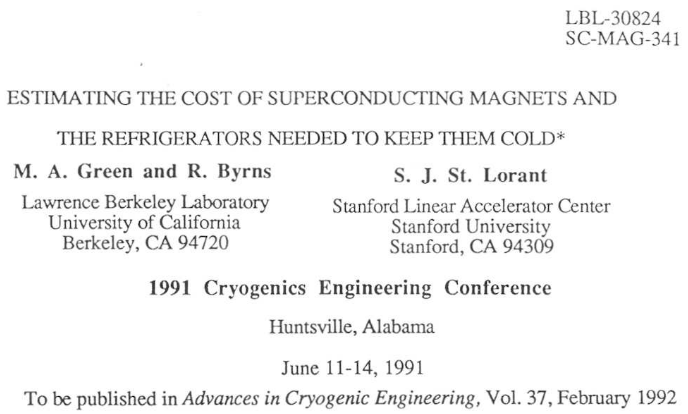
An elliptical combined fuction ring magnet

R. B. Palmer (BNL)
3/21/12

Cryogenic Efficie



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SC-MAG-341

ESTIMATING THE COST OF SUPERCONDUCTING MAGNETS AND

THE REFRIGERATORS NEEDED TO KEEP THEM COLD*

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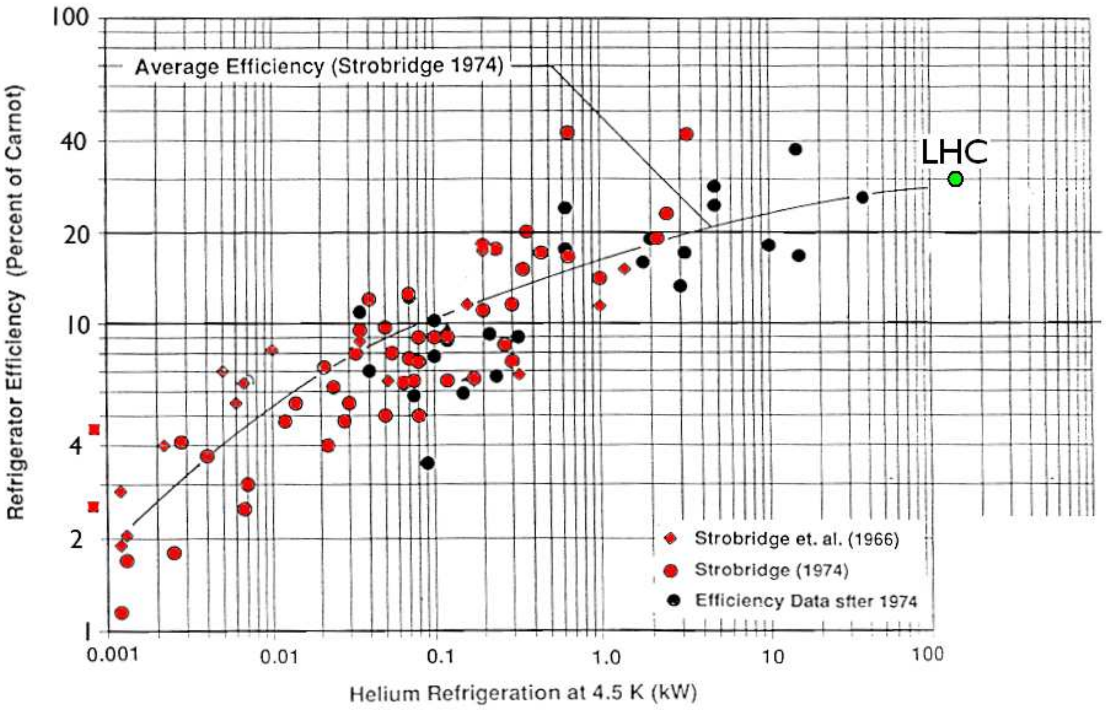


Figure 3. The Efficiency of Helium Refrigerators as a Function of 4.5 K Refrigeration

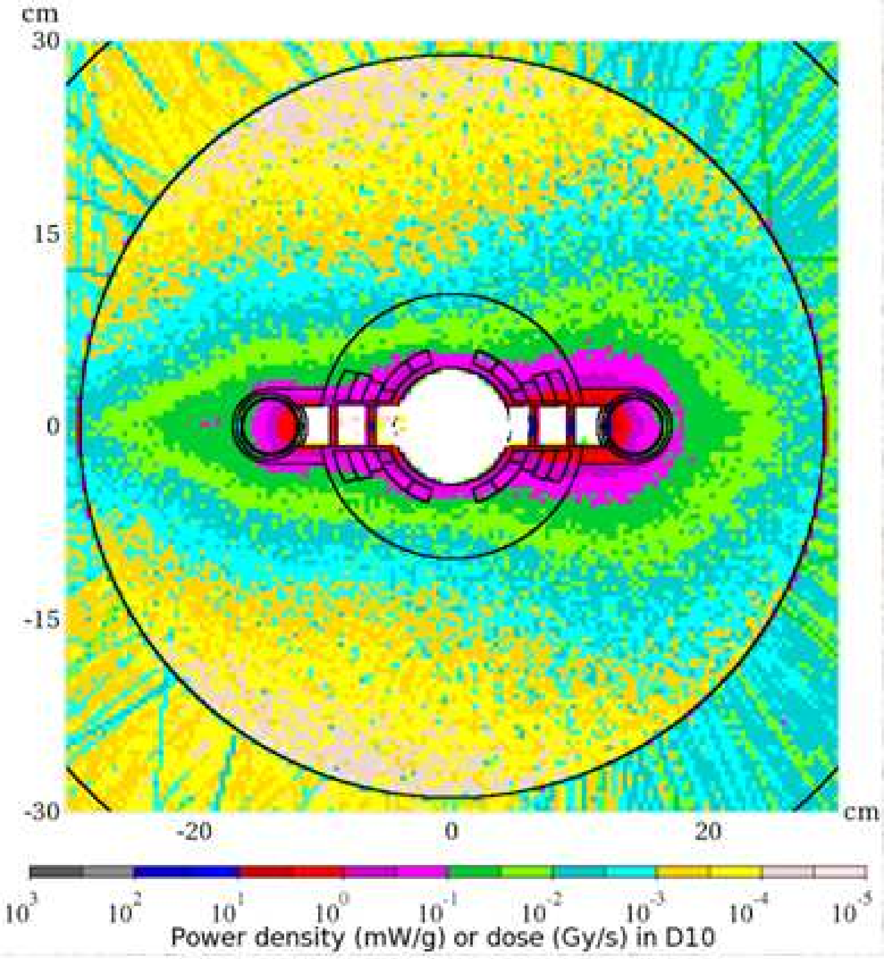
- LAC efficiency at 150 k at 4.5 beg $=$30% of Cannot (Shiltsev) is consistent
- LAC Distribution efficiency $=$ 68% (Shiltsev)
- So assume efficiency $30 \times 0.68 = 20$ % of Cannot
- for 4 beg: $\boxed{\text{Efficiency} \approx 0.2 \times 4/300 \approx 1/375}$
- To keep Wall Power for 4 beg cryogenics below 10 MW: losses must be less than $10{,}000/375 = \boxed{27\ \text{k}}$

Power to decay electrons and required attenuation

- Beam Power $= 2N_\mu Vef \; = \; 4\;10^{12} \times 750\;10^{9} \times 1.6\;10^{-19} \times 15 \; = \; 7.2\text{MW}$
- $\boxed{\text{Beam power dissipated as electrons} = 2.5 \text{ MW}}$ (as used by Mokhov)
- For loss at 4 degrees $= \boxed{27 \text{ k}}$
- Required shield attenuation $= 27/2{,}500 = 0.0108 \approx \boxed{1.0\%}$
- Note that we are assuming the same attenuation for all regions despite the dipoles only representing only 67% of the ring

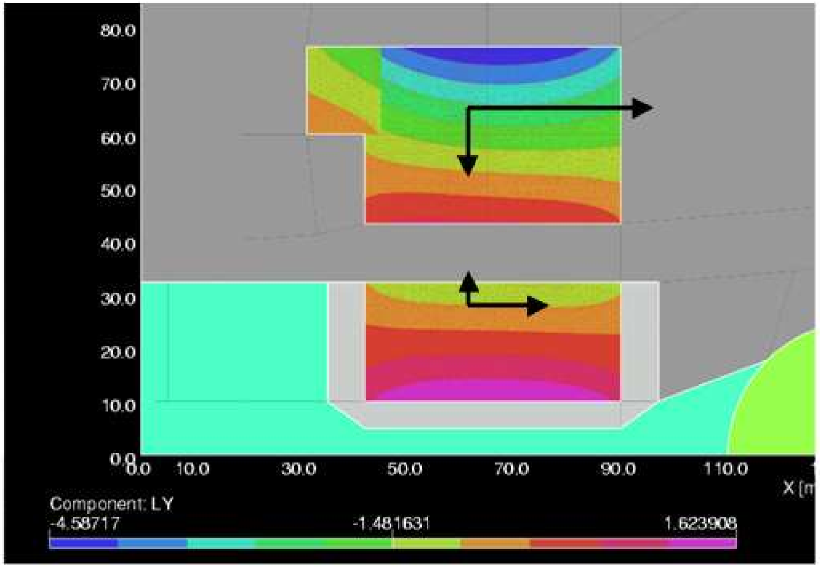
Option #1: Open Mid-Plane Dipole
Mokhov's MARS15 simulation

- Radiation on coils within quench limits
- Energy deposited in AlBe-Met bridge supports not apparently a problem
- But 45% of energy dumped in 4 degree coils and coil supports
- Distributions suggest upward and downward energy flows
- WHY ?

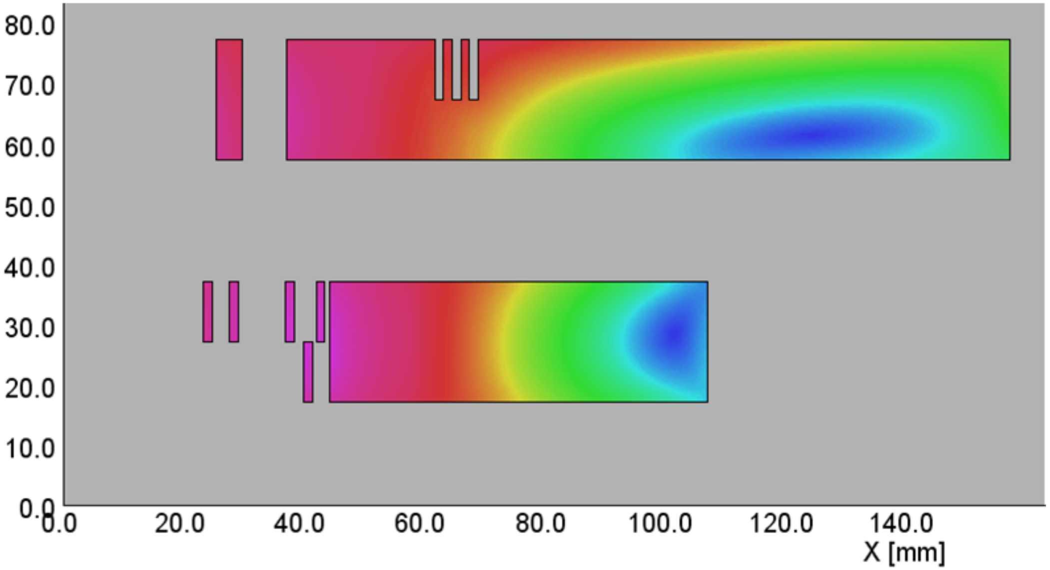


Engineering of open-mid-planes (BNL)

GU PTA



Principle of forces

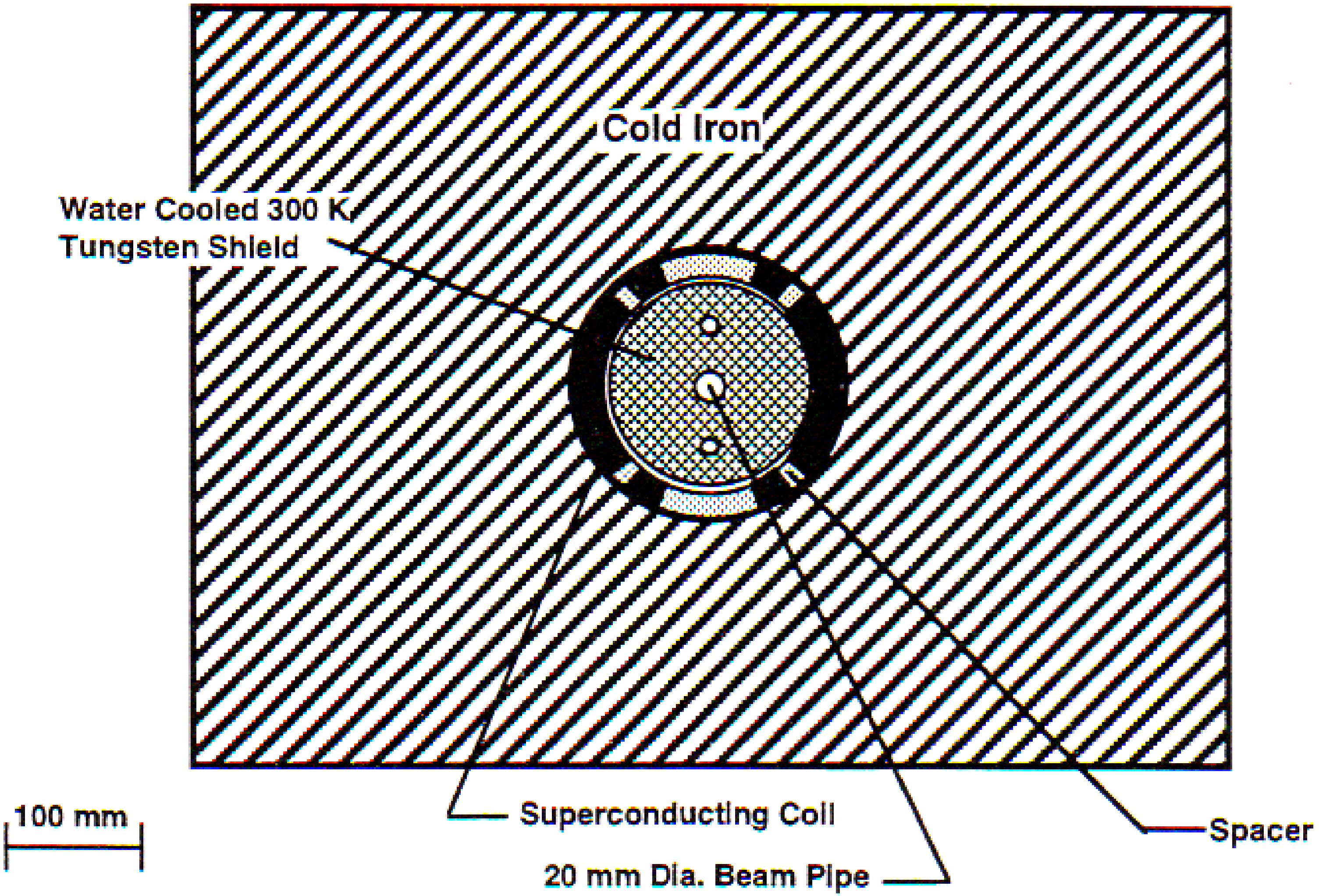


Design for Field Quality

- Designs for LAC Upgrade (CARP)
  - e.g. 13.6 T on axis 15 T on conductor deflections $< 150\ \mu$m b/B $< 3\ 10^{-5}$ to r=36 mm
- Design for SBIR POP
  - B(axis)=10 T T$<$ 400 Pa Deflections $< 90\ \mu$m

Option # 2: Thick tungsten beam pipe

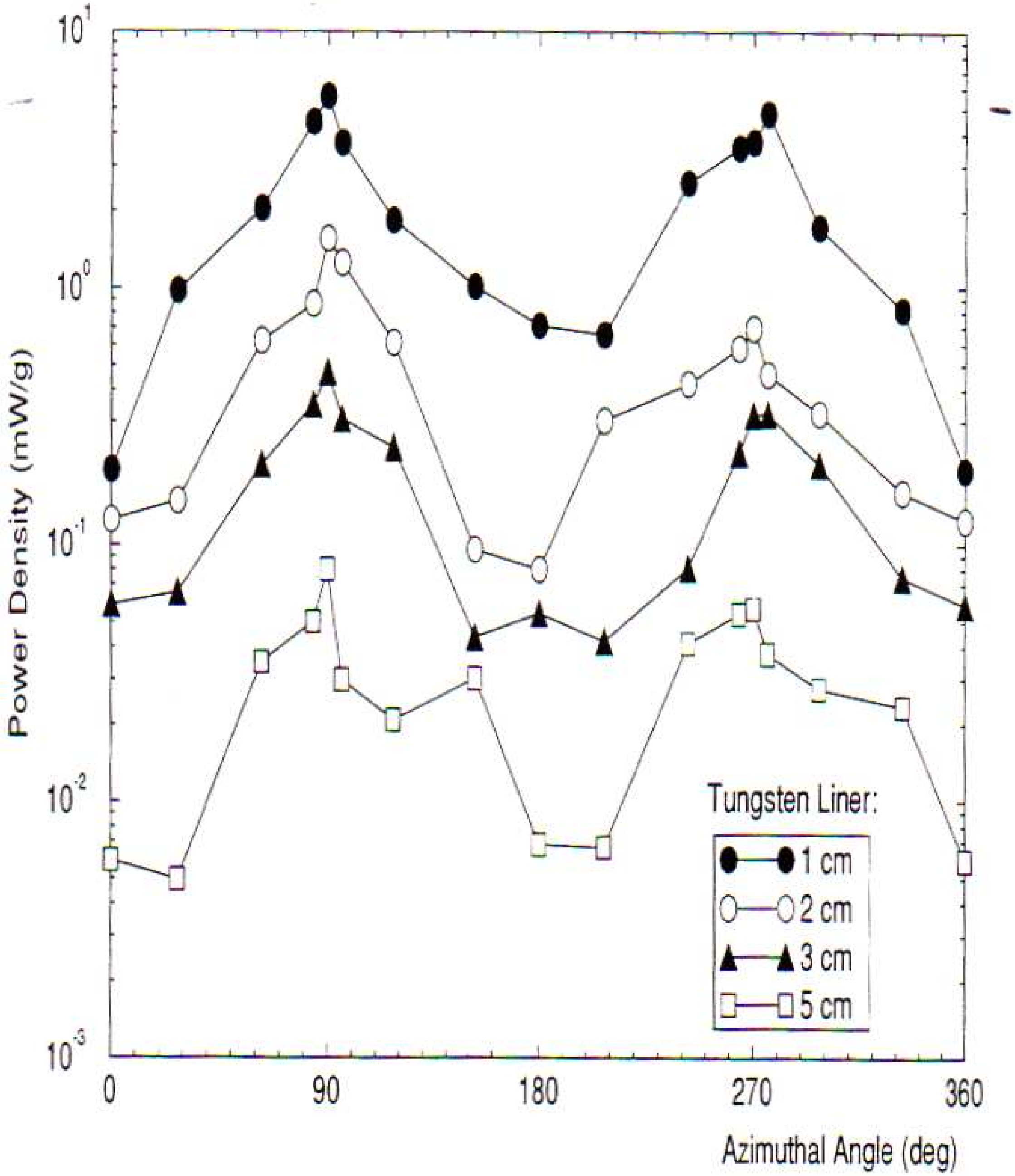
As discussed in 98 Feasibility Study



98 MARS for 4 T

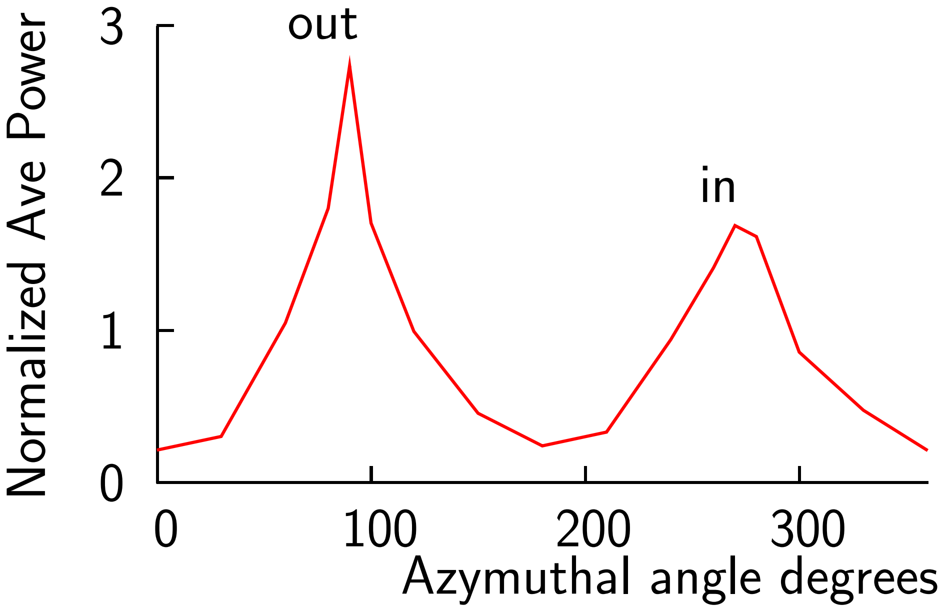
Mokhov 98 2+2 TeV distributions vs. angle for different thicknesses of tungsten shield

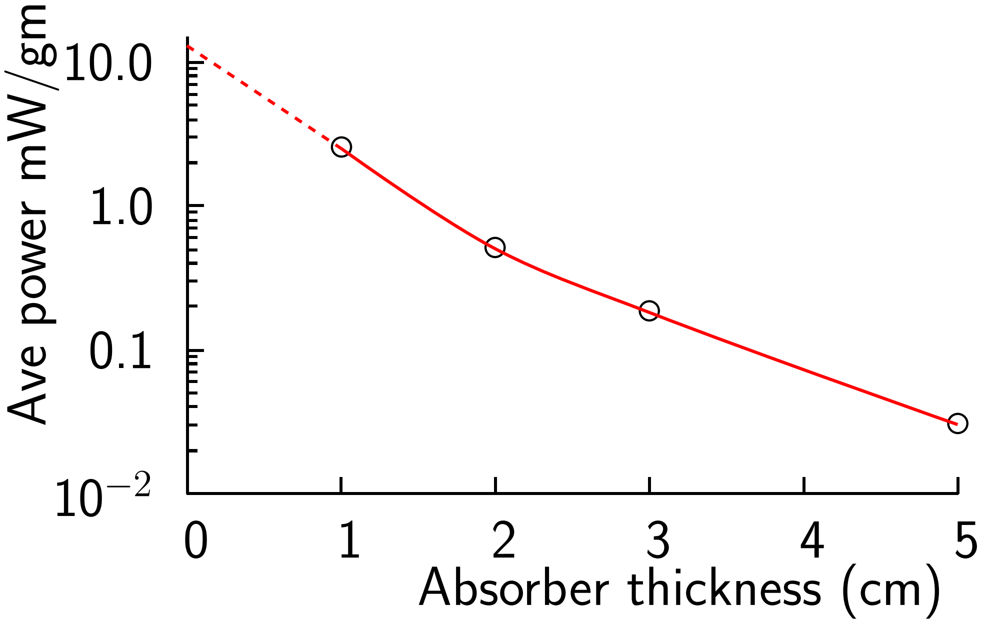
Shape of distributions approx independent of shield thickness



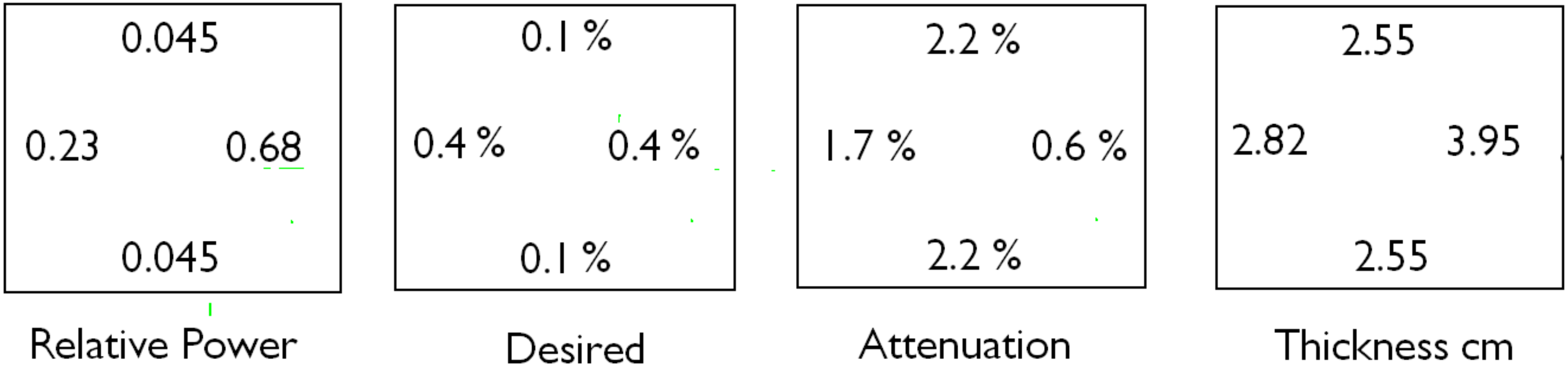
Attenuation and shape

- At 2+2 TeV
  - gamma radiation from higher E electrons (90 beg) is more than electron radiation ($\approx$ 4:3)
  - and more focused
  - up-down/side is $\approx$ 1/10
- at 0.75+0.75 TeV
  - gamma ad. will be relatively much less (e.g. 1:3)
  - assume up-down/side still 1/10
- Attenuation length
  - extrapolate to zero
  - initial slope steeper from narrower showers?





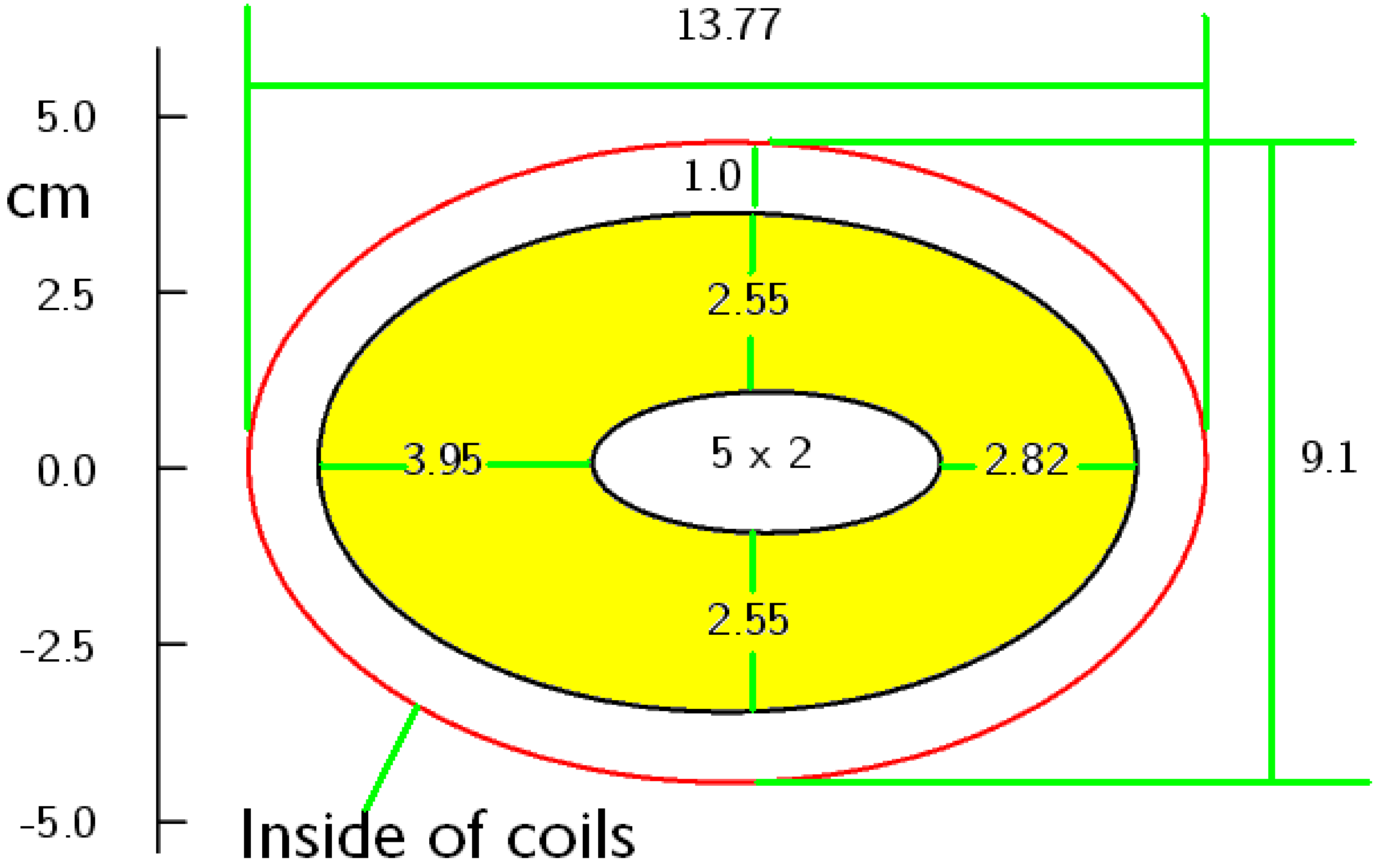
Required shield thicknesses



- Initial "Relative powers" (left, right, up, down) adding to 1.0
- "Desired" powers (left, right, up, down)) adding to 1 %
- Required "Attenuation"s = Desired/Initial
- Required shield "Thickness" as looked up from above plot
- This or like it would meet requirement

Section

- Inside pipe width = 5 cm
- Inside pipe height = 2 cm



Not quite as large as 98 study (14 x 14 cm) but large

- Most radiation in horizontal plane
- Shielding and magnet could be elliptical
- At 2 TeV almost equal in & out

Attenuation sideways $= 0.016 \times 10 = 0.16$

$\boxed{\text{Required thickness sideways} = 1.3\text{ cm}}$

Assumed ratio of (energy inwards) / (energy outwards) $= 3$ This is a guess

Attenuation inwards $= 1/1.5 \times 0.016 = 0.0107$

$\boxed{\text{Required thickness inwards} = 3.6\text{ cm}}$

Attenuation outwards $= 1/0.5 \times 0.016 = 0.032$

$\boxed{\text{Required thickness outwards} = 2.55\text{ cm}}$

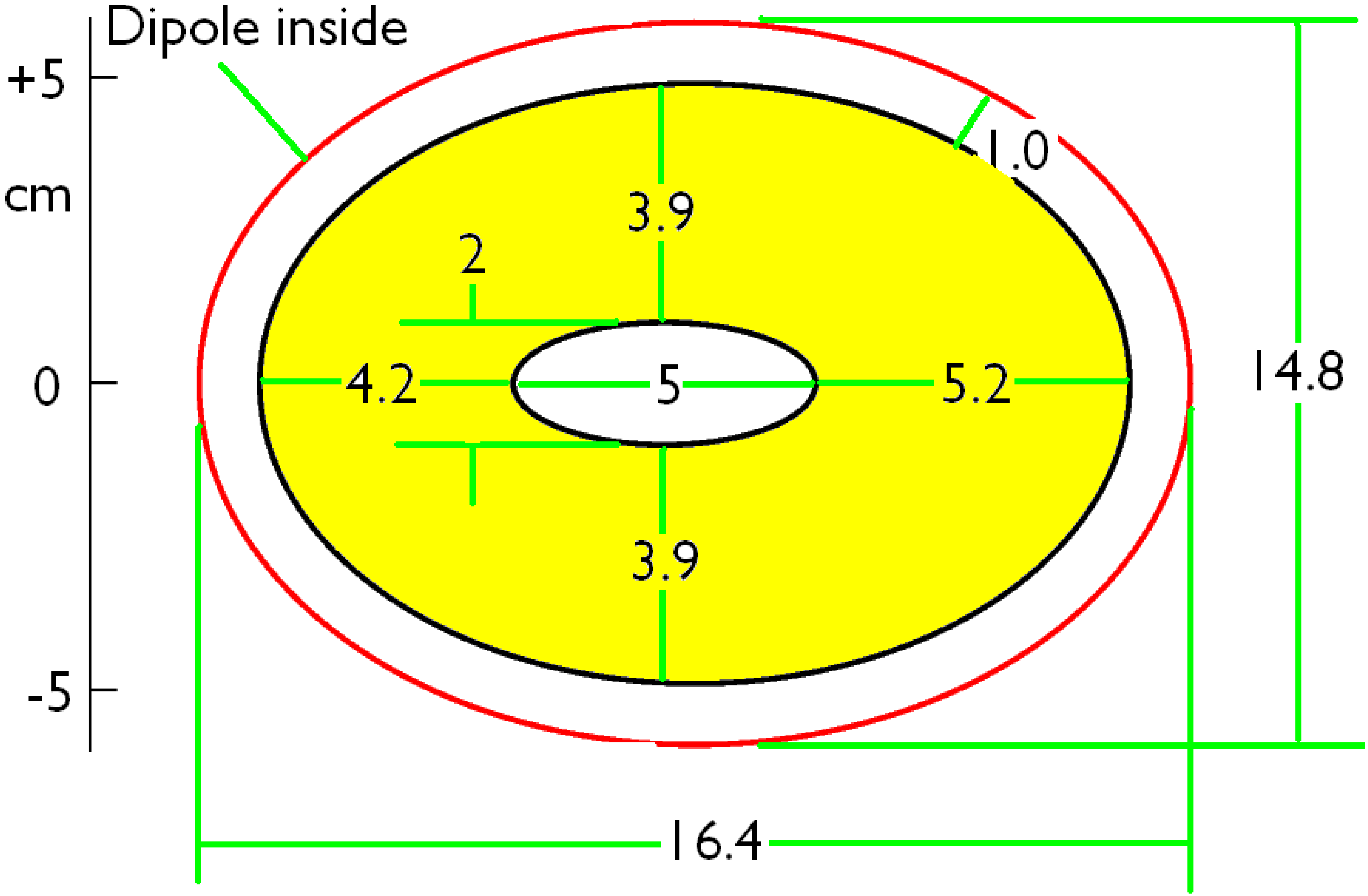

Dipole inside
+5
cm
0
-5
1.0
3.9
2
4.2
5
5.2
3.9
14.8
16.4

Table 1

shield wid$_L$ cm	shield wid$_R$ cm	shield height cm	beam wid cm	beam height cm	beam disp cm	gap gap cm	mag IR cm	B$_{dipole}$ field T	Quad grad T/m
3.95	2.82	2.55	5.00	2.00	0.57	1.00	6.89	8.00	80.0

Table 2: Initial fields

	B$_{left}$ T	B$_{center}$ T	B$_{right}$ T
Focus	13.96	8.45	2.94
De-focus	2.04	7.55	13.06

Table 3: Fields after lengths modified by factor=1.034

	B$_{left}$ T	B$_{center}$ T	B$_{right}$ T
Focus	13.50	8.17	2.85
De-focus	2.11	7.80	13.50

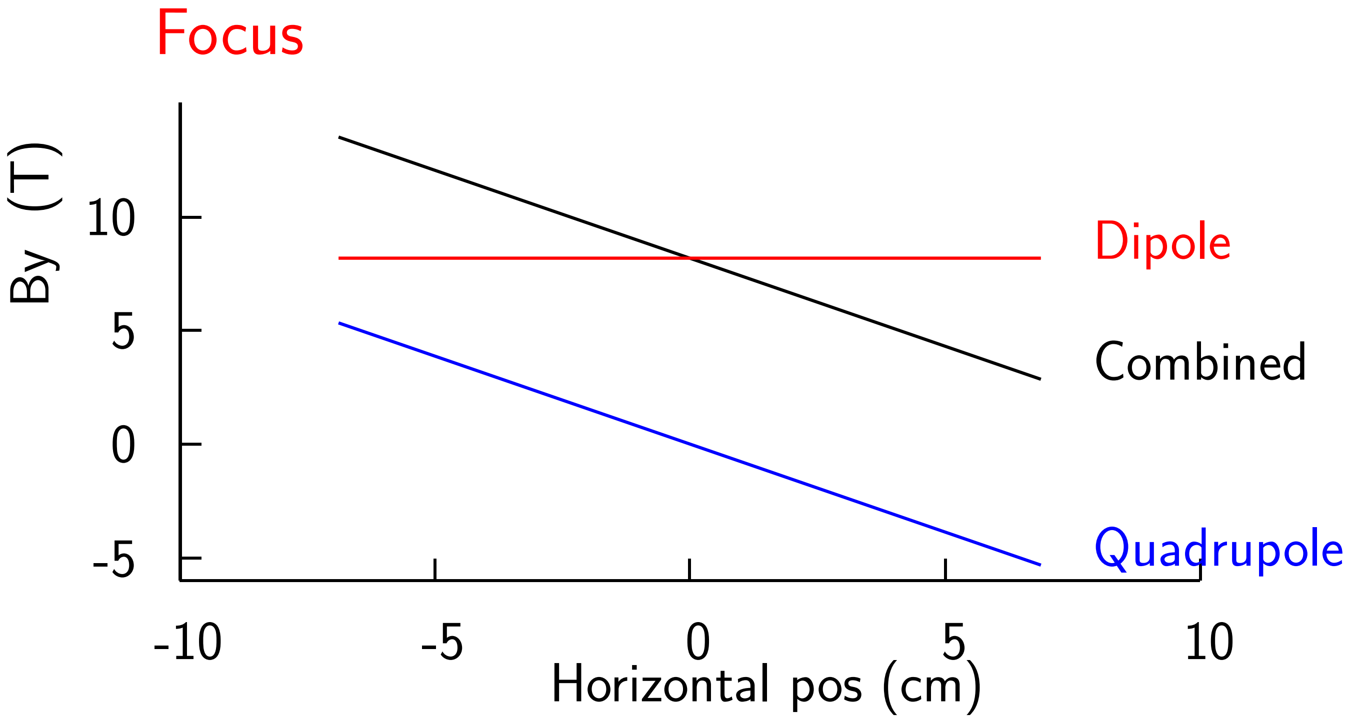

Focus
By (T)
10
5
0
-5
-10
-5
0
5
10
Horizontal pos (cm)
Dipole
Combined
Quadrupole

Fig. 1

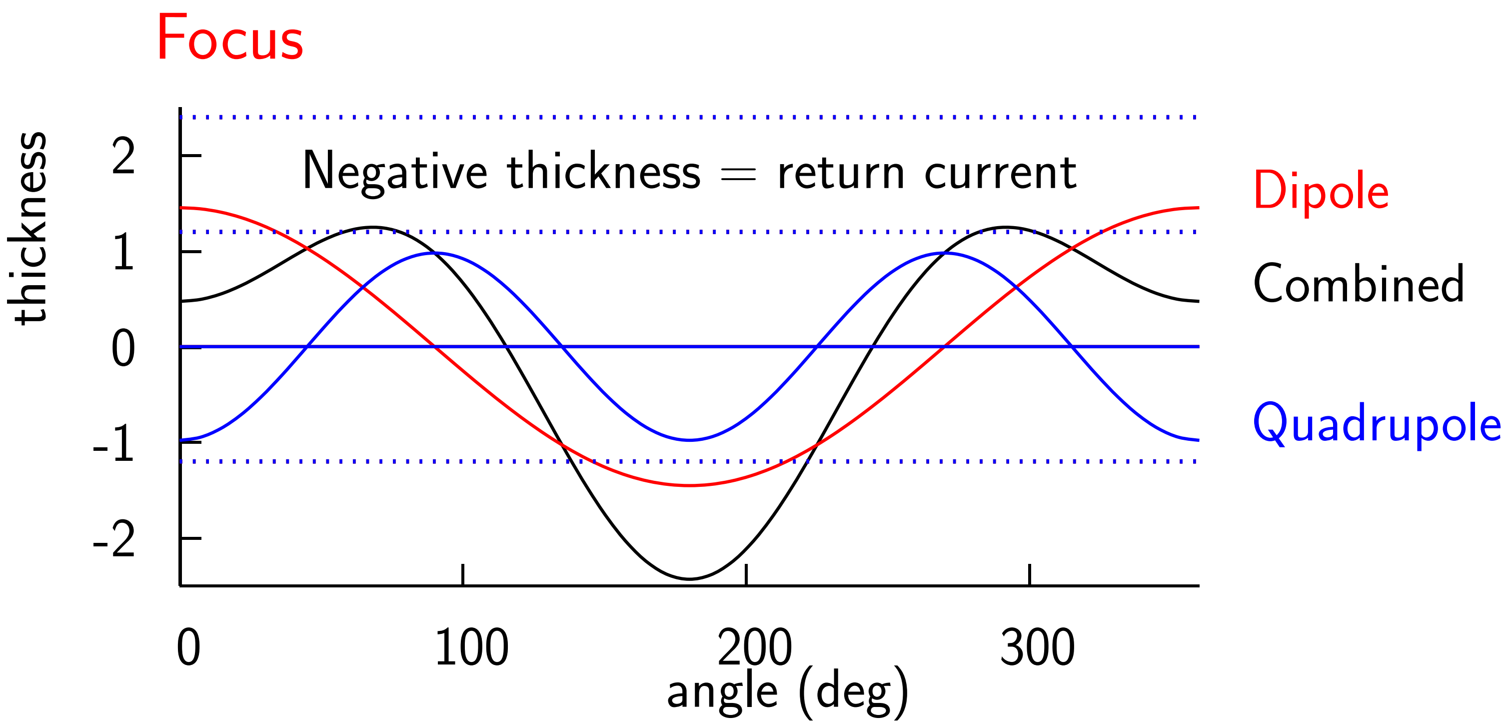

Focus
thickness
2
1
0
-1
-2
Negative thickness = return current
Dipole
Combined
Quadrupole
0
100
200
300
angle (deg)

Fig. 2

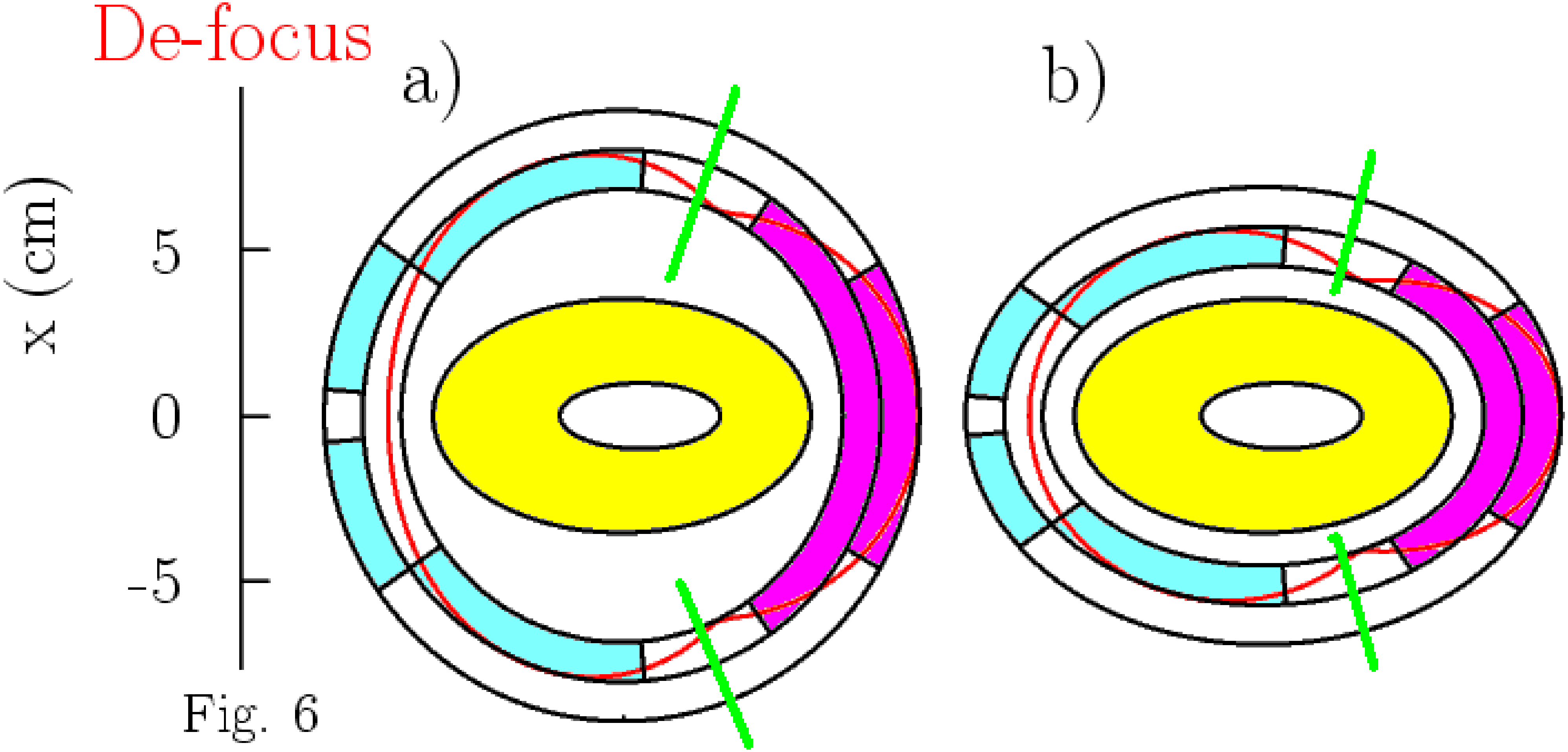


Fig. 6

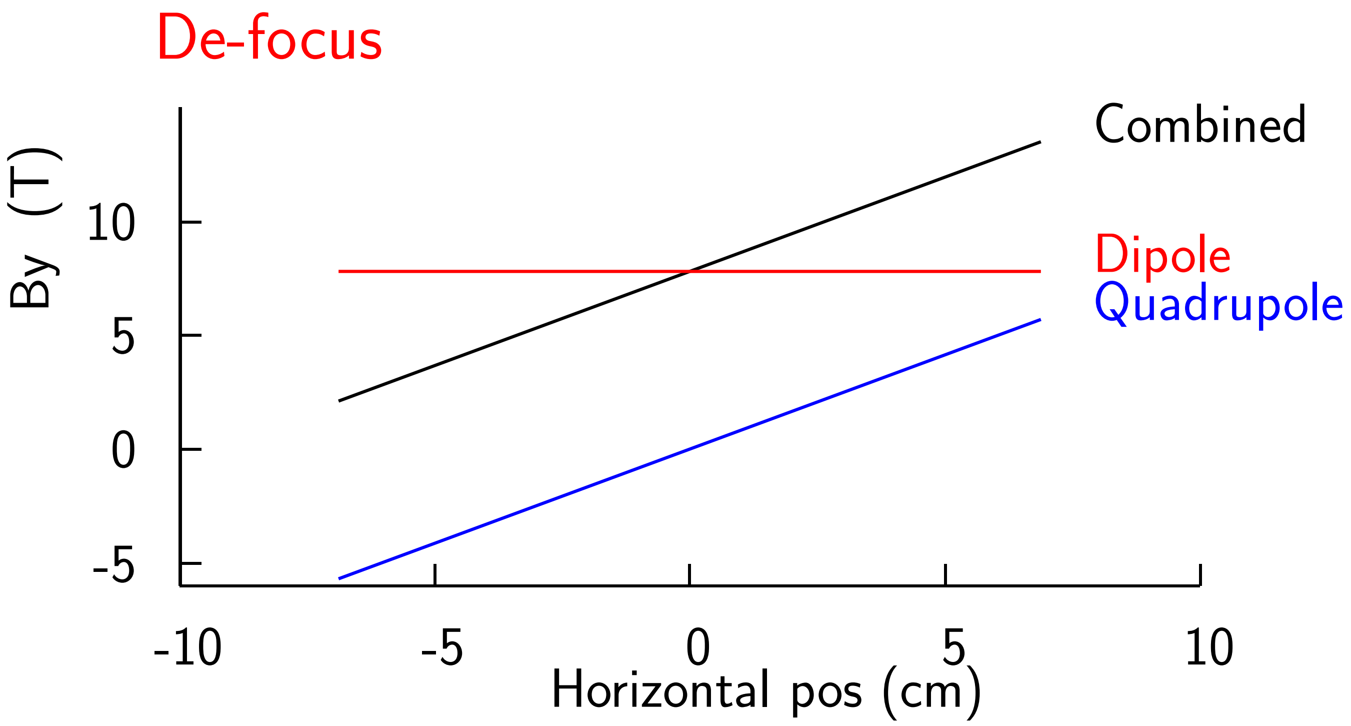

De-focus
Combined
Dipole
Quadrupole
By (T)
10
5
0
-5
-10
-5
0
5
10
Horizontal pos (cm)

Fig. 4

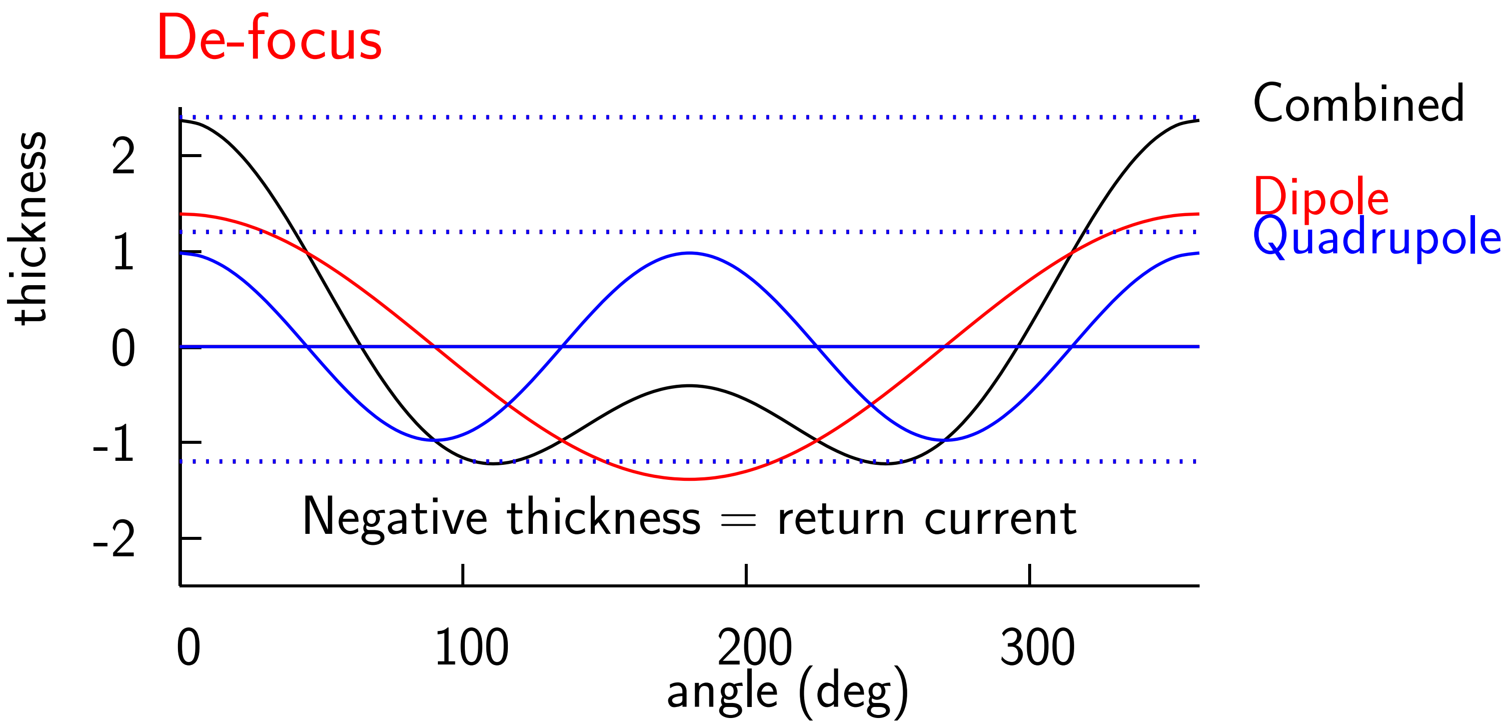

De-focus
Combined
Dipole
Quadrupole
thickness
2
1
0
-1
-2
Negative thickness = return current
0
100
200
300
angle (deg)

Fig. 5

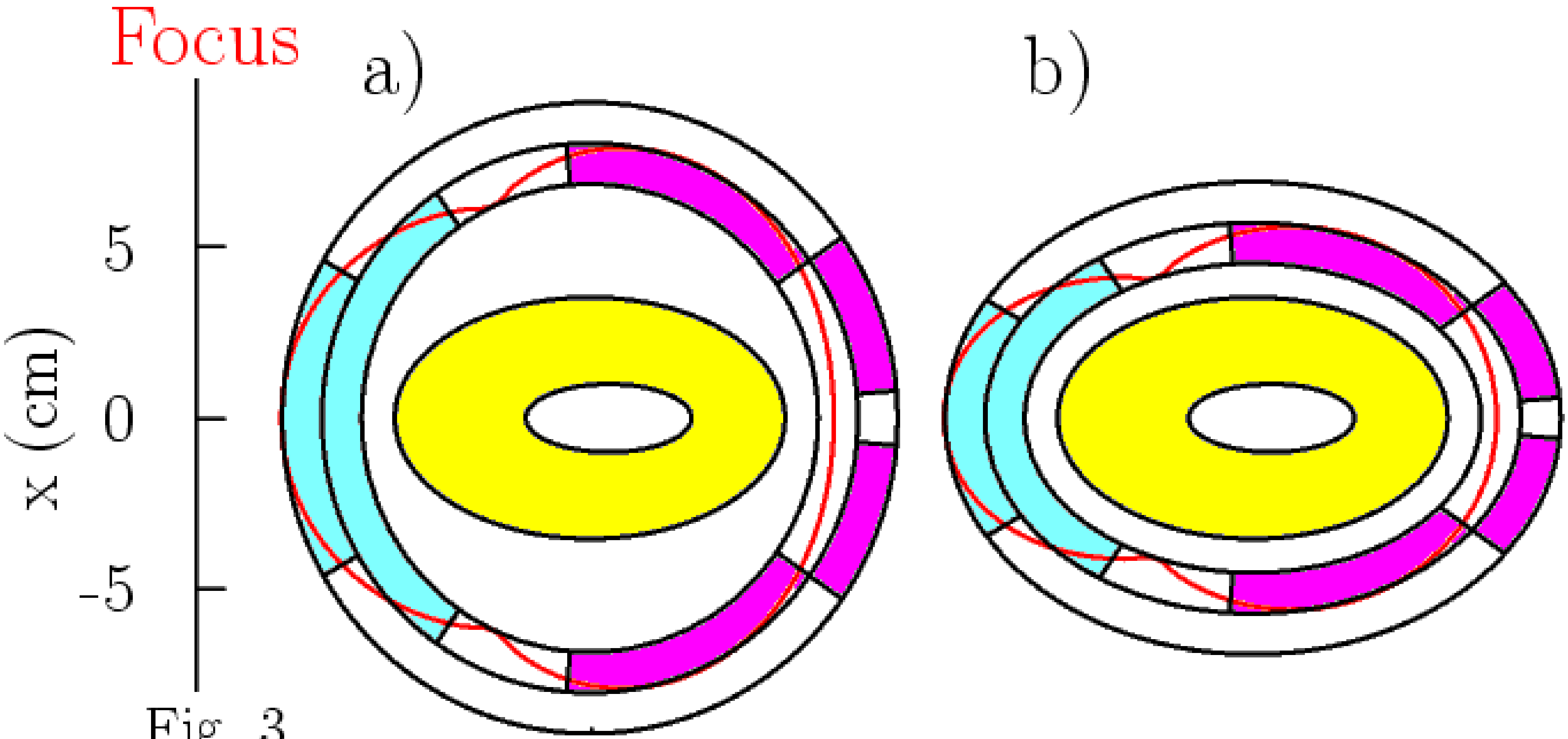


Fig. 3

Introduction

Fig. 0 shows the estimated shield shape designed to minimize the mass of tungsten, as shown at the mini-workshop. It is noted that it has more shielding on one side than the other and has less height, where there is less radiation, than on the sides. The smallest combined function magnet to fit around this, assuming 1 cm for nitrogen shield and insulation, will have a center displaced from the beam center, and will be elliptical.

For the 1.5 TeV collider, Yuri specifies 8T dipoles with superimposed gradients of 80 T/m. For the shield cross section discussed before, and 1 cm space from warm shield to 4.2 degree coils. These specifications are given in Table 1.

The distances from beam center to inside of coil are 7.45 cm on the left and 6.32 cm on the right. For the focusing magnets, this gives fields of 8 + .0745 x 80 = 13.96 on the left and 8 - .0632 x 80 = 2.95 on the right, with a central value of 8.18 T. For the defocusing magnets the fields are 2.04 on the left and 13.06 on the right and central field of 7.55, as given in Table. 2. We see that maximum are higher for the focus than the defocus coils, so I modify the magnet lengths making the focus magnets longer by 1.034 and the defocus magnets shorter by 1/1.034. With this modification the maximum fields are now the same for focus and defocus magnets as given in Table 3.

Fig 1 plots the vertical fields on the horizontal mid-plane as a function of horizontal position for the focus magnet. The fields are given for the dipole (red), quad (blue), and sum (black). The required coil thicknesses for an ideal focus magnet cross section, with uniform current densities, and arbitrary maximum thickness of 2.4 cm, are shown in figure 2. Again those needed for the dipole component (red) and quadrupole component (blue), are shown together with the combined thickness of the combined function magnet. Note that a negative value here means the return of the coils.

Fig. 3a shows an approximation as to how how these can be approximated with two layers with circular coil cross sections. A simulation would be required to determine the exact angles to give the fields of fig. 1. We see a lot of free unused space above and below the shield..

Fig. 3b shows what the coils might look like with an elliptical cross section. Now the thicknesses needed and angles drawn are only a guess as to what is needed to give the required field. A simulation is needed. This design will need less conductor and have lower mid-plane forces than that of fig 3a.

Figures 4,5 and 6 repeat this for the defocus magnet.

Two comments:

1. The shield dimensions used badly need refining. They were based on a simulation by Nikolai for the 4 TeV collider. We need a new simulation of radiation power flow vs radius and angle with the 1.5 TeV parameters and 2 x 5 cm hole. I doubt that the focusing is a big factor in this metric, so a quick MARS simulation with a bent hole and parallel beam would be a good starting point. Can Nikolai help here?
2. The choices I made to get the defined ellipticity may not be the best compromise. I had not appreciated that the field contribution from the quad gradient are so large compared with the dipole field. This suggests that a less elliptical shield with reduced horizontal thickness, might be preferred.