Beam-based alignment in CLIC RTML

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November 3, 2015

LCWS 2015 - Whistler BC, Canada

Ring To Main Linac(RTML) [?]

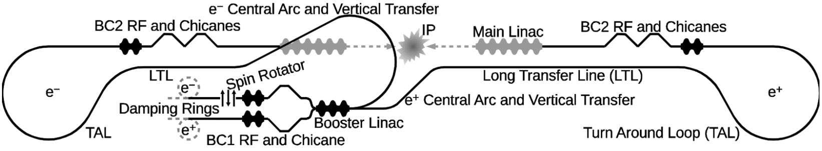


Figure: Sketch of RTML

- RTML connects the damping rings and the main linac
- Match beam properties, like bunch length and energy
- Two RTMLs with total length of approximately 27 km for each

Table: Beam properties at the start and end of the RTML for 3 TeV machine

Properties [unites]		Value at the start	Value at the end
Particle energy [GeV]	E_0	2.86	9
r.m.s. bunch length [μm]	σ_s	1800	44
r.m.s energy spread [%]	σ_E	0.12	1.7
Normalized emittance [nm rad]	$\epsilon_{n,x}$	500	≤ 600
	$\epsilon_{n,y}$	5	≤ 10

Beam-based Alignment in the Turnaround Loop (TAL)

The TAL is split in bins. Generally, each bin contains 8 cells with 4 cells overlap with the neighbor bins. Each cell is 31 m long, phase advance is 432° in the horizontal plane and 144° in the vertical plane.

The turn-left arc is split into 2 bins. First bin contain 8 cells and second bin contain other 2 cells with 4 cells overlapping with the first bin.

The matching lattice is one bin

The turn-right arc contains 9 bins

Simulation setup:

- All Quadrupoles and BPMs are misaligned.
- BPM resolution is 1 $\mu\mathrm{m}$
- The inject beam is the ideal beam at the start of TAL.
- Test beam with 0.5% energy difference is used to get dispersion.
- One-to-One and Dispersion-free Steering (DFS) are applied.

Average emittance growth along the TAL lattice

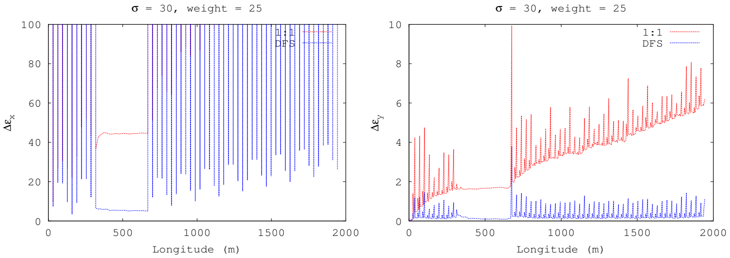


Figure: Emittance growth along the lattice

One-to-one improves the emittance. DFS is very effective.

- $\sigma_{\mathrm{pos}} = 30\mu\mathrm{m}$, $\sigma_{\mathrm{res}} = 1\mu\mathrm{m}$
- The fluctuation on horizontal plain is due to the bend magnet which introduce large dispersion.
- For the vertical emittance, we take last valley instead of final emittance.

TAL: Histogram of the emittance growth

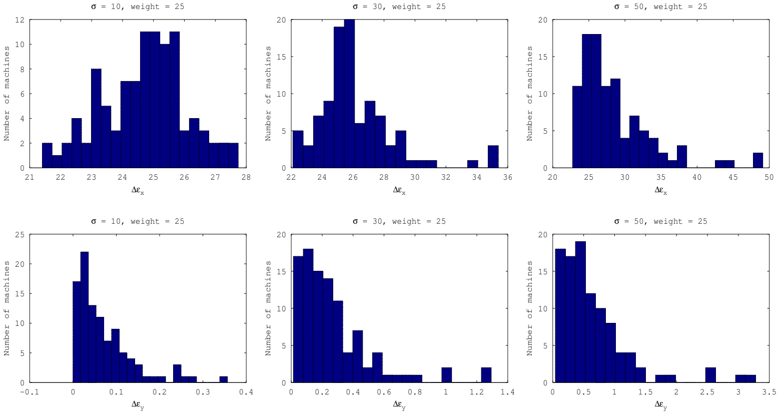


Figure: Number of machines v.s. emittance growth

DFS works well.

- All machines stay in the budget on horizontal direction for $\sigma_{\mathrm{pos}} = 50\mu\mathrm{m}$
- Some machines (less than 10%) go out the budget on vertical direction for $\sigma_{\mathrm{pos}} = 30, 50\mu\mathrm{m}$

Previous result on TAL — Emittance growth v.s. $\sigma_{\rm pos}$

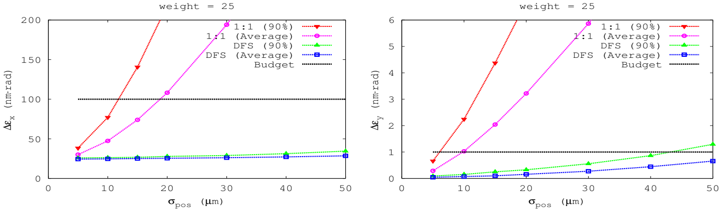


Figure: Emittance growth for different misaligned $\sigma_{\rm pos}$

- The DFS can align the quadrupoles and BPMs on horizontal direction up to $50\mu\mathrm{m}$
- If $\sigma_{\rm pos} < 40\ \mu\mathrm{m}$, DFS can also align the lattice within $\Delta\epsilon_y < 1\ \mathrm{nm}\cdot\mathrm{rad}$.

Four parts RTML setup

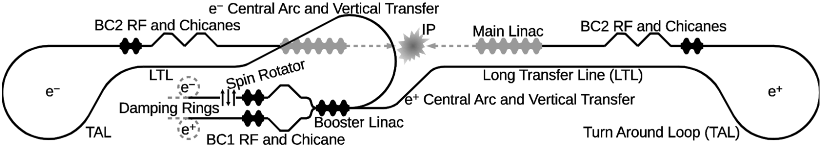


Figure: Sketch of RTML

Previously, RTML lattices were divided into four parts due to RF wakefield setup. Each part begun with an RF cavity.

- SR
- BC1
- Booster linac, CA, VT, LTL, TAL
- BC2

This was convenient for the wakefield definition, but complicated start-to-end simulations.

Integrated RTML to one beamline

In order

- to perform BBA in the whole RTML
- to apply global coupling correction using skew quadrupoles

we have needed to integrate the RTML into a single lattice file.

Differences:

- In the four part setup, beam can be injected four times. Wakefields are setup dynamically when inject the beam.
- Now we can only inject beam once, the wakefield must be setup statically.

Solution: Use Splines to define the wakefields.

- Calculated the wakefield and save them to disk file
- Create the Spline for transverse and longitudinal plane respectively
- Create the short-range wakefield
- Assign the short-range wakefield to RF cavity.

BBA on the whole RTML until BC2

All quadrupoles and BPMs are misaligned with $\sigma_{\rm pos} = 30\ \mu{\rm m}$. BPMs have a resolution 1 $\mu{\rm m}$. Dipole correctors are added to each quadrupoles.

RTML is to divided to 8 subsections: SR, BC1, BOO, CA, VT, LTL, TAL and BC2.

TAL is very long, so it is divided to TAL1 and TAL2 at the straight part.

Overlaps between each subsections, allow to smoothly correct the beam at the interfaces.

One to one and DFS corrections are applied.

For the DFS, we need to know the dispersion response property.
Two steps:

- Use test beam with different energy — This is simple in simulation but we can not do this at real machine.
- Scale the lattice.

Test beams for DFS

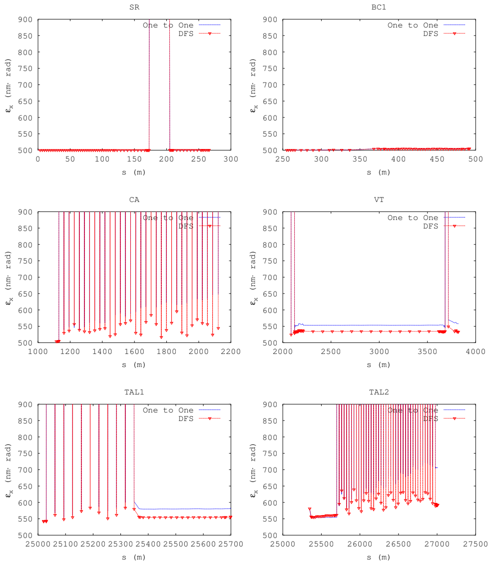
- Test beams in SR, BC1, CA, VT, LTL and TAL are obtained simply changing the beam energy at the beginning of each subsection.
- Test beam in BOOster is obtained by reducing the RF gradient.

The energy differences are 0.5%, 1.0%, 5.0%, 0.5%, 5.0%, 5.0%, 0.5%

The weight factor we used is 30 ($\omega^2 = \frac{\sigma_{\mathrm{pos}}^2+\sigma_{\mathrm{res}}^2}{2\sigma_{\mathrm{res}}^2}$).

Let us see the result — the average horizontal and vertical emittance along the lattice.

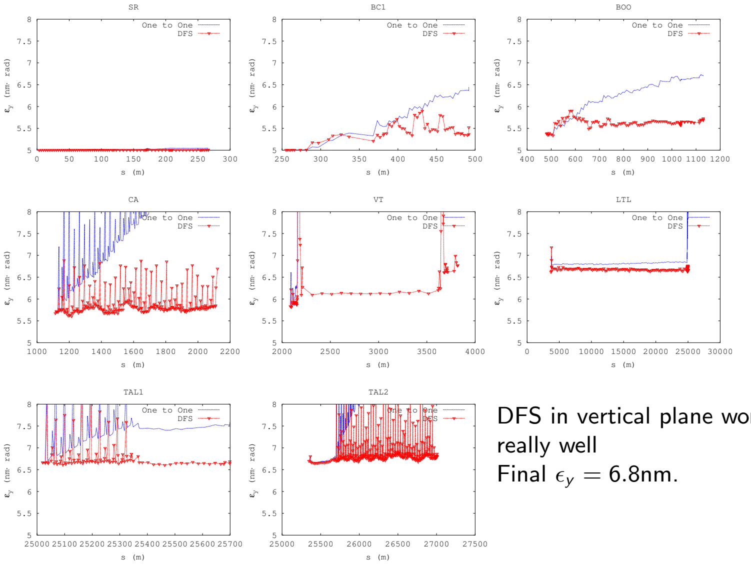
Horizontal emittance along the lattice — change energy



Final $\epsilon_x = 592 < 600$nm.

Figure: Average horizontal emittance along the lattice

Vertical emittance along the lattice — change energy



DFS in vertical plane works really well
Final $\epsilon_y = 6.8$nm.

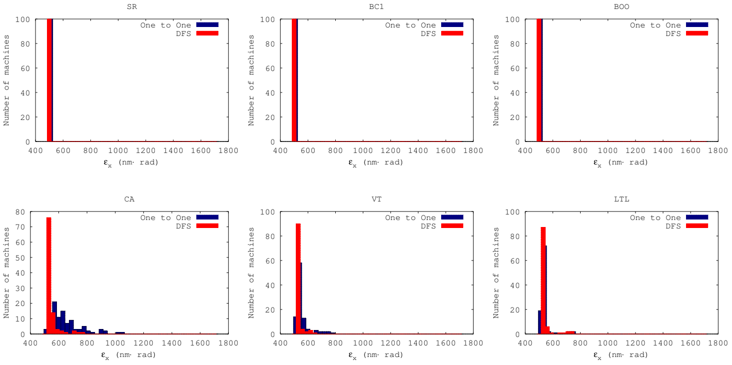
Figure: Average horizontal emittance along the lattice

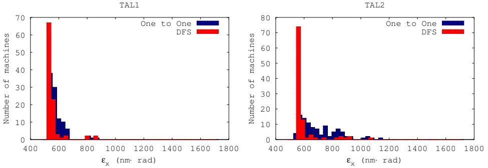
The result means that BBA works really well in the vertical plane. Whereas in the horizontal plane, the performances need to be improved.

By checking every simulated machine, we find that for most machines, DFS works. But in some machines DFS works really bad — even worse than 1:1 correction.

Number of machine v.s. horizontal emittance — Test beam

If DFS work bad, use 1:1





The large emittance growth for DFS in TAL2 disappeared.

Figure: Number of machines v.s. horizontal emittance growth

Number of machine v.s. vertical emittance — Test beam

If DFS work bad, use 1:1

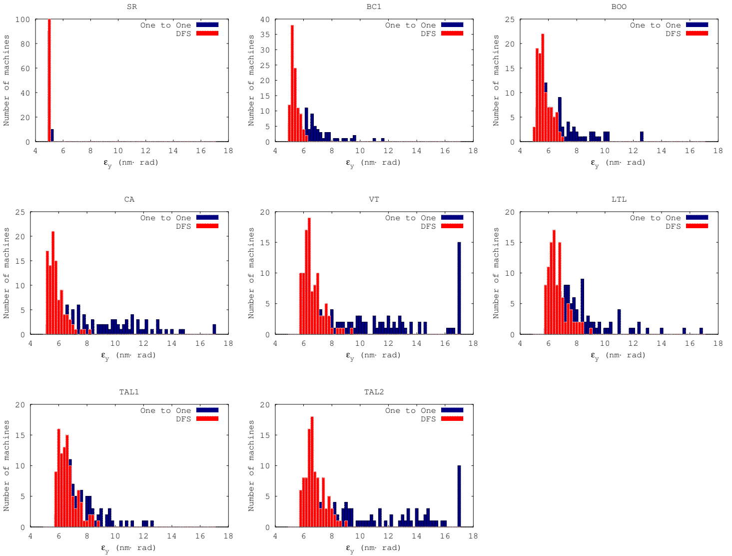


Figure: Number of machines v.s. vertical emittance growth

Get Dispersion by scaling the lattice

In real machine, it is impossible to get the test beam with different energy easily, especially for SR, CA, VT, LTL and TAL.

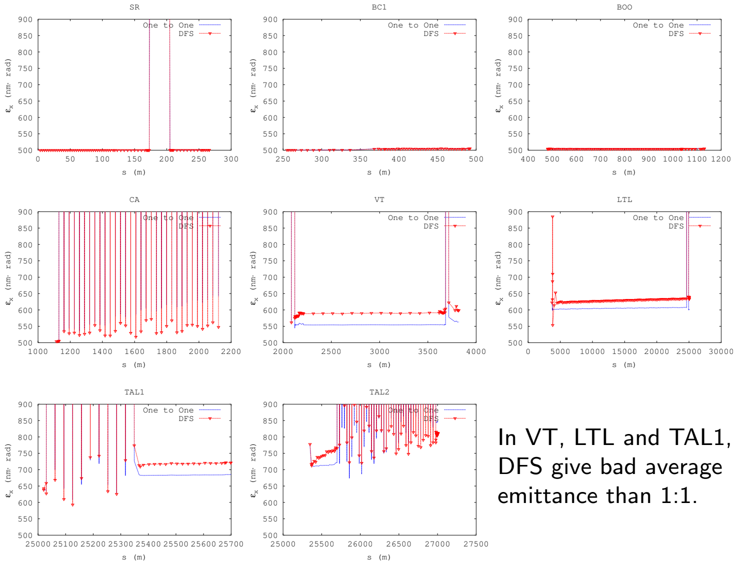
So we must use other method to create dispersion — Scale the lattice strength.

- Quadrupole - scale the strength by $1/(1+\delta)$
- Sextupole - scale the strength by $1/(1+\delta)$
- Sbend - scale the reference energy by $1/(1+\delta)$

It is important that the strength the dipole correctors should also be scaled when applying the DFS.

Let us see all results from the scaled-lattice dispersion

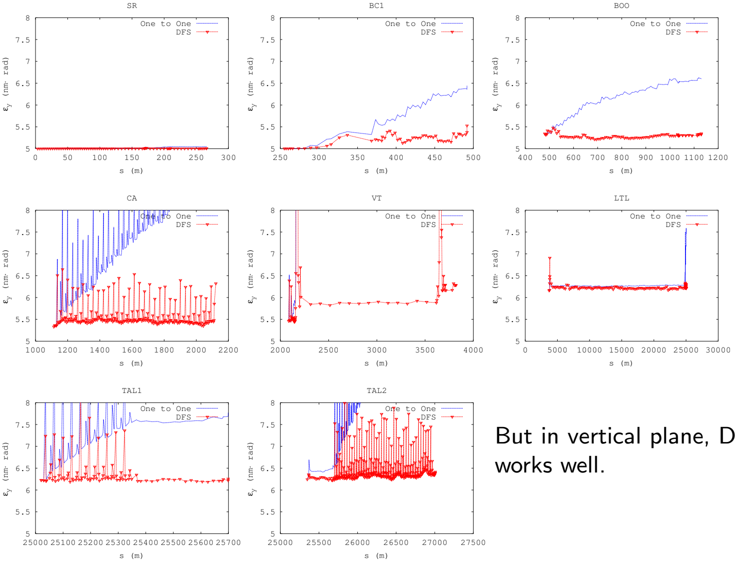
Horizontal emittance along the lattice — scale lattice



In VT, LTL and TAL1, DFS give bad average emittance than 1:1.

Figure: Average horizontal emittance along the lattice

Vertical emittance along the lattice — scale lattice



But in vertical plane, DFS works well.

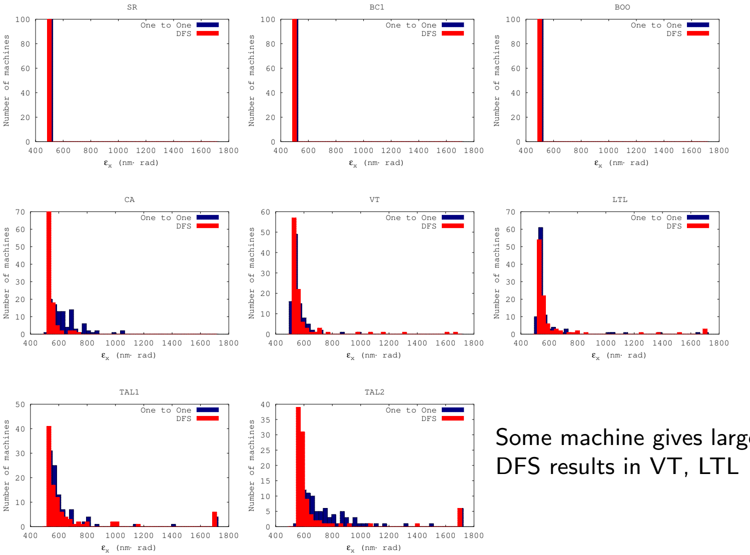
Figure: Average vertical emittance along the lattice

DFS works bad in later part of RTML. This may due to:

- The response matrix got by the scaled lattice is not the real response matrix of our machine, though the difference should be small when δ is small.
- There are some random seeds, the DFS works really bad.

Let us check the machine distribution

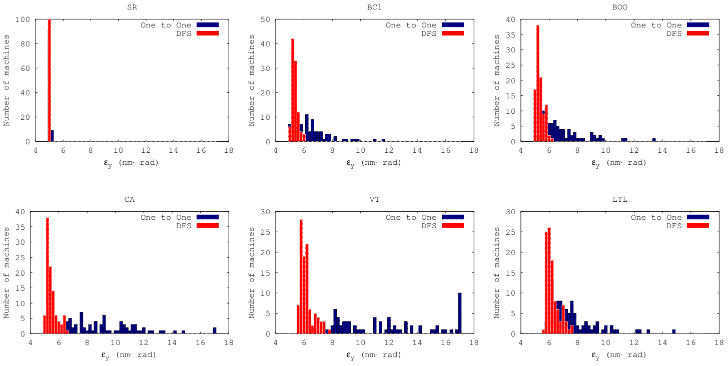
Number of machine v.s. horizontal emittance — scale lattice

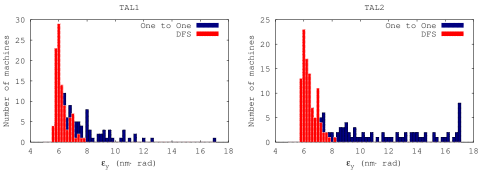


Some machine gives large DFS results in VT, LTL

Figure: Number of machines v.s. horizontal emittance growth

Number of machine v.s. vertical emittance — scale lattice



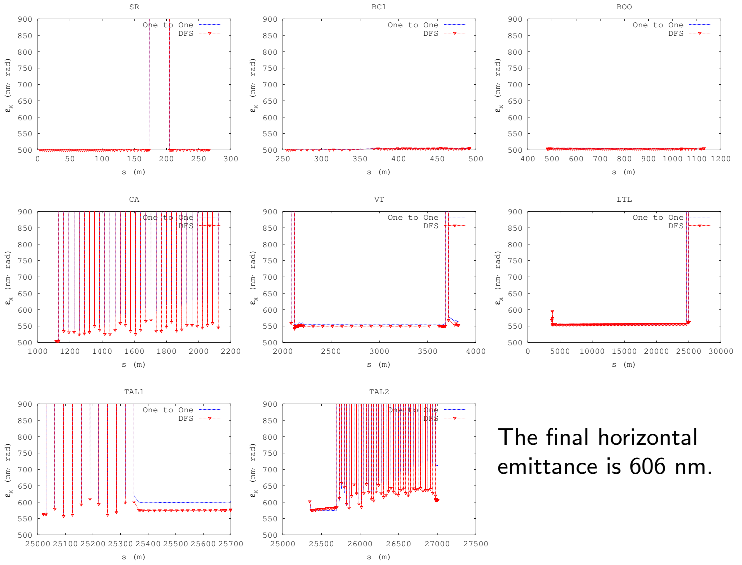


But in vertical plane, DFS works well.

Figure: Number of machines v.s. vertical emittance growth

We still do the test simulation: For horizontal plane, if DFS works worse than 1:1, then use the 1:1 result.

Horizontal emittance along the lattice — scale lattice



The final horizontal emittance is 606 nm.

Figure: Average horizontal emittance along the lattice

Vertical emittance along the lattice — scale lattice

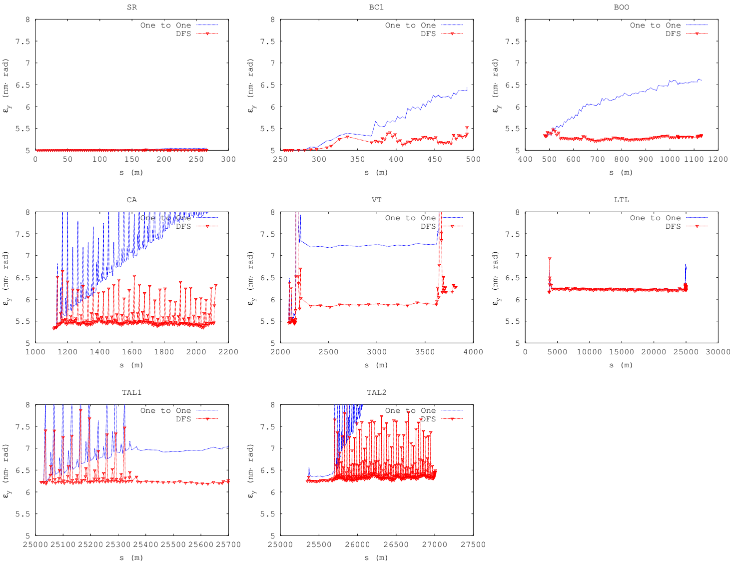
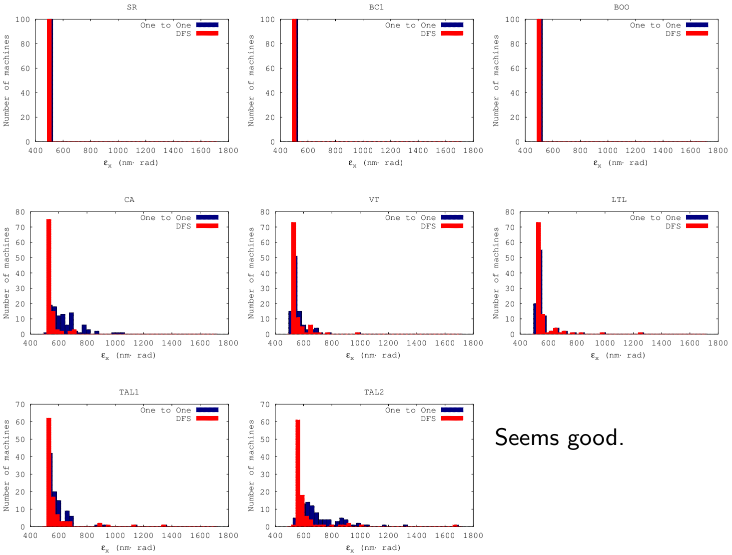


Figure: Average horizontal emittance along the lattice

Number of machine v.s. horizontal emittance — scale lattice



Seems good.

Figure: Number of machines v.s. horizontal emittance growth

Number of machine v.s. vertical emittance — scale lattice

If DFS work bad, use 1:1

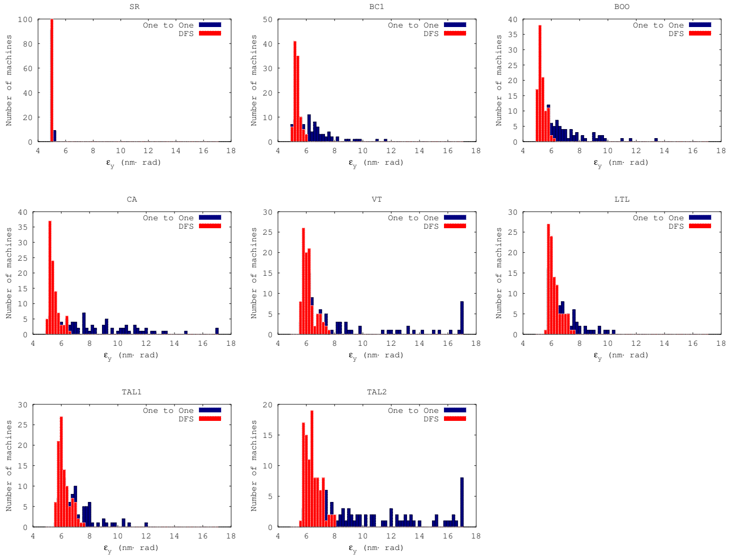


Figure: Number of machines v.s. vertical emittance growth

Conclusion

- The RTML is integrated to one beamline now, so we can do the whole RTML BBA conveniently..
- Using the test beam method, we managed to got the average emittance $\epsilon_x = 592$ and $\epsilon_y = 6.86$ nm at $\sigma_{\text{pos}} = 30\mu\text{m}$
- The results from the scaled lattice are $\epsilon_x = 606$ and $\epsilon_y = 6.49$ nm at $\sigma_{\text{pos}} = 30\mu\text{m}$

But we know there are some machines are not corrected well, we can focus on these bad machines.

We need to understand why some some machines works badly.

Thank you!