Decay Ring Design for Long Baseline NF a la NuMAX

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

D. Kelliher, STFC-RAL-ASTeC

20 May, 2015, FNAL, MAP Meeting

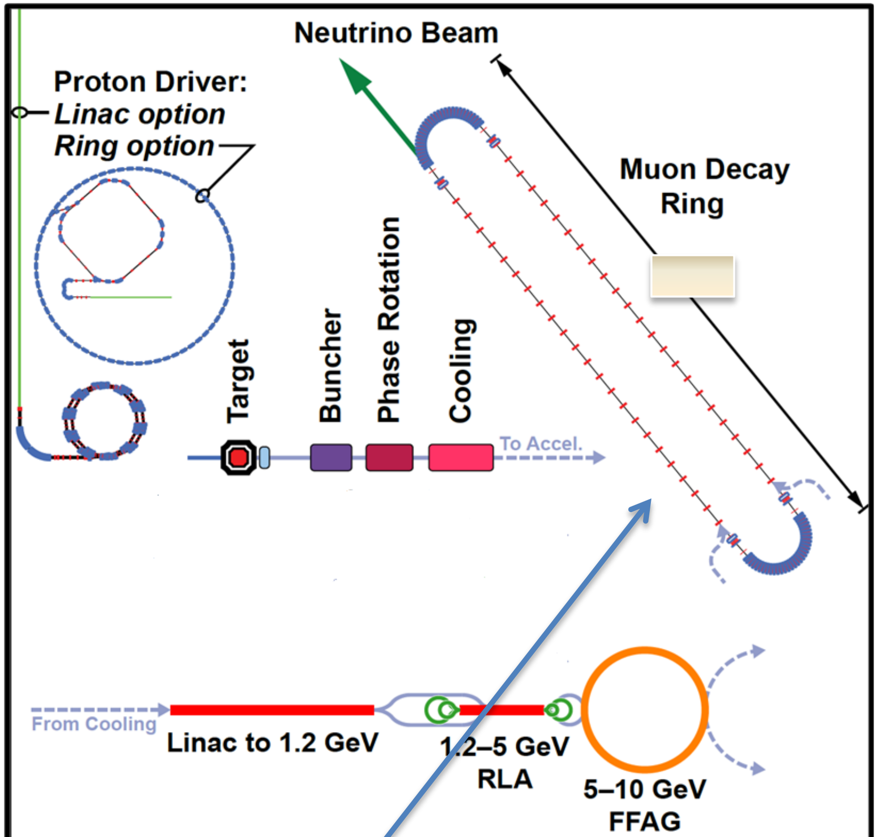
Outline

- Introduction
- IDS-NF decay ring
- FDDF ring for NuMax
- FODO ring for NuMax
- Injection considerations
- Neutrino flux calculations
- NuMax/nuSTORM comparison
- Conclusions and future plans

STFC ASTeC

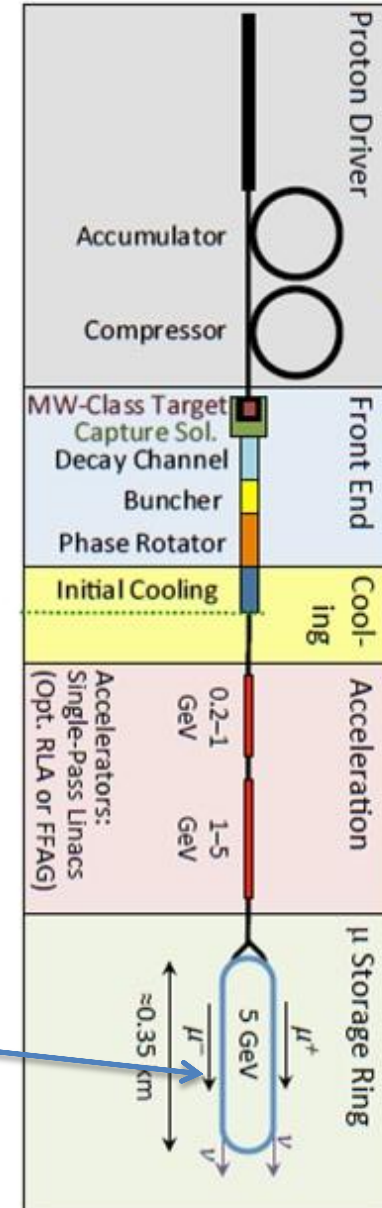
Introduction

Imperial College London



IDS-NF

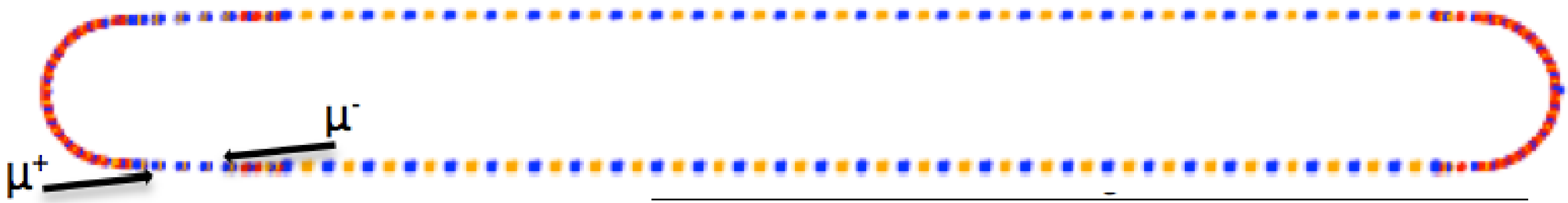
?



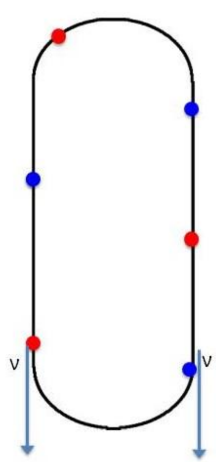
NuMAX

We looked at a possible design of the NuMAX decay ring using the IDS-NF decay ring design as a starting point,

IDS-NF Decay Ring

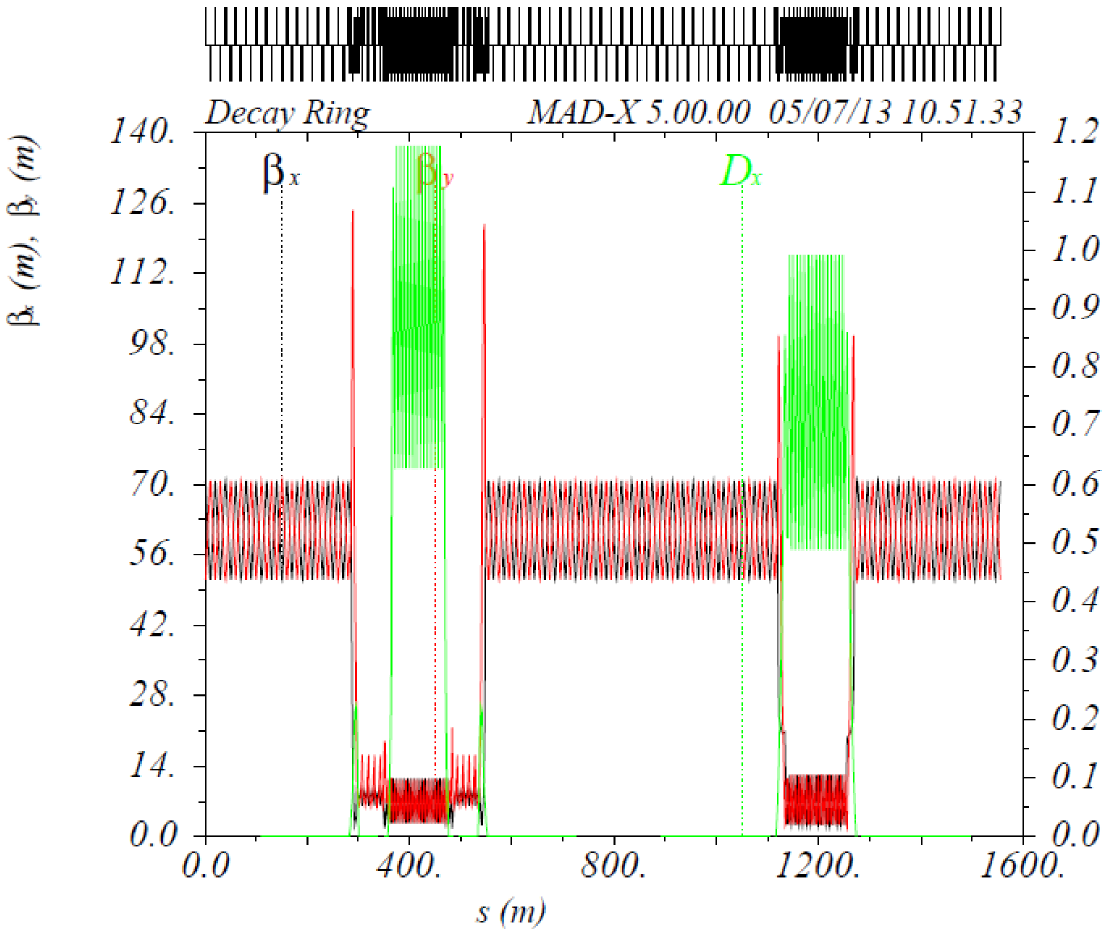


- Key assumption for IDS-NF is the need to accommodate 3+3 bunches.
- This makes the injection into the production straight impossible due to the kicker magnet limitations (rise/fall time) and requires a dedicated insertion.
- We have found a solution, however it pushes the ring circumference.

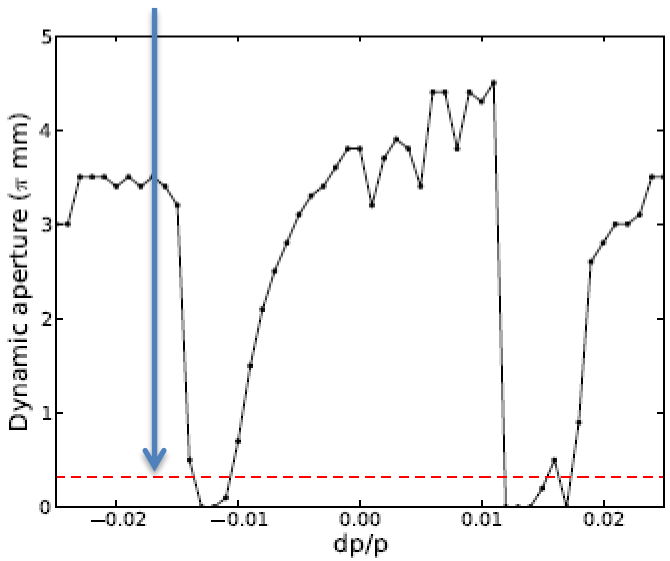


Production straight	562.0×2	m
Upper arc (incl. disp supp)	121.155	m
Lower arc	112.729	m
Insertion	46.4×2	m
Matching sections (total)	104.987	m
Circumference	1555.672	m
Width of ring	74.565	m
Length of ring	737.228	m
Angle of inclination	10	deg
Maximum depth of ring	128.02	m
Production efficiency η_p	$36.1\% \times 2$	
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



You can see the limitations from the integer and half-integer resonances, however it is good enough for the IDS-NF beam!

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 [pi mm rad]	30	20
Ring inclination	10°	5.8°

Design considerations

Design Aims
Maximize 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 << natural decay cone of neutrinos
- Imposes a minimum beta in the production straight

Beam divergence condition

$$x' = \sqrt{\frac{\varepsilon_{rms}}{(\beta_r \gamma_r)\beta}} < \frac{0.1}{\gamma_r} \quad \Rightarrow \quad \beta \propto \gamma_r$$

ε_{rms} =~ 5.7 π m rad (approximately) implies β >~ 25 m

STFC ASTeC

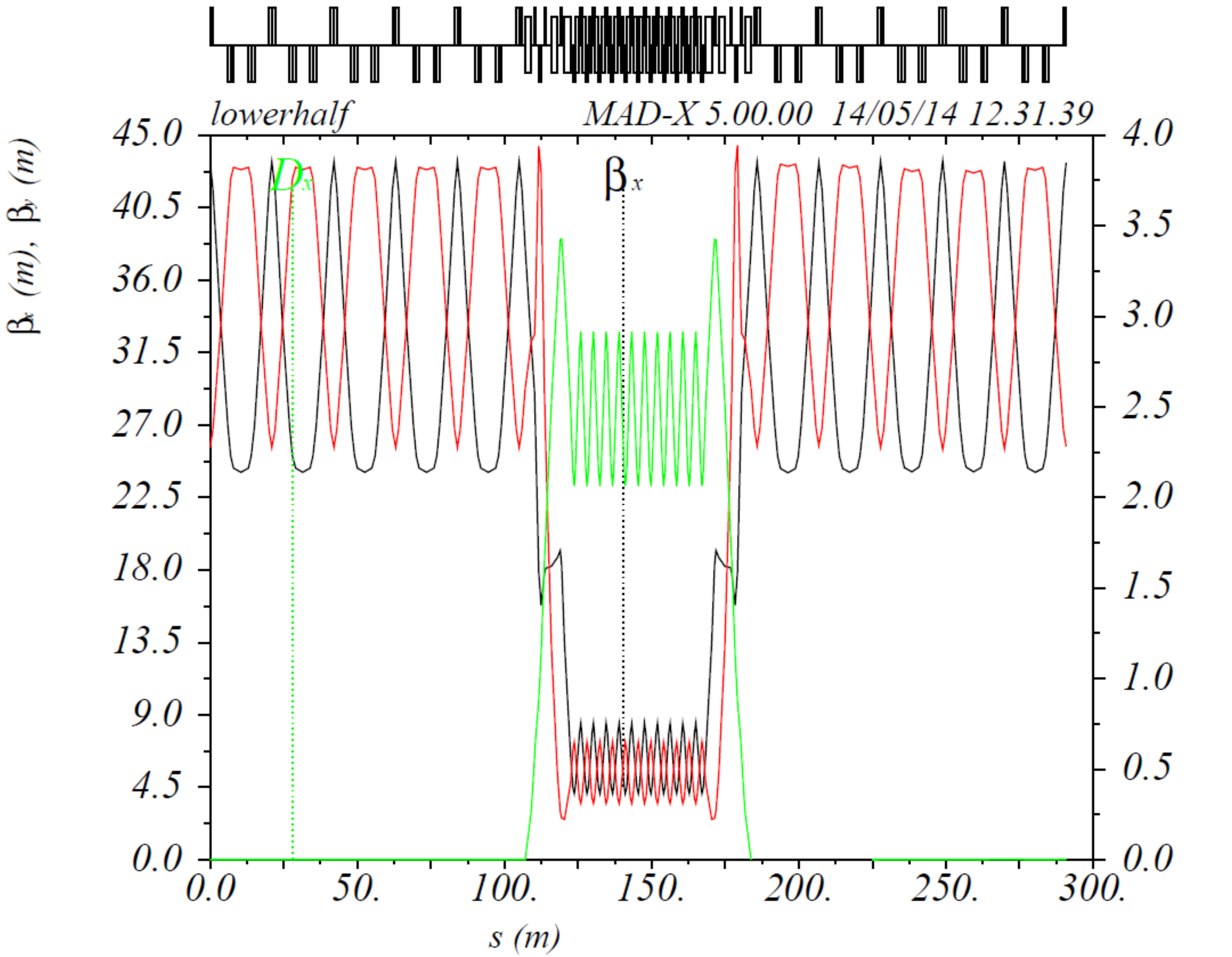
Lattice overview (FDDF in the production straight)

Imperial College London

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 (Qx, Qy)	5.4, 6.13 (needs readjusting		
Chromaticity (ξx, ξy)	-5.1, - 6.1		

Momentum acceptance is ~0.25/ξ~4%

FDDF optics

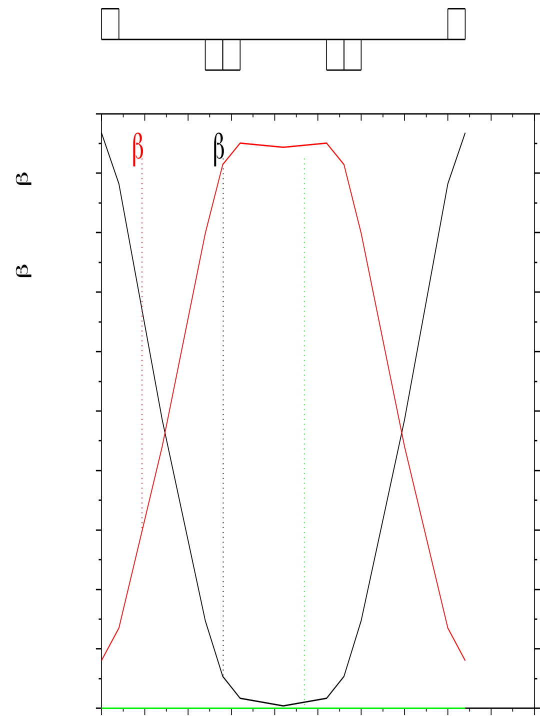


lowerhalf
MAD-X 5.00.00 14/05/14 12.31.39
D_x
β_x
β_x (m), β_y (m)
45.0
40.5
36.0
31.5
27.0
22.5
18.0
13.5
9.0
4.5
0.0
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0.0
50.
100.
150.
200.
250.
300.
s (m)

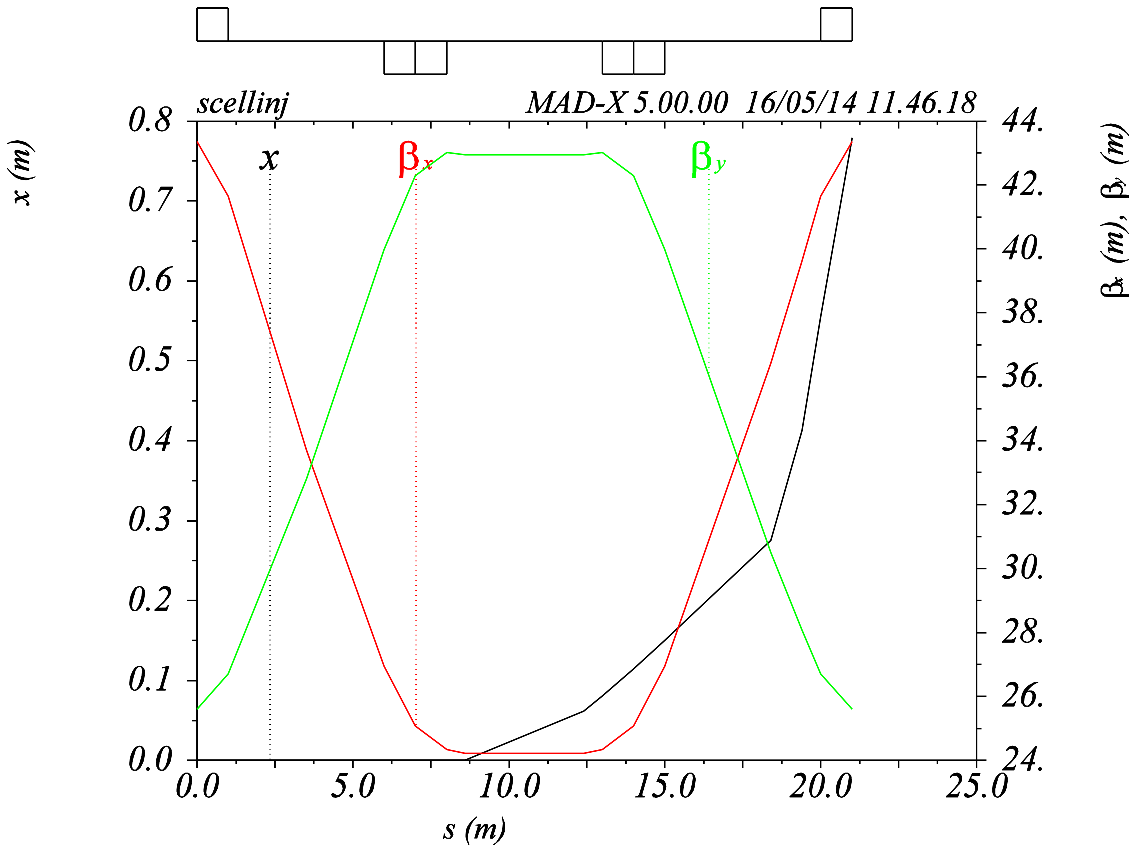
Production Straight (FDDF)

- 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 μs)
- Septum 1.67 T, 1m long

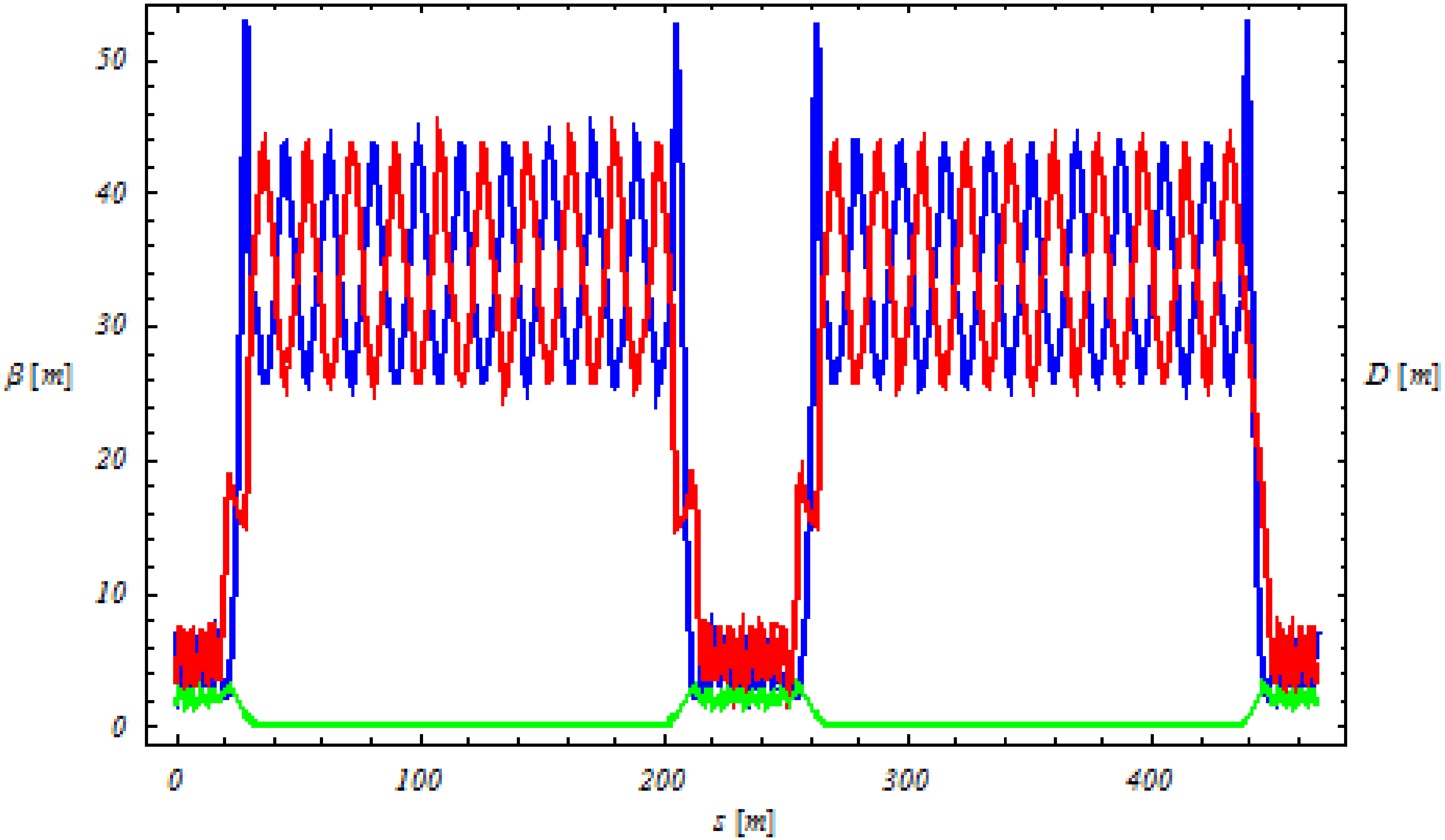
STFC ASTeC

Imperial College London

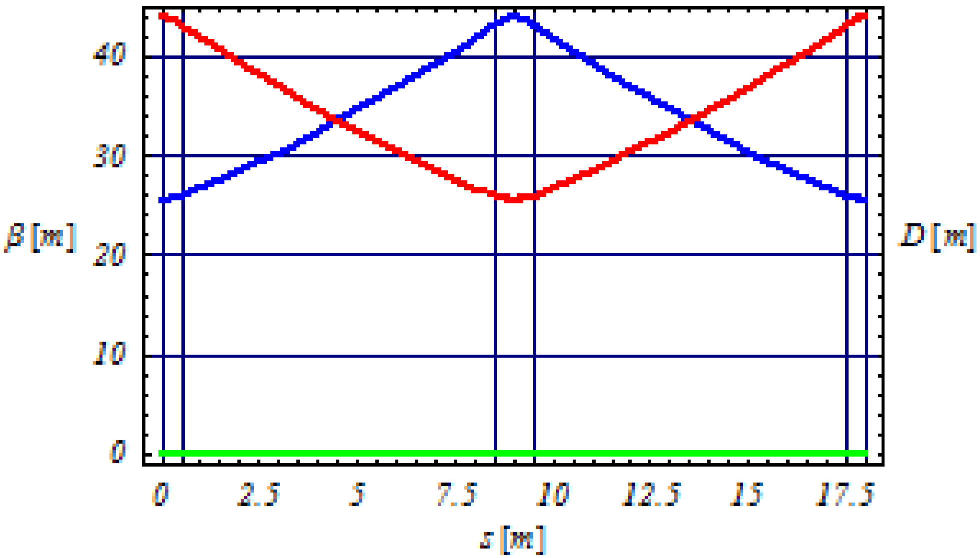
Lattice overview (FODO in the production straight)

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 (Qx, Qy)	4.65, 5.7 (needs readjusting)		

Preliminary NuMax ring with FODO production straight

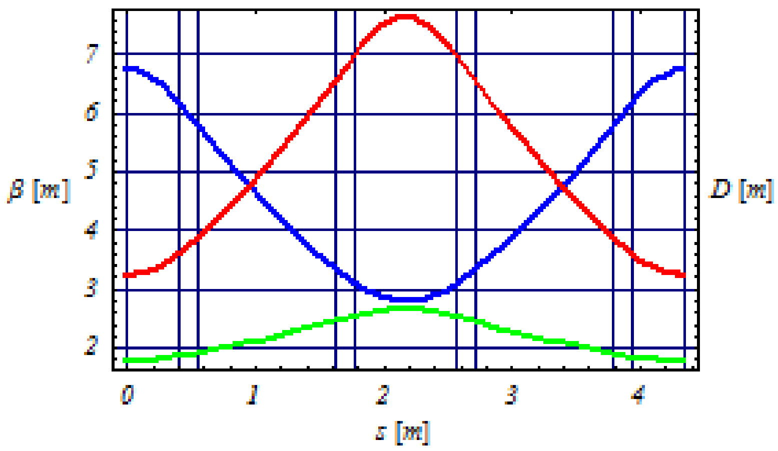


Cells of the ring with FODO-type production straight



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.

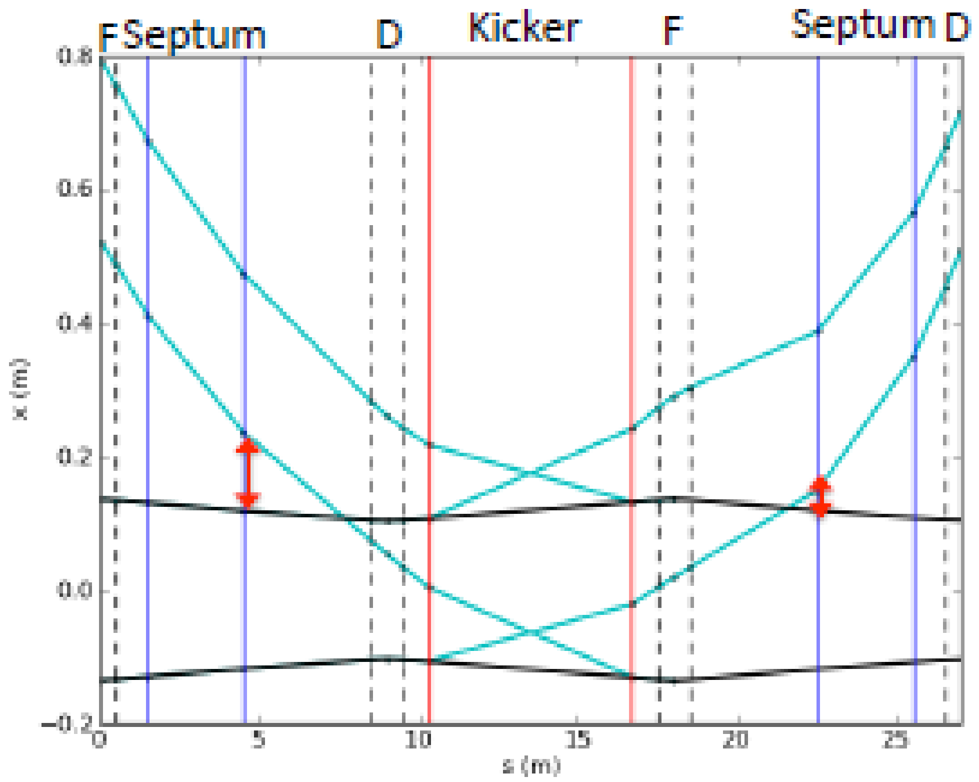
Dipole field 3 T.

- 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!

STFC ASTeC

Imperial College London

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.

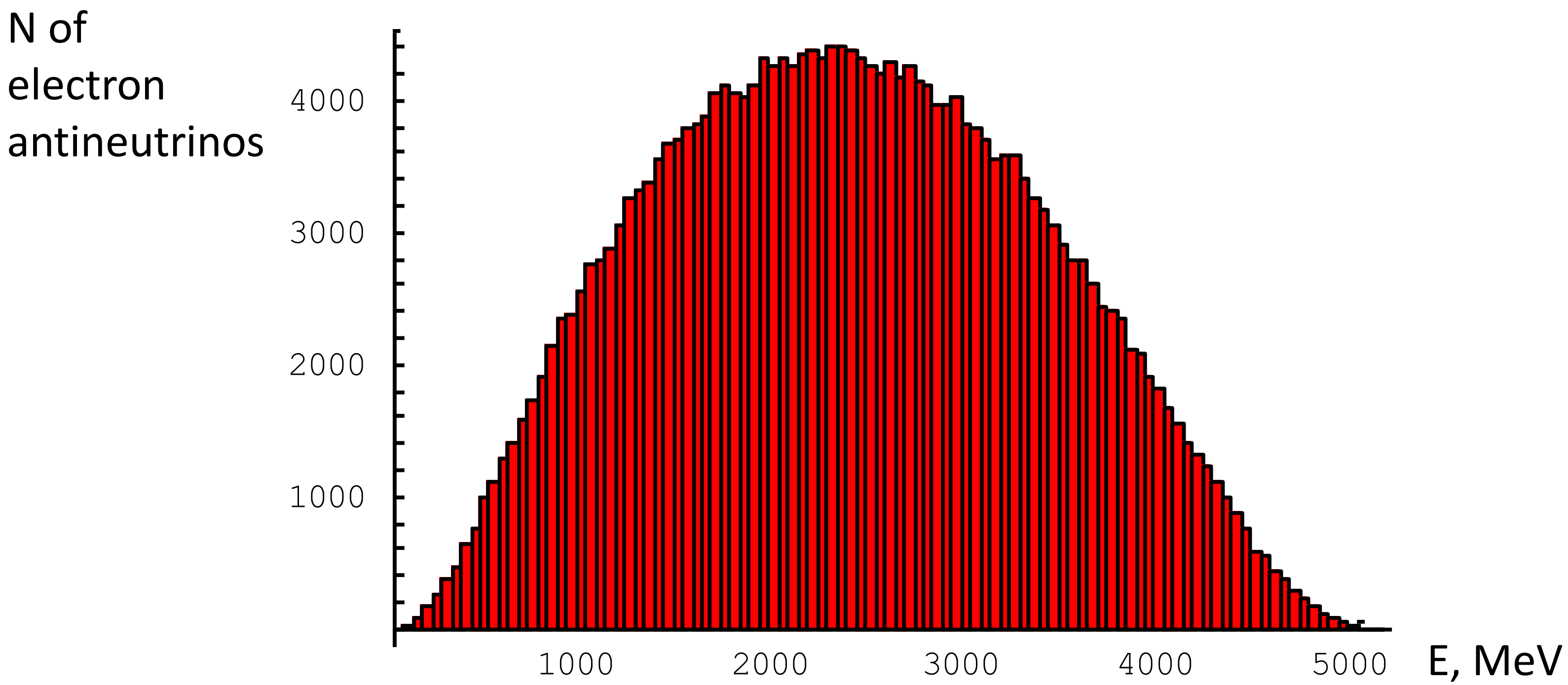
	Length (m)	Gradient
Drift	8	-
QF	1	1.03 T/m
QD	1	-1.03 T/m

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

NuMAX neutrino flux studies (1)

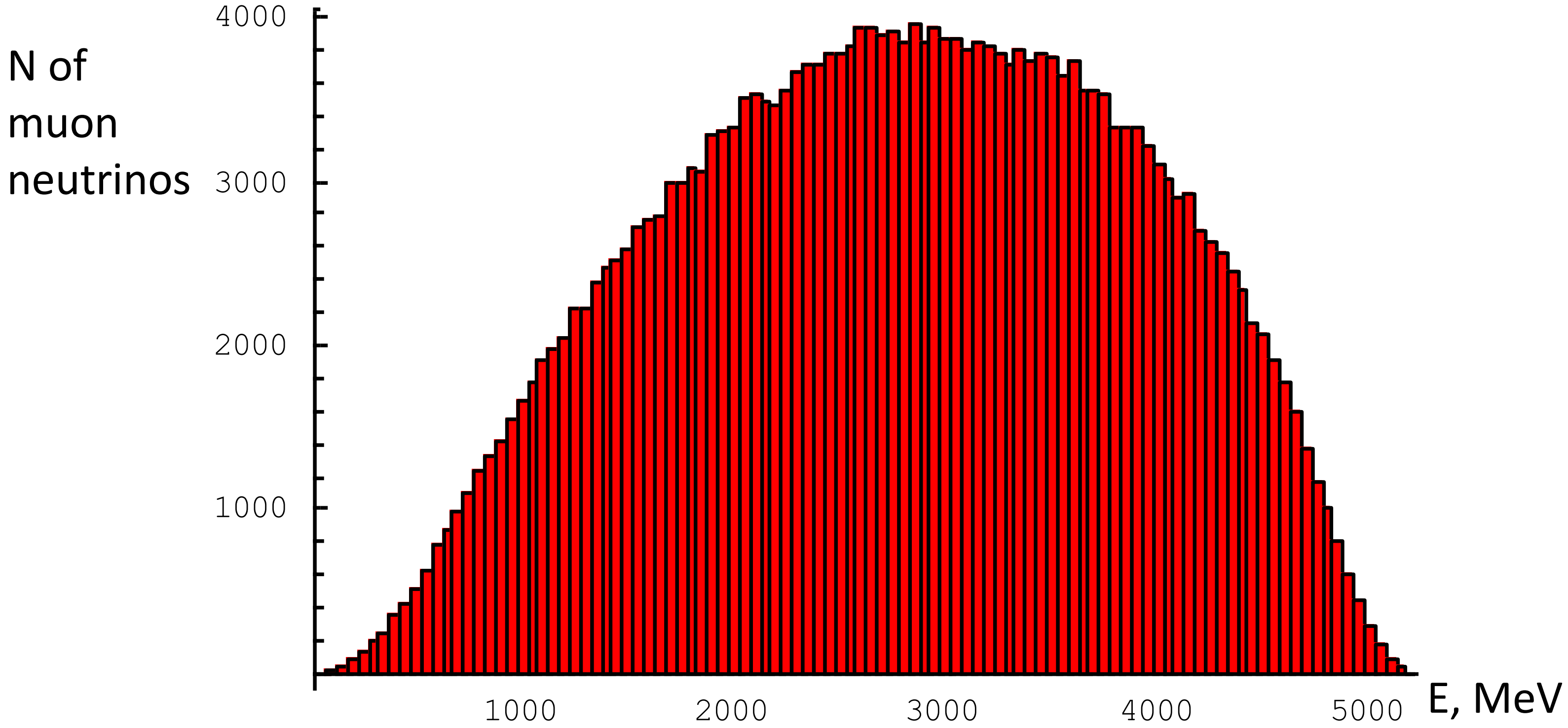
- Near detector: 50m distance, 5m diameter.

Results for 1000000 stored muons.

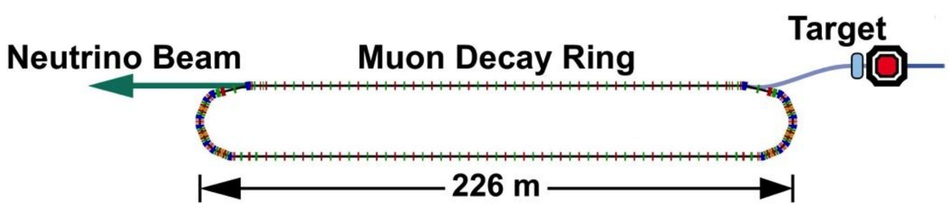


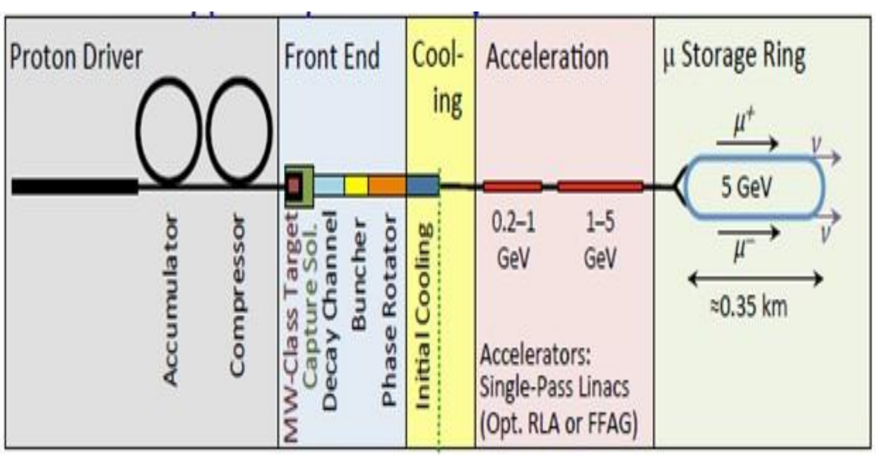
NuMAX neutrino flux studies (2)

- Near detector: 50m distance, 5m diameter. Results for 1000000 stored muons.



nuSTORM/NuMAX Global Parameters





	nuSTORM	NuMax
Muon Total Energy [GeV]	3.8	5
Bρ [Tm]	12.675	16.674
Geometrical acceptance [π.mm.mrad]	3000	423
Tilt angle [degree]	0-1	5.8
Momentum acceptance	±9(16)%	±6.3%
Long baseline length [km]	2	1400
Injection type	Stochastic	Full aperture with kicker

Comparison
(for fraction of parameters)

	nuSTORM-FODO	nuSTORM-RFFG	NuMax
Circumference [m]	480.3	500	468.2 (582)
Dipole B field [m]	4.14	3 (in combined f. mag.)	3
Dipole total aperture HxV [m]	~0.3x~0.27	~0.96x~0.56 (in c.f.m.)	~0.42x0.13
Production straight magnet aperture [m]	~0.6	~0.6 m	~0.35

Common technologies/elements for NuMax and nuSTORM

- SC magnets with large aperture
  - We know we can make them
  - ...but we want to make them efficiently
  - -> We want magnets with large aperture (including combined function ones -> nuSTORM FFAG option)
- Large aperture room temperature quads (or FFAG-type -> for nuSTORM FFAG option)
- Pion/muon beam instrumentation
  - To measure orbit, beam size, current, tune.
- Beam instrumentation for the neutrino beam monitoring
  - To measure divergence
  - To monitor beam energy

STFC ASTeC

Imperial College London

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.

STFC ASTeC

Imperial College London

Future plans

- Design update
  - Ring optics
  - Injection scheme confirmation
  - Injection line layout/optics
- Tracking studies
  - Using realistic field models
  - Including errors
- Neutrino flux studies -> to motivate neutrino physicists more...

We aim to finalise these goals this September!

Longer term R&D Goals

- Large aperture SC magnets
- Large aperture room temperature magnets
- Muon beam instrumentation
- Beam instrumentation for the neutrino beam monitoring