Lattice measurements, injection errors, diagnostics

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Talk outline

1. The status of MI-to-Tevatron beam transfers
2. Tevatron optics measurements
3. Instrumentation

Conclusions

1.The status of MI-to-Tevatron beam transfers

Emittances averaged for a few recent shots (July 8-14) for MI-to-Tevatron transfers

	Protons		Pbars	
	V	H	V	H
Emittance[1] in MI at 150 GeV, mm mrad	17-20	20	11	13
Emittance in Tevatron after injection, mm mrad	23-26	20-23	14	20
Emitt. growth associated with transfer, mm mrad	~6	~3	~3	~7

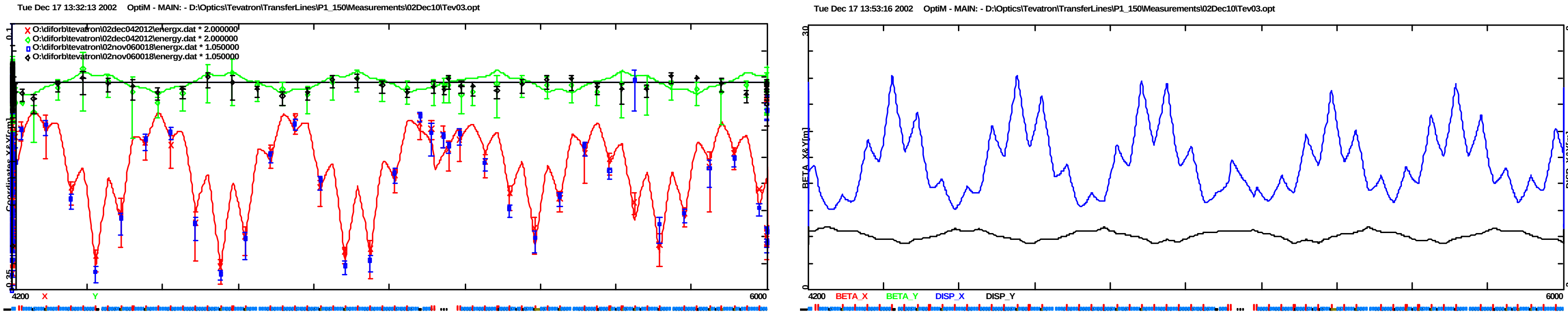
- For pbars
  - the vertical emittance growth of 3 mm mrad is at acceptable level
  - the horizontal one of 7 mm mrad is too large and requires improvements.
- For protons
  - the vertical emittance is too large and also needs to be reduced.

[1] All numerical values for emittances are presented for 95% normalized emittances

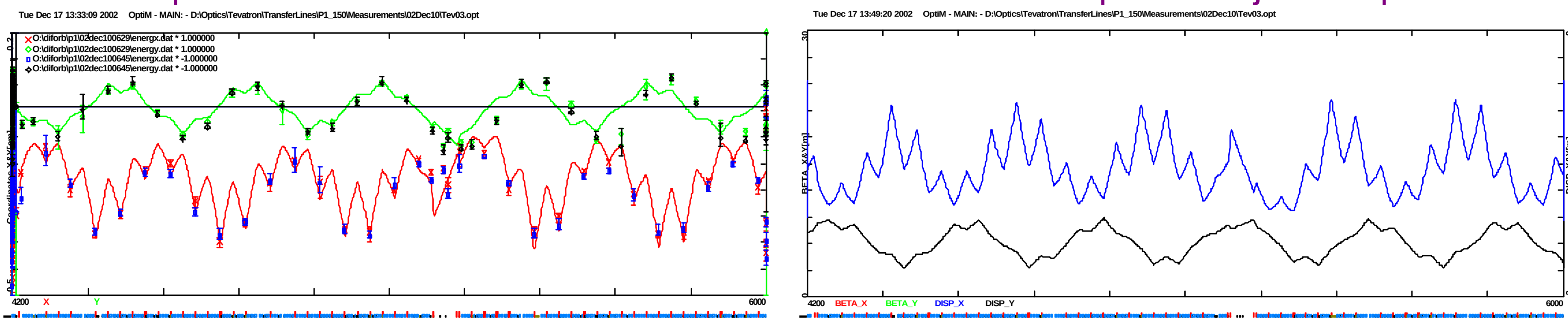
- New optics for A1 line was downloaded in October 2002
  - Optics measurements verified that there was not discrepancies with design intent
- While final optics was not downloaded into P1 line the measurements performed in December 2002 verified that optics is in a sufficiently good state
- Nevertheless the round trip measurements (MI-Tevatron-MI) with uncoalesced bunches showed that
  - the vertical emittance grew from 12 to about 16 mm mrad
  - while horizontal one from 12 to about 19 mm mrad
- Indirect evidence pointed out that the major fraction of the emittance growth is related to strong local coupling in Tevatron, which gets worse at the pbar helix

- **This forced us to undertake detailed study of Tevatron optics**
  - During recent half year the efforts were concentrated to achieve better understanding of the Tevatron optics and to develop or improve the beam instrumentation.
  - Considerable progress has been achieved in both directions.
- Note also that there is also significant beam-beam effect causing pbar emittance growth after “initiate collisions” (“scallop” effect), which causes additional emittance growth
- No measurements of transfer line optics were performed in 2003
  - There is indirect evidence that P1 line optics could deteriorate after power supply change

P1 line measurements performed in Dec.04/02



Dispersion measurements at central orbit downstream of proton injection point



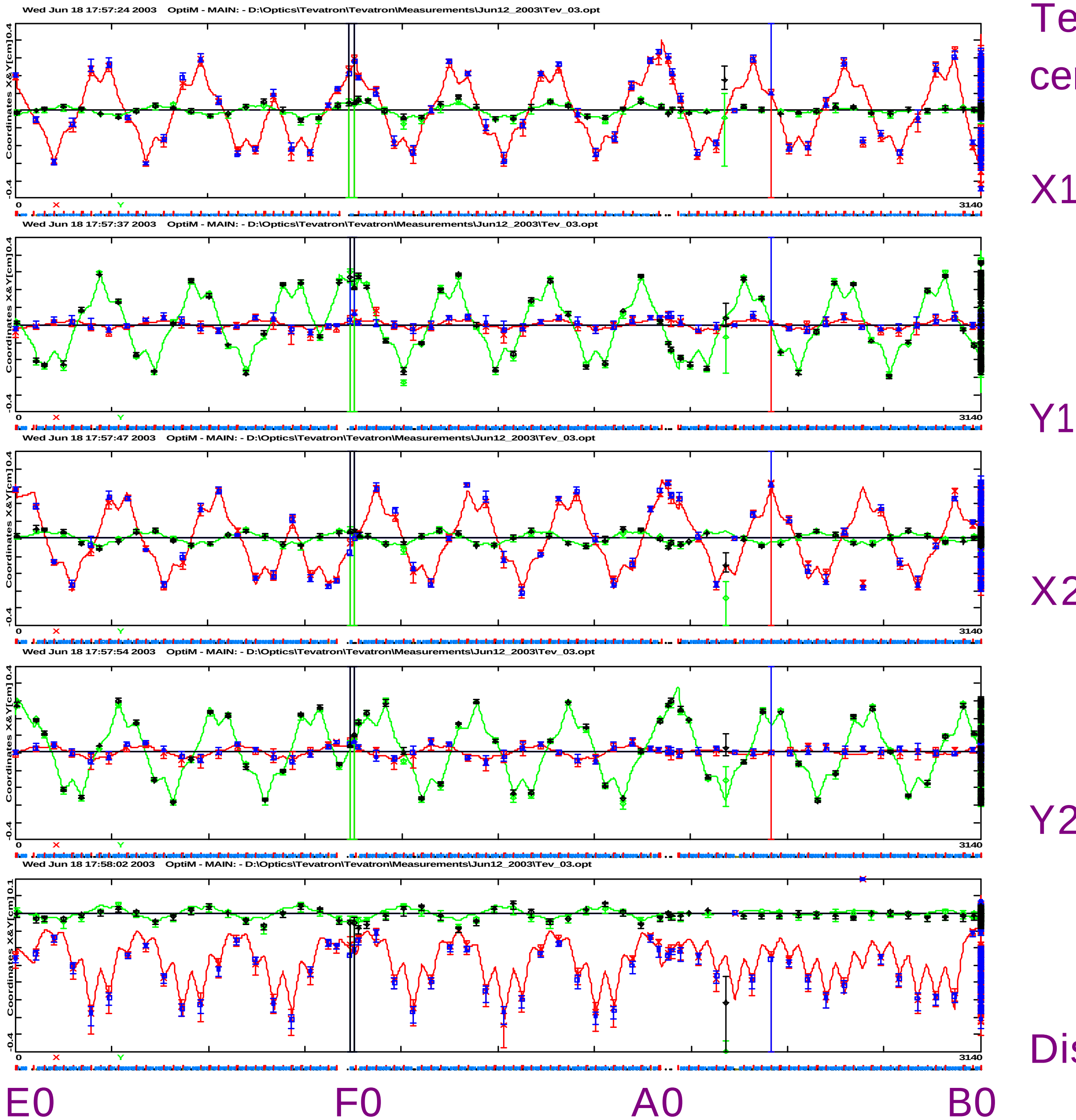
Dispersion measurements for injected proton beam at the first turn (First turn)

- Errors for both horizontal and vertical dispersions are about 1m
  - That corresponds to about 1 mm mrad emittance growth in both planes
- A1 line has slightly better dispersion match
- Betatron functions of the transport lines are matched to design β-functions
  - Fine tuning with orthogonal quads did not exhibit any decrease of emittance growth
  - That leaves coupling as the major offender

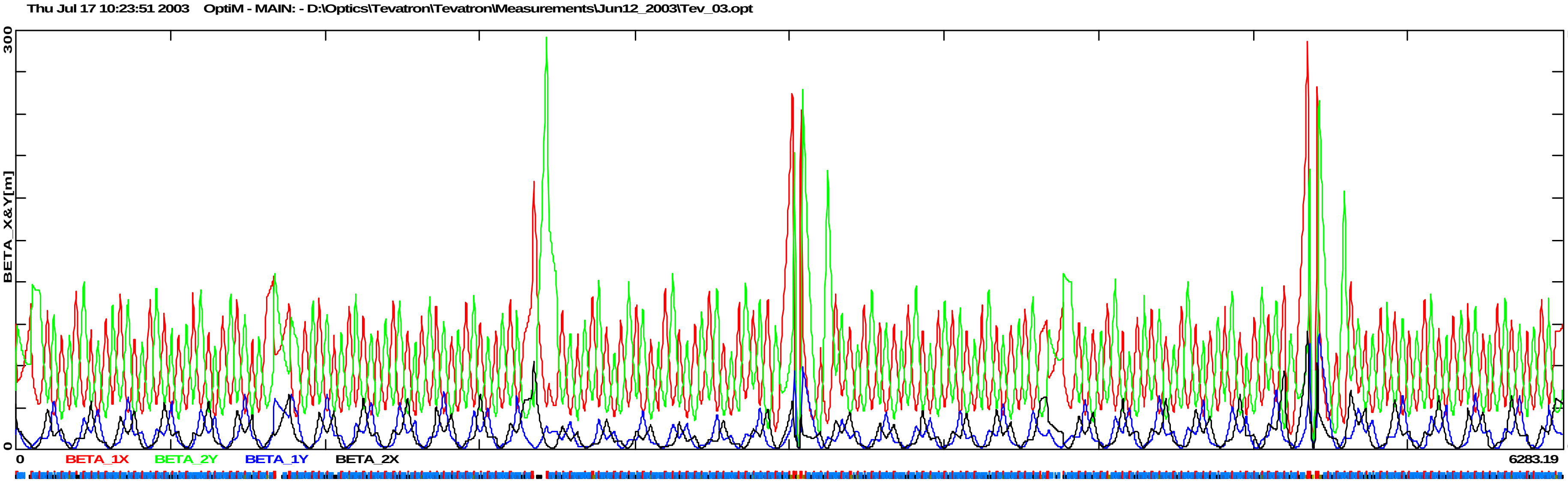
2. Tevatron optics measurements

- Presently, the optics measurements are performed with differential orbits measurements.
  - Four correctors (two horizontal and two vertical)
  - and energy change are used to excite the orbits.
- It allows one to determine linear optics and dispersions with X-Y coupling taken into account.
  - The accuracy of the measurements is about 10-15%.
- The measurements are fast (5-10 minutes) and can be easily acquired during shot setup when necessary.
- The analysis requires an experienced person and normally takes about one day.
- Presently, we acquired data at both top and injection energy, but only injection energy data were analyzed.

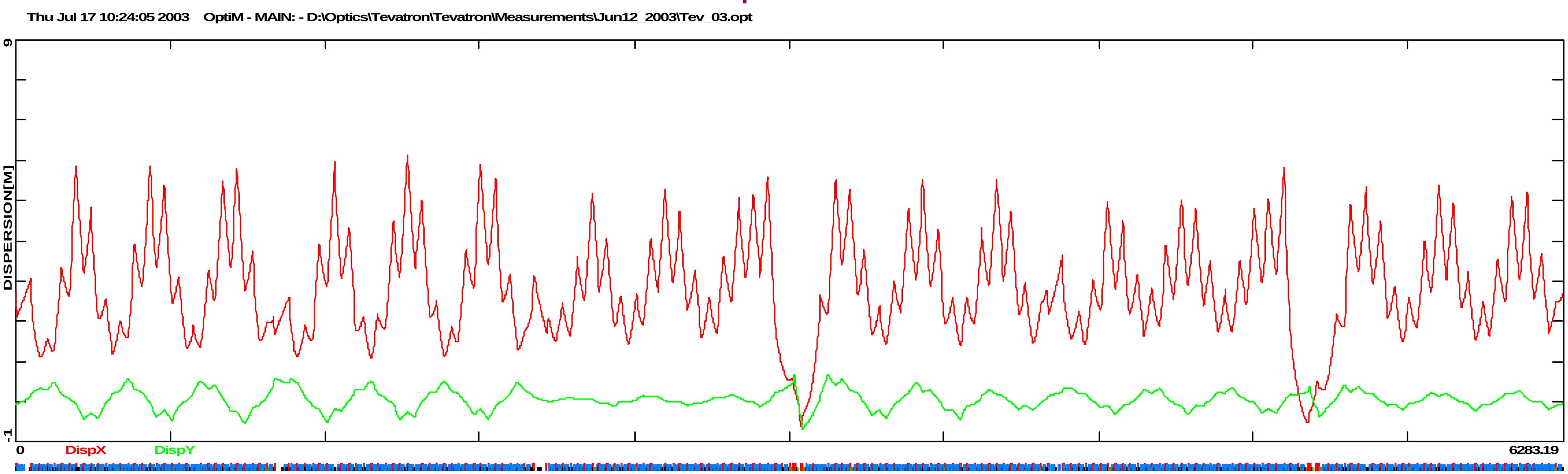
Differential orbits for the Tevatron first half at central orbit, June 12, 2003



Mais-Ripken beta-functions



Dispersions



E0 F0 A0 B0 C0 D0 E0

Results of the optics measurements performed at June 12, 2003 at the injection energy

	Model		Measured	
Tunes	Qx=20.583	Qy = 20.575	Qx=20.583	Qy = 20.575
Chromaticities	x**x = 25**	x**y = 23**	ξx = 7.7	ξy = 8.4
Tune split	Δν = 0.005		Was not meas.	
Momentum compaction	α = 0.00282122		**N/A**	

- **Global corrections for dipoles**
  - Edge focusing in dipoles of 0.995 deg is corrected by +2.11%
  - Skew quad in main dipoles: $GdLskewUnits = 1.5 units [2]
  - Sextupole in main dipoles: $SdLunits = -3.35 units
- **Global corrections for quads**
  - Focusing correction for quads on the main bus: $F_mq = +0.1925%

[2] 1 unit corresponds to $\Delta B/B=10^{-4}$ at 1 inch

Point corrections with known origin

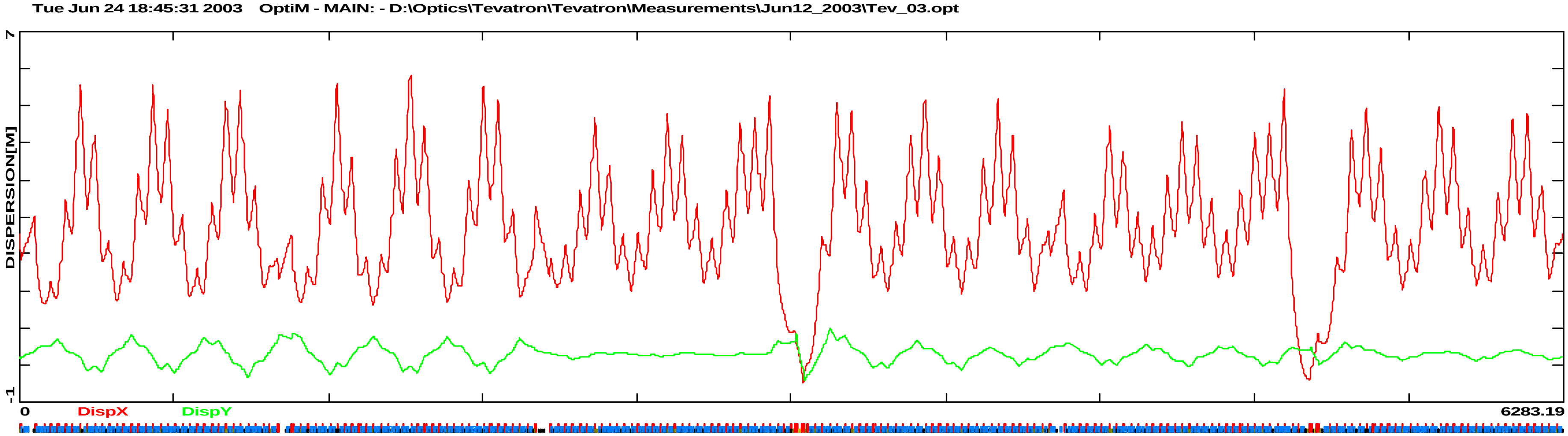
- GdL for A46 (skew) =-6 kG;
  - corresponds to +3.49 mm vertical displacement in mCS6A4AP
- GdL for C46 (normal) = 8 kG, (skew) = 4 kG
  - corresponds to +4.65 mm hor. displacement in CS6A4AP
  - corresponds to -2.32 mm vertical displacement in CS6A4AP
- IP point focusing;
  - $F_B0Q2= 0.25%; measured difference between setting and reedback
  - $F_D0Q2 = 0.6%; value lays between setting and reedback
  - $F_D0Q3 = 0.5%; value lays between setting and reedback

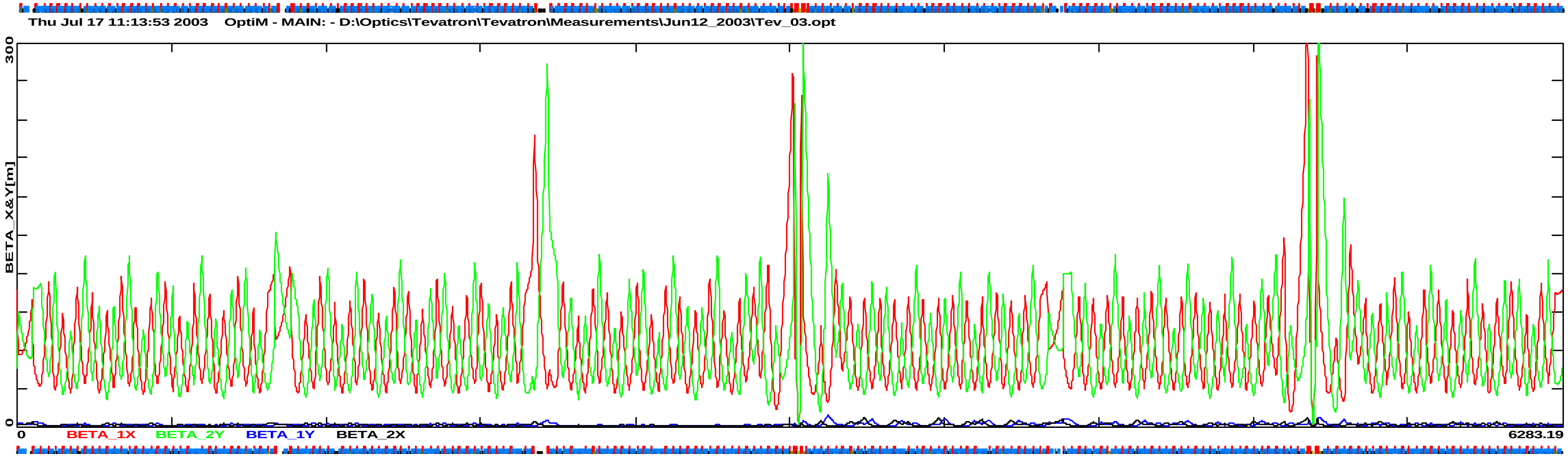
Point corrections with unknown origin

- GdL[3] for A22 (normal) = 3 kG (1.6%)
  - would require hor. displasment of +10 mm in chromaticity sextupole
- GdL for A24 (normal) = 6 kG (3.2%)
  - would require hor. displasment of +20 mm in chromaticity sextupole
- GdL for B38 (skew) = 6 kG (3.2%)
  - would require hor. displasment of +13 mm in chromaticity sextupole and nearby CS1B3AP, or 39 units of A1 in a single dipole

[3] Integral strength of regular main bus quad is 191.223 kG

Decoupling at central orbit

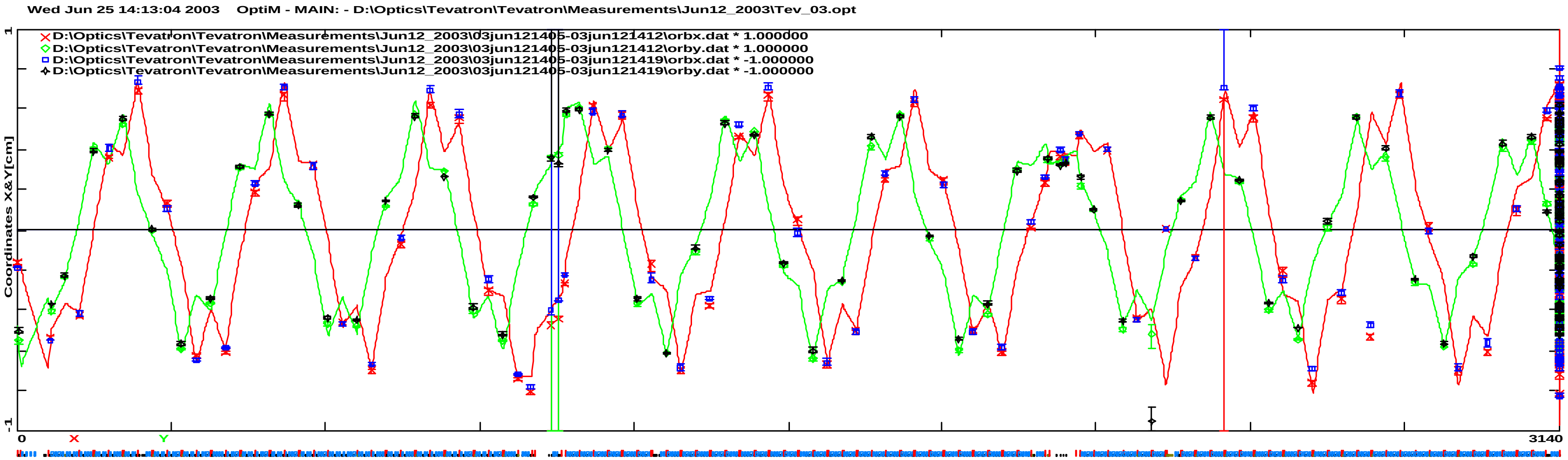




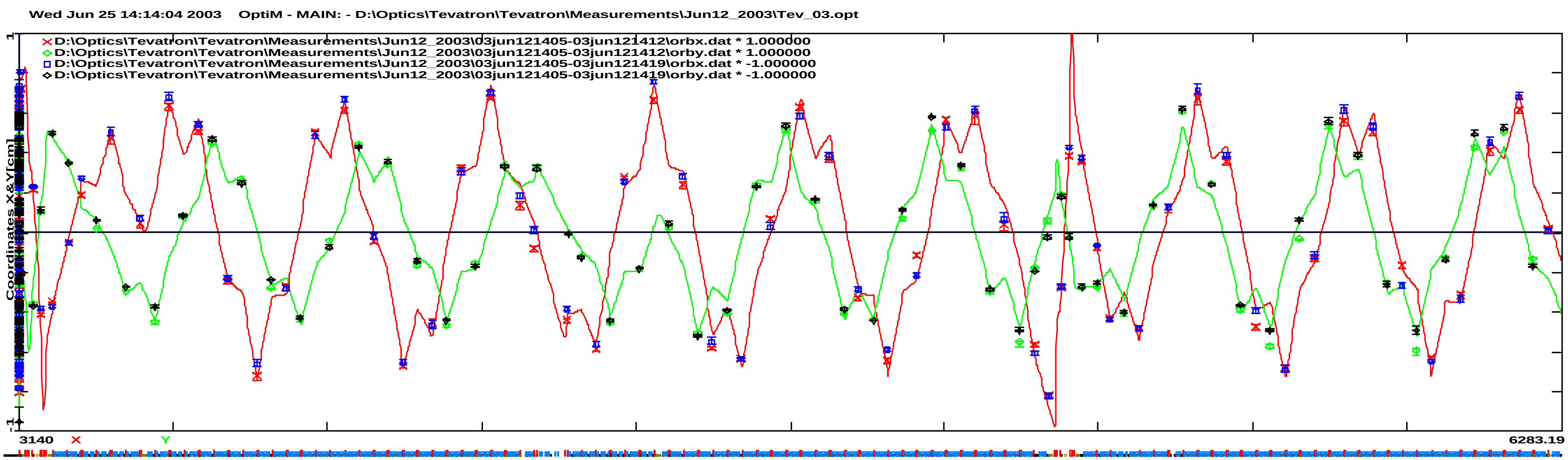
Maximum decoupling with use of all available skew-quads (SQ = -3.04617 A, SQA0 = 2.387595 A, SQA4 = 2.827271 A, SQB1 = -1.181689 A, SQD0 = -0.8 A, SQE0 = 1.481628 A).

Measured and predicted proton helix

(red and green crosses are the inverted data from pbar helix measurements)

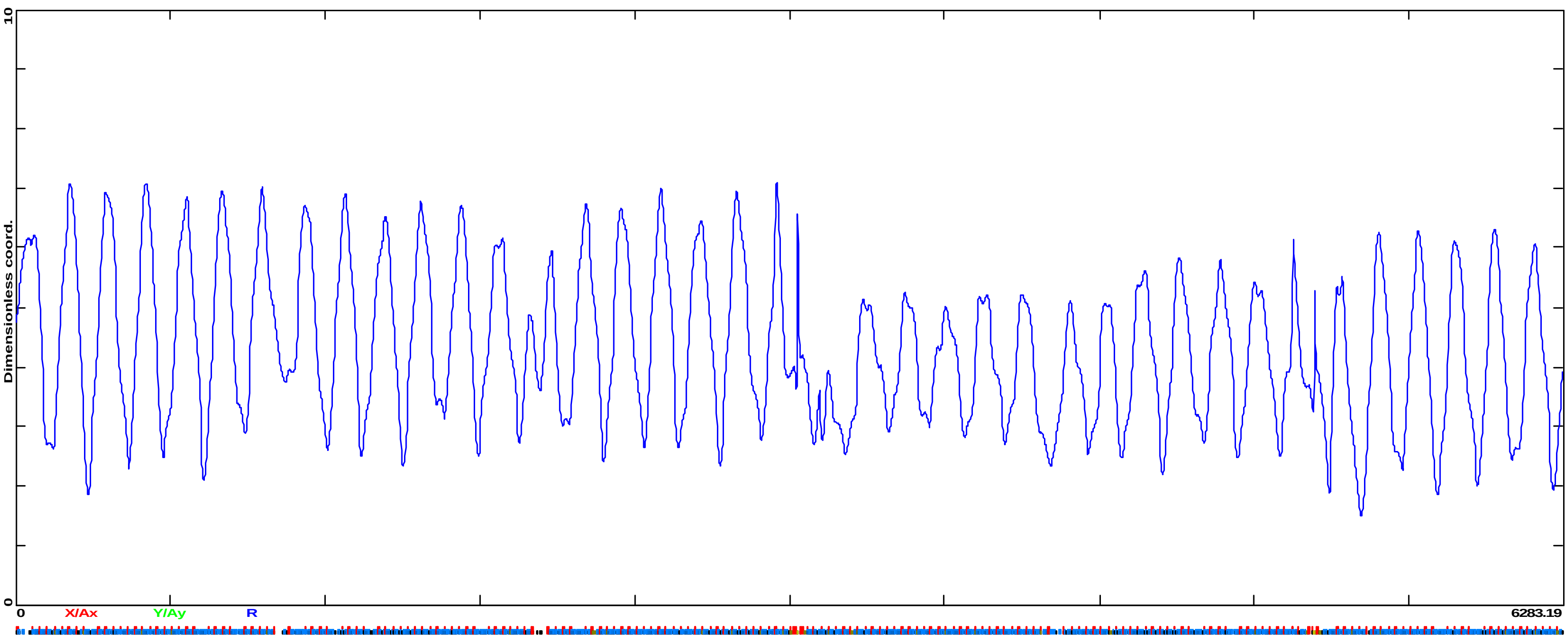


E0 F0 A0 B0



B0 C0 D0 E0

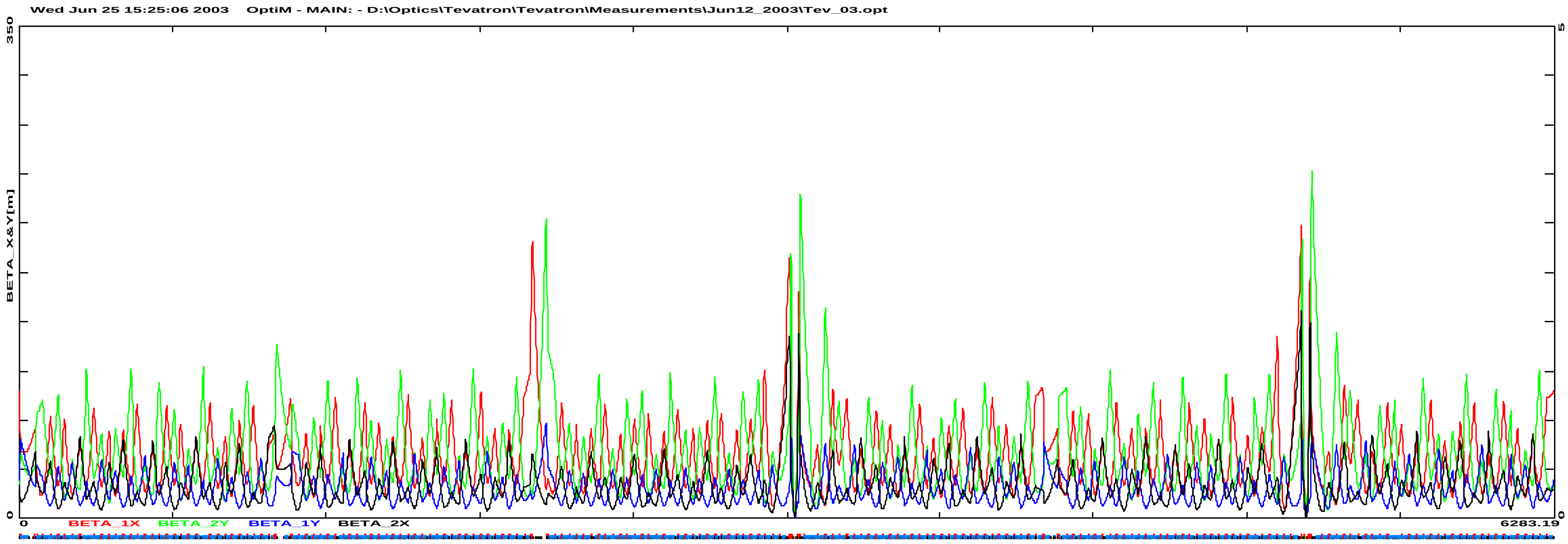
Wed Jun 25 14:21:44 2003 OptiM - MAIN: - D:\Optics\Tevatron\Tevatron\Measurements\Jun12_2003\Tev_03.opt



Relative (measured in sigmas of 20 mm mrad beam) half separation at injection

Optics on proton helix

Twiss functions at the proton helix after local decoupling at central orbit



- The model yields strong increase of local coupling at proton helix
  - **Tunes:** Qx=20.575154 Qy=20.586776
  - **Momentum compaction**: α = 0.00282046
  - **Path lengthening for excited orbit**: ΔL=0.069 cm
    - This path length change corresponds to the energy correction $-3.7{\cdot}10^{-5}$ at proton helix

Status of Tevatron optics studies

- Tevatron model uses real currents of all magnets
  - Global and local corrections are used to match measurements
- Linear model is built
  - Satisfactory agreement between the model predictions and measurements
  - Not all discrepancies are understood, more insight is required
- Non-linearities are in the model but discrepancies are large
  - ~10 units error in chromaticity calculations
    - Local non-linear fields not presented in the model
  - Tune shifts at local bumps were measured but data were not completely analyzed
    - There is a number of local bumps with large tune changes which are not predicted by the model
  - We just start putting non-linearities from the measurements

3. Instrumentation

- **Software for optics measurements at injection point**
  - It is based on the turn-by-turn BPM measurements after transverse kick of the beam.
  - It will report the beta-functions, dispersions and coupling parameters
  - Expected delivery time is September-October 2003.
  - This should address problems with on-line (during shot setup) optics measurements and correction.
- **Beam line tuner (BLT)**
  - Scope based BLT is a final choice
    - Numerical signal deconvolution to get the center of bunch gravity
    - Possibility to see head-tail motion in a bunch
- **Ionization profile monitor is under development. It will directly shows both** injection errors and optics mismatches

Plans for optics corrections and reduction of the emittance growth at transfers

1. Figure out the source of excessive current in S6 feeddown family and reduce/nullify the current – It will reduce optics dependence on orbit.
2. Achieve local decoupling at the injection point using all available skew-quads
3. Correct linear Tevatron optics
4. Develop software for on-line optics measurements near injection point and develop procedure for optics correction at shot setup
5. Arrange octupole families for correction of differential chromaticity and correct differential chromaticity (difference between proton and pbar helices)
6. Perform optics correction for A1 and P1 transfer lines
    a. Tevatron injection damper is expected in the fall 2003

Hardware improvements aimed for August 2003 shutdown

1. Correction of skew-quadrupole field in dipoles (smart bolts)
2. Correction of alignment and dipole rolls
3. Rearrange octupole families