Towards an optics baseline for HE-LHC

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Acknowledgements:

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19th HE-LHC design meeting, CERN, Sep. 22, 2017

Outline

- **Overview of the lattices and tools developed by Thys**
  - Lattices with different arc schemes
  - Tools for optics tuning
- **Comparison of various lattices**
  - Survey
  - Magnet parameters in arcs
  - Ring optics
  - n1 in arcs
- **Summary and Future plan**

1. Overview of the lattices and tools developed by Thys

➤ Recent updates of HE-LHC lattices by Thys

- Source files: /afs/cern.ch/eng/lhc/optics/HELHC/
- Use IRs of SLHCV3.1a for all of the lattices
- HE-LHC.17x90

```
-rw-r--r--. 1 riss si 292071 Sep 13 19:14 merged_HE-LHC.17x90_tr.seq
-rw-r--r--. 1 riss si  10436 Sep 15 11:27 merged_HE-LHC.17x90_tr.str
```

- HE-LHC.18x60 and HE-LHC.18x90

```
-rw-r--r--. 1 riss si 274907 Jul  9 16:44 merged_HE-LHC.18x60_tr.seq
-rw-r--r--. 1 riss si  10276 Sep 14 11:55 merged_HE-LHC.18x60_tr.str
-rw-r--r--. 1 riss si 295719 Sep 13 11:07 merged_HE-LHC.18x60_v102.seq
-rw-r--r--. 1 riss si  10278 Sep 14 11:55 merged_HE-LHC.18x60_v102.str
-rw-r--r--. 1 riss si  10462 Sep 13 19:18 merged_HE-LHC.18x90_v102.str
```

- HE-LHC.20x90

```
-rw-r--r--. 1 riss si 303240 Sep 13 19:12 merged_HE-LHC.20x90_v201.seq
-rw-r--r--. 1 riss si  10514 Sep 14 19:28 merged_HE-LHC.20x90_v201.str
```

- HE-LHC.24x60

```
-rw-r--r--. 1 riss si 377338 Sep 10 17:04 merged_HE-LHC.seq
-rw-r--r--. 1 riss si   9674 Sep 10 17:02 merged_HE-LHC.str
```

1. Overview of the lattices and tools developed by Thys

➤ Some features of the above lattices

- See Massimo's talk: HE-LHC design meeting 14, May 23, 2017
- Ring separation in arcs: defined by a variable

  bsep := 0.204; [current baseline]
- Use one type of dipoles for both arcs and dispersion suppressors
- Full IRs of SLHCV3.1a integrated: Crossing angle and related parameters defined as variables
- Tune (*.28, *.31) and chromaticity (+1, +1) matched to proper values [except 18x60 and 24x60]
- β^* at IPs in experimental IRs matched to (10, 10) m: Injection optics

1. Overview of the lattices and tools developed by Thys

➤ Tools for optics tuning

- **Source files: /afs/cern.ch/eng/lhc/optics/HELHC/toolkit/**
- **Script for chromaticity correction: chroma.madx**
- **Script for Twiss parameters at arc cells: GetArcPars.madx**
- **Matching conditions in IRs: rematch.ip*.madx**
- **Script for changing phase advance in arc cells: TuneCell.madx**

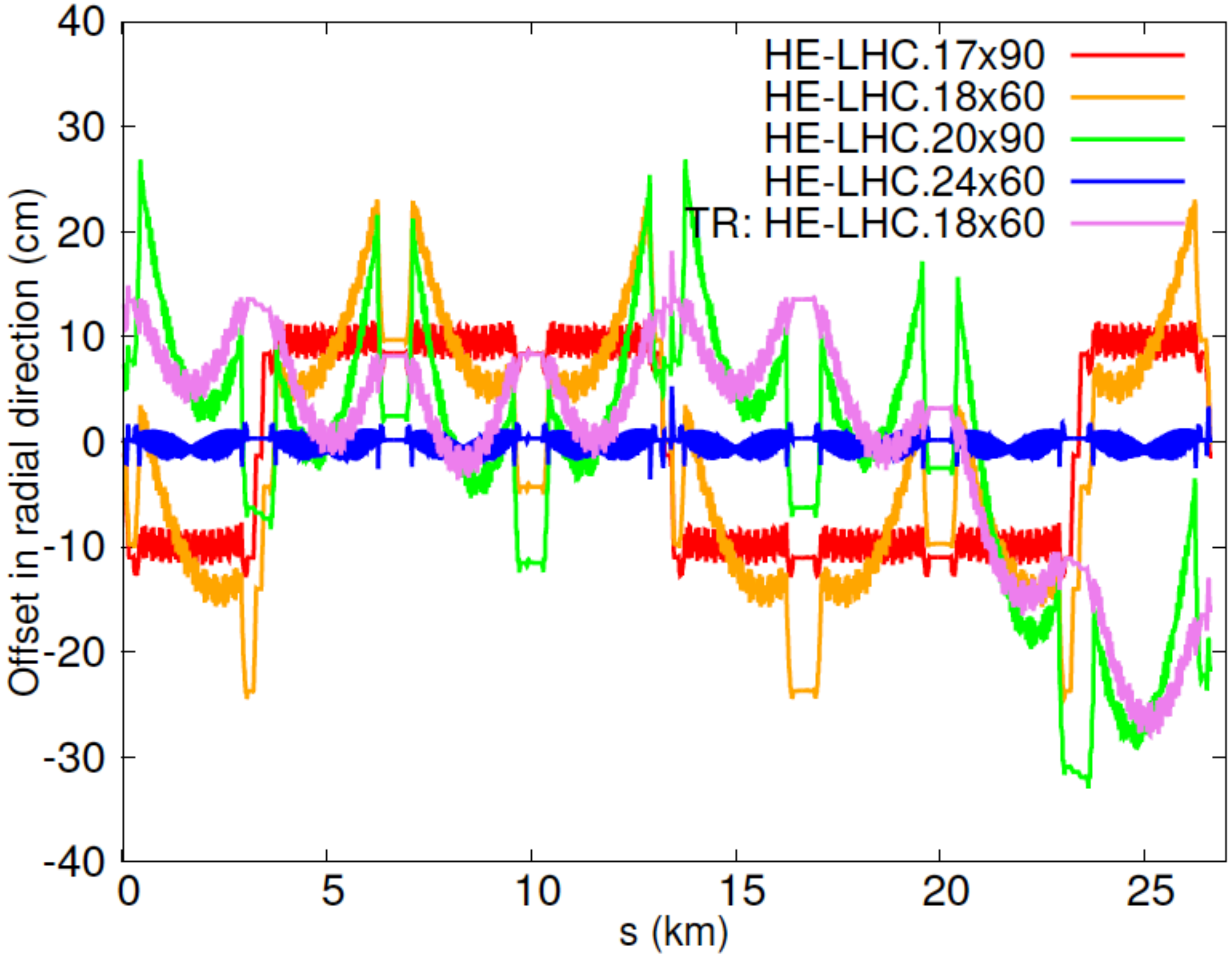
```
-rw-r--r--. 1 riss si  411 Sep 13 13:49 chroma.madx
-rw-r--r--. 1 riss si 1140 Sep 14 17:11 GetArcPars.madx
-rw-r--r--. 1 riss si  554 Sep 13 11:46 rematch.ip1.b1.madx
-rw-r--r--. 1 riss si 3186 Sep 13 13:48 rematch.ip2.b1.madx
-rw-r--r--. 1 riss si 2886 Sep 13 11:57 rematch.ip3.b1.madx
-rw-r--r--. 1 riss si 2989 Sep 13 12:09 rematch.ip4.b1.madx
-rw-r--r--. 1 riss si 3098 Sep 13 11:52 rematch.ip5.b1.madx
-rw-r--r--. 1 riss si 2645 Sep 13 12:00 rematch.ip6.b1.madx
-rw-r--r--. 1 riss si 2696 Sep 13 15:44 rematch.ip7.b1.madx
-rw-r--r--. 1 riss si 3059 Sep 13 12:04 rematch.ip8.b1.madx
-rw-r--r--. 1 riss si  794 Sep 16 19:39 TuneCell.madx
```

2. Comparison of various lattices

➤ Ring survey

- Refer to Massimo's talk: HE-LHC design meeting 14, May 23, 2017
- Likely two lattices do not close in survey?

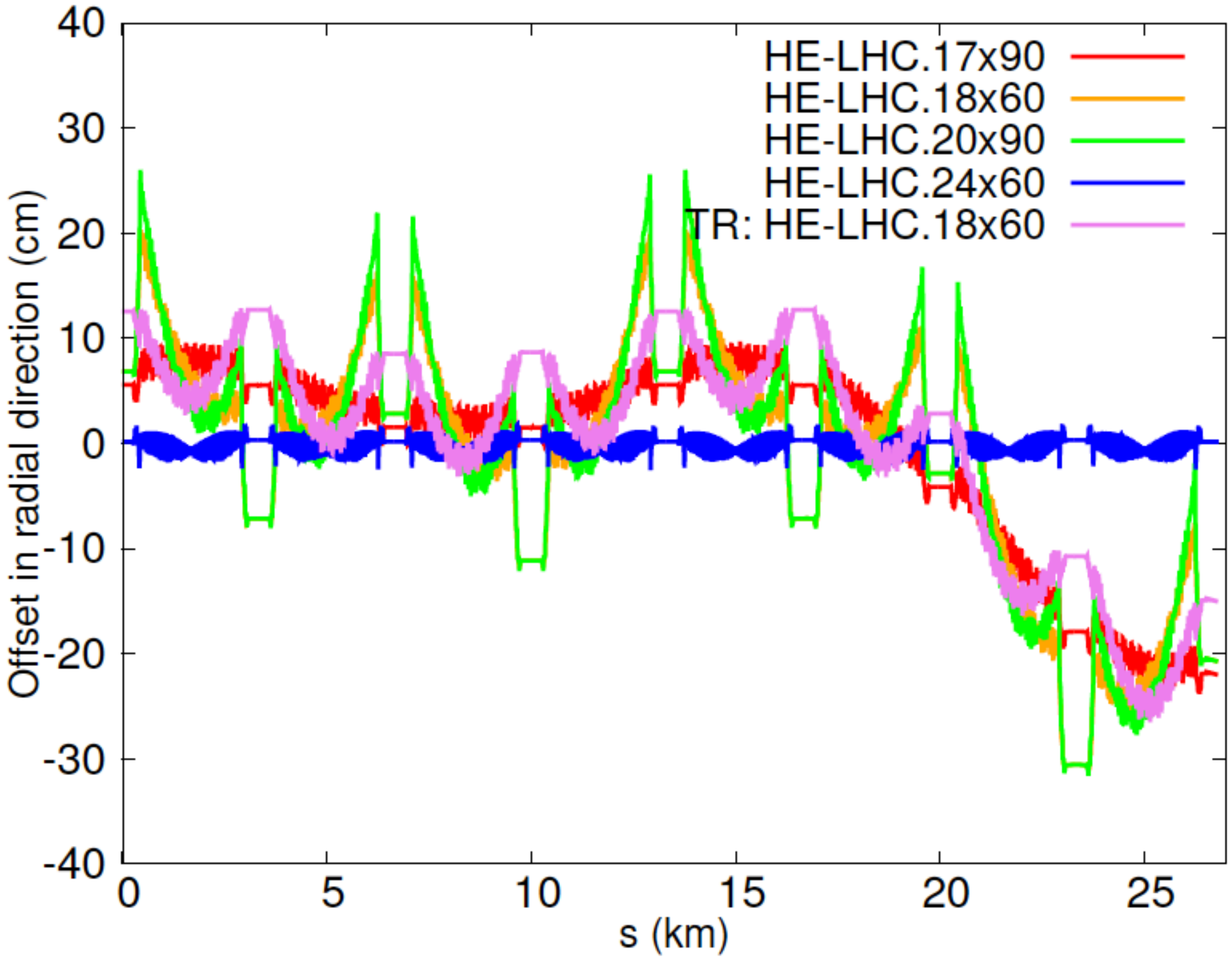
  merged_HE-LHC.18x60_tr.seq and merged_HE-LHC.20x90_v201.seq
- 17x90 and 24x60: well optimized
- 18x60 and 20x90: Further optimizations (similar to 17x90) possible?



2. Comparison of various lattices

➤ Ring survey

- **Ring separation in arcs set to zero as suggested by This**




```
real const aip1 = 0;
real const aip2 = 0;
real const aip3 = 0;
real const aip4 = 0;
real const aip5 = 0;
real const aip7 = 0;
real const aip8 = 0;
```

2. Comparison of various lattices

➤ Parameters for arc cells

- **LQ=3.1 m, LS=0.369 m**

	LHC	17x90	18x60	18x90	20x90	24x60
Arc cell phase	~90/90	90/90	60/60	90/90	90/90	60/60
Arc cell length [m]	107	144.4	137.2		124.8	102.9
K1 [m^{-2}]	0.009	0.0064	0.0048	0.0068	0.0076	0.0064
$\beta_{max/min}$ [m]	181/32	241/43	234/80	229/41	208/37	175/61
$\eta_{max/min}$ [m]	2.2/1.1	4/2	6.9/4.1	3.6/1.8	3.0/1.5	3.8/2.3
Dipole length [m]	14.3 [x6]	14.6 [x8]	14.18 [x8]		12.625 [x8]	13.56 [x6]
Dipole field [T] @13.5TeV	16.06	15.94	15.59		15.92	16.3
Quad. grad. [T/m] @13.5TeV	405	289	215	304	340	288
Sext. grad. [T/m²] @13.5TeV	4826	2035	~870	2470	2943	1997
Filling factor	0.802	0.809	0.827		0.809	0.791

2. Comparison of various lattices

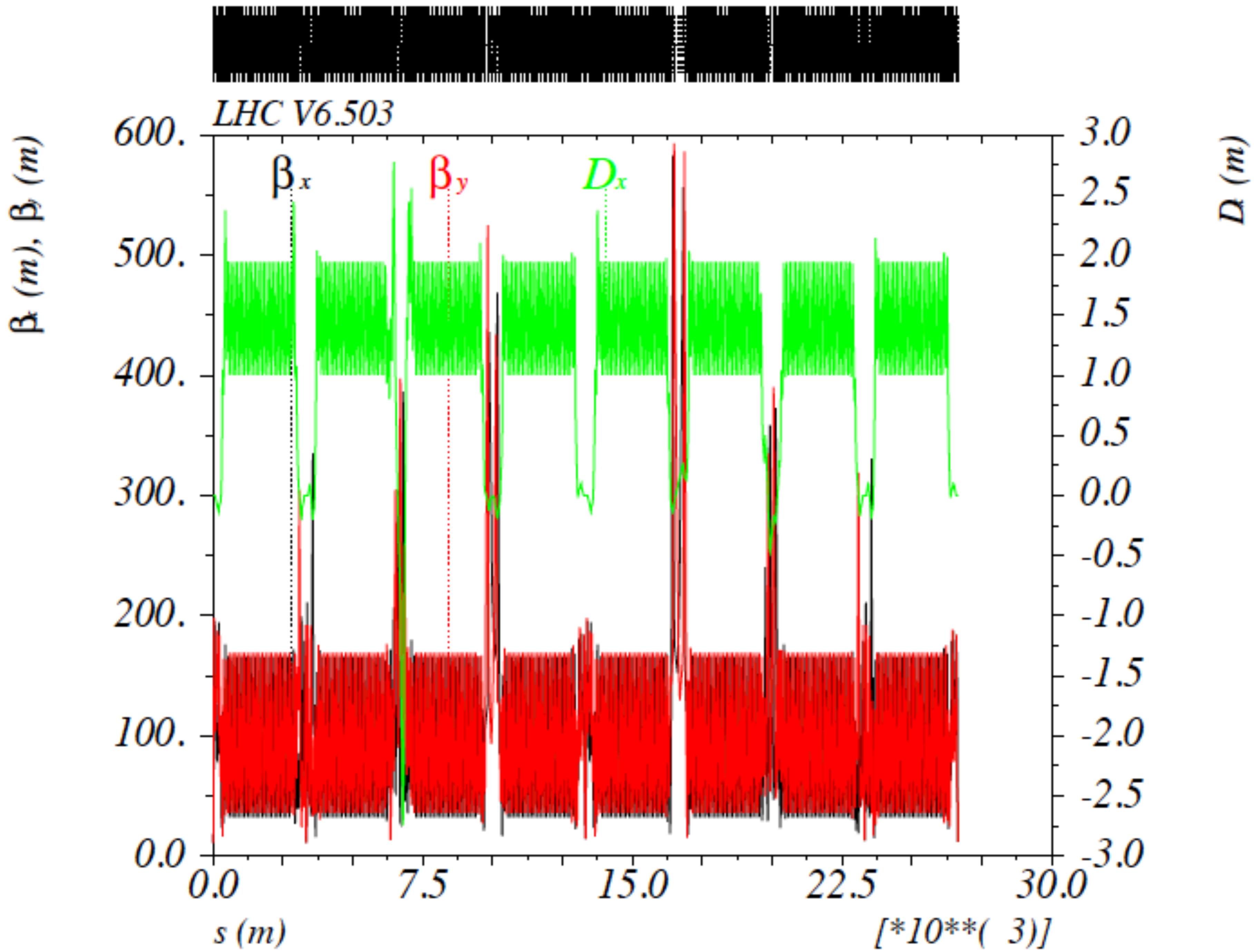
➢ Global parameters for injection optics

- Circumference=26658.8832 m
- Matching 18x60 and 24x60 lattice not successful

	LHC	17x90	18x60	18x90	20x90	24x60
Tune [x/y]	64.28/59.31	49.28/47.31	37.23/36.06	50.28/49.31	54.28/53.31	46./45.8
Nat. Chrom. [x/y]	-86.2/-81.5	-67.9/-68.0	-48.7/-48.4	-68.7/-70.5	-73.9/-74.9	-57.3/-57.7
Cor. Chrom. [x/y]	2/2	1/1	?	0.6/1	1/1	1.5/9.4
Mom. Compact.	3.22E-04	6.2E-04	1.14E-03	5.71E-04	4.75E-04	6.51E-04
β* (m) [x/y]	11/11	10/10	10/10	10/10	10/10	10/10
Beam separation at arcs (mm)	194	204	204	204	204	194

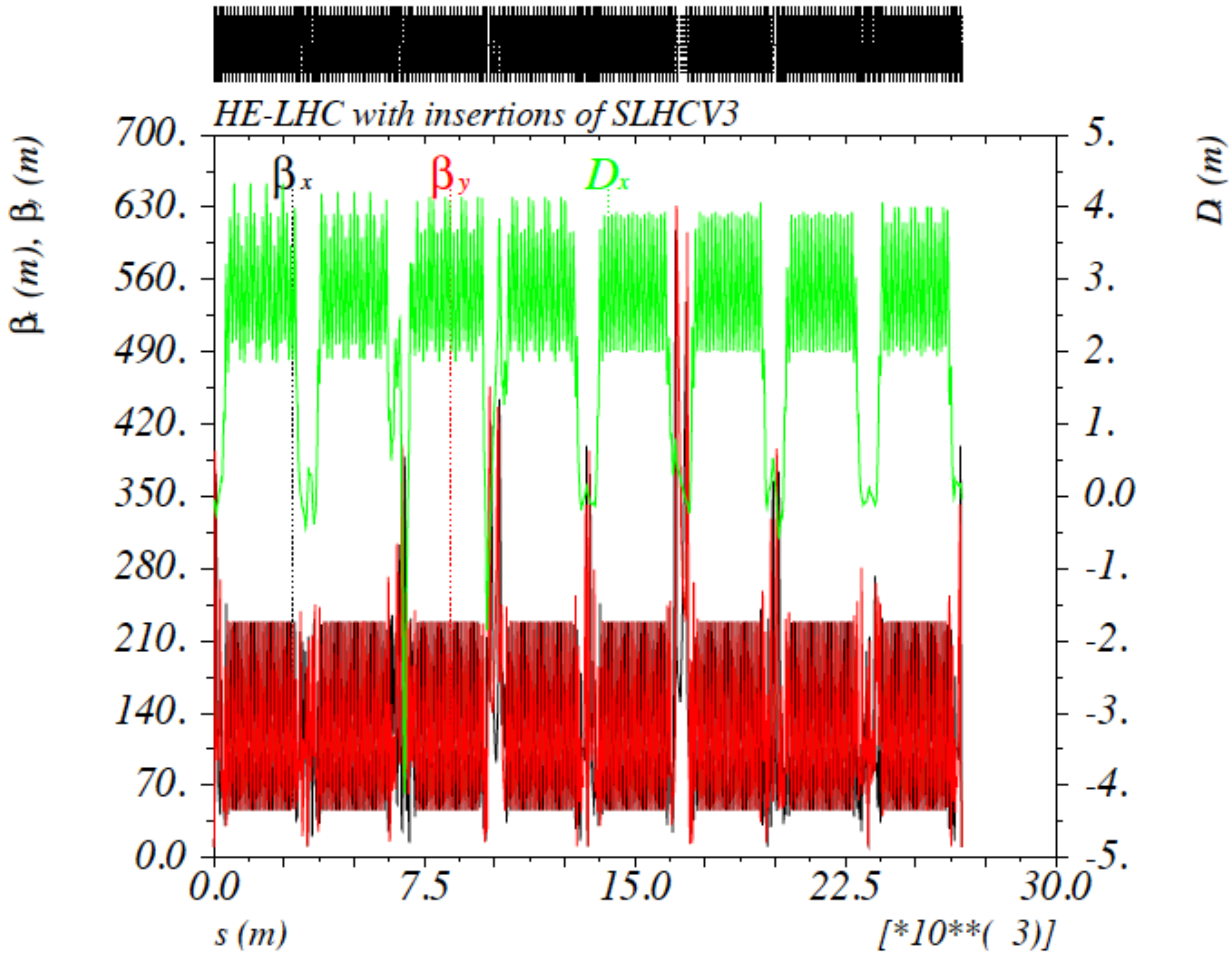
2. Comparison of various lattices

➤ Ring optics: LHC V6.503



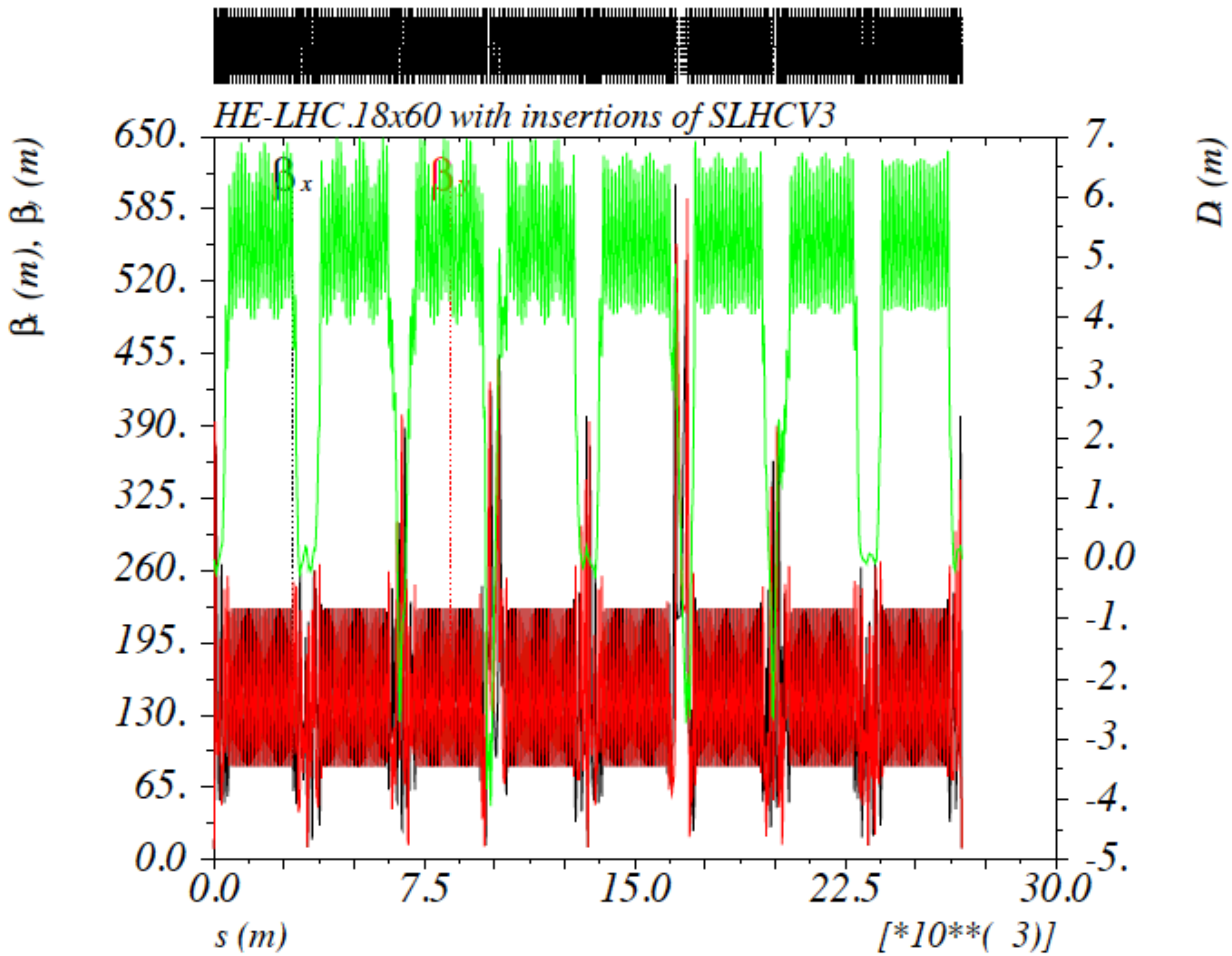
2. Comparison of various lattices

➤ Ring optics: HE-LHC 17x90



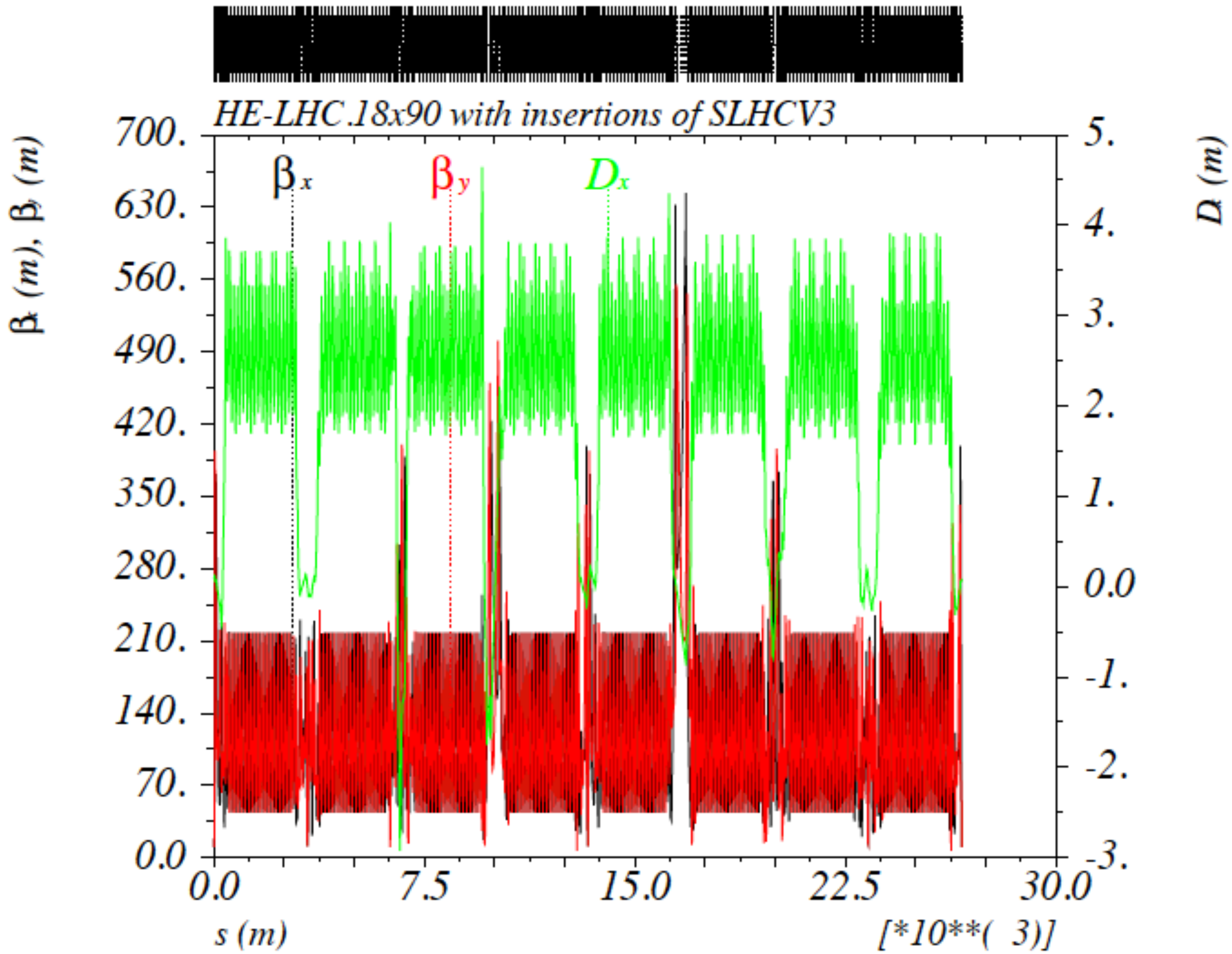
2. Comparison of various lattices

➤ Ring optics: HE-LHC 18x60



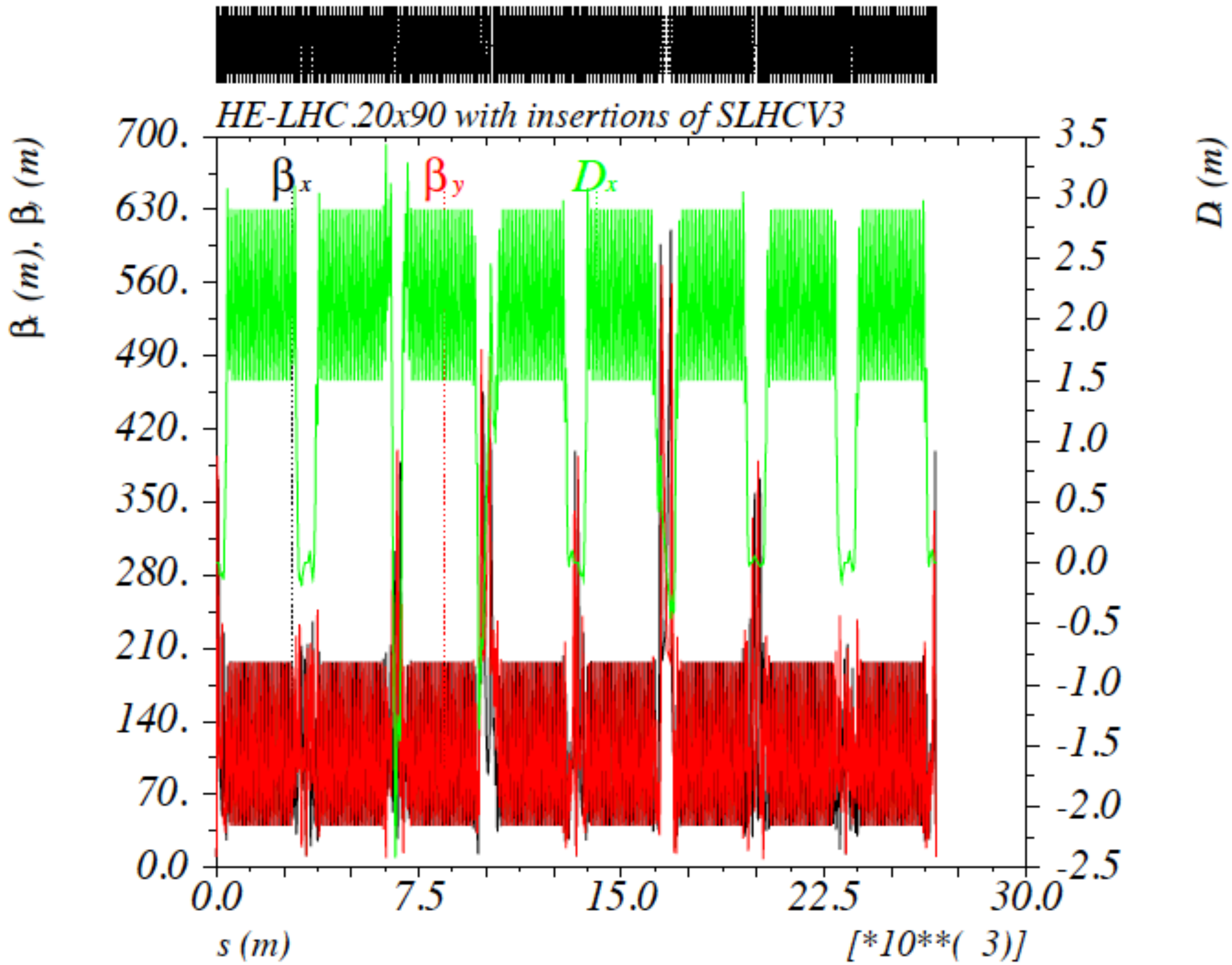
2. Comparison of various lattices

➤ Ring optics: HE-LHC 18x90



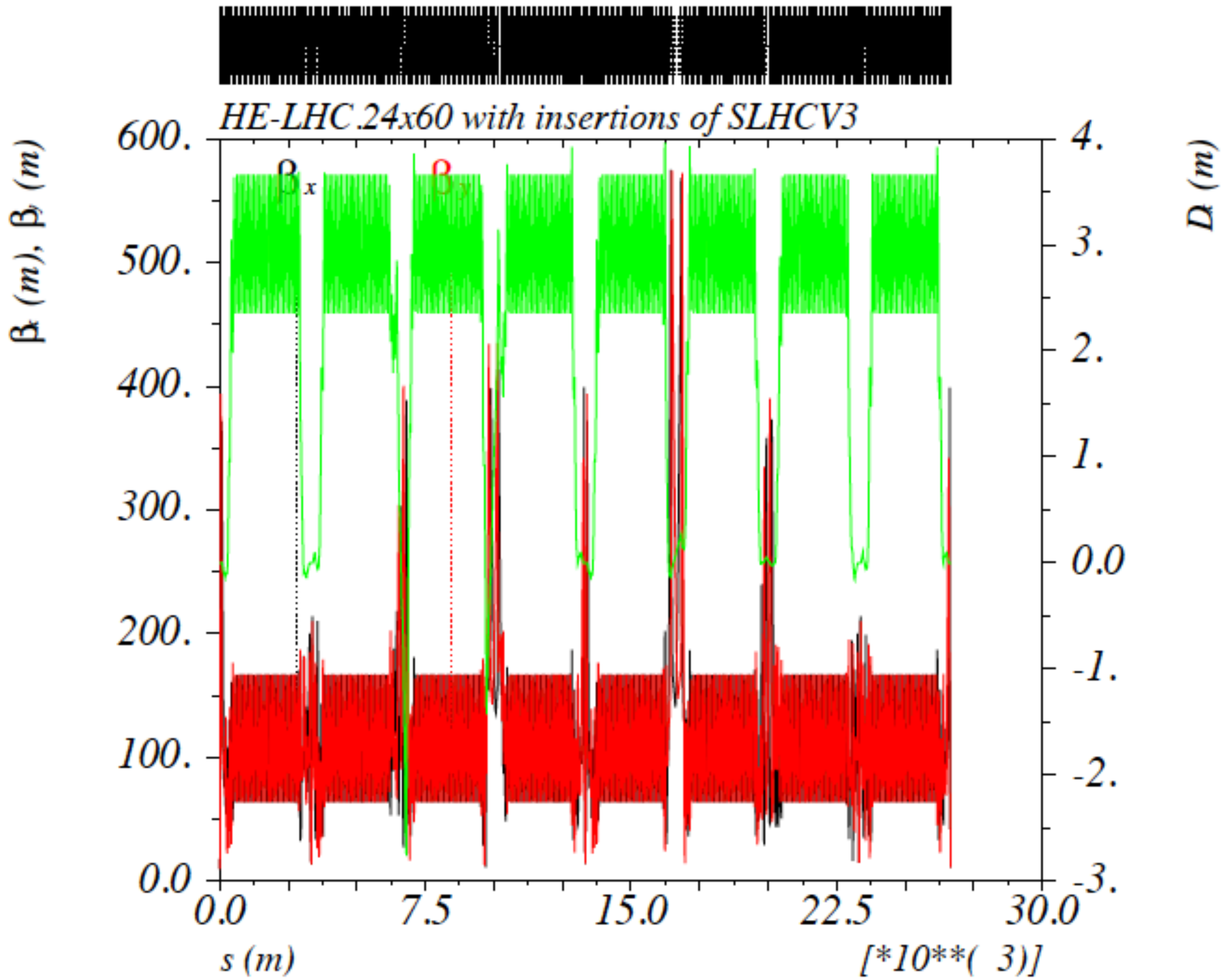
2. Comparison of various lattices

➤ Ring optics: HE-LHC 20x90



2. Comparison of various lattices

➤ Ring optics: HE-LHC 24x60



2. Comparison of various lattices

➤ Check n1

- **“1-D” aperture [Ref. J.B. Jeanneret and T. Risselada, LHC Project Note 66, 1996]**
- **Parameters [Ref. F. Zimmermann, 12th HE-LHC meeting, Apr.16, 2017]:**

  t_x=(2+1) mm, f_{arc}=0.14, δ_p=8.6*10^{-4}, ε_x=2.5 μm, k_β=1.05
- **See my talk in 18th HE-LHC design meeting for the analytic theory, Aug. 22, 2017**

$$n1_x = \frac{L_x - t_x - (1 + f_{\mathrm{arc}}) D_x \delta_p}{k_\beta \sigma_x}$$

$$\sigma_x = \sqrt{\beta_x \epsilon_x}$$

2. Comparison of various lattices

➤ General scaling laws

- **Assume ideal FODO cell [thin-lens, 100% filling factor]**

$$\sin(\Phi/2) = \frac{1}{4}\mathrm{K}_1\mathrm{L}_{\mathrm{cell}}$$

$$\beta_{\pm} = \frac{2\,(1 \pm \mathrm{K}_1\mathrm{L}_{\mathrm{cell}}/4)}{\mathrm{K}_1\sqrt{1-(\mathrm{K}_1\mathrm{L}_{\mathrm{cell}}/4)^2}}$$

$$\mathrm{B}\rho = \mathrm{P}_0/e$$

$$\eta_{\pm} = \frac{4}{\rho\mathrm{K}_1^2}\,(1 \pm \mathrm{K}_1\mathrm{L}_{\mathrm{cell}}/8)$$

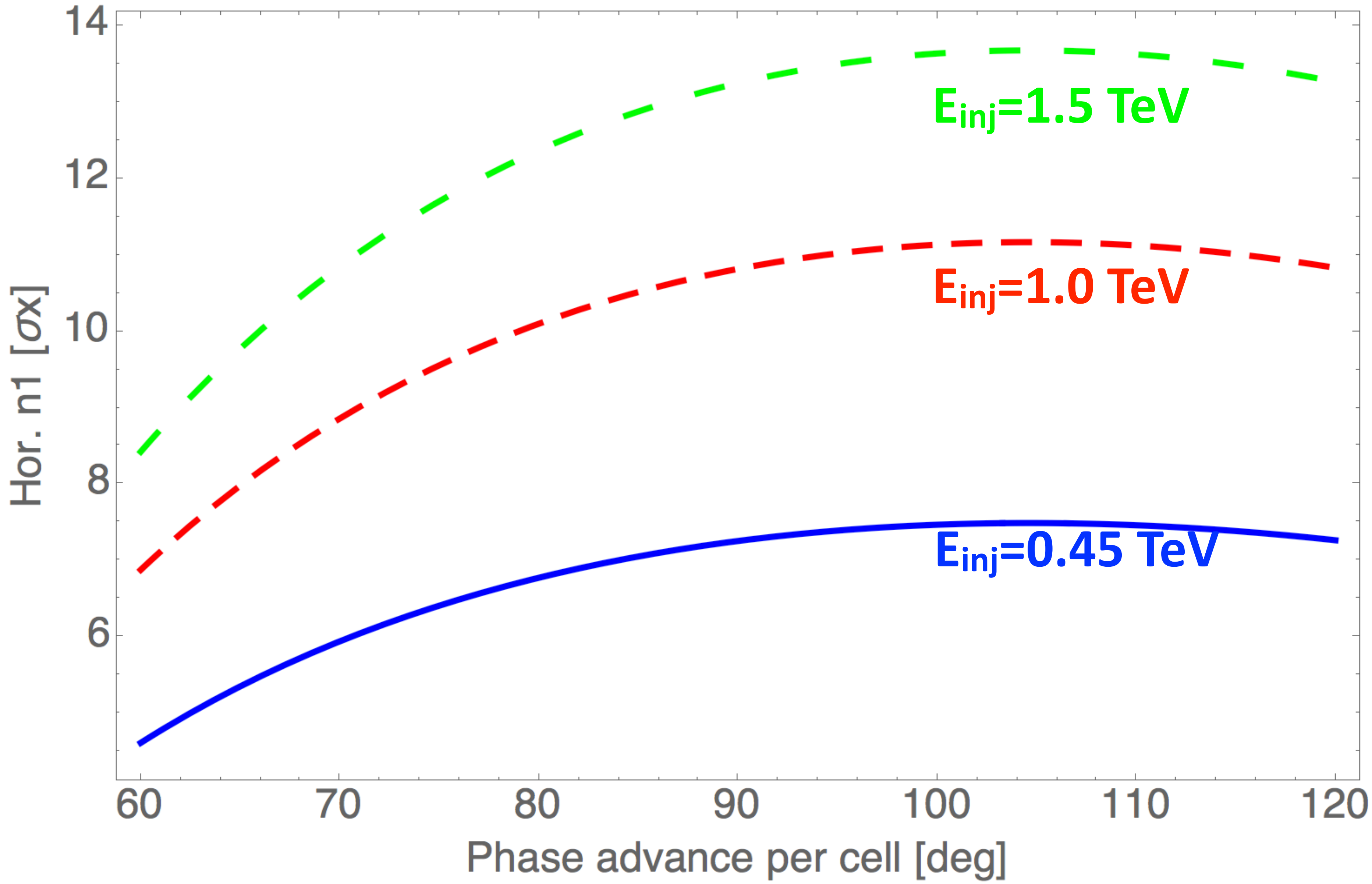
$$K_{2\pm} = \frac{K_1}{\eta_{\pm}}$$

Note:
Sextupole strength for chromaticity correction ONLY in arc cells.
IRs and DSs require higher K_2

2. Comparison of various lattices

➤ Check n1 at QF for 18-cell arcs

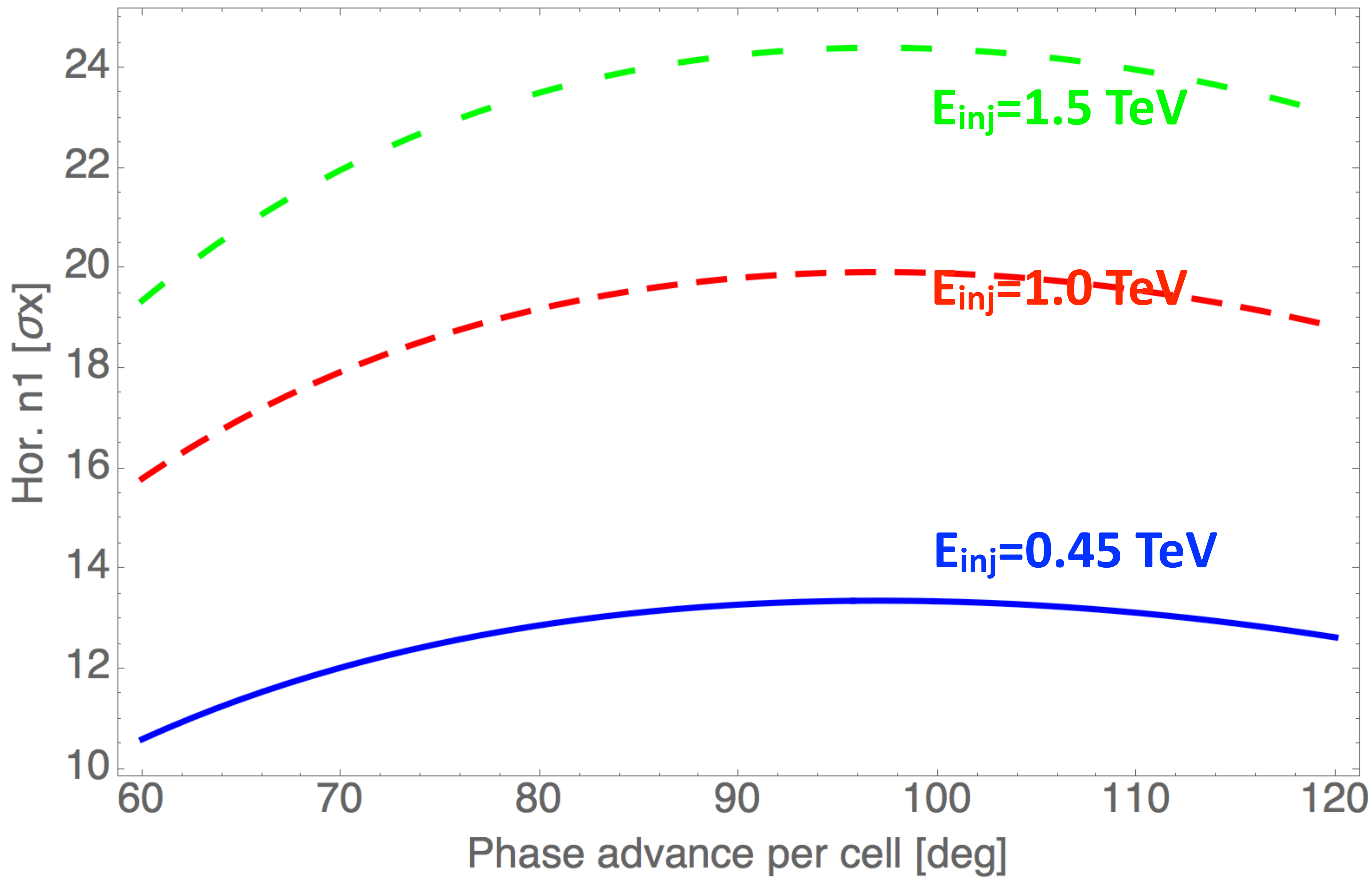
- FCC-hh beam screen: L_x=15 mm
- t_x=(2+1) mm, f_{arc}=0.14, δ_p=8.6*10^{-4}, ε_x=2.5 μm, k_β=1.05
- n1=4.6/6.8/7.3 @60/80/90 deg @E_{inj}=0.45 TeV



2. Comparison of various lattices

➤ Check n1 at QF for 18-cell arcs

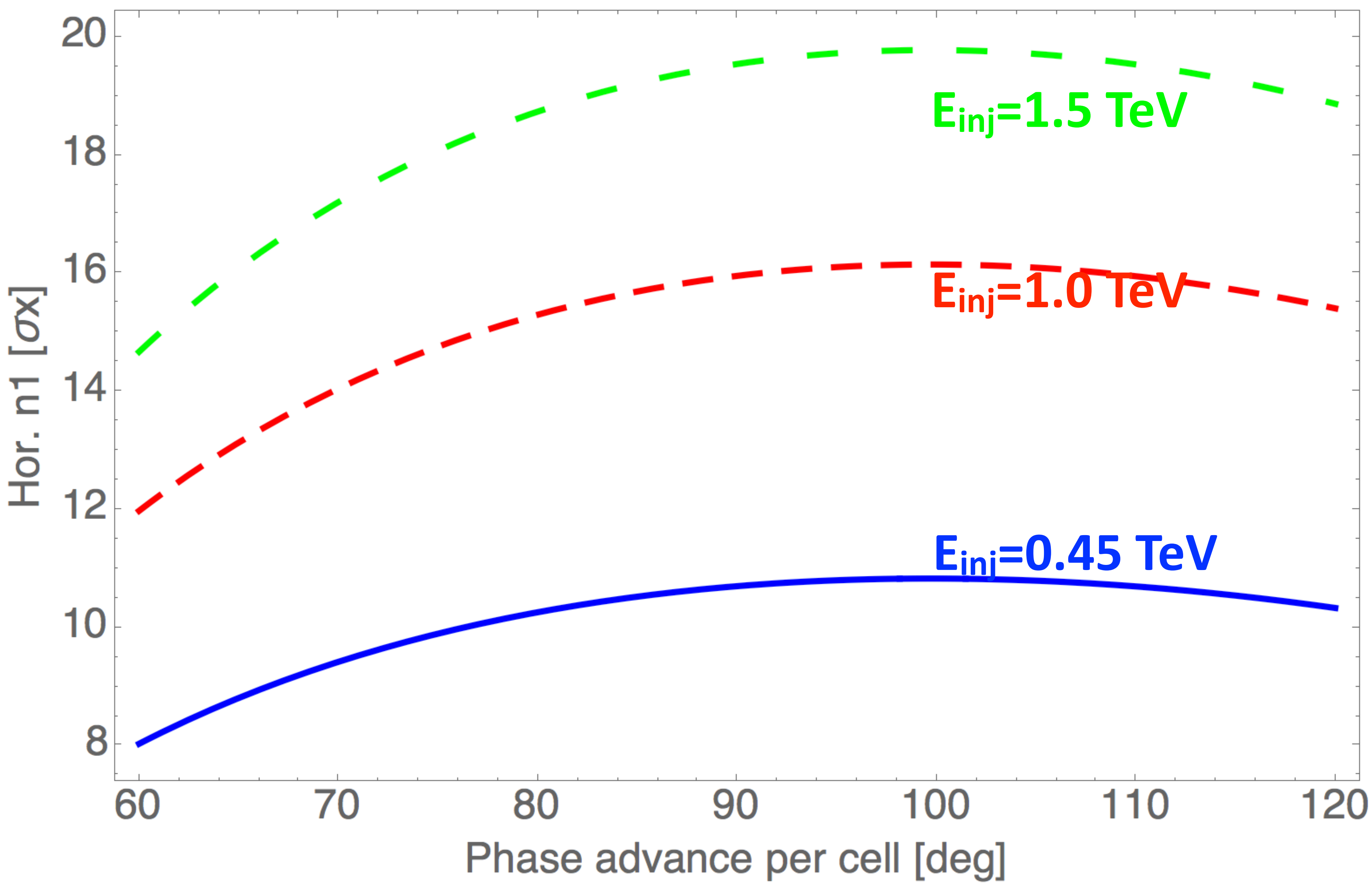
- **LHC beam screen: L_x=22 mm**
- **t_x=(2+1) mm, f_{arc}=0.14, δ_p=8.6*10^{-4}, ε_x=2.5 µm, k_β=1.05**
- **n1=10.6/12.9/13.3 @60/80/90 deg @E_{inj}=0.45 TeV**



2. Comparison of various lattices

➤ Check n1 at QF for 18-cell arcs

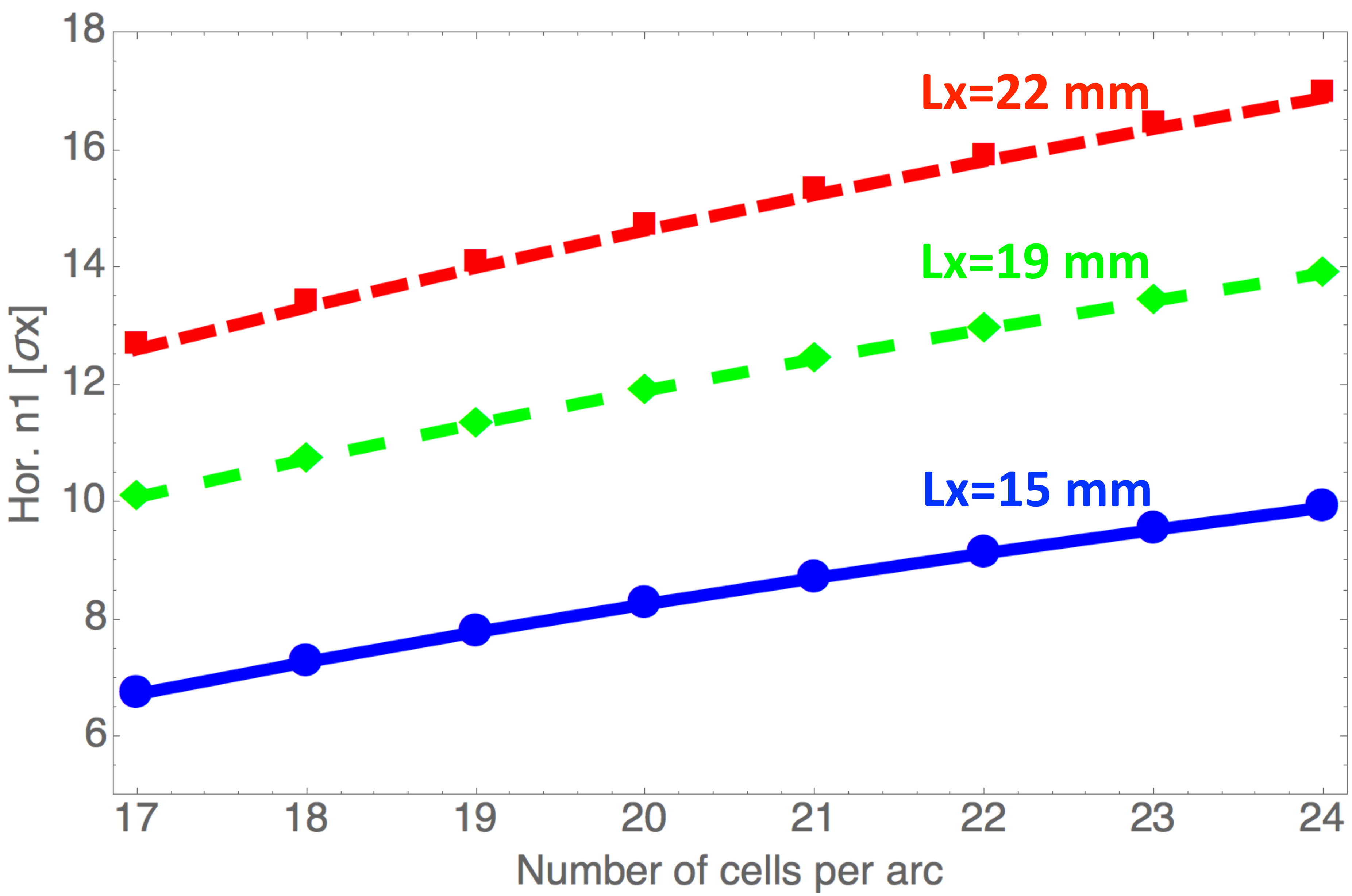
- Scaled LHC beam screen: L_x=19 mm
- t_x=(2+1) mm, f_{arc}=0.14, δ_p=8.6*10^{-4}, ε_x=2.5 µm, k_β=1.05
- n1=8.0/10.3/10.7 @60/80/90 deg @E_{inj}=0.45 TeV



2. Comparison of various lattices

➤ Check n1 at QF for N-cell arcs

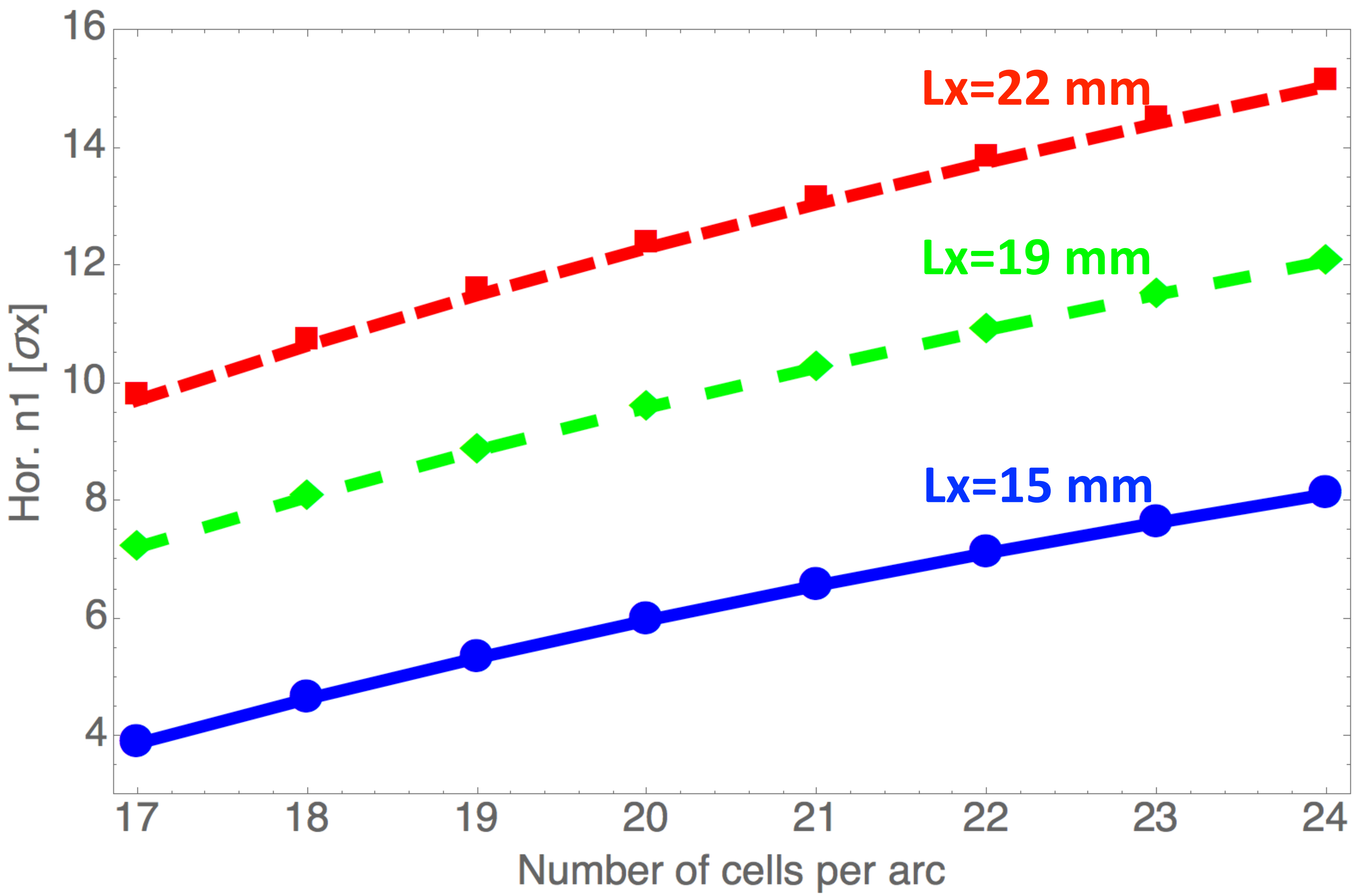
- Phase advance per cell: 90 deg [Assume fixed arc length: 2460 m]
- t_x=(2+1) mm, f_{arc}=0.14, δ_p=8.6*10^{-4}, ε_x=2.5 μm, k_β=1.05



2. Comparison of various lattices

➤ Check n1 at QF for N-cell arcs

- Phase advance per cell: 60 deg [Assume fixed arc length: 2460 m]
- t_x=(2+1) mm, f_{arc}=0.14, δ_p=8.6*10^{-4}, ε_x=2.5 µm, k_β=1.05



2. Comparison of various lattices

➤ Check n1 at QF in arcs

- **Further gain could be achieved by:**
  - * controlling COD distortion and mechanical misalignment: 3 => 2 mm?
  - * Reducing injection beam emittance: 2.5 => 1.5 μm?
  - * Increasing injection beam energy: 0.45 => 1 TeV?

3. Summary and future plan

➤ Lattice files and tools for HE-LHC

● Thanks to Thys' excellent work, full lattice files in madx format are available now

● Thanks to Thys and Michael Hofer, tuning tools are available now

➤ Toward an optics baseline for HE-LHC

● Upgrade of IRs: see Leon's talk

● Installation of tuning magnets, collision optics, optics corrections with errors, etc.: see Michael's talk

● 18x60 (poor n1 in arcs) and 24x60 (strong dipole field) rolled out?

● 18x90 lattice as the baseline?

 * Good DA: see Yuri's talk for the first comparison

 * Good margins for magnet strengths in arcs

 * Good matching to IRs (?)

 * Ring geometry needs to be improved? Possible?

 * n1 in arcs is good enough?

3. Summary and future plan

➤ Toward an optics baseline for HE-LHC (cont'd)

- 17x90 and 20x90 as the optional choices?
  - * 17x90 by Thys: Good fit to LHC geometry
  - * 20x90: better n1 in arcs, but need improvement in geometry?

➤ Future plan

- Further optics tuning and announce optics versions periodically for collaborators
- Detailed DA simulations and optimizations with errors
- Request and feedback from collaborative groups