Pre-Alignment and Beam-Based Alignment Needs for CLIC

D. Schulte

- Emittance preservation target and lattice design
- Static imperfections
  - modelling
  - beam-based alignment
  - tolerances

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Low Emittance Transport Challenges

- Main linac is a most important source of emittance growth, is closely linked to the technology and imperfections have been studied in some detail
  - it is anticipated that we will not allow for tighter specifications elsewhere
  - but remains to be confirmed
- Static imperfections

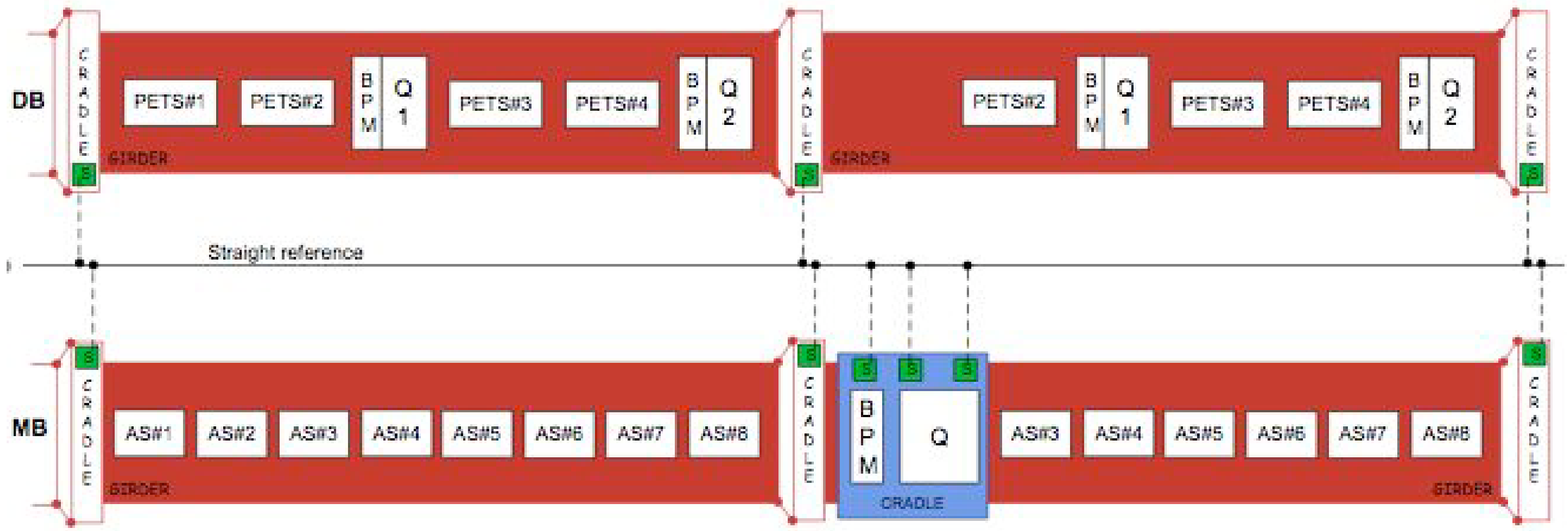
  errors of reference line, elements to reference line, elements...

  pre-alignment, lattice design, beam-based alignment, beam-based tuning
- Dynamic imperfections

  element jitter, RF jitter, ground motion, beam jitter, electronic noise,...

  lattice design, BNS damping, component stabilisation, feedback, re-tuning, re-alignment
- Vertical main linac emittance budget
  - $\Delta\epsilon_y \leq 5\,\mathrm{nm}$ for dynamic imperfections
  - $\Delta\epsilon_y \leq 5\,\mathrm{nm}$ for static imperfections (90% probability)
  - horizontal budget 6 times larger ($\rightarrow$ tolerances 2.5 times larger)

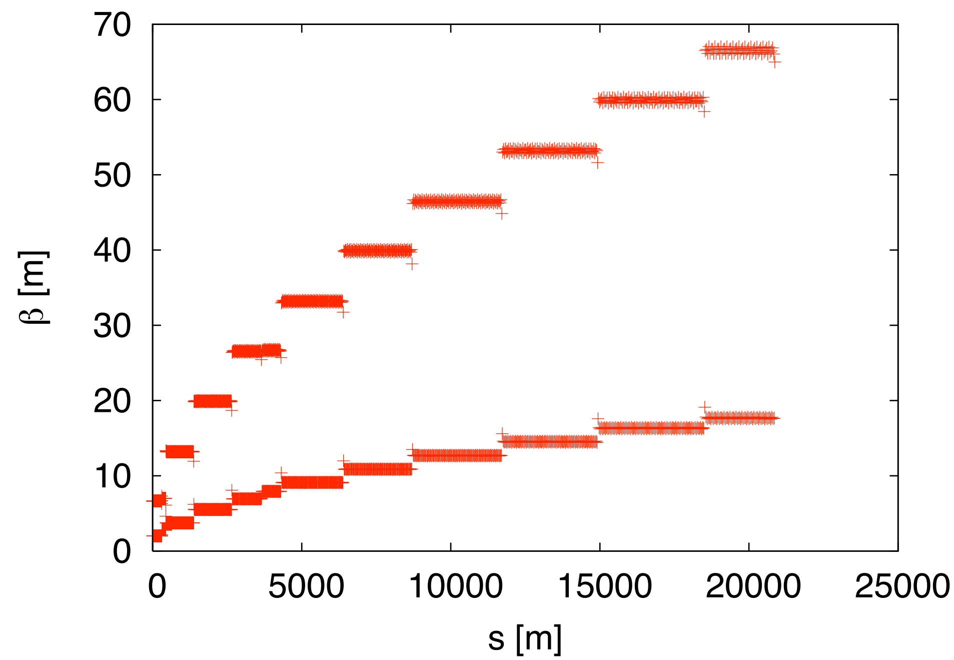
Module Layout



- Five types of main linac modules
- Drive beam module is regular

Lattice Design

- Used $\beta \propto \sqrt{E}$, $\Delta\Phi = \mathrm{const}$
  - balances wakes and dispersion
  - roughly constant fill factor
  - phase advance is chosen to balance between wakefield and ground motion effects
- Preliminary lattice
  - made for $N = 3.7 \times 10^9$
  - quadrupole dimensions need to be confirmed
  - some optimisations remain to be done
- Total length about 21km
  - fill factor more than 78%

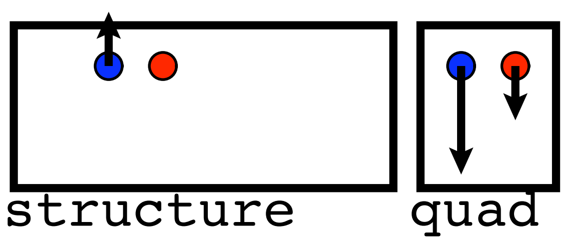


- 12 different sectors used
- Matching between sectors using 7 quadrupoles to allow for some energy bandwidth

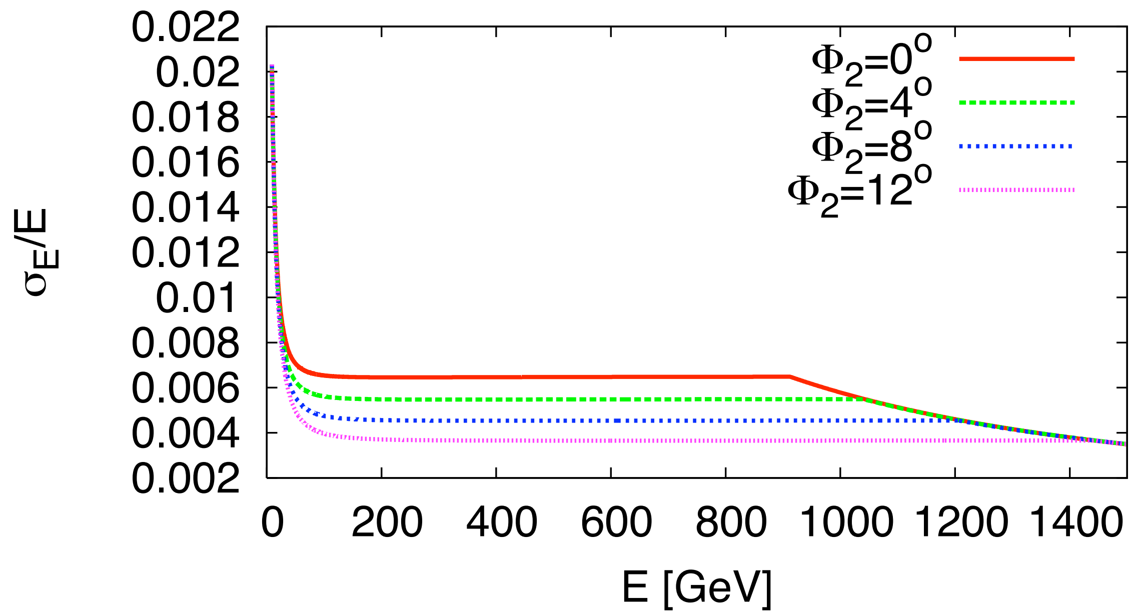
Energy Spread and Beam Stability

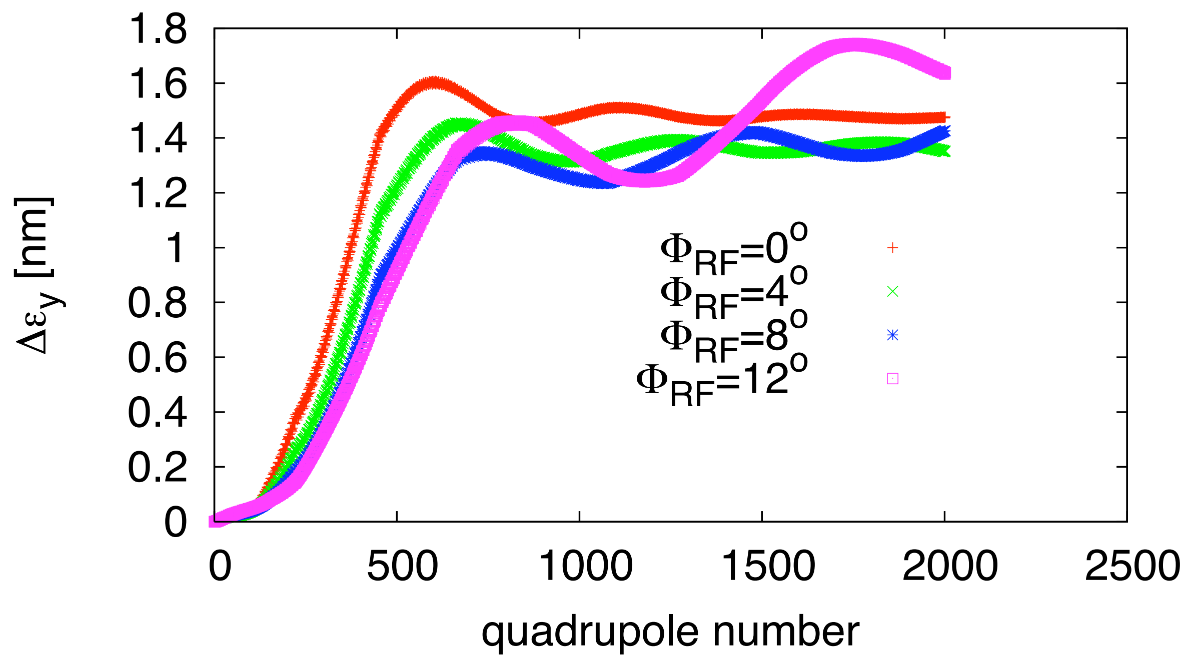
- Trade-off in fixed lattice
  - large energy spread is more stable
  - small energy spread is better for alignment

$\Rightarrow$ Beam with $N = 3.7 \times 10^9$ can be stable



- Some reserve for single bunch wakefields



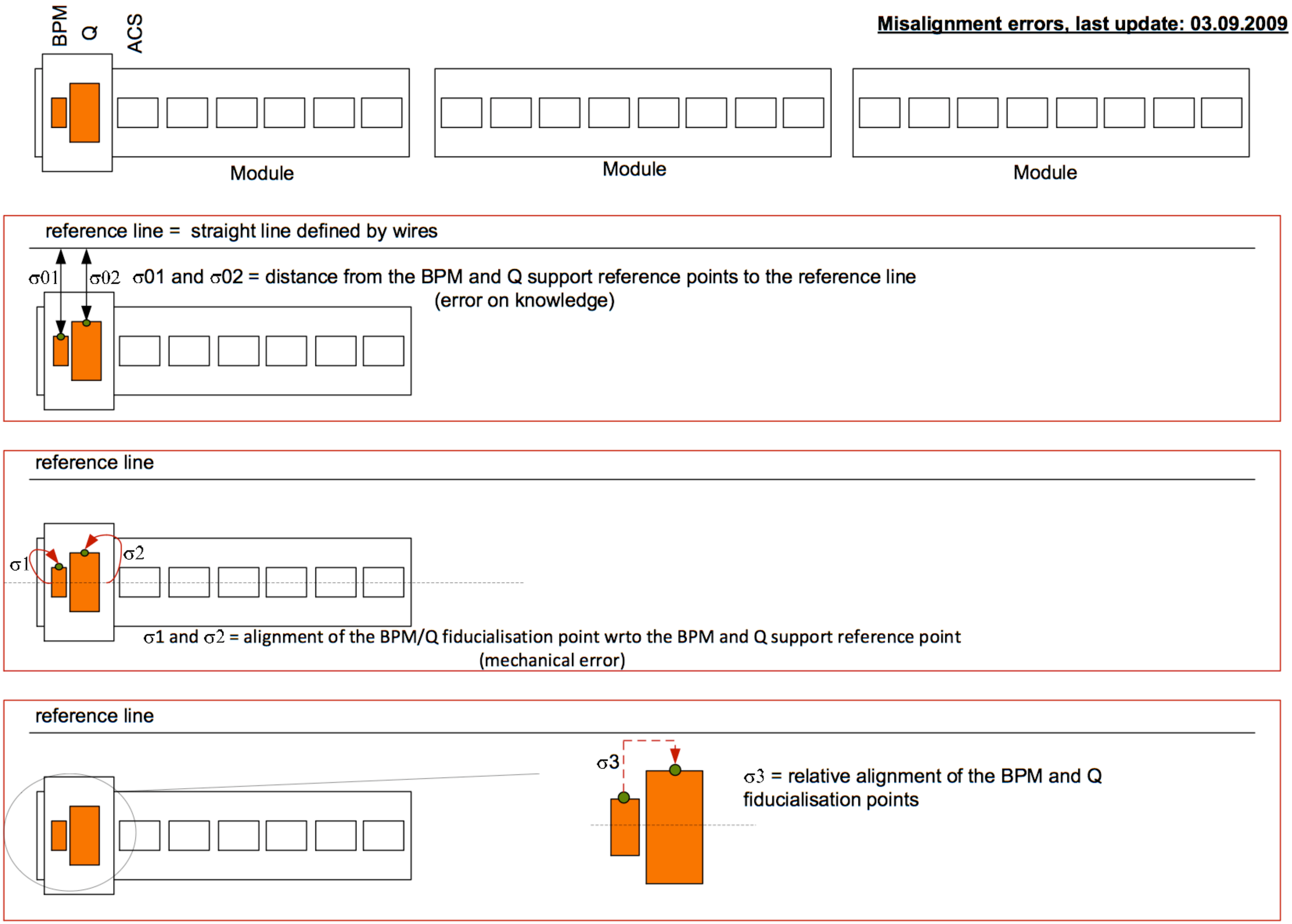


Indicative Static Main Linac Tolerances

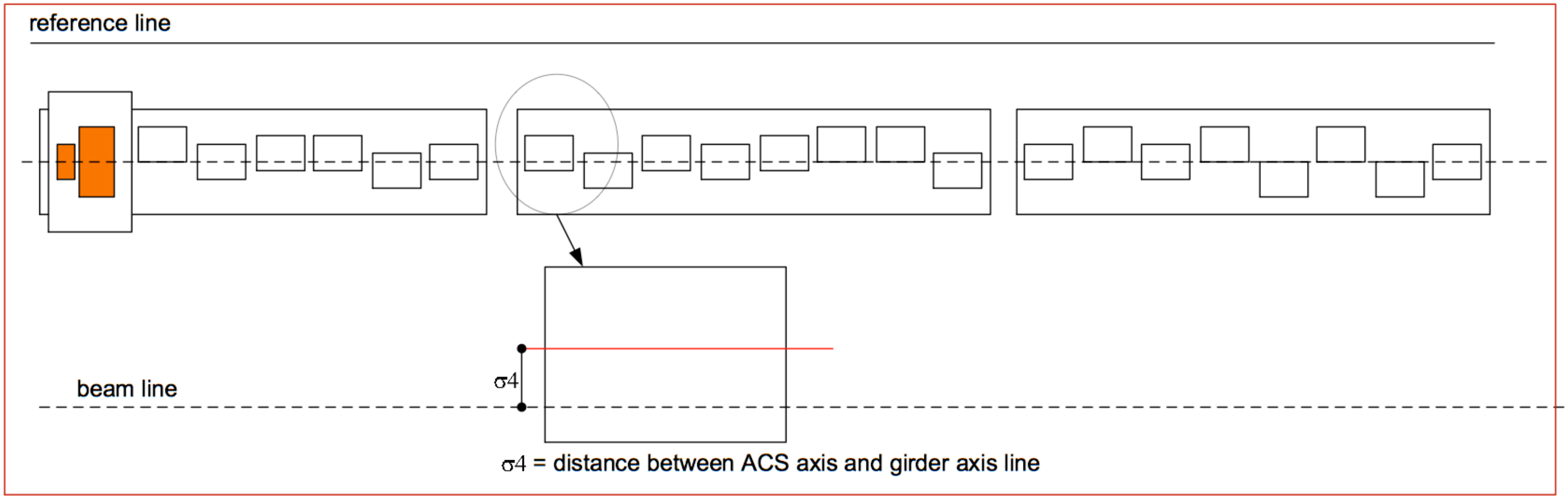
Element	error	with respect to	tolerance	
			CLIC	NLC
Structure	offset	beam	$5.8\ \mu$m	$5.0\ \mu$m
Structure	tilt	beam	$220\ \mu$radian	$135\ \mu$radian
Quadrupole	offset	straight line	—	—
Quadrupole	roll	axis	$240\ \mu$m	$280\ \mu$radian
BPM	offset	straight line	$0.44\ \mu$m	$1.3\ \mu$m
BPM	resolution	BPM center	$0.44\ \mu$m	$1.3\ \mu$m

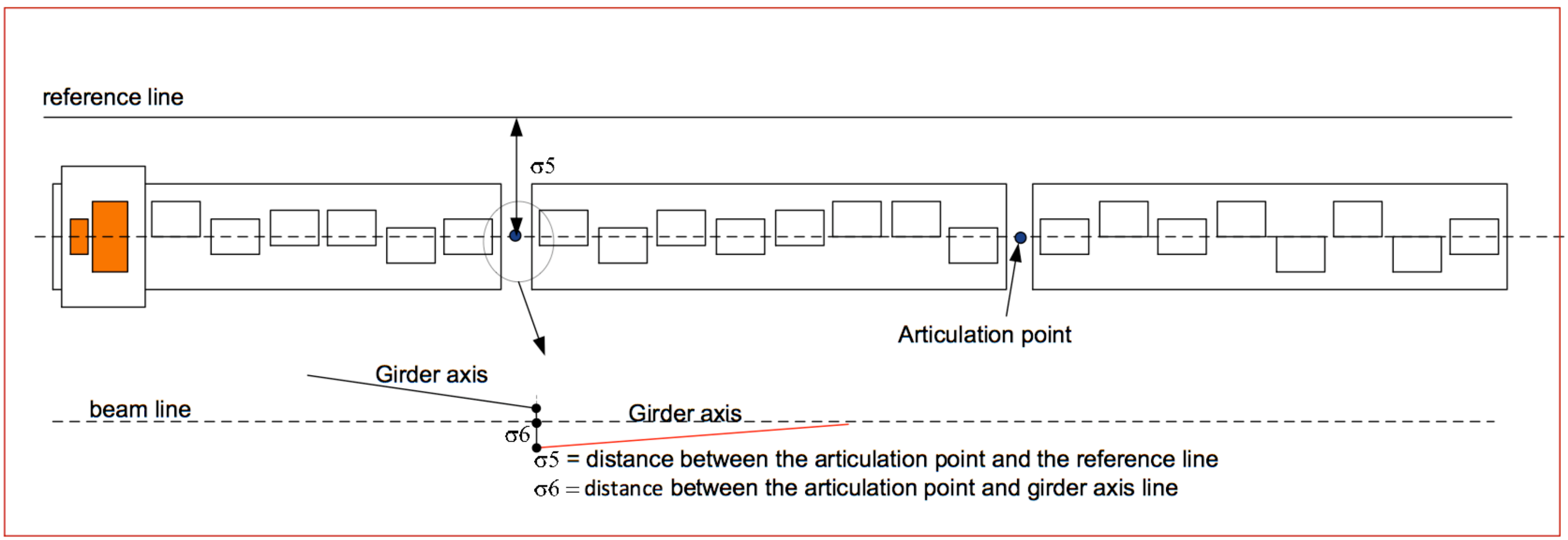
- All tolerances for 1nm growth after simple one-to-one steering
  - note: assume quadrupoles are moved for correction
- CLIC emittance budget is two times smaller than for NLC
- Tighter tolerances for BPM due to stronger focusing in CLIC
  - but therefore more relaxed tolerances for structures

Alignment Model

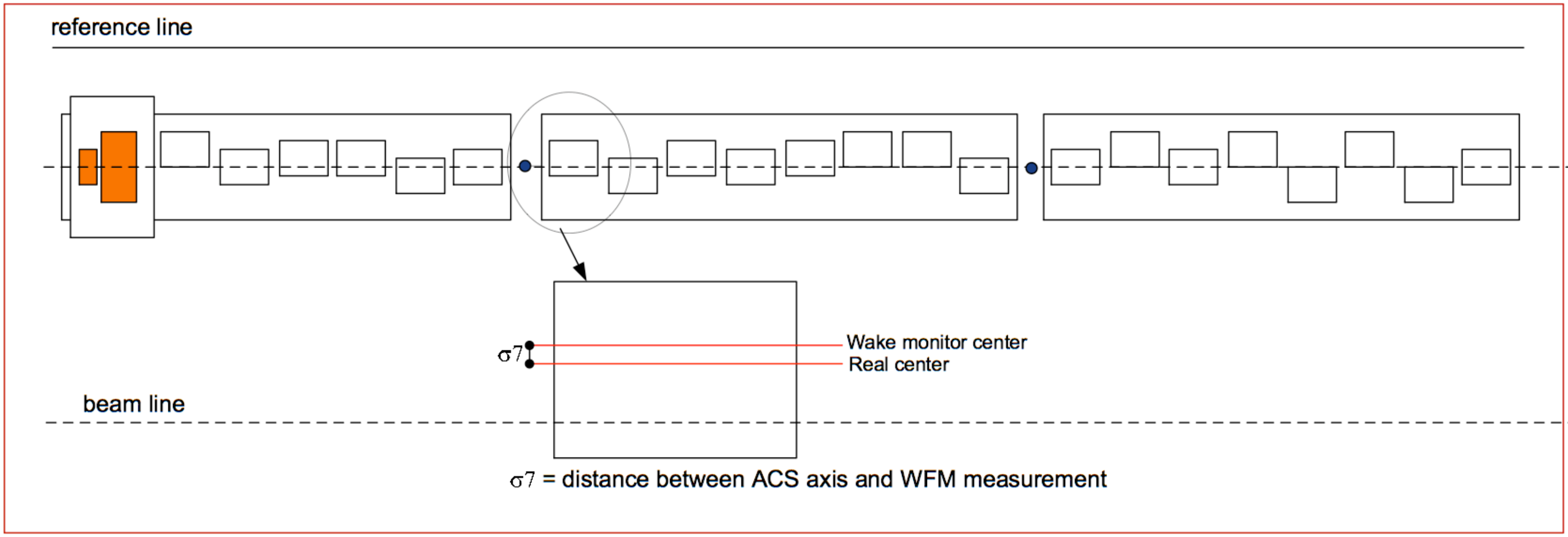


Alignment Model (cont)





Alignment Model (cont)



imperfection	with respect to	symbol	target value
BPM offset	wire reference	σ_{BPM}	14 μm
BPM resolution		σ_{res}	0.1 μm
accelerating structure offset	girder axis	σ_4	10 μm
accelerating structure tilt	girder axis	σ_t	200 μradian
articulation point offset	wire reference	σ_5	12 μm
girder end point	articulation point	σ_6	5 μm
wake monitor	structure centre	σ_7	5 μm
quadrupole roll	longitudinal axis	σ_r	100 μradian

Beam-Based Alignment and Tuning Strategy

- Make beam pass linac
  - one-to-one correction
- Remove dispersion, align BPMs and quadrupoles
  - dispersion free steering
  - ballistic alignment
  - kick minimisation
- Remove wakefield effects
  - accelerating structure alignment
  - emittance tuning bumps

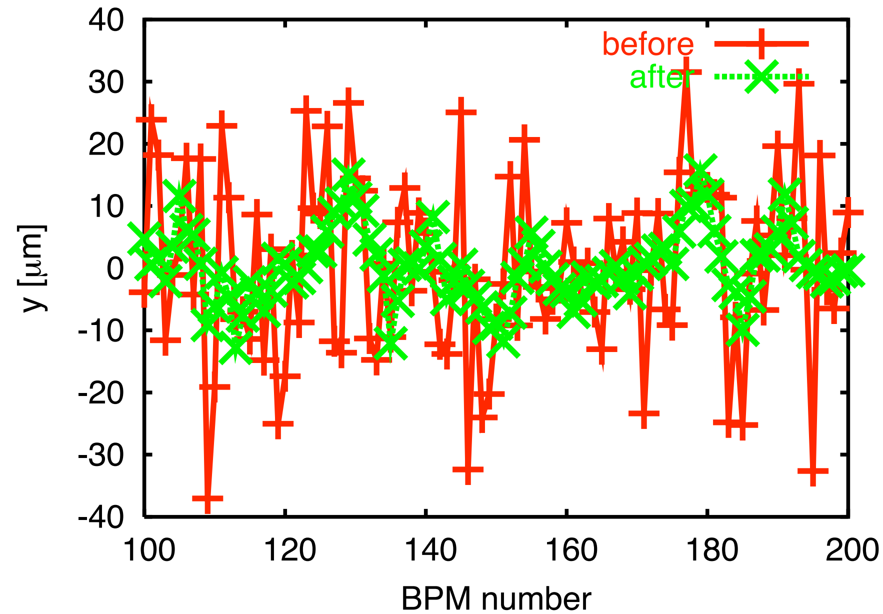
- Tune luminosity
  - tuning knobs

Dispersion Free Correction

- Basic idea: use different beam energies
- NLC: switch on/off different accelerating structures
- CLIC (ILC): accelerate beams with different gradient and initial energy
  - energies done by manipulation of bunch compressor

    demonstrated by A. Latina and P. Eliasson

  $\Rightarrow$ probe beam bunch length $\approx 70\,\mu\mathrm{m}$



- Optimise trajectories for different energies together:

$$S = \sum_{i=1}^{n} \left(w_i (x_{i,1})^2 + \sum_{j=2}^{m} w_{i,j} (x_{i,1} - x_{i,j})^2 \right) + \sum_{k=1}^{l} w'_k (c_k)^2$$

- Last term is omitted
- Idea is to mimic energy differences that exist in the bunch with different beams

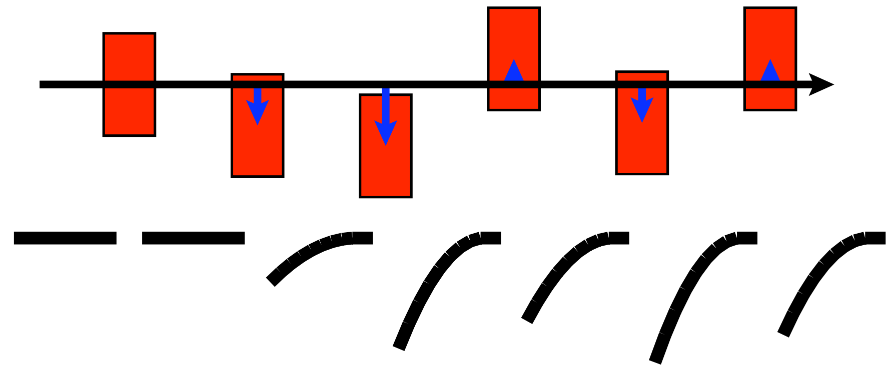
- For stability want to use two parts of one pulse

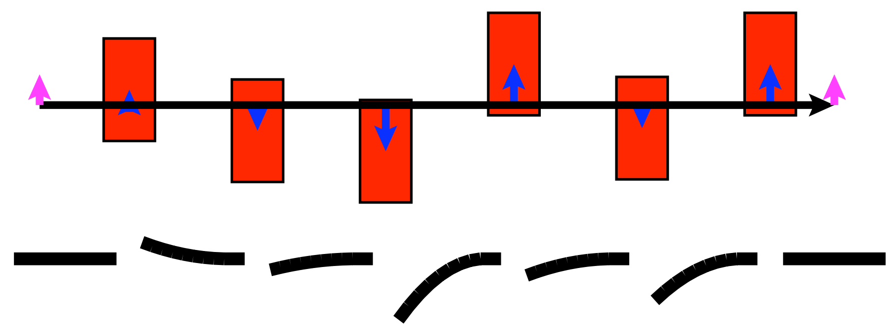
Beam-Based Structure Alignment

- Each structure is equipped with a wake-field monitor (RMS position error $5\,\mu\mathrm{m}$)
- Up to eight structures on one movable girders

$\Rightarrow$ Align structures to the beam

- Assume identical wake fields
  - the mean structure to wakefield monitor offset is most important
  - in upper figure monitors are perfect, mean offset structure to beam is zero after alignment
  - scatter around mean does not matter a lot
- With scattered monitors
  - final mean offset is $\sigma_{wm}/\sqrt{n}$
- In the current simulation each structure is moved independently
- A study has been performed to move the articulation points



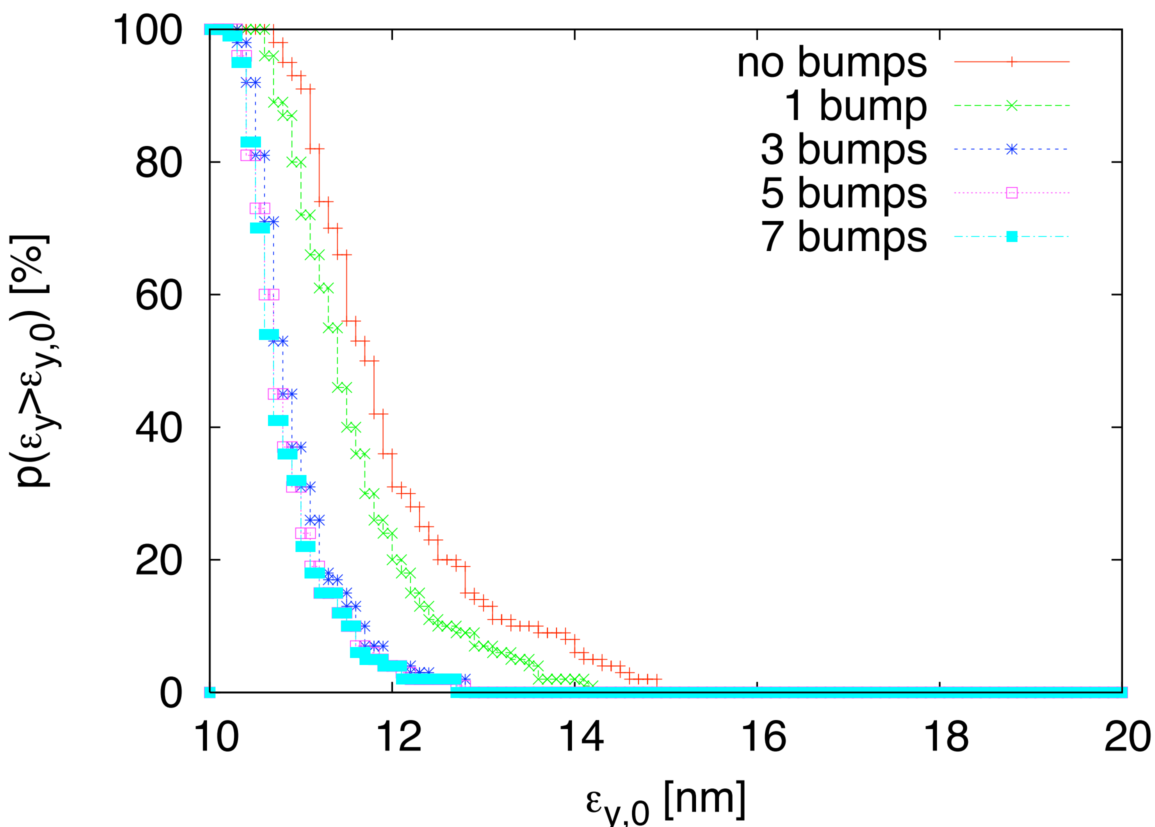


- For our tolerance $\sigma_{wm} = 5\,\mu\mathrm{m}$ we find $\Delta\epsilon_y \approx 0.5\,\mathrm{nm}$
  - some dependence on alignment method

Final Emittance Growth

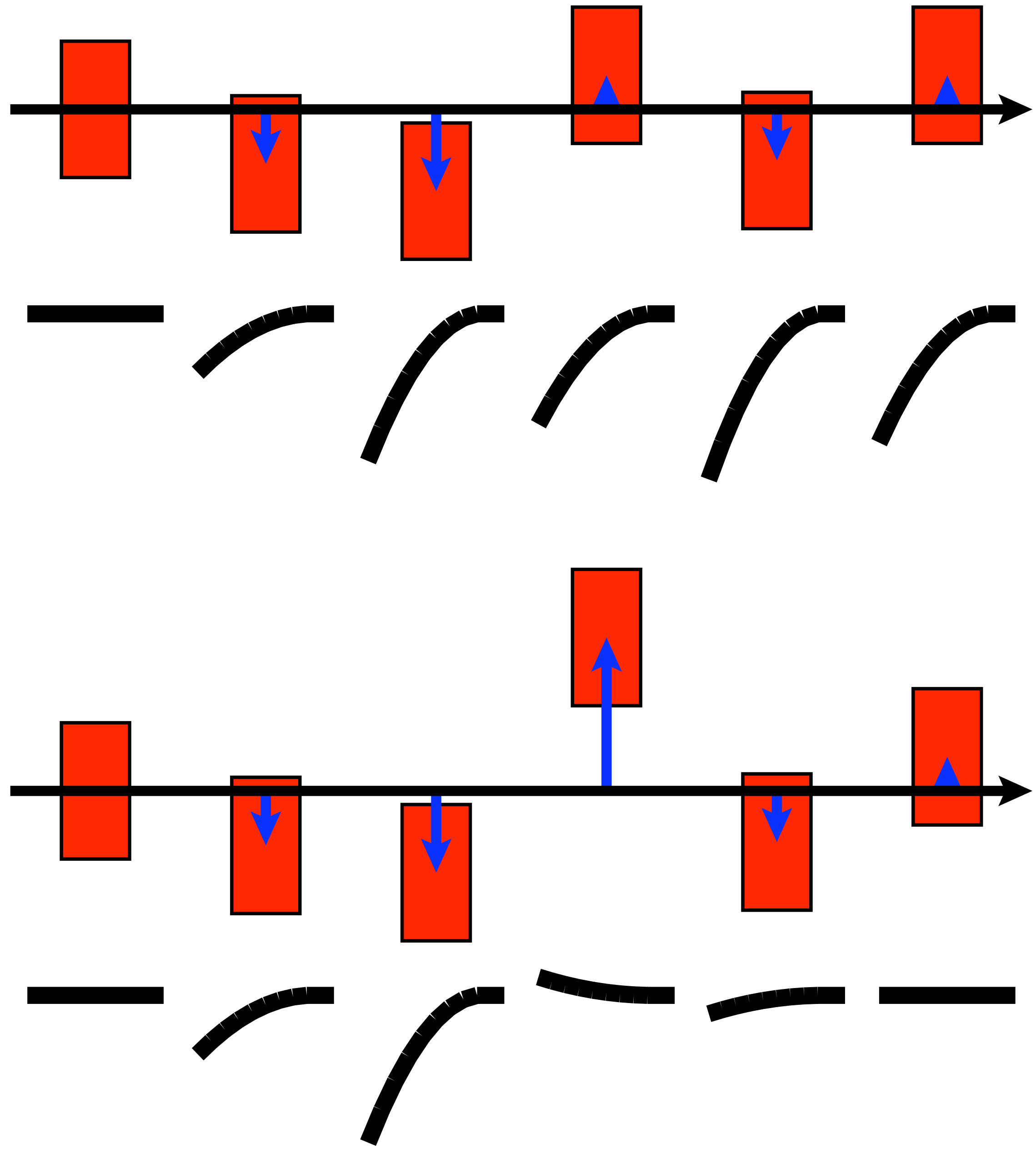
imperfection	with respect to	symbol	value	emitt. growth
BPM offset	wire reference	σ_{BPM}	14 μm	$0.367\,\mathrm{nm}$
BPM resolution		σ_{res}	0.1 μm	$0.04\,\mathrm{nm}$
accelerating structure offset	girder axis	σ_4	10 μm	$0.03\,\mathrm{nm}$
accelerating structure tilt	girder axis	σ_t	200 μradian	$0.38\,\mathrm{nm}$
articulation point offset	wire reference	σ_5	12 μm	$0.1\,\mathrm{nm}$
girder end point	articulation point	σ_6	5 μm	$0.02\,\mathrm{nm}$
wake monitor	structure centre	σ_7	5 μm	$0.54\,\mathrm{nm}$
quadrupole roll	longitudinal axis	σ_r	100 μradian	$\approx 0.12\,\mathrm{nm}$

- Selected a good DFS implementation
  - trade-offs are possible
- Multi-bunch wakefield misalignments of $10\,\mu\mathrm{m}$ lead to $\Delta\epsilon_y \approx 0.13\,\mathrm{nm}$
- Performance of local prealignment is acceptable



Emittance Tuning Bumps

- Emittance (or luminosity) tuning bumps can further improve performance
  - gobally correct wake-field by moving some structures
  - similar procedure for dispersion
- Need to monitor beam size
- Optimisation procedure
  - measure beam size for different bump seetings
  - make a fit to determine optimum setting
  - apply optimum
  - iterate on next bump



Luminosity Simulator

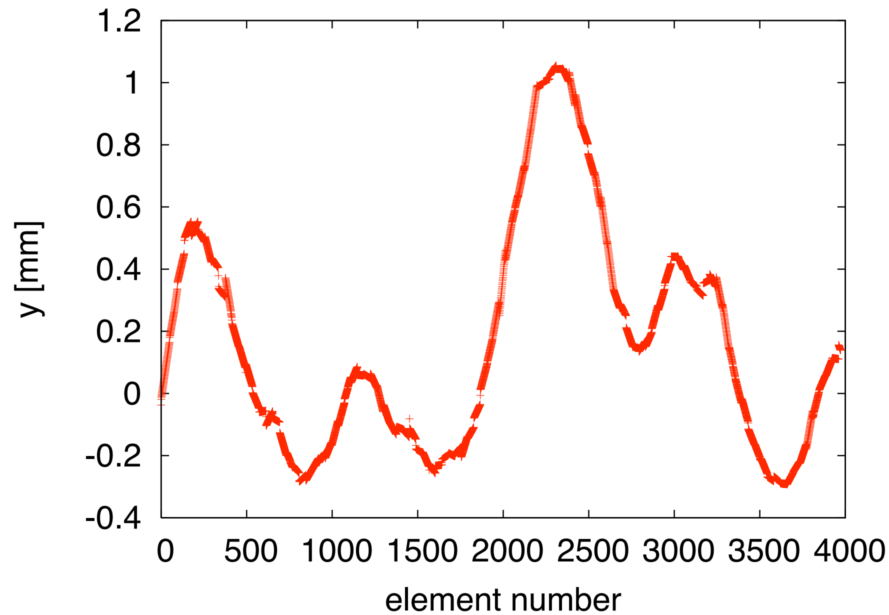
- Conventionally use laser wire that is smaller than the beam size
  - scan beam
  - fit relevant size
- Proposed use of luminosity simulator
  - laser wire can have roughly Gaussian transverse profile
  - collide beam with laser beam that has transverse dimension corresponding roughly to the target beam size
  - optimise beam-photon luminosity
- P. Eliasson has demonstrated this with simulations
  - using two wires at 90° phase advance
  - 3% RMS luminosity error per measurement
  - incorrect laser spot size does not compromise performance strongly
  - need to steer beam with BPM
  - need to optimise beam position in the BPM once in a while
- Further studies to optimise the design

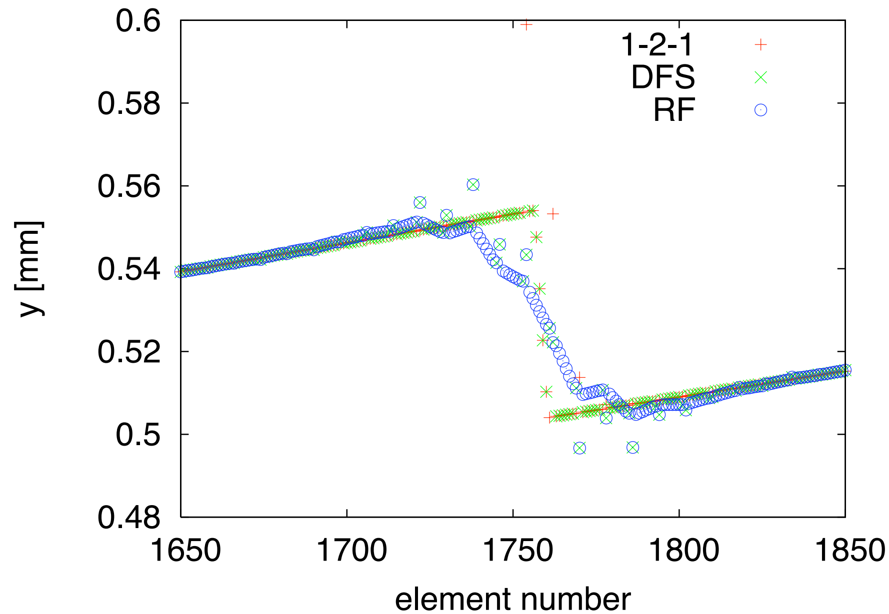
Wire System Misalignment Modelling

- Received a number of misalignments from Thomas Touzé
- Used 50 seeds for each error set
- Switched from one wire 1 to 2 at end point of 1 and back to 1 at end point of 2
- Used linear interpolation in between wire endpoints

  - no sag error

  - no error of geoid





Wire System Results and Further Work

- Different number of pits have been simulated

  $\Rightarrow$ seem to make little difference

- Different wire monitor accuracies have been studied

  $\Rightarrow$ makes a significant difference

case	wire length	no of pits	sensor accuracy	$\Delta\epsilon_y[\mathrm{nm}]$
1a	403.2	7	20 $\mu\mathrm{m}$	0.09
1b	403.2	7	5 $\mu\mathrm{m}$	≈ 0.01
2a	400	2	5 $\mu\mathrm{m}$	≈ 0.01
2b	400	3	5 $\mu\mathrm{m}$	≈ 0.01
2c	400	6	5 $\mu\mathrm{m}$	≈ 0.01

- Results with current model are acceptable

- More imperfections need to be included as they become available

  - systematic error of sensors
  - wire sag
  - geoid
  - ...

Conclusion

- Alignment tolerances for CLIC are tight
- Hardware R&D indicates that the requirements can be met
- More work to
  - improve imperfections model (e.g. wire sag)
  - balance difficulties for hardware
  - cost optimisation