Big Linac

Going round the bend

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2nd ILC Workshop
Snowmass August 16, 2005
(Updated September 27, 2005)

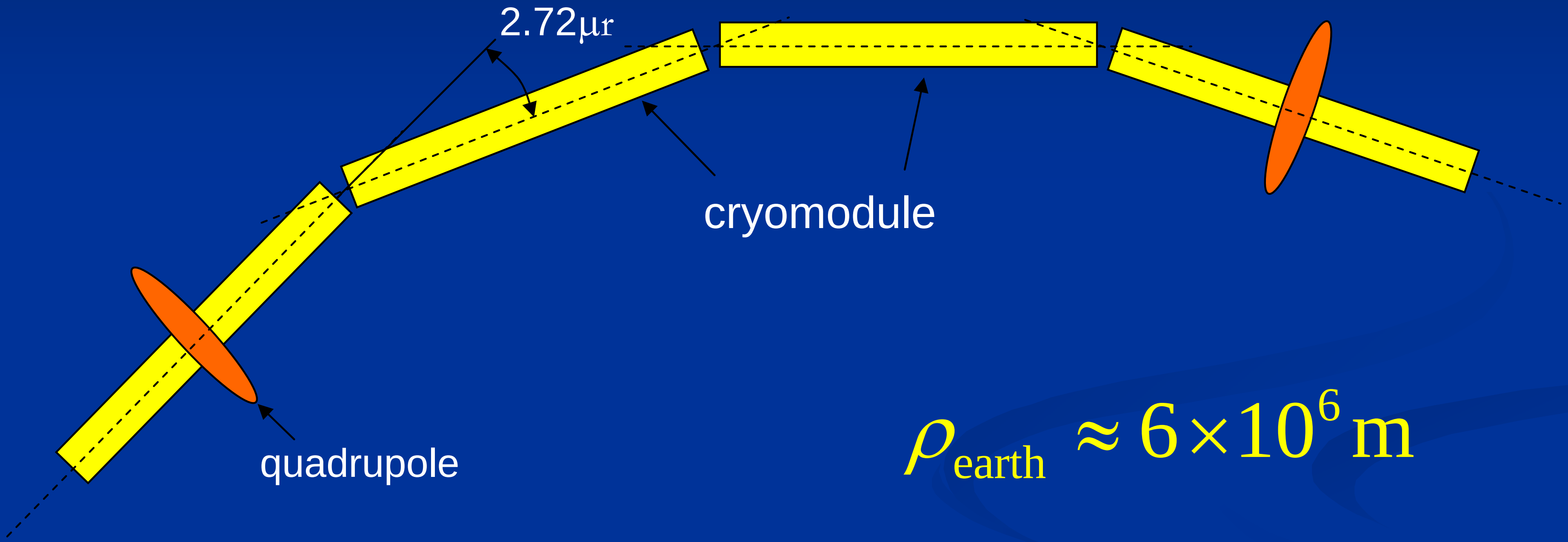
EUROTeV-Report-2005-017-1

The Possibilities

- Laser-straight
  - The canonically studied (simulated) scenario
  - Clearly leads to a relative deep tunnel (IR) $$
- Earth curvature following
  - Actually iso-gravitational potential following
  - Possibly the cheapest solution
  - Proposed for the TESLA TDR (DESY site)
- All options in between
  - Straight segmented options (→ PT's talk)

Extremes

Following the Earth's Curvature



$$\rho_{\text{earth}} \approx 6\times10^{6}\,\text{m}$$

What have I simulated?

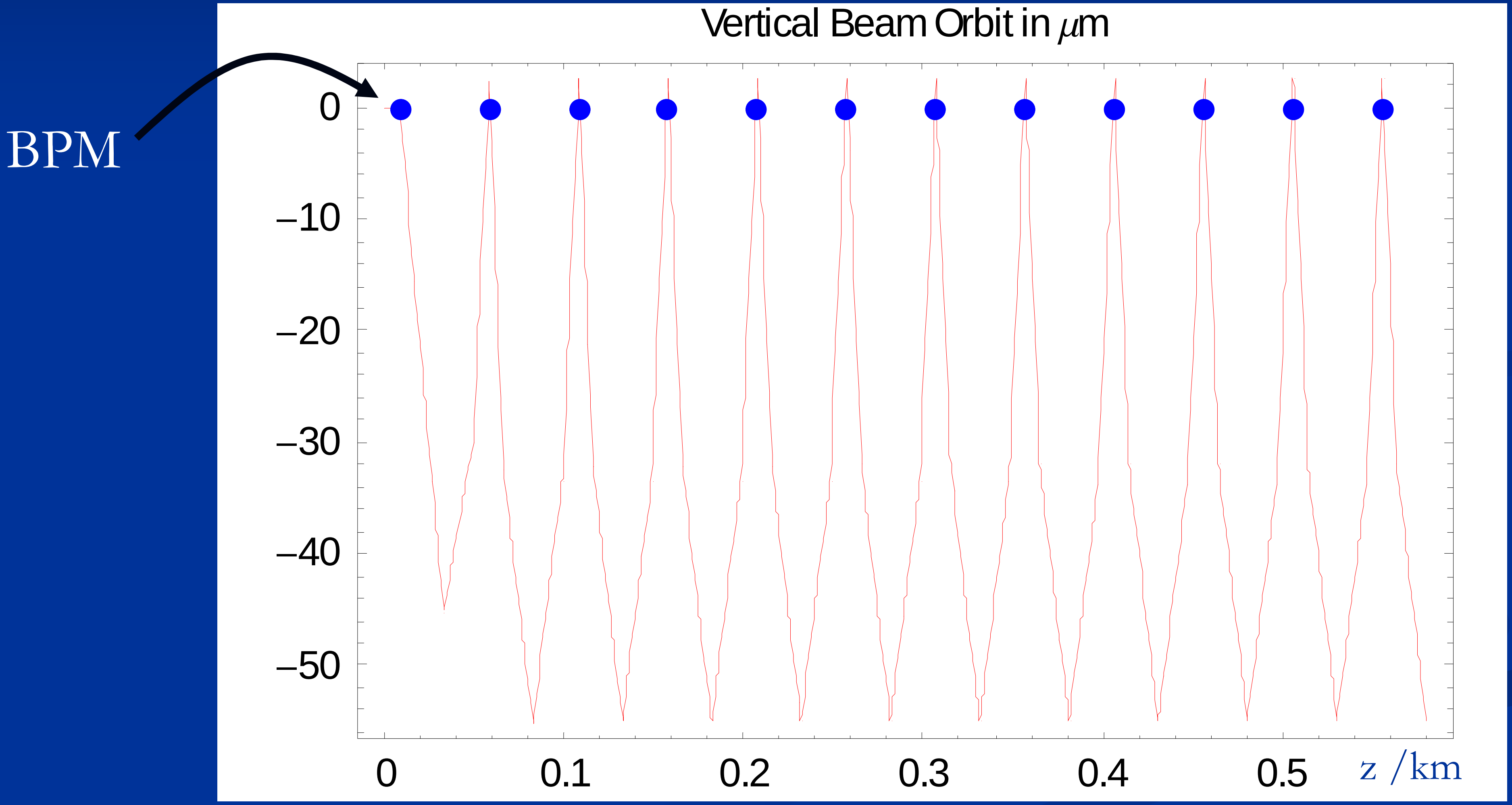
- A simple linac lattice which follows the curvature of the earth (r = 6000 km)
- Curvature implemented by having a 2.7μrad vertical ‘kink’ between cryomodules.
- Vertical dipole corrector windings on quadrupoles used to follow geometry
  - 2.7 μrad/CM corresponds to ~450 μm systematic offset of the quadrupoles
- Impact on DFS performance studied
  - Comparison of same machine with and without Earth curvature following

Chosen Linac Lattice

- Very simple lattice taken from TESLA TDR
- 60° FODO
- β_{max} = 172 m constant beta lattice
- 6 cryomodules / fodo cell (cell length = 99.5m)
- 12 cavity cryomodule
- 1 TeV machine studied
  - 35 MV/m gradient (ϕ_{RF} = 4.4°)
  - 385 quadrupoles

Steering the Earth

- One-to-one steering applied to zero BPM readings



Random Errors Studied

- RMS Errors (normally distributed):
  - quad offsets: 300 µm
  - quad rolls 300 µrad
  - cavity offsets: 300 µm
  - cavity tilts: 300 µrad
  - BPM offsets: 200 µm
  - BPM resolution: 5 µm ??
  - CM offsets: 200 µm

wrt CM axis

- TDR long. wakefield; trans. WF taken from Zagorodnov and Weiland, PAC2003.
- Initial uncorrelated energy spread taken as 2.8%

Same 1000 seeds used for laser-straight and curved geometries

Canonical DFS reviewed

$$\chi^2 = \frac{\Delta\mathbf{y}(\delta)\cdot\Delta\mathbf{y}(\delta)}{\sigma_{res}^2} + \frac{\mathbf{y}\cdot\mathbf{y}}{\sigma_{BPM}^{\mathbf{2}}}$$

$$\Delta\mathbf{y}(\delta) = \mathbf{y}(\delta) - \mathbf{y}(0)$$

measured energy difference orbit

$$\mathbf{y} = \mathbf{y}(0)$$

Absolute measured orbit

The General Case

- DFS (dispersion *free* steering) is the special case that has been studied:

$$\Delta\mathbf{y}(\delta) = 0$$

- DS is the more general case, where we have finite dispersion:

$$\Delta\mathbf{y}(\delta) = \Delta\mathbf{y}_{design}(\delta)$$

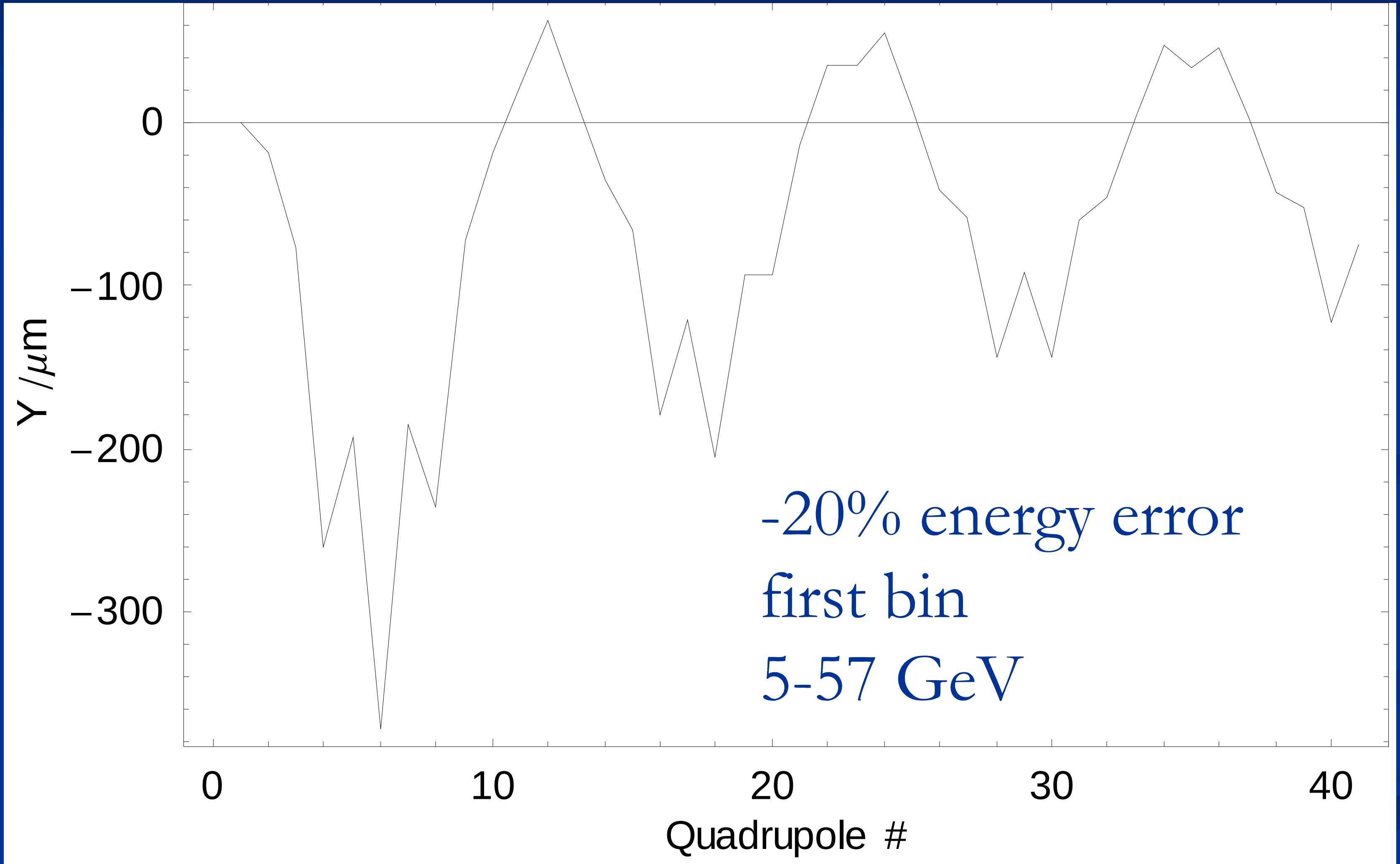
General DS

$$\chi^2 = \frac{\Delta\mathbf{y}(\delta)\cdot\Delta\mathbf{y}(\delta)}{\sigma_{res}^2} + \frac{\mathbf{y}\cdot\mathbf{y}}{\sigma_{BPM}^{\mathbf{2}}}$$

$$\Delta\mathbf{y}(\delta) = \mathbf{y}(\delta) - \mathbf{y}(0) - \Delta\mathbf{y}_{design}(\delta)$$

$$\mathbf{y} = \mathbf{y}(0)$$

Example of $\Delta y_{design}(\delta)$

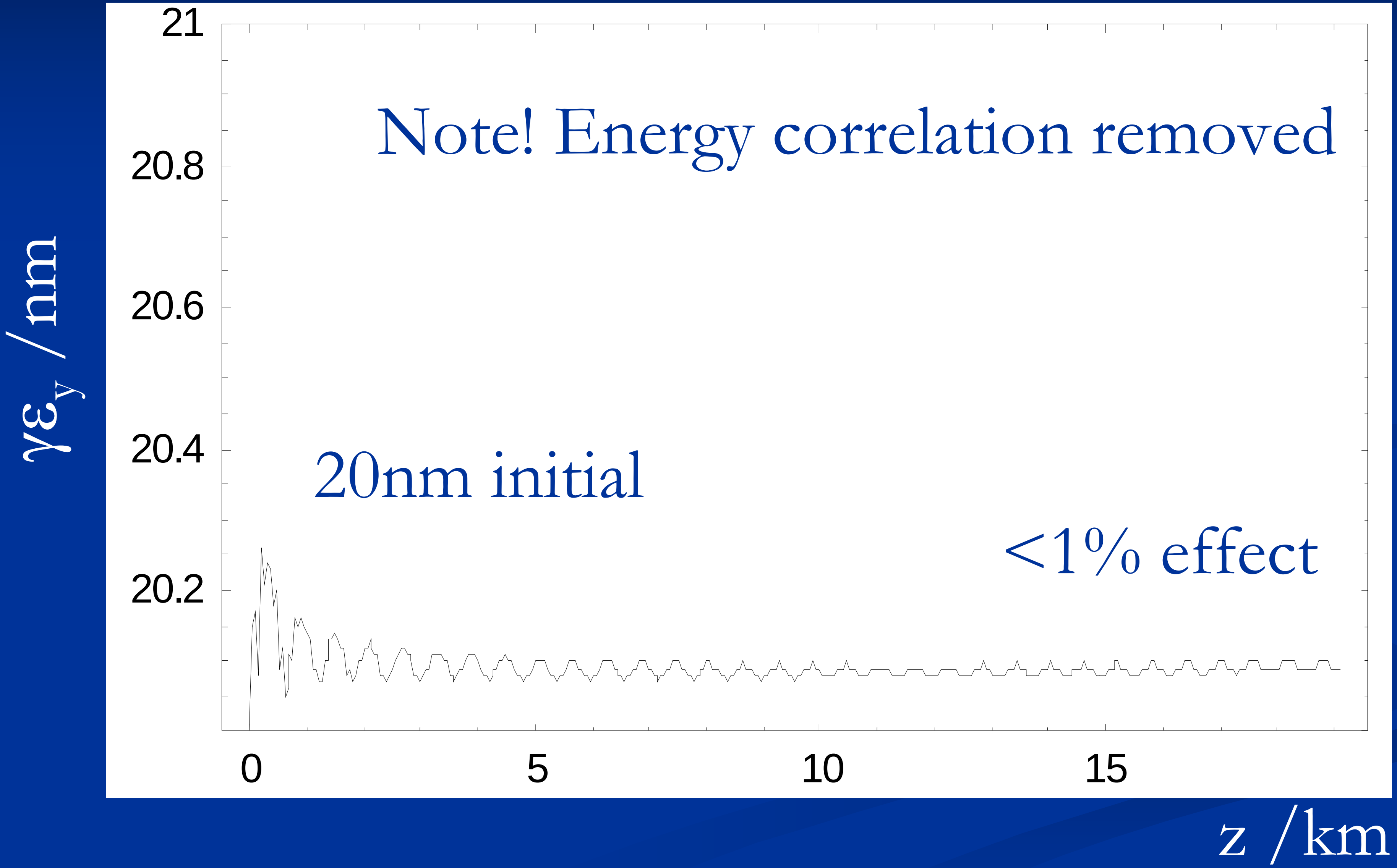


-20% energy error
first bin
5-57 GeV

The Design Machine

- Radius of curvature is *very* large
  - $r \approx 6\times 10^6$ m
- However, still enough to generate non-negligible vertical dispersion
- hence we need to *match* the dispersion to prevent emittance growth due to filamentation
- For model $\beta = 172$m 60° lattice ⇒ ~1.1 mm
  - at 5 GeV ($\delta_{\mathrm{RMS}} = 2.8\%$) $\gamma(\eta_y \delta_{RMS})^2 / \beta \approx 54\mathrm{nm}$
  - at 500 GeV ($\delta_{\mathrm{RMS}} = 0.05\%$) $\gamma(\eta_y \delta_{RMS})^2 / \beta \approx 0.54\mathrm{nm}$

Design Emittance Growth



Simulation of BBA (DFS)

- Disclaimer: not the purpose of this study is not to evaluate the performance of DFS, but to try to quantify impact of linac geometry
    - same approximate DFS algorithm applied to both cases.
- Several approximations (cheats!) used in computer model
    - ease of implementation
    - speed (1000 seeds simulated)
- Full Blown simulations still required (for completeness)

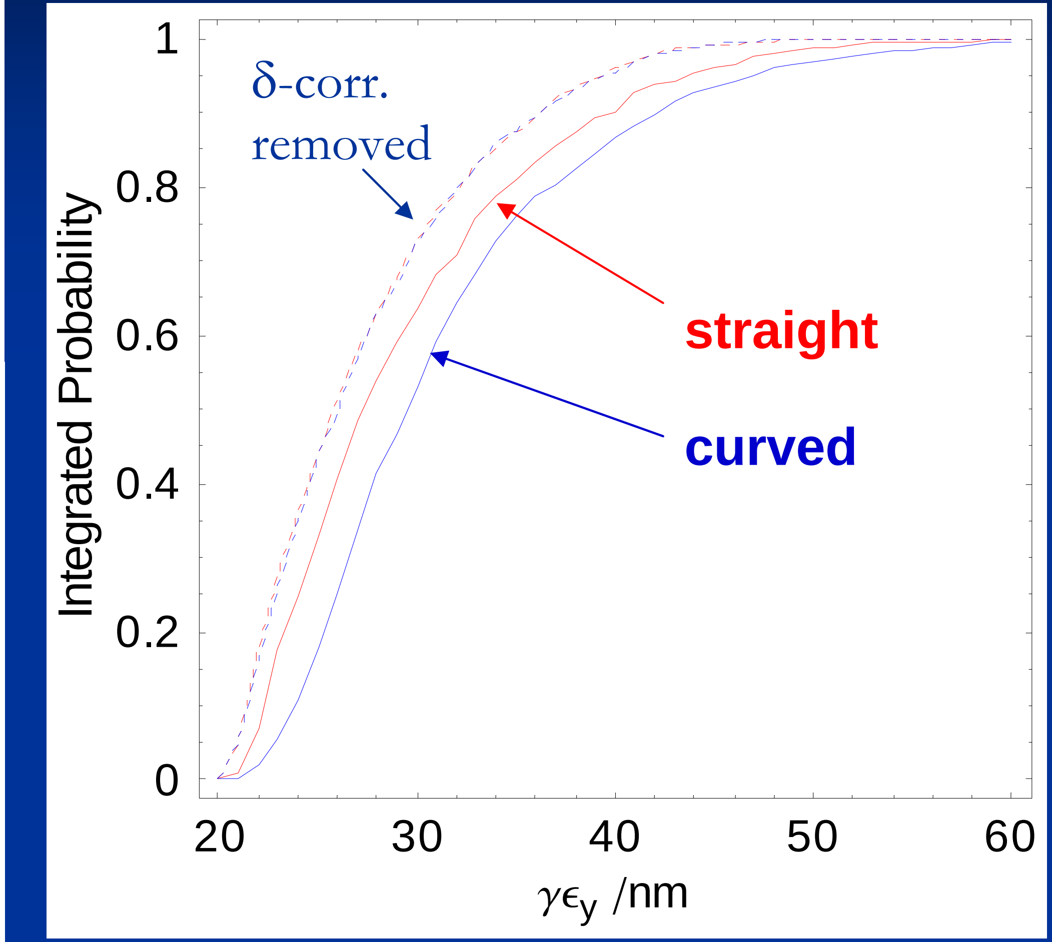
DFS simulated

- Sections of 40 quads (20 cells) BBA'd at a time
- Sections overlap by 20 quads
- Energy difference simply made by changing the initial beam energy
  - in 'real' life, would adjust linac amplitude / phase
  - impact of tilted cavities

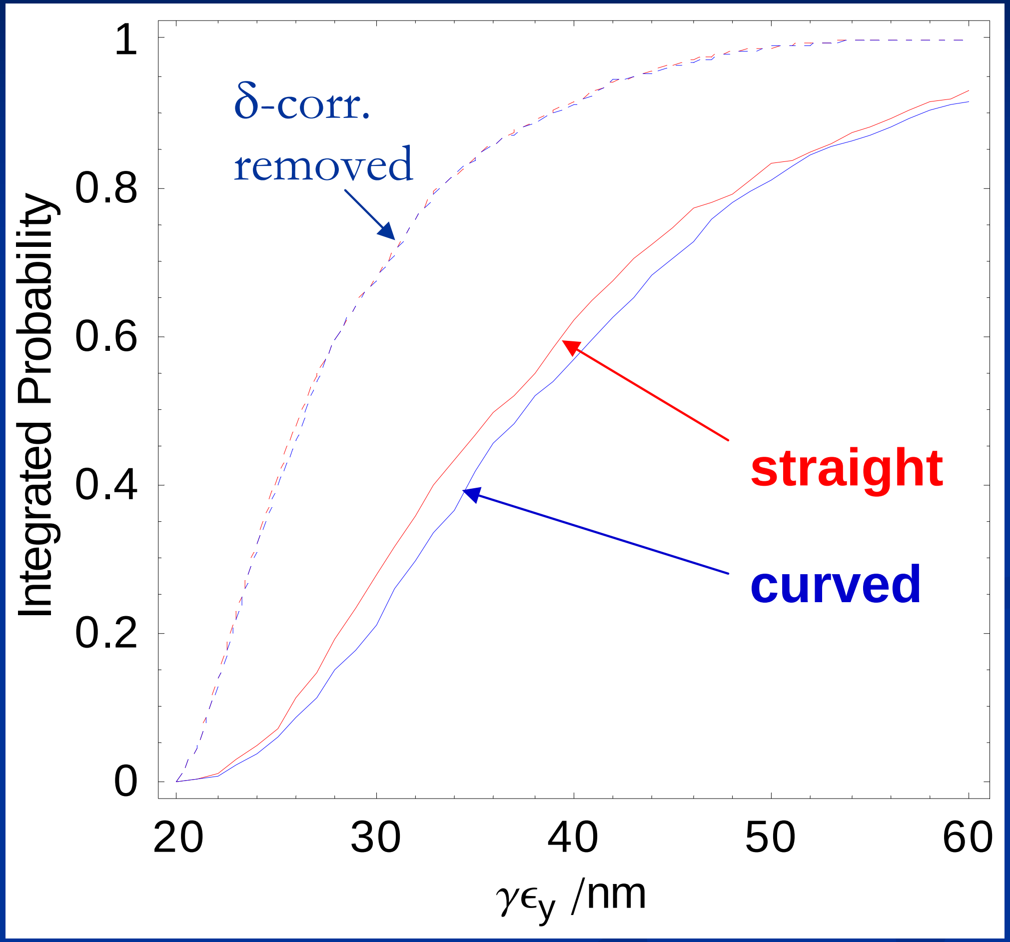
DFS simulated

- No jitter: assume launch conditions for each section are maintained (including for off-energy)
  - Would be achieved by feedback / steering or by fitting (BPM res. critical)
- Two energy difference scenarios studied
  - fixed -20% error
  - fixed -1 GeV error (-20% of 5GeV)

Results 250 GeV (1000 seeds)

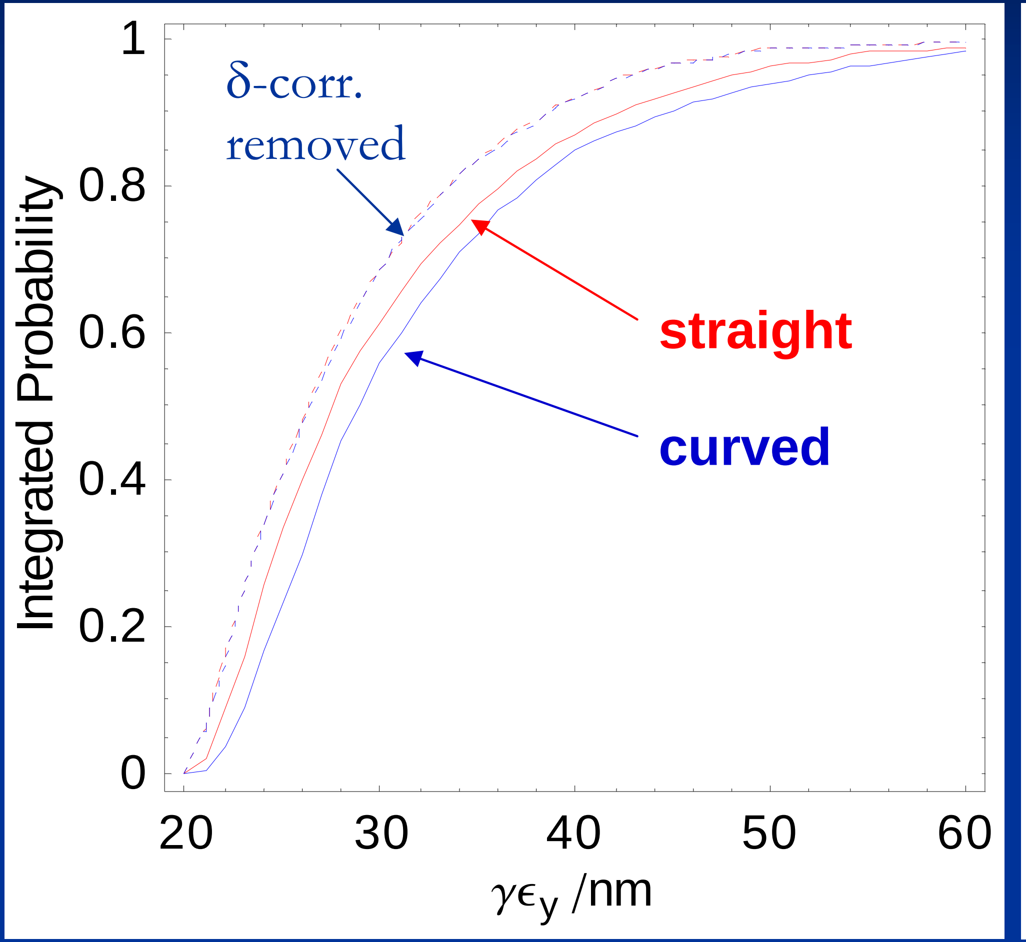


fixed -20%

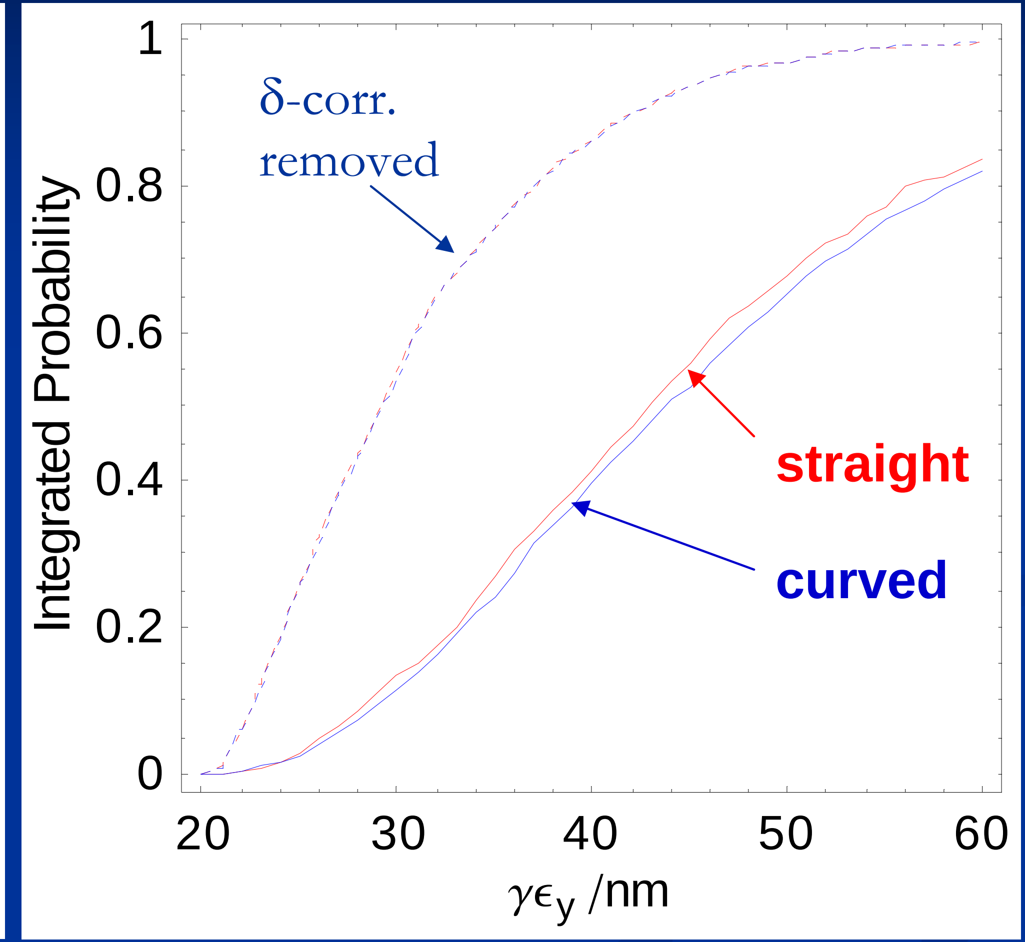


fixed -1 GeV

Results 500 GeV (1000 seeds)



fixed -20%



fixed -1 GeV

Summary (1000 seeds)

Note: energy correlation removed

250 GeV

ΔE	**% ≤30 nm**	**90%**
-20%	73%	36 nm
-1 GeV	68%	39 nm

500 GeV

ΔE	**% ≤30 nm**	**90%**
-20%	67%	39 nm
-1 GeV	54%	42 nm

no difference between straight and curved geometry

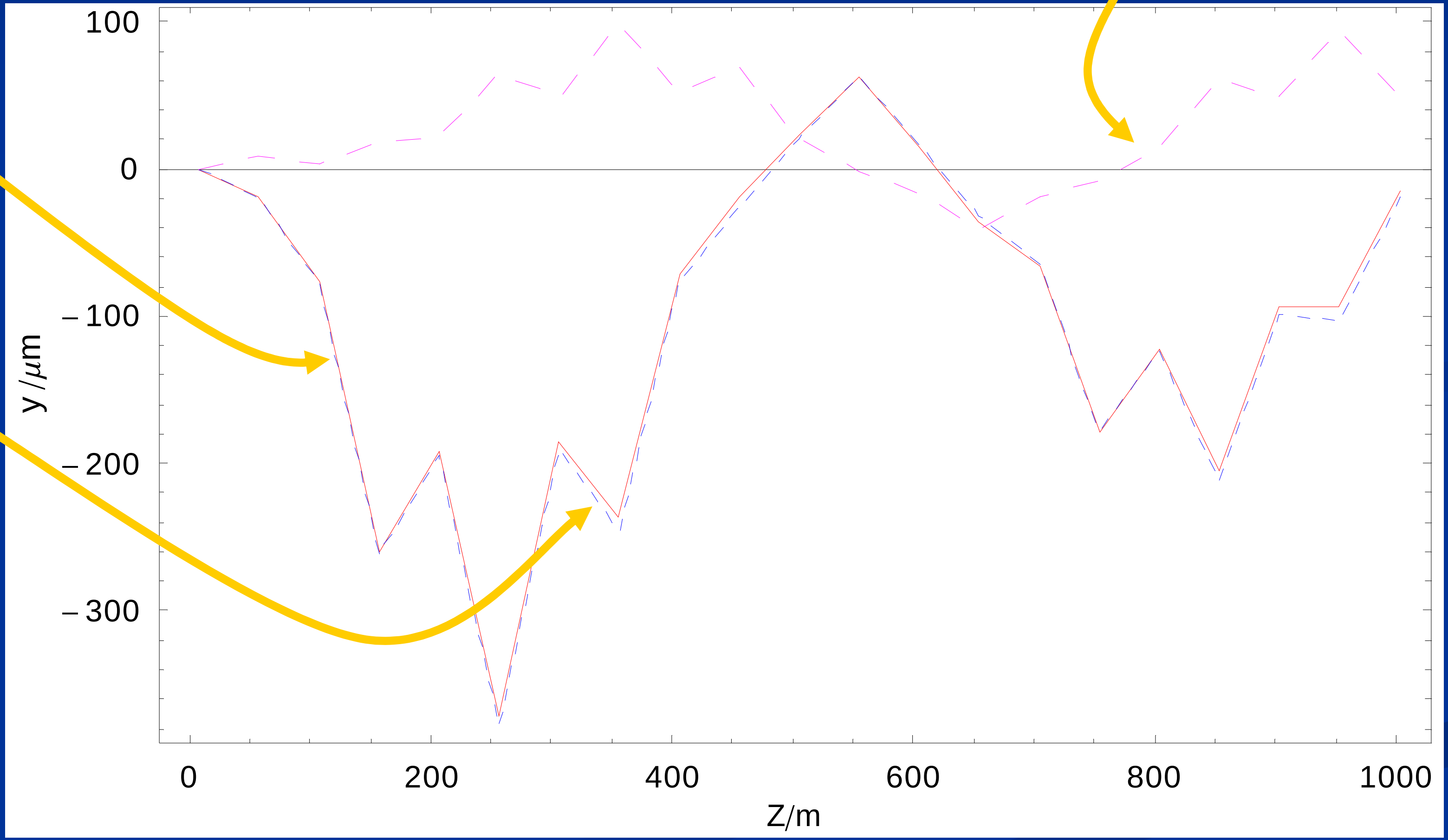
Remaining Questions

- Will the stated approximations (cheats) in the simulation impact the difference between straight and curved geometry?
    - Making simulation more ‘realistic’ <u>will</u> impact results
    - I don’t (currently) see why one geometry will become more worse than the other
        - one potential exception: changing the energy
- More sophisticated (realistic) simulations to follow
- Understanding fundamental problems/limits with DFS probably more critical

Potential Problems

- DFS no longer a nulling method
  - Scale errors on BPMs (non-linearity) or energy error during measurement will result in residual unmatched dispersion
    - Example: 10% scale error in measurement
    - $\Delta y_{max}(\Delta E/E=0.02)\approx 300\mu m \Rightarrow \delta\eta_y \approx 30\mu m/0.02=150\mu m$
    - $\Delta\varepsilon_y = (150\mu m\ \delta_{rms})^2/\beta_y \approx 1$ nm at $E = 5$ GeV

Impact of Wakefields on Measurement



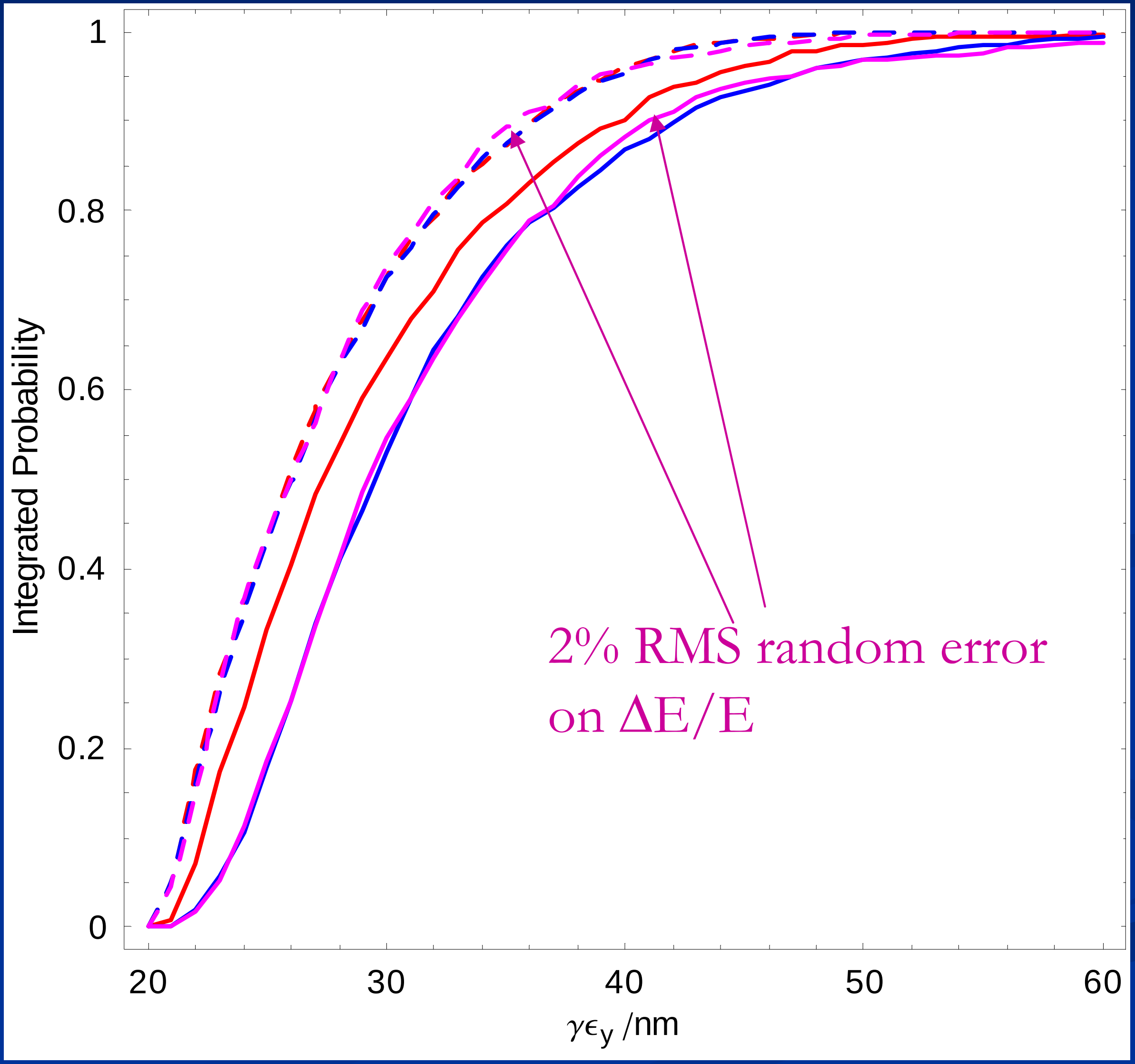
Δ×10

Single particle trajectory

Full beam model centroid including wakefields (dashed)

2% RMS Error on $\Delta E/E$

Effect of 2% RMS error on energy change appears negligible



2% RMS random error on $\Delta E/E$

250 GeV LINAC
Fixed -20% $\Delta E/E$

General Questions Concerning DFS/FDS

- Impact of systematic errors
  - Modelling errors
    - How accurate is our lattice model (energy profile?)
  - Measurement errors
    - How well do we know the energy / energy change
    - How accurate are the BPMs
    - How well calibrated are the correctors
  - Modelling the real world
    - Realistic steering (feedback, iteration)
    - The need to iterate the correction (does it always converge)

Summary

- Simple constant-β linac studied at 35MV/m
  - 250 GeV and 500 GeV machines simulated
- Curved geometry implemented as implied in the TDR
  - 2.6μrad kinks between cryomodules; simple use of quad corrector dipoles to steer beam.
- standard set of errors applied to 1000 machines
  - same error seeds used for straight and curved geometries
- Within limits of approximations used, no significant impact seen of curved geometry on emittance performance
  - there maybe other good reasons to have a straight machine, but linac beam dynamics does not seem to be one of them ☺