Damping Ring Lattice Update

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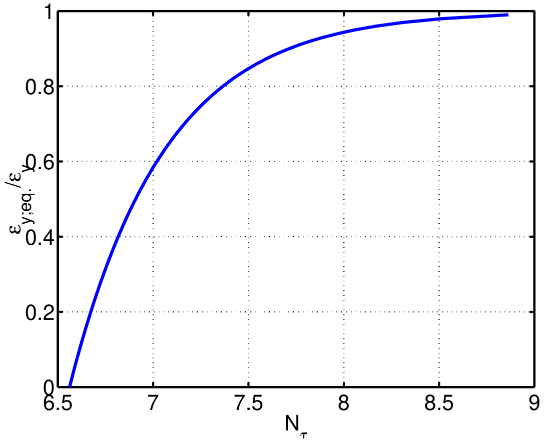
Introduction

New Parameters To Allow For Increased Luminosity:

	CDR	new set	determined by
hor. extracted emittance $\gamma\varepsilon_x$	$12 \times 10^{-6}\,\mathrm{m}$	$8 \times 10^{-6}\,\mathrm{m}$	luminosity
ver. extracted emittance $\gamma\varepsilon_y$	$0.2 \times 10^{-6}\,\mathrm{m}$	$0.02 \times 10^{-6}\,\mathrm{m}$	luminosity
eq. bunch length σ_z	$< 0.01\,\mathrm{m}$	$< 0.01\,\mathrm{m}$	bunch compressor
eq. momentum spread σ_p/P_0	$\approx 0.1\,\%$	$\approx 0.1\,\%$	bunch compressor
transverse acceptance $\gamma A_{x,y}$	$> 0.05\,\mathrm{m}$	$> 0.05\,\mathrm{m}$	$> 5 \times \gamma\varepsilon_{x,y;inj.}$
momentum acceptance A_p	$> 0.5\,\%$	$> 0.5\,\%$	
cycle time T_c	$200 \times 10^{-3}\,\mathrm{s}$	$200 \times 10^{-3}\,\mathrm{s}$	repetition rate
number of bunches n_b	1130	2820	bunch train
bunch spacing $\Delta\tau_b$	$50 \times 10^{-9}\,\mathrm{s}$	$20 \times 10^{-9}\,\mathrm{s}$	kicker raise/fall time
particles per bunch N_e	3.6×10^{10}	2×10^{10}	luminosity

Basic Damping Ring Parameters

- **Circumference:**
  - determined by kicker raise/fall time τ_k, number of bunches and ion clearing gap N_g
  - $C \geq c(N_b + N_g)\tau_k = c(2820 + 100) * 20\,\mathrm{ns} = 17520\,\mathrm{m}$
- **Number of Damping Times N_τ:**
  - set by reasonable relation of damping time and vertical equilibrium emittance
  - $\varepsilon_y = \varepsilon_{y;inj.} e^{-2N_\tau} + \varepsilon_{y;eq.}(1 - e^{-2N_\tau})$



  - $\Longrightarrow N_\tau \approx 7$ with $\varepsilon_{y;eq.} = 0.013\,\mu\mathrm{m}$
- **Damping Time:**
  - set by N_τ and LC repetition rate $f_{rep.}$
  - $\tau_{D;y} \leq \frac{1}{N_\tau f_{rep.}} \approx 29\,\mathrm{msec}$

Damping Time

- Depends on energy E, bend field $B_{dip.}$, total bending angle $2\pi F_D$, and ratio of emitted wiggler-/arc-power F_w

$$\tau_{D;y} \propto C \frac{1}{E^2 B_{dip.} F_D} \frac{1}{1 + F_W}$$

- Ratio of emitted wiggler-/arc-power

$$F_w = \frac{I_{2;wig}}{I_{2;arc}} = \frac{L_{wig} / < \rho^2_{wig} >}{2\pi F_D / \rho_{dip}}$$

- With $B_{dip.} \approx 1.6T$, $F_D = 2$, $F_W = 0$ one needs $E \approx 6.4\,\mathrm{Gev}$
- $\Longrightarrow$ need damping wigglers

Problem: Incoherent Space Charge Tune Shift

- Large ring length and relative low energy leads to huge incoherent space charge tune shift:

$$\Delta Q_{y;incoh} \approx -\frac{r_e N_e C}{(2\pi)^{3/2}\sqrt{\varepsilon_x \varepsilon_y}\sigma_z \gamma^2}$$

- $\Delta Q_{y;incoh} \approx 0.2$ for CDR parameters
- $\Delta Q_{y;incoh} \approx 0.43$ for high luminosity parameters
- Cures:
  * Increase ring energy
    - Needs lattice redesign
    - Higher rf-costs
    + Need less wiggler length
  * Decrease ring circumference
    - Kicker technology not available (?)
  * Increase bunch volume through local coupling and/or dispersion
    - Additional coupling in a small coupling ring
    + Probably low cost solution

  $\Rightarrow$ Needs more study

Horizontal Emittance

- Emittance of ring made of arcs and wiggler sections

$$\gamma\varepsilon_{x;eq.} = \frac{1}{J_x + F_w}(\gamma\varepsilon_{arc}J_x + \gamma\varepsilon_{wig}F_w)$$

- Emittance of wiggler

$$\gamma\varepsilon_{wig} \approx C_q E^3 \frac{2}{15\pi^3}\frac{\lambda^2 < \beta >}{\rho_{wig}^3}$$

- Emittance of arc

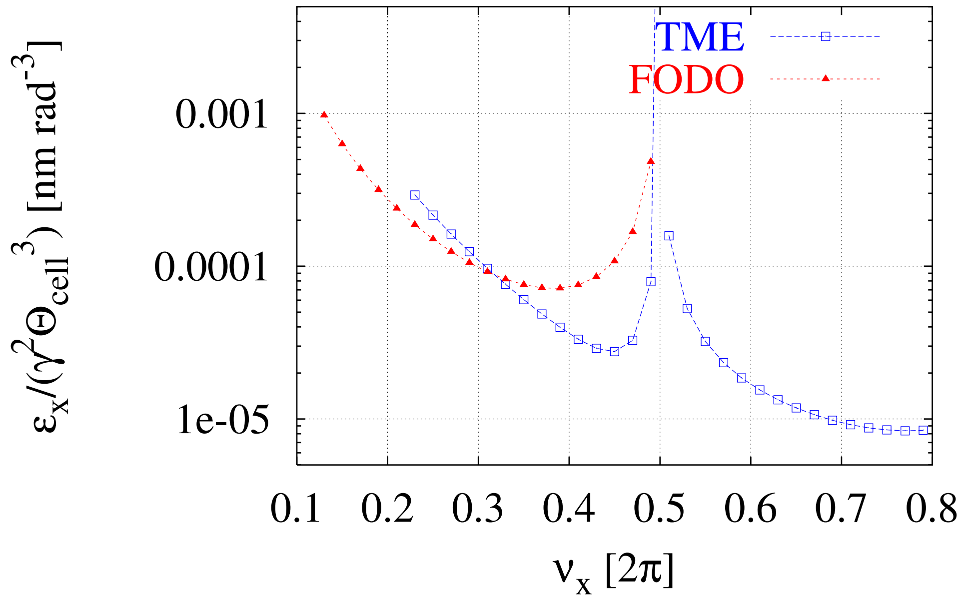
$$\gamma\varepsilon_{arc} = C_q E^3 F(lattice, \nu_x)\frac{1}{J_x}\theta_{dip.}^3$$

- In a ring with wiggler dominated damping and constant damping time the arc emittance contribution scale as γ^6

Arc lattice: Small emittance

- The minimum emittance for a cell of a given lattice type is:

$$\epsilon_{x,min} = F(lattice, \nu_x)\frac{\gamma^2}{J_x}\theta^3_{cell}$$



Arc lattice: Minimum emittance cells

- The theoretical minimum emittance for a given bending angle is reached in so-called 'TME' cells with $\alpha = \eta' = 0$ in the middle of the bend and

$$\beta_{x,min} = \frac{1}{2\sqrt{15}} l_{dip.} \qquad \eta_{x,min} = \frac{\theta l_{dip.}}{24}$$

- β and η functions scale roughly like the ratio $\varepsilon_r = \varepsilon/\varepsilon_{min}$
- Tune of one cell goes like (Rivkin, LC-97)

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

Momentum compaction factor

- Momentum compaction contribution of arc cells

$$\alpha_{c;arc} \approx \frac{1}{C} \frac{F_D 2\pi (\varepsilon_r + 1)}{24} \frac{l^2_{dip.}}{\rho}$$

- Momentum compaction contribution of wiggler cells

$$\alpha_{c;wig} \approx -\frac{1}{C} \left(\frac{\lambda}{2\pi}\right)^2 \frac{1}{\left\langle \rho^2_{wig.} \right\rangle} L_{wig}$$

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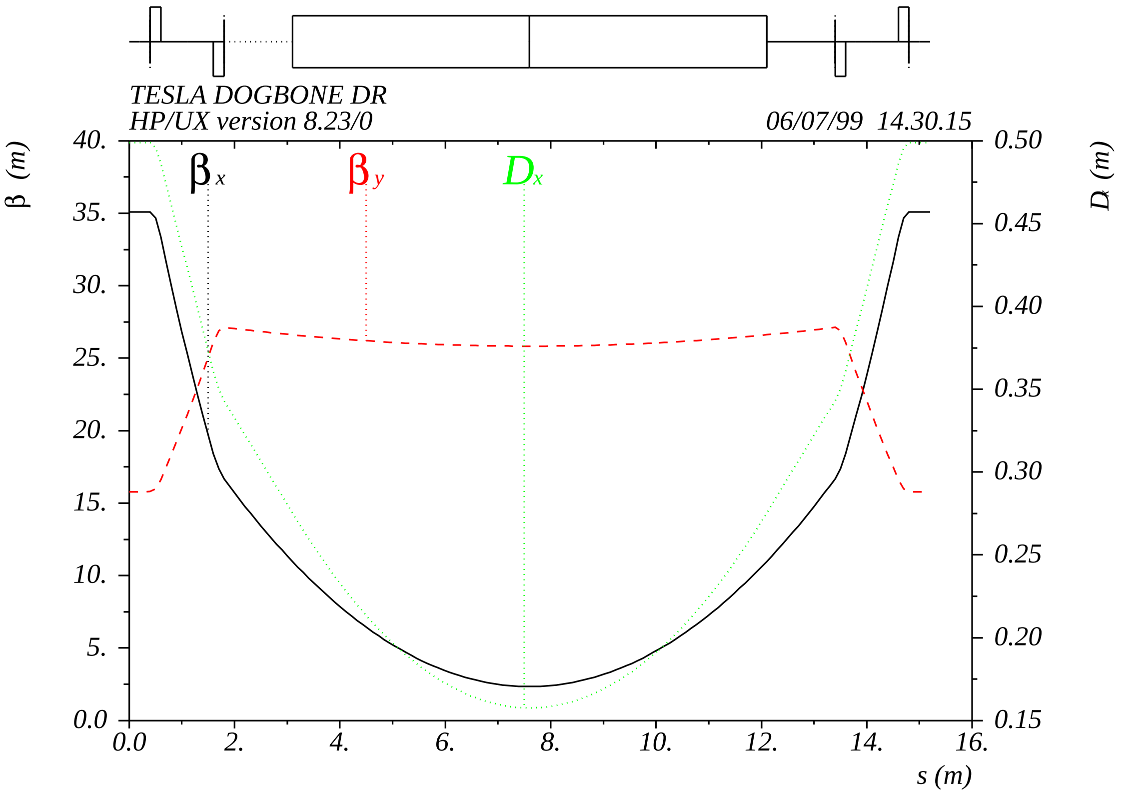
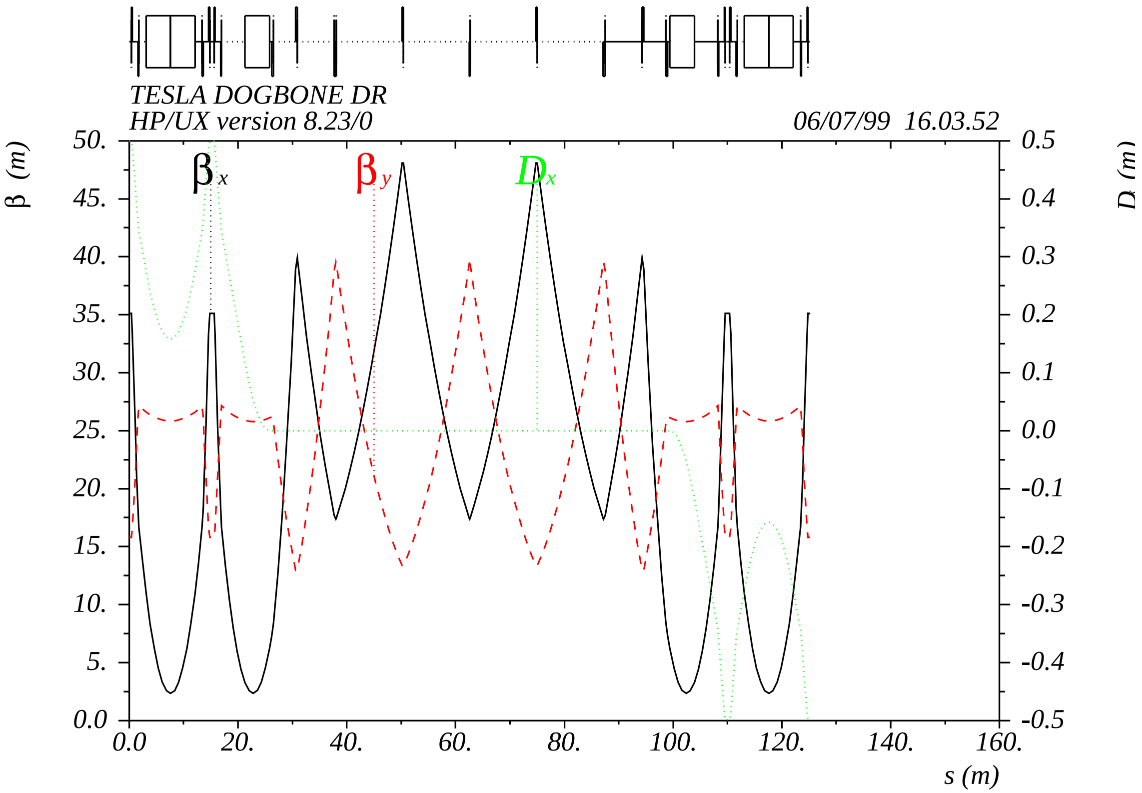
$$\alpha_c = \alpha_{c;arc} \left(1 - \frac{24}{(2\pi)^2} \frac{F_W}{(\varepsilon_r + 1)} \frac{\lambda^2}{l^2_{dip.}}\right)$$

Arc Cell



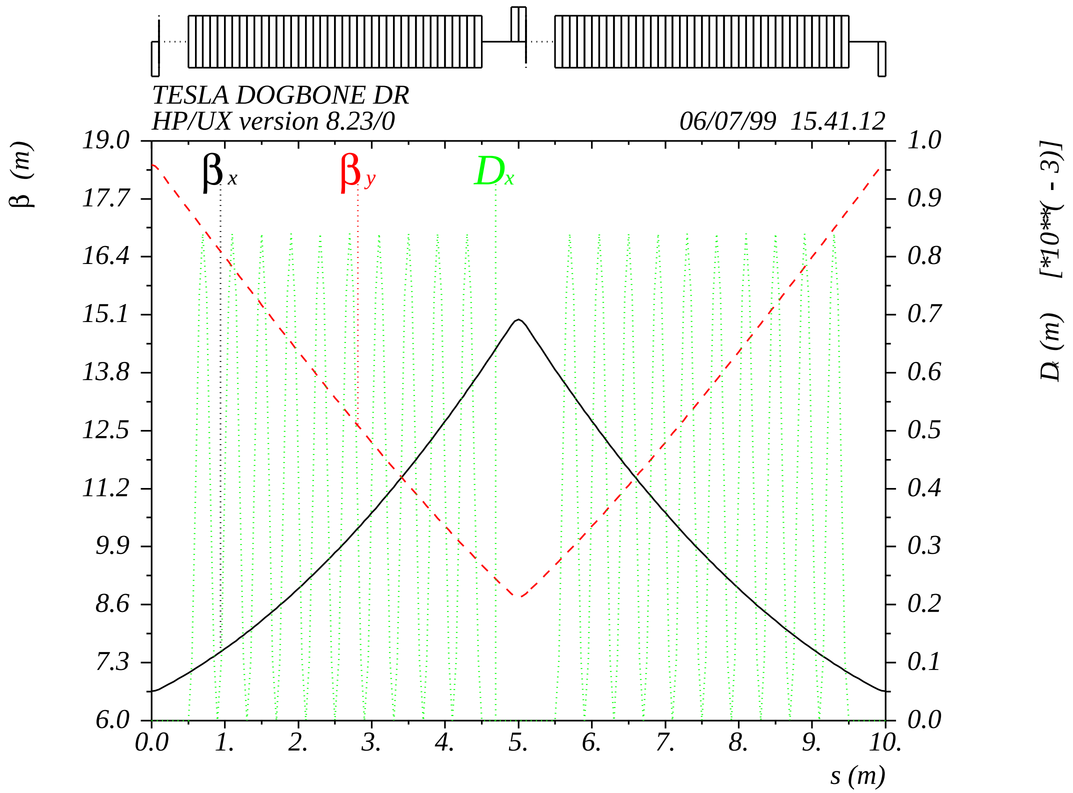
- 'detuning' $\varepsilon_r \approx 4$
- long dipole to increase β, η, α_c
- QF split for best placement of sextupole
- $\nu_x = 0.4, \nu_y = 0.1$ cancels 1^{st} order nonlinear terms after 5 cells
- $\theta = 6\,\mathrm{deg}$ gives $\gamma\varepsilon_{x;0} = 35\,\mu\mathrm{m}$ at $5\,\mathrm{GeV}$
- $U_0 = 1.1\,\mathrm{MeV/turn}$

Dispersion Match



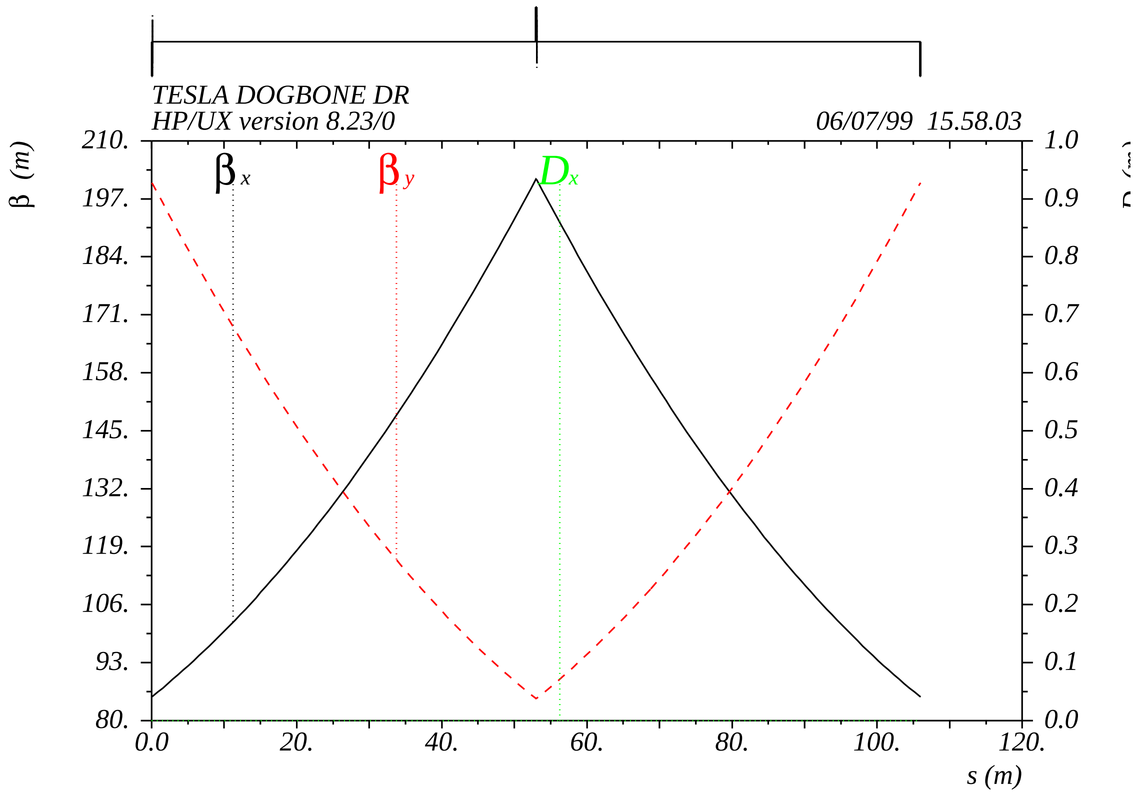
- $\frac{1}{2}$-dipole for η-match
- FODO-drift for length adjustment
- same η-match at wiggler side of arc

Wiggler Cell



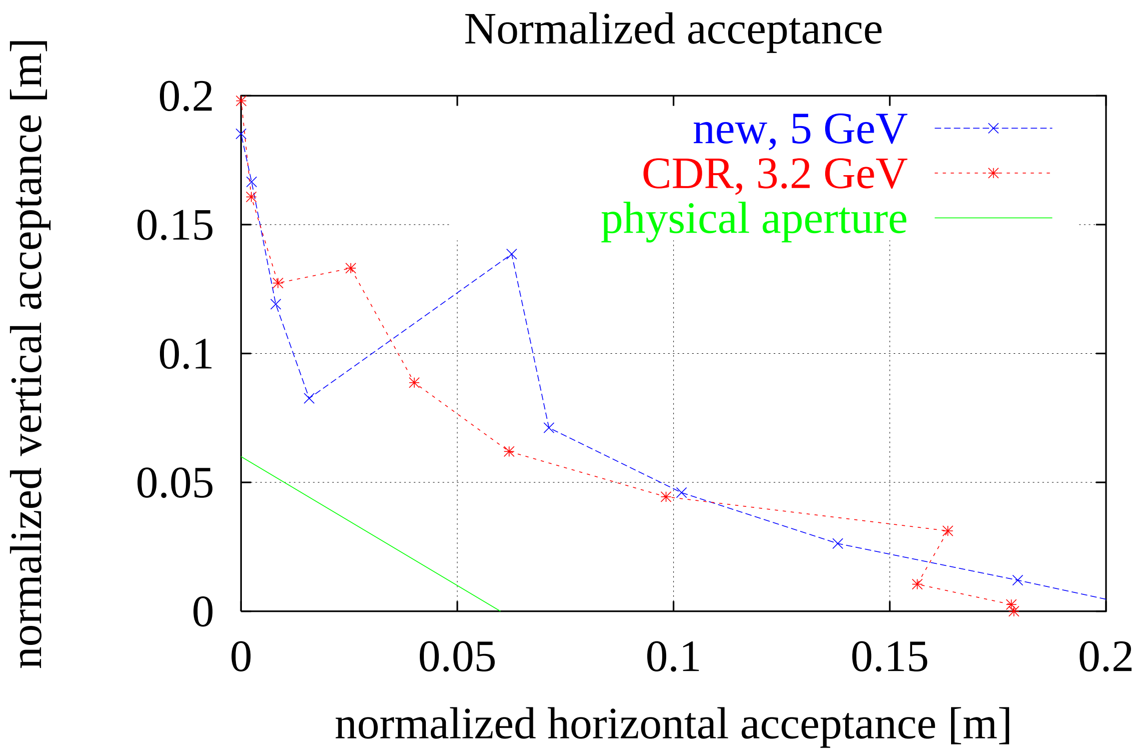
- $B = 1.5\,\mathrm{T}$, $\lambda = 0.4\,\mathrm{m}$
- cell length of $10\,\mathrm{m}$ and $\nu_x = 0.166$ gives $< \beta_x > \approx 10\,\mathrm{m}$
- $\varepsilon_{x;wig} = 7\,\mu\mathrm{m}$ at $5\,\mathrm{GeV}$
- Total of 36 cells leads to $U_0 = 18\,\mathrm{MeV/turn}$

Straight Section Cell



- long cell length reduces $\#_{Quads}$
- $\nu_x = \nu_y = 0.125$ to reduce chromaticity contribution
- enough space for injection, circumference correction, RF, ...
- due to high β very sensitive to errors (stray fields, ...)

Dynamic Aperture



- tracked with sextupoles misaligned to introduce optics distortion and coupling

Tolerances

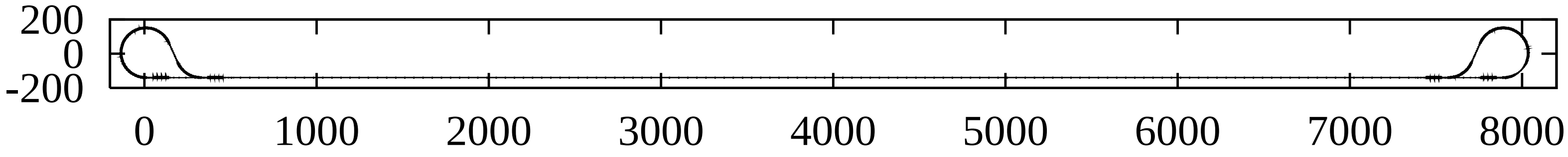
- Tolerances as in CDR allow to reach $\gamma\varepsilon_{y;0} = 0.1\,\mu\mathrm{m}$

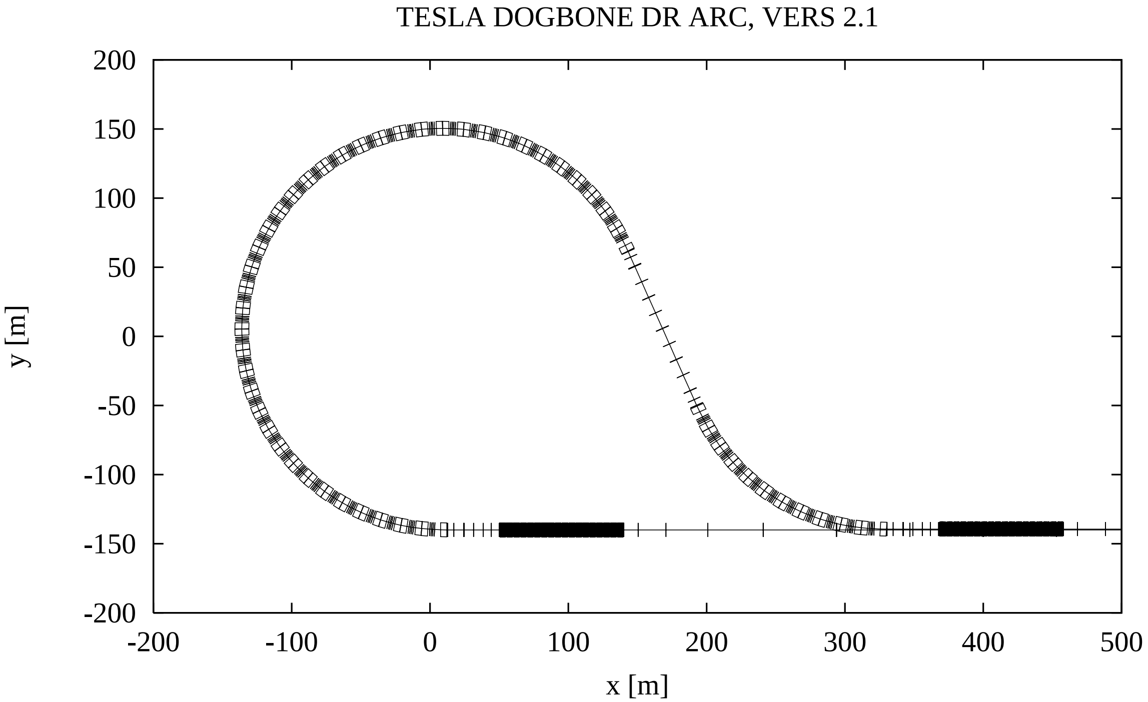
transverse position of elements :	$0.1\,\mathrm{mm}$
roll angle :	$0.2\,\mathrm{mrad}$
BPM resolution :	$0.01\,\mathrm{mm}$

- For $\gamma\varepsilon_{y;0} \approx 0.01\,\mu\mathrm{m}$ vertical dispersion correction is needed to a level of $D_{y;rms} \leq 2mm$ (need a $0.5\,\%$ momentum shift to measure with BPMs with $0.01\,\mathrm{mm}$ resolution)
- Tolerances for time-varying stray fields in the long straights are a few nT; first measurements (Jensen, Pillat) show values up to $100\,\mu\mathrm{T}$ in typical accelerator environments
- Need of circumference correction to adjust for tides, wiggler on/off (?)

$$\frac{\Delta C}{C} = \alpha_c \frac{\Delta p}{P} \leq 0.1 \times \sigma_p/P \rightarrow \Delta C \leq 270\,\mu\mathrm{m}$$

Layout





- Arc length 920 m
- Wiggler length 288 m
- $\xi_{x;arc} = -90$, $\xi_{x;straight} = -30$
- $\xi_{y;arc} = -32$, $\xi_{y;straight} = -30$

Summary of Parameters

energy	$5.0\,\mathrm{GeV}$	$3.2\,\mathrm{GeV}$
circumference	$17\,\mathrm{km}$	
arc length	$920\,\mathrm{m}$	$420\,\mathrm{m}$
hor./ver. tunes Q_x, Q_y	$71.85\,,\ 38.71$	$59.85\,,\ 57.71$
hor./ver. chromaticities ξ_x, ξ_y	$-120\,,\ -62$	$-70\,,\ -73$
hor. equilibrium emittance $\gamma\varepsilon_x$	$9\times10^{-6}\,\mathrm{m}$	$11\times10^{-6}\,\mathrm{m}$
transverse damping time $\tau_{D;x,y}$	$28\times10^{-3}\,\mathrm{s}$	$33.8\times10^{-3}\,\mathrm{s}$
transverse acceptance $\gamma A_{x,y}$	$0.06\,\mathrm{m}$	
equilibrium bunch length σ_z	$6\,\mathrm{mm}$	$9\,\mathrm{mm}$
equilibrium momentum spread σ_p/P_0	$0.13\,\%$	$0.1\,\%$
longitudinal damping time $\tau_{D;s}$	$14\times10^{-3}\,\mathrm{s}$	
energy loss per turn U_0	$20.3\,\mathrm{MeV}$	$10.7\,\mathrm{MeV}$
rf-voltage U_{rf}	$50\,\mathrm{MV}$	$25\,\mathrm{MV}$
momentum compaction α	0.12×10^{-3}	0.34×10^{-3}
wiggler field $B_{wiggler}$	$1.5\,\mathrm{T}$	
wiggler period length $\lambda_{wiggler}$	$0.4\,\mathrm{m}$	
total wiggler length	$288\,\mathrm{m}$	$388\,\mathrm{m}$
incoherent space charge tune shift	0.23	0.2

Injection/Ejection System

- Needed kicker strength assuming 3σ separation from septum and $\beta = 150\,\mathrm{m}$ at kicker
$$Bl = 3.4 \times 10^{-3} N \sqrt{\frac{\gamma\gamma\varepsilon_{x;inj.}}{\beta}} = 8.2 \times 10^{-3}\,\mathrm{Tm}$$
- Bunch to bunch stability for ejection is $10\,\%$ of $\sigma_{x;ej.}$ $\longrightarrow \frac{\Delta Bl}{Bl} \leq 1 \times 10^{-3}$
- Kicker raise/fall time $\leq 20\,\mathrm{ns}$, repeated every $300\,\mathrm{ns}$ for 2820 bunches; this with a frequency of 5 Hz
- First kicker prototype from Budker INP, DESY, FNAL reaches $2.8 \times 10^{-4}\,\mathrm{Tm}$ with approximately correct time structure but voltage decrease over pulse train (TESLA 96-11)

Further Work

- Further accelerator physics studies
  - lattice
  - orbit and emittance correction
  - other ways to circumvent tune shift problem
  - Investigate instability thresholds $\rightarrow$ C. Burnton
- Design and built kicker and pulser prototype
- Technical design of all components (magnets, RF, vacuum system, diagnostic, ...) and cost estimate $\rightarrow$ INFN