Cornell Laboratory for
Accelerator-Based Sciences
and Education (CLASSE)

Isochronous Bypass for EOC

Michael Ehrlichman

TTOSC Reminder

- TTOSC damping rates (according to Lebedev):
  - $\frac{\delta p}{p} = k\xi_0 \Delta s = k\xi_0 \left(M_{51}x_1 + M_{52}\theta_{x_1} + M_{56}\frac{\Delta p}{p} \right) \xrightarrow[\text{betatron motion}]{\text{in the absence of}} k\xi_0 \left(M_{51}D_x + M_{52}D'_x + M_{56} \right)\frac{\Delta p}{p}$
  - $\lambda_x = \frac{k\xi_0}{2}\left(M_{56} - \tilde{M}_{56} \right)$

    $\lambda_s = \frac{k\xi_0}{2}\tilde{M}_{56}$
  - i.e. wants no longitudinal displacement from pickup to kicker, EXCEPT for that due to J, of which it wants a lot.

- Also need to maximize damping envelope by minimizing:

$$\sigma_{\Delta s\varepsilon}{}^2 = \varepsilon\left(\beta_p M_{51}{}^2 - 2\alpha_p M_{51}M_{52} + \gamma_p M_{52}{}^2 \right)$$

$$\sigma_{\Delta sp}{}^2 = \sigma_p{}^2 \tilde{M}_{56}{}^2$$

Enhanced Optical Cooling (EOC)

- EOC requires that the bypass be isochronous R51, R52, and R56 = 0.
  - i.e. Longitudinal arrangement of particles is unchanged from pickup to kicker.
- R51 and R52 are easy to make zero.
- R56 can be difficult
  - Integral over R_{16}/ρ
    - Bends generate R_{16}

Example form EuroTEV turn around

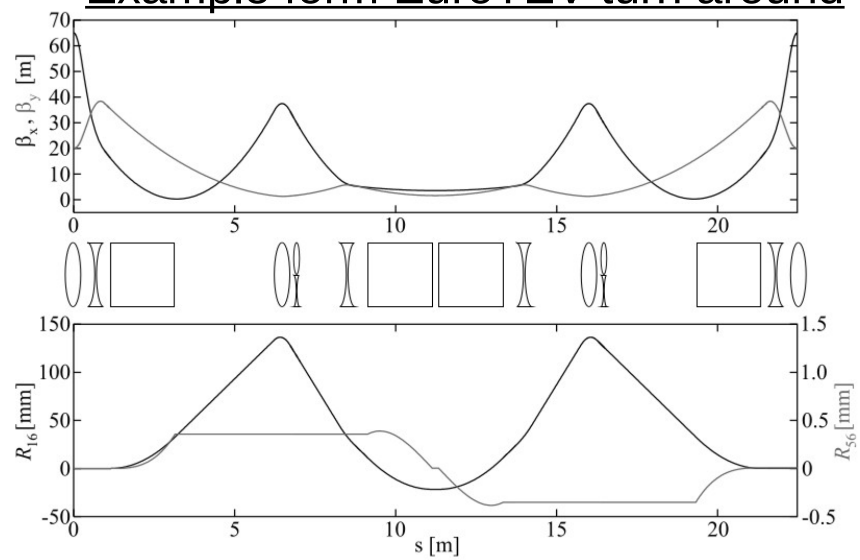


Figure 2: Beta functions β_x, β_y, dispersion R_{16} and momentum-compaction factor R_{56} along a single cell of the turn around loop.

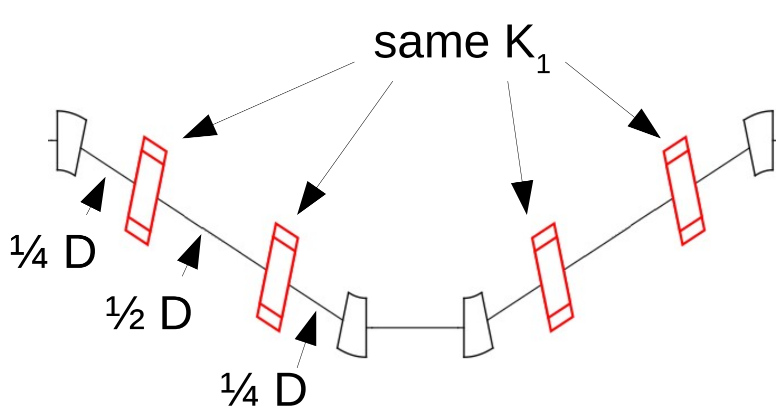
Reference for Bypass Design

A Modular Path Length Corrector for Recirculating Linacs

Hywel Owen[*,a], Peter Williams[b]

[a] Cockcroft Accelerator Group, School of Physics and Astronomy, University of Manchester, Manchester M13 9PL, UK
[b] STFC Daresbury Laboratory and Cockcroft Institute, Daresbury Science and Innovation Campus, Warrington WA4 4AD, UK

arXiv:1108.1709v1 [physics.acc-ph] 8 Aug 2011



5.2. Four-Dipole Chicane with Focusing

We next consider a similar four-dipole chicane, except in this case with a pair of quadrupoles inserted into each of the angled sections of the chicane. To suppress dispersion at the centre of the chicane the well-known scheme is used of placing the quadrupoles of each pair 1/4 and 3/4 of the way along each angled section, to give a back-to-back pair of doglegs with zero dispersion at each end, and zero dispersion at the centre. The total longitudinal dispersion for this focused chicane may be expressed, using a thin lens approximation for the quadrupoles, as

$$R_t|_{56} = \frac{1}{f^3\theta^2}\left\{ \begin{array}{l} 4L_b^2\,(f^2 - L_d^2)\sin^4\theta/2 \\ -\theta^2 L_d \sin^2\theta\,(2f + L_d)\,(L_d^2 - 2f^2) \\ +\,2\theta L_b(\cos\theta - 1)L_d\sin\theta \\ \quad\times(L_d\,(f + L_d) - 2f^2) \\ -2\theta L_b f^3\,[\theta + (\cos\theta - 2)\sin\theta)] \end{array} \right\},$$

where f is the focal length of each F-quadrupole, L_b is the length of the dipoles and L_d is the drift space length between the dipoles into which each quadrupole pair is placed. With sufficiently-strong quadrupoles the overall longitudinal dispersion may be made negative, in contrast to the conven-

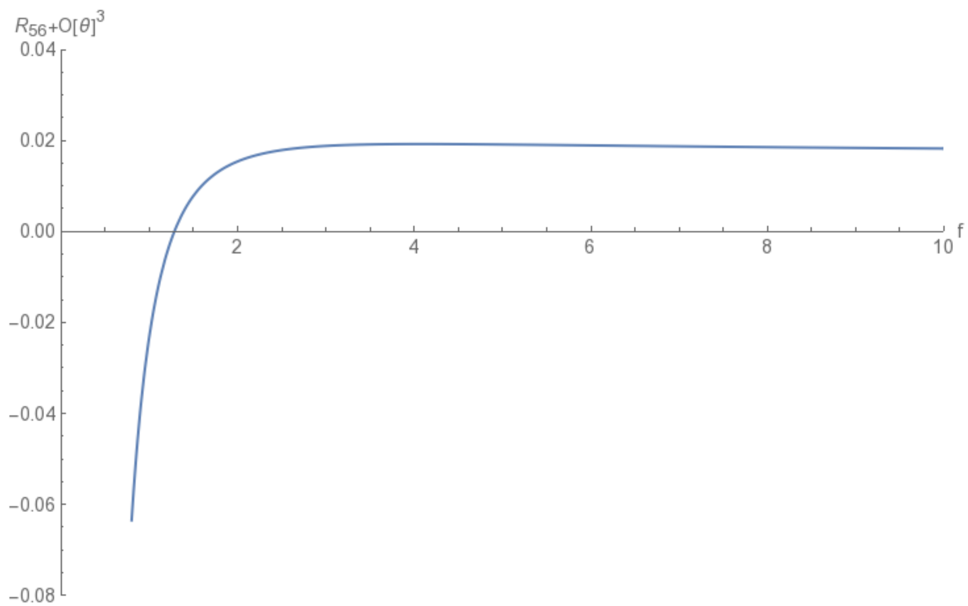
Expansion in θ

- Expand equation for R_{56} in bend angle (θ):

```
R[θ_] := 1/(f^3 θ^2) (4 Lb^2 (f^2 - Ld^2) Sin[θ/2]^4 -
    θ^2 Ld Sin[θ]^2 (2 f + Ld) (Ld^2 - 2 f^2) +
    2 θ Lb (Cos[θ] - 1) Ld Sin[θ] (Ld (f + Ld) - 2 f^2)
    - 2 θ Lb f^3 (θ + (Cos[θ] - 2) Sin[θ]));

Series[R[θ], {θ, 0, 2}] // Expand // FullSimplify
```

$$\frac{\left(-12\, f\, Ld^2\,(Lb+2\,Ld) - 3\,Ld^2\,(Lb+2\,Ld)^2 + 8\,f^3\,(Lb+6\,Ld) + 3\,f^2\,(Lb^2+8\,Lb\,Ld+8\,Ld^2)\right)\theta^2}{12\,f^3} + O[\theta]^3$$

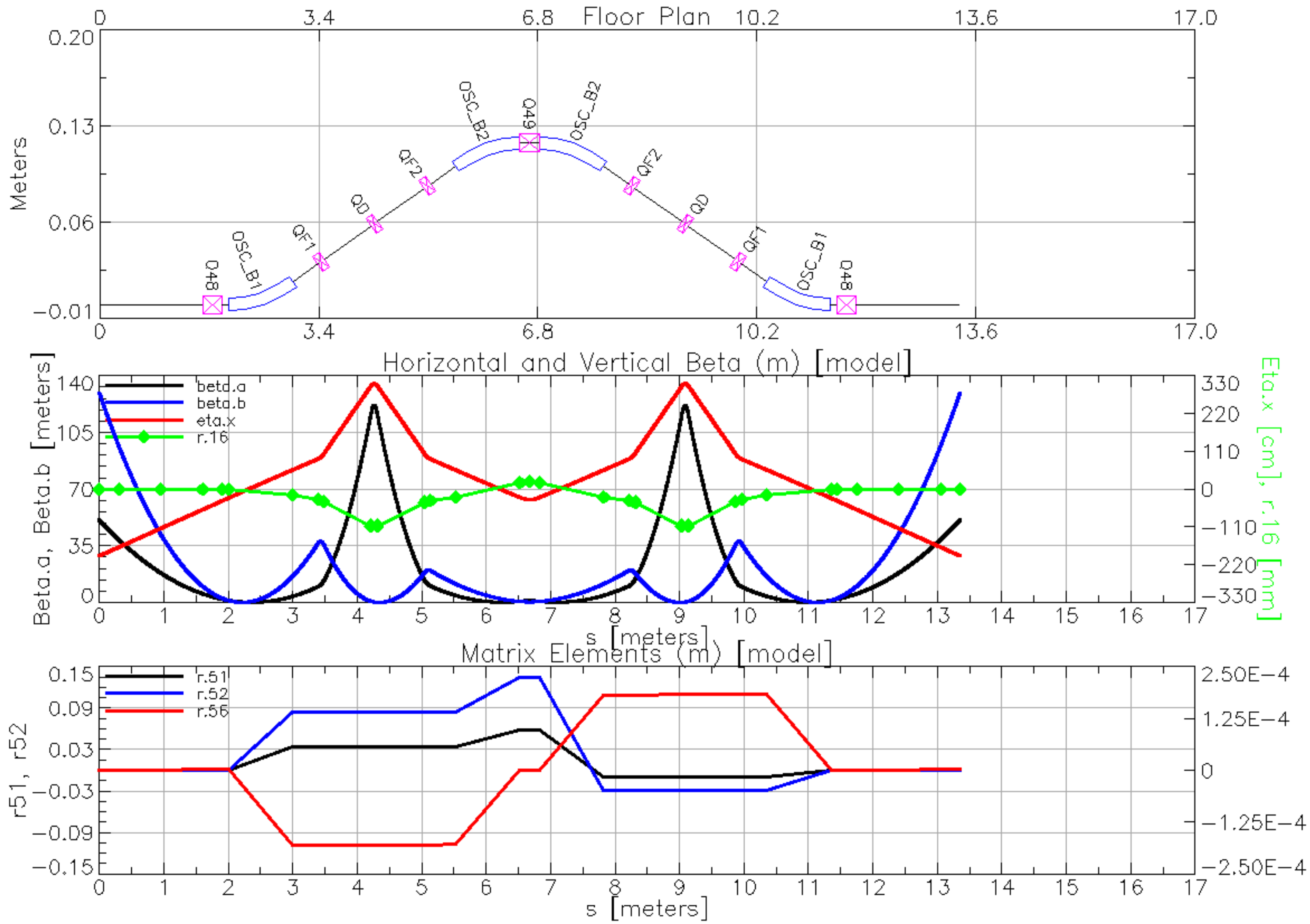
```
ser[Ld_, Lb_, f_, θ_] := Evaluate[Normal[Series[R[θ], {θ, 0, 2}]]]

With[{Ld = 1.75, Lb = 0.75, θ = 0.047}, Plot[ser[Ld, Lb, f, θ], {f, 0.8, 10}, AxesOrigin → {0, 0},
  PlotRange → {{0, 10}, {-0.08, 0.04}}, AxesLabel → {"f", "R56+O[θ]^3"}]]
```



*Solution for R56=0 is narrow … global optimization on quad strengths and locations did not find it.

Resulting EOC Proof-of-Principle

- Add quads qd and q49 to get R_{51}, R_{52} = 0
- q48 adds some sanity to β and α
- QF1=QF2, QD, Q49 set to make $R_{51}=R_{52}=R_{56} = 0$ … no consideration made for Twiss



- Any Twiss & dispersion can be matched into bypass without spoiling $R_{51}=R_{52}=R_{56} = 0$!

Open Issues With EOC Bypass

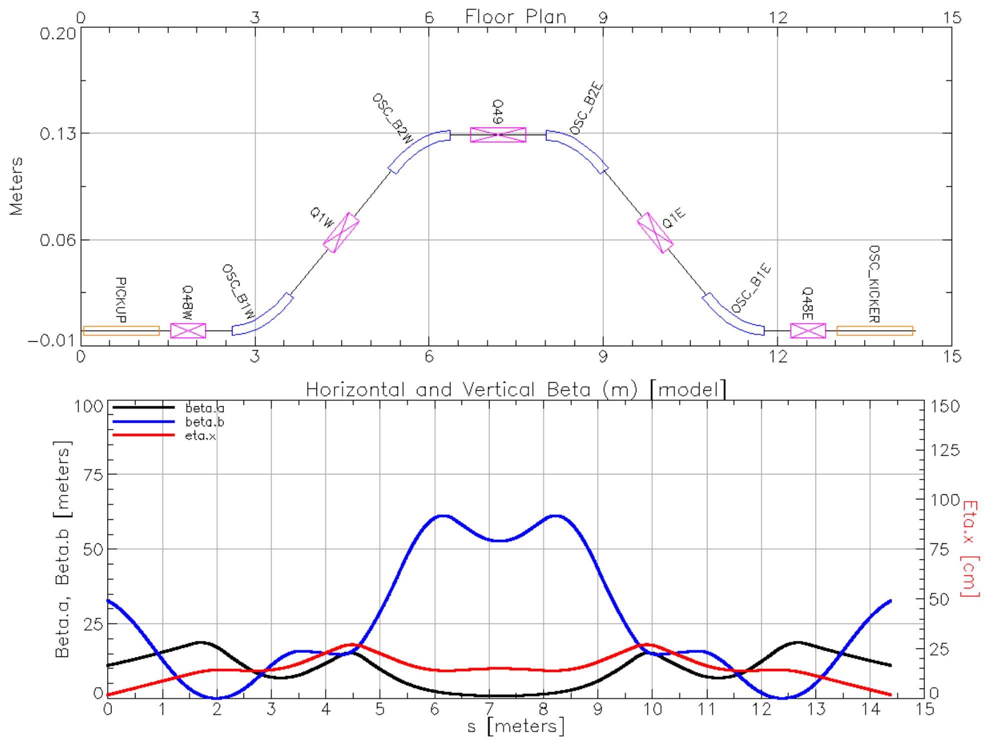
- Length not set yet.
- Undulators are drifts.
-

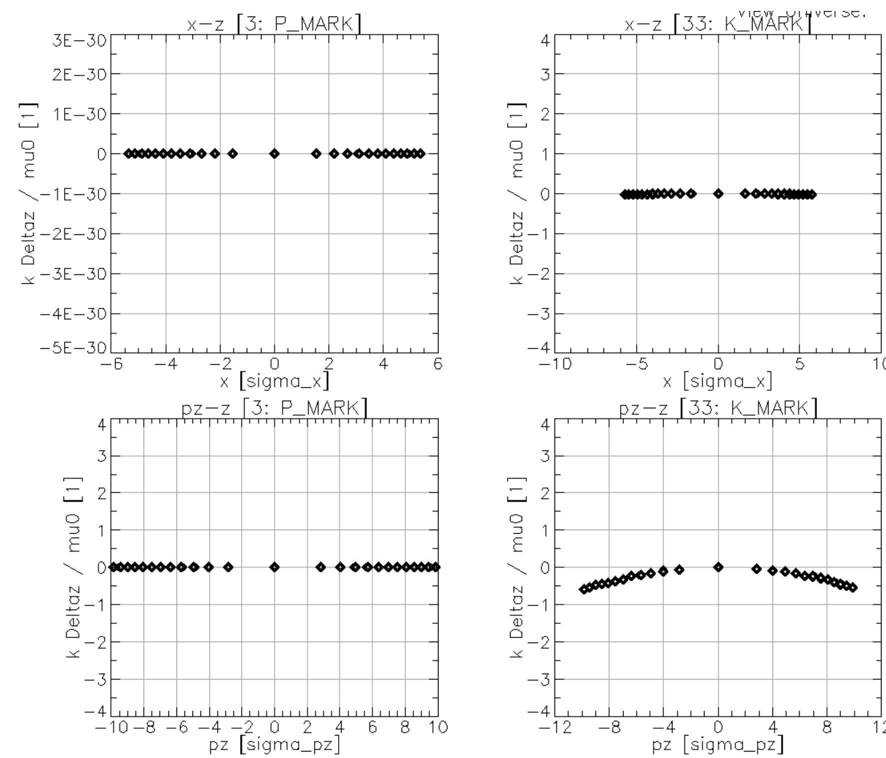
Quad	$\|K_1\|$ (m^{-2})	L (m)	∂B_1 (T/m)
Q48	0.01	0.3	0.017
QF1 = QF2	20.0	0.1	33.3
QD	17.7	0.1	29.5
Q49	18.4	0.3	30.7

For comparison

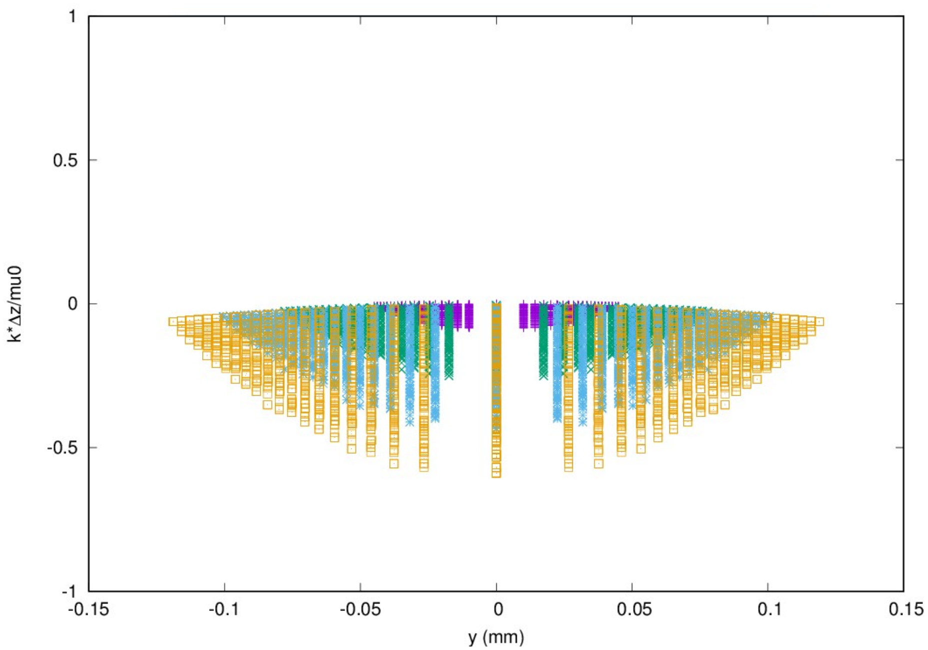
- ESRFU ∂B_1: 52 T/m, 82 T/m
- MAXIV ∂B_1: 30 – 40 T/m

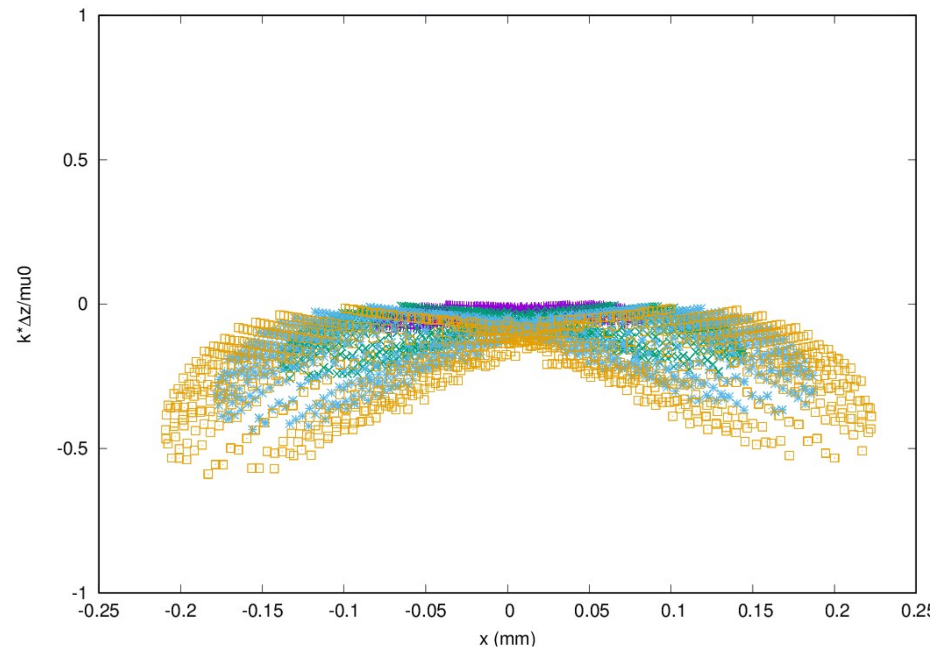
180° TTOSC Bypass

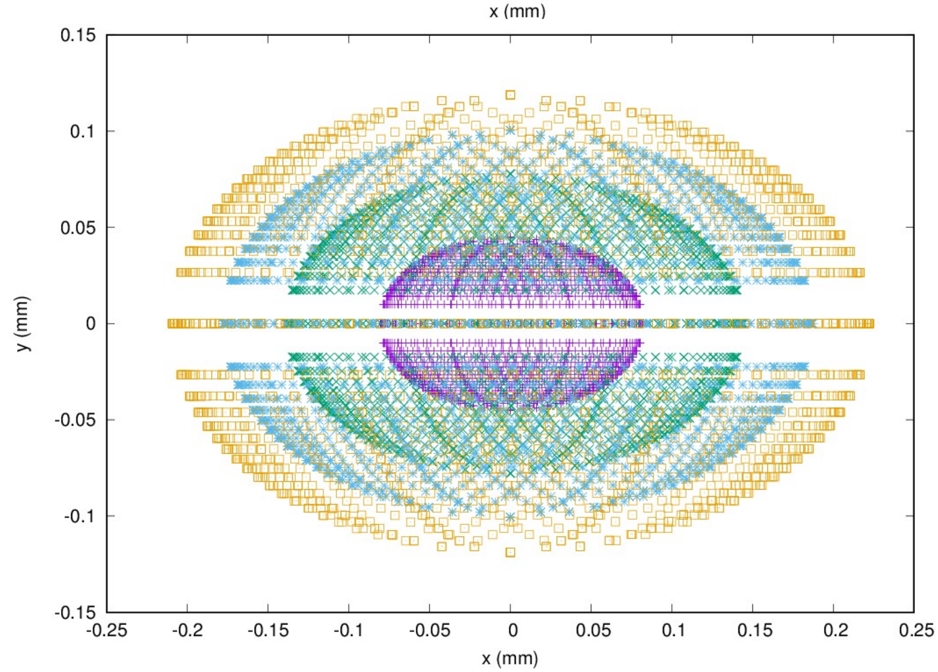




180° TTOSC Bypass







Parameters with % damped

	$\tilde{M}_{56}$			$\tilde{J}$			% in Damped Envelope		
Δs	180 sym	sym	unsym	180 sym	sym	unsym	180 sym	sym	unsym
2.7 mm		4.3×10^{-6}	1.0×10^{-6}		1.3×10^{-4}	4.9×10^{-5}		94	91
5.3 mm	$5.2\ 10^{-6}$	5.5×10^{-6}	6.1×10^{-8}	$1.3\ 10^{-3}$	2.1×10^{-4}	1.5×10^{-4}	92	82	80
10. mm		6.8×10^{-6}	2.2×10^{-8}		4.5×10^{-4}	2.0×10^{-4}		63	51