Possible layout for arc cells of HE-LHC

Demin Zhou and Yuri Nosochkov

Acknowledgements:

M. Benedikt, M. Crouch, R. De Maria, S. Fartoukh, M. Giovannozzi, M. Hofer, P. Martinez, K. Oide, T. Risselada, L. Riesen-Haupt, D. Sagan, D. Schoerling, R. Tomas, P. Thrane, E. Todesco, D. Tommasini, F. Zimmermann

18th HE-LHC design meeting, CERN, Aug. 22, 2017

1. Possible layouts for the arcs of HE-LHC

➤ Arcs designed by Y. Nosochkov

- **18x 60-deg (helhc_v102)**
- **20x 90-deg (helhc_v201) [Almost given up because of poor geometry fit to LHC layout]**
- **18x 80-deg (helhc_v300) [Preserve resonance cancelation condition: 4x2π]**

➤ Possible modifications using the same layout of helhc_v102

- **18x 90-deg [Preserve resonance cancelation condition if considering DS as a 90-deg cell: 4x2π => Add sextuples to DSs, similar as LHC]**

1. Possible layouts for the arcs of HE-LHC

➤ Integration of various arcs with IRs of SLHC3.1a by Thys

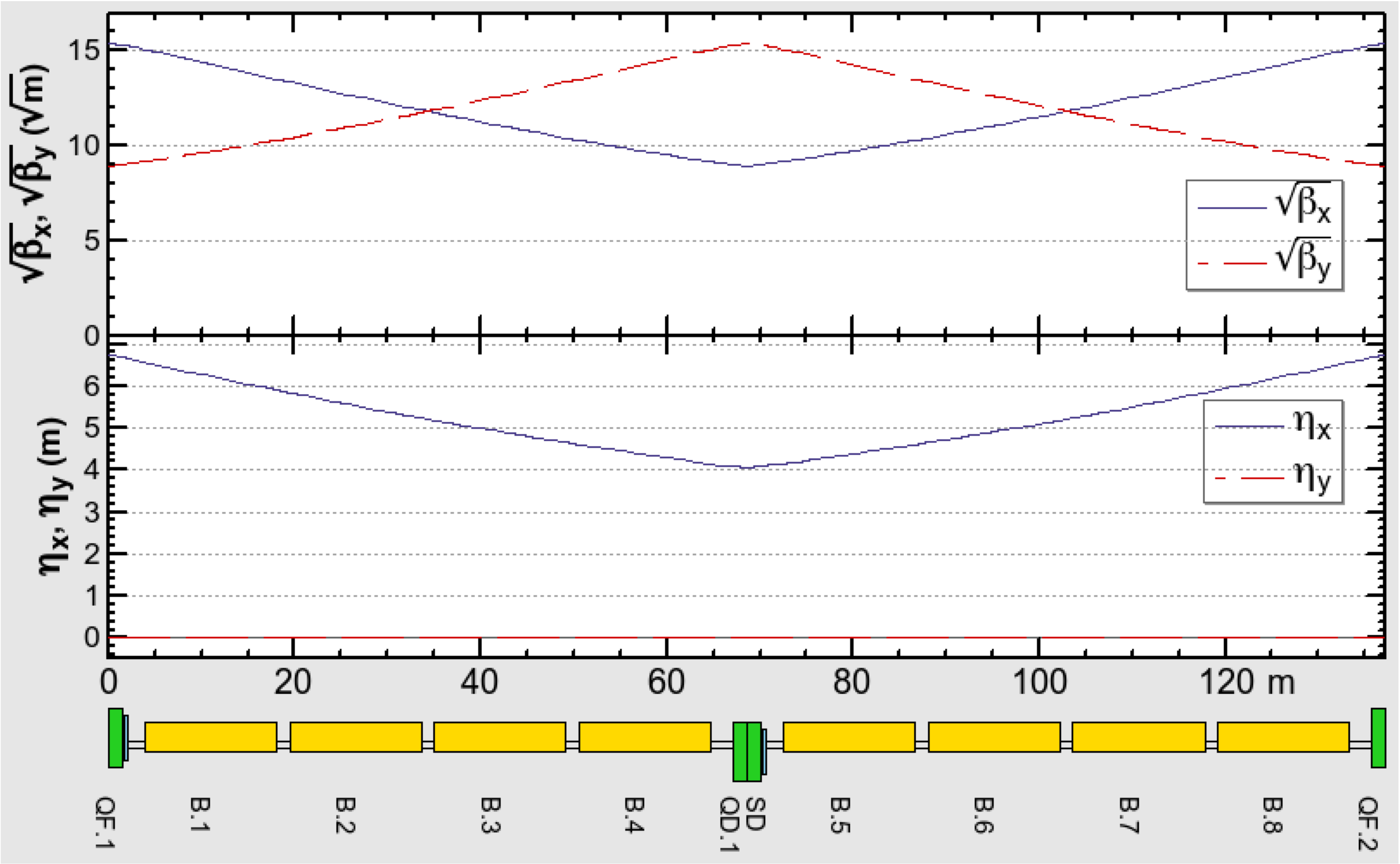
- **Official directory: /afs/cern.ch/eng/lhc/optics/HELHC**

```
-rw-r--r--. 1 riss si 292099 Jul 23 12:05 merged_HE-LHC.17x90_tr.seq
-rw-r--r--. 1 riss si  10276 Jul 30 10:13 merged_HE-LHC.17x90_tr.str
-rw-r--r--. 1 riss si 274907 Jul  9 16:44 merged_HE-LHC.18x60_tr.seq
-rw-r--r--. 1 riss si  10276 Jul 11 12:16 merged_HE-LHC.18x60_tr.str
-rw-r--r--. 1 riss si 295747 Jul  9 17:05 merged_HE-LHC.18x60_v102.seq
-rw-r--r--. 1 riss si  10278 Jul 11 12:19 merged_HE-LHC.18x60_v102.str
-rw-r--r--. 1 riss si 302843 Jul 11 10:41 merged_HE-LHC.20x90_v200_5657.seq
-rw-r--r--. 1 riss si  10283 Jul 28 10:31 merged_HE-LHC.20x90_v200_5657.str
-rw-r--r--. 1 riss si 303290 Jul 24 22:13 merged_HE-LHC.20x90_v201.seq
-rw-r--r--. 1 riss si  10278 Jul 28 11:32 merged_HE-LHC.20x90_v201.str
-rw-r--r--. 1 riss si 377354 May 20 15:35 merged_HE-LHC.seq
-rw-r--r--. 1 riss si   6515 May 19 17:11 merged_HE-LHC.str
```

1. Possible layouts for the arcs of HE-LHC

➤ 18x 60-deg (helhc_v102 by Y.N.)

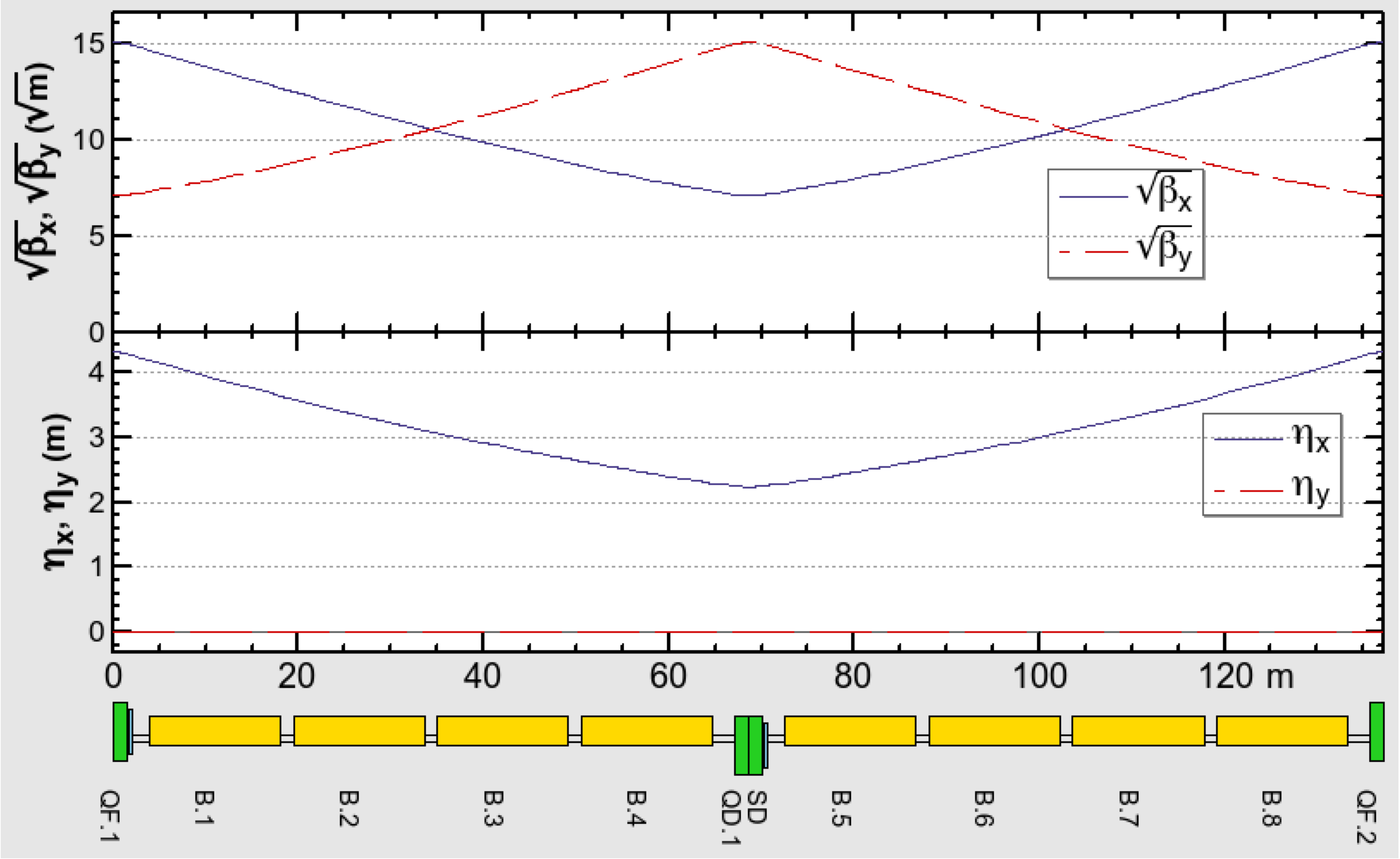
- LB=14.18m, LQ=3.1m, LS=0.369m
- LBQ=2.358m, LSB=1.829m, LQS=0.16m, LBB=1.36m



1. Possible layouts for the arcs of HE-LHC

➤ 18x 80-deg (helhc_v300 by Y.N.)

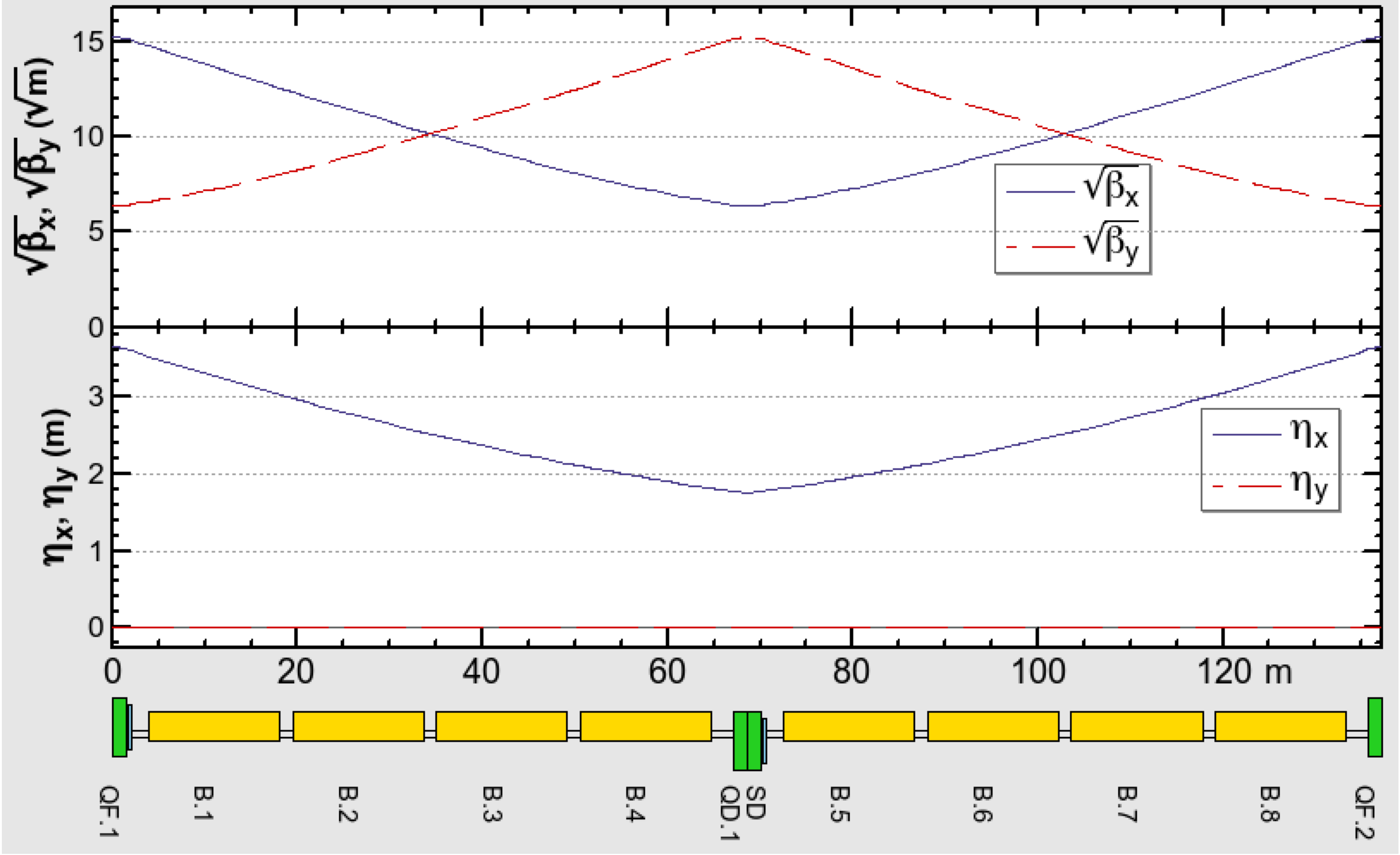
- LB=14.18m, LQ=3.1m, LS=0.369m
- LBQ=2.358m, LSB=1.829m, LQS=0.16m, LBB=1.36m
- Same geometry of helhc_v102



1. Possible layouts for the arcs of HE-LHC

➤ 18x 90-deg

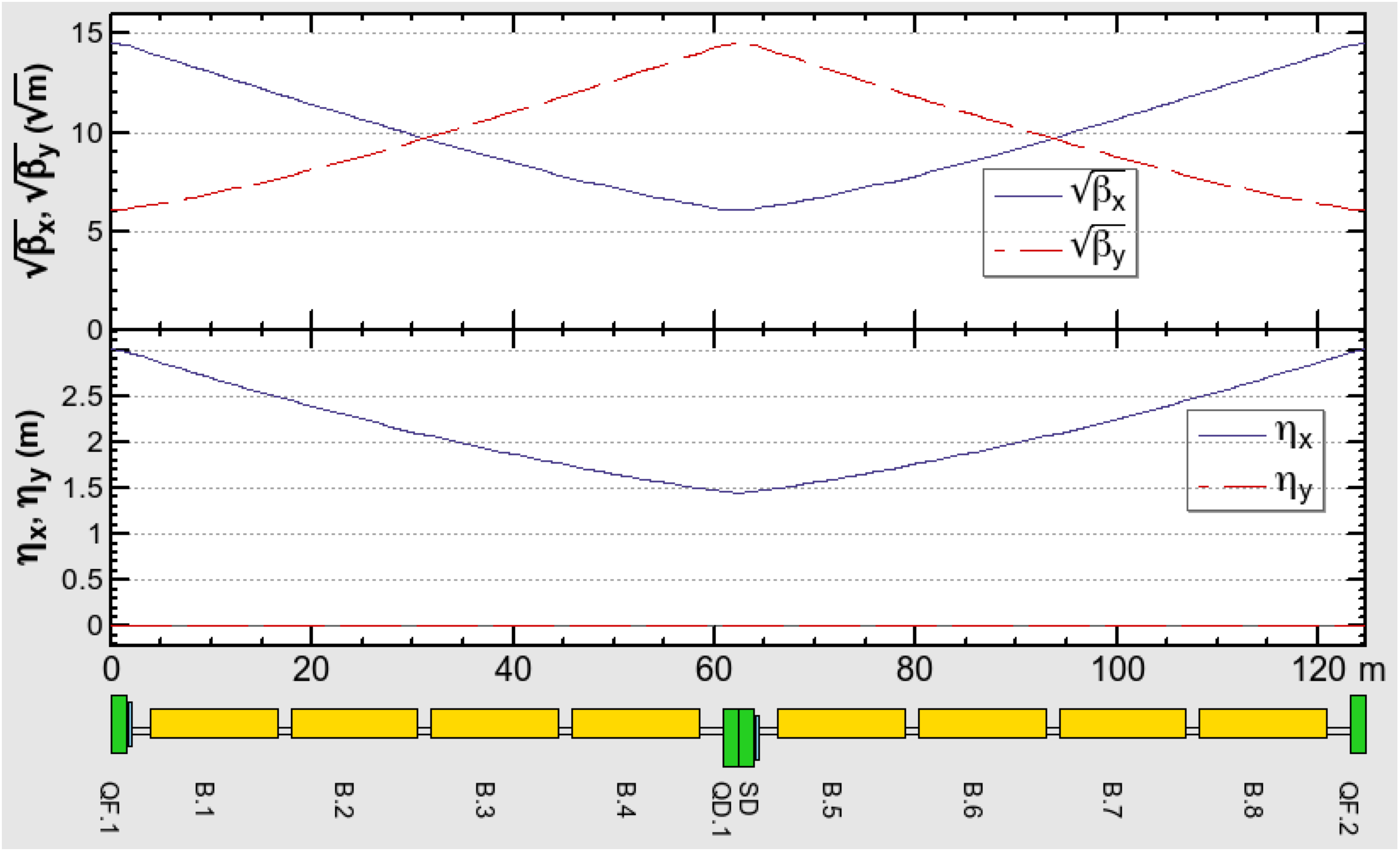
- LB=14.18m, LQ=3.1m, LS=0.369m
- LBQ=2.358m, LSB=1.829m, LQS=0.16m, LBB=1.36m
- Same geometry of helhc_v102



1. Possible layouts for the arcs of HE-LHC

➤ 20x 90-deg

- LB=12.625m, LQ=3.1m, LS=0.369m
- LBQ=2.36m, LSB=1.831m, LQS=0.16m, LBB=1.36m



1. Possible layouts for the arcs of HE-LHC

➤ FCC tech: 16 T@B, 400 T/m@Q, 7800 T/m²@S

	LHC-like	18x60⁰	18x80⁰	18x90⁰	20x90⁰
Arc cell phase advance [deg]	90/90	60/60	80/80	90/90	90/90
Arc cell length [m]	106.958	137.233			124.8
K1 [m^{-1}]	0.027	0.0148	0.019	0.021	0.023
$\beta_{max/min}$ [m]	181.3/31.5	236.7/79.5	227.7/50.0	233.0/40.4	211.7/36.8
$\eta_{max/min}$ [m]	2.2/1.1	6.7/4.1	4.3/2.2	3.6/1.8	3.0/1.5
Dipole length [m]	14.3 [x6]	14.18 [x8]			12.625 [x8]
Dipole field [T] @13.5TeV	16.06	15.59			15.92
Quad. gradient [T/m] @13.5TeV	391.7	214.8	276.2	303.9	334.7
Sext. gradient [T/m²] @13.5TeV	4883	866	1824	?	2940
Filling factor	0.802	0.827			0.809

1. Possible layouts for the arcs of HE-LHC

➤ General scaling laws

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

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

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

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

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

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

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

1. Possible layouts for the arcs of HE-LHC

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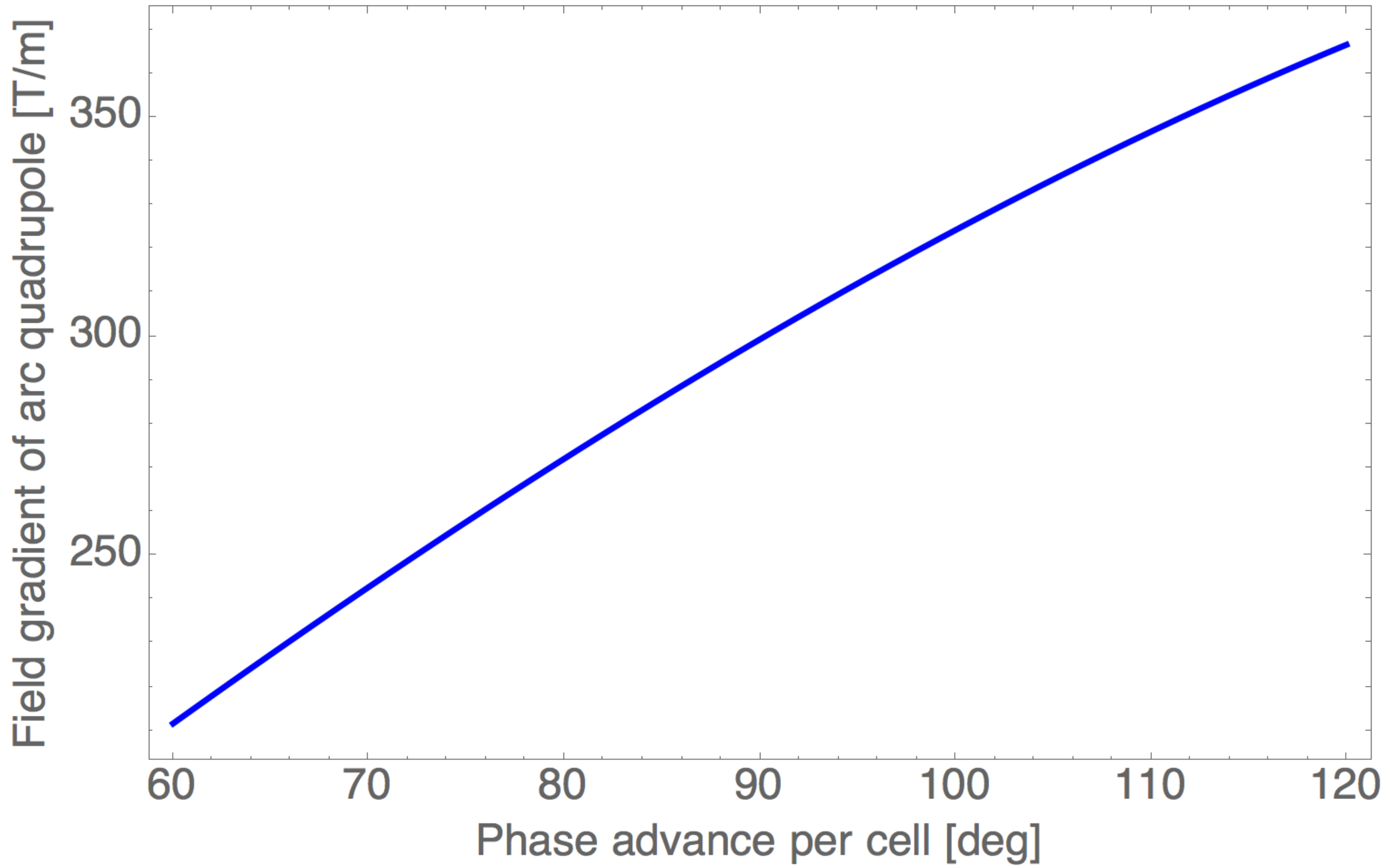
- **Assume ideal FODO cell [thin-lens, 100% filling factor]**
- **Use 18x60 layout:**

L_{cell}=137.233 m, L_Q=3.1 m, L_B=L_{cell}/2, L_S=0.369 m, E=13.5 TeV



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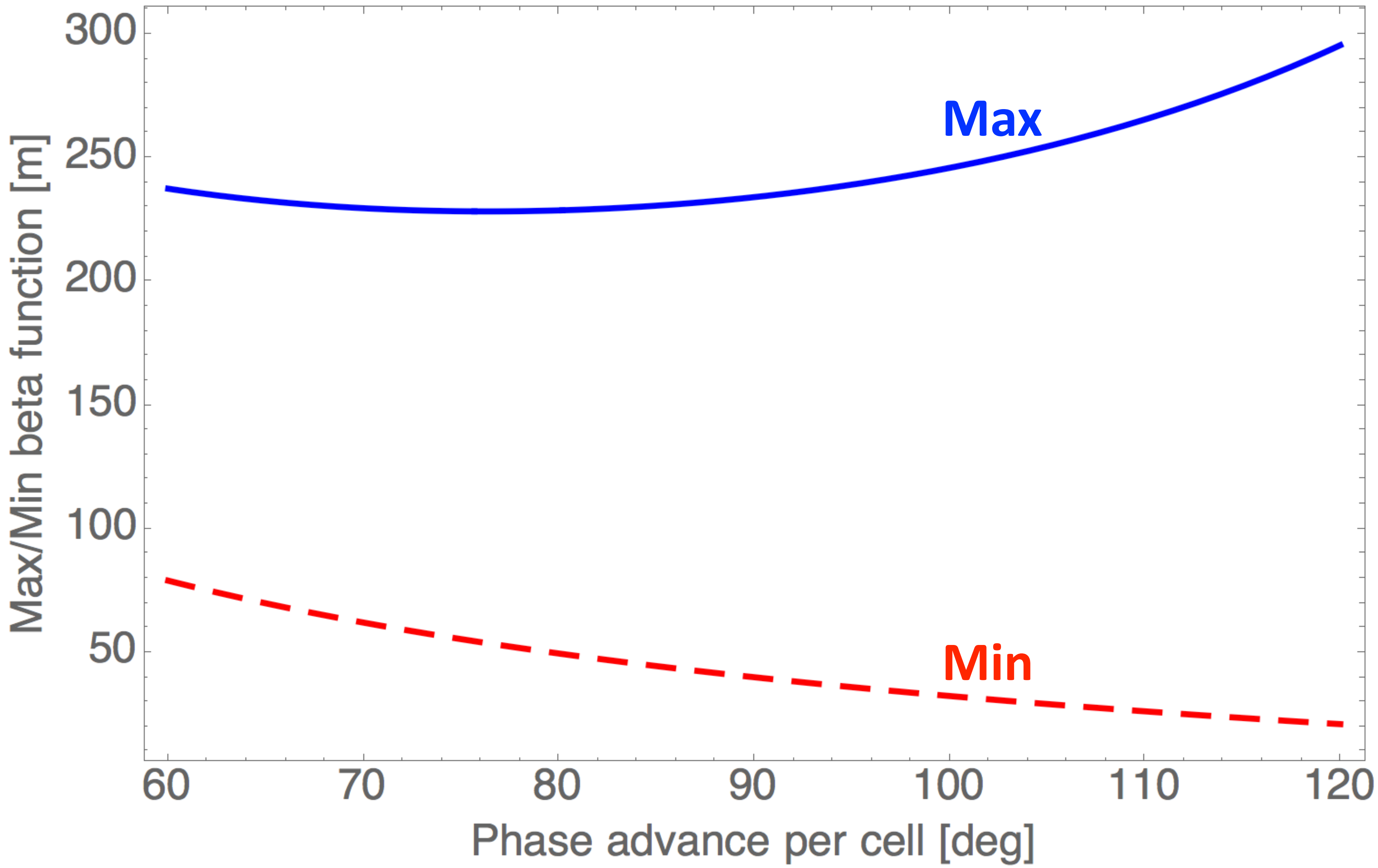

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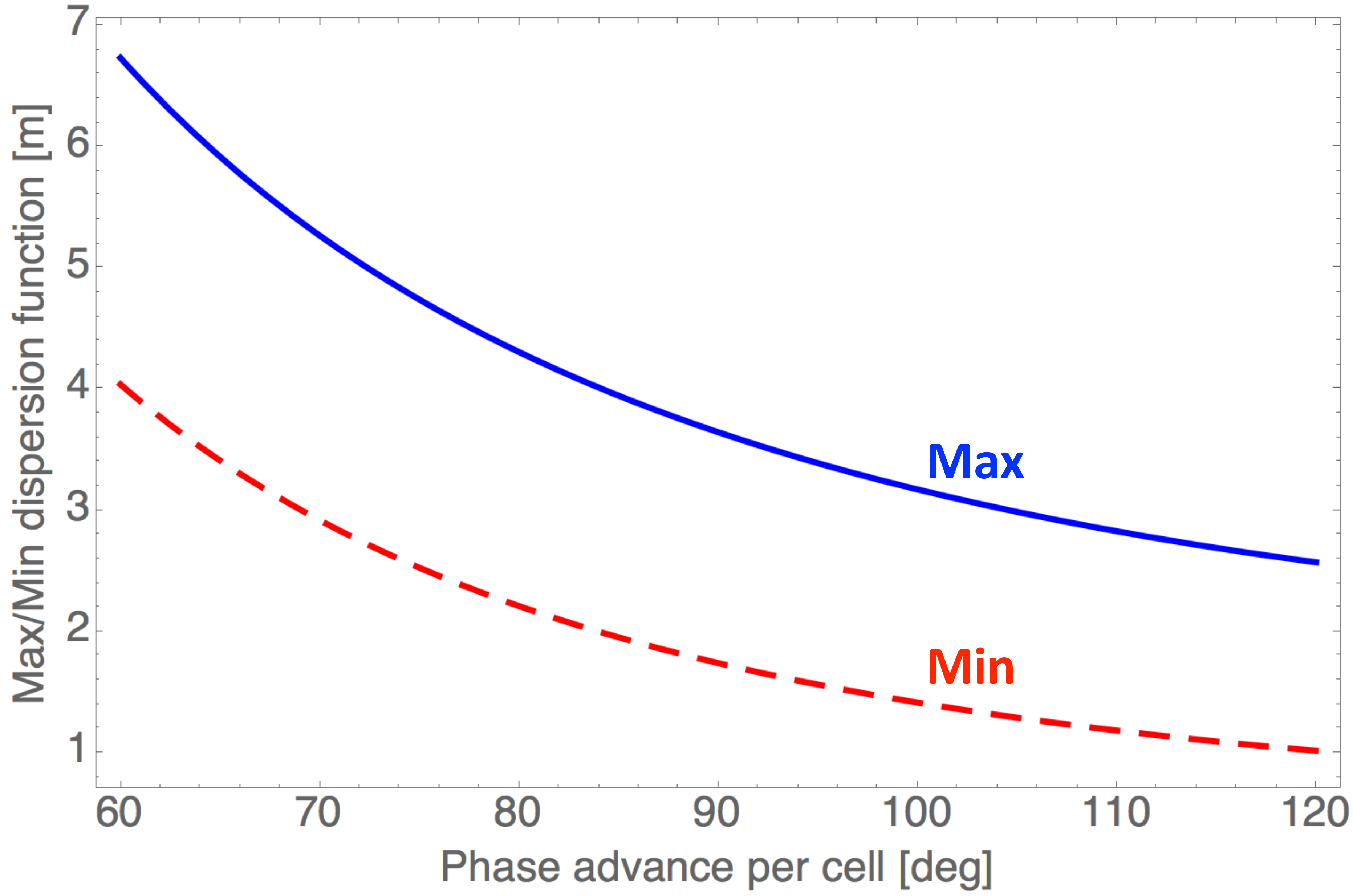

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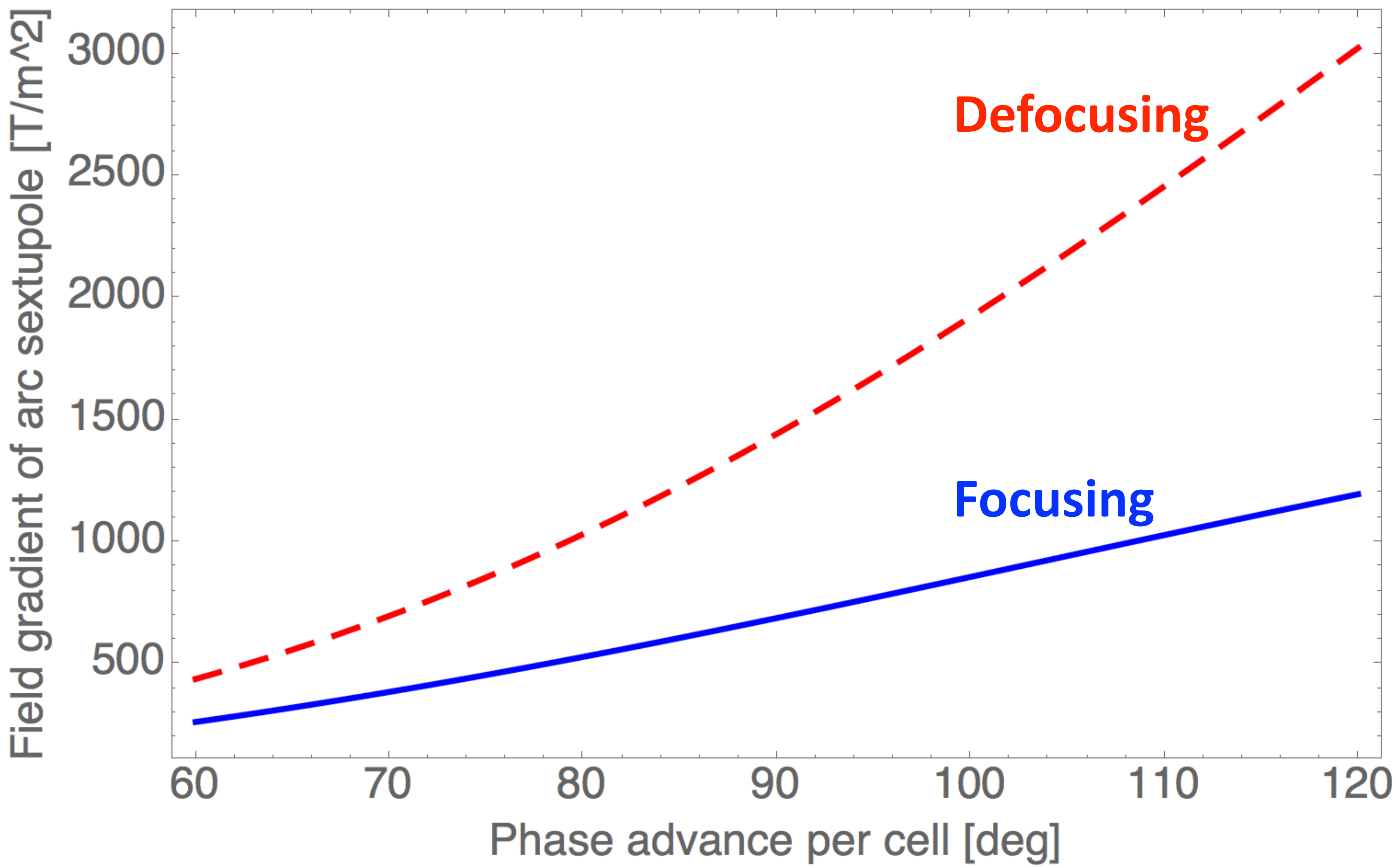

1. Possible layouts for the arcs of HE-LHC

➤ 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]:**

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

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

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

1. Possible layouts for the arcs of HE-LHC

➤ Check n1 at QF

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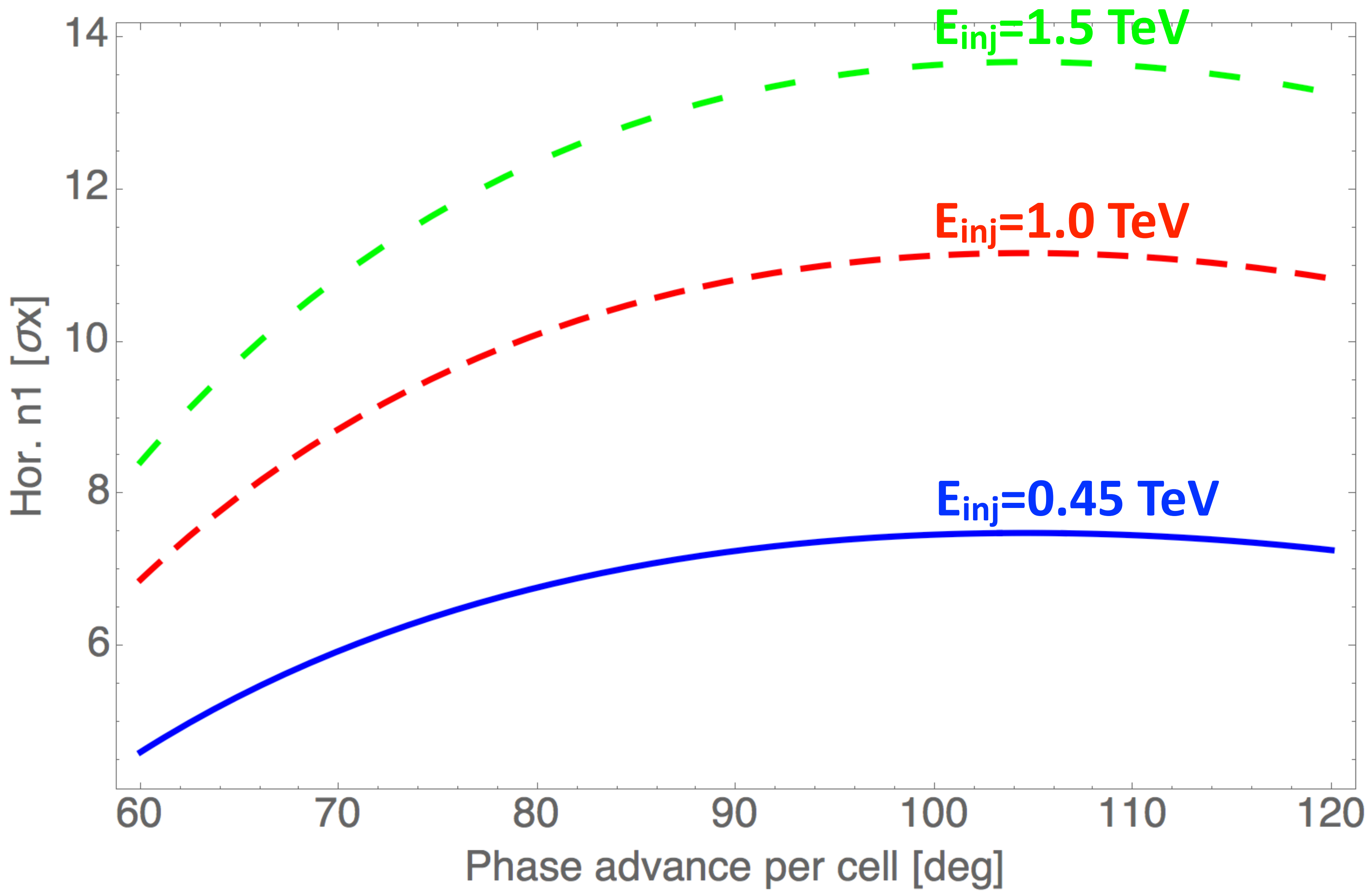

1. Possible layouts for the arcs of HE-LHC

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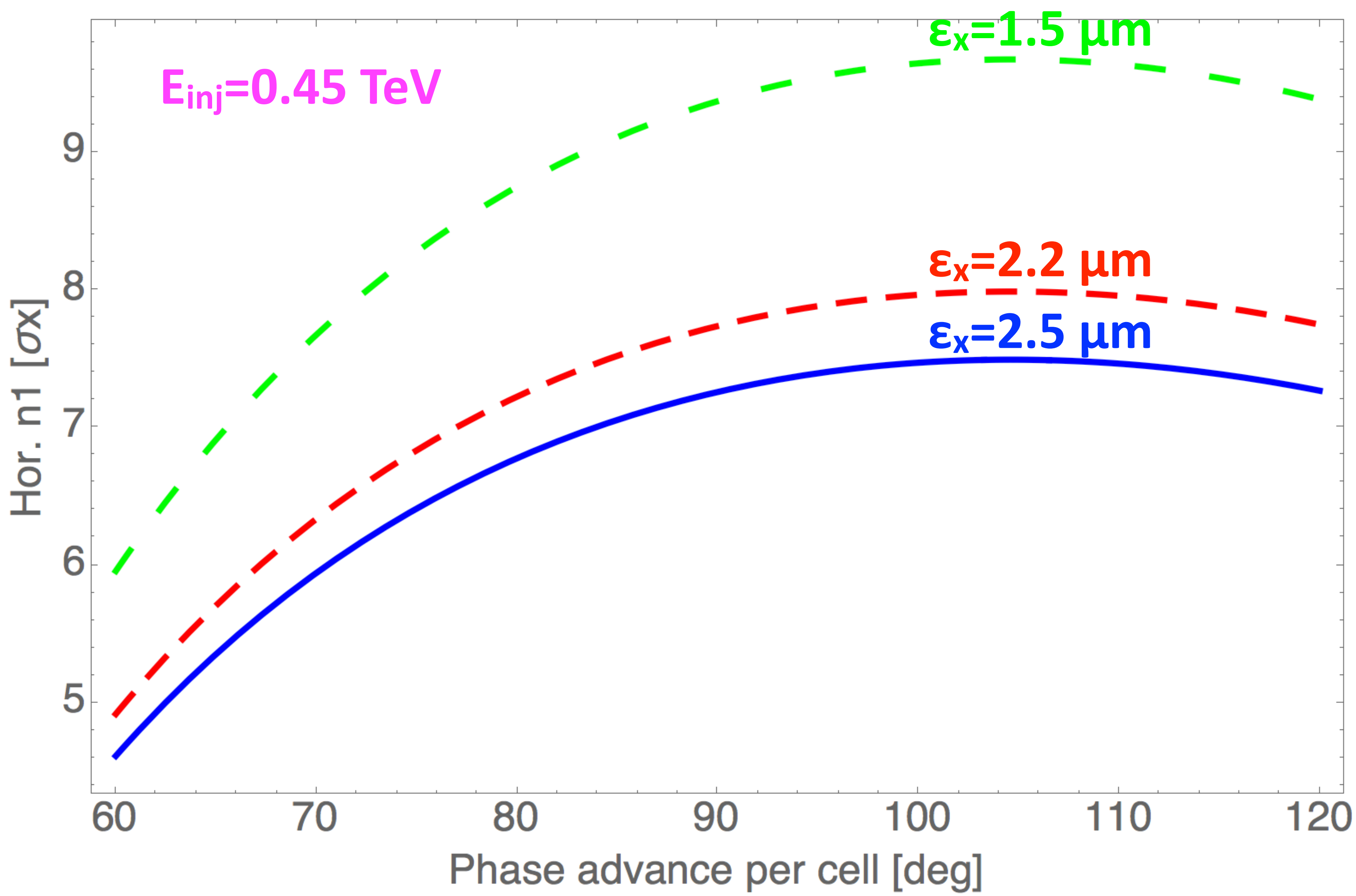

2. Summary

➤ "1-D" aperture n1

- In arcs, the limit in n1 is at QF [Maximum β_x and η_x]
- Very sensitive to dispersion function in arcs
- Inversely proportional to $[\varepsilon_x/E_{inj}]^{1/2}$
- Using nominal parameters of HE-LHC, n1=4.6/6.8/7.3 for 60/80/90 deg per cell with the 18-cell arc layout
- Open question: What is the minimum n1 for HE-LHC arcs, if we trust the simple "1-D" formula?

3. Strategy for HE-LHC design

➤ Task distribution

- Arc cells and DSs
- IR1 and IR5: Main experiment IRs
- IR3 and IR7: collimation
- IR4 and IR6: RF and beam dump
- Full lattice: Global matching&optimization/chromaticity correction/toolkits
- Beam-beam issues
- Collective effects
- … …

3. Strategy for HE-LHC design

➤ Iterative design process

- Step 1: Create arc cells, adjust DSs, matching to SLHC IRs [respect to LHC geometry]
- Step 2: IR design/update, repeat Step 1
- Step 3: Global matching&optimization/chromaticity correction
- Step 4: DA calculations with errors
- Step 5: Check challenges (technical and beam physics), if hit show-stopper, restart from Step 1
- Step 6: Collimation and other sub-system design/update (electron lens, crab cavity, etc.)

3. Strategy for HE-LHC design

➤ **Two series of meetings**

➤ **Design meeting: roughly every two weeks**

- **Overview of optics design**
- **Infrastructure**
- **Hardware, technologies, etc.**
- **Acc. physics-hardware "interfaces"**
- **…**

➤ **Optics meeting: tentatively weekly**

- **Focus on accelerator physics**
- **Optics design of arcs and IRs**
- **Optics matching/tuning/optimization**
- **Acc. physics simulations**
- **… …**