RHIC Optics Correction/ORM APEX

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Summary:

- Objective: Correct RHIC store beta beat to 5-10%
- Simulations and validation of methods
- Experience from previous runs; 2007 data quality
  - April 18 2007 optics analysis
  - New methods: Levenburg-Marquardt (IUCF/LBL)
- Plans for 2008 ORM optics correction

Orbit Response Matrix Background

- Orbit response matrix G_{ij}: $$G_{ij} = \frac{\partial x_i}{\partial \theta_j}(K_l, \vartheta_l, g_i, g_{j,} \ldots)$$

  where θ_j are corrector setting changes, x_i are measured orbits from these corrector settings, and $g_{i,j}$ are BPM/corrector gains.

- Compare model and measured response matrices G_{ij}, and iteratively make model changes to minimize χ^2 difference between model and measurement:
  - Model changes **b** include quad gradients, BPM/corr gains, …
  - Measures gradient errors, BPM/corr gain errors, skew errors, …

$$\chi^2(\mathbf{b}) = \sum_{ij} \left(\frac{G_{ij}(\mathbf{b})^{\{x,z\},\mathrm{model}} - G_{ij}^{\{x,z\},\mathrm{meas}}}{\sigma_{M_{ij}}} \right)^2 + \sum_{x,z} \left(\frac{\nu_{x,z}(\mathbf{b})^{\mathrm{model}} - \nu_{x,z}^{\mathrm{meas}}}{\sigma_{\nu_{x,z}}} \right)^2$$

  - This is an overconstrained nonlinear minimization problem; dim(**b**) < dim(i) x dim(j)

Minimizing χ^2

- Gradient descent: $b(n+1) = b(n) - \Delta \times \nabla \chi^2(b(n))$

- Gauss-Newton (or Taylor series):

$$b(n+1) = b(n) - H^T H \nabla \chi^2(b(n))$$

where H is the Hessian matrix of χ^2: $H_{ij} \equiv \partial^2 \chi^2 / \partial b_i \partial b_j$

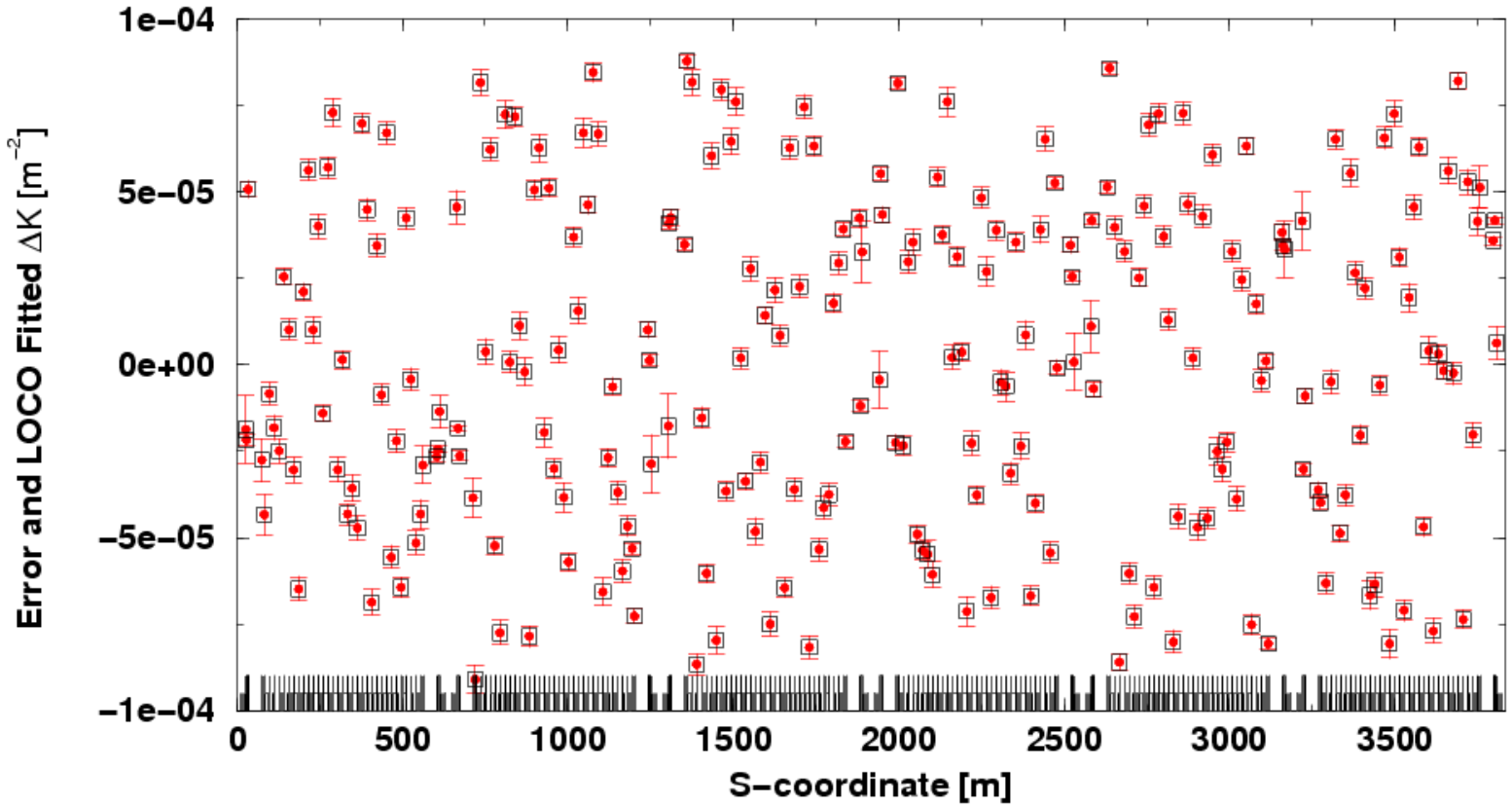
- Levenberg-Marquardt combines these with a scaling parameter λ:

$$b(n+1) = b(n) - (H^T H + \lambda S^T S) \nabla \chi^2(b(n))$$

S is the singular value diagonal matrix of H.
λ=0 is Gauss-Newton; $\lambda \rightarrow \infty$ is Gradient descent.

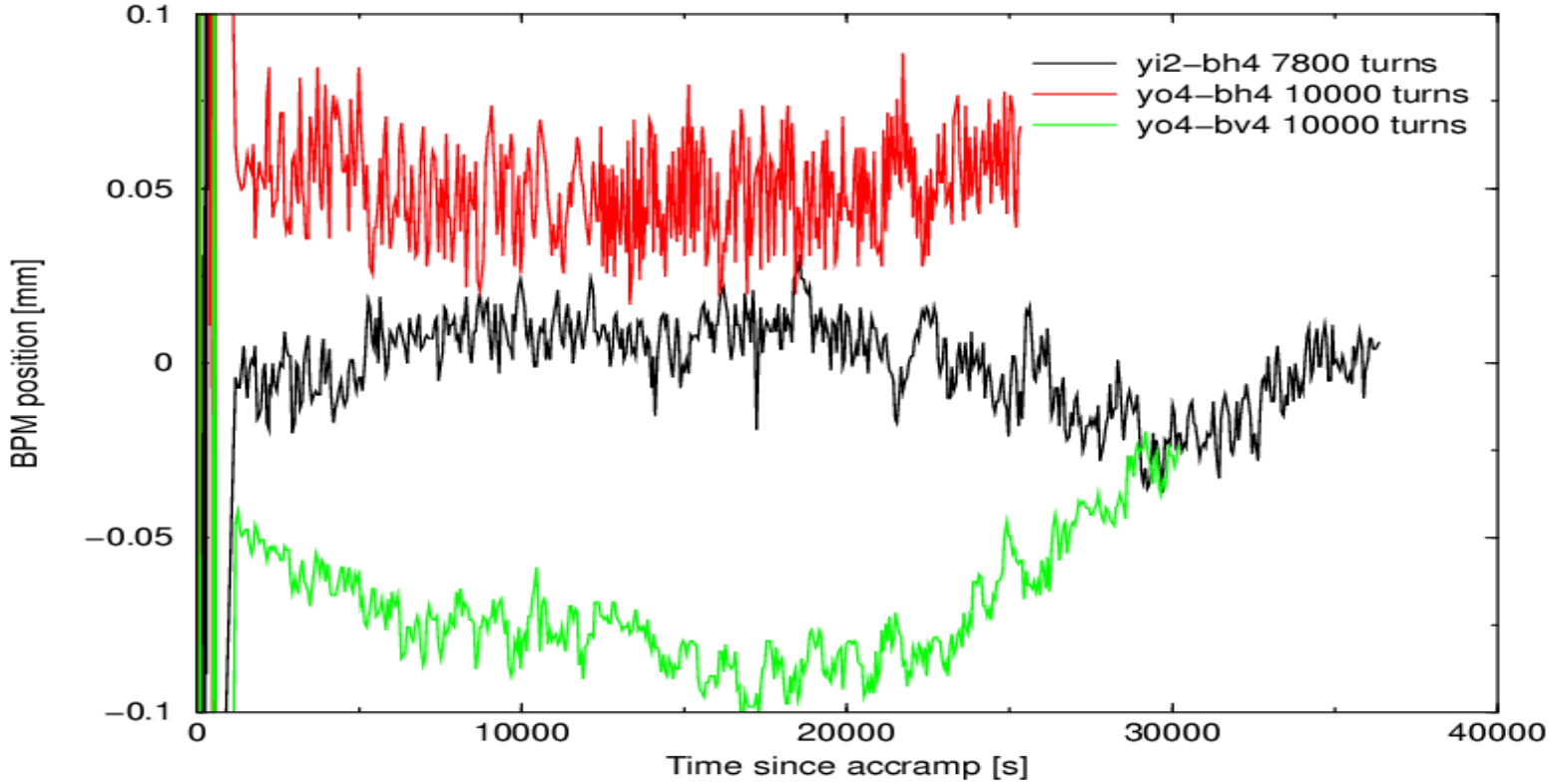
Former SVD approach only minimized χ^2 as a linear function

Simulation Results: No BPM Noise



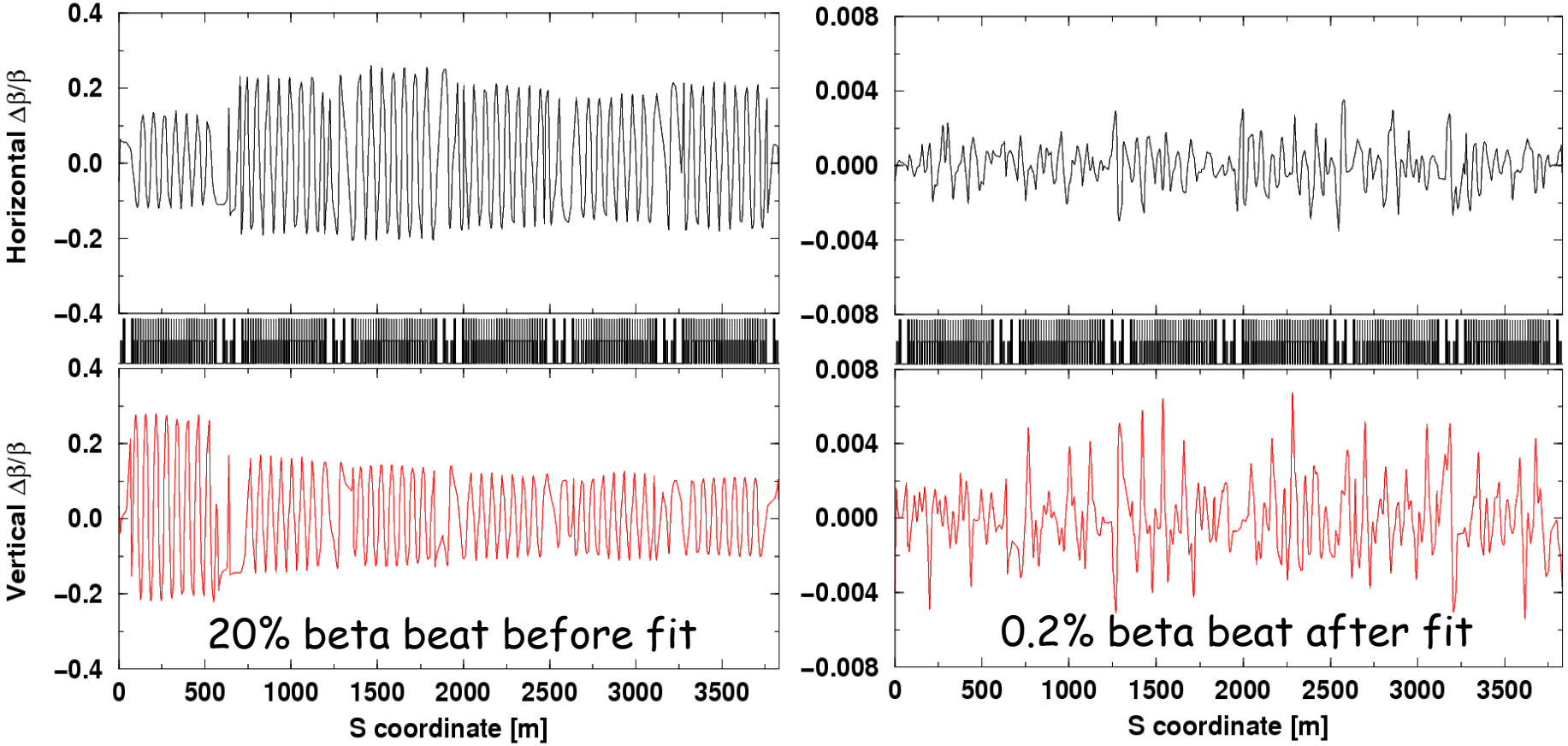
- Tested yellow Au70 store lattice, random –0.1 to 0.1% quad errs
- With no BPM noise, fitting is "perfect" for G-N and L-M fit methods
  - RHIC lattice is nondegenerate
  - Fitting time: 10 min/iteration, 5-10 iterations needed for realistic lattice

Issue: BPM Noise from 10 Hz



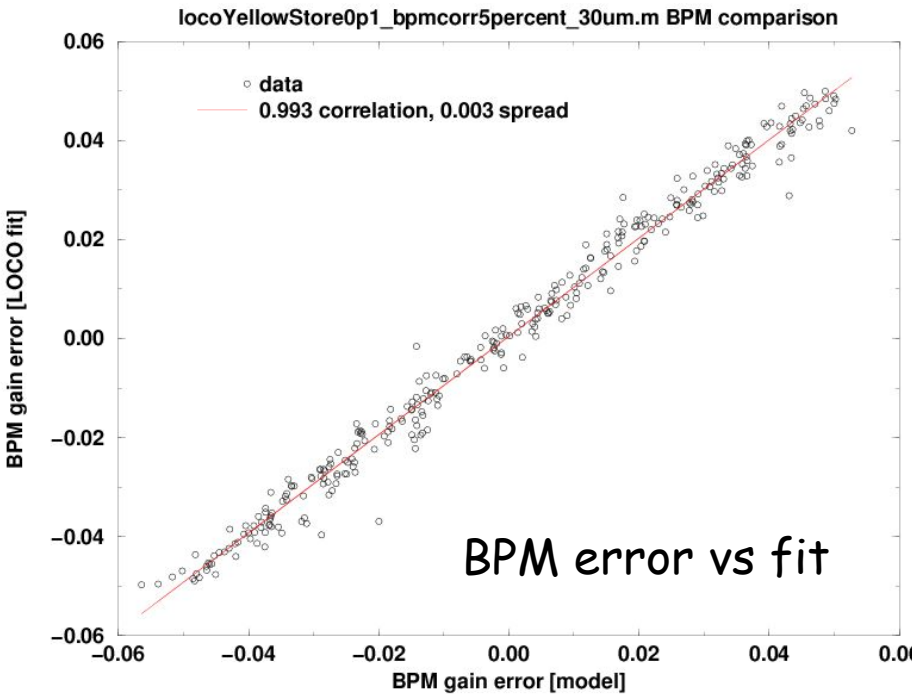
- Average orbit noise at store: 30-40 um horizontal peak-peak
- 7800 turn averaging gives 15-20 um peak-peak
- Need ~10 orbits per data point to achieve 5 um BPM noise, including BPM change to average orbit sampling period
- Total data acquisition time: 1 min/corrector, or ~4 hours for full ring ORM

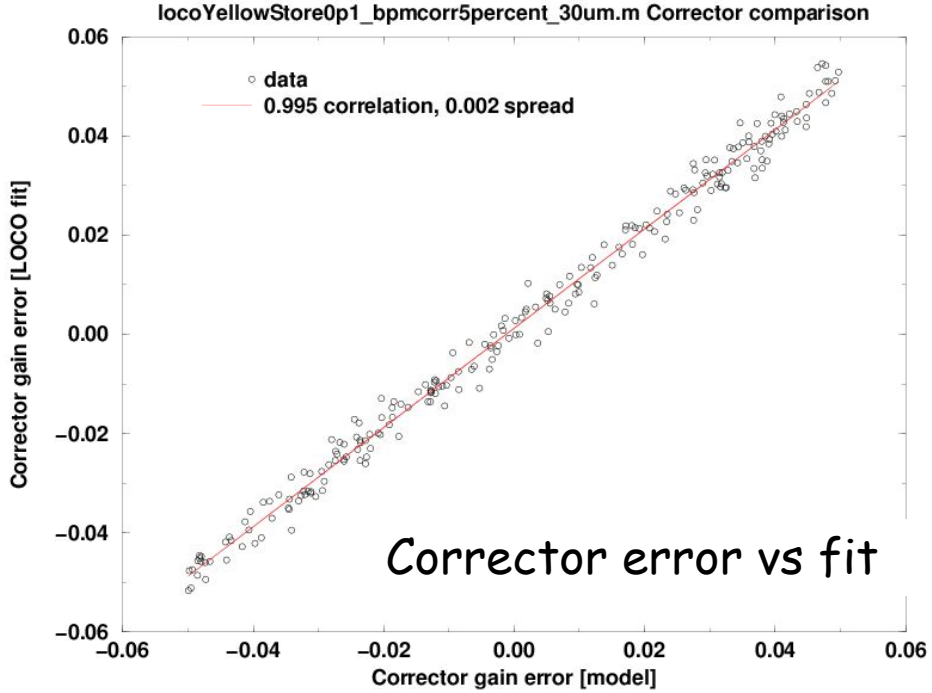
Simulation Results: 30 um BPM Noise



- With 30 um BPM noise, error bars are larger than errors
- Fits are inexact, but method still converges – not unique
- Beta beating is reduced by two orders of magnitude

Simulation Results: 30um BPM Noise and BPM/Corrector Gains

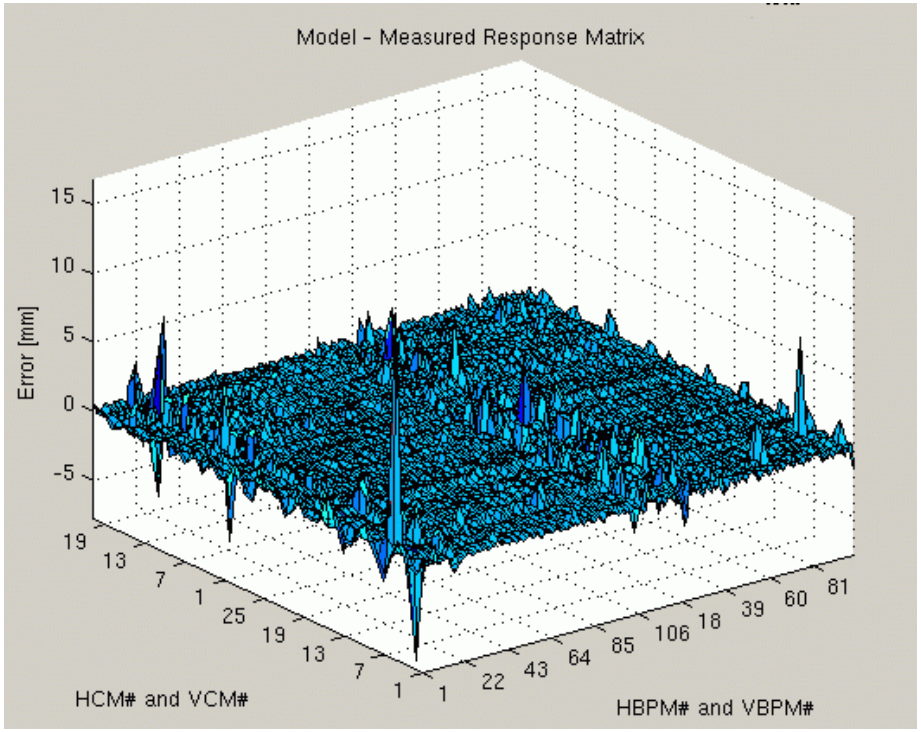


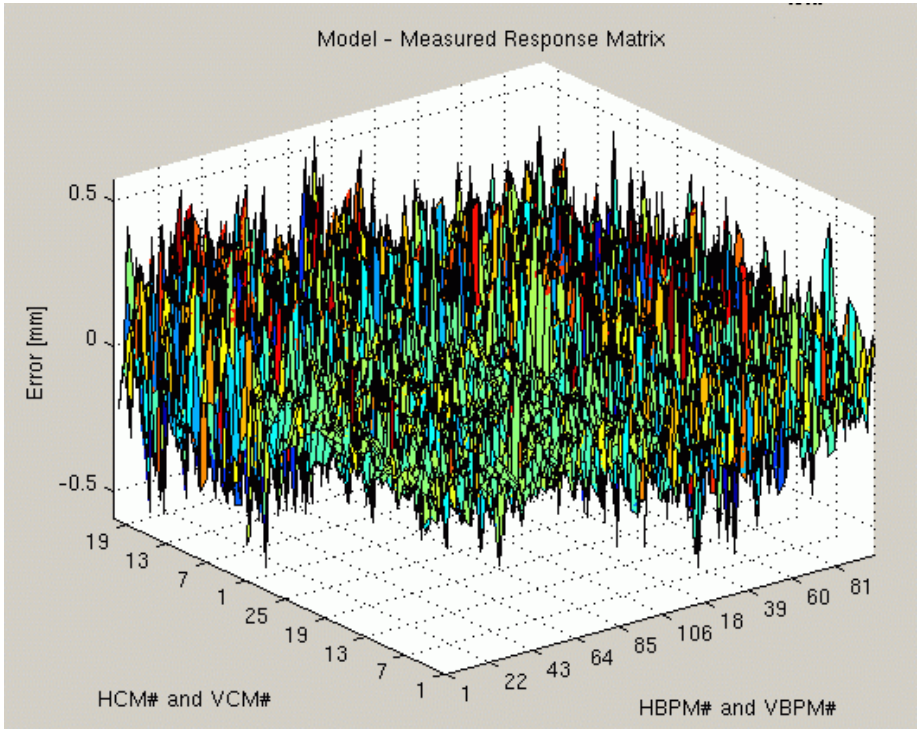


- Simulation fits of BPM/corrector gains, 30 um BPM noise
- Fits are very good, reduce gain errors by factor of 20

- BPM/gain errors and optics can be fit with 30 um BPM noise

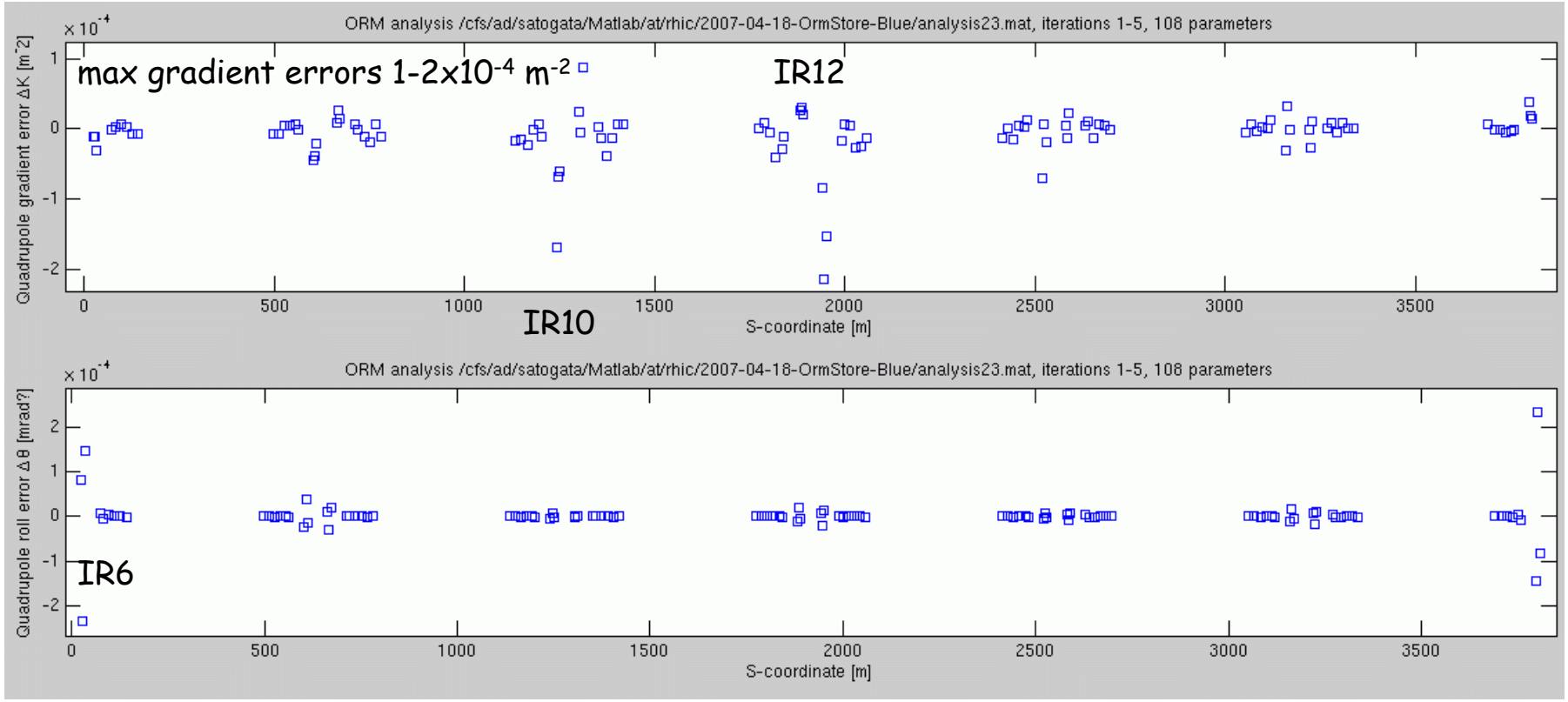
Blue Au72 May 2007 data set





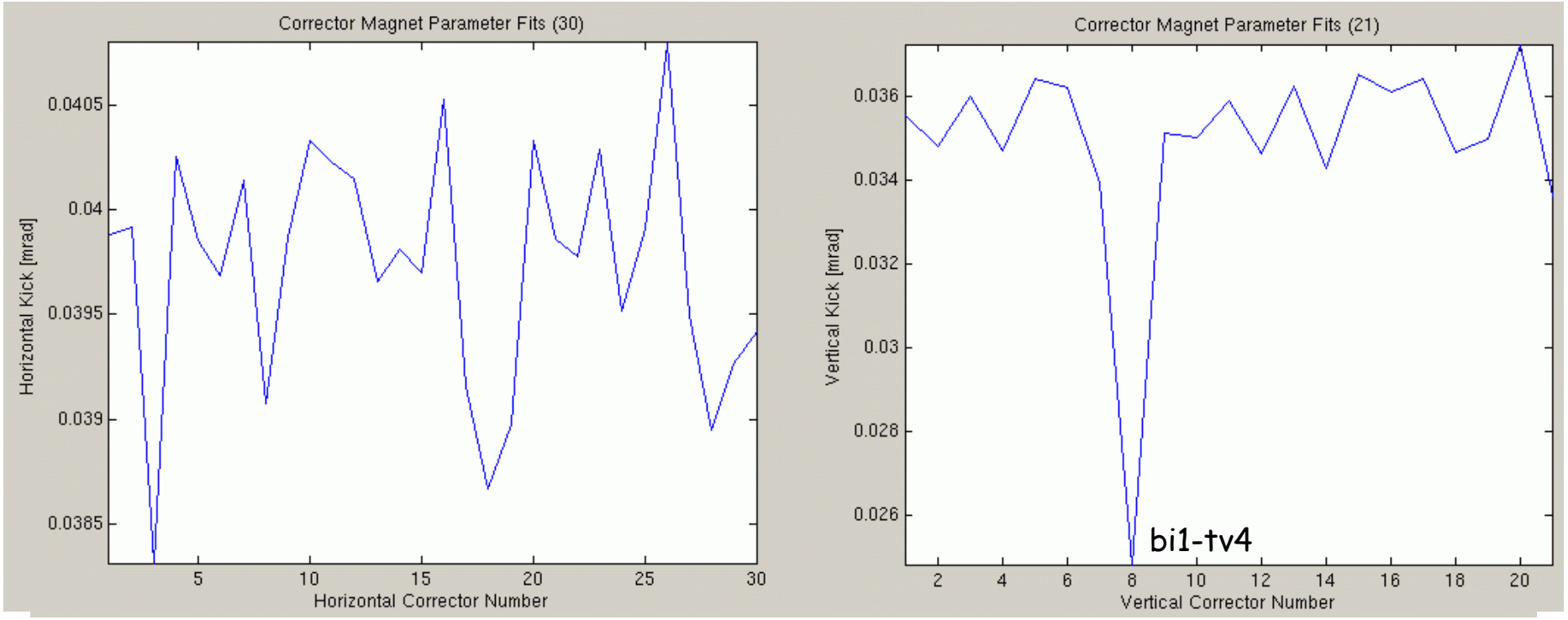
- analysis23 data set: about 25 correctors, 100 BPMs per plane
- Initial χ^2 /dof=250, final χ^2 /dof=24 (200 μm RMS difference)
- Maximum differences down from 5-10 mm to 500 μm, RMS 100 μm
- Fitted all Q1-Q9 gradient/roll, bpm/corr gains, 1e-4 SVD cutoff
- Scaled Levenberg-Marquardt optimization with $\lambda=10^{-6}$

Gradient and roll error fits: May 2007 data set



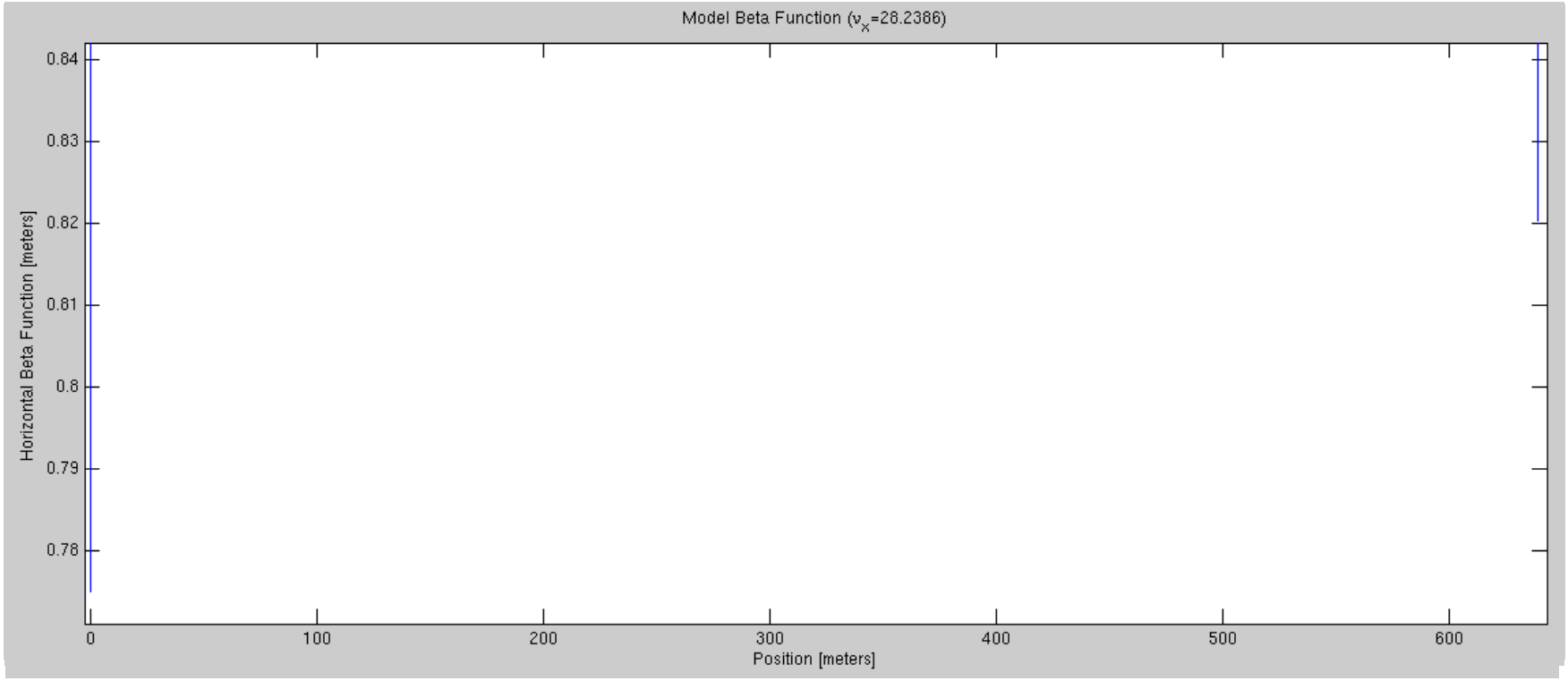
- Maximum gradient errors: 1-2x10^{-4} m^{-2} in IR10/12 triplet quads
- Maximum roll errors: 100-200 μrad in IR6 triplet quads
- Gradient errors are about 7-15 A in triplets at top energy

BPM and corrector gains: May 2007 data set



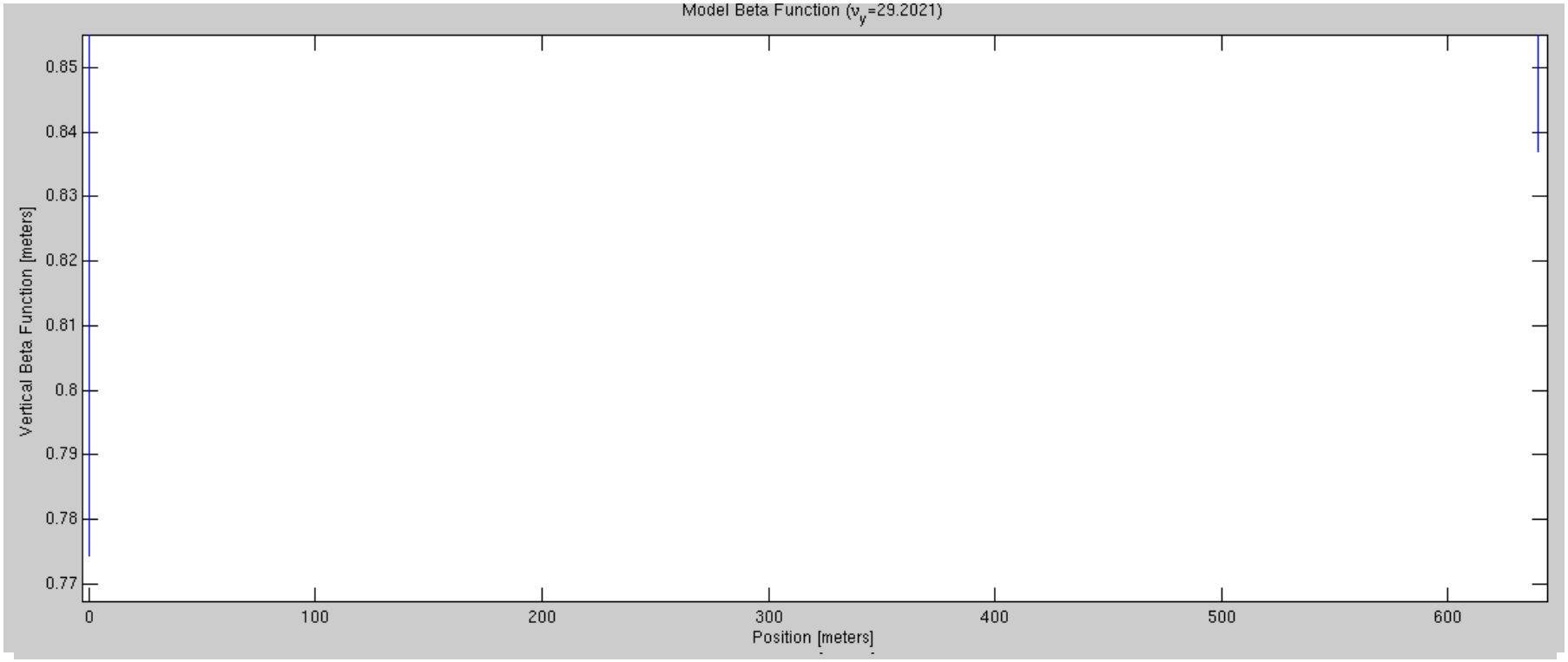
- BPM and corrector gains are also fit by analysis
- Intended kicks were 0.4 mrad, fit well by horizontal only
- Systematic discrepancy in vertical data, particularly bi1-tv4
  - These observations are consistent for all ORM fits

Blue horizontal optics



- Horizontal beta functions match pretty well
- Phases, amplitudes look good
- Horizontal beta* at IR6/8 are near right (0.775m, 0.820m)
- Horizontal tune (28.239) is also close

Blue vertical optics



- Vertical beta functions don't look nearly as good
- Phases and amplitudes are incorrect: systematic fitting problem?
- Vertical beta* at IR6 look reasonable: (0.775m, 0.837m)
  - 10% differences consistent with Run-7 STAR/PHENIX lumi

Plans

- Continued analysis
  - Existing data sets have limited usefulness
    - ⇨ 2007 data only uses ~1/5 of correctors
    - ⇨ 2006 data has marginal quality BPM data
  - L-M parameters permit tradeoff between aggressiveness of fit and size of correction terms
    - ⇨ Objective: Have a correction to test/implement in RHIC
  - A full data set should fit all quad gradient errors and rolls
    - ⇨ Light sources do this, so should we! G. Portmann will help
    - ⇨ Carefully verify good BPM function before APEX

- Measurement and correction plans
  - Controlled test at injection with known (large) magnet errors
    - ⇨ Full data set at all correctors/BPMs; analyze subsets
  - Early full data and correction at store (APEX or MD)
    - ⇨ Be careful about yellow ring DX aperture