Update on a New FFS Tuning Technique

(Impact of SR)

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Reminder: The Alignment Procedure

Four steps:

- With the multipole magnets switched Off

  1) Orbit Correction (1-to-1)

  2) Orbit $+$ Target Dispersion Steering

- Beam-based centering of the multipole magnets

  3) Multipole-shunting, one by one

- With the multipole magnets On

  4) Orbit $+$ Target Dispersion–Coupling–Beta-Beating Steering

$\Rightarrow$ A more detailed explanation of this method can be found in the Proceedings of LINAC10:

A. Latina, MOP026, LINAC10.

Reminder: The Systems of Equations

- Orbit + Target Dispersion Steering (step 2)

$$\begin{pmatrix} & & \mathbf{b} \\ \omega_1 & \cdot & (\boldsymbol{\eta} - \boldsymbol{\eta}_0) \\ & & \mathbf{0} \end{pmatrix} = \begin{pmatrix} & & \mathbf{R} \\ \omega_1 & \cdot & \mathbf{D} \\ \beta & \cdot & \mathbf{I} \end{pmatrix} \begin{pmatrix} \boldsymbol{\theta}_x \\ \boldsymbol{\theta}_y \end{pmatrix}$$

- Orbit + Target Dispersion–Coupling–Beta-Beating Steering (step 4)

$$\begin{pmatrix} & & \mathbf{b} \\ \omega_2 & \cdot & (\boldsymbol{\eta} - \boldsymbol{\eta}_0) \\ \omega_3 & \cdot & (\boldsymbol{\beta} - \boldsymbol{\beta}_0) \\ \omega_3 & \cdot & \mathbf{c} \\ & & \mathbf{0} \end{pmatrix} = \begin{pmatrix} & & \mathbf{R} \\ \omega_2 & \cdot & \mathbf{D} \\ \omega_3 & \cdot & \mathbf{B} \\ \omega_3 & \cdot & \mathbf{C} \\ \beta & \cdot & \mathbf{I} \end{pmatrix} \begin{pmatrix} \boldsymbol{\theta}_x \\ \boldsymbol{\theta}_y \end{pmatrix}$$

⇒ There are four free parameters to tune: $\boxed{\omega_1,\ \omega_2,\ \omega_3 \text{ and } \beta}$.

⇒ Optimization scan to find their optimal value

Reminder: Simulation Setup

- CLIC BDS, $L^* = 3.5$ m

- Misalignment 10 μm RMS for:
  - quadrupoles: x and y
  - multipoles: x and y
  - bpms: x and y

- Two extra BPMs:
  - one at the IP
  - one 3.5 meters downstream the IP (might this be the same used for the IP-Feedback?)

- Bpm resolution:
  - 10 nm

- Synchrotron radiation emission

⇒ All simulations have been carried out using placet-octave

Reminder: Synchrotron Radiation Emission

- Used optimal parameters ω_1, ω_2, ω_3 and β

- Synchrotron radiation emission has been taken into account for all magnets

- Precautions to stabilize the simulation

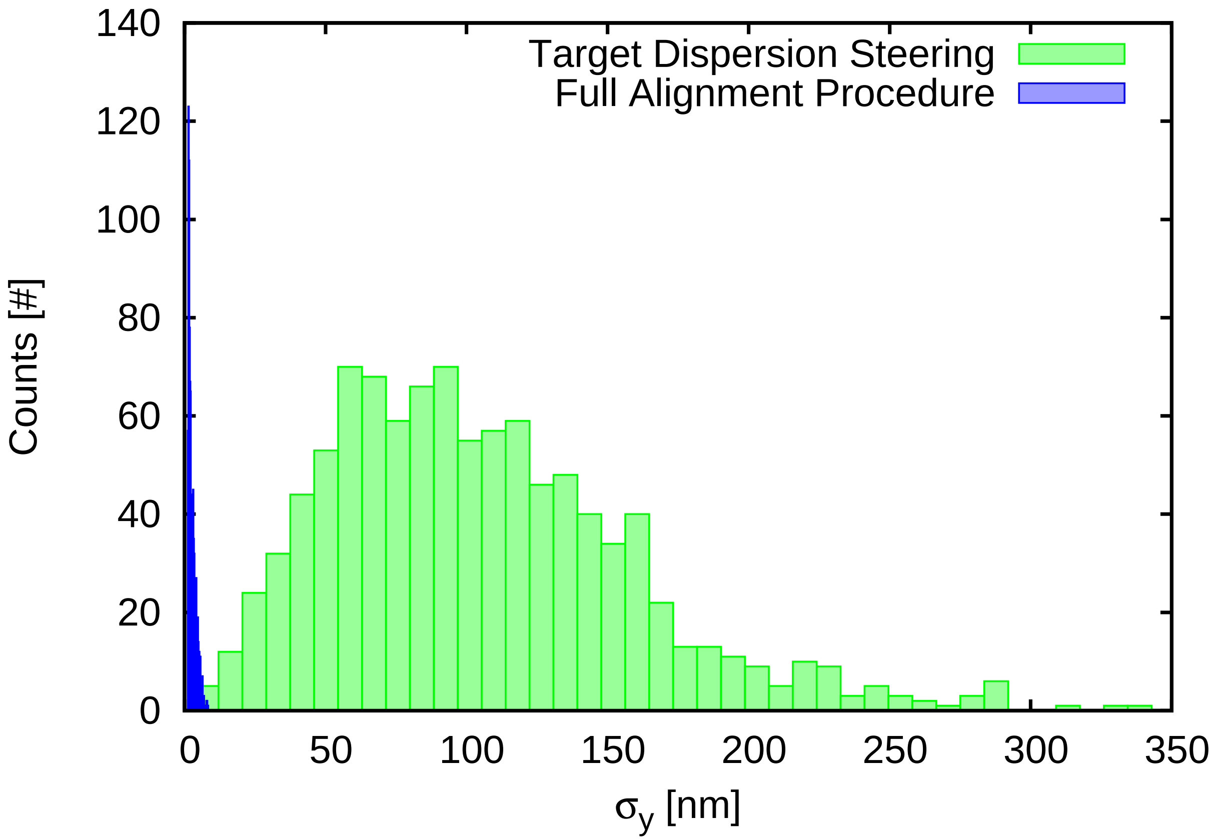
  ⇒ increase statistics: 100’000 macro-particles/bunch have been simulated

  ⇒ stabilize tracking: sbends and multipoles have been simulated in thin lens approximation with 50 thin lenses per magnet (the default, for multipoles, is 5)

⇒ Each step of simulation w/ SR is based on 100’000 macro-particles/bunch (very cpu intensive, computing time is about 2 days per seed)

Reminder: Simulation Results w/o SR

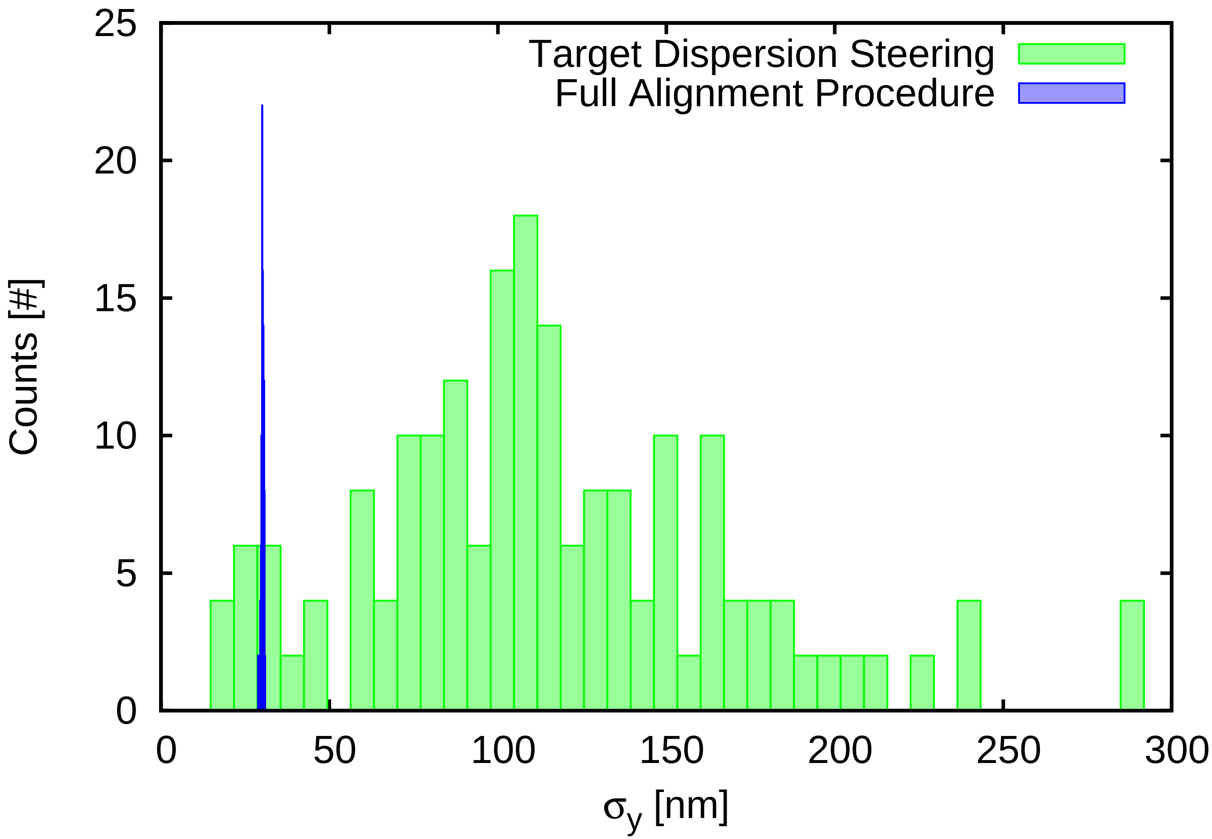
Histogram of **vertical beamsizes** at the IP for **1000 seeds**, bpm resolution 10 nm:



⇒ Final vertical beamsize is $\sigma_y = (2.6 \pm 1.3)$ nm (EXCELLENT!)

Reminder: Simulation Results w/ SR

Histogram of **vertical beamsizes** at the IP for **100 seeds**, bpm resolution 10 nm:



⇒ Final vertical beamsize is $\boxed{\sigma_y = (30.0 \pm 0.3)\ \text{nm}}$

What is the problem?

- When SR is On
  - the vertical beamsize grows from $\approx$ 2.5 nm to $\boxed{\approx 30\text{ nm}}$
  - the horizontal beamsize seems targeted around $\boxed{\approx 1250\text{ nm}}$
- When SR is Off
  - everything seems to work <u>very well</u>

What are the differences between the two cases?

1) The response matrices and target trajectories:
   - when SR is On, energy loss due to SR emission must be taken into account when calculating the response matrices
     (PLACET memorizes the integrated magnetic strength of the magnets: optics is energy dependent)
   - actually, the energy loss was taken into account. Was it computed accurately enough?
     (It was a Tcl `expr`-ession in the MADX-to-PLACET script: accuracy problem?)

2) The simulation procedure is slightly different (see later)

Difference 1: Optics and Response Matrices

First action taken: **improve the code** $\Rightarrow$ to improve the response matrices and the target trajectories

1) optics is energy dependent $\Rightarrow$ improve the optics scaling:

$\Rightarrow$ PLACET function `SetReferenceEnergy` modified and enhanced: it sets the energy reference, element by element, by tracking a nominal bunch and setting

$$E_{\text{ref}} = \frac{E_{\text{i}} + E_{\text{f}}}{2}$$

(this change has been committed to the CVS)

2) implemented in PLACET an average energy loss due to SR emission in all magnets, when tracking a single macro-particle: useful when calculating the response matrices—using a single-particle (in this case statistical synrad emission cannot be applied)

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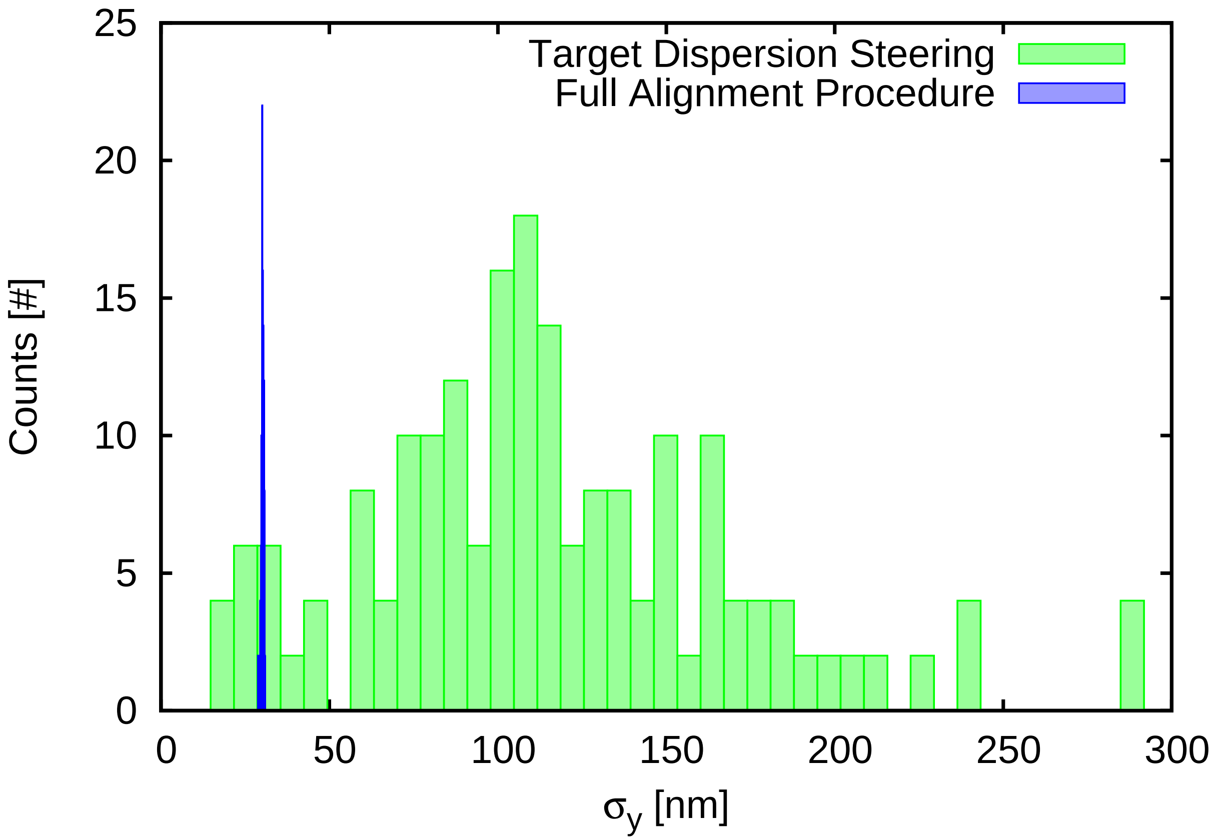
⇒ **Test 1:** full bunch tracking, using the new response matrices and the new optics, w/ SR

⇒ **Unfortunately the improvements are quite modest...**

Test 1: Improved Optics and Response Matrices w/ SR

Histogram of **vertical beamsizes** at the IP for **100 seeds**, bpm resolution 10 nm:



$\Rightarrow$ Final vertical beamsize is $\boxed{\sigma_y = (30.0 \pm 0.3)\ \text{nm}}$ (AS BAD AS BEFORE!)

Difference 2: Simulation Procedure

Simulation script w/o SR emission:

- Single-particle (core) tracking during the correction procedures
- Full bunch tracking, 100'000 macro-particles, only after correction : for beamsize calculation

Simulation script w/ SR emission:

- Full bunch tracking, 100'000 macro-particles, in **all** steps of the simulation (correction and beamsize calculation)

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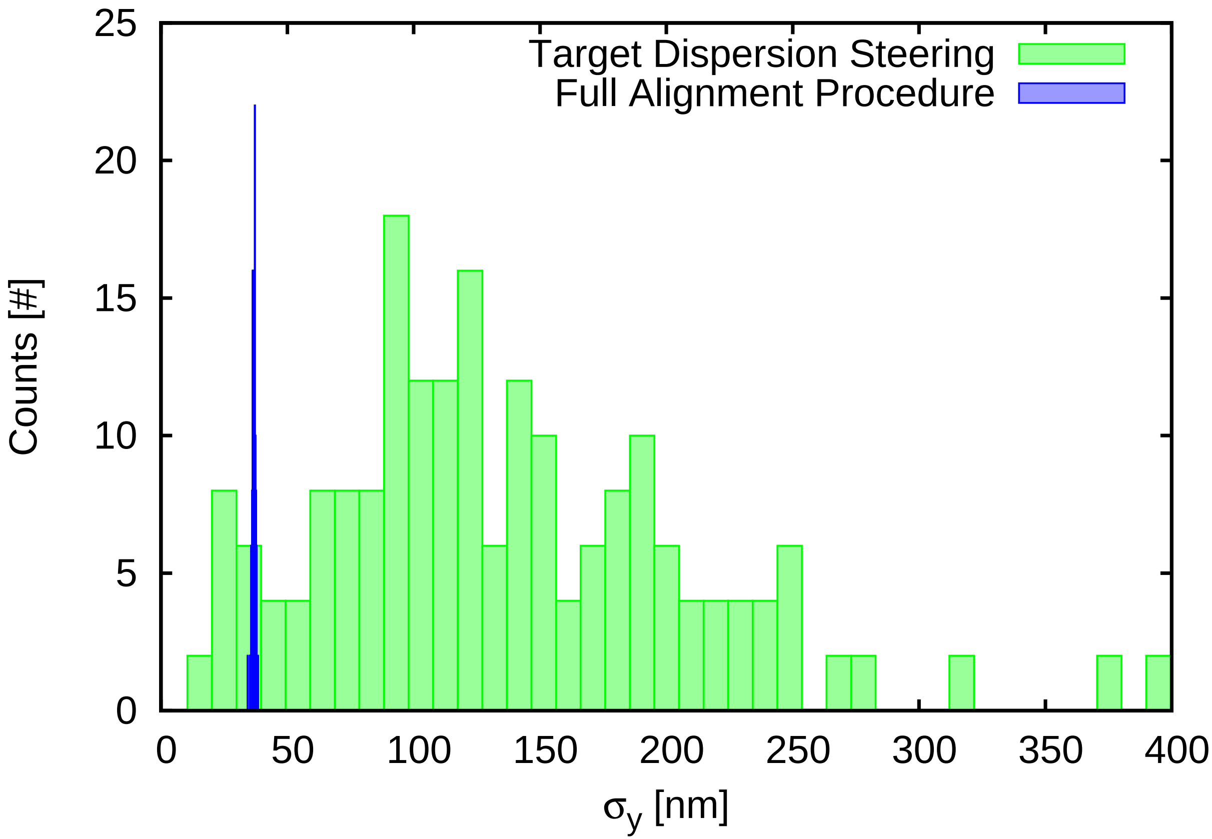
Simulation script w/ SR emission:

- Full bunch tracking, 100'000 macro-particles, in **all** steps of the simulation (correction and beamsize calculation)

⇒ **Test 2:** full bunch tracking, 100'000 macro-particles in all steps of the simulation, w/o SR
[previous result was $\sigma_y = 2.5$ nm, when using core tracking during correction]

Test 2: Full Bunch Simulation, w/o SR

Histogram of **vertical beamsizes** at the IP for **100 seeds**, bpm resolution 10 nm:



⇒ Final vertical beamsize is $\sigma_y = (36.7 \pm 0.6)$ nm (AS BAD AS w/ SR!!)

Two Remarks and a Question

Remark 1: When calculating the correction just using bunch core, w/o SR, everything works well

Remark 2: When calculating the correction using the full bunch, either w/ or w/o SR, it does not work

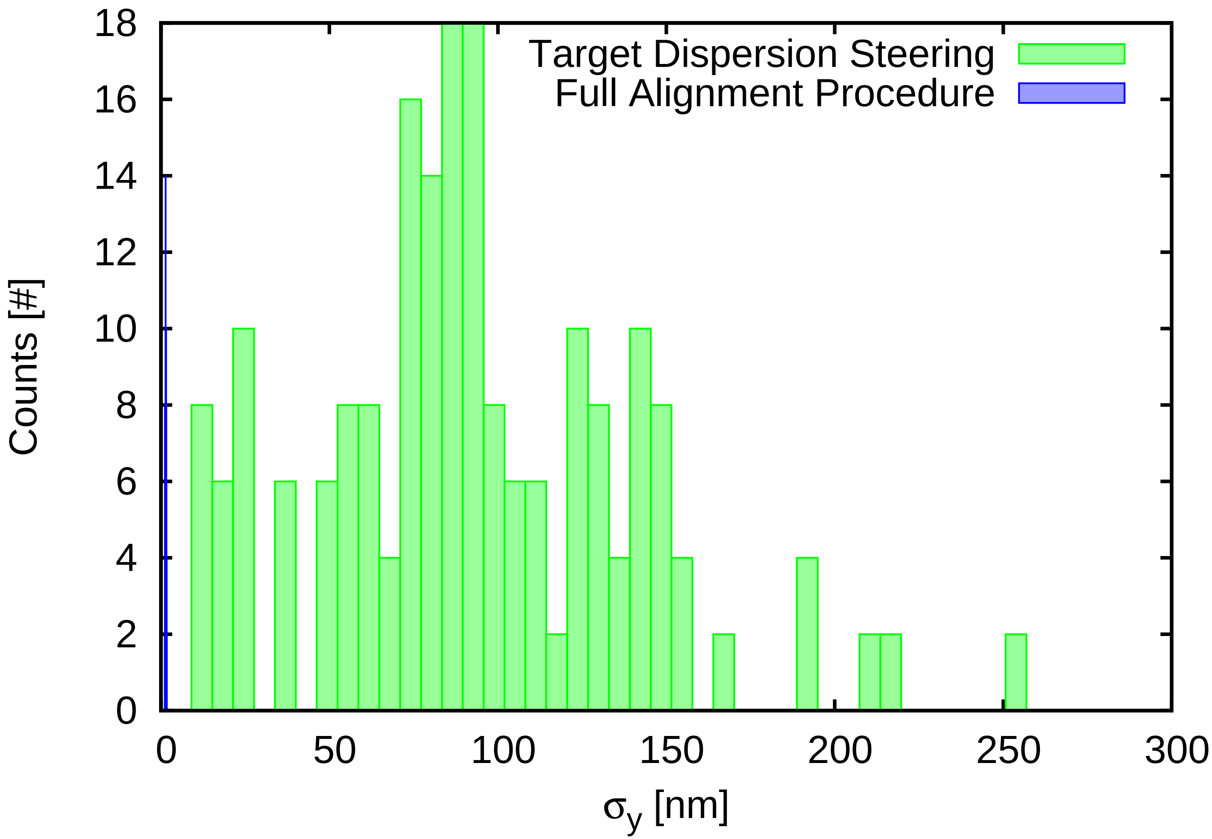
Question:

Might the problem depend on the energy spread?
[1% (uniformly distributed) energy spread was simulated]

⇒ **Test 3**: full bunch tracking, with 0 energy spread, w/ and w/o SR.

Test 3-a: Full Bunch Simulation, $\delta = 0$, w/o SR

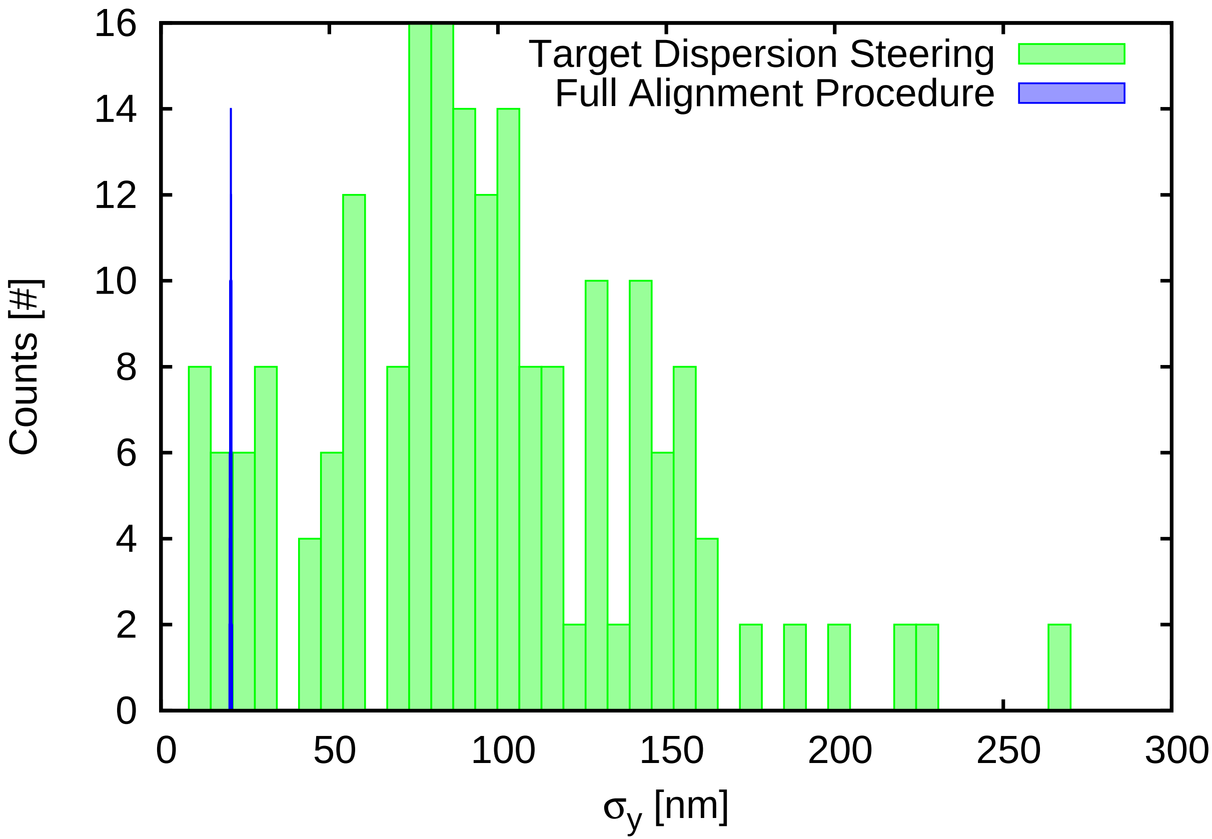
Histogram of **vertical beamsizes** at the IP for **100 seeds**, bpm resolution 10 nm:



$\Rightarrow$ Final vertical beamsize is $\boxed{\sigma_y = (1.4 \pm 0.1)\ \text{nm}}$ (WOW!! IT WAS 2.5 nm)

Test 3-b: Full Bunch Simulation, $\delta = 0$, w/ SR

Histogram of **vertical beamsizes** at the IP for **100 seeds**, bpm resolution 10 nm:



$\Rightarrow$ Final vertical beamsize is $\boxed{\sigma_y = (20.6 \pm 0.2) \text{ nm}}$ (SLIGHT IMPROVEMENT)

Summary Table, Conclusions and Next Steps

Summary Table

note	σ_x [nm]	σ_y [nm]	SR	tracking	optics	comment
-	43.5 ± 4.4	2.6 ± 1.3	0	core	OK	excellent!
-	1600.0 ± 1.0	30.0 ± 0.3	1	full	not OK	poor
-	129.3 ± 1.3	36.7 ± 0.6	0	full	OK	poor
-	1600.0 ± 1.0	30.0 ± 0.3	1	full	OK	poor
$\delta_E = 0$	39.80 ± 0.01	1.4 ± 0.1	0	full	OK	wow!
$\delta_E = 0$	101.8 ± 0.3	20.6 ± 0.2	1	full	OK	improvement

Conclusions

- The work is in progress...
- ...but a slender light has been cast...
- Synchrotron radiation might happen not be the “biggest” problem
- Comments?

Next steps

$\Rightarrow$ Need to improve the simulation with a more realistic energy spread? How large should it be?

$\Rightarrow$ Need to study how to deal with the energy spread

$\Rightarrow$ Tuning knobs?