Update on IOTA simulations with Synergia

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Outline

- *Update on simulation capabilities*
- *Higher order terms in nonlinear integrable optics*
- *Chromatic effects in the current IOTA lattice*

Synergia Simulations

- *Currently performing simulations using Synergia 2.1*
- *Capabilities include:*
  - *Full CHEF propagation - direct symplectic tracking for single particle dynamics*
  - *Dynamic lattice element adjustments*
    - *Polynomial map expansion to arbitrary order*
    - *Fit tunes or chromaticities to desired values*
  - *Construct lattice from MAD lattice file, or create arbitrary 6x6 matrix elements to study "toy" problems*
  - *Benchmarked description of nonlinear element, with bunch matching using generalized K-V distribution*
  - *Initial testing of 2.5D/3D space charge solvers*

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Higher order terms in the Nonlinear Hamiltonian

- *Previous analysis computed the single turn map for the ideal integrable optics lattice*
- *Expansion of the Hamiltonian lowest order correction to H in ν_0, the "tune-advance" through the nonlinear drift*

$$\mathscr{H} = \nu_0 \underbrace{\left\{ \frac{1}{2} \left(\vec{p}^2 + \vec{x}^2 \right) + tV(\hat{x}, \hat{y}) \right\}}_{\text{D.-N. Hamiltonian}} +$$

$$\frac{1}{6}\nu_0^3 \underbrace{\left\{ \frac{1}{4}[\vec{p}^2 + \vec{x}^2, [\vec{p}^2 + \vec{x}^2, tV(\hat{x}, \hat{y})]] - \frac{t^2}{2}[V(\hat{x}, \hat{y}), [V(\hat{x}, \hat{y}), \vec{p}^2 + \vec{x}^2]] \right\}}_{\text{Next-order correction}} + \mathcal{O}(\nu_0^5).$$

- *There is to leading order a correction to the invariant H_0 which scales with ν_0^3, and we should thus expect to see a variation in H from the first order estimate H_0*

$$\mathscr{H} = H_0 \nu_0 + H_2 \nu_0^3 + \ldots$$

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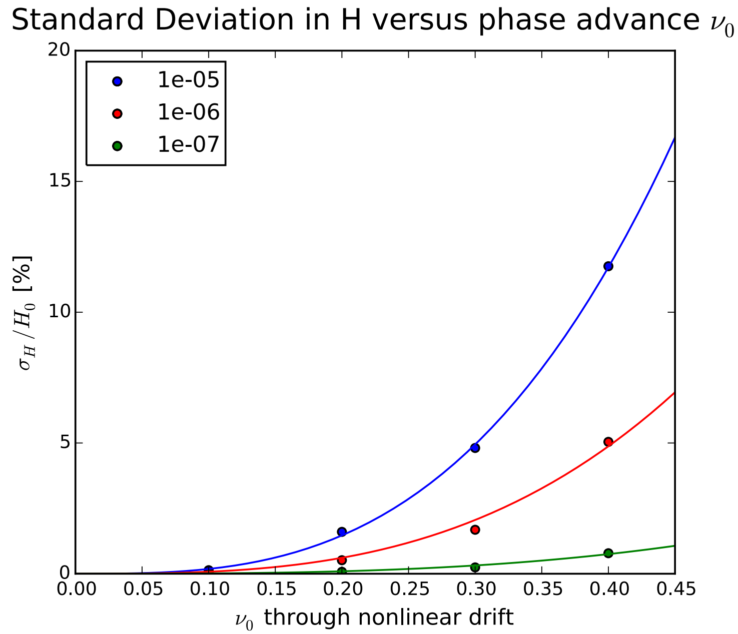
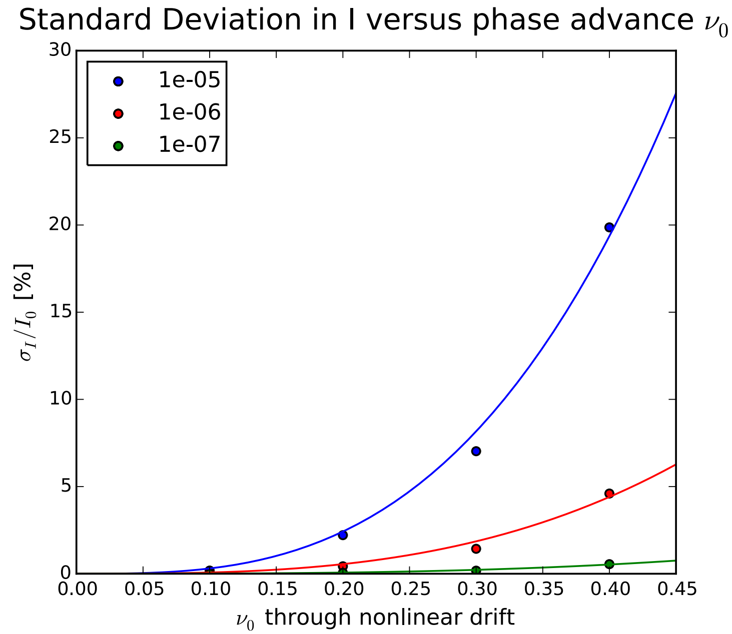
Variation in the first invariant - H_0

- *Simulated a toy-model IOTA lattice, comprised of a nonlinear element followed by a corresponding 6x6 matrix representing a thin double-focusing lens.*
  - *Variations of the nonlinear element with different ν_0 are calculated using the MADX script released by Fermilab*
  - *The same matched bunch is used for each ν_0*





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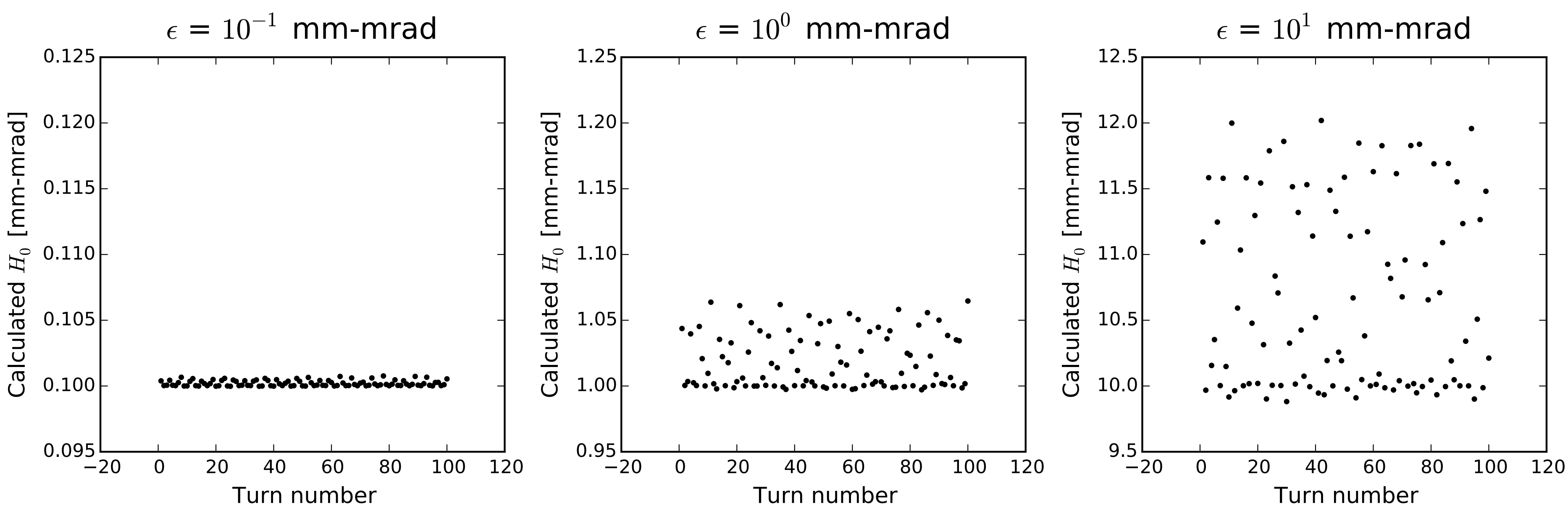
Variation in H_0 with increasing emittance

- *Greater variation in H_0 with increasing emittance — coefficients in the expansion of the Hamiltonian vary with ε^3.*
- *Ex. For a NL segment with ν_0 =0.3, a KV distribution with H_0 = 10 mm-mrad demonstrates an average r.m.s. variation of 5% in calculated value of of H_0.*



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Chromatic Considerations in IOTA

- *Recently, tests performed for matched bunches with energy deviations $\delta \leq 0.5\%$, with and without chromaticity correction*
- ***Simulations of chromaticity corrected lattice***
  - *Some beam loss (4%) even for a bunch with $\delta = 0.1\%$ and a normalized emittance of $\varepsilon_x = 0.03$ mm-mrad*
  - *Invariant clearly not preserved - $\sigma_H > 17\%$*
  - *As δ approaches 0.4%, the majority of the beam is lost*
- ***Uncorrected lattice** retains better single particle dynamics*
  - *For $\delta = 0.1\%$, no particle loss and $\sigma_H \approx 12\%$*
- ***Conclusion**: Off-energy particles in IOTA are more sensitive to sextupole fields than to natural chromaticity of the lattice.*

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Chromaticity Correction Schemes

- *For realistic energy spreads, chromaticity significantly perturbs integrable motion*

$$\overline{H} = \overline{H}_0 + \Delta_C \left(\overline{p}_x^2 + \overline{x}^2 - \overline{p}_y^2 - \overline{y}^2\right)$$

- *Recent work by Webb et al. presents a chromaticity correction scheme which preserves integrability*
  - *Require equal horizontal and vertical chromaticities $C_x = C_y$*
  - *Sextupoles separated by a phase advance of (2n +1)π*
- *Recover normalized Hamiltonian with adjustment to nonlinear strength parameter, t*

$$H_0 = \left(1 - \frac{\mu_0 C(\delta)}{\nu_0}\right)\left[\frac{1}{2}\left(p_x^2 + p_y^2 + x^2 + y^2\right) + \frac{1}{1 - \frac{\mu_0 C(\delta)}{\nu_0}} V(x,y)\right]$$

- *Current work is aimed at adjusting IOTA-1IO design to meet these requirements for basic testing*

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