

NUMAX decay ring

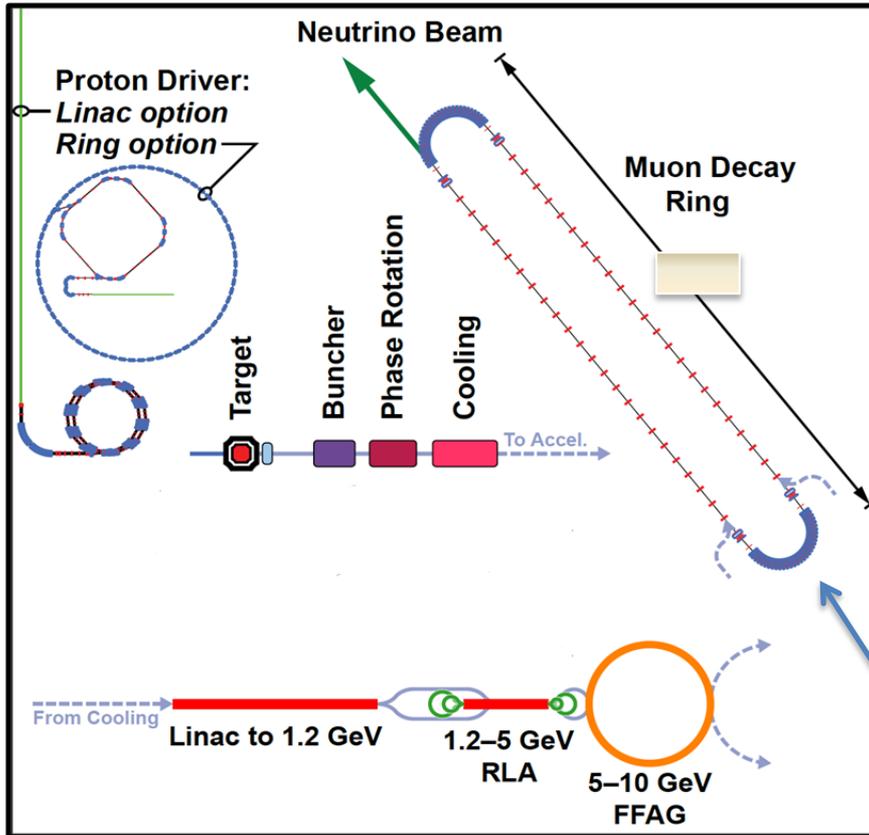
J. Pasternak, IC London/STFC-RAL-ISIS

D. Kelliher, STFC-RAL-ASTeC

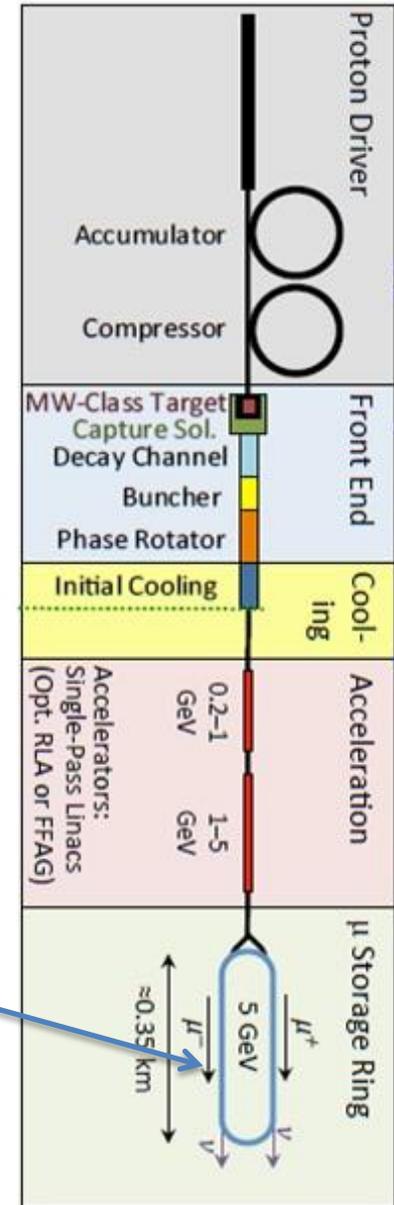
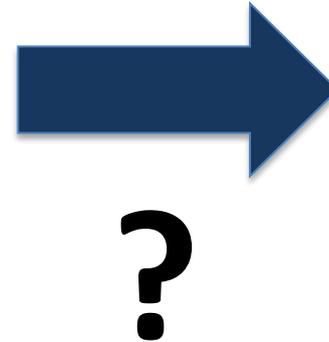
Outline

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- FDDF ring for NuMax
- FODO ring for NuMax
- Injection considerations
- Conclusions

Introduction



IDS-NF



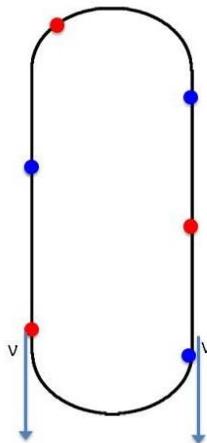
NuMAX

We were asked to look at possible design of the NuMAX decay ring. We decided to use our IDS-NF decay ring design as a starting point,

IDS-NF Decay Ring

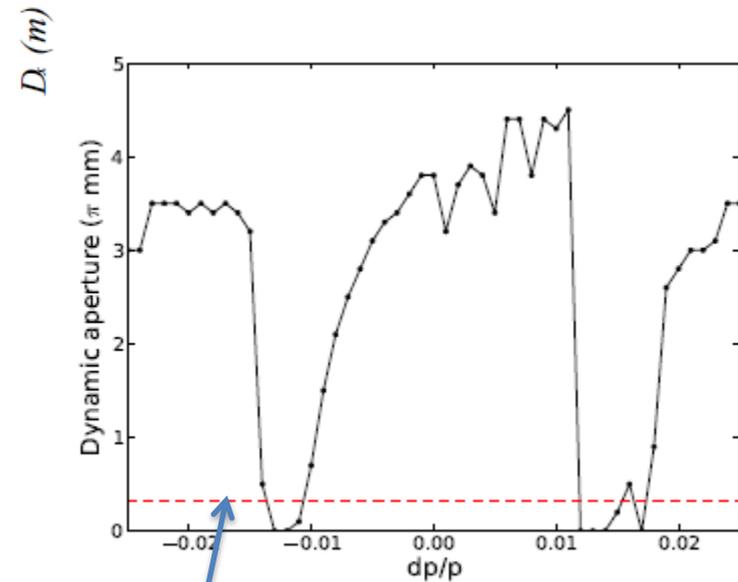
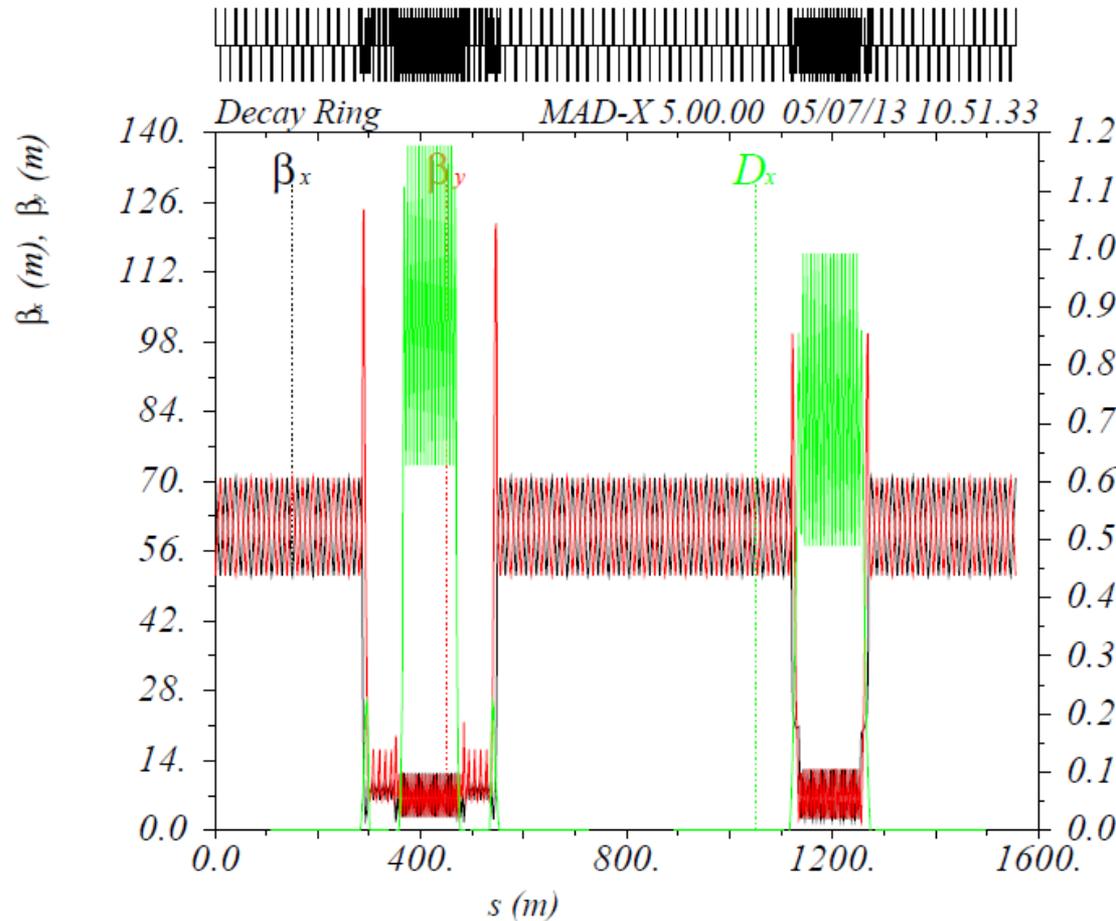


- Key assumption for IDS-NF is the need to accommodate 3+3 bunches.
- This makes the injection into the production straight impossible due to the kicker magnet limitations (rise/fall time) and requires a dedicated insertion.
- This pushes the ring circumference.



Production straight	562.0×2	m
Upper arc (incl. disp supp)	121.155	m
Lower arc	112.729	m
Insertion	46.4×2	m
Matching sections (total)	104.987	m
Circumference	1555.672	m
Width of ring	74.565	m
Length of ring	737.228	m
Angle of inclination	10	deg
Maximum depth of ring	128.02	m
Production efficiency η_p	$36.1\% \times 2$	
Total tune (H,V)	14.77, 13.73	
Chromaticity (H,V)	-17.11, -20.23	
Phase slip η	2.8×10^{-3}	
Turns per mean lifetime	40.07	

IDS-NF ring (optics and dynamics)



Requirement

IDS-NF vs NuMAX

	IDS-NF	NuMAX
Muon energy [GeV]	10	5
Number of bunch pairs	3	1
Bunch train [μs]	250	~ 170
Normalised acceptance [π mm rad]	30	20
Ring inclination	10°	5.8°

Design considerations

Design Aims

Maximise neutrino production efficiency (η)

Low beam divergence in production straight ($<0.1/\gamma$)

Maintain bunch separation (100 ns)

Allow realistic injection scheme

Ensure reasonable momentum acceptance

Beam divergence in production straight

- Want to keep beam divergence \ll natural decay cone of neutrinos
- Imposes a minimum beta in the production straight

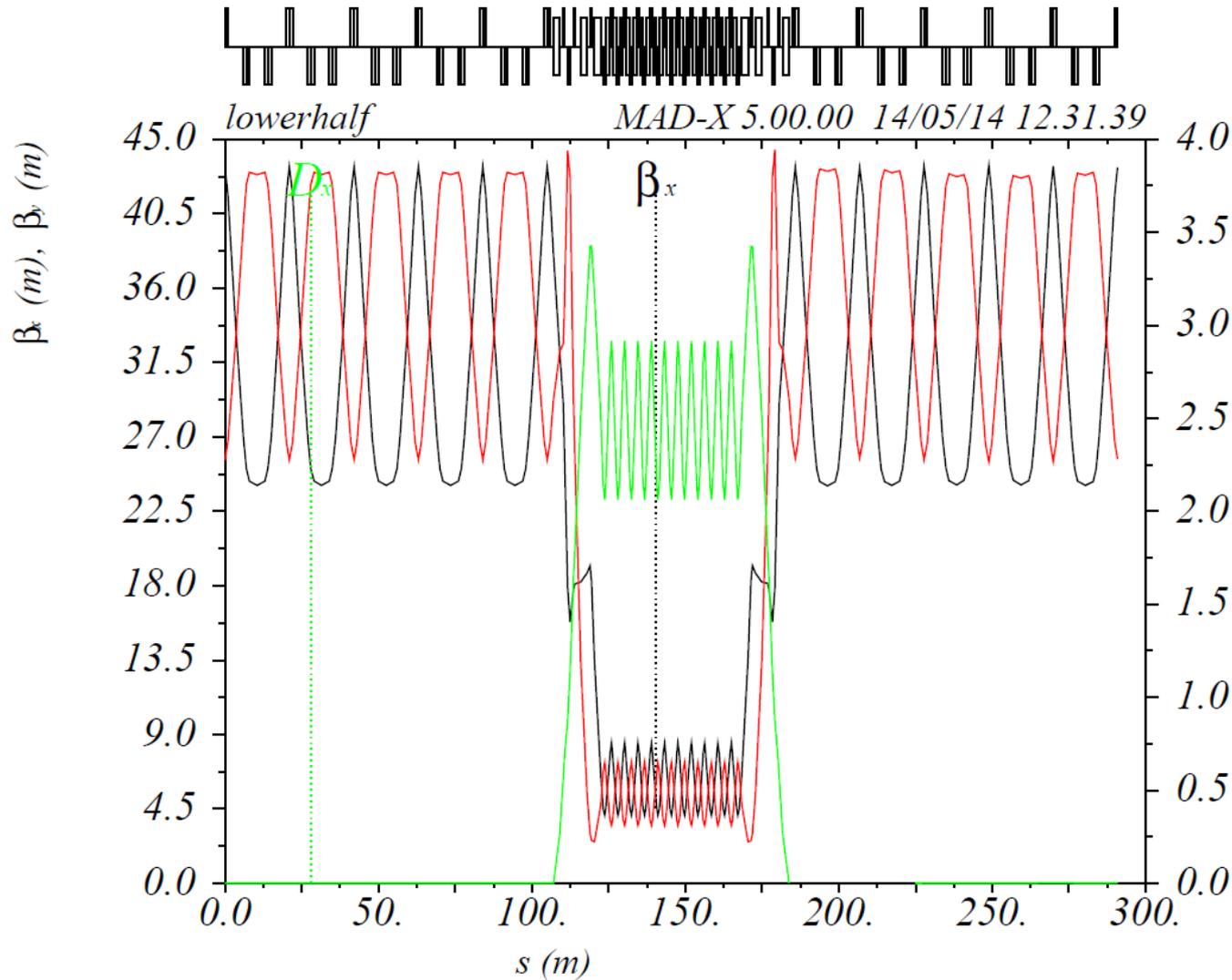
Beam divergence condition
$$x' = \sqrt{\frac{\epsilon_{rms}}{(\beta_r \gamma_r) \beta}} < \frac{0.1}{\gamma_r} \Rightarrow \beta \propto \gamma_r$$

$\epsilon_{rms} \approx 5.7 \pi$ m rad (approximately) implies $\beta > \approx 25$ m

Preliminary Lattice overview (FDDF in the production straight)

Section		Cell No.	Total length (m)
Production	21 m (cell length)	10	210x2
Matching	-	-	18.7x4
Arc	4.34 m (cell length)	10	43.41x2
Ring	-	-	581.62
Dipole field	2.4 T		
η	2x36.1%		
transition gamma	6.83		
Ring tune (Q_x, Q_y)	5.4, 6.13 (needs readjusting)		
Chromaticity (ξ_x, ξ_y)	-5.1, 6.1		

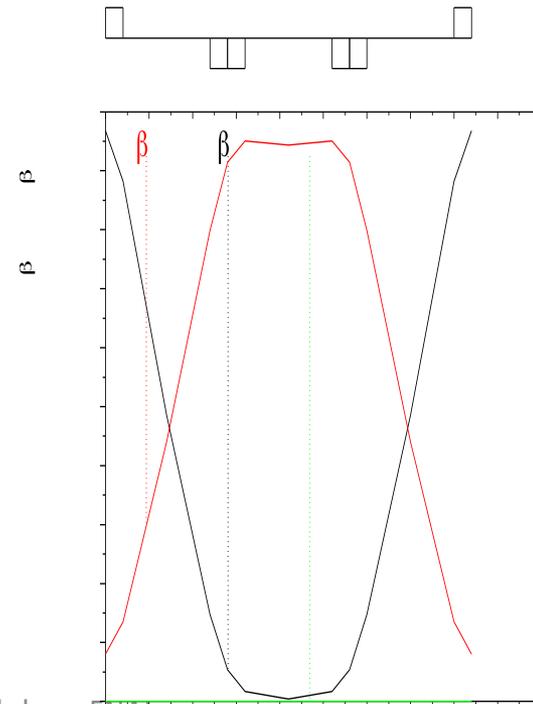
Preliminary optics



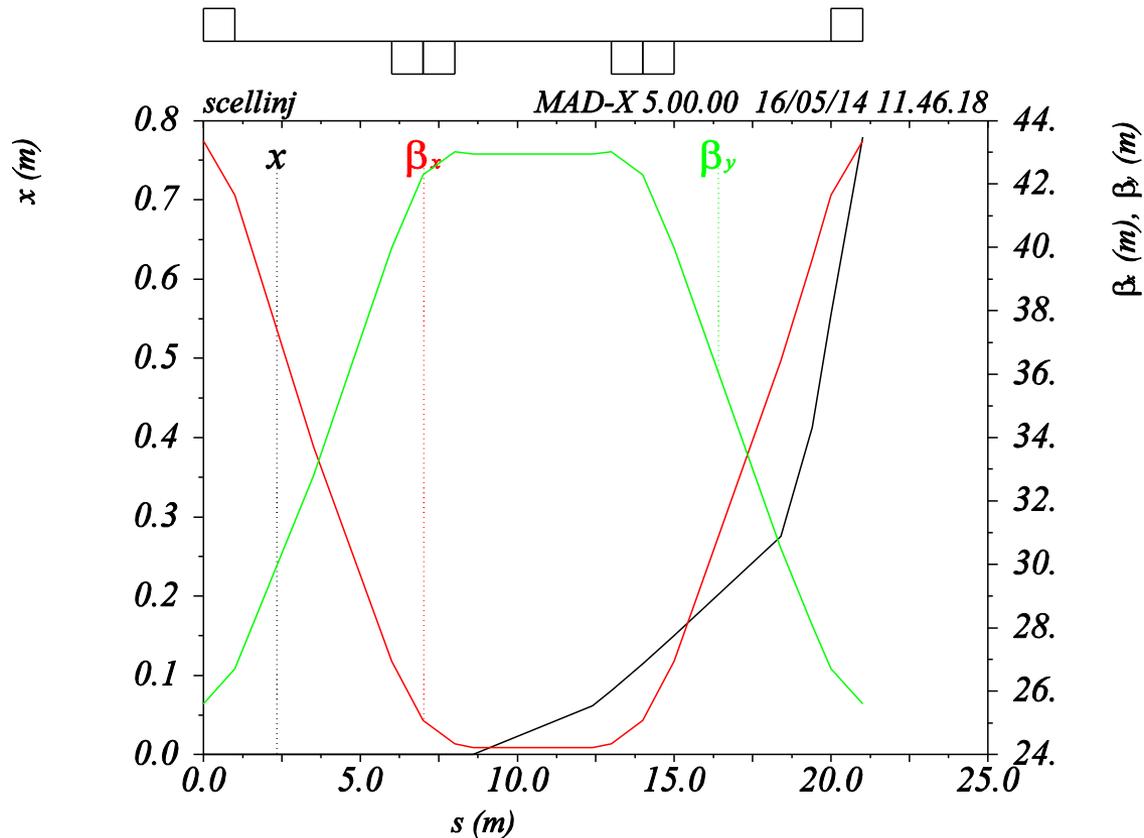
Production Straight (FDDF)

- FDDF lattice adopted for symmetric injection
- Drift length chosen to reduce variation of beta but allow space for injection elements

	Length	Field/Gradient
Drift	5 m	-
QF	2.0 m	0.65 T/m
QD	2.0 m	0.33 T/m
Beam envelope in quads	14.4 cm	-



Injection

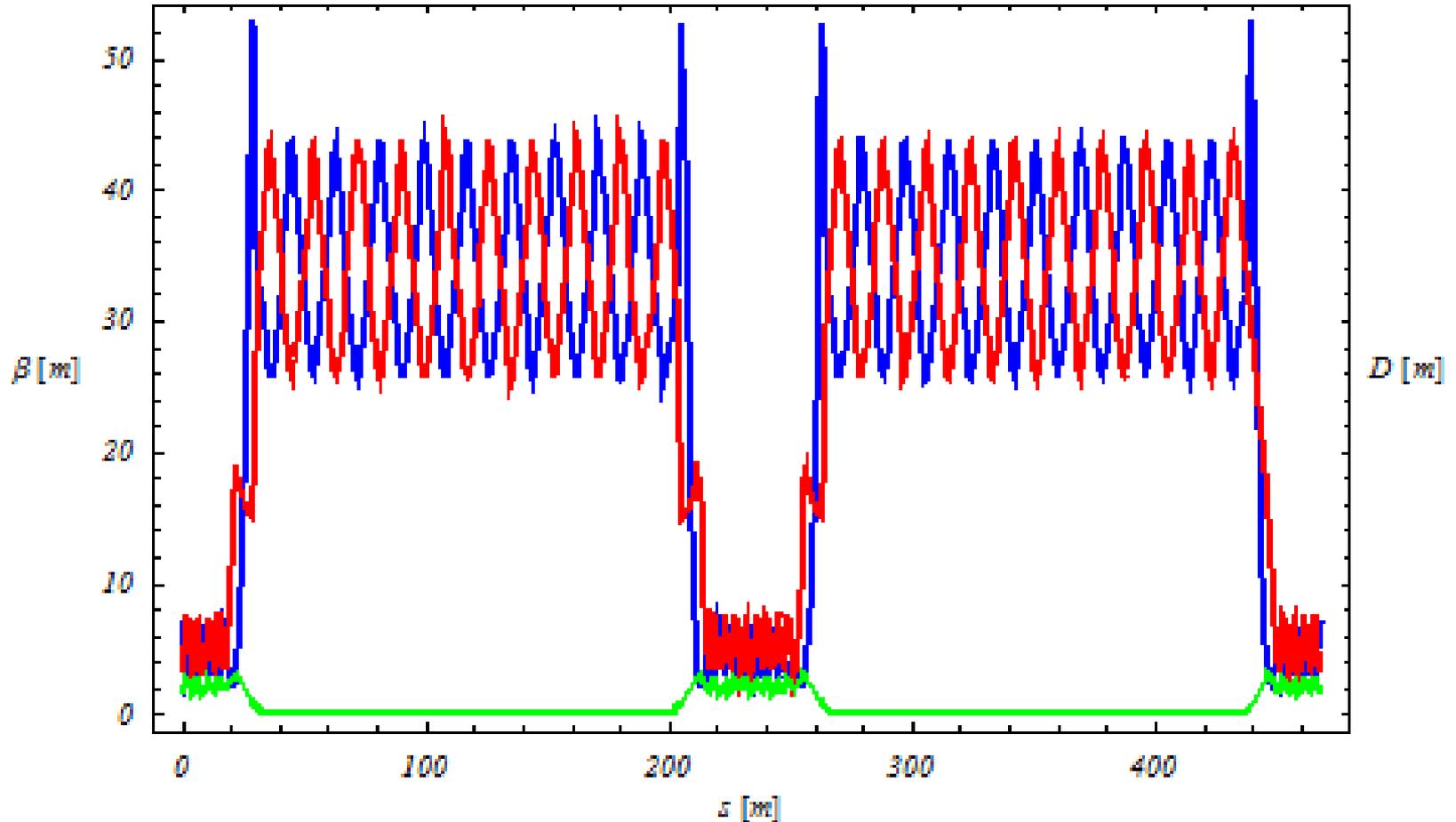


- FDDF allows for symmetric injection of both muon charges.
- Length of the straight section is 5 m.
- Single kicker scenario requires 0.14 T top B field (kicker) -> too much, but distributed kickers may work. Assumed kicker length – 3.8 m (fall time $1.76 \mu\text{s}$)
- Septum 1.67 T, 1m long

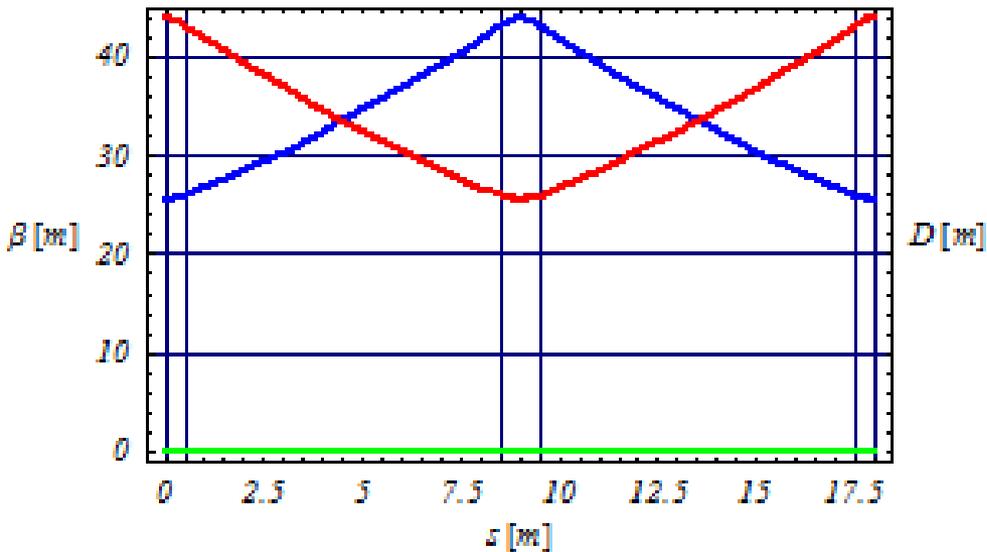
Preliminary Lattice overview (FODO in the production straight)

Section		Cell No.	Total length (m)
Production	18 m (cell length)	9	162x2
Matching	-	-	18.7x4
Arc	4.34 m (cell length)	8	34.7x2
Ring	-	-	468.2
Dipole field	3 T		
η	2x34.6%		
transition gamma	6.33		
Ring tune (Q_x, Q_y)	4.65, 5.7 (needs readjusting)		

Preliminary NuMax ring with FODO production straight

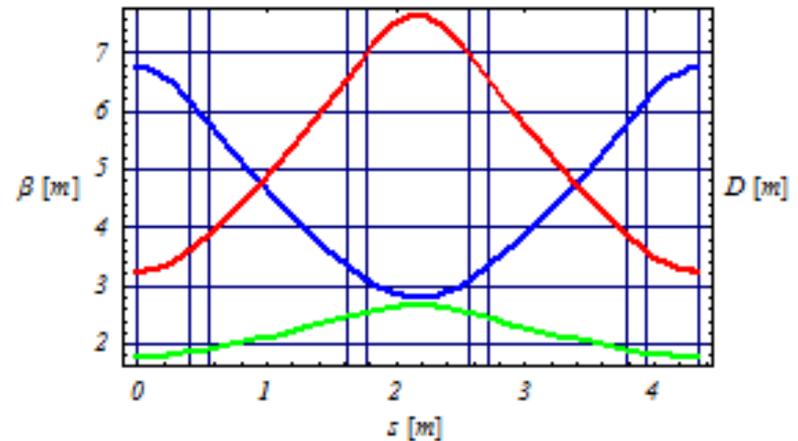


Cells of the ring with FODO-type production straight



FODO Production cell:

- 8 m drift
- Room temperature quads
- Large β
- Zero dispersion

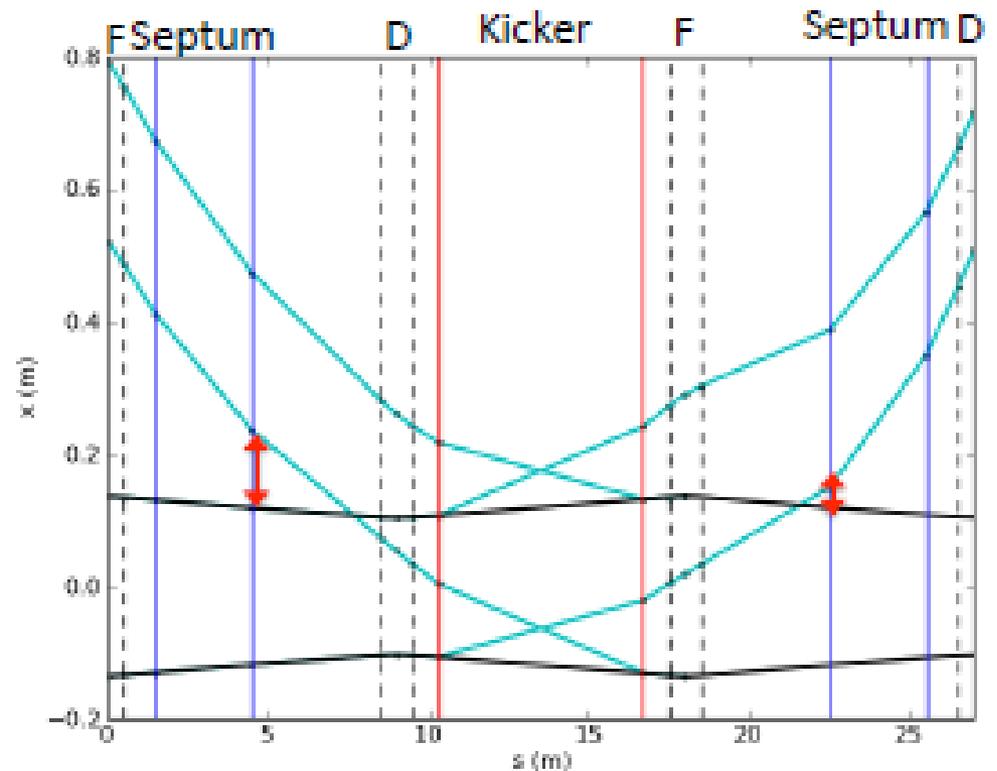


Arc cell:

- Very short drifts
 - All magnets SC in the common cryostat.
- Dipole field 3 T.
- Small β
 - Non-zero, but small dispersion

FODO injection

- Kickers and septa in consecutive cells.
- 6.8 m kicker with 0.09 T peak field
- 3 m septum with 0.4 and 0.2 T.
- Higher kicker field needed when injecting through the F than the D.
- In the FDDF case, the kicker peak field required is 0.14 T.



Alternative injection into the FODO ring

- This scheme assumes one empty drift between the kicker and septum
- Kicker approximate parameters:
 - 6.4 m long, subdivided into sub-kickers.
 - 0.05 T top B field
 - Rise/fall time ~ 1.4 us
 - Aperture ~ 0.35 m
- Septum – 1.2T, 3m long
- This scheme requires confirmation!

FODO vs FDDF production straight

- FDDF considered as it allows symmetric injection of both muon signs.
- However, longer straights possible in FODO easing the peak field kicker requirement.

	Length (m)	Gradient
Drift	8	-
QF	1	1.03 T/m
QD	1	-1.03 T/m

	Length (m)	Gradient
Drift	5	-
QF	2	0.65 T/m
QD	2	-0.33 T/m

Conclusions

- As NuMax design assumes only 1 bunch/charge, the ring size can be reduced.
- We have two preliminary designs of 581.6 and 468.2 m.
- In both rings production straight and matching can be based on room temperature magnets, but arcs need SC ones.
- Injecting directly into the production straight avoids the need for the dedicated insertion (like in the IDS-NF), which allows to makes the ring smaller.
- Limitation for the size of the ring is again fall time of the kicker.
- A large aperture kicker(s) with modest strength is(are) required, which seems to be feasible (to be confirmed).
- Large aperture quads are needed at injection region.