Beam Dynamics Tolerances for Module Design

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DESY/FNAL Module Meeting

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What Tolerances are Important?

- Alignment tolerances critical to emittance preservation
  – We would like everything exactly aligned to some reference “straight line”
- A 10-20 km straight line?
  – long wavelength ($>\lambda_\beta$) “wobbles” don’t matter*
  – short-distance (component-component) alignment is what counts

(* there are limits on the this also)

What Tolerances are Important?

- When beam dynamics people talk about cavity (or quadrupole) alignment, they refer to the EM centre of the field of interest:
  - Cavities: electrical centres of the HOM (transverse dipole modes $\rightarrow$ wakefields)
  - Quadrupoles: magnetic centre of field (null-point $\rightarrow$ no dipole field)

Standard Beam Dynamics Tolerances

BPM offsets	11 μm	RMS values to each give 1nm vertical emittance growth (TDR budget 10nm)
Cavity offset	300 μm	
Cavity tilt	240 μr	
Canonical installation tolerances (TDR)		
Cavity offset	300 μm	cryomodule
Cavity tilt	300 μr	cryomodule
Quadrupole	300 μm	cryomodule
BPM	200 μm	cryomodule
Cryomodule	200 μm	accelerator reference

Gaussian uncorrelated random numbers used in simulations

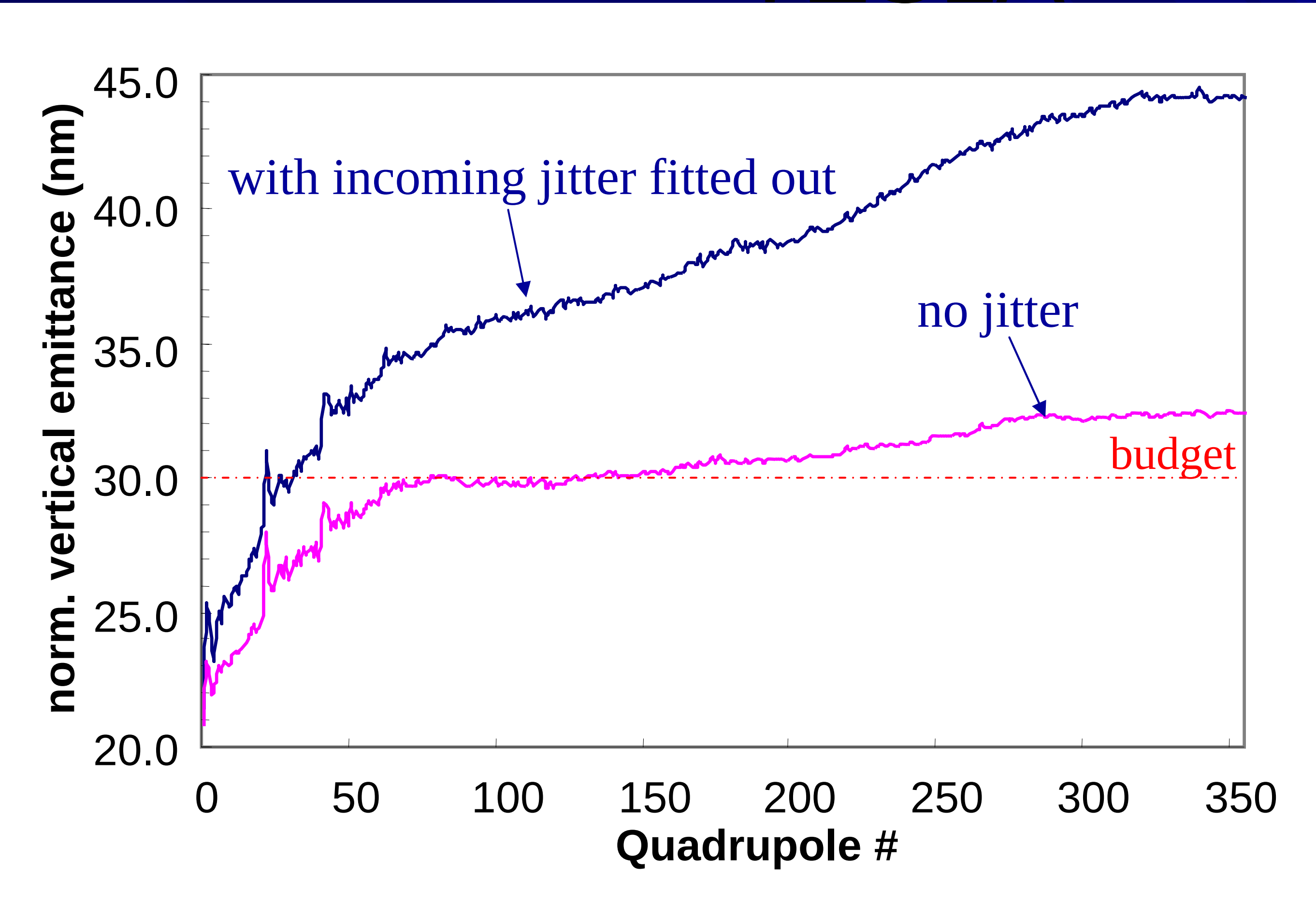
How these add

- $\Delta\varepsilon/\varepsilon$ scales as error^2
- Individual errors add $\Delta\varepsilon/\varepsilon = \Sigma\ \Delta\varepsilon_i/\varepsilon$
- Systematic errors generally more damaging that purely random ones.

Comments on Alignment

- Cavity alignment tolerances 'relaxed' enough
  - If we can mechanically (electrically?) achieve these, there's nothing left to do
  - We have other tools in our bag to help fix things
    - orbit bumps in or at the end of the linac
- BPM alignment (quad alignment) too tight!
  - Need to use BBA techniques to get emittance growth down

Dispersion Free Steering for TESLA



The effect of upstream beam jitter on DFS simulations for the TESLA linac.

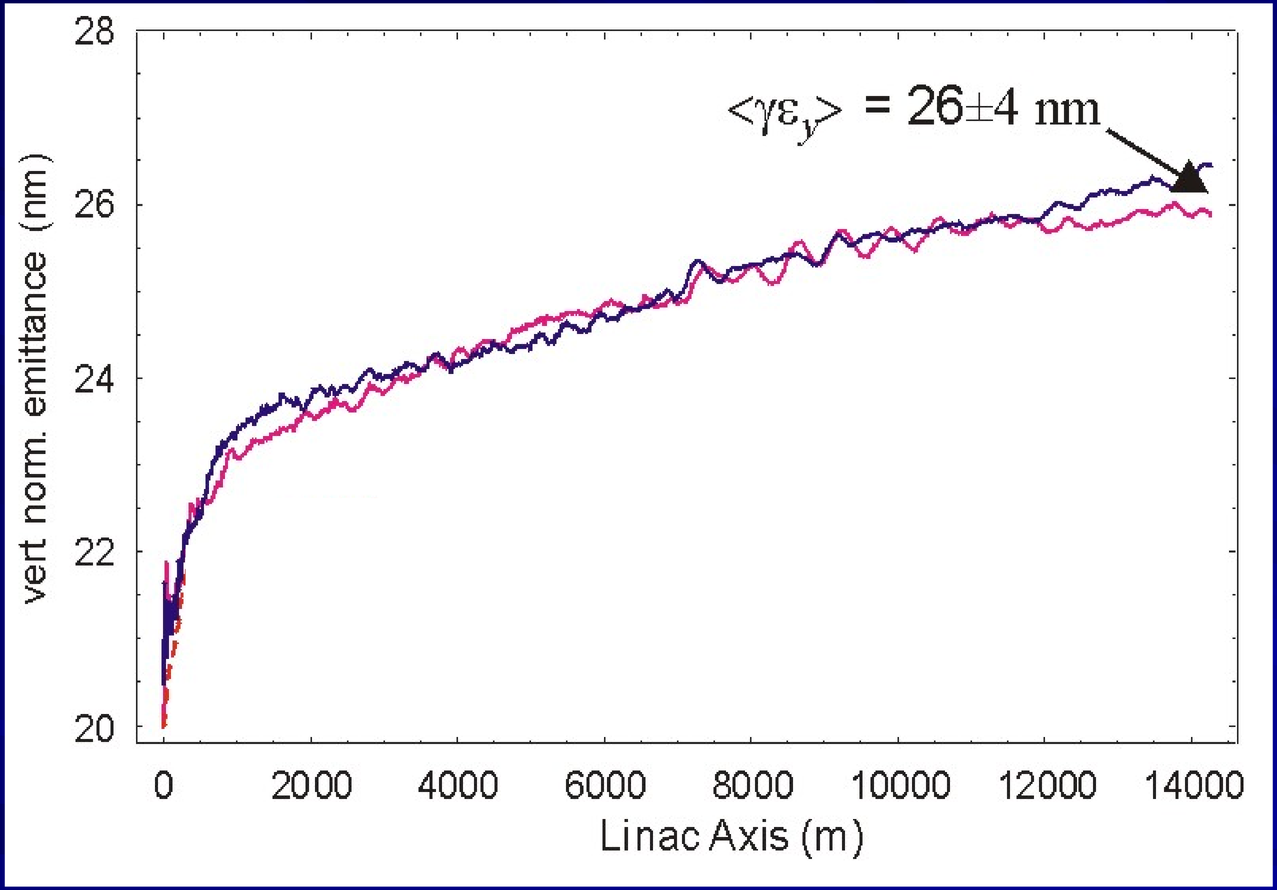
1 σ_y initial jitter

10 μm BPM noise

BPM resolution critical

average over 100 random machines

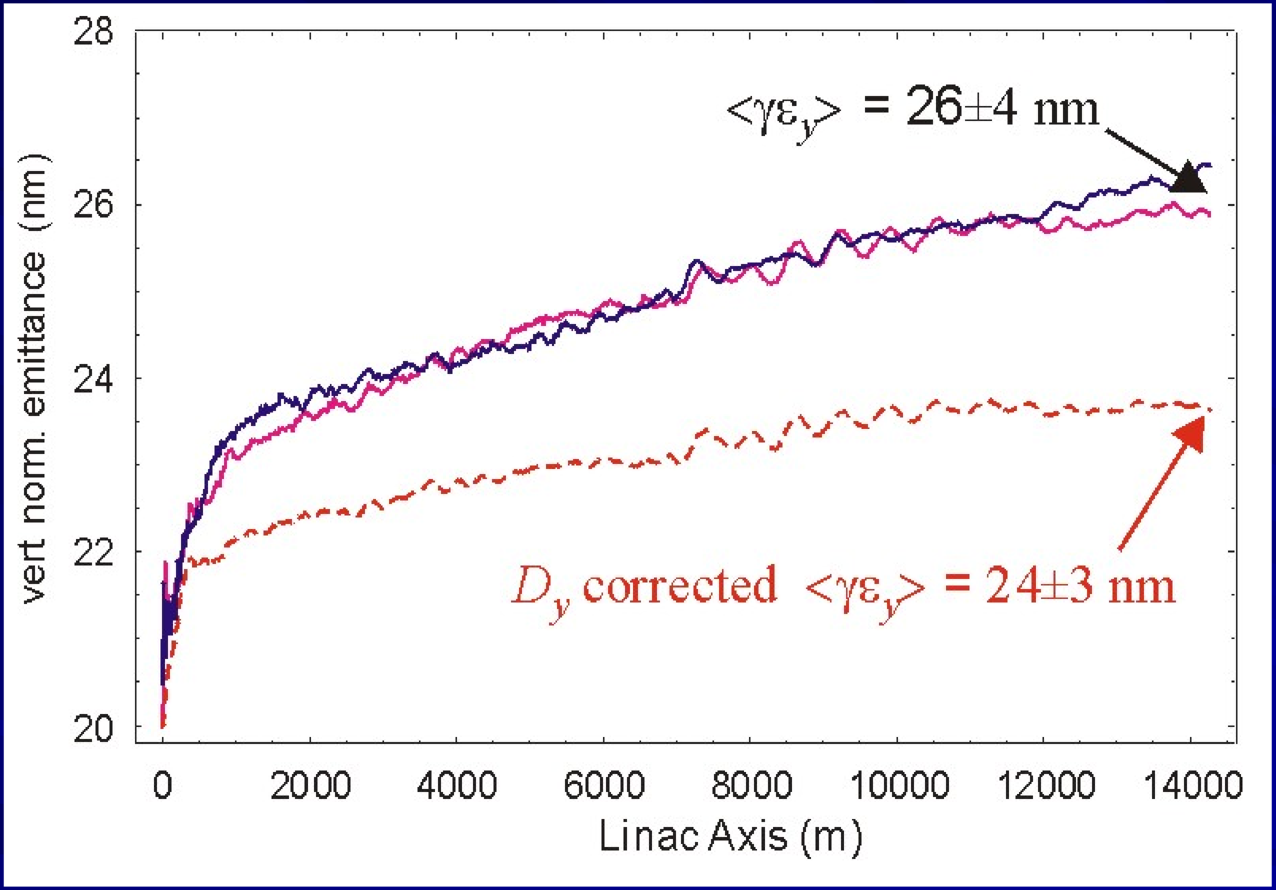
Ballistic Alignment



Less sensitive to
- model errors
- beam jitter

average over 100 seeds

Ballistic Alignment



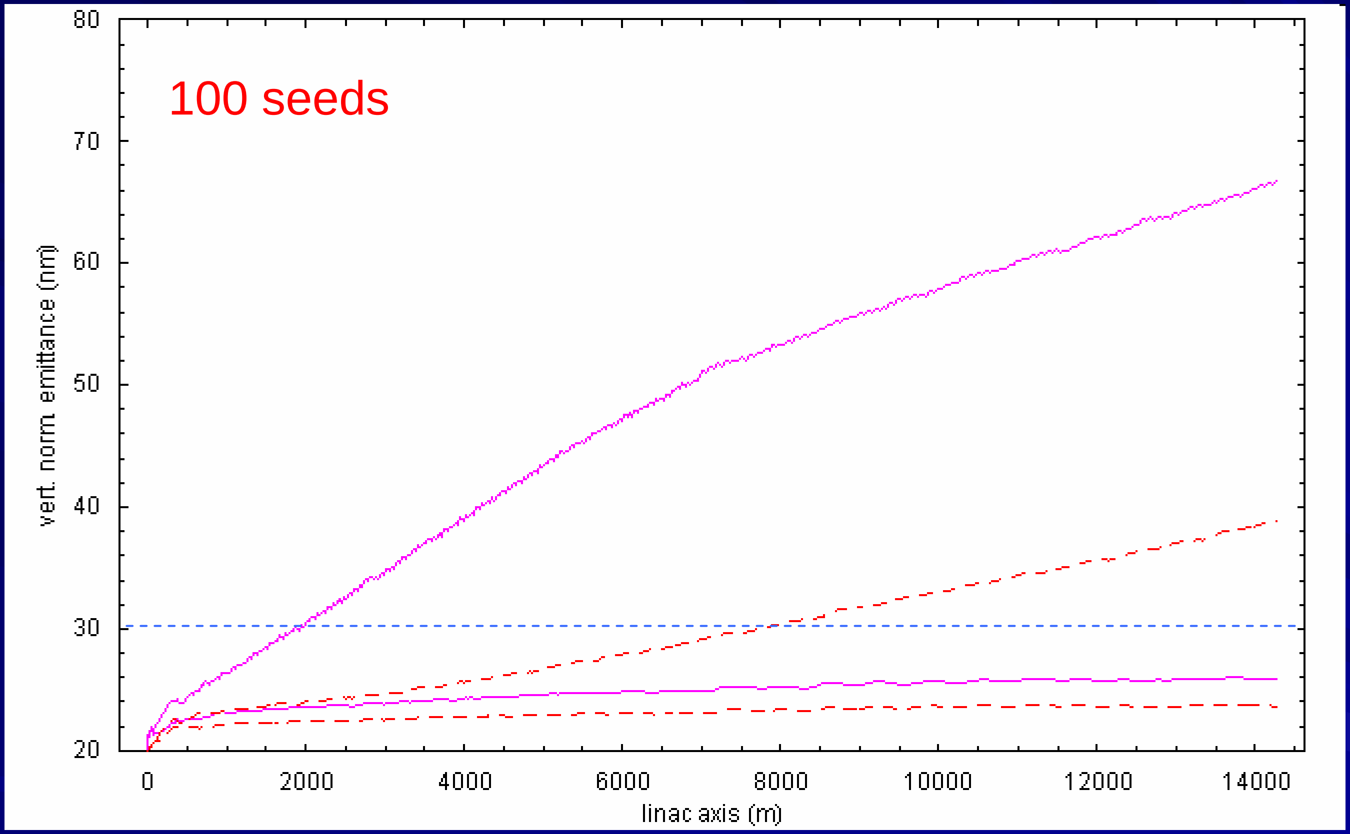
We can tune out linear $\langle y\delta \rangle$ and $\langle y'\delta \rangle$ correlation using bumps or dispersion correction in BDS

average over 100 seeds

Effects of stray (or residual) fields

- Ballistic alignment works because we *assume* the beam to follow a straight line when magnets/RF off
- Effects of stray fields or residual quad fields will perturb our straight line
- Simulated 10 μT.m RMS random field at every quadrupole during ballistic measurement.

Random Residual Quad Field



67.8 nm

38.9 nm

25.9 nm

23.6 nm

Effect scales as $B^2_{residual}$

Tolerance: 2.5 μT.m RMS

Vibrations

- Cavities: don’t care
  - cavities will not vibrate at the 300 μm level
- Quadrupole: somewhat critical
  - assume <100 nm RMS
  - Generates ~1 σ_y oscillation at linac exit
  - couple additional nm emittance growth
  - beam collision OK (fast feedback) but collimator wakefields may be problematic
    - more feedback may help: work to do!
  - Bottom line: try and keep quad vibration at or below 100nm level
    - “cryomodule” should not add additional vibration above ground motion.

Last Slide

- TDR canonical tolerances are probably still the baseline set
  - mechanical alignment has been achieved
  - can we really say we are finished here?
- Better BPM resolution (<10μm) will help with DFS
- Need more work on quadrupole vibrations
  - but there are other techniques to mitigate these effects
- All of this is now being reviewed *again* for ILC