Some RHIC & SPS MDs

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BNL/LARP

AB Seminar, July 17, 2008

Outline

– Brief Introduction

– β-beating experiment (RHIC)

– Vertical impedance localization experiment (SPS)

– SPS e-Cloud experiments

– Long range beam-beam experiments

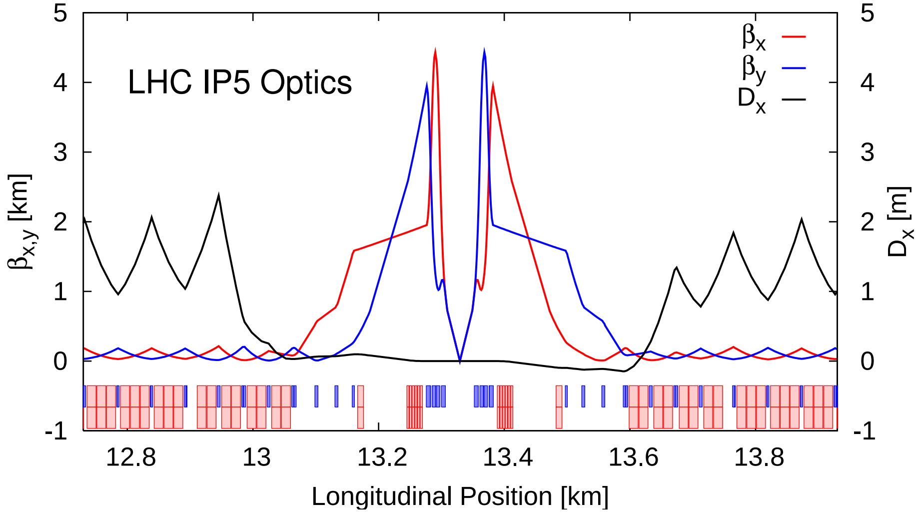
– LHC crab cavities

Ack: RHIC/SPS-Operations, M. Aiba, G. Arduini, M. Bai, T. Bohl, O. Bruning, H. Burkhardt, U. Dorda, W. Fischer, M. Giovannozzi, W. Herr, J. P. Koutchouk, E. Métral, G. Papotti, T. Pieloni, D. Quatraro, G. Rumolo, B. Salvant, E. Shaposhnikova R. Tomás, J. Tuckmantel, F. Zimmermann

What/How Does One Measure ?

$$x(s) - \bar{x} = A\sqrt{\beta(s)}\ \cos\left(\phi(s) + \delta\right) + D_x(s)\delta$$

$$\phi(s_1 \rightarrow s_2) = \int_{s_1}^{s_2} \frac{1}{\beta(s)}\ ds$$



†Some common techniques:

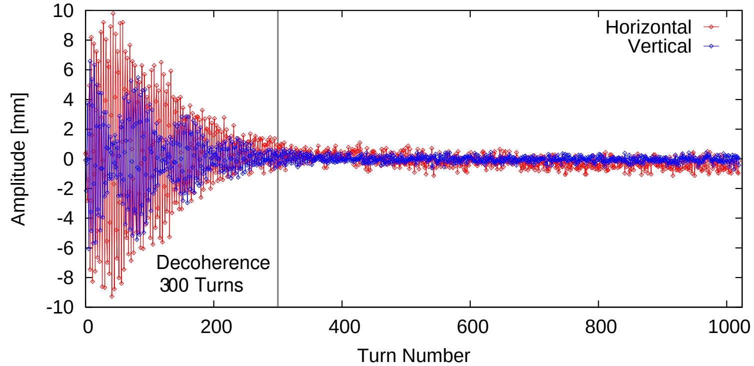
- k-modulation ($\Delta Q = \frac{\beta}{4\pi}\Delta K$)
- Orbit corr ($\mathcal{R}_{ij} \approx \sqrt{\beta_i\beta_j} cos(|\phi_i - \phi_j|)$)
- Freq analysis of turn-by-turn data
  - FFT‡, SVD, harmonic analysis
- Model independent analysis etc...

†See next AB seminar for more details (R. Tomás)

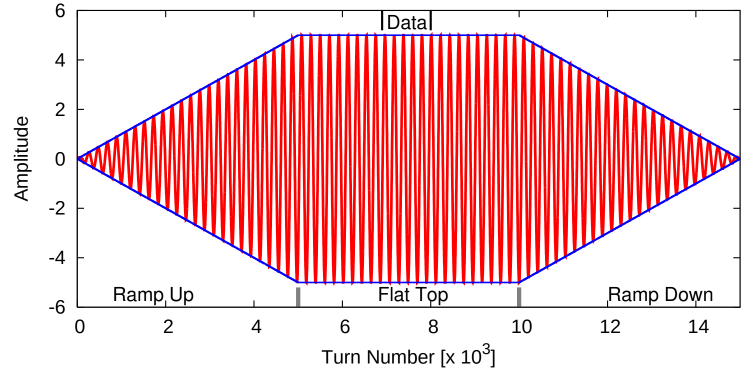
‡ Sussix, CERN SL/Note 98-017 (AP)

How Does One Measure ?

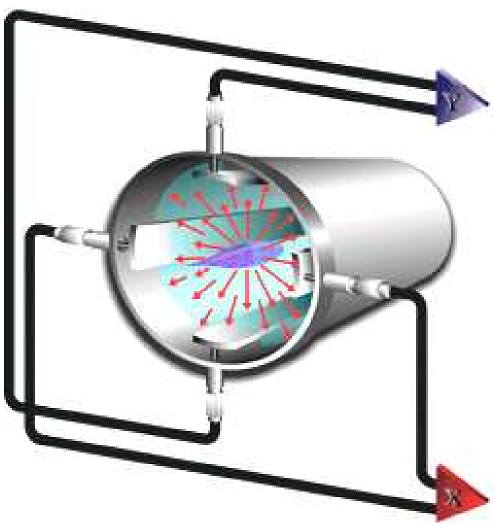
Transverse Kickers



AC Dipoles



Beam Position Monitors

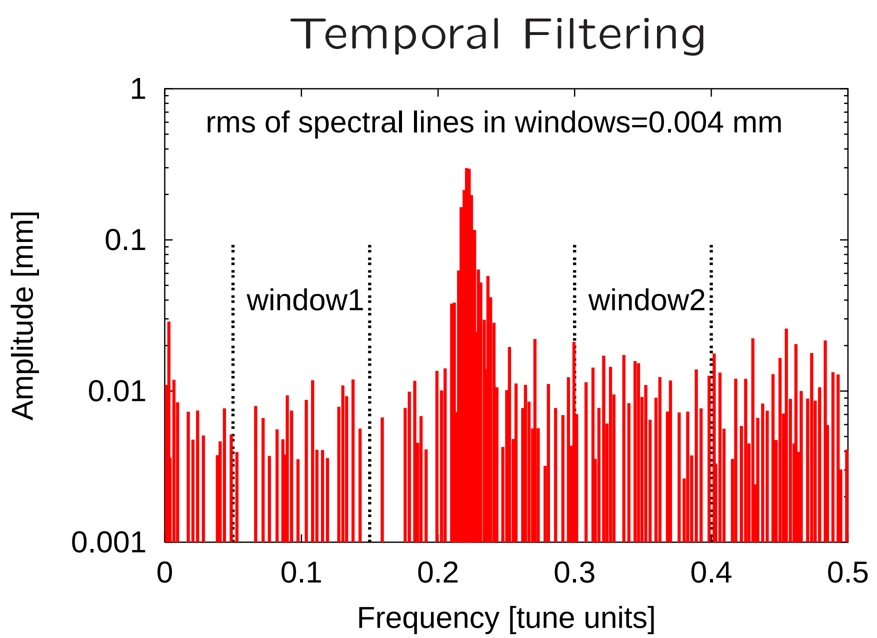


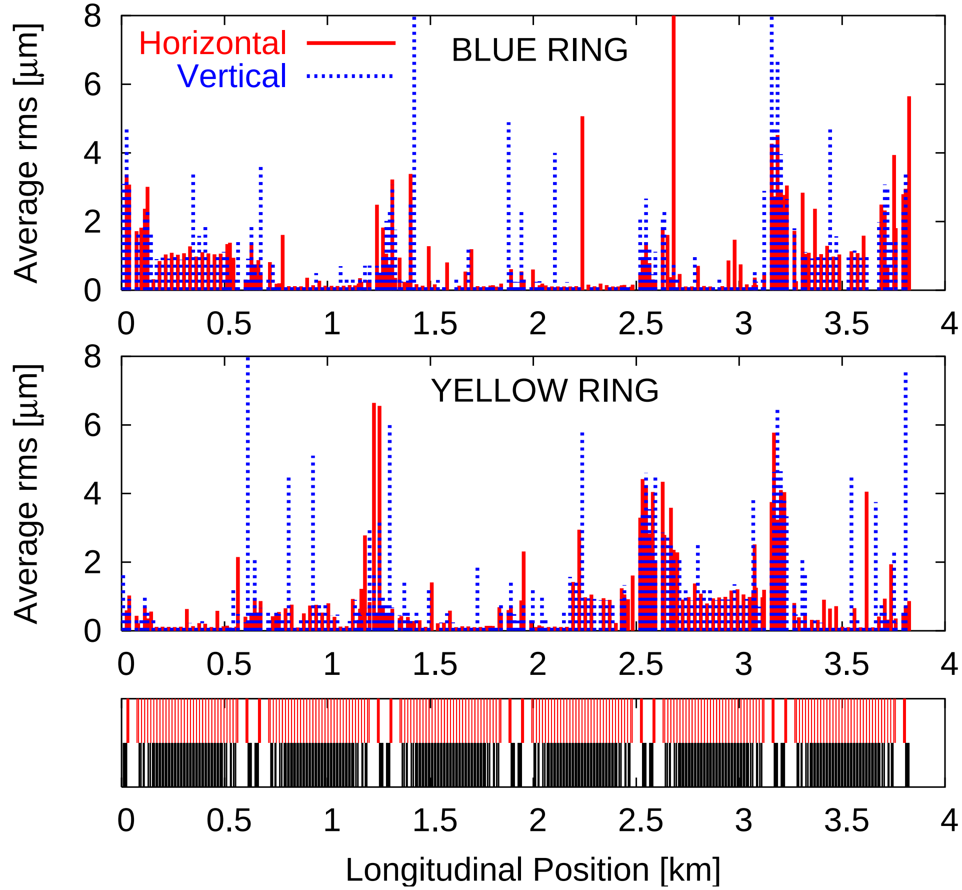
– Avg. Closed orbit
– Turn-by-turn data

$$x \approx \frac{w}{2}\left[\frac{U_+ - U_-}{U_+ + U_-}\right]$$

Faulty BPMs & Noise

Sample RHIC Data (2003)

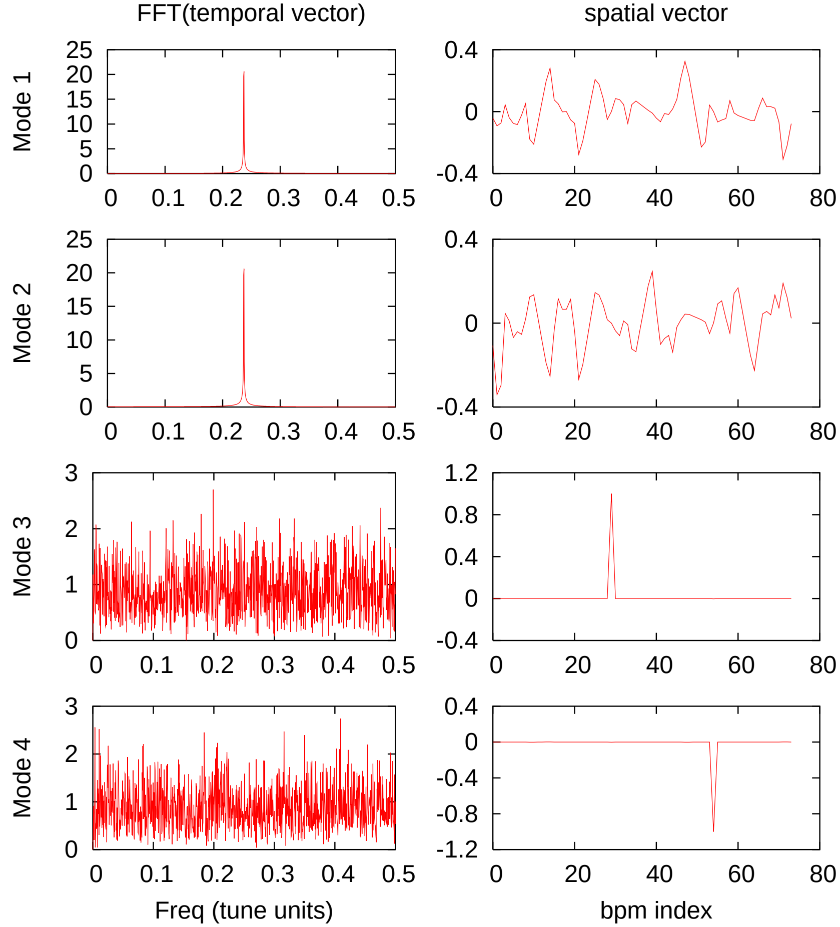




– For example: RMS of Background to determine a faulty BPM

– Several problems found at hardware & software level (lot of them fixed)

Spatial Filtering, using signal correlation



- Betatron signal is correlated around the ring
- Σ_i largest peaks of the spatial vectors are used as observables
- Tune windows, model phase adv etc... can also be used to filter BPMs

– PRST-AB 7, 042801 (2004)

Beta Beating & Correction

Quadrupole errors $\rightarrow$ β-wave:

$$\frac{\Delta\beta}{\beta} \approx -\Delta k\,\beta_0 \sin(2(\phi-\phi_0))$$

Correction (Global+Local):

$$\mathcal{A}_{\mathrm{ij}}\ \Delta\vec{k}_j = \left[\frac{\Delta\vec{\beta}}{\vec{\beta}}\right]_{1...i}$$

$$\left|\mathcal{A}\Delta\vec{k} - \frac{\Delta\vec{\beta}}{\vec{\beta}}\right|^2 = min, \qquad \Delta\vec{k} = (\mathcal{A}^T w \mathcal{A})^{-1}\mathcal{A}^T w \left[\frac{\Delta\vec{\beta}}{\vec{\beta}}\right]$$

Beta-bump (Local):

$$\Delta q_1 = -\frac{\Delta\beta_2}{\beta_2}\,\frac{1}{\beta_1}\,\frac{1}{\sin(2\psi_{21})}, \qquad \Delta q_2 = +\frac{\Delta\beta_2}{\beta_2}\,\frac{1}{\beta_2}\,\frac{\sin(2\psi_{31})}{\sin(2\psi_{32})\ \sin(2\psi_{21})}$$

$$\Delta q_3 = -\frac{\Delta\beta_2}{\beta_2}\,\frac{1}{\beta_3}\,\frac{1}{\sin(2\psi_{32})}$$

See also AB seminar next week (R.Tomás)

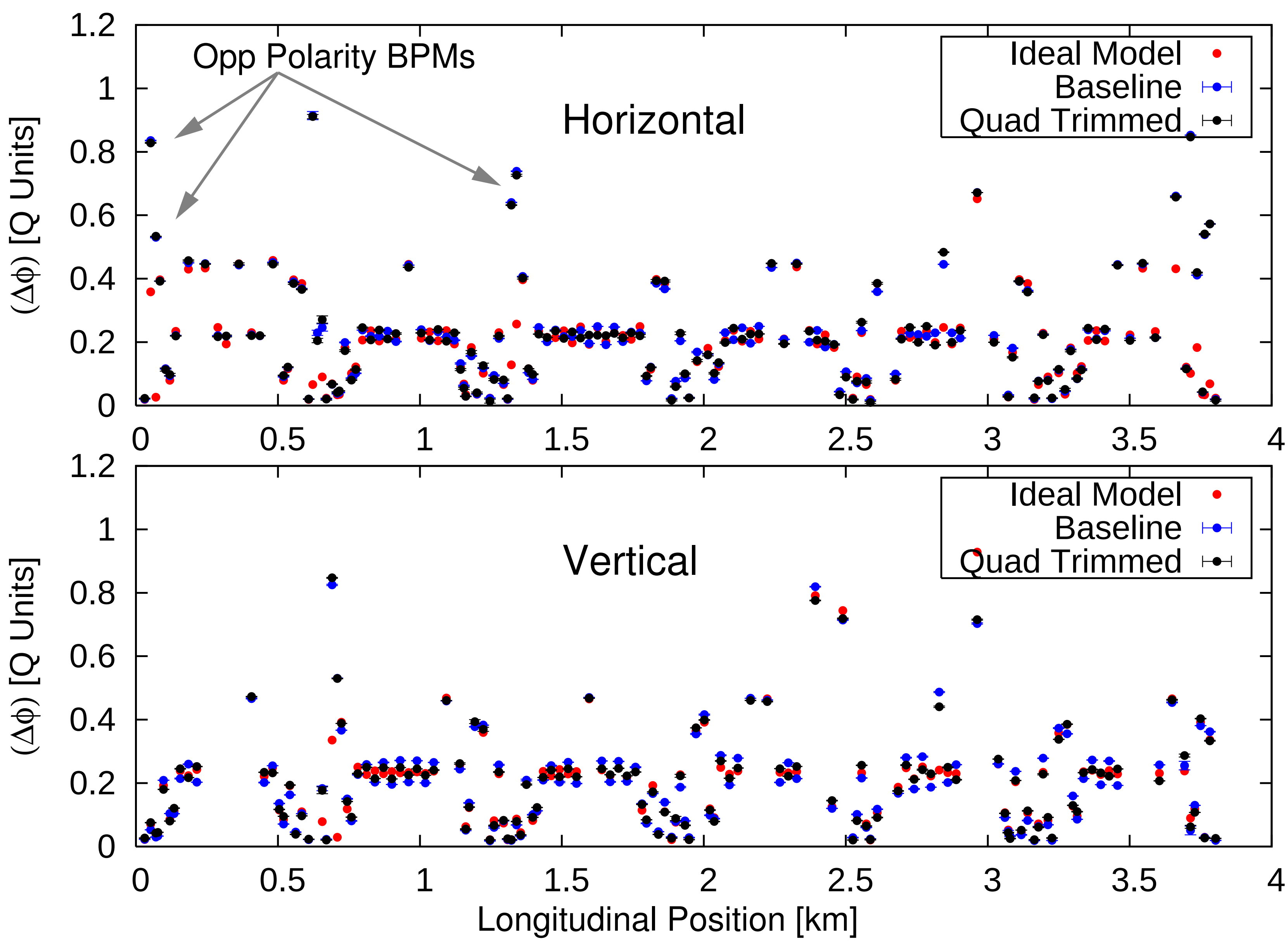
RHIC Measurements

Proof of principle

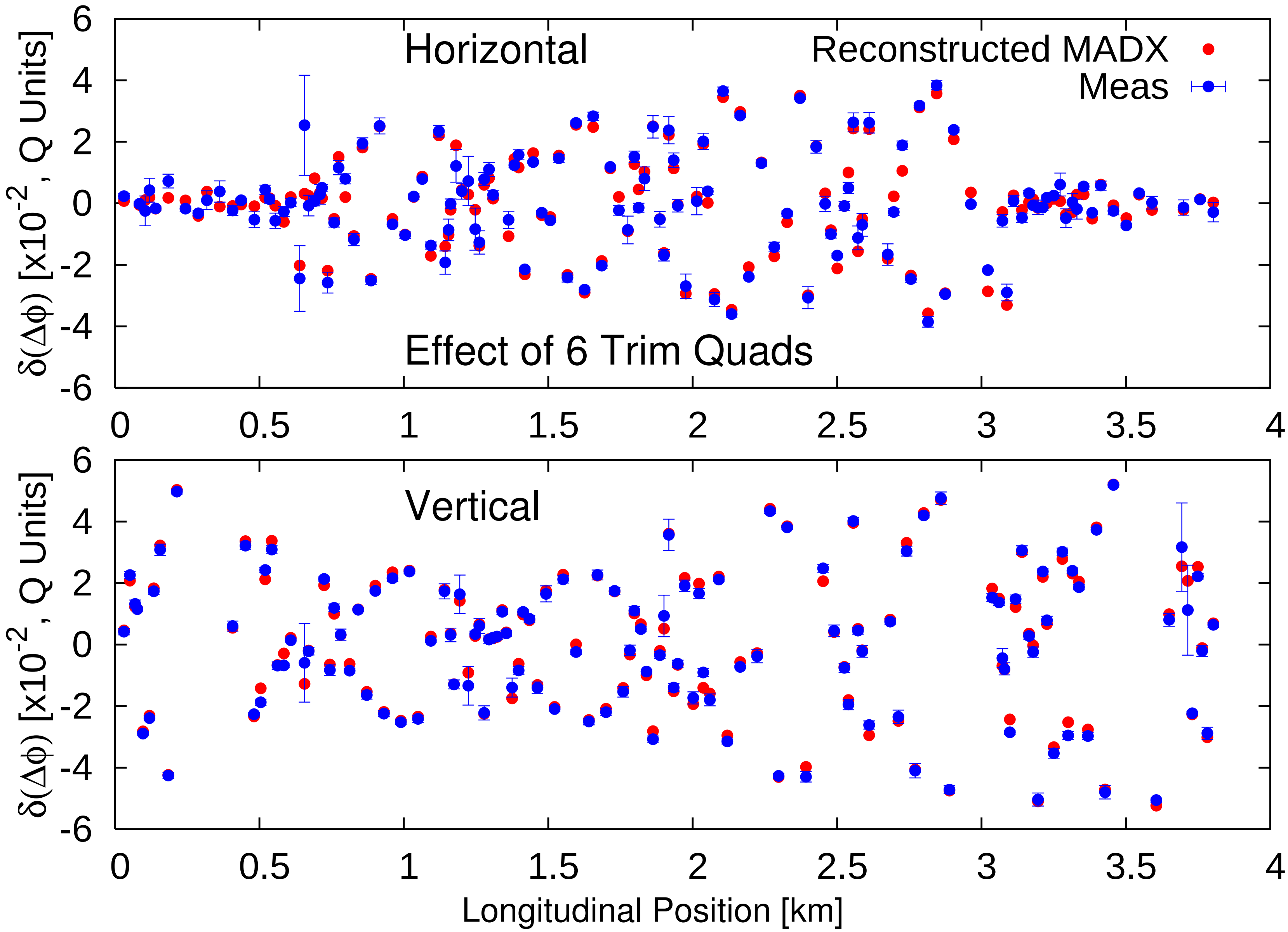
– Kicked Data: Six quadrupole errors (Exp I)

– AC Dipole: Single quadrupole error (Exp II)

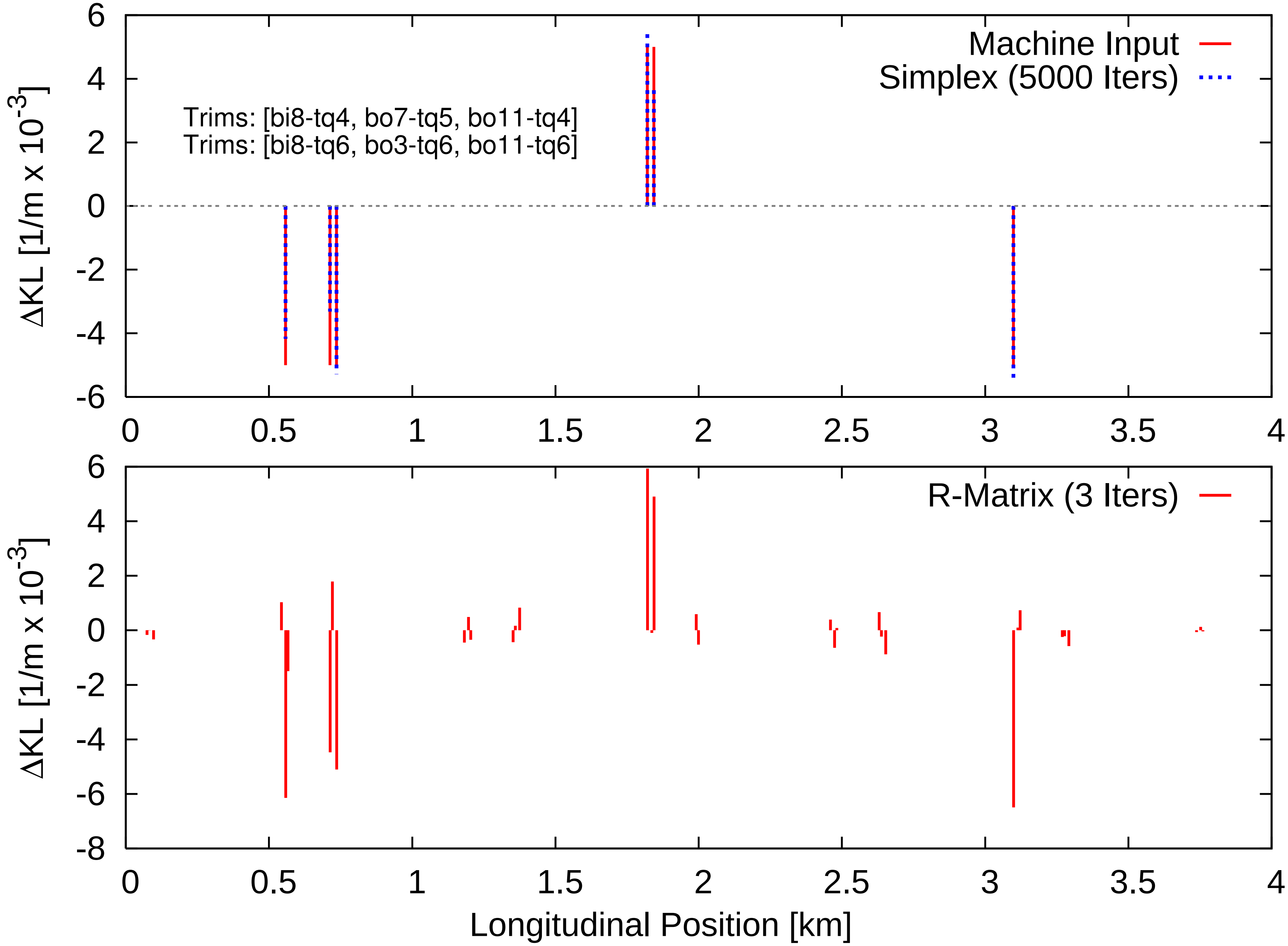
Exp I: Kicked ($\Delta\phi_{x,y}$, 6 Quads Trimmed)



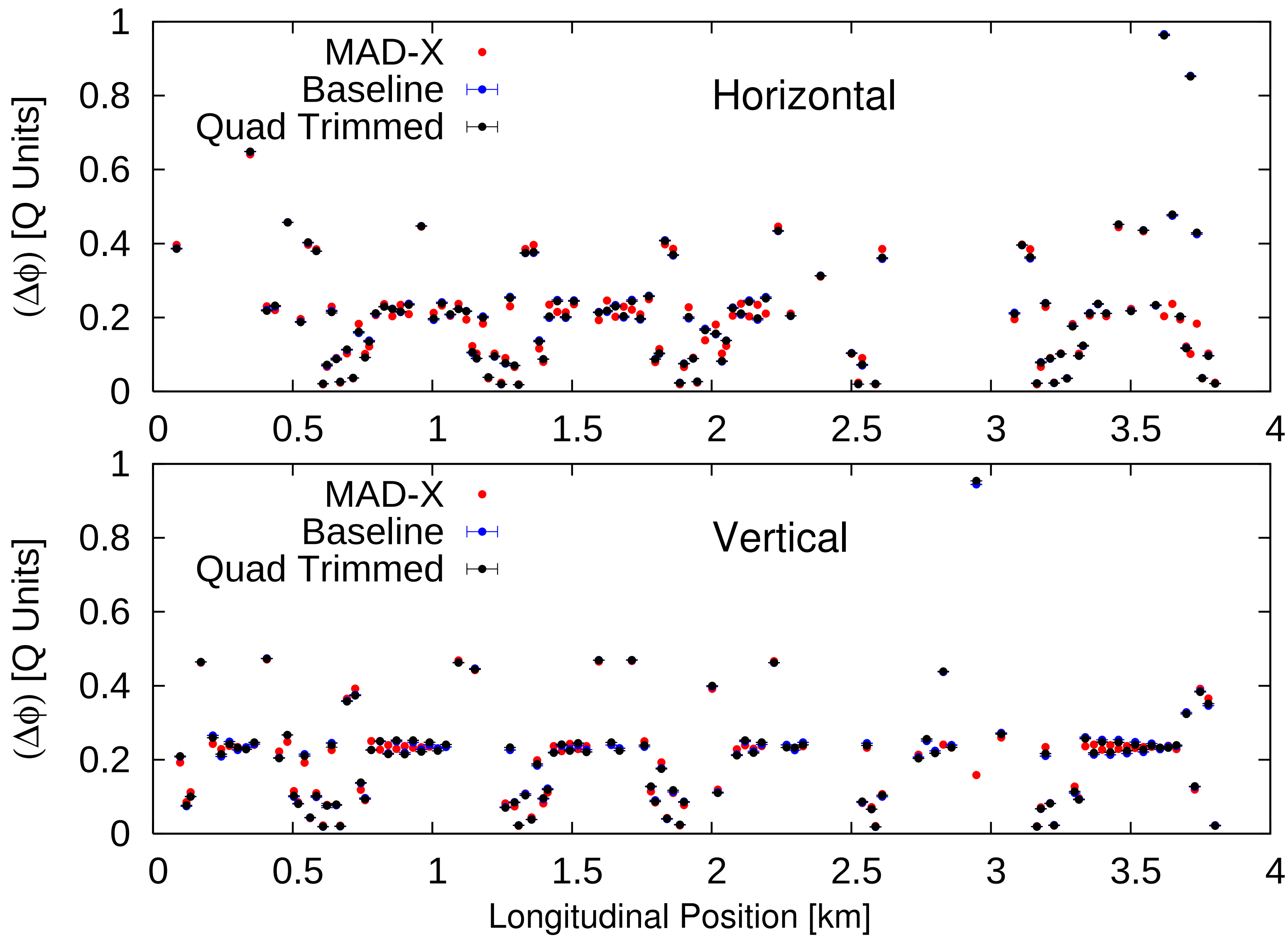
Exp I: Kicked ($\Delta\phi$-beat, Recons Machine)



Exp I: Reconstructed Trims, ΔKL (Kicked)

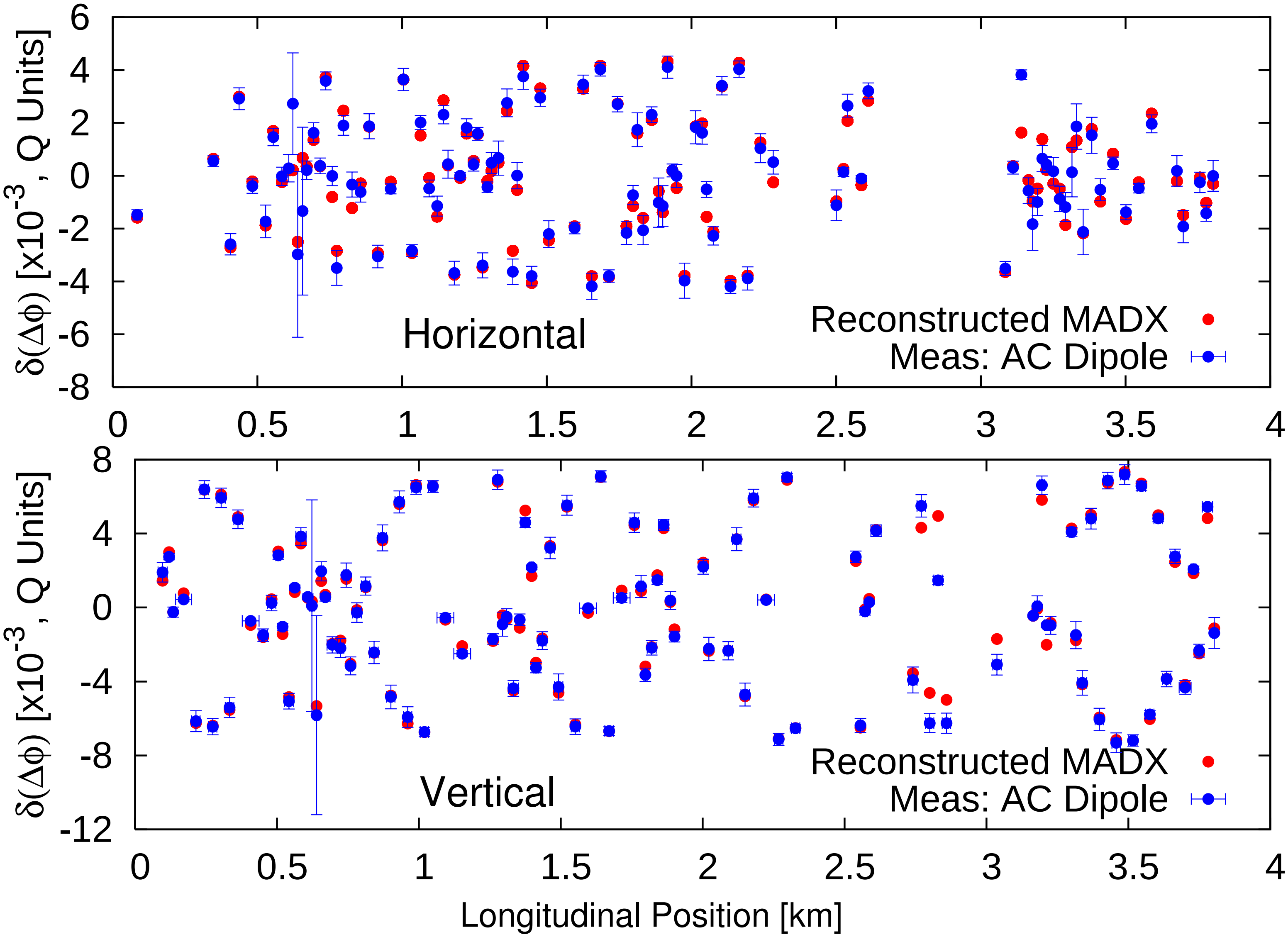


Exp II: AC Dipole



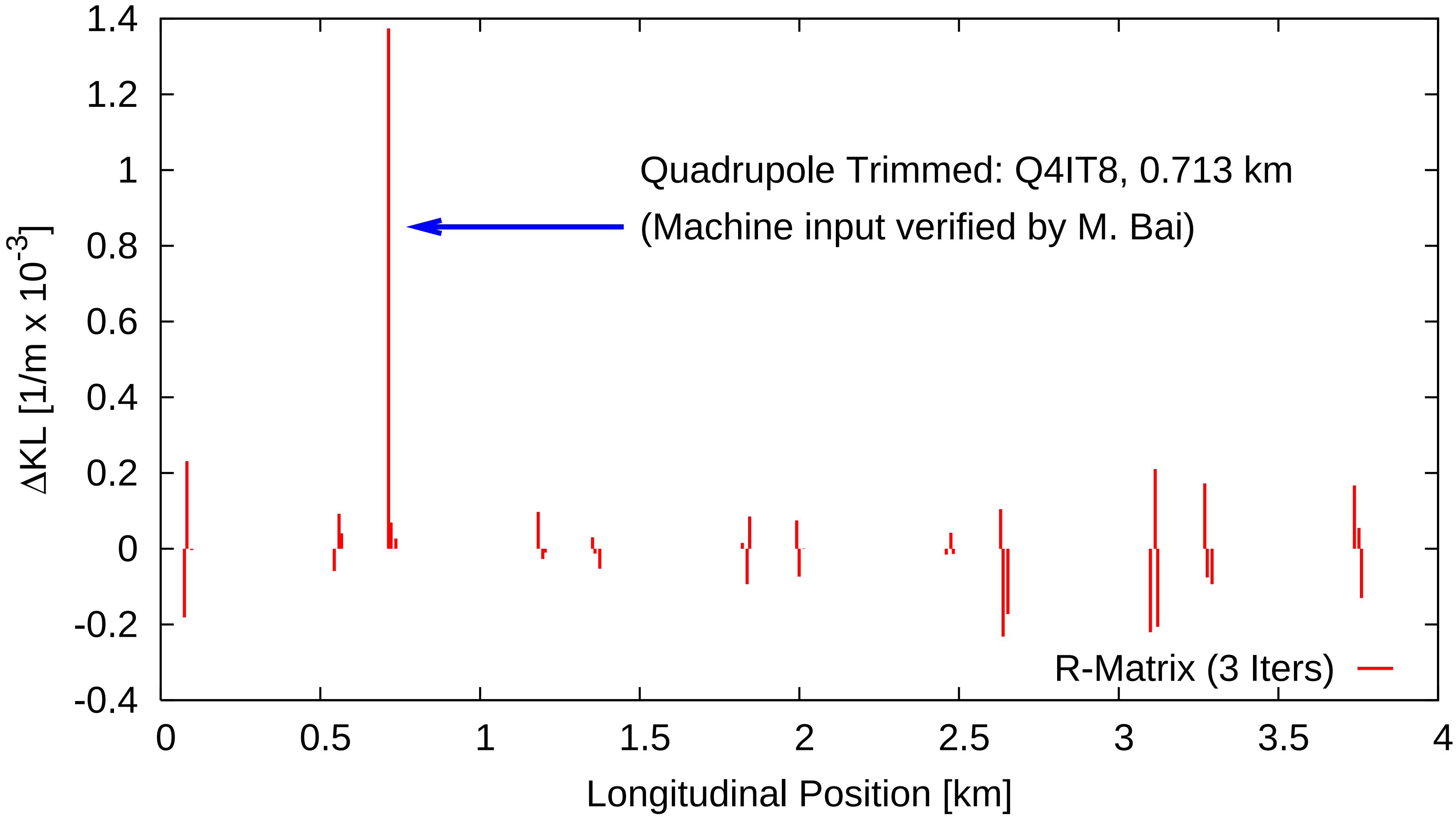
—— AC Dipole Data: Courtesy M. Bai

Exp II: AC Dipole ($\Delta\phi$-beat, Recons Machine)



—— AC Dipole Data: Courtesy M. Bai

Exp II: AC Dipole (Reconstructed ΔKL)

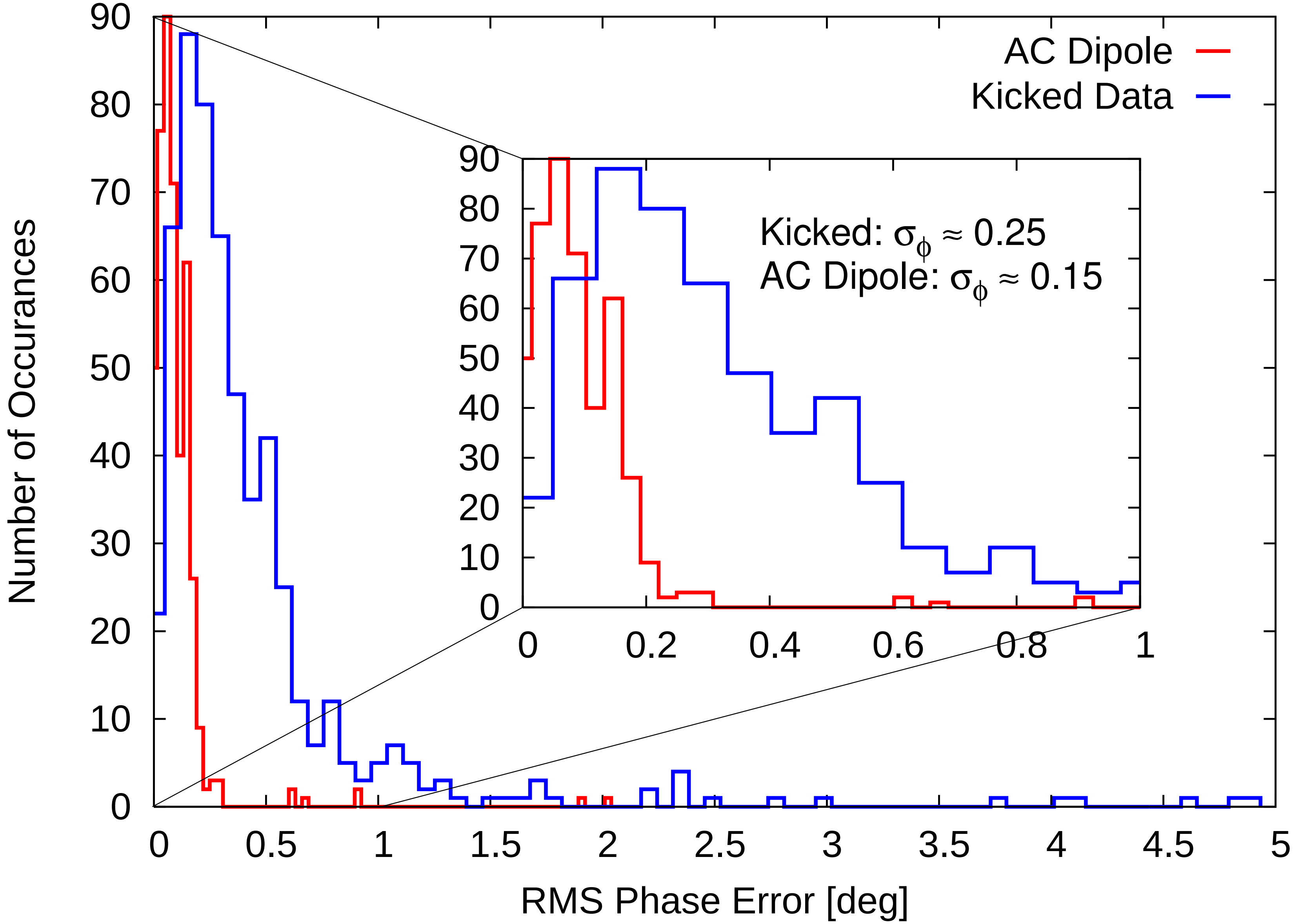


AC Dipole Data: Courtesy M. Bai

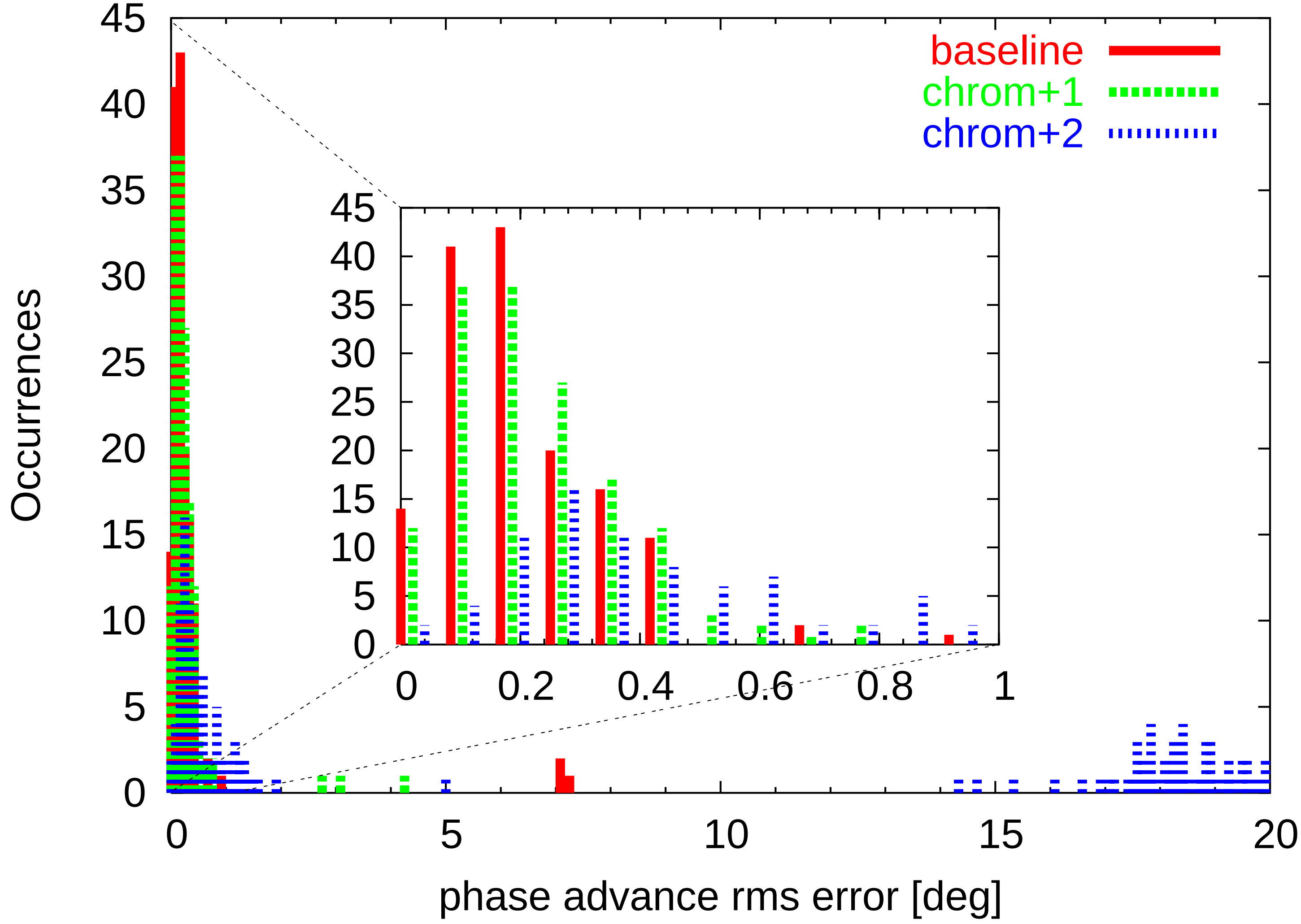
$\Delta\phi$ Measurement Err (σ_ϕ)

Kicked & AC Dipole Exps

Ph. Err (σ_ϕ), Low Chrom (Kicked & AC Dipole)



Ph. Err (σ_ϕ), Chromaticity Scan



– $\sigma_\phi \sim 0.25^\circ$ for low chromaticity (baseline)

– $\sigma_\phi \gg 1.0^\circ$ with larger chromaticity, but not seen in SPS (need confirmation)

SPS Measurements

Transverse Impedance Localization

- HEADTAIL Simulations (proof of principle)
- Measurements in the SPS

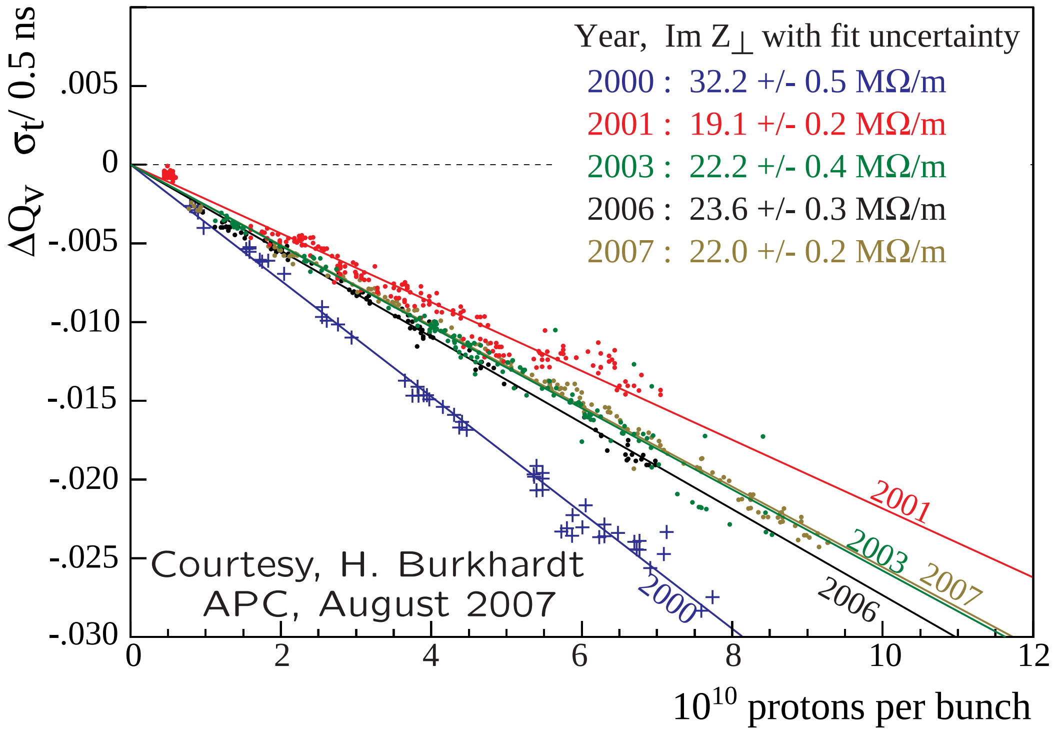
Partial Impedance Story

E. Métral, BEAM'07:

– 2001: Cavities, pumping ports, MKE kickers removed (↓)

– 2003-06: +7 MKE kickers in LSS4 & LSS6 (↑, smaller than expected)

– 2007: -1 MKE kicker & sheilded 1 MKE kicker (↓, but not obeserved)



– E_b =26 GeV, $\sigma_t = 0.5 - 0.6$ ns

– Some disagreement between predicted ↔ measured

– Also increase seen in $Z_{||}$ not observed in $Z_\perp$

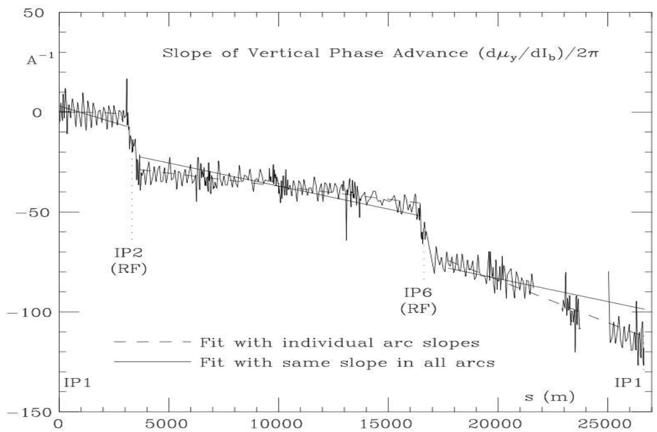
Many APC talks on impedance

Impedance Localization

Localization of the largest $Z_\perp$ sources using intensity depedent optics may help resolve some discrepancies.

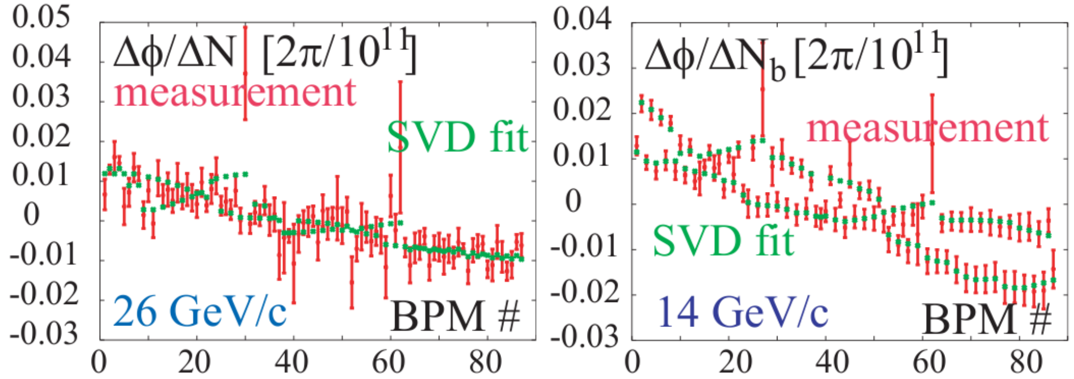
Already tried in LEP & SPS:

D. Brandt et. al, PAC 1995



- RF sections, IP2 & IP6
- 2800 shielded bellows

G. Arduini et. al. EPAC 2004



- Impedances concentrated in a few locations
- MKP, MKE kickers + some unidentified

$Z_\perp$ Localization, 2007-08

Reactive impedance can be approximated as a defocusing quadrupole:

$$K_{eff} = \frac{eN_b}{2\sqrt{\pi}\sigma_z(E_b/e)} Im\{Z_\perp\}_{eff}$$

To 1^{st} order, ΔK perturbation with intensity causes:

$$\Delta Q = \frac{1}{4\pi}\beta_k \Delta K$$

$$\frac{\Delta\beta(s)}{\beta(s)} = \frac{\beta_k \cos\left(2|\phi(s) - \phi_k| - 2\pi Q\right)}{2\sin\left(2\pi Q\right)}\Delta K$$

Procedure:

- Simulate/Measure phase advance between BPM pairs for varying intensities
- Appropriate noise cuts for BPM acceptance
- Linear fit: $\phi_I = \phi_0 + (\Delta\phi/\Delta N)N_b$
- $\Delta K = \mathcal{A}^{-1}\{\Delta\phi/\Delta N_b, Q_x, Q_y\}$, where $\mathcal{A}$ is model response matrix using
  - Quadrupoles (unconstrained/constrained)
  - Horizontal sextupole Bumps

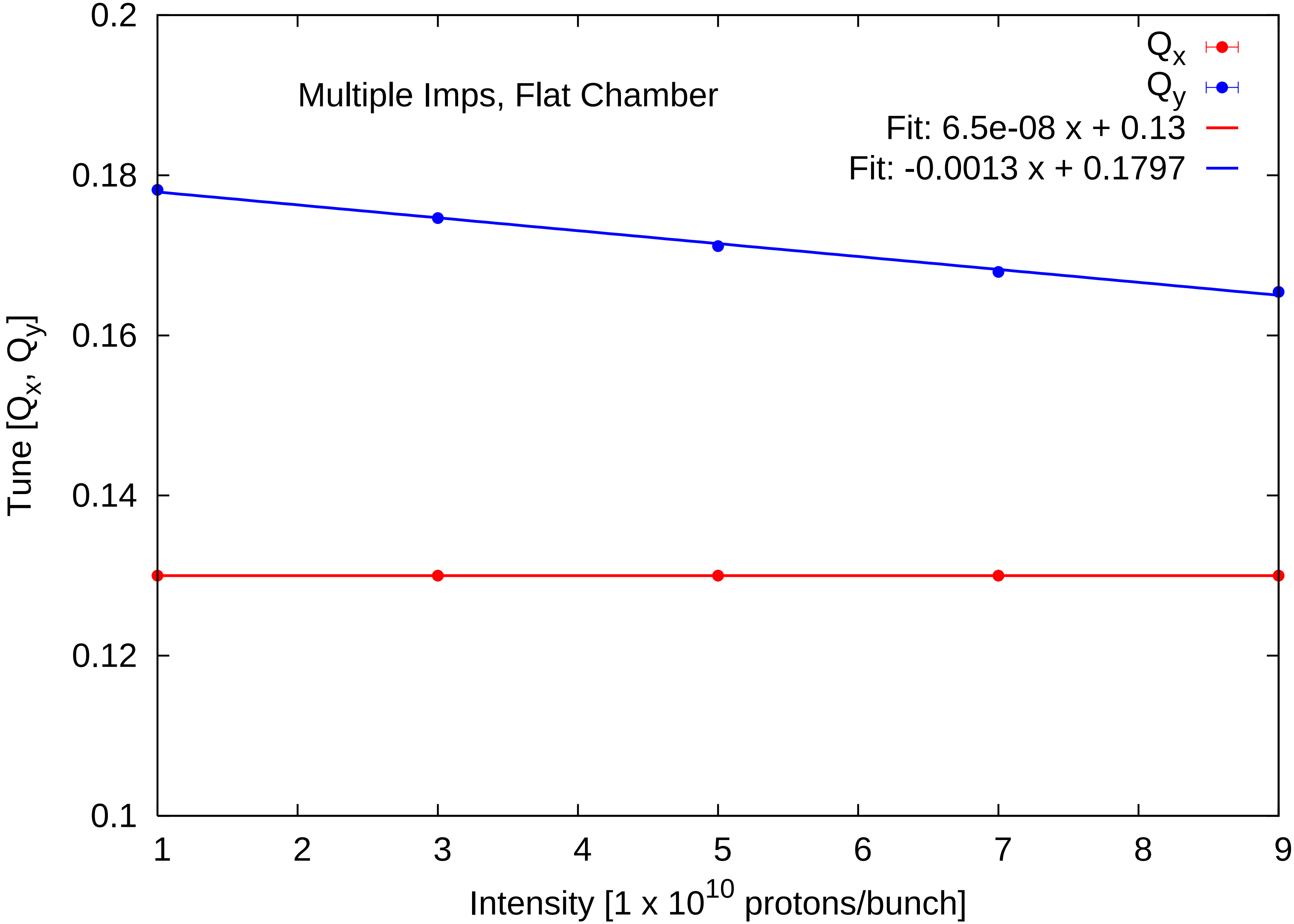
HEADTAIL Example

Impedance Localization Simulations

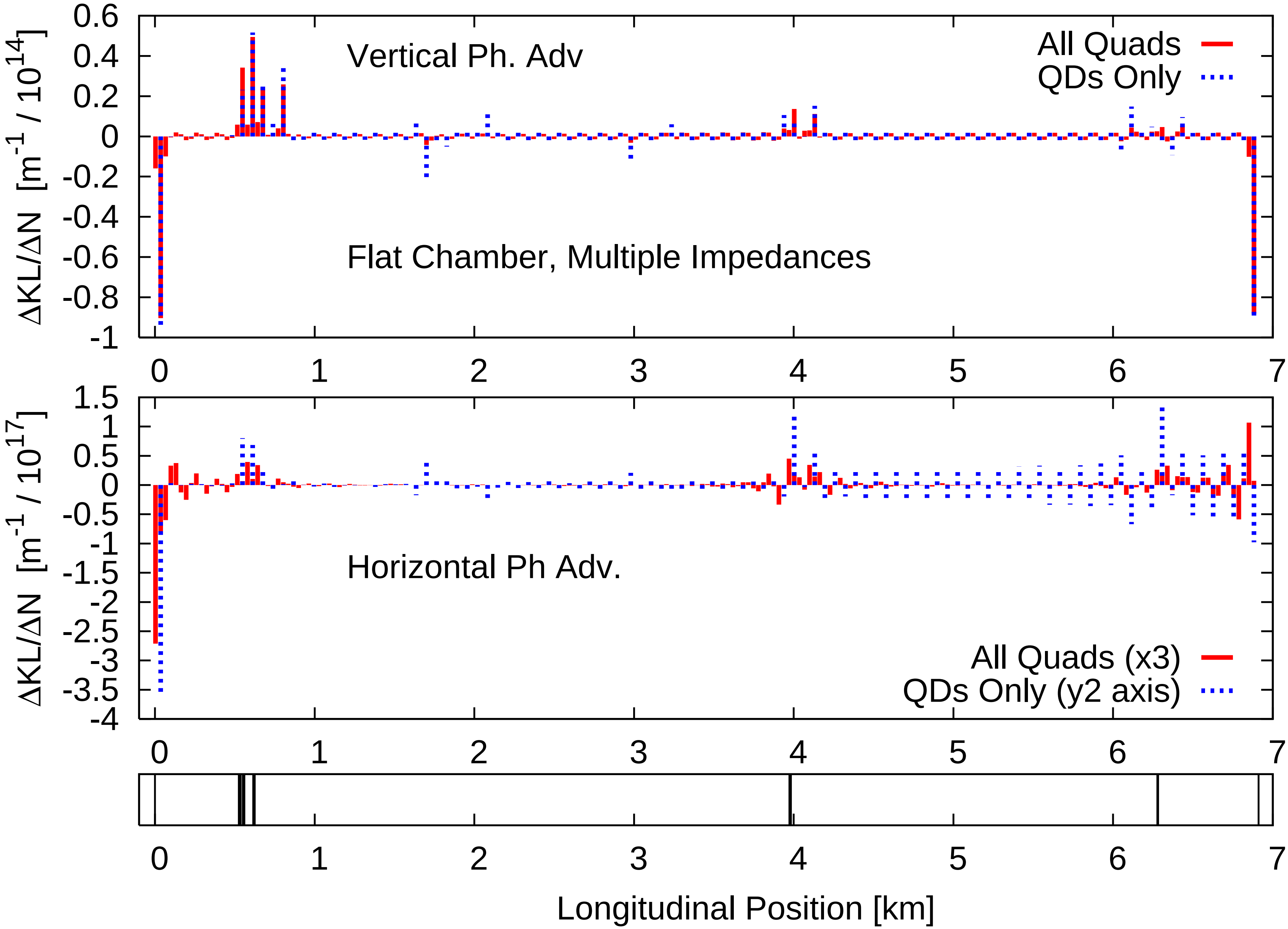
- Track particles SPS lattice with multiple impedance sources
- Records turn-by-turn orbits at BPM locations
- Five intensities to compute slope and reconstruct ΔK
  - Unconstrained
  - Constrained, defocusing in vertical plane

HT data courtesy: G. Rumolo, D. Quatraro

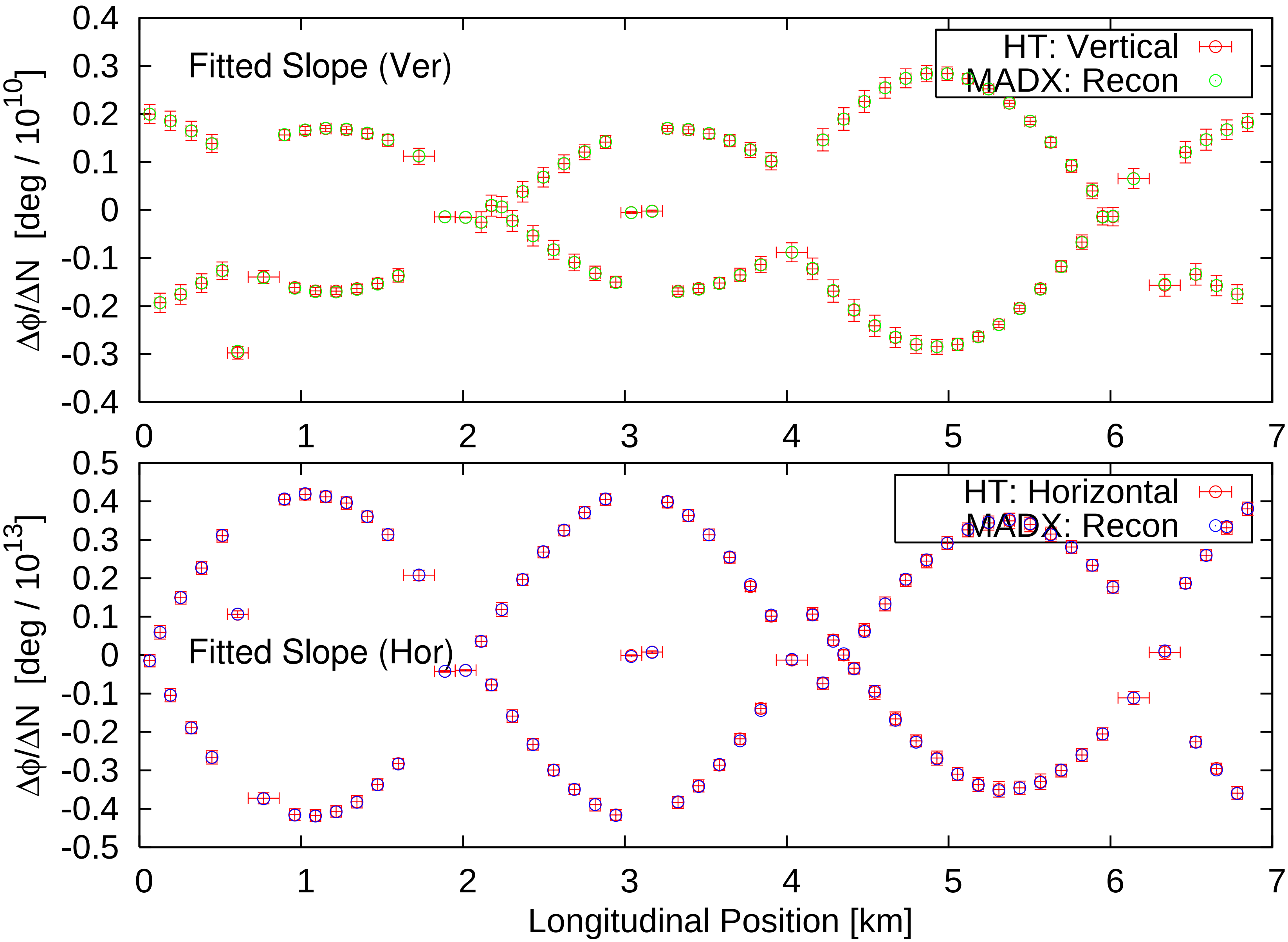
Tune Vs. Intensity



Reconstructed Sources

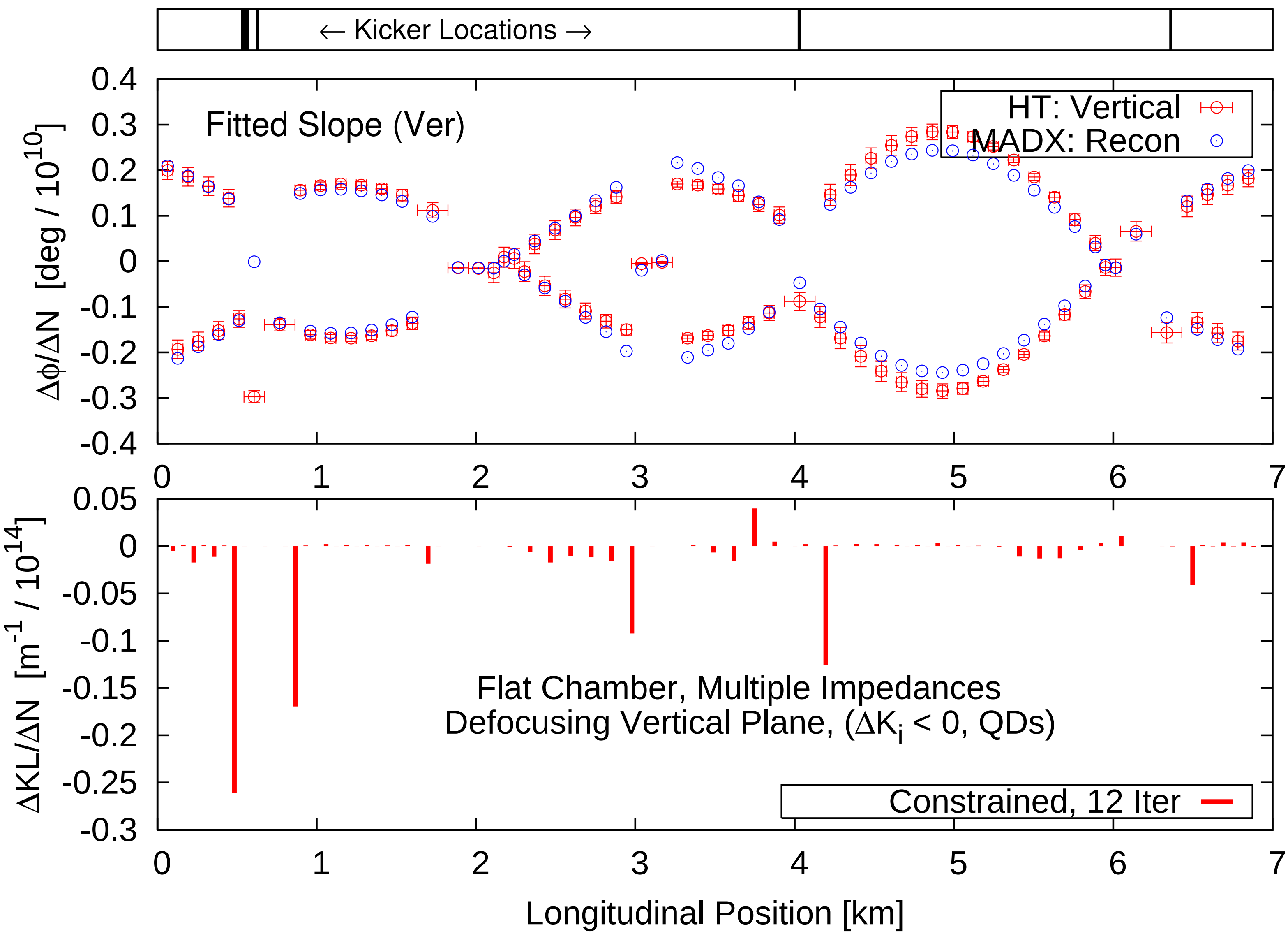


Intensity Fitted Slope $\{\Delta\phi_{a\to b}\}$



Constrained Reconstrution (Iterative)

$$[R, \vec{\lambda} I]\Delta\vec{K} = [\Delta\vec{\phi}, 0]^T \quad \{\Delta K_i < 0, \quad \text{QDs}\}$$

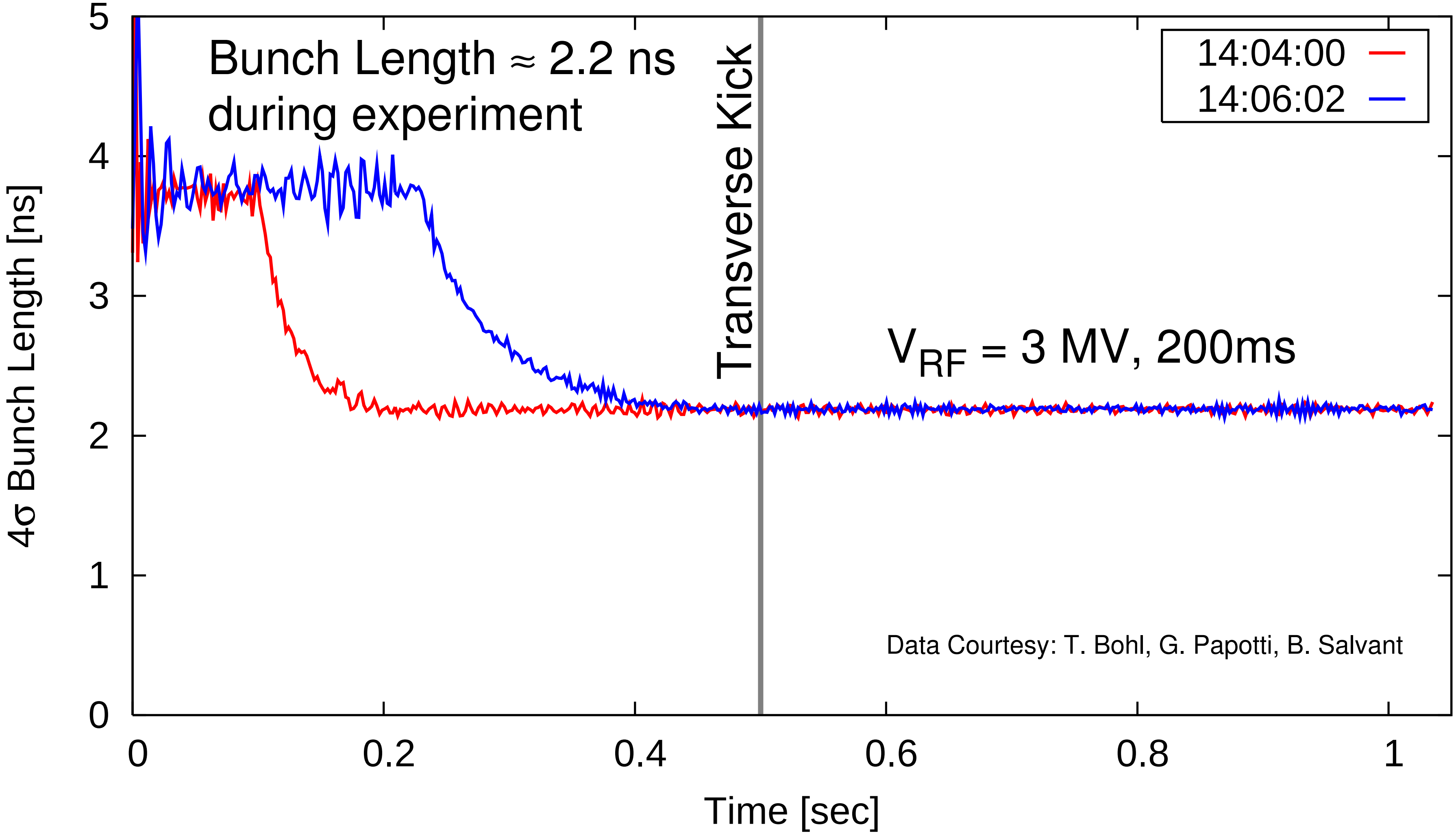


SPS Measurements

Impedance Localization Exps, Nov 2007

- MD1 Cycle, 26 GeV, $V_{RF} = 3$ MV, $\sigma_t = 0.55 \pm 0.05$ ns, $\xi_y \sim 1 - 3$ units
- Records turn-by-turn orbits at BPMs for $I_b = 5 - 140 \times 10^9$ p/bunch
- "Several" BPM filtering levels
- Reconstruct sources from intensity dependent optics

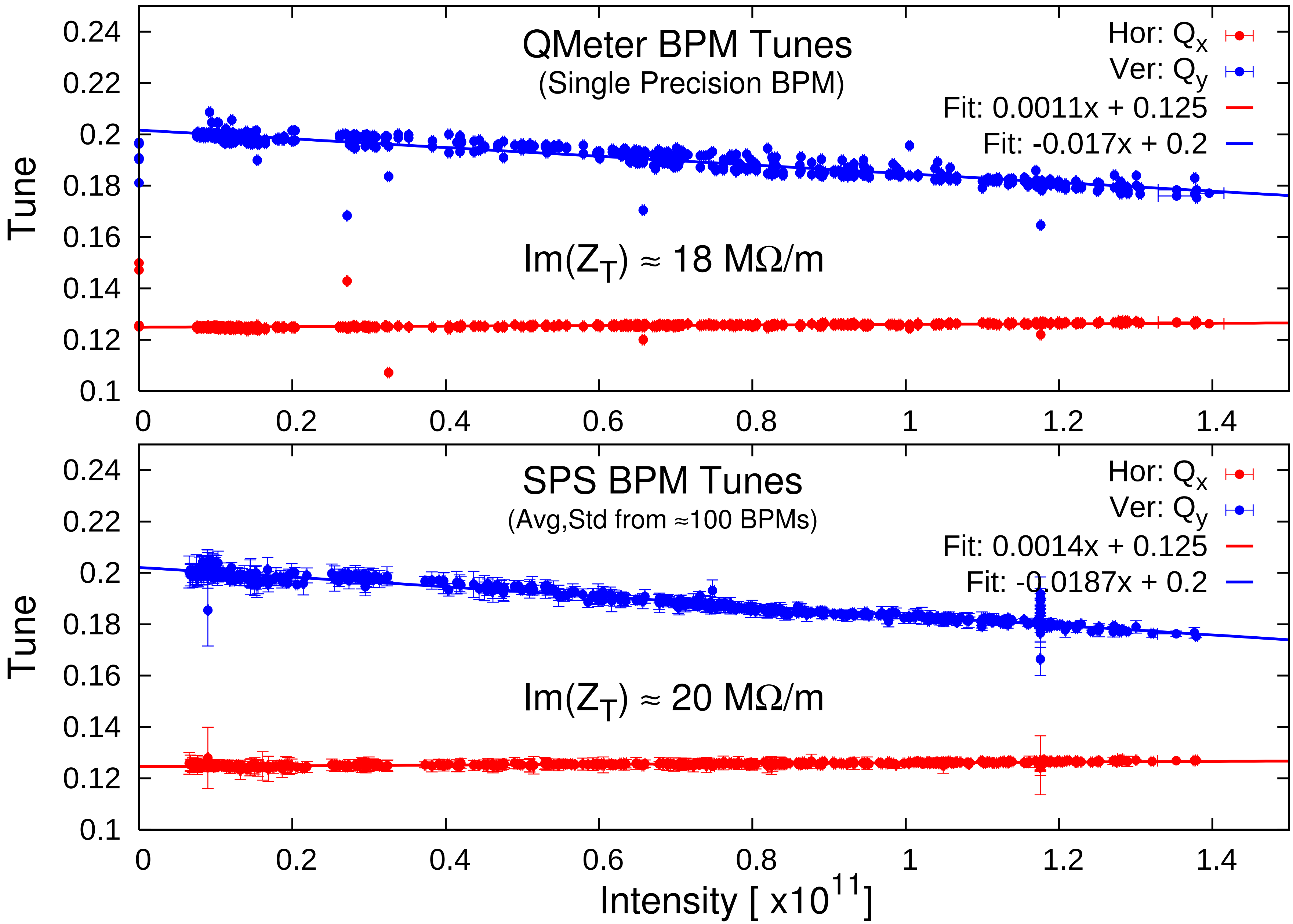
Bunch Length Measurement



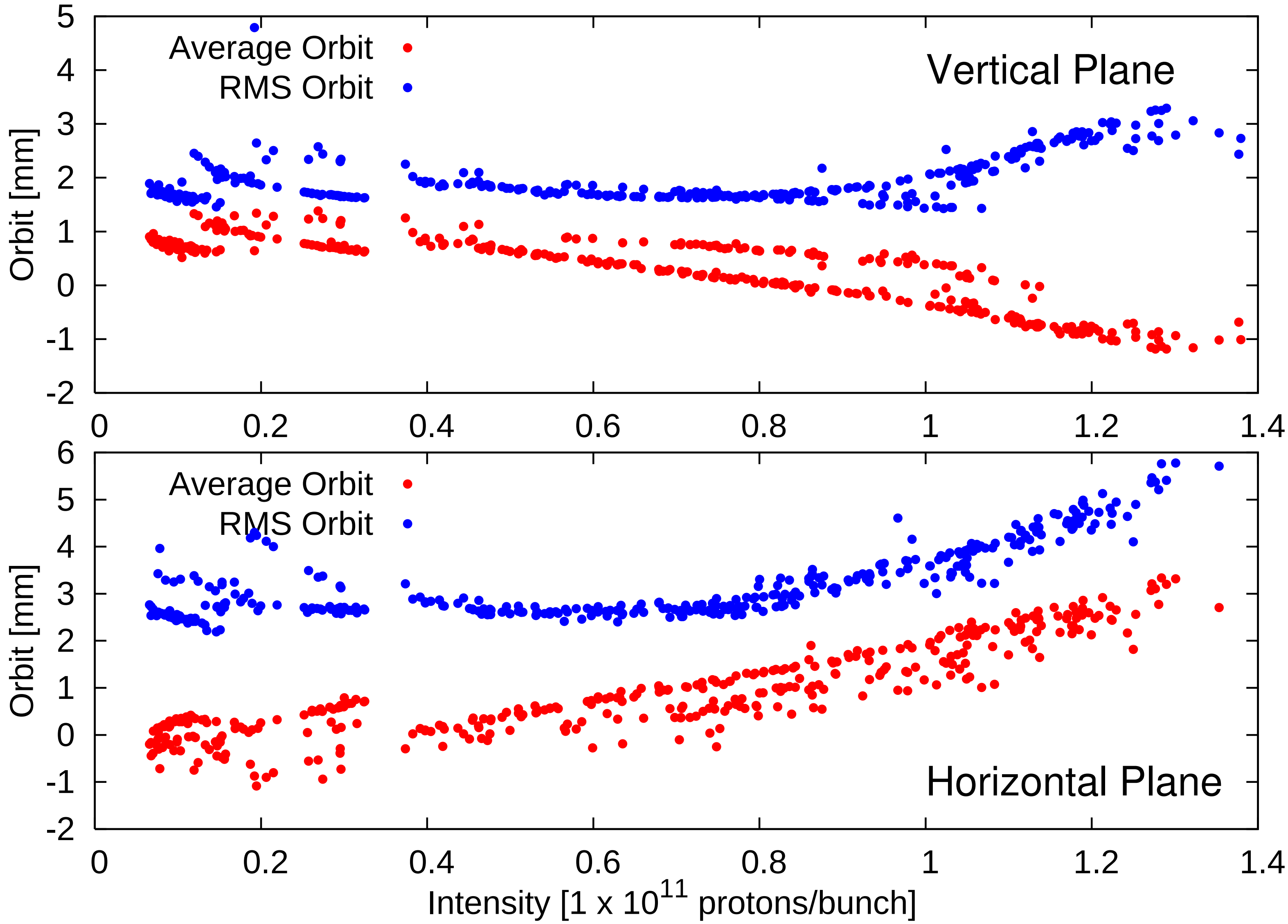
– Strong injection oscillations obsevered with high intensity

– RF voltage was set to 1.2 MV @100 ms, 3MV after 200 ms

Tune Vs. Intensity (Nov 2, 2007)

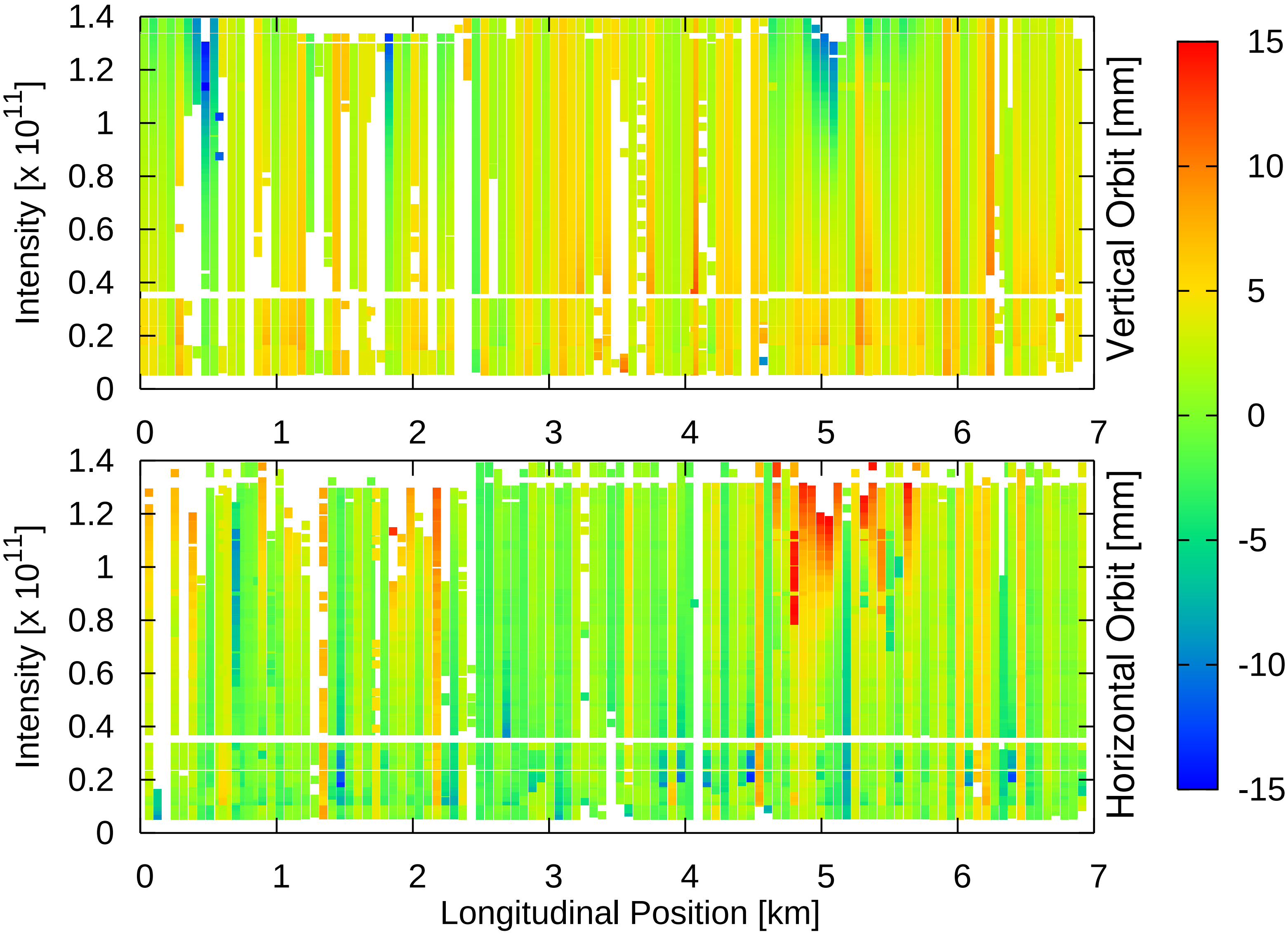


Orbit Shift Vs. Intensity



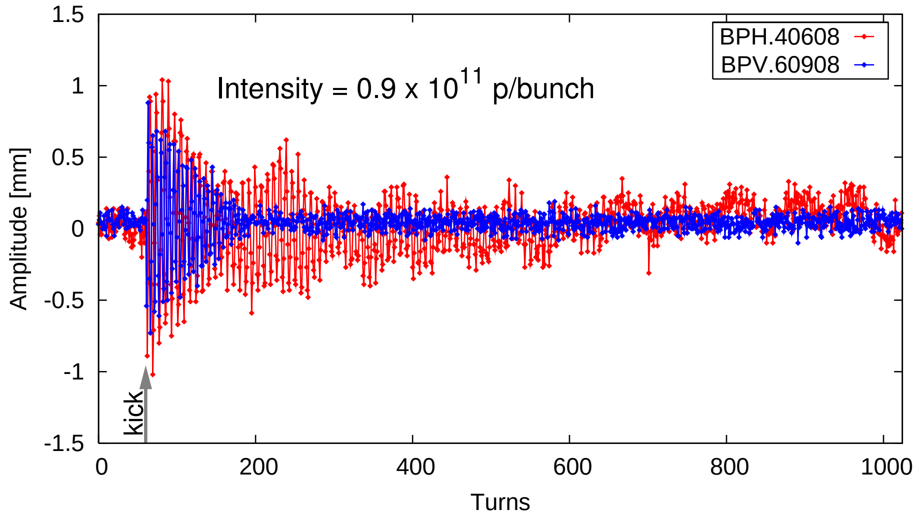
— Systematic change in average and RMS orbit $\longrightarrow \Delta Q_{x,y}$

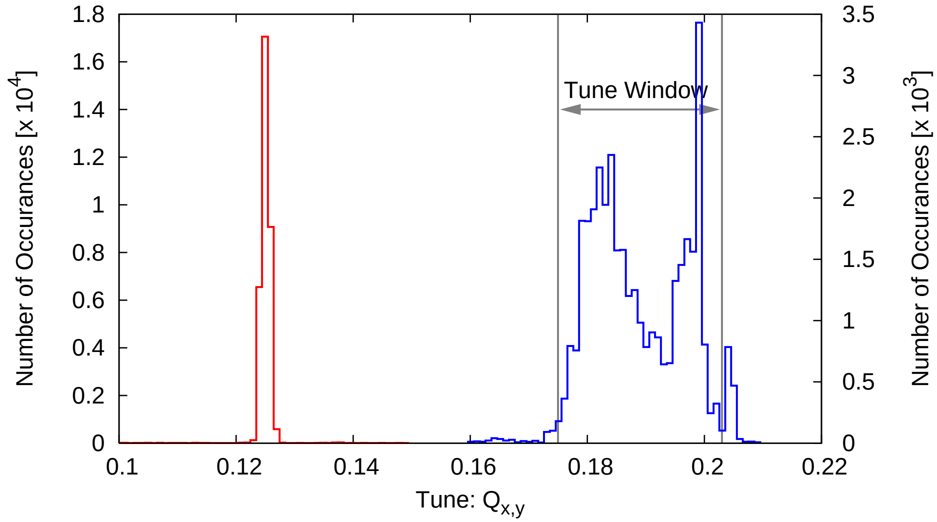
Orbit Shift Vs. Intensity Cont'd



— Orbit gradient mainly localized in a couple of sectors, ($\Delta\phi_{s_2 \to s_1}$ ok)

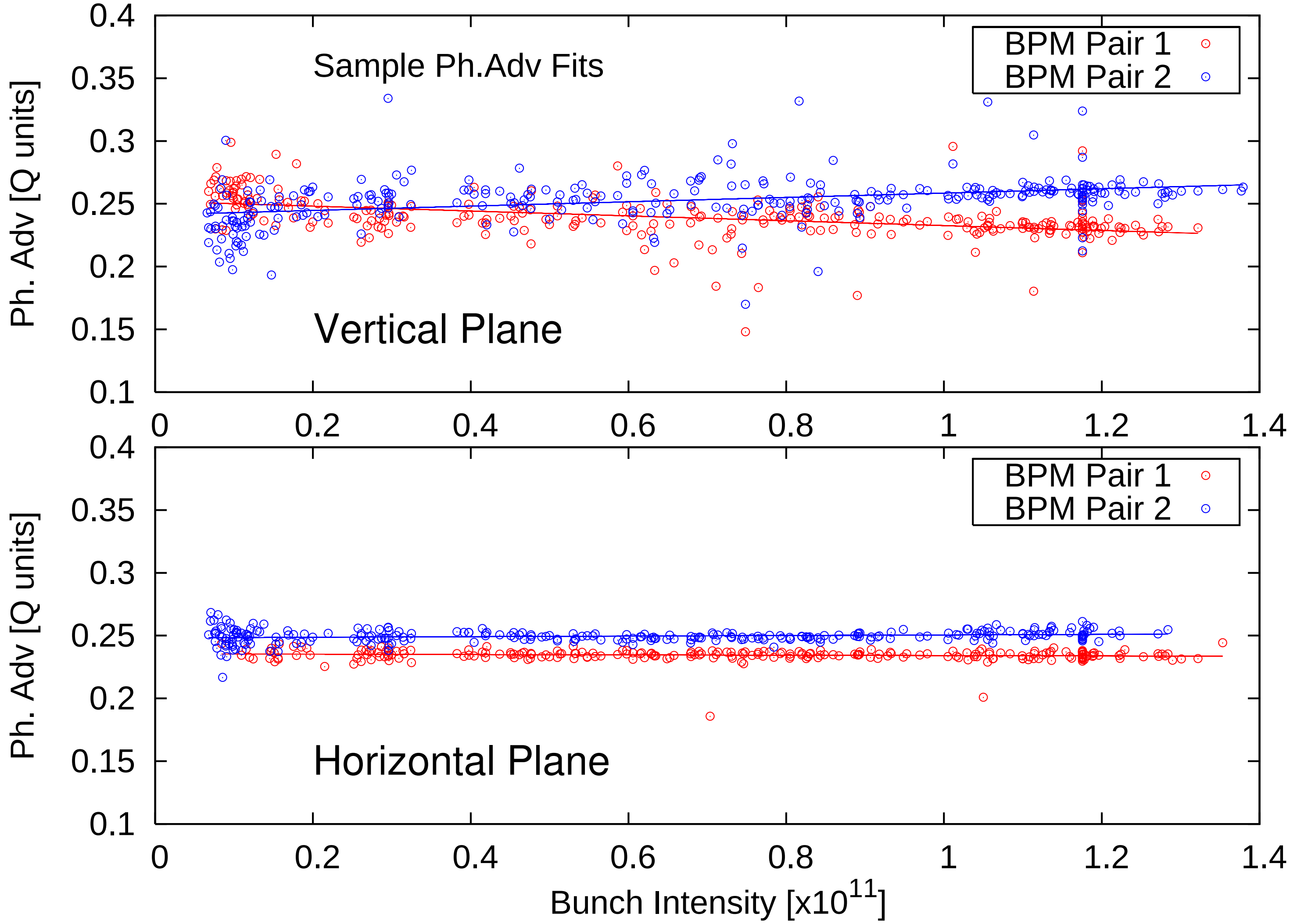
BPM Data Selection for $\Delta\phi_{s_2 \to s_1}$





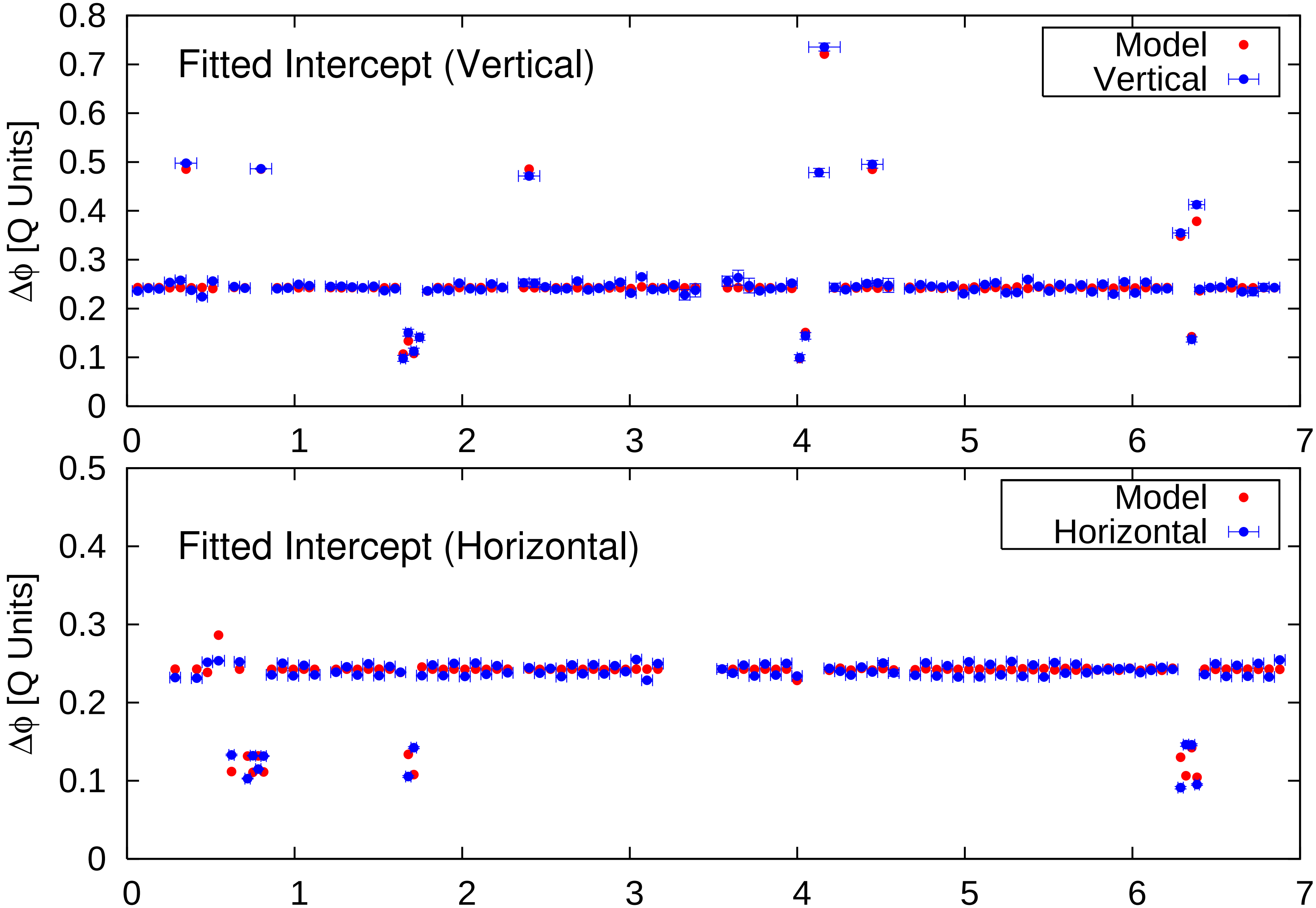
- Longer coherence observed at lower intensities ($\xi_{x,y}$ unchanged)
- Histogram of tunes from all BPMs ($\sim$100), all files ($\sim$410)
- Use Sussix to calculate frequency and phase within window
- Tune window & ph. adv of the (meas-model) used as selection criteria

Sample Fits (Nov 2, 2007)

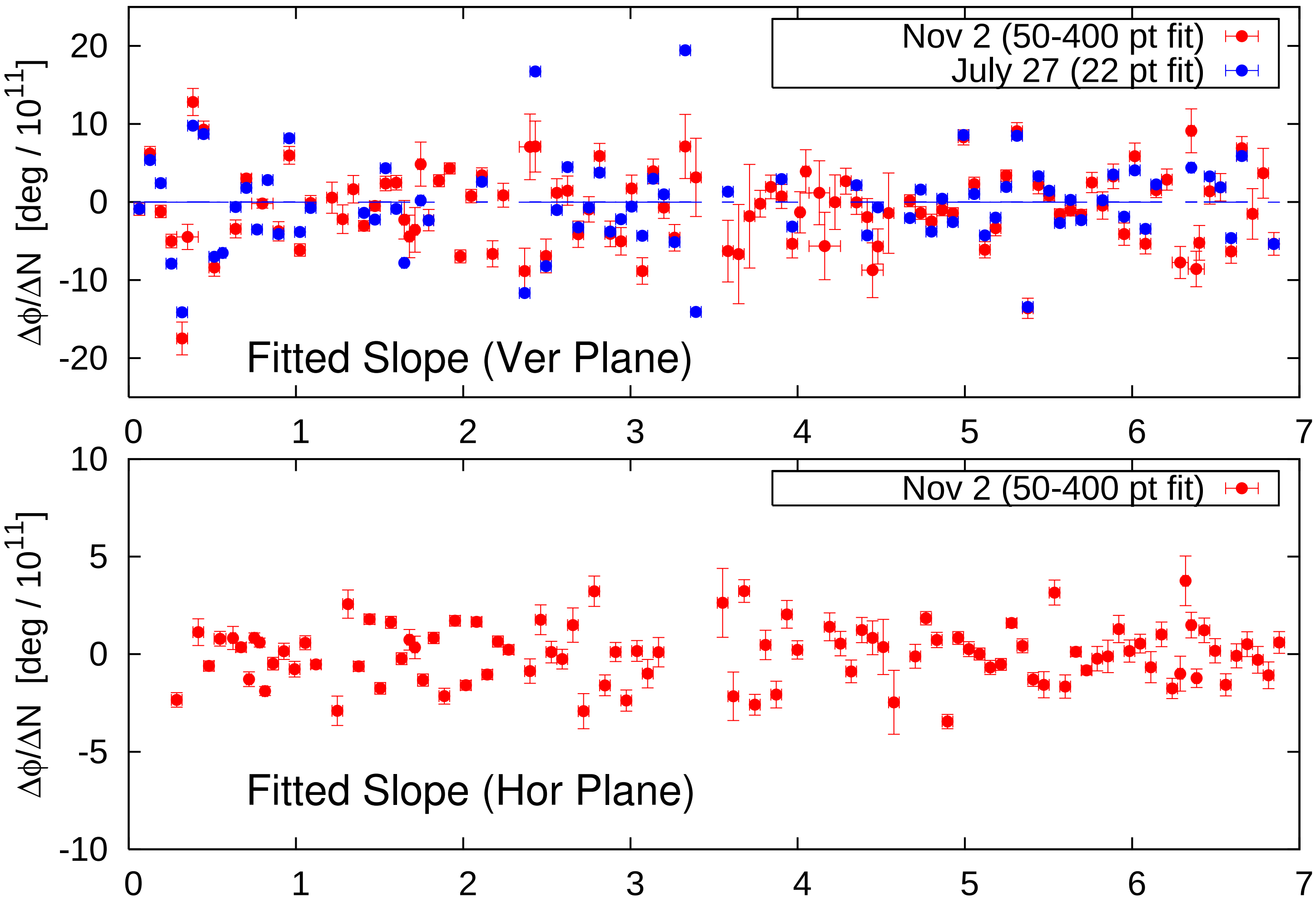


- Retain BPMs passing fit selection criteria
- Spread is larger in Vertical (Impedance, Chromaticity, ...)

SPS Zero Current Ph. Adv (Nov 2007)

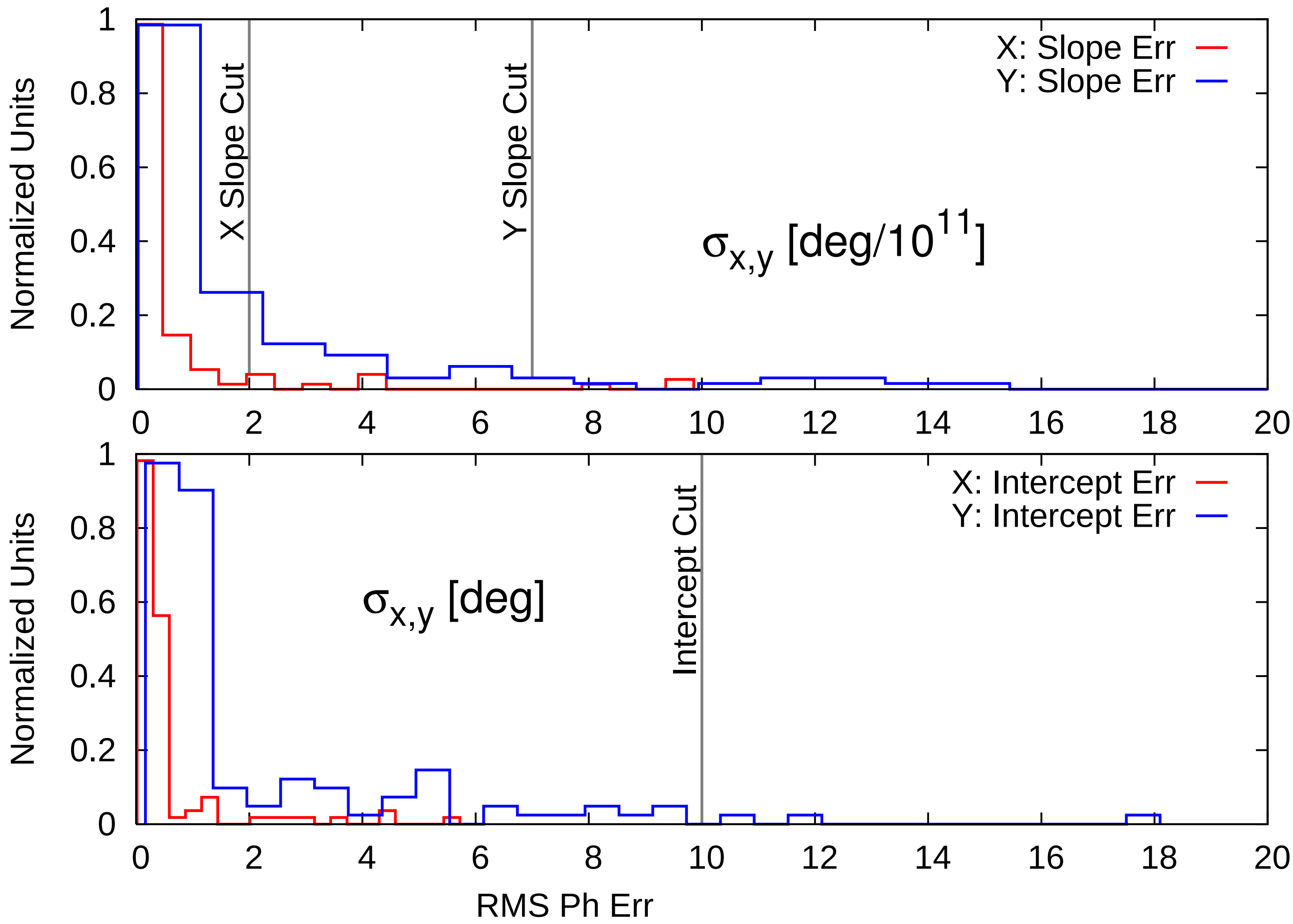


Fitted Slope $\Delta\phi/\Delta N$



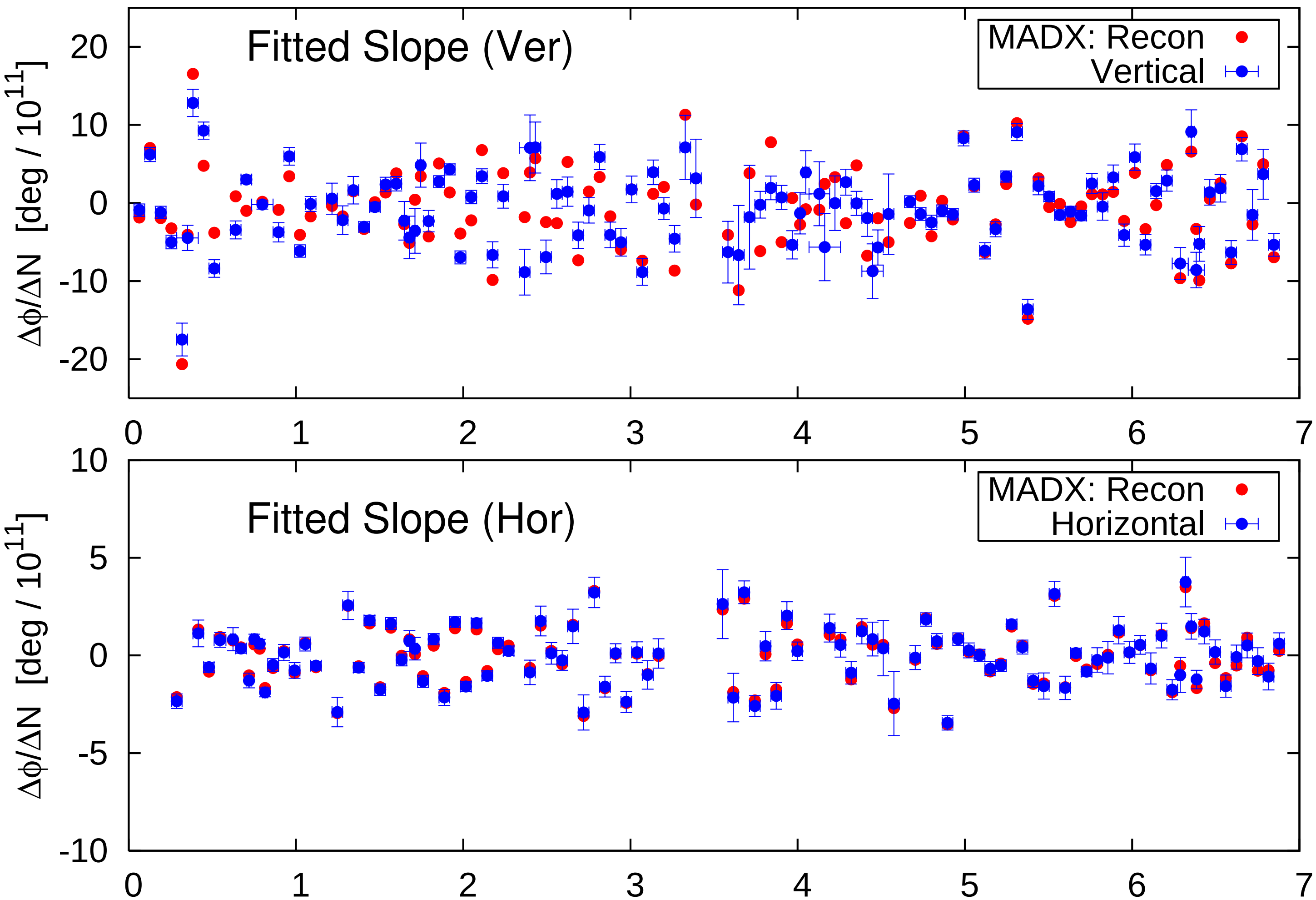
- Similar slopes from 2 exps: Nov 2 (400 data sets) & July 27 (22 data sets)
- Vertical slope errors larger than horizontal (probably due to $\xi_y > \xi_x$)

Error Cuts (Nov 2007)



- Error in phase adv < 1deg (a bit high)
- Error in slope is 1 order of magnitude smaller than slope

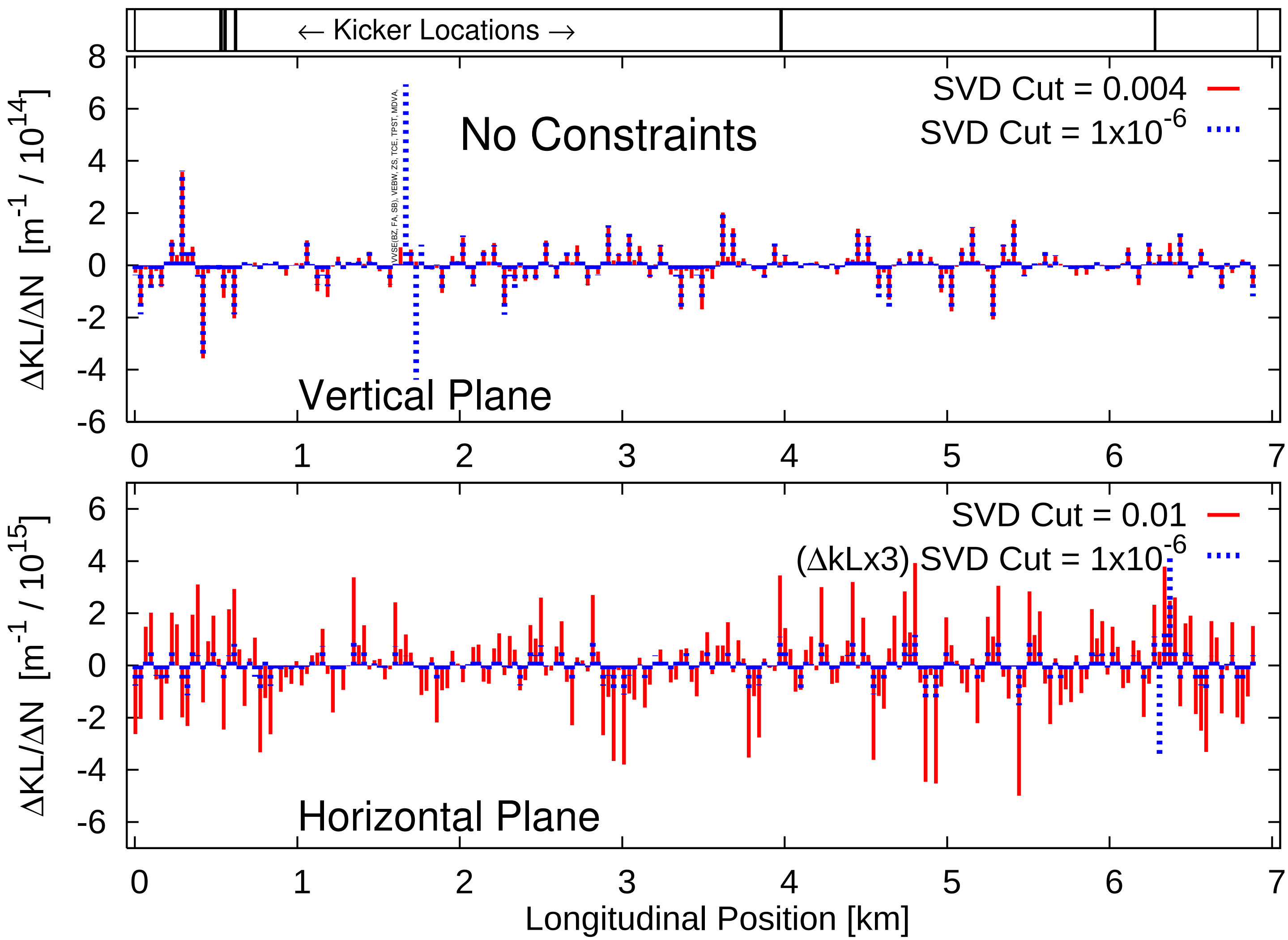
Fitted/Reconstructed Slope (Nov 2007)



– Similar slopes for 2 exps: Nov 2 (400 data sets) & July 27 (22 data sets)

– Relative error appears similar, not too much gain from statistics

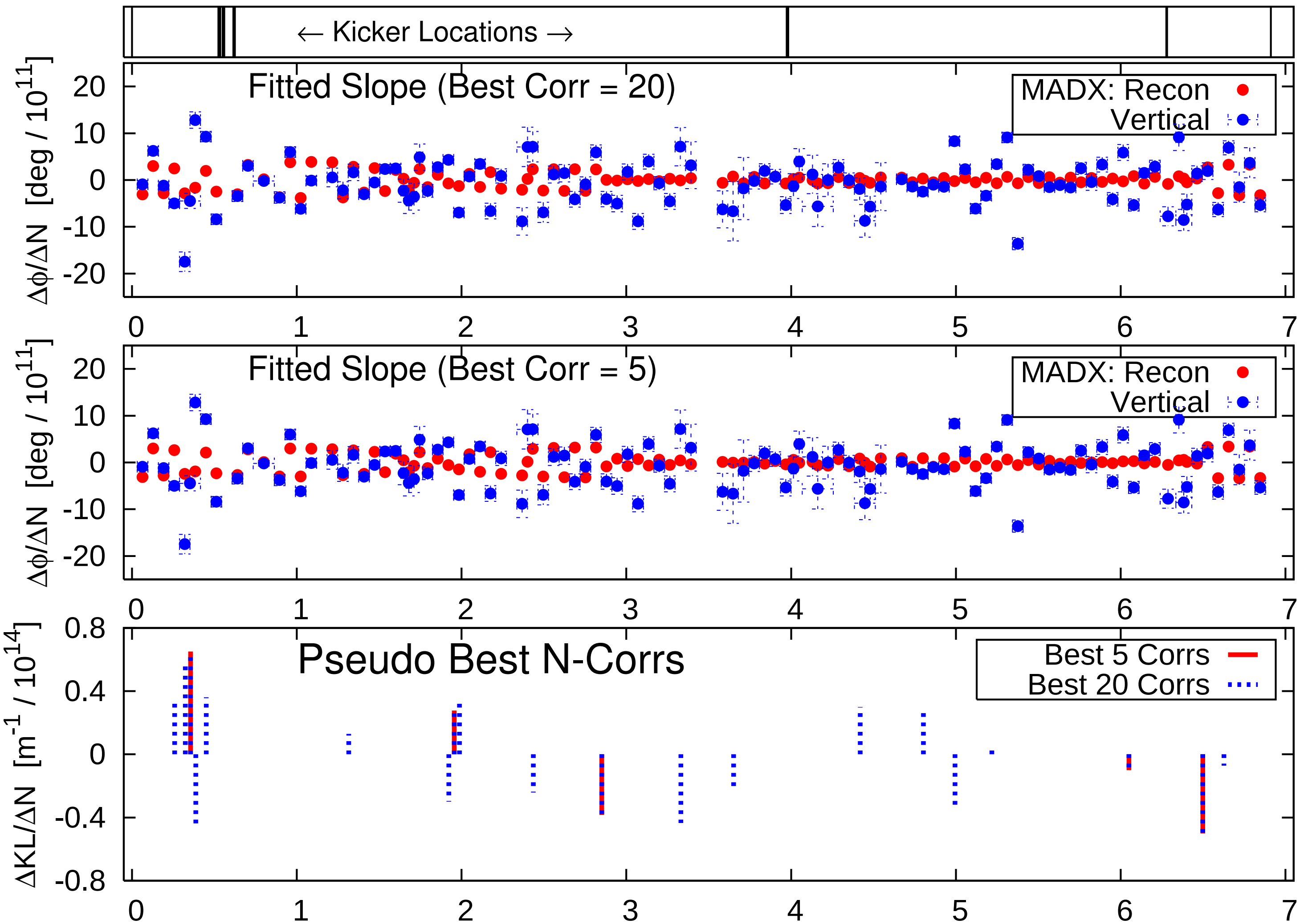
Estimated $Z_\perp$ Distribution, I



– Few sources, but reconstruction sensitive to SVD cut (1.7 km spikes)

– Horizontal plane is inconclusive

Estimated $Z_\perp$ Distribution, II

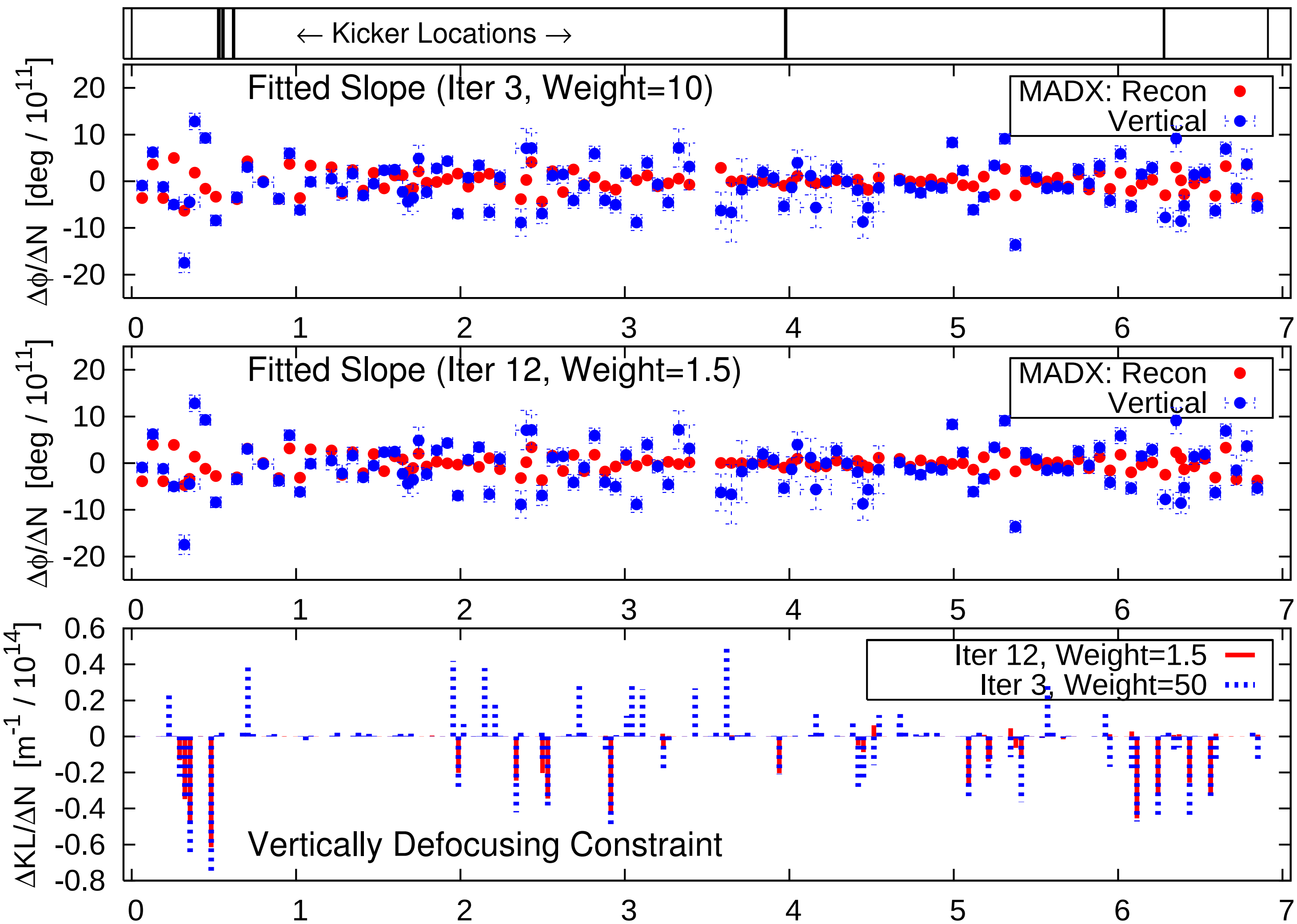


– Reconstruction not satisfactory, but main sources similar to unconstrained case.

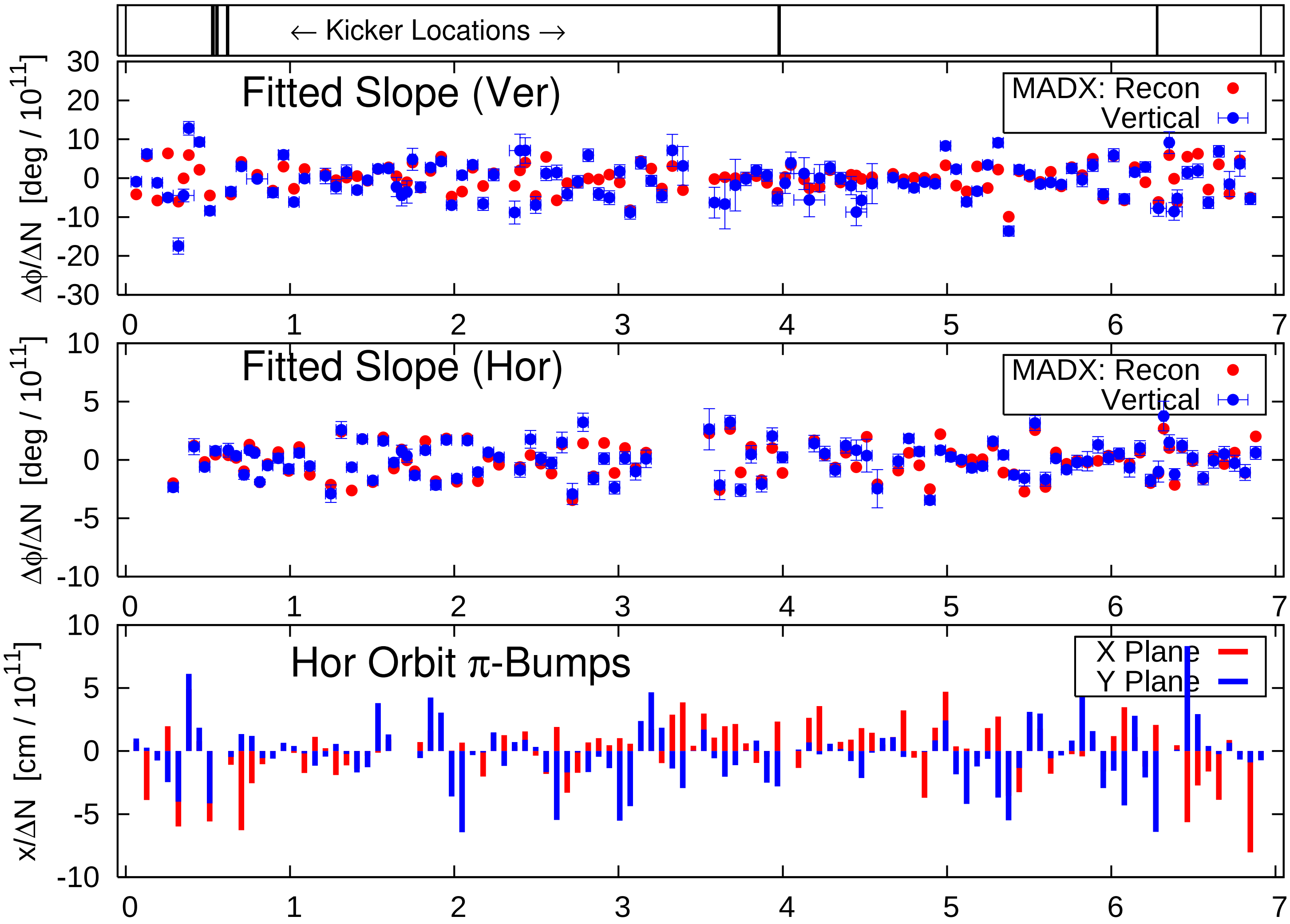
Estimated $Z_\perp$ Distribution, III

$$[R, \vec{\lambda} I]\Delta\vec{K} = [\Delta\vec{\phi}, 0]^T$$

$$\{\text{constraint: } \Delta K_i < 0,\ \text{QDs} \rightarrow \text{iterative weights}\}$$



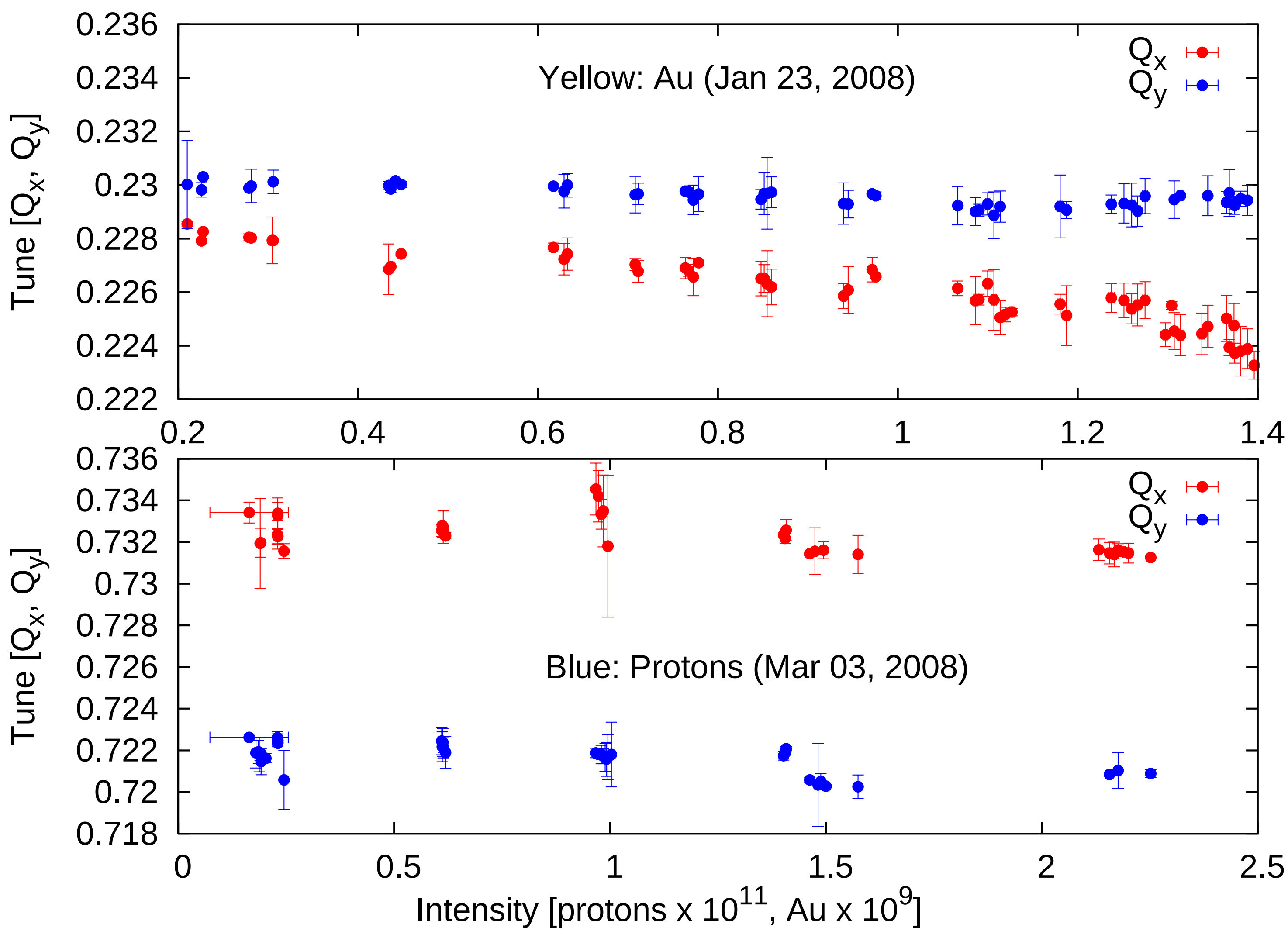
Estimated $Z_\perp$ Distribution, IV



– Phase beating induced by horizontal orbit bump, sextupole feed down

– Reconstruction useful for comparison, needs further investigation

Tune Vs. Intensity (RHIC)



– Observed tune shift negligible (need dedicated exps for confirmation)

– Need to separate Q_x, Q_y to eliminate coupling effects

Conclusions

– Powerful technique to localize largest impedance locations

– Careful machine setup and data quality assesement is of primary importance

– Approx similar impedance distribution observed with different techniques

– Detailed analysis underway to infer local impedance contribution

– Future SPS experiments planned:

  - Baseline optics measurements with intensity scan
  - $\delta p/p \neq 0$ for dispersion measurement with intensity, additional constraint
  - Local orbit bumps at specific locations to infer/calibrate impedance contribution

– RHIC needs dedicated experiments to repeat impedance measurements

— Bon Appetit