Neutrino Factory Decay Rings

Studies in the framework of IDS-NF

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Our collaboration working on the Decay Ring within the IDS-NF

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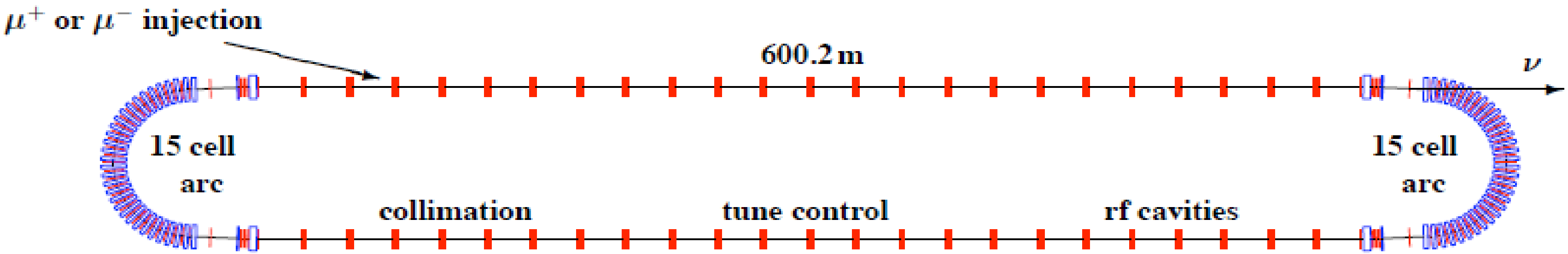
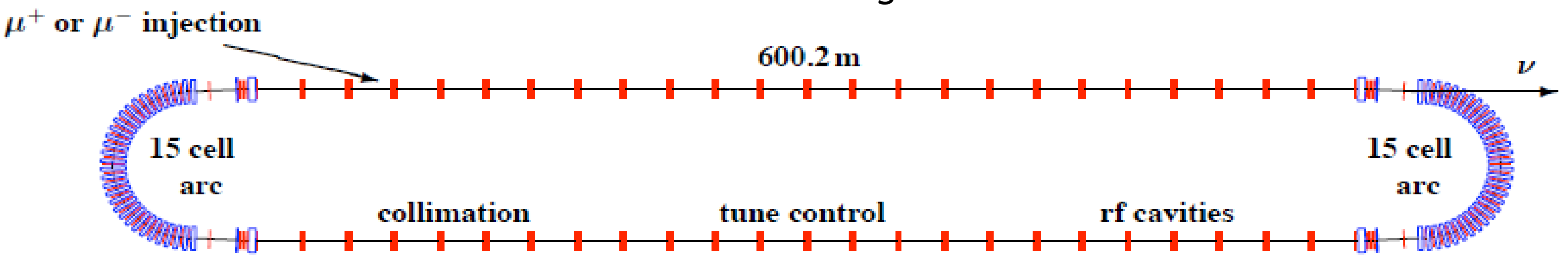


Introduction – Decay Ring

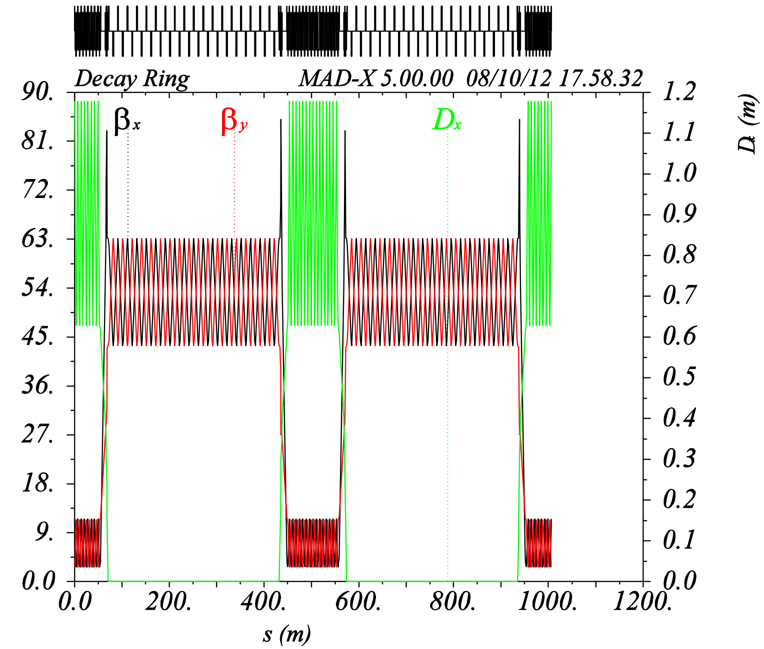
25 GeV design



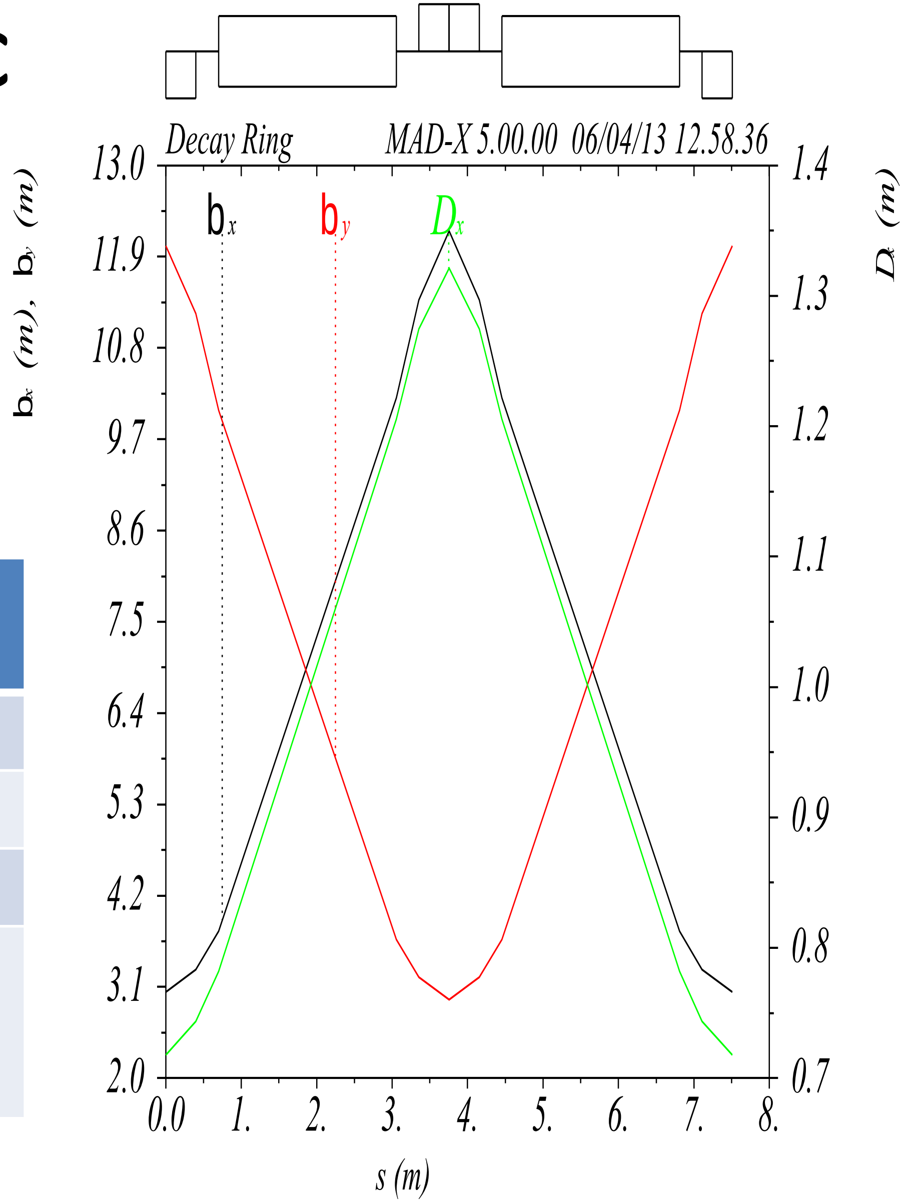
Design Aims
Reasonable neutrino production efficiency (η)
Low beam divergence in production straight (<0.1/γ)
Maintain bunch separation (100 ns)
Allow realistic injection scheme

10 GeV decay ring design (No insertion)

- Circumference 1006 m
- γ_T 13.927
- Production efficiency 35.8%
- Assumed total momentum spread ±2.5%
- Production straight length 360 m
- Arc length 106.2 m
- $(Q_{H,} Q_V) = (9.71, 9.55)$

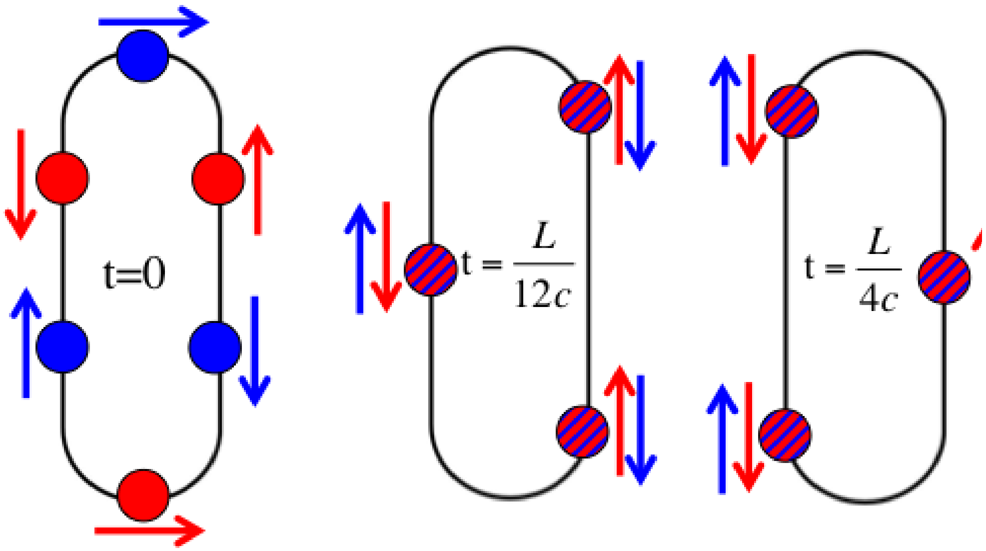


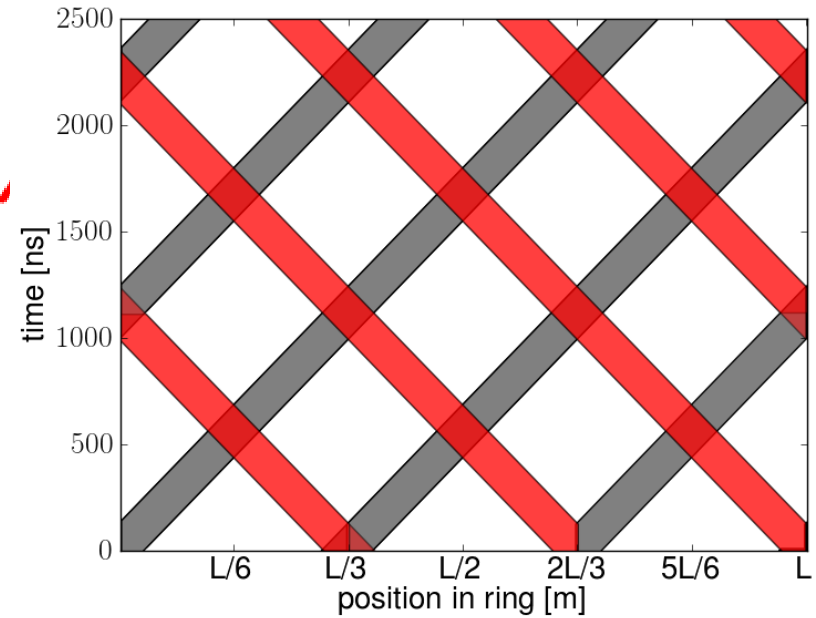
Arc



	Length	Field/Gradient
Drift	0.3 m	-
Dipole	2.35 m	1.46 T
Quad F&D	0.8 m	+/-14.78 T/m
Beam envelope in quads	6.0 cm	-

Ideal bunch crossing points

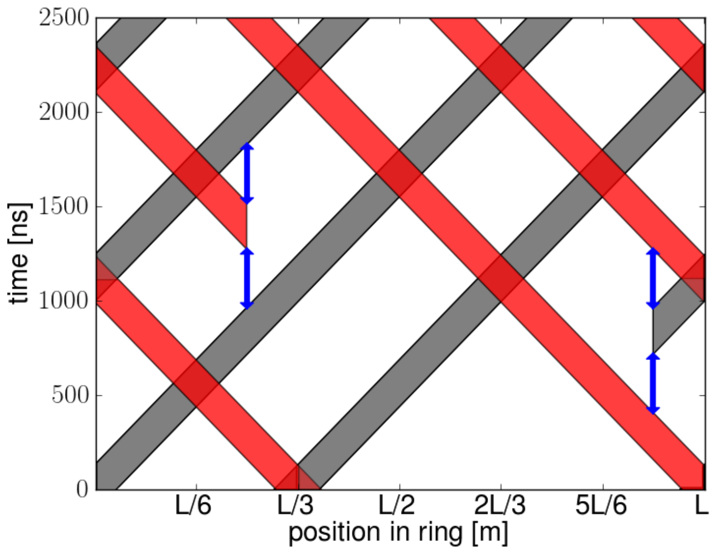




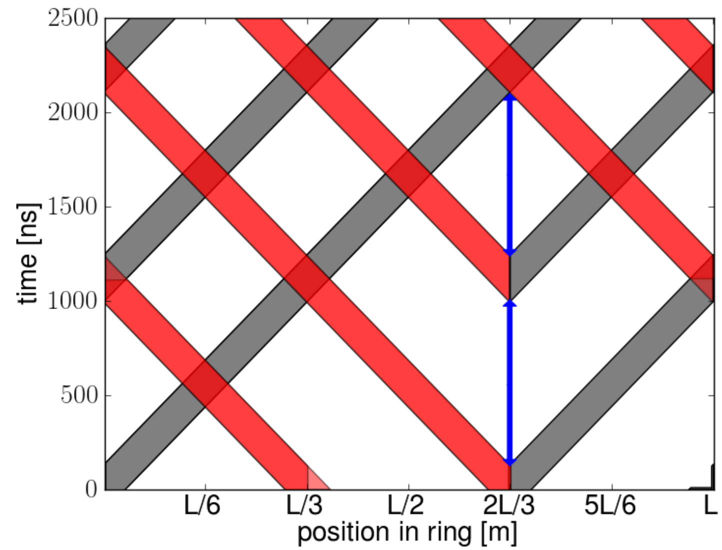
- When muon bunches are equally spread around the ring, two must be at arc centres to ensure equally spaced neutrino bursts.
- Bunches must cross at centre of production straight and ±L/6 away where L is the ring circumference.
- If $\eta \geq 2/3$, all crossing points will lie in production straight.

Injection timing

Inject in between crossing points



Inject into crossing points



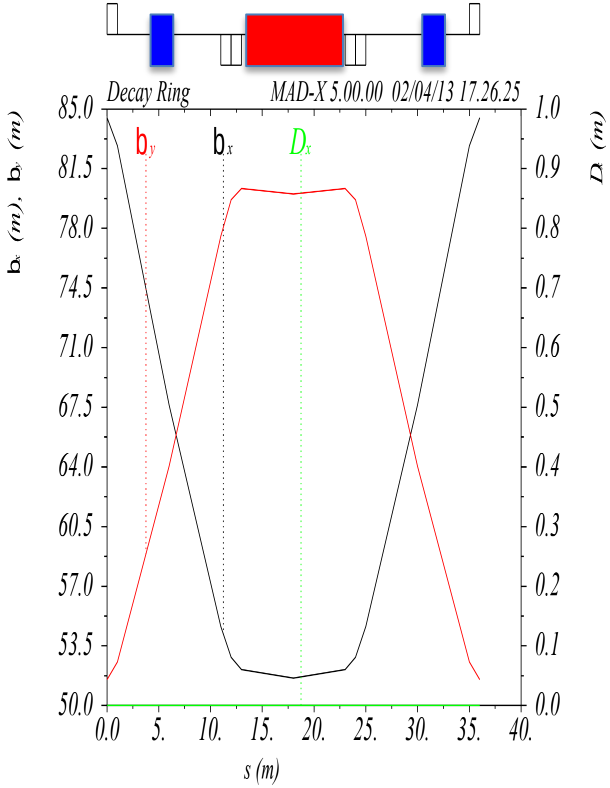
- Injection delay L/(6c)
- Kicker rise/fall time is L/(6c) $-t_{bunch}$

- Simultaneous injection
- Kicker rise/fall time is L/(3c) $-t_{bunch}$

In both cases delay between consecutive pairs of bunches is (n + 1/3)*L

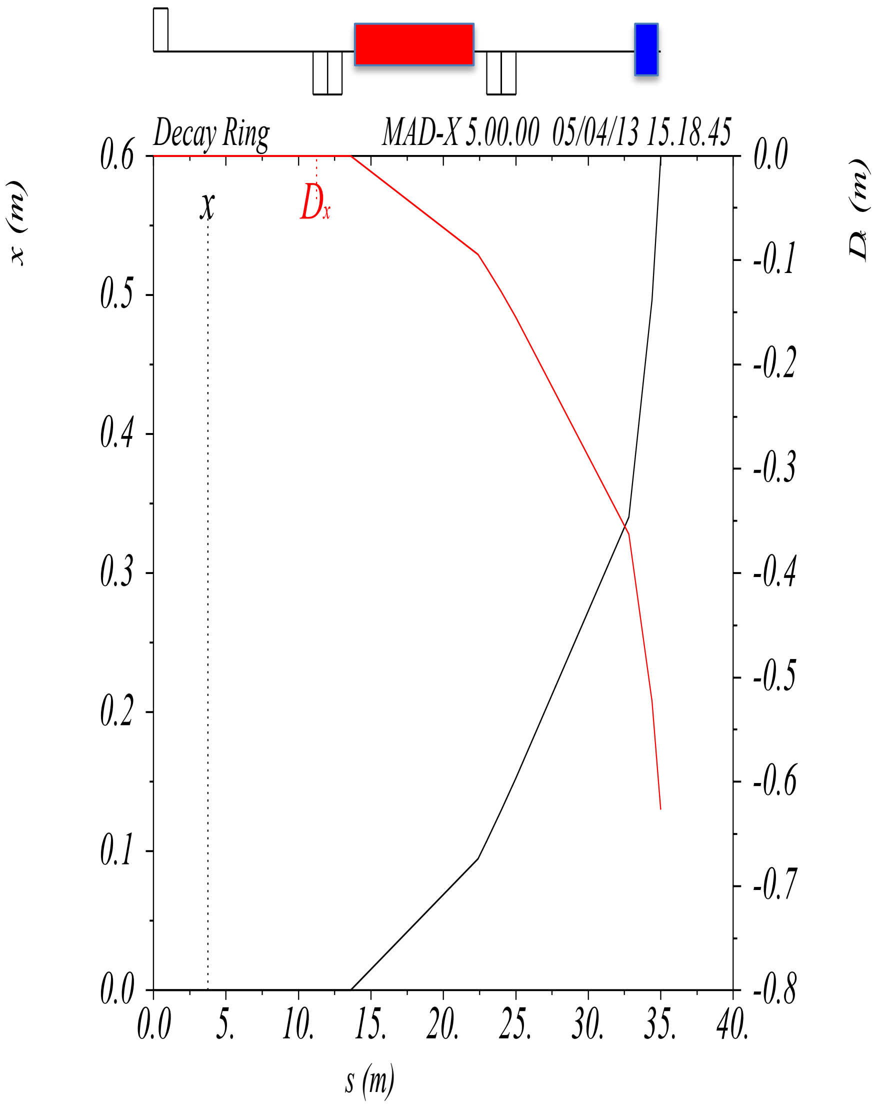
Injection into production straight (1)

- Ensure left-right symmtry for both sign injection – change lattice from FODO to FDDF.
- Injection section F-S-D-K-D-S-F
- Qx,Qy = 0.094, 0.084



	Length (m)	Gradient (T/m)	Aperture 1.3*√(εβ) (m)
D	2.0	-0.34	0.207
F	2.0	0.68	0.213
Drift	10.0	-	-

Injection into production straight (2)



- Ensure 2cm separation between injected and circulating beam at septum exit.
- Injected beam excursion in kicker magnet 9.5 cm, in D magnet 15.2 cm.

	Length (m)	Field (T)	Angle (rad)
Kicker	8.8	0.08	0.022
Septum	1.6	3.06	0.147

Kicker design for 25 GeV muon FFAG

Table XXVIII. Parameters of the kicker system

Kicker total aperture (h× v)	0.3× 0.3 m
Kicker length	4.4 m
Rise/ fall time (5-95%)	1.9 μs
Kicker max field	≈ 0.1 T
Kicker pulse duration at the top	0.3 μs
Charging voltage	60 kV
Peak current in the magnet	30 kA
Kicker inductance	5.1 μH
Kicker impedance	1 Ω
Peak current at switch	10 kA
Repetition rate	50 Hz
Number of sub-kickers	4-5
Number of PFNs per micro-pulse per sub-kicker	3
Total number of PFNs	36 (for 4 sub-kickers)
Total averaged power per kicker	≈ 1.25 MW
Total peak power per kicker	≈ 2.5 MW

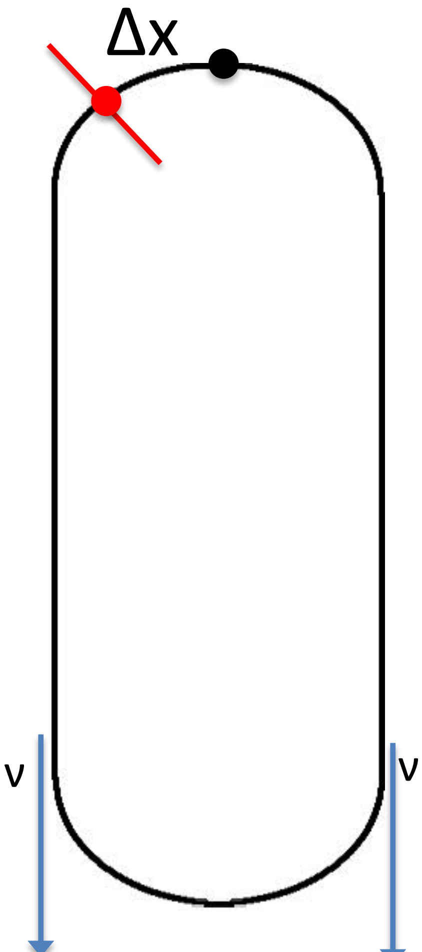
Decay ring injection at the production straight requirements

Kicker aperture 0.44 x 0.34 m

Rise/fall time 0.8 us

Difficult!

Injection into insertion
Injecting bunches simultaneously (1)



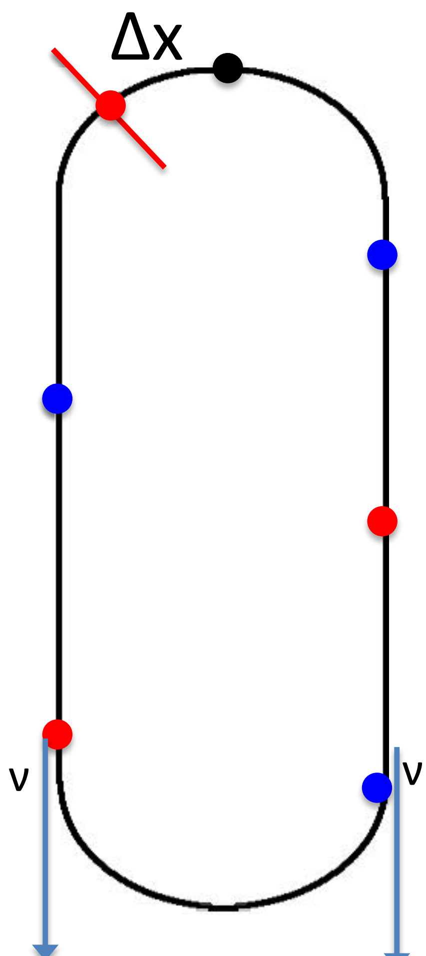
- Distance of injection point from arc center Δx should be enough to allow bunch separation at end of production straights.

$$Dx = \frac{c}{2}\left(t_b^{ini} + n_t h \frac{dp}{p} T_o + t_{gap} \right)$$

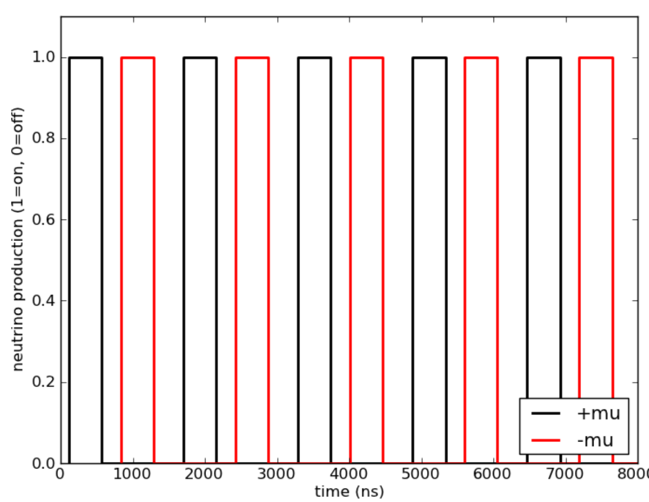
- Assuming 100ns minimum gap between signals for 4 mean lifetimes, and phase slip 0.005 then Δx = 83.7m.
- In current design half the arc is 53.1m, so injection point should be 30.6m further away from end of arc.

Injection into insertion

Injecting bunches simultaneously (2)

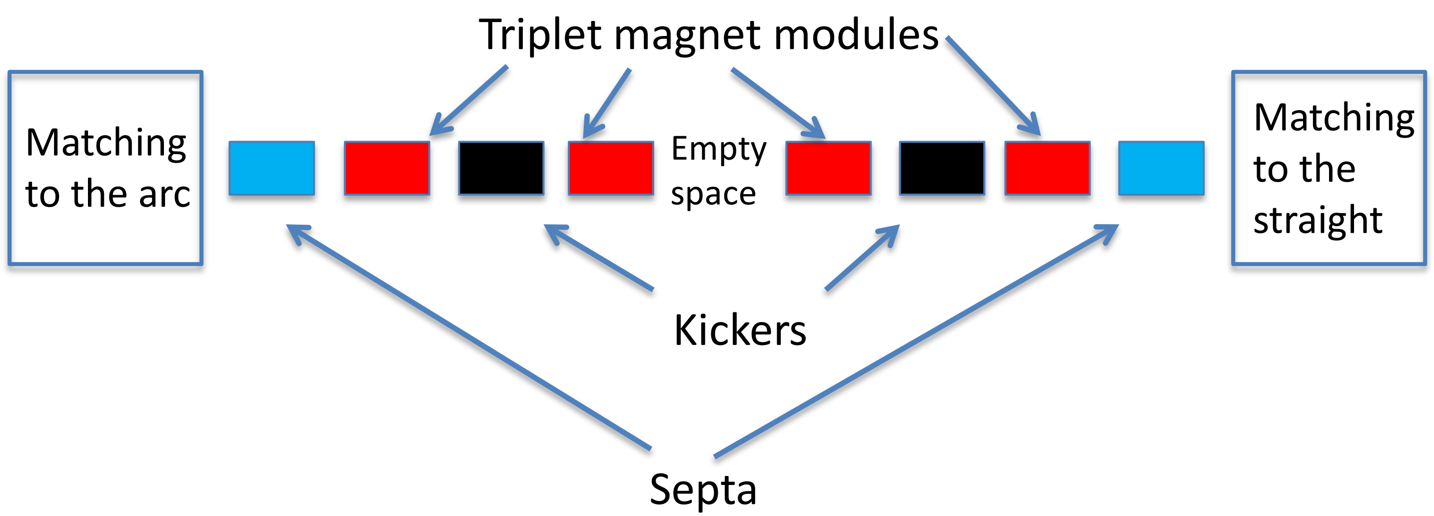


- Distribution of bunch crossing points is left-right assymetric, in general.
- Means neutrino bursts separated by two different time intervals which alternate.
- Time separation is still more than the 100 ns required by detectors.

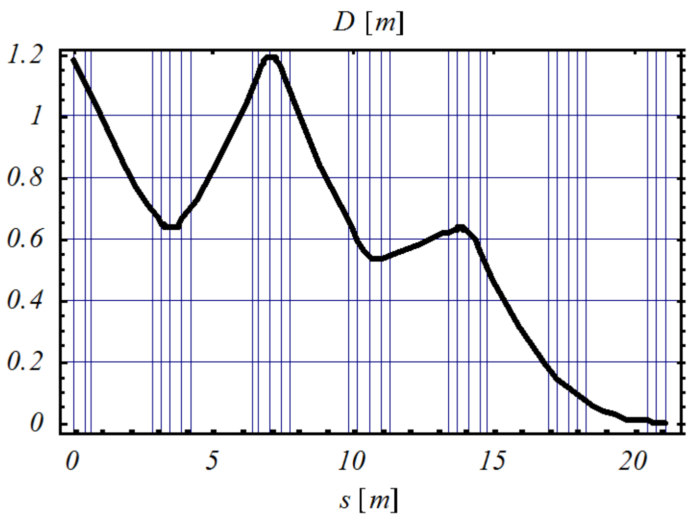


Conceptual layout of the injection insertion

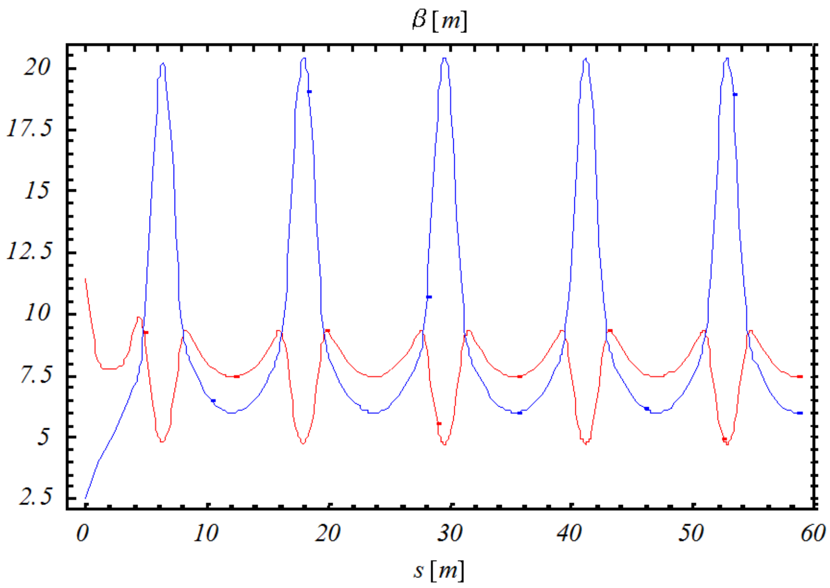
• Arc-type cells are to compact and straight cells has very large beam size and non-ideal phase advance for injection.
• Insertion based on triplets may provide additional length in the drift and phase advance can be optimised.
• Two kickers and two septa are needed in a symmetric configuration.



Optics of the injection straight



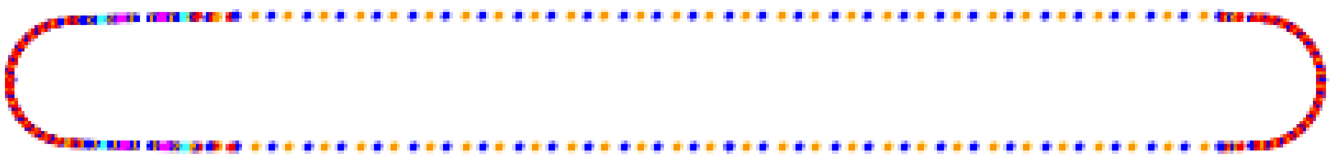
Dispersion matching at the end of the arc
Adding one more FODO cell and changing the dipole strength (relaxing some values)



Injection insertion matched to the arc

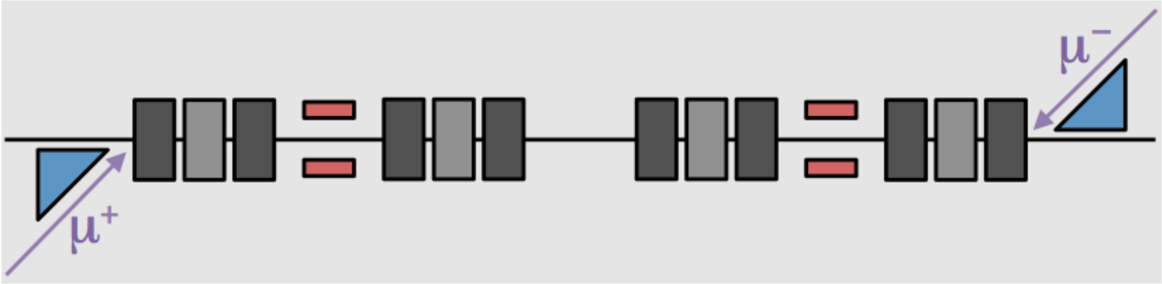
Matching to the straight: work in progress...

Ring with insertion



Circumference	1575.8
Production efficiency	35.56% x 2
Total tune	14.25, 14.88
Phase slip	2.8×10^{-3}
Turns per mean lifetime	39.6

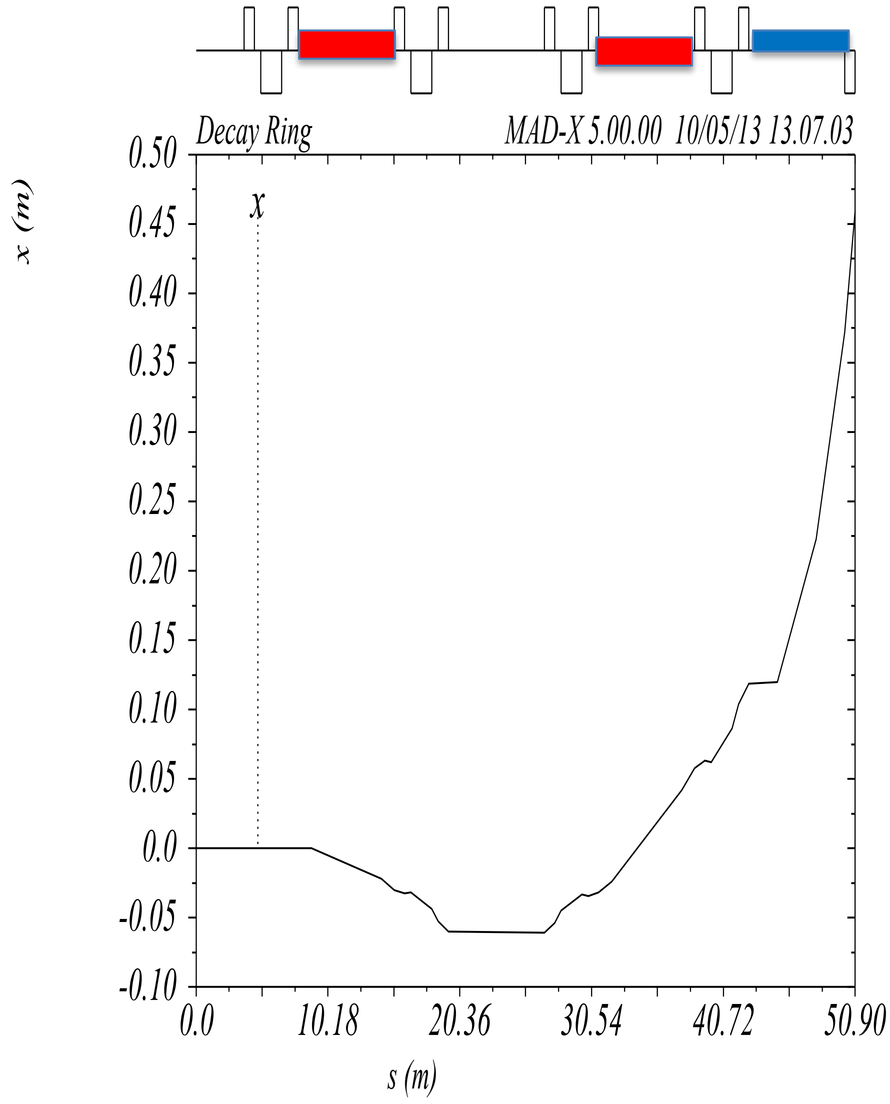
Insertion



- The insertion is located at either end of the upper arc. One insertion is used for injection, the other is included for left-right symmetry.
- The insertion is made up of four identical FDF Triplet cells with 5.6m long drift.

	Angle (mrad)	Length (m)	Field (T)	$\tau_{rise/fall}$ μs
Septum	67.5	3.0	0.75	-
Kicker	8.1	5.4	0.05	1.37

Injected beam trajectory

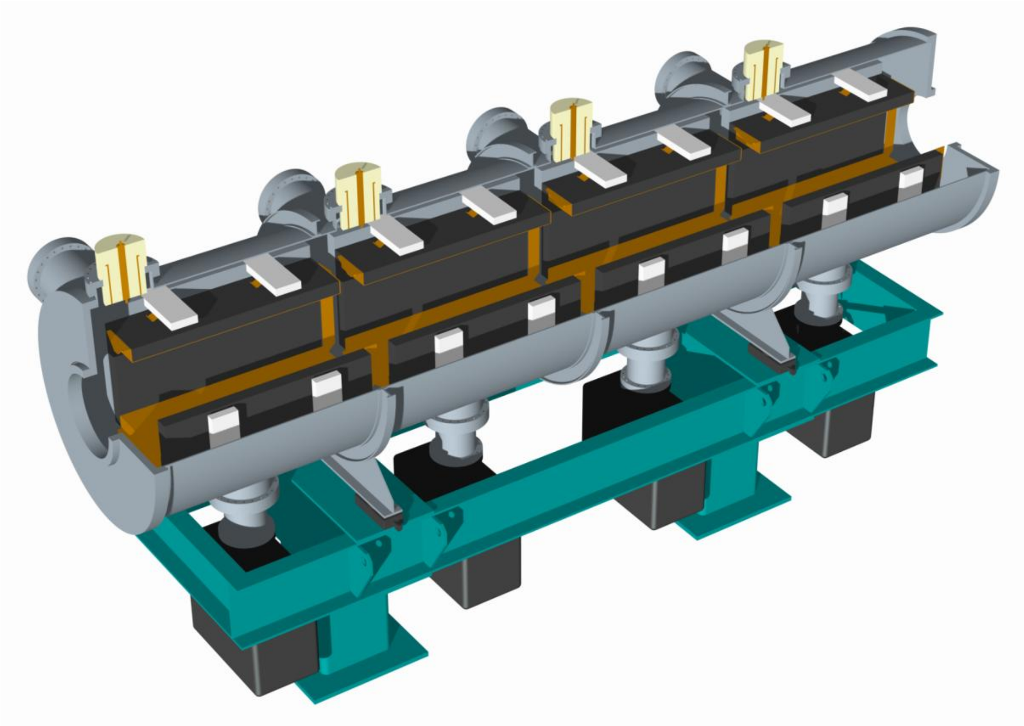


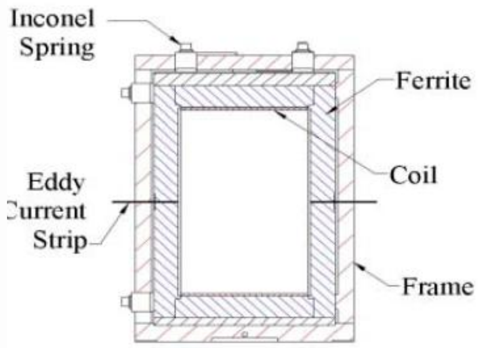
Injection trajectory of beam centroid. The injected beam is travelling from right to left.

Decay Ring Injection Kickers
Towards the realistic kicker parameters

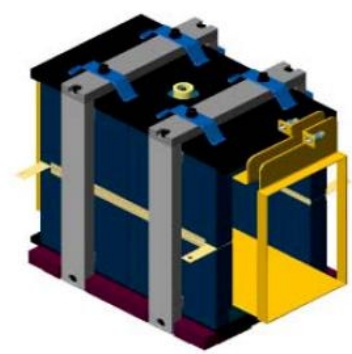
No of kickers	2
No of sub kickers	10
PFNs per kicker sub units	3
No of Pulse Forming Networks	30
Thyratrons	30
Travelling wave system design	
B field	0.06 T

Kicker aperture	0.18 x 0.18 m
Kicker length	5.4 m
Rise/Fall (5-95%)	1370 ns
Pulse duration at top	0.3 μS

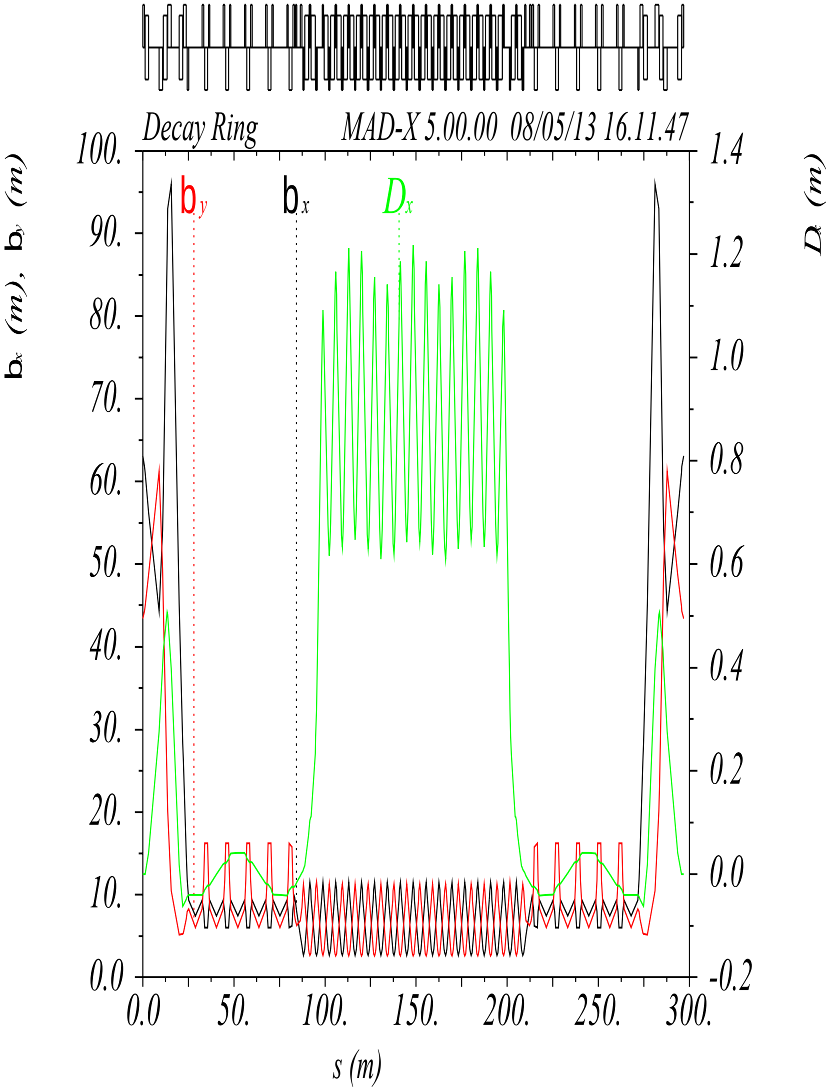




Cross Section

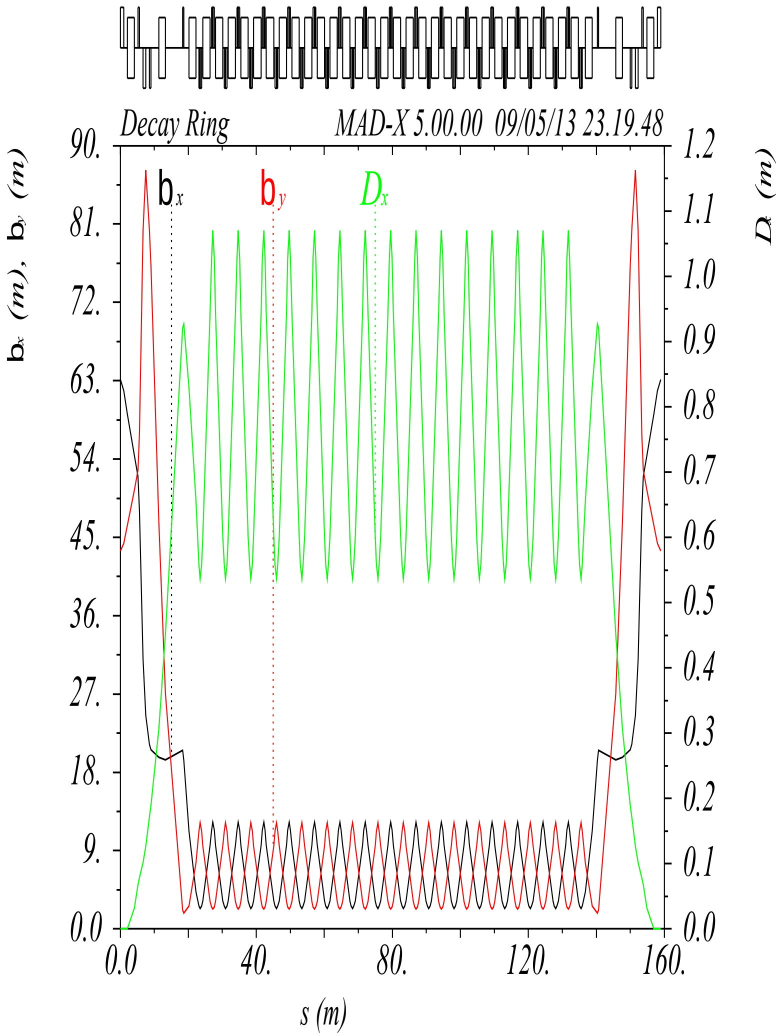

Magnet

Upper Arc



- Dispersion suppressor at either end of upper arc to eliminate dispersion before entering insertion. This should be further optimised.
- Optics matching from insertion to adjacent sections.
- Matching to production straight contains reverse bend to help collimate stray electrons and muons.

Lower Arc



- There is no need for insertions in lower part of the ring.
- The insertion contributes to the width of the racetrack since the arcs bend by less than 180 degrees. The lower arc should be scaled up to match this extra width.
- In order to use the same magnets as upper arc, just the drift lengths are scaled up. However, the focusing is adjusted by a small amount to optimise the working point.

Conclusions

- Injection into the production straight requires large aperture kickers with <1μs rise/fall time.
- Instead we consider adding an injection insertion. This adds to the decay ring circumference but allows a realistic injection scenario.
- Decay ring could be smaller (even by a factor of two), if single bunch could be used (like for a Muon Collider). Arc magnets could have higher field.