CLIC Main Linac

Reminder

- Main linac design is well advanced.
- Beam-based alignment, dynamic imperfections, fast ion instability and multi-bunch effects have been studied and presented at PAC09 and the last ACE Meeting.
- Emittance dilution by component misalignment can be kept at acceptable levels utilizing beam-based alignment. Requirements on alignment accuracy (5-10 µm, 100 µrad) and BPM resolution (0.1 µm) are reasonable.
- Quadrupoles need to be stabilized to nanometer and 100 nanoradians level. Requirements on RF structures are at micrometer and microradians level. RF phase and amplitude requirements are relaxed to a few 0.1 deg and a few 0.1% by an increased bandwidth of the BDS.
- Simulation of field ionization has been improved by implementing better model into the code. New vacuum specifications are being worked on.

F. Stulle, ACE February 2010

Pre-Alignment and Stabilisation Needs for CLIC

D. Schulte

- Emittance preservation target and lattice design
- Static imperfections

    modelling, beam-based alignment, tolerances
- Dynamic imperfections

    modelling, beam-based alignment, tolerances

CLIC ACE May 2009

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. . .

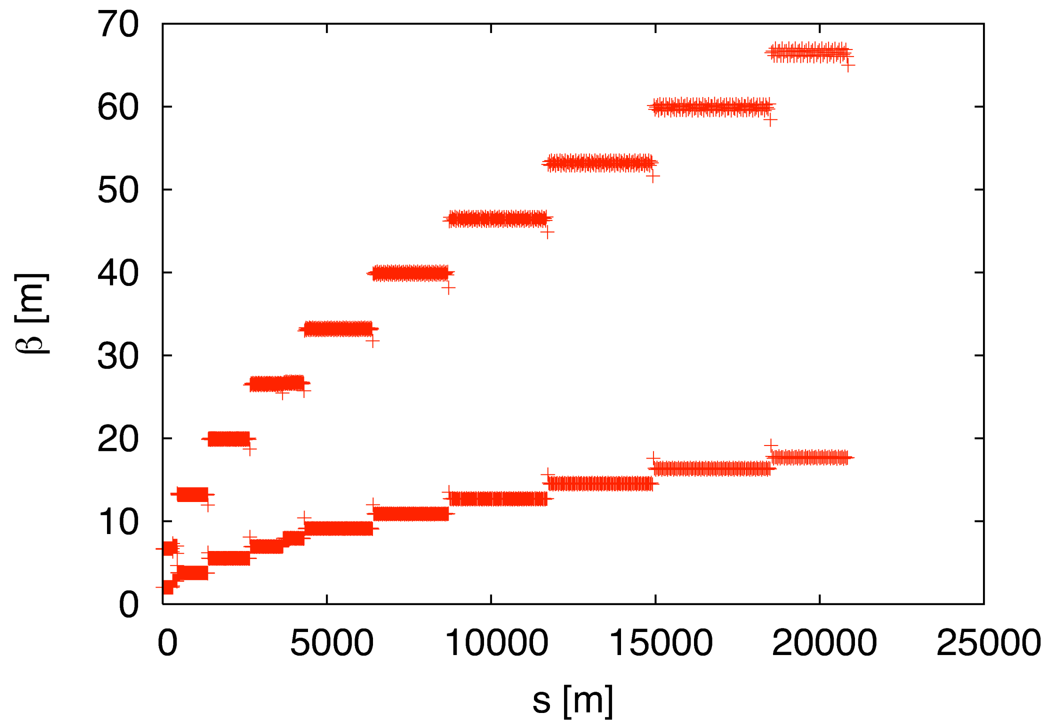
  pre-alignment, lattice design, beam-based alignment, beam-based tuning
- Dynamic imperfections

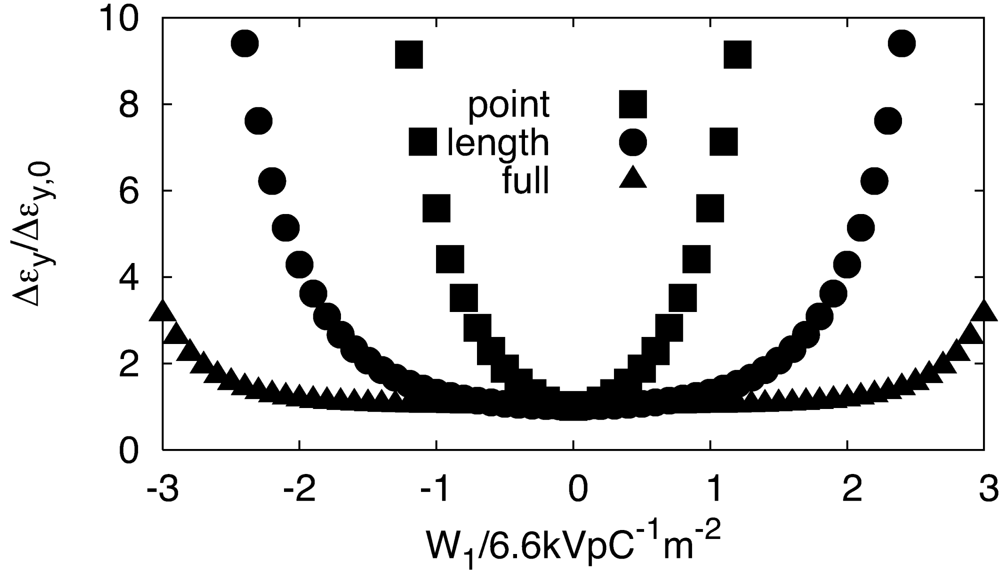
  element jitter, RF jitter, ground motion, beam jitter, electronic noise,. . .

  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)

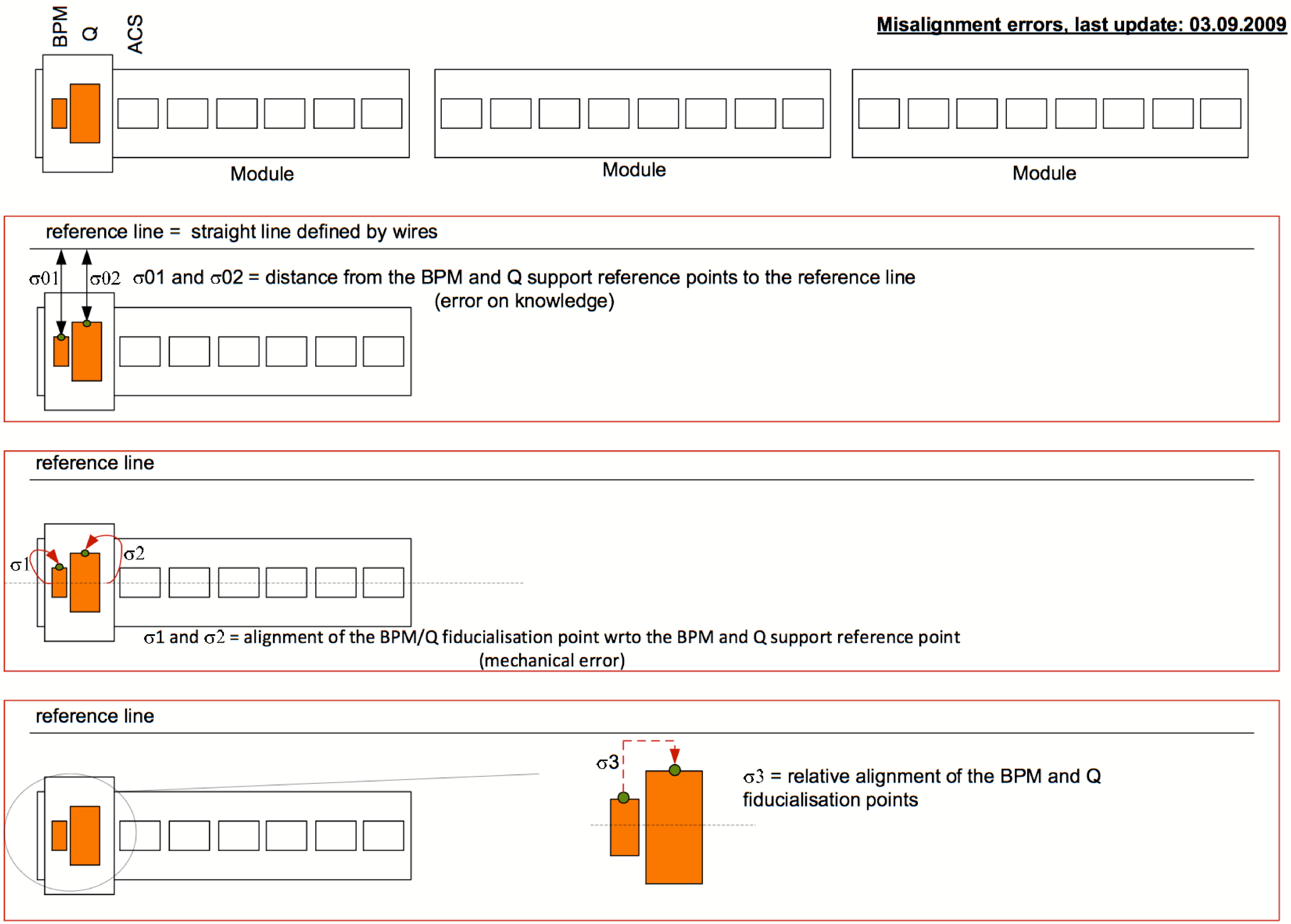
Lattice Design

- Used $\beta \propto \sqrt{E}$, $\Delta\Phi = \mathrm{const}$
  - balances wakes and dispersion
  - roughly constant fill factor
- Total length about 21 km
  - fill factor about 78.6%
- 12 different sectors used
- Matching between sectors using 7 quadrupoles to allow for some energy bandwidth
- Single bunch stability ensured by BNS damping
- Multi-bunch coherent offset leads to phase shift of $90°$ at linac end
- Bunch-to-bunch offset amplification shown

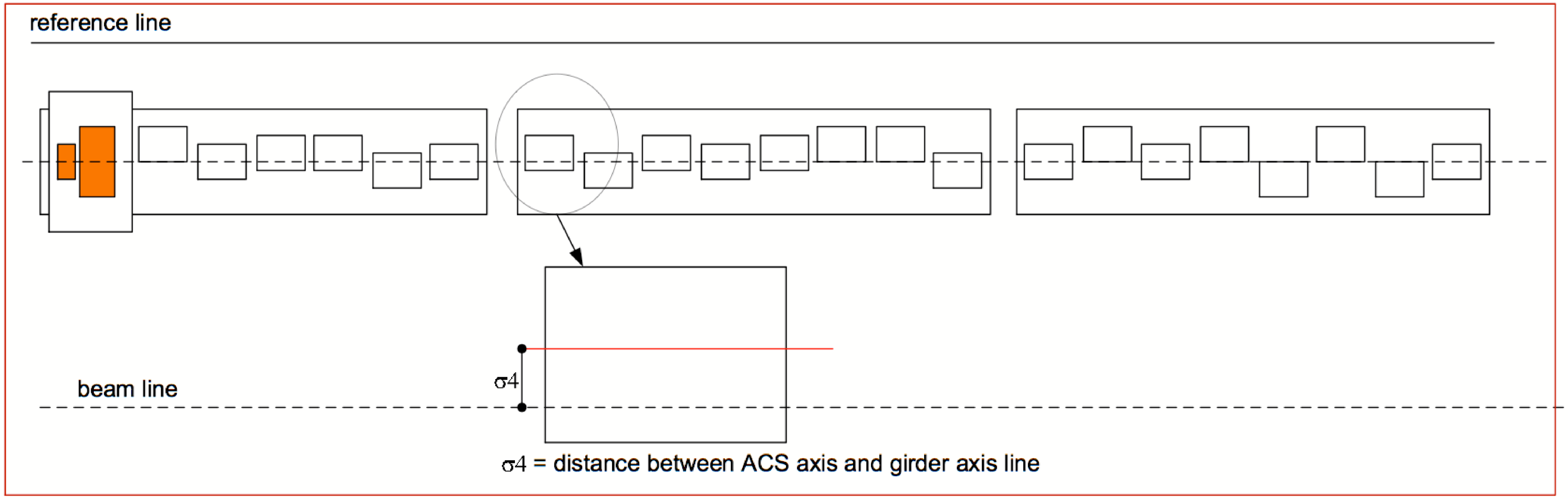


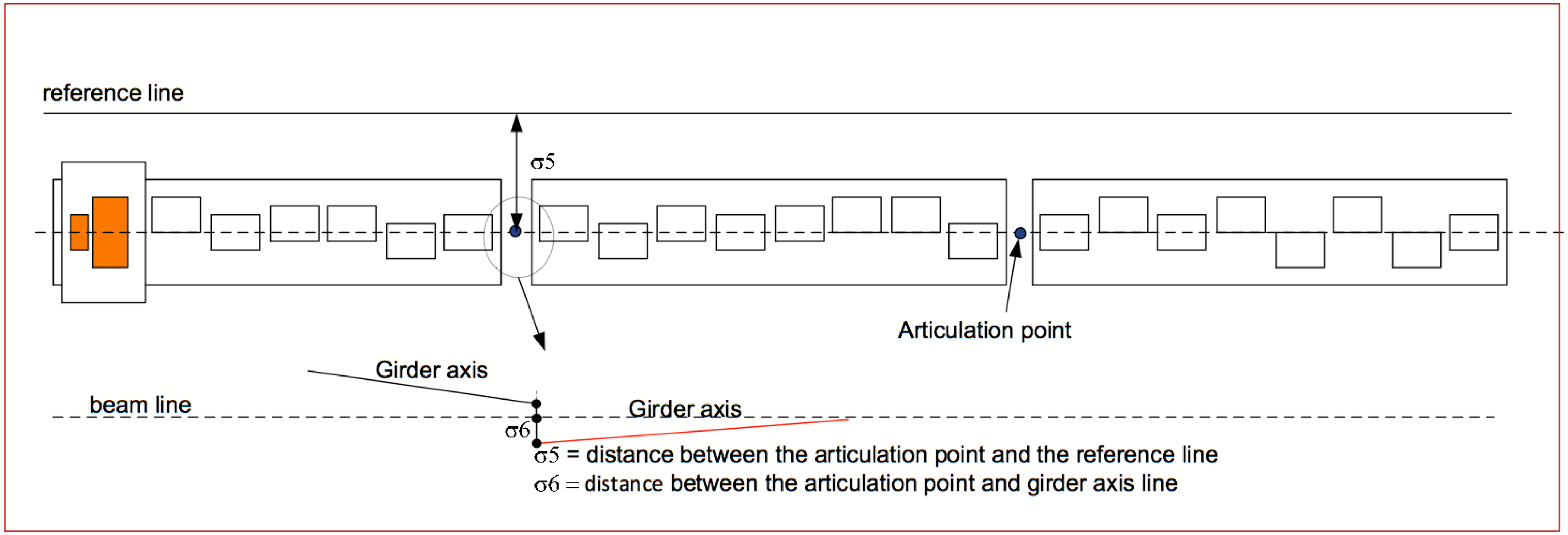


Alignment Model

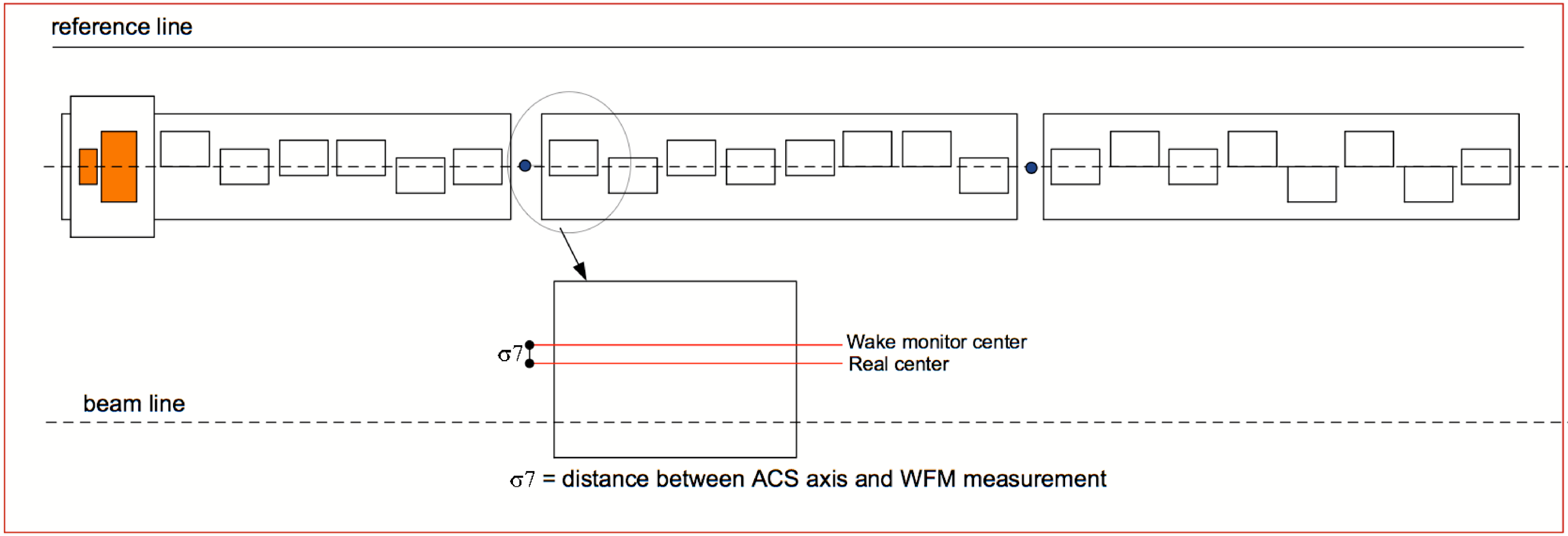


Alignment Model (cont)





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

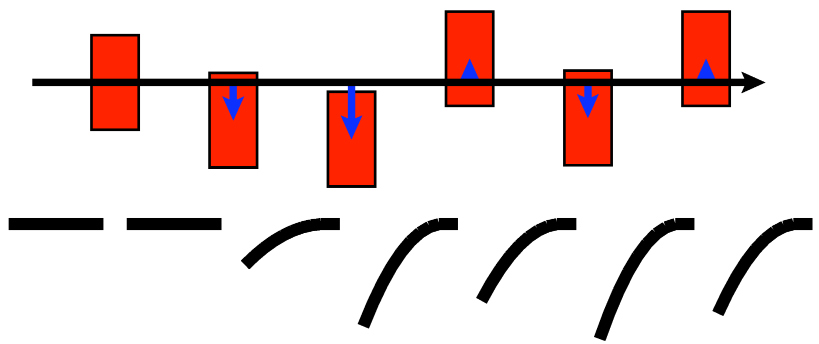
- Tune luminosity
  - tuning knobs

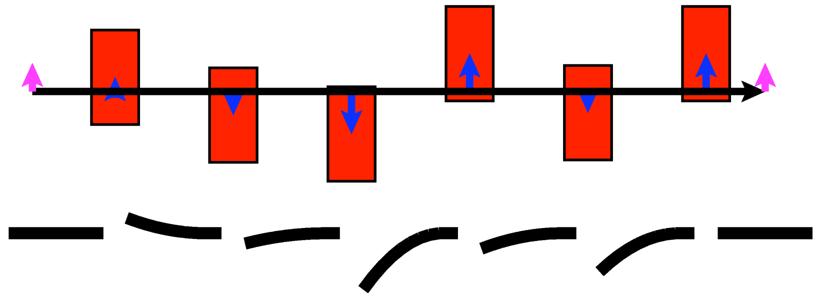
Beam-Based Structure Alignment

- 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



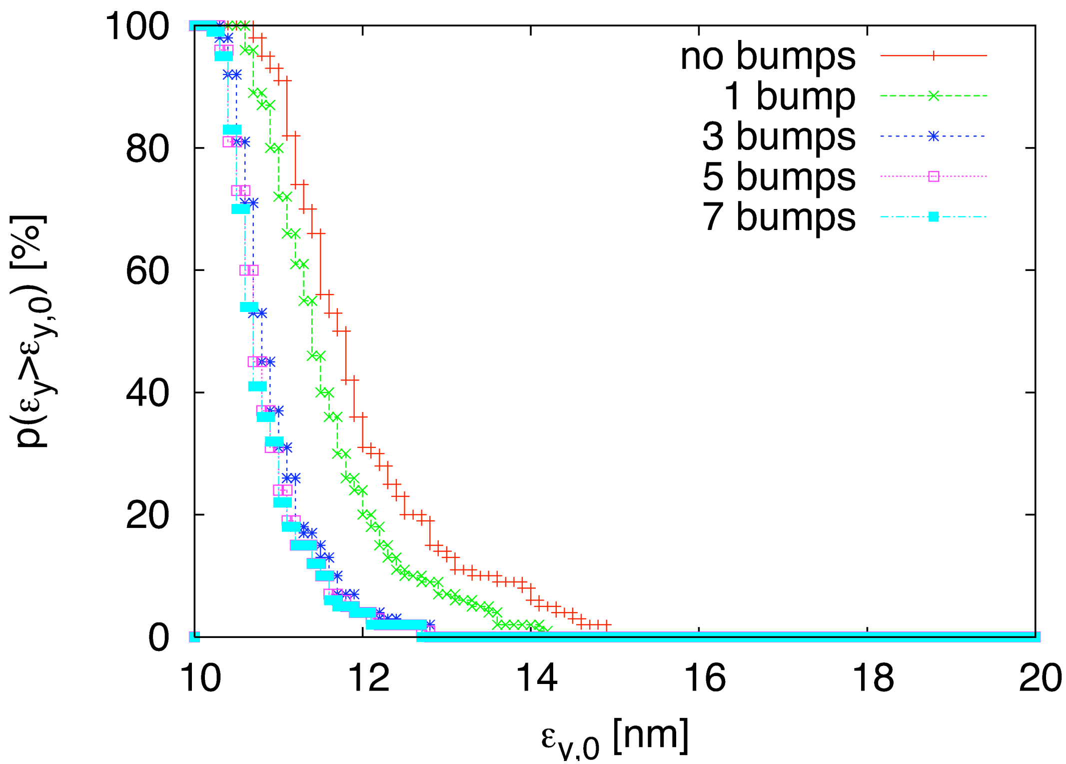


- For our tolerance $\sigma_{wm} = 5\,\mu\mathrm{m}$ we find $\Delta\epsilon_y \approx 0.5\,\mathrm{nm}$
  - some dependence on alignment method

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 pre-alignment is acceptable



Dynamic Imperfections

- Important is the multi-pulse emittance
- Counteract dynamic effects by
  - fast component stabilisation (between pulses)
  - beam-based orbit feedback
  - longitudinal feedback
  - slow component stabilisation (e.g. temperature drifts)
  - beam tuning
  - beam-based alignment when needed
  - repetition of pre-alignment
- Do not have a model of the imperfections
  - some models for ground motion
  - technical noise is not yet available
  - transfer by girder is not yet available (some model of the magnet exists)
  - impact of stabilisation feedback is not yet available

$\Rightarrow$ so we derive some specifications

Dynamic Imperfections

- Luminosity loss is part of the emittance budget
- But limit luminosity fluctuation to less than 10%
  - total luminosity fluctuation is not straightforwad

Source	budget	tolerance
Damping ring extraction jitter	0.5%	kick reproducibility $0.1\sigma_x$
Transfer line stray fields	?%	data needed
Bunch compressor jitter	1%	
Quadrupole jitter in main linac	1%	$\sigma_{jitter} \approx 1.8\,\mathrm{nm}$
RF amplitude jitter in main linac	1%	0.075% coherent, 0.22% incoherent
RF phase jitter in main linac	1%	0.2° coherent, 0.8° incoherent
RF break down in main linac	1%	rate$< 3 \cdot 10^{-7}\,\mathrm{m}^{-1}\mathrm{pulse}^{-1}$
Structure pos. jitter in main linac	0.1%	$\sigma_{jitter} \approx 880\,\mathrm{nm}$
Structure angle jitter in main linac	0.1%	$\sigma_{jitter} \approx 440\,\mathrm{nradian}$
Crab cavity phase jitter	2%	$\sigma_\phi \approx 0.017^\circ$
Final doublet quadrupole jitter	2%	$\sigma_{jitter} \approx 0.17(0.34)\,\mathrm{nm}$–$0.85(1.7)\,\mathrm{nm}$
Other quadrupole jitter in BDS	1%	
$\dots$	?%	

$\Rightarrow$ Long list of small sources adds up

$\Rightarrow$ Impact of feedback system is important

Conclusion

- Typical local alignment tolerances are of the order of $10\,\mu\mathrm{m}$
  - in particular BPM position and wake monitors
- The first results of wire reference system look very promising
  - more complete studies to follow
- Dynamic tolerances have been studied
  - but need a better model
  - produced some simple specifications sofar
- Feedback conceptual design is an important ingredient
  - main linac baseline feedback layout exists
  - BDS will follow soon
- Controler design
  - optimisation depends on noise model and feedback layout
  - knowledge of the system response is vital and is being studied
- Some resources are available for the beam dynamics work (J. Resta Lopez at JAI, J. Pfingstner (PhD student), J. Snuverink (fellow), fraction of DS)