Dynamic Aperture Survey of ILC Damping Ring using SAD

1. Wiggler fringe effect
2. Multipole errors

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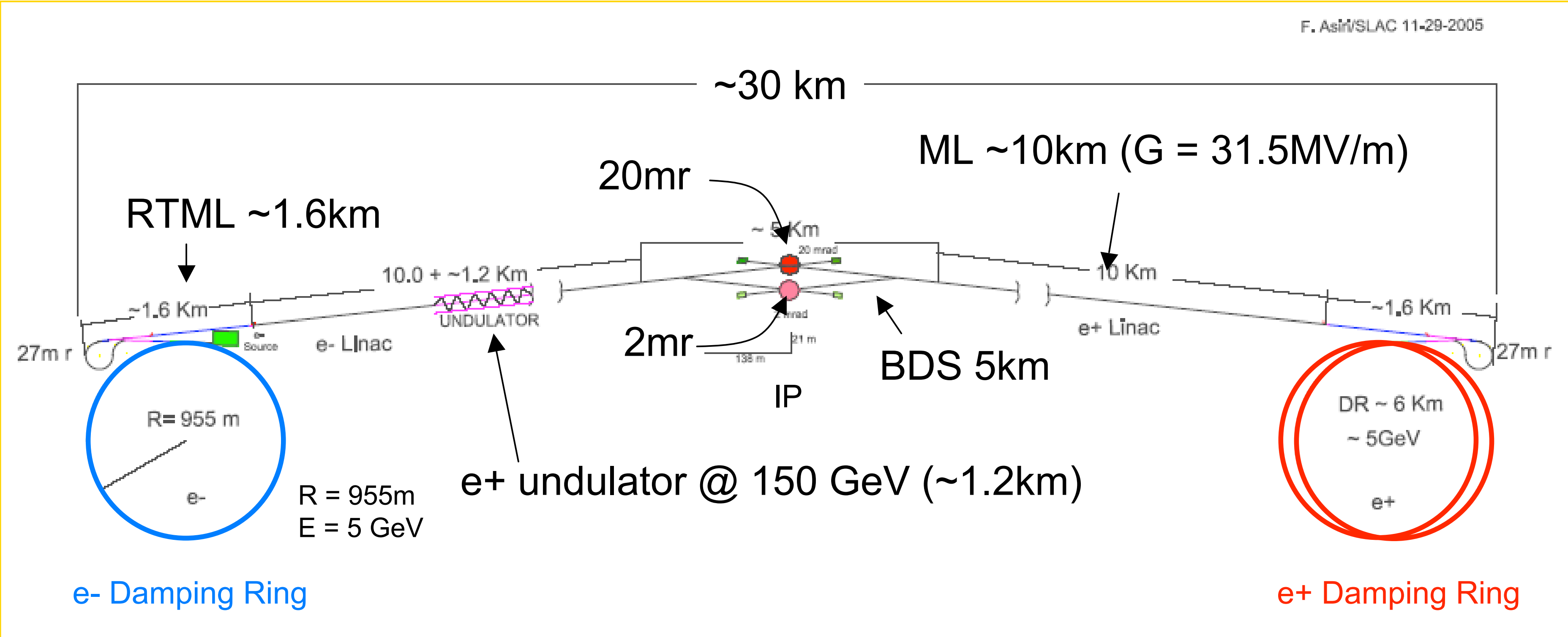
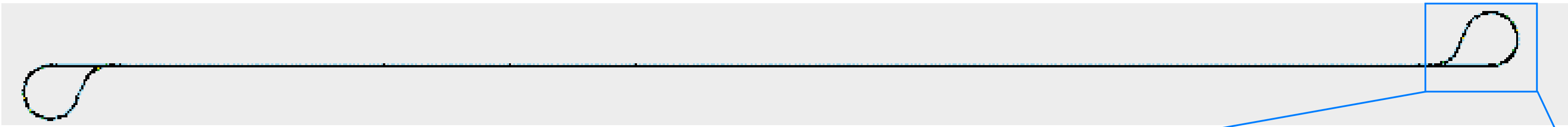
Workshop SAD2006

ILC Baseline Machine (500 GeV)



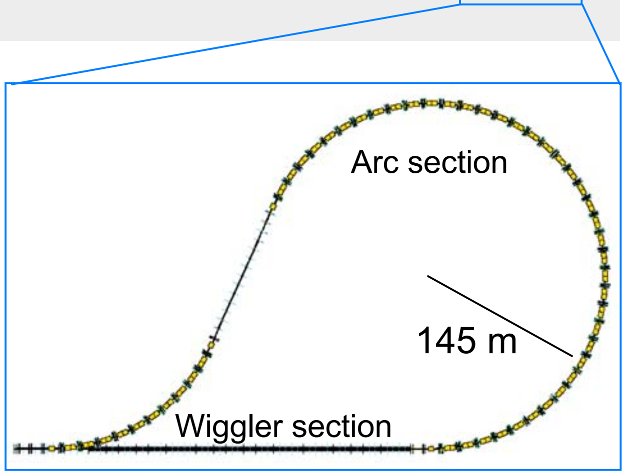
not to scale

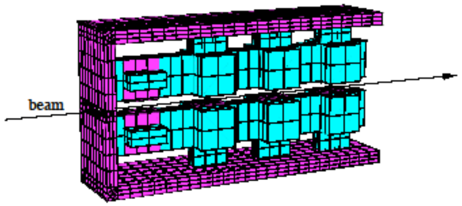


TESLA Dogbone Damping Ring

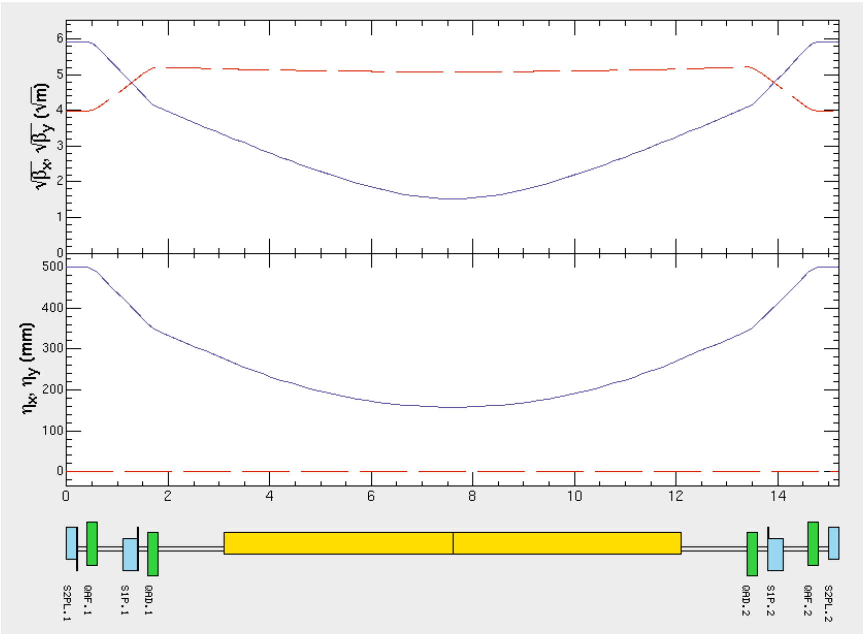
C = 17 km E = 5 GeV

```
$DisplayFunction=CanvasDrawer;
OpticsPlot[{{"BX","BY"},{"EX","EY"}},Region->{1,100}];
GeometryPlot[Region->{1,100}];
Update[];
```

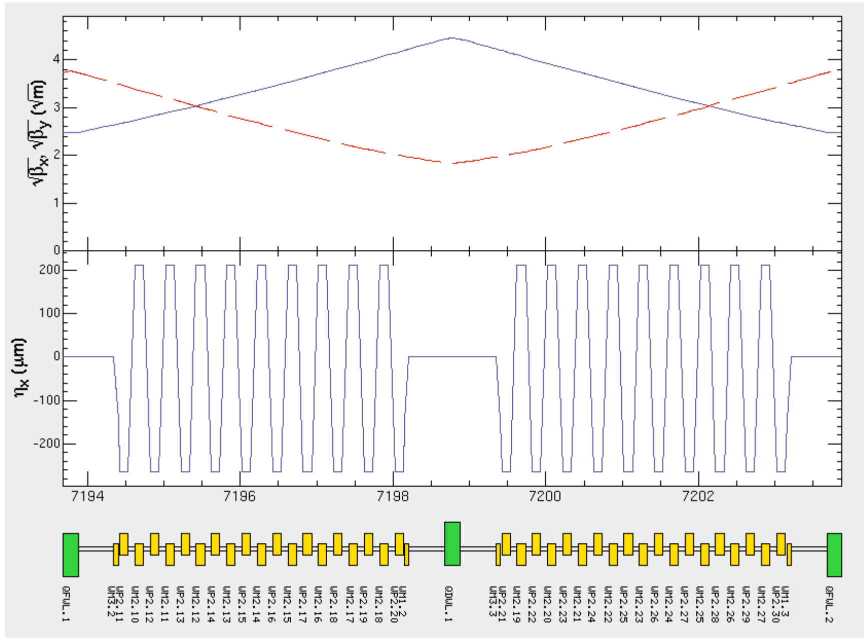




TME lattice

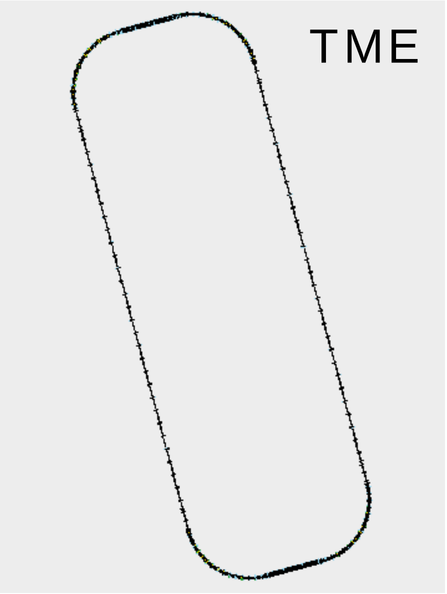


Wiggler cell



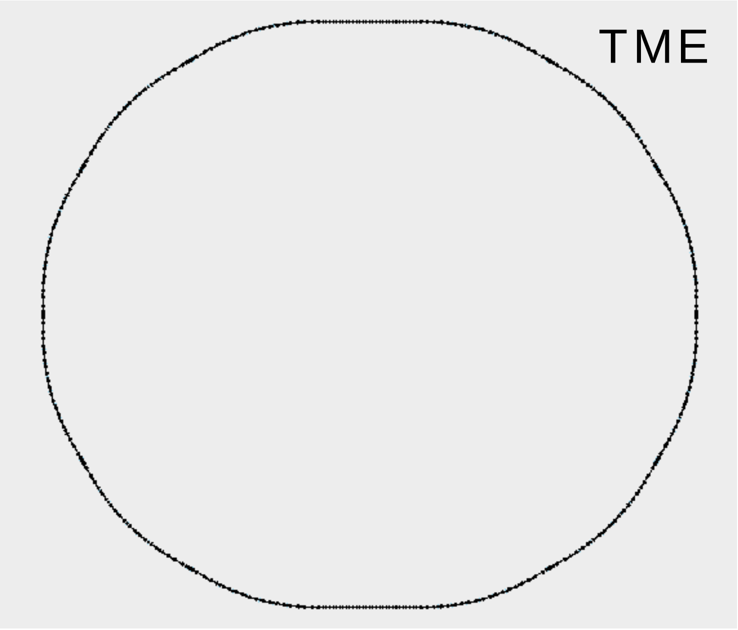
OTW Damping Ring

C = 3.2 km E = 5 GeV



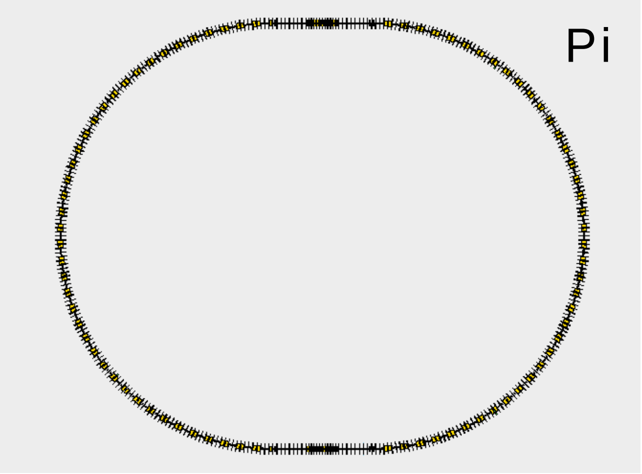
OCS Damping Ring

C = 6.5 km E = 5 GeV



PPA Damping Ring

C = 2.8 km E = 5 GeV



Nonlinear wigglers

SAD can deal with nonlinear wigglers due to fringe field.

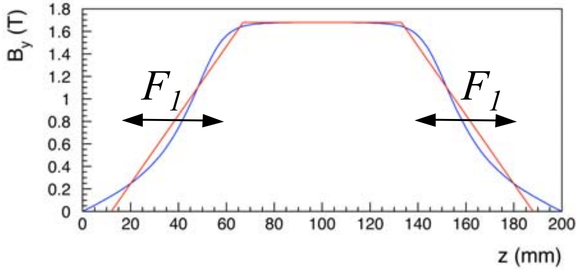
Wigglers (field map):

$B_0 = 1.68\ T$

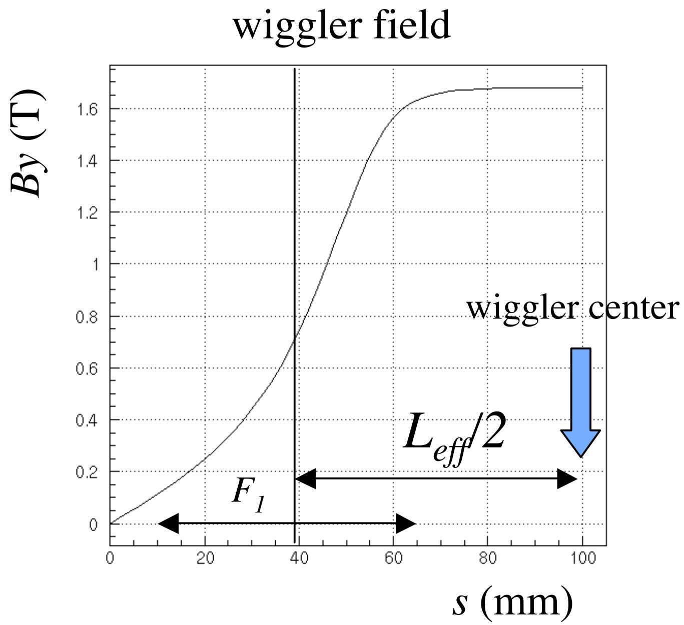
Effective length $L_{eff} = 121\ mm$

Fringe field: $F_1 = 55\ mm$

BEND WP2 =(L =.121 ANGLE =.0106 E1 =.5 E2 =.5 F1=0.055 FRINGE=1);



$$F_1 = 6\int_{-\infty}^{+\infty}\left\{\frac{B_y(s)}{B_0} - \left(\frac{B_y(s)}{B_0}\right)^2\right\}ds$$



Wiggler bending field is approximated by trapezoid.
Hamiltonian up to $O(y^4)$ is included in SAD.

$$H = H_0 + \frac{L_w}{4\rho_w^2}y^2 + \frac{L_w}{12\rho_w^2}k^2y^4, \qquad k = \frac{2\pi}{\lambda_w} \qquad y \approx \sqrt{2J_y\bar{\beta}_y}$$

$$= 4\pi\left(\nu_{x0}J_x + \nu_{y0}J_y + \nu_{z0}J_z + c_{xx}J_x^2 + c_{yy}J_y^2 + c_{zz}J_z^2 + \cdots\right)$$

Vertical betatron tune ($J_x=J_z=0$) analytically:

$$\nu_y = \frac{1}{4\pi}\frac{\partial H}{\partial J_y} = \nu_{y0} + 2c_{yy}J_y, \qquad c_{yy} = \frac{\bar{\beta}_y^2 L_w k^2}{12\pi\rho_w^2} \quad \ldots (1)$$

Nonlinear coefficient: c_{yy}

TESLA Dogbone:

$\beta_y = 8.7\ m$

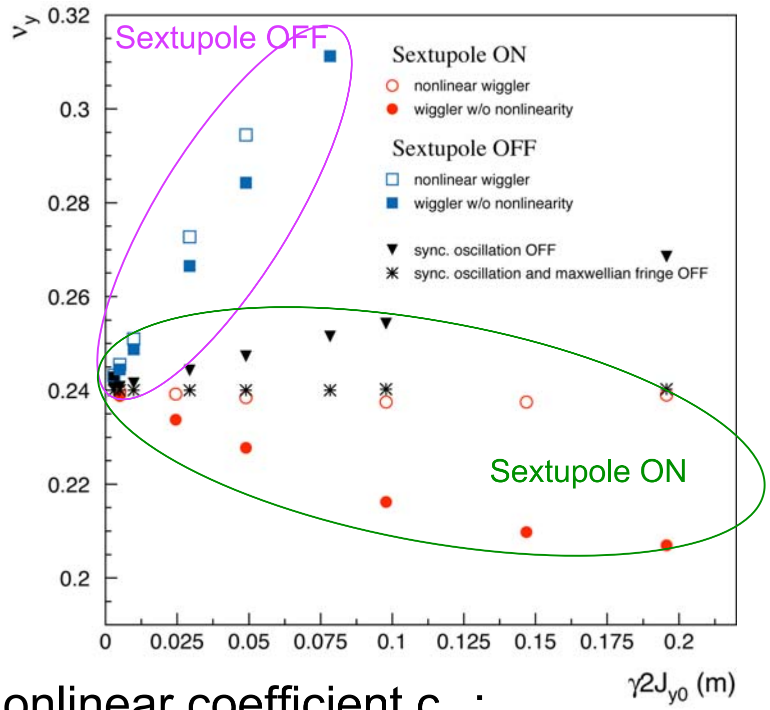
$L_w = 417\ m$

$\rho_w = 10\ m$

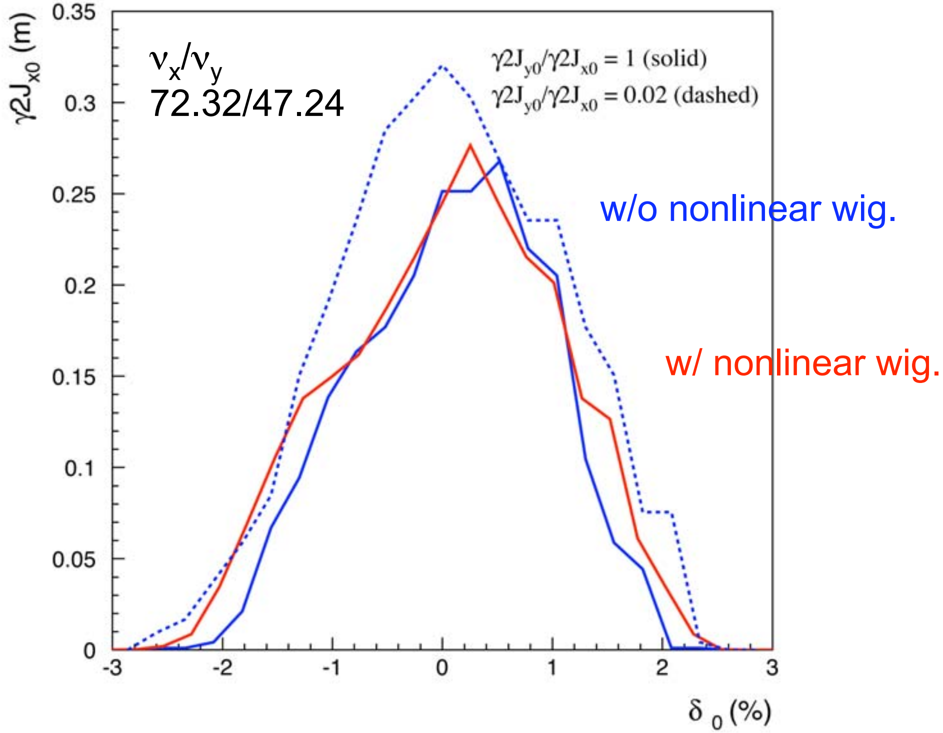
$\lambda_w = 0.4\ m$

Tracking simulations - TESLA Dogbone

Amplitude dependence of vertical tune
Tracking simulations



γ2J - δ plot



Nonlinear coefficient c_{yy}:

Sextupole	w/o nonlinear wig. (A)	w/ nonlinear wig. (B)	(B) - (A)	Analytic formula (1)
ON	-2361	-238	+2123	c_{yy} = +2066
OFF	+8858	+11061	+2203	

Tracking simulation well reproduces the octupole-like component of the wigglers.
There is no significant difference between without and with nonlinear wig. for DA.

Dynamic Aperture Survey with SAD

- 6-dimensional coordinate: $(x, x'=p_x/p_0, y, y'=p_y/p_0, z, \delta=\Delta p/p_0)$
- Survey region is divided by 51 regions.
- Start from the smallest initial amplitudes.
- Maximum initial amplitude is defined by "dynamic aperture" where the particle can circulate stable during the required turns.
- Option (default):

Ring or Transport beam-line	RING	TRPT
Synchrotron radiation	RAD	NORAD
Quantum excitation (need random seeds)	FLUC	NOFLUC
Acceleration by rf cavities	RFSW	NORFSW
COD with/without radiation loss p_0 changes with energy loss or constant(design value)	RADCOD	NORADCOD

Ordinary dynamic aperture survey uses:

RAD, NOFLUC, RFSW, RADCOD

SAD script

Dynamic aperture survey

```
nx=350;
k=1;
nz=22;
dnz=2;
nturns=500;
```

$$N_x = \sqrt{\frac{2J_x}{\varepsilon_x + \varepsilon_y}} \qquad N_y = \sqrt{\frac{2J_y}{\varepsilon_x + \varepsilon_y}} \qquad N_z = \sqrt{\frac{2J_z}{\varepsilon_z}} = \frac{\delta}{\sigma_\delta} \qquad k = \frac{J_y}{J_x} = \left(\frac{N_y}{N_x}\right)^2$$

$2J$: Courant-Snyder invariant

```
FFS["emit"];
result=DynamicApertureSurvey[{{0,nx},{0,nx*Sqrt[k]},Range[-nz,nz,dnz]},nturns,Output->6];

sigmap=MomentumSpread/.Emittance[];
dpop0=sigmap*result[[2,1,3]];
Nx=Transpose[result[[2,2]]][[2]]/51*nx;
Ax=EMITX*Nx^2;
score=result[[1]];
```

$$Ax = 2J_x = \varepsilon_x \times N_x^2 \qquad (\varepsilon_y << \varepsilon_x)$$

```
Maximum number of particles =161
 Range    Xmin:   0.000 Xmax: 350.000
         (Ymin:   0.000 Ymax: 350.000)
          Zmin: -22.000 Zmax:  22.000
 Display:   100 turns/character
      NZ     0----!----1----!----2----!----3----!----4----!----5
   -22.00  0 000000000000000000000000000000000000000000000000000
   -20.00  0 000000000000000000000000000000000000000000000000000
   -18.00  3 444000000000000000000000000000000000000000000000000
   -16.00  2 441000400000000000000000000000000000000000000000000
   -14.00  8 *44444440100000000000000000000000000000000000000000
   -12.00  9 **4444444110000000000000000000000000000000000000000
   -10.00  8 *44444441441100040000100000000000000000000000000000
    -8.00  9 **444444414014414020000000000000000000000000000000
    -6.00 12 *****44444441404400000000000000000000000000000000000
    -4.00 20 *************44444440440000000000000000000000000000
    -2.00 26 *******************44444440000000000000000000000000
     0.00 31 ************************444444400000000000000000000
     2.00 25 ******************44444440444400000000000000000000
     4.00 19 ************44444440414444000000000000000000000000
     6.00 16 *********44444440441400000000000000000000000000000
     8.00  7 444444404044040014000000000000000000000000000000000
    10.00 11 ****4444444101000000000000000000000000000000000000
    12.00  7 444444400000000000000000000000000000000000000000000
    14.00  6 444444144000000000000000000000000000000000000000000
    16.00  7 444444400144000004000000000000000000000000000000000
    18.00  2 442100000000000000000000000000000000000000000000000
    20.00  0 000000000000000000000000000000000000000000000000000
    22.00  0 000000000000000000000000000000000000000000000000000
      NZ     0----!----1----!----2----!----3----!----4----!----5
    Score:   228
```

Multipole errors for magnets

$$B_y + iB_x = B(r_0)\sum_{k=1}(b_k + ia_k)(x+iy)^{k-1}\frac{1}{r_0^{k-1}}$$

	PEP-II	PEP-II		SPEAR3
index	Dipole	Qudrupole		Sextupole
k	b_k/b_1	b_k/b_2	a_k/a_2	b_k/b_3
3	$1.6\text{x}10^{-4}$	$-1.24\text{x}10^{-5}$	$-1.15\text{x}10^{-5}$	
4	$-1.6\text{x}10^{-5}$	$2.30\text{x}10^{-6}$	$1.41\text{x}10^{-5}$	$2.0\text{x}10^{-4}$
5	$7.5\text{x}10^{-5}$	$-4.30\text{x}10^{-6}$	$6.20\text{x}10^{-7}$	$1.0\text{x}10^{-4}$
6		$3.40\text{x}10^{-4}$	$-4.93\text{x}10^{-5}$	$7.0\text{x}10^{-4}$
7		$3.00\text{x}10^{-7}$	$-1.02\text{x}10^{-6}$	$1.0\text{x}10^{-4}$
8		$6.00\text{x}10^{-7}$	$3.80\text{x}10^{-7}$	$1.0\text{x}10^{-4}$
9		$6.00\text{x}10^{-7}$	$-2.80\text{x}10^{-7}$	$1.0\text{x}10^{-4}$
10		$-6.17\text{x}10^{-5}$	$-5.77\text{x}10^{-5}$	$1.0\text{x}10^{-4}$
11		$-2.00\text{x}10^{-7}$	$-3.80\text{x}10^{-7}$	$1.0\text{x}10^{-4}$
12		$3.60\text{x}10^{-6}$	$-6.53\text{x}10^{-6}$	$3.2\text{x}10^{-3}$
13		$6.00\text{x}10^{-7}$	$1.20\text{x}10^{-6}$	
14		$1.00\text{x}10^{-6}$	$-7.40\text{x}10^{-7}$	
r_0 (m)	0.030	0.050		0.032

allowed multipoles

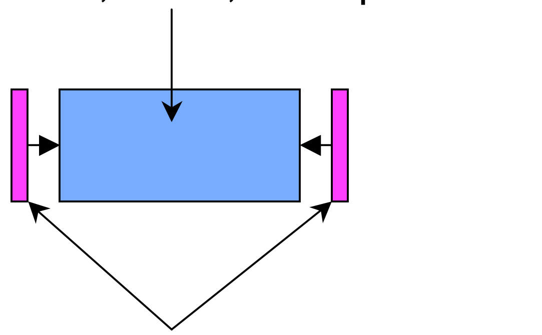
measured data (Y. Cai)

SAD script

Insertion of multipole elements

```
MULT        FQD1=()
            FQF1=()
            :
;
FFS;
nm=Element["NAME","BE*|Q{DF}*|S{DF}*"];
line=ExtractBeamLine[ringName];
 Do[
  line=line/.ToExpression[nm[[i]]]->
          BeamLine[ToExpression["F"//nm[[i]]],ToExpression[nm[[i]]],ToExpression["F"//nm[[i]]]];
  ,{i,1,Length[nm]}];
 FFS["visit line;"];
 FFS["calc;"];
```

define MULT components




```
 !!! Quadrupole
 quad=Element["NAME","Q{DF}*"];
 aquad={.....};
 bquad={.....};
 r0=0.05;
 mm=1;
 Do[
  Scan[(Element["K"//nn,"F"//#]=0.5*Element["K1",#]*Factorial[nn]*bquad[[nn+1]]/r0^(nn-mm))&,quad];
  Scan[(Element["SK"//nn,"F"//#]=0.5*Element["K1",#]*Factorial[nn]*aquad[[nn+1]]/r0^(nn-mm))&,quad];
  ,{nn,2,13}];
```

coefficient: a_n
coefficient: b_n
bore radius: r_0

Dynamic Aperture Survey - ILC Damping Ring

- Dynamic Aperture
  - Tracking simulations $(x, x'=p_x/p_0, y, y'=p_y/p_0, z, \delta=\Delta p/p_0)$
  - Stability during one betatron damping time
  - Dynamic aperture is reduced due to nonlinear field of sextupoles and wigglers.

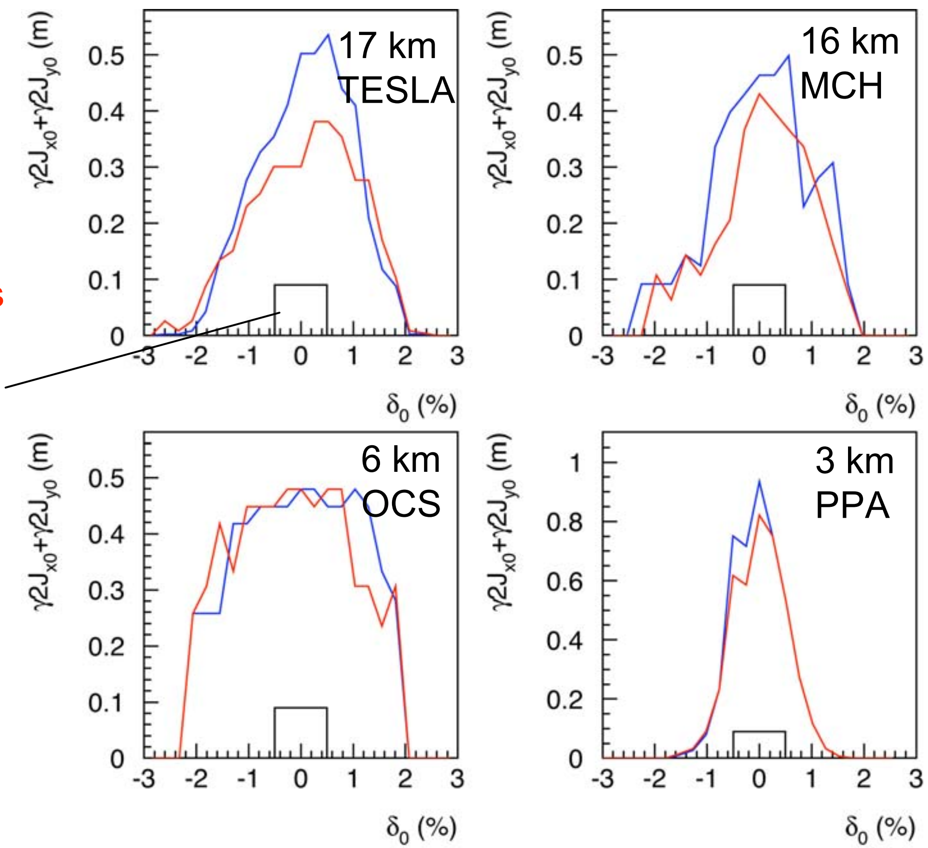
No machine error

Machine errors
with multipole errors

Required
aperture

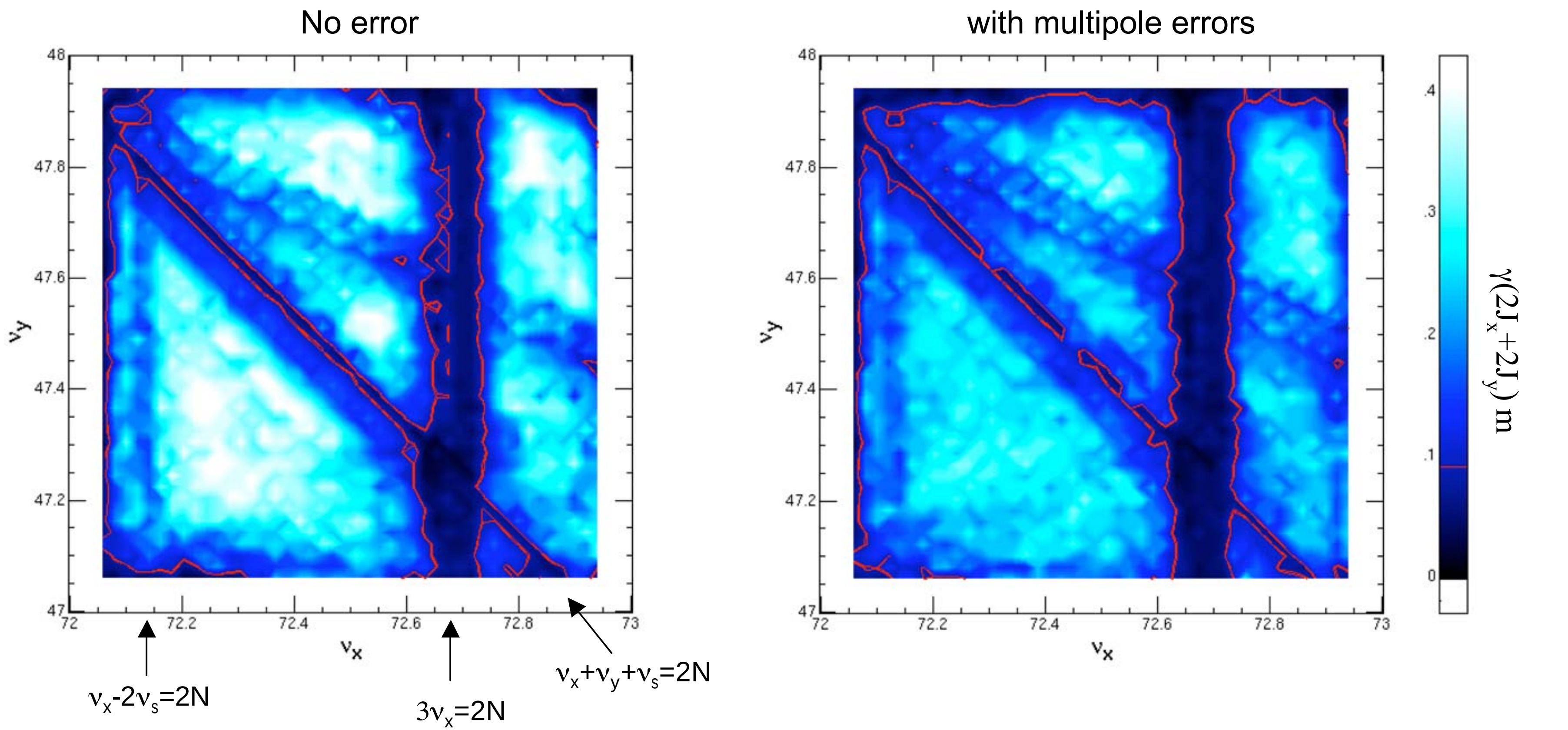
$\gamma(2J_x + 2J_y) = 0.09\ m$

$|\delta| = 0.5\ \%$



Tune Survey of ILC Damping Ring

- TESLA Dogbone (17 km)

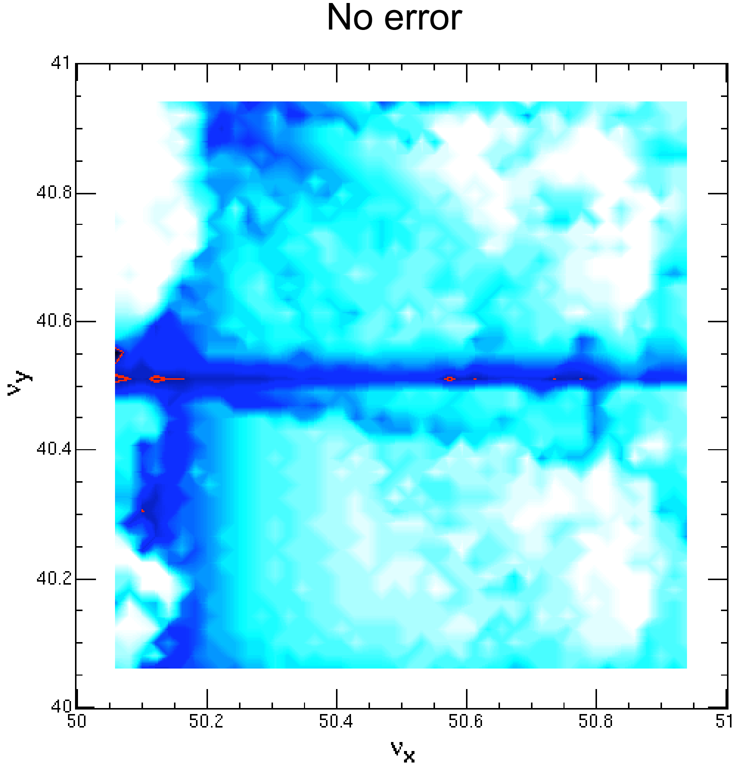


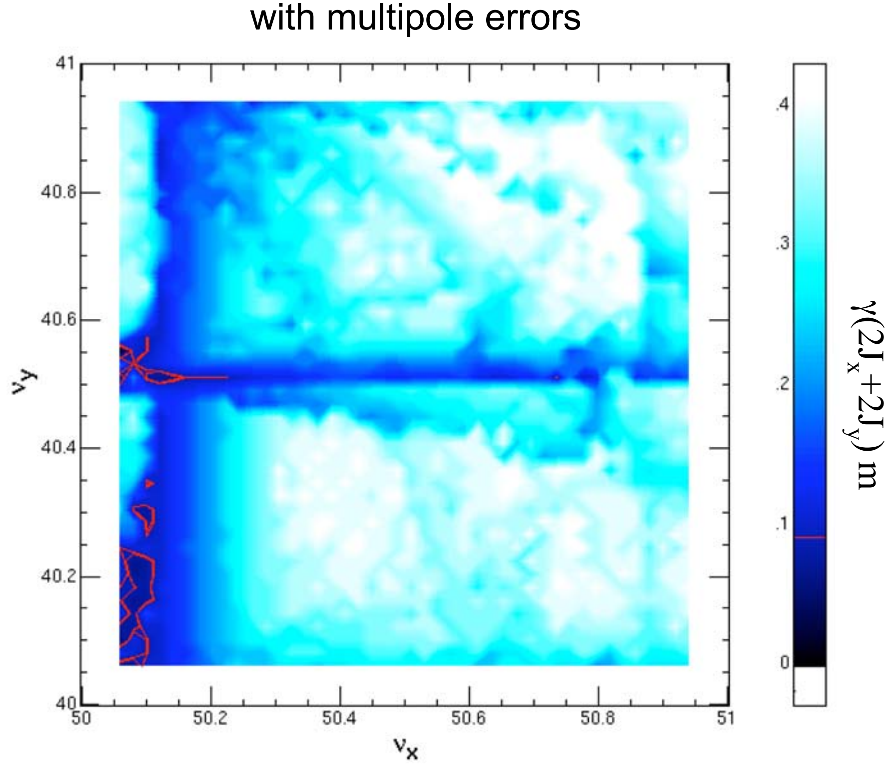
Smallest dynamic aperture with $|\delta| < 0.5$ % for each tune

Lighter color indicates larger dynamic aperture.

Tune Survey of ILC Damping Ring

- OCS (6.5 km)






```
g=ListContourPlot[score,
  PlotRange->{0.0,0.4},
  MeshRange->{{Nux1-Dnux/2,Nux2+Dnux/2},{Nuy1-Dnuy/2,Nuy2+Dnuy/2}},
  FrameLabel->{"`fn`n`dx`n","`fn`n`dy`n"},
  ContourColorFunction->colfx,Contours->100,DisplayFunction->Identity];
```

Summary

- Dynamic aperture survey
  - DynamicApertureSurvey[];
- Wiggler fringe field
  - F1
- Multipole errors
  - MULT
- Tune survey