Beam Delivery System Tuning and IP Feedback Simulations

Ryan Bodenstein

University of Oxford – John Adams Institute

CLIC UK – January 10, 2017

University of Oxford

Before I begin…

- It should be noted that I did not work alone on these tasks.
  - In the past, I worked with Jochem Snuverink (now at PSI) for both tuning and IP Feedback
  - Currently, I work with Edu Marin Lacoma for tuning, recycling many of his codes.

What will I be talking about?

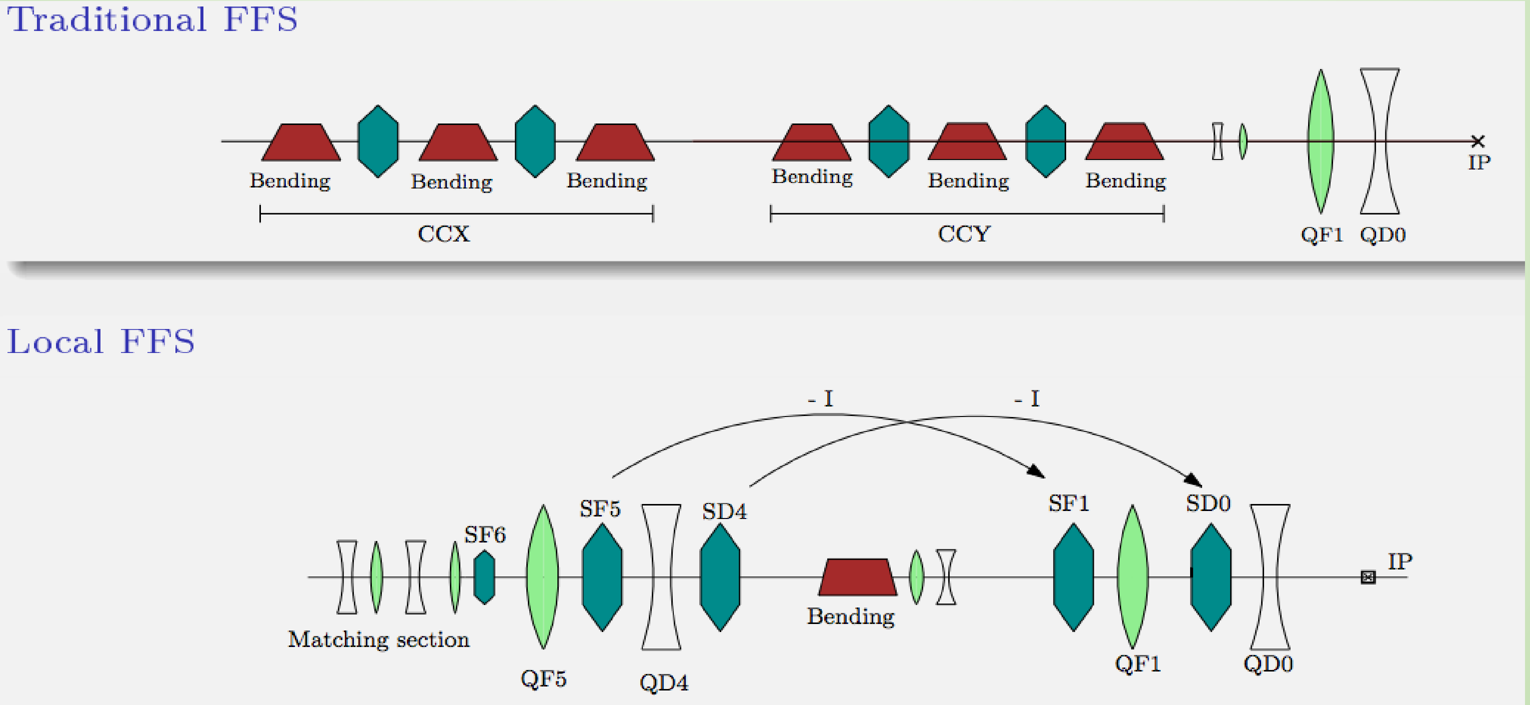
- Bit of background on the beam delivery system (BDS) of CLIC
- Development of new tuning procedures and changes to the lattice
- In-progress tuning work
- Previous IP Feedback simulations
- In-progress IP Feedback simulations

First up, single-beam tuning

- This tuning is for the 3 TeV “Traditional” final focus system
- At this point, the only imperfections applied to the beamline are static offsets in the transverse directions
  - Beam position monitor (BPM) resolution assumed to be 10 nm
- Two-beam tuning to be investigated once single-beam tuning goals reached

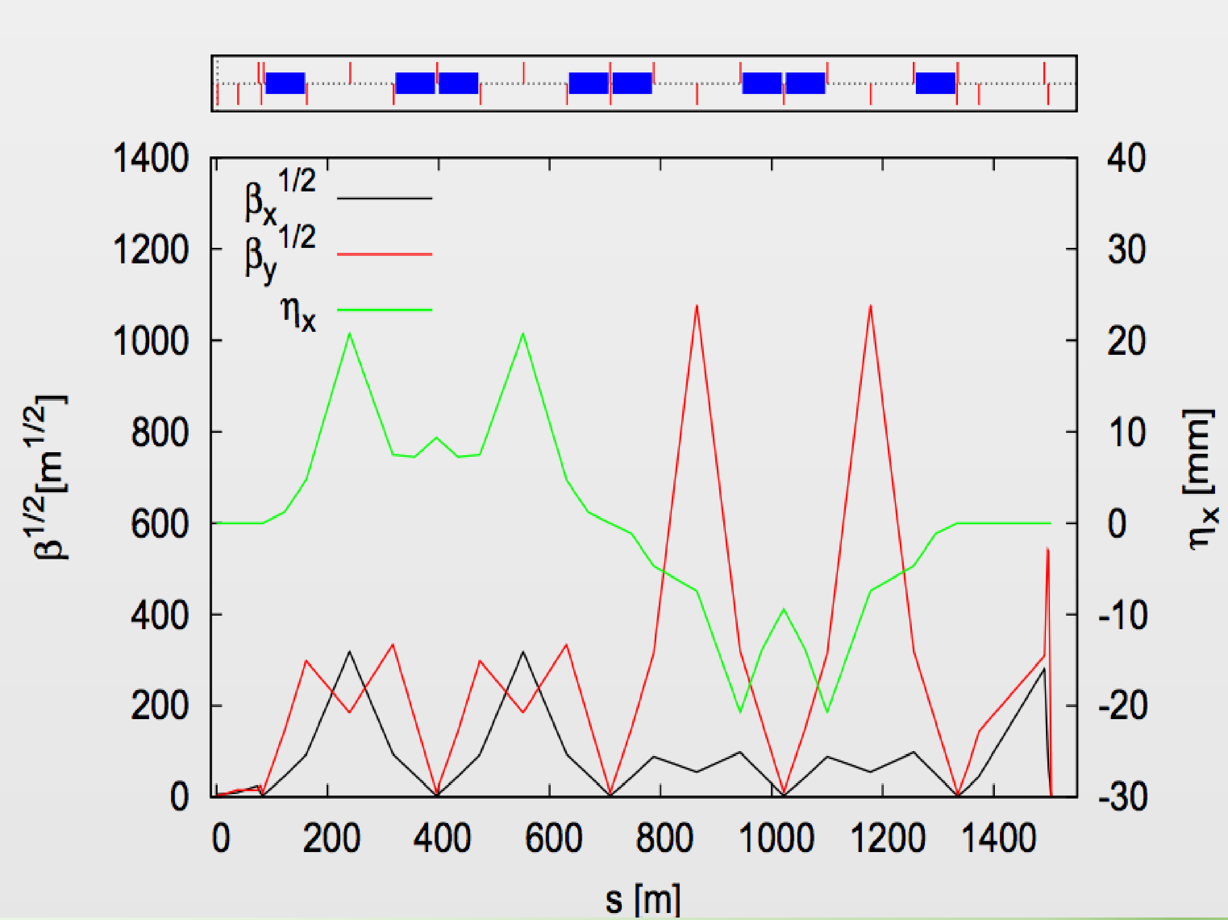
Some background

- Two separate sections for chromaticity correction
- Lattice by Hector Garcia, see e.g. his talk at CLIC WS 2014
- Relatively simple system for design and analysis



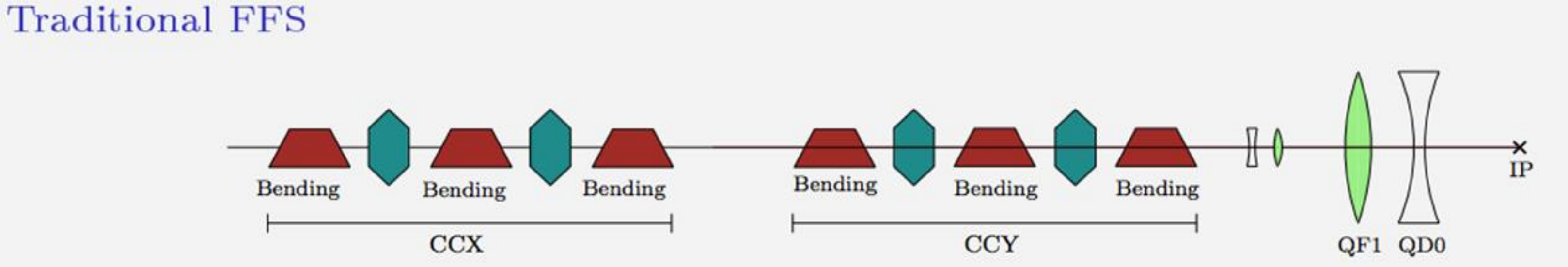
Traditional Final Focus

Parameter	Unit	Traditional "Optimized"	Local
Length	m	1460	450
Total Luminosity	$cm^{-2}s^{-1}$	$7.5 * 10^{34}$	$7.8 * 10^{34}$
Peak (1%) Luminosity	$cm^{-2}s^{-1}$	$2.4 * 10^{34}$	$2.4 * 10^{34}$



Optimized lattice achieves similar luminosity as local scheme.

Historical Tuning Procedure



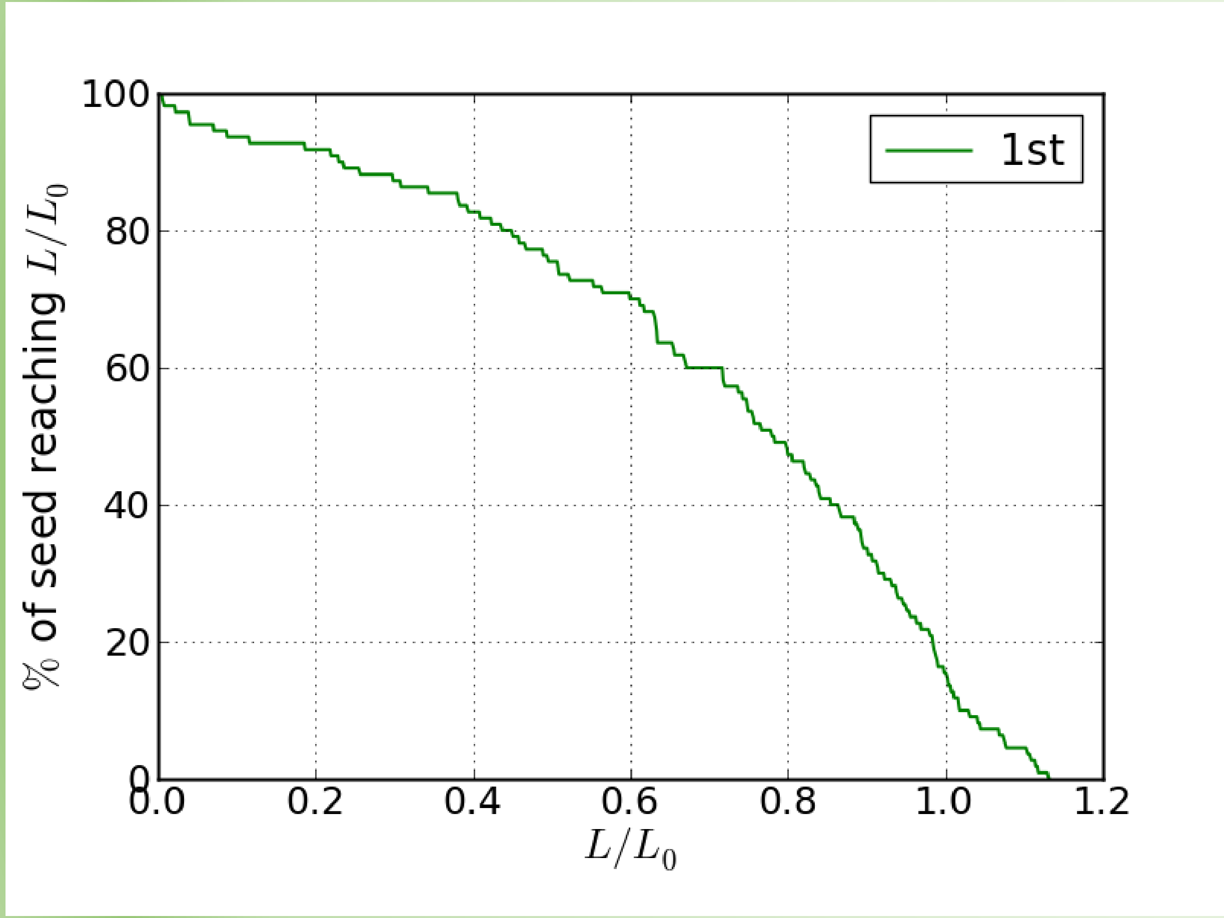
- Looking at the traditional final focus system, with 3 TeV collision energy.
- Simulations using PLACET and GUINEA-PIG
- Apply static offsets in x and y plane (10 µm RMS, 10 nm BPM resolution), then:

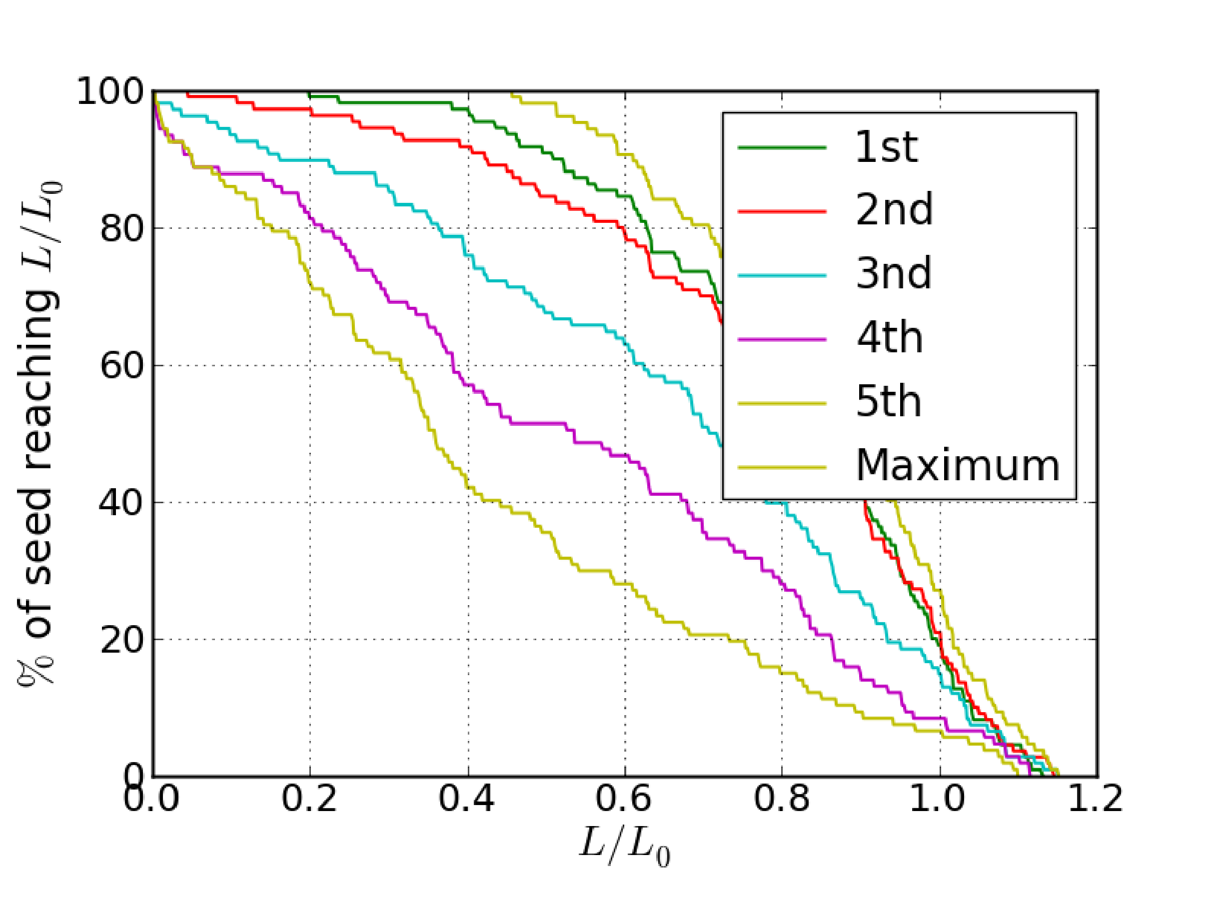
1. **1-2-1 Tuning** — First step applied to uncorrected beam
2. **Dispersion Free Steering – 1** — Bring dispersion to design values
3. **Tuning Knobs – 1** — Maximize Luminosity
4. **Dispersion Free Steering – 2** — Bring dispersion back toward design
5. **Tuning Knobs - 2** — Final shot to maximize Luminosity

Unfortunately, this isn't enough.

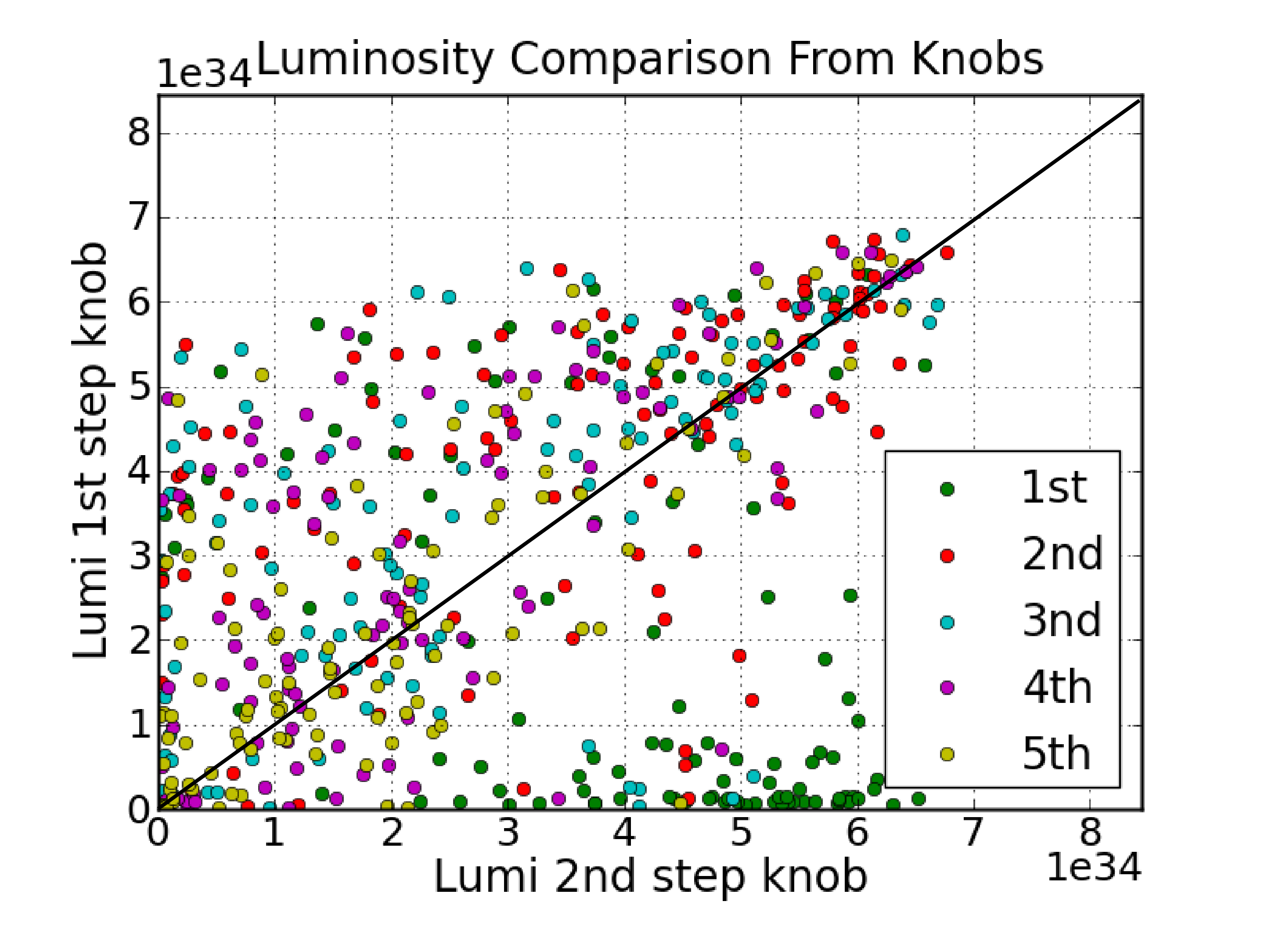
The goal is for 90% of seeds to reach 110%.

Doing multiple iterations, using the previous output as the input, surprisingly makes matters worse.

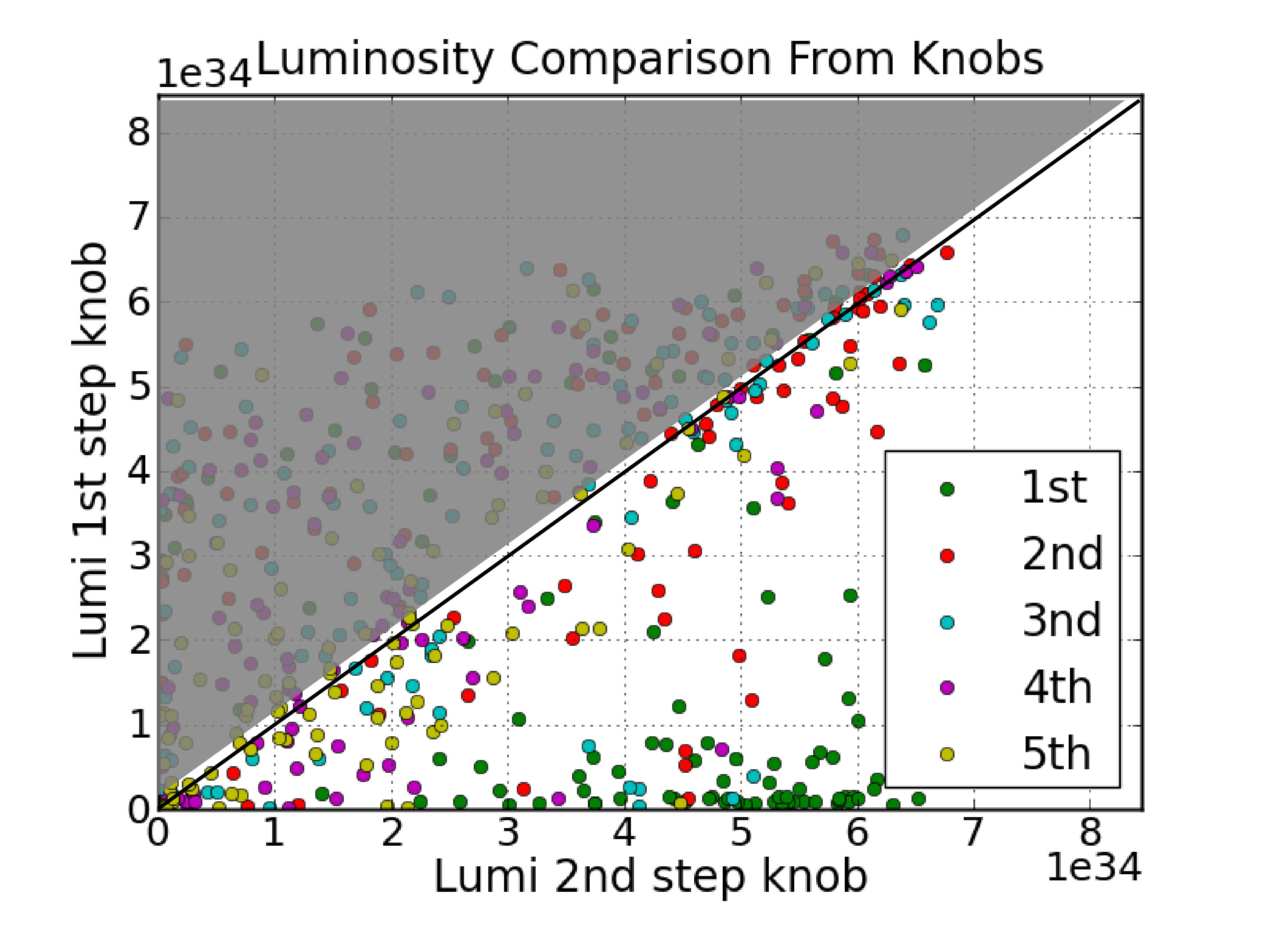




So, what's the problem?



It turns out, the 2nd DFS step decreases the luminosity of many seeds.



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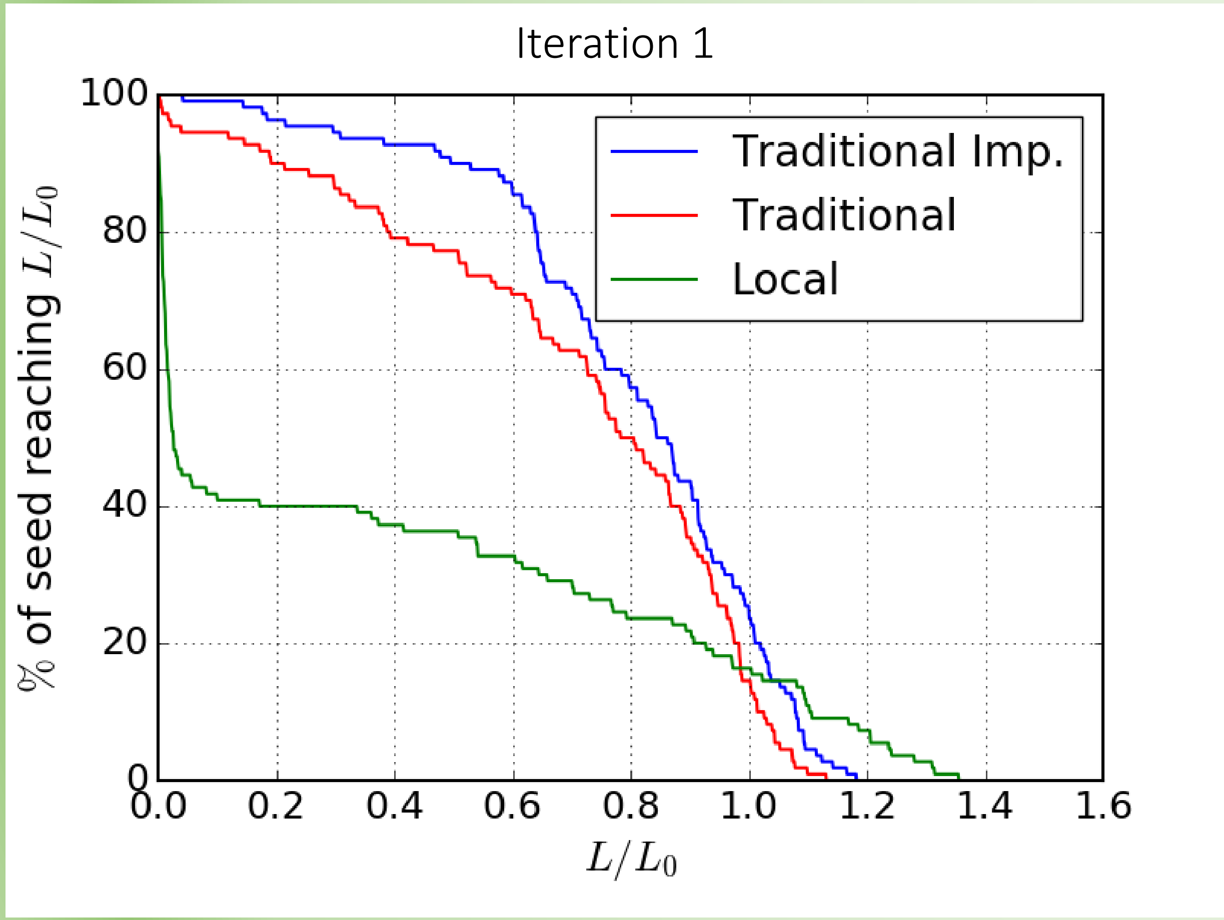
Developing new DFS knobs

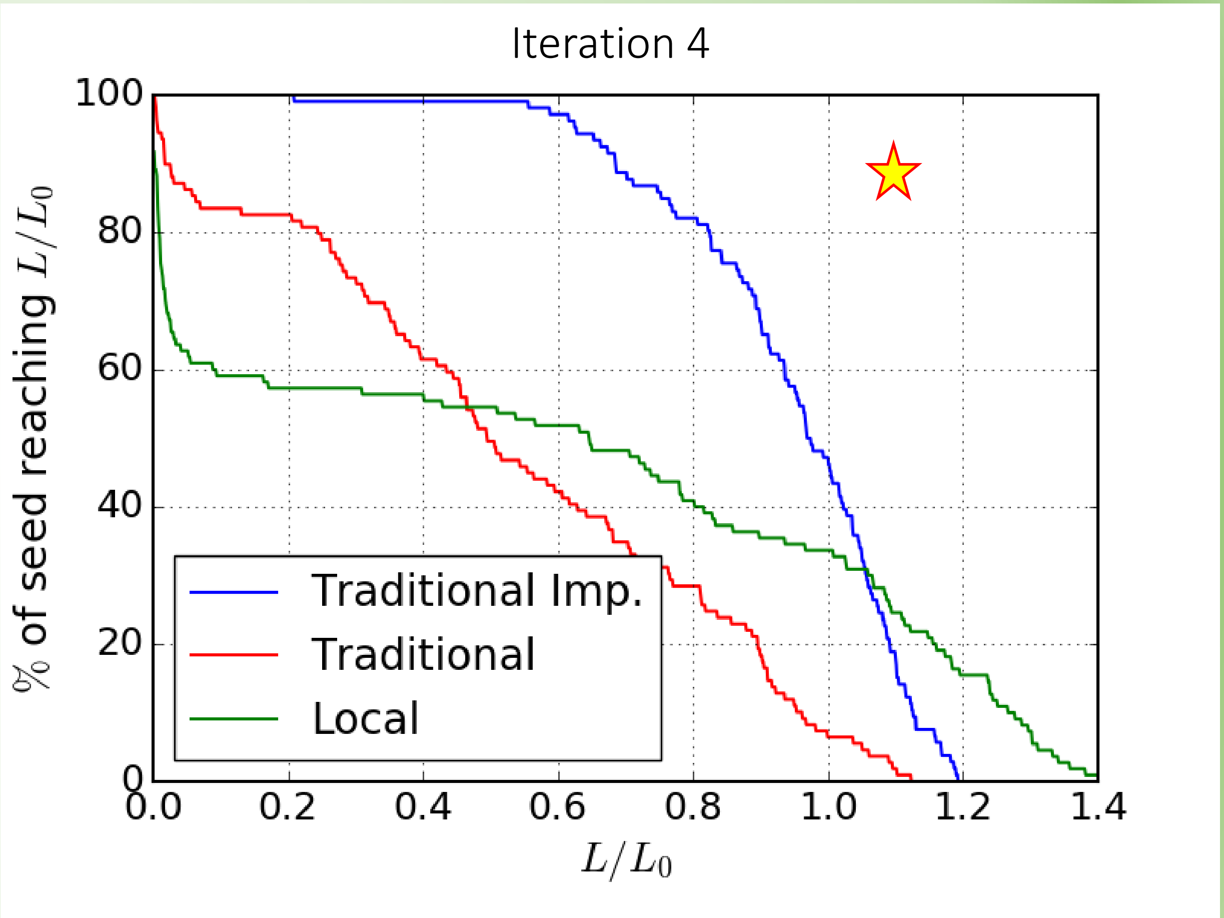
- 2nd stage DFS is not always beneficial
  - Algorithm works very well without synchrotron radiation (SR)
  - Performance is degraded with presence of SR since system becomes non-linear
- Goal: replace this step with more robust algorithm
- Several ideas
  - Use measured response matrix and update (not presented here)
  - DFS knobs that optimize luminosity (presented here)
  - Customized knobs which address specific aberrations (presented here)

Developing new DFS knobs

- Instead of matching dispersion, look for maximum luminosity signal
  - More robust, luminosity can only increase
- Classic DFS algorithm is transformed into a few knobs (using the same dipoles)
  - Achieved using Singular Value Decomposition (SVD)
  - Only applied to 2nd stage DFS
- DFS knobs change beam orbit and so won't be orthogonal with sextupole knobs
  - Orthogonality not crucial, but probably best to do DFS knobs first

Comparing Iterations - Different Methods





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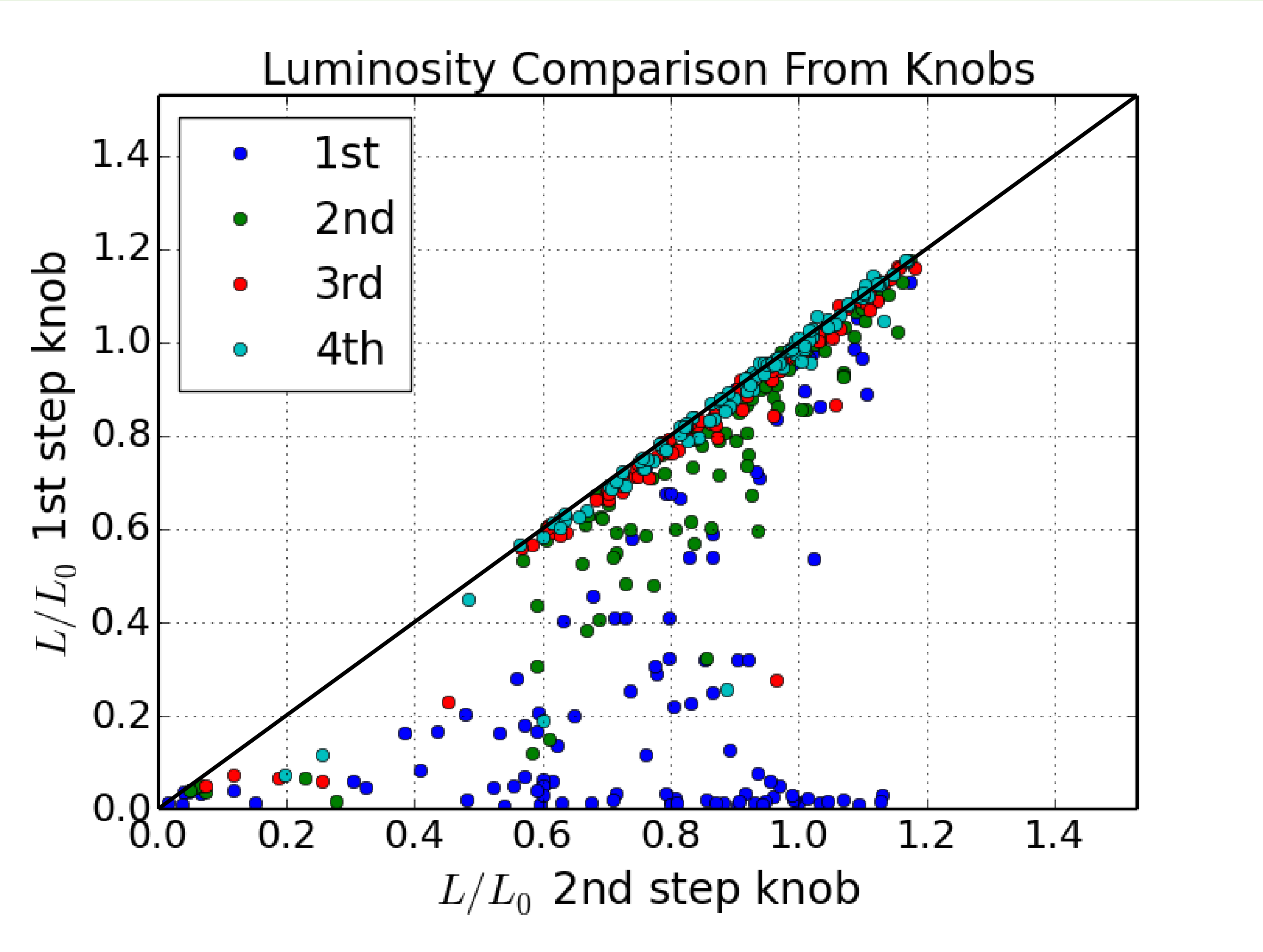
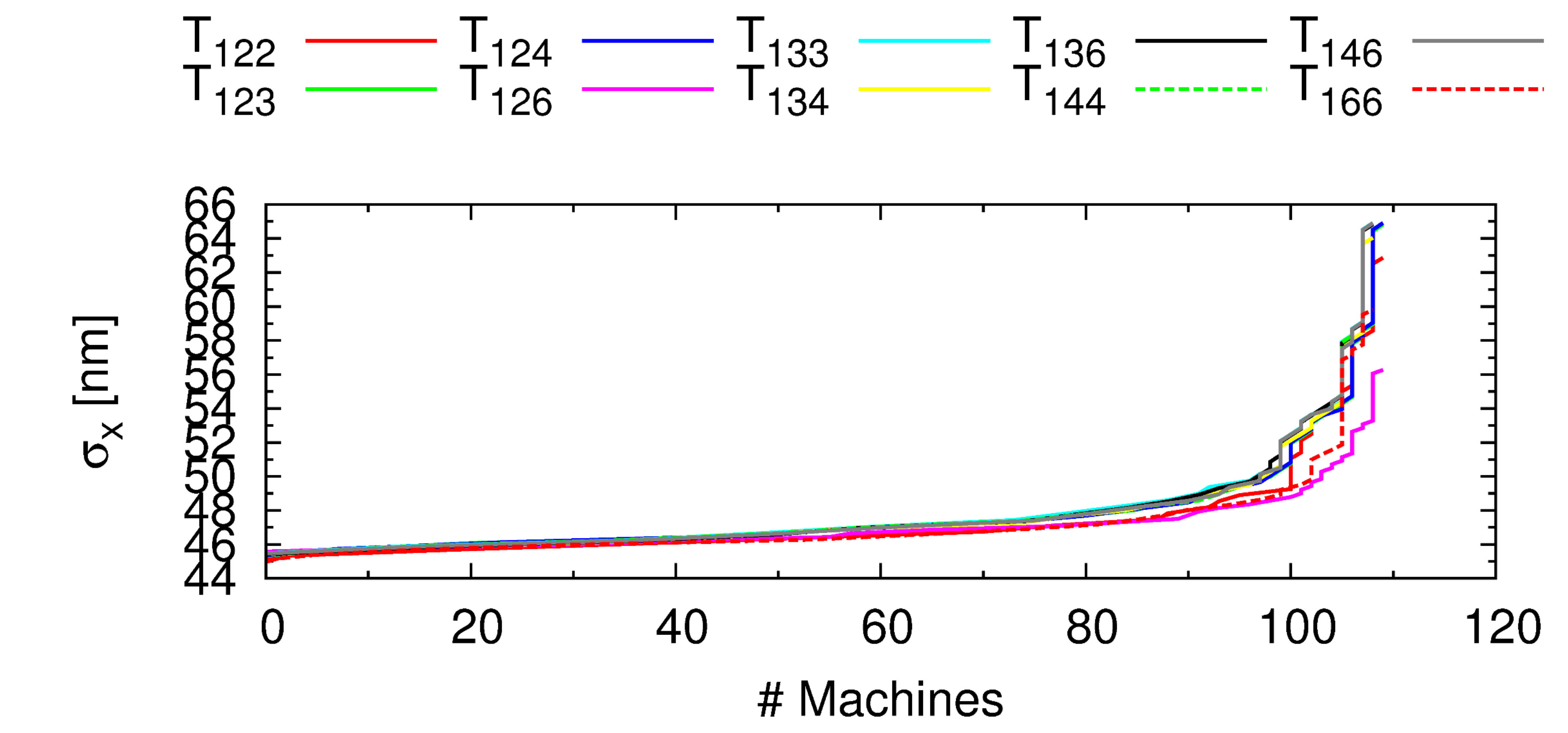
Are we still losing luminosity?



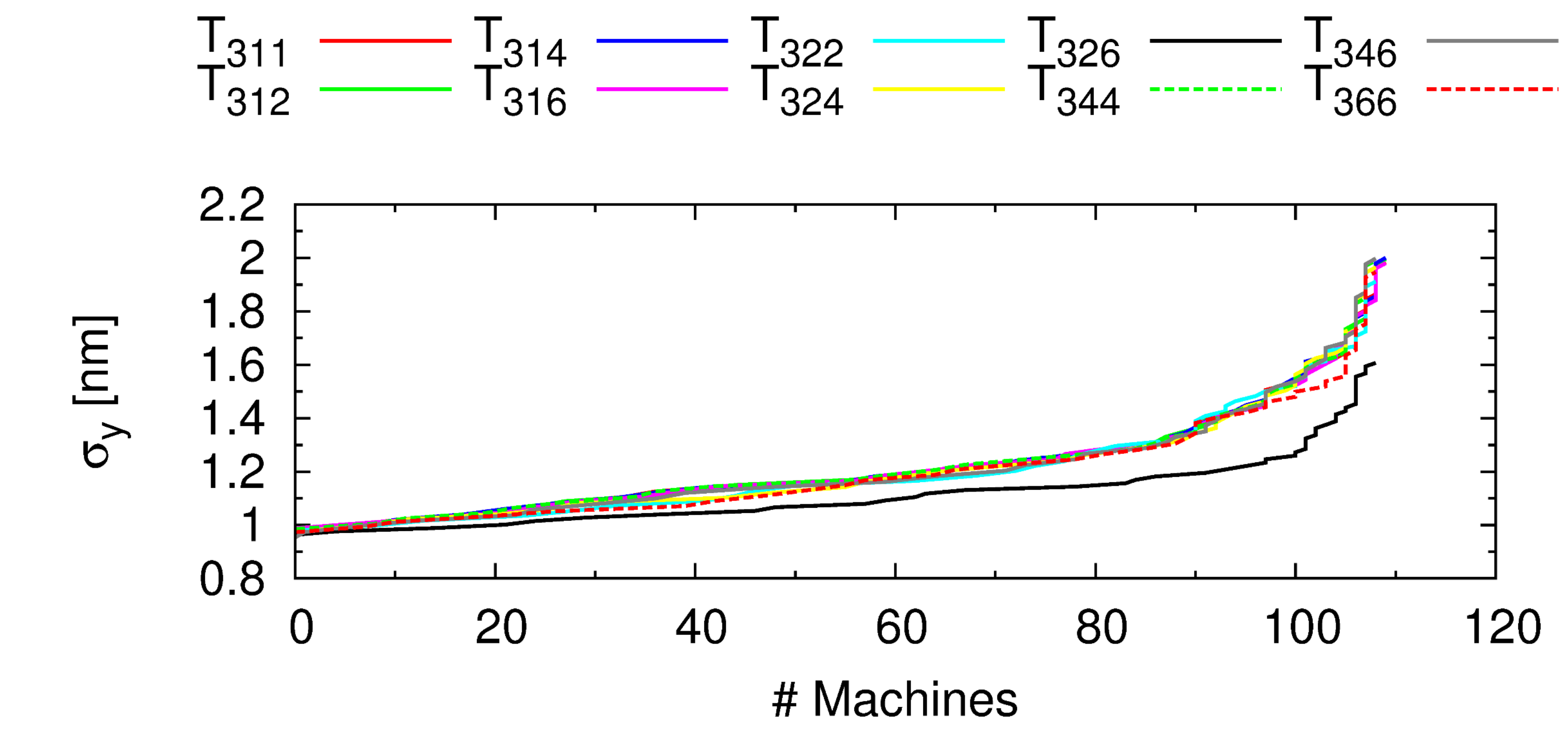
However, it's still not enough.

- Still nowhere near the goal of 90% of machines reaching 110% of the nominal luminosity
- To address this, need to design knobs which can correct for specific aberrations
  - Edu Marin Lacoma developed this method
- Analysis of the IP beam distributions identifies high order aberrations which can make further improvements of the luminosity measurement
  - In the X plane, these are: T126, T166, T122
  - In the Y plane, these are: T326

In the horizontal plane



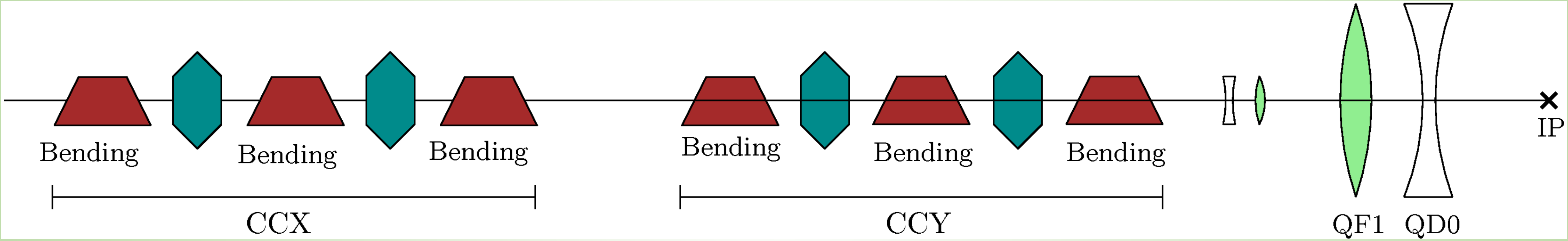
In the vertical plane



To construct the knobs

- Basically, you use a bit of mathematical wizardry on the response matrix to find various vectors that are orthogonal to each other
- Three methods used, primarily
  - Least Squares
  - Matrix Inversion
  - Singular Value Decomposition (SVD)
- Each method ends up with different results, so all three have to be investigated and a method selected
- Also, added dimensionless skew sextupoles to the lattice to address nonlinear aberrations

New, dimensionless skew sextupoles added



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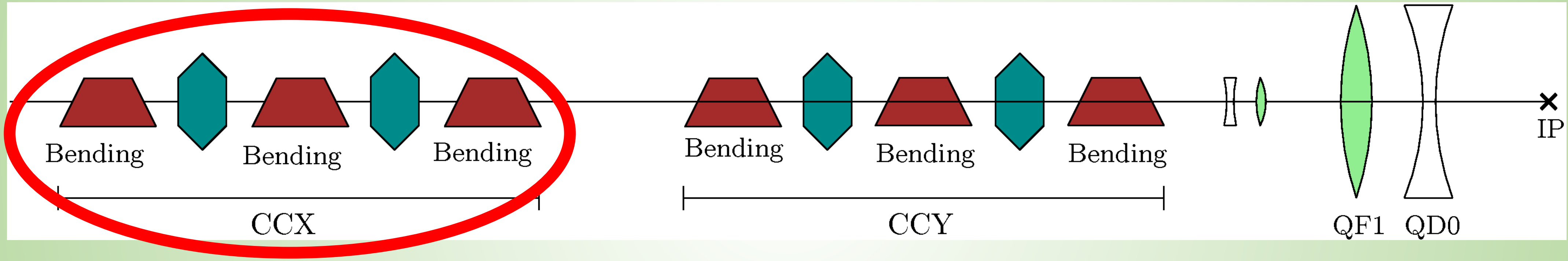
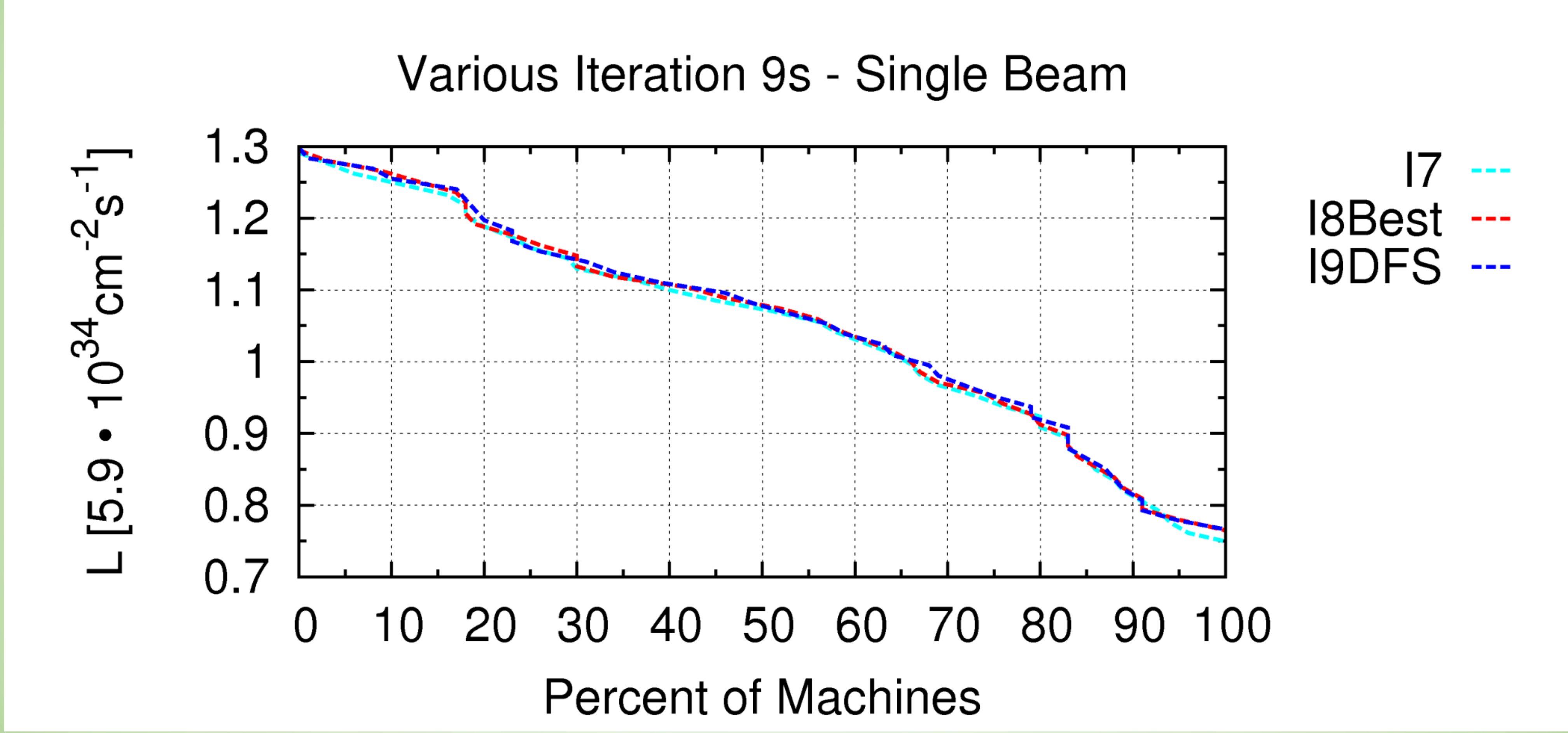


So, how did these changes perform?



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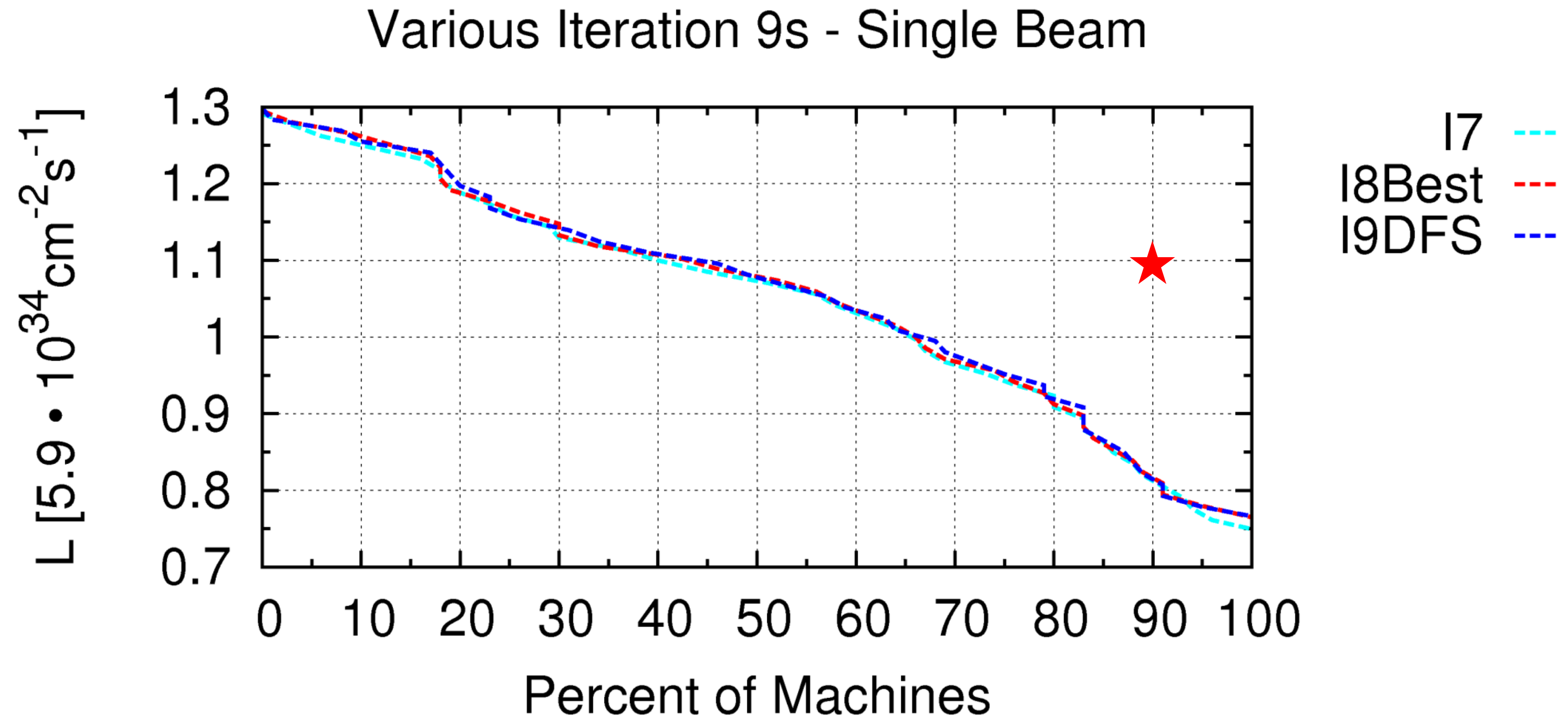

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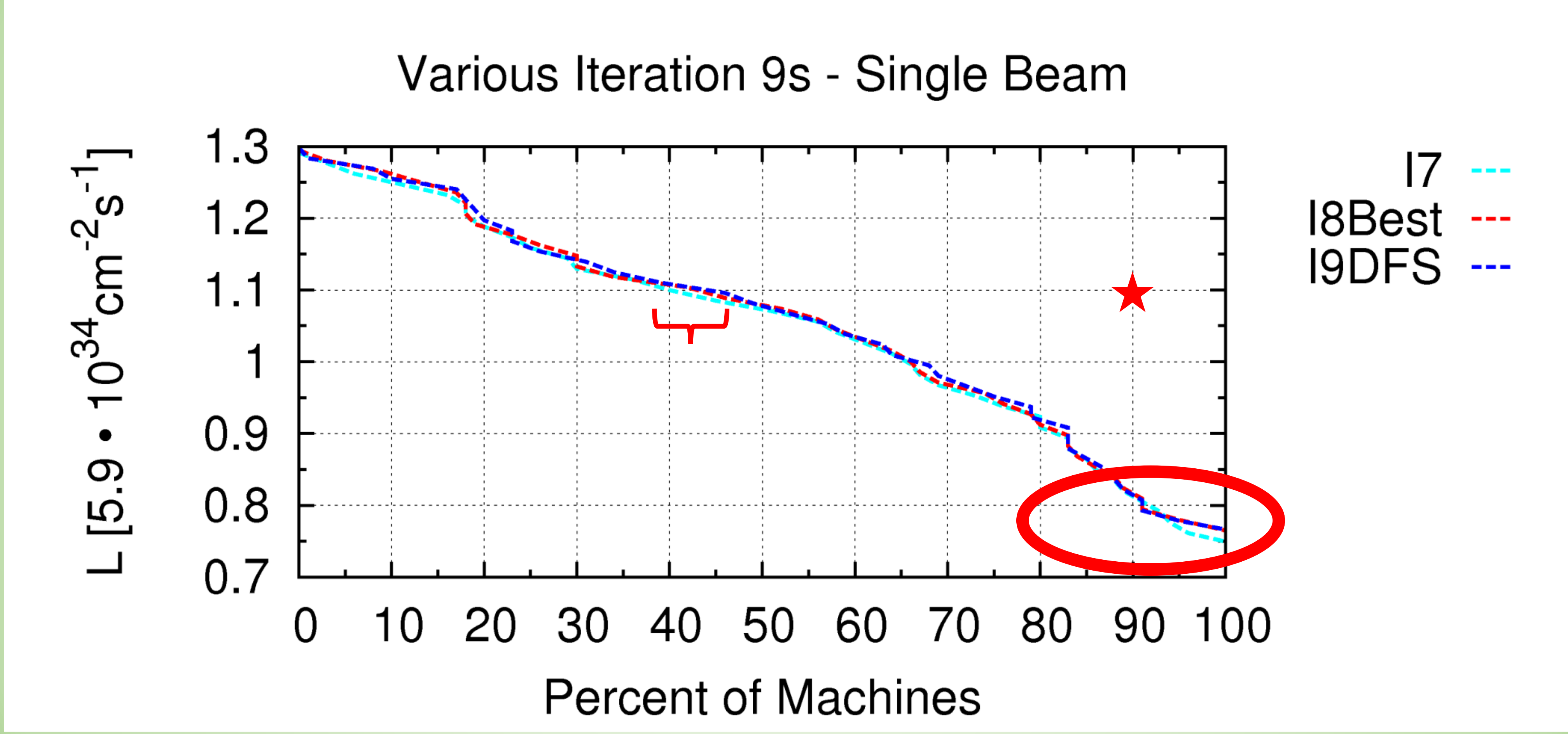

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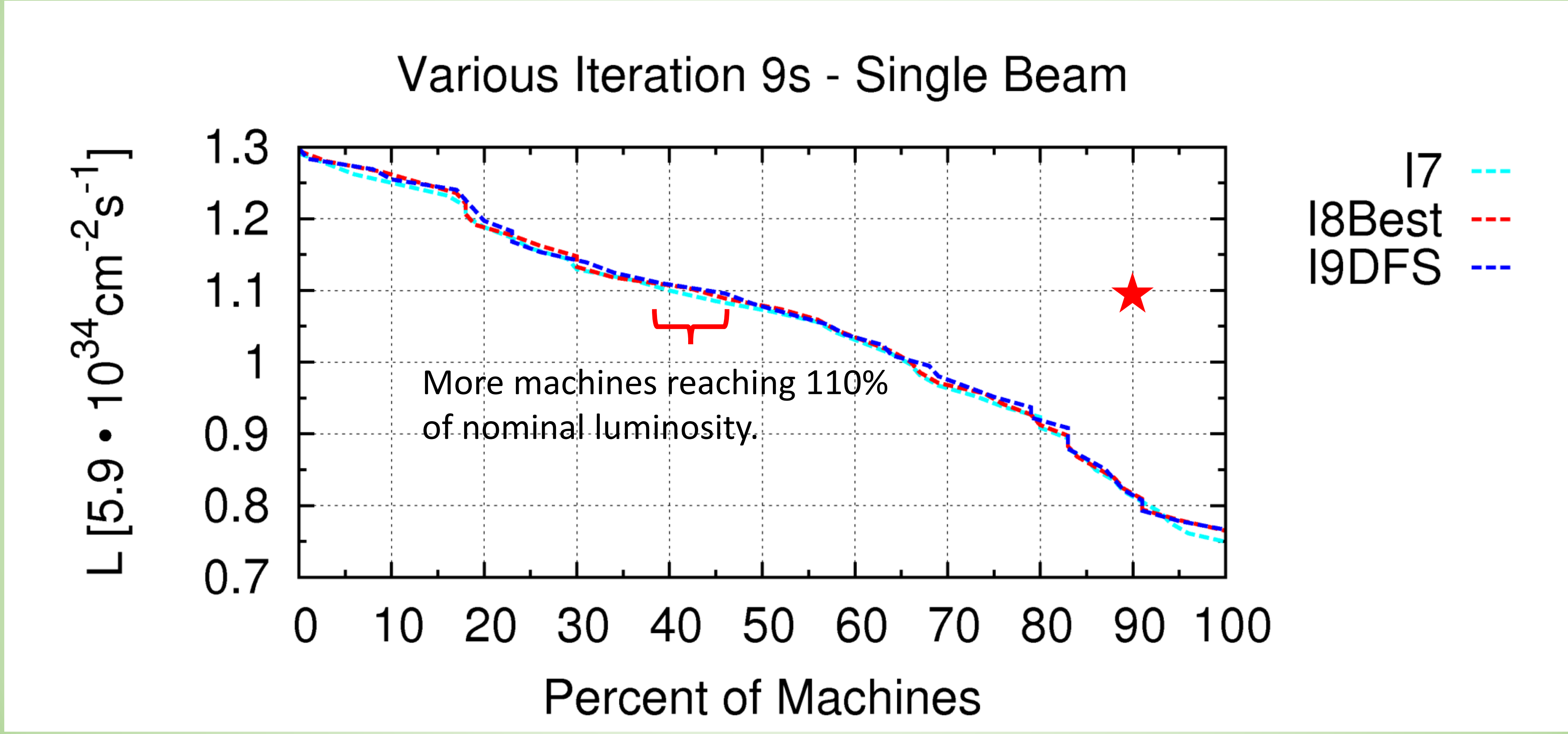

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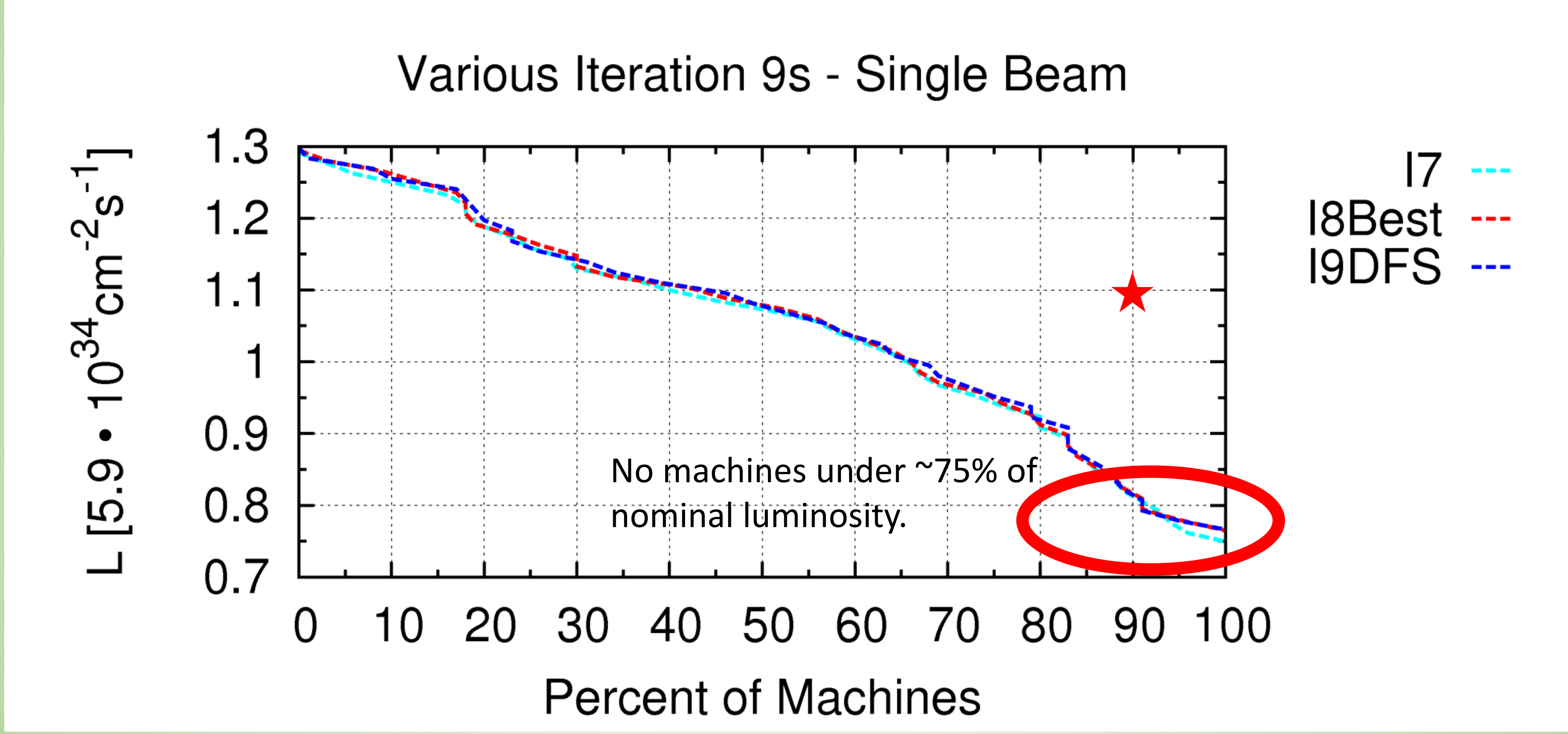

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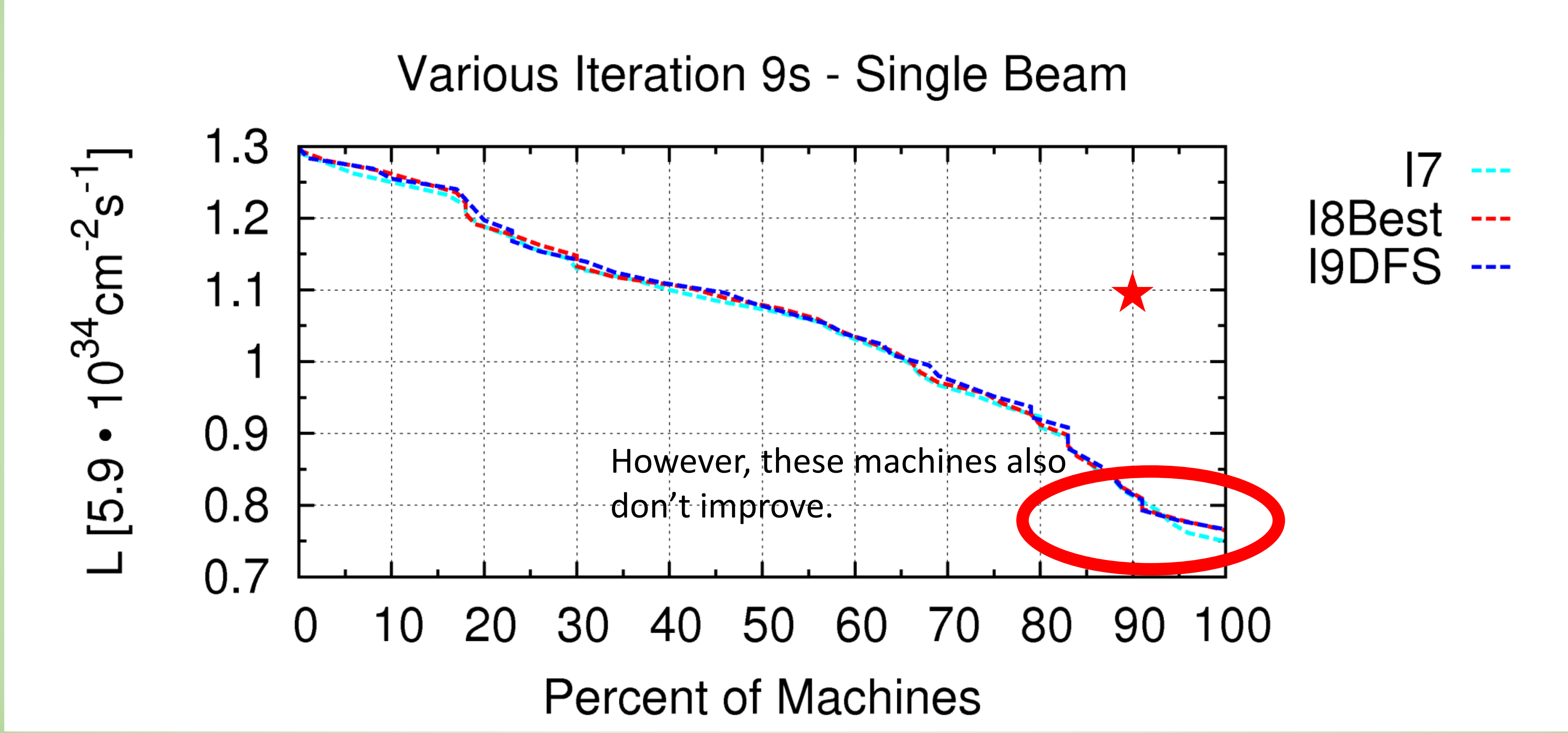
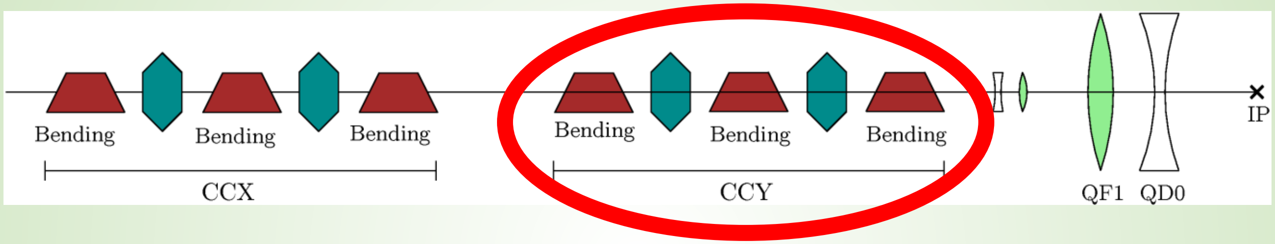


What else needs to be done?

- Several plans "in the works"
  - Place dimensionless skews in the CCY region of the lattice



  - Add initial, optics-based tuning step using quads to make sure the optics are behaving throughout the BDS
    - Would take place near beginning of procedure
  - Close investigation of misbehaving machines
    - Find ways to specifically tune these machines
      - Possibly "resetting" the machines through restarting tuning or introducing new perturbations

Tuning conclusions:

- In 9 iterations:
  - 45% of machines reach 110% of the nominal luminosity or more (some up to 130%)
  - 100% of machines above 75% of the nominal luminosity
- However:
  - Only halfway to the goal of 90% of machines at 110%
  - Bad machines stay bad
- Adding more skew sextupoles may help
- Optics-based tuning may help
- Must specifically address bad machines
- Cannot address two-beam tuning until goal reached with single-beam

Next up, IP Feedback simulations

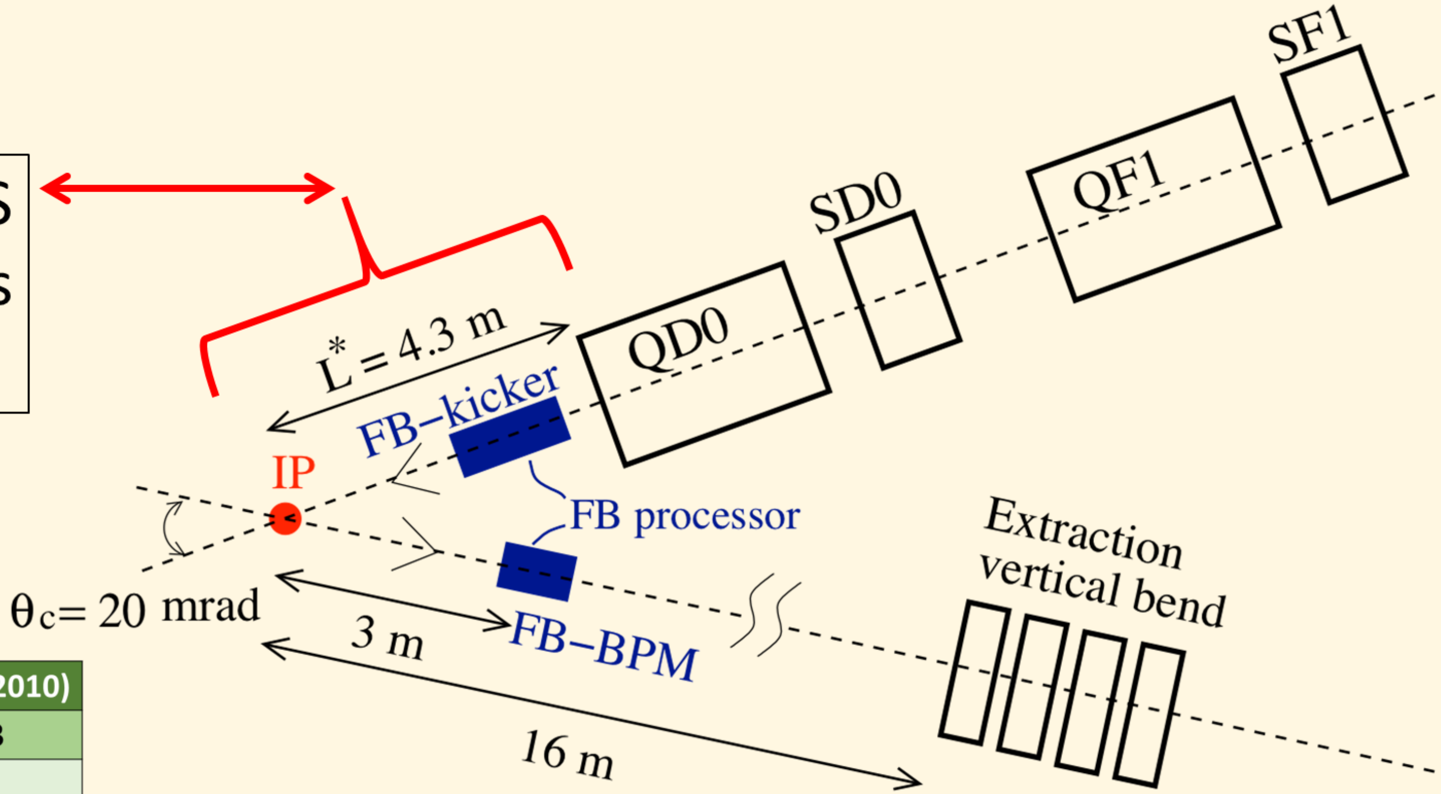
- Completed work for intra-beam IP Feedback simulations for the CLIC 380 GeV beam delivery system
  - 5 different ground motion models investigated
  - 2 different L* configurations investigated

- Currently investigating the same as above, but for the ILC

A bit of background

- Current plans for CLIC involve phased commissioning with lower-energy lattice for 380 GeV collision energy
- Previous studies focused on a BDS lattice designed for a 3 TeV collision energy
- New BDS designs have two L* configurations:
    - 4.3 meters, 6 meters
- Previous ground motion (GM) studies of 3 TeV machine performed for both 380 GeV designs
- Intratrain IP Feedback system used to correct perturbations from ground motion

In the new 380 GeV BDS designs, L* is 4.3 meters or 6 meters.



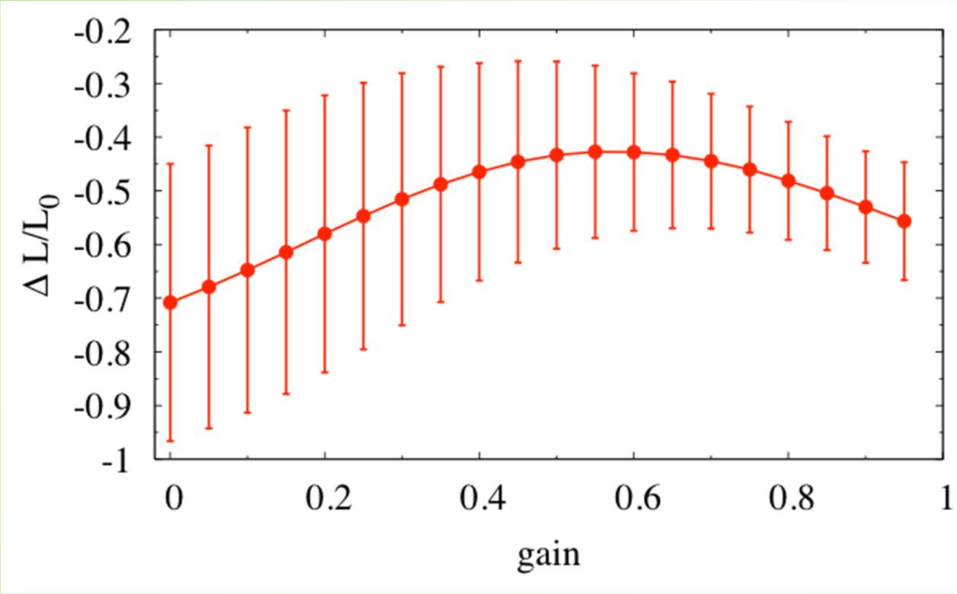
CLIC	380 GeV	380 GeV	3 TeV (2010)
L* (m)	**4.3**	**6**	**4.3**
$\mathcal{L}_{0,tot}$ ($10^{34}cm^{-2}s^{-1}$)	1.82	1.5	6
$\mathcal{L}_{design,tot}$ ($10^{34}cm^{-2}s^{-1}$)	1.5	1.5	6

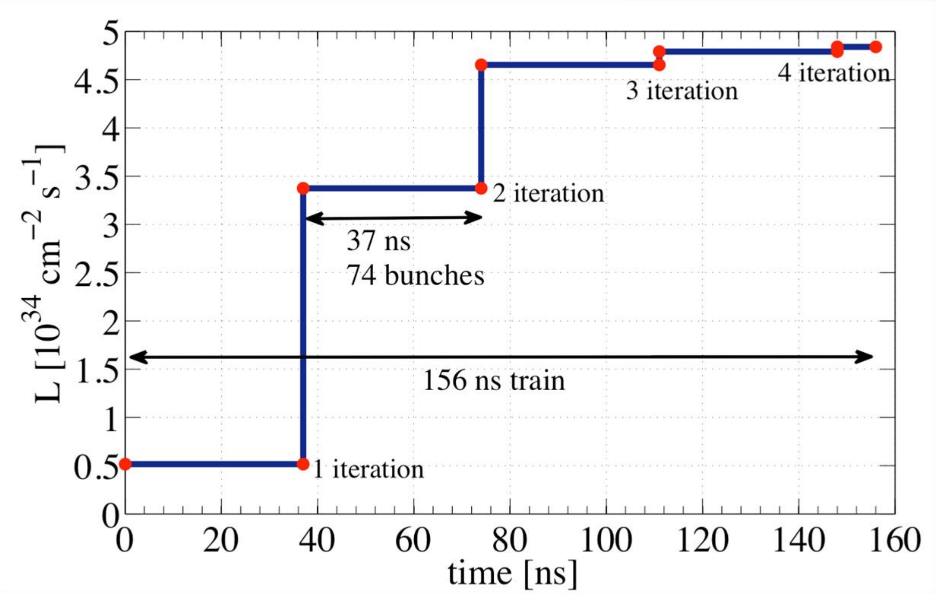
CLIC interaction region, highlighting IP Feedback kicker and BPM positions.

Previous study by Resta-López in 2010

- Focused on 4 GM models; A, B, C, and K
- PLACET and GUINEA-PIG used for simulation studies
- 3 TeV collision energy
- Train length = 156 ns
- Gain scan performed using 100 random seeds of GM

*Note: These plots are for Model C

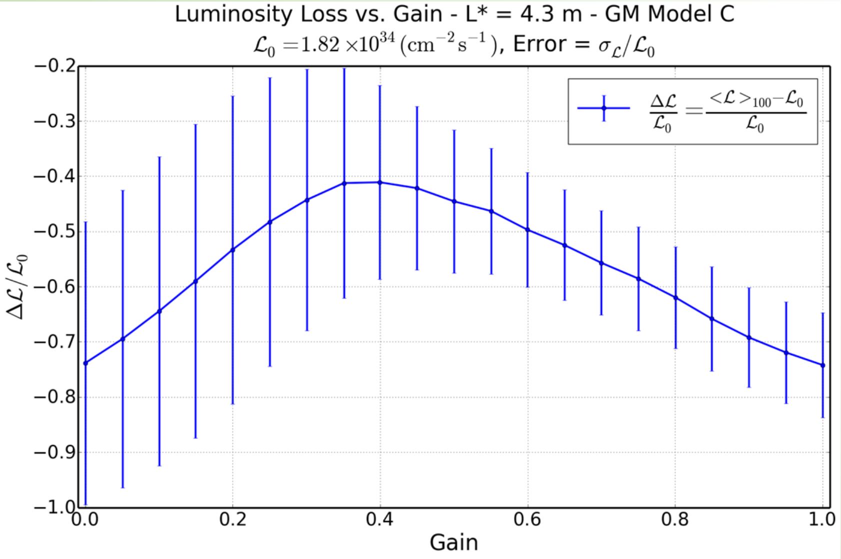


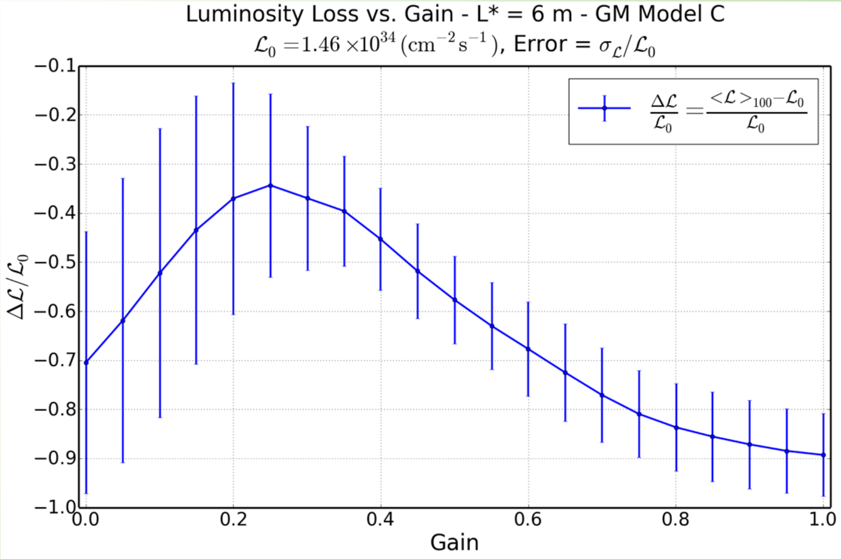


Recovery plot for single seed using best gain value

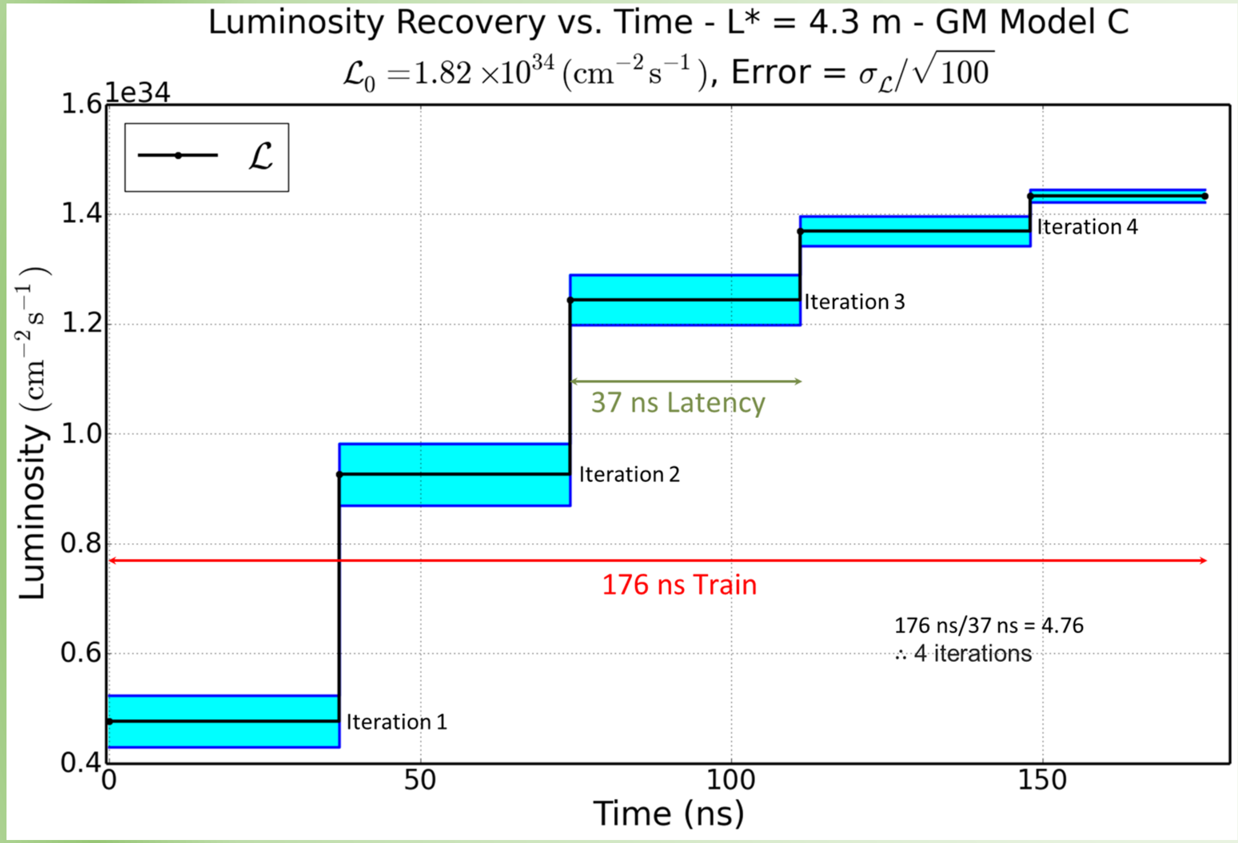
New study

- Focused on 5 GM models; A, B, C, D (also called B10), and K
- LinSim framework of PLACET and GUINEA-PIG used for simulation studies
- 380 GeV collision energy
- Train length = 176 ns
- Gain scan performed using 100 random seeds of GM
- Luminosity recovery plotted for average luminosity from 100 random seeds using the best gain value

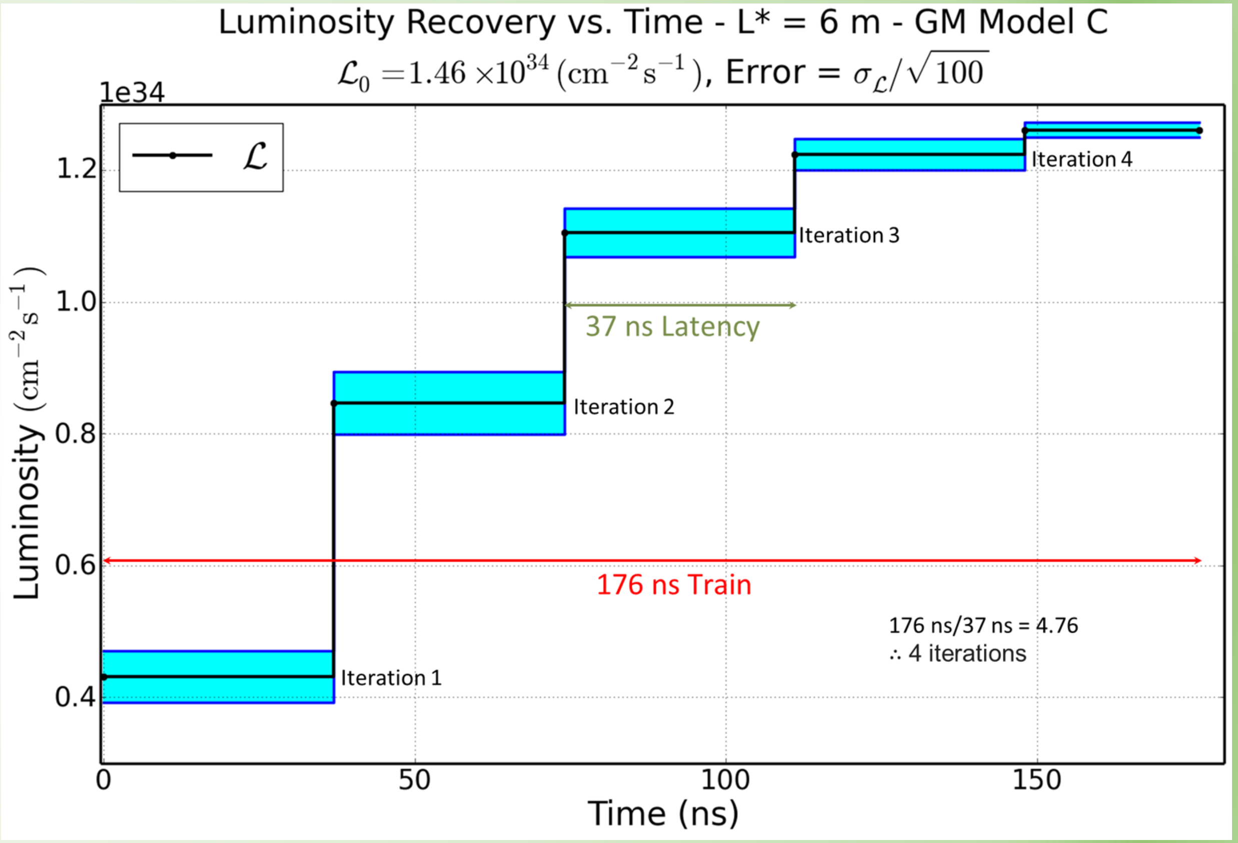




New study



Luminosity Recovery vs. Time - L* = 4.3 m - GM Model C
$\mathcal{L}_0 = 1.82 \times 10^{34}\,(\mathrm{cm}^{-2}\mathrm{s}^{-1})$, Error = $\sigma_{\mathcal{L}}/\sqrt{100}$
1e34
$\mathcal{L}$
Iteration 1
Iteration 2
Iteration 3
Iteration 4
37 ns Latency
176 ns Train
176 ns/37 ns = 4.76
∴ 4 iterations
Luminosity $(\mathrm{cm}^{-2}\mathrm{s}^{-1})$
Time (ns)



Luminosity Recovery vs. Time - L* = 6 m - GM Model C
$\mathcal{L}_0 = 1.46 \times 10^{34}\,(\mathrm{cm}^{-2}\mathrm{s}^{-1})$, Error = $\sigma_{\mathcal{L}}/\sqrt{100}$
1e34
$\mathcal{L}$
Iteration 1
Iteration 2
Iteration 3
Iteration 4
37 ns Latency
176 ns Train
176 ns/37 ns = 4.76
∴ 4 iterations
Luminosity $(\mathrm{cm}^{-2}\mathrm{s}^{-1})$
Time (ns)

Summarizing the results

- Studies completed for all 5 GM models
- For L* = 4.3 m, luminosity recovery same or better for 380 GeV
- For L* = 6 m, luminosity recovery similar to 3 TeV study results
  - 380 GeV achieves as good or better results than 3 TeV
  - Appears to be best overall results for all GM models

GM Model	3 TeV, L* = 4.3 m (2010)	380 GeV L* = 4.3 m	380 GeV L* = 6 m
A	$\Delta L/L_0 \lesssim 0.1\%$	$\Delta L/L_0 \lesssim 0.1\%$	$\Delta L/L_0 \lesssim 0.1\%$
B	$\Delta L/L_0 \lesssim 3\%$	$\Delta L/L_0 \lesssim 3\%$	$\Delta L/L_0 \lesssim 3\%$
C	$\Delta L/L_0 \lesssim 45\%$	$\Delta L/L_0 \lesssim 42\%$	$\Delta L/L_0 \lesssim 35\%$
D	No Data	$\Delta L/L_0 \lesssim 9\%$	$\Delta L/L_0 \lesssim 6\%$
K	$\Delta L/L_0 \lesssim 35\ \%$	$\Delta L/L_0 \lesssim 20\%$	$\Delta L/L_0 \lesssim 18\%$

Current study

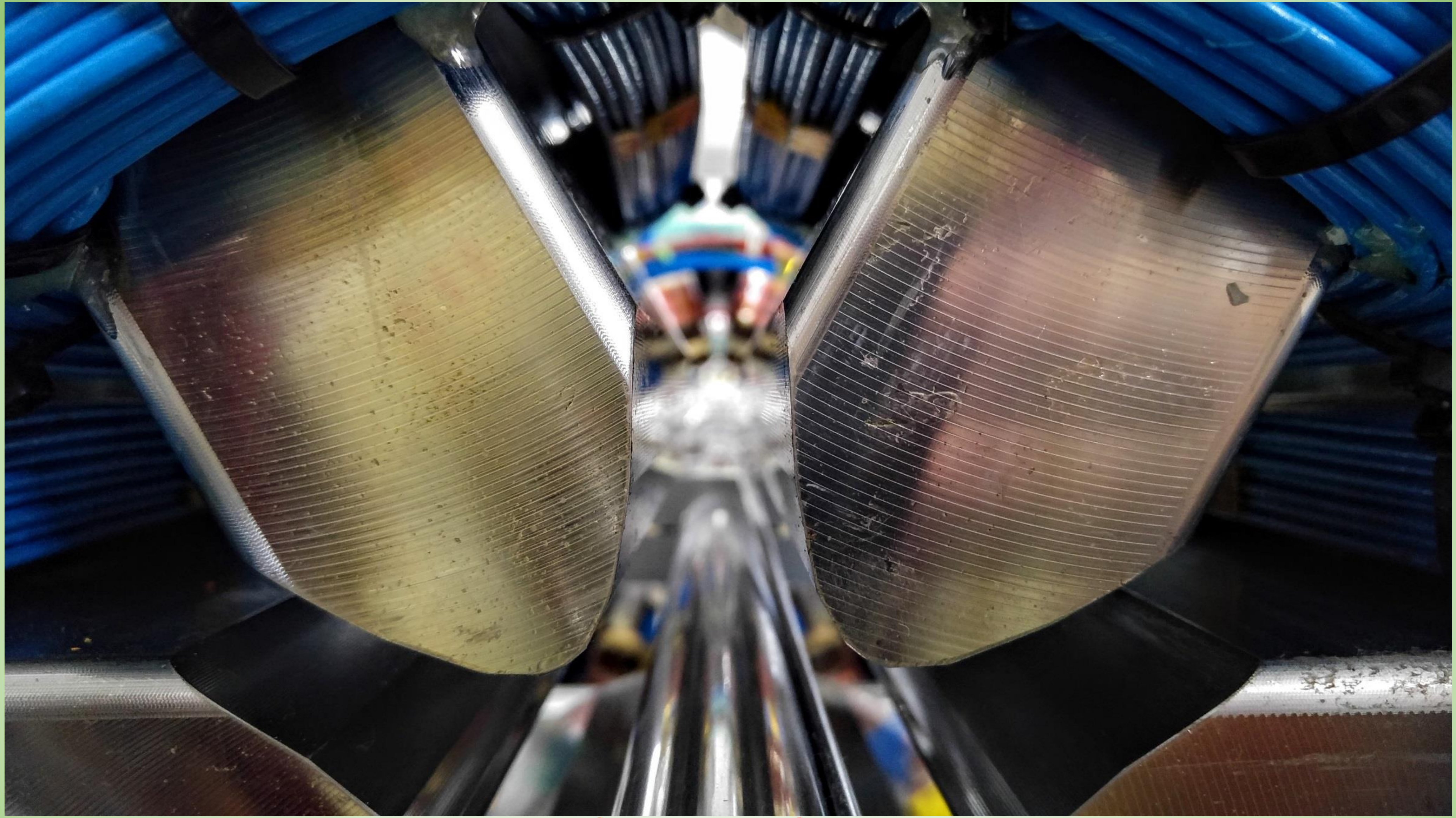
- Currently repeating the IP Feedback study for the ILC (parameters as in the TDR)
- Intra-train luminosity recovery should not be difficult, given much larger train length
- More important to find the proper gain value to properly maintain recovered luminosity

Final Thoughts

- Progress made on tuning the traditional 3 TeV BDS
  - Once goal reached, will then apply methods to two-beam tuning

- Intratrain IP Feedback simulations performed for 5 GM models for the 380 GeV CLIC BDS
  - Both 4.3 m and 6 m L* configurations

- Current/Continuing work:
  - Tuning the traditional 3 TeV BDS in collaboration with Edu Marin Lacoma
  - Applying CLIC IP Feedback simulations to the ILC



Thanks!