“It’s the latest wave
That you’ve been craving for
The old ideal
Was getting such a bore
Now you’re back in line
Going not quite as far
But in half the time”

Two Stage Bunch Compressor Proposal

Snowmass WG1

US BC Task Force

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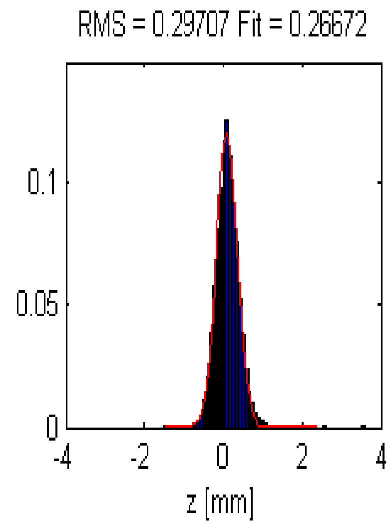
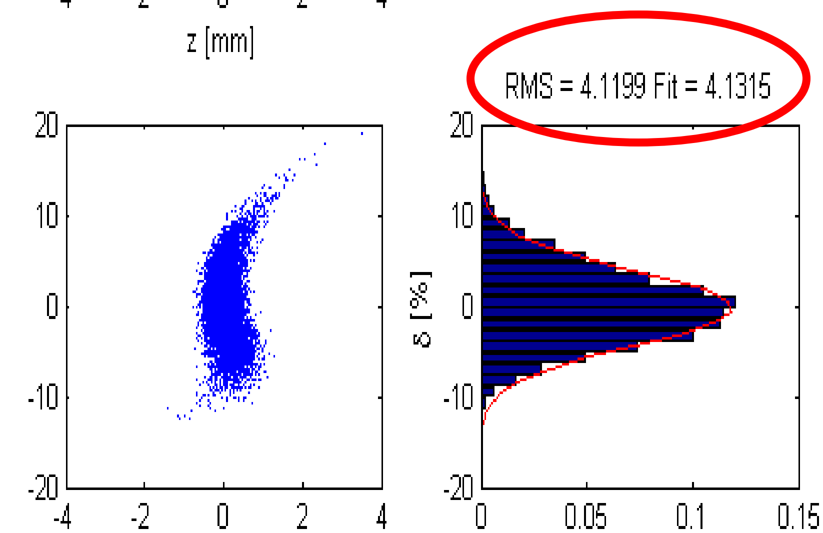
Motivation

- TDR used single-stage BC to compress from 6 mm to 0.3 mm RMS
  - Large energy spread at linac entrance
    - bad for emittance preservation
    - Limits achievable compression factor
- ILC DRs have larger energy spread than TDR
  - 0.15% vs 0.13% at full current
  - Big effect on BC design
- ILC parameters may require 0.15 mm RMS bunch length
- DR parameters may require 9 mm RMS bunch length
- Want smaller emittance growth for nominal parameters and/or capacity to operate with other parameters



Single-stage BC retuned to 0.15% initial energy spread, 1.3 GHz RF only!



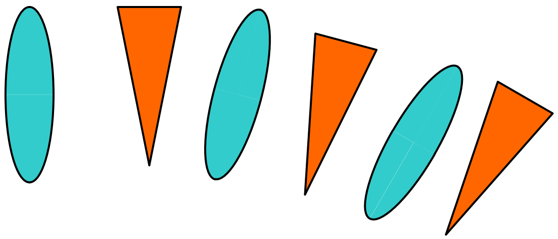
Motivation (2)

- Use of multiple stages of compression can reduce peak energy spread
  - Perform partial compression
  - Accelerate off-crest (accelerate and chirp beam)
  - Compress again at higher energy
- Results in “long” section with moderate energy spread
- System length, complexity, voltage greater than in single-stage system

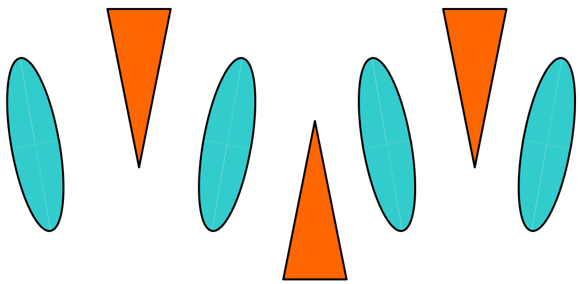
Overall Configuration

Basic choices are:

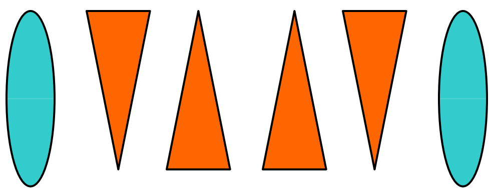
Arc or dogleg ($R_{56} > 0$ in TRANSPORT notation) – changes beamline geometry, requires T_{166} correction, R_{56} adjusted via quad lattice



FBDB configuration ($R_{56} < 0$) – straight beamline geometry, no T_{166} correction needed, R_{56} hard to adjust (except by mechanical intervention)



FCDC configuration – similar to FBDB but easier to adjust R_{56}, longer (more SR emittance growth than equivalent FBDB)

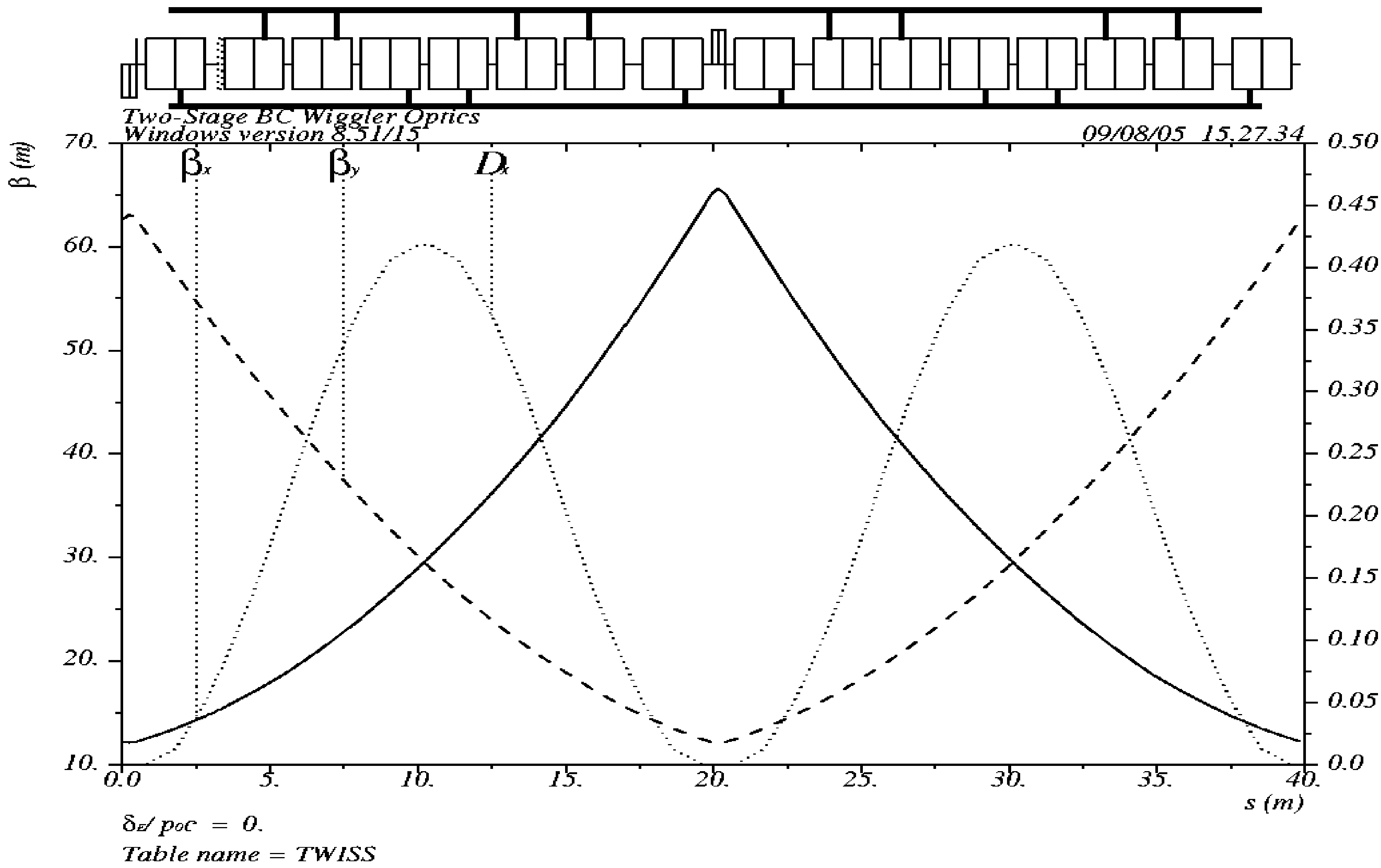


We chose FCDC for this exercise

Overall Configuration (2)

- FODO cell for wiggler = 90°
- 6 cells in each wiggler
- Normal/skew quads for dispersion correction
  - cells 1 and 3
  - cells 4 and 6
- BPMs for energy measurement
- 8 bends per chicane
  - Adjust bends 2, 3, 6, 7 to vary R_{56}
    - Corrector quads and BPMs between bends 1 and 2, 7 and 8
      - don't need to move when R_{56} varied

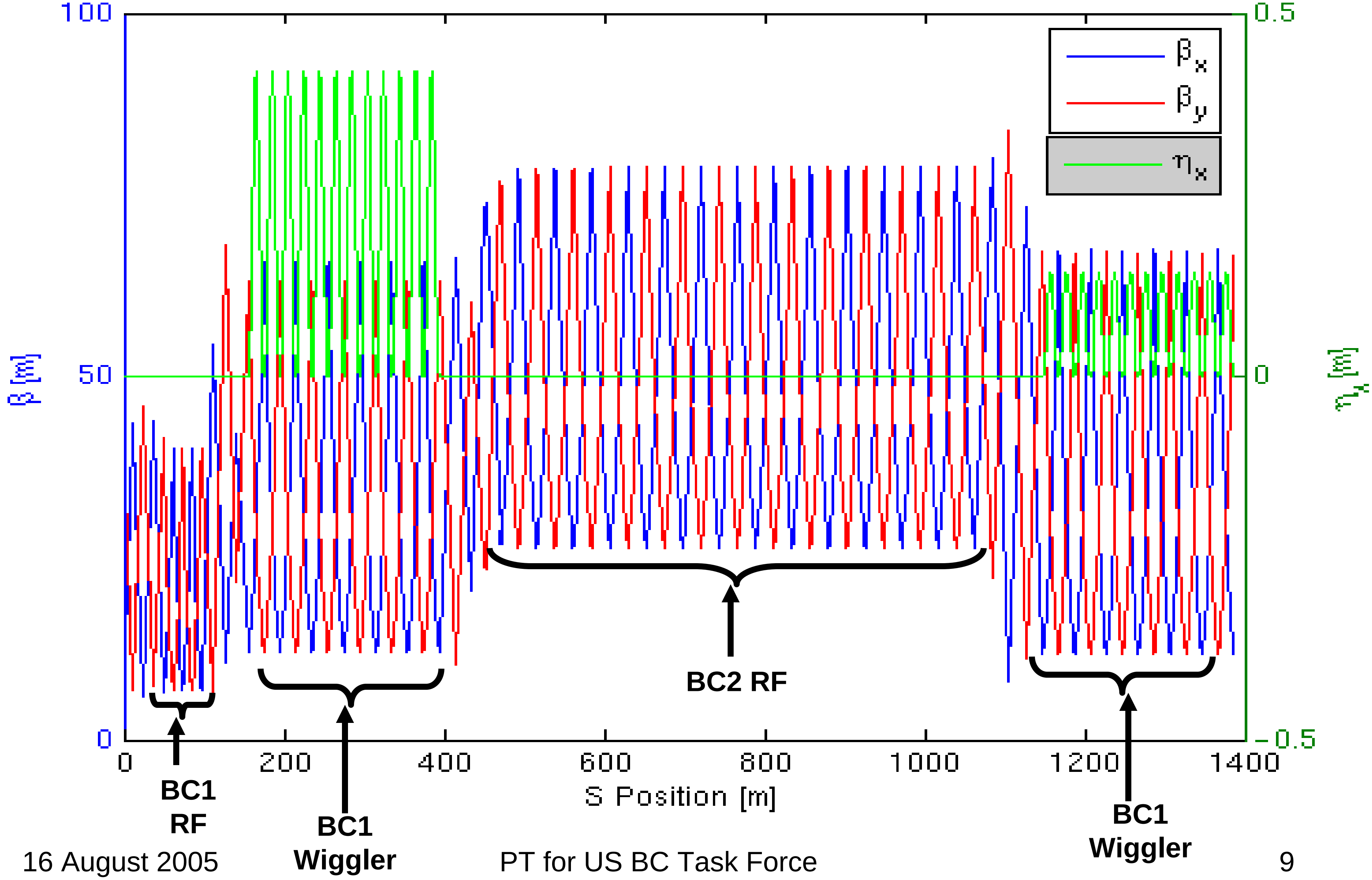
Wiggler Cell Optics



Longitudinal Optics

- Simplest approach: two “90°” rotations in longitudnal phase
  - R_{55} ~ 0 in each rotation
  - Overall $R_{55} \neq 0$
    - DR phase transients → linac phase errors
    - DR bunch lengthening → IP bunch lengthening
- Alternate approach: one “90°” rotation
  - first stage under-compresses
  - Overall R_{55} ~ 0
  - More energy gain in BC2 linac
  - Larger energy spread in BC2 linac
- Looked at both configurations, 300 um and 150 um final bunch length from 6 mm initial
- “A” parameters == 180° rotation
- “B” parameters == 90° rotation

Overall Lattice



Key Parameters

Parameter	300 “A”	300 “B”	150 “A”	150 “B”
Initial Energy [GeV]	5.0	5.0	5.0	5.0
Initial Energy Spread [%]	0.15	0.15	0.15	0.15
Initial Bunch Length [mm]	6.0	6.0	6.0	6.0
BC1 Voltage [MV]	348	610	253	580
BC1 Phase [°]	-100	-110	-100	-110
BC1 R_{56} [mm]	-550	-273	-750	-267
End BC1 Bunch Length [mm]	0.85	0.80	1.14	1.12
End BC1 Energy [GeV]	4.94	4.79	4.96	4.80
End BC1 Energy Spread [%]	1.12	1.93	0.82	1.83
BC2 Voltage [MV]	11,215	11,000	12,750	11,600
BC2 Phase [°]	-40	-22	-58	-45
BC2 R_{56} [mm]	-70	-59	-41	-42
End BC2 Bunch Length [mm]	0.30	0.30	0.15	0.15
End BC2 Energy [GeV]	13.5	15.0	11.7	13.0
End BC2 Energy Spread [%]	1.12	1.07	2.73	2.46

“Site Tax”

- 2-Stage BC is longer than 1 Stage…
- …but 2 Stage has additional energy gain
  – does part of the linac’s job
- What is a fair comparison?
- Consider the “site tax”
  – Additional length needed for BC when BC RF energy gain/loss is taken into account
    - Coasting lattice: site tax == length
    - Accelerating RF: site tax < length
    - Decelerating RF: site tax > length

Site Tax (2)

Item	1 Stage	300 “A”	300 “B”	150 “A”	150 “B”
Matching	51.1	51.1	51.1	51.1	51.1
BC1 RF	67.0	48.6	55.1	46.7	54.1
Matching	58.4	58.4	58.4	58.4	58.4
BC1 Wiggler	239.1	239.1	239.1	239.1	239.1
Matching	--	77.1	77.1	77.1	77.1
BC2 RF	--	161.6	81.4	253.1	181.0
Matching	--	86.0	86.0	86.0	86.0
BC2 Wiggler	--	238.8	238.8	238.8	238.8
Matching	112.2	112.2	112.2	112.2	112.2
Total	527.8	1072.9	999.2	1162.5	1097.8

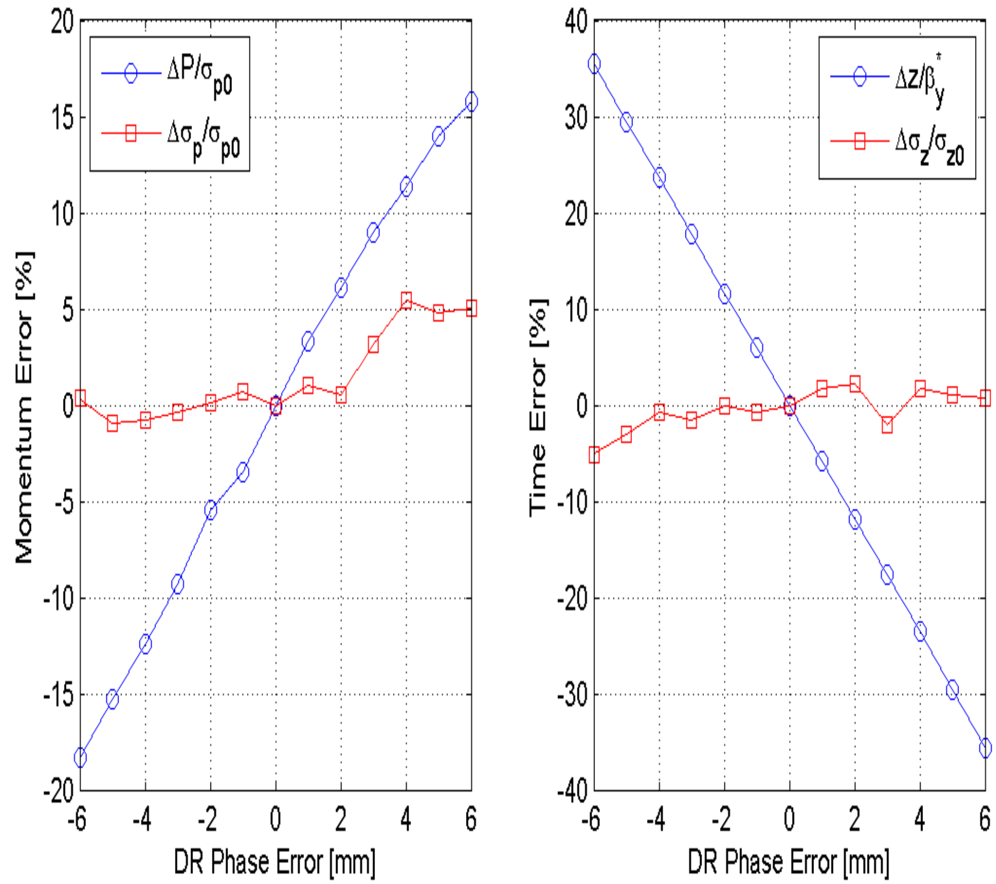
Note: 1 Stage wiggler could be made shorter (R_{56} requirement is small) – same wiggler used for 1 stage and 2 stage for optics comparison purposes

Performance Metrics

- Longitudinal tolerances
  - Sources
    - DR extraction phase
    - BC1 phase/amplitude variation
    - BC2 phase/amplitude variation
  - Effects
    - IP energy / energy spread
    - IP arrival time / bunch length
- Transverse tolerances
  - Emittance growth from
    - 10 um BPM offsets
    - 75 urad RF cavity pitches
    - 500 urad RF cavity offsets
  - Need to consider errors in the BC and the linac!
    - Don't want to make tolerances loose in BC by making them tight in the linac!

Longitudinal Dynamics

- Energy and energy spread effects small
  - Typical effects at level of 0.1% of beam energy or less
  - BDS bandwidth closer to 1%
- z / σ_z effects larger
  - Assume that 20% z variation and 5% σ_z are the limit
  - Assume that BC1 and BC2 RF have same phase and amplitude stability



Longitudinal Tolerances

Red = Arrival time driven tolerance, blue = IP bunch length driven tolerance

Parameter	1 Stage	300 “A”	300 “B”	150 “A”	150 “B”
DR Extraction Phase	1.5 mm	0.9 mm	5 mm	0.75 mm	2 mm
BC RF Amplitude	0.2%	0.1%	0.15%	0.08%	0.1%
BC RF Phase	0.07°	0.05°	0.12°	0.03°	0.06°

Transverse Emittance Growth

Error	1 Stage	300 “A”	300 “B”	150 “A”	150 “B”
10 um BPM Offsets	2.83 nm	0.51 nm	1.31 nm	3.73 nm	5.34 nm
75 urad Cavity Pitches	3.08 nm	0.52 nm	1.77 nm	2.30 nm	3.04 nm
500 um Cavity Offsets	2.07 nm	0.89 nm	1.63 nm	2.12 nm	2.68 nm

Conclusions

- Compared to Single-stage BC, two-stage system offers
  - reduced emittance growth at σ_z = 300 μm, or
  - emittance growth at σ_z = 150 μm comparable to single-stage emittance growth at σ_z = 300 μm
- Two stage system can be tuned to ease transverse tolerances or DR extraction tolerances
- Two stage system more tolerant of longer DR bunch
- RF tolerances pretty tight in all designs
- Two stage system is longer than one-stage
  - A shorter 2-stage with FBDB wigglers is possible
    - need to change quad yaw angles when tuning bunch length
  - May be some tradeoffs with stronger optics
    - Can reduce SR growth and thus length
    - May tighten transverse tolerances

How to choose?

- Are we really interested in 150 µm bunch length?
  - If so, two-stage probably essential
- Are we really interested in 9 mm DR bunch length?
  - If so, two-stage preferred (“B” configuration)
- What is the realistic emittance performance gain for 1 vs 2 stages?
- What is the real stability tolerance on IP bunch length?
  - 5% → tight DR phase tol or 2-stage “B” system
  - Looser tolerance on IP bunch length makes 1 stage more attractive