CERM Machine Advisory Committee
March 14th-15th, 2013
CERN, Geneva, CH

LHC Collimation Project Status

Stefano Redaelli
for the collimation project team

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

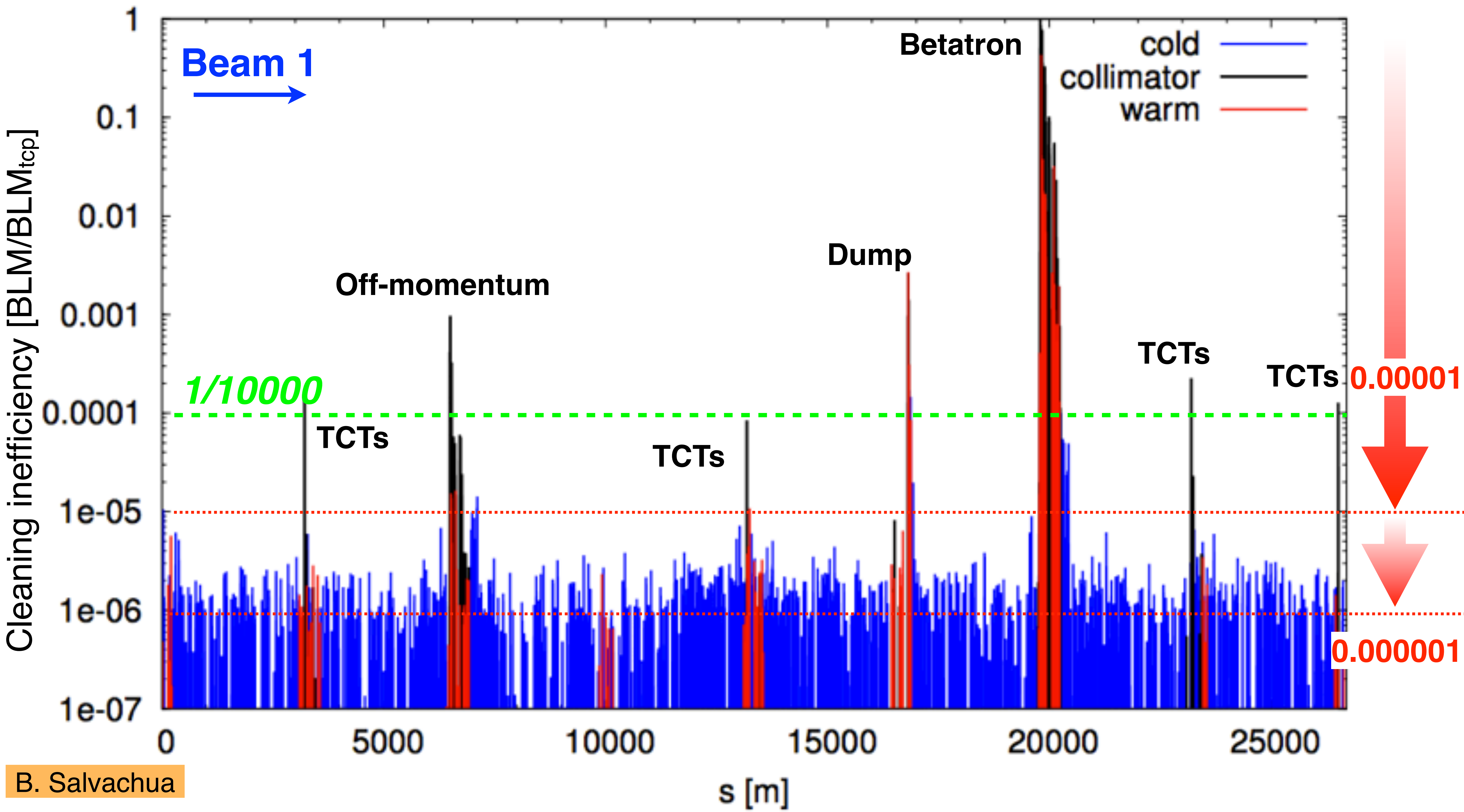
- **Baseline collimation upgrade strategy for LS1 defined in 2011**
  - *Decided to postpone major changes in the dispersion suppressors (DSs) and to put on hold the concept of "IR3 combined cleaning" (R. Assmann at the CMAC in 2011)*
  - *Other important upgrades will take place in LS1:* ***Collimators with BPM design***
- **The good performance at 4 TeV (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 Luca's talk.* ***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 for May 2013**
  - *<u>Scope</u>: present the baseline on collimation upgrades on mid and long term: (1) Full beam intensity and luminosity; (2) x2 design; (3) HL-LHC.*
  - *<u>Mandate</u>: advice on an appropriate strategy for the 11 T dipole R&D until post-LS1 operation.*
- **There are also important news on the additional studies within and outside CERN**

Outline

- Introduction
- Collimation up to 140 MJ
- Status of LS1 activities
- Update on other studies
- Conclusions

(Some) collimation people

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



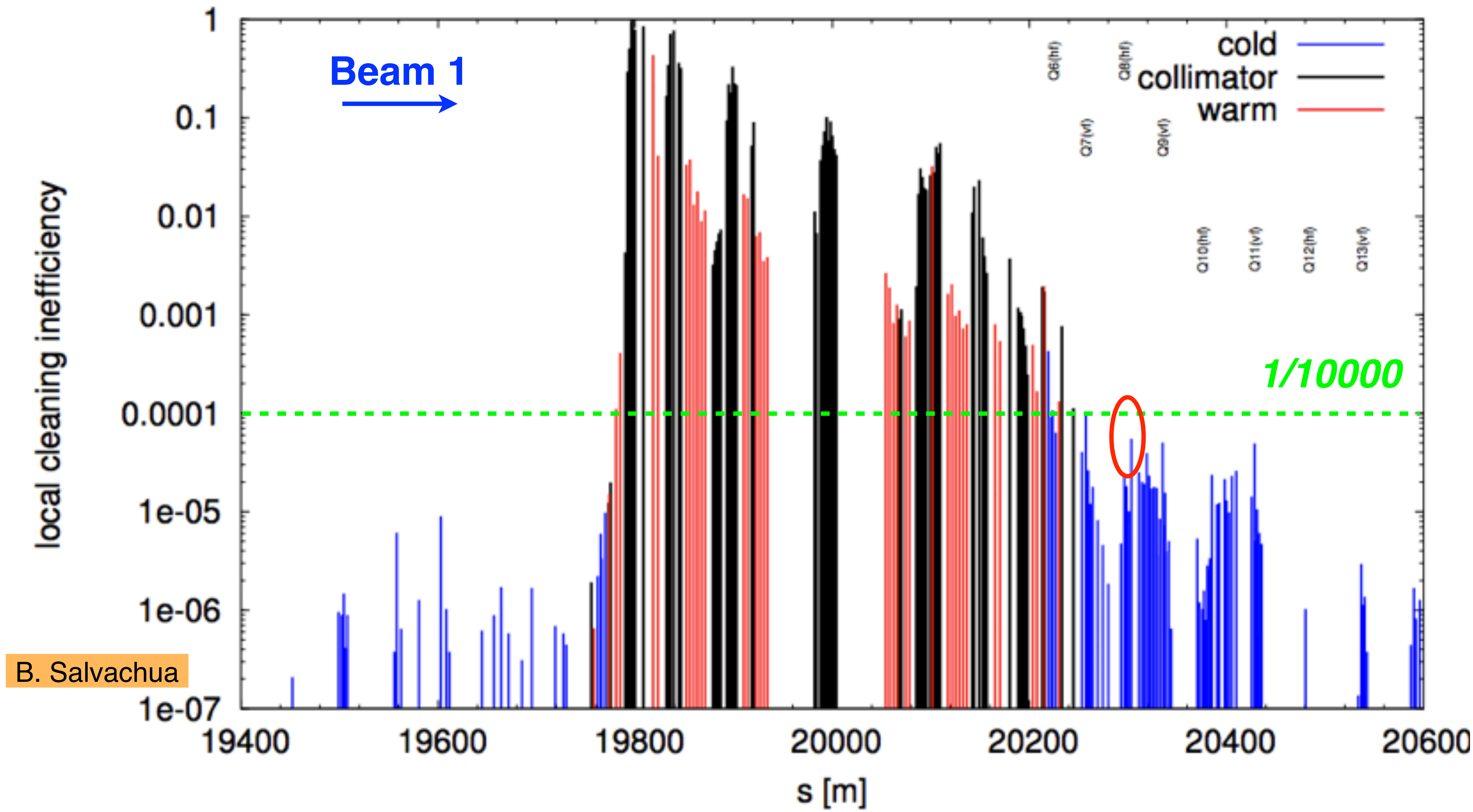
B. Salvachua

2012-13: “tight” collima

60

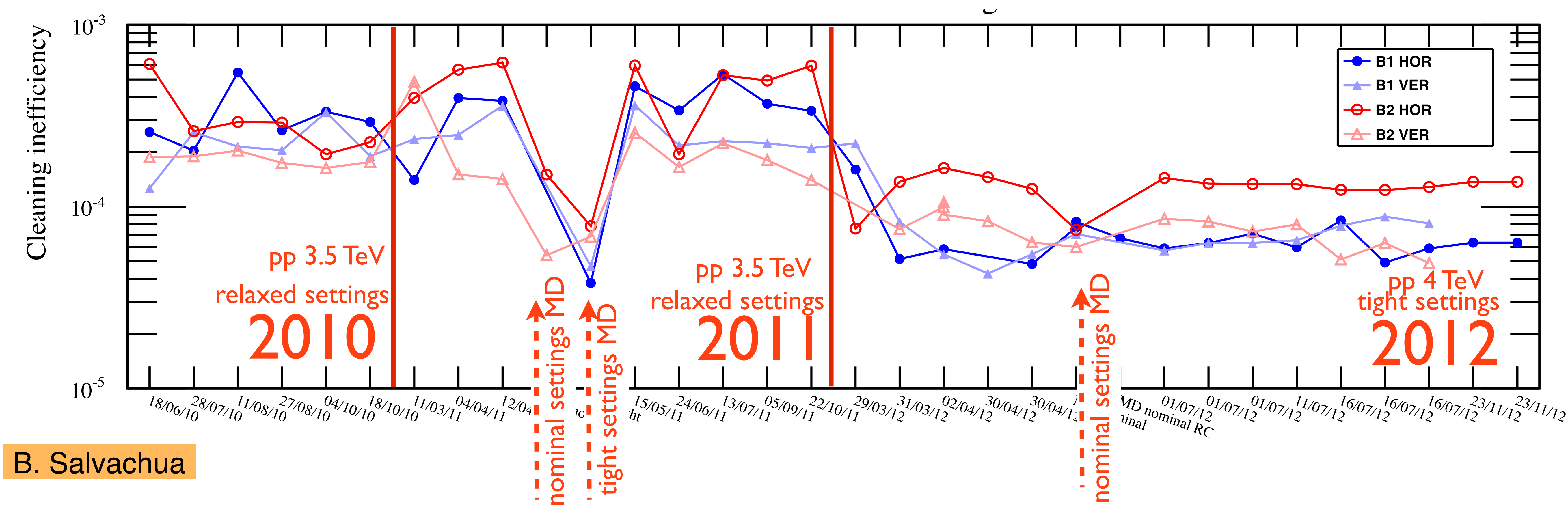
Highest COLD loss location: efficiency of > 99.99% !
Most of the ring actually > 99.999%

Loss maps in IR7



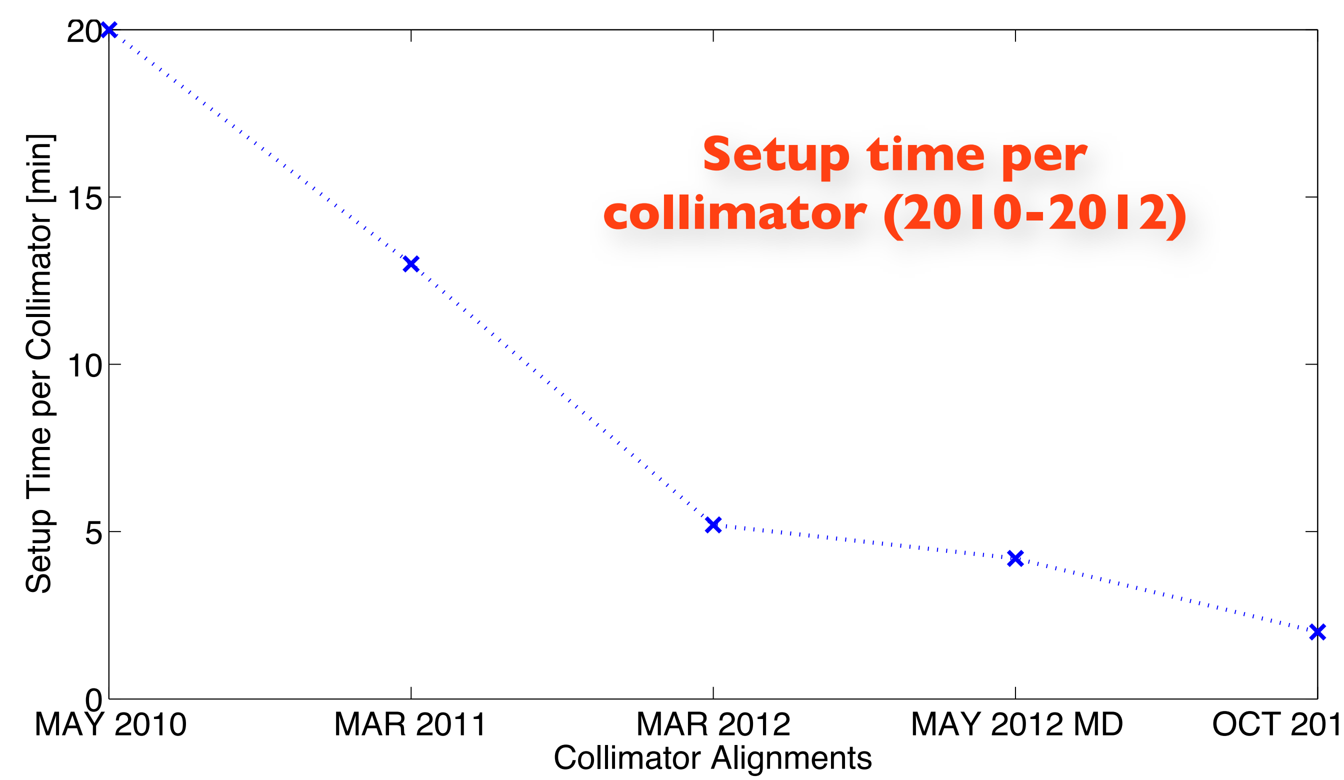
Critical location (both beams): losses in the dispersion suppressor (Q8) from single diffractive interactions with the primary collimators. No other significant limitations observed.

Stability of cleaning in 2010-12

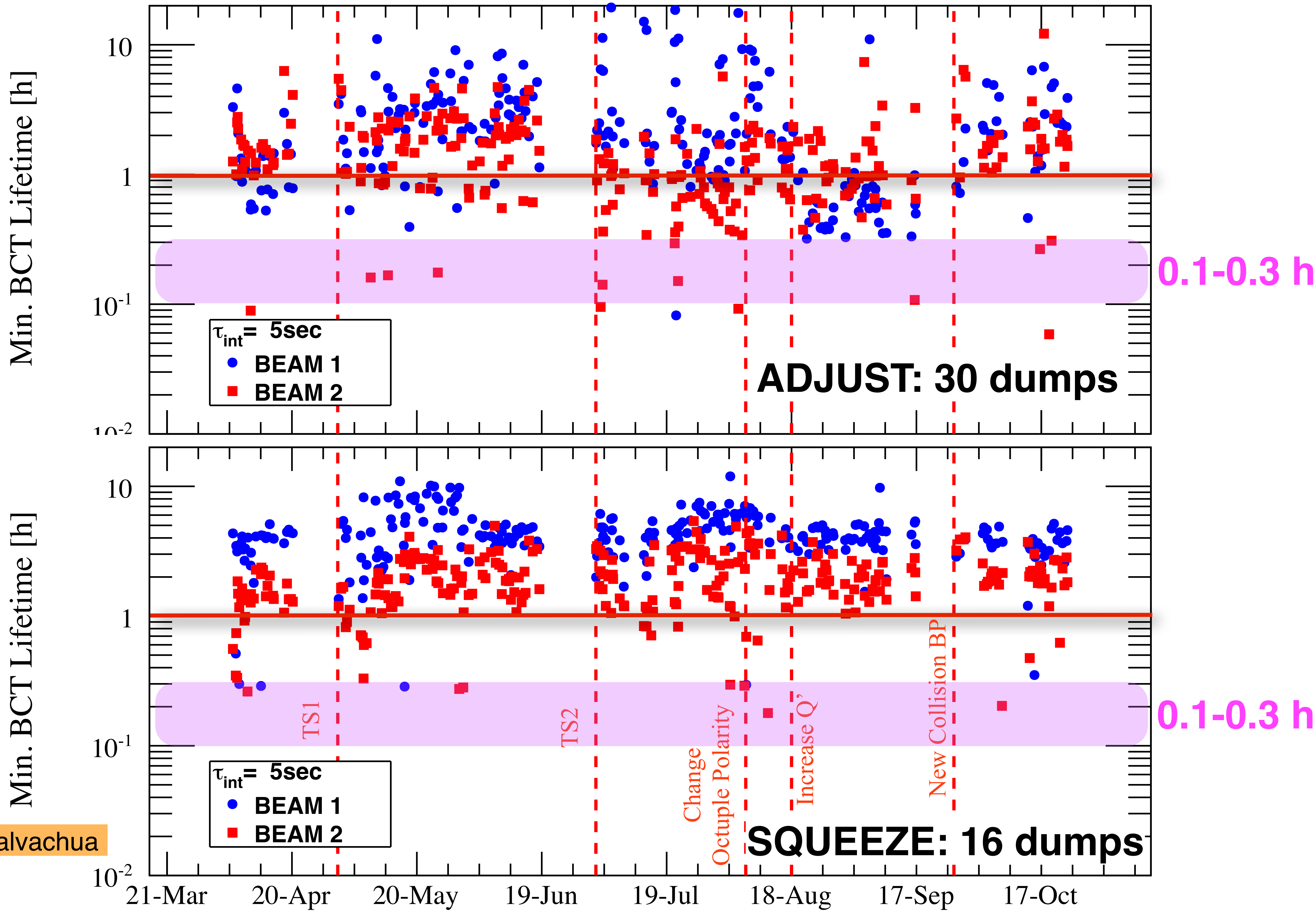


B. Salvachua

- **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!)*



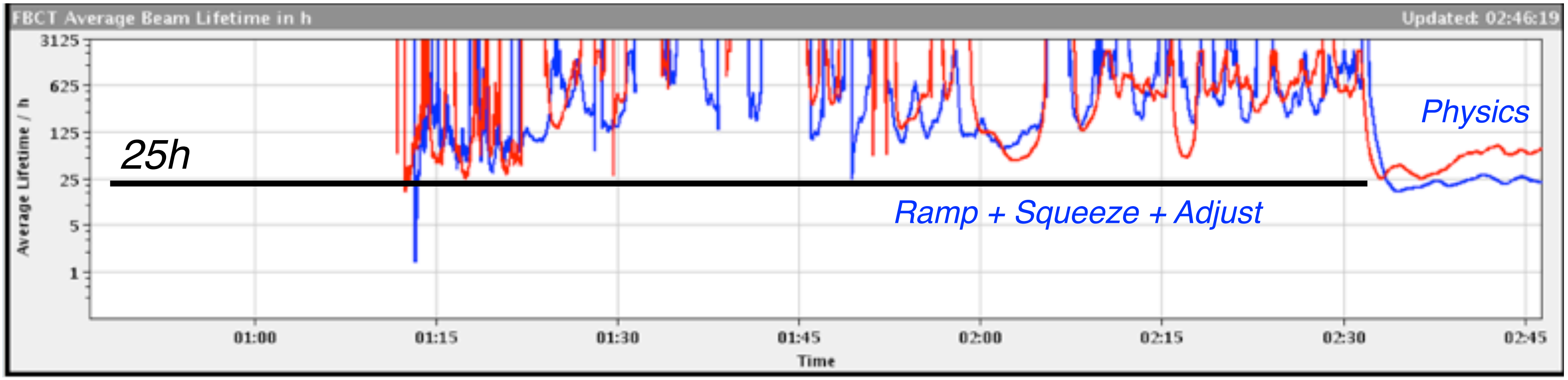
Beam lifetime analysis

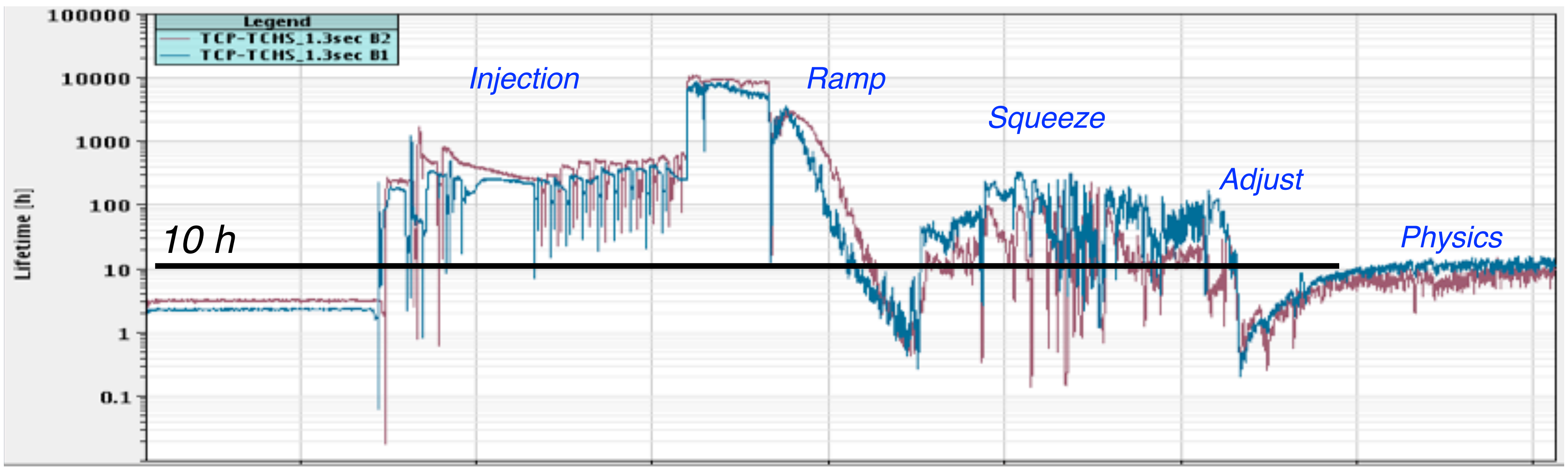


B. Salvachua

Lifetime during OP cycle

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

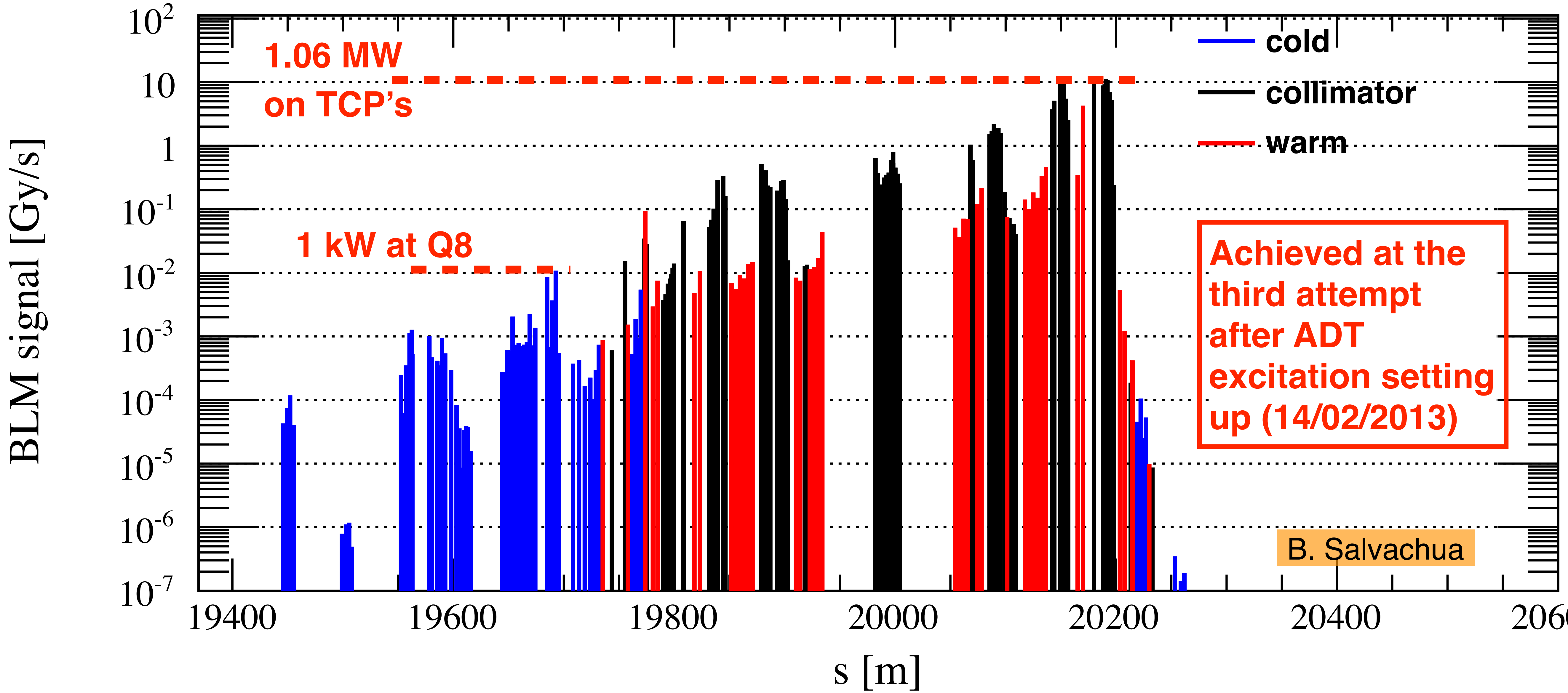




Will this be a serious issue after LS1?
Detailed analysis of quench tests will provide improved estimates.
Needs of possible scraping methods (hollow e-lens or similar) are being studied.
Can always open the collimators, at the **cost of larger β^***.

Collimator quench tests

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



Controlled beam excitation over several seconds: **Peak>1MW on TCP!**

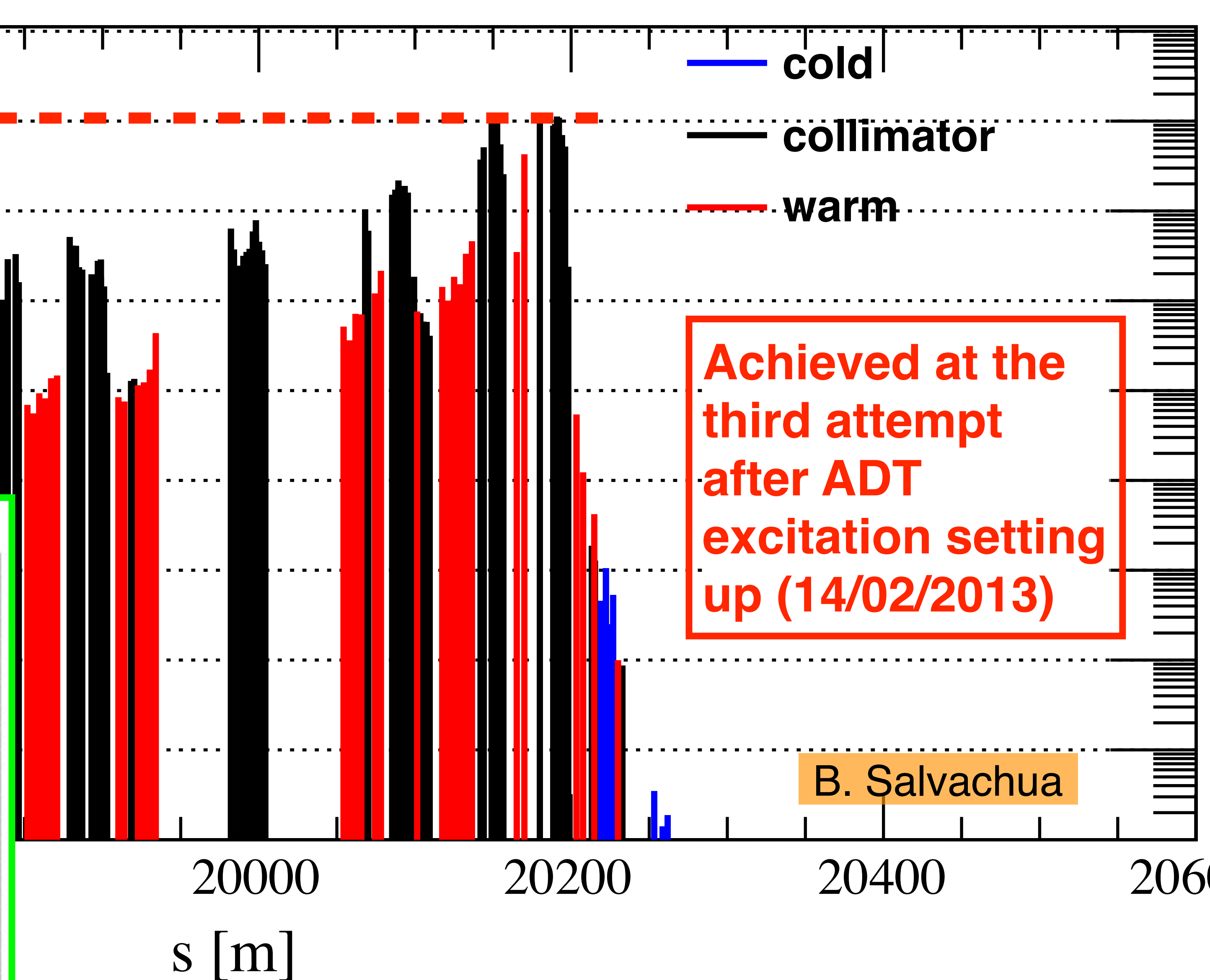
Worsened cleaning by relaxing collimator settings.

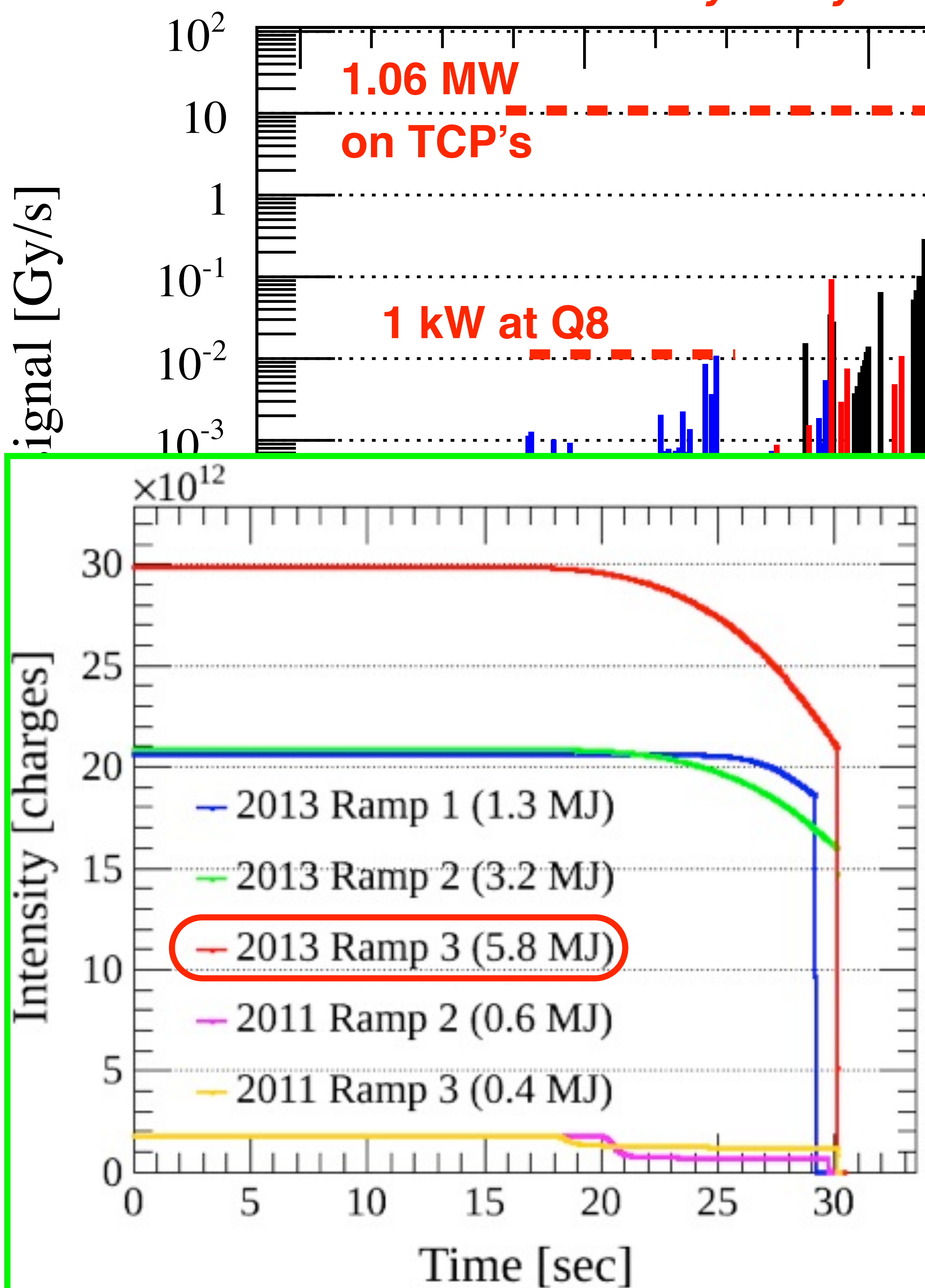
Achieved 3.4 times the assumed quench limit at 4.0 TeV **without quenching**!

(2011: only achieved ~65% of 3.5 TeV limit.)

Collimator quench tests

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





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relaxing collimator settings.

ench limit at 4.0 TeV **without quenching**!

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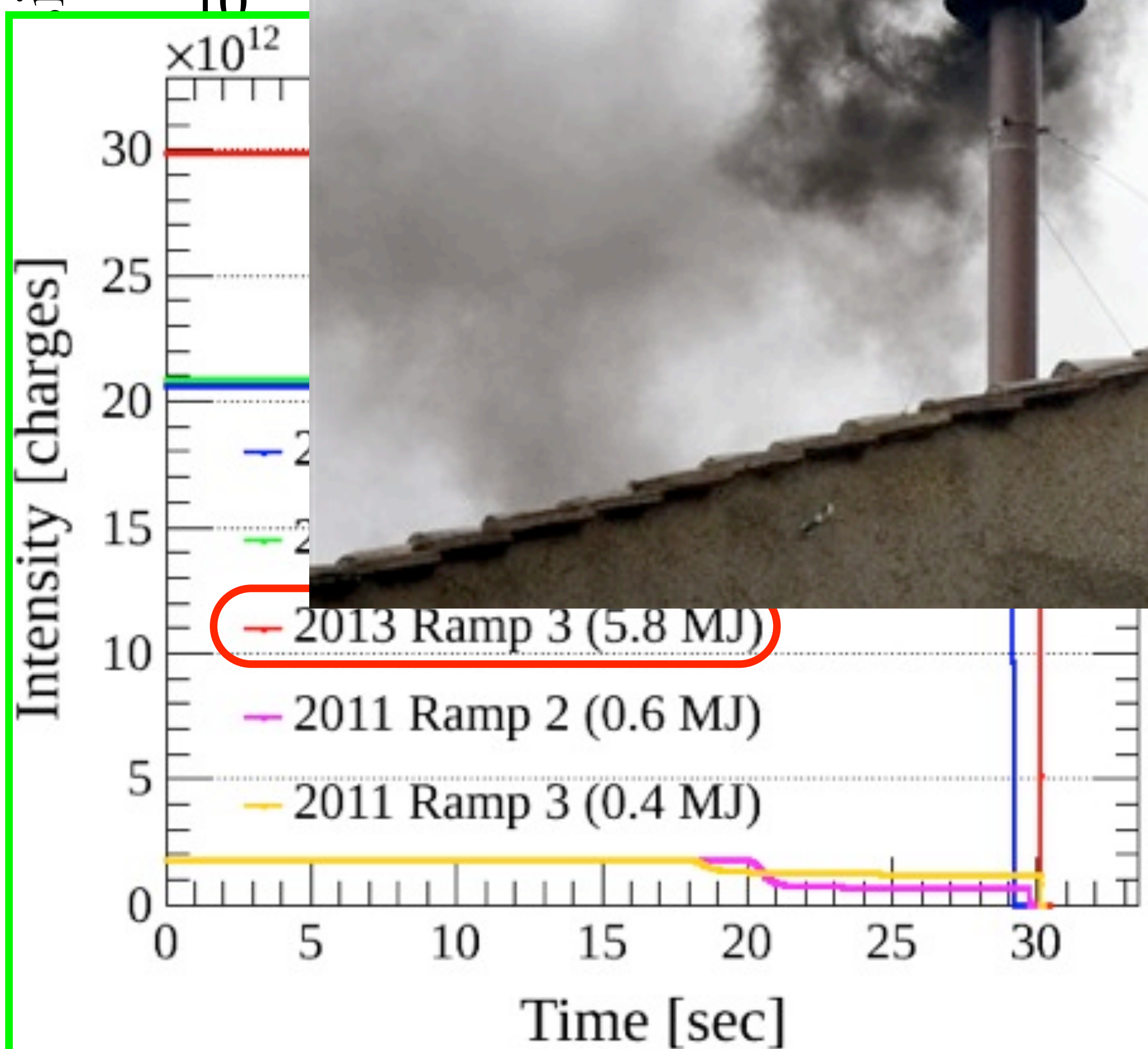
Collimator quench tests



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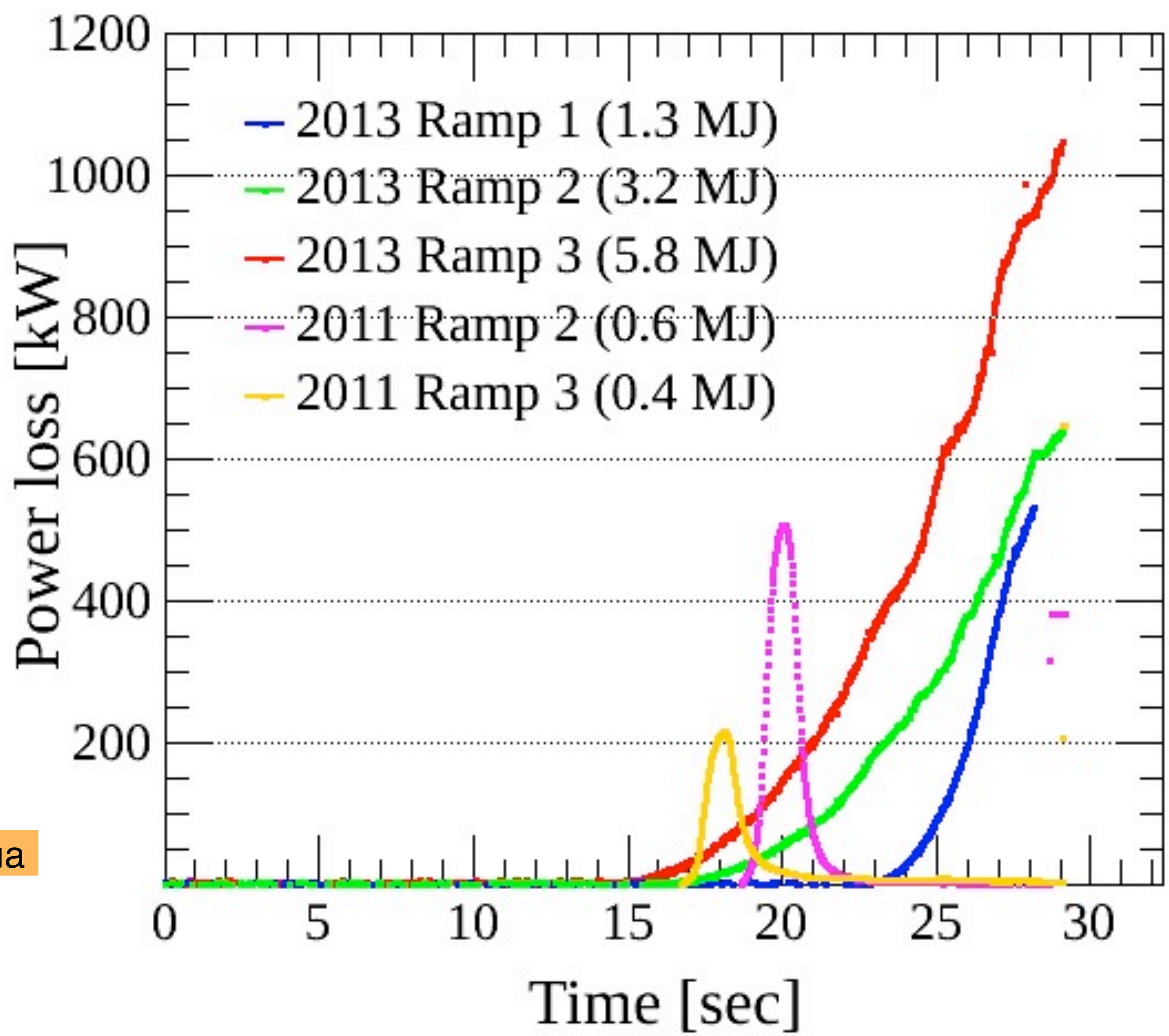
Comparison to 2011 quench tests



B. Salvachua

Could achieve higher and longer losses thanks to new method to excite controlled blow-up with the transverse damper (ADT), compared to tune resonance excitation in 2011.

Ongoing work for review

Minimum (assumed) beam lifetime

Quench limit of SC magnets

LHC total intensity reach from collimation
(estimates for Cham. 2012)

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

Collimation cleaning at limiting cold location

Preliminary 7 TeV performance estimate
based on ACHIEVED loss rates at 3.5 TeV
(500 kW for protons, 27 kW for ions, τ=1h)

→

Protons: ***> 1.5 x nominal***
Ions: ***5-25 x nominal***
Ions (L debris) *closer to limit!*

Some items being addressed:

- **Tracking + energy deposition** simulations of quench test conditions
  - *- Estimates are independent of simulations at 4 TeV, but we want to understand the deposited energy 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

Planned for 29-30 May *(but waiting for answer from some reviewers)*

- **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):**
  - *Scenarii for heat loads (protons and ions)*
  - *Technology choice and integration issues*
  - *11 T dipole status: what do we need to be ready in LS2*
- **HL-LHC challenges for collimation**
- **Component lifetime and radiation handling**
- **Status of Crystal**
- **Perspective of hollow lens**
- **New collimator material (impedance vs robustness)**
- **Possible plan**

Outline

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- **Status of LS1 activities**
- Update on other studies
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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**

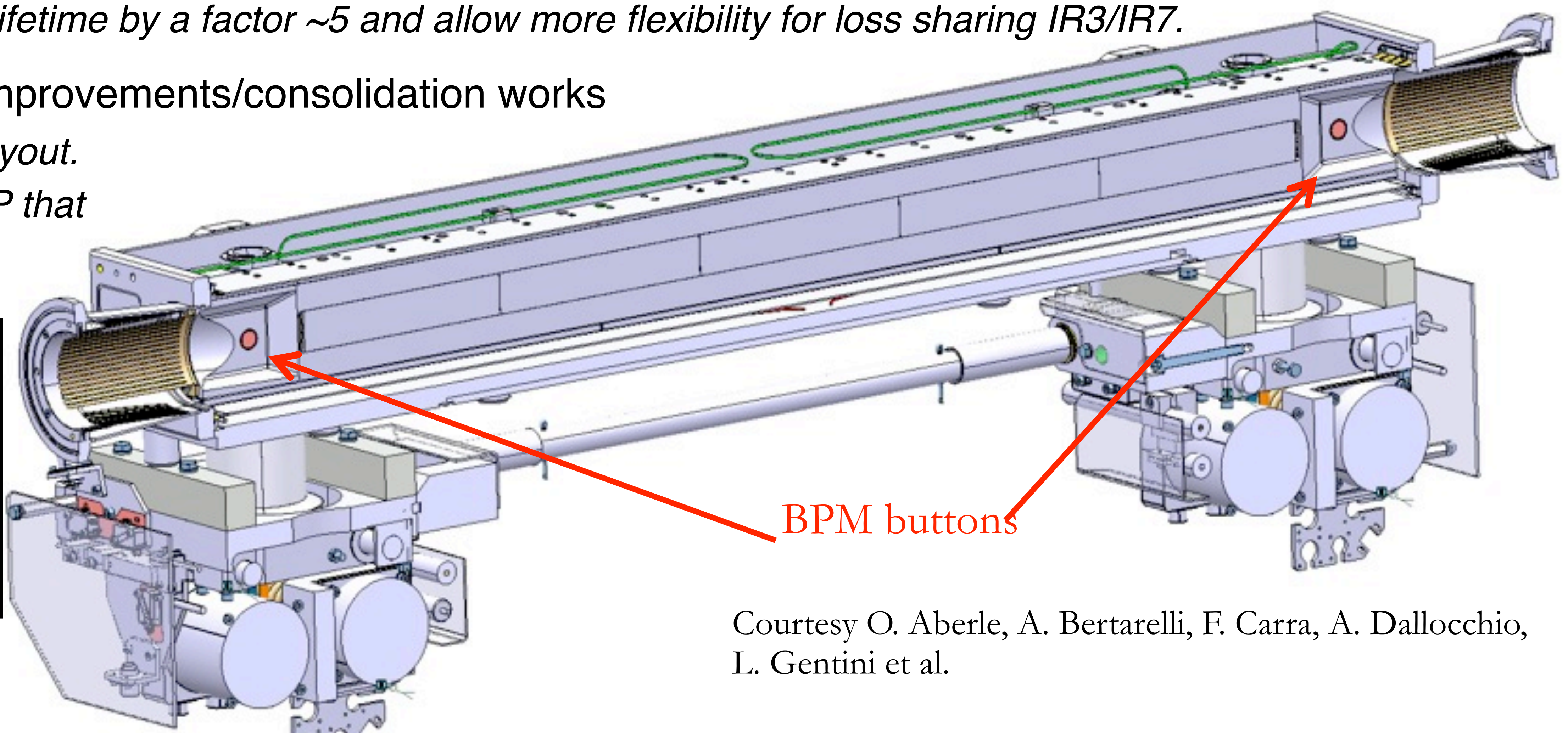
  ➙ *Improve lifetime by a factor ~5 and allow more flexibility for loss sharing IR3/IR7.*

- Other smaller improvements/consolidation works

  ➙ *IR8 vacuum layout.*

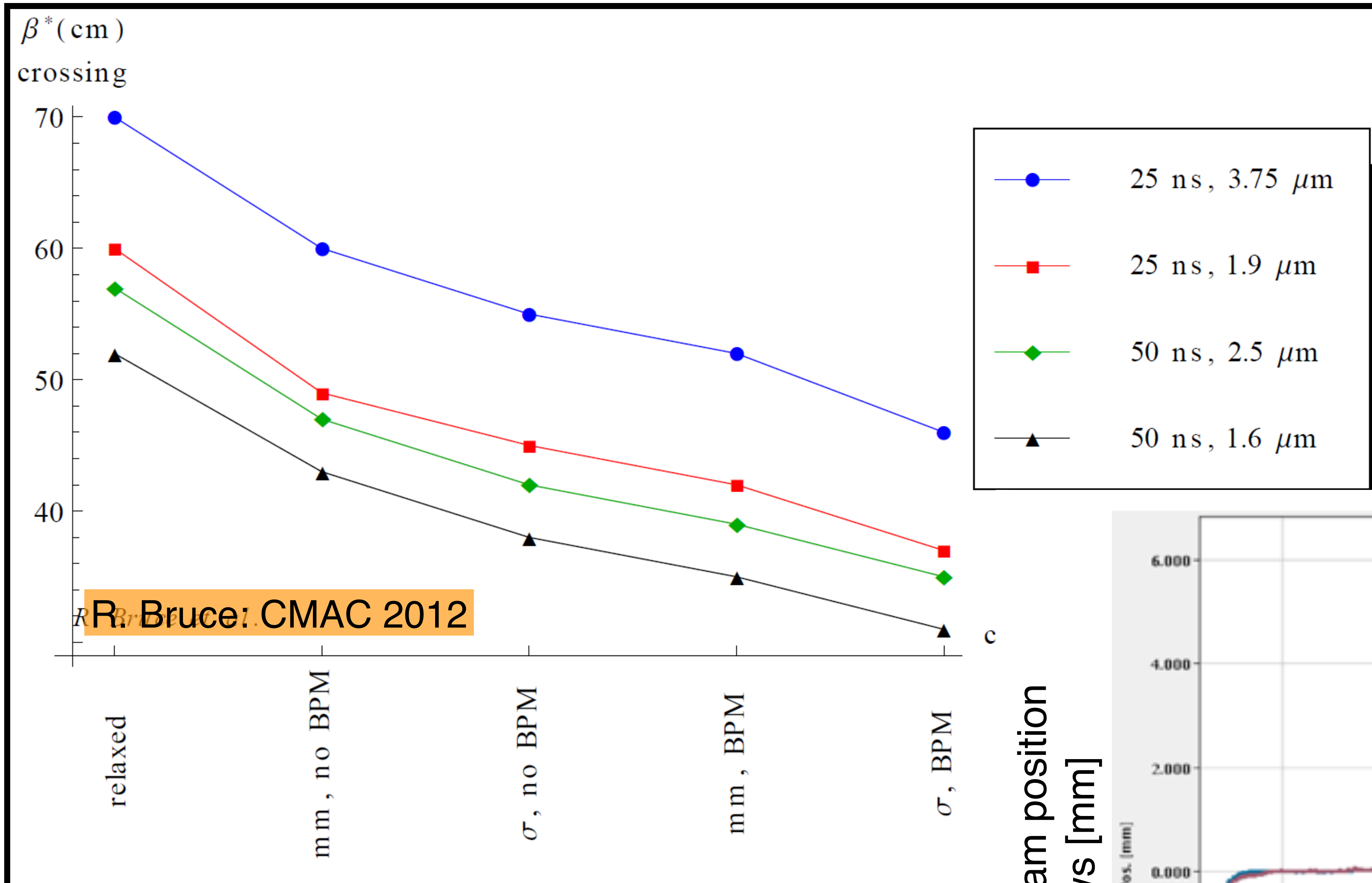
  ➙ *Replace a TCP that was heating.*

Final strategy endorsed at LMC Nov. 2012. Five ECR's circulating for approval.



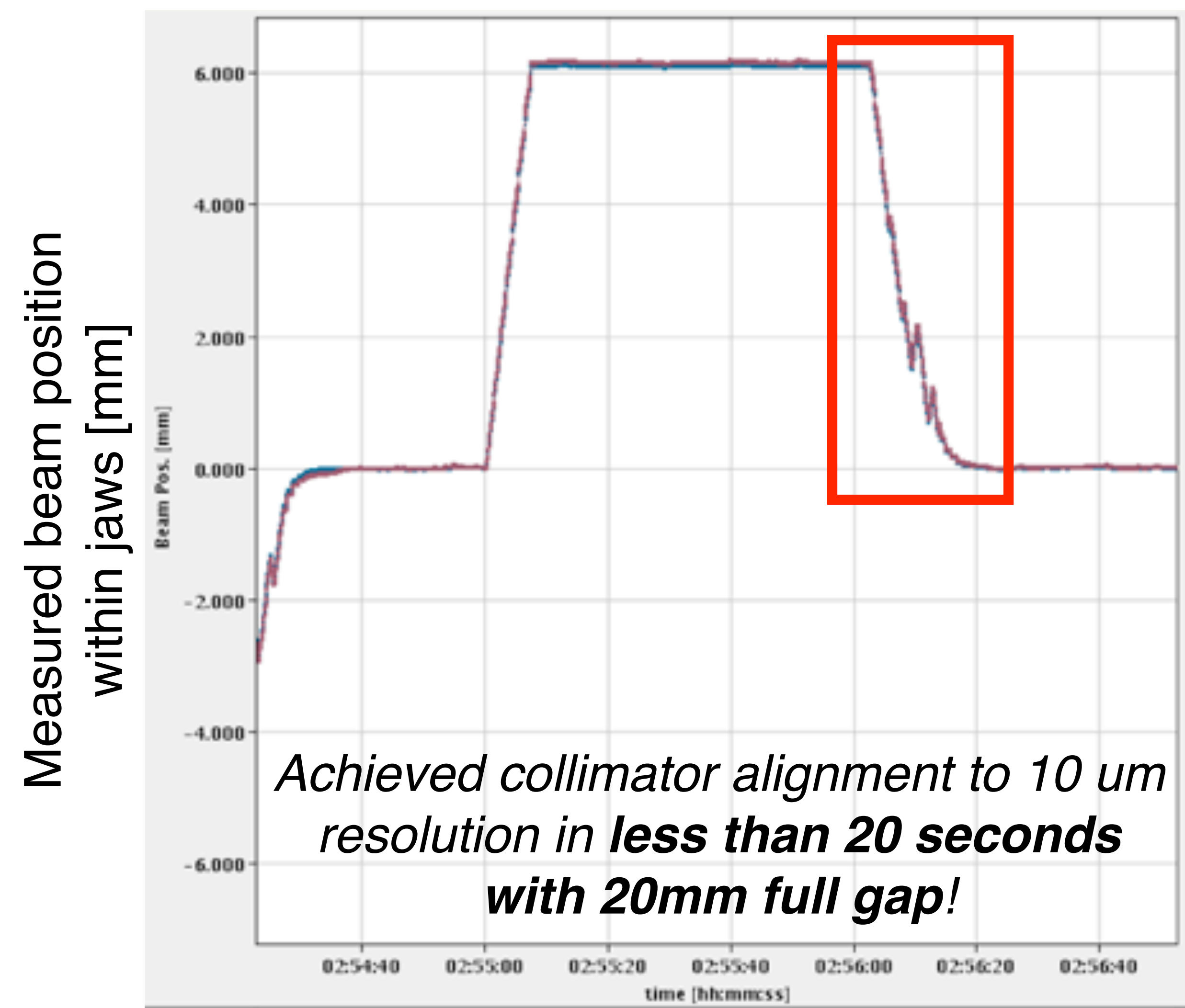
Courtesy O. Aberle, A. Bertarelli, F. Carra, A. Dallocchio, L. Gentini et al.

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



*Achieved collimator alignment to 10 um resolution in **less than 20 seconds with 20mm full gap**!*

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

BPM-collimator production in Nov. '12

- **Industrial production of 16 TCTP (3+1 spares) (O. Aberle, R. Losito):**
  - *Contract assignment and budget approval by FC in March 2012.*
    *Found a **very satisfactory solution** of the BPM cables that gave leak issues: pre-series for 4 collimators fully compliant!*
  - ***Jaw brazing technique**: **"final" proposal** by the company (gold-based).*
  - ***500cm jaw prototype before Christmas**: crucial milestone to validate all the key critical production phases*
  - *On track for 4 collimators/month ready for installation starting in **February 2014**.*
- **In-house production of 2 TCSP (+1 spare) (A. Bertarelli):**
  All components being received, movable tables prepared.
  Expect 6 jaws by March 2013, assembled in 3 tanks by May.
  *Aim at having two TCSP's ready for installation in **September 2013**.*
  Also working on one TCTP prototype: full assembly by March 2013.
- **A couple of issues are presently under investigation:**
  Bad vacuum of ferrite → improved thermal treatment at 1000 deg under test.
  Problems at the bld.113 might have an impact on availability of UHV-treated ferrite.
  BPM cable production must start as soon as possible to ensure cable availability.
- Cabling for BPM's of the new 18 collimators and IR8 layout change **fully approved** for implementation in LS1.

BPM-collimator production in Nov. '12

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  - Contract assignment and budget appro
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  - ***500cm jaw prototype before Christm***
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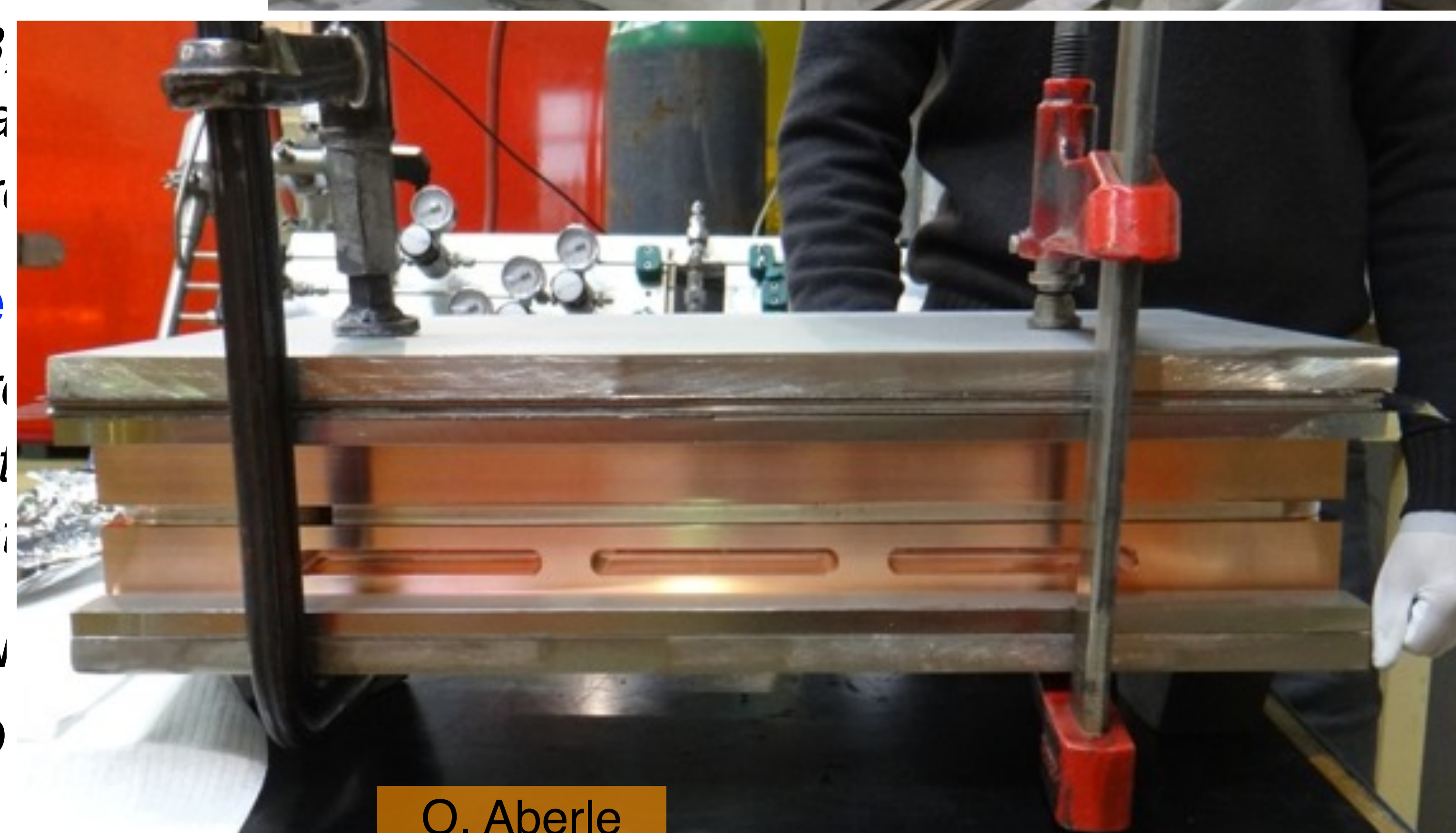
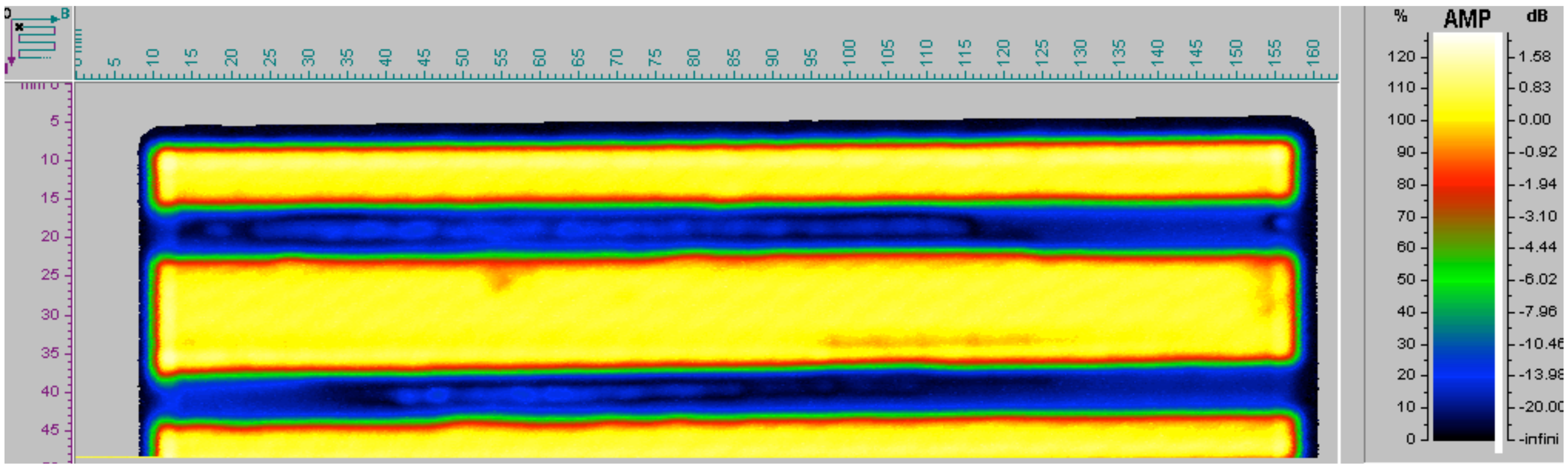
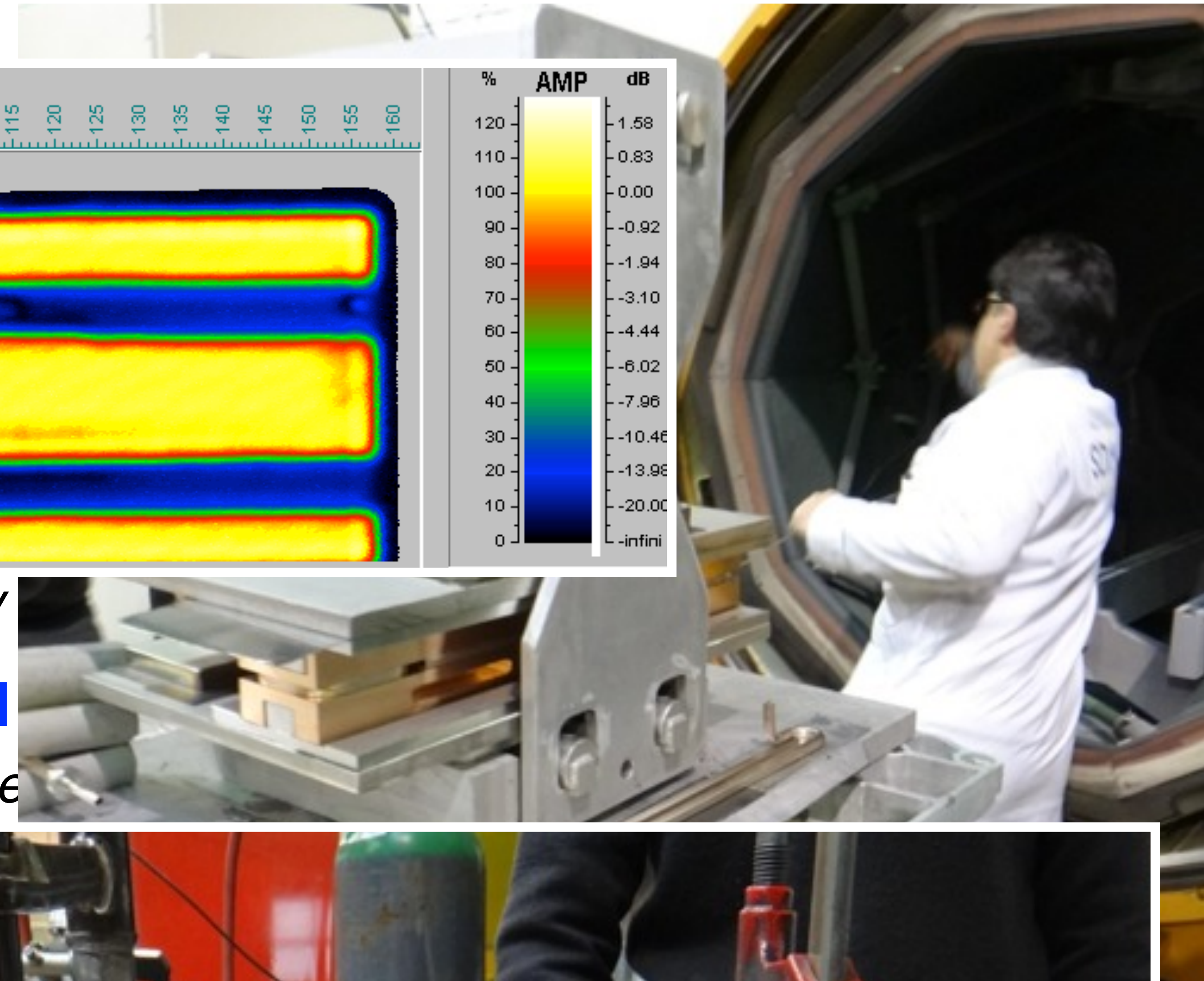


BPM-collimator production in Nov. ’12





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  All components being received, movable

  Expect 6 jaws by March 2013

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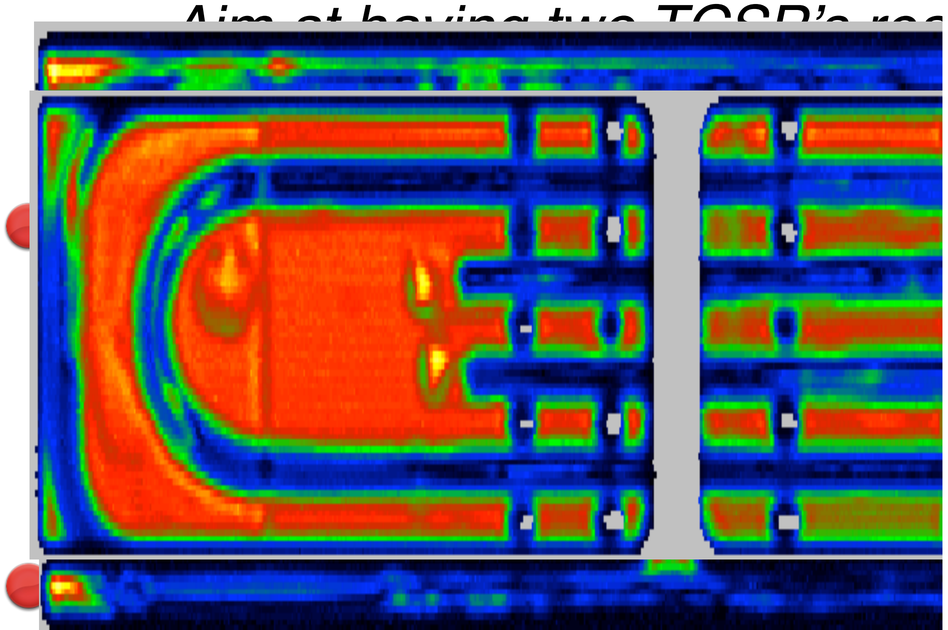
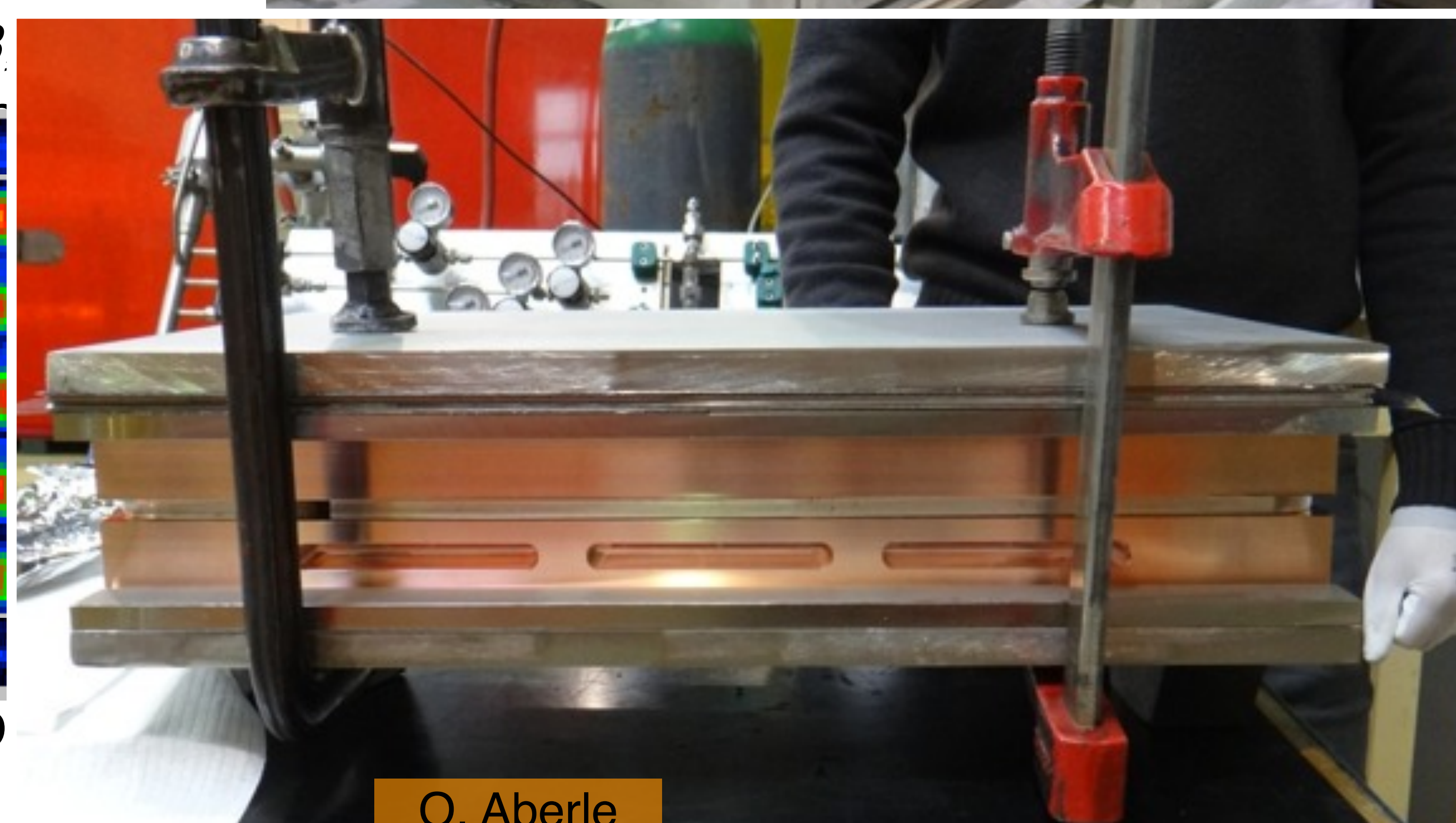




O. Aberle

approved for implementatio

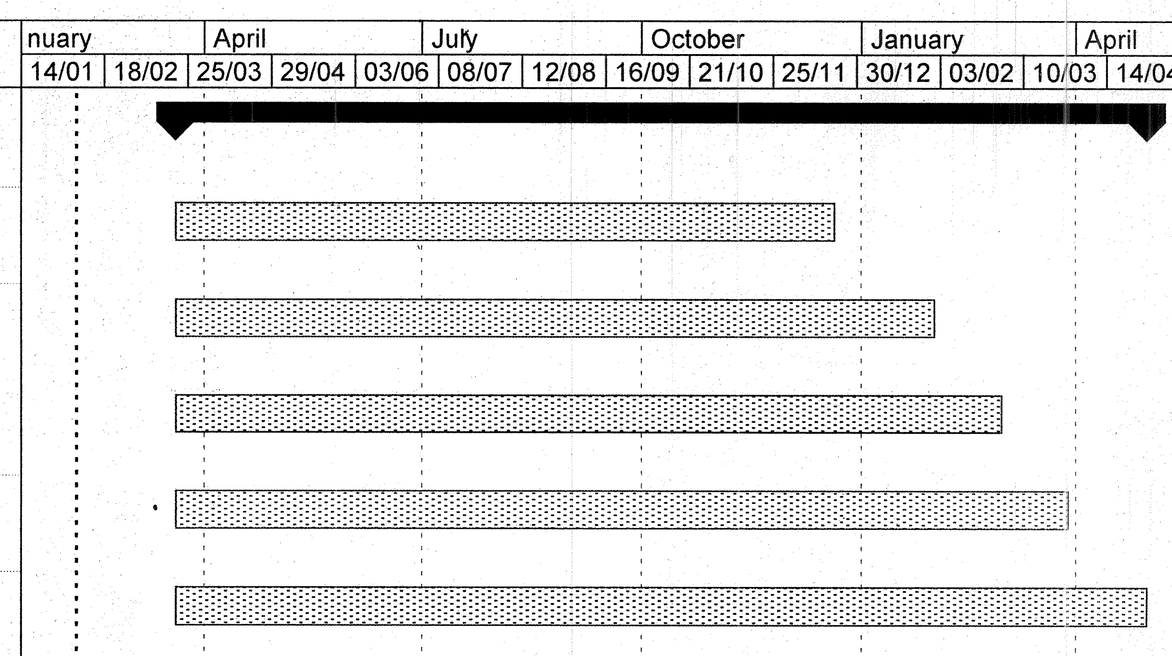
Production status now

Industrial production issues:

- The **financial crisis** of one of the subsidiaries of the company induced a major restructuring, resulting in the dismissal of several key persons for our contract (Jan.'13).
- Quickly clear that there was a mutual interest to stop "smoothly" the ongoing contract.
- Luckily, the company that was 2nd in the call for tender remained available for performing the production: **same price** and **delivery schedule** as in March 2012!
- **Must watch this carefully!** *They have experience in building collimator components.*
- Proceed with series machining without pre-series, while for all critical processes (welding and brazing) the concept of pre-series is maintained.

STRUMENTI SCIENTIFICI CINEL S.R.L. : TIME SCHEDULE FOR THE MANUFACTURING OF 20 COLLIMATORS

ID		Task Name	Duration	Start	Finish
1		**DELIVERY OF ONE SERIES (20 COLLIMATORS)**	**58,2 wks**	**Wed 20/03/13**	**Wed 30/04/14**
2		LOT1 OF 4 COLLIMATORS	39,6 wks	Wed 20/03/13	Fri 20/12/13
3		LOT2 OF 4 COLLIMATORS	45,6 wks	Wed 20/03/13	Fri 31/01/14
4		LOT3 OF 4 COLLIMATORS	49,6 wks	Wed 20/03/13	Fri 28/02/14
5		LOT4 OF 4 COLLIMATORS	53,6 wks	Wed 20/03/13	Fri 28/03/14
6		LOT5 OF 4 COLLIMATORS	58,2 wks	Wed 20/03/13	Wed 30/04/14



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- Proceed with series machining without pre-series, while for all critical processes (welding and brazing) the concept of pre-series is maintained.

In-house production:

- Production in very good shape!
- Completed the production of 6 jaw back plates, with acceptable flatness
- First assembled jaw ok: 20 micron flatness!
- Vacuum tests on assembled jaws will start next week (w12).

Miscellaneous

- **BPM cable production**: close to a solution to welding issues and series should start within a few weeks. Full series delivery in April.
- New thermal treatment of the **ferrite** tiles (1000 deg instead than 400deg) seem to have solved the outgassing issues. Dedicated collimation WG meeting will address this.

Status of in-house TCSP production

4 vacuum tanks + 8 movable tables ready (3 TCSP's + 1 TCTP prototype)
TCTP jaws (1 brazed + 1 bolted) available and under qualification (thermal conductance testing, creep…)
6 TCSP brazed assemblies produced.
First complete TCSP jaw measured:
~20 micron flatness
Vacuum tests to come starting from week 12.

A. Dallocchio for the MME team

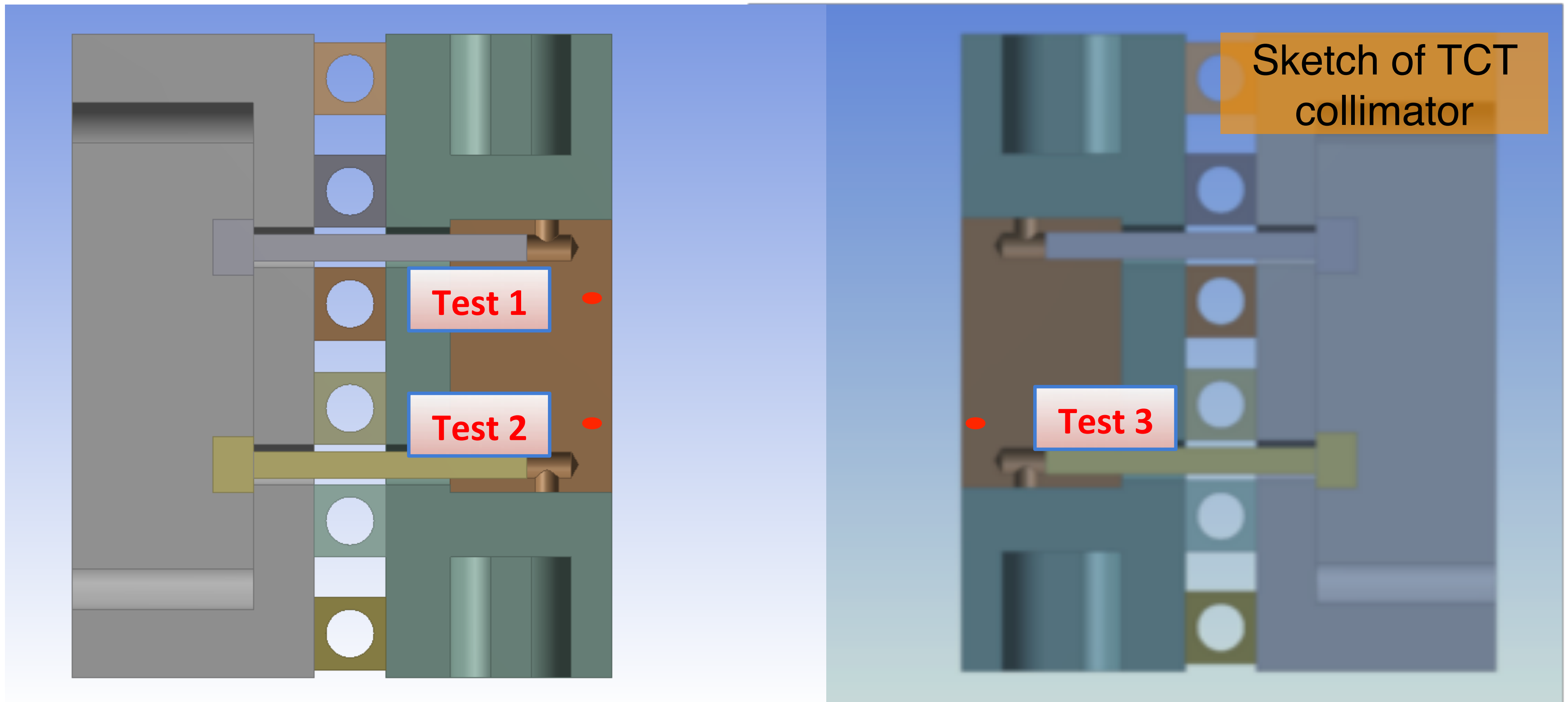
Outline

- Introduction
- Collimation up to 140 MJ
- Status of LS1 activities
- **Update on other 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.

Collimator robustness at HRM

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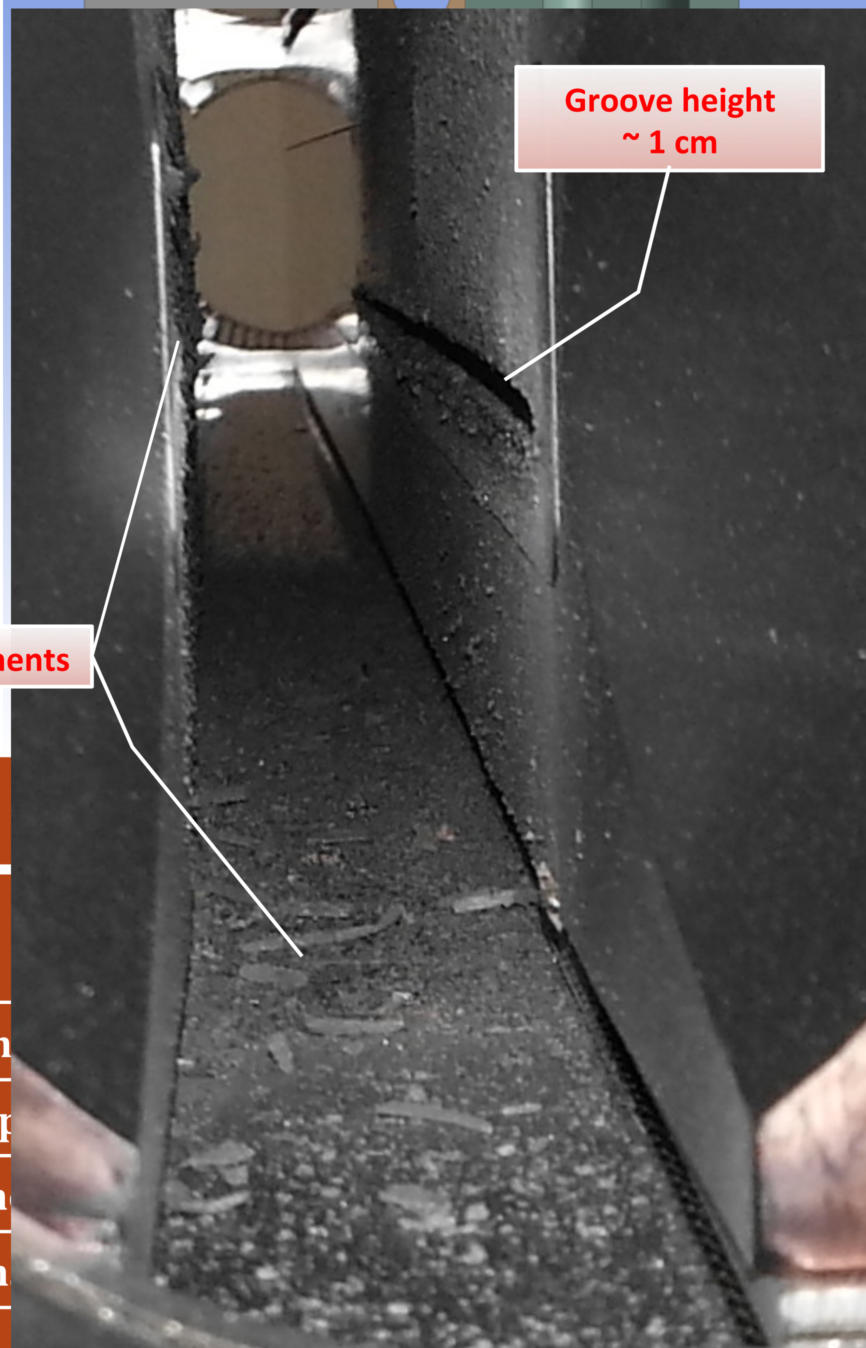
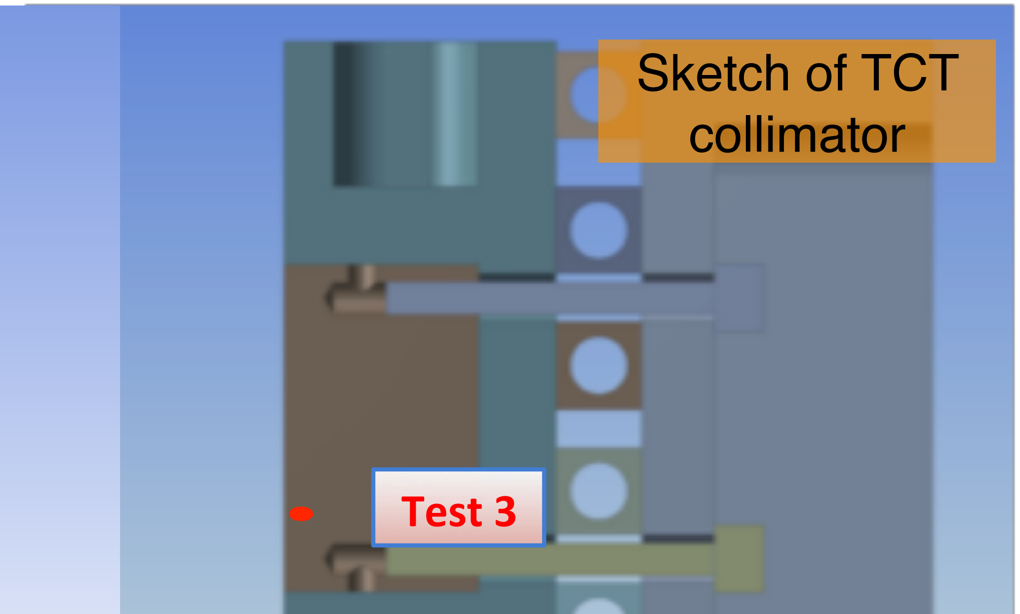
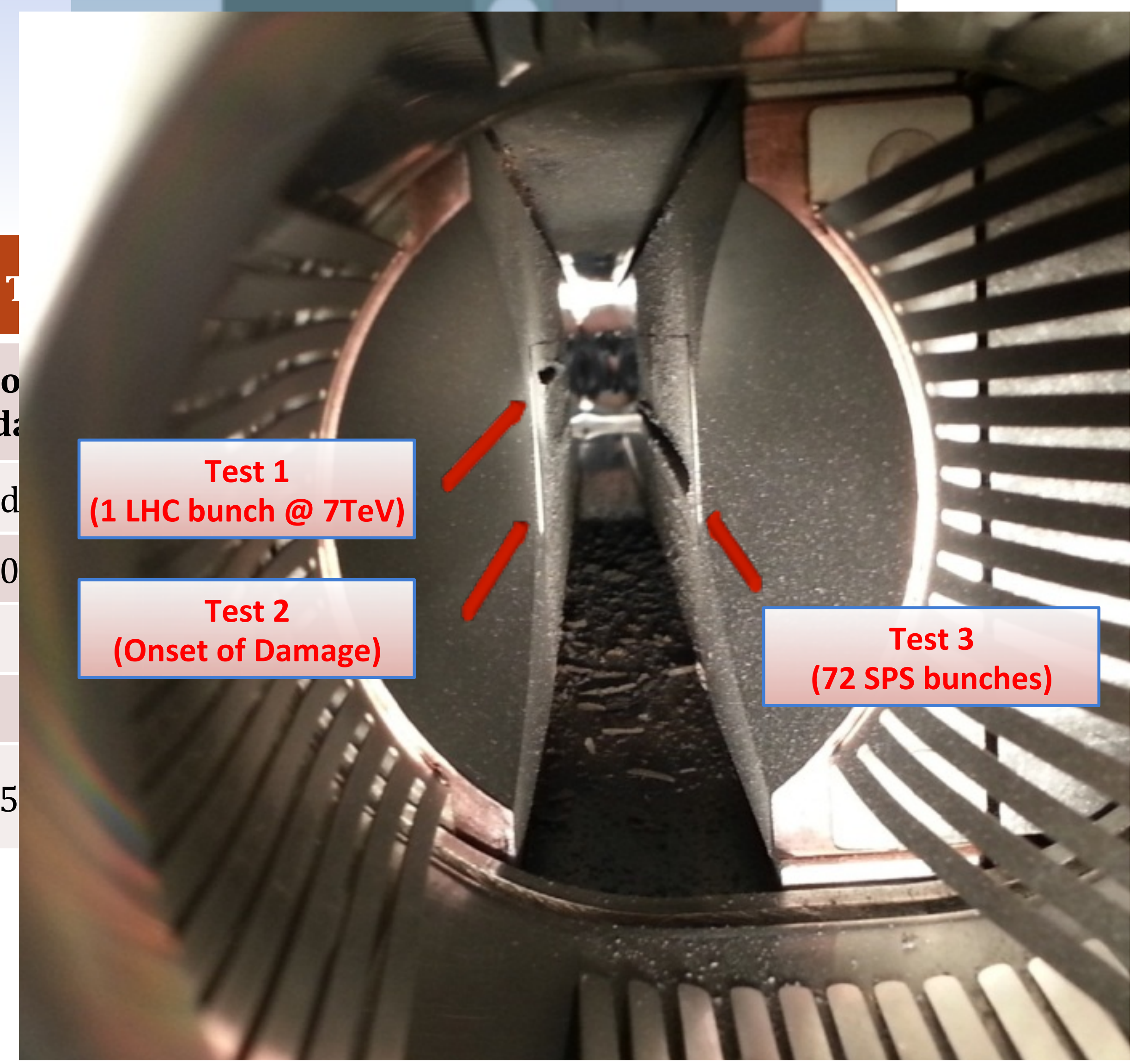






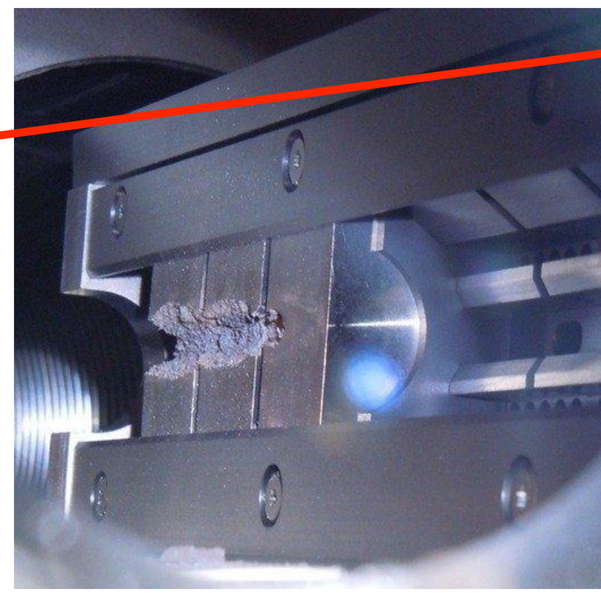
		T
Goal		ify o da
Impact location		w, d
Pulse intensity [p		1.0
Number of bunch		
Bunch spacing [n		
Beam size $[\sigma_x - \sigma_y$ mm]	0.53 x 0.36	12 0.5

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

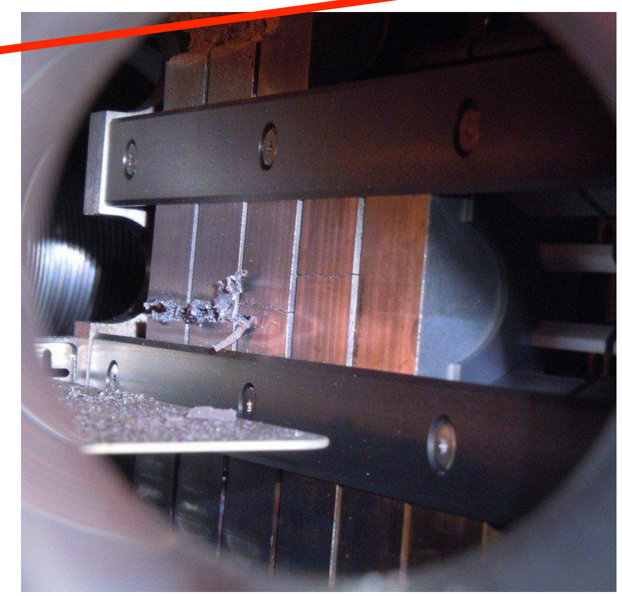
Updated robustness limits

- 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**

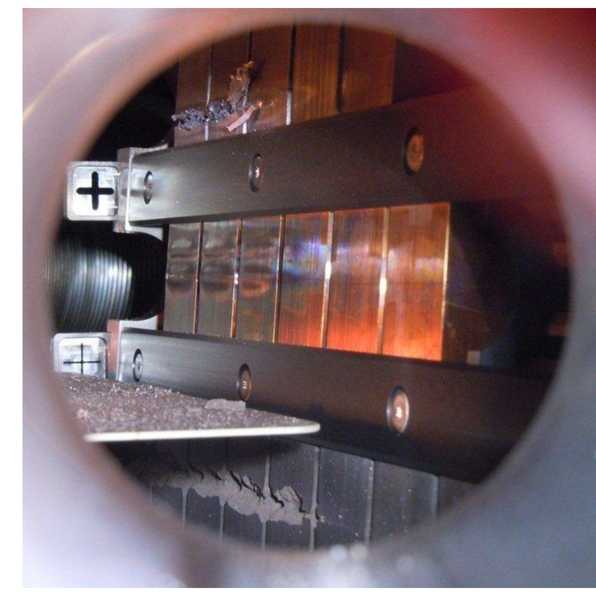
Challenge for the collimator commissioning at 7 TeV that required a few nominal bunches for collision and orbit setup! Need follow up!



Inermet 180, 72 bunches



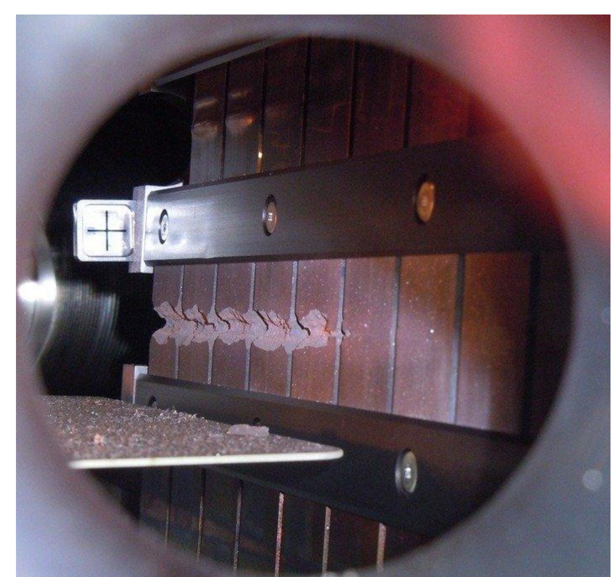
Molybdenum, 72 & 144 bunches



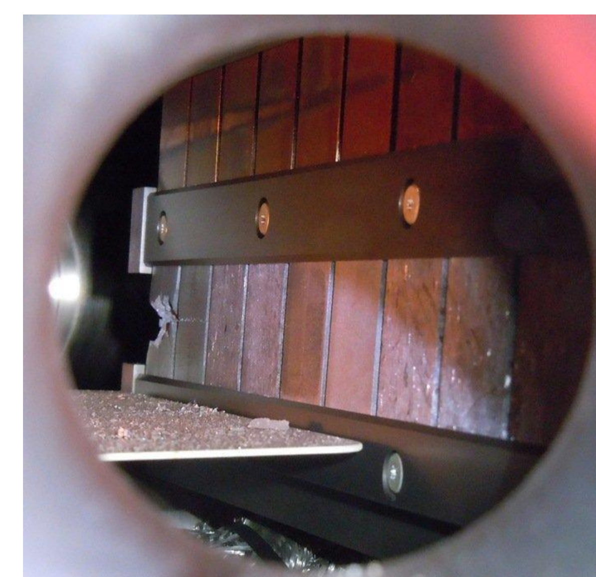
Glidcop, 72 bunches (2 x)

Studied alternative materials for future collimator jaws!

Copper-Diamond 144 bunches



Molybdenum-Copper-Diamond 144 bunches



Molybdenum-Graphite (3 grades) 144 bunches

A. Bertarelli, MP workshop 2013

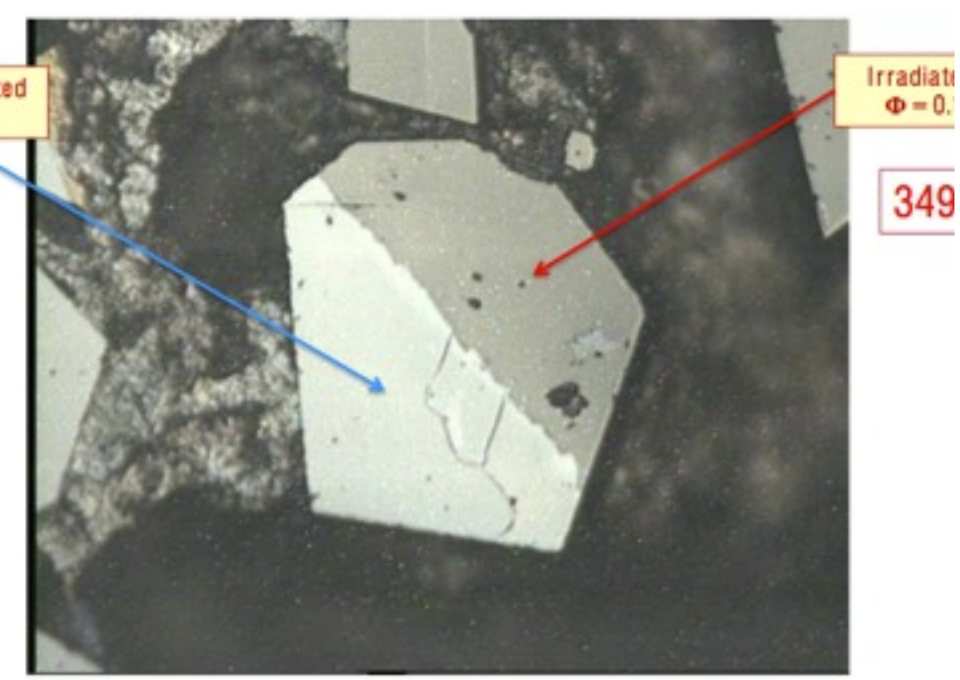
Material properties under high doses

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

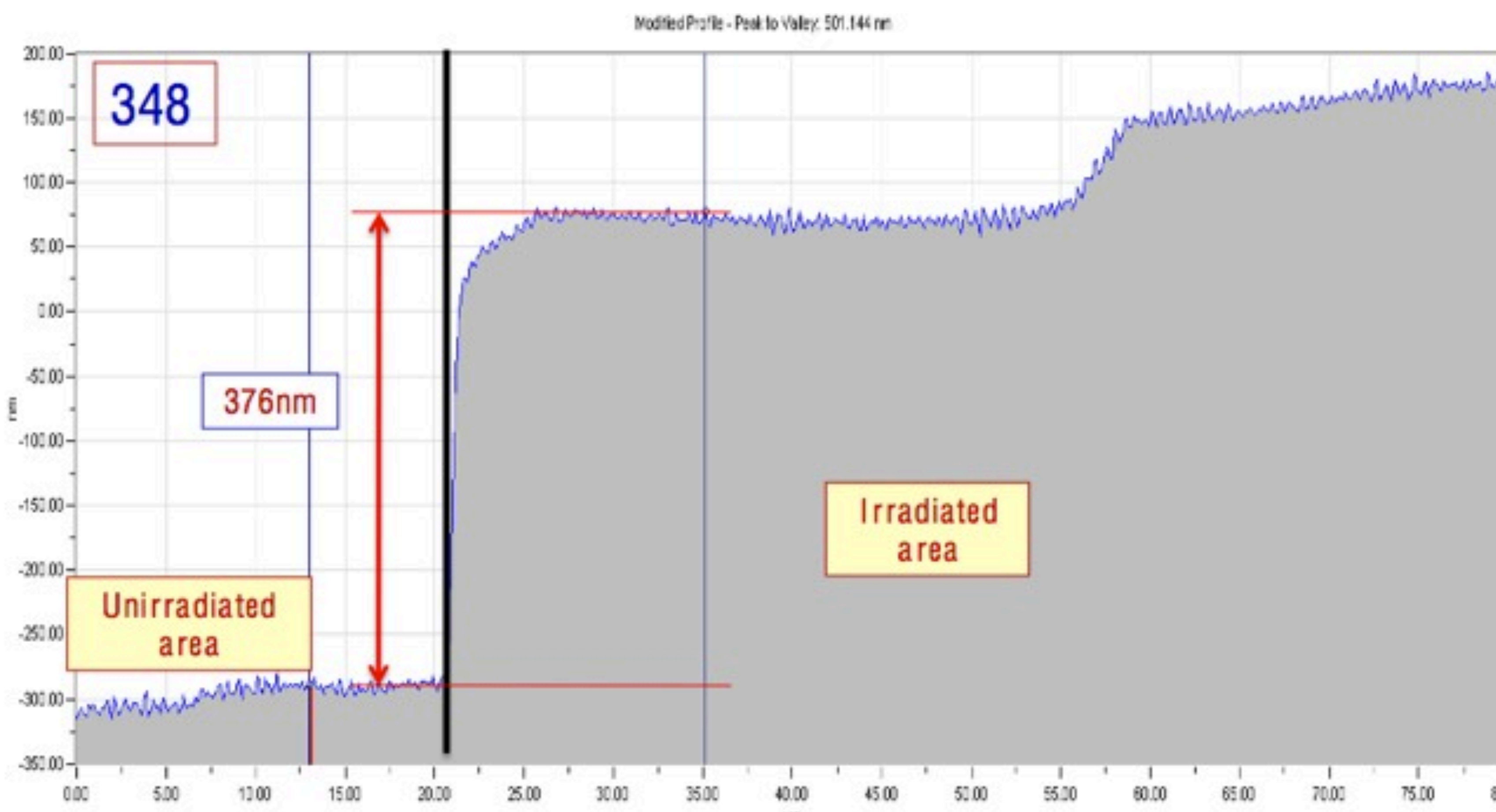
We are also addressing the material behaviour under high irradiation doses! Synergy between test in Russia (Kurchatov) and USA (BNL within LARP): panel of **6 new collimator materials**.

Thanks a lot to the US-LARP friends for supporting this new study proposed in 2012!

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



A. Ryazanov, Kurchatov



Additional ongoing activities

- **Established a program for hollow e-lens studies as LHC scraper**
  - *Defined strategy for US-LARP: will take they TEL2 but will focus studies during LS1 to define an optimum design for the LHC (see Oliver's talk)*
  - *Will focus on alternative scraping methods in case we need to cure loss spikes in the first operation at 7 TeV*
  - *Ideally, perform beam tests at RHIC*
- **Expecting soon the SLAC rotatory collimator at CERN.**
  - *Will define a beam test strategy to complete the validation of this design.*
  - *Initially plan to test rotatory mechanism robustness at HighRadMat. Reconsider SPS tests depending on delivery schedule.*
- **Participation to the definition of LHC layouts for the crystal collimation experiment**
  - *Plan to install one or two crystals at the LHC for MD purposes.*
- **Upcoming EuCARD2 program: focused on material studies for future generation of collimators.**
- **Prototyping of remote handling for collimators**
  - *Promising solutions for robots remotely controllable for first interventions on collimators*
  - *Scope: initial inspections, disconnection of vacuum, ...*

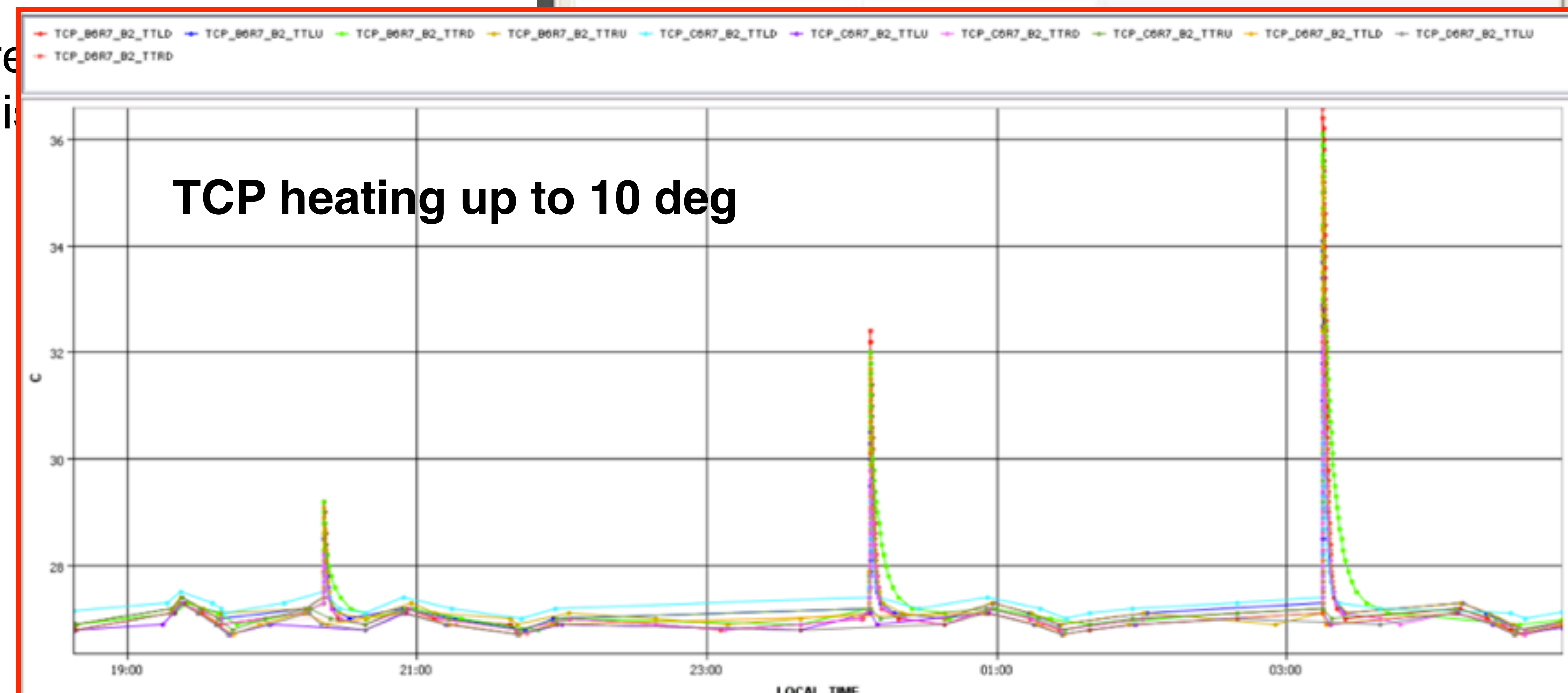
Conclusions

- Reviewed the status of the LHC collimation project
- The LHC and its collimation system performed very well in the first run 2010-2013, with stored energy of ~140MJ!
  - *Major changes of the system could be postponed until LS2, but we have to be ready to reach if the operation at 7 TeV shows problems.*
- Important upgrades have started in LS1
  - *Great expectations from new BPM design!*
  - *Production in a critical phase due to a recent change of contractor.*
  - *New IR1/5 layout for physics debris absorption and improved MQW shielding.*
- A collimator review in May is being organized to address mid and long term upgrade strategy
  - *Immediate goal to decide on the 11 T dipole strategy until post-LS1 operation.*
- Other exciting studies ongoing, in particular for finding an ideal collimator material (robust, low impedance)
  - *Important outcome of HRM results. Beam test should continue.*
  - *Possible actions for LS2.*

Reserve slides

Cryo observations during quench test

Temperature
at the mi

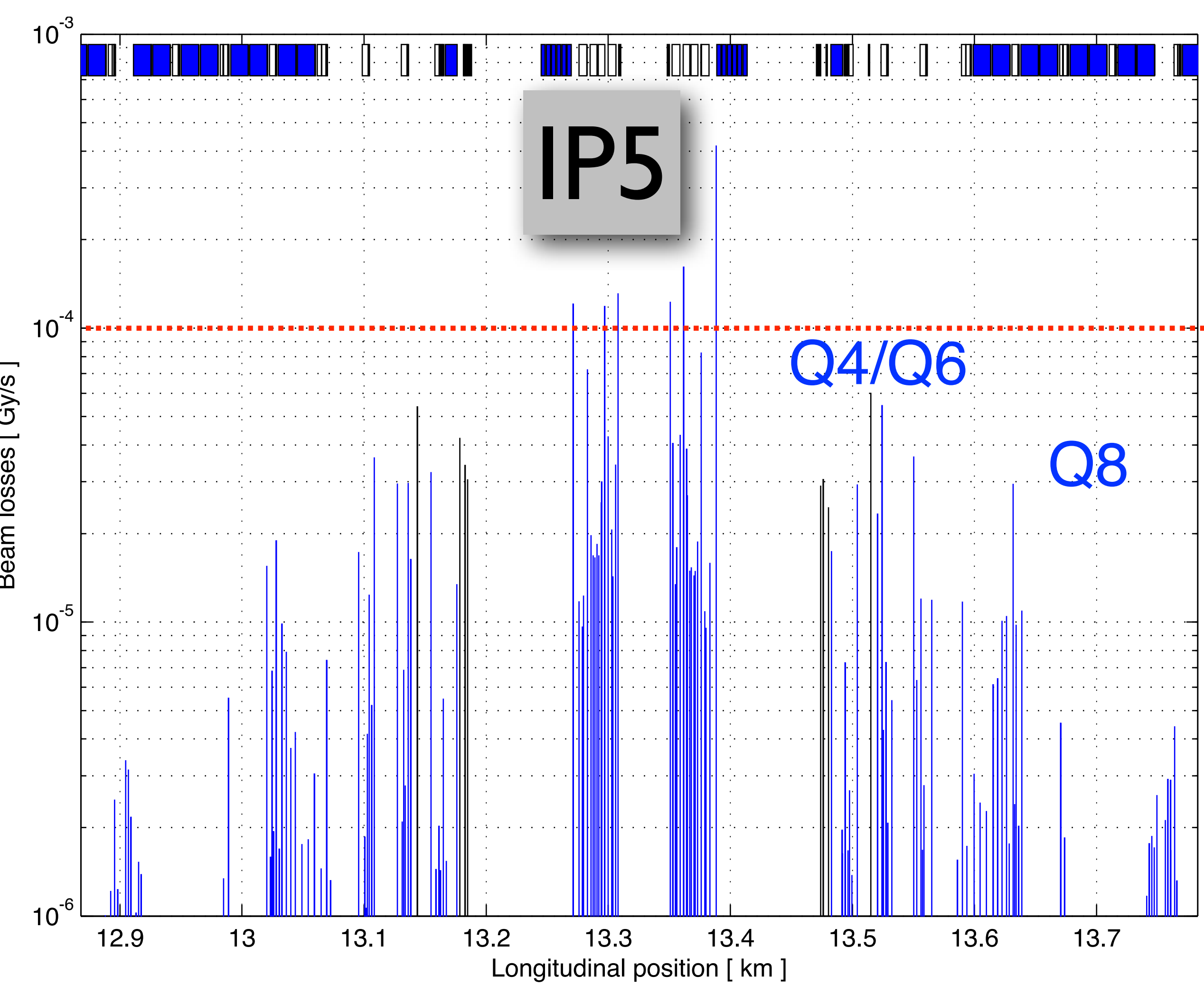


Losses from luminosity debris

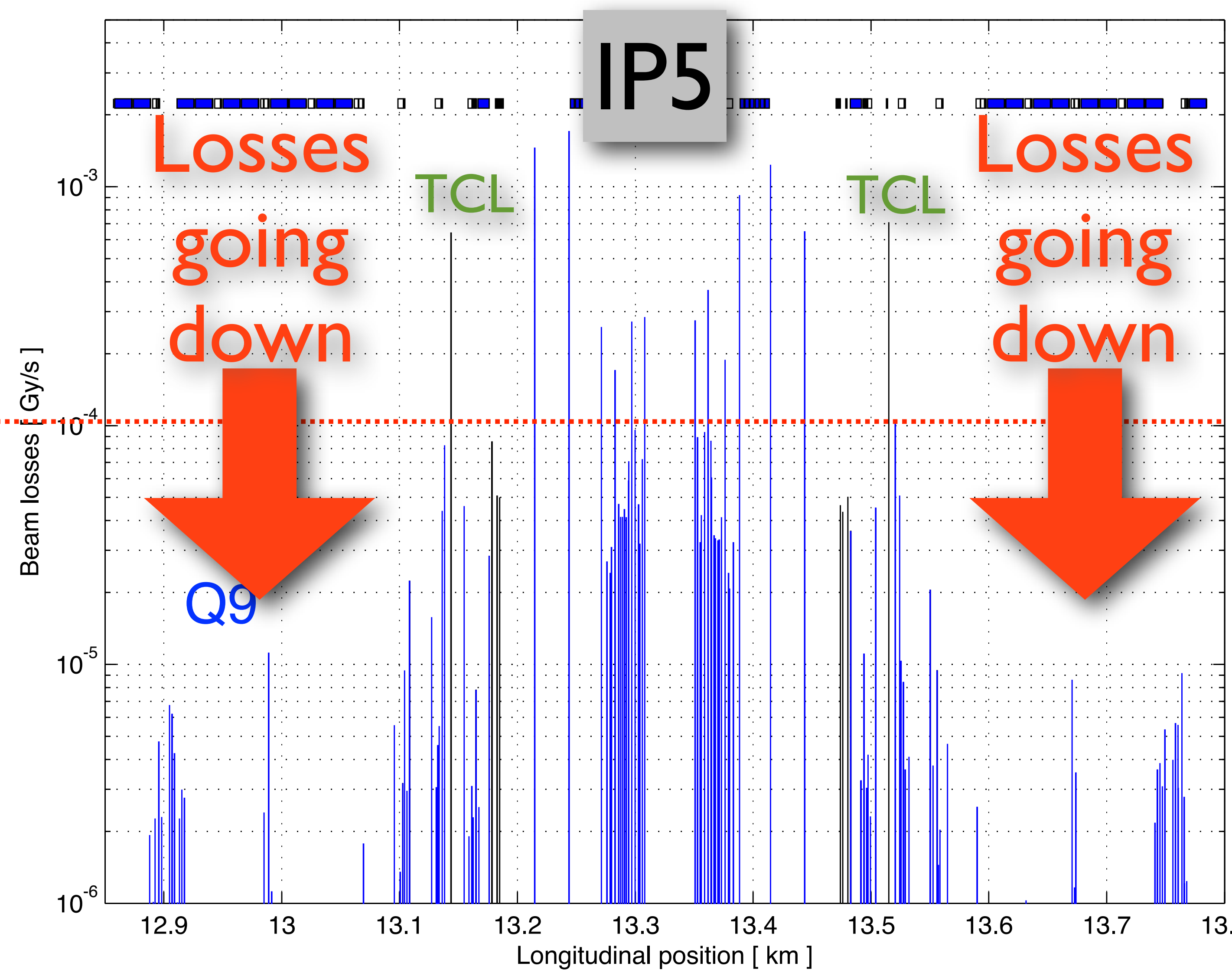
- In 2012, we have started using the TCL collimators in IP1 and IP5 that catch **physics debris**.
- Set to 10σ since the start of the run.
- We have performed TCLs scans to understand the impact on reducing the losses and the load to the magnets. At 10σ measured losses at Q8 reduced by a factor of 50!

Significant improvement of SEU's in IR1 and IR5

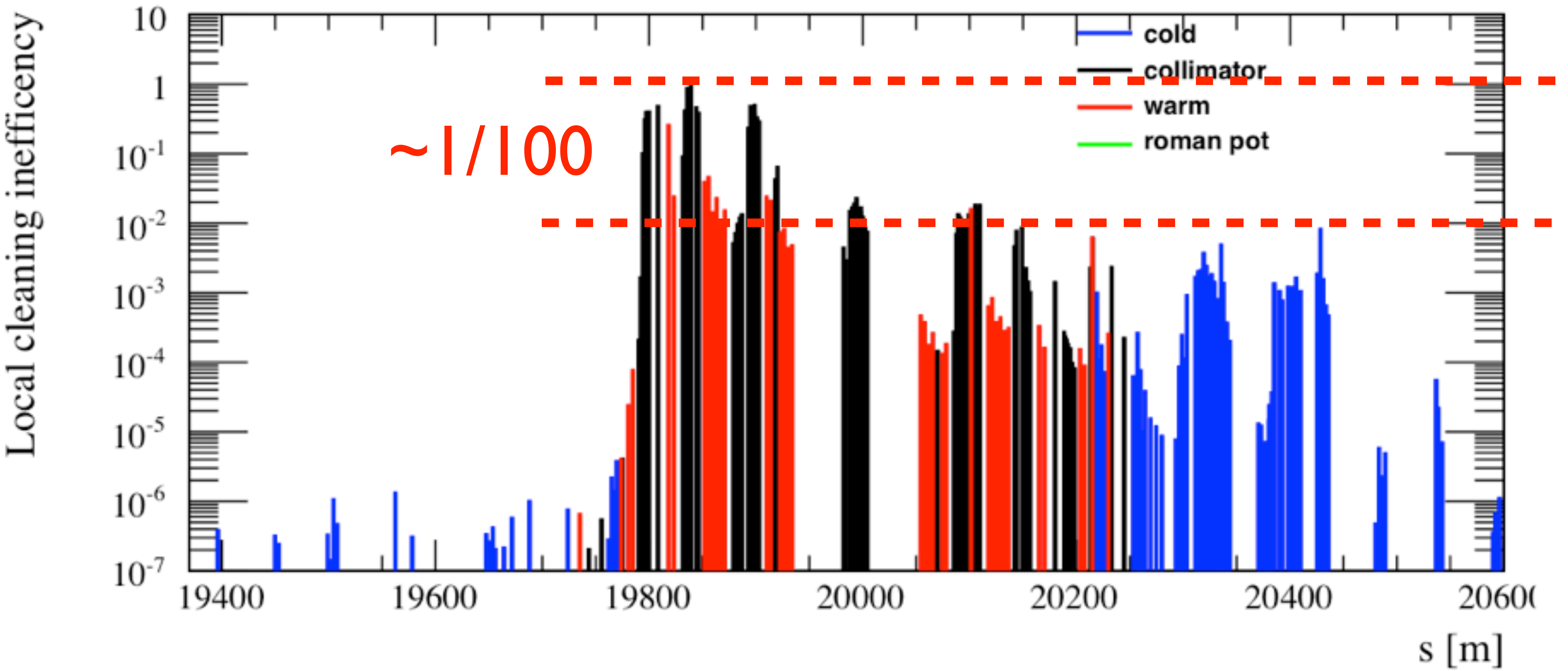
Proton operation in 2011



Proton operation in 2012



Pb collimation cleaning



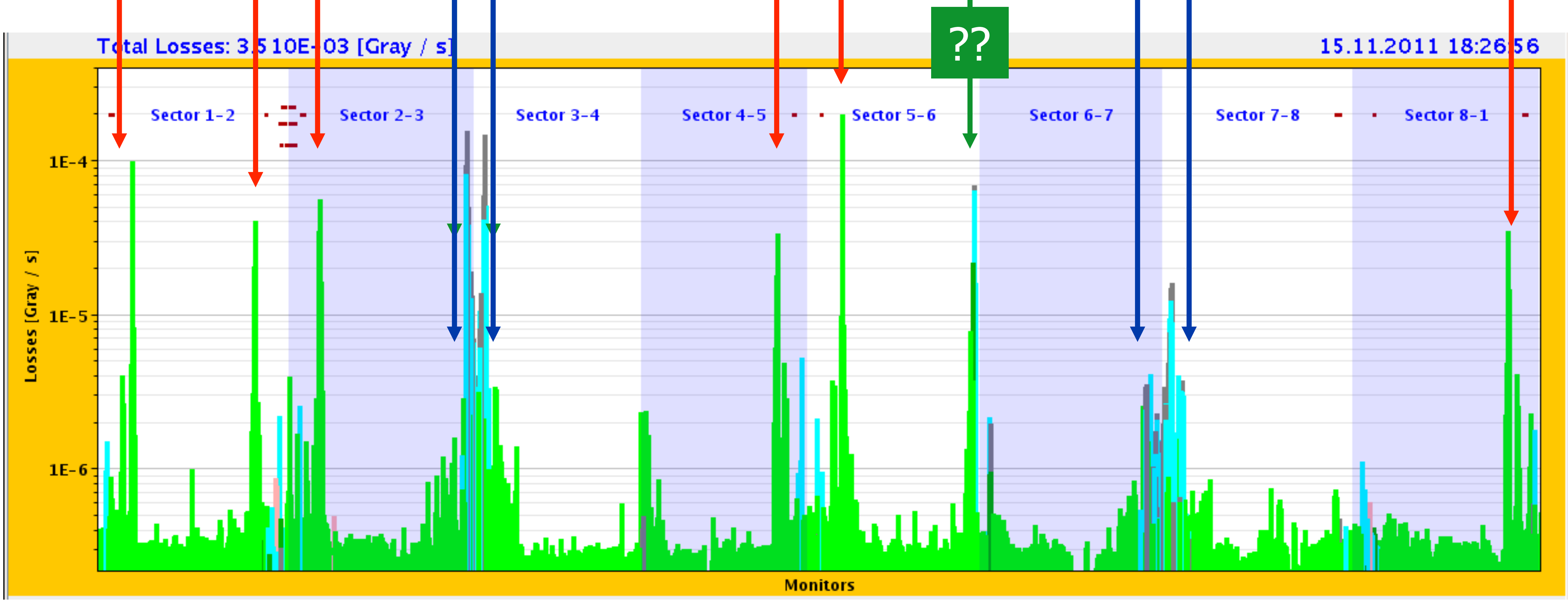
Experience at 4Tev confirmed the results at 3.5 TeV: IR7 cleaning in the order of percents!

3.5 TeV losses with Pb-Pb collisions

Bound-free pair production secondary beams from IPs

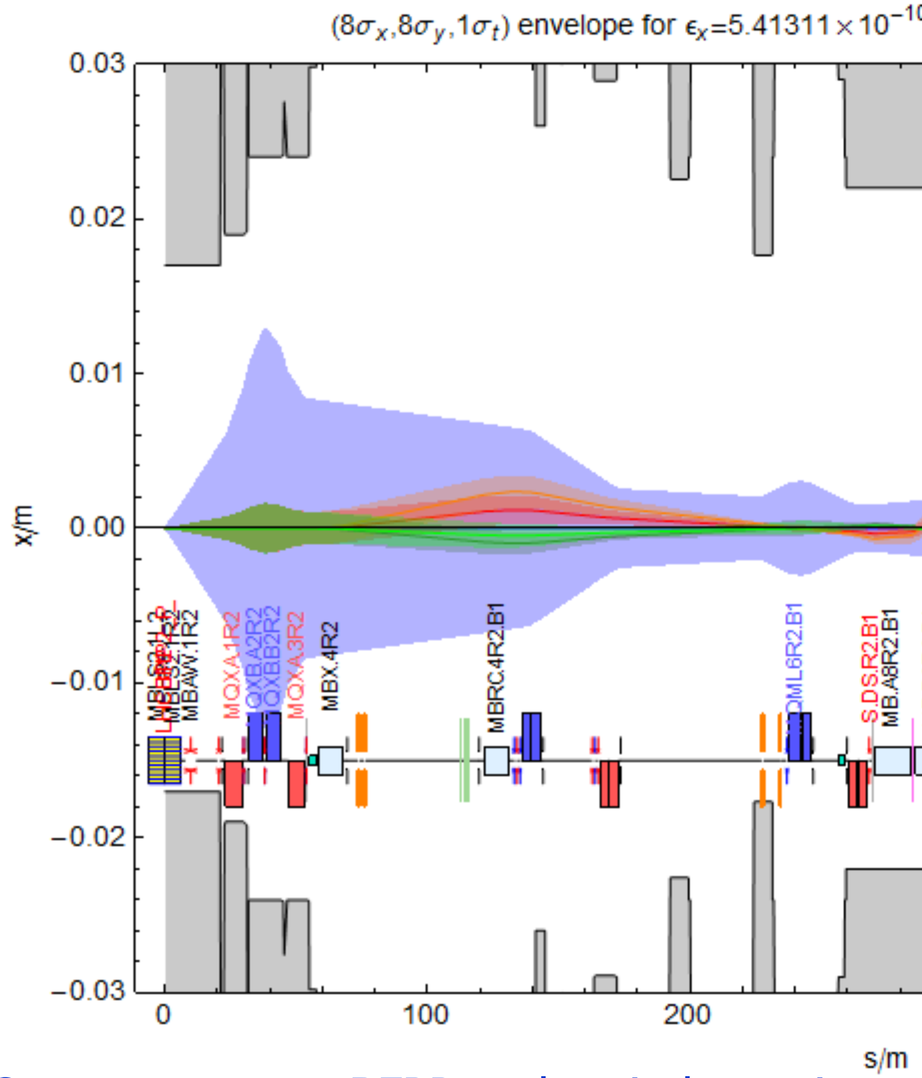
IBS & Electromagnetic dissociation at IPs, taken up by momentum collimators

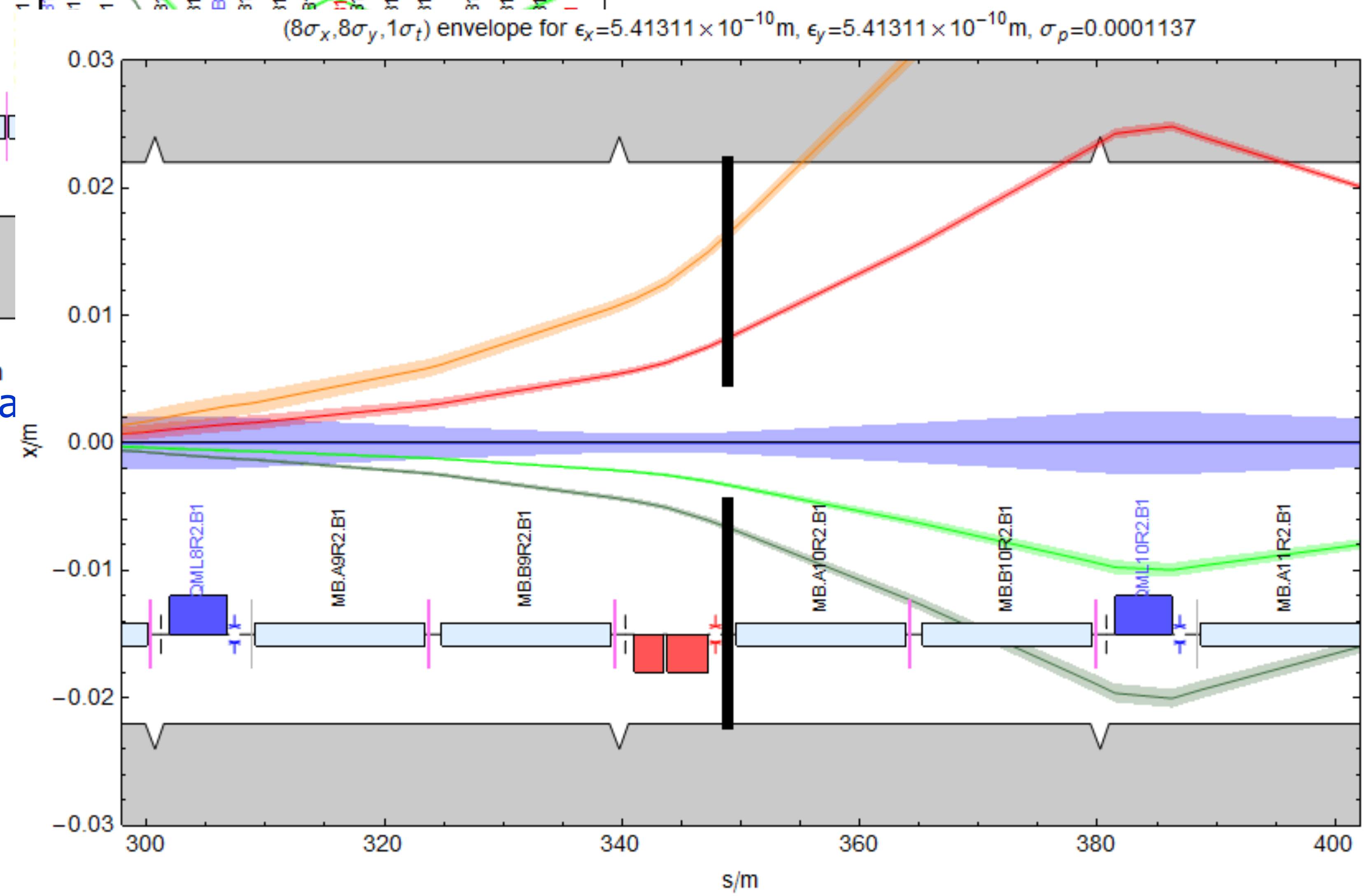
Losses from collimation inefficiency, nuclear processes in primary collimators



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

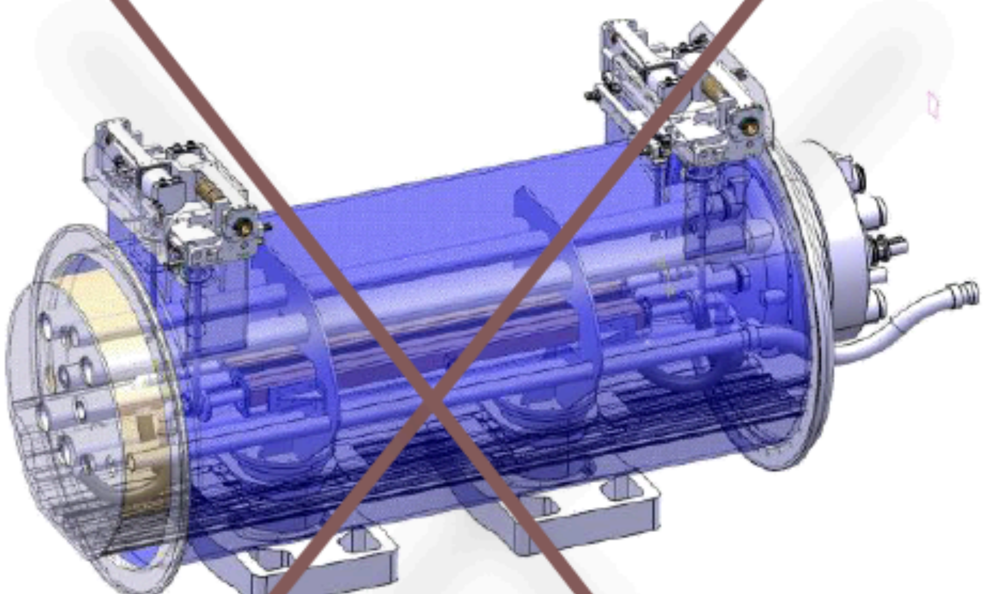
Prototyping of cryostat by-pass

Will be tested at SM18 in 2014

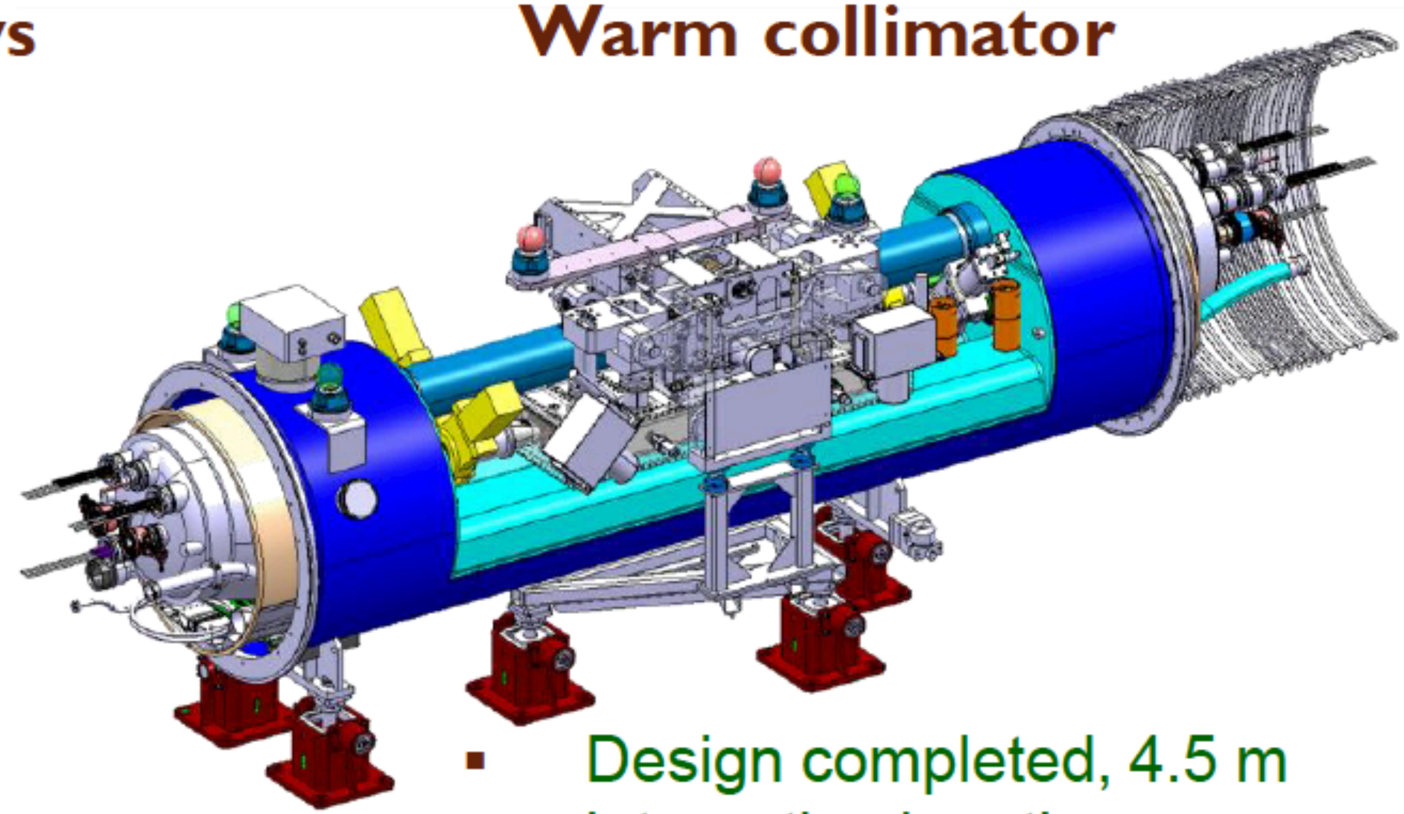
D. Duarte Ramos

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)

(Recent) timeline for hollow e-lens

- **CERN review in Nov. 2012**

  Brought up technical aspects for installation in LHC or SPS.

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

  Strong message about CERN interest to pursue this option in the future.

- **End of 2012**

  Hollow e-lens item back into the US-LARP agenda (item under observation)!

- **End of Jan. 2013**

  CERN internal executive meeting to propose a strategy base on the technical input of the the review. People involved: B. Goddard, M. Lamont, S. Myers, S. Redaelli, L. Rossi, H. Schmickler, R. Schmidt, J. Wenninger.

- **Today**

  Presentation to HLTC and proposal of working plan.

- **April 2013**

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

- **May 2013**

  More technical details at the collimation review: putting together lifetime analysis and results of quench tests.

Review outcome (1)

- The review was very well received: found a lot of **support/interest within CERN** for the hollow e-lens!
  - *Very good success in my opinion!*
- There are **very convincing indications** that
  - *The LHC operation could profit from the scraping functionality offered by the hollow e-lens (or equivalent devices, if possible).*
  - *The Tevatron experience accumulated in the context of collimation studies indicates that the hollow beams can work as efficient scraper.*
- We **cannot** firmly state now that without scraping the LHC performance will be severely limited!
  - *The final answer must wait until the first operational experience at ~7 TeV*
  - *More indications are being collected for the collimation review in May!*
- The **upgraded** Tevatron **"TEL2" hardware** is **fully appropriate** to serve as **scraper at the LHC** (and for beam tests at the **SPS**)
  - *Important simulation effort put in by the US-LARP colleagues - competence not yet available in-house.*
- The required time for an **implementation** in the LHC is **4-5 months** (limited by cryogenics works in IP4). Estimates for the SPS are being completed.
  - *Not really justified to install the "TEL2" in the long 2015 shutdown for MD studies.*
  - *Help from the HLTC team? Synergy with the crab-cavity project.*

Review outcome (2)

- There is a **lack of <u>proved</u> alternative scraping methods** that can work as the hollow e-lens.
  - *Several options on the table that require solid **experimental validation**.*
  - *Note that the scraping is needed in all machine phases, with varying tunes!*
- On the other hand, the available **e-beam cannot** be used for **both beams** at the LHC (one device only is available now)
  - *Solutions based on hollow e-lens cannot be implemented before LS2.*
  - *It is important to pursue alternative methods that could be quickly implemented in 2015 if the operation at ~ 7 TeV requires it.*
- E-beam are beautiful devices for many other machine studies. The e-beam shape can be adjusted to different distributions with short accesses.
  - *Tune shift compensation, beam-beam compensation, etc. Never used for that at the Tevatron, though! Focus only on collimation needs here!*
- **Technical challenges requiring more studies/beam tests:**
  1. ***Beams see the full e-beam when crossing the "edge" of the hollow e-lens. Emittance blowup? (In particular, with pulsed currents).***
  2. *Impedance ("TEL2" not optimized for the LHC parameters).*
  3. *Improved controls/diagnostics might be required for the LHC.*
  4. *Beam dynamics is complex: would be useful to test it with LHC beams*
- **Strong** message on the need to improve **halo diagnostics!**

Proposed CERN strategy

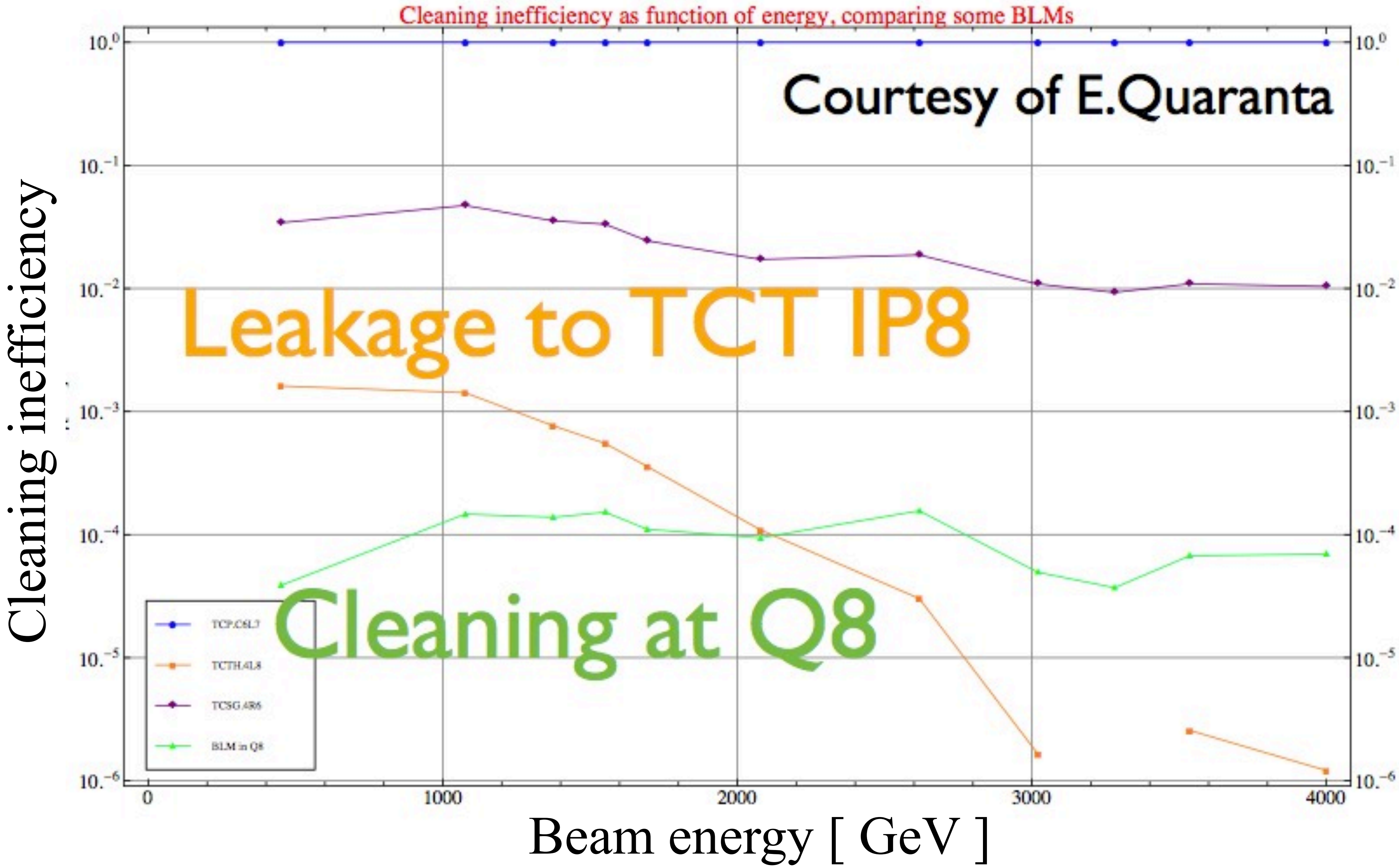
Taking into account the present financial situation and the manpower commitment to the LS1 activities, CERN cannot decide now on the installation of the available Tevatron hardware in the SPS or the LHC.

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 work with high priority towards the preparation of a possible production of 2 hollow e-lens devices optimized for the LHC parameters.

- **Design** of a LHC optimized device, with optimum e-beam parameters for 7 TeV and improved integration into the LHC infrastructure.
- 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.
- Work with very high priority on improving the halo diagnostic capabilities at the LHC in the context of the HL-LHC study.
- Continue working on alternative methods for halo scraping.

Cleaning versus energy



- Tested during 2 MDs in 2012
- Simulations being benchmarked against measurements to improve the extrapolations to 7 TeV!
- Complex dependence on beam dynamics and collimator settings that vary.

Collimator dump statistics

Big and distributed system!

Parameters	Number
Movable collimators in the ring	85
Transfer line collimators	13
Stepping motors	392
Resolvers	392
Position/gap measurements	584
Interlocked position sensors	584
Motor settings functions versus time	480
Motor discrete settings	1820
Threshold settings functions versus time	2880
Threshold discrete settings	8568
Threshold settings versus energy	196
Threshold settings versus β^*	384
Active (TCT's only)	64

(Without TCDQ)

Dump/faults statistics 2012-13:

- **11 dumps from position survey above 450 GeV**
    - *5 HW failure (4 in stable beams)*
    - *6 mistakes by OP or collimator expert*
    - *No spurious dumps*
- **3 temperature dumps**
    - *2 real, 1 spurious (fake sensor reading).*
- **1 TCDQ dump in 2013**
    - *Issue to be addressed with energy limits*

No issues of not-dumping when it should!

Injection:

10 "OP mistakes"/tests (5 without beam)
4 TDI hardware problems
1 glitch on beta* limits.

Thanks to B. Todd

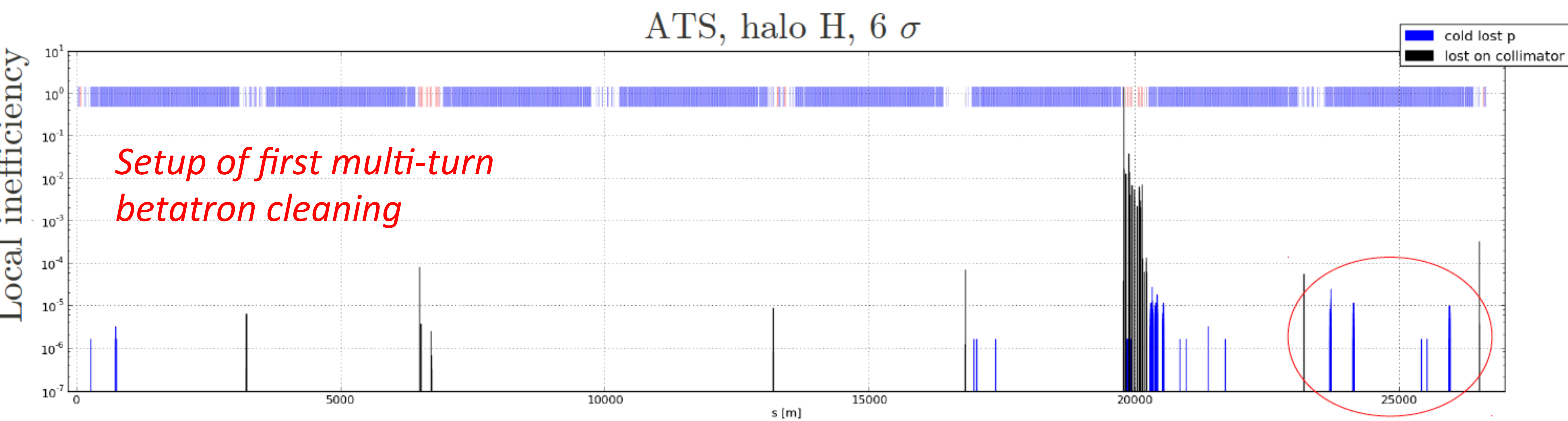
Estimate **downtime** from collimator intervention (remote or local), by A. Masi:

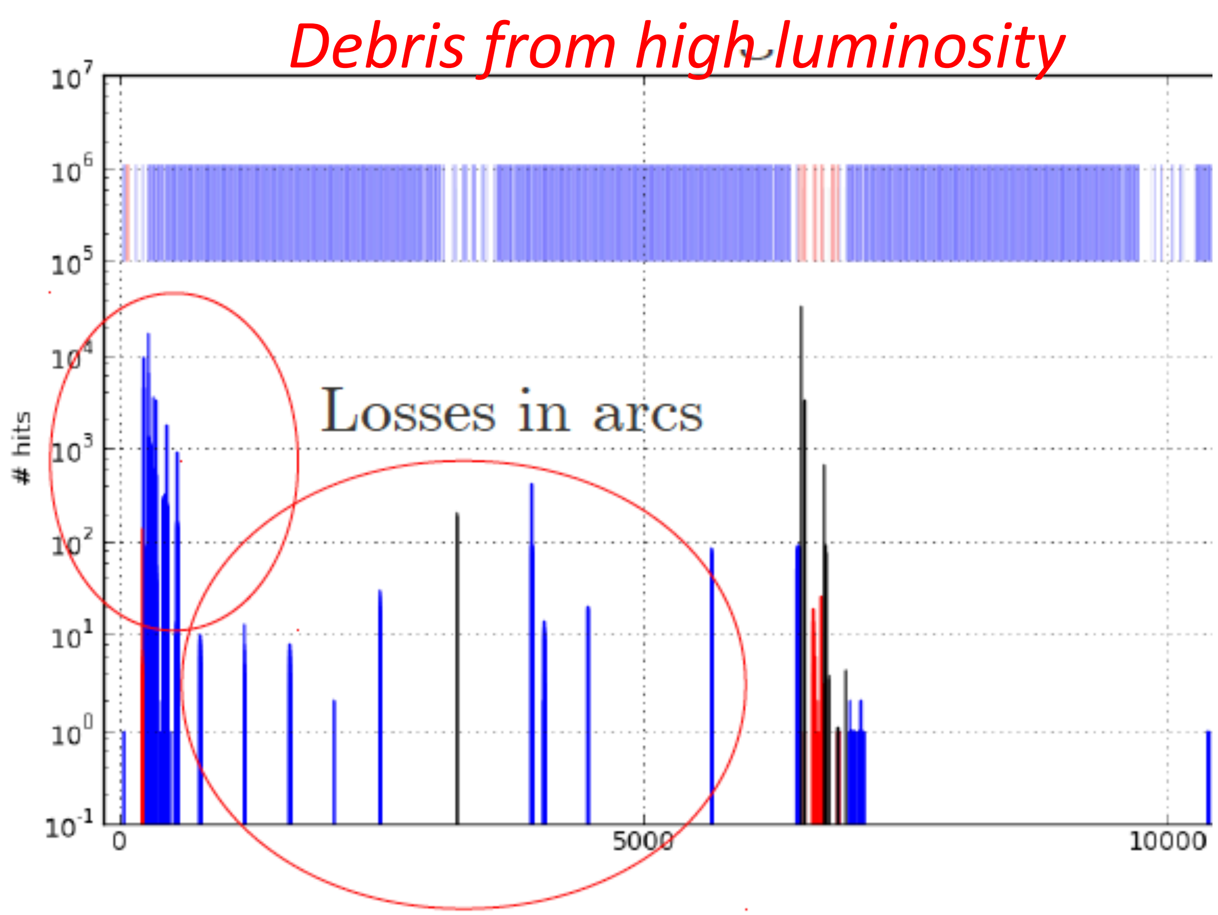
- **26.3 h** for LHC collimator faults in 2012-13; **10.6 h** for TDI problems.

Interestingly, longest downtimes triggered by faults that do not cause beam dumps!

Discuss this further at the reliability WG. Obviously, time for beam checks not included.

Cleaning for HL-LHC optics (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