# Optics Measurements, Corrections and Modeling for High-Performance Storage Rings Workshop

21. Juni 2011

## LHC Online Modeling


| | |
|---|---|
| PhD Student: | Johannes Gabriel Mueller |
| CERN Supervisor: | Dr. Stefano Redaelli (BE – OP – LHC) |
| Professor: | Prof. Dr.-Ing. Leon Urbas (Technische Universitaet Dresden) |
| Start Date: | 2009-03-16 |

# Agenda

- Why Online Modeling?
- Requirements
- Optic and Knob Management
- Online Modeling – Aperture Meter
- Conclusion / Outlook

# Why Online Modeling? ENERGY!!

➪ operating a high energy and intensity superconducting accelerator can cause → DANGER!!

| LHC | Stored Beam Energy [MJ] | Momentum [TeV/c] |
|---|---|---|
| Design | 362 | 7 |
| Current | 25 + | 3.5 |

➢ The 362 MJ stored in each beam correspond to ~90 kg of TNT.

✎ Plasma-hydrodynamic simulations indicate that the beam will drill a ~30 m long hole into solid copper.


⇒ losses of about $10^{-7/-9}$ of the design stored beam energie are already sufficient to

**quench superconducting Magnets**

QUESTIONS to answer:

1) **WHERE** is the Beam
2) How to **SAVELY MOVE** the Beam

# Why Online Modeling? COMPLEXITY!!

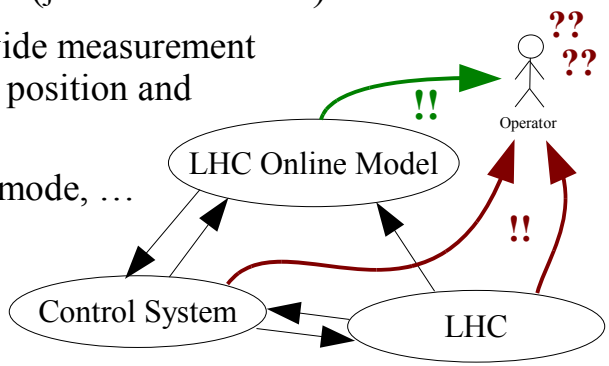
- Settings Challenge (already when only considering magnets)
  - ~2000 power converter require settings to create a certain optic definition
  - currently three optic schemes, containing sequences of optic definitions need to be managed (more to come?)
  - higher level parameters (knobs) need to be defined which allow to manipulate/adjust a certain optic definition to achieve desired beam configurations

| Optics Scheme | Nb. of Optics | Nb. of Knobs per Optic |
|---|---|---|
| ATS | 26 | 40 |
| TOTEM | 17 | 20 |
| NOMINAL | 14 | 50 |
| Total: | 57 | 2080 |

Table: number of optics and knobs currently in use for operation

- Vast amount of machine signals bombarding Operators (just to mention some)
  - ~1000 beam position monitors and ~100 collimators provide measurement data that contribute to the calculation of the current beam position and protection envelope configuration
  - Timing events delivering current optics id, energy, beam mode, …

→ combine/reduce signals and calculate higher level information

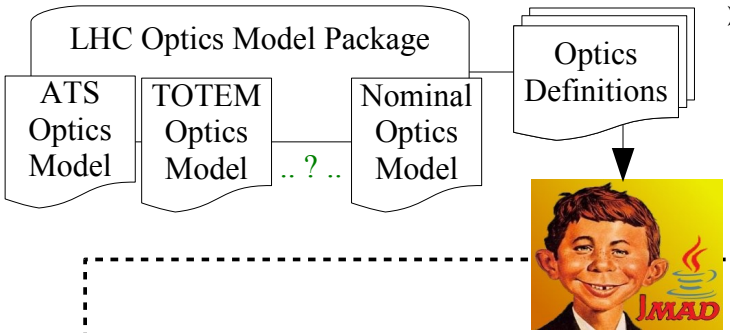


## Requirements

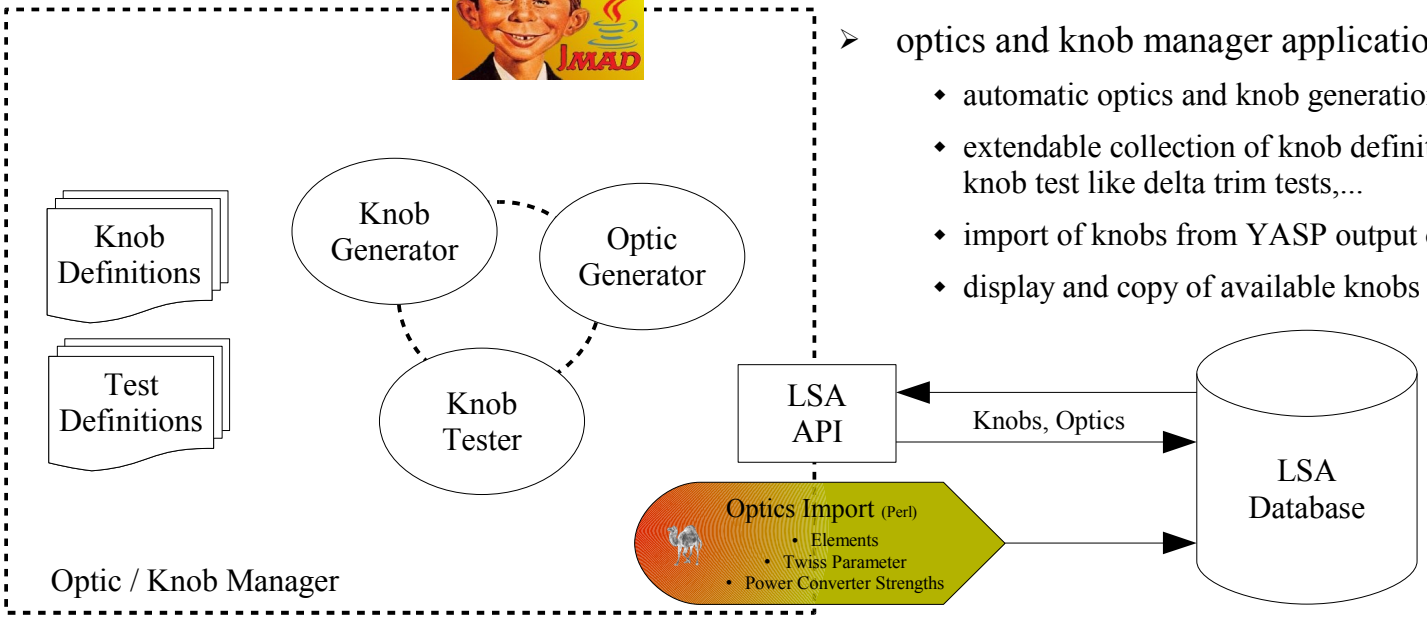
- Setting preparation for LSA (LHC software architecture)
  - (1) (semi-)automatic setting generation and upload of knobs and optics
  - (2) extendable architecture for future requirements
  - (3) automatic testing/verification where possible
  - (4) tools for setting extraction and recalculations in MAD-X

- Online Modeling → Aperture Metering
  - (1) simulate current machine optics to the best knowlege from the current settings available in LSA
  - (2) provide simulation data update on the scale of seconds, accepting less accurate optic model (e.g. based on nominal model)
  - (3) interpolate measured orbit to all machine elements
  - (4) incoorporate all available information about movable aperture devices (collimators and roman pots) into theoretical aperture model
  - (5) allow the simulation of setting changes at a given machine state

# Optic/Knob Management ➲ Generation

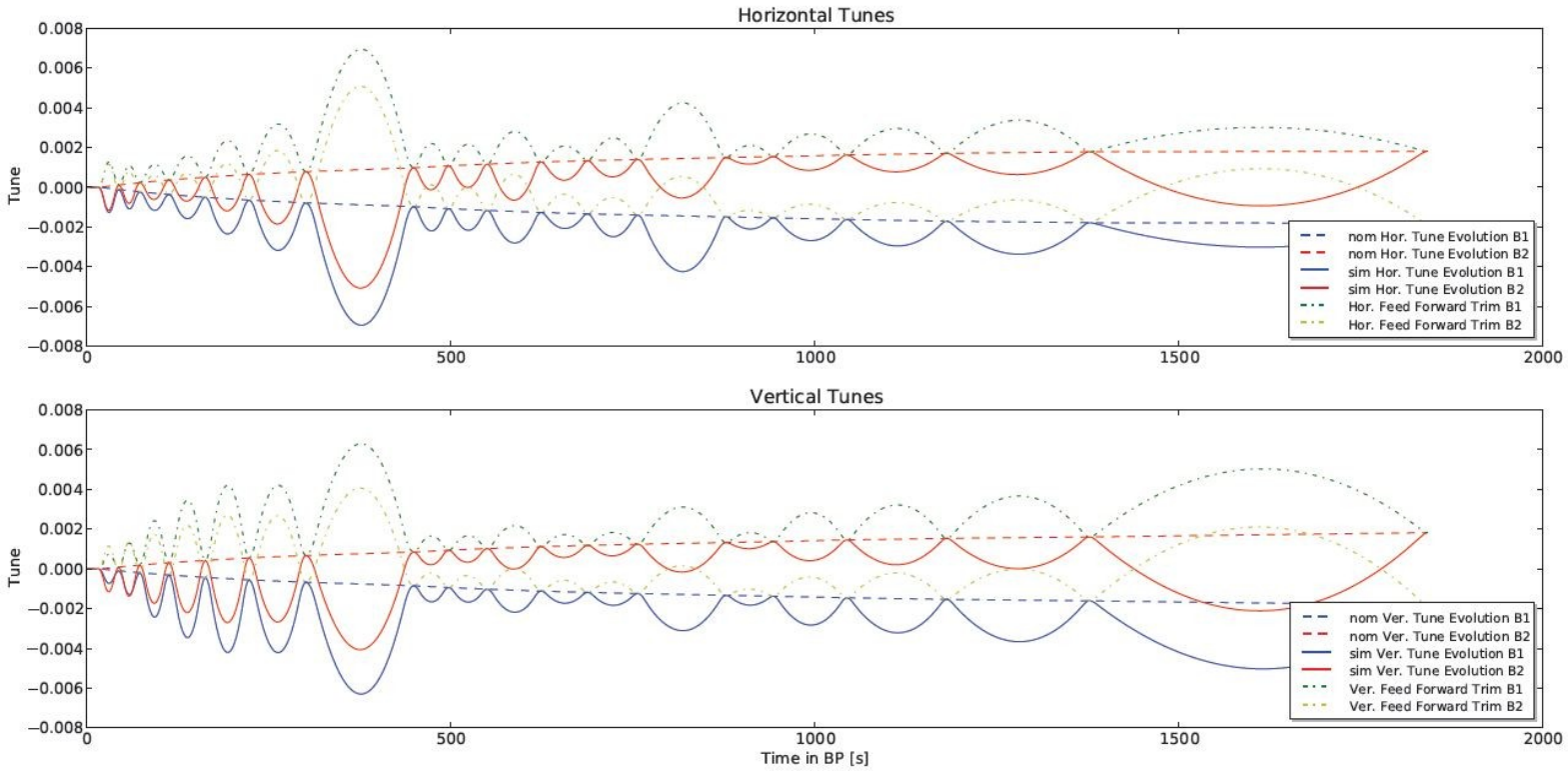



- optics model package providing optics definitions to all applications using JMad (Java API for MAD-X by K. Fuchsberger)
  - independently extendable
  - provides versioned madx input files and load sequence for consistent optics simulations



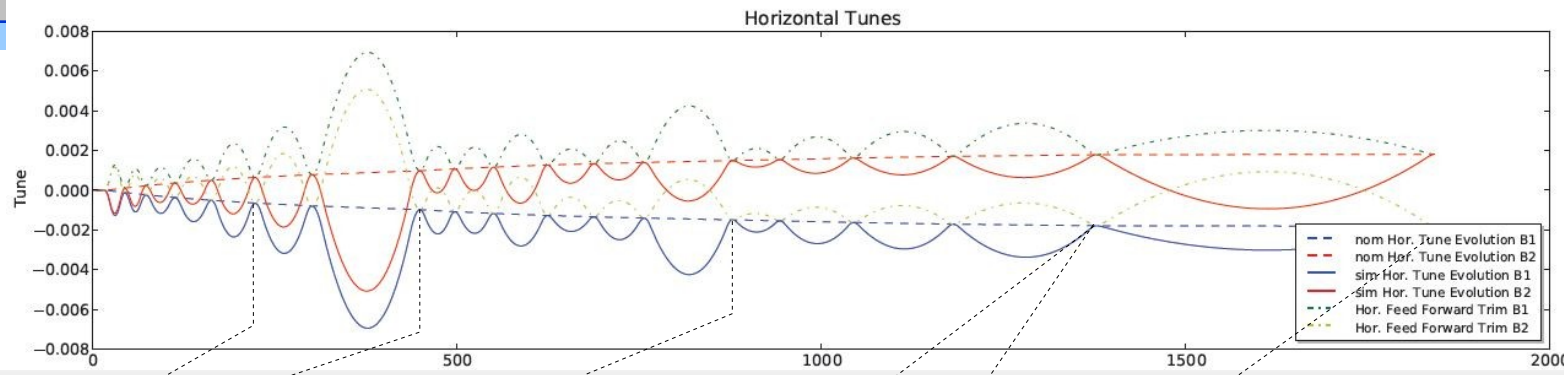

- optics and knob manager application
  - automatic optics and knob generation/upload
  - extendable collection of knob definitions and knob test like delta trim tests,...
  - import of knobs from YASP output or file
  - display and copy of available knobs in LSA

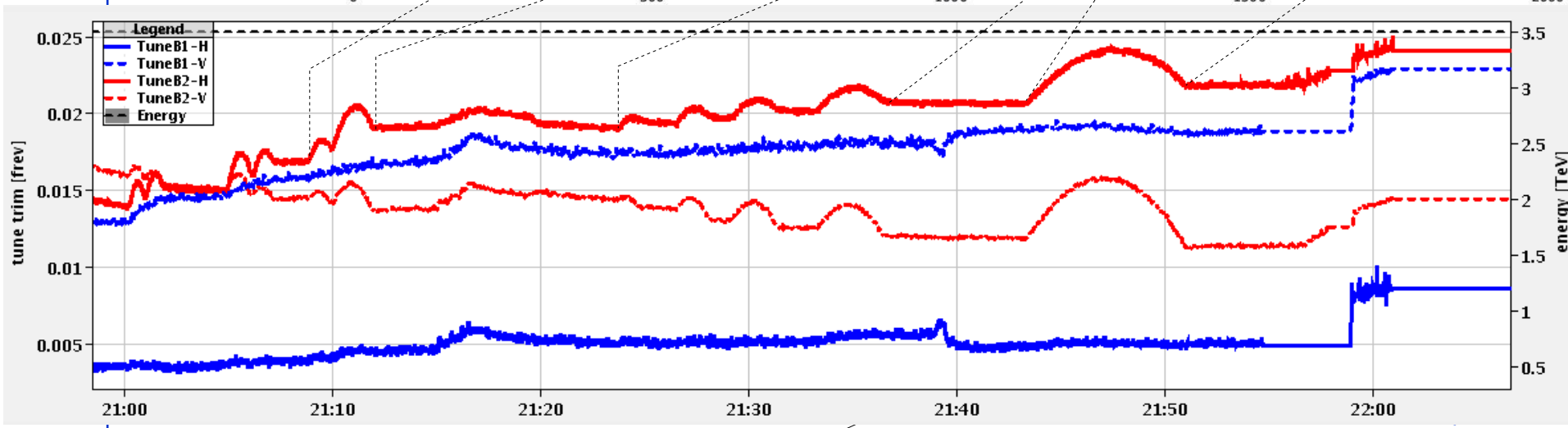
# Optic/Knob Management ➲ Verification




- ➲ automatic scans over generated settings of any beamprocess (developed in colaboration with X.Buffat)
- ➲ extract settings at given times in the beamprocess and calculate optic functions
- ➲ check of tune evolution in un-squeeze beamprocess for TOTEM
- ➲ comparison LSA reference value with simulated tunes
- ➲ calculate feedforward trim to reduce corrections required by the tune feedback → only on B1

# Optic/Knob Management ➲ Verification



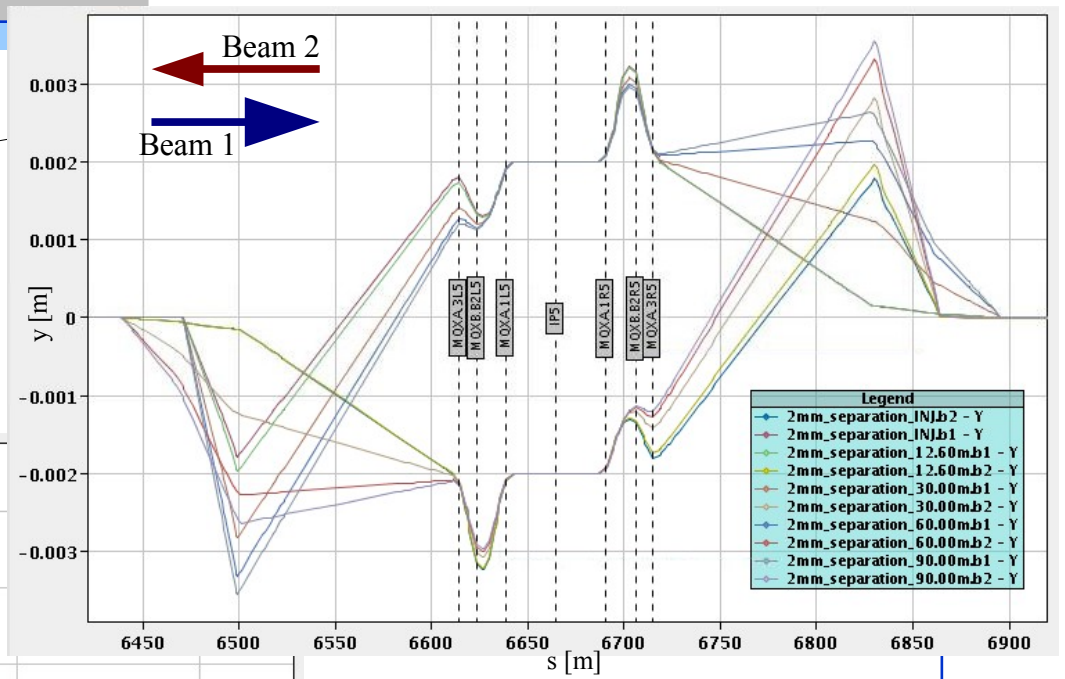



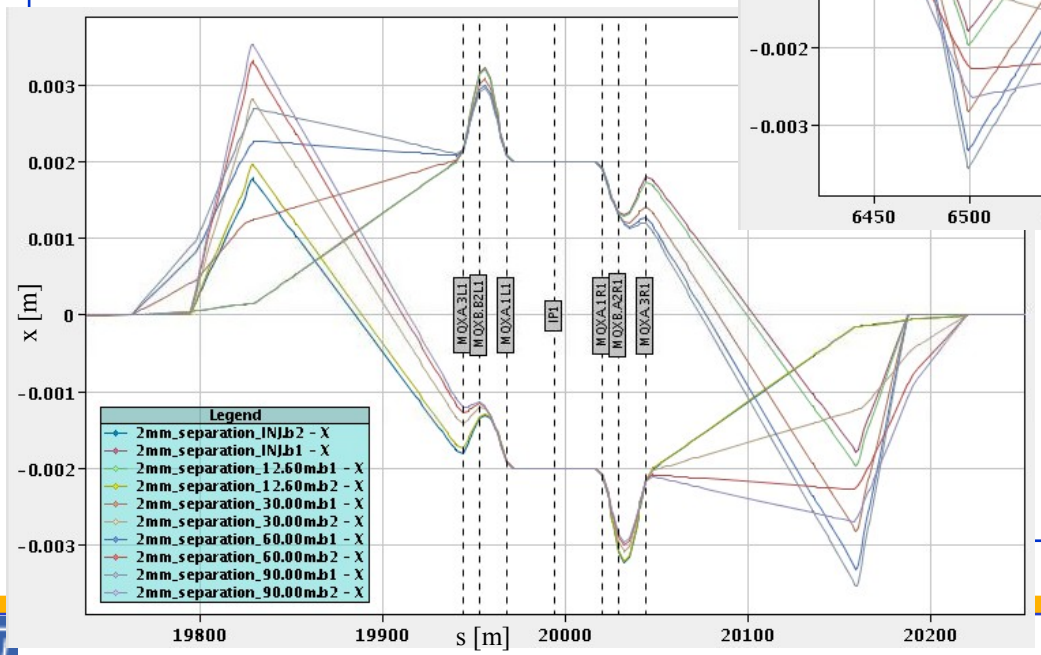

- ➲ un-squeeze was performed in steps for adjustments
- ➲ clearly visible reduced feedback trims on beam one
- ➲ very similar patterns observable in beam 2 trims

logbook entry of tune feedback real-time trims during TOTEM MD 2011-05-05

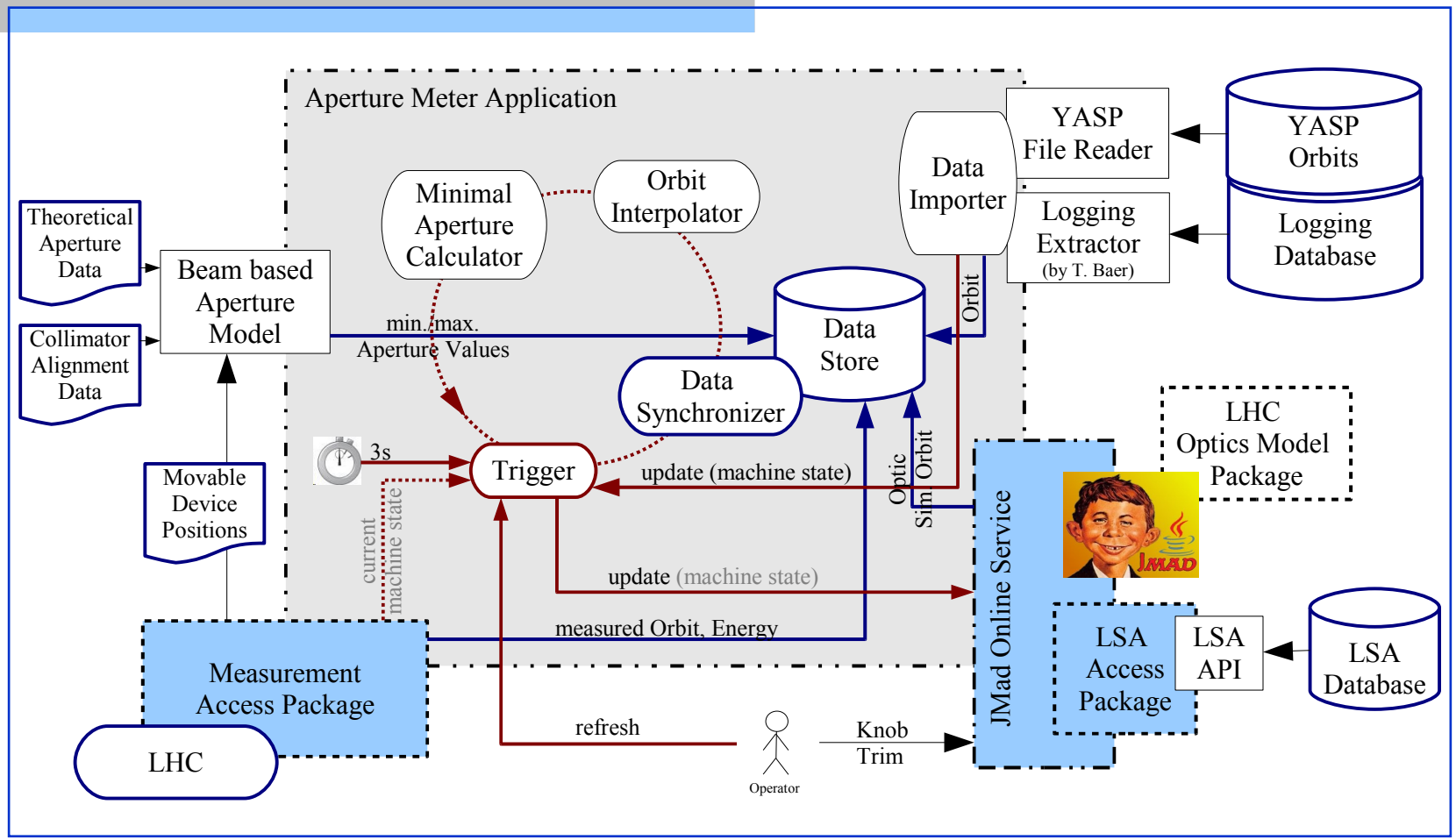
# Optic/Knob Management ➲ Verification

- ➲ check of beam-beam separation knob shape in TOTEM beam process
- ➲ trim knob parameter function to 2.0 mm
- ➲ extract settings at given times in the beamprocess and calculate orbit in MAD-X



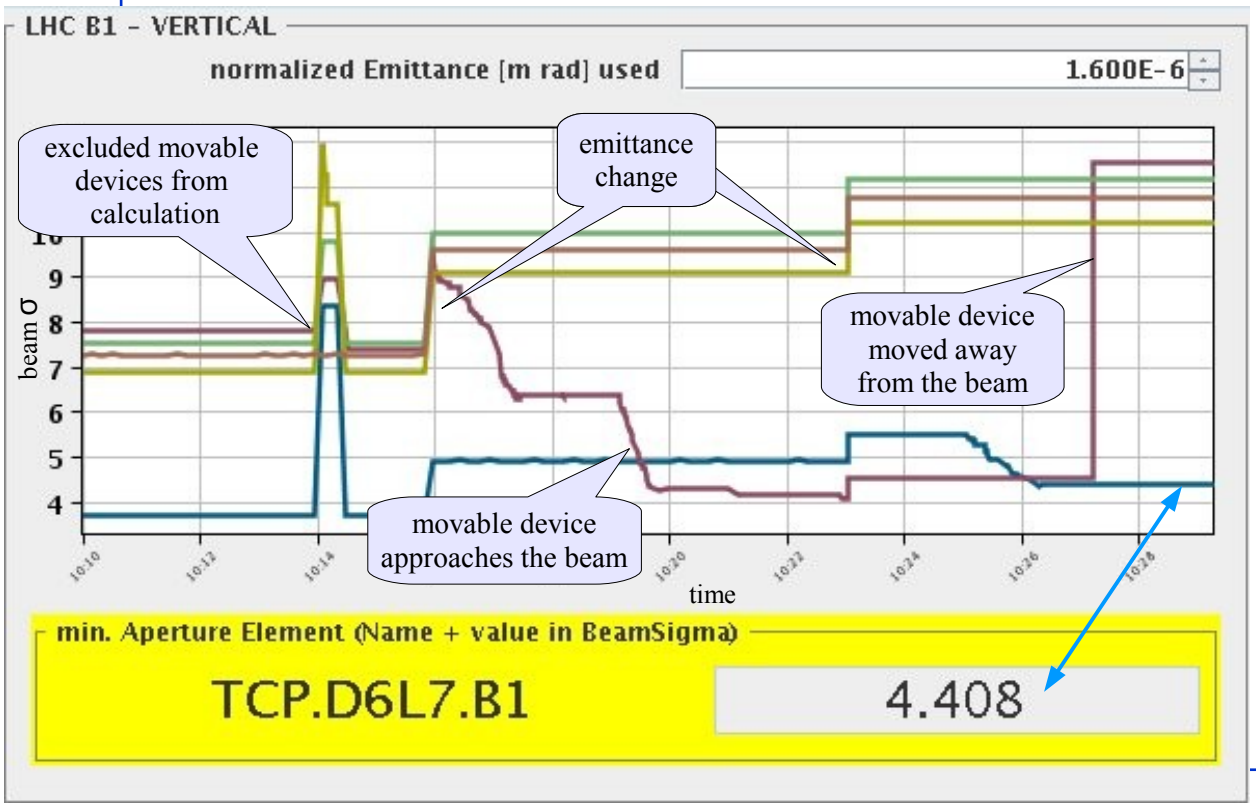



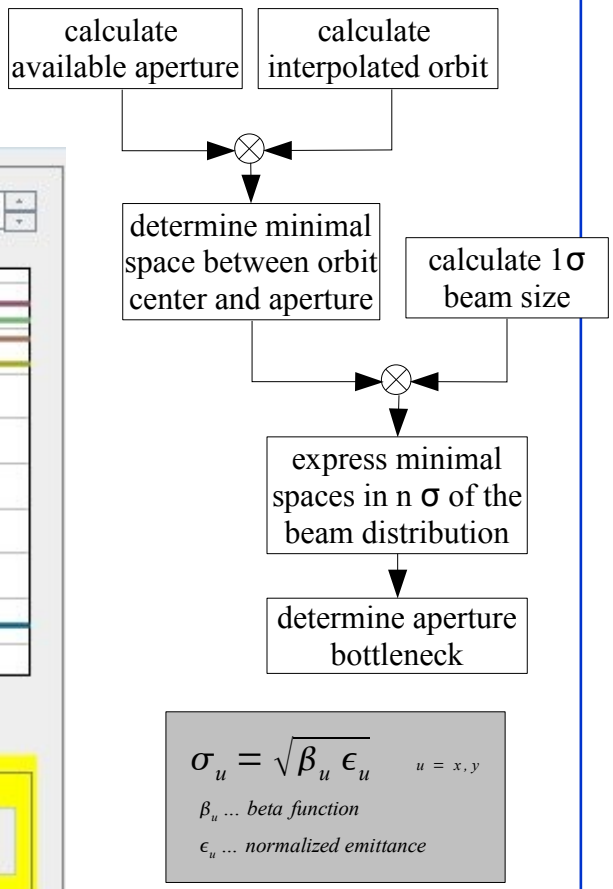
# Online Modeling ➲ Architecture



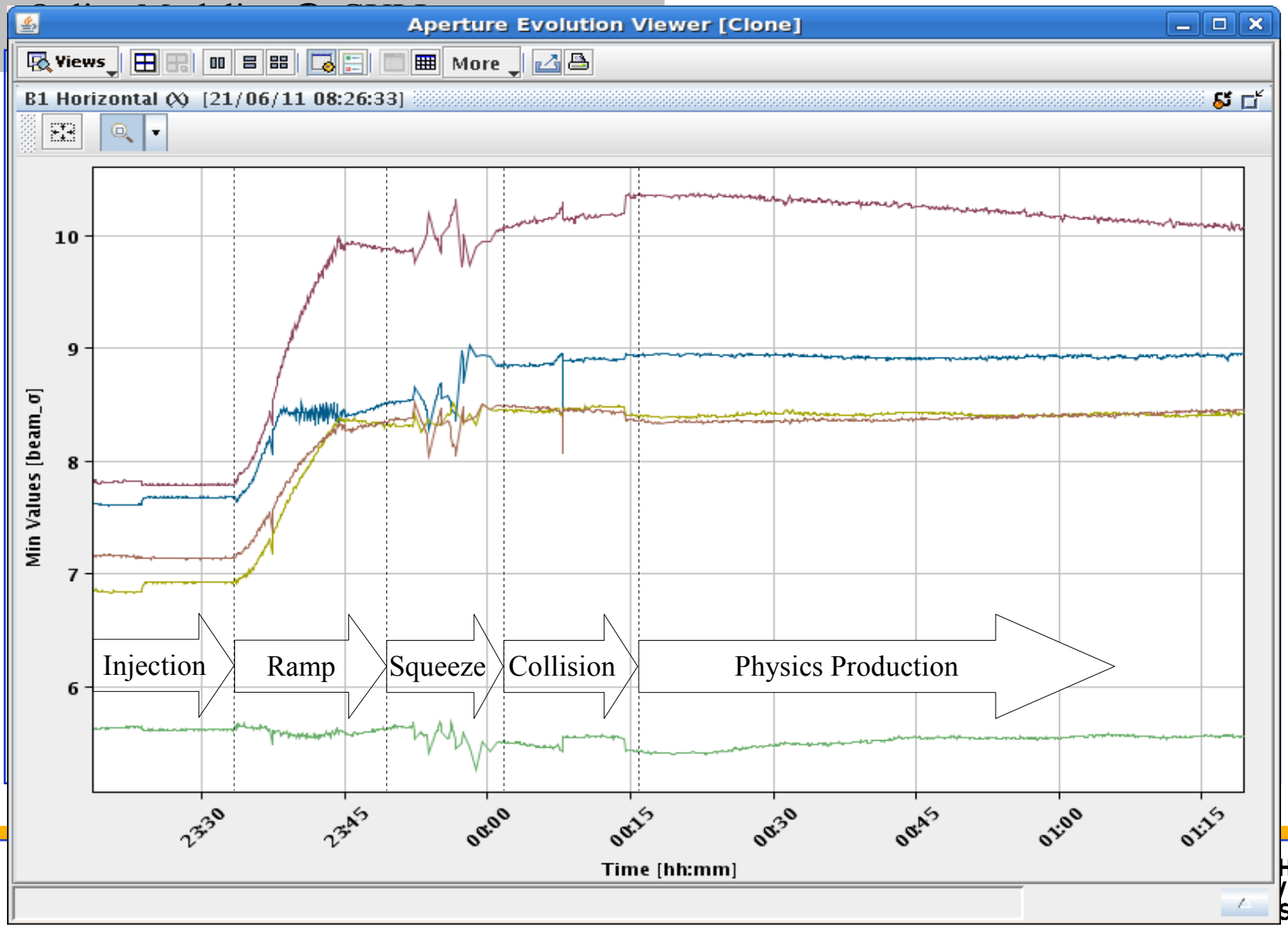
# Online Modeling ➲ PoC

Prove of concept for first Aperture Meter implementation during alignment of movable devices around the beam.



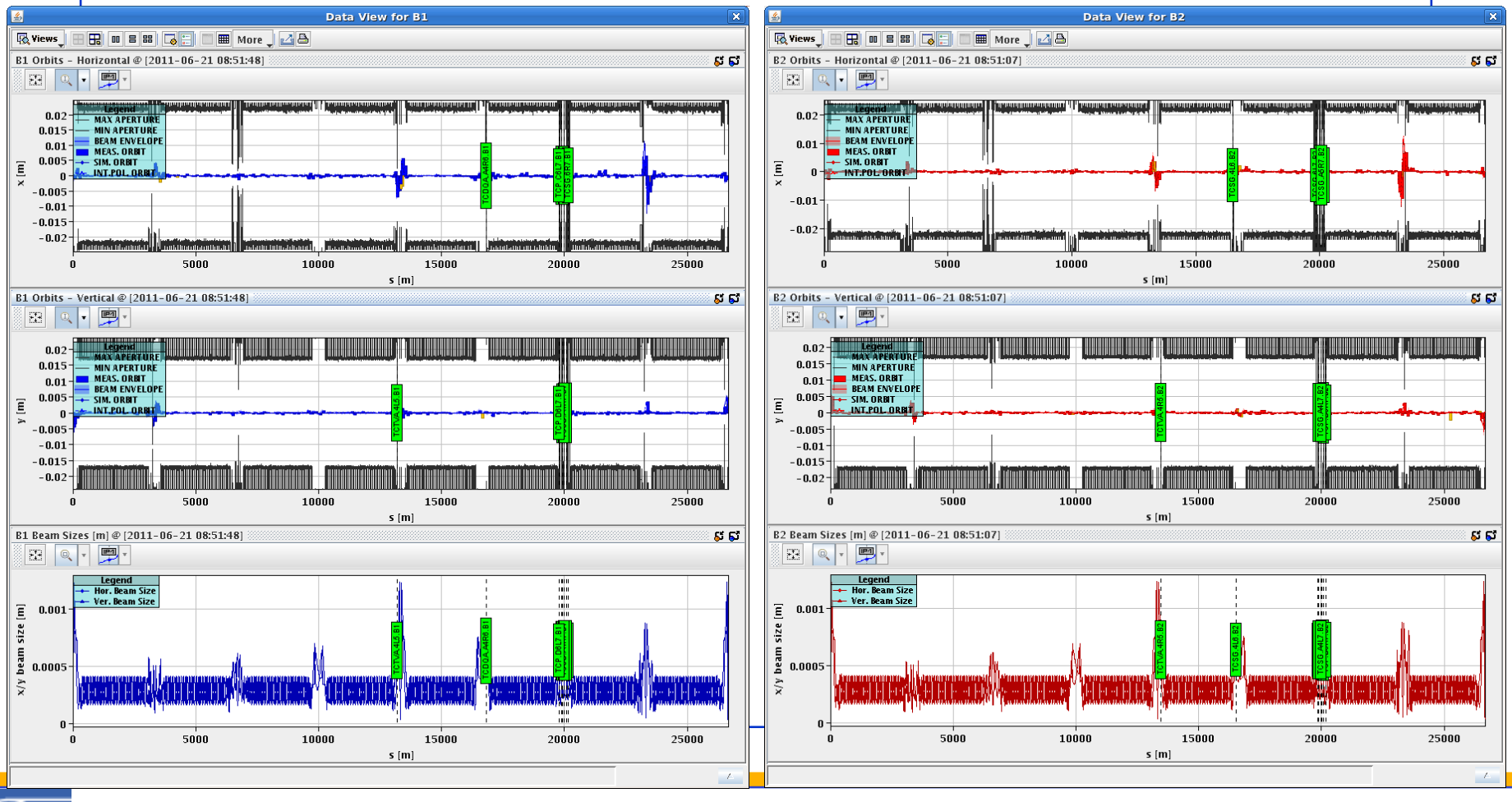




LHC Aperture Meter
B1
B2
PHYSICS [ 0000.00 ] @ 2011-06-21 08-24-06
RBA: lhcop
• current machine state
• time in setting function
LHC B1 - Horizontal (X) Aperture Bottleneck Display
Emittance [m] = 3.5E-6
dp/p = 0.0
Min Values [beam_σ]
Time [hh:mm]
Temperatur drifts in IR7 BPM measurements
Comment Jörg:
„... ahh a temperature meter!“
min. Aperture Element (Name + value in beam_σ)
TCP.C6L7.B1
5.246
LHC B2 - Horizo
dp/p = 0.0
Min Values [beam_σ]
Time [hh:mm]
min. Aperture Element (Name + value in beam_σ)
TCP.C6R7.B2
5.585
LHC B1 - Vertical (Y) Aperture Bottleneck Display
Emittance [m] = 3.5E-6
dp/p = 0.0
Min Values [beam_σ]
Time [hh:mm]
min. Aperture Element (Name + value in beam_σ)
TCP.D6L7.B1
5.242
LHC B2 - Vertical (Y) Aperture Bottleneck Display
Emittance [m] = 3.5E-6
dp/p = 0.0
Min Values [beam_σ]
evolution of aperture bottleneck values for current/last physics fill
→ primary collimators are aperture bottlenecks as expected
min. Aperture Element (Name + value in beam_σ)
TCP.D6R7.B2
5.131
Show/Hide Current Machine Info
resident BeamProcess: PHYSICS-2011_V3@56_[END]
active Optic: A150C150A1000L300_0.00875_2011
current Energy [GeV]: 3500.04
• Setting Information (beam process, optic)
• current Energy
07:46:04 - Size of name-indizes(7127) does not correspond to size of a list of values (13234). Maybe there is no column with element-name in the result, or there are some elements with the same names in the sequence?


Aperture Evolution Viewer [Clone]
Views
More
B1 Horizontal (X) [21/06/11 08:26:33]
Min Values [beam_σ]
10
9
8
7
6
Injection
Ramp
Squeeze
Collision
Physics Production
23:30
23:45
00:00
00:15
00:30
00:45
01:00
01:15
Time [hh:mm]

# Online Modeling ➲ GUI Layout

- beam display panels, while in collision
- beam-based aperture model + movable devices
- hor./ver. orbit and beam sizes

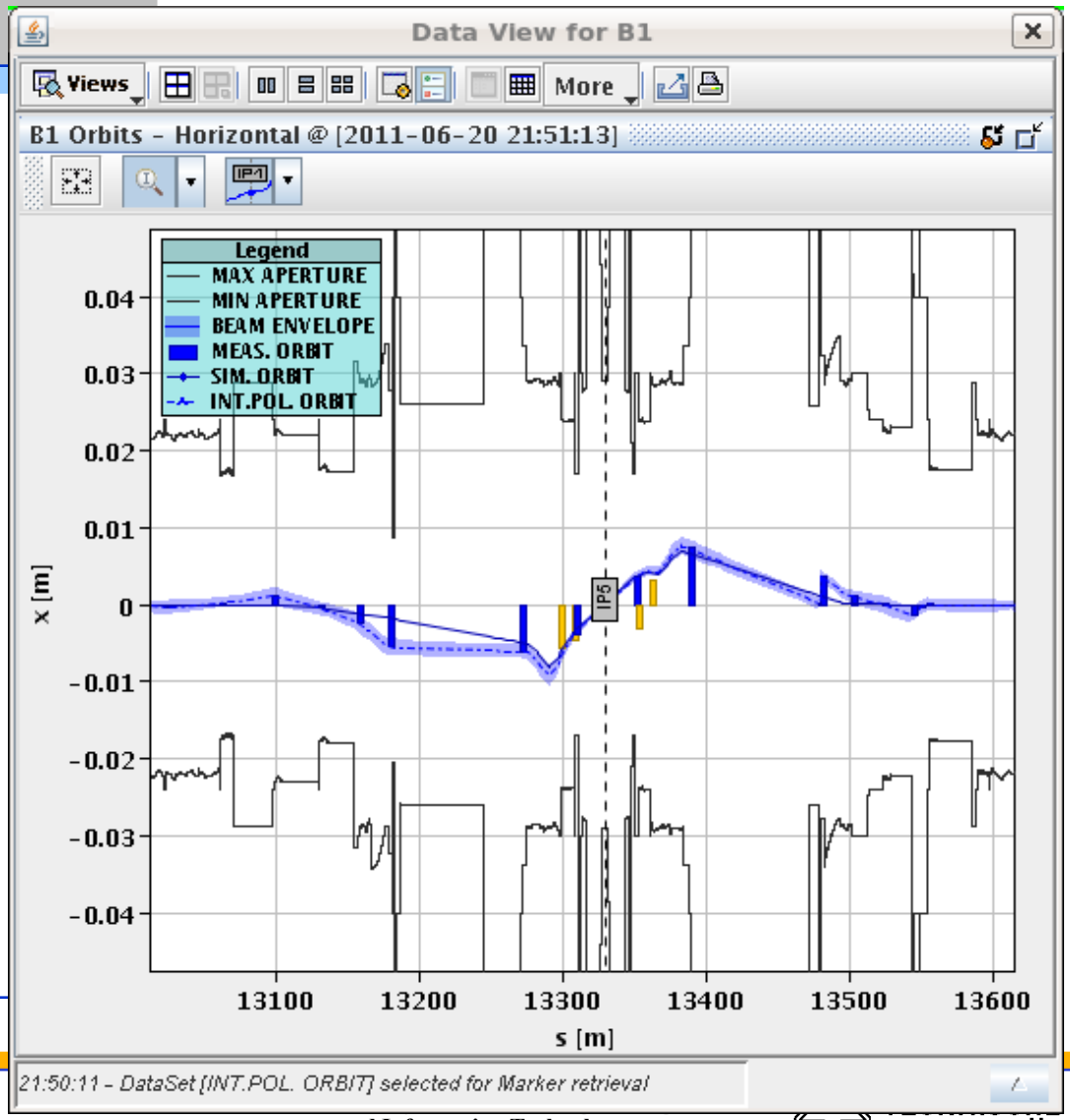


## Online Modeling ➲ Examples

Crossing angle in IP5 at Injection

- ➲ bar plot of measured orbit data
- ➲ interpolated orbit with 1σ envelope
- ➲ simulated orbit for comparison

→ Quite good agreement



## Online Modeling ➲ Examples

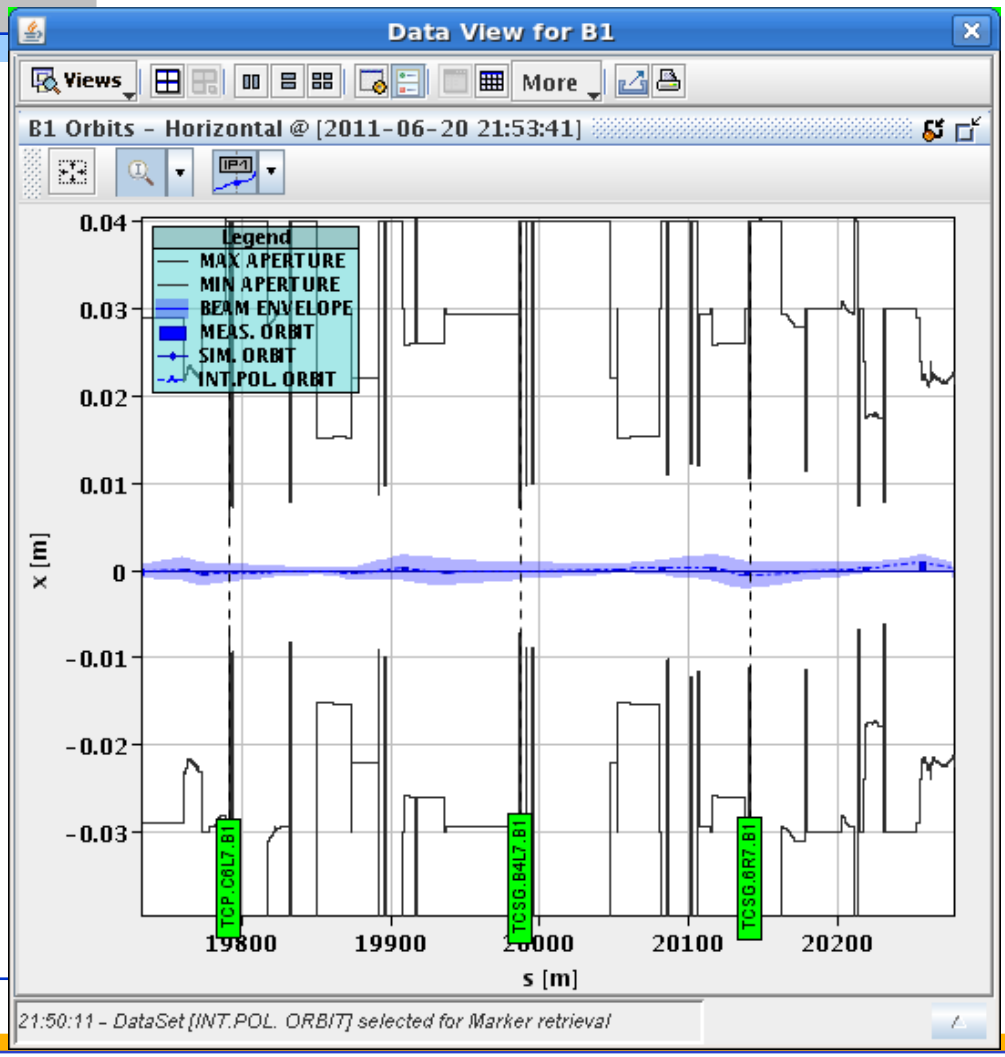
Crossing angle in IP5 at injection

- ➲ bar plot of measured orbit data
- ➲ interpolated orbit with 1σ envelope
- ➲ simulated orbit for comparison

  → Quite good agreement

Cleaning section in IP7 at injection

- ➲ approximately zero orbit
- ➲ collimators centered around interpolated orbit
- ➲ expected bottlenecks at primary and secondary collimators

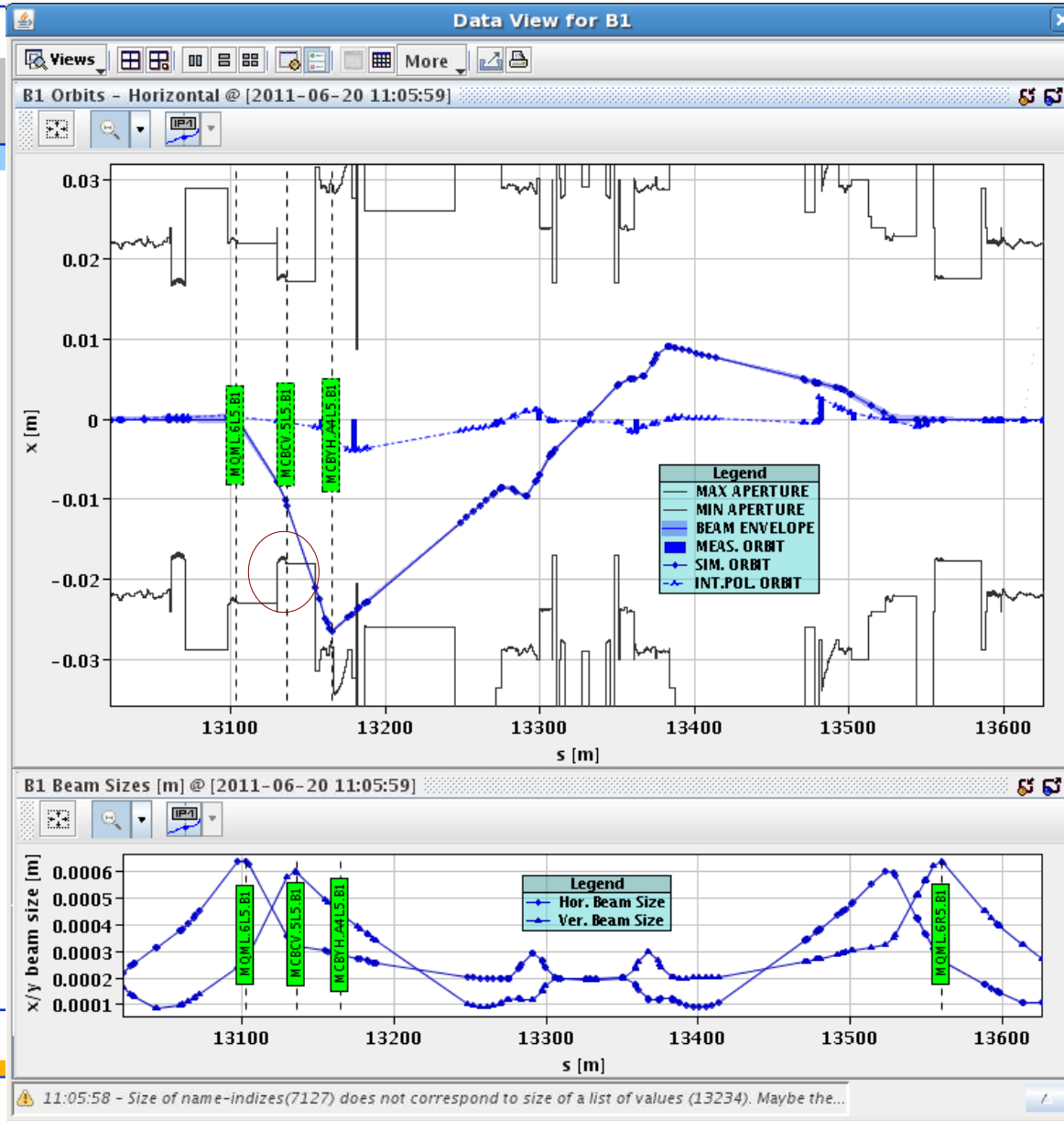


## Online Modeling ➲ Examples

Simulation of IP5
horizontal seperation scan knob
for luminosity adjustment at 90m
unsqueezed optics

- ➲ measured orbit from import of first un-squeeze
- ➲ collimator data not updated
- ➲ expected bottlenecks detected at maximal orbit excursion location and the elements with the maximal beamsize

Rendering problem of aperture model!



## Conclusion

Current Status of the LHC Online Modeling was presented

- optic and knob management well under control and tools ready, as proven during commissioning of two new optic schemes
- framework well integrated into the control system as well as connected to measurement and logging data sources
- state of the machine can be determined online from measurement data, including current time in setting functions
- beam-based aperture model with movable device positions and mechanics to adjust to outcomes of collimator alignment campaigns available
- aperture meter application has been presented and is in a far more advanced state than proof of concept

## Outlook

What comes next?!

- include aperure measurement results into beam-based aperture model
- solid beam-based validation of the modeling approach
  - evaluation of online determined aperture bottlenecks during daily operation as well as during aperture measurements
- complete the simulation mode of the aperture meter to allow aperture bottleneck calculations solely based on simulation data
- support the evolution of the current and possible future optics models
- improve and advance current implementations
- evaluate usability of framework for client applications and provide adequate interfaces/services

# Thank you for your attention!

Special acknowledgements for fruitful discussions and support to

Stefano Redaelli, Kajetan Fuchsberger, Tobias Baer,
Frank Schmidt and the Operations Crew

Questions?!

## Orbit Interpolation

- using linear transfer matrices
- interpolate per plane and segment (defined as the area between two bpm's)
- calculate the angle via the transfer matrix between the two bpm
- relatively quick:
  - ~4s to create the transfer matrices
  - ~1s or lower to interpolate
  - further testing required!!!
- currently ~10% error

$$\begin{pmatrix} u_j \\ u'_j \end{pmatrix} = M_{ij} \begin{pmatrix} u_i \\ u'_i \end{pmatrix} = \begin{pmatrix} C_{ij} & S_{ij} \\ C'_{ij} & S'_{ij} \end{pmatrix} \begin{pmatrix} u_i \\ u'_i \end{pmatrix}$$

$$M_{12} = \begin{pmatrix} \sqrt{\frac{\beta_2}{\beta_1}}(\cos(\psi_{12}) + \alpha_1 \sin(\psi_{12})) & \sqrt{\beta_1\beta_2} sin(\psi_{12}) \\ \frac{(\alpha_1-\alpha_2)}{\sqrt{\beta_1\beta_2}} \cos(\psi_{12}) - \frac{(1+\alpha_1\alpha_2)}{\sqrt{\beta_1\beta_2}} \sin(\psi_{12}) & \sqrt{\frac{\beta_1}{\beta_2}}(\cos(\psi_{12}) - \alpha_2 \sin(\psi_{12})) \end{pmatrix}$$

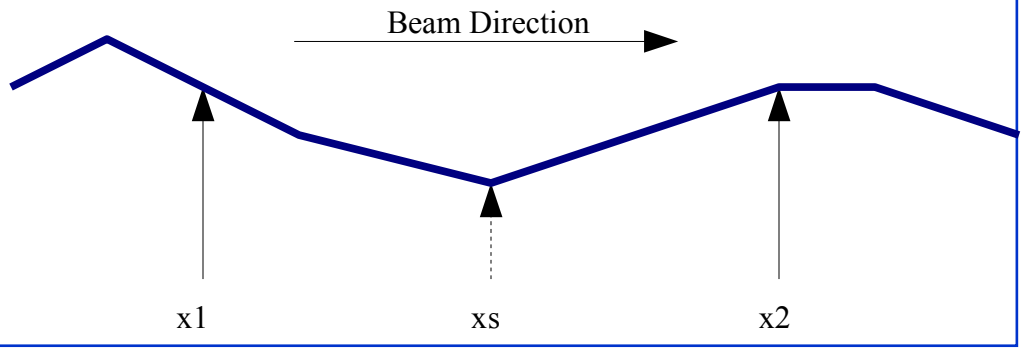
$$\begin{pmatrix} x_2 \\ x'_2 \end{pmatrix} = M_{12} \begin{pmatrix} x_1 \\ x'_1 \end{pmatrix}$$

$$\begin{pmatrix} x_s \\ x'_s \end{pmatrix} = M_{1s} \begin{pmatrix} x_1 \\ x'_1 \end{pmatrix}$$

$$x_2 = C_{12}x_1 + S_{12}x'_1$$

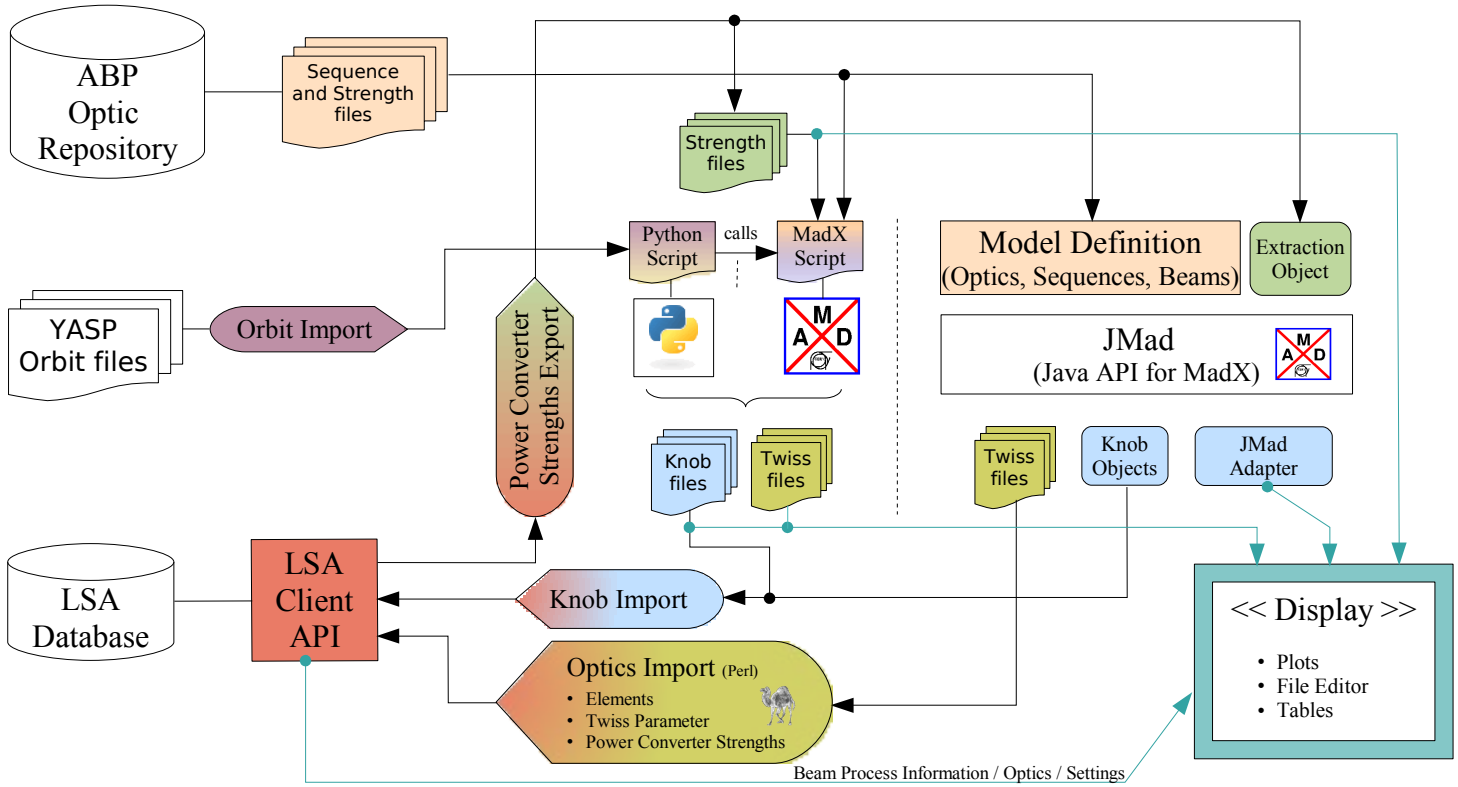
$$x'_1 = \frac{x_2 - C_{12}x_1}{S_{12}}$$

$$x_s = C_{1s}x_1 + S_{1s}\frac{x_2 - C_{12}x_1}{S_{12}}$$

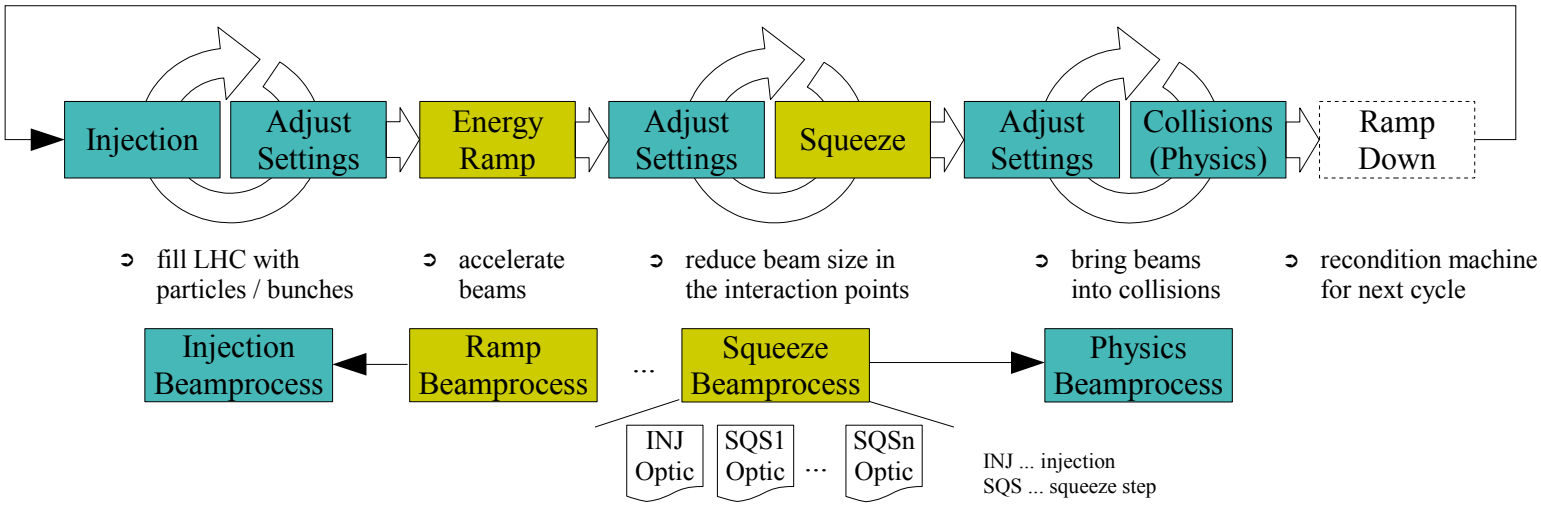


# Online Model Manager Overview

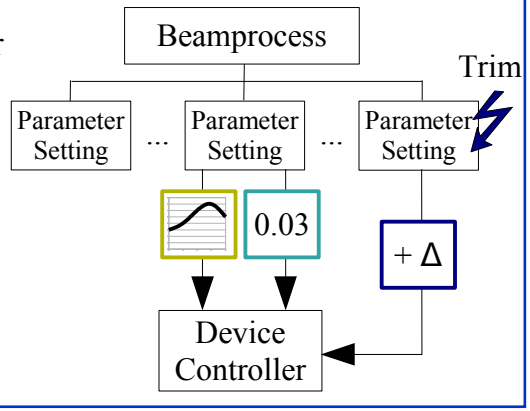
- How does it work? ⇨ Online Model Manager System Overview



# Operational Cycle vs. Control System




- LHC control system LSA (LHC Software Architecure) manages parameter settings required for the different phases of the operational cycle in beamprocesses (BP's) which are defined by a optic sequence
- changes on the parameter settings required during adjustment are called trims and are transmitted as delta values to the devices controllers
- parameters are organized in hierarchical dependencies
- knobs allow to trim a collection of parameters by a given delta multiplied with a factor defined for each dependant



# Creating LSA Setting Generation Input

- java package that contains required files to create a simulated machine
- definition of all optics available in the control system including corrections
- control applications can use same basis for calculation and simulations

**Model Definition**


- Java API for MadX [4]
- hide all interaction with MadX from user
- run simulations based on models initialized with a model definition
- allows data transfer between control environment and MadX on Java-level

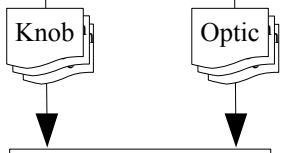
(concept and development by K. Fuchsberger)

- extract knob definition from optic
- match and normalize to standard units
- simulate trim for verification

**Knob Generator**

**Optic Generator**

- check tune and chromaticity agains references and rematch if needed
- dump optic functions to file




**LSA**

⇒ Online Model provides the knowledge about the available optics as well as the tools to automatically generate and upload the information