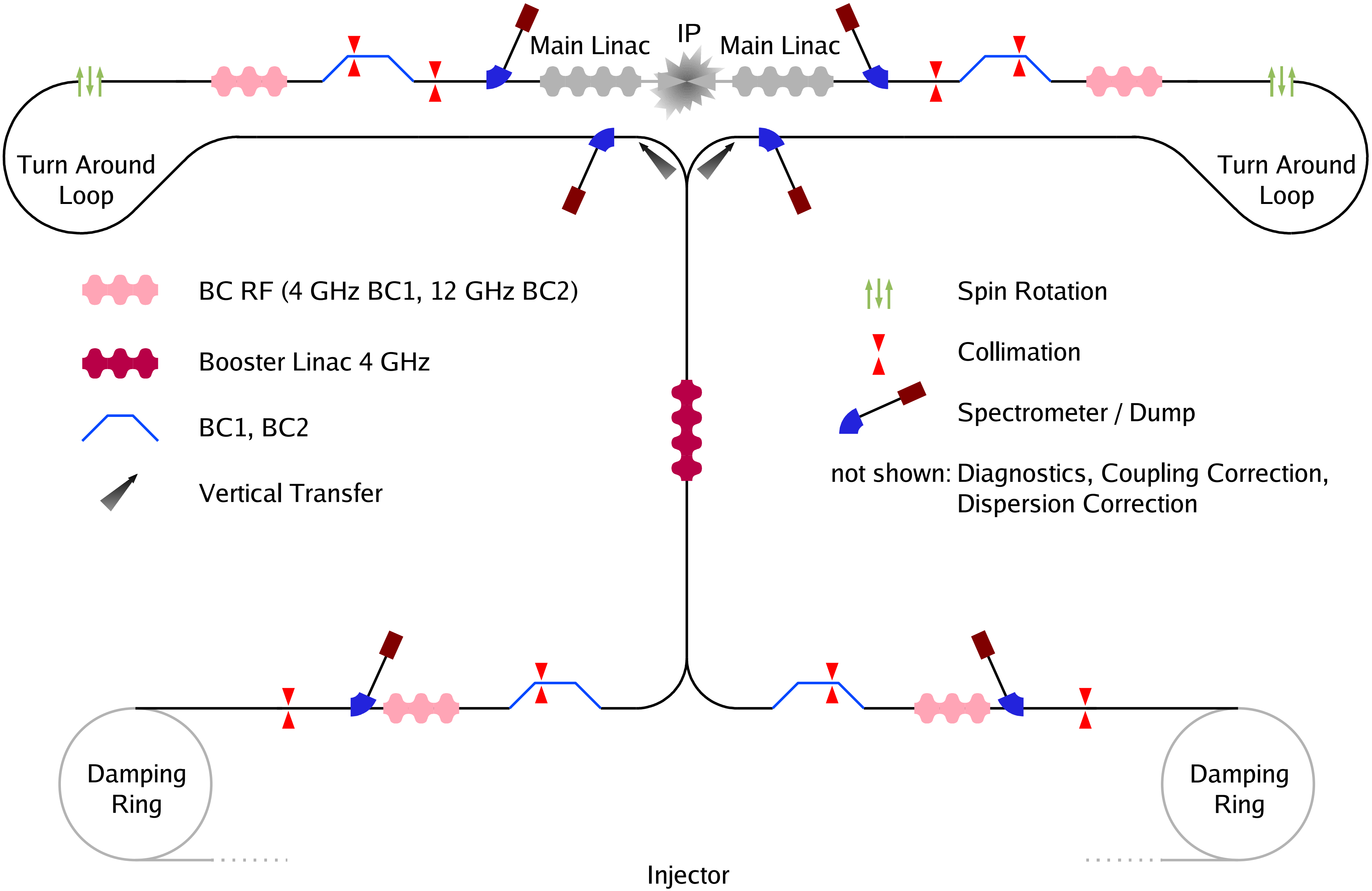
Low Emittance Transport

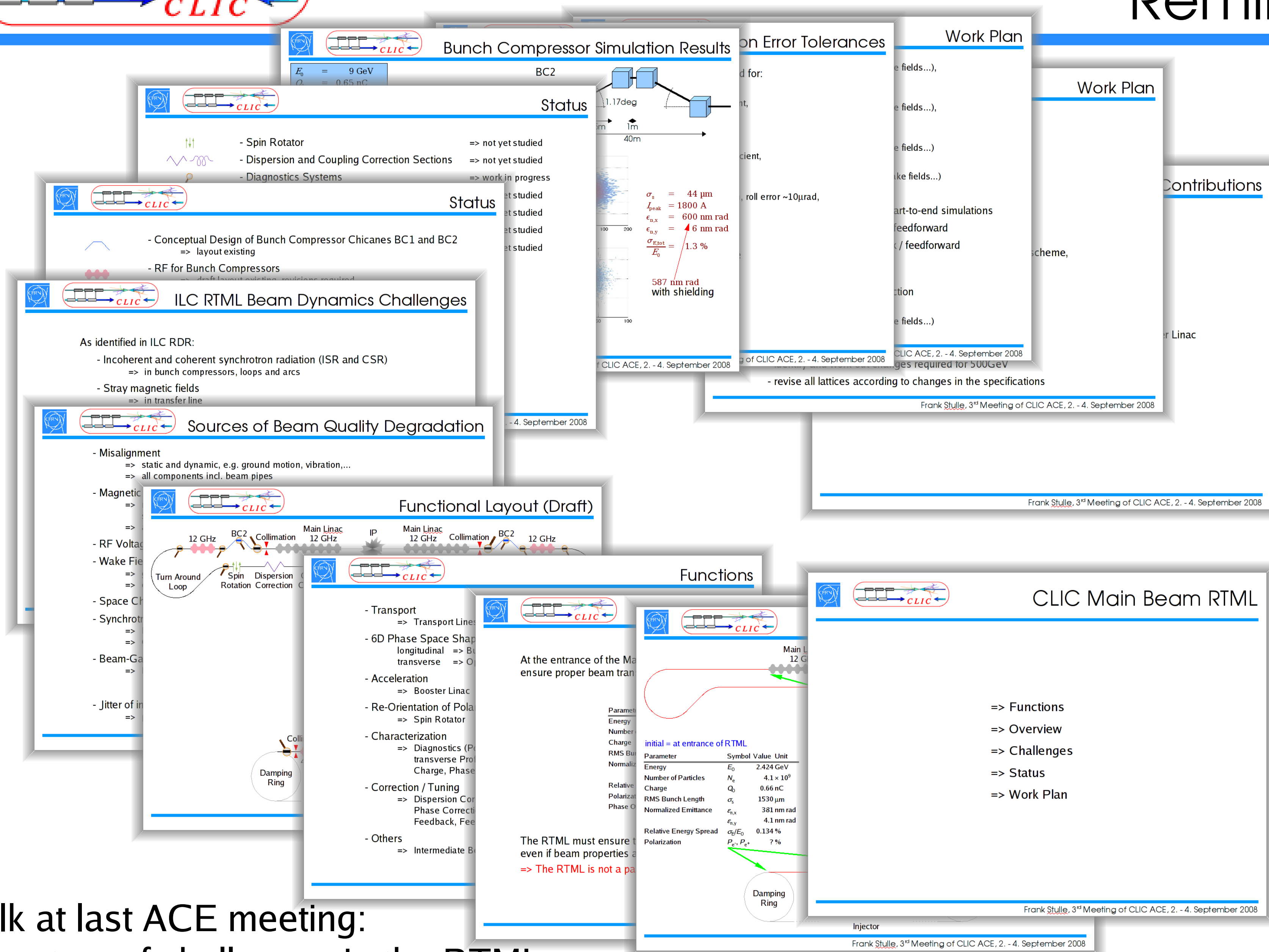
Main Linac covered by D. Schulte
BDS covered by R. Tomas

- Reminder of last years RTML status
- Update of the RTML status
- RTML @ 500 GeV
- Performance issues in RTML and Main Linac
  (CSR in the main beam bunch compressors had been pointed out by the TRC2 to be a serious risk.)
- Plans for the CDR

RTML Functional Layout (Draft)



Reminder



RTML talk at last ACE meeting:

- Inventory of challenges in the RTML
- Summary of the work which has been done
- Compilation of the work which has to be done

Last years status:

- Complete list of functions which the RTML has to fulfill
- Complete list of beam dynamics challenges which have to be mitigated
- Several beam lines already studied individually, i.e. bunch compressor chicanes and rf, booster linac, transfer line, turn around loop

but:

- Not all beam dynamics challenges studied
- Many lattice revisions required to improve performance
- Only preliminary tolerance studies
- No integrated studies
- No work at all for 500 GeV parameters

Update

Changes since the last ACE meeting:

- Improved lattice of the long transfer line (B. Jeanneret)
- Improved lattice of the turn around loop
- Studied booster linac (lattice, wake fields, quadrupole jitter) (D. Wang)
- Slightly adjusted initial (baseline) and final parameters (not yet baseline)

Property	Symbol	Value	Unit
Electron energy	E_0	2.86	GeV
Bunch charge	Q_0	0.65	nC
Bunch length	σ_s	1400	μm
Total energy spread	$\sigma_{E,tot}$	0.1	%
Normalized emittance	$\varepsilon_{n,x}$	500	nm rad
	$\varepsilon_{n,y}$	5	nm rad

Property	Symbol	Value	Unit
Electron energy	E_0	8-9	GeV
Bunch charge	Q_0	>0.6	nC
Bunch length	σ_s	44	μm
Total energy spread	$\sigma_{E,tot}$	< 1.5	%
Normalized emittance	$\varepsilon_{n,x}$	< 600	nm rad
	$\varepsilon_{n,y}$	< 10	nm rad

Changes of initial parameters are small and of no major importance for the RTML. Reducing final energy to 8 GeV would help reducing ISR in the Turn Around Loop by a factor of two. On the other hand, it would add complication to the main linac. The required optimization is ongoing.

Performed start-to-end simulations of the RTML:

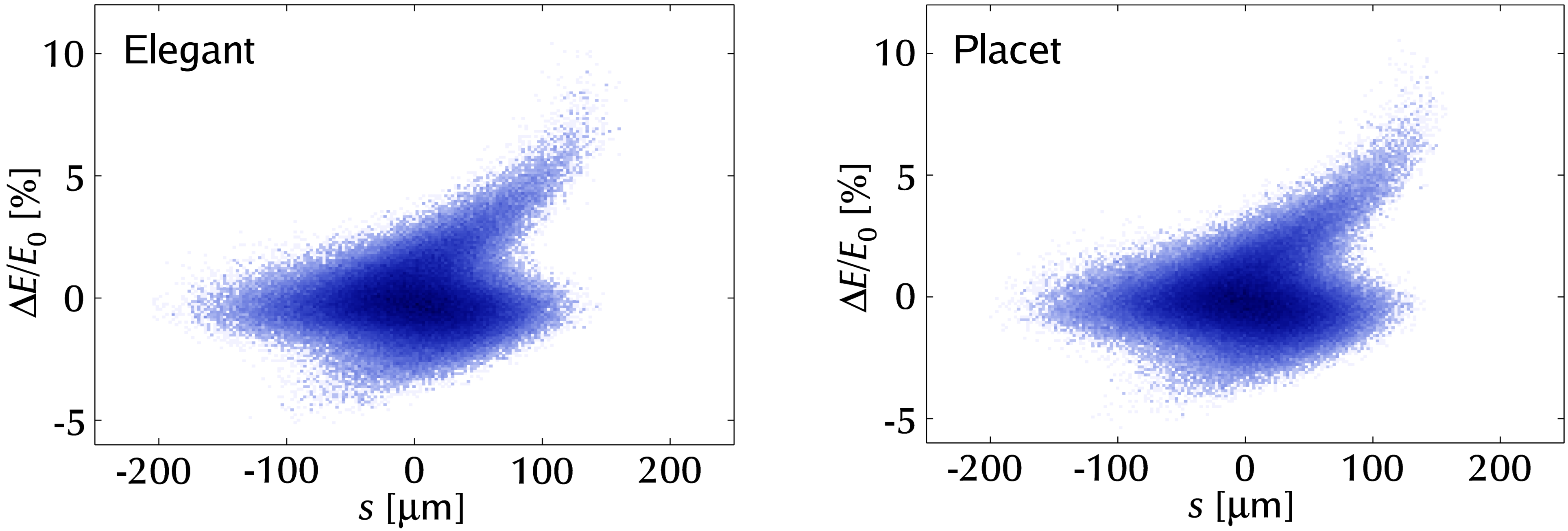
- BC1, Booster Linac, Long Transfer line, Turn Around Loop and BC2, all connected by straight simple optics matching sections
- Included incoherent synchrotron radiation and cavity wake fields
- Used the codes Elegant and Placet

- Good RTML performance and good agreement between codes

- Quickly checked CSR (using Elegant only)
- Total emittance growth is too large ($\Delta\varepsilon_{nx}$ = 200 nm rad, i.e. twice the sum of growth in individual beam lines), seems to partially stem from a dispersion mismatch induced by the CSR energy loss and shielding due to vacuum chamber was not taken into account (not possible in Elegant)
- This (low) emittance growth is encouraging

Work on integrated simulations of RTML, Main Linac and BDS has started (J. Snuverink).

final longitudinal phase space distribution



ISR, wake fields and chromatic effects lead to an emittance growth in the horizontal plane of $\Delta\varepsilon_{nx} = 50$ nm rad (Elegant) and $\Delta\varepsilon_{nx} = 60$ nm rad (Placet). Emittance in vertical plane is unchanged.

RTML @ 500 GeV

	3 TeV	500 GeV
Bunch charge	0.65 nC	1.2 nC
Initial bunch length	1400 μm	1400 μm
Final bunch length	44 μm	~70 μm
Emittance budget x	100 nm rad	500 nm rad
Emittance budget y	5 nm rad	5 nm rad

RTML specifications are the same for nominal and conservative cases.

- Doubling charge is a major issue, but larger final bunch length and larger horizontal emittance budget help.
- An RTML which is suitable for the 500 GeV case (double charge) should also be suitable for the 3 TeV case (normal charge).
- No upgrade would be required, neither from conservative to nominal parameters nor from 500 GeV to 3 TeV. This will be a design objective
  (clearly the length of the transfer line has to be adjusted, but for beam line design this is not too important).

- ...

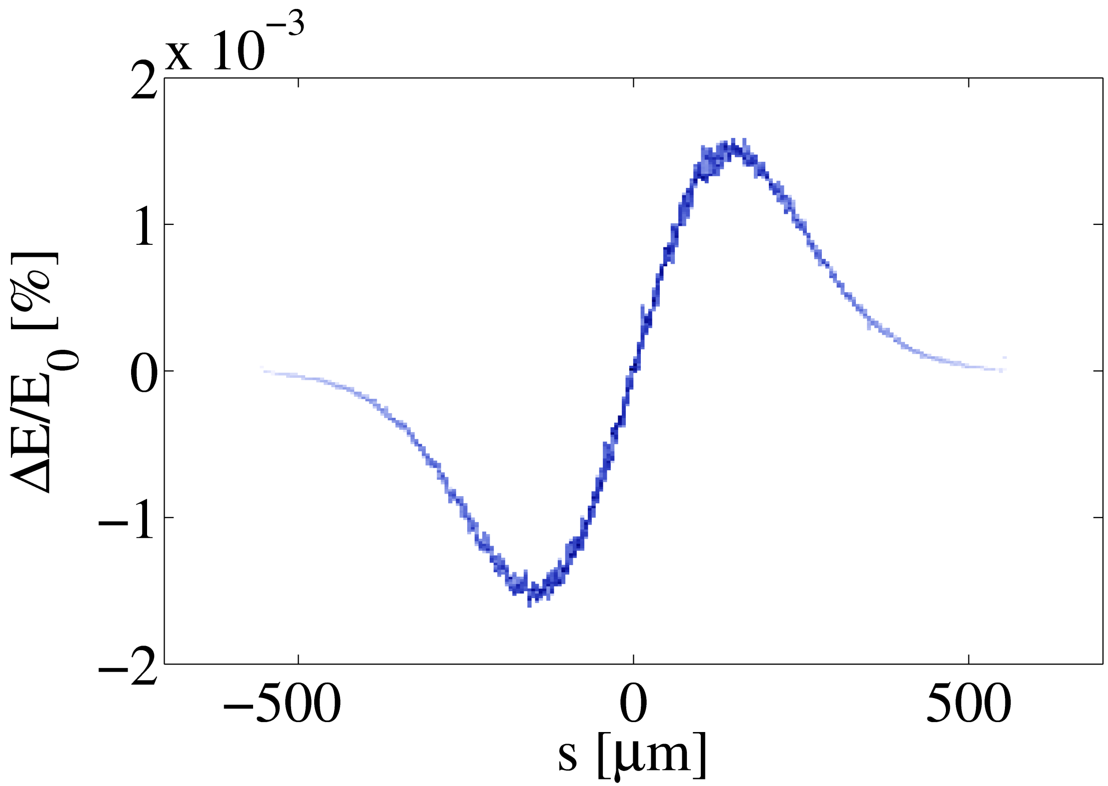
- Wake Fields (geometry, resistivity, surface roughness,...)
  - ➔ ~ Q_{bunch}
  - ➔ in cavities, collimators, beam pipes

- Fast Beam-Ion Instability
  - ➔ ~ Q_{bunch}
  - ➔ in long transfer line and the main linac

- Space Charge Forces
  - ➔ ~ Q_{bunch}
  - ➔ in transfer lines

- Coherent Synchrotron Radiation
  - ➔ ~ Q^2_{bunch}
  - ➔ in bunch compressors, turn around loop and vertical transfer

- ...



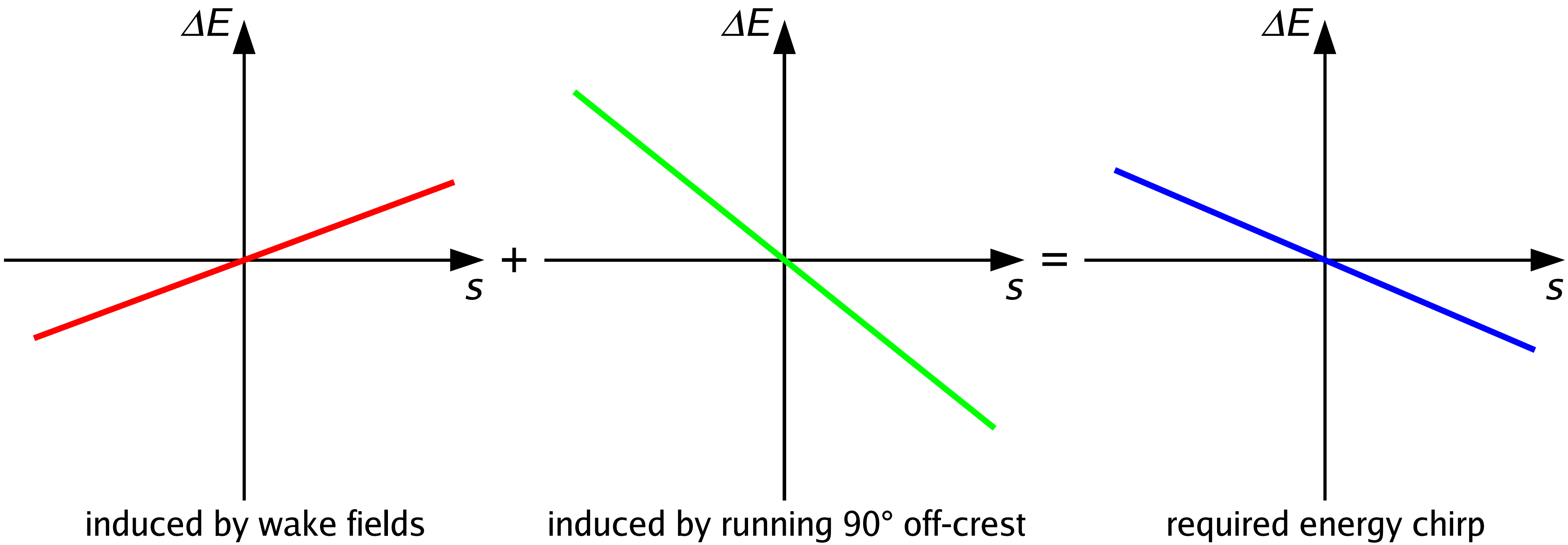
Quick test of LSC in long transfer line, Gaussian bunch, no energy spread, otherwise 3 TeV parameters

$$F_{SC} \propto \frac{Q_{bunch}}{\gamma^2}$$

Space charge forces might influence transverse and longitudinal momentum.
Due to the large beam energy of 8-9 GeV they should be small but a detailed study remains to be done using a more realistic bunch profile.

Wake Fields in RTML

Especially the 12 GHz cavities of the BC2 RF are a concern. Due to the small irises strong wake fields (transverse and longitudinal) will occur which spoil emittances. Additionally, the wake fields induce a positive energy chirp which counteracts the required negative energy chirp:



Fortunately, we recently figured out that the arguments for limiting the voltage in BC2 RF to 40 MV/m are not valid any more and we can use standard 500 GeV main linac structures with 80 MV/m. This seems to be sufficient to mitigate wake fields for the 500 GeV case and also helps for the 3TeV case. Detailed studies will follow.

In contrast to the wake fields, which seem to be mitigated by going to a higher gradient, CSR remains a challenge:

- Emittance growth induced by CSR is already too high for nominal charge
- It is unacceptable for double charge ($\Delta\varepsilon_x$ ~ 800 nm rad)
- The bunch compression system must be revised to improve for the 3 TeV parameters and to make 500 GeV parameters feasible.
  The main challenge is the last stage of compression, since bunches are shortest.

We are working on different options:

- Two or more chicanes consecutively lowering R_{56},
  bending angles would be a lot lower where the bunch is shortest and there is the possibility for proper beam focusing, which has an influence on CSR emittance growth (this is the reason why elongating the BC2 chicane is not an option)
- Long wiggler type compressor (like ILC),
  this scheme has similar advantages as the previous
- Compression in turn around loop do not use a chicane,
  currently we have a hard time to make it isochronous,
  having a small R_{56} might solve some additional problems (but we loose flexibility)
- Compression in turn around loop and in a chicane
- ... S-shaped, chicanes, asymmetric chicanes, ...

The main objective is to lower the bending angles where bunch is shortest.

CSR in RTML

Despite the required changes we can built on previous work performed for the BC system:

- We gained a more profound understanding of CSR and the parameters which influence CSR
- We know the simulation codes and their limitations better
- We have the tools to perform parameter scans and to analyze them
- Simulations have shown that changes in the beam dynamics induced by CSR can be controlled and they can be taken into account in the design
- Previous work makes us confidence that a solution exists
- Parameter space is still similar to the previously used one
- The new bunch compression system will soon be available

The fast beam-ion instability is expected to be an issue in the long transfer line:

- >20 km long FODO lattice
- weak quadrupoles and huge beta functions, $\beta_{avg} > 600$ m
- small emittances, ε_{nx} = 600 nm rad and ε_{ny} = 5 nm rad
- small bunch separation, L_{sep} = 0.15 m

- Ions will be trapped and a vacuum better then 0.1 nTorr would be required, such a low value could be reachable since in any case a huge beam pipe of about 10 cm diameter will used to reduce resistive wall wake fields.

In the 500 GeV case, charge will double but transverse emittance is four times larger

- Similar vacuum level required as for 3 TeV case, could even be relaxed since transfer line will be a lot shorter

Detail of beam dynamics in the long transfer line were presented at EPAC08 (J.B. Jeanneret et al.).

Previous calculations showed that:

- As in the long transfer line ions should be trapped.
- A vacuum level similar to the long transfer line would be required (0.1 nTorr).
- But transverse beam size shrinks fast during acceleration.
- The ions can drift outside the beam.
- Hence, no trapping occurs.
- A vacuum better then 10 nTorr is required.

  (Vacuum simulations show that a vacuum level of several nTorr should be feasible. Bake out or heat activation seem to be excluded due to the very tight alignment tolerances)

Fast Beam-Ion Instability in Main Linac

On the other hand, the electric field inside the electron bunch grows fast during acceleration and field ionization might occur:

- The first bunch ionizes all particles which lie within the region of sufficiently high field.
- Following bunches only ionize particles which drift into their path in the mean time.
- The level of ionization is a lot higher than achieved by normal beam-gas scattering.
- Required vacuum level strongly depends on the field strength for which field ionization starts, E_{ion} = 10 - 100 GV/m => 10 nTorr, E_{ion} < 10 GV/m => 1 nTorr.
  Unfortunately, E_{ion} does not seem to be well know, in literature its value fluctuates a lot.

Detail of fast beam-ion instability in the main linac were presented at PAC09 (G. Rumolo, D. Schulte).

Tolerance Studies / Feedback

Tolerance studies for the RTML were (slightly) improved:
(for Main Linac see D. Schulte's talk)

- ➔ But until now they only include magnet misalignment.
- ➔ Jitter of beam parameters (e.g. charge) and magnet properties (e.g. magnetic field strength) need to be included.
- ➔ No mitigation strategy has been evaluated for the RTML, but RTML will profit from the work done for the Main Linac. (Mitigation of static imperfections in the RTML has proven to be difficult in ILC and has not yet been solved to satisfaction.)
- ➔ The turn around loop will be the main challenge. Nevertheless, it should be easier than the Main Linac or the BDS.

Started to study RTML and Main Linac feedback system (J. Pfingstner).

Plans for the CDR (RTML)

Compared to previous planning we found some new challenges, but at least we found them earlier than anticipated. Start-to-end simulations and study of 500 GeV parameters were originally planned for a later time, although we expected them to reveal issues.

Our planning is now based on more profound understanding of the challenges in the RTML. For the CDR we will:

- ➔ Provide detailed beam parameter specifications including tolerances for all CLIC setups, i.e. 500 GeV and 3 TeV, conservative and nominal parameter sets.
- ➔ Provide a complete list of functions which the RTML has to fulfill and a detailed conceptual layout of the RTML.
- ➔ Provide a complete list of beam dynamics challenges.

Plans for the CDR (RTML)

- Compile a baseline RTML lattice consisting of all major beam lines except for the spin rotator, i.e. bunch compressor rf and chicanes, booster linac, vertical transfer, long transfer line, turn around loop, all connected by simplified optics matching sections.
- Optimize the beam lines to be suitable for 500 GeV and 3 TeV parameters, both conservative and nominal sets.
  (If this should not be possible, we will focus on nominal 3 TeV parameters and described what kind of additional work is required to adopt the RTML to the other parameters sets.)
- Study all major beam dynamics issues which are present in the beam lines and update existing studies, but not necessarily fully optimize them,
  e.g. CSR in the bunch compressors, the vertical transfer and the turn around loop, wake fields in the cavities, ISR in the turn around loop, fast beam-ion instability in the long transfer line.
- Explore tolerances on static and dynamic imperfections and their mitigation including misalignment, magnetic field errors and stray fields and jitter of initial beam parameters. We may not have a solution for all challenges.
- Evaluate vacuum requirements.
- Study requirements for feedback and feed forward systems.
- Prepare simplified models of the dynamic imperfections and the feedback to perform integrated studies.

Plans for the CDR (Main Linac)

- A reference lattice exists. Detailed studies of the impact of the hardware layout on the performance are ongoing.
- Beam-based alignment procedures have been devised to mitigate the impact of static imperfections. Simulations show that these procedures achieve the performance goal. Further refinement is expected for 2010 in the modeling of the survey performance and its impact on the beam.
- A program has been developed to estimate the fast beam-ion instability including field ionization. It is used to estimate the required vacuum level.
- Multi-bunch effects will be included in the simulations for 2010.
- A conceptual beam orbit feedback exists. Studies are ongoing to demonstrate the robustness of the design.
- Studies are being launched to model the transverse jitter of the quadrupoles.

- Integrated simulations will be performed from the entrance of the RTML up to the IP.