Electromagnets with High Gradients (for CLS 2)

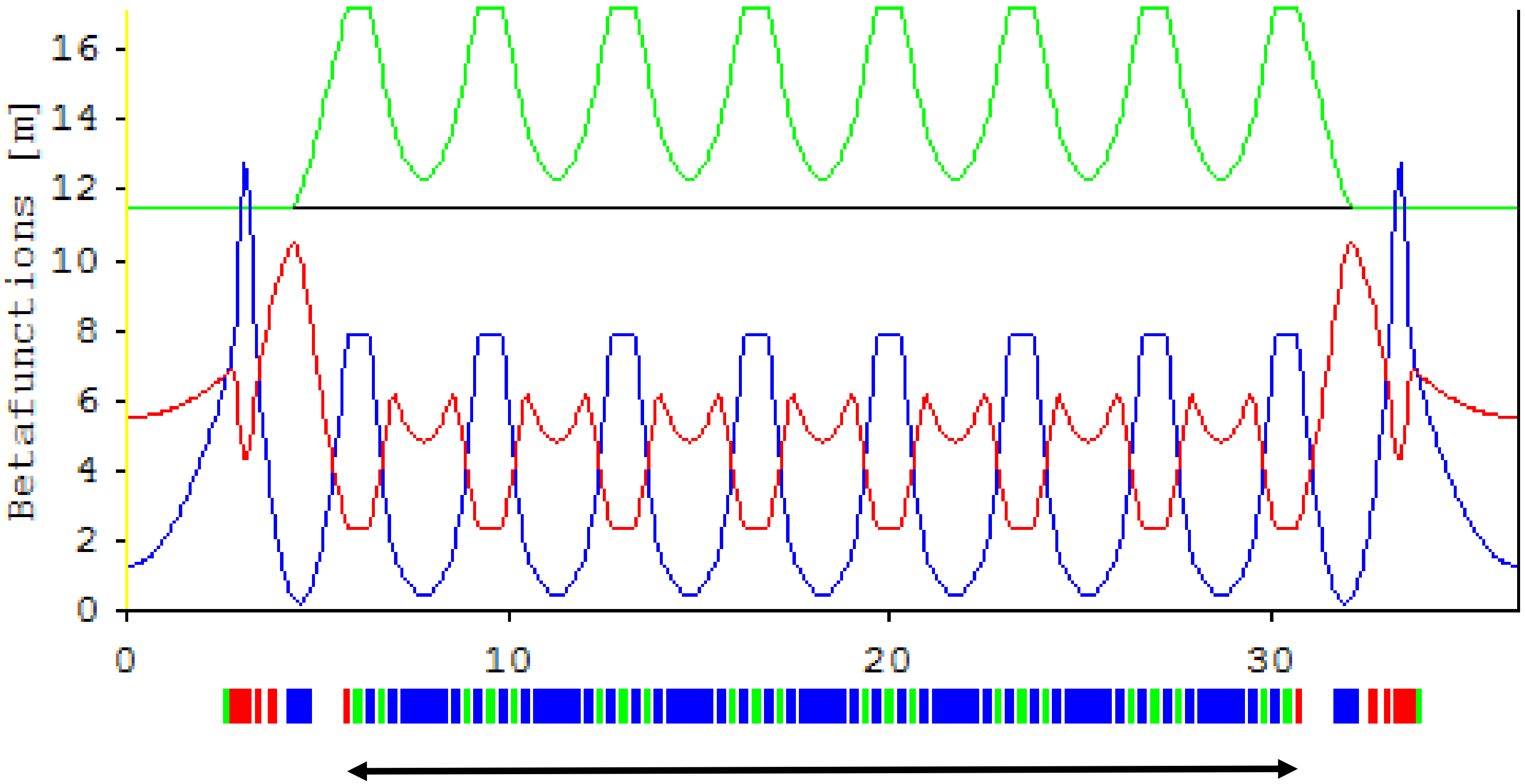
L. Dallin

ALERT 2019 Workshop

July 12, 2019

CLS 2 – 3 GeV Ultralow Emittance Light Source

(IPAC 19)



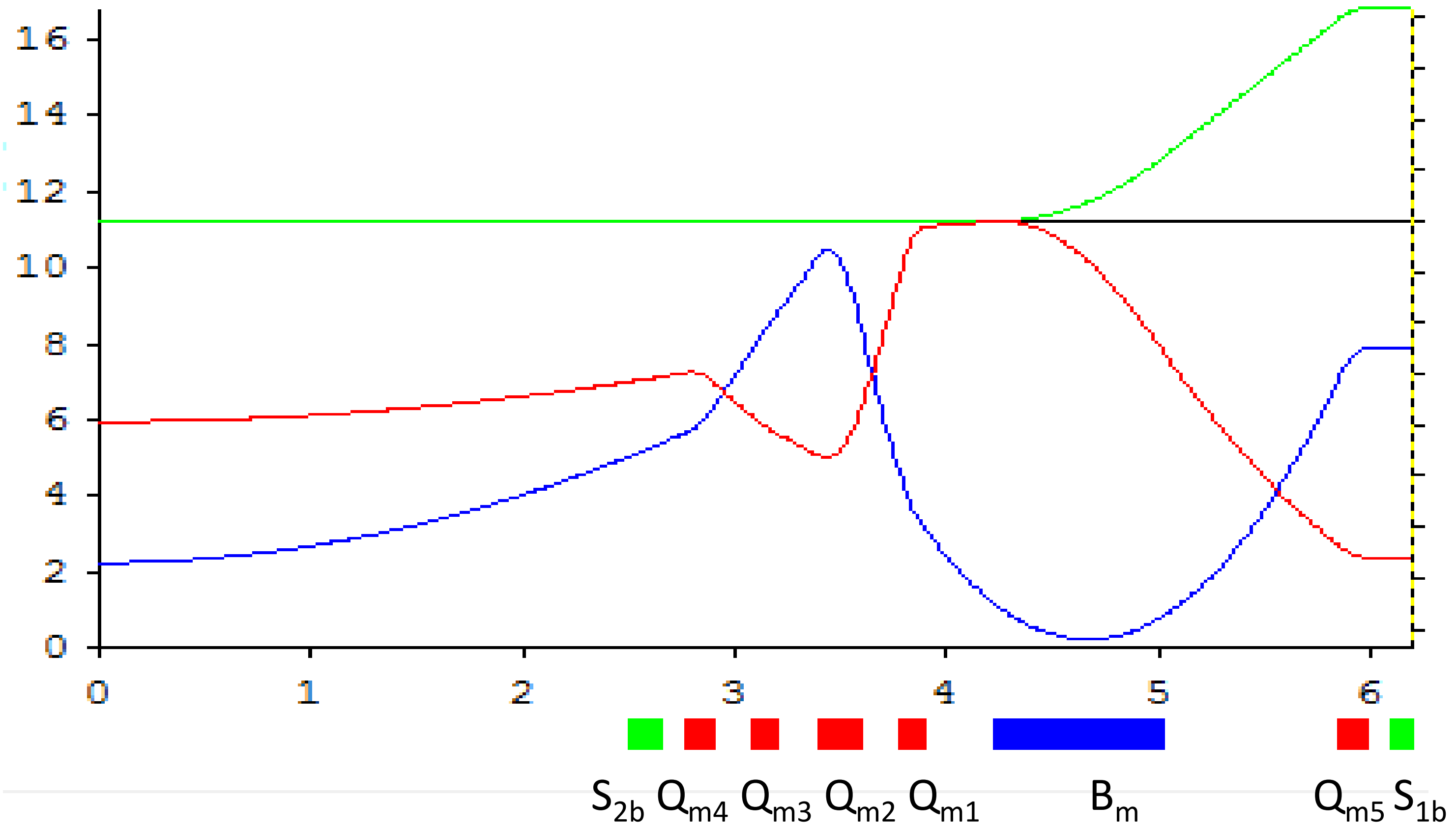
Matching

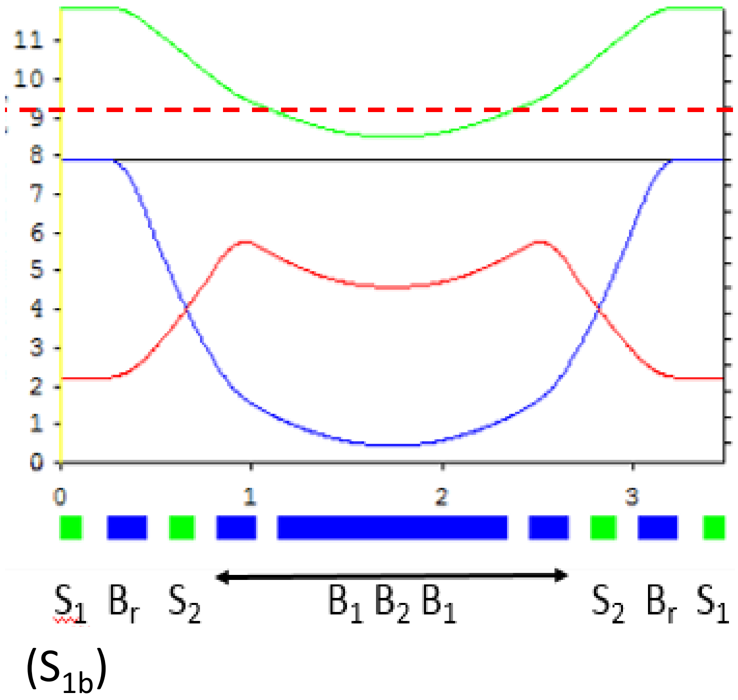
7 unit cells

Matching

CLS	2.2	
Energy	3.0	GeV
Size	588.0	m
Periodicity	16	
ν_x	66.15	
ν_y	21.3	
ε	**25**	pm
δ	0.10	%
Straights		
β_x	2.23	m
β_y	5.95	m
η_x	0.0	m
α_c	5.4	$\times 10^{-5}$
RF freq.	500	MHz
RF voltage	3.0	MV
Harm. #	980	
Current	300	mA
Coupling	10	%
Lifetime	9.2	hr

matching cell



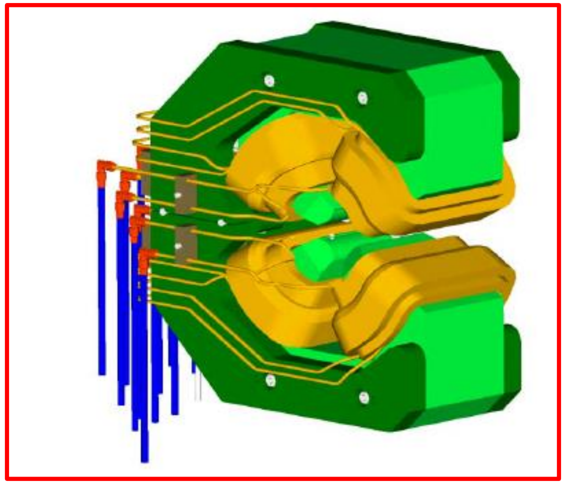


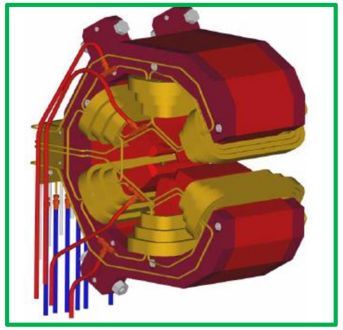
Required:

160 Quadrupoles, 348 Sextupoles, 144 Long Bend Magnets,
448 Short Bend Magnets (offset quadrupoles)

→ 1100 High Gradient Electromagnets (**AISI 1010 steel is considered**)

Separate elements are designed





Quadrupoles

CLS 2.2 lattice:

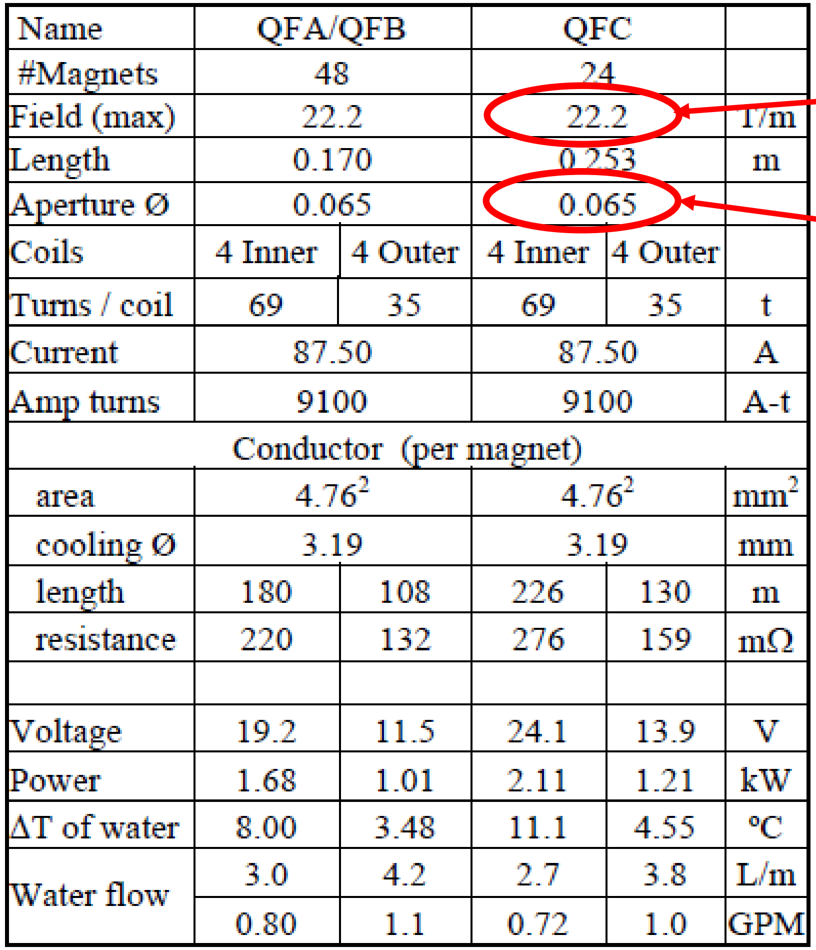
```
long : drift, l=2.503400,ay = 3.00;[mm]
d11:drift, l=0.11;  d12:drift, l=0.12;  d13:drift, l=0.13;
d18:drift, l=0.18;  d20:drift, l=0.20;  d33:drift, l=0.33;
d83:drift, l=0.831638,d10:drift,l=0.10;
{quadrupoles}
qm1:quadrupole, l=0.12, k= -8.52240;
qm2:quadrupole, l=0.20, k= 8.658014;
qm3:quadrupole, l=0.12, k= 0.958858;
qm4:quadrupole, l=0.12, k= -3.53309;
qm5:quadrupole, l=0.12, k= 6.615875;
{offset quadrupoles}
br:bending,l=0.20, t = -0.20, k = 4.85; [°]
b1:bending,l=0.20, t = 0.20, k = -4.85;
{bend magnets}
b2:bending, l=1.2, t = 2.712, k = 0.421,
         t1= 1.356, t2 = 1.356;
bm : bending, l = 0.8, t = 1.758, k = -0.6,
         t1= 0.0, t2 = 0.0;
{sextupoles}
s1  : sextupole, l = 0.12 k = 210.3;
s1b: sextupole, l = 0.12, k = -51.7;
s2  : sextupole, l = 0.15, k = -212.6;
s2b: sextupole, l = 0.15, k = 0.0;{corrector}
{segments}
pbend : b1, d12, b2, d12, b1;{pseudobend}
cell:s1,d13,br,d11,s2,d11,pbend,d11,s2,d11,br,d13,s1;
match:long,s2b,d10,qm4,d18,qm3,d20,qm2,d18,qm1,
          d33,bm, d83, qm5, d12, s1b;
mba:match,7*cell, -match;
ring:16*mba
```

	qm1	qm2	qm3	qm4	qm5
#	32	32	32	32	16
length [m]	0.12	0.20	0.12	0.12	0.12
aperture Ø[mm]	24	24	24	24	30
Gradient [T/m]	-85.22	86.58	9.59	-35.33	66.16
Gradient_{max}	90	90	30	45	70
coils	4	4	4	4	4
amp-turns	6000	6000	2000	3000	7000
windings	40	40	40	40	38
current [Amp]	150	150	50	75	184

(To do: change 24 mm to 25 mm?)

CLS Quadupole Design circa 2001

Table 1 Quadrupole Design Parameters.

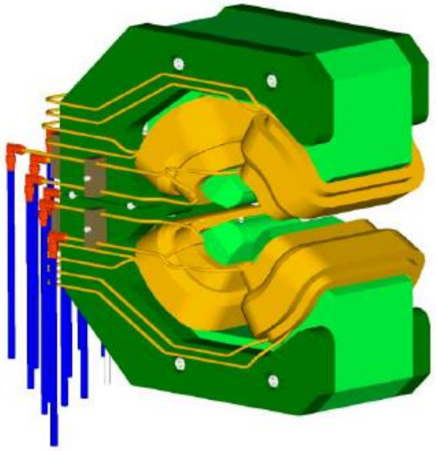


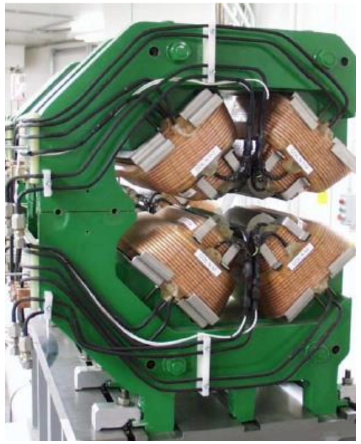
Name	QFA/QFB		QFC		
#Magnets	48		24		
Field (max)	22.2		22.2		T/m
Length	0.170		0.253		m
Aperture Ø	0.065		0.065		
Coils	4 Inner	4 Outer	4 Inner	4 Outer	
Turns / coil	69	35	69	35	t
Current	87.50		87.50		A
Amp turns	9100		9100		A-t
Conductor (per magnet)					
area	4.76^2		4.76^2		mm^2
cooling Ø	3.19		3.19		mm
length	180	108	226	130	m
resistance	220	132	276	159	mΩ
Voltage	19.2	11.5	24.1	13.9	V
Power	1.68	1.01	2.11	1.21	kW
ΔT of water	8.00	3.48	11.1	4.55	°C
Water flow	3.0	4.2	2.7	3.8	L/m
	0.80	1.1	0.72	1.0	GPM

22.2 T/m

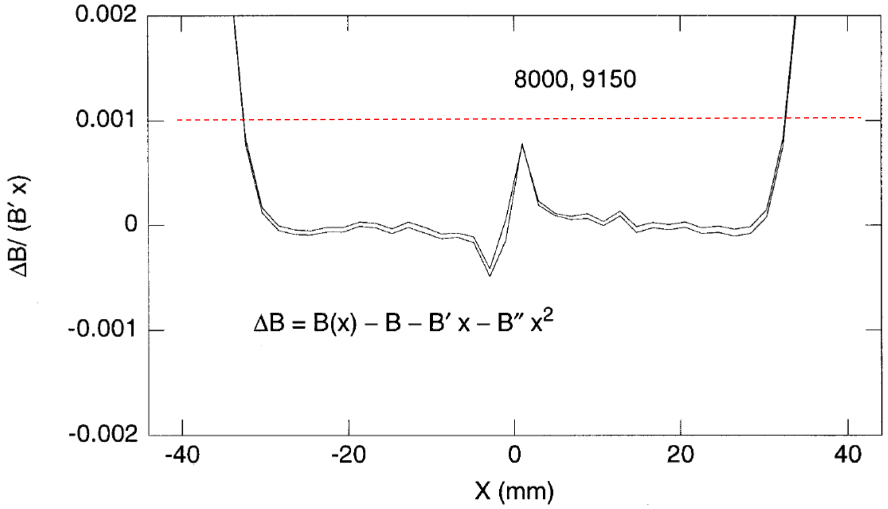
65 mm aperture

For High Gradient – reduce aperture

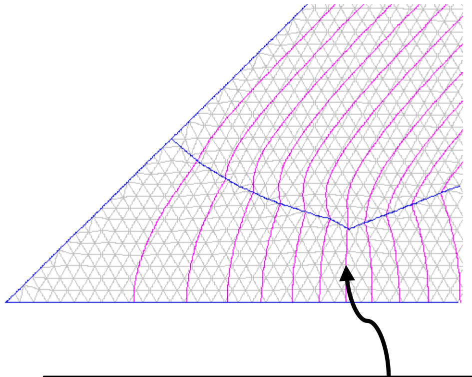




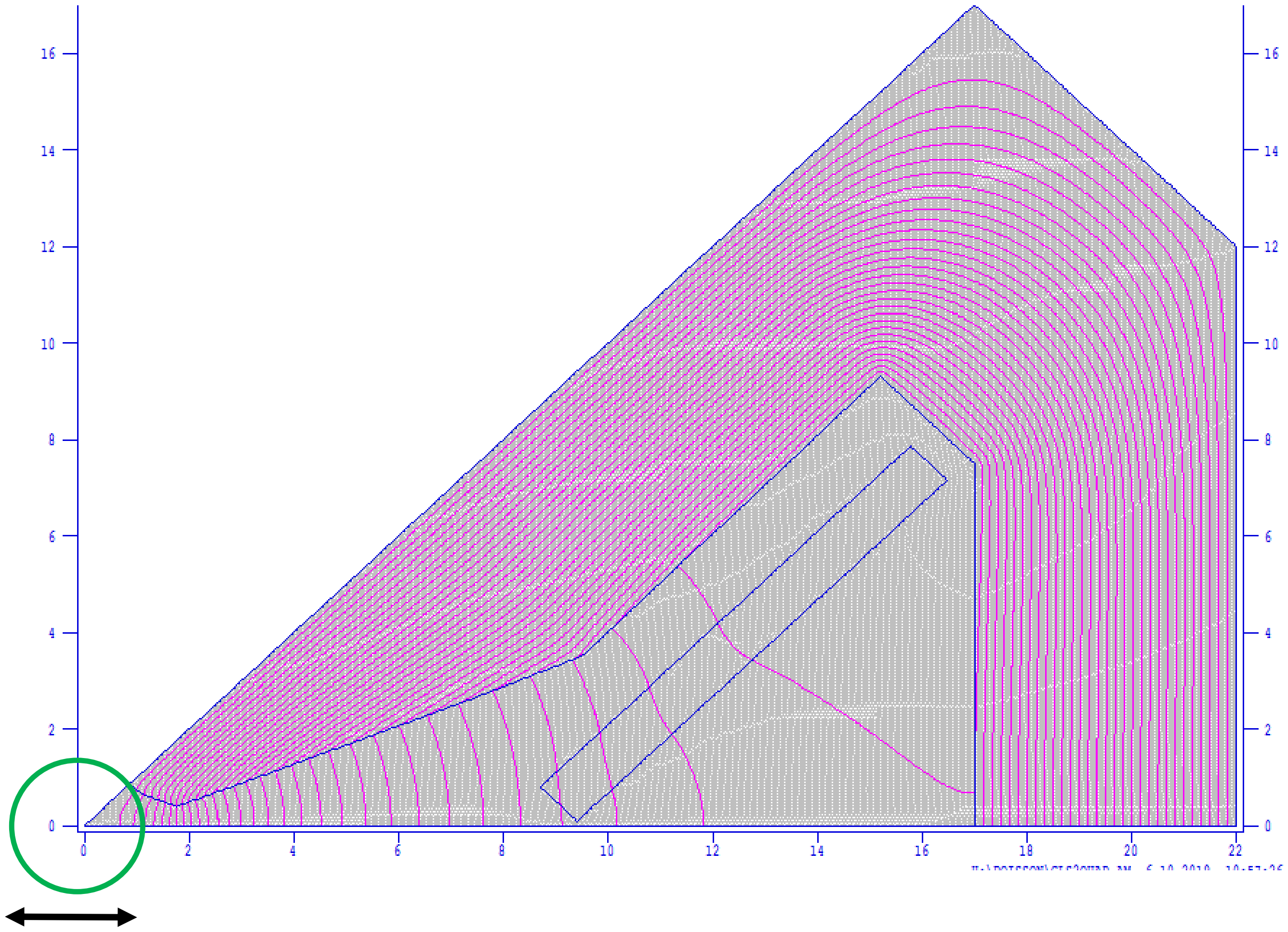
Good Field Region @ 0.1%: ±30 mm



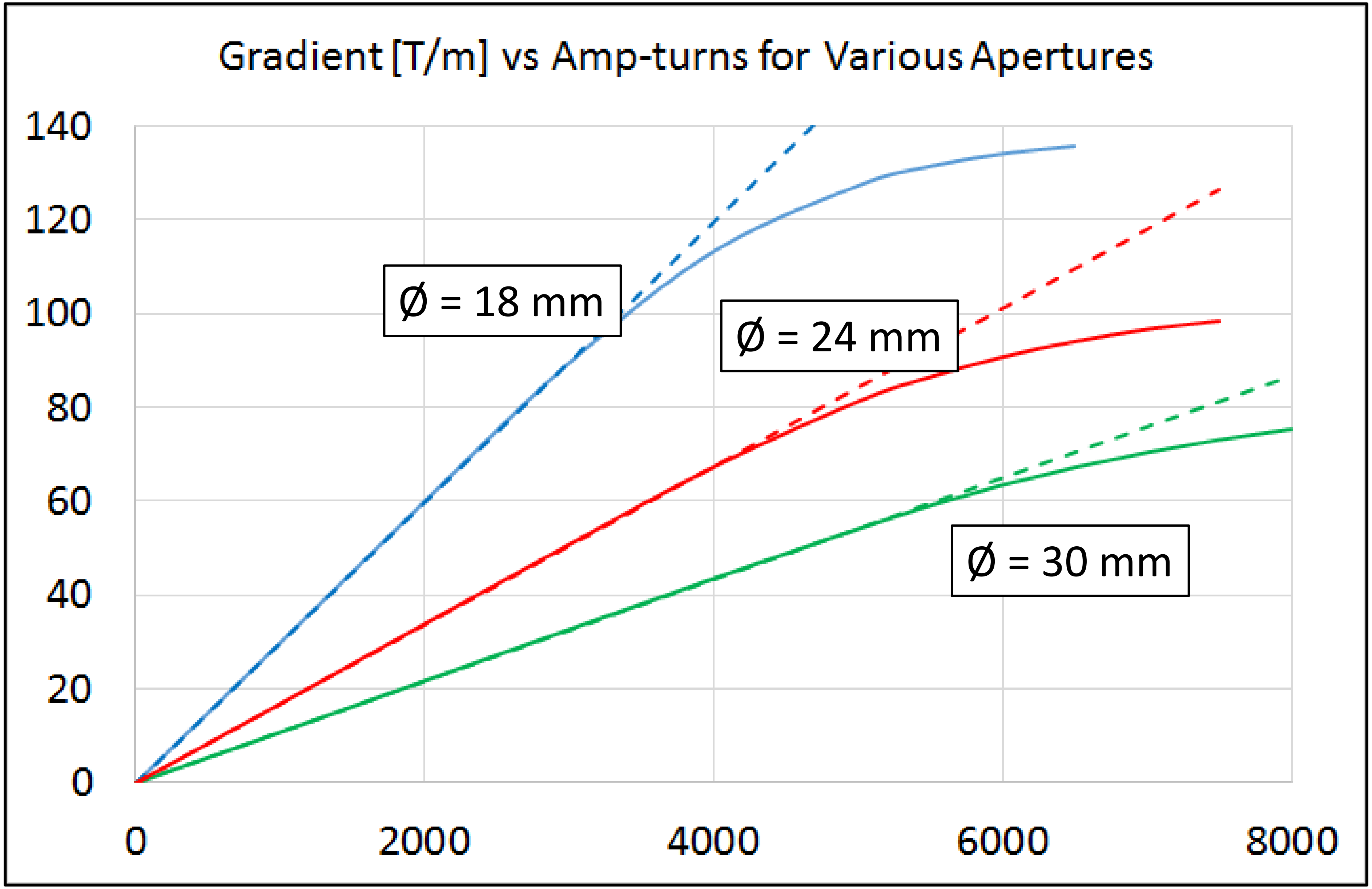
Adjust Ø to evaluate various quadrupole magnets



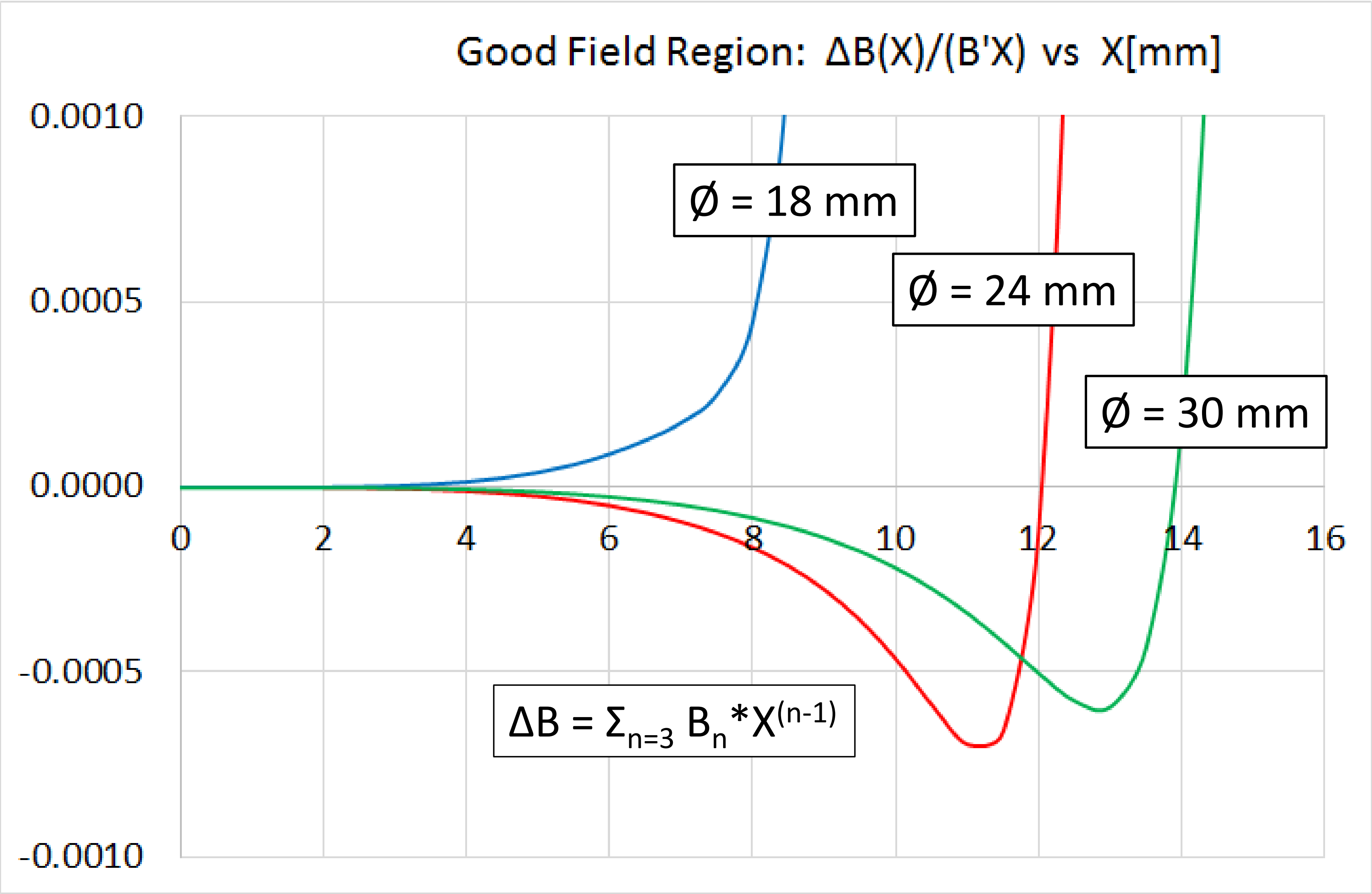
Pole tip optimized so reduce multipoles



Aperture Ø = 18 mm; 24 mm; 30 mm (on the same yoke)



Ø [mm]	B’ [T/m] (90% eff.)
18	120
24	90
30	73



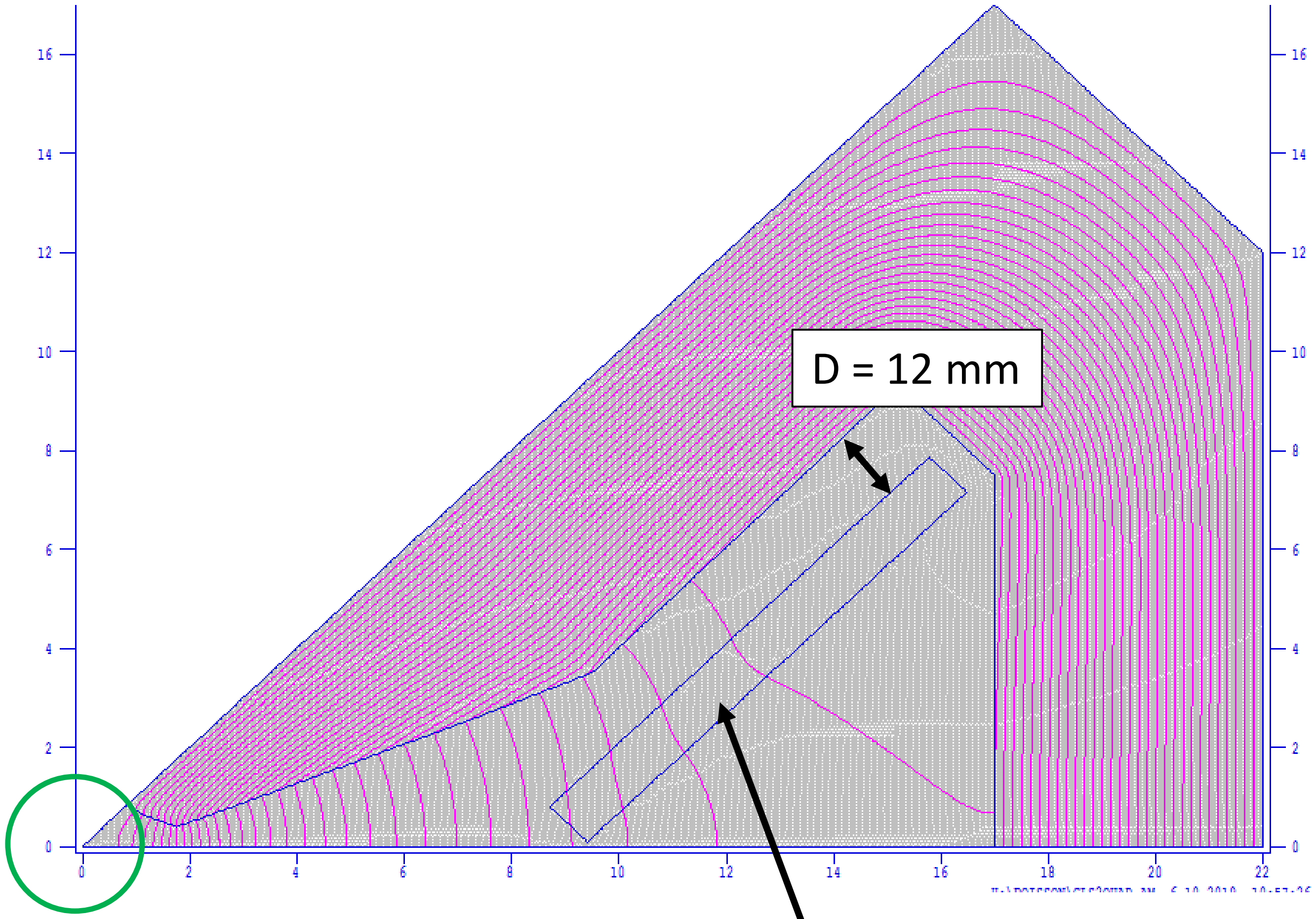
E.g.: Ø = 24 mm
Relative Multipoles
@ 10 mm

n	B_n/B_2
6	-9.8E-04
10	-8.6E-05
14	-1.8E-05
18	-2.7E-07
22	6.5E-06
26	1.3E-05

CLS 2 Quadrupoles

Qm1, Qm2, Qm3 and Qm4 magnets

- 12 mm aperture radius
- tall coils → small longitudinal length

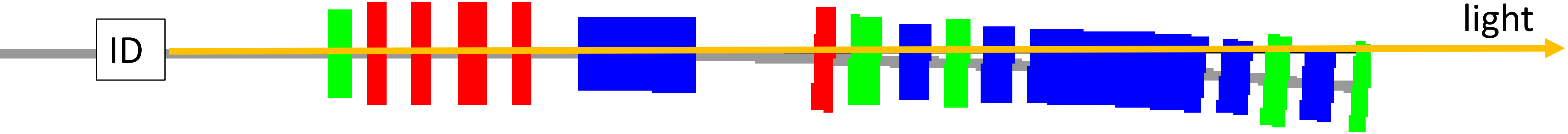


Ø = 24 mm

10 mm X 100 mm coil
→ 2x20 = 40 turns (4.8mm X 4.8mm conductor)

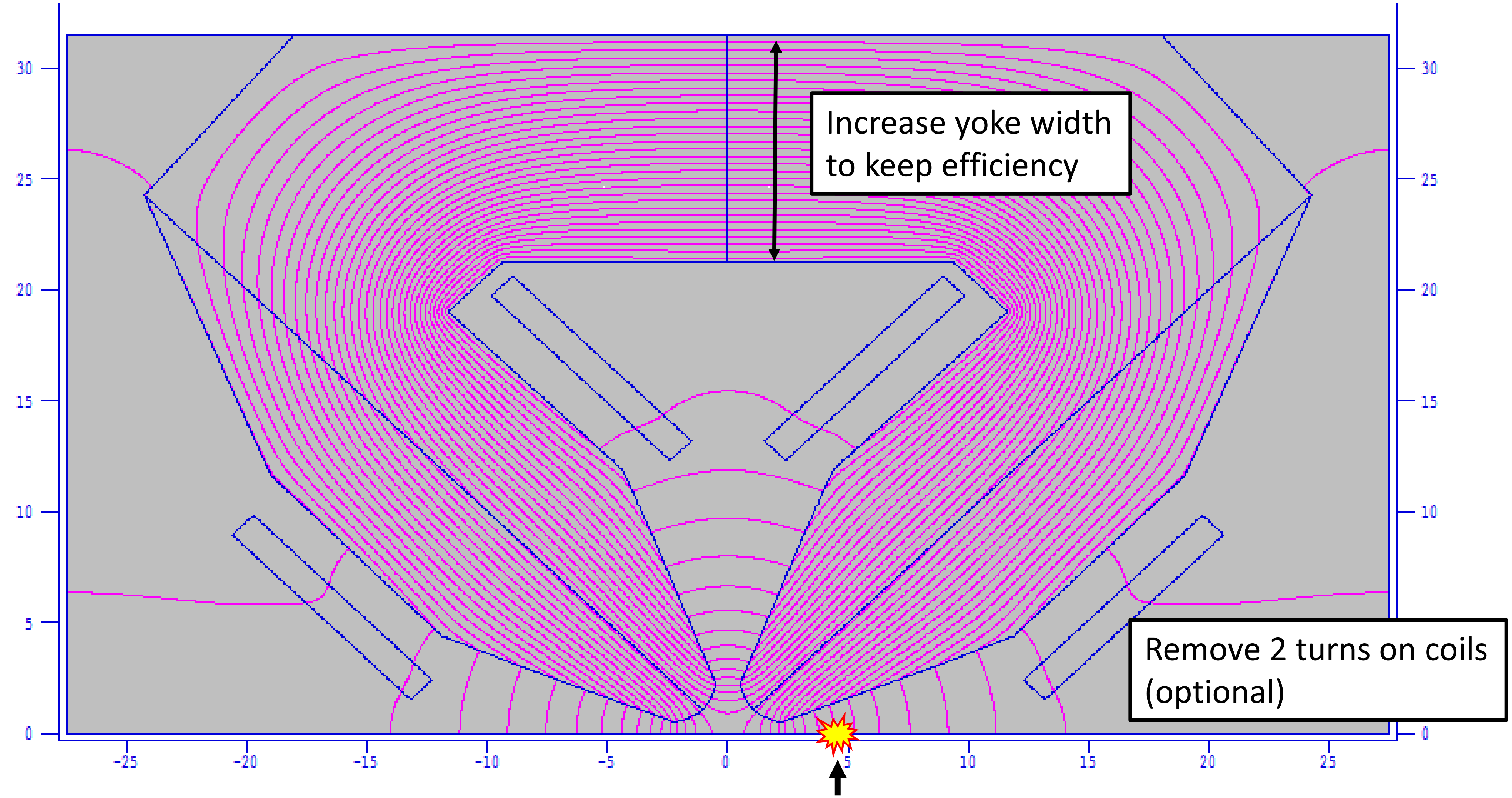
coil sticks out ~10 mm at end of magnet

Getting the photon beam out …….



Qm1
Photon beam @ 4.4 ↔ 4.8 cm

Getting the photon beam out: open-sided quadrupole Qm5 (Ø = 3.0 cm)

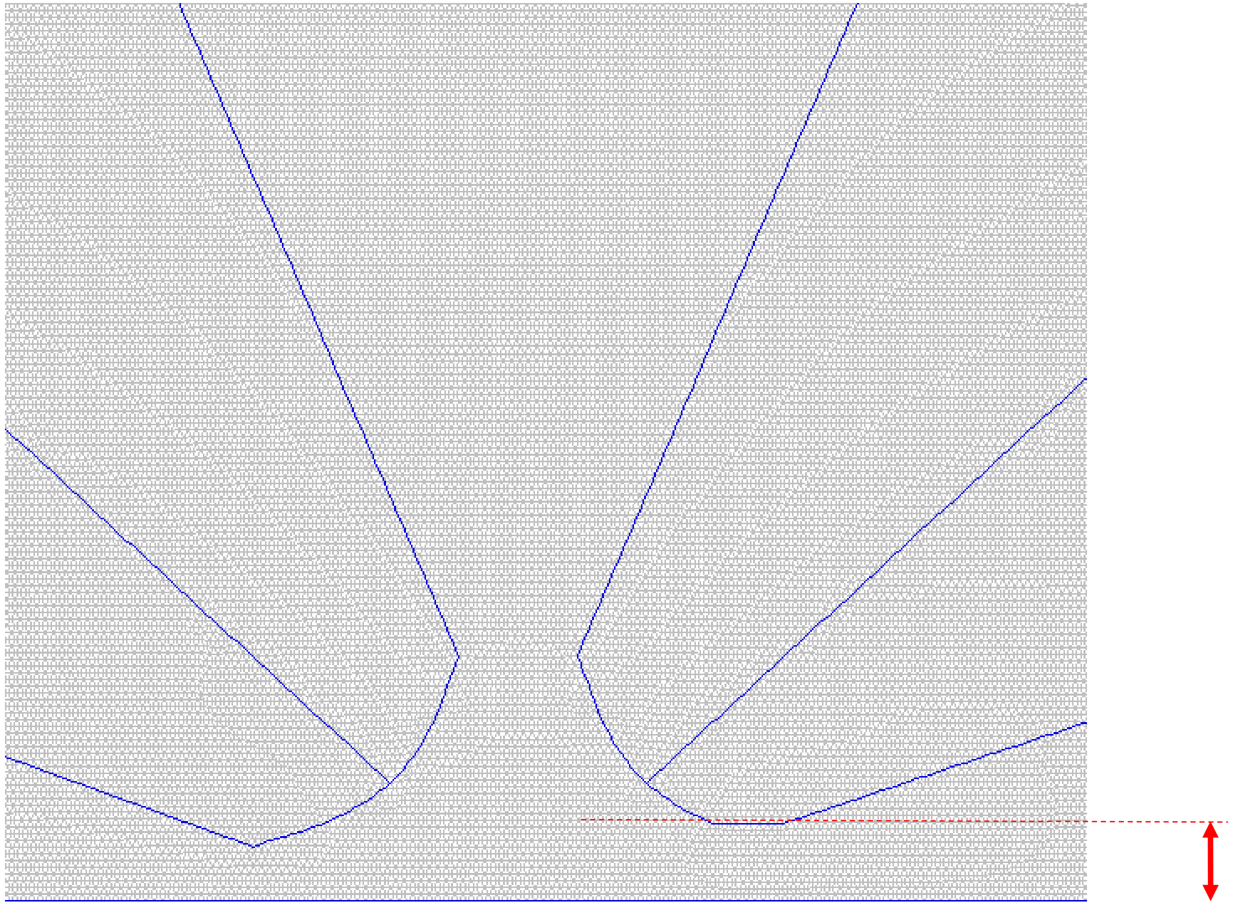


Increase yoke width to keep efficiency

Remove 2 turns on coils (optional)

Photon beam in Qm5

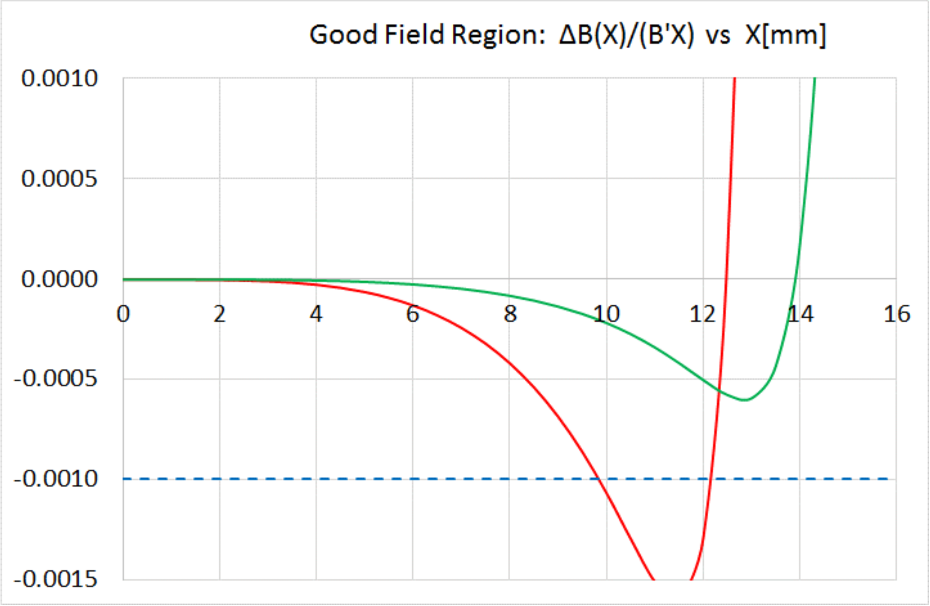
Getting the photon beam out:open-sided quadrupole Qm5



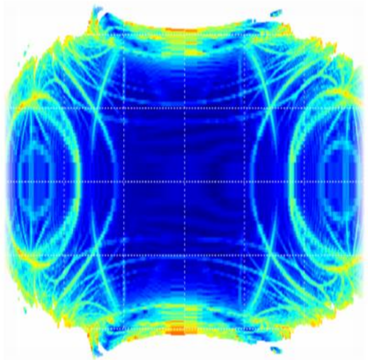
Single cut

6.25 mm x 2 = 12.5 mm

(is this enough?)



reduction of GFR



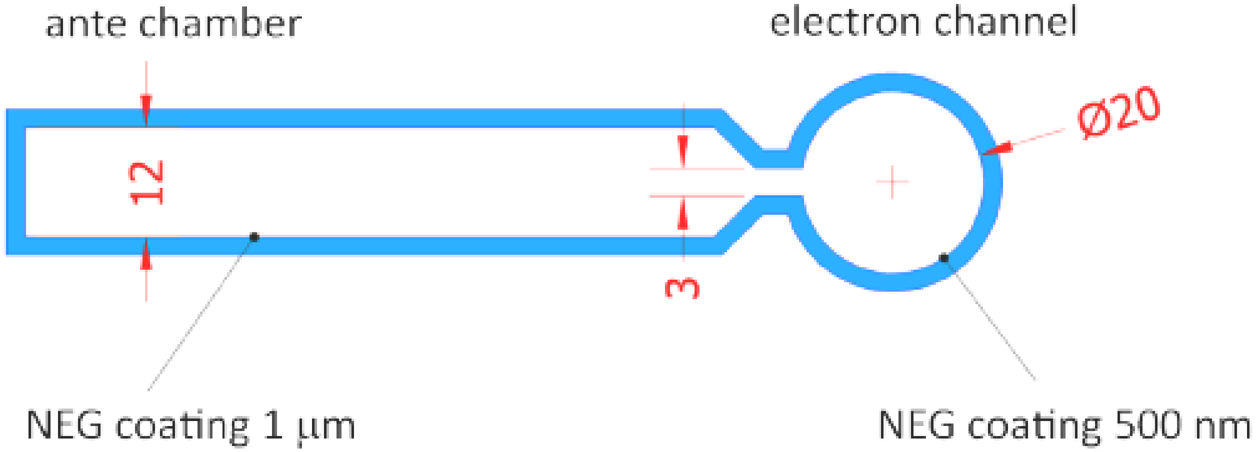
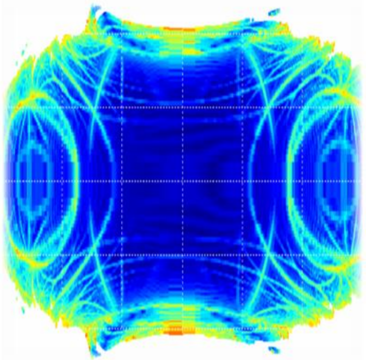


Figure 5.11: Dipole chamber cross section



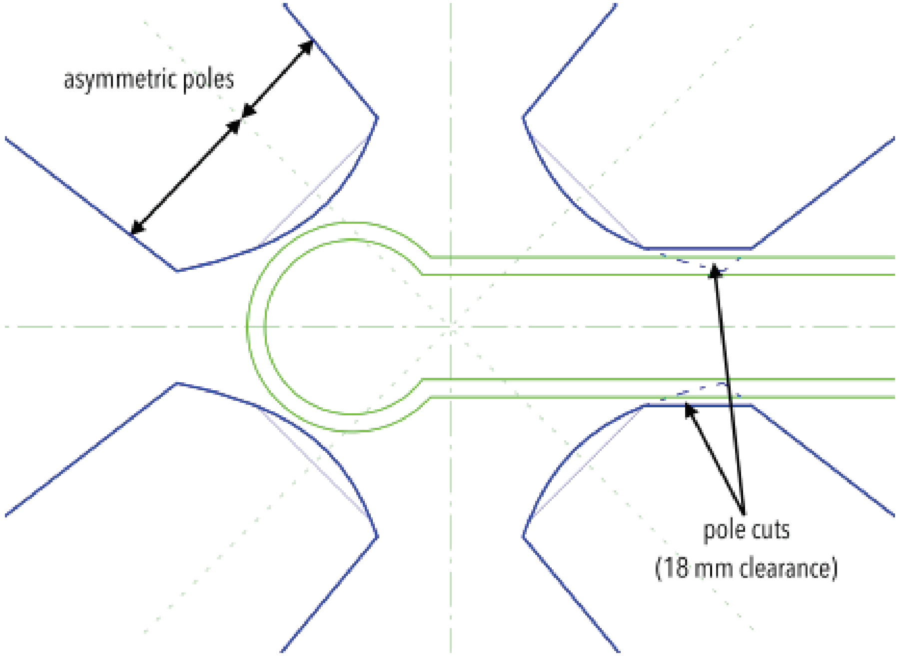
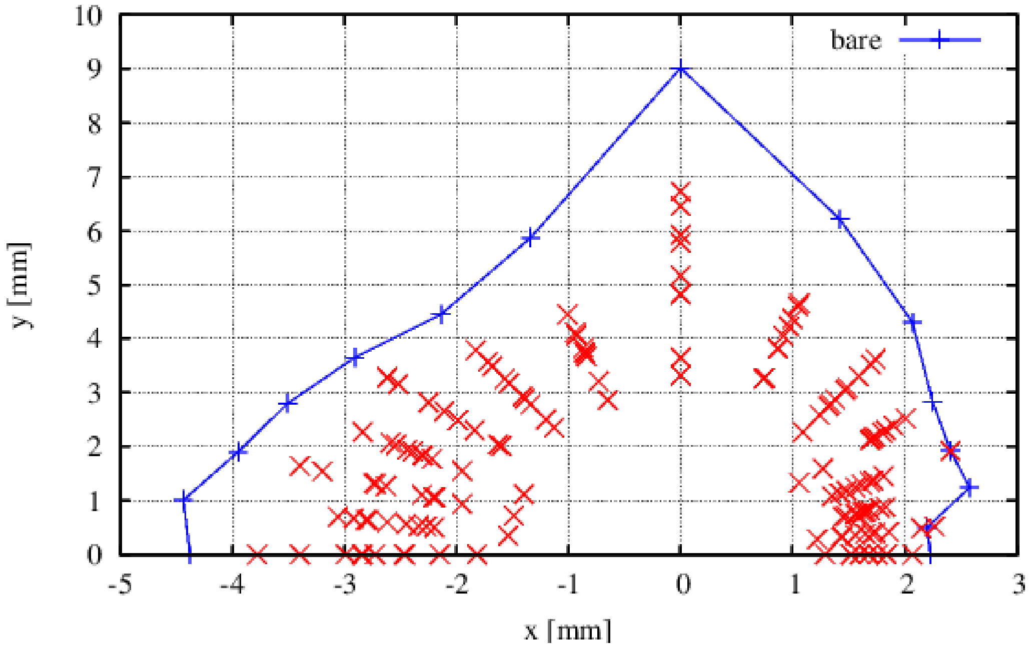


Figure 4.8: Detailed central region of the combined function reverse bend AN showing the ante-chamber and the need to modify the pole shape on that side.



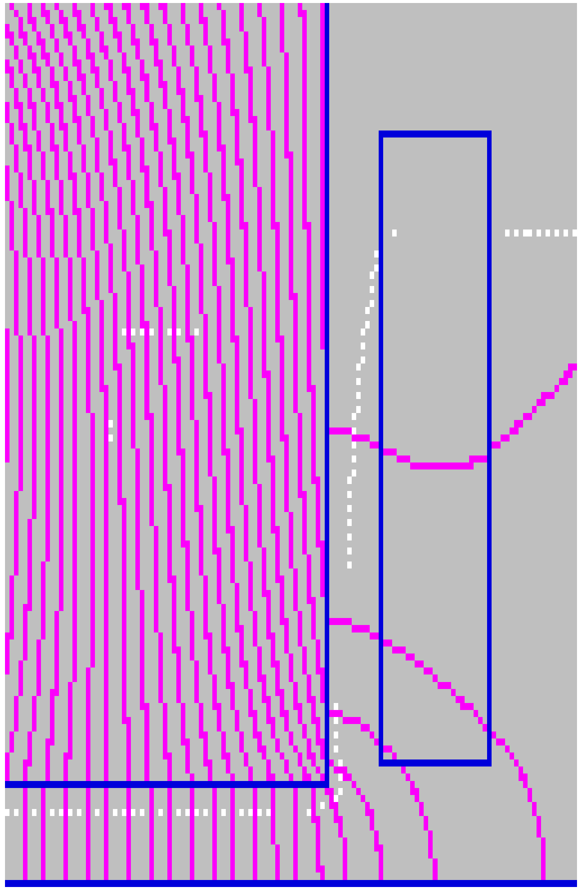
Dynamic Aperture at center of straight

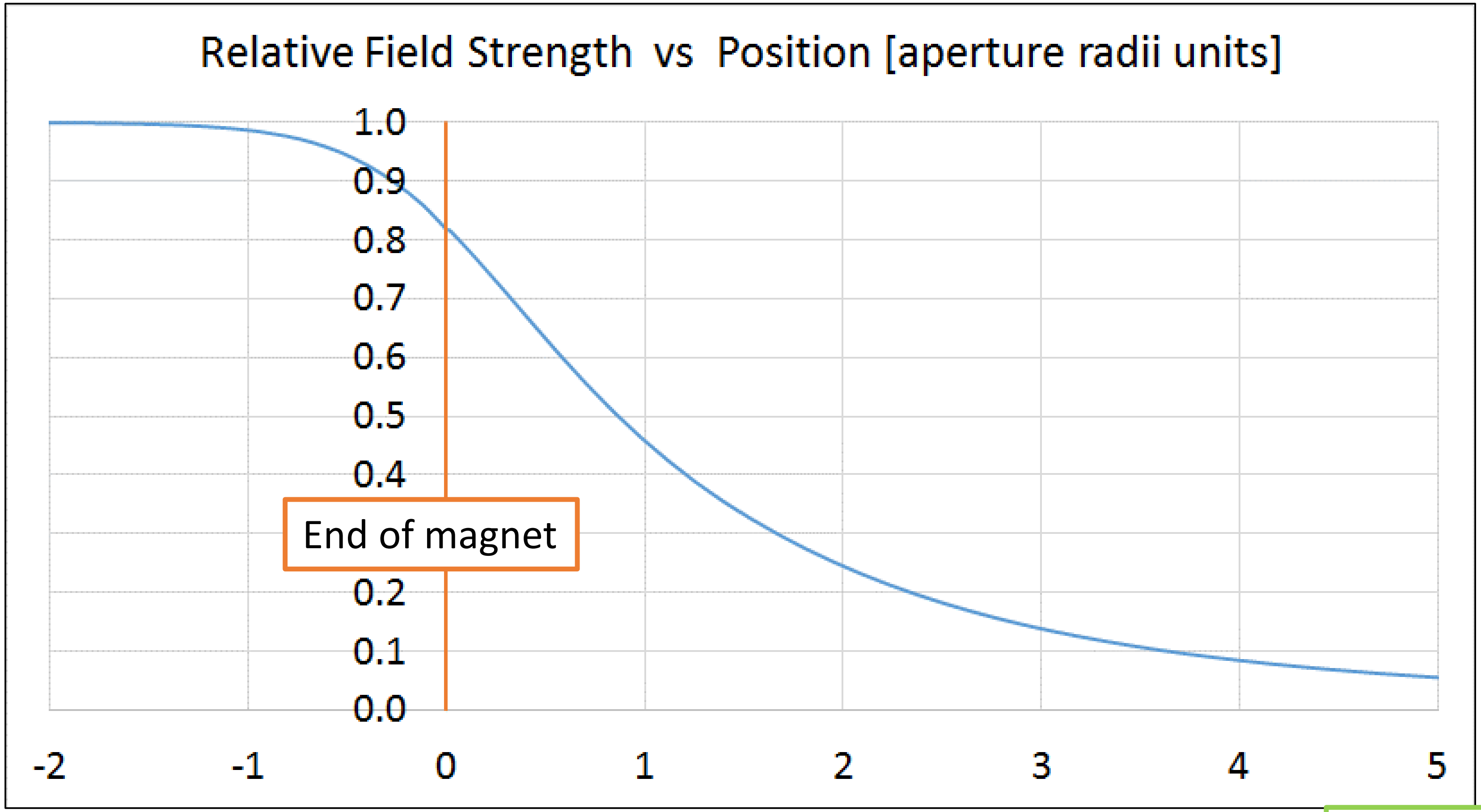
elsewhere:
DA = $(\beta/\beta_{straight})^{½}$ * $DA_{straight}$

Keep GFR > DA !!

Position	β_x	DA_x [mm]	β_y	DA_y [mm]
Straight center	2.23	4.5	5.95	9.0
Bm	0.84	2.8	7.77	10.2
Qm5	7.15	8.1	2.64	6.0
S1b	7.86	8.4	2.36	5.7
Br	6.45	7.7	2.94	6.3
S2	5.08	6.8	3.61	7.0
B1	1.47	3.7	6.03	9.1
B2	1.16	3.2	5.66	8.8

Small apertures → Shorter fringe fields





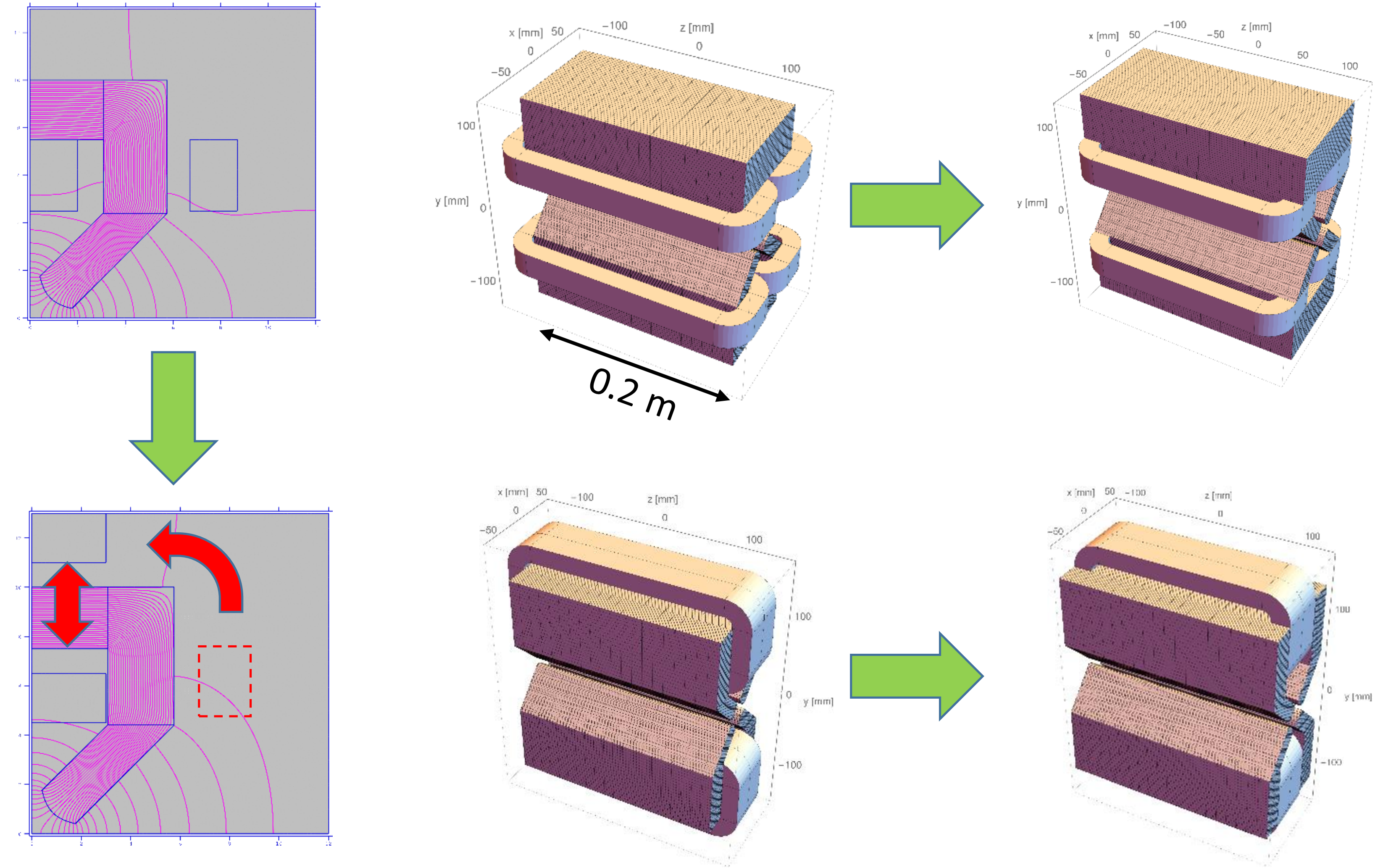
60 mm

Ø = 24 mm (R = 12 mm) → small field at 60 mm → 120 mm between magnets

or smaller?

Reducing the Longitudinal Footprint

MAGNET DESIGN CONSIDERATIONS FOR AN ULTRALOW EMITTANCE CANADIAN LIGHT SOURCE (IPAC 18)
L.O. Dallin, D. Bertwistle



17% loss
of efficiency

3% loss
of efficiency

(with thicker yoke)

http://accelconf.web.cern.ch/AccelConf/ipac2018/papers/wepmf021.pdf

Reducing the Longitudinal Footprint

MAGNETS FOR ELETTRA 2.0 (IPAC 19)
D. Castronovo, E. Karantzoulis

Recessed coils

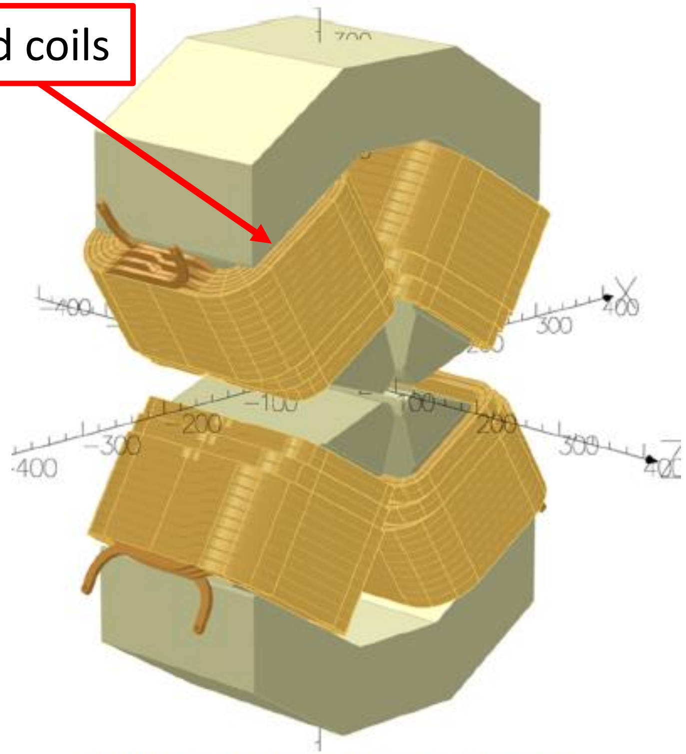


Figure 5: Prototype magnetic model.

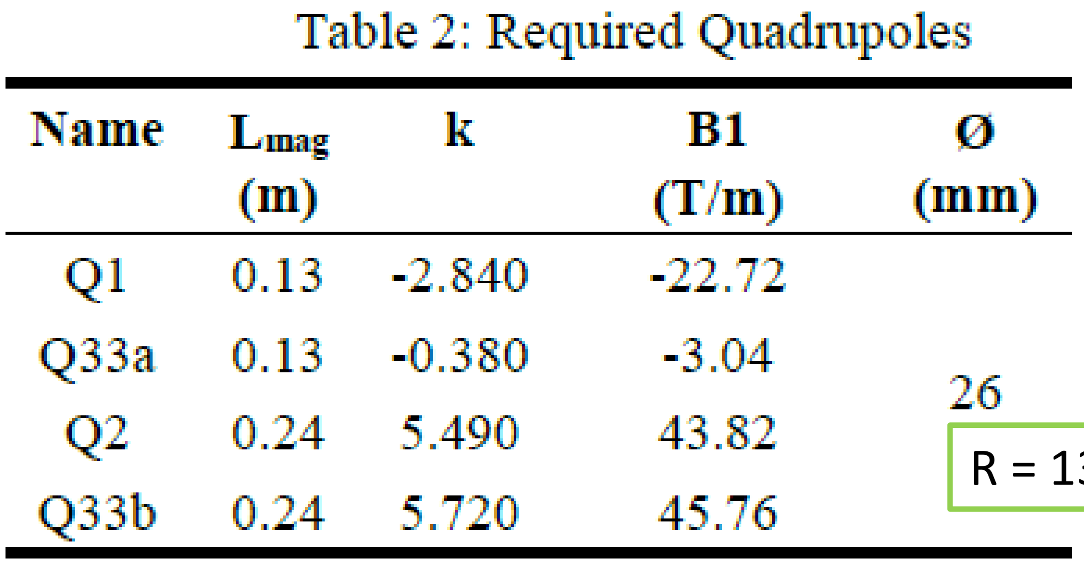


Table 2: Required Quadrupoles

Name	L_{mag} (m)	k	B1 (T/m)	Ø (mm)
Q1	0.13	-2.840	-22.72	26
Q33a	0.13	-0.380	-3.04	
Q2	0.24	5.490	43.82	
Q33b	0.24	5.720	45.76	

R = 13 mm

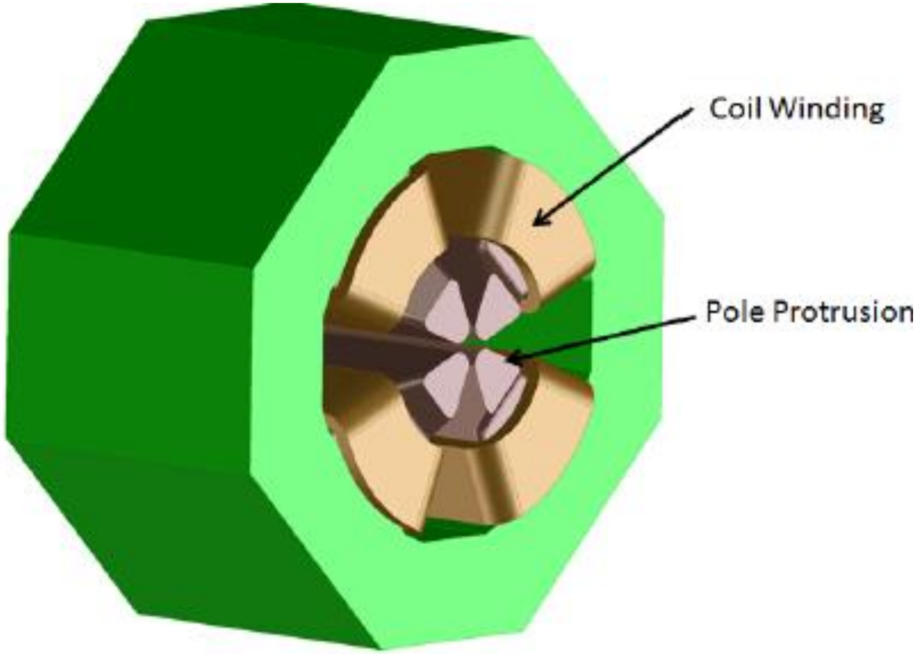


Figure 2: Illustration of axial pole extension employed in ALS magnets. Pole material can be pure iron or CoFe.

ALS-U Design

Charles Swenson et al.
IPAC 2016

With consideration of
Different pole tip material

Sextupole / Correctors

CLS 2.2 lattice:

```
long : drift, l=2.503400,ay = 3.00;[mm]
d11:drift, l=0.11;  d12:drift, l=0.12;  d13:drift, l=0.13;
d18:drift, l=0.18;  d20:drift, l=0.20;  d33:drift, l=0.33;
d83:drift, l=0.831638,d10:drift,l=0.10;
{quadrupoles}
qm1:quadrupole, l=0.12, k= -8.52240;
qm2:quadrupole, l=0.20, k= 8.658014;
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qm4:quadrupole, l=0.12, k= -3.53309;
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{offset quadrupoles}
br:bending,l=0.20, t = -0.20, k = 4.85; [°]
b1:bending,l=0.20, t = 0.20, k = -4.85;
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         t1= 1.356, t2 = 1.356;
bm : bending, l = 0.8, t = 1.758, k = -0.6,
         t1= 0.0, t2 = 0.0;
{sextupoles}
s1  : sextupole, l = 0.12 k = 210.3;
s1b: sextupole, l = 0.12, k = -51.7;
s2  : sextupole, l = 0.15, k = -212.6;
s2b: sextupole, l = 0.15, k = 0.0;{corrector}
{segments}
pbend : b1, d12, b2, d12, b1;{pseudobend}
cell:s1,d13,br,d11,s2,d11,pbend,d11,s2,d11,br,d13,s1;
match:long,s2b,d10,qm4,d18,qm3,d20,qm2,d18,qm1,
          d33,bm, d83, qm5, d12, s1b;
mba:match,7*cell, -match;
ring:16*mba
```
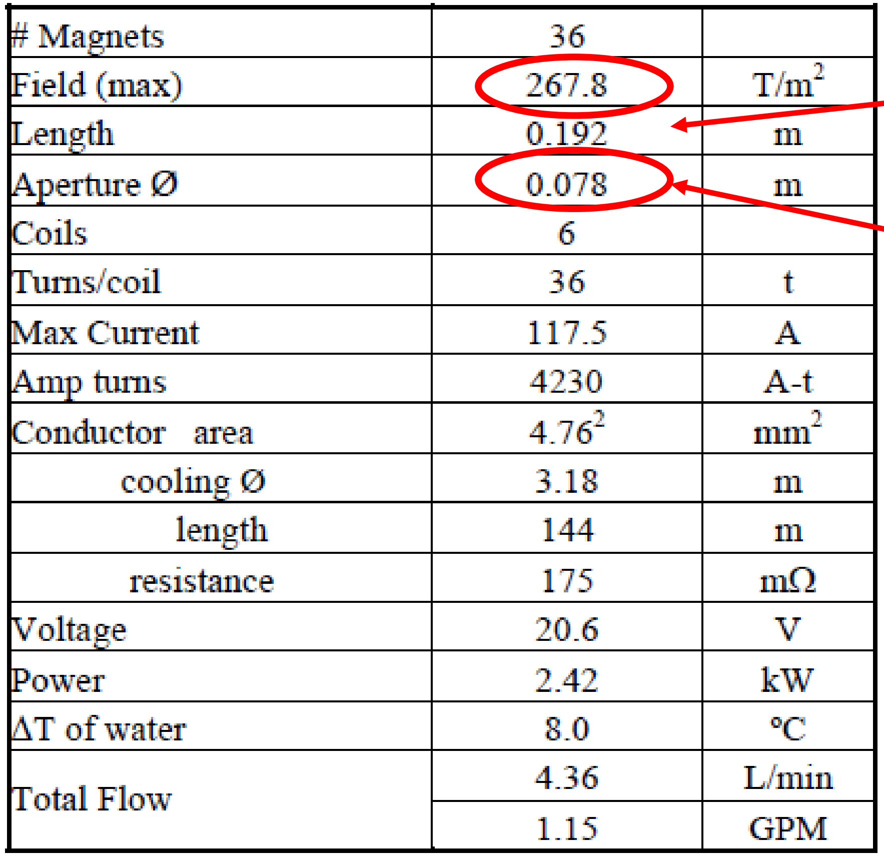

	S1*	**S1b***	**S2**	**S2b**	
#	224	224	224	224	
length [m]	0.24	0.24	0.15	0.15	
aperture [mm]	12	12	12	12	
Gradient $[T/m^2]$	2103	1586	2126	0	
Gradient_{max}	2224	2224	2224	corrector	
coils	6	6	6	only	
amp-turns	1200	1200	1200		
windings	20	20	20		
current [Amp]	60	60	60		

Note: S1* = S1 + S1
S1b* = S1 + S1b

CLS Sextupole Design circa 2001

Table 3: Sextupole Design Parameters

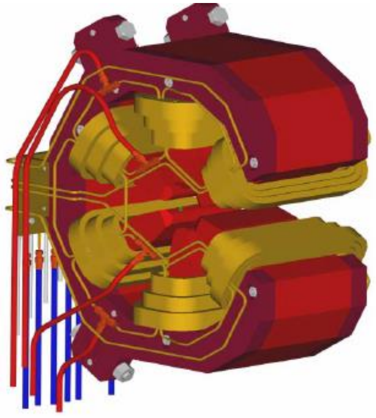


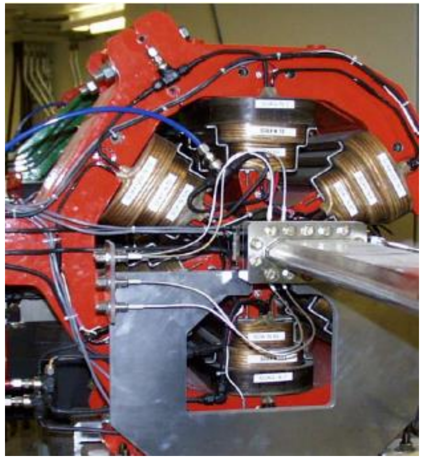
# Magnets	36	
Field (max)	267.8	T/m^2
Length	0.192	m
Aperture Ø	0.078	m
Coils	6	
Turns/coil	36	t
Max Current	117.5	A
Amp turns	4230	A-t
Conductor area	4.76^2	mm^2
cooling Ø	3.18	m
length	144	m
resistance	175	mΩ
Voltage	20.6	V
Power	2.42	kW
ΔT of water	8.0	°C
Total Flow	4.36	L/min
	1.15	GPM

267.8 T/m^2

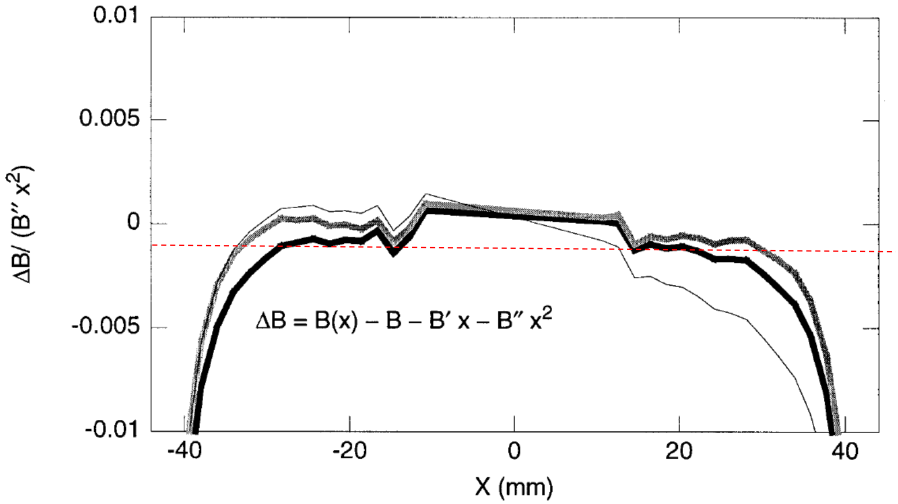
78 mm aperture

For High Gradient – scale down



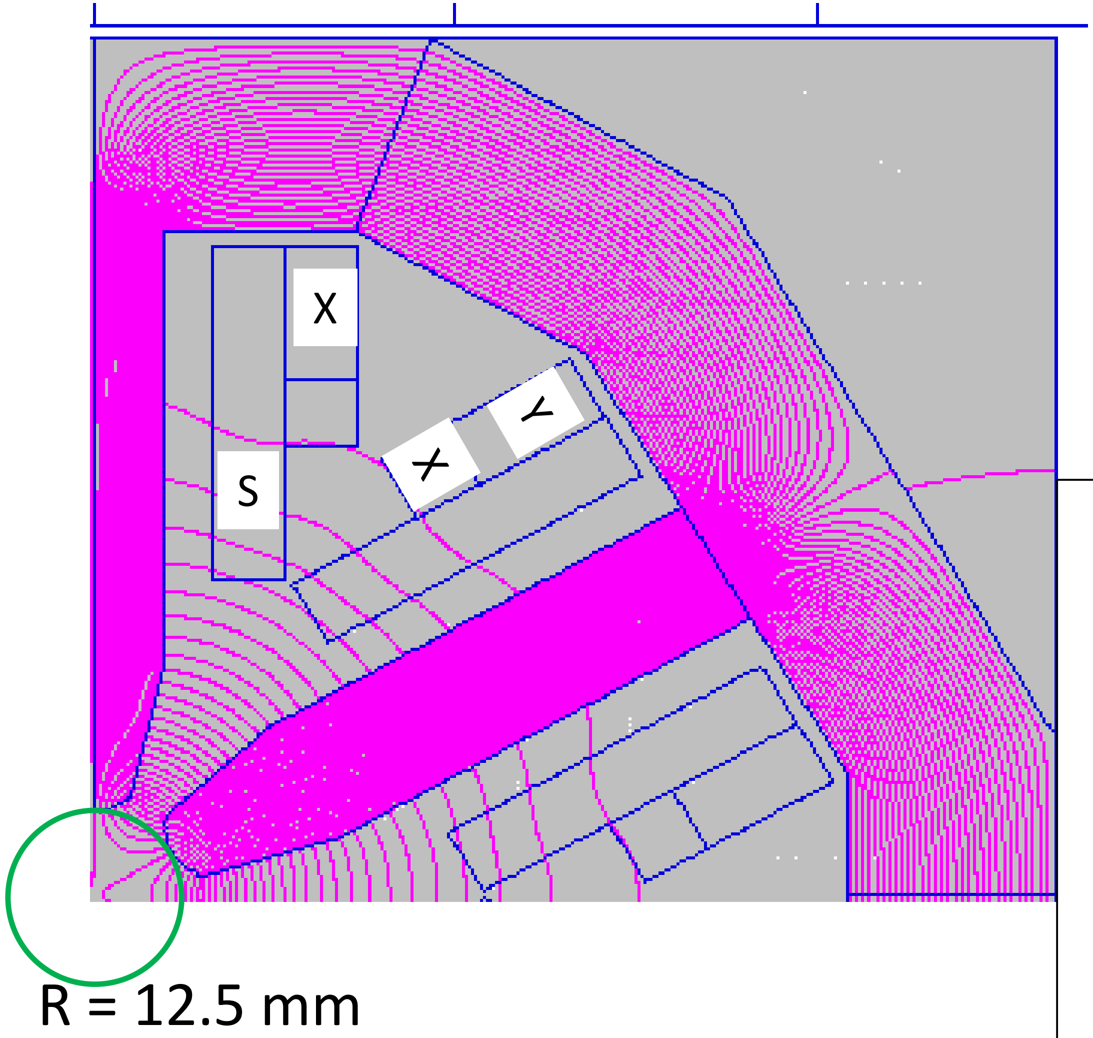


Good Field Region @ 0.1%: ±30 mm



S1, S2, S1b and S2b magnets

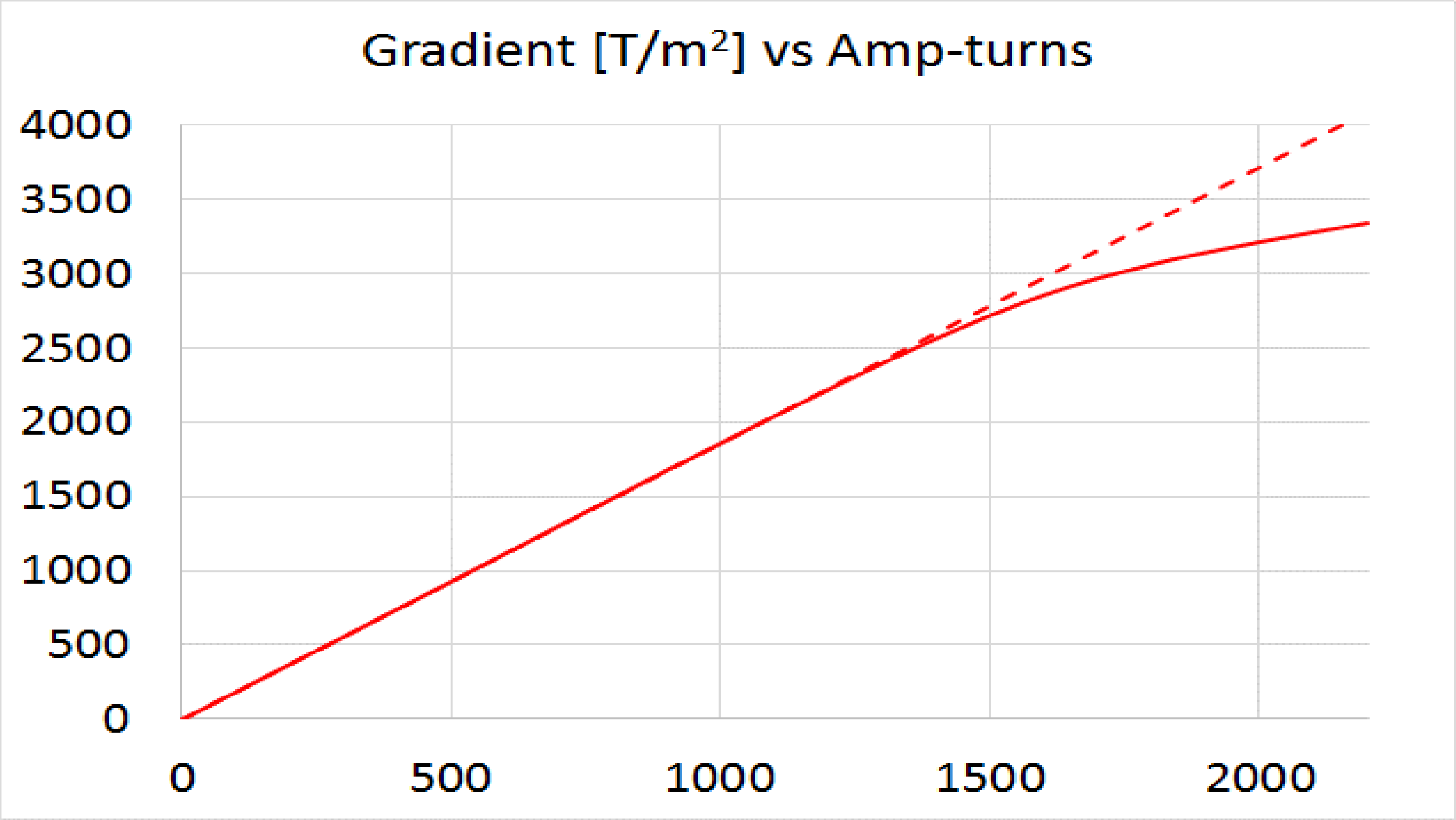
- 12.5 mm aperture radius
- coils for X and Y correctors



10 mm X 50 mm coil (Sextupole)
→ 20 turns (4.8mm X 4.8mm conductor)

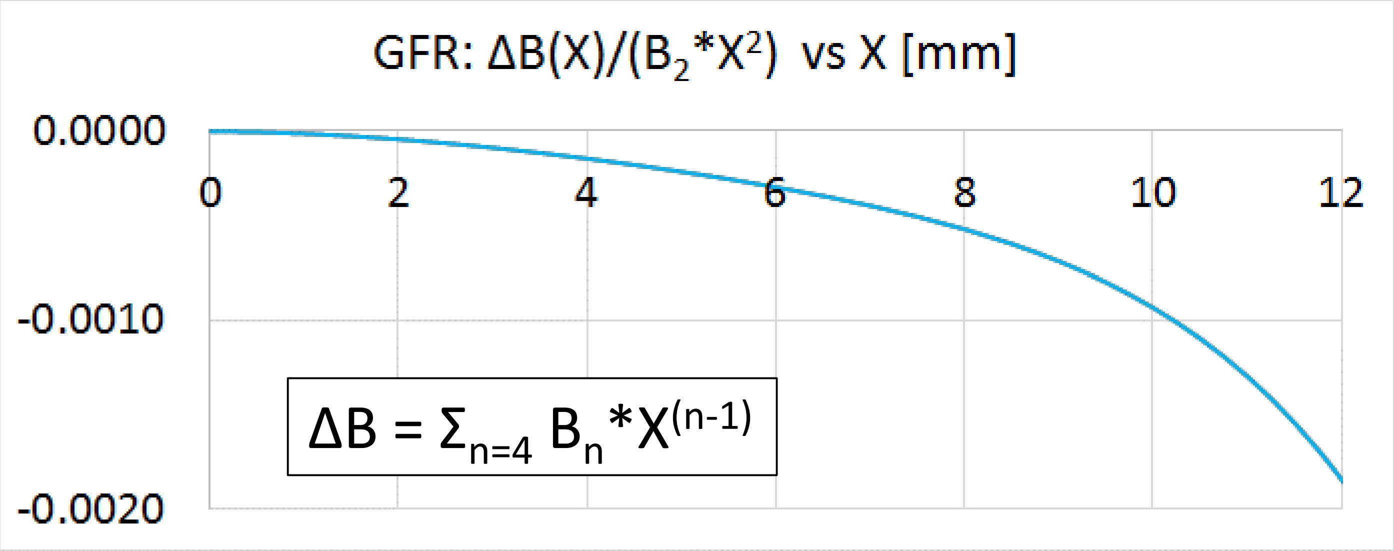
10 mm X 20 mm coil (X or Y corrector)
→ 8 turns
10 mm X 10 mm coil (X corrector)
→ 4 turns

coils sticks out ~20 mm at end of magnet

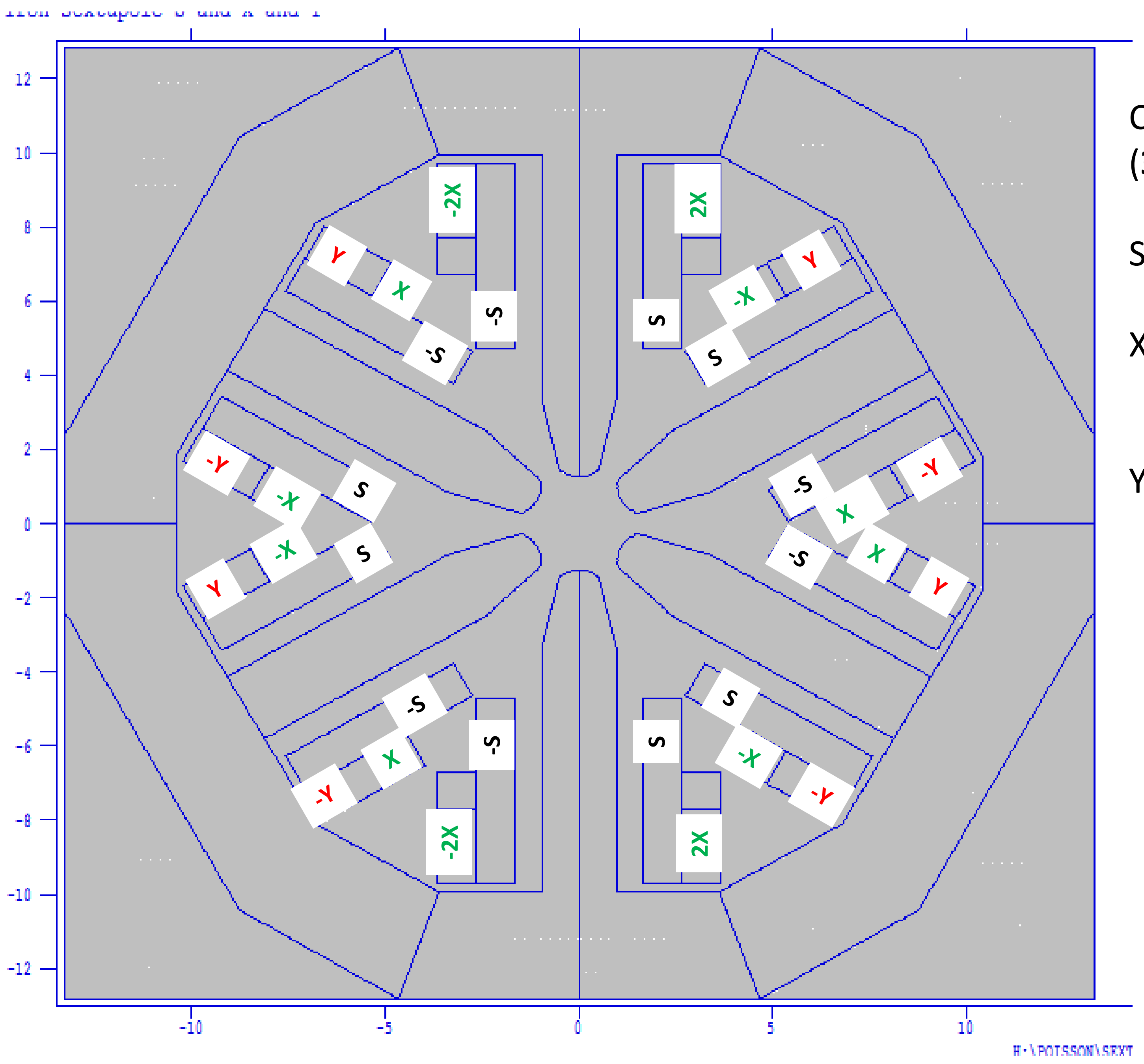


99.8% efficiency @ 1150 Amp-turns

B_2 = 2135 T/m^2



$\Delta B = \Sigma_{n=4} B_n * X^{(n-1)}$



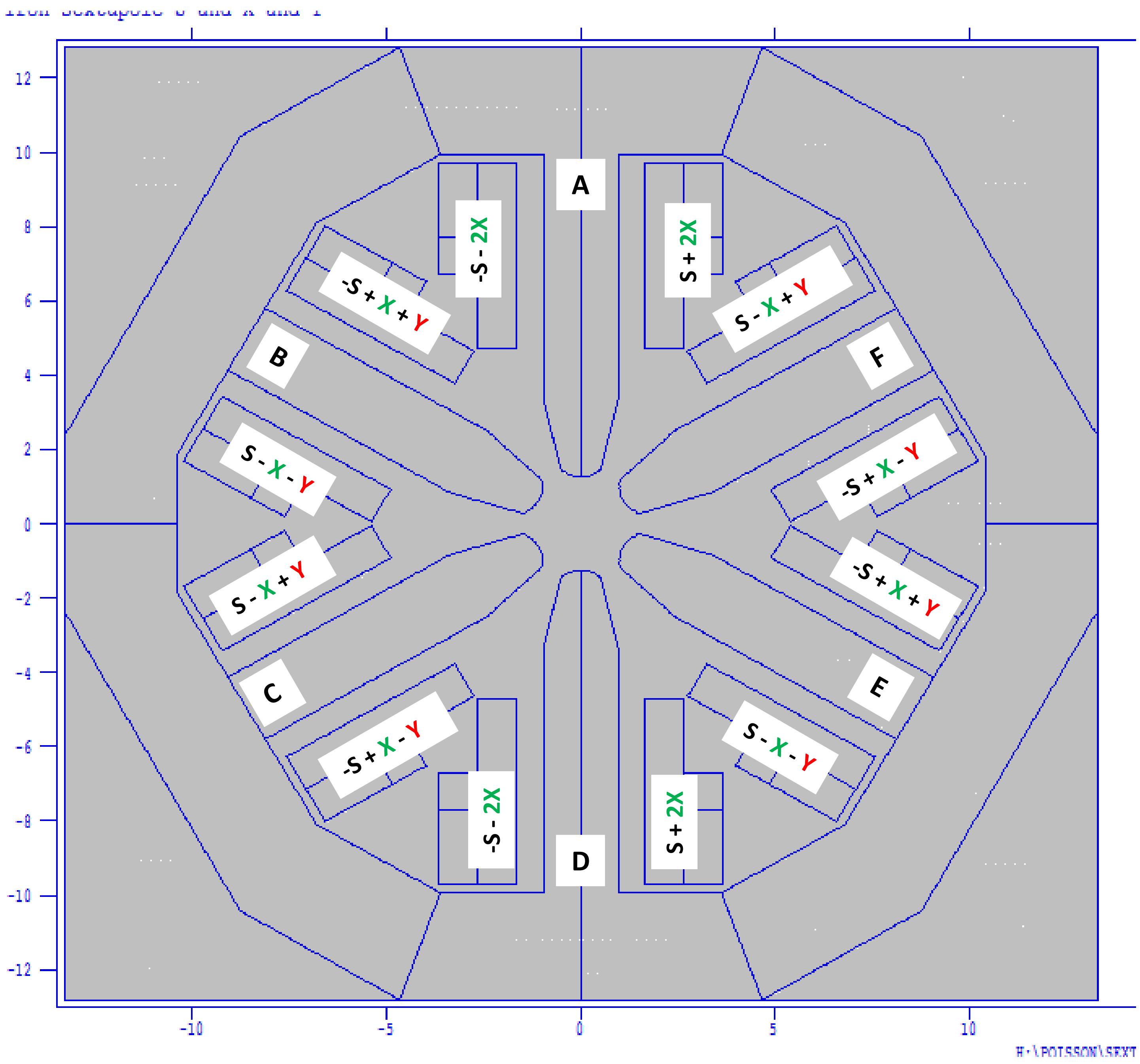
Coil Configuration (Option 1)
(3 separate windings per pole)

S: Sextupole (1150 Amp-turns)

X: X-corrector (up to 200/400 Amp-turns)
~ ½ mrad

Y: Y-corrector (up to 350 Amp-turns)
~ ½ mrad

Sextupole	P.S.	58 Amps
X-corr	P.S.	-50 to 50 Amps
Y-corr	P.S.	-44 to 44 Amps



Coil Configuration (Option 2)

1 winding per pole (32 turns)

Pole A ≡ Pole D
Pole B ≡ Pole E
Pole C ≡ Pole F

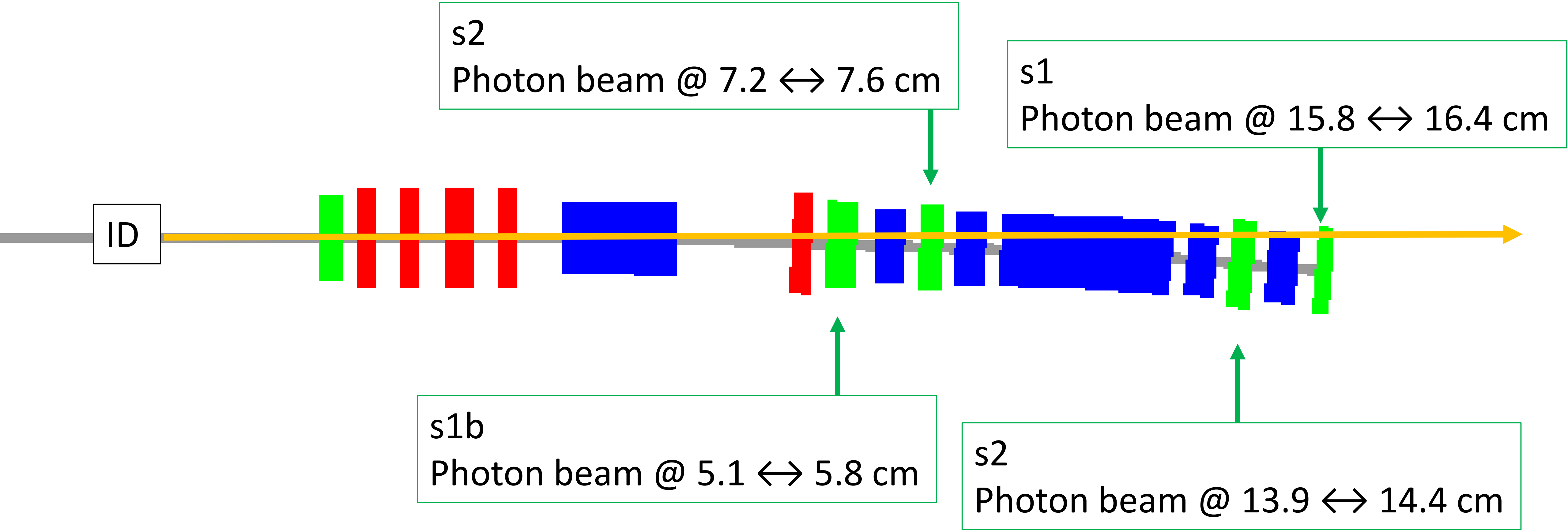
P.S. A: 37.5 +/- 12.5 Amps
P.S. B: 37.5 +/- 17.2 Amps
P.S. C: 37.5 +/- 17.2 Amps

(no zero crossing)

Effect on B_2 with correctors at maximum values

Amp-turns S	Amp-turns X	Amp-turns Y	B_2 [T/m²]	B_y [T]	B_x [T]	B_2 error	
1200	0	0	-2224.4				
0	400/200	0		345.94			
0	0	350			349.80		
1200	400/200	0	-2221.8	341.23		-0.11689	%
1200	0	350	-2222.4		346.72	-0.08991	%
1200	400/200	350	-2220.4	341.90	348.24	-0.17982	%

Getting the photon beam out ....

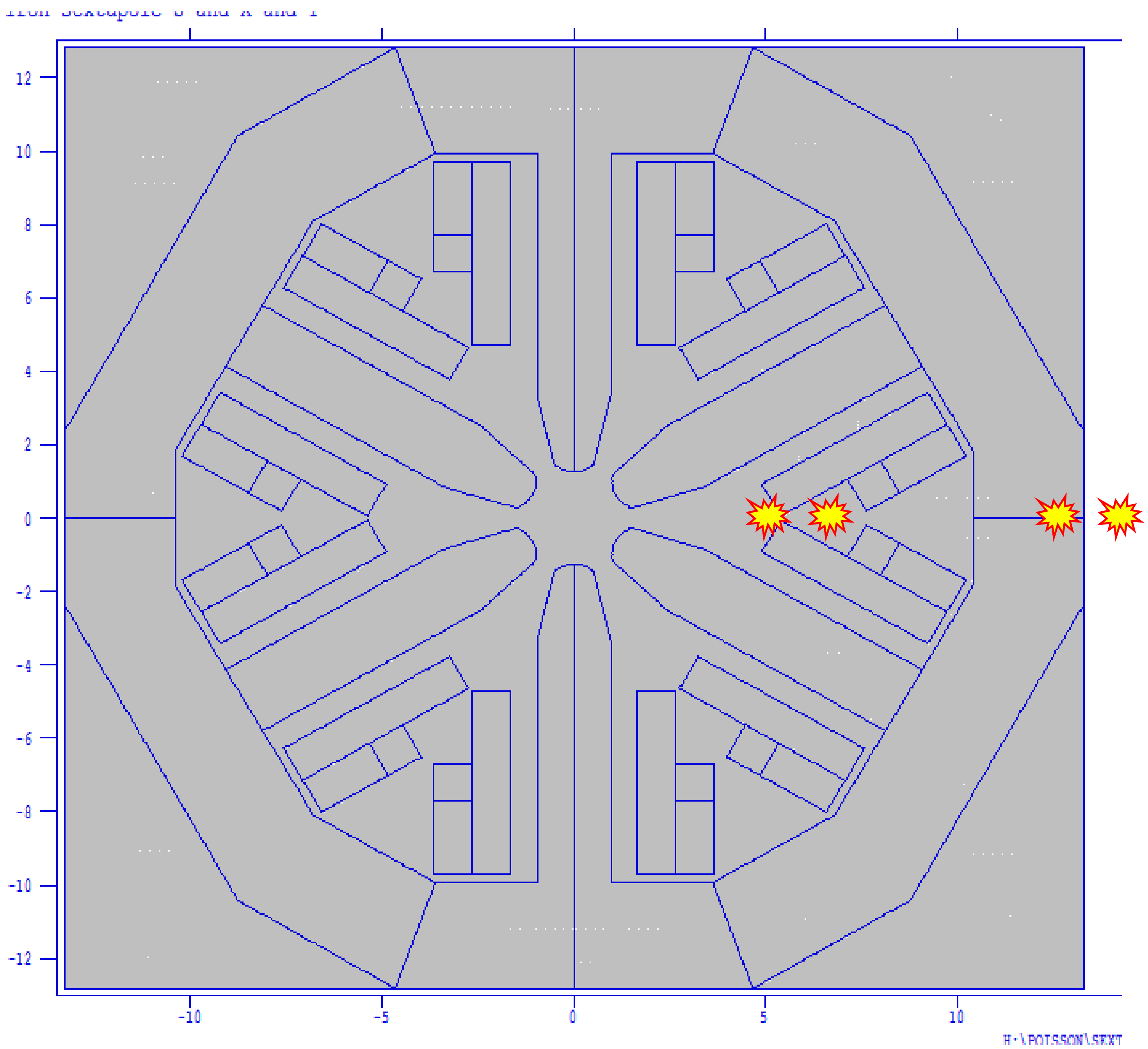


s2
Photon beam @ 7.2 ↔ 7.6 cm

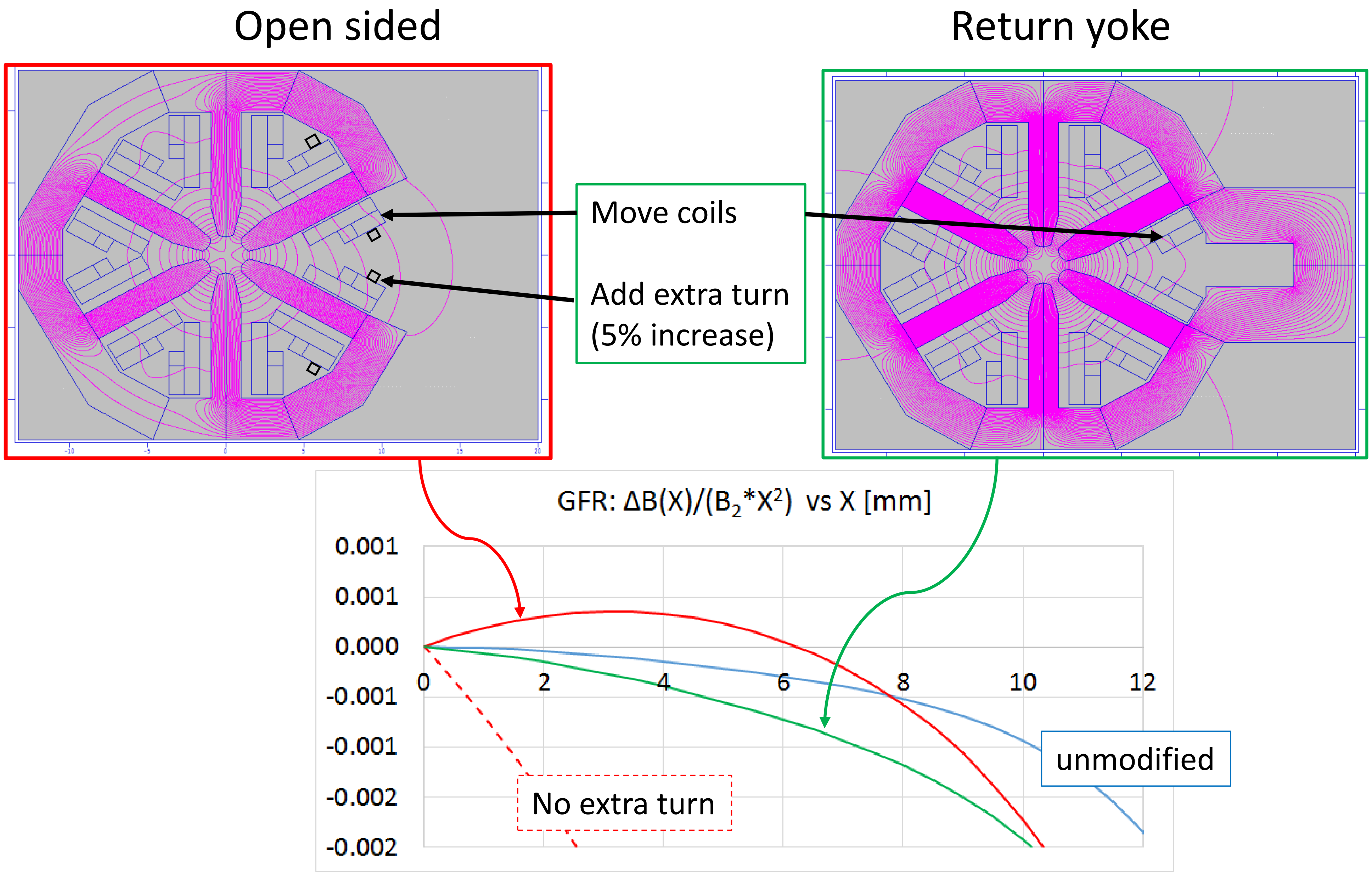
s1
Photon beam @ 15.8 ↔ 16.4 cm

s1b
Photon beam @ 5.1 ↔ 5.8 cm

s2
Photon beam @ 13.9 ↔ 14.4 cm


12
10
8
6
4
2
0
-2
-4
-6
-8
-10
-12
-10
-5
0
5
10
H:\POISSON\SEXT

Sextupole Modifications



Open sided

Return yoke

Move coils

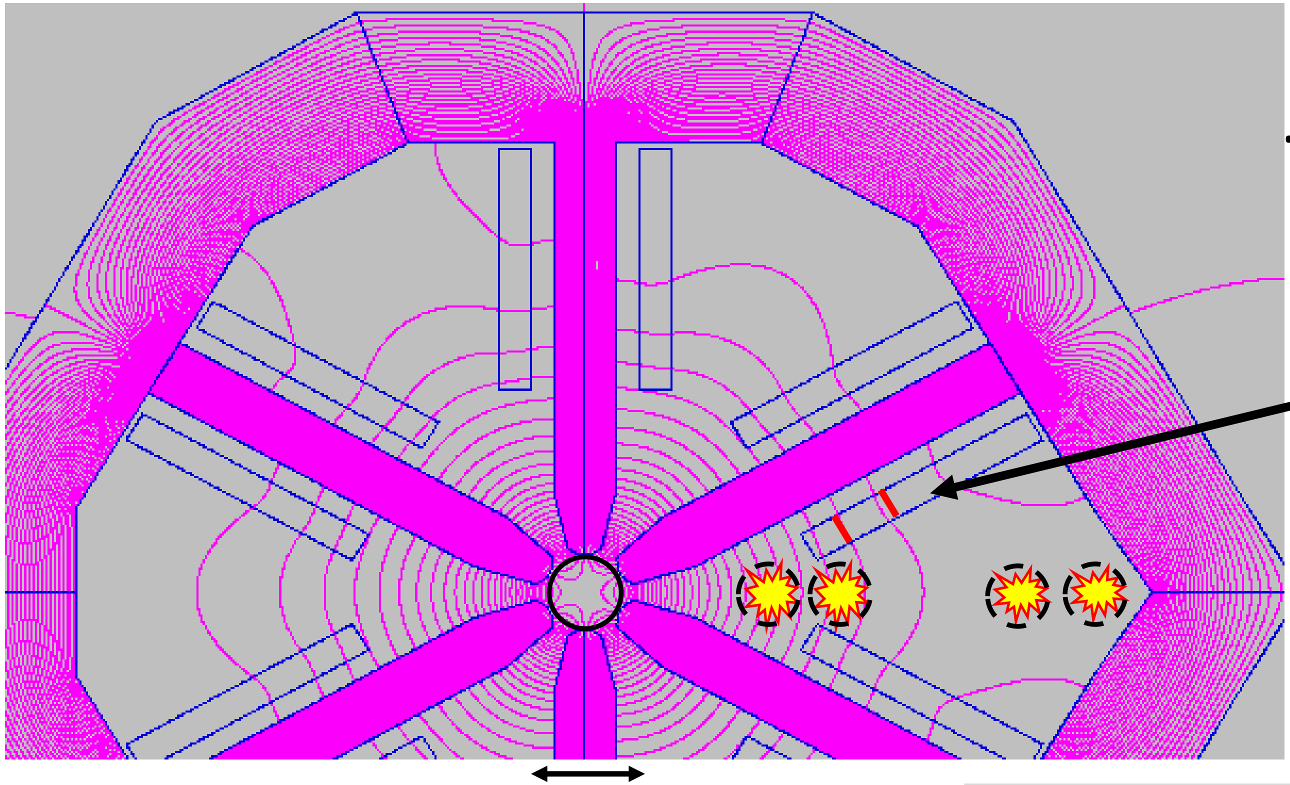
Add extra turn (5% increase)

GFR: $\Delta B(X)/(B_2 * X^2)$ vs X [mm]

unmodified

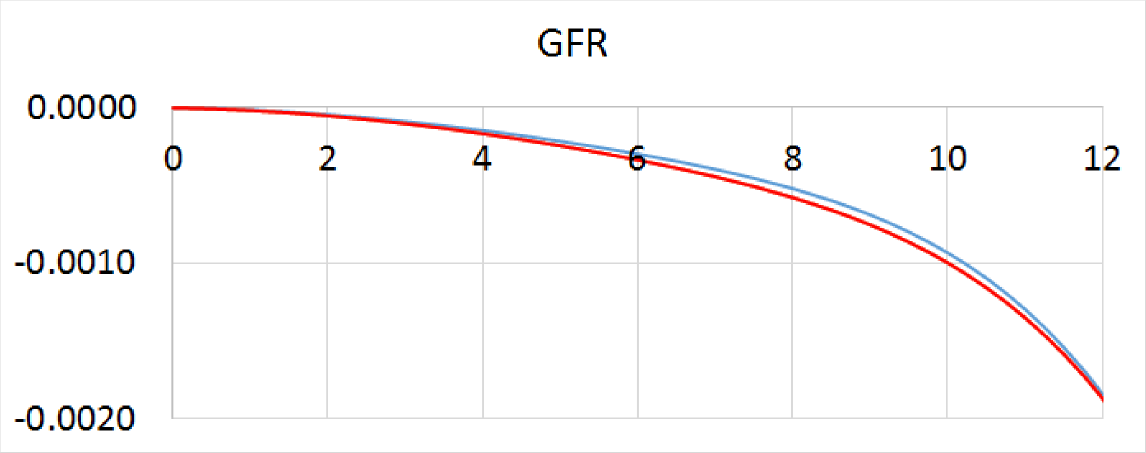
No extra turn

… or build a bigger sextupole

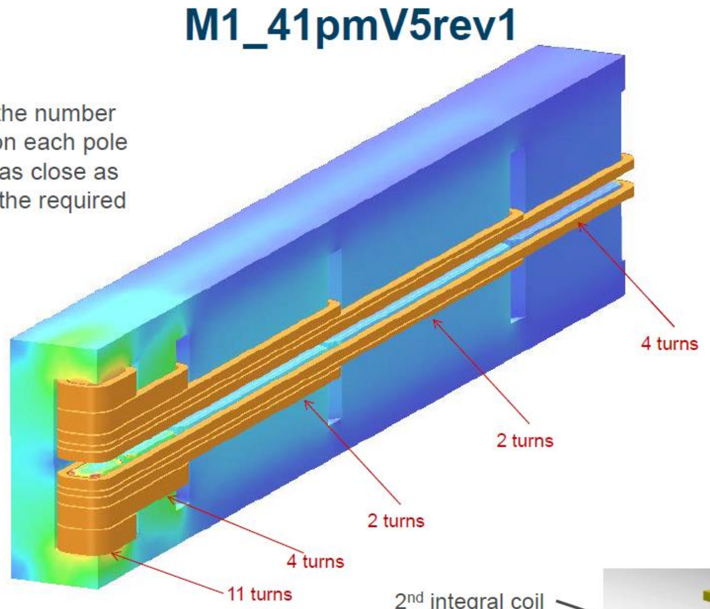


Coils:
- out of the way
- in a row

(poles could be wider)

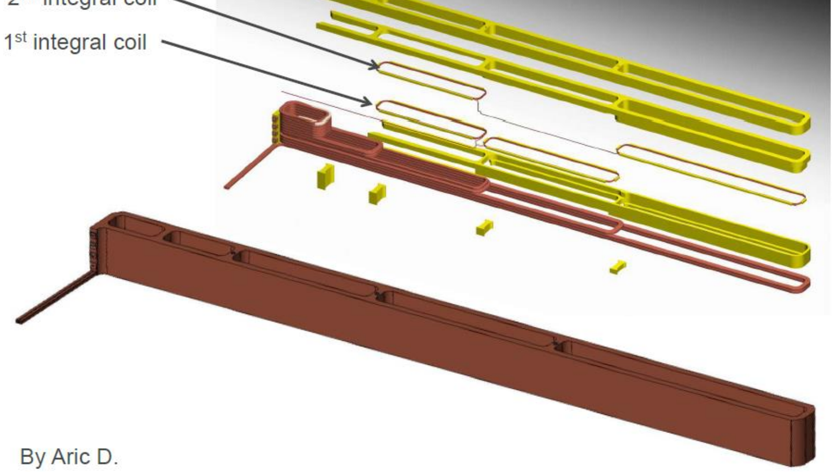


Bend Magnets
Use longitudinal gradient bends to reduce emittance



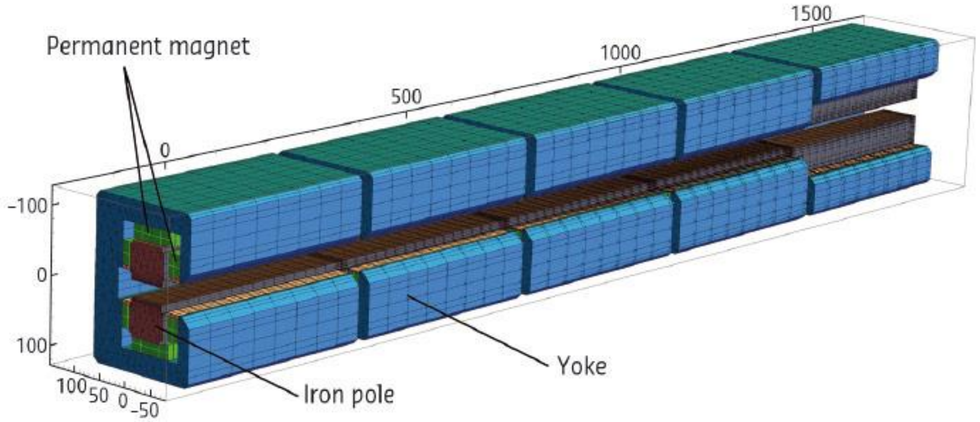
Change the number of turns on each pole to target as close as possible the required field.

E.g.: APS gradient dipole



By Aric D.

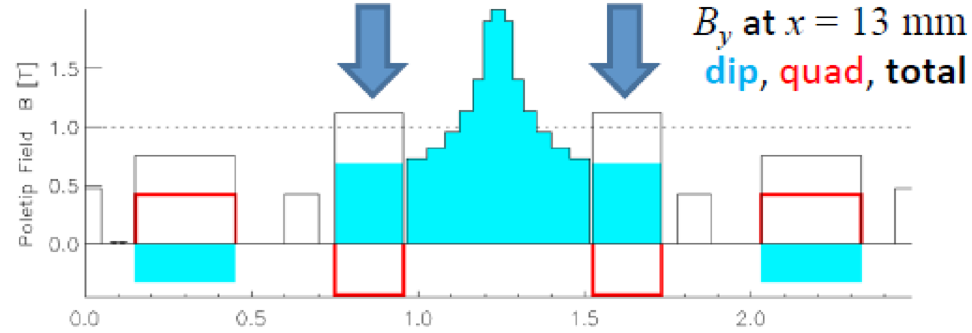
E.g.: ESRF gradient dipole



Magnets 1 - compound LGB

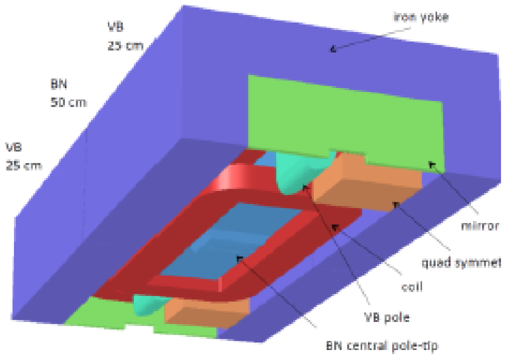
longitudinal/transverse gradient compound bend

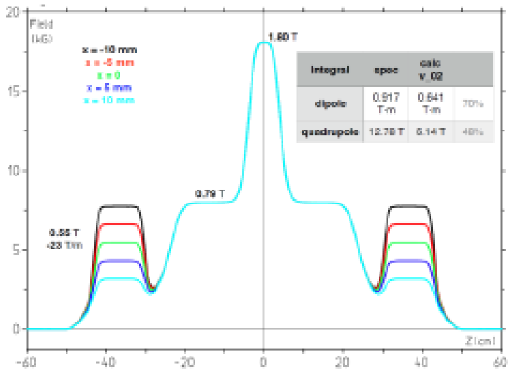
- use low field at LGB ends
- for vertical focusing gradient
- → save space, increase J_x



RC

resistive coil version

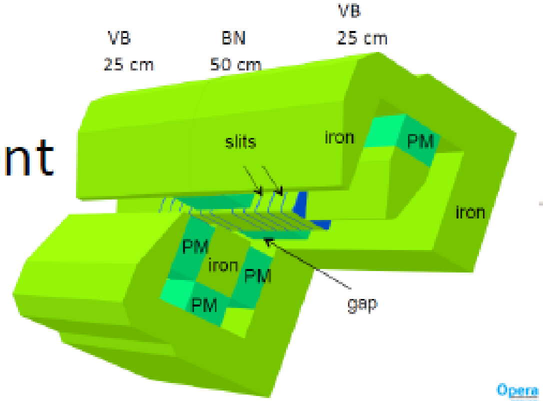


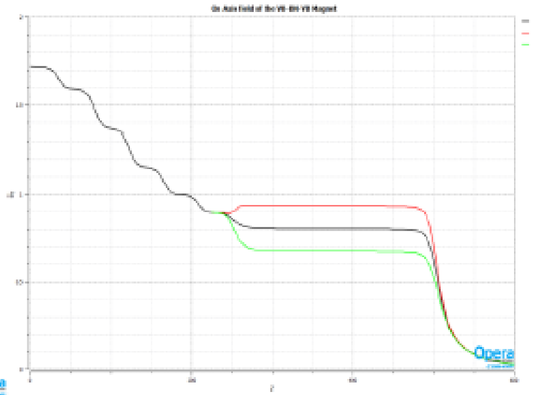


integral	spec	calc v_02	
dipole	0.917 T·m	0.641 T·m	70%
quadrupole	12.78 T	5.14 T	40%

PM

permanent magnet version





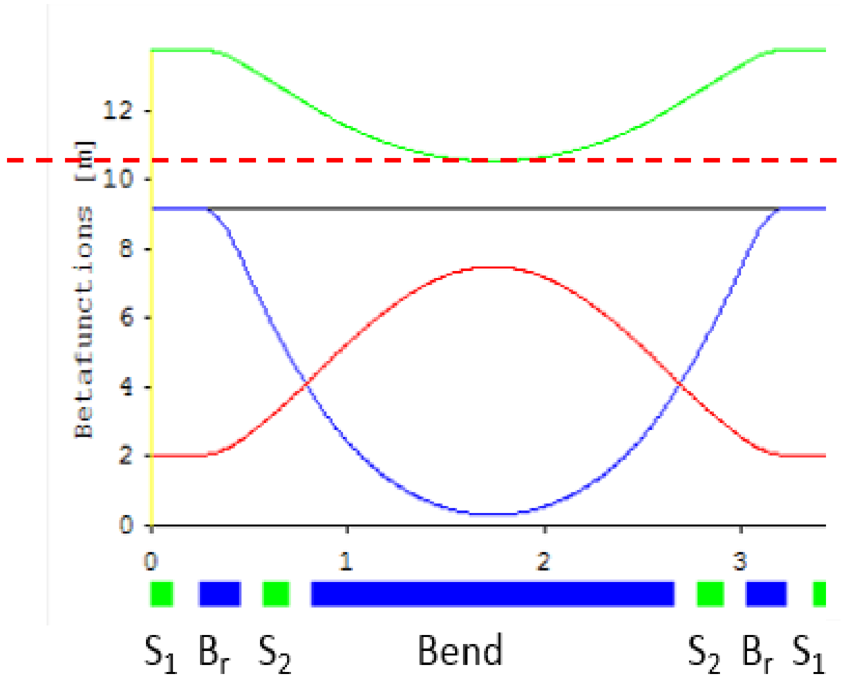
work in progress

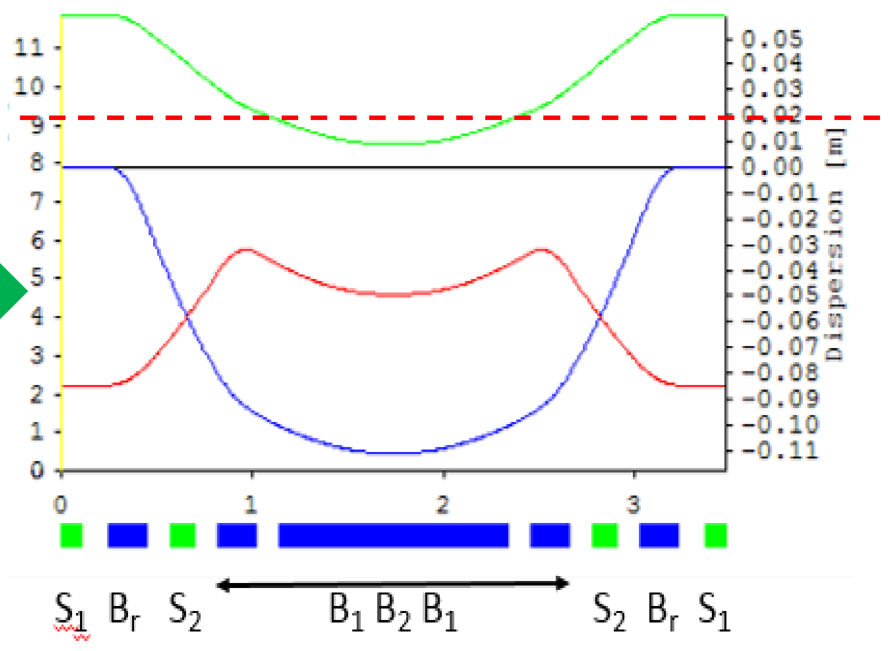
Alternatives:

- discrete quadrupoles?
- distributed gradient?
- incorporation of sextupole component too?
- tunability?

P. Lerch, M. Negrazus, V. Vrankovic

Alternative to longitudinal gradient:





Reduction of dispersion (and β_x)

Normal Bend → three (simple) bends

Bend 2 (B2) is focussing

Emittance is reduced by 36% (39 pm → 25 pm)

Bend Magnets

CLS 2.2 lattice:

```
long : drift, l=2.503400,ay = 3.00;[mm]
d11:drift, l=0.11;  d12:drift, l=0.12;  d13:drift, l=0.13;
d18:drift, l=0.18;  d20:drift, l=0.20;  d33:drift, l=0.33;
d83:drift, l=0.831638,d10:drift,l=0.10;
{quadrupoles}
qm1:quadrupole, l=0.12, k= -8.52240;
qm2:quadrupole, l=0.20, k= 8.658014;
qm3:quadrupole, l=0.12, k= 0.958858;
qm4:quadrupole, l=0.12, k= -3.53309;
qm5:quadrupole, l=0.12, k= 6.615875;
{offset quadrupoles}
br:bending,l=0.20, t = -0.20, k = 4.85; [°]
b1:bending,l=0.20, t = 0.20, k = -4.85;
{bend magnets}
b2:bending, l=1.2, t = 2.712, k = 0.421,
        t1= 1.356, t2 = 1.356;
bm : bending, l = 0.8, t = 1.758, k = -0.6,
        t1= 0.0, t2 = 0.0;
{sextupoles}
s1  : sextupole, l = 0.12 k = 210.3;
s1b: sextupole, l = 0.12, k = -51.7;
s2  : sextupole, l = 0.15, k = -212.6;
s2b: sextupole, l = 0.15, k = 0.0;{corrector}
{segments}
pbend : b1, d12, b2, d12, b1;{pseudobend}
cell:s1,d13,br,d11,s2,d11,pbend,d11,s2,d11,br,d13,s1;
match:long,s2b,d10,qm4,d18,qm3,d20,qm2,d18,qm1,
         d33,bm, d83, qm5, d12, s1b;
mba:match,7*cell, -match;
ring:16*mba
```

	BR	B1	B2	BM	
#	224	224	224	32	
length [m]	.20	.20	1.2	0.8	
half gap[mm]			15	15	
B [T]	-0.1745	0.1745	0.3944	0.3835	
B’ [T/m]	48.5	48.5	4.21	-6.0	
	Offset quadrupole				
Offset [mm] (B/B’)	-3.60	-3.60			
Aperture Radius [mm]	15	15			

CLS Dipole Design circa 2001

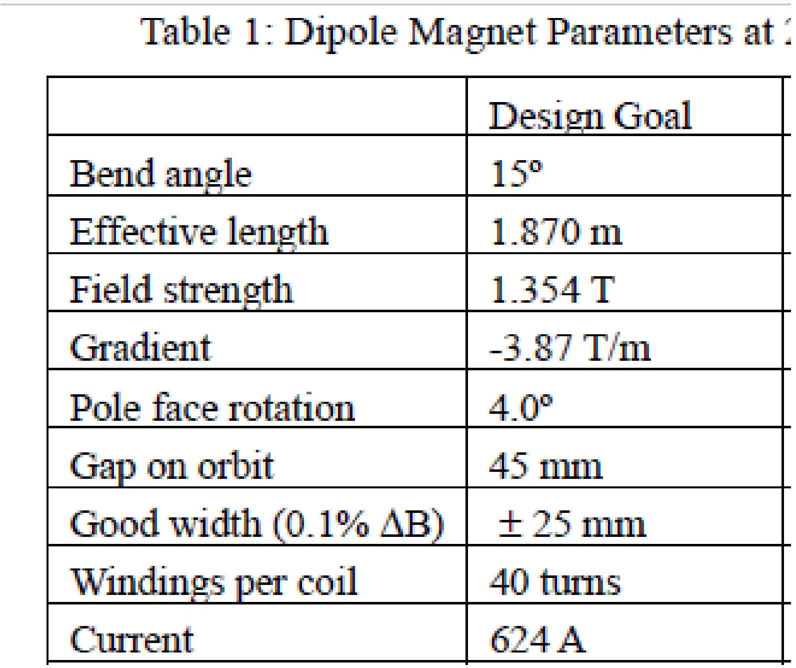


Table 1: Dipole Magnet Parameters at

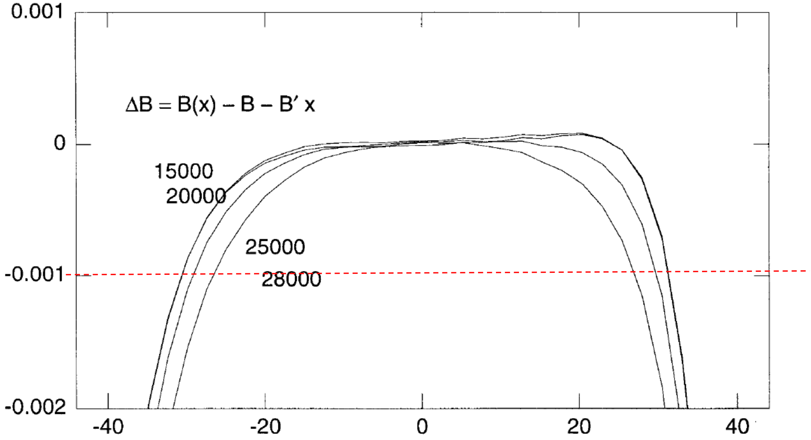
	Design Goal
Bend angle	15°
Effective length	1.870 m
Field strength	1.354 T
Gradient	-3.87 T/m
Pole face rotation	4.0°
Gap on orbit	45 mm
Good width (0.1% ΔB)	± 25 mm
Windings per coil	40 turns
Current	624 A

1.354 T

-3.87 T/m

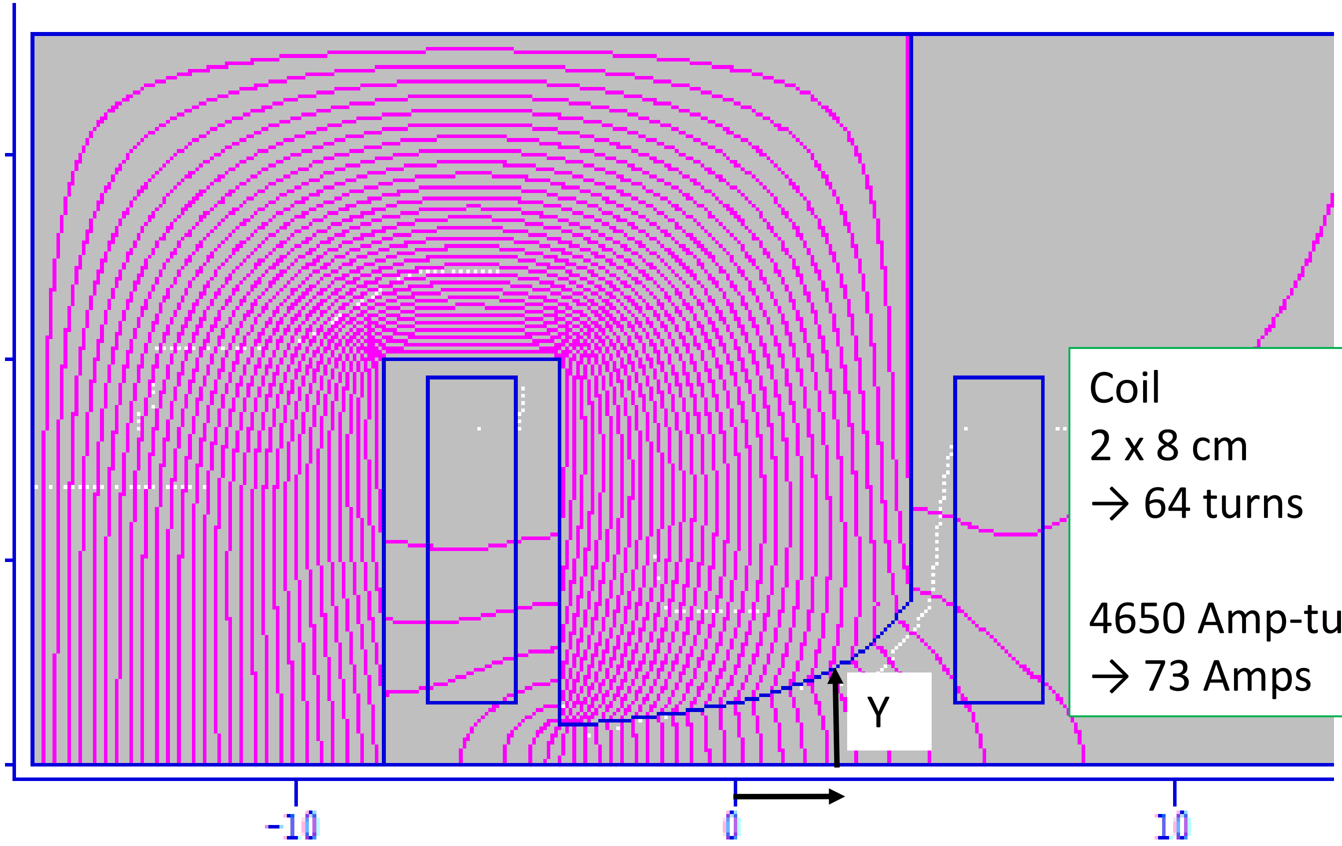
45 mm gap

Good Field Region @ 0.1%: ±30 mm



BM Design

half gap = 1.5 cm
B’$_{final}$ = 6.01 T/m (< 0.2% off)

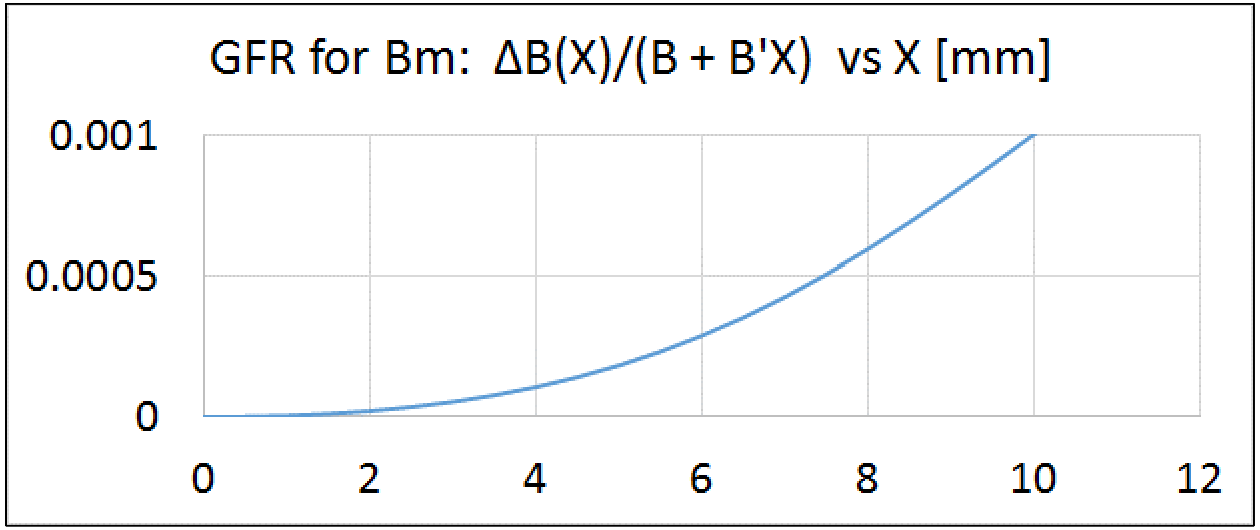


Coil
2 x 8 cm
→ 64 turns

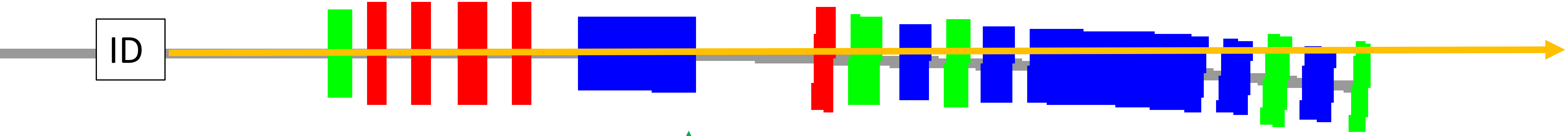
4650 Amp-turns
→ 73 Amps

B/B’ = 0.3835[T] / -6.0[T/m]
= 0.06392 m
= 6.392 cm

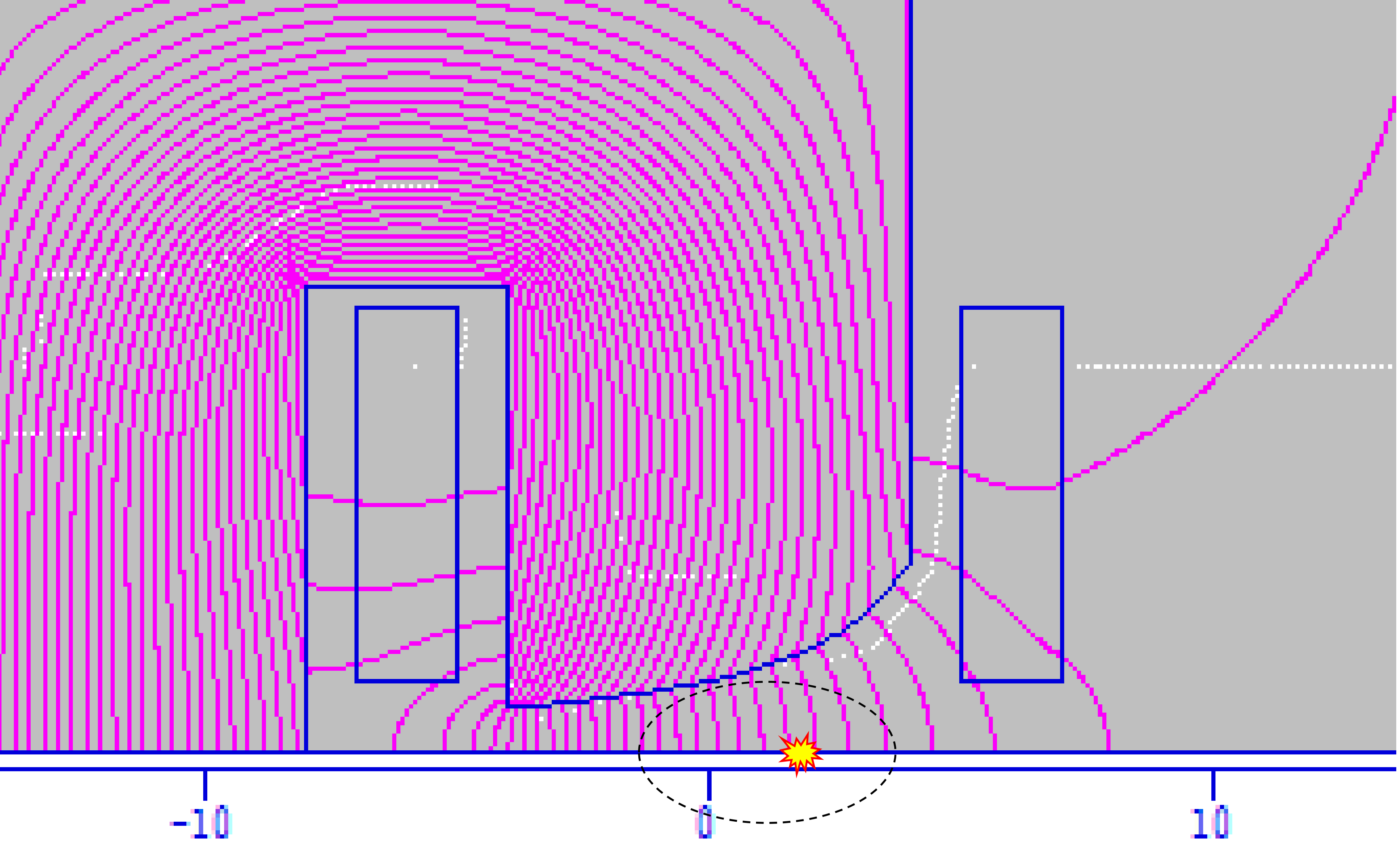
Y = -6.392*1.5 / (X – 6.392)



Getting the photon beam out ....



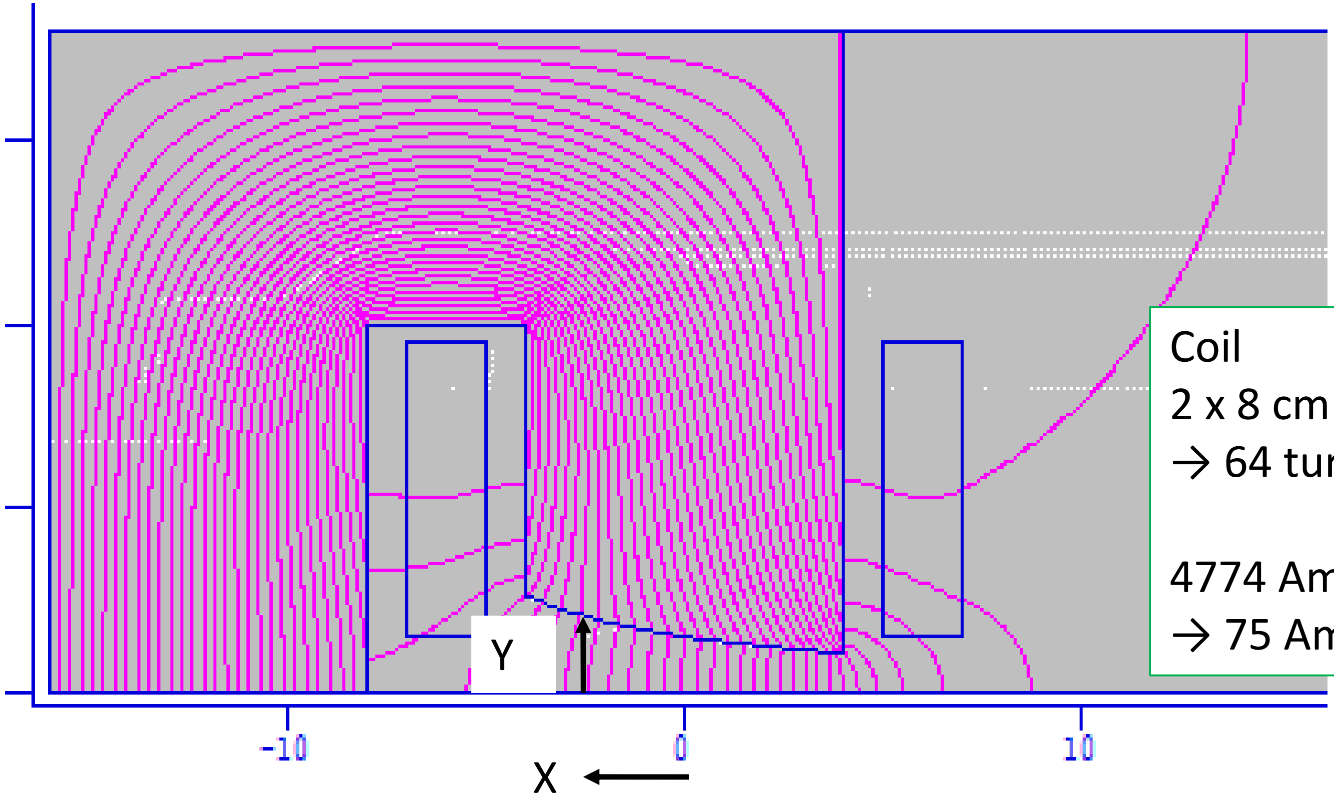
Bm
Photon beam @ 0 ↔ 1.84 cm


-10
0
10

B2 (focussing bend)

half gap = 1.5 cm

B'$_{\text{final}}$ = 4.23 T/m (< 0.5% off)

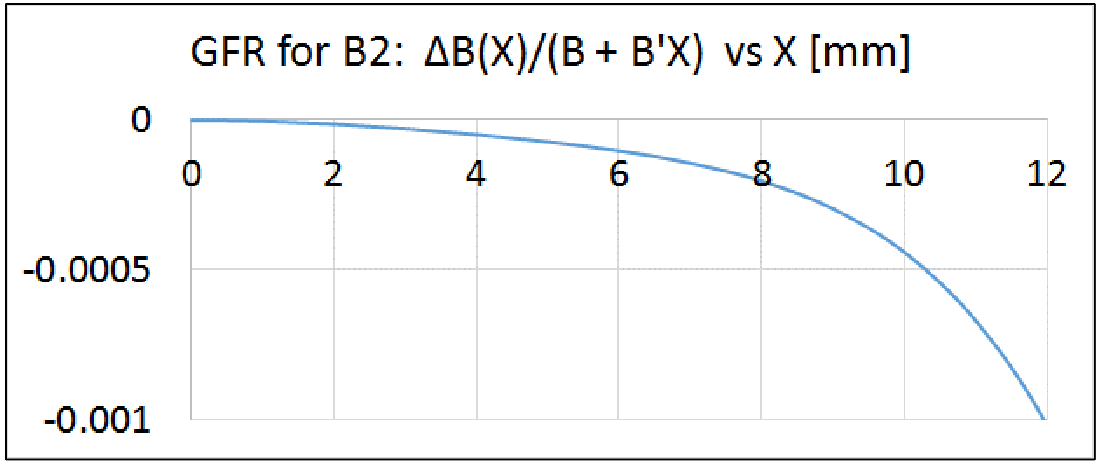


Coil
2 x 8 cm
→ 64 turns

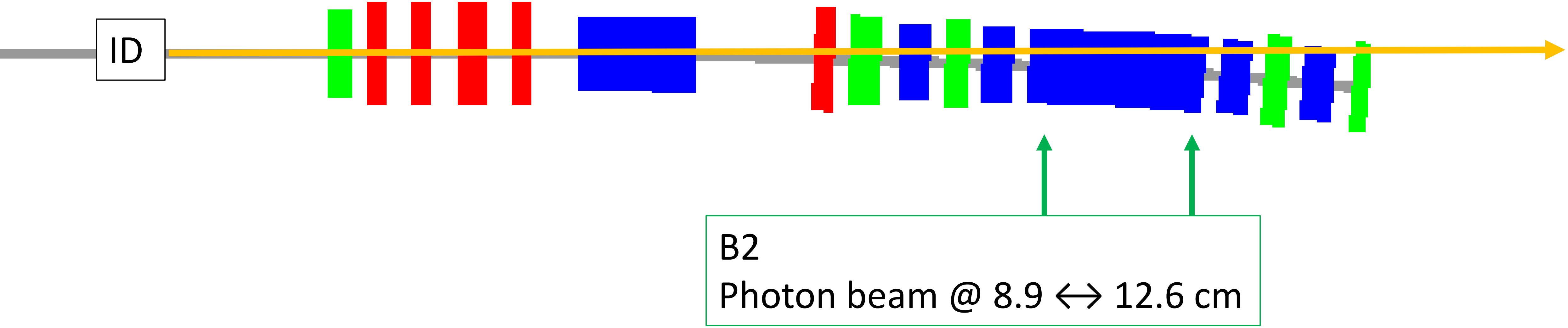
4774 Amp-turns
→ 75 Amps

B/B' = 0.3944[T] / 4.21[T/m]
= 0.09368 m
= 9.368 cm

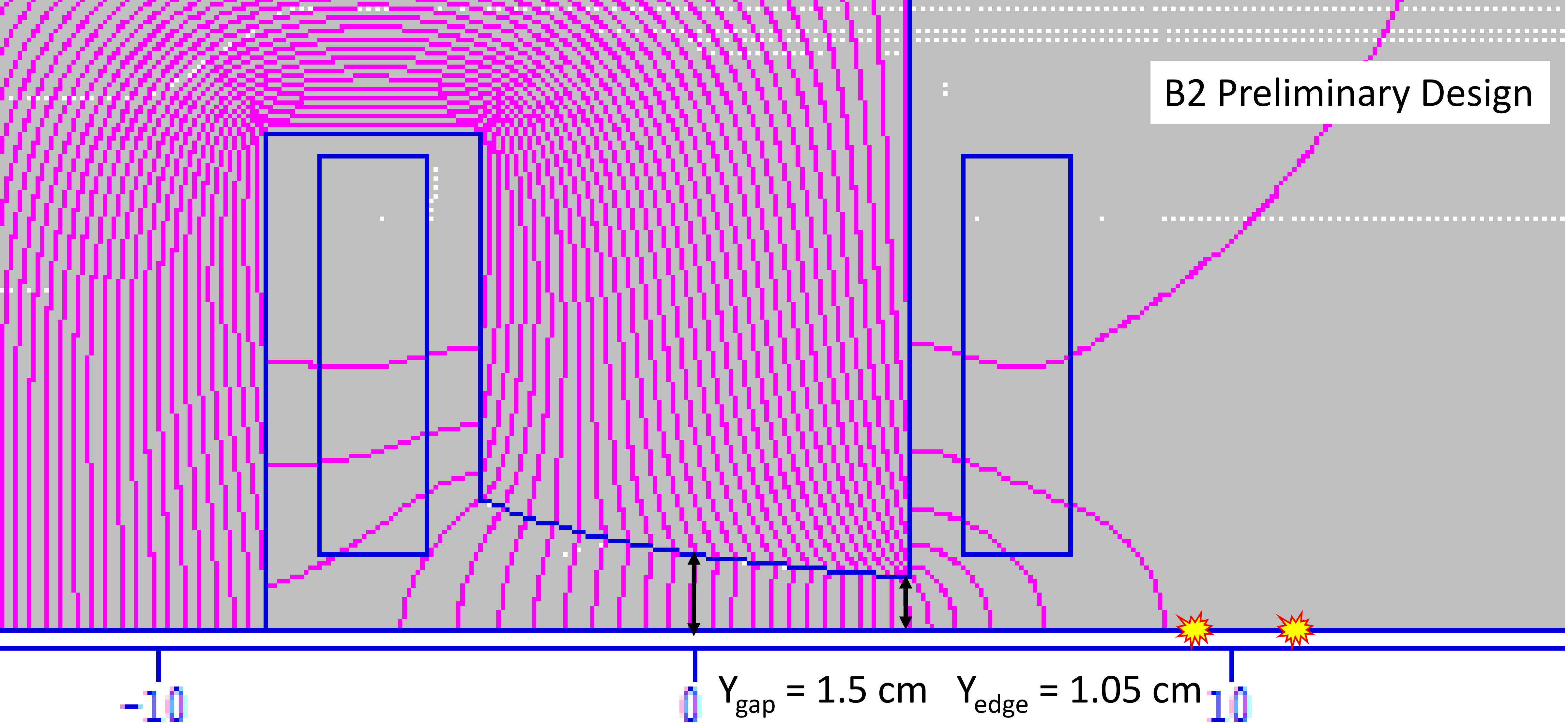
Y = 9.368*1.5 / (X + 9.368)



Getting the photon beam out …….

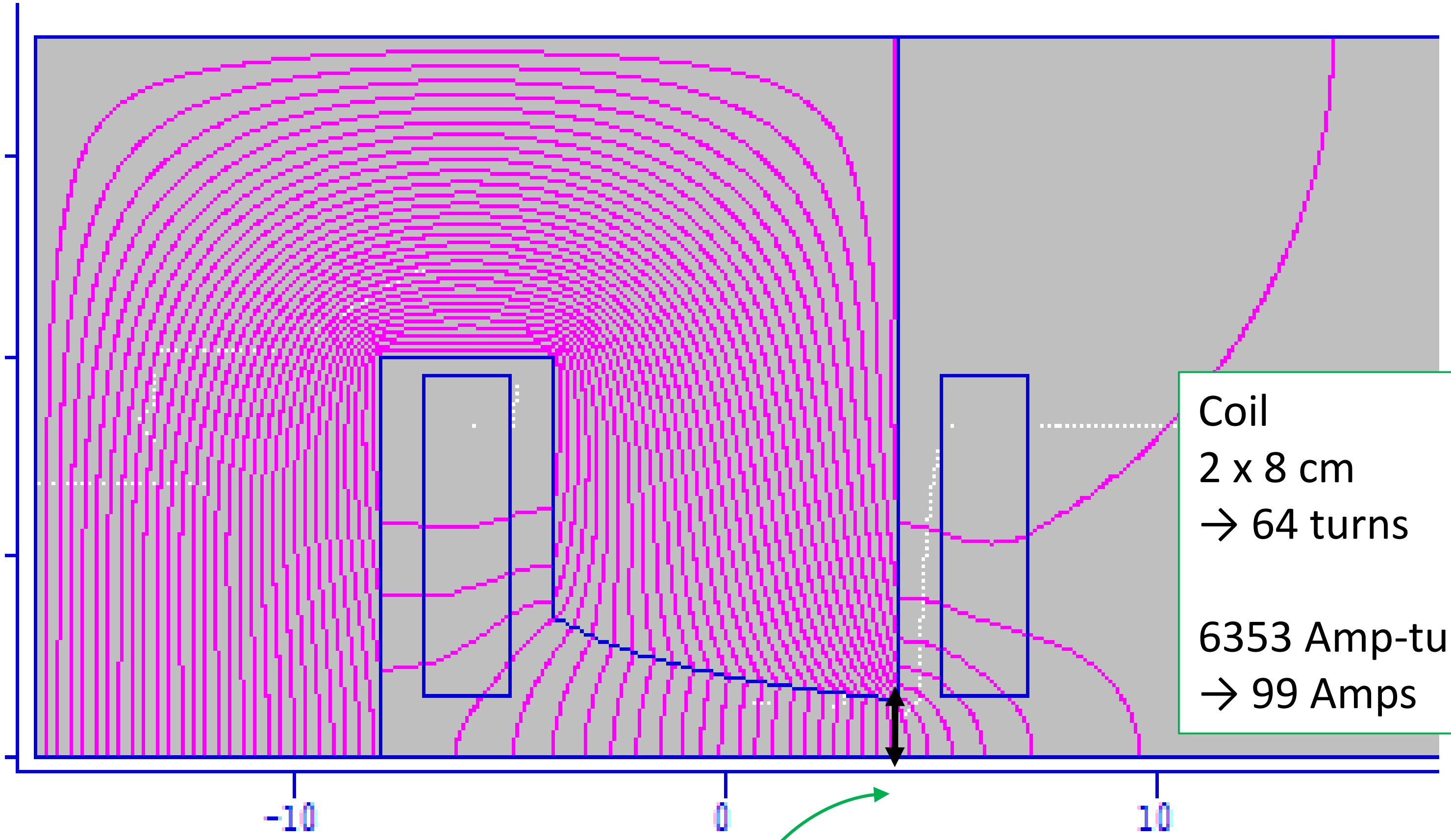


B2
Photon beam @ 8.9 ↔ 12.6 cm


B2 Preliminary Design
-10
0
10
Y_{gap} = 1.5 cm
Y_{edge} = 1.05 cm

B2 (Larger Gap Option)

half gap = 2.0 cm
B’ = 4.24 (< 1% off)

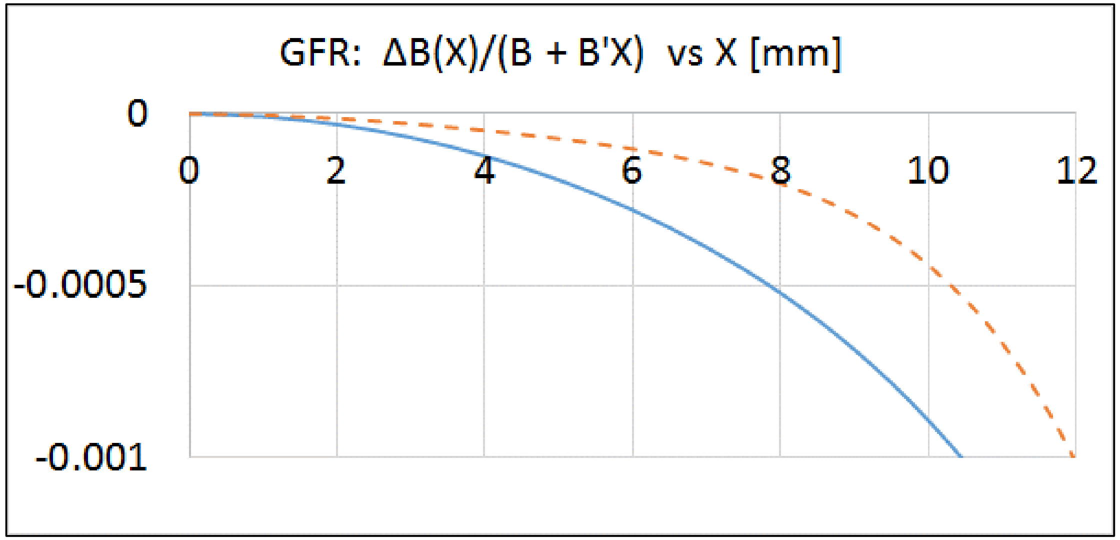


Coil
2 x 8 cm
→ 64 turns

6353 Amp-turns
→ 99 Amps

$Y = 9.368*2.0/ (X + 9.368)$

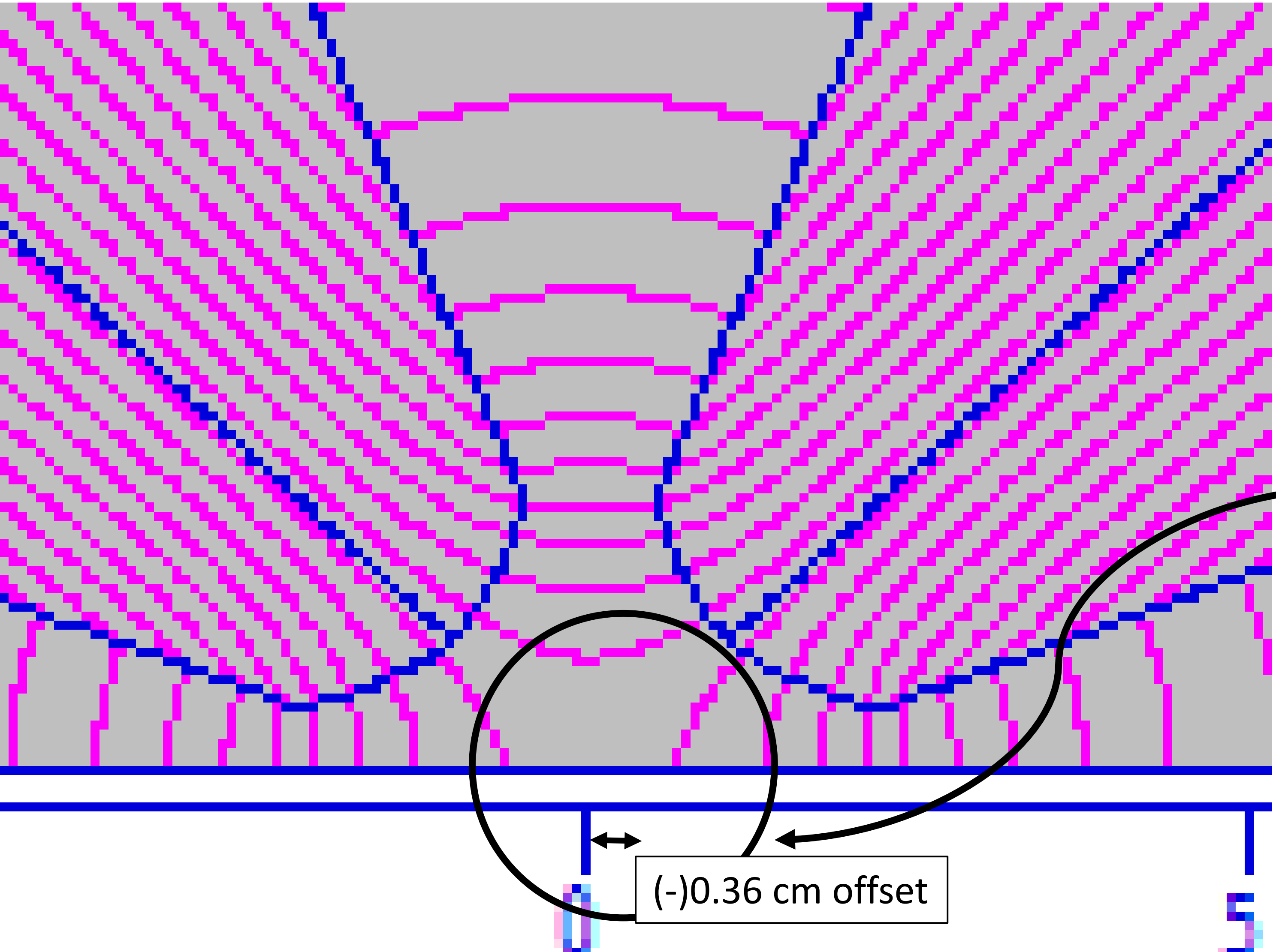
$Y_{edge} = 1.4$ cm



BR and B1 – Offset quadrupoles:

$$\text{Offset} = B/B' = -\,0.1745\ [\mathrm{T}]/48.5\ \mathrm{T/m}$$
$$= -\,0.0036\ \mathrm{m}$$
$$= -\,0.36\ \mathrm{cm}$$

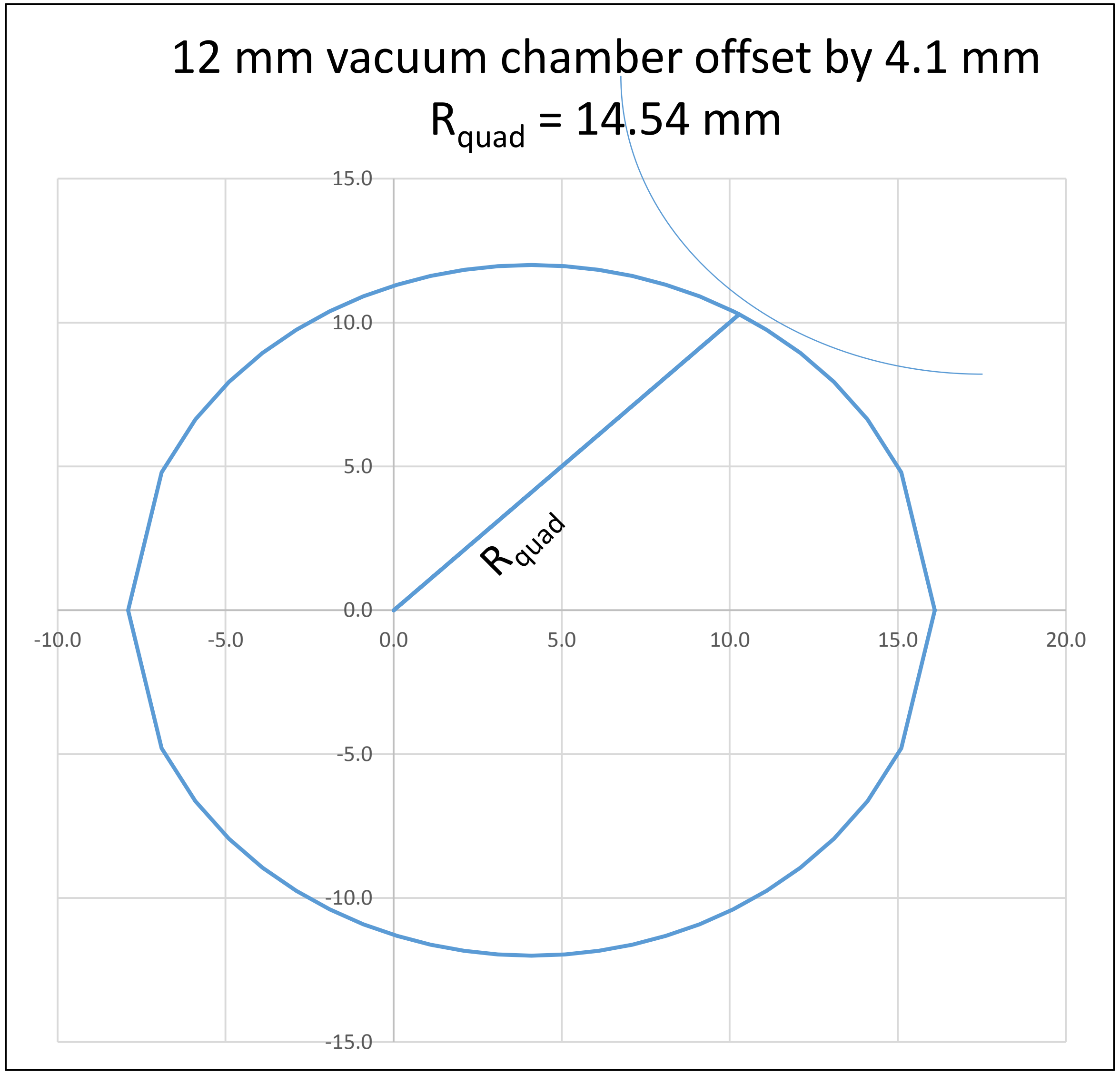
Use Ø = 3.0 cm quadrupole



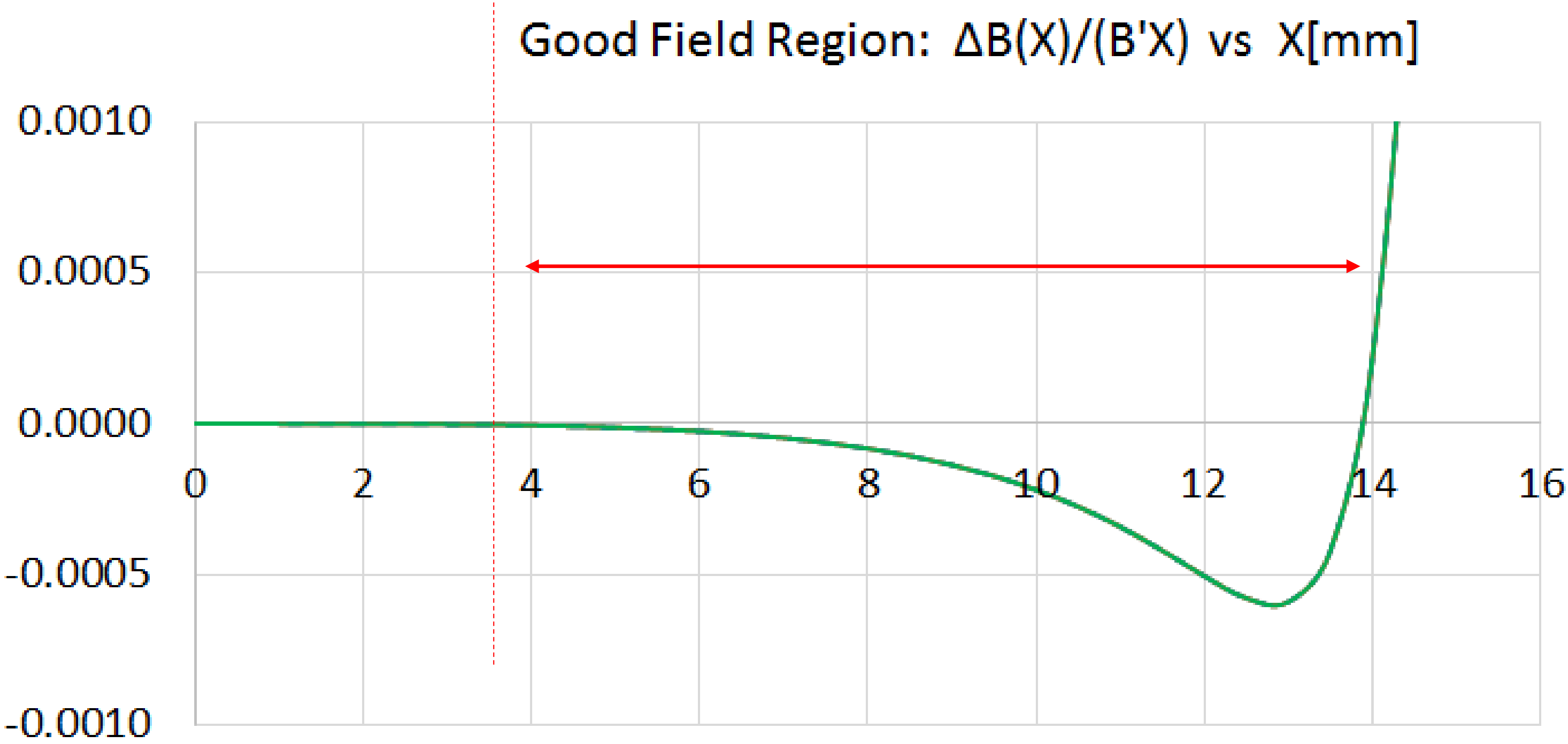
(-)0.36 cm offset

Room for beam pipe
with Ø = 2.4 cm

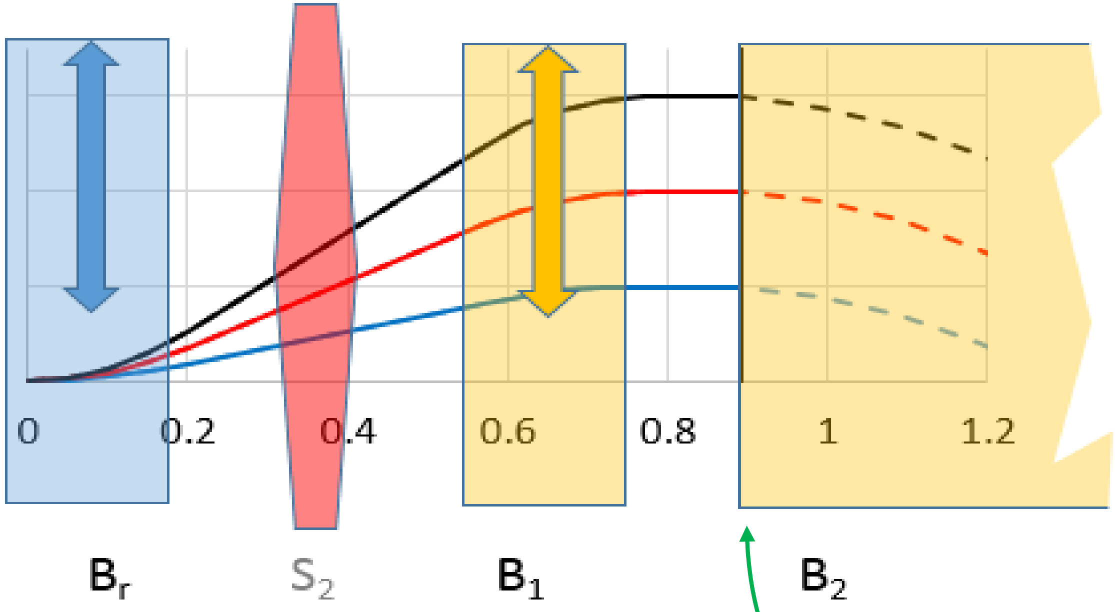
CLS 2.0 Reverse Bend with 4.1 mm offset



Beam axis GFR is reduced by 3.6 mm (on one side)

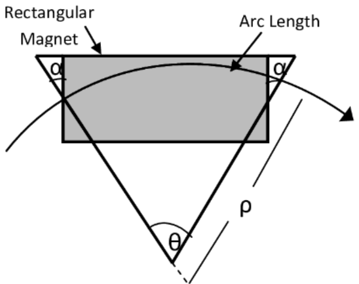


Different offsets for different optics



Br [°] = - B1 [°]

Pole face rotation optional



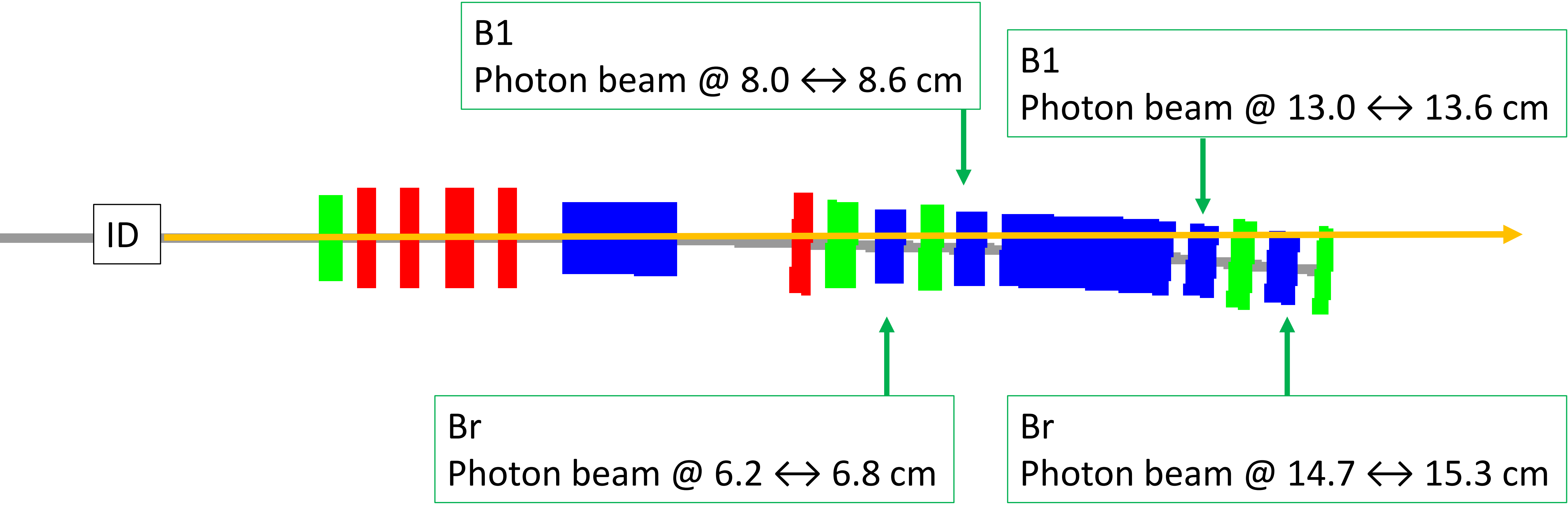
Relaxed optics for commissioning?

B_r [°]	J_x	α_c [e-5]	ε [pm]
-0.00	0.81	11.2	124
-0.05	1.30	9.7	68
-0.10	1.75	8.3	44
-0.15	2.16	6.8	32
-0.20	2.50	5.4	25
-0.25	2.78	3.9	22
-0.30	2.99	2.4	21

CLS 2.2 lattice:

```
 .....
{bend magnets}
b2:bending, l=1.2, t = 2.712, k = 0.421,
           t1= 1.356, t2 = 1.356;
......
```

Getting the photon beam out …….



B1
Photon beam @ 8.0 ↔ 8.6 cm

B1
Photon beam @ 13.0 ↔ 13.6 cm

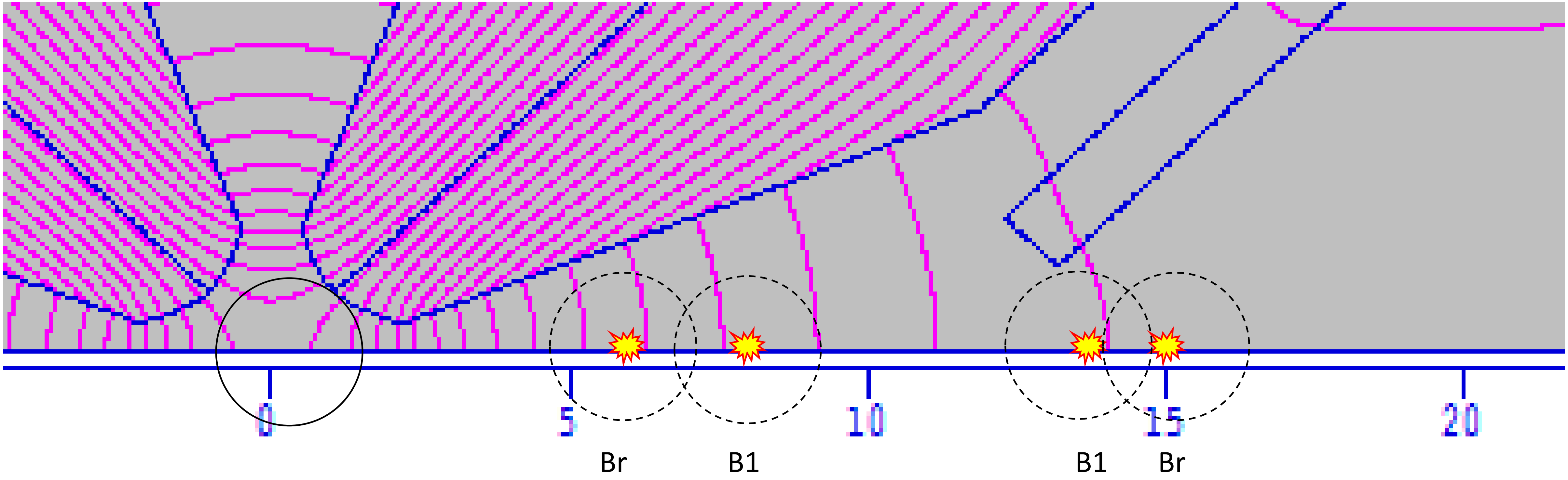
Br
Photon beam @ 6.2 ↔ 6.8 cm

Br
Photon beam @ 14.7 ↔ 15.3 cm

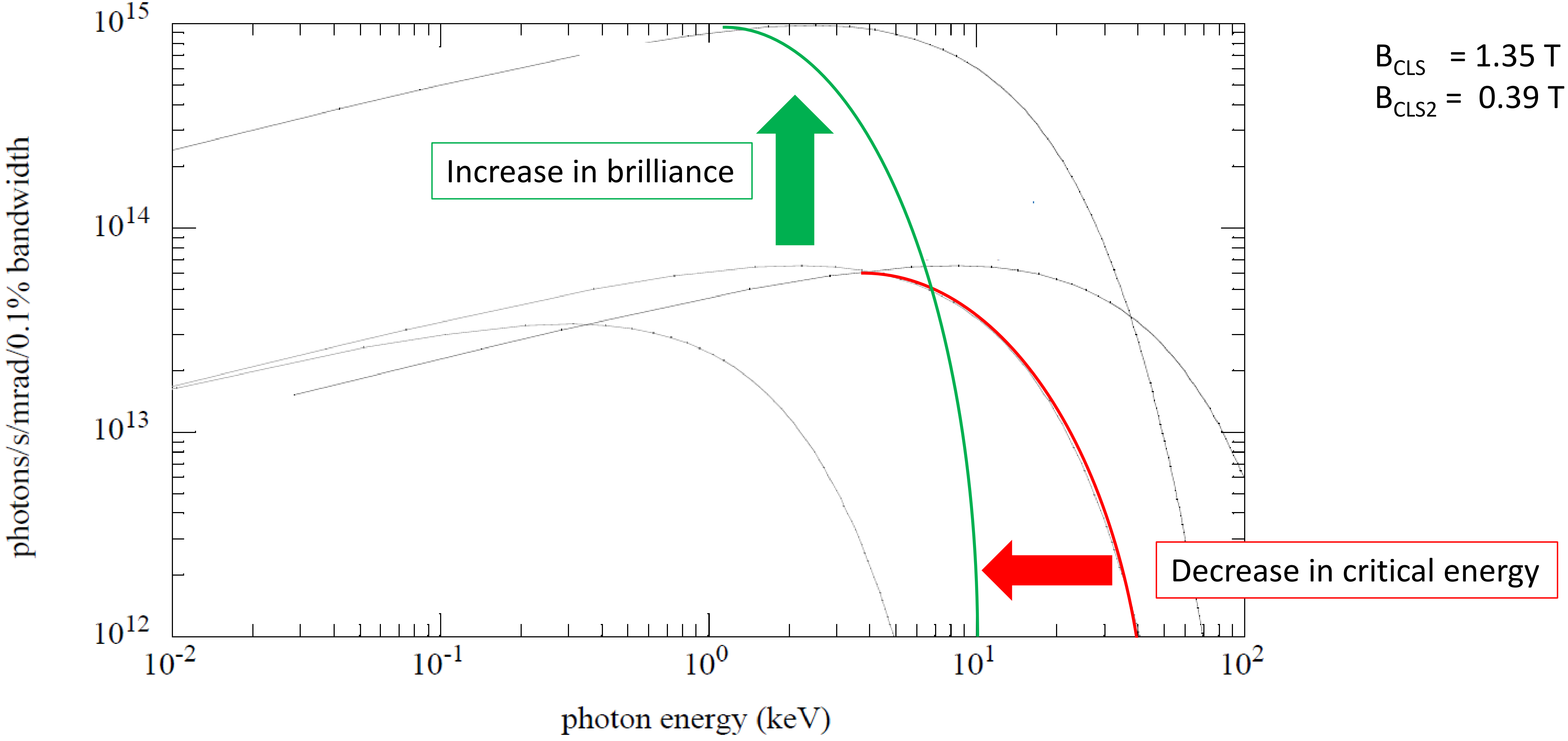
BR and B1 – Offset quadrupoles

Using Ø = 3.0 cm quadrupole

Offset = B/B' = -0.1745 [T]/48.5 T/m]
= -0.0036 m
= -0.36 cm



Beamlines from weak bend magnets with high brilliance



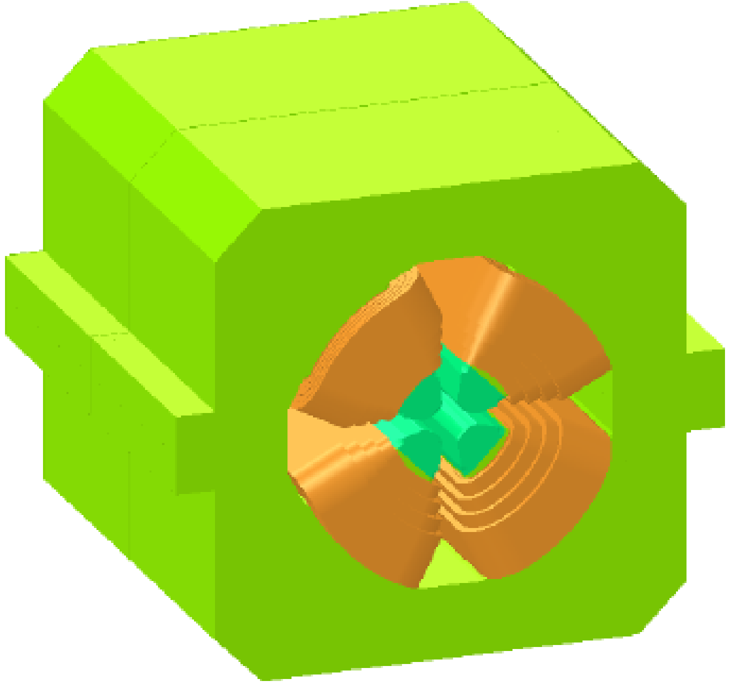
Increase in brilliance

Decrease in critical energy

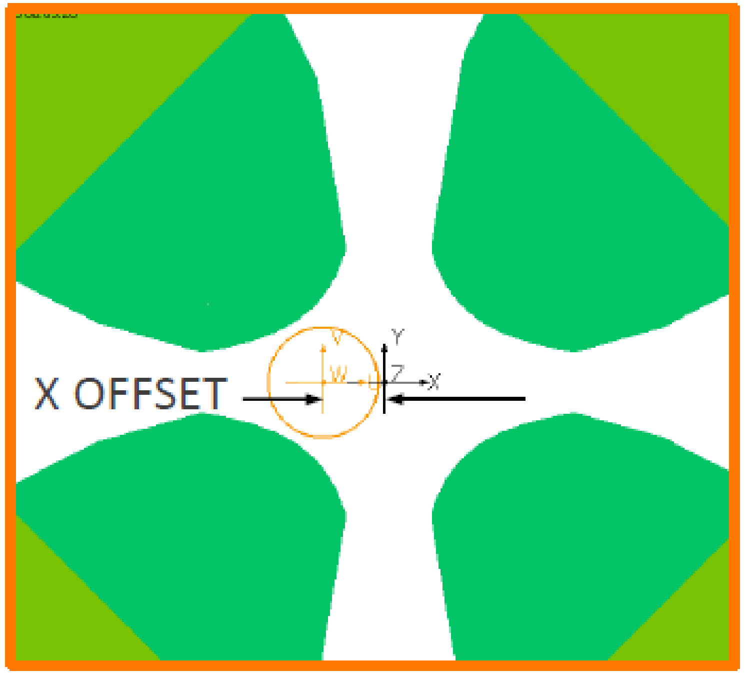
B_{CLS} = 1.35 T
B_{CLS2} = 0.39 T

Larger Offsets (at other facilities)

M4 41pmV4
x_offset 11.663 mm



The photon beam tube not considered yet



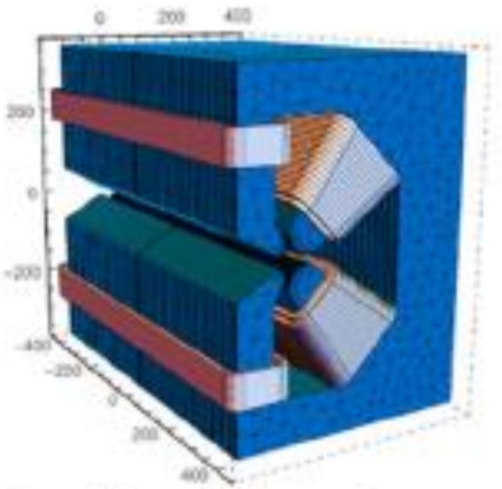
Offset

APS Upgrade: Magnets
Mark Jaski
April 12, 2017

Quad Aperture Ø = 41.4 mm
B = -0.61 T
B’ = 51.5 T/m
Offset = -11.7

Larger Offsets

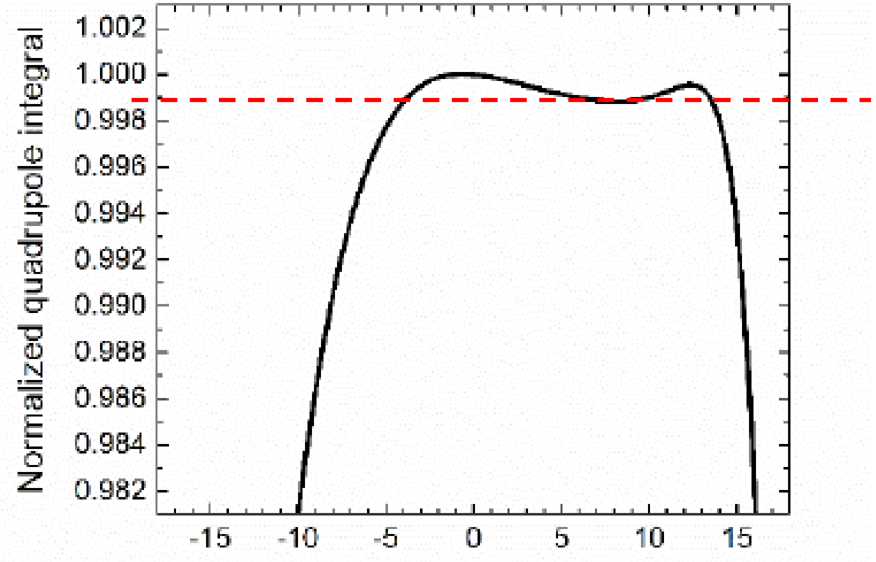
Asymmetric designs



Combined function magnet

B = .60 T
B’ = 27.1 T/m

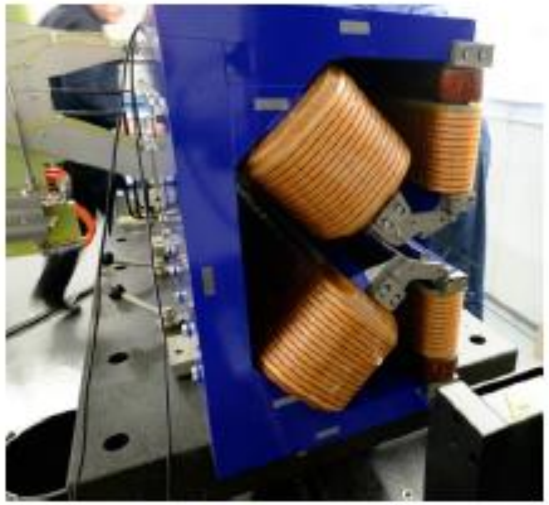
22 mm offset



Siam Photon Source II
P. Sunwong, et al. IPAC 19

B = .57 T
B’ = 36.8 T/m

15.5 mm offset



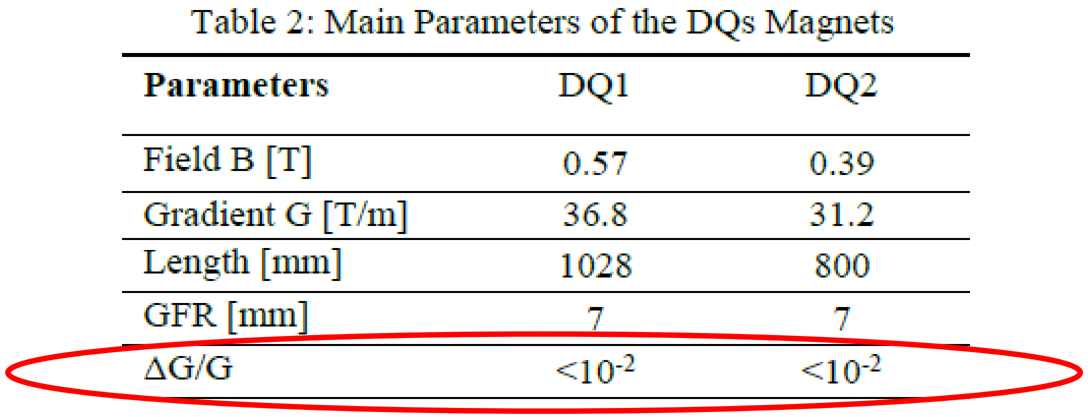
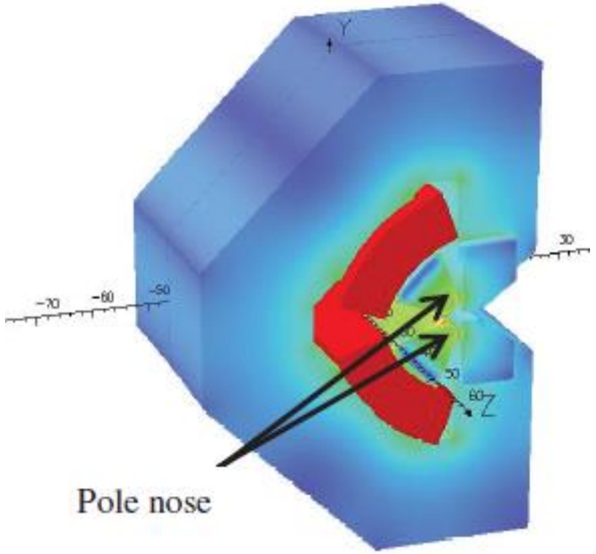


Table 2: Main Parameters of the DQs Magnets

Parameters	DQ1	DQ2
Field B [T]	0.57	0.39
Gradient G [T/m]	36.8	31.2
Length [mm]	1028	800
GFR [mm]	7	7
ΔG/G	$<10^{-2}$	$<10^{-2}$

ESRF –EBS Magntes
C. Benabderrahmane, et al. IPAC 18



ALS
-16 mm offset

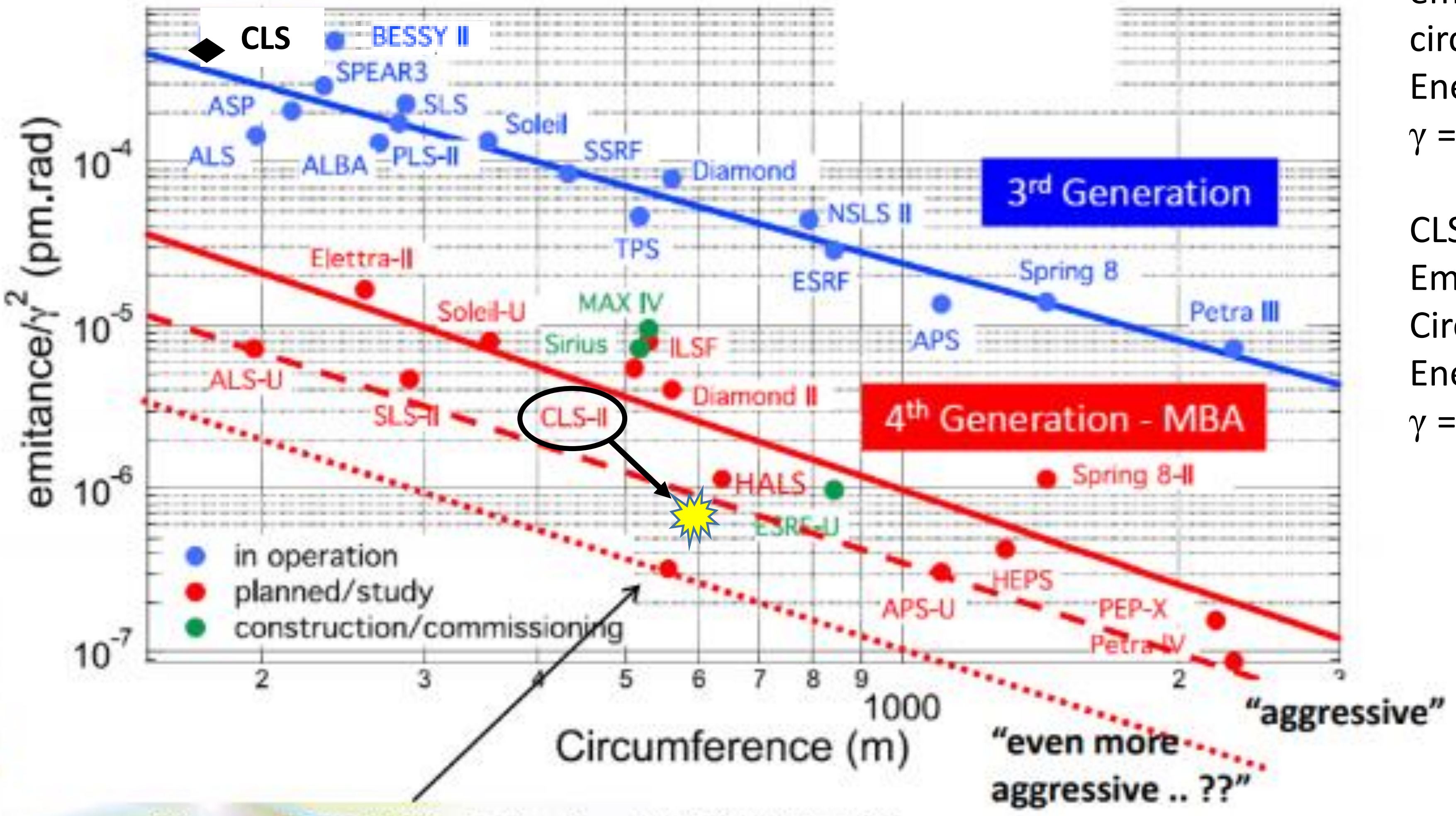
Preliminary designs for CLS 2 Magnets are in progress

- high gradient electromagnets are used
- “simple” designs are used
- no special steel is required

Ultralow Emittance is achieved: 25 pm-rad @ 3 GeV

(an aggressive optics design)

Trends in storage ring lattice design



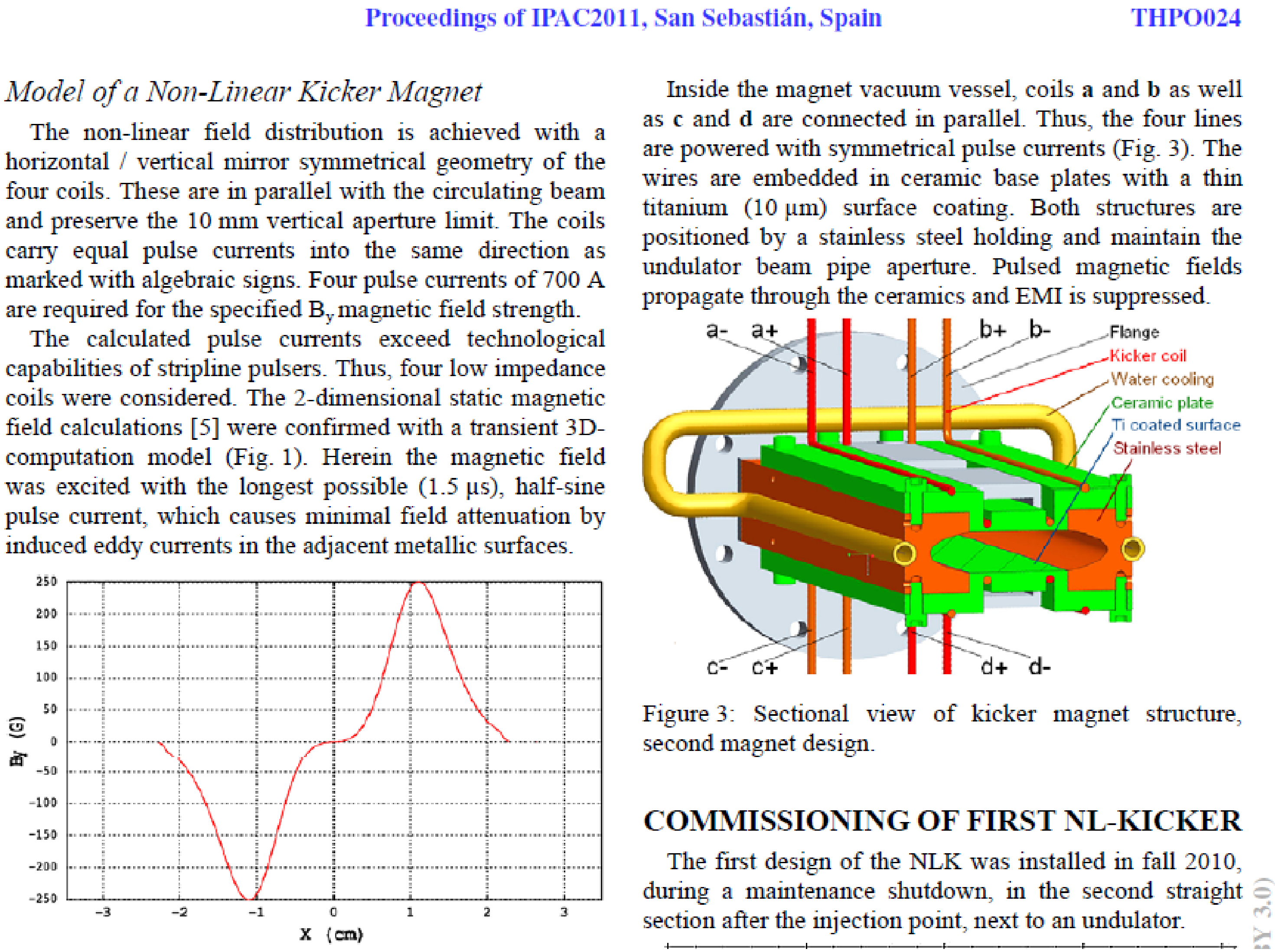
10 pm at 3 GeV in 550m ? MAX-V 19BA?

courtesy A. Nadji, Soleil

CLS ◆
emittance 18,000 pm-rad
circumference 171 m
Energy 2.9 GeV
$\gamma = 5675$

CLS-II ✸
Emittance 25 pm-rad
Circumference 588 m
Energy 3.0 GeV
$\gamma = 5871$

Off-axis injection with a Non-Linear Kicker ………..



Model of a Non-Linear Kicker Magnet

The non-linear field distribution is achieved with a horizontal / vertical mirror symmetrical geometry of the four coils. These are in parallel with the circulating beam and preserve the 10 mm vertical aperture limit. The coils carry equal pulse currents into the same direction as marked with algebraic signs. Four pulse currents of 700 A are required for the specified B_y magnetic field strength.

The calculated pulse currents exceed technological capabilities of stripline pulsers. Thus, four low impedance coils were considered. The 2-dimensional static magnetic field calculations [5] were confirmed with a transient 3D-computation model (Fig. 1). Herein the magnetic field was excited with the longest possible (1.5 µs), half-sine pulse current, which causes minimal field attenuation by induced eddy currents in the adjacent metallic surfaces.

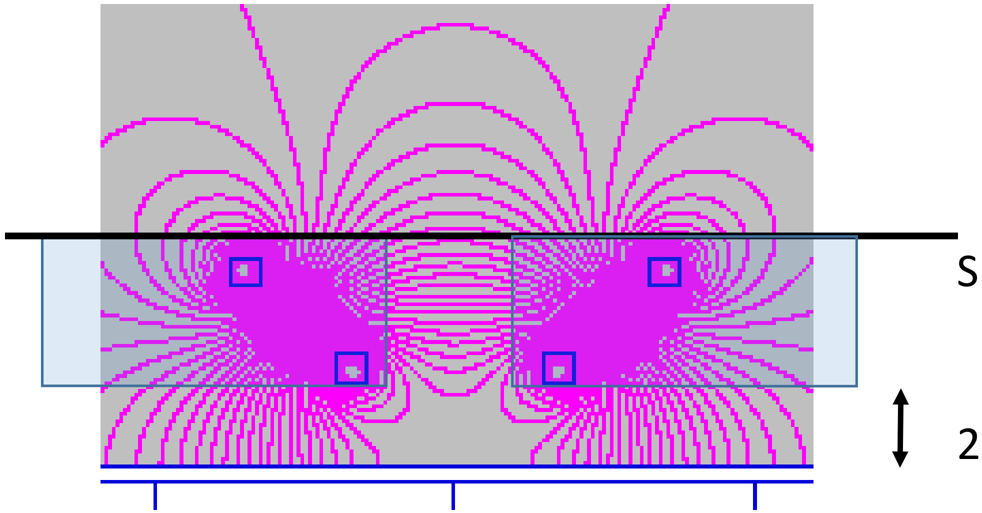
Inside the magnet vacuum vessel, coils **a** and **b** as well as **c** and **d** are connected in parallel. Thus, the four lines are powered with symmetrical pulse currents (Fig. 3). The wires are embedded in ceramic base plates with a thin titanium (10 µm) surface coating. Both structures are positioned by a stainless steel holding and maintain the undulator beam pipe aperture. Pulsed magnetic fields propagate through the ceramics and EMI is suppressed.

Figure 3: Sectional view of kicker magnet structure, second magnet design.

COMMISSIONING OF FIRST NL-KICKER

The first design of the NLK was installed in fall 2010, during a maintenance shutdown, in the second straight section after the injection point, next to an undulator.

……..at small amplitudes



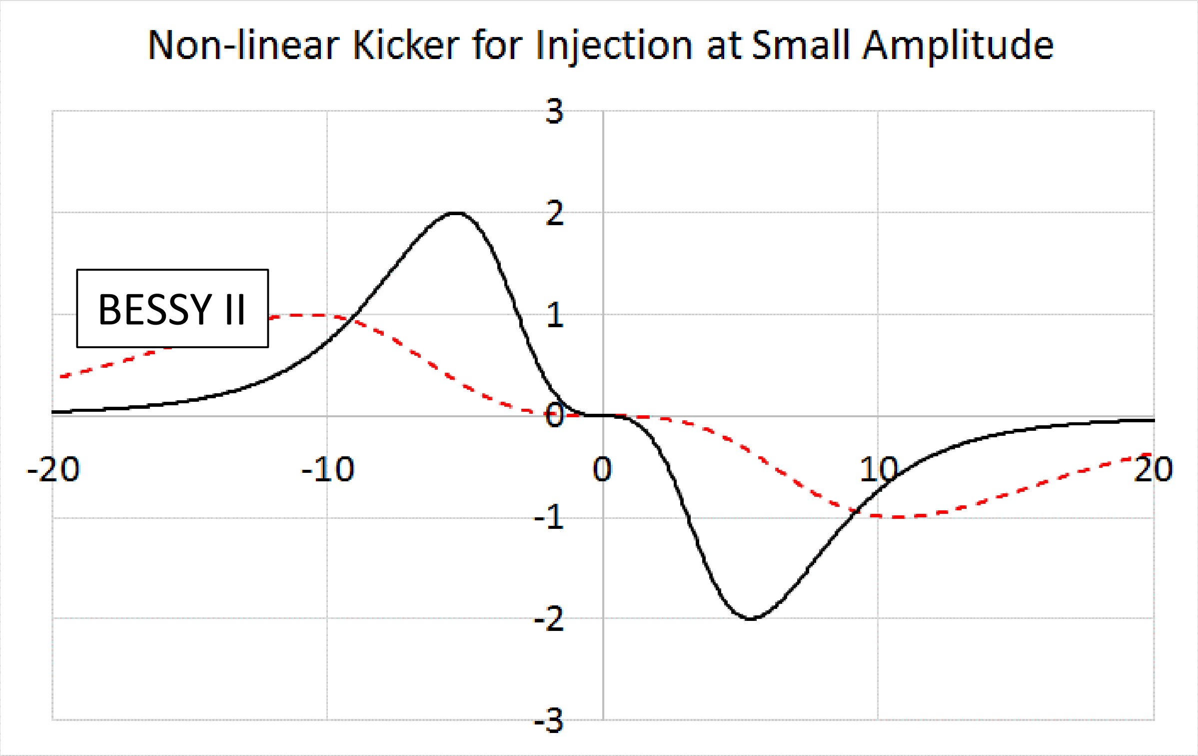
Support structure?

2.75 mm (similar to in vacuum ID)

Current strips at

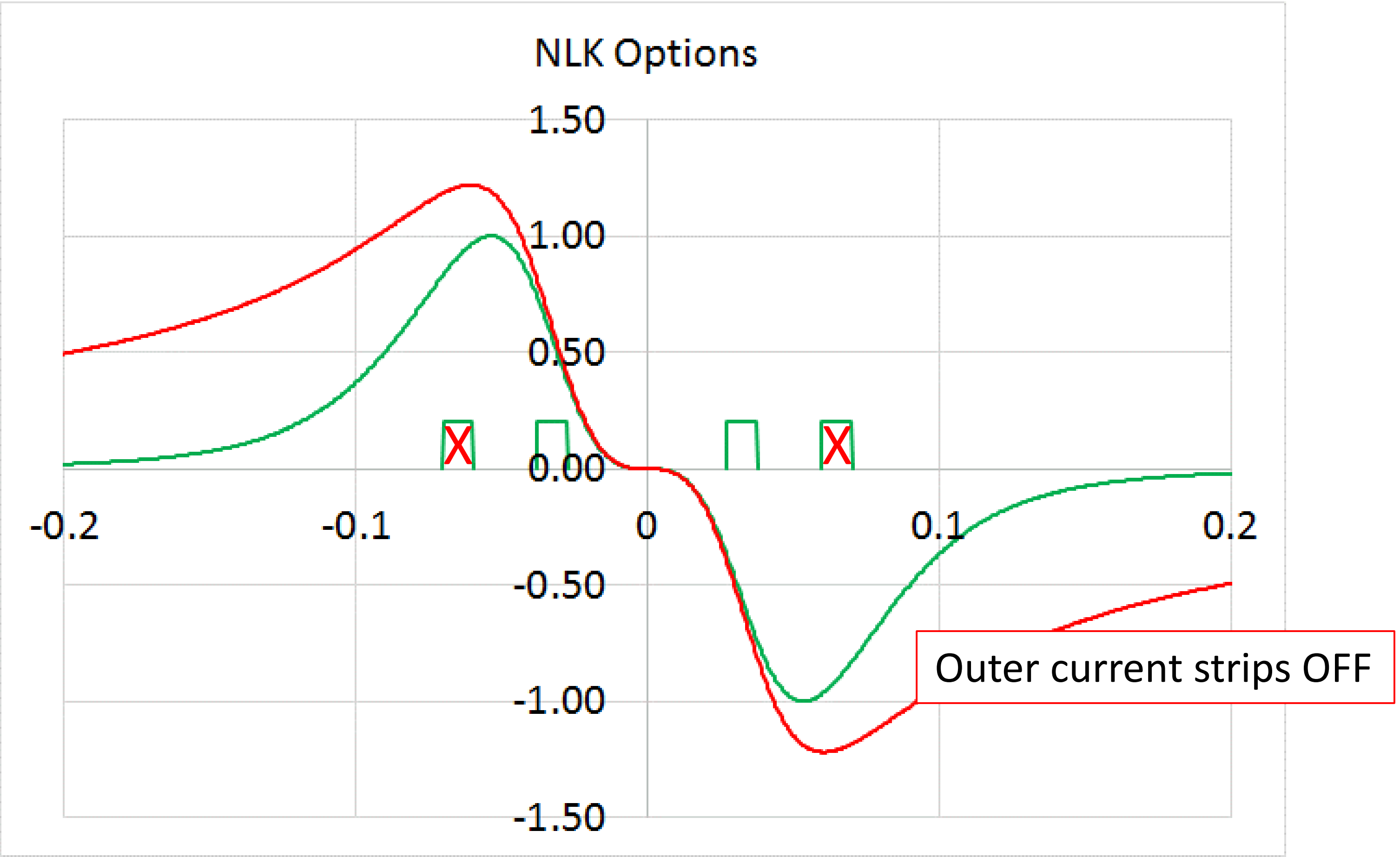
3.25 mm and 6.5 mm

In vacuum NLK?



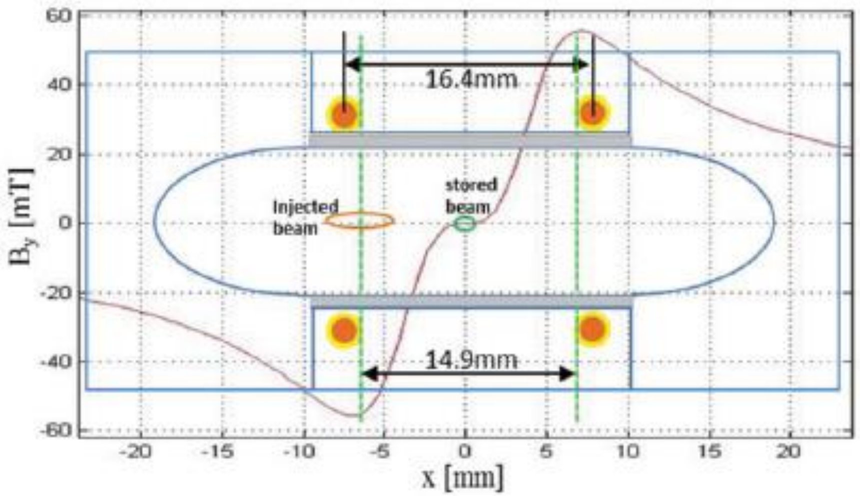
Relative strength
(same current)

double kick
at smaller
amplitude
(5.04 mm)



Outer current strips OFF

DIAMOND IPAC 2013



Electromagnets with High Gradients (for CLS 2)

L. Dallin

ALERT 2019 Workshop

July 12, 2019

Thank you for your attention

Compare
Sext +/- 19 cm
Quad +/- 32
Dipole +/- 18