Wigglers for Damping Rings

S. Guiducci

Super B-Factory Meeting

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Damping time and Emittance

Increasing $\int B^2 ds$ wigglers allows to achieve the short damping times and ultra-low beam emittance needed in Linear Collider Damping Rings;

- A good wiggler design is one of the key points for the Damping Rings operation.

Damping time and Emittance

$\tau = 2T_0E/U_{0\,;}$ $U_0 \propto E^2 \int B^2\, dl$

$U_0 = U_a+U_w;$ $F_w = U_w/U_a$

$\varepsilon_a \propto E^3$ flat $\theta_{bend}{}^3;$ $\varepsilon_w \propto B_{wig}{}^3\, \lambda^2 \langle\beta\rangle$

$\varepsilon_x = \varepsilon_a/(1+F_w) + \varepsilon_w\, F_w/(1+F_w) \approx \varepsilon_a/F_w\,;\quad F_w >> 1$

$$\tau \propto T_0/(E \int B^2 ds)\ ;\quad \varepsilon \propto E/\int B^2 ds$$

Increasing $\int B^2 ds$ wigglers allows to reduce both damping times and beam emittance at the same time

Radiated energy needed to get a given Damping time

$\tau = 2T_0E/\ U_0$

$U_0 = C_q/2\pi\ E^4 \int 1/\rho^2\ dl$

$C_q = 88.5e\text{-}5\ \text{Gev-3m}$

$U_0 \propto E^2 \int B^2\ dl$

$\tau \propto T_0/(E \int B^2\ dl)$

U_0 (MeV)

	τ=28 ms	τ=14 ms
17 km	20.3	40.5
6 km	7.1	14.3
3 km	3.6	7.1

Wiggler length needed to get a given Damping time

L_W (m) - B_{arc} = 0.2

	τ=28 ms	τ=14 ms
17 km	388	783
6 km	127	266
3 km	57	127

L_W (m) - B_{arc} = B_{wig}

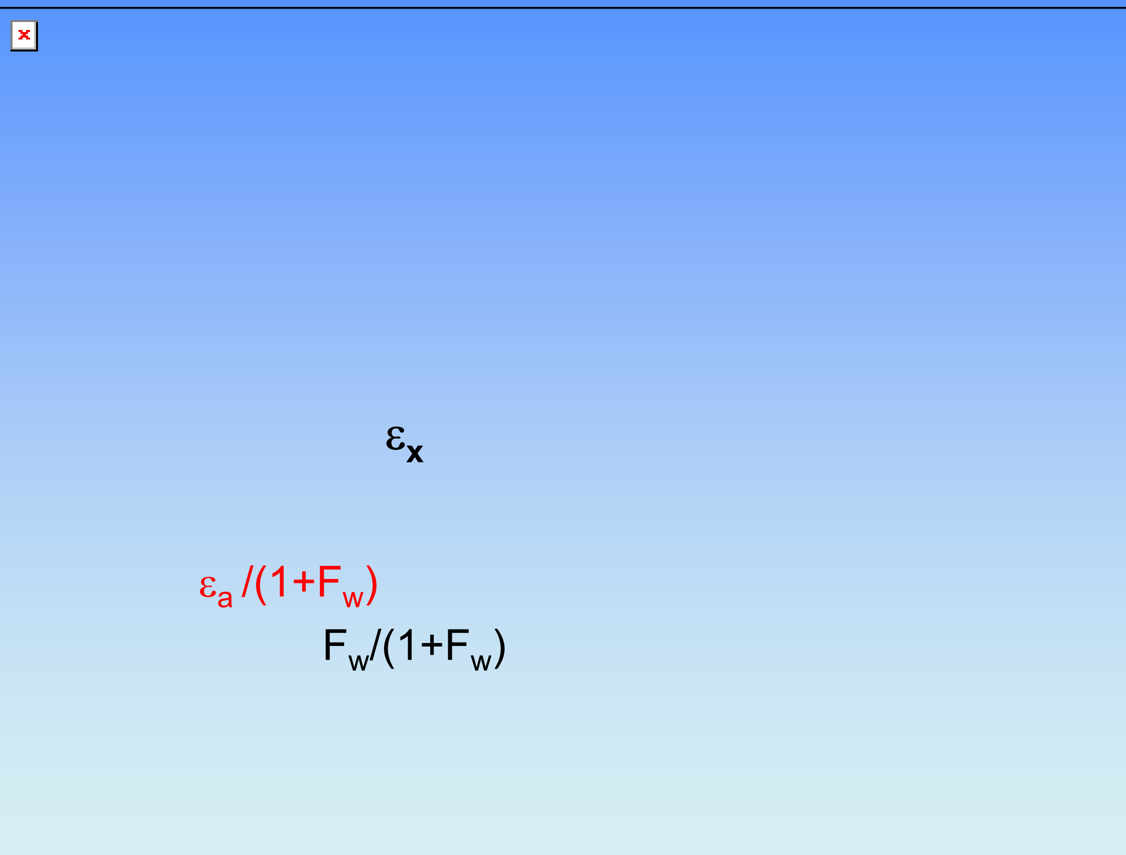
	τ=28 ms	τ=14 ms
17 km	288	684
6 km	32.8	172
3 km	0	32.8

a) B_{arc} = 0.2 T => low field to reduce emittance

b) B_{arc} = B_{wig} = 1.65T (100 m shorter wiggler)

Normalized Emittance

$$\varepsilon_x = \varepsilon_a/(1+F_w) + \varepsilon_w F_w/(1+F_w)$$



$\varepsilon_a \propto E^3$ flat $\theta_{bend}{}^3$

$\varepsilon_w \propto B_{wig}{}^3 \lambda^2 <\beta>$

$F_w = U_w/U_a$

F_w	13
τ_x (ms)	22
ε_a (m)	3.9e05
$\varepsilon_a/(1+F_w)$ (m)	2.8e06
$\varepsilon_w F_w/(1+F_w)$ (m)	2.7e-6
ε_x (m)	5.5e-6

Wiggler Parameters

$\varepsilon_w \propto B_{wig}^3 \lambda^2 \langle\beta\rangle$

There are three possibilities to reduce the wiggler emittance:

a) Long wiggler with relatively low field

- this gives a smaller rms relative energy spread σ_p, which is one of the requirements for a DR.
- The SR power emitted per unit length is also reduced making easier the vacuum system and SR absorbers.

b) Short period

- Low field and small gap or
- SC magnet

Wiggler Parameters

c) Small average beta

- A wiggler section is made of n cells each with a wiggler magnet with one (or more) quadrupole at each end.
- To reduce the <β> one can:

  - increase the strength of the quadrupoles (increasing chromaticity)

  - reduce the wiggler length (increasing cost).

Normalized emittance

B_w (T)	λ (m)	L_{wtot} (m)	τ_x (ms)	F_w	$\varepsilon_a/(1+F_w)$ (m)	$\varepsilon_w F_w/(1+F_w)$ (m)	ε_x (m)
1.65	0.4	165	22	13	2.8e-6	2.7e-6	5.5e-6
1.65	0.3	342	11	27	1.4e-6	1.6e-6	3.0e-6
1.5	0.4	322	14	21	1.8e-6	1.2e-6	3.0e-6
1.2	0.4	504	14	21	1.8e-6	1.1e-6	2.9e-6

Effect of wiggler nonlinearities on DA

- **Intrinsic octupole term** in the vertical plane for an **ideal wiggler** (infinite pole width)
- An **octupole term** comes from the combination of the oscillating trajectory with the decapole term due to the finite pole width.
- This octupole term produces a tune shift on amplitude which reduces the DA.
- Cures:
  - Increase pole width
  - Shimming of the pole shape (DAFNE wigglers, TESLA optimized)
  - Reduce the effect on the beam reducing $<\beta>$
  - Insert octupoles in the ring to compensate the effect on the beam

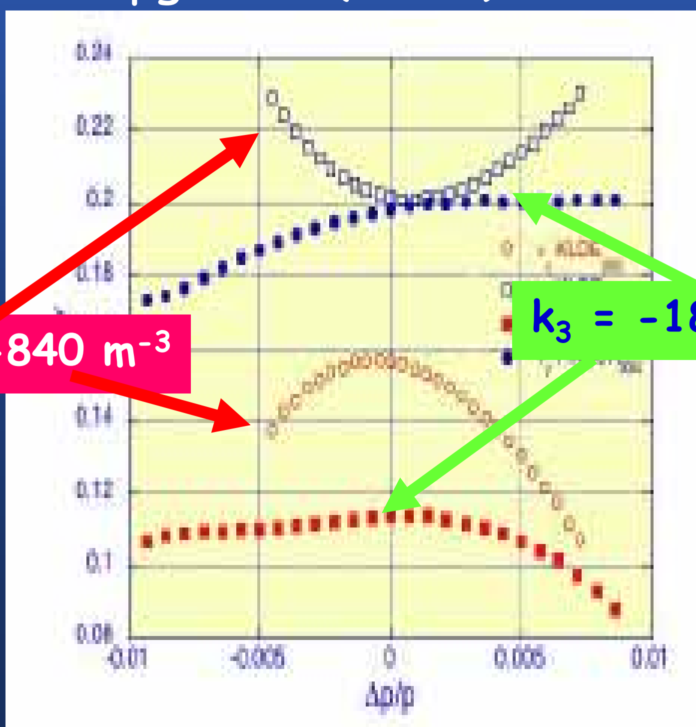
Measurements on DAΦNE wigglers (M. E. Biagini)

Tune shift vs energy with sextupoles OFF, wigglers ON & OFF

BEFORE

AFTER

Tune shift vs energy before (KLOE) and after (FINUDA) wigglers upgrade (2003)



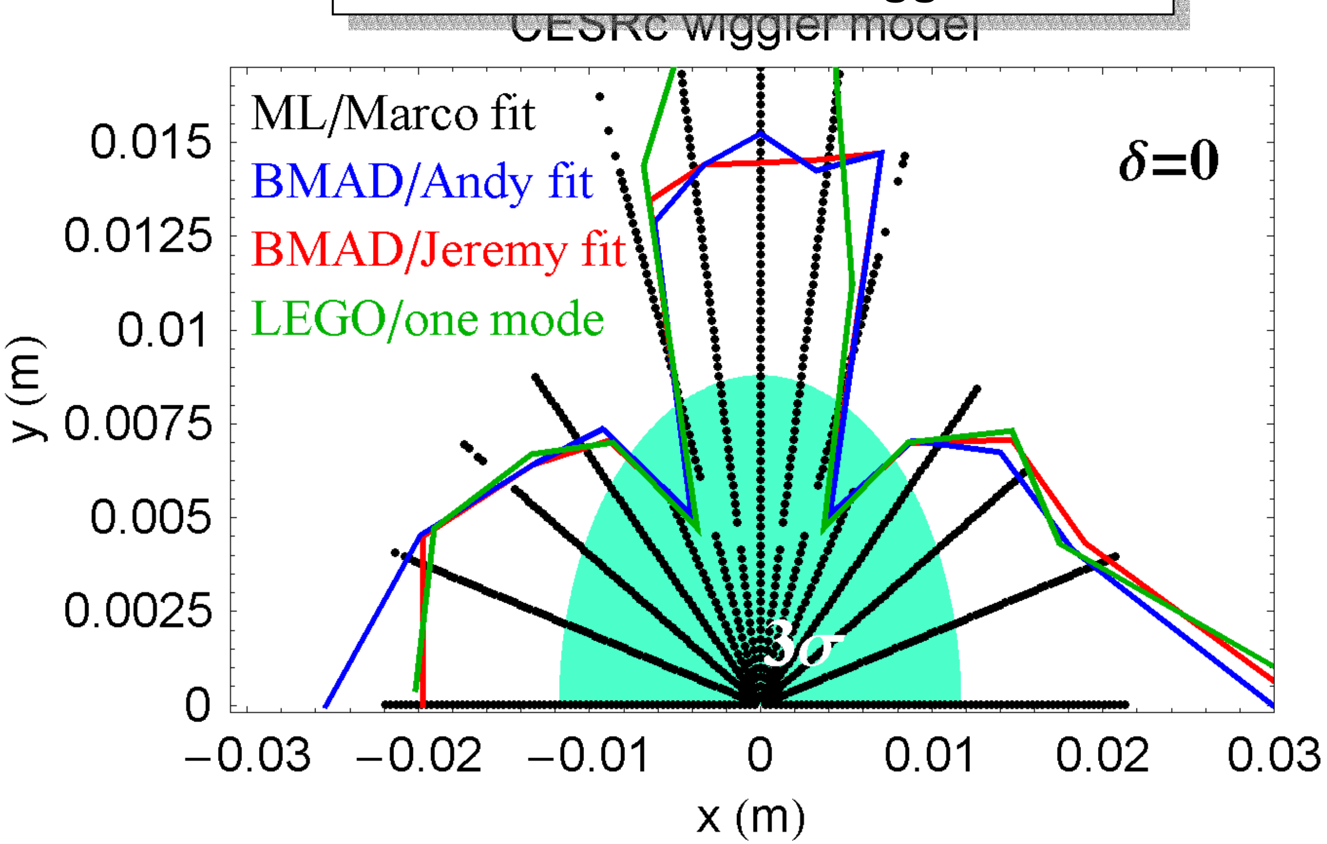
Why bothering with this exercise?

Damping rings rely heavily on wiggler insertions

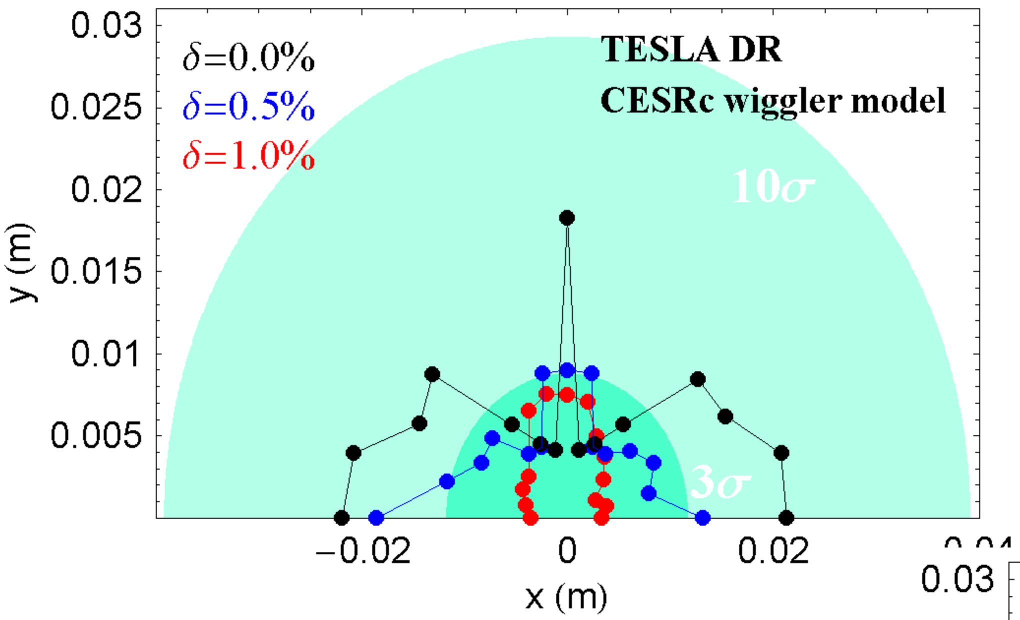
- A number of different methods/tools are being used for
  - **modeling** wiggler fields,
  - solving the equations of motion, find **transfer map**
  - doing **tracking**.
- Make sure different people using different tools get (reasonably) consistent results.
- Compare:
  - **Dynamic aperture** for TESLA DR (with scaled-down CESRc wiggler model or one-mode wiggler model)
  - **Taylor maps** for the wiggler insertion (if available)

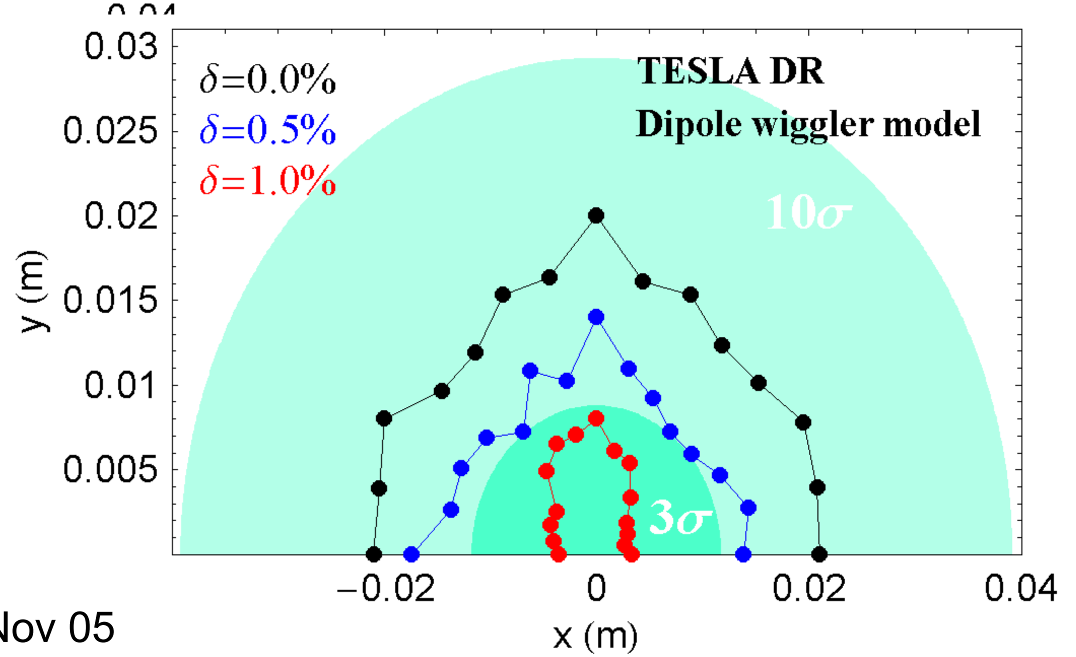
A closer look shows better agreement …

DA for TESLA DR with CESRc or one-mode wiggler model



CESRc *vs.* purely linear w-model





Tracking done by ML

Field Quality and Physical Aperture

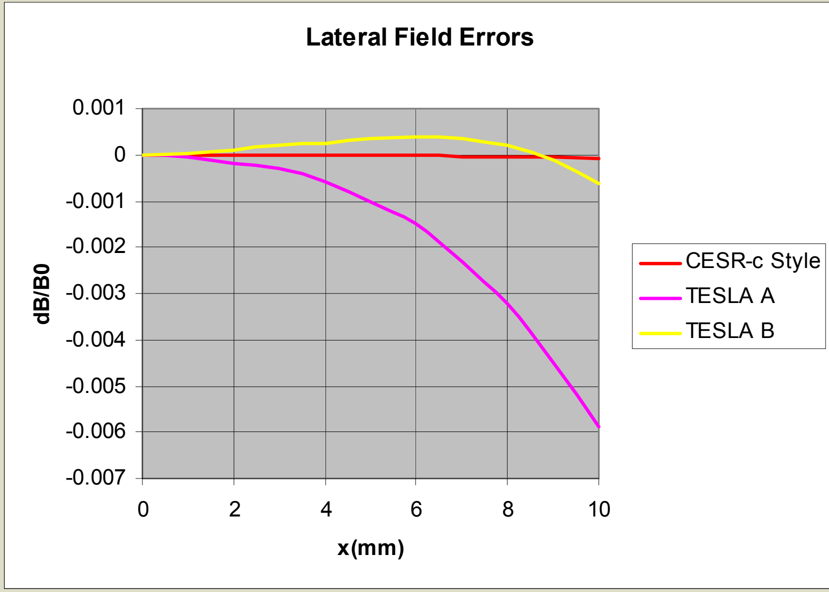
- **A high quality field** is needed to achieve the dynamic aperture necessary for good injection efficiency:
- increasing the gap between the poles,
- increasing the period,
- increasing the pole
- **Physical aperture** A large gap is needed to achieve the necessary acceptance for the large injected positron beam:
  - a full aperture of at least 32 mm is highly desirable in the wiggler for injection efficiency
  - a full aperture of at least 46 mm is highly desirable in the wiggler to mitigate e-cloud effects
- However, increasing the gap and pole width can add considerably to the power consumption for an electromagnetic device, or to the cost of magnetic material for a hybrid device.
- An alternative solution is that of modifyng the pole shape to follow the trajectory (Preger, Raimondi, Wiggle05).

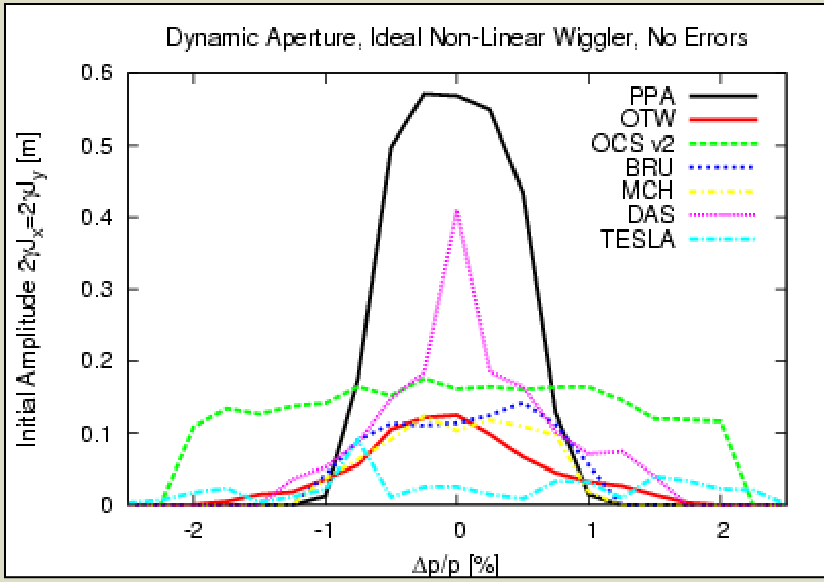
Technology Options

- Field requirements have led to 3 suggested options:
  - Hybrid Permanent Magnet Wiggler
  - Superferric Wiggler
  - Normal Conducting Wiggler
- Design Status
  - Hybrid PM based on modified TESLA design
    - Basic modified TESLA design (Tischer, *etal,* TESLA 2000-20)
      - 6 cm wide poles
      - Tracking simulations in hand
    - Next generation design (see note from Babayan, *etal*)
      - New shimming design
      - Improved field quality – field maps available at end of last week
      - Field fitting now underway, but no tracking studies yet
  - Superferric design based on CESR-c wiggler (Rice, *etal*, PAC03, TOAB007)
    - Tracking simulations in hand
  - No active design for normal conducting option
    - Will scale from TESLA (TESLA TDR) and NLC (Corlett, *etal*, LCC-0031) proposed designs

Field Quality

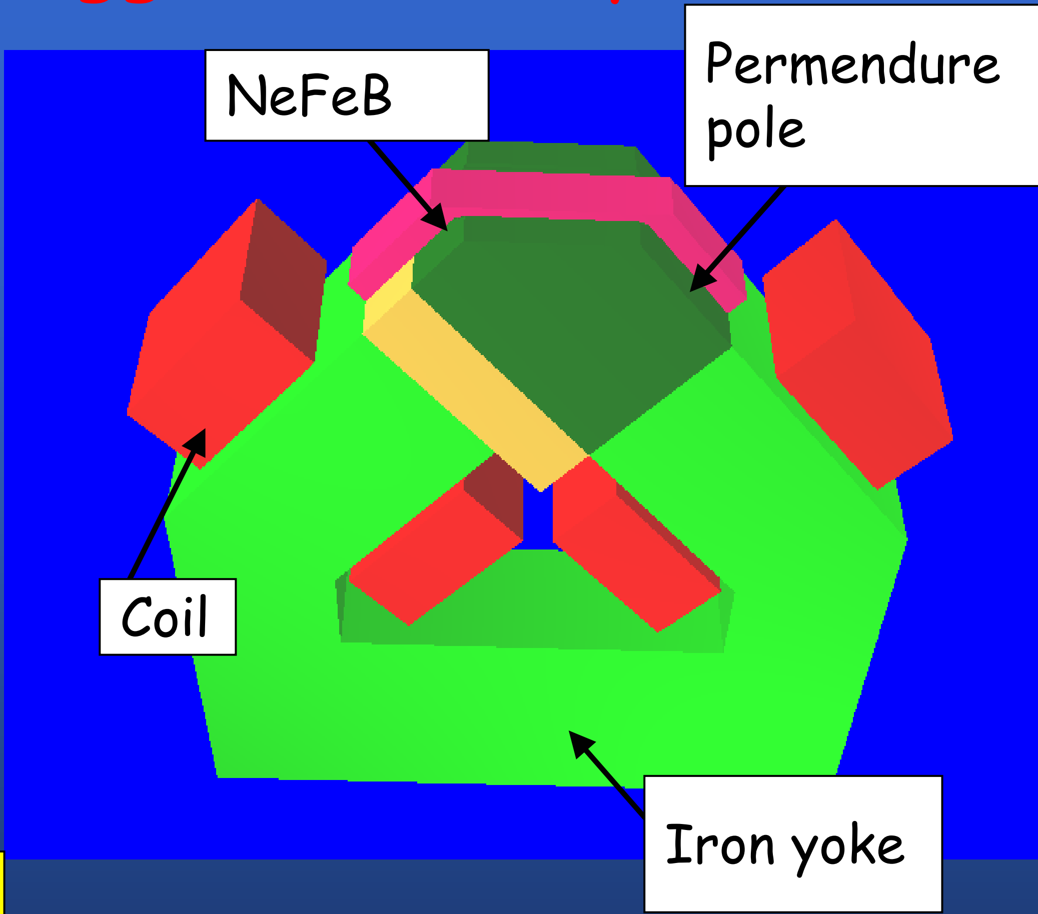
- Significance: A
- Primary Issue is Dynamic Aperture
- 3 pole designs in hand:
  - Superferric with
    $\Delta B/B \sim 7.7 \times 10^{-5}$ @ $\Delta x = 10$ mm (CESR-c)
    - Shows acceptable dynamic aperture!
    - However, most designs approaching DA limit for $\Delta p/p=1\%$!
  - Modified TESLA design (60 mm pole width)
    $\Delta B/B \sim 5.9 \times 10^{-3}$ @ $\Delta x = 10$ mm (TESLA A)
    - Dynamic aperture unacceptable!
    - Note that normal conducting designs (as is) are in this ballpark
  - Shimmed TESLA design (60 mm pole width)
    $\Delta B/B \sim 5.5 \times 10^{-4}$ @ $\Delta x = 10$ mm (TESLA B)
    - Detailed field map has just become available
    - Field fits and tracking studies not yet available
    - Concerned about potential impact on DA near $\Delta p/p = 1\%$





Electromagnet wiggler (P. Vobly)

Usual e.m. wigglers cannot be used as damping wigglers because it is difficult to achieve high field with small period. Combined pm/em devices (equipotential bus wigglers, K.Halbach) show good damping parameters, substantial decrease in period with simultaneous decrease in magnetic material volume can be achieved.



FEL undulator for KAERI (1999):

$g = 6$ mm

$\lambda_w = 25$ mm

B = 0.45 -> 0.7 T

L = 2 m

$\Delta B/B < 5\times10^{-4}$ @ 1 cm

Proposal for CLIC wiggler:

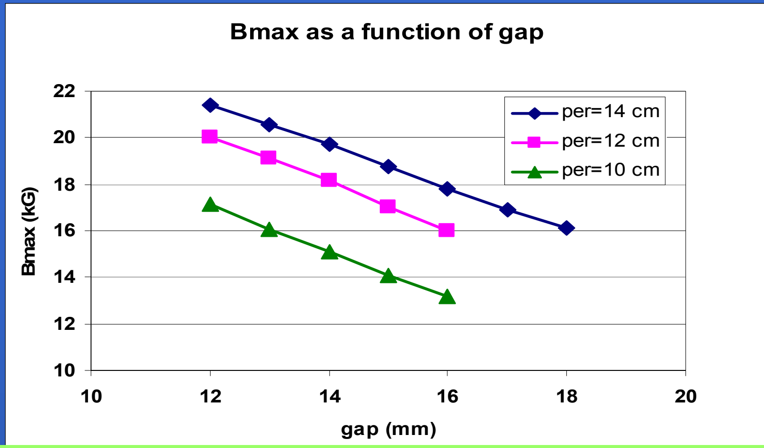
$g = 12$ mm

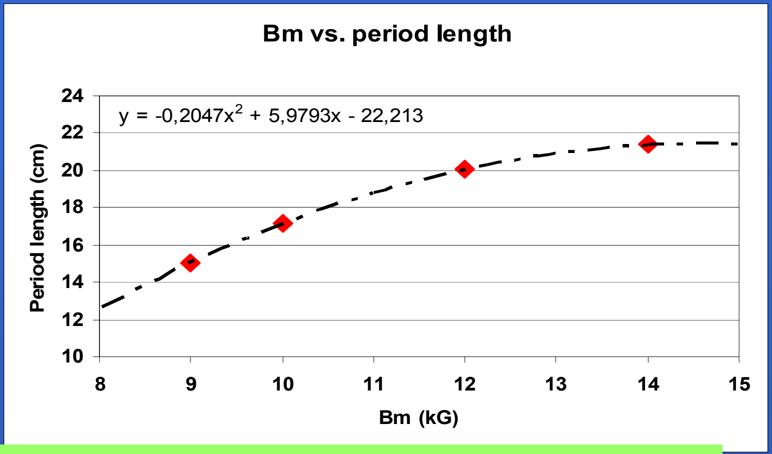
$\lambda_w = 76$ mm

B = 1.7 T

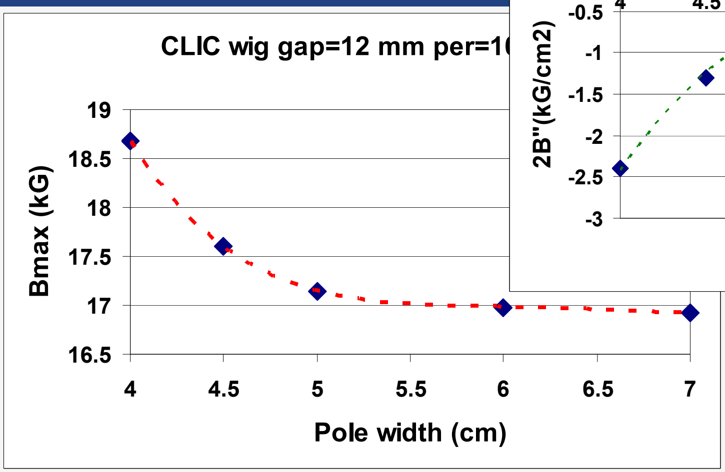
Wiggler Parameters

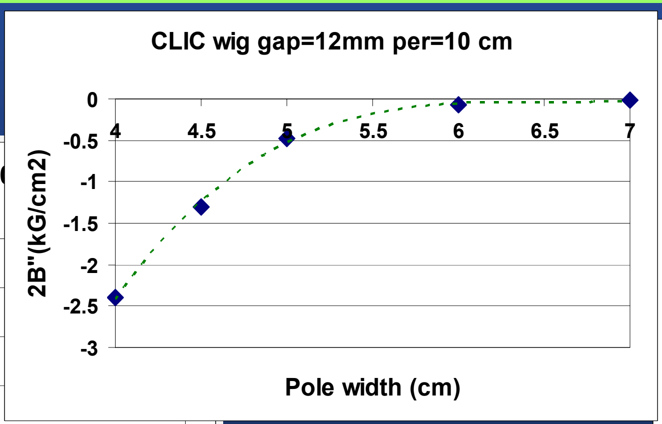
	TESLA	NLC	Petra3	CLIC	DAΦNE	CESR-c	Trieste
E (GeV)	5	1.98	6	2.4	0.51	1.88	2
Peak B (T)	1.67	2.15	1.5	1.7	1.8	2.1	3.5
Length (m)	430	40	80	152	2(x4)	1.3(x12)	1.6
Period (cm)	40	27	20	7.6	64	40	6.4
Gap (cm)	2.5	2	2.4	1.2	3.7	7.6	1.65
Type	pm	Hybrid	Hybrid Wedge-pole	Hybrid Wedge -pole	em	Superferric	SC

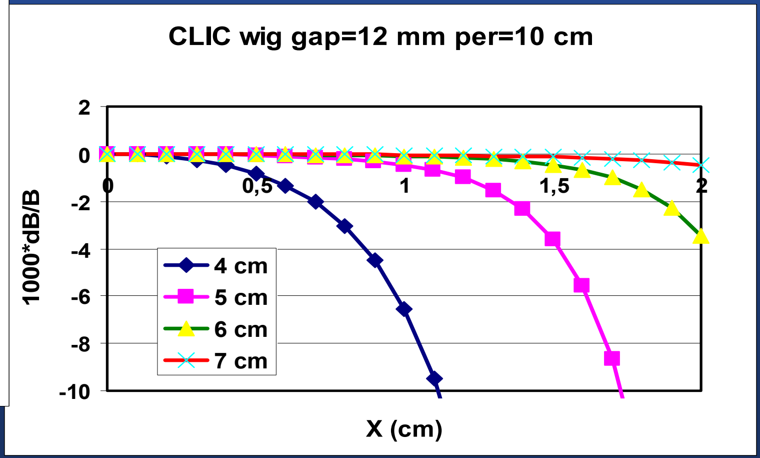




- B peak is linear for reasonably small change of pole gap
- B peak tends to be saturated with increasing of the period length
- B peak has to be compromised with acceptable transverse field quality
- By choosing proper pole size and shimming rather good transverse field quality can be achieved







E. Levichev, Wiggle05

Conclusions on technology (E. Levichev)

- Superconducting devices seem to be most effective as damping wigglers. The field up to 3.5-4 T can be achieved for 60-70 mm period and 15-20 mm gap.
  They are very expensive and require complicated cryogenic equipment.

- Permanent magnet devices can provide 1.5-2 T in gap 20-10 mm for period ~10…15 cm.
  Such wigglers are 4-5 times cheaper compared to the SC ones and rather reliable.

- Equipotential bus wigglers reach same parameters as pm wigglers and even better for approximately the same price.
  They need power supply system.
  They allow to change amplitude of the magnetic field in the range ±25%.

Emittance Increase due to Intra Beam Scattering (IBS)

- Inversely proportional to γ^4
- Proportional to the bunch density, which is fixed by design parameters
- Cures:
- Lattice design - keep $D_x \neq 0$ in most of the ring and Dx=0 at the extraction point. So $\sigma_x = \sqrt{(\varepsilon\beta + D_x 2\sigma_p)}$ in most of the ring is larger than at the extraction.
- Increase radiation damping - in fact the emittance results from the equilibrium between radiation damping and IBS.

ATF (J.Urakawa)

- Four wigglers (2m long) turned on
- Damping times and emittances were measured and found consistent with calculations
- Horizontal beam size, bunch length and energy spread growth, due to IBS effects after damping, was observed.
- Reduction of the damping time and suppression of IBS effect with wiggler operation observed
- Reduction of emittance with wigglers ON also observed

ATF Damping times

J. Urakawa, Wiggle05

Damping Time	Cal.,wiggler off	Cal.,wiggler on	Meas.wiggler off	Meas.wiggler on
Horizontal τ_x	17.5 ms	15.0 ms	19.3+/-0.63 ms	15.7+/-0.38 ms
Vertical τ_y	28.5 ms	23.0 ms	28.8+/-1.5 ms	25.4+/-0.67 ms
Longitudinal τ_z	20.5 ms	15.5 ms	21.4+/-3.9 ms	14.2+/-2.4 ms