Design options for emittance measurement systems for the CLIC RTML

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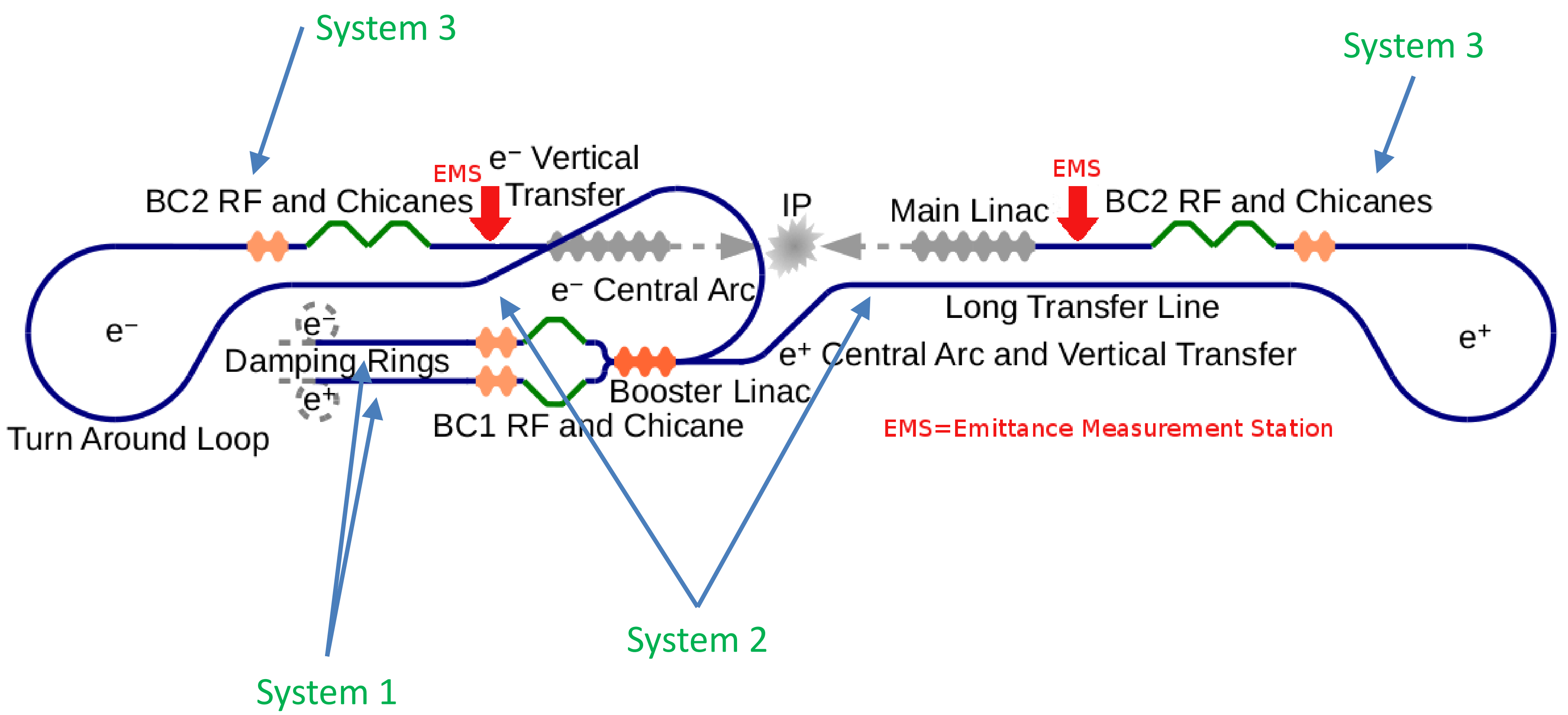
Proposed locations

1) Damping ring extraction line
   – Measure extraction emittance

2) Between central arc + vertical transfer in RTML
   – Measure emittance growth in BC1, booster linac and central arc

3) At end of RTML
   – Measure emittance at entrance of main linac

Proposed locations



Emittance measurement

- Use laserwire scanners to measure beam size
  - Non-destructive measurement
- 4 measurement locations (both H and V)
  - To reconstruct beam matrix at a reference point

$$\sigma_1 = R\sigma_0 R^T$$

$$\sigma_i = \begin{pmatrix} \sigma_{1,1} & \sigma_{1,2} \\ \sigma_{2,1} & \sigma_{2,2} \end{pmatrix} = \begin{pmatrix} \beta_i \varepsilon & -\alpha_i \varepsilon \\ -\alpha_i \varepsilon & \gamma_i \varepsilon \end{pmatrix}$$

$$\varepsilon = \sqrt{\det(\sigma)}$$

$$\begin{pmatrix} \sigma_{1,1} \\ \sigma_{1,2} \\ \sigma_{2,2} \end{pmatrix} = M^{-1} \begin{pmatrix} \sigma_{1,1}^{1} \\ \dots \\ \sigma_{1,1}^{N} \end{pmatrix}$$

$$M = \begin{pmatrix} R_{1,1}^{1} & -2R_{1,1}^{1} R_{1,2}^{1} & R_{1,2}^{1} \\ \dots & \dots & \dots \\ R_{1,1}^{N} & -2R_{1,1}^{N} R_{1,2}^{N} & R_{1,2}^{N} \end{pmatrix}$$

Laserwire scanner

- Laser fired perpendicular to electron beam
  - Produces Compton photon in electrons' direction of motion.
  - Compton detector downstream measures photons
    - Intensity proportional to electron beam intensity
    - Scan laser position to measure electron intensity profile
      → calculate beam size
  - Chicane to separate photons and electrons
    - 0.1m deflection needed to fit detector

Considered optics designs

- 4 FODO cells, 1 scanner per cell
  - 45^{o} (180^{o}/N) phase advance per cell (H and V)
    - Optimised to minimise emittance measurement error
- 2 FODO cells, 2 scanners per cell at each quad
  - 90^{o} phase advance per cell

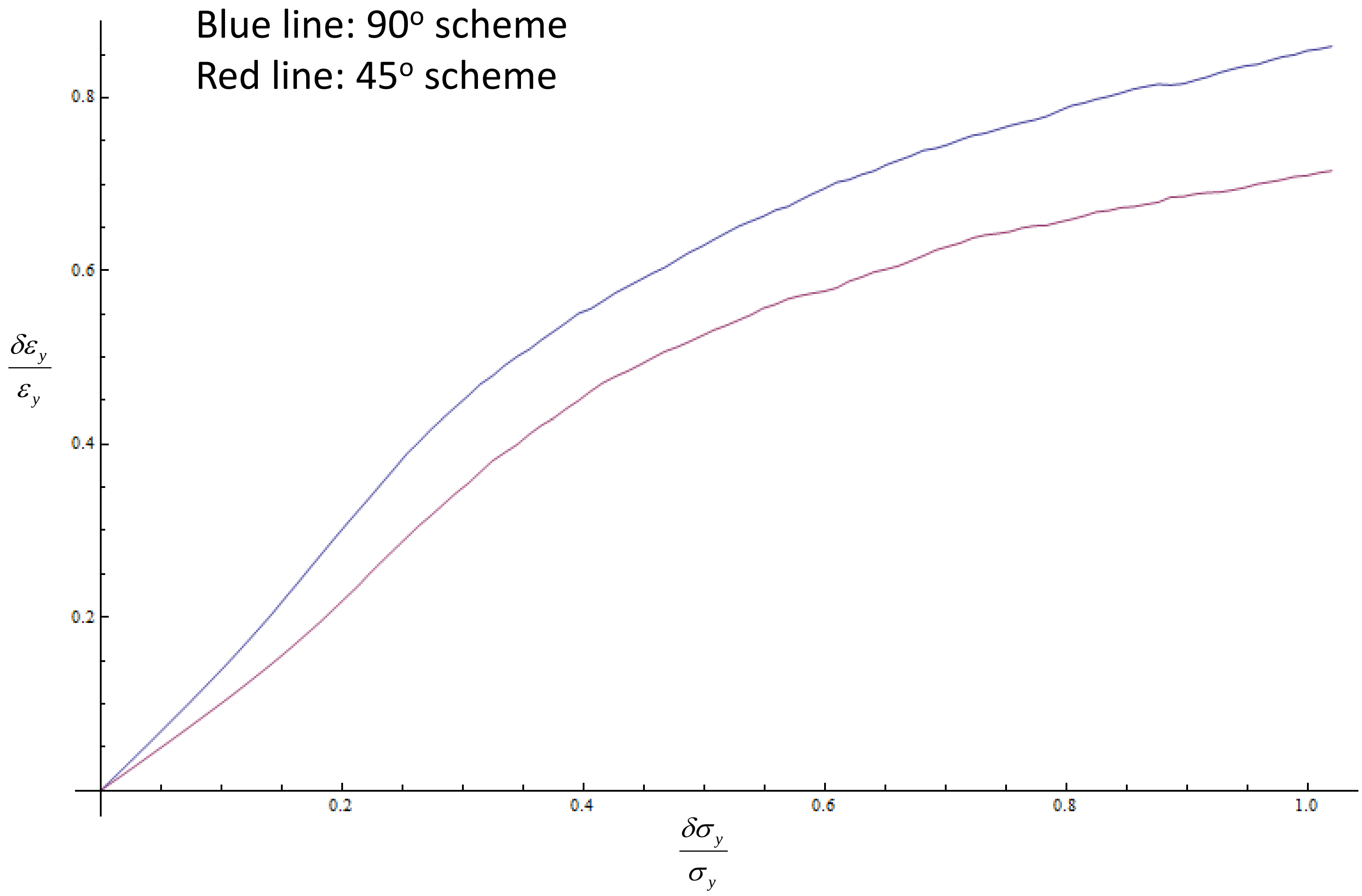
- Tracking simulations to compare schemes

Simulation outline

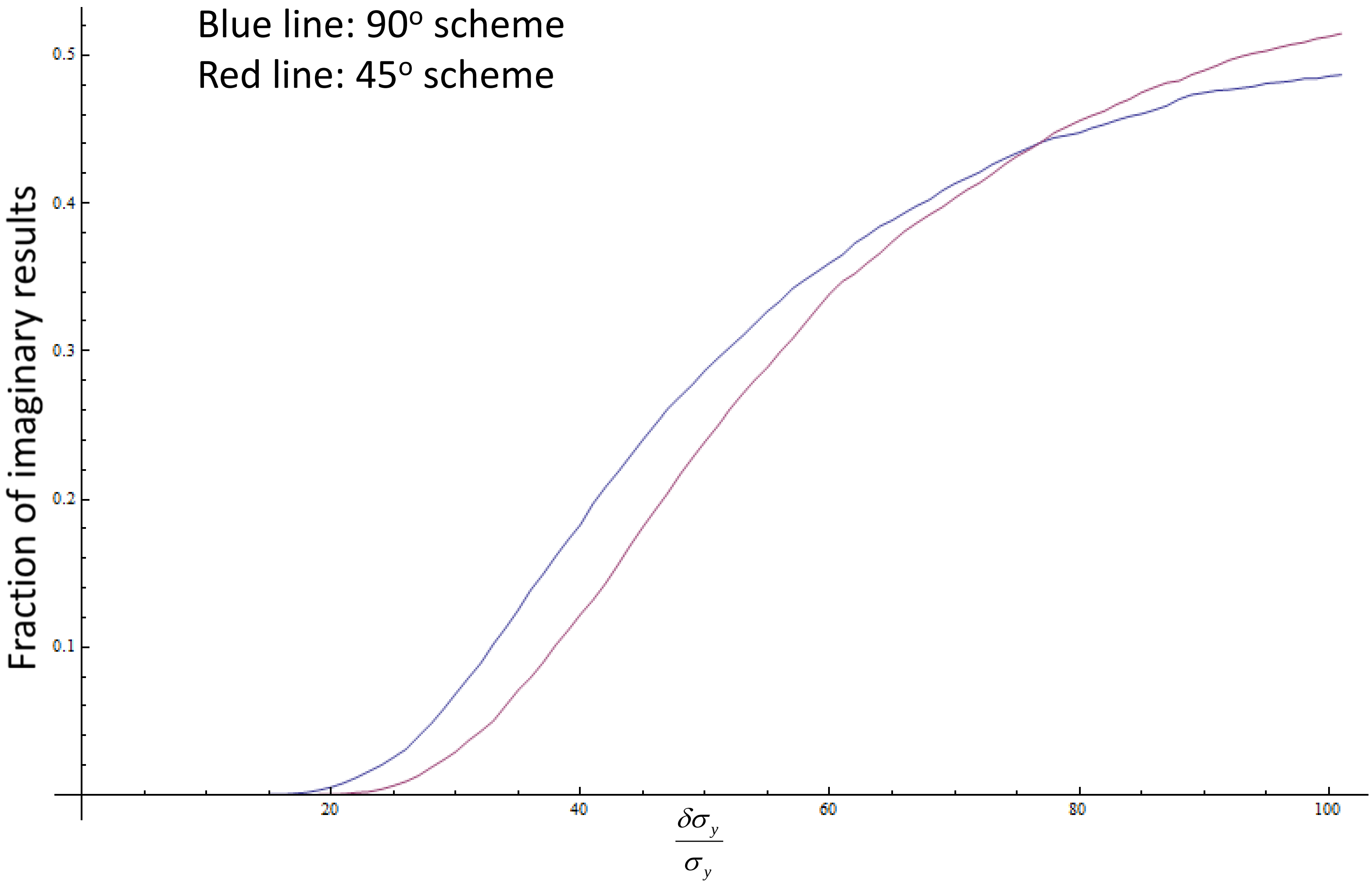
- 10^4 "particles" tracked through system
  - Measurement retaken 10^4 times with error
  - Fractional error at each scanner assumed equal
  - Calculate emittance for all 10^4 measurements
  - Use to calculate fractional error on emittance vs beam size measurement error
  - Same simulation procedure as described in:

    Yu. A. Kubyshin et al., "simulations of emittance measurement at CLIC", PAC11 proceedings, pp. 2270-2272

Design comparison



Design comparison



Comparison results

- 45^o scheme
  - Smaller error on emittance measurement
  - Smaller fraction of non-physical results
  - 2x 90^o FODO cells is ~50% longer than 4x 45^o cells

- 45^o scheme is clearly the design to adopt

System designs

1) Extraction line

– No design yet, should be easier than RTML

2) Mid-RTML emittance measurement

– Design described on next slides

3) Pre-linac emittance measurement

– Design optimised and documented

- Yu. A. Kubyshin et al., “simulations of emittance measurement at CLIC”, PAC11 proceedings, pp. 2270-2272

RTML optics

- 45° FODO cells

$$\beta_{\max} = 855.1 = \frac{L_{FODO}}{\sin(\mu/2)}\sqrt{\frac{1+\sin(\mu/2)}{1-\sin(\mu/2)}}$$

$$\beta_{\min} = 381.8 = \frac{L_{FODO}}{\sin(\mu/2)}\sqrt{\frac{1-\sin(\mu/2)}{1+\sin(\mu/2)}}$$

$$L_{FODO} = 438m$$

- Emittance measurement system

$$L_{system} \approx 2190m$$

$$6\sigma_x \approx 1.25mm$$

$$6\sigma_y \approx 190\mu m$$

Very long system, large beam sizes, difficult to measure accurately with laserwire scanner (spot size ~5µm). Laserwire scanner can measure beam sizes between approx 1-10 times laser spot size; accuracy deteriorates outside this range.

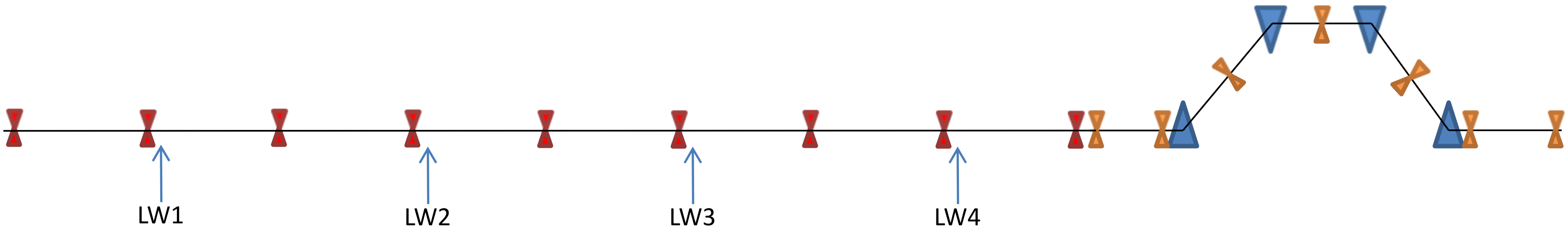
Need to reduce length and beam size
→ use matching cell

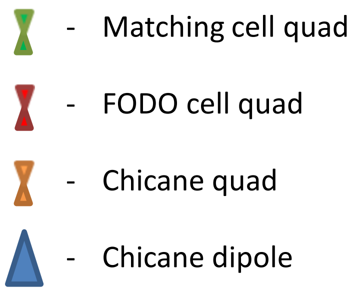
Improved measurement system

- Use matching cell
  - Squeeze β by factor of 4
    - Compromise between system length + quad strengths
    - Quad strengths: $k \sim 0.017 - 0.058 m^{-2}$; acceptable?
  - Normal RTML FODO quad strength: $k \sim 0.01 m^{-2}$
- To un-squeeze beam:
  - Use chicane to match β and correct dispersion
- Total system length ~ 1127m

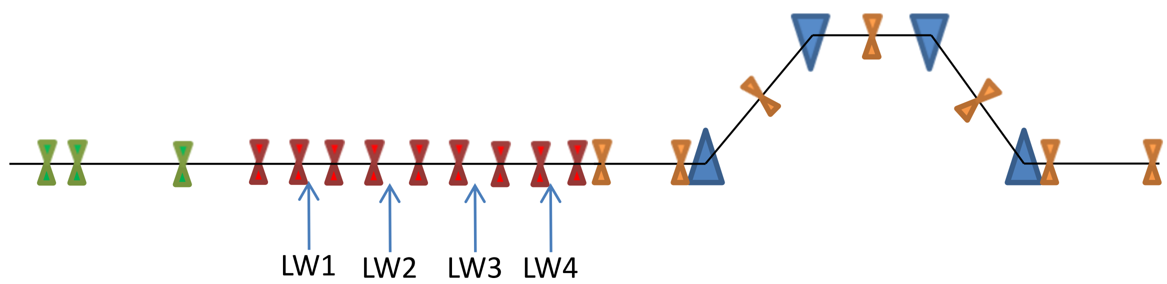
Optics layouts for Mid-RTML system

No matching cell (nominal optics)





Matching cell (“squeezed” optics)



Diagrams are not to scale

Emittance growth

- Dipoles in chicane:
  - Use same radius of curvature as dipoles in turn around sections (305m).

$$\frac{\Delta\varepsilon}{\varepsilon} \propto E_0^5 \frac{\theta^5}{L_{bend}}$$

- Quadrupoles:
  - Limit quad strengths to k ~ ±0.05m^{-2}

$$\frac{\Delta\varepsilon_x}{\varepsilon_x} \propto \frac{\beta_x^4}{f^4}$$

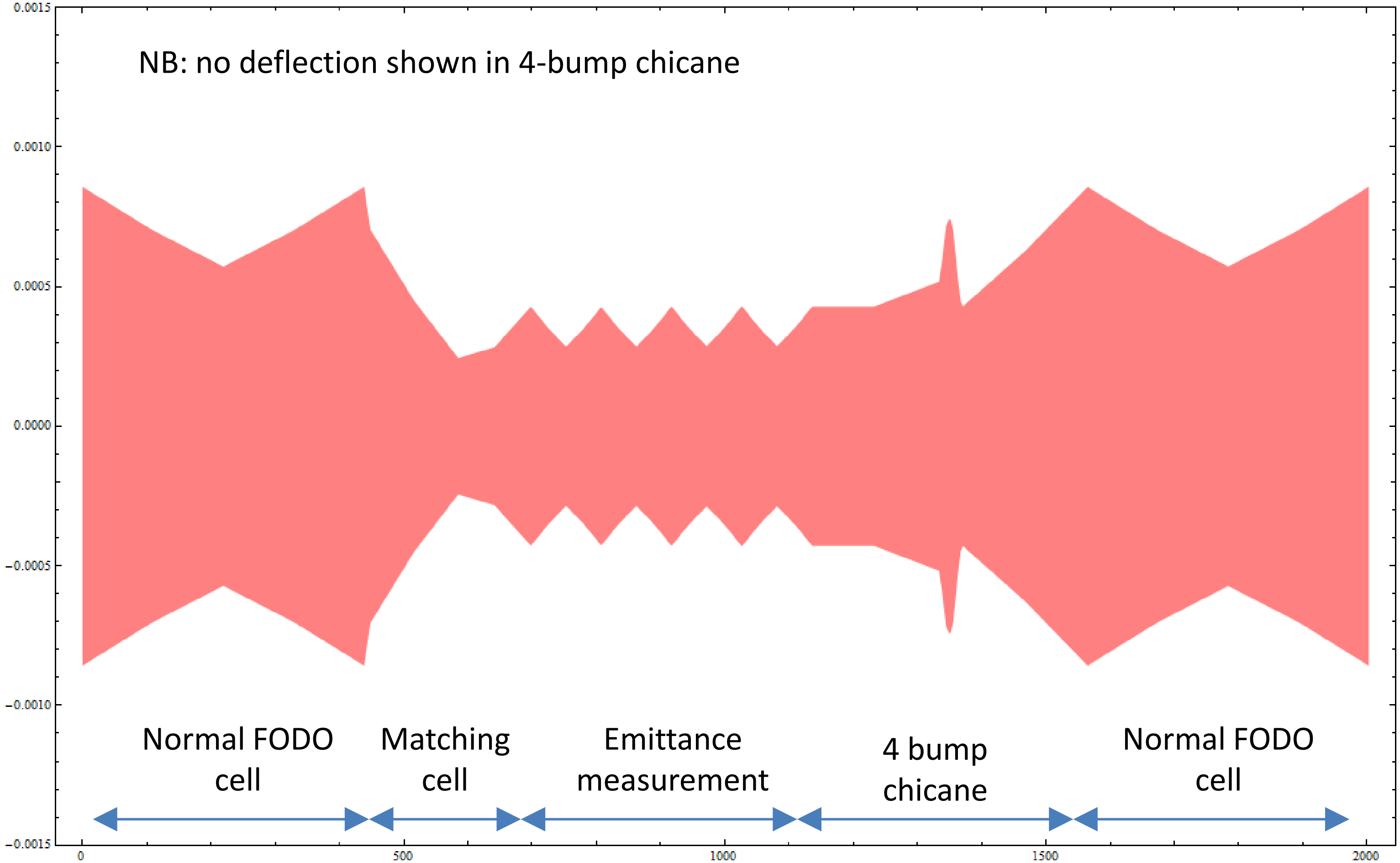
$$\frac{\Delta\varepsilon_y}{\varepsilon_y} \propto \frac{\beta_x^2\beta_y^2}{f^4}$$

These equations are taken from "RMS emittance growth due to intrinsic quadrupole aberrations", R. Baartman

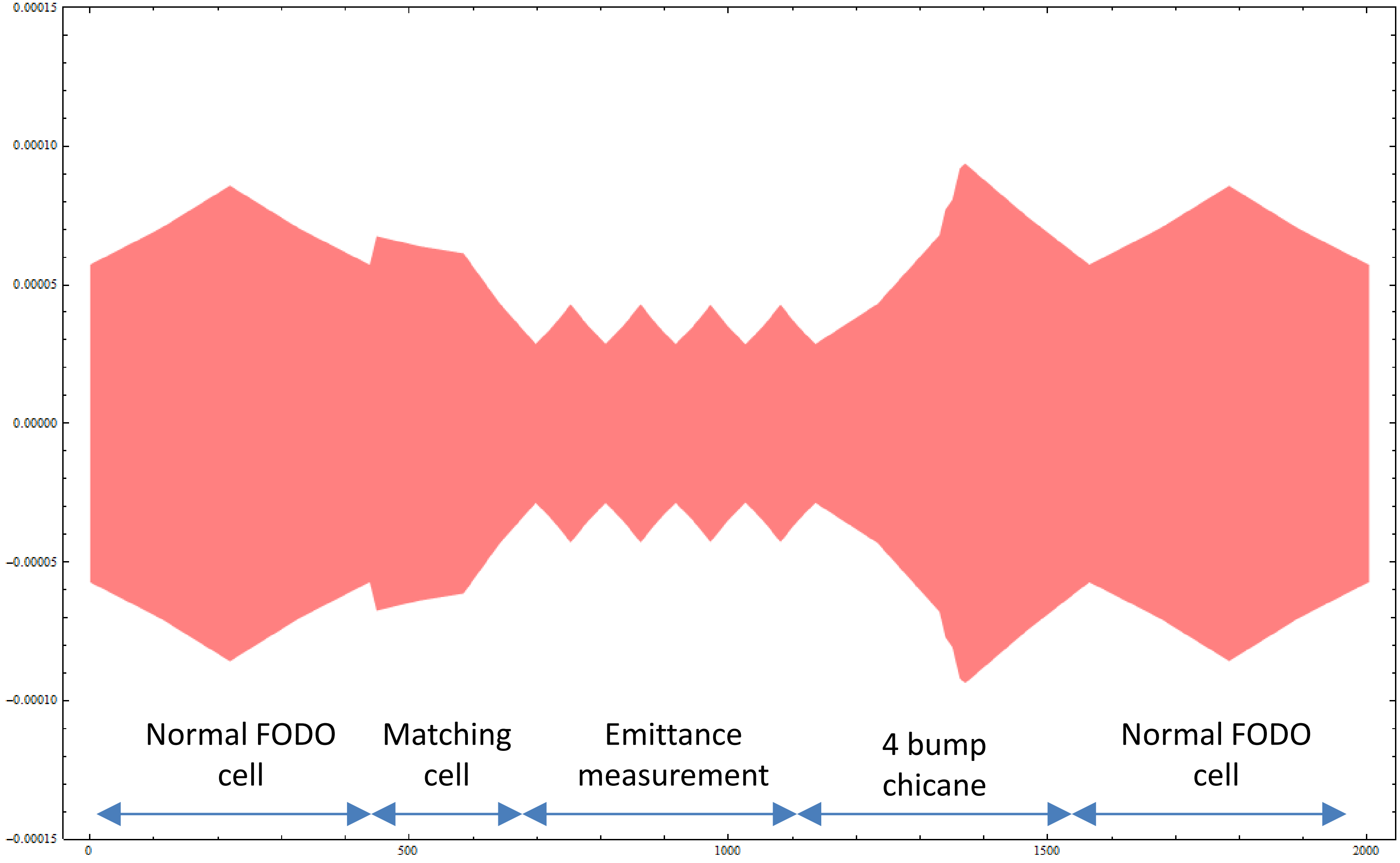
Emittance growth calculations

- Calculated emittance growth from each element in measurement system:
  - Quadrupoles:
    - Total contributions: $\frac{\delta\varepsilon}{\varepsilon} \approx 2.7\times10^{-15}$ for both H and V planes
      - Negligible emittance growth
    - Emittance growth from alignment errors will dominate
      - Still orders of magnitude less than dipole contributions!
  - Dipoles:
    - $\frac{\delta\varepsilon_x}{\varepsilon_x} \approx 2.7\times10^{-8}$
      - Neglect vertical emittance growth
      - Misalignments will significantly increase emittance growth

Horizontal beam profile



Vertical beam profile



Summary

- Pre-linac system ("system 3") previously designed and optimised
- Mid-RTML system ("system 2") design shown
  - Based on design of "system 3"
- Various optics designs examined to determine optimal performance.

Still to do…

- Design extraction line system ("system 1")
- Further tracking simulations to examine system performance.
- Emittance growth from alignment errors
  - Define tolerances
- Define requirements for each laserwire system