NLC Main Damping Ring Design

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- Design process and goals
- Parameters and results
- Work remaining

Parameters which drive the design choices...

parameter	symbol	value	unit
number of bunch trains stored simultaneously	N_t	3	
number of bunches per train	N_b	95	
bunch to bunch spacing within train	τ_b	2.8	nsec
gap between bunch trains for kicker rise/fall	τ_k	65	nsec
maximum collider repetition rate	f	120	Hz
injected hor./ver. emittance (norm., rms)	$\varepsilon_{x0,y0}$	<150	μm
extraction hor. emittance desired (norm., rms)	ε_x	<3.0	μm
extraction ver. emittance desired (norm., rms)	ε_y	<0.03	μm

- First four parameters define the minimum ring circumference
- Second four drive the lattice (damping) design

Circumference and Store Time

Circumference, $C = cT_0$ ...

$$C \geq cN_t\left[(N_b - 1)\tau_b + \tau_k\right] = 295.27\ \text{m}$$

$$C = hc / f_{RF} = (708)c/(714\ \text{MHz}) = 297.273\ \text{m}$$

Extracted vertical norm. emittance, ε_y ...

$$\varepsilon_y = \varepsilon_{y0} e^{-2N_\tau} + \varepsilon_{y,eq}\left(1 - e^{-2N_\tau}\right) < 0.03\ \mu\text{m}$$

- Equilibrium *y*-emittance sets *y*-tolerances: $\varepsilon_{y,eq} = 0.02\ \mu$m
- Initial *y*-emittance, $\varepsilon_{y0} \leq 150\ \mu$m, sets the number of damping times required per train: $N_\tau = 4.8$

Damping Time-Constant of Ring

Vertical damping time-constant, τ_y, is set by repetition rate, f, trains stored, N_t, and the store time per train, $N_\tau \tau_y$, as...

$$\tau_y \le \frac{N_t}{N_\tau f} = \frac{3}{4.8 \cdot (120\ \text{Hz})} \approx 5.2\ \text{msec} \ge \frac{\left(2.9\times 10^{12}\ \text{kG}\right) T_0}{B_0 \gamma^2}$$

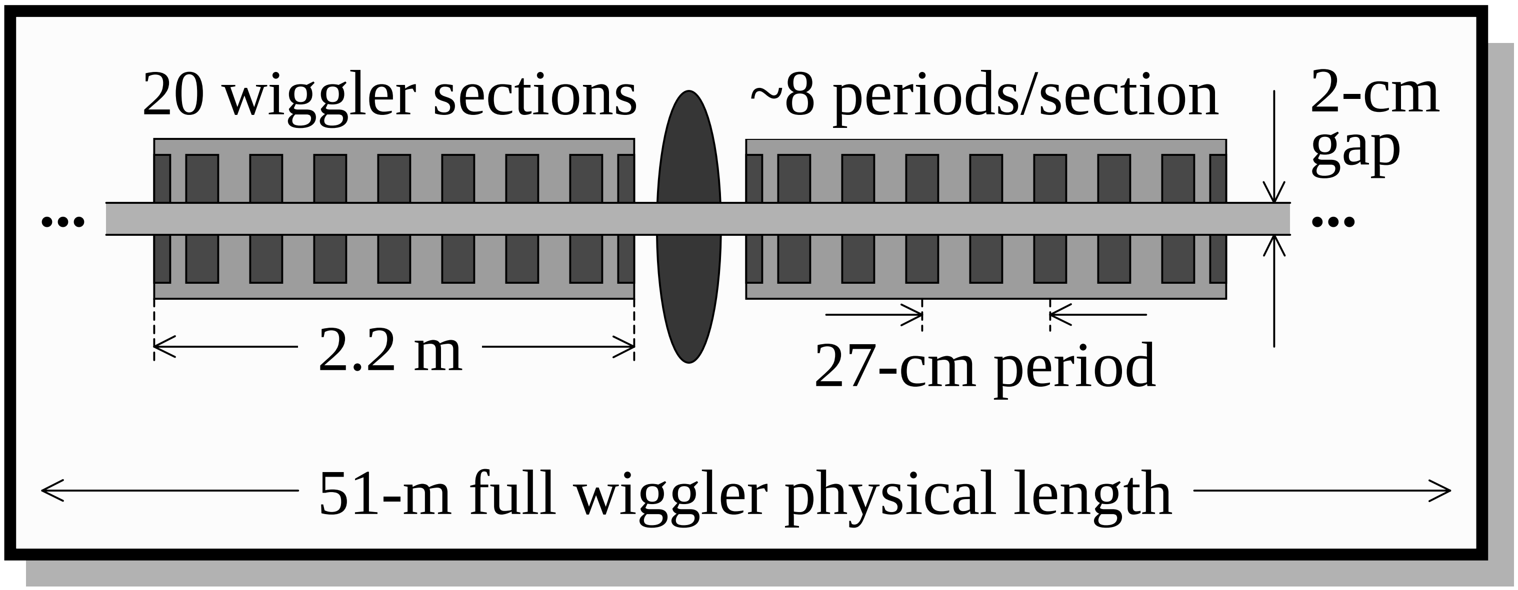
$B_0 < 18$ kG requires $\gamma mc^2 > 2.8$ GeV (RF costs ⇑, σ_z ⇑), therefore, at 1.98 GeV ($a\gamma = n+1/2$), we **need a long wiggler**.

$$B_0 \ge \frac{36.8\ \text{kG}}{1+F_w}, \quad F_w \equiv \frac{I_{2w}}{I_{2a}} = \frac{\text{wiggler energy loss/turn}}{\text{arcs energy loss/turn}} \ge 1$$

Wiggler at 1.98 GeV

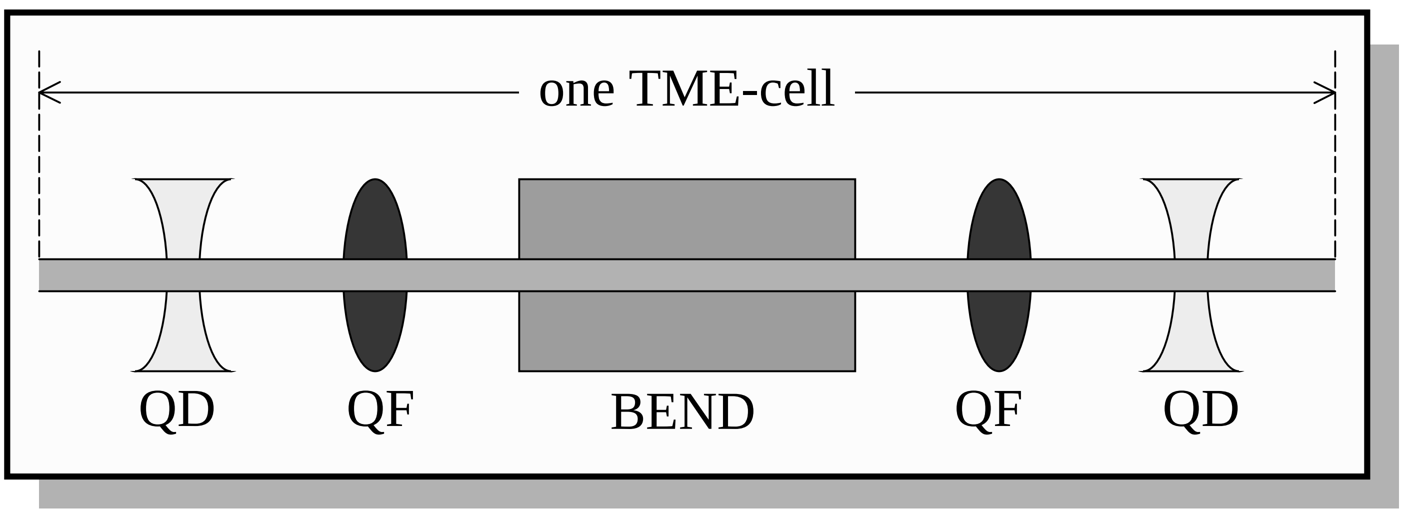
$$L_w \geq 6C \frac{(B\rho)^2}{r_e c \tau_y \gamma^3 \hat{B}_w^2} \cdot \frac{F_w}{1+F_w} \geq 33\,\text{m} \;@\; \hat{B}_w = 21.5\,\text{kG}$$

For increased momentum compaction (see next slides) we choose $F_w = 2.3$, which sets $L_w = 46.2$ m and $B_0 = 11.2$ kG.

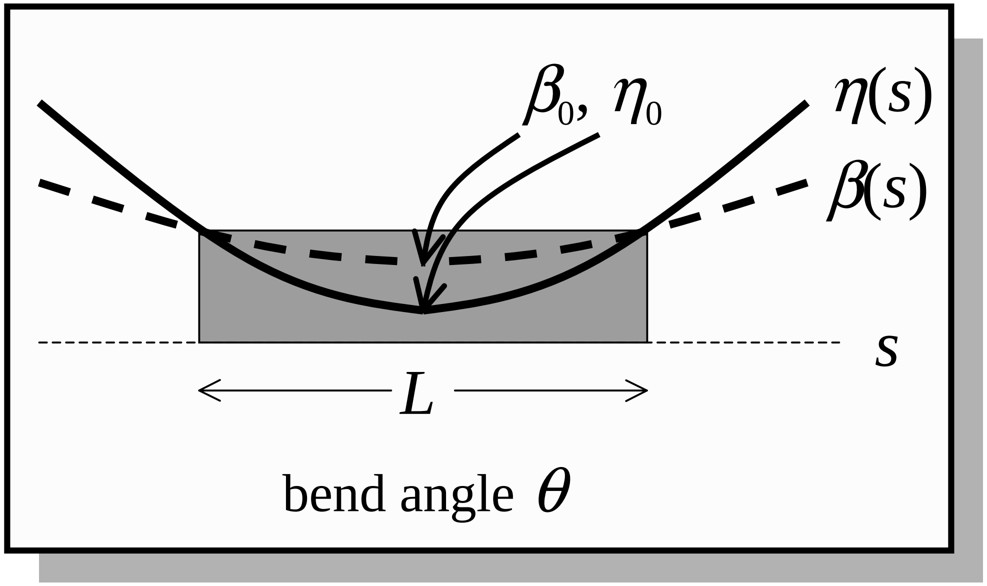


Use TME-cells for the arcs...
(Theoretical Minimum Emittance)

- Efficient: one bend magnet per cell
- Excellent dynamic aperture in studies (see ZDR)
- Tools for analysis well developed
- No field gradient necessary in bend



Equilibrium *x*-emittance & TME-cells...



With symmetry in bend...

$$\frac{d\beta_0}{ds} = \frac{d\eta_0}{ds} = 0$$

get <u>minimum</u> emittance at 'optimal' β_0 and η_0 ...

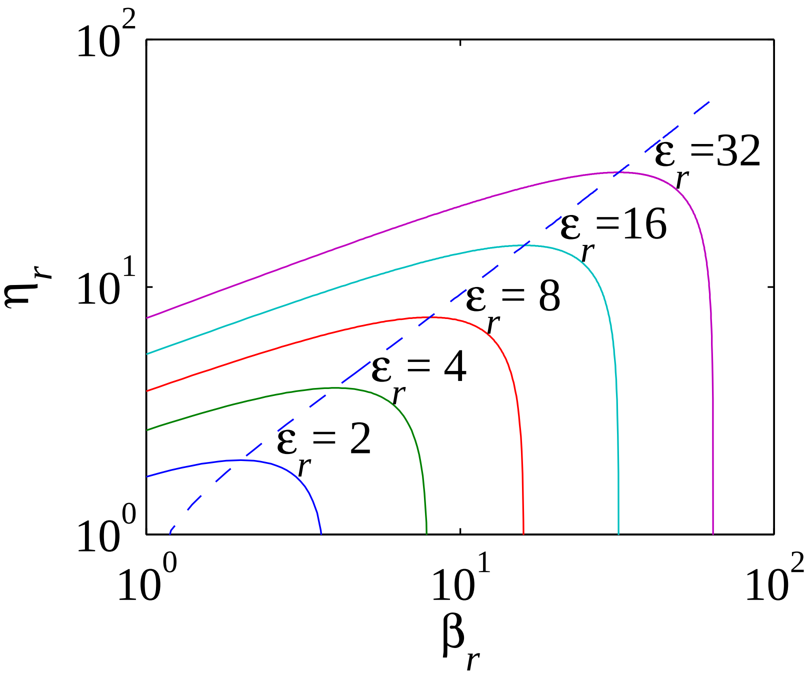
$$\gamma\breve{\varepsilon} \approx \frac{C_q \gamma^3}{J_x} \frac{\theta^3}{12\sqrt{15}}, \qquad \breve{\beta}_0 = \frac{L}{2\sqrt{15}}, \qquad \breve{\eta}_0 = \frac{L\theta}{24}$$

Now define <u>relative</u> parameters where cell is 'detuned' for $\varepsilon_r > 1$...

$$\varepsilon_r \equiv \varepsilon / \breve{\varepsilon} \geq 1, \quad \beta_r \equiv \beta_0 / \breve{\beta}_0 \geq 1, \quad \eta_r \equiv \eta_0 / \breve{\eta}_0 \geq 1$$

Maximize dispersion in the detuned cell...

$$\varepsilon_r = \frac{5}{8}\frac{\eta_r}{\beta_r}[\eta_r - 2] + \frac{9}{2}\left[\frac{1}{4\beta_r} + \frac{\beta_r}{9}\right]$$



Finally, maximize η_r "for weaker sextupoles" [Potier, Rivkin: PAC-97]...

$$\frac{d\eta_r}{d\beta_r} = 0 \rightarrow \quad \beta_r = \varepsilon_r \,, \quad \eta_r = 1 + \frac{2}{\sqrt{5}}\sqrt{\varepsilon_r^2 - 1}$$

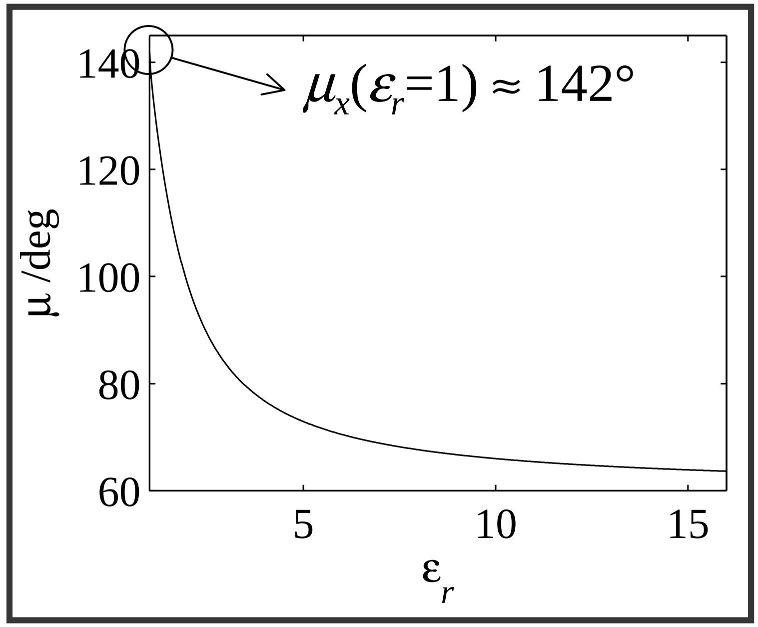
move along dashed line

Detune factor, phase advance & emittance

ε_r **is** the horizontal phase advance per half-cell, μ_x:

$$\tan\mu_x = \frac{\sqrt{3}\varepsilon_r}{\sqrt{\varepsilon_r^2 - 1} - \sqrt{5}}$$

[Rivkin, LC-97]

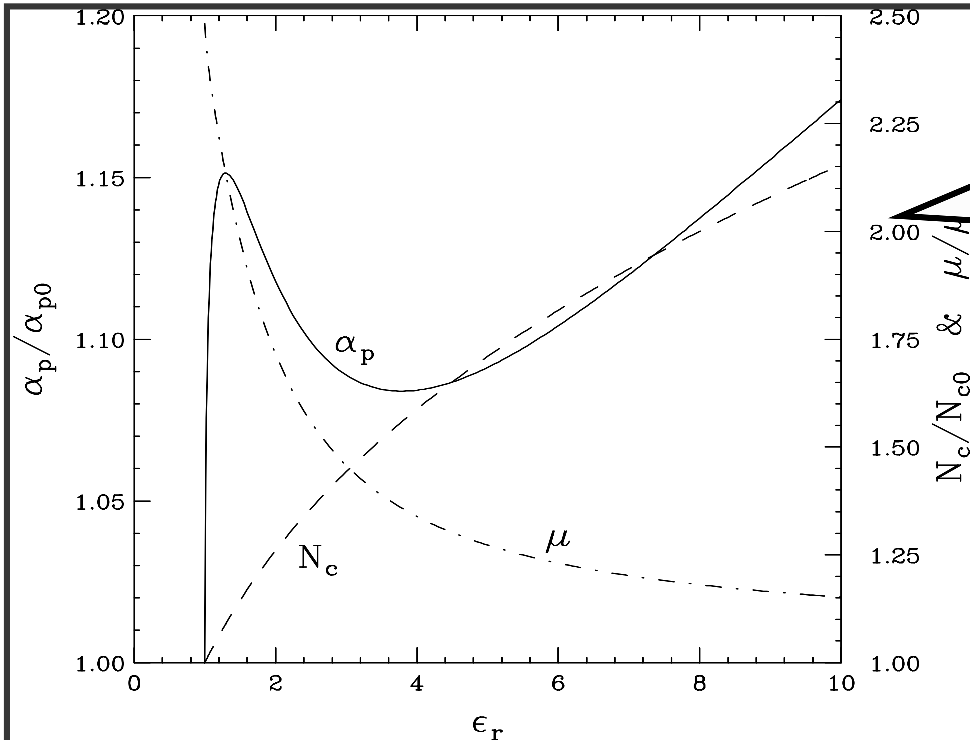


Now add wiggler's contribution to equilibrium emittance and study effects of ε_r and F_w variations...

$$\gamma\varepsilon_x \approx \frac{C_q\gamma^3}{12\left(J_{x_0} + F_w\right)}\left[\varepsilon_r \frac{\theta^3}{\sqrt{15}} + \frac{\langle\beta_x\rangle B_w^3 \lambda_w^2 F_w}{16(B\rho)^3}\right] < 3\mu\text{m}$$

Detuning, momentum compaction and N-cells...

$$\alpha_p \propto \frac{\gamma}{C}(1+F_w)^{5/3}\left(\gamma\varepsilon_0 - \frac{C_q\langle\beta_x\rangle\hat{B}_w^3\lambda_w^2\gamma^3}{192(B\rho)^3}\cdot\frac{F_w}{J_{x0}+F_w}\right)^{2/3}\left(1+\sqrt{\frac{\varepsilon_r^2-1}{5}}\right)\frac{1}{\varepsilon_r^{2/3}}$$

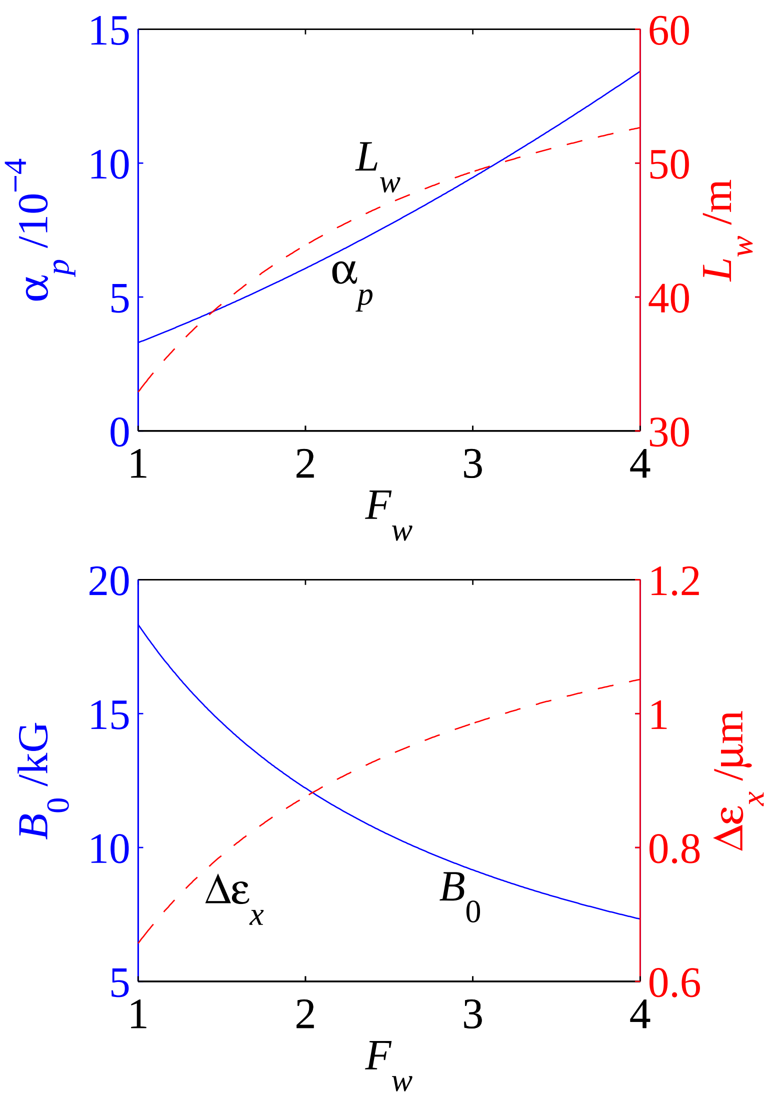


α_p not very sensitive to ε_r, but number of cells, $N_c \sim \varepsilon_r^{1/3}$, is.

Choose ε_r = 1.647…

- reasonable μ_x (=108°)
- near maximum α_p
- near minimum N_c cells

Effects of more wiggler damping...



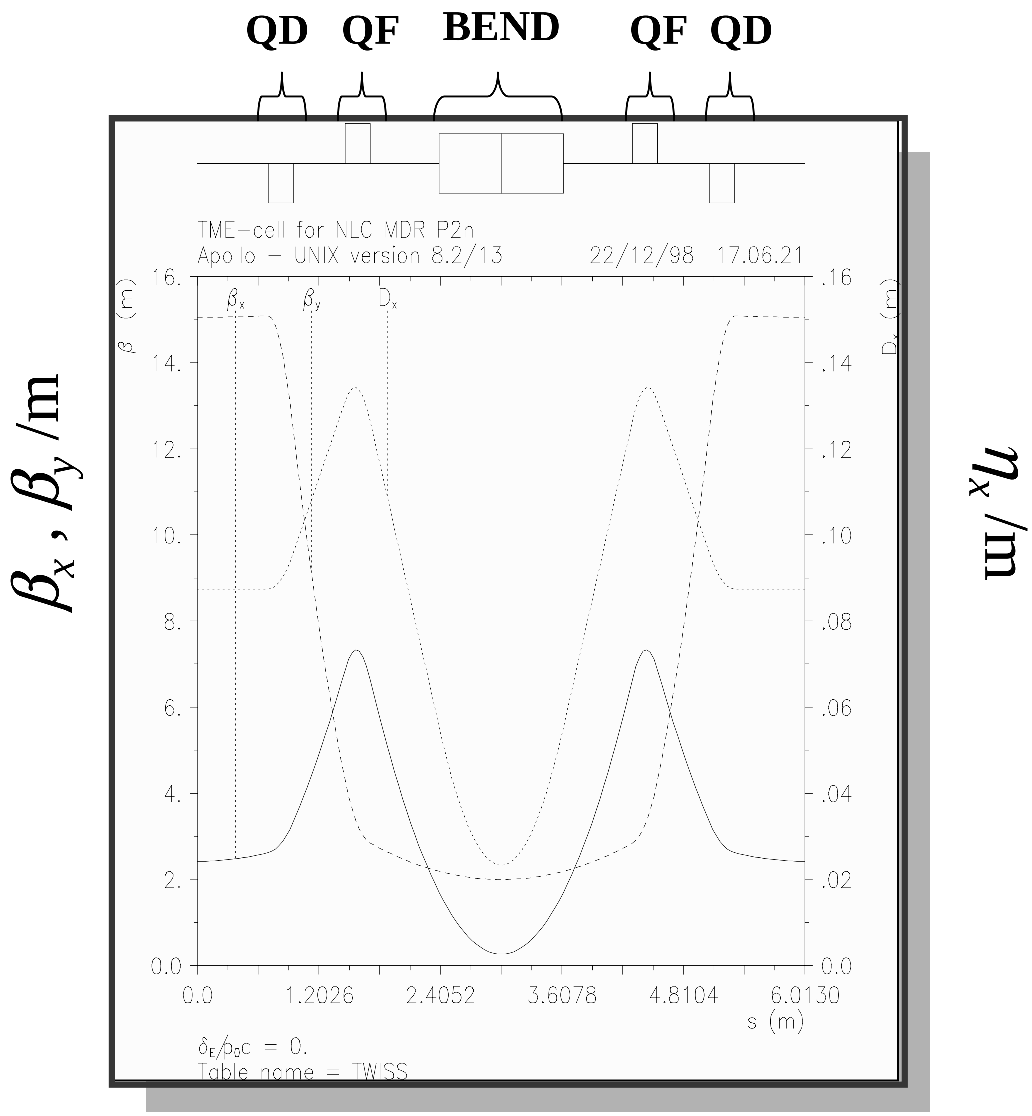
As F_w increases...

- momentum compaction increases: $\alpha_p \sim (1+F_w)^{5/3}$
- wiggler length asymptotes: $L_w \sim \dfrac{F_w}{1+F_w}$
- arc bend field decreases: $B_0 \sim \dfrac{1}{1+F_w}$
- wiggler's emittance asymptotes: $\Delta\varepsilon_w \sim \dfrac{F_w}{J_{x0}+F_w}$

Parameter choices...

- For simplicity, use bend with no gradient ($J_{x0} \approx 1$)
- Use B_w = 21.5 kG (probably too high)
- Keep $\langle\beta_x\rangle$ and λ_w reasonably small ($\langle\beta_x\rangle \approx 4.5$ m, λ_w= 27 cm)
- Choose F_w for 'large' α_p ($F_w = 2.3$, $\alpha_p = 6.6\times10^{-4}$)
- Solve θ for $\gamma\varepsilon_x = 3\ \mu$m ($\theta = 12°$)
- Calculate arc bend field for $\tau_y = 5.2$ msec ($B_0 = 11.2$ kG)
- Find total number of cells ($N_c = 2\pi/\theta = 30$)
- Get length of arc bends ($L_B = \theta(B\rho)/B_0 = 1.23$ m)
- Set TME-cell length ($L_c = (C - 2L_w - \Delta L_{match})/N_c = 6$ m)
- Build the arc TME-cell...

The arc TME-cell...

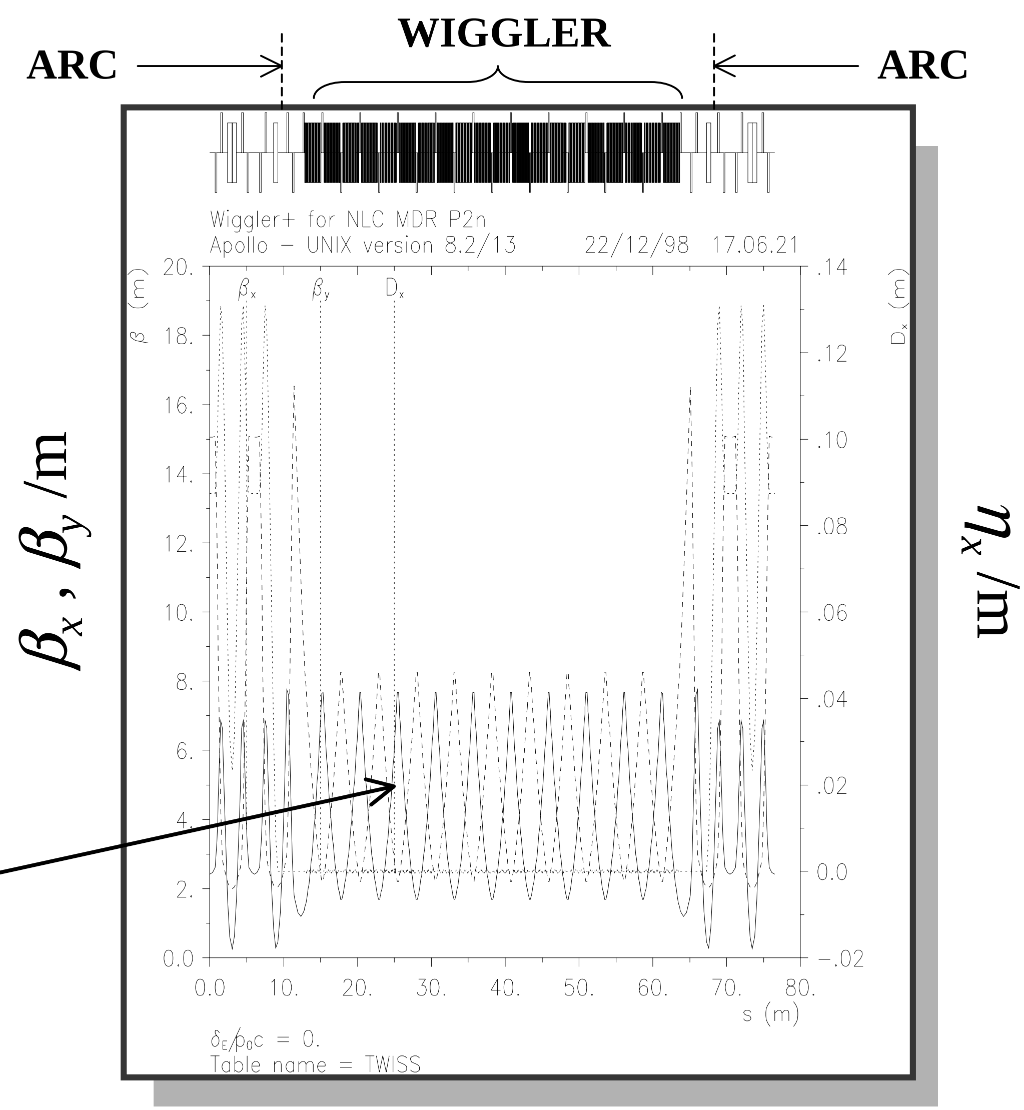


- μ_x = 108°, μ_y = 45°
- 30 cells (28 full)
- 6-m cell length
- 25-cm quad length
- 4-cm quad bore
- 7-kG max. field
- 4 sextupoles/cell ?

Reversed quadrupole scheme possible ⇒ more study

Wiggler straight section...

- 20 wiggler sections
- 2.2-m section length
- ten $\psi_x = 90°$ cells
- 15-cm quad length
- 6-cm quad bore
- 7.5-kG max. field
- adjustable matching

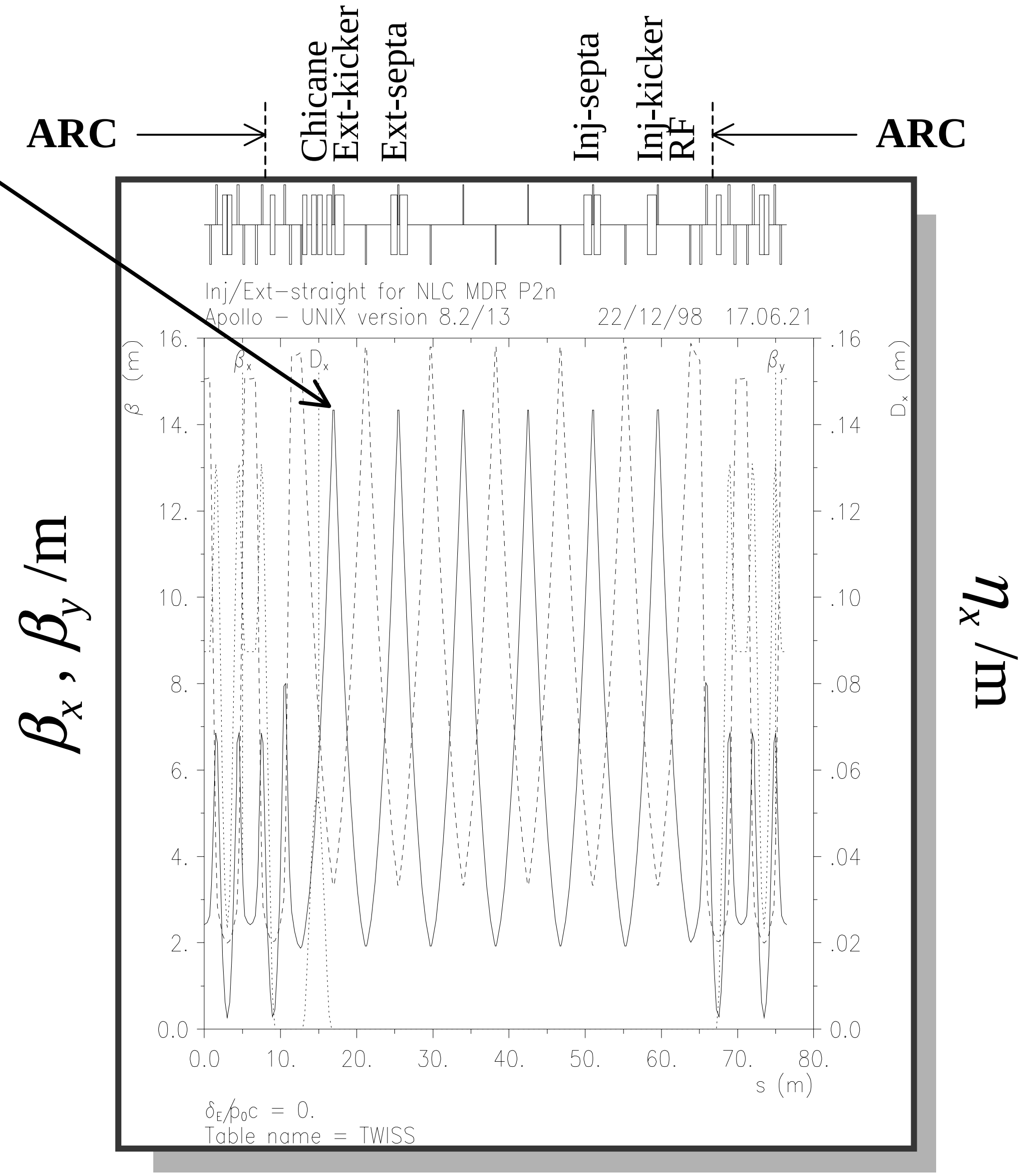


$\langle \beta_x \rangle \approx 4.5$ m

Injection/extraction straight section...

$\beta_{x,\max} \approx 14$ m

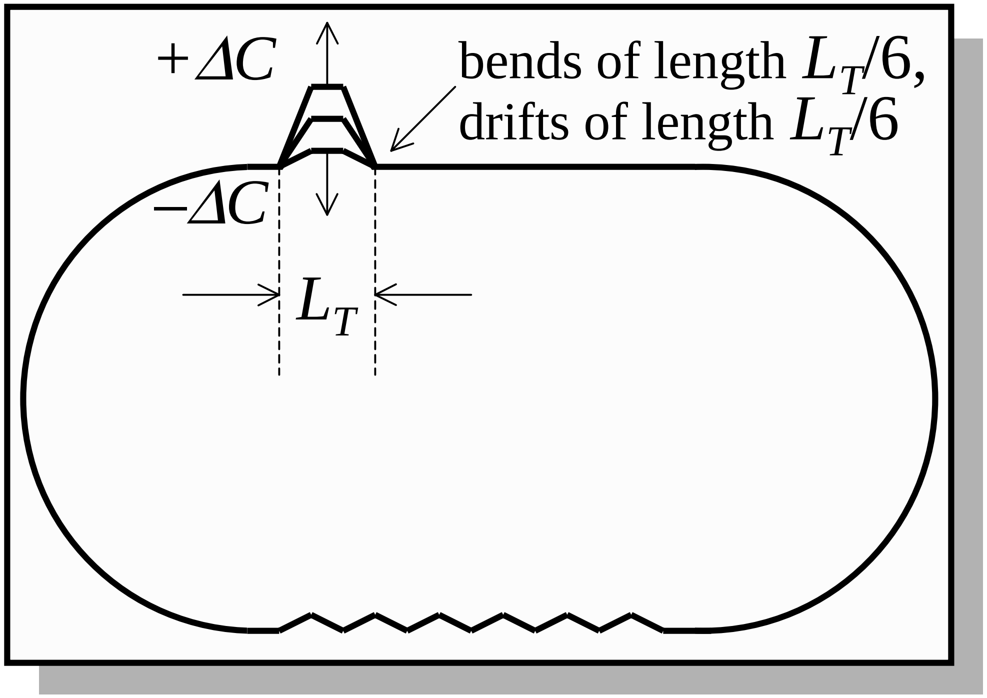
- Inj. & ext. kickers
- **–I** between kickers
- Inj. & ext. septa
- six $\psi_x = 108°$ cells
- 15-cm quad length
- 6-cm quad bore
- 5.0-kG max. field
- adjustable matching
- 3.6-m chicane
- 3 RF cavities



Some parameters...

Parameters (wiggler on full)	symbol	value	unit
electron/positron energy	E_0	1.98	GeV
horizontal tune	ν_x	23.85	2π
vertical tune	ν_y	11.23	2π
horizontal damping time constant	τ_x	5.171	msec
vertical damping time constant	τ_y	5.162	msec
extracted horizontal emittance (rms)	$\gamma\varepsilon_x$	2.98	μm
momentum compaction	α_p	6.6	10^{-4}
length of each straight section	L_s	58	m
total number of TME-cells	N_c	30	
TME-cell length	L_c	6.013	m
average radius of each arc	$\langle\rho_a\rangle$	28.85	m
extracted relative energy spread (rms)	σ_δ	0.089	%
energy loss per turn	U_0	760	keV
bunch length (rms @ 1.5 MV)	σ_z	4.00	mm
synchronous rf phase (@ 1.5 MV)	φ_{rf}	30.5	deg

Circumference adjustment...



Wiggler switched on extends circumference by...

$$\Delta C_w = \frac{N_s B_w^2 \lambda_w^3}{3072(B\rho)^2}[8N-1]$$

(≈ 1.7 mm) ⇒ Need at least ΔC_w-correction for 'wiggler-off' and also for unexpected errors.

$$\Delta\gamma\varepsilon_x \approx 393 \cdot C_q r_e c \frac{\tau_x \bar{\beta}_x \gamma^6}{C}\sqrt{\frac{\Delta C^5}{L_T^9}}$$

Emittance increase ~1.3% @ ΔC = +2 mm for chicane length of L_T = 3.6 m (±2 mm ΔC range).

Other parameters, α_p, τ_y, σ_z, ...etc., are changed insignificantly.

Work remaining...

- Dynamic aperture (studied in ZDR but not for new ring)
- Abort kickers (not added yet)
- Skew quads (for correction* and/or fast MPS ε_y-blowup)
- Wiggler radiation deposition problem
- Termite inspection
- Lots more...

* Full skew correction is available immediately after extraction in 1st bunch compressor