"With the fire from the fireworks up above..."

The Solenoid and the Crossing Angle

Nanobeams 2002

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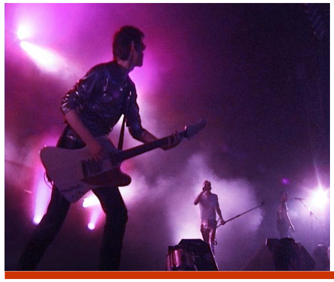
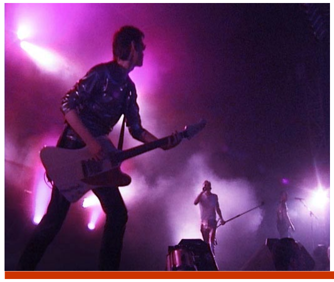


Actual work done by:

John Irwin

Tor Raubenheimer

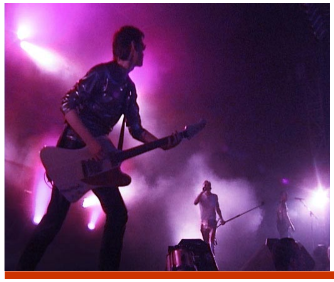
PT



Intro: Why Have a Crossing Angle?

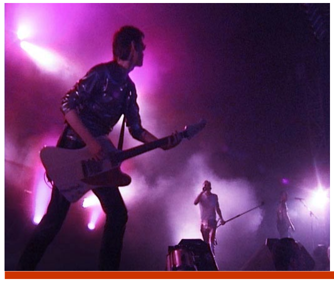
- Long bunch trains, short bunch spacing
  - NLC: 1.4 nsec
  - eliminates parasitic beam-beam effects
- Strong beam-beam interaction
  - lots of pairs, beamstrahlung, other junk
  - disrupted primary beam with big outgoing divergence, energy spread
  - can go out a different hole from incoming beam
- Removal of extracted beam
  - Don't need kickers, septa, etc to take outgoing beam to the dump

(I assume that the answer to, "Why have a solenoid in the detector?" is self-evident)



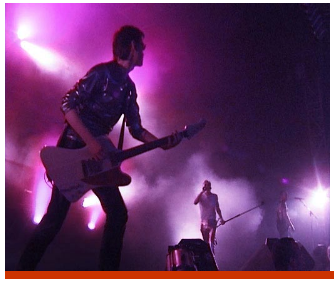
How big a Crossing Angle?

- Parasitic beam-beam: 3-4 mrad will take care of this
- Engineering, other constraints may push to bigger angles
- NLC: 20 mrad horizontal crossing angle
  - Leave room for doublet magnets, vacuum chambers, etc.
- CLIC: 20 mrad horizontal crossing angle
  - bigger angle needed at higher energy due to bigger divergence of collision debris

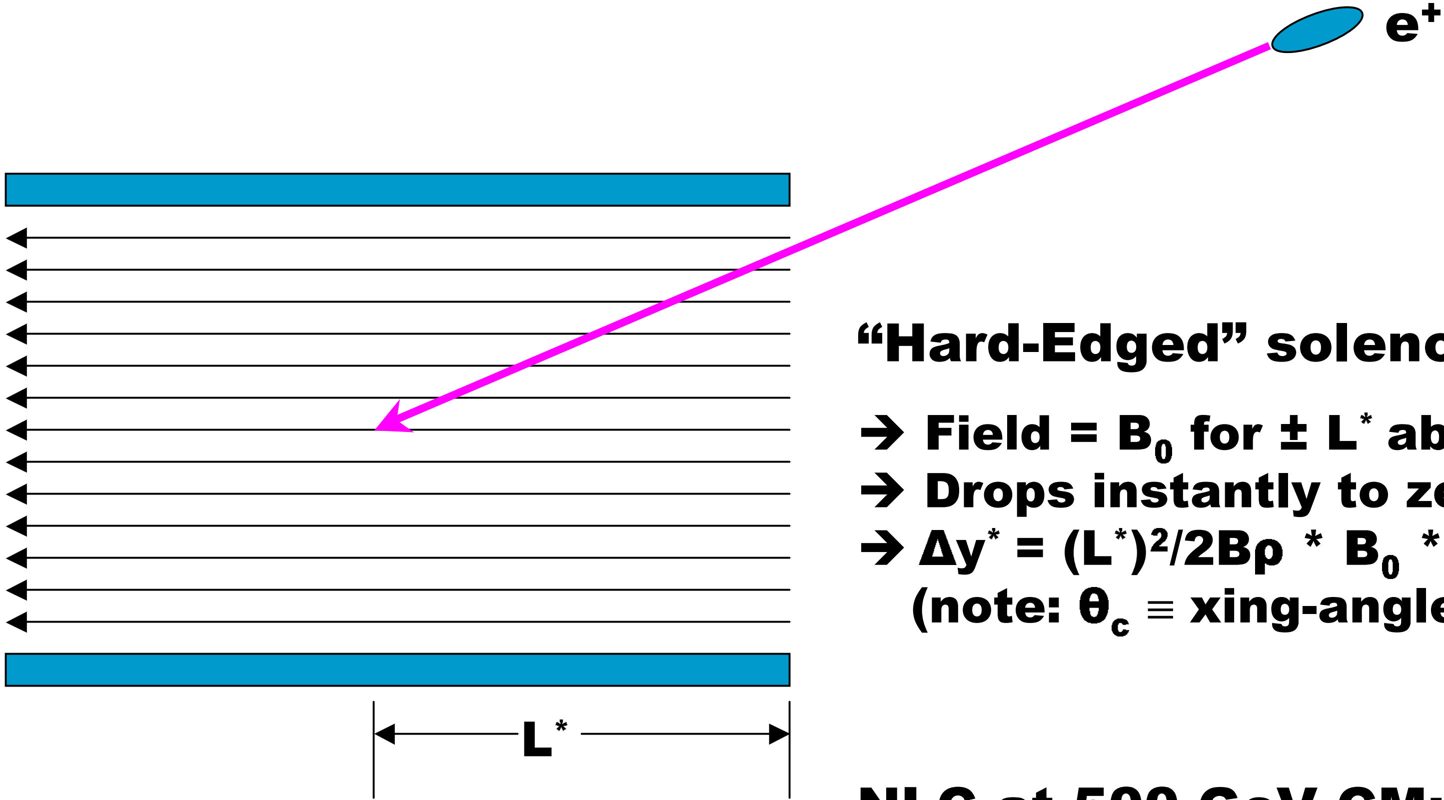


What's the Problem?

- Deflection of the beam in the solenoid field
  - produces offset, angle at IP – do the beams miss?
  - Produces dispersion and coupling – are the beams too big?
- Synchrotron Radiation
  - How much spot size growth from the quantum excitation?
- Consider *only* the solenoid for now
  - ignore any embedded quads – more complicated problem!



Optical Effects – What We're Afraid Of

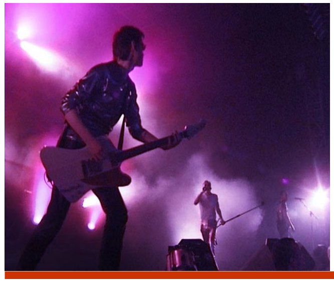


"Hard-Edged" solenoid model:

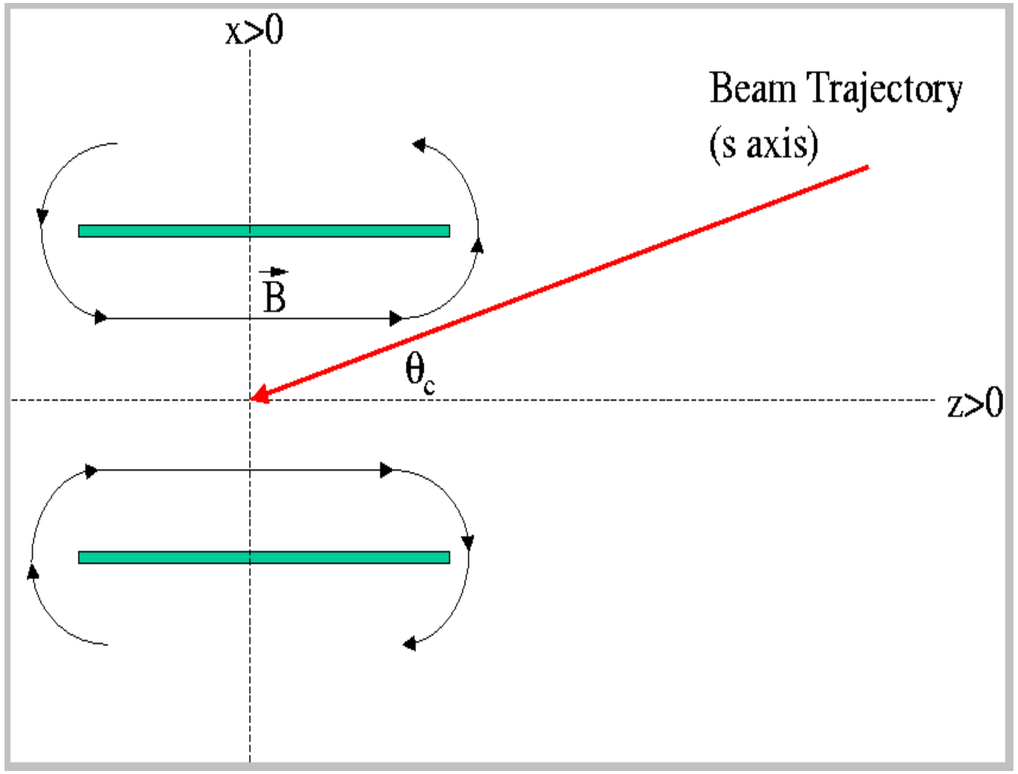
→ Field = B_0 for ± L^* about IP
→ Drops instantly to zero for $|z| > L^*$
→ $\Delta y^* = (L^*)^2/2B\rho * B_0 * \sin\theta_c$
(note: $\theta_c \equiv$ xing-angle / 2)

NLC at 500 GeV CM: 370 μm

Yikes!



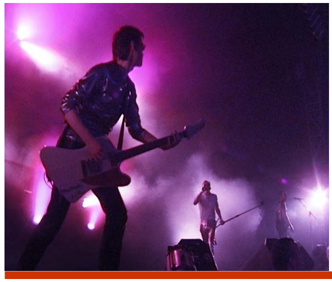
The Real Situation



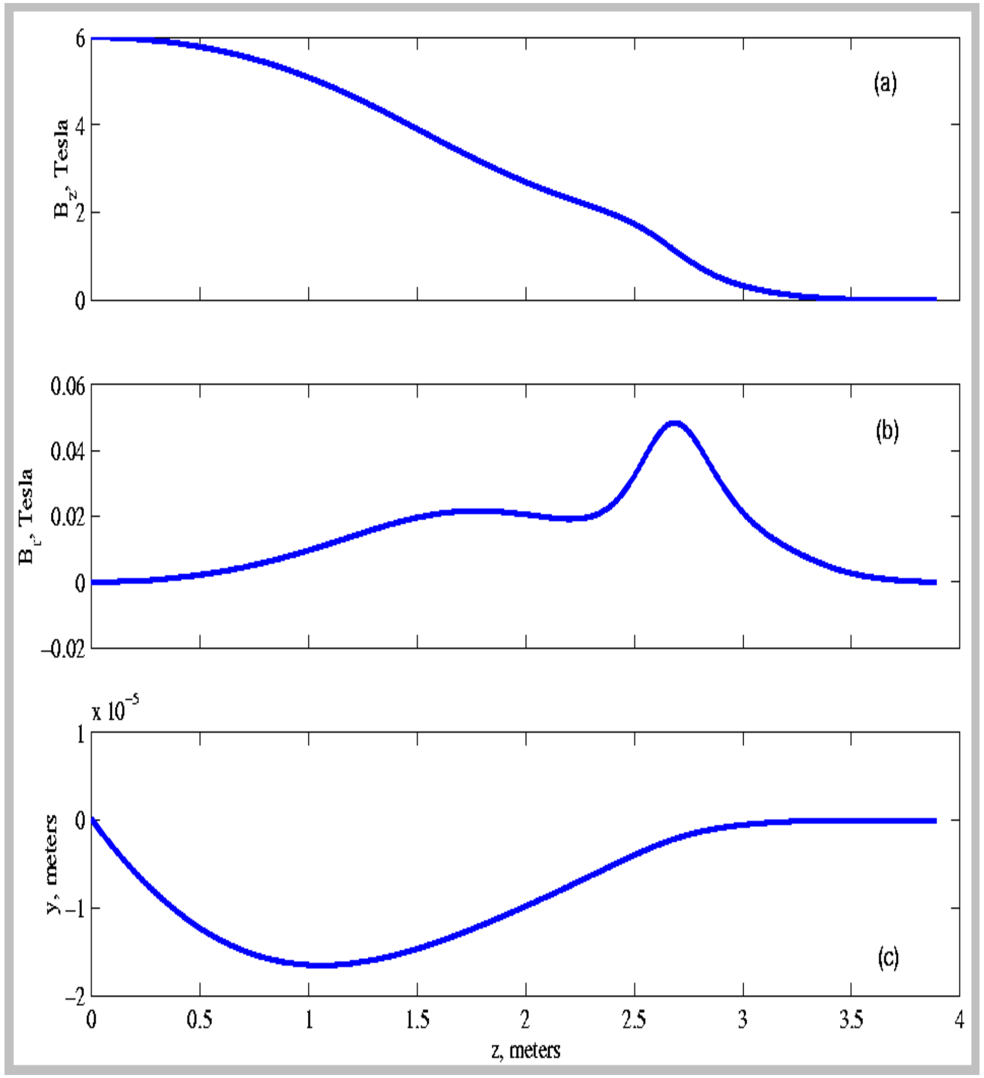
Longitudinal field deflects beam ~ sin θ_c

Radial field deflects beam ~ cos θ_c in opposite direction

Which one wins?



Which One Wins?



Radial and longitudinal deflections will cancel @ IP, **iff:**

- ➔ **Azimuthal symmetry preserved**
- ➔ **Beam initially aimed at symm point of the solenoid**
- ➔ **Beam does not pass thru solenoid windings (“barrel”) but only current-free (“endcap”) region**

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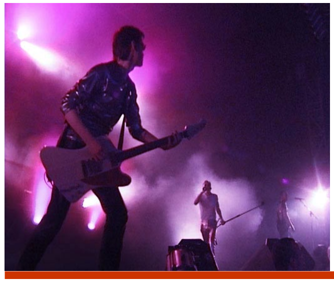
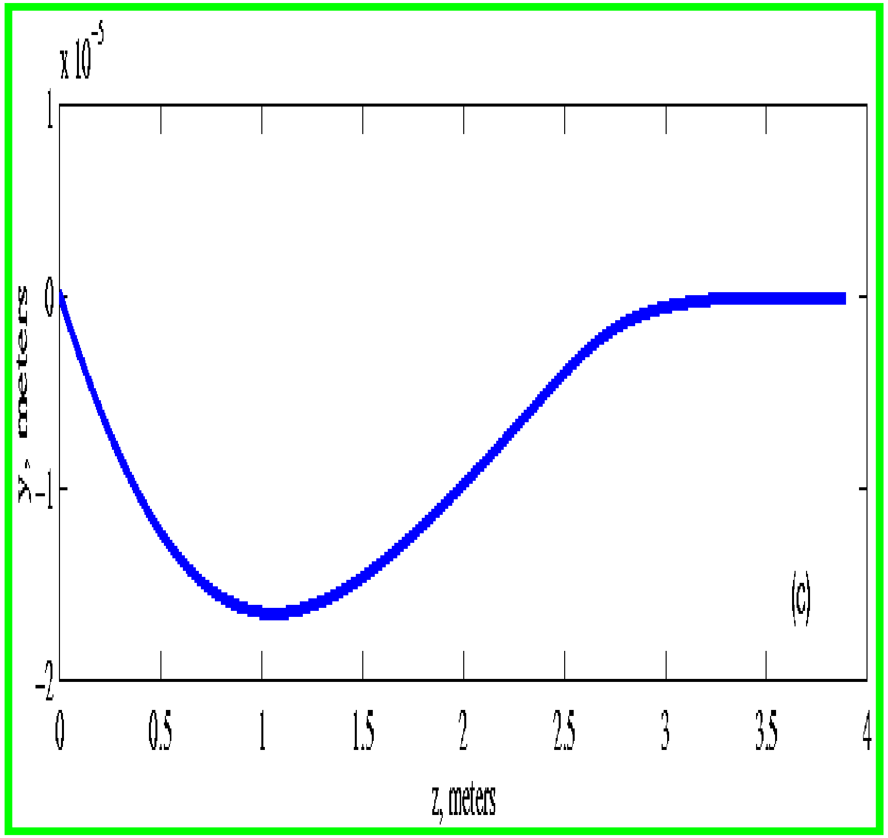


The Fine Print



Deflection cancels at IP

Hence dispersion, coupling, offset at IP → 0 also

y' at IP nonzero

Beams exit IR with vertical offset, sensitive to energy

can be up to 1 mm or more!

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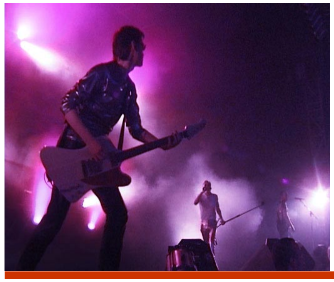
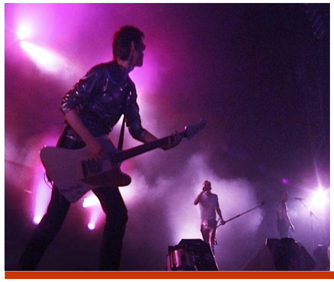


SR Spot Size Dilution

- Beam bends vertically in solenoid
  - first one direction, then the other
  - Must emit SR as a result of bending
- Dispersion zero at IP, but R_{36} from various points to IP nonzero
- Increase in RMS energy spread + nonzero R_{36} to IP = SR spot size dilution
- Unrecoverable luminosity loss!



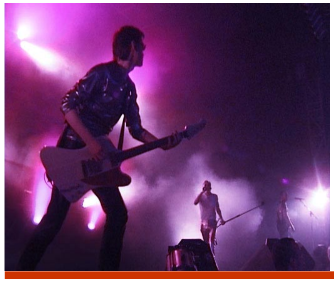
How Bad is SR blowup?

$$\Delta\sigma_y^2 = \Sigma_{points} \langle \text{MS E loss} \rangle * (R_{36} \text{ to IP})^2$$

$$\frac{55\, r_e\, \lambda_e \gamma^5}{24\sqrt{3}\, |\rho^3|}\, dz$$

$$R_{36}(z \rightarrow IP) =$$

$$\int_0^z z'dz'[B_z(z')\sin\theta_c - B_r(z')\cos\theta_c] \,/\, B\rho$$

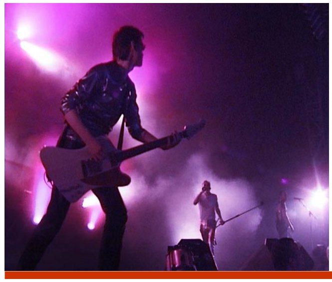


A Few Transformations...

Define $b(z) \equiv [B_z(z')\sin\theta_c - B_r(z')\cos\theta_c] / [B_z(z=0)\sin\theta_c]$

Define $z_{max} \equiv$ z position where $R_{36}(z \rightarrow IP) = 0$

Define $u \equiv z / z_{max}$



An Interesting Result

m² Tesla radians m

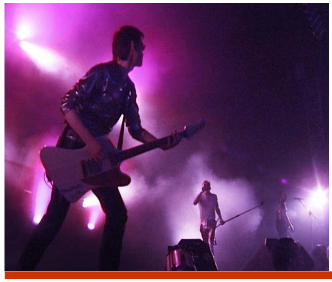
$$\Delta\sigma_y^2 \sim 1.0 \text{ x } 10^{-13} \, [B_z(0)\theta_c z_{max}]^5 \text{ x }$$

$$\int_0^1 du \, |b^3 (u)| \quad [\int_0^u du' \, u' \, b(u')]^2$$

→ **All dimensionful scaling parameters out front**

→ **All integrals over dimensionless "field shape" parameters**

→ **Beam size growth independent of energy!**



How Bad Is It?

- Putting in NLC parameters…
  - $\Delta\sigma_y$ is 0.03 to 0.1 nm (depends on details of solenoid map used in calc)
  - Adds in quadrature with 2-3 nm vertical beam size
  - Negligible!
  - But watch out for that 5th power scaling!