PC Interlock:
Recent updates and status

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Outline

- Introduction to PC Interlock
- Interlocking strategies
- Phase Advance Interlock
- Result

Previous Presentations and Material

- M. Schaumann, “PC Interlock status, next steps and feasibility of optics interlocking”, MPP 19/02/2016

  https://indico.cern.ch/event/495744/contributions/2016024/attachments/1231246/1805016/MPP_QuadrupoleInterlocking.pdf

- Marc-Antoine Galilee, “Optics Interlocking within PcInterlock”, TE-MPE-TM Group Meeting 30/06/2016

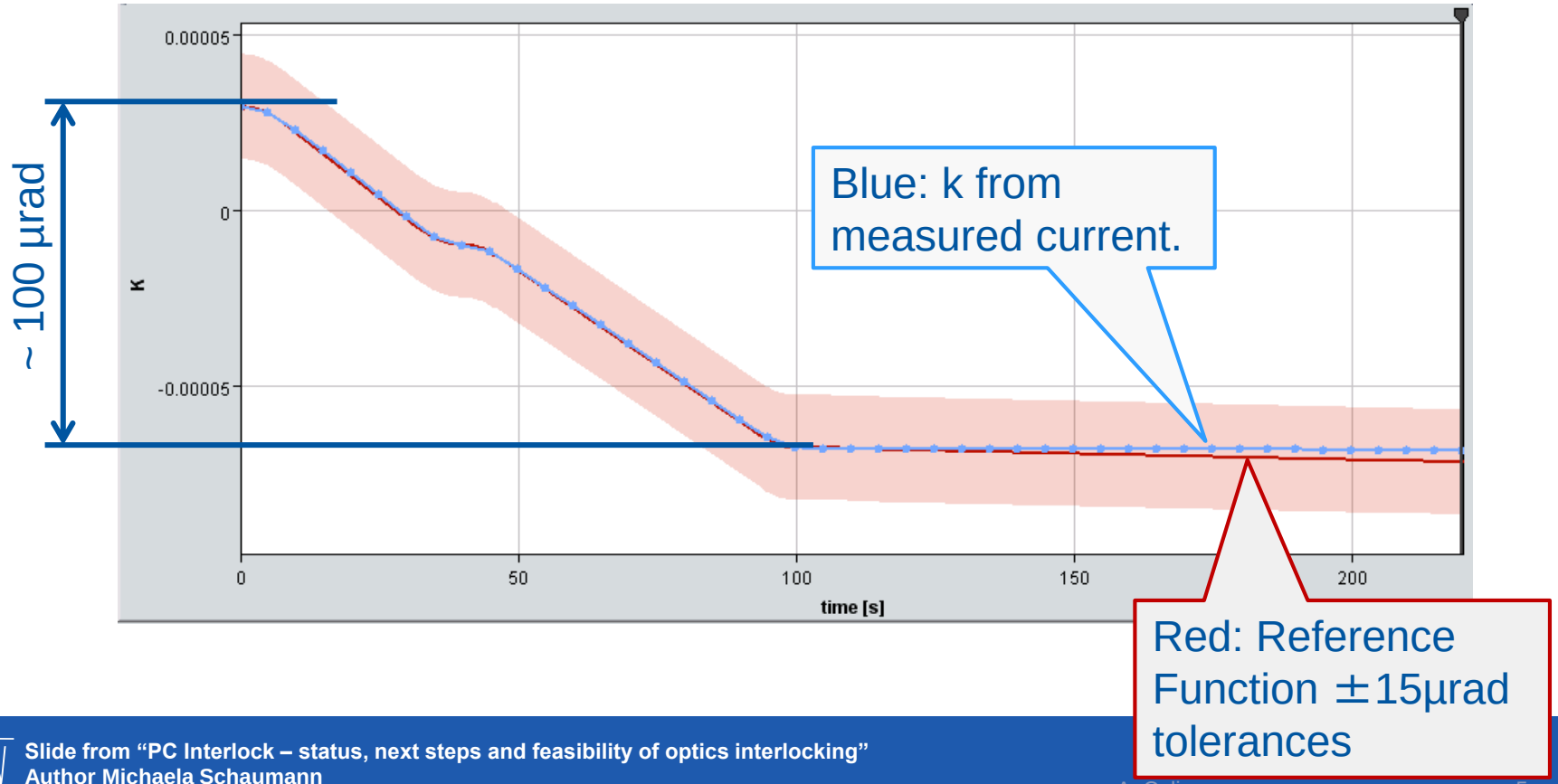
  https://indico.cern.ch/event/544818/contributions/2219877/

Introduction

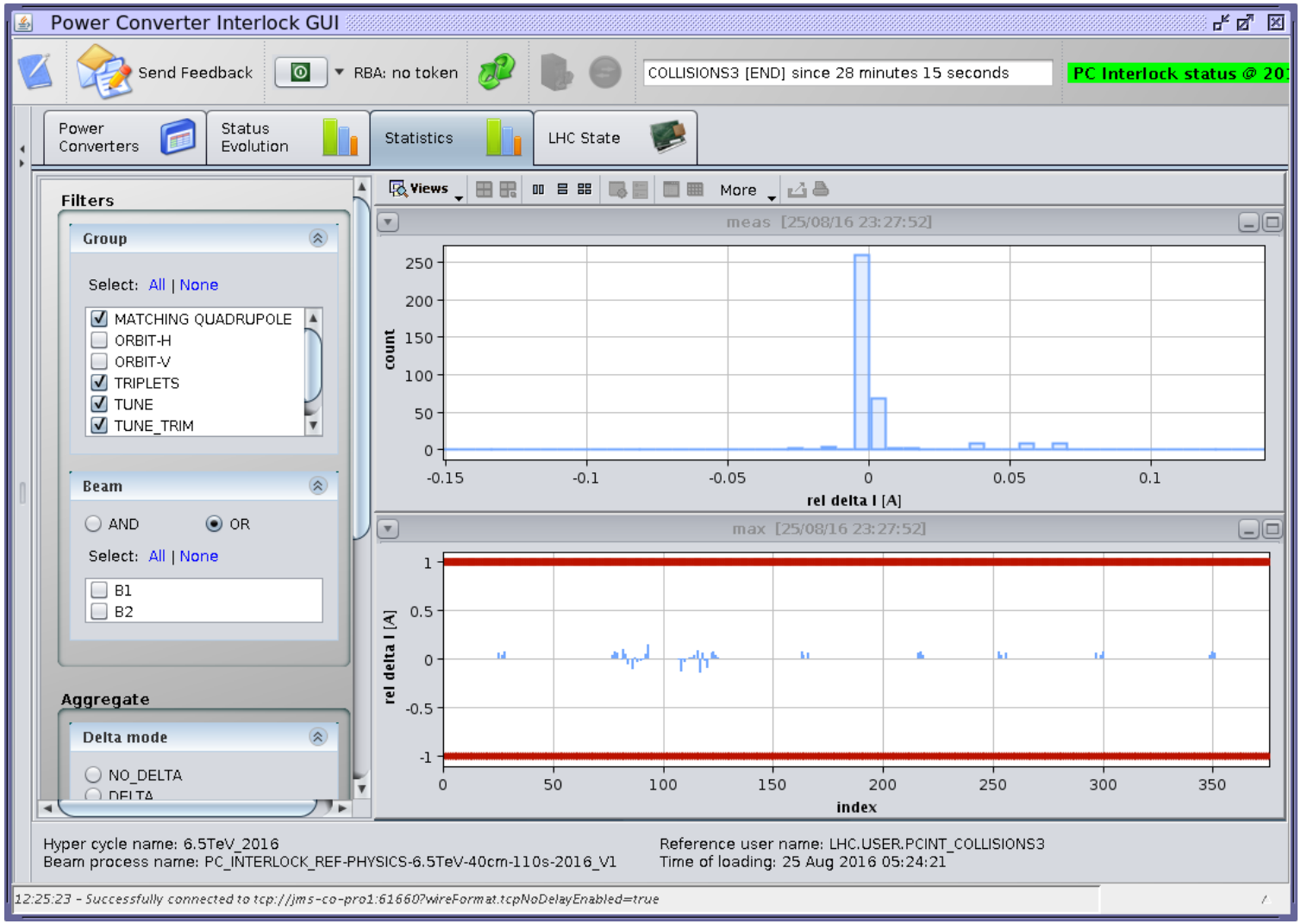
PC Interlock - Principle

Principle: Subscribes to Power Converters (PC) and compares measured current to reference ***functions*** ± tolerances (1 Hz).

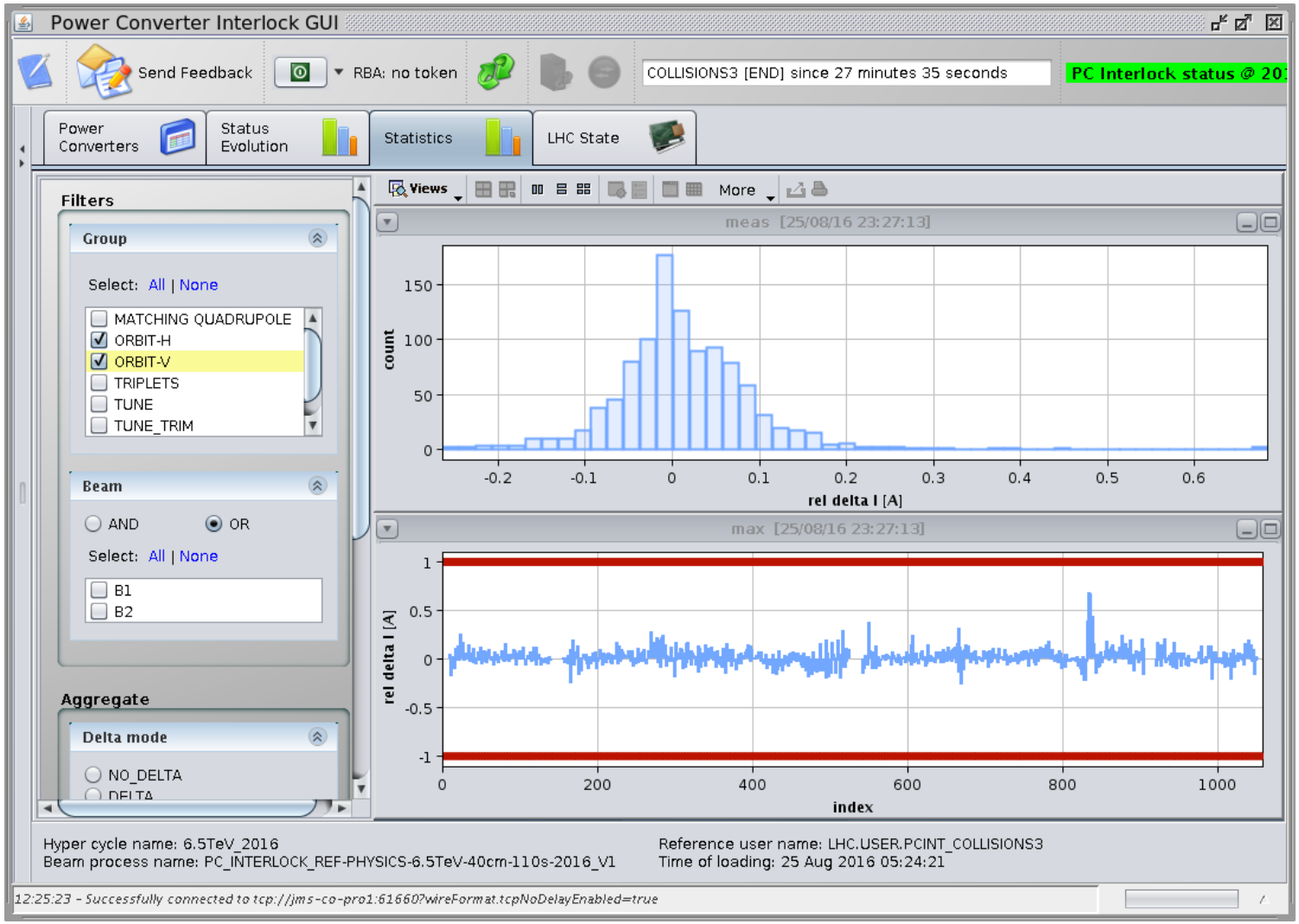
Example: RCBYVS4.L8B2 **(Orbit corrector)** during COLLISIONS Beam Process:



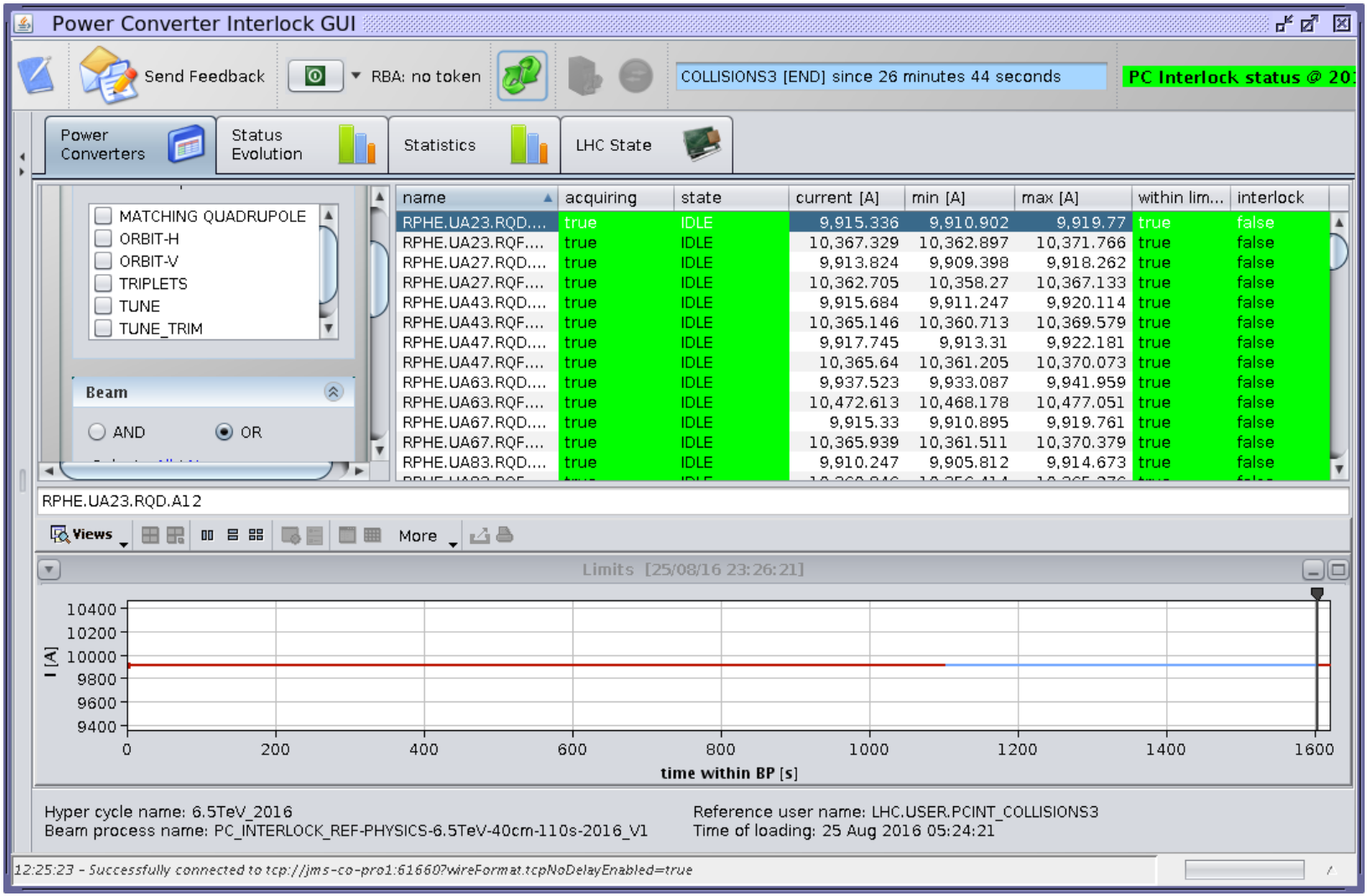
PC Interlock - Principle



PC Interlock - Principle



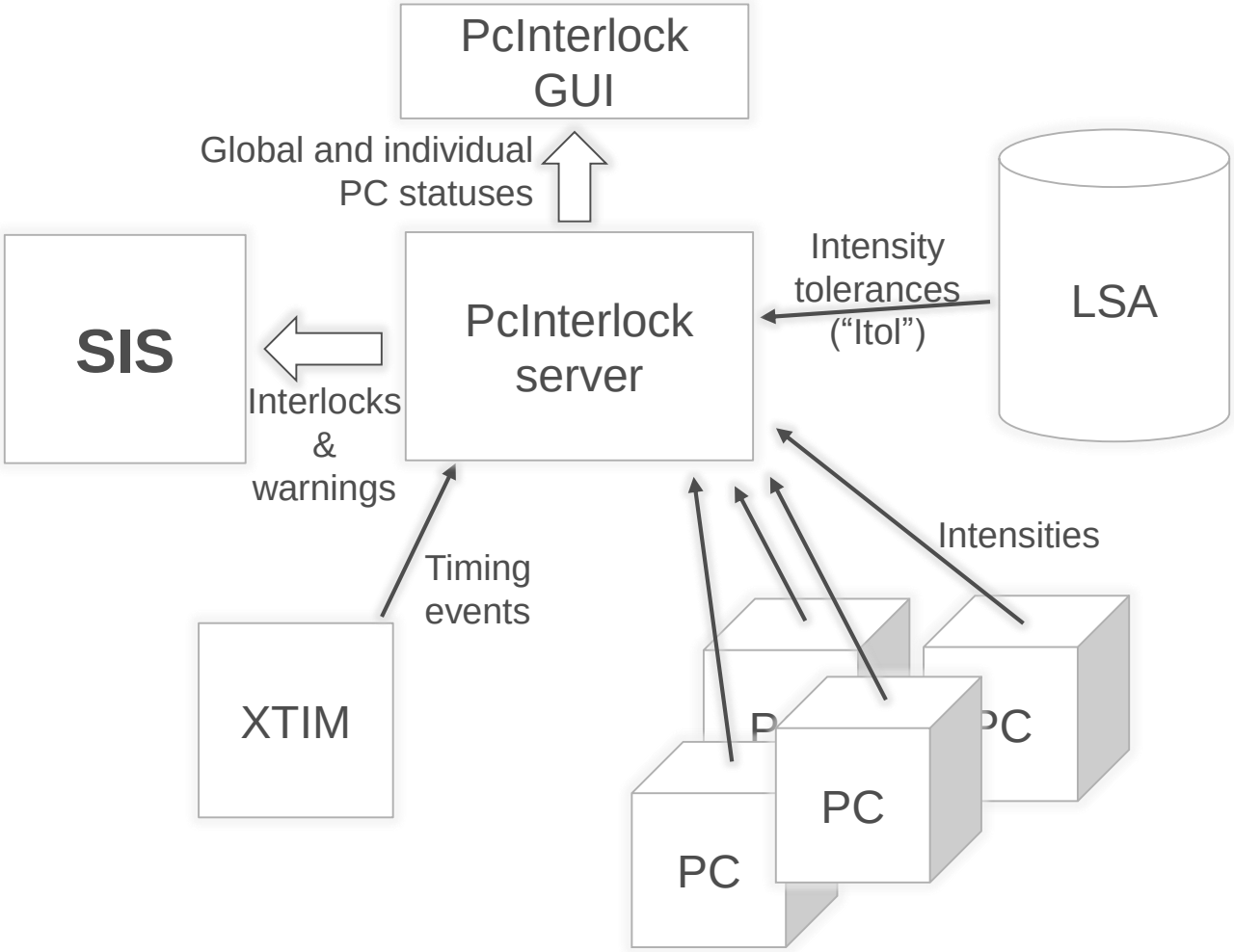
PC Interlock - Principle



Power Converter States

- 3 interlocking states of a Power Converter are defined:
  - Ok: Not interlocking, current is within limits (or PC is in any other state than STANDBY, IDLE, ARMED and RUNNING)
  - Warning: Trigger warning when current is 70% of interlock limit
  - Interlock: Trigger interlock when current is 100% of interlock limit

The PC-Interlock ecosystem

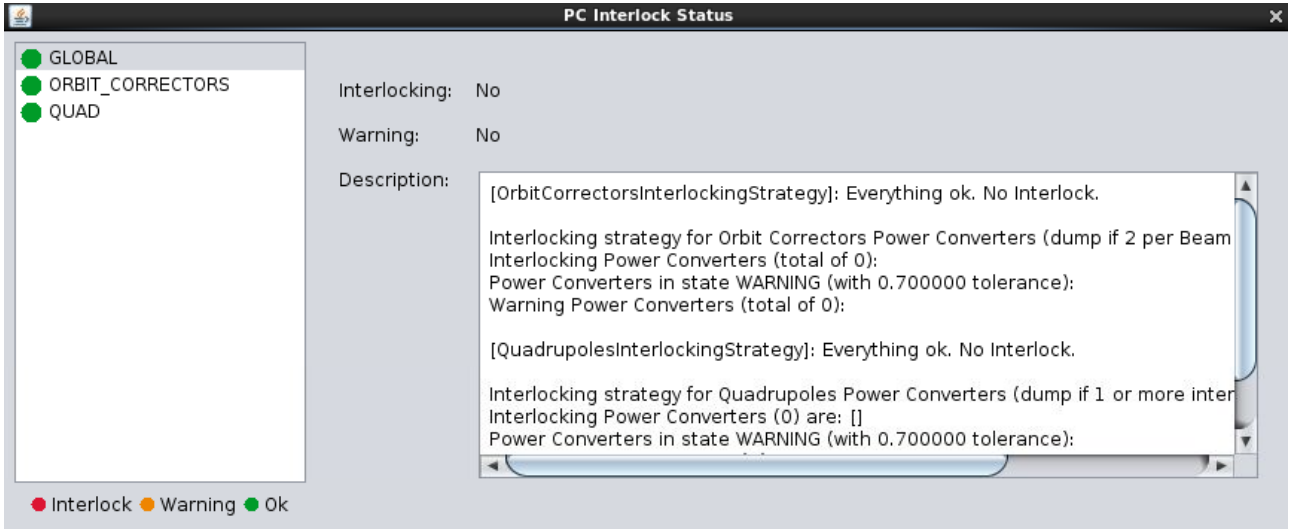


Interlocking strategies

Interlocking Strategy

- Strategy for deciding if an interlock should be triggered.

- Analysis of one or more Power Converter groups.



Power Converter Groups

- Set of Power Converter logically connected:
  - Orbit correctors
  - Matching Quadrupoles
  - …

Orbit correctors interlocking strategy

- Interlocks when:
  - >= 2 PCs per beam and plane are in interlock state
- Warning when:
  - 1 PC per beam and plane is in warning state

Quadrupoles interlocking strategy

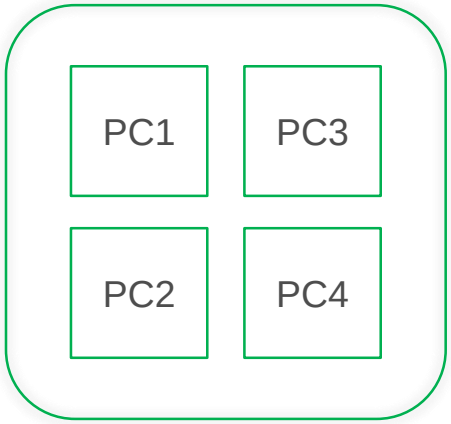
- Interlocks when:
  - >= 1 PCs is in interlock state

- Warning when:
  - 1 PC is in warning state

Interlocking strategy example

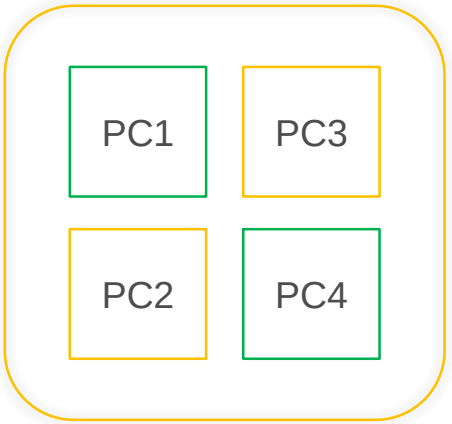
isOk = True

isWarning = False



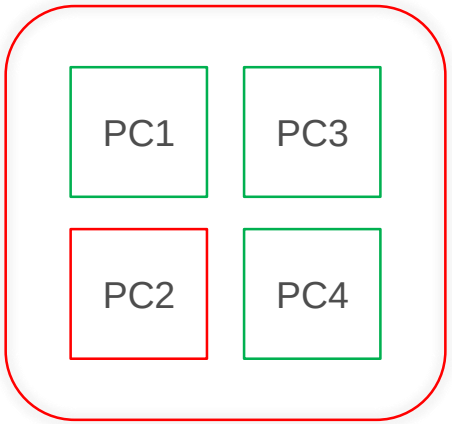
isOk = True

isWarning = True



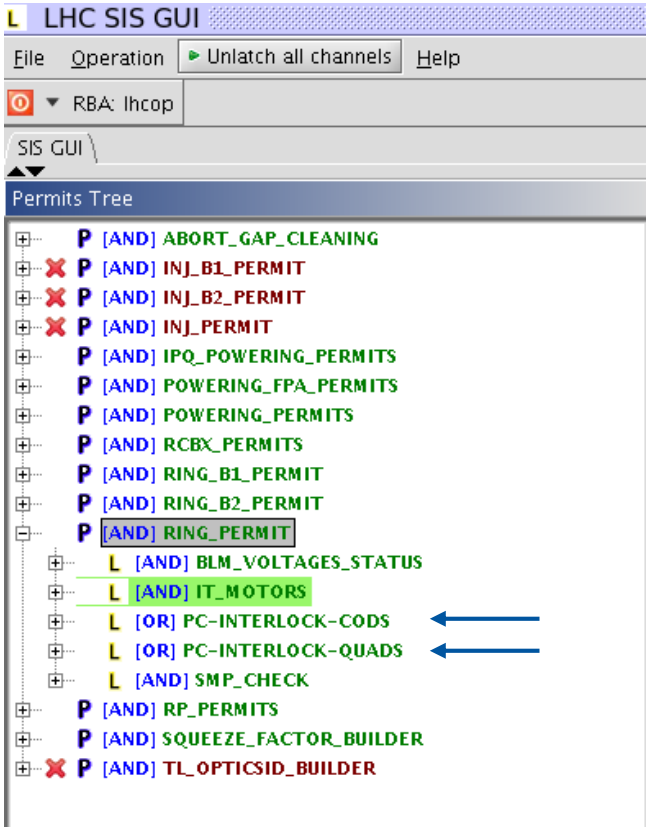
isOk = False

isWarning = True



Example using Quadrupole interlocking strategy

SIS Channel per strategy



Latest improvements

- Multiple interlocking strategies
- SIS: publish additional interlocking status per strategy
- Full quadrupole circuits support to allow for phase advance interlocking
- New handling of tolerances in the LSA parameters (K_TOL and I_TOL)

Phase Advance Interlock

Prevent damage of tertiary collimators (TCT) and triplets in the event of an asynchronous beam dump (*dump kicker (MKD) fires when beam passes*).

For protection, a phase advance between the MKD and TCTs in IP1 and IP5 should be kept within $\Delta\mu \leq 30°$.

Phase Advance Interlock

- An unwanted increment on the Power Converter current may produce a phase advance on the orbit.
- Phase Advance Interlock uses tolerances on the Power Converter current to avoid this behaviour.
- Generated tolerances are based on simulations of the closed-orbit phase using MADX

Tolerance Generation

- A tool was developed to automatically produce accurate limits, Ktol, in terms of magnet strength (k).

- After user confirmation the Ktol values are written to LSA. A make rule generates the corresponding Itol (current) limits.

- **Ktol** values are based on MADX simulations and the maximum allowed phase advance change, **Δμ**, *provided by collimation team*.

Tolerance Generation Families

- For easier configuration, the Tolerance Generation tool has a concept of families.
- A family is a set of magnets that will share the same Ktol.
- For example, the same type of magnets.
- The concept of families let the user decide the granularity of the tool according to needs.

Tolerance Generation Ranges

- In order to prevent damage in the TCTs in IP1 and IP5, we have to take into account 4 ranges of the LHC ring, starting from the dump location (IP6):
  - From IP6 to IP1 and IP5 per Beam

- The simulations of the phase advance are done per range individually.

Tolerance Generation Ranges

Relevant ranges for Beam 1

- R61B1: IP6 → IP1
- R65B1: IP6 → IP5

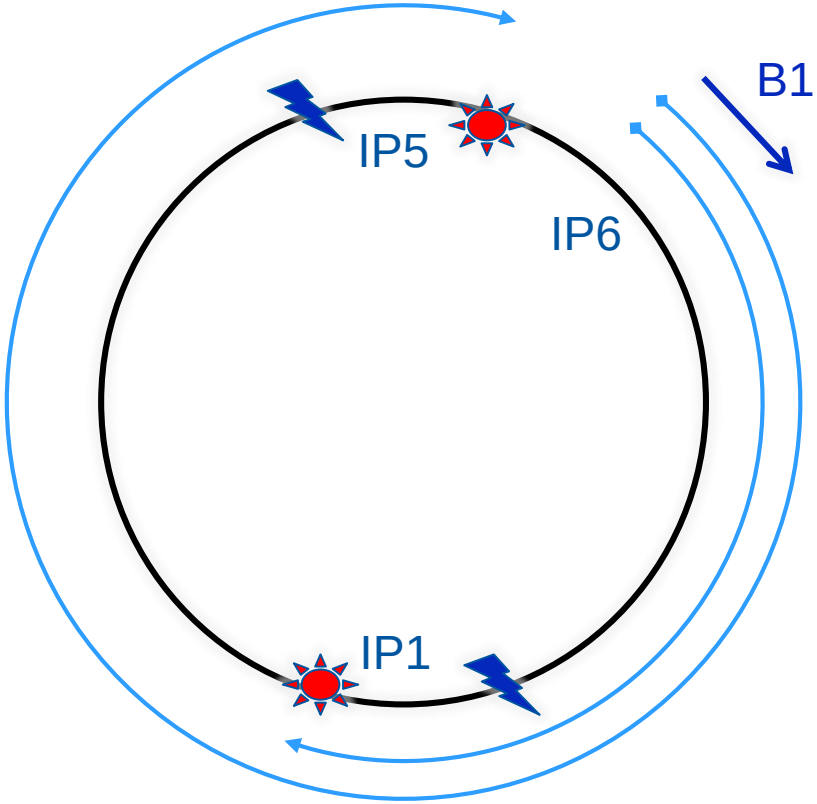


Image from “PC Interlock – status, next steps and feasibility of optics interlocking”
Author Michaela Schaumann

https://indico.cern.ch/event/495744/

Tolerance Generation Ranges

Relevant ranges for Beam 2

- R65B2: IP6 → IP5
- R61B2: IP6 → IP1

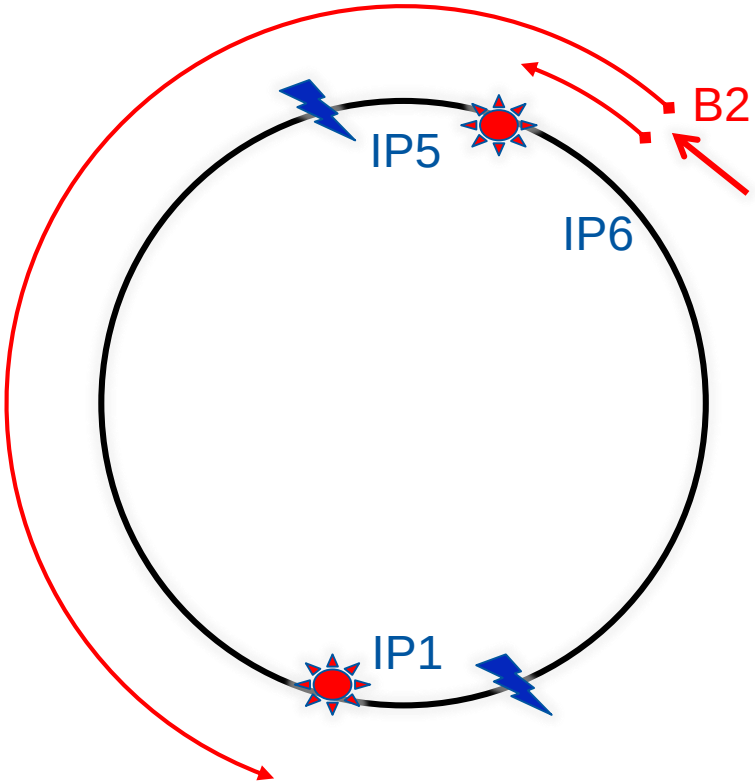


Image from “PC Interlock – status, next steps and feasibility of optics interlocking”
Author Michaela Schaumann

https://indico.cern.ch/event/495744/

Tolerance Generation

The allowed Δμ budget is distributed over all families.

$$\Delta\mu_{\text{budget}} > \sum_{\text{families}} \Delta\mu_{\text{budget,family}}$$

At the moment defined families are:
MQ, MQT, Matching quads, Triplets, Warm quads.

Tolerance Generation

The magnet phase response is the ratio of phase change over a segment resulting from a small strength increment.

$$r_{\mathrm{m,range}} = \frac{\Delta\mu_{\mathrm{range}}}{\Delta k}$$

$$\Delta k = 1.0e-5$$

The resulting family phase response consists of the sum of the member's phase response. The absolute value is used for taking into account the worst case scenario.

$$R_{\mathrm{family,range}} = \sum_{\mathrm{family\ magnets}} |r_m|$$

Tolerance Generation

The Ktol is then the ratio of the Δμ family budget over the family phase response.

$$k^{\mathrm{tol}}_{\mathrm{family,range}} = \frac{\Delta\mu_{\mathrm{budget,family}}}{R_{\mathrm{family,range}}}$$

The Ktol is calculated per range and the resulting family Ktol corresponds to the minimum.

$$k^{\mathrm{tol}}_{\mathrm{family}} = \min(k^{\mathrm{tol}}_{\mathrm{family,R61B1}}, k^{\mathrm{tol}}_{\mathrm{family,R65B1}}, k^{\mathrm{tol}}_{\mathrm{family,R65B2}}, k^{\mathrm{tol}}_{\mathrm{family,R61B2}})$$

Makerules

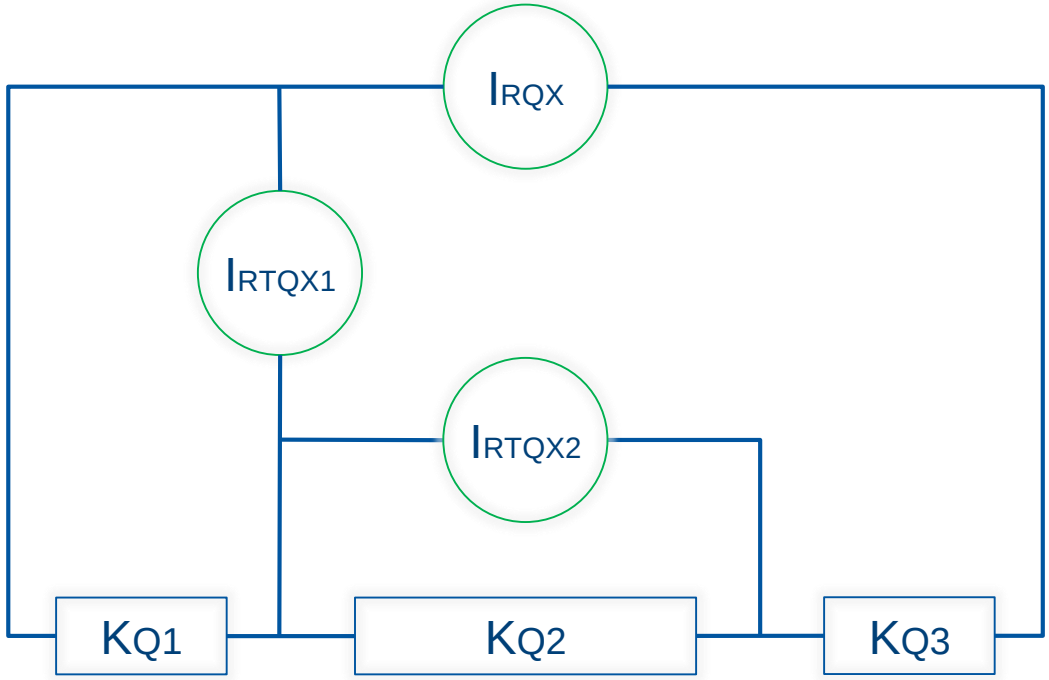
- Ktol values belong to magnets.
- The Itol value of the corresponding Power Converters is calculated using a Makerule in LSA.
- For most magnets it is a standard Makerule from K to I.
- Triplets are special due to their configuration (Itol_nested).

Makerule: Itol_nested

$$I_{\mathrm{RQX}} = \min\left(\frac{k_{\mathrm{Q1}}}{2}, \frac{k_{\mathrm{Q2}}}{2}, k_{\mathrm{Q3}}\right)$$

$$I_{\mathrm{RTQX1}} = \frac{k_{\mathrm{Q1}}}{2}$$

$$I_{\mathrm{RTQX2}} = \frac{k_{\mathrm{Q2}}}{2}$$



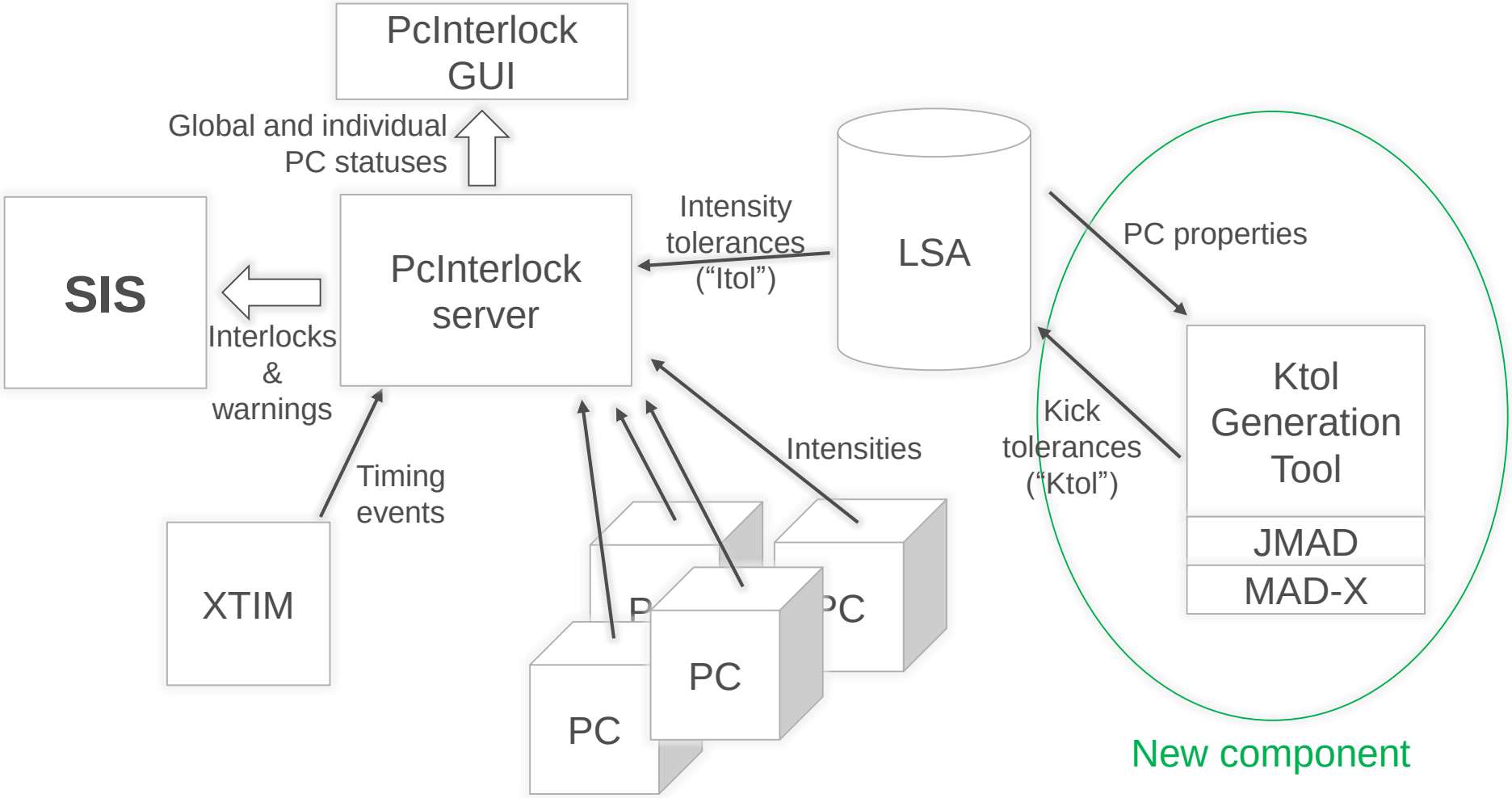
Latest Improvements

- Ktol Generation Tool

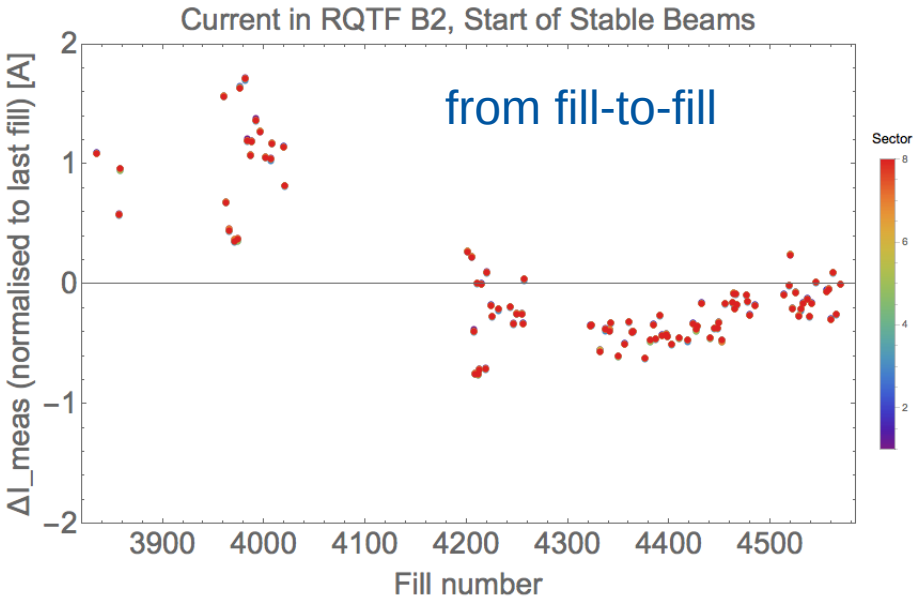
- Make rule (including Itol_nested for the triplets)

Results

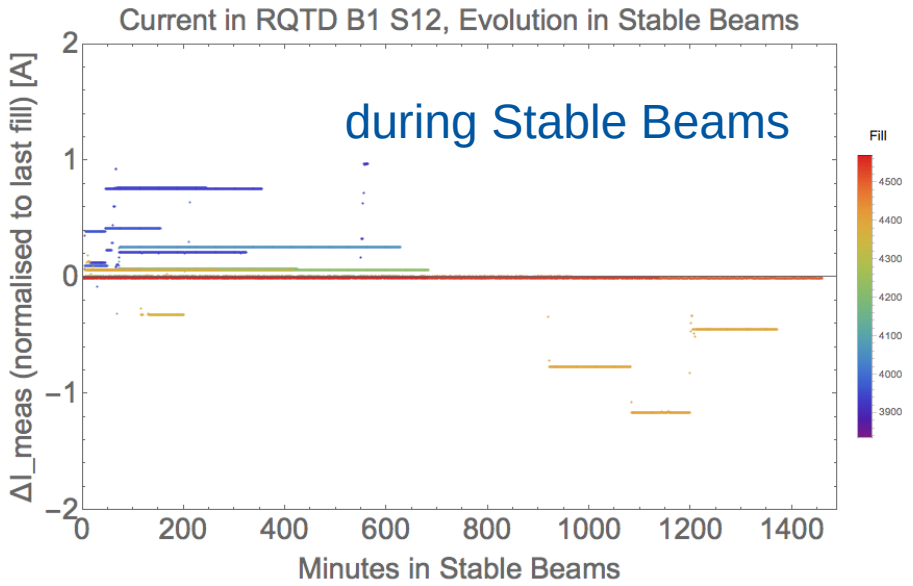
The PC-Interlock ecosystem



Current Fluctuation in Stable Beams



- Current variations ranges:
  - From fill-to-fill ~ **ΔI ≈ ±3A**
  - During Stable Beams **ΔI ≈±1.5A**



Families	$\Delta\mu_{budget}$	ΔI_{meas} (2015)	Itol (Preliminary)	Itol (LSA)	Ktol (LSA)
MQ	5°	± 0.02A	± 0.5A	± ~4.4A	~7.69E-6
MQT	15°	± 4.5A	± 5A	± ~22.2A	~2.45E-4
Matching Quad	5°	± 0.02A	± 0.5A	± ~[0.8, 5.1]A	~8.95E-5
Warm Quad	1°	± 0.02A	± 0.5A	± ~[5.3, 7.7]A	~1.33E-5
Triplet	10°	± 0.02A	± 0.5A	± ~3.8A (MQXA3.R8 = 2.2A)	~3.25E-6

ΔI_{meas} largest current variation found in 2015 Stable Beams data.

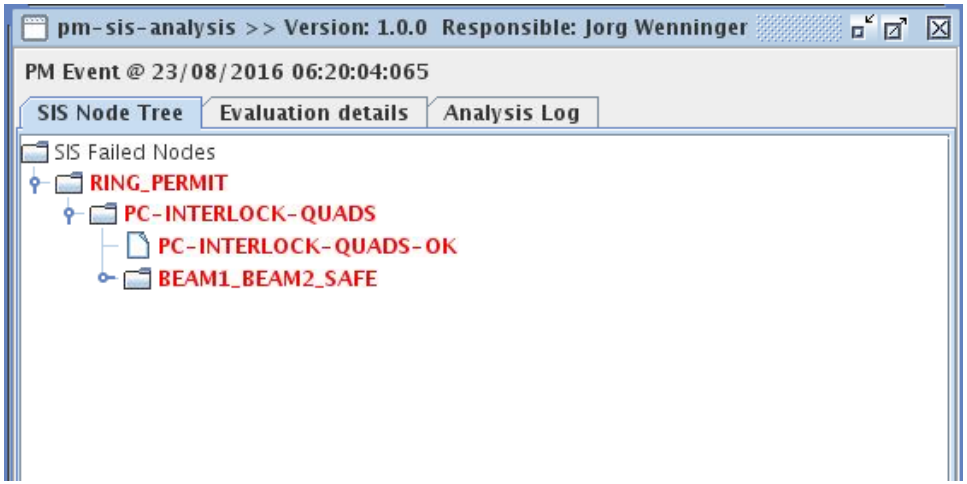
Requirement to avoid unnecessary beam dumps: Itol > ΔI_{meas}.

Ktol values per family are equal, while Itol values can be different, because of the magnet's calibration curves.

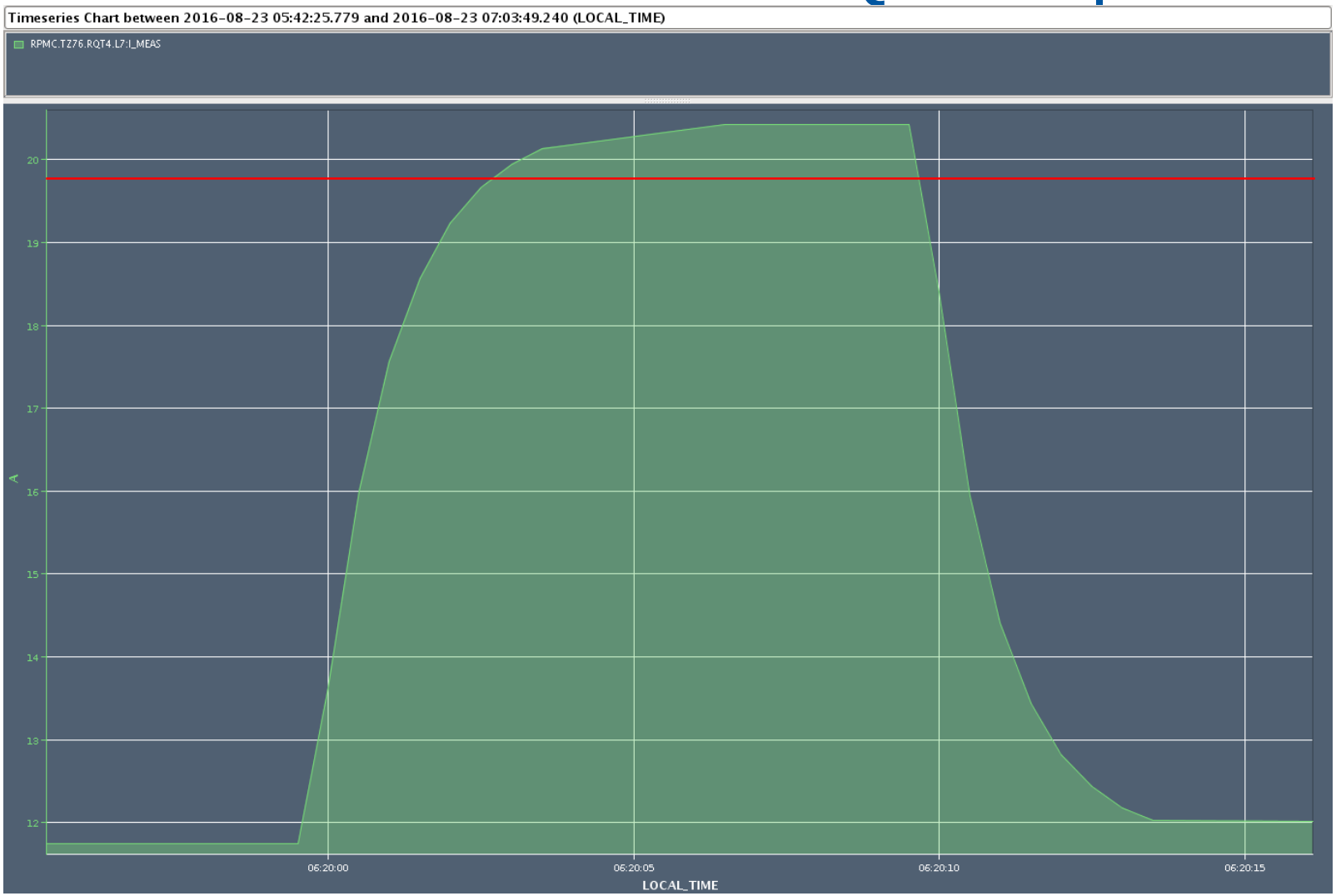
Optics used to generate the Ktol R2016a_A40C40A10mL300

Phase Advance Interlock Quadrupole

- On Quadrupole RQT4.L7
- Strategy: Quadrupole Interlocking Strategy
- 2016.08.23 @ 06:20:04 (MD)

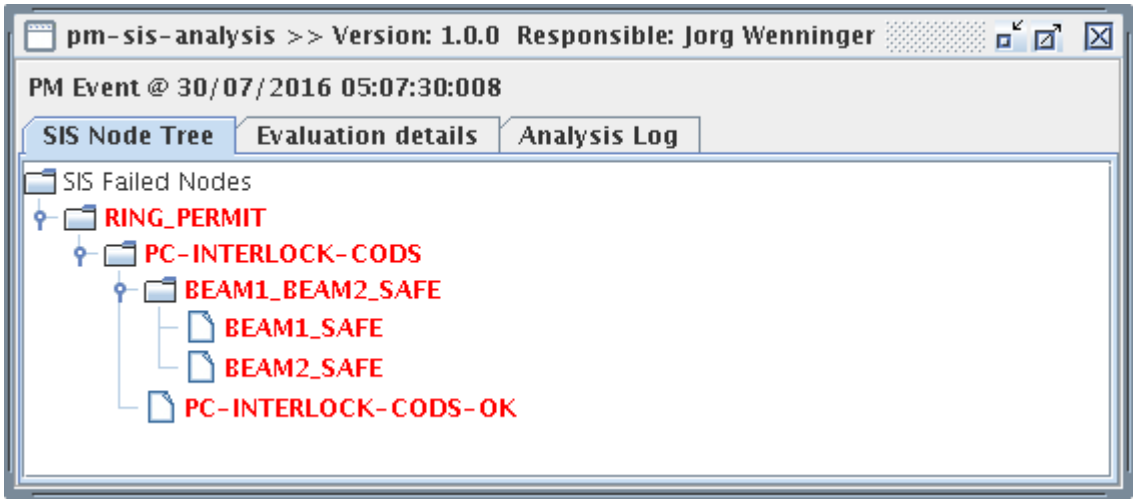


Phase Advance Interlock Quadrupole

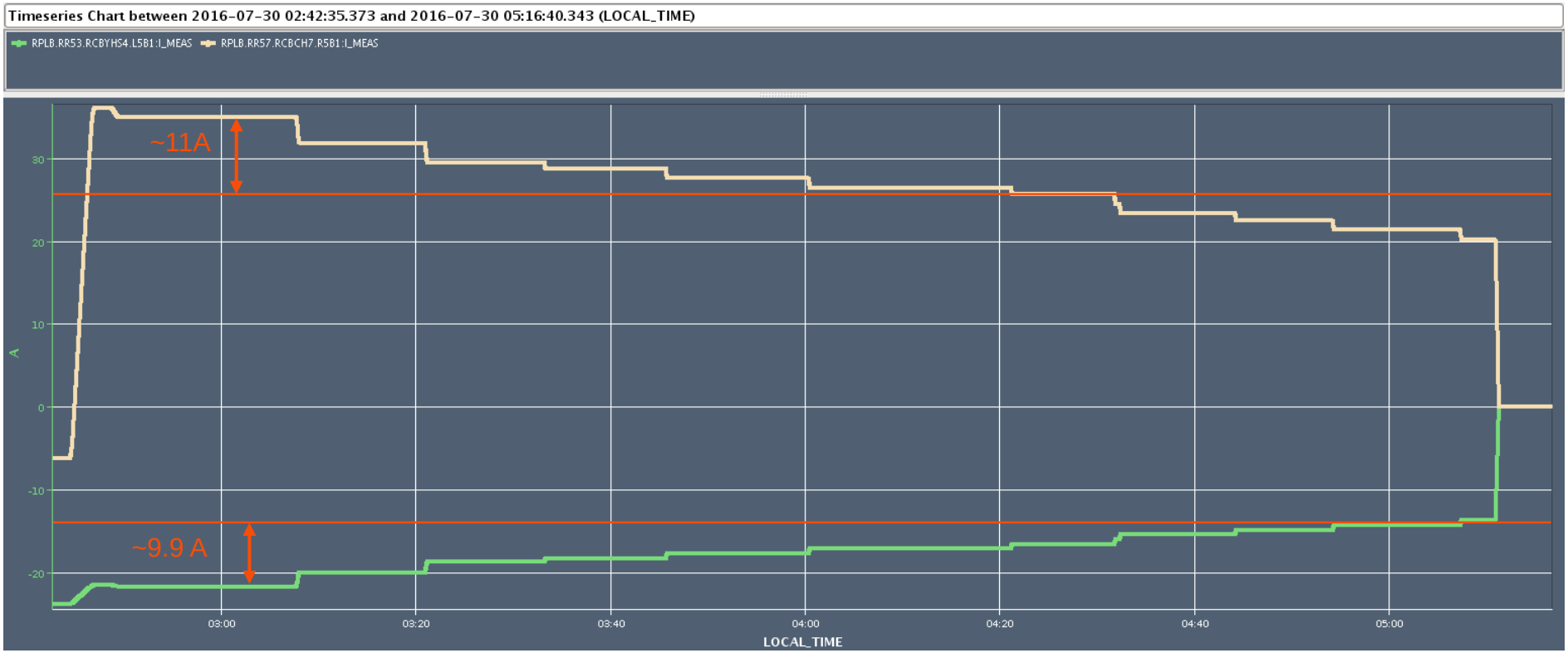


Phase Advance Interlock COD

- On RCBYHS4.L1B1 and RCBCH7.R5B1
- Strategy: Orbit Correctors Interlocking Strategy
- 2016.07.30 @ 05:07:30 (MD)



Phase Advance Interlock COD



Conclusions

- Everything is implemented and deployed.
- PCInterlock on quadrupoles is running since spring 2016
- Since 9th Aug. the SIS channel was un-masked.
- No interlocks occurred during PHYSICS.
- Interlocked correctly several times during MD.

Thank you

Do you have any question?

References for Java Classes

- Strategies configuration
  - /lhc-pcinterlock-core/src/java/cern/lhc/pcinterlock/conf/pcinterlock-strategies-beans.xml
- PC groups
  - cern.lhc.pcinterlock.domain.enums.PcInterlockPcGroup
- Interlocking strategies
  - cern.lhc.pcinterlock.service.manage.impl.AbstractInterlockingStrategy
  - cern.lhc.pcinterlock.service.manage.impl.OrbitCorrectorsInterlockingStrategy
  - cern.lhc.pcinterlock.service.manage.impl.QuadrupolesInterlockingStrategy
- PC state evaluator
  - cern.lhc.pcinterlock.service.decide.impl.WarningEvaluator
  - cern.lhc.pcinterlock.service.decide.impl.InterlockEvaluator

References for Java Classes

- Make rules (lsa-core-cern)
  - LHCNestedItolMakerule
  - LhcKTol2IRefTolMakeRule
- Lhc-pcinterlock-tolgeneration project
  - svn+ssh://svn.cern.ch/reps/acc-co/trunk/lhc/pcinterlock/lhc-pcinterlock-tolgeneration