FLASH / FEL–BeamDynamics Seminar

Beam Based Alignment in the FLASH Undulators Using the LCLS Method

(a Preliminary Status Report)

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...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

DESY

FLASH
Free–Electron Laser
in Hamburg

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) $\vec{z} \equiv (x_0, x'_0)^{\mathrm{T}}_k$

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

– **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 :**
  $\vec{X} := (\vec{X}_1^{\mathrm{T}}, \cdots, \vec{X}_P^{\mathrm{T}})^{\mathrm{T}}$, $\vec{Y} := \ldots$, $\vec{z} := \ldots$, $\vec{\xi} := \ldots$
  $\underline{\mathcal{L}} := \underline{\mathrm{diag}}(\underline{\mathcal{L}}_1, \cdots, \underline{\mathcal{L}}_P) \in \mathbb{R}^{PM \times P2}$
  $\underline{\mathcal{O}} := (\underline{\mathcal{O}}_1^{\mathrm{T}}, \ldots, \underline{\mathcal{O}}_P^{\mathrm{T}})^{\mathrm{T}} \in \mathbb{R}^{PM \times N}$
  $\underline{\mathcal{U}} := (\underline{1}_1^{M \times M}, \cdots, \underline{1}_P^{M \times M})^{\mathrm{T}} \in \mathbb{R}^{PM \times M}$

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

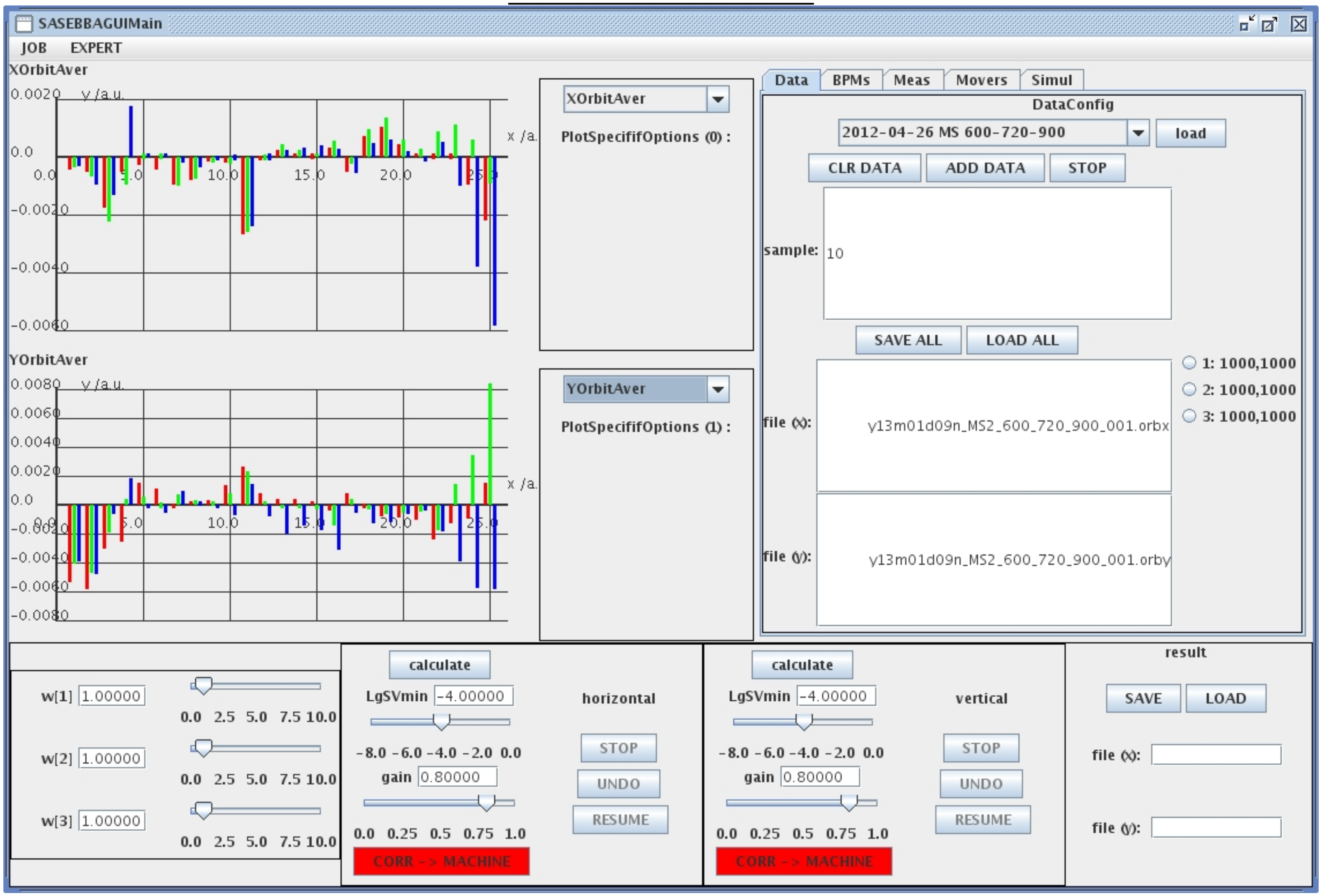
- **or:** $\boxed{\vec{Y} = \underline{\mathcal{A}}\, \vec{v} + \vec{\xi}}$ with $\underline{\mathcal{A}} := (\underline{\mathcal{L}}, \underline{\mathcal{O}}, \underline{\mathcal{U}})$ and $\vec{v} := (\vec{z}^{\mathrm{T}}, \vec{d}^{\mathrm{T}}, \vec{\Delta}^{\mathrm{T}})^{\mathrm{T}}$

- 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 $\{0 = \Delta_i - \Delta_i^{\mathrm{ref}}\}_{i=1,\ldots,M}$
  - or $\{0 = d_i - d_i^{\mathrm{ref}}\}_{i=1,\ldots,N}$

$\rightarrow$ $PM+$ “x” **constraints for $2P + N + M$ variables**

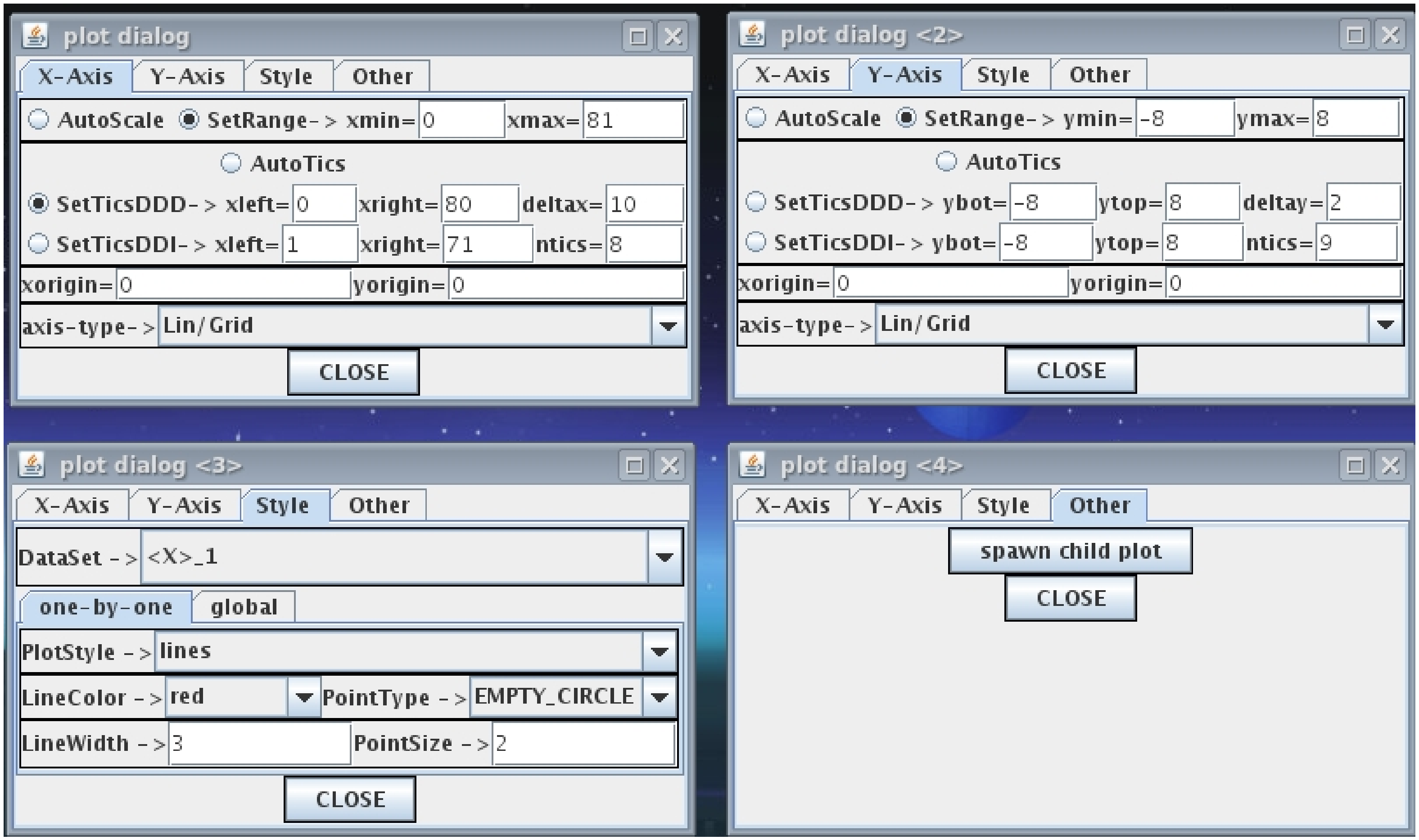
$\leftarrow$ **. . . each constraint can be given it’s own weight !**

SASEBBAGUIMain



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 →

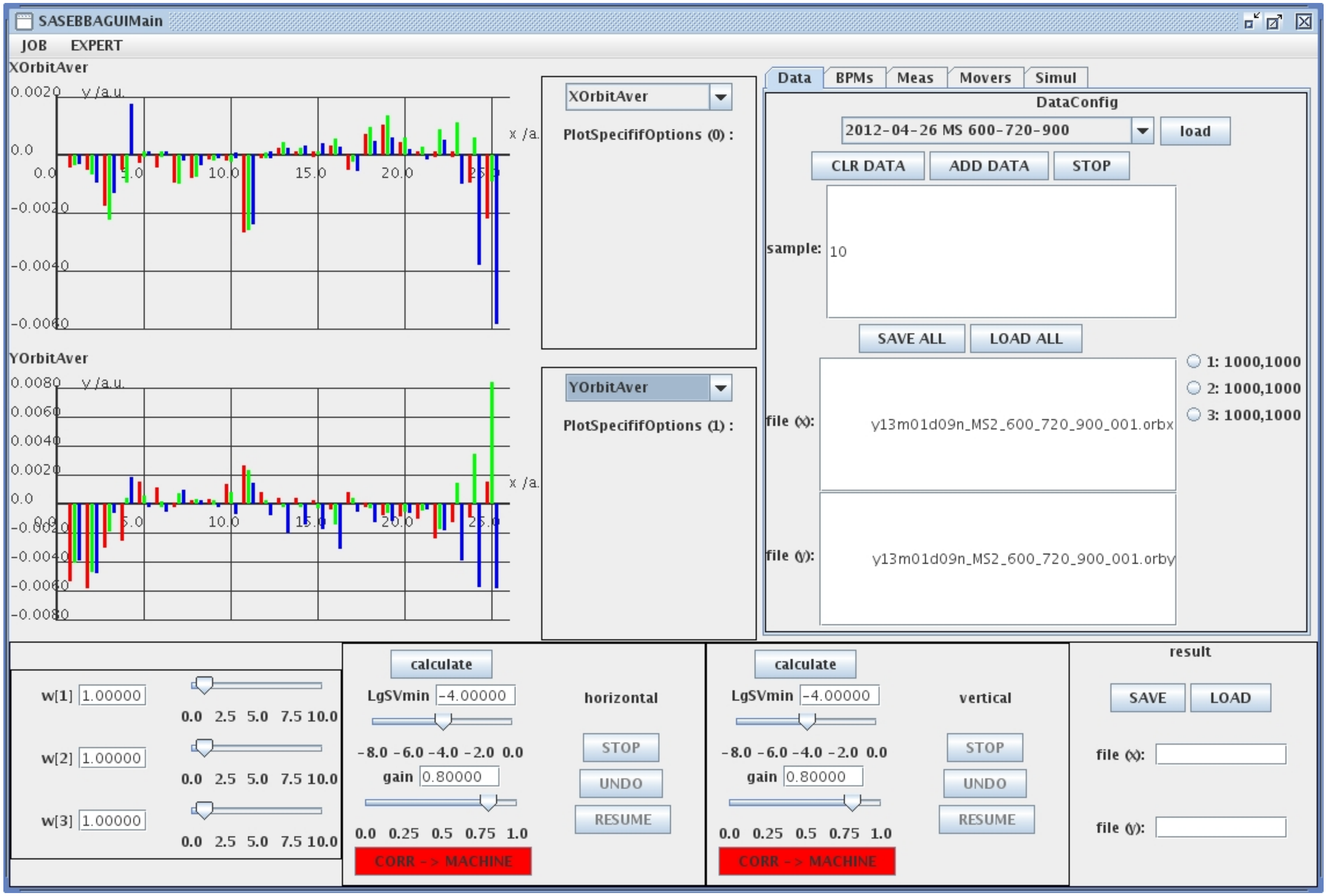
  → saved (2x) 3 undulator BBA data sets (100,1000 shots) for (600,720,900) MeV / AFTER CORRECTION (Jin Hyunchang)

  → for all three energies one establish a launch with decent losses in relatively little time !!!!!

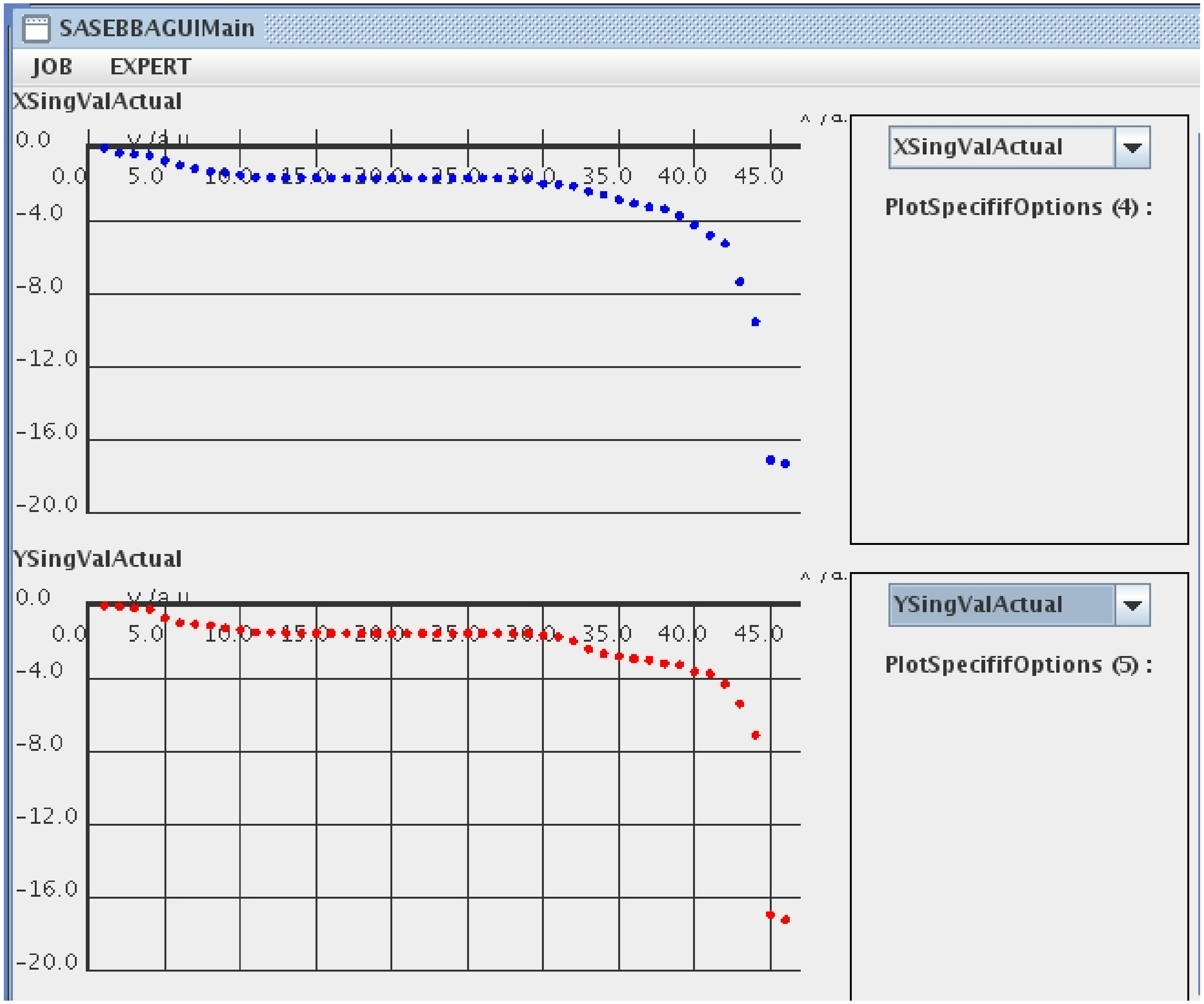
  → This strongly suggests that the correction computed by Jin does really straighten the beam !!!!!

  → Offline analysis will follow.

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

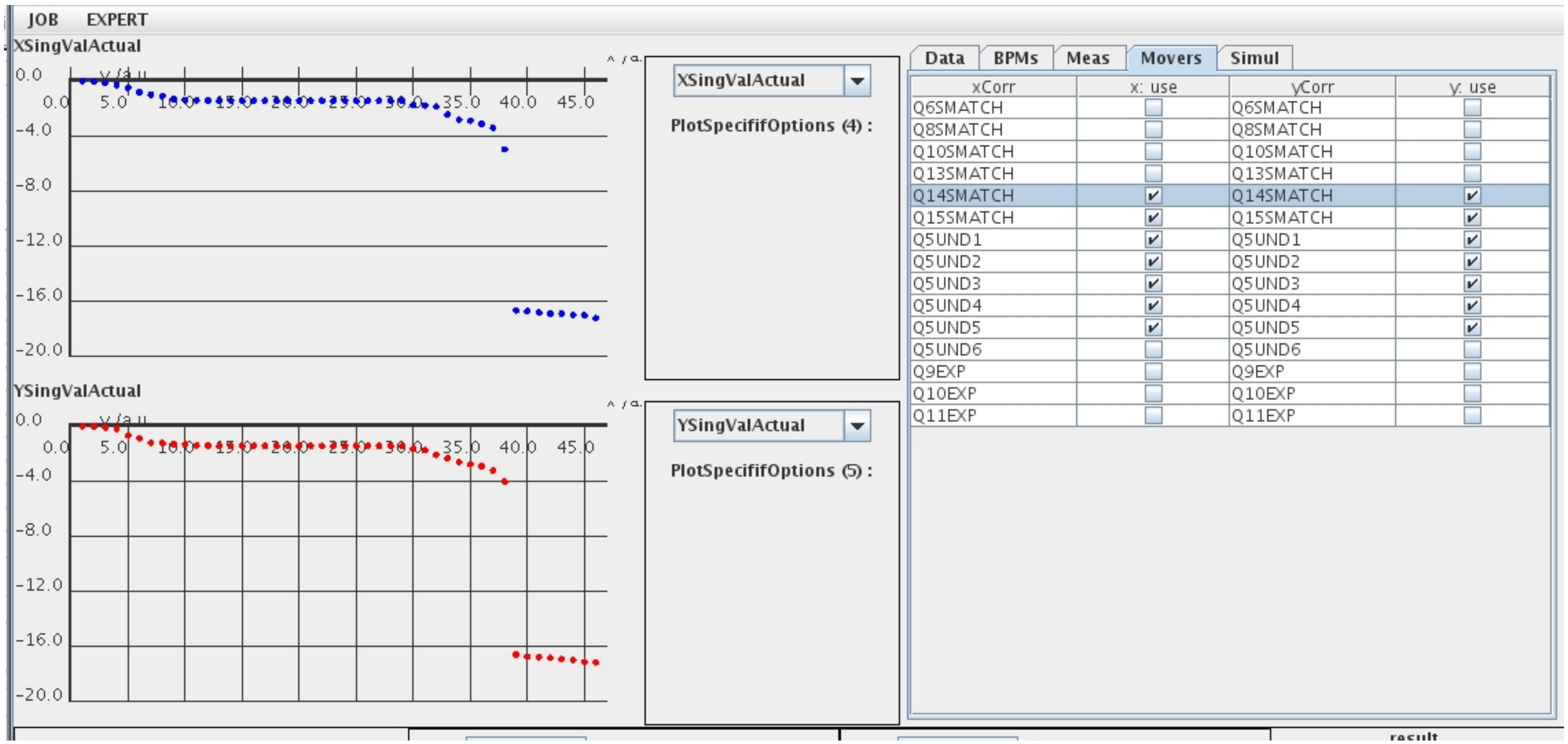


2013-01-09-n / 1-st set / "Plain" Singular Values



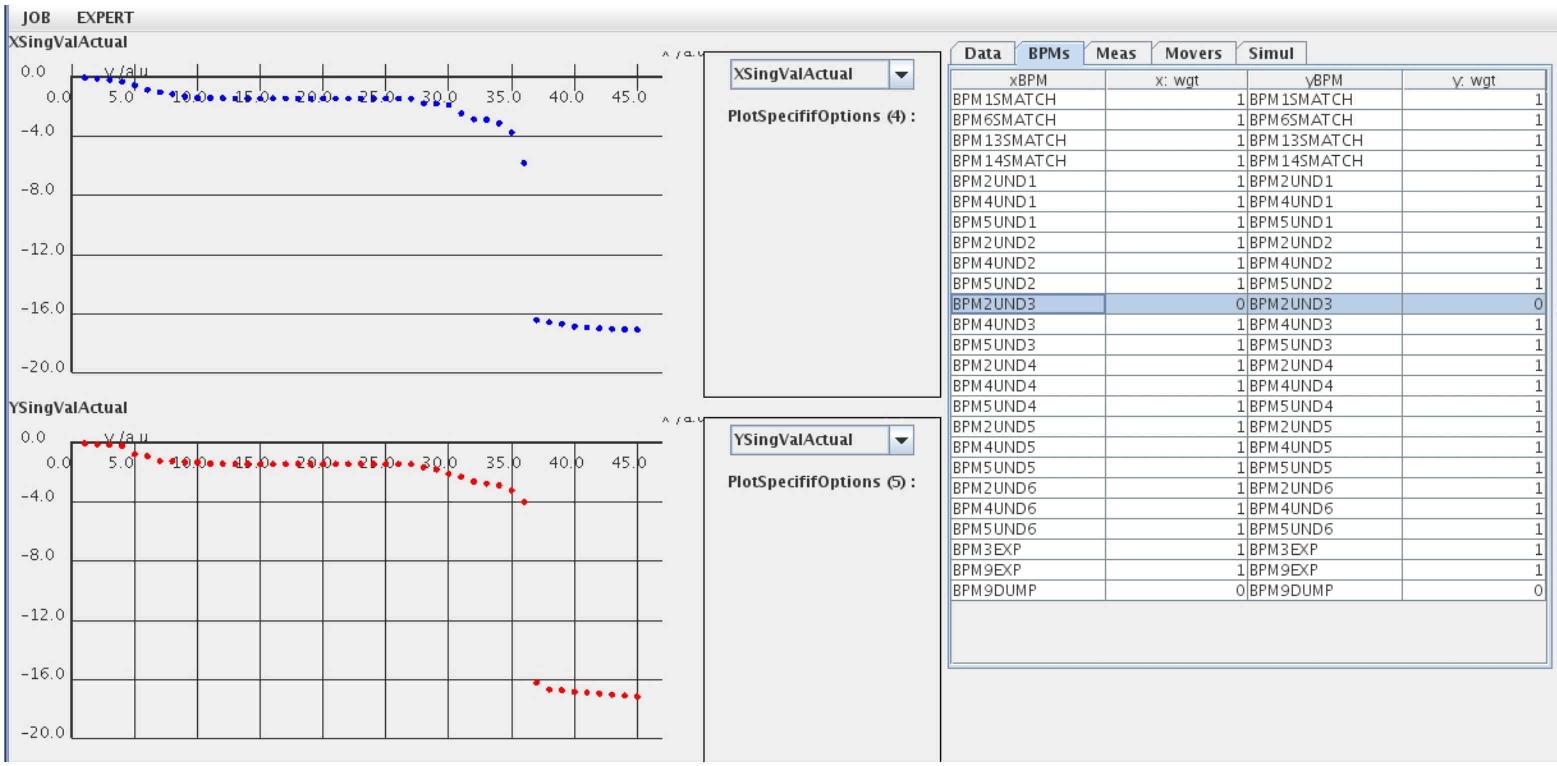
2013-01-09-n / 1-st set / SingVal's after restricting the Movers

- 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!)

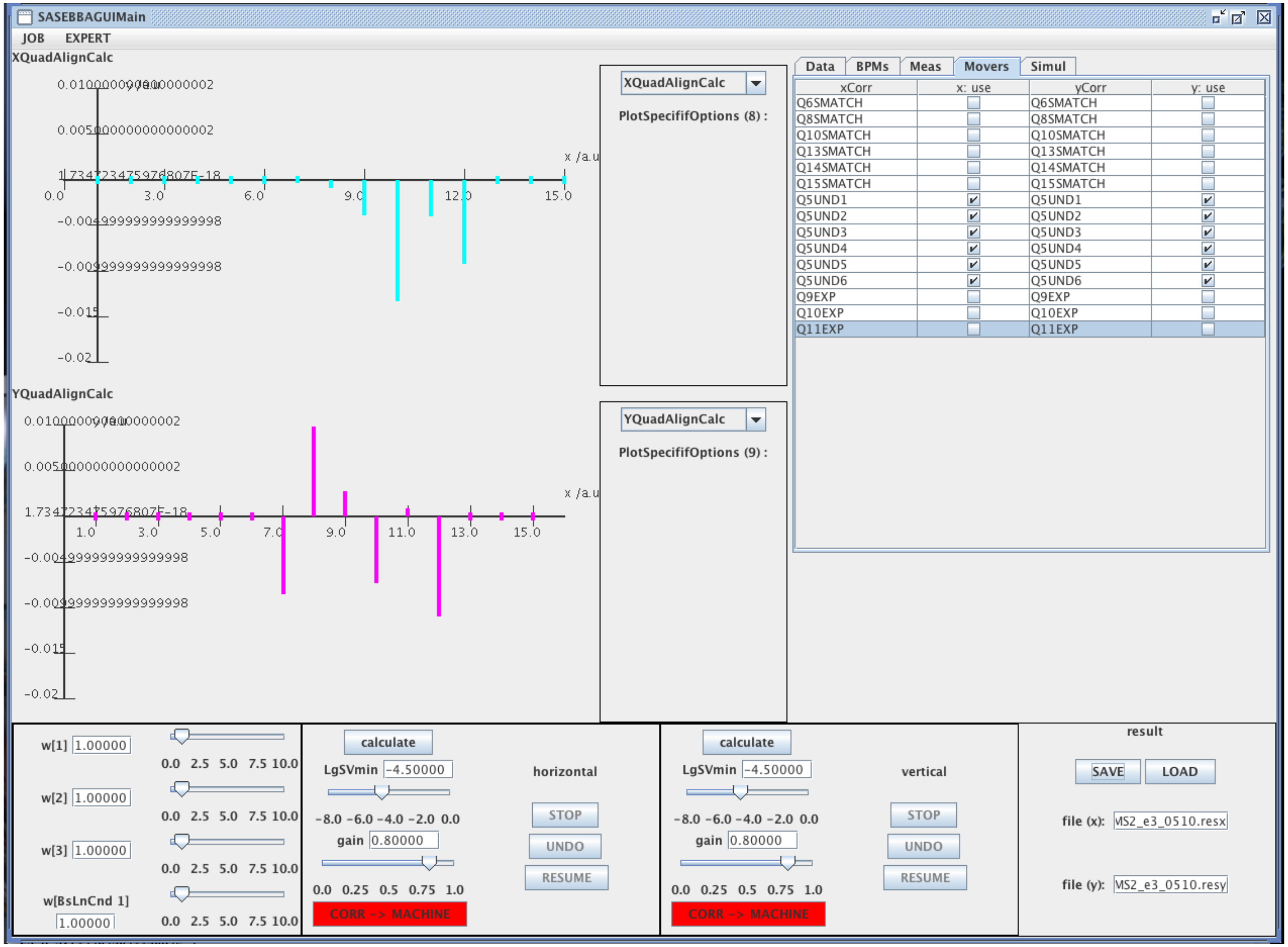
- In principle: all BPM2UNDx & BPM4UNDx could be given lower weights
- also BPM9DUMP ← beam sweeper!



xBPM	x: wgt	yBPM	y: wgt
BPM1SMATCH	1	BPM1SMATCH	1
BPM6SMATCH	1	BPM6SMATCH	1
BPM13SMATCH	1	BPM13SMATCH	1
BPM14SMATCH	1	BPM14SMATCH	1
BPM2UND1	1	BPM2UND1	1
BPM4UND1	1	BPM4UND1	1
BPM5UND1	1	BPM5UND1	1
BPM2UND2	1	BPM2UND2	1
BPM4UND2	1	BPM4UND2	1
BPM5UND2	1	BPM5UND2	1
BPM2UND3	0	BPM2UND3	0
BPM4UND3	1	BPM4UND3	1
BPM5UND3	1	BPM5UND3	1
BPM2UND4	1	BPM2UND4	1
BPM4UND4	1	BPM4UND4	1
BPM5UND4	1	BPM5UND4	1
BPM2UND5	1	BPM2UND5	1
BPM4UND5	1	BPM4UND5	1
BPM5UND5	1	BPM5UND5	1
BPM2UND6	1	BPM2UND6	1
BPM4UND6	1	BPM4UND6	1
BPM5UND6	1	BPM5UND6	1
BPM3EXP	1	BPM3EXP	1
BPM9EXP	1	BPM9EXP	1
BPM9DUMP	0	BPM9DUMP	0

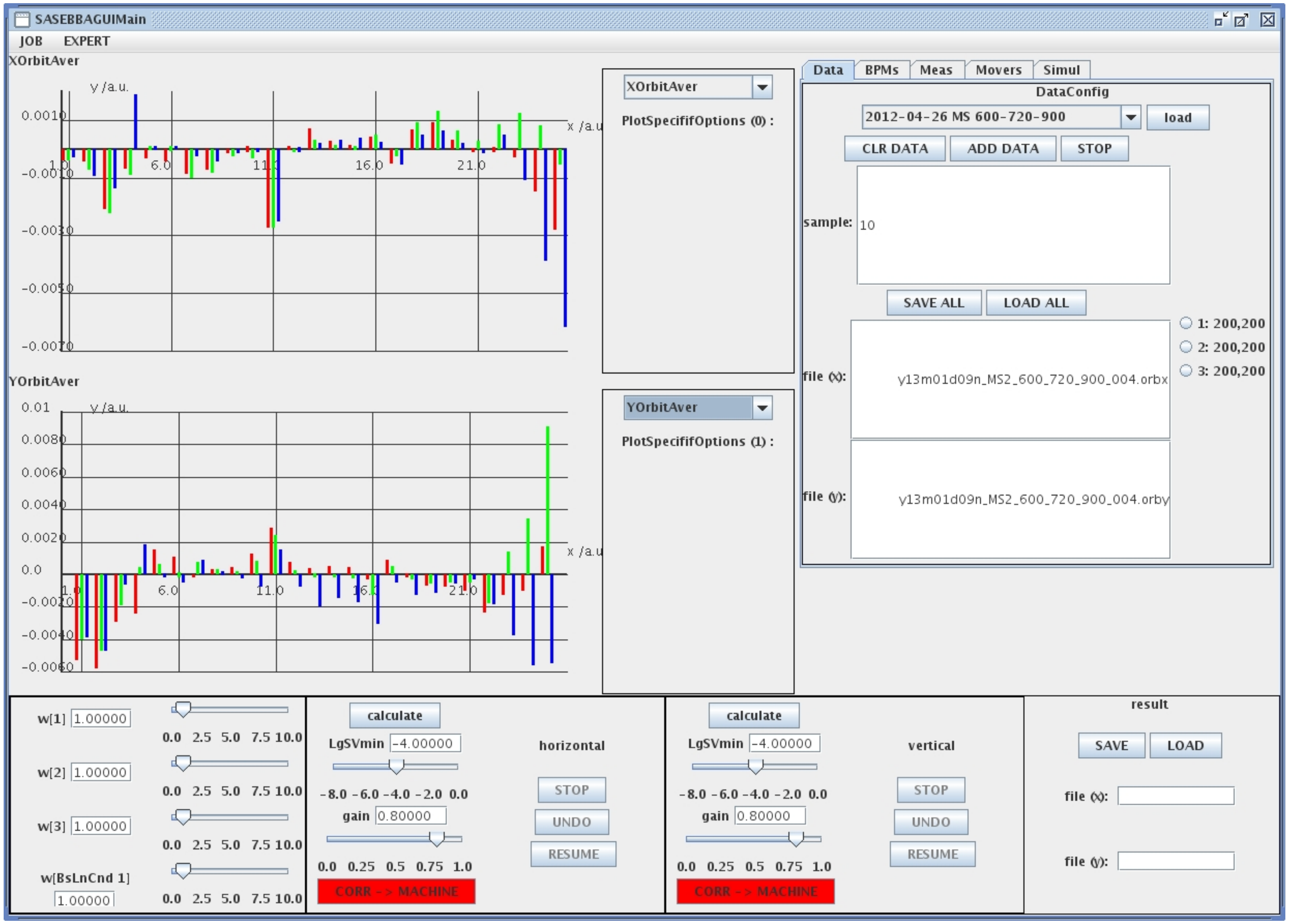
2013-01-09-n / 1-st set / Computed Quad–Alignment → e–log

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



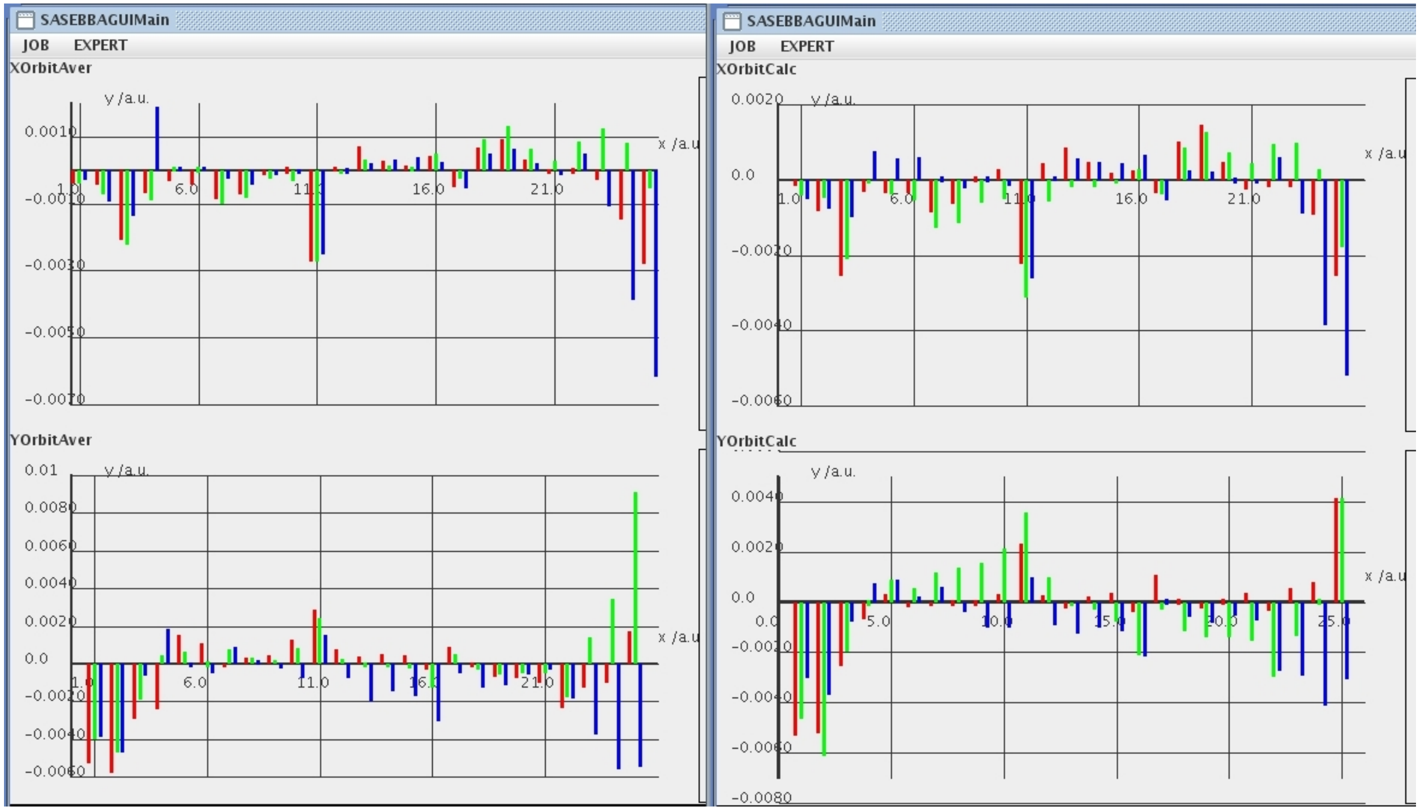
2013-01-09-n / 2-nd set / After applying corrections (scaled!)

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

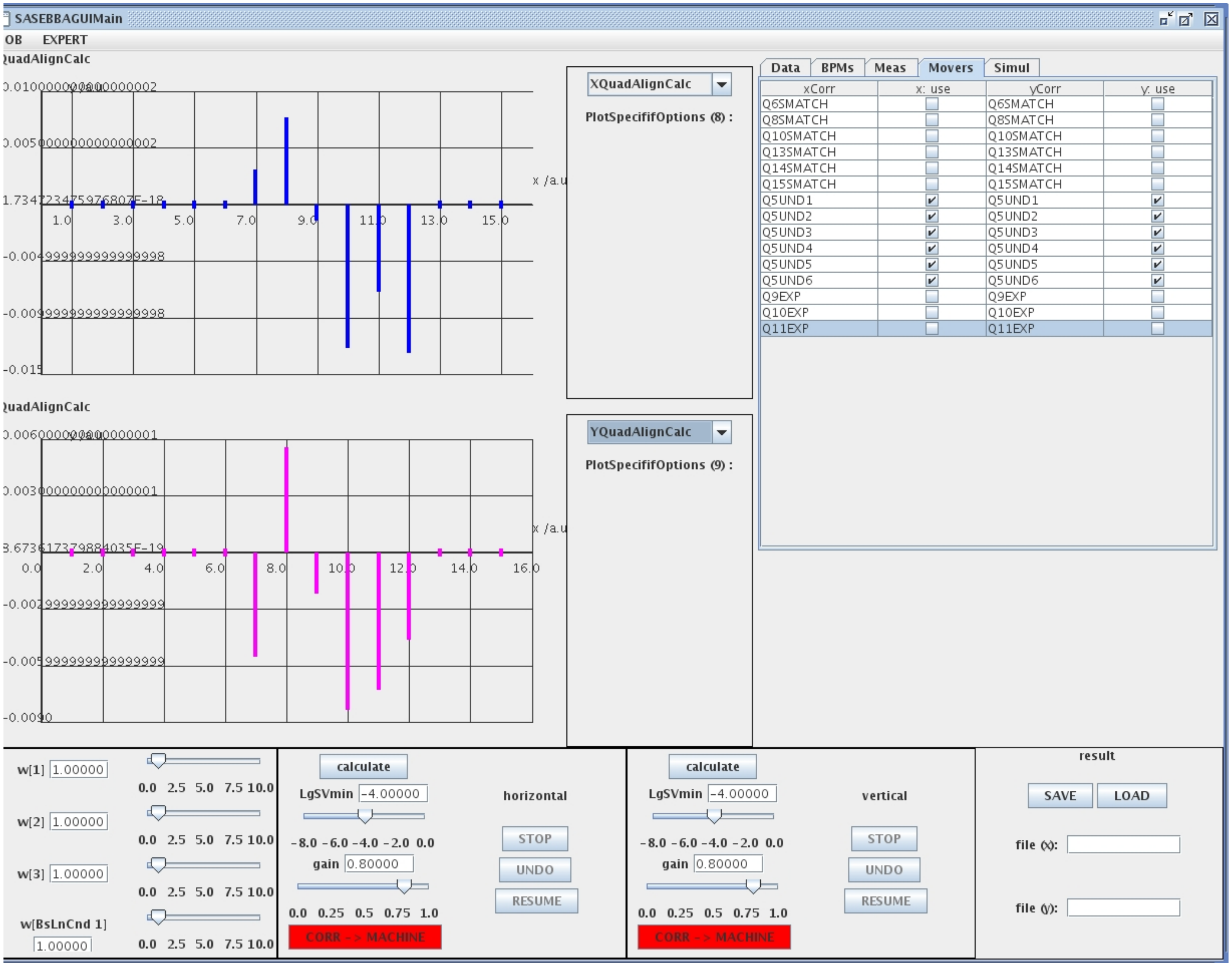


2013-01-09-n / 2-nd set / Comparison: Measured (L) vs. Predicted (R) Orbit

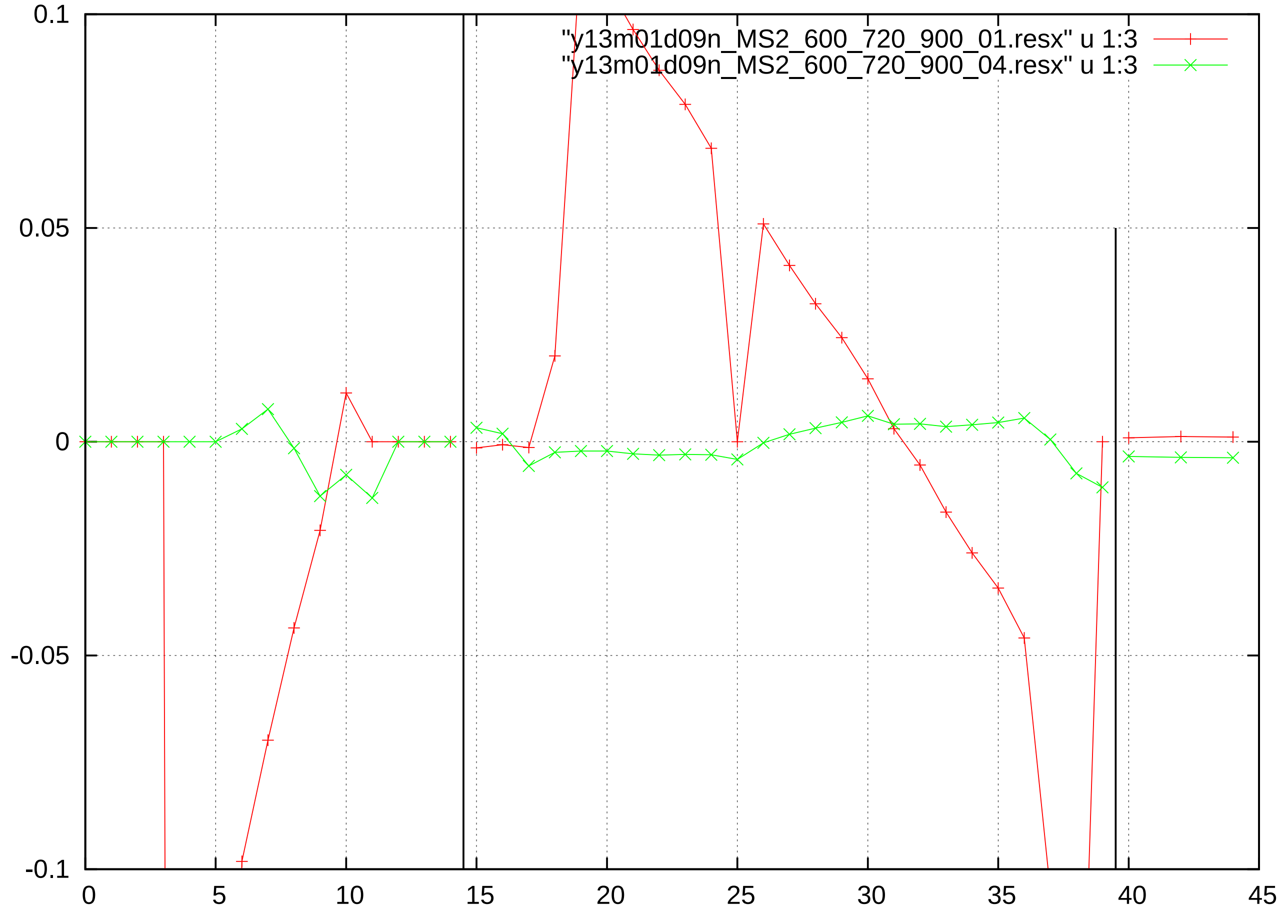
$\vec{v}_{\text{calculated}} = \underline{\widetilde{\mathcal{A}}}_{\tau,\vec{w},\dots}\ \vec{Y}_{\text{measured}}$ $\qquad$ $\vec{Y}_{\text{predicted}} = \underline{\mathcal{A}}\ \vec{v}_{\text{calculated}}$



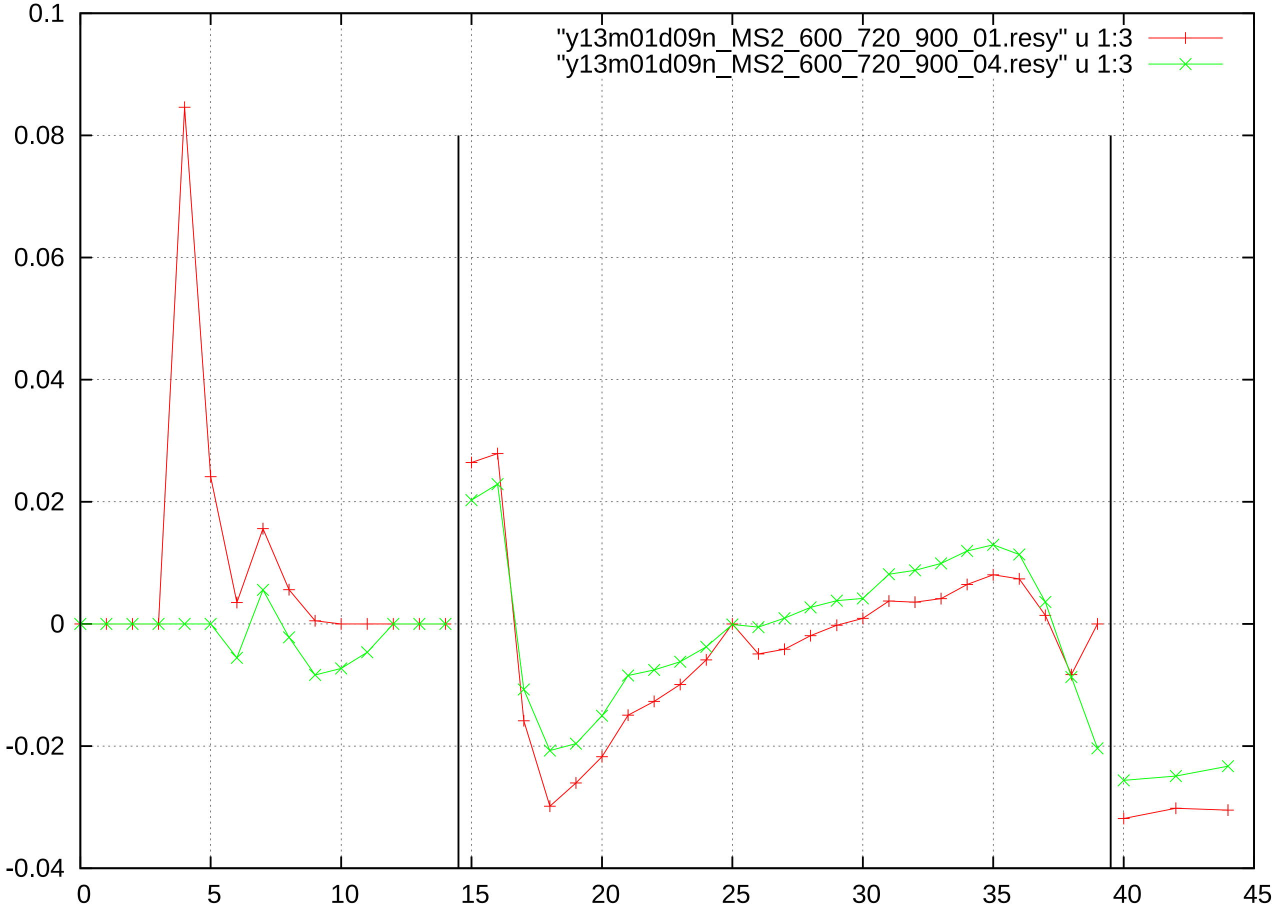
2013-01-09-n / 2-nd set / Calculated Quad Misalignments



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

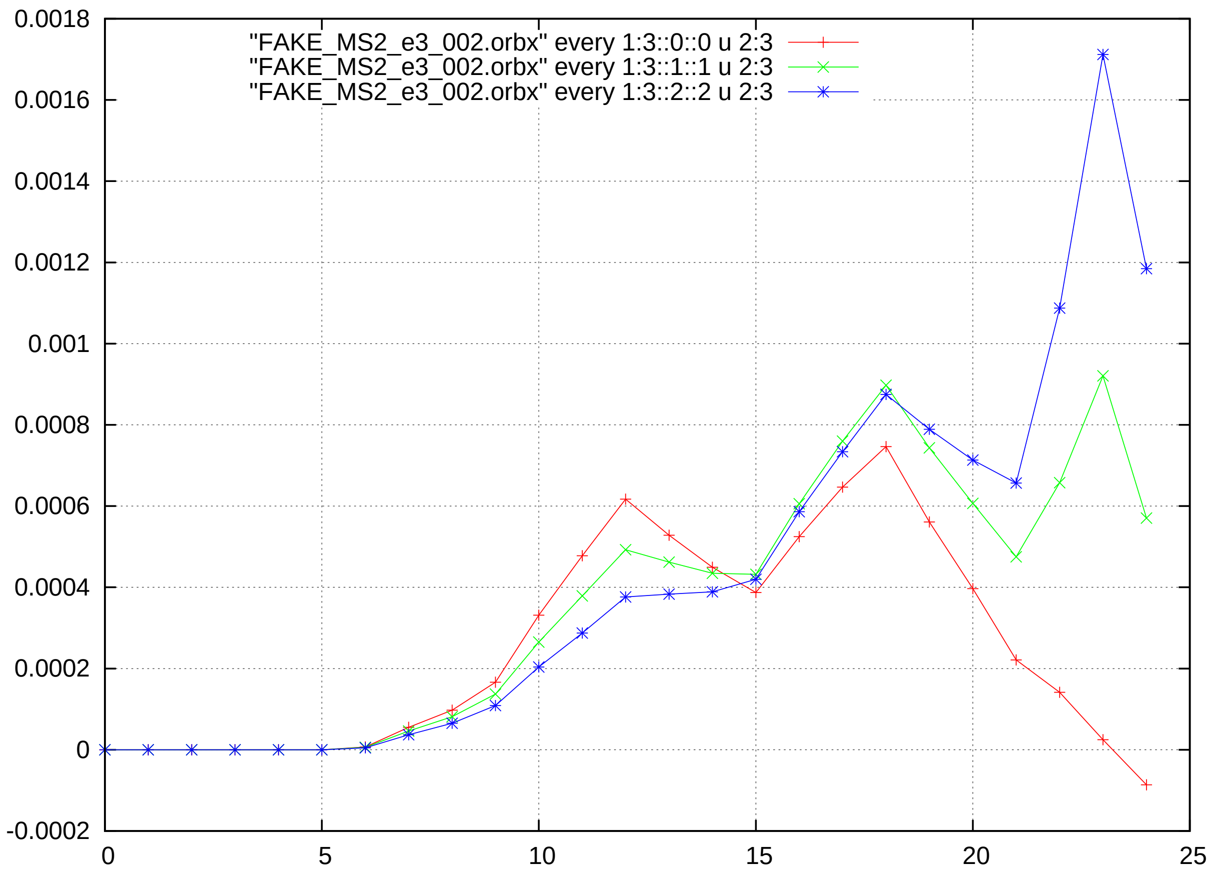


2013-01-09-n / 2-nd set / A hint of Vertical Convergence ?



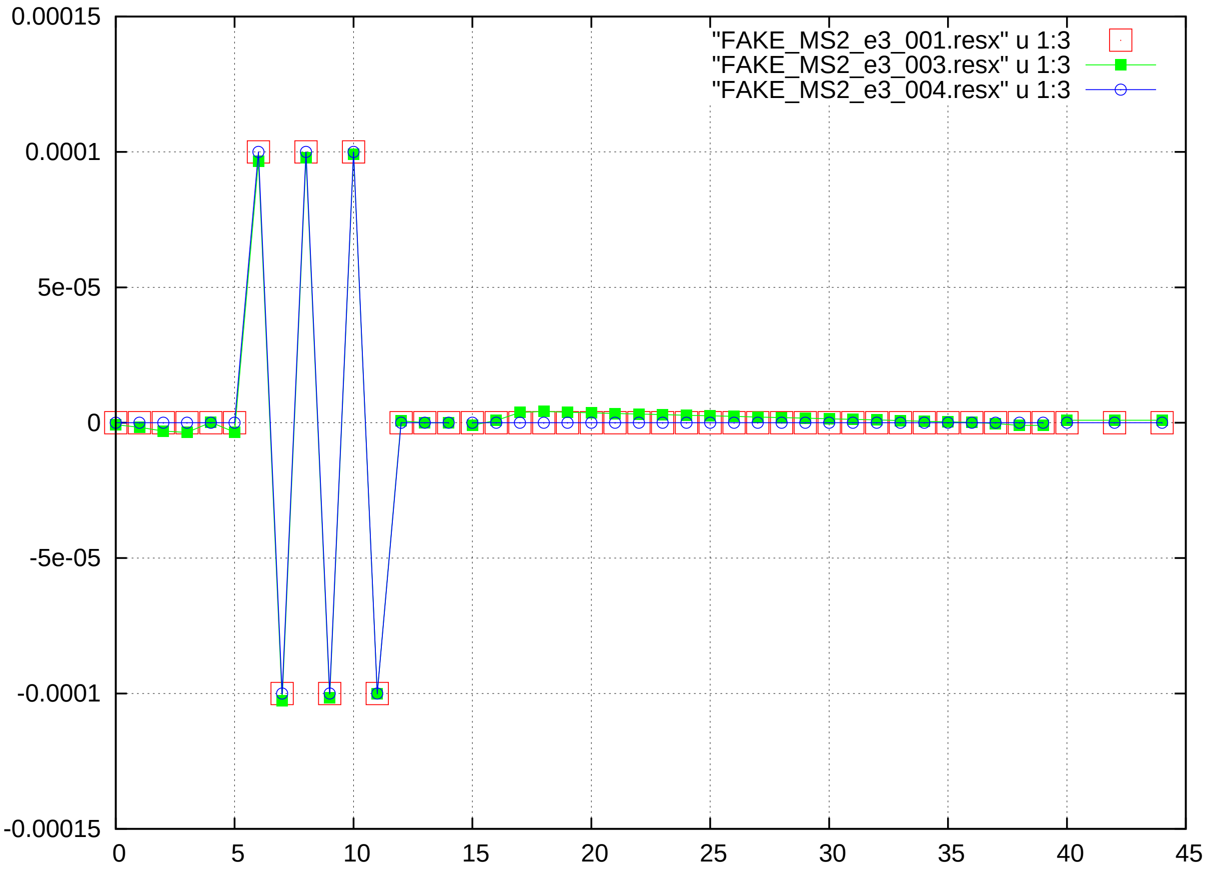
Example: FAKED Quad–Misal.'s → Calc. X–Orbit → Reproduced Quad-Misal.'s ?

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

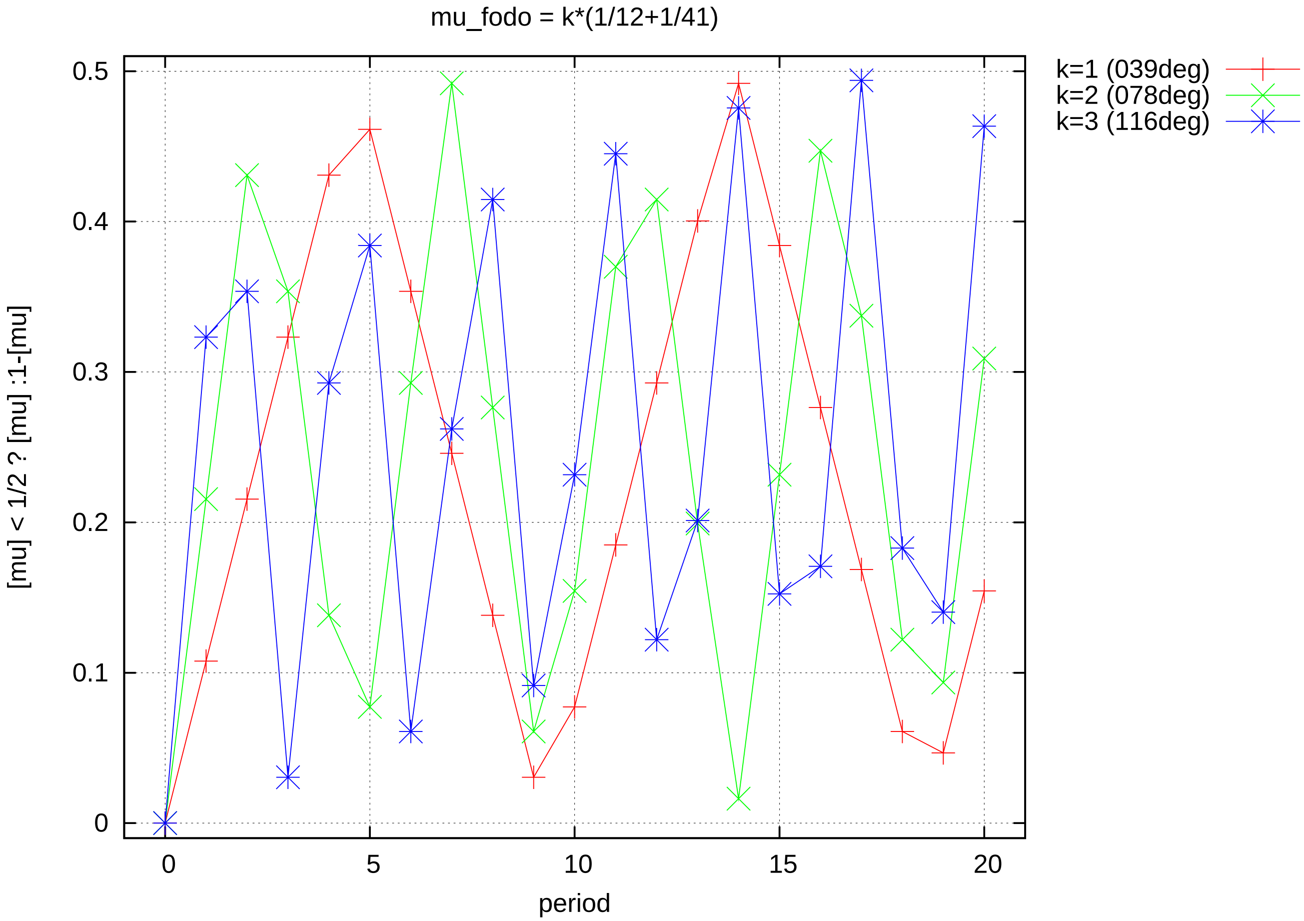


Example: FAKED Quad–Misal.'s → Calc. Orbit → Reproduced Quad-Misal.'s ?

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

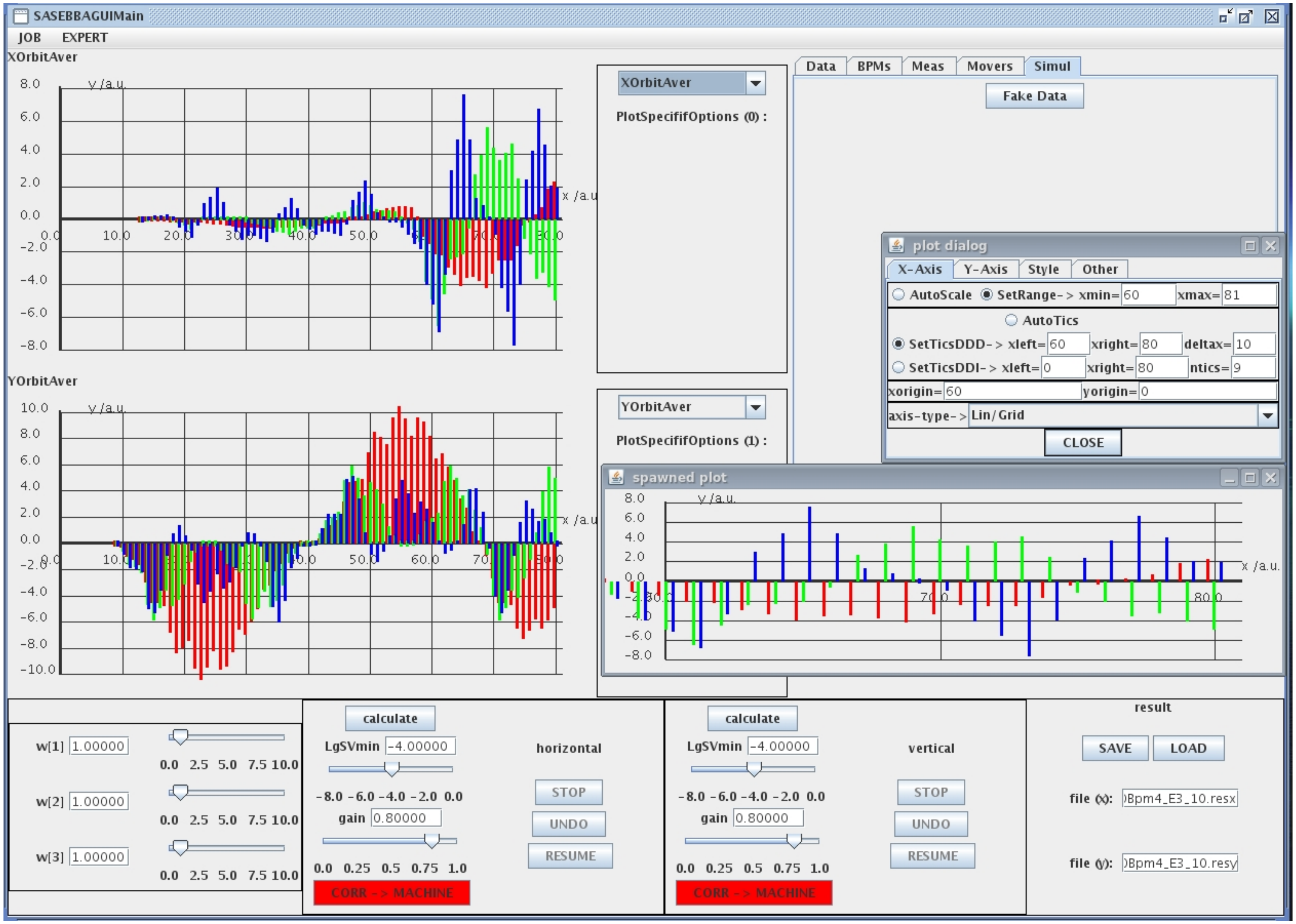


MODEL: Long (20xPer) FODO Section w/ "non–degenerate" Phase Advance



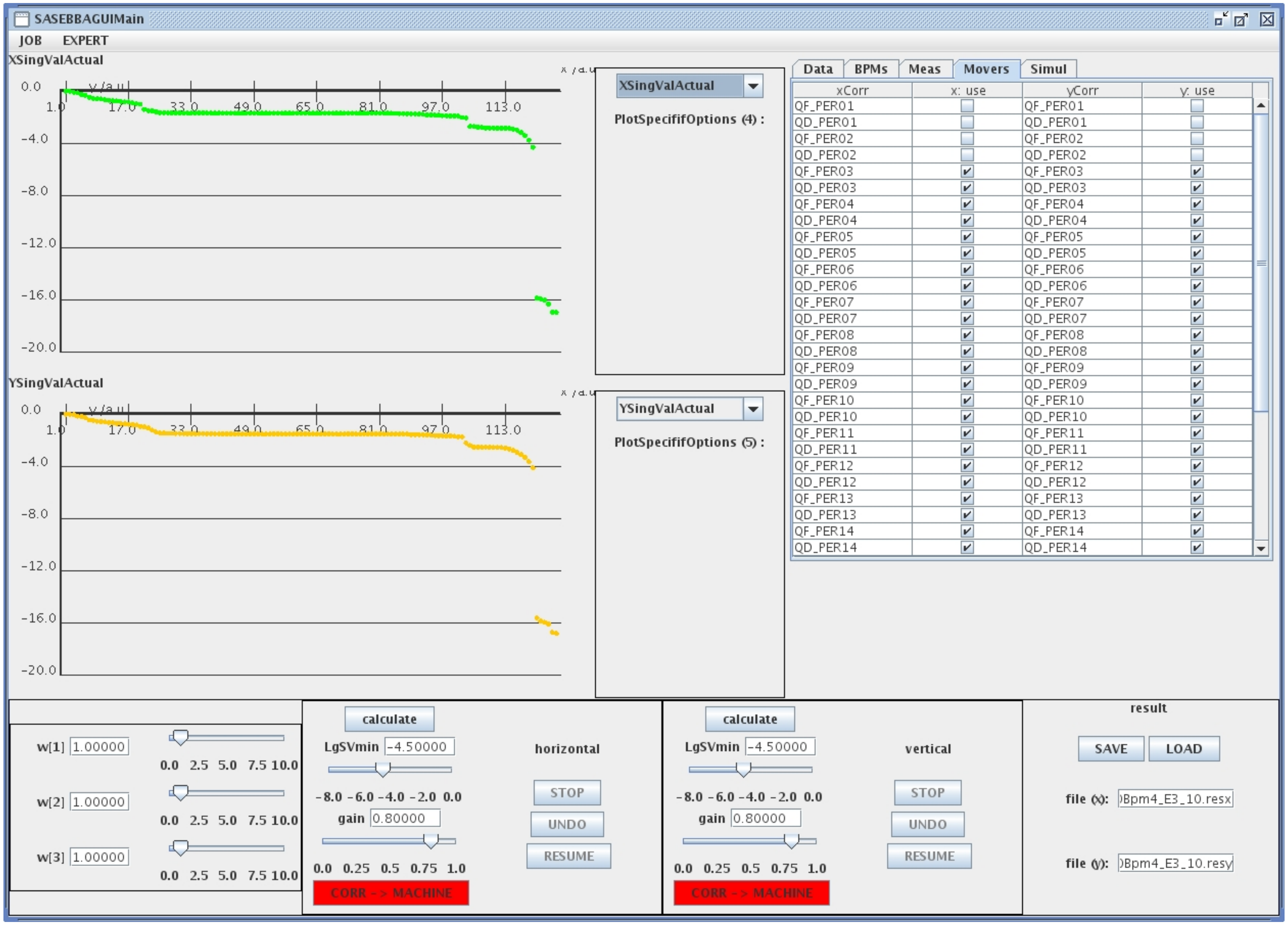
FODO: "Faked" Orbit (w/o errors!) from Assumed Misalignments

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



FODO: SingVal's after Movers have been Adjusted

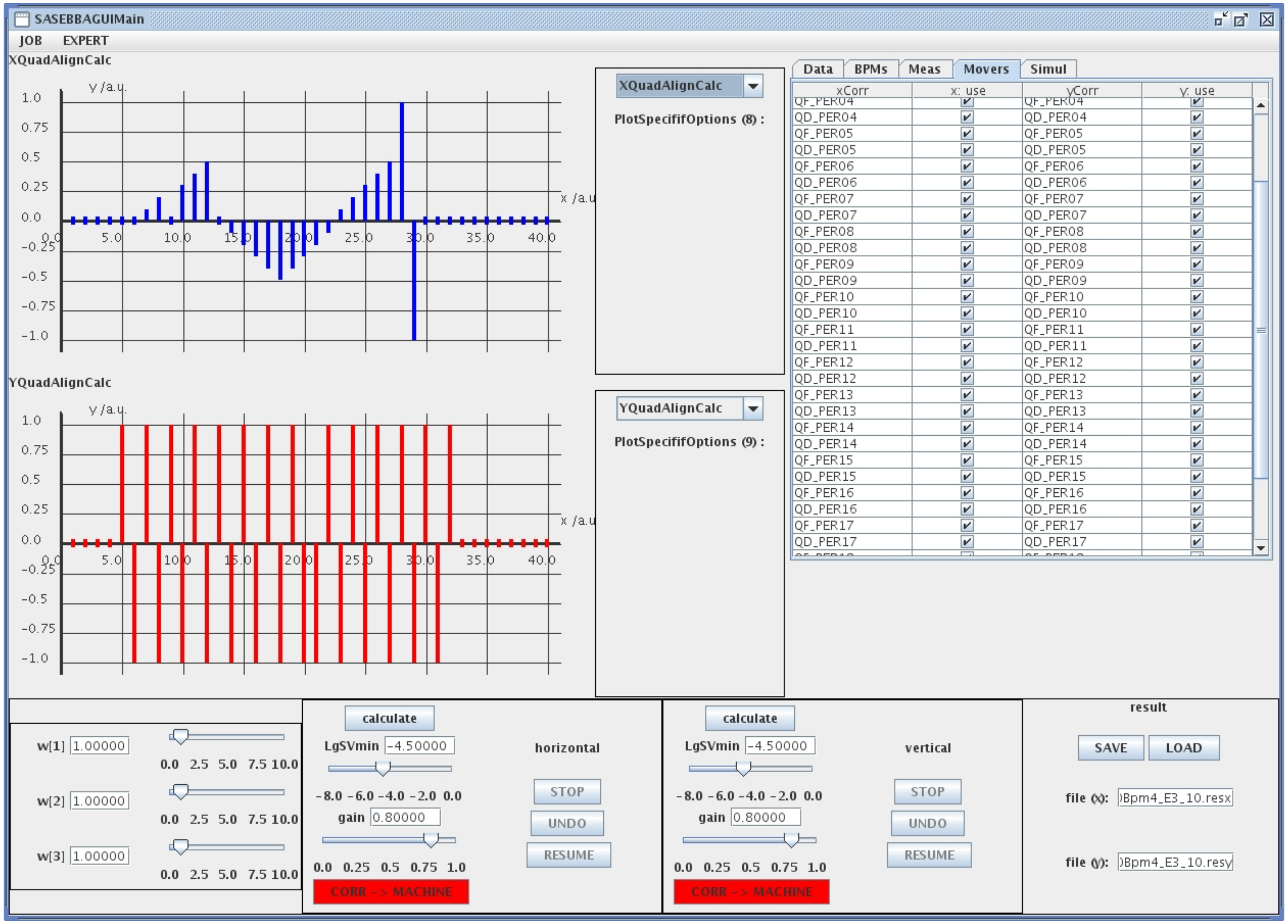
$\Rightarrow$ τ (SVD cut–off) should not be above $10^{-4.5}$



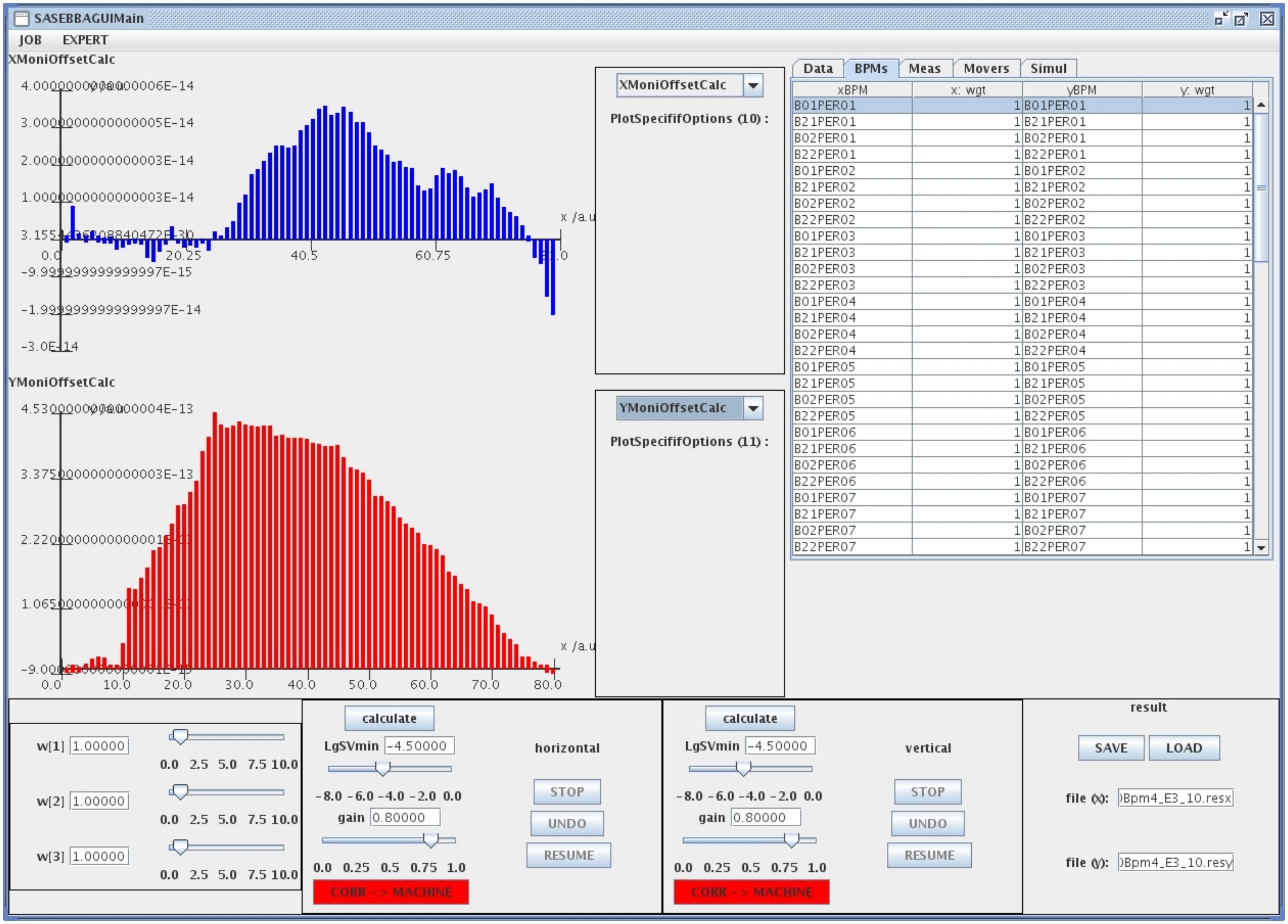
FODO: Reconstructed Quad Misalignments

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

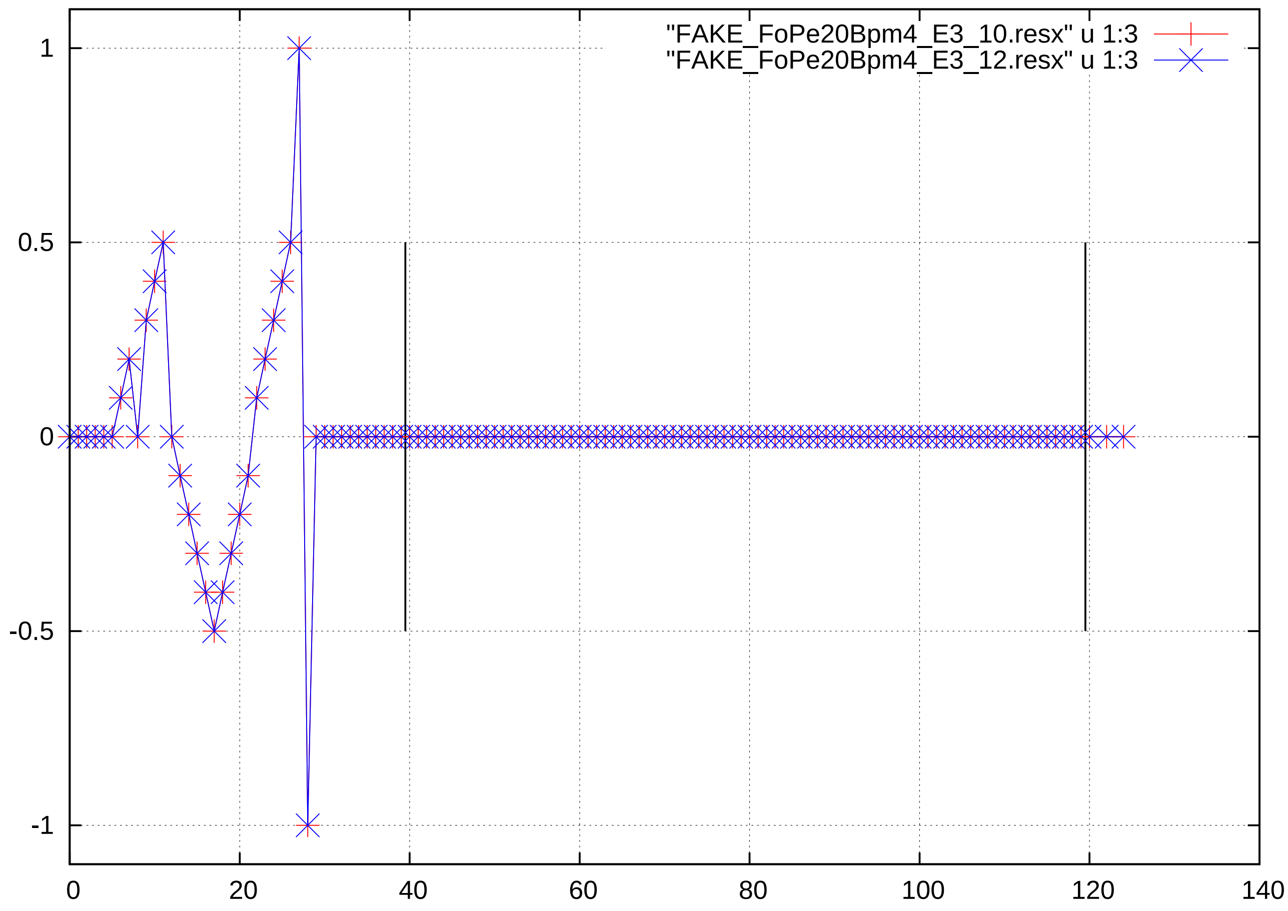
Remember: there's no noise in this simulation.



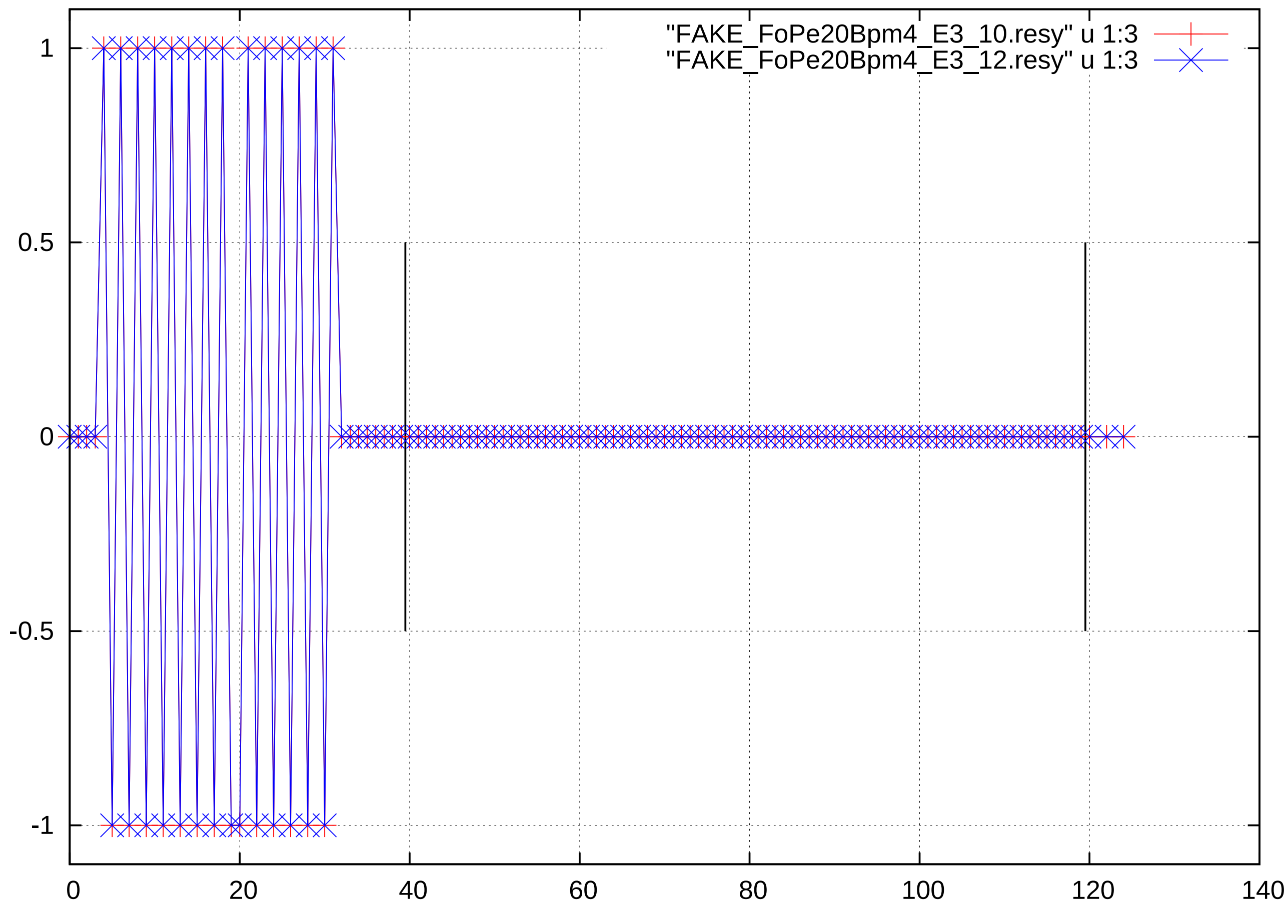
FODO: Reconstructed BPM Offsets (should be `0.D+0`) → into the noise



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