Run II Beam Physics

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Dept. of Energy Review
March 18, 2003

- Optics Investigations
- Beam-Beam and Space Charge
- Energy Deposition
- Future Work

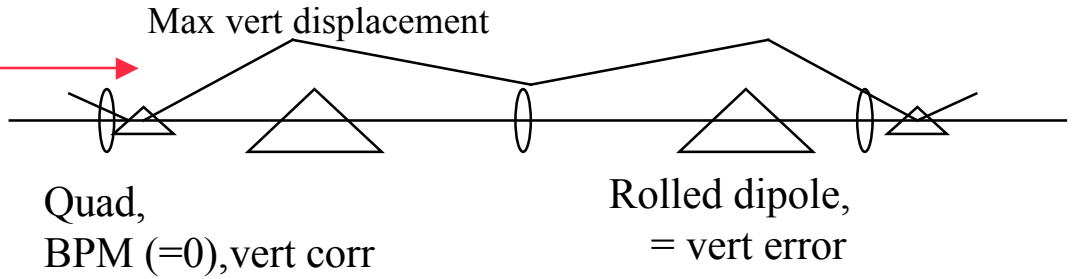
Optics Issues

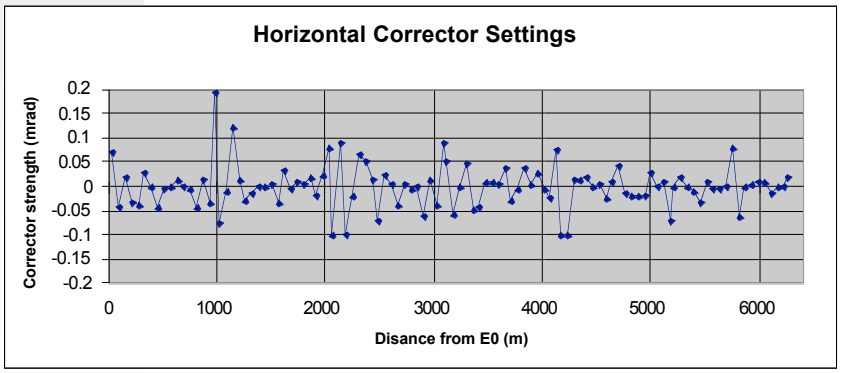
- **Tevatron**
  - **Strong orbit, coupling corrector settings**
    - **Vertical dipole correctors running strong -- <□> = 50-80 □rad in some regions (~0.4 km)**
    - **Skew quadrupole (0th harmonic) circuit running strong to minimize tune split -- ΔQ_{min} = 0.2 if left uncorrected; around long time, not understood**
  - **Helical orbit**
    - **Emittance growth at injection -- unknown source**
    - **Better separation scheme available?**
- **Booster**
  - **Injection orbit bumps**
  - **Modeling of Booster gradient magnets**

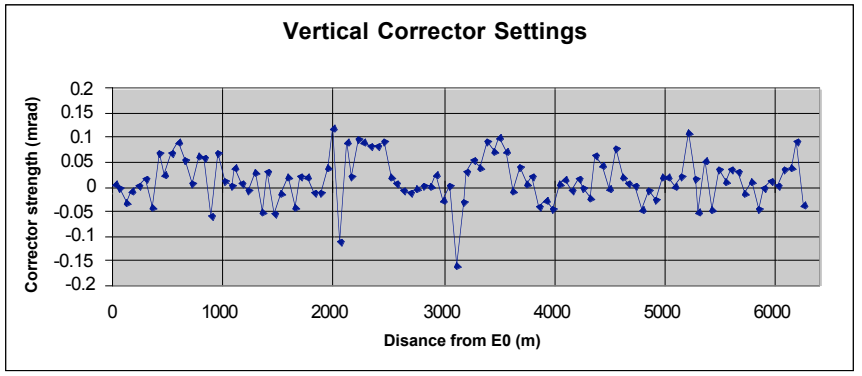
Strong Correctors in Tevatron

- **Local systematic offsets in vertical corrector settings due to regions of tunnel with rolled dipole magnets**
- **Roll measurements in January confirmed understanding**
- **Major rolls being taken care of as time allows**

~0.5 mm vertical offset through region…

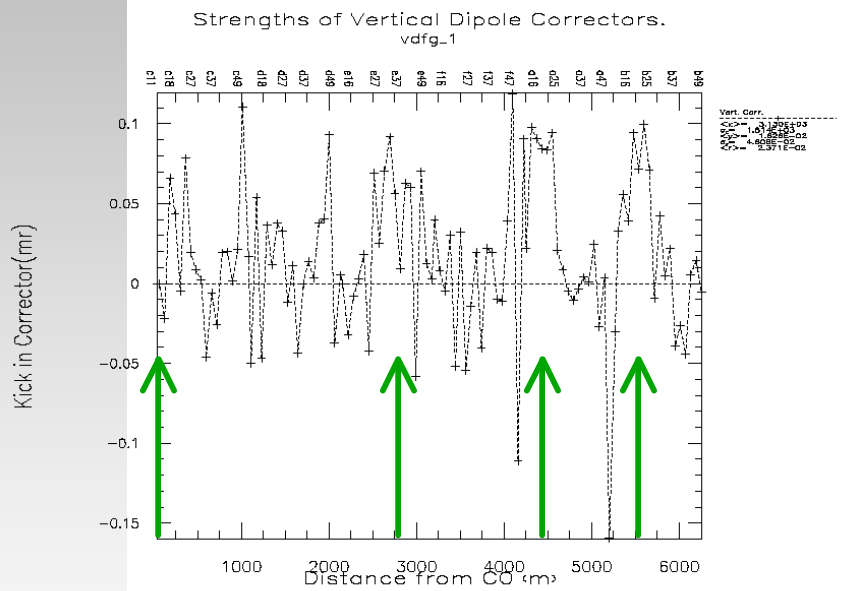


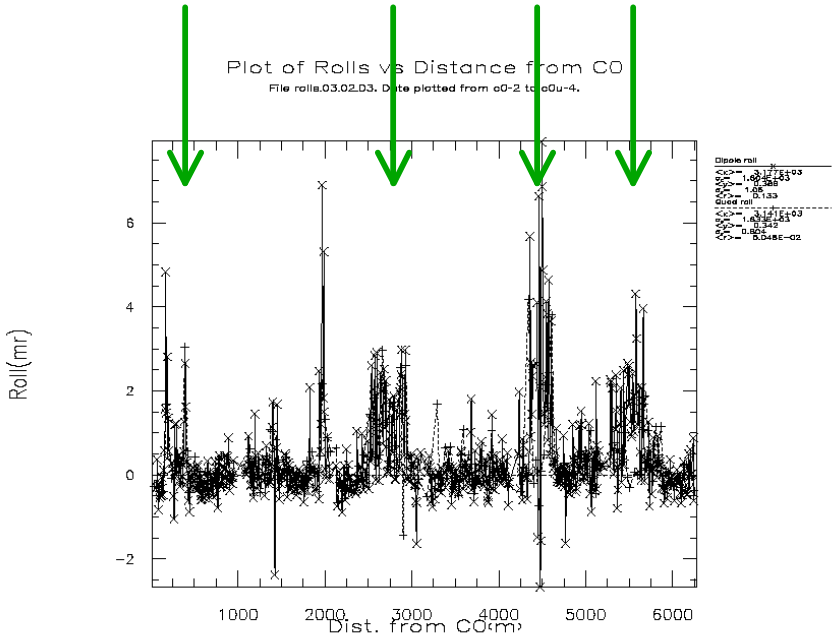




January Roll Measurements

R. Stefanski, et al.





Corrector Settings (V)

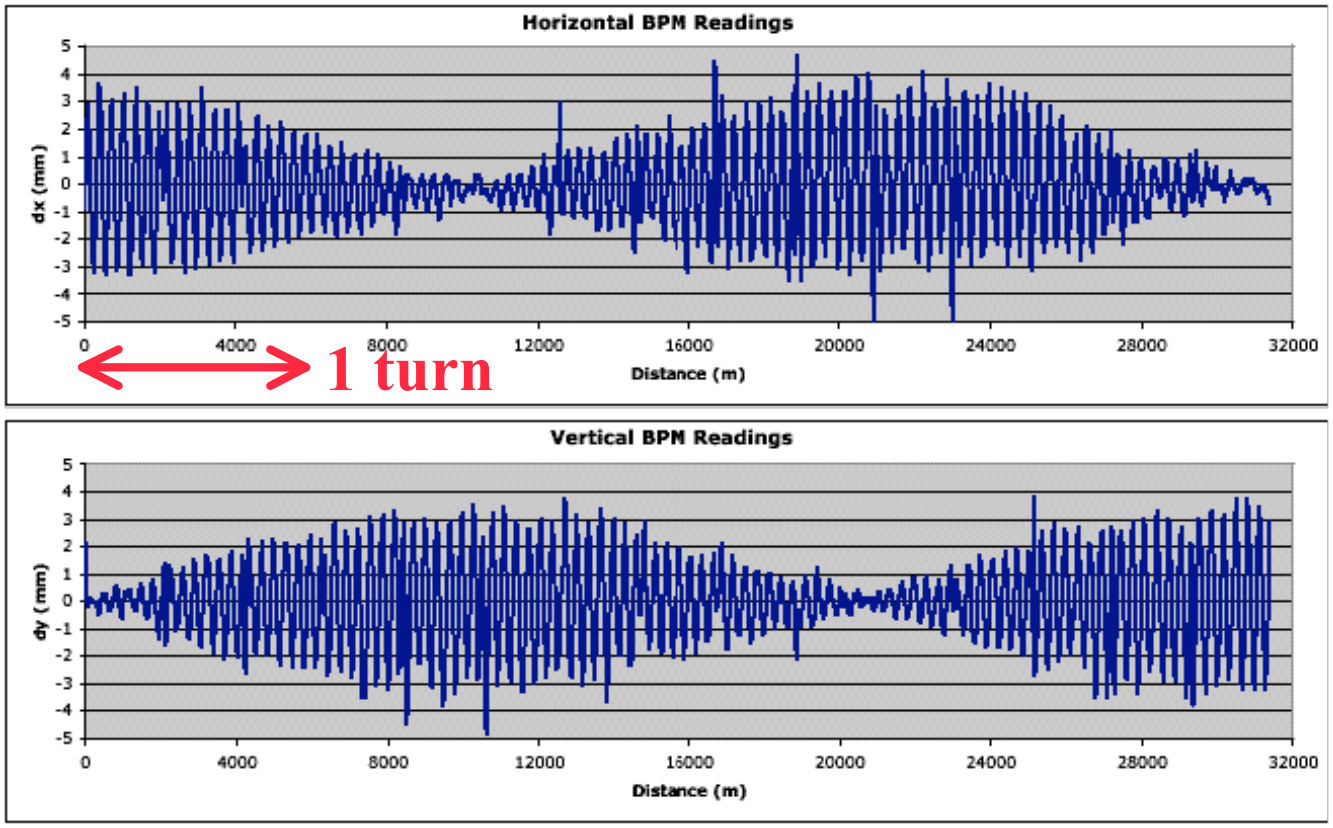
Measured Roll Angles

Strong Coupling in Tevatron

- **Source of strong coupling correction seen in skew quad circuit now understood**
  - **Systematic error distributed around ring:**
    - $\Delta\Delta_{min} = 2Fa_1 = 2*25m*(10^{-4}/25mm) = 0.2$
  - **Effect measured with beam, confirmed in simulations, analytic analyses**
- **Tevatron dipole magnets have developed skew quad component over time**
  - **Measurements in tunnel reveal coil has moved down wrt iron yoke by about 4 mil in 17 of the 18 dipole magnets looked at in January**

$$a_1 = 2\frac{(c/R)^2}{1+(c/R)^2}\frac{\Delta}{R^2} = 2\frac{0.25}{1.25}\frac{0.004}{(3.8)^2\,\text{in}} = 1.1\times 10^{-4}/\text{in}$$

Coupling data, Feb 27, 2003



G. Annala

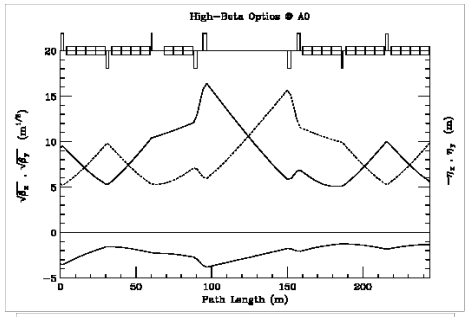
Data are consistent with systematic $a_1 \sim 10^{-4}$/in

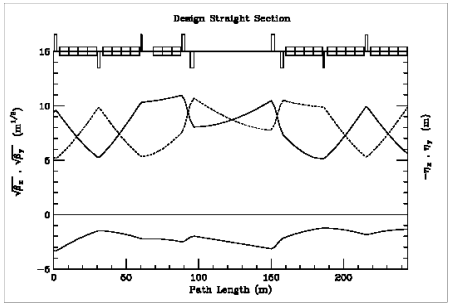
Optics, cont'd

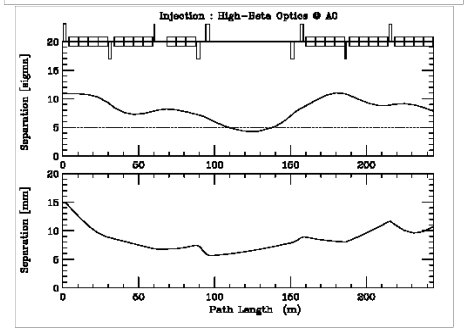
- **Zero-th harmonic skew quad circuit designed to deal with this very problem. Works effectively, though some components removed from circuit in favor of interaction region correctors. Other skew corr's exist.**
- **Continuing to improve model of Tevatron**
  - **Beam Physics Dept. and Tevatron Dept. working to understand optics at injection, identify error sources.**
  - **Emittance increase upon injection suggests possible mismatch between beam lines and Tevatron -- type/source unknown**
    - **Using collection of BPM orbit difference data to attempt to identify regions of suspicion**
    - **Studying effectiveness of helical orbits and possible gains through other configurations of electrostatic separators**

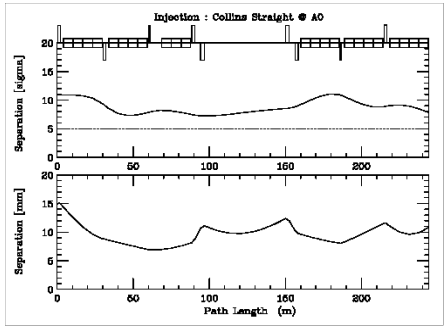
Beam-Beam -- Helix Optimization

- **Looking at possible gains by using more than 2 separators at injection, ramp**
- **Investigating A0 optics wrt improved beam separation on helix**









J.Johnstone

See Poster Session!

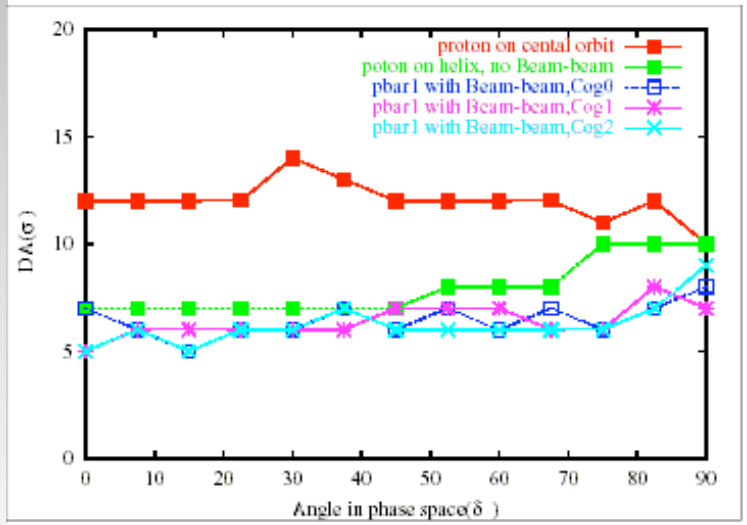
Injection Dynamic Aperture Calculations *(M. Xiao)*

Note:

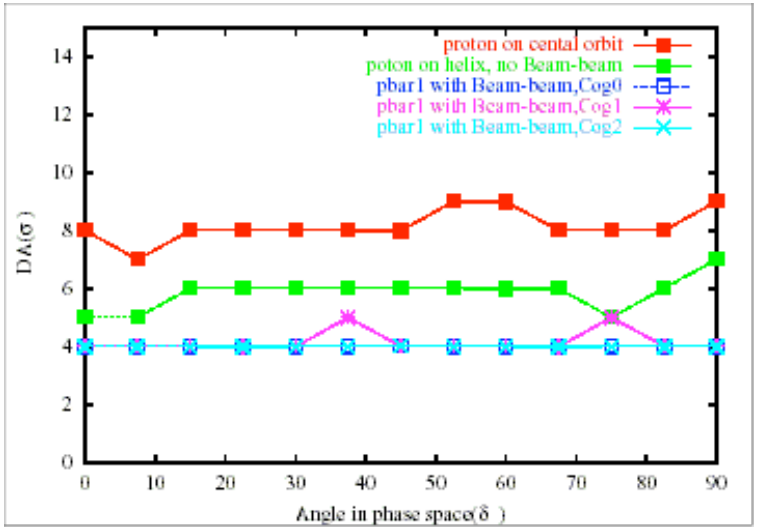
$(\Box\Box/6\Box\Box)^{1/2}$ ~ 1.5 mm

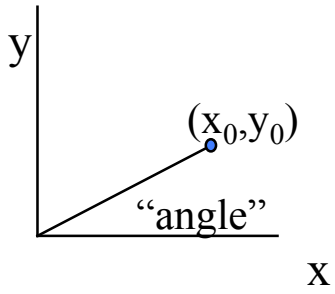
$D\,\Box_p/p$ ***~ 3 mm***

Pre/Early-Run studies
15□ emittance, dp/p=1e-4 (1□),
□$_{x,y}$=(0.585,0.575), Original helix



Present Conditions
25□ emittance, dp/p=13e-4 (3□),
□$_{x,y}$=(0.583,0.575), "new-new" helix





Starting at B0, center of beam - beam kick; 10^5 turns

Behavior on/off helix consistent with DA calculations

Roll of Momentum Spread in Tevatron Operation

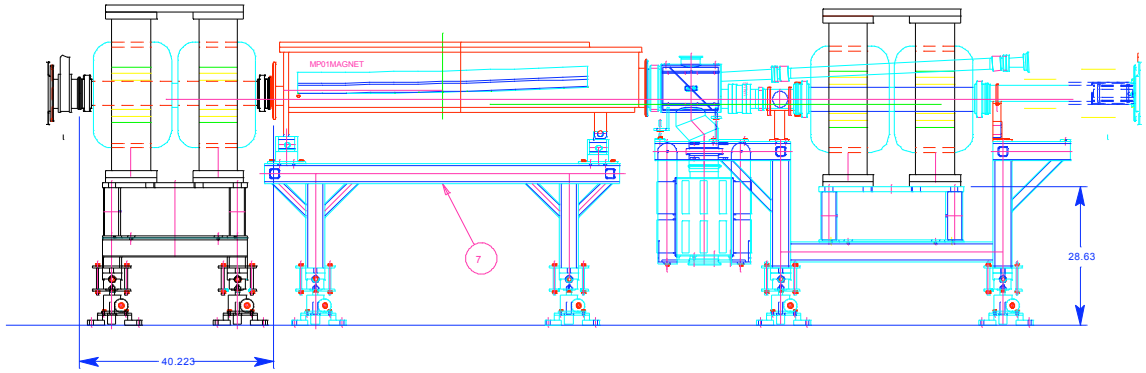
- With the large momentum spread of the incoming beam, beam size (H) at injection is dominated by dispersion
  - Affects beam separation (units of σ), beam-beam force nonlinearities
- Hour-glass effect: $\beta(s) = \beta^* + s^2/\beta^*$
  - since $\beta_z > \beta^*$ -- > makes a hit on luminosity
- Injection more sensitive to dispersion mismatch
- DC beam being generated (inject, ramp, HEP)
  - Bucket is "full" at injection; susceptible to rf noise, etc.
- Time dependence of injection losses (when on pbar helix, especially) often seen consistent with a longitudinal diffusion process more than transverse

See Poster Session!

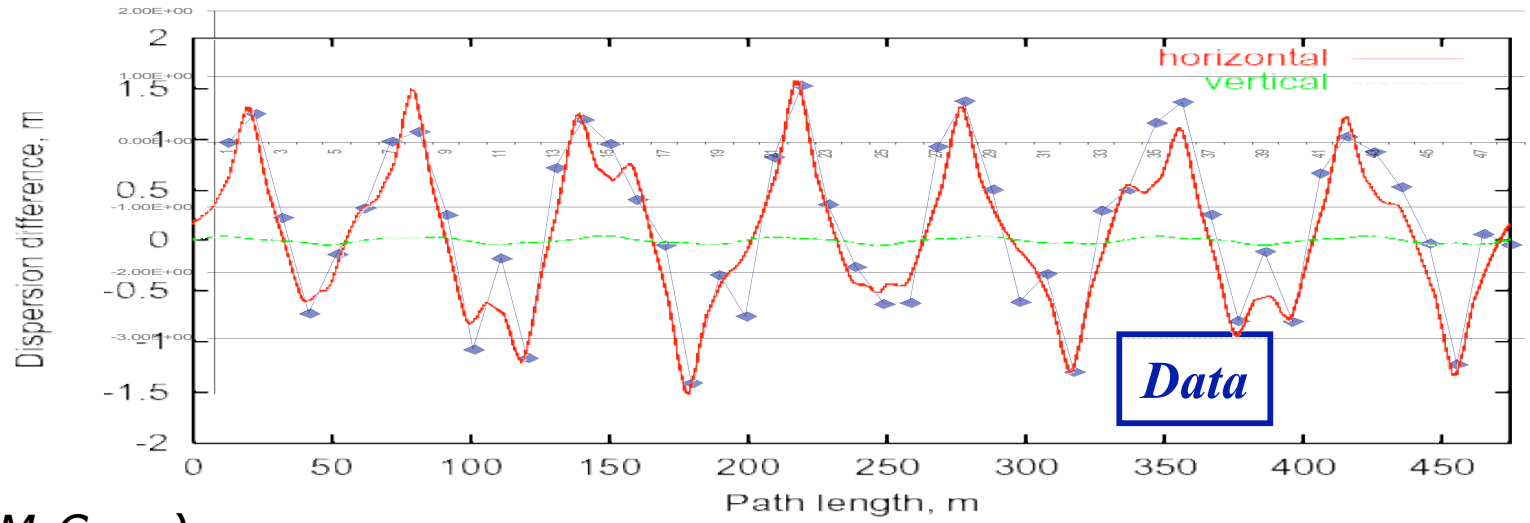
Booster Synchrotron

- **As in Tevatron, working toward an understanding of Booster synchrotron**
- **Injection orbit bumps (chicanes, or "doglegs")**
  - **Gearing up for space charge calculations, effect of orbit bump magnets on injection lattice was computed (*Drozhdin*)**
  - **Discovered "age-old" effects of sector focusing, edge focusing**
    - **Large vertical excursions generated away from 2 extraction septa at kinetic energy of 400 MeV**
    - **Strong focusing of the bending magnets not previously taken into account in Booster model**
    - **Generates strong mismatch of amplitude functions (50%) and dispersion function (100%!).**
  - **Beam tests confirmed the calculated mismatches**

Booster Injection (cont'd)



Injection girder



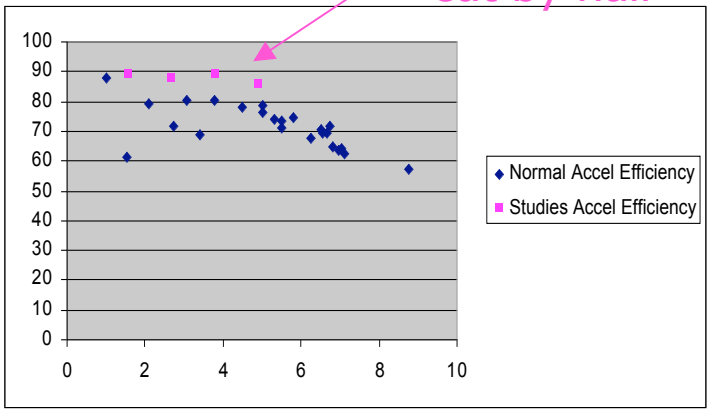
(courtesy E. McCrory)

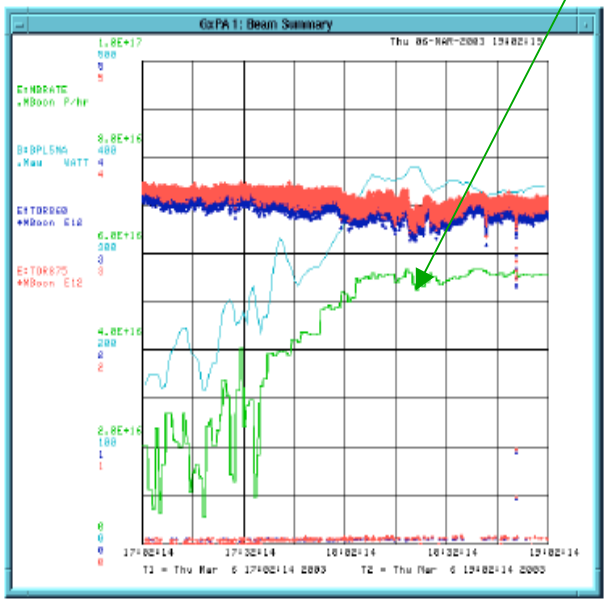
Booster Injection (cont'd)

- **Study period used to move 1 septum out of way, and turn off associated beam bump**
  - **Losses at injection reduced by 50%**
  - **Booster set record (and milestone) for protons/hr delivered to MiniBooNE experiment**
- **Septum had to be put back, awaiting more permanent solution**

MiniBooNE milestone: 5e16 pph

Beam loss cut by half





(Courtesy J. Lackey)

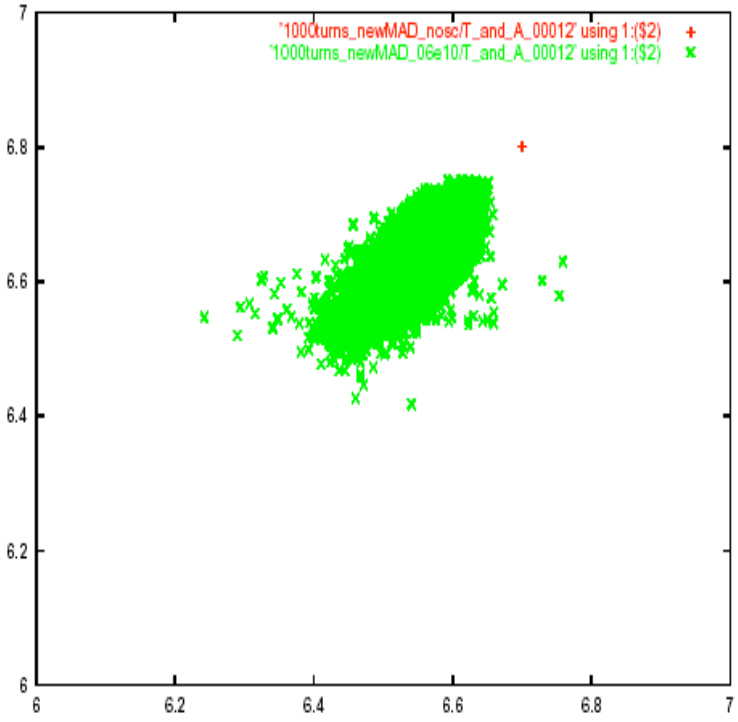
Booster Gradient Magnets

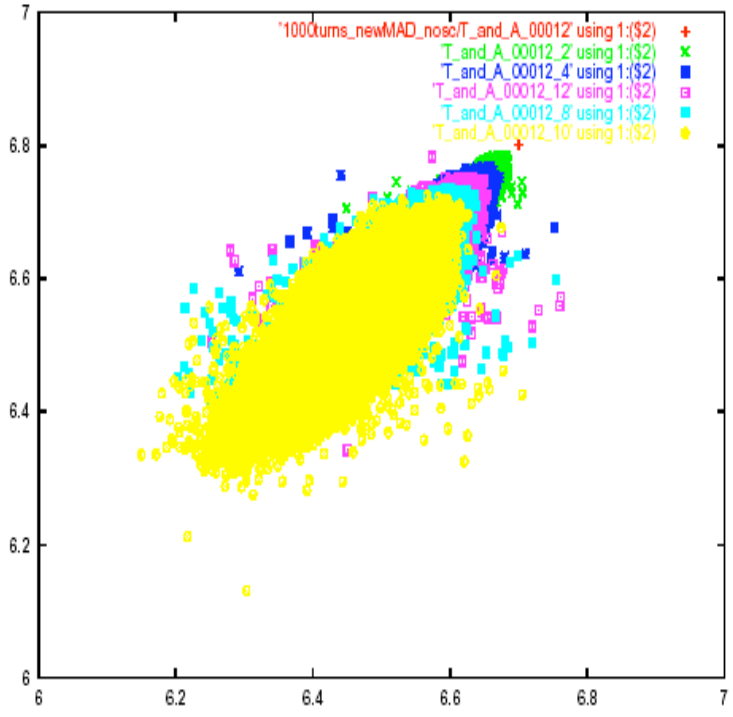
- **Part of the Booster effort includes proper understanding of main magnets**
  - **Existing magnet measurements scarce**
  - **Recently, 2 magnets measured to confirm**
  - **Beam-based chromaticity studies also performed**
  - **Both methods (blind study!) provide consistent results for integrated normalized sextupole field strength:**
    - **F-mag: ssf = -0.003 (MCR), 0.004 (E4)**
    - **D-mag: ssd = -0.045 (MCR), -0.041 (E4)**
  - **Body field (meas.): ssf = 0.026, ssd = -0.021**
  - **Confirm b_2(ends) = -b_2(body) in F magnets to compensate sextupole, but *adds* in D magnets!**
- **Chromaticity is known to change rapidly early in the cycle; with this info, and "dog leg" issue, beginning to understand…**

See Poster Session!

Space Charge

(Chou, Ostiguy, et al.; Spentzouris, Amundson)

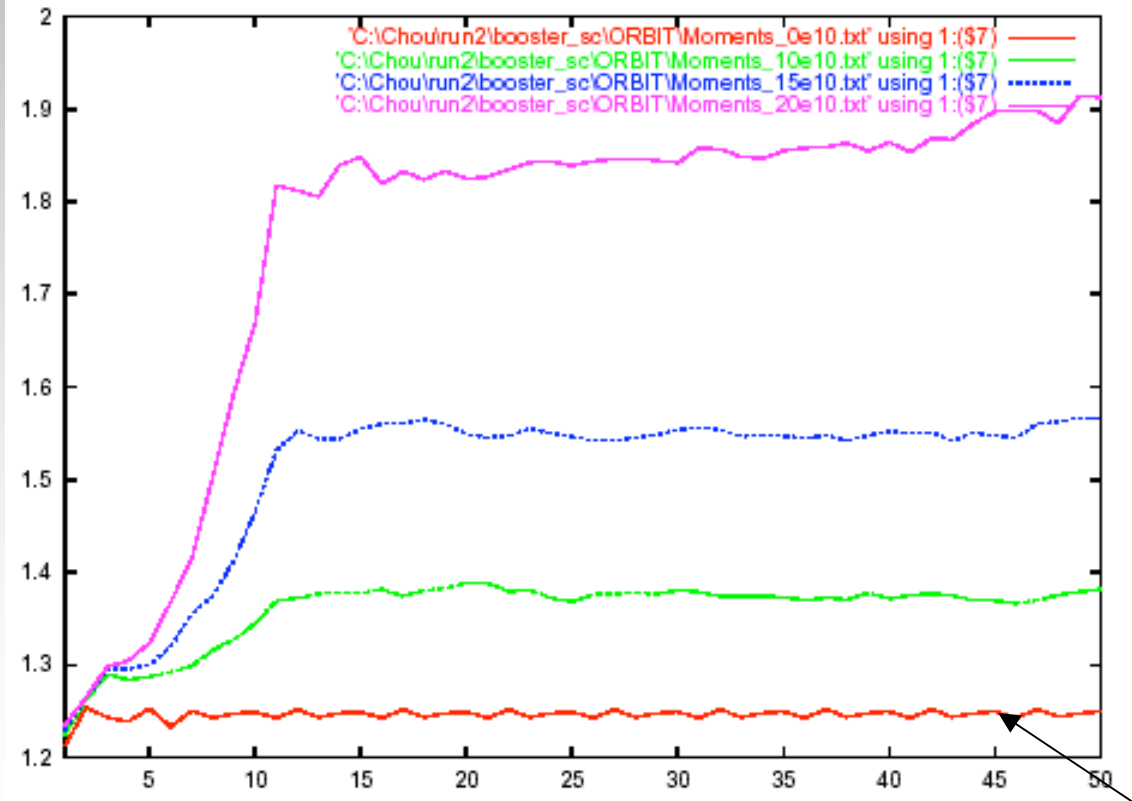




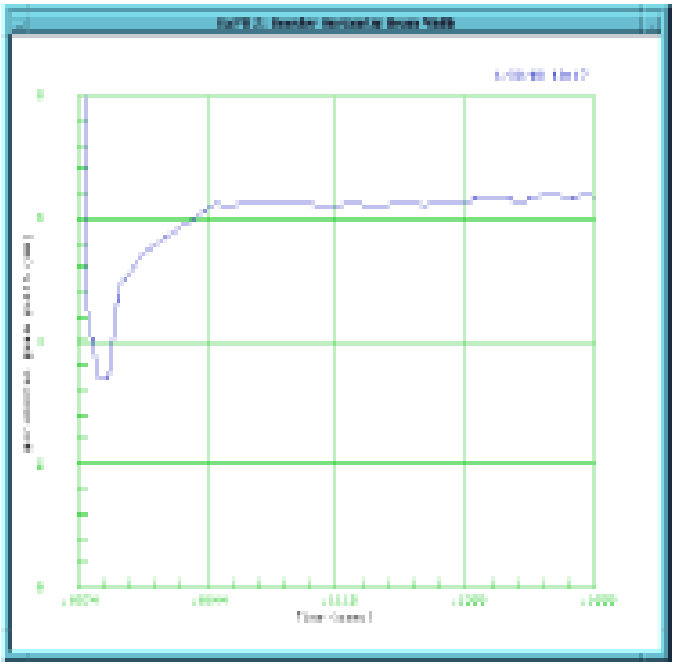
Laslett tuneshift: □□(sc) □ □0.3

Space Charge (cont'd)

ORBIT simulation



IPM data



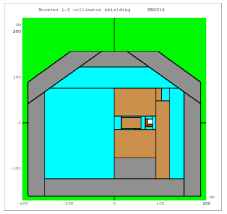
45 turns

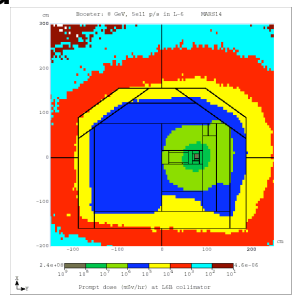
40 mA, 10-turn injection

No space charge

Energy Deposition *(Mokhov, et al.)*

- **Booster**
  - **Beam loss and radiation studies,collimation system design and installation of primary and secondary collimators.**

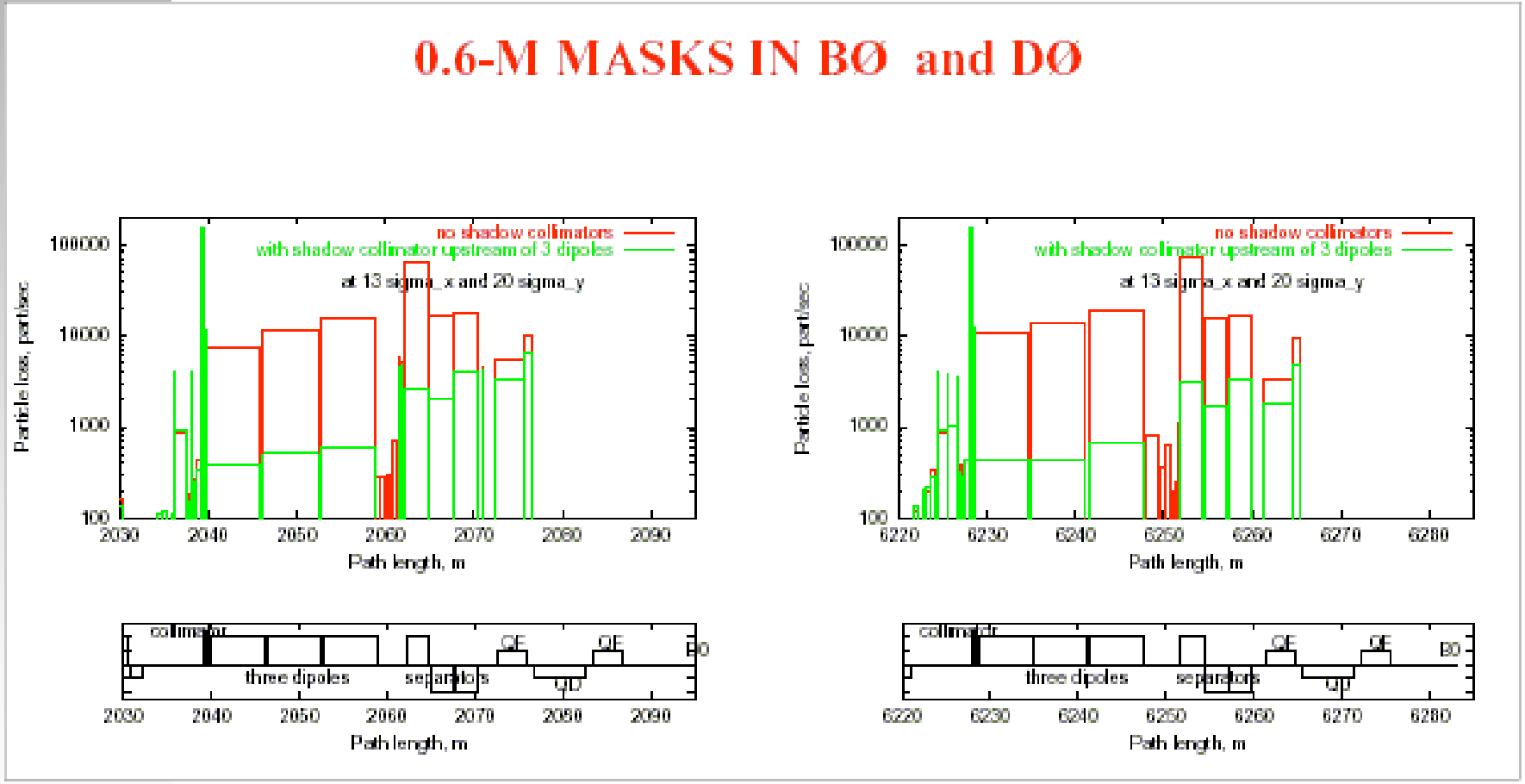




BOOSTER L-6 MARS MODEL AND DOSE

- **Tevatron**
  - **Loss rates in B0 (especially) and D0 an issue**
  - **Present system designed for cure of beam losses due to slow emittance growth – works well as designed; about 0.1% of particles escape system**
  - **Large angle elastic scattering off residual gas nuclei and Coulomb scattering, between collimators and IPs, result in higher loss rates at detectors**
  - **Detailed MARS model of A-sector, B0 and CDF (including Roman Pots) for beam loss and radiation studies -- suggests use of "shadow collimators"**

Energy Deposition *(Drozhdin)*



Initial study shown above; detailed study performed, implementation being pursued…

Summary

- Beam Physics emphasis has switched from future accelerators to Run II issues
- Reasons for large corrections (steering, coupling) in Tevatron uncovered; leads to more complete understanding of machine
- C0 vertical aperture opened up; attempt to better optimize helix at injection, up ramp
- Large fraction of Booster injection losses tied to linear optics; correctable with standard methods
- Gaining understanding of Booster components and developing better model of this synchrotron
- Space charge efforts bringing in first results; collaborations with Beams and Computing Div's, ORNL, BNL, SciDAC
- Tevatron Task Force -- looking at upgrade path for Run II
- Performance can dramatically increase only by fully understanding the accelerators