
Status of Work on Helix/Aperture

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Introduction

- The problem: separate the beams to weaken the beam- beam effects but
- Comply with aperture and other restrictions
- Each step in the Tevatron operation has its own specifics w.r.t. the helix design:
 - Injection: the helix amplitude is limited by
 - Physical aperture
 - High order magnet nonlinearities (dynamic aperture)
 - Ramp & Squeeze:
 - The helix amplitude is limited by the breakdown voltage
 - Collision:
 - Insufficient separation in the nearest parasitic IPs

Beam-beam effect at 150 GeV

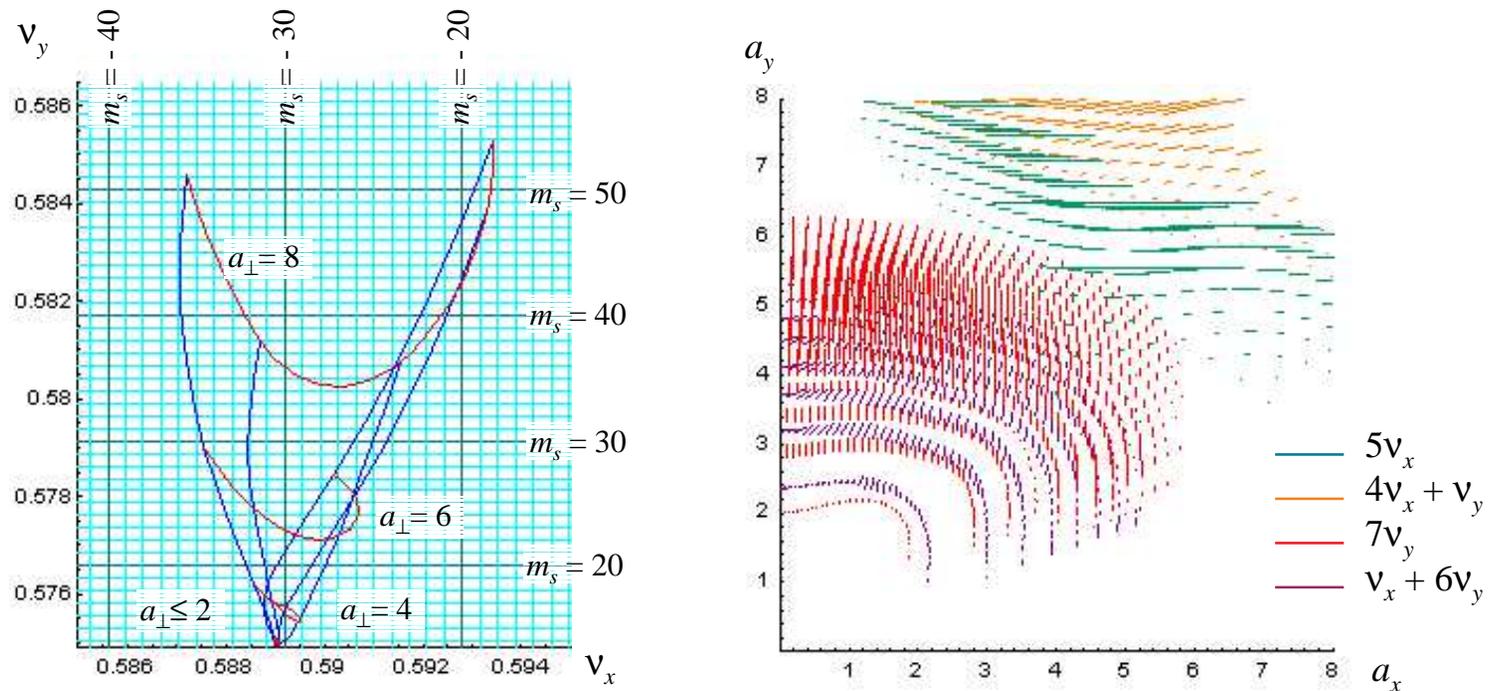


Figure 1. The 2001 injection helix. Footprint of pbar bunch #6 on the grid of the synchrotron satellite lines of $5v_x$ and $7v_y$ resonances (left) and amplitude beatings due to indicated resonances (right). Reference emittance 15π mm·mrad.

Present helix introduced in May 2002

By employing B11H and B11V separators (in addition to B17H and C17V) it was possible to increase the radial separation

$$S = \sqrt{\left(d_x / \sigma_x^{(\beta)}\right)^2 + \left(d_y / \sigma_y^{(\beta)}\right)^2}$$

from ≤ 4 (at A0) to > 5.5 (at C0 where the tightest restriction was)

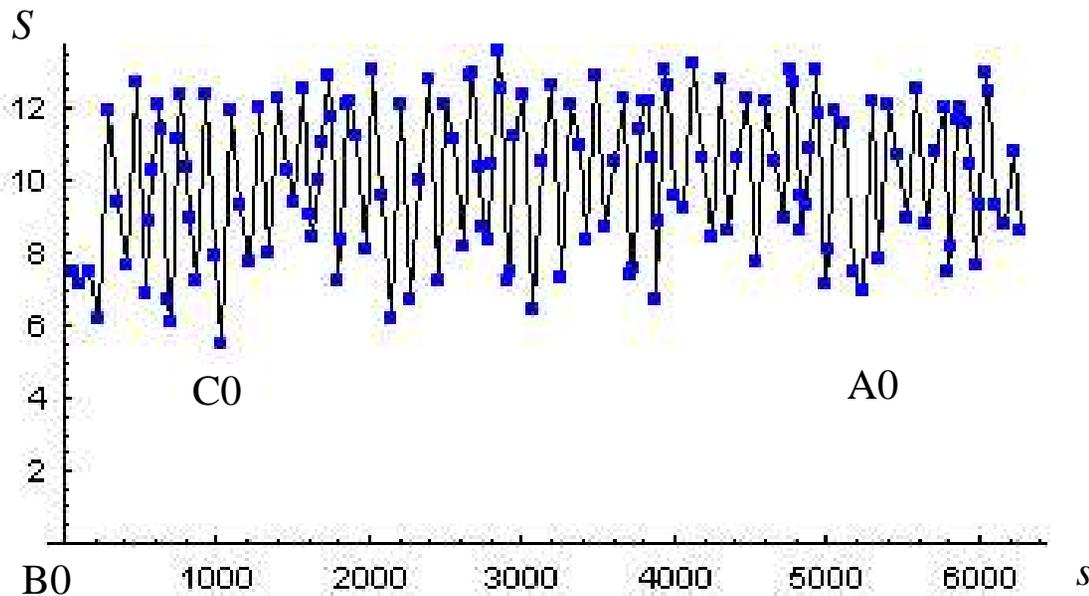
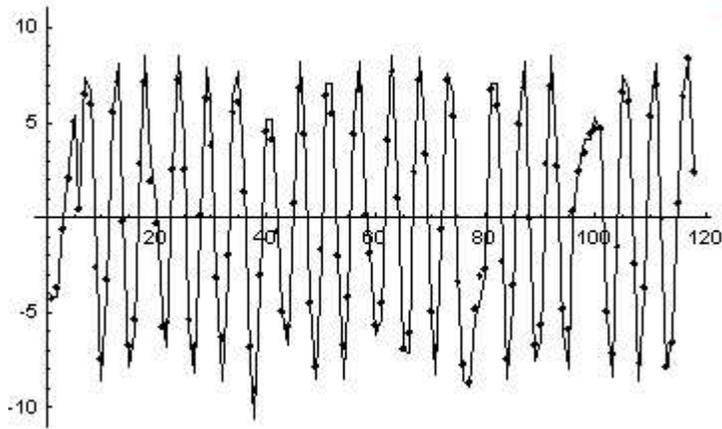
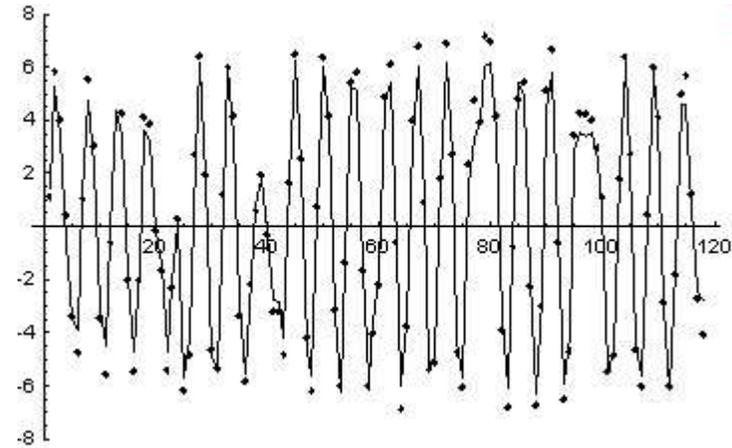


Figure 2. Radial separation S with the ideal optics. Reference emittance 20 mm mrad

Present helix introduced in May 2002



Horizontal orbit (mm) vs. BPM number



Vertical orbit (mm) vs. BPM number

Figure 3. Comparison of the design proton helix (solid lines) with the measured orbit (dots) starting from B0. Horizontally the measured values are ~12% smaller, vertically by the same amount larger.

Present helix introduced in May 2002

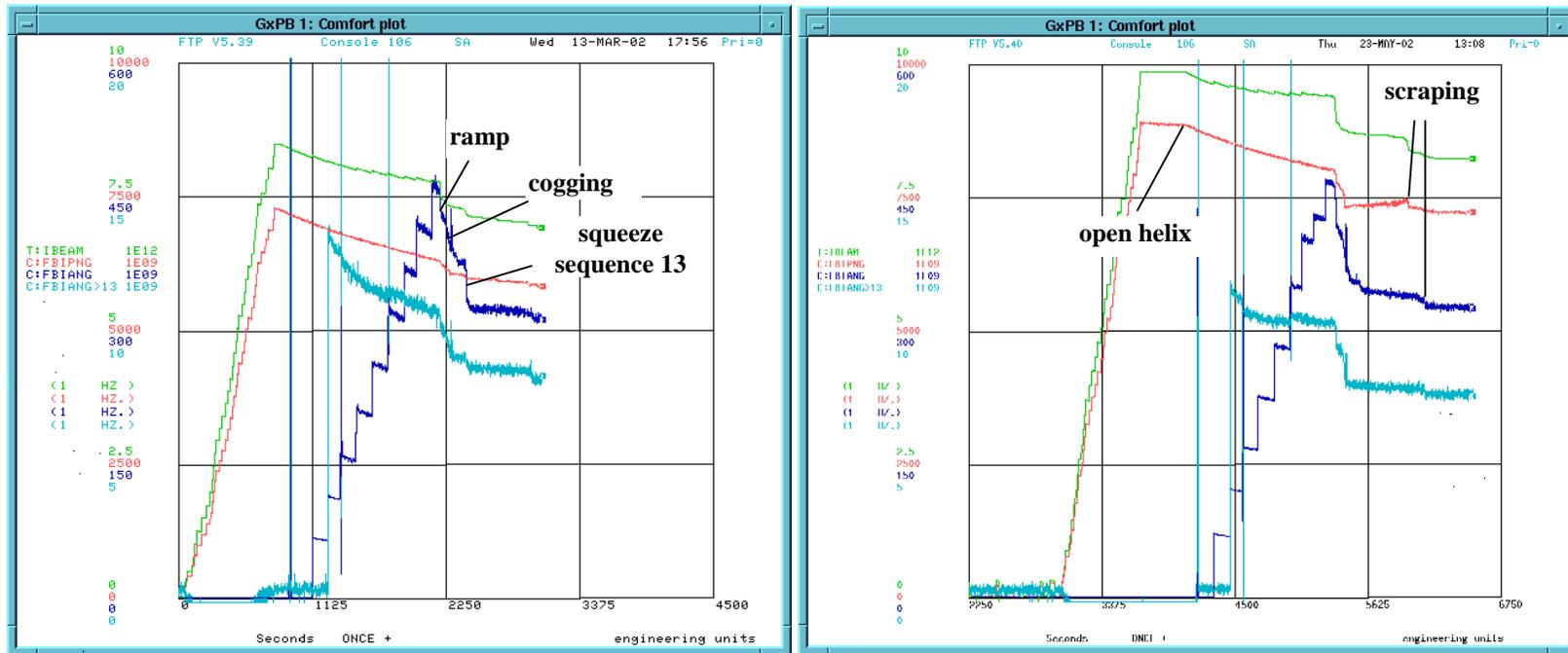


Figure 4. Effect of changes in the injection helix and squeeze seq.13. Left: store #1074 of 03/13/02, right: store #1356 of 05/23/02 (marred by a coherent instability up the ramp)

Situation after CO Lambertson magnets removal

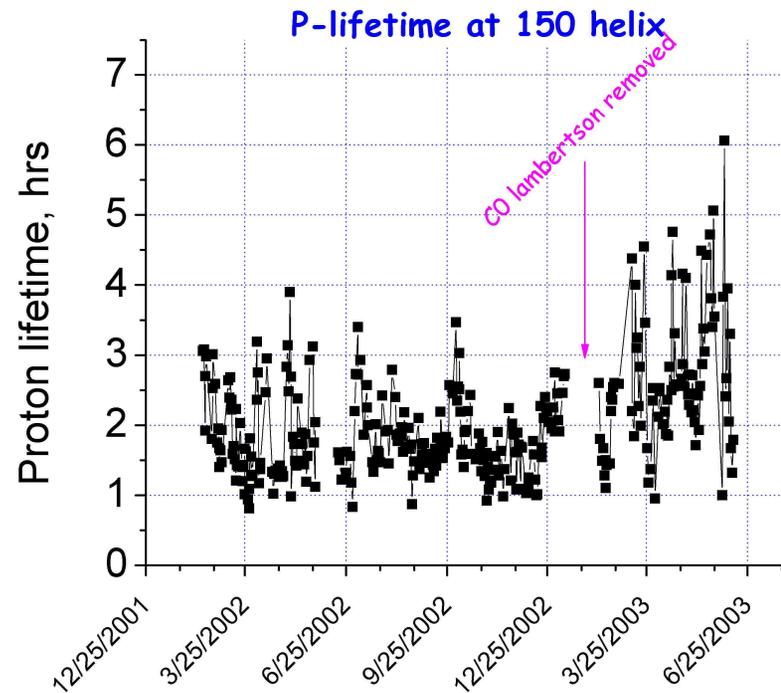


Figure 5. Proton lifetime during the first 10min after opening the helix.

Situation after CO Lambertson magnets removal

- Proton lifetime noticeably improved
- Attempts to fully materialize the advantage of the increased physical aperture have not succeeded so far
- On the contrary, ~3 months ago we had to REDUCE the separation by lowering voltage on all 4 separators by 5%
- Possible reasons for the failure to open the helix more:
 - Presence of strongly nonlinear elements in the lattice - now the aperture limitations are mostly dynamic (as seen from the dependence on chromaticity and emittances)
 - Significant optics perturbations (increasing with time!)
 - Remaining physical aperture restrictions (A0, F0)
 - Misalignments of the beam pipe
- It was decided to concentrate on the orbit correction and on the search for the sources of the dynamic aperture limitations rather than on attempts to introduce a new injection helix

Search for the origins of aperture restrictions

- Orbit centering was performed with the help of local 3-bumps (more than 100 in each plane)
- Regions containing strong nonlinear elements were found (the triplets, A11, E48, F48, A46, C46)
- The nonlinear elements in A46, C46 locations were identified as S6 feeddown sextupoles running at 19.2 A, they produce large tune variation with the horizontal orbit displacement:

$$\partial \nu_x / \partial x_{co} = -0.0045 / \text{mm}$$

- Linear optics is being checked with the help of difference orbits (V.Lebedev); maximum value of β_y (reached at A0, presently the most stringent vertical aperture restriction) increased during this year from ~250m to ~300m

Effect of orbit centering with 3-bumps

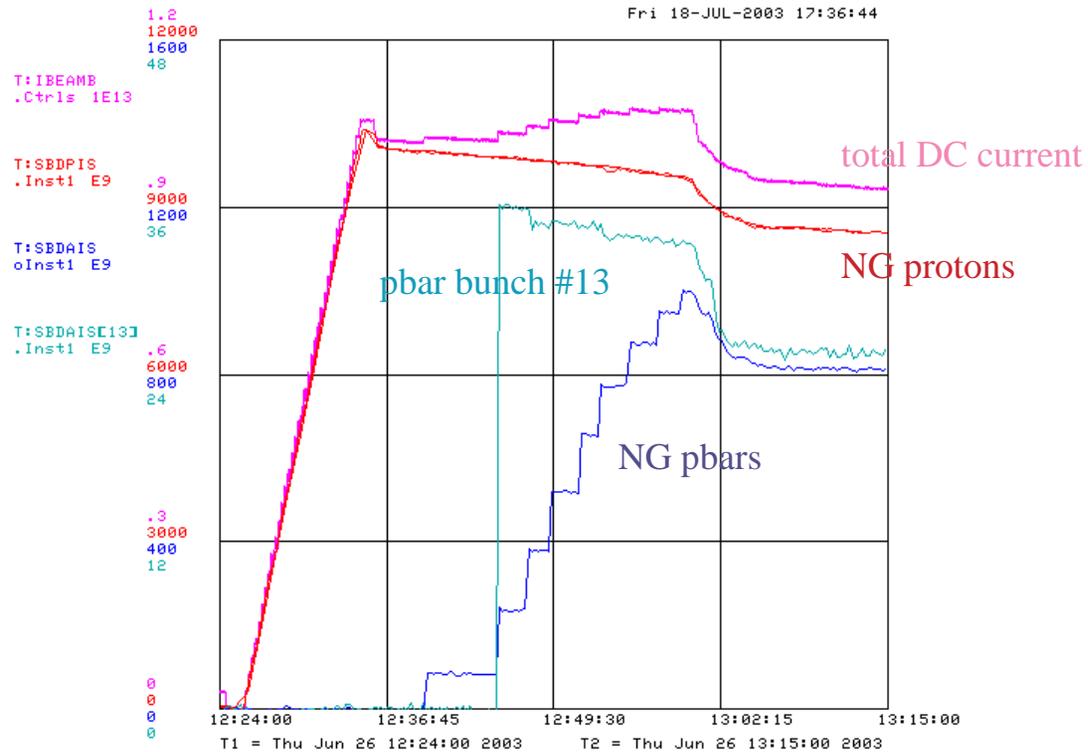


Figure 6. Proton and pbar intensities during injection, ramp @ squeeze. Store #2725 of 06/26/03 ($L=33.85e30$). At 150 GeV p-loss 6.9%, pbar loss 3.2%. Up the ramp p-loss 6.2%, pbar loss 9.5%.

Short-term plan for the injection helix

- Try to reduce current in S6 feeddown sextupoles - the strongest nonlinear elements in Tevatron (seems to be possible)
- Identify the source of and try to reduce the large (and growing!) chromaticity split between the proton and pbar orbits:

	06/16/02		06/21/03	
helix	Q_x'	Q_y'	Q_x'	Q_y'
proton	7.6	10.8	11.7	8.0
pbar	3.8	8.8	2.8	9.6

- Measure the optics functions with TBT
- Tailor the helix so that to minimize it in the regions with strong nonlinear fields or limited aperture without enhancing the beam-beam effect. The best solution employing C49V separator:

helix	S_{min}	tuneshifts		resonance terms	
		$ \Delta \nu_x $	$ \Delta \nu_y $	$ R_{50} \cdot 10^{12}$	$ R_{07} \cdot 10^{14}$
present	5.48	.0028	.0019	1.47	2.82
“five-star”	6.36	.0020	.0009	1.28	0.88

Table 1. Maximum beam-beam tuneshifts and resonance driving terms

Short-term plan for helix at ramp & squeeze

- Introduce new helix design employing B11H, B17H, B11V, C17V, C49V separators:

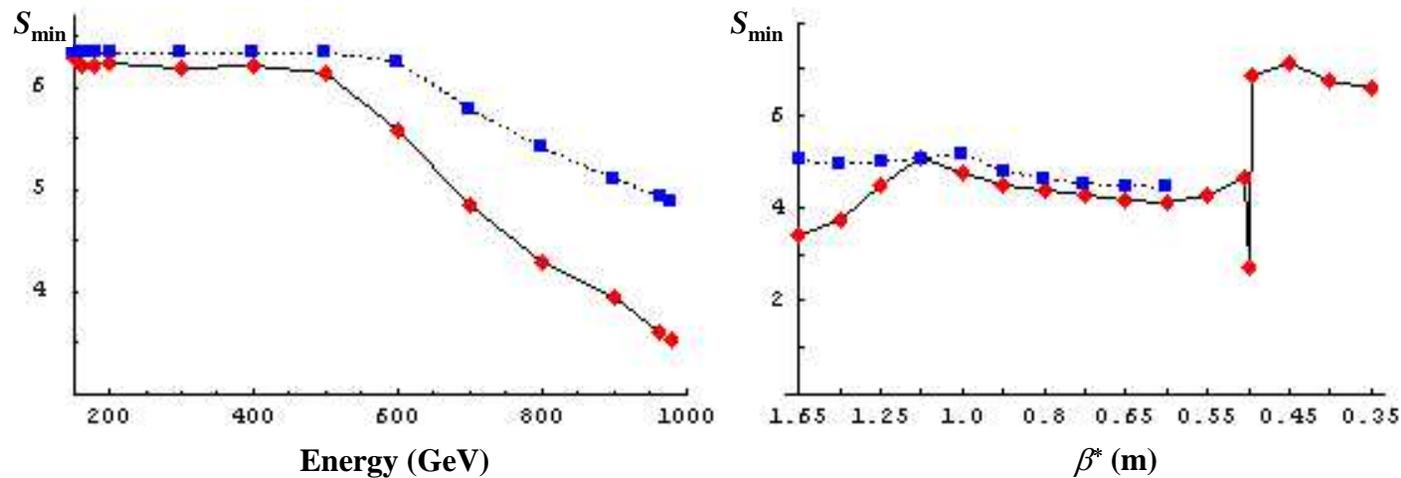


Figure 7. Radial separation up the ramp (left) and during the squeeze (right) with the present helix (red diamonds) and the new one (blue squares) starting from the same injection helix. Reference emittance 15 mm mrad.

Short-term plan for helix at ramp & squeeze

helix	step	S_{\min}	$ \Delta v_x _{\max}$	$ \Delta v_y _{\max}$	$ R_{50} _{\max} \cdot 10^{12}$	$ R_{07} _{\max} \cdot 10^{13}$
present	EoR	3.26	.0066	.0031	2.02	1.45
	BoS	3.09	.0078	.0031	2.33	2.54
new	EoR	4.46	.0033	.0016	1.07	0.31
	BoS	4.60	.0045	.0021	1.31	0.51

Table 2. Maximum beam-beam tunes shifts and resonance driving terms with the present and new helices. The cogging is different at the end of ramp (EoR) and the beginning of squeeze (BoS).

- Increase separator voltages at sequence 16 (former 13) of the squeeze. Now the maximum voltage at this step is 105kV whereas it can be temporarily raised to at least 130kV

Beam-beam effect at collision

With the bare lattice tunes $\nu_{x0}=20.585$, $\nu_{y0}=20.575$ the most dangerous are 5th order resonances excited almost completely at the nearest parasitic IPs

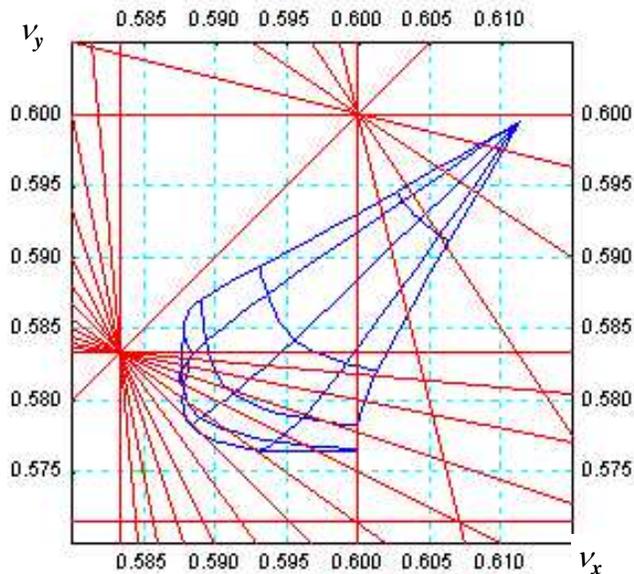


Figure 8. Footprint of pbar bunch #6 with the 'standard' WP (green dot). Arc lines drawn with step 2σ for the reference emittance 15 mm mrad.

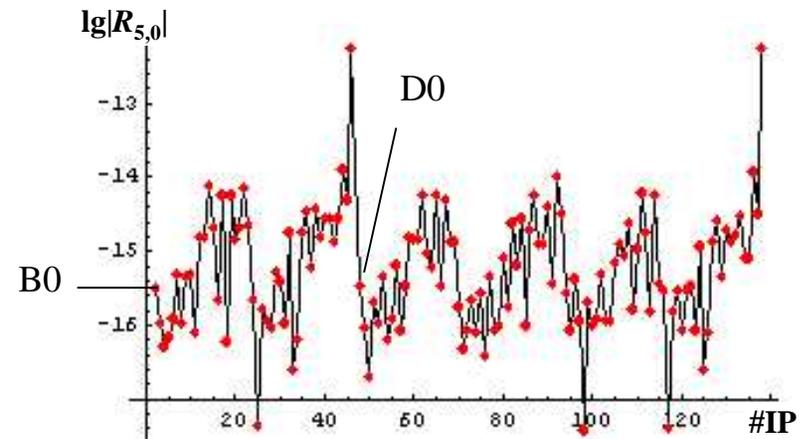


Figure 9. Contribution from all 138 IPs starting from B0 to the $5\nu_x$ resonance driving term at the horizontal amplitude $a_x = 3\sigma$.

Longer-term options

- Increase beam separation at nearest parasitic IPs at collision by some 40% by :
 - utilizing the space occupied by the presently unused Q1 quads
 - increasing breakdown voltage by coating the separator plates
 - introducing moderate crossing angle of $\pm 50 \mu\text{rad}$
 - increasing bunch-to-bunch distance from 21 to 23 RF buckets - this can be achieved by rearranging transfers from MI to Tevatron and modification of MI antiproton kicker
- Equip all separators with polarity reversal switches, and condition them to the voltages 130-150 kV, so that they could be run at higher voltages during short time of acceleration and squeeze