Status of the IR optics design for the 10 TeV Muon Collider

Kyriacos Skoufaris and **Christian Carli**

Special thanks to D. Calzolari, A. Lechner, K. Oide, P. Raimondi, D. Schulte and R. Tomas

21-June-2023

Outline

- Earlier Versions Recap (v0.4 & v0.5)
- Current 10TeV Muon Collider (v0.6)
  - Final Focusing Quads
  - Chromatic Correction & Matching Sections
- New Under Development Collider (v0.7)
- Summary

10TeV Muon Collider

TABLE I. 10 TeV center of mass energy muon collider.

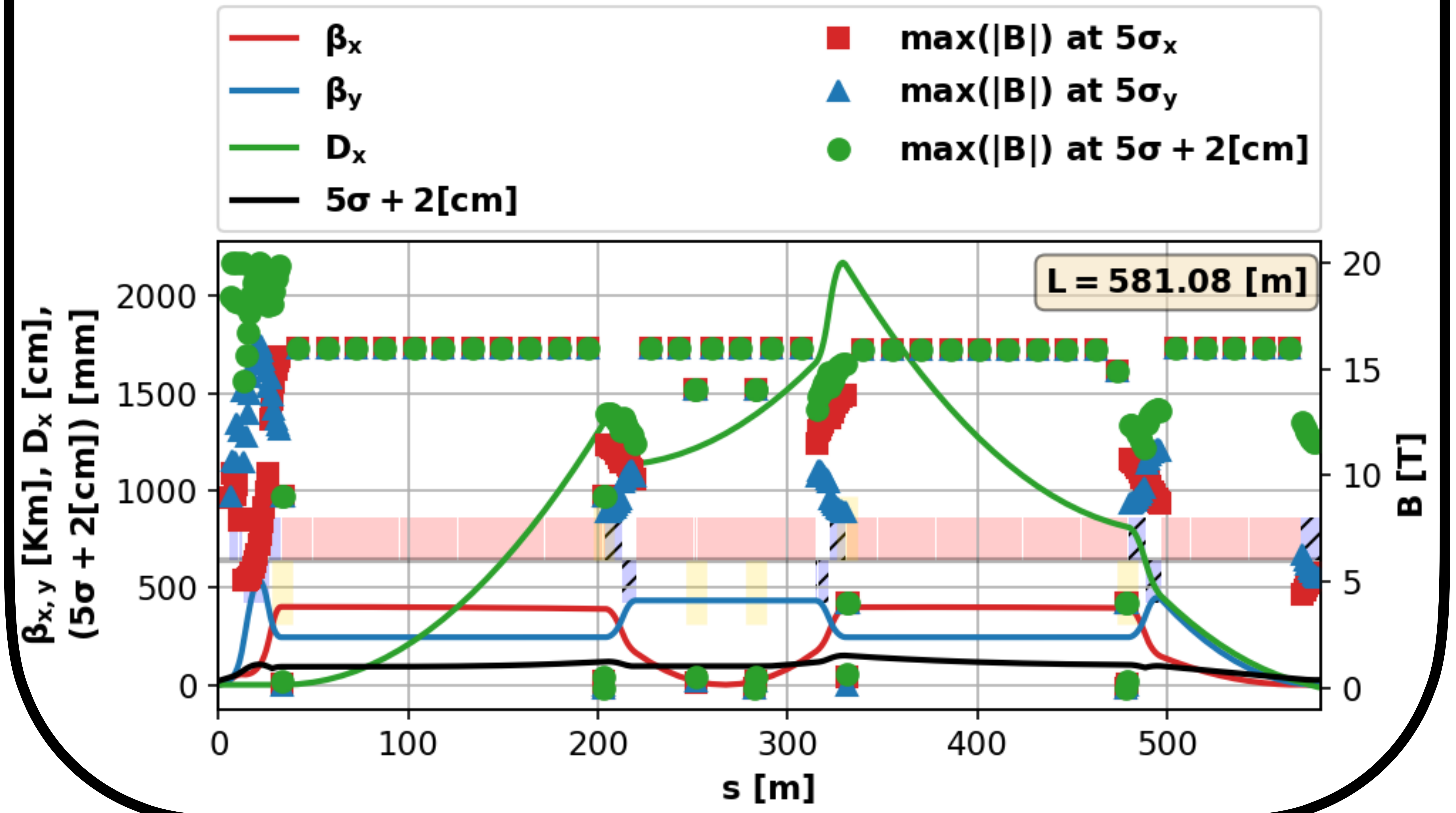
Parameters	Symbol	Unit	10TeV com mc
Particle energy	E	GeV	5000
Particle momentum	P_0	GeV c^{-1}	5000
Luminosity per IP	$\mathcal{L}$	10^{34} cm^{-2} s^{-1}	20
Bunch population	N_p	10^{12}	1.8
Transverse normalized rms emittance	$\varepsilon_{nx} = \varepsilon_{ny}$	μm	25
Transverse geometric rms emittance	$\varepsilon_{gx} = \varepsilon_{gy}$	nm	0.528
Longitudinal emittance ($4\pi\ \sigma_E\ \sigma_T$)	ε_l	eVs	0.314
Longitudinal geometric emittance ($\frac{\varepsilon_l c}{4\pi E_{0\mu}}$)	ε_{lg}	mm	70
Rms bunch length	σ_z	mm	1.5
Relative rms energy spread	δ	%	0.1
Beta function at IP	$\beta_x^\star = \beta_y^\star$	mm	1.5
Power per beam with 5 Hz repetition rate	P_{beam}	MW	7.2
Linear beam-beam tune shift per IP	ξ		0.078

10TeV Muon Collider **v0.4 & v0.5**
(Earlier designs)

10TeV Muon Collider - Extended Final Focusing

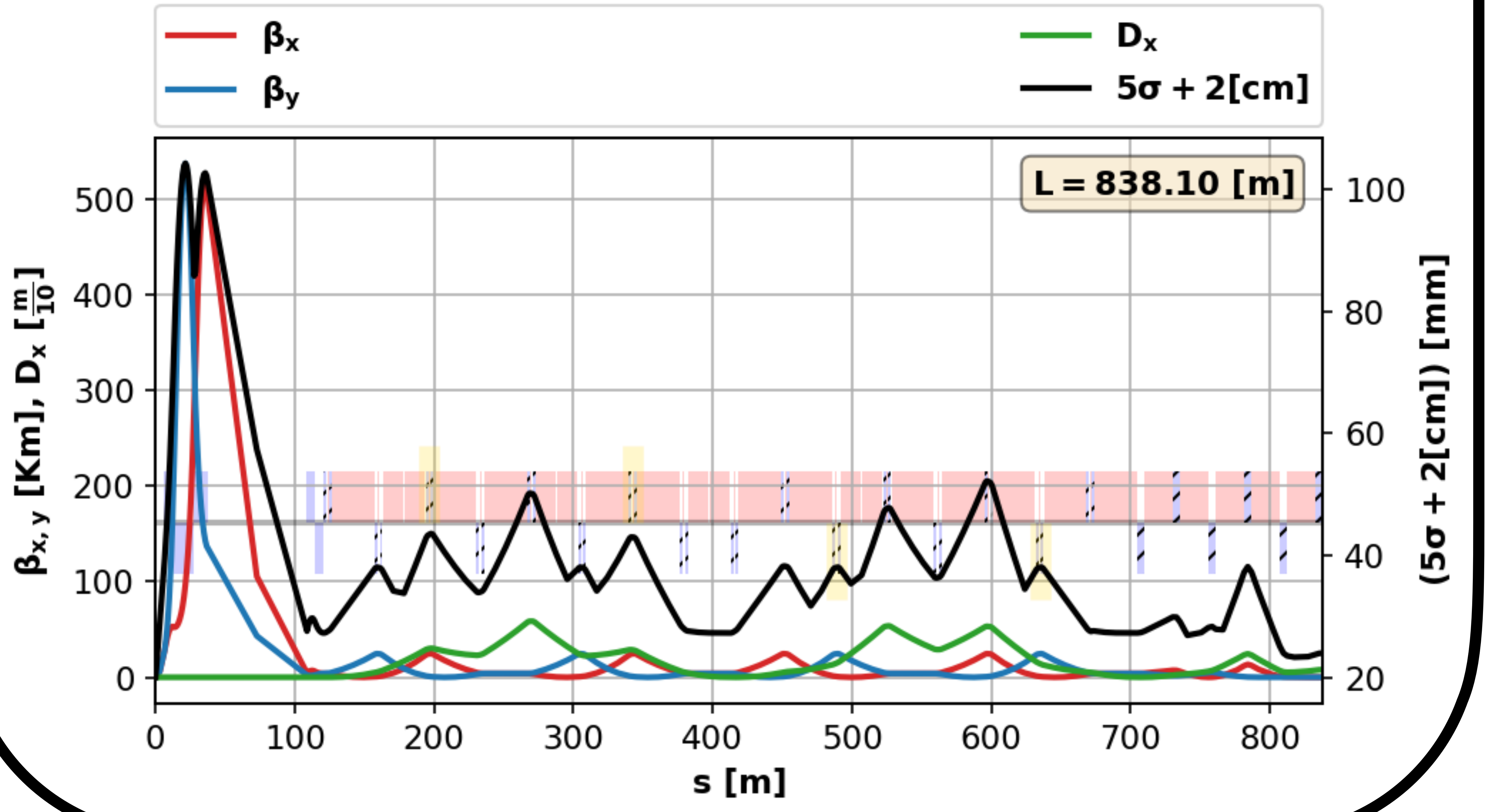
v0.4

- 3 doublets of dipole-sextuples
- use of I and -I transform between sextupoles of a given doublet
- 1m long dipole-sextupole with sextupolar components weaker than 0.2T



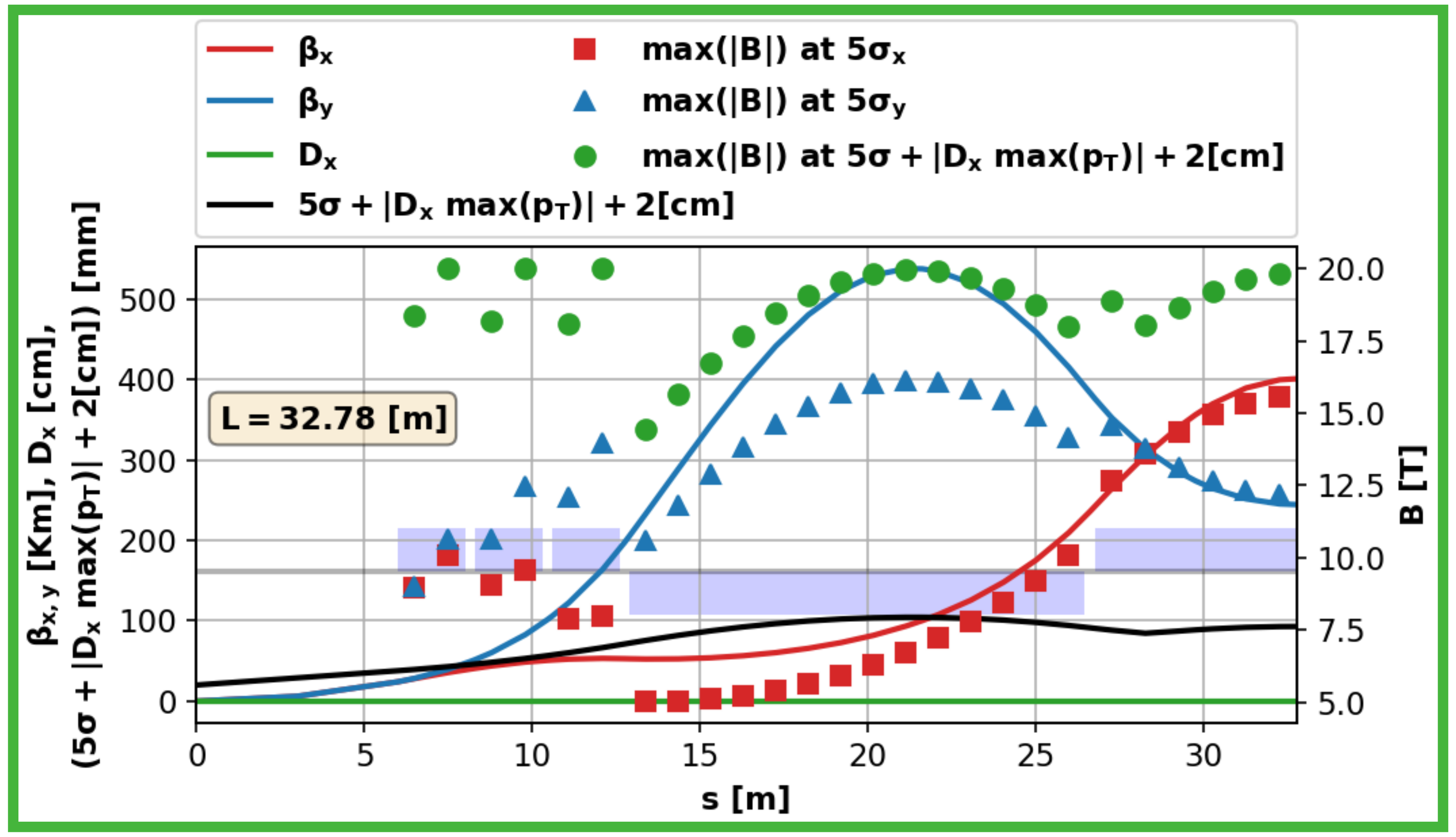
v0.5

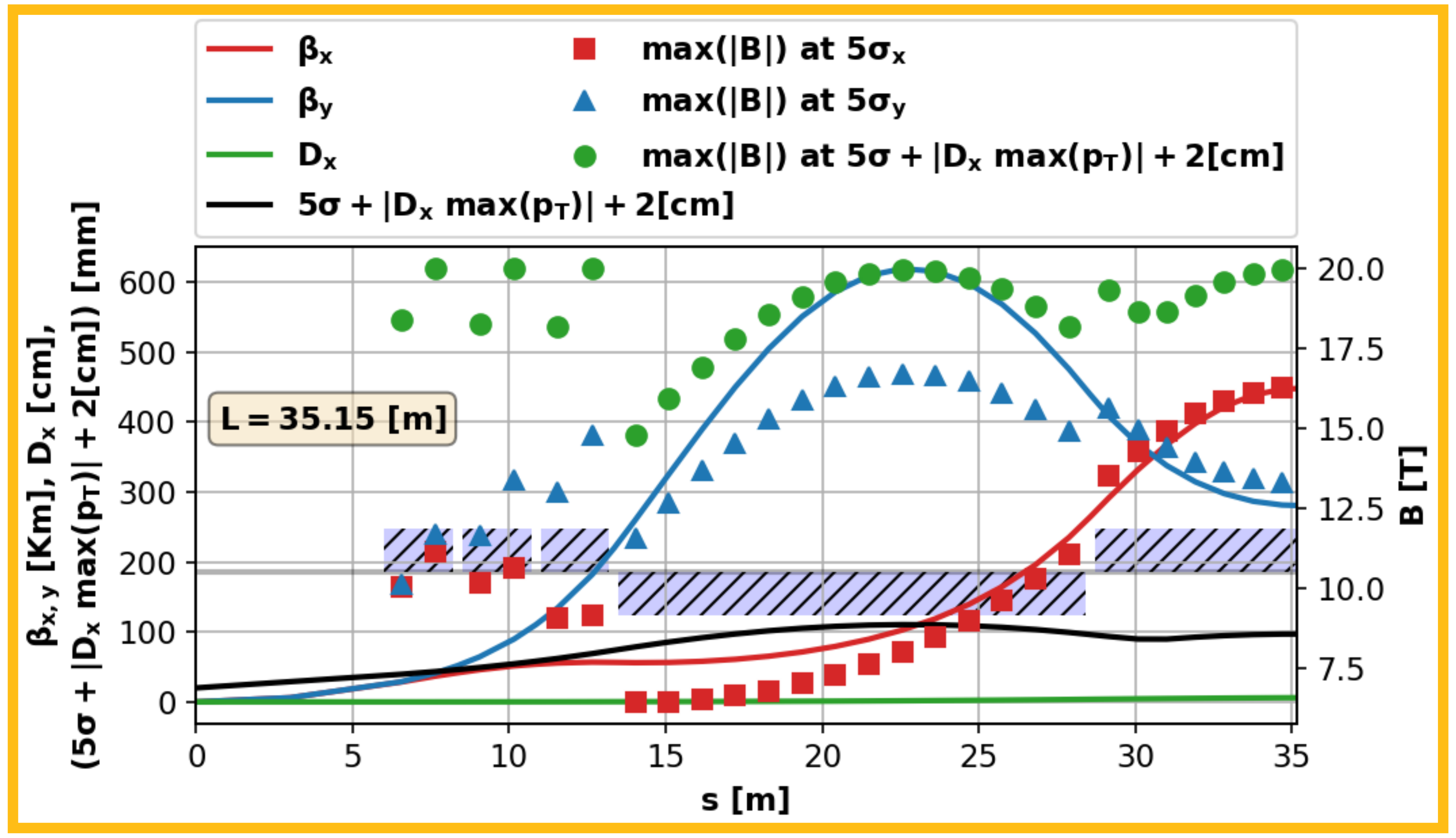
- 2 doublets of dipole-sextuples
- use of -I transform between sextupoles of a given doublet
- 1m long dipole-sextupole with dipolar components larger than 4T

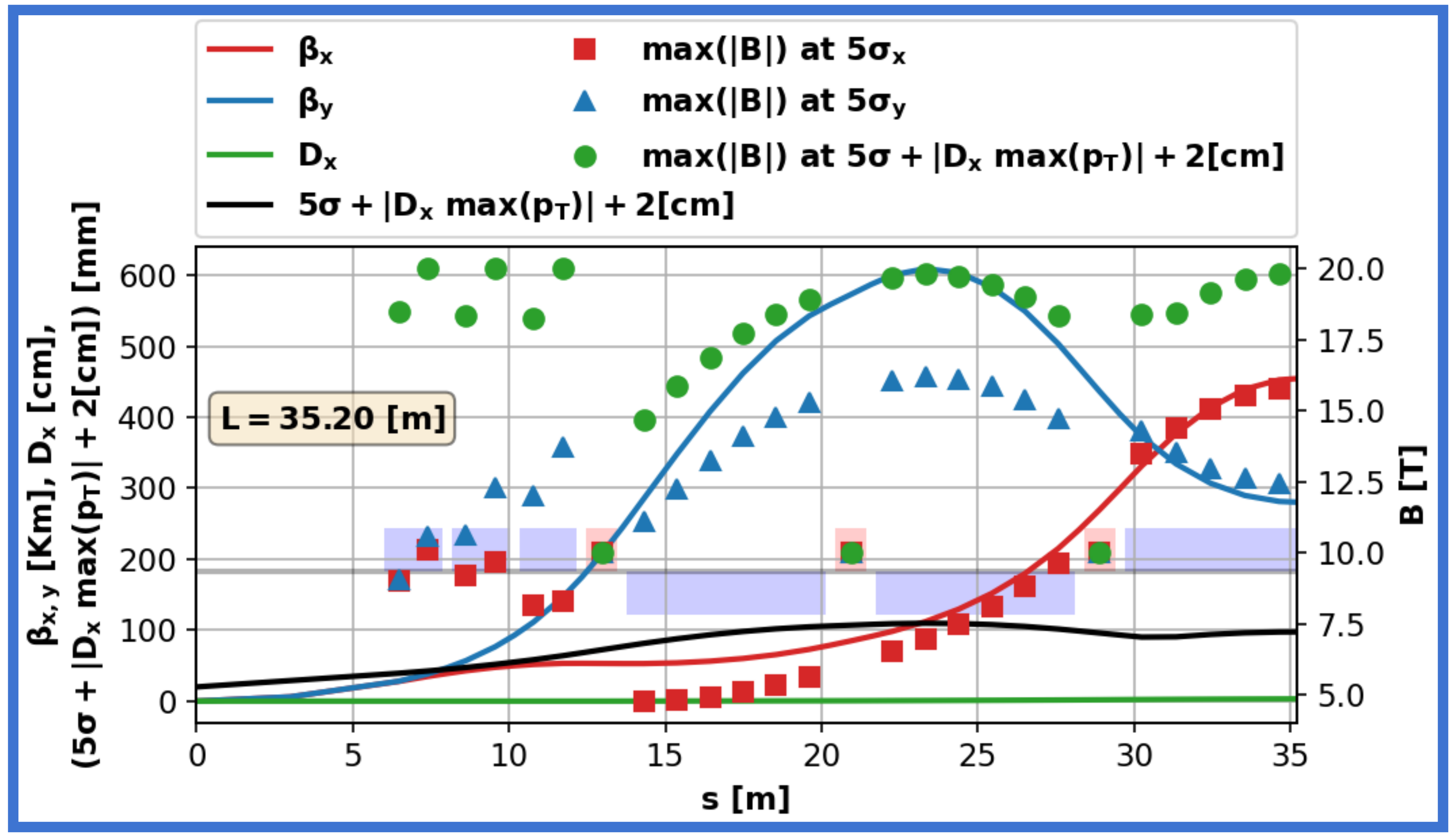


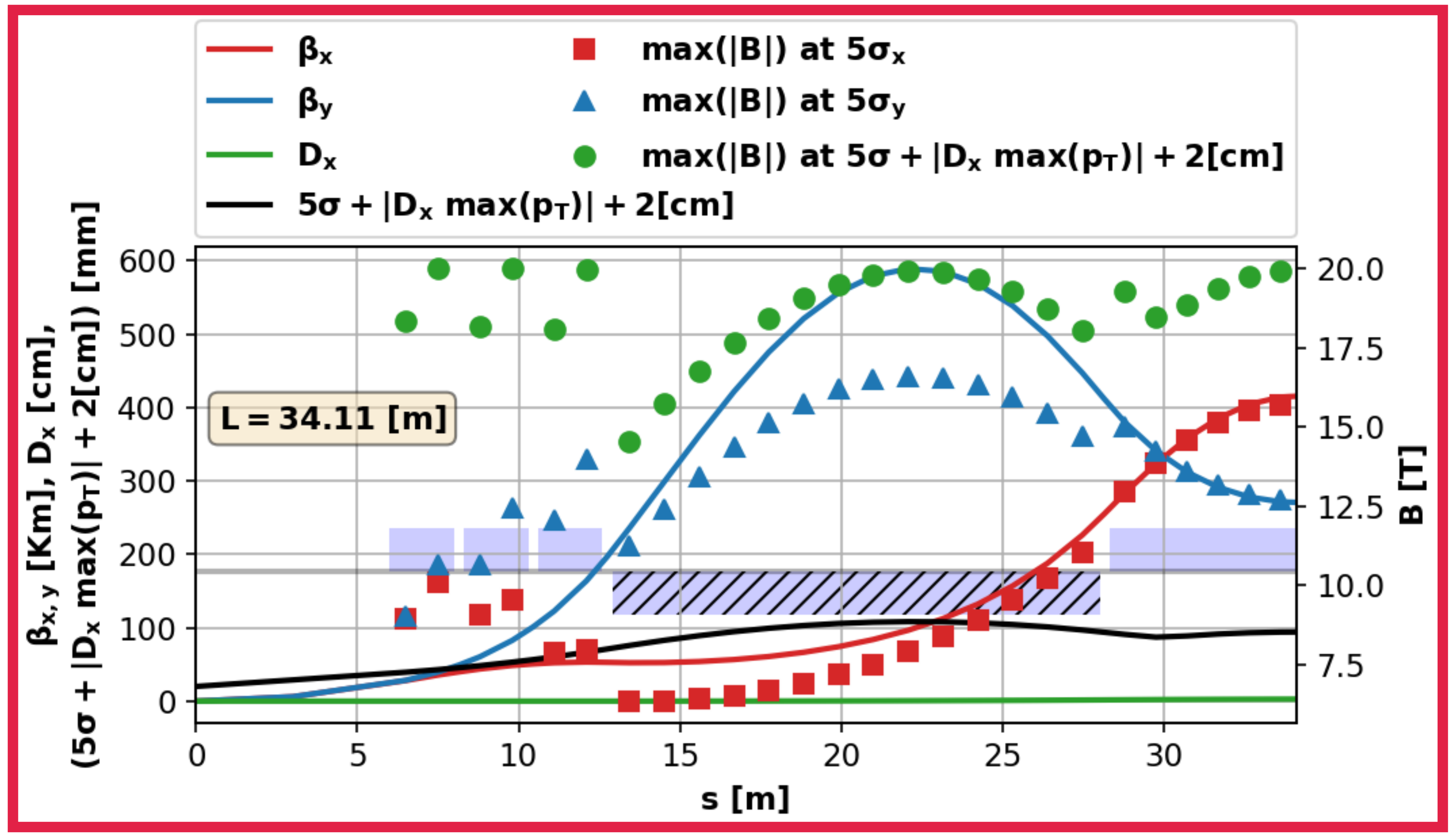
10TeV Muon Collider - Final Focusing Scheme v0.4

Due to muon decay along the interaction region, the Beam Induced Background (BIB) at the detectors area is significant thus in collaboration with the FLUKA team, the impact on BIB from the addition of dipolar components in the FF scheme is studied.



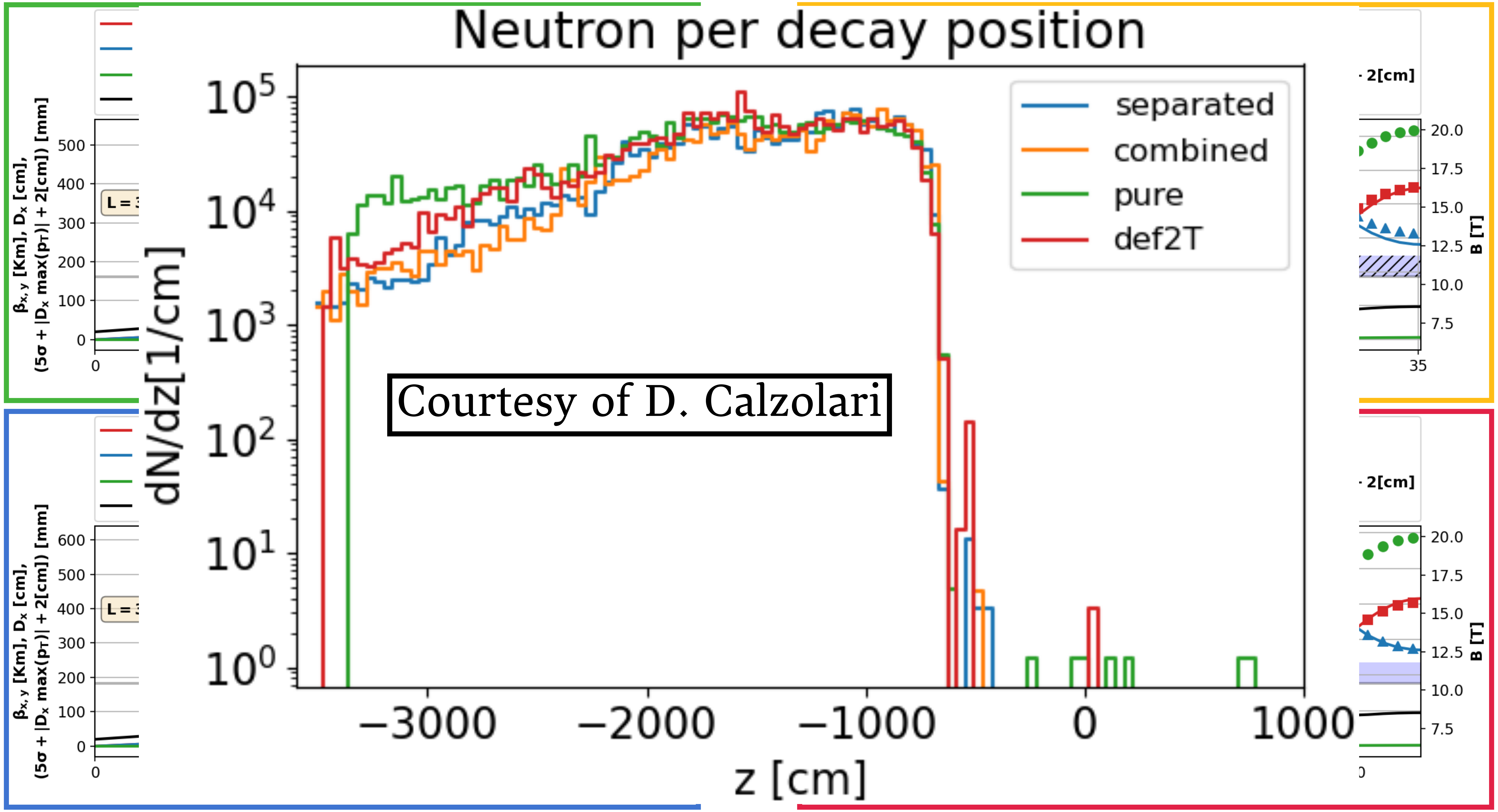






10TeV Muon Collider - Final Focusing Scheme v0.4

Due to muon decay along the interaction region, the Beam Induced Background (BIB) at the detectors area is significant thus in collaboration with the FLUKA team, the impact on BIB from the addition of dipolar components in the FF scheme is studied.

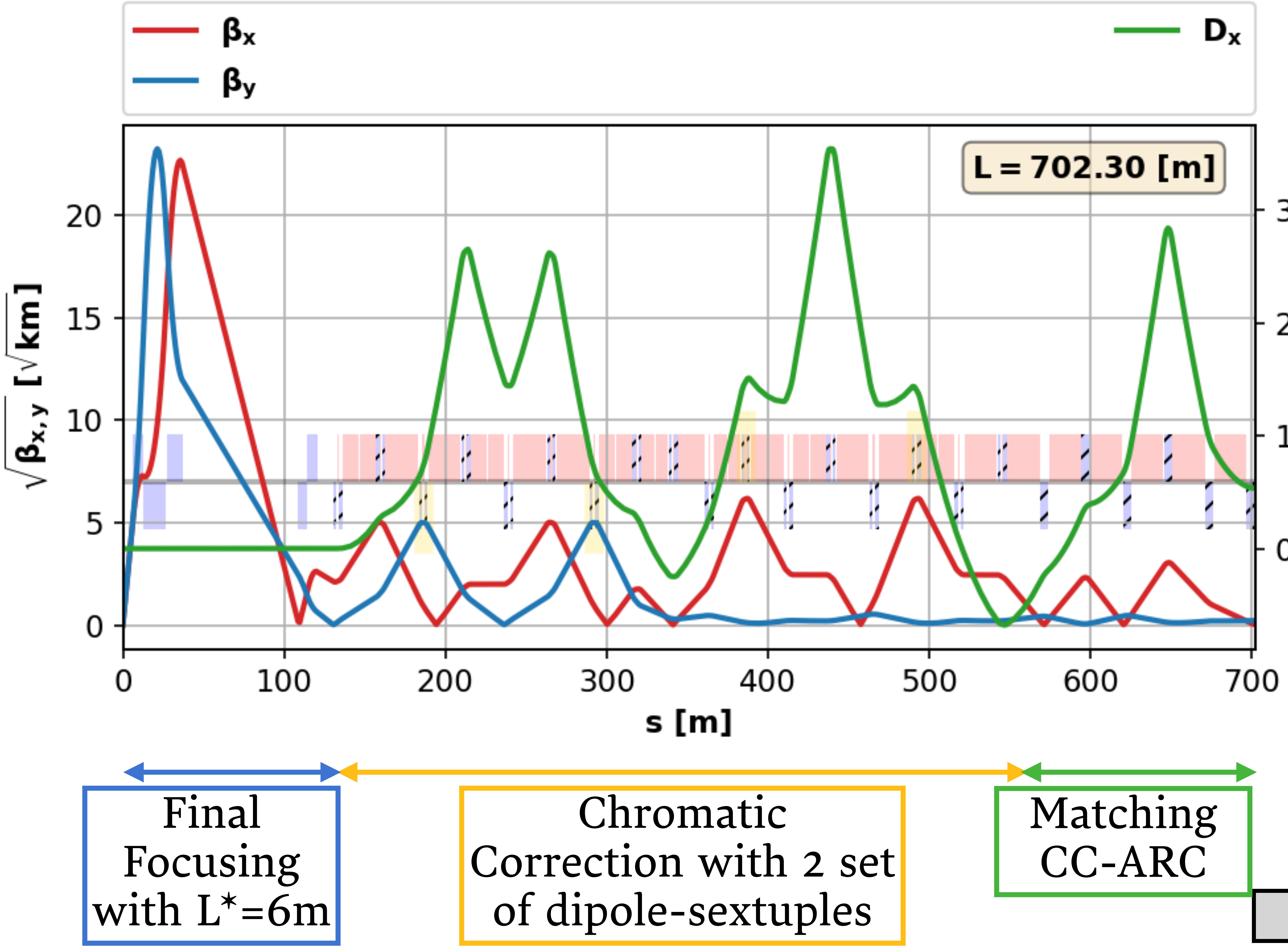


10TeV Muon Collider **v0.6**
(Current design)

10TeV Muon Collider - Extended Final Focusing

Colour code for lattice elements:

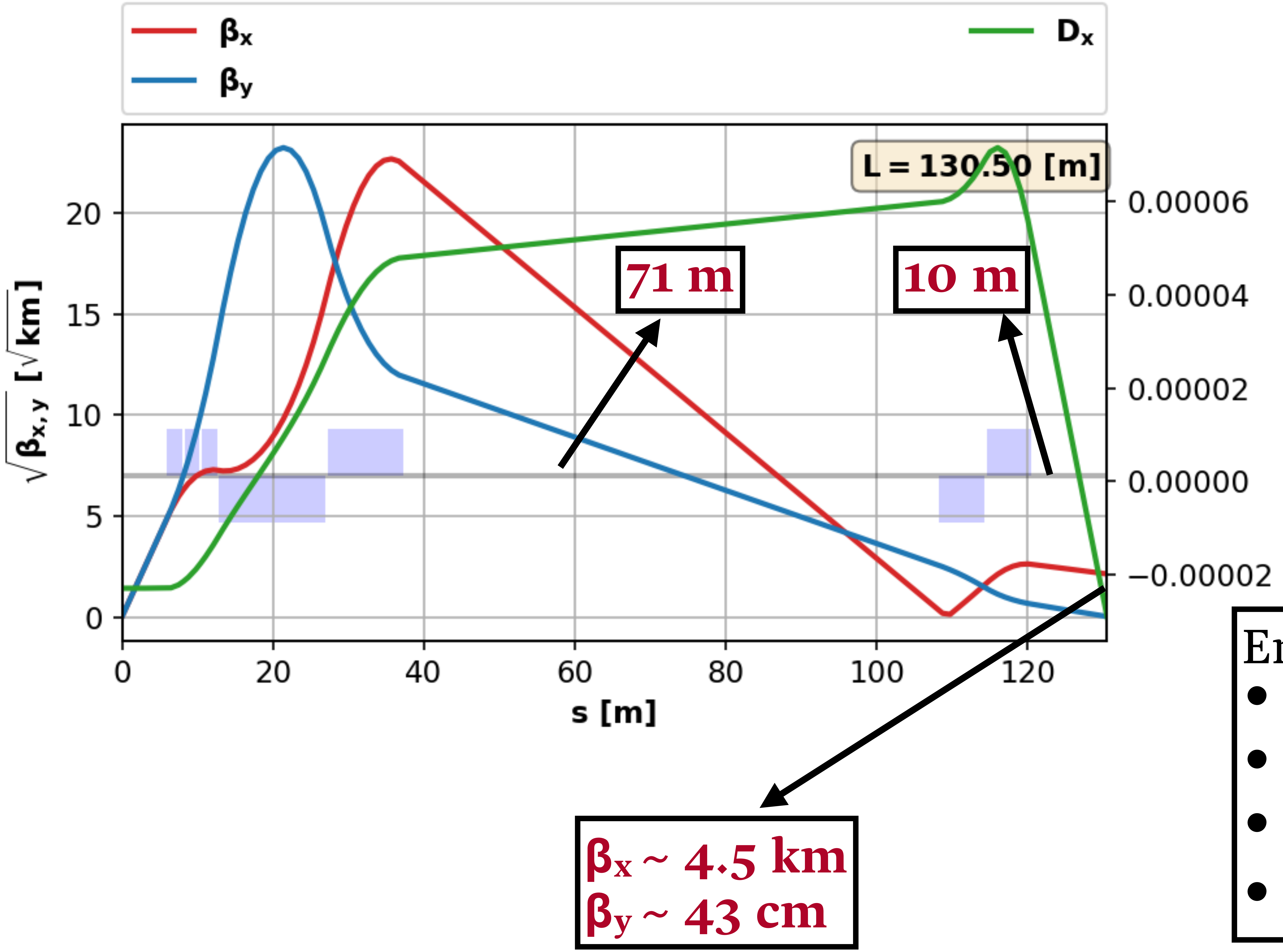
- Red dipoles
- Blue quadrupoles
- Hashed blue dipole-quadrupoles
- Red + Gold dipole-sextupoles (all 1m long)



10TeV Muon Collider - Final Focusing Quads

- $L^* = 6m$ and five quadrupoles are used.
- The maximum magnetic field at the magnet aperture is set to 20T.
- Due to the fast increase (decrease) of the β functions right after the IP, the first magnet is split in shorter ones with different gradient, reducing that way the length of the FF scheme.
- The $\beta_{x,y}$ are reduced by two order of magnitude at the end of the FF quads while the last four quadrupoles are used to control the $\beta_{x,y}$ and $\alpha_{x,y}$ in the chromatic correction section.
- Inclusion of a drift section for a smoother reduction/control of the beta values (β_x,β_y) at the end of the FF scheme. This help to keep the Montague chromatic functions at smaller values in the chromatic correction section.

10TeV Muon Collider - Final Focusing Quads



$$B\rho = 16678.205\ [Tm]$$

$$Aperture = 2(5\sigma + 0.02)\ [m]$$

$$\sigma_j = \sqrt{\frac{\beta_j \varepsilon_{nj}}{\beta_r \gamma_r} + (D_j \delta_p)^2}\ [m]\ with\ j = x, y$$

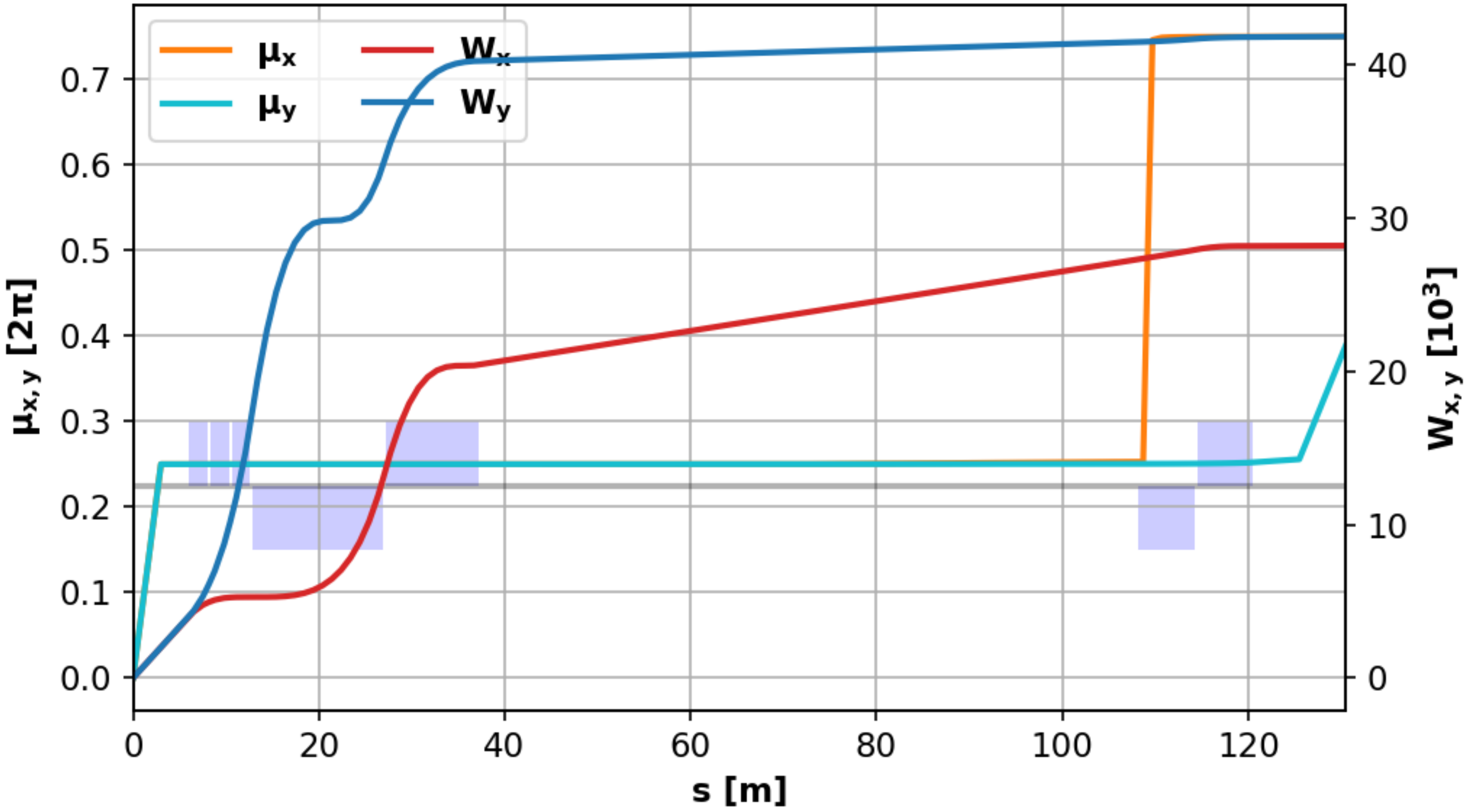
$$\sigma = max(\sigma_x, \sigma_y)\ [m]$$

Entering the CC with small βs:

- Smaller aperture
- Smaller Ws
- Smaller unwanted multipolar kicks
- Easier control of βs

10TeV Muon Collider - Final Focusing Quads

- Due to strong focusing quadrupoles (β^*=1.5mm), the Montague chromatic functions ($W_{x,y}$) that describe the optics perturbation for off-momentum particles w.r.t on-momentum one become very large.
- Together with the large momentum spread ($p_T=10^{-3}$), these W values indicate enormous chromatic effects that must be compensated, otherwise momentum acceptance orders of magnitude smaller than momentum spread.



10TeV Muon Collider - Chromatic Correction & Matching Schemes

- The maximum allowed magnetic field is assumed to be the 16T.

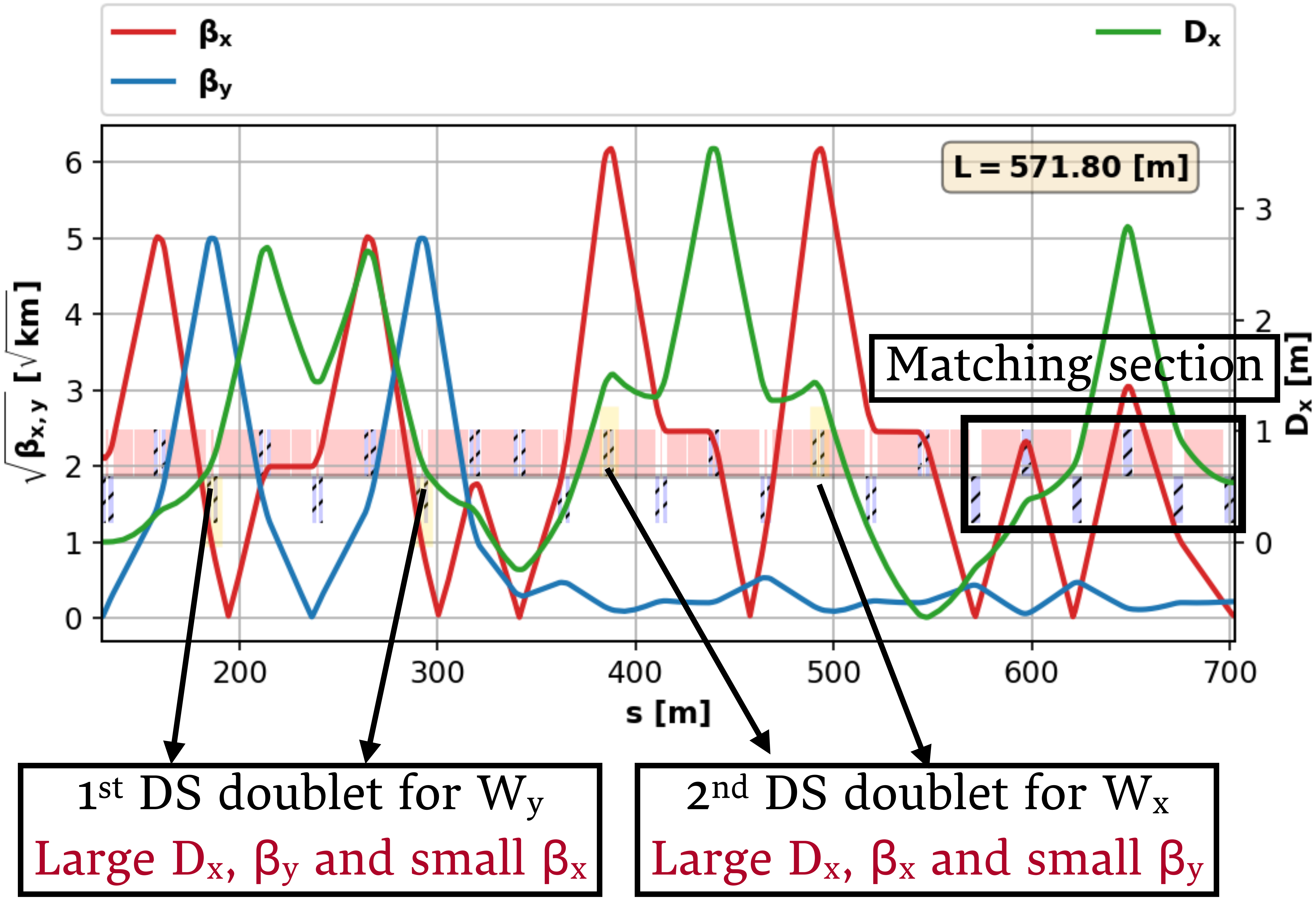
Chromatic Correction (CC) scheme

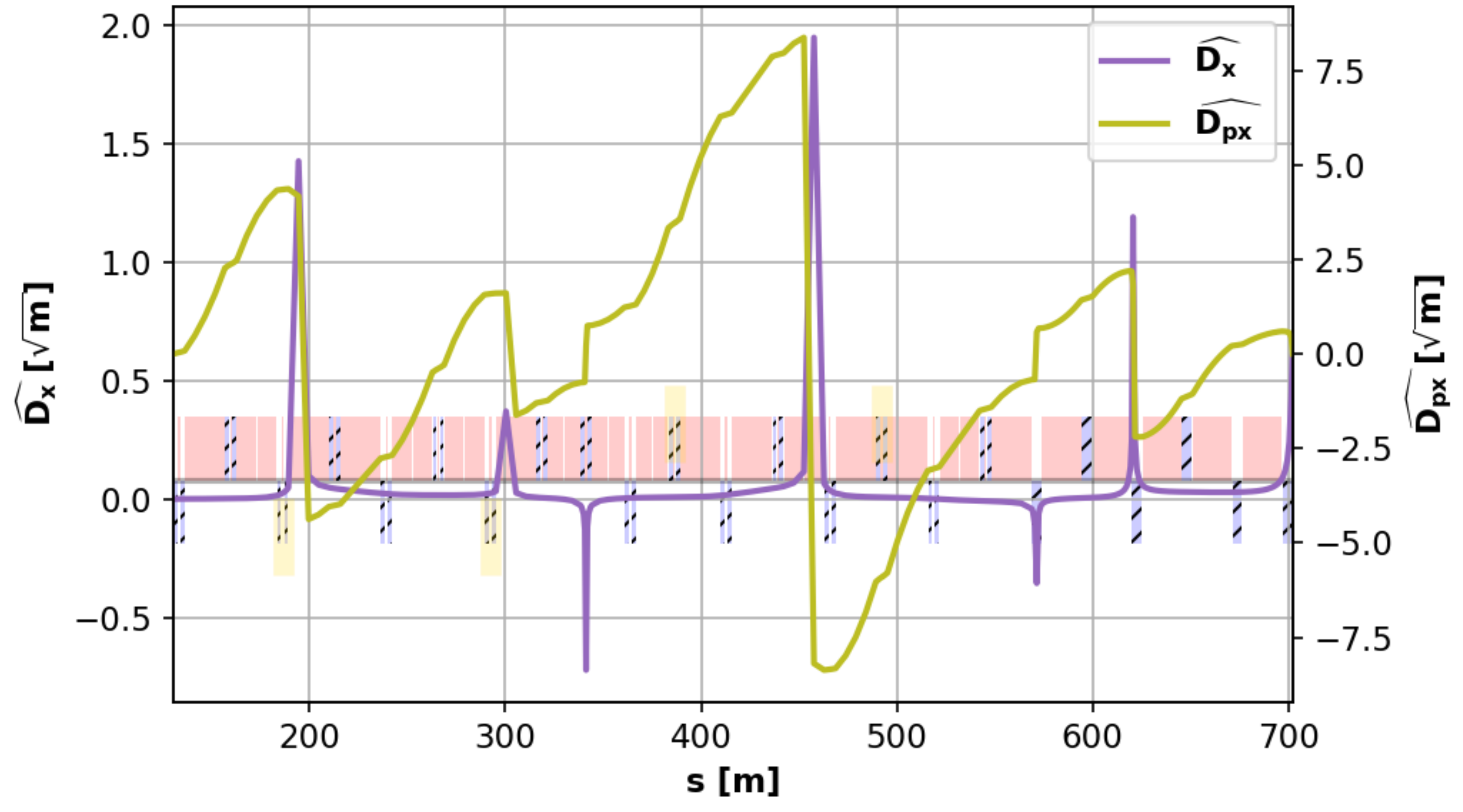
- The CC scheme include 2 sets (doublets) of combined function dipole-sextupole magnets and each set is placed at positions with large β_q, where q=x or y, for the correction of the W_q at the end of CC scheme.
- Each set include a pair of dipole-sextupole magnets with the same k_2 separated by -I transform at x and y planes for the compensation of the RDTs excited by the sextupolar component.
- The phase advance $\mu_y(\mu_x)$ between the IP and the first (third) dipole-sextupole magnets can be adjusted for a better control of higher order chromatic effects.

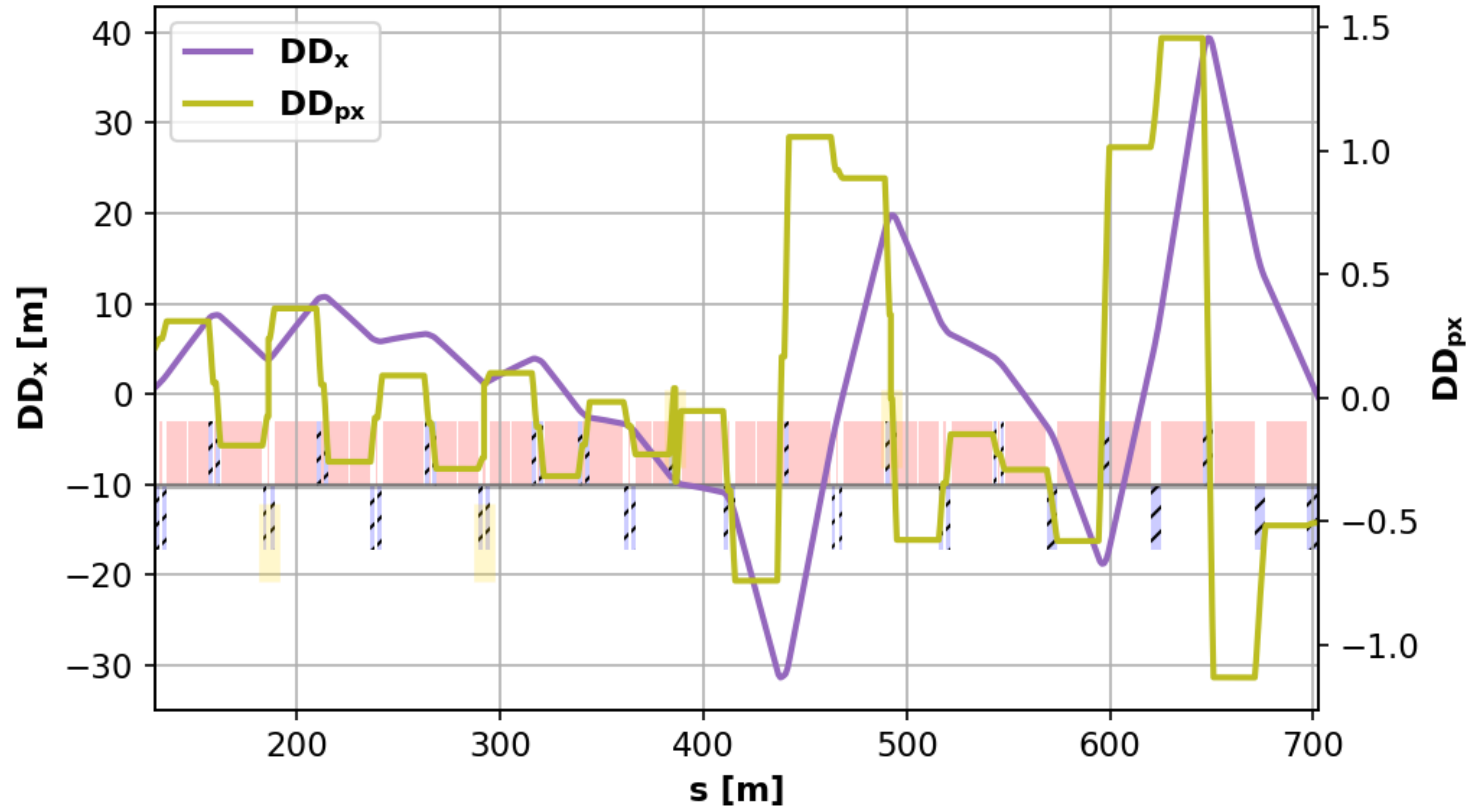
Matching scheme (CC-Arc)

- The $\beta_{x,y}$, $\alpha_{x,y}$, D_x and D_{px} are matched by controlling the strength of six dipole-quadrupole and the dipole length separating the dipole-quadrupole magnets.
- The matching of the optical functions is facilitated by controlling its value at the end of the CC scheme (keeping it to small values).

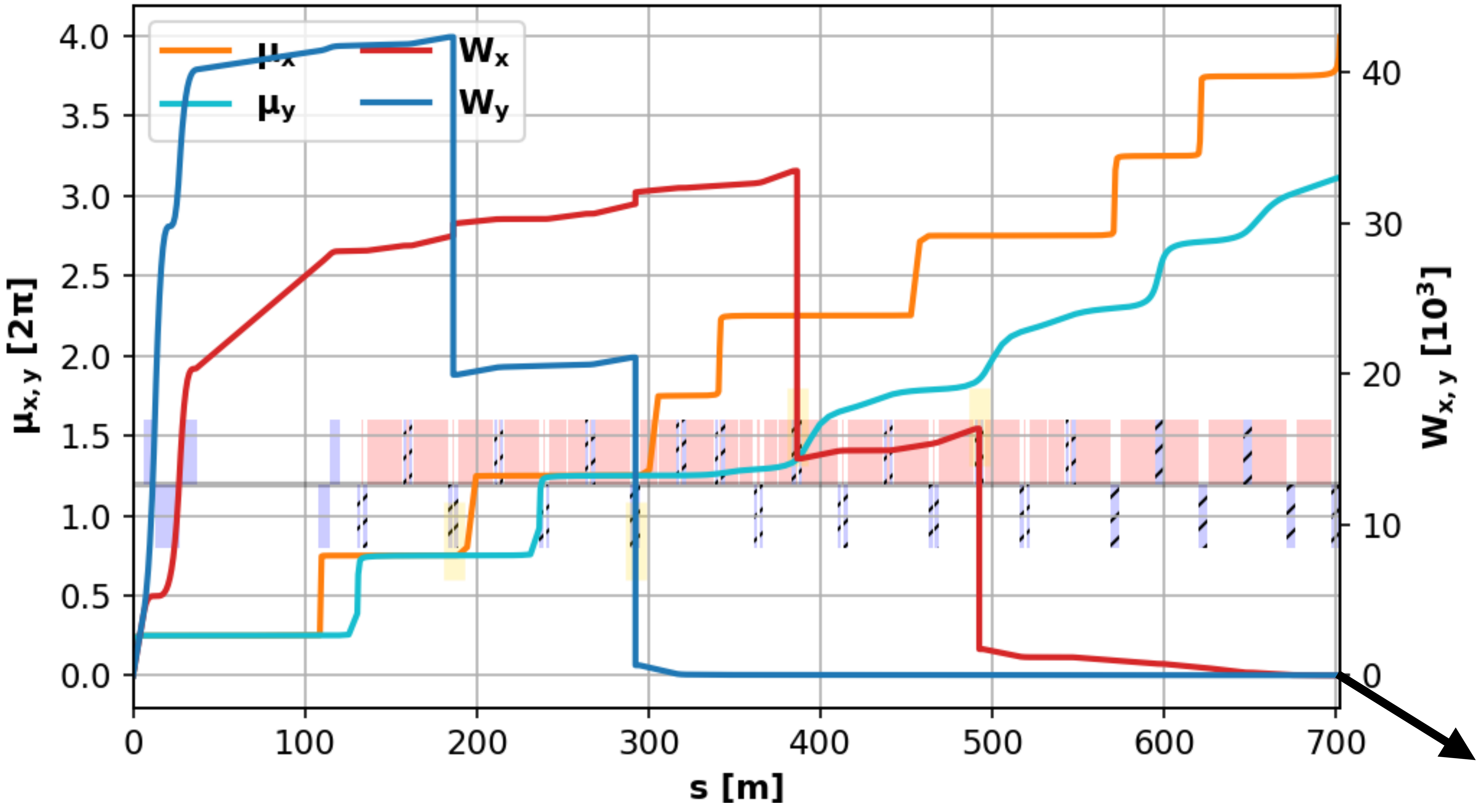
10TeV Muon Collider - Chromatic Correction & Matching Schemes

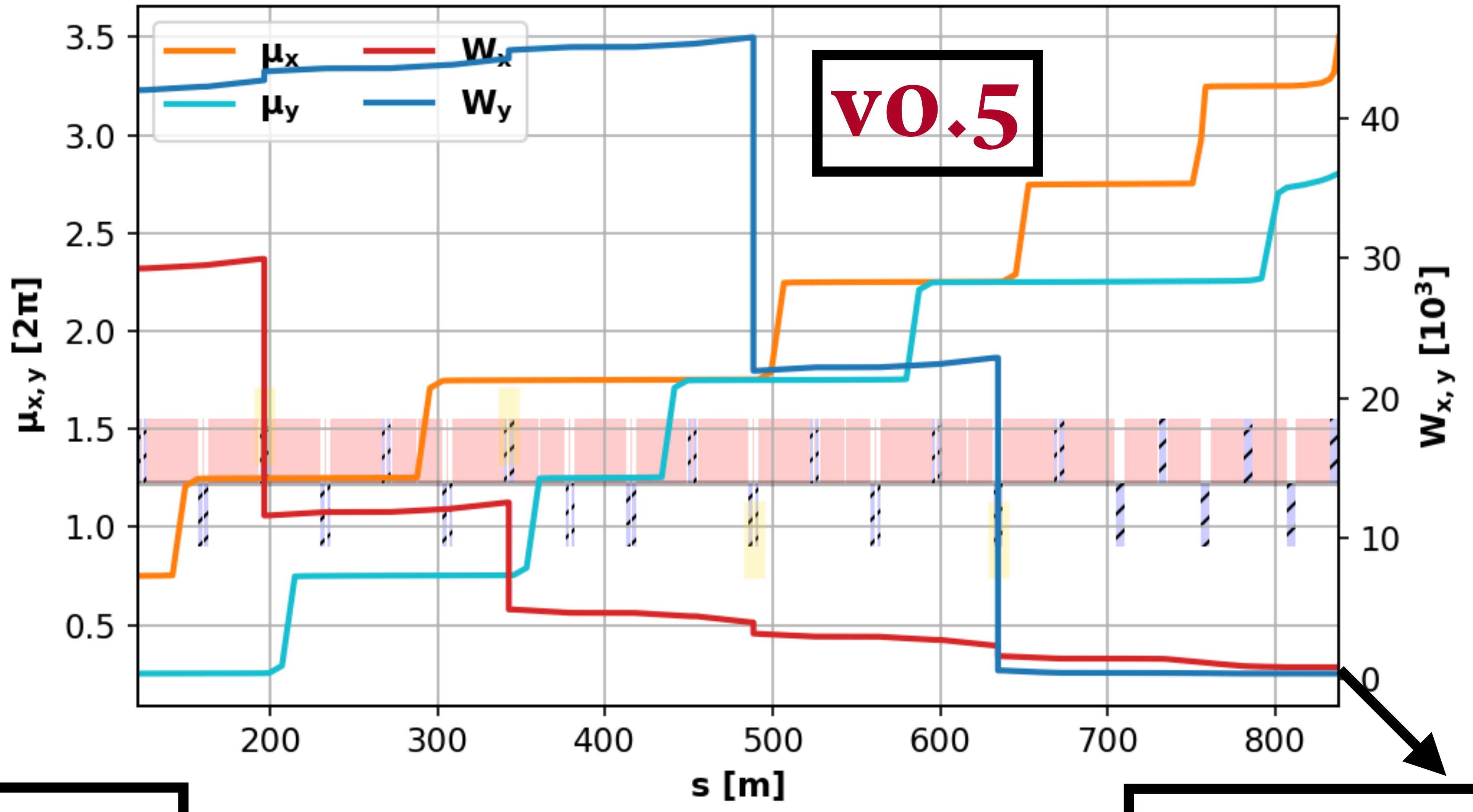






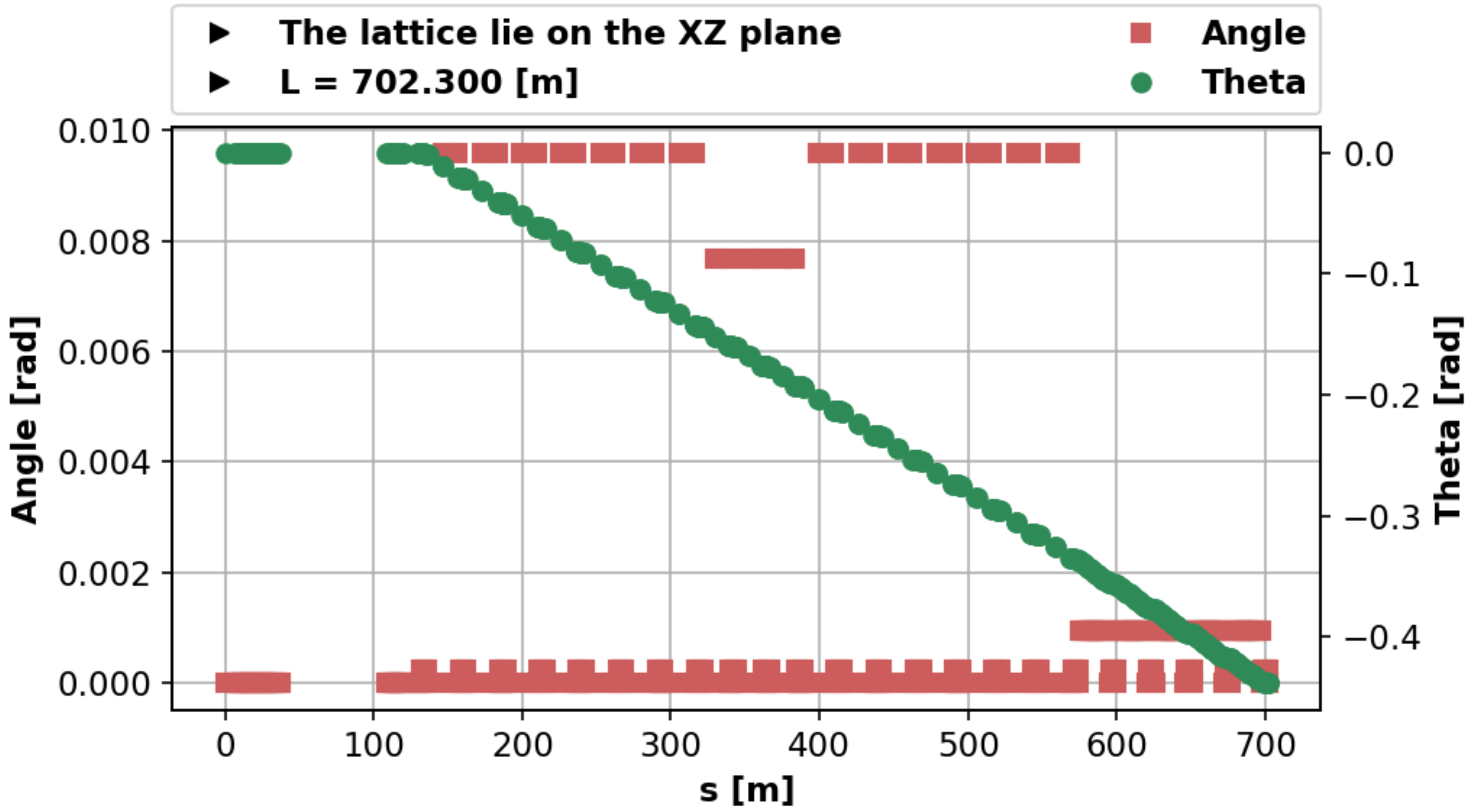
10TeV Muon Collider - Extended Final Focusing

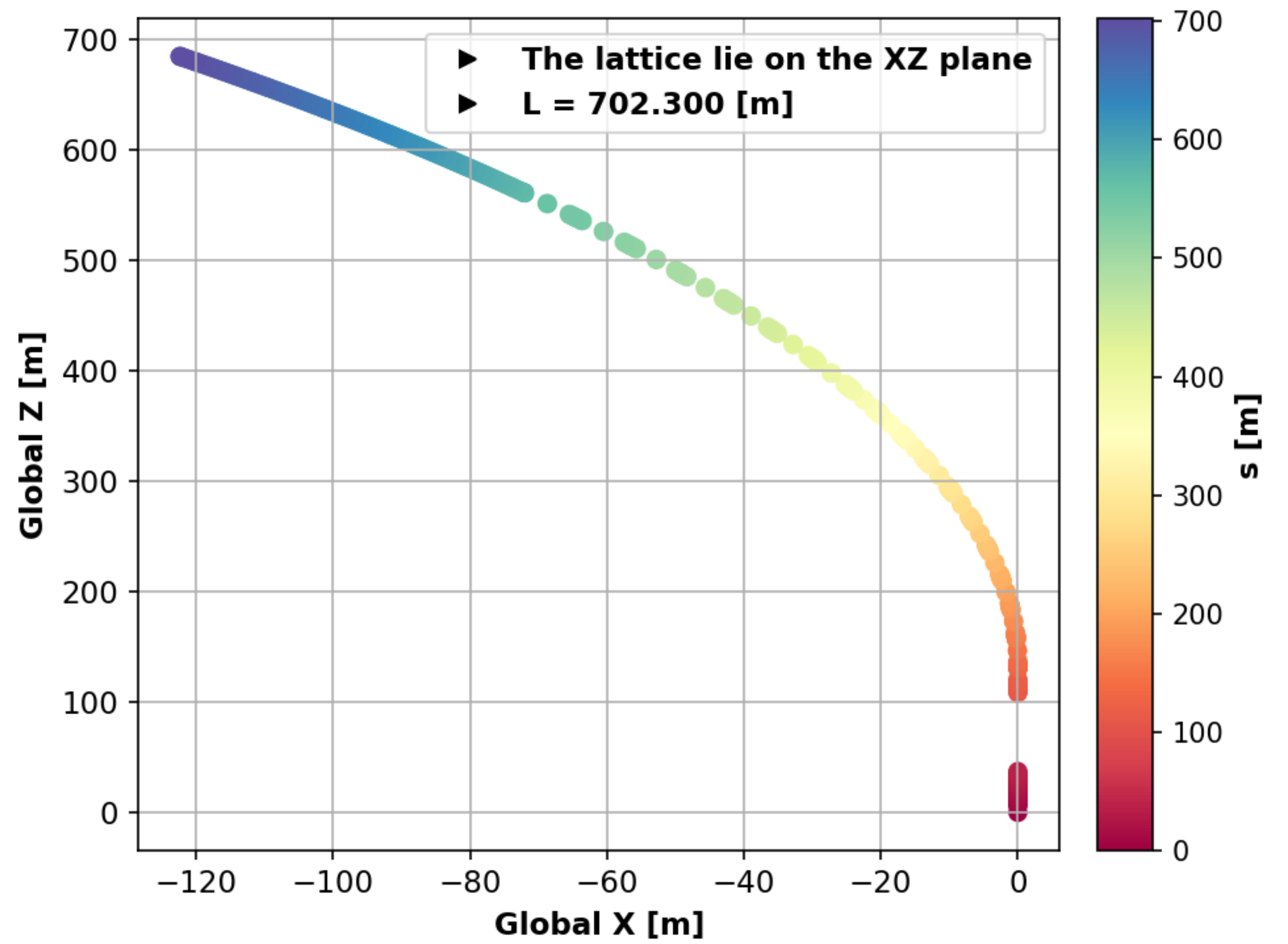




$\delta^{*}W_{x,y} < 0.02$

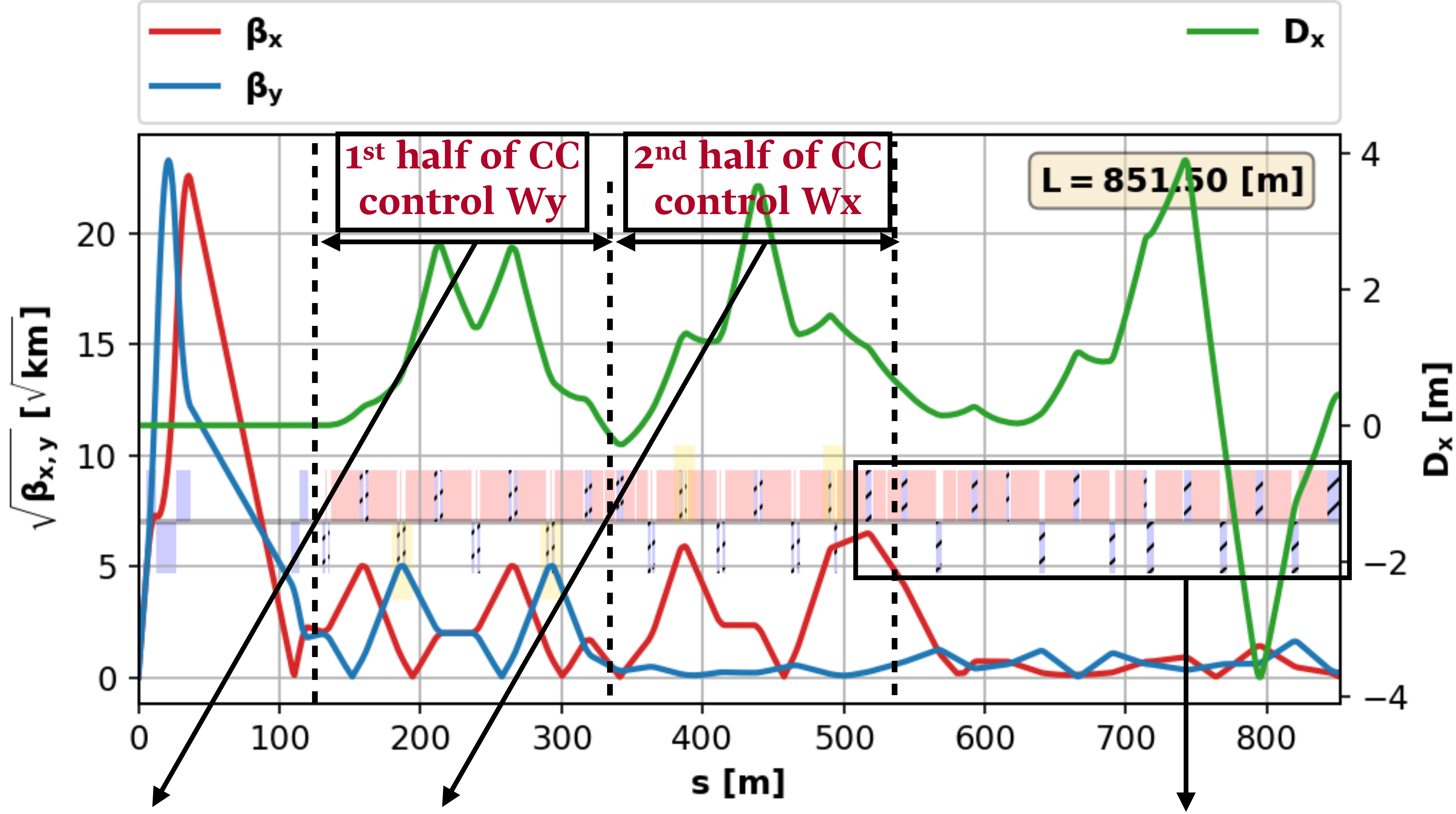
$\delta^{*}W_{x,y} < 1$





10TeV Muon Collider **v0.7**
(New design - work in progress)

10TeV Muon Collider - Extended Final Focusing Schemes



Compensate the energy aberrations of β* with the 2 dipole-sextuple families and the phase advance from IP

Control of working point and matching section

Summary

- Minimisation of the areas without dipolar components in order to evenly distribute the muon decay products (mostly the neutrino flux) and to minimise the collider length.
- The Final Focusing Quads section is elongated in the latest versions therefore, the BIB should be evaluated and check whether any mitigation technics are needed (see Daniele talk).
- The Extended Final Focusing section controls the Montague chromatic functions, the optics matching with the arc ones and the optics aberrations at the IP.

International
MUON Collider
Collaboration

Thank you for your time!

All the **presented studies** are **work in progress** thus, any input is very welcome.

International
UON Collider
Collaboration

home.cern

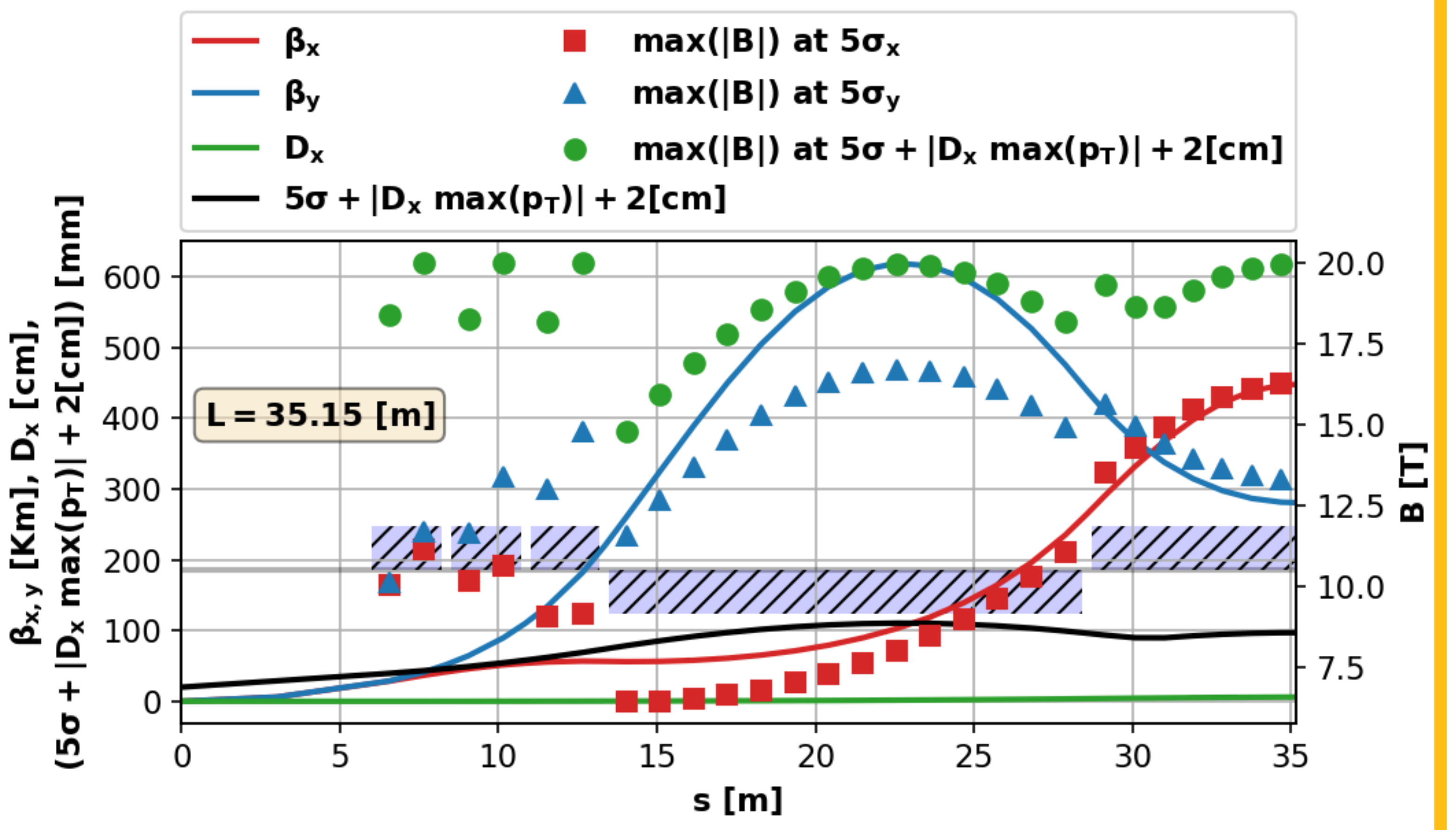
International
MUON Collider
Collaboration

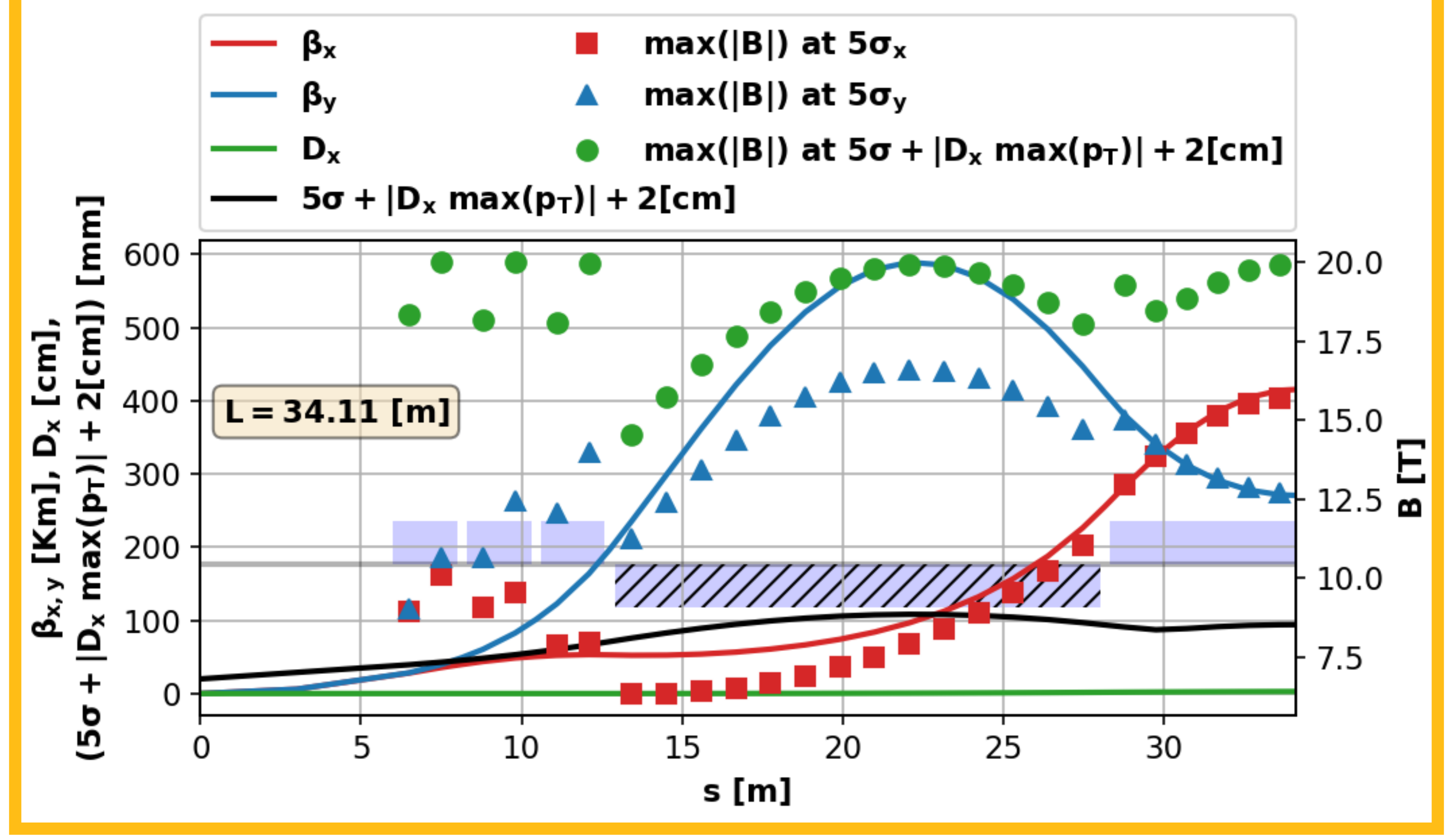
Backup

10TeV Muon Collider - Final Focusing Scheme

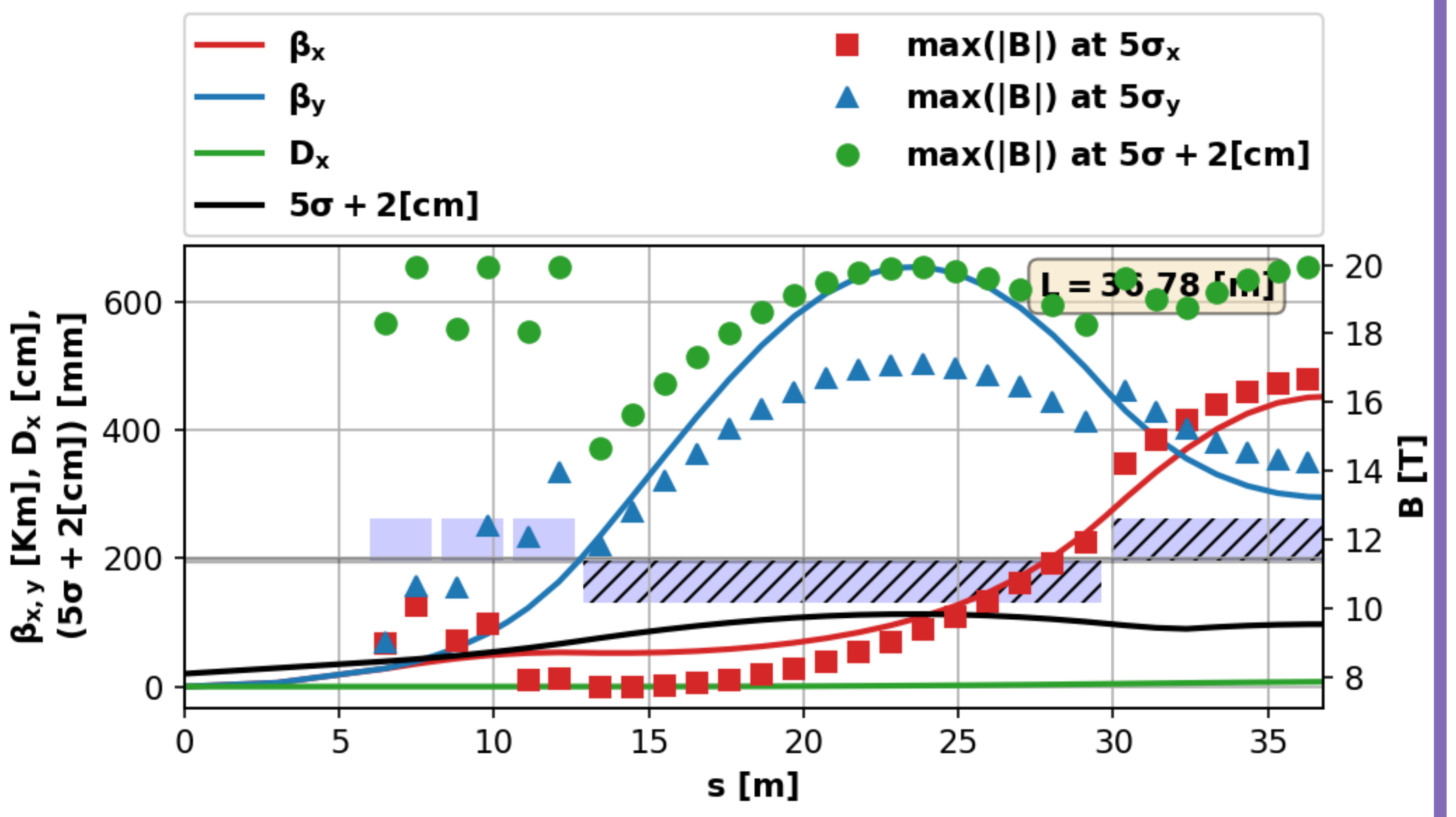
- For the v0.4 different FF schemes with dipolar components or an elongated L* are designed for the mitigation of the Beam Induced Background (BIB) but without any significant contribution.

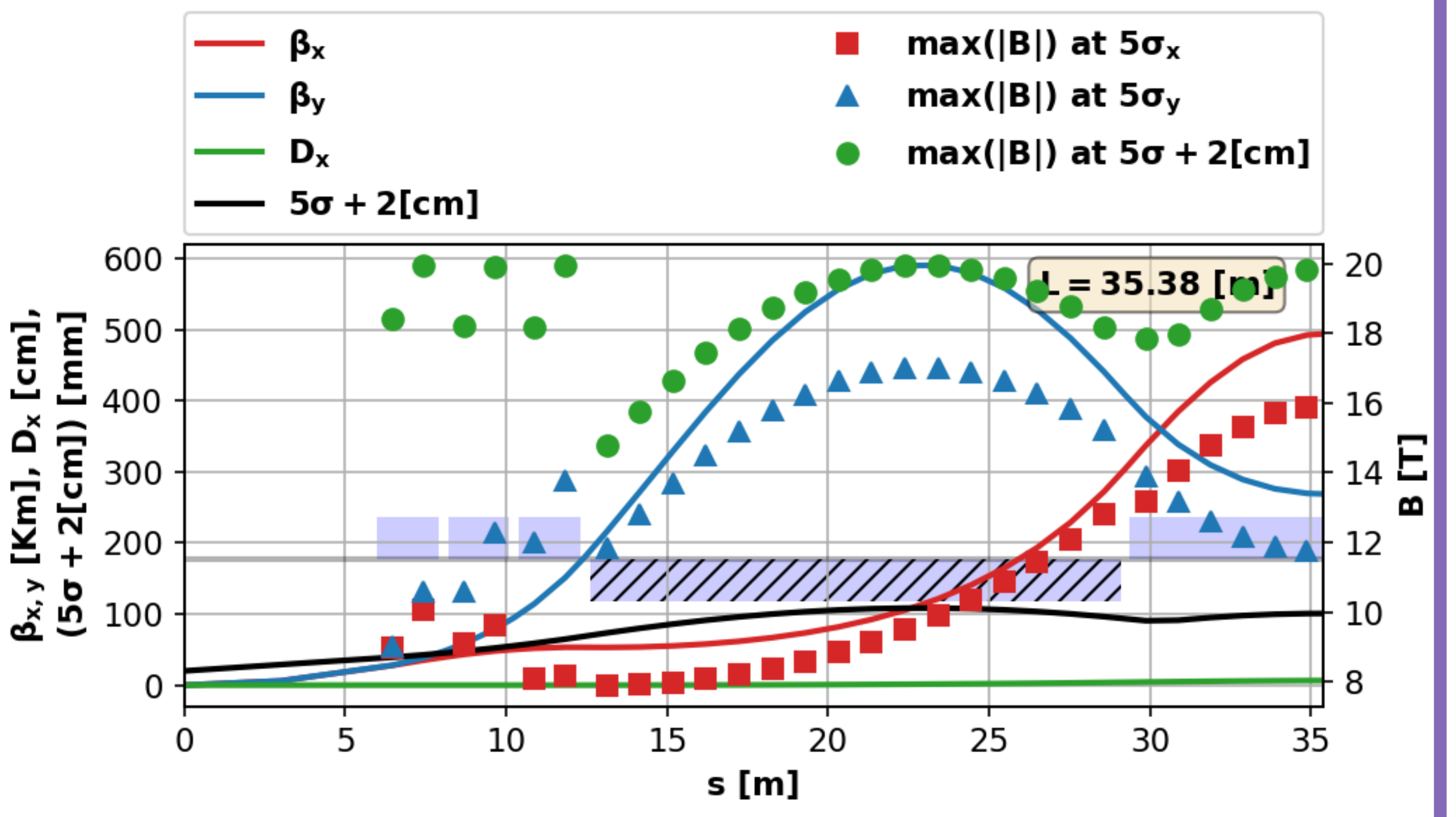
B_d = 2T



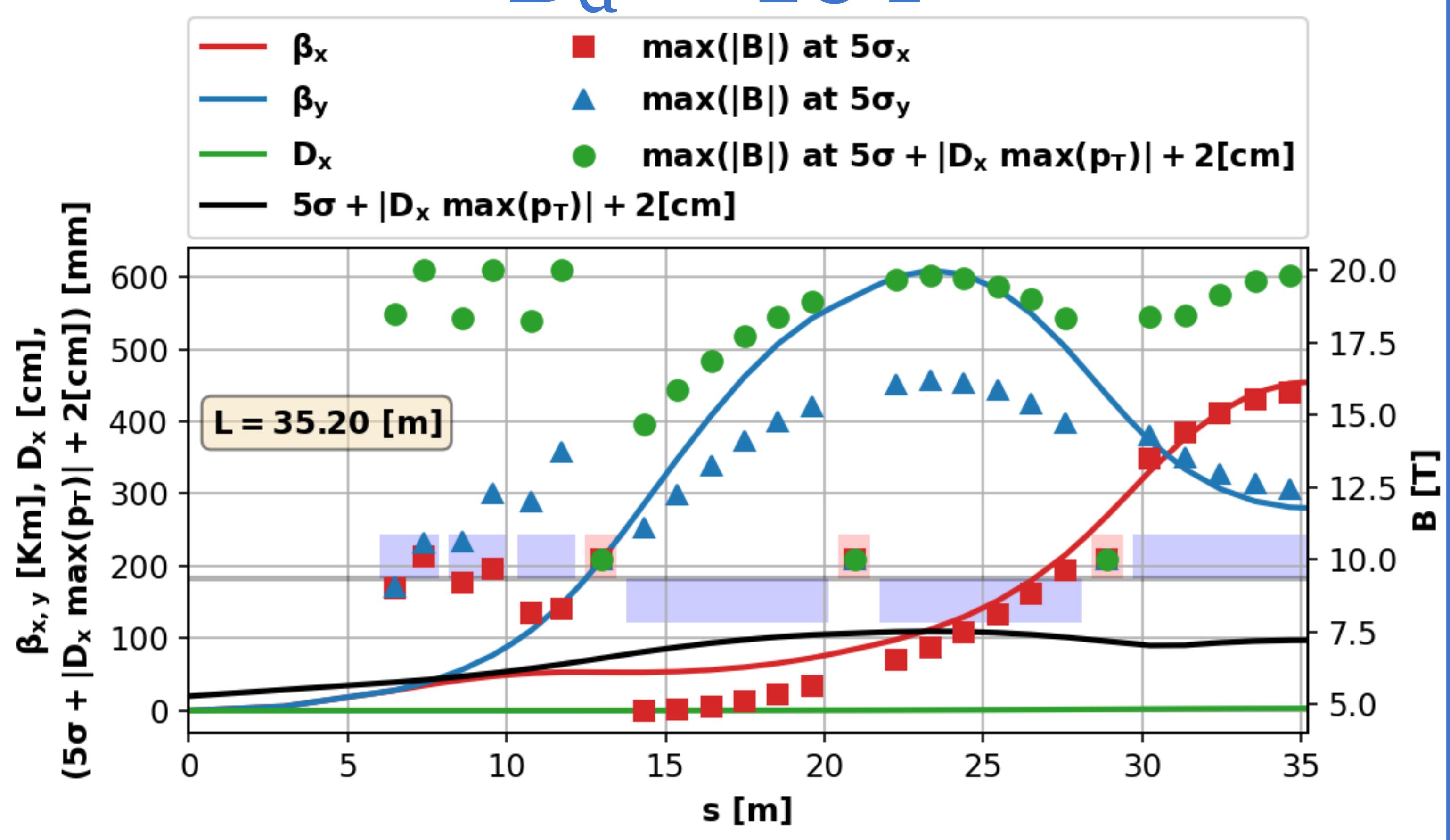


B_d = 4T

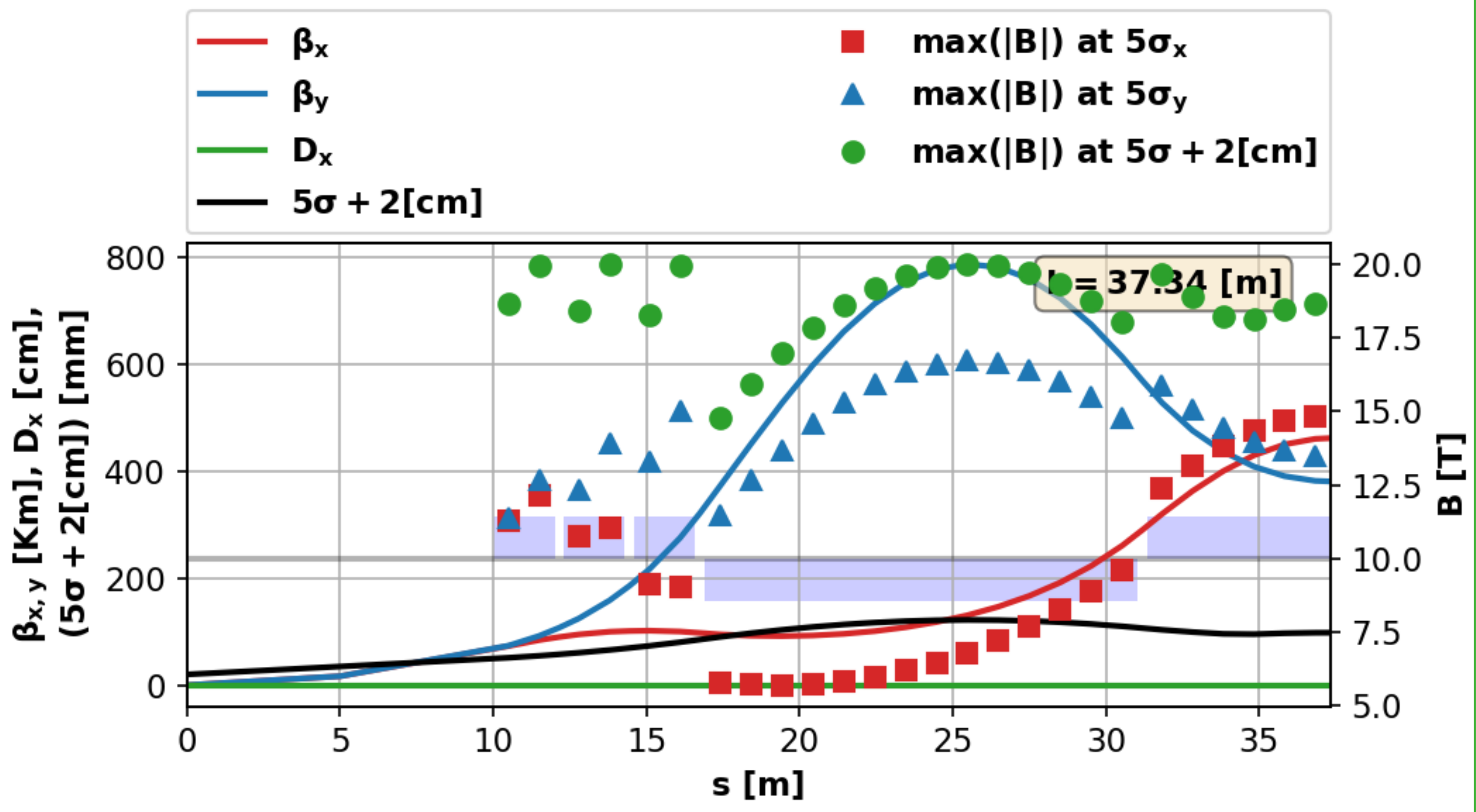




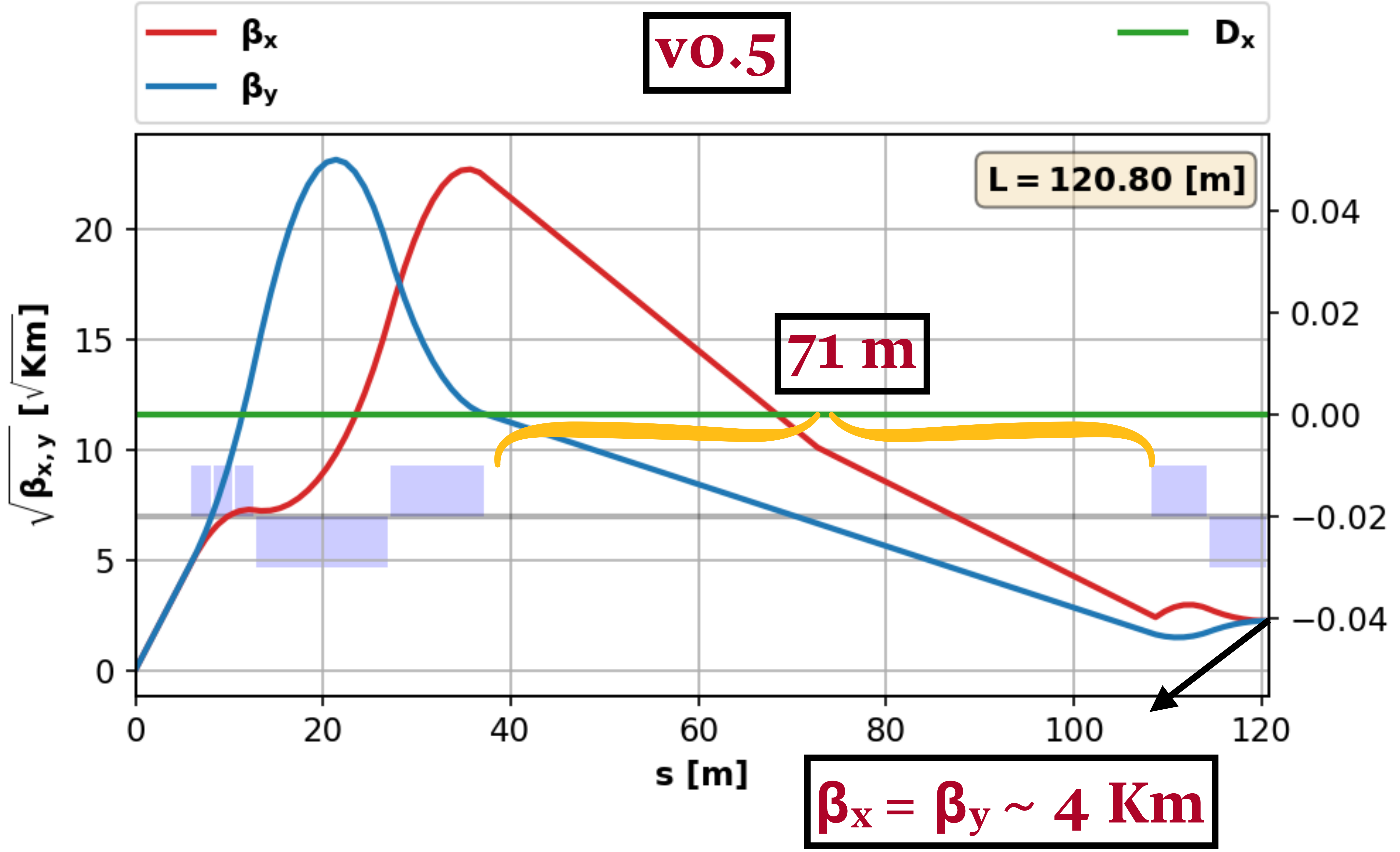
B_d = 10T



L* = 10m



10TeV Muon Collider - Earlier Final Focusing Schemes



$$B\rho = 16678.205\ [Tm]$$

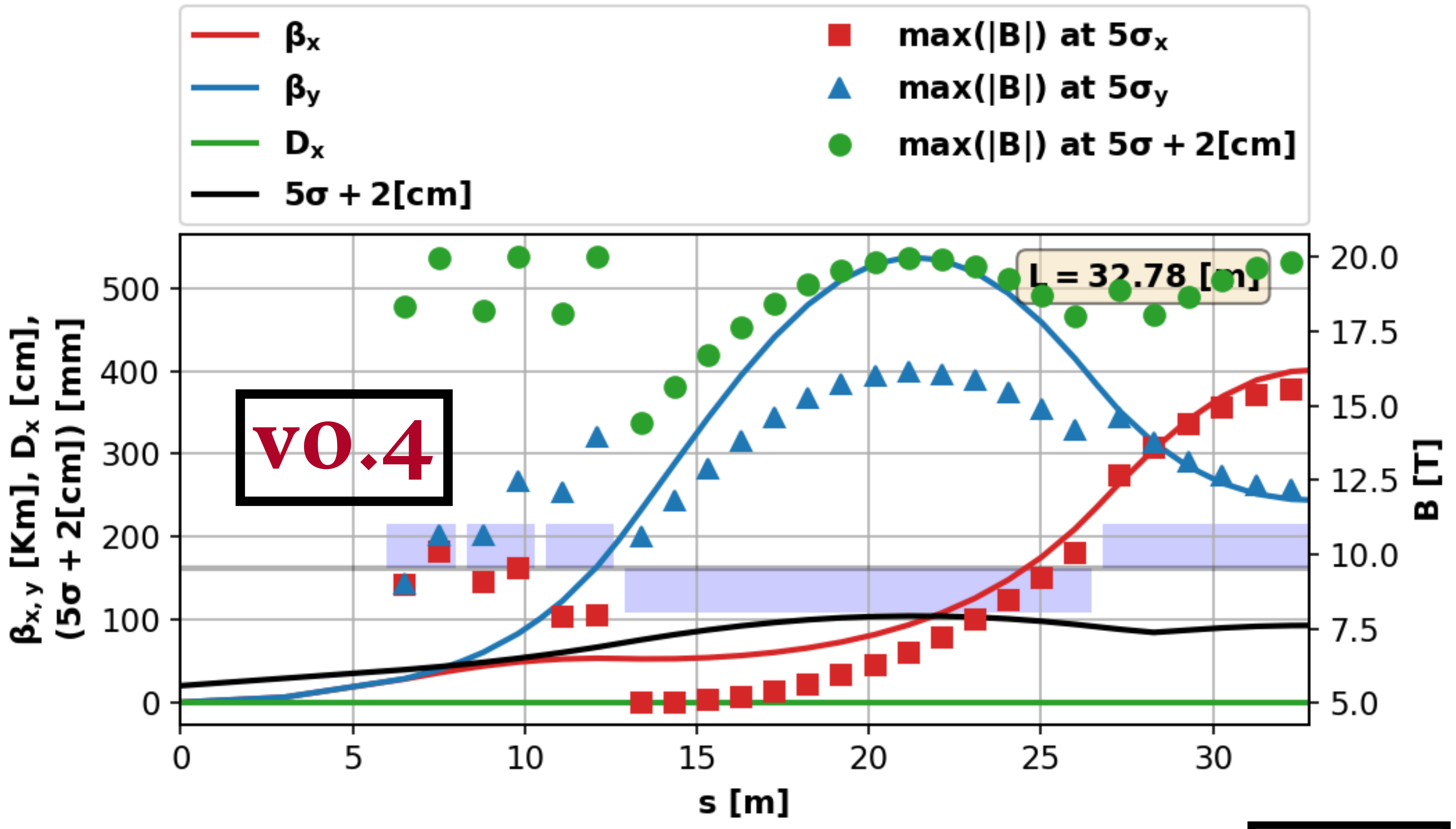
$$Aperture = 2(5\sigma + 0.02)\ [m]$$

$$\sigma_j = \sqrt{\frac{\beta_j \varepsilon_{nj}}{\beta_r \gamma_r} + (D_j \delta_p)^2}\ [m]\ with\ j = x, y$$

$$\sigma = max(\sigma_x, \sigma_y)\ [m]$$

Entering the CC with small βs resulted in:

- Smaller aperture
- Smaller Ws
- Less impact from unwanted multipolar components
- Easier control of βs



10TeV Muon Collider - Extended Final Focusing Schemes