Review of RTML Tuning Studies

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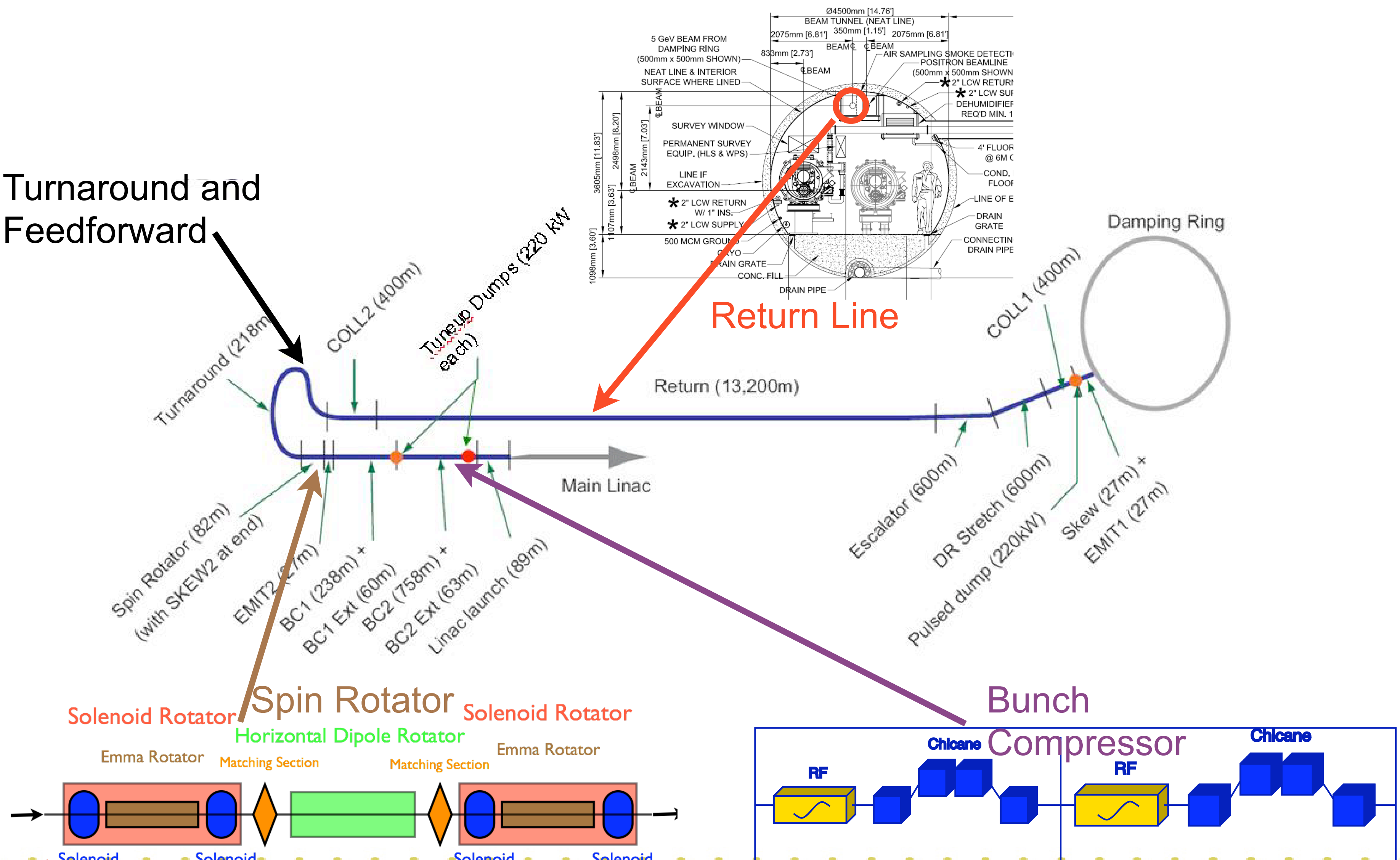
LET Beam Dynamics Workshop at SLAC

The Past

The Past

- LET studies in RTML have not necessarily been too organized.
- Only looked at static alignment
- Each subsection on its own
- Have shown that different BBA methods effective in different regions.
  - **Return Line**
    - Kick minimization works well on its own.
    - Magnet/beam jitter may be a problem => feed-forward may fix this
  - **Turnaround, spin rotator up to BC1**
    - Kick minimization not good enough on its own must be augmented with dispersion bumps => prefer not have to rely on magic dispersion bumps
    - Coupling correction critical
  - **Bunch compressor**
    - Dispersion Free Steering shows much promise.
    - Pitched RF cavities most critical, especially in BC1

The Ring To Main Linac



Survey Alignment

Our old canonical set, should consider more realistic misalignments...
Survey people would prefer we use cold specs for all components.

Error	Cold Sections	Warm Sections	With Respect To...
Quad Offset	300 μm	150 μm	Cryostat
Quad Tilt	300 μrad	300 μrad	Cryostat
Quad strength	0.25%	0.25%	Design Value
BPM Offset	300 μm	200 μm	Cryostat/Survey
BPM-Quad Shunting	20 μm?	7 μm	Quadrupole
BPM Resolution	1 μm	1 μm	True Orbit
Bend tilt	300 μm	300 μm	Survey Line
Bend Strength	0.5%	0.5%	
RF Cavity Offset	300 μm	n/a	Cryostat
RF Cavity Pitch	200 μrad	n/a	Cryostat
Cryostat Offset	200 μm	n/a	Survey Line
Cryostatic Pitch	20 μrad	n/a	Survey Line

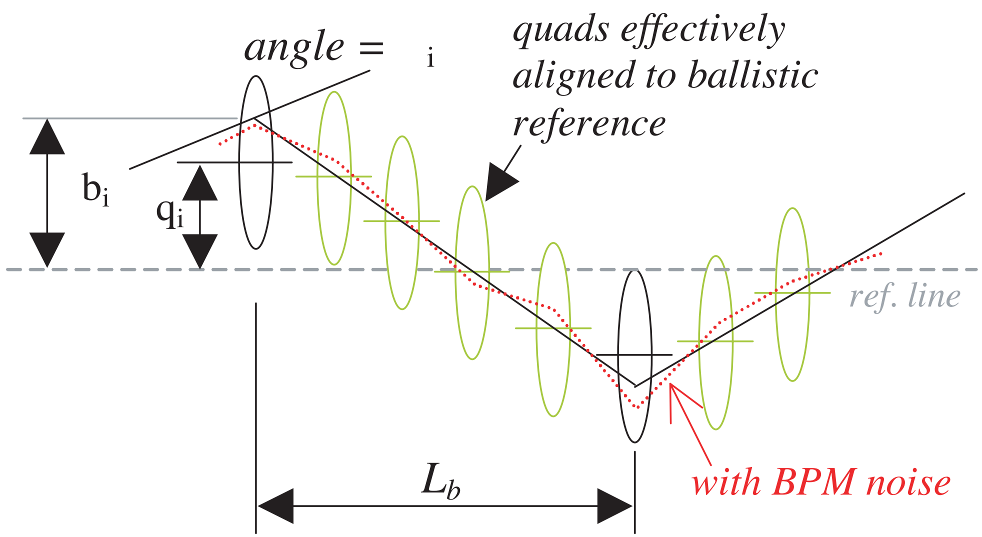
Beam-Based Alignment Algorithms

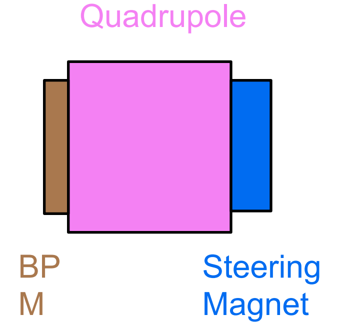
- ILC Beam-Based Alignment attempts to eliminate all sources of emittance growth
- There are several concerns
  - **Remove transverse coupling**
  - **Remove sources of dispersion**
  - **Make sure the beam doesn't filament (more for optics design)**
  - **Minimize wakefield effects (pretty weak, but, Wake Fest 07!)**
  - **Correct for stray fields**
  - **Ground motion**
  - **Power supply jitter -> Beam jitter**
  - **BPM resolution and scale error, Steering magnet error**

LET BBA @ ILC RTML

- Several BBA used (or may be used):
  - **Ballistic Alignment**
  - **Kick Minimization**
  - **Dispersion Free Steering**
  - **Dispersion Bumps**
  - **4D Coupling Correction**
- And maybe in the future:
  - **Adaptive Alignment?**
  - **Wakefield Bumps?**

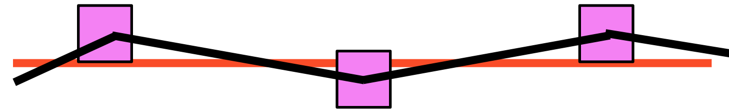
Ballistic Alignment





- Beam moving in straight line is perfectly aligned and has essentially no dispersion. BA attempts to find this orbit
- Turn off all field components in region and take and orbit. This orbit will follow a ballistic trajectory (straight line if no stray fields)
- Turn fields back on and steer beam to ballistic orbit
- Performance decreases with poor BPM resolution and stray fields; but can be very effective.
- Very SLOW: must to ramp up and down all those cold magnets.

Kick Minimization

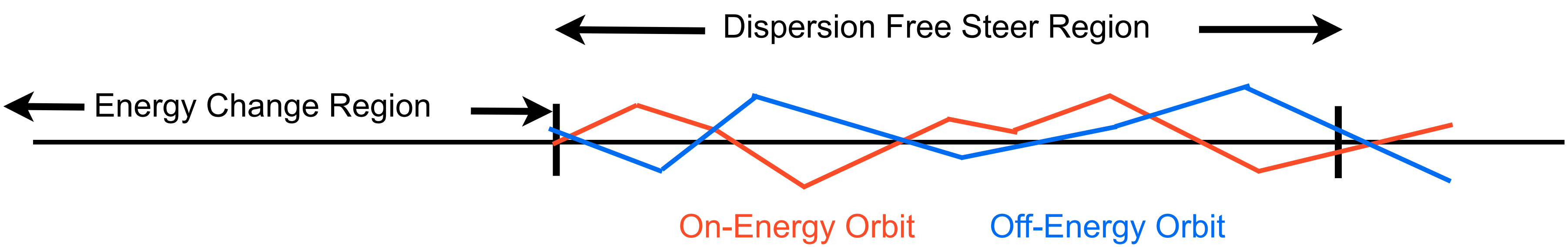


- Kick Minimization (or Kubo Method)
  - The dispersive kick due to each misaligned quadrupole will be

$$\theta = k_1 L_{quad} Y_{beam}$$

  - If Y is measured with the BPM at the quadrupole then a steering magnet located at the same quadrupole can be used to cancel this kick. When all kicks are negated the beam will essentially travel in a straight line.
  - Requires good fiducialization between BPMs and quadrupoles
    - ~7 um BPM-to-quad offset capability in warm magnets worse in cold magnets
  - Works better than 1-1 alignment (black curve in figure).
  - Need to also constrain the absolute orbit.
  - Degrades in performance when sources of dispersive emittance growth become prominent which do not have corresponding BPMs.
  - Does need to iterate and can be slower than 1-1
    - But still quicker than Dispersion Free Steering or Ballistic Alignment.

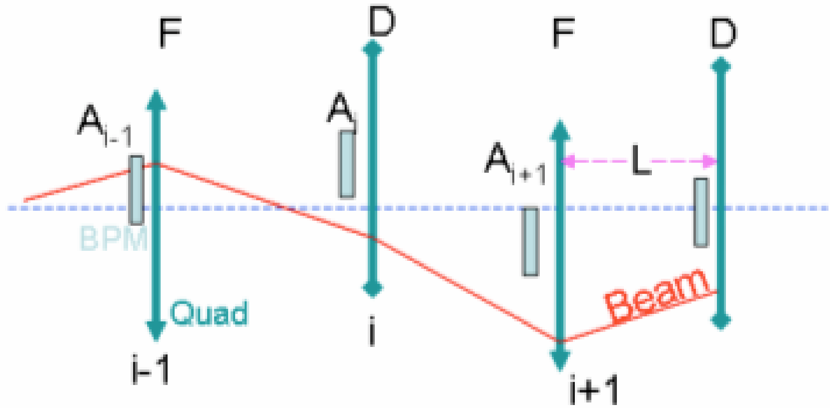
Dispersion Free Steering



- Principle source of emittance growth is dispersion so if the dispersion can be measured it can be zeroed
- The difference between beam orbits at different energies will effectively give the dispersion.
- In the curved linac there is a design dispersion so this must be included (so it's really Dispersion Design Steering)
- Use an optimizer to zero the orbit difference
- Absolute orbit and corrector magnet strengths should also be weighted

Adaptive Alignment

- Not yet used in RTML
- (figure and text From Nick Solyak and Kirti Ranjan PAC07 paper...)



AA is a local method in which the BPM readings (A_i) of the neighbouring quads are used to determine the necessary shifting of a central quad (y_i).

$$\Delta y_i = conv * [A_{i+1} + A_{i-1} - A_i * \{2 + K_i . L . (1 - \frac{\Delta E}{2E})\}]$$

conv : Speed of convergence of algorithm

A_i : BPM reading of the central quad and so on

K_i : Inverse of quad focusing length

L : Distance between successive quads

ΔE : Energy gain between successive quads

E : Beam Energy at central quad

Dispersion and Wakefield Bumps

- Dispersion bumps introduce set amounts of vertical dispersion into the line
  - **Three types**
    - Closed orbit bumps.
    - Pairs of quadrupoles -1 apart in regions with design vertical dispersion; leaks vertical dispersion out of region, but no change in beta function
    - Pairs of skew quads -1 apart in regions with design horizontal dispersion; leaks horizontal dispersion into the vertical, but no change in beta function
- Wakefield bumps are RF cavities, or cryomodules on vertical movers.
  - **Moving the cavities up or down introduces transverse wakefields**
  - **Can be used to remove emittance growth due to wakefields**
- Both methods require some way to measure emittance or vertical beam size
  - **2D or 4D emittance measurement stations (laser wires)**

Summary 2

Tolerable orbit jitter in the turn-around is about 0.75-sigma, which increase emittance about 5% in the region of the turnaround, considering orbit feed-forward.

Then, requirement of stray field in the long (~10 km) straight section of the RTML will be

$$B_{RMS} < 7.5 \times 10^{-9}\ \text{T}.$$

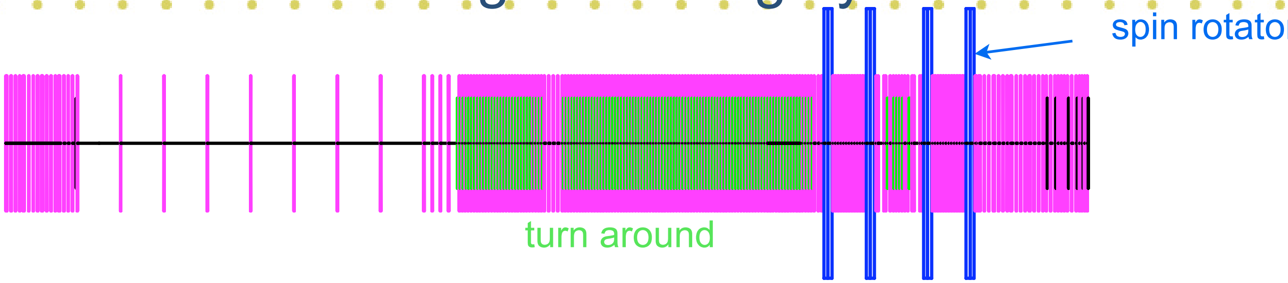
where B_{RMS} is the RMS of average stray field strength between two quads,

$$\int B_x(s)ds/l \qquad (B_x : \text{horizontal magnetic field},\ l : \text{quad spacing})$$

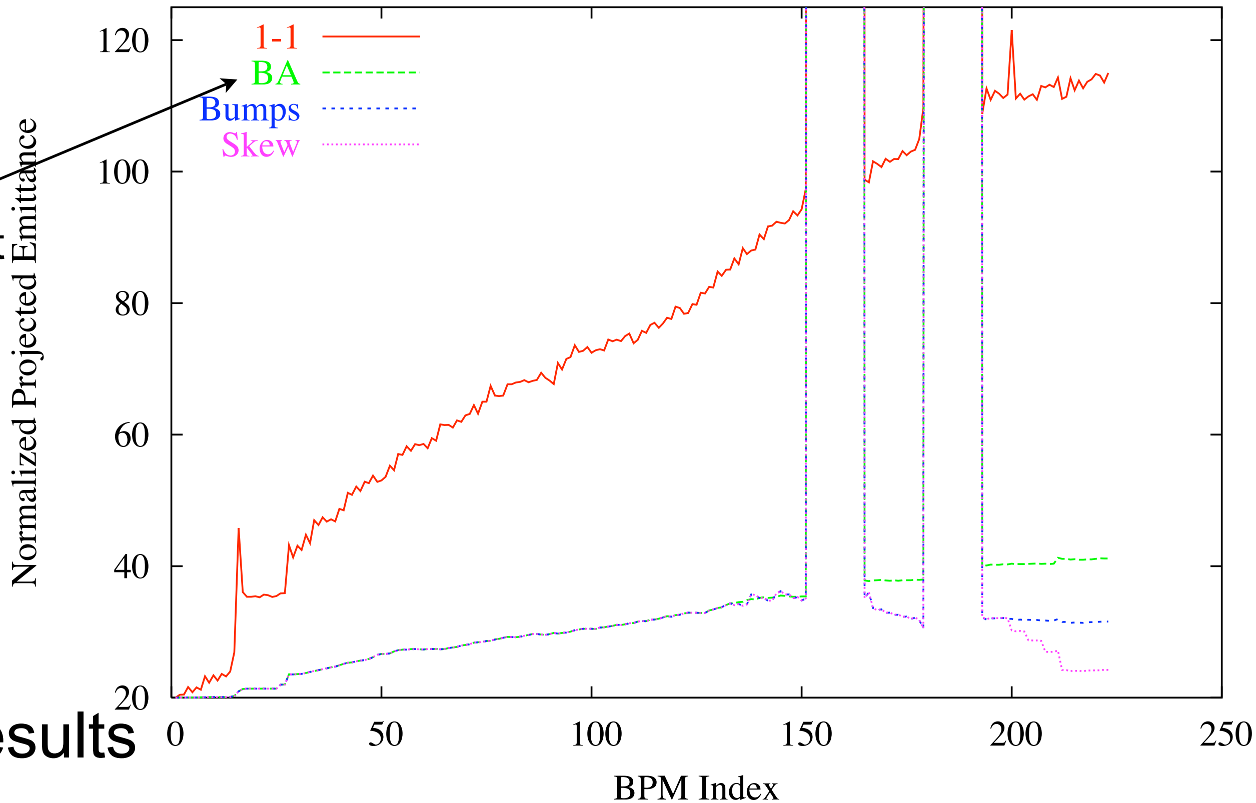
We assumed this average is independent and random for each section.

This limit is relevant for fields which change faster than orbit feedback, either inter-pulse or intra-pulse.

A bit of statuc tuning studies upstream of BC not good enough yet!



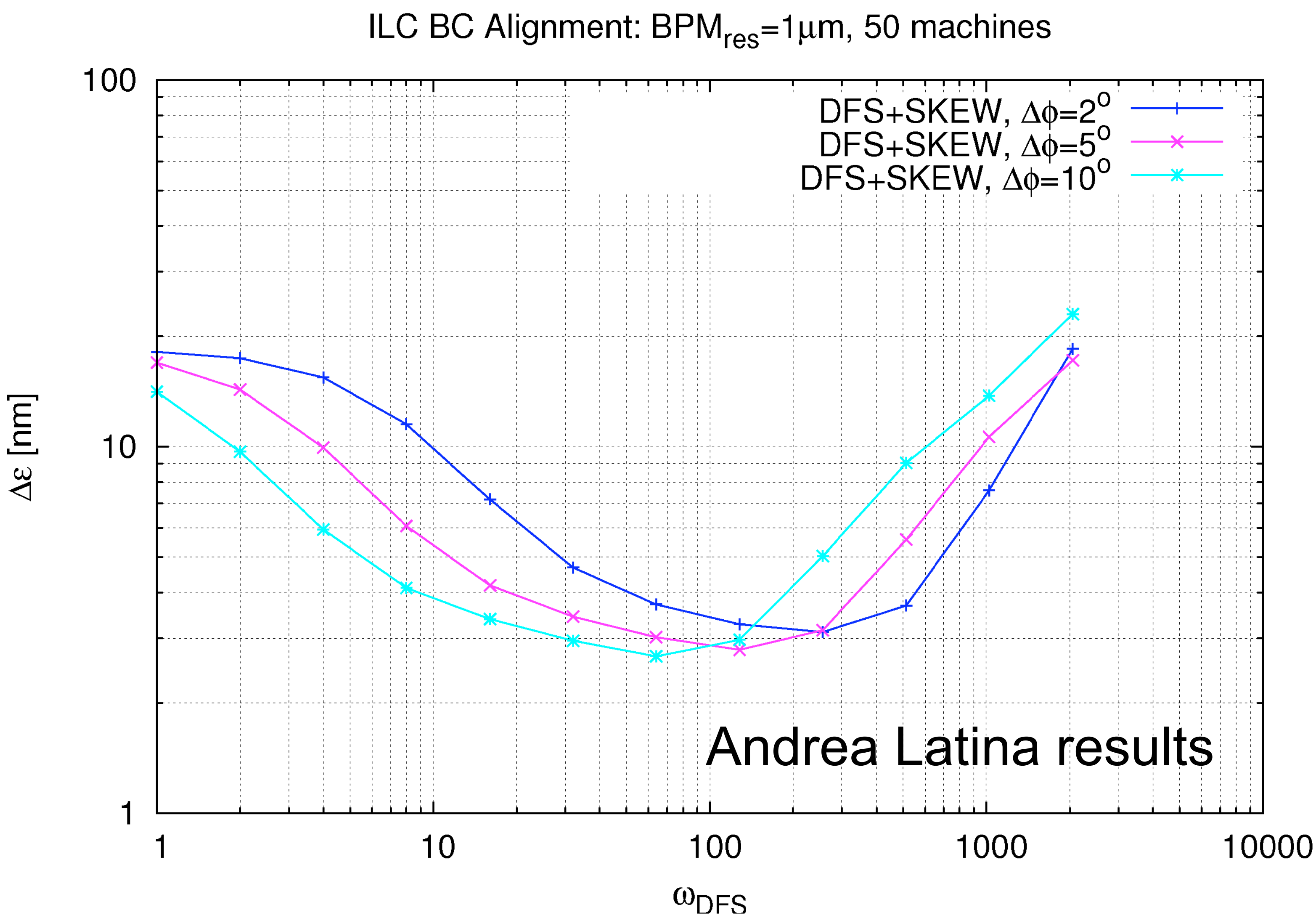
RTML: 1-1, BA, bumps, skew LM, BA, bumps, skew LM LOCALSKEW 20060824



KM works ~about the same as BA, A little better

Jeff Smith results

DFS in BC by adjusting RF phase
Looks promising



RTML

- Not there yet... Budget just 4 nm

Region	BBA method	Dispersive or Chromatic mean Emittance Growth	Coupling mean emittance Growth
Return Line	Kick Minimization and feed-forward to remove beam jitter	0.15 nm	2 nm (without correction)
Turnaround and spin rotator	Kick Minimization and Skew Coupling Correction	1.52 nm (mostly chromatic)	0.4 nm (after correction)
Bunch Compressor	KM or DFS and Dispersion bumps	greater than 4.9 nm (KM + bumps) 2.68 nm (DFS and bumps)	0.6 nm (without correction)
Total		~5 nm almost all from BC	3 nm (without complete correction)

Work still to be done

- We are way past the 4 nm budget!
  - **But we really haven't worked on it much yet and have more things to try.**
- Upstream of the Bunch compressor no serious problems apparent
  - **Well, provided stray fields in return line are no greater than 2 nTesla**
  - **...and we can measure coupling with the wire scanners.**
  - **Vertically displaced bends?**
- Need to address cavity pitches in Bunch Compressor.
  - **DFS may work if tweaked for BC #2 but BC #1 cannot be DF steered.**
  - **There's only three cryomodules in BC #1 perhaps we can treat these with extra care when aligning, or place them on movers.**
- **Phase errors/stability in BC**
- **Dynamic effects and Feedback??????**

Work still to be Done (2)

- Coupling Correction (Which is critical in Spin Rotator) dependent on how well we can measure coupling parameters and/or x/y projected emittance
  - **Requires more work on accurately modeling laser wires.**
- Virtical displacement of bends in turnaround?
- Steal some of the Main Linac emittance budget. We need it more than they do!

From Nikolay's intro talk from this conference

Sources of luminosity degradation we've thought about

- **Synchrotron radiation**
  - From DRX arc, turnaround, BC wigglers
- **Beam-ion instabilities**
- **Beam jitter**
  - From DR
  - From stray fields
- **Dispersion**
  - DR extraction
  - Misaligned quads
  - Rolled bends
- **Coupling**
  - DR extraction septum
  - Rolled quads
  - Misaligned bends
  - Quad strength errors in spin rotator
- **Pitched RF cavities (BC)**
  - Produce time-varying vertical kick
- **RF phase jitter (BC)**
  - Varies IP arrival time of beams
- **Beam halo formation**
- **Collimator Wakefields**

Sources we haven't thought enough about

- **Space charge (recent FNAL results)**
- **Resistive wall wakes in vacuum chamber**

Summary of studies done at RDR stage was presented by PT at RTML Kick-Off Meeting, Sept 27-29, 2007.

http://ilcagenda.linearcollider.org/conferenceDisplay.py?confId=1851

Summary of RTML LET results so far

- "Emittance Preservation in the International Linear Collider Ring To Main Linac Transfer Line," P. Tenenbaum, A Latina, J. C. Smith, K. Kubo. PAC07 Proceedings, THPMS056

The Future

The future

- Past studies on RDR lattice.
  - **Should be updated with changes to lattice**
- Reinvestigate canonical misalignments
- Every study should have at least one independent verification
- Virtually no dynamic studies (i.e. ground motion, power supply jitter) have been studied.
- Work Package Document distributed earlier.

RTML Work Packages

- Static Tuning 1
  - **Apply standard set of misalignments and errors (not necessarily realistic)**
    - Perfect BPMs (infinite resolution and no scale error)
    - Phase and voltage errors? Maybe add these
  - **Simulate BBA and confirm <4 nm emittance growth is achievable at 90% confidence**
  - **Whole RTML together using different methods for each section (if needed)**
  - **If 4 nm is not achievable given standard misalignments, identify improvements needed to achieve budget.**
    - Either tighter tolerances and/or better BBA
    - Best not to have to rely on magic bumps
      - They're our last line of defense and shouldn't need to use up our safety buffer.
  - **Deadline ~May 2008**

RTML Work Packages

- Work Package 2
  - **As more accurate/better misalignment models develop incorporate them into simulations.**
  - **Include:**
    - BPM scale and resolution errors.
    - Failure modes.
      - Failed BPMs, Corrector coils, maybe even failed quads and wire scanners
    - RF errors
      - phase and voltage
  - **Possible failed dependencies:**
    - WP relies on technical experts giving us accurate misalignment/ failure models
      - How do we update our canonical set of misalignments?
        - » i.e. what is the expected phase error for the RF?
  - **Deadline ~November 2009**

RTML Work Packages

- Work Package 3
  - **Re-examine error parameters developed during WP 2.**
  - **Make recommendations to Area Leaders on which realistic errors are unacceptable from an emittance preservation perspective.**
    - I.e. An RF phase error of 2% may be found to be unacceptable, and a reduction to 1% may be necessary for acceptable emittance growth.
  - **Deadline ~November 2009**

RTML Work Packages

- Work Package 4
  - **Dynamic Tuning**
  - **Develop requirements for orbit feedback systems**
  - **How many 5 Hz feedback loops and where to put them?**
  - **What about intra-train feedback?**
  - **Turnaround feed-forward**
  - **Simulations should include:**
    - ground motion
    - component and power supply jitter
    - stray fields
    - DR extraction kicker jitter
  - **Cannot commit to this work at this time**
    - May need more FTEs
    - Work on this WP should probably progress in parallel to other WPs