Beam Dynamics of the IR: The Solenoid, the Crossing Angle, The Crab Cavity, and All That

ALCPG Meeting

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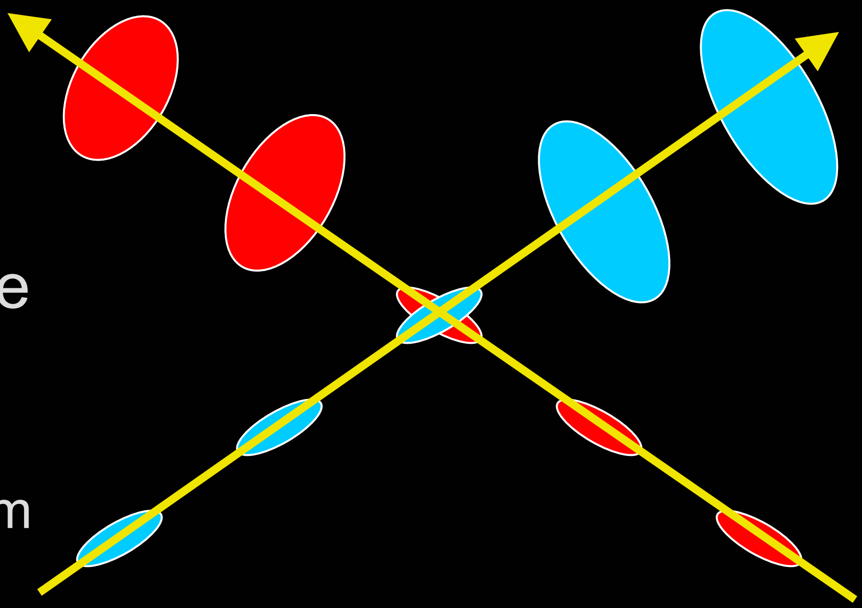
STANFORD LINEAR ACCELERATOR CENTER

GLC/NLC – X-Band Linear Collider

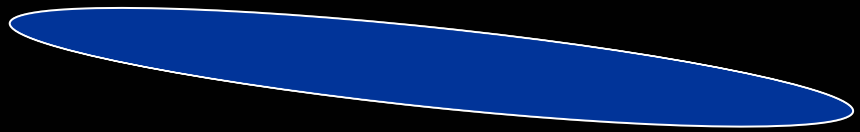
Why Have a Crossing Angle?

- Warm: minimize "parasitic collisions"
  - Collisions between bunches away from IP
- Warm or Cold: disrupted beam exits thru separate hole
  - Decouples incoming, outgoing beam requirements on doublet
  - Don't need dodgy kicker/septum extraction system in FF
  - Probably necessary for very high energy and/or luminosity



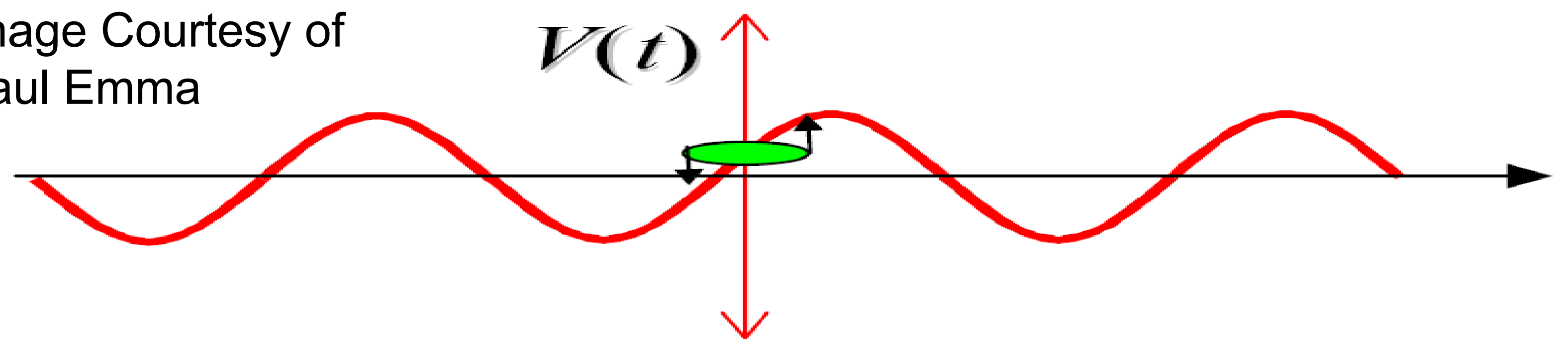
Aspect Ratio Problem

- Consider beam dimensions
  - Warm:
    - σ_z = 110 μm
    - σ_x = 240 nm
    - θ_{diag} = 2.2 mrad
  - Cold:
    - σ_z = 300 μm
    - σ_x = 500 nm
    - θ_{diag} = 1.7 mrad
- Crossing angle > θ_{diag} will blow up projected x beam size, reduce luminosity



Crab Cavity

Image Courtesy of
Paul Emma



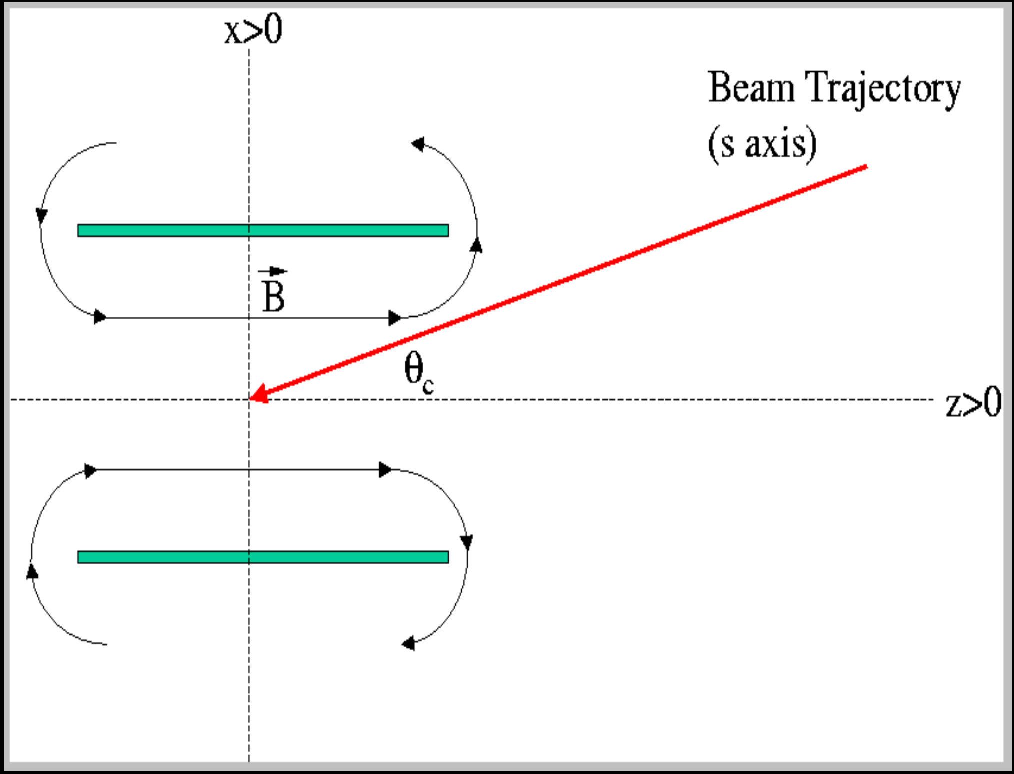
- Solution to Aspect Ratio problem: deflect head and tail to cancel growth in projected beam size
  - time-varying deflection can be provided by dipole-mode accelerating structure
    - "deflecting cavity"
  - put beam on zero crossing to kick head one way and tail the other
    - "crab cavity"

Crab Cavity Phase

- Key stability tolerance: *difference* in RF-to-beam phase between two beams
  - causes net transverse offset
  - 2% lumi lost if one RF-to-beam phase varies by 0.025º of S-band w.r.t. the other
  - Note: both warm and cold have similar tolerance on RF-to-beam stability of bunch compressor RF
    - 0.1 — 0.2º of L-band
  - Small number of systems to monitor (one cavity per side), conceptual engineering solutions exist
    - brute force: ultra-precise phase monitor ~ $250 k / channel

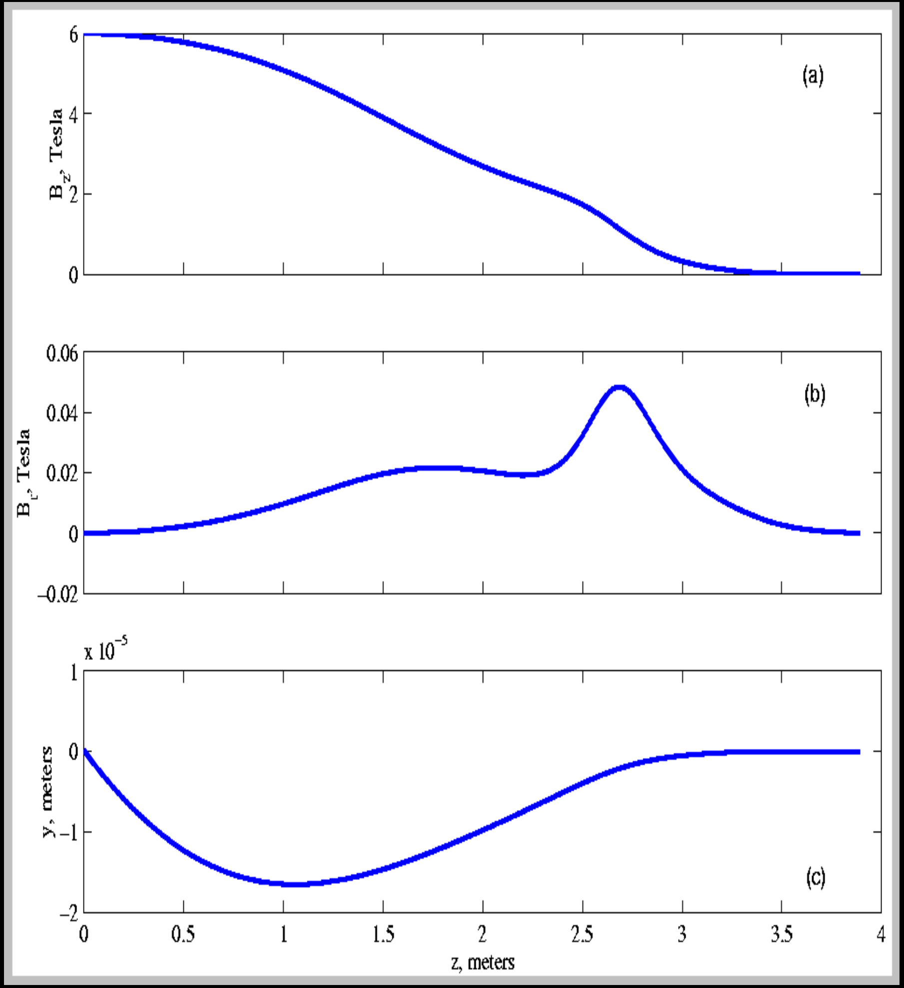
Solenoid with a Crossing Angle

- Beam passes thru solenoid fringe field…
- …and then thru the main field with an angle…
- …resulting in deflections thru IP
- Note that fringe field and main field have opposite effects



Note: For now, consider old LCD "S" solenoid (6 T, short), no quads in solenoid field, 500 GeV beam energy

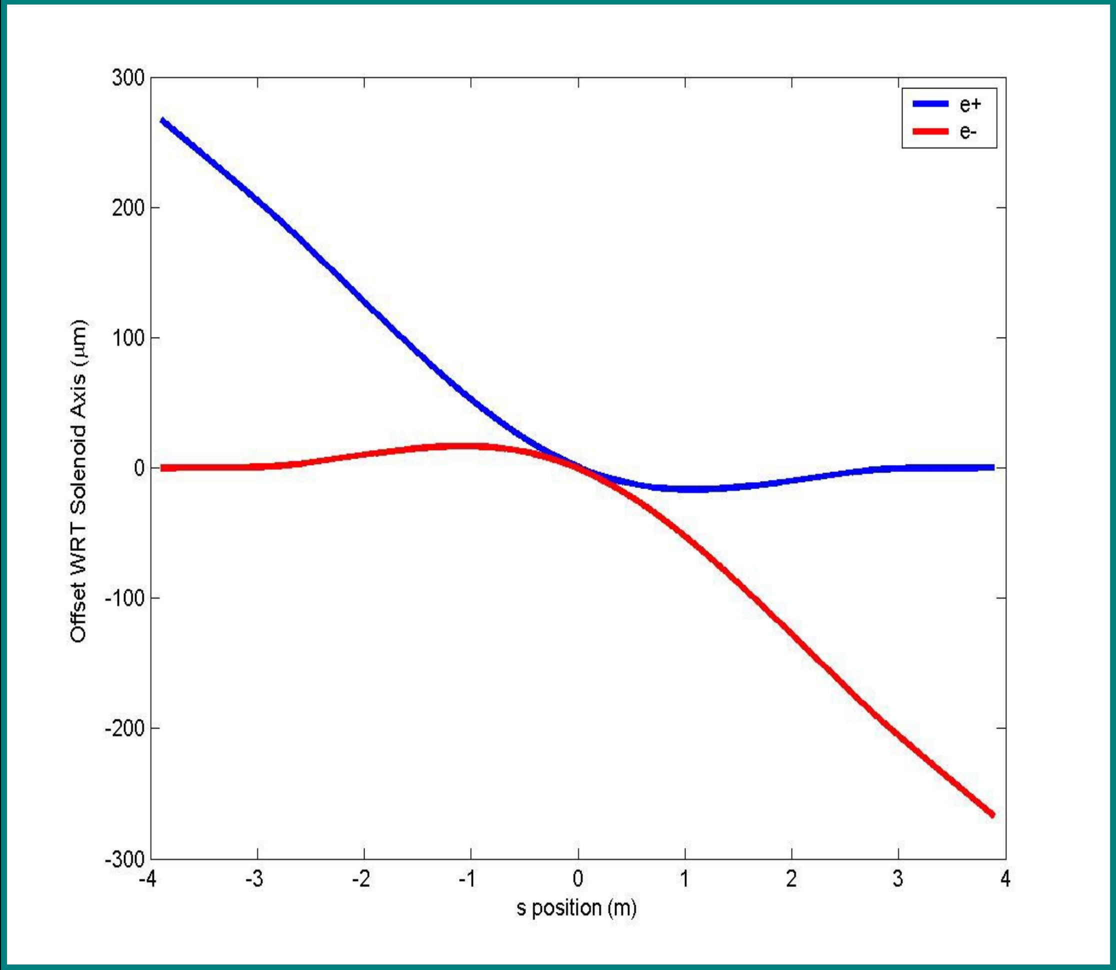
Deflection of Solenoid



- In a pure solenoid field, the fringe- and main-field deflections cancel at IP
- Check out *PRST-AB*, 6:061001 (2003) for details
- Implies that dispersion and x'y coupling also cancel at IP

Deflection of Solenoid (2): Outgoing Beam

- Beams collide with vertical angle wrt solenoid axis
- Solenoid bends outgoing beam more
- Energy loss @ IP (from collision) will change outgoing trajectory!
- In this example: 10% loss → 13 μm movement @ exit
- Will impact intra-train collision feedback



Deflection of Solenoid (3): Horizontal Motion

Horizontal motion of the solenoid breaks the symmetry which cancels IP vertical offsets → horizontal solenoid jitter becomes vertical beam jitter

$$\Delta y^* = \frac{\Delta x}{2B\rho}\cos\theta_c \int B_z dz$$

At high energies (500-1000 GeV CM), solenoid horizontal motion tolerance ~0.1 μm

At lower energies: depends on scaling of IP beam size (do we need to relax β^*?)

Synchrotron Radiation Spot Size Dilution

The deflection due to off-axis passage thru the solenoid leads to SR, thus spot size growth.

In general, estimating the spot size growth from SR requires a detailed calculation for a given field map.

Present example has 0.074 nm growth, added in quadrature with nominal beam size (ie, nothing).

Dilution scales as $(B\theta_c L_{sol})^{5/2}$ and is *independent* of energy!

Embedded Quads in Solenoid

- Quads in the solenoid field cause problems for the crossing-angle design
  - solenoid symmetry broken – IP offset, dispersion, coupling do not cancel
  - Settings that correct one problem (ie, offset) do not correct the others
- And also cause more general problems regardless of crossing angle
  - Coupling correction required – can be a big headache!

Embedded Quads in Solenoid – Old NLC FF (ZDR-like)

- Studied solenoid compensation with 2 m L^*, 6 T short solenoid
- What was needed
  - move last quad 2.6 μm (correct IP steering)
  - move SD sextupoles 1.5 μm (correct dispersion)
  - Tune FD skew quad and other coupling correction skew quads (a few gauss each)
- Spot size growth ~1.5% compared to no solenoid case

Embedded Quads in Solenoid – New FF

- Considerable changes to interaction region since February 1999
- new FF with different optics and larger L^*
- Different solenoid configurations
- Smaller emittances
- Larger crossing angle in LEIR
- Need to revisit solenoid compensation
  - my guess: hardest part will be getting skew compensation right (independent of crossing angle)