Accelerator Physics Issues for the VLHC

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The list is not new...

- Magnet Aperture
- Lattice Design
- Synchrotron Radiation
- Instabilities/feedback
- Longitudinal Parameters
- Beam-beam Effects
- Emittance Evolution/Control
- Energy Deposition
- Instrumentation and Diagnostics

… all issues present
in SSC, LHC designs

At 50 TeV, mostly just gets a bit harder...

- Synchrotron radiated power into magnets
- Stored beam energy
- Instability thresholds
- Ground motion sensitivity (motion amplitude vs. beam size)
- Etc…

… but, some possible advantages,

especially for high field options:

- Luminosity enhancement
- Simplified IR designs
- Integrated luminosity vs. initial emittances

Accelerator parameters (from Snowmass, 1996)

Parameter	High field-new technology	High field-known technology	Low Field	Units
CM Energy	100	100	100	TeV
Dipole field	12.6	9.5	1.8	T
Circumference	104	138	646	km
Synchrotron radiation damping time (horizontal amplitude)	2.6	4.6	*antidamped*	hr
Initial/peak luminosity	.35/1.2	.35/1.0	1./1.	10^{34} $cm^{-2}sec^{-1}$
Integrated luminosity per day	500	500	700	pb^{-1}
Number of stores per day	2	2	1	
Initial rms normalized emittance	1.	1.	1.	π μm-rad
β^*	20	20	20	cm
Protons/bunch	0.5	0.5	0.94	10^{10}
Number of bunches	20794	27522	129240	
Equilibrium emittance (x)	144.2	62	1.8	10^{-3} π μm-rad
Beam stored energy	.89	1.18	9.73	GJ
Synchrotron radiation power/ring	189	143	48	kW
Total protons/ring	1.1	1.5	12.2	10^{14}
Revolution frequency	2.89	2.18	.46	kHz
Synchrotron frequency	8.9	5.8	.86	Hz
Rf Voltage	100	100	100	MV
Radio-frequency	360	360	360	MHz
Energy loss/turn	3678	2778	526	keV
Rms relative energy spread(collision)	15.6	18.0	39.0	10^{-6}
Fill time	16.3	16.3	28	min.
Acceleration time	5.8	7.6	35.9	min.

Question: Can synchrotron radiation really help?

- Does SR at high field lessen the field quality requirements at injection?
- What is a viable magnet bore aperture, considering beam-screen requirements?
- Does SR simplify the IR optical design (doublets vs. triplets)

Magnet Aperture

Beam size vs.
pipe size vs.
coil diameter

- Cell length
- Phase advance
- Correctors
- Alignment

For phase advance

$$\mu = \sin^{-1}(L/2F) = 90^\circ$$

$$\hat{\beta} = 3.41\ L$$

$$\hat{D} = 2.71\frac{L^2}{R}$$

Where

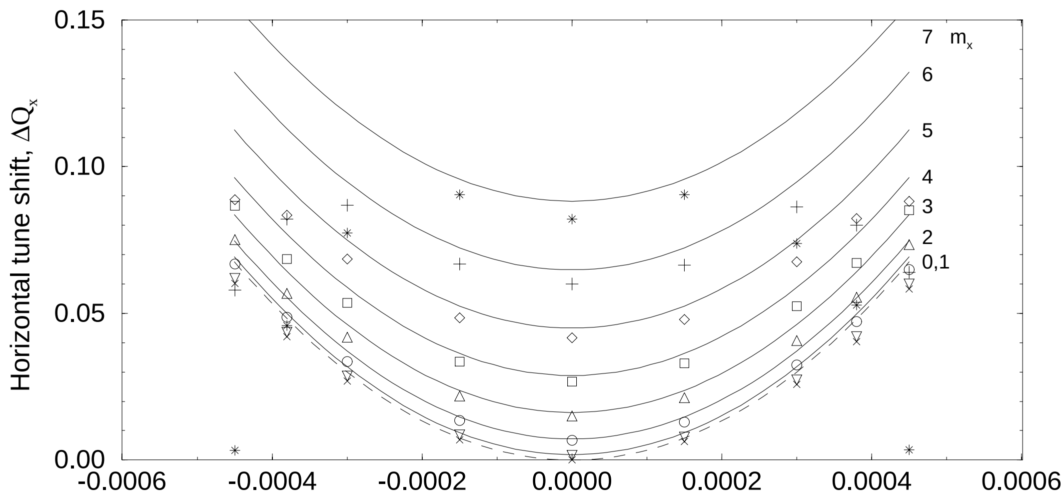
L = half cell length

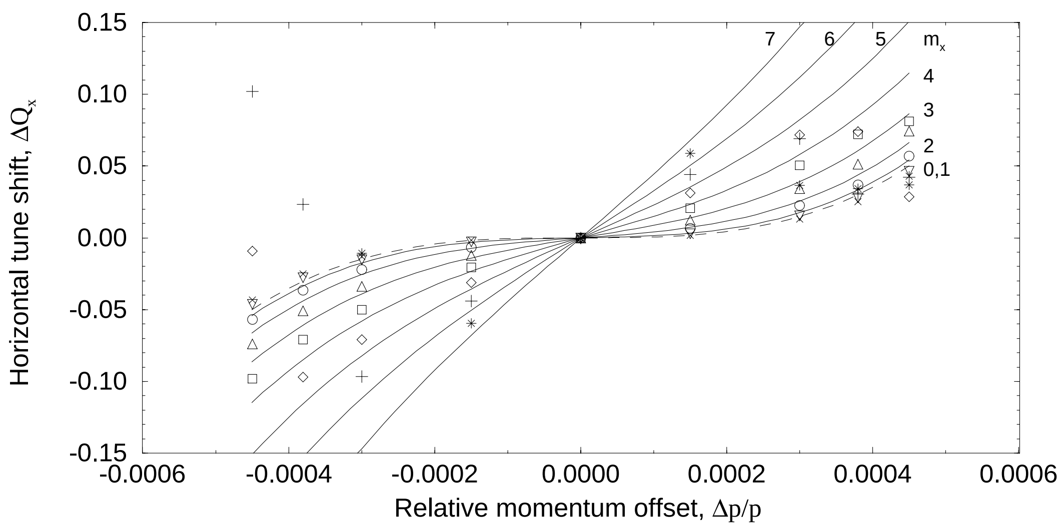
Tune shift due to systematic multipole, b_n:

n	Tune shift, $\Delta\nu$
1	$\langle\beta b_1\rangle/2$
2	$\langle b_2\beta D\rangle\delta$
3	$3\langle b_3\beta^2\rangle\varepsilon/8 + 3\langle b_3\beta D^2\rangle\delta^2/2$
4	$3\langle b_4\beta^2 D\rangle\varepsilon\delta/2 + 2\langle b_4\beta D^3\rangle\delta^3$

δ = rel. momentum, ε = emittance

TOP: octupole $b_3 = 5 \times 10^{-4}$ at $r_0 = 16$ mm.

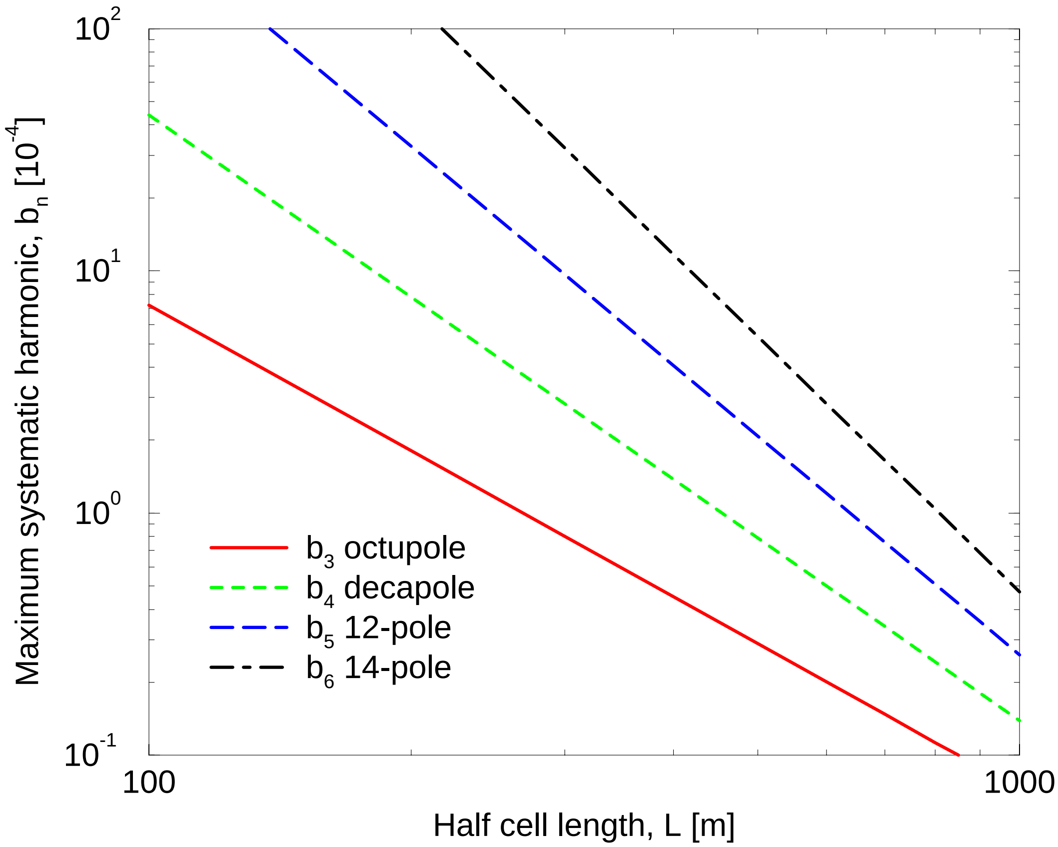




BOTTOM: decapole $b_4 = 30 \times 10^{-4}$.

Lines are prediction, symbols are numerical data.

How big can L be? How big can b_n be?



Maximum allowable systematic harmonics versus half cell length, when $\widehat{\Delta Q}_x = 0.1$, $\phi_c = 90$ degrees, $\epsilon_x = 1\mu$m, and $m = 3$, at an energy of 1 TeV, with a reference radius of $r_0 = 16$ mm.

Lattice Design

Utility Regions:

Injection, extraction, rf, instrumentation

Interaction Regions:

Low beta, orbit/tune/chromaticity control, dispersion, crossing angle

Arcs:

standard cells

- half cell length; correction packages
- dispersion suppressors at ends of arcs
- enhancement of SR damping times (e.g., using small constant gradients in bending magnets -- high field option)

access/corrector regions

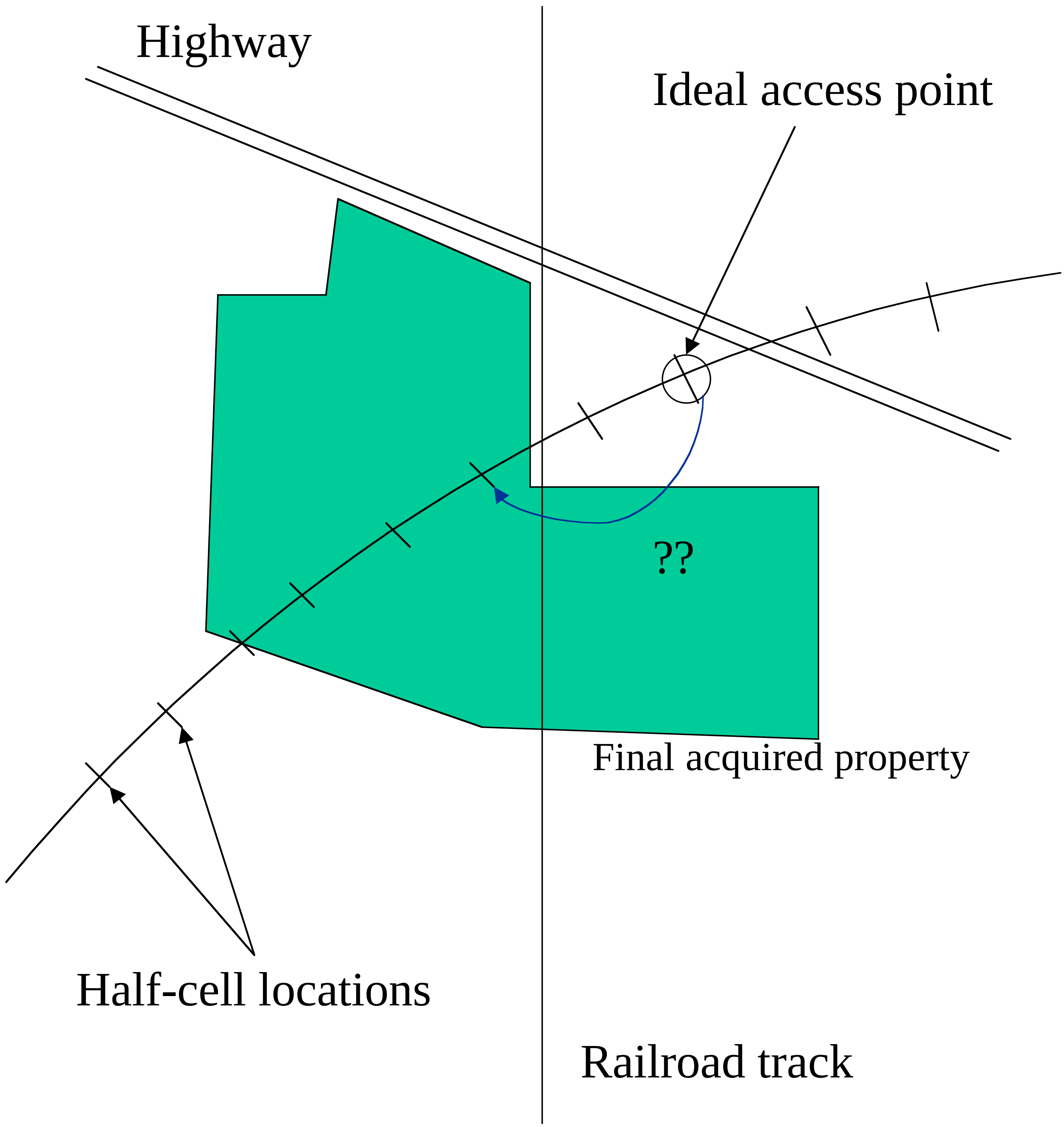
- localize correctors to be near tunnel access areas?

warm/free space

power/feed points, future upgrades (e.g., dampers, instrumentation, spin devices, etc.)

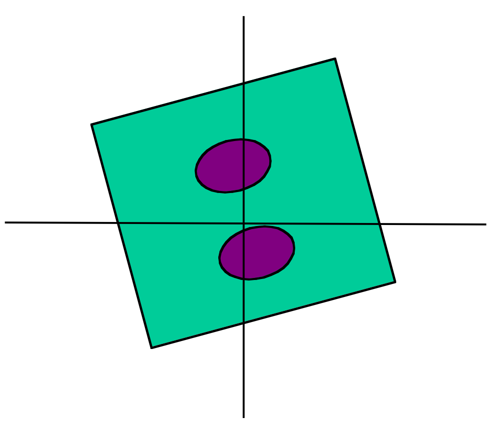
*** ***modularity*** ***

Incorporate engineering needs (power/cryo feed points, recoolers, etc.) into lattice design as soon as practical


Highway
Ideal access point
??
Final acquired property
Half-cell locations
Railroad track

Alignment Issues

- Orbit control vs. cell length
  - Accuracy of local smoothing of magnet placement, etc.
- Local coupling and its effects
  - Quadrupole roll
- Ground Motion
  - Long term motion, re-alignment
- Alignment of "two rings" while using 2-in-1 magnets

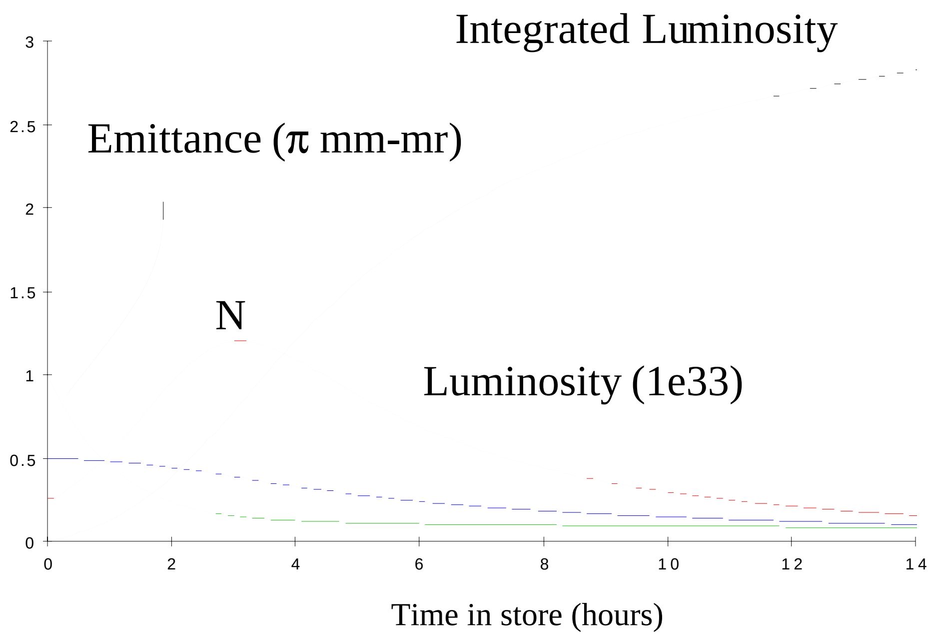


Synchrotron Radiation

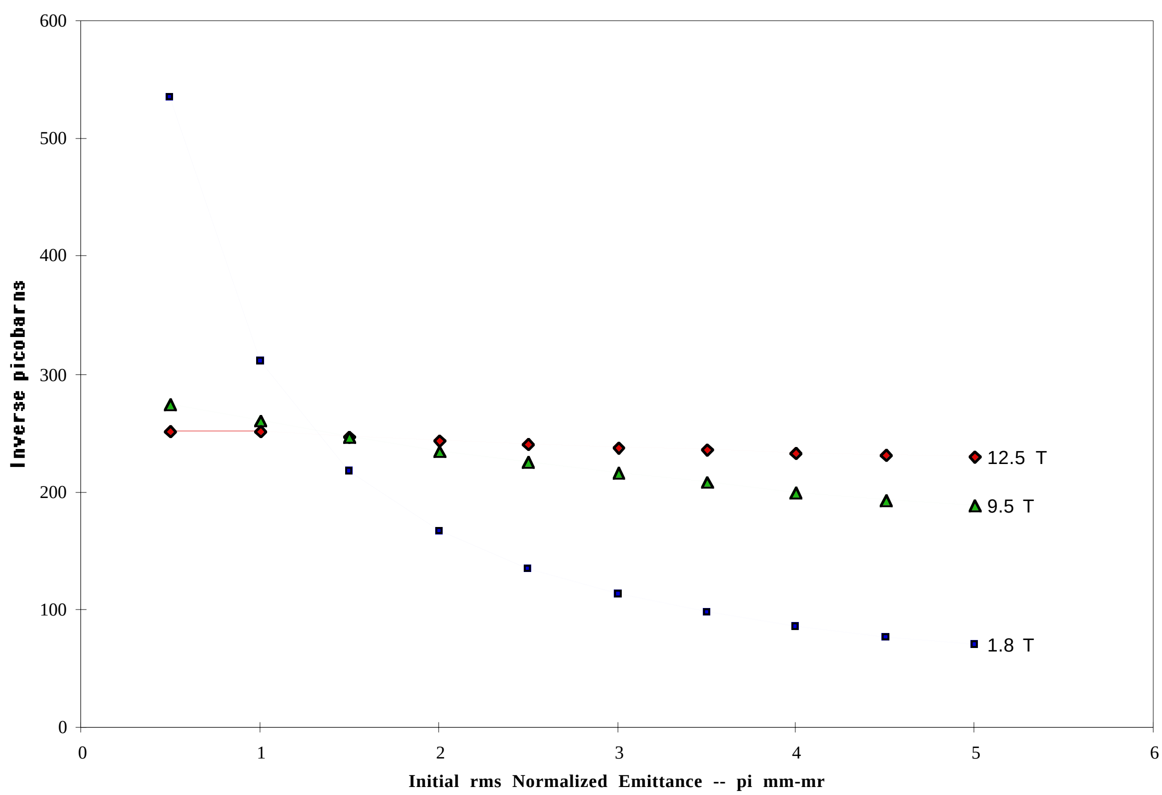
- Impacts on
  - cryo system
  - beam screen/liner
  - (and hence, magnet design…)

  - Low-field (Snowmass): 48 kW / (646 km * 0.8)
    = 0.09 W/m
  - Hi-field (Snowmass): 189 kW / (104 km * 0.8)
    = 2.3 W/m

- Enhancement of luminosity
  - high field option



Integrated Luminosity over 10 hours vs. Initial Emittance



Longitudinal Parameters

- Accelerating voltage (w/ or w/o Synch. Rad.)

- Choice of radio frequency and bunch length

- Longitudinal heating for IBS lifetime control,
  Landau damping, etc.

Instabilities and Cures

- resistive wall, head-tail, multibunch, etc.
  Beam pipe requirements: diameter, material, etc.

- ring-wide impedance budget and its control
  beam pipe AND rf cavities, BPM's, kickers, septa,
  magnet interconnects, etc.

- feedback and *feedforward* systems
  Low field -- resistive wall multibunch instability
  growth times (Snowmass) < *1 turn!*

Beam-beam Effects

- Head-on incoherent tune shift tolerance
  Reduced with flat beams (high field?)

- H.O. tune shift compensation using electron beams?
  test set-up at Fermilab (Shiltsev, et al.)

- Parasitic crossings
  long range coherent tune shifts, compensation

Emittance Growth and Control

- injection errors
  e.g., $\Delta x/\sigma_x$ = 1mm/0.5mm ---> 3x emitt. growth

- ground motion, power supply ripple, RF noise, etc.

- synchrotron radiation mitigates the deterioration
  of transverse emittance in the high field designs;
  how much *can* we tolerate at injection, though?

Energy Deposition

- Beam induced radiation effects
- Beam Abort Systems
- Beam Halo Scraping Systems

Comparisons:

Tevatron:	1 TeV x 2e13 = 0.003 GJ
SSC:	20 TeV x 1e14 = 0.3 GJ
LHC	7 TeV x 5e14 = 0.6 GJ
VLHC (hi)	50 TeV x 1e14 = 0.9 GJ
VLHC (low)	50 TeV x 1e15 = 9.0 GJ

- Interaction Region Element Protection

power delivered into IR quads:

50 TeV x 10^{34} $cm^{-2}sec^{-1}$ x 130 mbarn

10 kW *in each direction*

Instrumentation and Diagnostics

- Instruments to measure...
  - Beam positions
  - Tunes
  - Beta functions
  - Chromaticity
  - Transverse profiles
  - Bunch length
  - Etc...
- Data analysis and database issues
- Hardware reliability, radiation hardness, etc.
- Measurements usually to ~10% accuracy

Do we need better? (likely YES!)
Can we do better? (…..*????*)

Future Directions...

- Need to learn from experiences at SSC and other large projects (HERA, RHIC, LHC, …)
- Need to look for new and innovative ideas…
  - 4-bore full-range magnet? (Gupta)
  - Low-field injector with high-field storage ring?? (Dugan)
  - ??????
- Upcoming event:

  VLHC Accelerator Physics Workshop

  Feb. 22-25, 1999

  Fontana, WI (on Lake Geneva)

A Common Coil Magnet System for VLHC

(May eliminate the need of a high energy booster)

A 4-in-1 magnet for a 2-in-1 ring