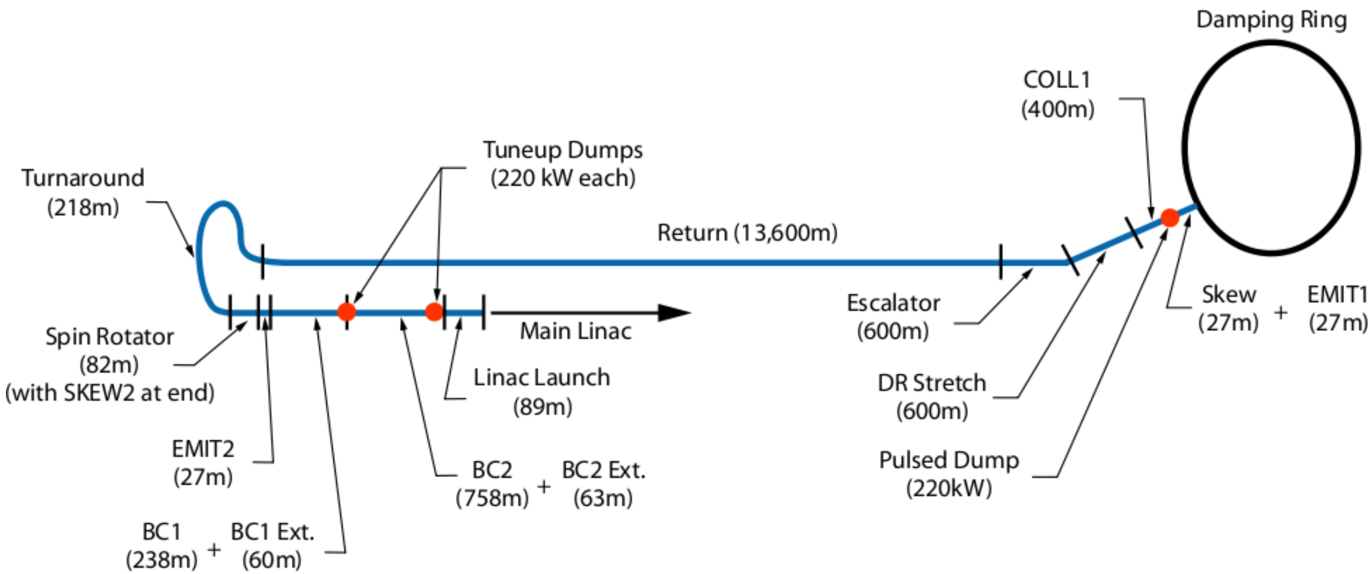
ILC RTML Overview

Andrea Latina, Fermilab

IWLC2010 - CERN, Geneva - October 18-22, 2010

ILC RTML Sketch



- the RTML brings the beam from the Damping Rings exit to the Main Linac entrance
- it is an **active** component because it modifies the beam phase space in several respects

  ⇒ change in energy, length, polarization, position: diagnostics; dumps
- its total length is about 13 km ⇒ the long Return Line is curved

⇒ Two designs: RDR (Reference Design Report) - SB2009 (Strawman Baseline Design)

Why SB2009?

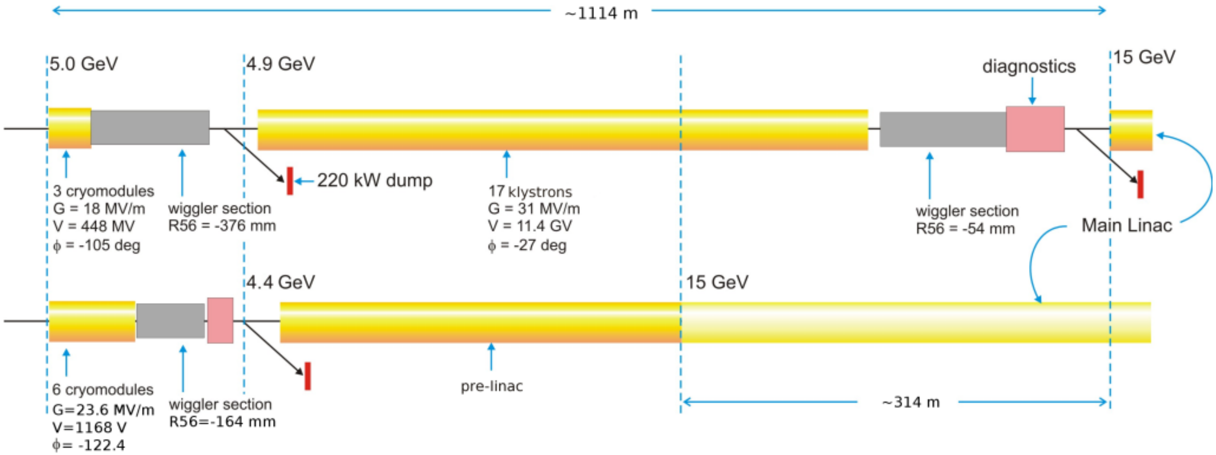
⇒ Because it is likely to be cheaper

⇒ RTML ⇒ from two-stage bunch compressor (BC1-BC2) to single-stage bunch compressor (BC1S)

- **ILC Baseline: Two-Stage Bunch Compressor**
  - Bunch length at damping rings extraction: 6/9 mm, compression down to 200/300 μm at main linac entrance (compression ratio: up to $\sim$45)
  - * **Pro**: more flexibility
  - * **Cons**: two diagnostics sections, two extraction lines

- **Minimum cost machine: Single-Stage Bunch Compressor**
  - New design of the damping rings allows 6 mm bunch length with a smaller radius
  - Compression factor can be fixed to $\sim$20
  - * **Pro**: Shorter beamline and associated tunnel length (314 meters); Removal of the second 220 kW/15 GeV beam dump and extraction line components; Removal of one section of beam diagnostics
  - * **Cons**: Less flexibility; Larger energy spread at BC exit; Possible emittance preservation issues (see DFS in the main linac)

What do we gain or loose with BC1S ?



- **What do we gain**
  - Reduction in beamline and associated tunnel length (314 meters)
  - Removal of the second 220 kW/15 GeV beam dump and extraction line components
  - Removal of one section of the beam diagnostics
- **What do we loose**
  - Less flexibility
  - Larger energy spread at BC exit
  - Emittance preservation and additional tuning issues (see DFS in the main linac)

RDR Beam Parameters

⇒ Bunch length at Damping Rings exit can be either 6 or 9 mm

⇒ Two stages of bunch compression ⇒ final bunch length can be 150 or 300 μm

⇒ Main Linac start at 15 GeV

- Damping Ring exit

Property	Symbol	Value	Unit
Energy	E_0	5	GeV
Bunch charge	Q_0	3.2	nC
RMS bunch length	σ_0	6 / 9	mm
RMS energy spread	σ_E/E_0	0.15	%
Normalized emittance	$\epsilon_{\eta,x}$	10'000	nm
	$\epsilon_{\eta,y}$	20	nm

- Main Linac entrance

Property	Symbol	Value	Unit
Energy	E_0	15	GeV
Bunch charge	Q_0	3.2	nC
RMS bunch length	σ_0	150 / 300	μm
RMS energy spread	σ_E/E_0	1.07	%
Normalized emittance	$\epsilon_{\eta,x}$	$<$ 12'000	nm
	$\epsilon_{\eta,y}$	$<$ 25	nm

SB2009 Beam Parameters

⇒ Damping Ring exit bunch length is fixed to 6 mm

⇒ Single-Stage Bunch Compressor ⇒ final bunch length fixed to 300 μm

⇒ Main Linac starts at 4.4 GeV

- Dampig Ring exit

Property	Symbol	Value	Unit
Energy	E_0	5	GeV
Bunch charge	Q_0	3.2	nC
RMS bunch length	σ_0	6	mm
RMS energy spread	σ_E/E_0	0.15	%
Normalized emittance	$\epsilon_{\eta,x}$	10'000	nm
	$\epsilon_{\eta,y}$	20	nm

- Main Linac entrance

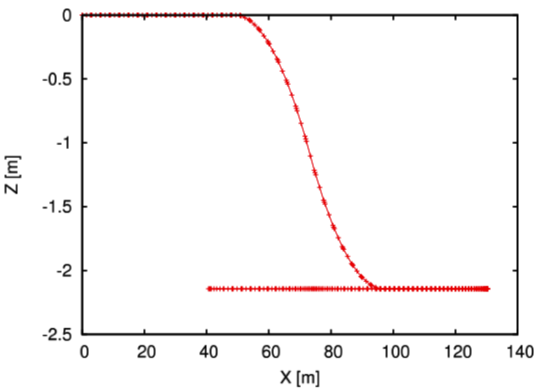
Property	Symbol	Value	Unit
Energy	E_0	4.4	GeV
Bunch charge	Q_0	3.2	nC
RMS bunch length	σ_0	300	μm
RMS energy spread	σ_E/E_0	3.4 (1.07*)	%
Normalized emittance	$\epsilon_{\eta,x}$	$<$ 12'000	nm
	$\epsilon_{\eta,y}$	$<$ 25	nm

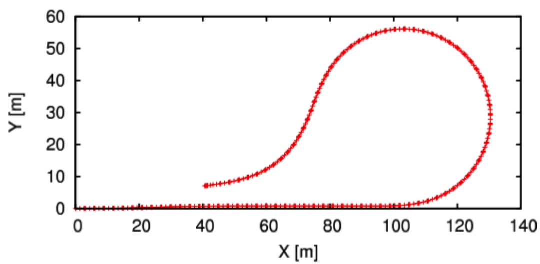
* at 15 GeV

Status of the Lattice Files

- Beam Dynamics view point = production phase

- **RDR**
  - Full lattice decks exist both for e^+ and e^-, in XSIF, MAD-X and PLACET formats
  - Magnets Counts for Cost estimates
  - Estimates of Heat Loads, and Power Consumption exist
- **SB2009**
  - Full lattice decks exist both for e^+ and e^-, in XSIF, MAD-X and PLACET formats
  - Magnets Counts for Cost estimates
  - Estimates of Heat Loads, and Power Consumption exist





Status of the L.E.T. Simulations

- Static misalignment in the whole RTML has been studied
  - Emittance growth is kept within the budget, 10 nm

- Dynamic studies have to be performed

- Stray fields, previous studies stated that:
  - to limit the resulting vertical beam jitter at the feed-forward to about 10% of the beam size, the RMS of the stray fields should not exceed about 2 nT.
  - there is another limit, which is that a beam with a bad orbit in the turnaround will get emittance growth from dispersion. The limit on this appears to be looser, more like 7.5 nT RMS.

Simulation of Static Effects

- Alignment Errors:
  - Standard "COLD" model: crymodules
  - Standard "WARM" model
  - Bpm resolution error: $\sigma_{\mathrm{bpmres}} = 1\ \mu$m

- RF-Kick and Wakes due to Couplers of the RF structures
  - See:

    N. Solyak et al., "Final Results on RF- and Wake- Kicks Caused by the Couplers in the ILC Cavity" presented ICAP 2009

    A. Latina et al., "Emittance Dilution Caused by the Couplers in the Main Linac and in the BC of the ILC", presented PAC 09

Beam-Based Alignment in the RTML

1) **1-to-1 Correction**: orbit correction

2) **Kick Minimization**: orbit correction after quad-shunting

3) **Dispersion Free Steering**: dispersion correction

- a phase offset is applied to the RF cavities of the BC1S (BC1) in order to generate the energy difference for the DFS's test beams

  (in BC1S the test beams are synchronized to the PRE-LINAC's RF phase at its entrance)

$$\chi^2 = \sum_{i=1}^{n} y_{0,i}^2 + \sum_{j=1}^{m} \sum_{i=1}^{n} \omega_{1,j} \left(y_{j,i} - y_{0,i}\right)^2$$

$\Rightarrow$ we **scan** the weight $\omega_{1,j}$ to find the optimum

4) **Dispersion Bumps**: emittance minimization

- we used two *dispersion* bumps η, η' as global correctors

$$\begin{cases} y_i & \Leftarrow & y_i + \eta \, \frac{E_i - E_0}{E_0} \\ y'_i & \Leftarrow & y'_i + \eta' \, \frac{E_i - E_0}{E_0} \end{cases}$$

- two dispersion *knobs*: tune dispersion at entrance to minimize the final vertical emittance

5) **Girder Pitch Optimization**: correction of intra-bunch effects

Coupling Correction

- Coupling is generated by
  - element rolls and
  - solenoids in spin rotator
- It is corrected simultaneously:

1) Including $\mathbf{M}_{xy}$ and $\mathbf{M}_{yx}$ in the response matrices. See for instance Kick Minimization

$$\begin{pmatrix} \mathbf{b}_x \\ \mathbf{b}_y \\ \omega \mathbf{c}_x \\ \omega \mathbf{c}_y \end{pmatrix} = \begin{pmatrix} \mathbf{M}_{xx} & \mathbf{M}_{xy} \\ \mathbf{M}_{yx} & \mathbf{M}_{yy} \\ \omega \mathbf{I} & \mathbf{0} \\ \mathbf{0} & \omega \mathbf{I} \end{pmatrix} \begin{pmatrix} \Delta \boldsymbol{\theta}_x \\ \Delta \boldsymbol{\theta}_y \end{pmatrix}$$

2) Using two sets of 4 skew quadrupoles located in the Getaway and at the end of the Spin Rotator

$\Rightarrow$ Simplex optimization of the final emittance

Simulation Setup in the Warm Regions

- Warm Region: RTML "Front End" (i.e. RTML without RF the sections)
- A number of random seed were simulated, with Gaussian distributed misalignments
  - X/Y Misalignments
    - $\sigma_{\text{quad offset}} = 150\ \mu$m RMS w.r.t. design orbit
    - $\sigma_{\text{bpm offset}} = 7\ \mu$m RMS w.r.t. quadrupole center
    - $\sigma_{\text{bpm res}} = 1\ \mu$m
  - Strength errors
    - $\sigma_{\text{quad strength}} = 0.25\%$ RMS
    - $\sigma_{\text{bend strength}} = 0.5\%$ RMS
  - Roll errors
    - $\sigma_{\text{quad roll}} = 300\ \mu$rad RMS w.r.t. design orbit
    - $\sigma_{\text{sbend roll}} = 300\ \mu$rad RMS w.r.t. design orbit

- 1000 seeds
- Bunches of 50000 macro-particles
- ILC2007b lattice
- All simulations have been performed using PLACET

Simulation Setup in the Cold Regions

- Cold Region: Bunch Compressors (i.e. regions with cryomodules)
- A number of random cases were simulated, with Gaussian distributed misalignments
  - X/Y Misalignments
    - $\sigma_{\text{quad offset}} = 300\ \mu$m RMS w.r.t. design orbit
    - $\sigma_{\text{bpm offset}} = 300\ \mu$m RMS w.r.t. design orbit
    - $\sigma_{\text{bpm res}} = 1\ \mu$m
  - Strength errors
    - $\sigma_{\text{quad strength}} = 0.25\%$ RMS

- 100/1000 seeds
- Bunches of 50000 macro-particles
- ILC2007b / SB2009 lattice

- PLACET

Cases Studied (1/2)

1) **Getaway + Escalator + Return Line**

- Only X/Y misalignments
- Add Quadrupole and Sbend strength errors
- Add Quadrupole and Sbend roll errors

⇒ Correction technique:

- 1:1 + Kick Minimization
- Dispersion Tuning Knobs
- Skew Coupling Correction

2) **Turnaround + Spin Rotator** (Solenoids OFF and ON)

- Only X/Y misalignments
- Add Quadrupole and Sbend strength errors
- Add Quadrupole and Sbend roll errors

⇒ Correction technique:

- 1:1 + Kick Minimization
- Dispersion Tuning Knobs

Cases Studied (2/2)

3) **Getaway + Escalator + Return Line + Turnaround + Spin Rotator**

- Only X/Y misalignments
- Add Quadrupole and Sbend strength errors
- Add Quadrupole and Sbend roll errors

⇒ Correction technique:

- 1:1 + Kick Minimization
- Dispersion Tuning Knobs
- Skew Coupling Correction

4) **Bunch Compressors**

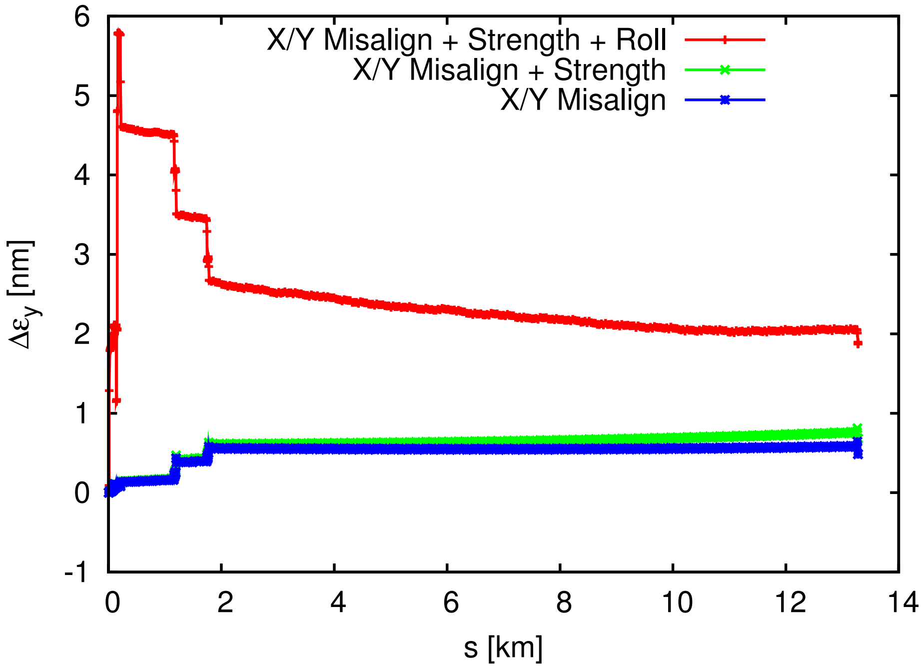
- Only X/Y misalignments
- Coupler Effects

⇒ Correction technique:

- 1:1 + Dispersion Free Steering
- Dispersion Tuning Knobs
- Girder Pitch Optimization

1) Getaway + Escalator + Return Line

- Correction: 1-TO-1 + Kick Minimization + Dispersion Bumps + Coupling Correction
- Emittance growth along the line for 1000 seeds:



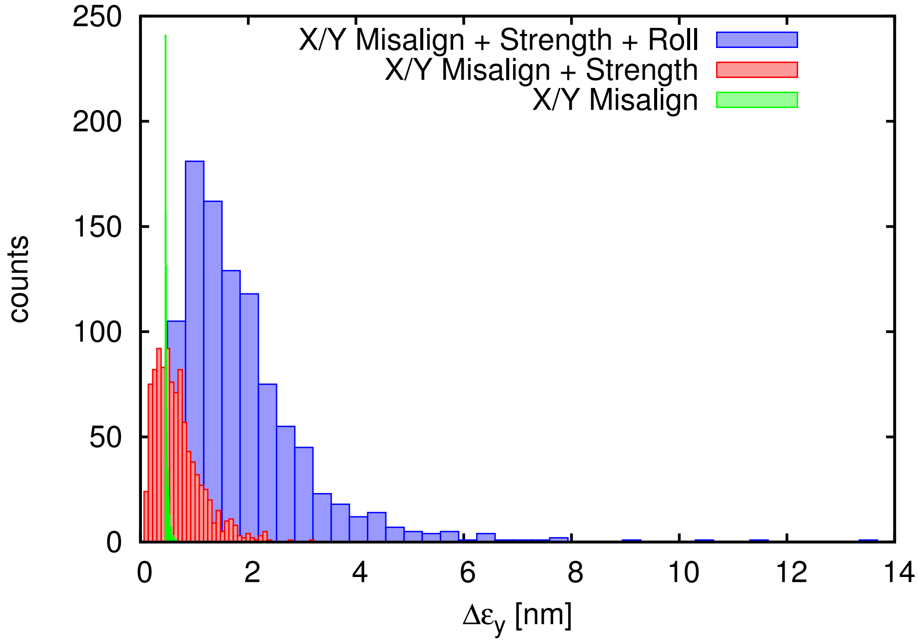
⇒ X/Y Offsets: Final average emittance growth is 0.48 nm (0.52 nm 90% c.l.)

⇒ Add Quad/Sbend Strength: Final average emittance growth is 0.68 nm (1.25 nm 90% c.l.)

⇒ Add Quad/Sbend Roll: Final average emittance growth is 1.87 nm (3.23 nm 90% c.l.)

1) Getaway + Escalator + Return Line

- Correction: 1-TO-1 + Kick Minimization + Dispersion Bumps + Coupling Correction
- Histogram of final emittance growth for 1000 seeds:



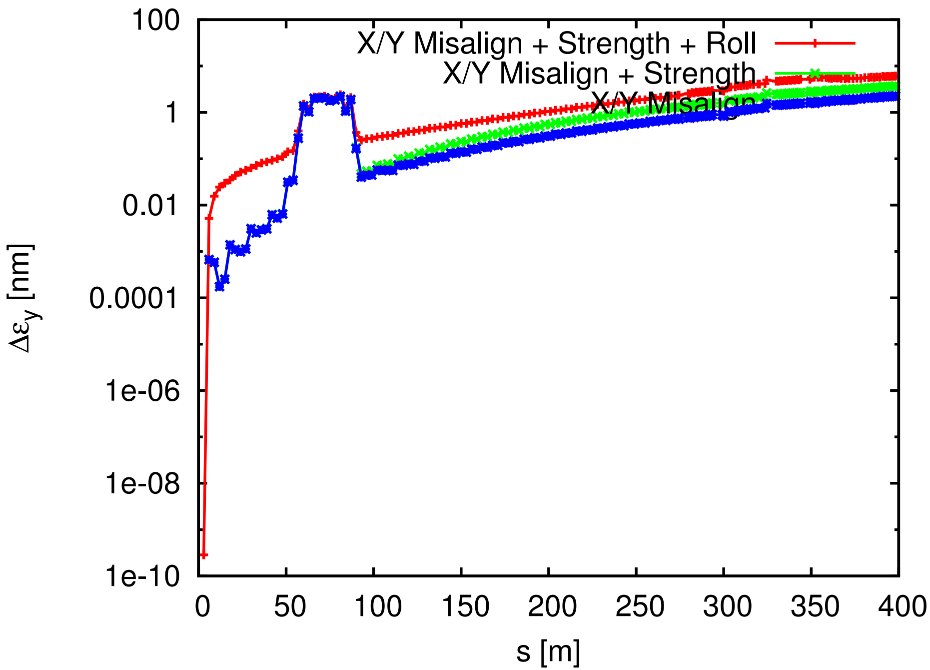
⇒ X/Y Offsets: Final average emittance growth is 0.48 nm (0.52 nm 90% c.l.)

⇒ Add Quad/Sbend Strength: Final average emittance growth is 0.68 nm (1.25 nm 90% c.l.)

⇒ Add Quad/Sbend Roll: Final average emittance growth is 1.87 nm (3.23 nm 90% c.l.)

2) Turnaround + Spin Rotator (Solenoids OFF)

- Correction: 1-TO-1 + Kick Minimization + Dispersion Bumps
- Emittance growth along the line for 1000 seeds:



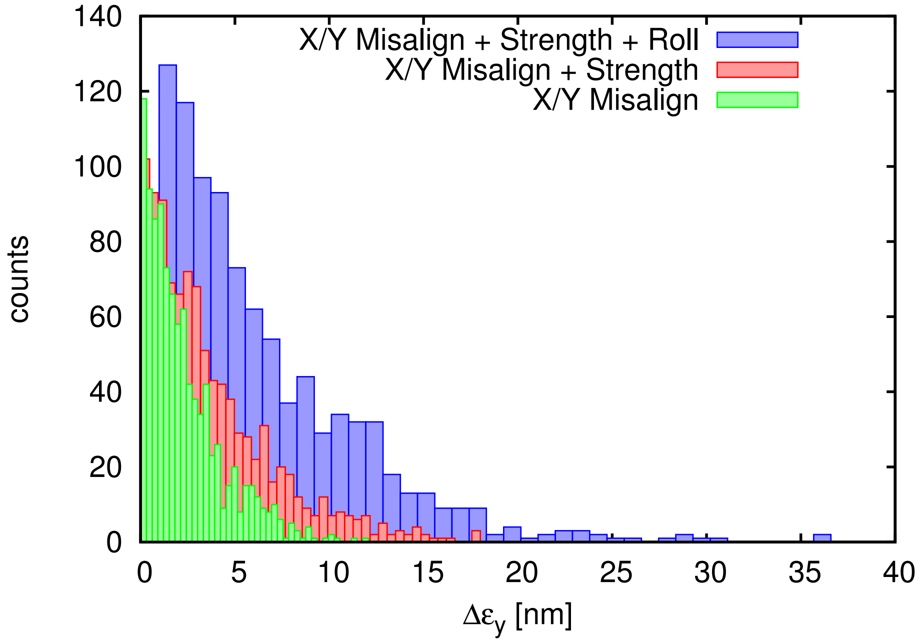
⇒ X/Y Offsets: Final average emittance growth is 2.26 nm (5.33 nm 90% c.l.)

⇒ Add Quad/Sbend Strength: Final average emittance growth is 3.69 nm (8.12 nm 90% c.l.)

⇒ Add Quad/Sbend Roll: Final average emittance growth is 6.11 nm (12.73 nm 90% c.l.)

2) Turnaround + Spin Rotator (Solenoids OFF)

- Correction: 1-TO-1 + Kick Minimization + Dispersion Bumps
- Histogram of final emittance growth for 1000 seeds:



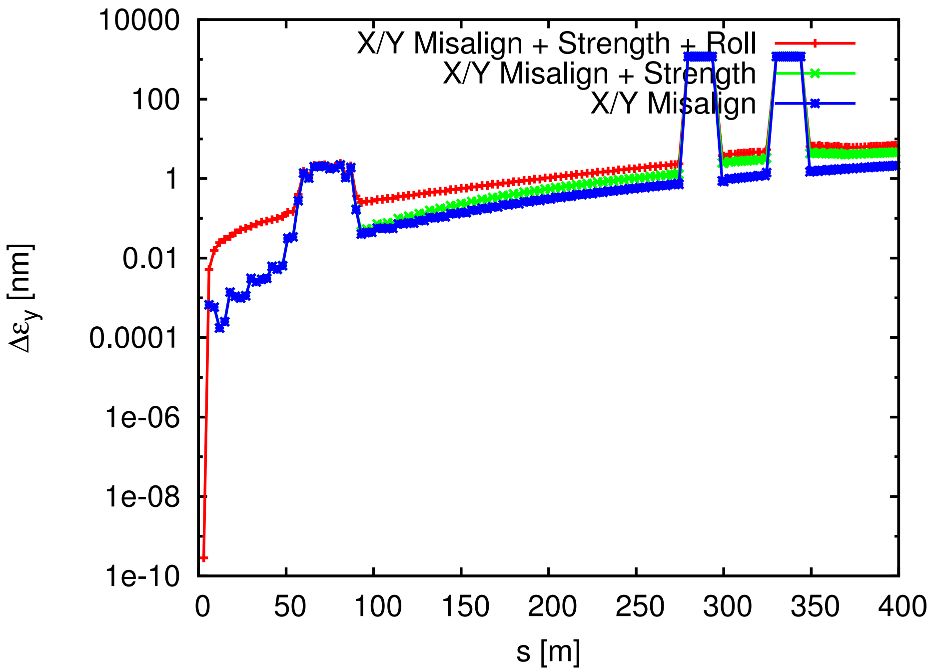
⇒ X/Y Offsets: Final average emittance growth is 2.26 nm (5.33 nm 90% c.l.)

⇒ Add Quad/Sbend Strength: Final average emittance growth is 3.69 nm (8.12 nm 90% c.l.)

⇒ Add Quad/Sbend Roll: Final average emittance growth is 6.11 nm (12.73 nm 90% c.l.)

2) Turnaround + Spin Rotator (Solenoids ON)

- Correction: 1-TO-1 + Kick Minimization + Dispersion Bumps
- Emittance growth along the line for 1000 seeds:



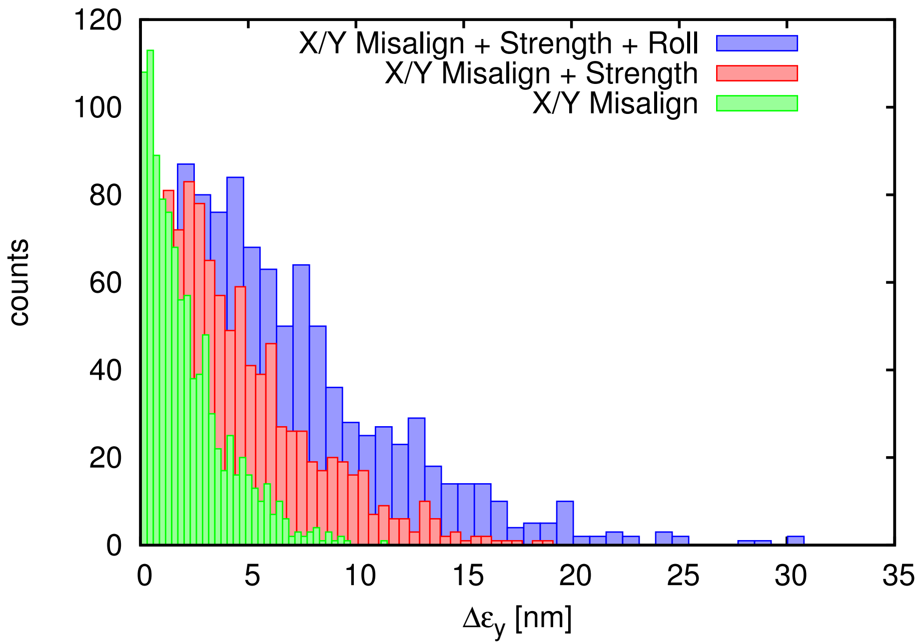
⇒ X/Y Offsets: Final average emittance growth is 2.14 nm (4.83 nm 90% c.l.)

⇒ Add Quad/Sbend Strength: Final average emittance growth is 4.63 nm (9.42 nm 90% c.l.)

⇒ Add Quad/Sbend Roll: Final average emittance growth is 6.86 nm (13.66 nm 90% c.l.)

2) Turnaround + Spin Rotator (Solenoids ON)

- Correction: 1-TO-1 + Kick Minimization + Dispersion Bumps
- Histogram of final emittance growth for 1000 seeds:



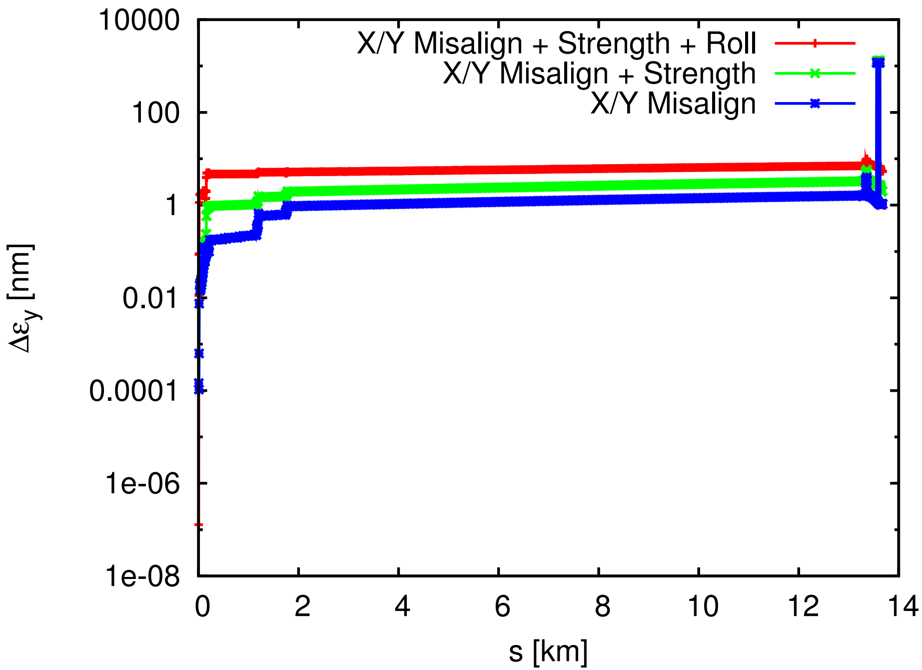
⇒ X/Y Offsets: Final average emittance growth is 2.14 nm (4.83 nm 90% c.l.)

⇒ Add Quad/Sbend Strength: Final average emittance growth is 4.63 nm (9.42 nm 90% c.l.)

⇒ Add Quad/Sbend Roll: Final average emittance growth is 6.86 nm (13.66 nm 90% c.l.)

3) Entire "Front End"

- Correction: 1-TO-1 + Kick Minimization + Dispersion Bumps + Coupling Correction
- Emittance growth along the line for 1000 seeds:



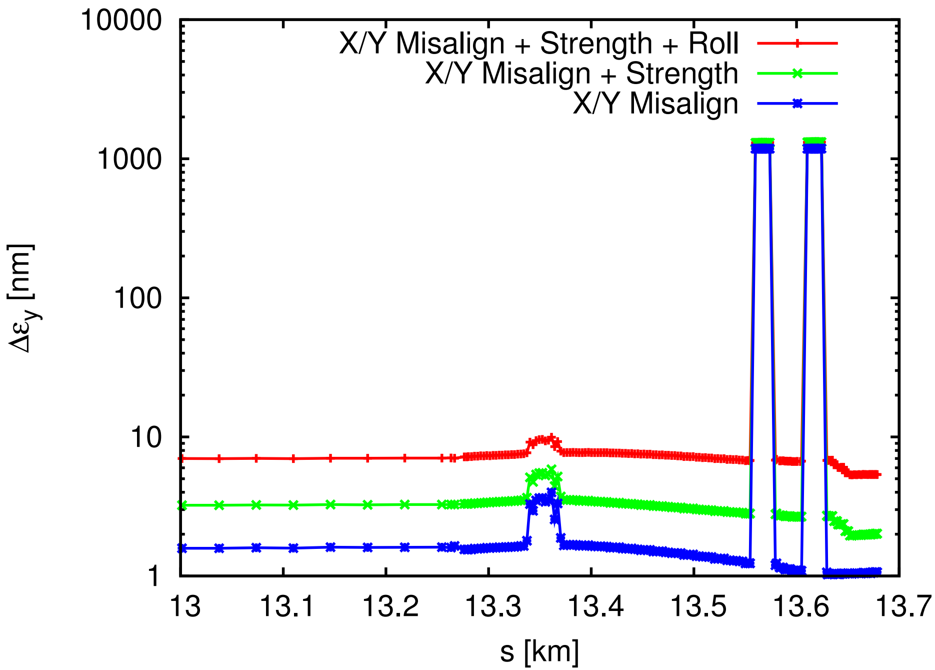
⇒ X/Y Offsets: Final average emittance growth is 1.06 nm (1.58 nm 90% c.l.)

⇒ Add Quad/Sbend Strength: Final average emittance growth is 2.01 nm (3.51 nm 90% c.l.)

⇒ Add Quad/Sbend Roll: Final average emittance growth is 5.36 nm (9.94 nm 90% c.l.)

3) Entire "Front End" (last 700 meters)

- Correction: 1-TO-1 + Kick Minimization + Dispersion Bumps + Coupling Correction
- Emittance growth along the line for 1000 seeds:



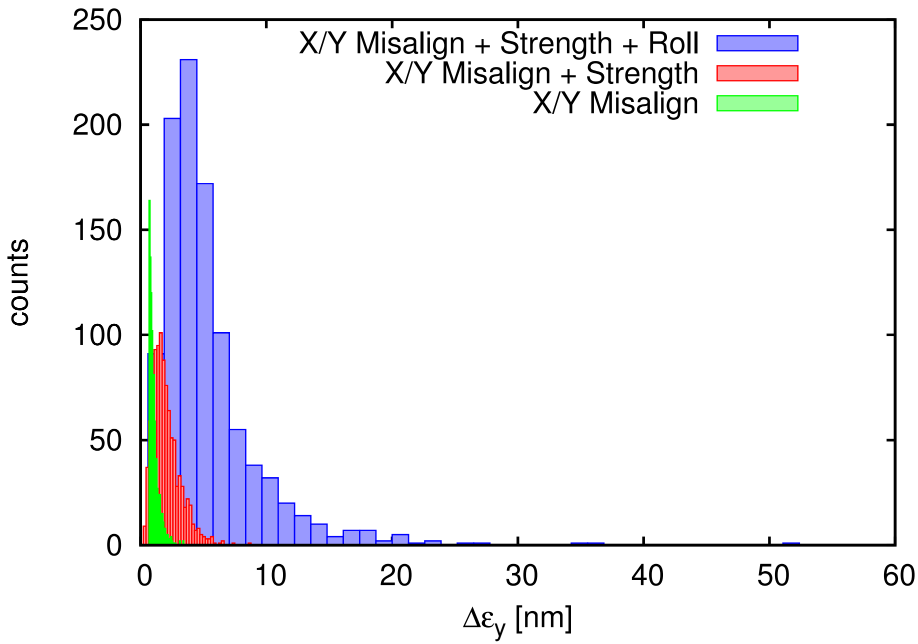
⇒ X/Y Offsets: Final average emittance growth is 1.06 nm (1.58 nm 90% c.l.)

⇒ Add Quad/Sbend Strength: Final average emittance growth is 2.01 nm (3.51 nm 90% c.l.)

⇒ Add Quad/Sbend Roll: Final average emittance growth is 5.36 nm (9.94 nm 90% c.l.)

3) Entire "Front End"

- Correction: 1-TO-1 + Kick Minimization + Dispersion Bumps + Coupling Correction
- Histogram of final emittance growth for 1000 seeds:



⇒ X/Y Offsets: Final average emittance growth is 1.06 nm (1.58 nm 90% c.l.)

⇒ Add Quad/Sbend Strength: Final average emittance growth is 2.01 nm (3.51 nm 90% c.l.)

⇒ Add Quad/Sbend Roll: Final average emittance growth is 5.36 nm (9.94 nm 90% c.l.)

Summary Tables for the "Front End"

- These simulations:

Region	Errors	Emittance Increase (nm)		Correction
		average	90% CL	
Escalator + Getaway + RL	X/Y Offsets	0.48	0.52	KM + knobs + CC
	+ Quad Strength	0.68	1.25	KM + knobs + CC
	+ Quad/Sbend Roll	1.87	3.23	KM + knobs + CC
Turnaround + Spin Rotator (OFF)	X/Y Offsets	2.26	5.33	KM + knobs
	+ Quad/Sbend Strength	3.69	8.12	KM + knobs
	+ Quad/Sbend Roll	6.11	12.73	KM + knobs
Turnaround + Spin Rotator (ON)	X/Y Offsets	2.14	4.83	KM + knobs
	+ Quad/Sbend Strength	4.63	9.42	KM + knobs
	+ Quad/Sbend Roll	6.86	13.66	KM + knobs
Entire "Front End"	X/Y Offsets	1.06	1.58	KM + knobs + CC
	+ Quad/Sbend Strength	2.01	3.51	KM + knobs + CC
	+ Quad/Sbend Roll	5.36	9.94	KM + knobs + CC

Summary Tables for the “Front End”

- PT’s summary table

  SLAC-Tech-Note-07-002:

Table 1:

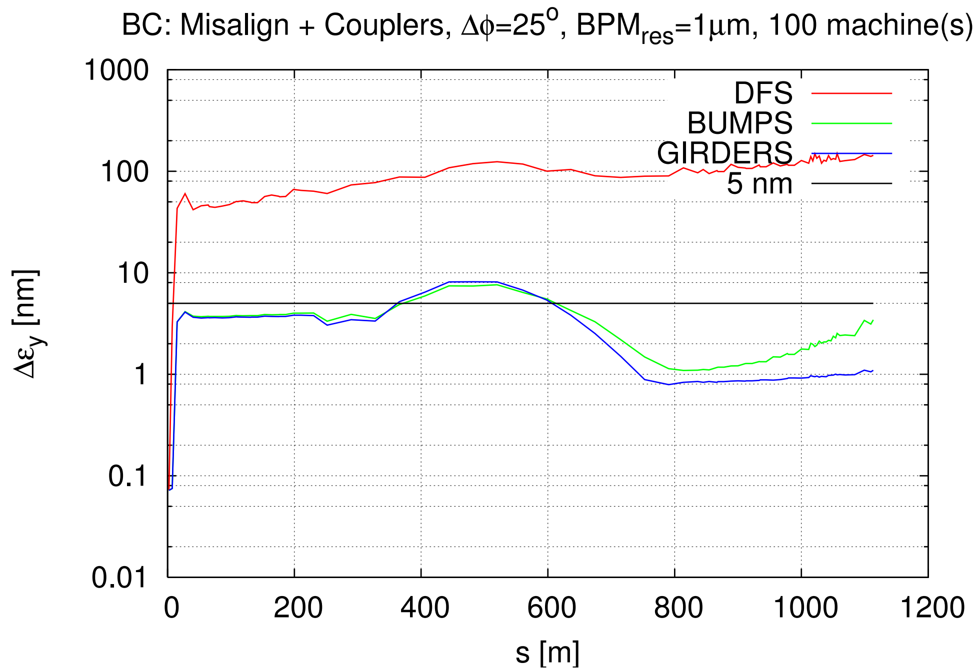
Errors	After KM	After KM + Knobs
X/Y Offsets	2.13 nm	0.37 nm
Add Quad Strength	5.36 nm	3.20 nm
Add Bend Strength	6.12 nm	3.25 nm
Add Quad Rolls	23.22 nm	7.60 nm
Add Bend Rolls	23.31 nm	7.61 nm

- Kiyoshi’s table, LCWS2010 Beijing:

	Emittance increase (nm)		Corrections
	average	90% CL	
Return line	2.15	?	Kick minimization without coupling correction
Turn-around and spin rotator	1.9	?	Kick minimization and skew coupling correction
Bunch compressor	3.3	?	DFS and dispersion bumps
Main linac	6.5	12	DFS (DMS) without coupling correction

4) BC1+BC2, misalignment and couplers

- Correction: 1:1 + DFS + Dispersion Bumps + Girder Optimization
- Emittance growth along the line for 100 seeds:

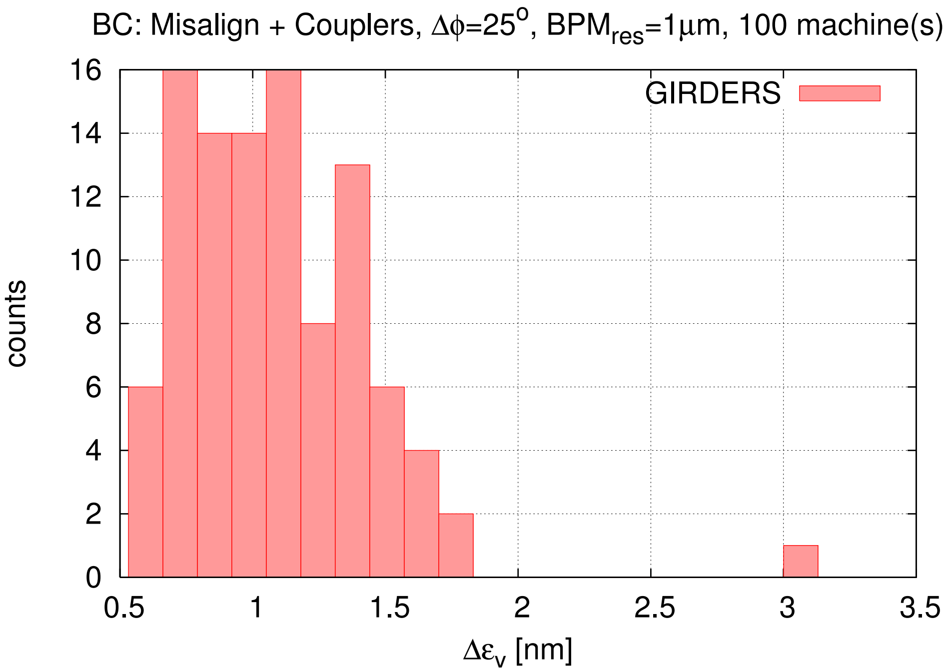


⇒ Minimum of the emittance is at $\omega = 2048$

⇒ Average of final vertical emittance growth is 1.09 nm (1.48 nm 90% c.l.)

4) BC1+BC2, misalignment and couplers

- Correction: 1:1 + DFS + Dispersion Bumps + Girder Optimization
- Emittance growth along the line for 100 seeds:

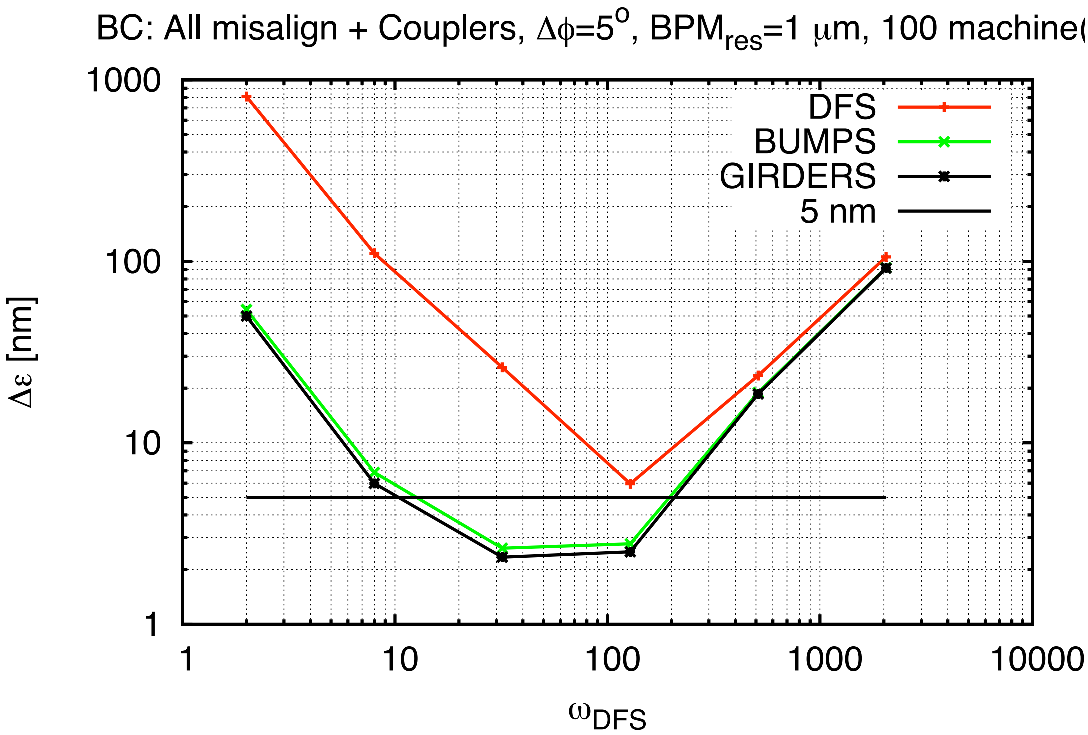


⇒ Minimum of the emittance is at $\omega = 2048$

⇒ Average of final vertical emittance growth is 1.09 nm (1.48 nm 90% c.l.)

4) BC1S, misalignment and couplers

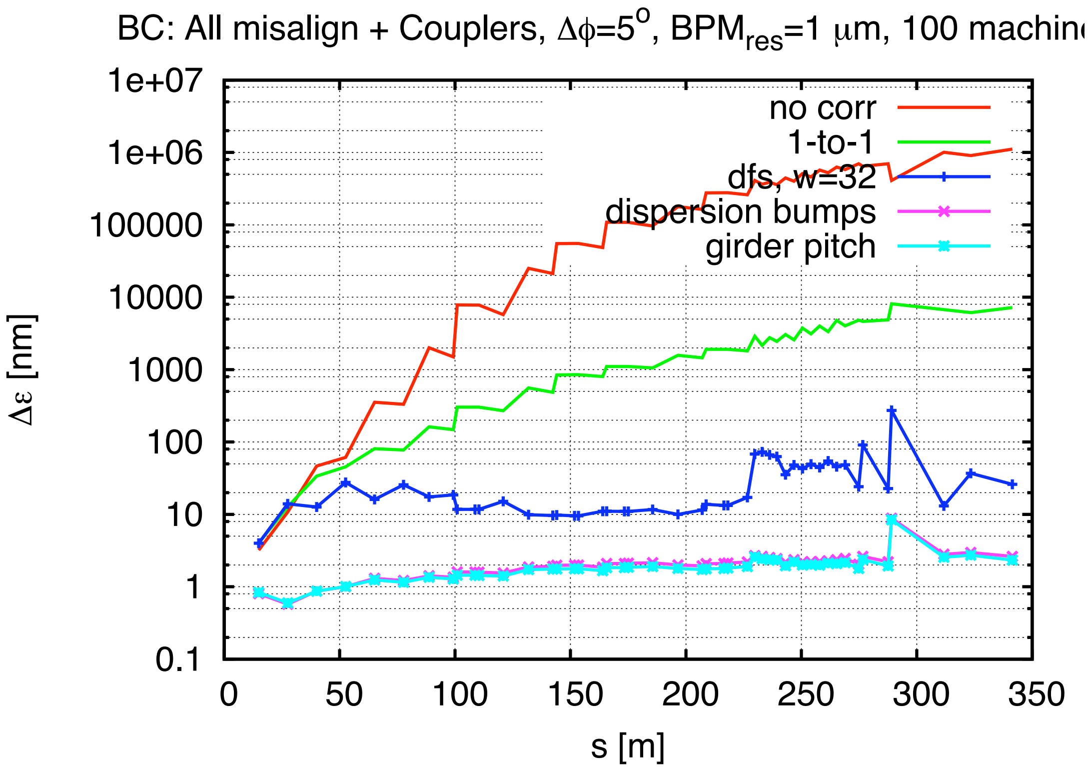
- Vertical emittance along BC1S in case of misalignments
- Couplers kicks are considered



⇒ final emittance growth is 2.3 nm

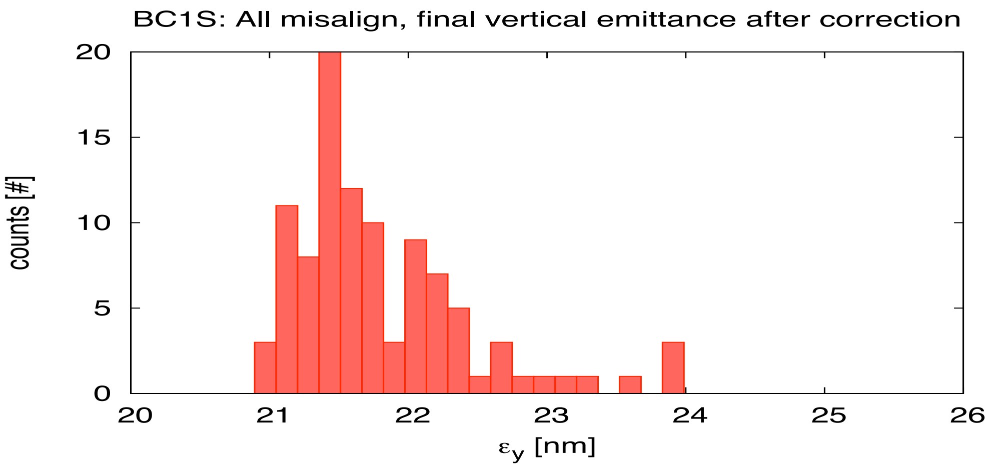
4) BC1S, misalignment and couplers

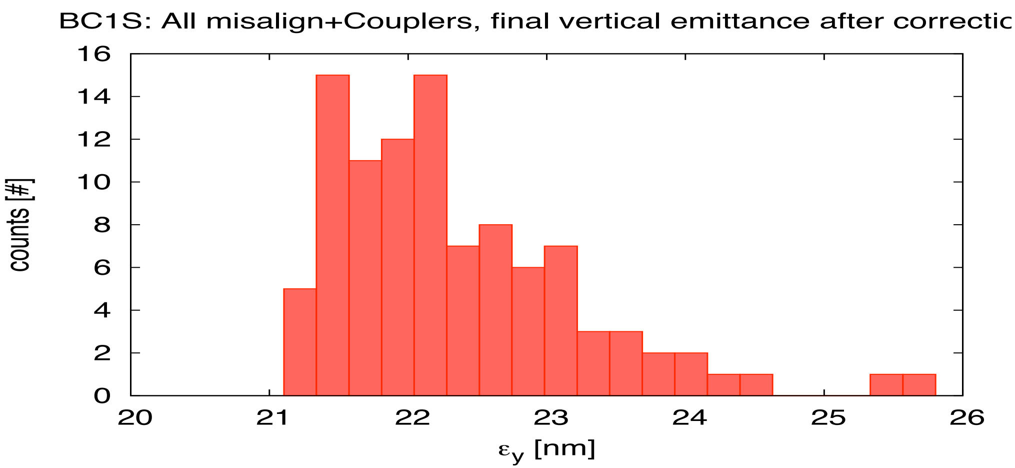
- Vertical emittance along BC1S in case of misalignments
- Couplers kicks are considered



⇒ final emittance growth is 2.3 nm

4) BC1S, misalignment and couplers





Summary Tables for the Bunch Compressors

- These simulations:

Region	Errors	Emittance Increase (nm)		Correction
		average	90% CL	
BC1+BC2	X/Y/X'/Y' Offsets	0.98	1.6	DFS + knobs + Girders
	+ Quad Strength	-	-	DFS + knobs + Girders
BC1+BC2 w/Couplers	X/Y/X'/Y' Offsets	1.09	1.48	DFS + knobs + Girders
	+ Quad Strength	-	-	DFS + knobs + Girders
BC1S w/Couplers	X/Y/X'/Y' Offsets	2.3	-	DFS + knobs + Girders
	+ Quad Strength	-	-	DFS + knobs + Girders

Conclusions and Next Steps

- ILC RTML is in good shape, both RDR and SB2009

- Performances of the entire RTML have been evaluated, and resulted satisfactory

⇒ Integrated simulations of the entire RTML including bunch compressor are in progress

⇒ 90% CL emittances of the bunch compressors must be evaluated

- Dynamic Simulations must be performed