IR Update (v7)

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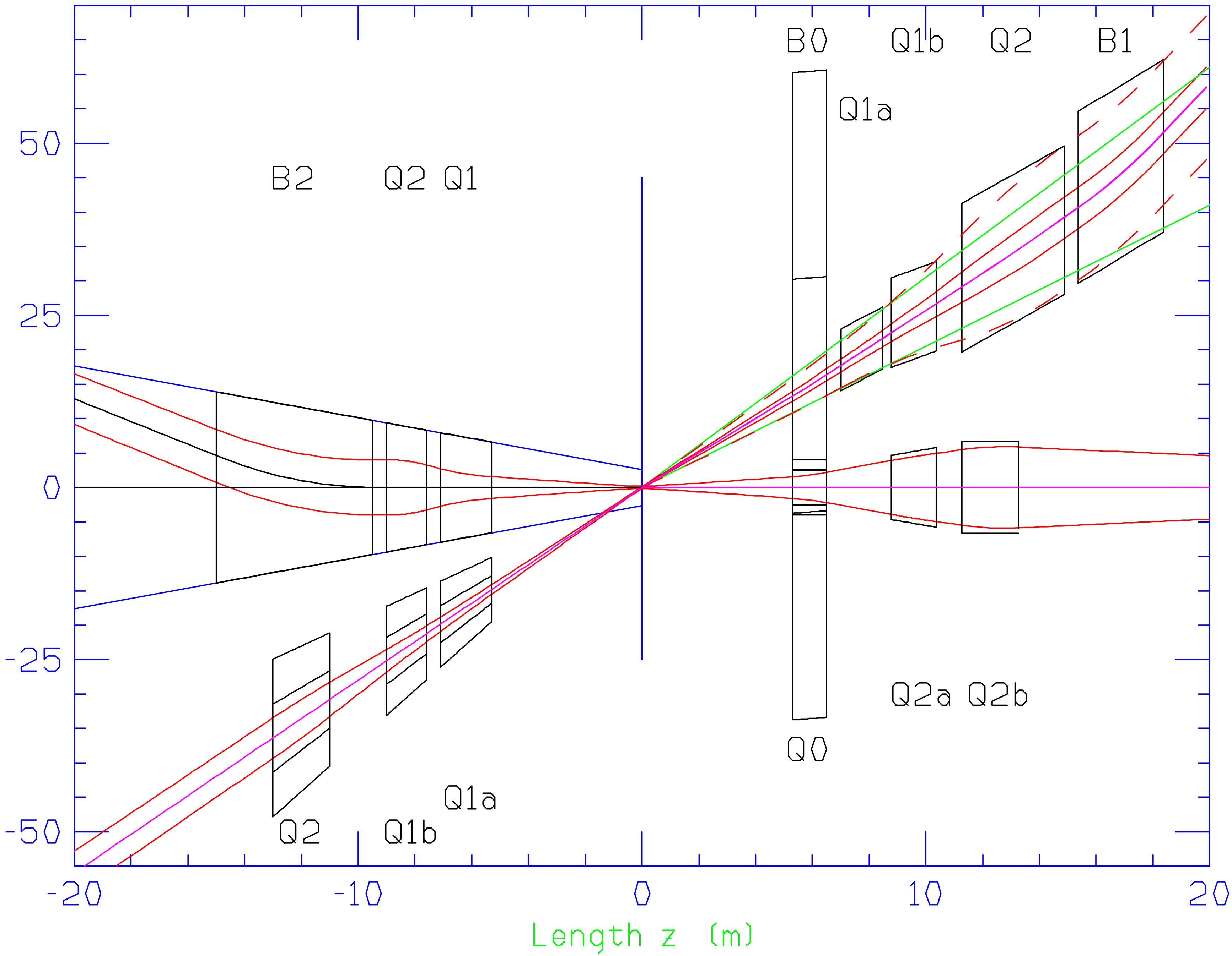
9/21/2018

1. IR changes to lower cost by using NbTi vs. Nb_3Sn conductors: forward e and hadron focus magnets side-by-side instead of alternating.
2. Moving rear electron focus magnets closer to each other to reduce the rear x chromaticity and maximum β
3. Consideration of use of Forward e quad inside detector to reduce the SR fan, forward x and y chromaticities, and maximum βs



B0
Q1b
Q2
B1
Q1a
B2
Q2
Q1
Q2a
Q2b
Q0
Q1a
Q2
Q1b
50
25
0
-25
-50
-20
-10
0
10
20
Length z (m)

1. LOWER GRADIENT HADRON IR MAGNETS

Too reduce IR cost, these designs are intended to have lower forward gradients hopefully allowing use of NbTi (vs. Nb3Sn).

In the pCDR version, the pole tip fields (gradient × aperture) for Q1pF and Q2pF were 5.57 T and 4.96 T respectively and required the use of Nb_3Sn conductor.

These have been reduced by locating e and p magnets beside each other, instead of alternating along the axis. This could require a somewhat larger crossing angle, but allows longer, and weaker, quadrupoles with lower fields and smaller radial coil thicknesses.

The lowest fields are achieved using tapered magnets with reverse tapered gradients to achieve constant pole tip fields along the magnet, but stepped shorter straight magnets are preferred.

Stepped vs, tapered magnets

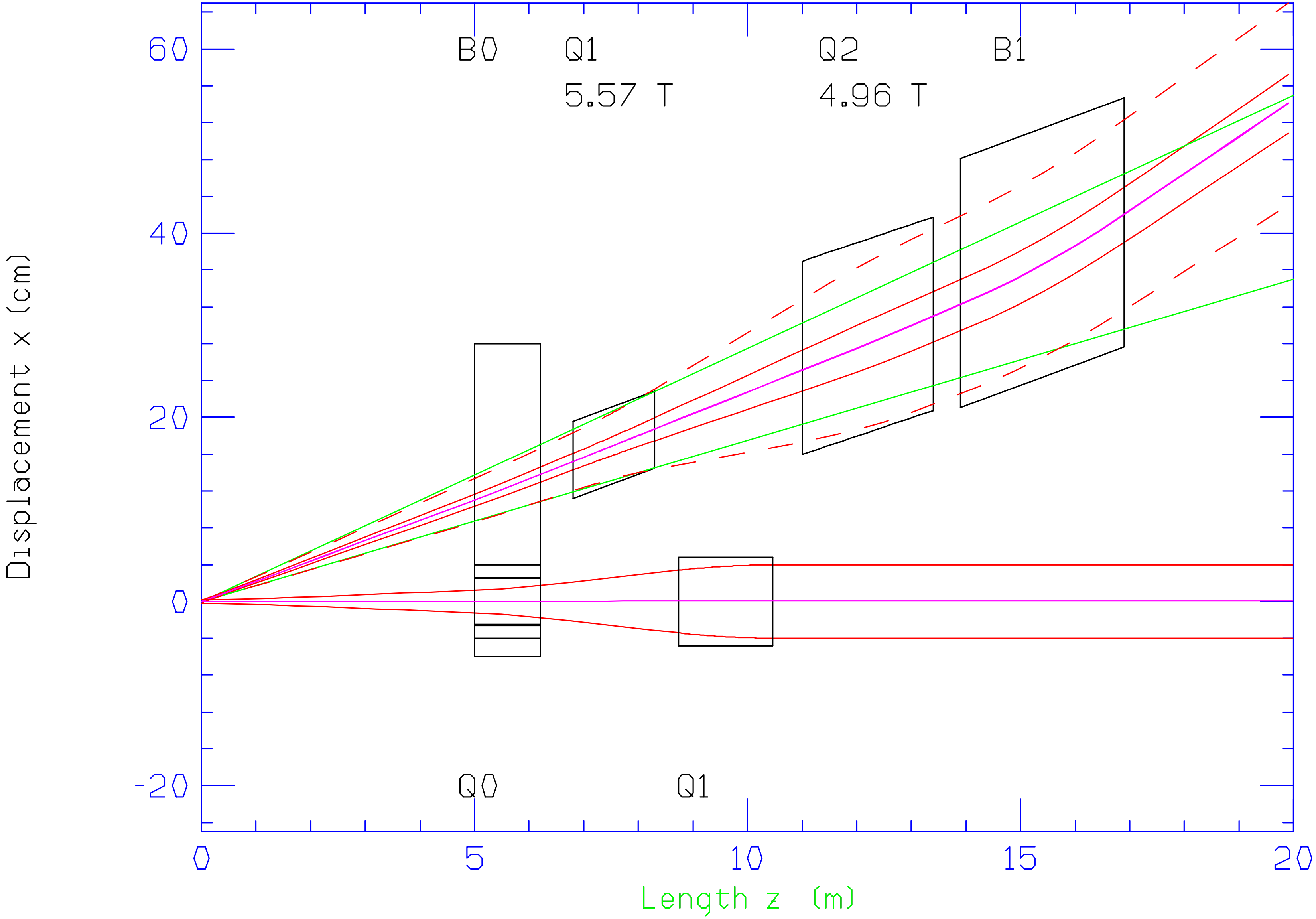
Designing a tapered magnet, even with appropriately reverse tapered gradient, appears relatively straightforward using 'Direct Wind' technology. But this would be much more difficult using more conventional collared coils, as may be required for the stronger hadron magnets. Thus our preferred solution is stepped straight hadron magnets, tapered magnets should be allowed for the electrons.

For stepped magnets, pCDR magnets are broken into two equal lengths with a space between their magnetic lengths of 30 cm. Their apertures are each set to the required beam acceptance at their ends further from the IP.

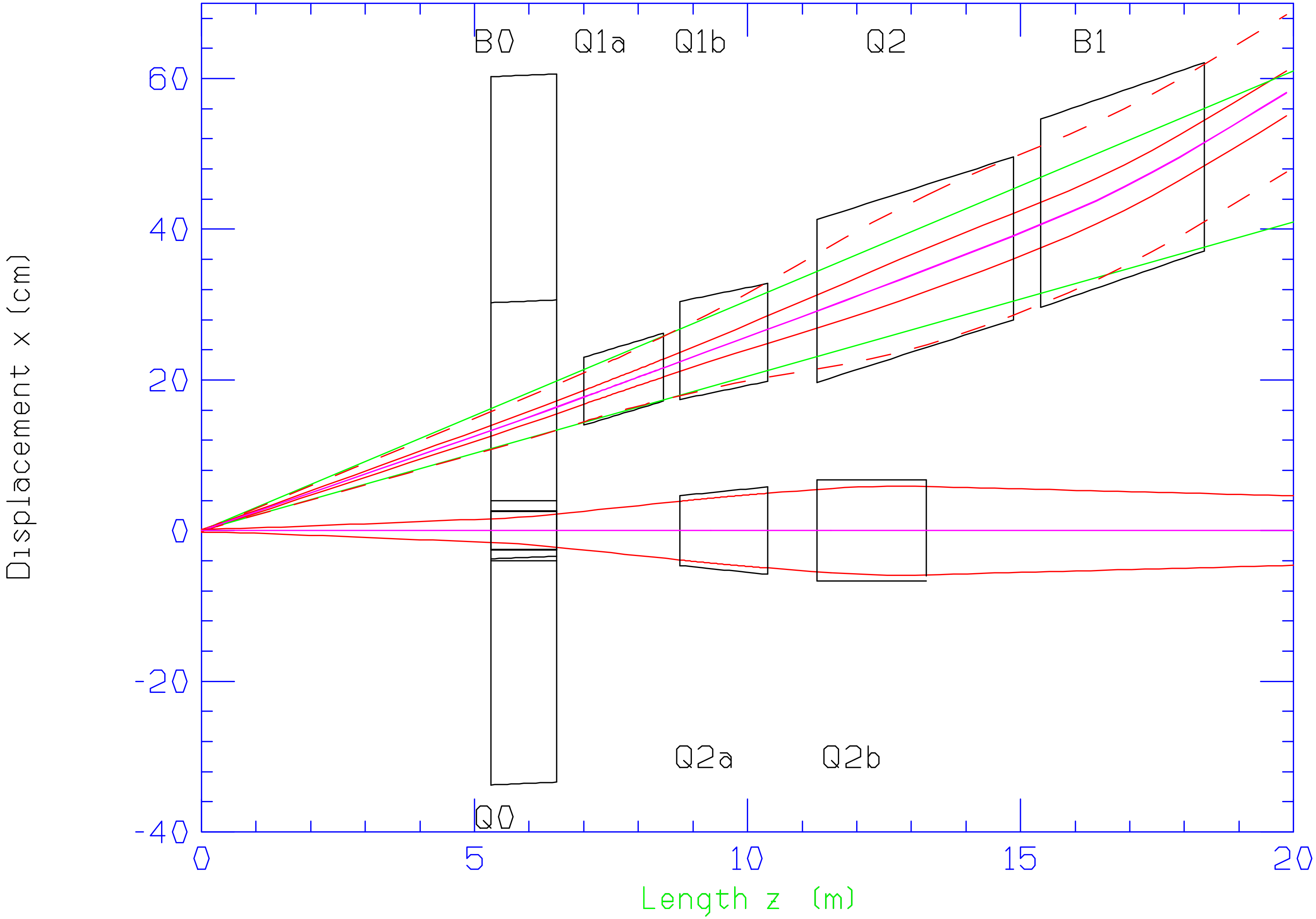
FORWARD HADRON MAGNETS

c.f. Old pCDR Alternating Quads Layout

(dnnb3iw)



NEW Stepped side-by-side Quads) (dnnbF)



Pre-CDR Hadrons Parameters for (275) GeV

Chrom y 21.17 'Chrom x 3.85 ' mom = 275 GeV/c

		L1 m	DL m	gap m	x cm	θ mrad	IR cm	Bpt T	B T	Grad) T/m
B0Fp	3	5.00	1.20	0.60	11.0	0.00	17.00		1.299	
Q1Fp	5	6.80	1.50	2.70	15.4	22.00	4.20	5.57		-132.649
Q2Fp	7	11.00	2.40	0.50	26.4	20.00	10.50	4.96		47.223
B1Fp	9	13.90	3.00	20.90	34.6	22.00	13.50		4.571	

Subscripts 1 nearer IP, 2 further from IP B_1 & B_2 are pole tip fields

New Stepped Side-by-side Magnets (mnnp335)

Chrom y 15.61 ' Chrom x 3.91 ' mom = 275

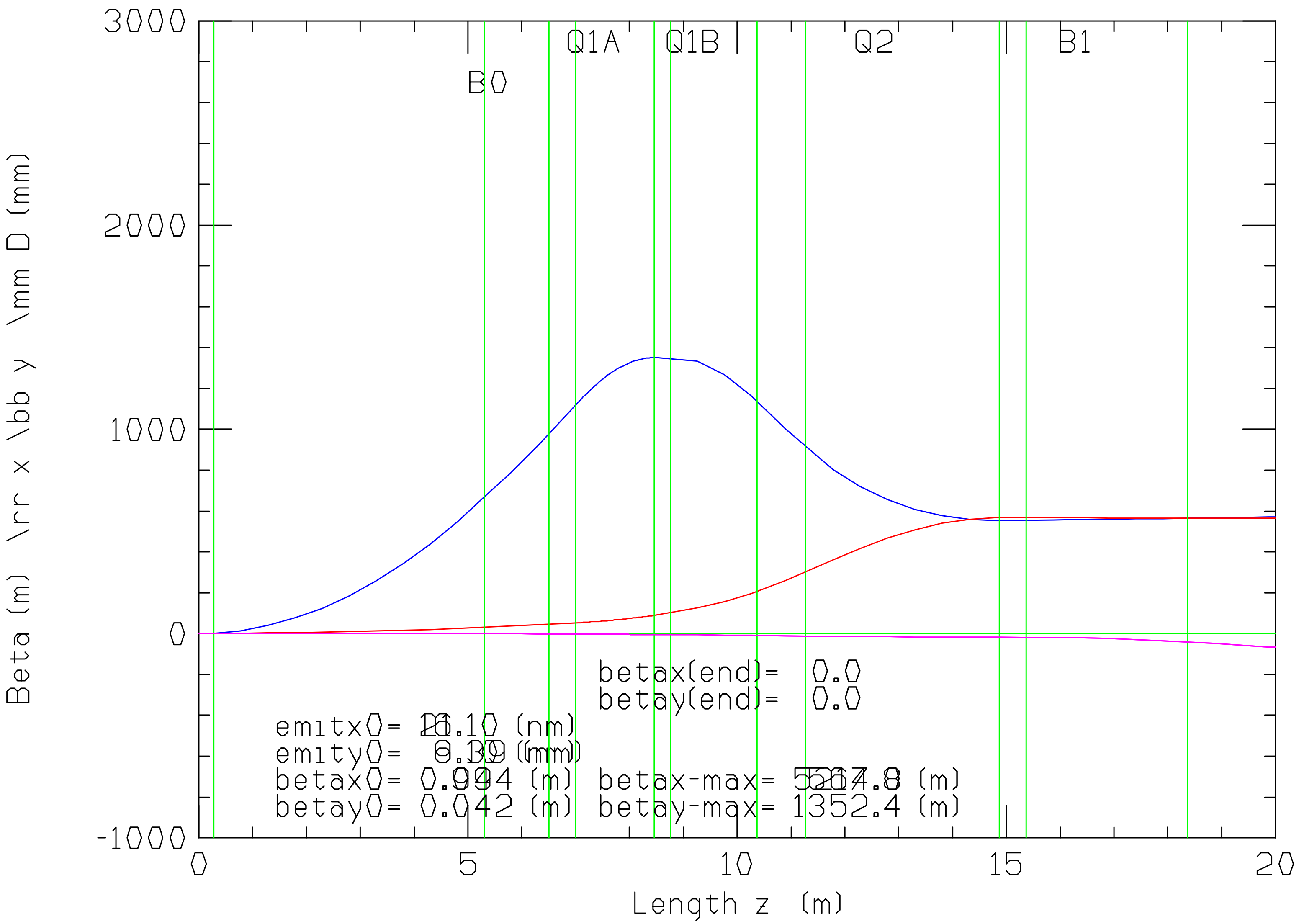
		L1 m	DL m	gap m	x cm	θ mrad	IR1 cm	IR2 cm	OR cm	B1 T	B2 T	B T	Grad1 T/m	Grad2 T/m
B0	3	5.30	1.20	0.50	13.3	3.00	17.00	17.00	30.0	0.000	0.000	1.300	0.000	0.000
Q1A	5	7.00	1.46	0.30	19.5	15.00	4.50	4.50	0.0	3.506	3.506	0.000	-77.903	-77.903
Q1B	7	8.76	1.61	0.90	23.9	15.00	6.50	6.50	0.0	4.097	4.097	0.000	-63.028	-63.028
Q2	9	11.27	3.60	0.50	34.5	12.00	10.80	10.80	0.0	4.29	4.29	0.000	39.736	39.736
B1	11	15.37	3.00	20.90	42.1	25.00	12.50	12.50	0.0	0.000	0.000	4.570	0.000	0.000

Comments

The rising pole tip fields with successive magnets was found to minimize the local peak fields in their designs.

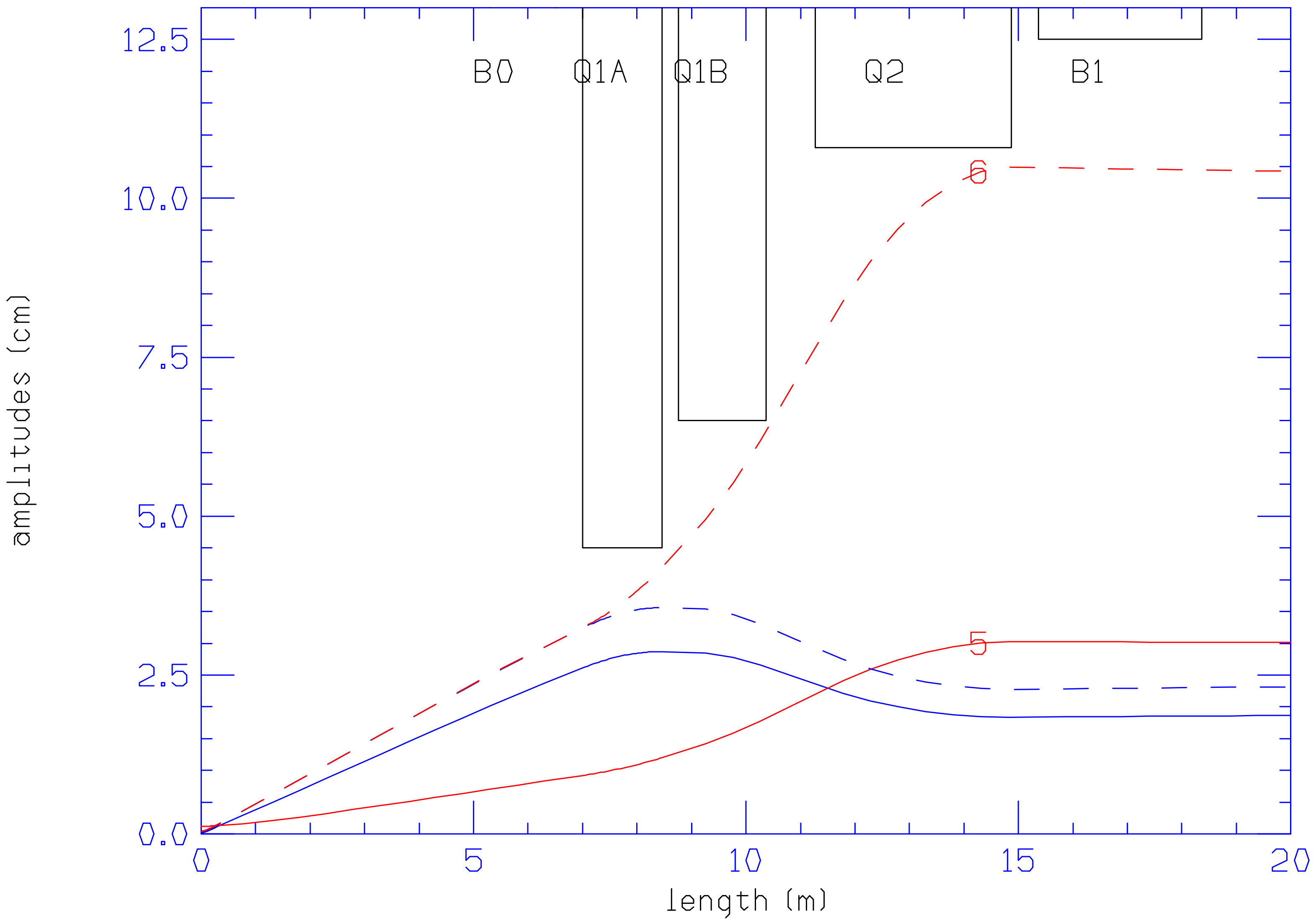
In all cases, these appear doable with NbTi conductors.

Forward Hadron Betas (bnnp335.eps)



Betas flat heading for ≈580 m

Forward Hadron amplitudes (annp335.eps)



Required p aperture of good hadron field

The above slides, at 275 GeV, suggests good field is only required over the quite limited central part of the aperture where the beam is present only in a limited central part of the apertures. But at lower energies the beam will be displaced in the apertures, requiring good field over a much larger part of the apertures reuiring good field everywhere.

At 100 GeV, the spectrometer field can be amintained at 1.3 T to give maximum momentum resolution. The beam is then displaced through Q1, Q2 and B1. The fields of B1 and B2 can be adjusted to return the beam to its nominal center. This requires good field over a wider area (see following slide).

At 41 GeV momentum determinations can be even better with B0=0.9 T and the beam now up against the magnet apertures, needing good field up to that bound: a demanding requirement that could require further lowering the B0 field.

FORWARD ELECTRONS

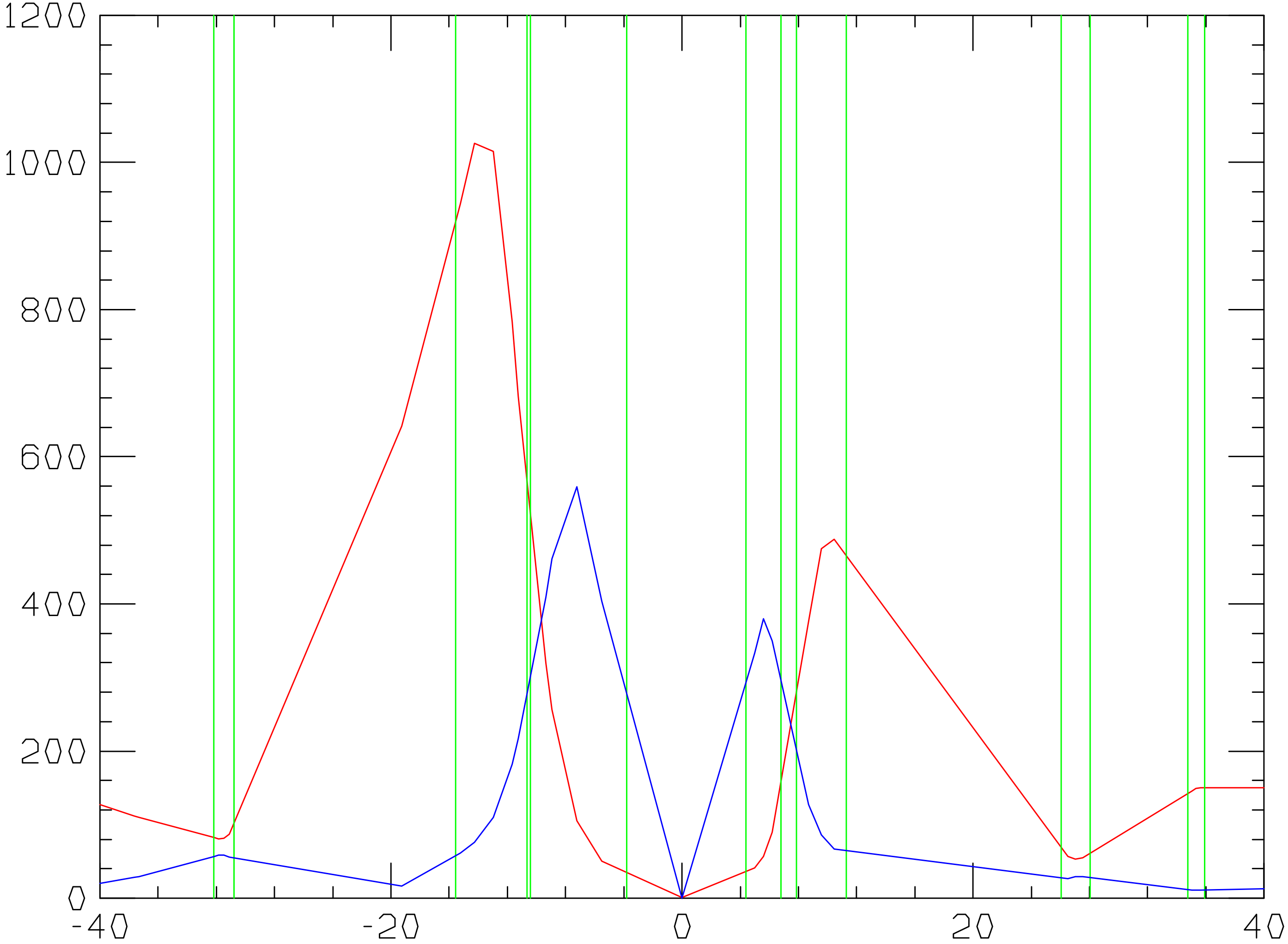
The focus magnets are designed to give betas that roughly match Steve's pCDR lattice.

The low β_y* inevitably gives a high y chromaticity (6.6)

The spacing between the focus and defocus magnets is relatively large to minimize the angles of the SR fan. Unfortunately this gives rise to relatively large x chromaticity (6.3).

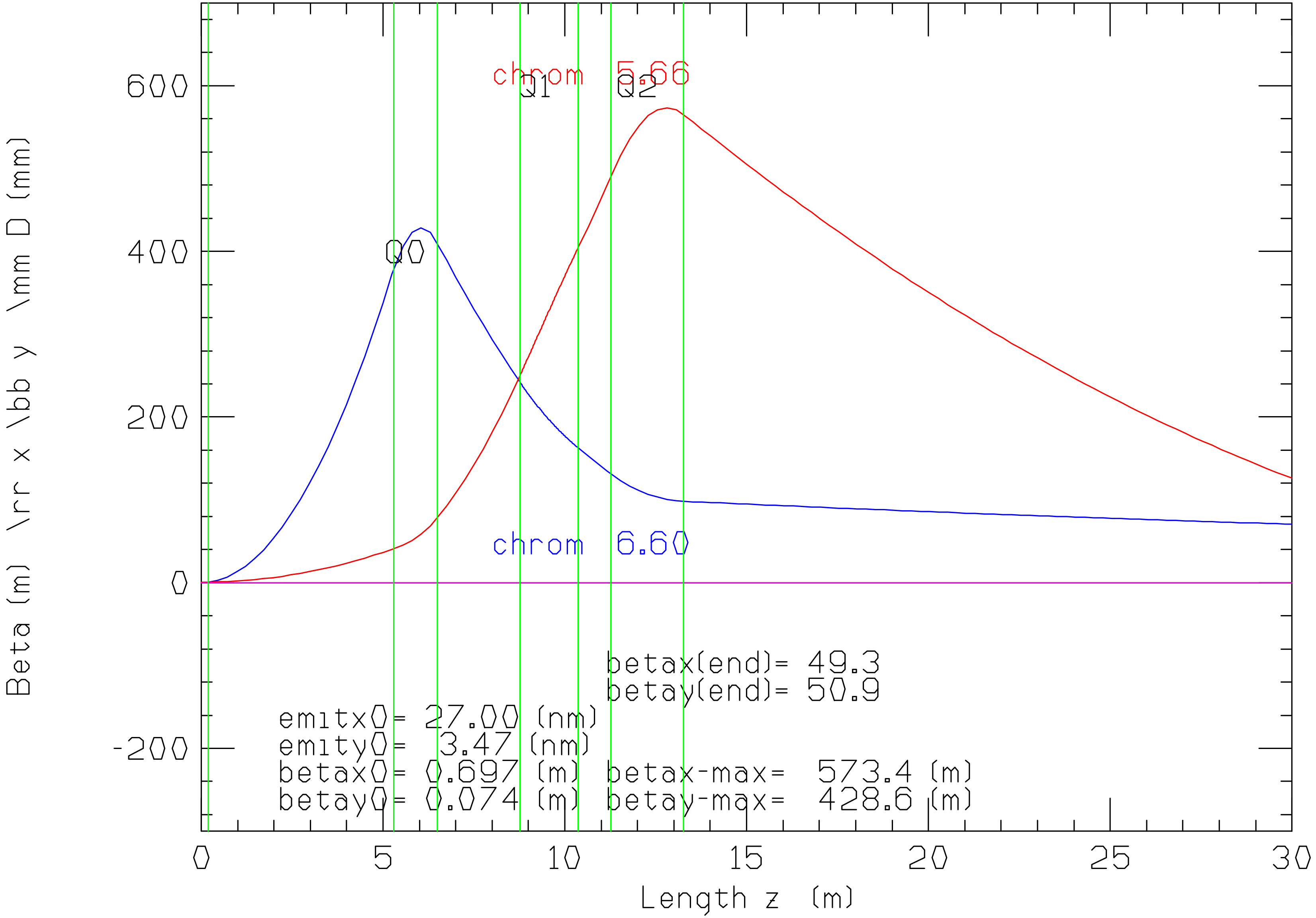
c.f. pCDR electron betas from Steve

(xyebet.eps)

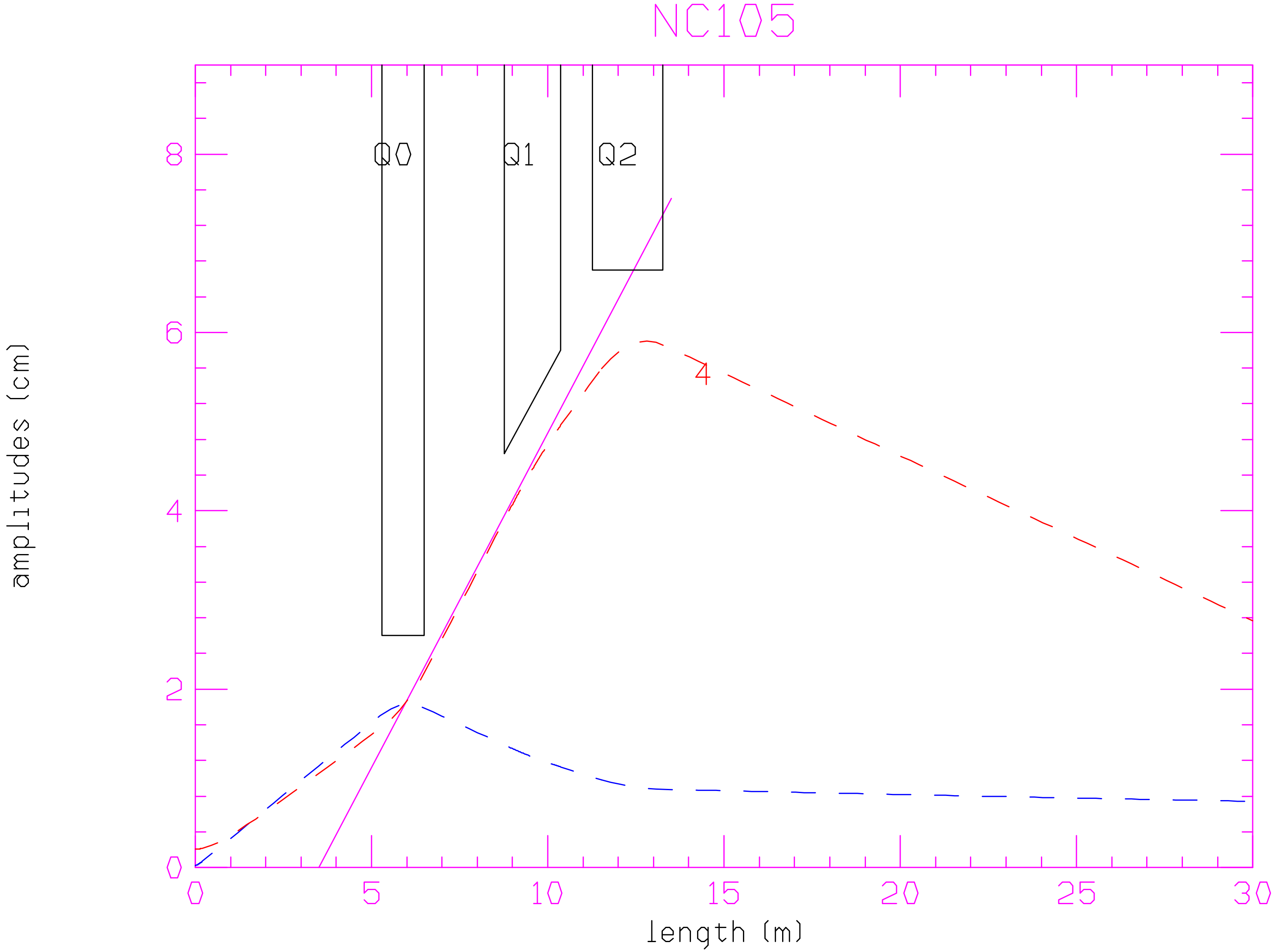


betas are converging to about 150 (x) 80 (y) m at z=27 m and much the same at -33 m in the rear.

Forward Electron betas bnne38



Forward Electrons amplitudes (anne38)



These are for the 105 GeV case with its larger divergences

c.f. Pre-CDR Forward Electron Parameters

Gradients from Steve multiplied by 1.8 for 18 GeV/c

chrom y 5.88 Chrom x3.69 E 18 GeV

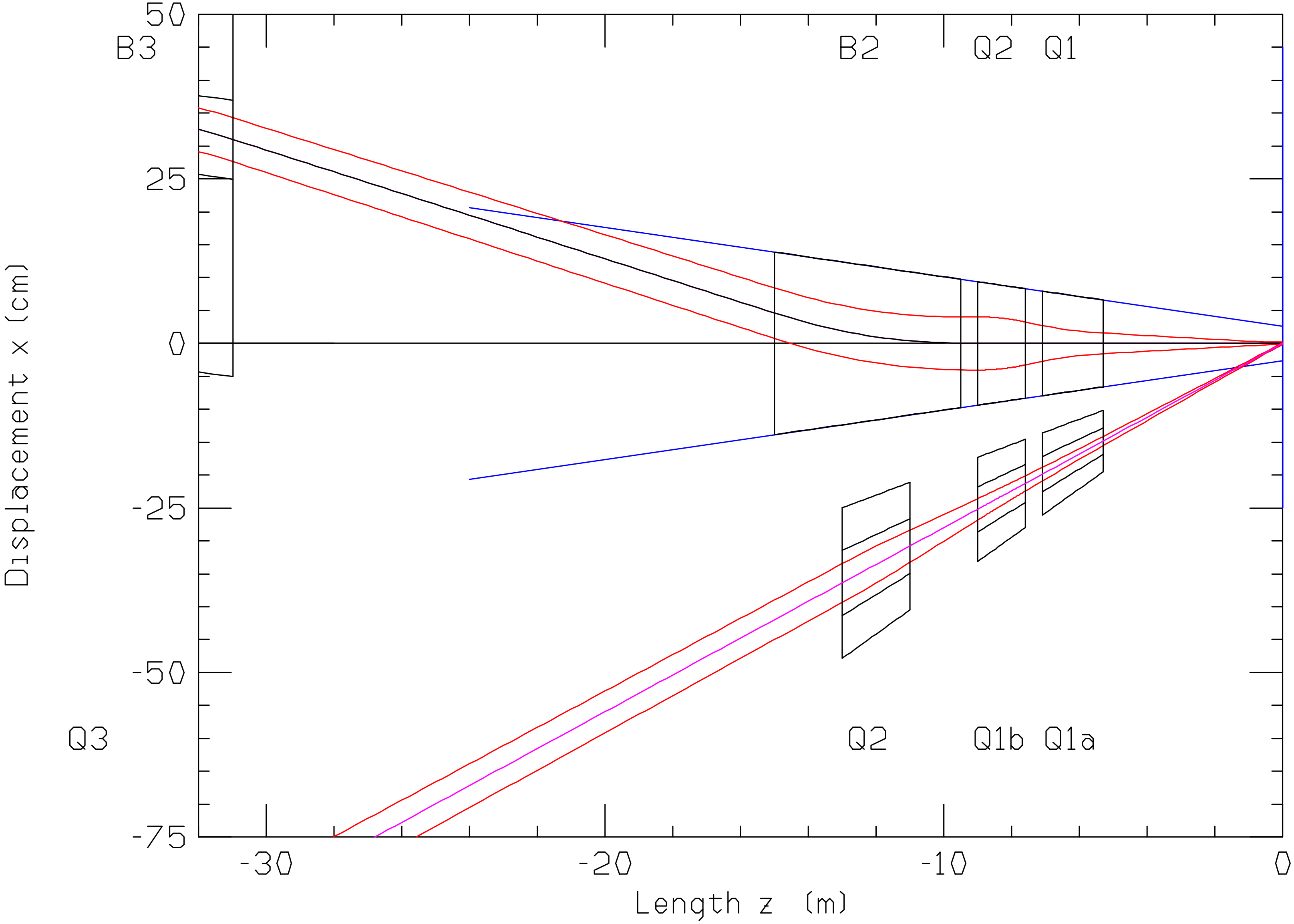
		L1	DL	gap	x	θ	IR	Bpt	Grad)
		m	m	m	cm	mrad	cm	T	T/m
Q0Fe	3	5.00	1.20	2.54	0.0	0.00	2.85	0.494	-17.33
Q1Fe	5	8.74	1.72	7.02	0.0	0.00	5.00	0.376	7.79

New Forward Electron Magnets **mnne39**

Chrom y 6.59 ' Chrom x 6.30 ' mom = 18

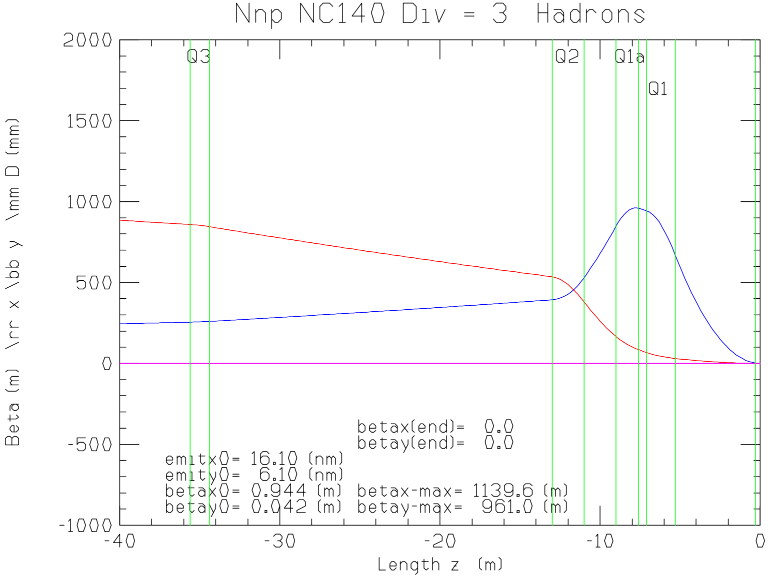
		L1	DL	gap	x	θ	IR1	IR2	OR	B1	B2	B	Grad1	Grad2
		m	m	m	cm	mrad	cm	cm	cm	T	T	T	T/m	T/m
Q0	3	5.30	1.20	2.26	0.0	0.00	2.60	2.60	0.0	0.331	0.331	0.000	-12.713	-12.713
Q1	5	8.76	1.61	0.90	0.0	0.00	4.64	5.80	0.0	0.078	0.097	0.000	1.675	1.675
Q2	7	11.27	2.00	20.40	0.0	0.00	6.35	6.35	0.0	0.244	0.244	0.000	3.846	3.846

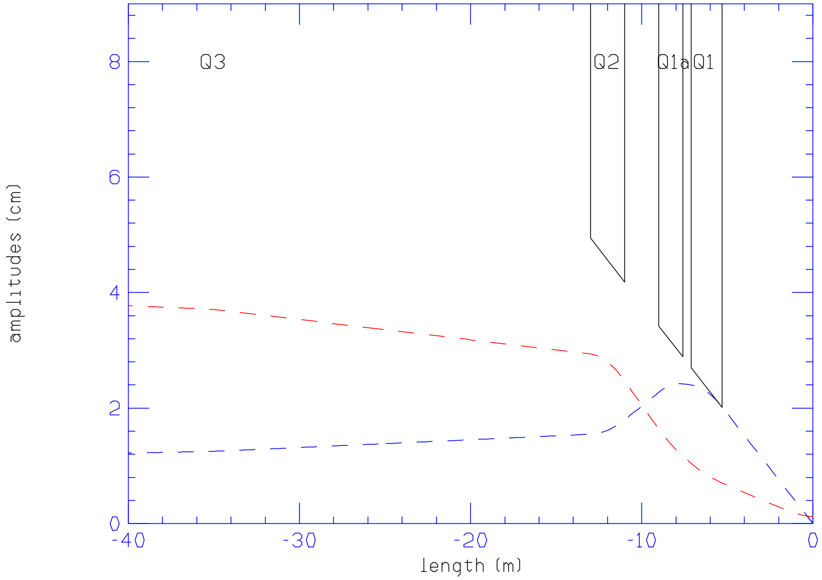
REAR LAYOUT (rearv6.eps)



REAR PROTON MAGNETS

These are much the same as in the pCDR, but Q1pR is split to match the lengths of electron Q2eR

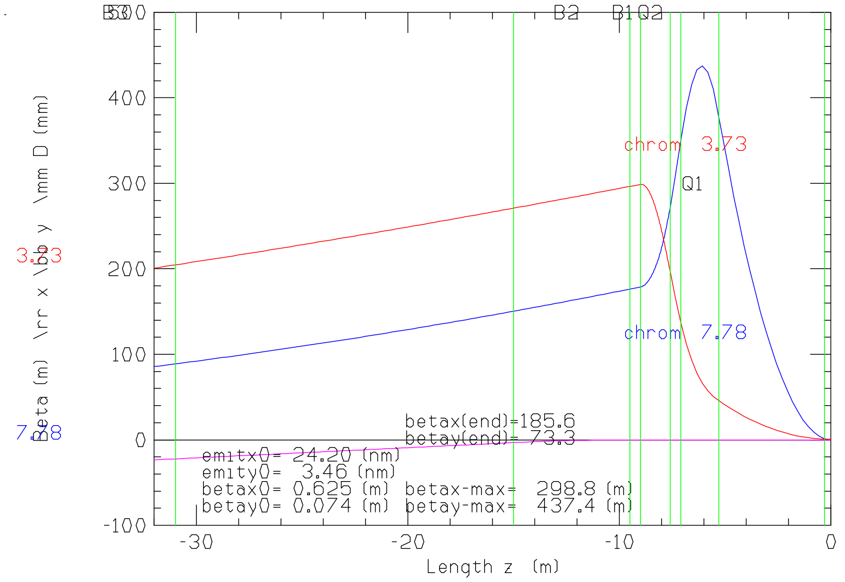


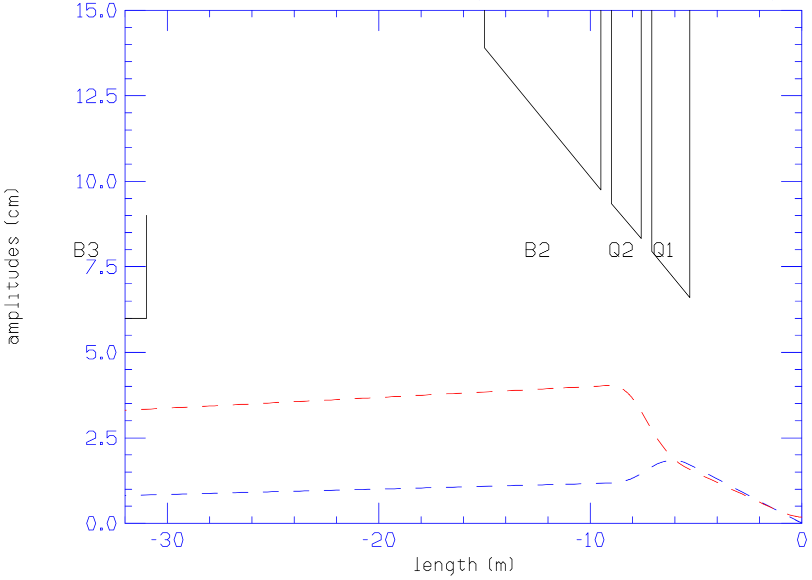


Chrom y 13.41 ’ Chrom x 5.14 ’ mom = 275

		L1	DL	gap	x	θ	IR$_1$	IR$_2$	B	Bpt	Grad)
		m	m	m	cm	mrad	cm	cm	T	T	T/m
Q1	3	5.30	1.80	0.50	-14.8	-28.00	2.01	2.70	0.000	2.048	-75.900
Q1a	5	7.60	1.40	2.00	-21.3	-28.00	2.89	3.42	0.000	2.596	-75.900
Q2	7	11.00	2.00	21.40	-30.8	-28.00	4.18	4.94	0.000	3.125	63.250

REAR ELECTRON MAGNETS (bnne3R7w)





Chrom y 7.75 ' Chrom x 3.81 ' mom = 18

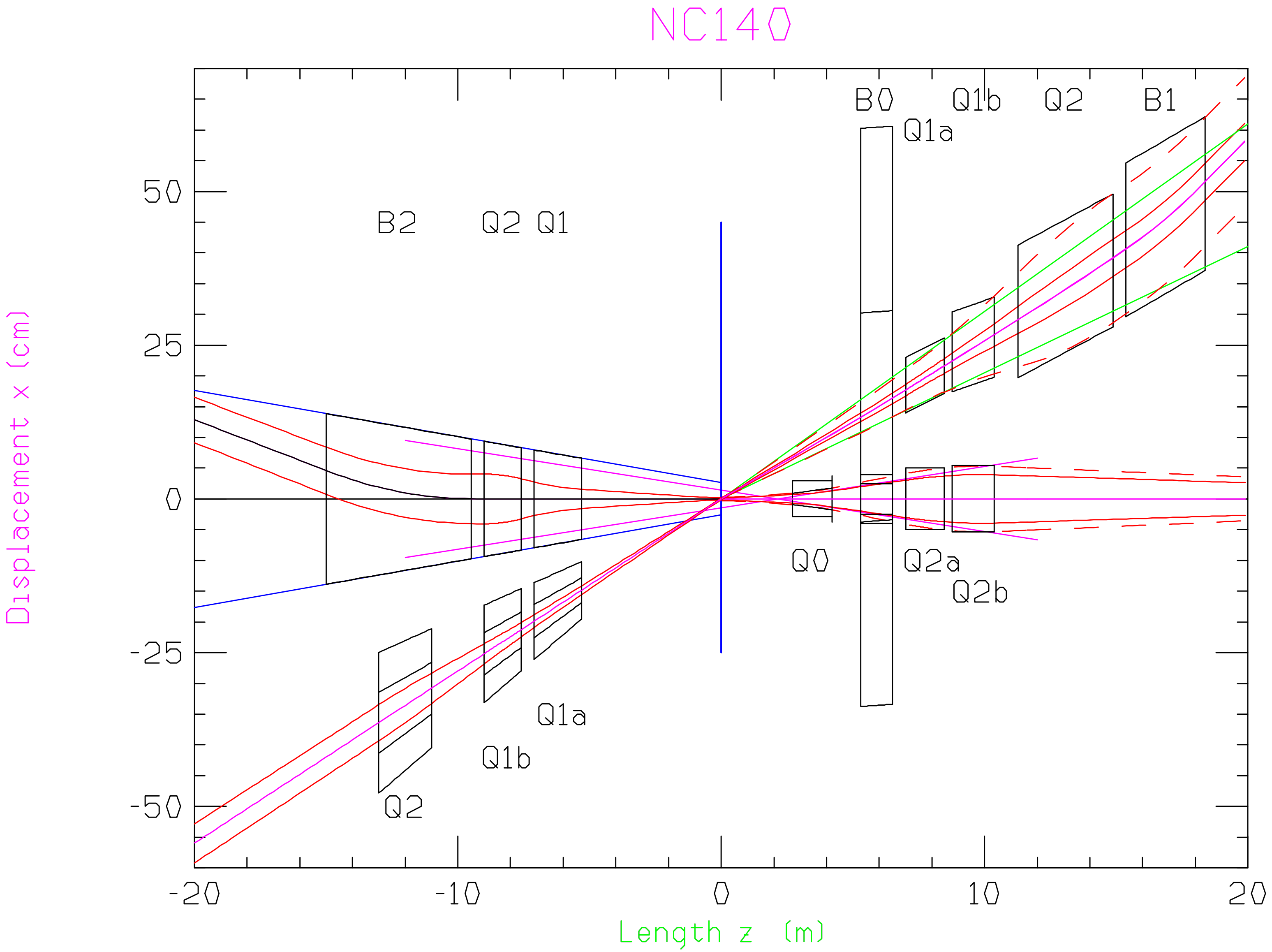
		L1	DL	gap	x	θ	IR_1	IR_2	B	Bpt	Grad)
		m	m	m	cm	mrad	cm	cm	T	T	T/m
Q1	3	5.300	1.800	0.50	0.0	0.00	6.60	7.95	0.000	1.026	-12.900
Q2	5	7.600	1.400	0.50	0.0	0.00	8.32	9.38	0.000	1.181	12.600
B1	7	9.500	0.000	0.00	0.5	5.30	7.50	7.50	0.000	0.000	0.000
B2	9	9.500	5.500	15.98	0.0	0.00	9.75	13.88	0.180	0.000	0.000

2. OPTION (Not the baseline)

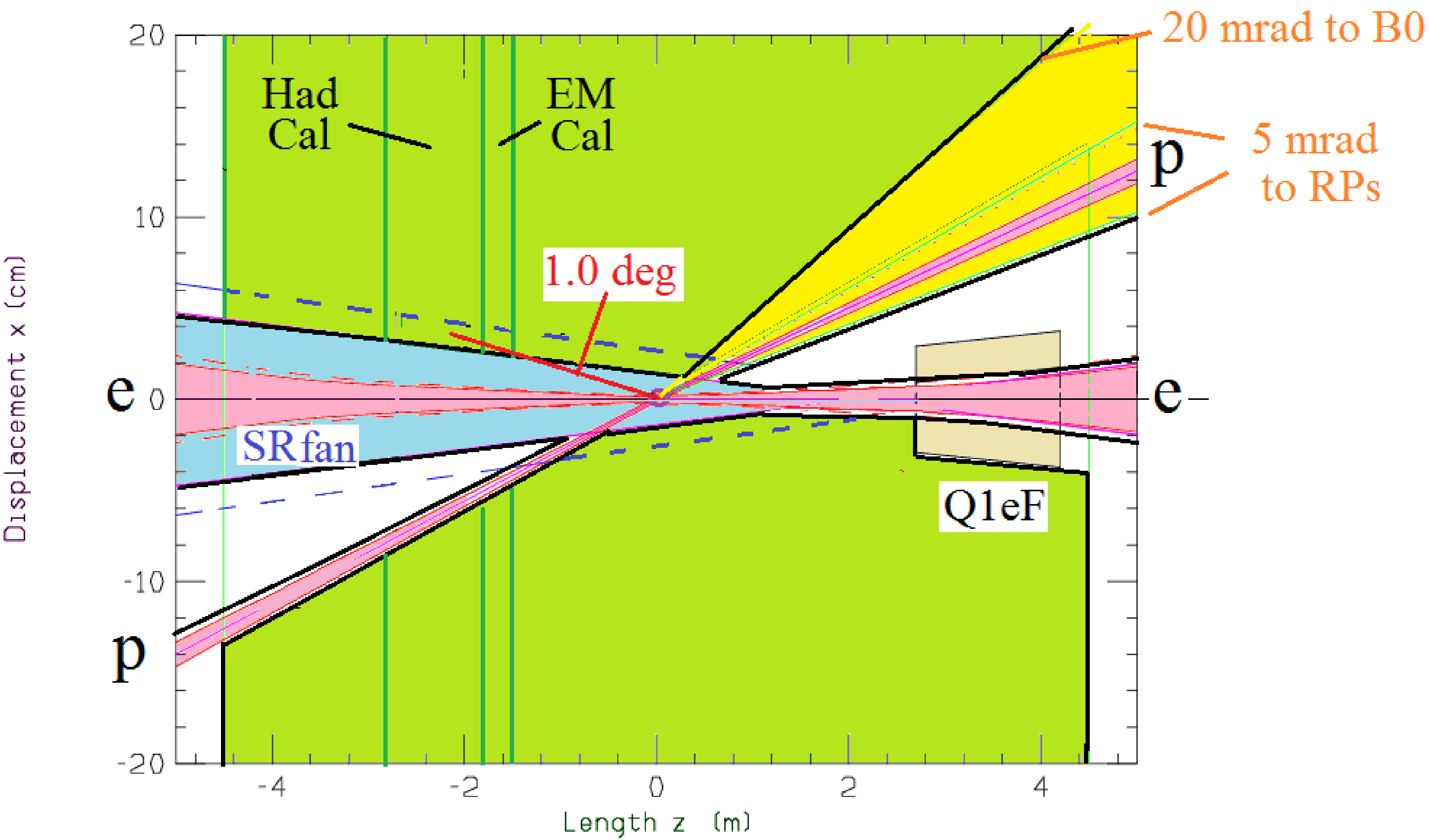
FORWARD ELECTRON QUAD INSIDE

- reduces beta maximum and chromaticity
- reduces the SR fan size and angle
- reduces the beam pipe diameter at the IP (an probably its thickness)
- reduces the minimum electron angles seen by the rear EM Calorimeter

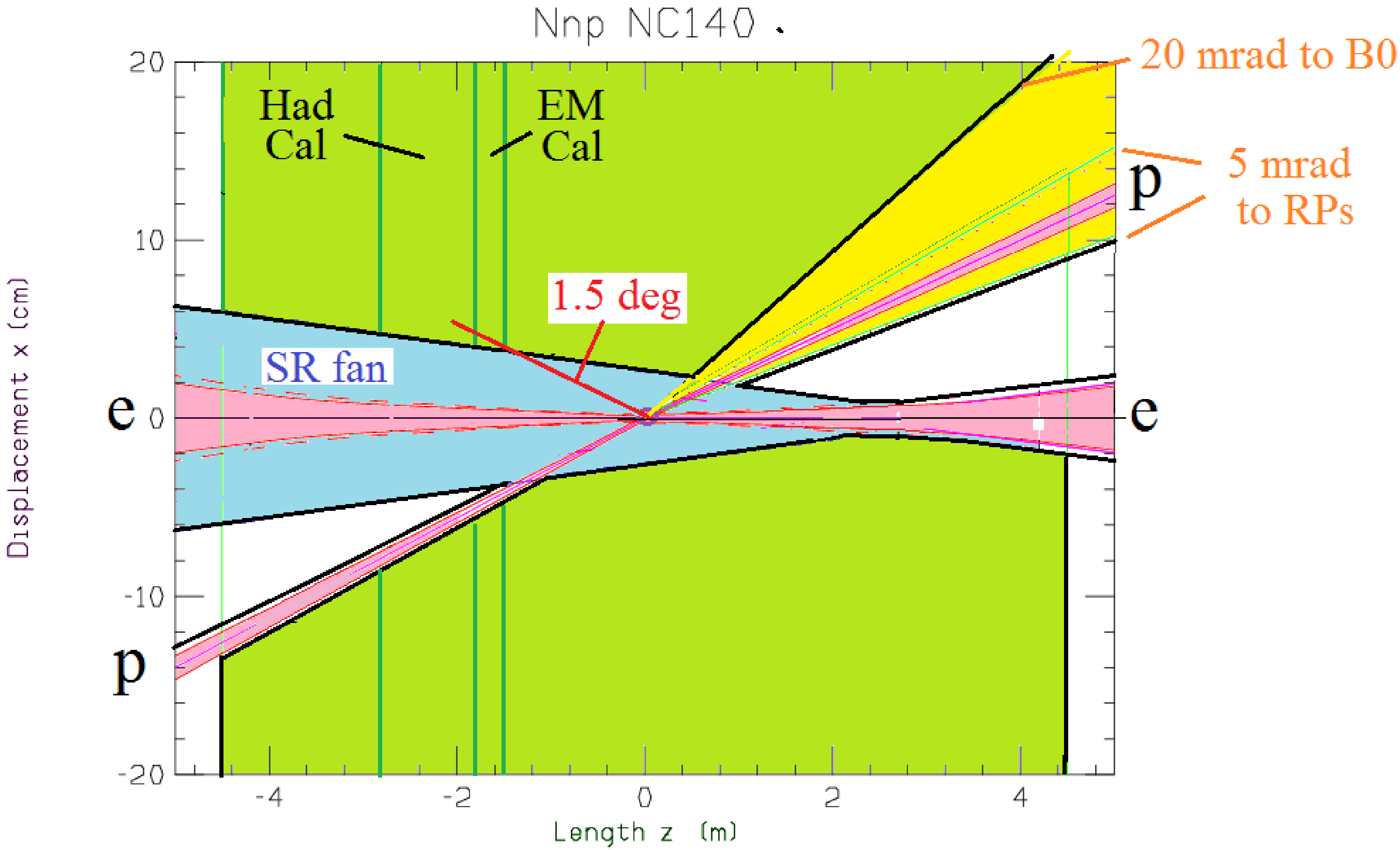
Layout with quad inside (allin)



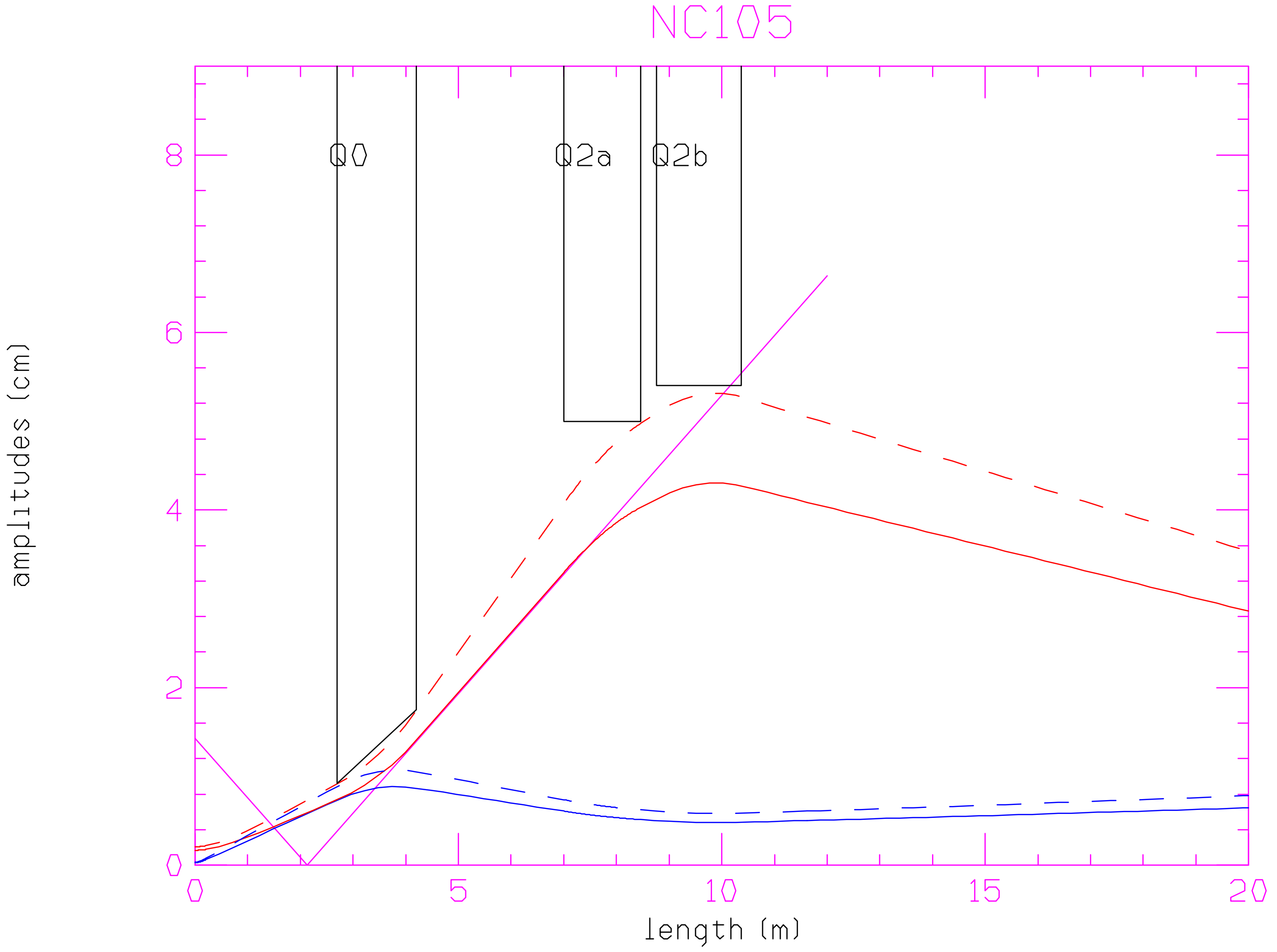
layout inside detector (v6-layout)



c.f. Baseline (v4-layout)



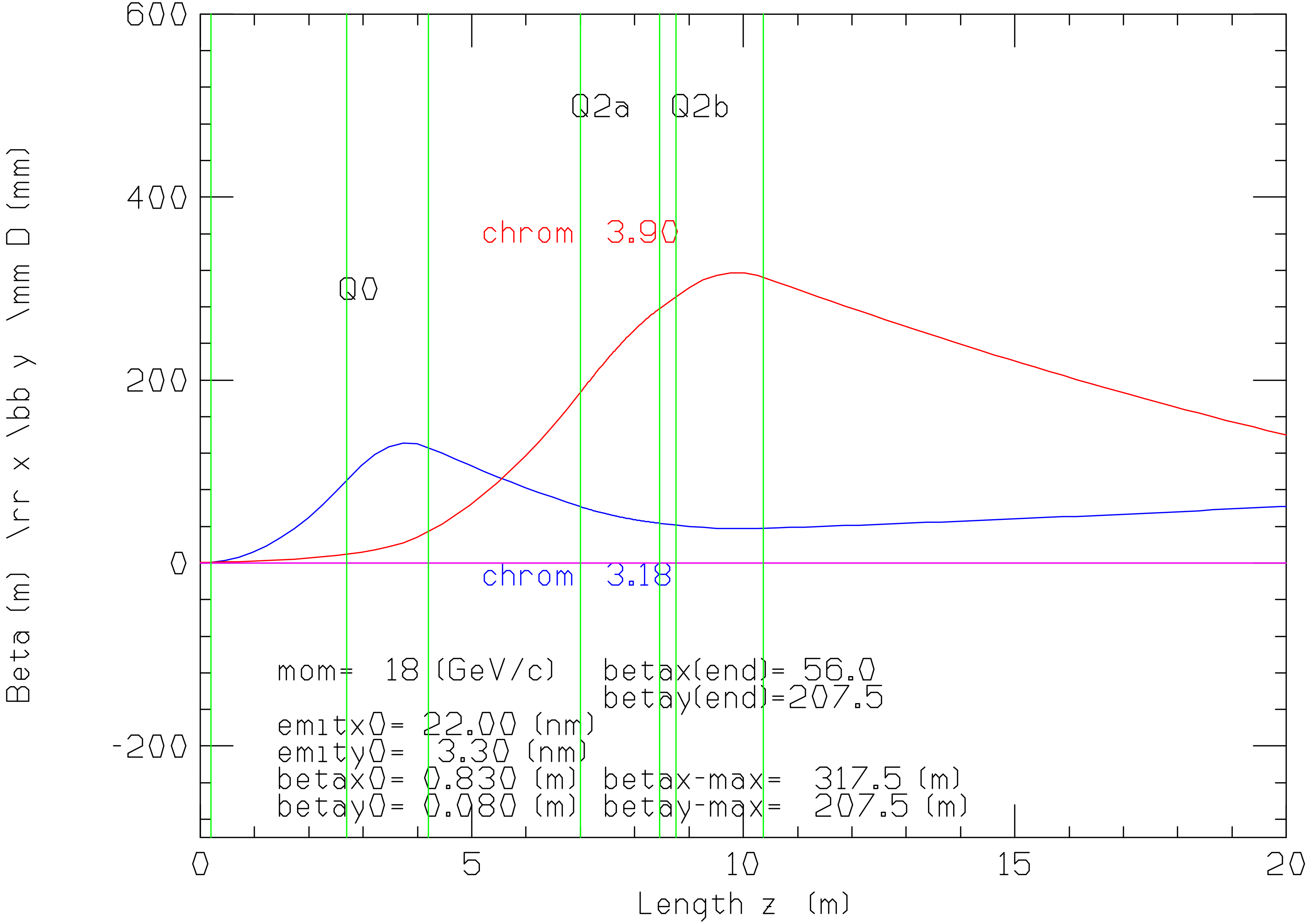
Amplitudes for 105 GeV parameters (anne381)



105 GeV c of m, with E_e= 10 GeV used to define SR fan because it has larger beam divergence tahn the 140 GeV case.

fan shown in magenta fan= (Z+2.1)6.7/1000

Forward Electron Betas for 18 GeV (bnne382)



Forward e Magnets for 140 GeV (Ee=18 GeV)

Chrom y 3.16 ' Chrom x 3.15 ' mom = 18 (mnne382.tab)

		L1 m	DL m	gap m	x cm	θ mrad	IR1 cm	IR2 cm	OR cm	B1 T	B2 T	B T	Grad1 T/m	Grad2 T/m
Q0	3	2.70	1.50	1.10	0.0	0.00	0.92	1.75	0.0	0.145	0.276	0.000	-15.795	-15.795
Q2	7	7.00	3.22	20.40	0.0	0.00	5.60	5.60	0.0	0.170	0.170	0.000	3.034	3.034

Magnet considerations

The Focus quadrupoles further from the IP, that are outside the detector and are similar in strength and location to those in the current design. There should be no new difficulty with these superconducting magnets, shielded from the hadrons by the presence of iron.

The forward focus magnets nearer to the IP start 2.7 m from it, extend to 4.2 m, and are fully inside the detector.

If made with coils, normal conducting or superconducting, their stray field could be a problem for the nearby hadrons. Iron shielding cannot be used because they are in the 0.8 T stray field from the detector solenoid.

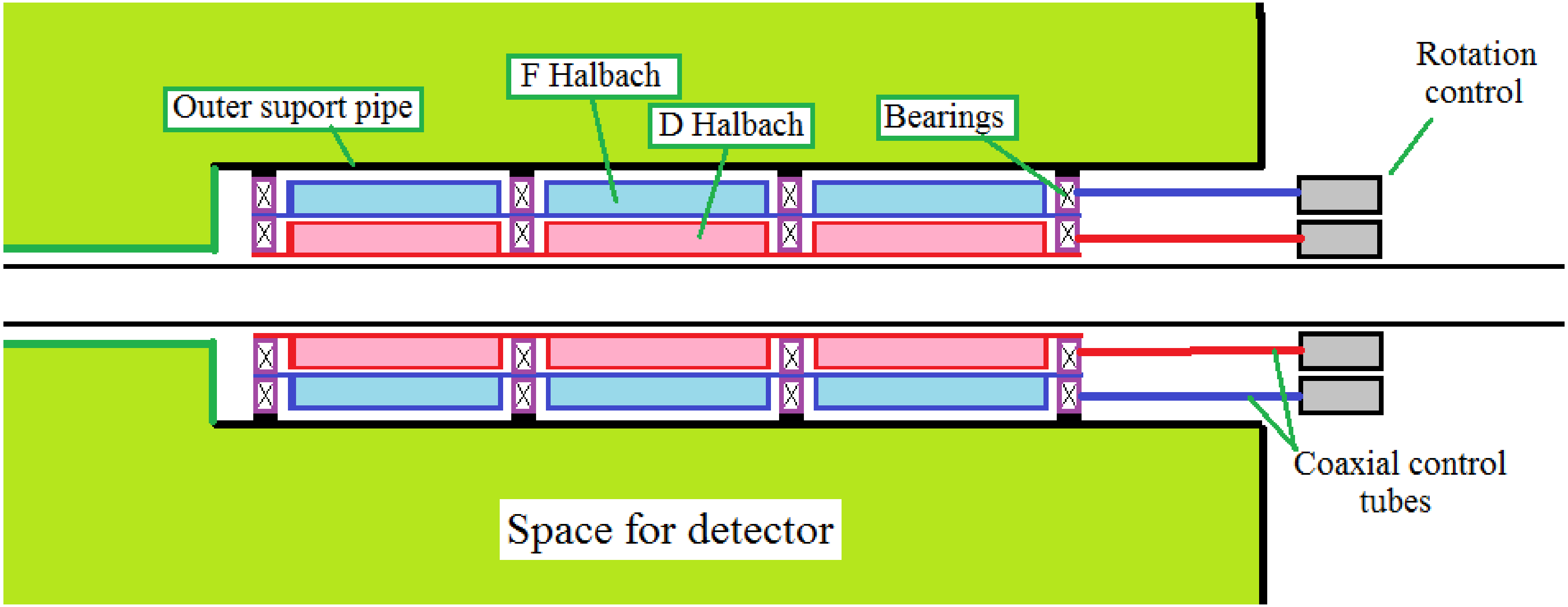
If made with Halbach permanent magnets, there is essentially no stray field. But how to trim the permanent magnets without the use of iron wires (that would saturate) is a challenge.

Options

- Magnet designs are still very preliminary

		small end mm	large end mm
Forward Options			
Inside Radii		9	18
Outside radii	Nested rotatable Halbachs	28	32
Outside radii	SC with dynamic shield	40	54

Possible nested Halbach mechanisms



- Tapering not shown
- Not to scale
- This concept has rotation controls outside of detector
- Possibly supported from outside the detector ends
- Needs more study

CONCLUSION on quads inside detector

- Placing the first forward electron IR quad inside the detector:
  - Lowers the maximum y betas
  - Approximately halves the y Chromaticity
  - Approximately halves the beam pipe dimensions at the IP
  - Reduces the minimum electron angle observable
  - Appears practical with SC actively shielded quads

- Placing the first rear electron IR quad inside the detector:
  - Lowers the maximum y betas
  - Approximately halves the y Chromaticity
  - But has challenging dimensions and interferes with small angle EM detection

Quads inside the detector are not in the agreed baseline, but having just the forward quad inside the detector seems to give significant advantages

Summary

	pCDR	New	Inside
FORWARD			
$\beta{*}_x$ (m)	480	560^1	320^2
$\beta{*}_y$ (m)	360	420^1	130^2
REAR			
$\beta{*}_x$ (m)	1200^3	300^3	
$\beta{*}_y$ (m)	560	460^4	

Notes

1 Worse because magnets further from IP for warm-cold transition

2 Big gains only in y because only y focus quad inside

3 Worst problem fixed without magnets inside

4 Gain by bringing rear quads close together - not possible forward because it increased SR fan