Single-beam Tuning of the CLIC 3 TeV Traditional Lattice

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Morioka, Japan

Before I begin…

- It should be noted that I did not work alone on this task.
  - In the past, I worked with Jochem Snuverink (now at PSI)
  - Currently, I work with Edu Marin Lacoma, recycling many of his codes.

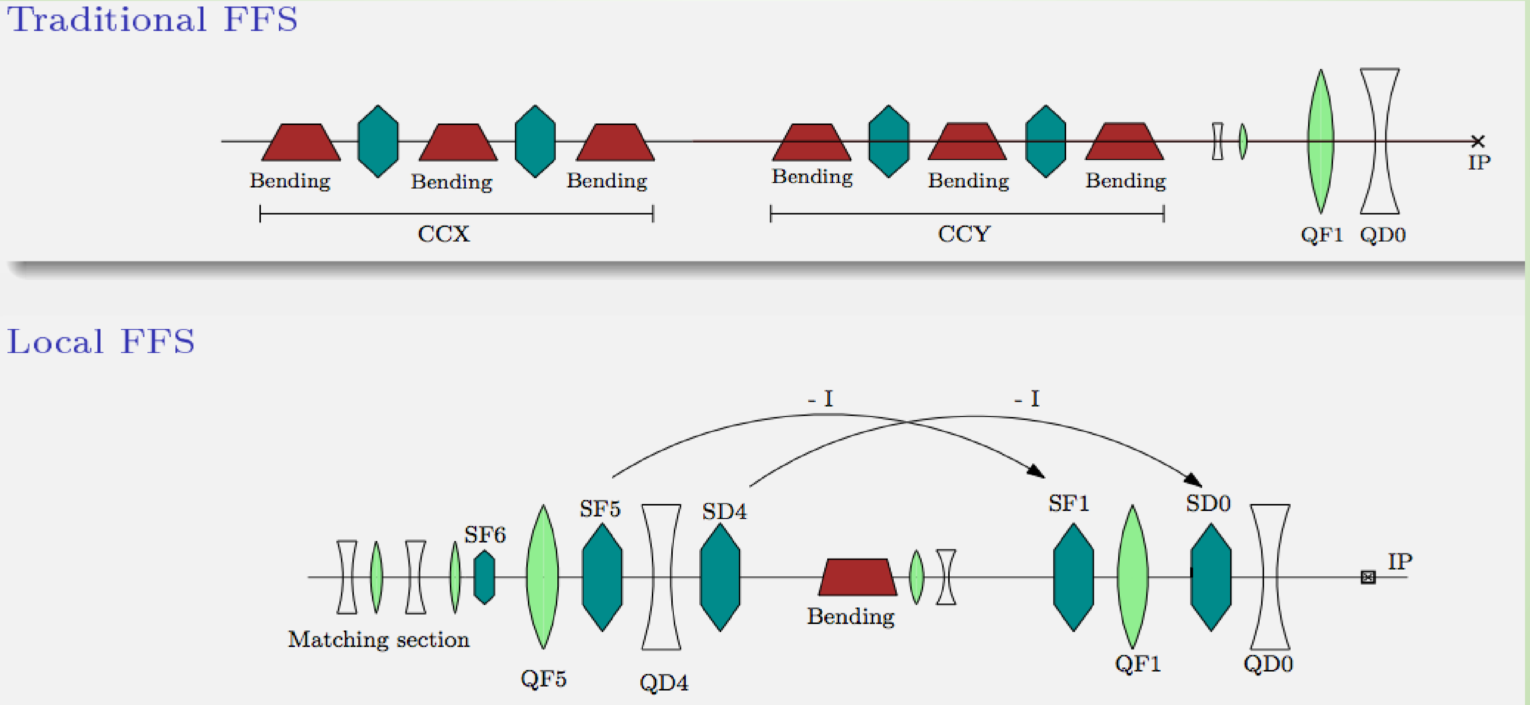
- I will be giving this talk (at least similar talks) twice this week: Tuesday and Thursday afternoon.

What will I be talking about?

- Bit of background on the beam delivery system (BDS) of CLIC
- Past attempts at tuning the traditional final focus system (FFS) lattice
- Development of new tuning procedures and changes to the lattice
- In-progress tuning work

Some background

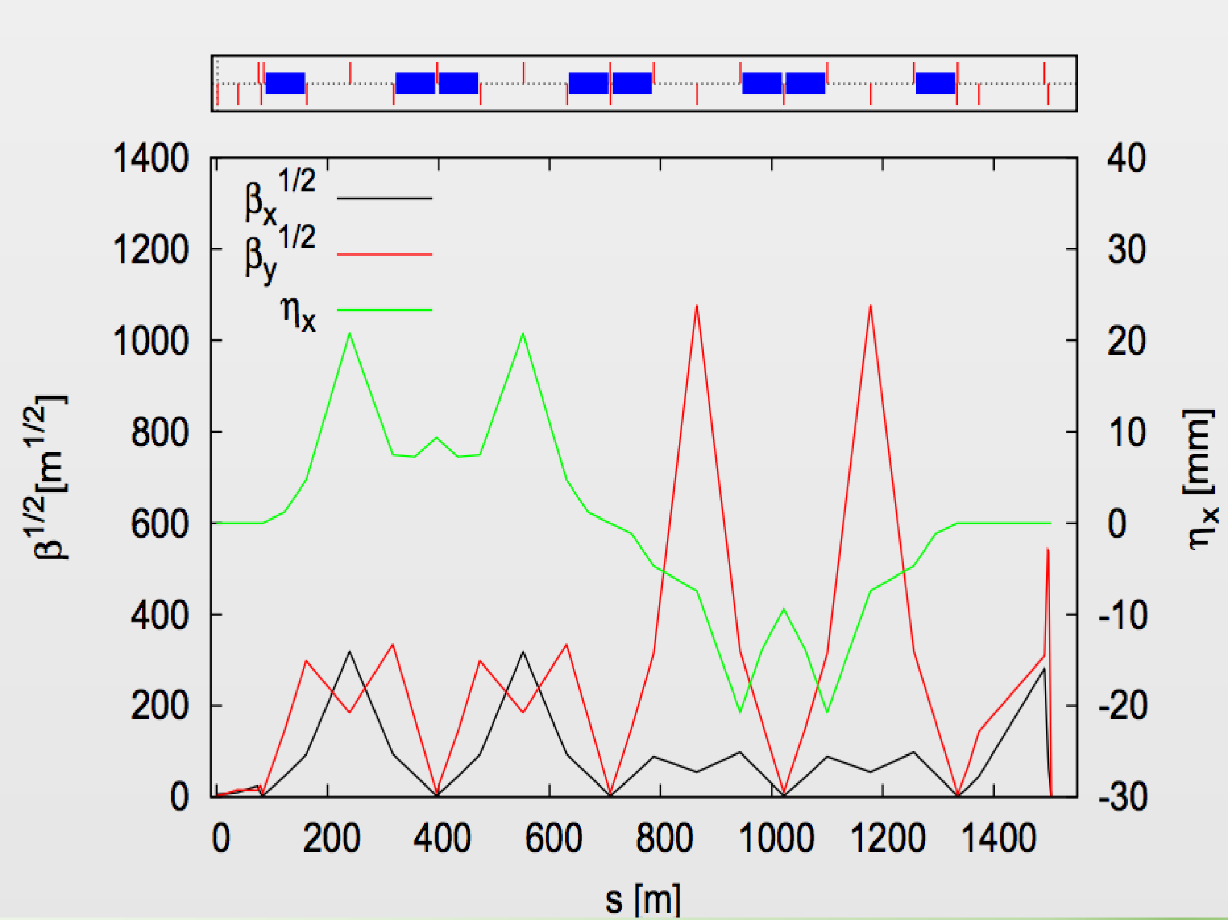
- Two separate sections for chromaticity correction
- Lattice by Hector Garcia, see e.g. his talk at [CLIC WS 2014]
- Relatively simple system for design and analysis



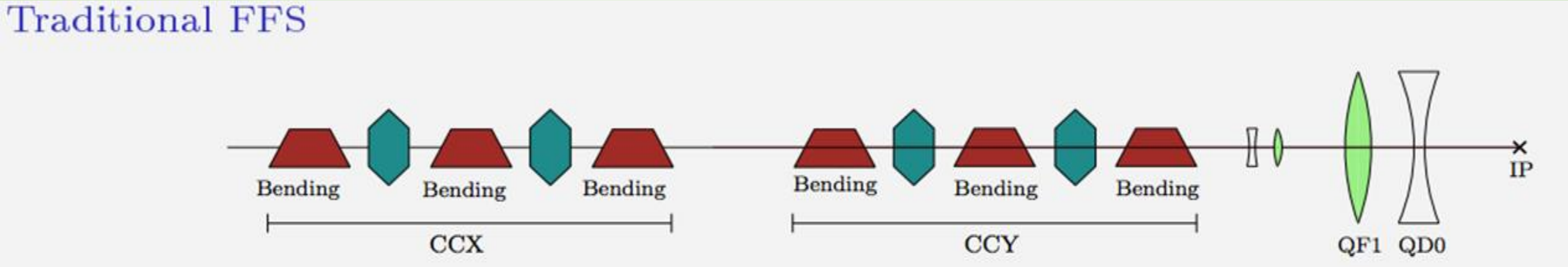
Traditional Final Focus

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

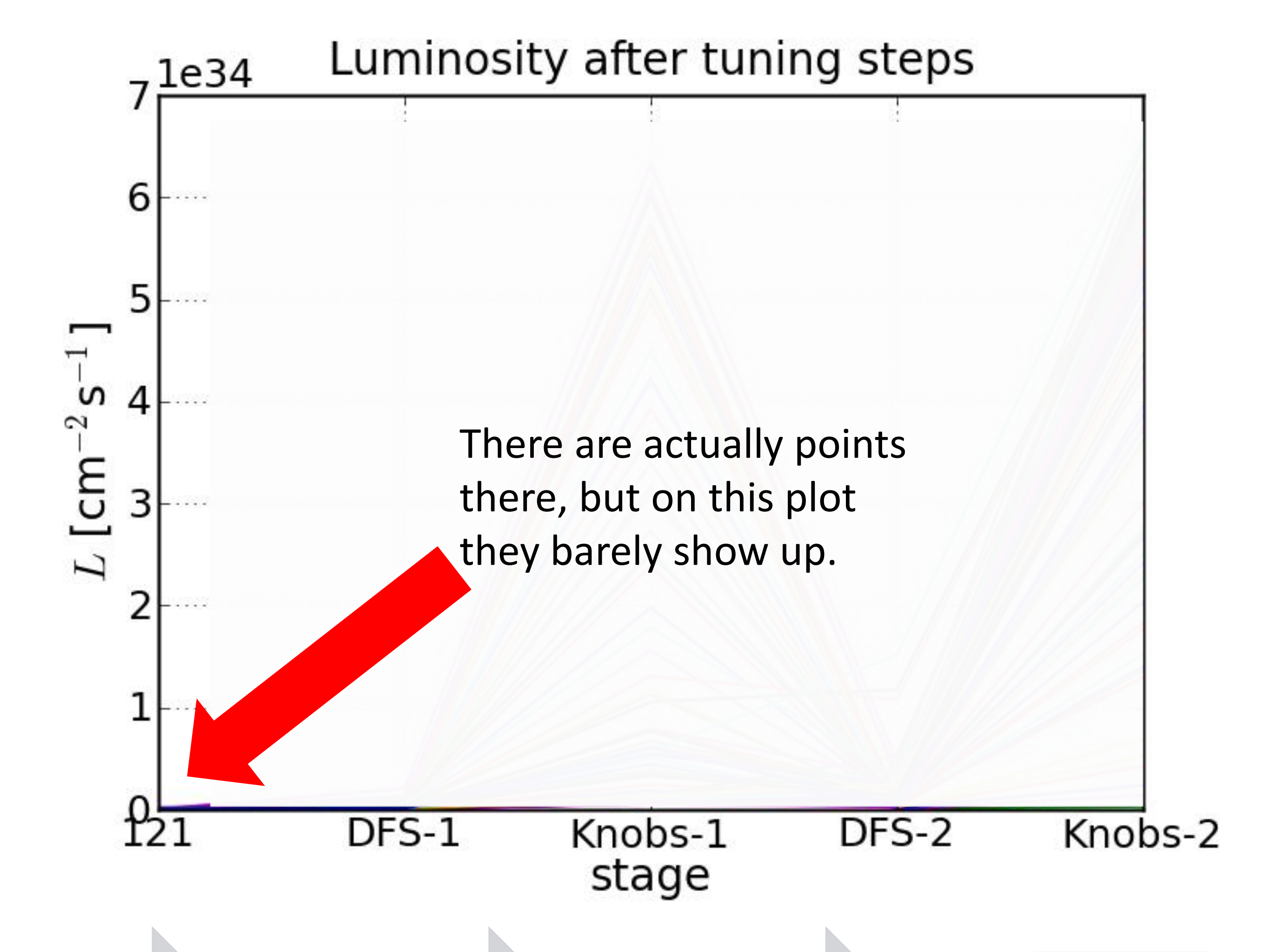


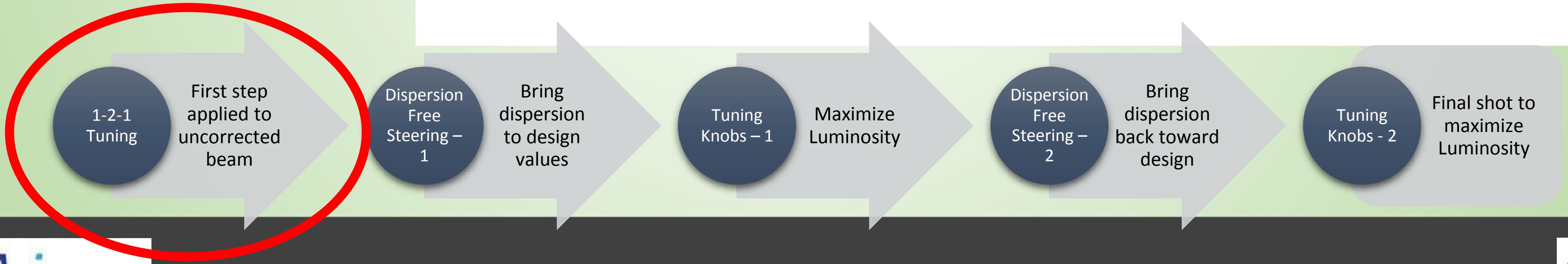
- Looking at the traditional final focus system, with 3 TeV collision energy.
- Simulations using PLACET and GUINEA-PIG
- Apply static offsets in x and y plane (10 µm RMS, 10 nm BPM resolution), then:

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

Step by step…

1. Apply the first corrections to the uncorrected beam

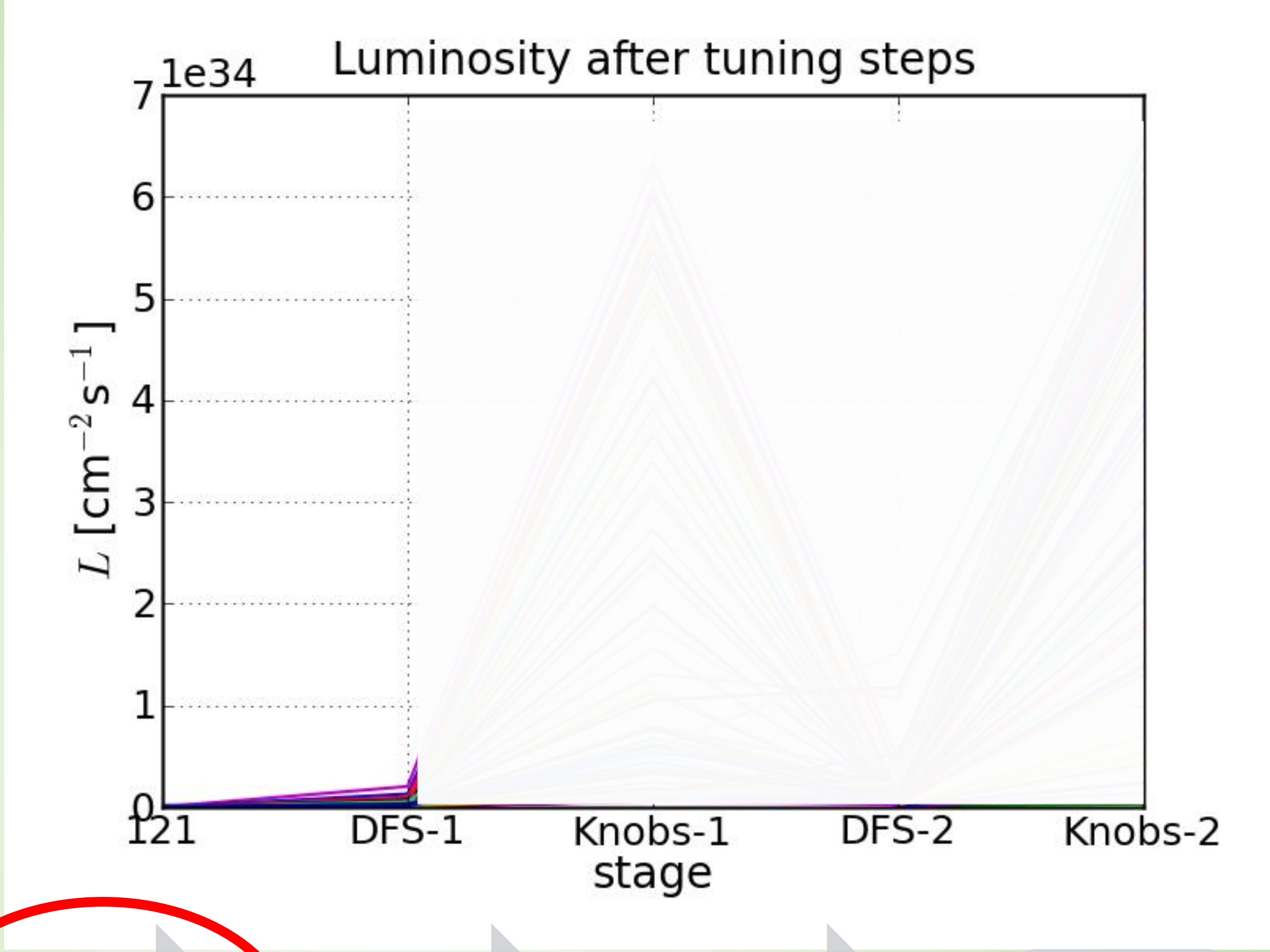


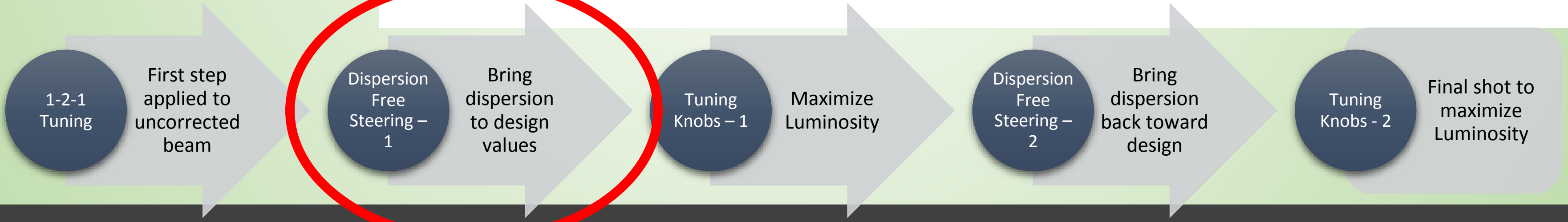


Step by step…

1. Apply the first corrections to the uncorrected beam

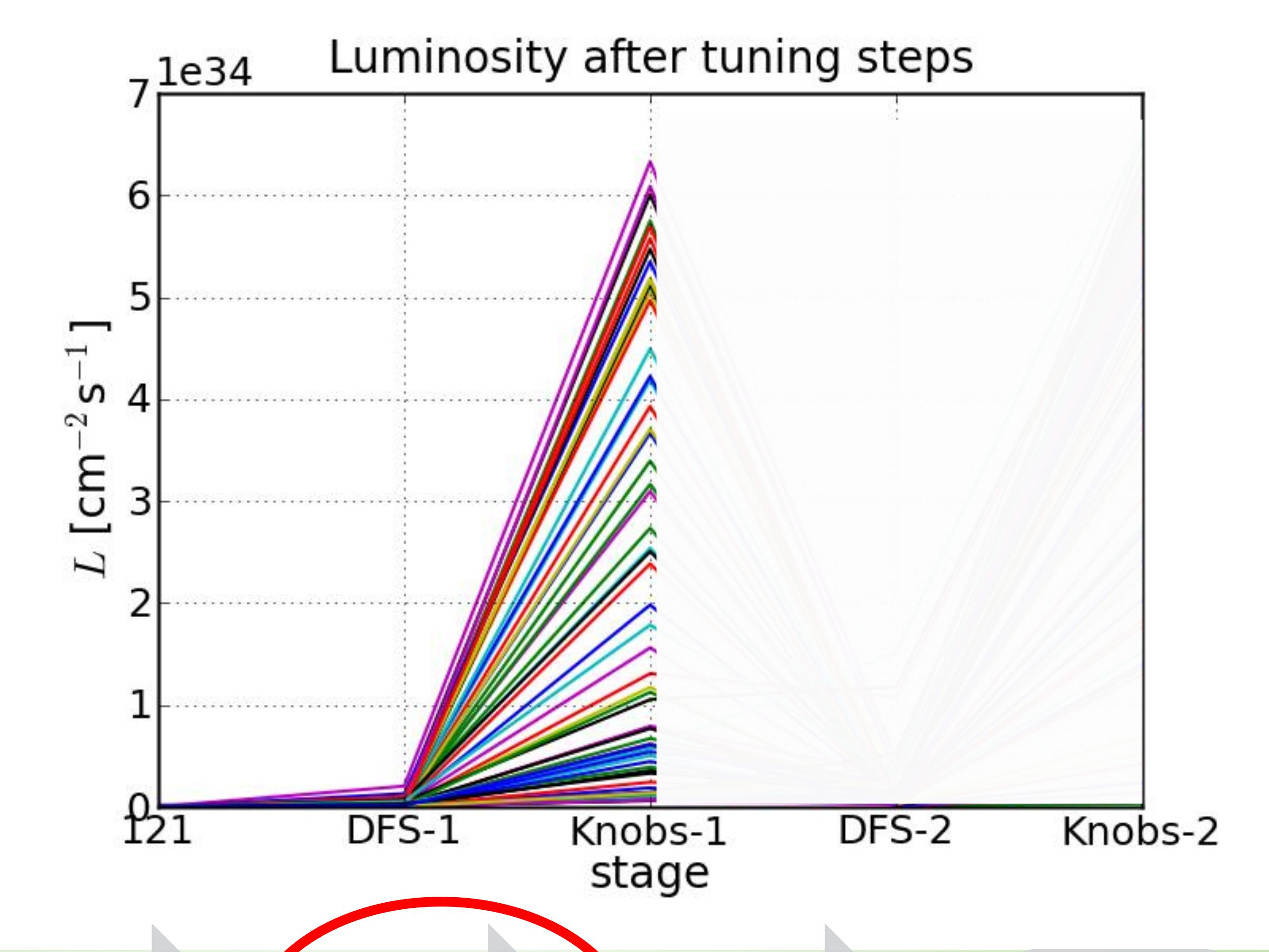
2. Correct the dispersion to approach design values

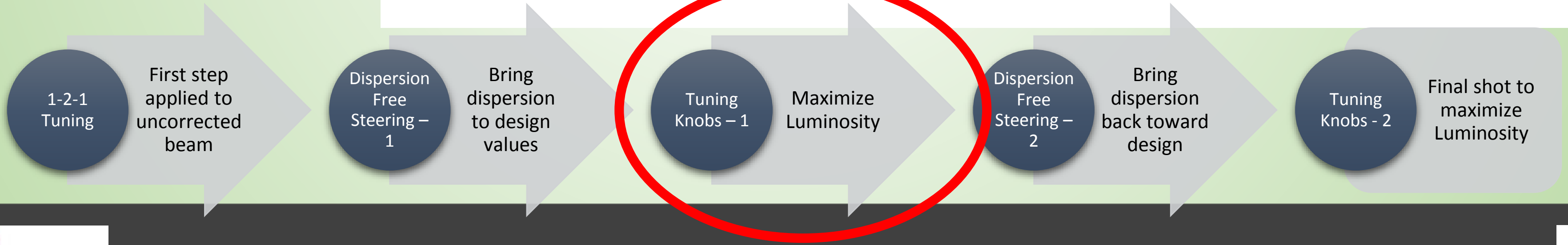




Step by step…

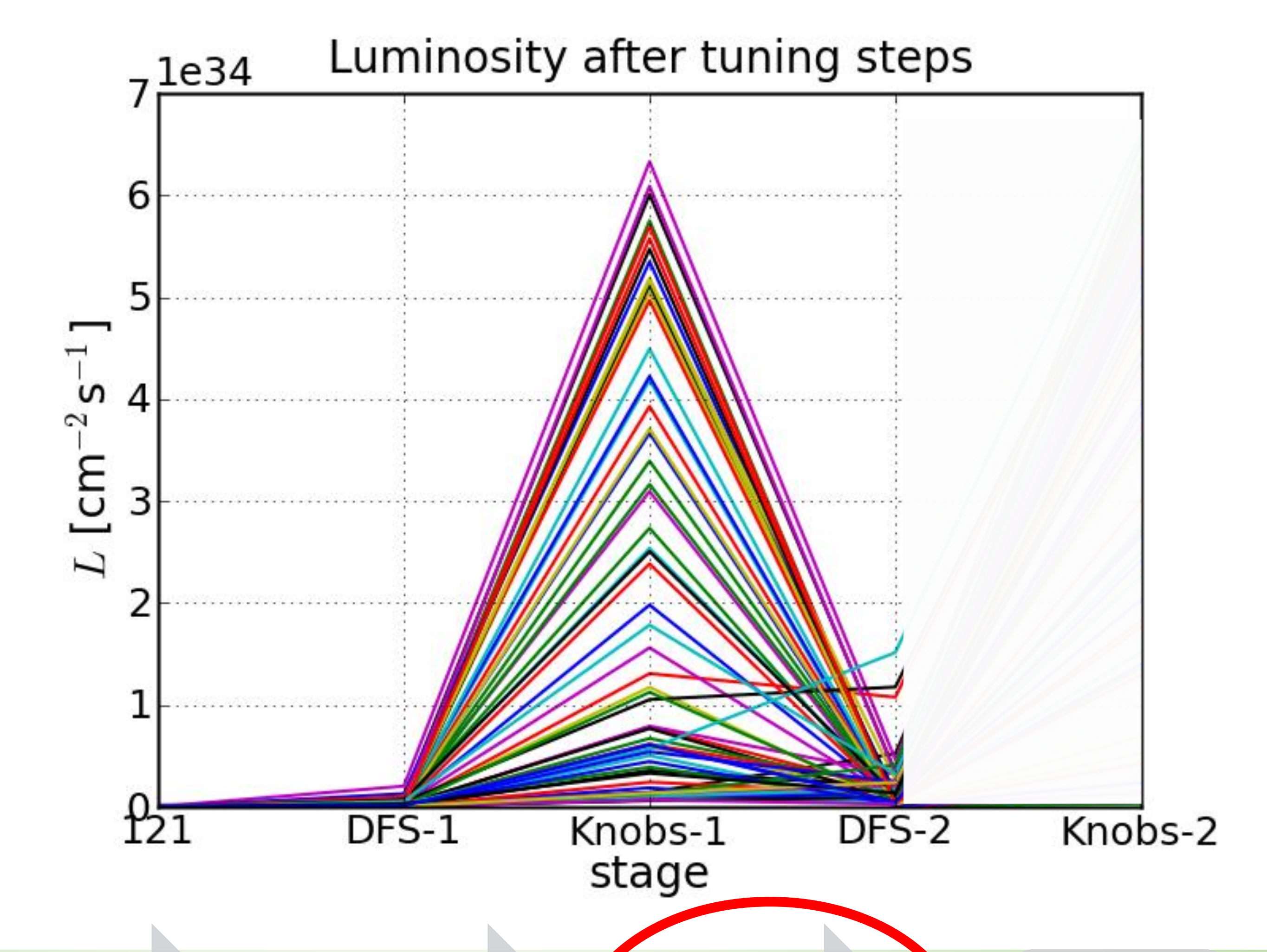
1. Apply the first corrections to the uncorrected beam
2. Correct the dispersion to approach design values
3. Use the tuning knobs to maximize luminosity





Step by step…

1. Apply the first corrections to the uncorrected beam
2. Correct the dispersion to approach design values
3. Use the tuning knobs to maximize luminosity
4. Attempt to optimize dispersion again



1-2-1 Tuning — First step applied to uncorrected beam

Dispersion Free Steering – 1 — Bring dispersion to design values

Tuning Knobs – 1 — Maximize Luminosity

Dispersion Free Steering – 2 — Bring dispersion back toward design

Tuning Knobs - 2 — Final shot to maximize Luminosity

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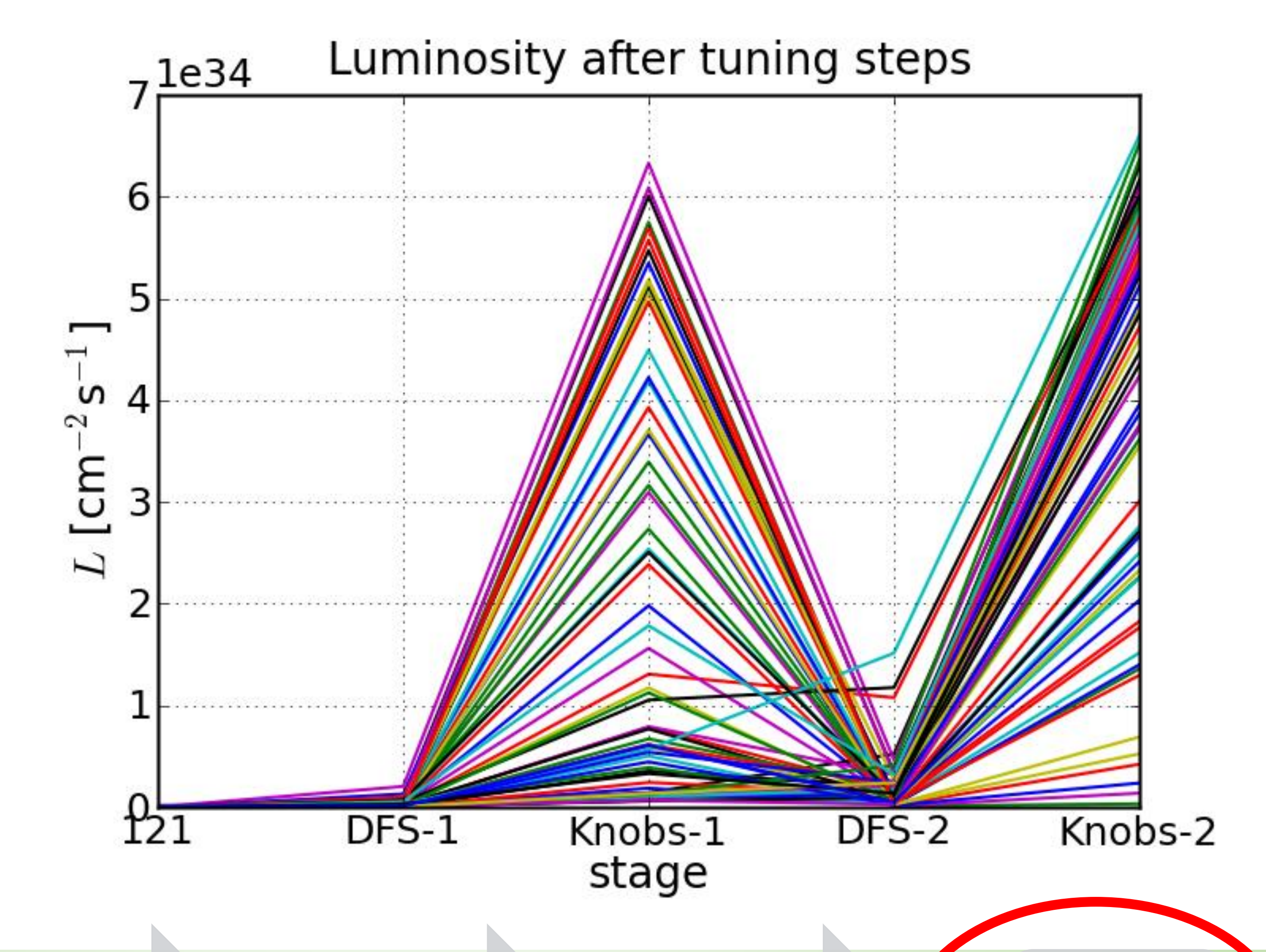
Step by step…

1. Apply the first corrections to the uncorrected beam
2. Correct the dispersion to approach design values
3. Use the tuning knobs to maximize luminosity
4. Attempt to optimize dispersion again
5. Maximize luminosity once more



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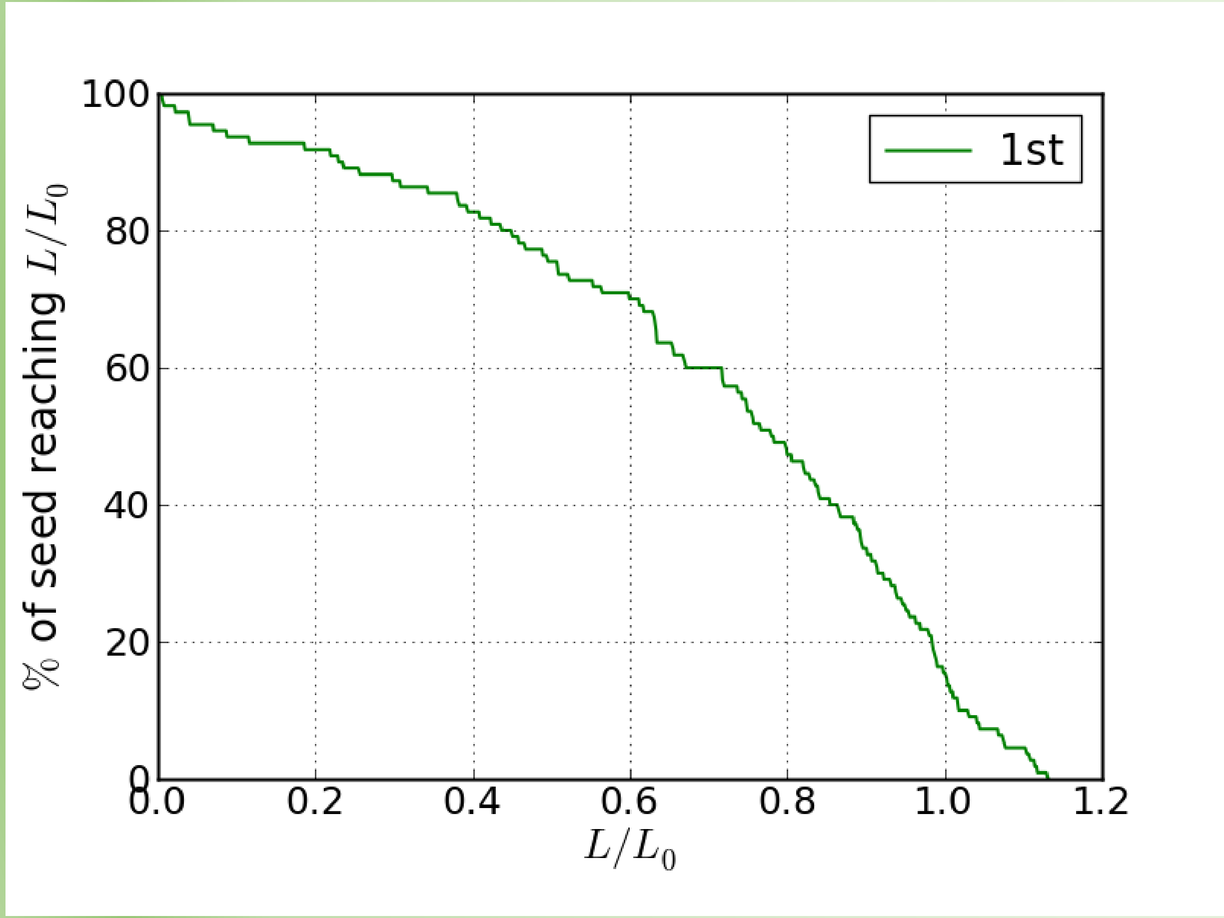
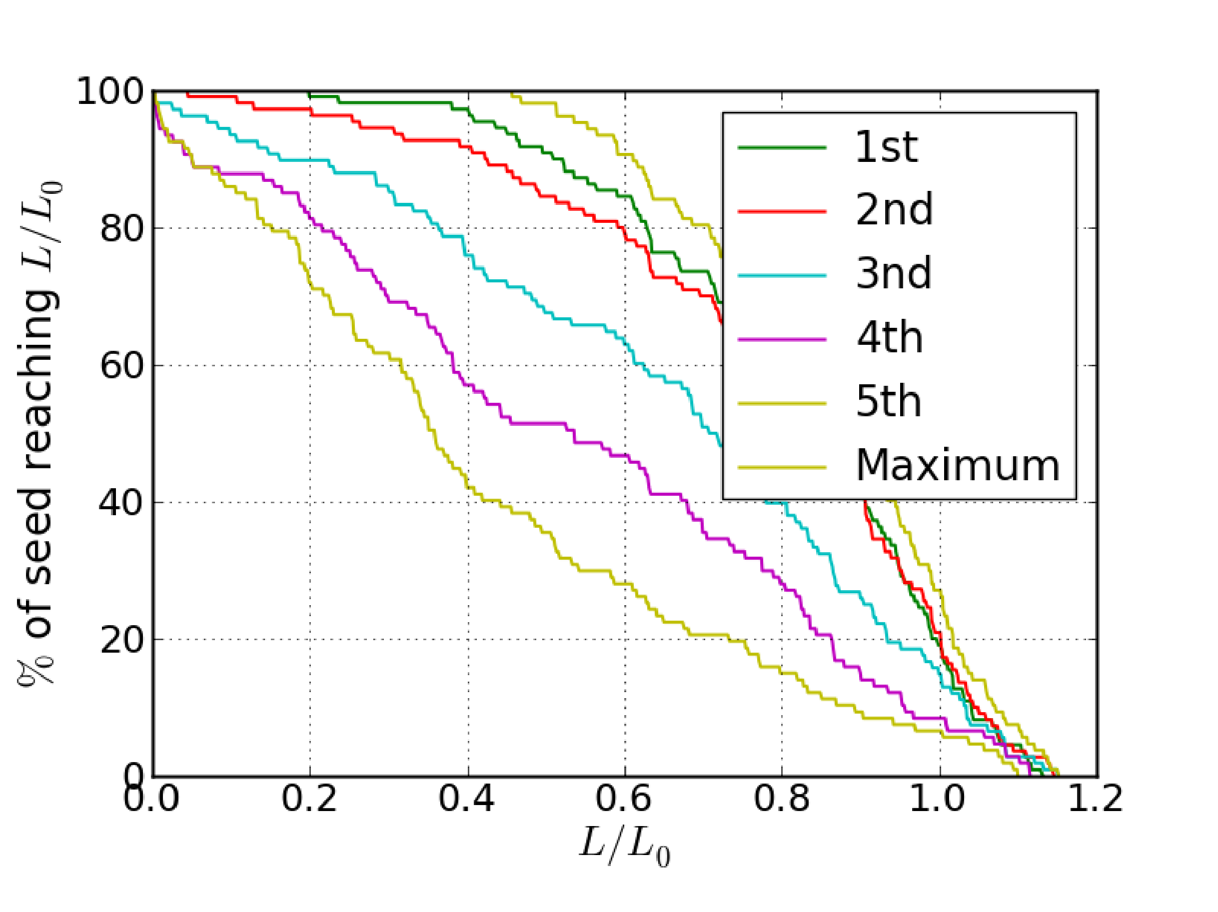
Unfortunately, this isn't enough.

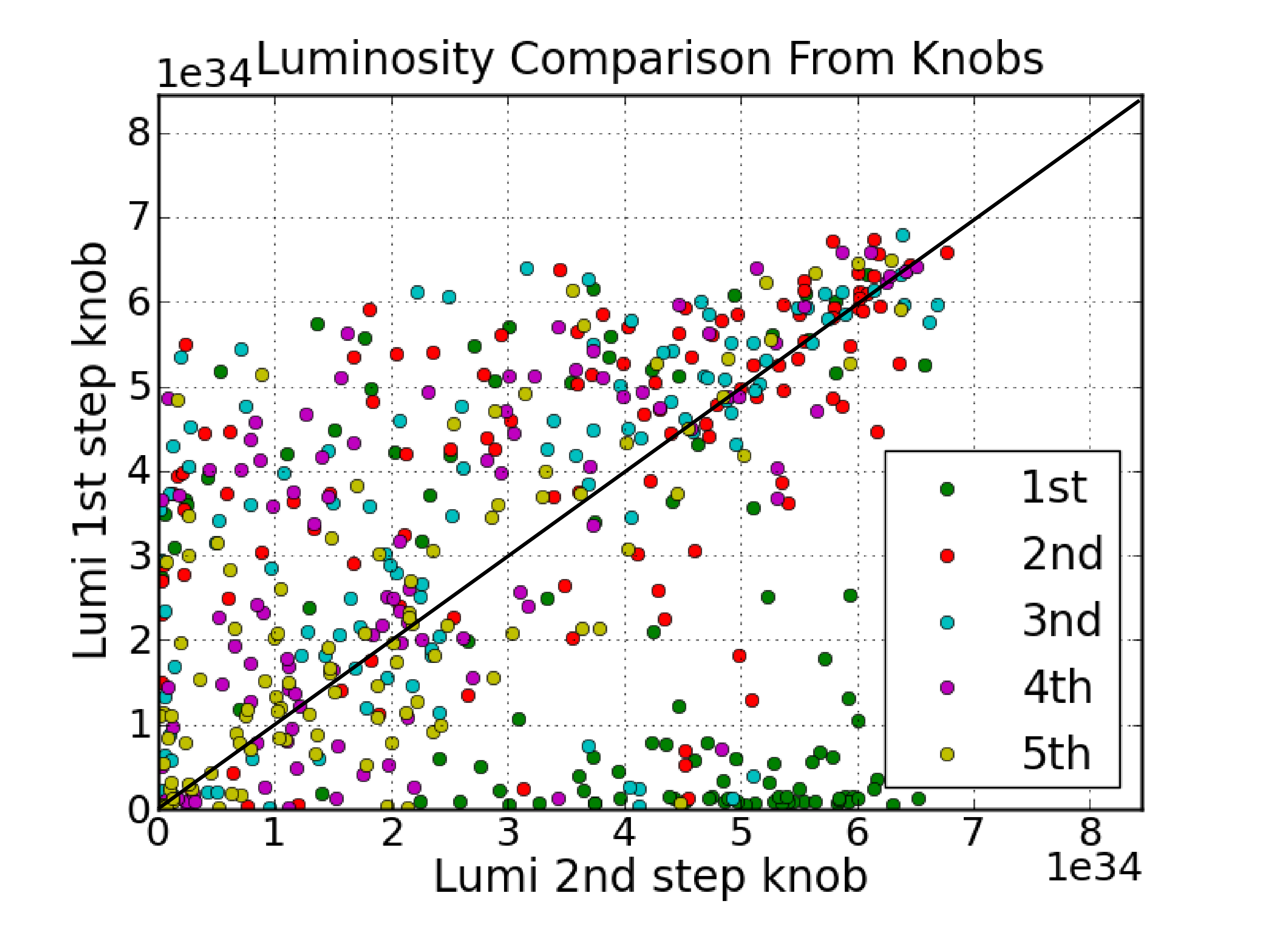
The goal is for 90% of seeds to reach 110%.

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

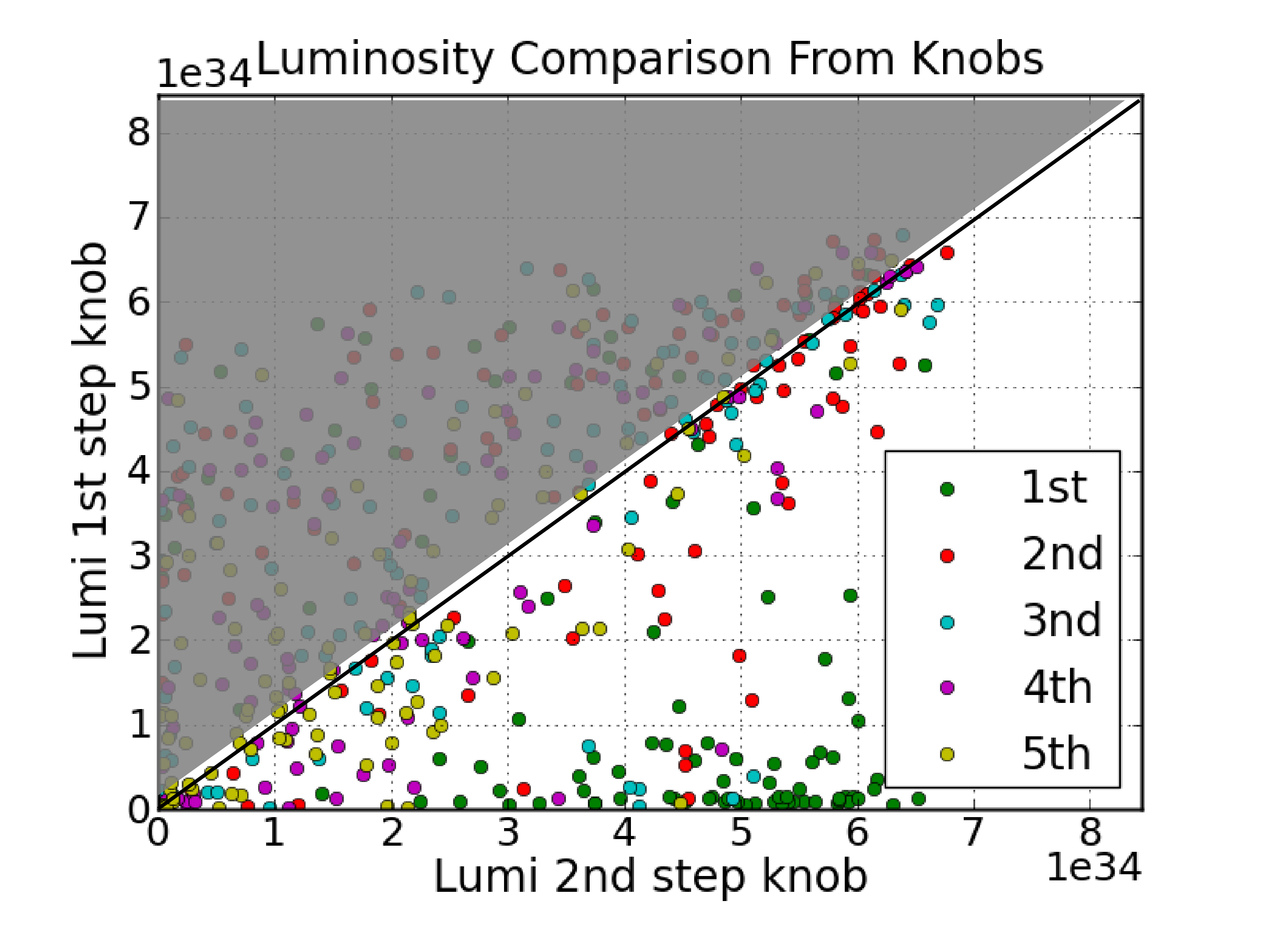




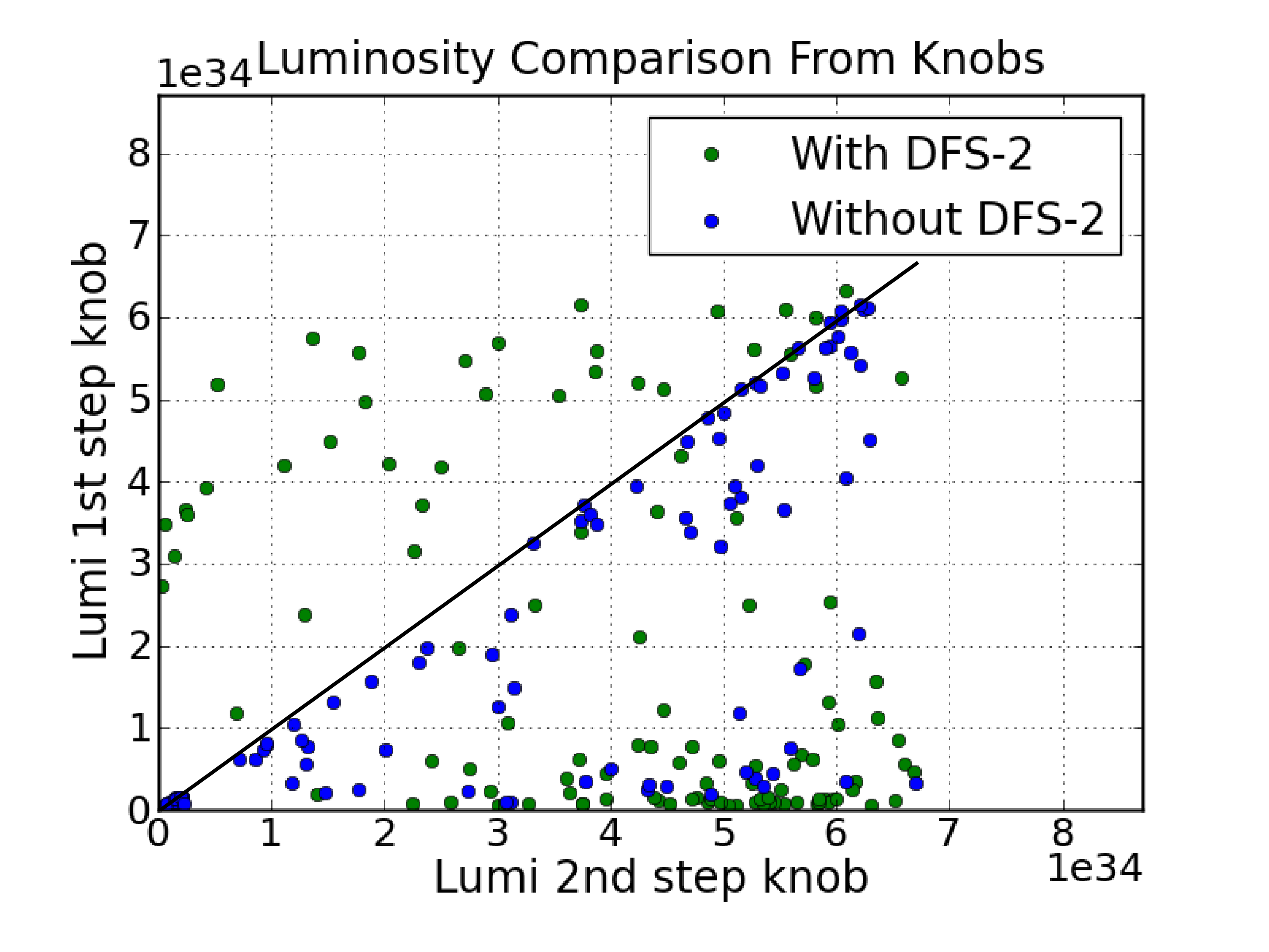
So, what's the problem?



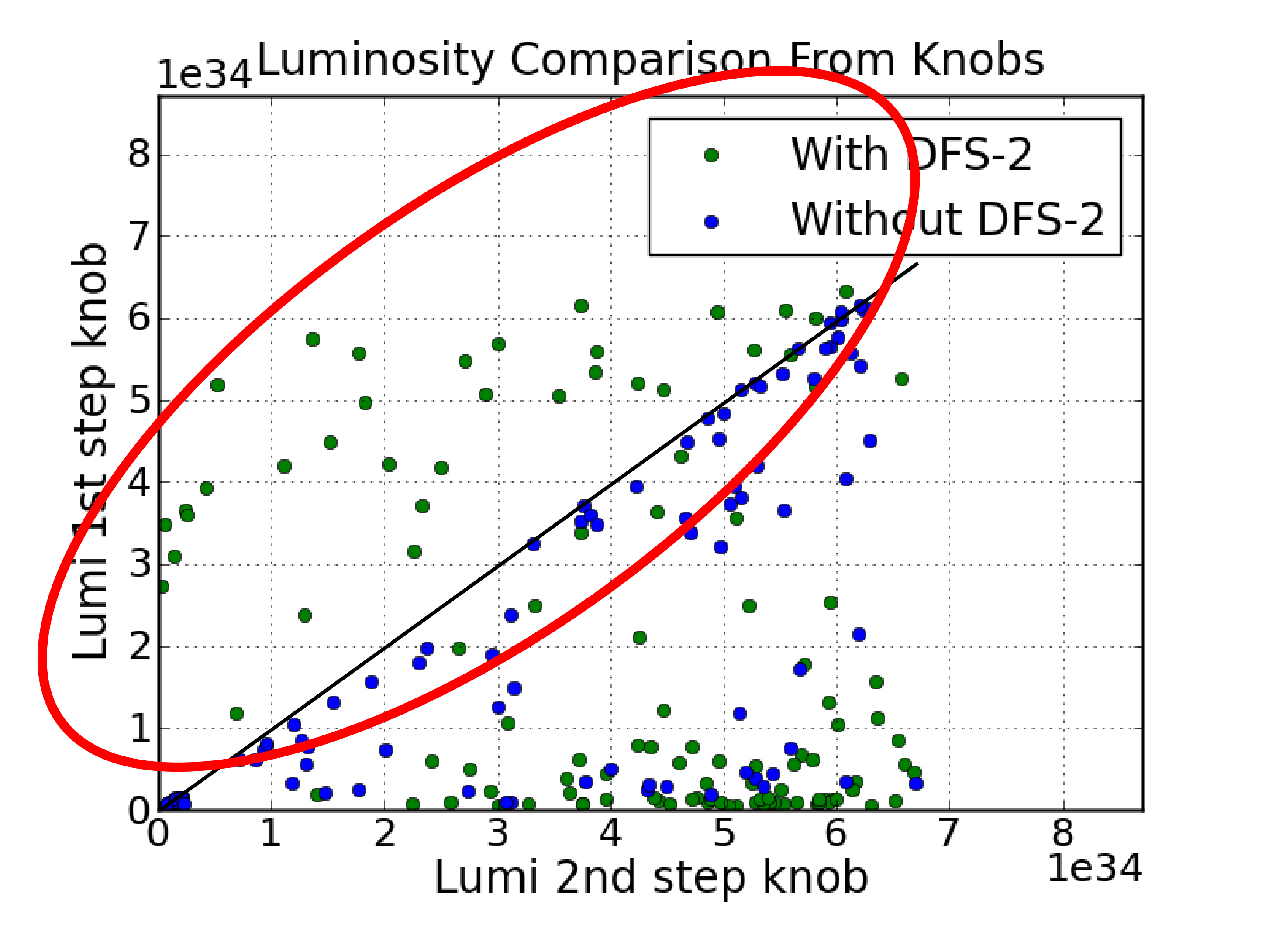
It turns out, the 2nd DFS step decreases the luminosity of many seeds.



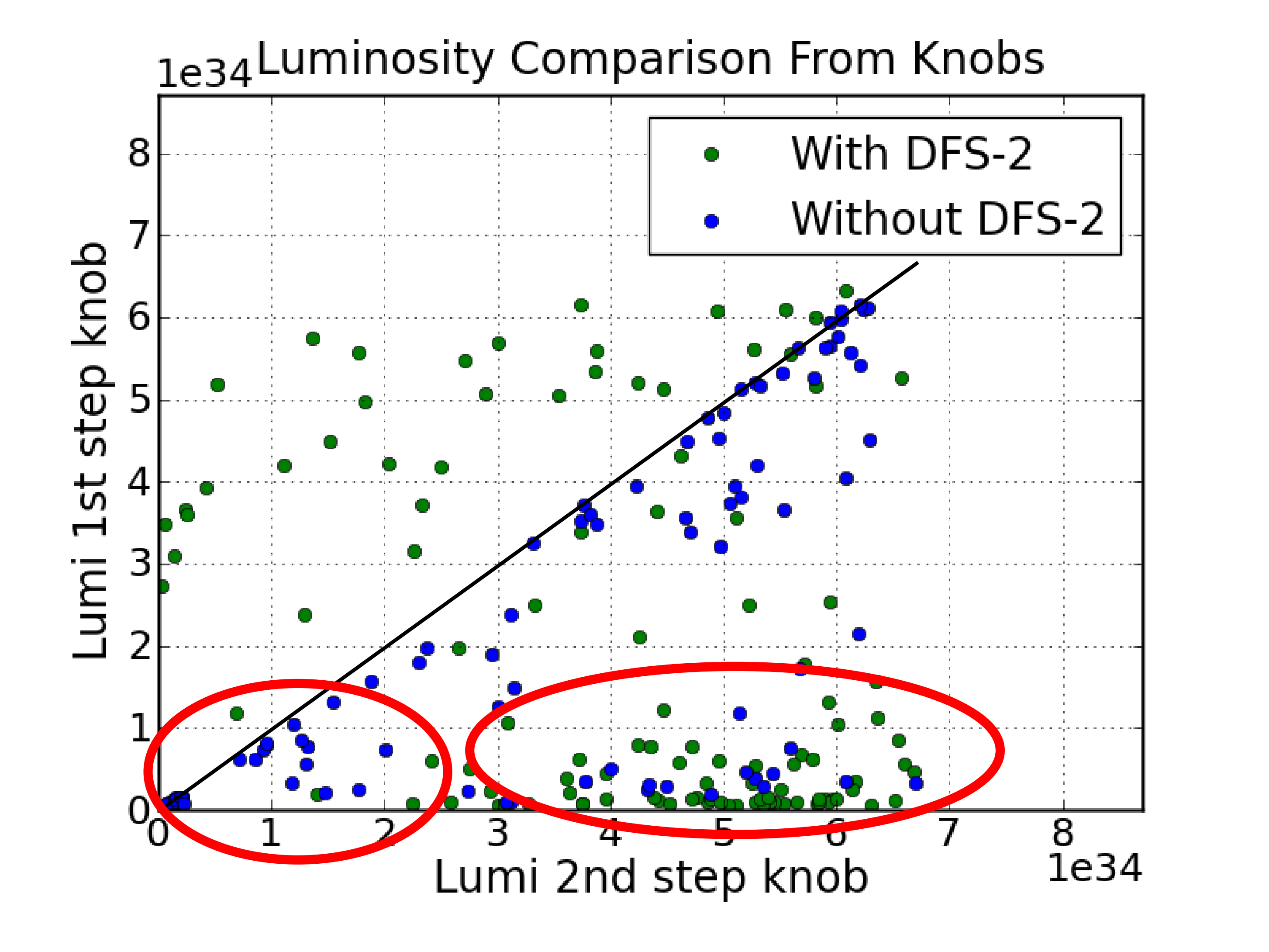
Tried simply skipping that step…



The Good


Luminosity Comparison From Knobs
1e34
With DFS-2
Without DFS-2
Lumi 1st step knob
Lumi 2nd step knob
1e34
0
1
2
3
4
5
6
7
8

The Bad



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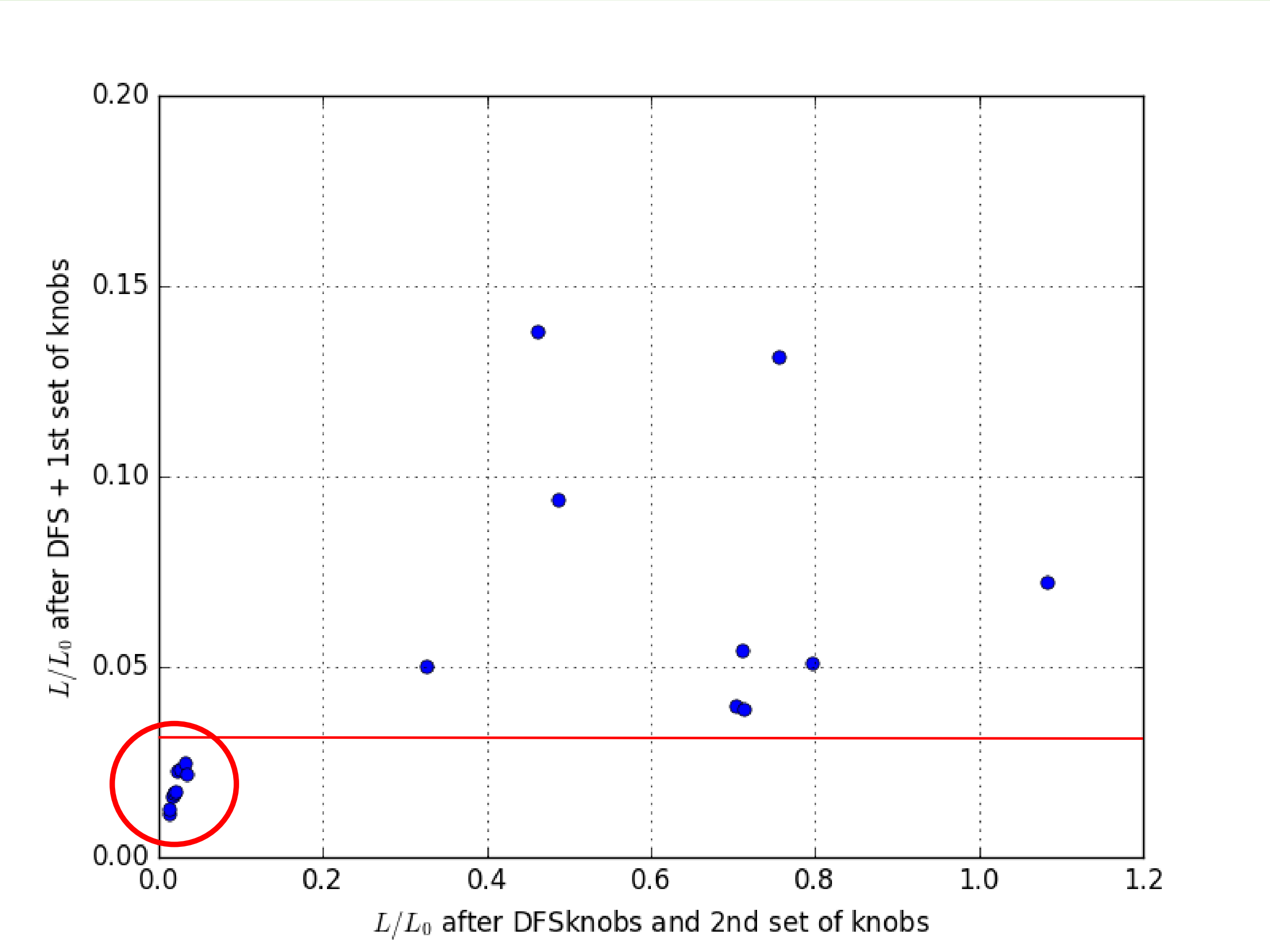
Zooming in on the low end…



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 2^{nd} 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

DFS Knobs Algorithm

$$\begin{pmatrix} y \\ \omega(\eta - \eta_0) \\ 0 \end{pmatrix} = \begin{pmatrix} \mathbf{R} \\ \omega\mathbf{D} \\ \beta\mathbf{I} \end{pmatrix} \begin{pmatrix} \theta_1 \\ \vdots \\ \theta_m \end{pmatrix}$$

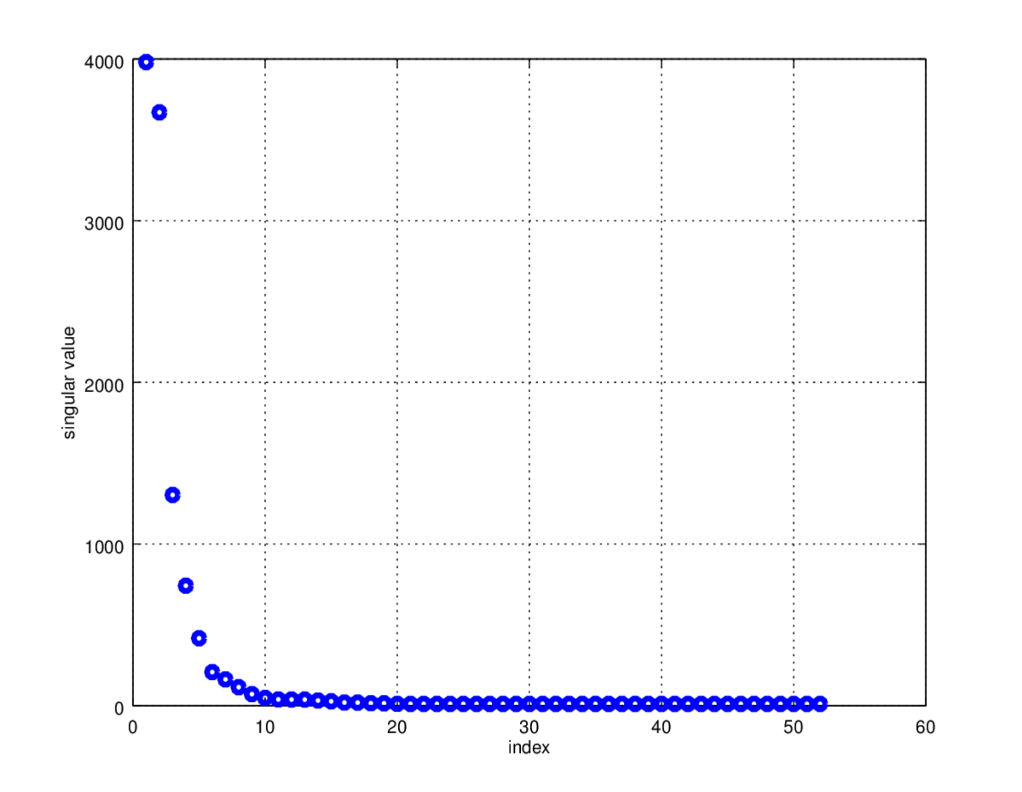
R = Response matrix nominal beam
D = Response matrix off-energy beam
θ = Correctors
ω = Weight for DFS
β = Regulation parameter
(Equivalent to cutting on singular values)

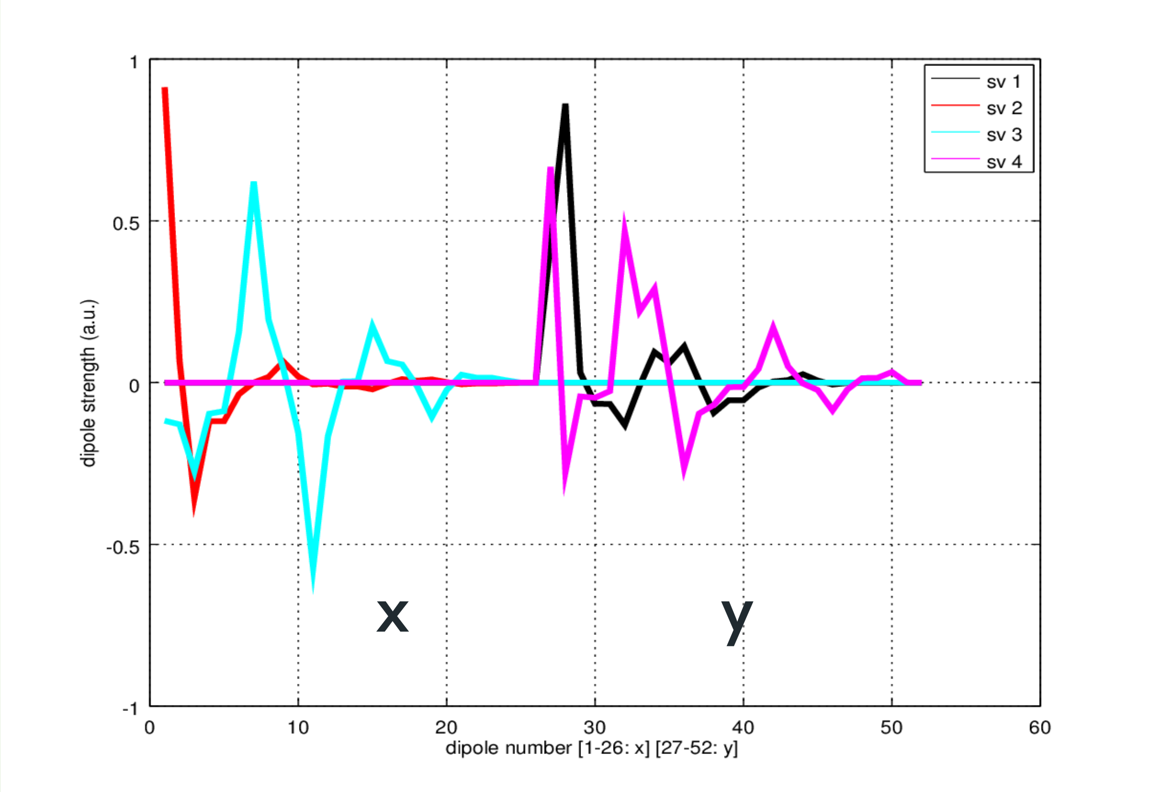
Solution: $$\begin{pmatrix} \theta_1 \\ \vdots \\ \theta_m \end{pmatrix} = \begin{pmatrix} R \\ \omega D \\ \beta I \end{pmatrix}^{-1} \begin{pmatrix} y \\ \omega(\eta - \eta_0) \end{pmatrix}$$

- Usual knob construction:
  - Take SVD and apply first few singular values
  - How many singular values are needed?

Selecting the number of singular values

- Despite coupled system the actual modes are decoupled
- 4 singular values seems good (two each plane) – 5th does not improve tuning

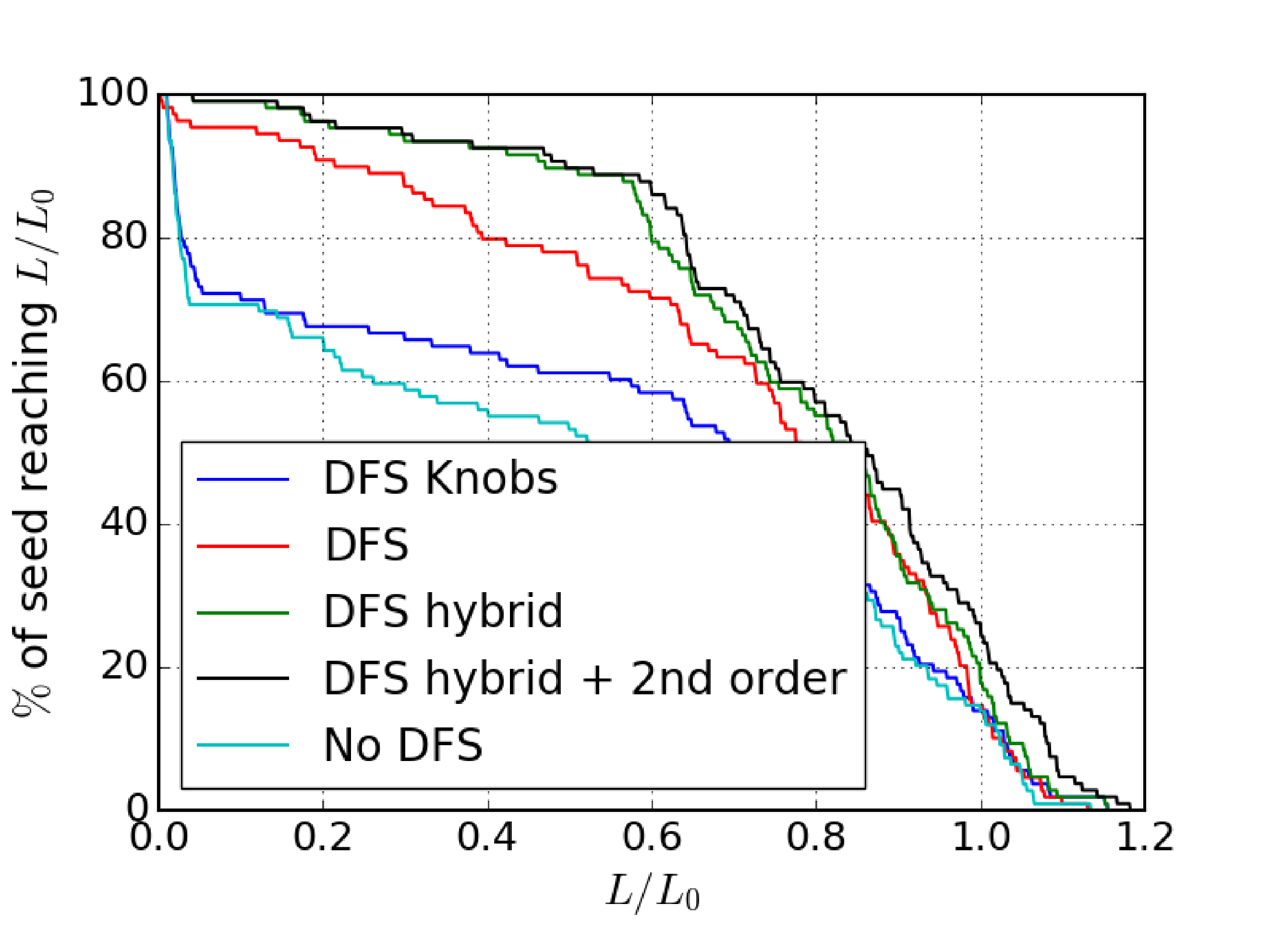




Done with weights for DFS-1, but first 4 directions look very similar (expected).

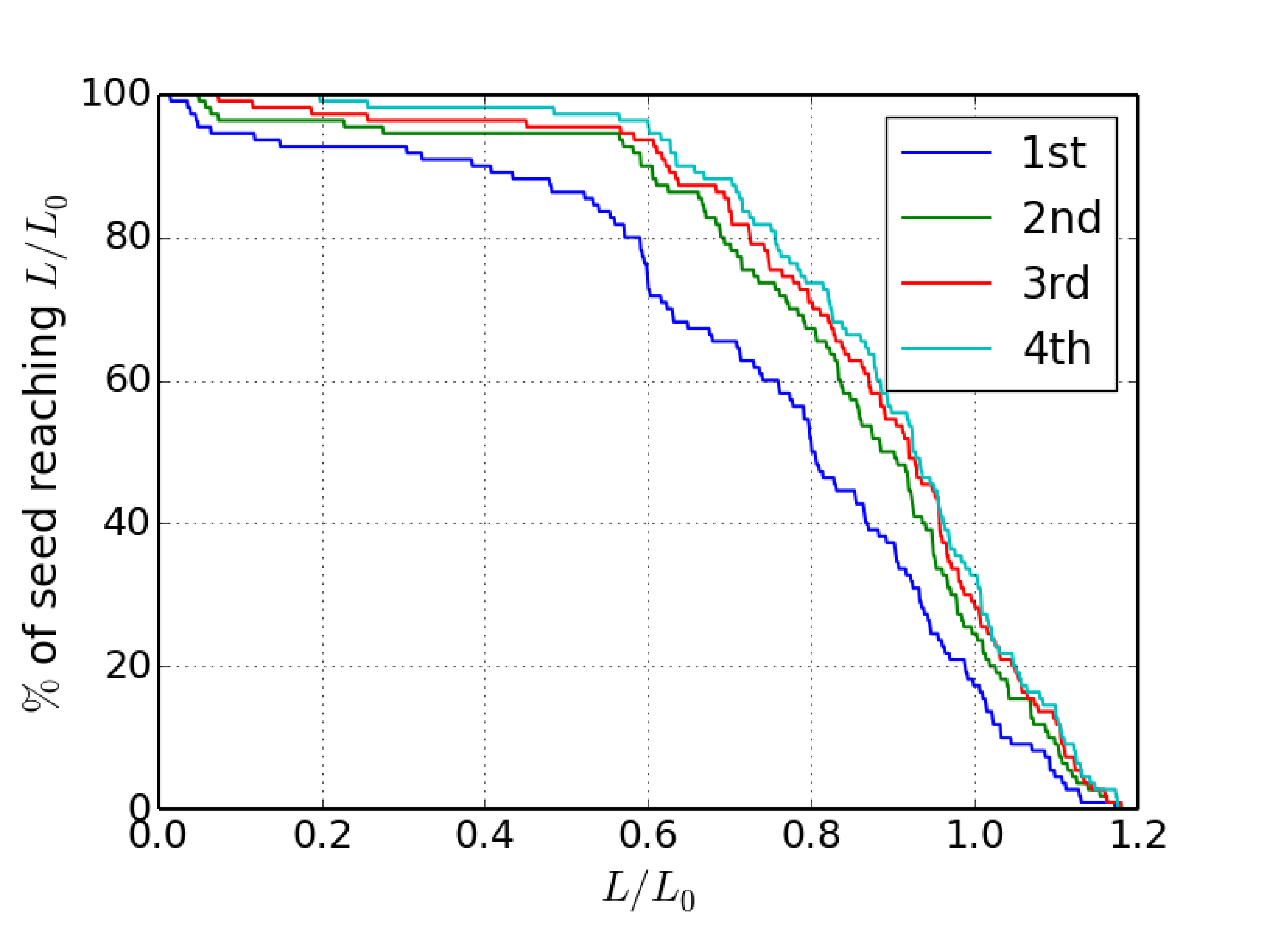
Comparing single iterations

- DFS hybrid:
  - If relative luminosity > 3%, perform DFS knobs
  - Else DFS as usual
- 2nd order:
  - 1 round of 8 simple 2nd order knobs (scanning tilts and strengths of sextupoles used in the knobs).
  - Tilt scan didn't really help.
    - Expected since there is no tilt misalignment



What about multiple iterations?

- Good improvement for 2nd iteration.
  - Only small improvements with further iterations
  - Seeds with low luminosity improving
  - This only applies hybrid knobs, not 2nd order corrections
  - Need to address 2nd order corrections and correct specific aberrations



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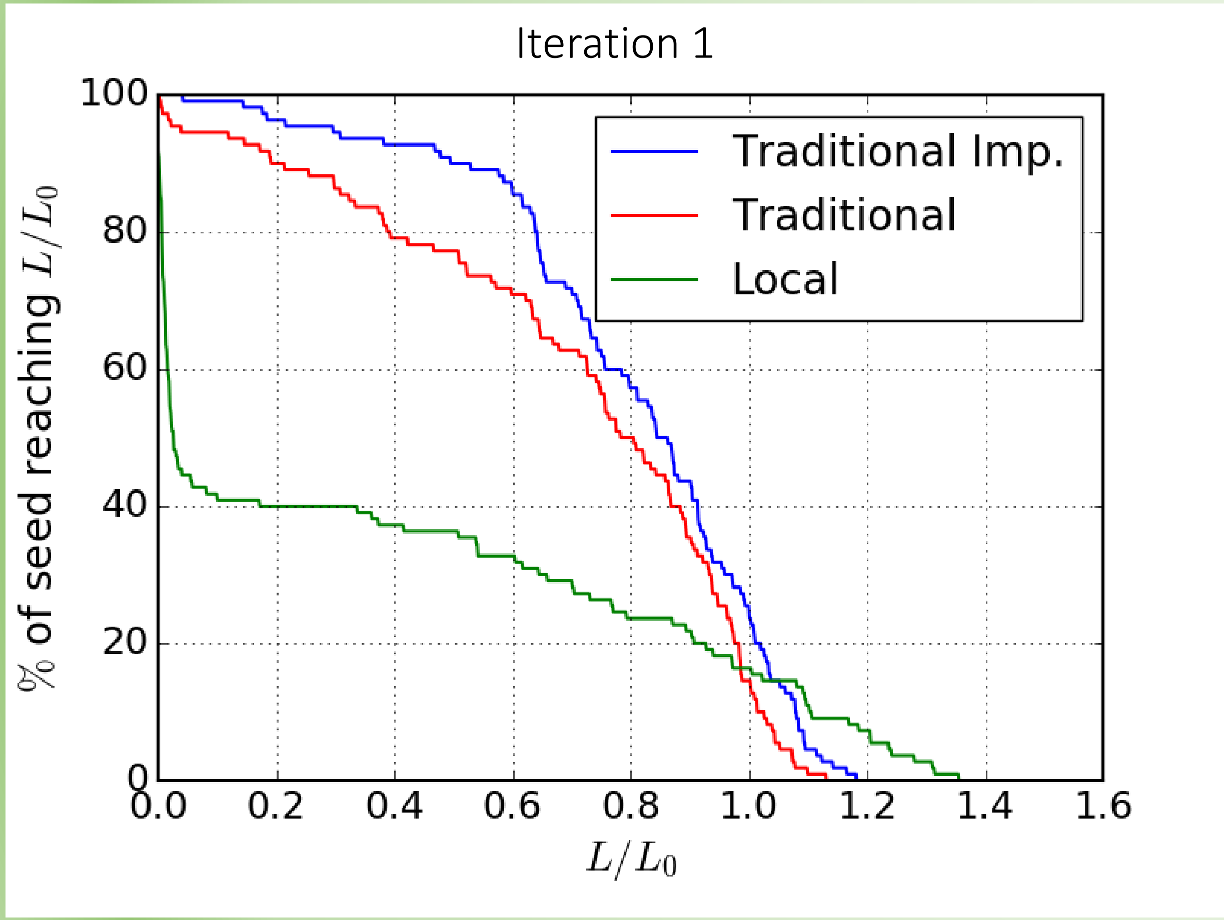
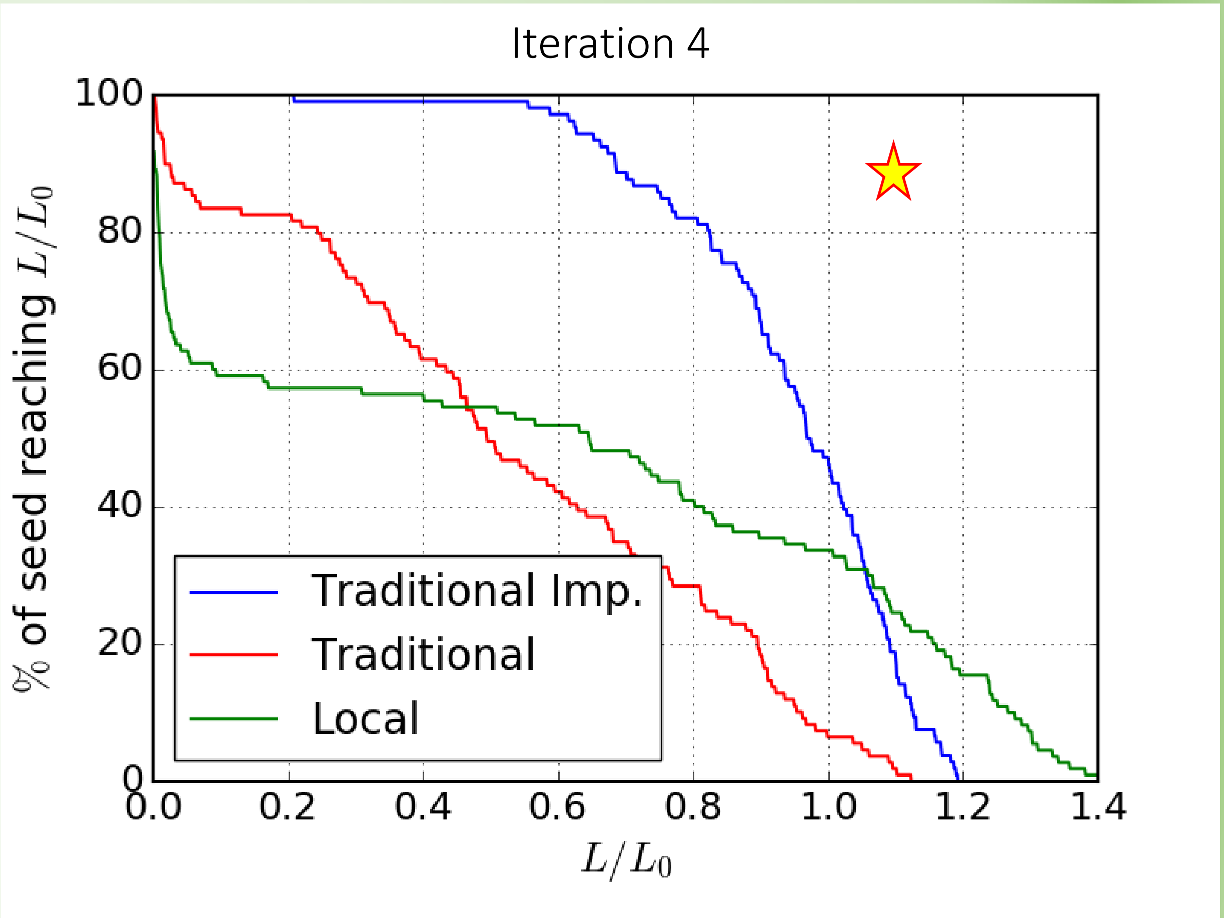
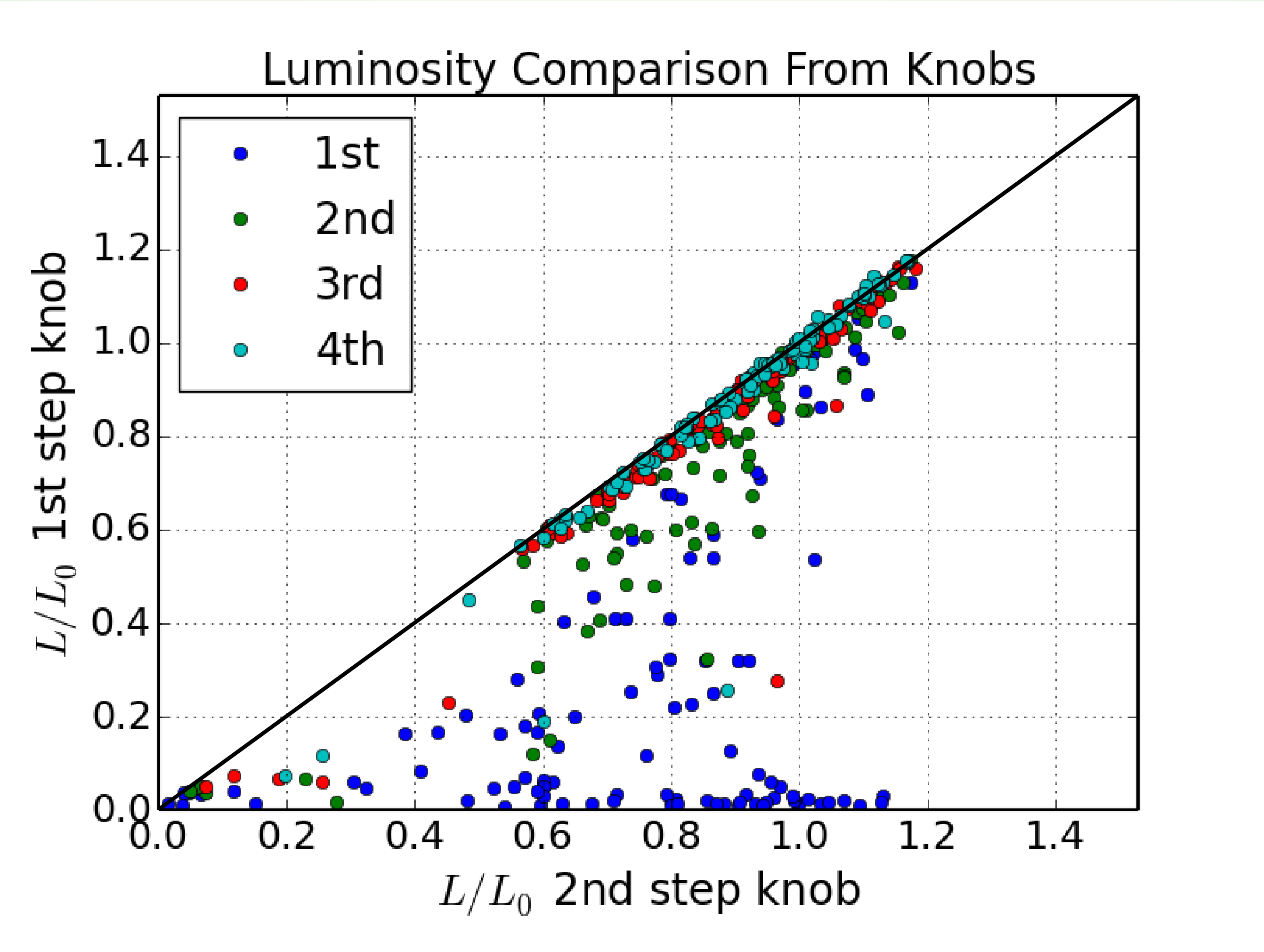
Comparing Iterations - Different Methods





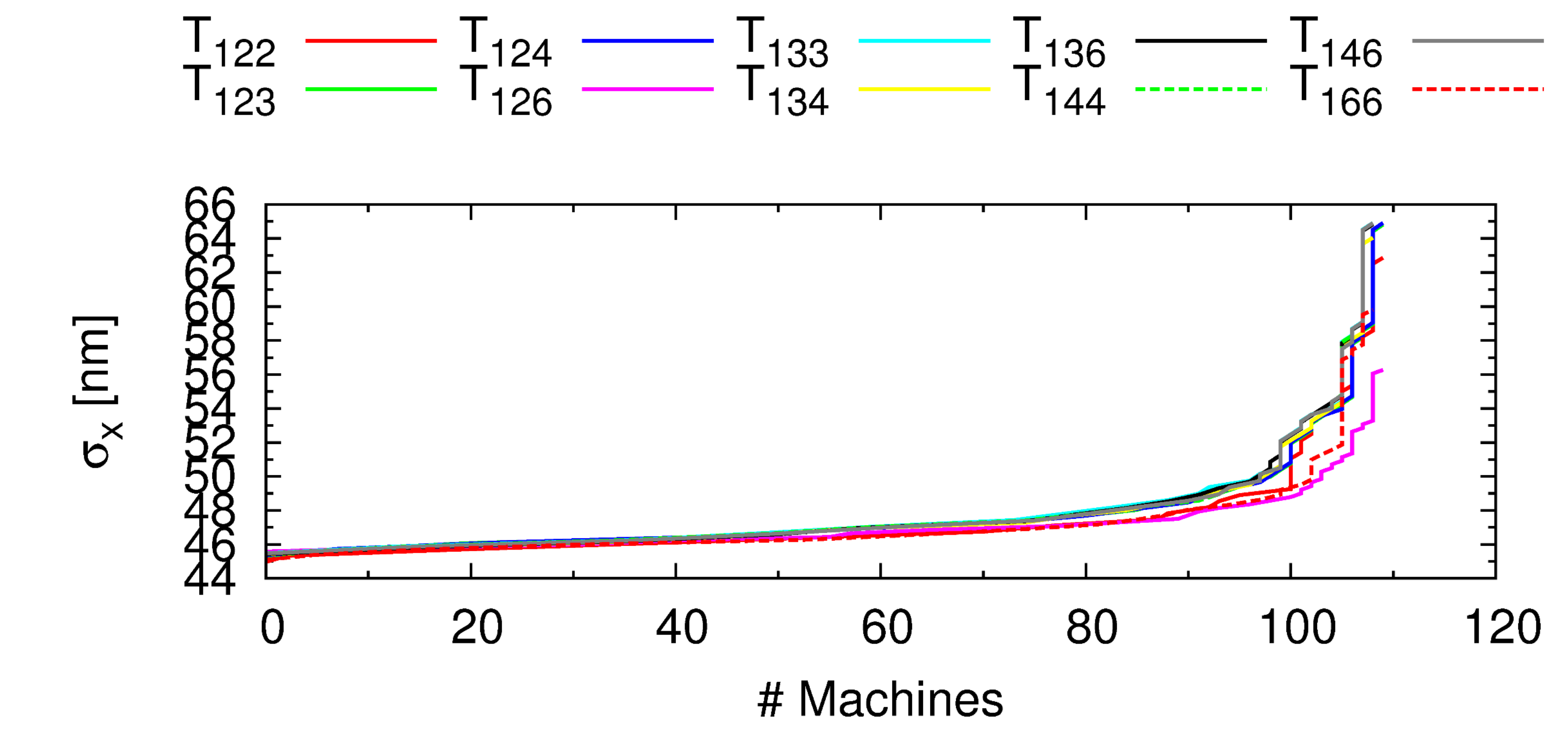
Are we still losing luminosity?



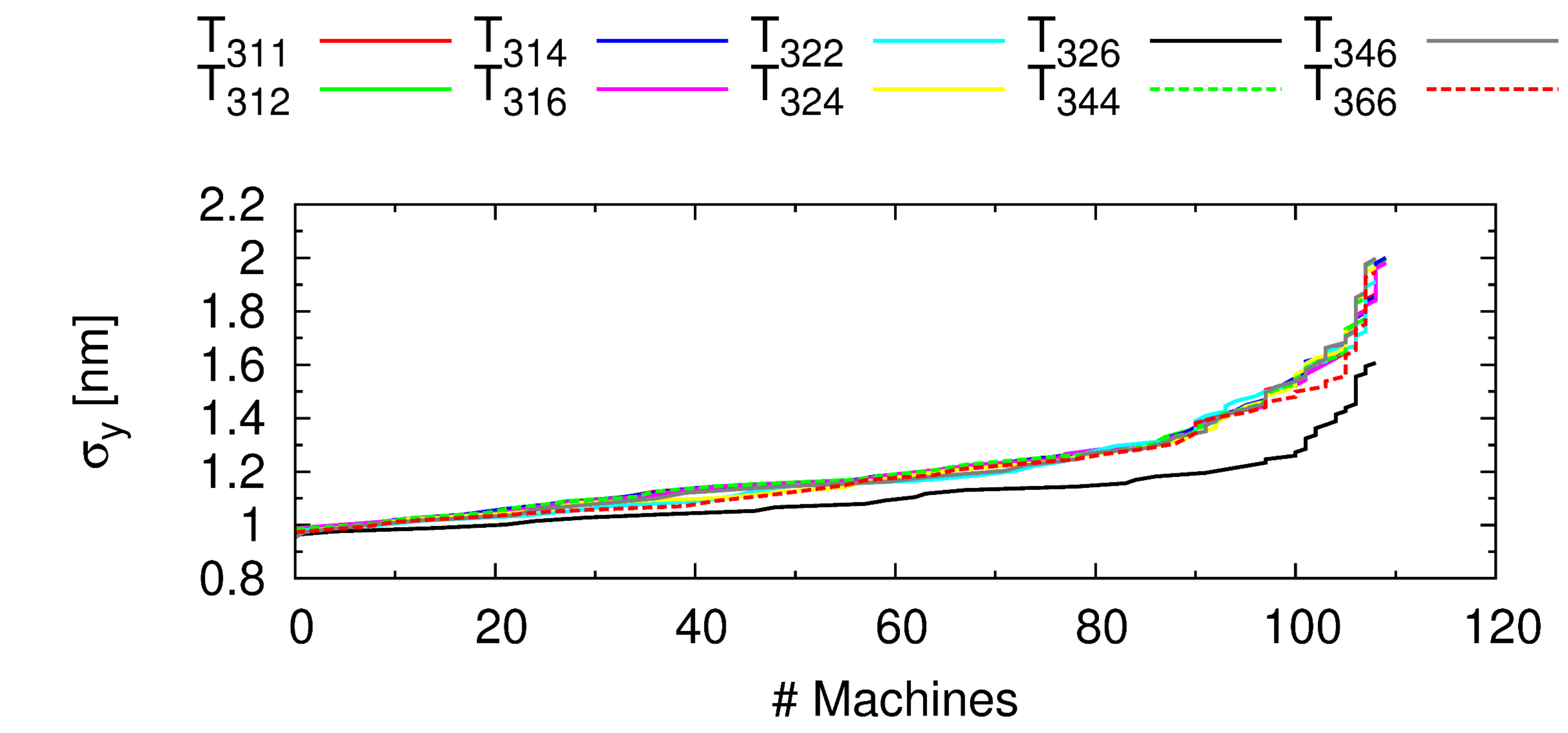
However, it's still not enough.

- 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 (see his talk prior to this)
- 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



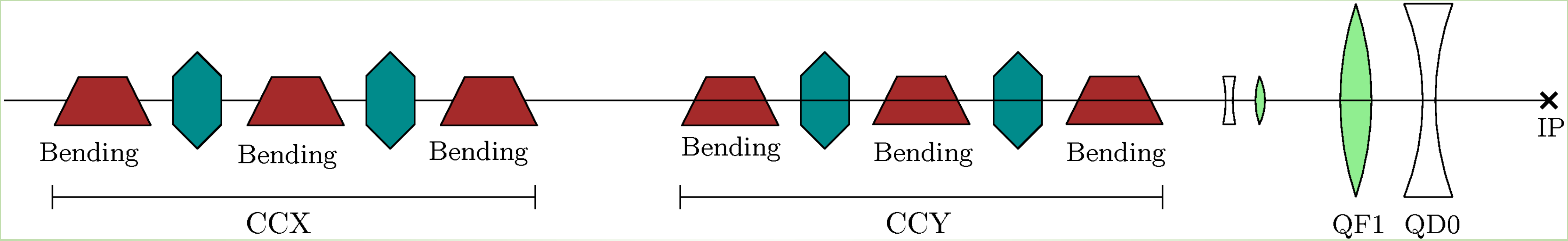
In the vertical plane



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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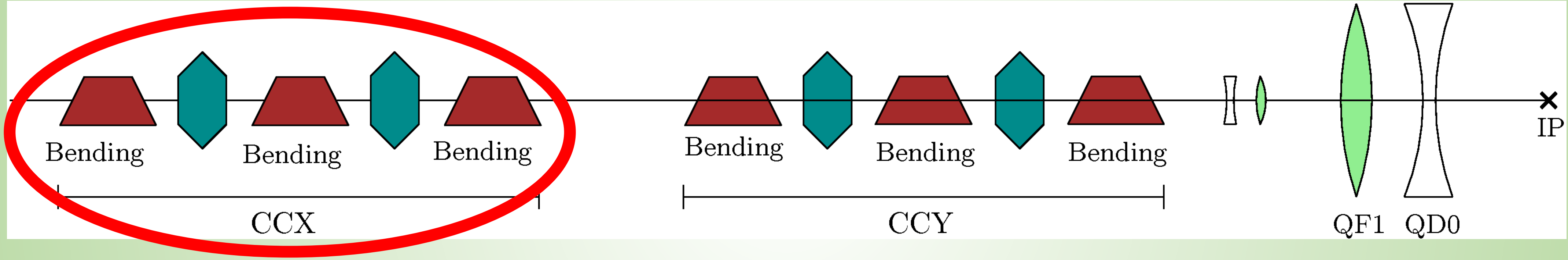
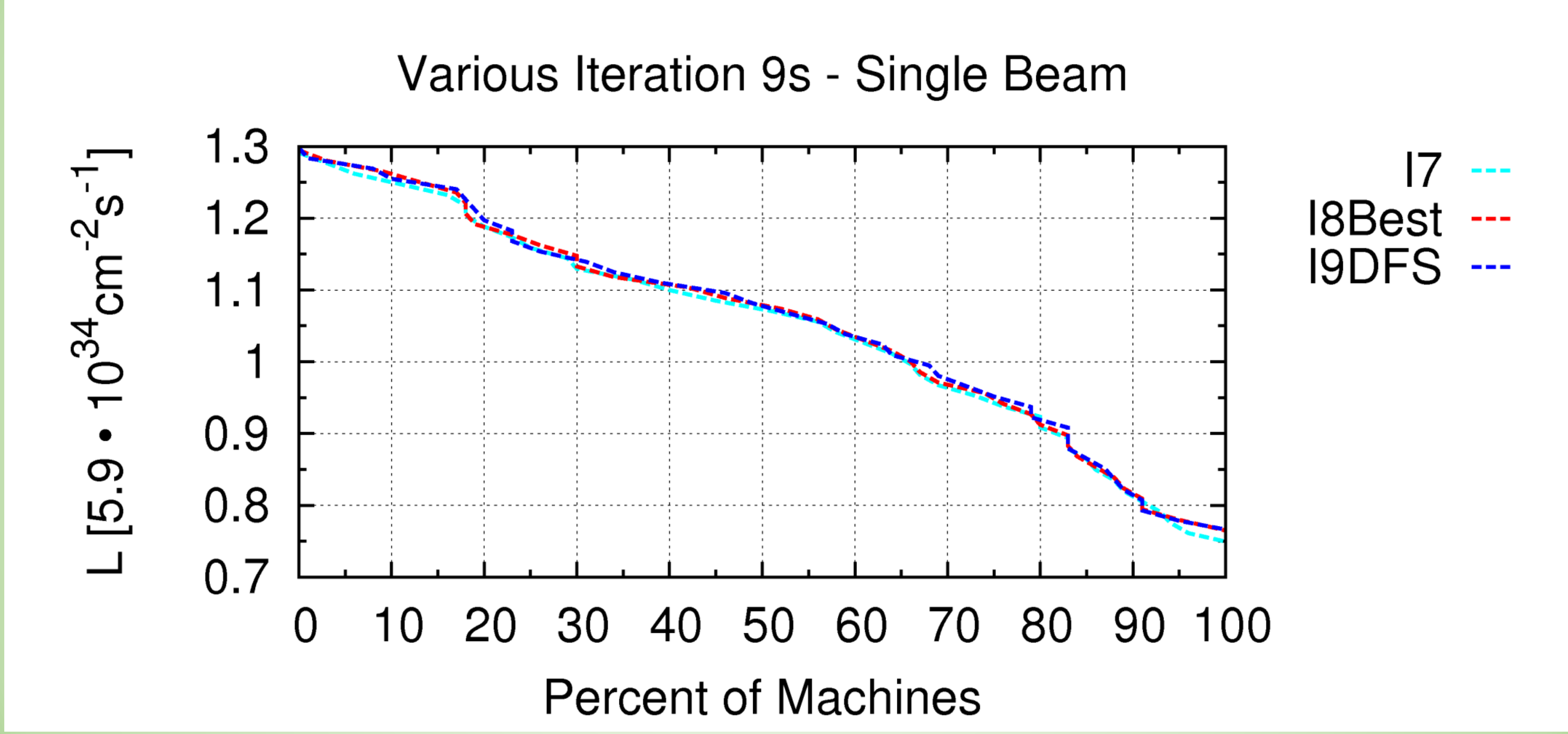


So, how did these changes perform?



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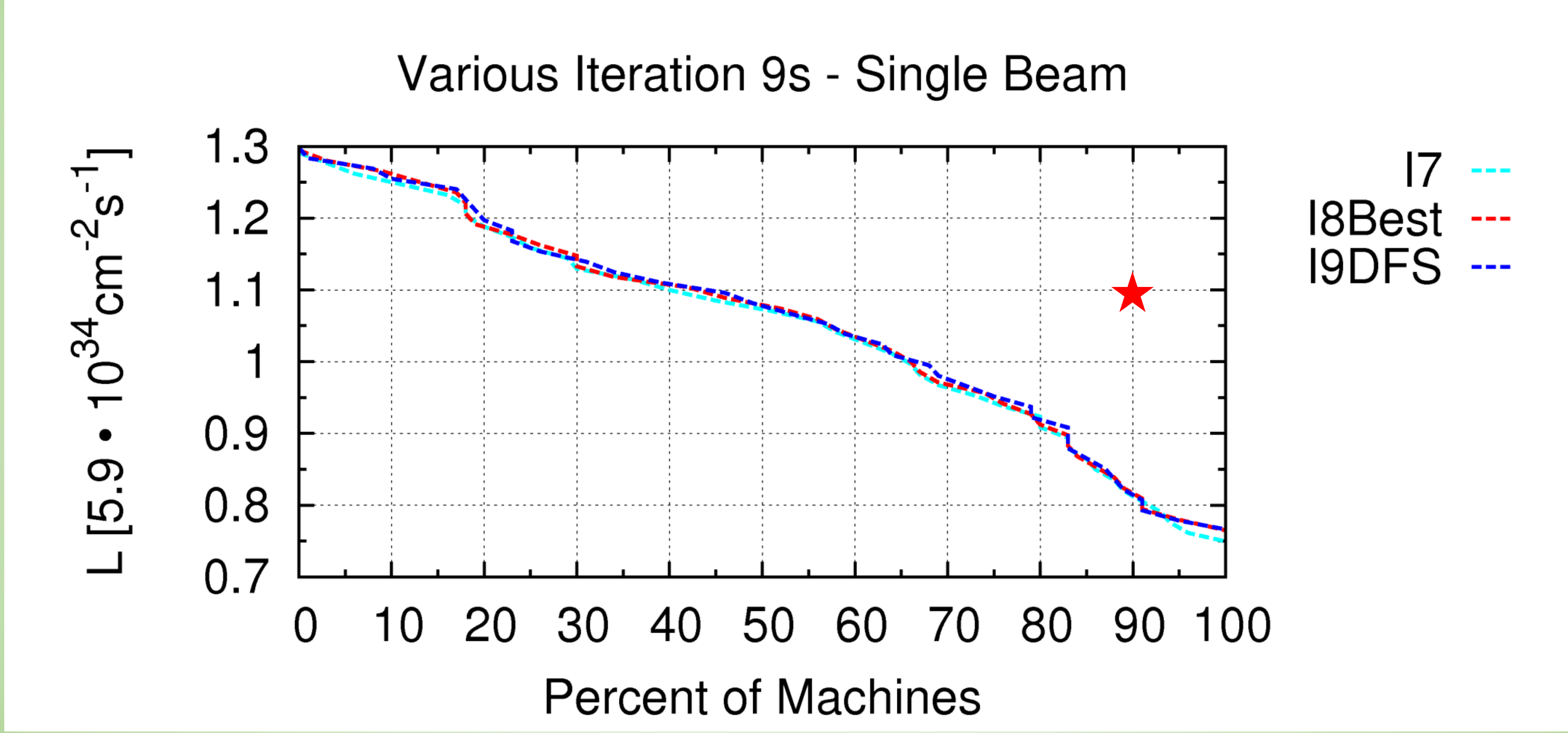

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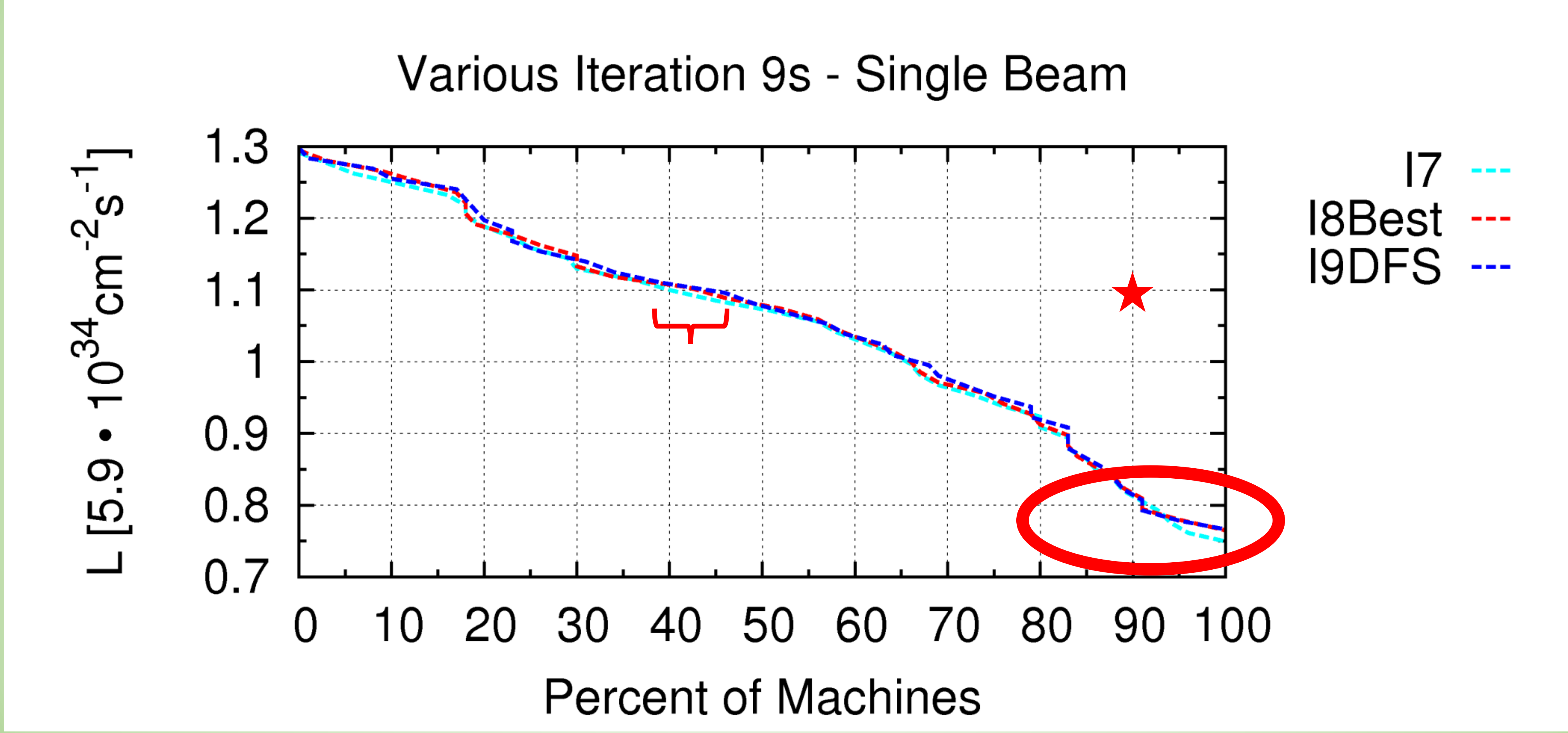

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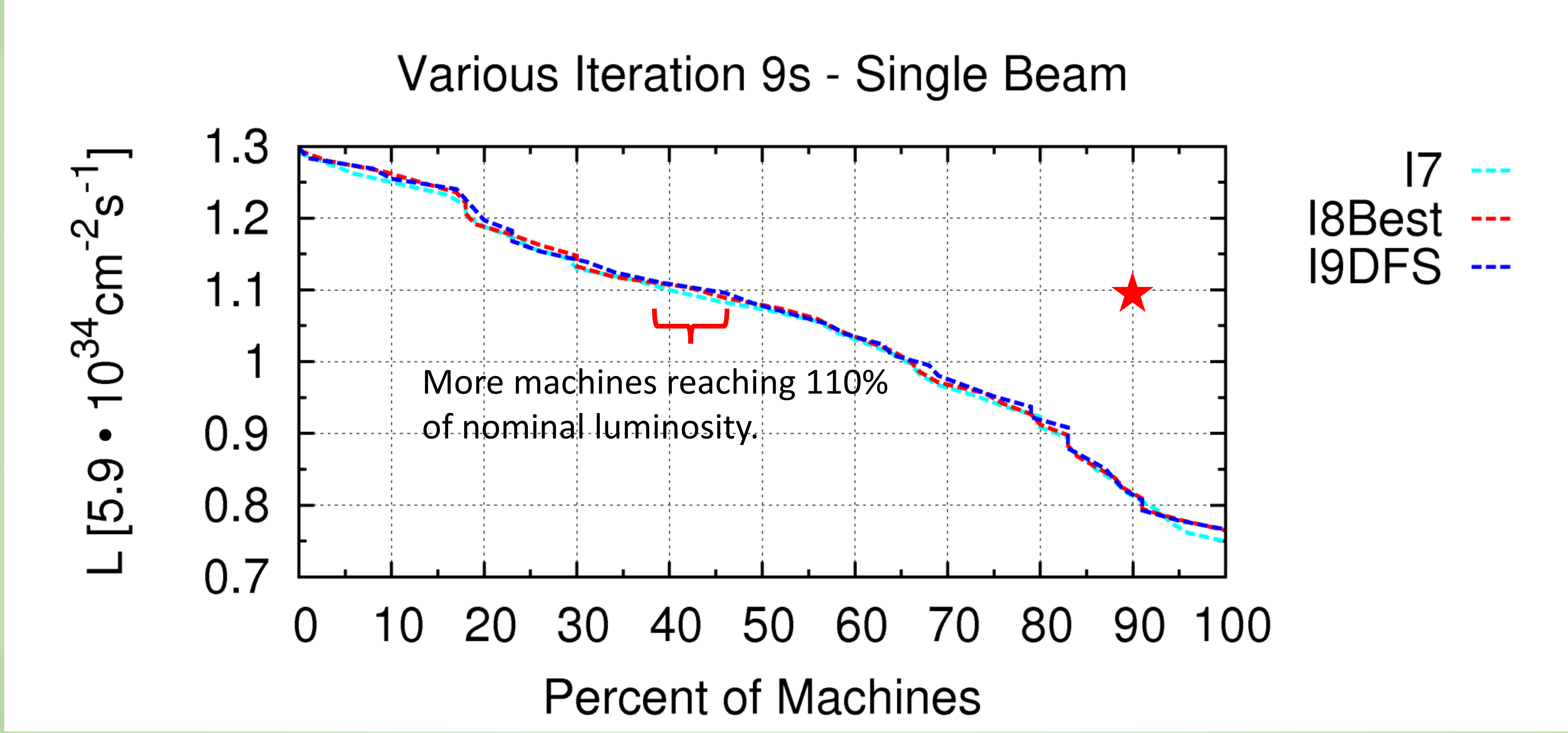

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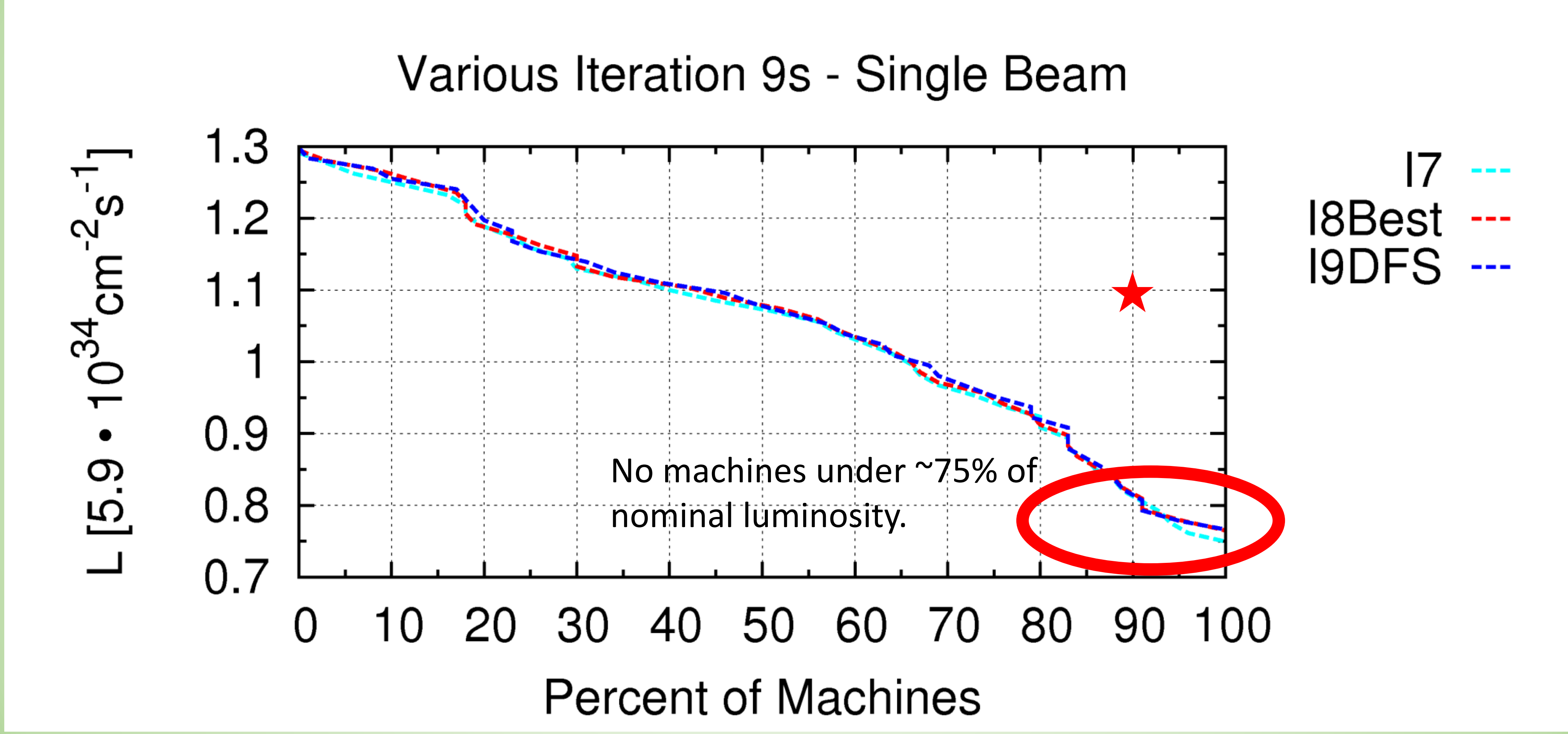

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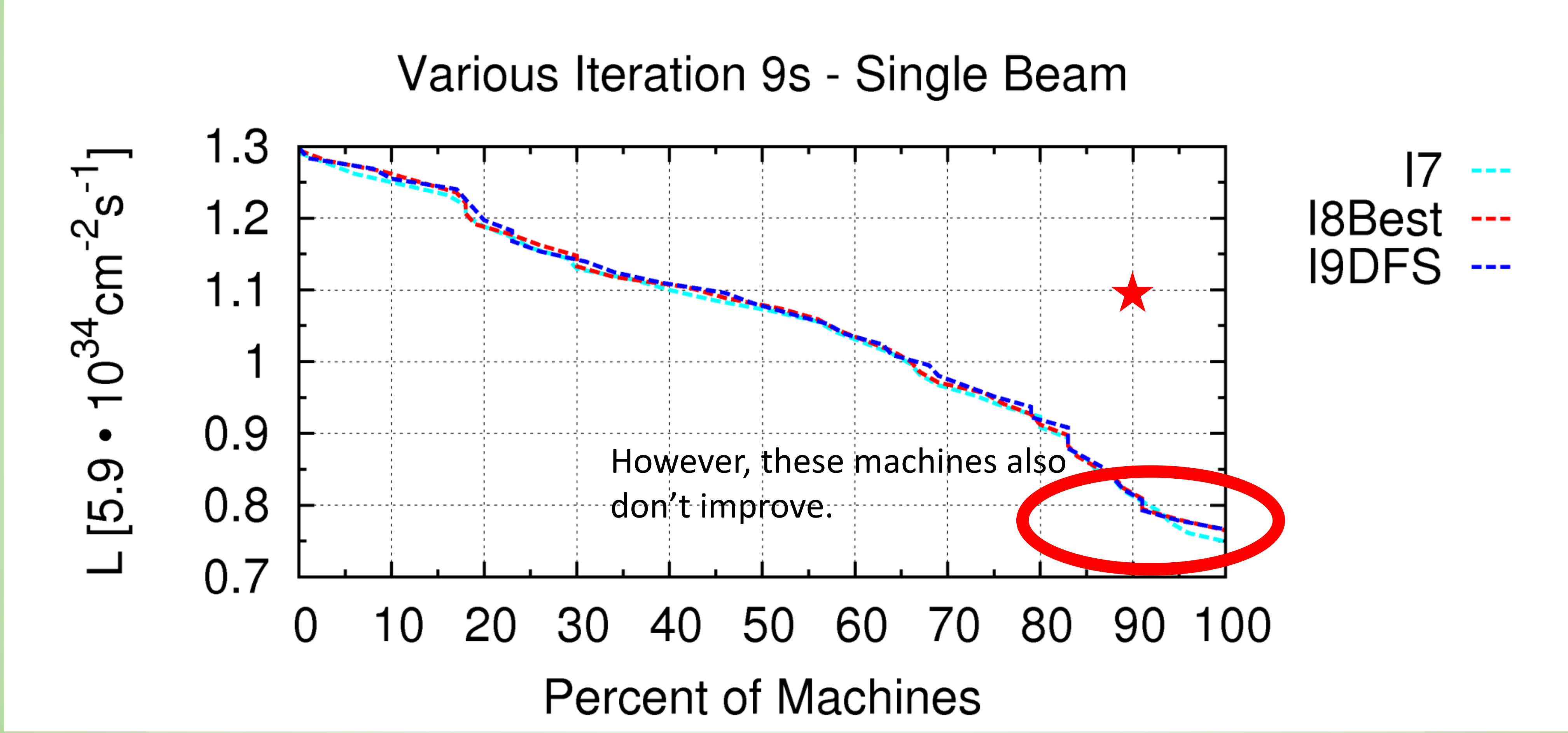
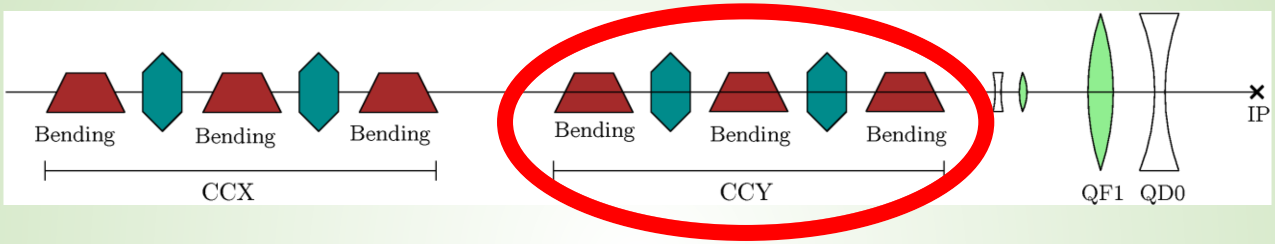


What else needs to be done?

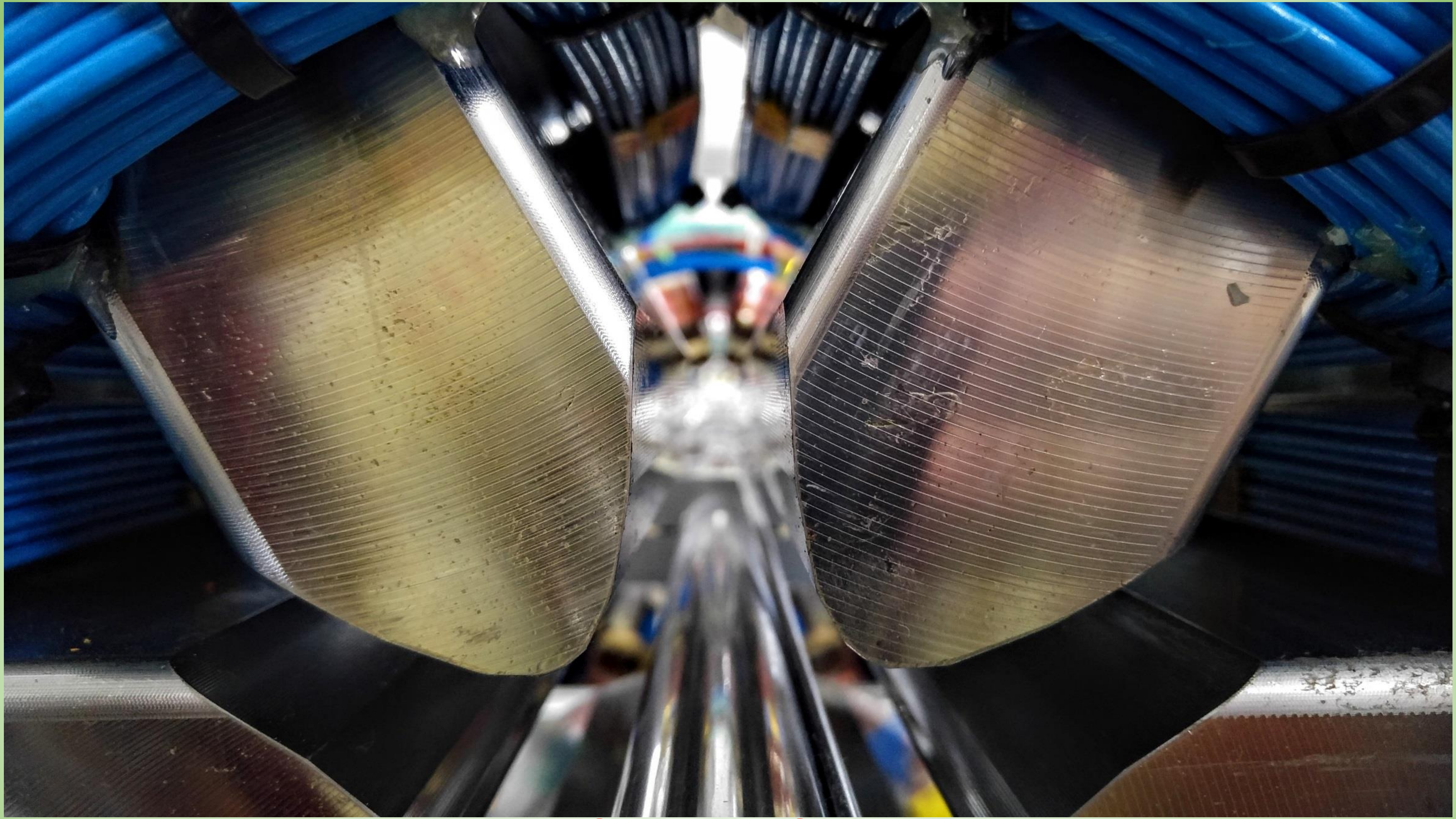
- Several plans "in the works"
  - Place dimensionless skews in the CCY region of the lattice



  - 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

In conclusion…

- 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



Thanks!