CERN Contribution to Main Linac Studies

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- Main linac studies are based on TESLA TRC lattice

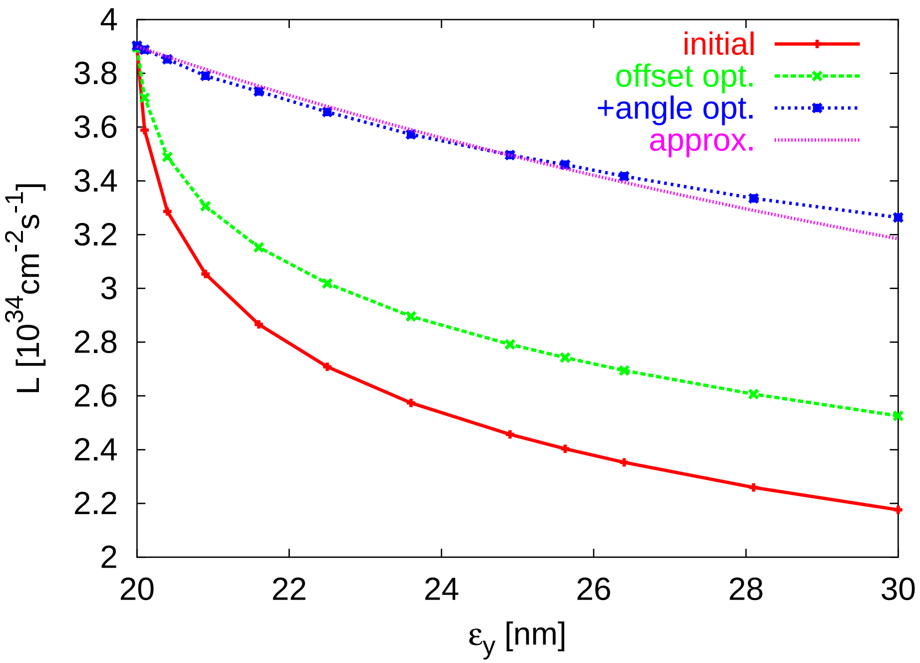
  $\Rightarrow$ will be updated when we agree on new lattice

Emittance as Performance Measure

- Banana effect could make emittance as measure for linac performance questionable
- Luminosity can be optimised by scanning offset and angle
- Certainly more complicated than feedback with BPM

⇒ Emittance seems good measure for static case

⇒ For dynamic integrated simulation is required



Misalignment Model

- TRC model
  - $\sigma_{quad} = 300\,\mu\mathrm{m}$
  - $\sigma_{cav} = 300\,\mu\mathrm{m}$
  - $\sigma'_{cav} = 200\,\mu\mathrm{radian}$
  - $\sigma_{bpm} = 200\,\mu\mathrm{m}$
  - $\sigma_{res} = 10\,\mu\mathrm{m}$
  - $\sigma_{module} = 200\,\mu\mathrm{m}$
- LICAS based model
  - is implemented
  - needs further discussion

- Need consistent model

  $\Rightarrow$ WG2

Simulation Tools

- All simulations are performed with PLACET
- Two different options exist
  - efficient tracking and correction of static machine
    $\Rightarrow$ only dynamic error is beam jitter
  - full seperation of tracking and correction
    $\Rightarrow$ quite realistic modelling including all noise sources
    $\Rightarrow$ much slower than the other solution
    $\Rightarrow$ will be used more when full lattice design exists
- Efficient pseudo multi-particle tracking is in preparation

  $\Rightarrow$ no loss of information from bunch compressor to beam delivery system

Steering Methods

- One-to-one
  - does not meet the required performance
- Ballistic alignment
  - sensitive to remanent fields
- Quadrupole shunting method
- Dispersion free steering
  - can be implemented via changes of quadrupole strengths
  - or modification of beam energy
  - beam energy can potentially be modified within a pulse
    $\Rightarrow$ potentially removes most of pulse-to-pulse jitter effects
- Tuning bumps directly modify emittance or luminosity

Ballistic Alignment

- Beam line is devided into sectors in each of which
  - quadrupoles are switched off
  - beam steered into last BPM (could use mean of all BPMs)
  - BPMs are aligned to beam
  - quadrupoles are switched on and one-to-one correction is performed
- Resulting emittance growth is about $10\,\mathrm{nm}$ for $\sigma_{res} = 5\,\mu\mathrm{m}$
- External fields matter
  - could be dealt with by using different energy beams
  - using more than one BPM to define ballistic line will help
- Requires switching of quadrupoles $\Rightarrow$ slow since low repetition frequency

Quadrupole Shunting Method

- Align BPM to quadrupole
- Perform optimisation of beam trajectory
- Preliminary simulations show $\Delta\epsilon_y \approx 15\,\mathrm{nm}$

Dispersion Free Steering

$$\chi^2 = w_1 \sum_{i=1}^{n} b_{0,i}^2 + \sum_{j=1}^{m} \Sigma(b_{j,i} - b_{0,i})^2 + w_2 \sum_{i=1}^{n} d_i^2$$

$b_{j,i}$: Offset of beam j in BPM i ($i = 0$ nominal beam)

d_i strength of corrector i

- Three different beams are used
  - with 20% less than nominal energy
  - with 10% less than nominal energy
  - nominal beam
- The difference between each of the first two beams and the nominal is minimised together with the offset of the nominal beam
- Varying the gradient is easy, varying the initial energy is not easy

Correction with Different Gradients

- Only different gradients are used

  $\Rightarrow$ can be easily implemented in reality

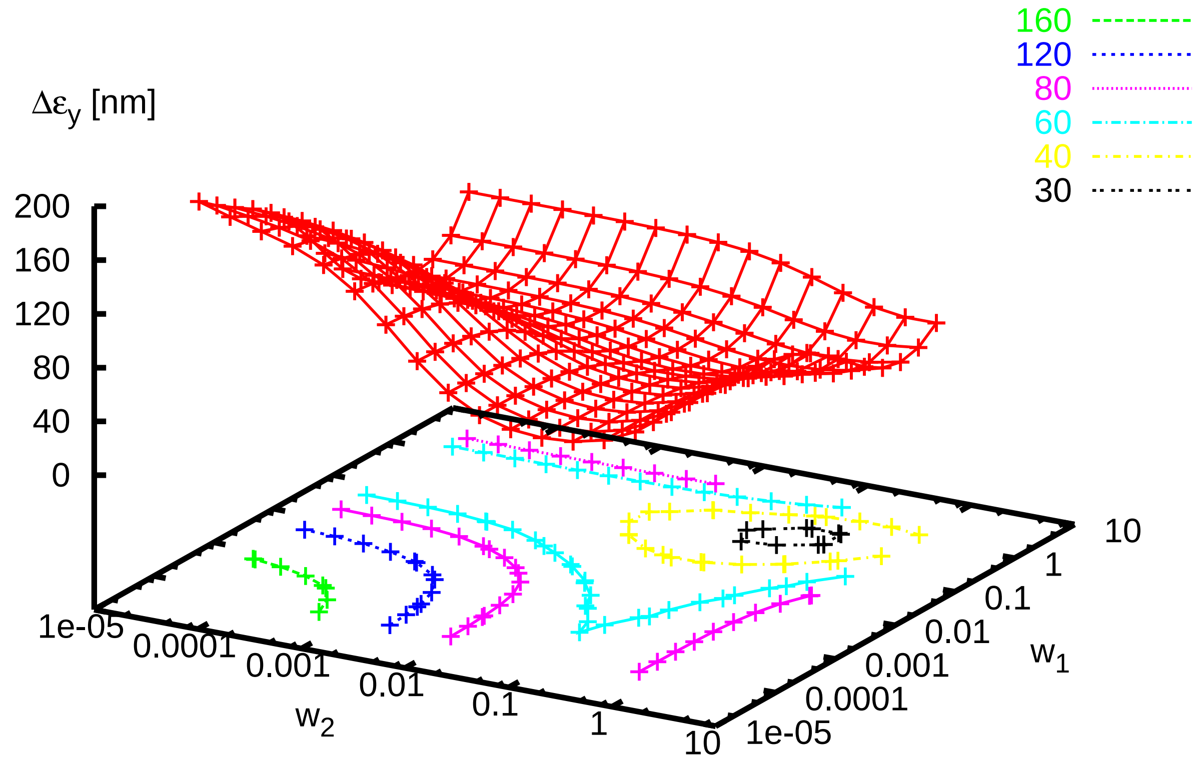
  $\Rightarrow$ can potentially be done in single pulse
- Full TRC misalignment model
- BPM resolutions $\sigma_{res} = 10, 5, 2, 1\,\mu\mathrm{m}$ simulated
- Beam position and angle are fit at start of each bin
- Weights w_1 and w_2 for orbit and corrector strengths are scaned

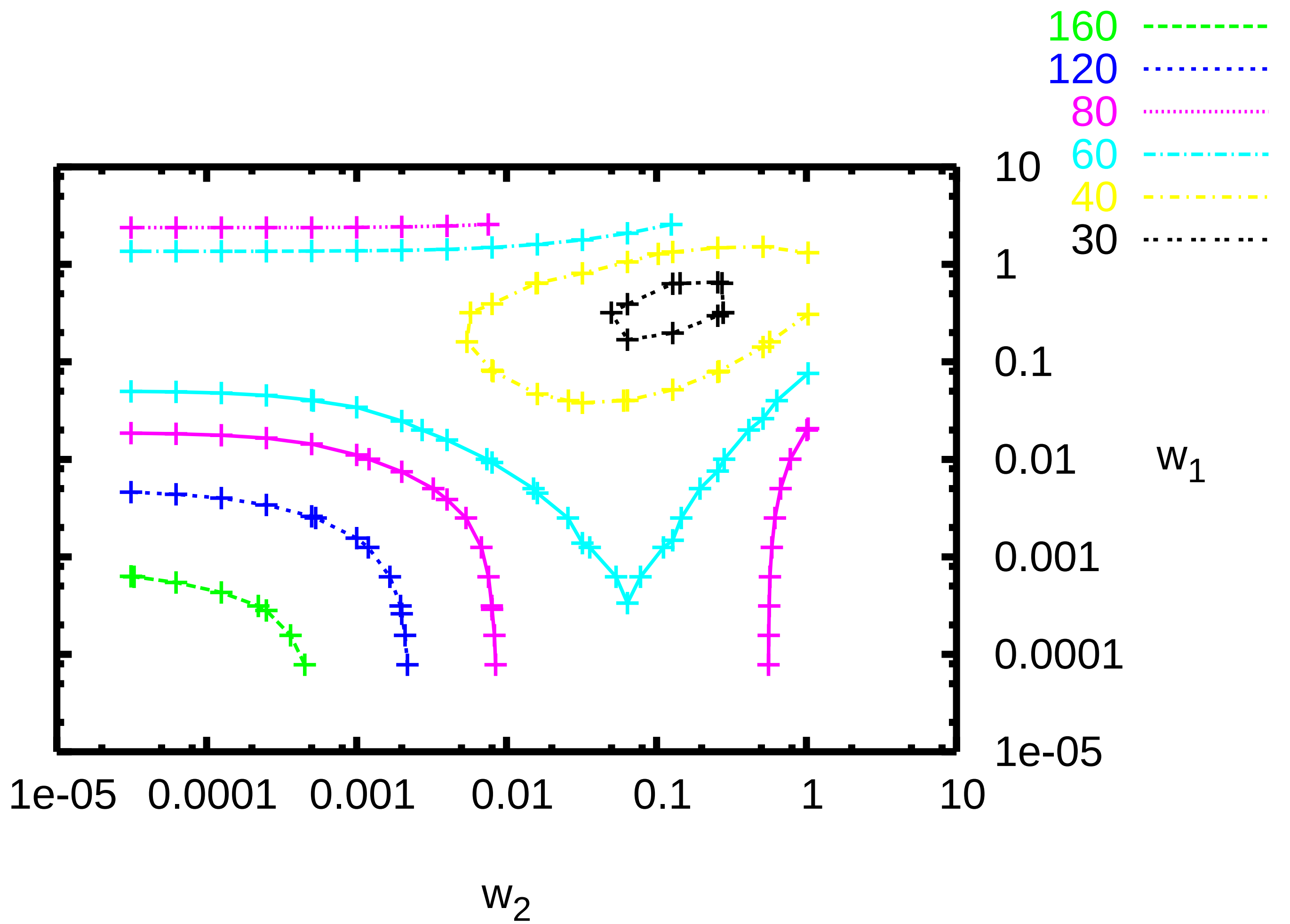
  - assumed constant value along the linac, could be optimised

Results

- BPM resolution $BPM_{res} = 10\,\mu\text{m}$

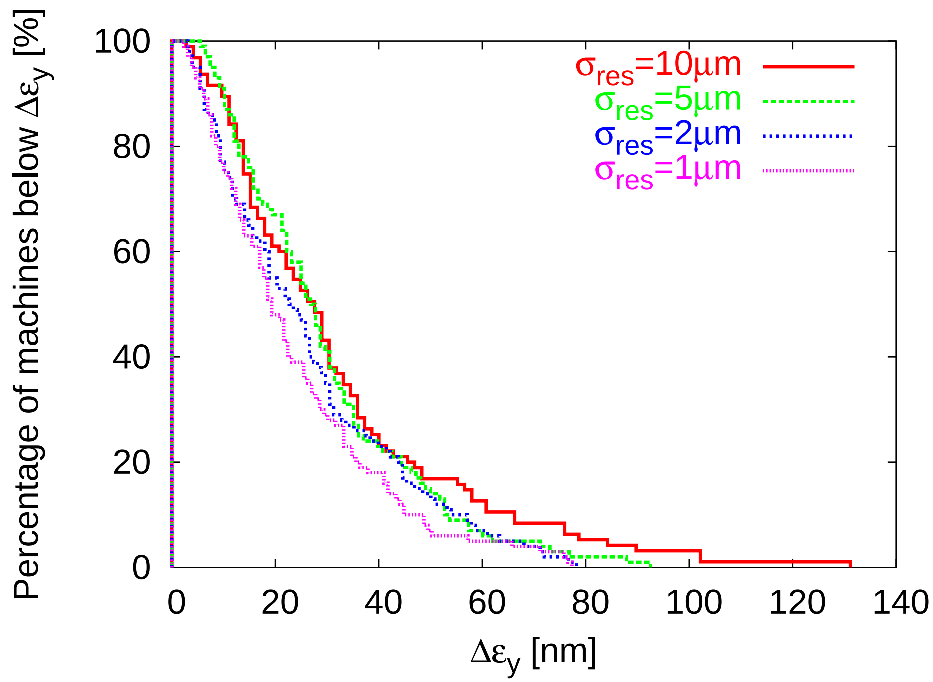
$\Rightarrow$ Target of less than $20\,\text{nm}$ cannot be reached even for average




160
120
80
60
40
30
10
1
0.1
0.01
0.001
0.0001
1e-05
w_1
1e-05
0.0001
0.001
0.01
0.1
1
10
w_2

Better BPM Resolution

- The BPM resolution acts on beam
  - incorrect reconstruction of beam position locally
  - wrong reconstruction of incoming beam offset and angle
- Reconstruction of incoming beam is only necessary if jitter is too large
- One can assume that the error of reconstructing incoming beam is the same as BPM resolution



- Best w_1, w_2 for each case

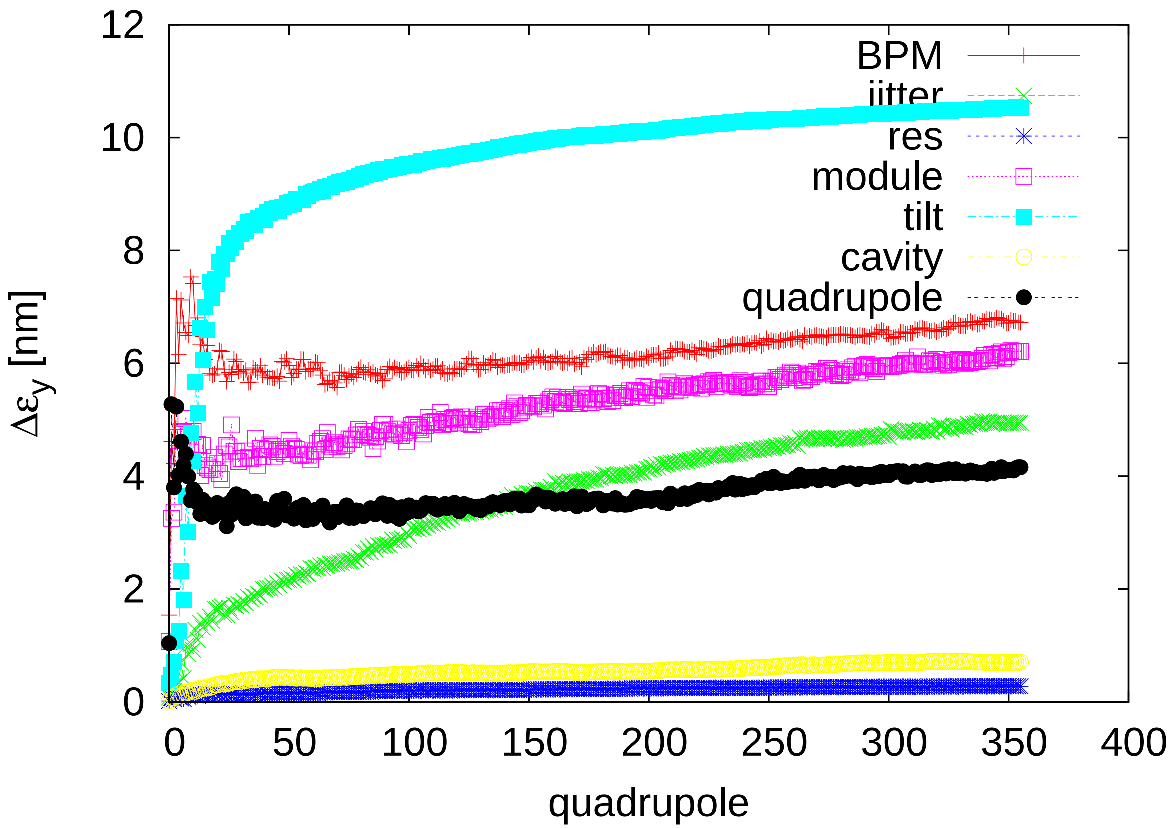
$\Rightarrow$ The impact of the BPM resolution is not very large

Origin of Emittance Growth

- Best w_1, w_2

$\Rightarrow$ Need to improve alignment of first part of main linac

- Initial energy difference
  - but it needs to be define how to do that, e.g. switch off some cavities
- Vary w_1, w_2 along linac



Using Initial Energy Difference

- need to figure out how to do it
- Optimum weights used according to individual scans
- BPM resolution $\sigma_{res} = 10\,\mu\mathrm{m}$ (upper) and $\sigma_{res} = 1\,\mu\mathrm{m}$ (lower table)

$\Rightarrow$ Initial energy difference helps, but

$\Rightarrow$ Even with precise BPMs barely sufficient

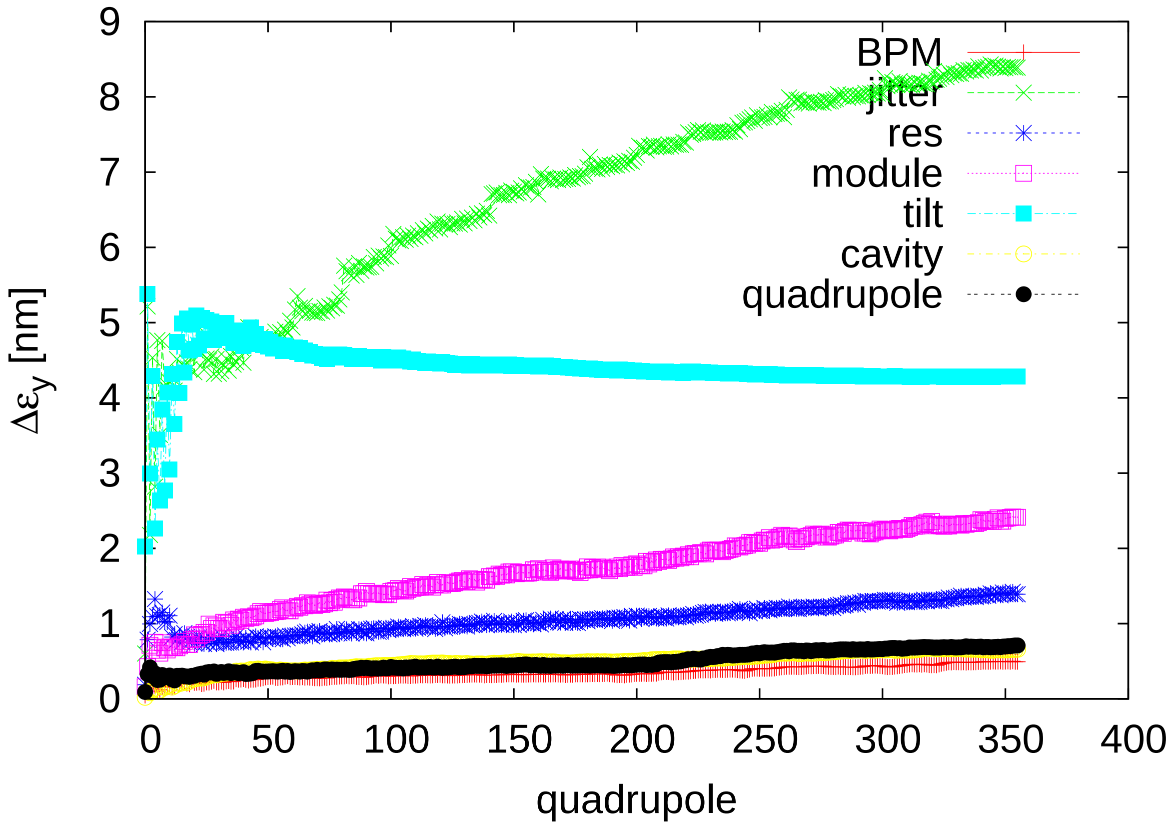
$\Rightarrow$ energy difference below 10% is of little help for $\sigma_{res} = 10\,\mu\mathrm{m}$

$\Delta G_1/G_0$	-0.2	-0.2	-0.2	-0.2
$\Delta G_2/G_0$	0.0	0.0	0.0	-0.1
$\Delta E_1/E_0$	0.0	0.0	0.0	0.0
$\Delta E_2/E_0$	-0.2	-0.1	-0.05	0.0
$\langle\Delta\epsilon_y\rangle$ [nm]	12	15	24	28
$\hat{\Delta\epsilon_y}(90\%)$ [nm]	53	52	69	190

$\Delta G_1/G_0$	-0.2	-0.2	-0.2	-0.2
$\Delta G_2/G_0$	0.0	0.0	0.0	-0.1
$\Delta E_1/E_0$	0.0	0.0	0.0	0.0
$\Delta E_2/E_0$	-0.2	-0.1	-0.05	0.0
$\langle\Delta\epsilon_y\rangle$ [nm]	7	8	14	26
$\hat{\Delta\epsilon_y}(90\%)$ [nm]	24	28	30	120

Emittance Growth

- Case with 20% gradient difference and 10% energy difference is shown
- Relative importance of imperfections very different from case with gradient variation only
- Beam jitter most important via BPM resolution)



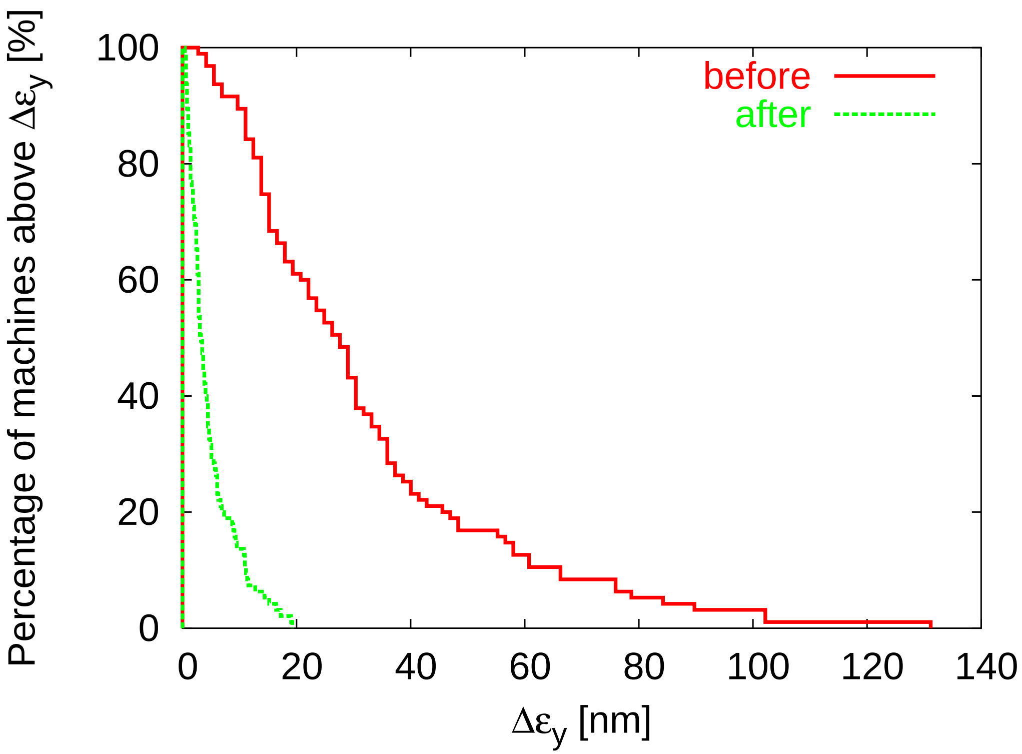
Improvement with Dispersion Bumps

- Simulations performed by Peder Eliasson
- Simple bump model: just add dispersion
- One bump before, one after the linac

  $\Rightarrow$ four degrees of freedom

$\Rightarrow$ Dispersion free steering with gradient differences only is not sufficient

$\Rightarrow$ Emittance growth is acceptable after bump tuning



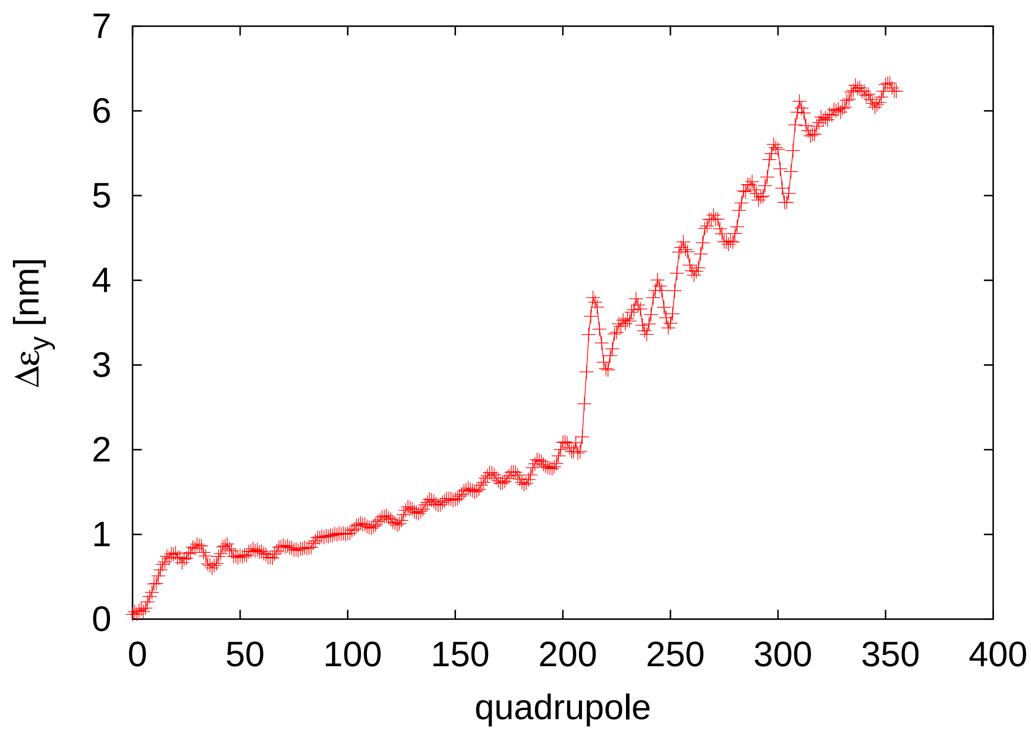
Results for LICAS (Preliminary)

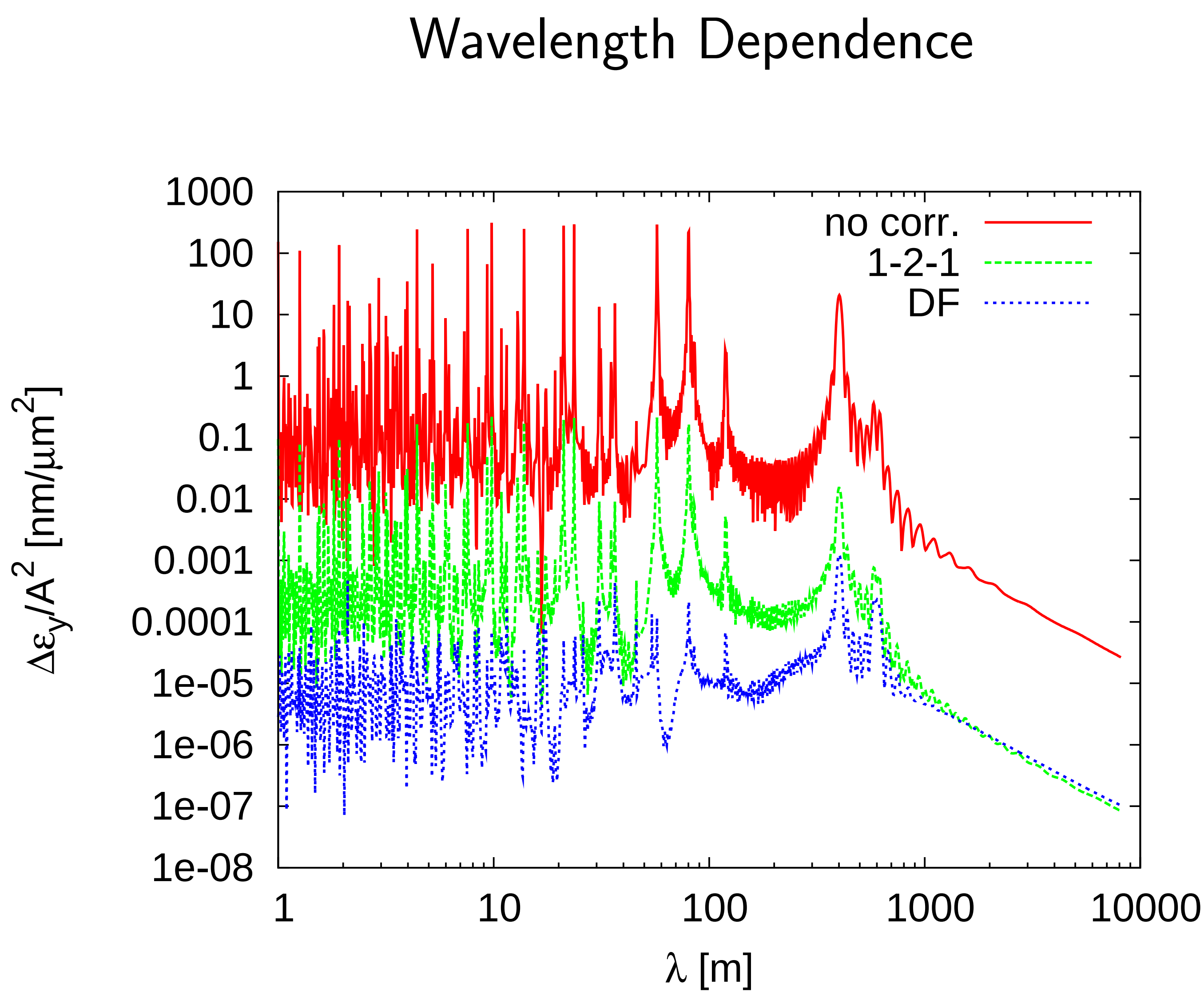
- LICAS model provided by Grzegorz Grzelak, Armin Reichold

  ⇒ interfaced to PLACET

- Only random walk included
- No errors like stakeout etc
- No correction for final point position/reference direction change
- No tuning bumps

⇒ Deserves more detailed investigation





Wavelength Dependence
no corr.
1-2-1
DF
1000
100
10
1
0.1
0.01
0.001
0.0001
1e-05
1e-06
1e-07
1e-08
1
10
100
1000
10000
$\Delta\varepsilon_y/A^2$ [nm/μm^2]
λ [m]

Conclusion

- Using dispersion free steering with different gradients seems not to give satisfactory results
- Adding dispersion tuning bumps seems to solve the problem
- Improvements are possible and need to be studied
- More studies once we converge on a lattice
- LICAS needs to have a close look
- Study of correction with full seperation of tracking and correction started
- Comparison of different alignment methods