Beam Dynamics, Alignment, Stability, Luminosity and Background

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- Strategy for Parameter Choice
- Main Linac Design and Tolerances
- Luminosity and Beam-Beam Effects
- Low Energy Parameter
- Conclusion

Luminosity

Goal is to provide $L_{bx}(f, a, \sigma_a, G)$, $N(f, a, \sigma_a, G)$ and criterium for Δz to Alexej

$$\mathcal{L} = H_D \frac{N^2 f_{rep} n_b}{4\pi\sigma_x\sigma_y}$$

$$\mathcal{L} \propto H_D \frac{N}{\sqrt{\beta_x\epsilon_x}\sqrt{\beta_y\epsilon_y}}\eta P$$

- Efficiency η depends on beam current that can be transported

  $\Rightarrow$ decrease bunch distance $\Rightarrow$ long-range transverse wakefields in main linac

  $\Rightarrow$ increase bunch charge $\Rightarrow$ short-range transverse and longitudinal wakefields in main linac, other effects

- Horizontal beam size σ_x
  beam-beam effects, final focus system, damping ring, bunch compressors

- Vertical beam size σ_y
  need to collide beams, beam delivery system, main linac, beam-beam effects, damping ring, bunch compressor

- Will start at IP and try to explain limitations at new parameter set

Beam Size Limit at IP

- The vertical beam size had been $\sigma_y = 0.7\,\mathrm{nm}$ (BDS)

  $\Rightarrow$ challenging enough, so keep it $\Rightarrow$ $\epsilon_y = 10\,\mathrm{nm}$

- Fundamental limit on horizontal beam size arises from beamstrahlung

Two regimes exist depending on beamstrahlung parameter

$$\Upsilon = \frac{2}{3}\frac{\hbar\omega_c}{E_0} \propto \frac{N\gamma}{(\sigma_x+\sigma_y)\sigma_z}$$

$\Upsilon \ll 1$: classical regime, $\Upsilon \gg 1$: quantum regime

At high energy and high luminosity $\Upsilon \gg 1$

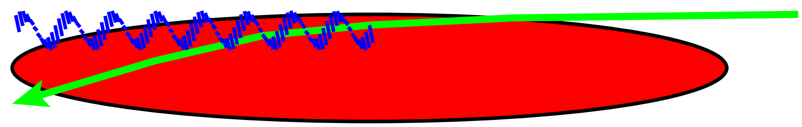
$$\mathcal{L} \propto \Upsilon\sigma_z/\gamma P\eta$$

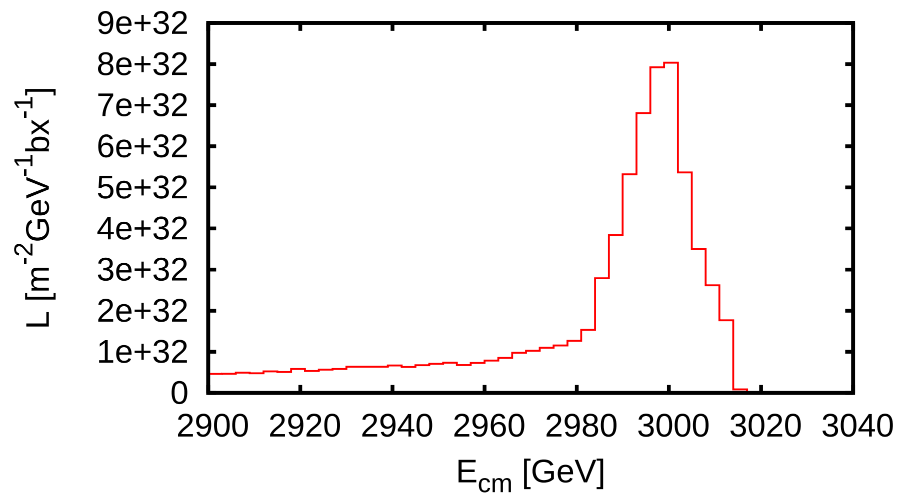
$\Rightarrow$ partial suppression of beamstrahlung

$\Rightarrow$ coherent pair production

In CLIC $\langle\Upsilon\rangle \approx 6$, $N_{coh} \approx 0.1N$

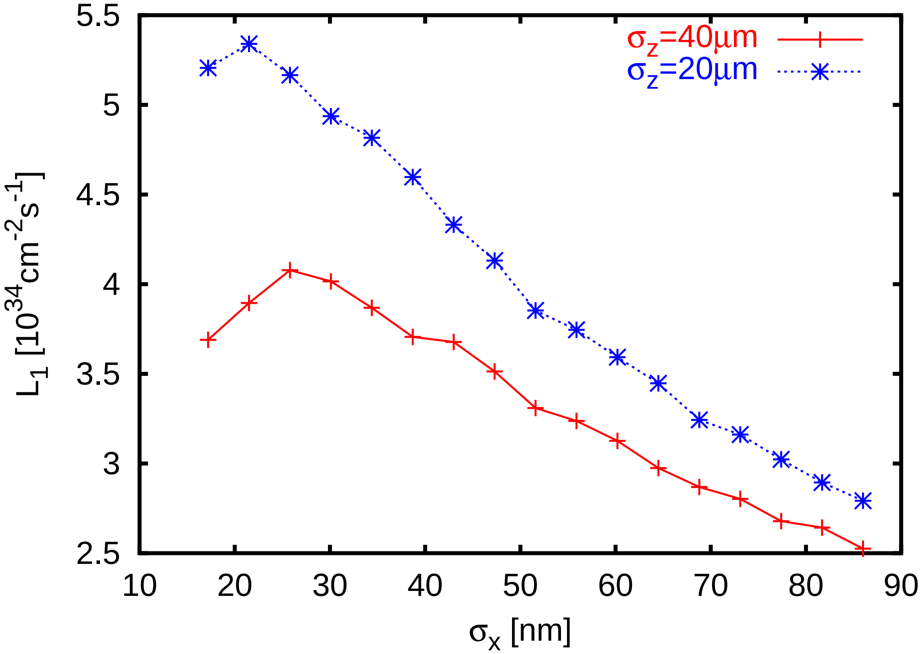
$\Rightarrow$ somewhat in quantum regime

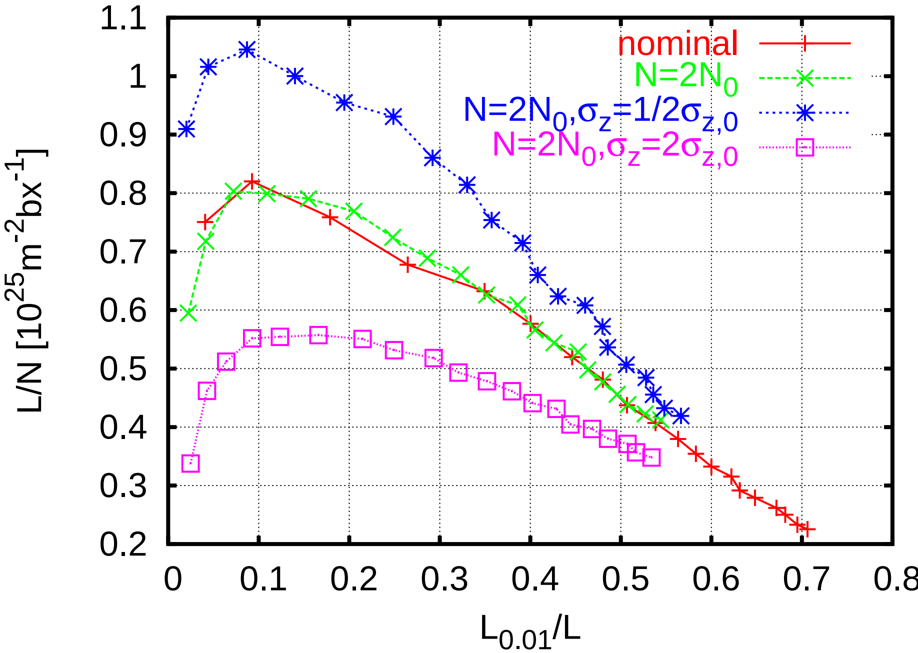




$\Rightarrow$ Use luminosity in peak as figure of merit

Luminosity Optimisation at IP





Total luminosity for $\Upsilon \gg 1$

$$\mathcal{L} \propto \frac{N}{\sigma_x}\frac{\eta}{\sigma_y} \propto \frac{n_\gamma^{3/2}}{\sqrt{\sigma_z}}\frac{\eta}{\sigma_y}$$

large n_γ $\Rightarrow$ higher $\mathcal{L}$ $\Rightarrow$ degraded spectrum

chose n_γ, e.g. maximum $L_{0.01}$ or $L_{0.01}/L = 0.4$ or ...

$$\mathcal{L}_{0.01} \propto \frac{\eta}{\sqrt{\sigma_z}\sigma_y}$$

Other Beam Size Limitations

- Final focus system squeezes beams to small sizes with main problems:
  - beam has energy spread (RMS of $\approx 0.35\%$) $\Rightarrow$ avoid chromaticity
  - synchrotron radiation in bends $\Rightarrow$ use weak bends $\Rightarrow$ long system
  - radiation in final doublet (Oide Effect)
- Large $\beta_{x,y}$ $\Rightarrow$ large nominal beam size
- Small $\beta_{x,y}$ $\Rightarrow$ large distortions
- Beam-beam simulation of nominal case: effective $\sigma_x \approx 60\,\mathrm{nm}$, $\sigma_y \approx 0.7\,\mathrm{nm}$

- even for $\epsilon_x = 0$ one found $\sigma_x \approx 40\,\mathrm{nm}$

$\Rightarrow$ lower limit of σ_x $\Rightarrow$ for small N optimum n_γ cannot be reached

  - new FFS reaches $\sigma_x \approx 40\,\mathrm{nm}$, $\sigma_y \approx 0.7\,\mathrm{nm}$

- Assume that the transverse emittances remain the same
  - not strictly true
  - emittance depends on charge in damping ring (e.g $\epsilon_x(N = 2 \times 10^9) = 450\,\mathrm{nm}$, $\epsilon_x(N = 4 \times 10^9) = 550\,\mathrm{nm}$)

Beam Dynamics Constraints on Optimisation

- The parameter optimisation has been performed keeping the main linac beam dynamics tolerances at the same level as for the original 30 GHz design
- The spot size at the IP is defined by BDS
  - adjusted σ_x for large bunch charges
- For each of the different frequencies and values of a/λ a scan in bunch charge N has been performed
  - the bunch length has been detetermined by requiring the final RMS energy spread to be $\sigma_E/E = 0.035\%$ and running 12° off-crest
  - the transverse wakekick at $2\sigma_z$ has been determined
  - the bunch charge which gave the same kick as the old paramters has been chosen
- The wakefields have been calculated using some formulae from K. Bane
  - used them partly outside range of validity

    $\Rightarrow$ but still a good approximation, confirmed by RF experts

New Luminosity Determination

- For the vertical emittance a budget has been established
  - $\epsilon_y \leq 5\,\mathrm{nm}$ after damping ring extraction
  - $\Delta\epsilon_y \leq 5\,\mathrm{nm}$ during transport to main linac
  - $\Delta\epsilon_y \leq 10\,\mathrm{nm}$ in main linac
- For the horizontal emittance the old design gave
  - $\epsilon_x = 550\,\mathrm{nm}$ after damping ring extraction
  - $\epsilon_x = 660\,\mathrm{nm}$ before the beam delivery system with the growth mainly in the RTML
- The emittance budget
  - includes design, static and dynamic effects
  - requires 90% of the machines to perform better than the target
- The luminosity is calculated
  - using $\epsilon_x \leq 660\,\mathrm{nm}$, $\epsilon_y \leq 20\,\mathrm{nm}$ before the beam delivery system
  - tracking the beam through a perfect beam delivery system ($L^* = 4.3\,\mathrm{m}$, $L^* = 3.5\,\mathrm{m}$ needs optimisation)
  - simulating the beam-beam effects
  - dividing the found luminosity by 1.2

Parameter Adjustment

- For the current structure, the scaling yielded $N = 5.8 \times 10^9$ and $\sigma_z = 75\,\mu\mathrm{m}$
  - this has been a bit high, since small effects were not included in the scaling
- Same difficulty as in old design is reached by $N = 5.2 \times 10^9$ and $\sigma_z = 65\,\mu\mathrm{m}$
- Emittance target has been to achieve $\epsilon_{y,0} \leq 5\,\mathrm{nm}$ and $\Delta\epsilon_y \leq 2.5\,\mathrm{nm}$ (90% probability) from static effects
  - has been relaxed to $\epsilon_{y,0} \leq 10\,\mathrm{nm}$ and $\Delta\epsilon_y \leq 5\,\mathrm{nm}$
- Charge has been reduced to $N = 4 \times 10^9$ rather than $\sigma_x = 80\,\mathrm{nm}$
- Simulations are still for more agressive parameter set $N = 5.2 \times 10^9$ and aiming at lower emittance

N 10^9	σ_z [$\mu\mathrm{m}$]	σ_x [nm]	$\epsilon_{y,f}$ [nm]	rel. wake NLC	rel. wake CLIC0	L_1 [$10^{34}\,\mathrm{m}^{-2}\mathrm{bx}^{-1}$]	L_1 [$10^{34}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$]
5.2	65	40	10	2.8	1.0	2.5	4.0
5.2	65	80	10	2.8	1.0	2.0	3.0
4.0	44	40	10	1.5	0.5	2.1	3.2
4.0	44	40	20	1.5	0.5	1.3	2.0

Wakefield Effects

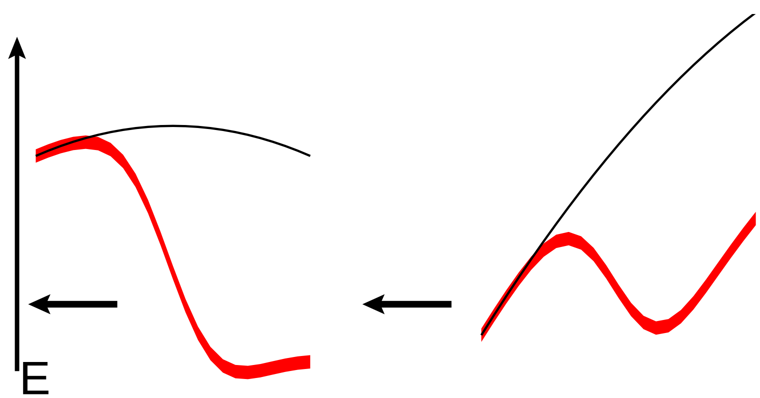
- Emittance growth scales as

$$\Delta\epsilon_y \propto (W_\perp \sigma_z)^2 (\Delta y)^2 L_{typical} 1/G$$

  $\Rightarrow$ aim for shortest possible bunch

- Energy spread into the beam delivery system should be limited to about 1% full width or 0.35% rms
- Multi-bunch beam loading compensated by RF
- Single bunch longitudinal wakefield needs to be compensated

  $\Rightarrow$ accelerate off-crest

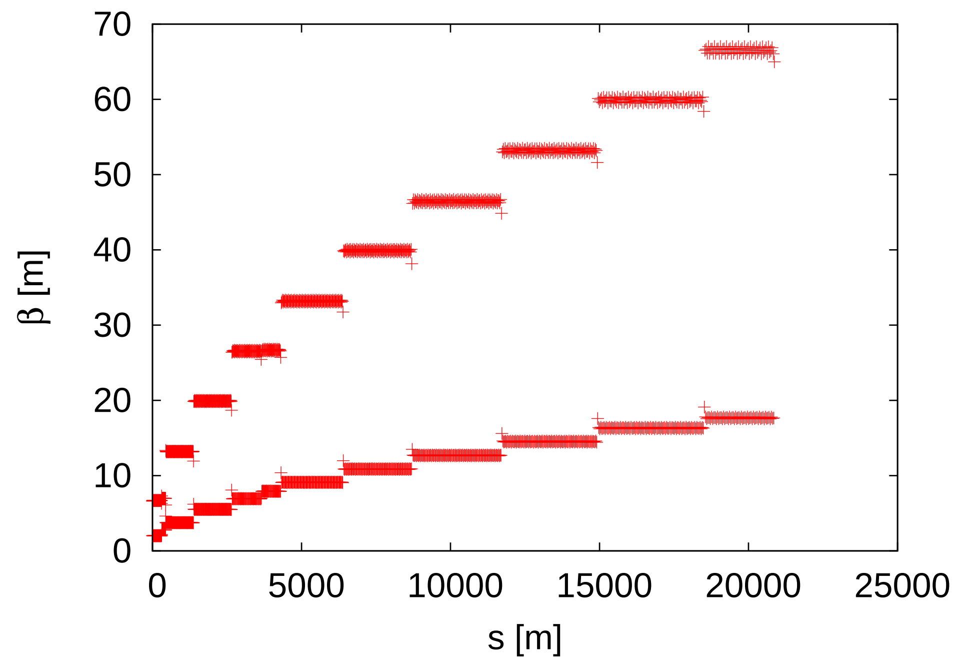


- Limit around average $\Delta\Phi \leq 12^\circ$

  $\Rightarrow \sigma_z = 65\,\mu\mathrm{m}$ for $N = 5.2 \times 10$

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 $N = 5.2 \times 10^9$
  - quadrupole dimensions need to be confirmed
  - some optimisations remain to be done
- Total length 20867.6m
  - fill factor 78.6%

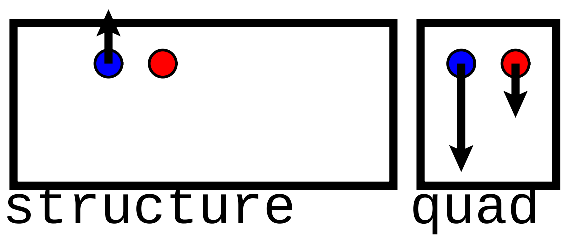


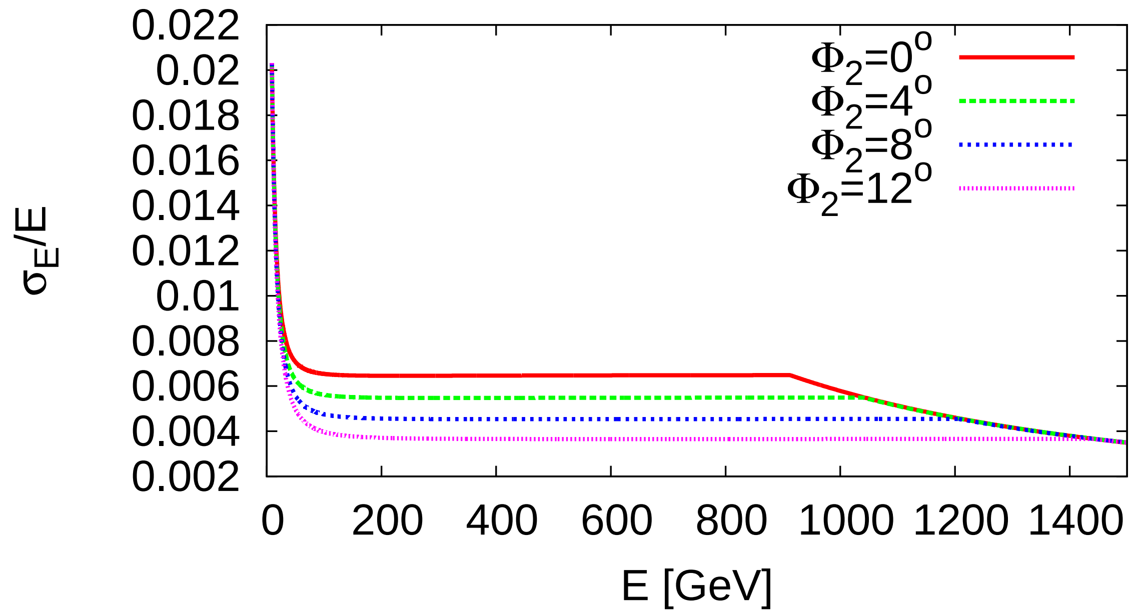
- 12 different sectors used
- Matching between sectors using 5 quadrupoles to allow for some energy bandwidth

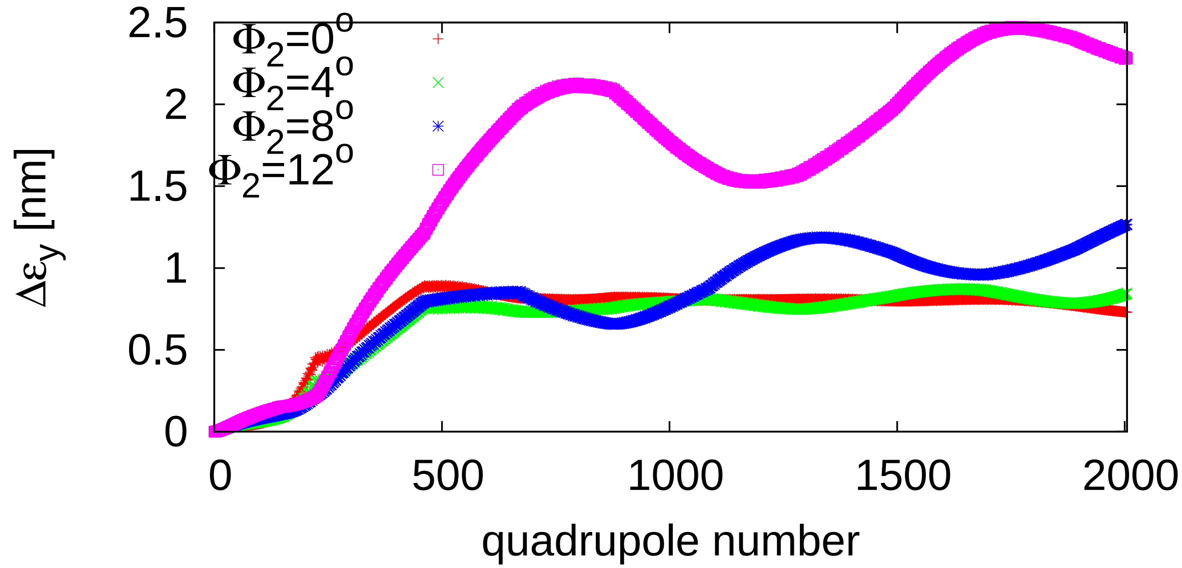
Energy Spread and Beam Stability

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

$\Rightarrow$ Beam with $N = 5.2 \times 10^9$ can be stable







Single Bunch Dynamic Tolerances

- For jitters assumed no correction

$\Rightarrow$ multi-pulse emittance is important

- Value is given for 0.1 nm emittance growth

  - quadrupole position: $0.8\,\mathrm{nm}$

  - structure position: $0.7\,\mu\mathrm{m}$

  - structure angle: $0.55\,\mu\mathrm{radian}$

$\Rightarrow$ Tolerances are very tight

  - in particular for quadrupole

- ATL-model 1.2 nm for $10^5\,\mathrm{s}$ with $A = 0.5 \times 10^{-6}\,\mu\mathrm{m}^2\mathrm{s}^{-1}\mathrm{m}^{-1}$ using one-to-one steering

$\Rightarrow$ tuning bumps are needed

  - for three bumps $0.45\,\mathrm{nm}$, for seven $0.25\,\mathrm{nm}$

$\Rightarrow$ realignment every few days

Error Sources

- Most important are
  - BPM position errors
  - BPM resolution
  - structure to beam misalignment
  - quadrupole roll
- BPM position errors and resolution determine the final dispersion left in the beam
- Structure offsets determine the final wakefield effect in the beam
  - if the wakefields are identical in two consecutive structures, the mean offsets is important
  - if wakefields are different, scattering of structures around mean value matters
    - should not matter for short-range wakefields
    - could matter for long-range wakefields

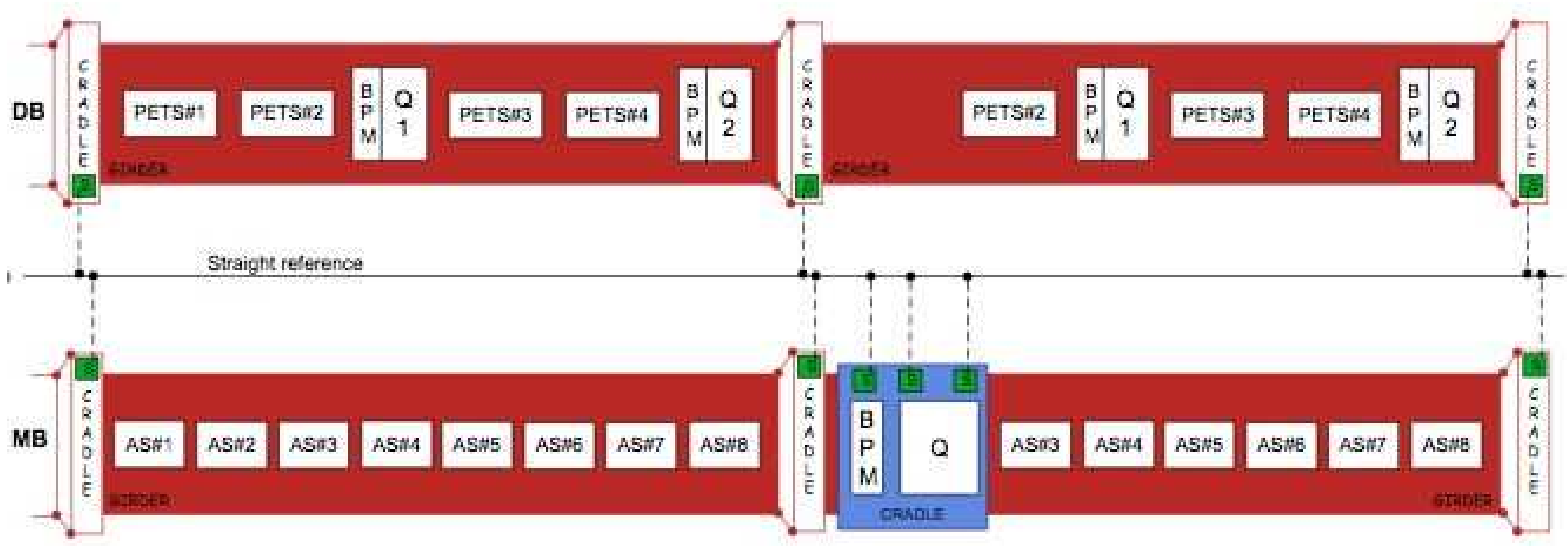
Main Linac Tolerances

Element	error	with respect to	tolerance CLIC	tolerance NLC
Structure	offset	beam	$4.3(5.8)\ \mu$m	$5.0\ \mu$m
Structure	tilt	beam	$220\ \mu$radian	$135\ \mu$radian
Quadrupole	offset	straight line	—	—
Quadrupole	roll	axis	$240(240)\ \mu$m	$280\ \mu$radian
BPM	offset	straight line	$0.4(0.44)\ \mu$m	$1.3\ \mu$m
BPM	resolution	BPM center	$0.4(0.44)\ \mu$m	$1.3\ \mu$m
Art. point	offset	straight line	$1.7(3)\ \mu$m	
End point	offset	Art. point	$2.0(3.8)\ \mu$m	

- All tolerances for 1nm growth after one-to-one steering
- CLIC emittance budget is two times smaller than for NLC

  $\Rightarrow$ divide tolerances by $\sqrt{2}$
- In brackets values for $N = 4 \times 10^9$
- Using DFS relaxes BPM position but constrains BPM resolution (example case 57 μm and 0.18 μm)
- Bumps help

Misalignment Model: Module



- Sensors connect beam line to reference system
- Excellent prealignment of elements on the girders

(G. Riddone, module working group)

Pre-Alignment Performance

PRE-ALIGNMENT

Ref.	1	Inherent accuracy of reference	10 μm	1σ
Ref. to cradle	2	Sensor accuracy and electronics (reading error, noise,..)	5 μm	1σ
	3	Link sensor/cradle (supporting plates, interchangeability)	5 μm	1σ
Cradle to girder	4	Link cradle/girder	5 μm	1σ
Girder to AS	5a 5b	Link girder/acc. structure Inherent precision of structure	5 μm	1σ
		TOTAL Tolerance	14 μm 40 μm	1σ 3σ

BEAM-BASED ALIGNMENT
6) relative position of structure and BPM reading 5 μm 1σ

5

(H. Mainaud Durand)

PRE-ALIGNMENT

Ref.	1	Inherent accuracy of reference	10 μm	1σ
Ref. to cradle	2	Sensor accuracy and electronics (reading error, noise,..)	5 μm	1σ
	3	Link sensor/cradle (supporting plates, interchangeability)	5 μm	1σ
Cradle to Q	7a	Link cradle/quadrupole	5 μm	1σ
	7b	Inherent precision of quadrupole	10 μm	1σ
		TOTAL Tolerance	17 μm 50 μm	1σ 3σ

PRE-ALIGNMENT

Ref.	1	Inherent accuracy of reference	10 μm	1σ
Ref. to cradle	2	Sensor accuracy and electronics (reading error, noise,..)	5 μm	1σ
	3	Link sensor/cradle (supporting plates, interchangeability)	5 μm	1σ
Cradle to BPM	8a	Link cradle/quadrupole BPM axis	5 μm	1σ
BPM	8b	Inherent precision of quadrupole BPM axis	5 μm	1σ
		TOTAL Tolerance	14 μm 40 μm	1σ 3σ

BEAM-BASED ALIGNMENT:
8c) relative position of quadrupole and BPM reading 10 μm 1σ

Assumed Alignment Performance

Element	error	with respect to	alignment NLC	alignment CLIC
Structure	offset	girder	$25\,\mu$m	$5\,\mu$m
Structure	tilts	girder	$33\,\mu$radian	?(cost)
Girder	offset	survey line	$50\,\mu$m	$9.4\,\mu$m
Girder	tilt	survey line	$15\,\mu$radian	$9.4\,\mu$radian
Quadrupole	offset	survey line	$50\,\mu$m	$17\,\mu$m
Quadrupole	roll	survey line	$300\,\mu$radian	$\leq 100\,\mu$radian
BPM	offset	quadrupole/survey line	$100\,\mu$m	$14\,\mu$m
BPM	resolution	BPM center	$0.3\,\mu$m	$0.1\,\mu$m
Structure BPM	offset	wake center	$5\,\mu$m	$5\,\mu$m

- In NLC quadrupoles contained the BPMs, they are seperate for us
- In FFTB very good alignment has been observed over some distance

$\Rightarrow$ Importance of wakefields will be larger in CLIC

$\Rightarrow$ Importance of BPM misalignments will be comparable in CLIC

$\Rightarrow$ Importance of BPM resolution will be larger in CLIC

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
- Remove wakefield effects
  - accelerating structure alignment
  - emittance tuning bumps

\- Tune luminosity

  - tuning knobs

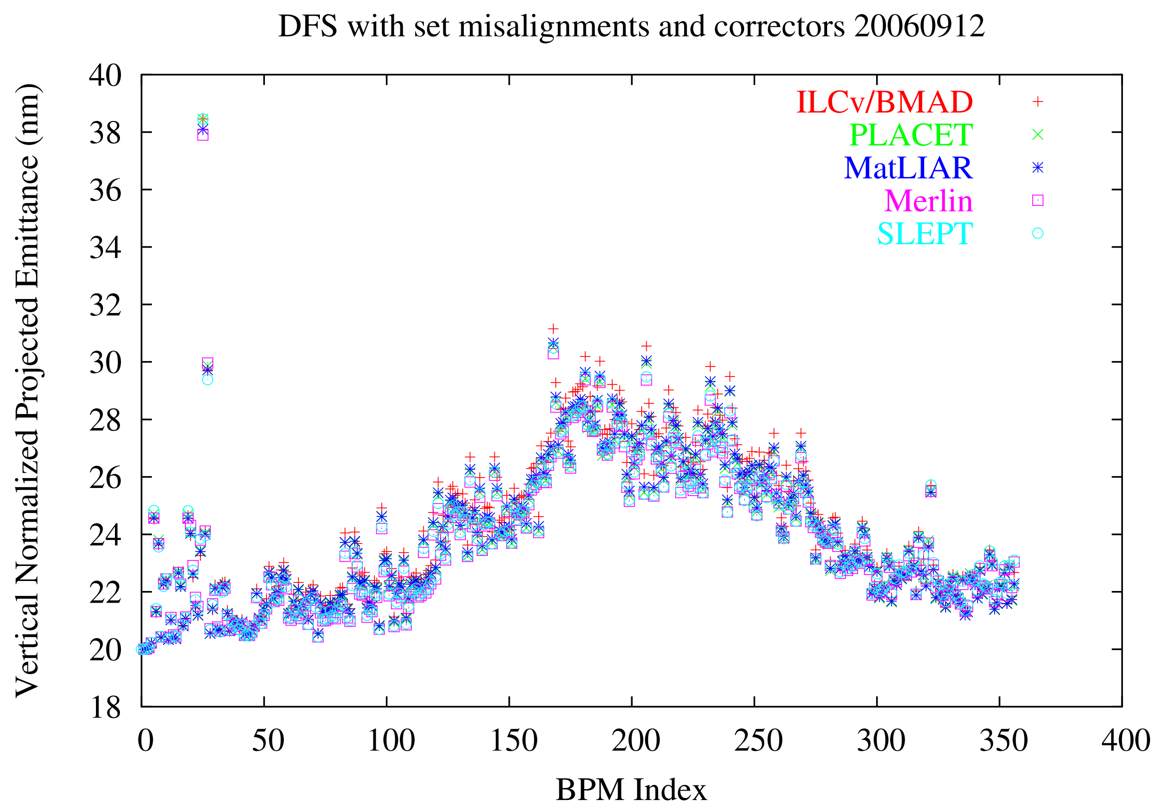
- currently noise during correction is being studied (e.g. beam or quadrupole jitter)

Simulation Procedure and Benchmarking

- All simulation studies are performed with PLACET
  - based on 100 different machines
- Benchmarking of tracking codes is essential
- Comparisons performed in ILC framework
  - tracking with errors
  - alignment methods

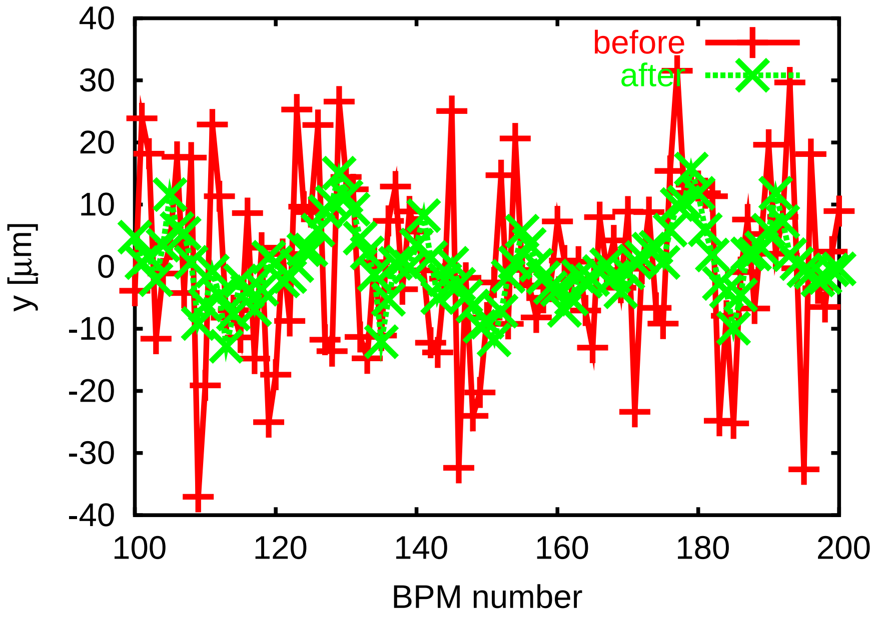
  ⇒ agreement is very good

(J. Smith, ILC friends)



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



- 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

Beam-Based Structure Alignment

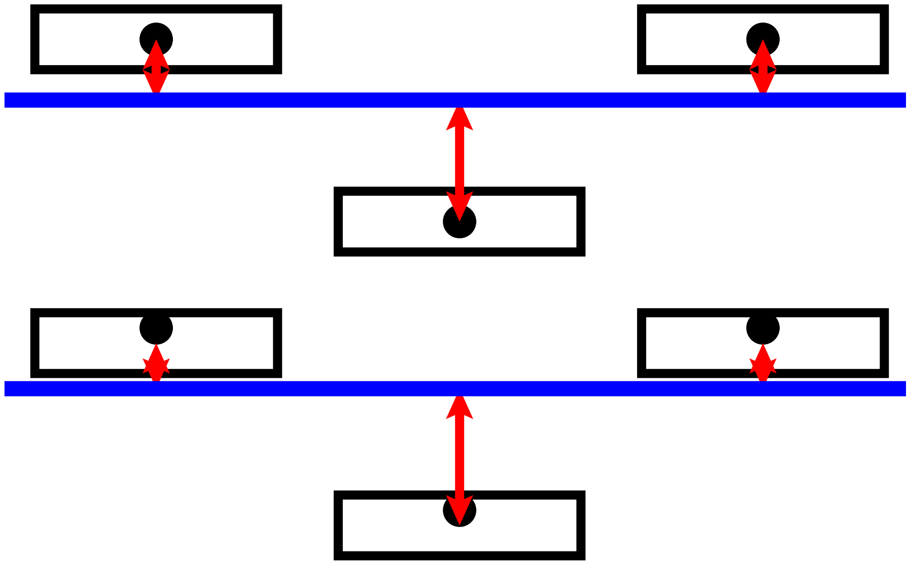
- Each structure is equipped with a BPM (RMS position error $5\,\mu\mathrm{m}$)
- Up to eight structures are mounted on movable girders

$\Rightarrow$ Align structures to the beam

- In the current simulation each structure is moved independently
- A study had been performed to move the articulation points

  $\Rightarrow$ negligible additional effect if additional articulation point exists at quadrupoles

- For wakes that are identical in each structure
  - relevant is error of structure BPM to structure centre
- For wakes that differ from structure-to-structure
  - relevant is structure to beam offset

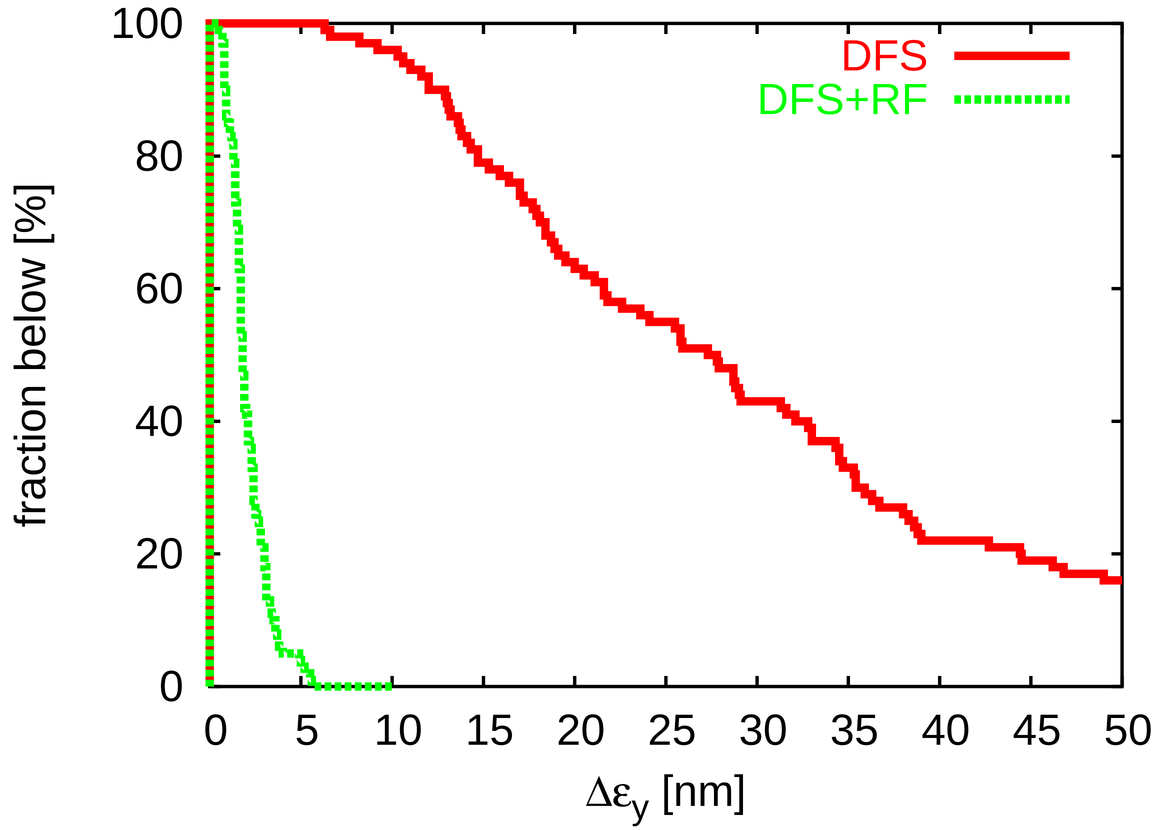


- Tolerance and performance prediction are similar for CLIC and NLC
  - $4.3(5.8)\,\mu\mathrm{m}/\sqrt{2}$ vs. $5\,\mu\mathrm{m}$
  - $5\,\mu\mathrm{m}$ vs. $5\,\mu\mathrm{m}$

DFS Results

⇒ With RF alignment we can have more then 90% of the machines below 5nm

⇒ But not much margin



Tuning Bumps

- Tuning bumps will be used to reduce the wakefield effects

  the beam accumulates wakefield kicks as

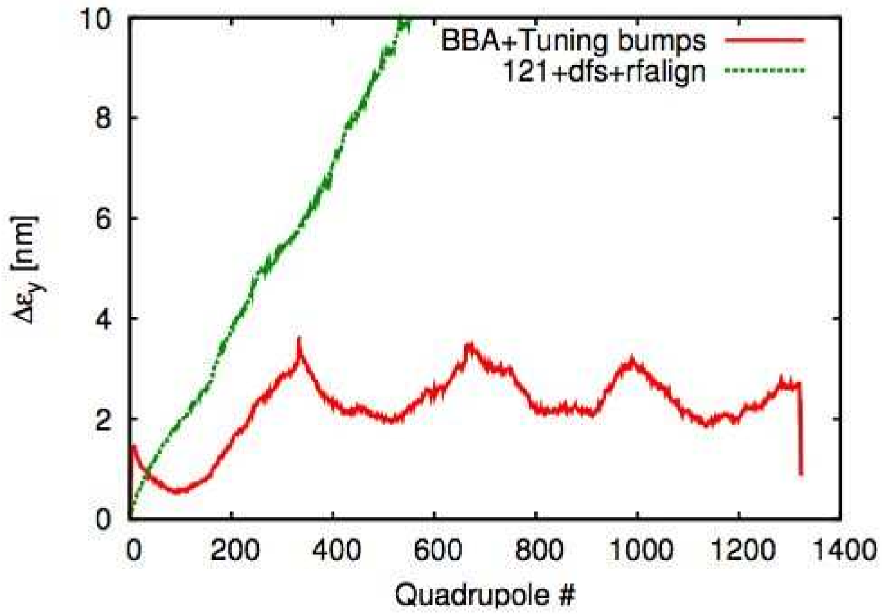
$$F(z) = w_{\perp}(z) \sum_{i=1}^{n} A_i y_i$$

  the bump is used to zero the sum

$$F'(z) = w_{\perp}(z) \left(\sum_{i=1}^{n} A_i y_i + A_j \Delta y_j \right)$$

  Residual remains

  - energy spread in the beam (slight z-dependence of A)
  - imperfect measurement/correction



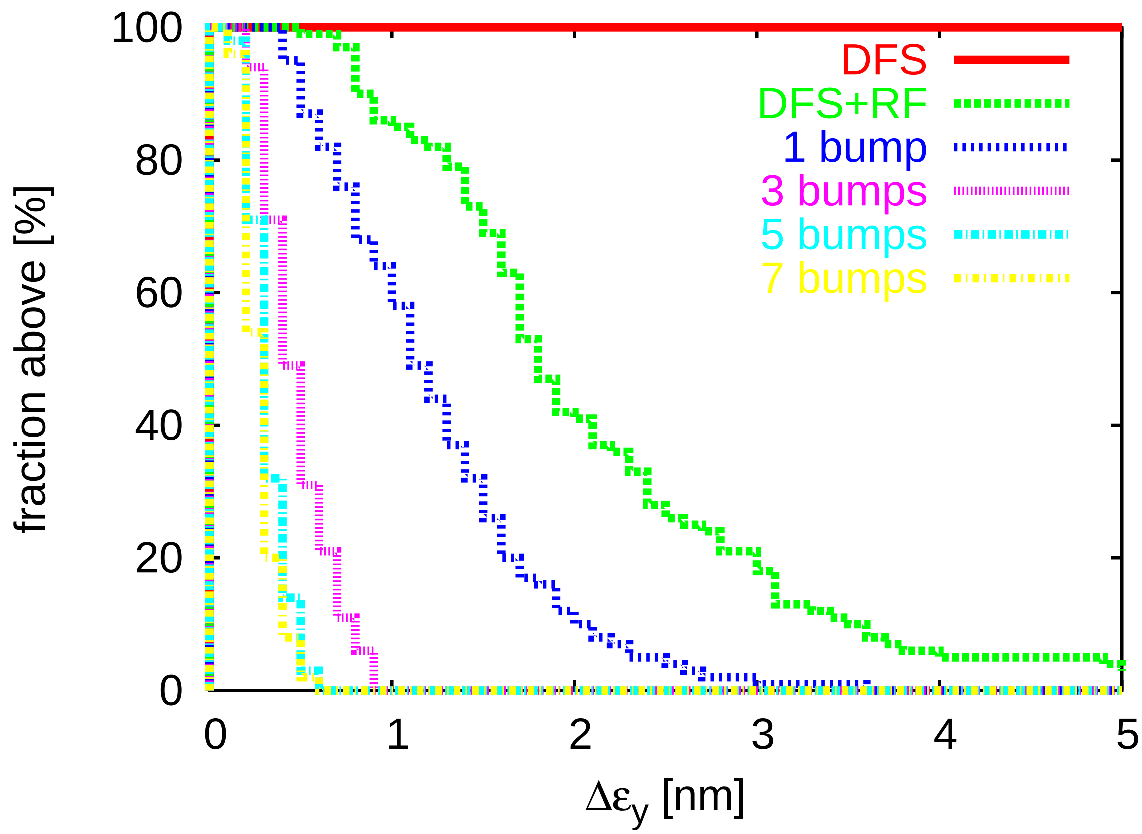
- Bumps are simulated by moving a single structure transversely
  - previous studies showed that this is a good enough model (P. Eliasson, D.S.)

Results for DFS and Bumps

- Simulation includes all misalignments but quadrupole roll
- Weigths for correction are optimised for best overall performance
- After RF alignment performance is marginally acceptable
- Already a single bump (two degrees of freedom) yields significant improvement
  - but we would use 3 or 5

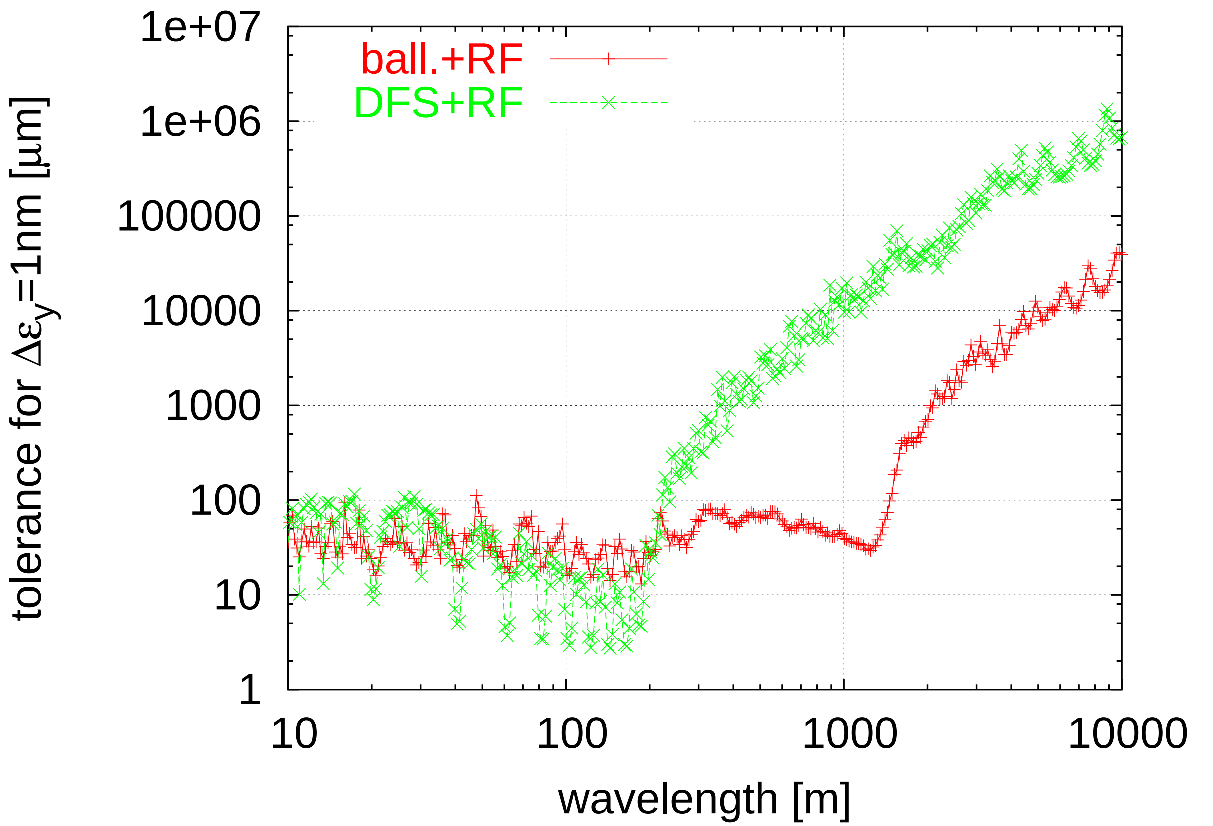
$\Rightarrow$ Need to optimise taking into account time for convergence

- Final average emittance in nm (bumps): 2.0 (0), 1.1 (1), 0.4 (3), 0.2 (5), 0.15 (7)



Long Distance Alignment

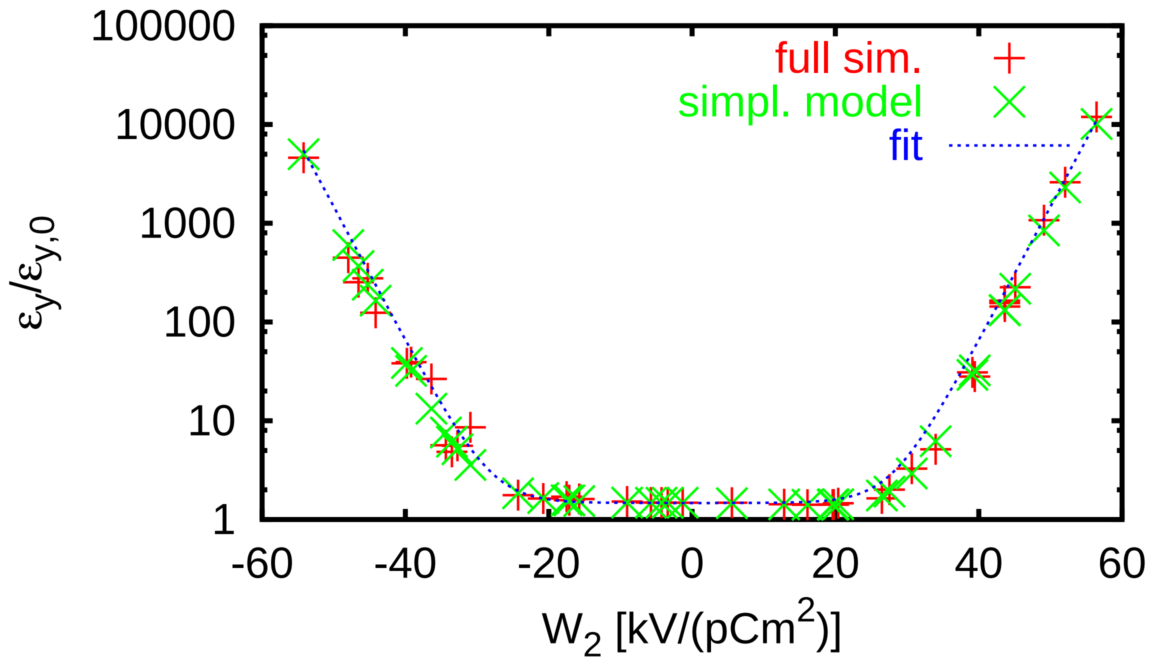
- Beam line elements are more difficult to align over long distances
  - we are investigating the alignment performance for this case
  - testing good material for long distance wires
- Simulation results to illustrate the point



⇒ The alignment tolerance depends on the correction method

Multi-Bunch Effects

- Efficiency also depends on bunch spacing
  - shorter bunch spacing improves efficiency
- Exponential additional emittance growth as function of long-range wakefield
- Small below $20\mathrm{kV}/(\mathrm{pCm}^2)$ for $N = 4 \times 10^9$



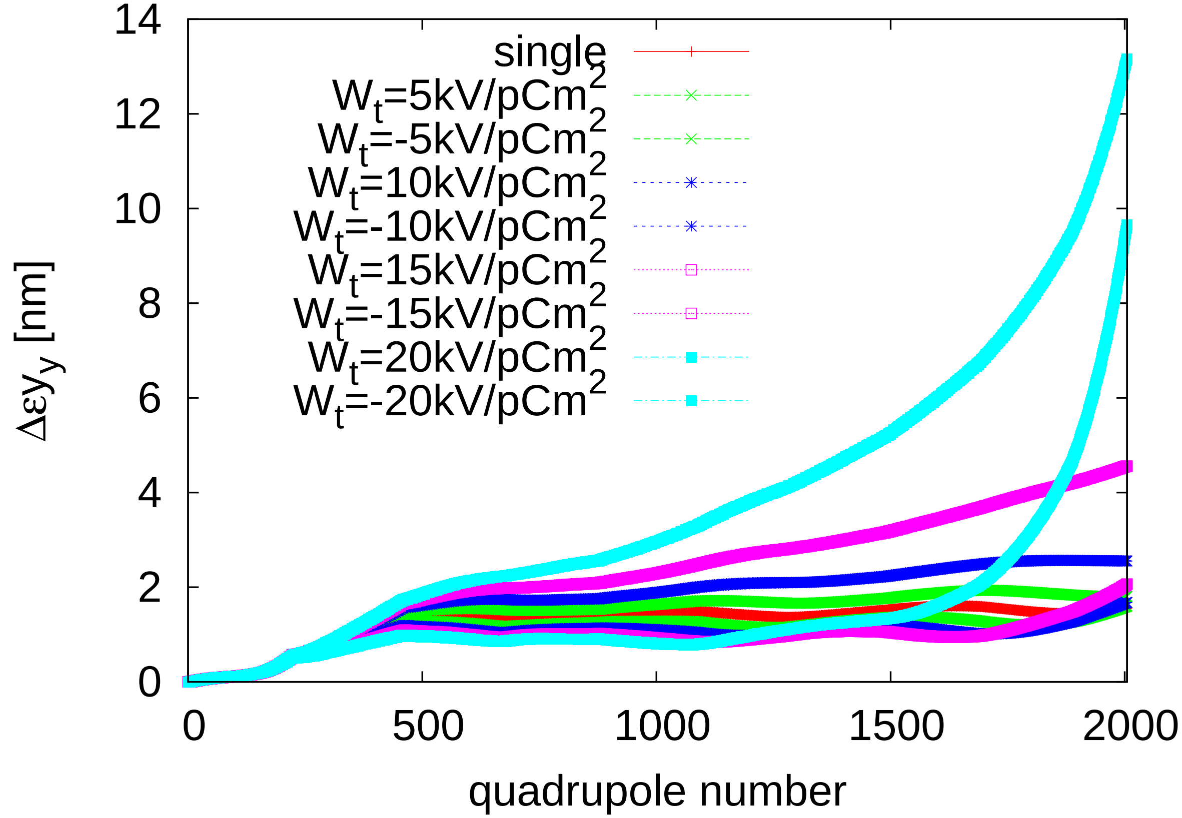
- Example for old parameters

$\Rightarrow$ require $W_\perp < 10\mathrm{kV}/(\mathrm{pCm}^2)\frac{4 \times 10^9}{\mathrm{N}}\frac{\mathrm{G}}{150\,\mathrm{MV/m}}$

CLIC Longrange Wakefields

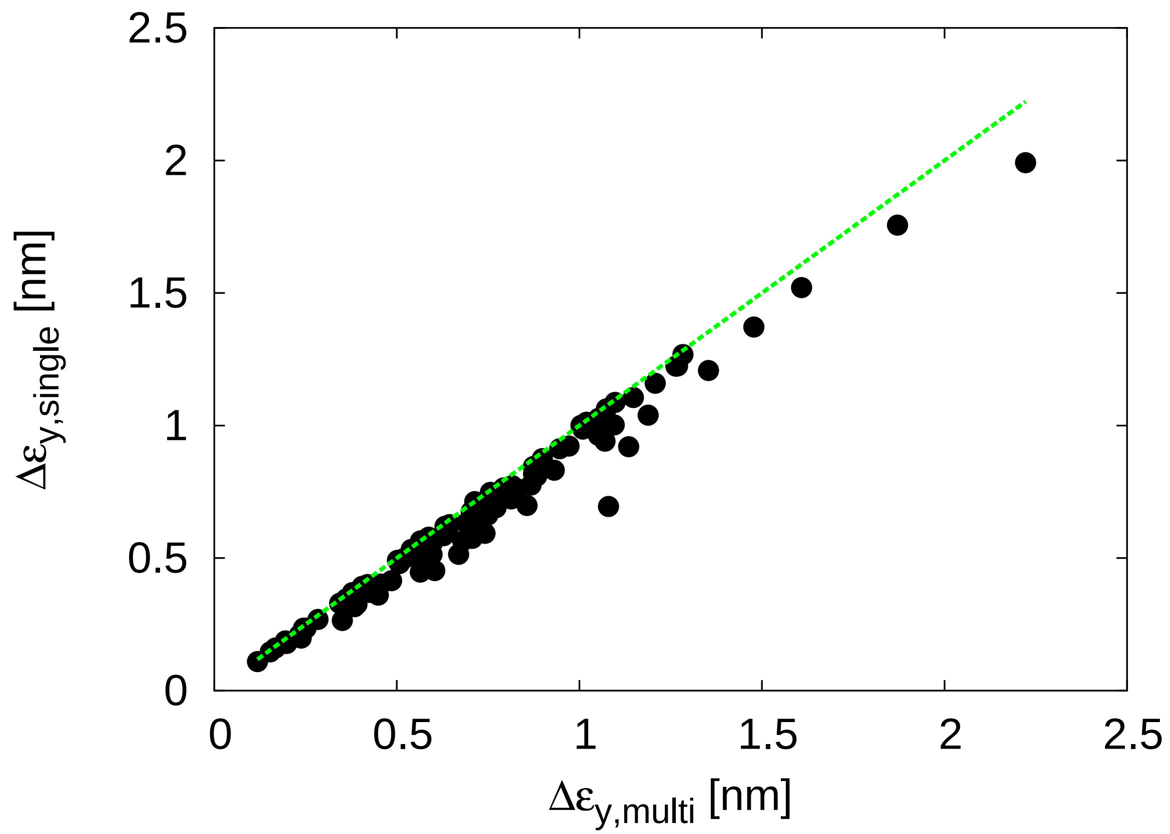
- Long-range wakefields are important
- Simulation of emittance growth due to beam jitter
  - no energy spread (pessimistic)
- Allowed wakefield envelope at second bunch is $\approx 4.5\,\mathrm{kV/pCm^2}$

$\Rightarrow$ seems acceptable



Beam-Based Correction

- Ballistic alignment with ten local tuning bumps
  - one-to-one steering and reoptimisation of tuning bumps for the multi-bunch case
- Comparison of single and multi-bunch is shown



⇒ Need more study of static long-range effects

- current bumps cure long and short range wakes at the same time
- realistic wakefield variations from structure to structure
- could use longrange bumps (train straightener)

Hardware Requirements and Status

- Structure BPM error of $2\,\mu\mathrm{m}$ has been achieved at SLAC
  - but for different structure design
  - we still need to demonstrate this for our design
- BPM resolution 40 nm has been achieved
  - 100 nm with different technology will be demonstrated in EUROTeV

  $\Rightarrow$ depends on outcome of that study, likely some follow up (long-term stability etc.)
- Quadrupole jitter of $0.8\,\mathrm{nm}$ has been achieved
  - but not in accelerator
  - and only using a costly suppport
  - in FFTB $2\,\mathrm{nm}$ with respect to ground have been achieved

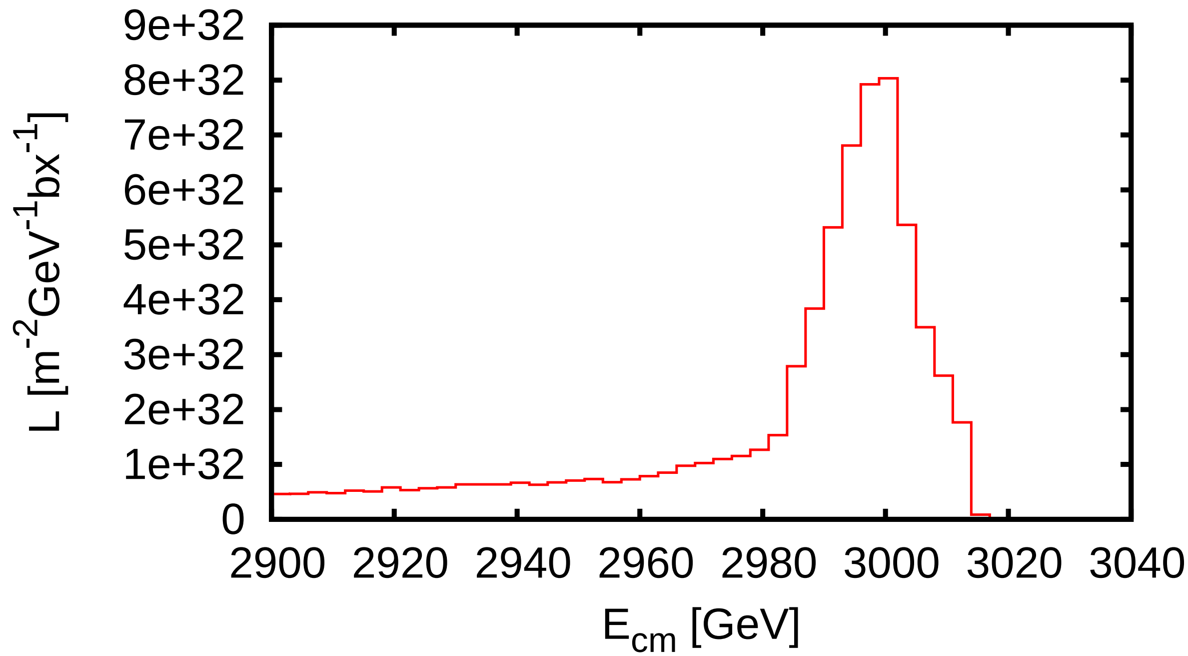
  $\Rightarrow$ more work is critical

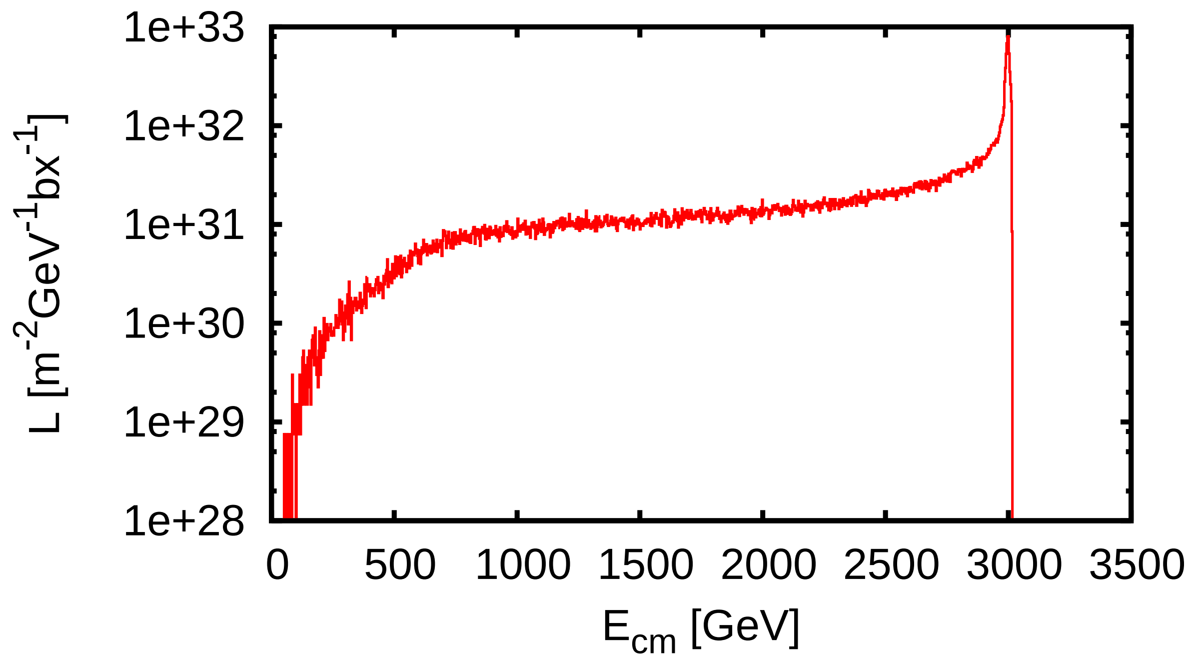
  $\Rightarrow$ tolerance for the final doublet is even tighter
- (BPM) alignment of 10 $\mu\mathrm{m}$ is expected to be achieved in LHC
  - needs verification and further improvements
  - alignment over longer distances are critical

Luminosity Spectrum

- Peak luminosity $2 \times 10^{34}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$
- Total luminosity $7 \times 10^{34}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$
- Peak width is 1%
  - from initial beam energy spread
- Discussion with J. Ellis and A. Deroeck:

  ⇒ The luminosity spectrum is acceptable



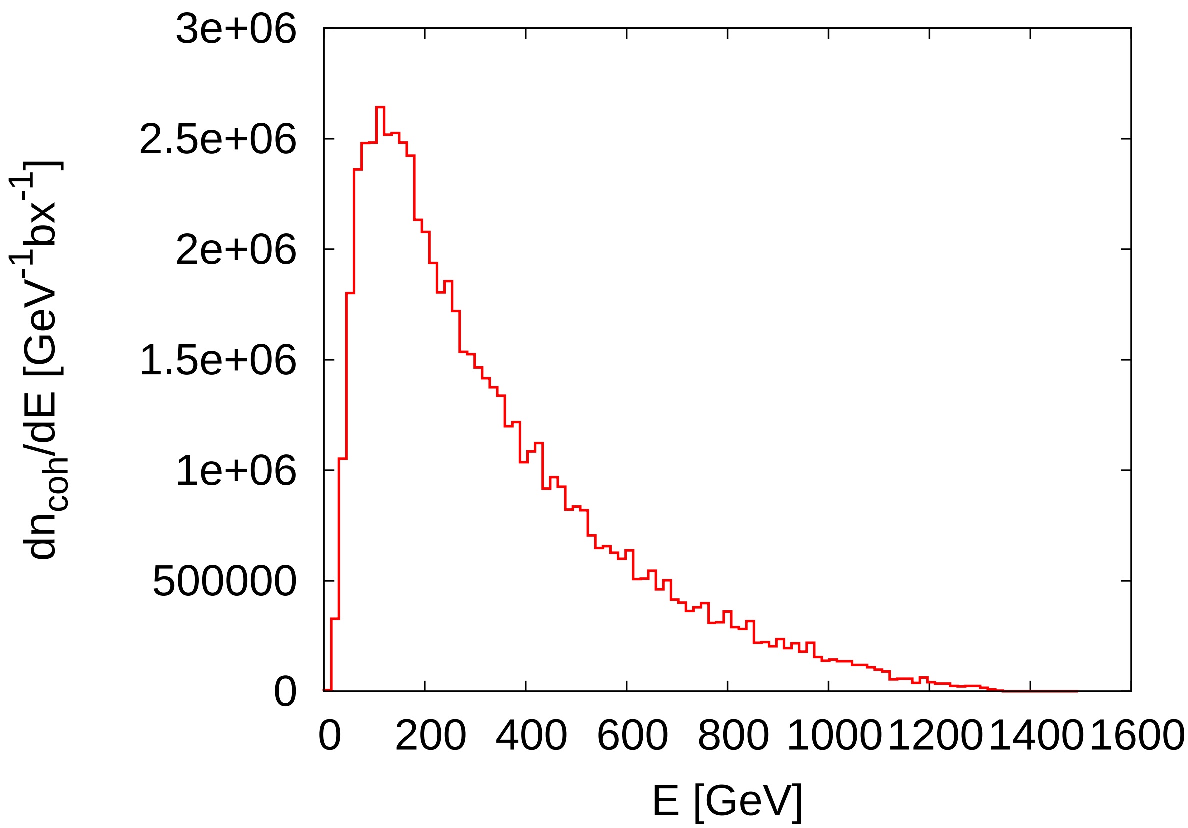


Coherent Pairs

- Coherent pairs are generated by a photon in a strong electro-magnetic field
- Cross section depends exponentially on the field

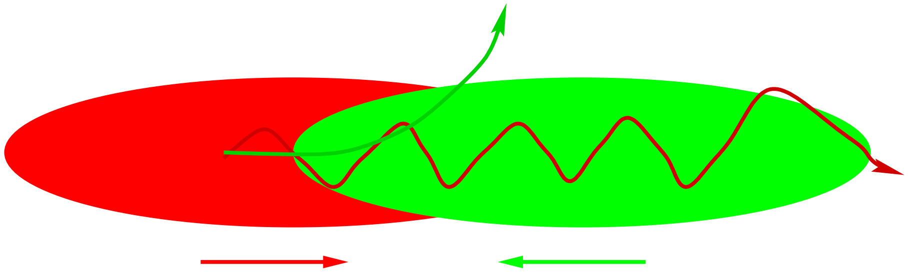
⇒ Rate of pairs is small for centre-of-mass energies below $1\,\mathrm{TeV}$

⇒ In CLIC, rate is substantial



- Can also calculate incoherent pairs, hadronic background including event generation, Bhabha scattering with deflection, see Physics Working Group

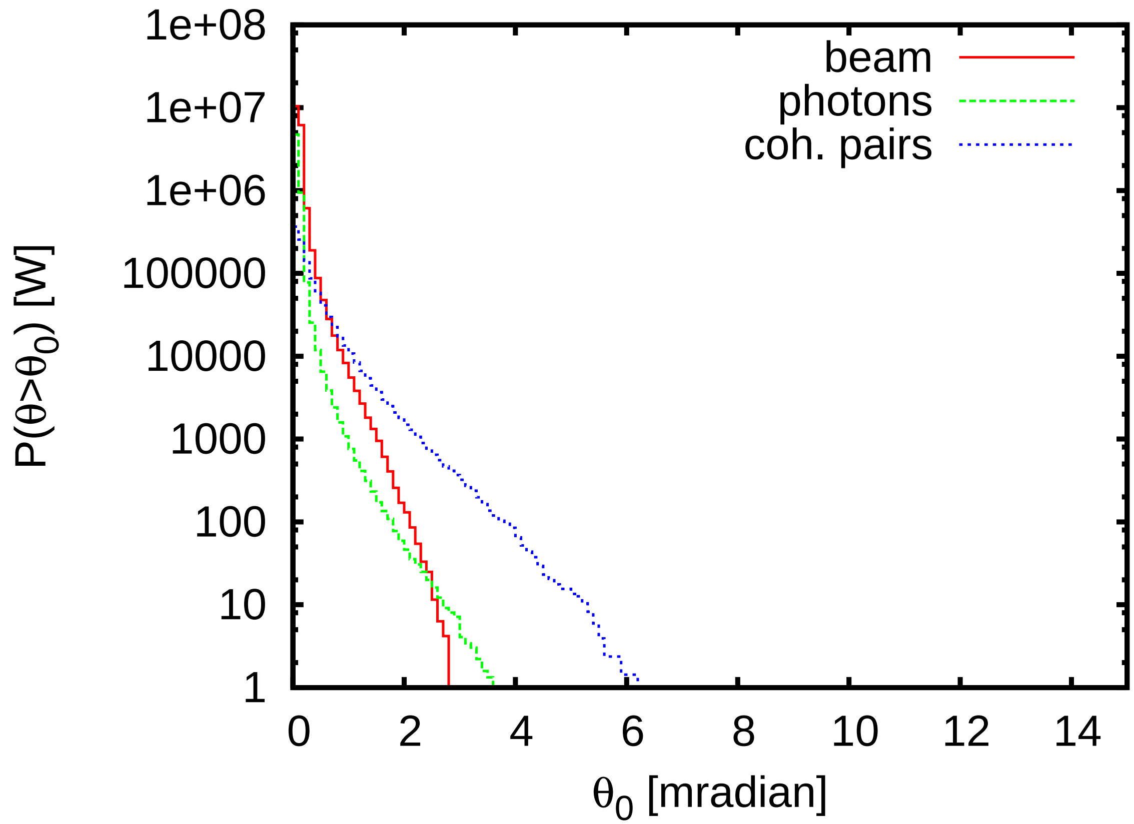
Spent Beam



- Crossing angle needs to be large enough to extract spent beam
- For new parameters we need 10mradian angle
  - plus space for quadrupole

$\Rightarrow$ 20 mradian seems OK

- Study of radiation in detector field had indicated $\theta_c = 20\,\mathrm{mradian}$



Need to foresee large enough exit hole (about 10mradian)

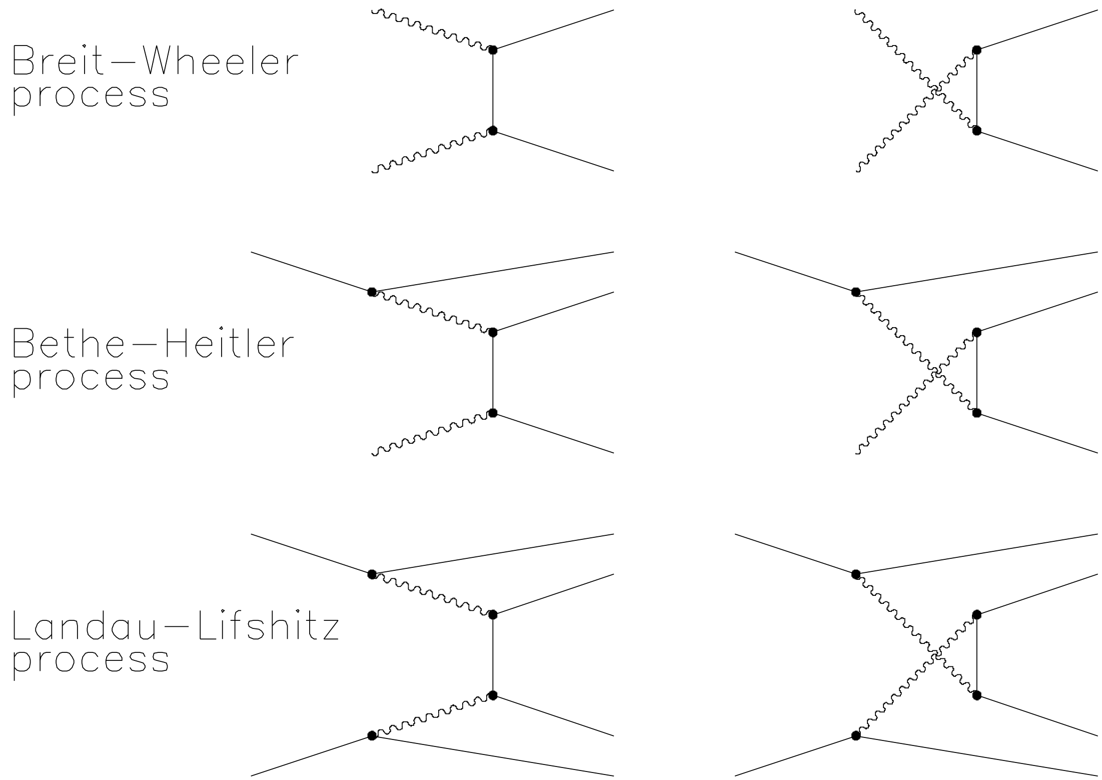
Incoherent Pair Production

Three different processes are important

- Breit-Wheeler
- Bethe-Heitler
- Landau-Lifshitz

The real photons are beamstrahlung photons

The processes with virtual photons can be calculated using the equivalent photon approximation and the Breit-Wheeler cross section

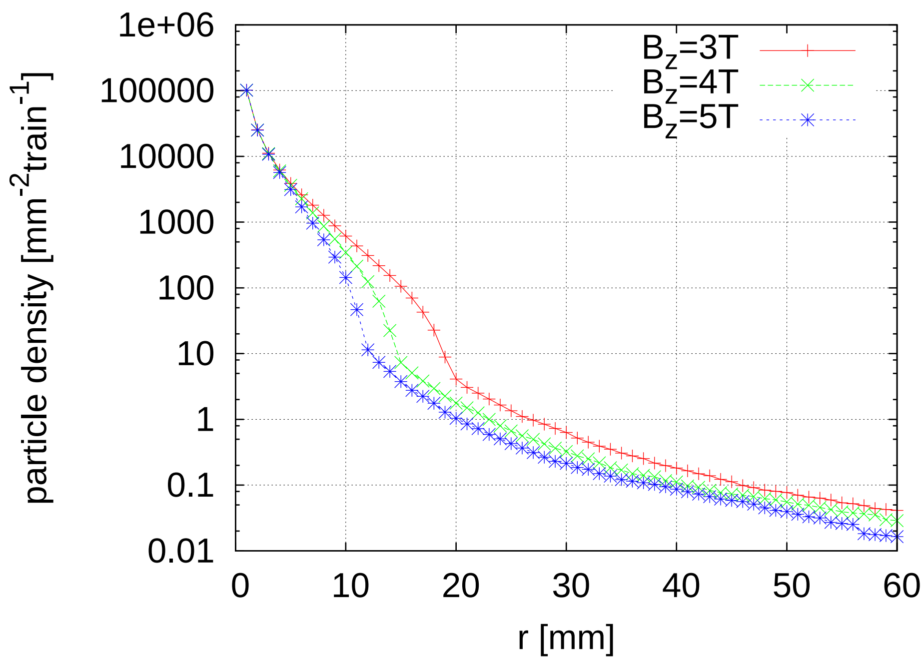


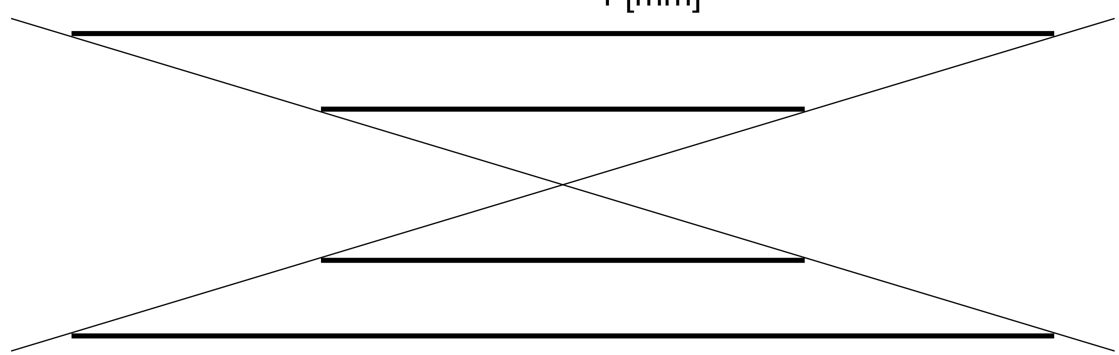
Impact of the Pairs on the Vertex Detector

Hits of the pairs in the vertex detector can confuse the reconstruction of tracks

Can avoid this problem by combination of two means

- use sufficient opening angle of the vertex detector
- confine pairs to small radii by use of longitudinal magnetic field
  this exists in the detector anyway



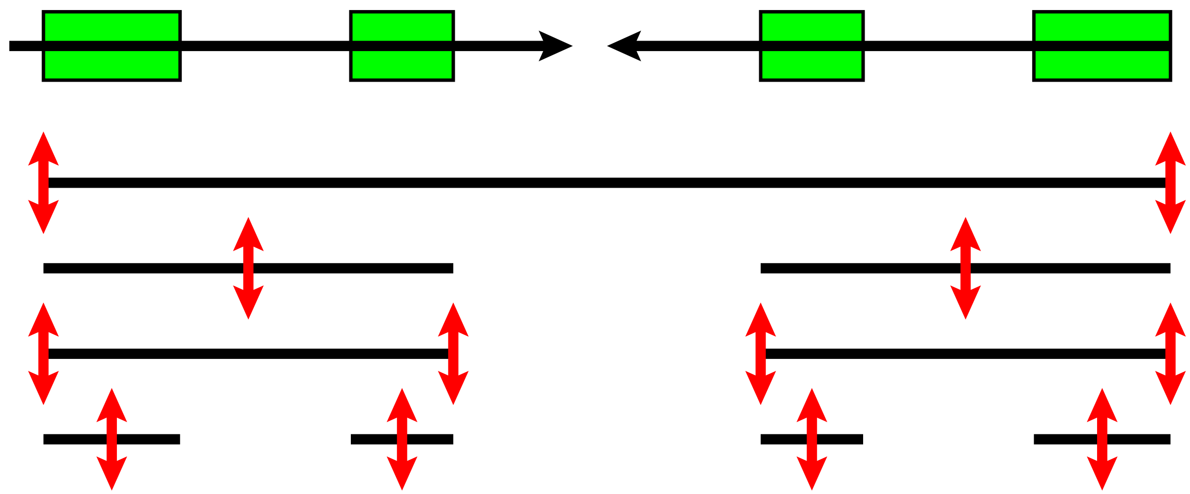


Final Doublet Jitter Types

- One support structure
  - relative tolerance on end points ≈ 4–$5\sigma_{beam-beam}$
- Two support structures
  - relative tolerance of mid points $\approx 0.7\sigma_{beam-beam}$
  - relative tolerance of end points $\approx 0.64\sigma_{beam-beam}$
- Four support structures
  - relative tolerance of mid points $\approx 0.5\sigma_{beam-beam}$

$\Rightarrow$ Two supports yields better tolerance but motion on support needs to be limited

$\Rightarrow$ Four is conservative assumption

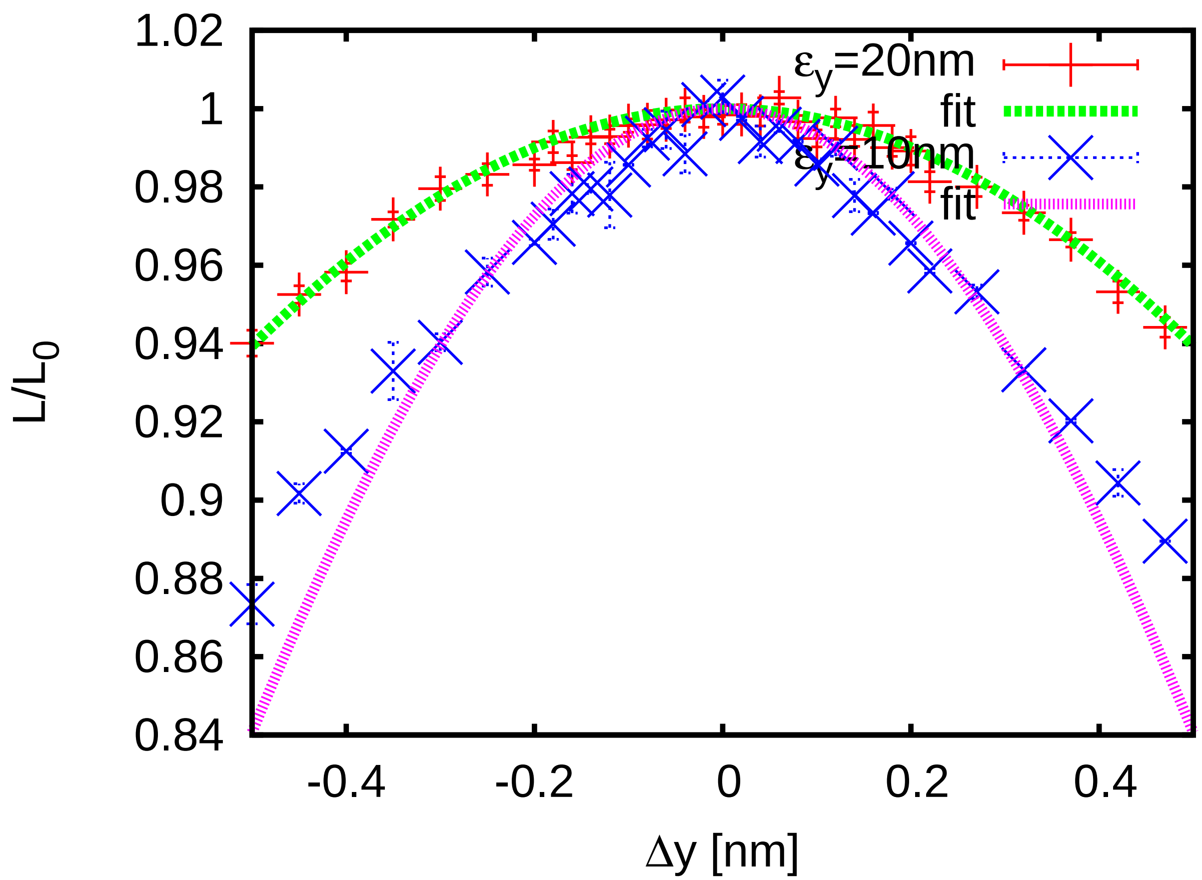


Beam-Beam Jitter Tolerance

- For a vertical emittance of $20\,\mathrm{nm}$ one finds for $0.2\,\mathrm{nm}$ beam-beam vertical position jitter
  - 1.0% loss with rigid bunch

  $\Rightarrow$ tolerances 0.15–$0.2\,\mathrm{nm}$
- Inclusion of beam-beam effects finds almost the same values
  - 1.0%
  - 0.28 nm yields 2.2%

    $\Rightarrow$ tolerances 0.14–0.18 nm



- Limit value for enhancement of coherent beam jitter is

$$\Delta y = \frac{\Delta y_0}{1 - n_c \frac{4Nr_e}{\gamma\theta_c^2}\frac{\delta y'}{\delta \Delta y_0}}$$

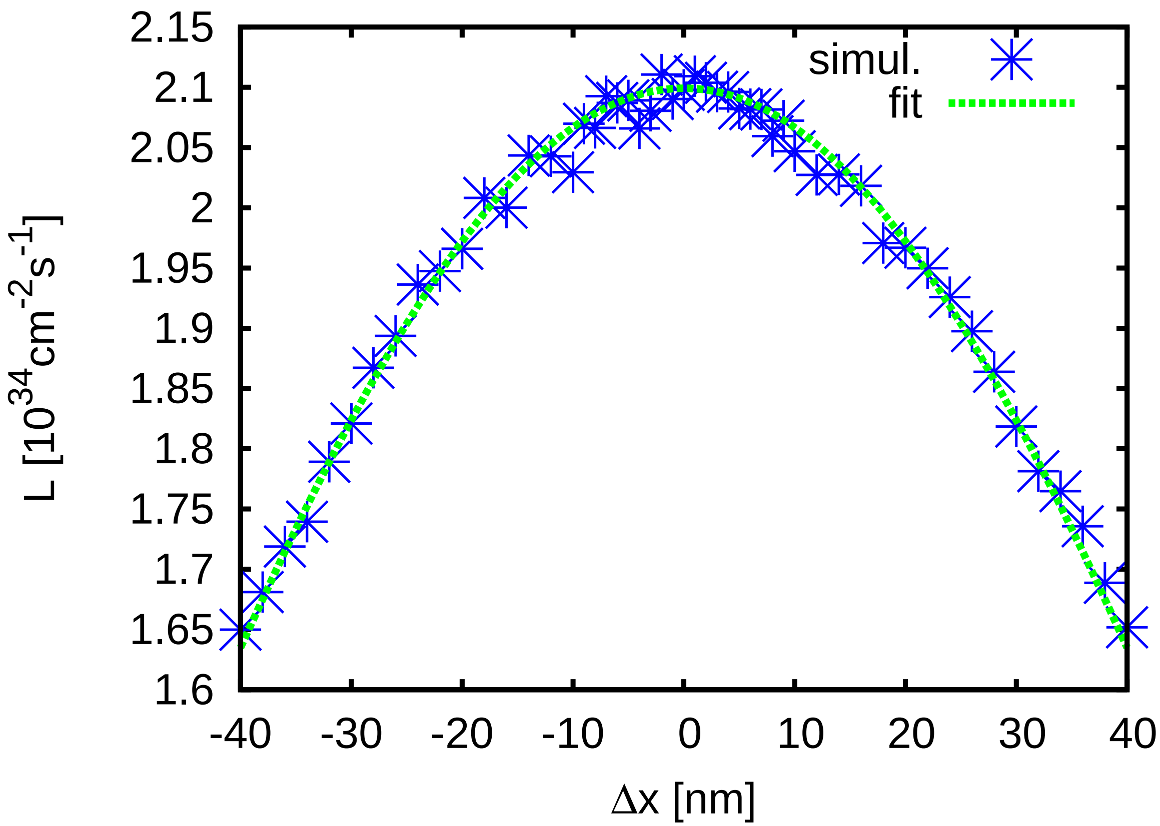
- $\Delta y = 1.09\Delta y_0$

Crab Cavity Phase Stability

- Required phase stability can be easily calculated
- What matters is relative phase of electron and positron crab cavity
- Horizontal offset at IP is

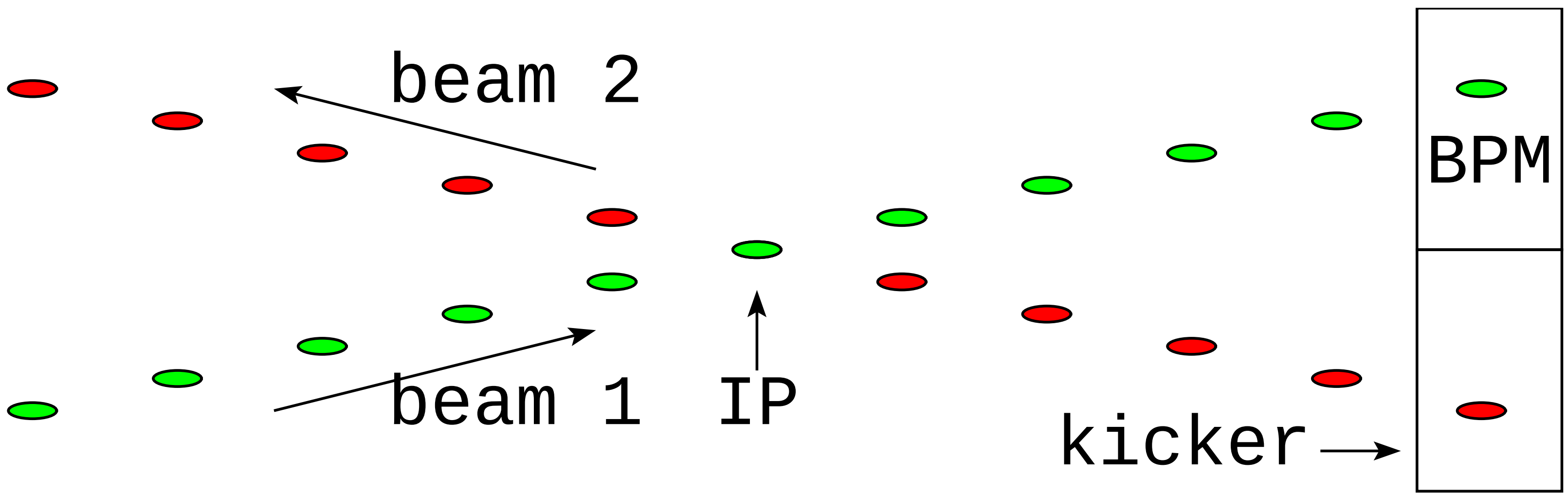
$$\Delta x = \frac{\theta_c}{2}\Delta\Phi$$

- For one 1% luminosity loss $\Delta\Phi \leq 0.011^\circ$



Intra-Pulse Interaction Point Feedback

- Reduction of jitter is dominated by feedback latency
  - IP to BPM
  - electronics
  - Kicker to IP
- Assuming 40 ns one can hope for about a factor 2
- Only cures offsets



Strategy for Lower Energy Parameter

- We aim for $E_{cm} = 3\,\mathrm{TeV}$

  $\Rightarrow$ try to minimise changes for lower energy parameters

- The same bunch emittances, charge and length is assumed, as well as bunch distance and number of bunches per pulse

  - Shorter linac, emittance growth might be slightly different

- Beam delivery system is replaced by simple estimate of achieveable beta-functions

  - Choice is $\beta_x \geq 10\,\mathrm{mm}$ and $\beta_y = 0.1\,\mathrm{mm}$, comparable to old NLC design

  - At lower energies it is easier to reach target beta-functions

  $\Rightarrow$ First concentrate on optimisation of $\sqrt{s} = 3\,\mathrm{TeV}$ system

- Design at lower energies should be performed if serious physics studies are carried out

- At 50Hz, our beam current is much below the ILC (22%–32%)

  $\Rightarrow$ can use higher repetition rate

Luminosity and Background Values

		CLIC	CLIC	CLIC	ILC	NLC
E_{cms}	$[TeV]$	0.5	1.0	3.0	0.5	0.5
f_{rep}	[Hz]	100	75	50	5	120
N	$[10^9]$	4.0	4.0	4.0	20	7.5
ϵ_y	$[nm]$	20	20	20	40	40
L	$10^{34}cm^{-2}s^{-1}$	2.14	2.7	7.0	2.0	2.0
L_1	$10^{34}cm^{-2}s^{-1}$	1.36	1.5	2.0	1.45	1.28
n_γ		1.10	1.20	2.4	1.30	1.26
$\Delta E/E$		0.07	0.11	0.31	0.024	0.046
N_{coh}	10^5	0.01	7.19	5.5×10^3	—	—
E_{coh}	10^3TeV	0.15	216.28	3.9×10^5	—	—
n_{incoh}	10^6	0.05	0.09	0.44	0.1	n.a.
E_{incoh}	$[10^6GeV]$	0.25	1.30	32.4	0.2	n.a.
n_t		11.5	17.1	66	28	12
n_{had}		0.10	0.29	3.2	0.12	0.1

- Target is to have about one beamstrahlung photon per beam particle
  - similar effect to initial state radiation

  $\Rightarrow$ average energy loss is larger in CLIC than ILC
- Note: shorter bunches increase the photon energy but not the number

Critical Issues

- Implications of dynamic effects
  - feedback systems
  - alignment and tuning in noisy machine
- Multi-bunch effects
  - wakefields with variations
  - electron cloud
  - space charge
  - fast beam ion instability
- Lattice determination precision and tuning robustness
- Complex instrumentation
  - laser wires, developments for ILC
  - luminosity monitors, specific for CLIC
- Machine protection
- Other issues to be checked and the forgotten problems

Also Critical

- Cost issues
  - sofar concentrated on feasibility
  - cost is also vital

  $\Rightarrow$ need to review details in terms of cost
- This requires lots of detailed studies
  - need to balance with feasibility issues

Damping Ring

- Current target: $\epsilon_x \leq 550\,\mathrm{nm}$, $\epsilon_y \leq 5\,\mathrm{nm}$, $\epsilon_z \leq 5\,\mathrm{keVm}$
- Design achieves: $\epsilon_x \leq 400\,\mathrm{nm}$, $\epsilon_y \leq 4.2\,\mathrm{nm}$, $\epsilon_z \leq 5\,\mathrm{keVm}$
  - vertical emittance has significant contribution from dispersion, not so much from coupling

    $\Rightarrow$ can probably be improved, but might increase horizontal emittance via IBS
- Will be revisited
- Critical issues are
  - final emittance is dominated by intra-beam scattering

    $\Rightarrow$ needs verification in selfconsistent way
  - electron cloud

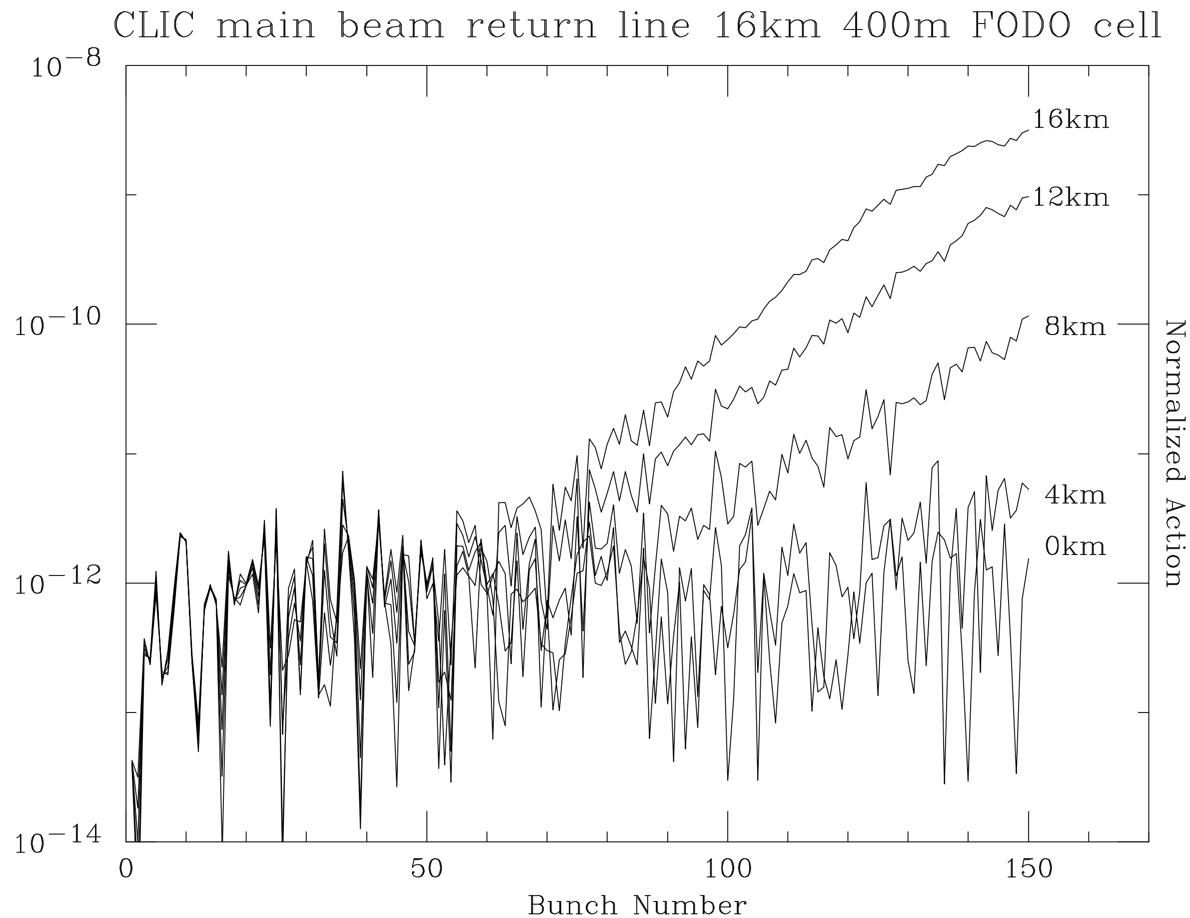
    $\Rightarrow$ similar problems needs to be solved for the ILC
  - other collective effects

    e.g. impedances incl. transients, FBII
  - vertical emittance dominated by dispersion

    $\Rightarrow$ improved alignment algorithm

RTML

- Target is to transport beam with initial emittance of $\epsilon_y = 5\,\mathrm{nm}$ to the main linac with $\Delta\epsilon_y \leq 5\,\mathrm{nm}$
- Full design of the system remains to be made
  - learned from ILC that it can yield tight tolerances
- One concern has been the coherent synchrotron radiation in bunch compressors
  - problem is addressed by PSI (F. Stulle)
  - designed bunch compressor chicanes
  - impact of coherent synchrotron radiation is very small
  - is being updated



- Fast-beam ion instability can be significant in transfer line
  - vacuum of 0.1 ntorr (T. Raubenheimer)
  - lattice design, dispersion
- Stray fields

Beam Delivery System and Post Collision Line

- Design of BDS is now quite mature (R. Tomas)
  - can now optimise for different L^*, minimum $\sigma_x = 40\,\mathrm{nm}$
  - instrumentation integrated, to be checked
- Main issues
  - alignment and tuning
  - dynamic effects
  - wakefield effects (e.g. resistive wall wake)
  - Machine protection
- Have a first promising post collision line design (Uppsala, A. Ferrari)
  - more work is needed
- Main issues are
  - losses (looks OK for the moment)
  - instrumentation

    difficult due to high losses

    vital for luminosity tuning
  - background

    need input from physics working group

Drive Beam

- Stability studies
  - accelerator, need update
  - combiner ring, need update
  - decelerator, seems OK
- Beam-based alignment and tuning
  - accelerator, needs update
  - decelerator, being updated and improved
- Drive beam phase stability
- Beam loading compensation for drive and main beam
- Machine protection
- CTF3

Fast Beam Ion Instability

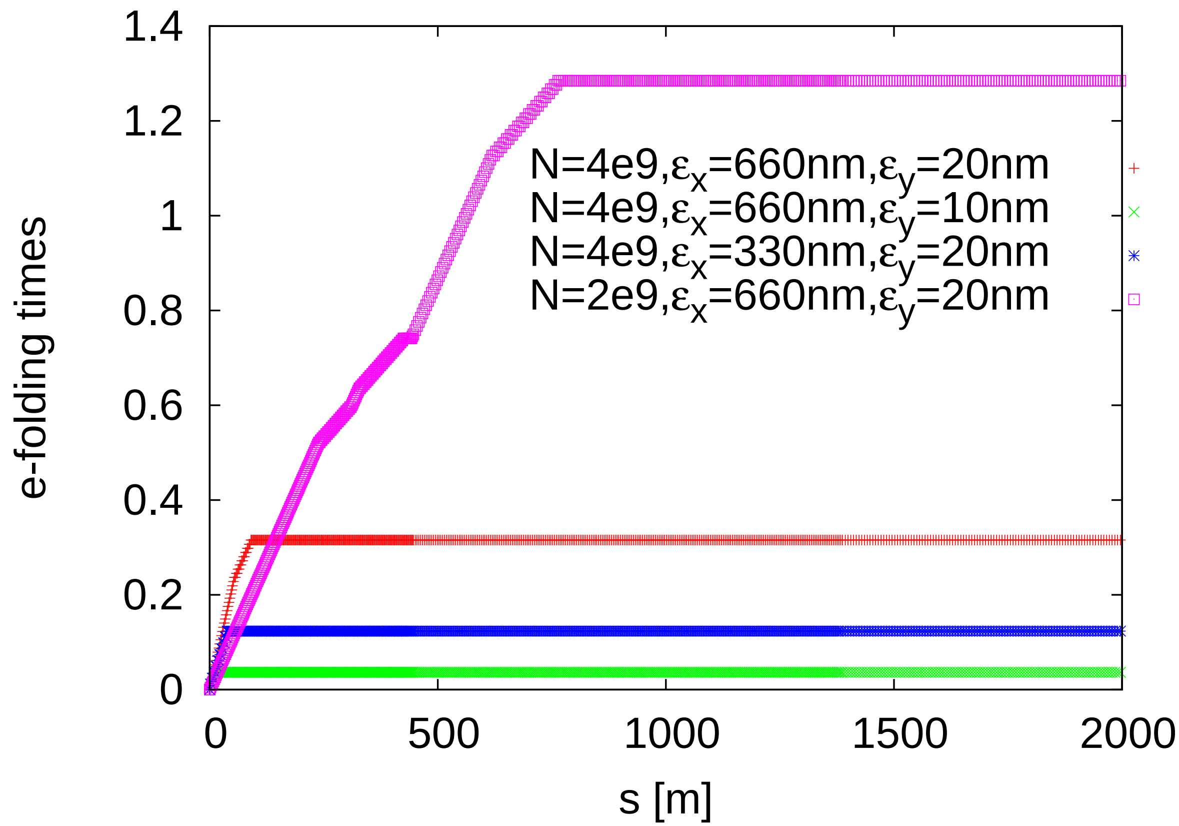
- Growth rate does not depend much on optics, approximately

$$\frac{1}{\tau_e} = \frac{p\sigma_{ion}}{kT} \frac{Nnr_ec}{\sqrt{18}\sqrt{\epsilon_x\epsilon_y}a} \frac{1}{\sqrt{Q}}$$

  75 e-folding times for 10ntorr

- But for small beam dimensions ions are not trapped

  $\Rightarrow$ in plot stop growth when traping condition is not fullfilled any more



- Uncertainty is large
  - tunneling can increase ion production rate (one to two orders of magnitude in CLIC)
  - ions outside the beam can still affect it
  - beam parameters are important (e.g. small N)

Summary

- Critical performance issues still need to be adressed
- Did not find a show stopper
  - but still want to check a number of potential problems

Reserve Slides

Bunch Charge Limitation

- Constant gradient:
  - for constant linac layout the wakefield induced emittance growth is

$$\Delta\epsilon_y \propto (W_\perp(2\sigma_z)N\Delta y)^2$$

  - dispersive growth is scaling similarly, due to BNS damping ($\sigma_E \propto W_\perp(2\sigma_z)N$)

$\Rightarrow$ keep $W_\perp(2\sigma_z)N$ constant

- Modified gradient
  - emittance tuning bumps are necessary in CLIC and change emittance growth dependence

$$\Delta\epsilon_y \propto (W_\perp(2\sigma_z)N\Delta y)^2\sigma_E^2 \propto (W_\perp(2\sigma_z)N)^4\Delta y^2$$

  - bunch length is cen be kept constant if

$$N \propto G$$

  - Inclusion of bumps leads to

$$\Delta\epsilon_y \propto (W_\perp(2\sigma_z)N\Delta y L_{bumps})^2\sigma_E^2 1/G \propto (W_\perp(2\sigma_z)N)^4(1/G)^3\Delta y^2$$

  - One could use $N \propto G^{7/8}$ but $N \propto G$ seems better due to the uncertainties

Deflection by the Beams

Most of the produced particles have small angles

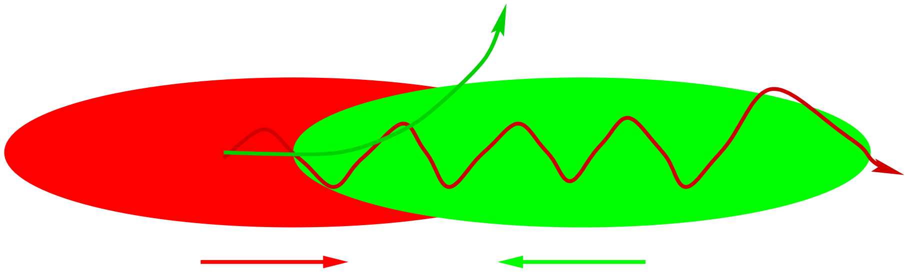
The forward or backward direction is random

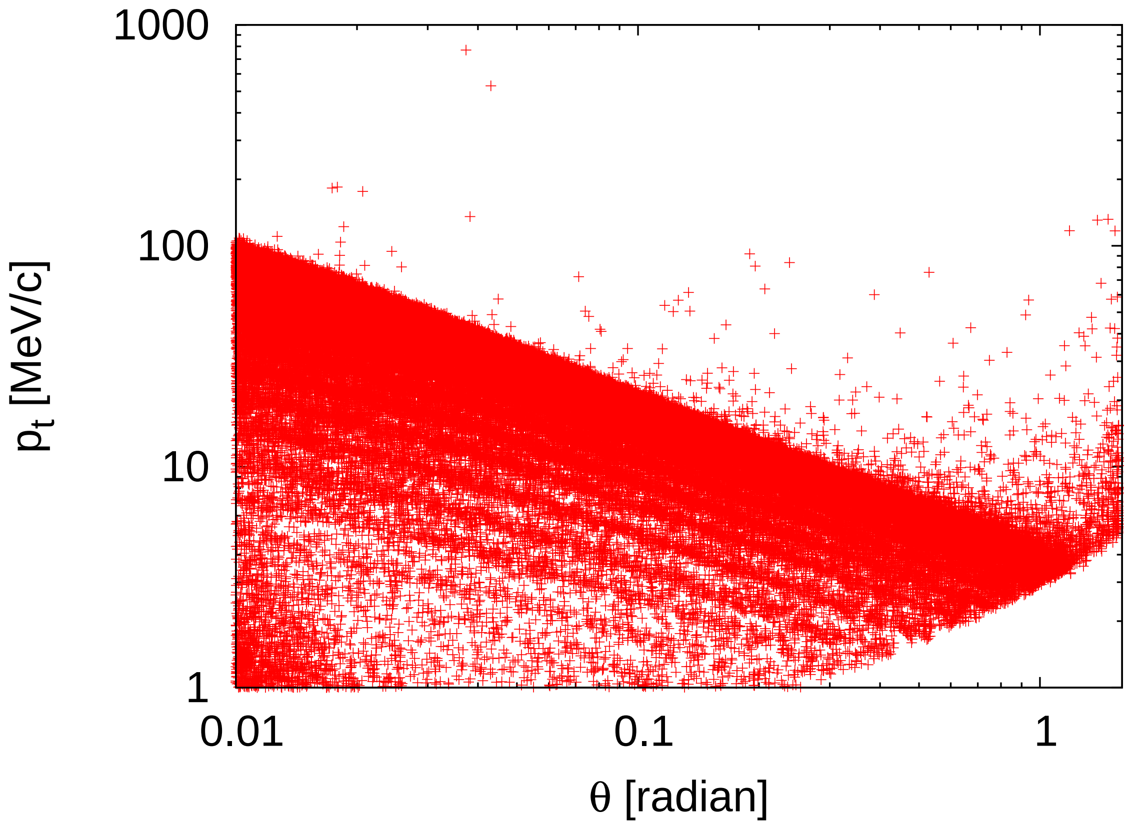
The pairs are affected by the beam

$\Rightarrow$ some are focused some are defocused

Maximum deflection

$$\theta_m = \sqrt{4\frac{\ln\left(\frac{D}{\epsilon}+1\right)D\sigma_x^2}{\sqrt{3}\epsilon\sigma_z^2}}$$





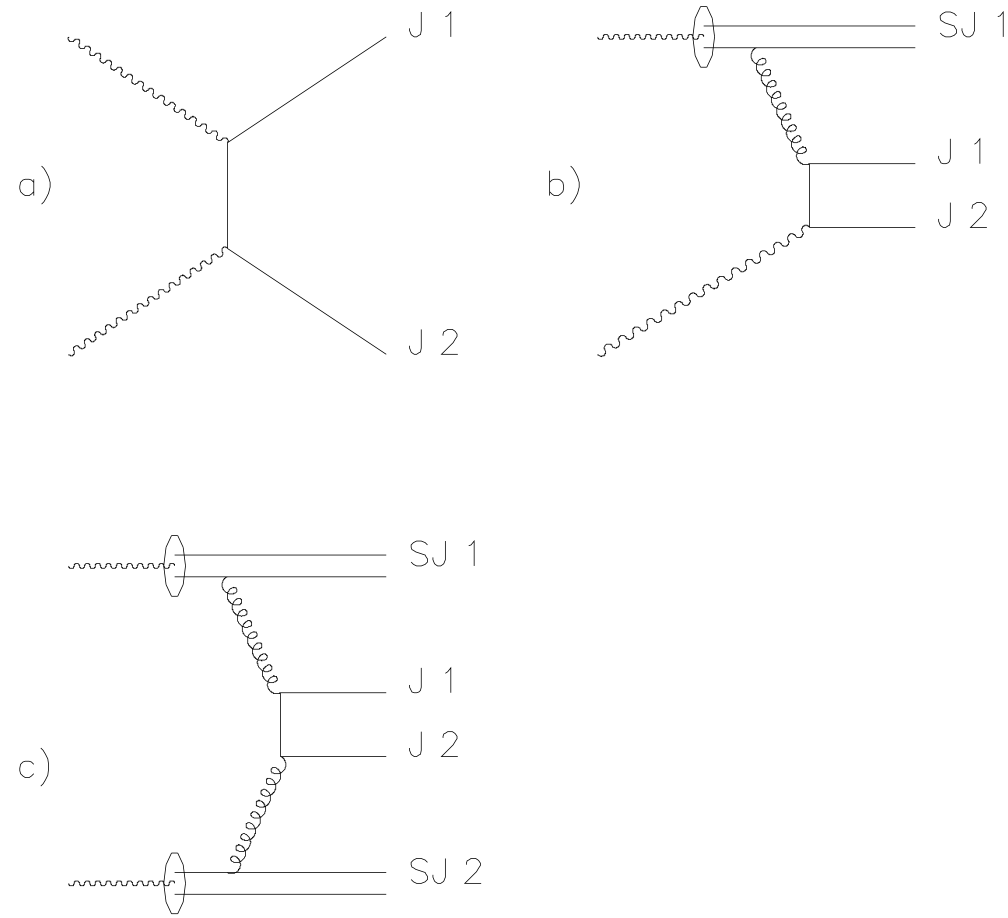
Hadronic Background

A photon can contribute to hadron production in two ways

- direct production, the photon is a real photon
- resolved production, the photon is a bag full of partons

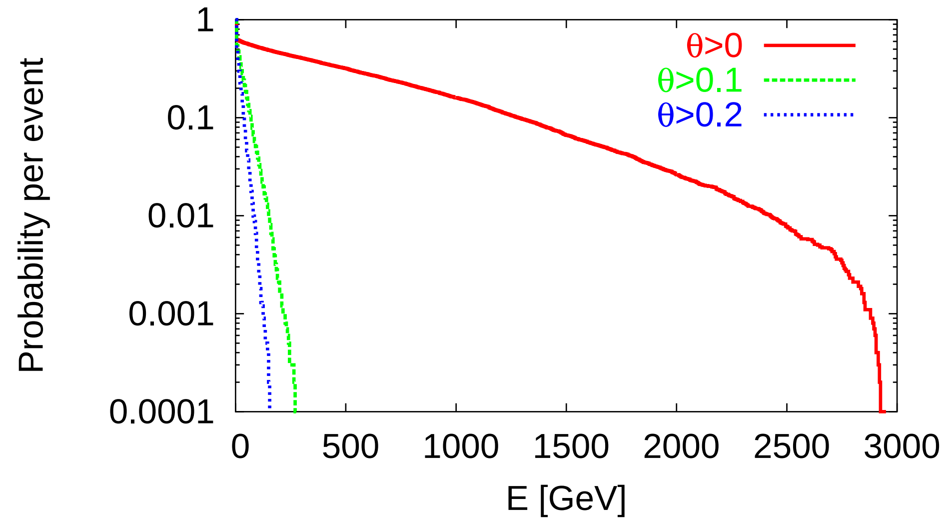
Hard and soft events exist

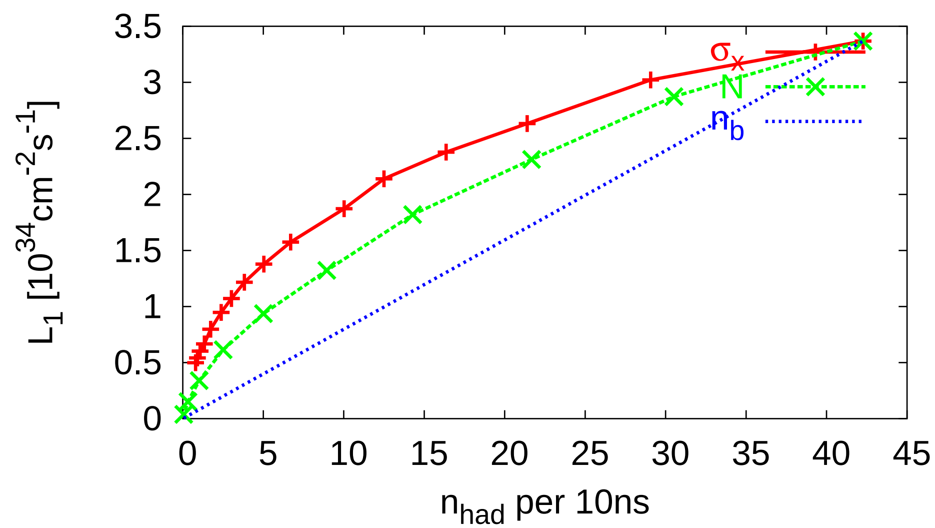
e.g. “minijets”



Hadronic Events

- Hadronic events with $W_{\gamma\gamma} \geq 5\,\mathrm{GeV}$
- Most energy is in forward/backward direction
  - $E_{vis} \approx 450\,\mathrm{GeV}$ per hadronic event for no cut
  - $E_{vis} \approx 23\,\mathrm{GeV}$ for $\theta > 0.1$
  - $E_{vis} \approx 12\,\mathrm{GeV}$ for $\theta > 0.2$
  - 20% from e^+e^-

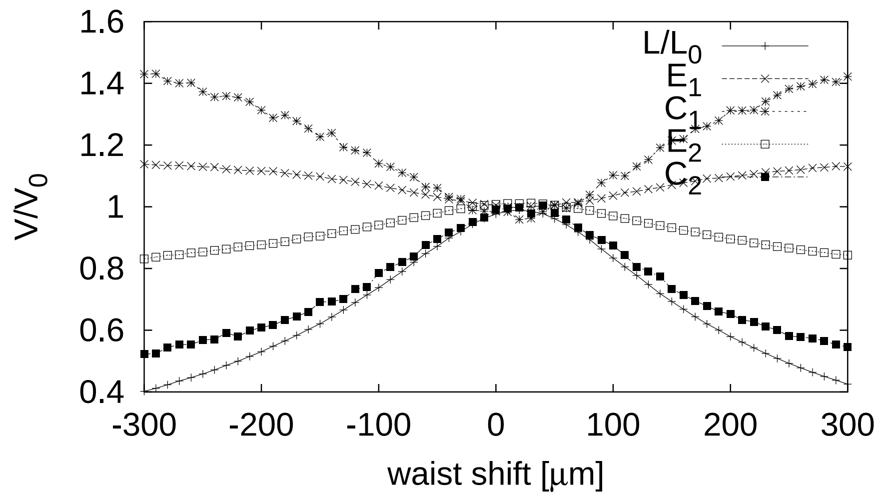


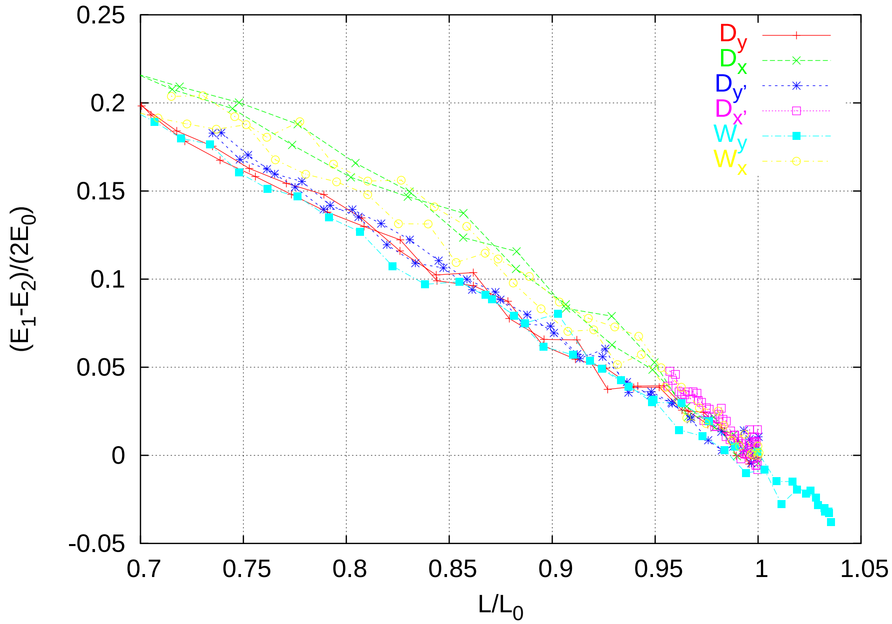


Orbit Feedback Concept

- RTML
  - not yet studied
  - assume feed-forward at turn-around, to correct jitter
- Main linac
  - 40 localised, connected feedback loops would work
  - MICADO style pulse to pulse orbit feedback being studied
  - stabilise quadrupoles
- Beam delivery system
  - intra-pulse offset feedback at the IP
  - pulse-to-pulse orbit feedback
  - stabilise magnets
  - use dithering feedback for tuning knobs

Tuning Knobs





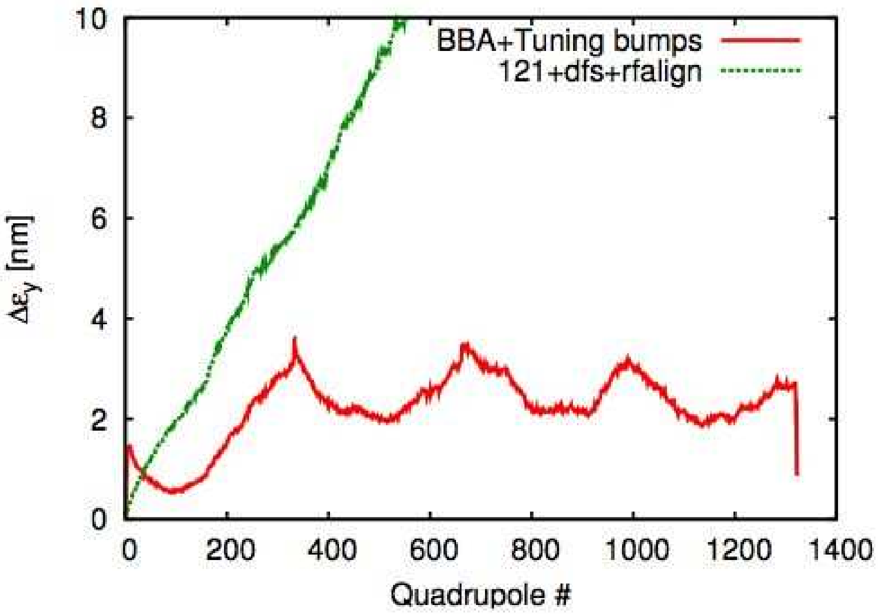
- Use luminosity and emittance tuning
- No direct signal for luminosity that is fast
- Use signals to tune knobs
- Good candidate is beamstrahlung

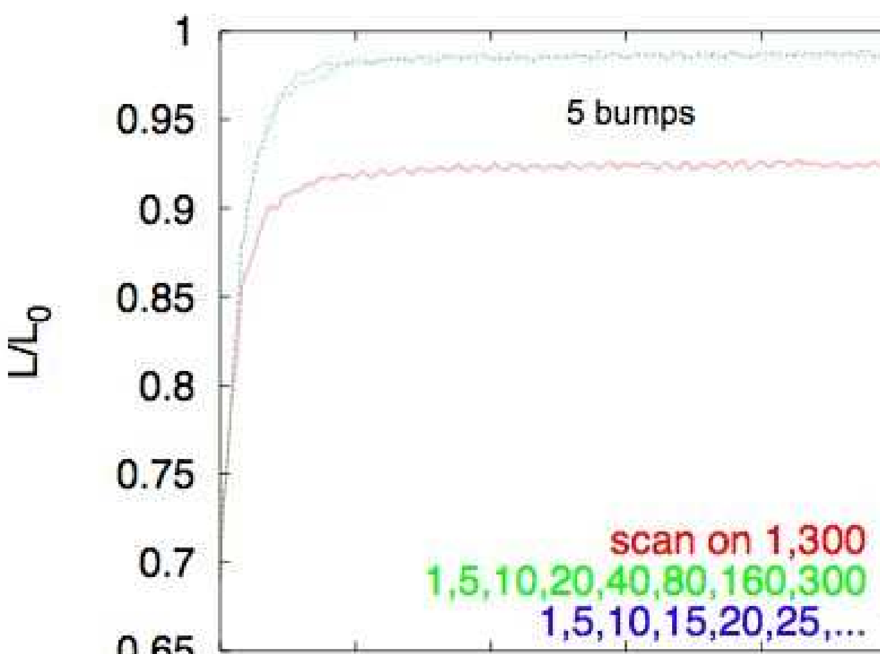
(P. Eliasson, D.S.)

Tuning Knobs

- Use luminosity and emittance tuning
- Emittance is measured at the end of the linac
- For emittance tuning optimise overlapp of beam with Gaussian
  - each knob is optimised in turn
    convergence is faster if they are made orthogonal
  - emittance tuning works fine with 3% error

(P. Eliasson, D.S.)





BDS Feedback

- Very tight BPM resolution tolerance

  ⇒ need to optimise feedback layout

  - fewer correctors
  - better weighting of BPMs
  - maybe better algorithm

- Need to use bumps quite often

  ⇒ study feedback for tuning knobs

(A. Latina, D.S.)