CLIC BDS design with $L^* = 6$ m

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OUTLINES

1. Motivations for a longer L*

2. CLIC 3 TeV BDS with L* = 6 m optimization and performance
   - FFS optics comparison at 3 TeV
   - Higher order optimization of the BDS
   - Tuning under realistic static error conditions

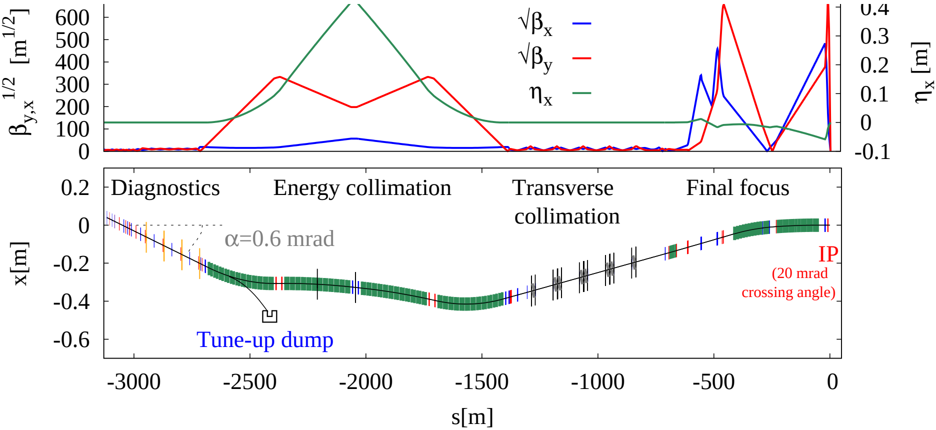
3. CLIC 380 GeV BDS design and performances
   - BDS design with L* = 4.3 m and L* = 6 m
   - Tuning performances

4. Summary

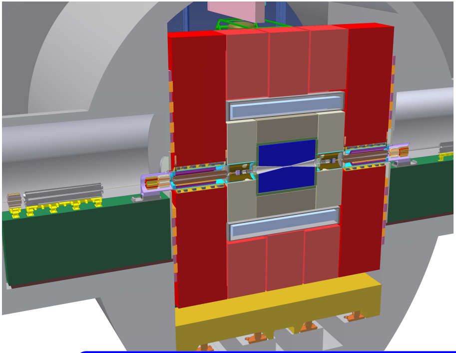
The CLIC Beam Delivery System (BDS)

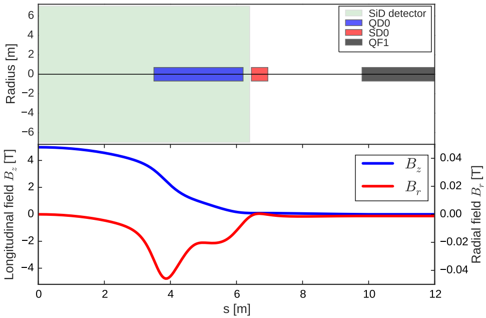
BDS ⇒ Diagnostics, beam collimation, **beam focusing in the FFS while correcting higher order transport aberrations to deliver the design IP beam sizes.**

Energy staging : **from 380 GeV to 3 TeV**
CDR BDS layout : $L^* = 4.3$ m (1st stage) & $L^* = 3.5$ m (top energy stage)
New proposed BDS : $L^* = 6$ m



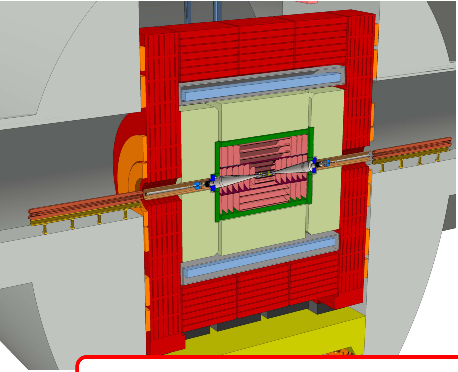
CLIC MDI layout for L* = 3.5 m (CDR)

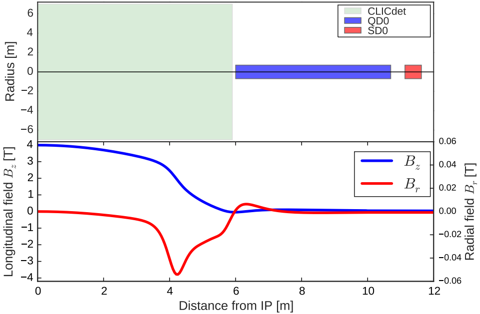




- QD0 inside the experiment **on the detector support**
- Imposes the **integration of a pre-insulator system** to mitigate vibrations of QD0 to the 0.1 nm level
- Critical components around **QD0 requires longer interventions** due to the lack of space and access, leading to integrated luminosity loss
- **QD0 surrounded by the strong magnetic field of the detector**
- QD0 requires to be shielded by an **anti-solenoid**
- The shielding **takes away a good fraction of the forward acceptance**

CLIC MDI simplification with $L^* = 6$ m

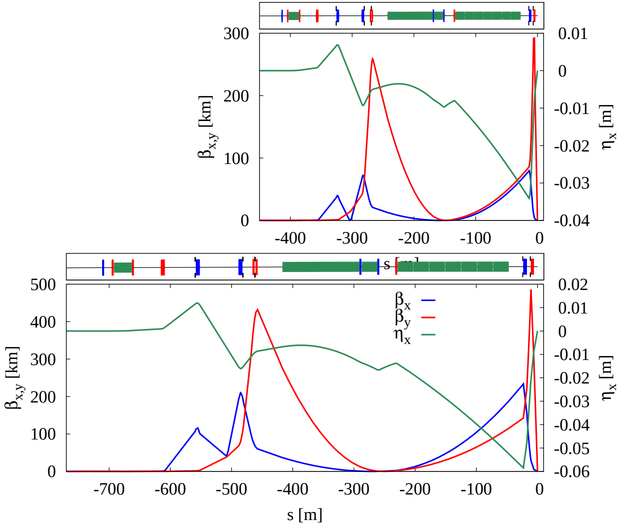




- The reduced end-cap and barrel yoke allows **QD0 to be placed on the more stable tunnel ground with an L^* of 6 m**
- **No pre-insulator** required for QD0 stabilization
- **Easier acces** for interventions on the QD0 region
- The detector longitudinal and radial fields are zeroed at the QD0 entrance and thus **no antisolenoid shielding is needed**
- **Gain in the detector acceptance**
- New detector model *CLICdet* details in *"CLICdet : The post-CDR CLIC detector model"* (CLICdp-Note-2017-001)

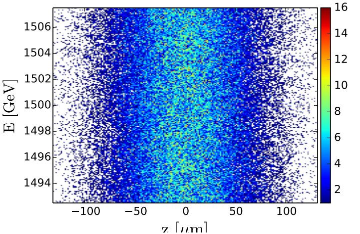
FFS optics comparison at 3 TeV

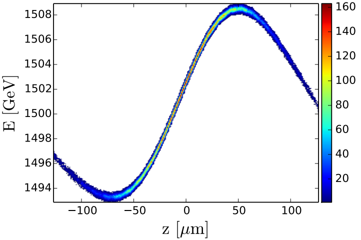
- The **FFS length has been scaled with respect to** L^* in order to preserve the chromaticity correction properties along the system
- The $L^* = 6$ m design is **320 meters longer** than the nominal design



BDS performance comparison at 3 TeV

Design	$\mathcal{L}_{\text{total}}$ $[10^{34}\text{cm}^{-2}\text{s}^{-1}]$	$\mathcal{L}_{1\%}$
$L^* = 3.5$ m (linac shape energy spread)	**7.6**	**2.4**
$L^* = 6$ m (1% full width energy spread)	**6.4**	**2.16**
$L^* = 6$ m (linac shape energy spread)	**5.93**	**2.13**



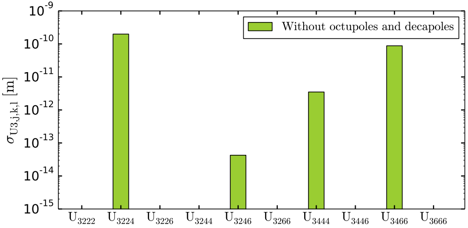


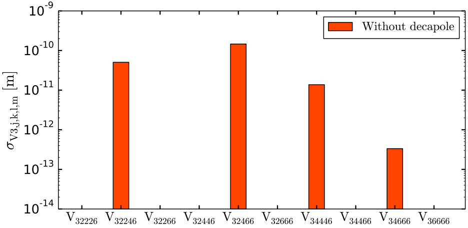
- Luminosity simulated assuming 1% full width energy spread and simulated assuming a more realistic energy spread shape coming from the main linac and taking into account uncorrelated energy spread of 1.6% of the pre-linac beam energy with a gaussian distribution.

- **As for the $L^* = 3.5$ m design, higher order multipoles have been introduce in the $L^* = 6$ m FF beamline in order to push up the luminosity** (see next slides)

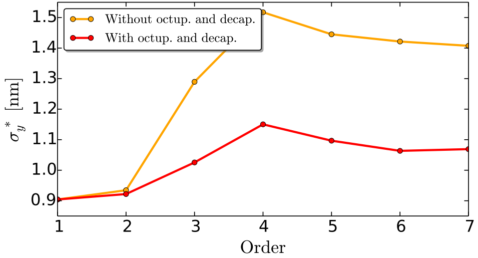
Higher order optimization of the BDS : octupoles + decapole

The remaining higher order contributions to σ_y^* are identified



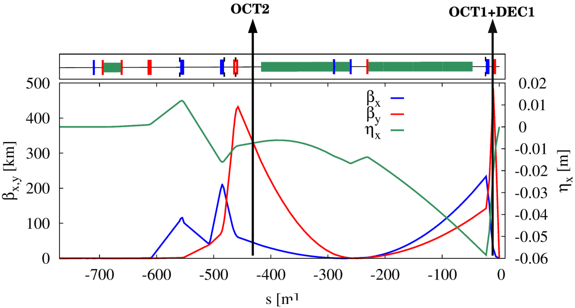


- 3^{rd} order geometrical aberration U_{3224} contributes to 0.2 nm of σ_y^* $\Rightarrow$ corrected by OCT2 located in low-η_x region
- 3^{rd} order chromatic aberration U_{3466} contributes to 0.08 nm of σ_y^* $\Rightarrow$ corrected by OCT1 located in high-η_x region
- residual 4^{th} order chromatic aberrations are corrected by DEC1 located in high-η_x region



Vertical beam size σ_y^* reduced from 1.4 nm to 1.07 nm by using octupoles and a decapole at the appropriate locations

Higher order optimization of the BDS : octupoles + decapole



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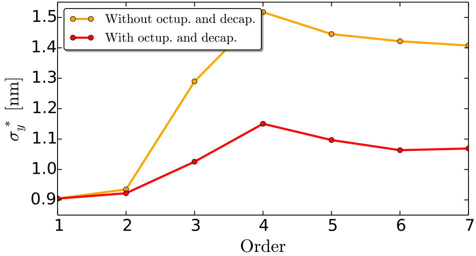

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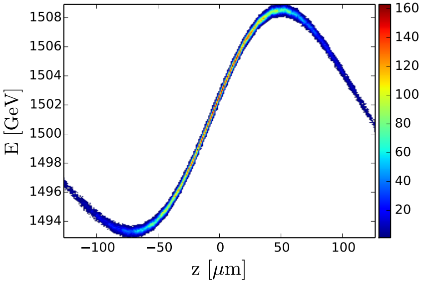
Higher order optimization of the BDS : octupoles + decapole



- Luminosity simulated assuming a more realistic energy spread shape coming from the linac
- The updated lattice optimized with higher order multipoles provide a **luminosity increase of 8.5% in the peak**
- **The difference in the peak luminosity $\mathcal{L}_{1\%}$ between the nominal and the L^* = 6 m lattice is 5.3%**

Design	$\mathcal{L}_{\text{total}}$ $[10^{34}\text{cm}^{-2}\text{s}^{-1}]$	$\mathcal{L}_{1\%}$
L^* = 3.5 m (linac energy spread)	7.6	2.4
L^* = 6 m (linac energy spread)	**6.4**	**2.28**

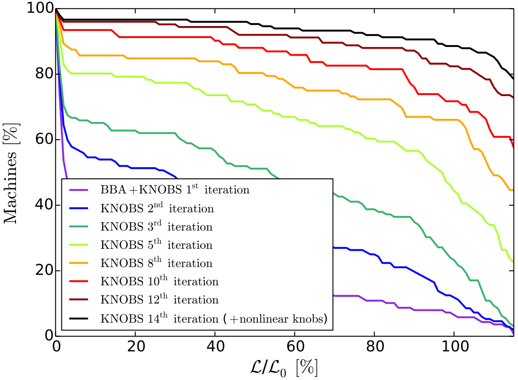
FFS tuning at 3 TeV

Table – Errors applied to the lattice

σ_{offset} (Quadrupoles, Sextupoles and BPMs)	10μm
BPM resolution	10 nm
σ_{roll} (Quadrupoles, Sextupoles and BPMs)	300μrad
Strength error (Quadrupoles and Sextupoles)	0.01%

Tuning simulations : **1-beam tuning / 1% full width beam energy spread / before introducing higher order multipoles**

- **$\Rightarrow$ 90% of the machines reach $\geq$ 97% of $\mathcal{L}_0$ = 5.9 $\times 10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ in $\approx$ 6300 luminosity measurements.**
- or 85% of the machines reaching $\geq$ 110% of $\mathcal{L}_0$
- 13^{th} and 14^{th} iterations include the 2^{nd} order knobs (T122, T126, T166, T324, T346 corrections)
- Additional knob scans can further improve the tuning performance



CLIC 380 GeV BDS design and performances

BDS design with $L^* = 4.3$ m and $L^* = 6$ m

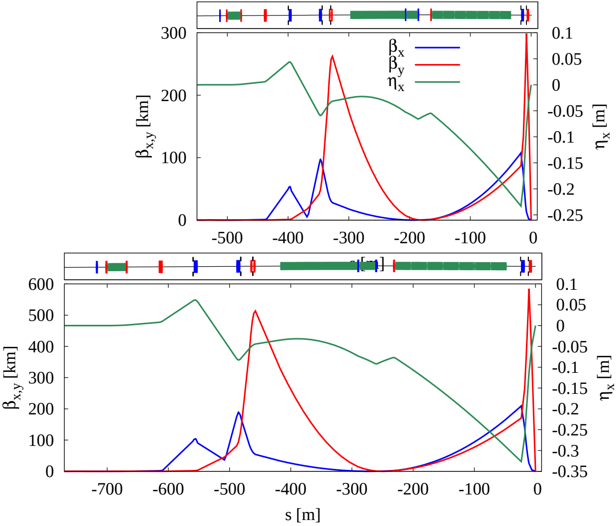
- In the framework of the CLIC rebaselining at 380 GeV, **two L^* options for the FFS** have been optimized :
  - **$L^* = 4.3$ m** $\Rightarrow$ provides optimal maximum luminosity but QD0 partially located inside the experiment.
  - **$L^* = 6$ m** $\Rightarrow$ ease MDI, QD0 stabilization and avoid interplays between the QD0 and detector fields

Table – CLIC 380 GeV design parameters for both L^* options

L^* [m]	4.3	6
Final focus system length [m]	**553**	**770**
$\gamma\epsilon_x/\gamma\epsilon_y$ [nm]	**950/30**	**950/30**
β_x^*/β_y^* [mm]	**8/0.1**	**8/0.1**
$\sigma^*_{x,\text{design}}$ [nm]	145	145
$\sigma^*_{y,\text{design}}$ [nm]	2.3	2.3
$L_{\text{tot, design}}$ $[10^{34}\ \text{cm}^{-2}\text{s}^{-1}]$	1.5	1.5
$L_{1\%,\text{ design}}$ $[10^{34}\ \text{cm}^{-2}\text{s}^{-1}]$	0.9	0.9
Chromaticity ξ_y ($\approx L^*/\beta_y^*$)	43000	60000

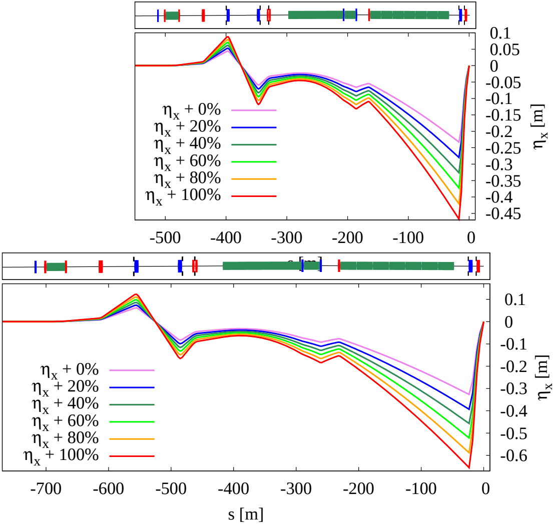
BDS design with $L^* = 4.3$ m and $L^* = 6$ m

- The **FFS length has been scaled with respect to** L^* in order to preserve the chromaticity correction properties along the system
- The $L^* = 6$ m design is **220 meters longer** than the nominal design with $L^* = 4.3$ m

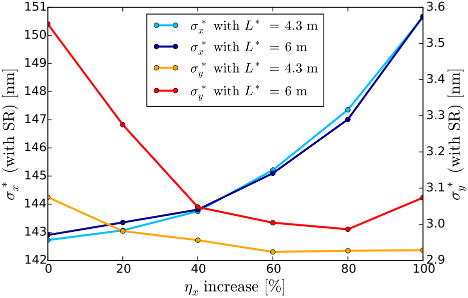


BDS design with $L^* = 4.3$ m and $L^* = 6$ m

- A scan of the dispersion profile has been performed in order to optimize the luminosity for both L^* options

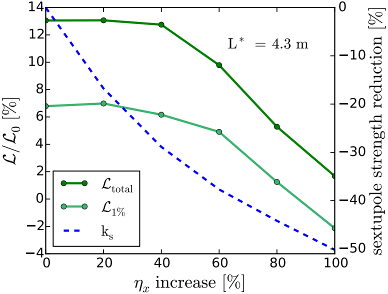


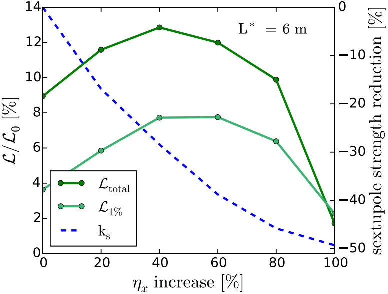
BDS design with $L^* = 4.3$ m and $L^* = 6$ m



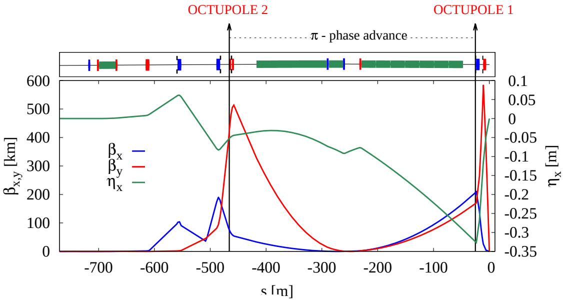
- For $L^* = 4.3$ m no increase of dispersion needed to improve luminosity

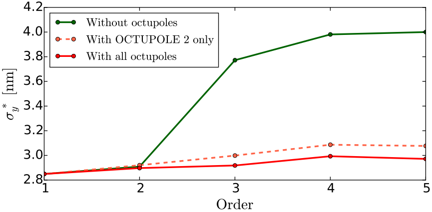
- For $L^* = 6$ m the optimal dispersion increase was found for η_x **= 60%**

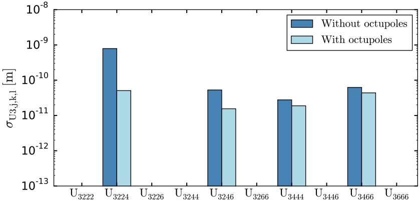




BDS design with $L^* = 4.3$ m and $L^* = 6$ m



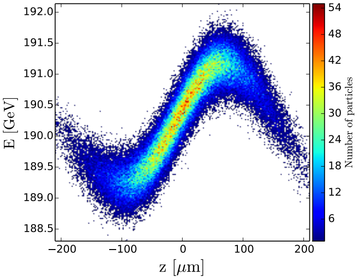




- For $L^* = 6$ m, octupolar corrections were needed in order to bring the vertical beam size towards the design value
- σ_y^* dominated by U_{3224}, corrected by OCT2

BDS design with L^* = 4.3 m and L^* = 6 m

Linac energy spread

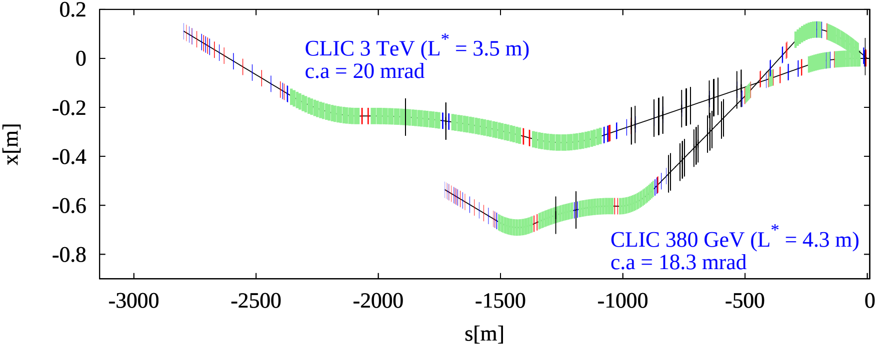


Design	σ_x^* [nm]	σ_y^* [nm]	$\mathcal{L}_{\text{total}}$ $[10^{34}\text{cm}^{-2}\text{s}^{-1}]$	$\mathcal{L}_{1\%}$ $[10^{34}\text{cm}^{-2}\text{s}^{-1}]$
$L^* = 4.3$ m	148.2	3.22	1.55	0.93
$L^* = 6$ m	151.2	3.20	1.52	0.91

- Both lattices fulfill the luminosity requirements
- The 20% of luminosity budget is included in the larger assumed emittances in simulations : ϵ_x^* = 950 nm (design = 920 nm) and ϵ_y^* = 30 nm (design = 20 nm)
- Small luminosity difference between both L^* options ⇒ L^* = 6 m lattice optimized with octupoles

Optics optimized w.r.t to the energy upgrade to 3 TeV

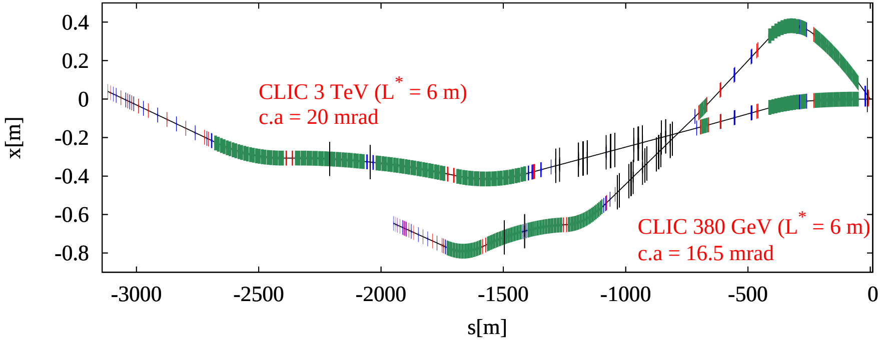
- The lattice of the 380 GeV BDS was optimized by taking into account the alignment of the Linacs of the different CLIC stages in the tunnel
- In the case of the short L^* options for CLIC, the crossing angle for the 1st stage is **18.3 mrad** and 20 mrad for CLIC 3 TeV



Optics optimized w.r.t to the energy upgrade to 3 TeV

- The lattice of the 380 GeV BDS was optimized by taking into account the alignment of the Linacs of the different CLIC stages in the tunnel

- In the case of the L^*= 6 m options for CLIC, the crossing angle for the 1st stage is **16.5 mrad** and 20 mrad for CLIC 3 TeV



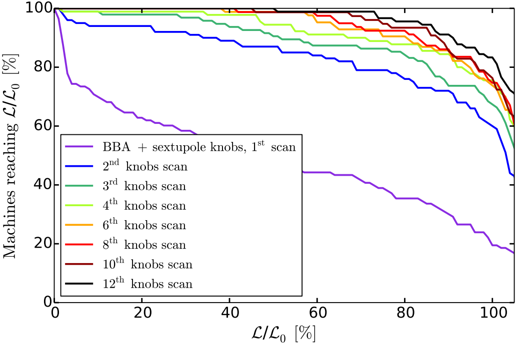
Tuning performances : L^*= 4.3 m

Table – Errors applied to the lattice

σ_{offset} (Quadrupoles, Sextupoles and BPMs)	$10\mu\mathrm{m}$
BPM resolution	$10\ \mathrm{nm}$
σ_{roll} (Quadrupoles, Sextupoles and BPMs)	$300\mu\mathrm{rad}$
Strength error (Quadrupoles and Sextupoles)	0.01%

Tuning simulations : **1-beam tuning / 1% full width beam energy spread**

- **⇒ 90% of the machines reach $\geq$ 92% of $\mathcal{L}_0$ = 1.5 $\times 10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ in ≈ 6300 luminosity measurements.**
- or 84% of the machines reaching $\geq \mathcal{L}_0$
- 2^{nd} order knobs (T122, T126, T166, T324, T346 corrections) included from the 1^{st} iteration
- Additional knob scans can further improve the tuning performance



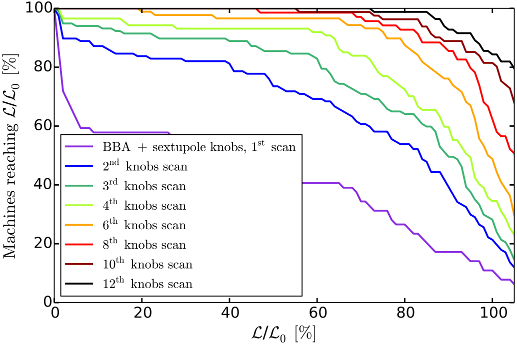
Tuning performances : L^{*}= 6 m

Table – Errors applied to the lattice

σ_{offset} (Quadrupoles, Sextupoles and BPMs)	10μm
BPM resolution	10 nm
σ_{roll} (Quadrupoles, Sextupoles and BPMs)	300μrad
Strength error (Quadrupoles and Sextupoles)	0.01%

Tuning simulations : **1-beam tuning / 1% full width beam energy spread**

- **$\Rightarrow$ 90% of the machines reach $\geq$ 96% of $\mathcal{L}_0$ = 1.5 $\times 10^{34}\text{cm}^{-2}\text{s}^{-1}$ in $\approx$ 6300 luminosity measurements.**
- or 85% of the machines reaching $\geq \mathcal{L}_0$
- 2^{nd} order knobs (T122, T126, T166, T324, T346 corrections) included from the 1^{st} iteration
- Additional knob scans can further improve the tuning performance



Summary

CLIC 3 TeV BDS

- For $L^* = 6$ m the peak luminosity $\mathcal{L}_{1\%}$ is 5.3% lower than the nominal design with $L^* = 3.5$ m
- The luminosity comparison does not take into account the MDI simplification impact for the $L^* = 6$ m option :
  - QD0 vibration reduction
  - No field interplays between QD0 and the experiment
  - Easier access for interventions in the QD0 region
  - Gain in detector acceptance
- Tuning efficiency under realistic static error conditions falls closely to the tuning goal $\Rightarrow$ 90% of the machines reach $\geq 97\%$ of $\mathcal{L}_0$.
- The collimatior openings should not be tightened for $L^* = 6$ m (https ://journals.aps.org/prab/abstract/10.1103/PhysRevAccelBeams.21.011002)

CLIC 380 GeV BDS

- Both designs with $L^* = 4.3$ m and $L^* = 6$ m (optimized with octupoles) achieve the luminosity requirements for CLIC including 20% of luminosity budget for static and dynamic imperfections
- Tuning performances under realistic static imperfections are similar for both L^* options and are very close to the tuning goal

The demonstration tunability of the FFS for CLIC 3 TeV and CLIC 380 GeV will requires 2-beam tuning simulations including dynamic imperfections.