Conceptual Design Review of the Phase II LHC Collimation

Geneva, 2nd-3rd April 2009

Operational Aspects: Inputs for Collimation Upgrades

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Acknowledgment: Results of 2008 system commissioning are shown on behalf of the whole collimation team.

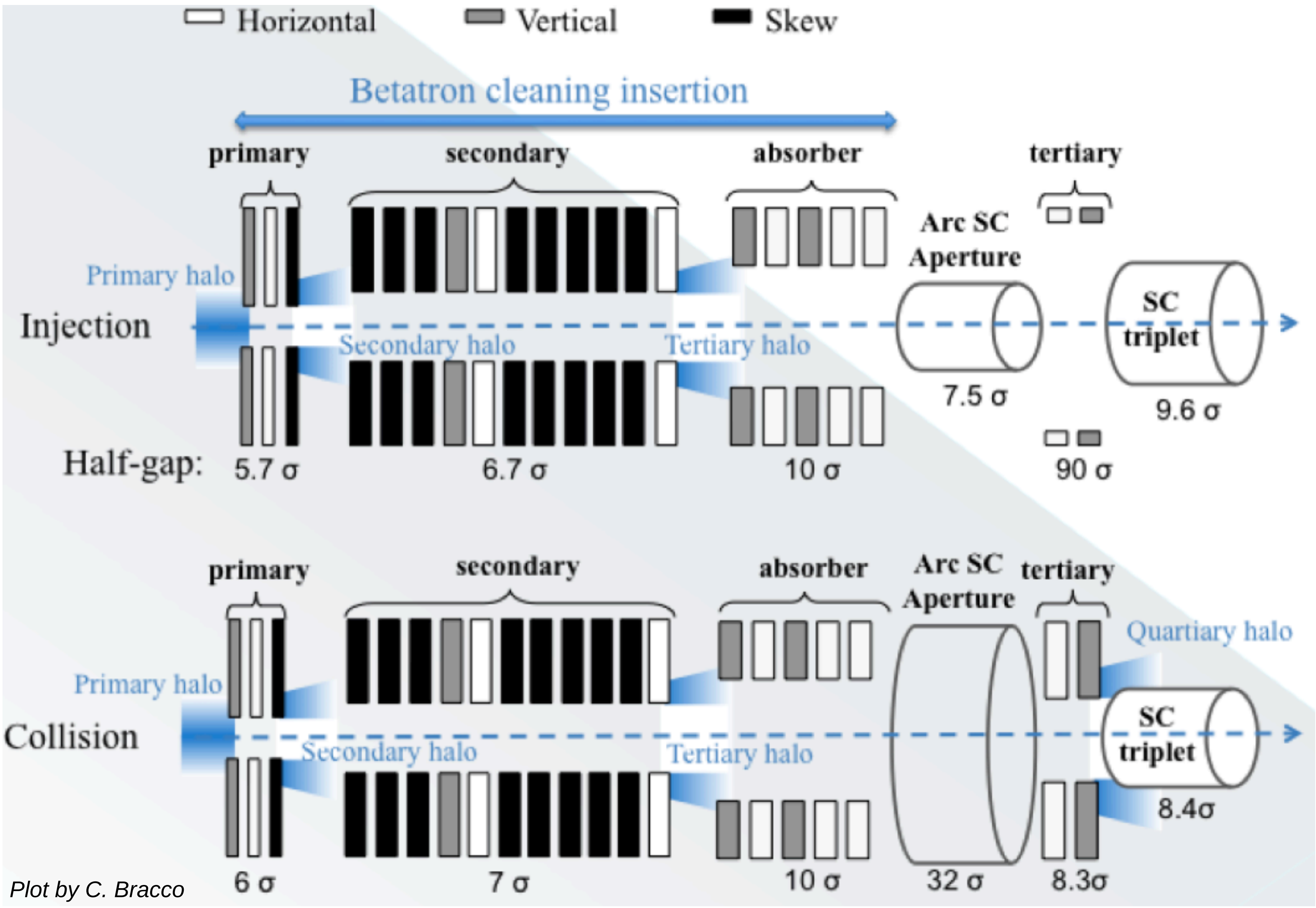
Scope

- Provide **feedback/inputs for the proposed collimator system upgrades** (cryo-collimators, metallic secondaries, integrated BPM's) based on the **operational experience** on:
  - *- Performance of mechanical design / remote control of the system*
  - *- Beam-based set-up of the collimators*
  - *- Evaluation of impact on operational tolerances on imperfections*
- **Caveat: NO yet experience with circulating beam at the LHC!**
  - *- Accident in 3-4 occurred 2 shift before our first scheduled beam tests*
  - *- Cannot present the "real" performance of Phase I system*
- **Operational feedback presented here is based on:**
  - *- Remote commissioning without beam of 80 movable collimators*
  - *- 4 years of operational experience with a full-scale secondary collimator in the Super-Proton Synchrotron (SPS) since 2004*
  - *- Feedback from other operating machines*
  - *- Simulation results....*

Outline

- **Operational requirements**
- **2008 commissioning experience**
  - *Highlights of remote commissioning*
- **Beam based alignment**
  - *Experience from SPS beam tests*
  - *Advantages of integrated BPM design*
- **Tolerance with imperfections**
  - *Effect of aperture alignment errors*
  - *Improvement from cryo-collimators*
- **Conclusions**

Operational challenges (I)

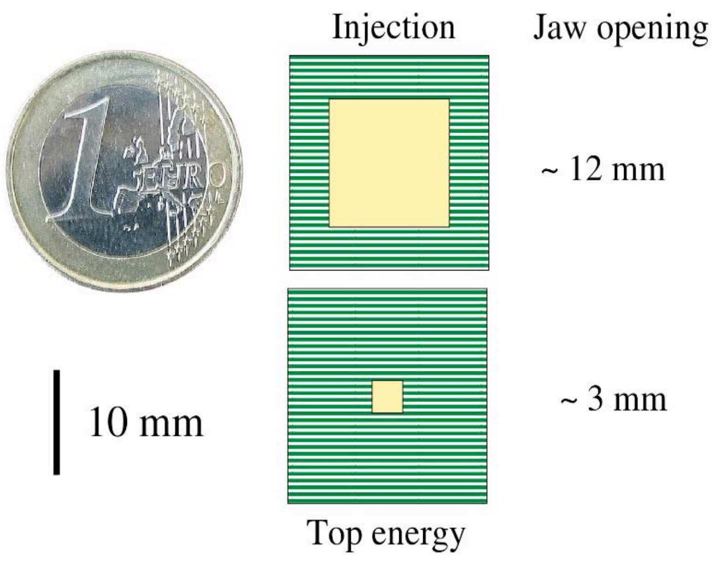


Plot by C. Bracco

Beam energy: **362 MJ**

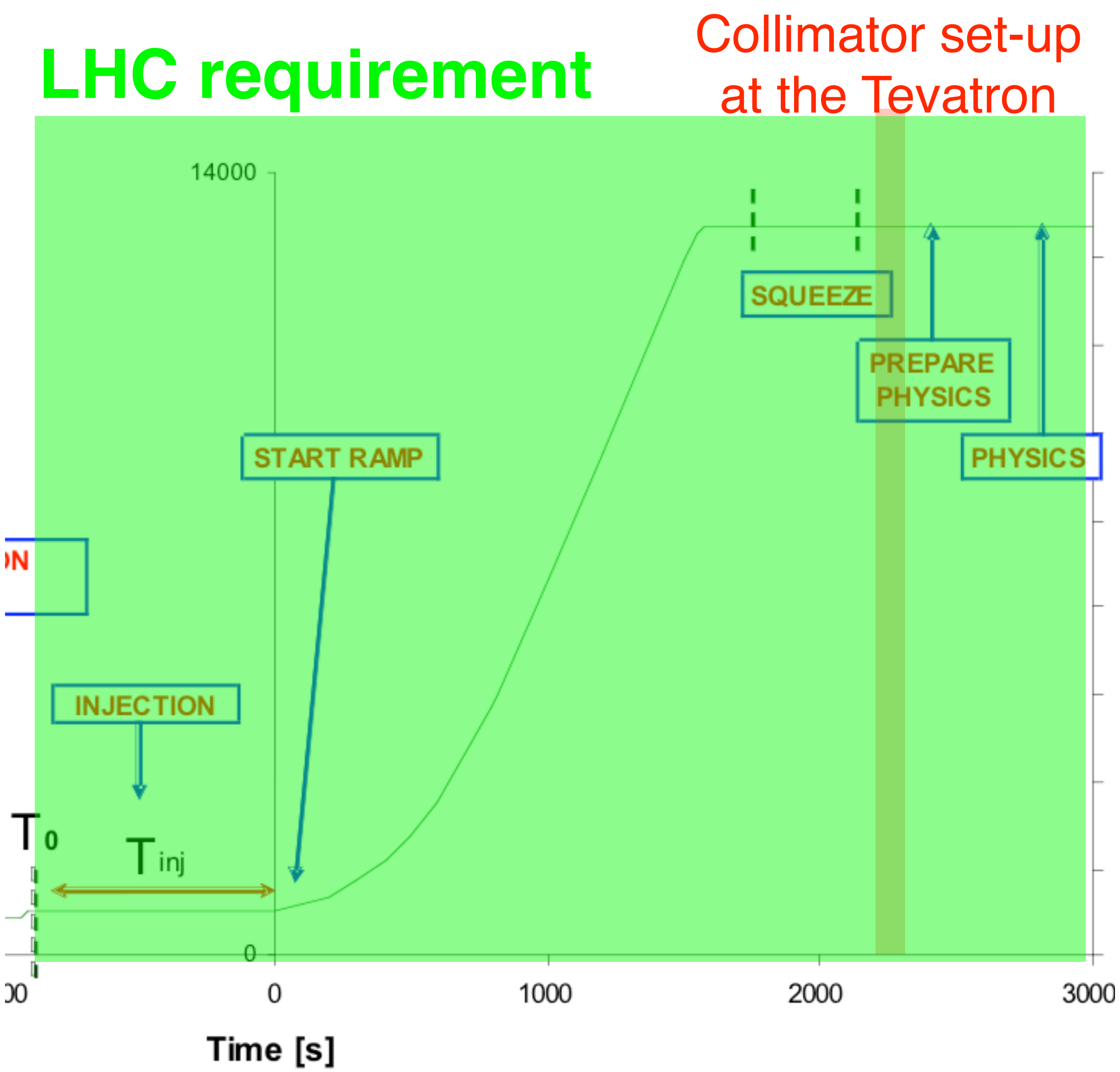
vs.

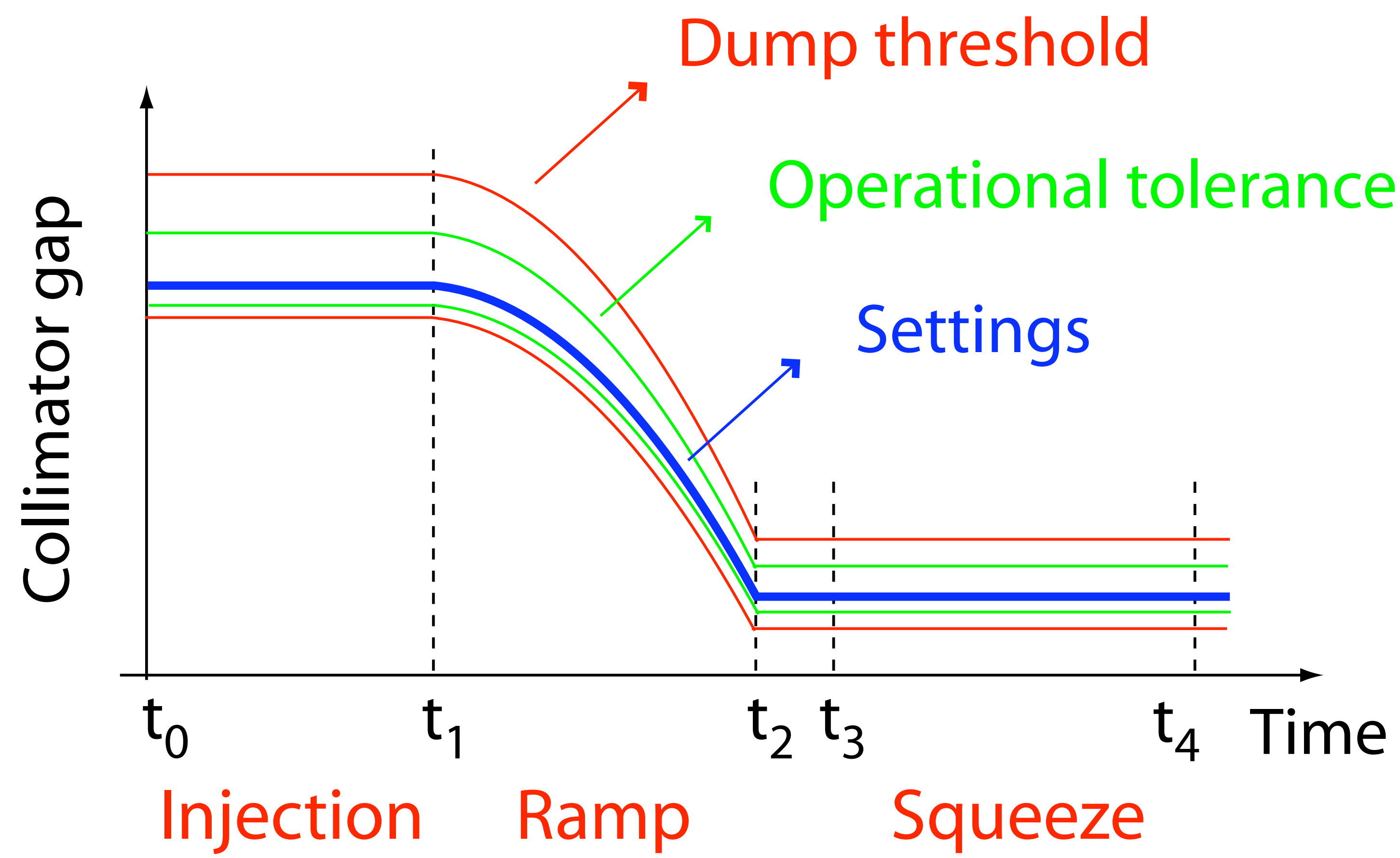
Quench limit: **8.5 W/m**



- ***Tight settings*** *for optimum cleaning* — ***6 / 7 σ***
- *Relative* ***retraction*** *of distant elements is critical* — ***< 1 σ***
- ***Centring*** *around the local beam orbit beam* — ***0.3 σ***
- ***Small beam size*** *at top energy (~**200 μm**) accuracy* — ***~ 20 μm***

Operational challenges (II)





LHC: cleaning and protection are **required** all the time: injection → 7 TeV → physics!

- ***Complex*** *controls to manage all cycle types*
- ***Function-driven motion*** */ discrete settings*
- ***Synchronization*** *around the machine (~20ms around 27 km)*
- *Accuracy, interlock limits (6 axes per collimator)*

2008 collimation system

Ring collimators:

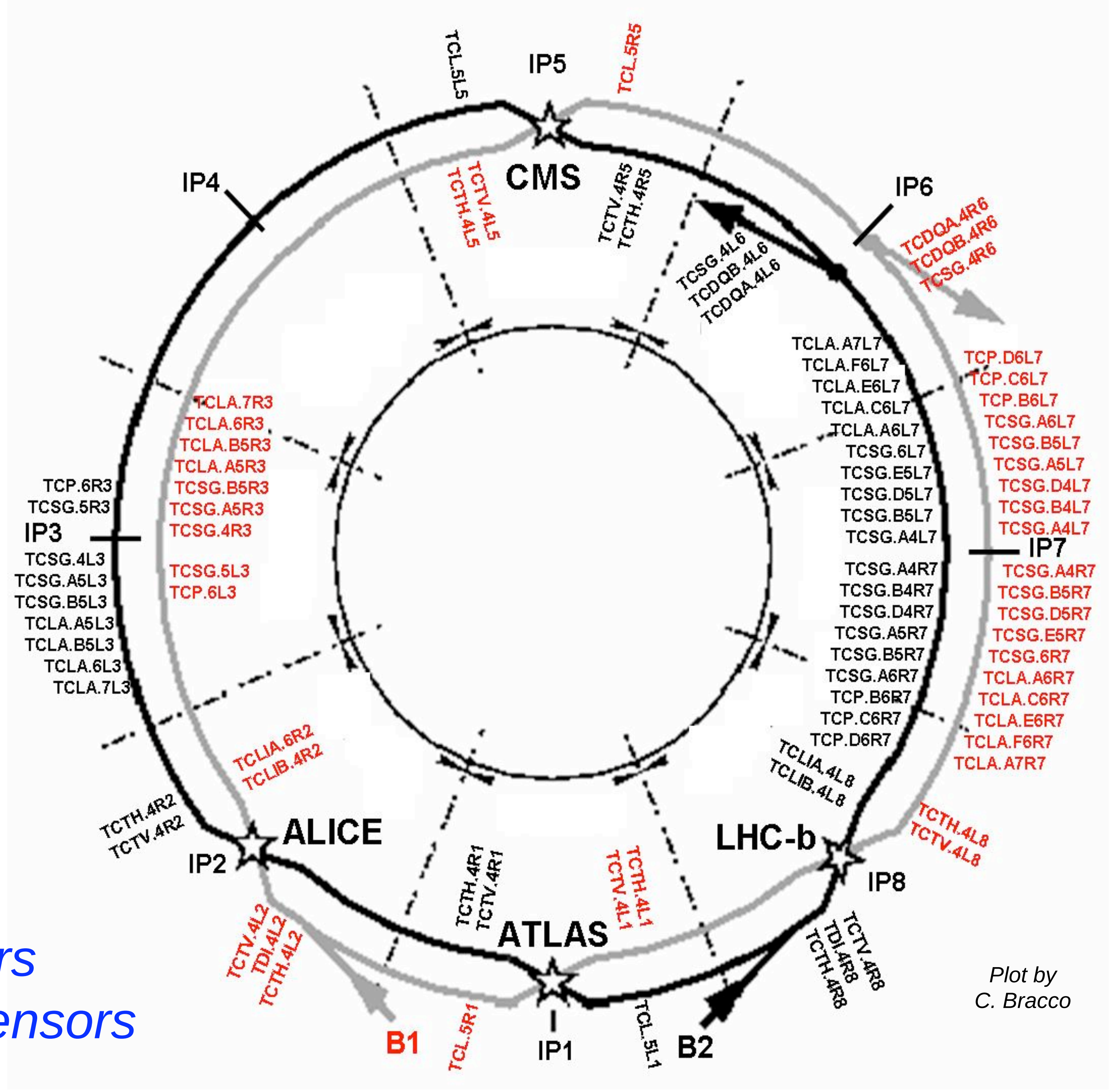
- **62 of type TCP, TCSG, TCLA, TCLI and TCT**
- **2 TCDQ (dump)**
- **2 TDI + 1 TCDD (injection protection)**

Transfer lines:

- **13 TCDI's**

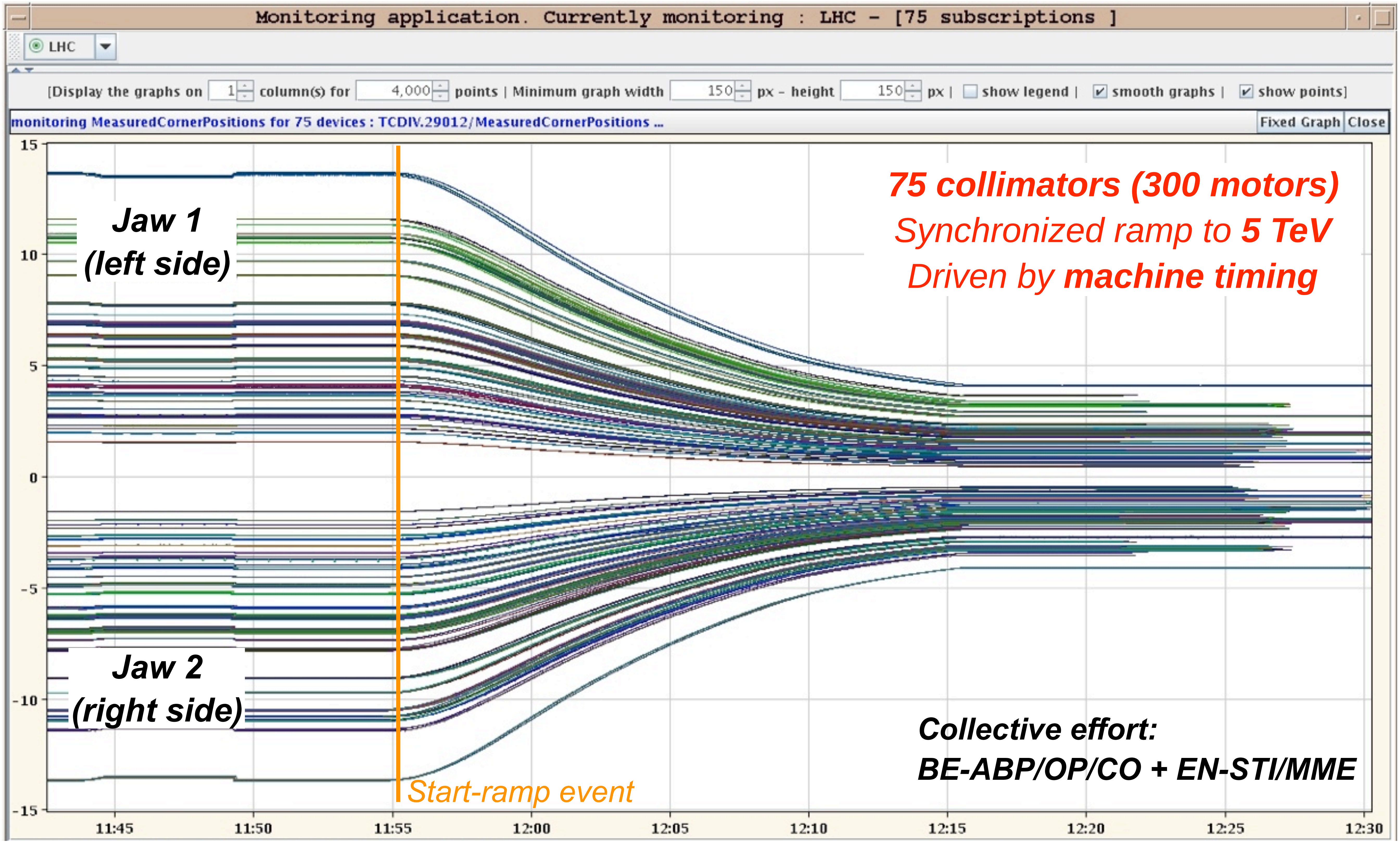
***80 movable** LHC collimators for the 2008 system:*

- ***316** stepping motors*
- ***468** interlocked position sensors*
- ***403** interlocked temperature sensors*
- ***160** beam loss monitors for beam-based set-up*



Plot by C. Bracco

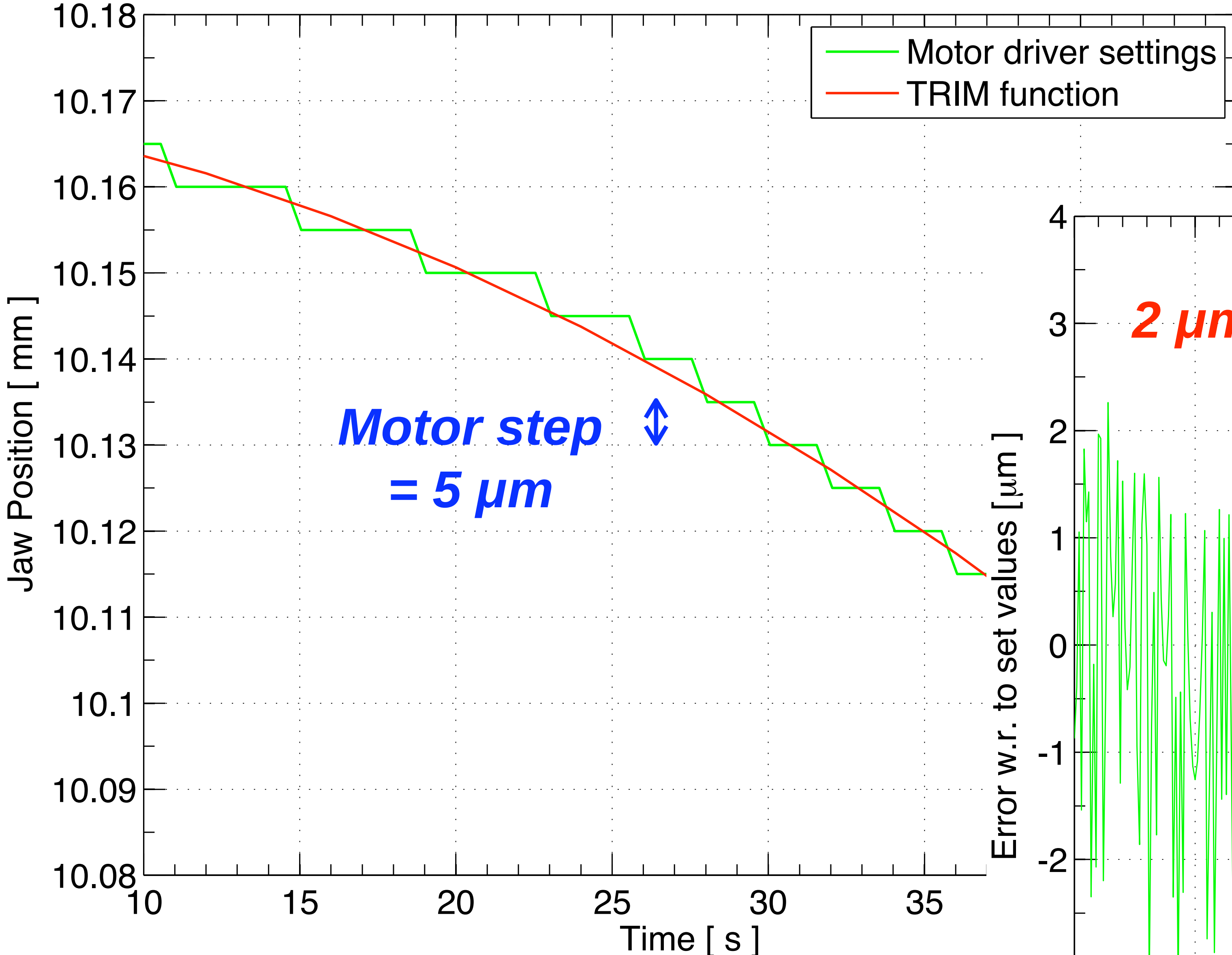
First synchronized ramp test

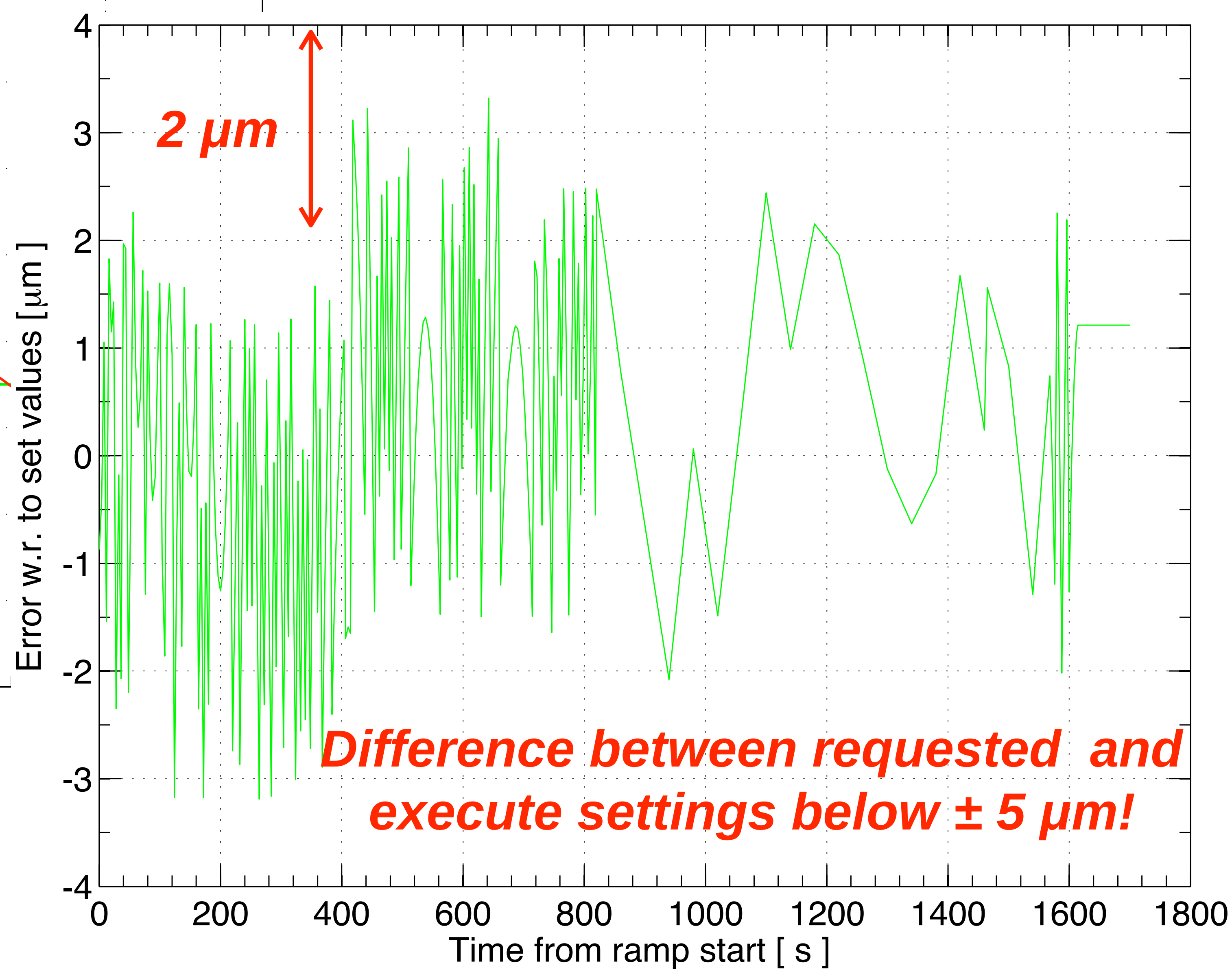


Initial gap values are determined by the local σ_x and σ_y and are different for each collimator.

Accuracy of function execution

Requested/executed settings vs. time

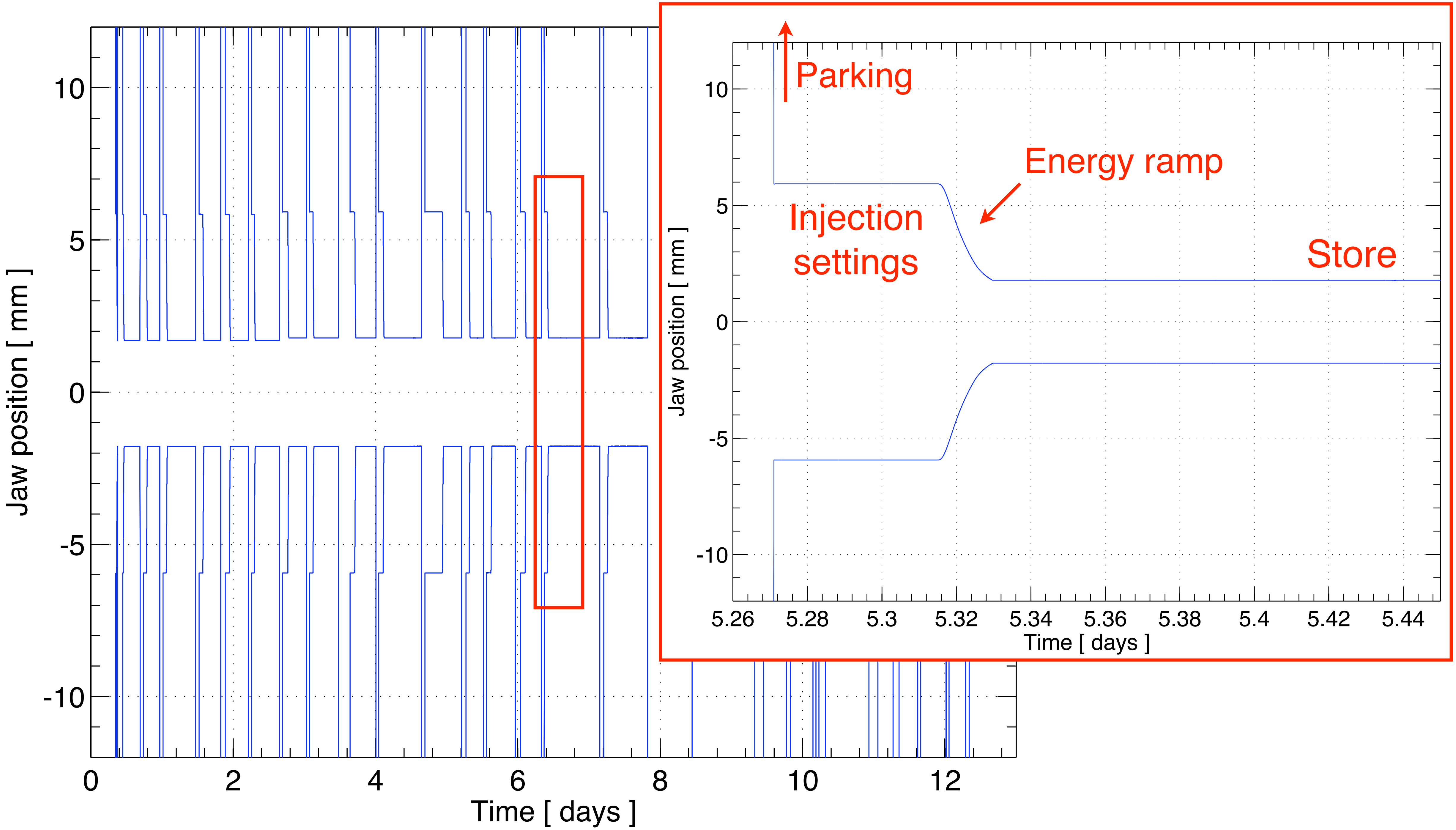




- Motor step = **5 µm**
- Operational motor speed = 2 mm/s
- "Slow" functions are interpolated with the appropriate rate of step execution

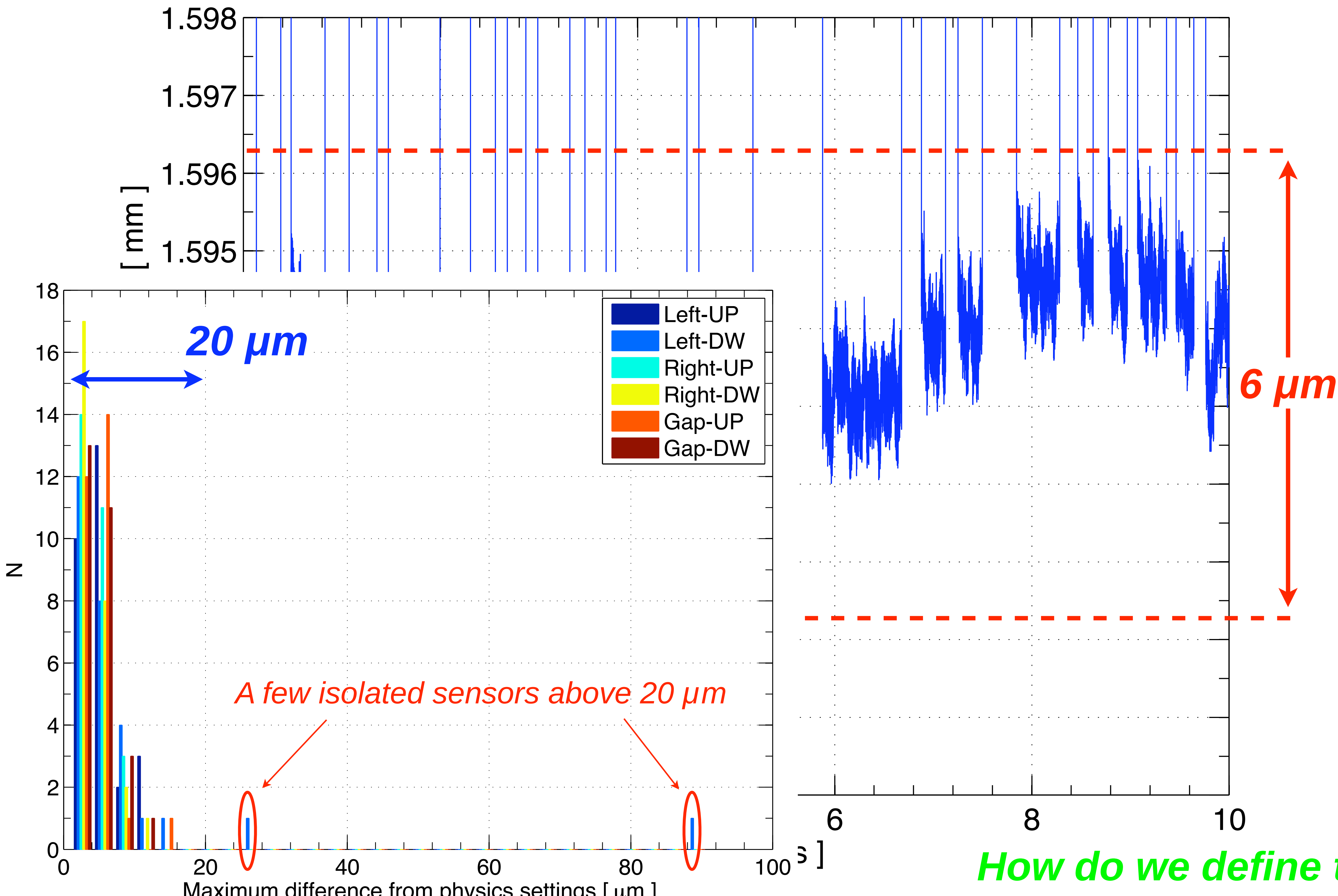
Low-level implementation in the PXI system by A. Masi

Reproducibility of operational settings



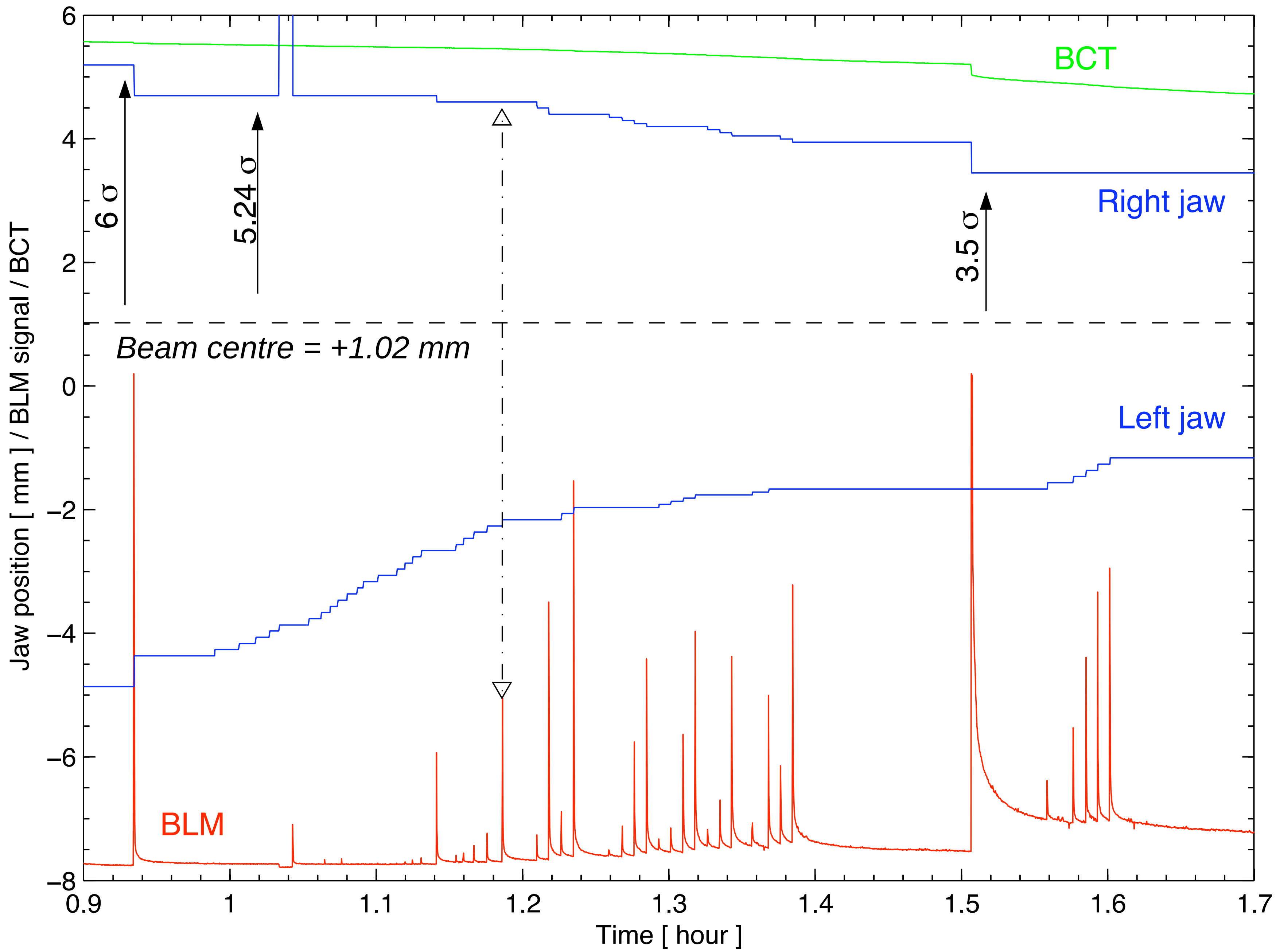
- Reproducibility tests: nominal operational cycles on **all 28 collimators in IP7**
- ~30 full cycles repeated during 10 days
- Real ramp functions to 5 TeV, nominal optics (different for each collimator)
- “Handed over” to operation crew *(special thanks to the LHC OP team)*

Reproducibility: results



How do we define the collimator settings?

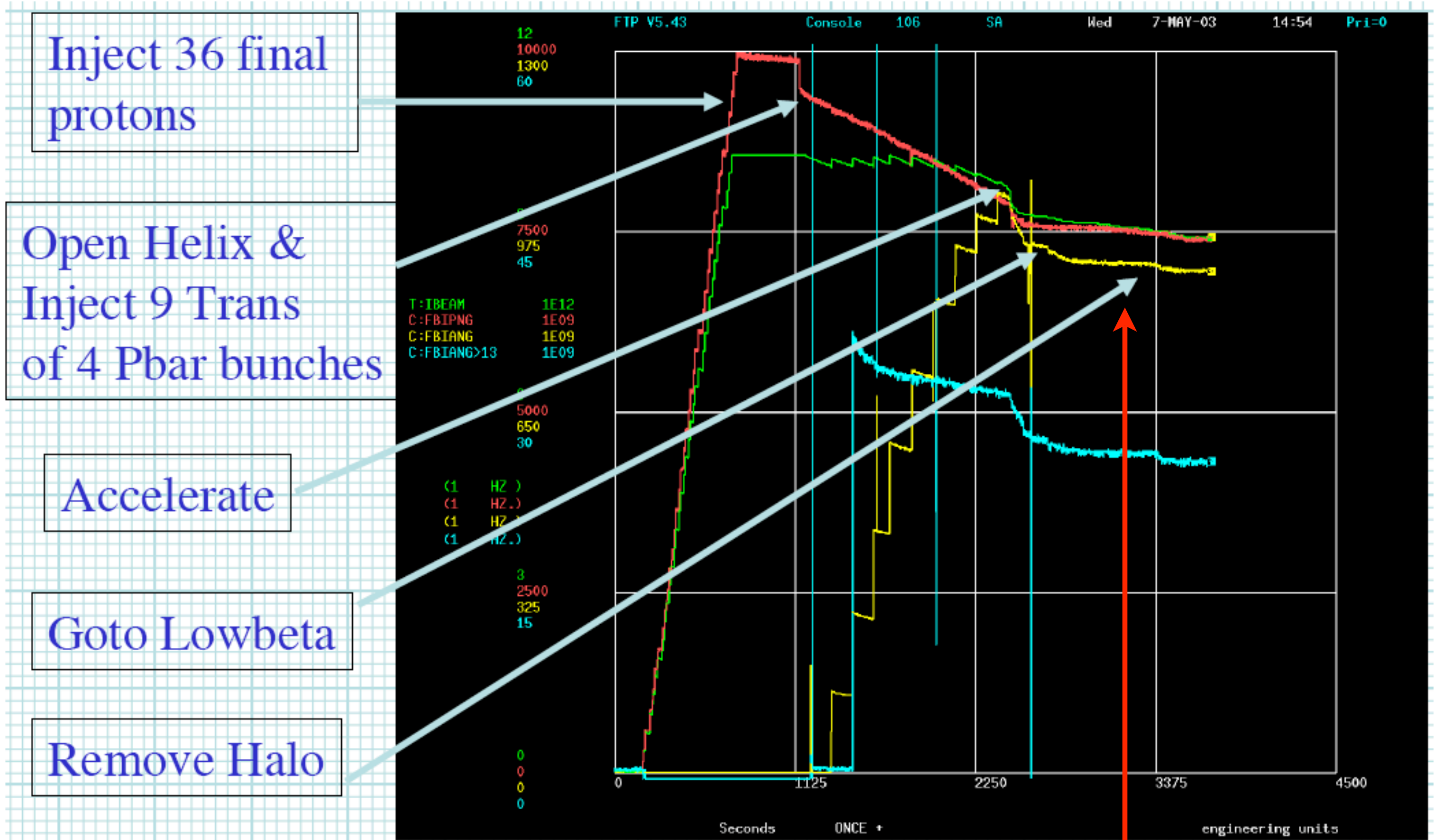
Beam-based alignment

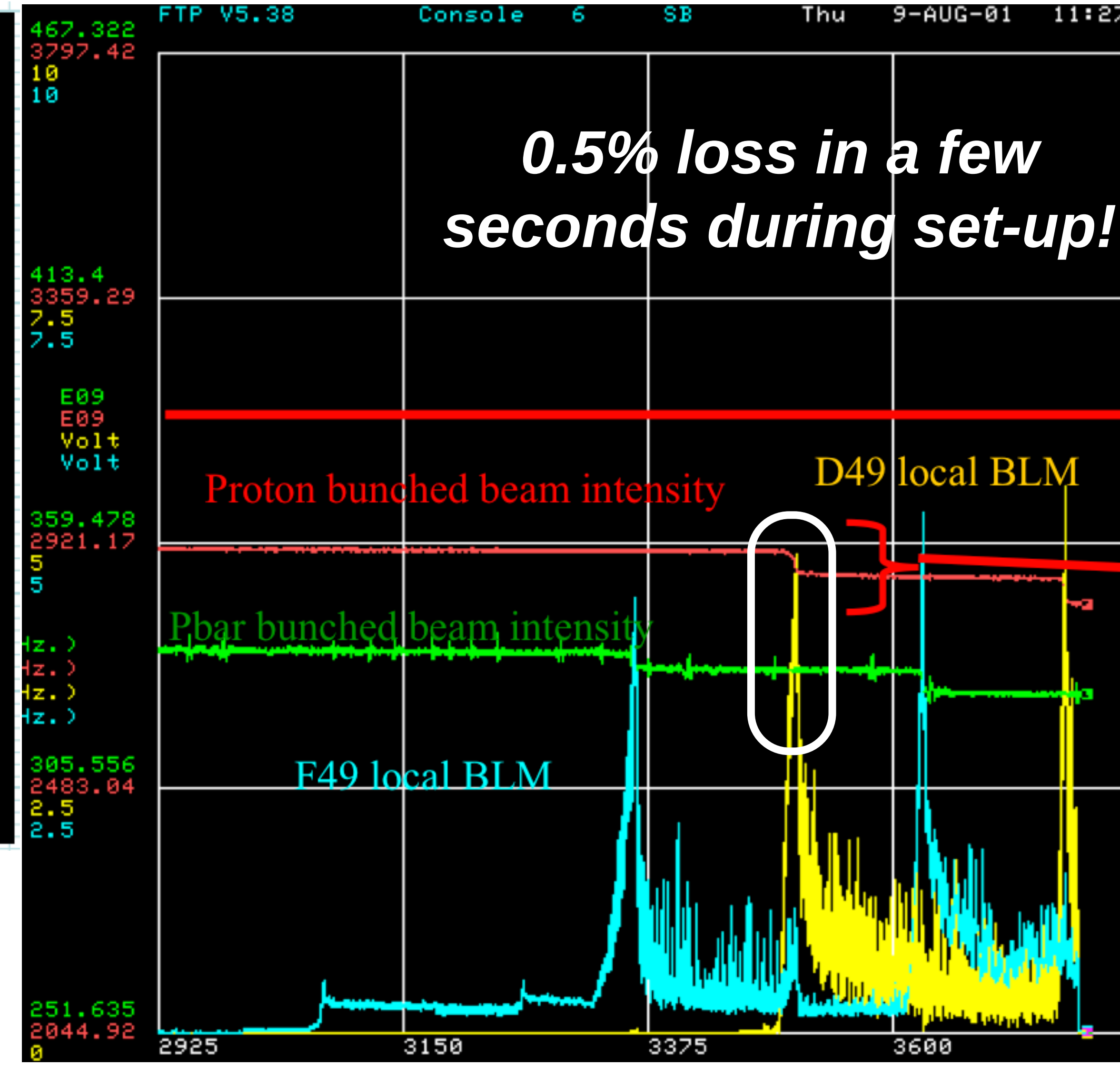


See details of SPS systematic effects in C. Bracco's thesis

- *Based on measurements of local beam losses during* ***halo scraping***
- *<u>Time consuming</u>: about* ***20 minutes per collimator***
- ***Cannot*** *perform this procedure with* ***high LHC stored beam energies****!*
  - ***Quench*** *in single stage cleaning during set-up (limit: a few bunches at 7 TeV)*
  - ***Damage*** *the metallic collimators (7 TeV pilot bunch close to damage limit!)*

Collimator set-up at the Tevatron





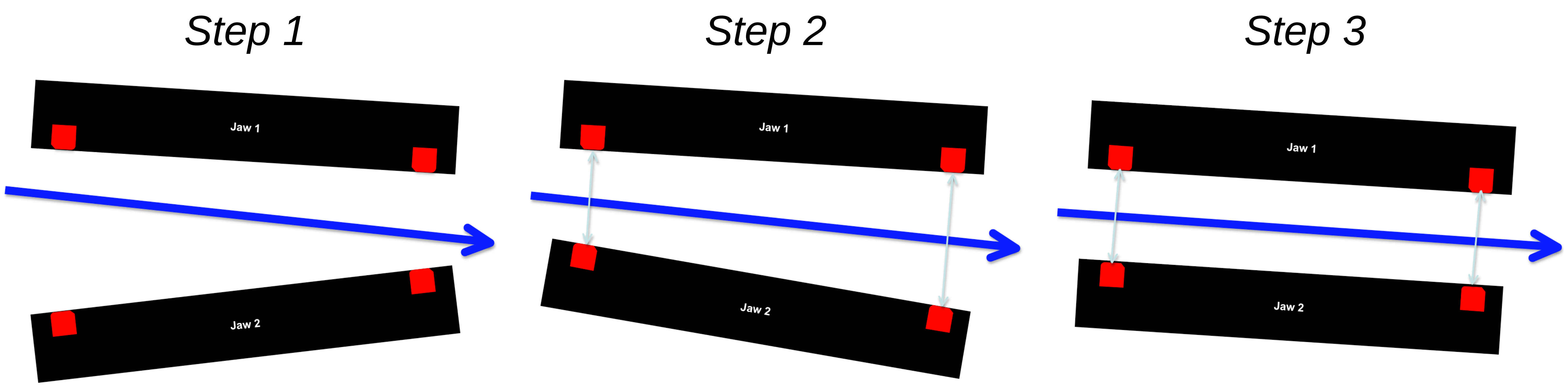
Courtesy of D. Still

Collimator set-up done at every fill after the squeeze.

LHC: 0.5% = 1.8 MJ → almost full Tevatron beam!!

With the present system, the collimator settings at top energy MUST rely on *calibrations at low-intensities* + *machine reproducibility* + *orbit measurements* (no direct measurements)

Advantages of integrated BPM



Clearly, this concept ***requires*** *validation* ***with beam tests***

Prototype under construction for ***beam tests in 2010 at the SPS****!*

Potential advantages *with respect to present scheme:*

- Allows beam-based set-up with ***UNSAFE beams****: no need to scrape the halo!*

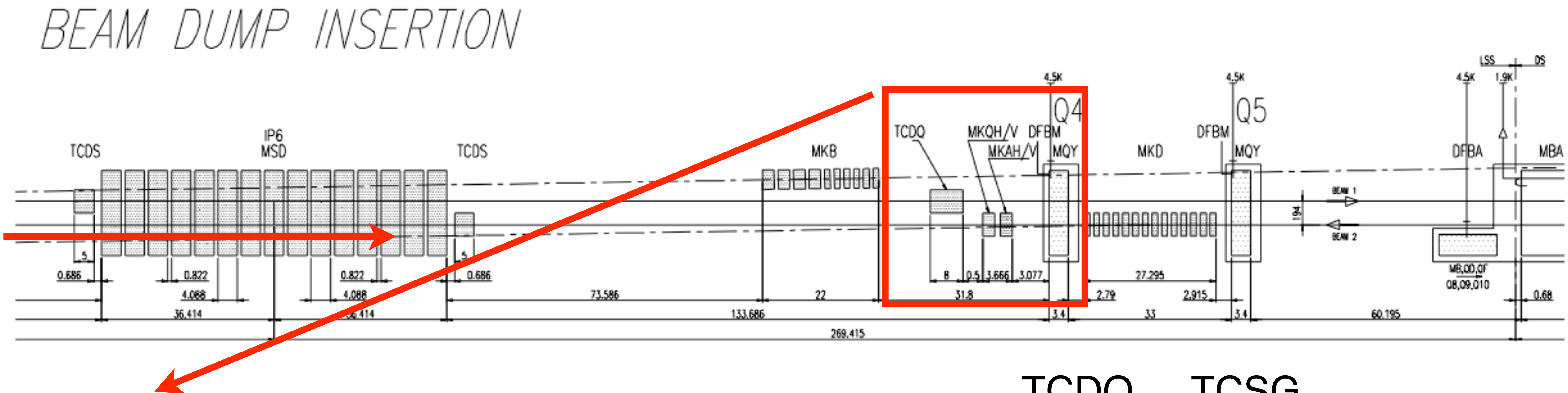
- ***Continuous monitoring*** *- and possible re-tuning - during ramp, squeeze, store!*

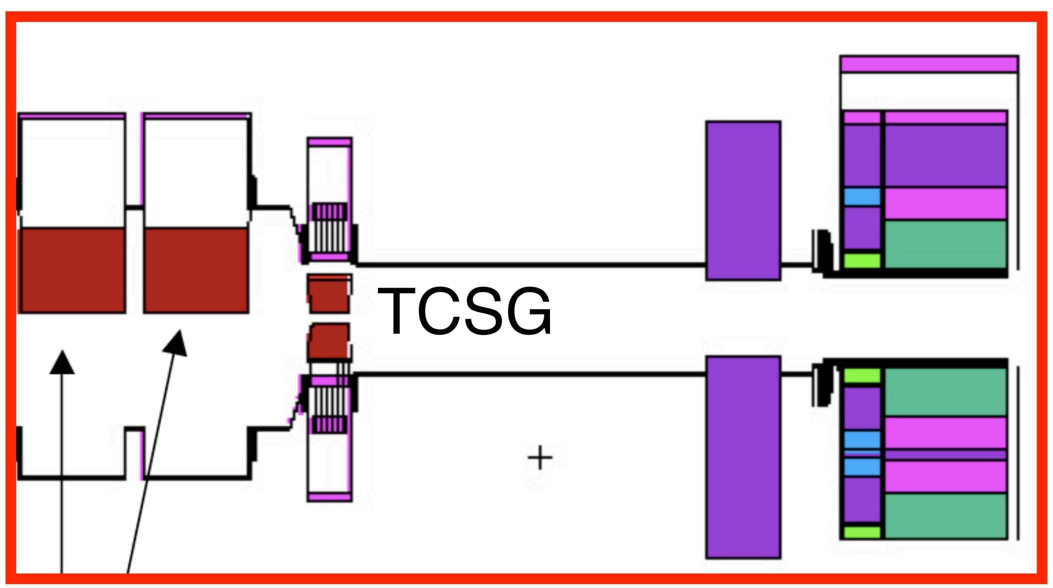
- Can be done at ***every fill*** *and at any energy*

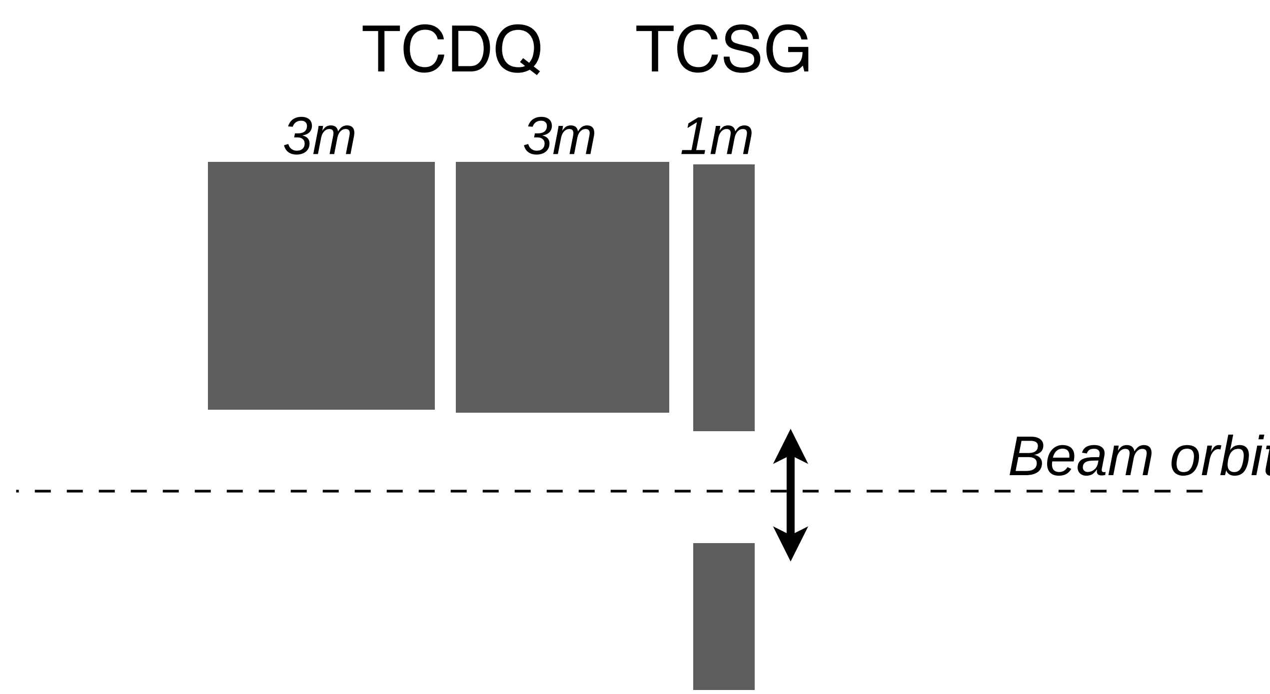
- ***Save set-up time****: < 1 minute per collimator (instead than 20 minutes)*

*- Allows setting the jaws parallel to the beam orbit (****angle adjustment****)*

Collimators for the LHC beam dump





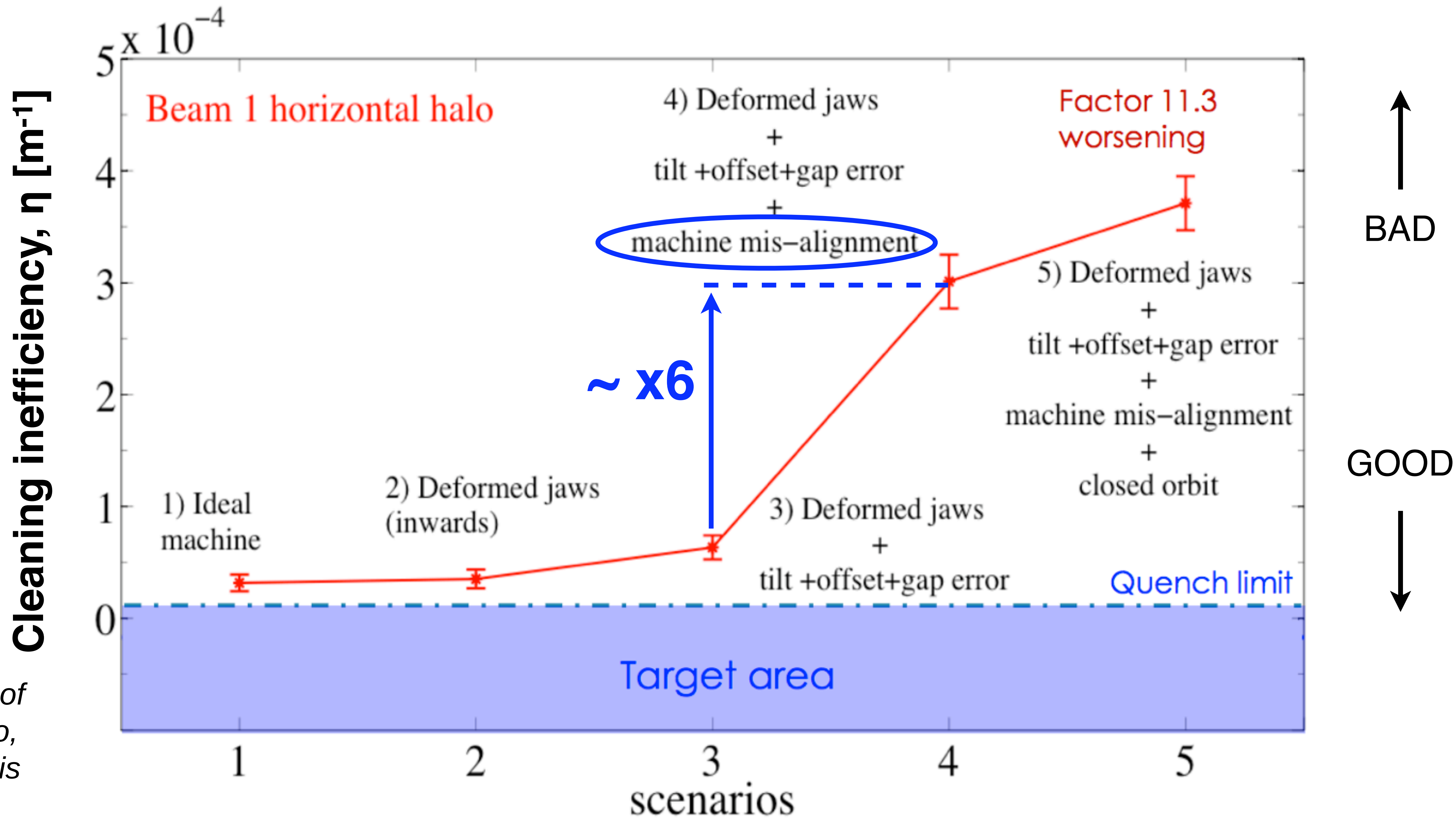


Protection *against failures of the beam dump system rely on the centring of the beam in protection collimators.*

Present strategy: ***software interlocks*** *on BPM, collimator positions, TCDQ positions*

Could build an ***hardware interlock*** *with the integrated BPM design!*
Can we have ***one-side bottoms*** *for TCDQ??*

Effect of imperfections on cleaning

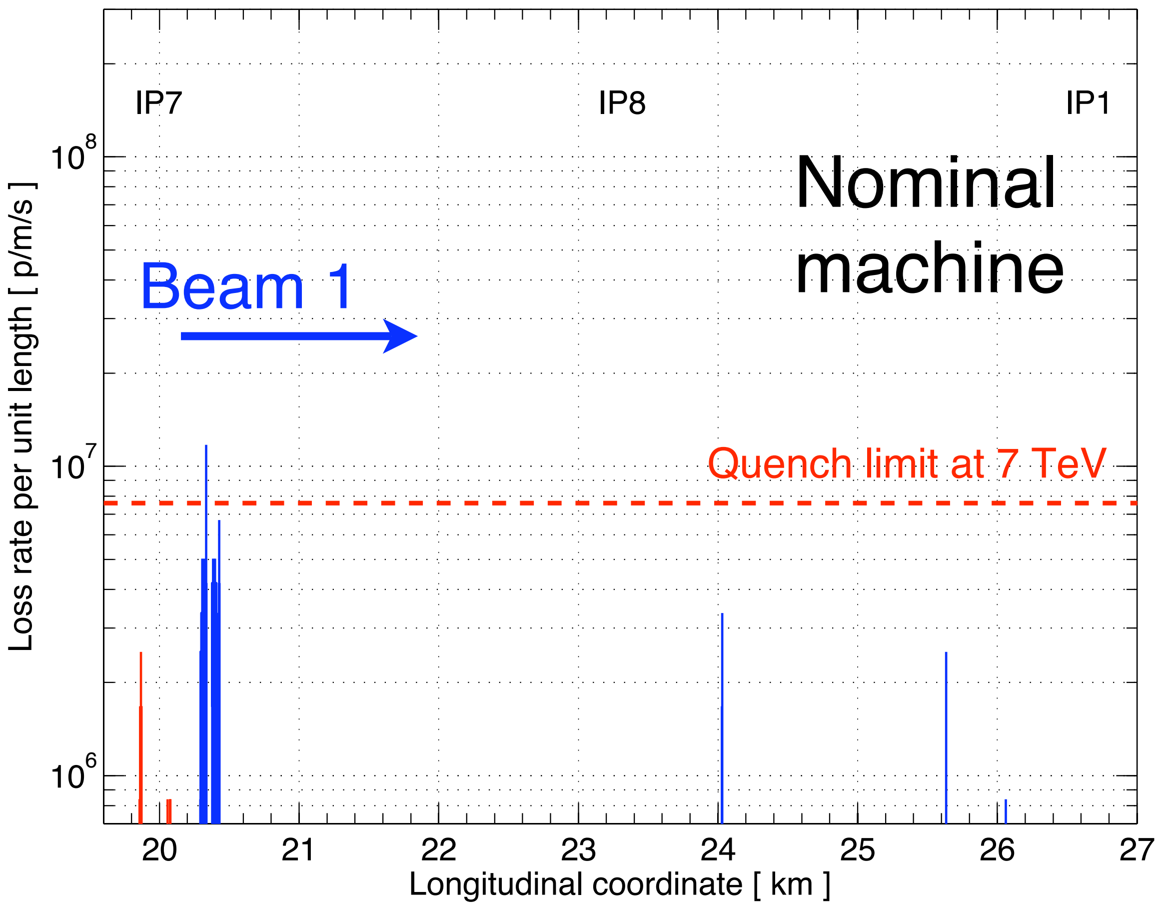


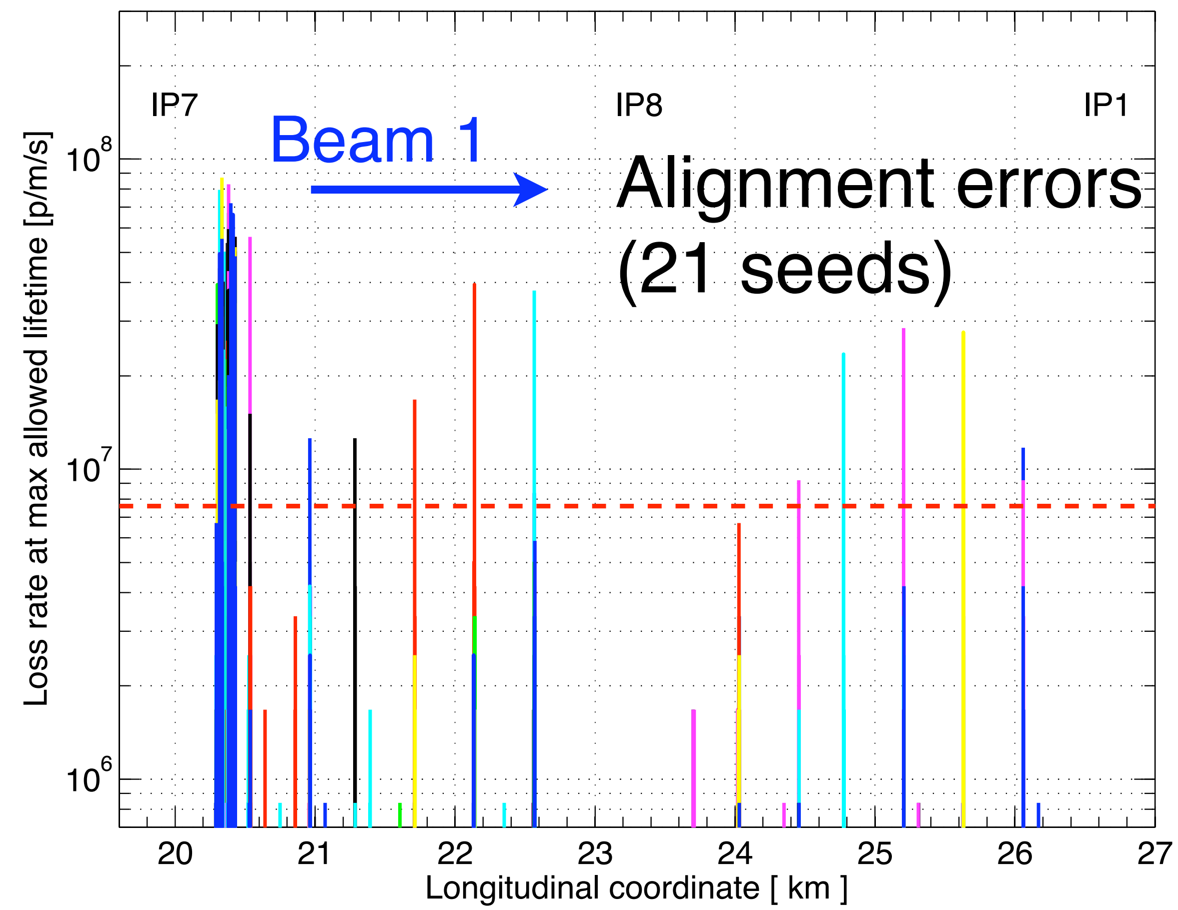
Courtesy of C. Bracco, PhD thesis

*Predominant effect (in simulations): Aperture alignment errors → loose a **factor 6***

Can the proposed Phase II solution help relaxing tolerances on imperfections?

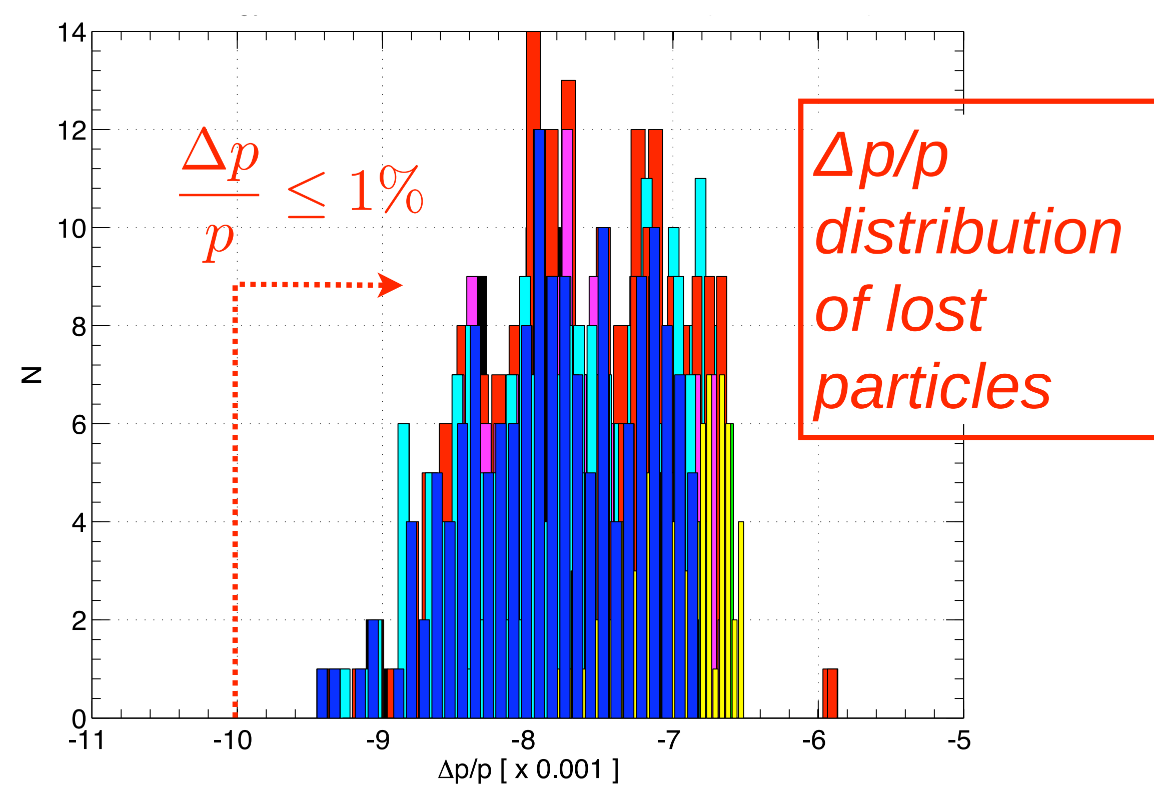
Effect of aperture errors at 7 TeV



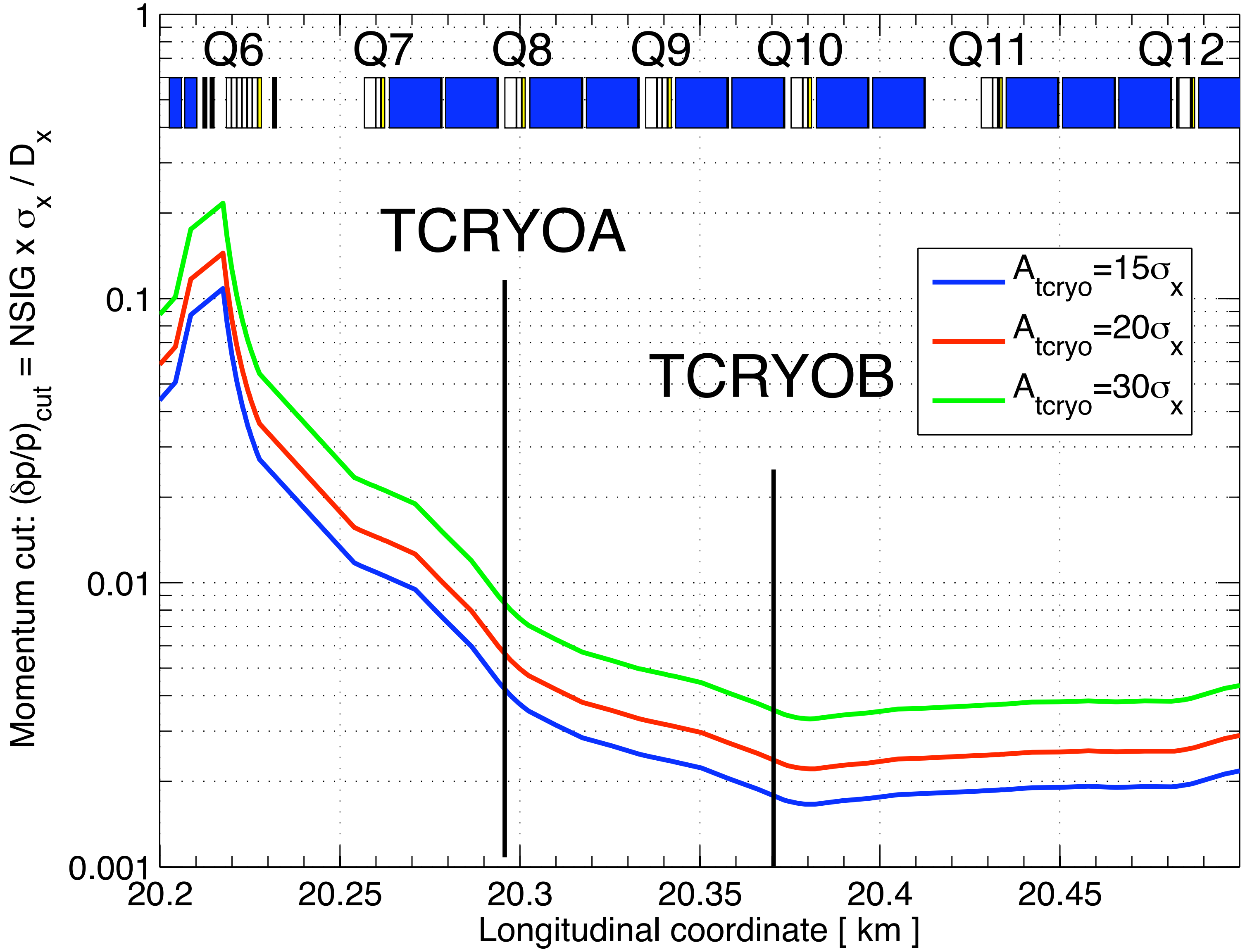


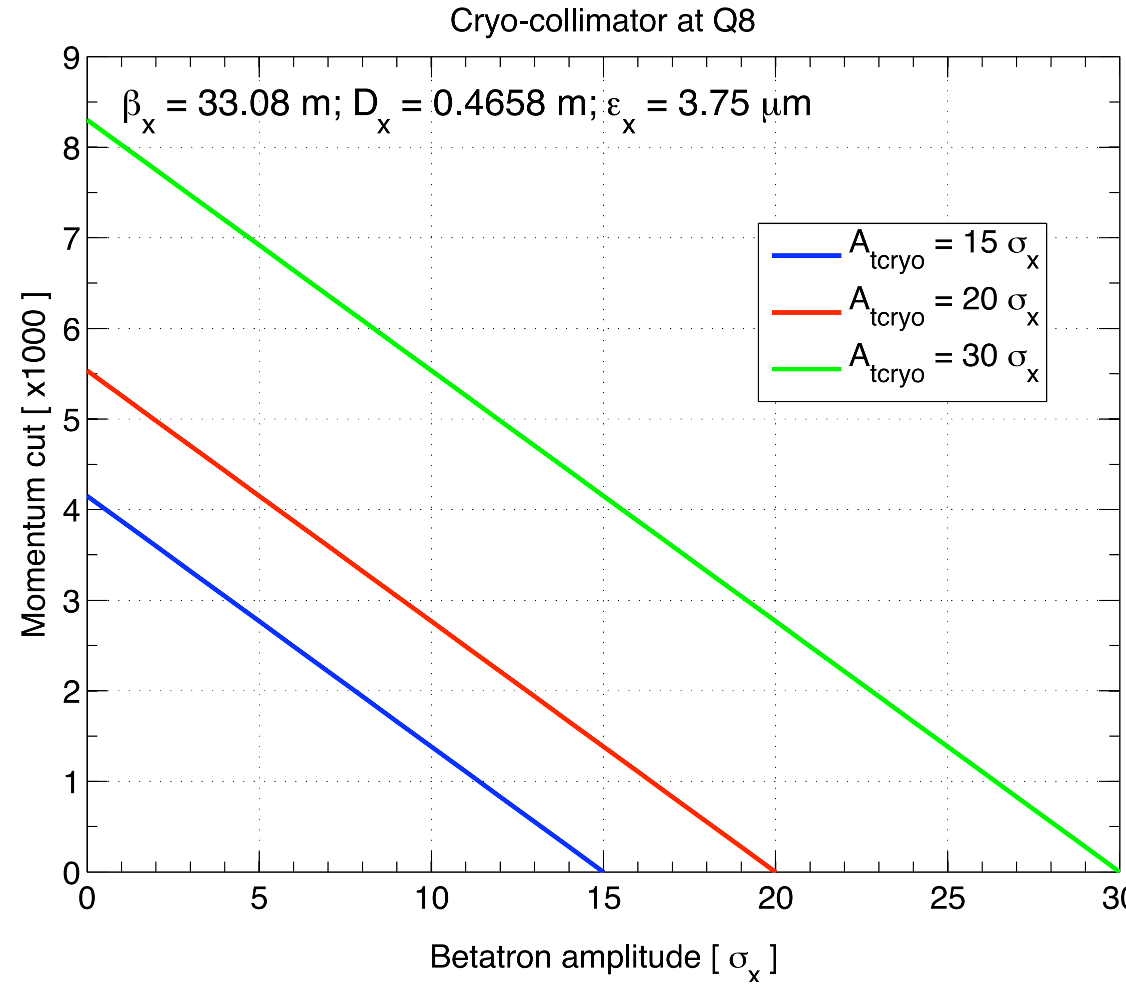
Limiting hot stop: suppressor downstream of IR7 *(single diffractive losses from the primaries)*
Factor 6 worse with aperture errors.
Additional loss locations in the arc, at high dispersion locations.

Are these particles caught by the cryo-collimators?



Momentum cut of cryo-collimators





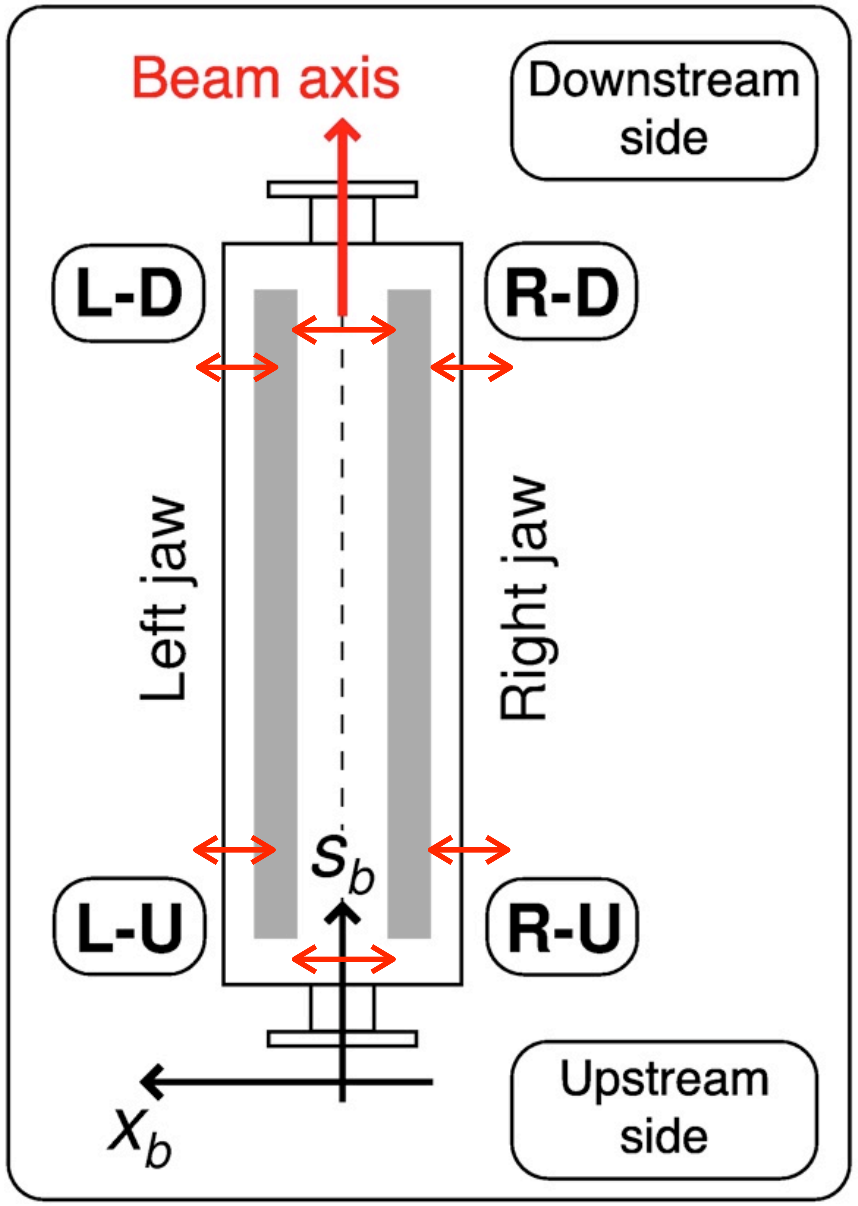
- Approximated figures with the nominal optics are given
- Reduce the losses in the dispersion suppressor (see T. Weiler talk)
- Momentum cuts below 1% at 30 sigmas (TCRYOA=0.8%, TCRYOB=0.35%)
  - Losses in the arc due to aperture errors will also be reduced!
  - Can relax settings and operate at ~30 sigma
- Dedicated tracking campaign need to confirm these conclusions

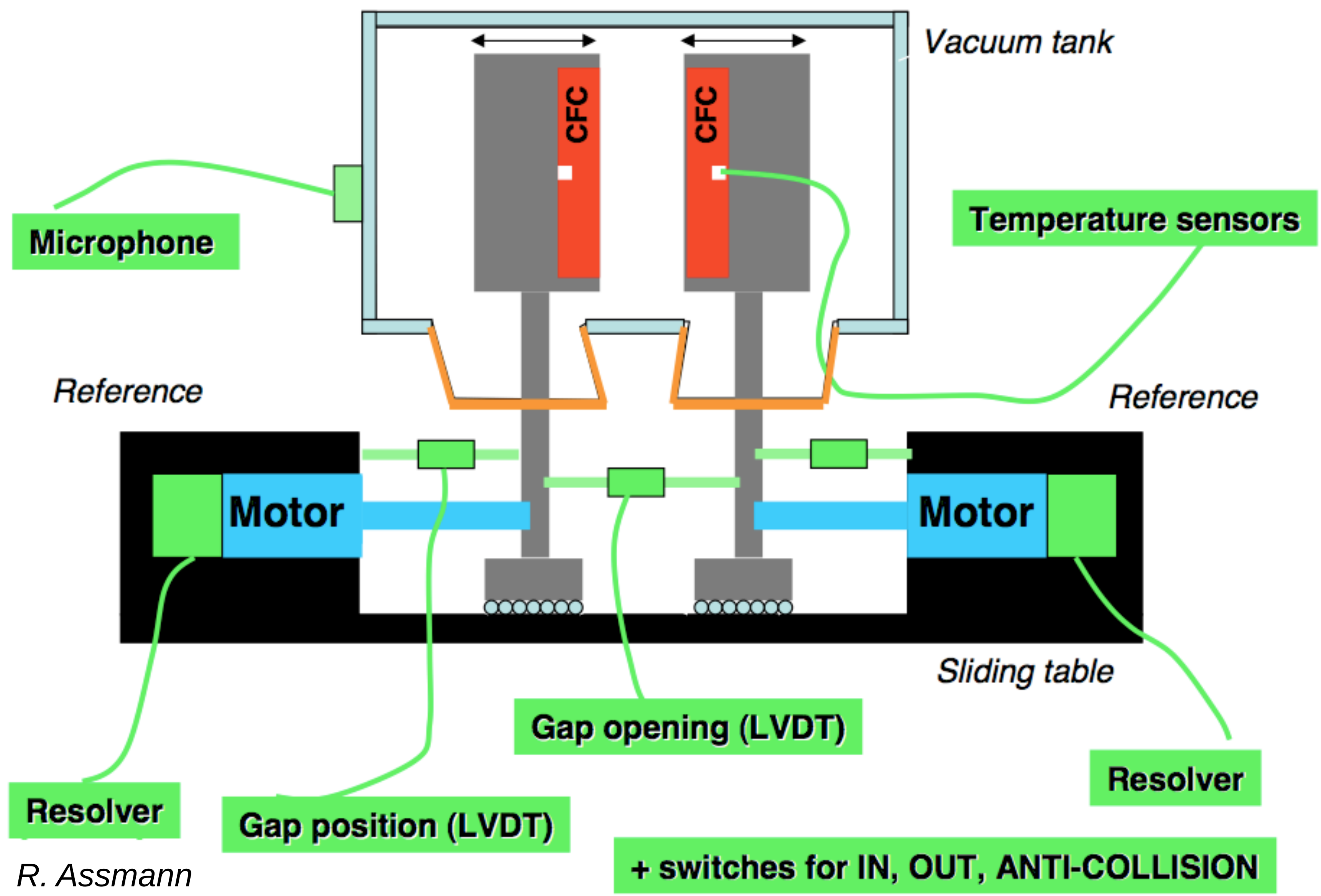
Conclusions

- Reviewed various **operational aspects** of the **Phase I collimation**
- Advanced solutions of **mechanical design** and **control system** seem adequate for the LHC challenges (but still miss beam tests)
  - *Achieved a close to nominal performance without beam!*
  - *Powerful controls, fully integrated into the LHC framework*
- **Integrated BPM design - if validated - will be crucial**
  - *Seems the only way to perform set-up with unsafe beams*
  - *Faster set-up, continuous monitoring of local orbit*
  - *Suggested to profit of this solution also for critical protection locations*
- **Cryo-collimators efficiently catch the off-momentum losses: improved cleaning and reduced sensitivity to imperfections**
  - *Indications that at least a **factor 6** can be gained with aperture errors*
  - *Can relax tolerance for off-momentum losses in the arcs*
  - *Require more simulations for other perturbation sources*

Reserve slides

Collimator positioning system





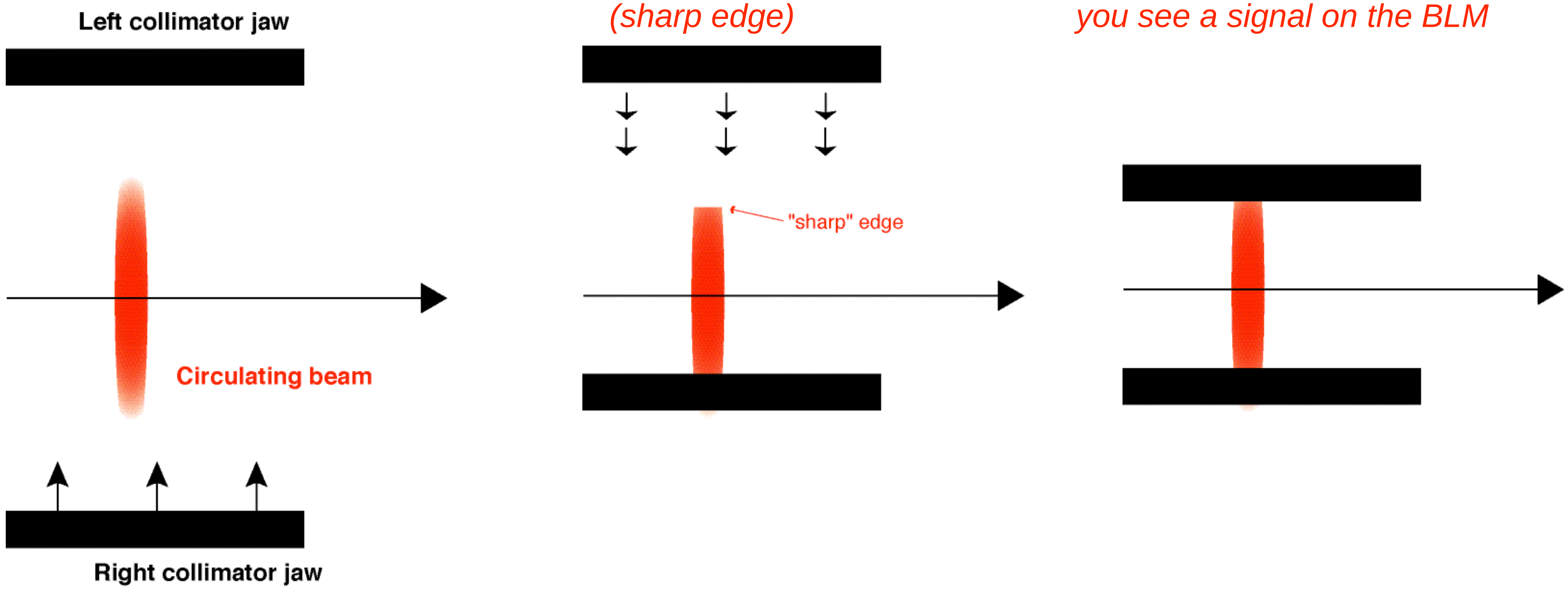
Settings: **4 stepping motors** for jaw corners - 1 motor for tank position.

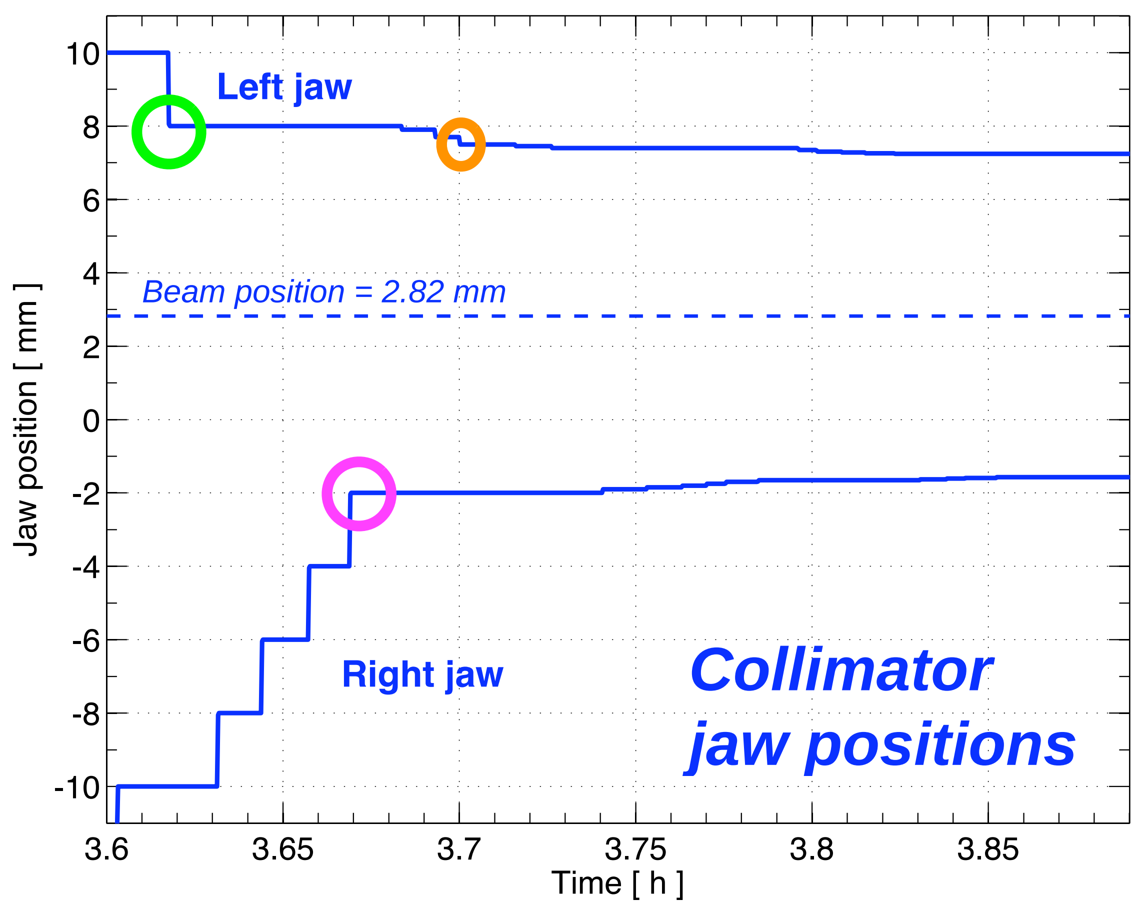
Survey: 7 direct measurements: **4 corners** + **2 gaps** + tank
4 resolvers that count motor steps
10 switch statuses (full-in, full-out, anti-collision)

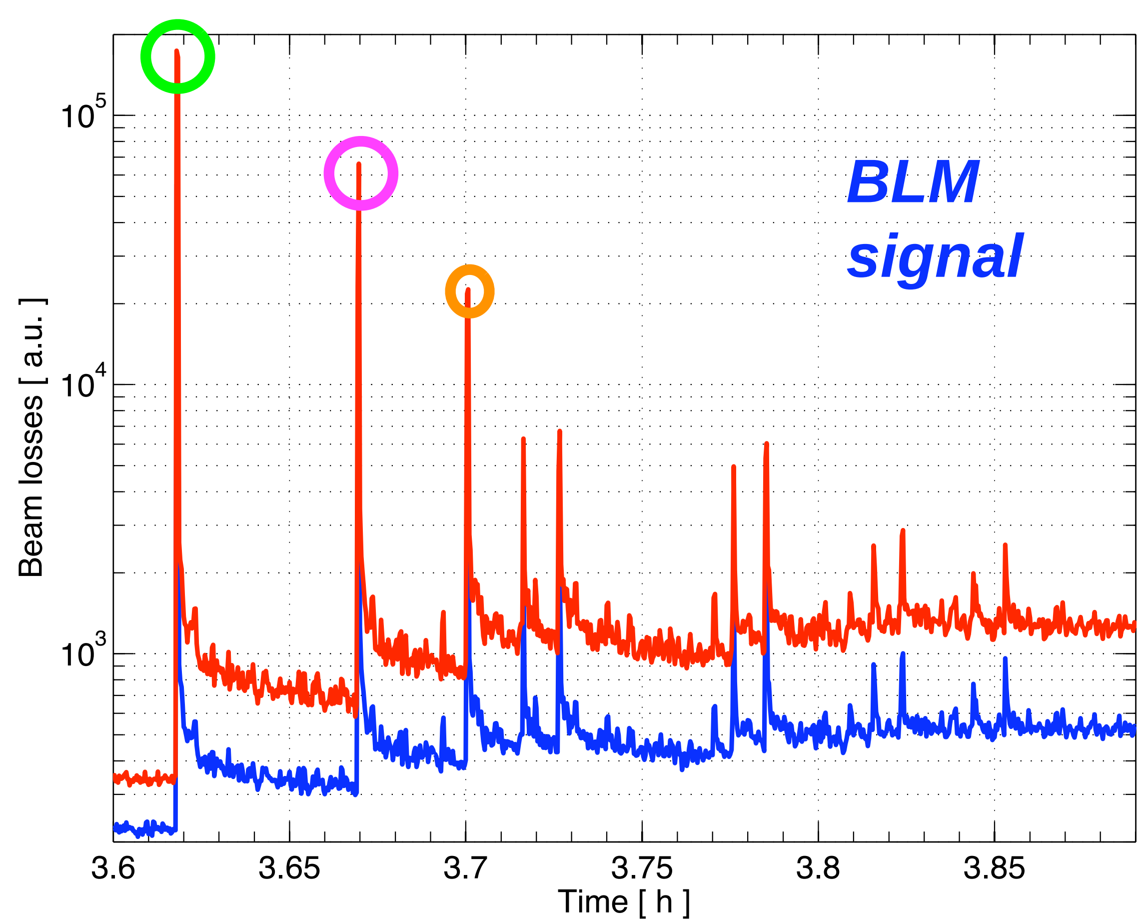
Redundancy: motors+resolvers+LVDT's (*Linear Variable Differential Transformer*) = 14 position measurements per collimator

Beasm-based alignment

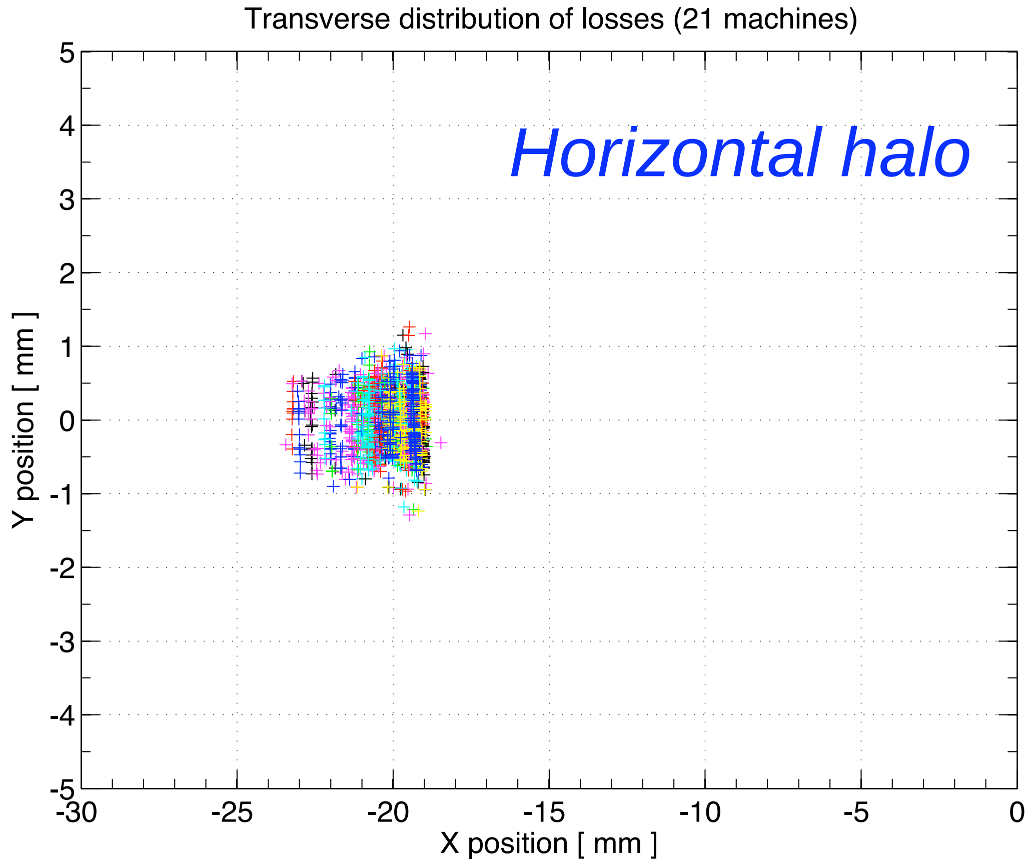
1. Move one jaw in — *2. Scrape the beam (sharp edge)* — *3. Move the other jaw until you see a signal on the BLM*

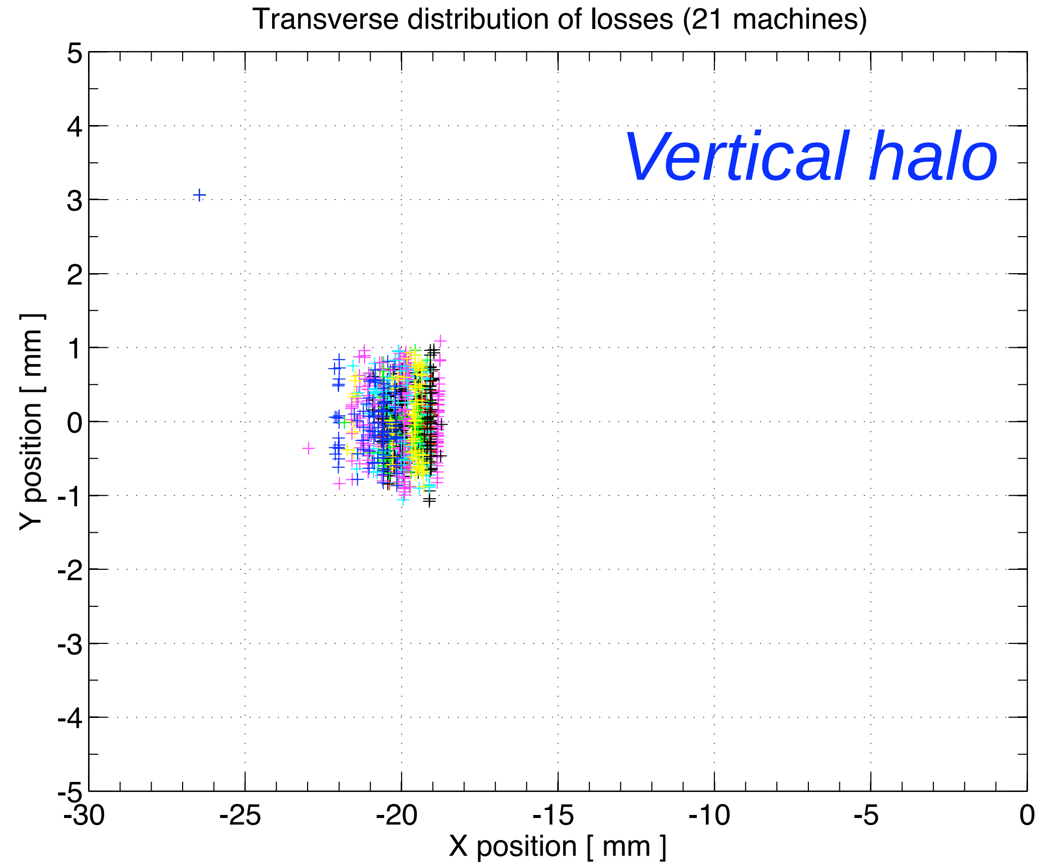


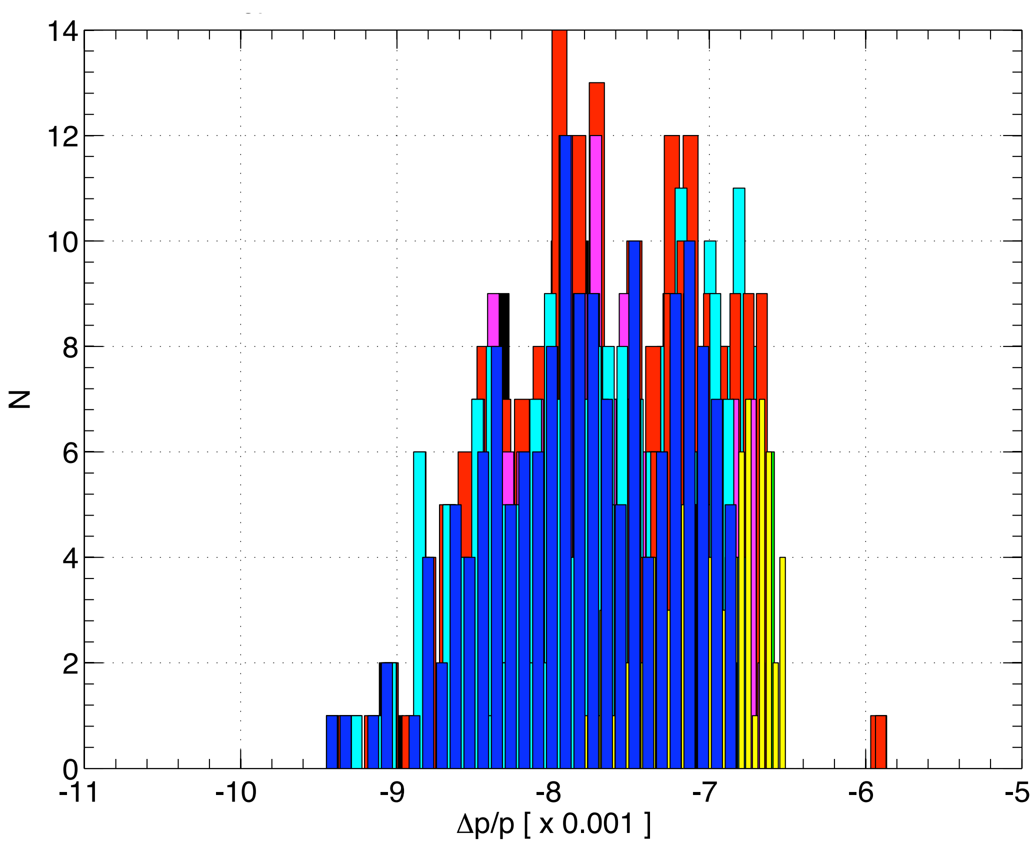


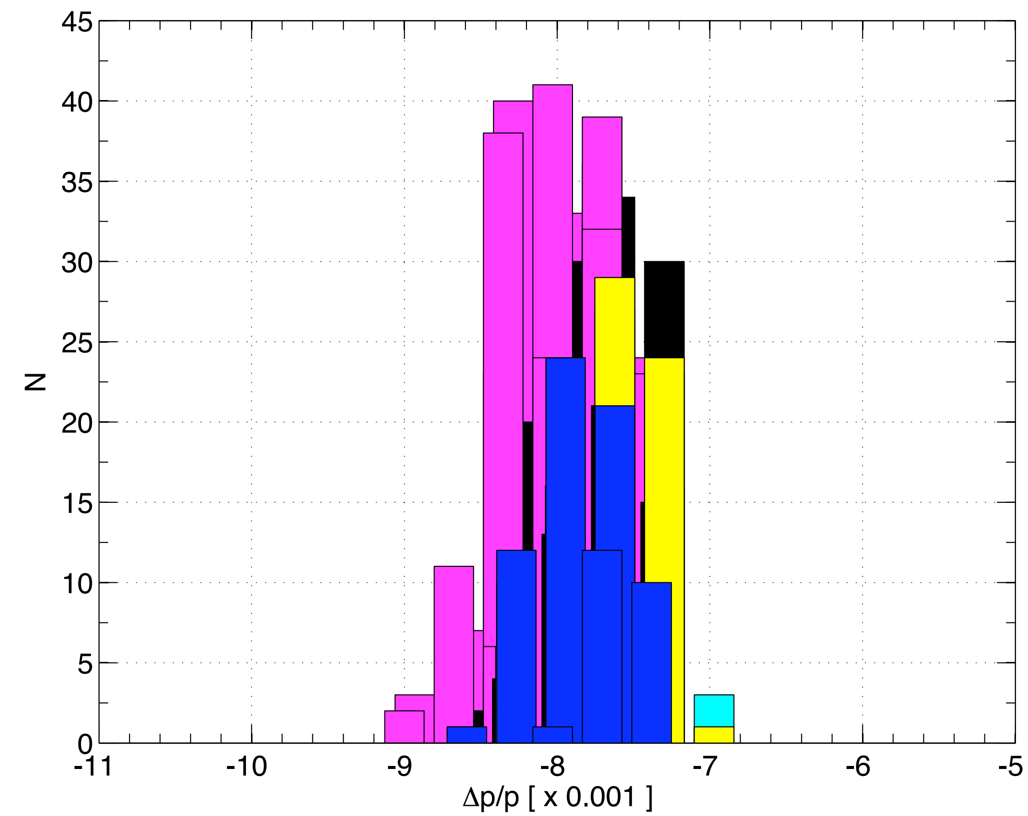


Transverse loss distribution

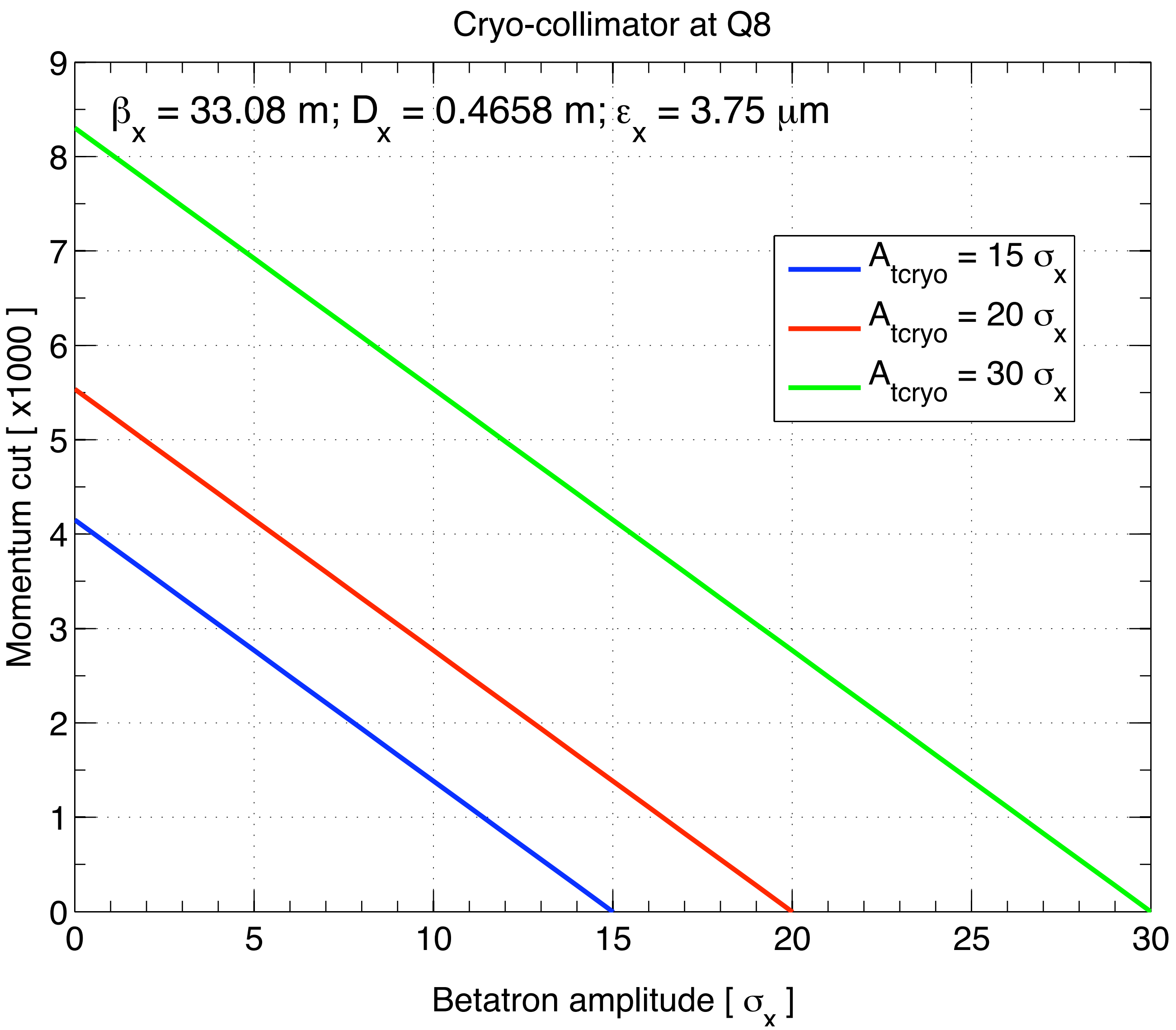


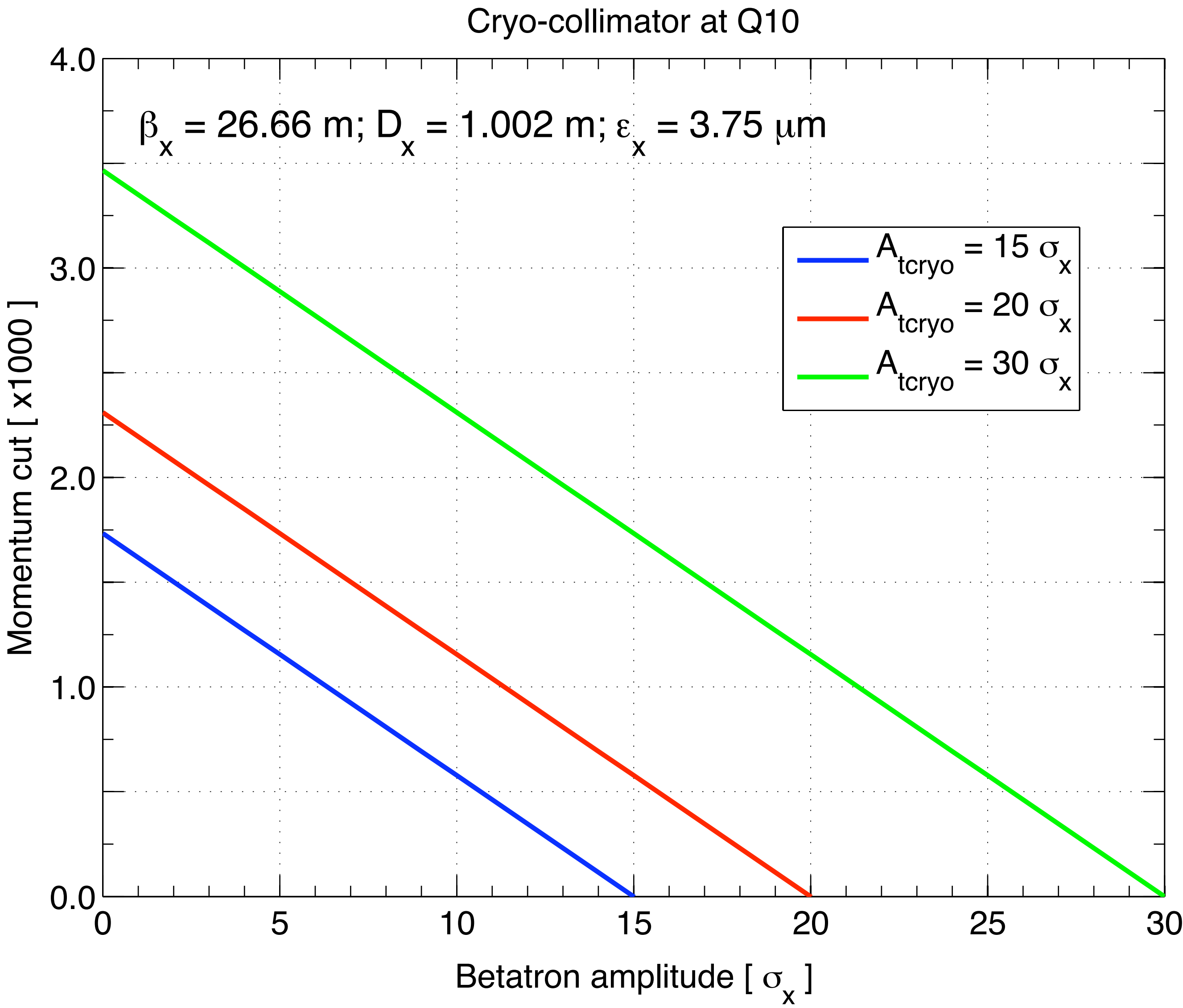






Momentum cut at the cryo-collimators





Approximated figure: taken nominal optics at Q8 and Q10.

Betatron squeeze and collimators

Full 2009 system will be in place for 2009 operation

- *No limitations of β* in IP2 and IP8 from triplet protection (TCTVB's available for 2009)*

Every β step will need, in principle, checks/adjustments of collimator settings

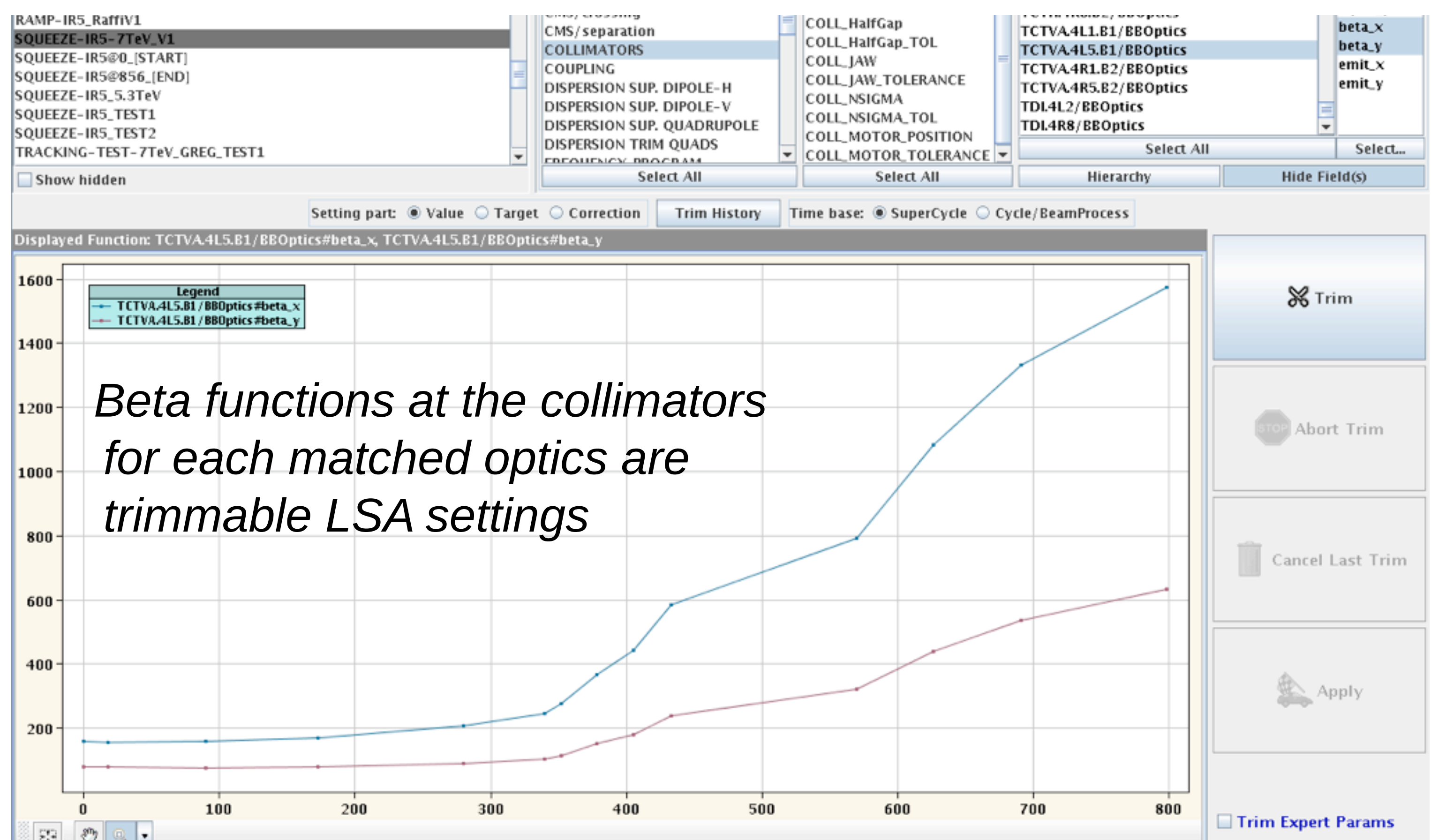
- *Cleaning collimators in IR7; dump protection in IR6; tertiary collimator for MQX protection*
- *In practice, only needed when triplet aperture becomes bottleneck (Ex.: β*≤6m at 7 TeV)*
- *Move collimator to tighter settings before trimming squeeze to* ***MQX ensure protection***

Mechanics of the squeeze dry-tested during cold check-out (as for power converters)**:**

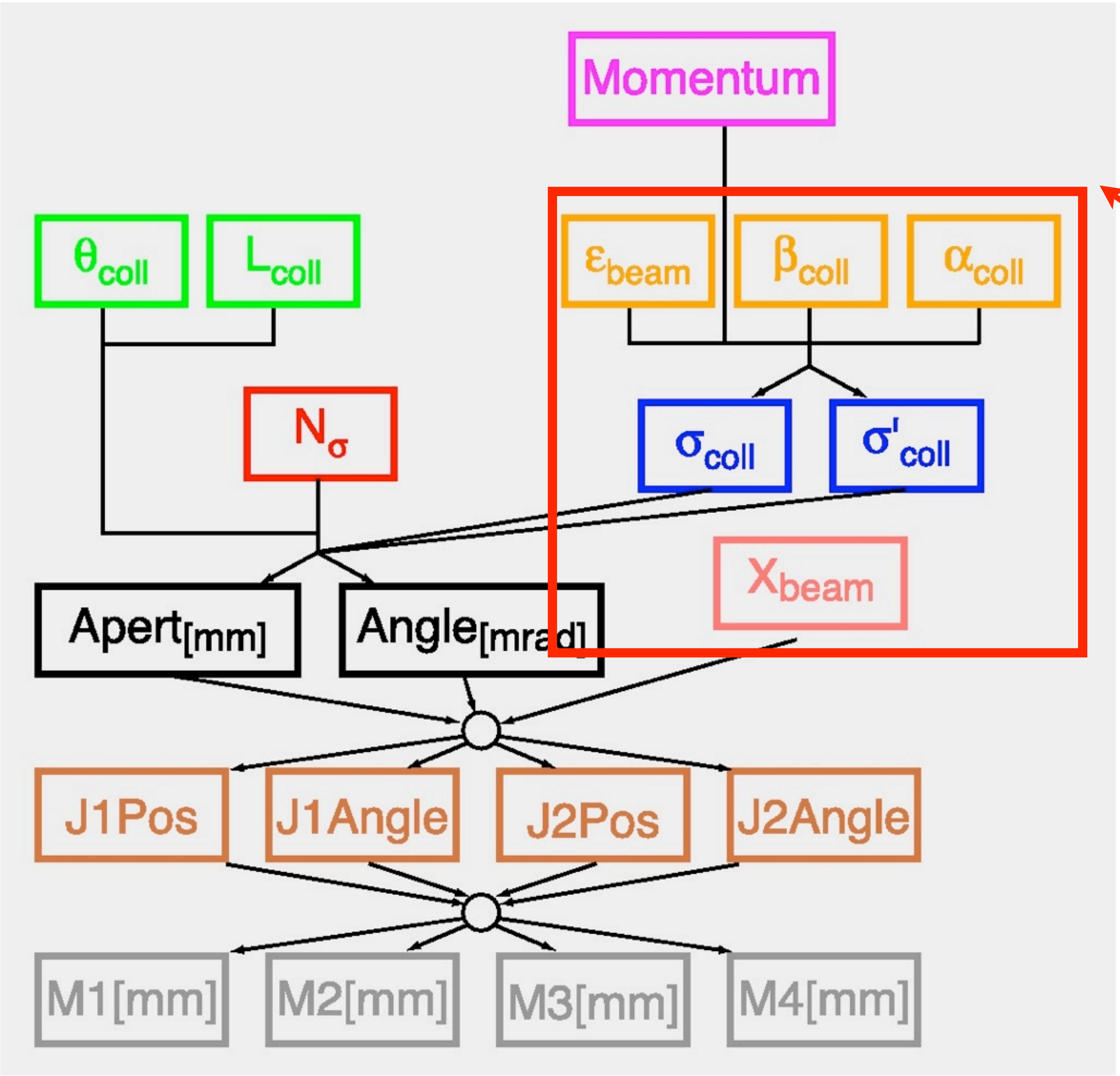
- *Functions generated within LSA like for the power converters*
- *New functionality:* ***"interrupt"/"re-start"*** *at matched points (A. Masi). Tests ongoing.*

Lot of work from the collimation team to define ***optimized settings****:*
R. Assmann: Cham.2006 + LHCCWG num. 18
C. Bracco's thesis - see chapter on "Optimized strategy for LHC collimator commissioning"

*Need updated settings for final operational scenario of energy and β**



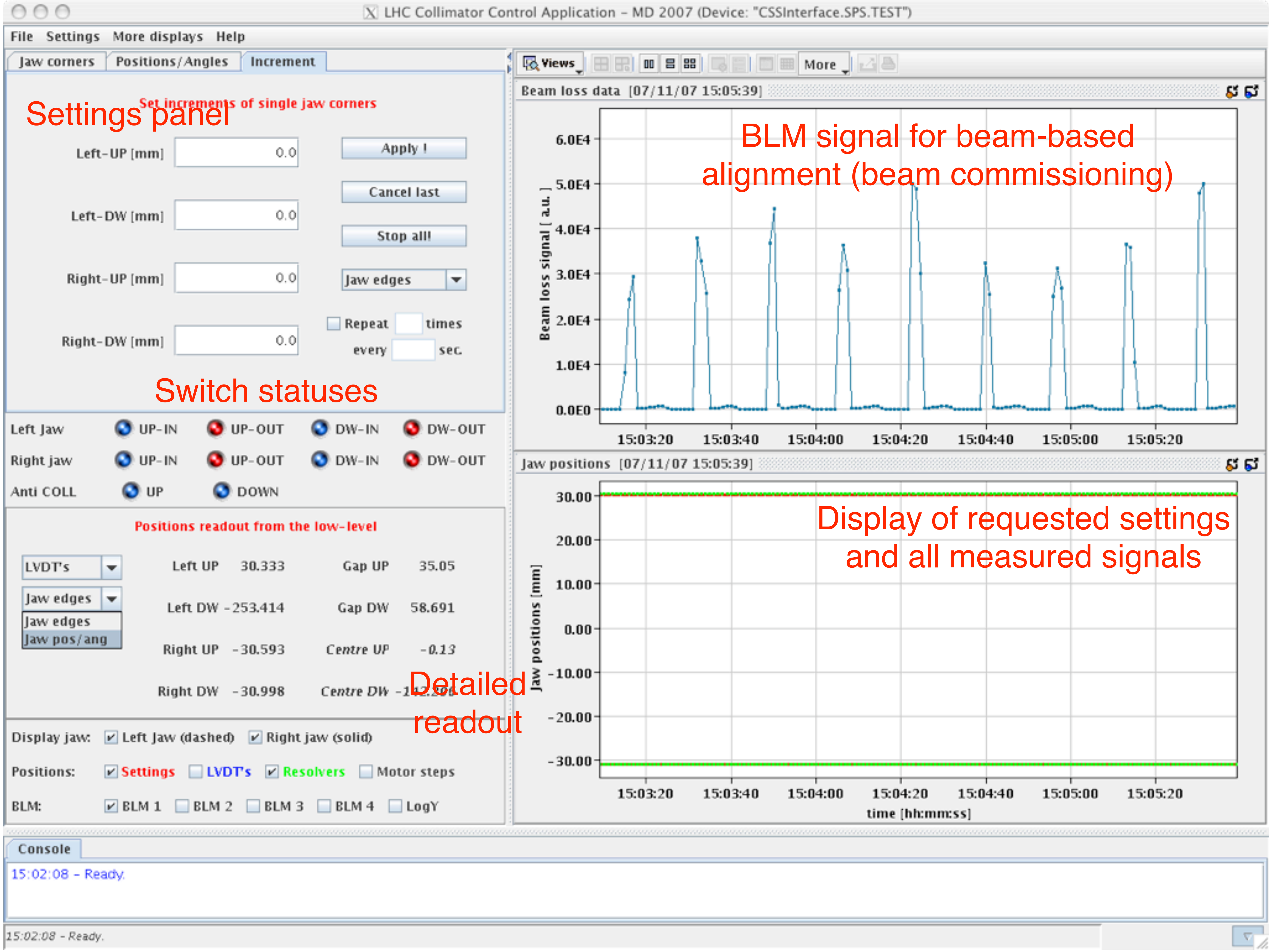
Setting in unit of beam size



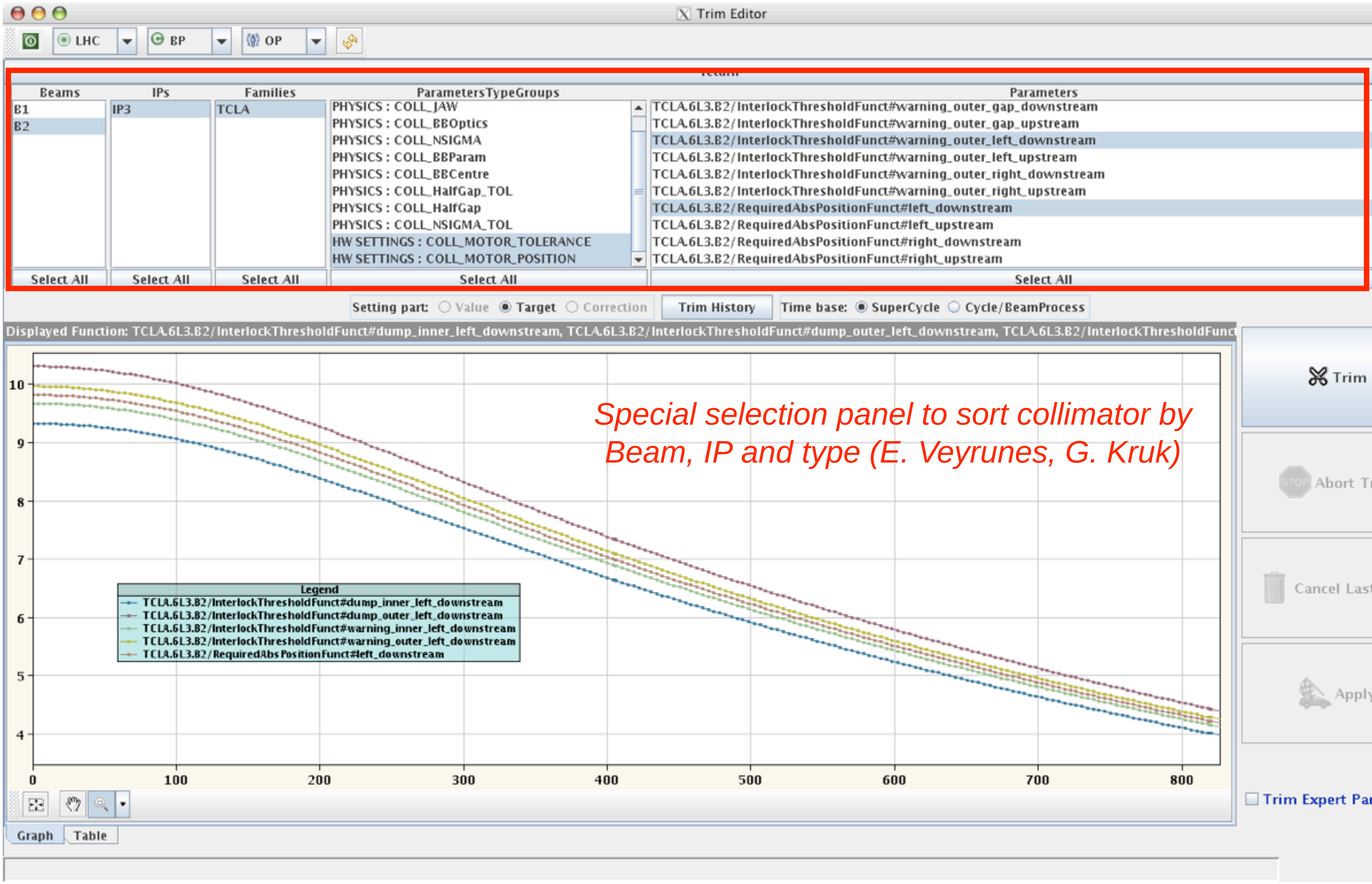
Parameter space for settings in **units sigma**!
(trims at all levels possible!)

Beam-based parameters will be determined for each collimator with beam and stored in the setting DB
(now: nominal values imported at the generation level)

Collimator control application (I)

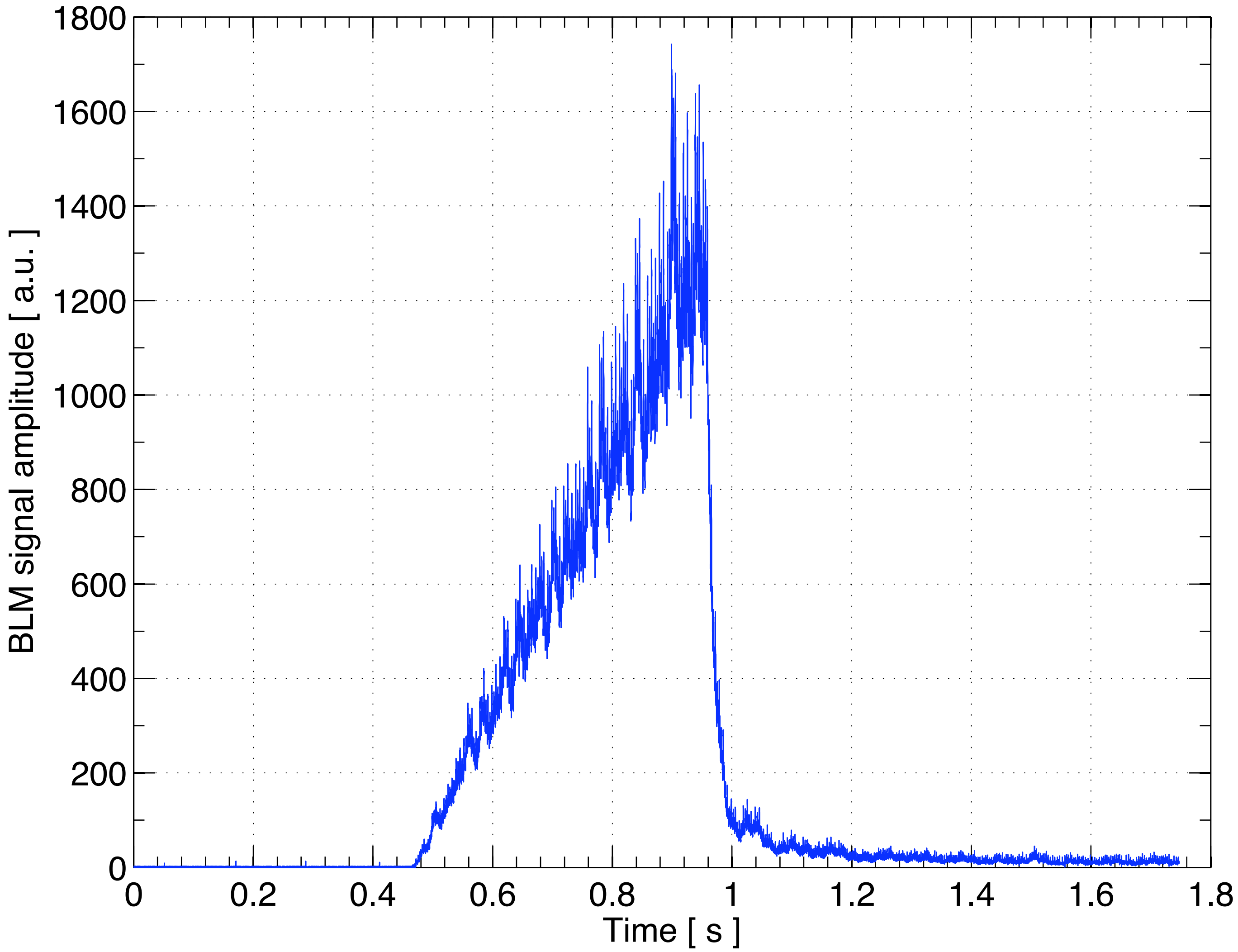


Collimator control application (II)



Special selection panel to sort collimator by Beam, IP and type (E. Veyrunes, G. Kruk)

Fast beam losses at the collimator



Beam tests at the SPS:

- Dedicated collimator buffer HW triggered by collimator movements
- Special acquisition of the **Post-Mortem buffer** 43000 points at 40 μs !!
- Capture mode of 4048 points at 2.56 ms or 40 μs