Beam Delivery System Design Differences

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Introduction

Fundamental Warm/Cold differences vs. Design Choice:

a. dE/E
b. E vs. z correlation
c. Bunch Length
d. L*
e. Positron production
f. Flexibility of parameters for special running
g. Off-energy running: updated parameter lists(?)
h. IP1 vs. IP2 Performance

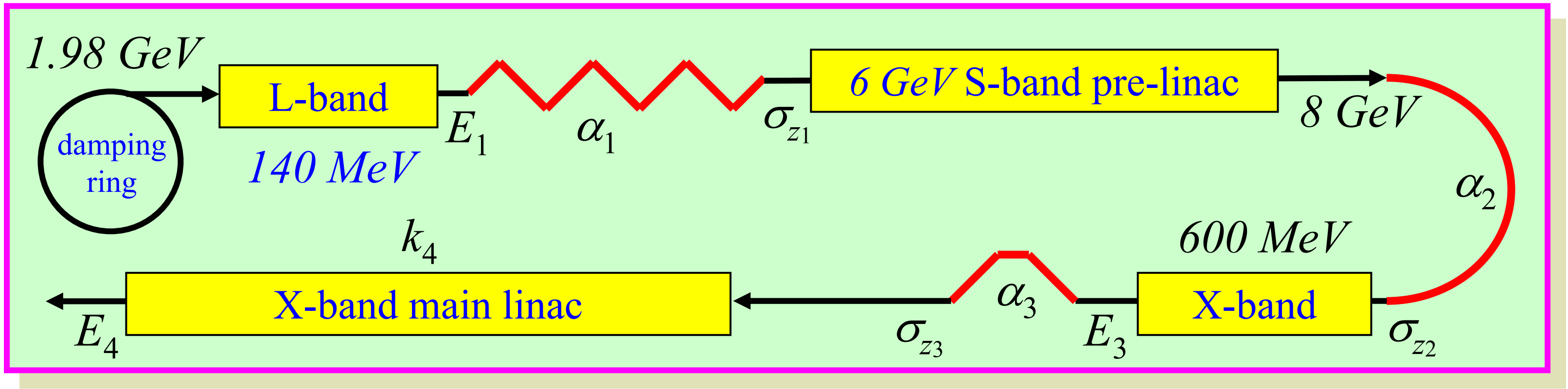
Bunch Length: warm / cold Differences

- The bunch length must be reduced from the damping ring length of ~ 5 mm to the linac length of a few hundred μm
  - Reduces hourglass (minimum β* ~ σz)
  - Reduces transverse wakefields (increases longitudinal wakes)
- Bunch length reduced in magnetic bunch compressors
  - Longitudinal phase space is essentially conserved

    Intrinsic energy spread: ΔE * σz in the DR = ΔE * σz in BC
  - Relative energy spread decreases with acceleration
  - Emittance dilutions tend to scale with $(\Delta E/E)^2$
- SC has higher energy DR (larger longitudinal emittance)
  - Uses single stage compressor to go from 6 mm → 300 μm
- NC uses 2-stage compressor to go from 5 mm → 110 μm
  - Keeps ΔE/E small and maintains ϕ-E relation but is more complex
  - Allows for feed-forward from DR extraction

Bunch Compression: warm / cold Differences

- NLC 2-stage compressor (See LCC-0021)



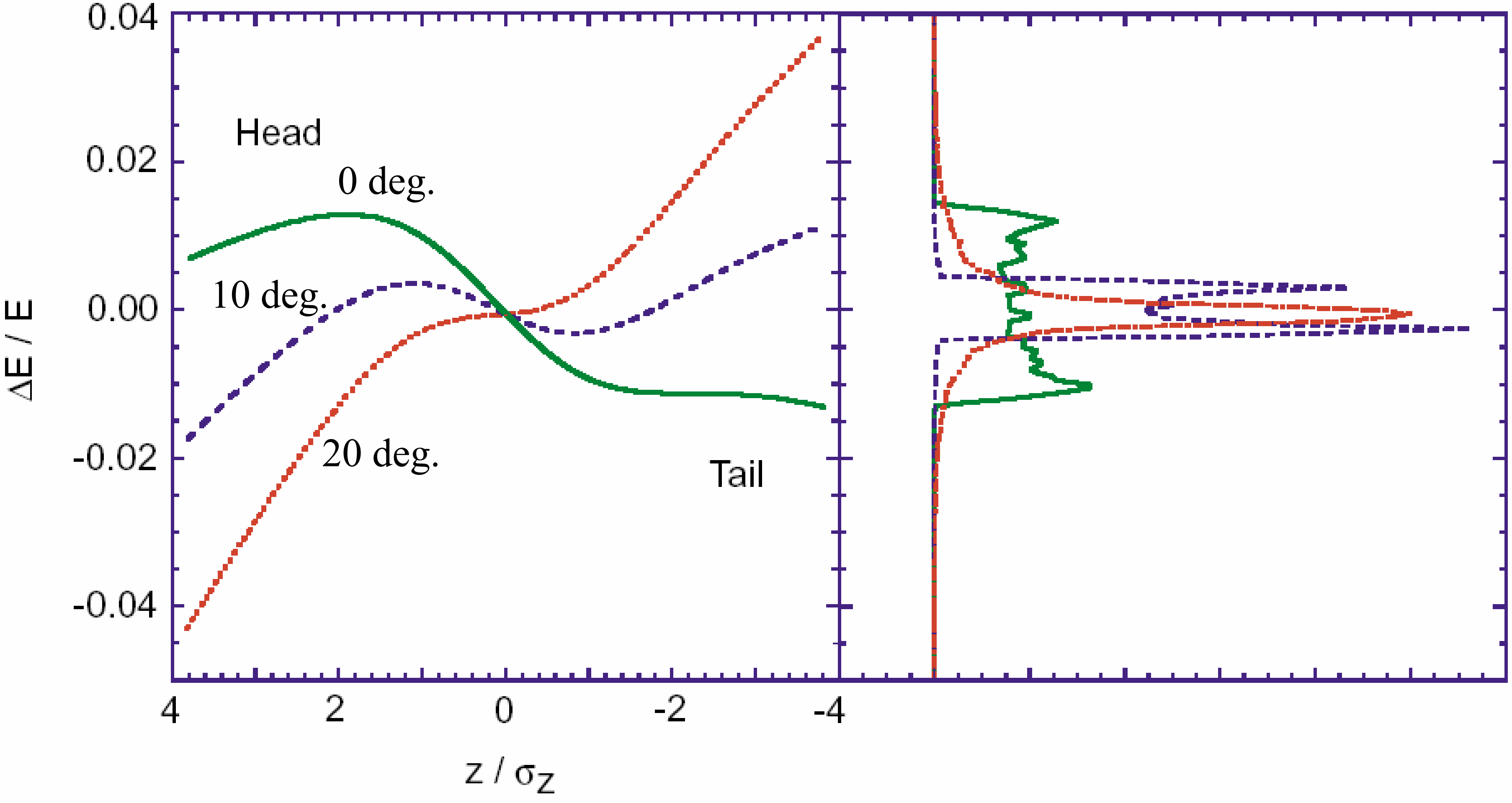
- Important to minimize the ‘turn-around’ energy
  - Minimizes emittance growth $\Delta\gamma\varepsilon \sim E^6$ and V_{RF} required scales as E / f_{RF}
  - However larger energy spread in BC2 leads to dispersive $\Delta\varepsilon/\varepsilon$
- Duplicating NLC system for TESLA would lead to 600% $\Delta\varepsilon/\varepsilon$ and would require 15 GeV of L-band rf
- Compressing another factor of 2 at 10 GeV would probably double the linac emittance growth from 50 → 100%

Energy Spread: warm / cold Differences

- The energy spread in the beam is a combination of:
  - Incoherent energy spread from the bunch compressors, DR, or e+ source
    - Intrinsic energy spread is smaller in NLC than in TESLA because DR longitudinal emittance is smaller (low energy)
  - Correlated energy spread from the longitudinal wakefields and the rf
    - Stronger wakefields in NC design leads to large correlated energy spread along the bunch
      - Nominal profile is double peaked distribution
      - Can reduce core spread with slight decrease in luminosity
    - In SLC, the nominal correlated spread was similar ~0.25%
      - FJD developed technique of shaping the longitudinal current distribution to minimize wakefield impact ➔ 0.1%
    - Easy to trade correlated energy spread against emittance
      - Reduce charge and increase bunch length
      - Factor of 3 luminosity reduction for $\Delta E/E$ ➔ 0.05%

Energy Spread vs. RF Phase Angle

- Changing rf phase angle will decrease core energy spread but increase energy tails

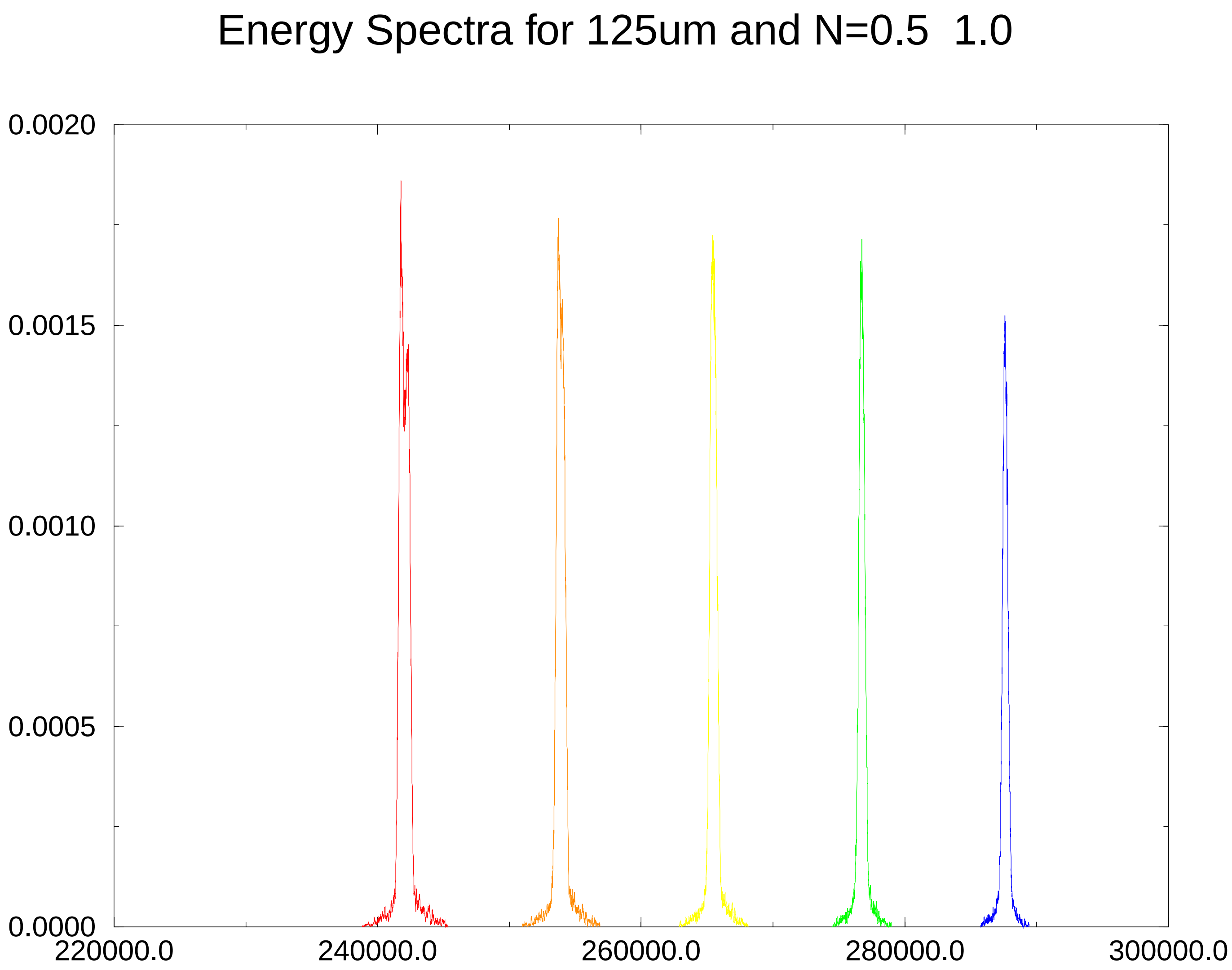


Luminosity for Low Energy Operation

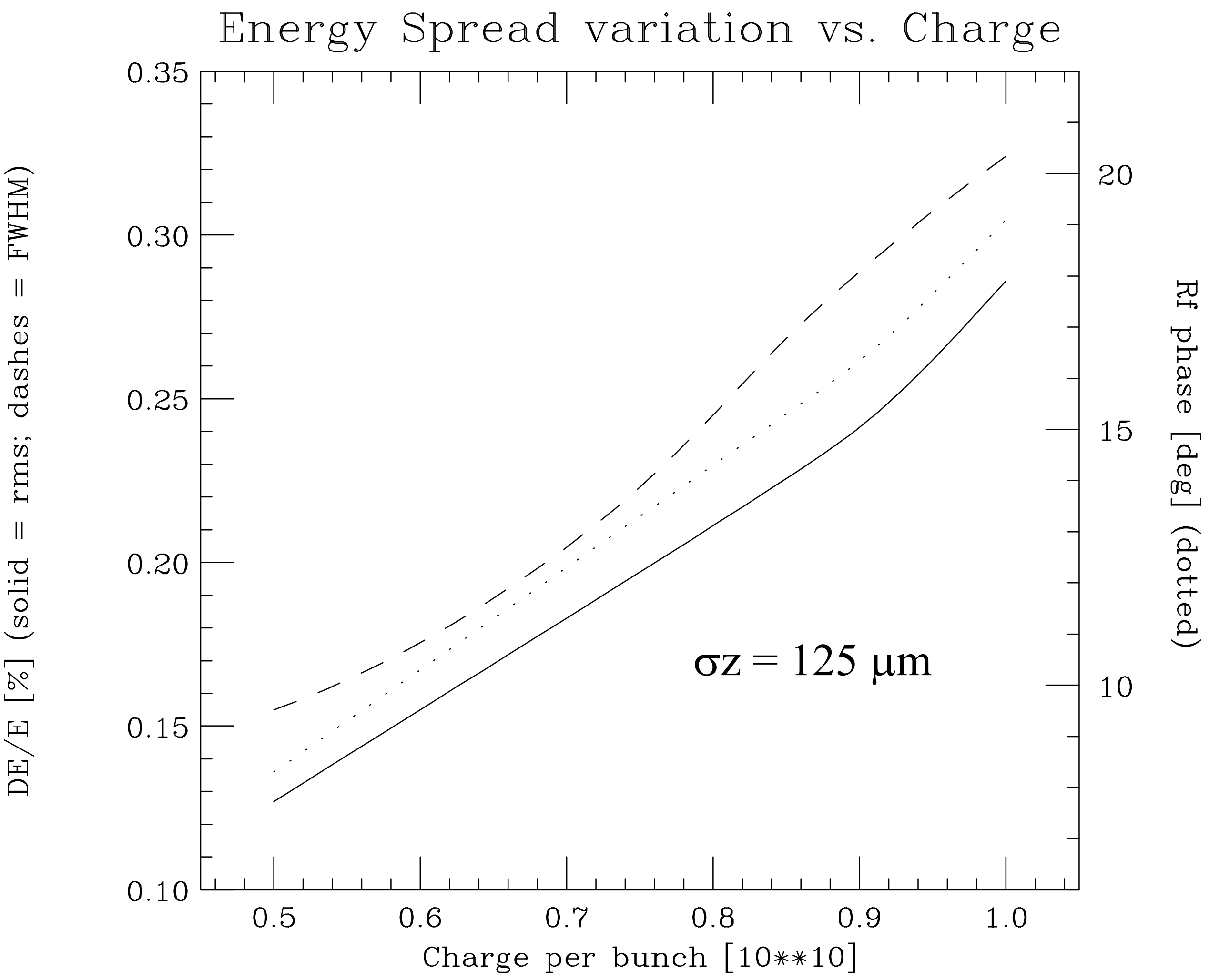
Many ways to optimize
In past asked to reduce beamstrahlung – now energy spread!

	IP Parameters for Low Energy Operation					
	90 GeV		250 GeV		350 GeV	
	1.4 ns	**Low δB**	**1.4 ns**	**Low δB**	**1.4 ns**	**Low δB**
Luminosity (10^{33})	**3.9**	**1.3**	**10.5**	**3.6**	**14.7**	**5**
Pinch Enhancement	1.4	1.5	1.4	1.5	1.4	1.5
Repetition Rate (Hz)	**120**	**120**	**120**	**120**	**120**	**120**
Bunch Charge (10^{10})	**0.75**	**0.4**	**0.75**	**0.4**	**0.75**	**0.4**
Bunches/RF Pulse	192	192	192	192	192	192
Bunch Separation (ns)	1.4	1.4	1.4	1.4	1.4	1.4
Injected $\gamma\varepsilon_x / \gamma\varepsilon_y$ (10^{-8})	300 / 2	300 / 2	300 / 2	300 / 2	300 / 2	300 / 2
$\gamma\varepsilon_x$ at IP (10^{-8} m-rad)	360	360	360	360	360	360
$\gamma\varepsilon_y$ at IP (10^{-8} m-rad)	**4**	**4**	**4**	**4**	**4**	**4**
β_x / β_y at IP (mm)	8 / 0.10	4 / 0.15	8 / 0.10	4 / 0.15	8 / 0.10	4 / 0.15
σ_x / σ_y at IP (nm)	**566 / 6.7**	**400 / 8.2**	**343 / 4.0**	**243 / 5.0**	**290 / 3.4**	**205 / 4.2**
σ_z at IP (um)	110	170	110	170	110	170
L0 / Ltotal (%)	62	78	47	67	43	63
Beamstrahlung δB (%)	0.25	0.11	1.5	0.7	2.7	1.3
Photons per e+/e-	0.56	0.43	0.89	0.67	1.02	0.8
Energy spread	**0.25%**	**0.11%**	**0.25%**	**0.07%**	**0.25%**	**0.05%**

Energy Spread vs. Bunch Charge



Energy Spread vs. Bunch Charge



Scaling δ_B and δ_E with Luminosity

- Can reduce beamstrahlung and beam energy spread at the expense of the luminosity
  - Assuming flat beams:

$$L \propto \frac{N^2}{\sigma_x \sigma_y} \qquad \delta_B \propto \frac{N^2}{\sigma_z \sigma_x^2} \qquad \delta_E \propto \frac{N}{\sigma_z} \sim \frac{N}{\sqrt{\sigma_z}}$$

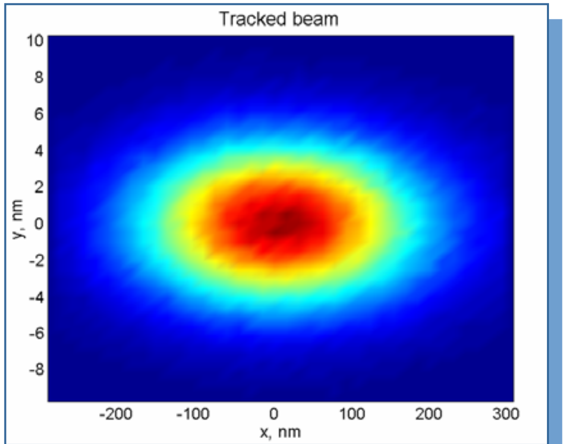
$$y_{align} \propto \frac{1}{N\sigma_z}$$

- Decrease beamstrahlung by increasing horizontal beam size
- Decrease energy spread and beamstrahlung by increasing bunch length (tightens alignment tolerances)
- Decrease energy spread and beamstrahlung by decreasing bunch charge

IP Parameter Variation

- Cannot decrease Y β^* much below 100 μm before aberrations become important
  - Hourglass prevents any gains in luminosity unless σz decreases also
- Probably could decrease X β^* by 3~4x ➔ 2X higher luminosity but lots of beamstrahlung!
  - Can be used to recover luminosity at lower current
  - Have to still look at the collimation issues (becomes like SLC)
  - At high energy, the Oide-effect will be worse
  - Similar reduction is probably possible in the cold BDS although larger X emittance may give some difficulty
  - Always possible to go to larger β^* to reduce beamstrahlung!

Nominal: 121.3 x 3 nm^2
Tracked: 132.56 x 3.21 nm^2
$\sigma_{x0}\ \sigma_{y0}\ /\ (\sigma_x\ \sigma_y)$=85.5% with σ_E=0.25%



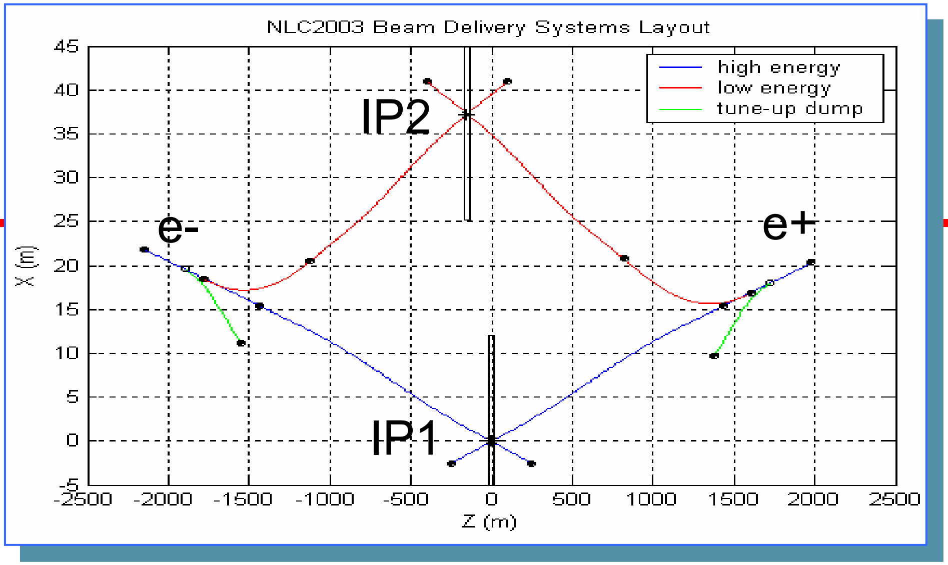
IP Free Space (L*): warm / cold Differences

- The IP chromaticity must be corrected with sextupoles
  - The chromaticity scales as: $\xi \sim L^* / \beta^*$
  - Larger L* means larger chromaticity
    - Need to scale magnet apertures with L* due to physical aperture as well as wakefield effects
    - Magnetic gradient decreases with larger L* however Oide effect increases with L* (for same quad length)
  - Stronger sextupoles mean larger aberrations and tighter drift tolerances
  - Without including disruption effects, thw NC BDS tolerances are ~2x tighter than SC tolerances because $\beta^* = 400$ µm versus 100 µm
    - The larger disruption makes the tolerances comparable (some tighter and some looser)

- Bottom line: no temperature dependence!

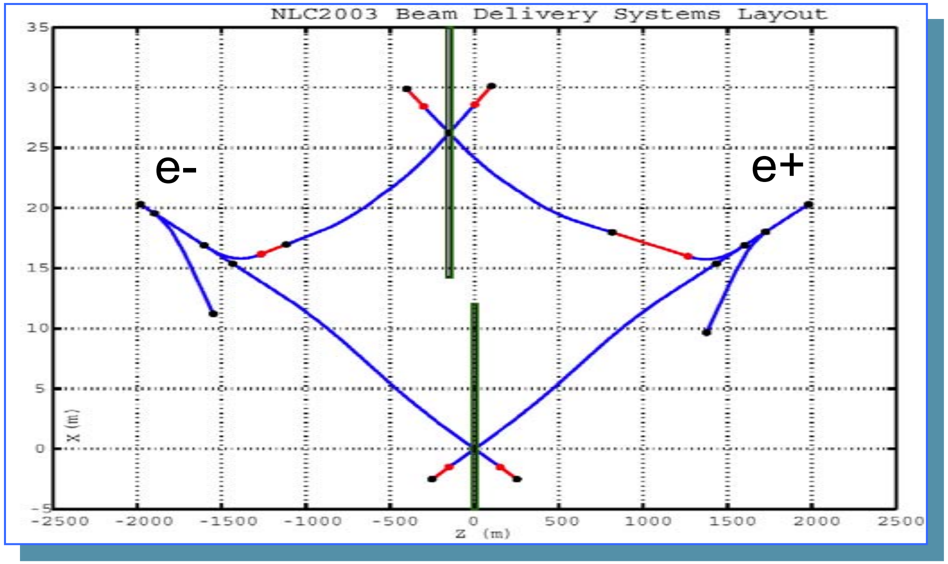
NLC layout

evolution



May 03: 1st IR : full length (1430m) BDS
2nd IR : 2/3 length (970m) BDS

Big Bend has to be long (600m) to allow for $\delta\varepsilon/\varepsilon < 30\%$ @ 650 GeV/beam



June 03: 2nd IR : 2/3 length one way bending BDS

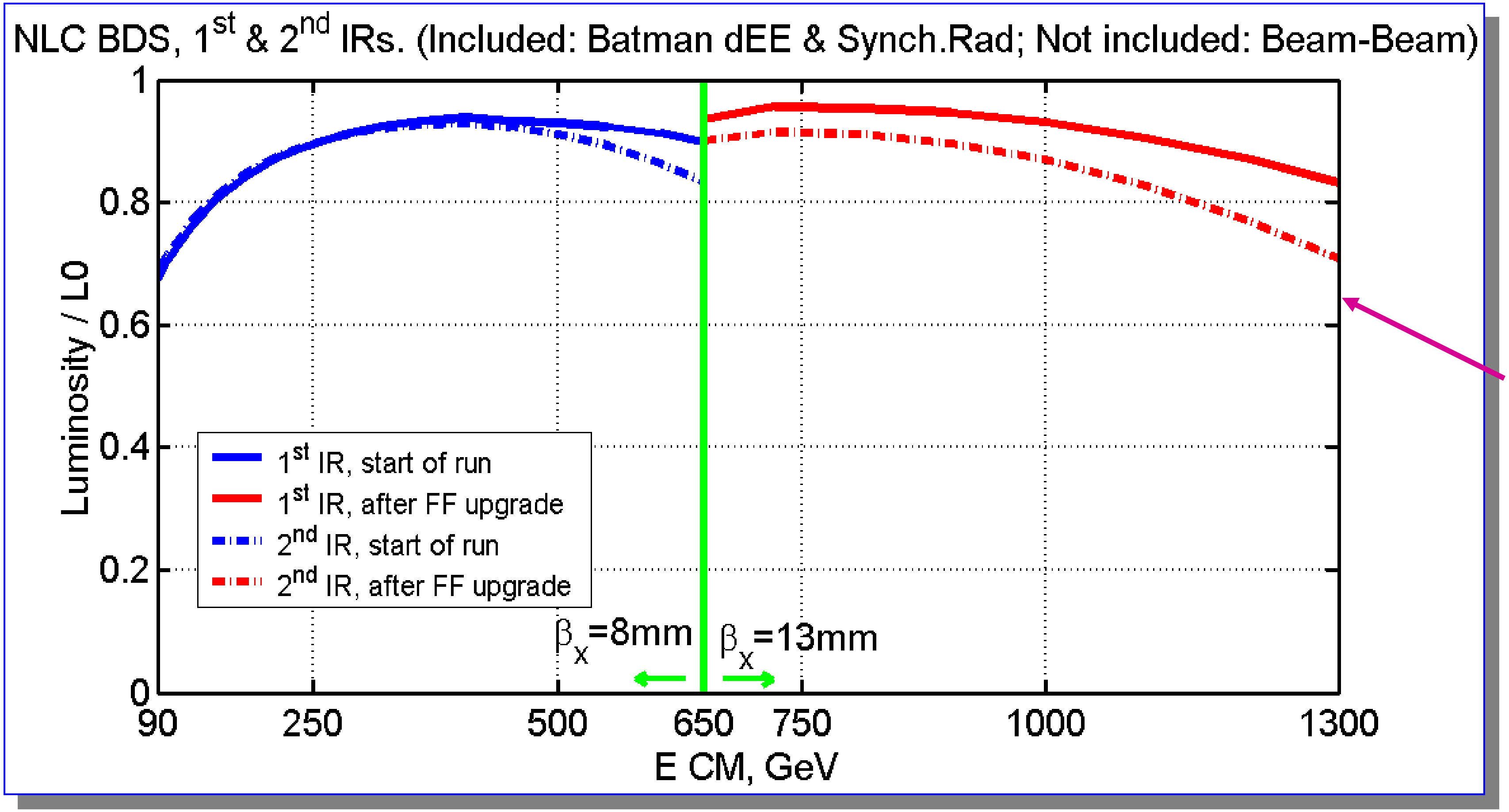
Big Bend shortened from 23 cells to 10

Saved 125m in e- and 450m in e+ beamlines of 2nd IR

July 03: Use extra space to lengthen the e+ 2nd IR BDS to full length
The e- 2nd IR BDS is still 2/3 length

BDS performance (July layout)

1st and 2nd IR



The e- 2nd IR BDS can still be lengthened to improve performance

Geometric luminosity (normalized) of NLC BDS. Include effect of aberration and synchrotron radiation. Beam-beam enhancement is not included.

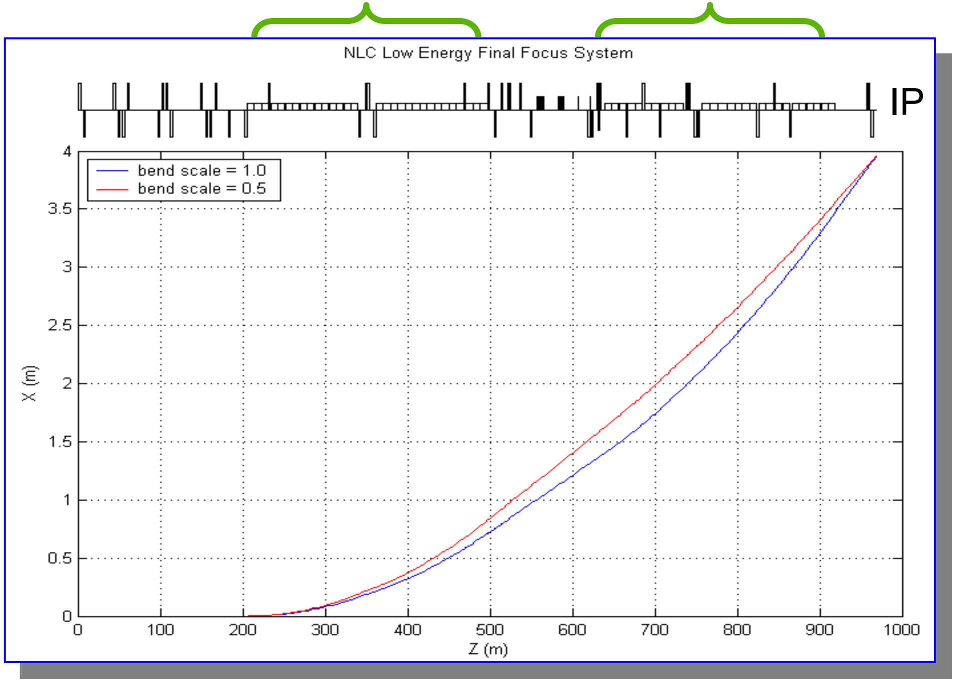
Same normalized emittances assumed for the entire range.

FF upgrade means (1):

reduce bending angle in FF

E-Collimation bends: Increase angle by 15%

FF bends: reduce angle twice

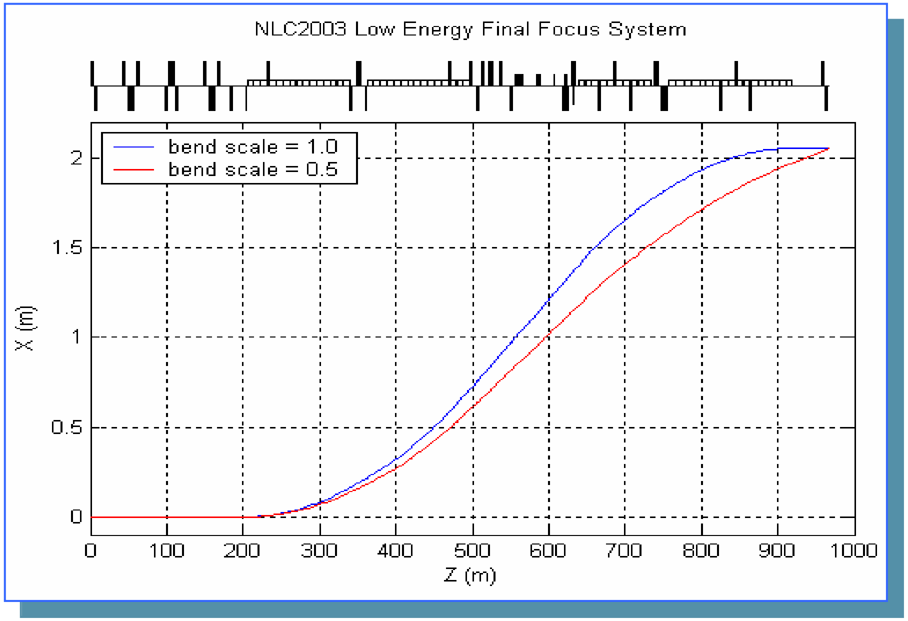


One way bending BDS for 2nd IR

To reduce synch.radiation in FF magnets:

Reduce bending angle in FF twice, and increase bending angle in E-Collimation by ~15%.

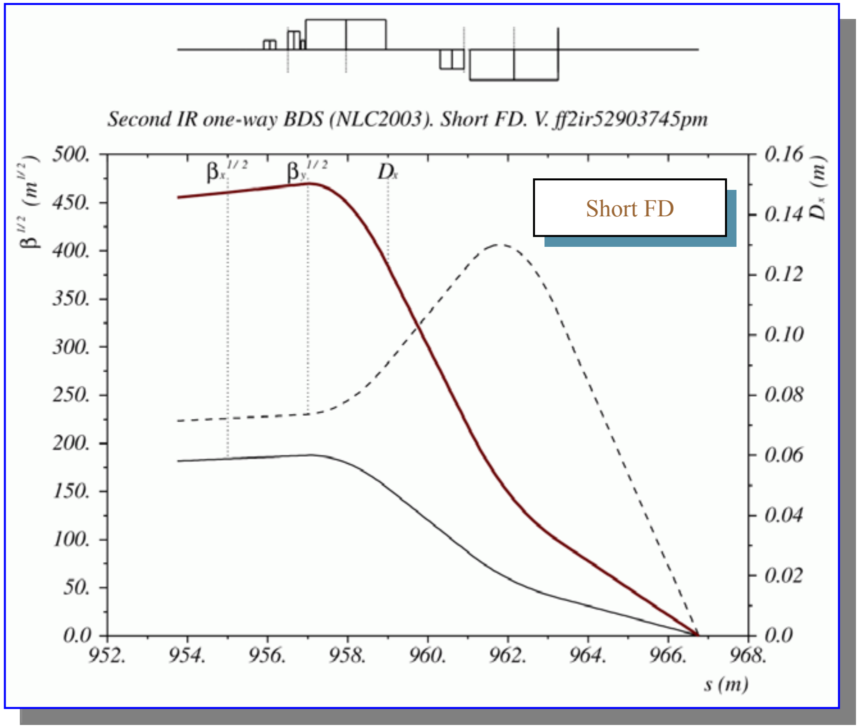
Location of IP is fixed. BDS magnets need to be moved by ~20cm. Outgoing angle change by ~1.6 mrad



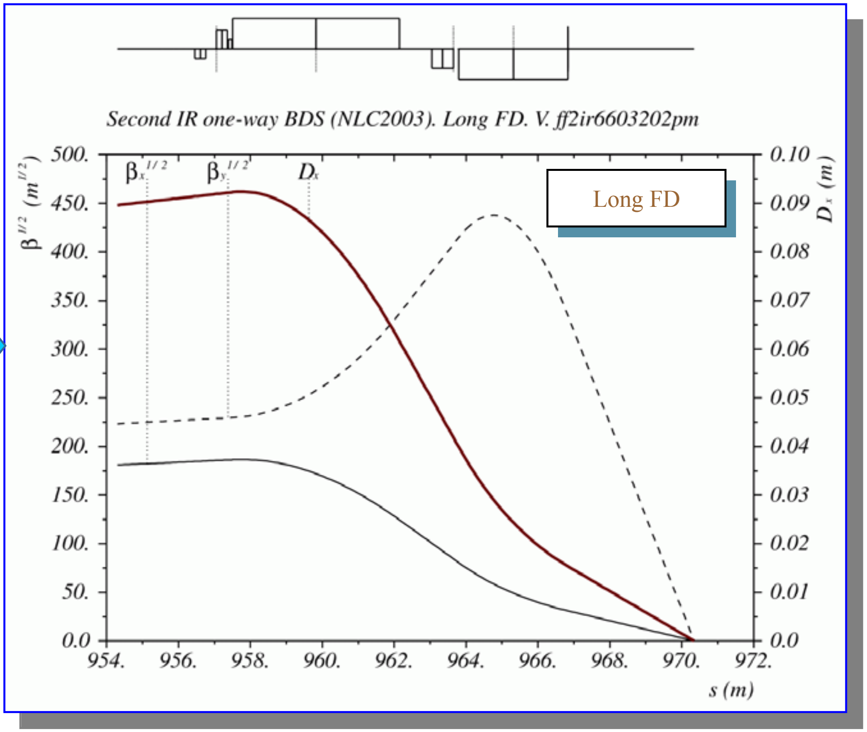
“Standard” (two way bending) BDS

FF upgrade means (2):
use longer Final Doublet

Longer FD allow to reduce luminosity degradation due to synch.radiation in FD (Oide effect).



2nd IR FD optimized for 90-650 GeV CM range



2nd IR FD optimized for the energy upgrade

IP1 and IP2: warm / cold Differences

- Not much fundamental difference
  - Arcs are optimized to keep horizontal emittance dilution small
  - SC design has larger horizontal emittance so one might re-optimize the arcs slightly
    - The $\Delta\varepsilon/\varepsilon$ scales as Θ_B^3 ➔ reduce number of cells by 30%
  - Disruption angles tend to be slightly larger in the SC design than in the NC design but this is a 20% effect
  - Smaller energy spread in the SC design is better for spin precession in arcs but this is sub-% reduction in polarization

Positron Source: warm / cold Differences

- Many unresolved questions regarding target viability of *both* undulator-based source and conventional source for *both* NC and SC designs
  - Target in SC design must be larger and rotate rapidly (see LCC-0133)

- Need to invest additional effort on the conventional source: 2~3x more *L* in the first few years!

	NC Conv.	**SC Conv.**	**NC Und.**	**SC Und.**
E beam [GeV]	6.2	6.2	153	153
Ne-/bunch [1e10]	0.75	2.00	0.75	2.00
Undulator Len. [m]	-	-	150	150
Energy/pulse [J]	477	28000	1130	44300
Target Mat.	WRe	WRe	Ti	Ti
Target Thick. [rl]	4	4	0.4	0.4
Absorption	14.0%	14.0%	8.6%	8.6%
Spot size [mm]	1.6	2.5	0.75	0.75
# targets/spares	3 / 1	2 / 1	1 / 1	1 / 1
Target radius [m]	0.125	0.8	0.125	0.8
Rotation [rpm]	46	1500	46	1200
ΔT [C]	189	256	422	410
Yield	1.5	1.5	1.5	1.5

Summary

- Beam Delivery System is very similar for warm and cold LC's
- Few intrinsic differences:
  - Larger correlated energy spread in the warm → for cases that matter, ΔE/E can be traded against luminosity
  - Larger longitudinal phase space in cold DR makes further bunch compression difficult (not impossible!)
    - Further bunch compression could be used to reduce disruption or increase the luminosity

  - L* and β* variation are temperature invariant
  - Crossing angle requirements are similar

  - Outgoing beam sizes are slightly larger in cold design but …
  - Positron target is a bit more difficult in cold design but …