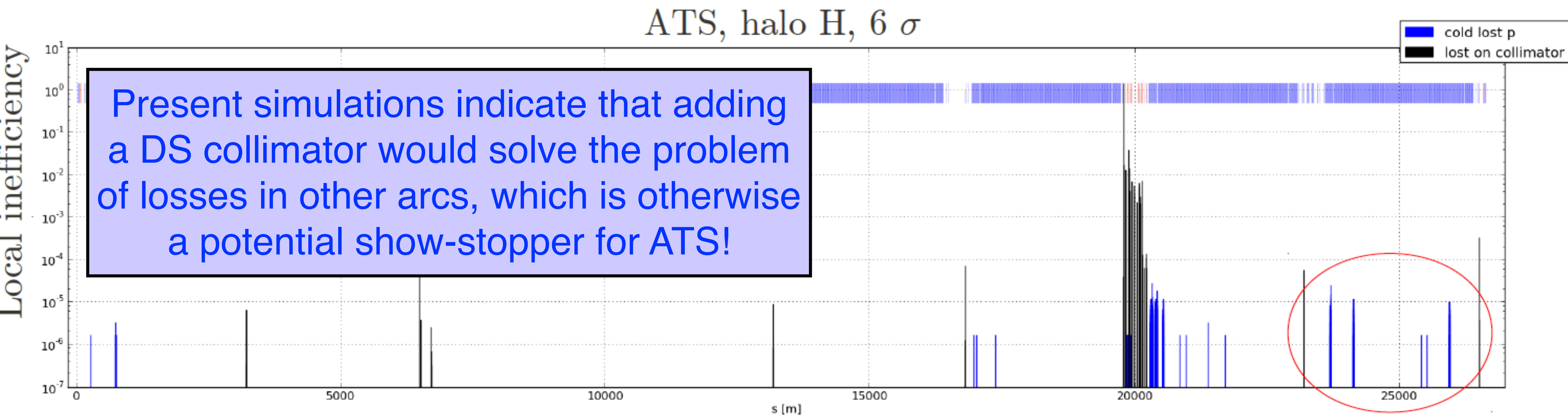


Conclusions

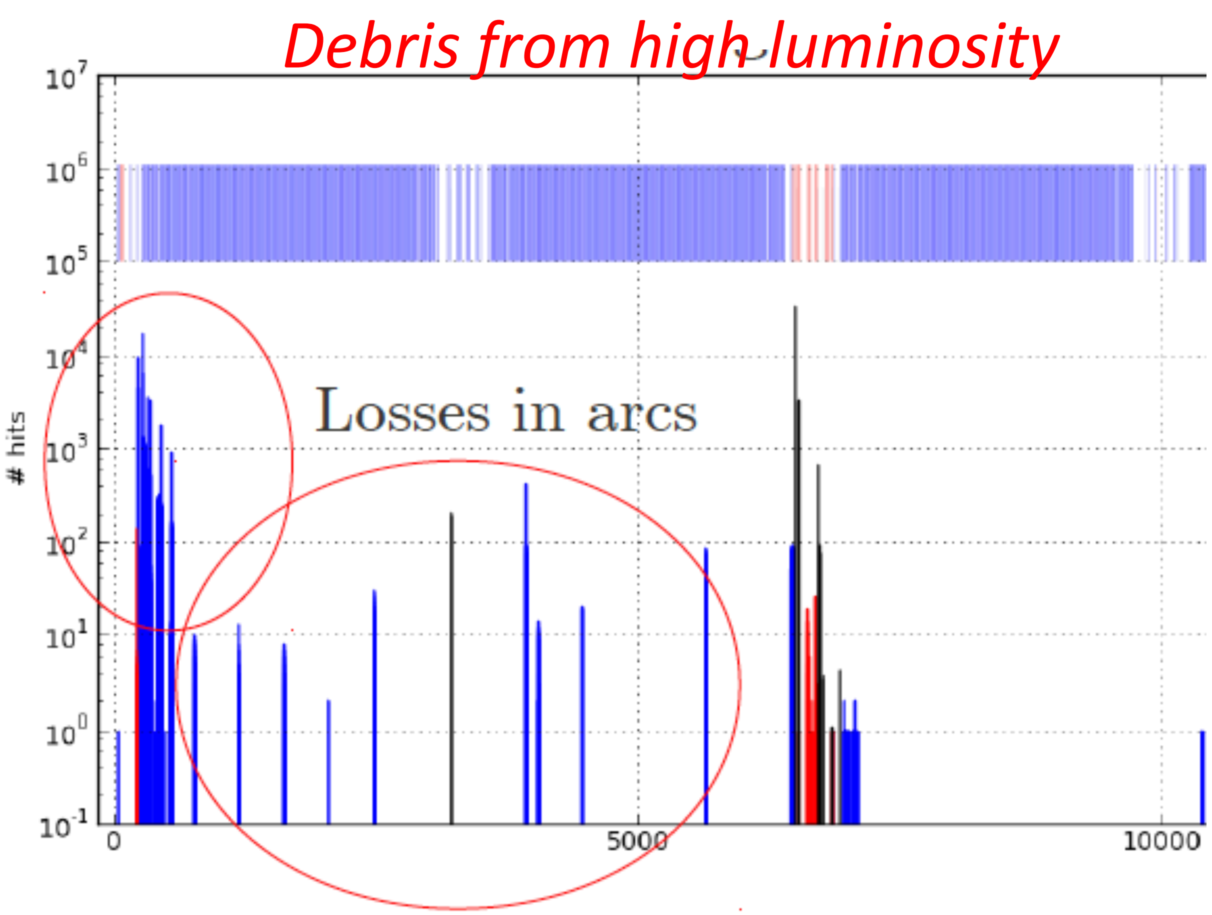
- The LHC and its collimation system performed remarkably well in the Run1 with stored energies up to ~140MJ!
  We could postpone major collimation until after LS1, but we must be be ready if the operation at 7 TeV shows problems.
- The upgrade strategy is being reviewed based on the OP experience: a **collimator review** in May will address mid- and long-term plans.
  Immediate goal: decide on the 11 T dipole strategy until post-LS1 operation. Can we get them in LS2 if the operation at 2015 show that they are needed? It seems clear that they will be needed for HL-LHC.
- Other exciting studies are ongoing to meet the HL-LHC challenges.
  Important material studies, different aspects (slow/fast losses, impedance, ..)
  New collimator designs (improved present design, BPM design, SLAC RC, ...)
  Advanced concepts like hollow e-lens, crystals, etc.
- The contribution to collimation from US-LARP is much appreciated!
  New proposed strategy for the hollow e-lens, which relies on the competence!
  Defined a plan for BNL material studies that complements our studies.
  Hoping to motivate the USA friends on new R&D topics!

Reserve slides

Cleaning for HL-LHC optics (ATS)



Present simulations indicate that adding a DS collimator would solve the problem of losses in other arcs, which is otherwise a potential show-stopper for ATS!



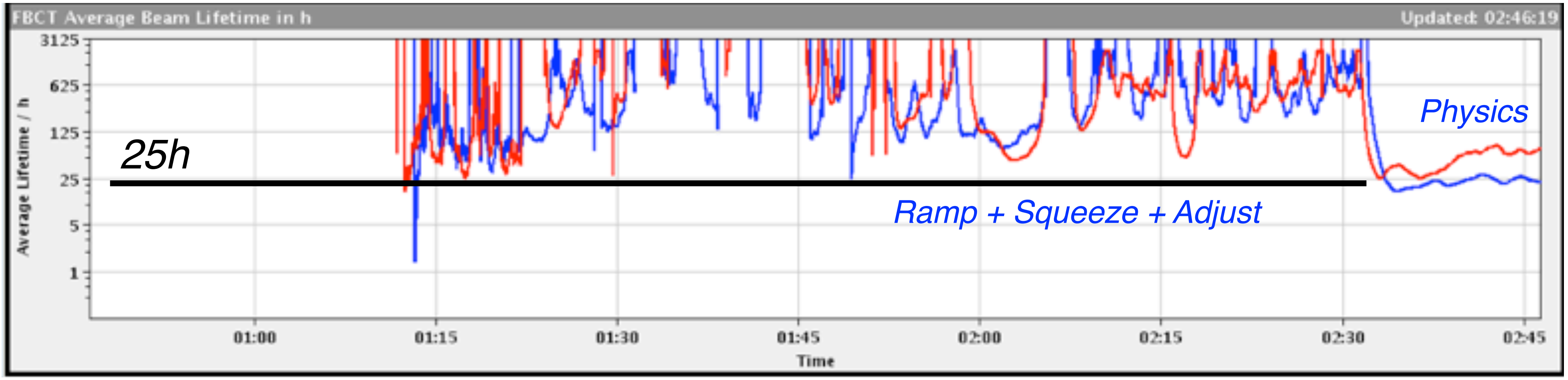
Setup of first complete loss maps with HL optics baseline (ATS for 15cm). Identified possible critical loss locations outside DS of IR7 -> need to improve the IR7 cleaning!

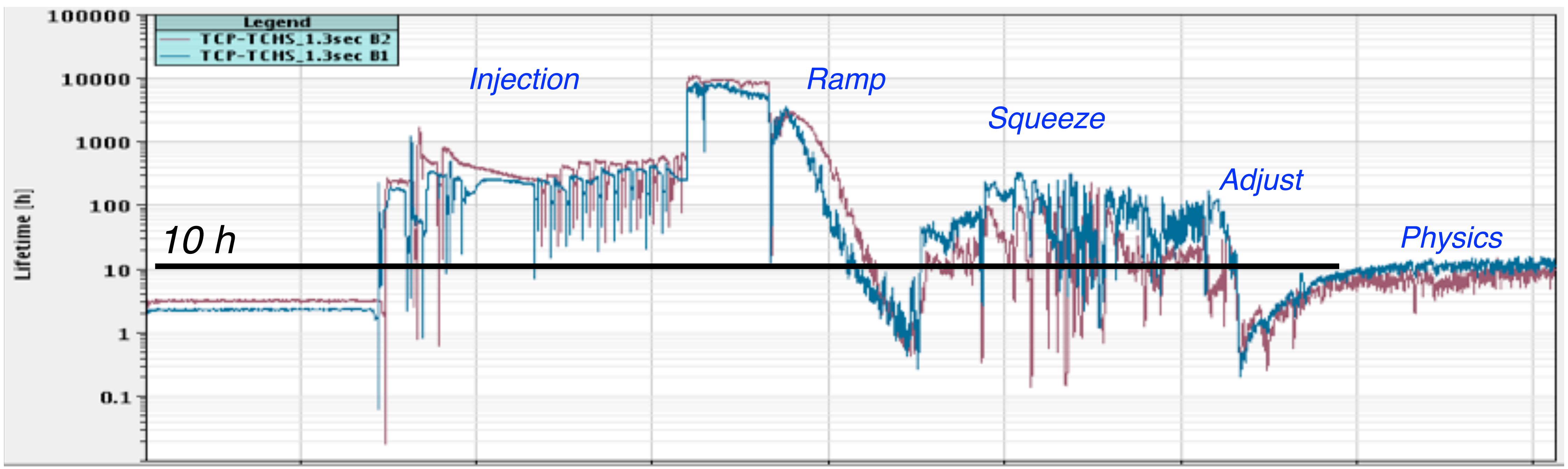
Simulation of physics debris losses for proton collisions.

A. Marsili, BE-ABP

Lifetime during OP cycle

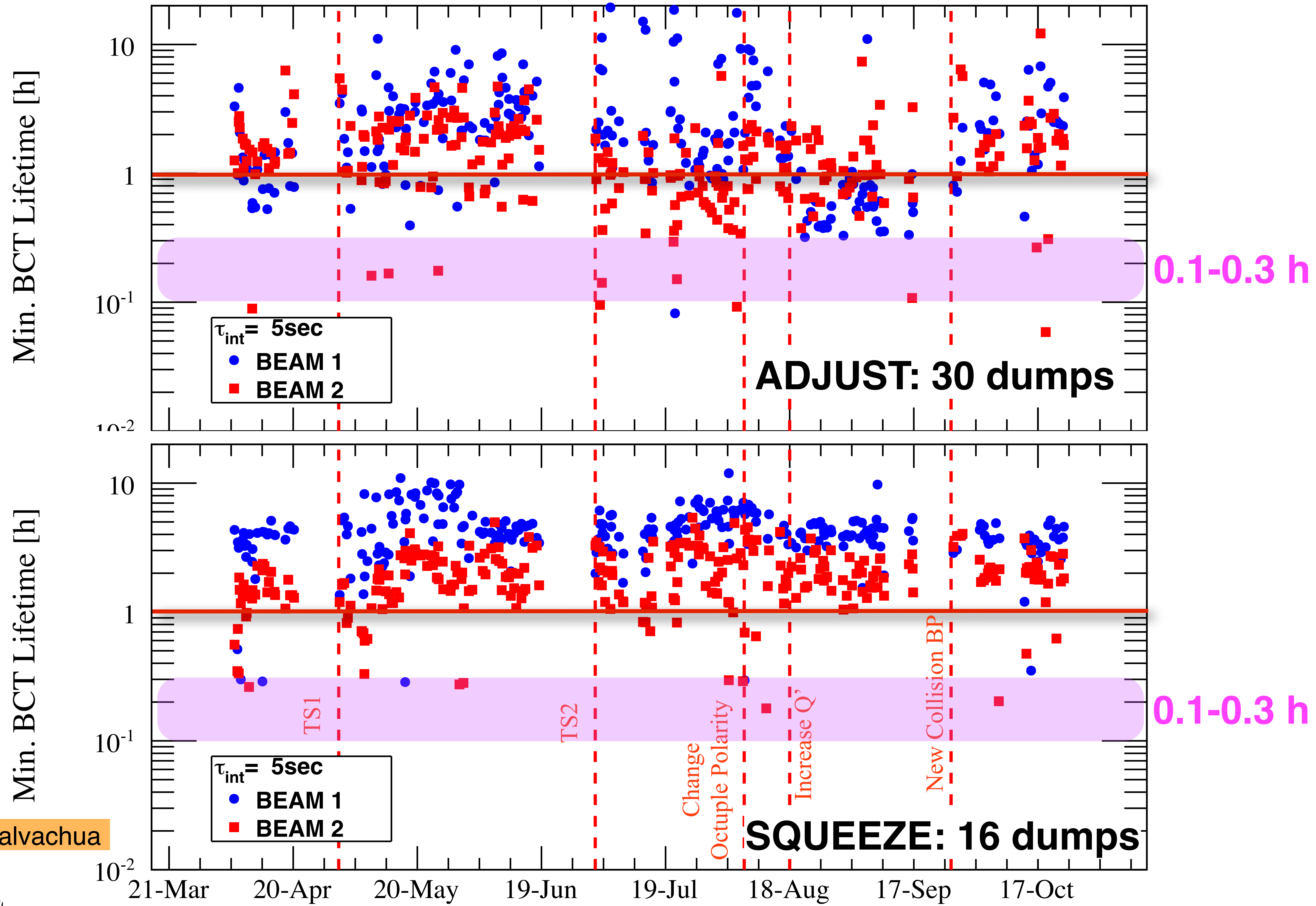
Couple of illustrative examples taken randomly from the LHC elogbook...





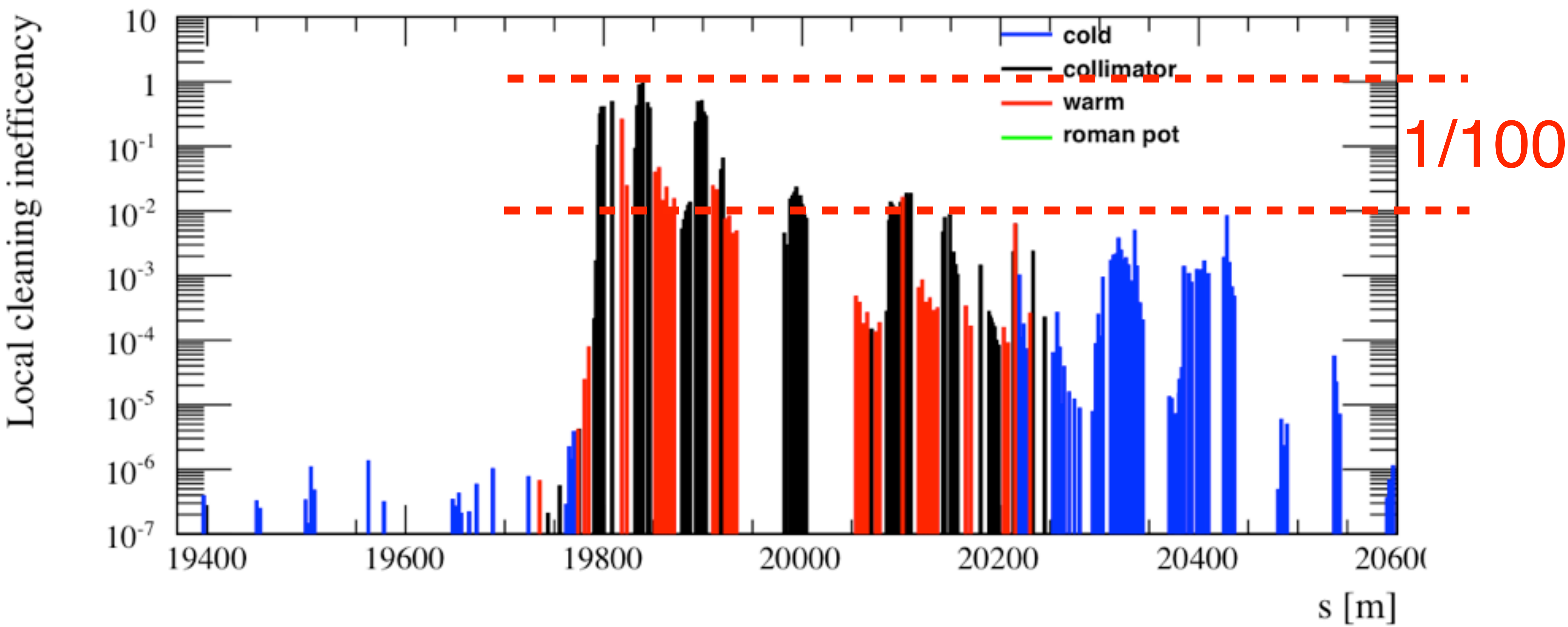
Will this be a serious issue after LS1?
Detailed analysis of quench tests will provide improved estimates.
Needs of possible scraping methods (hollow e-lens or similar) are being studied.
Can always open the collimators, at the **cost of larger β^***.

Beam lifetime analysis



B. Salvachua

Cleaning for Pb ion beams at 4 TeV



Experience at 4 TeV confirmed the 2011 results at 3.5 TeV: Betatron cleaning of a few percent only, i.e. more than a **factor 100 worst** than for protons.

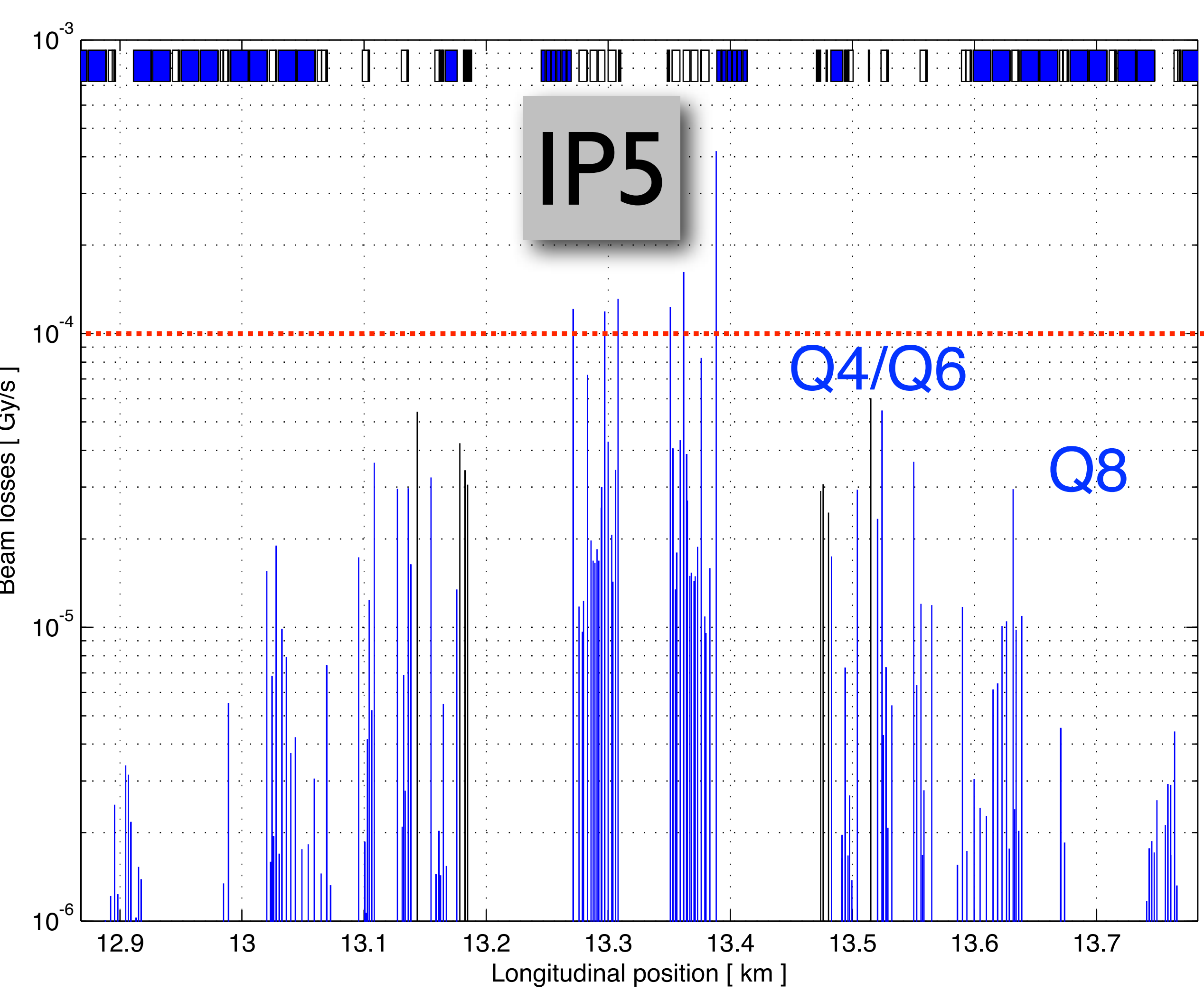
Limiting location still the **dispersion suppressor**, but different loss distribution than for protons: fragmented ion beams lost at specific locations.

Losses from luminosity debris

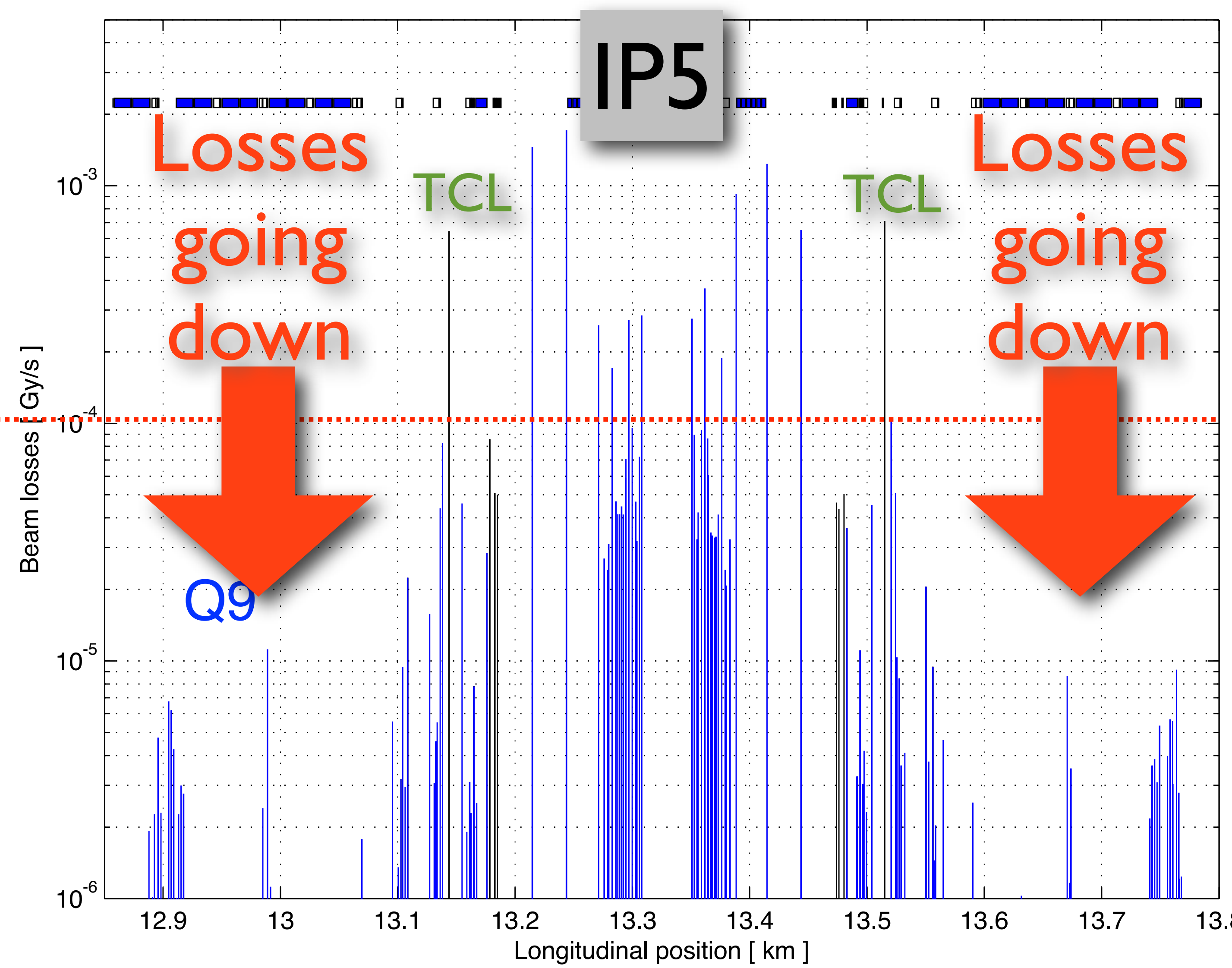
- In 2012, we have started using the TCL collimators in IP1 and IP5 that catch **physics debris**.
- Set to 10σ since the start of the run.
- We have performed TCLs scans to understand the impact on reducing the losses and the load to the magnets. At 10σ measured losses at Q8 reduced by a factor of 50!

Significant improvement of SEU's in IR1 and IR5

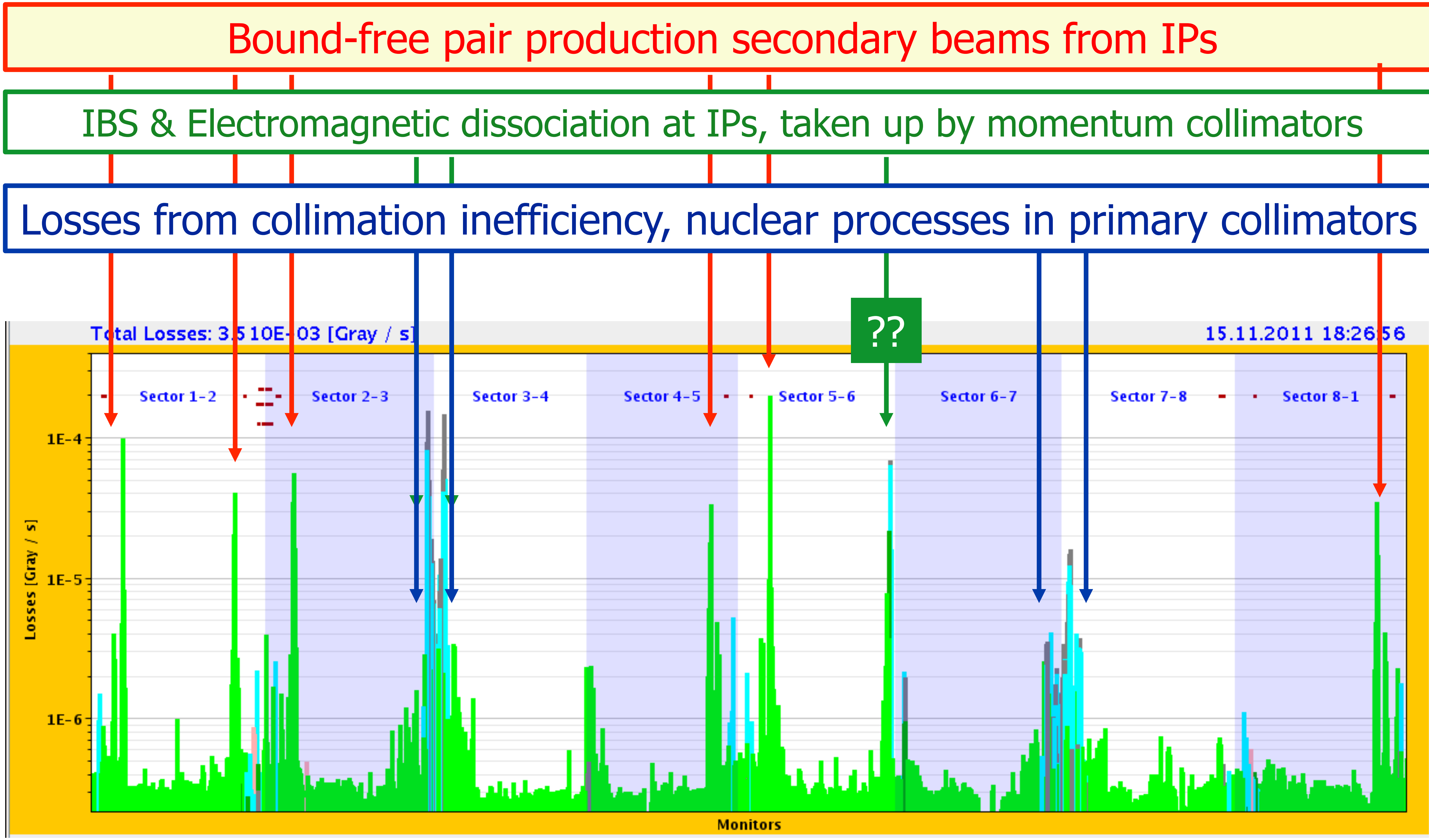
Proton operation in 2011



Proton operation in 2012

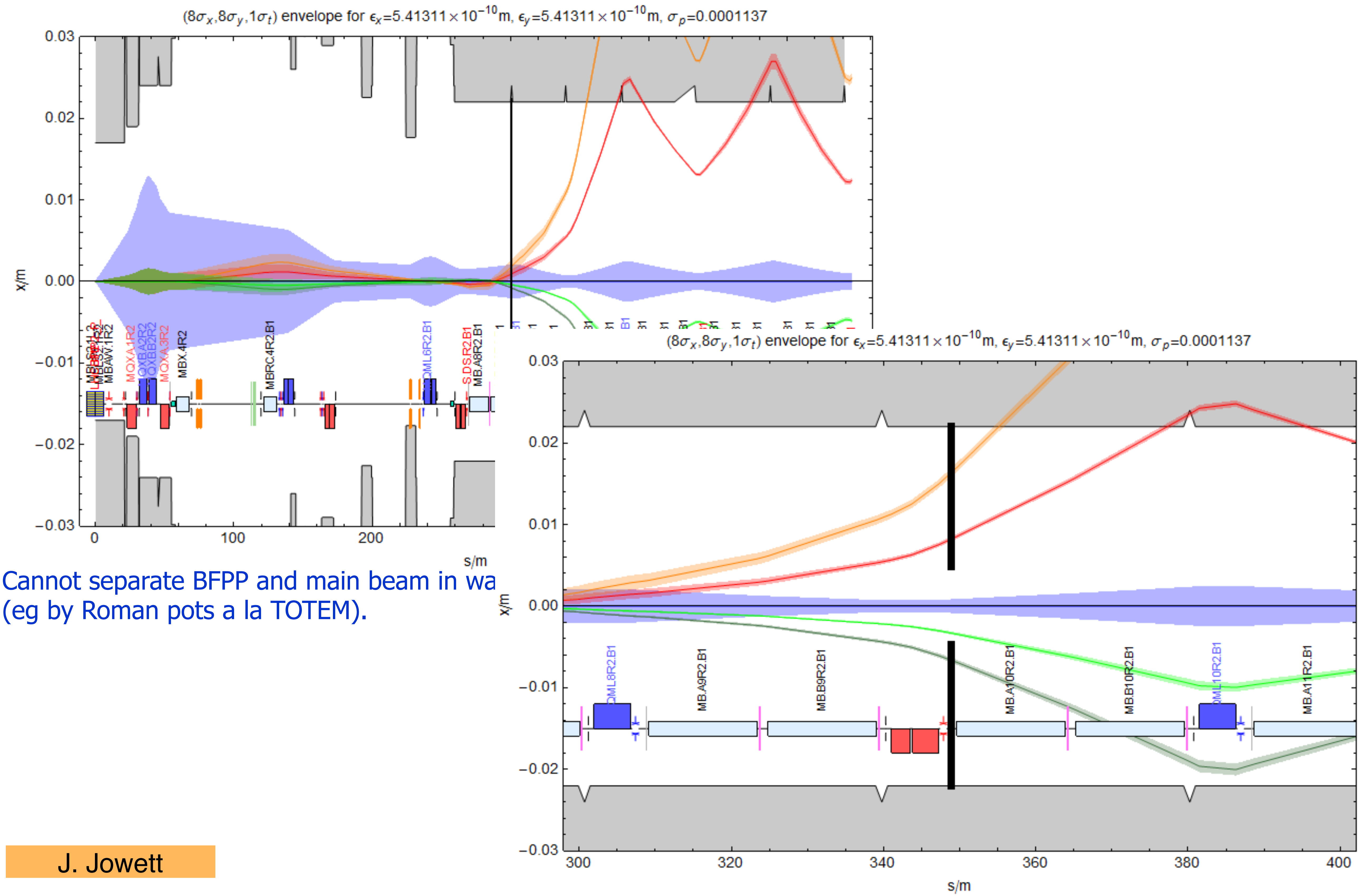


3.5 TeV losses with Pb-Pb collisions



J. Jowett

Secondary beam at the IR2 DS



Cannot separate BFPP and main beam in wa
(eg by Roman pots a la TOTEM).

J. Jowett

LS1 collimation activities

- **16 Tungsten TCTs** in all IRs and the **2 Carbon TCSGs in IR6** will be replaced by new collimators with **integrated BPMs**.

  Gain: can align the collimator jaw without "touching" the beam → no dedicated low-intensity fills.

  → *Drastically reduced setup time => more flexibility in IR configurations*

  → *Reduced orbit margins in cleaning hierarchy => more room to squeeze β*: ≥ ~**30 cm (R. Bruce)***

  → *Improved monitoring of local orbit and interlocking strategy*

- Updated **TCL layouts in IR1/5** for physics debris absorption

  → *Add 1-2 TCL collimator per beam. Expected to be compatible with HL proton luminosity.*

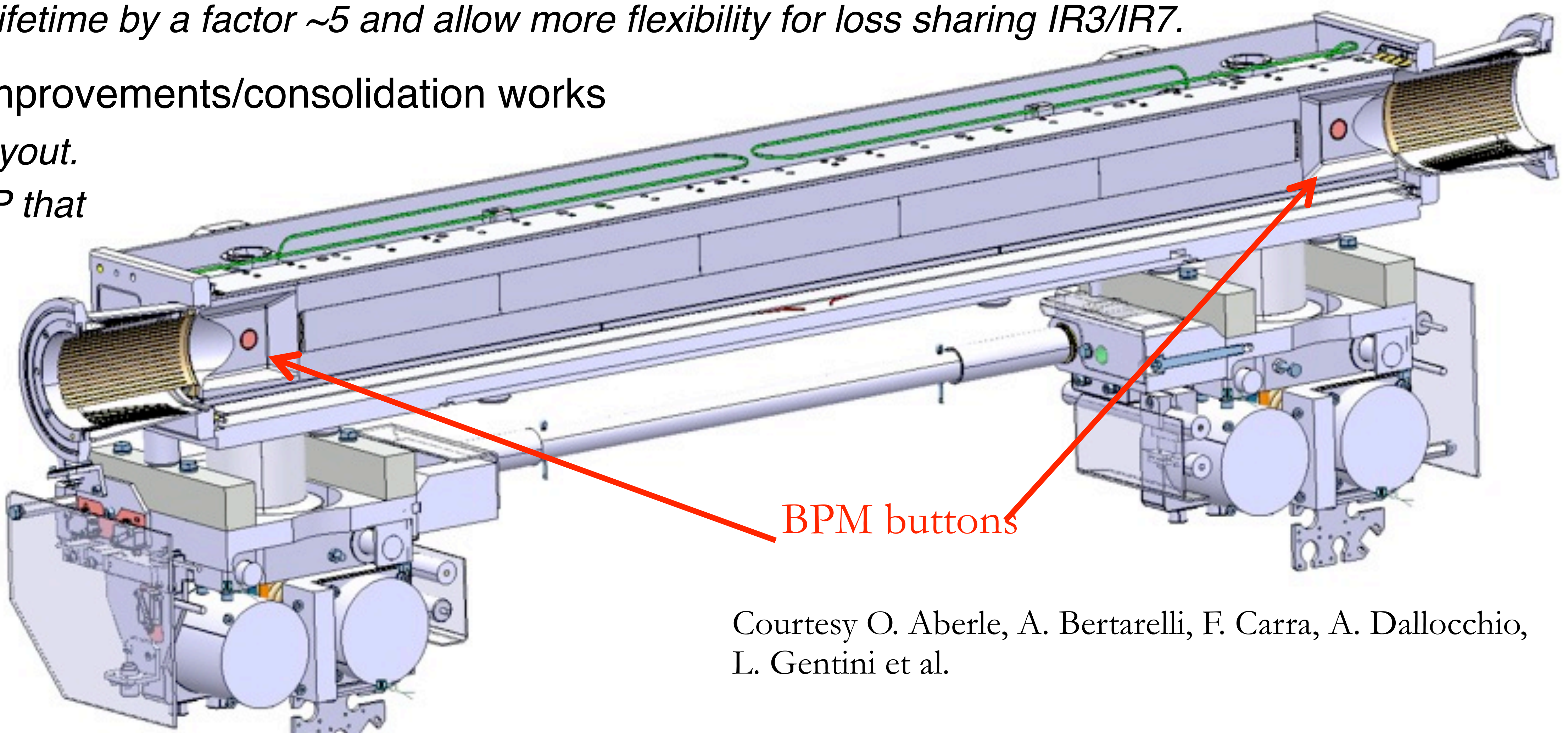
- Improve protection of warm MQW magnets in IR3 by adding **passive absorbers**

  → *Improve lifetime by a factor ~5 and allow more flexibility for loss sharing IR3/IR7.*

- Other smaller improvements/consolidation works

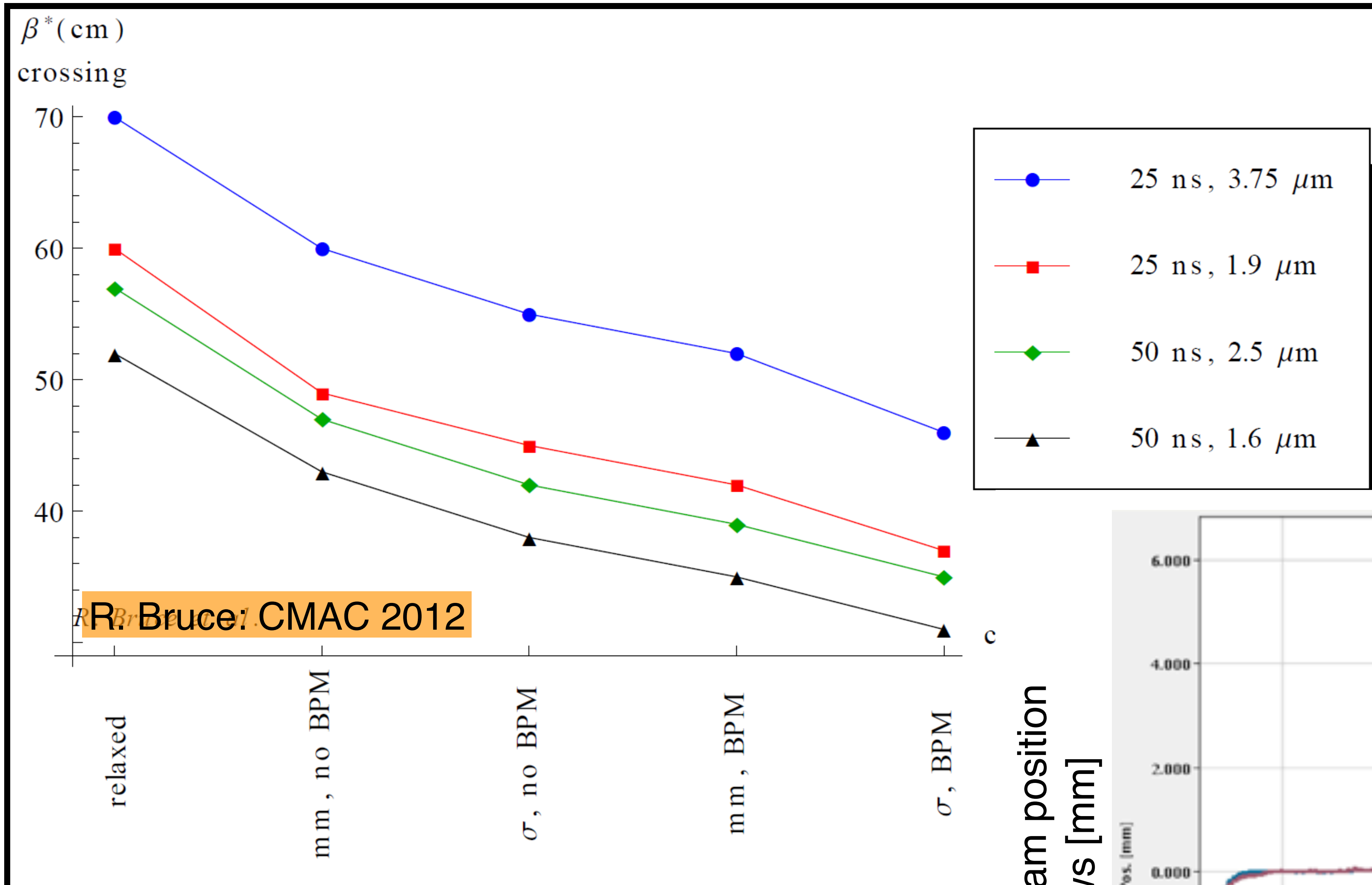
  → *IR8 vacuum layout.*

  → *Replace a TCP that was heating.*



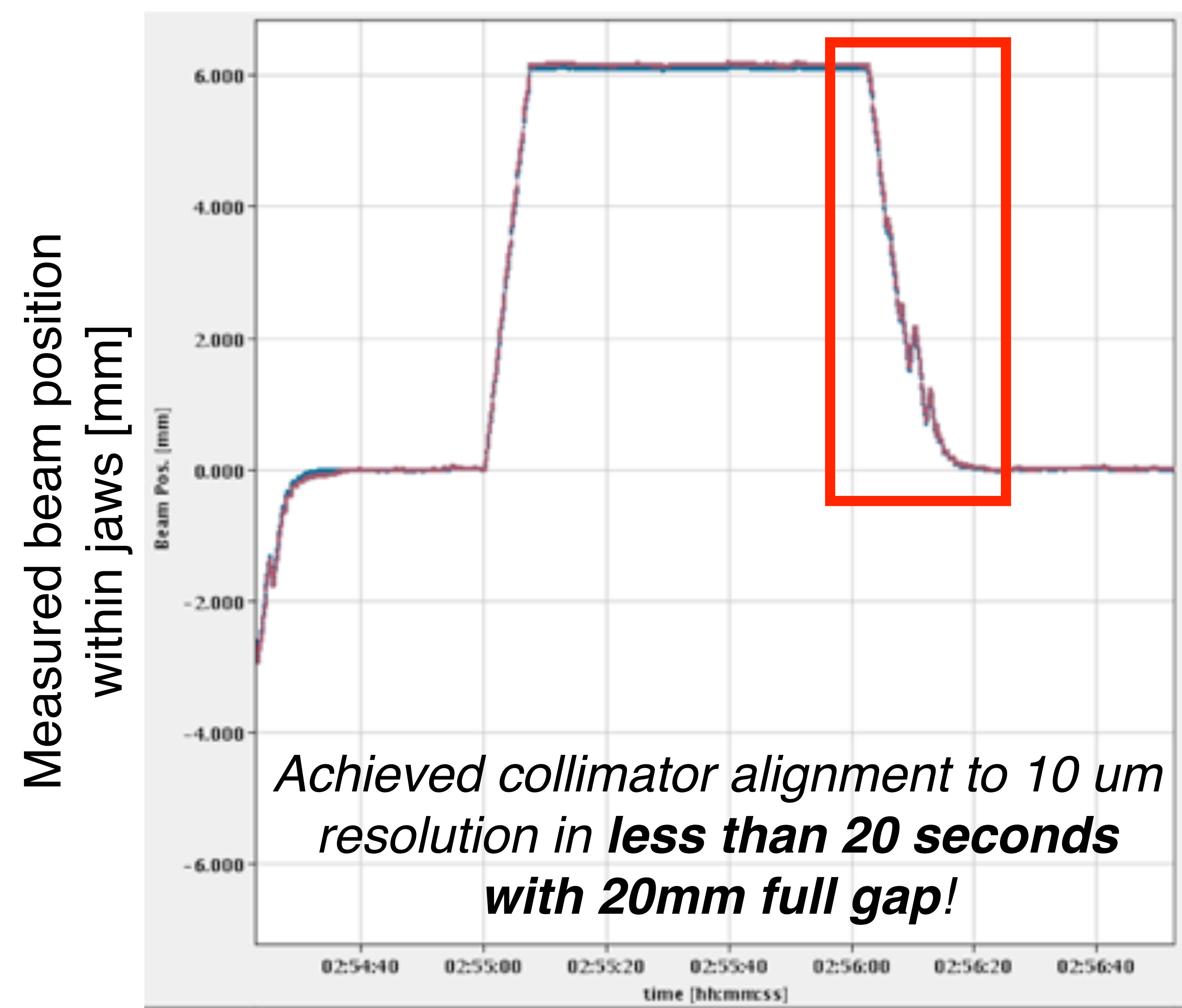
Courtesy O. Aberle, A. Bertarelli, F. Carra, A. Dallocchio, L. Gentini et al.

Main features of BPM collimators



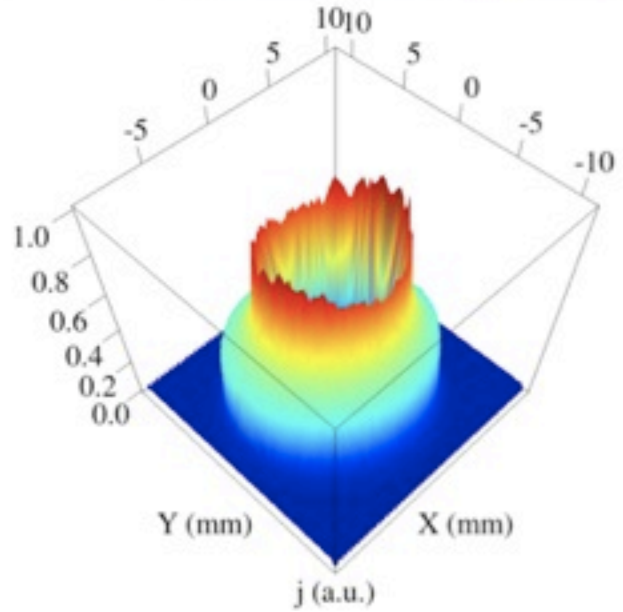
Equip dump region + TCT: allows reducing orbit margins for protection and gives flexibility for IR configurations.

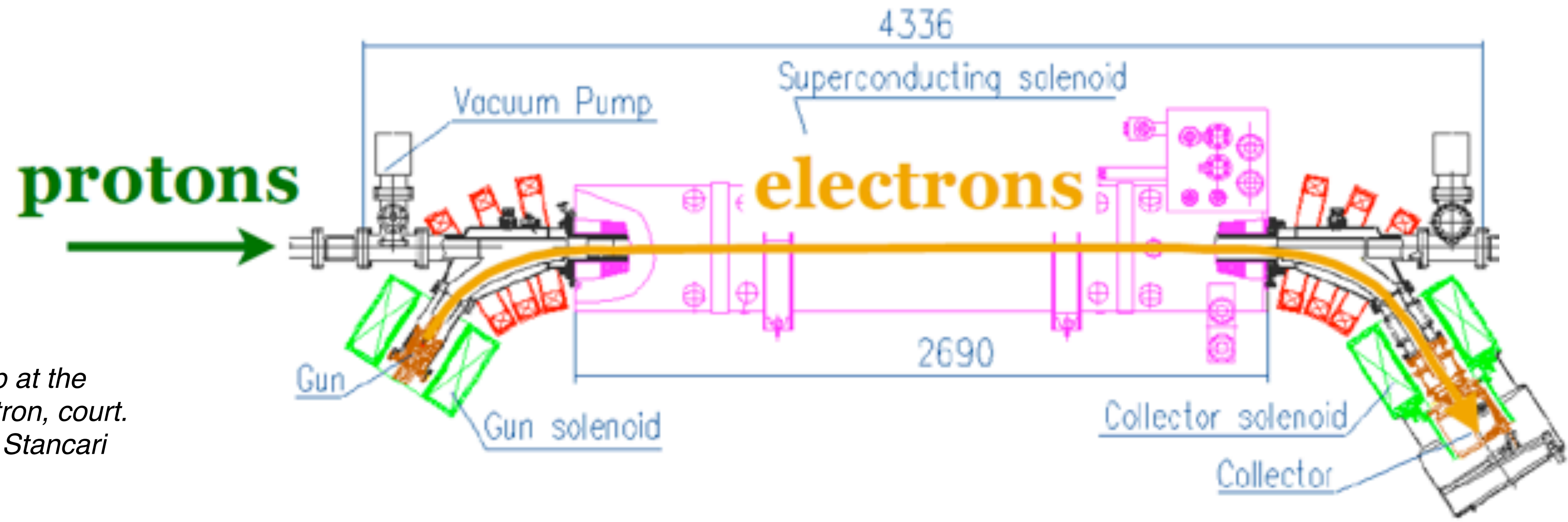
G. Valentino, M. Gasior



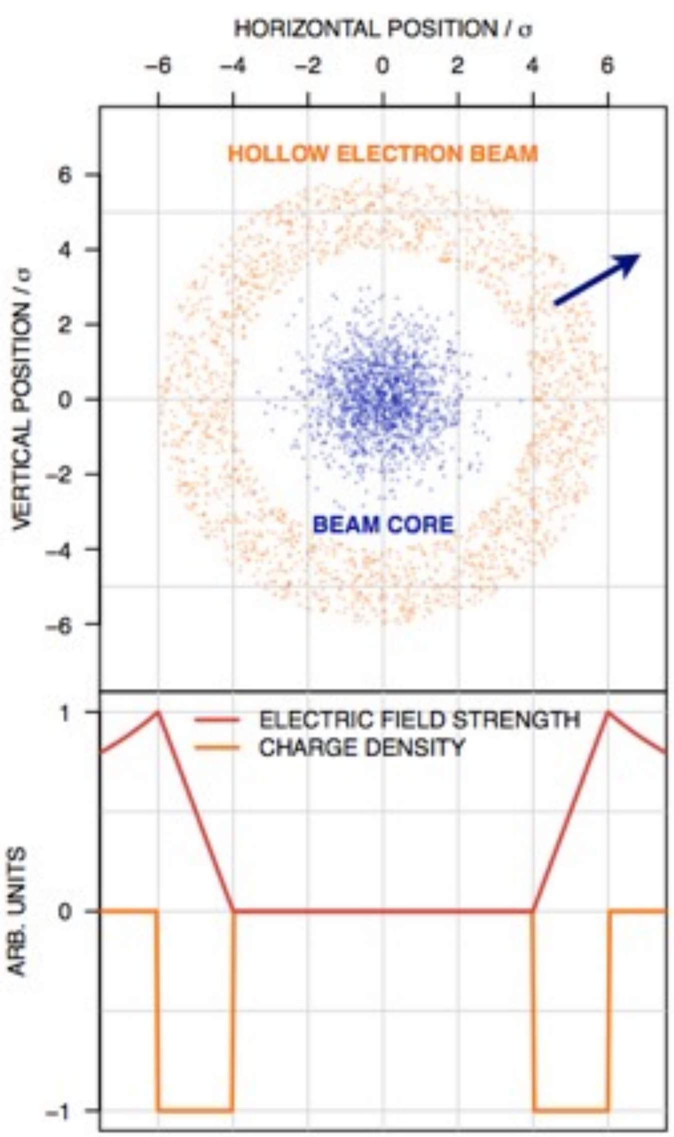
Machine Protection workshop at Annecy (11-13/03/2013): acknowledged great potential of this new feature for MP purposes!

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.

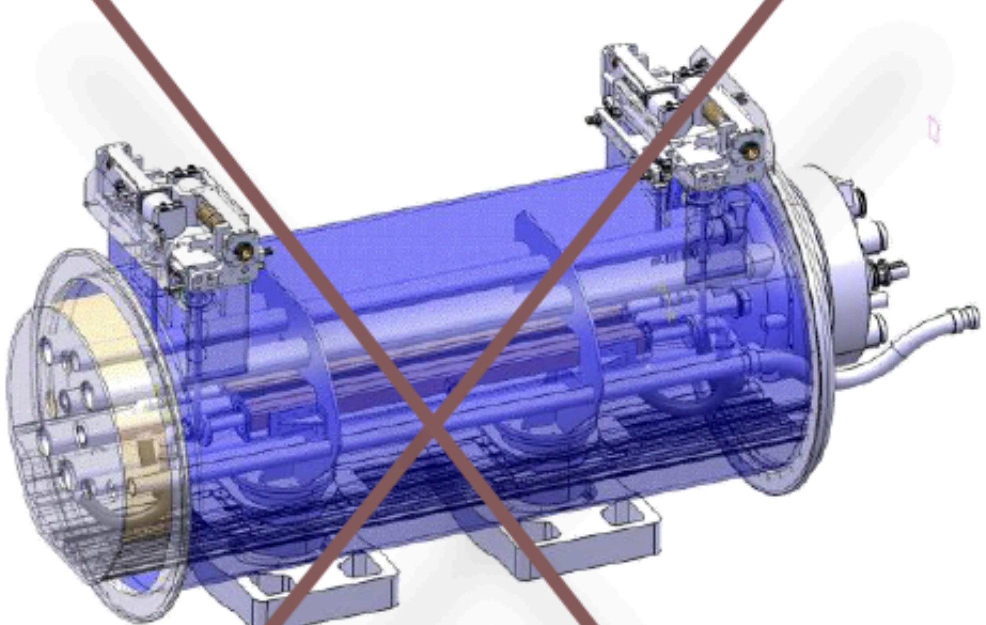
Prototyping of cryostat by-pass

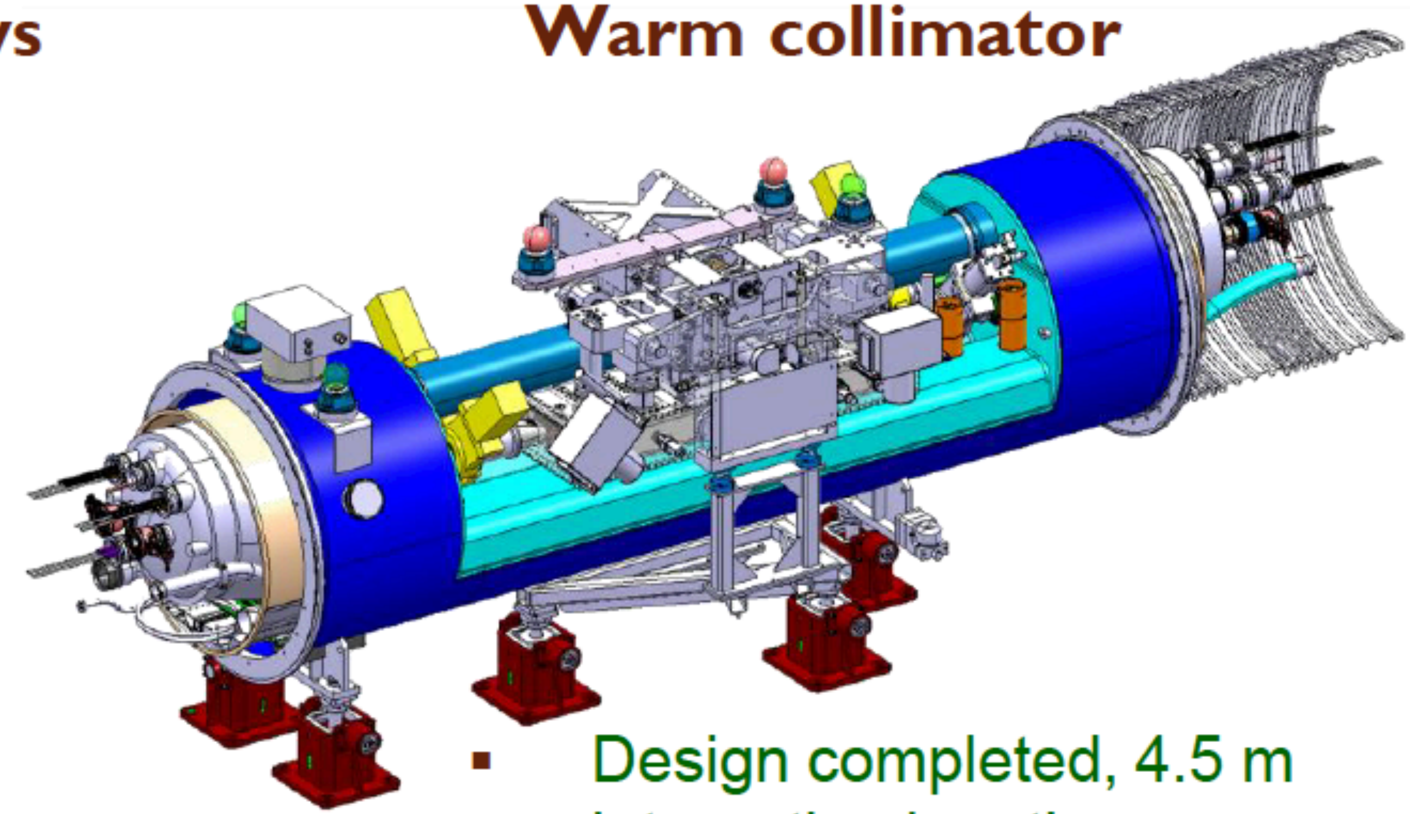
Will be tested at SM18 in 2014

D. Duarte Ramos

Technology choice for DS collimator

Cold collimator vs **Warm collimator**





- Potentially shorter but not feasible within schedule
- Many open issues, possible showstoppers

- Design completed, 4.5 m integration length
- Prototyping of collimator actuation and cryostat

Work of the Cold Collimator Feasibility Study team: concluded that the “warm” DS collimator with a by-pass cryostat is the best solution for the LHC.

R&D on cold collimation design will continue (EuCARD)