



SPS Transverse Feedback System

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Acknowledgments: S. Cettour, K. Li, H. Pahl

Overview

- **Working principle & hardware location**
- **High-level parameter model**
- **Tools & procedures**
- **Future plans & final remarks**

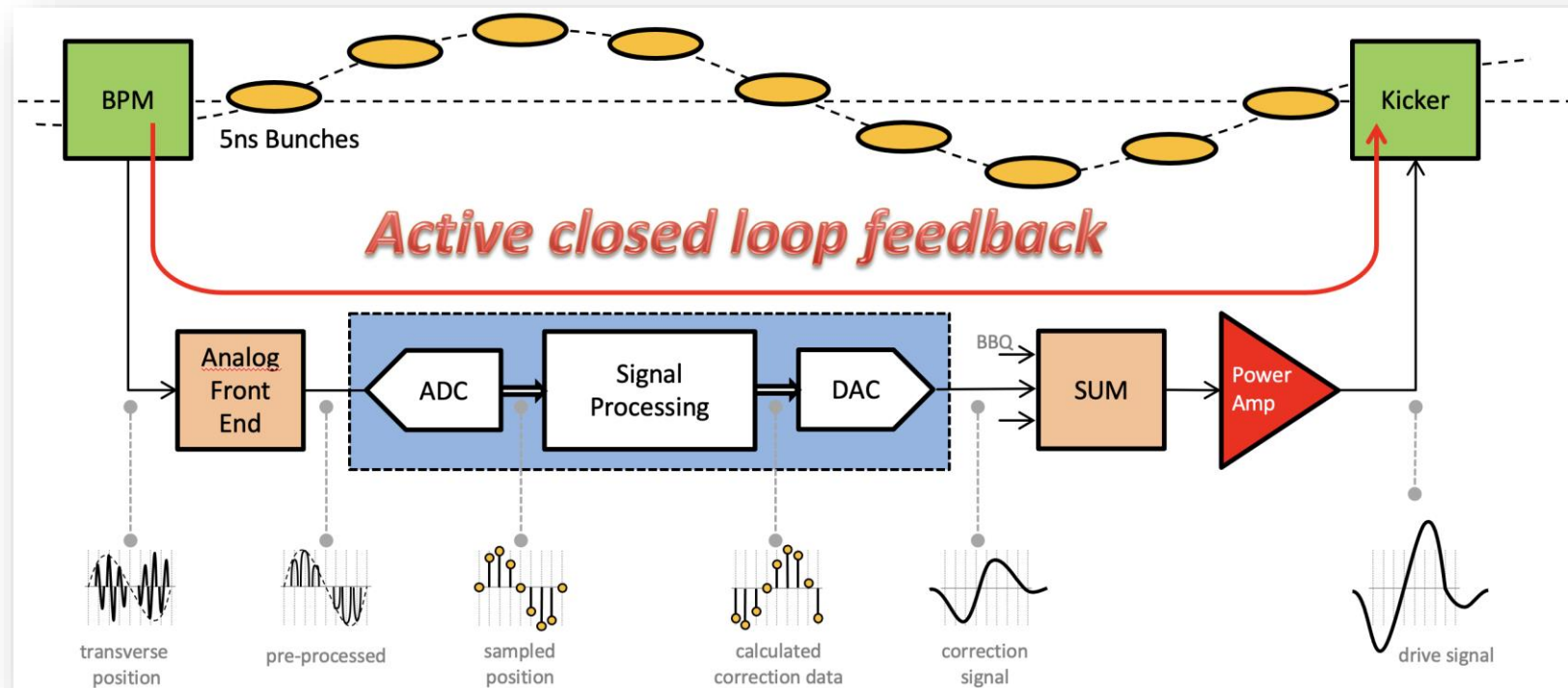
Working principle & hardware location

Working principle

Overview

The transverse damper is a feedback system to reduce horizontal and vertical bunch oscillations

1. At every turn, measure **bunch-by-bunch transverse oscillations** with a pick-up / BPM
2. Based on position data, **calculate correction signal**, accounting a. o. for phase advance BPM \leftrightarrow kicker
3. **Kickers apply amplified correction signal to individual bunches** to reduce their oscillation amplitudes



Working principle

Damping process

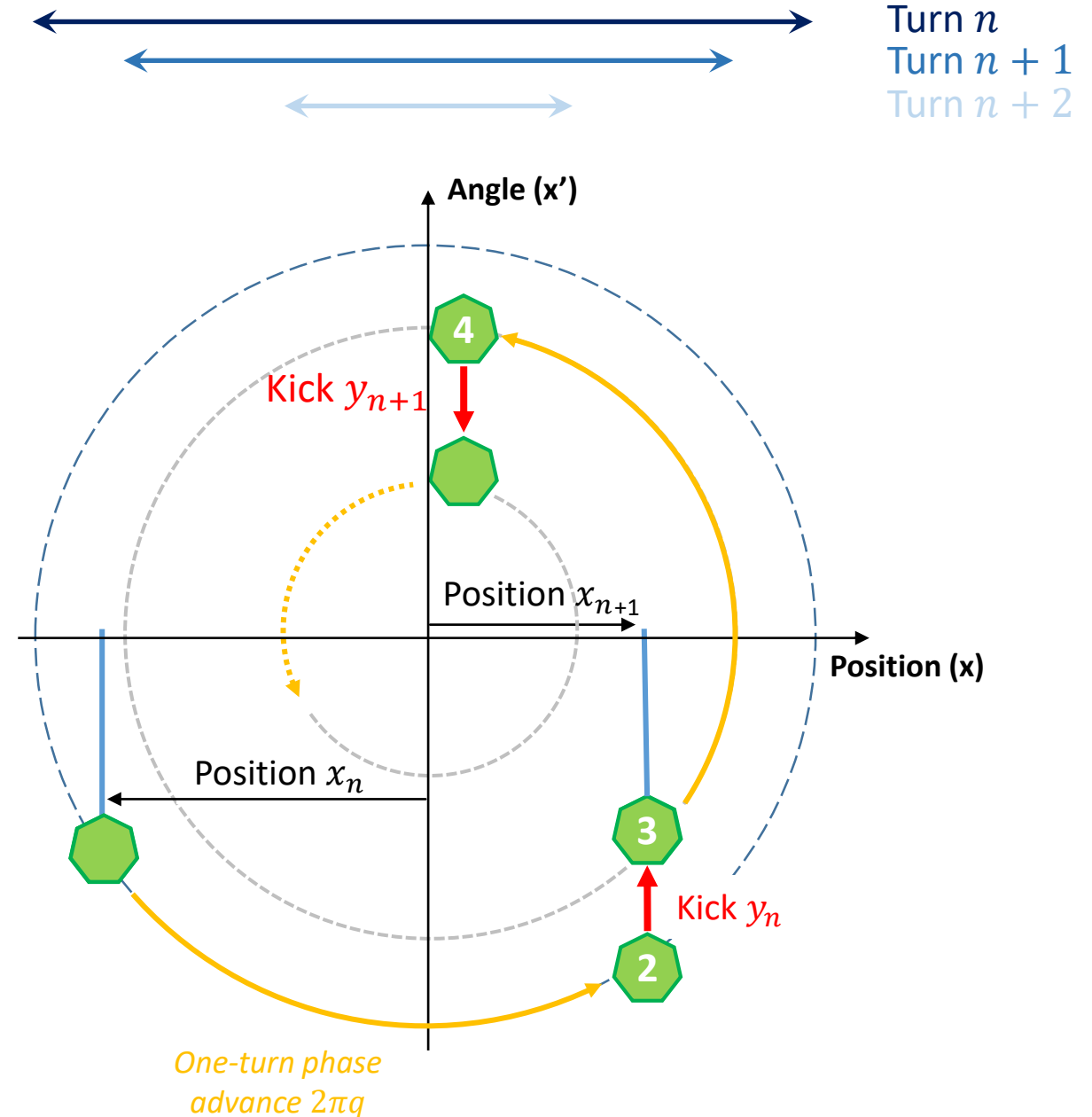
Feedback action

1. Measure bunch position x_n
2. Calculate and apply kick y_n to reduce oscillation amplitude taking into account phase advance

Repeat at every turn

➔ **Bunch oscillation amplitudes are reduced over time (exponential decay)**

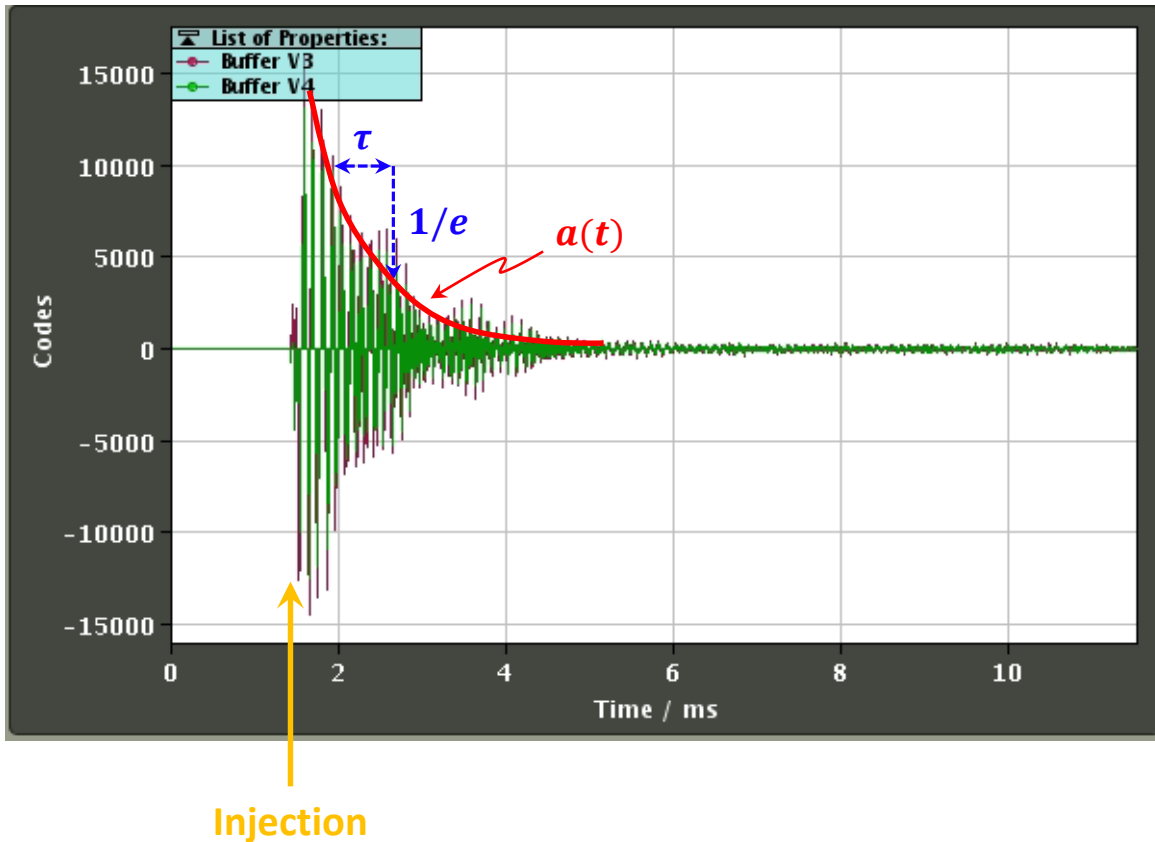
Assumptions: one-turn delay, pickup & kicker at same location in the ring, linear machine. Typically not the case.



Working principle

Damping process

SPS injection oscillation damping



- Bunch **oscillation amplitude** under influence of TFB is described by **exponential decay**

$$a(t) = a_0 e^{-t/\tau}$$

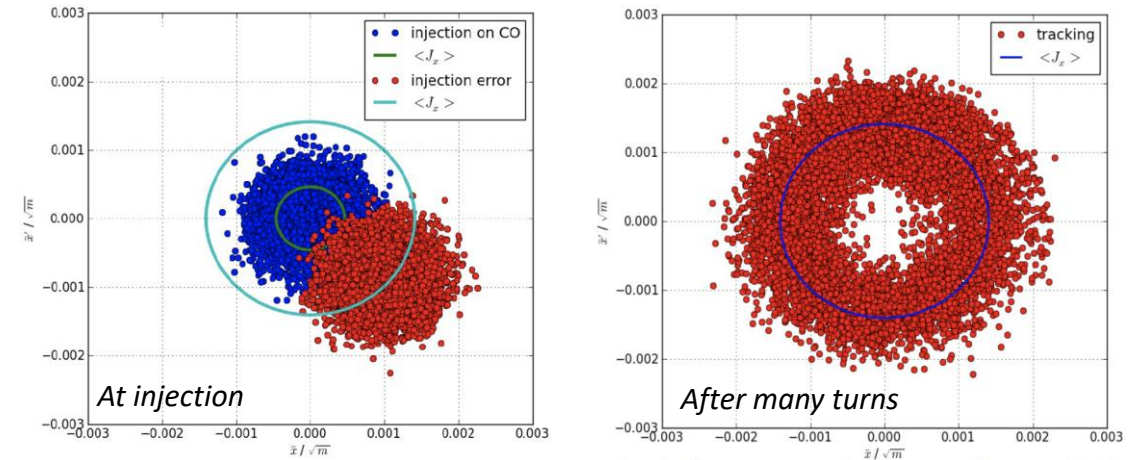
- **Damping time τ** is
 - time it takes for amplitude to drop by $1/e$
 - inversely proportional to loop gain
- **SPS TFB** can achieve damping times of **about 20 turns** (~ 0.5 ms)
- *N.B.: amplitude decay is also partially due to decoherence*

Working principle

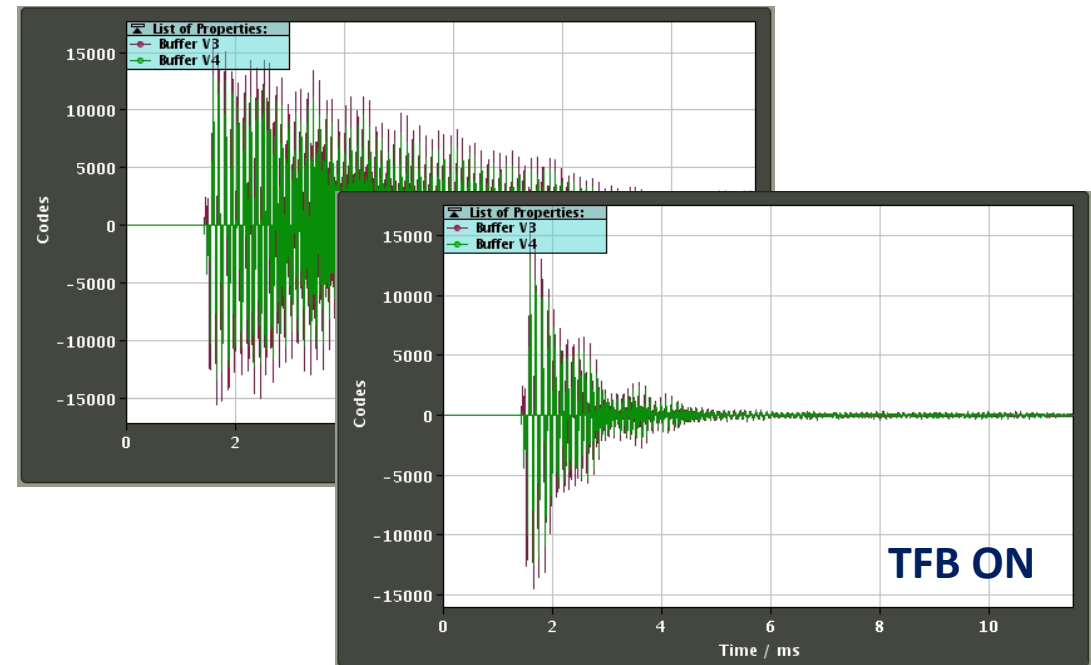
SPS TFB use case

- **Take care of injection errors and its consequences**
 - **Injection damping** (*up to several mm*)
 - **Reduce emittance blow-up** induced by non-linearities thanks to **fast enough** damping times.
Note that the TFB does not create blow-up
- **Cure coupled-bunch instabilities (CBI)**
 - In particular **resistive-wall-induced CBI**
Threshold 5×10^{12} p beam intensity
 - **Suppress all CBI** at 25 ns bunch spacing, i.e. up to 20 MHz (highest-order coupled-bunch mode)
- **SPS operational TFB not designed to suppress intra-bunch motion / single-bunch instabilities**
(bandwidth not sufficient → “wideband feedback”)

Injection error leading to emittance blow-up



[H. Schmickler, Feedback systems, CAS, 2017](#)



SPS TFB

Hardware

Per plane

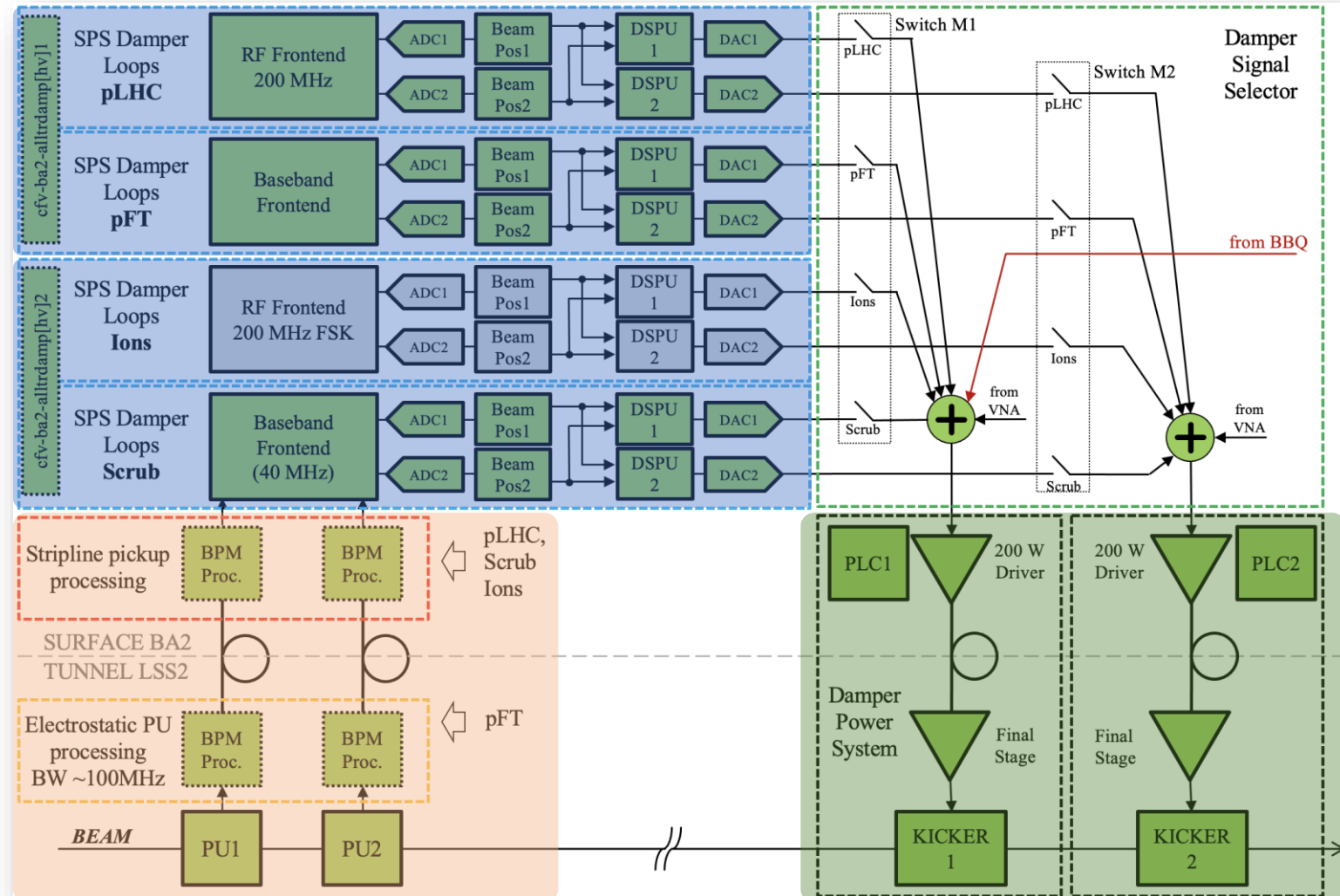
4 signal processing systems

- **pLHC**: LHC beams (25 ns)
- **pFT**: SFTPRO
- **Ions**
- ~~Scrub~~: doublet beam

Pickups

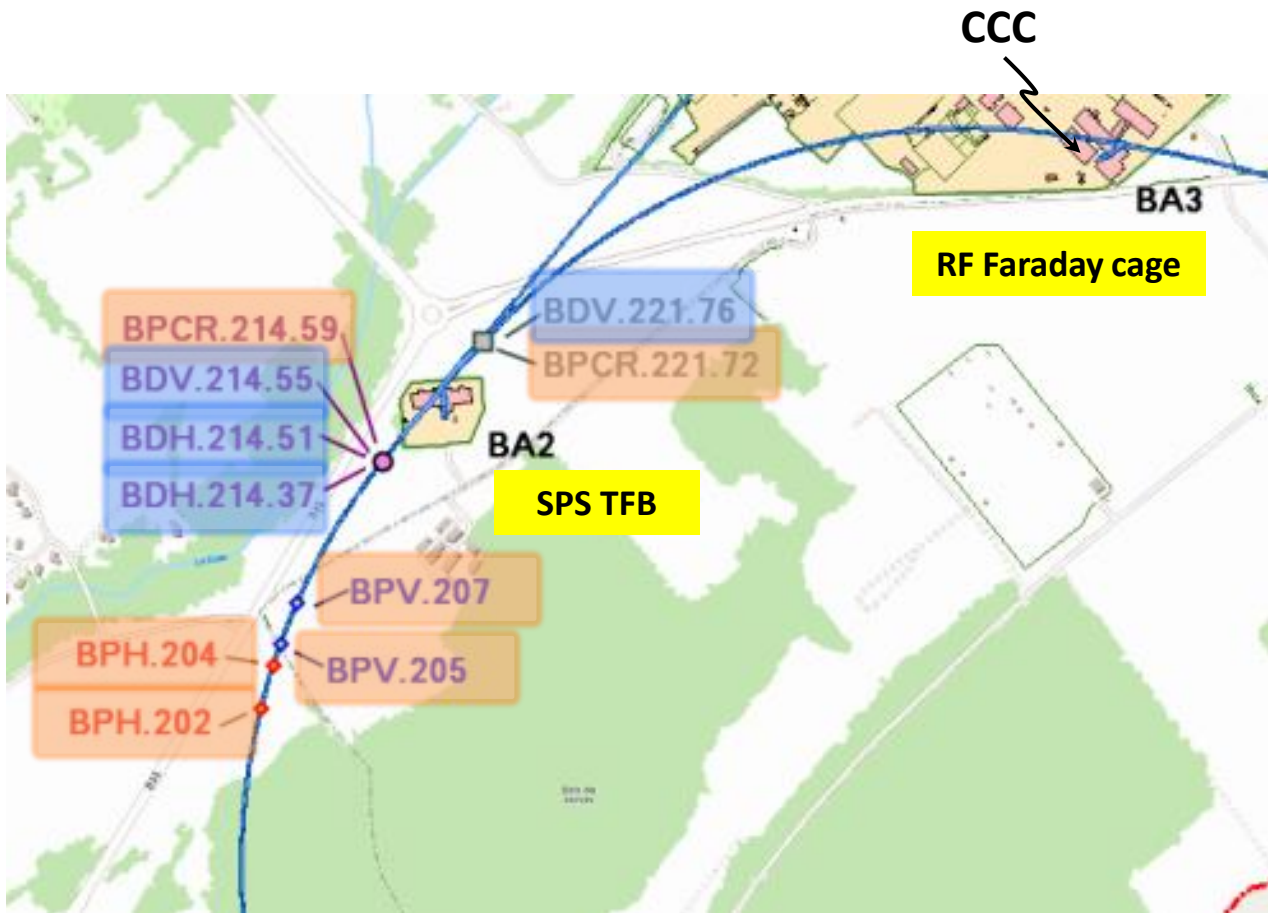
- **pFT**: 2 electro-static, processing in tunnel
- **pLHC, Ions, Scrub**: 2 striplines, processing on surface

Power system with 2 kicker modules



SPS TFB

Pickup and kicker locations



Pickups

- **pFT**
BPH.202, BPH.204
BPV.205, BPV.207
- **LHC-type beams (*p, ions, scrub*)**
BPCR.214.59 (H/V)
BPCR.221.72 (H/V)

Kickers

- **Horizontal**
BDH.214.37: module H1
BDH.214.51: module H2
- **Vertical**
BDV.214.55: module V1
BDV.221.76: module V2

SPS TFB

Take away

- SPS TFB **reduces oscillation amplitudes** on **bunch-by-bunch level**
- Amplitude damping follows **exponential decay** with time constant typically **~20 turns** (0.5 ms)
- **Main purpose:** take care of **injection errors** to limit emittance blow-up, and mitigate **coupled-bunch instabilities**
- **Hardware**
 - Located in / near BA2
 - 4 processing systems optimized for different beams (e.g. SFTPRO vs LHC-type beams)
 - Different pairs of pick-ups for SFTPRO and LHC-type beams
 - 2 kicker modules per plane



High-level parameter model

High-level parameter model

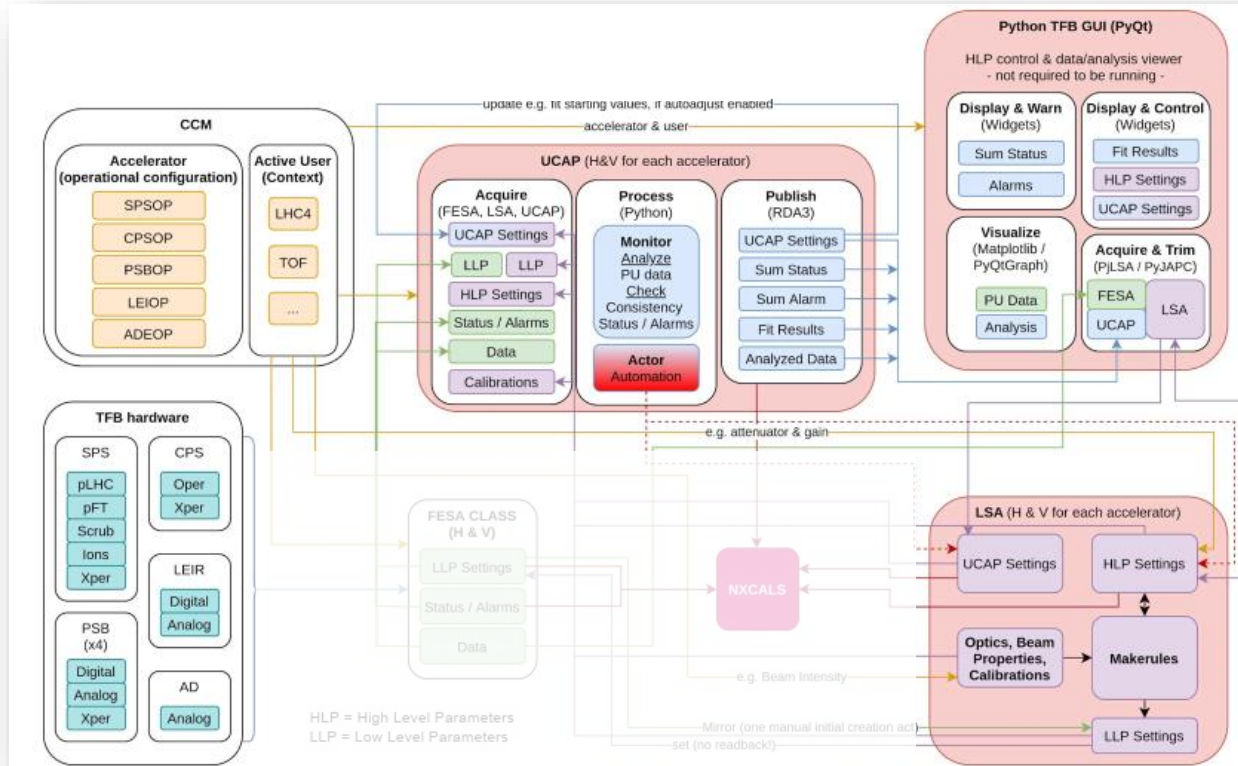
Motivation

Goal: simplify TFB commissioning and operation, expose relevant features

1. **Cycle generation:** automatically provide correct / reasonable settings
2. **Provide clear interface to change settings**
 - **Feedback modes:** *Hilbert*, *VectorSum*, *Komppula*, **bandwidth**, **active time** in cycle, etc.
 - **Phase calculation:** based on *phase advances* between pickups and kickers from *optics along cycle*, *programmed tune functions*, and *HLP phase* for fine tuning or MDs
 - **Front-end gain calculation:** injected intensity, bunch length, oscillation amplitude, calibration
 - **Adjust loop gain** throughout cycle
3. **Monitoring / control:** Python GUI for main settings, status overview, and diagnostics

High-level parameter model

Status



- LSA: value generators & makerules
- Python GUI
- UCAP

First implemented and used in 2021 – still partially under development, but LSA model & GUI mostly “stable”

H. Pahl (BE-OP-PS) working on this

F. Armbrorst et al.

High-level parameter model

LSA model: overview

- **Logics:** 2 Makerules for discrete and function parameters, respectively
- **Value generators:** CONST_VG & SPS_TFBHLP_VG
Default values for all HLP settings
- Rather wide tree of parameter relations:
4 different systems, 2 planes, many LL switches, ...
- **Goal is not to have to deal with LL settings during OP**

SPSTFBDISCRETEMR

```
int desiredValue = Math.round(-analogGaindB); // transform to 'attenuation' and round to int
int distance = Math.abs(availableValues.get(0) - desiredValue);
int idx = 0;
for (int c = 1; c < availableValues.size(); c++) {
    int cdistance = Math.abs(availableValues.get(c) - desiredValue);
    if (cdistance < distance) {
        idx = c;
        distance = cdistance;
    }
}
int setValue = availableValues.get(idx);
return "Atten_" + setValue + ".dB";

private String getLpDamperPlane(String parentParamName) {
    String damperPlane = "";
}
```

SPSTFBFUNCTIONSMR

```
// For discrete source params., would otherwise go through all BPs, incl. BeamOut which results in
// an exception further down when getting the HLP phase function.
if (mra.getBeamProcess().getCategory().isBeamOut()) {
    return null;
}

if (mra.getBeamProcess().getCategory().equals(BeamProcessTypeCategory.DISCRETE)) {
    logger.warn("TFB MakeRules not implemented for discrete beam processes, e.g. COAST.");
    return null;
}

// Extract damperPlane ("H" or "V")
String damperPlane = getLpDamperPlane(mra.getParentParameters());

// Child parameter is one of "PHASE_(H,V){1,2}_PU{1,2}/Functions" or "CDEF_(H,V){1,2}_b{1,2}"
Parameter childParameter = mra.getParameter();
String childParamName = childParameter.getName();
```

SPS_TFBHLP_VG

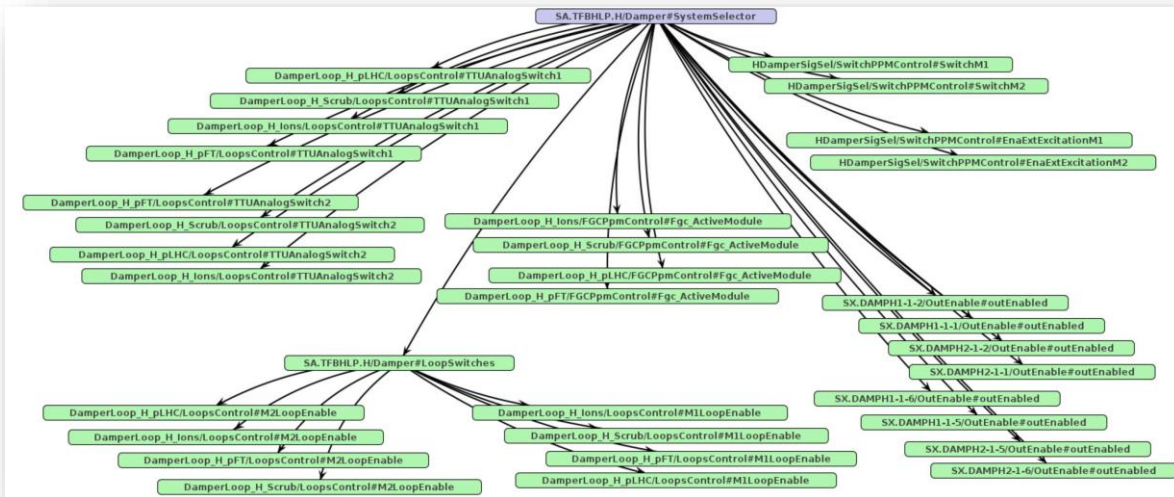
```
package cern.lsa.ext.sps.generation.generator.rf;

import cern.accsoft.commons.value.*;
import cern.lsa.core.generation.ValueGeneratorArguments;
import cern.lsa.core.generation.spi.generator.SimpleValueGenerator;
import cern.lsa.domain.settings.BeamProcess;
import cern.lsa.domain.settings.GenerationException;
import cern.lsa.domain.settings.type.CycleType;
import cern.lsa.ext.sps.generation.initializer.SPSRNGGenerationInitializer;

import java.util.Arrays;

public class SpsTfbhlpValueGenerator extends SimpleValueGenerator {

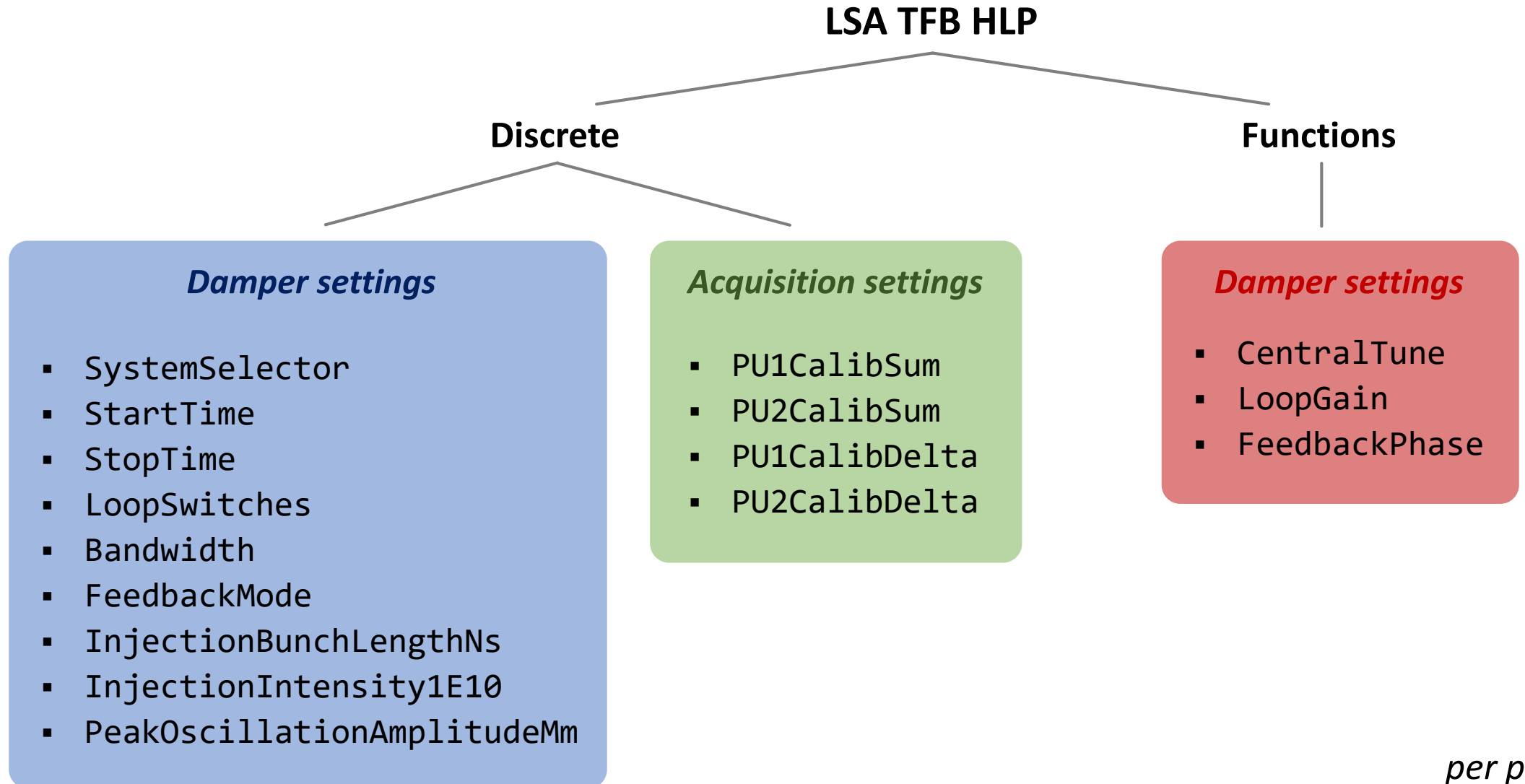
    private static final String SYSTEM_SELECTOR_H_PARAMETER_NAME = "SA_TFBHLP.H/Damper#SystemSelector";
    private static final String SYSTEM_SELECTOR_V_PARAMETER_NAME = "SA_TFBHLP.V/Damper#SystemSelector";
}
```



High-level parameter model

LSA model: overview

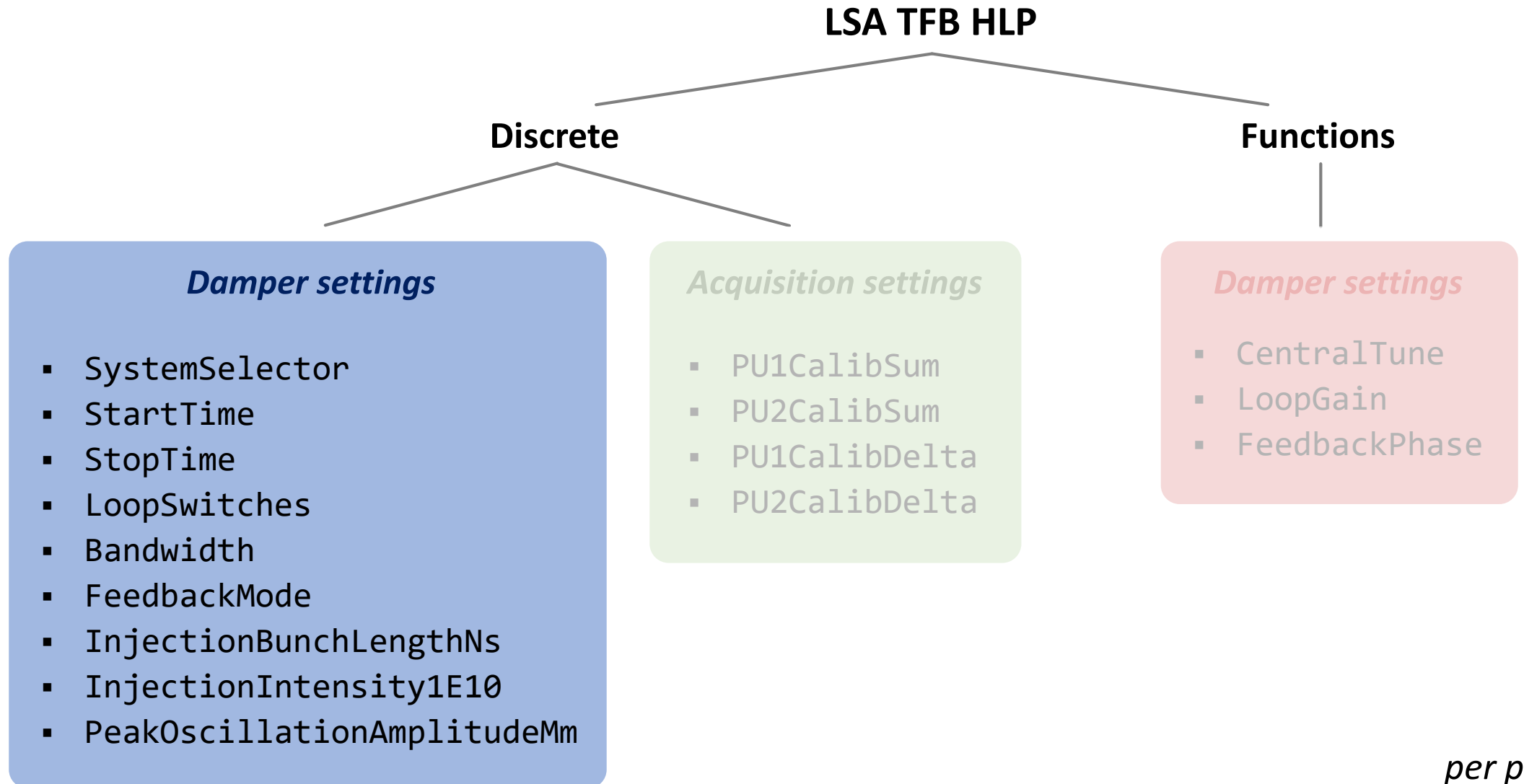
All these parameters are accessible and editable from the Python GUI (see later on)



per plane

High-level parameter model

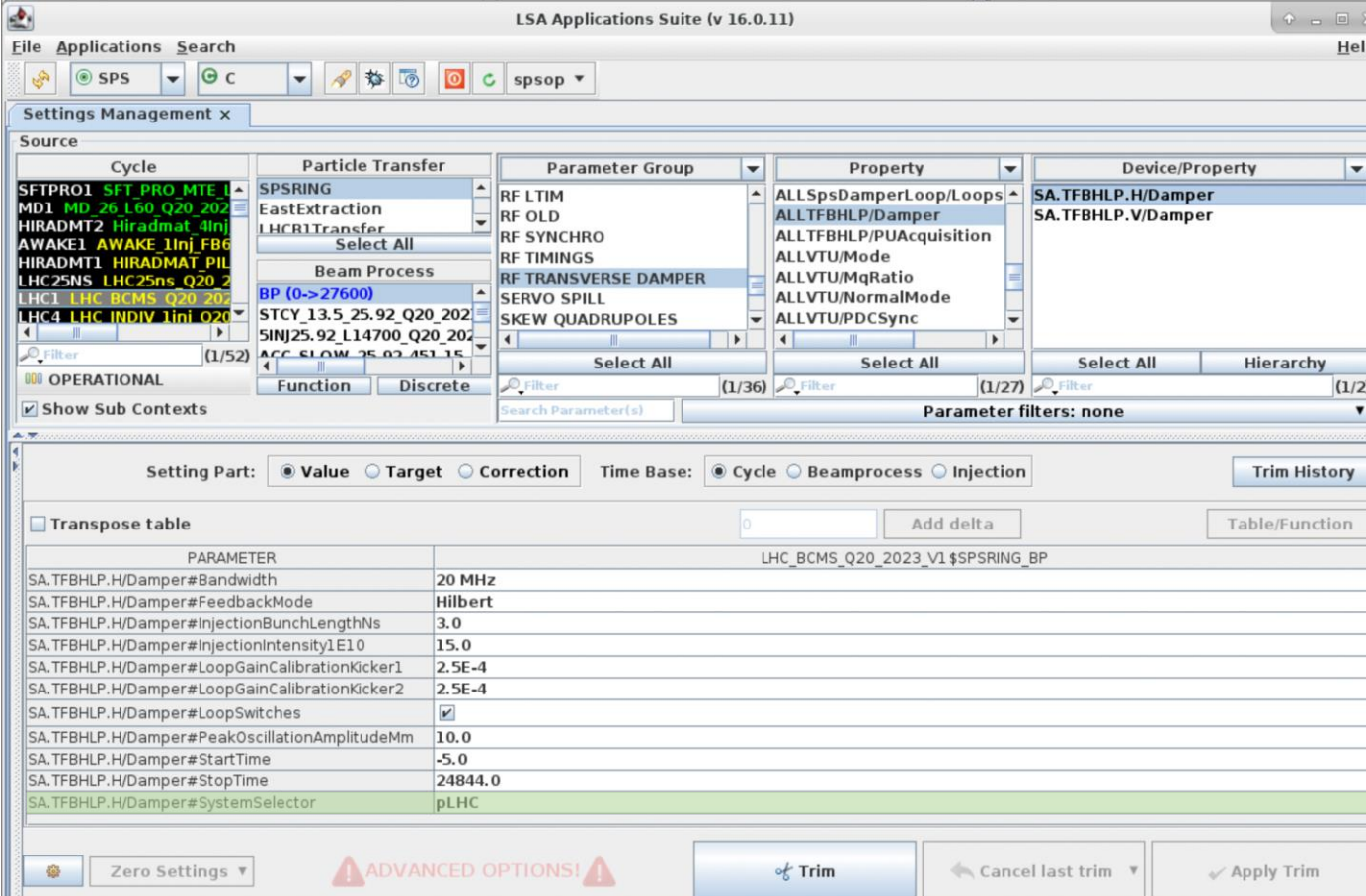
LSA model: overview



per plane

High-level parameter model

LSA model: discrete damper parameters



The screenshot shows the LSA Applications Suite (v 16.0.11) interface. The main window is titled "Settings Management x" and displays a tree view of parameters. The "Parameter Group" is set to "SPSRING". The "Property" is "SA.TFBHLP.H/Damper". The "Device/Property" is "SA.TFBHLP.V/Damper". The "Setting Part" is "Value". The "Time Base" is "Cycle". The "Transpose table" is checked. The table below shows the values for the parameters:

PARAMETER	Value
SA.TFBHLP.H/Damper#Bandwidth	20 MHz
SA.TFBHLP.H/Damper#FeedbackMode	Hilbert
SA.TFBHLP.H/Damper#InjectionBunchLengthNs	3.0
SA.TFBHLP.H/Damper#InjectionIntensity1E10	15.0
SA.TFBHLP.H/Damper#LoopGainCalibrationKicker1	2.5E-4
SA.TFBHLP.H/Damper#LoopGainCalibrationKicker2	2.5E-4
SA.TFBHLP.H/Damper#LoopSwitches	<input checked="" type="checkbox"/>
SA.TFBHLP.H/Damper#PeakOscillationAmplitudeMm	10.0
SA.TFBHLP.H/Damper#StartTime	-5.0
SA.TFBHLP.H/Damper#StopTime	24844.0
SA.TFBHLP.H/Damper#SystemSelector	pLHC

SystemSelector: *OFF, pLHC, pFT, IONS, SCRUB*

- Depending on beam type, pick suitable system
- Nearly all LL parameters depend on it ...

SPS_TFBHLP_VG

- LHC-type beams: pLHC
- SFTPRO: pFT
- Ions: IONS

High-level parameter model

LSA model: discrete damper parameters

The screenshot shows the LSA Applications Suite (v 16.0.11) interface. The main window is titled "Settings Management x" and displays a tree view of parameters. The tree view is organized into several categories: Cycle, Particle Transfer, Parameter Group, Property, and Device/Property. The "Parameter Group" category is expanded, showing "RF TRANSVERSE DAMPER". The "Property" category is also expanded, showing "ALLVtu/MqRatio". The "Device/Property" category is expanded, showing "SA.TFBHLP.H/Damper" and "SA.TFBHLP.V/Damper".

Below the tree view, there are several controls: "Setting Part: Value Target Correction", "Time Base: Cycle Beamprocess Injection", and "Trim History". A "Transpose table" is also visible, with a value of "0" and an "Add delta" button. The table below shows the parameter values for "LHC_BCMS_Q20_2023_V1.\$SPSRING_BP".

PARAMETER	Value
SA.TFBHLP.H/Damper#Bandwidth	20 MHz
SA.TFBHLP.H/Damper#FeedbackMode	Hilbert
SA.TFBHLP.H/Damper#InjectionBunchLengthNs	3.0
SA.TFBHLP.H/Damper#InjectionIntensity1E10	15.0
SA.TFBHLP.H/Damper#LoopGainCalibrationKicker1	2.5E-4
SA.TFBHLP.H/Damper#LoopGainCalibrationKicker2	2.5E-4
SA.TFBHLP.H/Damper#LoopSwitches	<input checked="" type="checkbox"/>
SA.TFBHLP.H/Damper#PeakOscillationAmplitudeMm	10.0
SA.TFBHLP.H/Damper#StartTime	-5.0
SA.TFBHLP.H/Damper#StopTime	24844.0
SA.TFBHLP.H/Damper#SystemSelector	pLHC

At the bottom of the window, there are buttons for "Zero Settings", "ADVANCED OPTIONS!", "Trim", "Cancel last trim", and "Apply Trim".

StartTime, StopTime: active time in cycle

- Sets delays in RF TIMINGS LTIM/Delay and corresponding event flags / triggers
- Measured with *injection time reference*

VGs

- StartTime: -5 ms (CONST_VG)
- StopTime: 5 ms after beamOut (SPS_TFBHLP_VG)

High-level parameter model

LSA model: discrete damper parameters

The screenshot shows the LSA Applications Suite (v 16.0.11) interface. The 'Settings Management' window is open, displaying a tree view of sources and parameters. The main window shows a parameter table for the LHC_BCMS_Q20_2023_V1.\$SPSRING_BP parameter group.

PARAMETER	Value
SA.TFBHLP.H/Damper#Bandwidth	20 MHz
SA.TFBHLP.H/Damper#FeedbackMode	Hilbert
SA.TFBHLP.H/Damper#InjectionBunchLengthNs	3.0
SA.TFBHLP.H/Damper#InjectionIntensity1E10	15.0
SA.TFBHLP.H/Damper#LoopGainCalibrationKicker1	2.5E-4
SA.TFBHLP.H/Damper#LoopGainCalibrationKicker2	2.5E-4
SA.TFBHLP.H/Damper#LoopSwitches	<input checked="" type="checkbox"/>
SA.TFBHLP.H/Damper#PeakOscillationAmplitudeMm	10.0
SA.TFBHLP.H/Damper#StartTime	-5.0
SA.TFBHLP.H/Damper#StopTime	24844.0
SA.TFBHLP.H/Damper#SystemSelector	pLHC

LoopSwitches

- Sets $M\{1,2\}$ LoopEnable switches in LoopsControl based on SystemSelector
- *N.B.: cannot disable individual module with HLP. To be done on LL (see later)*

CONST_VG

- Initialized to *False (!)*

High-level parameter model

LSA model: discrete damper parameters

The screenshot shows the LSA Applications Suite (v 16.0.11) interface. The main window is titled "Settings Management x" and displays a list of parameters in a table. The selected parameter is "SA.TFBHLP.H/Damper#Bandwidth", which is set to "20 MHz". The interface includes a menu bar (File, Applications, Search, Help), a toolbar with various icons, and a search bar. The parameter list is organized into columns: Source, Cycle, Particle Transfer, Parameter Group, Property, and Device/Property. The selected parameter is highlighted in green. Below the parameter list, there are controls for "Setting Part" (Value, Target, Correction), "Time Base" (Cycle, Beamprocess, Injection), and a "Trim History" button. A "Transpose table" section is also visible, showing a table of parameters and their values. At the bottom, there are buttons for "Zero Settings", "ADVANCED OPTIONS!", "Trim", "Cancel last trim", and "Apply Trim".

PARAMETER	Value
SA.TFBHLP.H/Damper#Bandwidth	20 MHz
SA.TFBHLP.H/Damper#FeedbackMode	Hilbert
SA.TFBHLP.H/Damper#InjectionBunchLengthNs	3.0
SA.TFBHLP.H/Damper#InjectionIntensity1E10	15.0
SA.TFBHLP.H/Damper#LoopGainCalibrationKicker1	2.5E-4
SA.TFBHLP.H/Damper#LoopGainCalibrationKicker2	2.5E-4
SA.TFBHLP.H/Damper#LoopSwitches	<input checked="" type="checkbox"/>
SA.TFBHLP.H/Damper#PeakOscillationAmplitudeMm	10.0
SA.TFBHLP.H/Damper#StartTime	-5.0
SA.TFBHLP.H/Damper#StopTime	24844.0
SA.TFBHLP.H/Damper#SystemSelector	pLHC

Bandwidth: ZERO, FLAT, 3 MHz, ..., 24 MHz

- 32 FIR Gain eq. coeffs. in DSPU{1,2}
- 32 FIR Phase eq. coeffs. In DSPU{1,2} (fixed to 6.5 MHz for now)

SPS_TFBHLP_VG

- LHC-type single bunch: 3 MHz
- LHC 25 ns multi-bunch: 20 MHz
- SFTPRO: 14 MHz

N.B.: lower bandwidth means larger kick strength, but TFB can potentially no longer act bunch-by-bunch

High-level parameter model

LSA model: discrete damper parameters

The screenshot shows the LSA Applications Suite (v 16.0.11) interface. The main window displays a list of parameters for the device SA.TFBHLP.H/Damper. The 'FeedbackMode' parameter is highlighted in green and set to 'Hilbert'. Other parameters include Bandwidth (20 MHz), InjectionBunchLengthNs (3.0), and SystemSelector (pLHC).

PARAMETER	Value
SA.TFBHLP.H/Damper#Bandwidth	20 MHz
SA.TFBHLP.H/Damper#FeedbackMode	Hilbert
SA.TFBHLP.H/Damper#InjectionBunchLengthNs	3.0
SA.TFBHLP.H/Damper#InjectionIntensity1E10	15.0
SA.TFBHLP.H/Damper#LoopGainCalibrationKicker1	2.5E-4
SA.TFBHLP.H/Damper#LoopGainCalibrationKicker2	2.5E-4
SA.TFBHLP.H/Damper#LoopSwitches	<input checked="" type="checkbox"/>
SA.TFBHLP.H/Damper#PeakOscillationAmplitudeMm	10.0
SA.TFBHLP.H/Damper#StartTime	-5.0
SA.TFBHLP.H/Damper#StopTime	24844.0
SA.TFBHLP.H/Damper#SystemSelector	pLHC

FeedbackMode: Hilbert, VectorSum, Kompula

- Sets switches in DSPU{1,2}, FGC, and LoopsControl depending on mode
- Triggers calculation of LL PHASE functions based on CentralTune, SystemSelector, FeedbackPhase, and optics throughout cycle

SPS_TFBHLP_VG

- LHC-type beam, ions: Hilbert
- SFTPRO: VectorSum

High-level parameter model

LSA model: discrete damper parameters

LSA Applications Suite (v 16.0.11)

File Applications Search Help

Settings Management x

Source

Cycle	Particle Transfer	Parameter Group	Property	Device/Property
SFTPRO1 SFT PRO MTE 1	SPSRING	RF LTIM	ALLSpsDamperLoop/Loops	SA.TFBHLP.H/Damper
MD1 MD 26 L60 Q20 202	EastExtraction	RF OLD	ALLTFBHLP/Damper	SA.TFBHLP.V/Damper
HIRADMT2 Hiradmat 4Inj	LHCBITransfer	RF SYNCHRO	ALLTFBHLP/PUAcquisition	
AWAKE1 AWAKE 1Inj_FB6	Select All	RF TIMINGS	ALLVTU/Mode	
HIRADMT1 HIRADMAT_PIL	Beam Process	RF TRANSVERSE DAMPER	ALLVTU/MqRatio	
LHC25NS LHC25ns Q20 2	BP (0->27600)	SERVO SPILL	ALLVTU/NormalMode	
LHC1 LHC BCMS Q20 202	STCY 13.5_25.92_Q20_202	SKEW QUADRUPOLES	ALLVTU/PDCSync	
LHC4 LHC INDIV 1ini 020	SINJ25.92_L14700_Q20_202	Select All	Select All	Select All
	ACC_SLOW_25.02_451_15	Filter (1/36)	Filter (1/27)	Filter (1/2)

OPERATIONAL (1/52)

Show Sub Contexts

Setting Part: Value Target Correction Time Base: Cycle Beamprocess Injection Trim History

Transpose table

PARAMETER	Value
SA.TFBHLP.H/Damper#Bandwidth	20 MHz
SA.TFBHLP.H/Damper#FeedbackMode	Hilbert
SA.TFBHLP.H/Damper#InjectionBunchLengthNs	3.0
SA.TFBHLP.H/Damper#InjectionIntensity1E10	15.0
SA.TFBHLP.H/Damper#LoopGainCalibrationKicker1	2.5E-4
SA.TFBHLP.H/Damper#LoopGainCalibrationKicker2	2.5E-4
SA.TFBHLP.H/Damper#LoopSwitches	<input checked="" type="checkbox"/>
SA.TFBHLP.H/Damper#PeakOscillationAmplitudeMm	10.0
SA.TFBHLP.H/Damper#StartTime	-5.0
SA.TFBHLP.H/Damper#StopTime	24844.0
SA.TFBHLP.H/Damper#SystemSelector	pLHC

Zero Settings ADVANCED OPTIONS! Trim Cancel last trim Apply Trim

InjectionBunchLengthNs,
InjectionIntensity1E10,
PeakOscillationAmplitudeMm

- Calculate and set front-end (FE) gains for sum & delta signals to best use dynamic range
- Depends on SystemSelector (RF or BB FE) and calibration factors for PU

VGs

- InjectionBunchLengthNs: 3 ns (CONST_VG)
- PeakOscillationAmplitudeMm: 10 mm (CONST_VG)

N.B.: InjectionIntensity1E10

- Controlled by SPSGAINMR (*Y. Le Borgne*)
- **Hence, please change on even higher level:** SpsGainCalculation/IntensityPerBunchE10 (parameter group: INSTRUMENTATION)

High-level parameter model

LSA model: discrete damper parameters

LSA Applications Suite (v 16.0.11)

Settings Management x

Source

Cycle	Particle Transfer	Parameter Group	Property	Device/Property
SFTPRO1 SFT PRO MTE 1	SPSRING	RF LTIM	ALLSpsDamperLoop/Loops	SA.TFBHLP.H/Damper
MD1 MD 26 L60 Q20 202	EastExtraction	RF OLD	ALLTFBHL/Damper	SA.TFBHLP.V/Damper
HIRADMT2 Hiramdat 4Inj	LHCBITransfer	RF SYNCHRO	ALLTFBHL/PUAcquisition	
AWAKE1 AWAKE 1Inj FB6	Select All	RF TIMINGS	ALLVTU/Mode	
HIRADMT1 HIRADMAT PIL	Beam Process	RF TRANSVERSE DAMPER	ALLVTU/MqRatio	
LHC25NS LHC25ns Q20 2	BP (0->27600)	SERVO SPILL	ALLVTU/NormalMode	
LHC1 LHC BCMS Q20 202	STCY_13.5_25.92_Q20_202	SKEW QUADRUPOLES	ALLVTU/PDCSync	
LHC4 LHC INDIV 1Inj 020	SINJ25.92_L14700_Q20_202	Select All	Select All	Select All
	ACC_SLOW_25.02_451_15	Filter (1/36)	Filter (1/27)	Hierarchy (1/2)

OPERATIONAL

Show Sub Contexts

Setting Part: Value Target Correction Time Base: Cycle Beamprocess Injection Trim History

Transpose table

PARAMETER	Value
SA.TFBHLP.H/Damper#Bandwidth	20 MHz
SA.TFBHLP.H/Damper#FeedbackMode	Hilbert
SA.TFBHLP.H/Damper#InjectionBunchLengthNs	3.0
SA.TFBHLP.H/Damper#InjectionIntensity1E10	15.0
SA.TFBHLP.H/Damper#LoopGainCalibrationKicker1	2.5E-4
SA.TFBHLP.H/Damper#LoopGainCalibrationKicker2	2.5E-4
SA.TFBHLP.H/Damper#LoopSwitches	<input checked="" type="checkbox"/>
SA.TFBHLP.H/Damper#PeakOscillationAmplitudeMm	10.0
SA.TFBHLP.H/Damper#StartTime	-5.0
SA.TFBHLP.H/Damper#StopTime	24844.0
SA.TFBHLP.H/Damper#SystemSelector	pLHC

Zero Settings ADVANCED OPTIONS! Trim Cancel last trim Apply Trim

LoopGainCalibrationKicker{1,2}

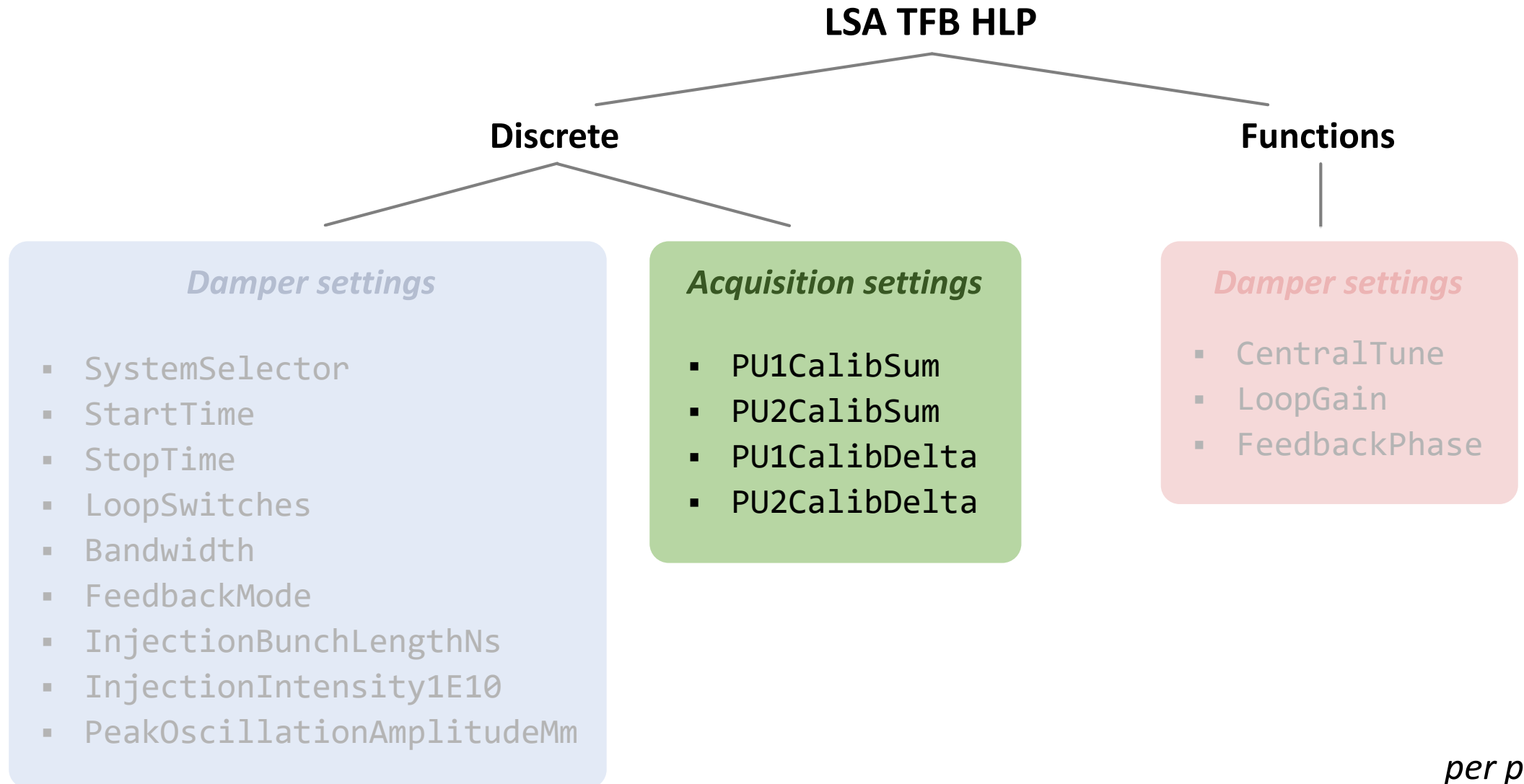
- Multiplication factor to LoopGain function for the two kicker modules (*see next*)
- Could be calibrated for LoopGain to correspond to specific damping time (*this has not been done*)

CONST_VG

- Initialized to 2.5E-4

High-level parameter model

LSA model: overview



per plane

High-level parameter model

LSA model: discrete acquisition parameters

LSA Applications Suite (v 16.0.11)

Settings Management x

Source

Cycle	Particle Transfer	Parameter Group	Property	Device/Property
SFTPRO1 SFT_PRO MTE 1	SPSRING	RF LTIM	ALLSpsDamperLoop/Loops	SA.TFBHLP.H/PUAcquisition
MD1 MD_26_L60_Q20_202	EastExtraction	RF OLD	ALLTFBHLP/Damper	SA.TFBHLP.V/PUAcquisition
HIRADMT2 Hiradmat_4Inj	LHC1Transfer	RF SYNCHRO	ALLTFBHLP/PUAcquisition	
AWAKE1 AWAKE_1Inj_FB6	Select All	RF TIMINGS	ALLVTU/Mode	
HIRADMT1 HIRADMAT_PIL	Beam Process	RF TRANSVERSE DAMPER	ALLVTU/MqRatio	
LHC25NS LHC25ns Q20_2	BP (0->27600)	SERVO SPILL	ALLVTU/NormalMode	
LHC1 LHC BCMS Q20_202	STCY_13.5_25.92_Q20_202	SKEW QUADRUPOLES	ALLVTU/PDCSync	
LHC4 LHC INDIV 1Inj_020	SINJ25.92_L14700_Q20_202	Select All	Select All	Select All

OPERATIONAL (1/52)

Setting Part: Value Target Correction Time Base: Cycle Beamprocess Injection

Transpose table: 0 Add delta Table/Function

PARAMETER	Value
SA.TFBHLP.H/PUAcquisition#PU1CalibDelta	7.0E-4
SA.TFBHLP.H/PUAcquisition#PU1CalibSum	0.15
SA.TFBHLP.H/PUAcquisition#PU2CalibDelta	7.0E-4
SA.TFBHLP.H/PUAcquisition#PU2CalibSum	0.15

Zero Settings ADVANCED OPTIONS! Trim Cancel last trim Apply Trim

Acquisition#PU{1,2}Calib{Delta,Sum}

- PU calibration factors
- PU-, and hence beam-type dependent
- Enter FE gain calculations
- Defined in 2021 when setting up with beam^(*)

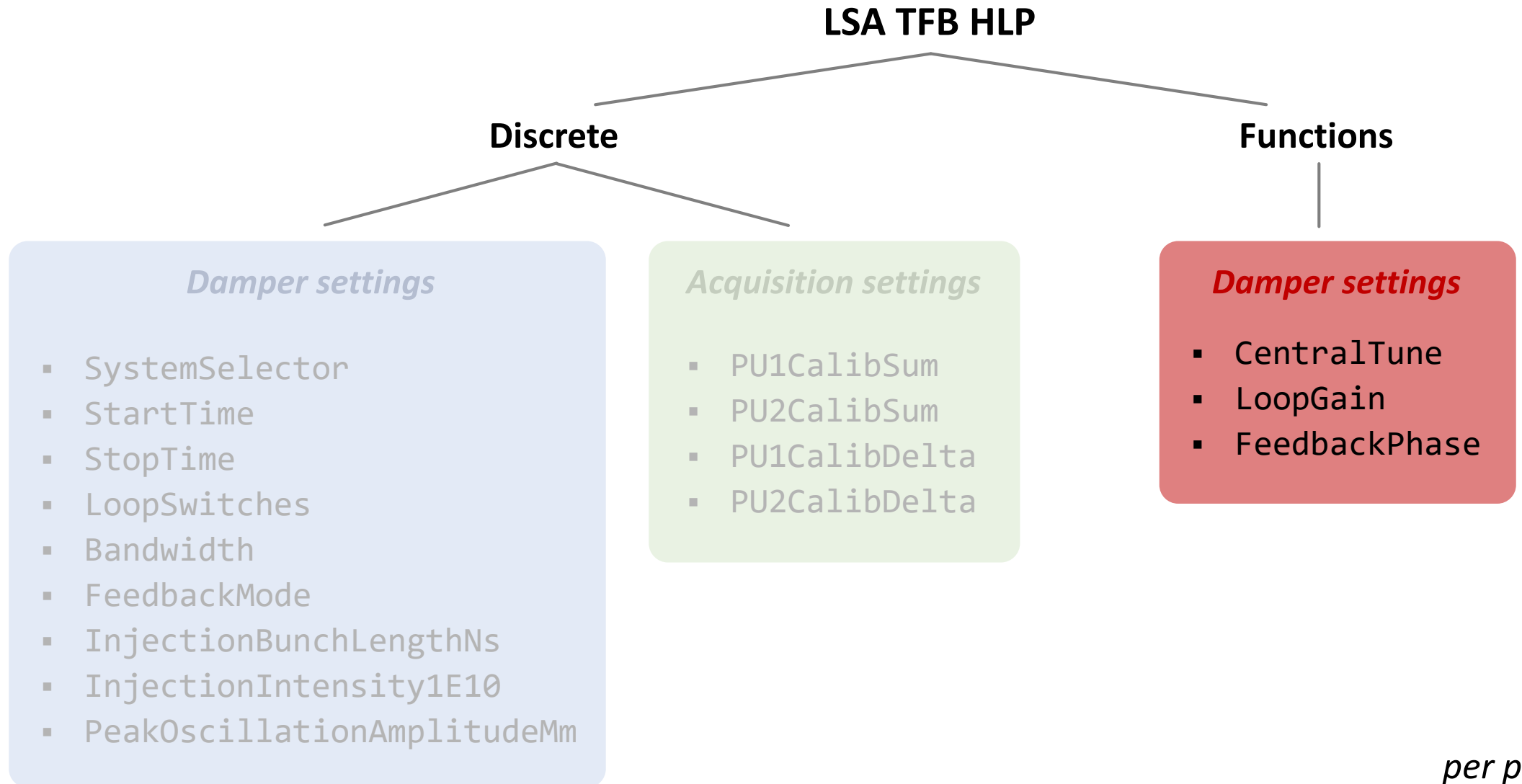
SPS_TFBHLP_VG

- LHC-type
 - PU{1,2}CalibSum: 0.15
 - PU{1,2}CalibDelta: 7E-4
- SFTPRO
 - PU{1,2}CalibSum: 0.25
 - PU{1,2}CalibDelta: 2E-3

^(*)<https://logbook.cern.ch/elogbook-server/GET/showEventInLogbook/3284228>

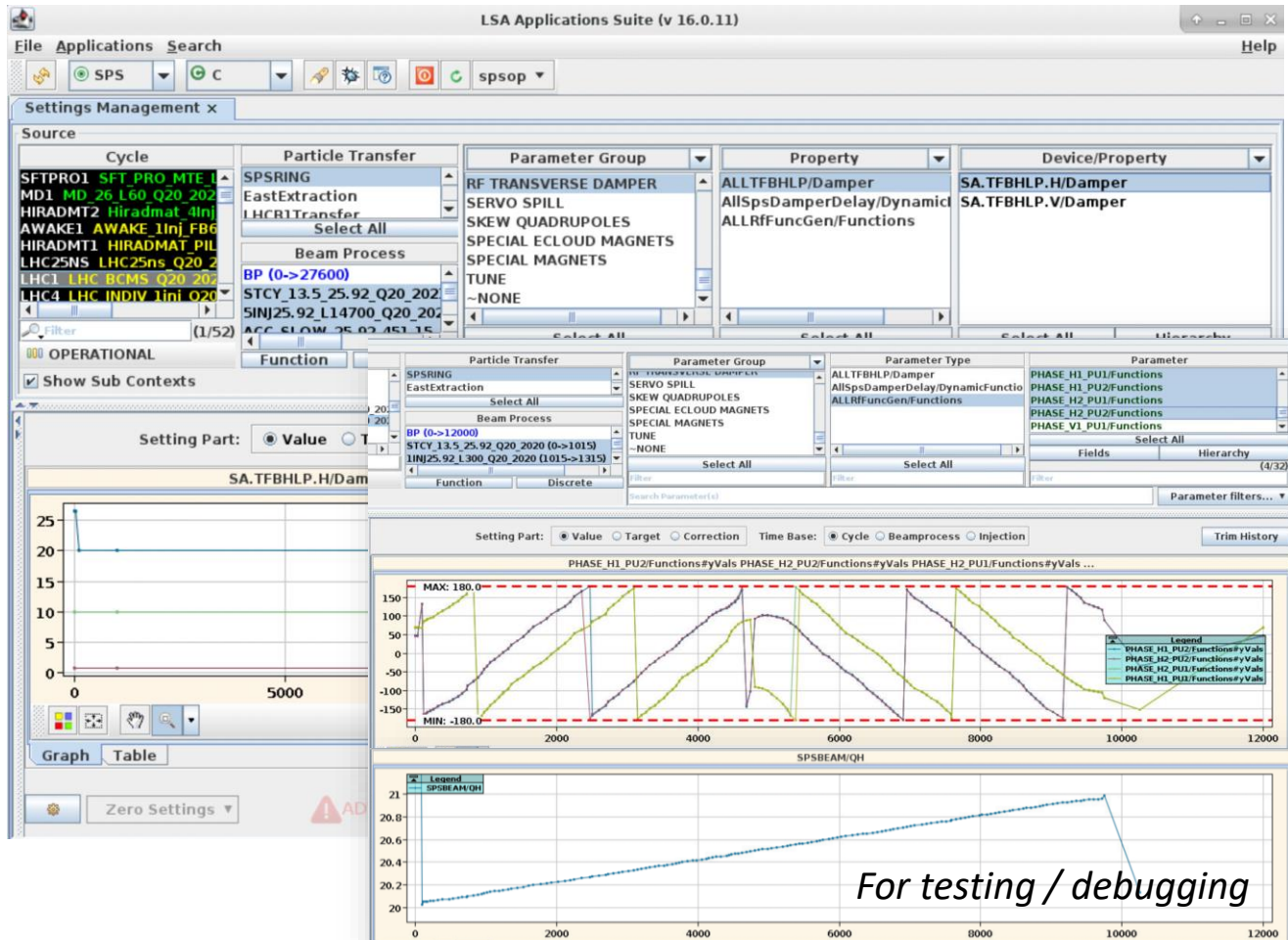
High-level parameter model

LSA model: overview



High-level parameter model

LSA model: functions



- **CentralTune**: should correspond to machine tune to ensure proper calculation of feedback phase
- **FeedbackPhase**: additional phase offset that is added on top of the one calculated from optics model. Used for fine-tuning / MDs.
- **LoopGain**: damper gain setting in arbitrary units. Check LL parameter to verify if in saturation

VGs

- **CentralTune**: SPSBEAM/Q{H,V} (target)
- **FeedbackPhase**: 0 deg (*)
- **LoopGain**: 0 (!)

(*) If optics model is accurate and tunes are properly set, FeedbackPhase zero is ideal setting. Runs in '21 & '22 have shown this is mostly the case except for multi-bunch, high-intensity beams where we expect an offset.

High-level parameter model

Take away

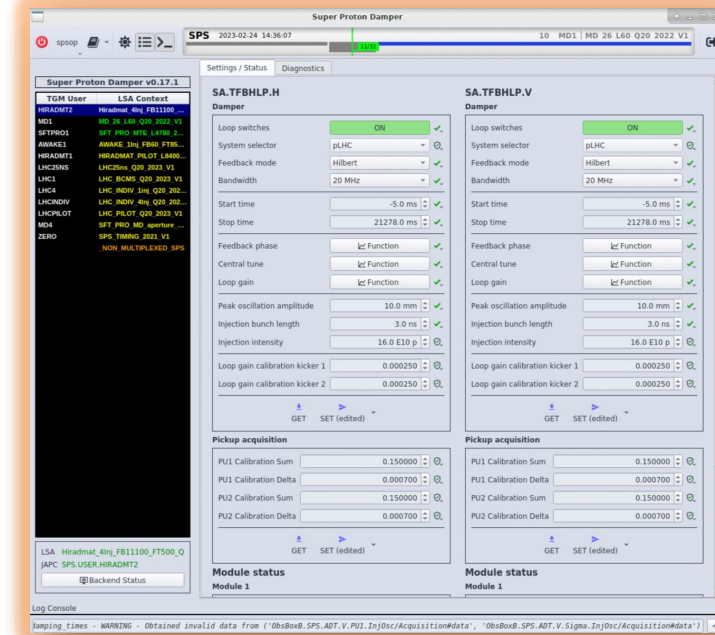
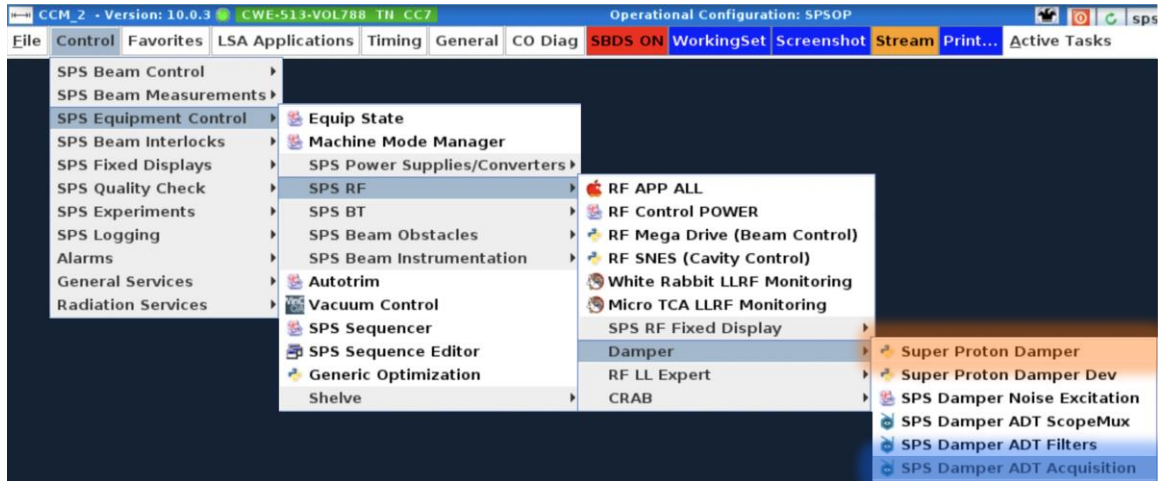


- Typically, HLP settings do not need to be changed during operation
- Notable exceptions
 - Intensity steps
InjectionIntensity1E10 via SpsGainCalculation/IntensityPerBunchE10
in parameter group INSTRUMENTATION.
 - In case of instabilities, e.g. after intensity steps, you can try to adjust
SA.TFBHLP.{H,V}/Damper#LoopGain
N.B.: check also LL if not in saturation already: GAIN_{H,V}{1,2}_OUTA/Functions#yVals.
 - Once injection trajectory corrected: reduce PeakOscillationAmplitudeMm to improve resolution
 - MDs
- When generating HLP settings: LoopSwitches and LoopGain function are initialized to False and zero, resp., i.e. damper OFF

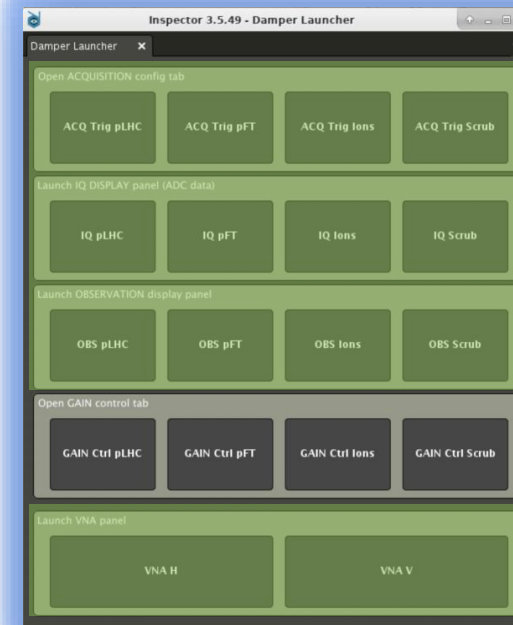
Tools & procedures

Tools & procedures

Overview



Python GUI “Super Proton Damper”
Day-to-day operation



Inspector panel “Damper Launcher”
Commissioning, TFB diagnostics, e.g. to validate phase & delay settings

Tools & procedures

Python GUI

Settings

- All HLP settings visible & trimmable
- They are **subscriptions** and hence update automatically when changed elsewhere
- Parameters can be set **individually or as a group**
- Some **parameters are protected** to prevent accidental changes (*e.g. calibration factors*)

The screenshot displays the 'Super Proton Damper' Python GUI. The window title is 'Super Proton Damper'. The top status bar shows 'SPS 2023-02-24 14:36:07' and '10 MD1 | MD 26 L60 Q20 2022 V1'. The main interface is divided into several sections:

- Super Proton Damper v0.17.1**: A table listing TGM Users and LSA Contexts. The selected user is 'HIRADMT2' with context 'Hiradmat_4Inj_FB11100 ...'. Other users include MD1, SFTPRO1, AWAKE1, HIRADMT1, LHC25NS, LHC1, LHC4, LHCINDIV, LHCPILOT, MD4, and ZERO.
- Settings / Status** and **Diagnostics** tabs are visible.
- SA.TFBHLP.H Damper** and **SA.TFBHLP.V Damper**: Two panels showing identical settings for 'Loop switches' (ON), 'System selector' (pLHC), 'Feedback mode' (Hilbert), 'Bandwidth' (20 MHz), 'Start time' (-5.0 ms), 'Stop time' (21278.0 ms), 'Feedback phase' (Function), 'Central tune' (Function), 'Loop gain' (Function), 'Peak oscillation amplitude' (10.0 mm), 'Injection bunch length' (3.0 ns), 'Injection intensity' (16.0 E10 p), and 'Loop gain calibration kicker' (0.000250).
- Pickup acquisition**: Two panels showing 'PU1 Calibration Sum' (0.150000), 'PU1 Calibration Delta' (0.000700), 'PU2 Calibration Sum' (0.150000), and 'PU2 Calibration Delta' (0.000700).
- Module status**: Two panels for 'Module 1'.
- Log Console**: Shows a warning: 'WARNING - Obtained invalid data from ('ObsBoxB.SPS.ADT.V.PU1.InjOsc/Acquisition#data', 'ObsBoxB.SPS.ADT.V.Sigma.InjOsc/Acquisition#data')'.

Tools & procedures

Python GUI

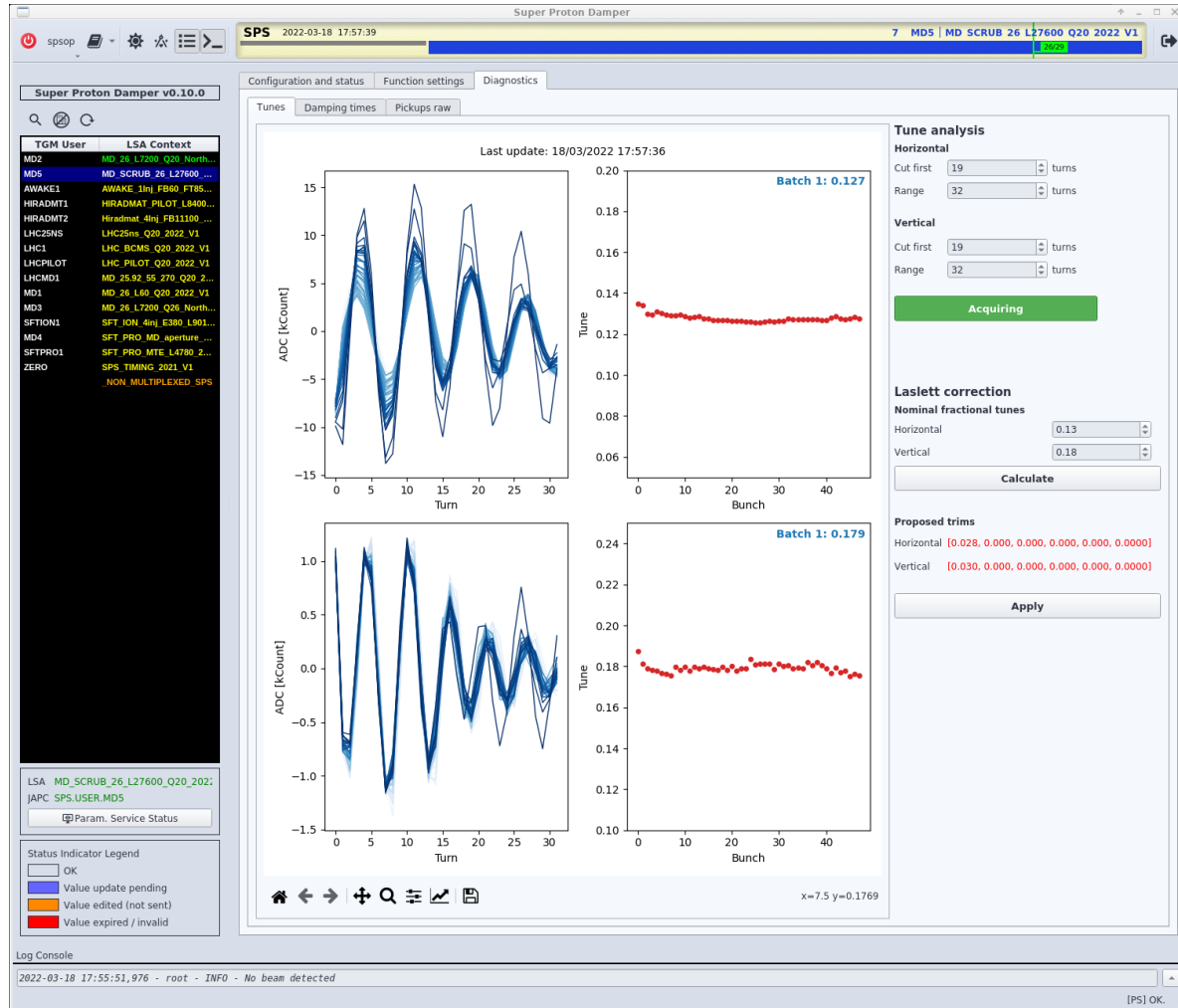
Status

- Loops and trigger status per module & plane
Updates at end of cycle
- Power system not integrated as there is a separate app and display

Power systems display

Tools & procedures

Python GUI



Diagnostics tab

- Bunch-by-bunch **tunes and damping times** as measured using old TFB ObsBox **injection oscillation buffer**
- Results **not always reliable** (H/V coupling, S/N)
- To measure bunch-by-bunch tunes accurately, **can also use Laslett application** (LHC BPMs & MKQ)

Old version

Tools & procedures

ObsBox buffer

Objective: validate injection damping

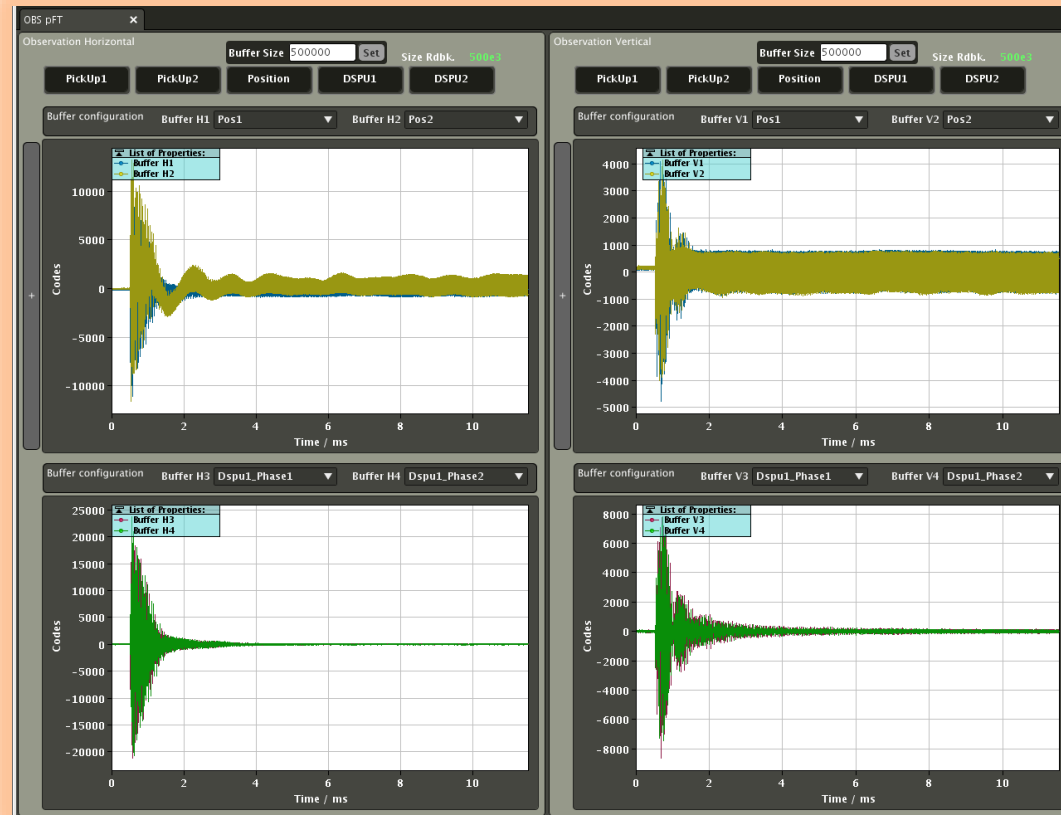
1. SPS Damper ADT Acquisition



2. ACQ TRIG *damper module*



3. OBS *damper module*



1. Set "Buffer Size" to 500k or less if it freezes, adapt trigger time
2. Use "Position" preset
3. Signals should be within [-32k, 32k] and show damping times ~ 1 ms
4. **If no signal or if saturated:** likely wrong front-end gain setting. Check HLP bunch intensity, bunch length, max. oscillation amplitude.

1. Delay is with F1KFO: *forewarning 1000 ms, first occurrence*
Marks when buffer is frozen
2. To see 1st inj., 1012 ms is a good setting if buffer has length 500k
3. Press "Configure" button

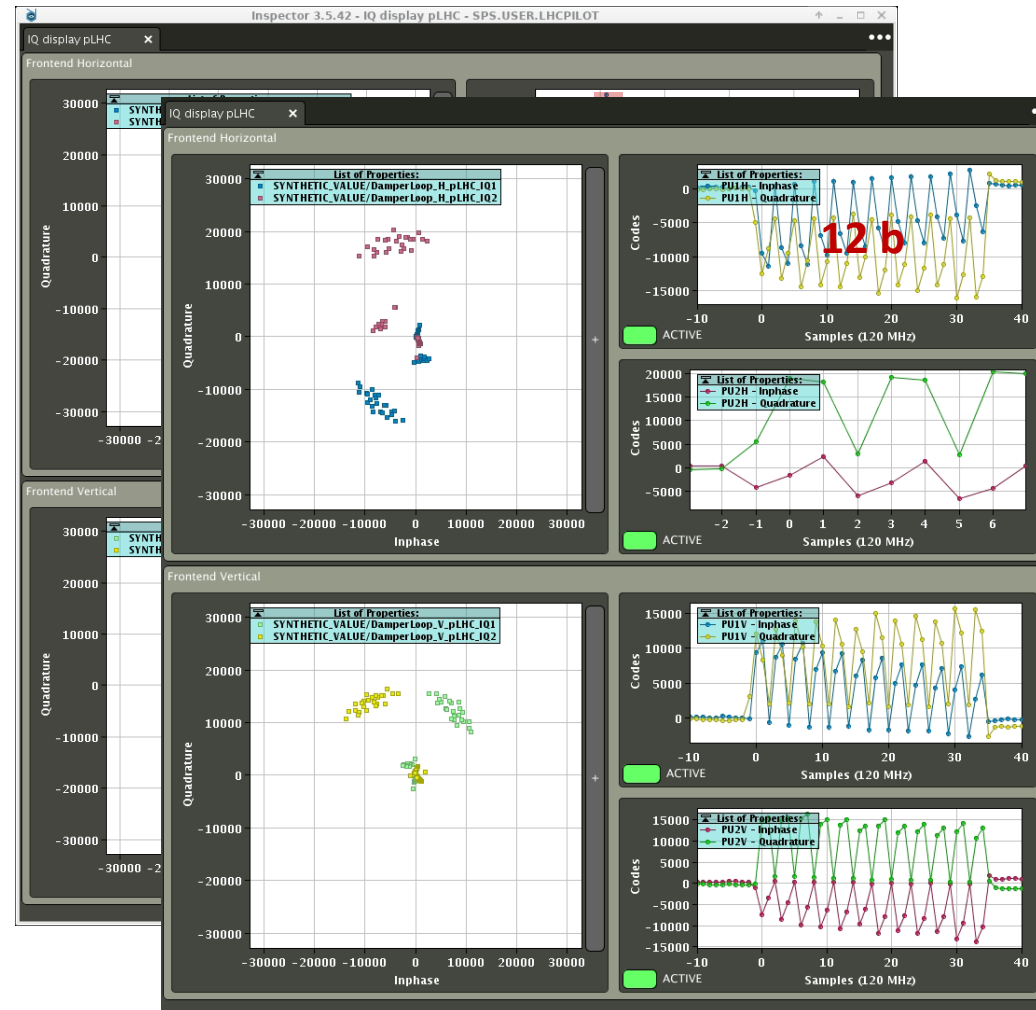
Tools & procedures

IQ display

Objective: clock sync / adjustment

1. SPS Damper ADT Acquisition

2. IQ **damper module**



1. Shows PUs 1 & 2, H & V
Here: single bunch, resp. 12 b.
Sampling at 120 MHz, i.e. 3 samples per 25 ns slot
2. Signal from first bunch should be aligned with sample 0
3. *If not, adjust LSA clock parameters (LL)*

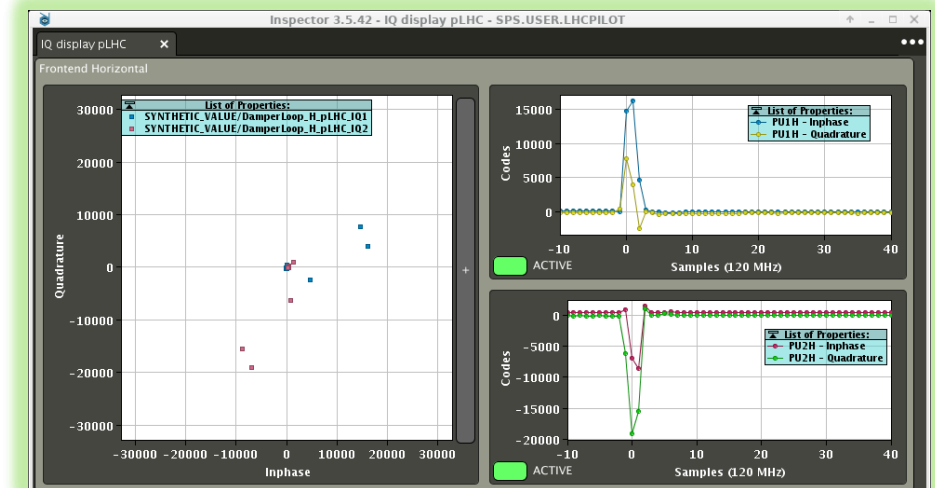
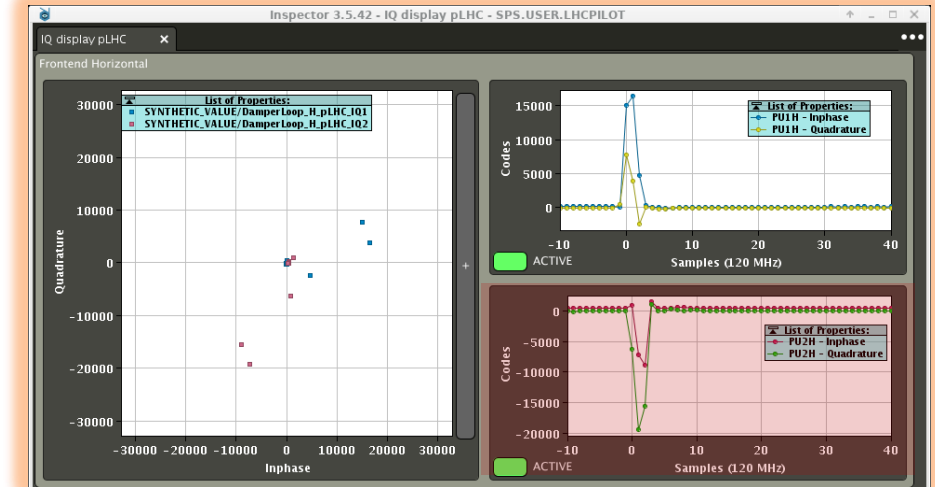
Tools & procedures

IQ display

1. Identify PU signal that is “misaligned” (here PU2H)
2. Find clock parameter for PU, plane, and module in Trim Editor
3. Change ClkTagDelta & ClkTagSum consistently
1 tick corresponds to 1/120 MHz = 8.333 ns

Objective: clock sync / adjustment

PARAMETER	Value	Target	Correction
DamperLoop_H_pLHC/CLOCKPpmControl#ClkDelayModulus	833		
DamperLoop_H_pLHC/CLOCKPpmControl#ClkTagBeamFreeldx	0		
DamperLoop_H_pLHC/CLOCKPpmControl#ClkTagDelta1Idx	1842		
DamperLoop_H_pLHC/CLOCKPpmControl#ClkTagDelta2Idx	1770		
DamperLoop_H_pLHC/CLOCKPpmControl#ClkTagGP1Idx	0		
DamperLoop_H_pLHC/CLOCKPpmControl#ClkTagGP2Idx	0		
DamperLoop_H_pLHC/CLOCKPpmControl#ClkTagOut1Idx	2184		
DamperLoop_H_pLHC/CLOCKPpmControl#ClkTagOut2Idx	2182		
DamperLoop_H_pLHC/CLOCKPpmControl#ClkTagSum1Idx	1842		
DamperLoop_H_pLHC/CLOCKPpmControl#ClkTagSum2Idx	1770		
DamperLoop_H_pLHC/CLOCKPpmControl#ClkTagSyncIdx	910		

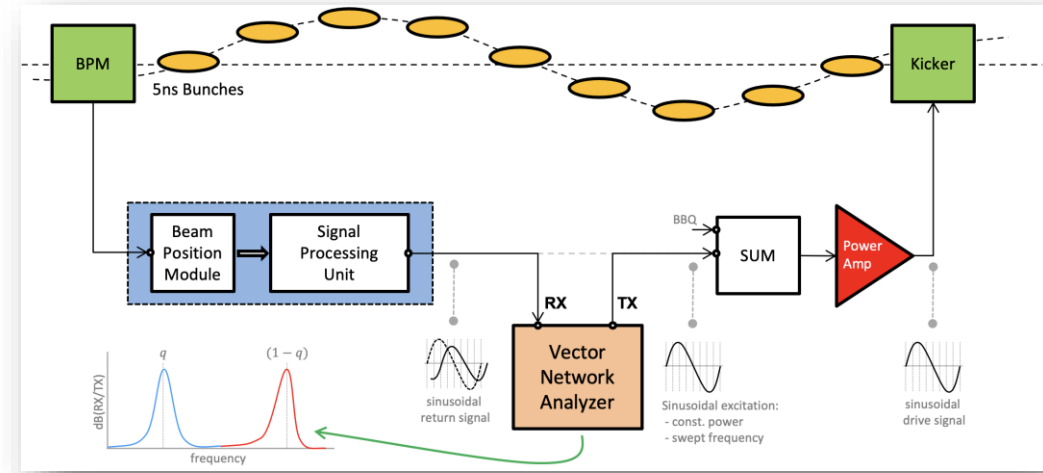


N.B. these parameters should be identical for all LHC-type beams (pFT beams resp.), and typically not change during a run

Tools & procedures

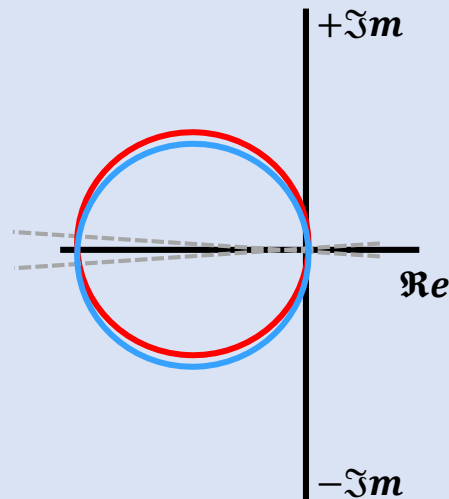
Beam transfer function (BTF)

- **BTF with Vector Network Analyzer (VNA)**
 - Excite transverse resonances with sinusoidal signal (TX)
 - Measure narrowband beam response and display as polar plots (RX)
- **Two settings issues** can be identified with BTF
 - **Feedback phase:** should be OK thanks to HLP Makerule (for single bunch)
 - **Fine delay:** may need to be adjusted during commissioning (during run for thermal effects)



Target: aligned

NB: $\arg(G) + \omega T + \phi_{PK} = -180^\circ$



Tools & procedures

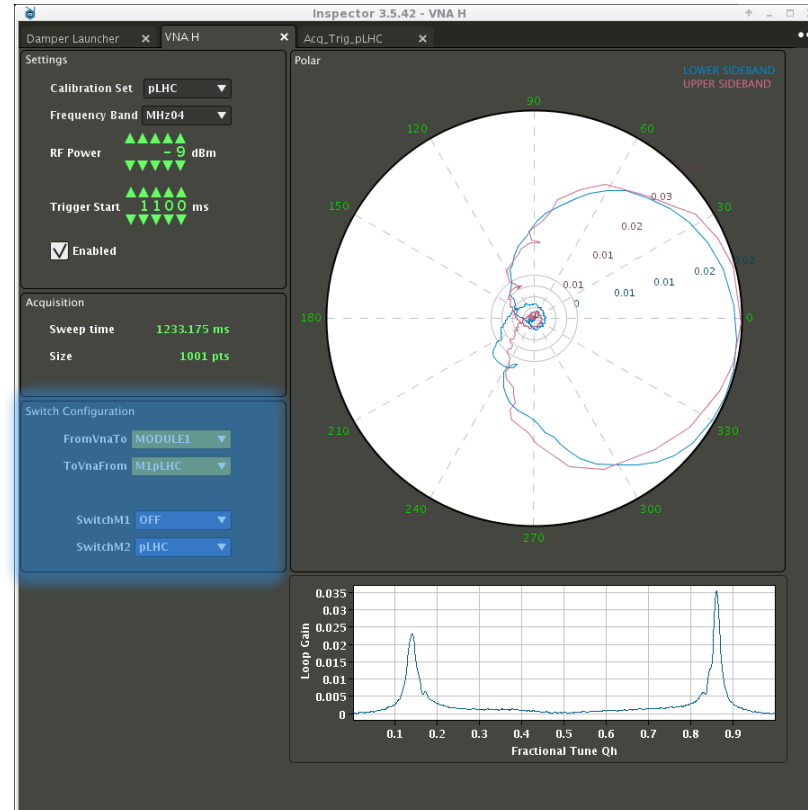
Vector Network Analyzer (VNA)

Objective: delay and phase validation

1. SPS Damper ADT Acquisition



2. VNA H / V



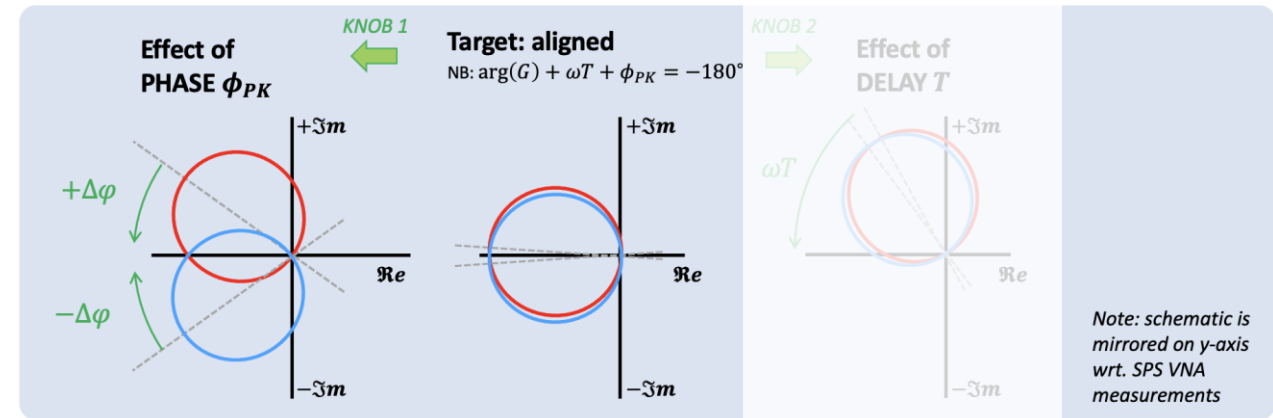
1. Frequency Band: start low, e.g. at 1 MHz and move up in steps, but stay within HLP Bandwidth
 - Low freq.: phase adjustments*
 - High freq.: fine delay adjustments*
2. RF Power between -30 dBm to -10 dBm. If too high can trip power system.
3. Trigger Start: 1100 ms
4. Enabled: True
5. Switch configuration: here e.g. open-loop measurement for module 1, with module 2 actively damping
6. HLP LoopSwitches must be set to True
7. Revert settings when done
VNA chirp visible in MultiQ

N.B.: the VNAs crash / freeze occasionally. G. Kotzian and M. Schenk have accounts to reset and restart them.

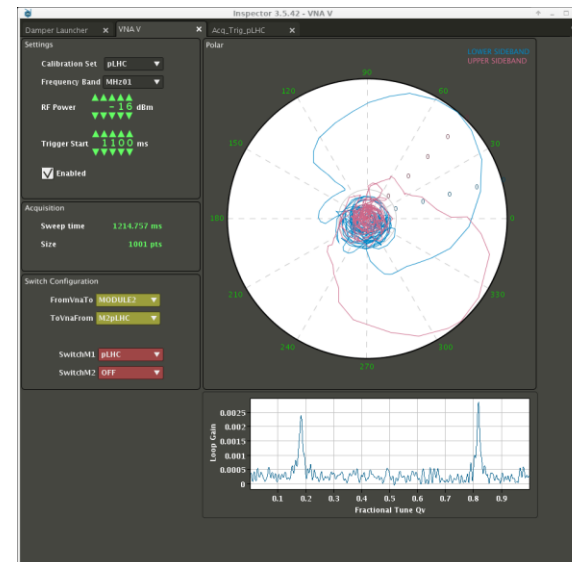
Tools & procedures

VNA: phase adjustment

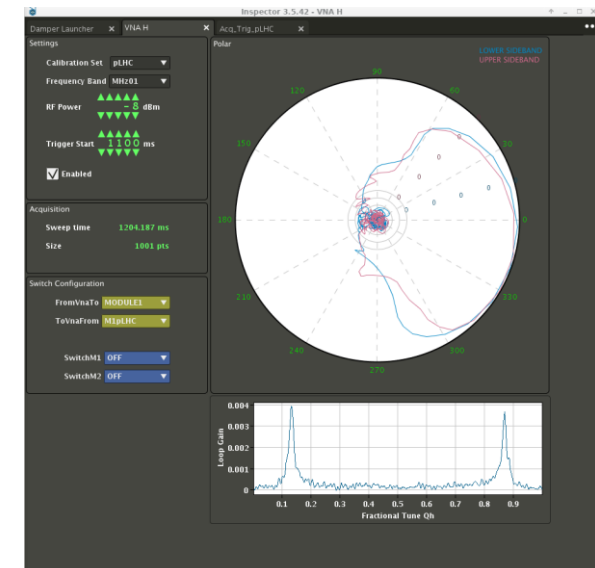
- In case you observe phase error, verify first that
 - HLP CentralTune corresponds to machine tune
 - HLP FeedbackPhase is set to zero
- If these settings are correct and phase error persists, use HLP FeedbackPhase parameter to adjust
- Move e.g. in steps of ± 20 deg
- N.B.:** if phase is badly set, TFB can cause tune shift or worse, drive beam unstable (*anti-damping*)



Phase is off



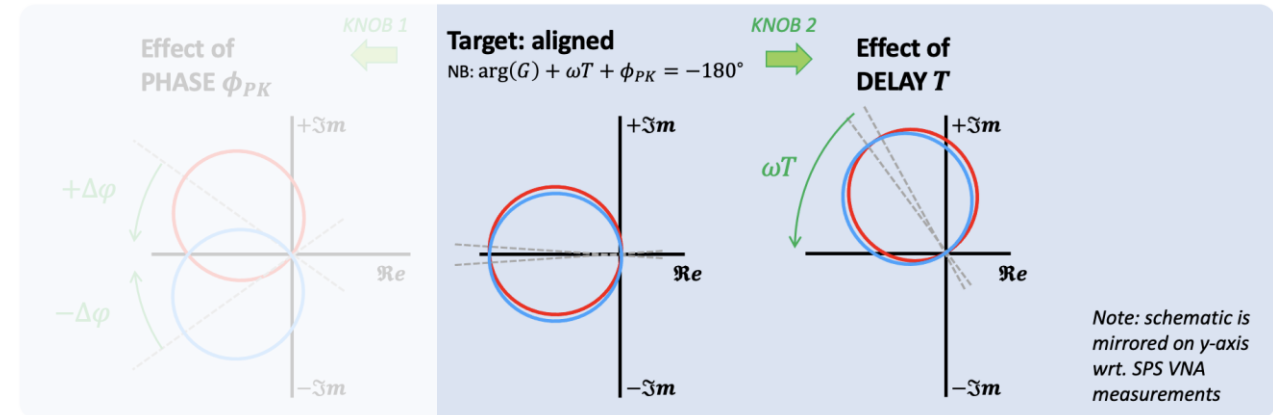
Phase well set



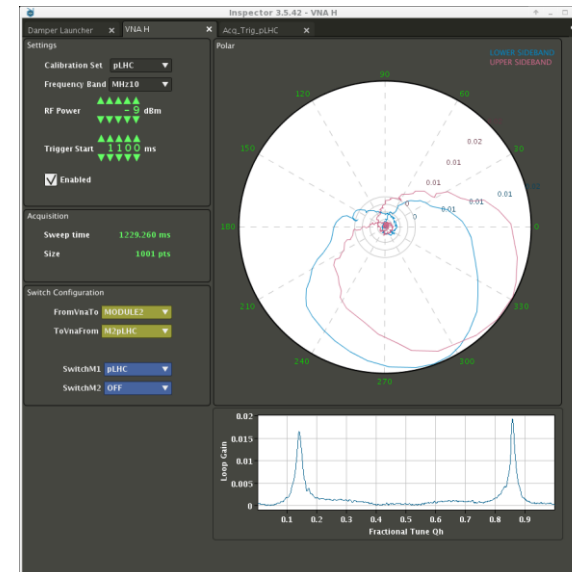
Tools & procedures

VNA: fine delay adjustment

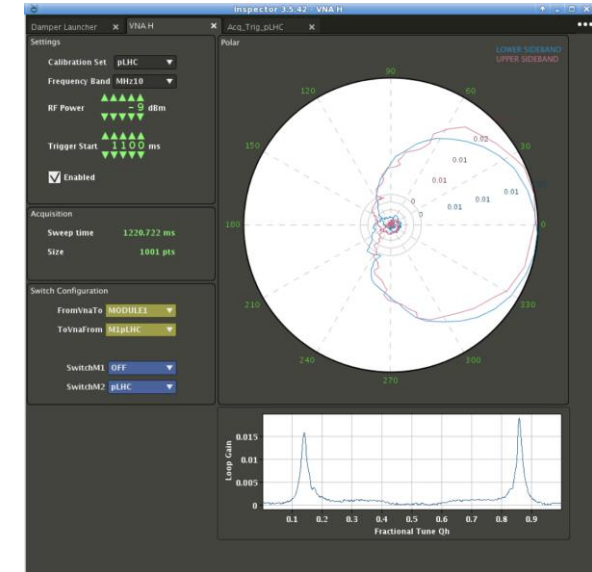
- Consider LSA parameter
DampDelayFunc/FineDelayValues#fineDelayOUT{1,2}{H,V} for the concerned plane and module
- Move in small steps. Can be tricky.
“Sensitivity” to delay mismatch depends also on Frequency Band chosen for BTF
- **Delay should ideally not change during run. Inform damper expert if you suspect this kind of problem.**



Delay off



Phase & delay well set



Tools & procedures

Disabling modules

Objective: disable individual kicker modules

- E.g. when suspicion that one module is not doing its job
- **This can neither be done from the GUI nor the HLP settings**
The HLP loop switch will always enable / disable both kicker modules
- **To disable individual kicker module:** go to DamperLoop_{H,V}_{pLHC,pFT,Ions}/LoopsControl and untick either of the M{1,2}LoopEnable switches
- **N.B.:** if you trim entire HLP Property (incl. HLP LoopSwitches), both M1 and M2 will be re-enabled.

The screenshot shows the 'Settings Management' window with the following configuration:

- Source: Cycle
- Particle Transfer: SPSRING
- Parameter Group: RF TRANSVERSE DAMPER
- Property: ALLSpsDamperLoop/LoopsControl
- Device/Property: DamperLoop_H_pLHC/LoopsControl

Setting Part: Value Target Correction Time Base: Cycle Beamprocess Injection

PARAMETER	Value
DamperLoop_H_pLHC/LoopsControl#DSPU2SwitchCh2	<input checked="" type="checkbox"/>
DamperLoop_H_pLHC/LoopsControl#DSPU2SwitchLoopA	<input checked="" type="checkbox"/>
DamperLoop_H_pLHC/LoopsControl#DSPU2SwitchLoopB	<input type="checkbox"/>
DamperLoop_H_pLHC/LoopsControl#M1LoopEnable	<input checked="" type="checkbox"/>
DamperLoop_H_pLHC/LoopsControl#M2LoopEnable	<input checked="" type="checkbox"/>
DamperLoop_H_pLHC/LoopsControl#TTUAnalogSwitch1	<input checked="" type="checkbox"/>
DamperLoop_H_pLHC/LoopsControl#TTUAnalogSwitch2	<input checked="" type="checkbox"/>
DamperLoop_H_pLHC/LoopsControl#TTUDisNormalization	<input type="checkbox"/>

Future plans & final remarks

Future plans

- **Use “pLHC” module for all beam types:** reduce from 4 systems to 1
 - Requires White Rabbit to RF
 - Greatly simplify LSA HLP Makerules, parameter relations, and maintenance thereof
 - First parasitic tests done by G. Kotzian in 2022 (pLHC for SFT). To be continued this year (MD)
 - Challenge: with pLHC module, cannot “see” SFTPRO beam < 2E13 p (amps needed for PUs?)
- **Fine delay adjustments**
 - Should eventually become obsolete thanks to White Rabbit (temperature drift compensating)
 - To be tested this year
- **New ObsBox installed:** running in parallel, to be tested
- **Data analysis on UCAP:** WIP
- **Bunch-by-bunch tune corrections** using TFB? -> MD

Final remarks

- **Thanks to HLP model & VGs**
 - Most of setting up is straightforward, incl. feedback phase & mode, FE gains, LL switches, etc.
 - Significantly fewer expert interventions needed, now handled by OP
- **Main knobs to tweak during OP**, e.g. after intensity changes: bunch parameters (intensity), and potentially loopGain
- **Main commissioning work:** phase and delay validations.
- **Let us know about issues / improvements that would be helpful for OP**

Questions?

Backup

Working settings 2022

25 ns LHC-type multi-bunch beams

Horizontal

SA.TFBHLP.H/Damper#Bandwidth	20 MHz
SA.TFBHLP.H/Damper#FeedbackMode	Hilbert
SA.TFBHLP.H/Damper#InjectionBunchLengthNs	3.0
SA.TFBHLP.H/Damper#InjectionIntensity1E10	15.0
SA.TFBHLP.H/Damper#LoopGainCalibrationKicker1	2.5E-4
SA.TFBHLP.H/Damper#LoopGainCalibrationKicker2	2.5E-4
SA.TFBHLP.H/Damper#LoopSwitches	<input checked="" type="checkbox"/>
SA.TFBHLP.H/Damper#PeakOscillationAmplitudeMm	10.0
SA.TFBHLP.H/Damper#StartTime	-5.0
SA.TFBHLP.H/Damper#StopTime	24844.0
SA.TFBHLP.H/Damper#SystemSelector	pLHC

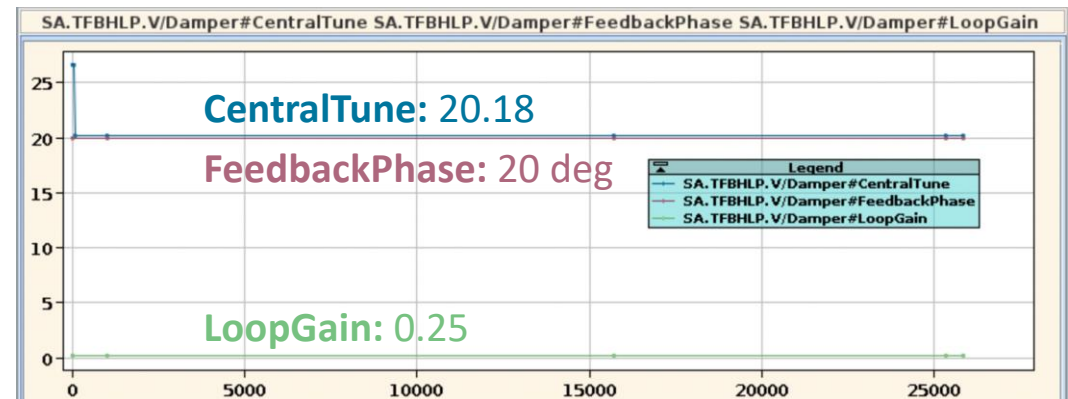
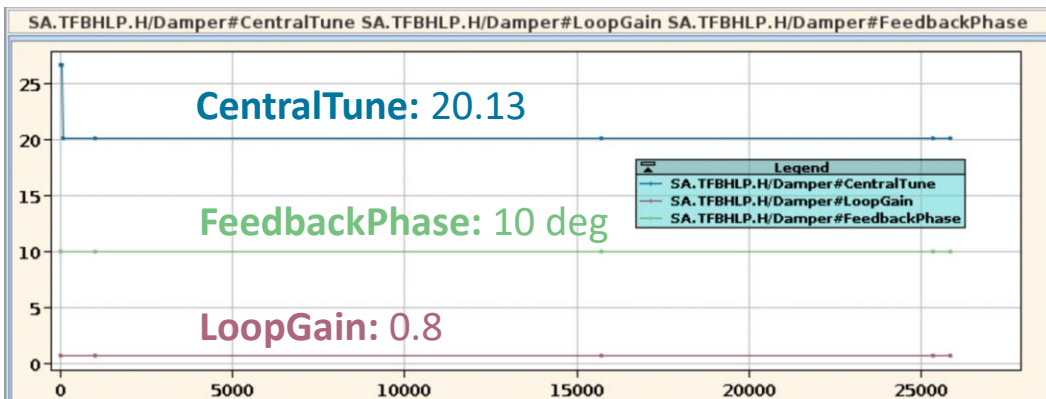
SA.TFBHLP.H/PUAcquisition#PU1CalibDelta	7.0E-4
SA.TFBHLP.H/PUAcquisition#PU1CalibSum	0.15
SA.TFBHLP.H/PUAcquisition#PU2CalibDelta	7.0E-4
SA.TFBHLP.H/PUAcquisition#PU2CalibSum	0.15

Vertical

SA.TFBHLP.V/Damper#Bandwidth	20 MHz
SA.TFBHLP.V/Damper#FeedbackMode	Hilbert
SA.TFBHLP.V/Damper#InjectionBunchLengthNs	3.0
SA.TFBHLP.V/Damper#InjectionIntensity1E10	15.0
SA.TFBHLP.V/Damper#LoopGainCalibrationKicker1	2.5E-4
SA.TFBHLP.V/Damper#LoopGainCalibrationKicker2	2.5E-4
SA.TFBHLP.V/Damper#LoopSwitches	<input checked="" type="checkbox"/>
SA.TFBHLP.V/Damper#PeakOscillationAmplitudeMm	10.0
SA.TFBHLP.V/Damper#StartTime	-5.0
SA.TFBHLP.V/Damper#StopTime	24844.0
SA.TFBHLP.V/Damper#SystemSelector	pLHC

SA.TFBHLP.V/PUAcquisition#PU1CalibDelta	7.0E-4
SA.TFBHLP.V/PUAcquisition#PU1CalibSum	0.15
SA.TFBHLP.V/PUAcquisition#PU2CalibDelta	7.0E-4
SA.TFBHLP.V/PUAcquisition#PU2CalibSum	0.15

For single bunches, use 3 MHz



Working settings 2022

SFTPRO

Horizontal

SA.TFBHLP.H/Damper#Bandwidth	14 MHz
SA.TFBHLP.H/Damper#FeedbackMode	VectorSum
SA.TFBHLP.H/Damper#InjectionBunchLengthNs	3.5
SA.TFBHLP.H/Damper#InjectionIntensity1E10	5.0
SA.TFBHLP.H/Damper#LoopGainCalibrationKicker1	2.4998188E-4
SA.TFBHLP.H/Damper#LoopGainCalibrationKicker2	2.4998188E-4
SA.TFBHLP.H/Damper#LoopSwitches	<input checked="" type="checkbox"/>
SA.TFBHLP.H/Damper#PeakOscillationAmplitudeMm	7.0
SA.TFBHLP.H/Damper#StartTime	-5.0
SA.TFBHLP.H/Damper#StopTime	9045.0
SA.TFBHLP.H/Damper#SystemSelector	pFT

SA.TFBHLP.H/PUAcquisition#PU1CalibDelta	0.0019999743
SA.TFBHLP.H/PUAcquisition#PU1CalibSum	0.25
SA.TFBHLP.H/PUAcquisition#PU2CalibDelta	0.0019999743
SA.TFBHLP.H/PUAcquisition#PU2CalibSum	0.25

Vertical

SA.TFBHLP.V/Damper#Bandwidth	14 MHz
SA.TFBHLP.V/Damper#FeedbackMode	VectorSum
SA.TFBHLP.V/Damper#InjectionBunchLengthNs	3.5
SA.TFBHLP.V/Damper#InjectionIntensity1E10	5.0
SA.TFBHLP.V/Damper#LoopGainCalibrationKicker1	2.4998188E-4
SA.TFBHLP.V/Damper#LoopGainCalibrationKicker2	2.4998188E-4
SA.TFBHLP.V/Damper#LoopSwitches	<input checked="" type="checkbox"/>
SA.TFBHLP.V/Damper#PeakOscillationAmplitudeMm	7.0
SA.TFBHLP.V/Damper#StartTime	-5.0
SA.TFBHLP.V/Damper#StopTime	9045.0
SA.TFBHLP.V/Damper#SystemSelector	pFT

SA.TFBHLP.V/PUAcquisition#PU1CalibDelta	0.0019999743
SA.TFBHLP.V/PUAcquisition#PU1CalibSum	0.25
SA.TFBHLP.V/PUAcquisition#PU2CalibDelta	0.0019999743
SA.TFBHLP.V/PUAcquisition#PU2CalibSum	0.25

