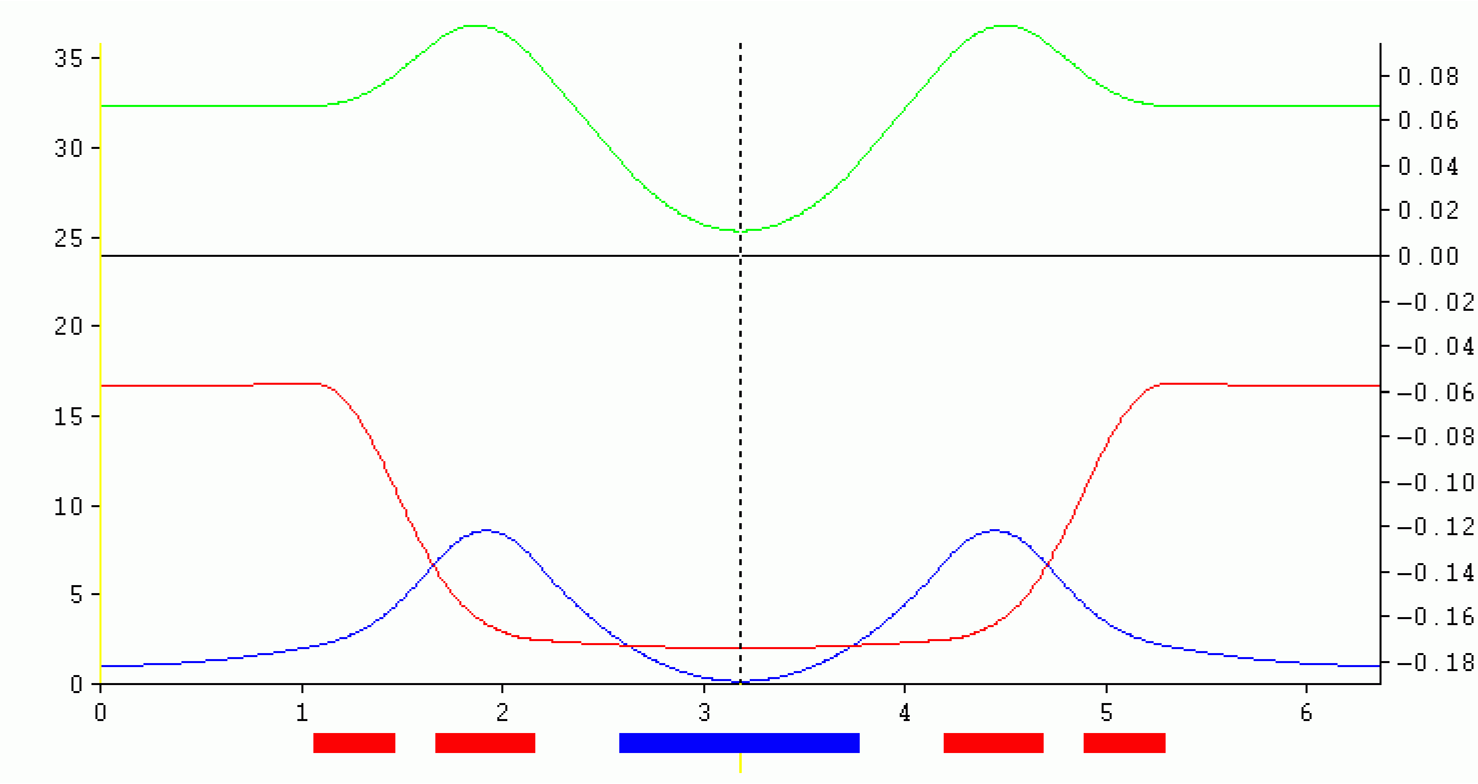
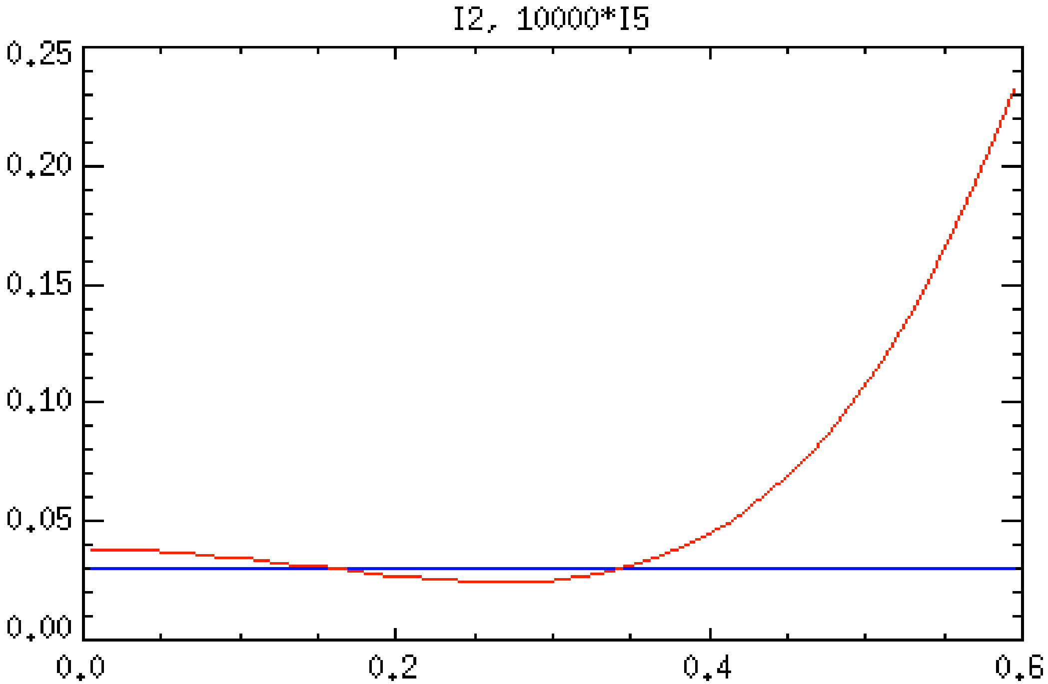
Compact low emittance lattices with longitudinal gradient bends ?

T.M.E. cell example: 12° dipole, 2.4 GeV → ε = 1.67 nm, μ_x = 284°



Longitudinal variation of radiation integrands inside TME dipole

center edge



$I5 = \int \mathcal{H} \, h^3 \, ds$

$I2 = \int h^2 \, ds$

$\Phi = \int h \, ds$

$h = B / (B\rho)$

Problem: $\varepsilon \, J_x / \gamma^2 = C_q \, I5 / I2 \rightarrow min$
while Φ = const.

→ Lower field towards edges....

Previous work

J.Guo & T.Raubenheimer

LOW EMITTANCE E-/E+ STORAGE RING DESIGN USING BENDING MAGNETS WITH LONGITUDINAL GRADIENT , EPAC-2002

Factor 2..3 emittance reduction possible, application to NLC damping rings.

A.Wrulich & R.Nagaoka (1992)

EMITTANCE MINIMIZATION WITH LONGITUDINAL DIPOLE FIELD VARIATION, Joint PSI-Synchrotron SOLEIL Accelerator Physics Report, 2004

ATTEMPT TO MINIMIZE THE EMITTANCE WITH LONGITUDINAL DIPOLE FIELD VARIATION, Small emittance light source workshop, Lund, 2004

Analytical and numerical treatment of exponential and polynomial field decays

Zero emittance for infinite B-field in magnet center

Factor 4 emittance reduction with ~ feasible magnets in DBA lattice (SOLEIL)

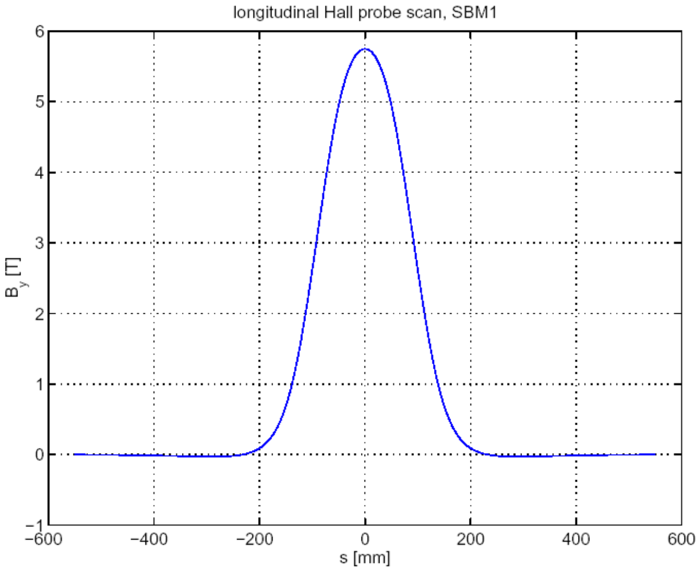
A.Ropert et al.

PROSPECTS FOR A LONG TERM LATTICE UPGRADE AT THE ESRF, EPAC 2004

Application to existing ESRF geometry with 1.8T magnets: 0.5 nm minimum emittance

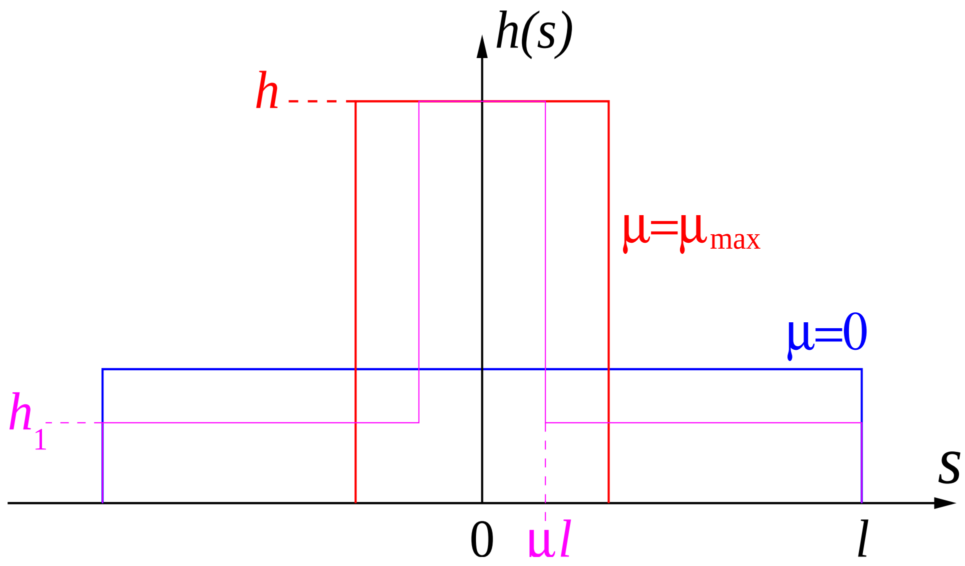
Trial: superbend

ALS superbend



≅

approximation



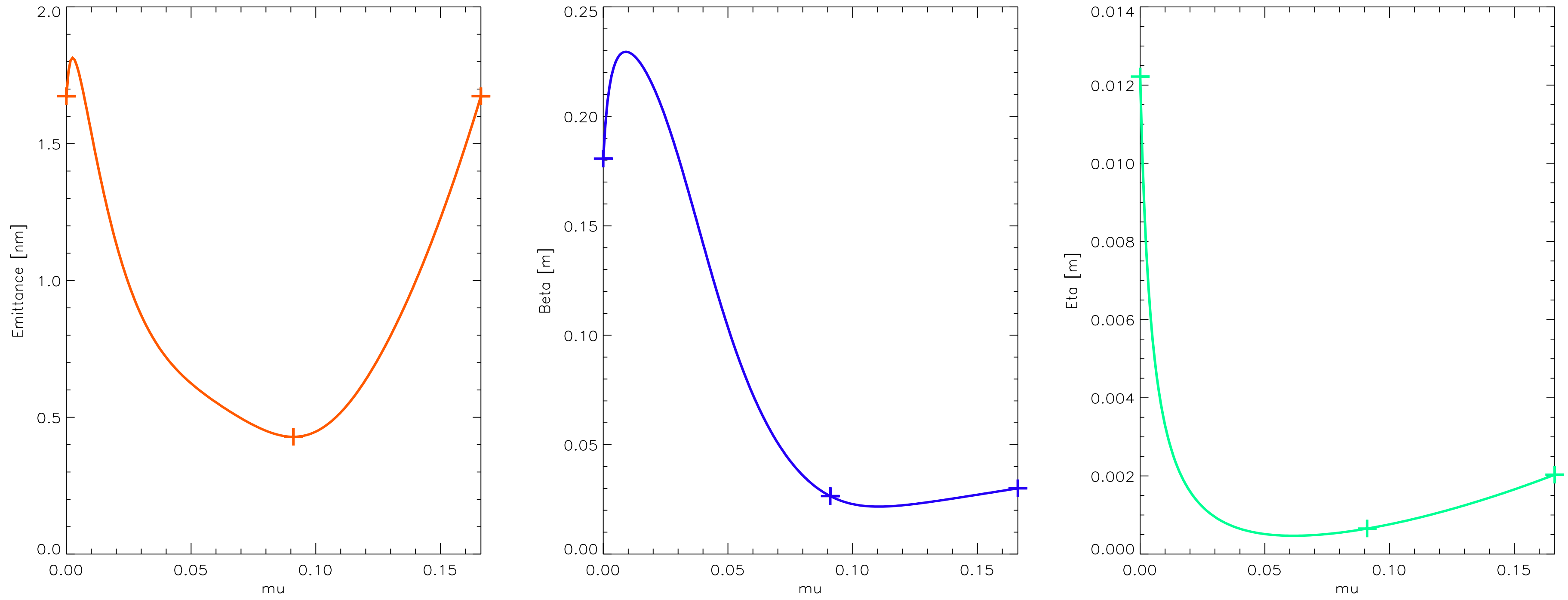
2-field dipole: $\mu = 0$ pure normal dipole

$\mu = \mu_{max}$ pure s.c. dipole

$\Rightarrow$ μ for $\varepsilon \rightarrow$ *min* ?

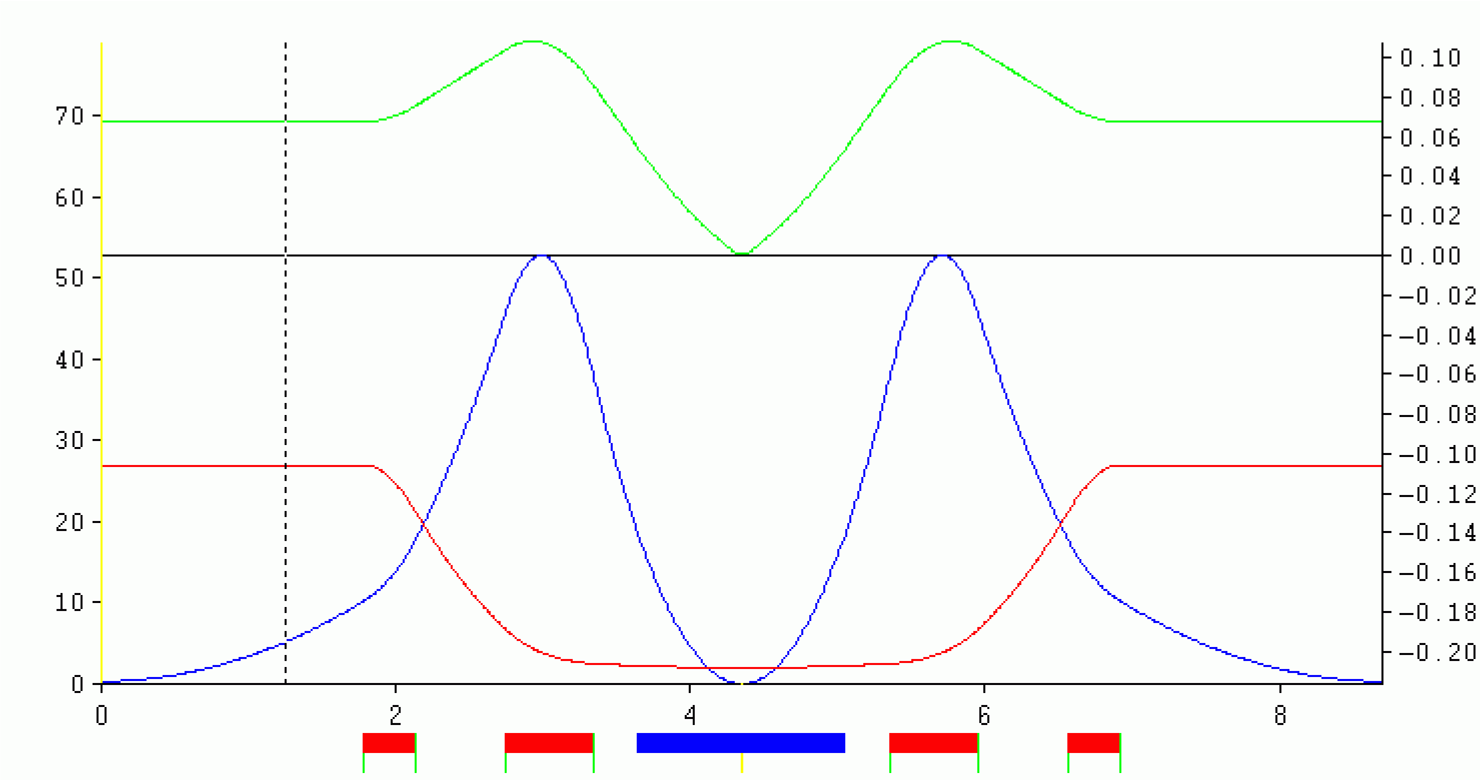
Analytical solution for 2-field dipole

$$\partial^2 \varepsilon \, (\beta_{xo}, \eta_o, \mu) \, / \, \partial \beta_{xo} \, \partial \eta_o \rightarrow \mathit{min} \;\; \Rightarrow \;\; \varepsilon_{min} \, (\mu)$$



sub-T.M.E. Cell: **ε = 0.43 nm (~ ¼ T.M.E.)** at 2.4 GeV

based on 2-field 12° dipole: 2.7°(0.6T) + 6.6° (7.2 T) + 2.7°(0.6T)

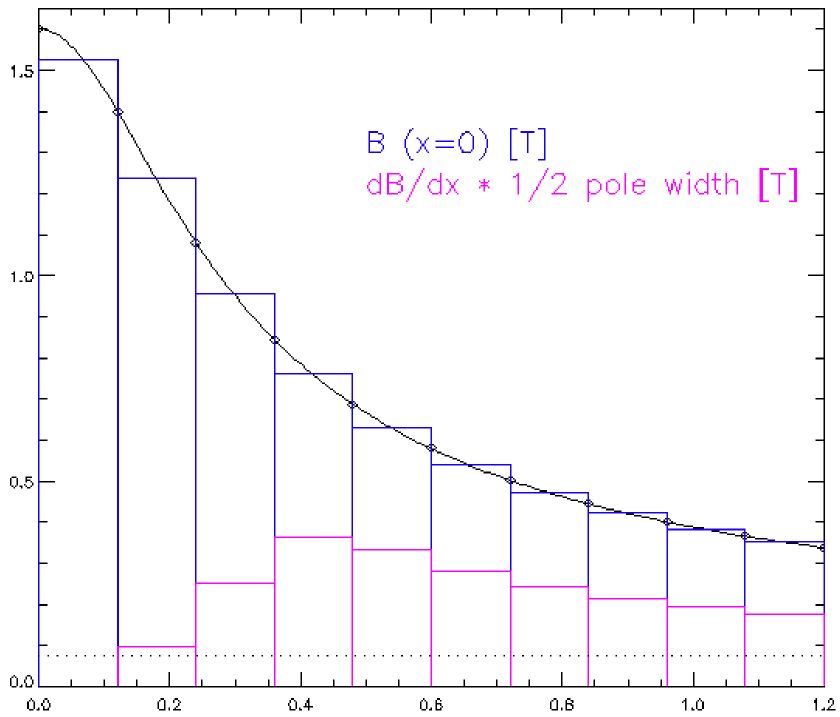


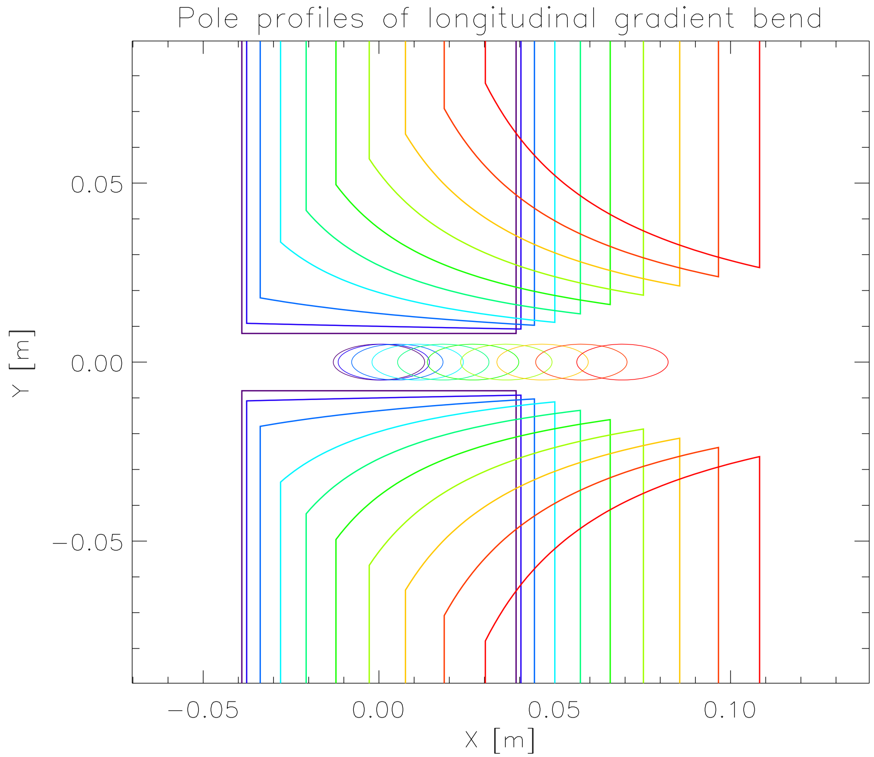
but: $\mu_x = 345°$ $\xi_x / Q_x = -10$ ☠ → too small β_{xo}

Trial: combined function bend

Longitudinal profile $B(s) = (B_{max} - B_{off}) / (1 + (\alpha\, s)^2)^{½} + B_{off}$

Numerical minimization of $\varepsilon\ (\beta_{xo}, \eta_o, \alpha)$ for given L, Φ



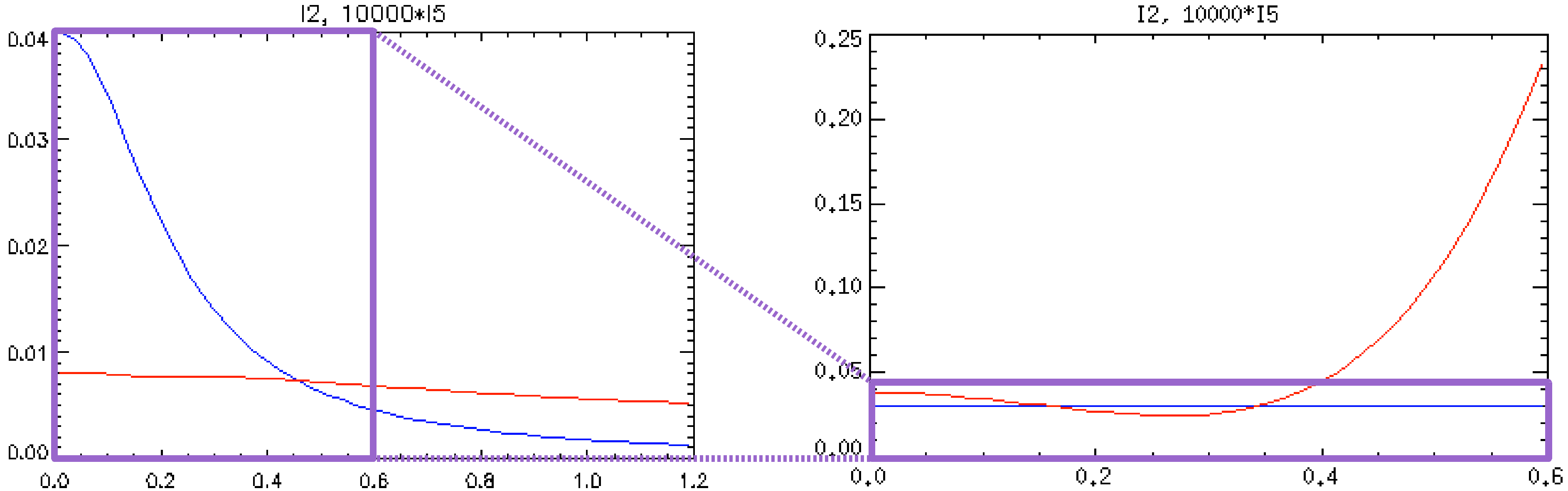


Longitudinal variation of radiation integrands

Optimum longitudinal profile and optics
Result of $\varepsilon\,(\beta_{xo}, \eta_o, \alpha) \rightarrow min$

Constant field bend in TME mode

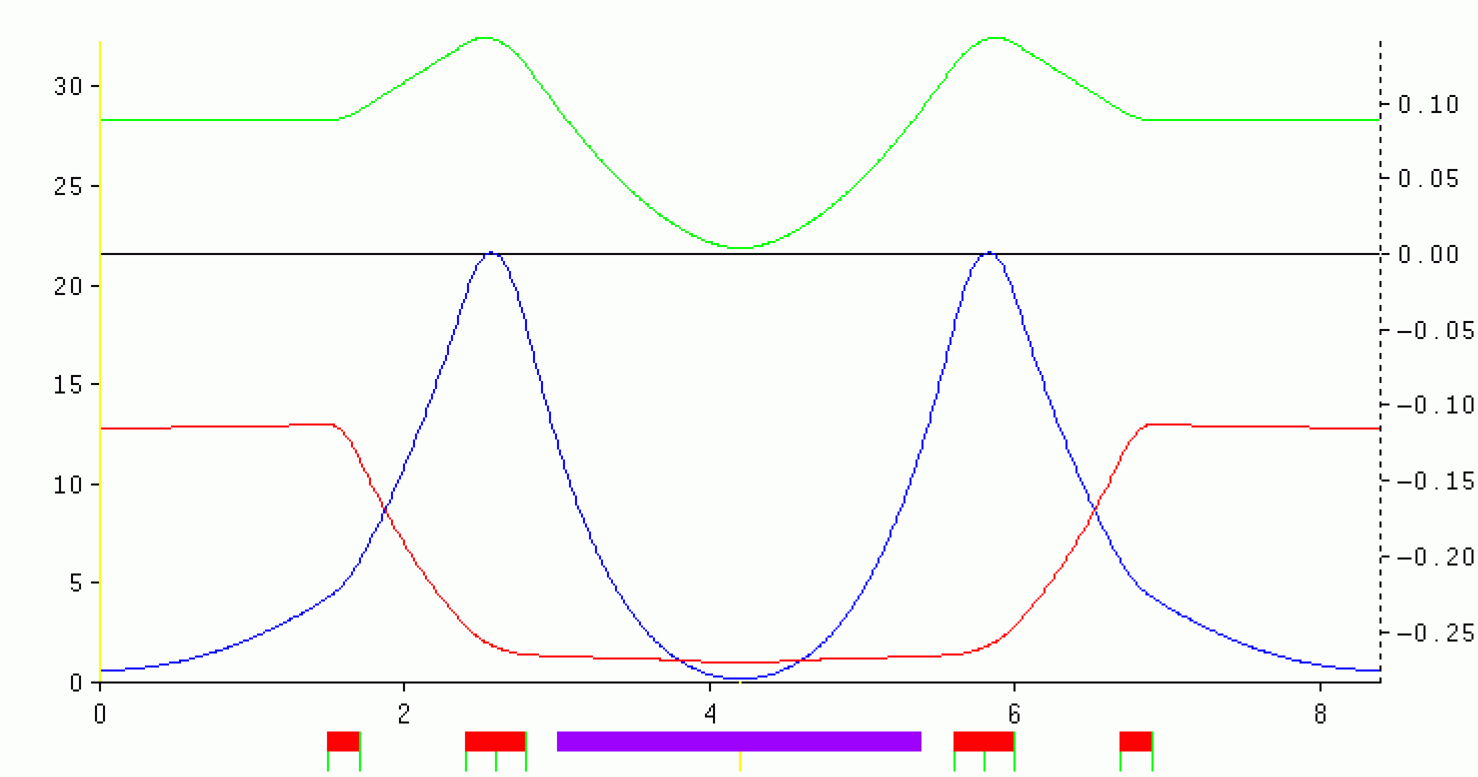
center edge center edge



$I5 = \int \mathcal{H}\ h^3\,ds$ $I2 = \int h^2\,ds$ $\Phi = \int h\,ds$ $h = B / (B\rho)$

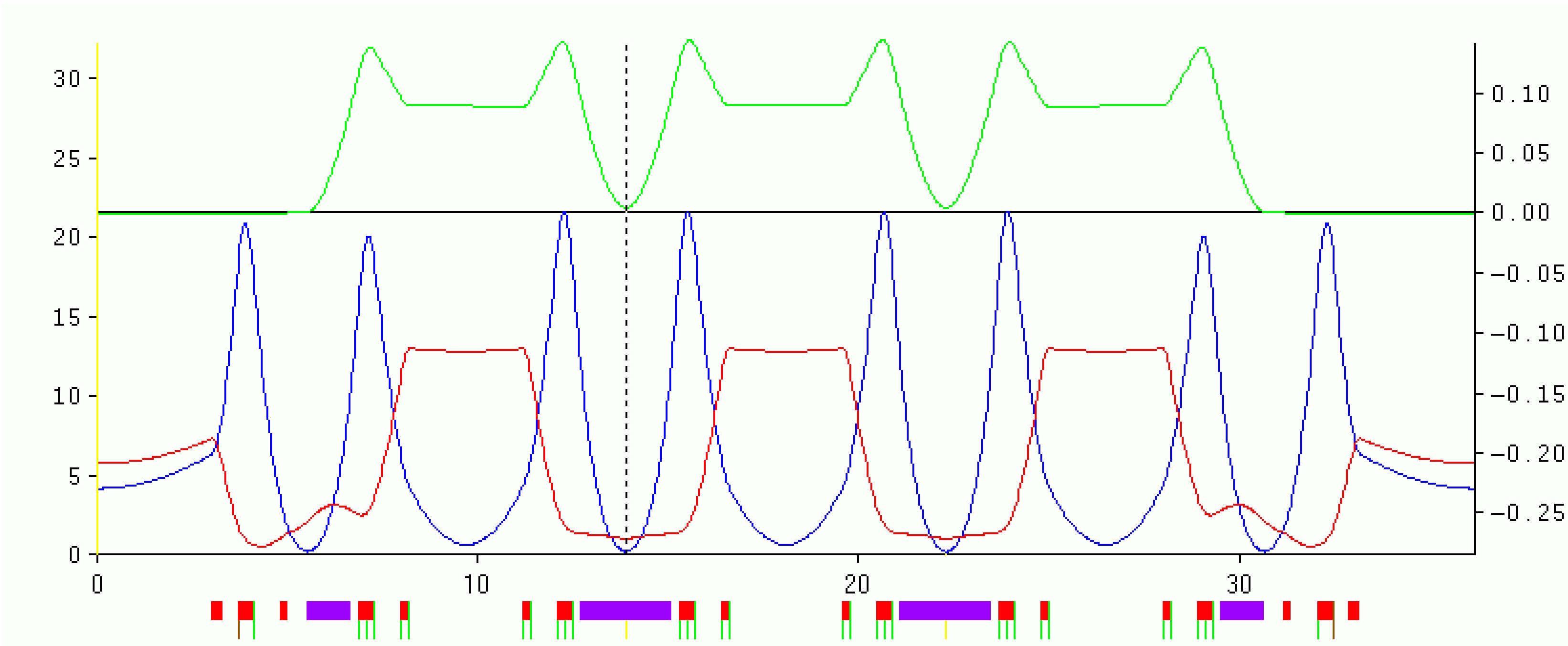
sub-T.M.E. Cell: **ε = 0.46 nm** (J_x= 1.3) at 2.4 GeV

based on 12° combined function bend (max. 1.6 T)



D.A. ~ ✓ (ideal cell) μ_x = 311° → long cell 8.4 m

Utopian lattices ...



10 x 36° arc, 362 m circumference, ε = 0.47 nm at 2.4 GeV
straights: 10 x 6 m dispersions free, 30 x 3 m dispersive ....

dynamic aperture, tunability, error sensitivity .... → ***relax ?***

Relaxed cell: $\beta_{xo}\uparrow$ $\eta_o\uparrow$ $\Rightarrow$ less variation of $\mathcal{H}(s)$

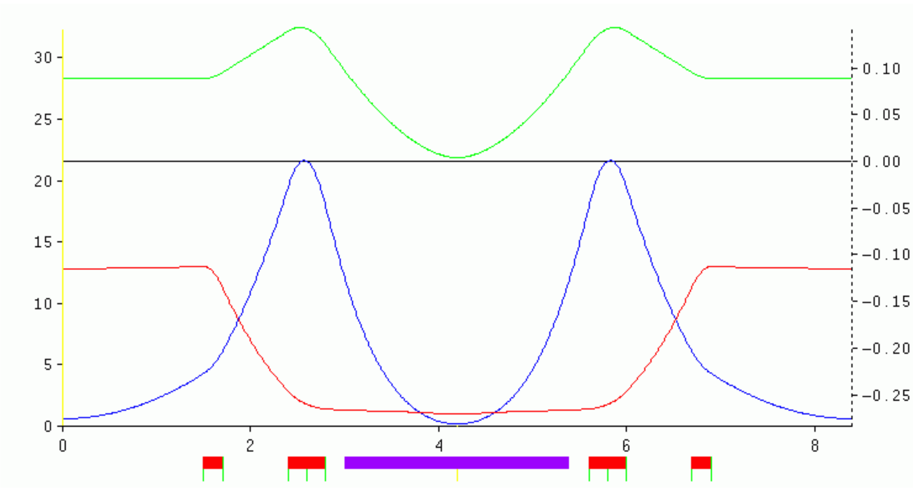
$\Rightarrow$ ***less gain from longitudinal gradient***

Alternative: give up on long.grad.bend ☹ $\varepsilon \rightarrow \sim \varepsilon \times 4$

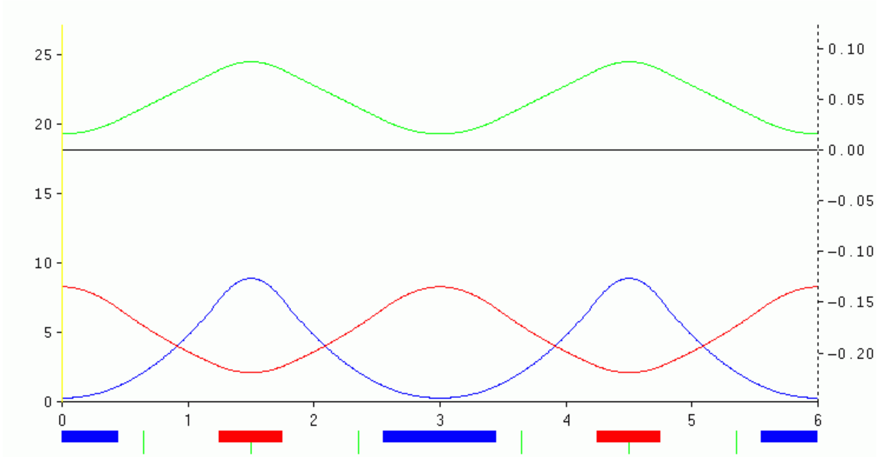
relax the cell $\varepsilon \rightarrow \sim \varepsilon \times 3$

split bend (use $\mu_x > 180°$ space !) $\varepsilon \rightarrow \varepsilon / \mathbf{8}$

$\boldsymbol{\varepsilon \rightarrow \sim 1.5 \times \varepsilon}$

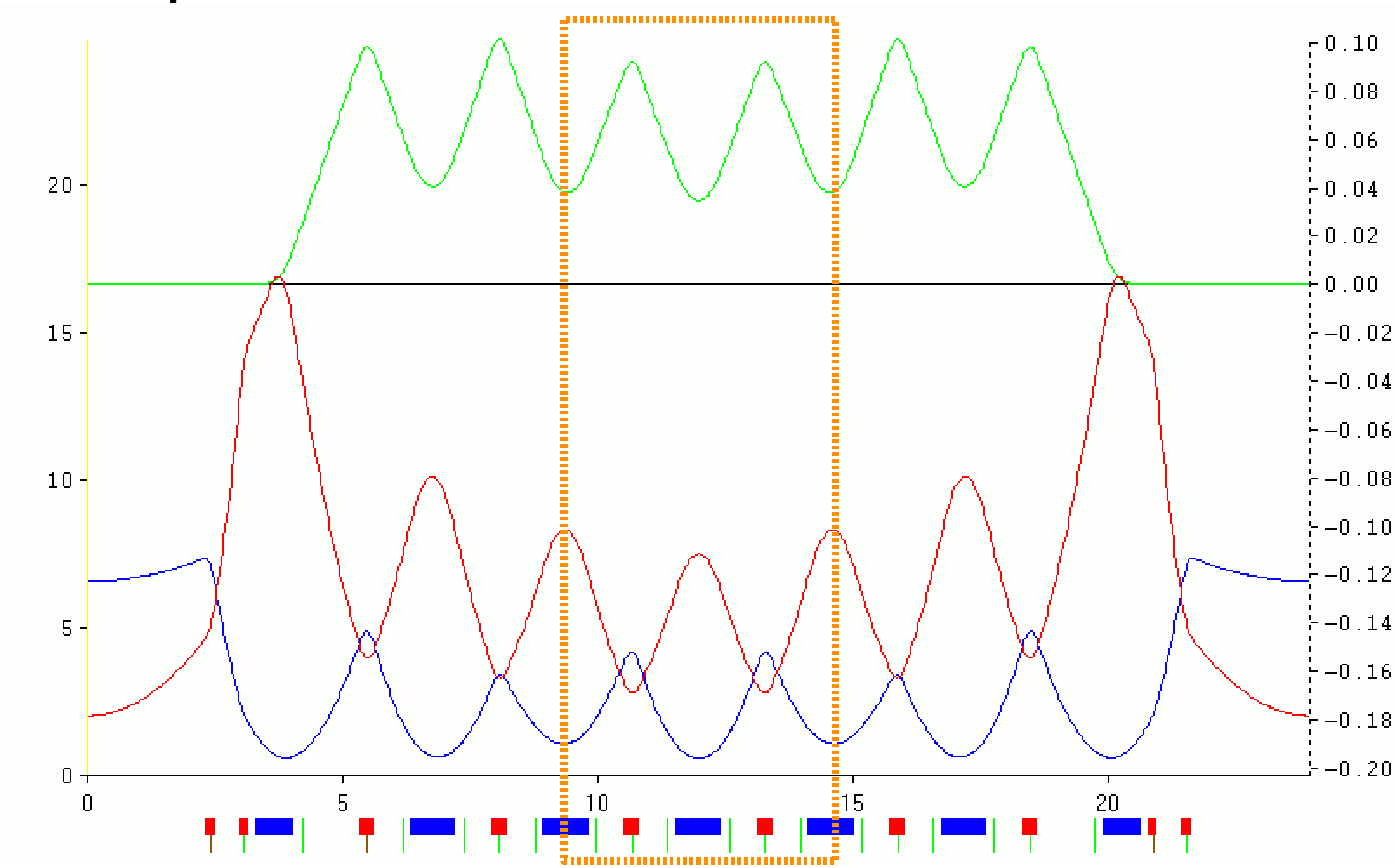


$\Rightarrow$



12°, 8.4 m, ε = 0.46 nm, μ_x = 310° 12°, 6.0 m, ε = 0.65 nm, μ_x = 2 x 150°

Example: MAX-4



ε = 1.4 nm at 3 GeV, excellent D.A.

287 m circumference, 12 x 4.6 m straights

Conclusion

- Feasible bending magnets with longitudinal gradient provide an emittance which is about ¼ of the T.M.E.
- This works well only for ideal cells with exact matching, having serious disadvantages:
  - horiz. phase advance > 180° requires a 2^{nd} focus and a long cell
  - sensitive to errors and little tunability
  - large chromaticities and little flexibility on phases restrict D.A.
- In relaxed cells, the particular emittance reduction from the longitudinal gradient is partially lost.
- Longitudinal gradient bends offer a promising way to build compact low emittance lattices, but more studies are required to achieve at realistic designs.