FFAG injection studies

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FFAG lattices

Design criteria (J. Scott Berg)

- Number of cells a multiple of 4 for symmetry purposes
- 20 drifts allocated to injection/extraction systems plus unspecified hardware
- Must inject/extract both signs in one ring – doublet looks impractical
- Three candidate lattices – A FODO with a cavity cell per drift, and triplet with one or two cavity cells per lattice cell (FCDC,FDFC, FDFCC)

Candidate FFAG lattices (J. Scott Berg)

Configuration	FDFC	FCDC	FDFCC
Cells	80	68	64
D length (m)	1.494717	1.420965	1.956090
D angle (mrad)	119.328	123.810	150.387
D shift (mm)	24.993	41.551	36.140
D field (T)	4.742932	5.090108	4.624750
D gradient (T/m)	-25.723141	-13.774185	-16.530751
F length (m)	0.997549	2.238741	1.286477
F angle (mrad)	-20.394	-31.410	-26.106
F shift (mm)	5.157	1.716	9.154
F field (T)	-1.112544	-0.793097	-1.077459
F gradient (T/m)	24.734679	11.442032	16.318167
Cavity cells	60	116	88
RF voltage (MV)	763.066	1475.261	1119.163
turns	17.3	9.0	11.8
D radius (mm)	87	94	115
D max field (T)	7.0	6.4	6.5
F radius (mm)	115	200	153
F max field (T)	3.9	3.1	3.6
Circumference (m)	519	521	546
Decay (%)	7.7	4.1	5.6
Cost (A.U.)	146.1	170.3	171.4
Long drift length (m)	**2.0**	**2.0**	**3.0**

Injection/Extraction schemes

Injection/Extraction assumptions

- Each kicker and septum assumed to be 60cm shorter than long drift – i.e. 1.4m or 2.4 m long
- All kickers have same top field, polarity may change
- Configurations must be mirror (anti)symmetric to allow use of one set of kickers by both muon signs
- Track 30 pi mm particle amplitude, i.e. the acceptance of the muon beam
- Aim for 2cm separation at entrance of septum
- No fringe field included

Superconducting magnet at J-PARC

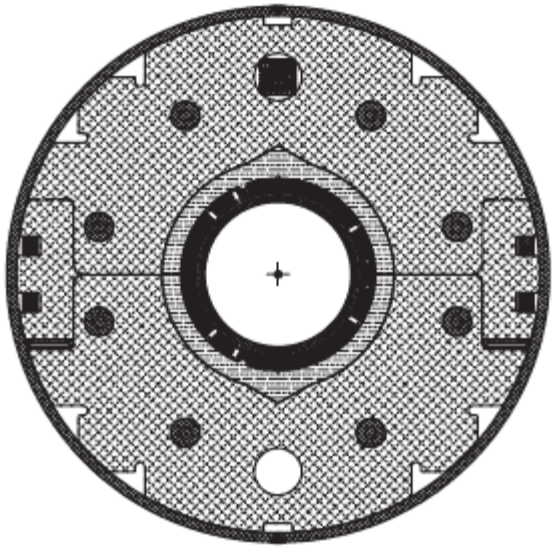


Figure 1: Cross sectional view of the superconducting combined function magnet, SCFM, for the 50 GeV proton beam line for the J-PARC neutrino experiment.

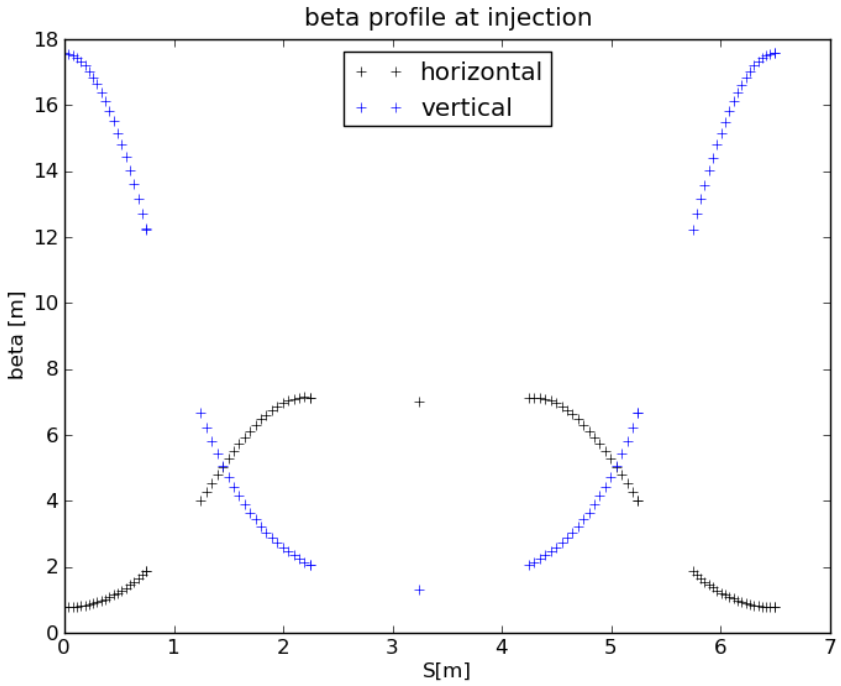
Table 1: Main Design Parameters for the SCFM

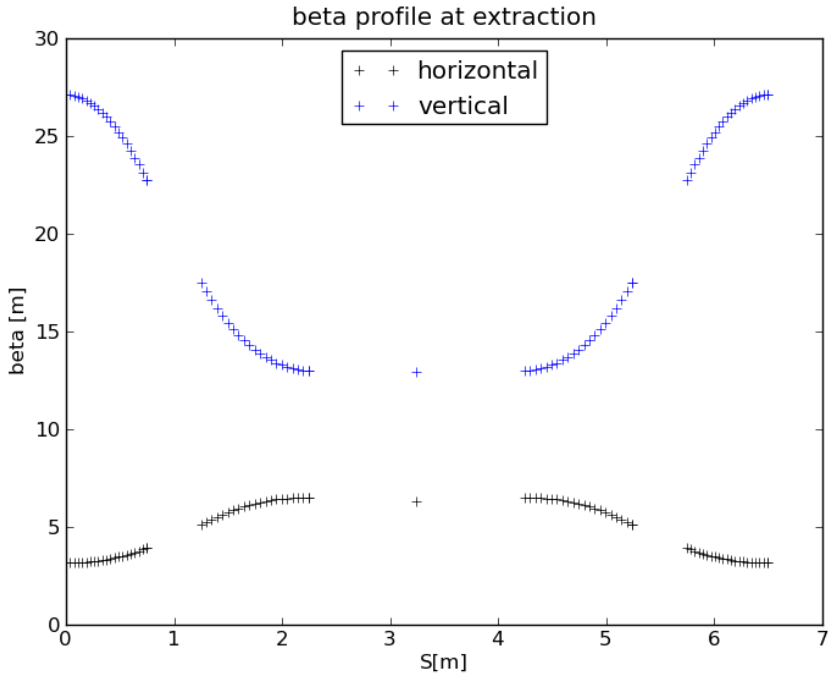
Physical & Magnetic Length	3630 & 3300 mm
Coil In. & Out. Diameter	173.4 & 204.0 mm
Yoke In. & Out. Diameter	244 & 550 mm
Shell Outer Diameter	570 mm
Dipole & Quad. Field	2.59 T & 18.7 T/m
Coil Peak Field	4.7 T
Load Line Ratio	72 %
Operational Current	7345 A
Inductance & Stored Energy	14.3 mH & 386 kJ

In the absence of magnet design – assume magnets will look like SCFM at J-PARC

"Status of Superconducting Magnet System of the J-PARC Neutrino beam line " – T. Ogitsu et. al. IEEE. Trans. Appl. Supercond. Vol. 19, No. 3 June 2009

Triplet 1 – FDFC

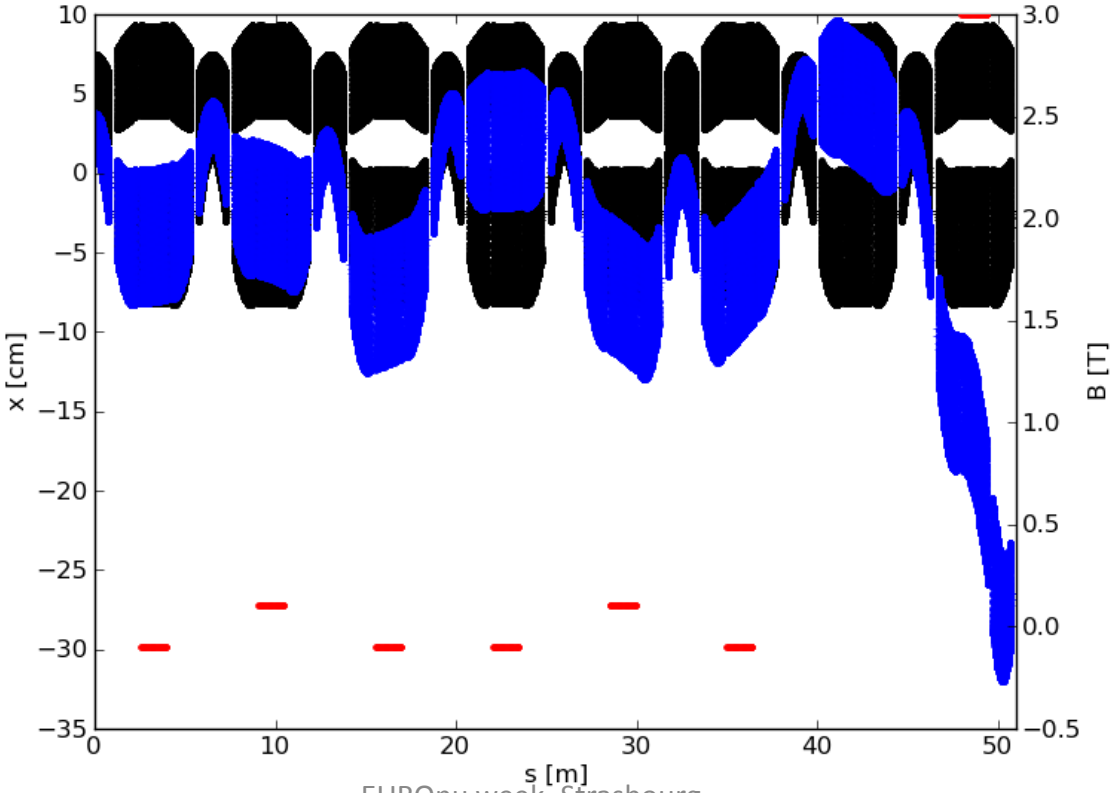




- Optics favour horizontal injection and vertical extraction

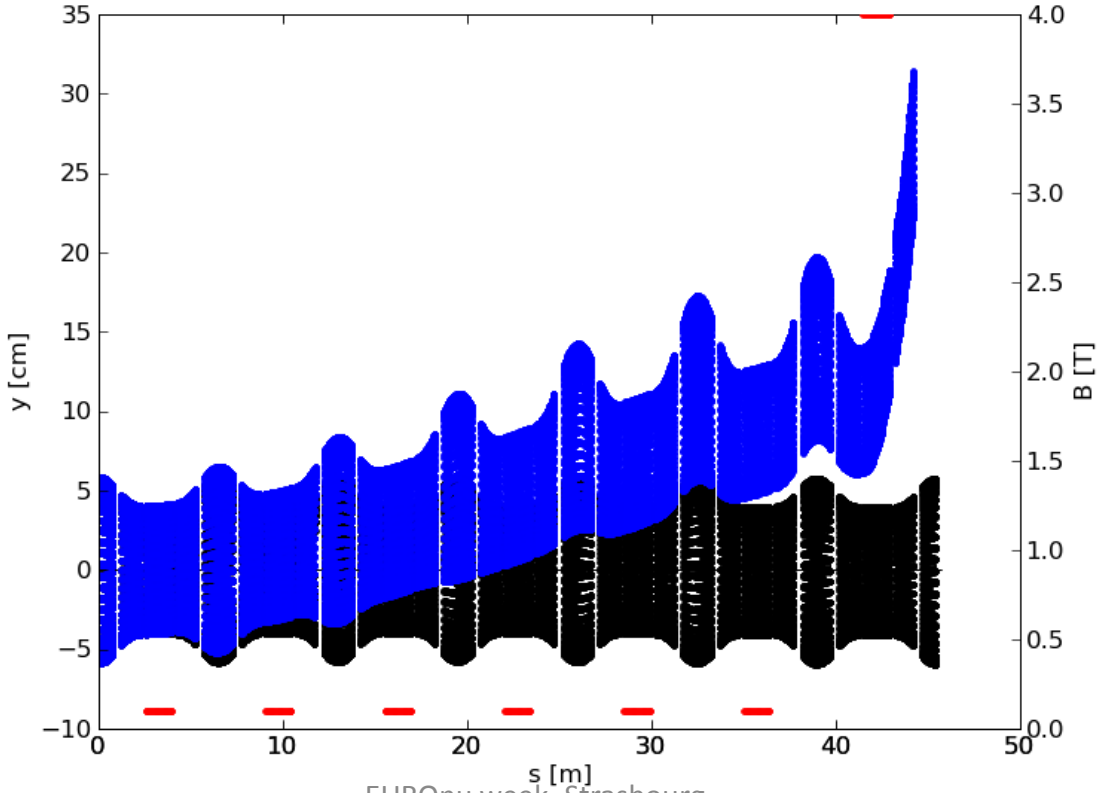
FDFC - Horizontal injection

- 6 kickers at 0.1025 T in consecutive drifts
- Septum at 3T
- Gap between kicked and circulating beam at septum entrance is 2cm
- F Magnet immediately after the septum require large aperture
- Injected beam 21cm from magnet axis of F before septum
- Kicker arrangement mirror-symmetric

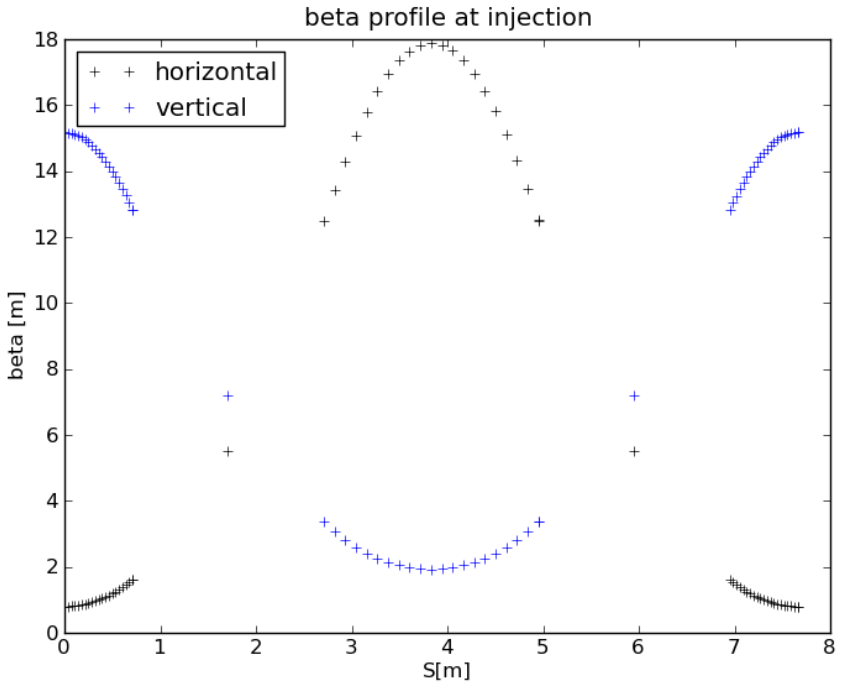


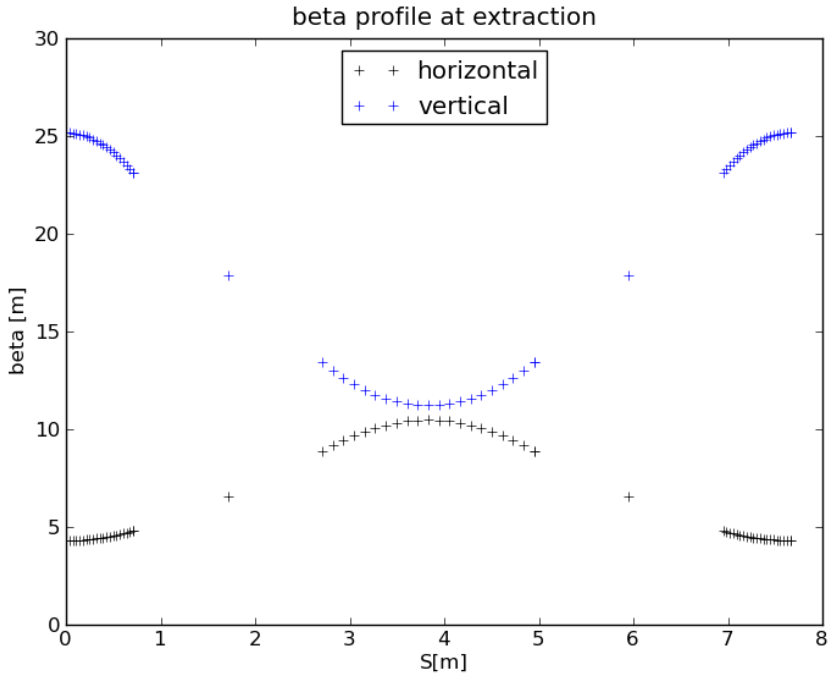
FDFC - Vertical extraction

- 6 kickers at 0.103 T in consecutive drifts
- Septum at 4T
- Several magnets require large aperture
- Extracted beam 13cm from magnet axis of F after septum



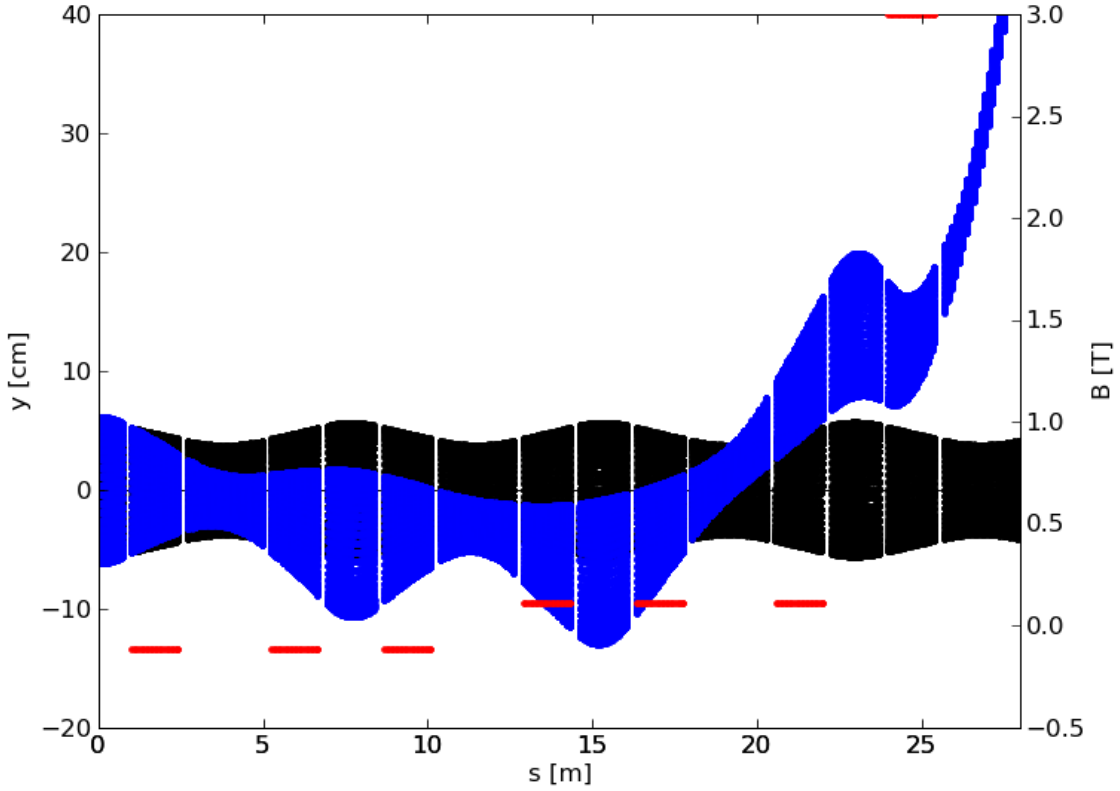
FODO - FCDC


beta profile at injection
horizontal
vertical
beta [m]
S[m]
0
2
4
6
8
10
12
14
16
18
0
1
2
3
4
5
6
7
8


beta profile at extraction
horizontal
vertical
beta [m]
S[m]
0
5
10
15
20
25
30
0
1
2
3
4
5
6
7
8

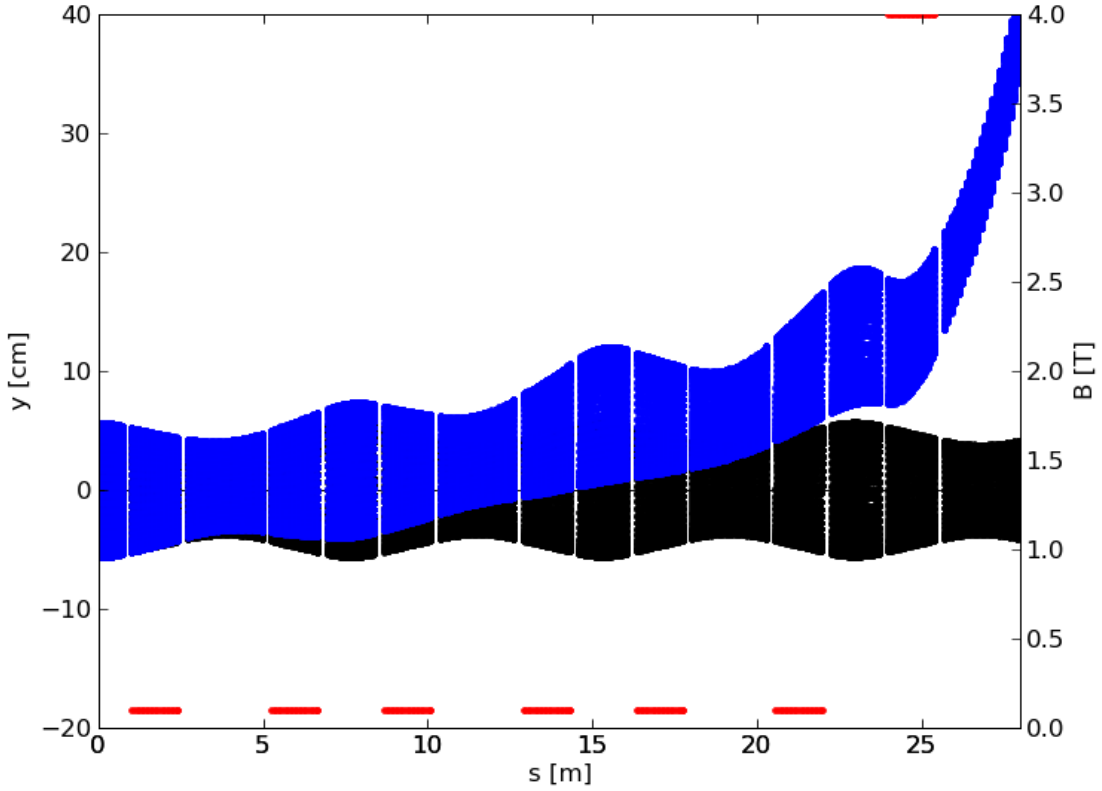
FCDC - Vertical injection

- 6 kickers at 0.113 T in consecutive drifts
- Septum at 3T
- F Magnet immediately after the septum require large aperture
- Injected beam 15cm from magnet axis of F before septum

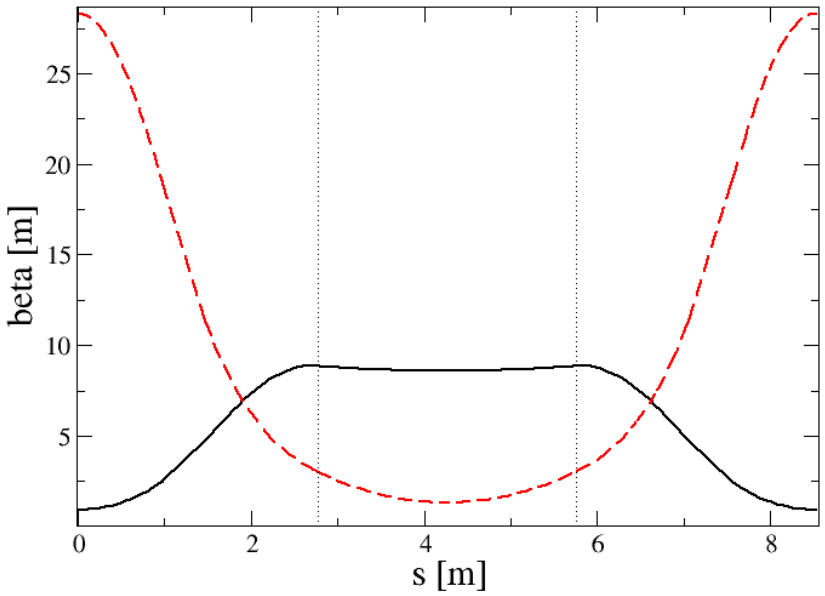


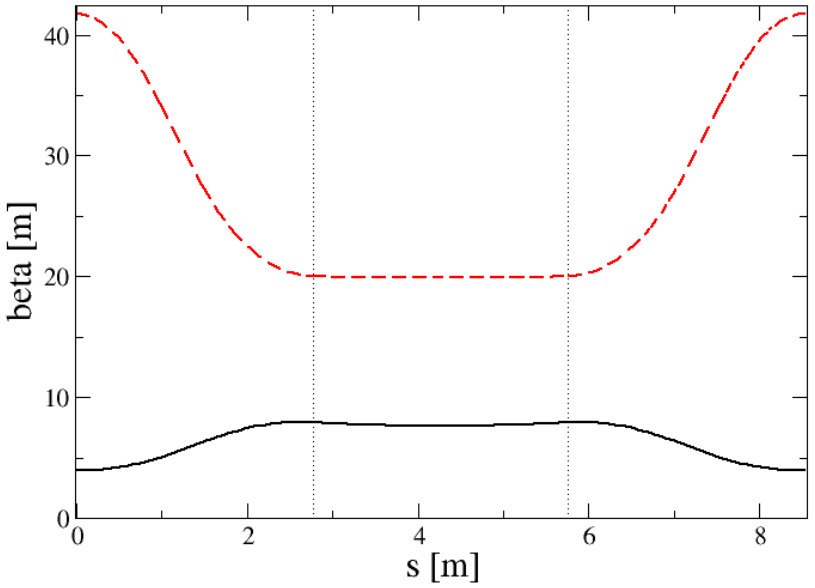
FCDC - Vertical extraction

- 6 kickers at 0.101 T in consecutive drifts
- Septum at 4T
- Several magnets require large aperture
- Injected beam 13cm from magnet axis of F before septum



Triplet 2 - FDFCC

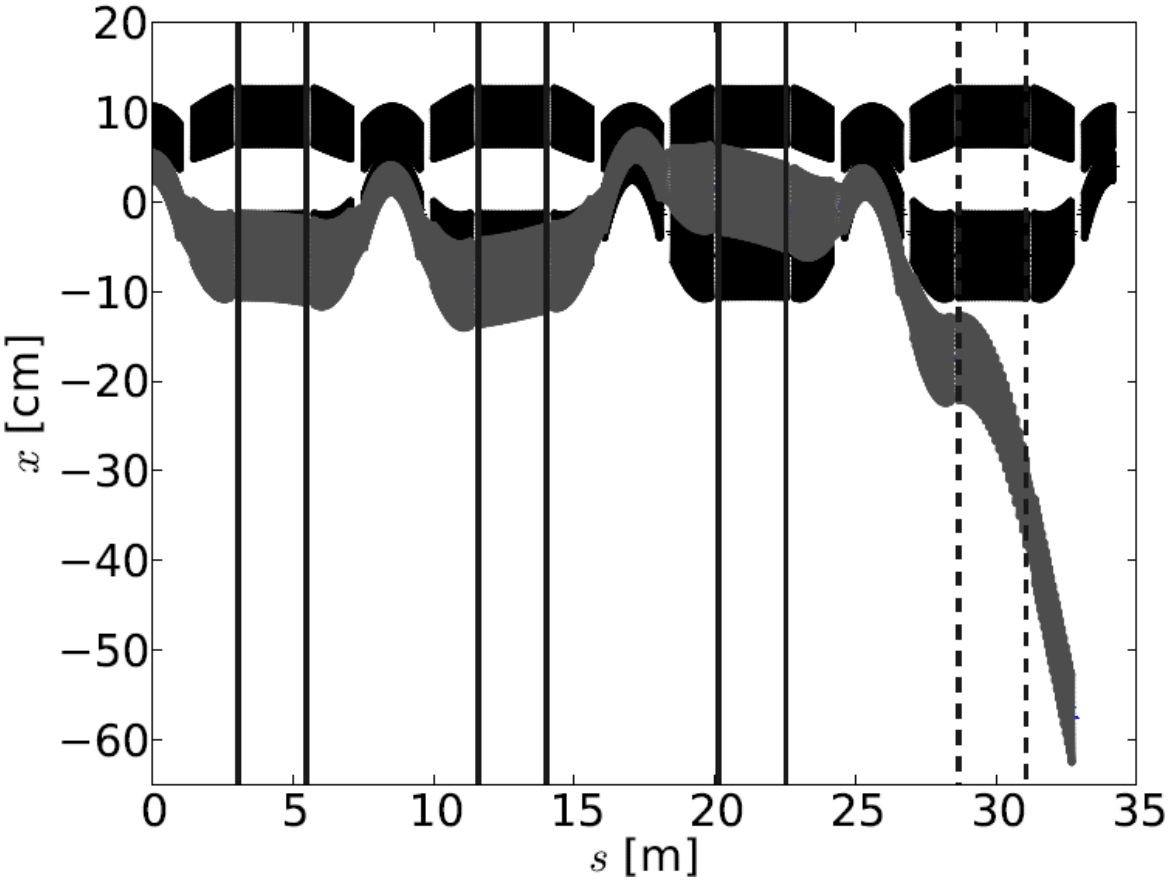




- Optics favour horizontal injection and vertical extraction

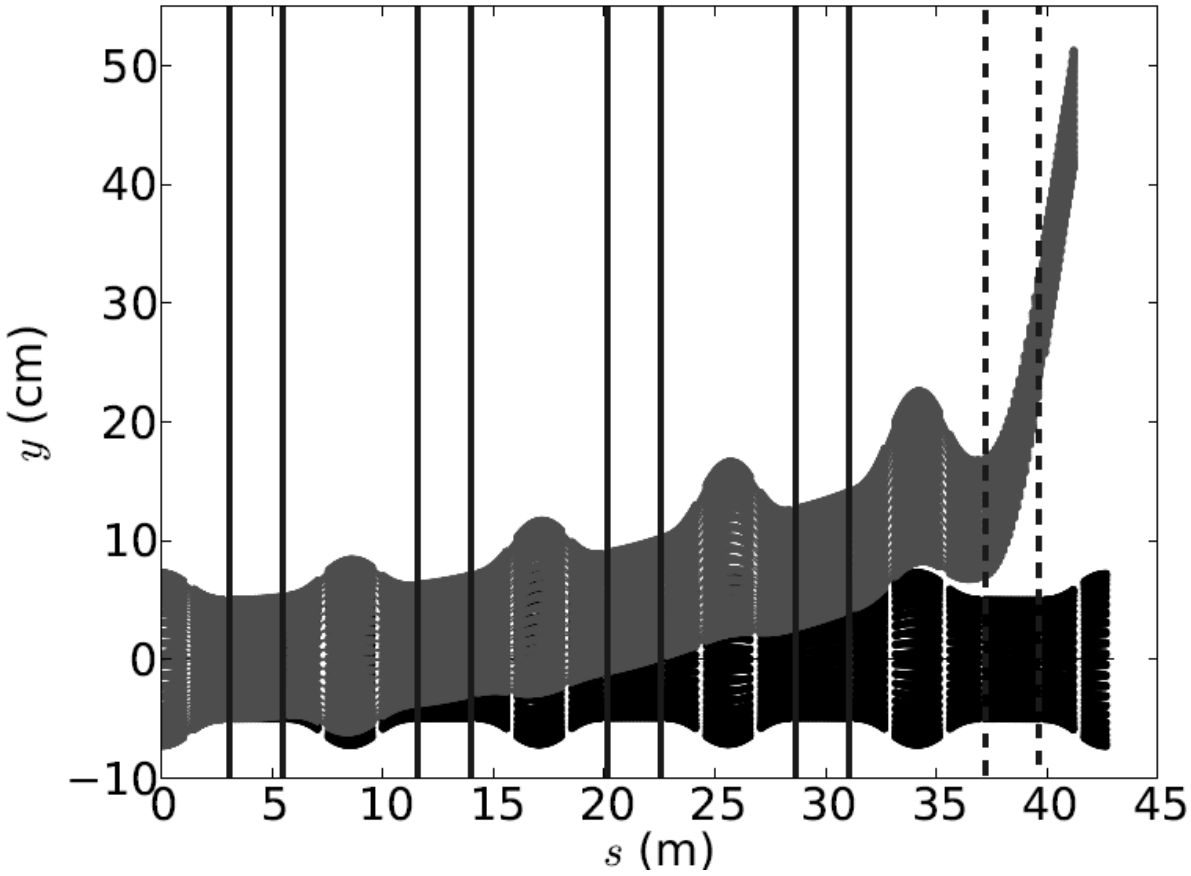
FDFCC - Horizontal injection

- 3 kickers at 0.089 T in consecutive drifts
- Septum at 2T
- F Magnet immediately after the septum require large aperture
- Injected beam 30cm from magnet axis of F before septum



FDFCC - Vertical extraction

- 4 kickers at 0.078 T in consecutive drifts
- Septum at 4T
- Several magnets require large aperture



Summary of parameters for injection/extraction (updated lattices)

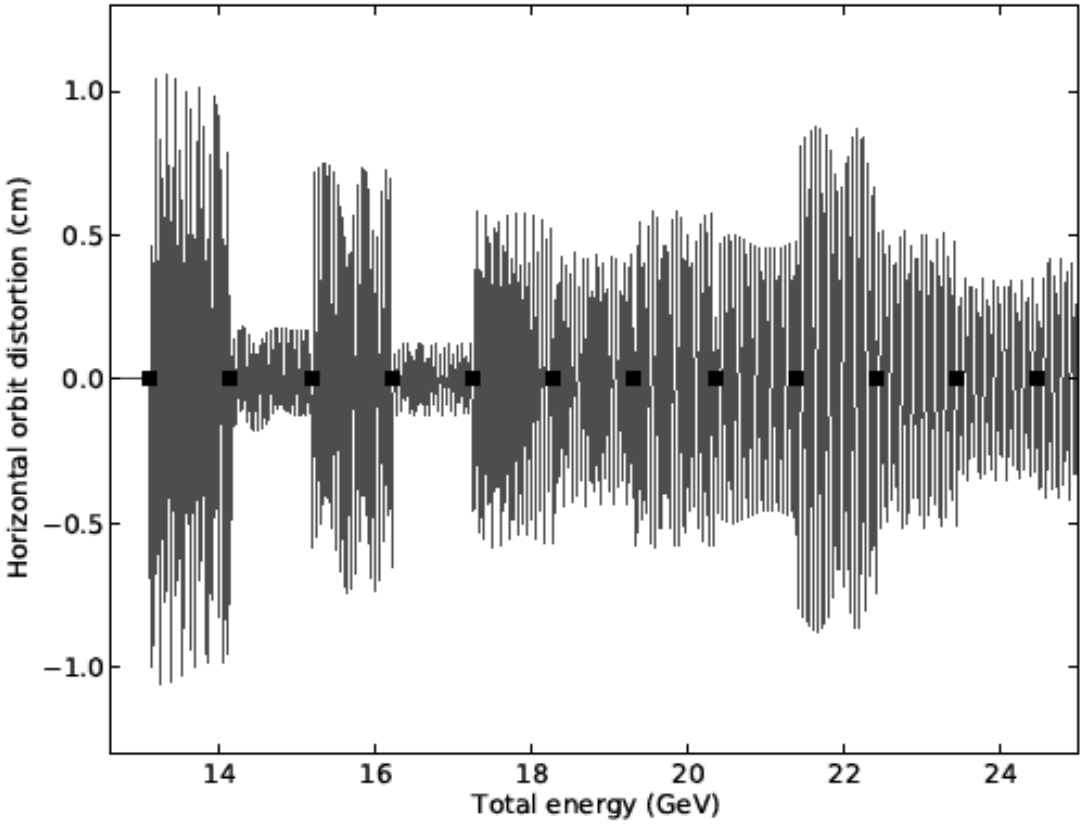
	Triplet 1		FODO		Triplet 2	
Scheme	**FDFC Injection**	**FDFC Extraction**	**FCDC Injection**	**FCDC Extraction**	**FDFCC Injection**	**FDFCC Extraction**
Plane	Horizontal	Vertical	Vertical	Vertical	Horizontal	Vertical
No. Kickers	6	6	6	6	3	4
Kicker top field [T]	0.103	0.103	0.113	0.101	0.089	0.078
Septum top field [T]	>3	>4	>3	>4	2	4
Kicker/Septum length [m]	1.4	1.4	1.4	1.4	2.4	2.4
Cells needed	8	8	5	5	5	6

Orbit distortion due to “special” magnets

- Special large aperture magnets needed to accommodate kicked beam
- Longer fringe field breaks the symmetry of the lattice
- Leads to difference in integrated field experienced by the beam – dipole kick

	Injection Aperture (cm)	Extraction Aperture (cm)
F normal/special	23.5 / 34.2	23.5/41.3
D normal/special	17.7/-	17.7/46.7

Orbit distortion due to special magnets



Distortion due to one set of large aperture triplet magnets required for extraction

Conclusion

- Triplet 2 looks the easiest from point of view of injection/extraction - uses fewer kickers and with lower peak field than other lattices
- Much progress has already been made on kicker magnet design. The design of the septa is underway.
- Orbit distortion created by long fringe field extent of large aperture magnets can be minimised by shifting the magnets (J. Pasternak).