TOOHIG Fellow

Summer Experience @CERN

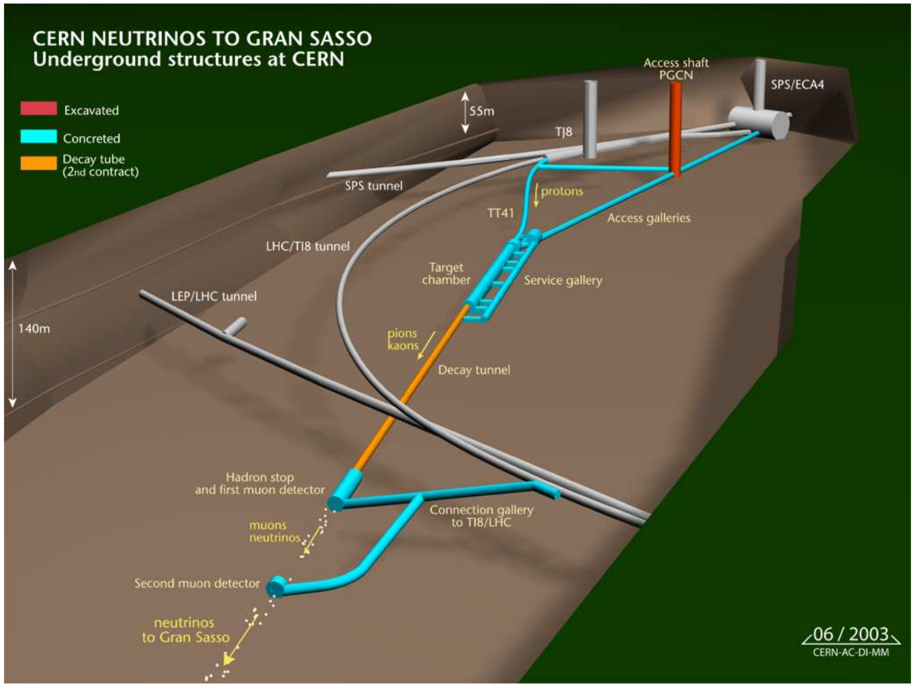
Rama Calaga

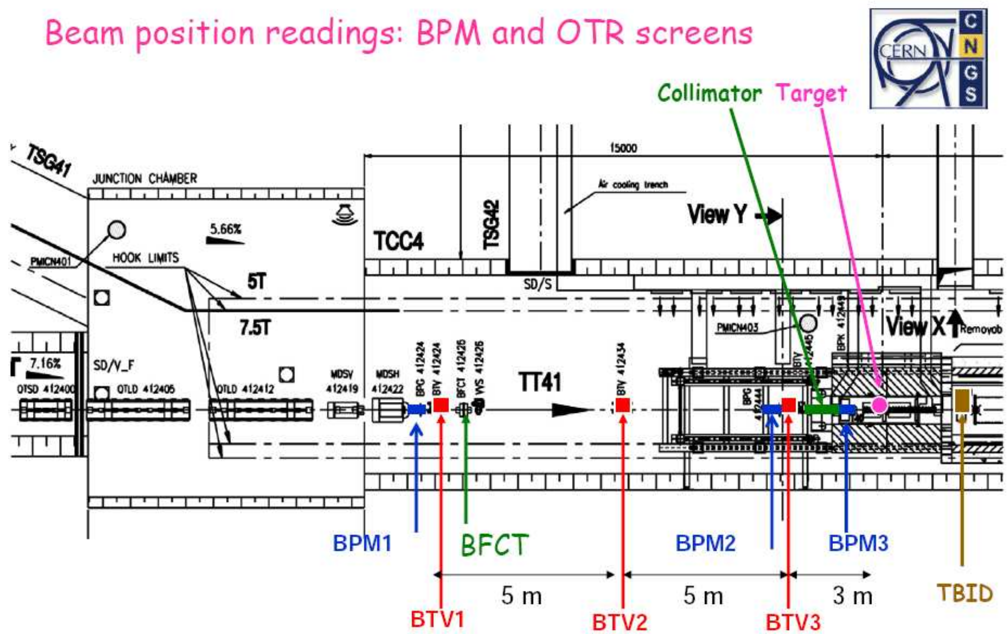
LARP Collaoration Meeting,
Oct 25, 2006

EPAC/CERN/LUMI-06 (June 24-Oct 21, 2006)

- SPS Exps
  - CNGS beam line commissioning
  - SPS optics measurements
  - Linear and non-linear chromaticity measurements on SPS ramp
  - Lifetime studies in SPS
- LHC Work
  - Beta-beat and dispersion beat correction for LHC injection
  - Crab cavity studies for LHC IR upgrade
- BBLR Experiments & Wire Compensators
- TOOHIG-Tips Website & General Comments

CNGS Line

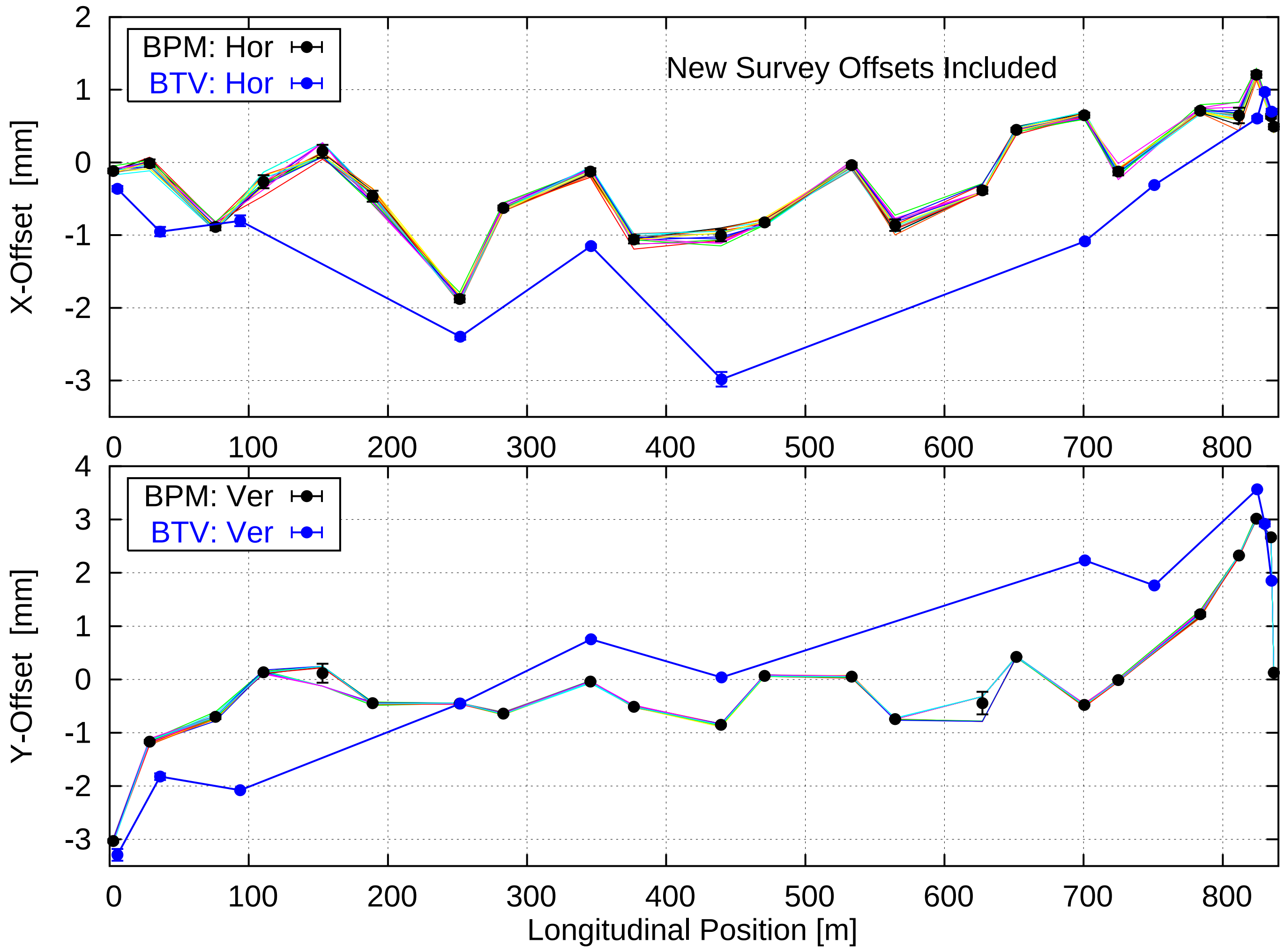




Courtesy: CNGS Group

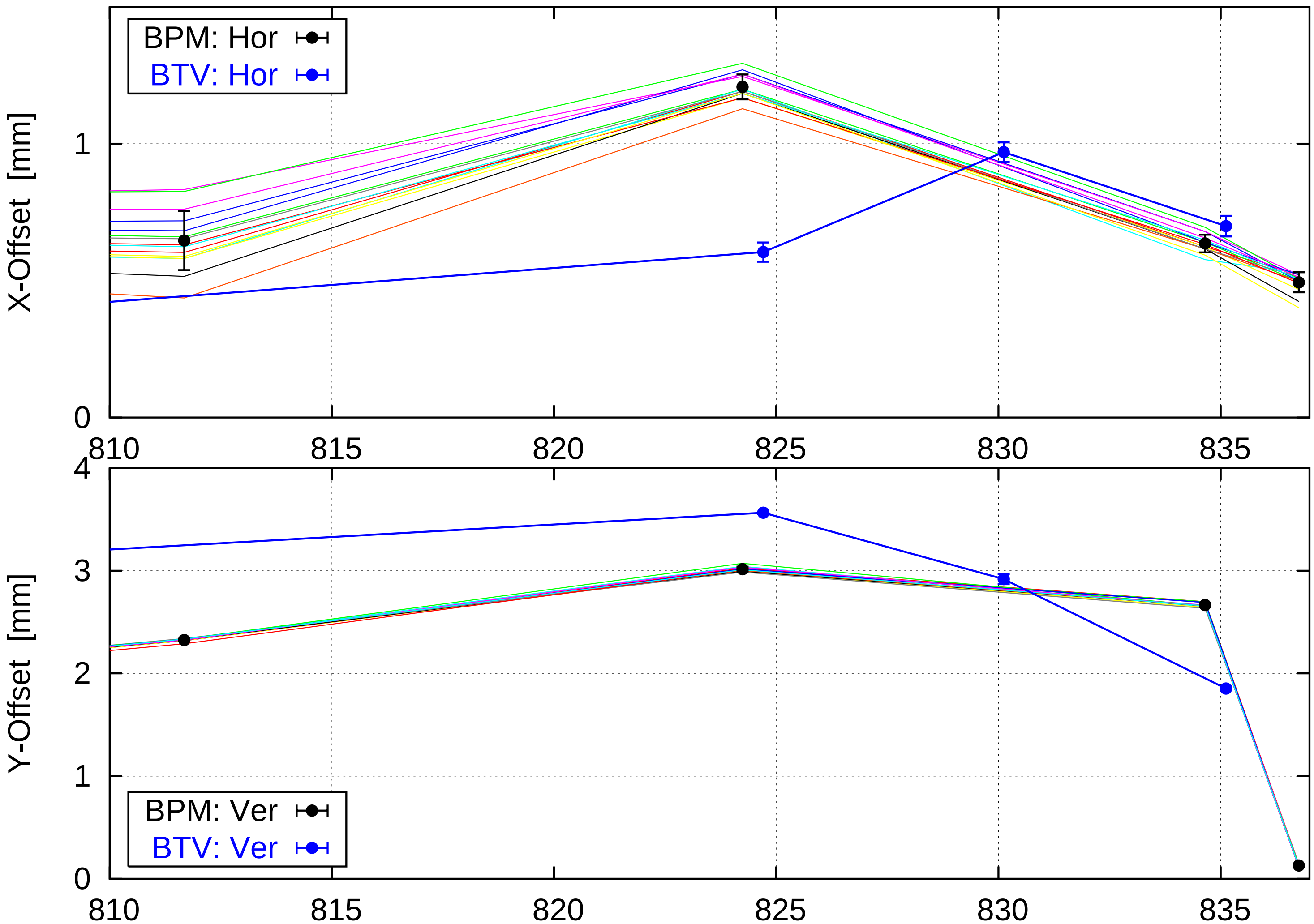
- 18 button electrodes along the line (60 mm aperture)
- 8 Profile monitors, transitions radiation screens
- Last two cameras have less resolution (E. Bravin)
- My Job: Calculate beam positions, emittances, $\Delta p/p$ using BPMs & BTV and compare to MADX model (Thanks: M. Medahhi, T. Pieloni, W. Herr)

CNGS Line: Beam Positions



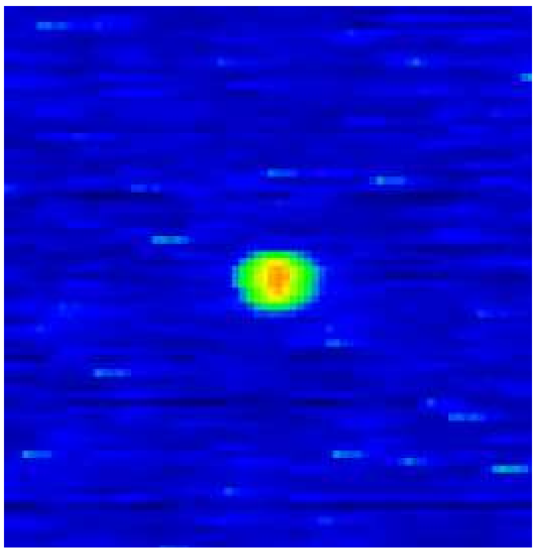
- Disagreements between BPMs & BTVs (under investigation)
- BPM positions to be trusted (E. Bravin)

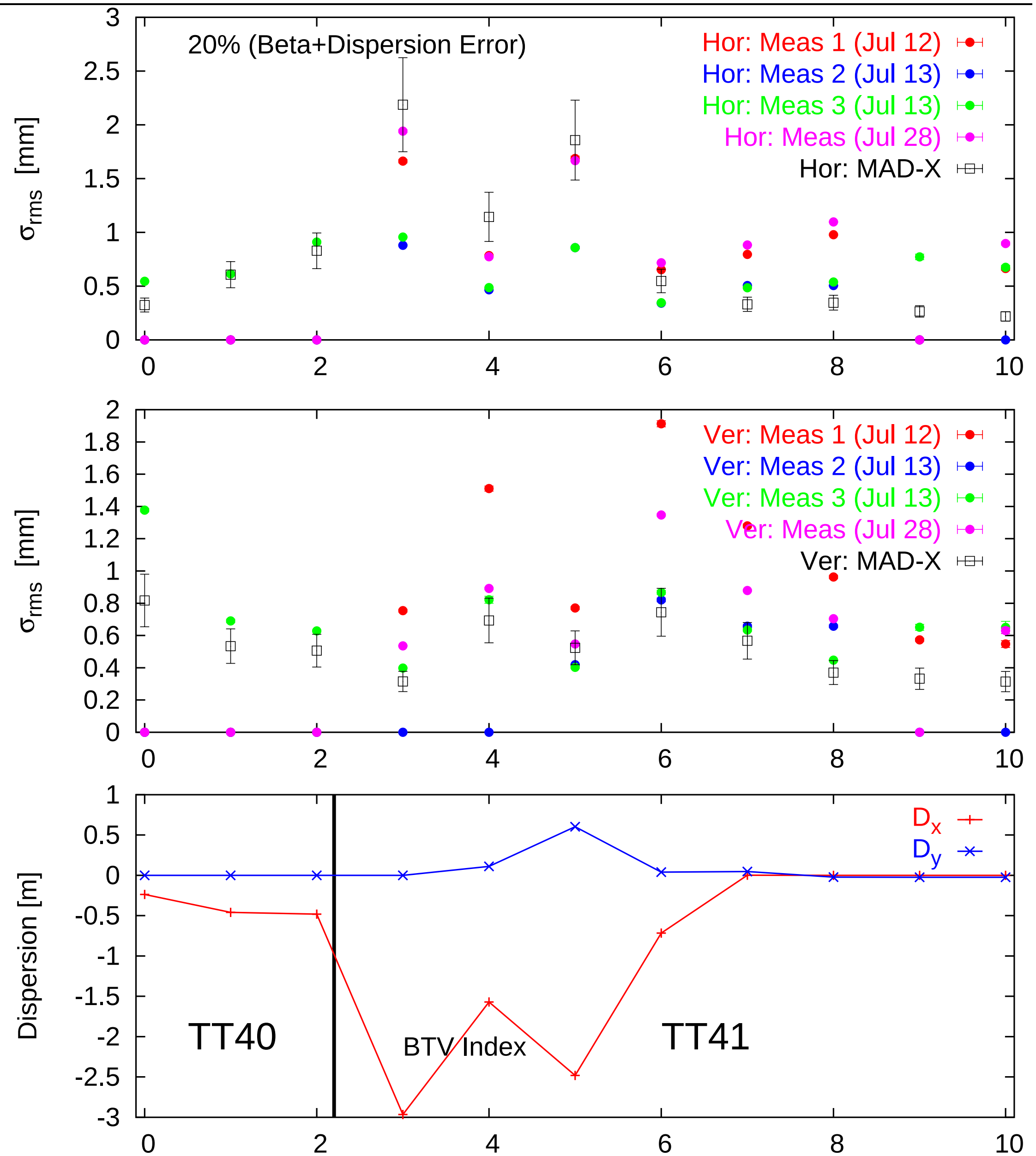
CNGS Line: Last 3 BTVs Before Target



**LHC note in preparation

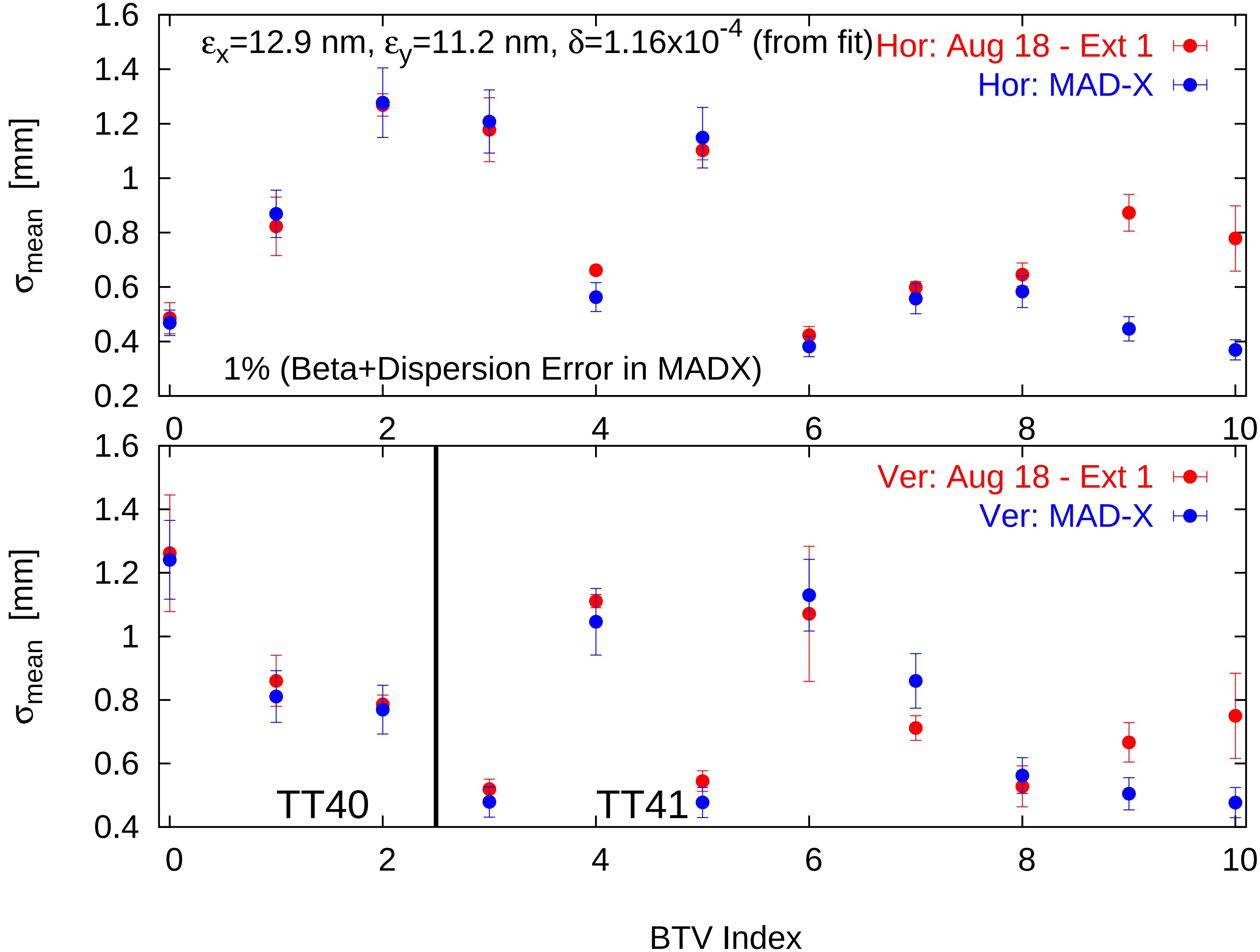
CNGS Line: Beam Sizes & Emittances





- No automatic script
- Background
- Manual calculation time consuming

CNGS Line: Beam Sizes & Emittances



Lifetime Studies of LHC Beams

From 2004 measurements, more losses at the end of the bunch train (possibly due to ecloud type instabilities).

LHC type beam at coast

- 270 GeV
- 72 bunches, $\sim 1 \times 10^{11}$/bunch
- Q_x, Q_y: 26.13, 26.19

Bunch by bunch

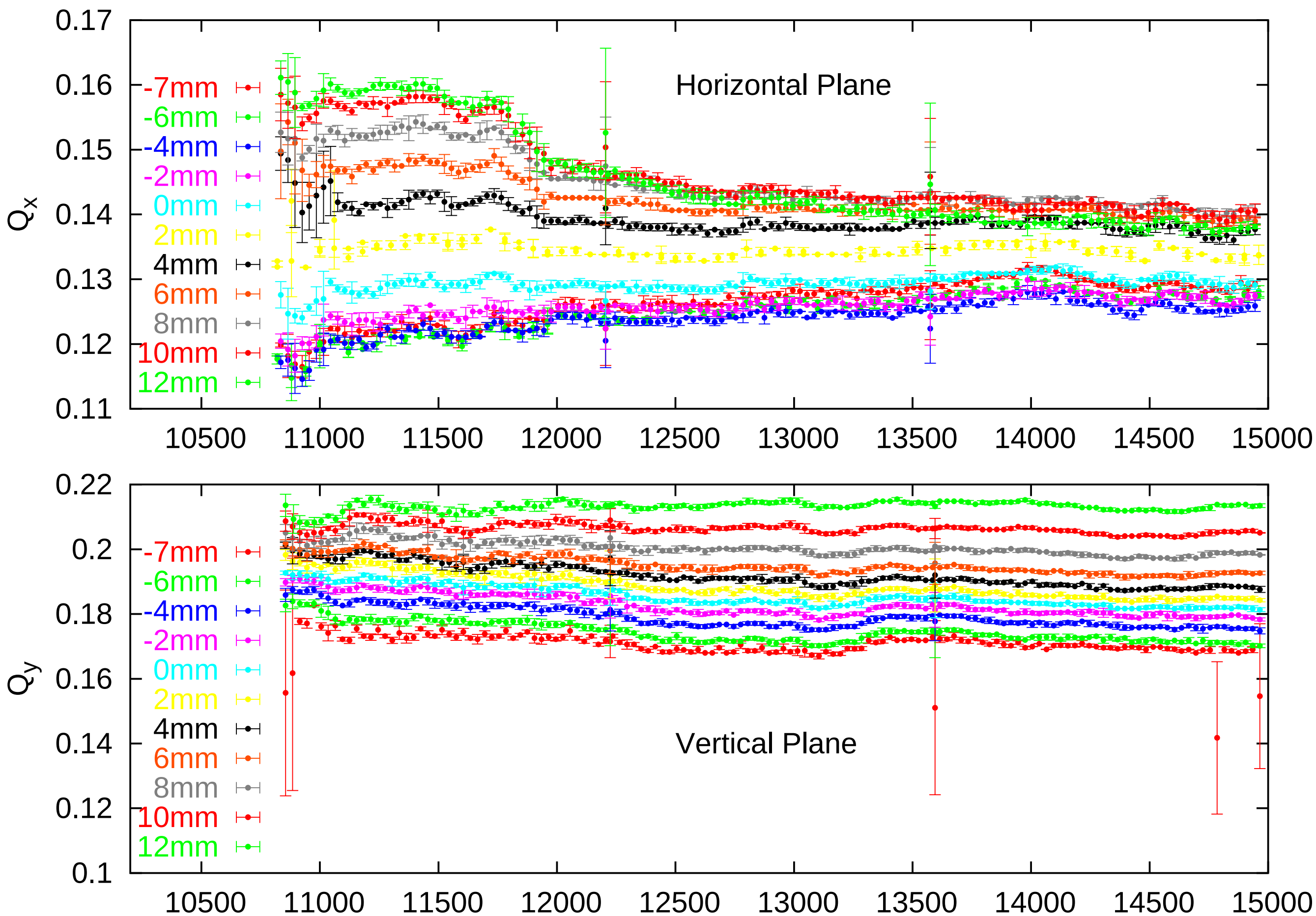
1. Fast BCT measurements
2. Bunch length
3. Turn-by-turn (LHC type BPM - tech. difficulty)

Observations:

1. PS horizontal instability before injecting into SPS
2. Lifetime was much better at 270 GeV than 26 GeV

Data to be analyzed (G. Rumolo, E. Beneddetto, E. Metrál, F. Zimmermann,).

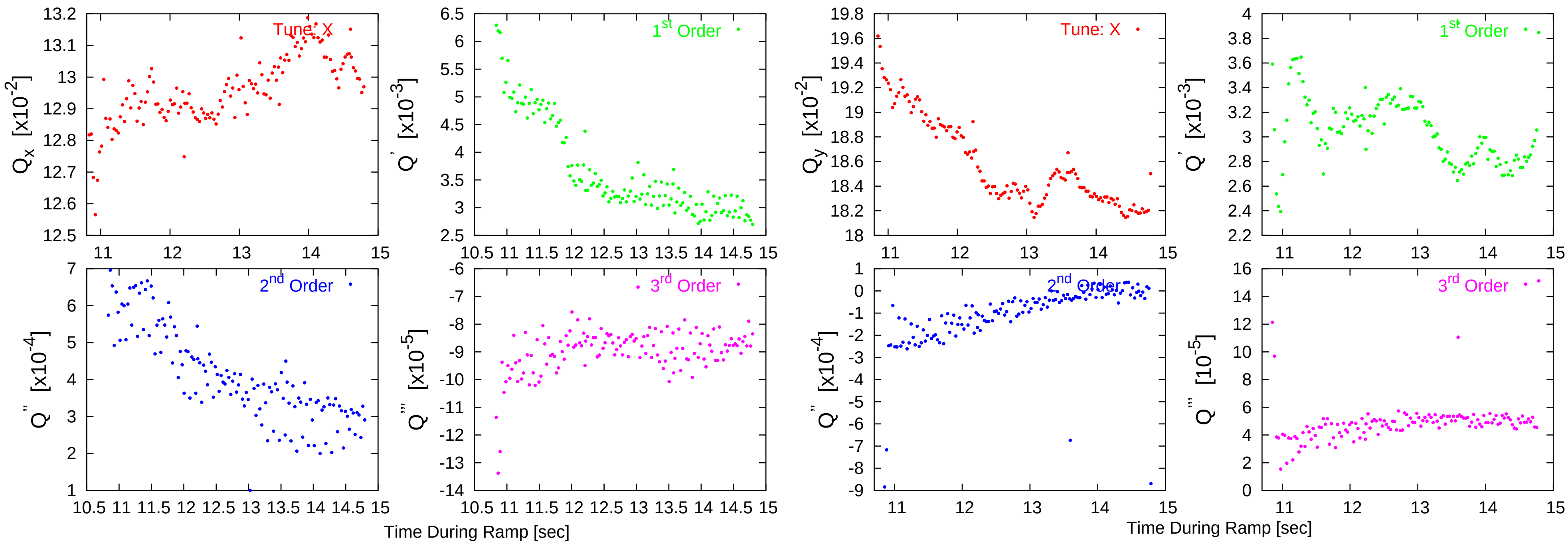
Non-Linear Chrom on SPS Ramp



- Non-linear effects visible in the horizontal plane
- Limit on negative radial offset (-7mm)

Non-Linear Chrom on SPS Ramp

Horizontal　　　　　　　　Vertical



- Chromaticity on the ramp corrected using measurements
- MD last night to linearize 2^{nd} order using octupoles (remote operations)
- Fit data to model to determine evolution of multipoles

LHC and Upgrade Simulations

- Beta Beta
- Crab Cavities

Ack: R. Tomás, M. Giovannozzi, O. Bruning, S. Fartoukh, F. Zimmermann

Beta-Beat @LHC Injection

- Realistic magnetic errors from MADX error tables
- Observables

$$\Delta\vec{\phi}_x,\ \Delta\vec{\phi}_y : \text{ Indep. of BPM Calibration (FFT, SVD)}$$
$$\Delta\vec{D}_x : \text{Calibration Dependent - } \pm 4\% \text{ (Rad. Steering)}$$

- Specifications:

$$\left\{\frac{\Delta\beta_x}{\beta_x},\ \frac{\Delta\beta_y}{\beta_y}\right\}_{peak} < \ 15\% \quad \text{[Rep.501]}$$
$$\left|\frac{\Delta D_x}{\sqrt{\beta_x}}\right|_{RMS} < \ 0.013\sqrt{m} \quad \text{[Rep. 501]}$$

- BPM Resolution: 200μm
- 210 Variables:

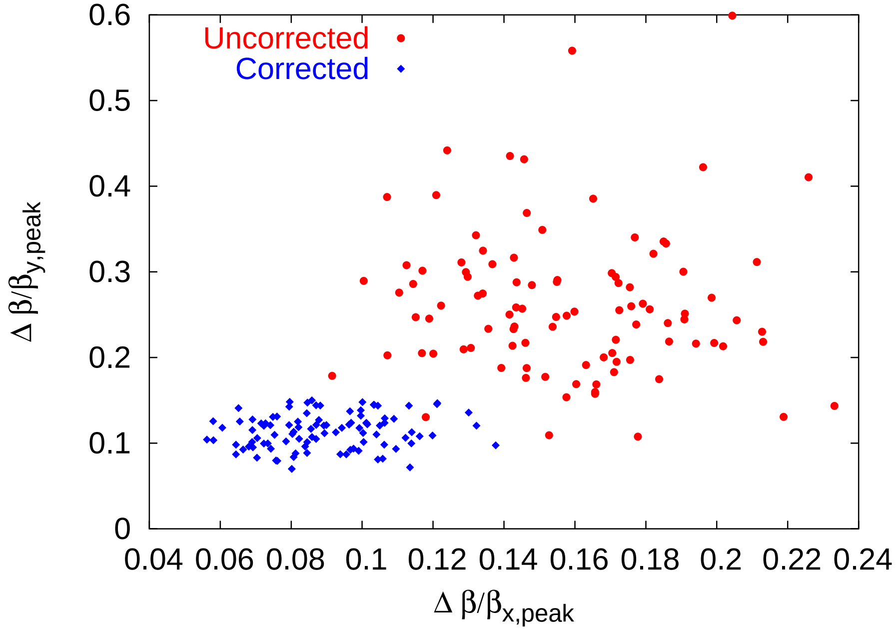
$$\vec{k}_1\text{: } \{\text{KQ[4-10]},\ \text{KQX},\ \text{KQF},\ \text{KQD},\ \text{KQT}, \cdots\}$$

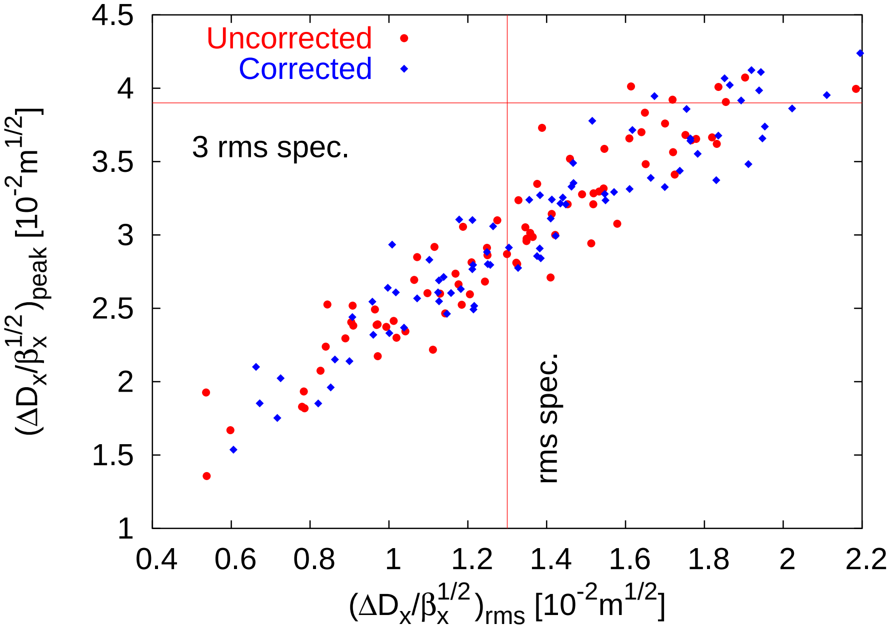
- Correction:

$$\Delta\vec{k}_1 = -R^{-1}\left[w_\phi\Delta\vec{\phi}_{(x,y)},\ w_D\Delta\vec{D}_x,\ \Delta Q_x,\ \Delta Q_y\right]^T$$

EPAC 2006

- All errs from measurements + 5 units of Gaussian noise to b_2
- Chrom sextupole misalignments: $\sigma_{x,y} = 2$ mm
- RMS misalignments of MCS, $\sigma_{x,y} = 0.5$ mm
- Gaussian noise $\sigma_\phi = 0.25°$, $\sigma_{D_x} = 0.01$ m





- Best β-beat correction in the 5% level
- Dispersion gets worse if not included in response matrix
- Dispersion impossible to correct !! (perhaps misuse of KQ[4-10] ?)

Dispersion Correction Strategy

- Allow for flexible weights (Ex: w, $1-w$):

$$\begin{aligned} R\Delta\vec{k} &= \vec{b} \\ \Delta\vec{k} &= (R^T W R)^{-1} R^T W \vec{b} \end{aligned}$$

  where W = $[\phi_x,\ \phi_y,\ D_x,\ Q_x,\ Q_y]$

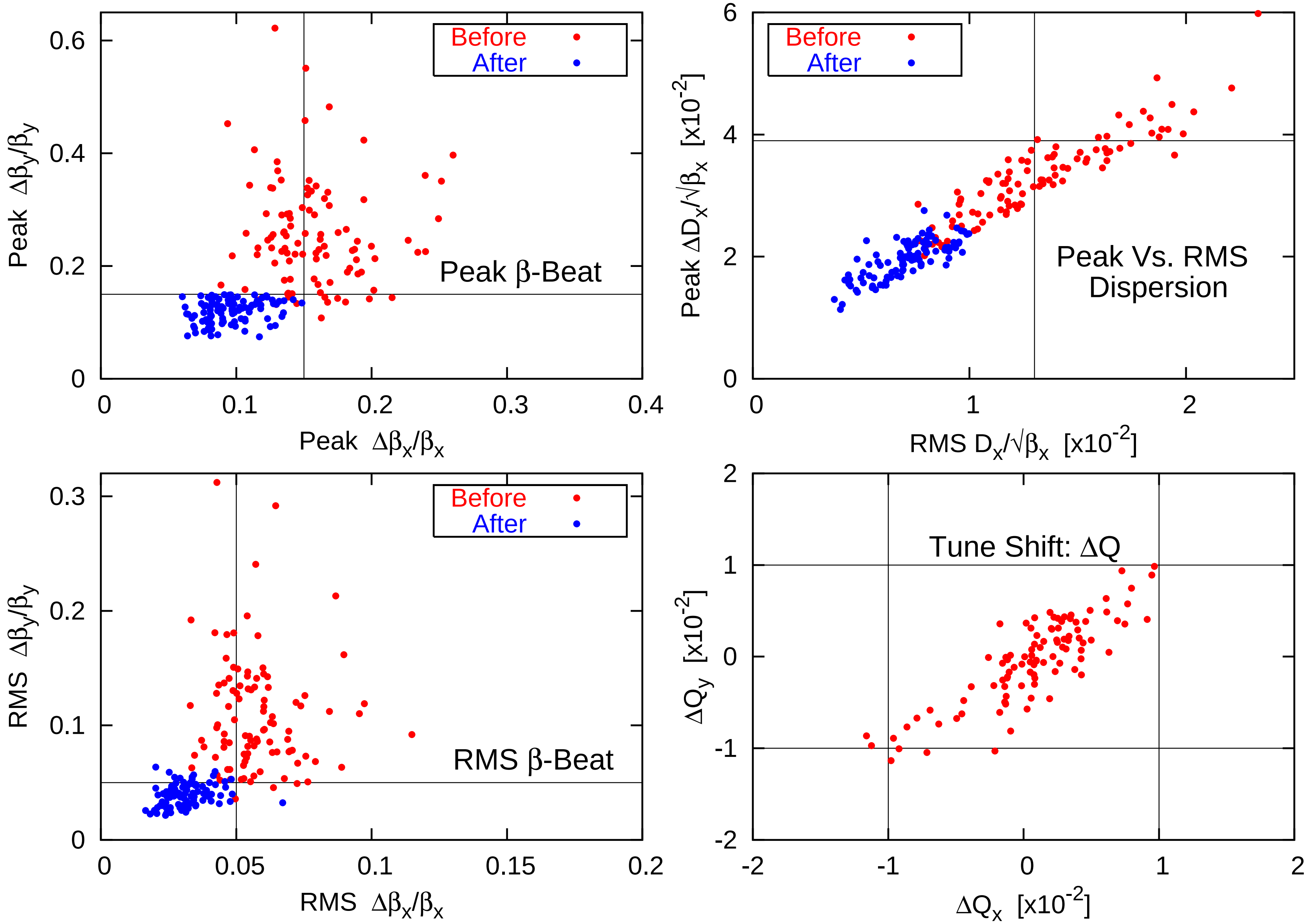
- Test with RANDOM ERRS instead of measured errs (speed):
  - Enlarged b_2 Errors, Sextupole Misalignments: $\sigma_{x,y} = 1$ mm
  - Gaussian nosie $\sigma_\phi = 0.25^\circ$, $\sigma_{D_x} = 0.01$ m

- Effect of weights, # of Sing. Vals, Remove IR Quads, etc...

$$\chi^2_{\frac{\Delta\beta}{\beta}} = \sum \left(\frac{\Delta\beta_{x,y}}{\beta_{x,y}}\right)^2_{rms} + \left(\frac{\Delta\beta_{x,y}}{\beta_{x,y}}\right)^2_{peak}, \quad \chi^2_{\frac{\Delta D_x}{\sqrt{\beta_x}}} = \sum \left(\frac{\Delta D_x}{\sqrt{\beta_x}}\right)^2_{rms} + \left(\frac{\Delta D_x}{\sqrt{\beta_x}}\right)^2_{peak}$$

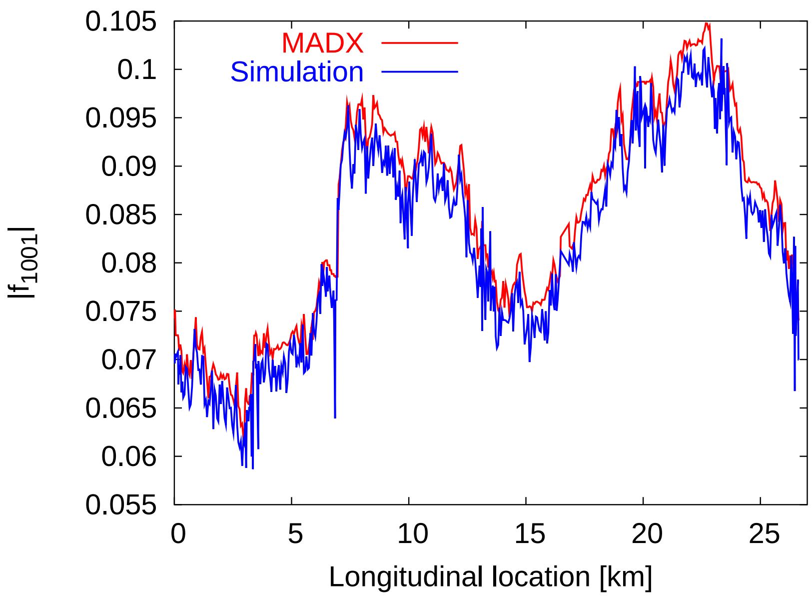
- R-Matrix Dispersion Observable (D_x or $D_x/\sqrt{\beta_x}$)

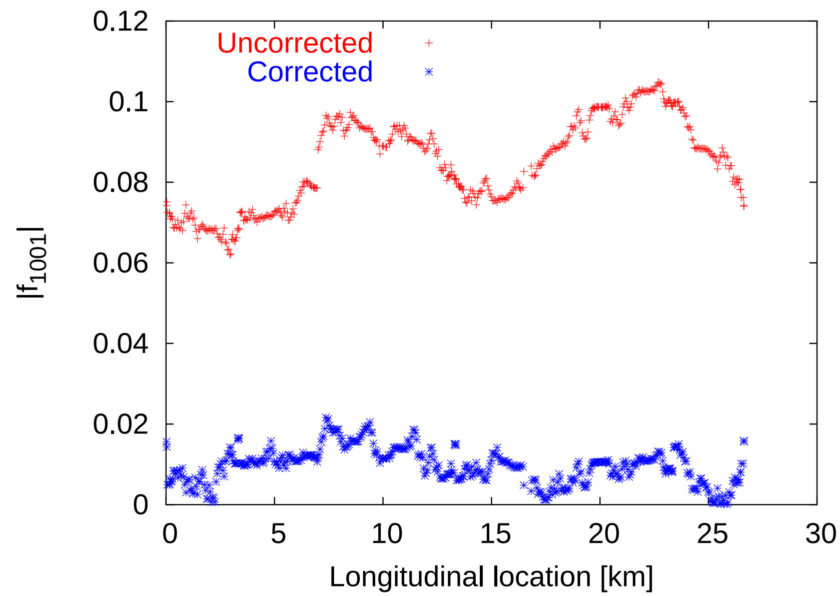
β & $D_x/\sqrt{\beta_x}$ Beat Corr. Measured Errors



Local Coupling @LHC

- Random Quad Tilts + Large Tilt (6km) + BPM Tilts (2mrad)
- BPM Resolution: 200 μm
- Coherent Oscillations: 400 Turns





Large Coupling Source Identified, and local correction feasible
Further improvements to algorithms is foreseen

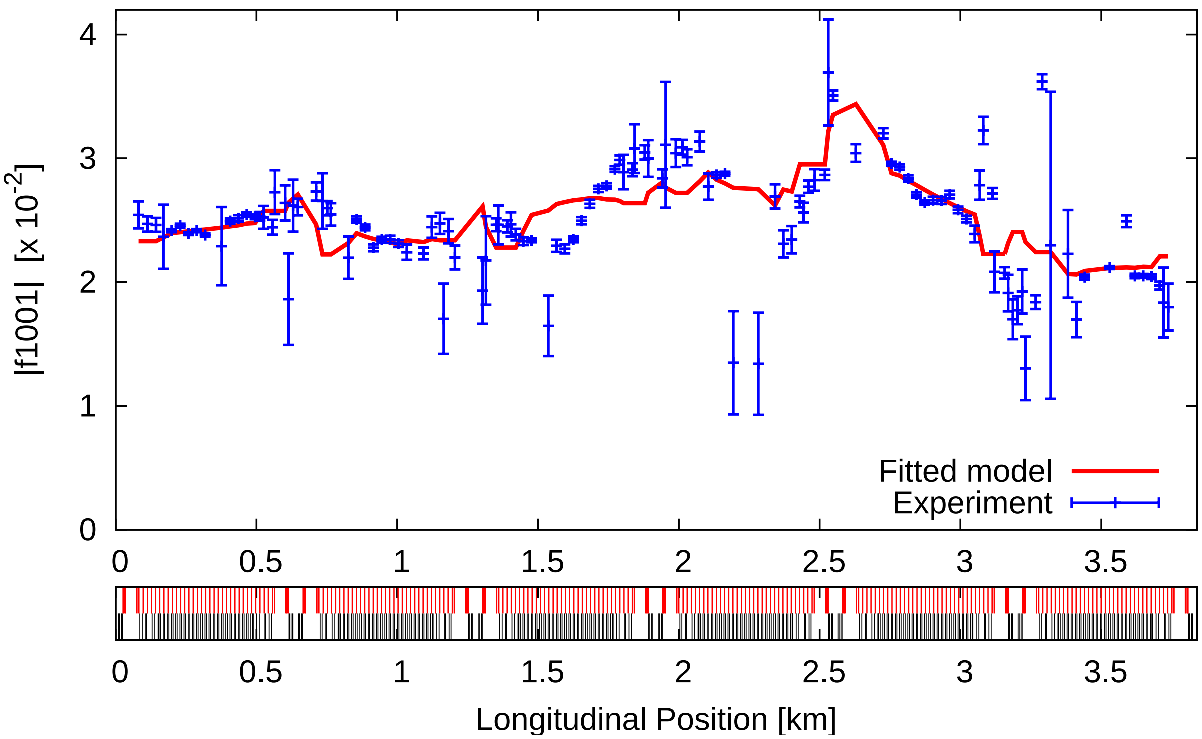
Benchmarking on Real Machines

- SPS:
  - Very linear & well behaved optics
  - Introduce β-beat and apply correction
  - Only 4 knobs (too few, not really scalable to LHC case)
- RHIC:
  - Observable β-beat $\sim$ 15-20%
  - Arc Circuits + IR Quads (many knobs, closer to LHC)
  - AC Dipole Vs. Free Oscillations (compare correction)
- Limitations - faulty BPMs, reproducibility

RHIC Coupling Measurements

Fitting Variables:

$$\lim_{\Delta\to 0}\left[\Delta f_{1001}^{(meas-mod)}\right] \rightarrow \left[\begin{array}{c}\text{Arc Quad Tilts (6-families)}\\ \text{IR Skew Correctors}\\ \text{IR Quad Tilts } (Q_1 \text{ - } Q_{10})\\ \vdots \end{array}\right] \rightarrow \text{MADX Iterate}$$

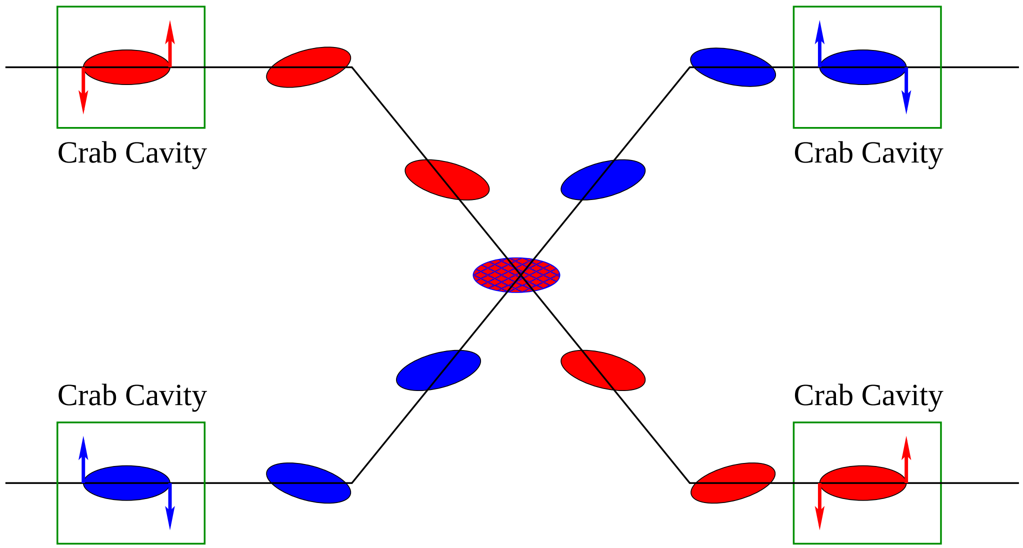


Application & Commissioning

- Requirements for Effective Corr:
  - Well Functioning and Synchronized BPM System (Turn-By-Turn)
  - Coherent Oscillations ($\sim$ 400 turns, perhaps AC Dipole)
  - Reproducibility
- Application:
  - High level JAVA application (Optics, Coupling, Correction)
  - Interface with FESA and Online MAD Model
  - Option to apply trim corrections
- Commissioning:
  - At most 5-6 Iterations (re-adjust injection)
  - Participants: Rogelio, Rama interested

$\Delta\beta/\beta$ & $\Delta D_x/\sqrt{\beta_x}$ correction feasible

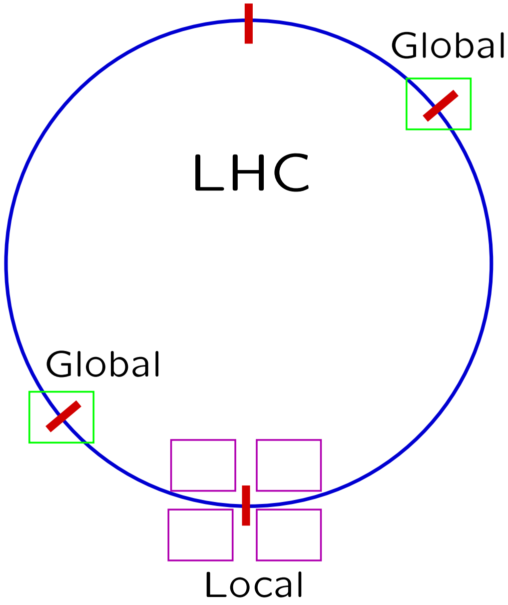
Crab Cavities for LHC Upgrade



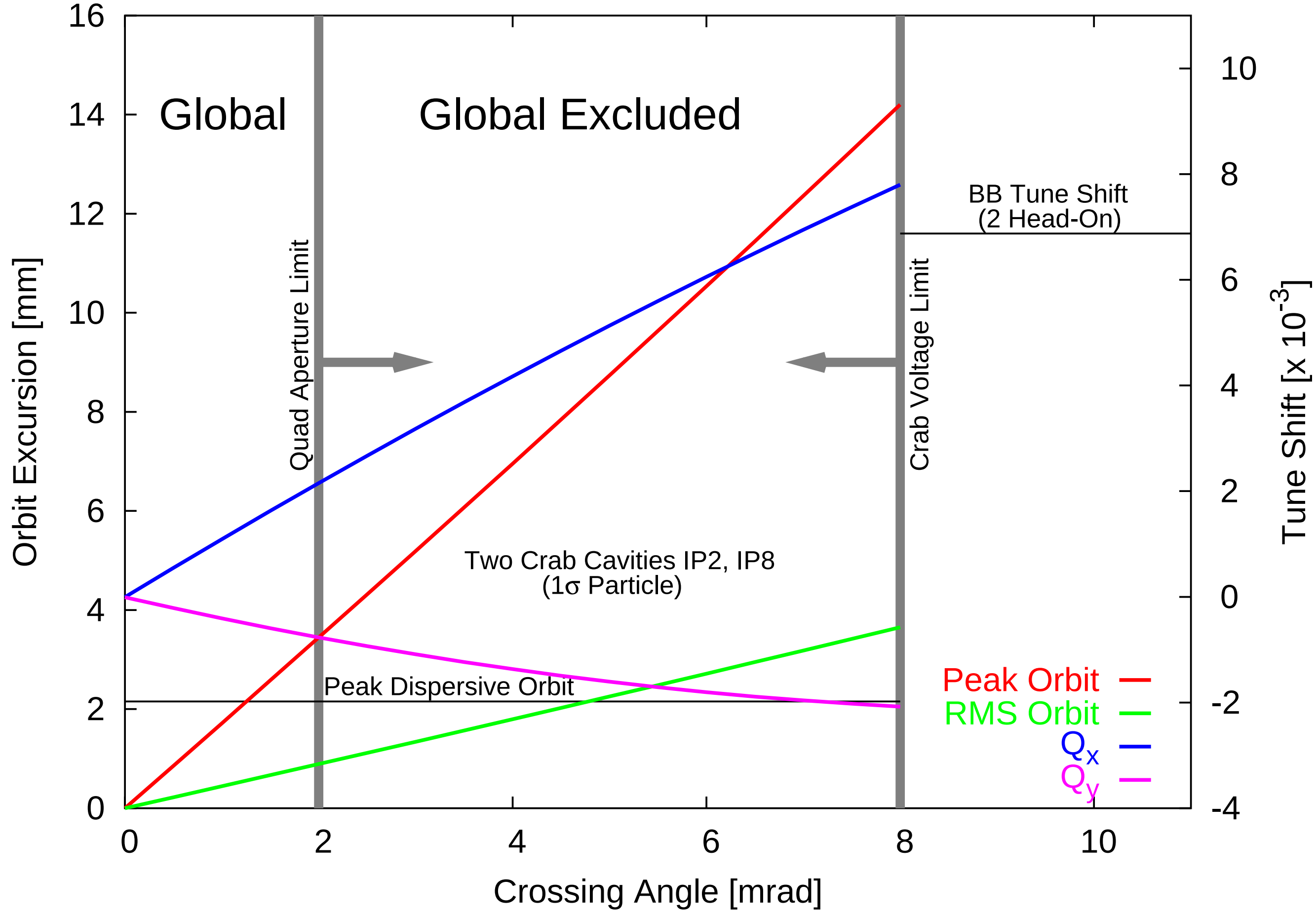
- Geometric luminosity loss

$$\frac{L}{L_\circ} \approx \left[1 + \left(\frac{\sigma_z}{\sigma_x^*} \tan\left(\theta_c/2\right)\right)^2\right]^{1/2}$$

- Long range beam-beam
- Simple IR design (Sep. Quads)
- β^* reduction & flexibility



Orbit Excursion & Tune Spread



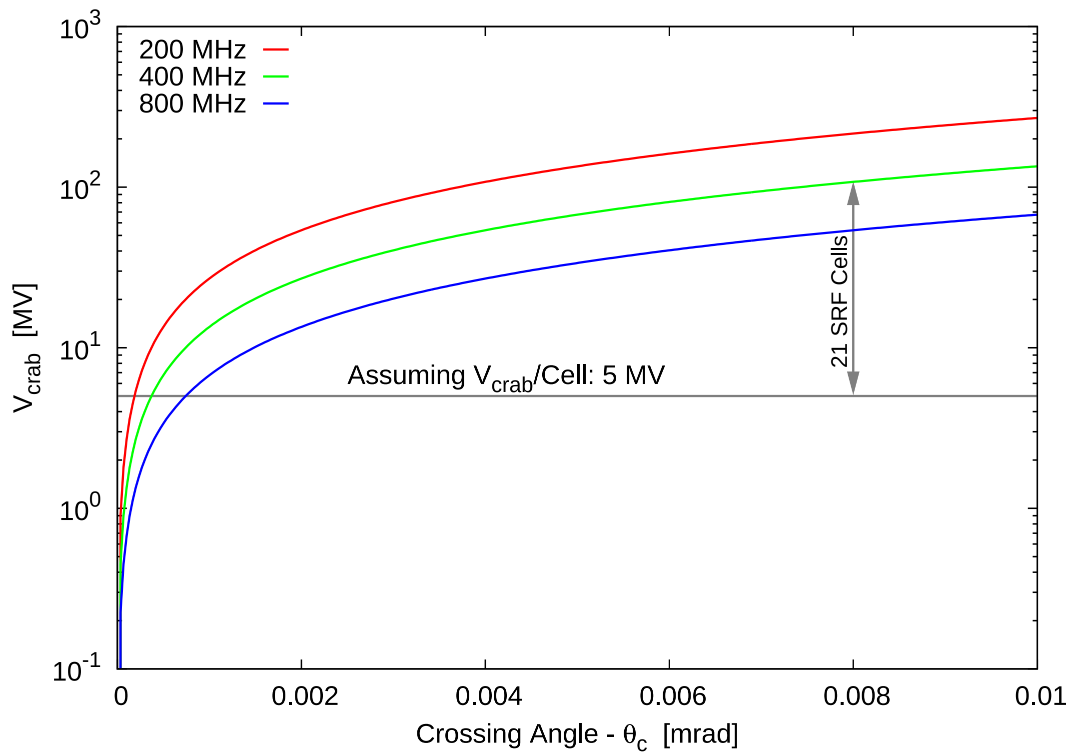
0.4-2 mrad	4-6 mrad	8 mrad
Nom. Quad-First $V_{crab} < 15$ MV Cavity Simple	Sep. Quads (Exotic) $V_{crab} \sim$ 50-70 MV Exotic Cavity	Sep. Quads (Simple) $V_{crab} \sim$ 111 MV Voltage Limit

Crab Voltage Requirement

$$V_{crab} = \frac{cE_0 \tan(\theta_C/2)}{\omega_{RF}\sqrt{\beta_{crab}\beta^*}} \quad \{\sigma_z \ll \lambda_{RF}\}$$

X-Angle	1 mrad	5 mrad	8 mrad
200 MHz	27 MV	134 MV	216 MV
400 MHz	14 MV	67 MV	108 MV
800 MHz	7 MV	34 MV	54 MV

(Assuming $R_{12} = 31$ m)

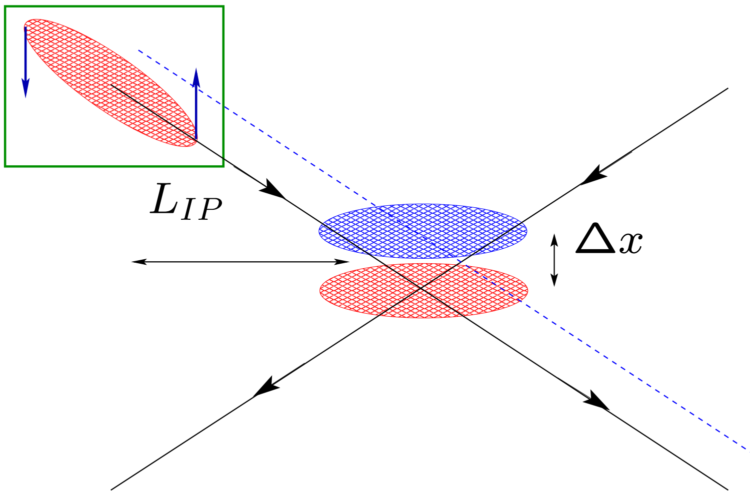


- Reduce # Cavities
  - Increase Real-Estate Gradient
  - **Increase β_x^* & β_x^{crab} (Flat Bear**
  - Reduce bunch length ($$$)
    + Increase Frequency ($\times$2)
- Lower X-Angle
  - Reduce Transverse Dimensions
  - Exotic Shapes

Noise Tolerances

Phase jitter introduces random offset:

$$\Delta x_{IP} = \frac{c\theta_c}{\omega_{RF}} \delta\phi$$



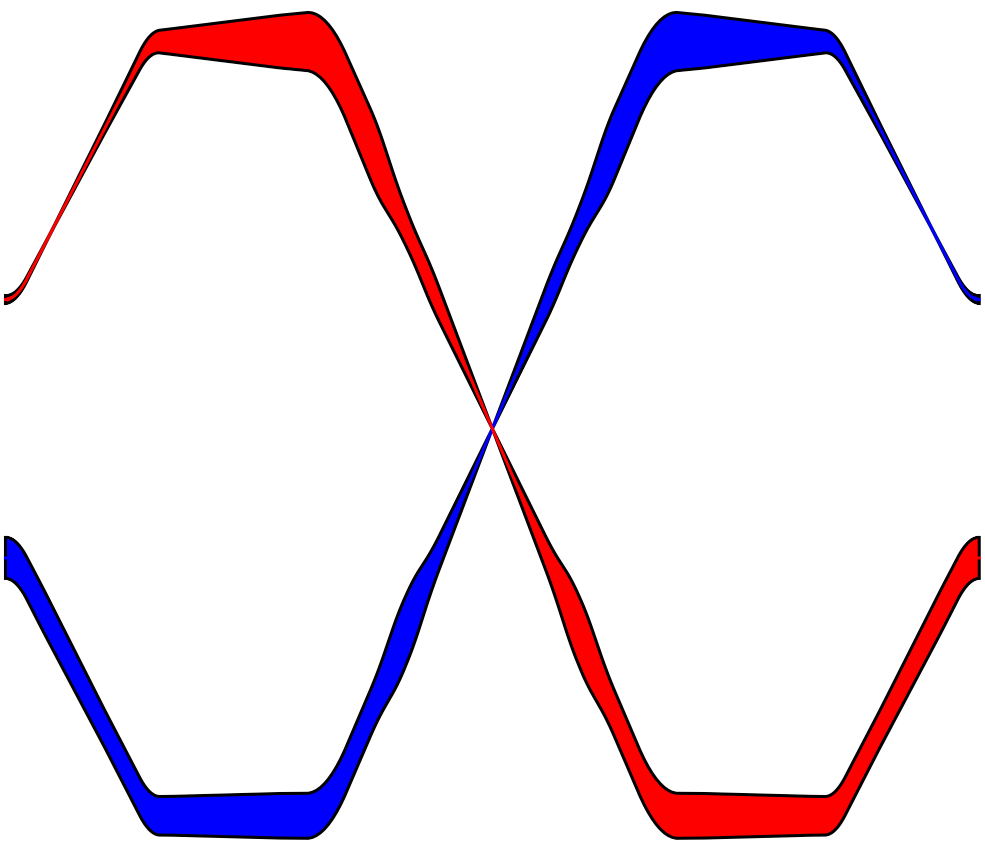
X-Angle: 8 mrad & $\Delta\epsilon/\Delta t = 10\%/\text{Hr}$

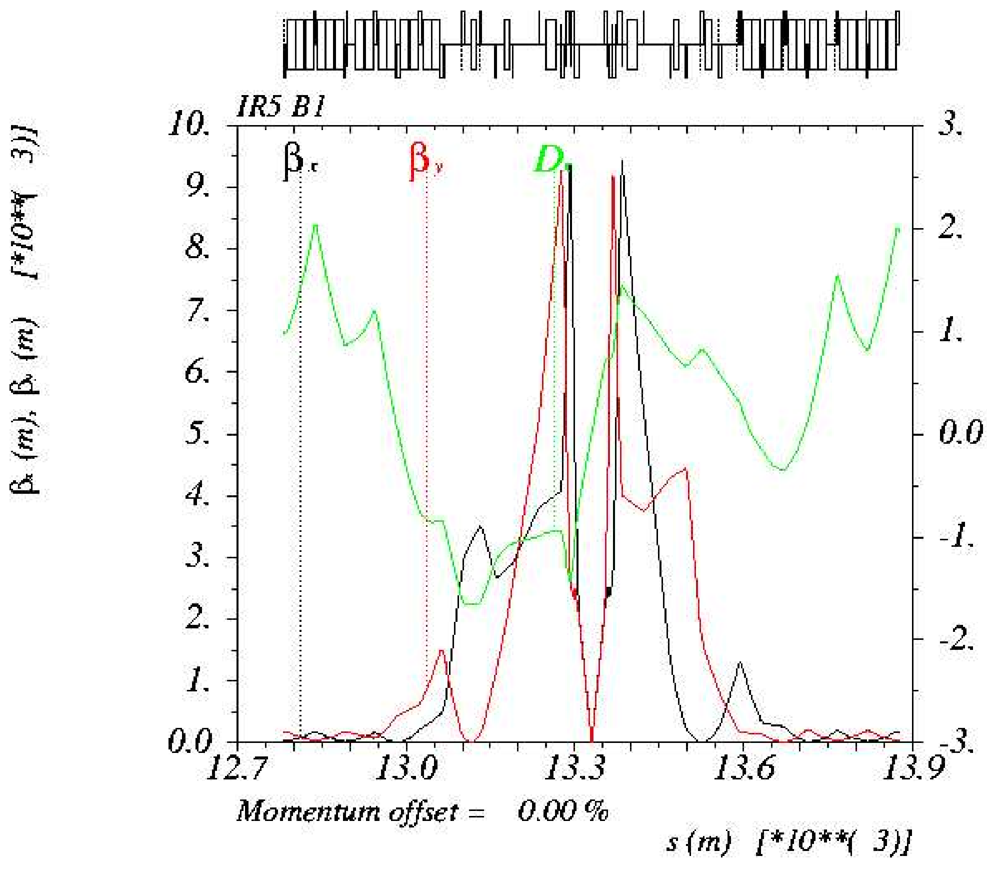
$\Delta\phi_{BB} \leq 0.001^\circ$ $\Delta\phi_{CC} < 10^{-4}$ deg ($\Delta x/\sigma_x^* < 10^{-3}$ perhaps too pessimistic)

$\Delta\phi_{rel} = 0.003^\circ$ (feasible $\rightarrow$ ILC)

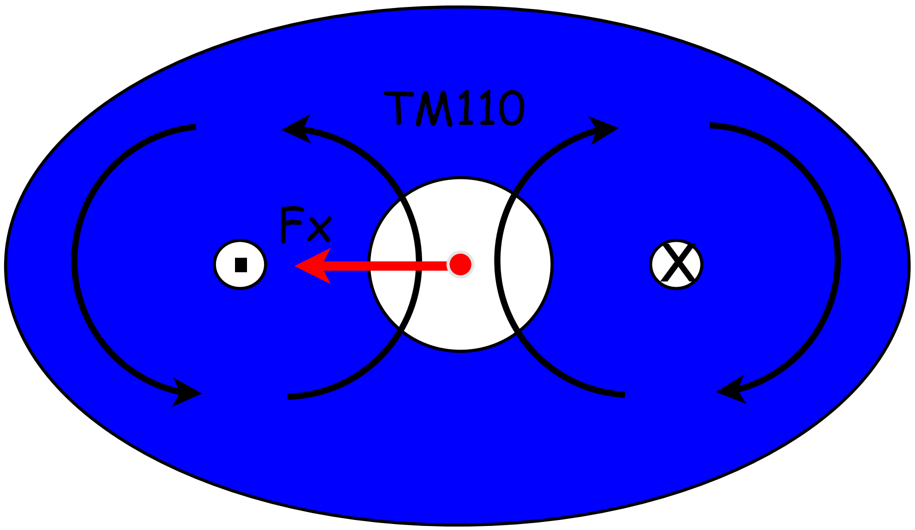
Tolerances maybe relaxed due to transverse feedback

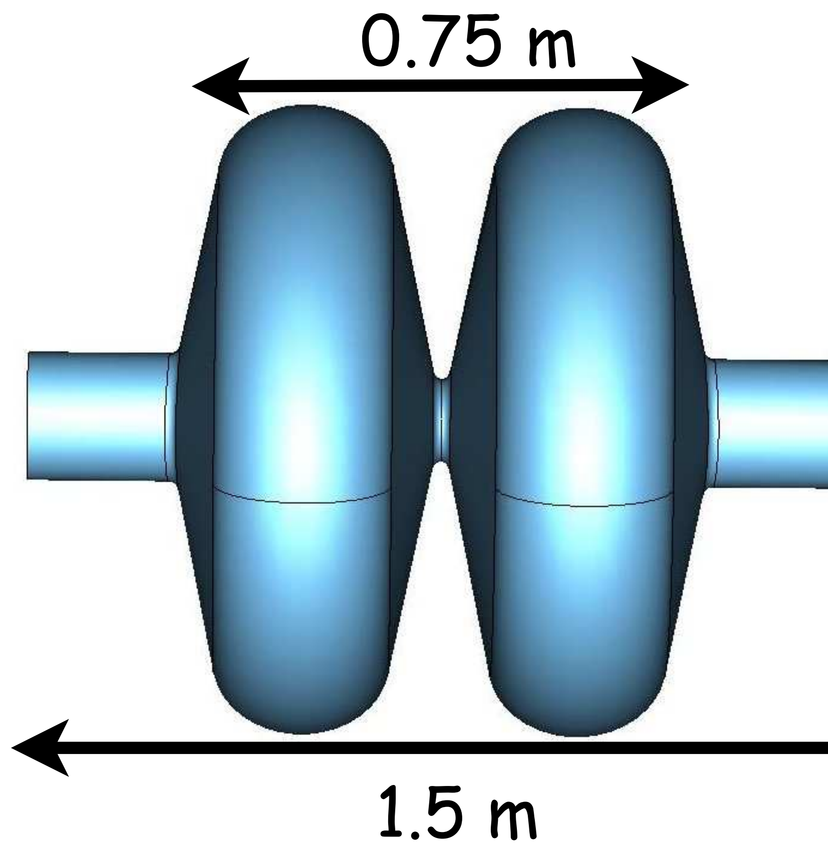
8 mrad Optics (Courtesy R. Tomás)





Baseline: Elliptical & Squashed





Half Cell Length, $L = \frac{\lambda\beta}{4}$	18.75 [cm]
Two Cells + Beam Pipe	$\sim$ 1.5 [m]
Horizontal Eq. Radius, R_{iris}	**53 [cm]**
Horizontal Eq. Radius, R_{iris}	37.5 [cm]
Squash Ratio	0.75
Beam Pipe Radius	15 [cm]
Wall Angle, α	$\sim$ 6 [deg]
Equator Dome Radius	12.0 [cm]
Cavity Beta, $\beta = \frac{v}{c}$	1.0

- Two Cells $\sim$ 5 MV/Structure
- LOM + HOM Couplers
- Polarize for mode separation
- Tuners, Cryostat, $\cdots$

Conclusions

- Crab cavities well accepted at HHH-LUMI-06
  - Integrate small angle CC with Quad-First or D0 options
  - BBLR compensator required
  - Moderate increase crossing angle
- Issues with RF frequency & cavity dimensions need R&D
- Noise estimates for phase tolerance looks too pessimistic
  - Multiparticle simulations for noise tolerances
  - Include machine details ($\delta E/E$, ξ_x, lattice Errors, coupling, etc..)
- R&D Effort: CERN, BNL, & LBNL (Optics, Cavity Design, RF Control, etc..)
- Benefit from ILC crab cavity activity

TOOHIG Tips Website

http://www.agsrhichome.bnl.gov/People/rcalaga/toohig.html
(Under Construction)

Nice Summer

Many Thanks to CERN Hospitality

Isle of Mull: July 2, 2006

Should have toured Europe a bit more