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Commissioning optics:

Larger dynamic aperture and Touschek Lifetime at the (temporary) cost of larger horizontal emittance in 4th generation light sources.

Tessa Charles,
Rohan Dowd, Eugene Tan, Frank Zhang
Australian Synchrotron

Science. Ingenuity. Sustainability.

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- 3rd generation light source with double-bend achromat lattice
- Began operations in 2007
- Expected lifetime around 25 – 30 years
- What comes next?

Australian Synchrotron 2.0 (AS2)

- Greenfield, 4th generation light source proposal
- CDR in early stages of being developed

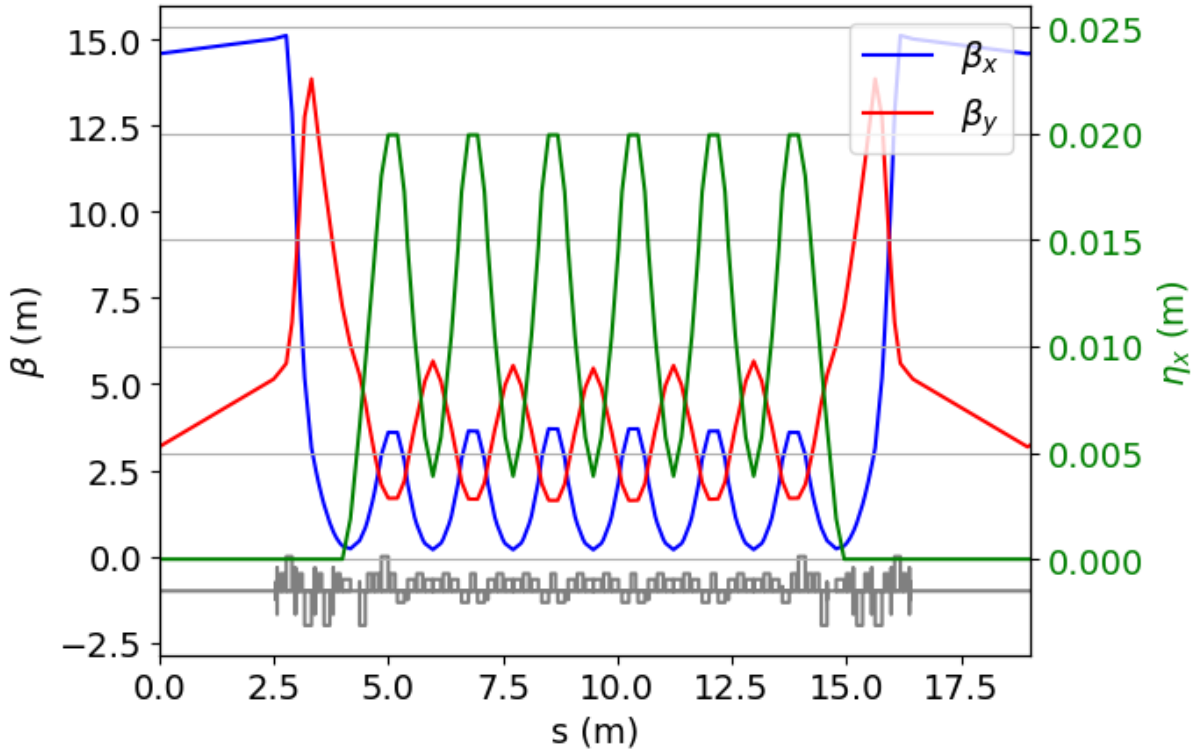
AS2

See Frank Zhang's poster TUPG10

Preliminary design parameters

Parameter	value
Energy [GeV]	3
Circumference [m]	454.8
Emittance [pm]	50
Momentum compaction factor	0.56×10^{-4}
dE/turn [keV]	785
Touschek lifetime [h]	7.3
Transverse tunes (Qx, Qy)	70.25, 20.81
Natural chromaticities	-151.522, -76.141
Bore radius [mm]	12.5
Max. Dipole [T]	1.048
Max. Quad [T/m]	110
Max. Sext [T/m^2]	10 000

AS2



MBA lattices ⇒ gentle bending & strong focusing
⇒ smaller ε_x

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Traits & Challenges of 4th Gen Light Sources

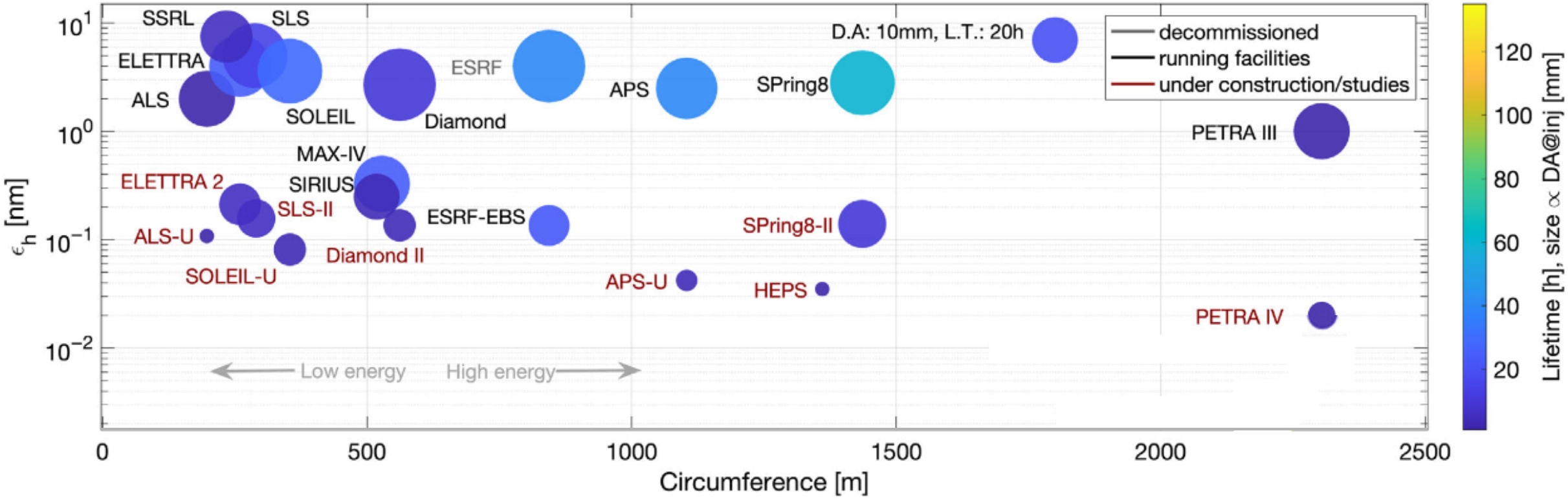
MBA lattices ⇒ gentle bending & strong focusing.

Smaller η_x ⇒ stronger sextupoles.

Stronger sextupoles ⇒ reduced DA and TLT.

In addition, stronger sextupoles & quadrupole ⇒ more sensitive to misalignment errors.

Traits & Challenges of 4th Gen Light Sources



Legend

: DA = 10 mm & LT = 20 h

Figure: Pantaleo Raimondi and Simone Liuzzo

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Dynamic aperture reduction

Challenge: tighter focusing, smaller η_x => smaller DA and shorter lifetime.

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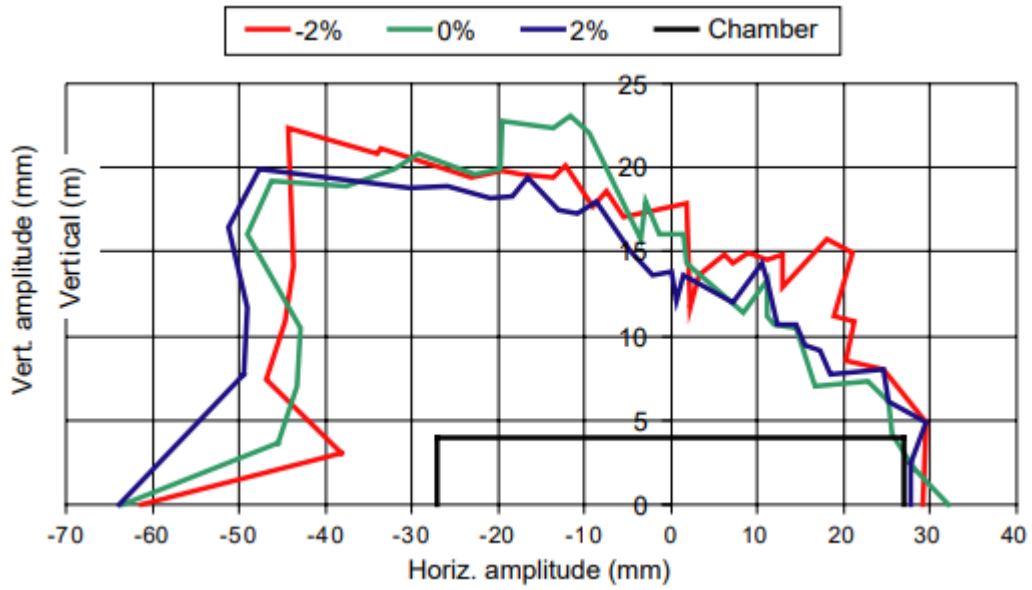

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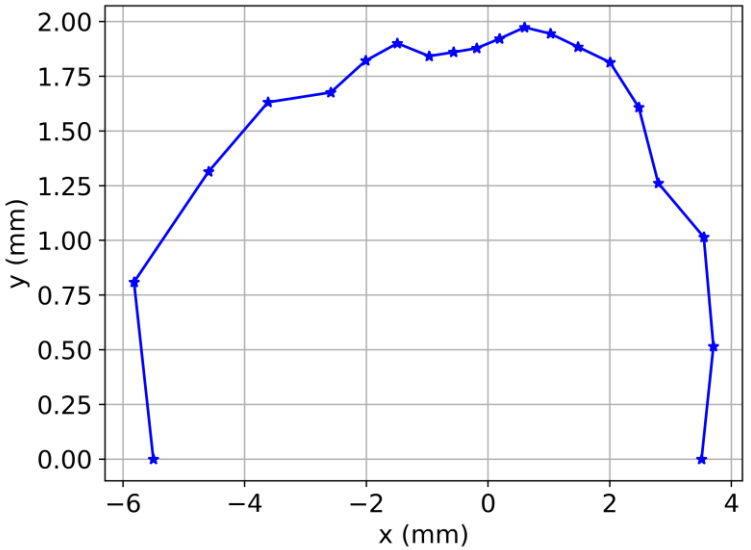


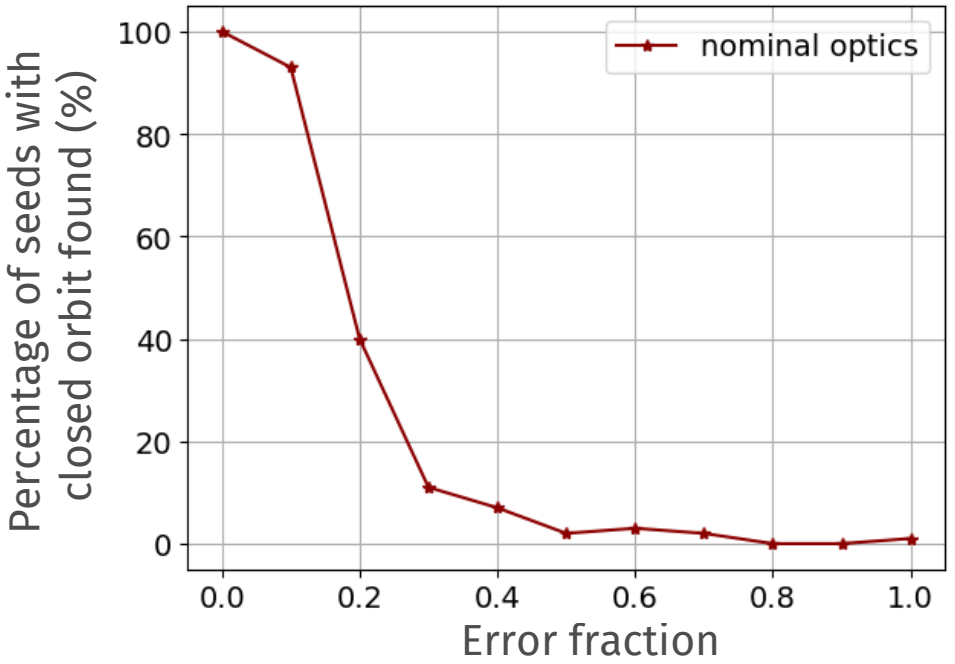
-> Factor of 4 reduction in the vertical available aperture
-> Factor of 6 reduction in the horizonal available aperture

Assessing the magnitude of the commissioning challenge

Misalignments and field errors:

Type	ΔX (μm)	ΔY (μm)	ΔPSI (μrad)	Fractional field error
Dipoles	30	30	100	1e-4
Quadrupoles	30	30	100	1e-4
Sextupoles	30	30	100	1e-4

Note: these alignments and field errors are not tolerances. Tolerance specifications still need to be determined.



As is the case for many 4th gen light sources, **with realistic errors, the closed orbit does not exist.**

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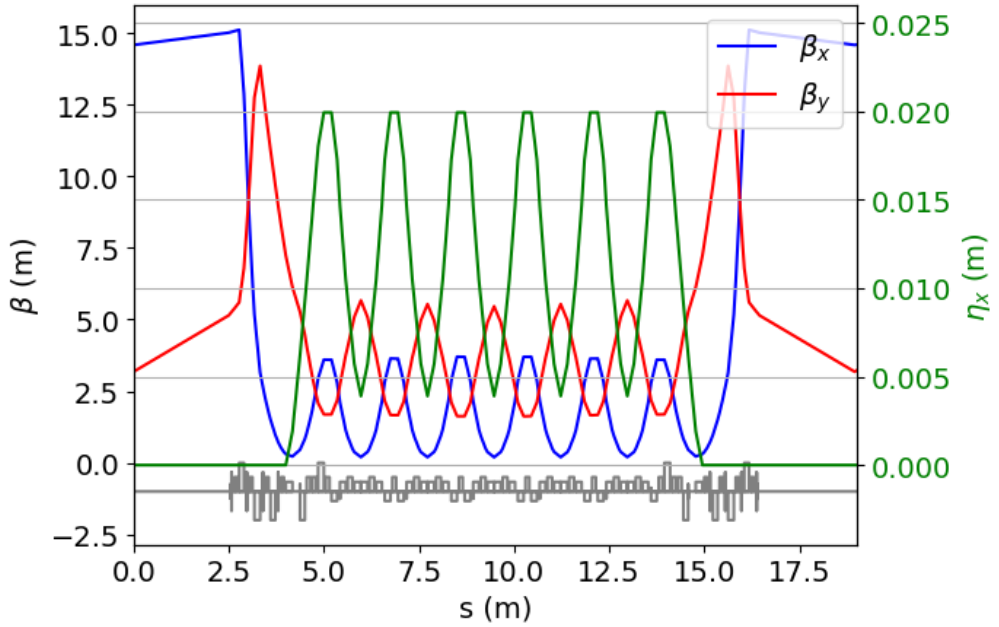
Often it's **only after BBA and optics corrections are applied, that the DA be sufficient** for reasonable injection efficiency.

Our aim: to find a more relaxed optics solution for commissioning, with larger DA and lifetime.

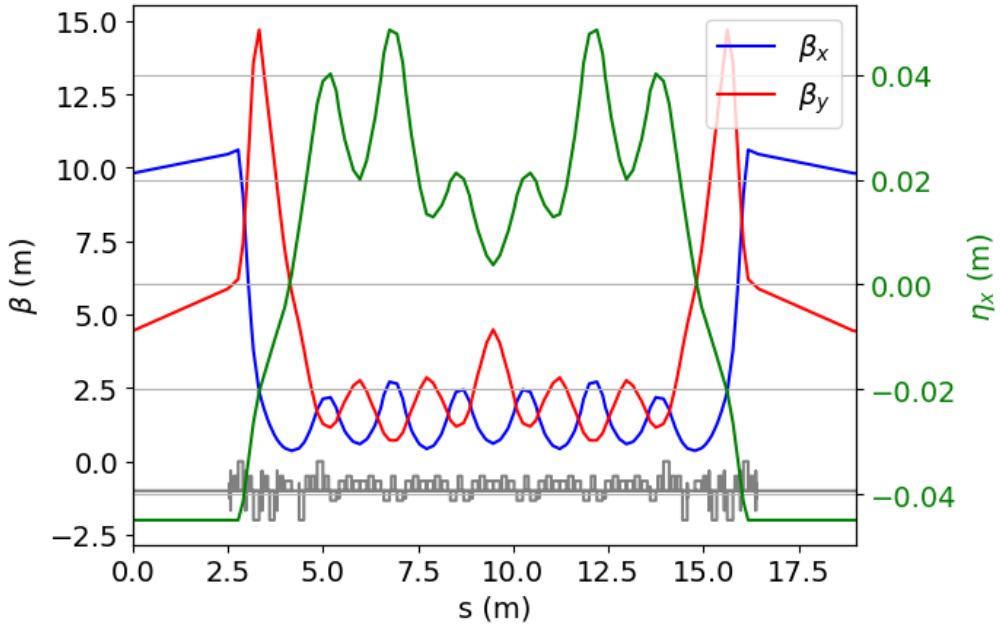
The larger DA and TLT will **reduce risk** and allow for **more rapid commissioning.**

Commissioning optics

Nominal optics



Commissioning optics



Requires independent focusing in one family of combined function magnets.

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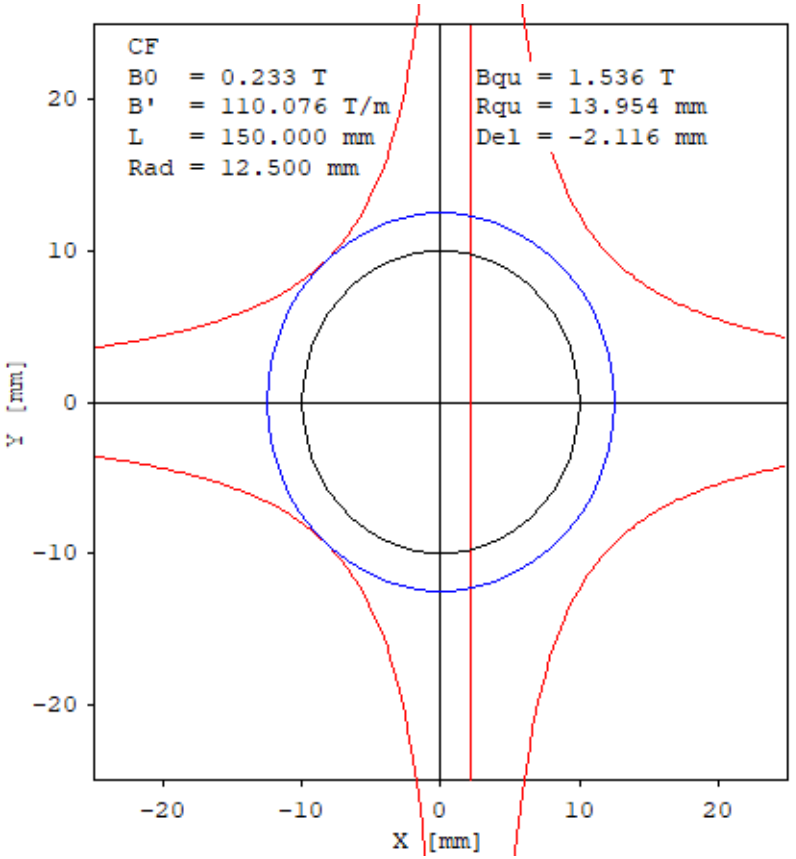
Offset quadrupole

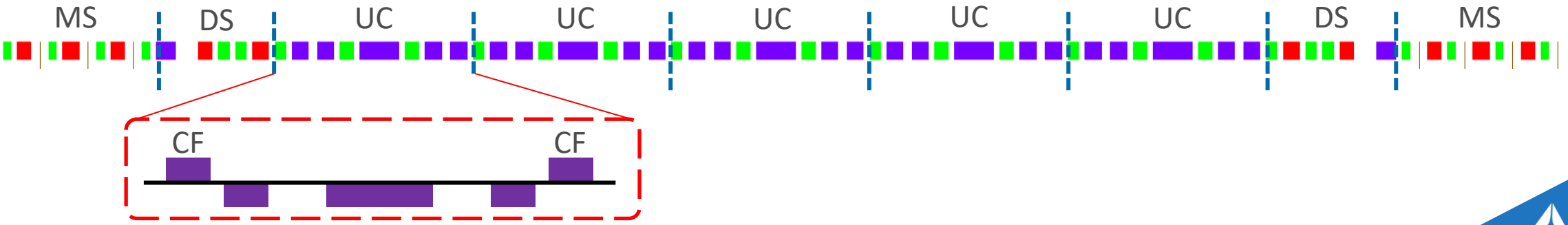
Reverse bends achieved with offset quadrupoles (CF).

Commissioning optics achieved by reducing quad strength by 78% and reinstating bend angle, through either:

1. Increasing offset by 574 μm, or
2. Additional coils (to quadrupole or vacuum chamber)



Optics	K_1 (m^{-2})	θ (deg)	B_0 (T)	offset (mm)
Nominal	11	-0.2	0.233	-2.116
Commissioning	8.65	-0.2	0.233	-2.690



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Commissioning optics key parameters

	Nominal	Comm optics
Natural chromaticities $(\xi_{x,0}, \xi_{y,0})$	-151.522, -76.141	-82.72, -67.09
Chromaticities (ξ_x, ξ_y)	0.99, 0.99	0.06, 0.05
Momentum compaction (α_c)	0.056e-3	0.182e-3
Hor. Emittance (ε_x)	50 pm	213 pm
Espread	1.11e-3	4.22e-3
Tunes	70.251, 20.811	53.084, 29.601

→ **SF K_1 ↓ 73.4%**
SD $|K_1|$ ↓ 45.5%

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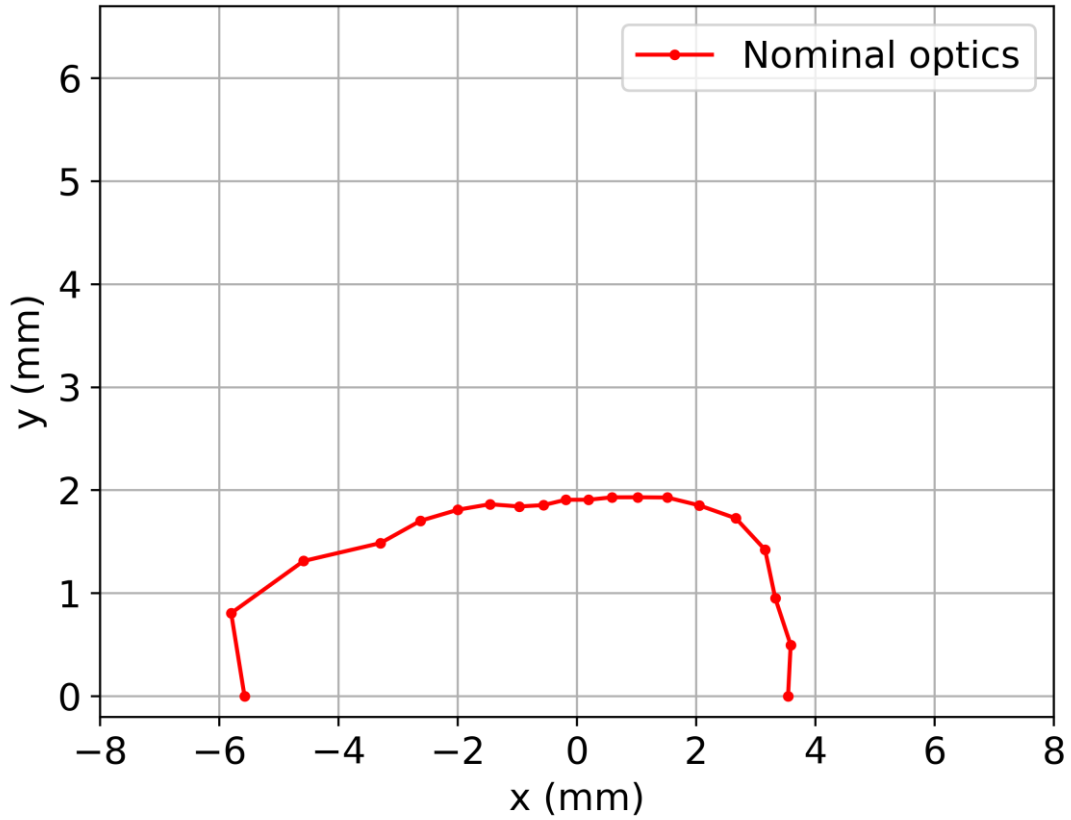
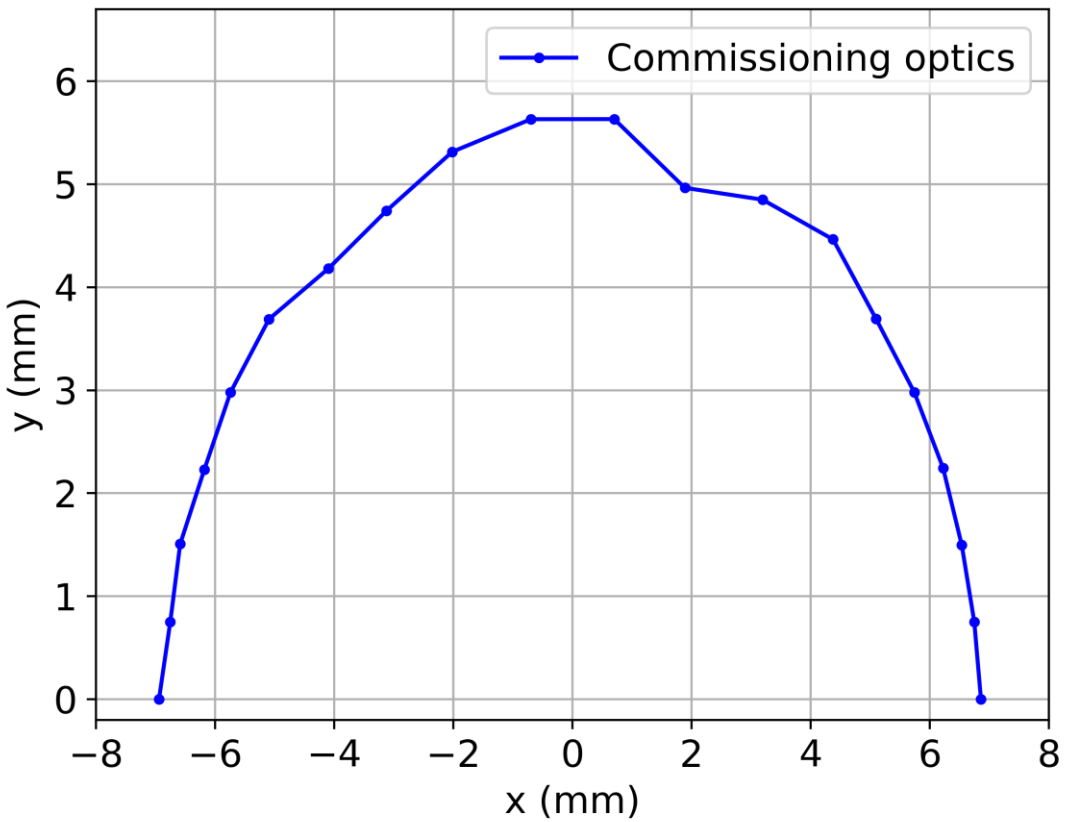
Dynamic Apertures

Nominal optics



1000 turns
$\beta_x = 9.8$ m
$\beta_y = 4.8$ m

Commissioning optics



1000 turns
$\beta_x = 14.6$ m
$\beta_y = 3.2$ m

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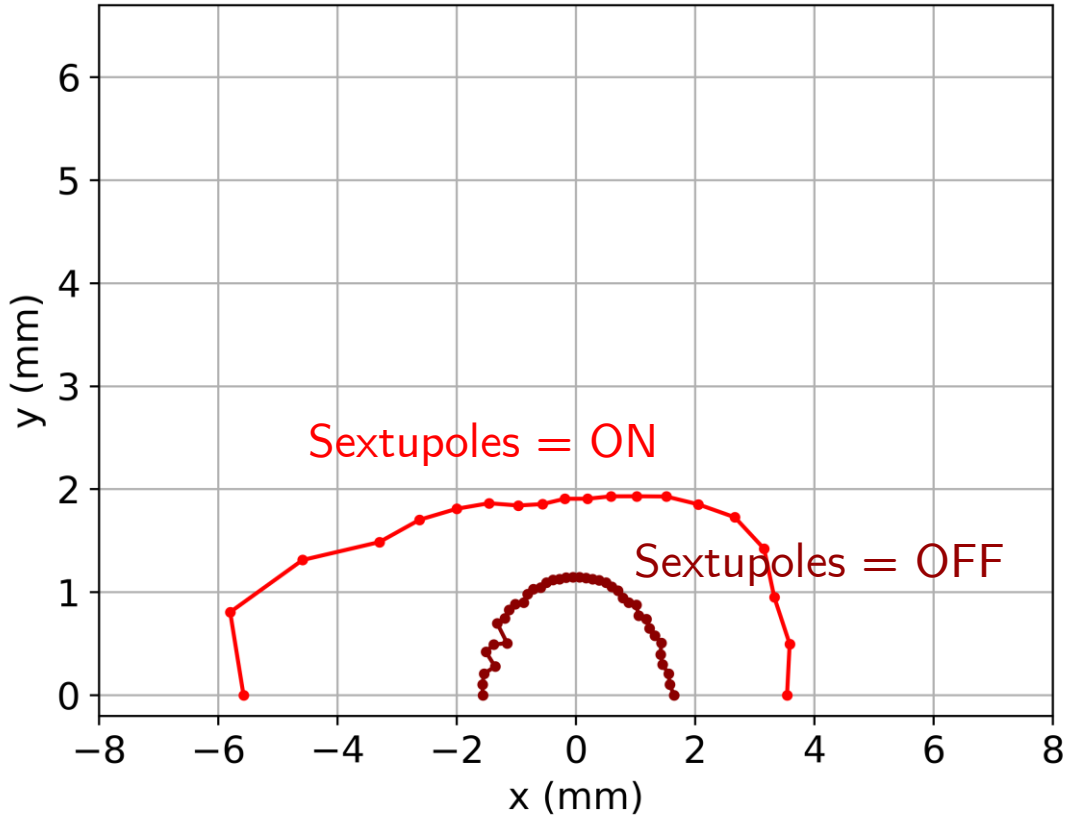
Dynamic Apertures

Nominal optics



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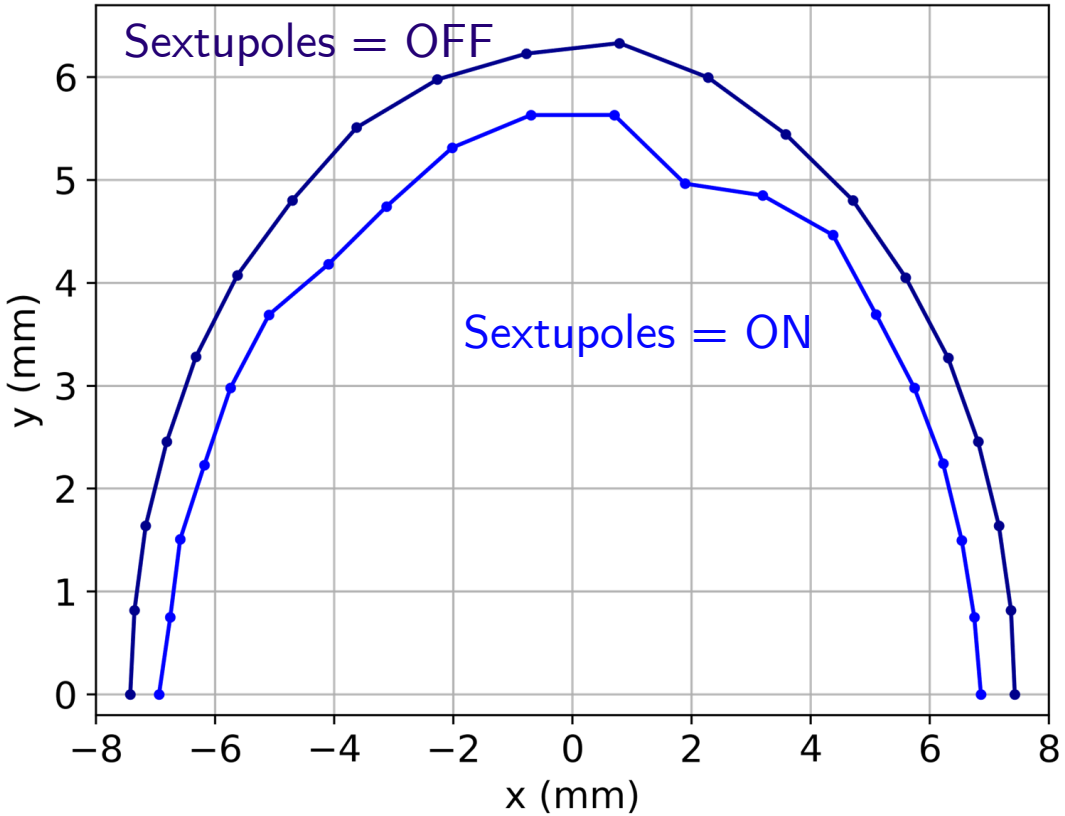

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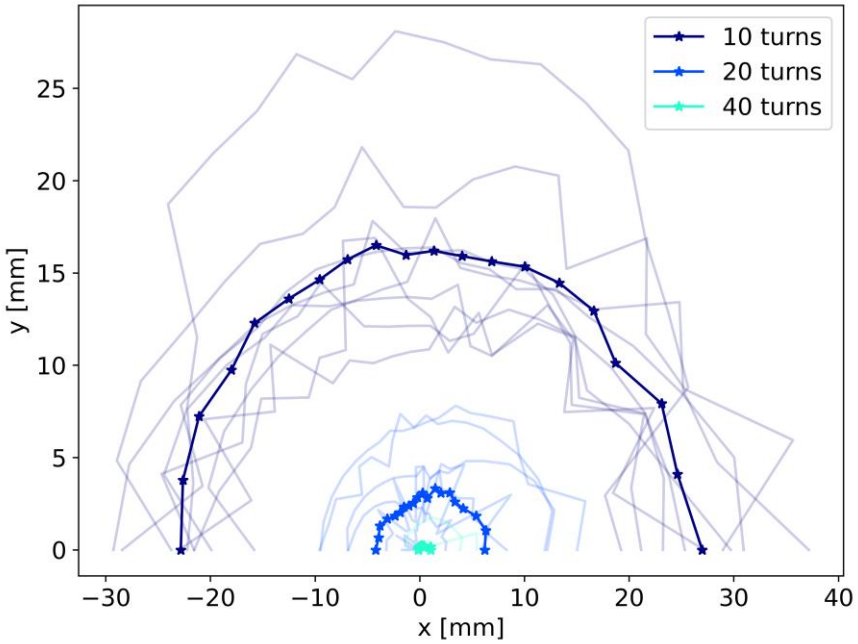
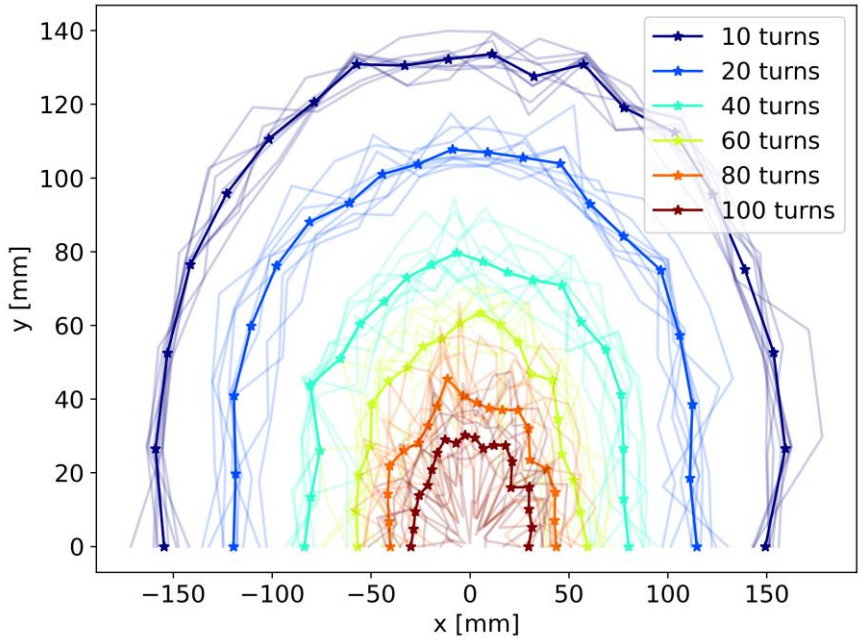
DA with sextupoles off, with errors included

Nominal optics



Commissioning optics



Without errors, turning off sextupoles reduces the DA.
However when only calculated over only 10s of turns, the DA is increased.

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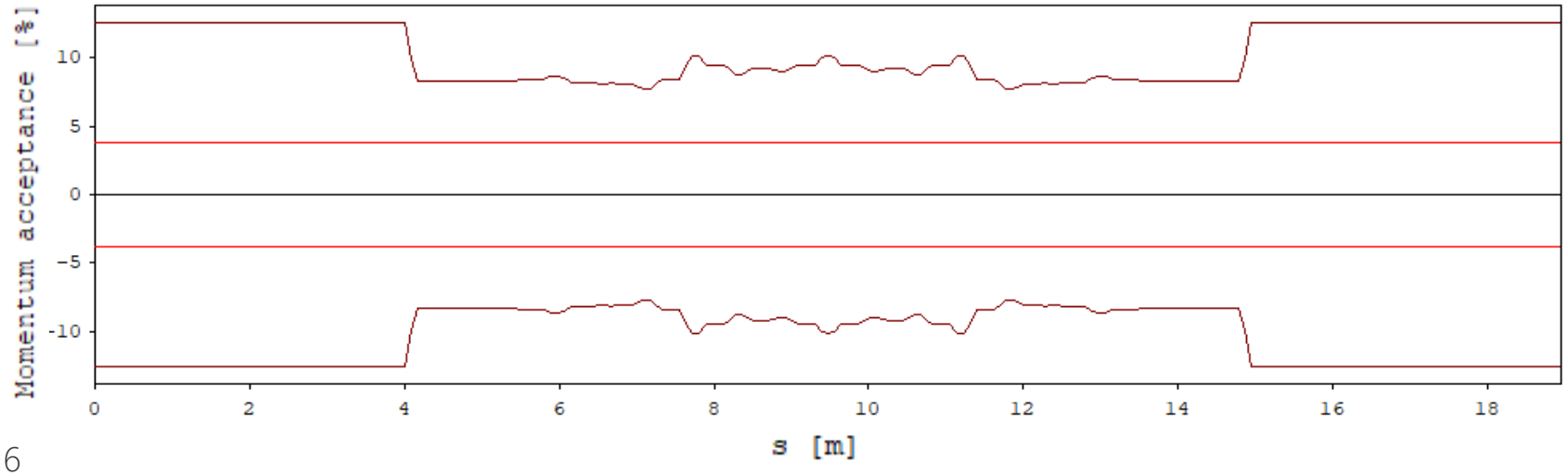
Touschek lifetime and Momentum Acceptance

Parameter	Nominal Optics	Commissioning Optics
Coupling	1%	
Total beam current	200 mA	
No. bunches	700	
Harmonic number, h	758	
Momentum compaction (α_c)	0.056e-3	0.182e-3
Cavity voltage	2.3 MV	2.3 MV
Momentum acceptance	7.87 %	3.99 %
RMS bunch length	2.03 mm	13.94 mm
Touschek lifetime	**6.5 h**	**21.36 h**



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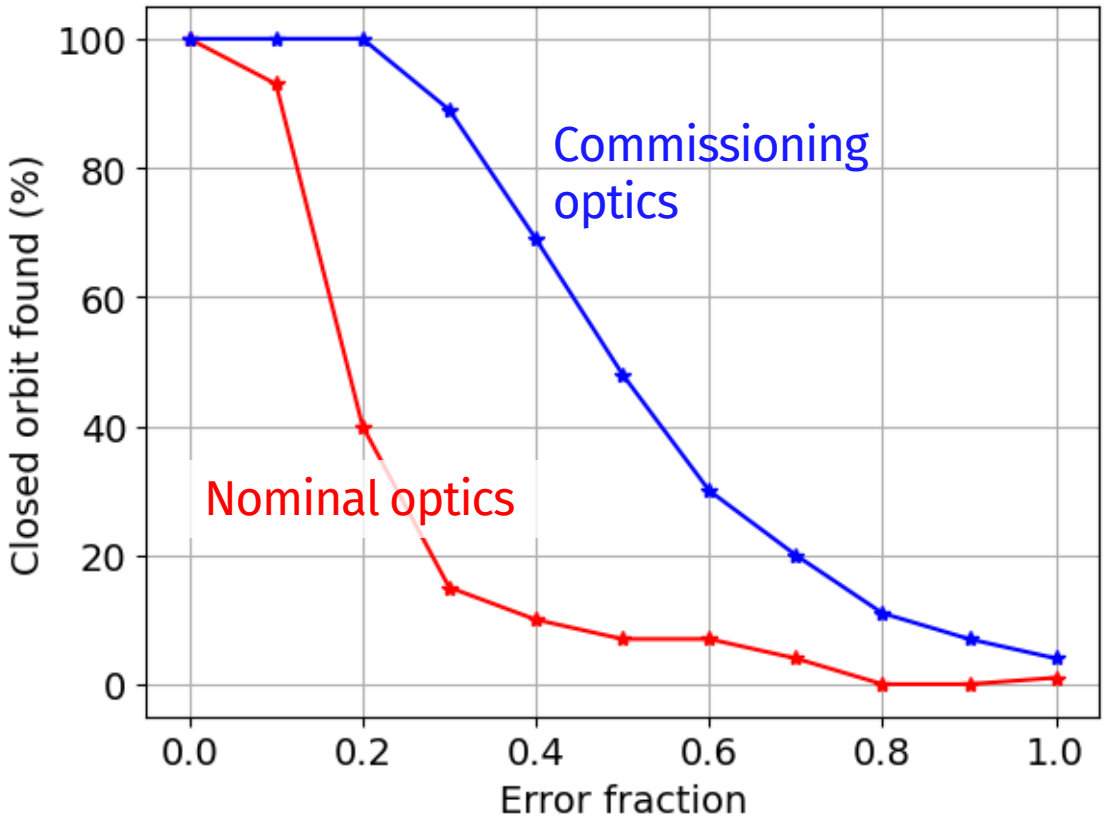
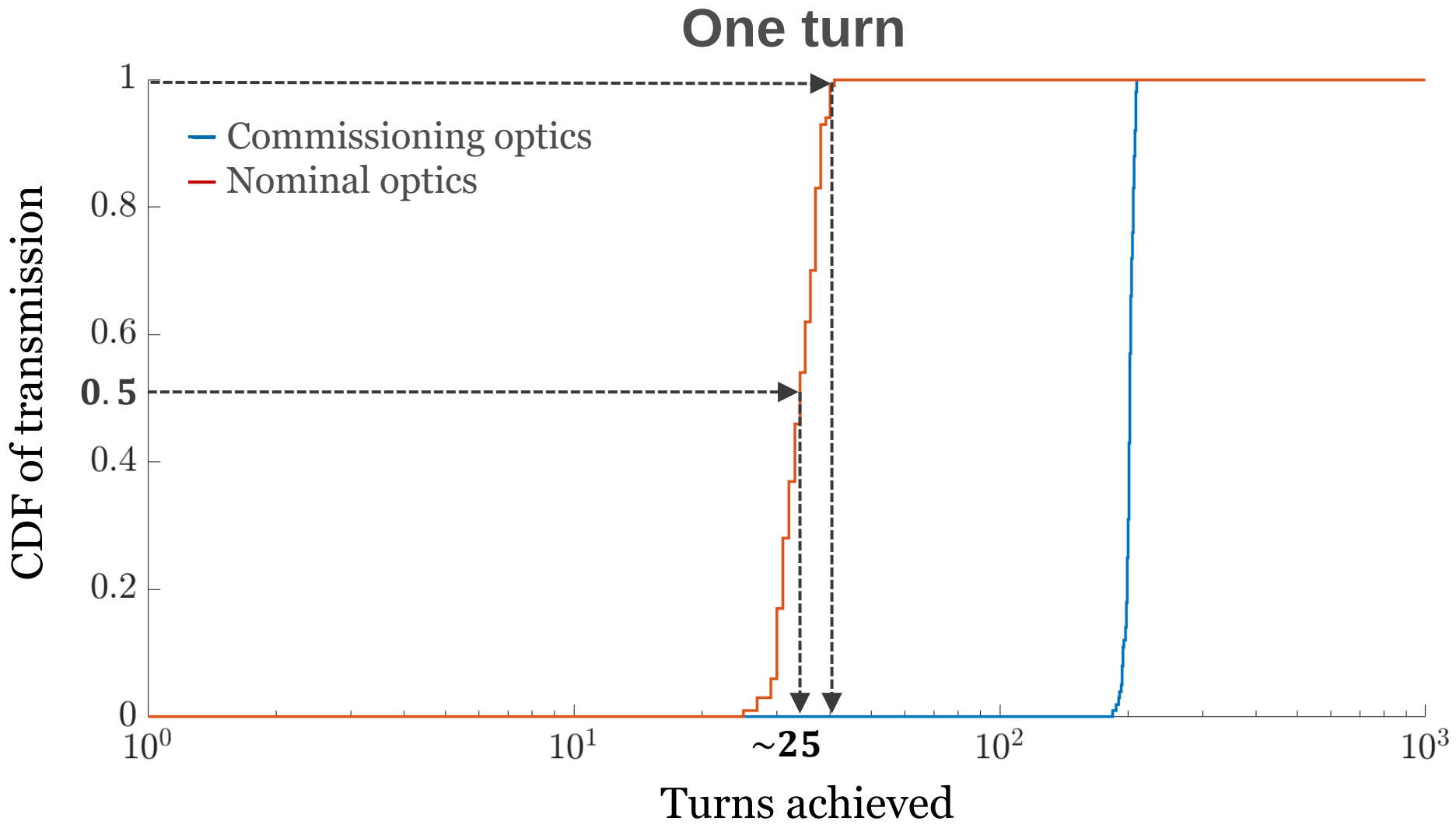


Transmission during early stages of commissioning



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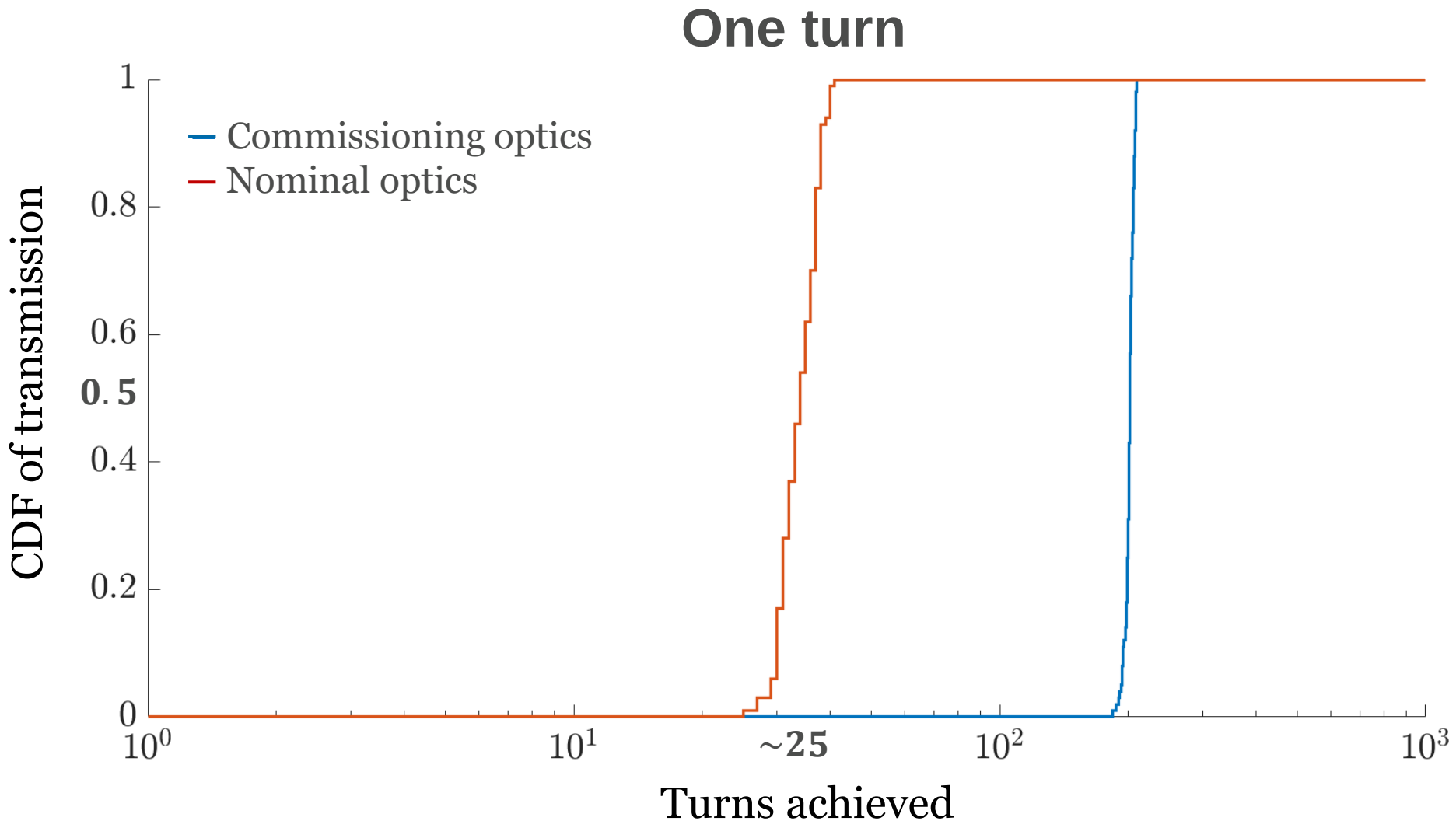

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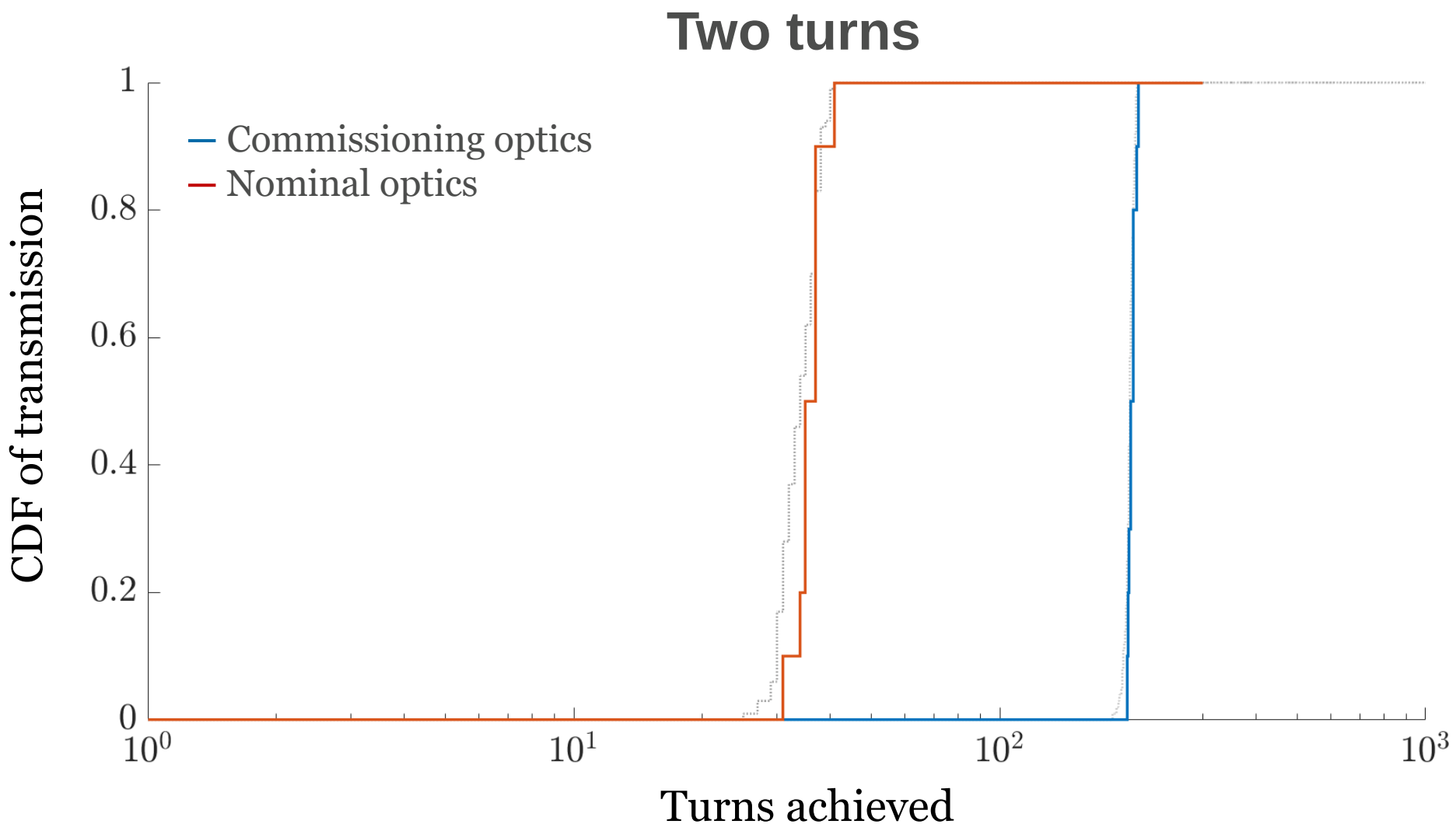

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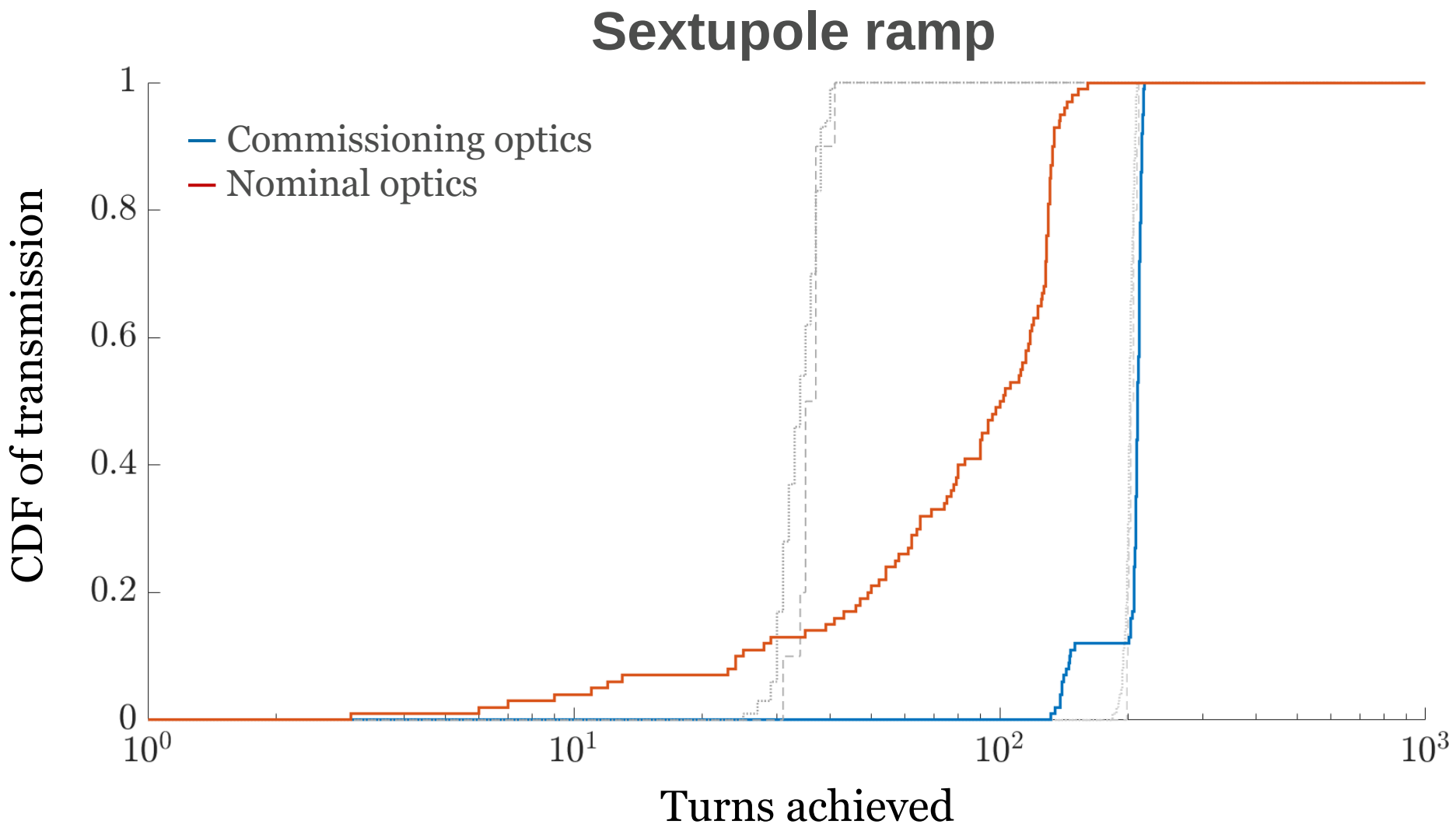

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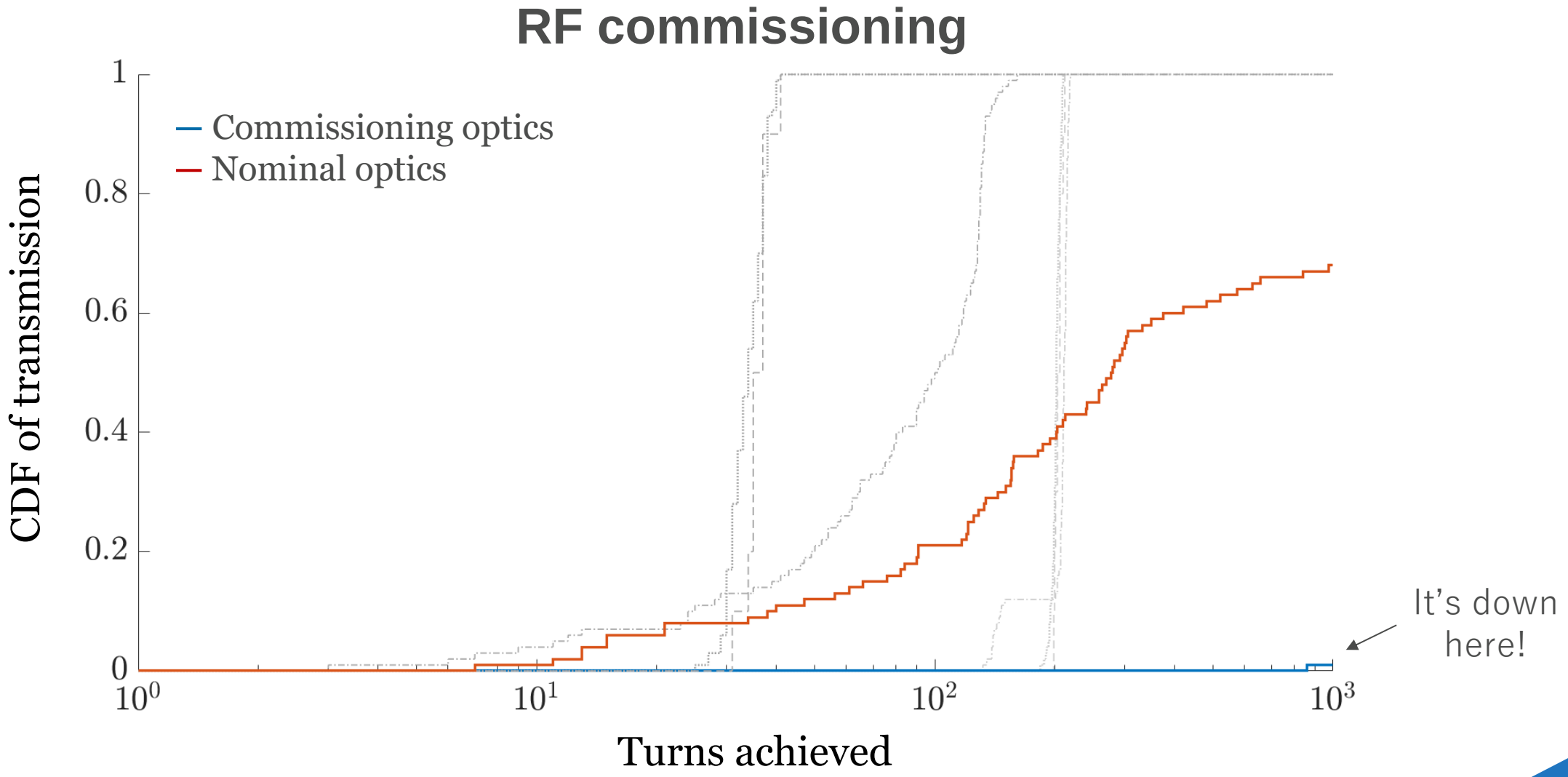
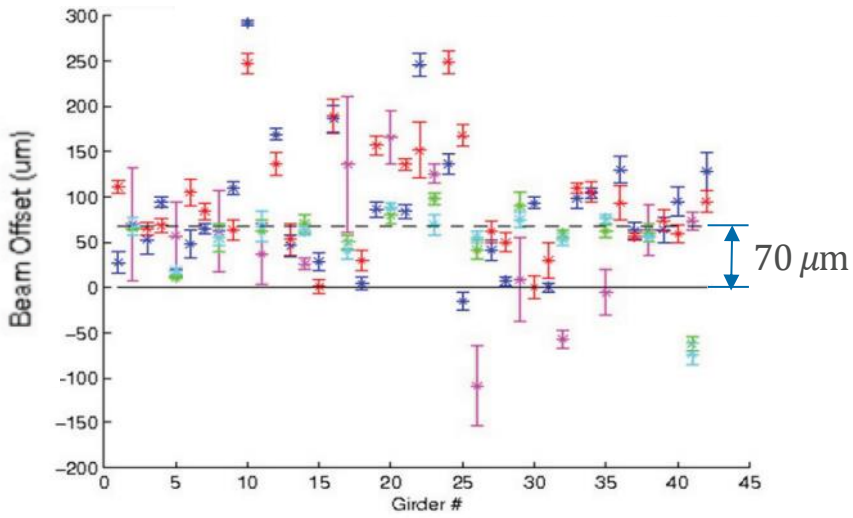
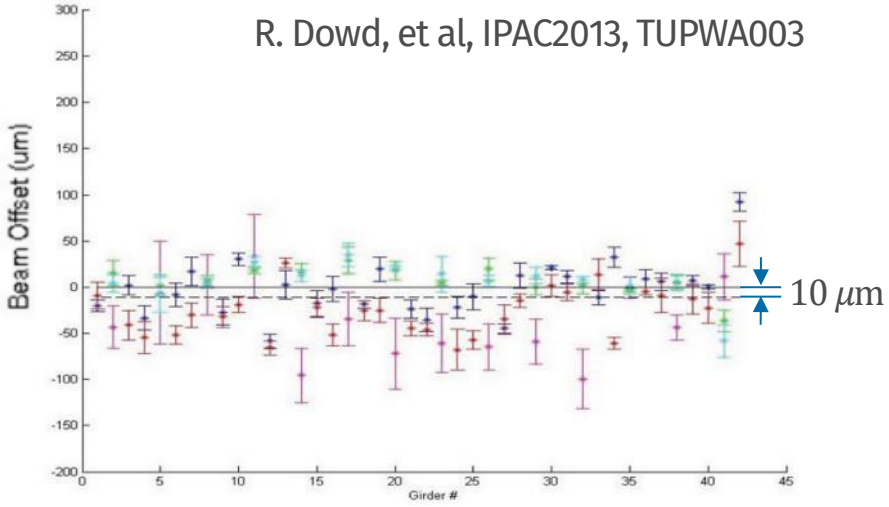


Example from Australian Synchrotron of Sextupole Realignment



R. Dowd, et al, IPAC2013, TUPWA003



Procedure to determine sextupole vertical alignment:

1. Shunt each sextupole family at different strengths
2. Perform LOCO and fit skew quad terms to each sextuople
3. Gradient of skew field vs sextupole field gives vertical offset
4. Shims of 25 μm introduced to individual magnets

After realignment **vertical emittances measured indirectly to be below 1 pm.**

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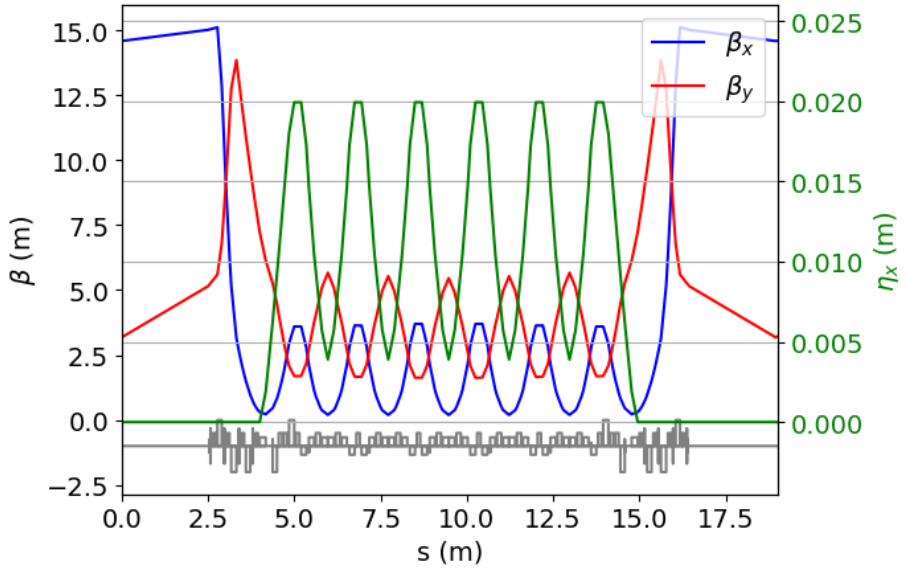
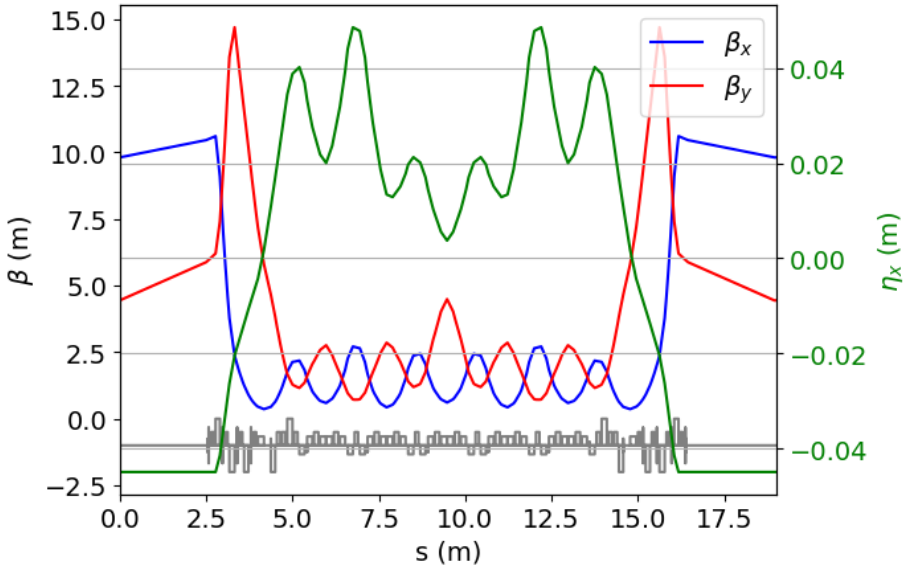
Conclusion

"Commissioning optics" is a more relaxed optics configuration, compatible with the nominal optics. We achieved this solution with an offset quadrupole at a greater relative offset.

Nominal optics



Commissioning optics



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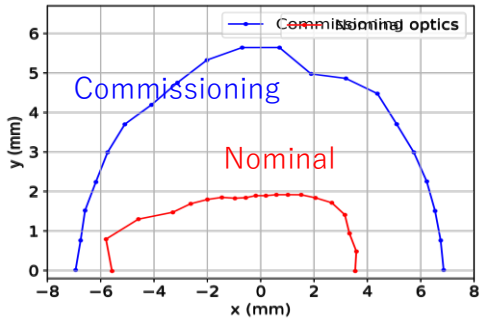
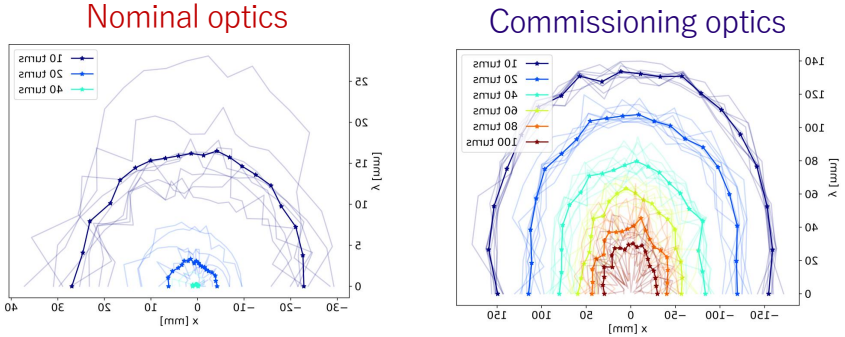
Conclusion

Commissioning optics allows for…

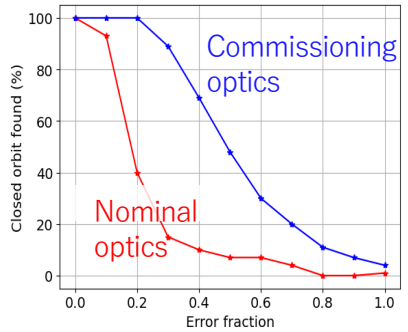
Larger DA



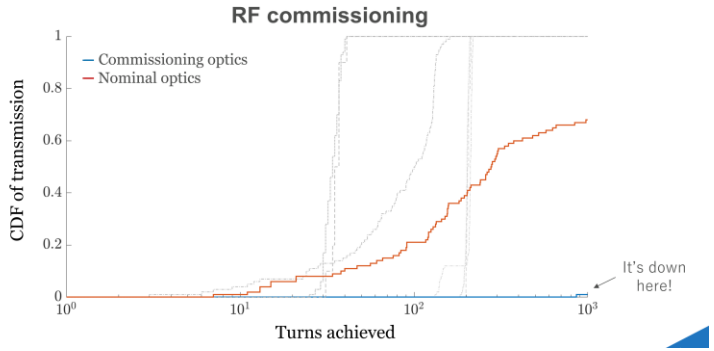
Larger DA for more turns with errors



Greater likelihood of finding closed orbit



Better transmission during early stages of commissioning

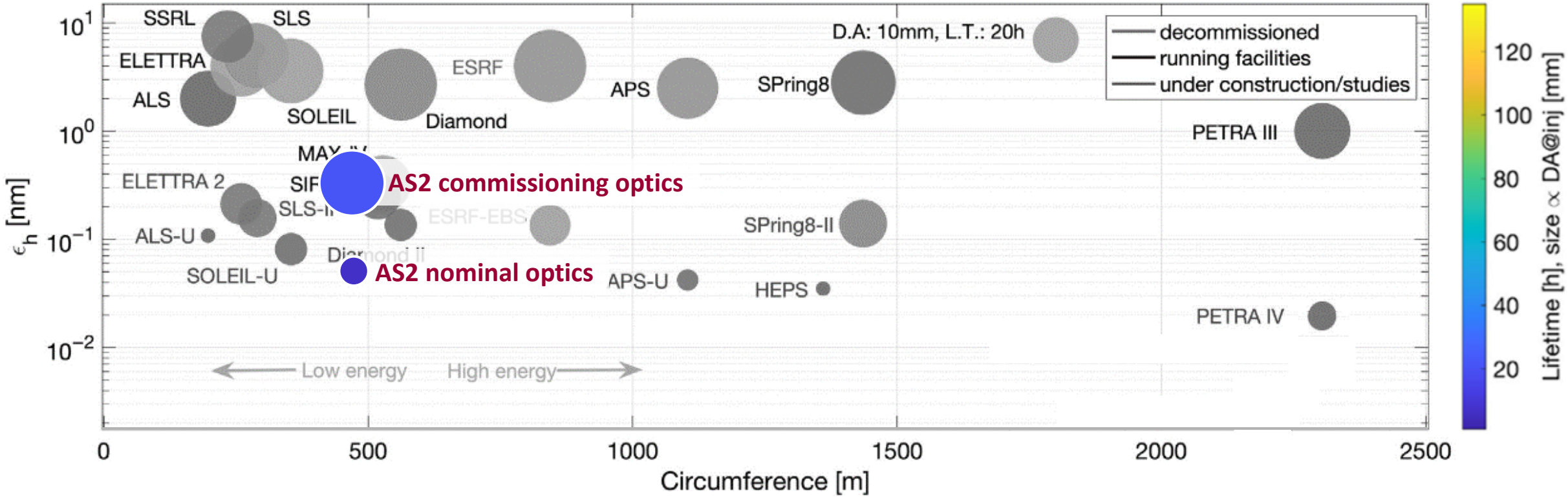


Longer lifetime

Parameter	Nominal Optics	Commissioning Optics
Coupling	1%	
Total beam current	200 mA	
No. bunches	700	
Harmonic number, h	758	
Momentum compaction (α_c)	0.056e-3	0.182e-3
Cavity voltage	2.3 MV	2.0 MV
Momentum acceptance	7.87 %	3.99 %
RMS bunch length	2.03 mm	13.94 mm
Touschek lifetime	**7.16 h**	**21.36 h**

And **reduces risk,** allowing for smoother, **more rapid commissioning.**

Traits & Challenges of 4th Gen Light Sources



Original figure: Pantaleo Raimondi and Simone Liuzzo

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