Orthogonality of beam waist corrections in the presence of IPBSM fringe tilt and residual <xy> correlation at the IP

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Motivation

- A tilt in the interference fringes or, equivalently, a finite σ_{13} correlation, increases the measured vertical beam size due to coupling from the horizontal dimension:

$$\sigma_{\overset{\square}{y}}{}^{2} = \sigma_{y}{}^{2} + \sigma_{x}{}^{2} \sin^{2}\theta$$

- The presence of a tilt of the IP Shintake monitor fringe pattern with respect to the x-y coordinate system of the beam and the residual beam σ_{42} σ_{31} can break the orthogonality in the main σ_{34} and σ_{32} waist corrections required to reduce the vertical beam size at IP, which are the main first order optical adjustments to reduce the vertical beam size at the IP in the presence of imperfections.
- Analytical and simulation study of this effect are done.

Outline

- Analytical treatment of the waist correction in case of the Shintake monitor interference fringes rotated and input beam σ_{13},σ_{24}
- Simulation study of the waist correction in the presence of the IPBSM tilt and input beam σ_{13},σ_{24}
- Investigation of influence on the horizontal waist correction in the presence of the fringe tilt and input beam σ_{13},σ_{24}; Reliability check in the presence of other imperfections
- Proposed experimental method for diagnosis
- Conclusions

Analysis of waist correction

- Correction of non-zero σ_{34} and σ_{32} correlations is achieved using pre-calculated orthogonal combinations of sextupole movements in the horizontal and vertical directions, respectively. As a function of such correctors, labeled K and S, the combined effect of the two lenses on the beam is:

$$\sigma_{out} = R\sigma_{in}R^t \qquad \text{with } R= \begin{pmatrix} -K & 1 & -S & 0 \\ -1 & 0 & 0 & 0 \\ -S & 0 & K & 1 \\ 0 & 0 & -1 & 0 \end{pmatrix} \qquad (1)$$

where $\sigma_{in,out}$ are the beam matrices describing the four-dimensional phase-space at the waist and in the lenses.

- From (1), the beam size at the waist can be shown in the thin lens approximation that the vertical beam size at the IP can be written:

$$\sigma_{33}(K,S)=\sigma_{33}(0,0)+K^2\sigma_{44}+S^2\sigma_{22}-2K\sigma_{34}-2S\sigma_{32}+2KS\sigma_{42} \qquad (2)$$

Analysis with rotation matrix

- The corrections for the residual σ_{34} and σ_{32} correlations at the IP are then also no longer orthogonal. This can be seen introducing an additional coordinate rotation M in the calculation of (1).

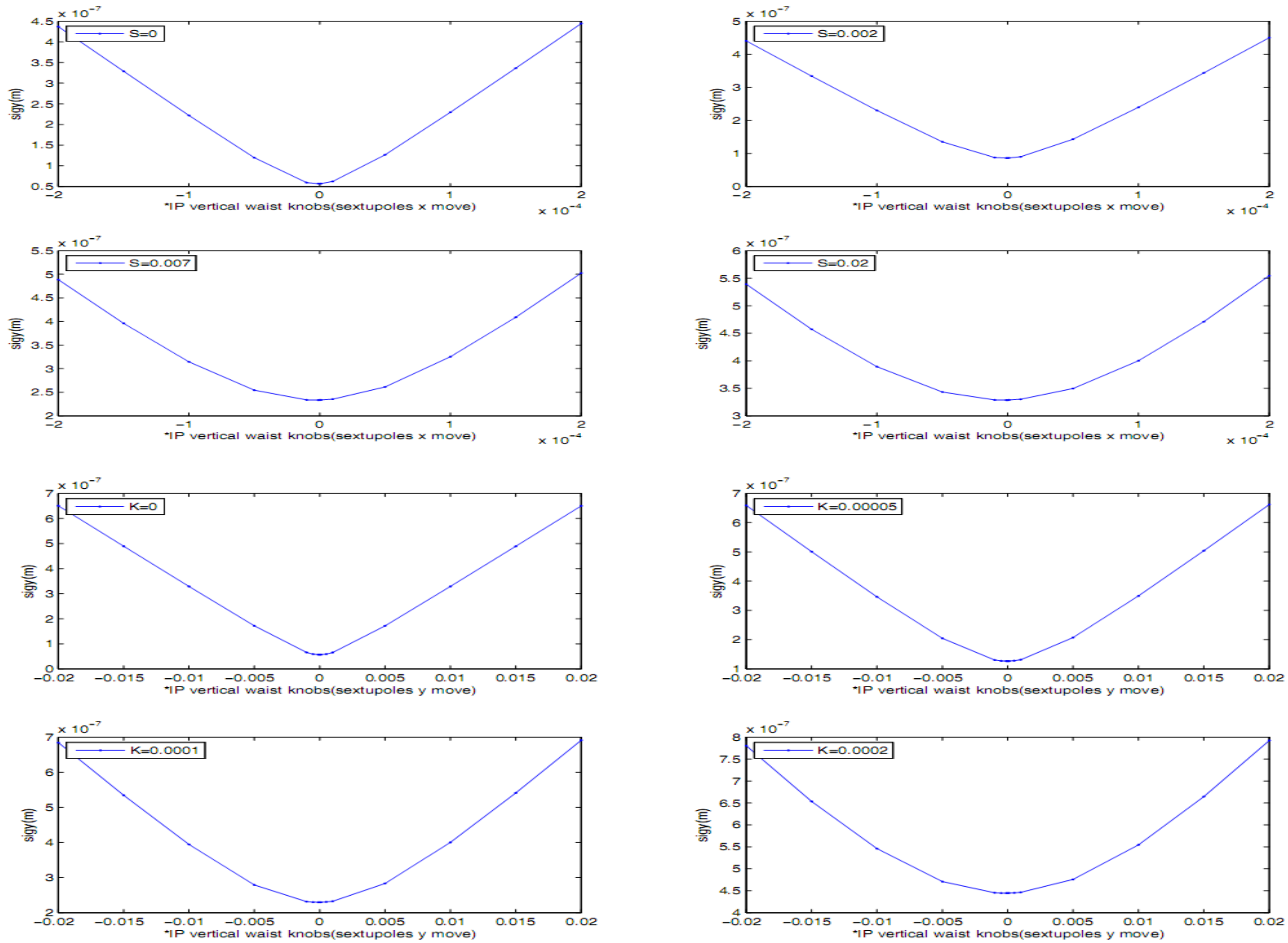
$$M = \begin{pmatrix} \cos\theta & 0 & \sin\theta & 0 \\ 0 & \cos\theta & 0 & \sin\theta \\ -\sin\theta & 0 & \cos\theta & 0 \\ 0 & -\sin\theta & 0 & \cos\theta \end{pmatrix} \quad (3)$$

- Assuming a negligible σ_{42} residual correlation at the IP:

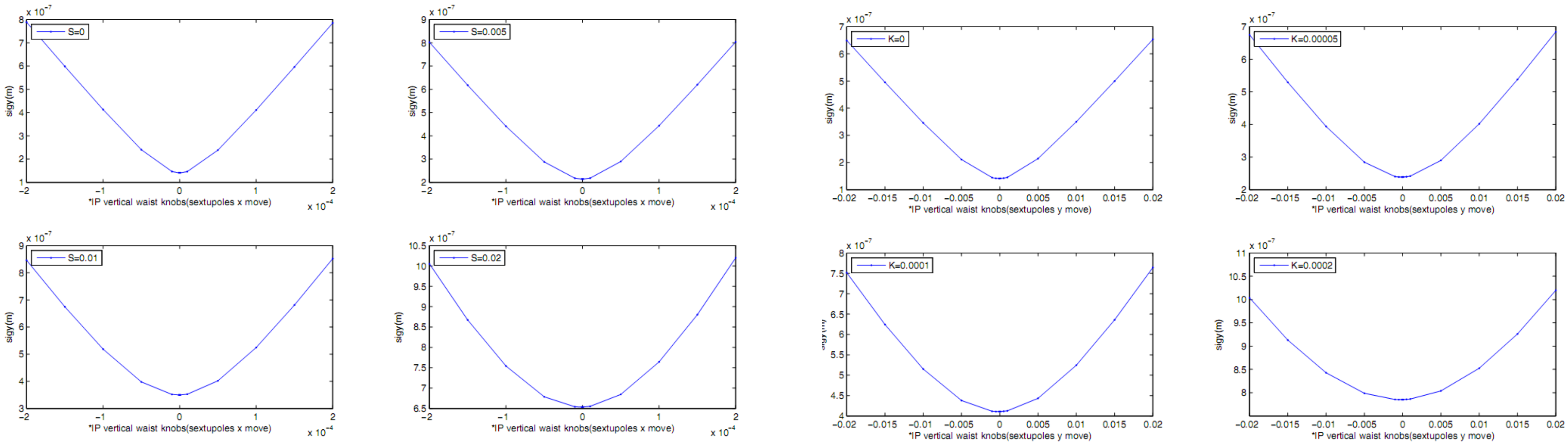
$$\begin{aligned} \sigma_{33}(K,S) = {} & \sigma_{33}(0,0) + K^2\sigma_{44} + S^2\sigma_{22} - 2K\sigma_{34} - 2S\sigma_{32} \\ & + \theta^2 [\, \sigma_{11}\,(S=0) + S^2\sigma_{44} - 2S\sigma_{14} \,] \qquad (4) \\ & -2\theta\, [\, \sigma_{13} + K\,(\sigma_{14} - \sigma_{23}) - S\,(\sigma_{21} + \sigma_{43}) + SK\,(\sigma_{22} - \sigma_{44}) \,] \end{aligned}$$

where, due to the mixed term in (4), the K and S correctors are no longer orthogonal.

Influence of waist correction with σ_{24}



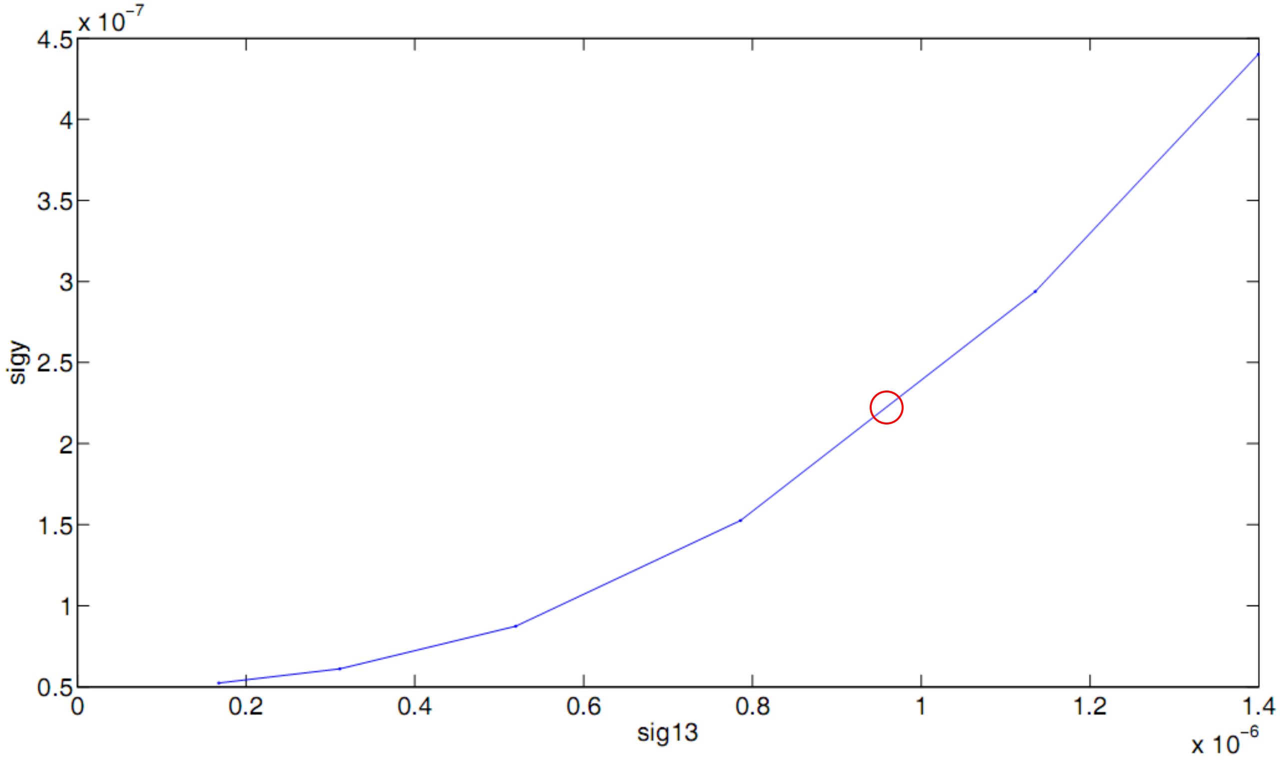
IP BSM fringe tilt 30mrad



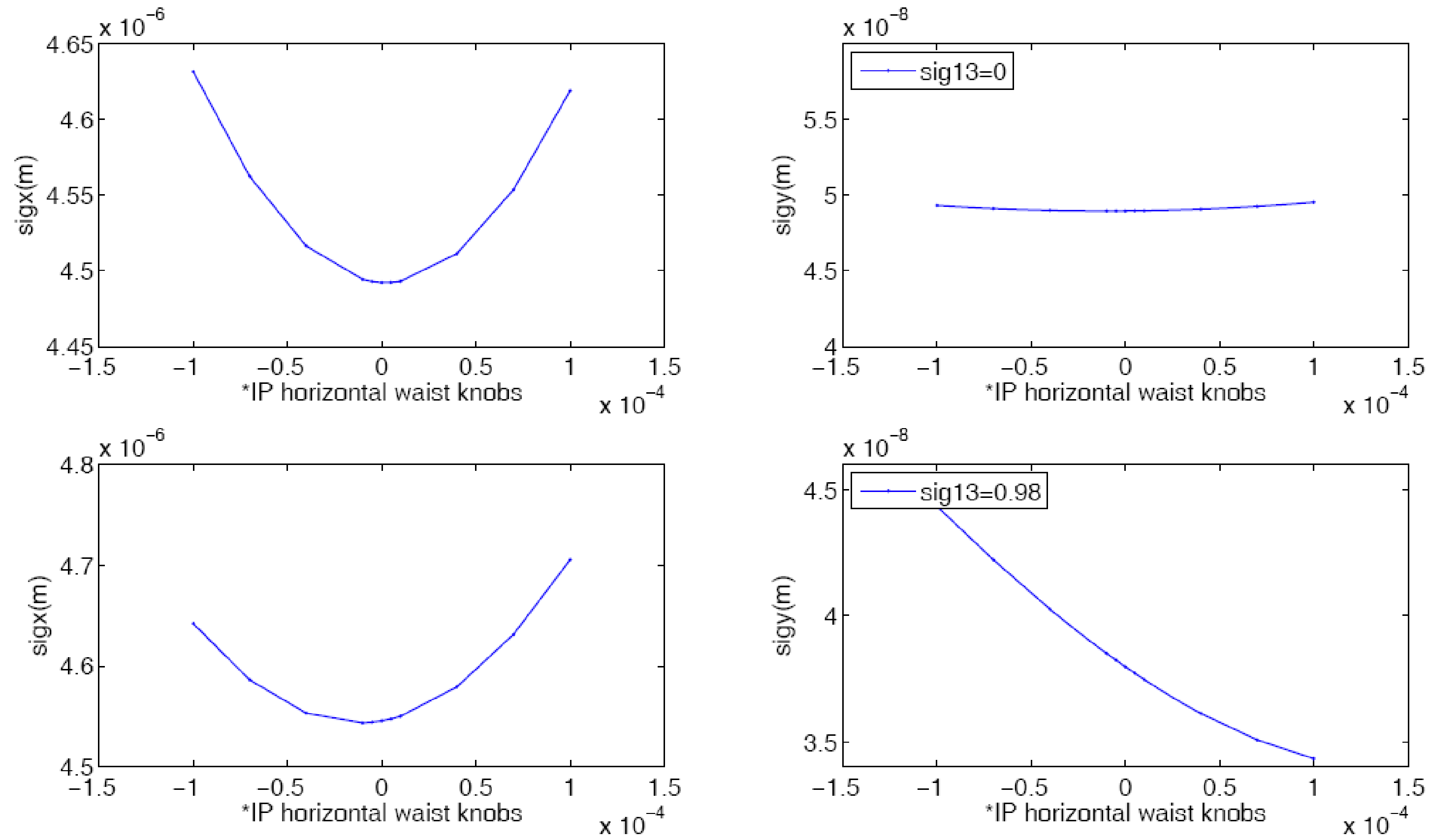
- With a residual tilt in the IP Shintake monitor fringes, the horizontal and vertical sextupole multiknob orthogonality is not significantly broken.
- In any case, for any of the optics, having a residual tilt in the fringes still remains a severe problem.
- An idea to find out the fringe tilt is to use the α_x waist knob and the simulation results show that the vertical beam size depends on it in the presence of fringe tilt.

σ_y vs σ_{13}

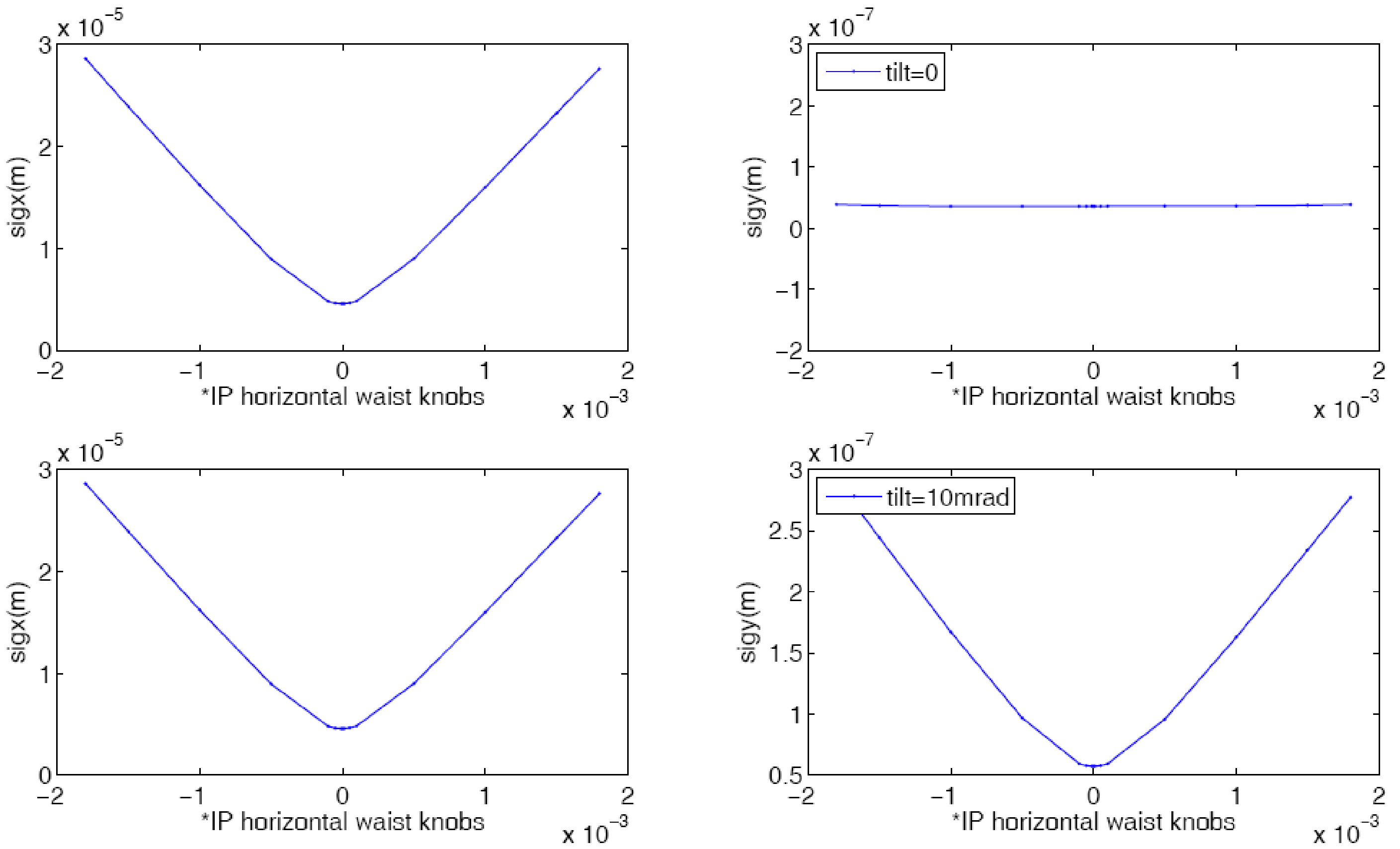
- Choose a given value of σ_{13}=0.98 to increase σ_y and KLQK1~4 are four times larger.



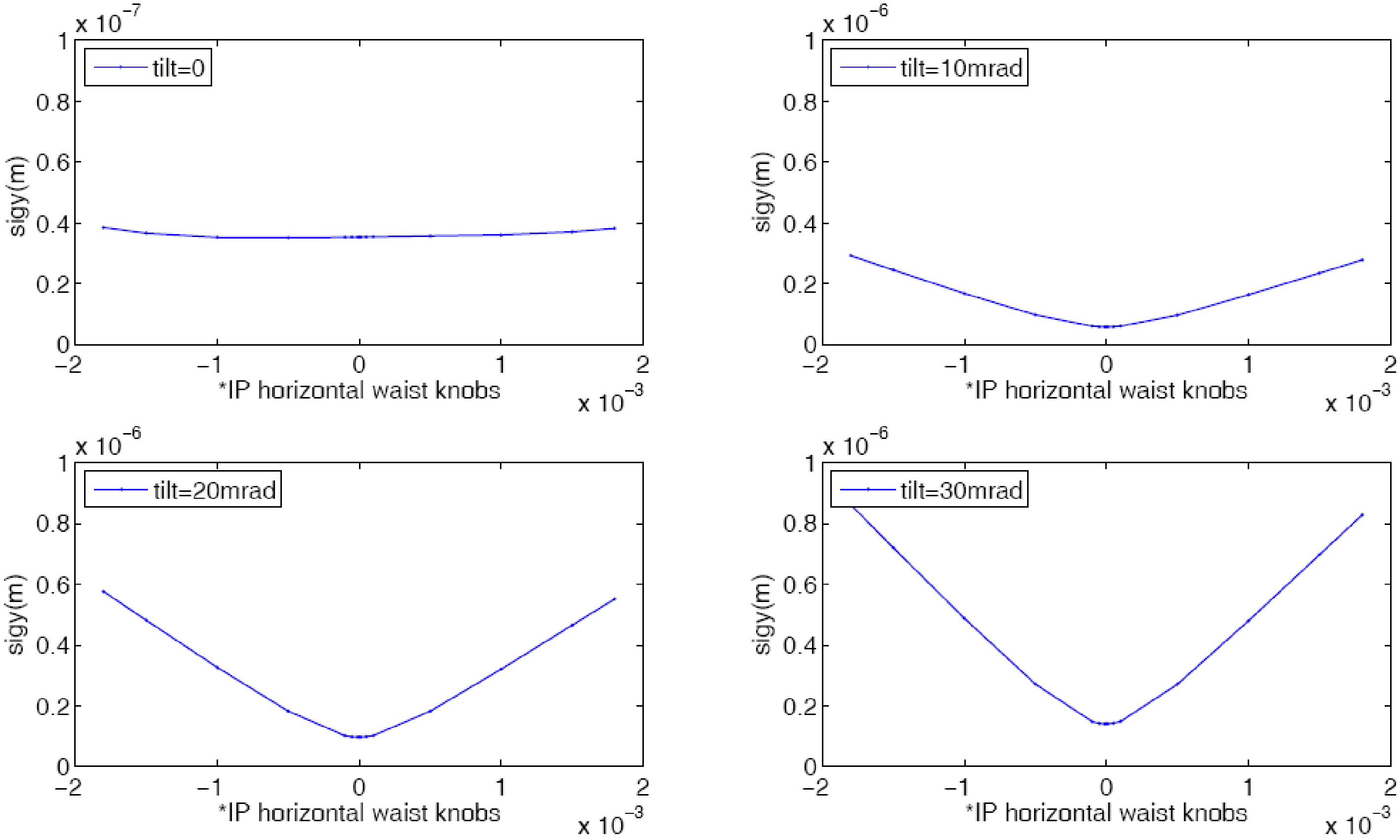
σ_{13} effects



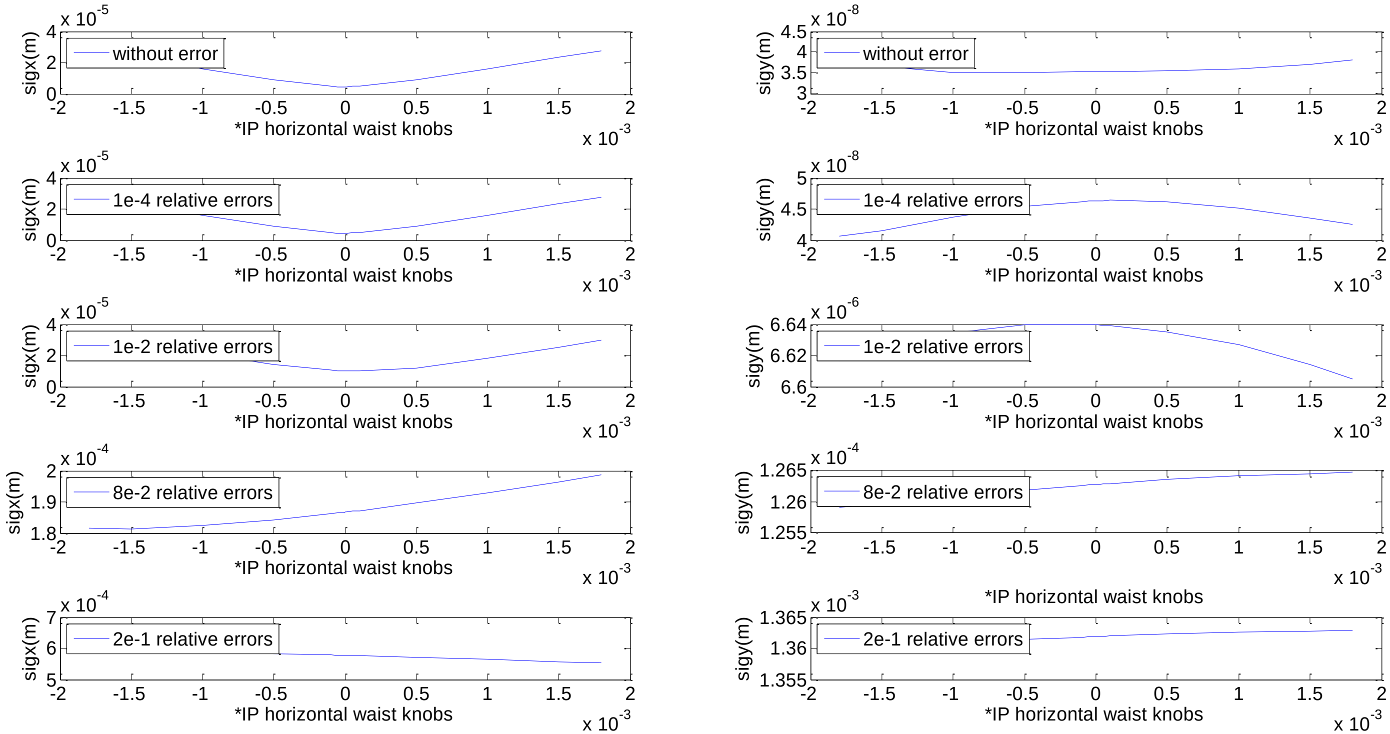
IP BSM fringe tilt effects



IP BSM fringe tilt effects

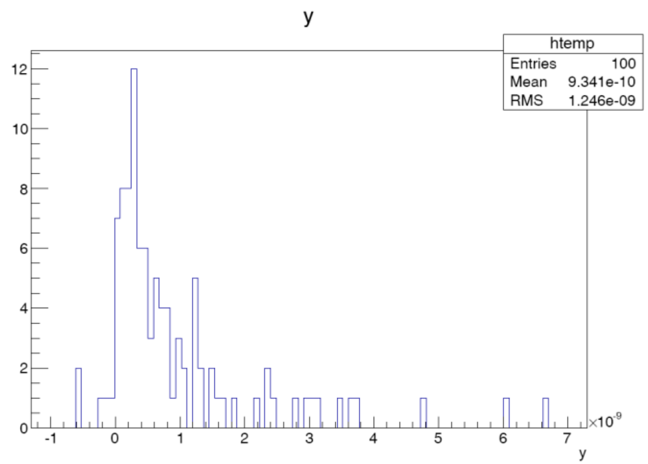


Orthogonality of α_x scan

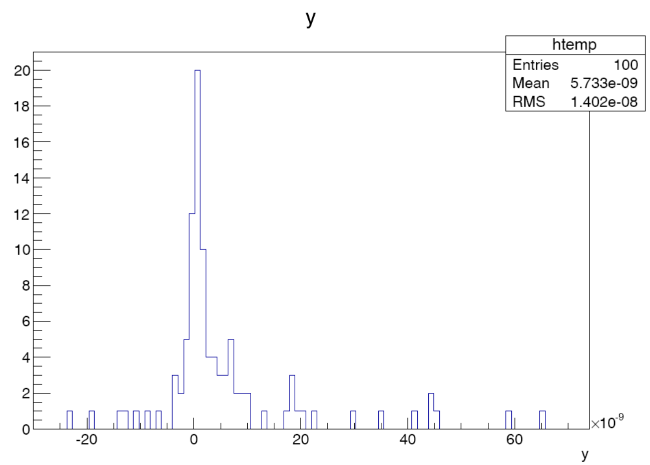


Breaking of orthogonality of α_x knob

quadrupole normal strength error



1e-3

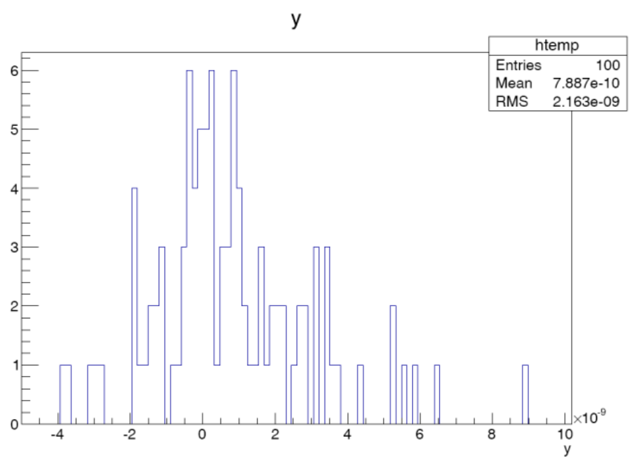


4e-3

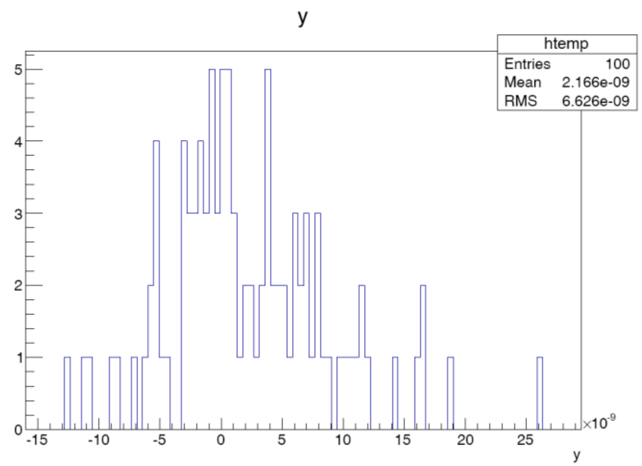
- The blue histogram shows the difference of the minimum vertical beam size at IP after the α_x and α_y correction using the sextupole multiknobs and the vertical beam size by changing σ_x by a factor 2 or 3.
- For the gradient error 1e-3, the RMS ~ 1nm. Orthogonality is not much broken.
- Orthogonality breaking down happened when the gradient errors increased to 4e-3, and the difference of the two beam sizes become much larger to ~10 nm.

Breaking of orthogonality of α_x knob

quadrupole roll error



300urad



800urad

- For the roll error magnitude 300urad which is from the standard simulation error parameters in ATF2 beam line, the orthogonality of α_x knob still keeps.
- The orthogonality breaks down until the roll errors increased to 800urad.

Proposed experimental method for diagnosis

1) check for the presence of σ_{24} (essentially a tilt on the screen in front of the FD), if there is one, correct with appropriate skew quad multiknob.

2) check for the presence of σ_{13} with the proposed method of scanning the α_x knob and measureing σ_y (if needed, a correction can be done with the appropriate skew quad multiknob, or one should consider the fringes...).

3) after (1) and (2), the α_y and σ_{23} should be orthogonal and the minimum beam size should not be dominated by σ_{13} or an IPBSM fringe tilt.

Conclusions

- With a residual tilt in the IP Shintake monitor fringes, the horizontal and vertical sextupole multiknob orthogonality is not significantly broken.
- In any case, for any of the optics, having a residual tilt in the fringes still remains a severe problem.
- An idea to find out the fringe tilt is to use the α_x waist knob and the simulation results show that the vertical beam size depends on it in the presence of fringe tilt.
- Reliability is checked in the presence of other imperfections and orthogonality is still kept for the standard simulation error parameters in ATF2 beam line.
- An experimental method for diagnosis is proposed.