***HL Technical Committee***

*March 8th, 2013*

*CERN, Geneva, CH*

# Outcome of Hollow e-Lens Review and Action Plan

***Stefano Redaelli, CERN, BE-ABP***

*Based on material presented at the November review:*
***many thanks*** *to speakers and reviewers.*
*Special thanks: R. Bruce (review's scien. secr.); G. Stancari, A. Valishev (FNAL); W. Fischer (BNL); L. Rivkin (EPFL)*

# Outline

- ☑ Introduction
- ☑ Recap. of hollow e-lens
- ☑ Review: executive summary
- ☑ Detailed work plan
- ☑ Conclusions

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  - *The review did not address exhaustively the need for scraping at the LHC: waiting for complete performance analysis (quench tests, lifetime, cleaning, ...)*
- **Scope of this meeting:**
  Present an **executive summary** of the review with a proposed **work plan**.
  - *Immediate goal: steer the US-LARP collaboration effort.*

# (Recent) timeline

- **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.*

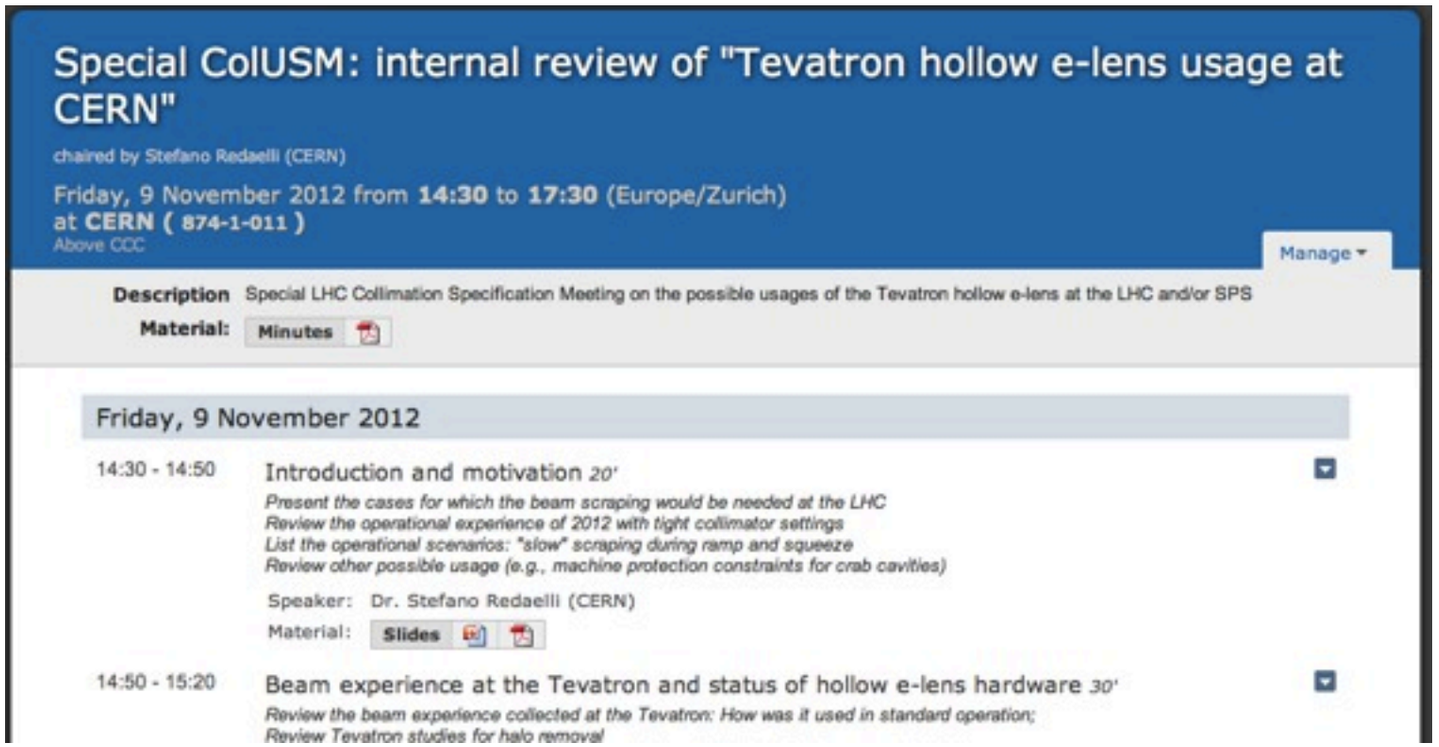
- **April 2013**

  *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 on Nov. 9th, 2012




Scope:

**Review the possible usage of the Tevatron "TEL2" hardware for LHC collimation purposes. Address the basic compatibility for beam tests at LHC or SPS. Identify possible alternative methods for scraping at the LHC: collect all elements to establish a followup plan.**

Bottom-line: Need to provide US-LARP with a baseline strategy from CERN side.

Justification of needs for scraping at the LHC not addressed in detail.

https://indico.cern.ch/conferenceDisplay.py?confId=213752

Reviewers from different domains. No formal report required.

- Rudiger Schmidt (machine protection)
- *Brennan Goddard (LHC beam dump + SPS upgrade)*
- Serge Claudet (LHC + SPS cryogenics)
- Massimo Giovannozzi (accelerator physics, optics)
- Erk Jensen (LHC RF + crab cavities)
- Elias Metral / Alexej Grudiev (LHC impedance)
- *Karel Cornelis (SPS operations)*
- Roberto Losito (collimation hardware)
- Mike Lamont (LHC operations)
- *Oliver Bruening (accelerator physics)*
- Bernd Dehning (Beam instrumentation)
- Wolfgang Hofle (LHC damper system)
- *Katy Foraz (LS1 planning)* → Julie Coupard
- Joerg Wenninger (MP + operations)
- Markus Zerlauth (machine protection)

*Italic: could not make it.*

Thanks a lot to all the colleagues for the active participation! More than **40 people** animated the discussion.

# Agenda of the review

- **Introduction and motivation**
  *(Stefano Redaelli, CERN)*
- **Beam experience at the Tevatron and status of hollow e-lens hardware**
  *(Giulio Stancari, Fermilab)*
- **Simulations of hollow e-lens in the LHC and SPS**
  *(Valentina Previtali, Fermilab)*
- **Feasibility of installation in the LHC and SPS**
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- **Possible alternatives for halo scraping at the LHC**
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Limited number of focused talks to leave appropriate time for discussion!

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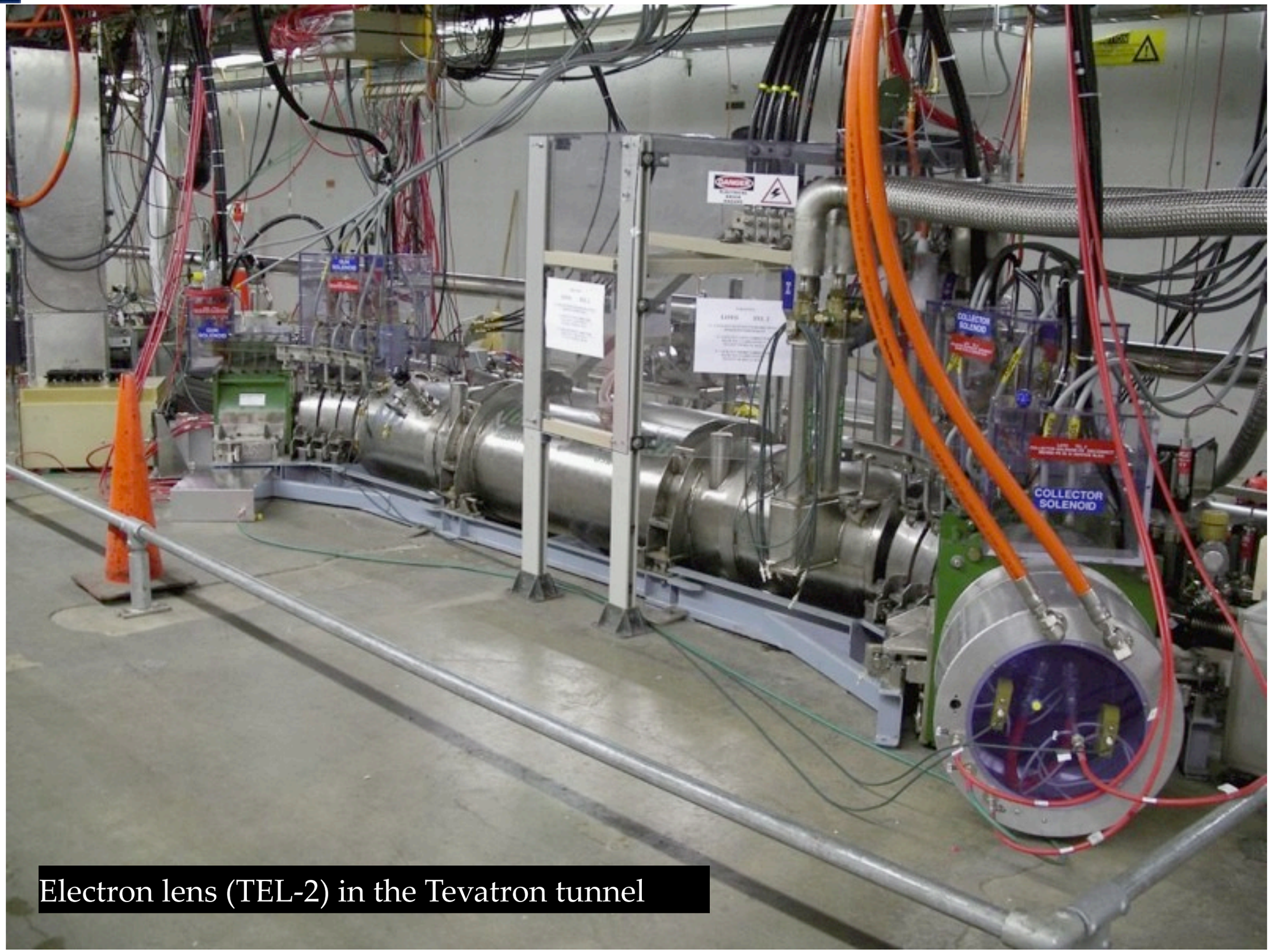
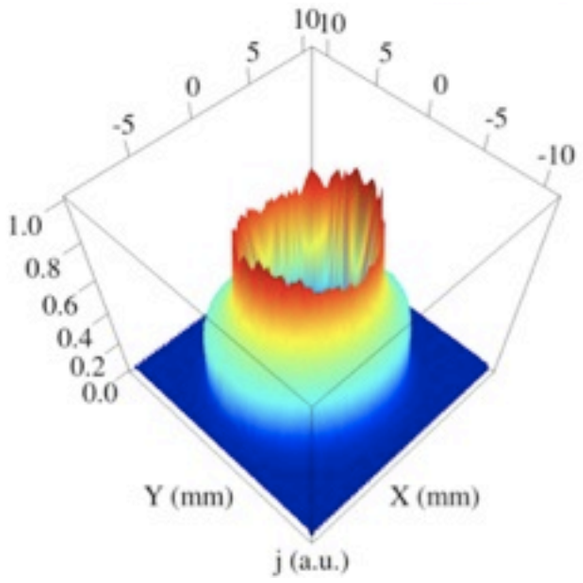
# TEL2 hardware at the Tevatron

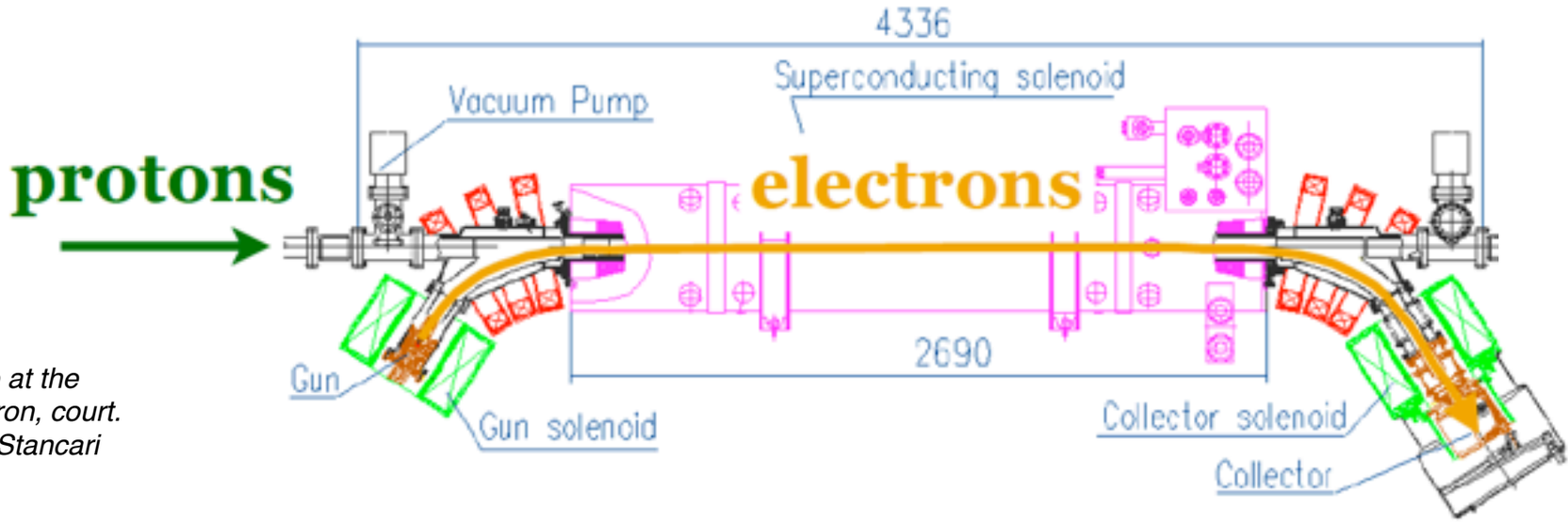



Electron lens (TEL-2) in the Tevatron tunnel

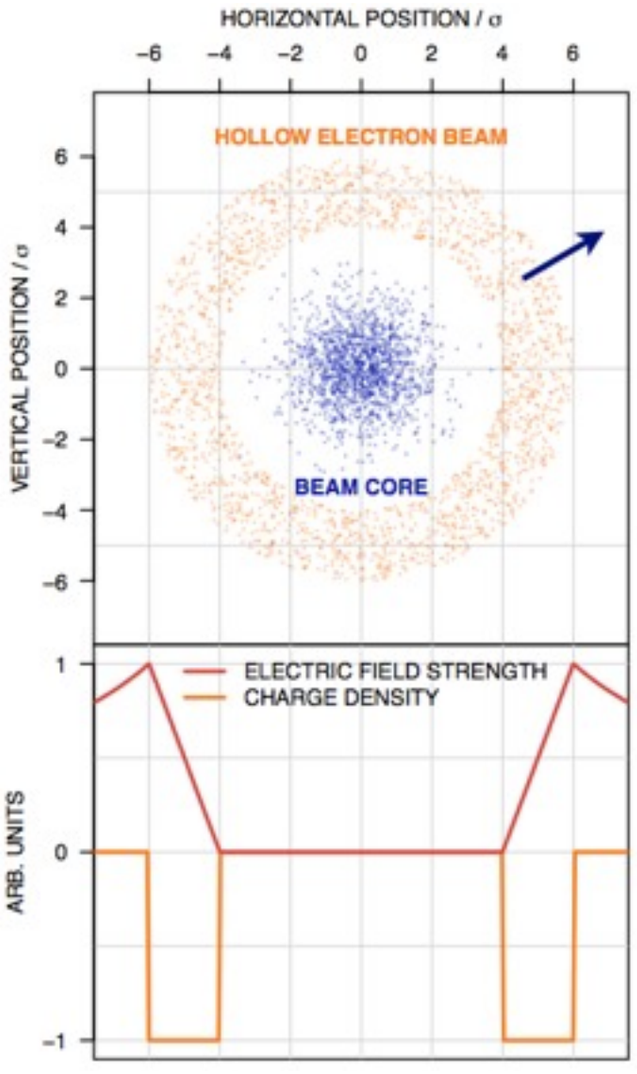
**Courtesy G. Stancari**

# Basic concepts



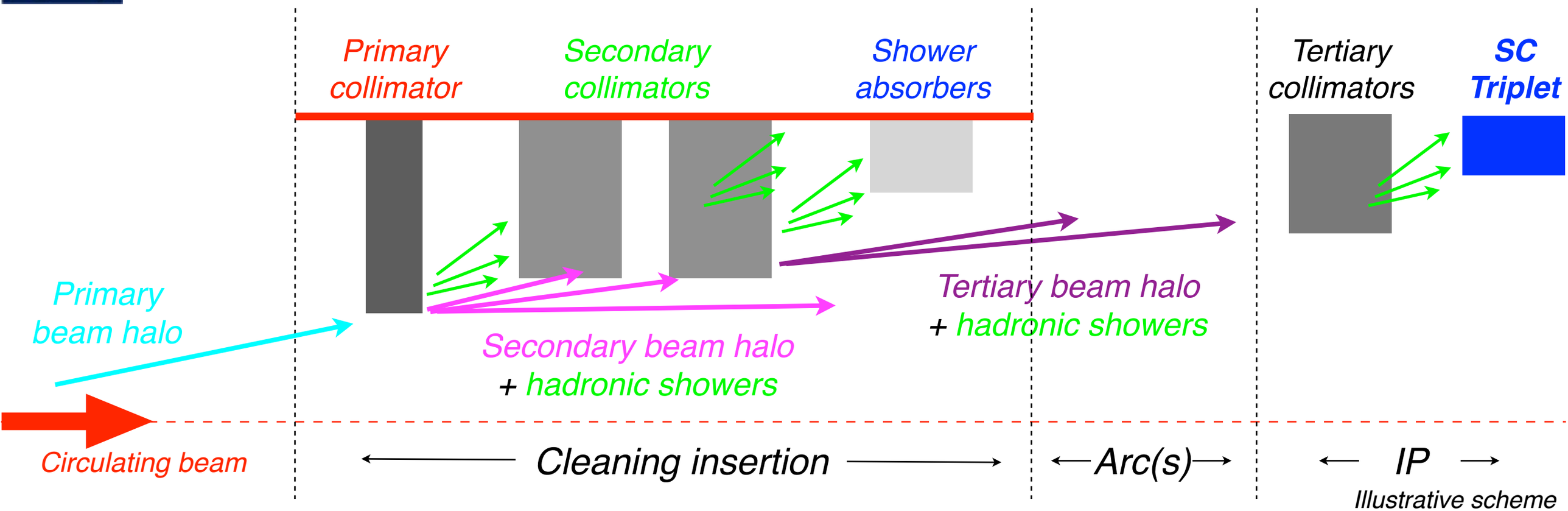




*Setup at the Tevatron, court. of G. Stancari*




- **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.

# Integration in multi-stage cleaning




- The hollow e-lens itself does not absorb the halo particles!
- The standard **LHC multi-stage collimation** must be maintained.

  *All collimator remains in place: the hollow e-lens controls the impact speed on TCP's.*
- No change of assumptions for machine protection: single-turn kicks are small.
- Compatibility with ions collimation and future collimation concepts.
- The lens does not need to be located close to the collimators.

  *- Indeed, it better be elsewhere as it is a superconducting device!*

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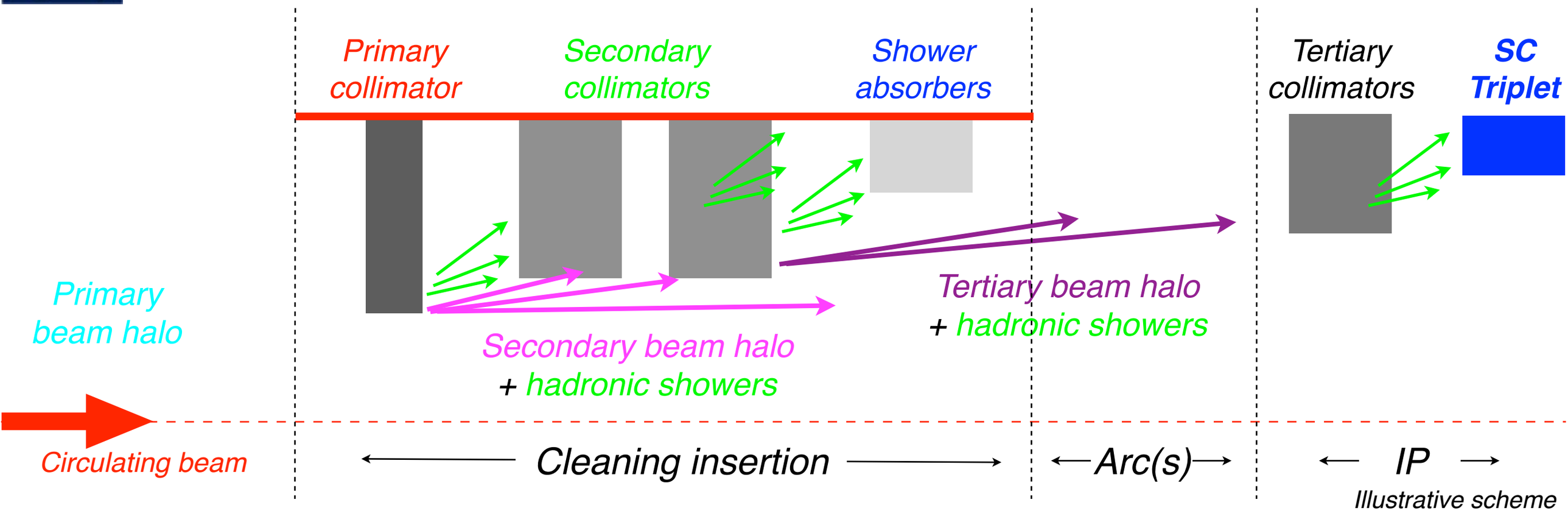


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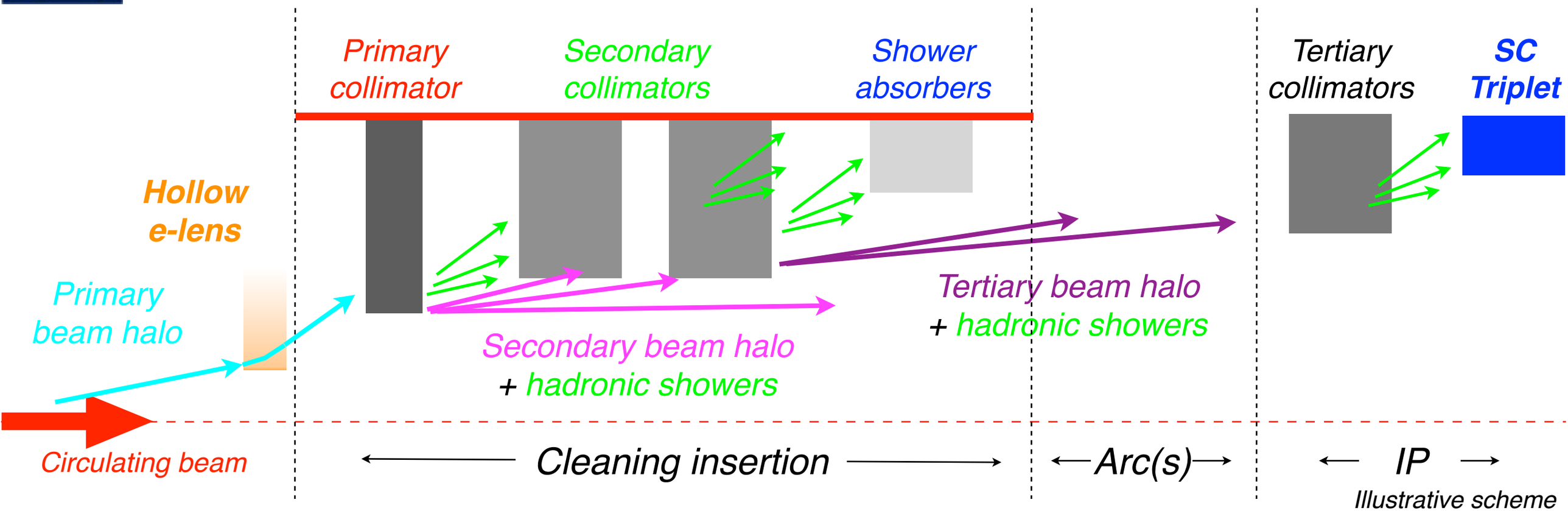


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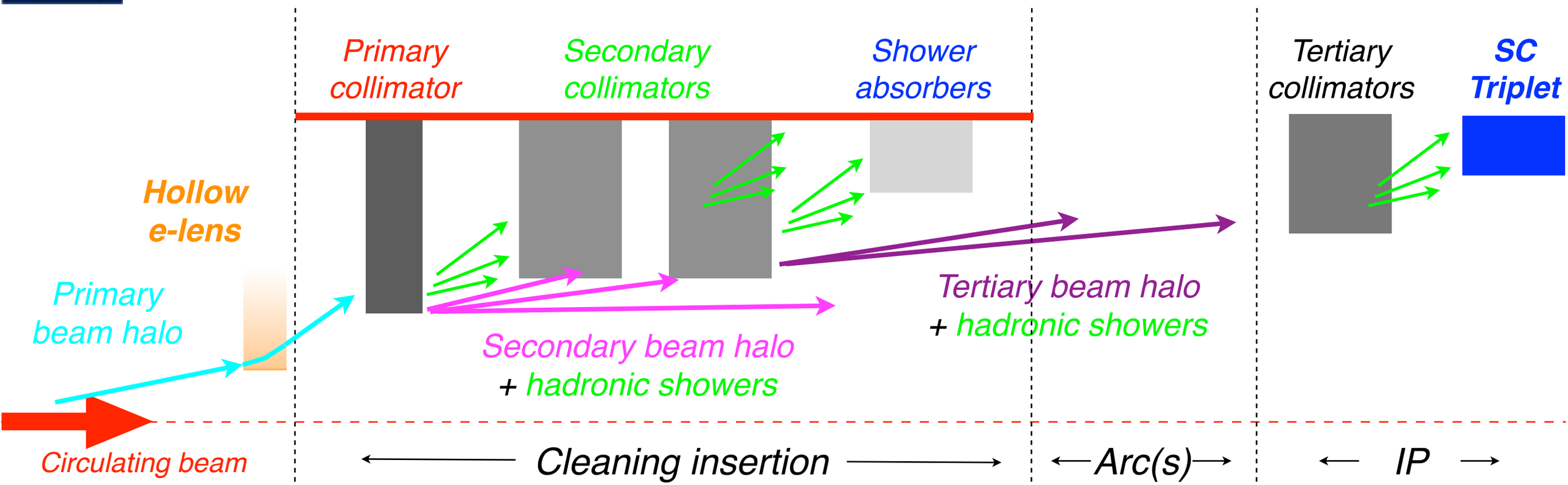


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No more details here - lots of reserve slides in case of questions!

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- 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.*

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  *Several options on the table that require solid **experimental validation**.*
  *Note that the scraping is needed in all machine phases, with varying tunes!*

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  4. *Beam dynamics is complex: would be useful to test it with LHC beams*
- **Strong** message on the need to improve **halo diagnostics!**

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*Remarks:*
*- Ideally one would test the "TEL2" also in the LHC but the massive works on the cryogenics system prevent an installation in 2015.*
*- SPS beam tests are not exciting from the expected outcome (lower energy than Tevatron, not possible to address impact on luminosity) but would give the unique chance to build experience at CERN (controls, instrumentation, ...)*

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- Work with very high priority on improving the halo diagnostic capabilities at the LHC in the context of the HL-LHC study.

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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.

# Outline

- ☑ Introduction
- ☑ Recap. of hollow e-lens
- ☑ Review: executive summary
- ☑ **Detailed work plan**
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- Need to define solid beam test plan.

  *My first thought:*

  *- Repeat a selection of Tevatron results.*

  ***- Address the issue of e-beam edges with pulsed excitation***

  *- Develop **appropriate controls and beam experience** for specific usage, like in ramp and squeeze (never used at Tevatron).*

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- Expect strong participation from CERN team.

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# EPFL activities

*(Based on discussions with L. Rivkin)*

- L. Rivkin would like to pursue electron beam studies for beam-beam compensation at the LHC.
- It is clear in my opinion that, if this interest is confirmed, we should profit from this synergy and converge to a common program that includes hollow beams!
- Present status: informal discussion between the two of us.
  I am confident that we can count on their **concrete support**, on a program to be defined in detail.

# Conclusions

- The review was very successful: we collect a lot of useful information and built up some momentum from CERN side on this exciting topics!
- Preliminary analysis of 2012: strong indication that the operation could profit from efficient scraping tools at the LHC. But we cannot conclude now on apparent limitations for post-LS1 operation.
- This, and the major implications on cryo, suggested a prudent strategy

  *Propose to steer the (limited?) available resource in being well prepared if the operation in 2015 indicate serious issues.*

- The present strategy is to aim at a being able to build 2 devices starting in 2015, if needed and other solutions fail.

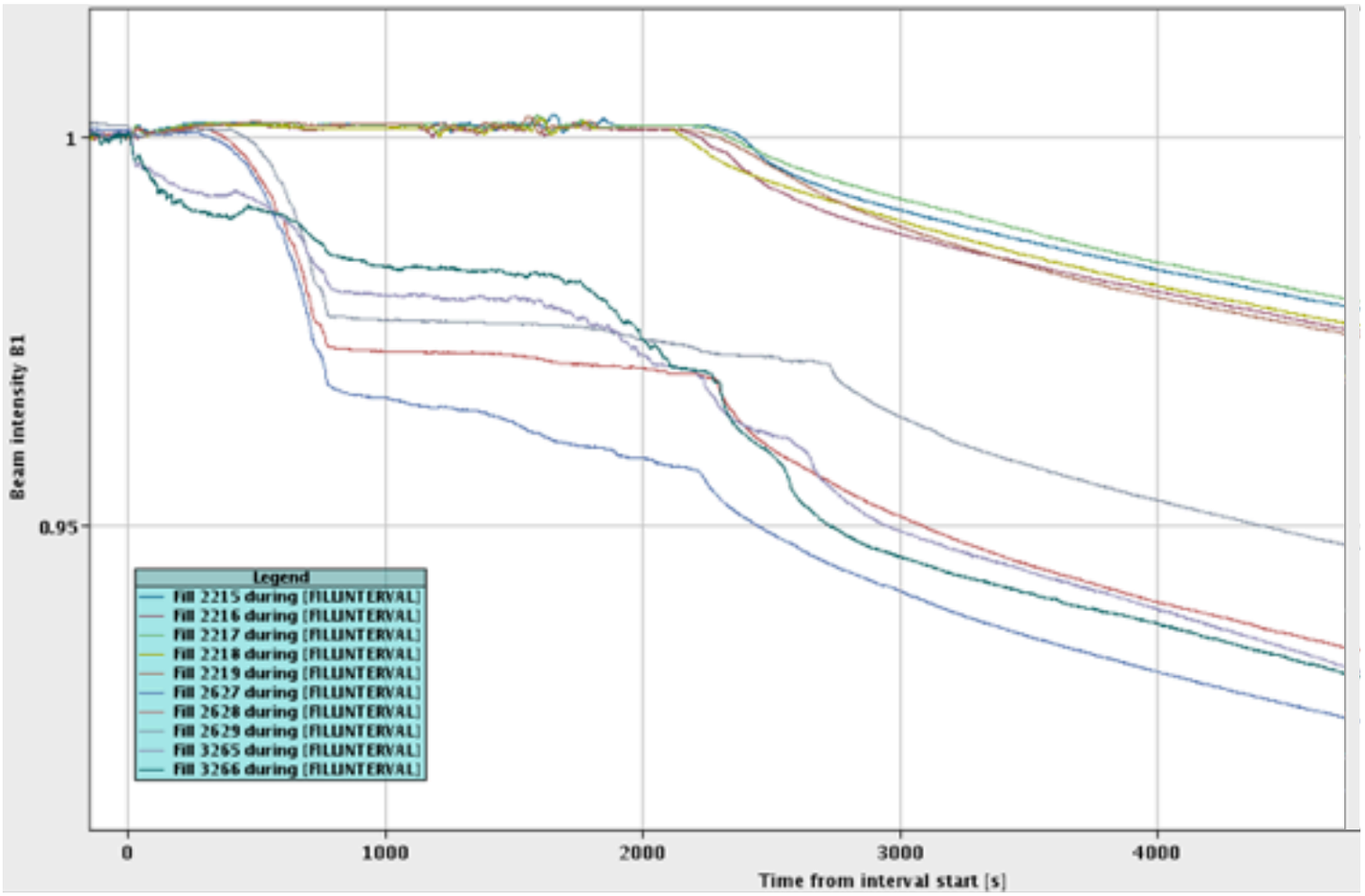
  *Very ambitious: clearly appreciate help from external collaborators on that.*

- Outlined a first concrete proposal on possible activities from the different teams.
- Important to agree on this strategy for the US-LARP meeting in April.
- Resource allocation from CERN side will have to be followed up.

# Reserve slides

# Losses during the LHC cycle

*Beam transmission from start of ramp for a few random fills*



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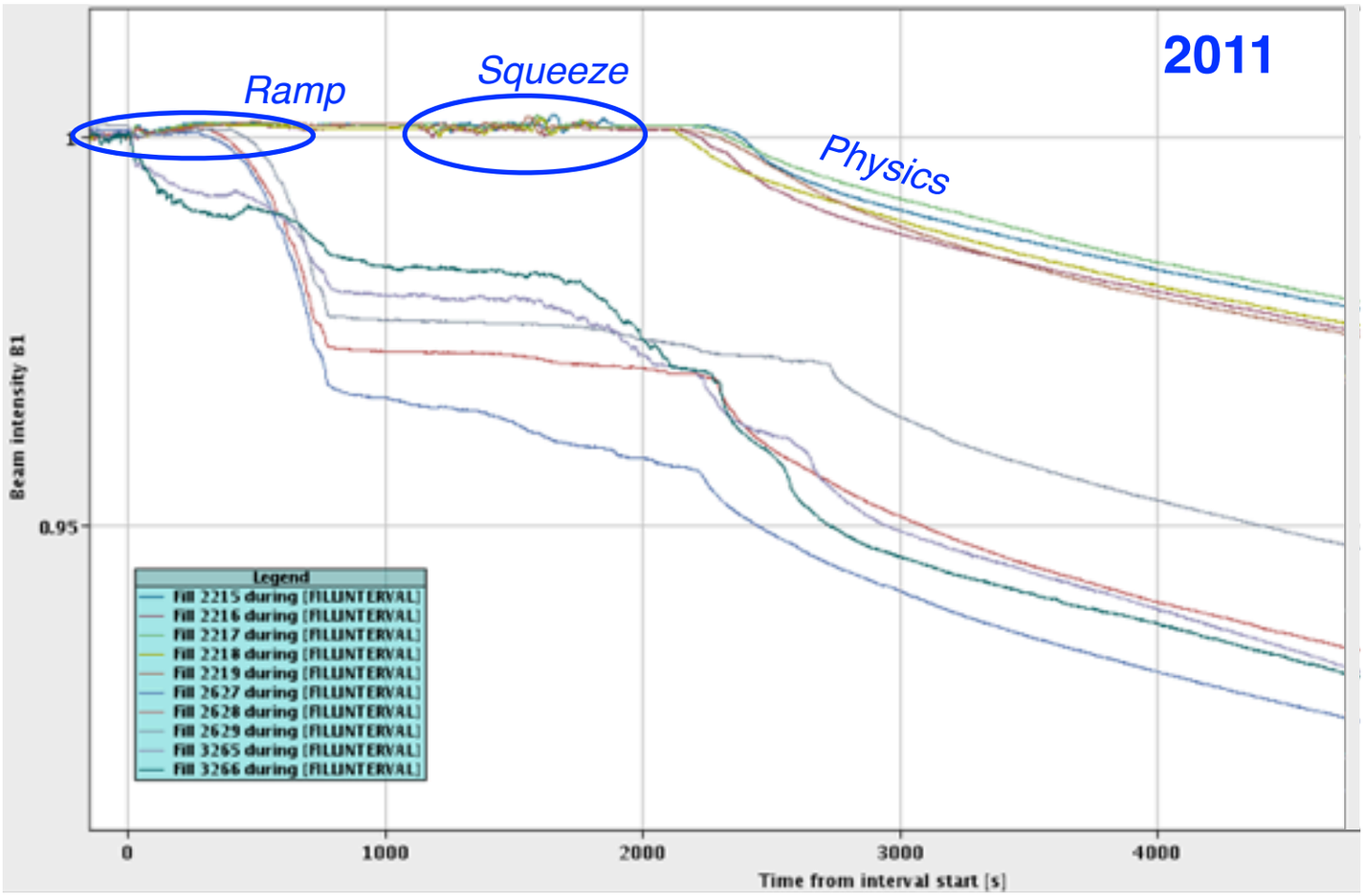

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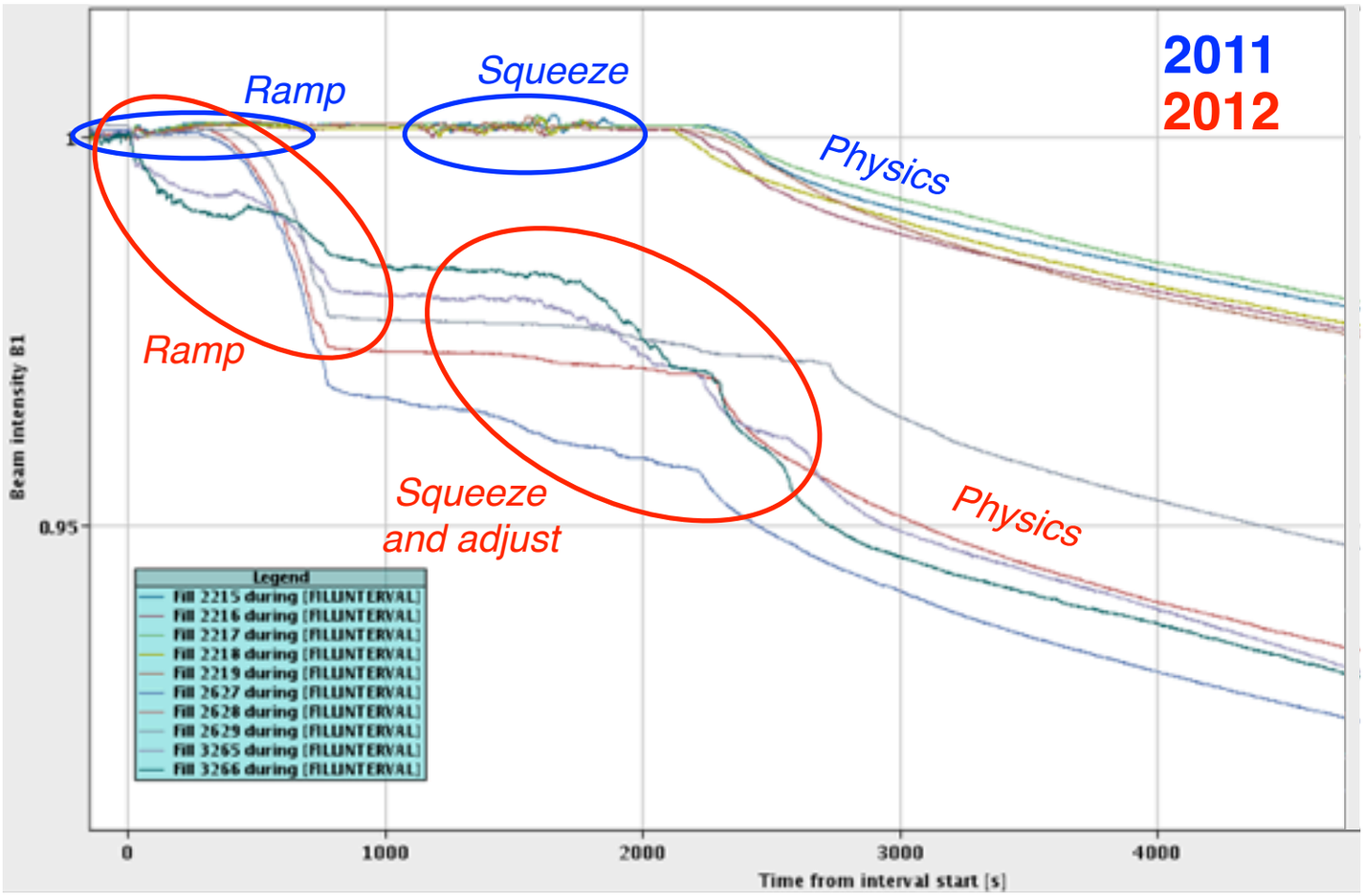

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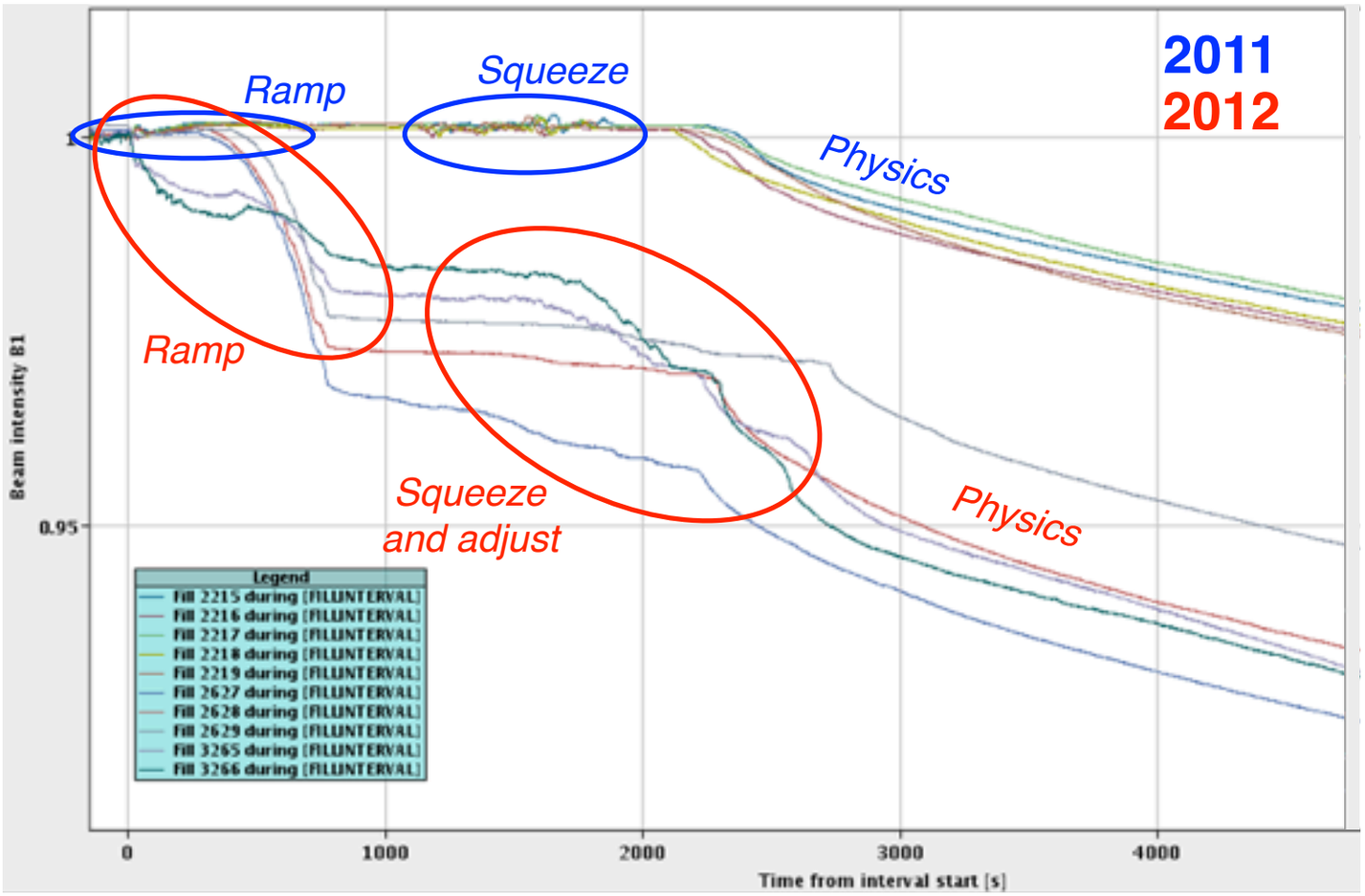


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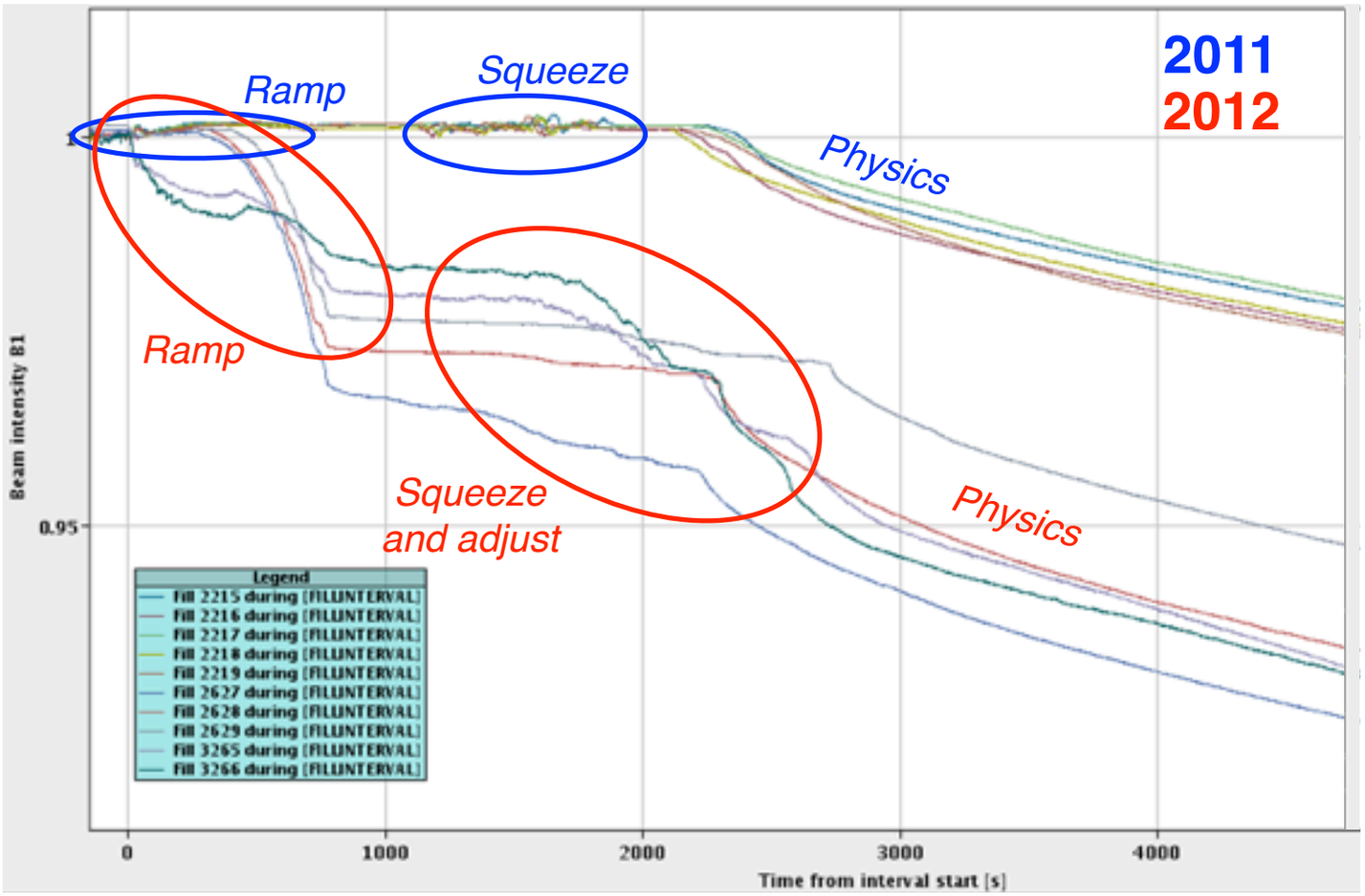


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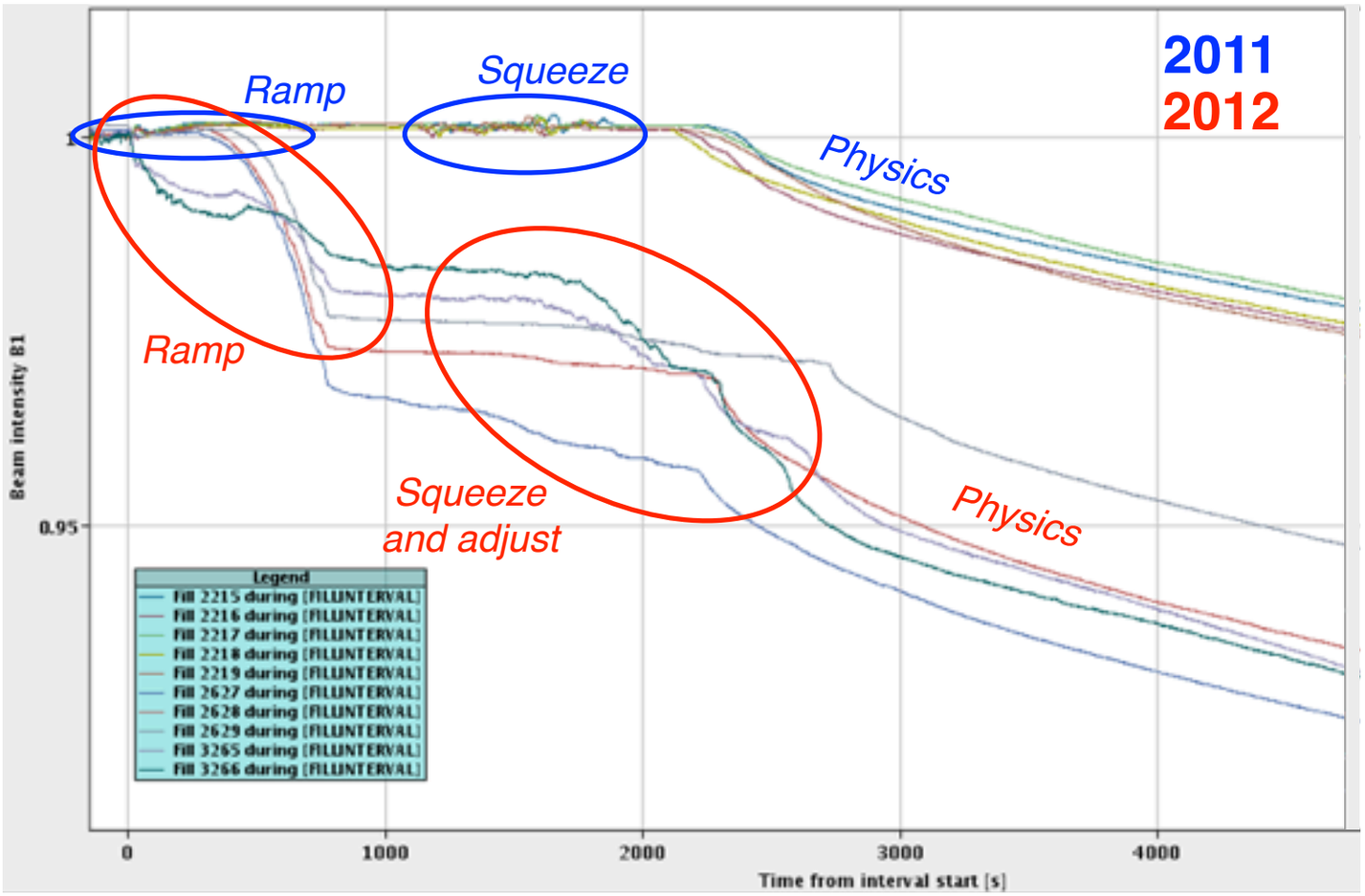


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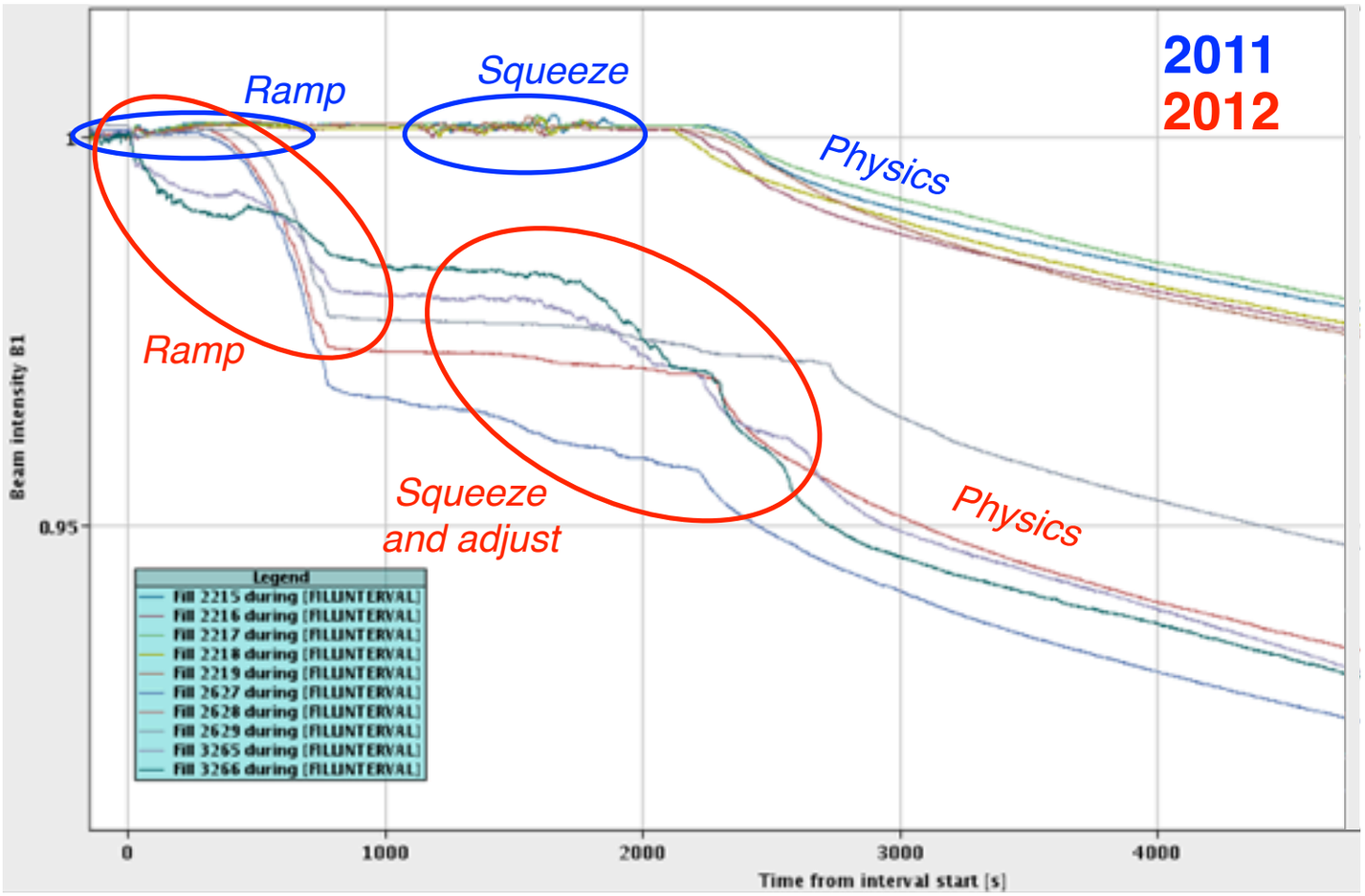


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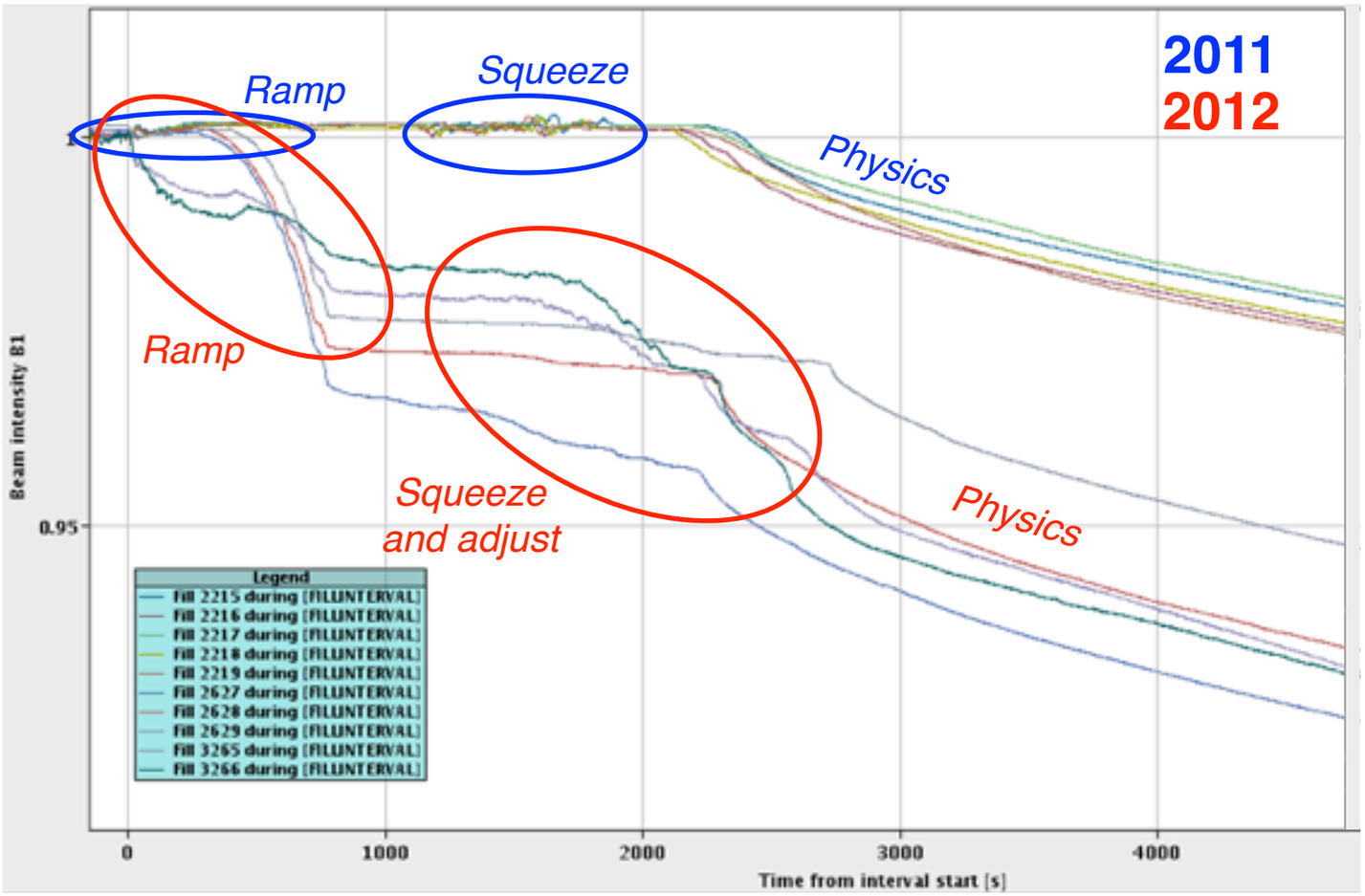


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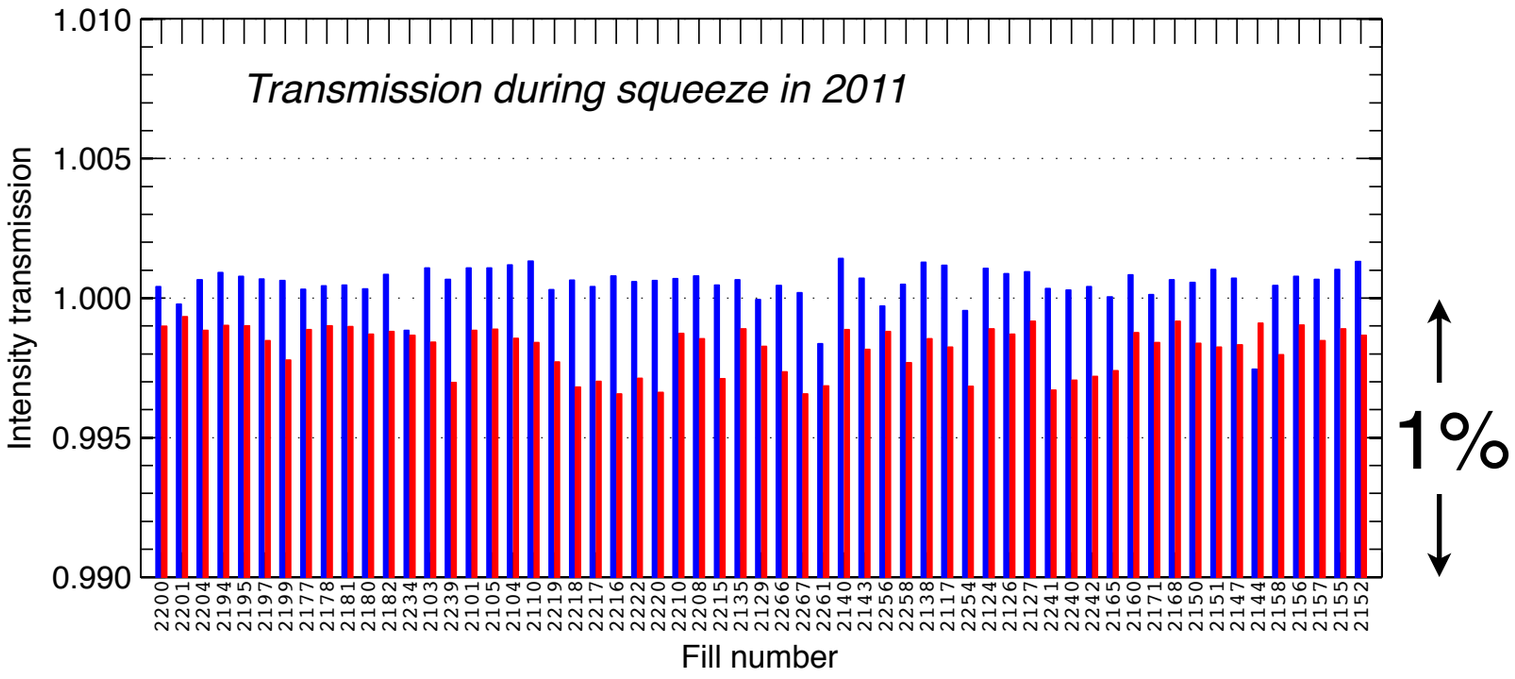
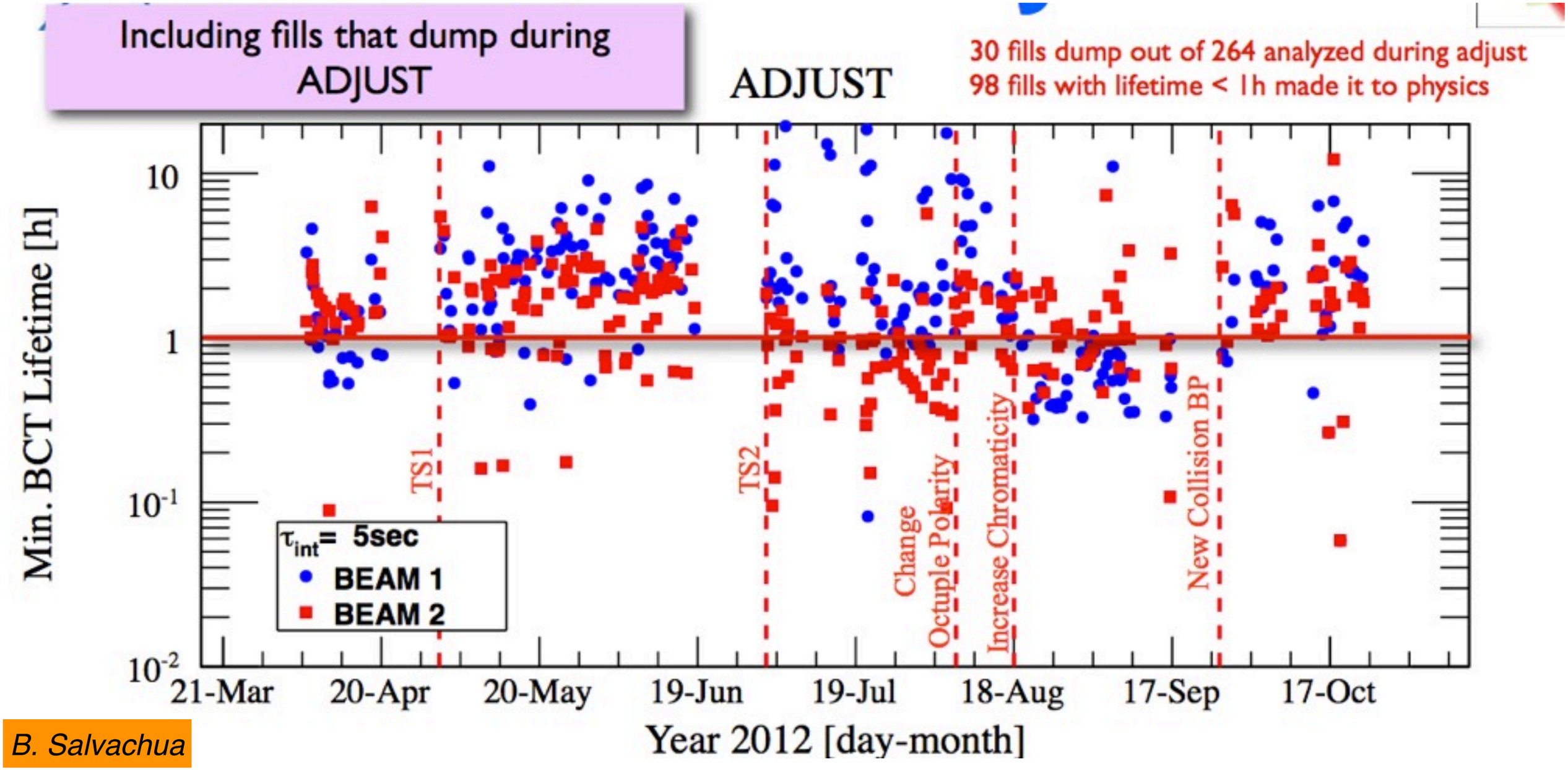


# Lifetime in 2012

Including fills that dump during ADJUST

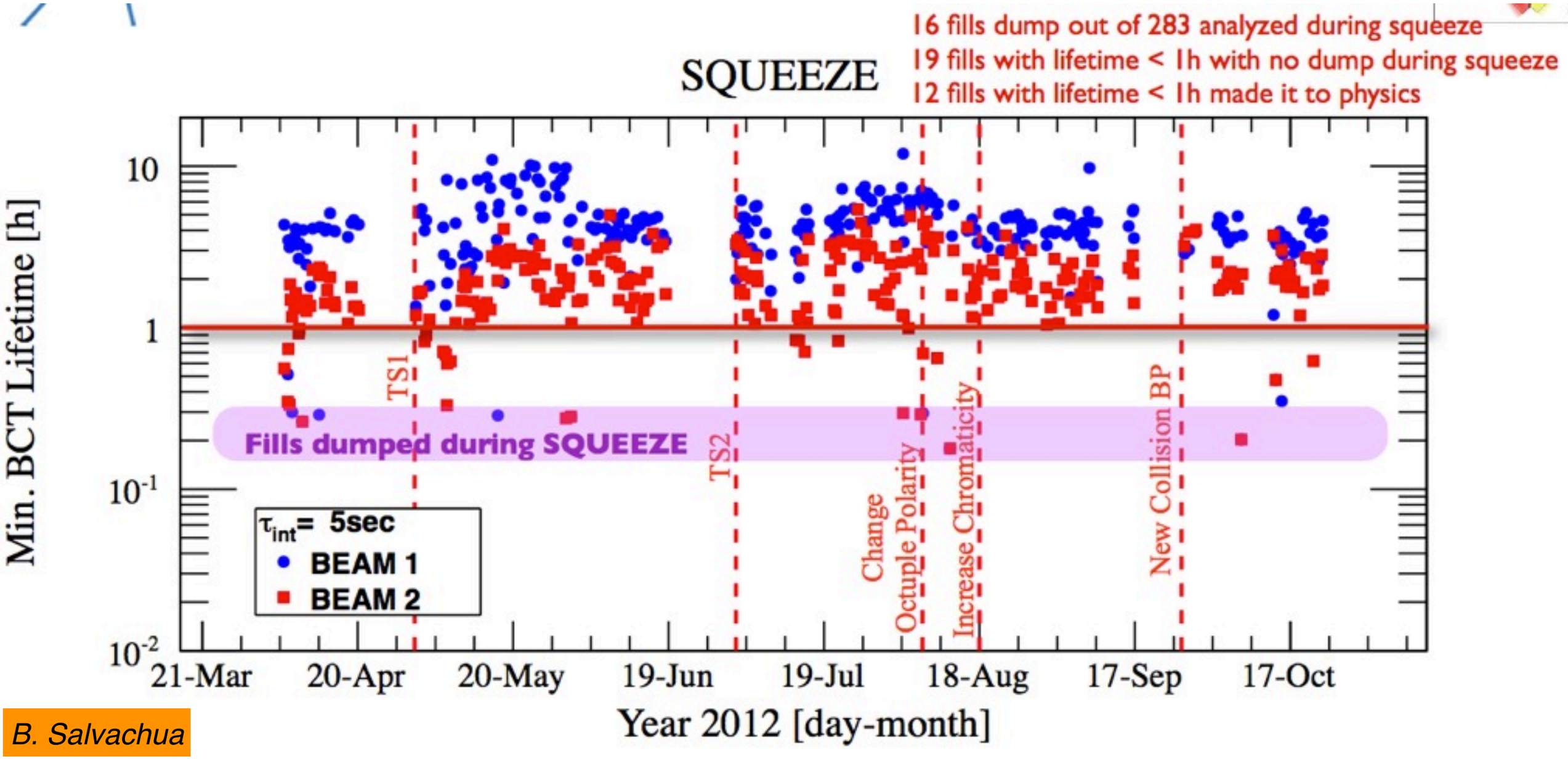
30 fills dump out of 264 analyzed during adjust
98 fills with lifetime < 1h made it to physics




*B. Salvachua*

Minimum lifetime systematically dropping below 1 h in 2012!
We experienced **~ 45 dumps** of physics fills with “tight” collimator settings that are more relaxed than the nominal 7 TeV settings!

# Lifetime in 2012 - squeeze

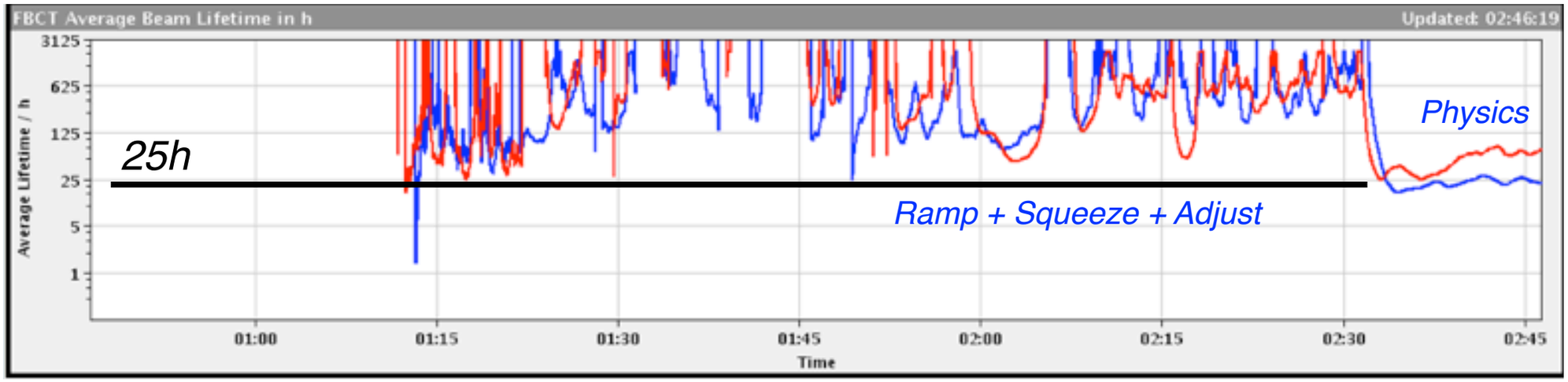



*B. Salvachua*

Will this be a serious issue after LS1?
Waiting the results of quench tests for improved estimates.
Can always open the collimators, at the cost of larger $\beta^*$.

# Beam lifetime during OP cycle

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



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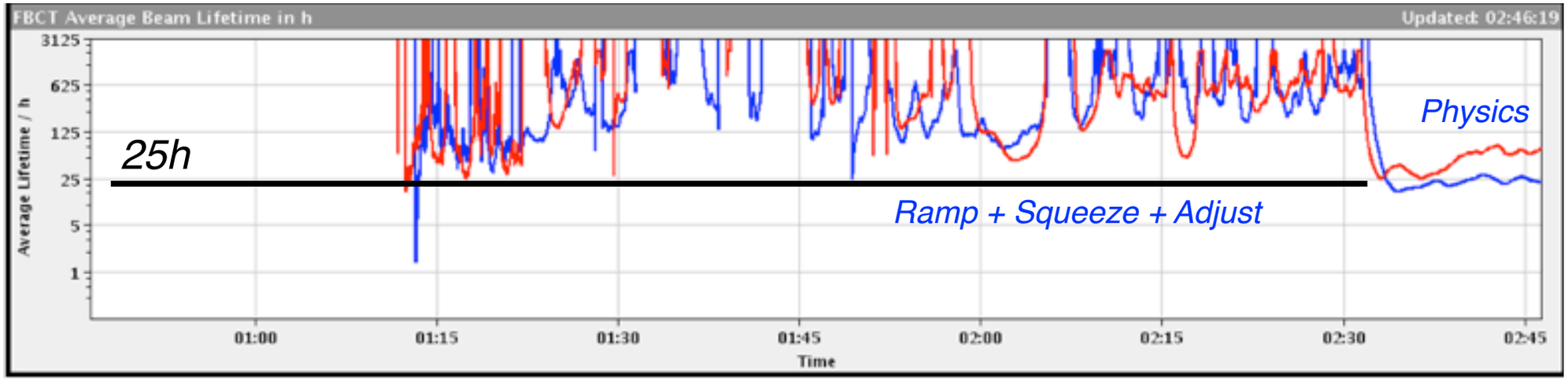


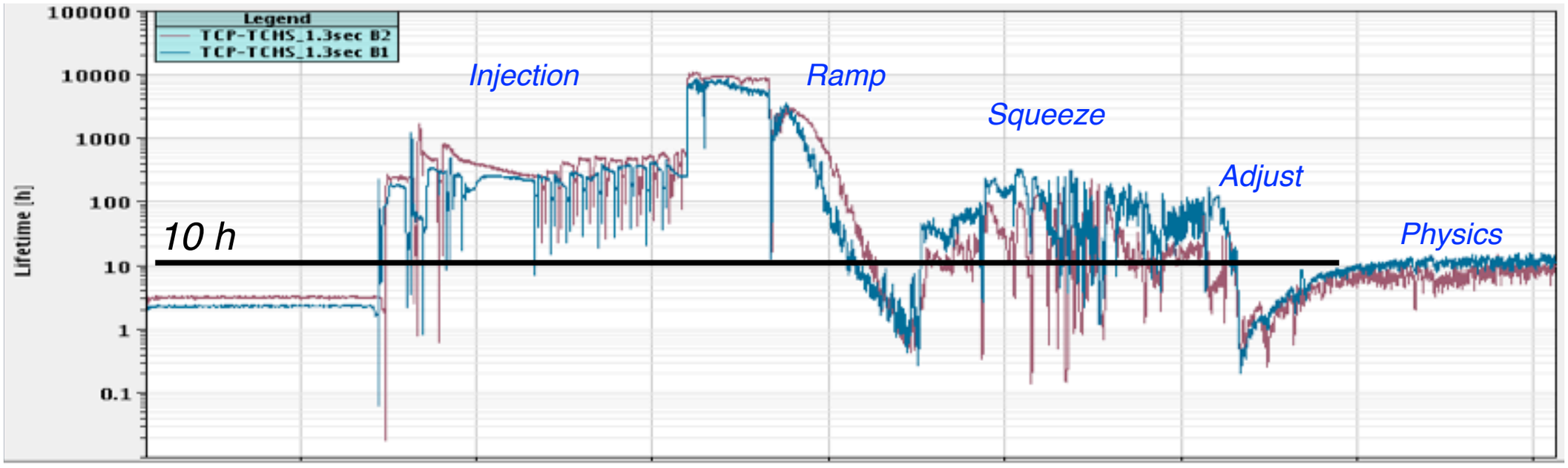

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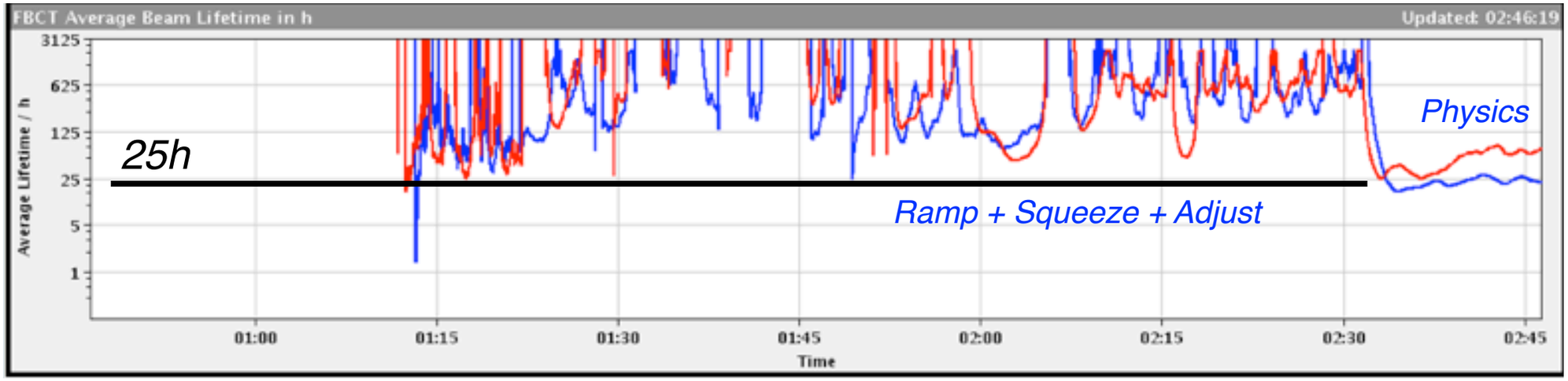
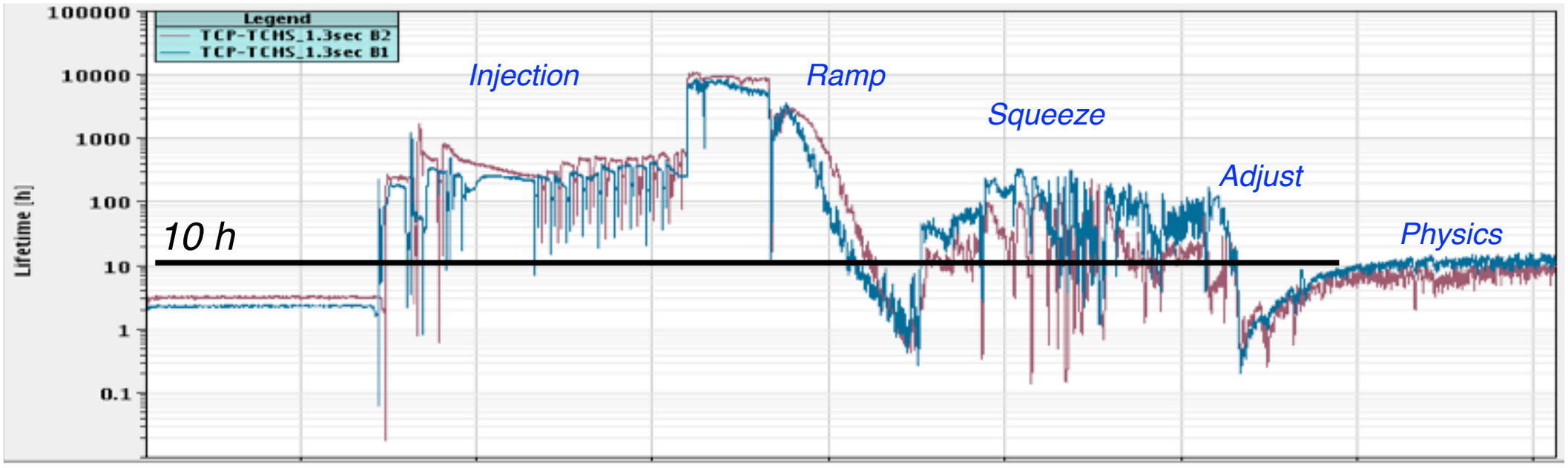



## What could be cured/improved by scraping?

| | |
|---|---|
| Ramp losses | ➙ Loss profile in time can be optimized. Not critical though. |
| Squeeze losses | ➙ Can be cured by removing correlation to orbit drifts! |
| Instabilities | ➙ Not obvious help from hollow e-lens. |
| Collision losses | ➙ Possible mitigation if tails are removed before (to be demonstrated). |

# Another requirement

## Transverse Distribution

- Highly overpopulated tails observed:
  - *In horizontal plane about **4%** of beam beyond **4$\sigma_{meas}$***
  - *Corresponds to **≈20-25 MJ** with HL-LHC parameters.*
- Need to **deplete tails** (e.g. by **hollow electron lens**) such that crab cavity failures are compliant with collimation system specifications.

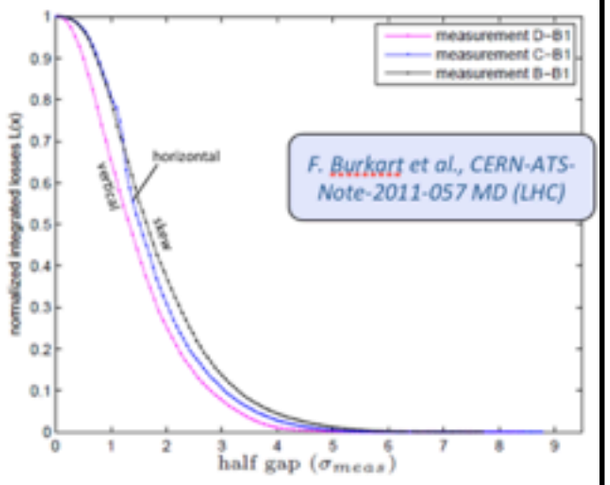


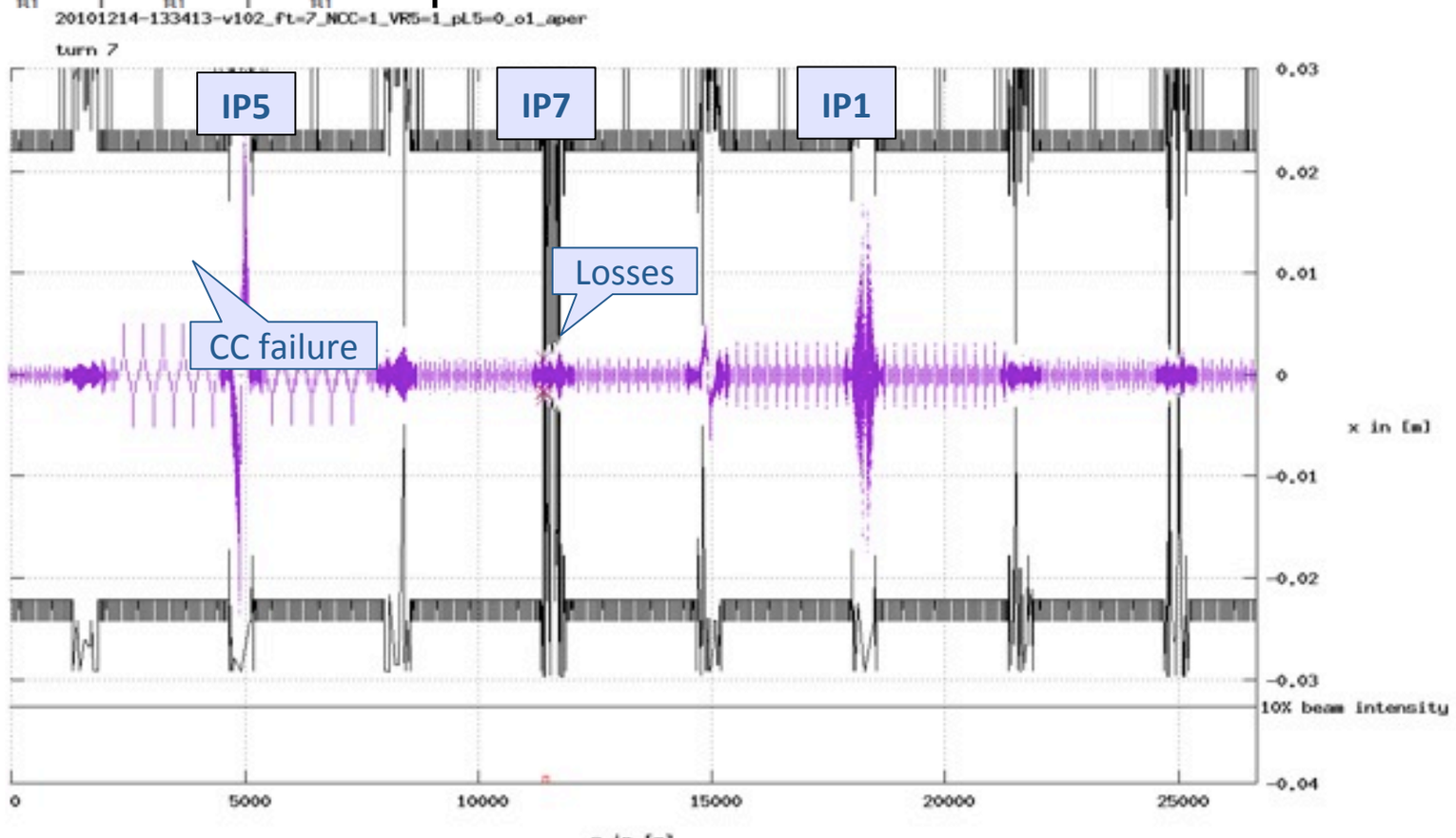

Table 3: Measured fraction of beam intensity in the tails of the beam outside selected multiples of the measured beam size, $\sigma_{meas}$, at 450 GeV.

| u [$\sigma_{meas}$] | $I_{tot,lost}(u)/I_{total}$ vertical B1 | $I_{tot,lost}(u)/I_{total}$ horizontal B1 | $I_{tot,lost}(u)/I_{total}$ skew B1 |
|---|---|---|---|
| 4 | | | |
| 5 | | | |
| 5.7 | | | |

May, 11th 2012 Tobias Baer

- Continuous control of the tail population is mandatory for using the crab cavities in the HL-LHC era!
- This requires scraping **during stable beams**: cannot be done by moving with collimators!

Comment by WH: do we loose stability if the tails are removed??




*S. Redaelli, HLTC 08-03-2013*

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   - *Too late now to go into the LHC during LS1!.*

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1. **Installation and prototype beam tests in LHC before LS2.**
   - *Too late now to go into the LHC during LS1!.*
2. **Installation and prototype beam tests in the SPS before LS2, followed by installation in the LHC.**
   - *Can advance preparatory works in the LHC during LS1?*
   - *What is the added value of beam tests in the SPS at 270 GeV?*

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If scraping with hollow e-lens is needed at the LHC (i.e. if there are problems at 7TeV), **we must aim for an installation during LS2.**
This means having 2 hollow e-lens devices ready for the LHC.

**Different scenarios** can be envisaged:

1. **Installation and prototype beam tests in LHC before LS2.**
   - *Too late now to go into the LHC during LS1!.*
2. **Installation and prototype beam tests in the SPS before LS2, followed by installation in the LHC.**
   - *Can advance preparatory works in the LHC during LS1?*
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**SPS installation proposed as a test bed for the LHC.** Possible interest in using it for LHC beam scraping in the SPS is being considered.

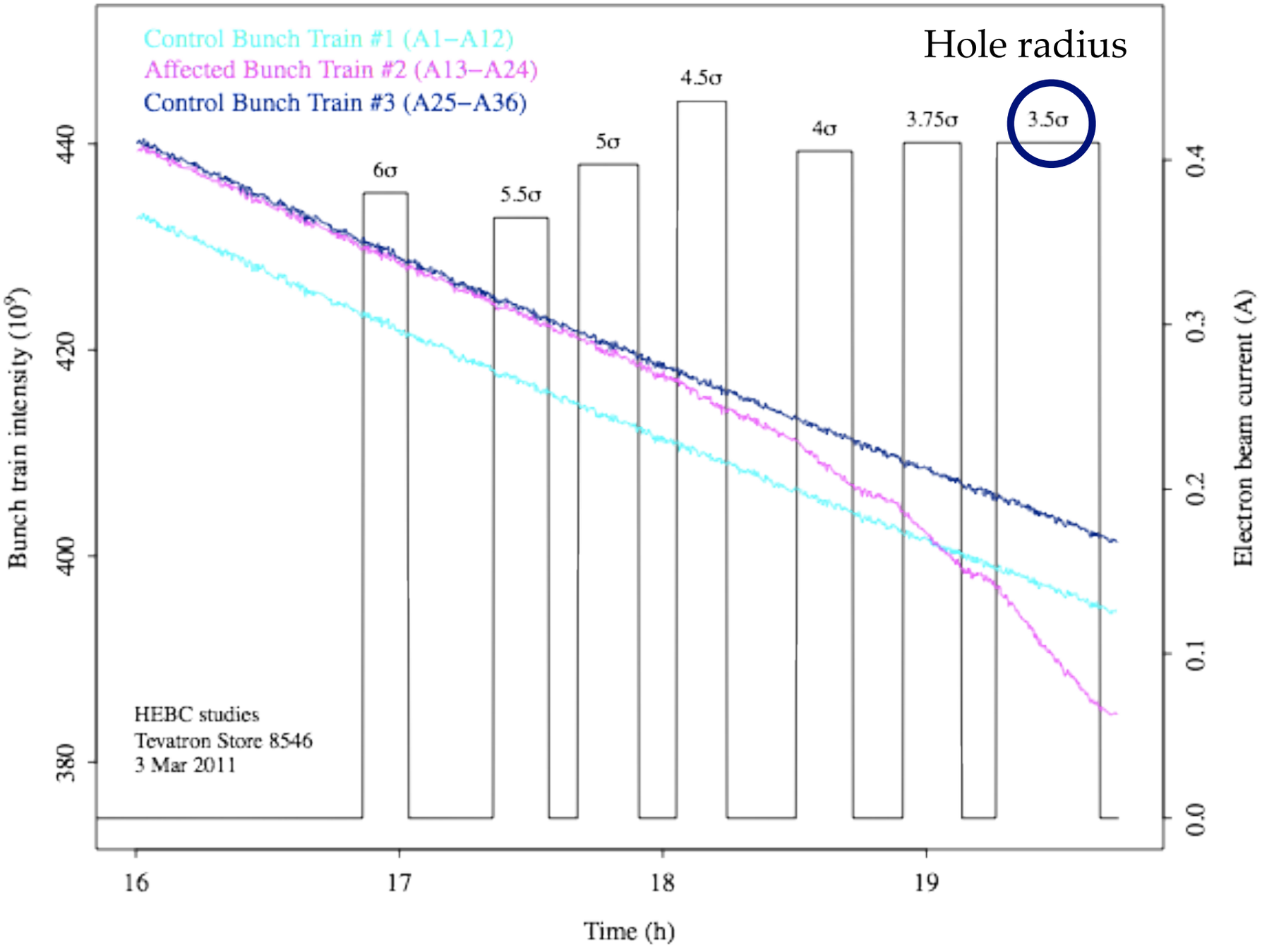
# Tevatron experience

## Experimental studies of hollow electron beam collimation

- Tevatron experiments (Oct. '10 - Sep. '11) provided experimental foundation
- Main results
  - **compatibility with collider operations**
  - **alignment** is reliable and reproducible
  - **smooth halo removal**
  - **removal rate vs. particle amplitude**
  - **negligible effects on the core** (particle removal or emittance growth)
  - **suppression of loss-rate fluctuations** (beam jitter, tune changes)
  - effects on **collimation efficiency**
  - transverse beam halo **diffusion enhancement**

My conclusion: **very convincing experimental data** of the concept! No time here to show all nice measurements.
Also note that it was used reliably in operations for 10 years (not for the initial purpose that it was conceived for, though!)

# No effect on beam core emittance



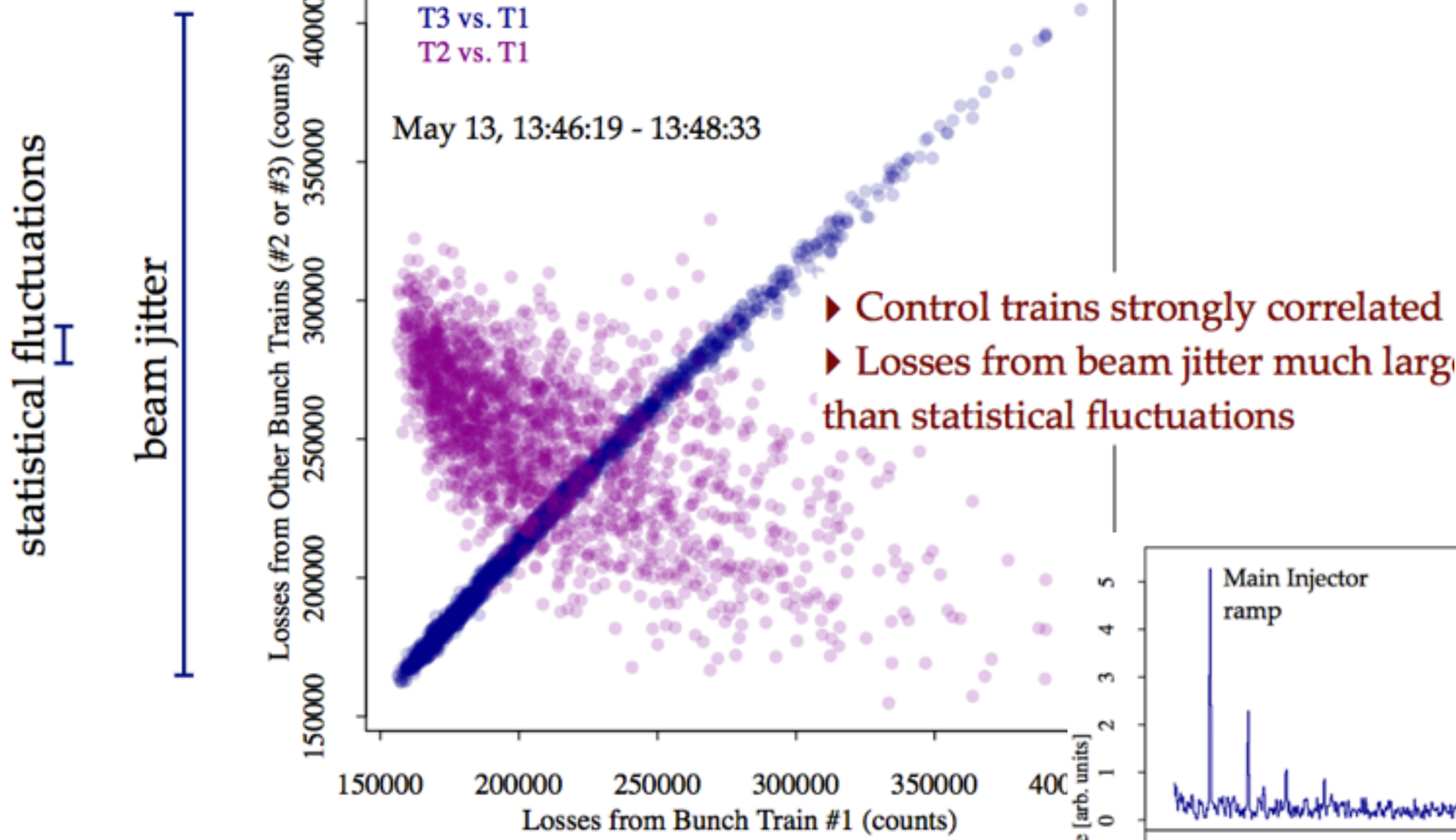

*G. Stancari*

Core not affected when tails are blown out!

*Validated also by looking at luminosity lifetime (not reported here)*

# Reduce sensitivity of losses on jitters

## Correlation of steady-state losses

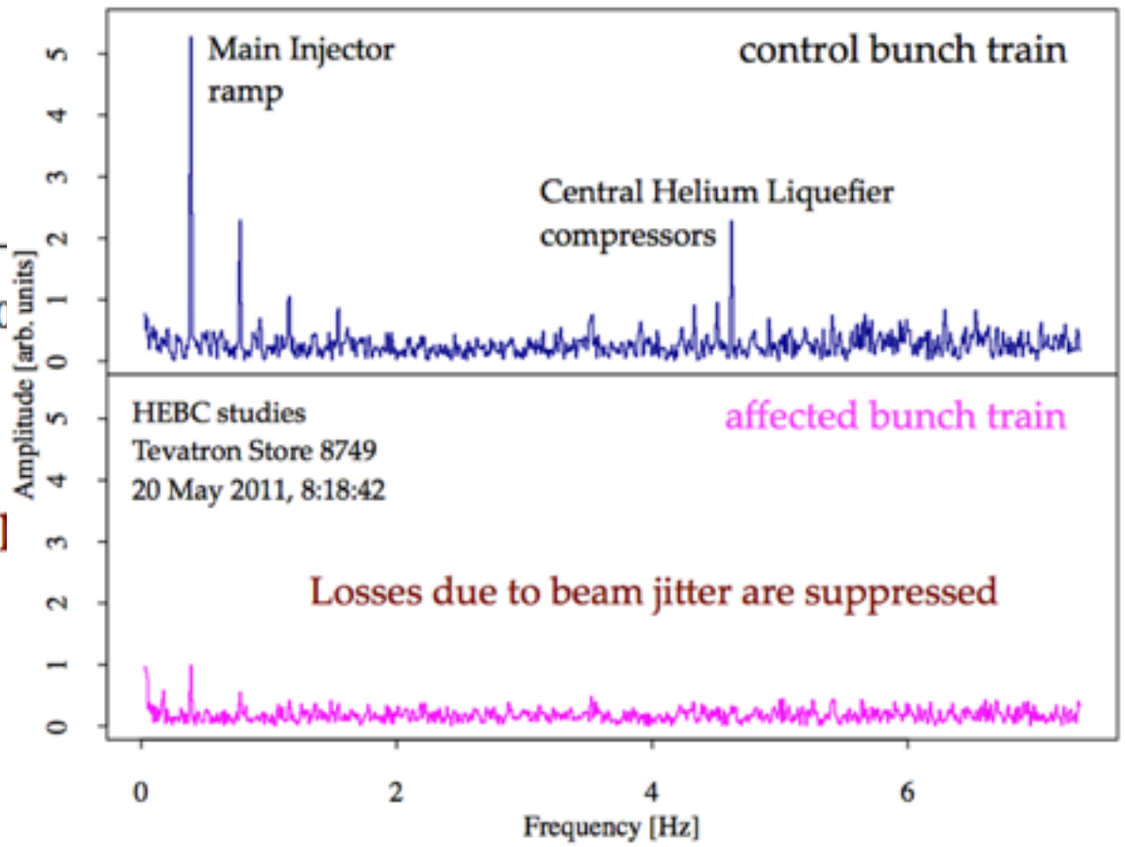



- Control trains strongly correlated
- Losses from beam jitter much larg
than statistical fluctuations

- Hollow beam eliminates correlations among trains
- Interpretation: larger diffusion rate, lower tail population, l

*G. Stancari*

On paper, this can remove the losses at the LHC during squeeze!




*S. Redaelli, HLTC 08-03-2013*

# Can we use TEL2 with LHC beams?

Electron lens cookbook

Recipies from simulations

V. Previtali, A. Valishev
G. Stancari, I. Morozov, D. Shatilov

Thanks for the helpful discussions with
S. Redaelli, B. Salvachua Ferrando, A. Rossi

V. Previtali's presentation: is the Tevatron HW suited for meaningful beam tests at the LHC?
**Tevatron**: used with colliding beams to enhance non-linearities.
**LHC**: need in all OP cycle. Machine very linear!

## 4 basic recipes


1. DC mode: e-lens is always ON
2. AC mode: e-lens switched on-off in resonance with the particle transverse motion
3. random mode: e-lens is randomly switched on-off turn by turn (coin toss!)
4. harmonic mode: e-lens is switched on every n turns (tevatron mode), simulations in progress

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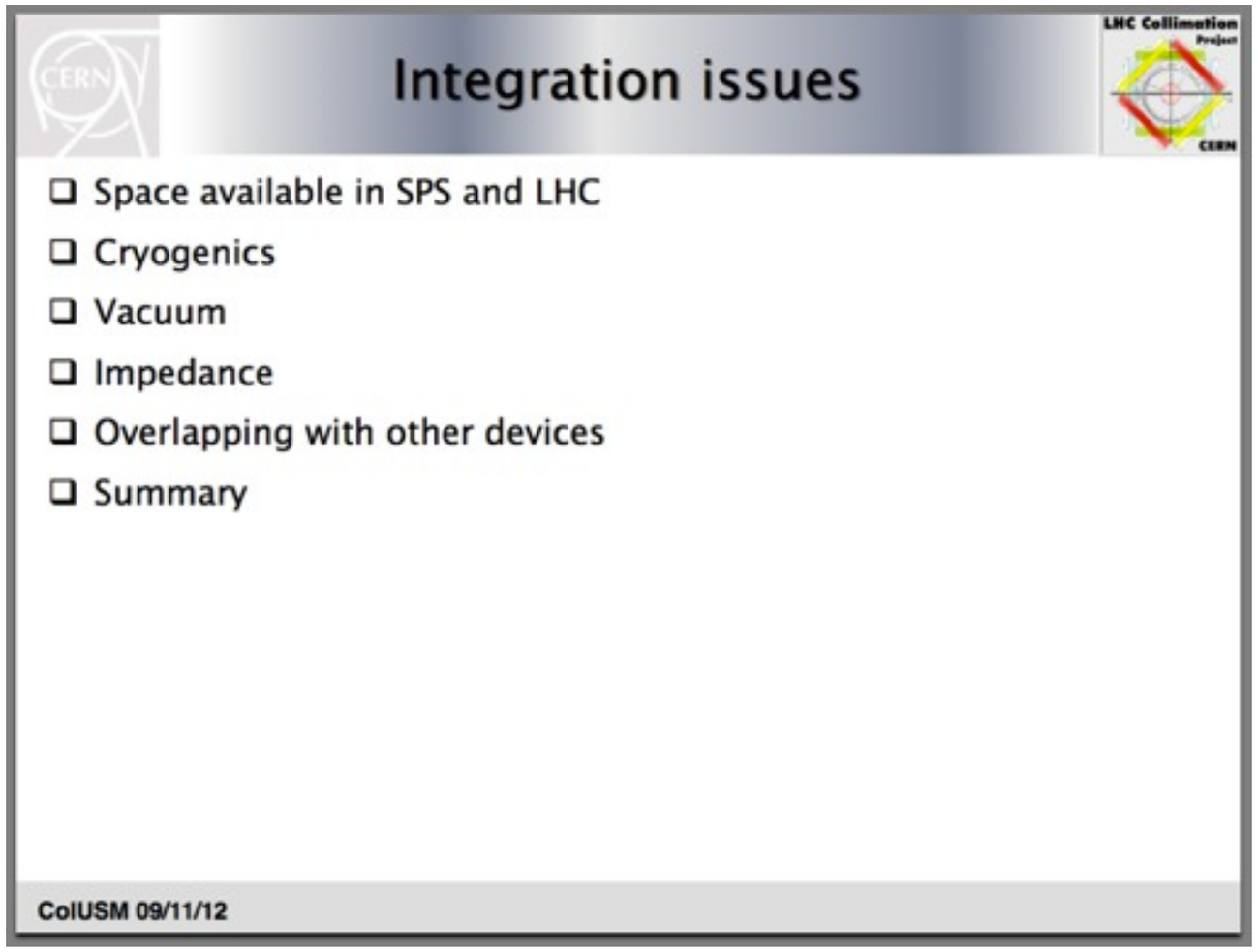
Rely on FNAL colleagues for simulations. Requested an implementation in SixTrack to bring the competence "in house".
Simulations are complex - beam validation mandatory.

# Integration in LHC and SPS




Clearly, many issues to be considered. Preliminary list presented by A. Rossi.

Identified the main key points, but no conclusive answers yet.

Also, discussion did not include yet budget estimate.

Major player if cryo: 4-5 months of work to go into LHC. SPS estimates ongoing.

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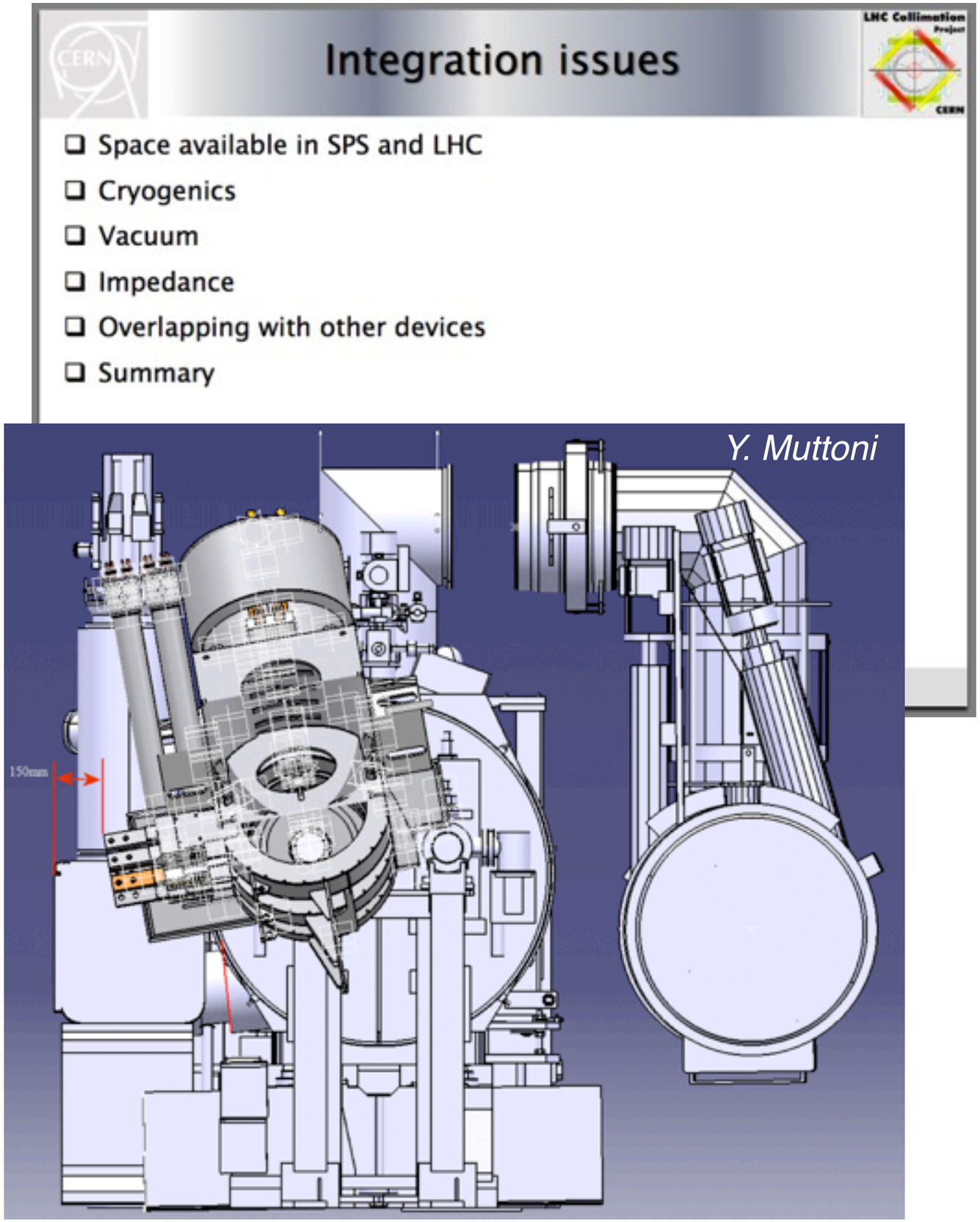


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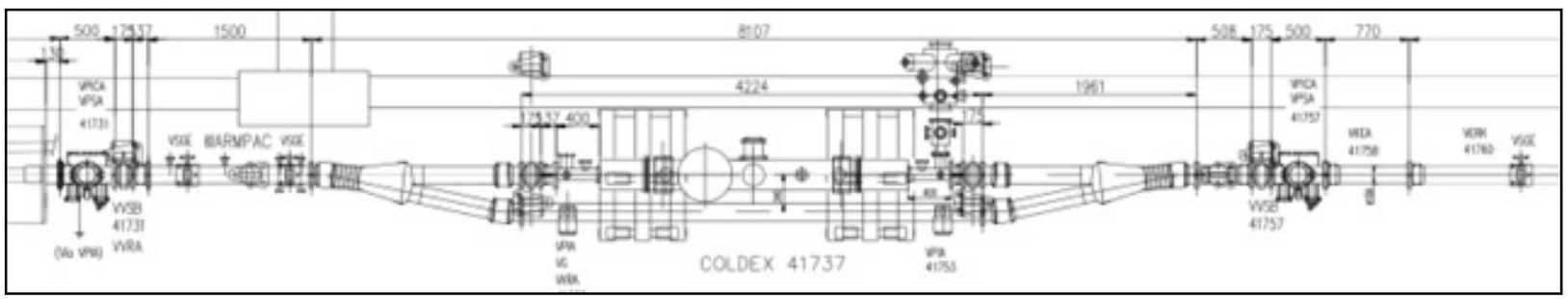
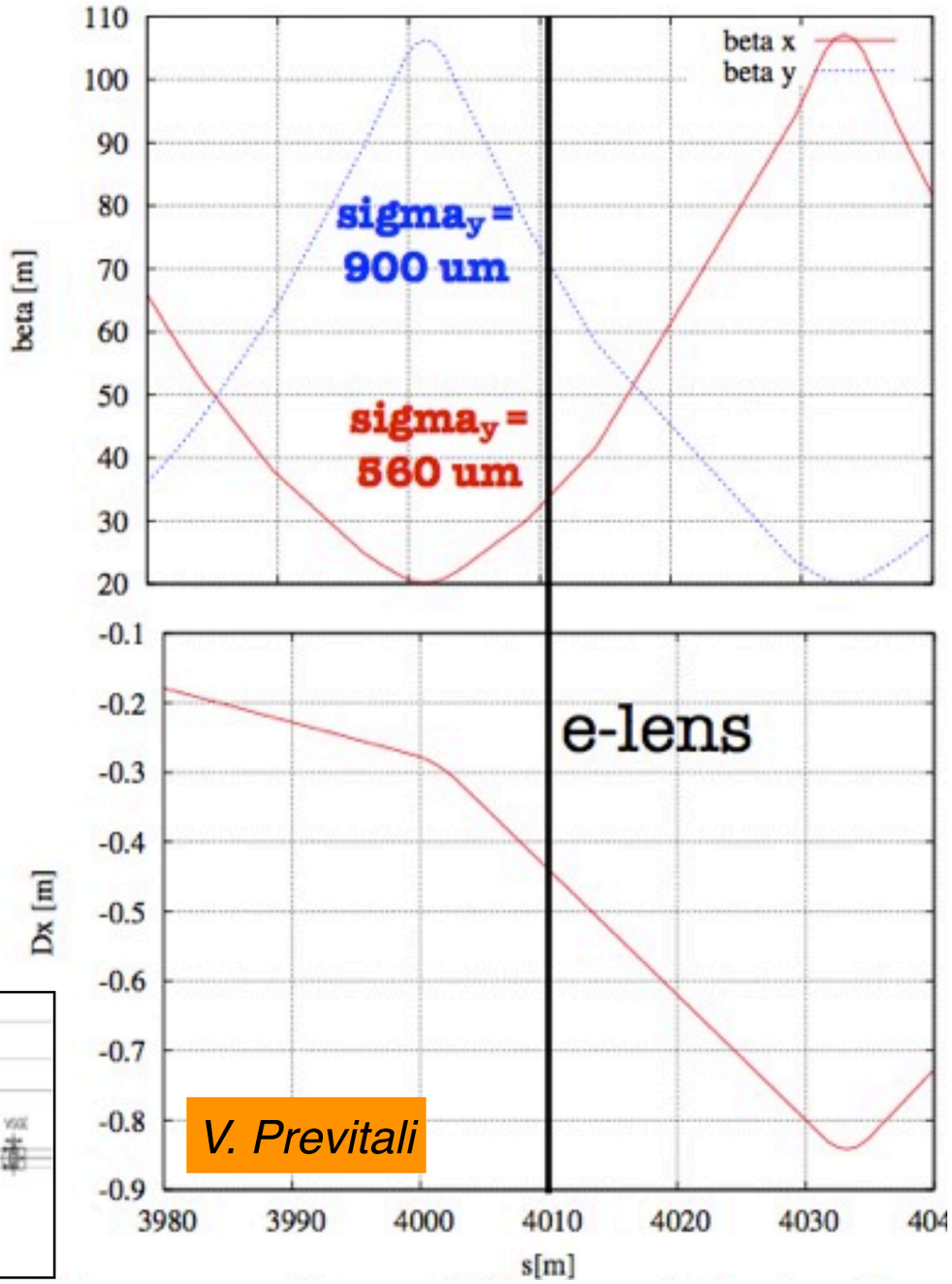
- LHC: Candidate layout is IP4
- Available Tevatron hardware could fit in the present layout.
- IP4 also considered as final option for a complete implementation for both beams.
- Need synergy with crab-cavity project.
- CRYO works require about 4-5 month for integration in present system. Too tight for 2015 shutdown.

# Layout for SPS installation


*A. Rossi et al.*




*V. Previtali*

Best candidate location is the **Coldex region**: probably ok for collimation study purposes.

*Ideally, would like round beams → alternative option could be one-side excitation.*

Requirements from cryo being addressed (S. Claudet's team).

Conflicts with Coldex (operational during 2015?) and crab-cavity test-stand are being evaluated.