BTEV LOW–BETA OPTICS IN THE TEVATRON*

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Abstract

A low–β insertion has been designed for the BTeV experiment to be installed in the Tevatron C0 straight section. With ±12 m for detector space, a β* of 0.5 m can be achieved using 170 T/m magnets in the final focus triplets. A half-crossing angle of 240 μr keeps the beams separated by 5σ at the 2nd parasitic crossing; 39.5 m from the IP. There are two possible low–β Tevatron Collider operating modes: CDF & D0 with collisions, but not C0, and; C0 with collisions, but not B0 or D0.

1 DESIGN CONSIDERATIONS

A new C0 Interaction Region (IR) insertion must operate in a manner that does not impact established Run IIb Tevatron parameters. This implies creating a localized insertion – one which is completely transparent to the rest of the machine. This constraint has several design implications, some of which are outlined below:

- The Run II design (fractional) tunes can be retained by adding 2 low-β's in each plane, thereby boosting the machine tunes by a full integer.
- The B0 & D0 IR's are not optically-isolated entities. The lattice functions at any point in the ring, and the phase advances across any section of the ring vary through the low–β squeeze sequence. The C0 insertion must be able to track these fluid matching conditions.
- Low–β collisions at all 3 IP's simultaneously would require additional separators in the short B0 → C0 & C0 → D0 arcs. There is zero arc space available for more separators, so completely controlled low–β collisions can only be created at B0 & D0, or just C0, but not all three simultaneously.

2 PHYSICAL LAYOUT

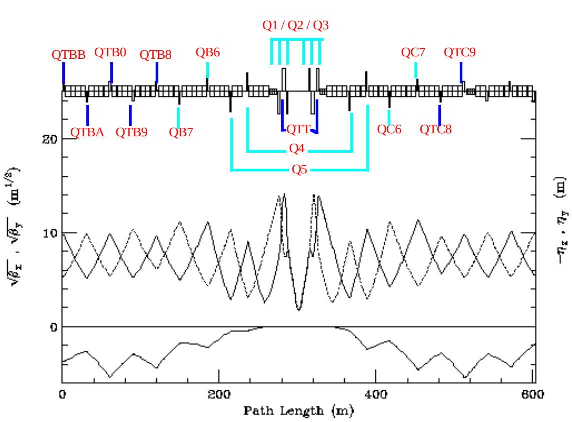

Figure 1: Power circuits of the IR quadrupoles.

The IR quadrupole circuits are illustrated in Fig. 1. The magnets required fall into 3 gradient ranges: LHC-like magnets operating at or below 170 T/m (the gradients are limited in this application by the Tevatron 4.2K cryogenics); high-field 140 T/m quadrupoles removed from CDF & D0 for Run II at the Q1 locations, and; strong (≤ 40 T/m) correction spools for completing the final optical match into the arcs.

Three new standard Tevatron electrostatic separators located outboard of the triplets at the B49 & C11 locations provide postion control at the IP.

Composition of the quadrupole circuits is described below, with the indicated lengths being magnetic lengths:

- The triplets:

Q1	: 96.5"	170 T/m
Q2	: 173.5"	170 T/m
Q3	: 96.5"	170 T/m

The final focus magnets run in series. Correction packages between the Q2 & Q3 magnets contain short, strong trim quads. Variation of the QTT gradients is sufficient to complete the match to the IP optics.

- B48/C12 & B47/C13:

Q4	: 75"	170 T/m
Q5	: 54"	170 T/m

The Q4 & Q5 magnets are the same LHC-like design as the triplet quadrupoles. New, short (56.175") spools containing multipole correctors also provide the magnet power feed & transport the main bus.

- B46 & C14:

Q6	: 55.19"	140 T/m

The regular 66" arc quads and their spools at B46 & C14 are replaced by independently-powered (existing) high–field 55" magnets plus new spools identical to those at the Q4 & Q5 locations.

- B45 & C15:

Q7	: 55.19"	140 T/m

At B45 & C15 the Tevatron 66" arc quads and their short spools are replaced by independently-powered (existing) 55" quadrupoles plus new, short (44.175") spools which provide the power feed to the magnets plus contain multipole correctors.

- B38 → B44 & C16 → C17:

QTx	: 25"	40 T/m

The QTx trim quads are allocated in a lop-sided configuration, with 2 more installed in the upstream end of the insert. In B-sector it is possible to extend insert elements a good distance back into the arc before interfering with Run IIb operations. Not so in C-sector. The 4 vertical separators at C17 are integral components of Run IIb controls and, therefore, define the downstream insert boundary.

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3 OPTICS

With the Q1 magnets at C0 situated roughly 15' farther from the IP than those at B0 & D0, βmax is considerably larger here for a given value of β*. With β* = 50 cm, βmax = 1163m (Fig.2), which is comparable to the βmax for β* = 35 cm at the other IP's.

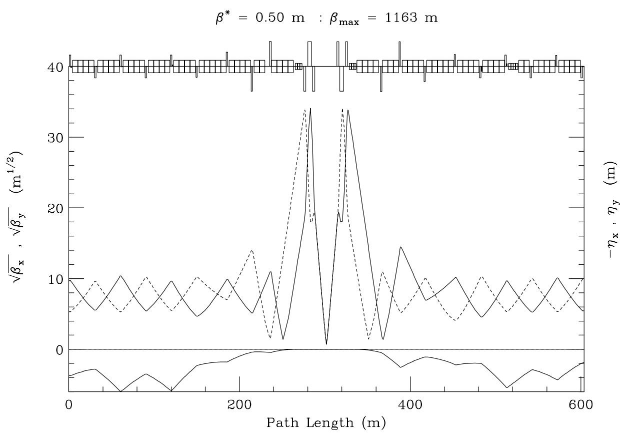

Figure 2: C0 collision optics.

Every stage of the squeeze from β* = 2.60 → 0.50 m at C0 can match exactly to any step in the B0 & D0 injection → β* = 0.35 m squeeze:

- β*=2.60 @ C0 : Injection β's @ B0/D0
- β*=2.60 @ C0 : β* = 0.35 @ B0 & D0
- β*=0.50 @ C0 : Injection β's @ B0/D0
- β*=0.50 @ C0 : β* = 0.35 @ B0 & D0

Table 1 shows the range of C0 gradients that arise while spanning this operational matrix. Magnets that must change polarity at some point are highlighted.

Table 1: Maximum & minimum C0 gradients.

	B' [max] T / m	B' [min] T / m
Q1, Q2, Q3	167.997	166.421
QTT	37.696	0.268
Q4	167.764	140.691
Q5	166.247	147.714
QB6	116.180	87.503
QC6	121.899	91.247
QB7	91.884	71.738
QC7	94.789	74.967
QTB8	11.860	7.438
QTC8	32.941	15.710
QTB9	**10.731**	**-6.271**
QTC9	**19.056**	**-5.304**
QTB0	**5.168**	**-7.268**
QTBB	**1.455**	**-6.498**

4 BEAM SEPARATION & COLLISIONS

To reduce the number of interactions per crossing in Run IIb bunch spacing in the Tevatron will be decreased from 396 → 132 nsec. With the first parasitic crossings then occurring just 19.86 m from the IP's, crossing angles are necessary to obtain separated beams [1].

The favored Run IIb collision helix solution has B0 & D0 half-crossing angles of (x'*,y'*) = (+170, -170) μrad; giving 5σ of separation at the 1st crossing for β* = 35 cm, and 20π emittance (95%, normalized) beams.

4.1 B0 & D0 Collisions – Not C0

With collisions at just B0 & D0, the C0 optics remain in the injection configuration with β* = 2.60 m, and the B49 & C11 separators are turned off. The resulting matched helix from B38 → C21 is shown below. Beam separation is ≥5σ everywhere. The circles indicate the potential collision points at 7 half-bucket intervals.

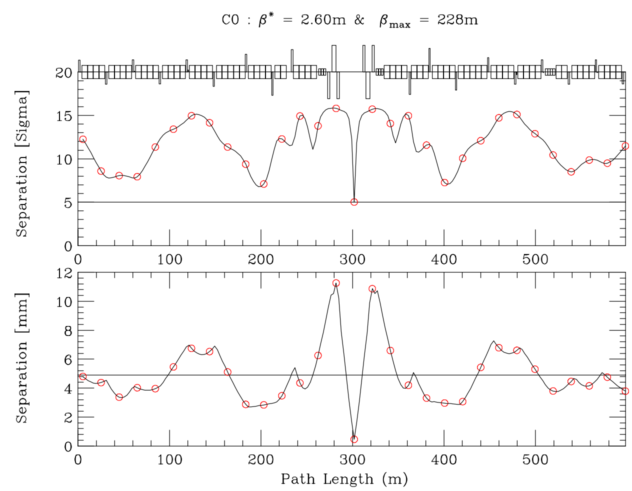

Figure 3: Separation at C0 during B0 & D0 collisions.

4.2 Low–β C0 Collisions – Not B0 or D0*

For collisions at C0 with β* = 50 cm the optics at B0 & D0 remain in their injection configuration. All the separators in the ring then become available for bringing beams together at the C0 IP, while keeping them separated everywhere else. For half-crossing angles at C0 of (x'*, y'*) = (-170, +170) μrad, one possible (minimal) separator solution is listed in Table 2 below.

Table 2: Separator settings for C0-only collisions.

Separator Gradients (MV / m) Horizontal			Vertical		
A49	2	2.32078	A49	1	2.32078
B11	1	-2.32078	B11	2	-2.32078
B17	4	-0.99823			
B49	2	-4.0	B49	1	4.0
C11	1	4.0	C11	2	-4.0
			C17	4	0.22304
C49	2	1.19549	C49	1	1.19549
D11	1	-1.19549	D11	2	-1.19549

The resulting beam separation around the ring is illustrated in Figure 4. The closest approach occurs in the insert at the 2nd parasitic crossing, where separation is about 5σ. Elsewhere, the average separation is 10→13σ.

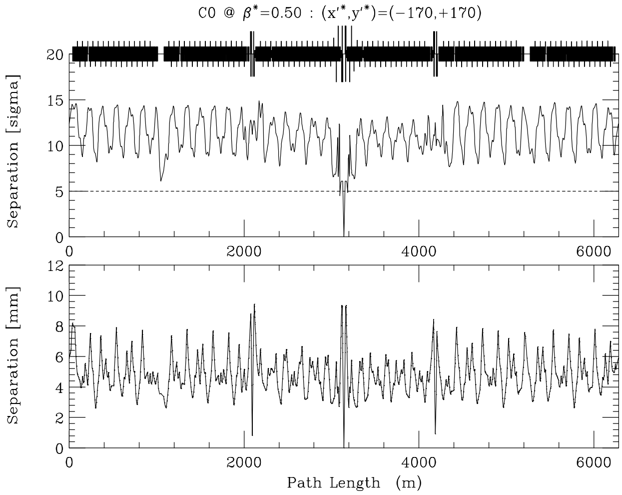

Figure 4: Beam separation during C0–only collisions

4.3 High–β* C0 Collisions + B0 & D0 Collisions

There are just 5 sets of separators in each plane between B0 & D0, including the new B49 & C11 modules. With the B0 & D0 crossing angles fixed at their Run IIb values of (x'*, y'*) = (+170, -170) µrad it is not possible to control beam position & angle at the C0 IP while simultaneously maintaining adequate beam separation through the arcs [2]. However, if the insistence on complete beam control at C0 is relinquished, collisions *can* be created at all 3 IP's, but at a reduced luminosity.

By very slightly adjusting the gradients (<<1%) of just 1 additional separator in each plane of the short B0→C0→D0 section, collisions can be created at C0 without impacting B0 & D0 collisions or noticeably altering beam separation through the arc.

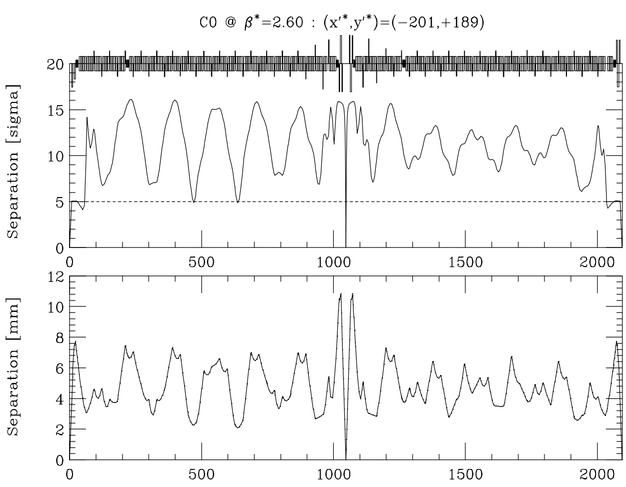

Figure 5: Separation in the short arc B0 → C0 → D0: β*=2.60 m @ C0

With crossing angles of (x'*,y'*) = (+170, -170) µrad fixed at B0 & D0, Fig. 5 & Table 3 illustrate one possible separator solution leading to C0 collisions. At C0 β* remains at the injection value of 2.60 m & the total half-crossing angle is 275.9 µrad, giving ≈16σ separation at the 1st parasitic crossing. At C0 luminosity is ≈1/4 that at B0 & D0, and ≈1/3 the nominal C0 luminosity with β* = 0.50 m [3].

Table 3: Separator gradient changes in the short B0 → D0 arc to create high- β* collisions at C0

Separator Gradients (MV / m)					
Run IIb Nominal			B0,C0, & D0 Collisions		
B11H	1	-4.18408	B11H	1	-4.18496
B11V	2	-4.10724	B11V	2	-4.10660
B49H	2	0.0	B49H	2	-3.33144
B49V	1	0.0	B49V	1	-3.26163
C11H	1	0.0	C11H	1	-3.55194
C11V	2	0.0	C11V	2	-3.05772

Very modest gains in luminosity at C0 can be realized by lowering β* from 2.60 m. However, the limiting factor with this approach is the fairly alarming rate at which beam separation increases in the triplets.

5 SUMMARY

By adding an integer of betatron phase advance locally at C0, a low–β* BTeV insert can be designed that is optically transparent to the rest of the Tevatron, with no impact on nominal Run IIb operating parameters.

IR quadrupole construction requires 2 new technologies:

- The final-focus triplets plus Q4 & Q5 magnets are LHC designs, operating at gradients of 170 T/m.
- Strong quadrupole correctors (25 T.m/m) are needed for the final optical match into the arcs.

New separator modules at the B49 & C11 locations provide position control at the IP during C0–only collisions, and are also useful in creating B0, D0, *plus* C0 collisions — albeit at reduced luminosity. There are insufficient separators through the short B0 → C0 → D0 arc to provide independent position & angle control at all 3 IP's simultaneously.

6 REFERENCES

[1] S.D. Holmes, *et al.*, "132 nsec Bunch Spacing in the Tevatron Proton-Antiproton Collider", FERMILAB-TM-1920, December 1994.

[2] J.A. Johnstone, "Conceptual Designs for IR Optics at C0", FERMILAB-TM-2122, August 2000.

[3] J.A. Johnstone, "C0 Low–β Optics", FERMILAB-TM-2139, 2000.