C0 LOW–β INTERACTION REGION

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OUTLINE:

- Design Constraints
- IR Layout & Magnets
- Optics
- Beam Separation
- Continuing Studies

The C0 IR optics are designed to accommodate 2 low–β, high-luminosity collision options:

1. Full luminosity at C0 [ß* = 0.35 m] & separated beams at B0/D0 [ß* = 1.65 m], and;

2. No collisions at C0 [ß* = 3.50 m], and design luminosity at B0/D0 [ß* = 0.35 m].

Collision scenarios assume 36x36 operations will continue from Run II into the BTeV era, but 132x132 bunches are also possible with re-tuning of the separators generating the helix.

DESIGN CONSIDERATIONS:

Continued successful Tevatron collider operation requires that the nominal Run II lattice functions remain undisrupted outside of the C0 IR region:

- An IR solution like the CDF/D0 triplets is unacceptable (and wouldn't fit anyway). A single low-ß would add 1/2 integer to the tunes, raising them from 20.5 → 21.0. Adding 2 low-ß's in each plane, raising the tunes by a full integer to ~21.5, makes retention of the nominal fractional operating point possible.

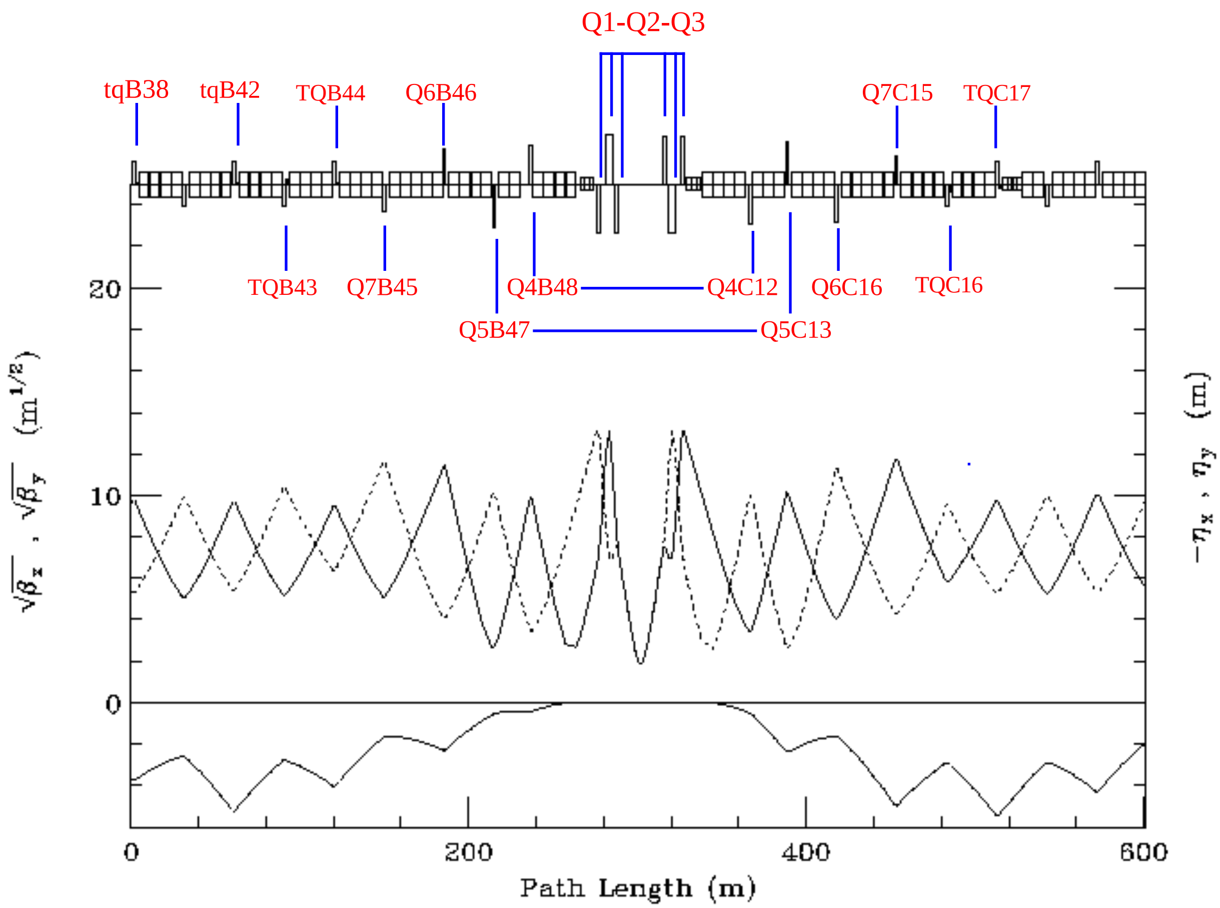
- With collisions at B0 & D0, but not C0, the integer of tune added at C0 ensures that the incoming & outgoing helices are matched. New B49 & C11 separators provide position control at the C0 IP, but high-luminosity collisions at all 3 IP's would require additional separators in the arcs.

  There is **zero** space for more separators in the short B0 → C0 → D0 arc.

  So, high luminosity collisions can be created at B0 & D0, or just at C0, but not at all 3 IP's simultaneously.

- CDF & D0 are not optically-isolated entities. The Run II low-ß squeeze involves adjusting the distributed F & D tune quad strings in addition to the IR magnets. Lattice functions at any point in the ring, and the phase advance across any portion of the ring, vary through the squeeze sequence. The C0 optics must track these elusive matching conditions.

IR PHYSICAL LAYOUT



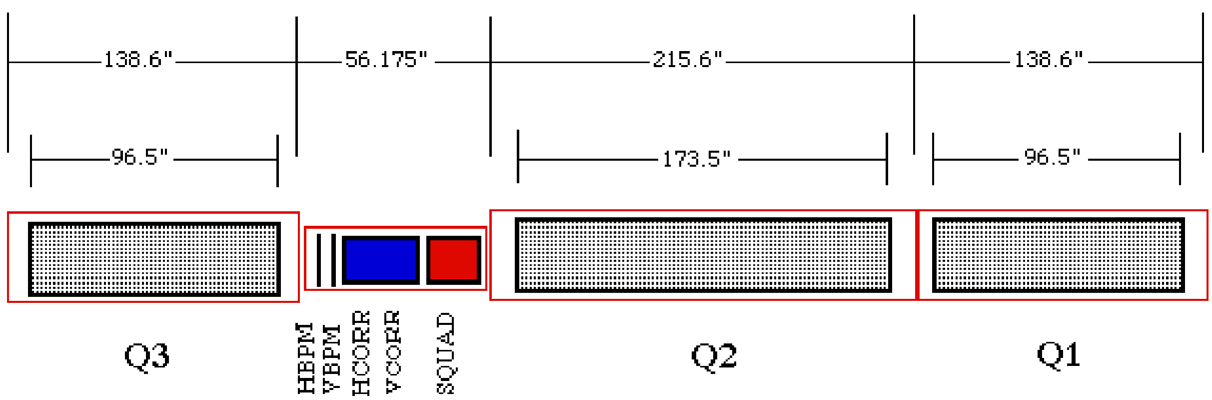
- From the IP to first quadrupole is ~ ±40'.
- Non-standard separations appear between some inner arc quadrupoles – 3 dipole slots between Q4 & Q5 [B48/B47 & C12/C13], and 5 between Q6 & Q7 [B46/B45 & C15/C16].
- The C17 separators define the D/S insert boundary, leading to more trim quads on the B-sector side of the IP.
- 3 standard Tevatron electrostatic separators (new) appear outboard of the triplets.

IR MAGNETS

Specialized IR quadrupoles fall into 3 gradient ranges:

- LHC-like magnets operating at up to 170 T/m (limited by the 4.2K Tevatron cryogenics).
- High-field quads @ 140 T/m (the "Q1" LBQ magnets removed from B0 & D0 for Run II).
- Strong (25 T·m/m) quad correction spools for final optical matching into the arcs.

Triplets:



- Q1, Q2, & Q3 powered in series at (170 T·m/m @ 9560A).
- A corrector spool package is installed between Q2 & Q3 at $ß_x = ß_y > 60\%$ of $ß_{max}$:

  HCORR & VCORR are almost exactly 90º from the IP, for position control, and;

  With almost exactly 0º of phase advance across the triplet, SQUAD is ideally situated for roll mis-alignments.

B48/C12 & B47/C13 170 T/m Magnets:

- The cold masses of Q4 & Q5 magnets are identical designs to the triplet quads, apart from overall length. [The cryostats have sufficient space for ancillary hardware plus allowing the quad's magnetic centers to be fixed equidistant from the IP].
- New, short (1.427 m) spools provide the magnet power feeds & also contain BPM's plus dipole correctors in each plane.

B46 → B45 & C14 → C15 140 T/m Magnets:

- The four Q6 & Q7 magnets are independently-powered, high-field, 55" magnets removed from the "Q1" locations at CDF & D0 – defunct quadrupoles for Run II optics.
- The Q6 & Q7 magnets are accompanied by TSP spools which currently reside with the CDF & D0 "Q1" quads. These have BPM's and dipole correctors in each plane, plus a skew quadrupole. The P-spools also provide the Q6 & Q7 magnets' power feeds & transport the main Tevatron bus.

B43 → B44 & C16 → C17 25 T·m/m Trims:

- 72" spools containing 25 T·m/m quadrupoles, plus sextupole & dipole correctors replace the normal 72" arc spools.

B38 → B42 7.5 T·m/m Trims:

- Trim quad spools at B38 & B42 are removed from the tune quad circuits for final optical matching into the arcs.

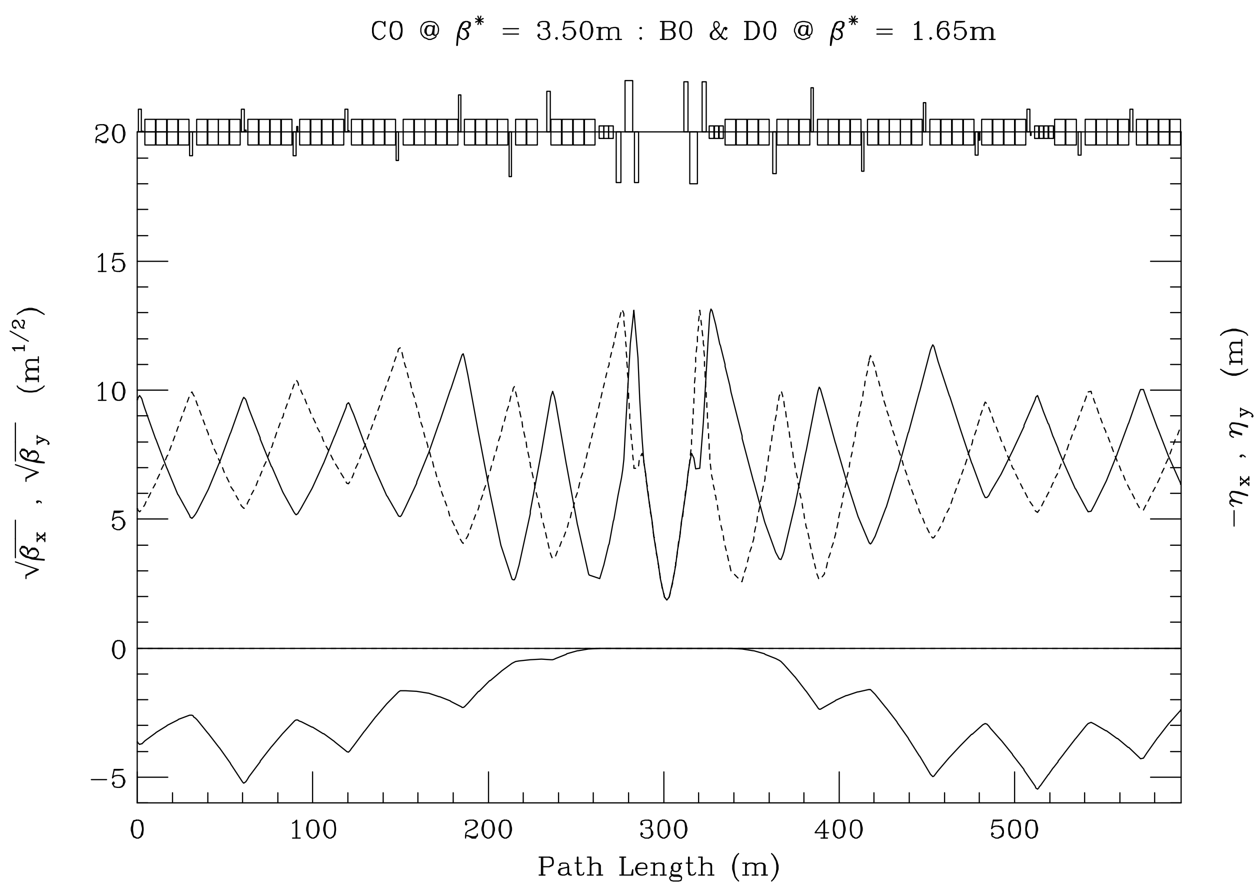
OPTICS

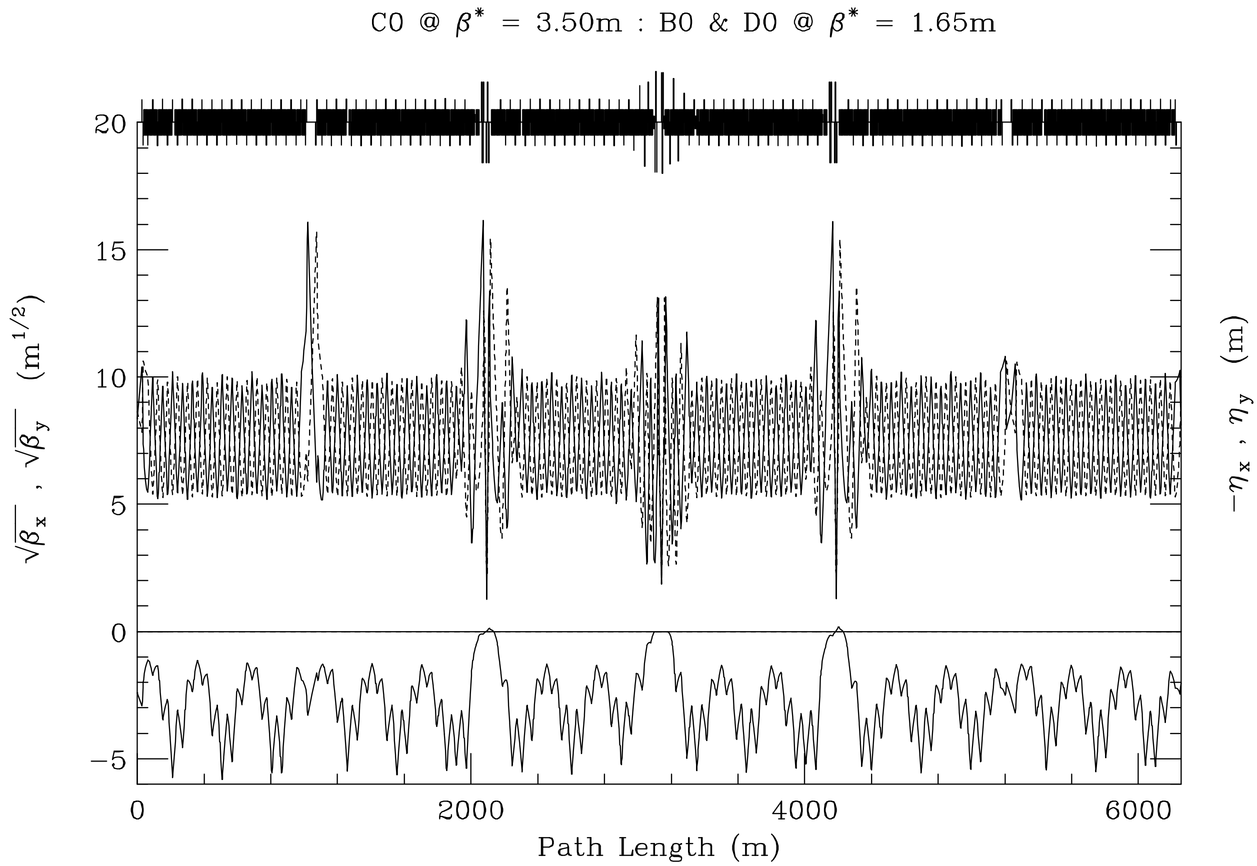
- 14 Parameters & 14 Constraints – matching to $ß_X$, α_X, η, η', $ß_Y$, α_Y at the IP & back into the arcs, and; the appropriate unperturbed $\Delta\mu_X$ & $\Delta\mu_Y$ are preserved across the insert.

  [$ß_X$(max) = $ß_Y$(max) in the triplets].

- Every stage of the $\beta^* = 3.50 \rightarrow 0.35$ m squeeze at C0 can match exactly to any step in the B0/D0 Injection $\rightarrow \beta^* = 0.35$ m squeeze.

INJECTION :

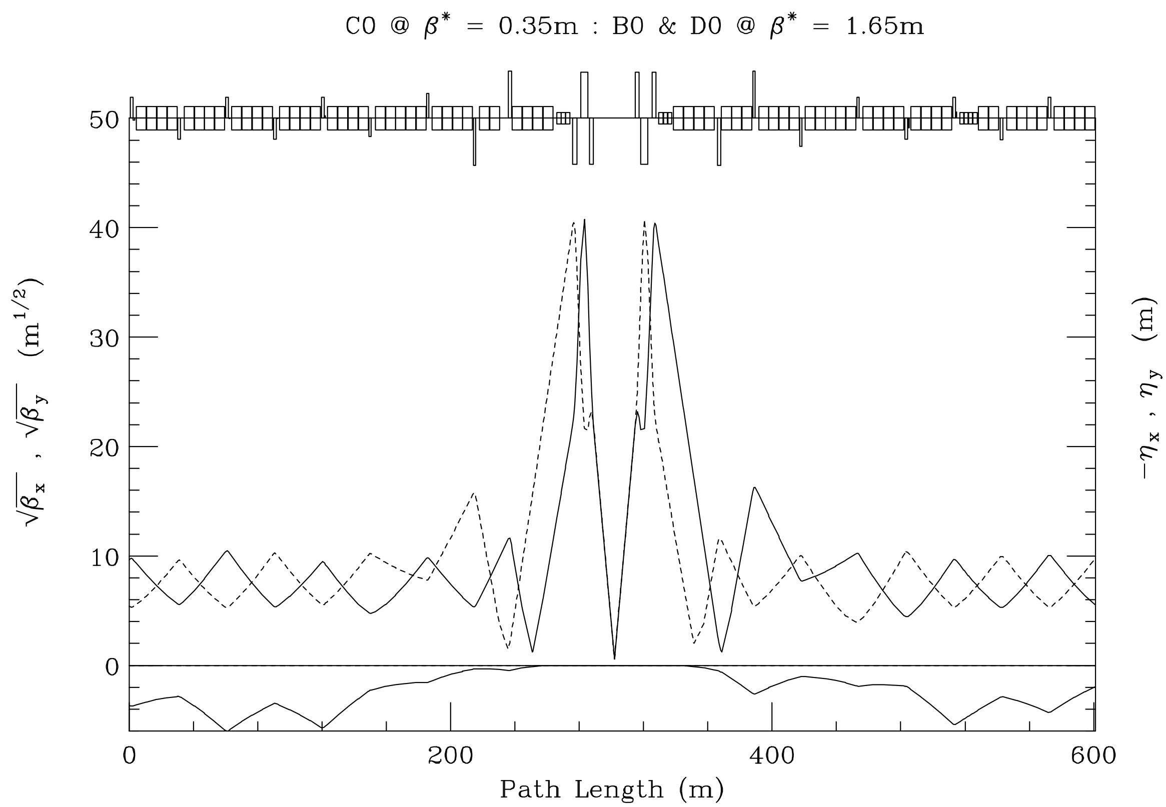


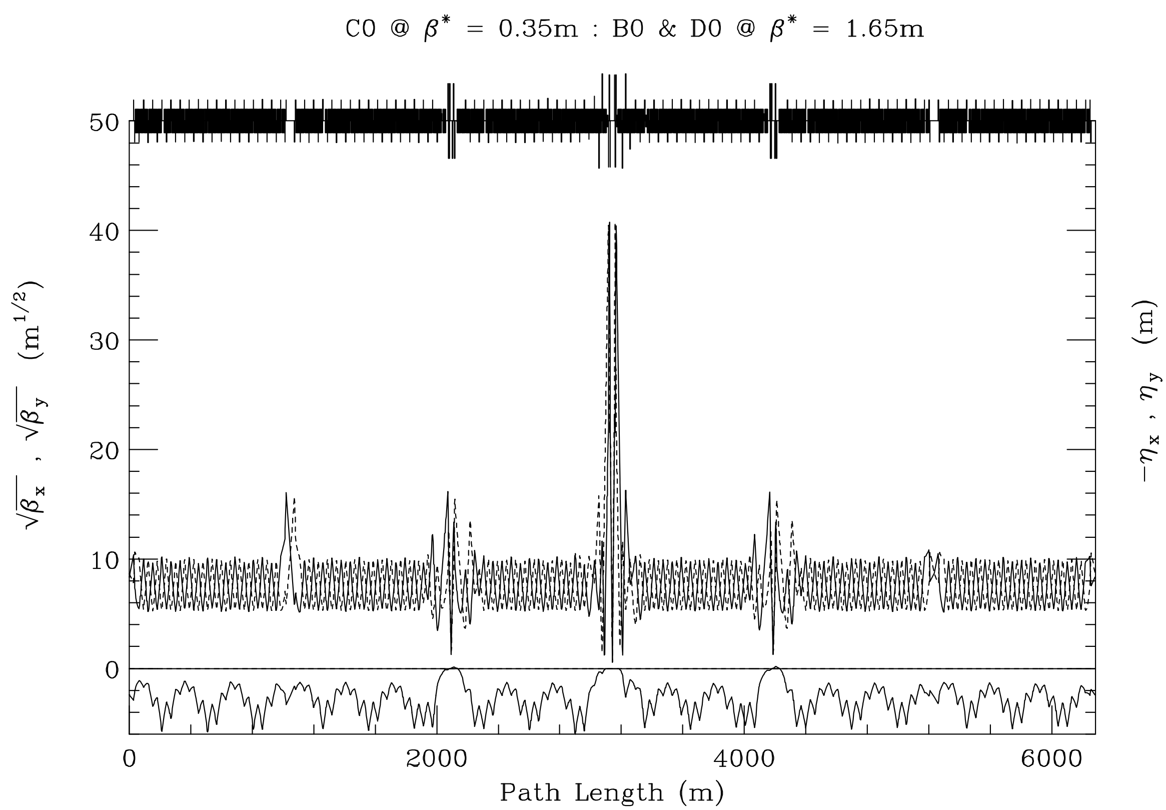


- ßmax = 175 m at C0 in the injection lattice is appreciably less than the >240 m at B0 & D0, so aperture should not be an issue.

INJECTION OPTICS : C0 @ β^* = 3.50m : B0/D0 @ β^* = 1.65m **1 TeV/c**					
	Gradient (T/m)	Current (A)		Gradient (T/m)	Current (A)
Q1D	-164.783	9267	Q1F	164.783	9267
Q2F	168.814	9493	Q2D	-168.814	9493
Q3D	-164.783	9267	Q3F	164.783	9267
Q4B48	133.019	7480	Q4C12	-133.019	7480
Q5B47	-145.047	8157	Q5C13	145.047	8157
Q6B46	117.055	4045	Q6C14	-122.786	4248
Q7B45	-92.551	3198	Q7C15	92.940	3211
TQB44	4.939		TQC16	-25.569	
TQB43	17.724		TQC17	-10.470	
tqB42	6.793				
tqB39	0				
tqB38	3.013				

C0 COLLISION OPTICS β* = 0.35 m:

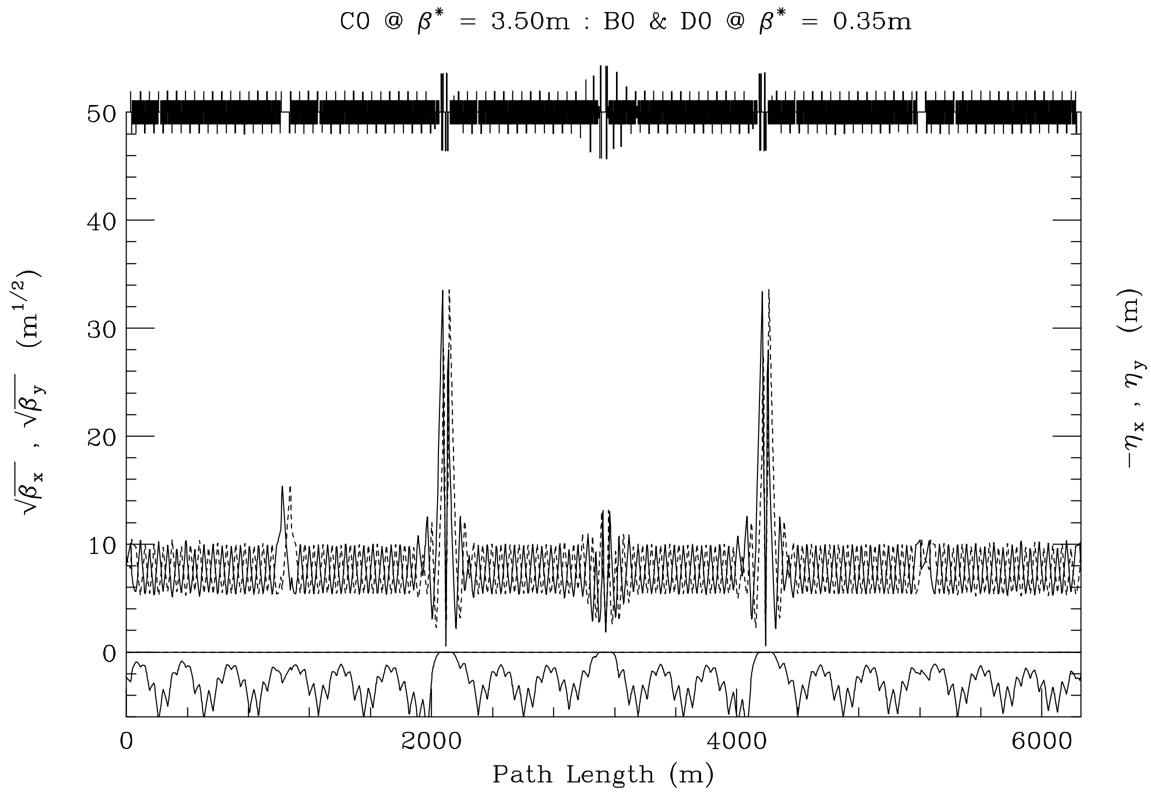




- For C0 collisions ß* is squeezed to 0.35 m – the same as for B0/D0 collisions. C0 luminosity will, therefore, be identical to that of B0/D0 at the end of Run II.
- For ß* = 35 cm at C0, ßmax is ~1660 m. Although larger than ßmax at B0/D0 during collisions, dynamic aperture studies indicate this will not a problem due partly to the higher quality LHC magnets.

C0 COLLISIONS @ β* = 0.35 m : B0/D0 @ β* = 1.65 m **1 TeV/c**					
	Gradient (T/m)	Current (A)		Gradient (T/m)	Current (A)
Q1D	-169.228	9517	Q1F	169.228	9517
Q2F	165.397	9301	Q2D	-165.397	9301
Q3D	-169.228	9517	Q3F	169.228	9517
Q4B48	169.688	9524	Q4C12	-169.688	9524
Q5B47	-168.875	9497	Q5C13	168.875	9497
Q6B46	91.625	3166	Q6C14	-101.95	3523
Q7B45	-66.539	2299	Q7C15	76.322	2637
TQB44	9.528		TQC16	-35.373	
TQB43	-0.819		TQC17	22.589	
tqB42	-0.844				
tqB39	0				
tqB38	-7.424				

B0/D0 Collision Optics β* = 0.35 m:



B0/D0 COLLISIONS @ β* = 0.35 m : C0 @ β* = 3.50 m @ **1 TeV/c**					
	Gradient (T/m)	Current (A)		Gradient (T/m)	Current (A)
Q1D	-165.998	9335	Q1F	165.998	9335
Q2F	168.619	9482	Q2D	-168.619	9482
Q3D	-165.998	9335	Q3F	165.998	9335
Q4B48	131.721	7407	Q4C12	-131.721	7407
Q5B47	-144.299	8115	Q5C13	144.299	8115
Q6B46	117.055	4045	Q6C14	-122.786	4248
Q7B45	-92.551	3302	Q7C15	92.940	3211
TQB44	8.059		TQC16	-15.743	
TQB43	9.440		TQC17	-8.110	
tqB42	6.252				
tqB39	0				
tqB38	3.870				

C0 IR Correction Elements:

Site	Spool Type	Elements	βx (m)	μx (2π)	ηx (m)	βy (m)	μy (2π)
B38	TSE	HD, QTF, SxF	90.4	0.005	3.66	29.6	0.018
B39	TSB	VD, QTD, SxD	33.2	0.104	3.00	87.2	0.110
B42	TSC	HD, QTF, SxF	103.6	0.182	5.87	30.0	0.217
B43	X1	VD, QT, SxD	29.8	0.278	3.57	100.2	0.301
B44	X1	HD, QT, SxF	84.6	0.371	5.54	32.3	0.395
B45	TSP	H&VD, SQ, H&VBPM	23.1	0.491	2.22	102.7	0.476
B46	TSP	H&VD, SQ, H&VBPM	92.9	0.622	1.48	66.6	0.552
B47	X2	H&VD, H&VBPM	33.4	0.723	0.32	210.6	0.588
B48	X2	H&VD, H&VBPM	123.8	0.767	0.43	1.70	0.777
B49	TSH	H&VD, SQ, VBPM	160.7	1.240	0.00	875.0	1.047
C0U	X3	H&VD, SQ, H&VBPM	1042.	1.247	0.00	1017.	1.049
C0*			0.35	1.494	0.00	0.35	1.297
C0D	X3	H&VD, SQ, H&VBPM	1017.	1.742	0.00	1042.	1.545
C12	X2	H&VD, H&VBPM	17.3	1.778	0.43	95.4	2.018
C13	X2	H&VD, H&VBPM	253.4	2.207	2.53	30.6	2.087
C14	TSP	H&VD, SQ, H&VBPM	59.9	2.247	1.03	95.7	2.171
C15	TSP	H&VD, SQ, H&VBPM	99.0	2.320	1.88	17.0	2.356
C16	X1	VD, QT, SxD	20.6	2.447	2.08	104.1	2.474
C17	X1	HD, QT, SxF	90.1	2.558	5.32	29.7	2.571

HBPM & VBPM	- position monitors	
HD & VD	- trim dipoles	0.48 T·m
QTF & QTD	- tune quads	7.5 T·m/m
SxF & SxD	- chromaticity sextupoles	450 T·m/m^2
QT	- strong trim quads	25 T·m/m
SQ	- skew quadrupole	7.5 T·m/m

BEAM SEPARATION:

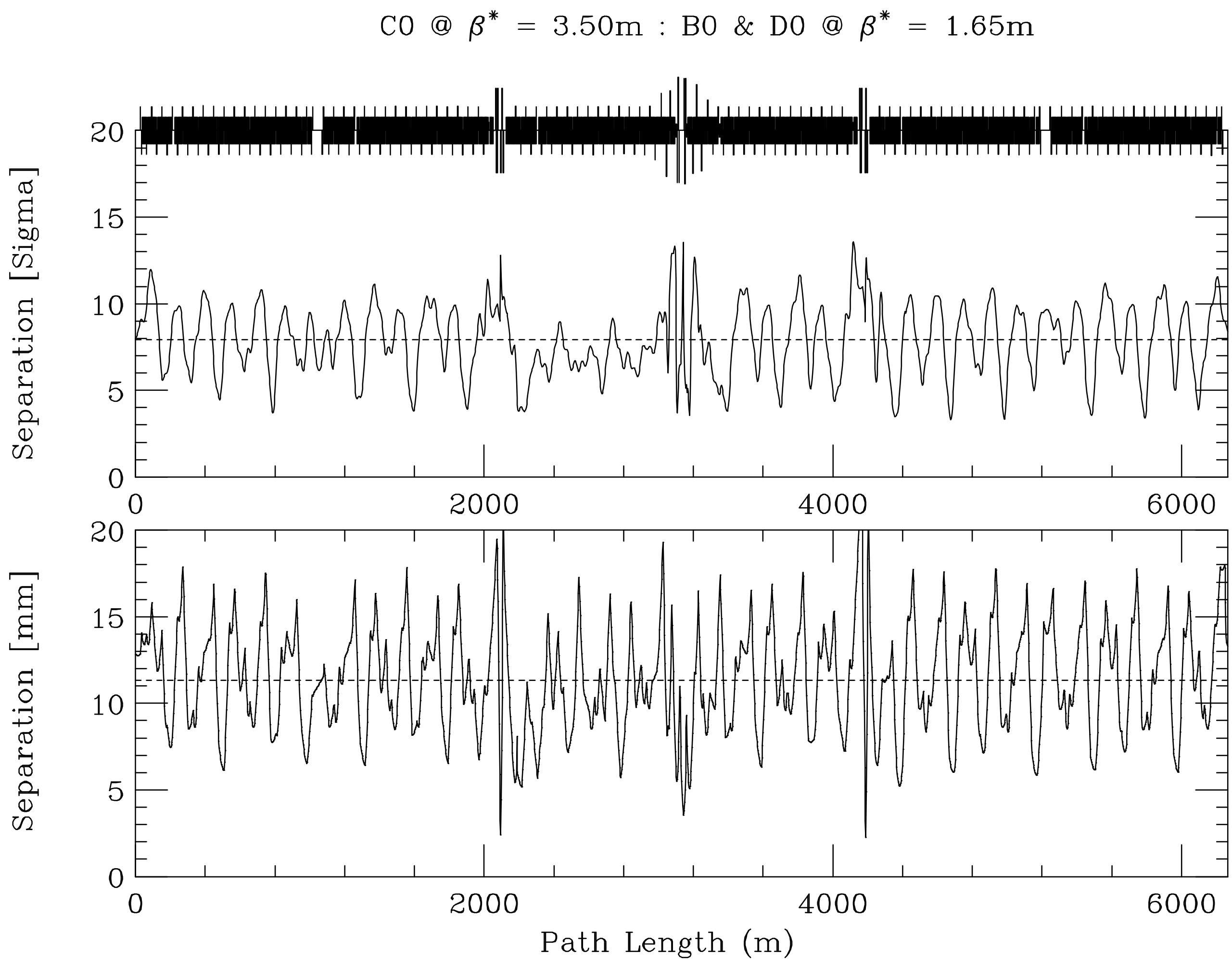
- With 36x36 operation there are 72 potential collision points of the p & pbar beams. Currently there are 6 sets of electrostatic separator modules to keep the beams separated everywhere except the B0/D0 IP's.
  The Run II Upgrade Project includes several possible improvements to the separator configuration – these are not considered here.

- New electrostatic separators at B49 (2H,1V) & C11 (1H, 2V) provide position control at C0.

INJECTION HELIX:

- At 150 GeV a small sub-set of the 12 available separator sets are used. Polarity & gradients are determined by limiting apertures & beam orientation at the F0 Lambertson.

INJECTION: C0 @ β^* = 3.50m : B0/D0 @ β^* = 1.65m **150 GeV/c**					
Horizontal			Vertical		
	#	kV/cm		#	kV/cm
A49	1	0.0	A49	2	0.0
B11	2	-14.800	B11	1	-9.050
B17	4	25.740			
B49	2	0.0	B49	1	0.0
C11	1	0.0	C11	2	0.0
			C17	4	-26.150
C49	1	0.0	C49	2	0.0
D11	2	0.0	D11	1	0.0
D48	1	0.0			
			A17	1	0.0



- 150 GeV/c & $\varepsilon_N = 20\pi$ μm & σ_p/p = 6.E-4.

- Outside the B38 → C17 insertion the helix is unchanged from the Run II configuration.

- Average ring-wide separation is ~8σ.

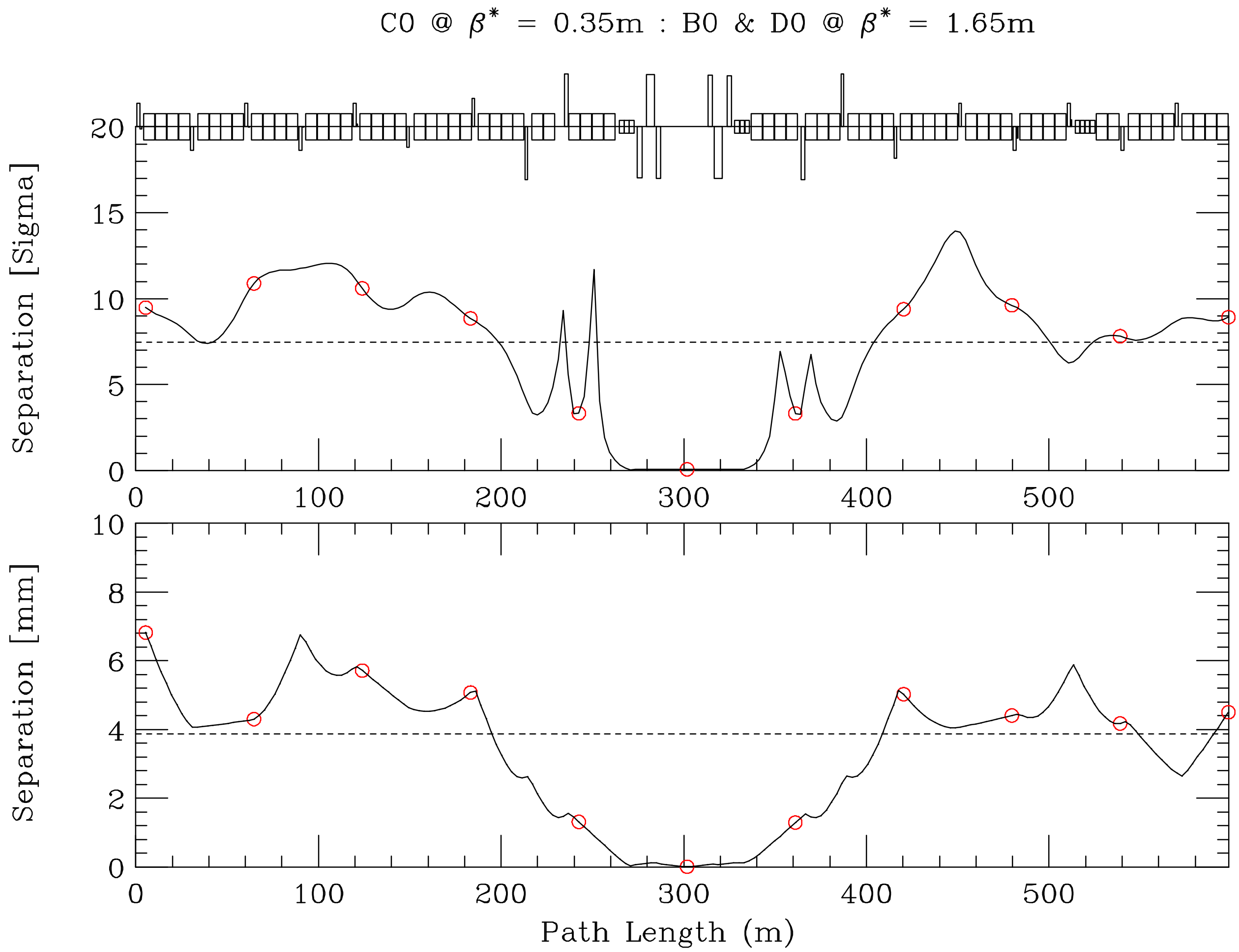
C0 COLLISIONS:

- All the ring separators are available to bring beams together at the C0 IP, while keeping them separated everywhere else.
- One of many, many possible helix solutions is shown below:

C0 COLLISIONS @ β^* = 0.35 m : B0/D0 @ β^* = 1.65 m

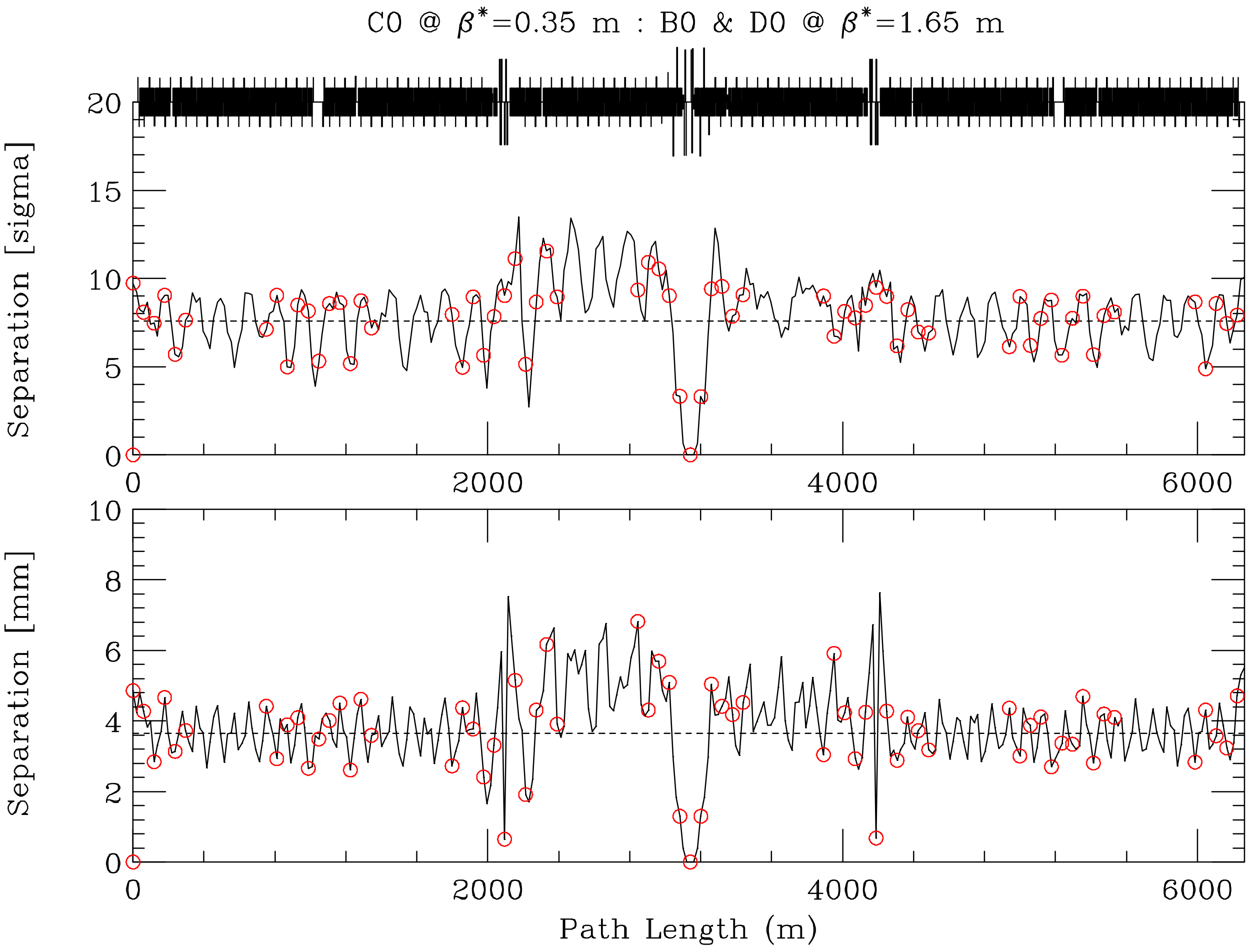
1 TeV/c

Horizontal	#	kV/cm	Vertical	#	kV/cm
A49	1	0.0	A49	2	25.744
B11	2	0.0	B11	1	-25.744
B17	4	18.112			
B49	2	-40.000	B49	1	-40.000
C11	1	40.000	C11	2	40.000
			C17	4	-20.355
C49	1	13.486	C49	2	0.0
D11	2	-13.486	D11	1	0.0
D48	1	0.0			
			A17	1	0.0



- 1 TeV/c & $\varepsilon_N = 20\pi$ μm & σ_p/p = 1.47E-4.

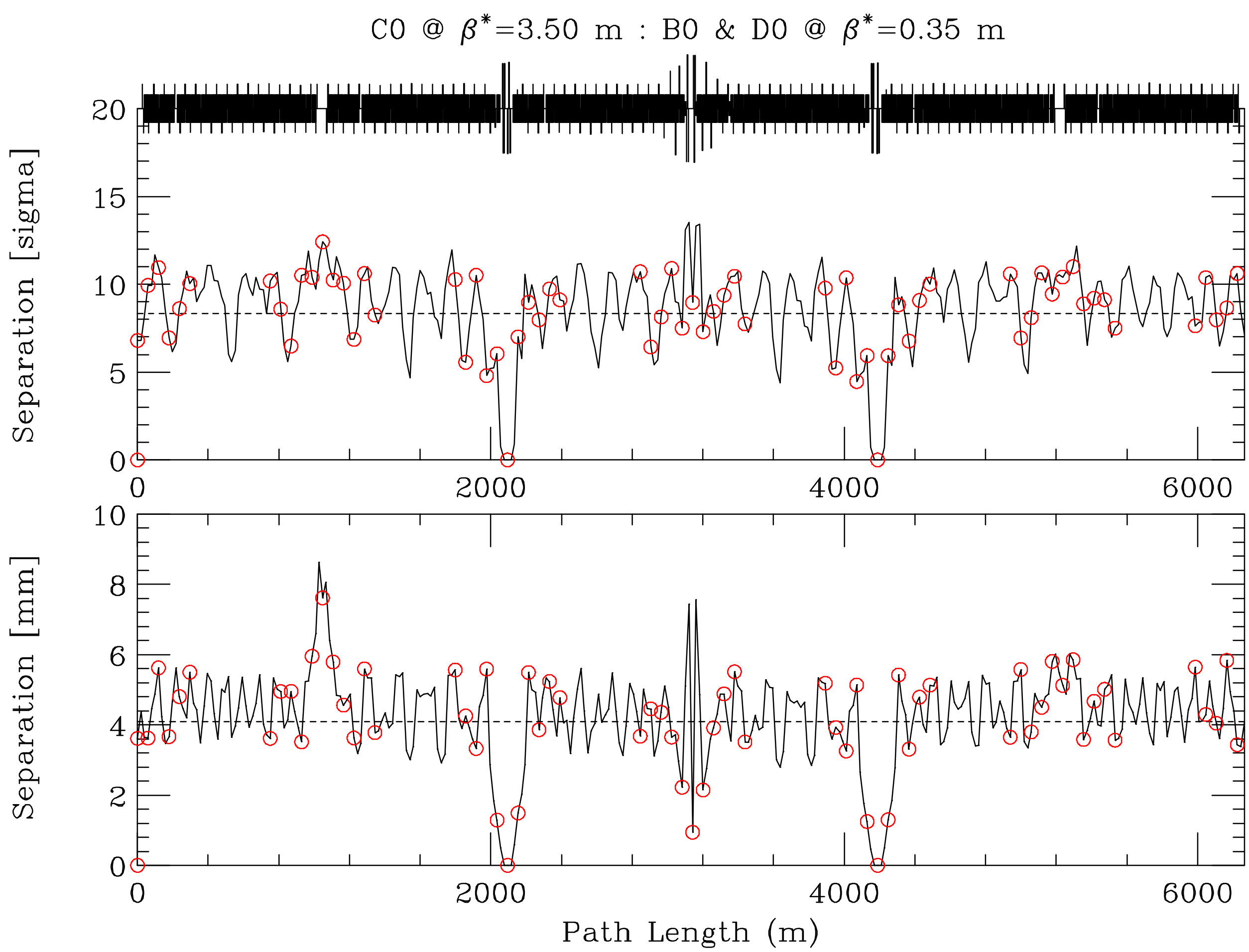
- The closest approach occurs at the 1st parasitic crossing, where separation is about 3.7σ. Although 5σ is generally believed to be the minimum acceptable separation in the Run II B0/D0 collision lattice, dynamic aperture studies indicate that these 1st parasitic crossings are comparatively benign for C0 collisions.



- Average ring-wide separation is ~8σ.
- Oscillations from maximum to minimum separations could be further smoothed using a larger sub-set of separators.

B0 & D0 COLLISIONS:

- With ß* = 0.35 m at B0 & D0, the C0 optics remain in the injection configuration, with ß* = 3.50 m.
- The B49 & C11 separators are powered to produce local horizontal & vertical separation bumps at C0. Outside the C0 insertion region the Run II collision helix solution is essentially unchanged.



- 1 TeV/c & ε_N = 20π μm & σ_p/p = 1.47E-4.

- The closest approaches occur at the U/S 2nd parasitic crossings, where separation is about 5σ. Elsewhere in the ring, the average beam separation is ~8.5σ.

B0/D0 COLLISIONS @ β* = 0.35 m : C0 @ β* = 3.50 m

1 TeV/c

Horizontal	#	kV/cm	Vertical	#	kV/cm
A49	1	40.000	A49	2	-33.287
B11	2	40.000	B11	1	40.000
B17	4	-18.864			
B49	2	40.000	B49	1	40.000
C11	1	40.000	C11	2	40.000
			C17	4	-19.180
C49	1	37.197	C49	2	33.414
D11	2	-34.509	D11	1	40.000
D48	1	-5.162			
			A17	1	1.736

CONTINUING ACCELERATOR PHYSICS STUDIES

- Many accelerator physics issues still remain, many of which will require extensive tracking simulations to resolve:
  - optimization of helices & their evolution through all stages from injection to collision;
  - dynamic aperture calculations [**M. Xiao**, **T. Sen**];
  - beam halo & collimation [**N. Mokhov**, **S. Drozhdin**];
  - ……..

SUMMARY

- A stand-alone C0 IR has been designed that reaches ß* = 0.35 m using LHC quadrupoles in the final focus, and provides ±12.2 m of detector space. The insert is optically transparent to the rest of the machine & has no impact on Run II nominal operating parameters.

Ω