TBL optics studies and automatic steering

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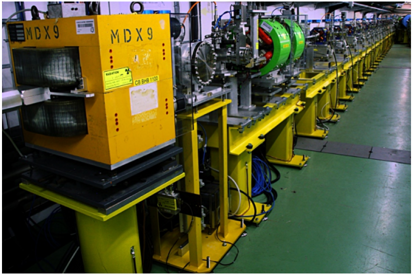
Acknowledgments to S. Döbert and R. Lillestøl and the CTF3 team

The Test Beam Line

- TBL is the first prototype of the CLIC decelerator.
- One of its goal is to demonstrate stable beam transport for a heavily decelerated beam.
- For more: "TBL status and results", S. Döbert, 29 Sep 11:30



TBL optics

- 8 FODO cells,
- 4 PETS in the first 2 FODO cells. Additional 4 PETS soon...
- one independent power supply per quadrupole allowing different gradient tapering scheme and phase advance,
- one BPM per quadrupole and one H/V movers per quadrupole for the maximum steering flexibility,

TBL beams with ϵ_n 150 mm mrad target

- 1x combination: 120 MeV, 3.5 A at 3 GHz,
- 4x combination: 120 MeV, 14 A at 12 GHz,
- 8x combination: 120 MeV, 28 A at 12 GHz.

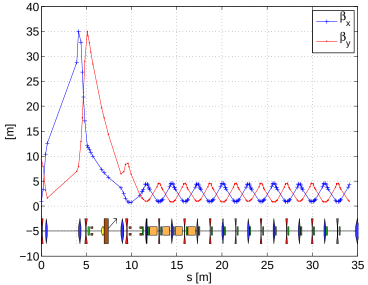


Figure: TBL optics, $\mu_{FODO} = \pi/2$.

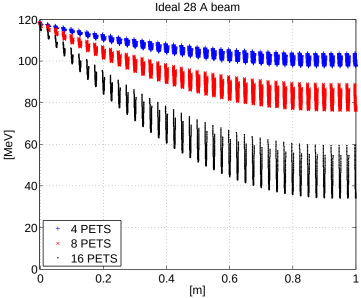


Figure: Induced beam energy spread.

Steering is important

- to test the CLIC BBA algorithms in CTF3.
- for TBL operation to improve the beam stability.

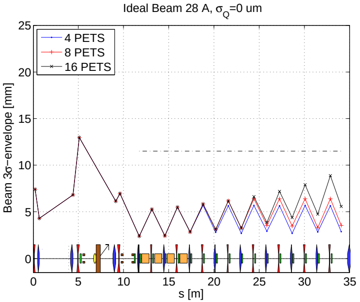


Figure: Ideally aligned quadrupoles.

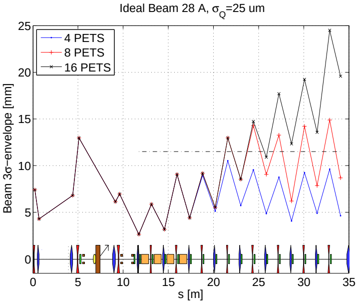


Figure: Misaligned quad's ($\sigma_q = 25\ \mu$m).

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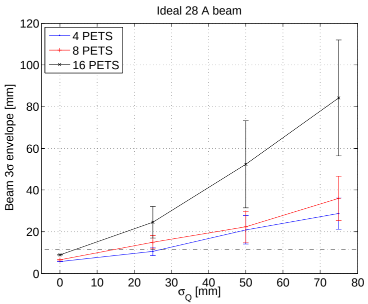
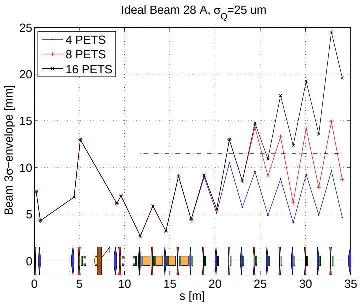


Figure: Envelope vs misalignment.



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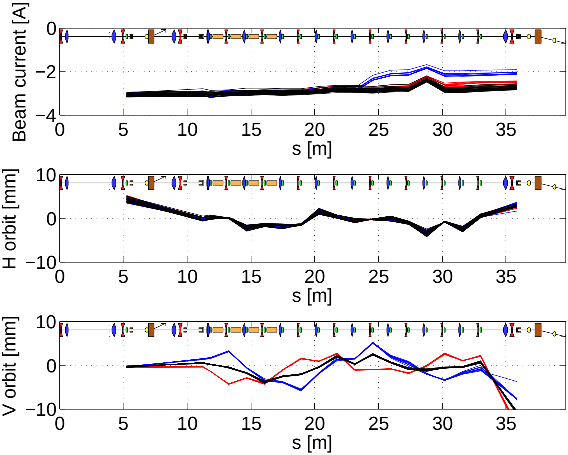
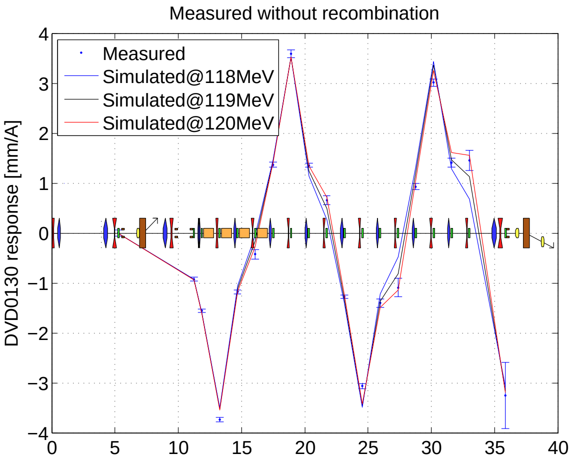
How we proceeded for the optics study...

We started by studying the response matrix measurements: this is usually done with uncombined beam (trade-off between stability and BPM SNR ratio).



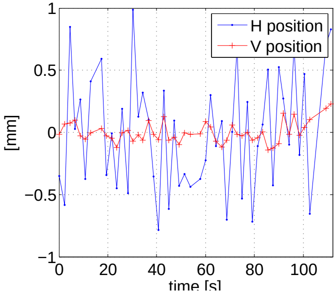
The linear optics is well under control...

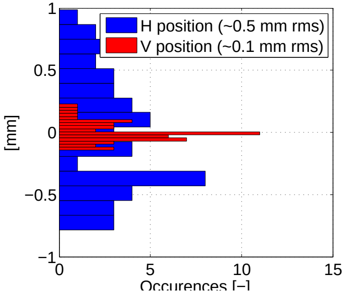
- good agreement between measurements and simulations
- Movers, BPMs, kickers polarities are ok (H and V planes).



A lot of (parasitic) information on...

- jitter of the incoming orbit: $\approx 0.5/0.1$ mm rms H/V





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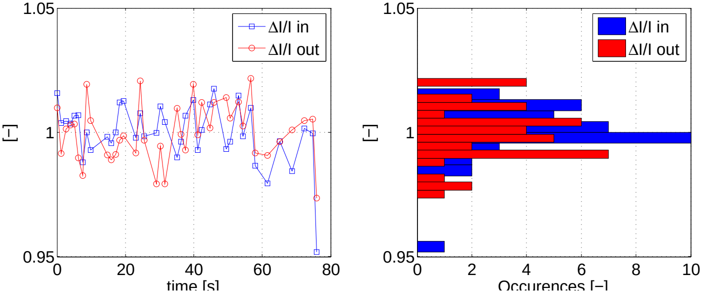
- jitter of the incoming orbit: $\approx 0.5/0.1$ mm rms H/V
- current stability at the TBL entrance/exit ($\approx 2\%$).



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- jitter of the incoming orbit: $\approx 0.5/0.1$ mm rms H/V
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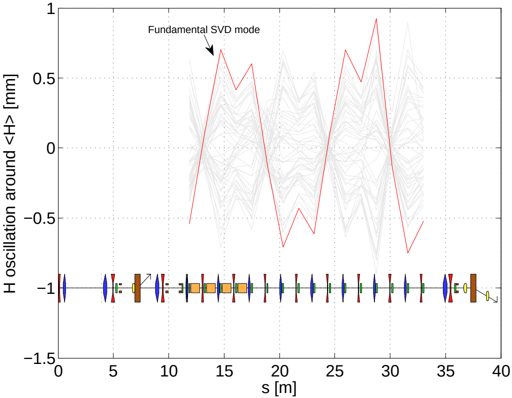
- SVD analysis to pin down betatronic modes.



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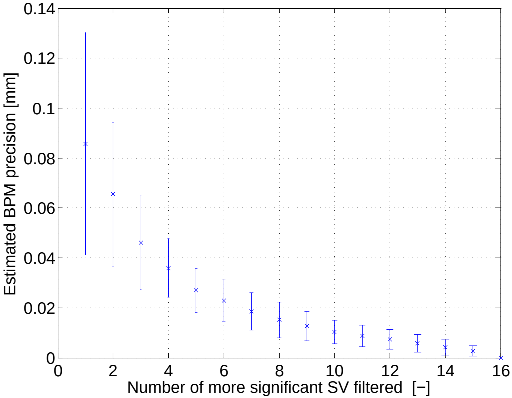
- SVD analysis to pin down betatronic modes.
- BPM precision estimation based on SVD.



Beam conditions: the beam is our instrument

- Orbit jitter and Energy jitter due to klystron (see T. Pettersson's talk)
- Emittance target of $\epsilon_n = 150$ mm mrad.

Hardware performance for measuring and correcting the orbit

- Bpm resolution (see S. Doebert's talk).
- Mover target resolution 5 μm.
- We do not start from a pre-aligned machine
- Quadrupole magnetization.
- Data acquisition systems.

Thanks to the CTF3 team for the work done/foreseen to improve the stability.

Measurement description

- 3 mover steps ($\pm$ 500μm).
- 2 quadrupole currents ($\pm$ 10%).
- 20 pulses at each step.

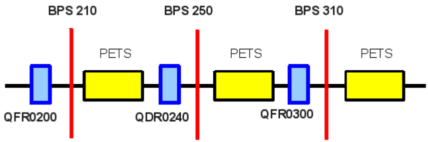


Figure: TBL schematic.

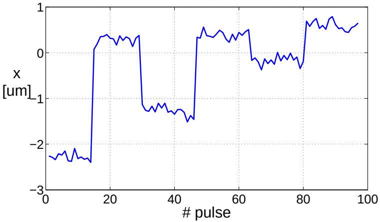


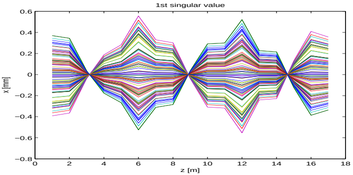
Figure: BPM measurement.

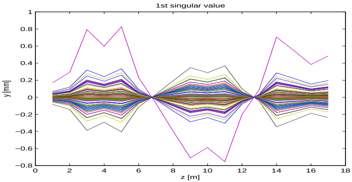
Synchronization

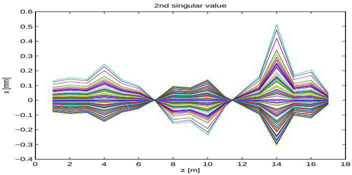
In order to analize properly the data, the pulses must be synchronized. Normally 80% of the pulses are synchronized.

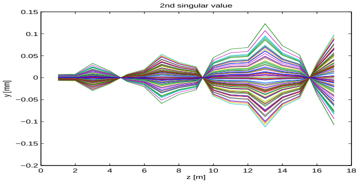
SVD analysis

The 1^{st} and 2^{nd} singular values may represent betatronic oscilations.









Collected measurements

MAGNET	OFFSET [μm]	
	DX [μm]	DY [μm]
QFR200	413±50	180±126
QDR240	626±36	813±136
QFR300	870±303	826±405
QDR340	1150±620	366±85
QFR400	460±31	217±70
QFR440	305±67	285±43
QFR500	990±353	583±152
QFR540	237±136	412±238

Average offsets:

Horizontal plane:
x_0=631 ± 200 μm

Vertical plane
y_0=460 ± 160 μm

Iteration process

NOTE: The mover range and the magnet current variation are optimized in order improve the measurement resolution.

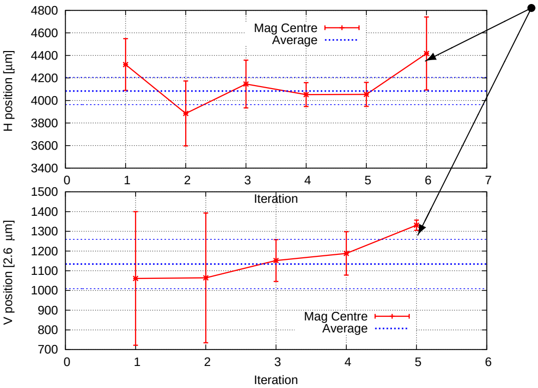


Figure: Iteration process.

Current change 20%

Final offsets:

Horizontal plane:
x_0=252 $\pm$ 106 μm

Vertical plane:
x_0=194 $\pm$ 26 μm

The 1-to-1 steering in TBL

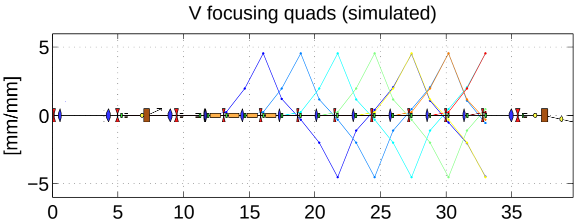
- Applying to CLIC decelerator the Quadrupole Shunting method is time consuming and HW limited: 1-to-1 is envisaged as a 1st BBA step.
- In principle, assuming that we know the linear response of the mover/BPM and assuming the BPM signal is due only to the movers misalignment, we can center the orbit wrt the BPM center.
- The 2nd stage of the alignment is to minimize dispersion (DFS, not yet applied in TBL).

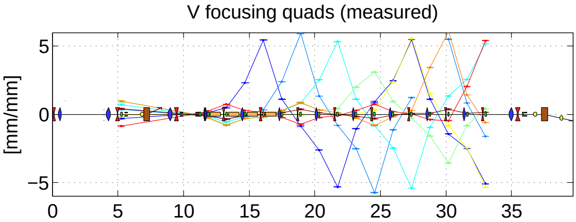
I present here results and limitations of the 1-to-1 steering in TBL

1. linear model of the system $\rightarrow \Delta X_{BPM} = R \times \Delta X_Q$
2. identification of the system $\rightarrow \Delta X_Q = R^+(n_{SV}) \times \Delta X_{BPM}$
3. correction $\rightarrow X_Q^{NEW} = X_Q^{OLD} - \Delta X_Q$

Response matrices...

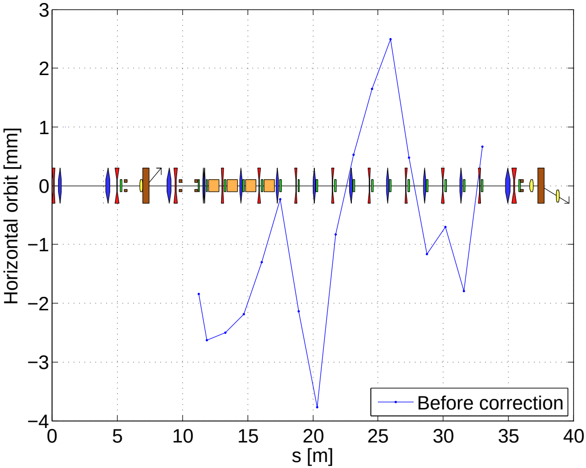
The agreement between the model and the measurements is good and mainly limited by the precision of the response matrix measurements (dominated by the incoming beam non idealities).





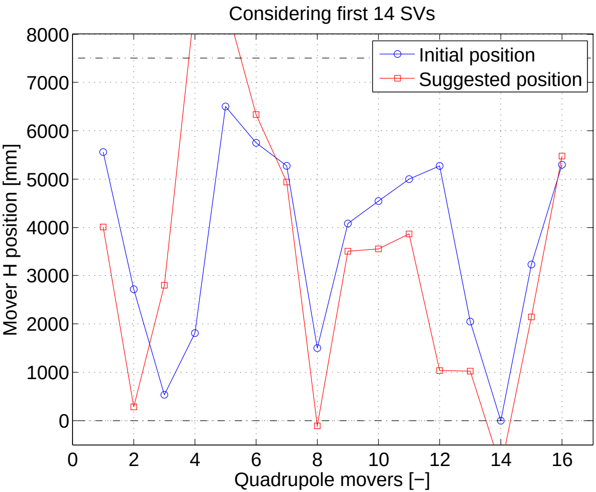
An example of orbit before alignment...

After the alignment we expect to observe a similar signals on the first BPMs.



How do we chose the parameter n_{SV} of $R^+(n_{SV})$?

In general is driven by the BPM precision, in TBL is driven by the movers range.



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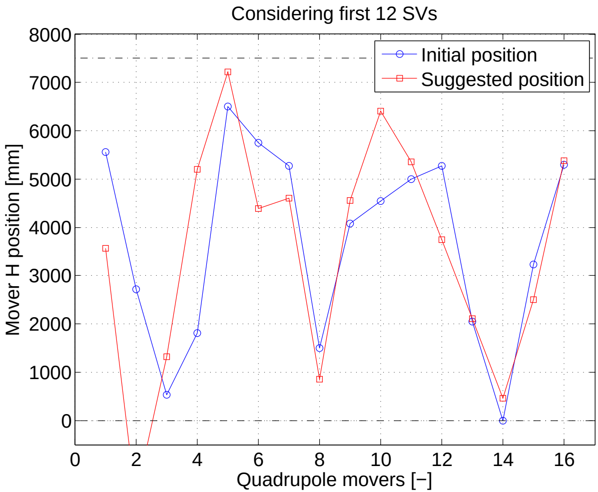

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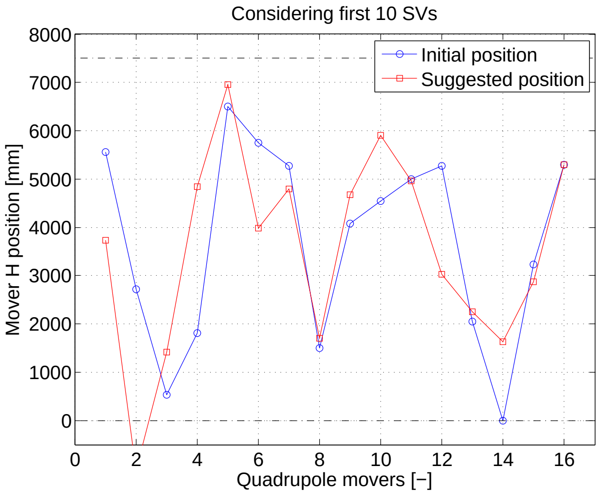

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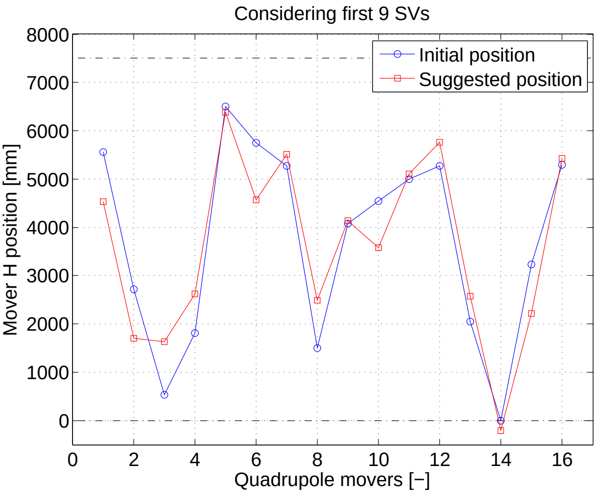
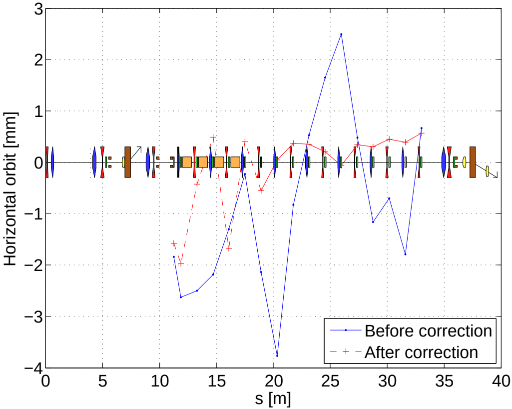


The incoming mis-steering is dumped by the correction.

The damping length depends on the n_{SV}. In our case is $n_{SV} = 9$.

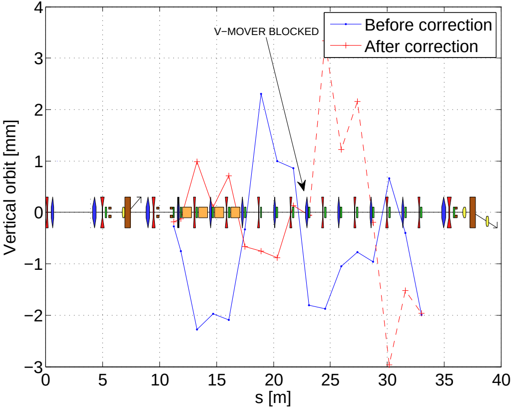
	Before	After (last 11 BPMs)
Mean [mm]	-0.90	0.22
RMS [mm]	1.65	0.31



On the V plane...

RMS reduced up to the mover that is blocked after we see the induced oscillation.

	Before	After (first 10 BPMs)
Mean [mm]	-0.69	-0.07
RMS [mm]	1.30	0.61



Conclusions

- TBL is a unique opportunity to test the CLIC decelerator beam physics: with 16 PETS installed a BBA algorithm is required to transport the 28 A beam.
- The measured linear optics agrees with the model within the measurements errors dominated by the machine jitter.
- An iterative quadrupole shunting method to center the quadrupole on the beam a precision of 106/26 μm in the H/V plane.
- The 1-to-1 steering allows to reduce the RMS orbit from
  - H plane: 1.65$\longrightarrow$ 0.31 mm
  - V plane: 1.30$\longrightarrow$ 0.61 mm.

  There still a long way to go: the goal is the DFS.

Plans

- To stabilize the incoming orbit slow drift and center the beam orbit with a orbit feedback in front of the TBL FODO lattice.
- To repeat the Quadrupole shunting and the 1-to-1 steering after the new pre-alignement of the line.
- To test the DF steering.