Status of the NF decay ring design

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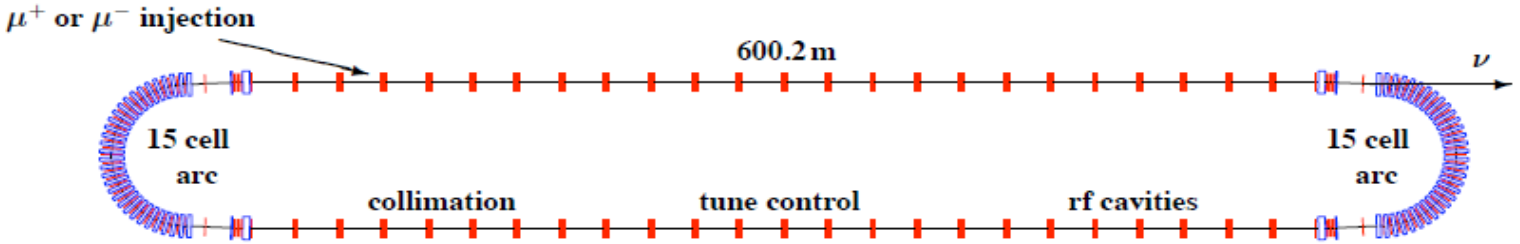
Introduction – Decay Ring

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

- Existing 25 GeV design has been effectively frozen since the ISS report (scaled from 20 GeV design).
- Modify design for lower energy muons.
- 12.6 GeV design for EURONu report. 10 GeV design in progress.

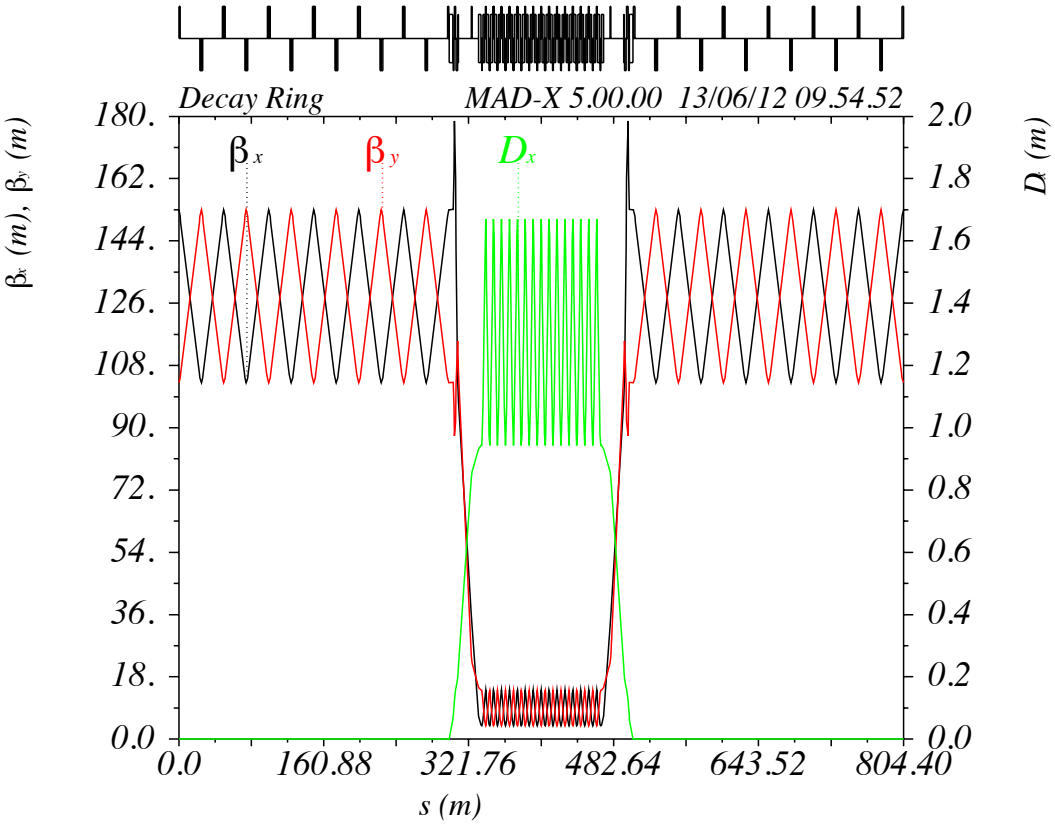
25 GeV lattice



Main parameters	
Circumference	1608.8 m
Production efficiency	2x37.25%
Depth at 18%	233 m
Depth at 36%	444 m
Transition gamma	14.53
Ring tunes (Qx,Qy)	8.52,8.21

Section	Length (m)
Straight	600.2
Matching	36.1
Arc	132

25 GeV Decay Ring Optics



Straight – High beta values to minimise beam divergence (< 0.1/γ

Matching – Includes bend to remove neutrinos from muons of high divergence.

Arc – Low beta value to minimise aperture.

Changes that effect decay ring design

Large theta13 measurement, lower muon energy

- Lower beta allowable in production straight
- Single decay ring required
- Shorter baseline - tilt reduced to about 10°

Bunch train structure

- ISS report - five 400ns bunches
- Now three 250ns bunches
- Room to reduce decay ring circumference

Lab/Detector pairs – decay ring tilt (data from Chris Prior)

NF site	Detector	Distance (km)	Tilt from vertical (degrees)
CERN	Oulu, Finland	2287	10.34
	Boulby, UK	1043	4.70
FNAL	Homestake, SD	1286	5.8
	Henderson, CO	1479	6.67
	Gaspe, Montreal	1996	9.01
	WIPP_Carlsbad, NM	1732	7.81
J-PARC	Yongwang, Korea	1274	5.73
	Daya Bay, China	2914	13.21
RAL	Oulu, Finland	2075	9.37
	Norsaq, Greenland	2806	12.72

Ring size and debunching

- To maintain minimum separation t_{gap} require the circumference is at least

$$L = n_b c \left(t_{gap} + n_\tau \tau \eta \frac{dp}{p} + t_{bunch} \right)$$

- Assume 2% rms momentum spread
- With transition gamma 14.193, debunch rate is 1.43 ns per turn
- The required circumference for 4 mean decay times is 1265.94 m

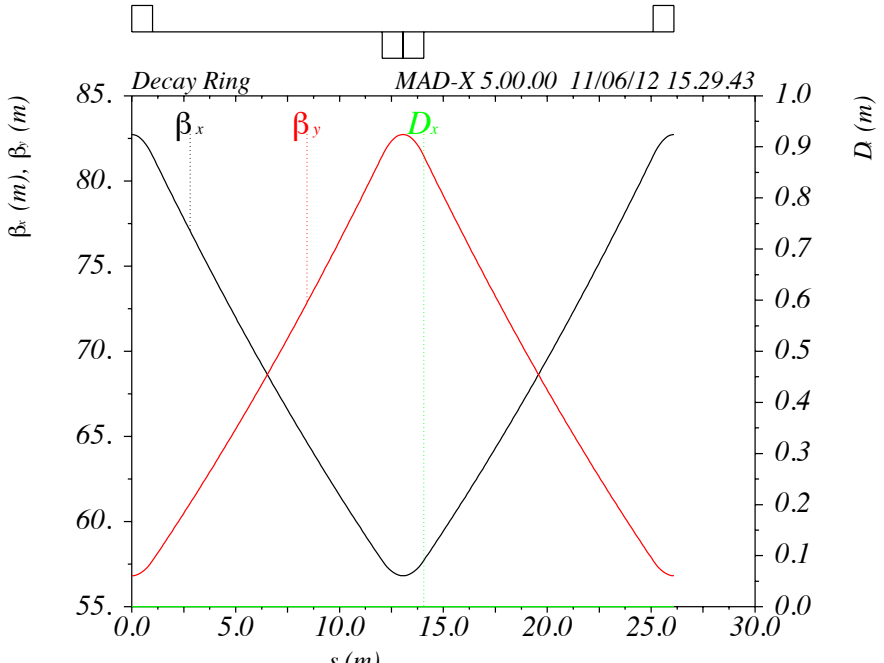
Production Straight at 12.6 GeV

Beam divergence condition

$$x' = \sqrt{\frac{\varepsilon_{rms}}{(\beta_r\gamma_r)\beta}} < \frac{0.1}{\gamma_r} \underset{\beta_r \approx 1}{\Rightarrow} \beta \propto \gamma_r$$

ε_{rms} = 4.8 π m rad implies β > 57.2 m at 12.6 GeV

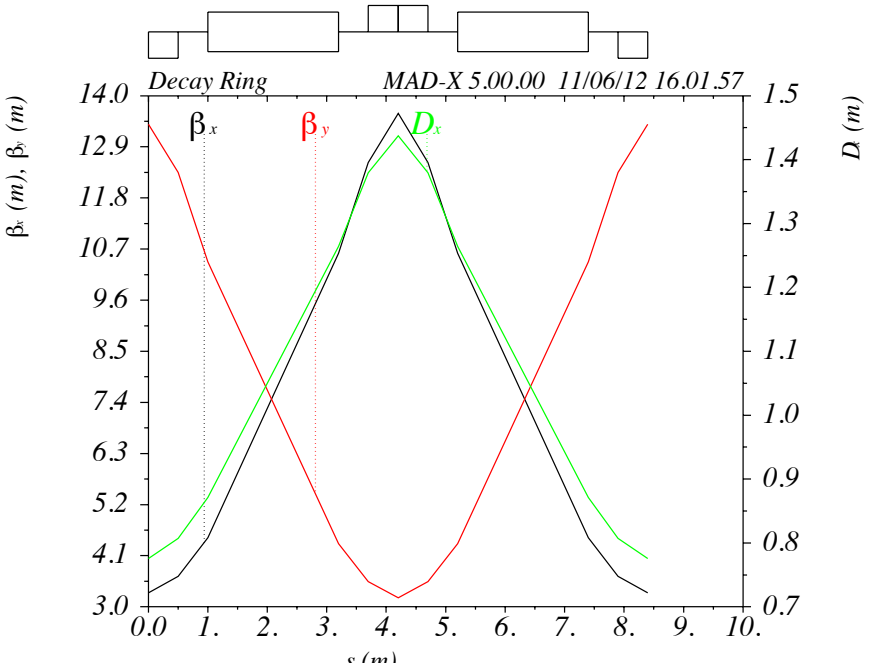
	Length	Field/ Gradient
Drift	11.05 m	-
Quad gradients	2.0 m	0.65 T/m
Beam envelope in quads	14.4 cm	-



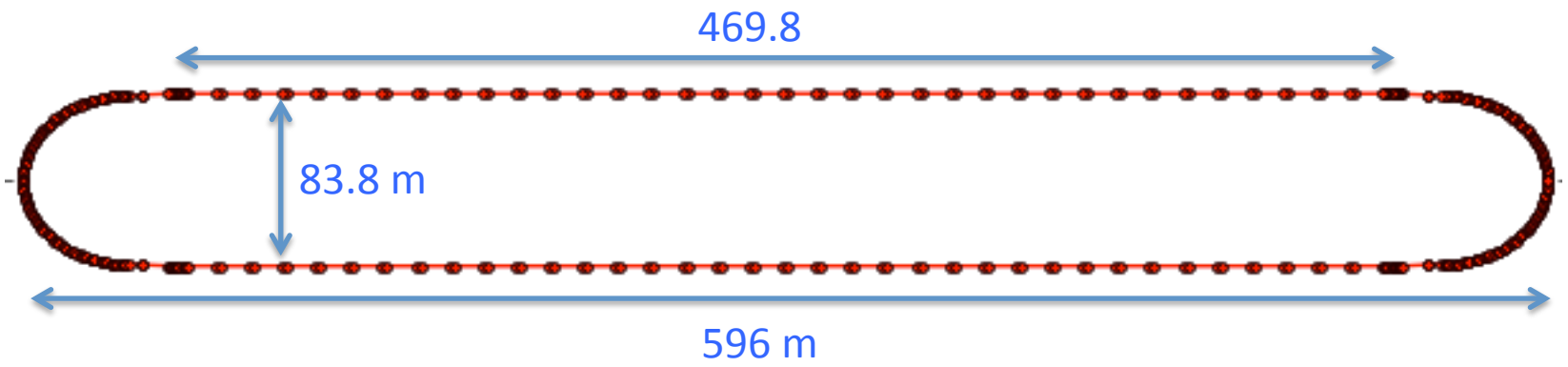
Arc at 12.6 GeV

- Reduce total length of arc but ensure transition gamma Υ_t is high enough to ensure debunching rate is low
- Reduce beta to reduce beam envelope, increase transmission.

	Length	Field/ Gradient
Drift	0.5 m	-
Dipole field	2.2 m	2.05 T
Quad gradients	1.0 m	13.7 T/m
Beam envelope in quads	5.8 cm	-



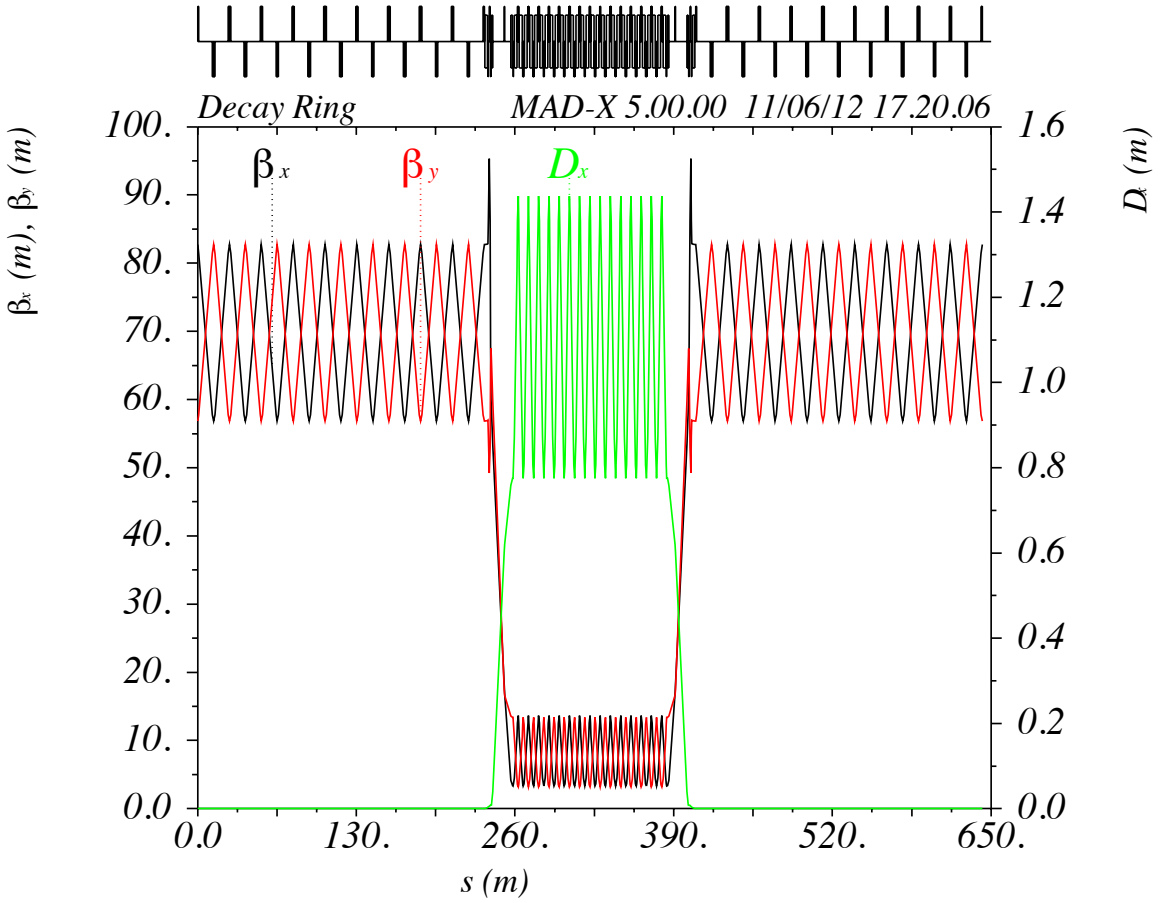
12.6 GeV lattice



Main parameters	
Circumference	1285.6 m
Production efficiency	2x36.55%
Depth at 10%	103 m
Gamma-transition	14.193
Ring tunes (Qh,Qv)	9.62, 9.4

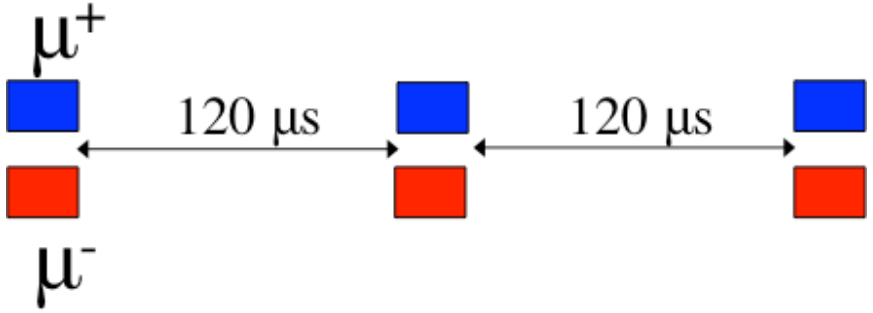
Section	Length (m)
Straight	469.8
Matching	23.5
Arc	126

12.6 GeV Decay Ring Optics

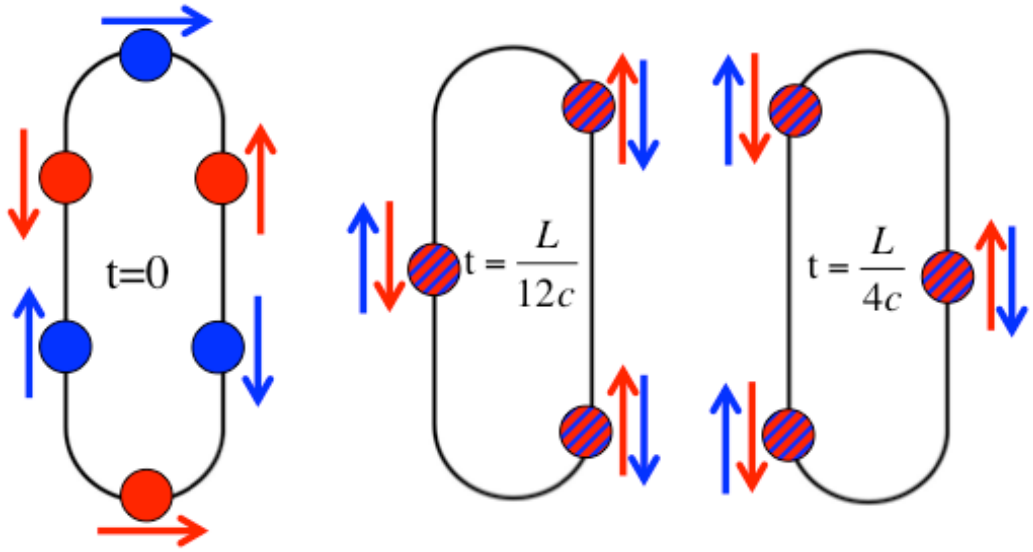


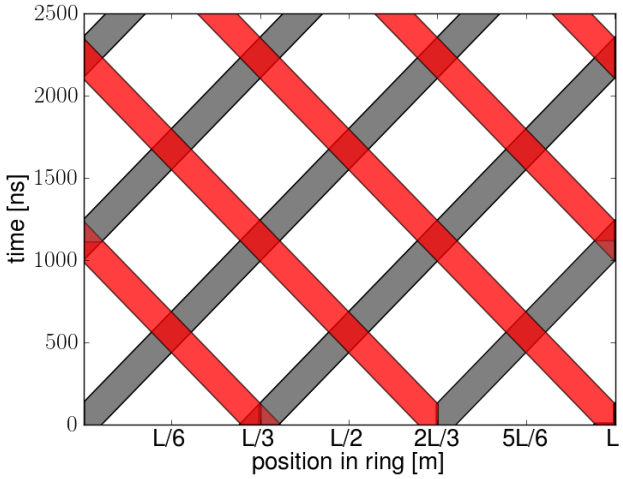
Bunch train structure

- Bunch train 240 μs - 3 short bunches (248 ns) separated by 120 μs. Repetition 50 Hz.



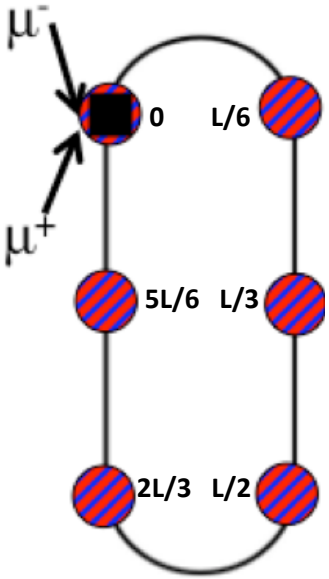
Bunch crossing points

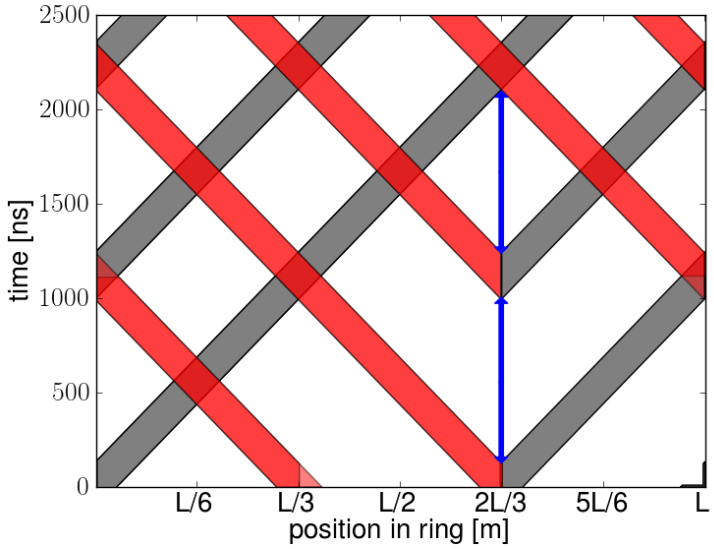




- When muon bunches are equally spread around the ring, two must be at arc centres to ensure equally spaced neutrino bursts.
- Bunches must cross at centre of production straight and ±L/6 away where L is the ring circumference.
- If η≥2/3, all crossing points will lie in production straight.

Injection Scheme





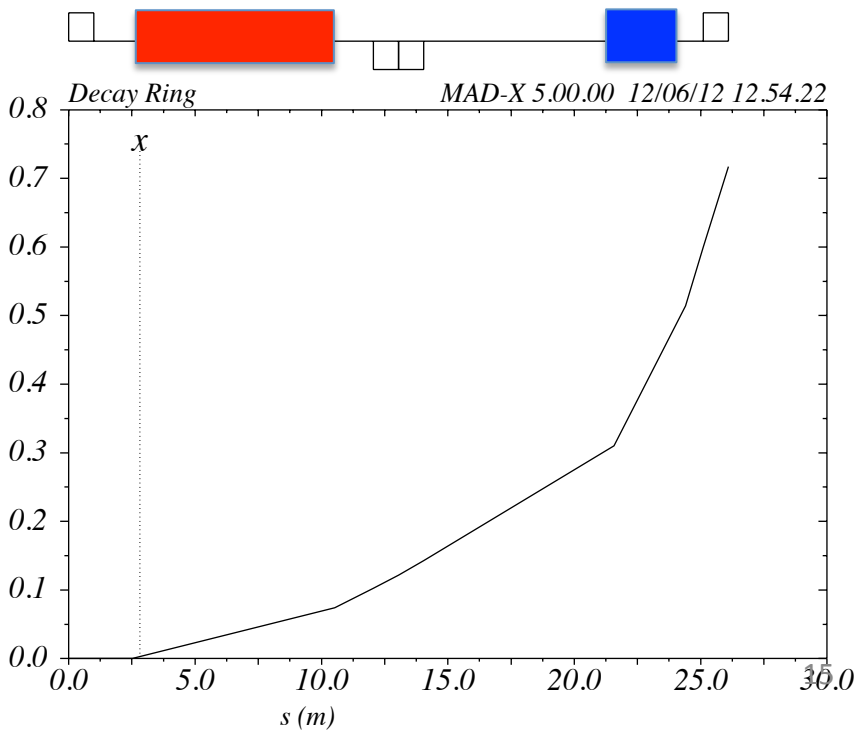
- Simultaneous injection of each bunch pair into crossing point
- Delay between consecutive bunch pairs (n + 1/3)*L
- Kicker rise/fall time is L/(3c) -t_{bunch}

Injection kicker

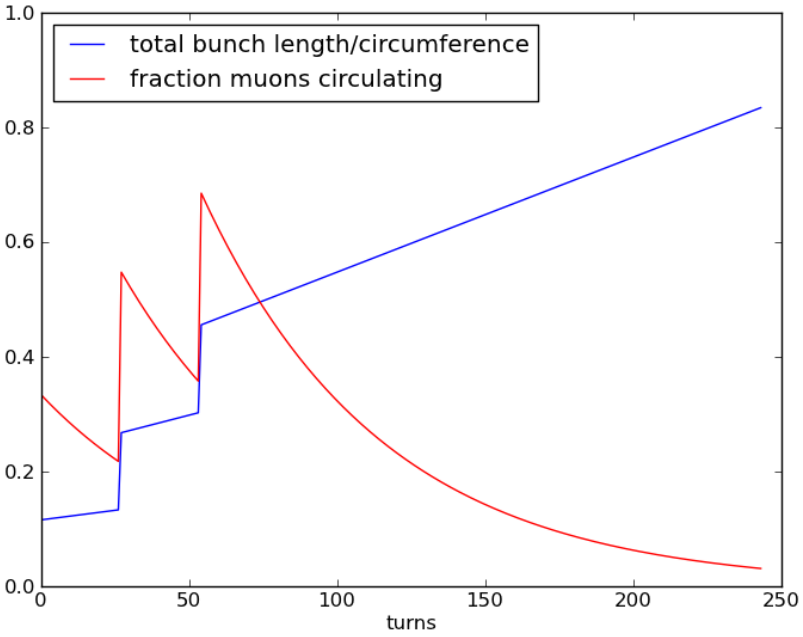
- Assume injection scheme 2 and injection into production straight.
- For symmetry require kicker at centre of drift.
- 1285m circumference implies 1.1 μs rise/fall for ideally placed kicker.

Element	Length	Angle	Field
Units	m	mrad	T
Kicker	8.0 m	18.5	0.097
Septum	2.825 m	100.0	1.488

Like muon FFAG kicker in terms of peak field and aperture. But kicker here is 3.6 m longer and 0.8 μs lower rise/fall time.



Extraction



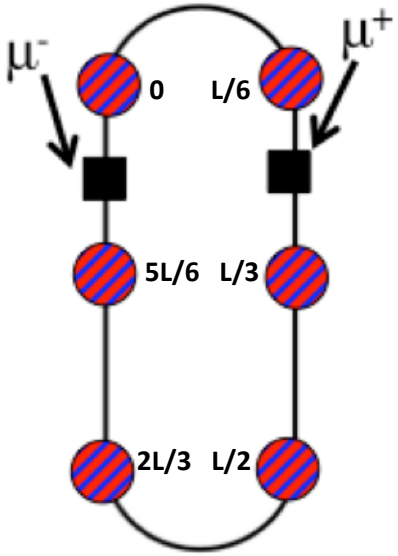
- Minimum bunch separation after 4 mean decay times (~250 turns)
- May need extraction system to avoid subsequent bunch merging and ensure clean signal for detectors.
- Just 3% of muons remaining at 250 turns. Dedicated extraction system or maybe reuse injection kicker?

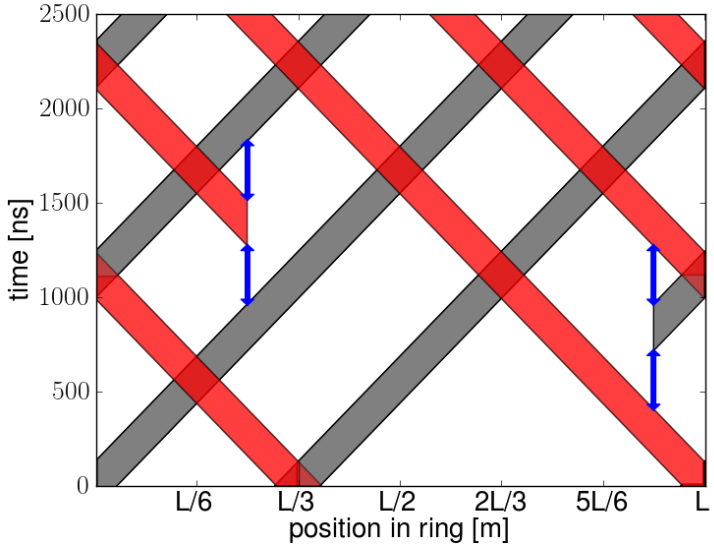
Discussion

- 12.6 GeV decay ring design established. 10 GeV design in progress.
- Engineering design also in progress (Collomb).
- Circumference lower limit given by kicker rise/ fall time and bunch merging.
- Injection scheme presented. Extraction scheme needs to be looked at.
- Decay ring period should be related to proton driver via $mT_p = (n + 1/3)*T_{d.}$

ADDITIONAL SLIDES

Alternative Injection Scheme





- Inject in between crossing points.
- Delay L/(6c) between both bunches in pair
- Delay between consecutive bunch pairs (n + 1/3)*L
- Kicker rise/fall time is L/(6c) -t_{bunch}