Dogleg Correction

W. Chou, February 27, 2003

1. Brainstorming:

- Enlarge the spacing between doglegs (Sasha)
- Relocate Dogleg-13 (Jim, Weiren)
- Lower the dogleg operation current (Ray)
- Use 3 legs instead of 4 legs (Milorad, Jim)
- Remove Dogleg-13 (Jim, Weiren)
- Use 45-degree legs (Jim, Weiren)
- Use correction wedge magnets (Weiren)
- Use correction quadrupoles (Weiren)
- Remove doglegs by employing horizontal extraction (Chuck)

2. first order perturbation theory:

A thin quadrupole at location 1 with strength:

$$q = B'L/B\rho = 1/f \quad \text{(H)}$$
$$-q \quad \text{(V)}$$

(Recall that for a dogleg in L3, $q \cong \theta^2 / L = 0.02244\ \text{m}^{-1}$ in H-plane, $q = 0$ in V-plane)

- The tune change:

$$\Delta\nu(x) = q \times \beta_1(x) / 4\pi$$
$$\Delta\nu(y) = -q \times \beta_1(y) / 4\pi$$

- The beta-wave at location 2:

$$\Delta\beta_2(x) = -q \times \beta_1(x) \times \beta_2(x) \times \sin 2\psi(x)$$
$$\Delta\beta_2(y) = q \times \beta_1(y) \times \beta_2(y) \times \sin 2\psi(y)$$

β_1, β_2 = beta-functions of the unperturbed lattice
$\psi = \mu_2 - \mu_1$ = phase advance from 1 to 2

- The dispersion wave at location 2:

$$\Delta D_2 = -q \times D_1 \times \{\beta_1(x) \times \beta_2(x)\}^{1/2} \times \sin\psi(x)$$

D_1 = dispersion of the unperturbed lattice
(Note that the beta-wave frequency is twice that of the dispersion wave.)

3. Correction using quadrupoles:

- To correct the beta-wave:
  - Same sign of q, $(n+1/2)\pi$ apart, or
  - Opposite sign of q, $n\pi$ apart.

- To correct the dispersion wave:
  - Same sign of q, $(2n+1)\pi$ apart, or
  - Opposite sign of q, $2n\pi$ apart.

- To correct both:
  - Opposite sign of q, $2n\pi$ apart.

4. Difficulties in correcting the dogleg effect:

- The dogleg effect is in the H-plane only. But a correction quadrupole, while correcting the beta-wave in the H-plane, will generate a beta-wave in the V-plane.

- In a set of doglegs, there are 4 legs and 8 edges. The 8 edges cannot be approximated by a single focal lens, because the phase difference between the first and last edge is about 30° (in H-plane).

- The beta-wave and dispersion wave cannot be corrected inside the $2n\pi$ section.

5a. Effects of removing one dogleg:

Case	$\Delta\nu(x)$	$\beta_{max}(x)$ (m)	$D_{max}(x)$ (m)	Max $\varepsilon(x)$ (mm-mrad)	Acceptance Increase
Two doglegs	0.064	46.5	5.89	8.5π	(base)
Dogleg-03 only	0.031	40.5	4.36	11.7π	38%
Dogleg-13 only	0.028	39.9	4.25	12.1π	42%
No dogleg	0	33.7	3.19	16.2π	91%

$$A = \{\beta_{max} \times \varepsilon_N/\beta\gamma\}^{-1/2} + D_{max} \times \Delta p/p + \text{c.o.d.}$$

Parameters used in this calculation:

E = 400 MeV

$\beta\gamma = 1.0$

$\varepsilon = \varepsilon_N$

$\Delta p/p = \pm 0.13\%$

Closed orbit distortion (c.o.d.) = 3 mm

Aperture = ± 1.2 inch

Dogleg parameters: (using Lackey's calibration)

Effective length = 0.24722 m

Bending angle scaling: 26 mm / 446.047 A

Dogleg-03: I = 480 A $\rightarrow \theta_3 = 62.51$ mrad

Dogleg-13: I = 460 A $\rightarrow \theta_{13} = 59.88$ mrad

5b. Effects of removing one dogleg: (higher Dogleg-03 current)

Case	$\Delta\nu(x)$	$\beta_{max}(x)$ (m)	$D_{max}(x)$ (m)	Max $\varepsilon(x)$ (mm-mrad)	Acceptance Increase
Two doglegs	0.082	48.7	6.84	7.1π	(base)
Dogleg-03 only	0.045	42.7	4.93	10.4π	46%
Dogleg-13 only	0.030	39.2	4.23	12.3π	73%
No dogleg	0	33.7	3.19	16.2π	128%

$$A = \{\beta_{max} \times \varepsilon_N/\beta\gamma\}^{-1/2} + D_{max} \times \Delta p/p + \text{c.o.d.}$$

Parameters used in this calculation:

E = 400 MeV

$\beta\gamma = 1.0$

$\varepsilon = \varepsilon_N$

$\Delta p/p = \pm 0.13\%$

Closed orbit distortion (c.o.d.) = 3 mm

Aperture = ± 1.2 inch

Dogleg parameters: (using Lackey's calibration)

Effective length = 0.24722 m

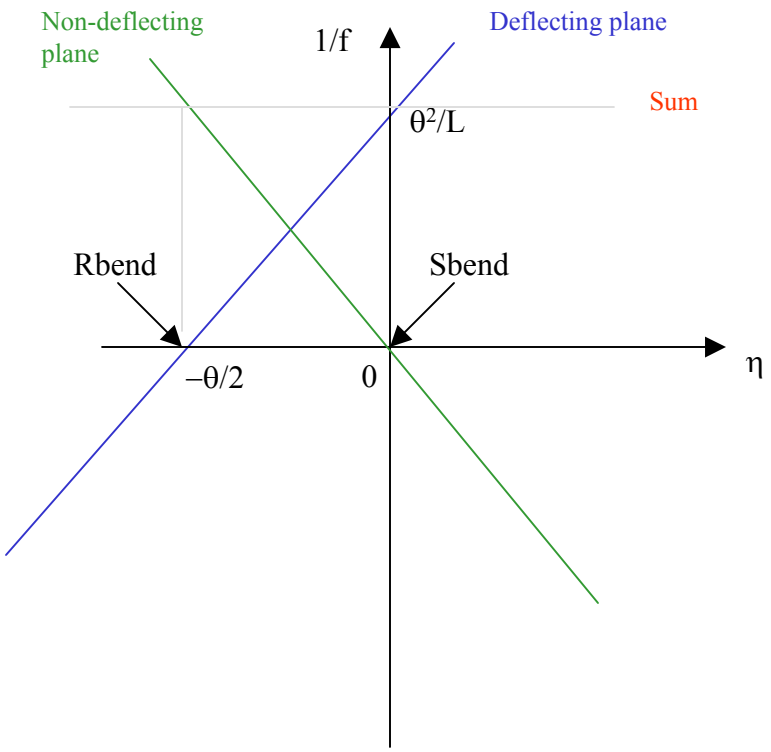
Bending angle scaling: 26 mm / 446.047 A

Dogleg-03: I = 572 A $\rightarrow \theta_3 = 74.49$ mrad

Dogleg-13: I = 459.8 A $\rightarrow \theta_{13} = 59.88$ mrad

Edge Focusing of a Wedge Magnet

Focusing strength as a function of edge angle η:



L = magnet length

θ = bend angle

η = edge angle

Sector magnet (Sbend): $\eta = 0$

Rectangular magnet (Rbend): $\eta = -\theta/2$

Focusing strength: (> 0 focusing)

Deflecting plane:

$$1/f = 2\eta\theta/L + \theta^2/L$$

Non-deflecting plane:

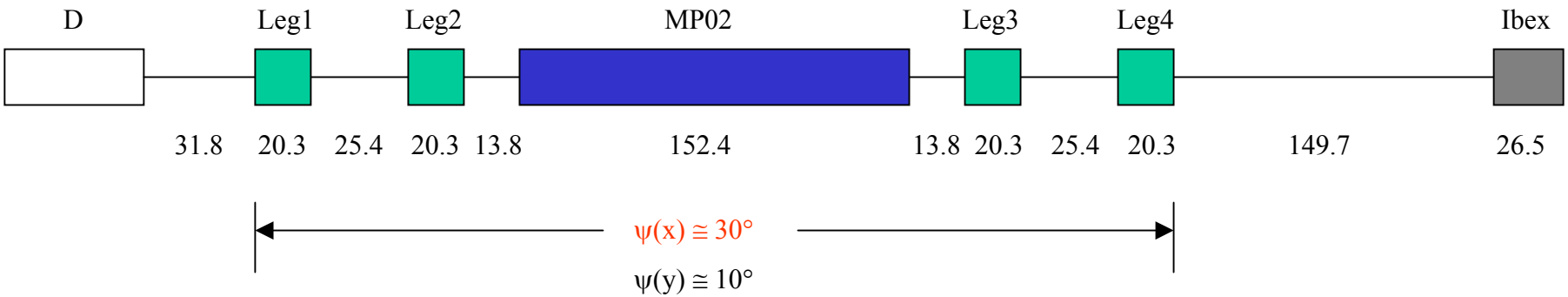
$$1/f = -2\,\eta\theta/L$$

Sum = θ^2/L (always focusing!)

To be more precise, this sum is from the body focusing in the deflecting plane. The sum of the edges in the two planes is zero.

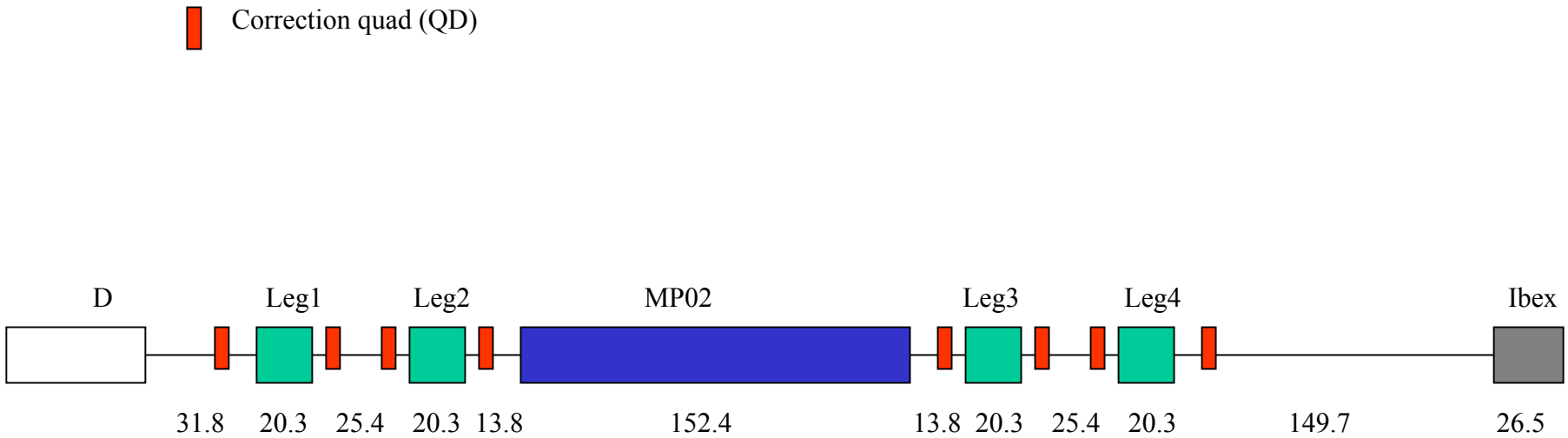
L3 Dogleg Layout

(unit in cm)



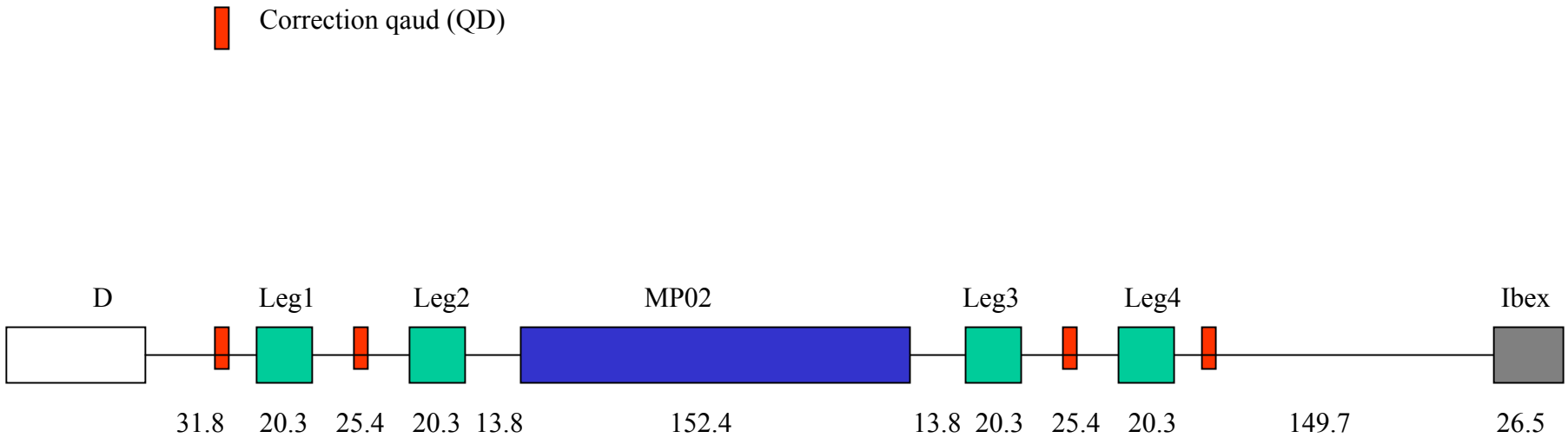
L3 Dogleg Correction Using 8 Quads

(unit in cm)



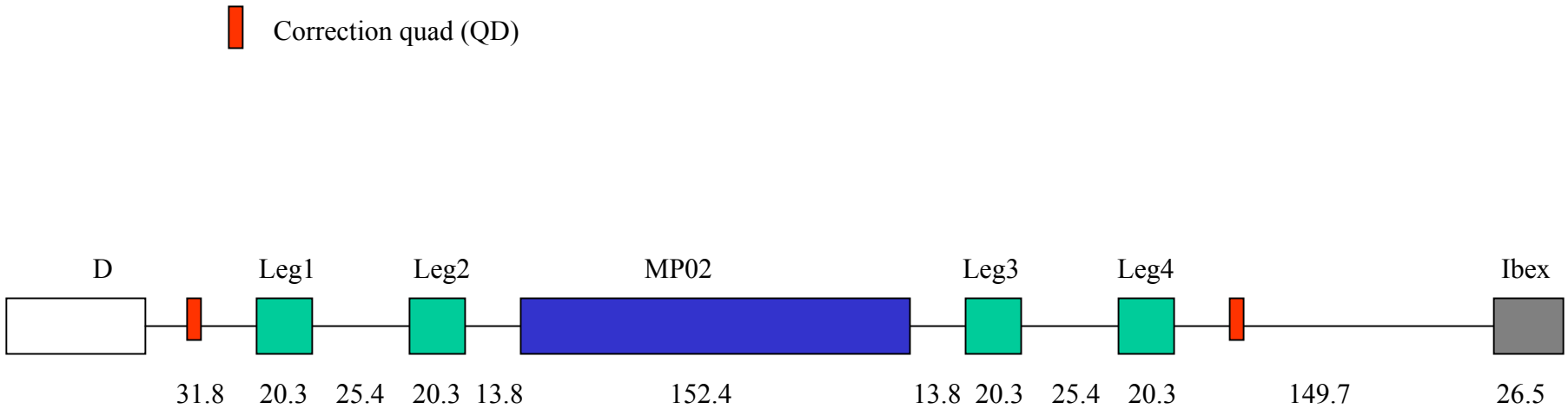
L3 Dogleg Correction Using 4 Quads

(unit in cm)



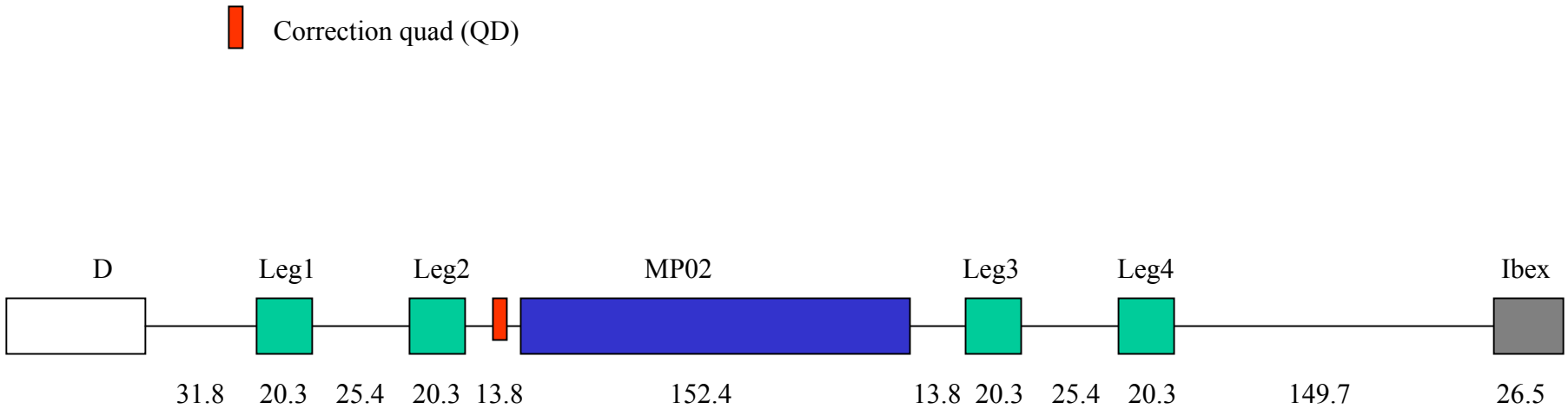
L3 Dogleg Correction Using 2 Quads

(unit in cm)



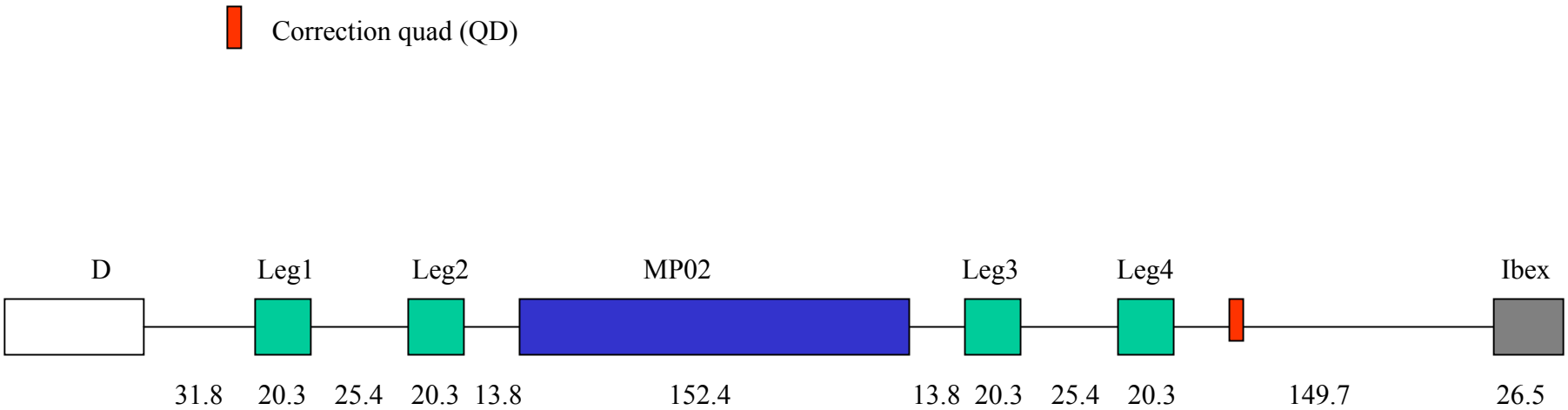
L3 Dogleg Correction Using 1 Quads

(unit in cm)



L3 Dogleg Correction Using 1 Quads

(unit in cm)



Correction with Different Number and Layout of Quadrupoles

NO DOGLEGS:

total length =	474.202754	Qx =	6.699721	Qy =	6.799965
delta(s) =	0.000000 mm	Qx' =	3.671194	Qy' =	-11.119681
alfa =	0.337183E-01	betax(max) =	33.679540	betay(max) =	20.460394
gamma(tr) =	5.445873	Dx(max) =	3.189910	Dy(max) =	0.071312
		Dx(r.m.s.) =	2.480809	Dy(r.m.s.) =	0.023090

DOGLEG03 WITH NO CORRECTION QUADS:

total length =	474.202754	Qx =	6.730798	Qy =	6.799964
delta(s) =	0.000000 mm	Qx' =	2.582392	Qy' =	-7.069763
alfa =	0.332114E-01	betax(max) =	40.449277	betay(max) =	20.460649
gamma(tr) =	5.487273	Dx(max) =	4.353720	Dy(max) =	0.077498
		Dx(r.m.s.) =	2.509874	Dy(r.m.s.) =	0.025280

DOGLEG03 WITH 8 CORRECTION QUADS (ONE FOR EACH EDGE):

total length =	474.210754	Qx =	6.699839	Qy =	6.923242
delta(s) =	0.000000 mm	Qx' =	3.635760	Qy' =	-24.910214
alfa =	0.337121E-01	betax(max) =	33.694484	betay(max) =	60.142373
gamma(tr) =	5.446369	Dx(max) =	3.190579	Dy(max) =	0.095541
		Dx(r.m.s.) =	2.475334	Dy(r.m.s.) =	0.038359

DOGLEG03 WITH 4 CORRECTION QUADS (ONE FOR EACH LEG):

total length =	474.206754	Qx =	6.699624	Qy =	6.923497
delta(s) =	0.000000 mm	Qx' =	3.605126	Qy' =	-25.202650
alfa =	0.337120E-01	betax(max) =	33.898100	betay(max) =	60.358225
gamma(tr) =	5.446375	Dx(max) =	3.206717	Dy(max) =	0.095311
		Dx(r.m.s.) =	2.478046	Dy(r.m.s.) =	0.038136

DOGLEG03 WITH 2 CORRECTION QUADS (BEFORE #1, AFTER #4):

total length =	474.204754	Qx =	6.699264	Qy =	6.922219
delta(s) =	0.000000 mm	Qx' =	3.637774	Qy' =	-24.496359
alfa =	0.337099E-01	betax(max) =	33.865929	betay(max) =	59.156691
gamma(tr) =	5.446547	Dx(max) =	3.194984	Dy(max) =	0.067170
		Dx(r.m.s.) =	2.479314	Dy(r.m.s.) =	0.028055

DOGLEG03 WITH 1 CORRECTION QUAD (AFTER #2):

total length =	474.203754	Qx =	6.700177	Qy =	6.933350
delta(s) =	0.000000 mm	Qx' =	3.376615	Qy' =	-30.246601
alfa =	0.336961E-01	betax(max) =	35.348193	betay(max) =	69.871017
gamma(tr) =	5.447658	Dx(max) =	3.315170	Dy(max) =	0.204508
		Dx(r.m.s.) =	2.479651	Dy(r.m.s.) =	0.112906

DOGLEG03 WITH 1 CORRECTION QUAD (AFTER #4):

total length =	474.203754	Qx =	6.703247	Qy =	6.931417
delta(s) =	0.000000 mm	Qx' =	4.034909	Qy' =	-23.689408
alfa =	0.336837E-01	betax(max) =	37.393908	betay(max) =	67.944646
gamma(tr) =	5.448663	Dx(max) =	3.468042	Dy(max) =	0.067902
		Dx(r.m.s.) =	2.481822	Dy(r.m.s.) =	0.024100

Comparison of 90-degree and 45-degree Doglegs

NO DOGLEGS:

total length =	474.202754	Qx =	6.699721	Qy =	6.799965
delta(s) =	0.000000 mm	Qx' =	3.671194	Qy' =	-11.119681
alfa =	0.337183E-01	betax(max) =	33.679540	betay(max) =	20.460394
gamma(tr) =	5.445873	Dx(max) =	3.189910	Dy(max) =	0.071312
		Dx(r.m.s.) =	2.480809	Dy(r.m.s.) =	0.023090
		xco(max) =	0.000000	yco(max) =	0.000000
		xco(r.m.s.) =	0.000000	yco(r.m.s.) =	0.000000

DOGLEG03 WITH ONE 90-DEGREE LEG (#1):

total length =	474.202754	Qx =	6.708678	Qy =	6.799964
delta(s) =	0.000000 mm	Qx' =	3.564105	Qy' =	-10.098851
alfa =	0.335071E-01	betax(max) =	35.701317	betay(max) =	20.460437
gamma(tr) =	5.463006	Dx(max) =	3.459935	Dy(max) =	1.017283
		Dx(r.m.s.) =	2.475067	Dy(r.m.s.) =	0.576976
		xco(max) =	0.000000	yco(max) =	0.000000
		xco(r.m.s.) =	0.000000	yco(r.m.s.) =	0.000000

DOGLEG03 WITH TWO 90-DEGREE LEGS (#1, #2):

total length	=	474.202754	Qx	=	6.717015	Qy	= 6.799964
delta(s)	=	0.000000 mm	Qx'	=	3.354231	Qy'	= -8.890775
alfa	=	0.334717E-01	betax(max)	=	37.650486	betay(max)	= 20.460477
gamma(tr)	=	5.465891	Dx(max)	=	3.780531	Dy(max)	= 0.094832
			Dx(r.m.s.)	=	2.479282	Dy(r.m.s.)	= 0.033662
			xco(max)	=	0.000000	yco(max)	= 0.000000
			xco(r.m.s.)	=	0.000000	yco(r.m.s.)	= 0.000000

DOGLEG03 WITH ONE 45-DEGREE LEG (#1):

total length	=	474.202754	Qx	=	6.704183	Qy	= 6.812854
delta(s)	=	0.000000 mm	Qx'	=	4.319430	Qy'	= -12.518876
alfa	=	0.338704E-01	betax(max)	=	34.671178	betay(max)	= 22.328975
gamma(tr)	=	5.433625	Dx(max)	=	3.401872	Dy(max)	= 1.096908
			Dx(r.m.s.)	=	2.489210	Dy(r.m.s.)	= 0.624357
			xco(max)	=	0.000000	yco(max)	= 0.000000
			xco(r.m.s.)	=	0.000000	yco(r.m.s.)	= 0.000000

DOGLEG03 WITH TWO 45-DEGREE LEGS (#1, #2):

total length	=	474.202754	Qx	=	6.708365	Qy	= 6.826078
delta(s)	=	0.000000 mm	Qx'	=	3.669581	Qy'	= -11.046799
alfa	=	0.335649E-01	betax(max)	=	35.617577	betay(max)	= 24.497145
gamma(tr)	=	5.458297	Dx(max)	=	3.533421	Dy(max)	= 0.708466
			Dx(r.m.s.)	=	2.474793	Dy(r.m.s.)	= 0.396466
			xco(max)	=	0.000000	yco(max)	= 0.000000
			xco(r.m.s.)	=	0.000000	yco(r.m.s.)	= 0.000000