

FLASH / FEL-BeamDynamics Seminar

Beam Based Alignment in the FLASH Undulators Using the LCLS Method (a Preliminary Status Report)

Mathias Vogt (DESY-MFL)

...with a lot of help and inspiration from Jin Hyunchang & Duan Gu !

- The (modified) LCLS Method
- SASEBBAGUIMain
- The Measurements 2013-01-09 in FLASH
- A Long FODO Channel w/ Optimized Phase Advance



The LCLS Method (H.Loos/SLAC) here: for **one Phase-Plane**, say (x, p_x)

- At P different Energies $\{E_k\}_{k=1,P}$
- Given : M BPMs with offsets $\vec{\Delta} \in \mathbb{R}^M$

→ for each k :

- Actual orbit \vec{X}_k , measured Orbit \vec{Y}_k with random errors $\vec{\xi}_k$

$$\Rightarrow \boxed{\vec{Y}_k = \vec{X}_k + \vec{\Delta} + \vec{\xi}_k}$$

- Given : N perturbations(= misaligned quads) and/or correctors(= movers)

→ : misalignments $\vec{d} \in \mathbb{R}^N$ independent of energy !!!

- For each k : initial cond.(= launch) $\vec{z} \equiv (x_0, x'_0)_k^T$

$$\Rightarrow \boxed{\vec{X}_k = \underline{\mathcal{L}}_k \vec{z}_k + \underline{\mathcal{O}}_k \vec{d}}$$

- **LaunchResponseMatrix (LRM)** $\underline{\mathcal{L}}_k$
- **OrbitResponseMatrix (ORM)** $\underline{\mathcal{O}}_k$

The LCLS Method (H.Loos/SLAC) (2)

- Now **join over all P energies** :

$$\vec{X} := (\vec{X}_1^T, \dots, \vec{X}_P^T)^T, \vec{Y} := \dots, \vec{z} := \dots, \vec{\xi} := \dots$$

$$\underline{\mathcal{L}} := \text{diag}(\underline{\mathcal{L}}_1, \dots, \underline{\mathcal{L}}_P) \in \mathbb{R}^{PM \times P^2}$$

$$\underline{\mathcal{O}} := (\underline{\mathcal{O}}_1^T, \dots, \underline{\mathcal{O}}_P^T)^T \in \mathbb{R}^{PM \times N}$$

$$\underline{\mathcal{U}} := (\underline{\mathbf{1}}_1^{M \times M}, \dots, \underline{\mathbf{1}}_P^{M \times M})^T \in \mathbb{R}^{PM \times M}$$

$$\Rightarrow \boxed{\vec{Y} = \underline{\mathcal{L}} \vec{z} + \underline{\mathcal{O}} \vec{d} + \underline{\mathcal{U}} \vec{\Delta} + \vec{\xi}}$$

- or: $\boxed{\vec{Y} = \underline{\mathcal{A}} \vec{v} + \vec{\xi}}$ with $\underline{\mathcal{A}} := (\underline{\mathcal{L}}, \underline{\mathcal{O}}, \underline{\mathcal{U}})$ and $\vec{v} := (\vec{z}^T, \vec{d}^T, \vec{\Delta}^T)^T$

- Possibly add more objectives (soft constraints) :

- either $0 = \sum_{i=1}^M \Delta_i$ & $0 = \sum_{i=1}^M s_i \Delta_i \leftarrow \Delta_i = \Delta^{(0)} + \Delta^{(1)} s_i$

- or $0 = \sum_{i=1}^N d_i$ & $0 = \sum_{i=1}^N s_i d_i \leftarrow d_i = d^{(0)} + d^{(1)} s_i$

- or $\{0 = \Delta_i - \Delta_i^{\text{ref}}\}_{i=1, \dots, M}$

- or $\{0 = d_i - d_i^{\text{ref}}\}_{i=1, \dots, N}$

→ $PM +$ “x” constraints for $2P + N + M$ variables

← ... each constraint can be given it's own weight !

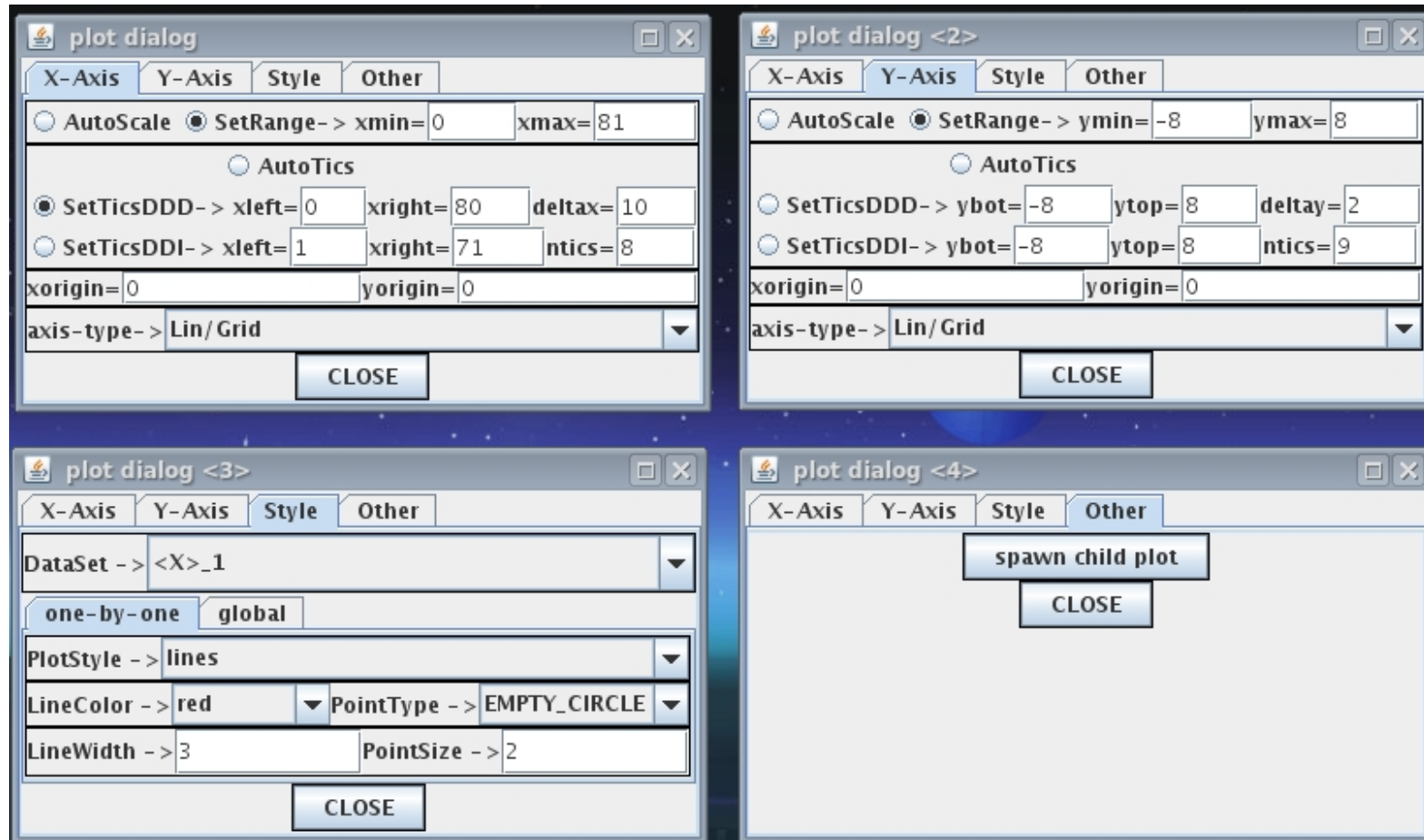
SASEBBAGUIMain

The screenshot displays the SASEBBAGUIMain software interface, which is used for controlling and monitoring the SASE beamline. The interface is divided into several sections:

- Top Left:** Two plots showing orbit averages. The top plot is labeled "XOrbitAver" and the bottom plot is "YOrbitAver". Both plots show the average orbit (v/a.u.) versus position (x/a.u.) from 0.0 to 25.0. The XOrbitAver plot shows a significant dip at approximately 25.0 x/a.u., while the YOrbitAver plot shows a significant peak at the same position.
- Top Right:** A "DataConfig" panel with tabs for "Data", "BPMs", "Meas", "Movers", and "Simul". The "Data" tab is active, showing a date and time selection ("2012-04-26 MS 600-720-900") and buttons for "load", "CLR DATA", "ADD DATA", and "STOP". Below this are fields for "sample:" (10) and "file (s):" (y13m01d09n_MS2_600_720_900_001.orbx and y13m01d09n_MS2_600_720_900_001.orby). There are also "SAVE ALL" and "LOAD ALL" buttons.
- Bottom Left:** A control panel for the horizontal beamline. It includes three weight sliders (w[1], w[2], w[3]) all set to 1.00000. A "calculate" button is present, along with a "LgSVmin" slider set to -4.00000 and a "gain" slider set to 0.80000. A "CORR -> MACHINE" button is highlighted in red. There are also "STOP", "UNDO", and "RESUME" buttons.
- Bottom Right:** A control panel for the vertical beamline, mirroring the horizontal panel. It includes a "calculate" button, a "LgSVmin" slider set to -4.00000, and a "gain" slider set to 0.80000. A "CORR -> MACHINE" button is highlighted in red. There are also "STOP", "UNDO", and "RESUME" buttons.
- Far Right:** A "result" panel with "SAVE" and "LOAD" buttons and two "file (s):" input fields.

Interlude: LIVE DEMO →

jplot/PlotDialog(s)



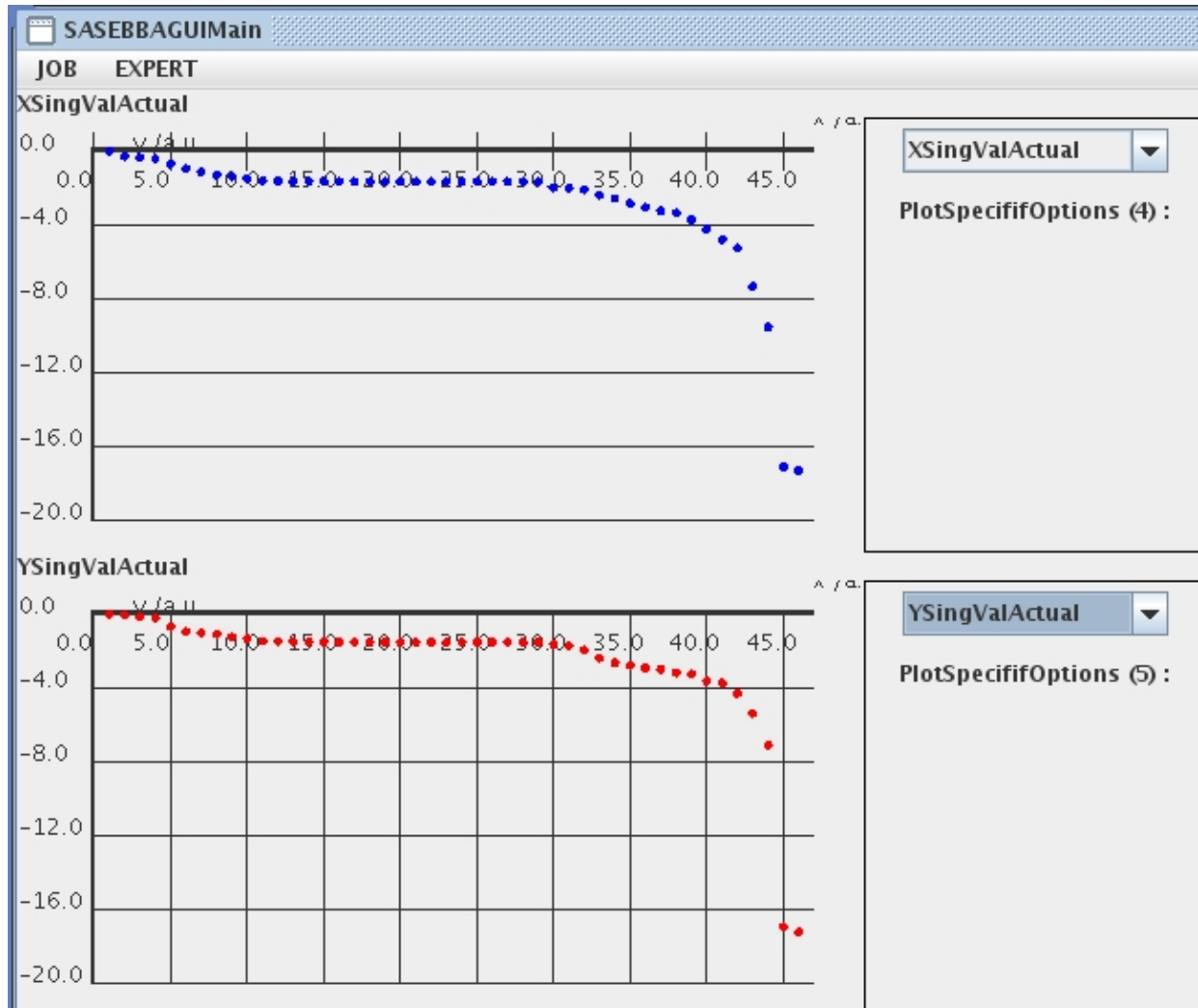
Measurements 2013-01-09-night

- 2013-01-09n
- e-log : Achievements →
 - Took one set (3 data sets) of undulator BBA measurements in the files prepared Monday/Late (600,720,900 MeV) with quad movers “as is”.
 - Preliminary evaluation of the data suggests a correction which we applied manually.
 - Took another set of Undu-BBA measurements w/ quad mover corrections applied.
- 2013-02-14n (first 3h)
- e-log : Achievements →
 - saved (2x) 3 undulator BBA data sets (100,1000 shots) for (600,720,900) MeV / AFTER CORRECTION (Jin Hyunchang)
 - for all three energies one establish a launch with decent losses in relatively little time !!!!!
 - This strongly suggests that the correction computed by Jin does really straighten the beam !!!!!
 - Offline analysis will follow.

2013-01-09-n / 1-st set / all 3 orbits (Energies)

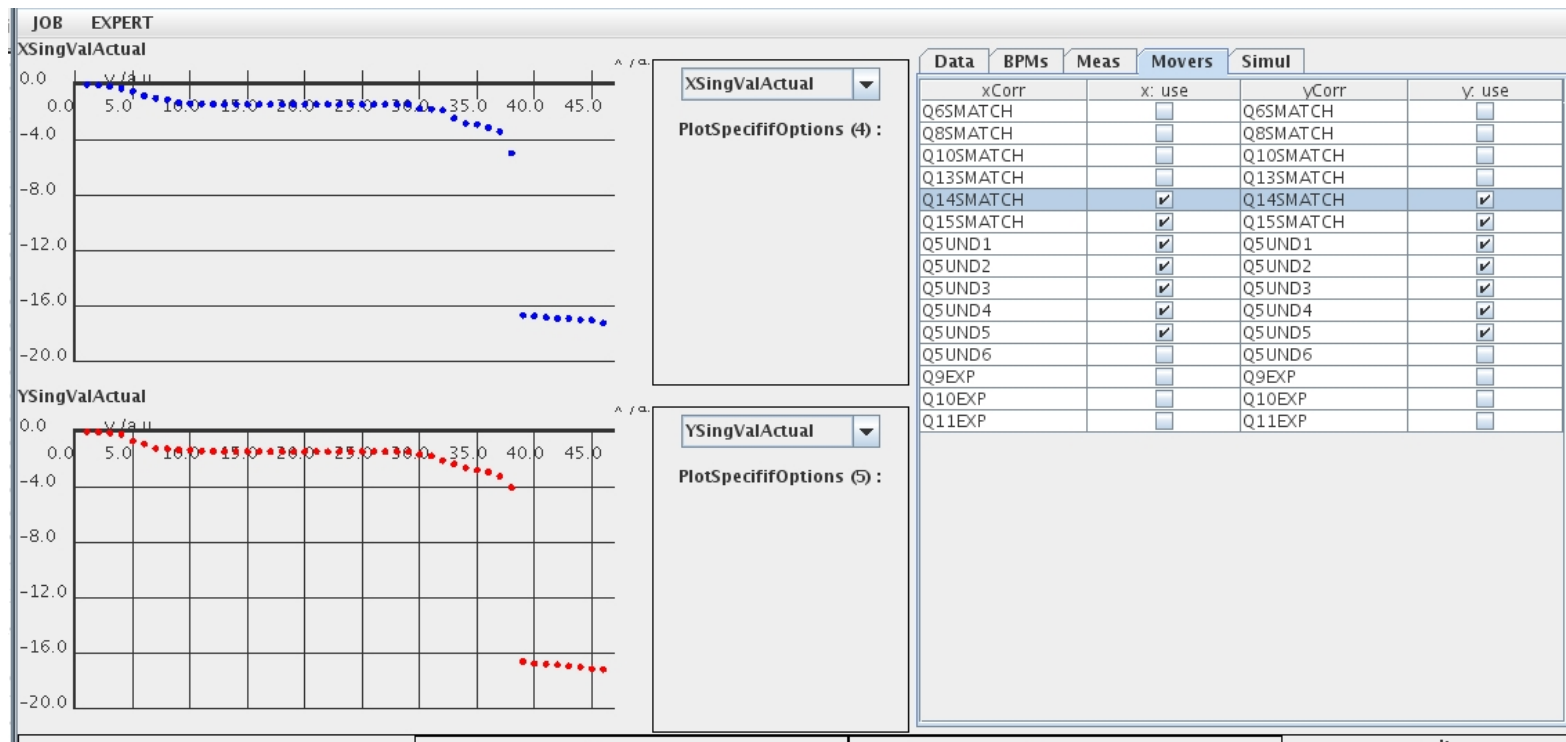
The screenshot displays the SASEBAGUI software interface, which is used for controlling and monitoring the SASE (Self-Amplified Spontaneous Emission) system. The interface is divided into several sections:

- Top Left:** Two plots showing orbit data. The top plot is labeled "XOrbitAver" and the bottom plot is "YOrbitAver". Both plots show the average orbit position (x/a.u. and y/a.u.) versus time (0 to 25.0). The data is represented by colored bars (red, green, blue) indicating different orbits.
- Top Right:** A "DataConfig" panel with a dropdown menu set to "2012-04-26 MS 600-720-900". It includes buttons for "CLR DATA", "ADD DATA", "STOP", "SAVE ALL", and "LOAD ALL". There are also radio buttons for selecting different data sets: "1: 1000,1000", "2: 1000,1000", and "3: 1000,1000".
- Bottom Left:** A control panel for the "horizontal" orbit. It features three sliders for "w[1]", "w[2]", and "w[3]", each set to "1.00000". Below the sliders are buttons for "calculate", "STOP", "UNDO", and "RESUME". A red button labeled "CORR -> MACHINE" is also present.
- Bottom Middle:** A control panel for the "vertical" orbit. It features three sliders for "LgSVmin" (set to "-4.00000"), "gain" (set to "0.80000"), and another slider (set to "0.00000"). Below the sliders are buttons for "calculate", "STOP", "UNDO", and "RESUME". A red button labeled "CORR -> MACHINE" is also present.
- Bottom Right:** A "result" panel with "SAVE" and "LOAD" buttons, and two input fields for "file (x):" and "file (y):".

2013-01-09-n / 1-st set / "Plain" Singular Values

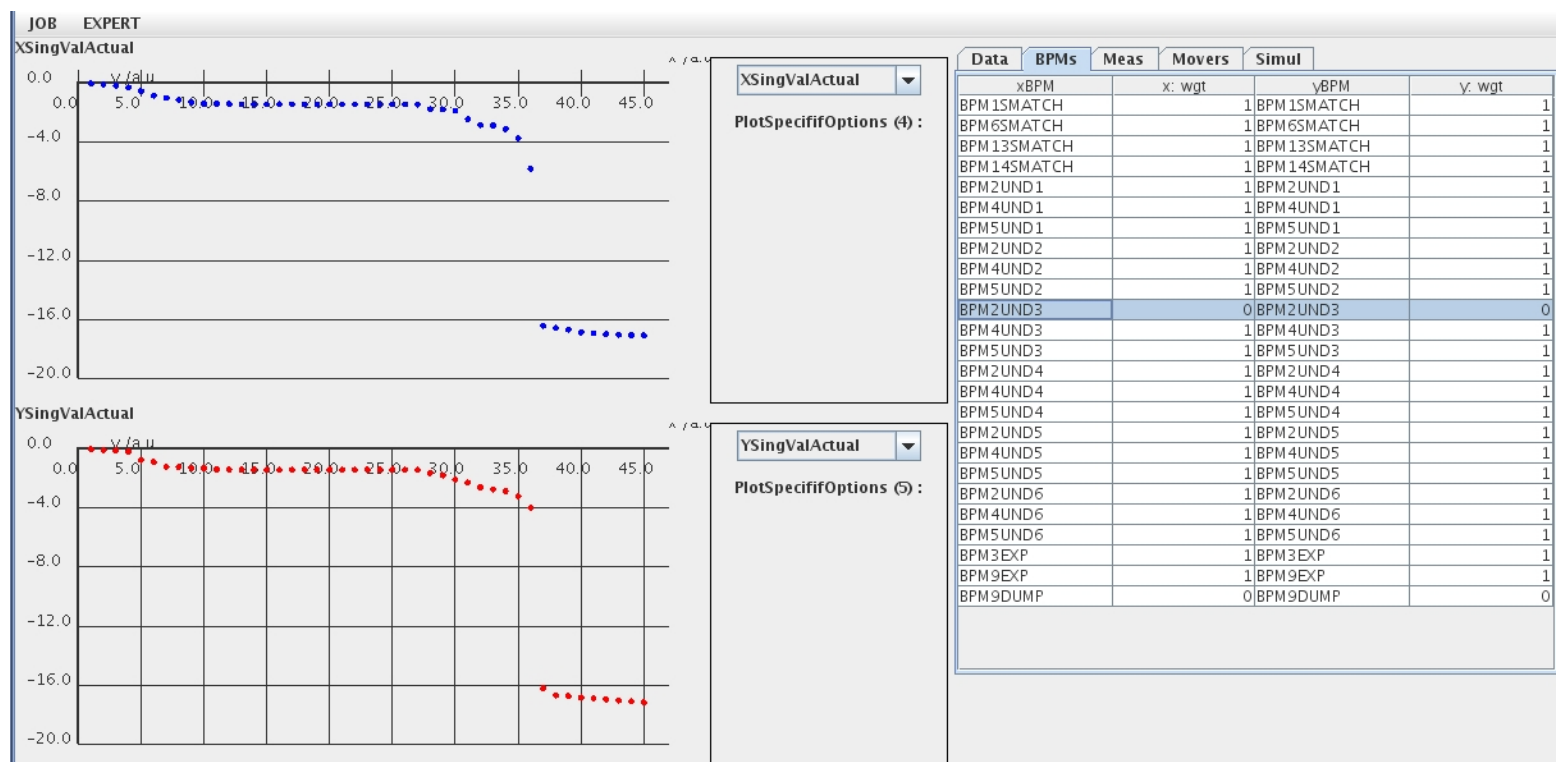
2013-01-09-n / 1-st set / SingVal's after restricting the Movers

- Not all quads have movers!
- First quad misalignments are equivalent(degenerate) to initial condition
- Last quads: no influence on SASE and too few BPMs downstream



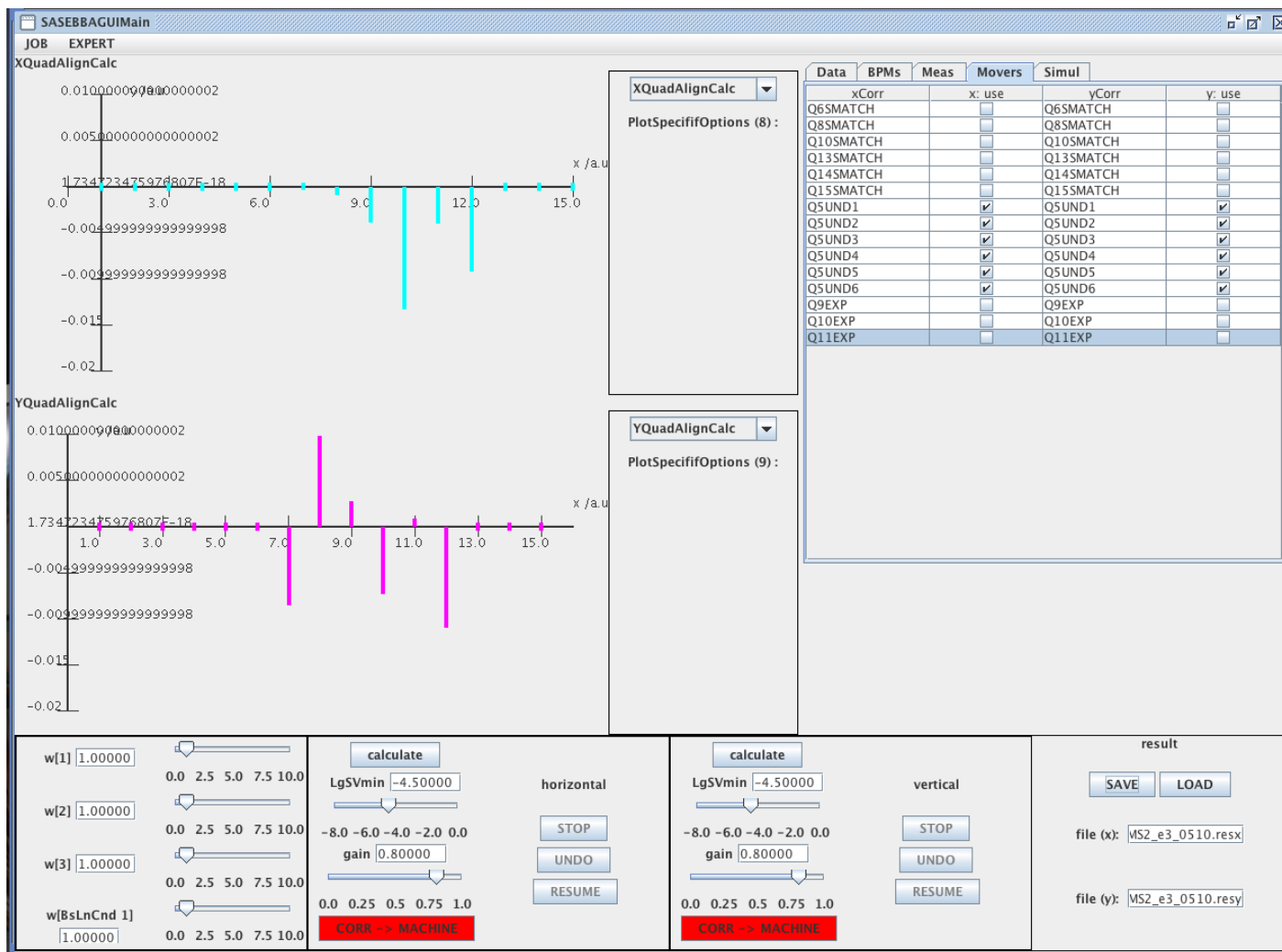
2013-01-09-n / 1-st set / SingVal's after removing BPM2UND3 (← sucks!)

- In principle: all BPM2UND_x & BPM4UND_x could be given lower weights
- also BPM9DUMP ← beam sweeper!



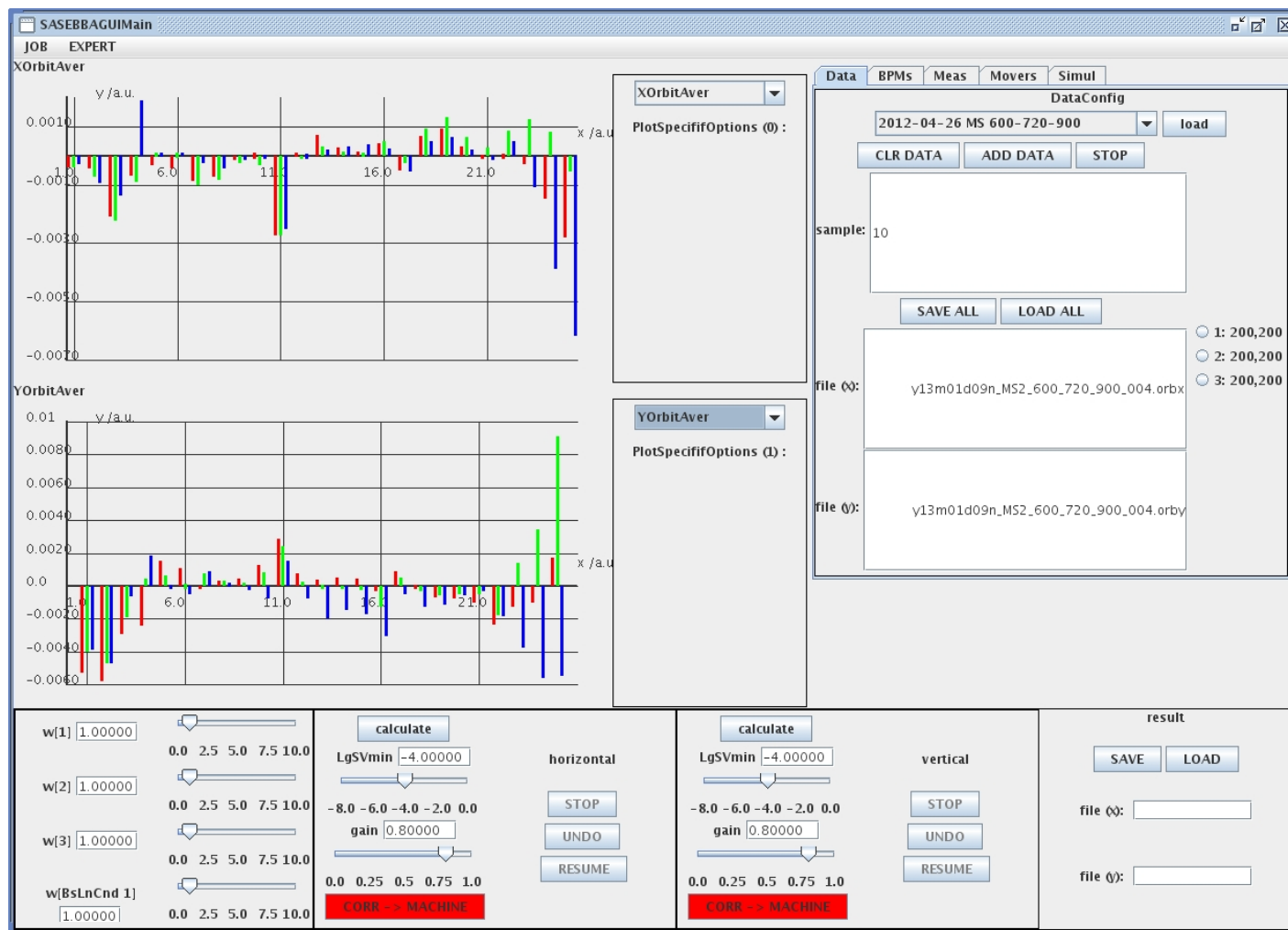
2013-01-09-n / 1-st set / Computed Quad-Alignment → e-log

Hor.: quad index (as in list) ; Vert.: misal. (in m) → too high → scale??



2013-01-09-n / 2-nd set / After applying corrections (scaled!)

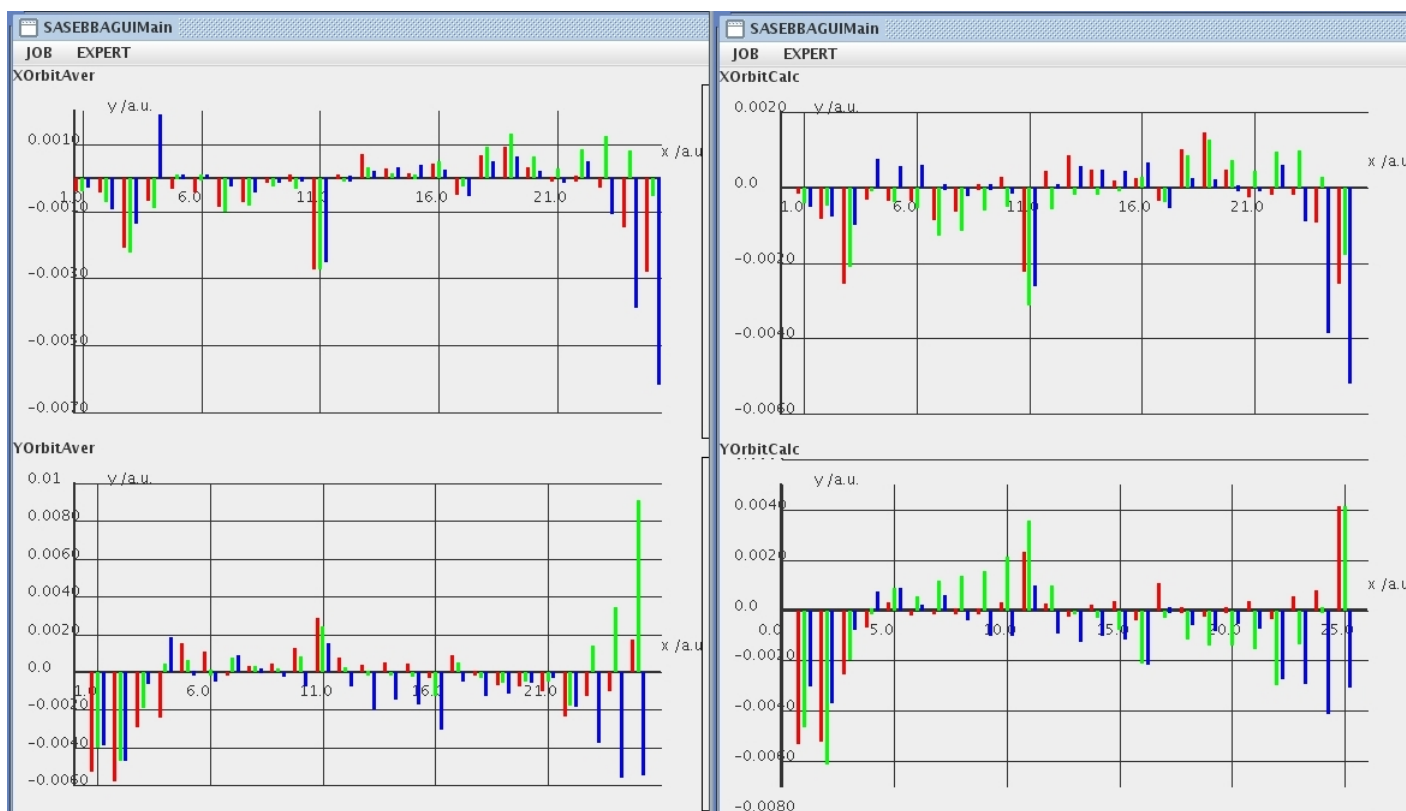
$$\vec{Y}_{\text{measured}} = \underline{A} \vec{v}_{\text{machine}} + \vec{\xi}_{\text{error}}$$



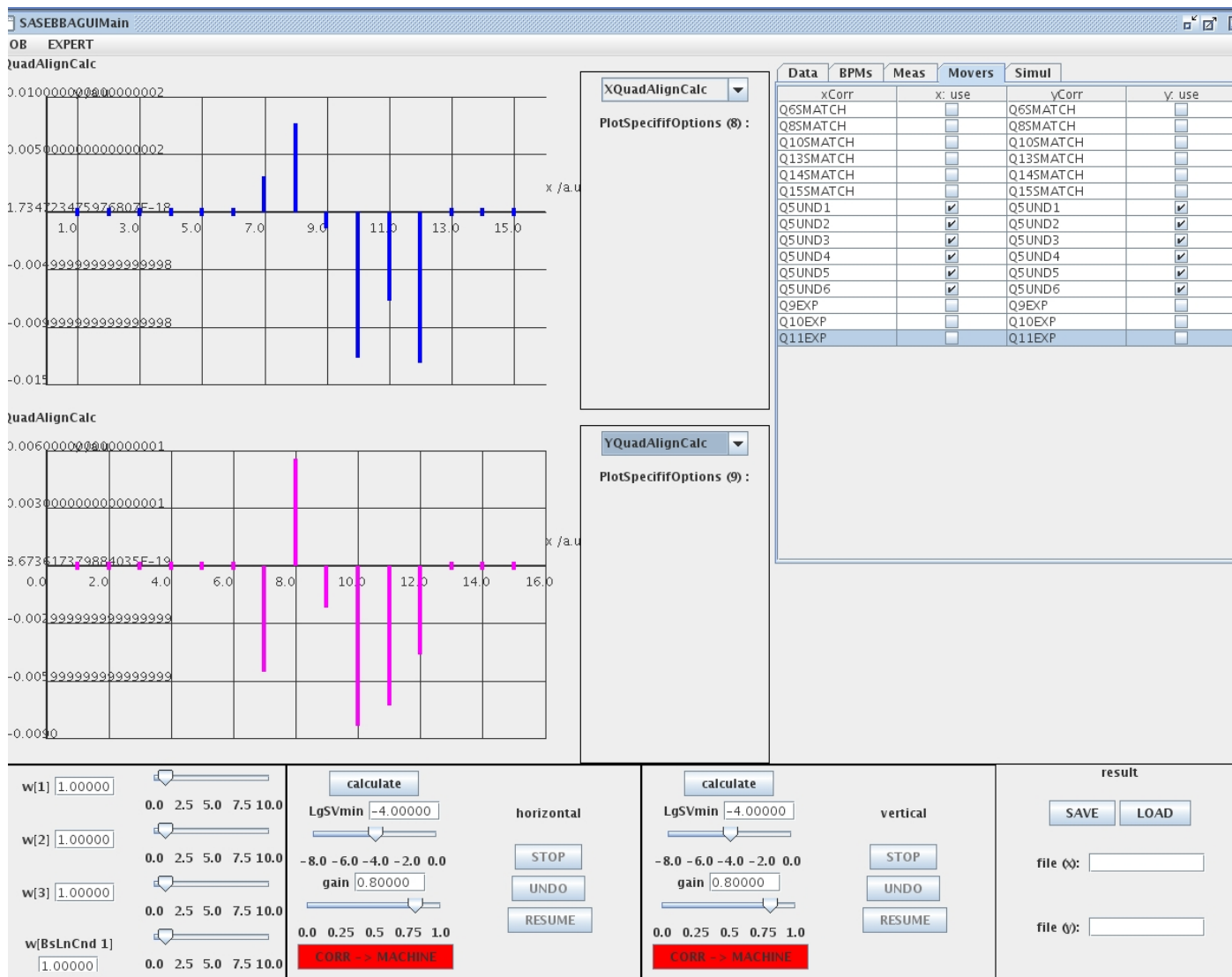
2013-01-09-n / 2-nd set / Comparison: Measured (L) vs. Predicted (R) Orbit

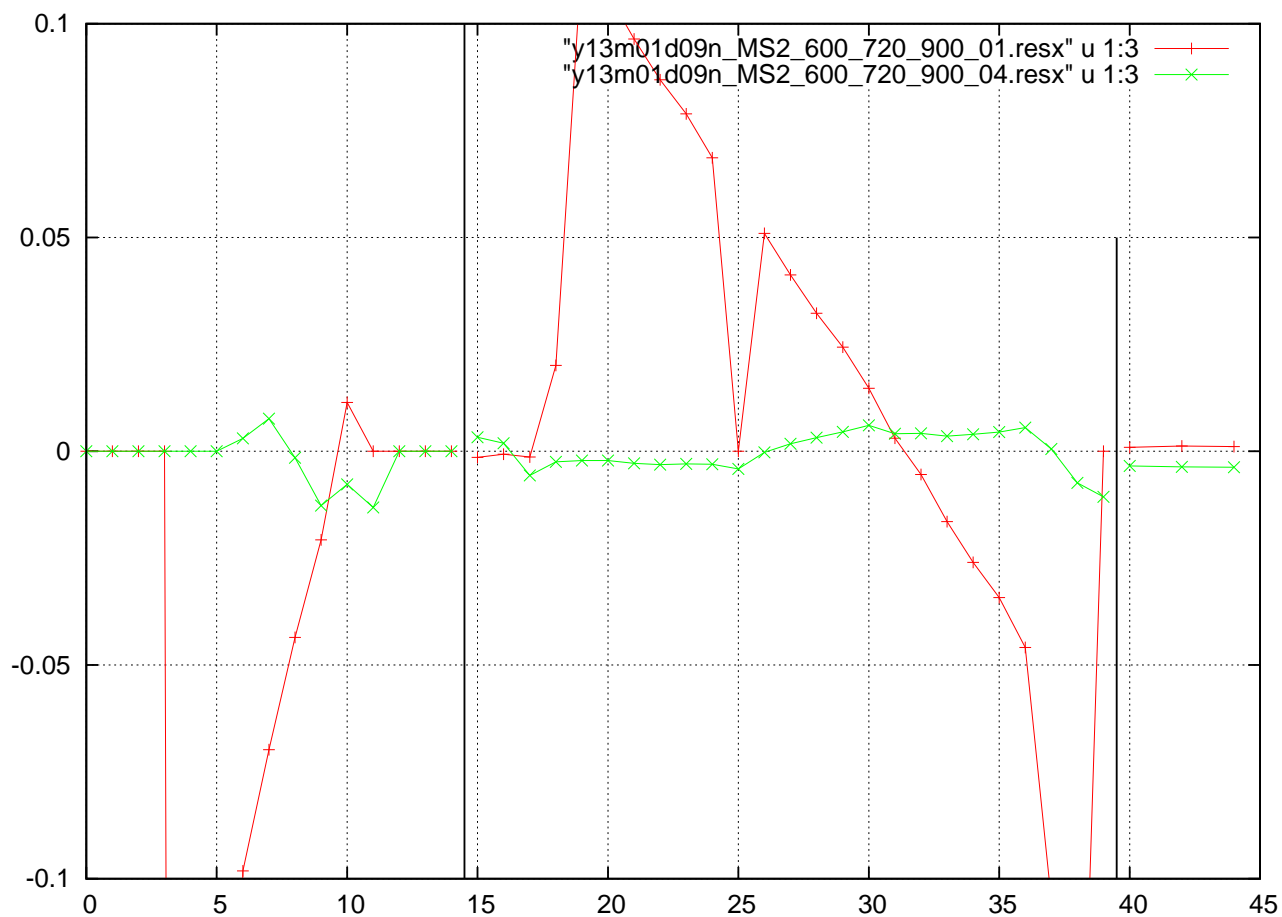
$$\vec{v}_{\text{calculated}} = \tilde{\mathcal{A}}_{\tau, \vec{w}, \dots} \vec{Y}_{\text{measured}}$$

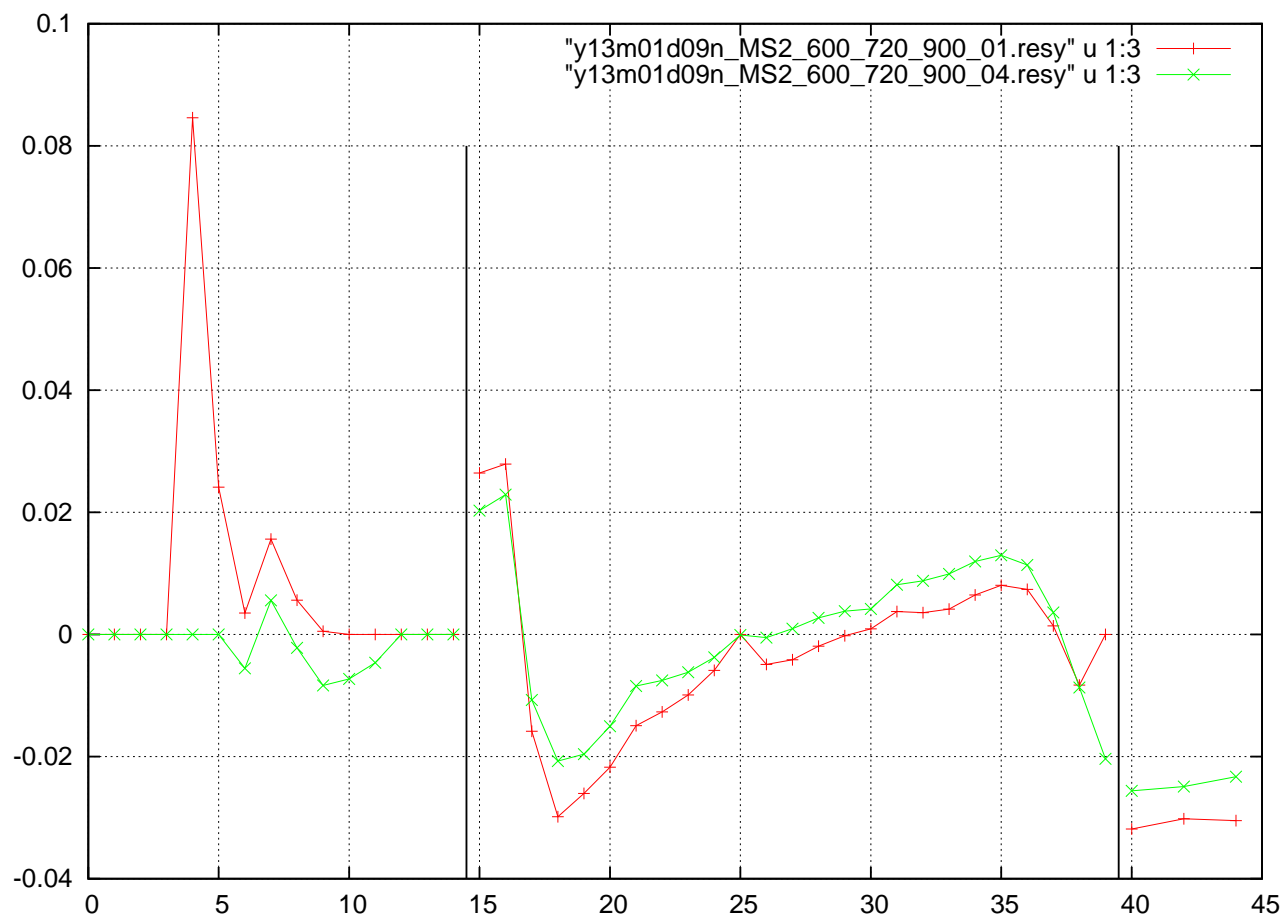
$$\vec{Y}_{\text{predicted}} = \mathcal{A} \vec{v}_{\text{calculated}}$$



2013-01-09-n / 2-nd set / Calculated Quad Misalignments

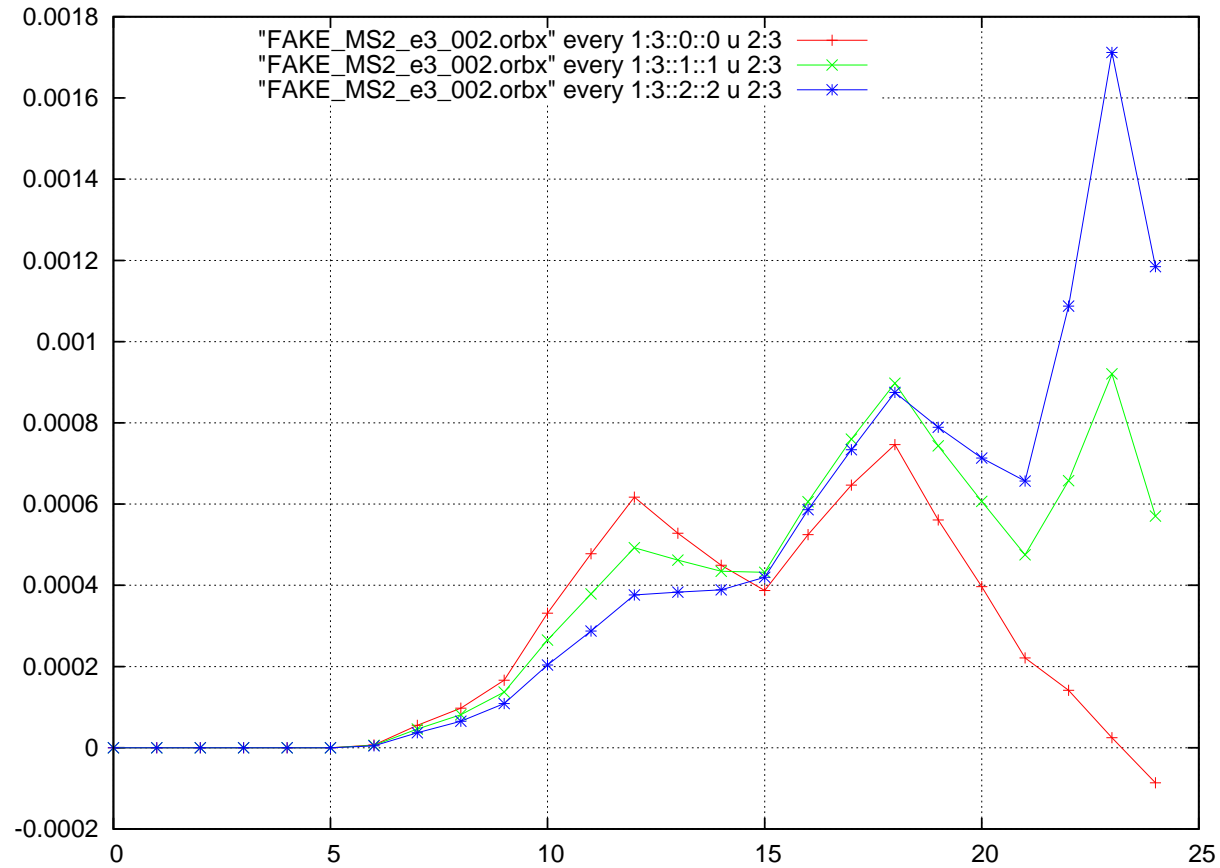


2013-01-09-n / 2-nd set / A hint of Horizontal Convergence ?

2013-01-09-n / 2-nd set / A hint of Vertical Convergence ?

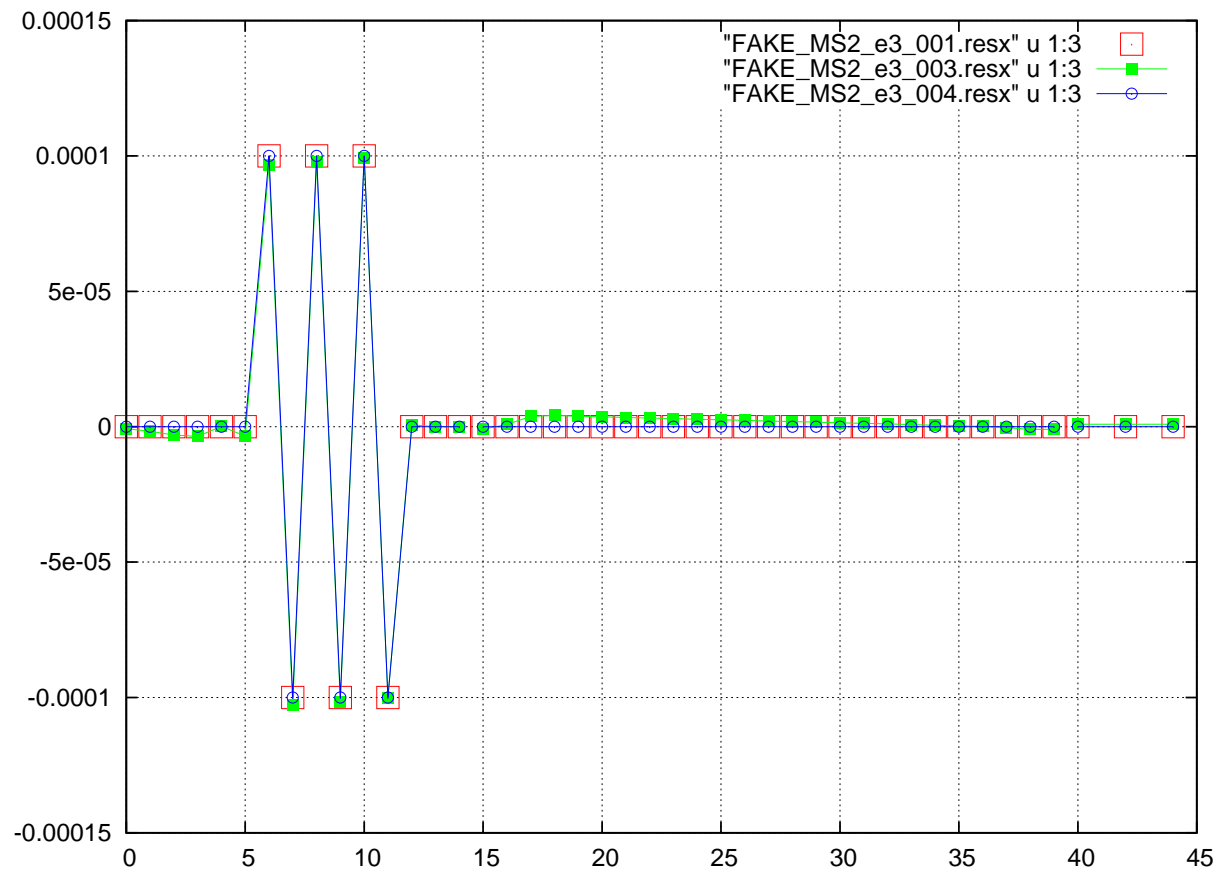
Example: FAKED Quad-Misal.'s → Calc. X-Orbit → Reproduced Quad-Misal.'s ?

600 MeV → $\approx 1/4$ β -tron oscillation, , 720 MeV → $\approx 1/6$ 900 MeV → $\approx 1/8$

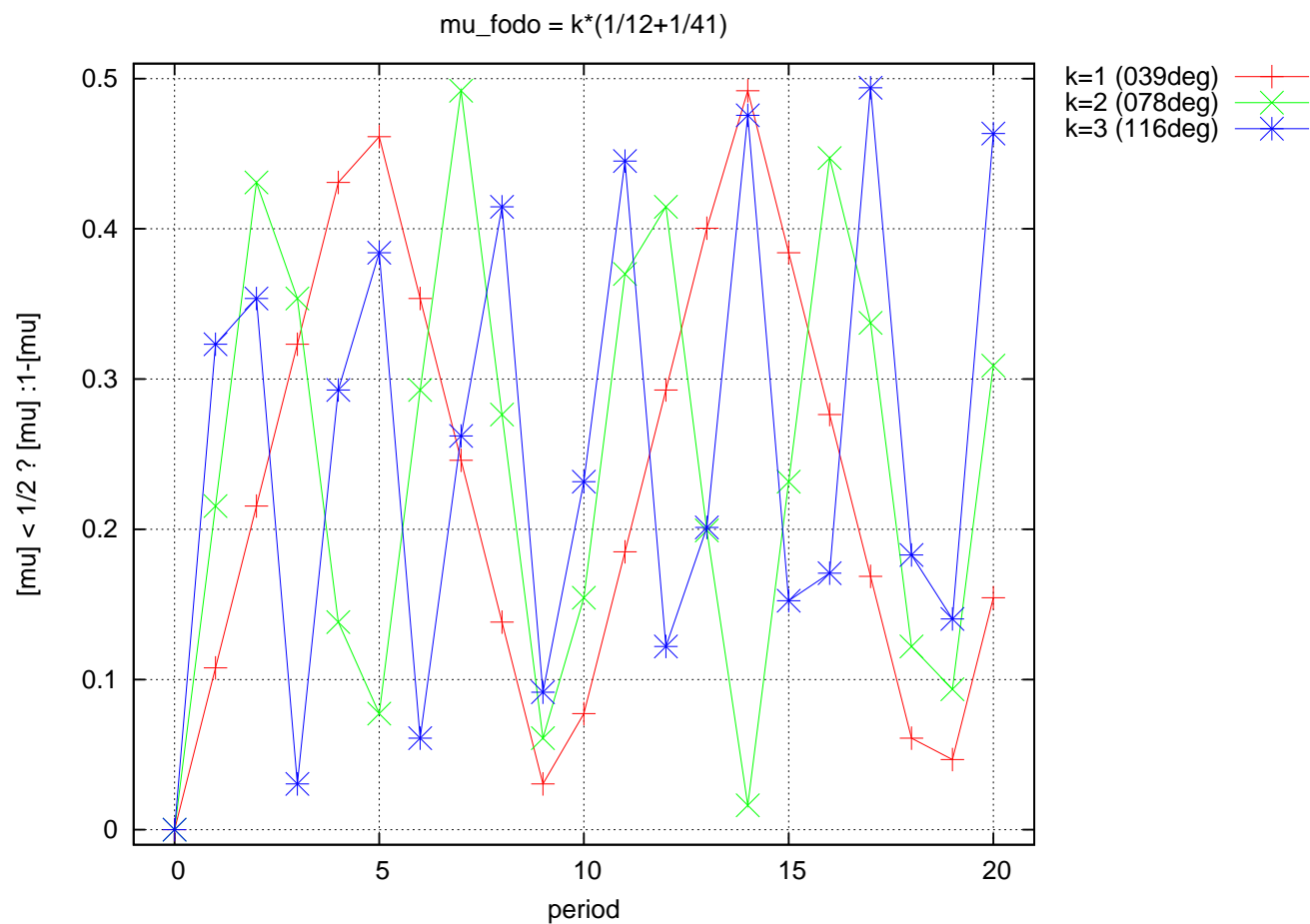


Example: FAKED Quad-Misal.'s → Calc. Orbit → **Reproduced Quad-Misal.'s ?**

input, reproduced with $\tau = 10^{-4.0}$ → small artefacts, reproduced with $\tau = 10^{-4.5}$ → 100%

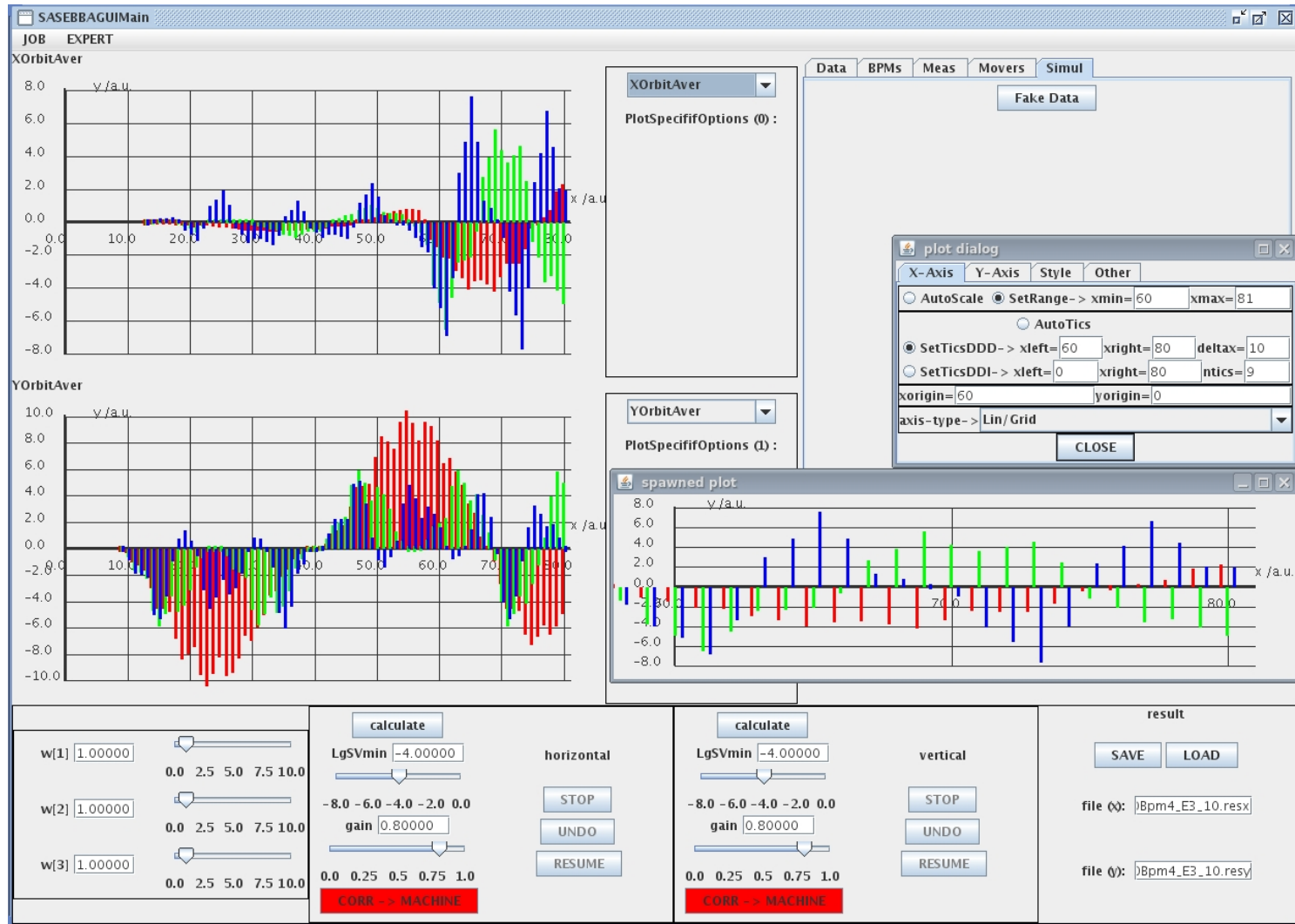


MODEL: Long (20xPer) FODO Section w/ "non-degenerate" Phase Advance



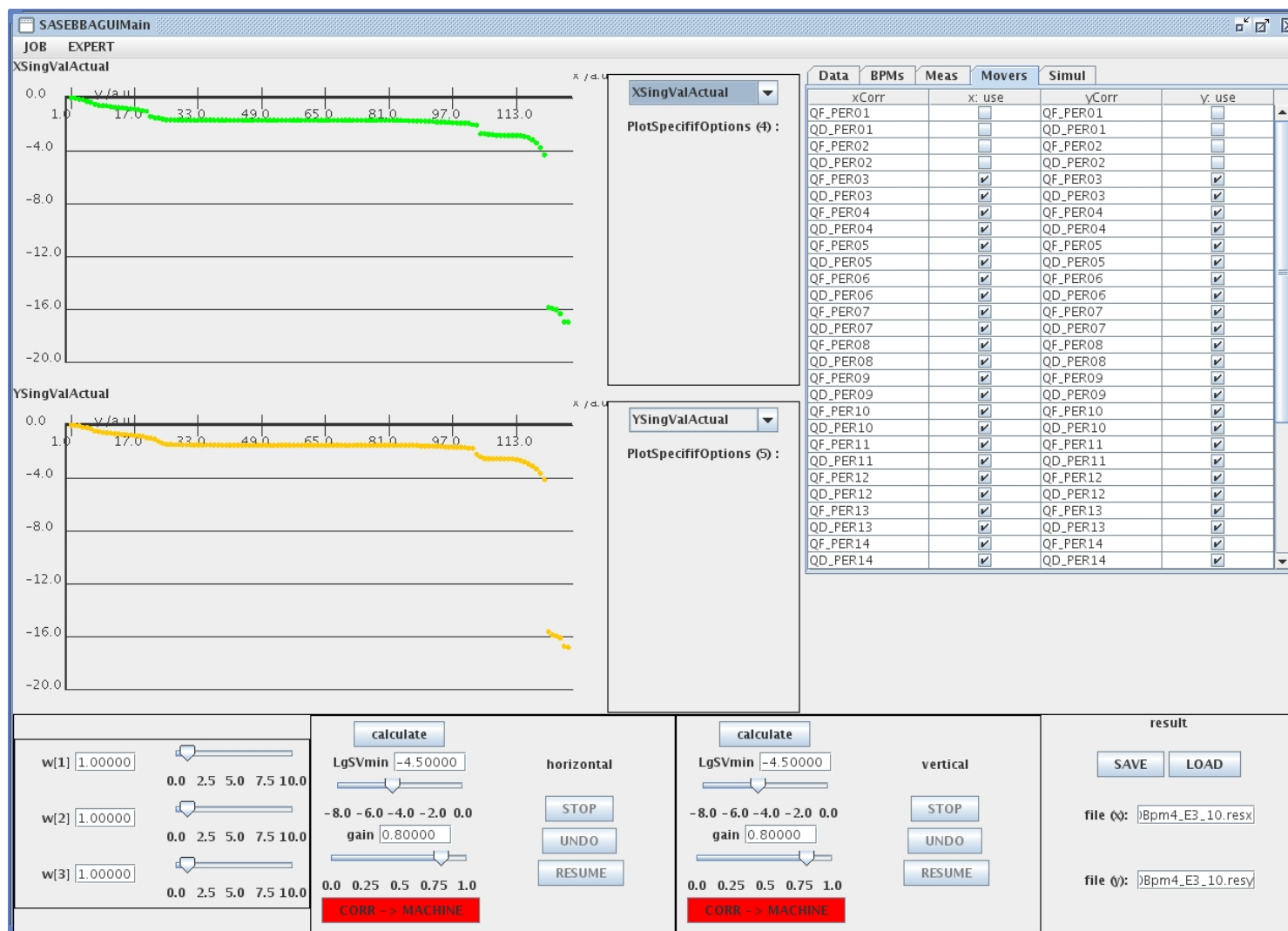
FODO: “Faked” Orbit (w/o errors!) from Assumed Misalignments

N.B.: there’s no noise in this simulation.



FODO: SingVal's after Movers have been Adjusted

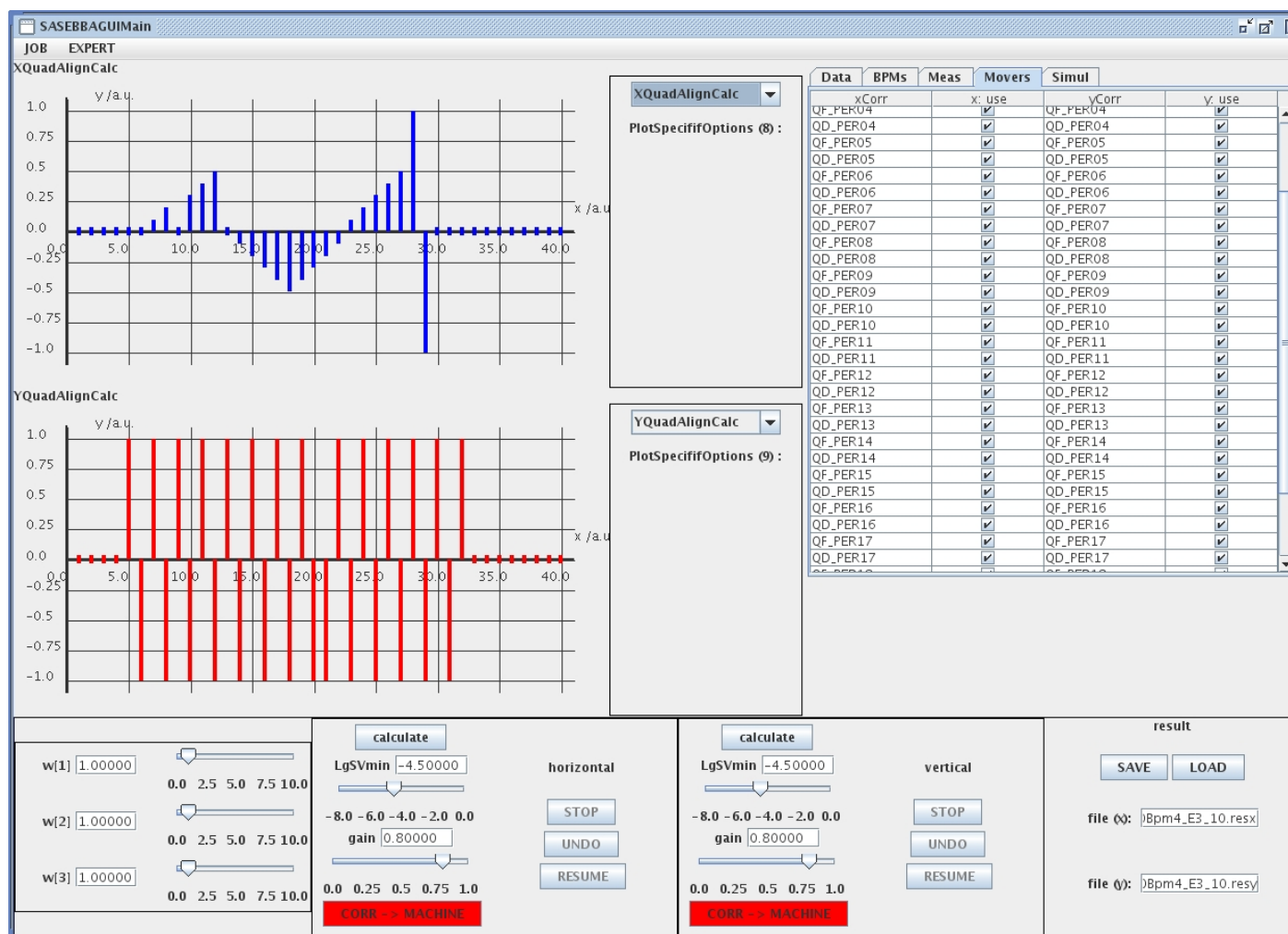
⇒ τ (SVD cut-off) should not be above $10^{-4.5}$



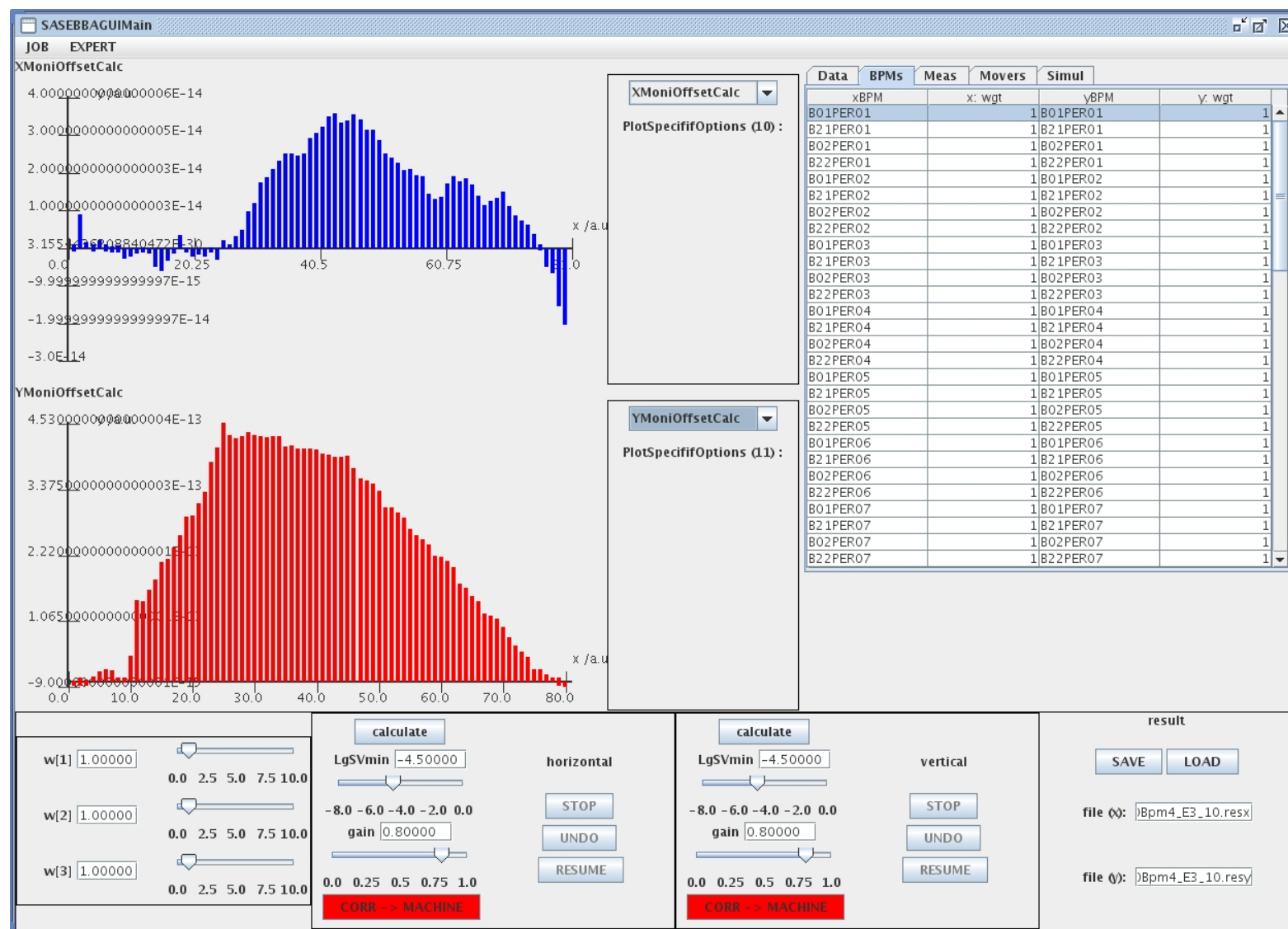
FODO: Reconstructed Quad Misalignments

Input reproduced on the level of 10^{-8} ; orbit residue (least square's fit) $\approx 10^{-12}$

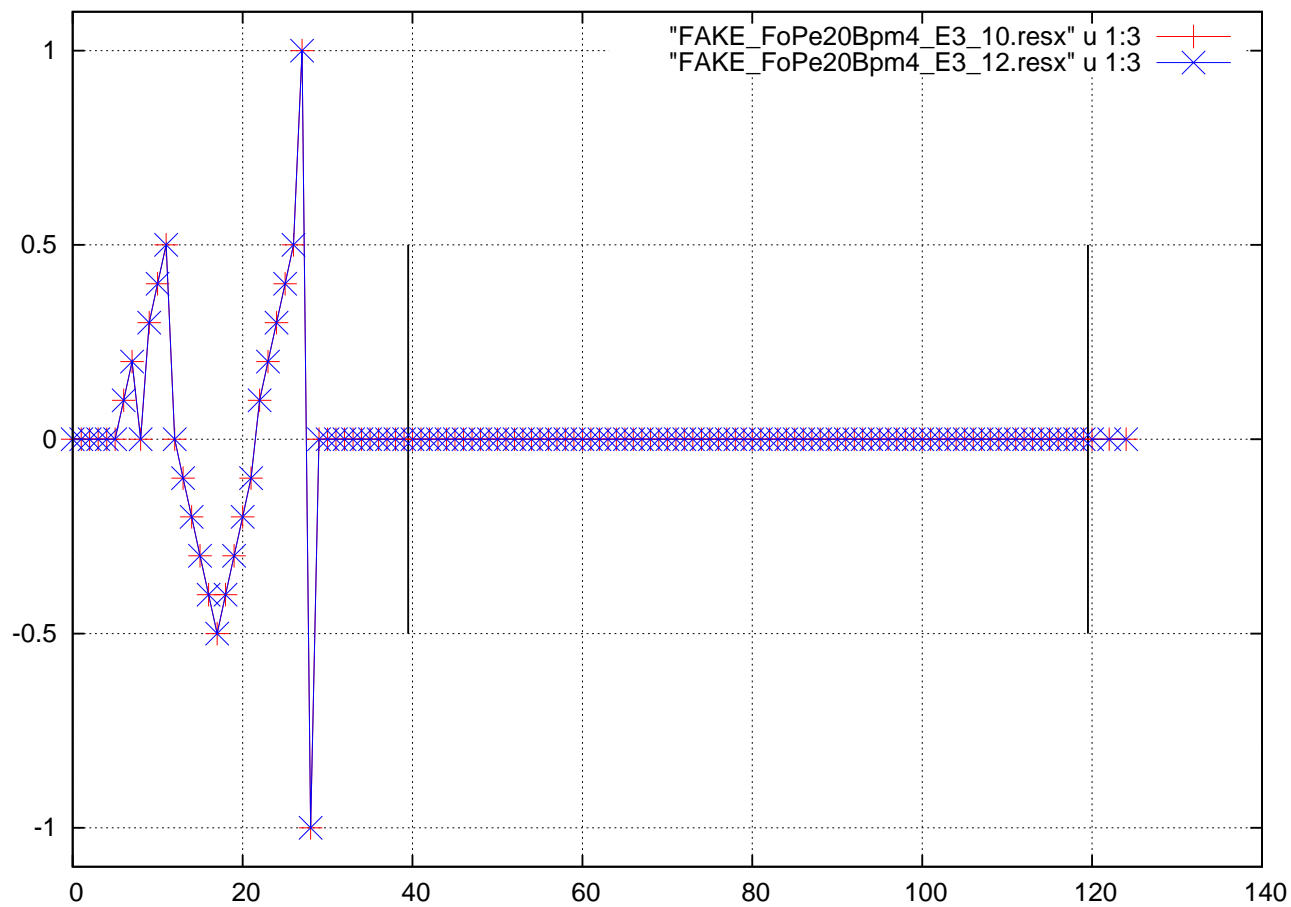
Remember: there's no noise in this simulation.



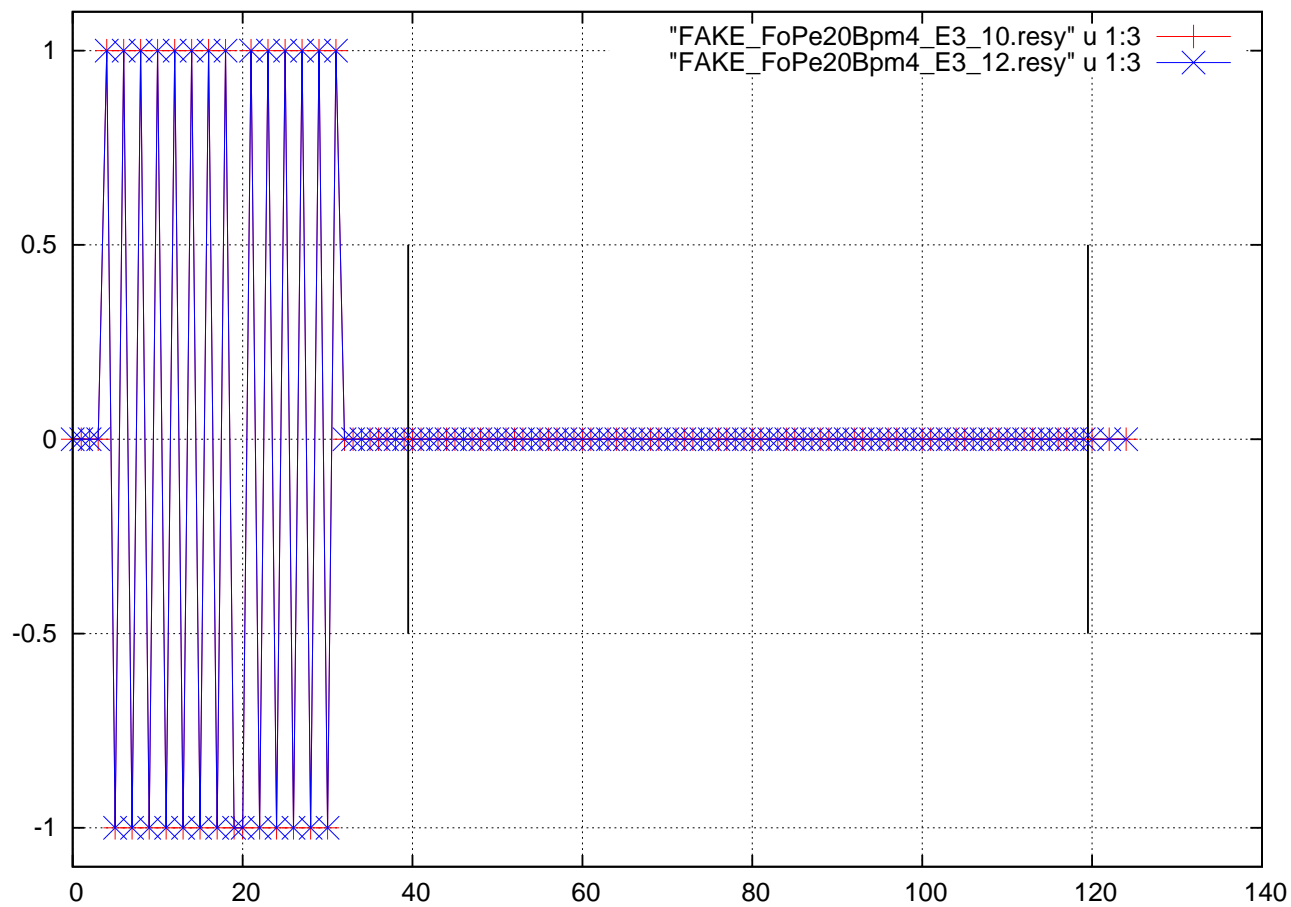
FODO: Reconstructed BPM Offsets (should be 0.D+0) → into the noise



FODO: Horizontal Input vs. Reconstructed Misalignments/Offsets/Launches



FODO: Vertical Input vs. Reconstructed Misalignments/Offsets/Launches



Summary

- First indications are that the modified LCLS approach can be applied (in some way) to FLASH
- But so far no fully convincing prove for a real improvement was found in FLASH:
 - 2013-01-09n : algorithm seemed to converge, but no “improved” transmission (quick-n-dirty!)
 - 2013-02-14n : slightly wrong optics model used, still better transmission ! → Hmmm...
- This is work in progress ; so much in progress that I have to apologize for the ugly slides!
- Maybe also try **sFLASH** & **FLASH2** ?!?!
- Long structures are beneficial → EU-XFEL