Acceptance Issues for the ILC Damping Rings

Y. Cai/Y. Ohnishi

August 15, 2005

The 2nd ILC workshop at Snowmass

Task Force Members

- A. Wolski, I. Reichel, M. Venturini, W. Wan (LBNL)
- L. Emery, M. Borland (ANL)
- A. Xiao (FNAL)
- J. Urban (Cornell University)
- S. Guiducci (INFN)
- A. Dragt (University of Maryland)
- Y. Ohnishi (KEK)
- Y. Cai (SLAC)

Statement of Tasks

- Determine dynamic aperture of the lattices
  - **Specification of multipole errors (Cai, July 1)**
  - **Frequency analysis (Wolski, Xiao, July 15)**
  - **Ideal lattices & linear wigglers (Ohnishi, Urban, July 15)**
  - **Lattice with multipole errors & single-mode wigglers (Urban, Ohnishi, July 15)**
  - Benchmark wiggler codes (Venturini, Wan, Dragt, September 15)
  - Lattice with multipole errors and full nonlinear wigglers (**Urban**, Cai, August 15, October 15)
  - Lattice with alignment errors, multipole errors, and full nonlinear wigglers (Ohnishi, Borland, October 1, November 15)
- Determine the injection efficiency and beam loss
  - Define physical apertures (Wolski, Guiducci, August 1)
  - Realistic positron distribution & without physical aperture (Reichel, Xiao, August 15)
  - Realistic positron distribution, physical apertures, multipole errors, nonlinear wigglers (Guiducci, Emery, September 1, November 15)

Results can be found at Wolski's website: http://www.desy.de/~awolski/ILCDR

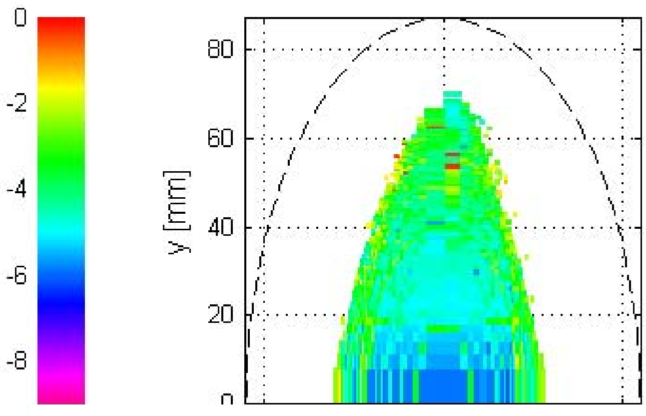
Lattices and Configurations

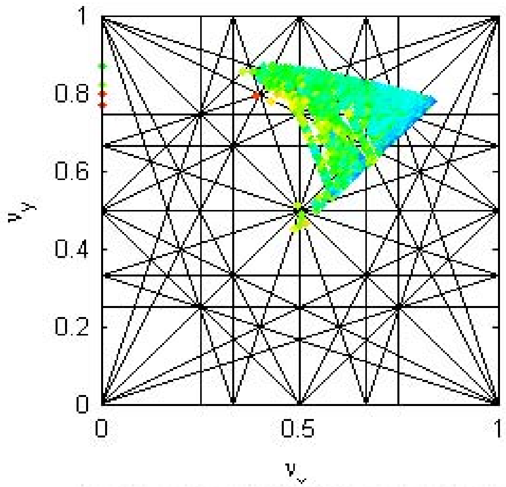
NAME	C (km)	E (Gev)	σ_z (mm)	Shape	Cell	Chromatic scheme
OTW	3.2	5	6	Racetrack	TME	Interleaved
PPA	2.8	5	6	Racetrack	PI	Non-interleaved
OCS	6.1	5.07	6	Circular	TME	Interleaved
BRU	6.3	3.74	9	Dogbone	FODO	Interleaved
TESLA	17	5	6	Dogbone	TME	Interleaved
MCH	16	5	9	Dogbone	FODO	Interleaved
DAS	17	5	6	Dogbone	PI	Non-interleaved

Dogbone Damping Rings

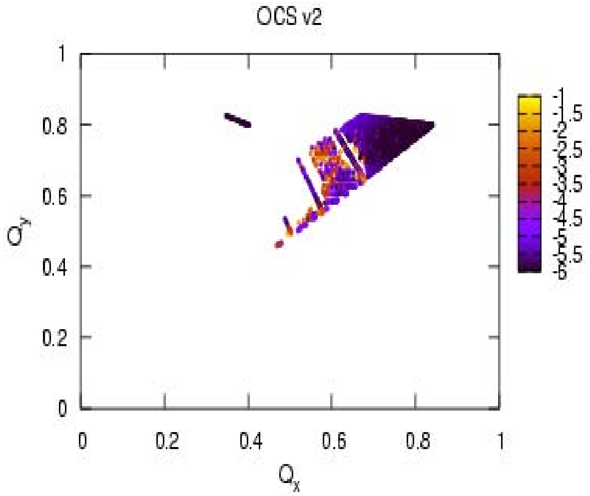
Parameters	TESLA	DAS	MCH
Energy E(Gev)	5	5	5
Circumference (m)	17,000	17,014	15,815
Horizontal emittance (nm)	0.50	0.62	0.68
Damping time (ms)	28	27	27
Tunes, ν_x,ν_y,ν_s	76.31, 41.18, 0.071	83.73, 83.65, 0.072	75.78, 76.41, **0.19**
Momentum compaction α_c	$1.22\text{x}10^{-4}$	$1.11\text{x}10^{-4}$	**$4.74\text{x}10^{-4}$**
Bunch length σ_z (mm)	6.04	5.90	**9.0 (10)**
Energy spread σ_e/E	$1.29\text{x}10^{-3}$	$1.30\text{x}10^{-3}$	$1.40\text{x}10^{-3}$
Chromaticity ξ_x, ξ_y	-125,-62.5	-105.27, -106.70	-90.98, -94.86
Energy loss per turn (Mev)	20.4	21.0	19.75
RF Frequency (MHz)	500	500	650
RF Voltage (MVolt)	50	50	66 (53.7)

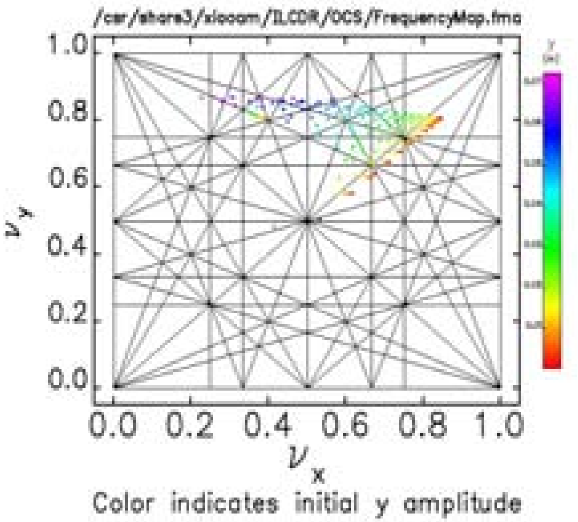
Frequency Map Analysis of OCS Lattice





by A. Wolski





by A. Xiao

by J. Urban

Tune vs. Amplitude and Energy Deviation

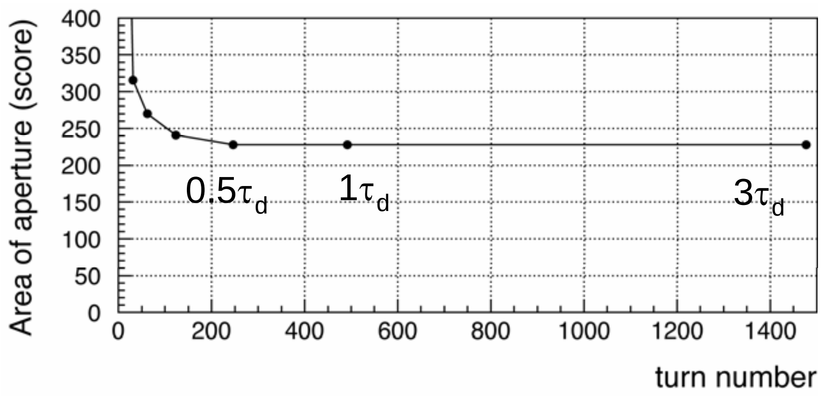
(LEGO & LIELIB)

NAME	$\frac{\partial \nu_x}{\partial \varepsilon_x}$	$\frac{\partial \nu_y}{\partial \varepsilon_y}$	$\frac{\partial \nu_x}{\partial \varepsilon_y}, \frac{\partial \nu_y}{\partial \varepsilon_x}$	$\frac{\partial^2 \nu_x}{\partial \delta^2}$	$\frac{\partial^3 \nu_x}{\partial \delta^3}$	$\frac{\partial^2 \nu_y}{\partial \delta^2}$	$\frac{\partial^3 \nu_y}{\partial \delta^3}$
OTW	**-2045**	**-5759**	**6298**	**476**	**25288**	**493**	**-16145**
PPA	**-4903**	**-1153**	**-616**	**233**	**5713**	**112**	**8912**
OCS	**-5938**	**982**	**-5593**	**-18**	**-270**	**2**	**42**
BRU	**-484**	**-1001**	**-3236**	**-37**	**5218**	**-78**	**2400**
TESLA	**-7929**	**-2772**	**1917**	**318**	**12219**	**-68**	**2566**
MCH	**-712**	**-1130**	**-4008**	**-78**	**3825**	**-128**	**3337**
DAS	**-1583**	**-860**	**-320**	**343**	**50751**	**358**	**25538**

Clearly, the OCS lattice has the best chromatic properties.

Procedures for Evaluating Dynamic Aperture

- Emittance of injected beam (1σ): $\gamma\varepsilon_x=\gamma\varepsilon_y$=0.01 m
- Linear chromaticity is around 0~1.
- Tracking for 1 radiation damping or 1000 turns (made no difference)

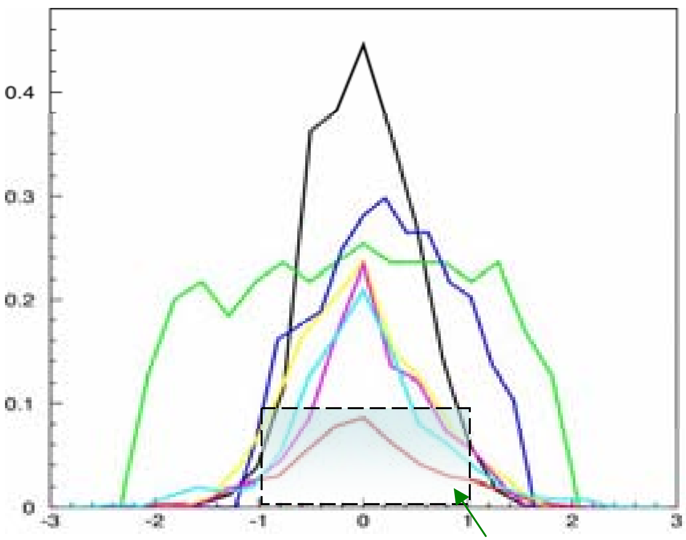


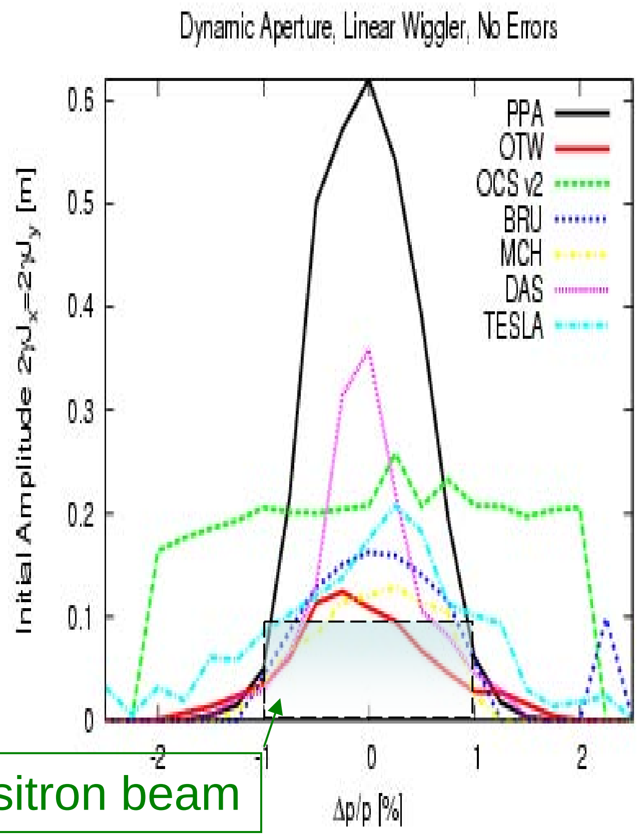
- With synchrotron oscillation
- Radiation damping on or off (saw some difference)

Dynamic aperture for Ideal Lattices and Linear Wigglers with Radiation Damping

Two lattices stand out: OCS and PPA

Initial amplitude $\gamma 2J_{x0} = \gamma 2J_{y0}$ (m)





3σ injected positron beam

δ (%)

δ (%)

By Y. Ohnishi using SAD

by J. Urban using BMAD

Measured multipole errors

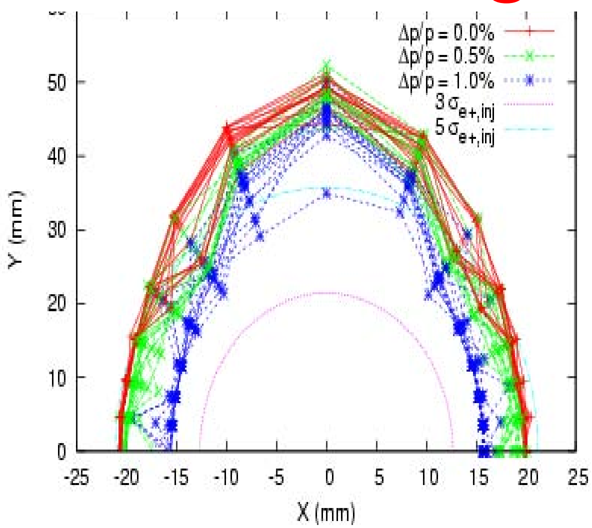
analyzed by Y. Cai

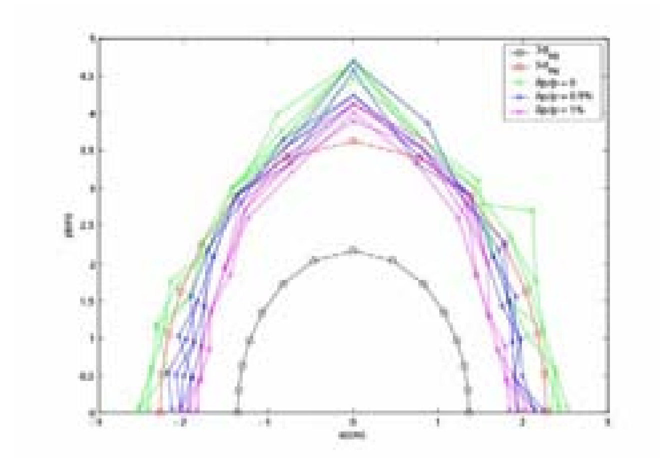
	PEP-II	PEP-II		SPEAR3
index	Dipole	Qudrupole		Sextupole
k	b_k/b_1	b_k/b_2	a_k/b_2	b_k/b_3
3	**1.6×10^{-4}**	-1.24×10^{-5}	-1.15×10^{-5}	
4	-1.6×10^{-5}	2.30×10^{-6}	1.41×10^{-5}	2.0×10^{-4}
5	**7.5×10^{-5}**	-4.30×10^{-6}	6.20×10^{-7}	1.0×10^{-4}
6		**3.40×10^{-4}**	-4.93×10^{-5}	7.0×10^{-4}
7		3.00×10^{-7}	-1.02×10^{-6}	1.0×10^{-4}
8		6.00×10^{-7}	3.80×10^{-7}	1.0×10^{-4}
9		6.00×10^{-7}	-2.80×10^{-7}	1.0×10^{-4}
10		**-6.17×10^{-5}**	-5.77×10^{-5}	1.0×10^{-4}
11		-2.00×10^{-7}	-3.80×10^{-7}	1.0×10^{-4}
12		3.60×10^{-6}	-6.53×10^{-6}	3.2×10^{-3}
13		6.00×10^{-7}	1.20×10^{-6}	
14		1.00×10^{-6}	-7.40×10^{-7}	
r0 (m)	0.03	**0.05**		0.032

Imply that the radius of beam pipe has to be larger than 5cm.

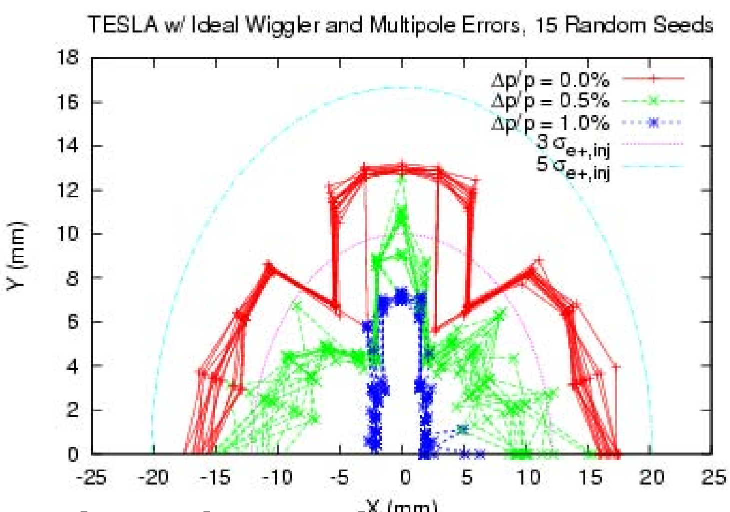
Dynamic Aperture with Multipole Errors and Single-Mode Wigglers

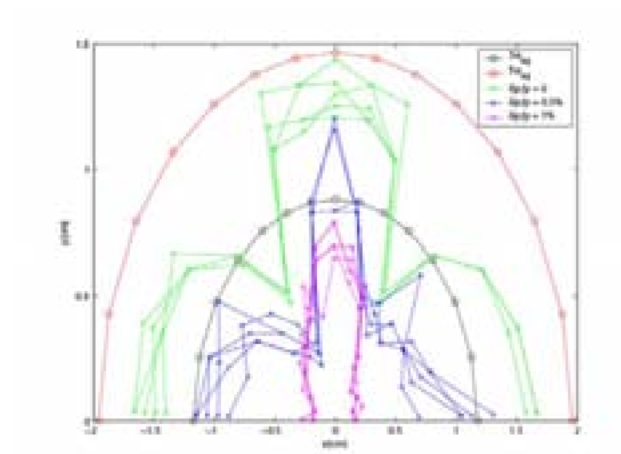
OCS





TESLA





by Urban using BMAD **by Cai using LEGO**

Averaged Dynamic Aperture

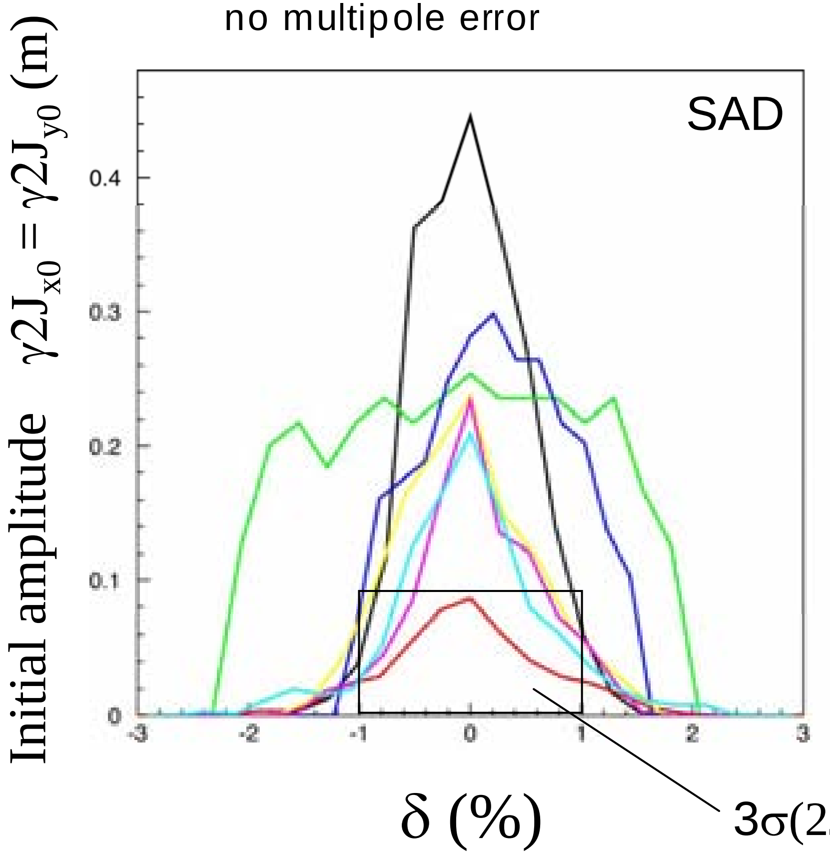
Agreed by J. Urban using BMAD and Y. Cai using LEGO

NAME	Ideal lattice with linear wigglers	Multipole errors and dipole wigglers	Ideall Lattice with single-mode wigglers	Multipole errors and single-mode wigglers
OTW	3.42	3.19	3.41	3.13
PPA	7.29	6.02	7.20	6.09
OCS	6.01	5.07	5.57	4.80
BRU	7.07	3.51	5.92	3.52
TESLA	3.22	2.62	2.75	2.28
MCH	6.09	3.76	5.28	3.75
DAS	5.18	3.59	4.78	3.55

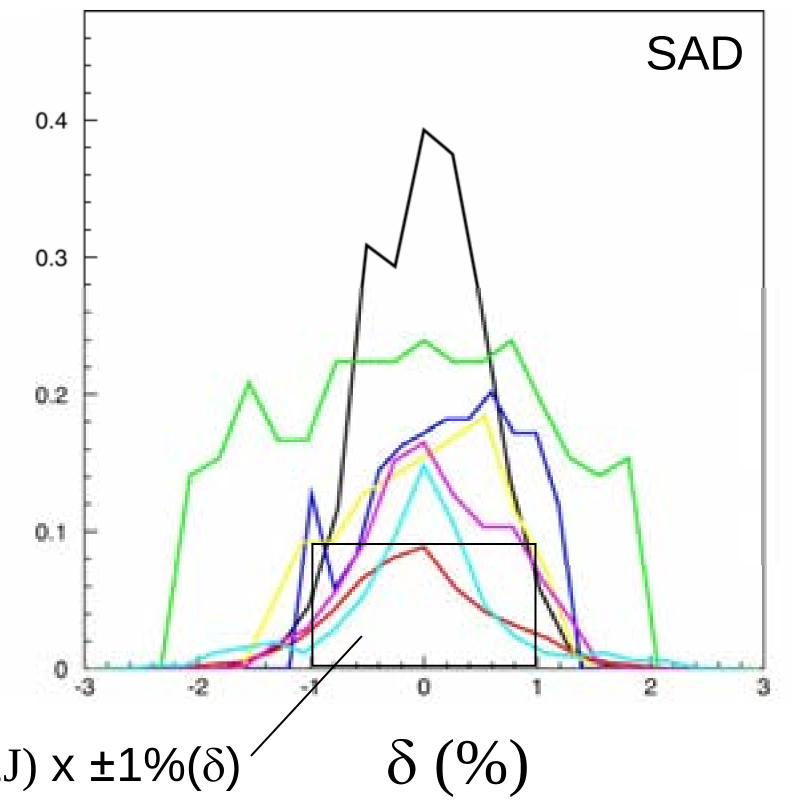
Dynamic aperture

PPA (2.8 km)
OTW (3.2 km)
OCS (6.1 km)
BRU (6.3 km)
MCH (16 km)
DAS (17 km)
Tesla(17 km)

Hard edge wiggler, no multipole error



Hard edge wiggler with multipole error (PEP-II, SPEAR)



$3\sigma(2J)$ x $\pm 1\%(\delta)$

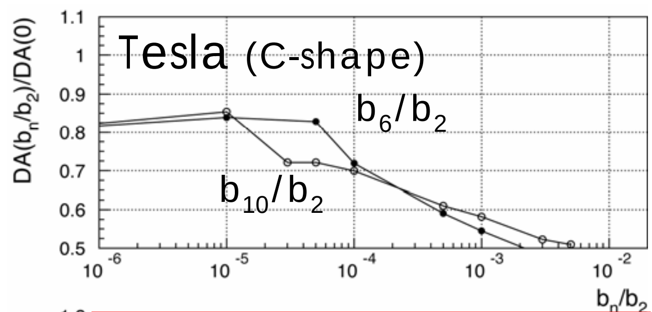
*Bunch length
BRU: 9.6 mm
MCH: 10 mm
others: 6 mm

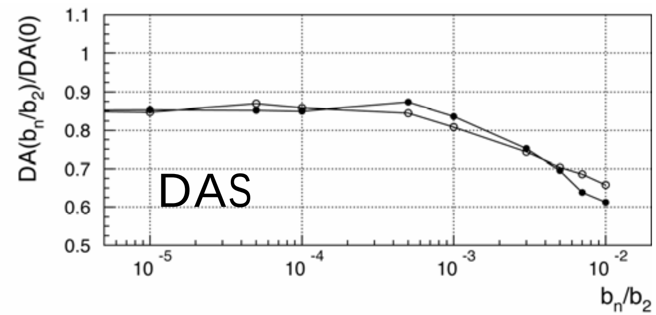
Multipole errors of quads at high β reduce dynamic aperture. (Short rings are less affected.)

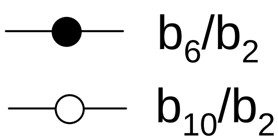
Effects of allowed multipole errors(SAD)

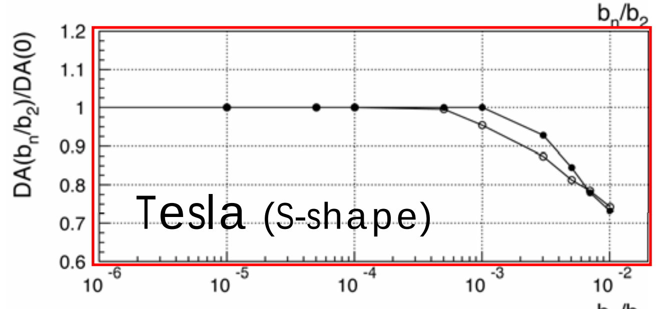
<u>Only quadrupole magnets</u>

DA is defined by area of $3\sigma(2J)$ x $\pm1\%(\delta)$

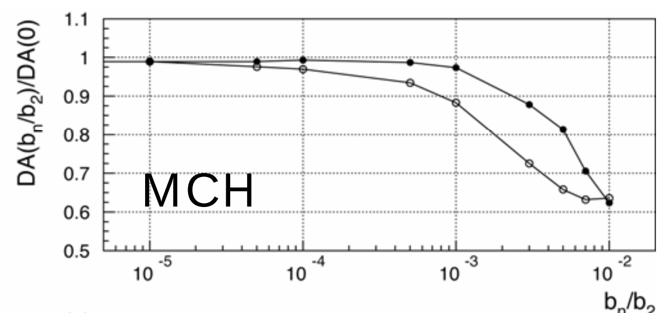


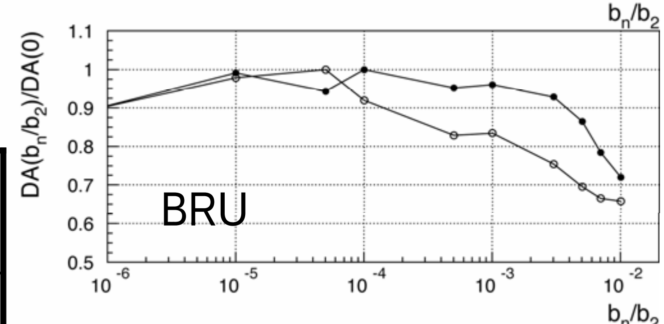






same sextupoles





Requirement: 2% loss of DA(0)

	Tesla (C-shape)	Tesla (S-shape)	DAS	MCH	BRU
b_6/b_2	6×10^{-5}	1×10^{-3}	1×10^{-3}	1×10^{-3}	5×10^{-3}
b_{10}/b_2	1×10^{-5}	6×10^{-4}	7×10^{-4}	1×10^{-4}	2×10^{-4}

r_0 is 30 mm(quads at low β) or 50 mm(quads at high $\beta > 100$ m).

Large Beam Pipe and Better Quadrupoles in the Long Straights (Suggested by Ohnishi and Emery)

NAME	C (km)	E (Gev)	σ_z (mm)	Shape	DA (σ_{inj}) r_0=5cm	DA (σ_{inj}) r_0=10cm
OTW	3	5	6	Racetrack	3.13	3.13
PPA	3	5	6	Racetrack	6.09	6.09
OCS	6	5	6	Circular	4.80	4.80
BRU	6	3.74	9	Dogbone	3.52	3.70
TESLA	17	5	6	Dogbone	2.28	2.38
MCH	16	5	9	Dogbone	3.75	3.95
DAS	17	5	6	Dogbone	3.55	4.02

Injection Efficiency Study with a Realistic Positron Distribution (Ideal lattice without physical aperture) by A. Xiao

	BRU	DAS	MCH	OCS	OTW	PPA	TESLA
Energy	3.74	5.0	5.0	5.0	5.0	5.0	5.0
Turn	1208	476	506	1090	1126	2124	492
111*	97%	99%	100%	100%	99%	100%	99%
112*	84%	97%	95%	100%	96%	97%	98%
441*	96%	91%	98%	99%	76%	93%	96%
442*	81%	85%	91%	99%	76%	89%	92%

*xxx indicates nEx-nEy-ndeltaP/P

It is not clear why the TESLA lattices has a good injection efficiency, which is inconsistent with the dynamic aperture study. Maybe that is because the beta functions at the injection is not normalized. The injection efficiency will be carefully evaluated later.

Injection Efficiency Study with a Realistic Positron Distribution (Ideal lattice with physical aperture) by I. Reichel

	BRU	DAS	MCH	OCS	OTW	PPA	TESLA
Energy	3.74	5.0	5.0	5.0	5.0	5.0	5.0
Turn	1208	476	506	1090	1126	2124	492
111*	97%	99%	100%	100%	99%	100%	99%
112*	84%	97%	95%	100%	96%	97%	98%
441*	96%	91%	98%	99%	76%	93%	96%
442*	81%	85%	91%	99%	76%	89%	92%
16 mm	96%	97%	99%	100%	96%	97%	82%
12 mm		94%		98%		97%	

Scrapped on the pipe in the long straight section

Radiation damping is switched on and beta functions are normalized.

Summary of Dynamic Aperture Study

with Multipole Errors and Single-mode Wigglers

NAME	C (km)	E (Gev)	σ_z (mm)	DA (σ_{inj}) δ=0%	DA (σ_{inj}) δ=0.5%	DA (σ_{inj}) δ=1.0%	<DA> (σ_{inj})
OTW	3	5	6	4.51	3.19	1.68	3.13
PPA	3	5	6	7.65	6.57	4.05	6.09
OCS	6	5	6	5.25	4.74	4.40	4.80
BRU	6	3.74	9	4.21	3.76	2.59	3.52
TESLA	17	5	6	3.62	2.11	1.11	2.28
MCH	16	5	9	4.58	4.01	2.66	3.75
DAS	17	5	6	4.89	3.38	2.40	3.55

Conclusion

- All “volunteers” from many different labs in the world are working extremely well together as a team and getting work done before the Snowmass meeting
- Modern tracking codes such as SAD, BMAD, and LEGO are matured. They gave essentially identical results of dynamic apertures. We saw more deviation with radiation damping
- Smaller rings with more symmetries such as PPA and OCS perform better and OCS has excellent chromatic properties
- Original TESLA dogbone lattice does not work if we require that the dynamic aperture should be larger than 3σ on average.
  - S-shaped TESLA dogbone seems to be satisfy required dynamic aperture by SAD, however, it is necessary to check by other codes.
- Other dogbone lattices (MCH, BRU, DAS) have marginal acceptance and they need to be improved if we have to select them for the other reasons.
- Important progress has been made since the first ILC workshop. Now, we have at least one lattice that has an adequate acceptance compare to none a year ago.

Acceptance Issues

- The codes for nonlinear wiggler model need to be benchmarked carefully. Wiggler model in lattices should be made more realistic.
- Tune survey is needed to determine better working point. (It should be compromised on the space charge in case of lattice having long straight section.)
- Detail design such as coupling bumps, injection, and realistic RF sections may be necessary for the further evaluation
- BPM and correctors need to be included in the lattices for evaluation of misalignment effects
- Injection efficiency needs to be studied with full realistic errors and physical aperture

Proposals

- Reduce the possible configurations from seven to three with three different circumferences, namely 3, 6, 17 km.
- Reduce types of wiggler magnet so as to use single field map. It is unbiased to evaluate nonlinear wiggler effects.
- Determine bunch length. 6 mm or 9 mm
  - If 9 mm bunch length is irrelevant, lattice candidates are reduced.
- Improve the lattices further so that the acceptance is not a critical issue for selecting the baseline configuration.
- Reduce the redundant works for the future and mix the assignments so that the ownership of the baseline lattice can be shared.
- Results should be reported biweekly to in an international teleconference meeting (For example, extend the wolski's meeting)