Going round the bend

Big Linac

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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 ($\rightarrow$ PT's talk)

Extremes

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 corresponds to ~450 μm systematic offset of the quadrupoles

- Impact on DFS performance studied

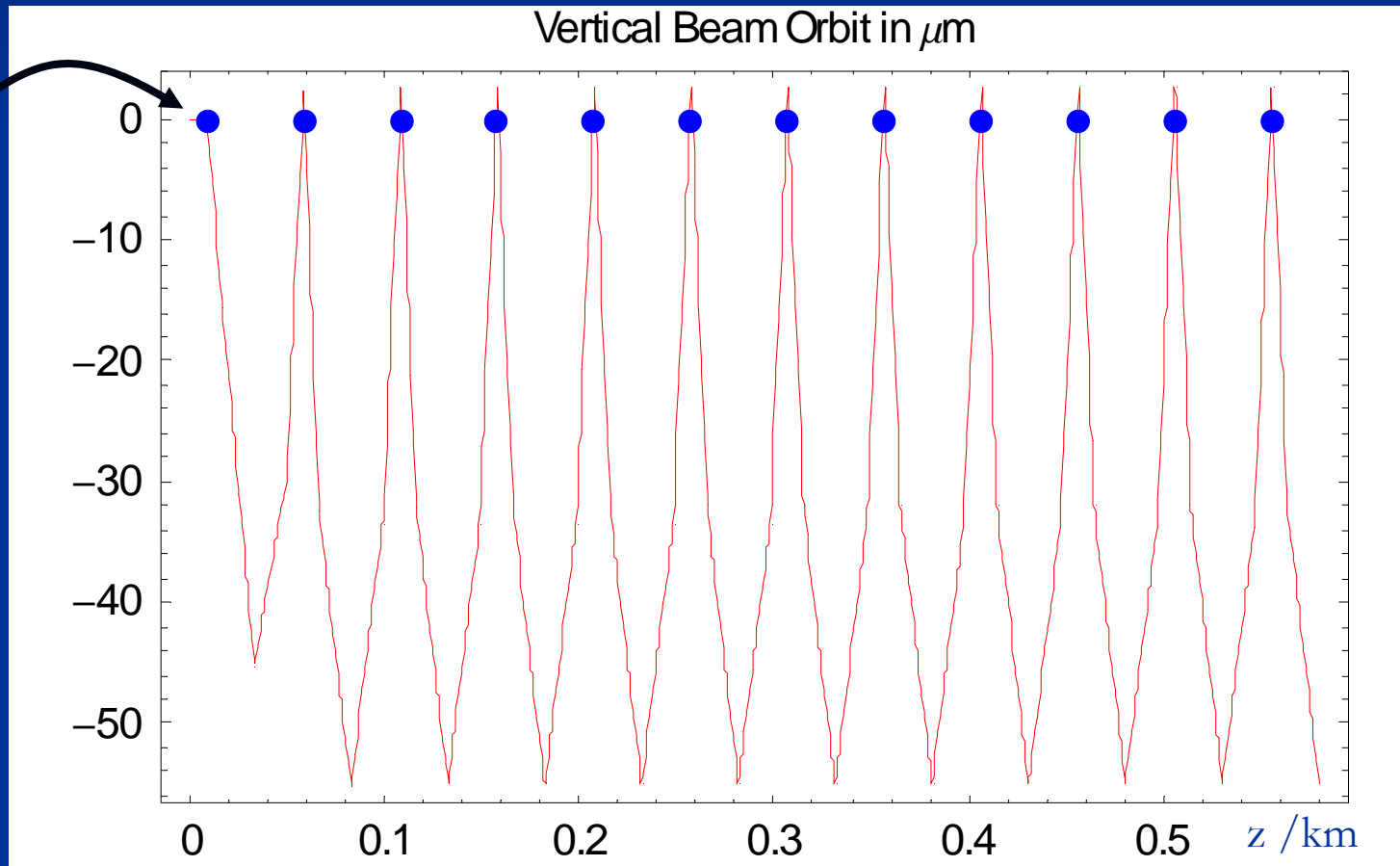   - Comparison of same machine with and without Earth curvature following

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

Vertical Beam Orbit in μm

BPM

z /km

Random Errors Studied

- RMS Errors (normally distributed):
    - quad offsets: 300 µm ⎤
    - quad rolls   300 µrad ⎪
    - cavity offsets: 300 µm ⎬ wrt CM axis
    - cavity tilts: 300 µrad ⎪
    - BPM offsets: 200 µm ⎦
    - BPM resolution: 5 µm ??
    - CM offsets: 200 µm

- 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

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

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

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:

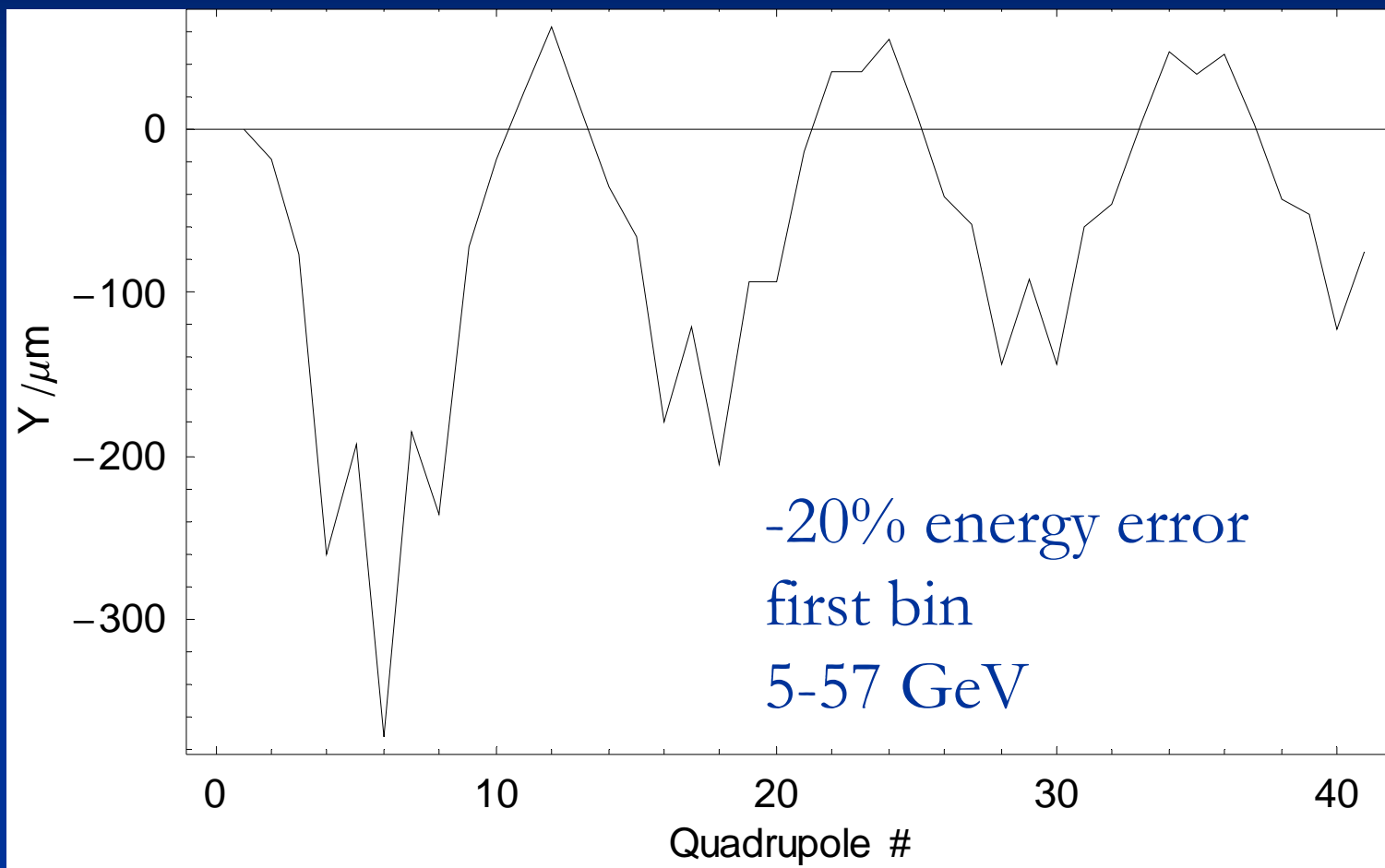$$\Delta \mathbf{y}(\delta) = \Delta \mathbf{y}_{design}(\delta)$$

General DS

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

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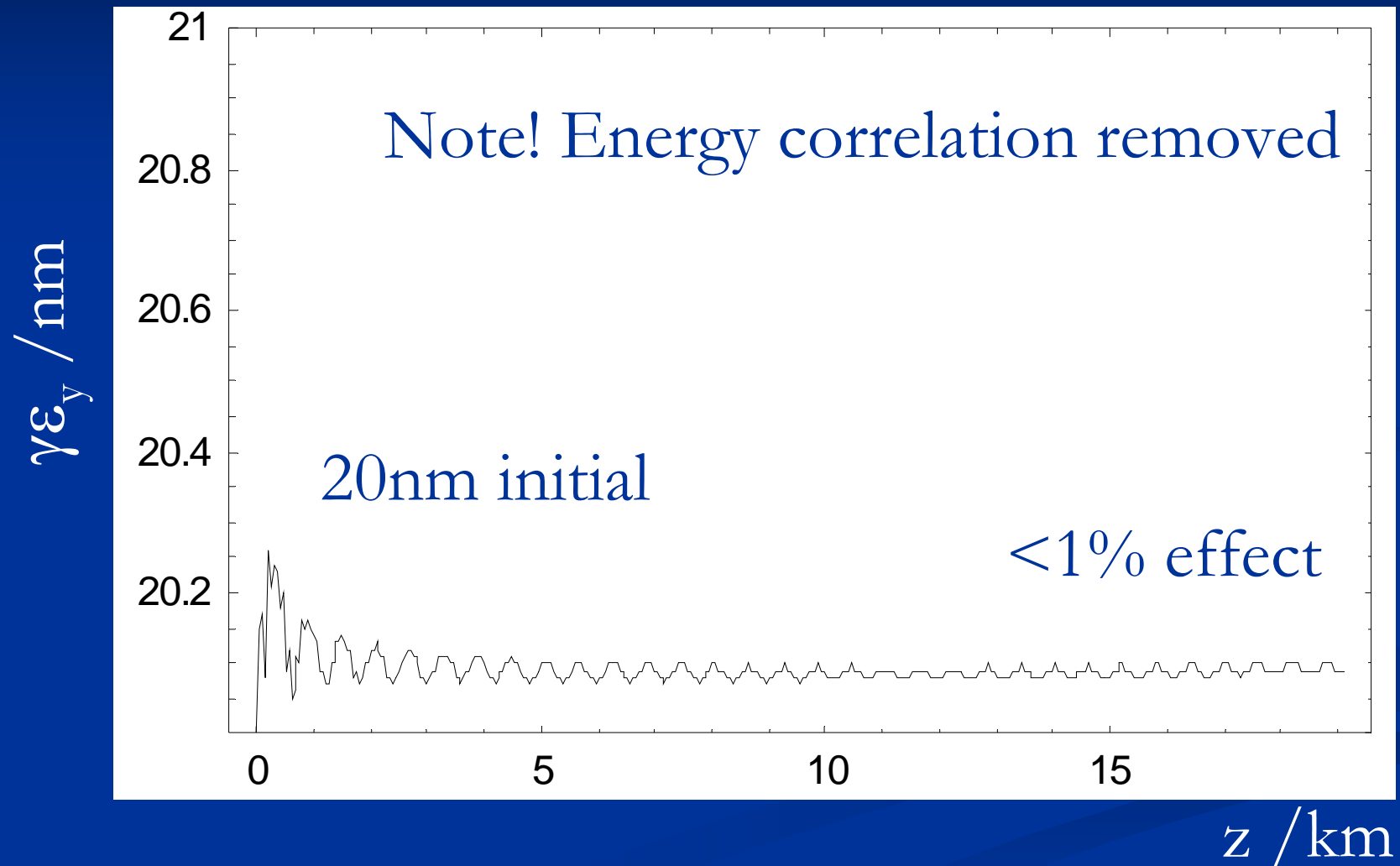
$$\mathbf{y} = \mathbf{y}(0)$$

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 $\Rightarrow$ ~1.1 mm
  - at 5 GeV ($\delta_{RMS} = 2.8\%$) $\quad \gamma(\eta_y \delta_{RMS})^2 / \beta \approx 54$nm
  - at 500 GeV ($\delta_{RMS} = 0.05\%$) $\quad \gamma(\eta_y \delta_{RMS})^2 / \beta \approx 0.54$nm

Design Emittance Growth

Note! Energy correlation removed

20nm initial

<1% effect

$\gamma\varepsilon_y$ /nm

z /km

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
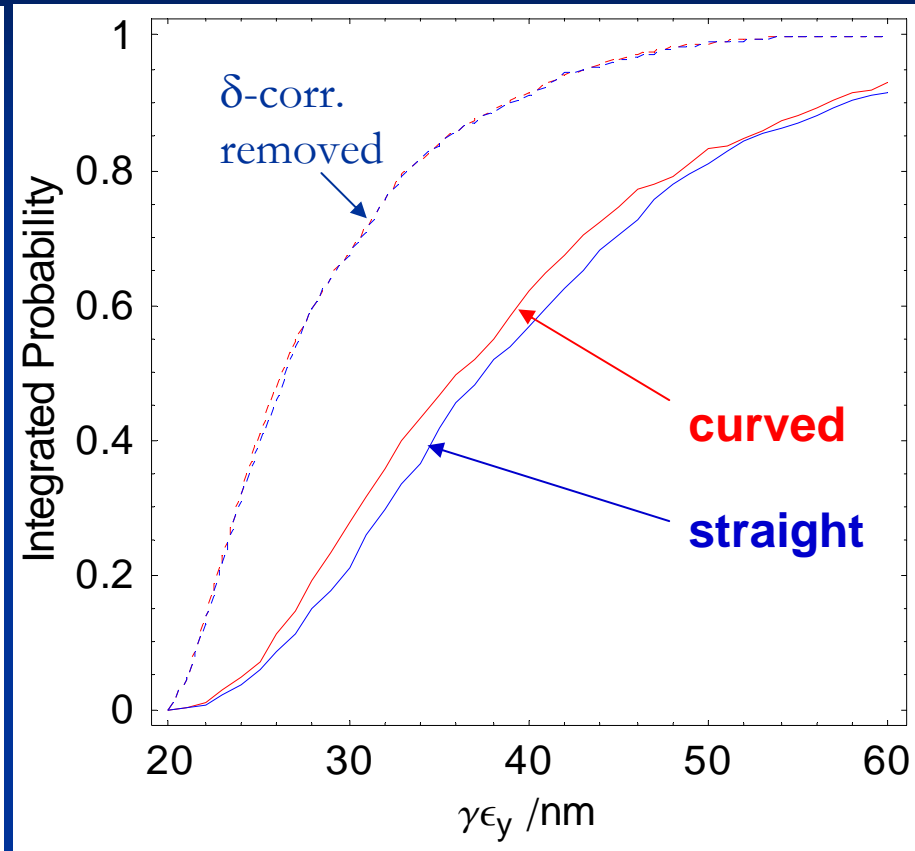 - impact of tilted cavities

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)
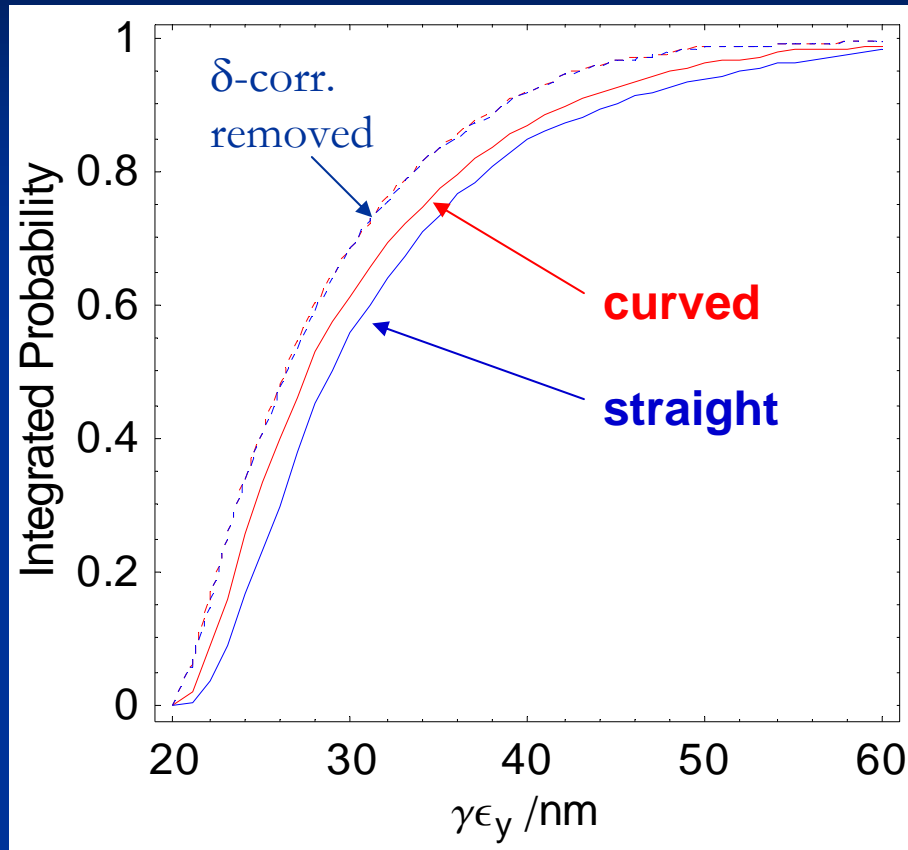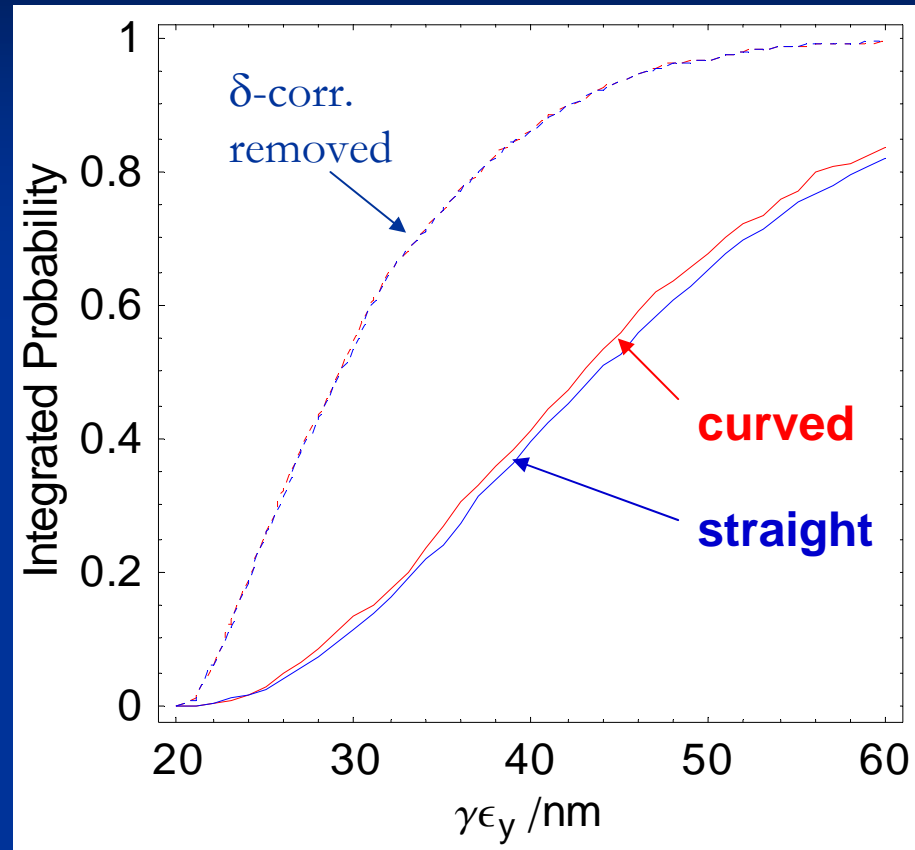
Results 250 GeV (1000 seeds)
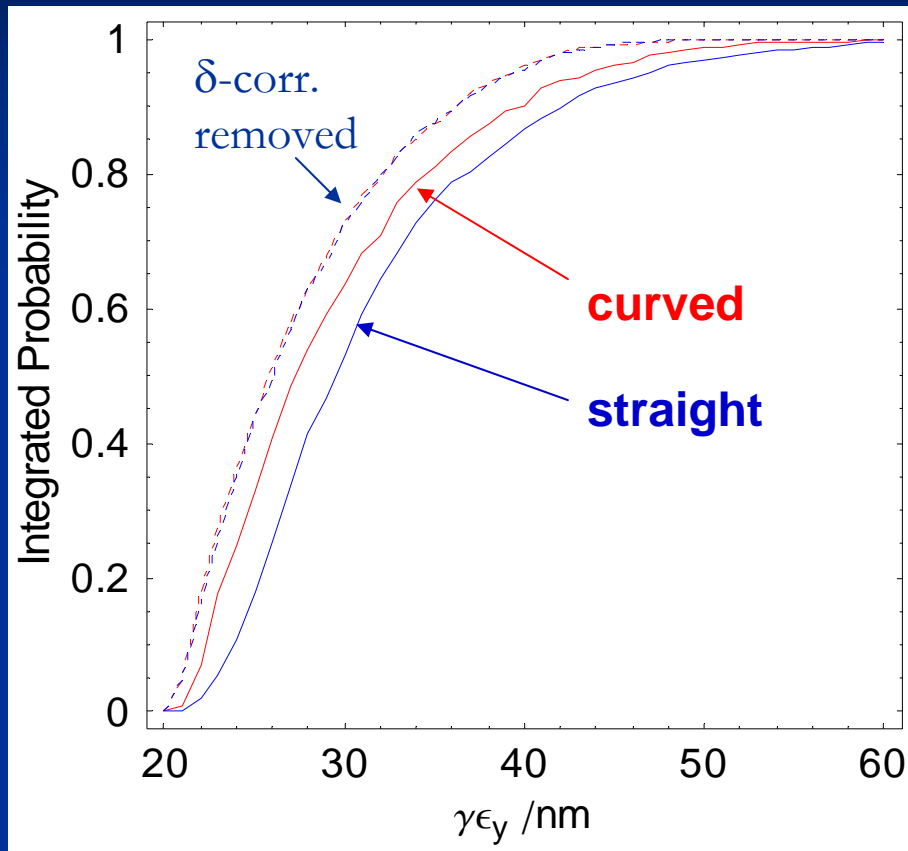
fixed -20%   fixed -1 GeV

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

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 ☺