Beam Delivery System Risk Issues

American Linear Collider Physics Meeting

SLAC

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Introduction

- Analyze risks to the LC project completion
  - Considered four categories:
    - Type: beam physics; engineering; production
    - Impact: impact on luminosity or energy reach
    - Time: when the problem would be uncovered
    - Consequence: impact of fixing the problem
  - Rankings in each category were then multiplied together
- Risk is evaluated against the design parameters: E & Lum.
- Risks is based on present evaluation
  - Many risks will change as R&D progresses
- Only considered a subset of relevant items – broad scope
  - A total of ~40 items for each of US warm and US cold are listed

Example 1: SLED-II

- SLED-II Demonstration
  - Technology: State of the art = 4
  - Effect: linear impact on energy = 3
  - Time: R&D Stage = 1
  - Consequence: Back to R&D = 4
  - Total = 48
- SLED-II Production
  - Engineering: Feasible but untested = 3
  - Effect: linear impact on energy = 3
  - Time: PED Stage = 2
  - Consequence: Major rework = 3
  - Total = 54
- SLED-II Operations – Example (not actually included)
  - Total = 36

Example 2: Active Vibration Suppression

- Demonstration – Example (not actually included)
  - Technology: R&D prototypes but extrapolation remains = 3
  - Effect: impact on luminosity is quadratic or steeper = 4
  - Time: R&D Stage = 1
  - Consequence: Back to R&D = 4
  - Total = 48
- Operations
  - Engineering: Feasible but untested = 3
  - Effect: impact on luminosity is quadratic or steeper = 4
  - Time: Pre-ops Stage = 3
  - Consequence: Major rework = 2
  - Total = 72
- Many items identified in BDS were high risk because uncovered late in the project cycle

Risk Evaluation

- High risks are attached to issues that are not understood or have not been demonstrated
- Risks are high when issues are demonstrated late in the project cycle
- One problem: all of us understand the warm better than cold
  - Much of cold design is based on the TESLA TDR but this has lots of known errors (and possibly a few unknown errors)
    - E+ source target damage
    - E+ source operations impact
    - Ions and e-cloud in DR
    - DR impedance
    - Collimation system efficiency
    - Single tunnel LC design
    - E+ source yield
    - DR dynamic aperture
    - DR tolerances
    - Emittance growth in LET
    - Head-on collision extraction
    - IP feedback
  - I think we overcompensated in an attempt to be ‘unbiased’

BDS Risks

- Compiled by Mike Harrison and myself
- Much of the BDS is conventional
  - Elements which are more novel include the superconducting final focusing magnets, the beam collimators, the vibration suppression systems, and the fast feedback systems
  - Beam dynamics issues which is novel are related to the short bunches, the higher energy, and the small beam emittances
- Operation of the BDS depends on the input beams
  - Emittances are designed to be the same
  - One significant difference between warm and cold is the incoming beam jitter
  - Another difference is the pulse structure

Table of LC BDS Parameters

	SLC	FFTB	US Warm	US Cold
Beam energy [GeV]	46	47	250	250
βx / βy [mm]	3 / 4	10 / 0.1	8 / 0.1	15 / 0.4
γεx / γεy [mm-mrad]	55 / 10	30 / 3	3.6 / 0.04	9.6 / 0.04
sx / sy [µm]	1.4 / 0.7	1.8 / 0.055	0.248 / 0.0030	0.554 / 0.0057
N [10^{10}]	3.6	0.7	0.75	2.0
Nb	1	1	192	2820
Rep Rate [Hz]	120	30	120	5
Dy	2		12.8	21.9
Hd	2.2		1.46	1.77
Beam power [MW]	0.035	0.002	6.9	11.3
Solenoid [T]	0.6	0	3.0 ~ 6.0	3.0 ~ 6.0
Luminosity [$cm^{-2}s^{-1}$]	3e30		2.1e34	2.6e34

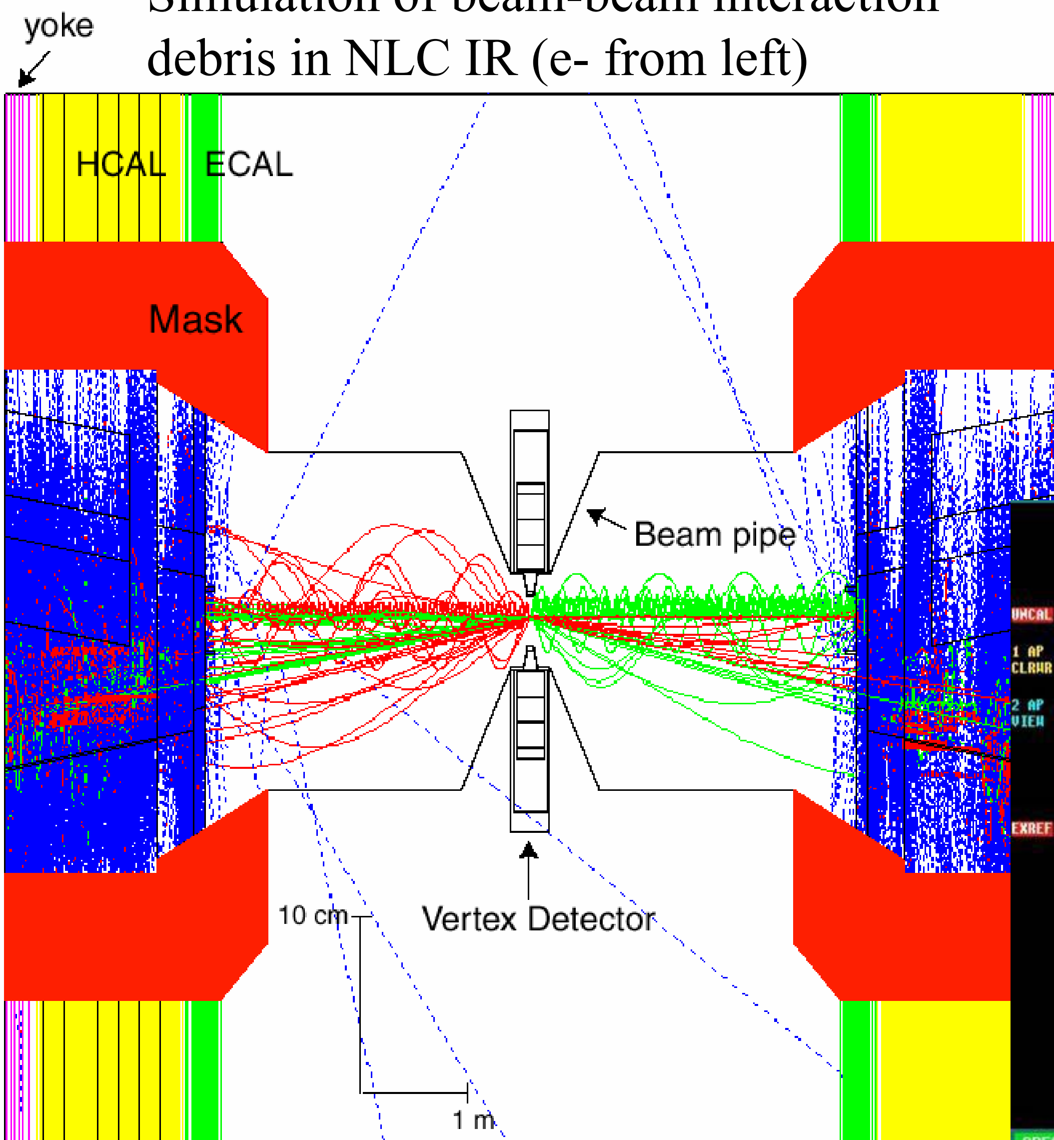
Emittance and Jitter Budgets

- LET simulation codes benchmarked against each other
- Schulte and Walker, PAC 2003 and PT get similar results for the linacs
  - 40% growth through the linacs → round up to 50%
- Some BDS tolerances tighter for cold and some looser
- Warm BC more complicated but lower $\Delta E/E$
  - Estimate for $\Delta\varepsilon/\varepsilon$ larger in cold BC than in warm but …

	Warm LC			**Cold LC**		
	$\Delta y/\sigma$	$\gamma\varepsilon x$	$\gamma\varepsilon y$	$\Delta y/\sigma$	$\gamma\varepsilon x$	$\gamma\varepsilon y$
Damping ring	10%	3.0E-06	2.0E-08	10%	8.0E-06	2.0E-08
Bunch comp	15%	10%	20%	15%	10%	20%
Main Linac	30%	5%	50%	100%	5%	50%
Beam Delivery	40%	5%	30%	30%	5%	30%
IP	0.53	3.60E+00	4.00E-08	1.06	9.60E-06	4.00E-08
Geo. Lum.	1.42E+34			1.45E+34		
H_D	1.42			1.78		
Luminosity	**2.08E+34**			**2.57E+34**		

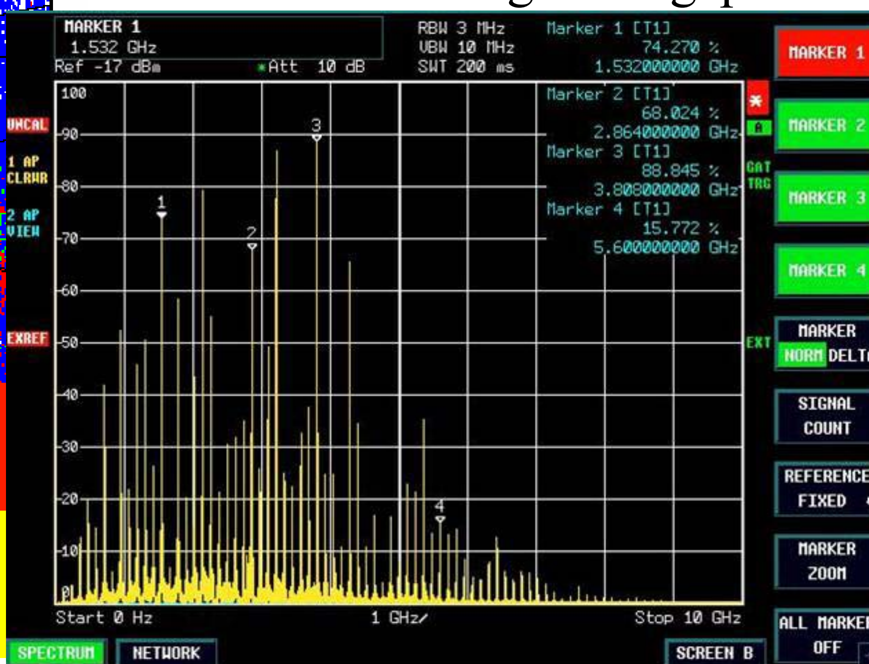
LC Environment

Simulation of beam-beam interaction debris in NLC IR (e- from left)



Not quite as clean as people might like!

BPM measurements on PEP-II IR BPMs during abort gap



BDS Risks (1)

- Backgrounds = 81
  - Beam physics: Poor or ambiguous data indicates a problem = 3
  - Effect: linear impact on luminosity = 3
  - Time: Pre-Ops Stage = 3
  - Consequence: Major redesign = 3

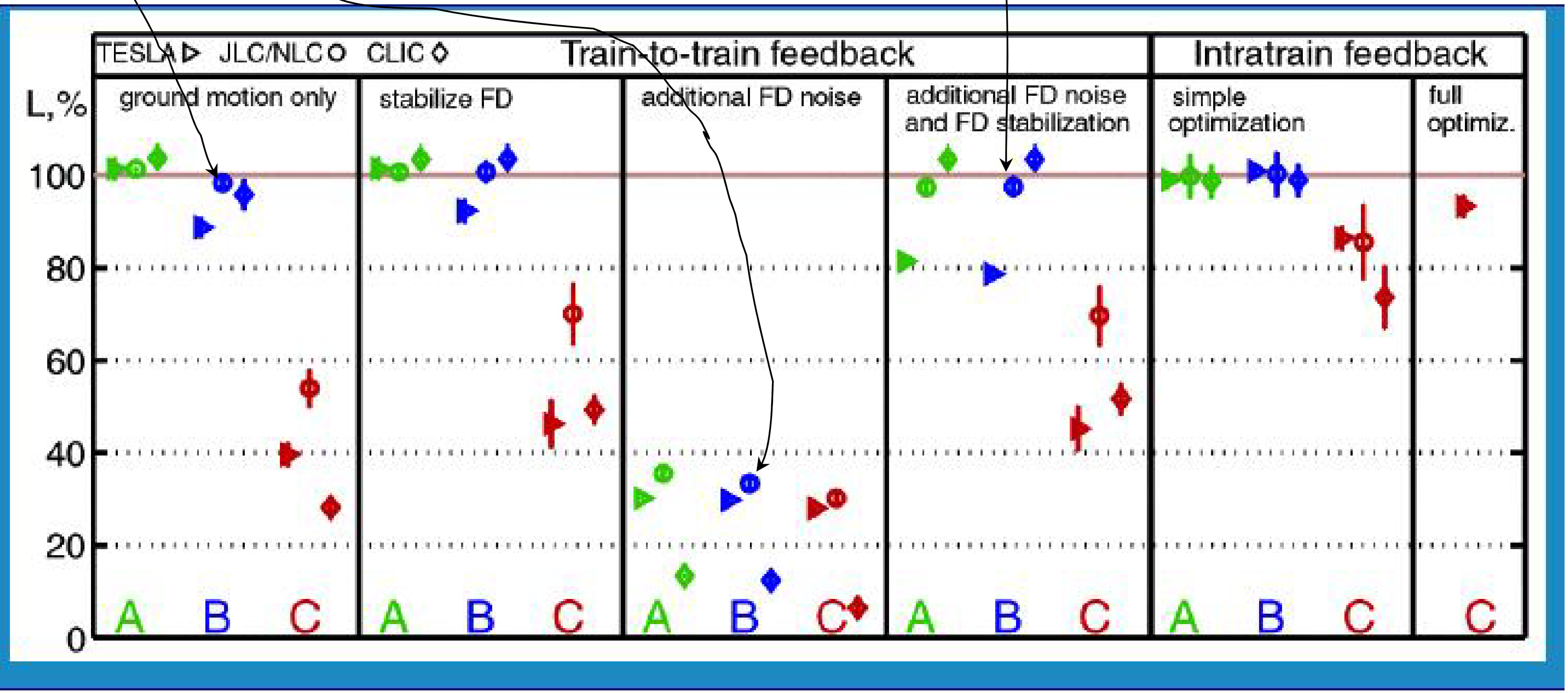
- Why is there a risk?
  - We can model and design extensively now, but, turn the machine on and &*%^%!
  - This is the experience of most colliding beam facilities
    - Hard to fully model all parts of the problem
  - The LC is probably in better shape because we are so concerned
  - Calculated beam tails are similar in warm and cold designs at 10^{-6} of the beam – calculations are incomplete

BDS Risks (2)

- Final Magnet Stabilization = 72 (warm) = 0 (cold)
  - Engineering/Design: Feasible but untested = 3
  - Effect: Quadratic or steeper impact on luminosity = 4
  - Time: Pre-Ops Stage = 3
  - Consequence: Minor redesign = 2

- Why is there a risk?
  - Natural motion should be less than ~20 nm based on SLD measurements
    - Want to stabilize at the 0.5 nm level
    - Done in other cases but not in the IR environment
  - ***Important*** for operation (FONT may provide some backup)
  - Possible to develop in the lab and build a full mock-up during the PED phase (there is some risk associated with the lab development)
  - However, impossible to fully duplicate actual installation

Scenario 1: No stabilization, no FONT, quiet detector.
Scenario 2: No stabilization, need FONT*, noisy detector.
Scenario 3: Stabilization, no FONT, noisy detector.



Percentage of luminosity obtained for each LC with ground motion models A ,B, C, with and without additional vibration of FD, and with different combinations of IP feedbacks and FD stabilization. With the intra-train feedback, neither FD noise nor stabilization was included. Averaged over 256 trains (50 for TESLA).

BDS Risks (3)

- IP Feedback Implementation = 48 (warm) = 72 (cold)
  - Engineering/Design: R&D prototype =2 (warm)
  - Engineering/Design: Feasible but untested = 3 (cold)
  - Effect: Quadratic or steeper impact on luminosity = 4
  - Time: Pre-Ops Stage = 3
  - Consequence: Minor redesign = 2
    - Note categories need to be interpreted broadly
- Why is there a risk?
  - ***Absolutely essential*** for luminosity after a few seconds
  - Unprecedented requirements – sub-nm accuracy
- Why is cold harder than warm?
  - Higher resolution required for the same $\Delta L/L$
  - More complex system: multiple interacting feedbacks

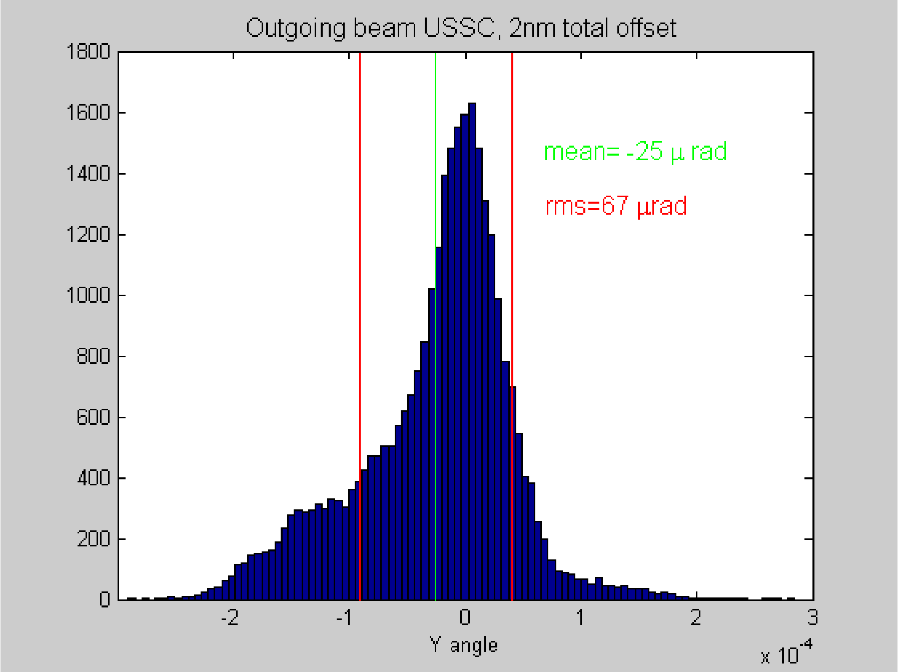
Beam-Beam Deflection Resolution

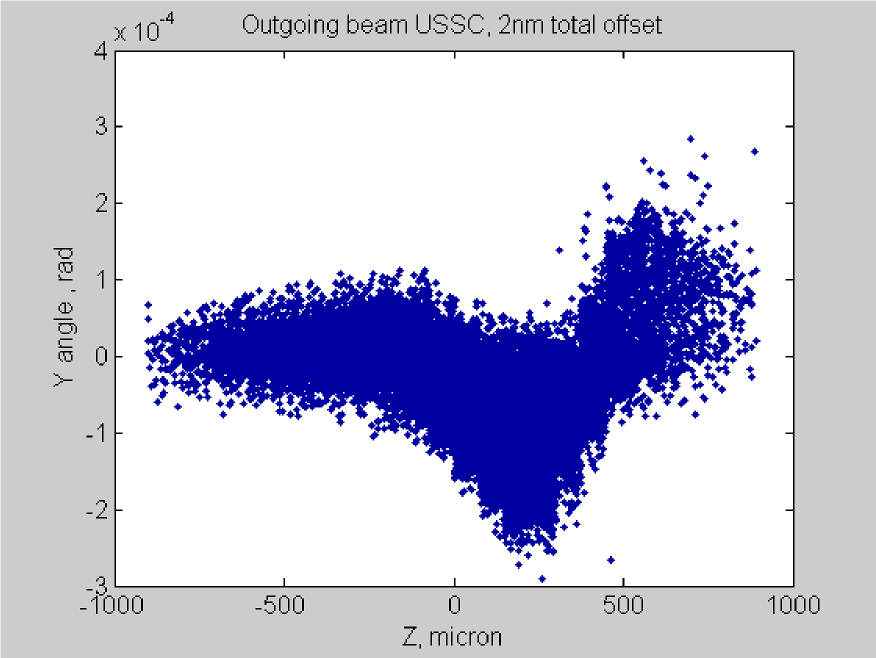
- Required resolution is determined by the outgoing angles
  - Tolerances are 1.5 ~ 2x tighter in cold LC

	Warm LC		Cold LC	
95% DL/L	1.1 nm	24 ur	0.65 nm	15 ur
90% DL/L	1.9 nm	30 ur	1.2 nm	20 ur
80% DL/L	3.5 nm	58 ur	2.6 nm	29 ur
50% DL/L	11.1 nm	166 ur	10.5 nm	84 ur

Outgoing Distribution

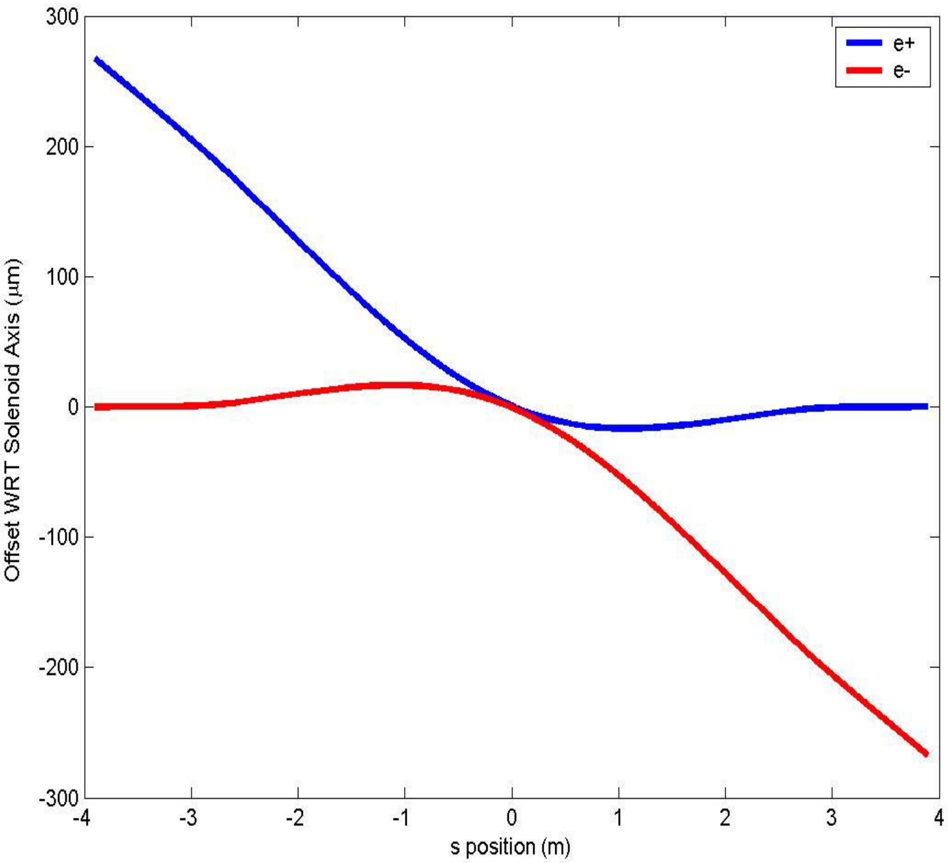
- High disruption makes the outgoing distribution highly nonlinear
  - May be difficult to determine ‘centroid’
  - RF bpms may not work
  - It ‘appears’ that close to maximal luminosity is attained when the beam-beam deflection centroid is minimized





Solenoid and Crossing Angle

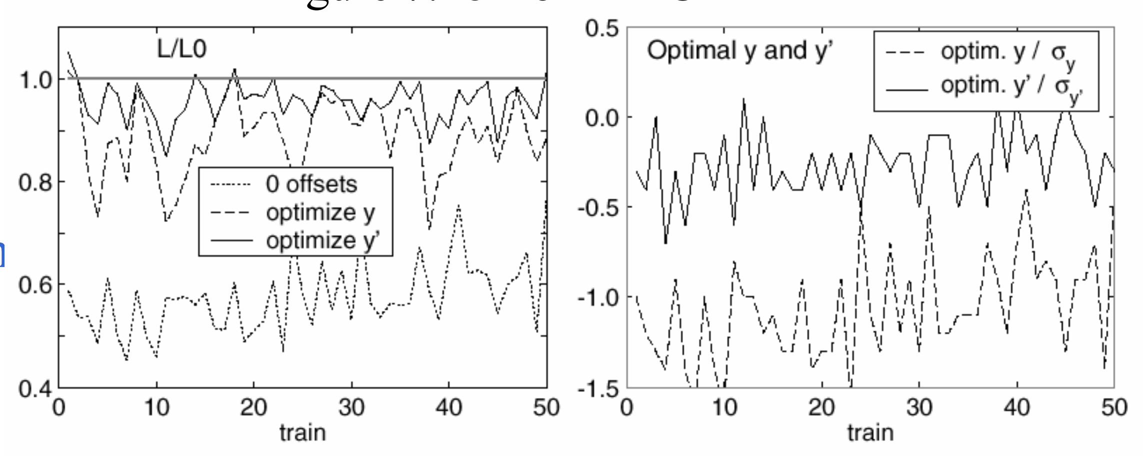
- Strong solenoid with the crossing angle will cause variation of the vertical trajectory with the horizontal position and with the energy loss
  - These may degrade the effective resolution
  - Outgoing spectrum has a large fraction of beam particles at less than 50% energy
  - Low energy particles will get large deflection and may cause backgrounds



More Complex Feedback System (1)

- The higher disruption and the larger incoming beam jitter of the cold LC requires two linked feedback systems
  - TDR design has angle feedback ~850 meters upstream of IP
- Both angle and position setting change from pulse-to-pulse
  - Beam trajectory changes from pulse-to-pulse by ~ sigma
  - Impact of BDS wakefields has not been considered
    - Trajectory changes will generate varying beam tails
    - TDR design has 5% ΔN/N → trajectory changes from bunch-to-bunch

Figure 7.18 from TRC

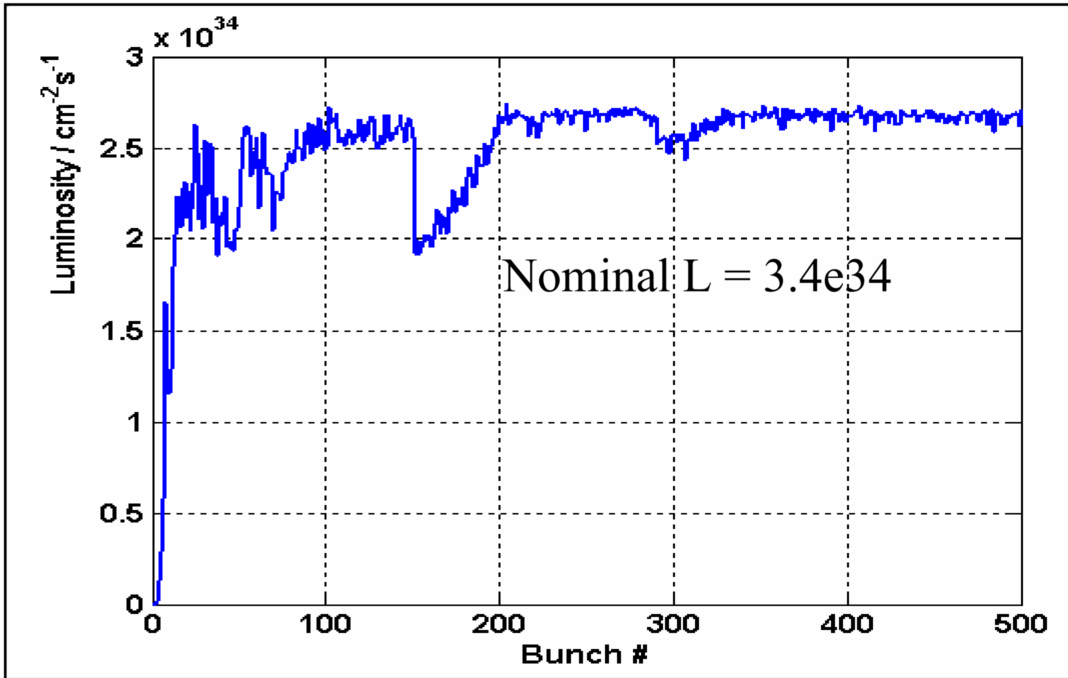


More Complex Feedback System (2)

- Changing IP angle through BDS will confuse BDS drift feedbacks
  - Drifts feedbacks are required to stabilize the trajectory at the BDS sextupoles at the sub-um level
  - 1-sigma angle change corresponds to ~100 um trajectory change
- Cold LC may need intra-train luminosity feedback as well as position and angle feedback
  - Require fast luminosity monitor that will not be impacted by changes in backgrounds
  - Beamstrahlung spectrum, energy loss, and deflections are very sensitive to collision parameters and tails
- Higher bandwidth not a fundamental limitation but complicates implementation
  - 3 MHz feedback requires significant faster processing → much faster BPMs and kickers

Simulation Results

- Early TDR simulations were incomplete
- Glen White has performed 'full' simulations of TESLA system - still 'work in progress'
  - Results published at PAC03 by Schulte, Walker, White showed an average luminosity of ~ 2.2e34 — result below presented at SLAC
  - Each case depends on trajectory jitter – see Figure 7.18 from TRC
    - No wakefields and no correlations between backgrounds and trajectory



Summary

- Many other risk issues identified in BDS
  - Collective effects
  - Magnet jitter in BDS
  - Heating of SC IR magnets
  - Collimator performance and MPS limitations
  - Aberration tuning procedures
  - Crab cavity
- The upper 3.5 items are also issues that can only really be determined late in the project cycle
- Risks in the BDS are high because, although unlikely, there is significant luminosity impact and little time for remediation
- Given present knowledge, the risks in warm and cold BDS are very similar