WG7 Low Emittance Transport and Integrated Simulations

Low Emittance Transport = everything behind the Damping Rings...
...except for Beam Delivery System (see WG 5)

Frank Stulle for the conveners of WG7 (K. Kubo, N. Solyak, F. Stulle)

Scope

- ILC and CLIC
  - Ring to Main Linac (RTML)
  - Main Linac
- Integrated Simulations
- Feedback Studies
- General Beam Dynamics Studies
- Femto-Second Timing and Beam Phase Stability (with WGs 2,6,8)
- BDS and Interaction Region (with WG 5)
- ATF2 (with WG 5)
- Alignment and Stabilisation (with WG 8)

Why SB2009?

⇒ Because it is likely to be cheaper

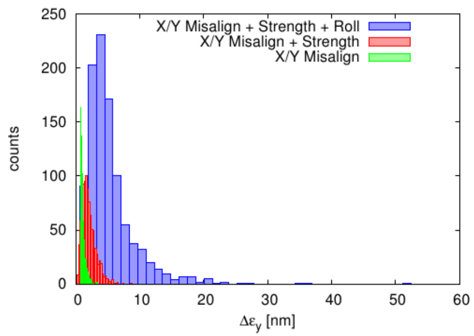
⇒ RTML ⇒ from two-stage bunch compressor (BC1-BC2) to single-stage bunch compressor (BC1S)

- **ILC Baseline: Two-Stage Bunch Compressor**
  - Bunch length at damping rings extraction: 6/9 mm, compression down to 200/300 μm at main linac entrance (compression ratio: up to ∼45)
  - * **Pro**: more flexibility
  - * **Cons**: two diagnostics sections, two extraction lines

- **Minimum cost machine: Single-Stage Bunch Compressor**
  - New design of the damping rings allows 6 mm bunch length with a smaller radius
  - Compression factor can be fixed to ∼20
  - * **Pro**: Shorter beamline and associated tunnel length (314 meters); Removal of the second 220 kW/15 GeV beam dump and extraction line components; Removal of one section of beam diagnostics
  - * **Cons**: Less flexibility; Larger energy spread at BC exit; Possible emittance preservation issues (see DFS in the main linac)

3) Entire "Front End"

- Correction: 1-TO-1 + Kick Minimization + Dispersion Bumps + Coupling Correction
- Histogram of final emittance growth for 1000 seeds:



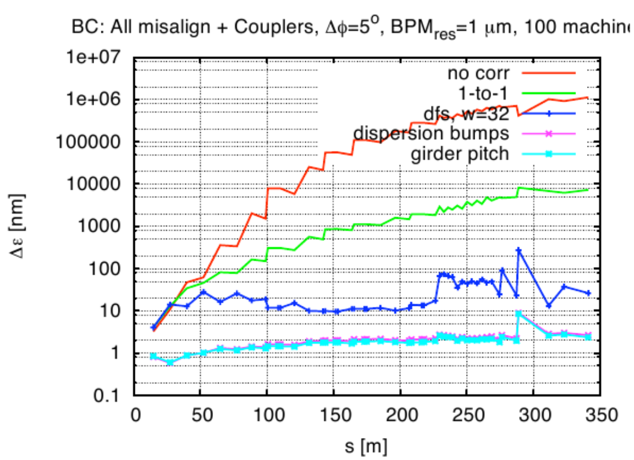
⇒ X/Y Offsets: Final average emittance growth is 1.06 nm (1.58 nm 90% c.l.)

⇒ Add Quad/Sbend Strength: Final average emittance growth is 2.01 nm (3.51 nm 90% c.l.)

⇒ Add Quad/Sbend Roll: Final average emittance growth is 5.36 nm (9.94 nm 90% c.l.)

4) BC1S, misalignment and couplers

- Vertical emittance along BC1S in case of misalignments
- Couplers kicks are considered



⇒ final emittance growth is 2.3 nm

Conclusions and Next Steps

- ILC RTML is in good shape, both RDR and SB2009
- Performances of the entire RTML have been evaluated, and resulted satisfactory

⇒ Integrated simulations of the entire RTML including bunch compressor are in progress

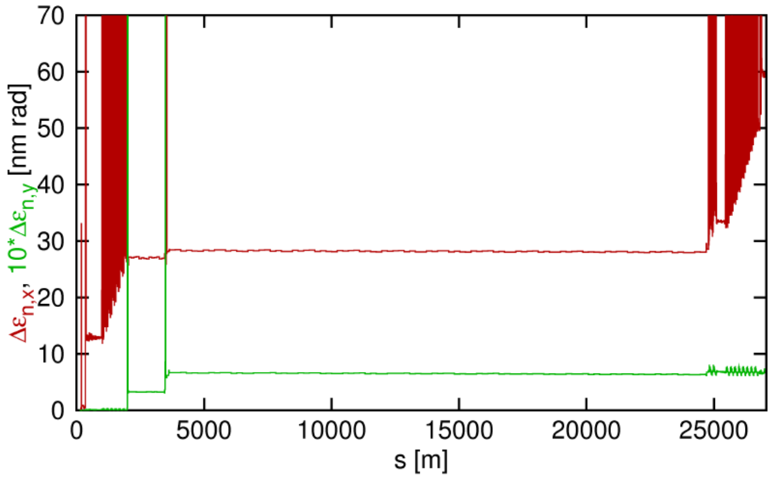
⇒ 90% CL emittances of the bunch compressors must be evaluated

- Dynamic Simulations must be performed

A. Latina

CLIC RTML

- Lattices have been created for the codes Elegant and Placet.
- Simulations are performed using a perfect lattice, i.e. no magnet misalignment, no magnet field errors, no incoming bunch jitter.
- The incoming bunch has a 6D Gaussian charge distribution.
- Single bunch wake fields and incoherent synchrotron radiation (ISR) are included. Emittance plot also includes coherent synchrotron radiation (CSR) (no shielding).

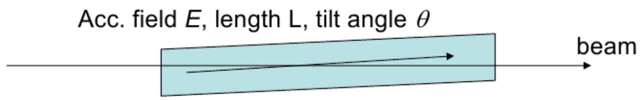


Growth of normalized emittances $\varepsilon_{n,x}$ (red), $\varepsilon_{n,y}$ (green) with single bunch wakes, ISR and CSR

- Agreement of Elegant and Placet is almost perfect.
- Performance of the perfect RTML is good.
- Largest emittance dilution due to ISR in arcs and loops.
- CSR in chicanes is second largest contribution. This could be improved by utilizing the shielding effect of narrow vacuum chambers.
- But before improving the perfect RTML we urgently need to study imperfections, i.e. magnet misalignment, magnet field errors, incoming bunch jitter, … and we have to study multi bunch wake fields.
- In previous studies we saw already that the error acceptance of the turn around loop was not sufficient. Its lattice has been improved, but there might be other surprises.

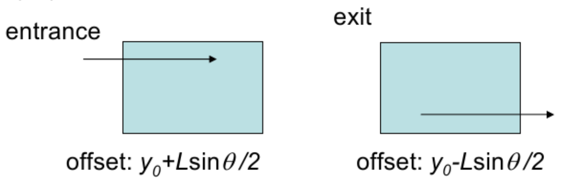
F. Stulle

Transverse effect of acc. field with cavity tilt



Transverse kick in the cavity: $\Delta pt = \sin\theta \, eV$

Edge (de)focus



Transverse kick at the entrance: $\Delta pt = -eE\,(y_0+\sin\theta\, L/2)/2$
Transverse kick at the exit: $\Delta pt = eE\,(y_0-\sin\theta\, L/2)/2$

→Total transverse kick by the cavity: $\Delta pt = \sin\theta\, eV/2$

Dynamic sources of orbit jitter and emittance growth

	Source	Assumption	Induced orbit	Induced emittance growth
RTML Return Line	Quad vibration (offset change)	10 nm	0.02 sigma	small
RTML Return Line	Stray field	2 nT (5 nT)	0.2 sigma (0.5 sigma)	0.15 nm (1 nm) in turnaround
ML	**Quad vibration (offset change)**	**100 nm**	**1.5 sigma**	**0.2 nm**
ML	**Quad+steering strength jitter**	**1E-4 (too big?)**	**1 sigma**	**0.1 nm**
ML	**Cavity tilt change**	**3 urad (too big?)**	**0.8 sigma**	**0.5 nm**
ML	**Cavity to cavity strength change, assuming 300 urad fixed tilt**	**1% (without correction in ML)**	**0.8 sigma**	**0.5 nm**
Warm sections	Quad strength jitter	1E-5	small	small

sigma: nominal beam size assuming $\gamma\varepsilon$ = 20 nm.

Summary

- Static alignment
  - Spec of local misalignment have been well studied and presented.
  - Long range alignment requirement has not yet specified.
    - Assumed to be OK (?). But we will need help from survey/alignment experts.
- Other static errors
  - Specs are presented, but have not studied in details.
  - Not considered to be serious problem.
- Dynamic errors
  - Specs (assumptions) and effects have been presented.
  - Some of them (e.g. RF jitter) are not easy but probably achievable.
  - Need post ML intra-pulse feedback.
  - (Dynamic error effects are dominant in BDS.)

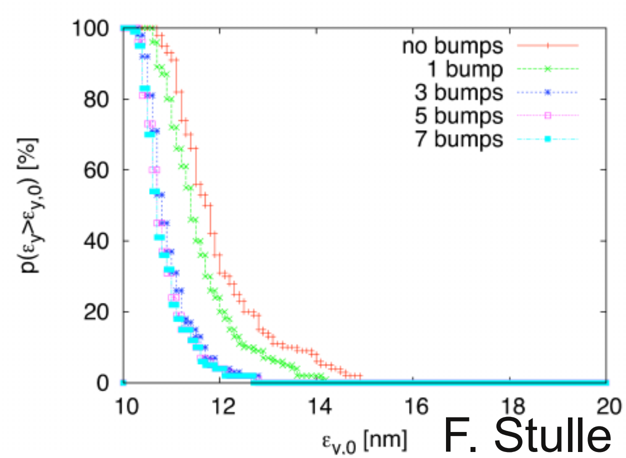
K. Kubo

CLIC Main Linac

- 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.

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

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



F. Stulle

CLIC Main Linac

D. Schulte, CLIC ACE May 2009:

- The first results of wire reference system look very promising
  - more complete studies to follow

- Feedback conceptual design is an important ingredient
  - main linac baseline feedback layout exists
  - BDS will follow soon

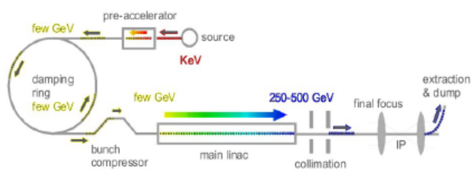
- Controler design
  - optimisation depends on noise model and feedback layout
  - knowledge of the system response is vital and is being studied

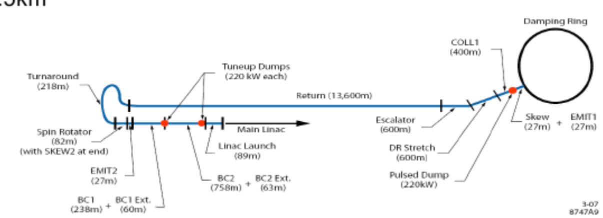
F. Stulle

ILC Integrated Simulations

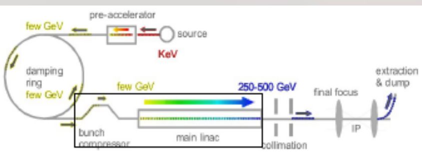
Start-to-end Simulations

- S-to-E: usually simulation from Damping Rings to Interaction Point (but it might include sources)
- RTML ~14km
  - Damping Ring Extraction ~200m
  - Escalator / Doglegs / Diagnostics ~1km
  - Return Line following the Earth curvature ~12km
  - Turnaround ~300m
  - Spin Rotator ~125m
  - Bunch Compressor(s) ~350m
- Main Linac ~11km
- Beam Delivery System ~2.5km
  - Collimation
  - Final Focus

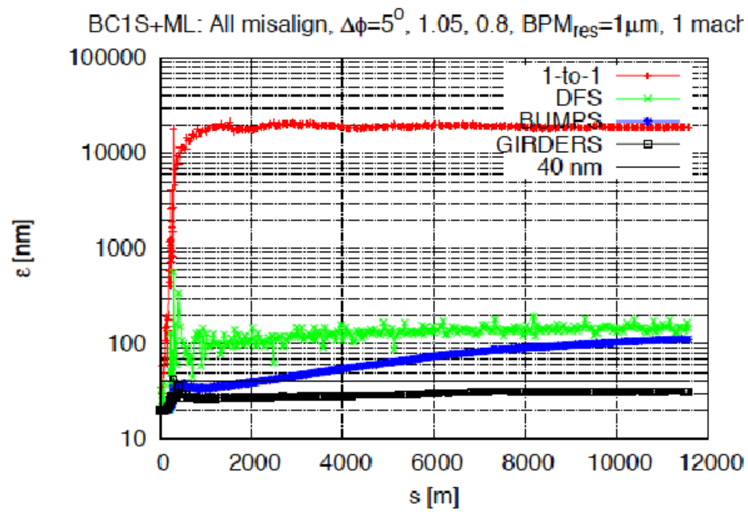




BC1S + ML



- Vertical emittance along BC1S+ML in case of misalignments
- Couplers kicks are not considered, wakefields are not considered

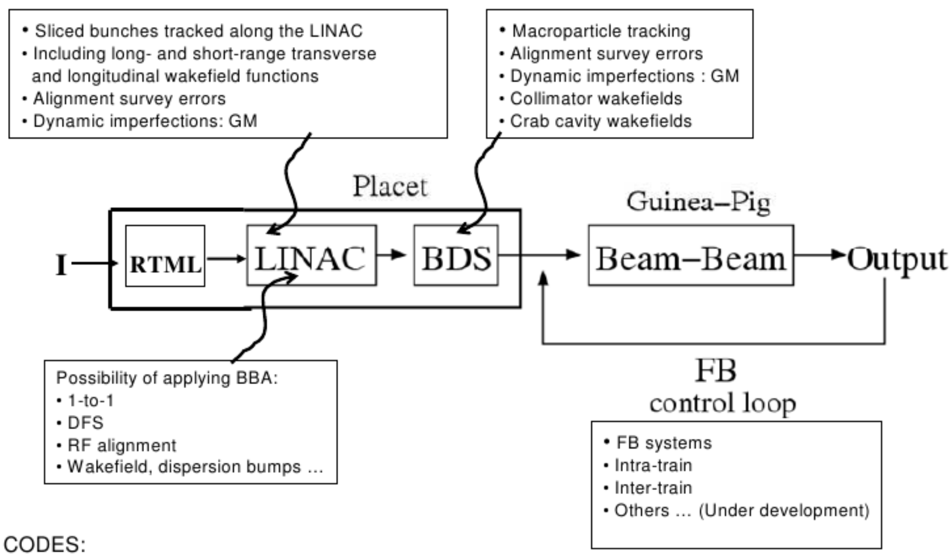


⇒ final emittance is 31.5 nm

A. Latina

CLIC Integrated Simulations

Simulation procedure



CODES:

PLACET: allows the simulation of the different LC subsystems in a modular fashion

GUINEA-PIG: performs realistic simulations of the beam-beam interaction

Summary

- The first steps towards a fully integrated start-to-end simulation of CLIC have been made

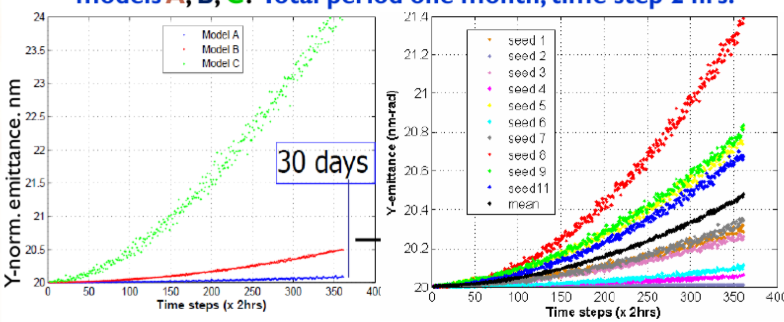
J. Resta Lopez

Feedback Studies

ILC Feedback System Studies

AA FB control for one month of GM.

Y norm. emitt. at the ML exit after 100 AA iterations for GM models A, B, C. Total period one month, time step 2 hrs.



Average of 10 GM seeds for each model . Convergence (gain) = 0.2;

Individual GM seeds for model B.

Individual variation for different seeds & GM models can affect substantially on beam emittance

N. Solyak

J. Pfingstner

Adaptive control scheme for the main linac of CLIC

Adaptive feedback strategy

- Good feedback needs very good system knowledge
- Accelerator behavior can change strongly during operation, due to the large phase advance

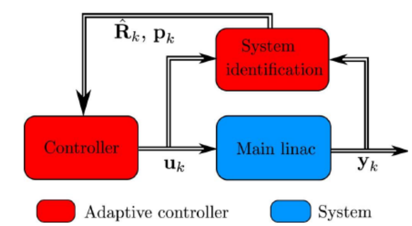
=> **Adaptive controller** (see [2])

1.) System Identification

- Establishes and updates on-line a model of the accelerator behavior

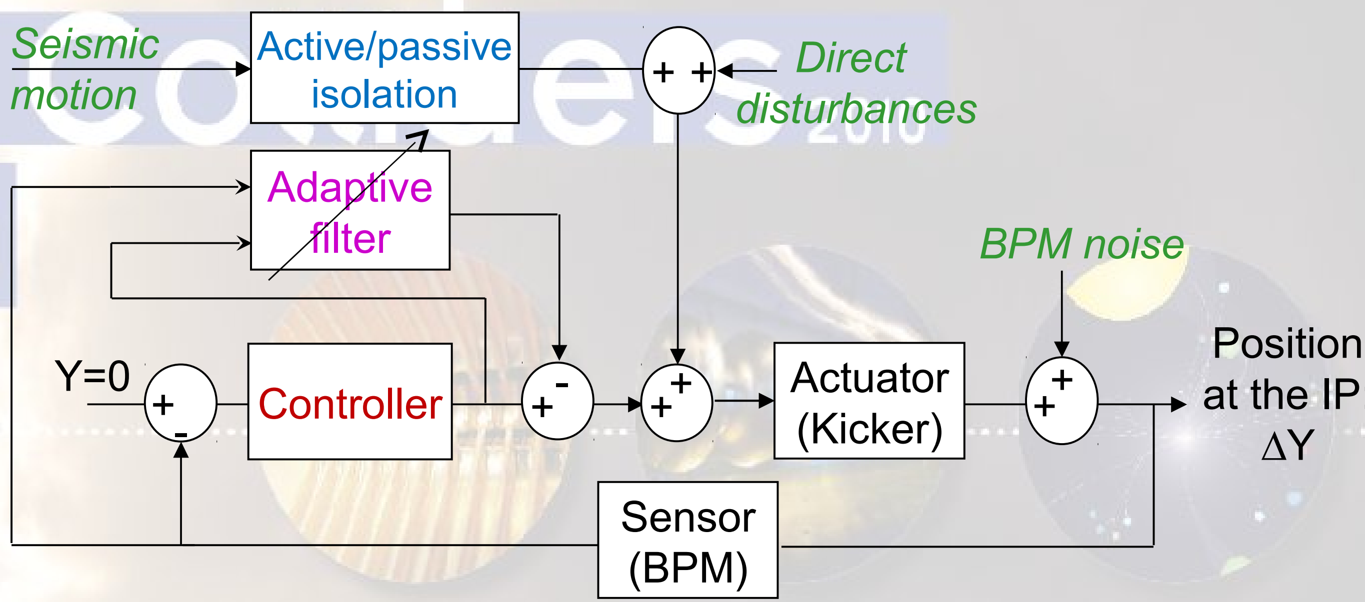
2.) Controller

- Uses the estimated system model, to optimally mitigate ground motion effects



Optimization of the final focus stabilization for CLIC

G. Balik



more Beam Dynamics Studies

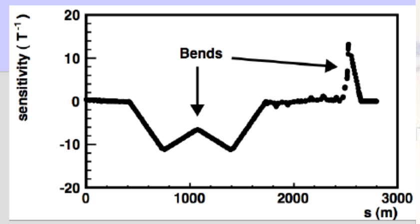
CLIC Magnetic Stray Field Studies

H. Garcia

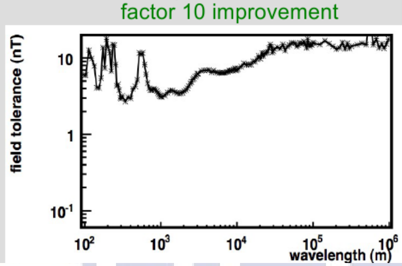
J. Snuverink

BDS: collimation bends

- BDS sensitivity caused by collimation bends
- Shielding these regions would reduce sensitivity factor 10
- Could be done with superconducting bends

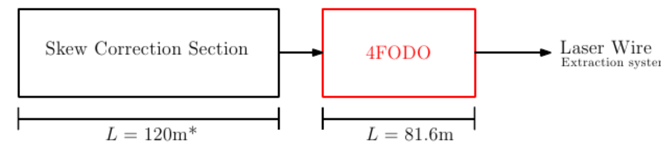


anti-symmetric wrt IP
factor 10 improvement

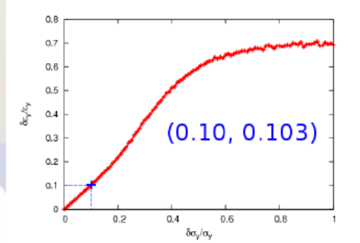


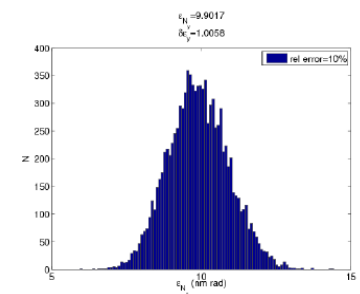
CLIC RTML Emittance Measurement

- Line proposal[2]:



- $\delta\varepsilon_x/\varepsilon_x = \delta\varepsilon_y/\varepsilon_y = 10\% \Rightarrow \delta\sigma_y/\sigma_y \approx 10\% \rightarrow \delta\sigma_y \approx 0.5\mu m$





Fast Beam-ion Instabilities

Vacuum Specifications in CLIC Main Linac

A. Oeftiger

FASTION code produces several output files, e.g.

- bunch by bunch offsets x, x', y, y' over whole train for all lattice points

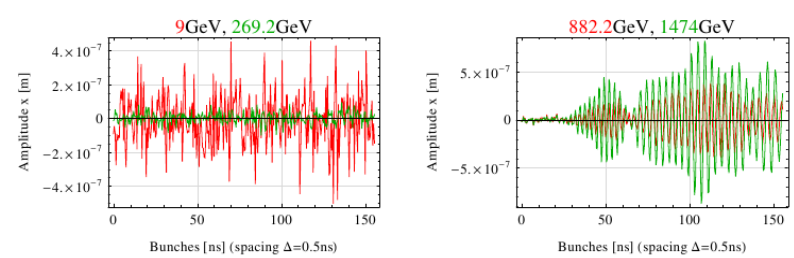


Figure: Bunch offsets – ion species: H_2O, pressure: 20nTorr

Summary / Outlook

- ILC and CLIC low emittance transports are well studied, some parts better (main linacs), some less (CLIC RTML).
- Studies are on-going (and shifting away from lattice design).
- But many issues still wait to be addressed.
- Though some challenges are unique for ILC, e.g. coupler kicks, or CLIC, fast beam ion instability, several challenges are of interest for both:
    - Magnetic Stray Fields
    - Feedback Design
    - Tuning Algorithms
    - Simulation Code Validation / Benchmarks
    - ...