# Collider Rings for HEMC's

(writeups from 6-month HEMC study)

B. King (BNL)

Topics:

- 4 TeV lattices from '96 : Johnstone & Garren, Oide
- 30 TeV lattice : Raimondi & Zimmermann
- $\mathcal{L}$ scaling → request for lattice designers

# Luminosity Scaling with Final Focus & Cooling

$$\mathcal{L} \sim \frac{f N^2}{\sigma^2} \sim \frac{(fN)\, N}{\epsilon_\perp \beta^*}$$

freq. $f$; $N$: $\mu$'s/bunch; $\sigma$: spotsize; $I$; $N \propto \Delta\nu$ beam-beam tuneshift

$(\sigma^2 = \epsilon_\perp \beta^*)$

assume:
- $I$ limited by $\nu$ rad$^n$.
- $\epsilon_6 \sim \delta\beta^* \epsilon_\perp^2$, can partition freely
- brightness $B_6 \equiv \frac{N}{\epsilon_6}$

$$\cdots \Rightarrow \mathcal{L} \sim \frac{\Delta\nu}{\beta^*}$$ if limited by $\Delta\nu$ ($\sim 0.1$)

(lattice design ← magnets)

$$\mathcal{L} \sim \sqrt{\frac{\delta N B_6}{\beta^*}}$$ if not limited by $\Delta\nu$

$B_6$: cooling; $\beta^*$: lattice design & magnets

$\Rightarrow$ push hard on final focus lattice design & magnets (quads.)

$g = 250$ T/m LHC
$g = 320$ T/m LBL des
↓ high $T_c$ SC etc.
$g = 400$ T/m HEM

Also smaller $N$ $\Rightarrow$ smaller $\epsilon_6, \epsilon_\perp$ (constant $B_6$) $\Rightarrow$ easier apertures recommend

Carol Johnstone & Al Garren's 4 TeV lattice

(Snowmass '96)

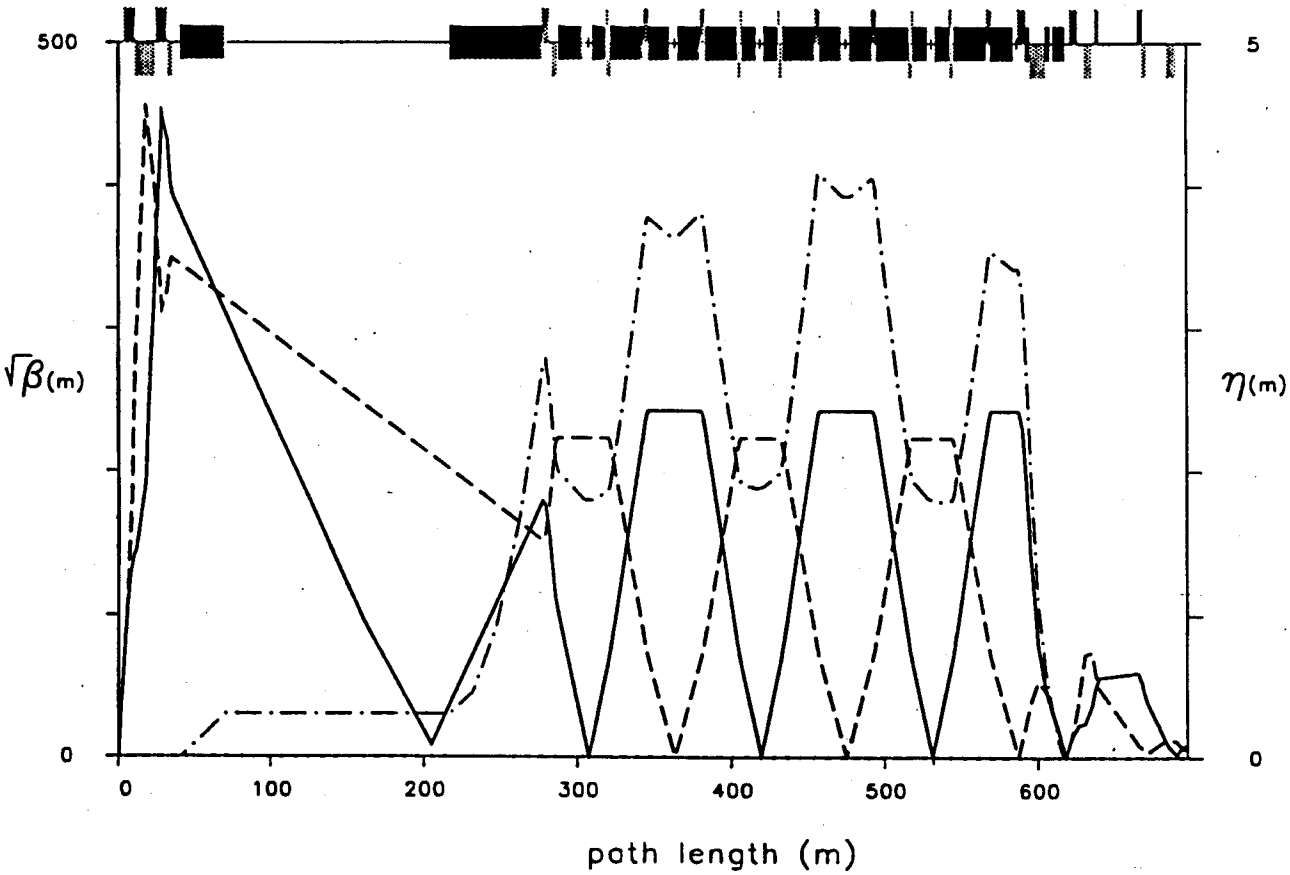
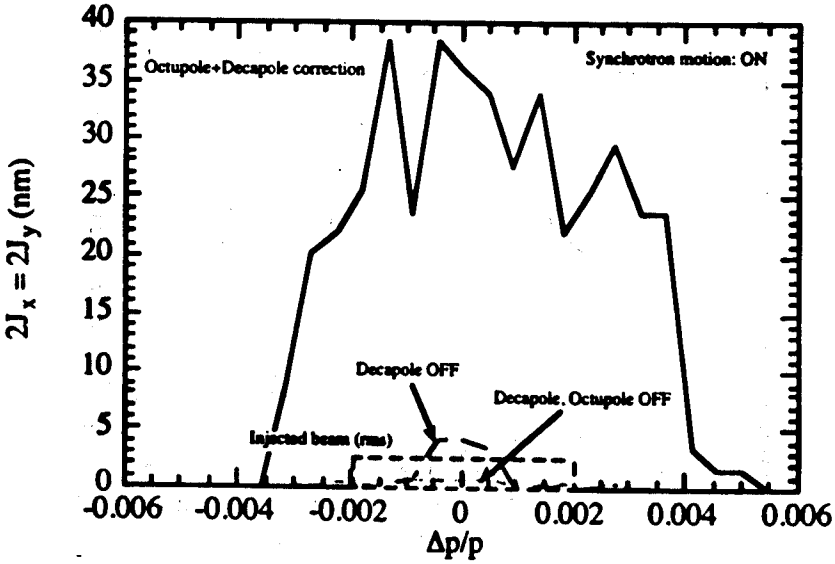


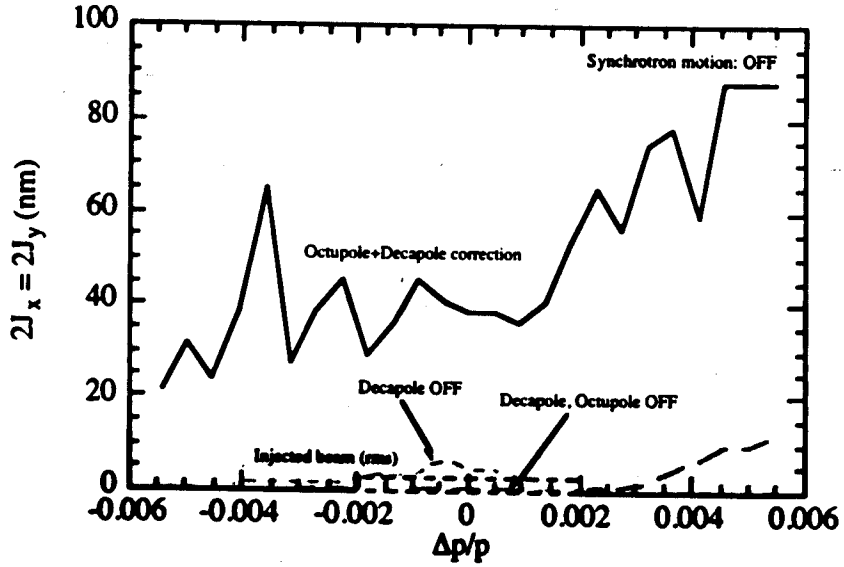

Figure 2: Experimental Insert (half) with a 3 mm beta function at the IP. ($\beta_x$: solid line, $\beta_y$: dash-line, dispersion: dot-dash line)

Figures 8 and 9 show the results of the dynamic aperture with and without synchrotron motion, respectively. The effects of octupoles and decapoles look quite strong.




Dynamic aperture including synchrotron motion

Figure 8: Dynamic aperture of this ring with synchrotron motion. Octupole and decapole corrections improve the aperture drastically.




" without synchrotron motion

**Figure 9: Dynamic aperture of this ring without synchrotron motion. Octupole and decapole corrections improve the aperture drastically.**

Oide 4 Tev

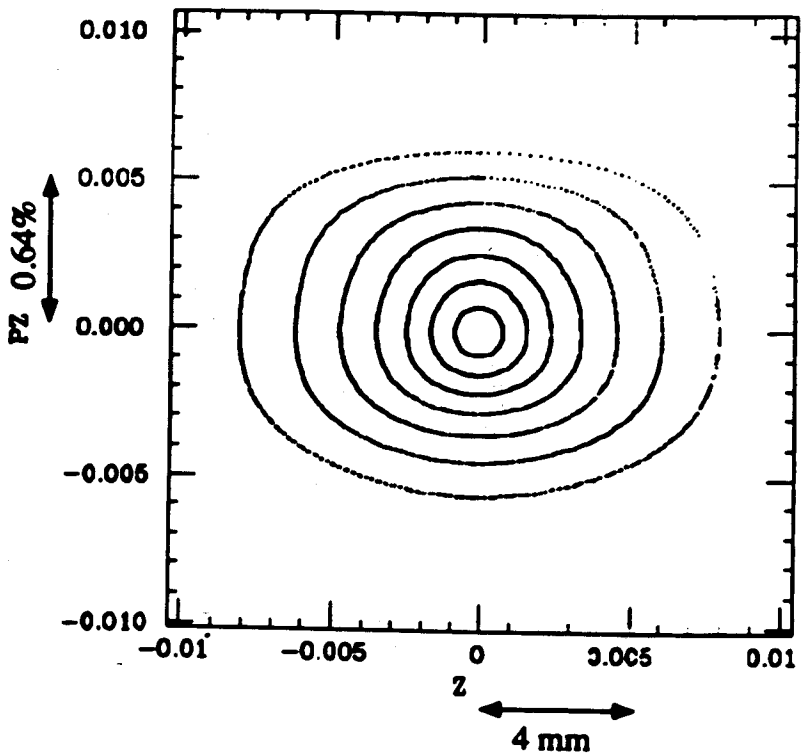



Figure 4: Shape of the longitudinal phase space.

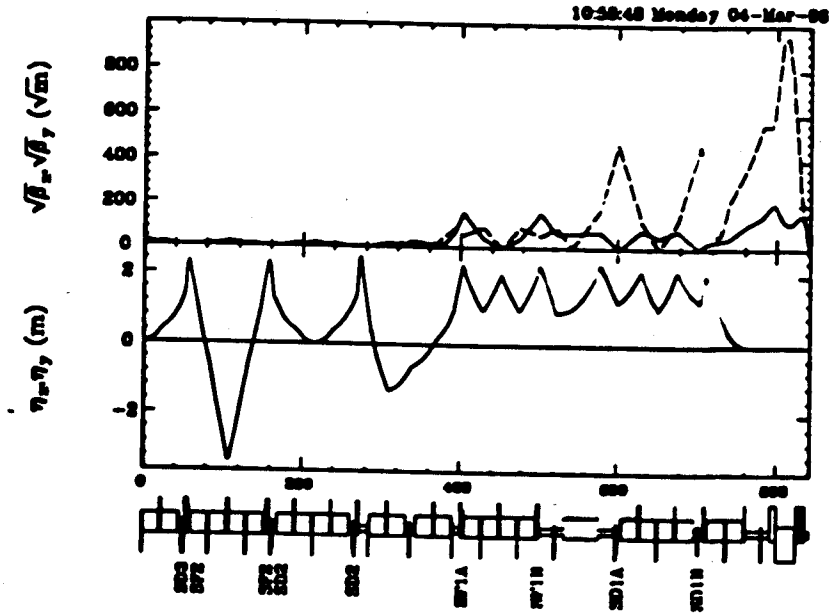



Figure 5: Optics of the local chromaticity correction section

Oide 4 TeV

Table 1: Parameters of this design comparing with BNL–62740.

| | | This design | BNL–62740 | |
|---|---|---|---|---|
| Beam energy | $E$ | 2 | | TeV |
| Lorentz factor | $\gamma$ | 18900 | | |
| Inj. emittances | $\gamma\varepsilon_{x,y}$ | 50 | 50 | $\mu$m |
| Inj. mom. spread | $\sigma_\delta$ | 0.2 | 0.2 | % |
| Inj. bunch length | $\sigma_z$ | 3 | 3 | mm |
| Bending field | $B_D$ | 10 | 9 | T |
| Circumference | $C$ | $\sim 6$ | 7 | km |
| Effective turns | $n_{\rm eff}$ | $\sim 1000$ | $\sim 900$ | |
| Beta at IP | $\beta_x^*/\beta_y^*$ | 3/3 | 3/3 | mm |
| IP free length | $\ell^*$ | 6 | 6.5 | m |
| IP beam sizes | $\sigma_x^*/\sigma_y^*$ | 2.8/2.8 | 2.8/2.8 | $\mu$m |
| IP quad field | $B_0$ | 6.5 | 6.4 | T |
| IP quad radius | $a$ | 200 | 120 | mm |
| Momen. compact. | $\alpha_p$ | $5.4 \times 10^{-6}$ | | |
| Rf voltage[1] | $V_c$ | 2.2 | | GV |
| Synch. tune | $\nu_s$ | 0.003 | | |
| Repetition rate | $f$ | – | 15 | Hz |
| Muons/bunch | $N$ | – | $2 \times 10^{12}$ | |
| Bunches/beam | $N_B$ | – | 2 | |
| Luminosity | L | – | $1 \times 10^{35}$ | $\rm cm^{-2}s^{-1}$ |

- It would be better (not yet confirmed) to have a non-interleaved sextupoles to reduce the nonlinearity of sextupoles.

A $2.5\pi$ cell, which has been applied to KEKB, has a capability to satisfy above requirements. Figure 1 shows the unit cell of this design. This unit cell has a momentum compaction $\alpha_p = -2.2 \times 10^{-4}$ which results $\alpha_p = 5.4 \times 10^{-5}$ together with the compaction from the interaction region(IR). Some parameters like number of cells/ring (24 in this design), length of quads, etc. have not been optimized yet.

# Quasi-Isochronous Ring

When the linear momentum compaction is small, the higher order momentum compaction limits the size of the rf-bucket.

- The third order term can be controlled by sextupoles with the term $H = k'\eta^3\delta^3/6$. The solution is obtained simultaneously with the chromaticity correction.
- The the fourth order is significant. This is also optimized by sextupoles in this design, but octupoles may be more efficient (not yet tried).



Oide 4 TeV

# Performance of a Compact Final-Focus System for a 30-TeV Muon Collider

did the lattice

P. Raimondi, SLAC, Stanford, USA
F. Zimmermann, CERN, Geneva, Switzerland

examined its performance (these plots)

**Abstract.** A final-focus optics for a 30-TeV round-beam muon collider has been developed. It is based on the novel design approach for linear colliders. Here, we demonstrate that this system promises a very satisfactory performance. In particular, we evaluate the energy bandwidth, sensitivity to the transverse emittance, magnet-position and stability tolerances, and the luminosity for successive turns.

## I INTRODUCTION

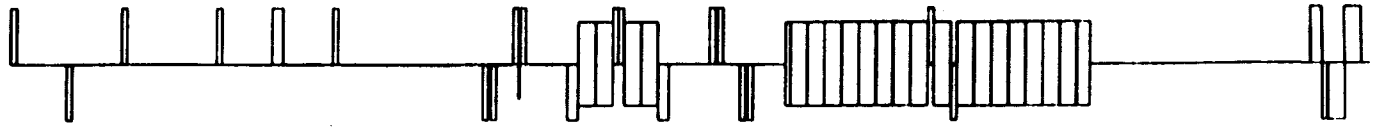
In response to the results of the 1999 HEMC workshop [1], the parameter sets [2] were revised [3]. Present research efforts focus on a 30-TeV collider, where synchrotron radiation is still moderate. Relevant parameters are summarized in Table 1.

**TABLE 1.** Parameters of the 30-TeV Muon Collider [3].

| parameter | symbol | value |
|---|---|---|
| beam energy | $E_b$ | 15 TeV |
| Lorentz factor | $\gamma$ | 142,000 |
| bunch population | $N_b$ | $2.3 \times 10^{12}$ |
| transv. emittance [$\mu$m] | $\epsilon_{x,y}$ | $1.9 \times 10^{-10}$ m |
| transv. normalized emittance [$\mu$m] | $\gamma\epsilon_{x,y}$ | 27 $\mu$m |
| rms bunch length | $\sigma_z$ | 4.8 mm |
| IP beta function | $\beta^*_{x,y}$ | 4.8 mm |
| IP rms spot size | $\sigma^*_{x,y}$ | 950 nm |
| rms energy spread | $\delta_{rms}$ | $2 \times 10^{-4}$ |

Side constraints for the final-focus optics design are that (1) quadrupole fields remain either below a maximum gradient of 400 T/m or below a peak field of 15 T at $5\sigma$, and (2) the free space from the exit face of the last quadrupole to the IP, $l^*$, is kept larger than 6 m.

A system was designed by Raimondi following the approach described in Ref. [4]. This system fulfills all the requirements above. Its total length is about 1 km per side. Optical functions are displayed in Fig. 1. For the round beams of the muon collider, the



L*= 6.1 m, Bx,y*= 4.8 mm

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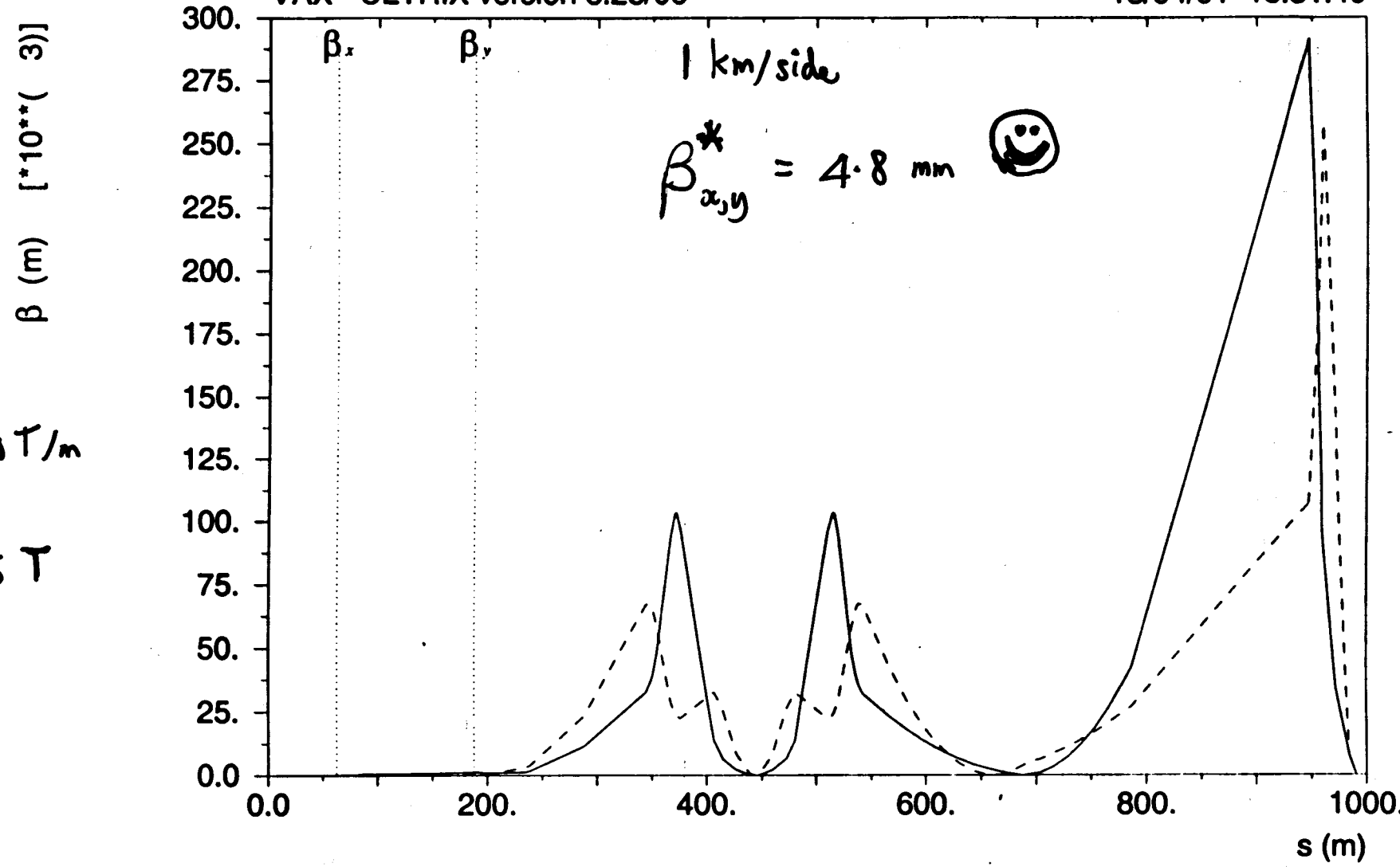


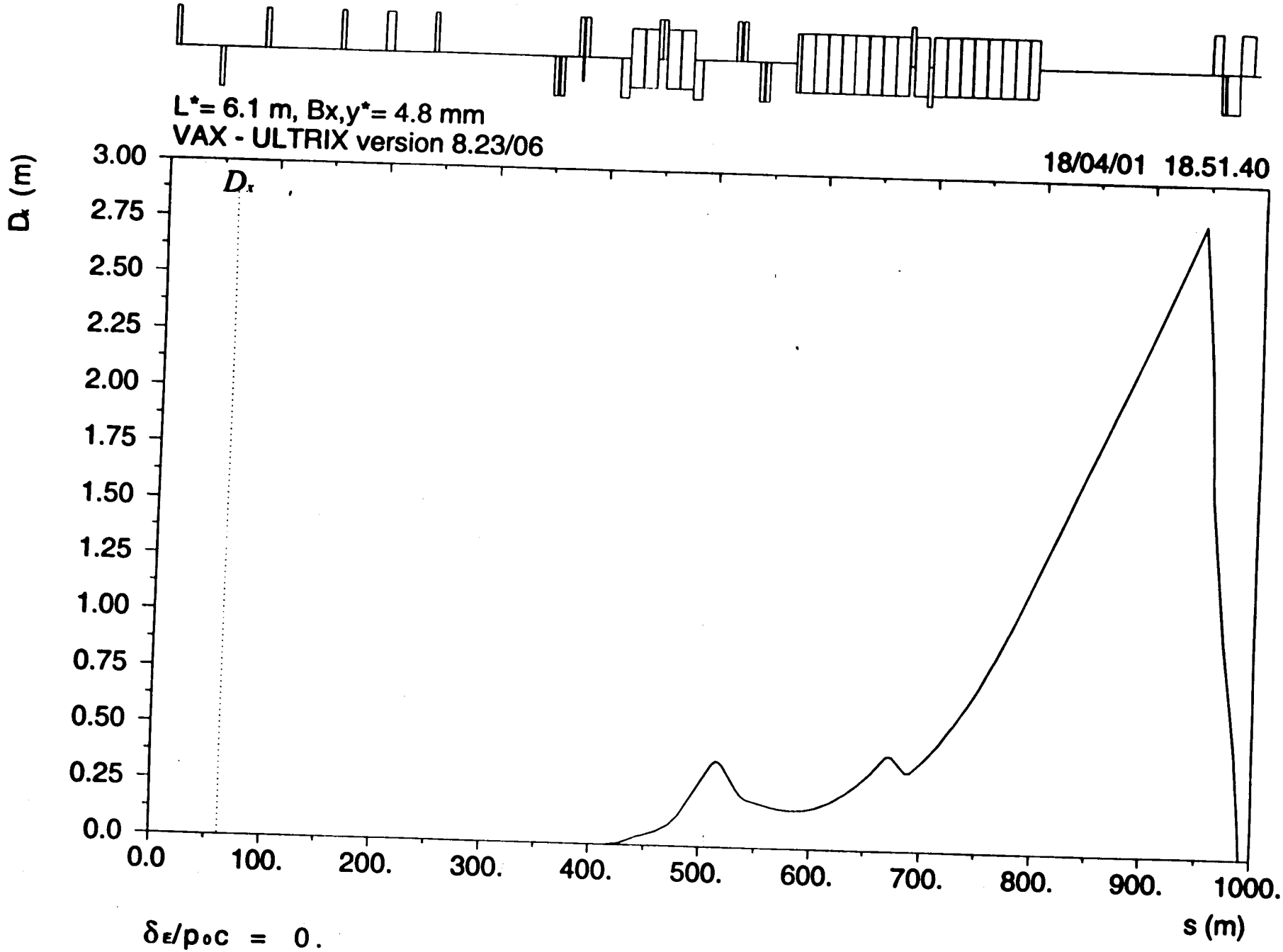

$g^{max.} = 400$ T/m

$B^{max}_{5\sigma} = 15$ T

$\delta_E/p_0c$ = 0.

Table name = TWISS

Raimondi 30 TeV β functions

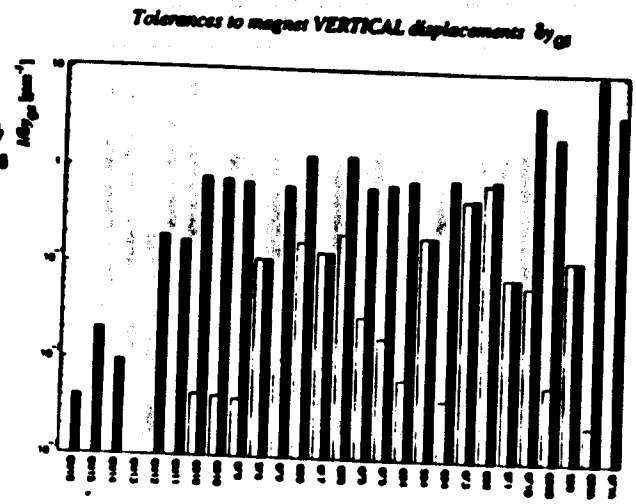



Raimondi 30 TeV Dispersion

# Raimondi 30 TeV

worst is

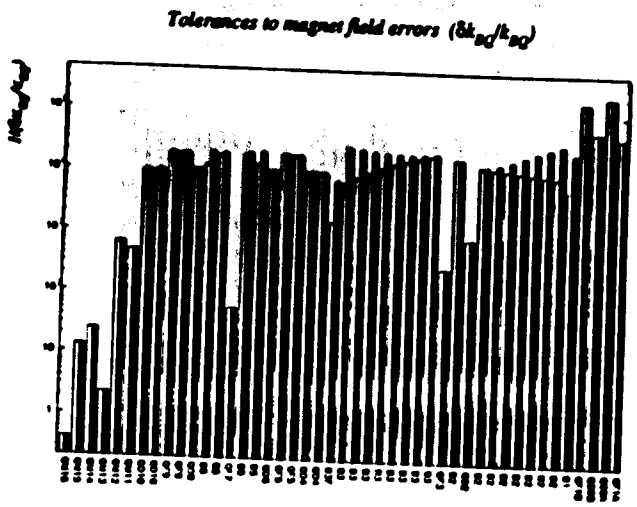
00 nm for $\Delta\mathcal{L} = -2\%$




magnet displacement tolerances

worst is

$5 \times 10^{-6}$ for 2% $\mathcal{L}$ loss




field strength tolerances

**FIGURE 6.** Single-pass vertical-displacement (top) and field-strength (bottom) tolerances [7] for quadrupole and sextupole magnets. Each value displayed corresponds to a luminosity loss of 2% per element and per beam. The full bars represent pulse-to-pulse 'jitter' tolerances, due to the induced orbit motion. The open bars are 'drift' tolerances referring to increases in the IP spot size. The final triplet magnets are on the right.

(OK)

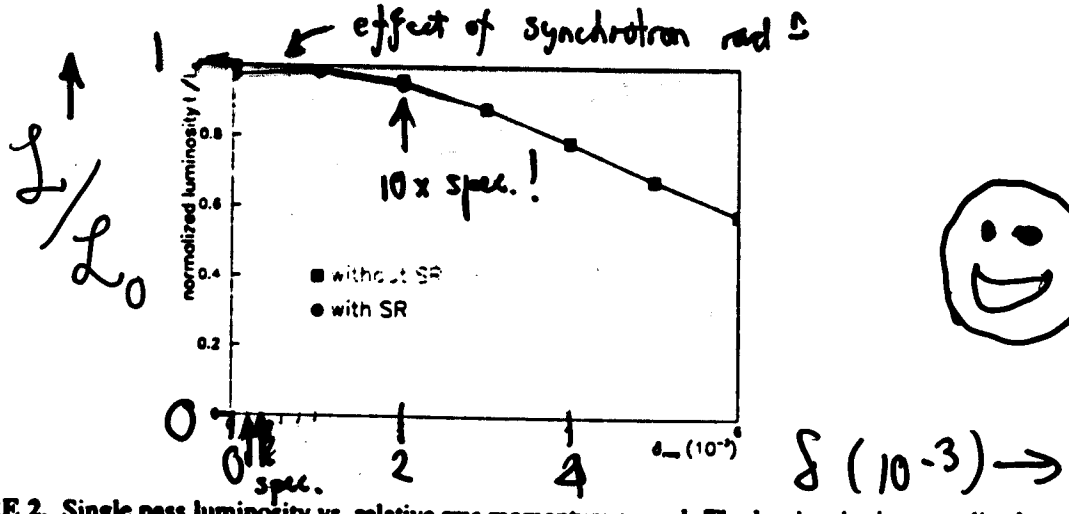



**FIGURE 2.** Single pass luminosity vs. relative rms momentum spread. The luminosity is normalized to the ideal goemetric luminosity. The two curves refer to simulations with and without synchrotron radiation.

a tolerance of 1 $\mu$m. The most challenging field-stability requirements are found for two of the final quadrupoles, for which the field must be stabilized to within $5 \times 10^{-6}$.

Spot size vs. $\delta p/p$ (single pass)

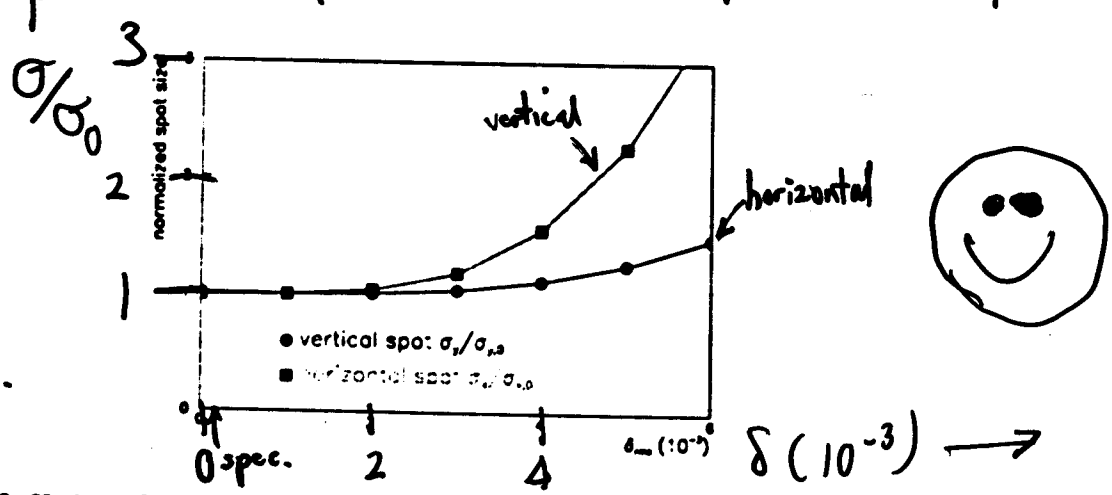



**FIGURE 3.** Horizontal and vertical rms spot sizes vs. the rms momentum spread for a single pass. Synchrotron radiation was included in the simulation. The spot sizes are normalized to the ideal linear ones, about 950 nm.

Raimondi 30 TeV

Spot size vs. emittance (single pass)

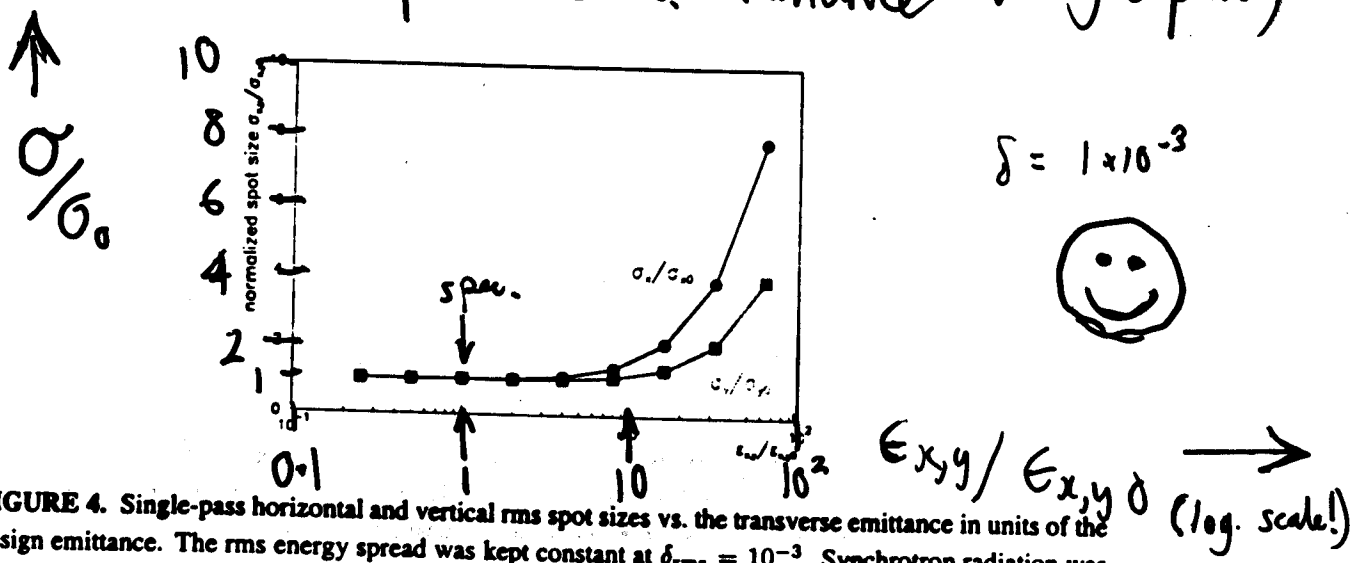



**FIGURE 4.** Single-pass horizontal and vertical rms spot sizes vs. the transverse emittance in units of the design emittance. The rms energy spread was kept constant at $\delta_{rms} = 10^{-3}$. Synchrotron radiation was included in the simulation. The spot sizes are normalized to the ideal linear ones.

$\mathcal{L}$ vs. turn number

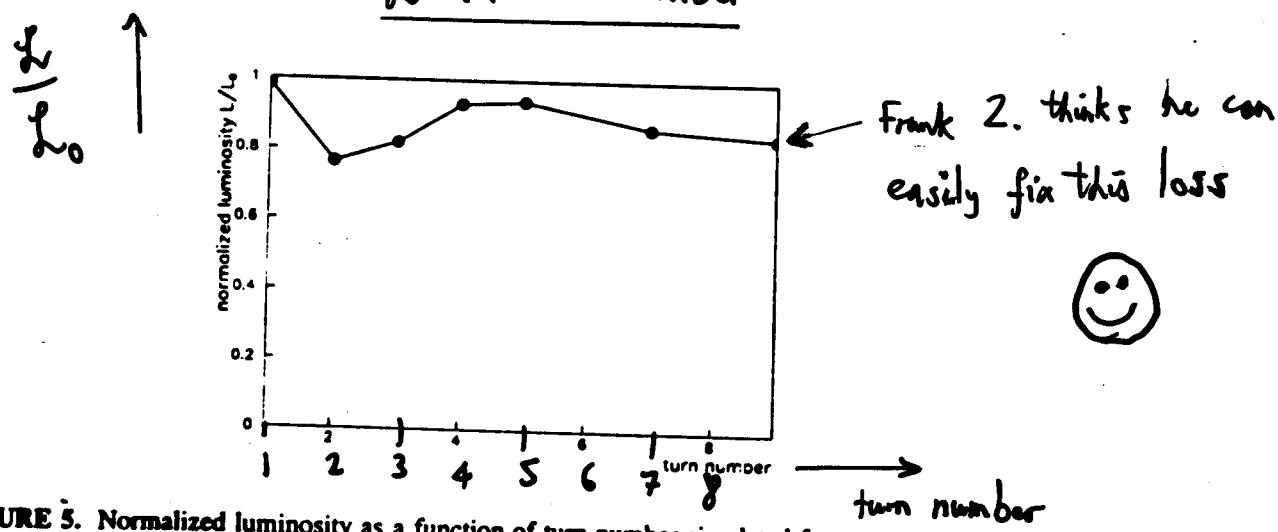



**FIGURE 5.** Normalized luminosity as a function of turn number simulated for a constant momentum spread of $\delta_{rms} = 10^{-3}$, including synchrotron radiation. The arc is modelled by a simple rotation matrix. The tunes are adjusted to $Q_x = 4.28$ and $Q_y = 3.31$.

Raimondi 30 TeV

# Conclusions

- thanks to Carol, Al & Katsunobu for writeups on '96 lattice designs
- super-duper new 30 TeV final focus from Raimondi & Zimmermann
- request to lattice designers:

  scale Raimondi lattice to few-TeV
  using $g = 400$ T/m $\rightarrow$ aim for strawman $\mu$-TESLA para.
  $\beta^* = 1$ mm
  $\delta = 3 \times 10^{-3}$