

*LHC Beam Commissioning Workshop*

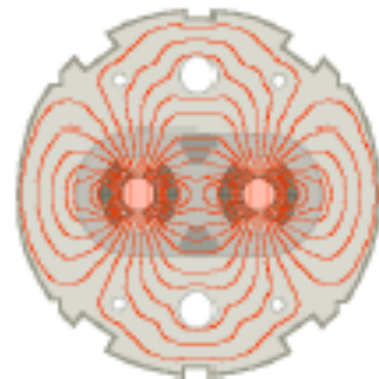
*Hilton Hotel, Evian, France*

*December 7<sup>th</sup>-9<sup>th</sup>, 2010*

# How to improve the turn-around

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***CERN - BE department - OP group***





# Acknowledgments



Xavier Buffat (EPFL, Lausanne, CH)

Verena Kain

Mike Lamont

**Chris Roderick**

Ralph Steinhagen

Walter Venturini Delsolaro

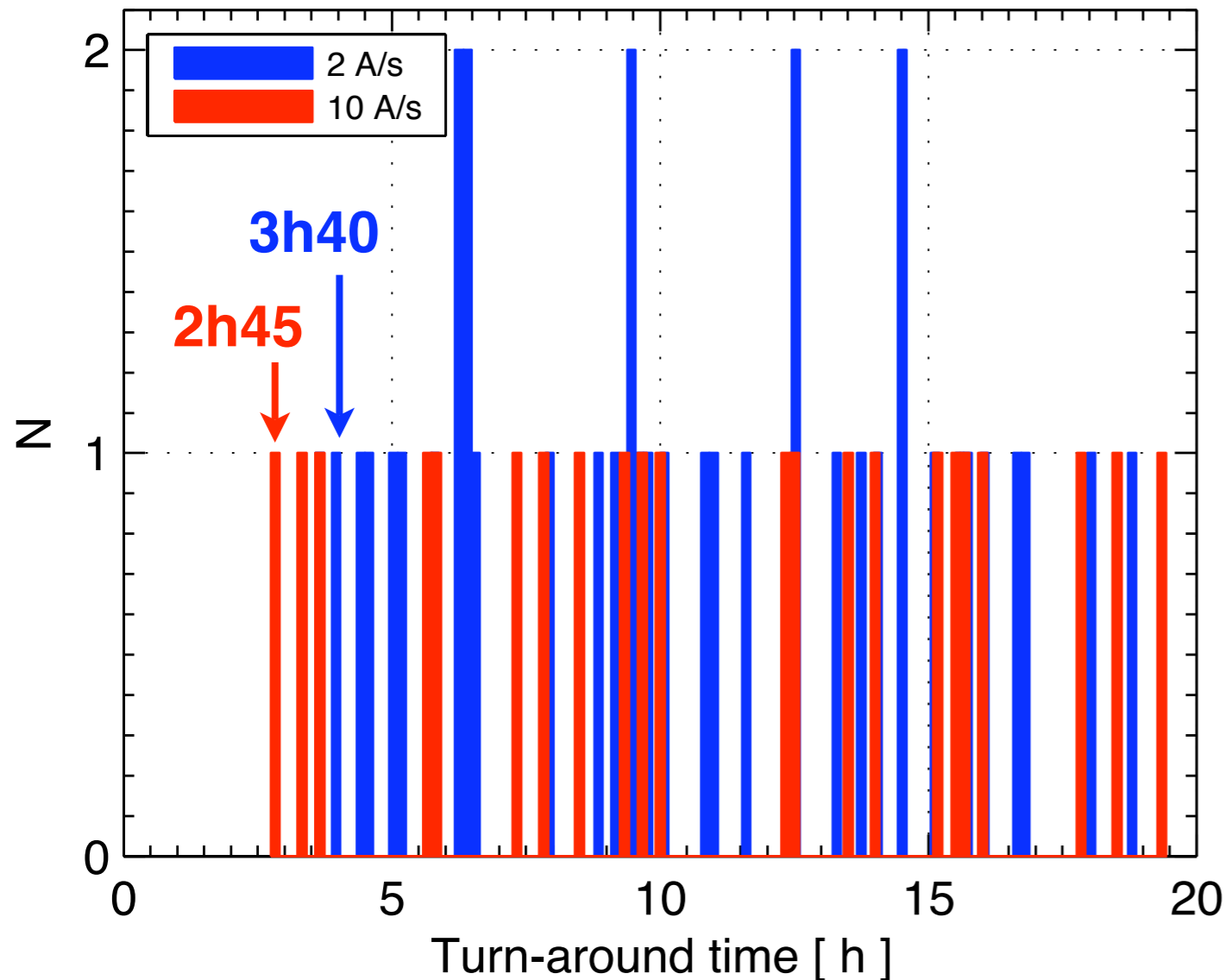
Jörg Wenninger



- Introduction**
- Scope and assumptions**
- Time lost / improvements**
- Conclusions**



*Dump to stable beam turn-around time*

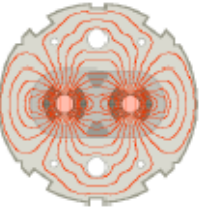


Minimum with 2010 parameters

| Machine phase   | Time [ s ]    |
|-----------------|---------------|
| Pre-cycle combo | 2100+300      |
| Inject probe    | 300           |
| Inject physics  | 1900 (=50x38) |
| Prepare Ramp    | 120           |
| Ramp            | 1400          |
| Flat top        | 0             |
| Squeeze         | 1041          |
| Adjust          | 108           |
| <b>TOTAL</b>    | <b>2h00</b>   |

The record turn around time (proton operation, 10 A/s, 38 injections) is **45 minutes** longer than the best achievable with the 2010 parameters.  
 The distribution is well above the **3h-4h!**

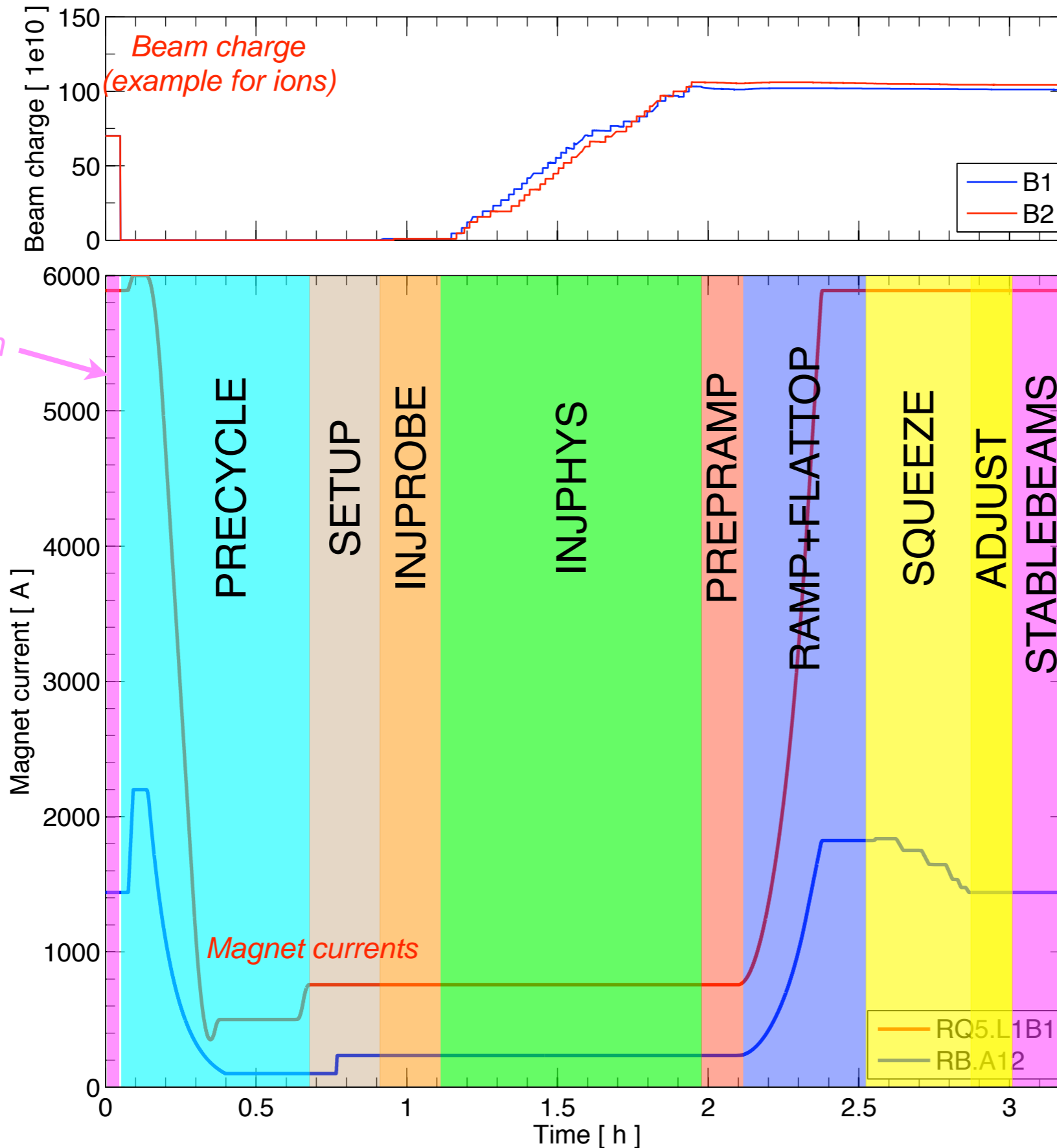
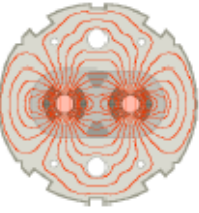
**Where did we loose this time? What can be improved in 2011?**



- ☑ **Focus on the proton “Run II”, brief mention of ion operation**
  - “Stable” operation for physics in Sep./Oct.: 2 MJ → **25 MJ**.
  - Bunch trains, crossing angles, ramp rate of 10 A/s.
- ☑ **Statistics based on physics fill only (machine available)**
  - Machine setups, system commissioning time end EOFs disregarded.
- ☑ **“Soft” times of machine mode changes used for statistics**
  - Uncertainty on the scale of some minutes.
- ☑ **Compare achieved times with “theoretical” minimum values**
- ☑ **Assume that the HWC parameters are not changed**
  - Times for pre-cycle, ramp and squeeze are GIVEN.

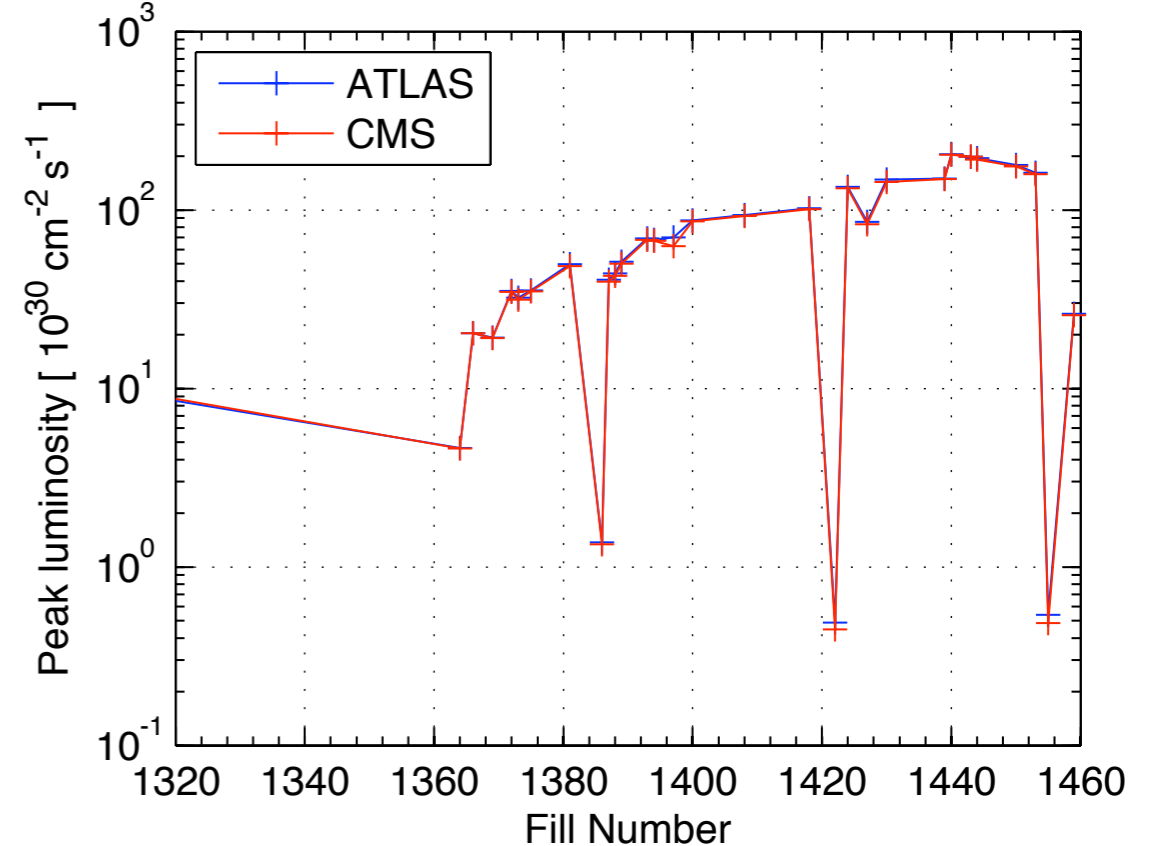
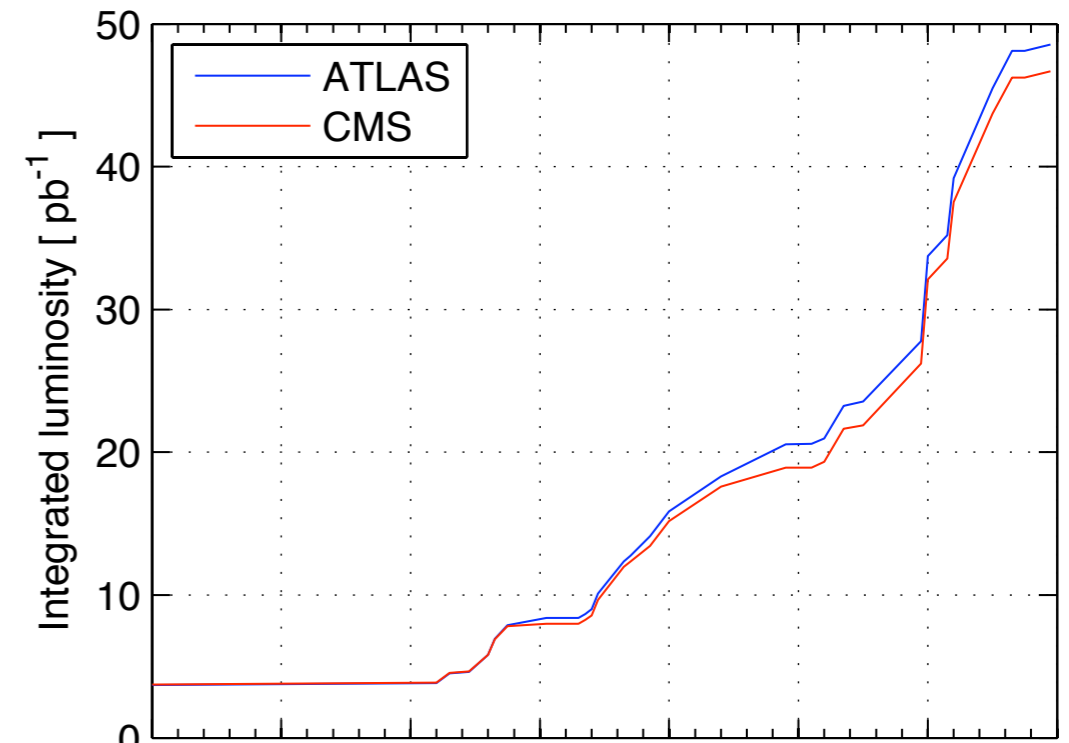
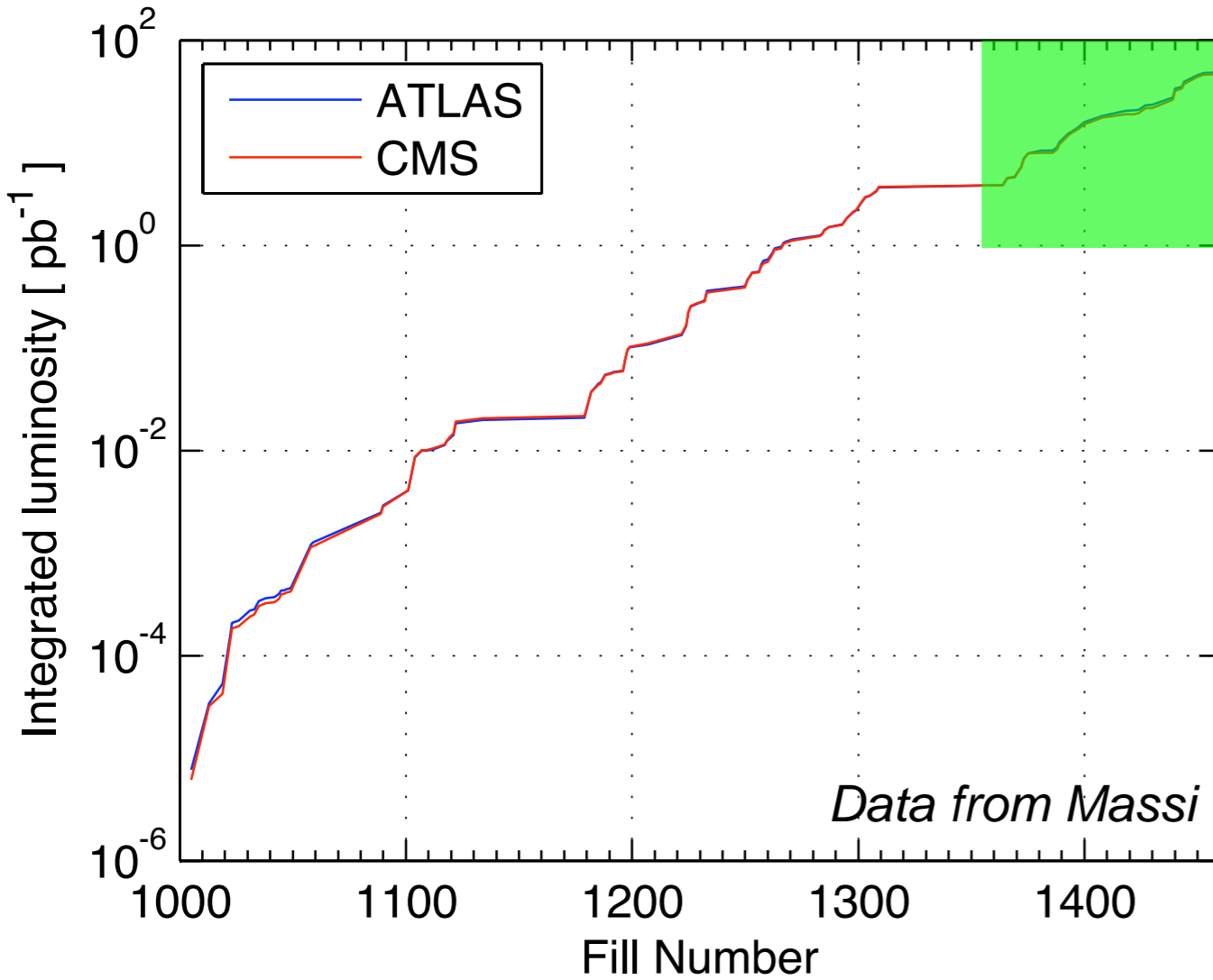
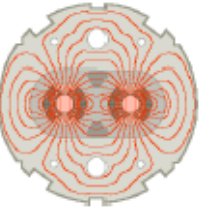
Figures are preliminary!

# Analysis of machine modes



- Remarks:
- Analysis of **successful fills** leading to StBeams
  - “Soft” timing for modes (sequencer or manual)
  - Calculate average time for each mode
  - Pre-cycle and setup considered together
  - Handshakes considered separately

# Physics fills considered



## Proton "Run II":

Stored energy up to ~ 25 MJ

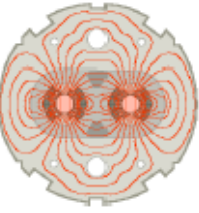
Bunch trains, Crossing angles

29 good fills with Stable Beams

Peak luminosity > 2 x 10<sup>32</sup> cm<sup>-2</sup> s<sup>-1</sup>



# Table with information on physics fills



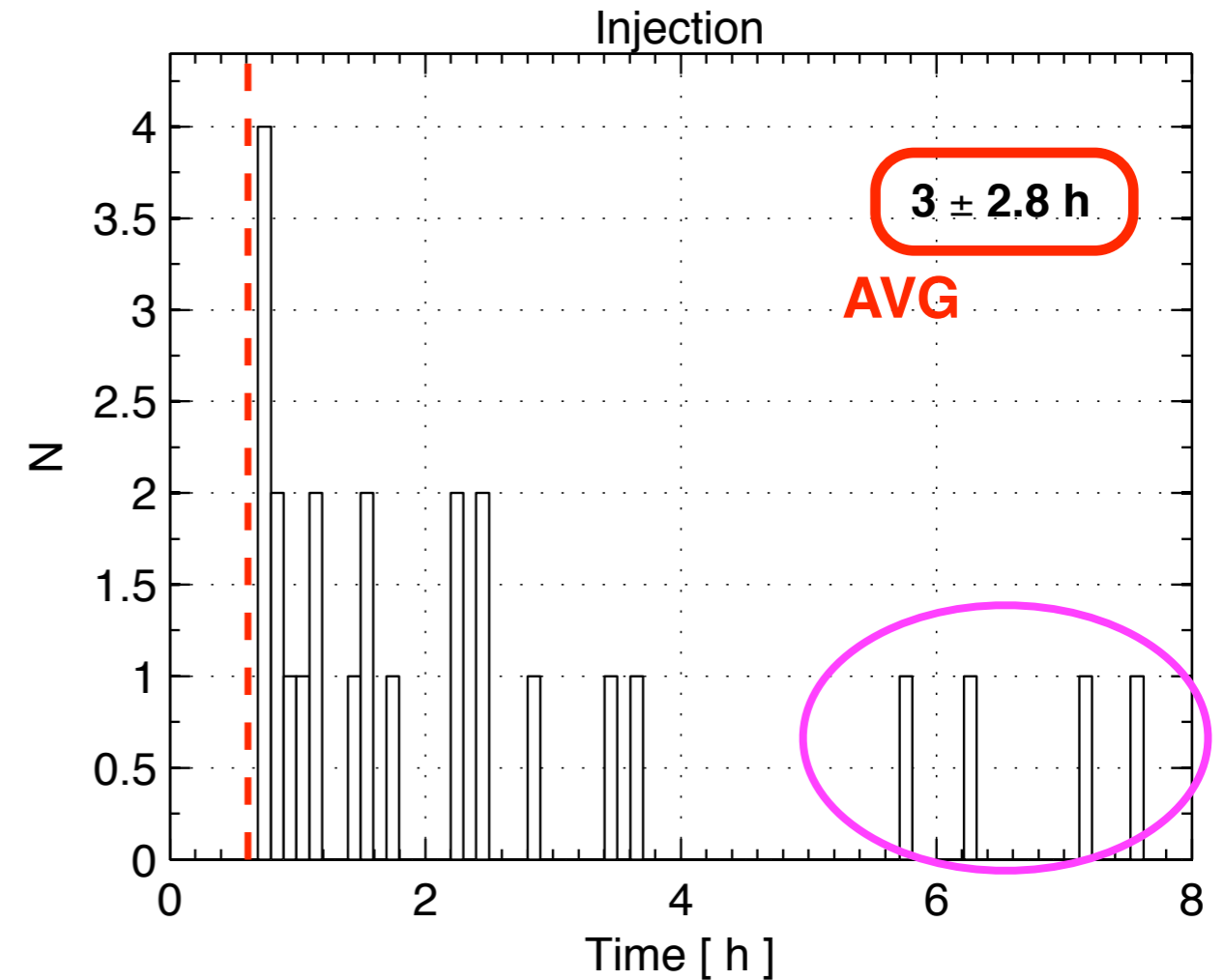
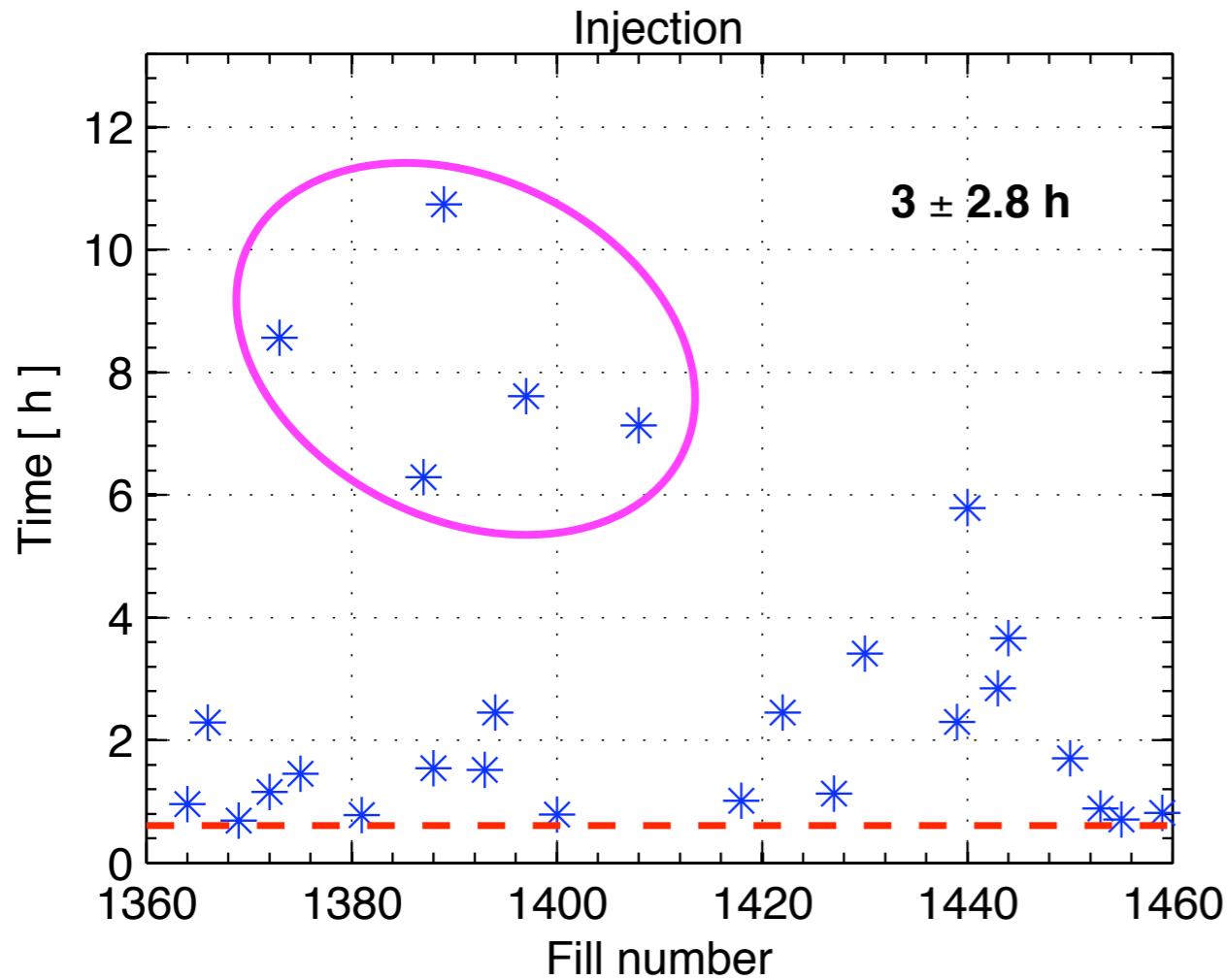
| FILL | DATE                  | INJPR | INJPH | PRRAMP | RAMP | FLATTOP | SQUEEZE | ADJUST | STABLE | DUMP |
|------|-----------------------|-------|-------|--------|------|---------|---------|--------|--------|------|
| 1364 | Sep 22, 2010 14:55:00 | 1969  | 1469  | 899    | 1532 | 409     | 2187    | 1432   | 49311  | 339  |
| 1366 | Sep 23, 2010 17:10:00 | 8224  | 0     | 166    | 1494 | 198     | 2028    | 1138   | 50486  | 350  |
| 1369 | Sep 25, 2010 7:39:00  | 621   | 1868  | 682    | 1533 | 178     | 1996    | 508    | 5331   | 355  |
| 1372 | Sep 25, 2010 17:40:00 | 2496  | 1663  | 287    | 1466 | 256     | 1675    | 652    | 49706  | 391  |
| 1373 | Sep 26, 2010 19:27:00 | 19946 | 10897 | 323    | 1880 | 125     | 3820    | 29     | 45079  | 663  |
| 1375 | Sep 28, 2010 0:23:00  | 2053  | 3187  | 310    | 1461 | 60      | 2853    | 300    | 32427  | 318  |
| 1381 | Sep 30, 2010 0:25:00  | 0     | 2807  | 434    | 1480 | 284     | 3694    | 949    | 11644  | 0    |
| 1386 | Oct 1, 2010 11:30:00  | 0     | 0     | 361    | 1767 | 78      | 1660    | 1523   | 10978  | 0    |
| 1387 | Oct 2, 2010 3:08:00   | 19027 | 3601  | 688    | 2319 | 472     | 3281    | 194    | 7452   | 573  |
| 1388 | Oct 2, 2010 8:56:00   | 3455  | 2105  | 371    | 1449 | 276     | 2366    | 145    | 7968   | 1243 |
| 1389 | Oct 3, 2010 11:17:00  | 34570 | 4082  | 1043   | 2649 | 2232    | 2010    | 1073   | 26156  | 0    |
| 1393 | Oct 4, 2010 18:01:00  | 1570  | 3882  | 212    | 1455 | 256     | 1512    | 734    | 49411  | 167  |
| 1394 | Oct 5, 2010 21:58:00  | 1829  | 6990  | 246    | 1611 | 858     | 1448    | 1061   | 6505   | 0    |
| 1397 | Oct 7, 2010 2:23:00   | 20924 | 6463  | 183    | 1557 | 486     | 1536    | 613    | 23422  | 336  |
| 1400 | Oct 8, 2010 0:36:00   | 378   | 2443  | 152    | 1460 | 273     | 1654    | 588    | 24003  | 0    |
| 1408 | Oct 11, 2010 19:20:00 | 13831 | 11856 | 923    | 1470 | 290     | 2107    | 936    | 35829  | 294  |
| 1418 | Oct 14, 2010 1:38:00  | 707   | 2941  | 335    | 1612 | 89      | 1881    | 547    | 30712  | 268  |
| 1422 | Oct 15, 2010 11:13:00 | 4075  | 4735  | 1220   | 1517 | 204     | 2025    | 454    | 19173  | 134  |
| 1424 | Oct 16, 2010 0:30:00  | 0     | 0     | 513    | 1484 | 219     | 1710    | 1000   | 3348   | 371  |
| 1427 | Oct 16, 2010 20:58:00 | 1274  | 2782  | 344    | 1446 | 162     | 1460    | 457    | 38071  | 307  |
| 1430 | Oct 18, 2010 2:25:00  | 0     | 12293 | 368    | 1330 | 378     | 1515    | 941    | 2398   | 304  |
| 1439 | Oct 24, 2010 8:00:00  | 3761  | 4513  | 1247   | 1544 | 785     | 2146    | 625    | 38544  | 331  |
| 1440 | Oct 25, 2010 0:35:00  | 8025  | 12821 | 234    | 1496 | 327     | 1581    | 649    | 40803  | 749  |
| 1443 | Oct 26, 2010 3:34:00  | 4627  | 5617  | 334    | 1445 | 150     | 1437    | 526    | 8430   | 0    |
| 1444 | Oct 26, 2010 11:35:00 | 1797  | 11385 | 224    | 1540 | 444     | 1495    | 653    | 25962  | 273  |
| 1450 | Oct 27, 2010 22:44:00 | 3341  | 2798  | 1147   | 1362 | 3140    | 1664    | 978    | 52357  | 1597 |
| 1453 | Oct 29, 2010 2:16:00  | 1030  | 2169  | 147    | 1096 | 444     | 1471    | 696    | 22823  | 360  |
| 1455 | Oct 30, 2010 3:33:00  | 1577  | 965   | 427    | 1485 | 27      | 2240    | 22614  | 10713  | 0    |
| 1459 | Oct 31, 2010 0:24:00  | 1382  | 1542  | 538    | 1455 | 617     | 1563    | 2184   | 21676  | 317  |





- Introduction
- Scope and assumptions
- Time lost / improvements**
- Conclusions

# Time spent at injection



Average time for injection (INJPROBE + INJPHYSICS) = **3h!!**

A few outliers above 6h (statistically not relevant?) but main distribution between **1h and 4h**.

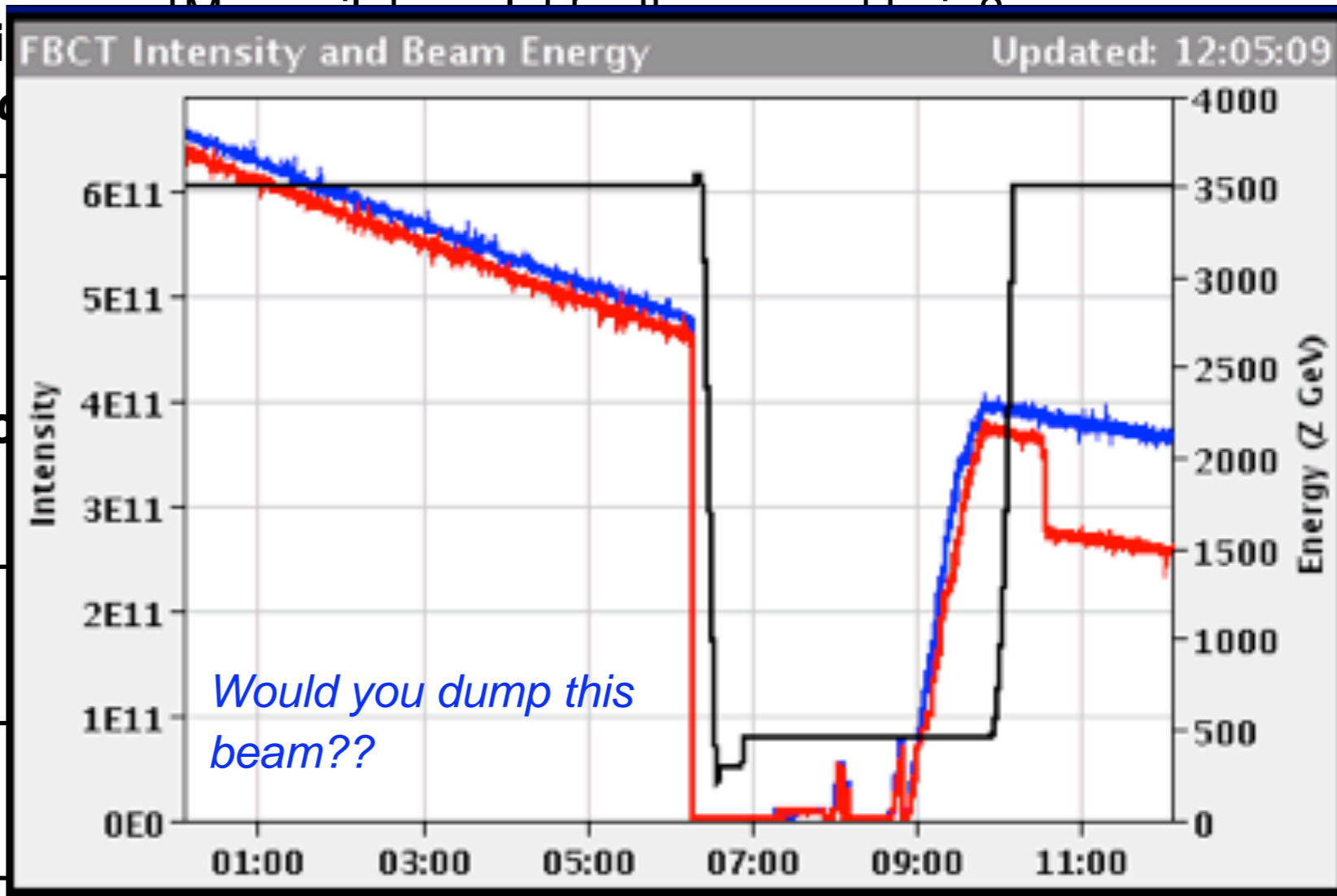
No significant improvement as we increase the operational experience.

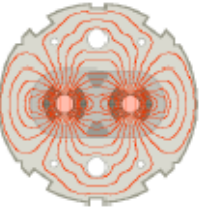


| Issue  | Possible solution(s)   |
|--|--|
| <b>Losses in the lines / un-bunched beam</b>   | Not treated here! ( <i>Philippe + Wolfgang talks</i> )   |
| <b>LHC beam setup in the injectors</b>   | Improve the communication: <b>EARLY requests!</b><br>Finish the beam setup in the pre-cycle!<br>Check beam availability/quality <b>before dumping!</b>                                       |
| <b>Over-injection and “coups à vide”</b><br><i>(“Shit, we kicked out the pilot!”-syndrome)</i> | Move pilot on slot for the second train?<br>Leave 1 witness pilot in slot “1”?<br>SPS cycle with pilot and probe.  |
| <b>Injection quality</b>   | Longitudinal (BQM) ( <i>Giulia s talk</i> ) Transverse ?   |
| <b>IQC: reaction time and fake latches</b>   | Need <b>faster</b> response (data availability).<br><b>Separate injection request</b> of one beams from the IQC result of the other beam.<br><b>Realistic thresholds</b> for IQC parameters. |
| <b>RF loops</b>  | Set well-defined limits on the allowed loop errors. Do we adjust on the pilot or on the trains?  |
| <b>Set-up of pilot beams</b>   | <b>Preventive trims</b> should be formalized. Ideally, time-dependent trims for decay. <i>See Ezio s talk!</i>   |
| <b>Tools</b>   | Automatic eLog entries for images?   |

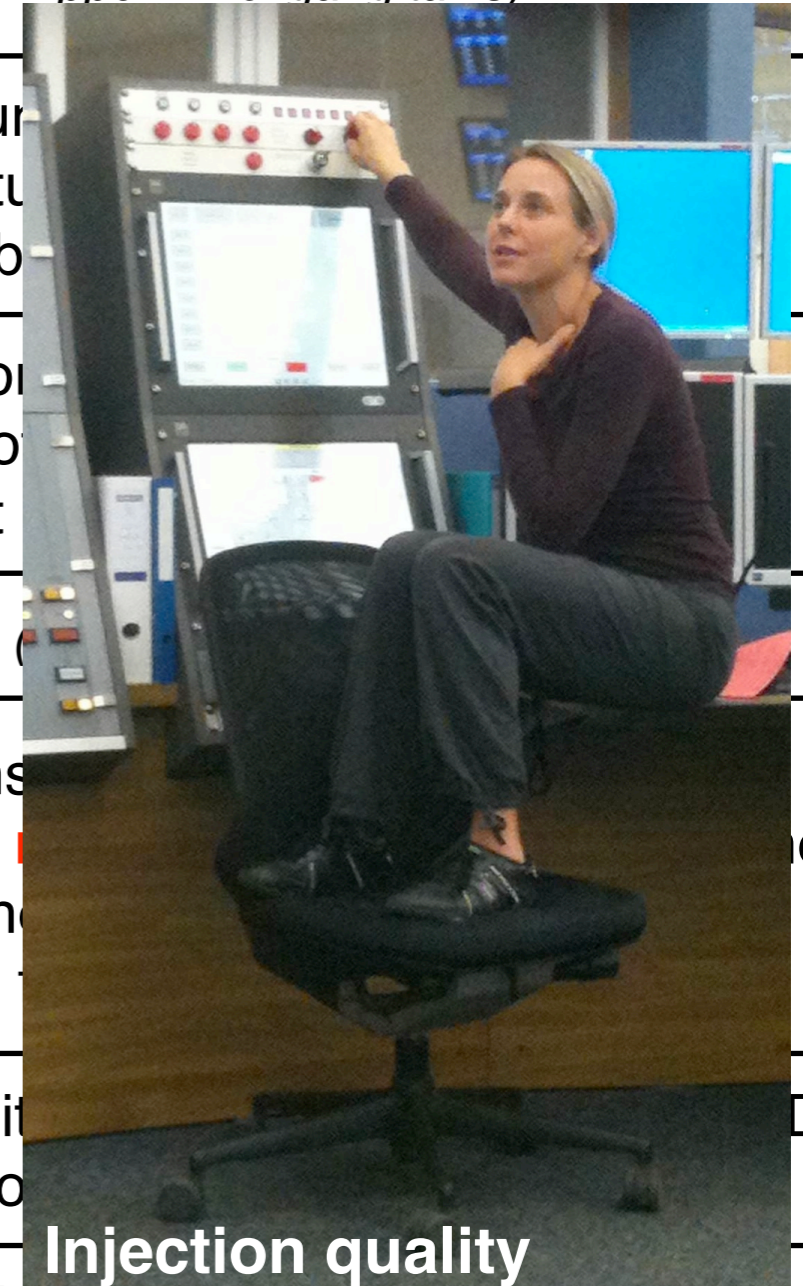


| Issue  | Possible solution(s)   |
|--|--|
| Losses in the lines / un-bunched beam  | Not treated here! ( <i>Philippe + Wolfgang talks</i> )   |
| LHC beam setup in the injectors  | Improve the communication: <b>EARLY requests!</b><br>Finish the beam setup in the pre-cycle!<br>Check beam availability/quality <b>before dumping!</b> |
| Over-injection and “coups à vie”<br>(“ <i>Shit, we kicked out the pilot!</i> ”-sync) | Maximize the number of successful injections<br>Minimize the number of failed injections   |
| Injection quality  |  |
| IQC: reaction time and fake late   |  |
| RF loops   |  |
| Set-up of pilot beams  |  |
| Tools  | Automatic eLog entries for images?   |

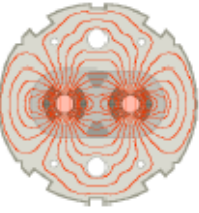




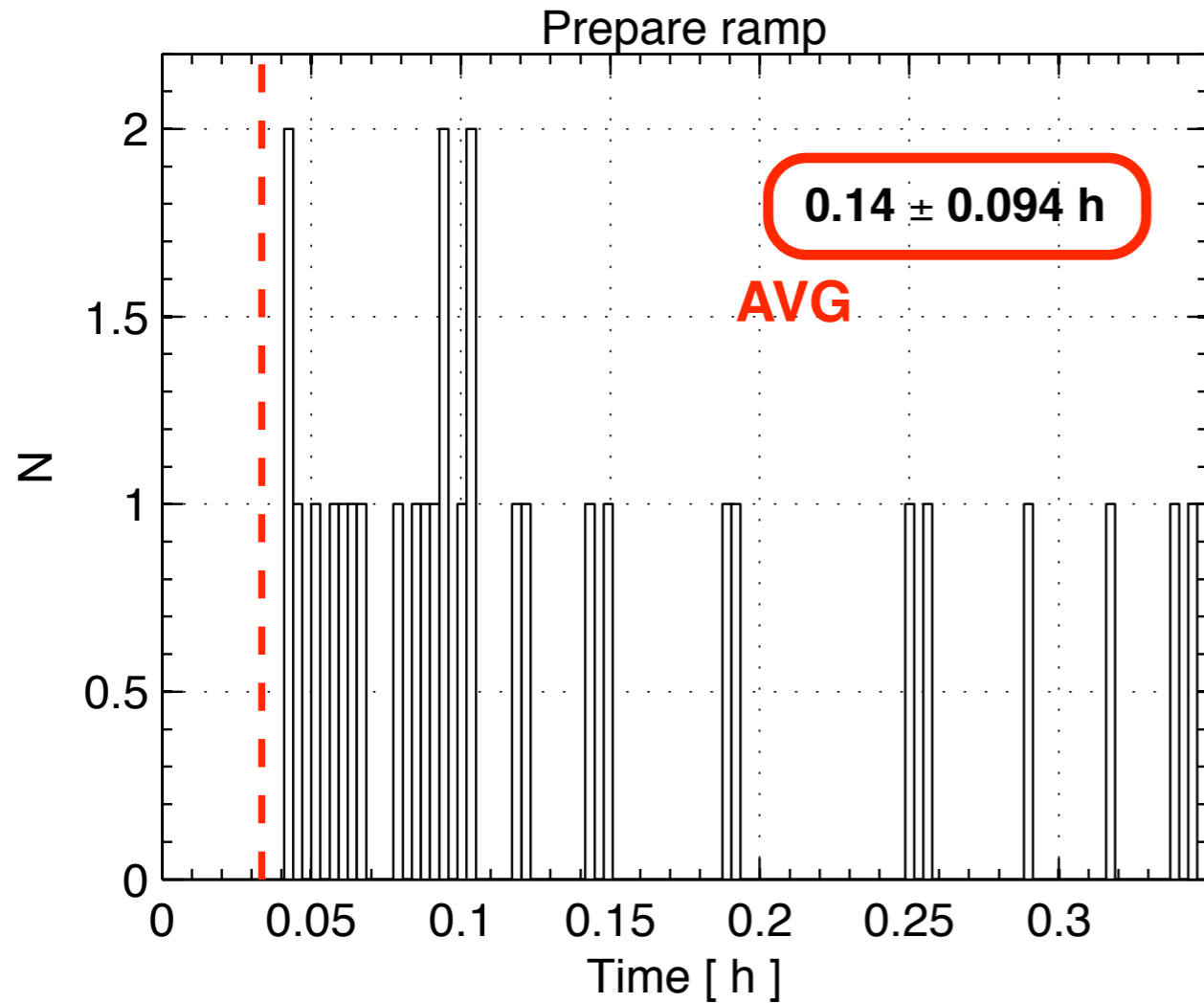
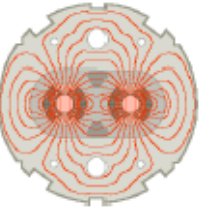
| Issue   | Possible solution(s)  |
|---|---|
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| RF loops  | Set well-defined limit<br>we adjust on the pilo   |
| Set-up of pilot beams   | <b>Preventive trims</b> should be formalized. Ideally, time-dependent trims for decay. <i>See Ezio s talk!</i>  |
| Tools   | Automatic eLog entries for images?  |



Injection quality



| Issue  | Possible solution(s)   |
|--|--|
| Losses in the lines / un-bunched beam  | Not treated here! ( <i>Philippe + Wolfgang talks</i> )   |
| LHC beam setup in the injectors  | Improve the communication: <b>EARLY requests!</b><br>Finish the beam setup in the pre-cycle!<br>Check beam availability/quality <b>before dumping!</b> |
| <b>Over-injection and “coups à vide”</b><br><i>(“Shit, we kicked out the pilot!”-syndrome)</i>   | Move pilot on slot for the second train?<br>Leave 1 witness pilot in slot “1”?<br>CPS cycle with pilot and probe                                       |
| <p>The figure contains two plots. The left plot, titled 'LHC RF Injection Phase Error - Beam 2', shows the phase error in degrees over the first 90 turns. The error starts at approximately -6 degrees, rises to 0 by 10 turns, and then fluctuates between 2 and 4 degrees. The right plot, titled 'LHC RF Injection Synchro Error - Beam 2', shows the synchro error in degrees over 1800 turns. It features a sharp peak of about 28 degrees at 150 turns, followed by a decay to a noisy baseline around 8 degrees.</p> |  |
| RF loops   | Set well-defined limits on the allowed loop errors. Do we adjust on the pilot or on the trains?  |
| Set-up of pilot beams  | <b>Preventive trims</b> should be formalized. Ideally, time-dependent trims for decay. <i>See Ezio s talk!</i>   |
| Tools  | Automatic eLog entries for images?   |



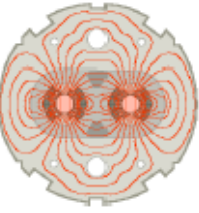
What do we do:

- Re-check orbit, tune and chroma
- Switch on feedback
- Incorporate settings into ramp
- Open injection collimators
- Close injection handshake
- Secure MKIs

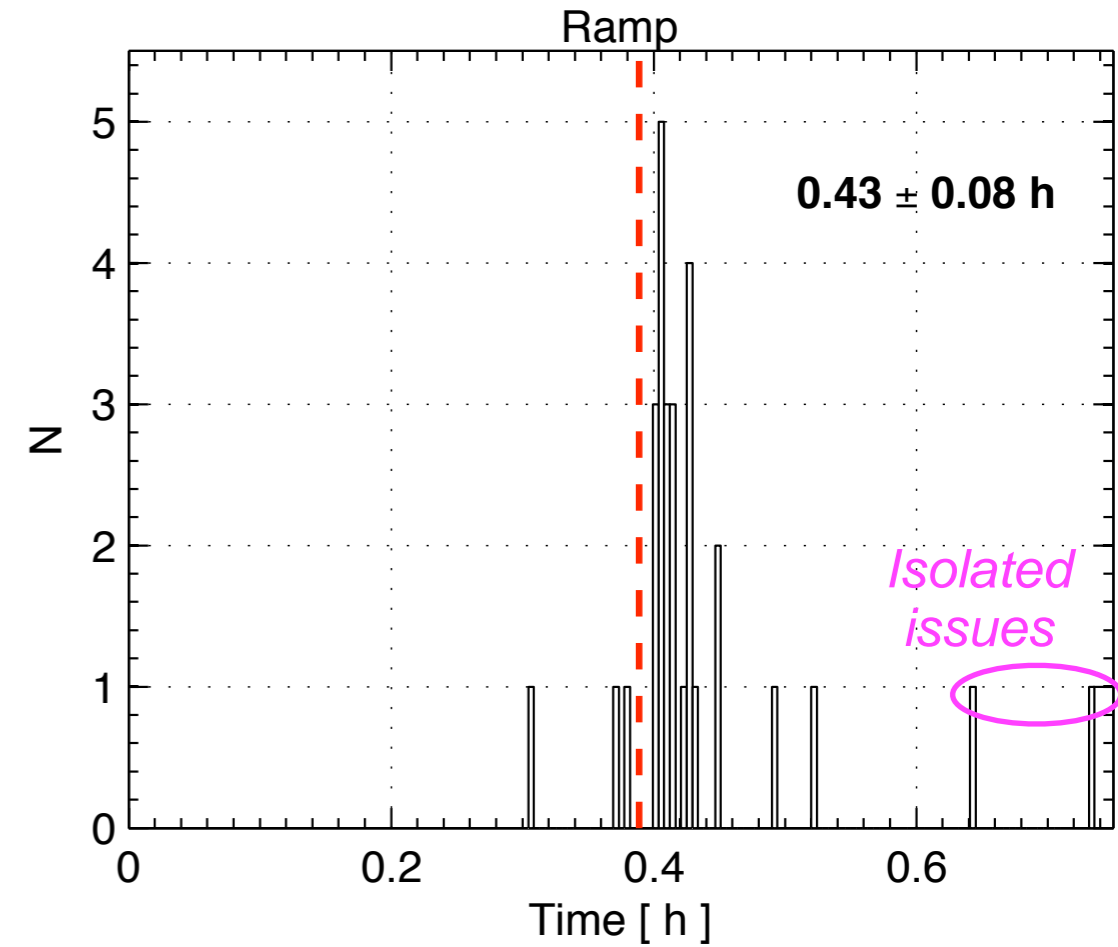
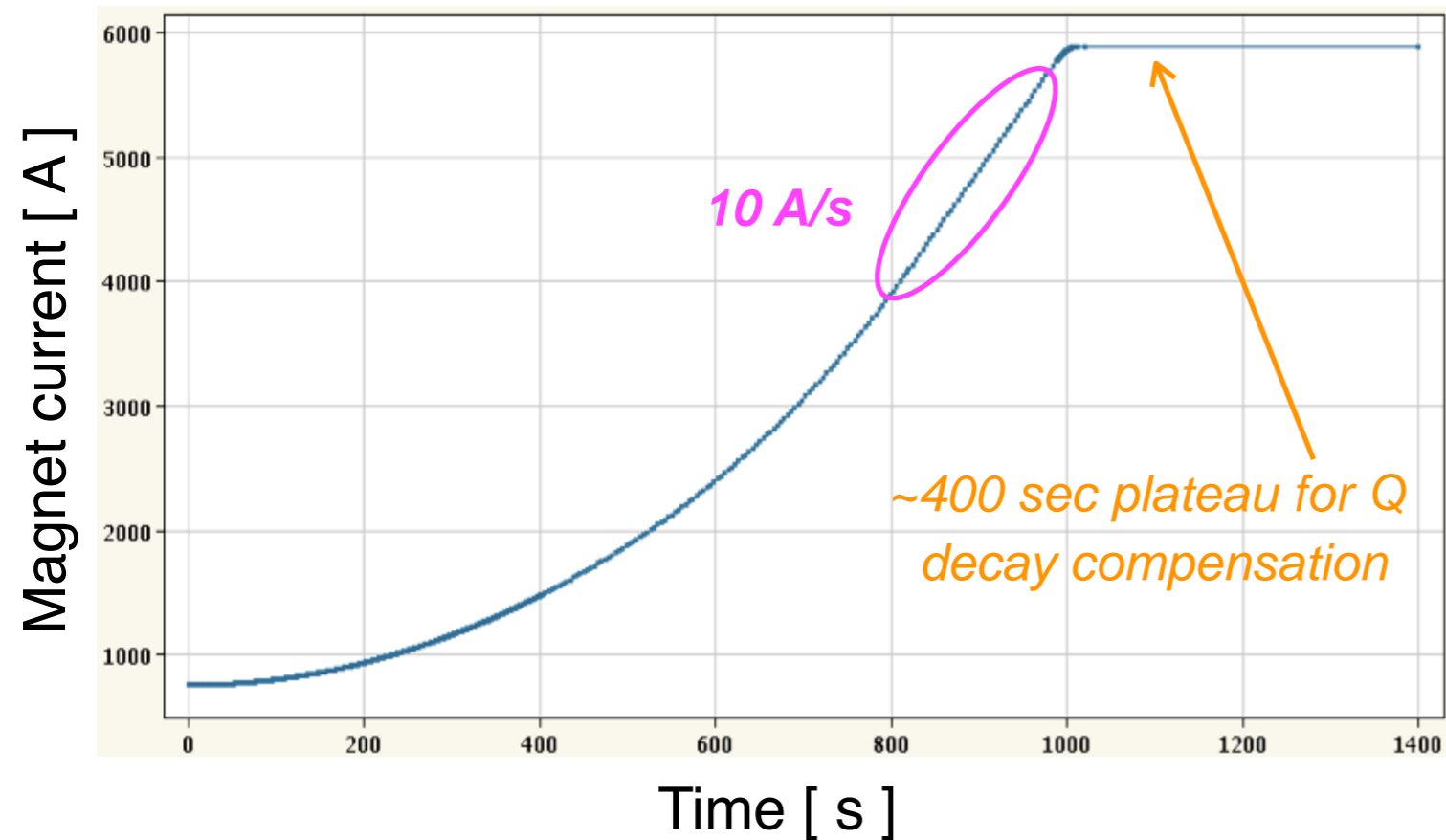
Possible improvements:

- Switch on the orbit and tune feedbacks while injecting!
- Perform the setting incorporation after switching FBs on.
- Automatic trims of chroma should be envisaged.

# Energy ramp



Main dipole current settings (1400s)

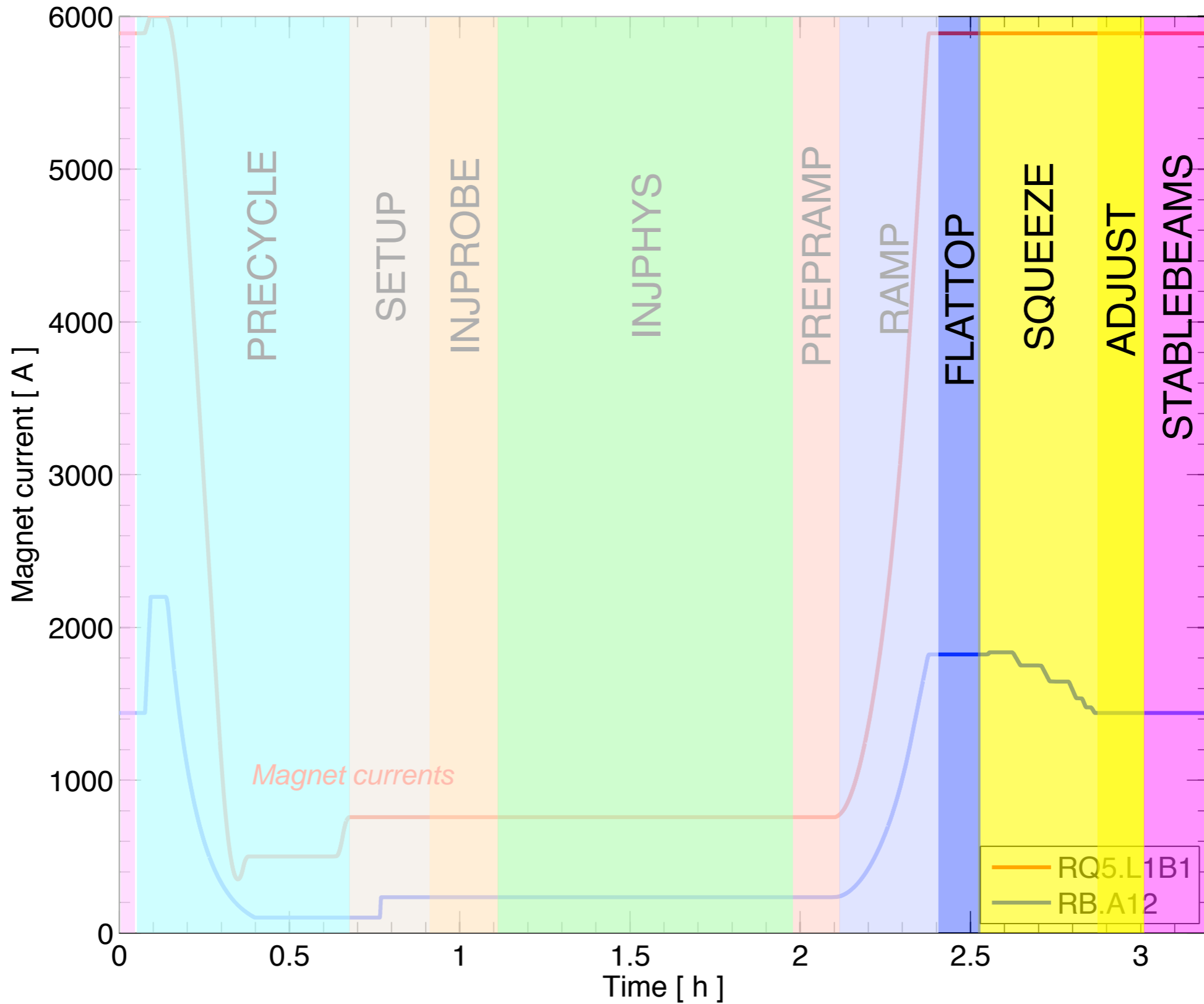


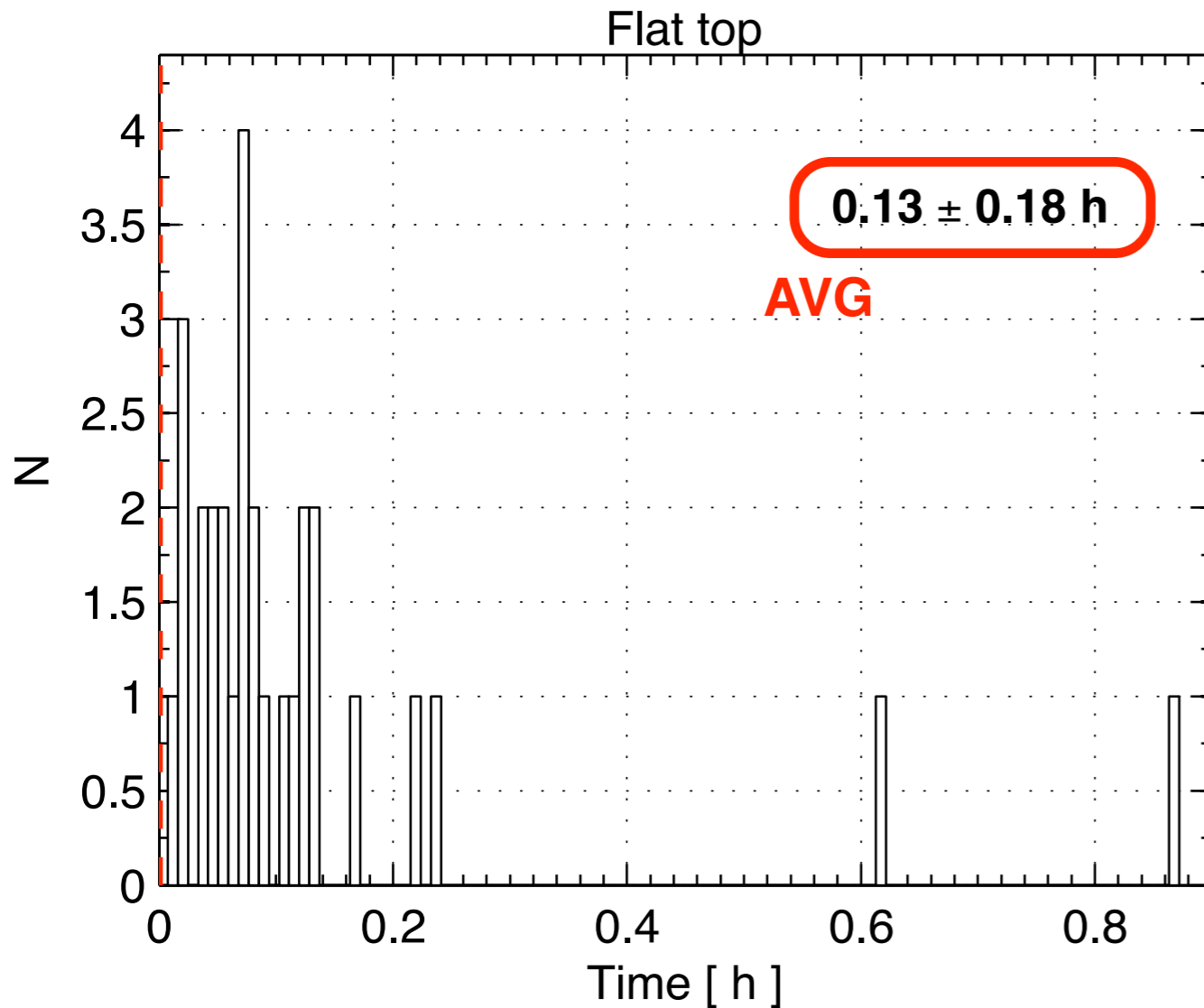
Time fixed by the magnet parameters - little margin for improvement unless:

- Review the current profile in the first part of the ramp ( $dl/dt \ll 10$  A/s)
- Do we need ~400 seconds for the decay?



# Where we are





What do we do:

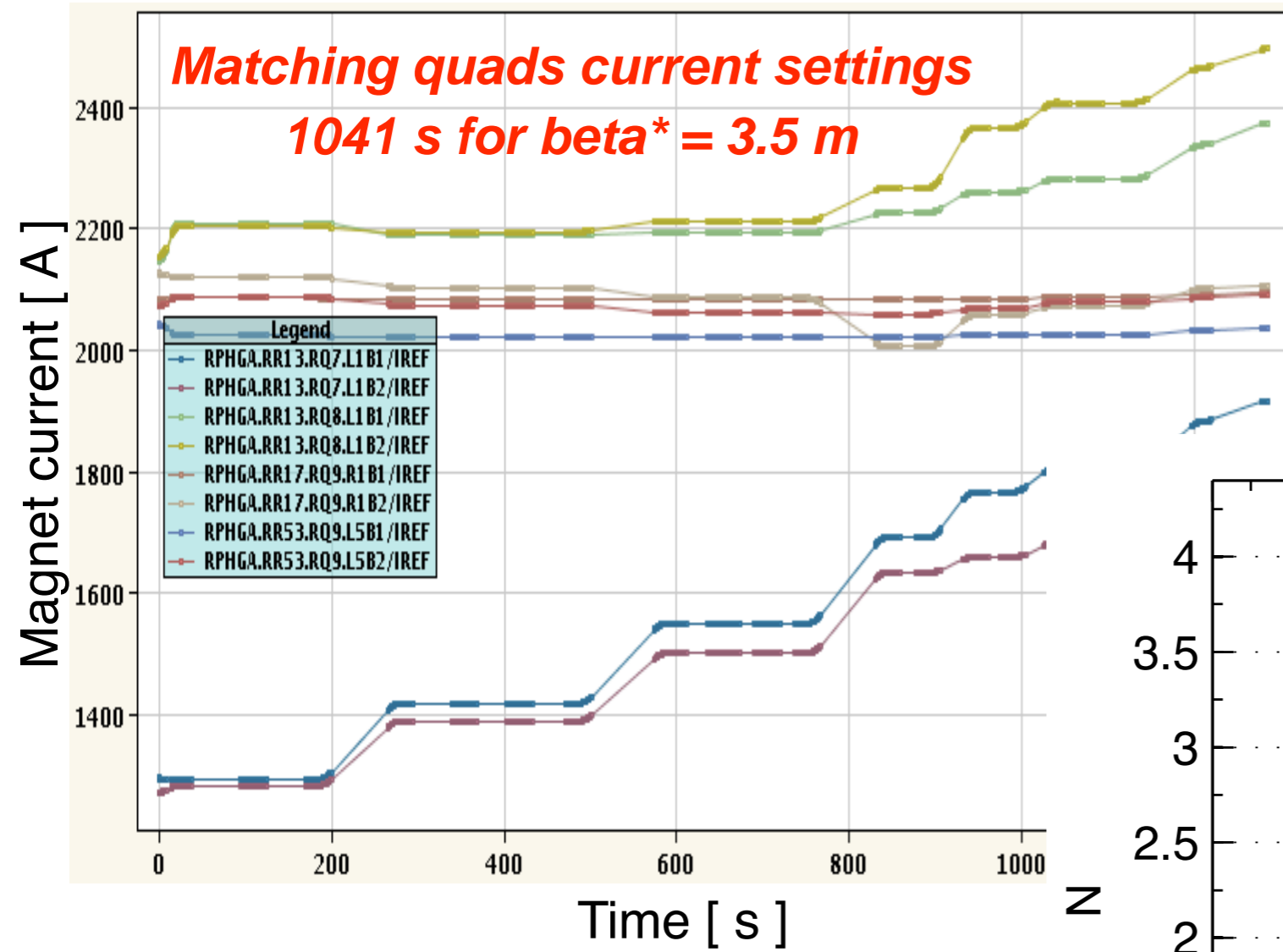
- Re-check orbit, tune and chroma.
- Update/check feedback refs.
- Incorporate settings into sq. functions.

## Possible improvements:

- Start incorporation and FB preparation during the ramp.
- Establish a policy for the chromaticity measurements.

*Almost NEVER done with several MJ in the machine!*

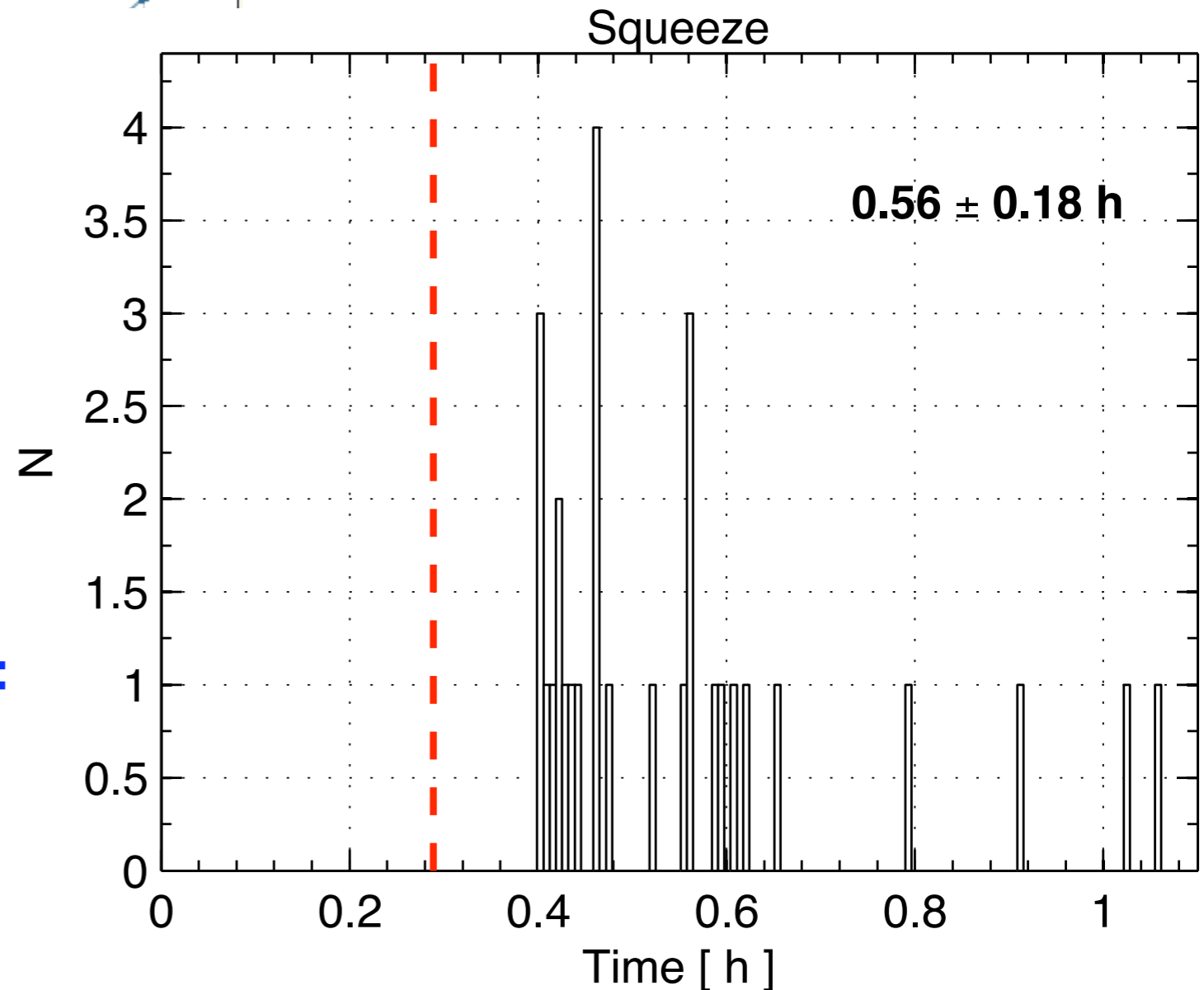
# Betatron squeeze



Like for ramp, predefined duration.

We stop TWICE:

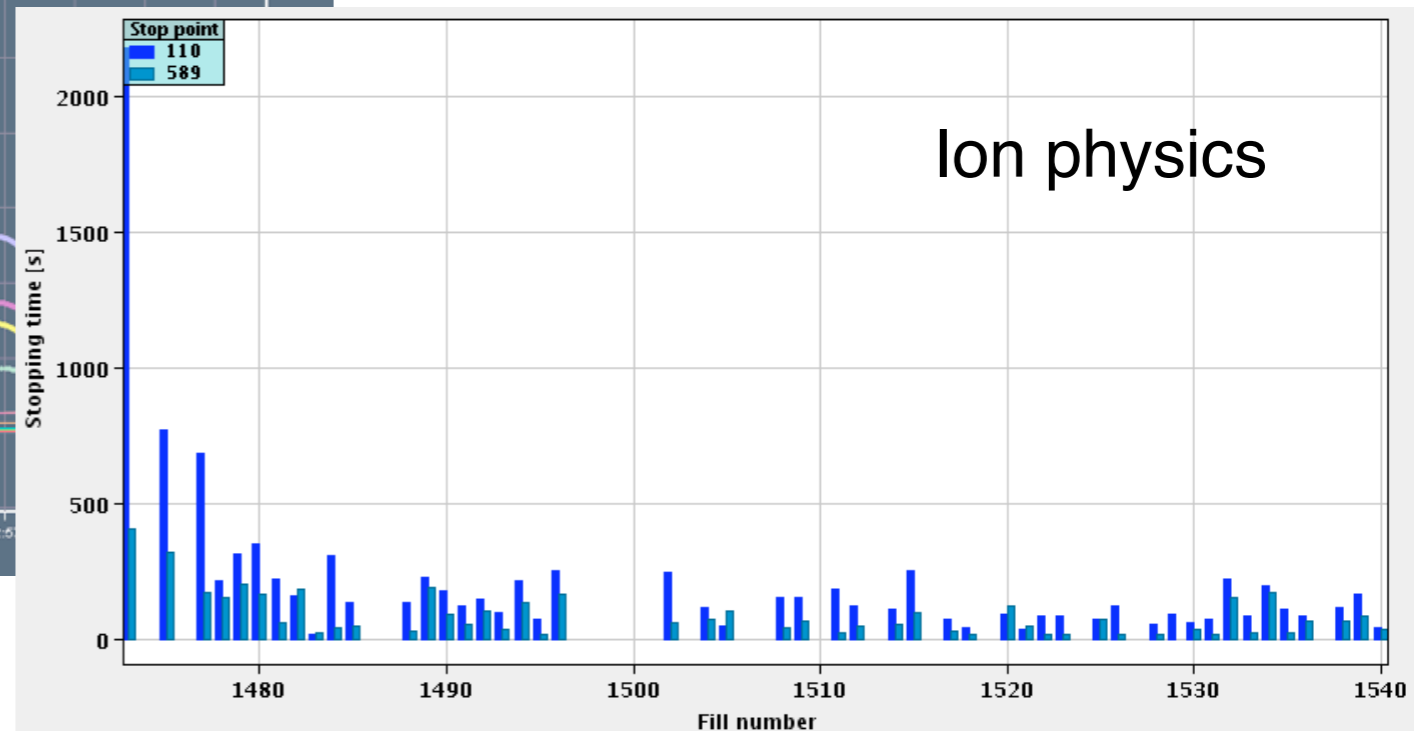
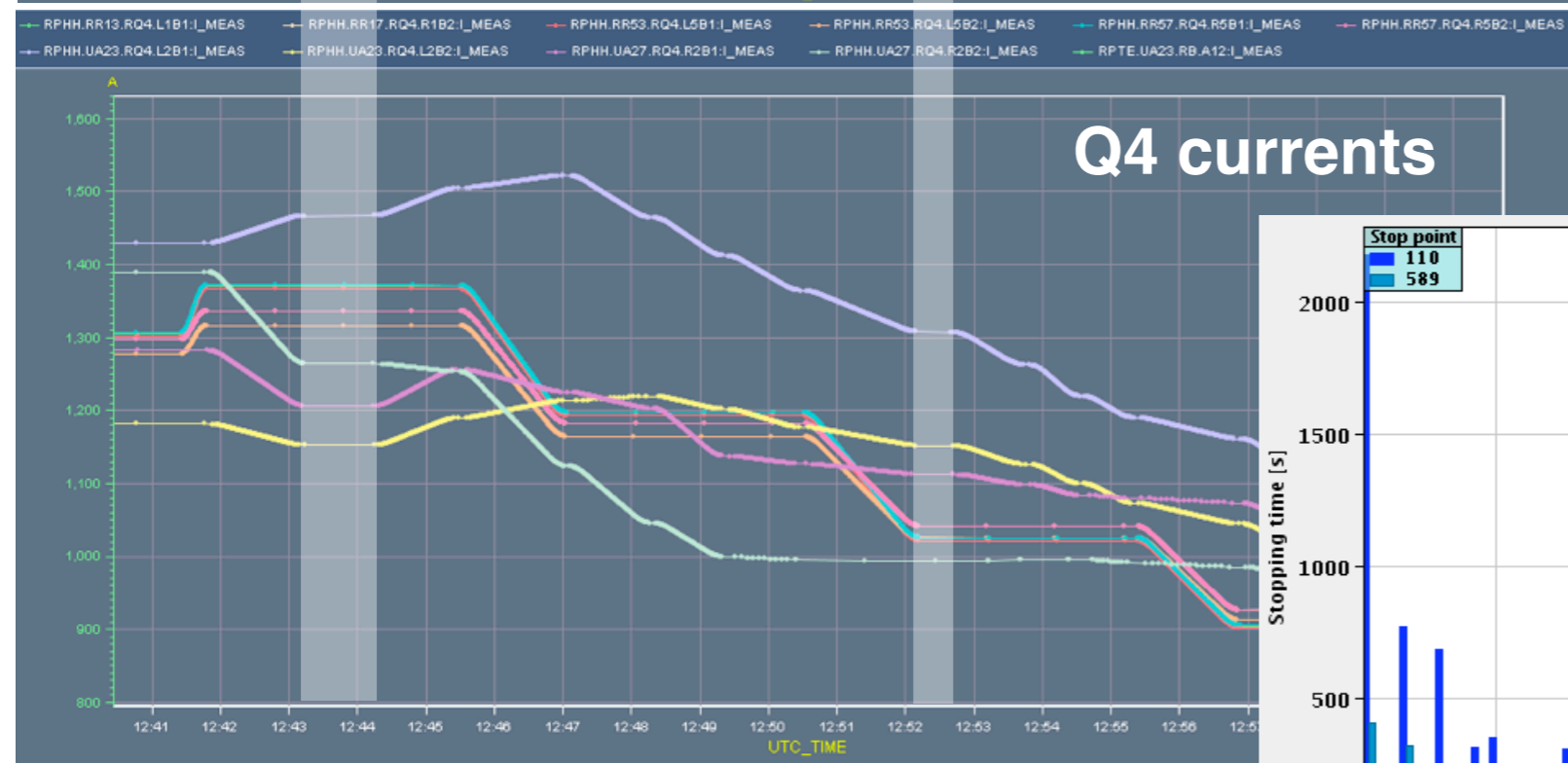
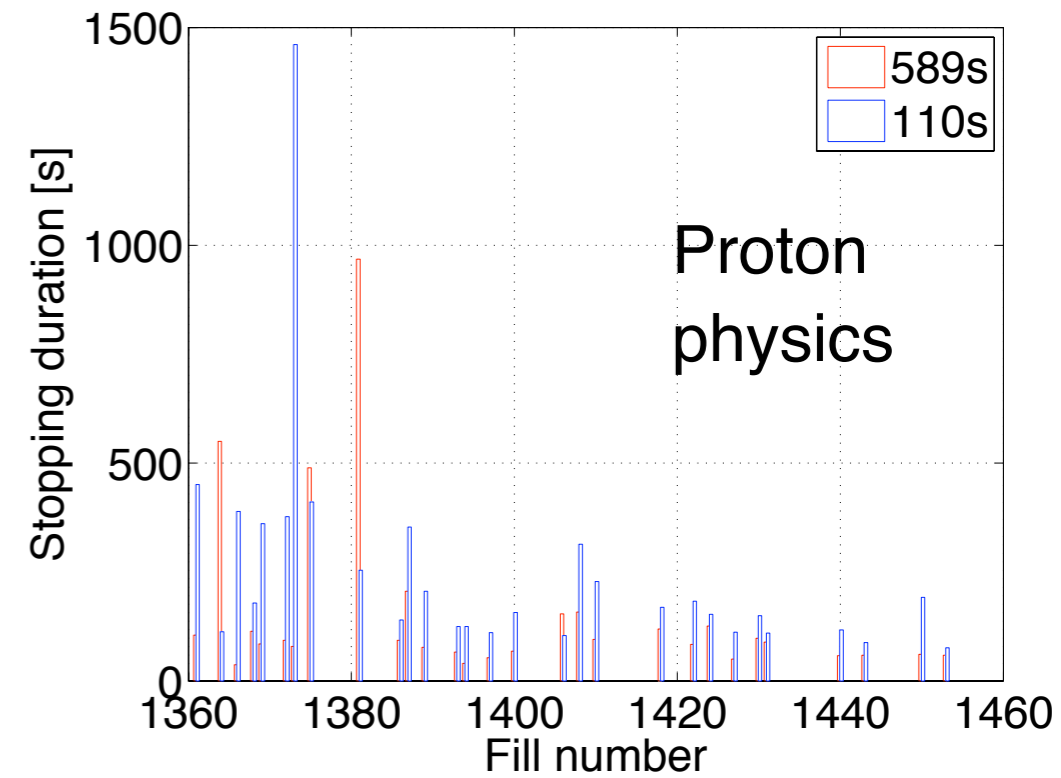
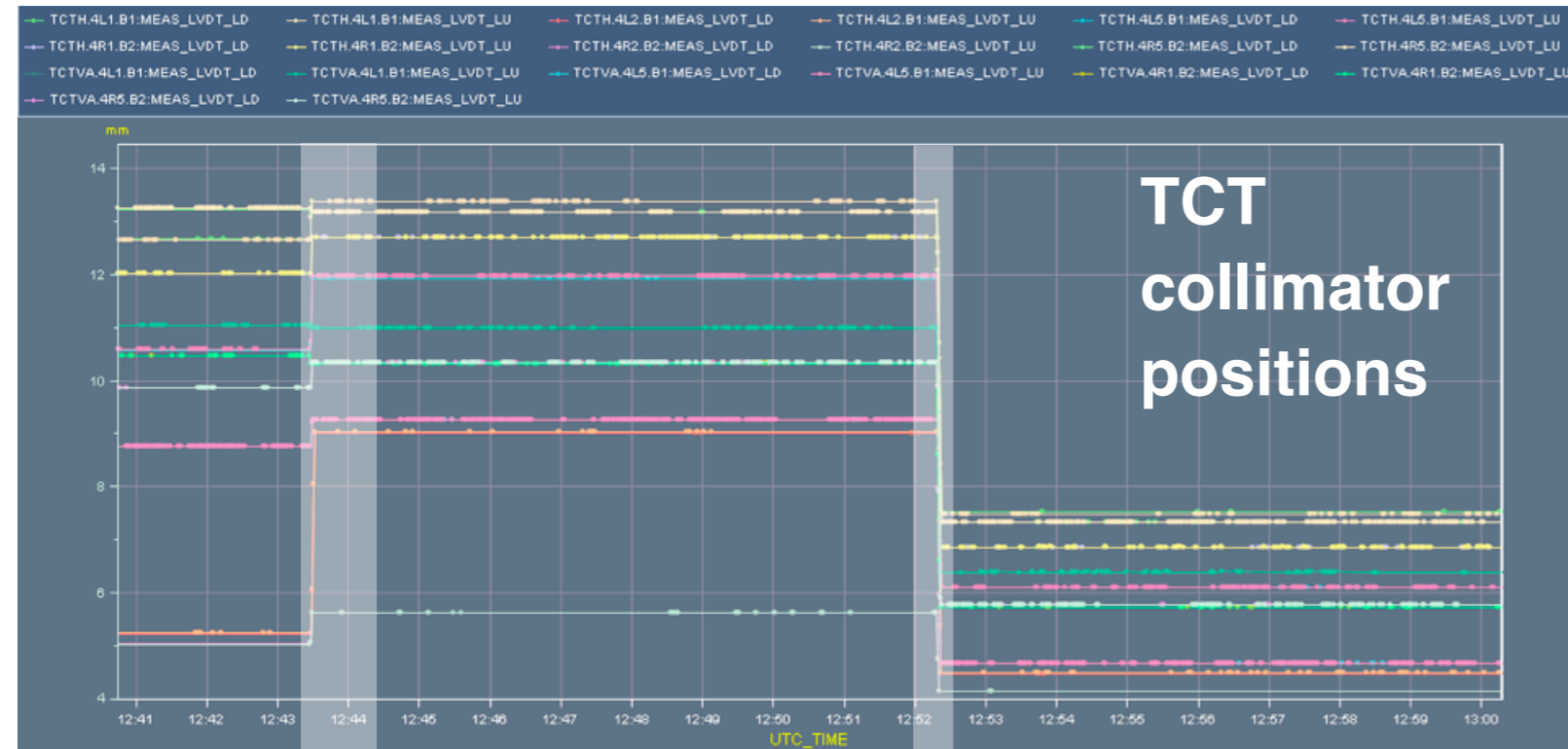
- Change orbit FB reference at 110s
- Move collimators at 5 m



**Squeeze sequences work WELL, but:**

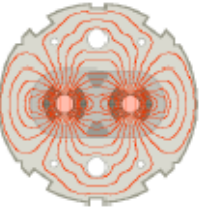
- Stop points leave room to errors!
- Discrete collimator movement not optimum.

# Squeeze - where do we loose time



X. Buffat

# Squeeze - continuous functions



**Human errors** are minimized if we remove the stopping points!

With the present configuration, this is possible if:

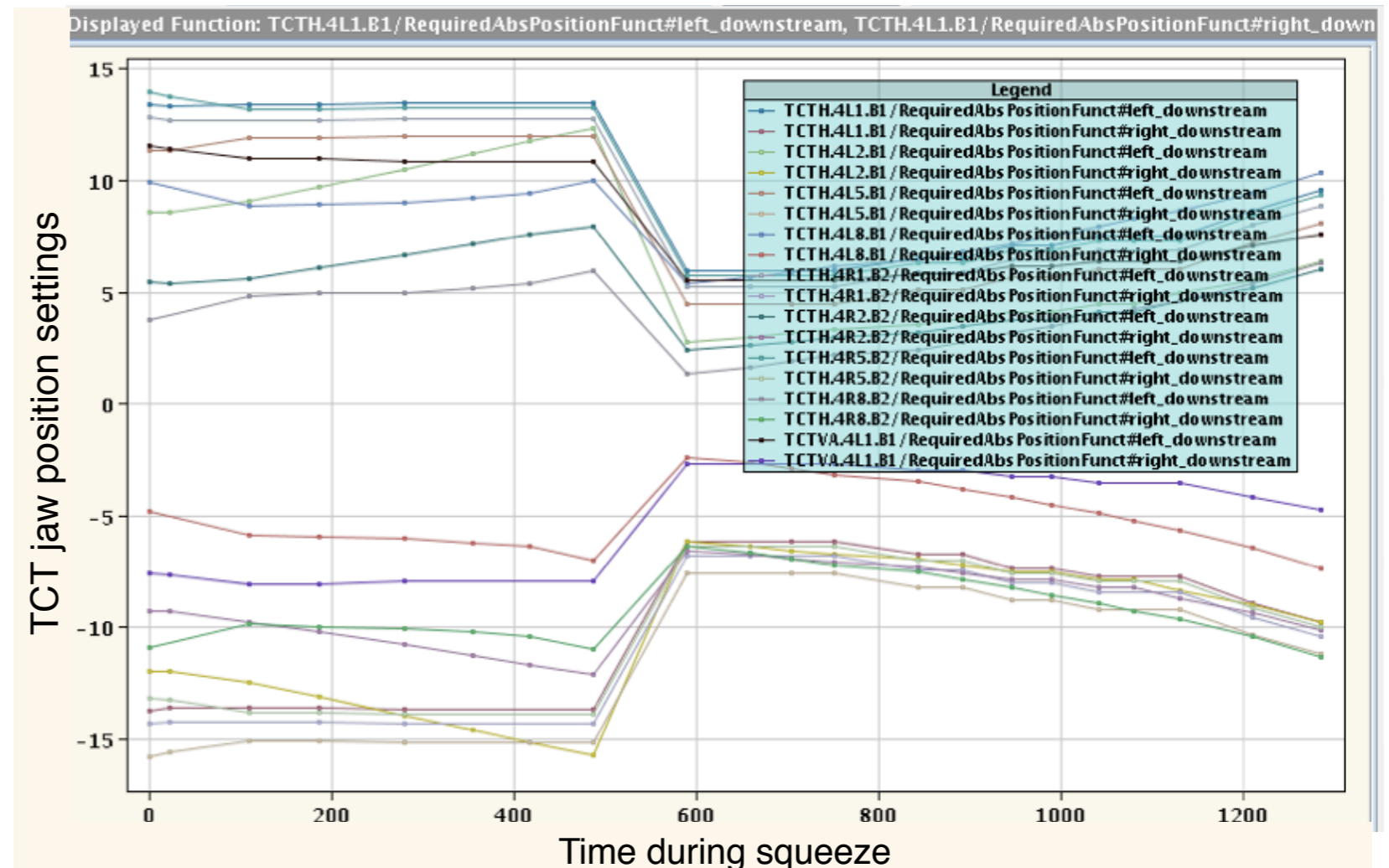
- The same orbit reference is used throughout the squeeze

OR

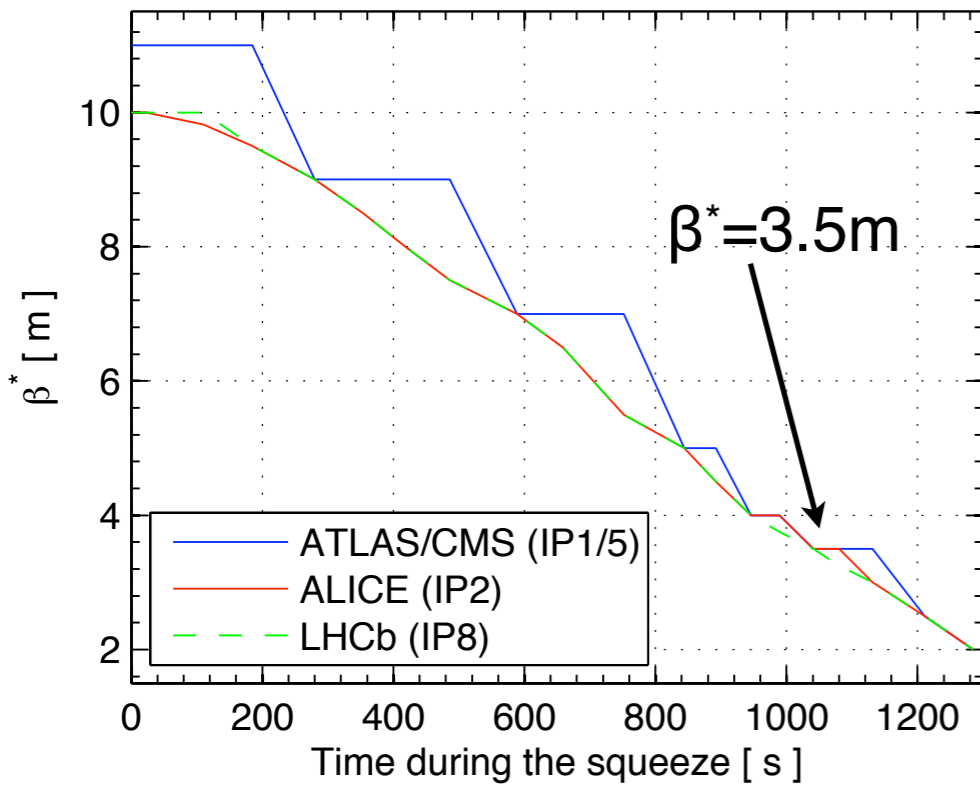
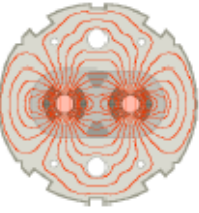
- Dynamic references are possible for the orbit feedback.

Note that **collimator functions are ready**. They could not be used because we cannot stop in the middle of critical limit functions.

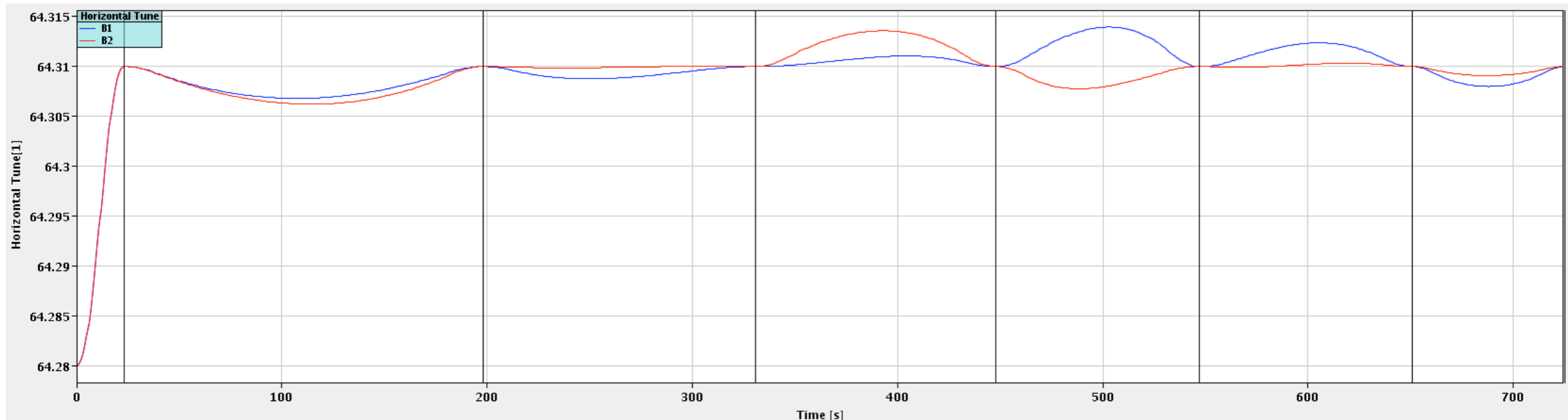
**Continuous functions:**  
**Gain ~ 10 min**  
**Save a few dumps...**



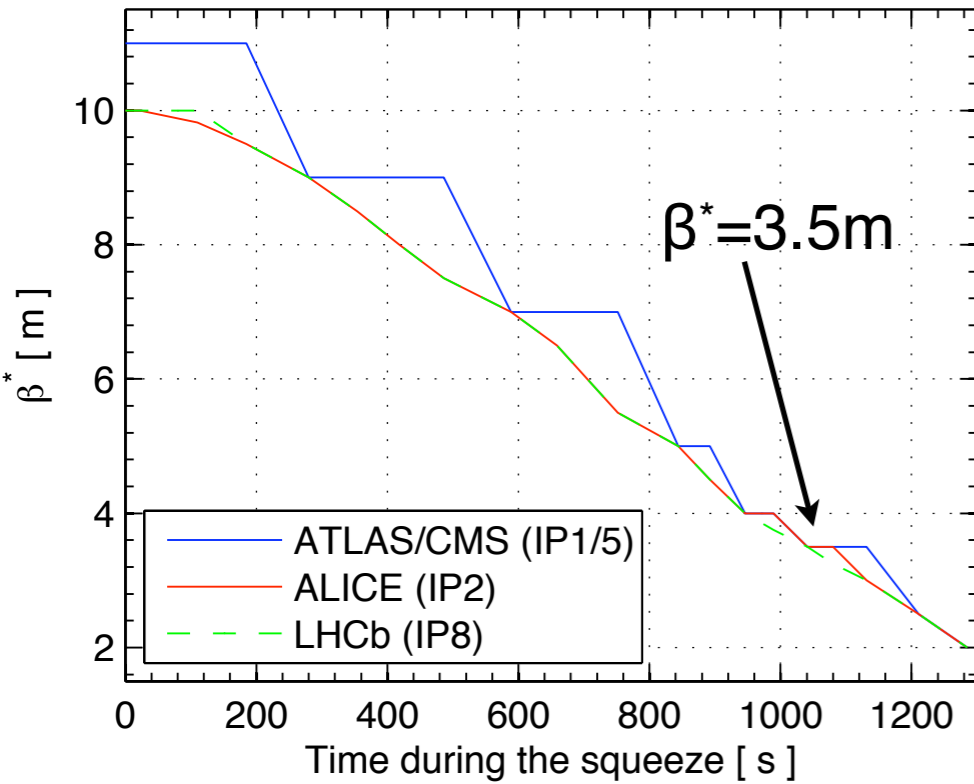
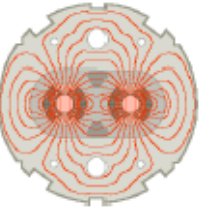
# Improving squeeze time



Conservatively, in 2010 we used ALL the optics available from ABP for all points (1280 s for  $\beta^*=2\text{m}$ ). Studies are ongoing to optimize the time: final results for Chamonix. Need to finalize them for the 2011 optics configurations!!

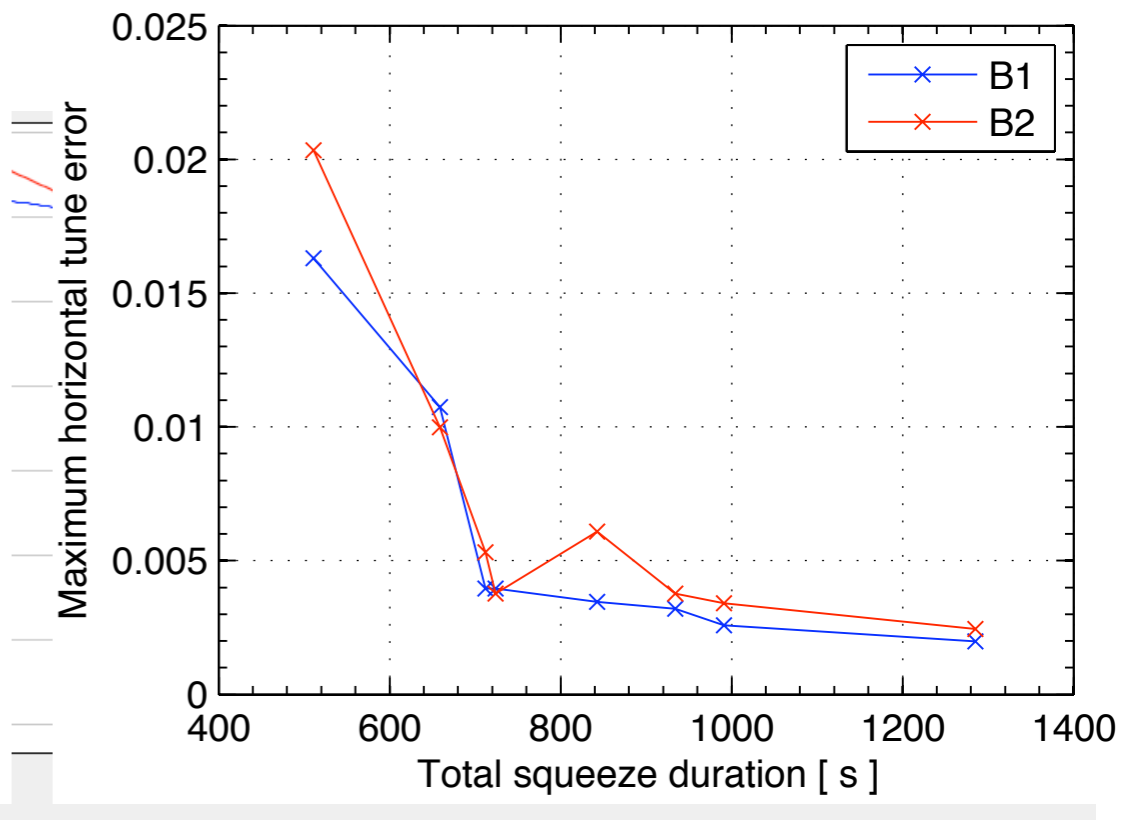
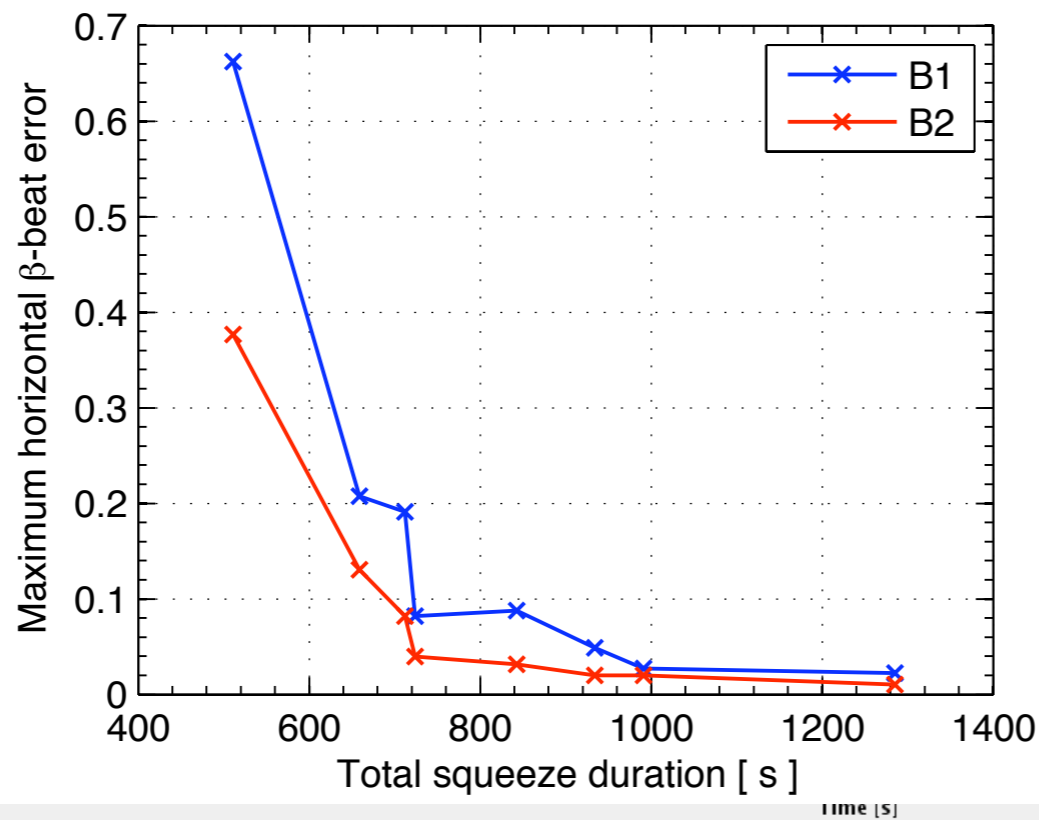
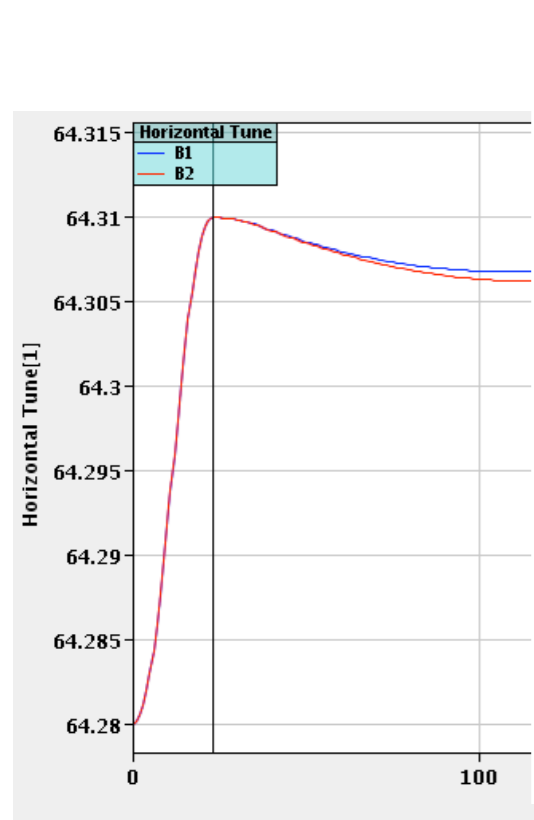


# Improving squeeze time

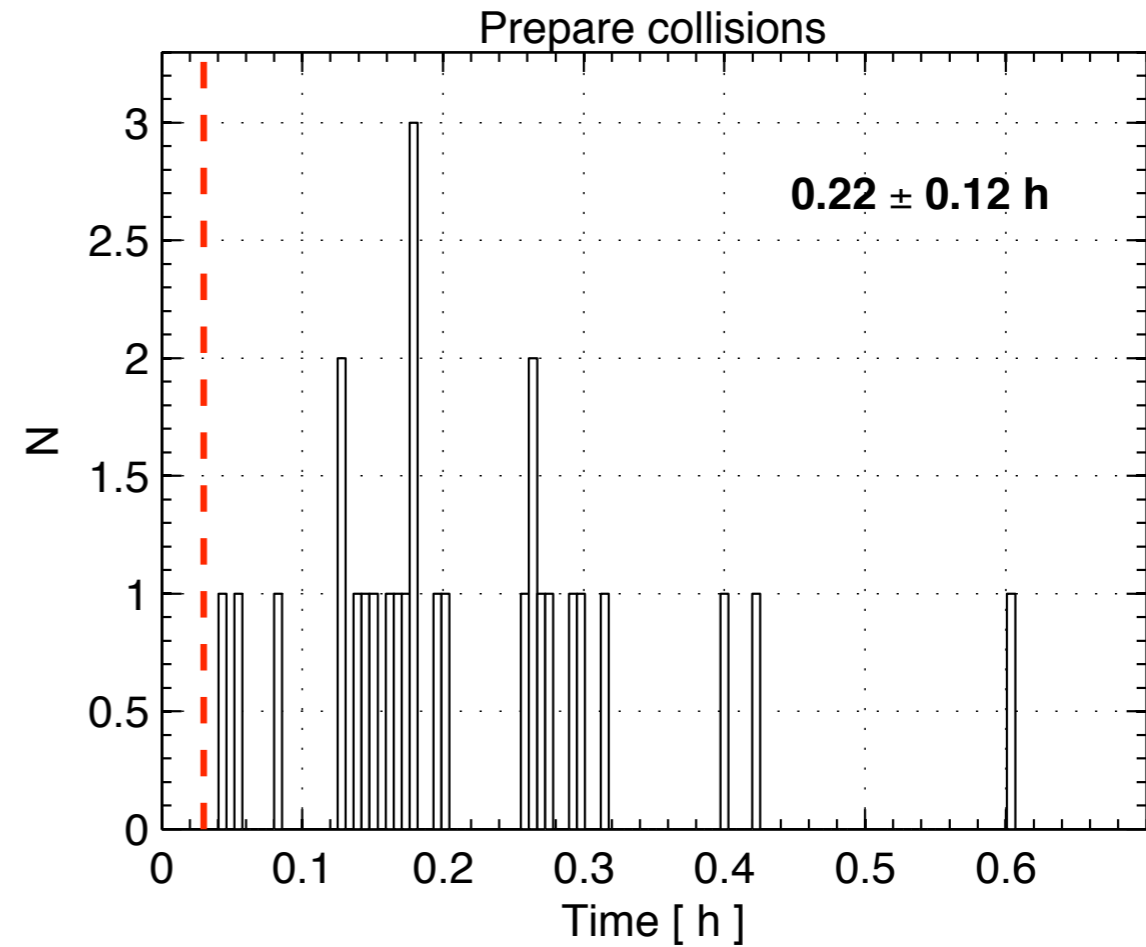
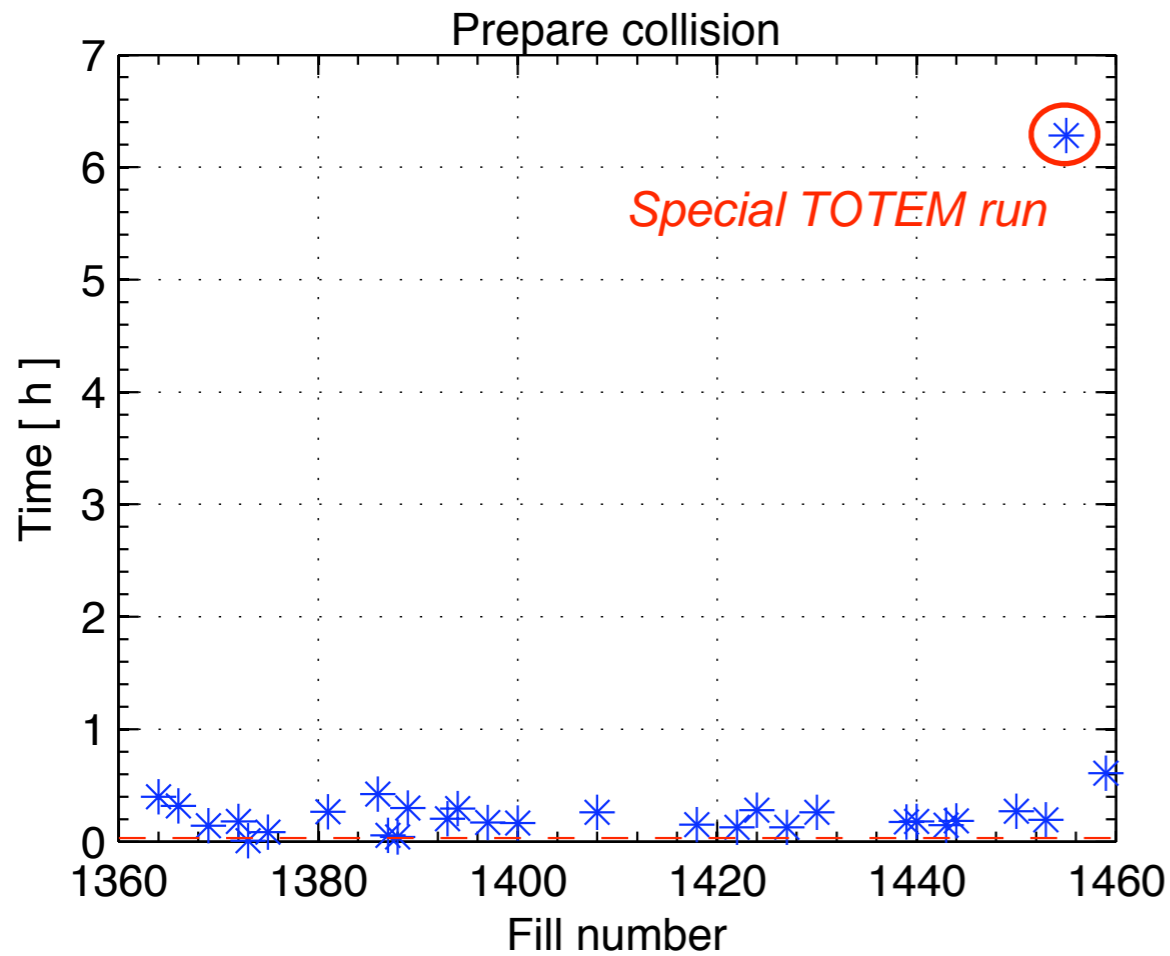
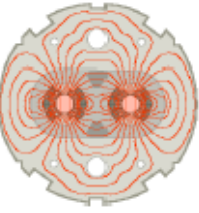


Conservatively, in 2010 we used ALL the optics available from ABP for all points (1280 points,  $\beta^* = 2m$ ). Studies are ongoing to optimize the results for Chamomile. Need to finalize the 2011 optics configuration.

**Can gain 5-8 minutes!**



# Prepare collisions (ADJUST)

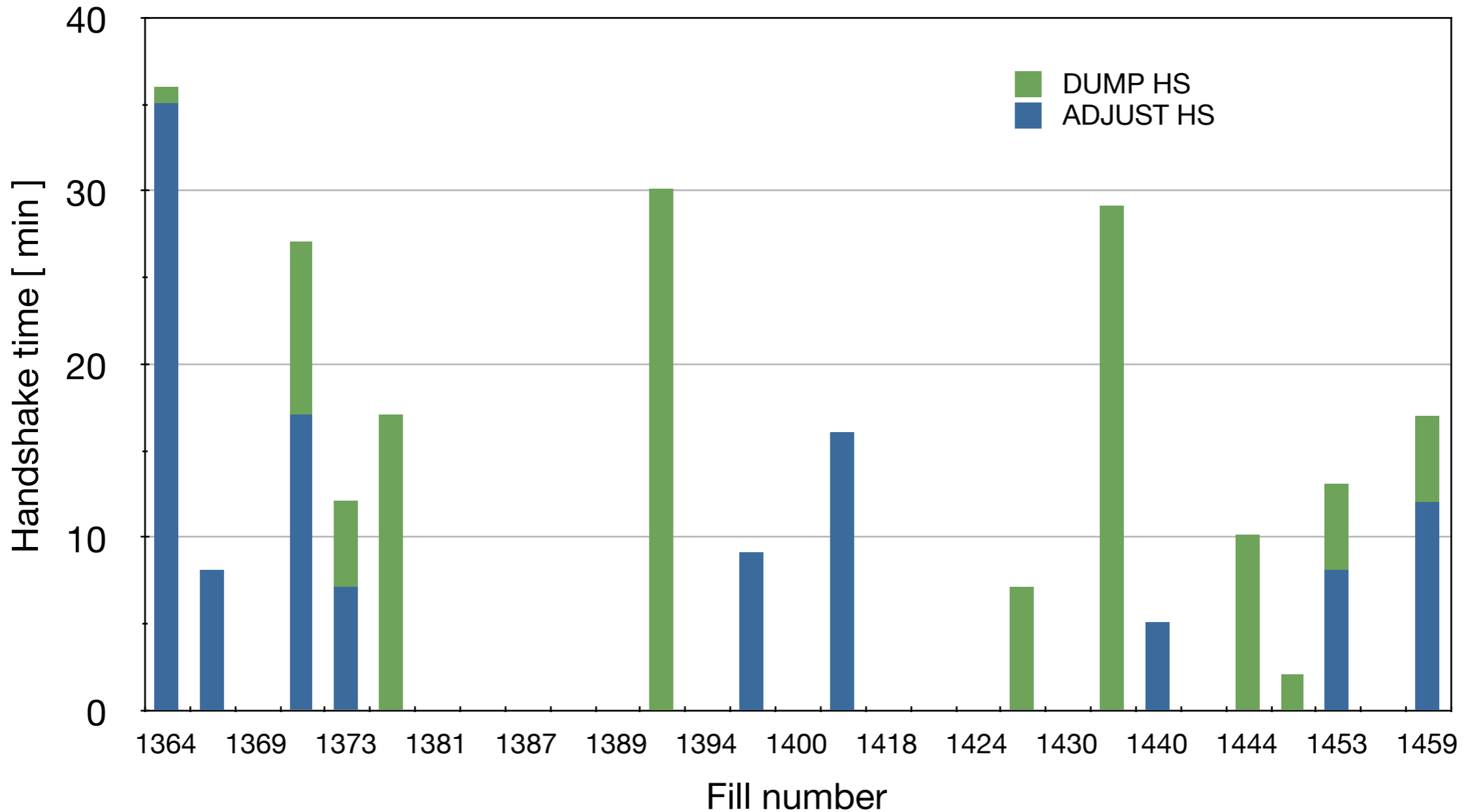


Lost in average **15 minutes** to bring the beams in collision! Min time = 108 s.

- Which measurements do we need to perform?
- Can improve by reducing the **parallel beam separation** during the ramp.
- Profit by declaring “Stable Beams” before starting lumi scans (Helpful for the experiments).



# Adjust and Dump on handshakes



Injection handshake is ok (in the shade of the pre-cycle)

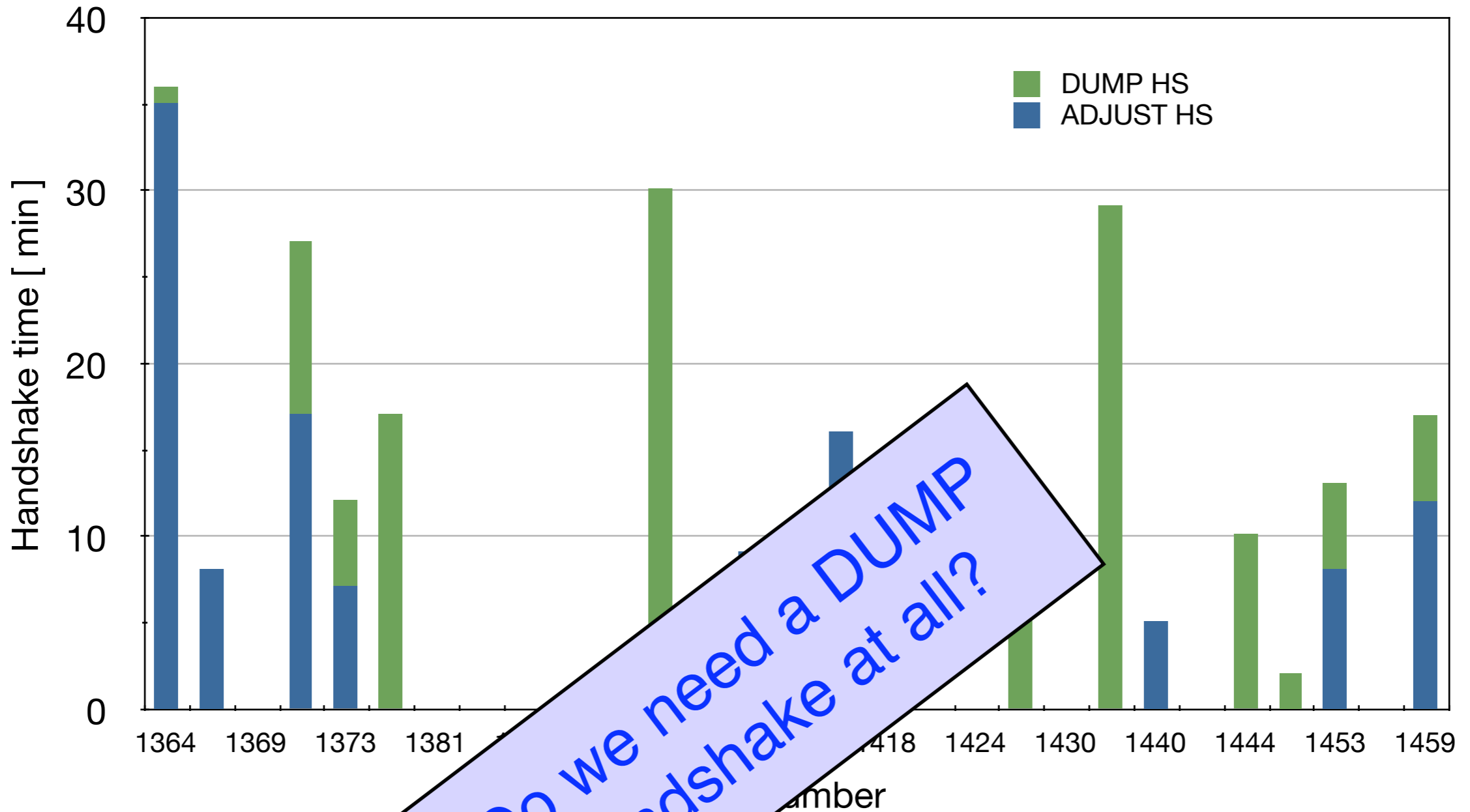
Rarely problems when closing an handshake

Statistics over 29 fills: 11 dump and 9 adjust handshakes.

AVG duration: 13 min (dump) and 11 min (adj)

Max duration up to 30 minutes!

# Adjust and Dump on handshakes



Do we need a DUMP handshake at all?

Injection handshake is (10% of the pre-cycle)

Rarely problems when creating an handshake

Statistics over 29 fills: 11 dump and 9 adjust handshakes.

AVG duration: 13 min (dump) and 11 min (adj)

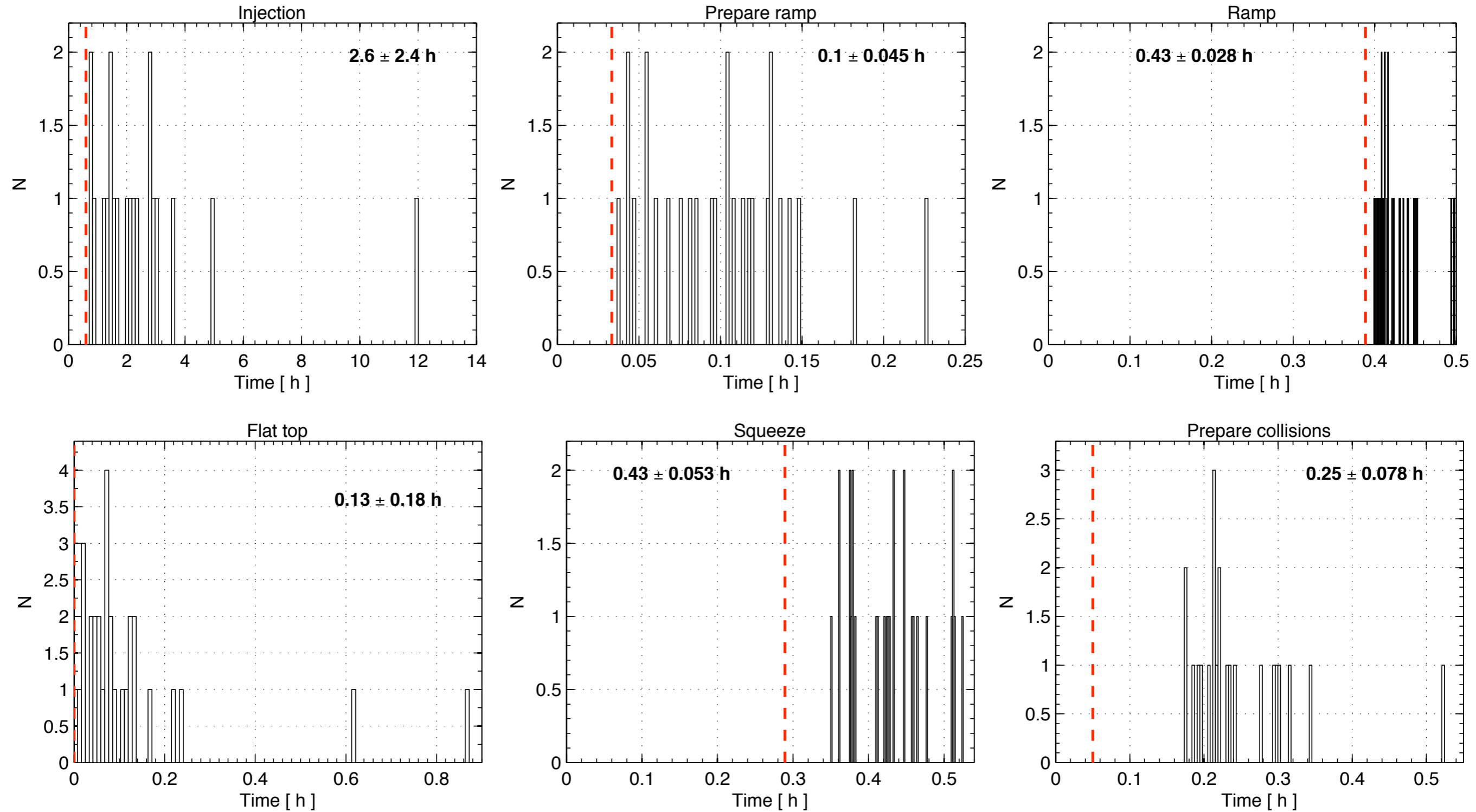
Max duration up to 30 minutes!

# Summary with 2010 times

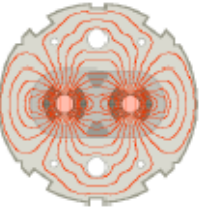


| Machine phase   | 2010 param [ s ] | Achieved [ s ]       |
|-----------------|------------------|----------------------|
| Pre-cycle combo | 2100+300         | n. a.                |
| Inject probe    | 300              | 5603 ± 8264          |
| Inject physics  | 1900 (=50x38)    | 4409 ± 3869          |
| Prepare Ramp    | 120              | 495 ± 338            |
| Ramp            | 1400             | 1565 ± 289           |
| Flat top        | 0                | 473 ± 655            |
| Squeeze         | 1041             | 2000 ± 651           |
| Adjust          | 108              | 1524 ± 4080          |
| <b>TOTAL</b>    | <b>2h00</b>      | <b>4h27 + 40 min</b> |

# A look at the ion operation



*Some improvements (-20% for squeeze),  
but ballpark figures do not change.*



## ☑ We have seen that:

- We lose time at injection.
- Sequences are well developed and established: reduced margin of errors, efficient run-through.
- But we still lose time in the phases that require manual interventions:
  1. Prepared ramp;
  2. Flat-top (preparation for squeeze);
  3. Squeeze stop points;
  4. Prepare collisions.

## ☑ Concrete improvements are possible:

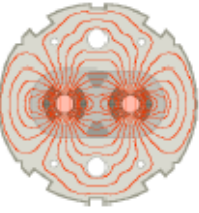
- Improvement on different fronts for the injection;
- Continuous run through the squeeze (less time, less errors);
- Improved operational procedures: clearer definitions and procedures; improvements;
- Optimized squeeze times by reducing the number of stop points.

## ☑ Required implementation:

- Dynamic reference for orbit and tune feedback

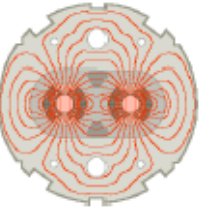
Will this be enough?

# 2011 estimates



| Machine phase   | Ideal [ s ]   | 2010 [s]           | 2011 [s]    |
|-----------------|---------------|--------------------|-------------|
| Pre-cycle combo | 2100+300      | n. a.              | 2100+300    |
| Inject probe    | 300           | 5603 ± 8264        | 300         |
| Inject physics  | 1900 (=50x38) | 4409 ± 3869        | 1900        |
| Prepare Ramp    | 120           | 495 ± 338          | 120+300     |
| Ramp            | 1400          | 1565 ± 289         | 1400        |
| Flat top        | 0             | 473 ± 655          | 0+300       |
| Squeeze         | 1041          | 2000 ± 651         | 550*        |
| Adjust          | 108           | 1524 ± 4080        | 60+300      |
| <b>TOTAL</b>    | <b>2h00</b>   | <b>4h27 + 0h40</b> | <b>2h07</b> |

Only gain if injection is faster!



**The 2010 experience on turnaround was reviewed**

*Turnaround time dominated by the injection time: more than 2h lost!  
On average, about 1h can be lost in various preparation phases.*

**Possible improvements were proposed for each phase**

**We hope to achieved turnaround time close to 2h**

*Requires significant improvement of the injection.*

*“Manual” changes should be reduced to a minimum.*

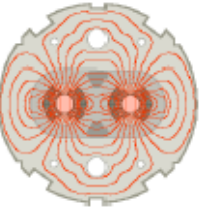
*Can gain probably 10-15 min with the squeeze.*

**We do not seem to be yet in the position to gain from aggressive approaches**

*Continuous functions for ramp, squeeze and collision or combined*

*Ramp&Squeeze become interesting when present issues are solved.*

**Each plot is also available vs EiC and MC names!**



# *Reserve slides*



# Further improvements (1)



## Combine in a continuous function Ramp, Squeeze and Collision

### PRO's

- Virtually reduces to zero human errors;

### CON's

- Limited time gain (up to 10 min);
- Reduced flexibility;
- Requires (frequent) pilot ramps to stop and set-up (collimator critical limits).

# Further improvements (2)



## ☑ Perform part of the squeeze in the ramp

### ☑ PRO's

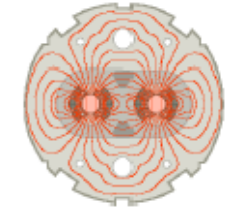
- Reduced human errors;
- Reduce time;
- Some steps done at lower stored energy.

### ☑ CON's

- Effectively, only larger beta\* steps can be done during the ramp;  
Critical beta steps still done at top energy.
- Limited gain in time: < 300 s.
- Reduced possibility to measure and correct at stop points in the ramp  
Critical for coupling!
- Setup of collimators and loss maps not possible.
- Crossing angle changes become difficult.

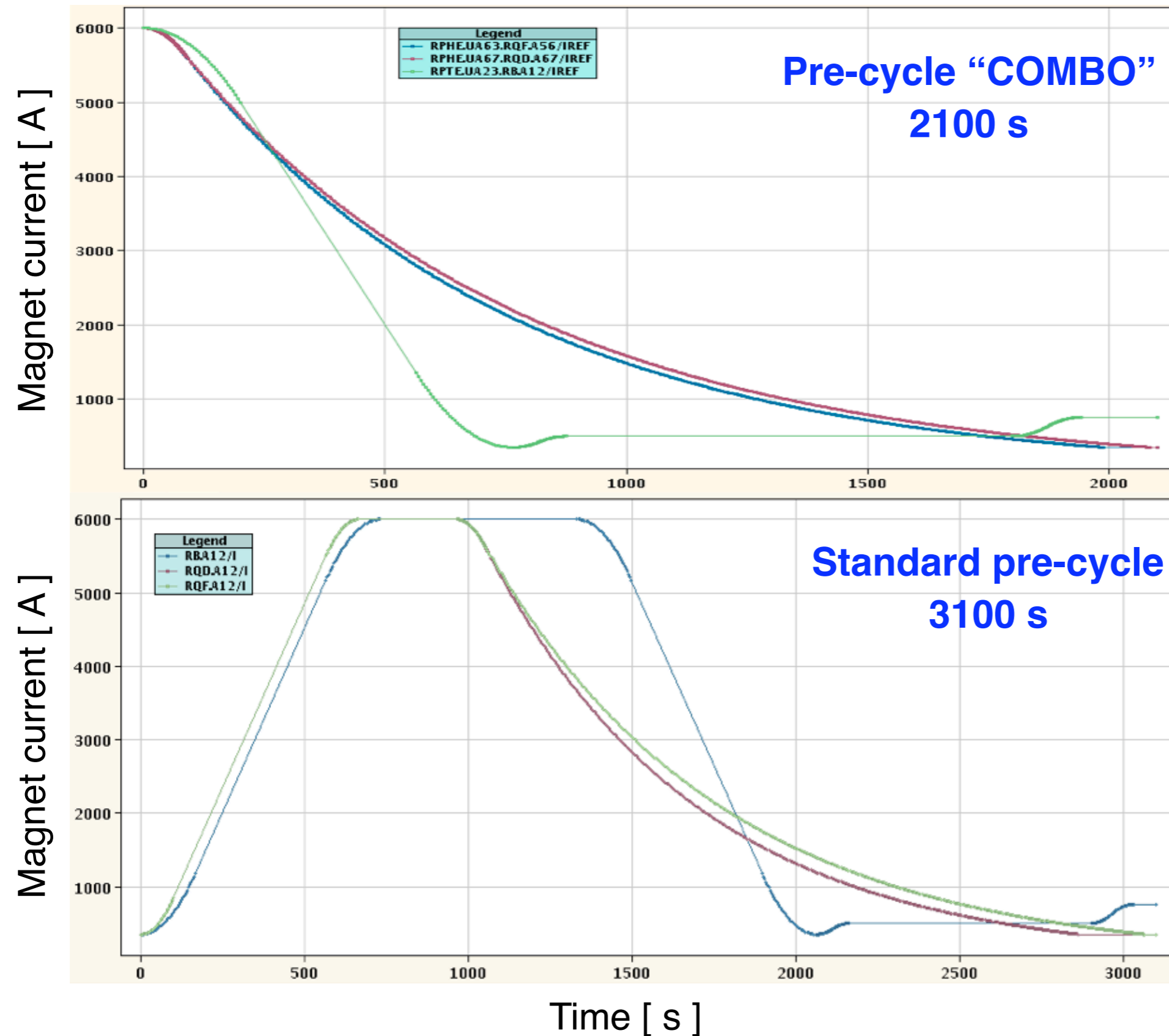


# 2011 estimates: combined functions



| Machine phase   | Time [ s ]    | 2010 time [ s ] | Combined [s] | Realistic [s] |
|-----------------|---------------|-----------------|--------------|---------------|
| Pre-cycle combo | 2100+300      | n. a.           | 2100+300     | 2100+300      |
| Inject probe    | 300           | 5603 ± 8264     | 300          | 300           |
| Inject physics  | 1900 (=50x38) | 4409 ± 3869     | 1900         | 1900          |
| Prepare Ramp    | 120           | 495 ± 338       | 120          | 120+300       |
| Ramp            | 1400          | 1565 ± 289      | 1400         | 1400          |
| Flat top        | 0             | 473 ± 655       | +<br>550     | 0+300         |
| Squeeze         | 1041          | 2000 ± 651      | +<br>60      | 550           |
| Adjust          | 108           | 1524 ± 4080     | 60           | 60+300        |
| <b>TOTAL</b>    | <b>2h00</b>   | <b>4h27</b>     | <b>1h51</b>  | <b>2h07</b>   |

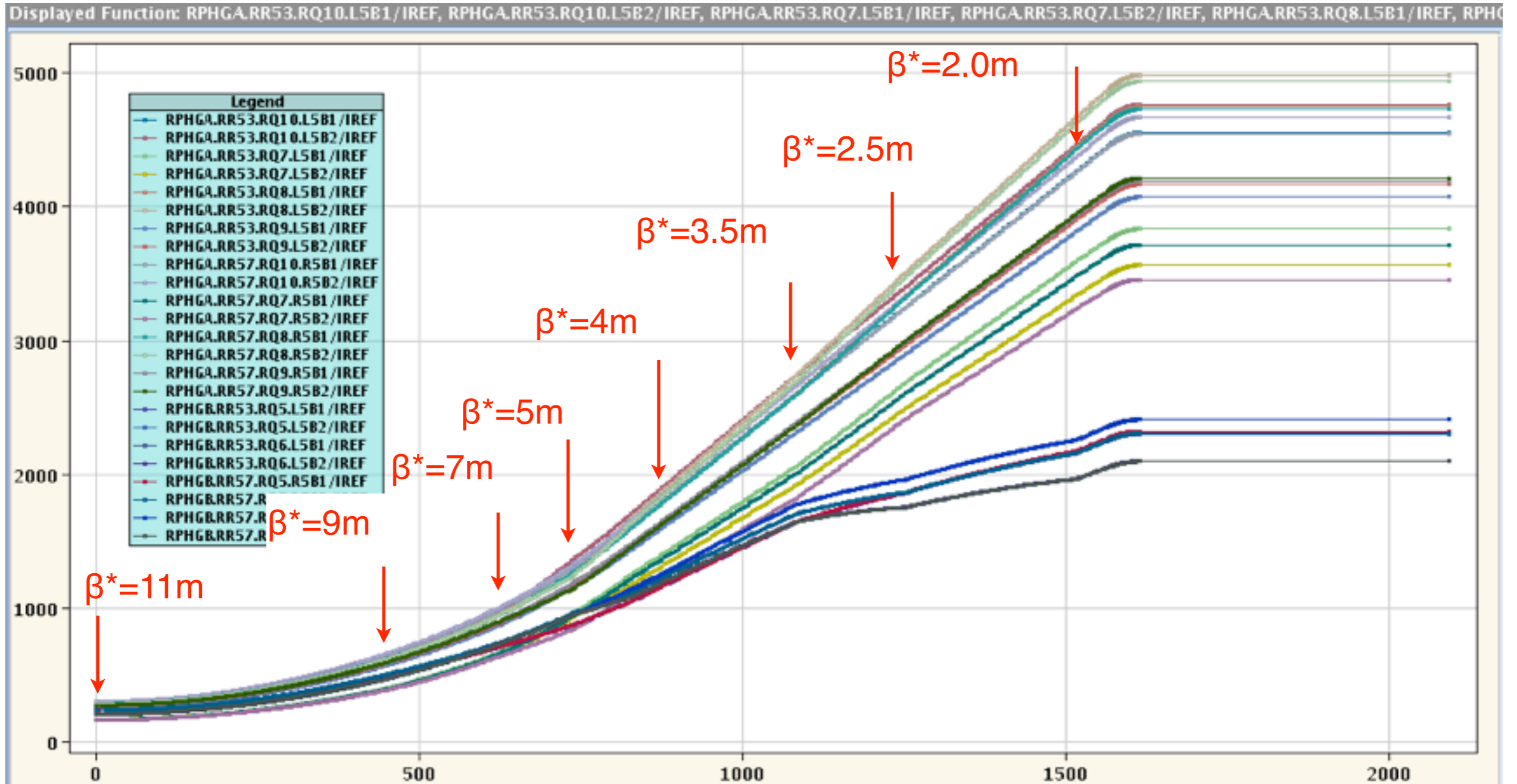
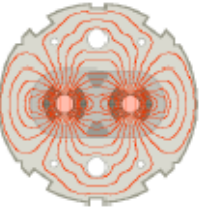
# Shortening the pre-cycle



Now:  
 any access costs ~1h  
 of pre-cycle.

Possible margin for  
 improvements in case  
 of updated access  
 procedure (do not lock  
 all sector circuits).

# Squeeze combined with ramp



# Time in "SETUP" mode

