

Strong Dipole Magnet for DIRAC experiment

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1. Current setup

The current set up of the dipole magnet in the target chamber is shown in Fig. 1. The installed permanent magnet is shown in Fig. 2. The peak magnetic field is designed low (<0.16T) so as not to break up the $\pi^+\pi^-$ atoms ($A_{2\pi}$) in the magnetic field while keeping the integrated value BL as 1T cm, so that the π^+ and π^- particles broken-up from the $\pi^+\pi^-$ atoms are swept out (see Fig. 3). The direction of the magnetic field is horizontal, which sweeps out charged particles vertically from the orbit of the neutral particles. The gap width is 60mm for the beam halo not to hit the magnet. The magnet and the target holder are hanged by wires and two actuators lift them independently (see Fig. 4). The heights can be adjusted by remote control.

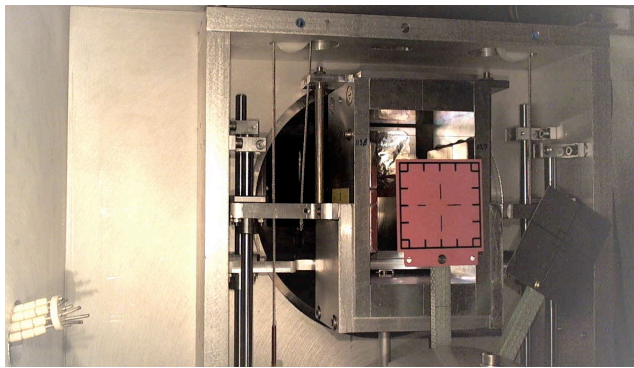


Fig. 1 Weak dipole magnet in the target chamber.

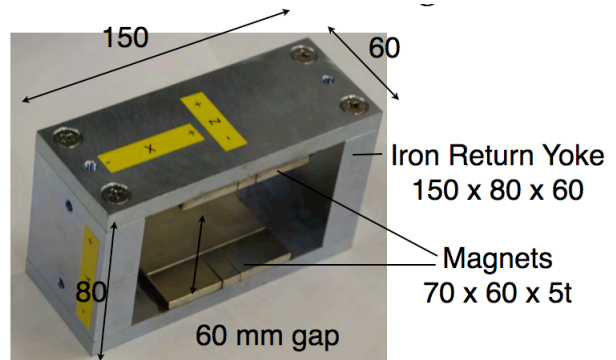


Fig. 2 The weak magnet.

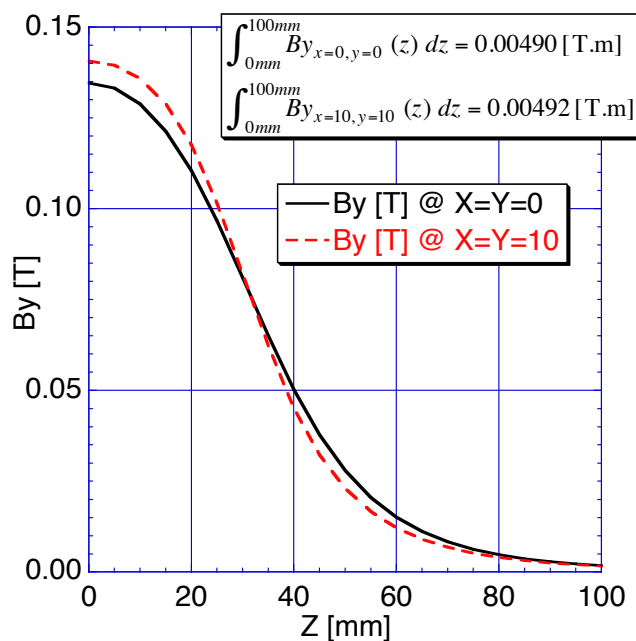


Fig. 3 Magnetic field distribution for the weak magnet.

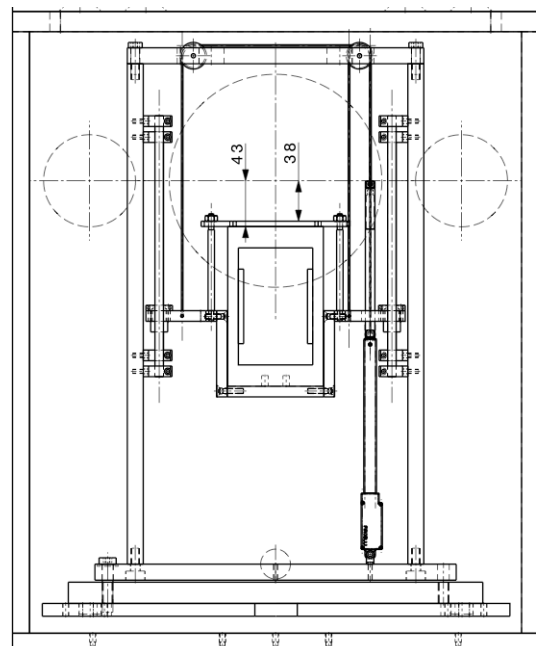


Fig. 4 Magnet and target holder.

2. Strong magnet

Next step for the DIRAC experiment is to measure a Lamb-shift of $A_{2,}$. A strong magnetic field can provide such function. In order to generate such strong magnetic field, Halbach configuration should be suitable [1,2], where the space surrounding the bore is filled with anisotropic permanent magnet material for a big stored energy. The magnet material used in the following calculations is NdBFe magnet with remanent field of 1.36T, which produces magnetic flux in the direction of so called “easy axis”. The geometrical constraints are, 1) big bore radius to avoid the hit of the beam halo, 2) magnet holder size, 3) capability of the holder to support the magnet weight. A 60 mm ϕ bore diameter seems safe according to an investigation using beam. The distance between the production target and the stopping target limits the magnet length to 70mm, while the current magnet holder allows the horizontal magnet width of 90mm and height of 150 mm. Up to 10 kg would be pulled by the current actuator. Under these constraints, two sizes of magnet are investigated: one series has outer dimensions of 150 x 90 x 70 mm, while the other one has 150 x 105 x 70 mm. In Fig.6, each series is represented by two curves, one has a simple flat magnetic field distribution and the other has a peaky distribution. Four magnets investigated are shown in Fig. 5. The weighs of the magnets are also shown. As can be seen, the bore sizes are rather large compared to the magnet height, which restricts the absolute magnetic field strength.

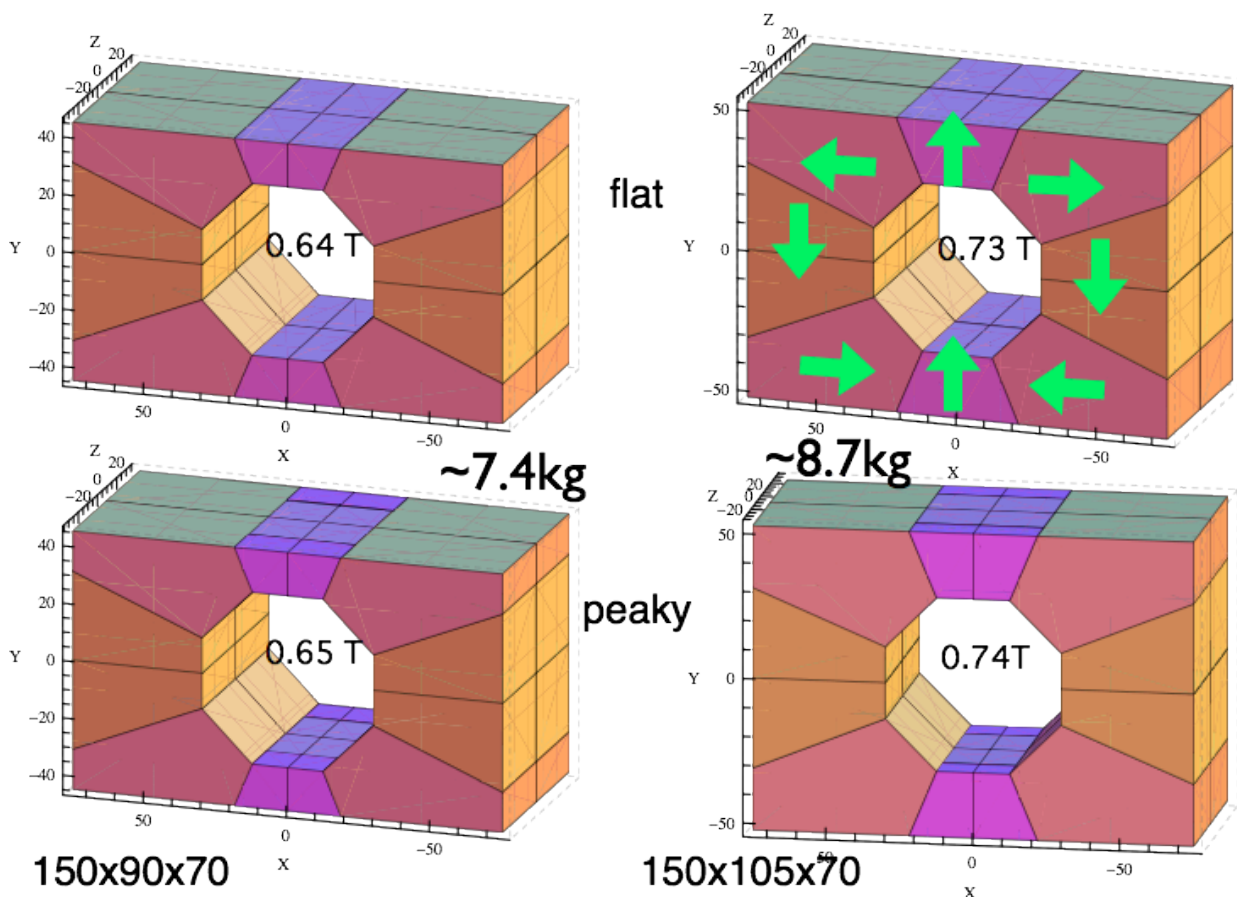


Fig. 5 Four types of magnets. The easy axes of the magnets are shown by green arrows.

The easy axes of the magnets are shown by the green arrows in the figure. The vertical and horizontal lines that seem to divide the magnets shown in the figure are symmetry lines; the flat magnets consist of 8 pieces of magnets, while the peaky magnets consist of 12 pieces. The magnetic field distributions along the beam axis are shown in Fig. 6. The peaky designs show the quick change in the direction, while the flat design shows wider distribution. Figure 7 shows the magnetic field distributions along the other axis. Only B_y (horizontal) component can be seen on these axes because of the symmetry.

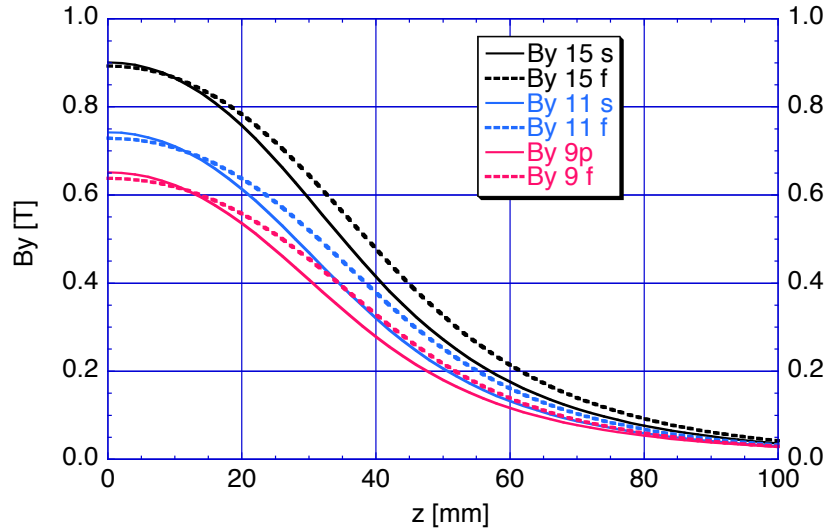


Fig. 6 Magnetic field distribution along the beam axis. The broken lines show the flat designs and solid lines show the peaky designs. The numbers in the legend denote the widths of the magnets in cm unit. The characters “s” and “p” after the numbers denote peaky designs while “f” denotes flat design.

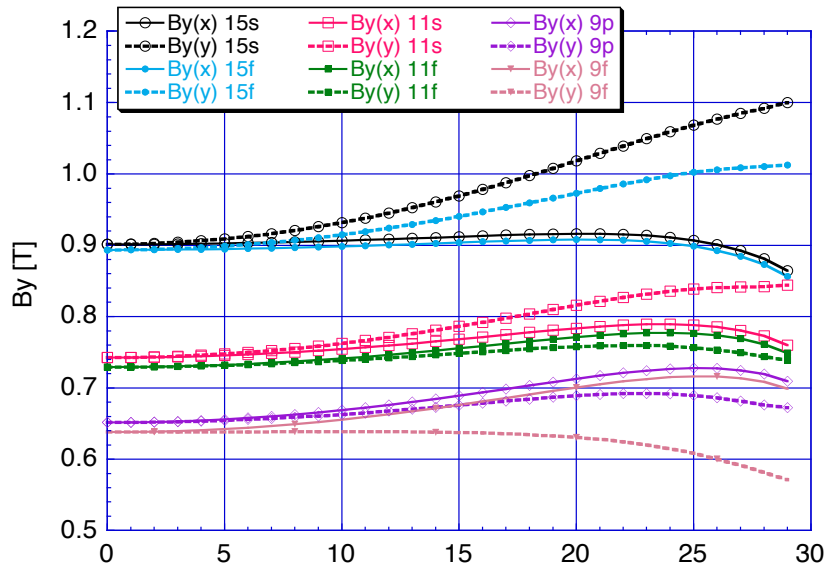


Fig. 7 Magnetic field distribution along the other axes. The solid lines show the distribution along x-axis (vertical) and the broken lines show that along y-axis (horizontal) at $z=0$. The numbers in the legend denote the widths of the magnets in cm unit. The characters “s” and “p” after the numbers denote peaky designs while “f” denotes flat design.

In addition, these figures include cases for a further big magnet 150 x 150 x 70 mm in size as shown in **Fig. 8**. This geometry gives the 0.89T at the center. Because the length of the magnet is almost comparable to the bore diameter, the peak field available in the present modest design would be a little bit less than 1 T. In order to install the big magnet, a small modification to the magnet holder can be proposed as shown in Fig. 9. Three plates should be newly fabricated (red parts in the figure); by moving the guide poles and actuators 40mm towards both sides the space to accommodate the big magnet. A counter balance at the actuator side of the wire would reduce the load to the actuator to less than 10 kgf.

3. Discussions

One magnet piece is formed from an ingot that has a limited sizes, where the maximum available thickness along the easy axis is around 50 mm. Because all the cases calculated above have a length of 150mm in X-direction (vertical when they are installed), all the corner pieces have the same extents (>72 mm) along the easy axis (the side magnets as

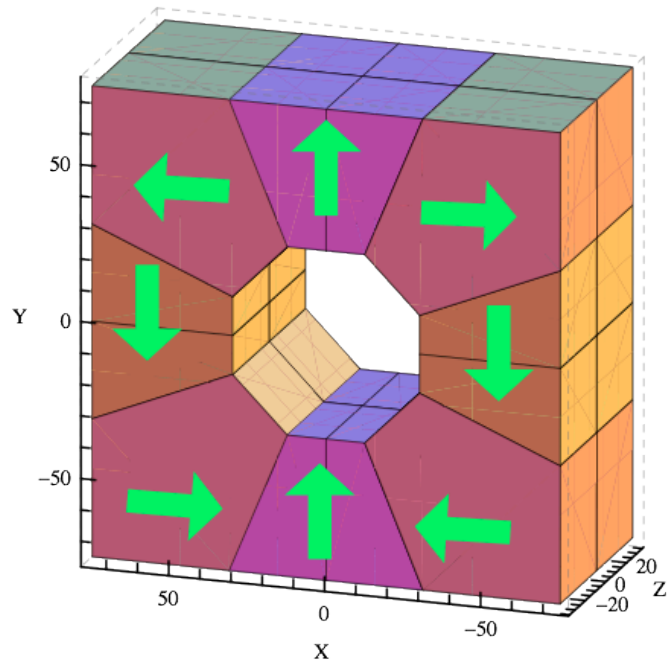


Fig. 8 150 x 150 x 70 magnet that generates

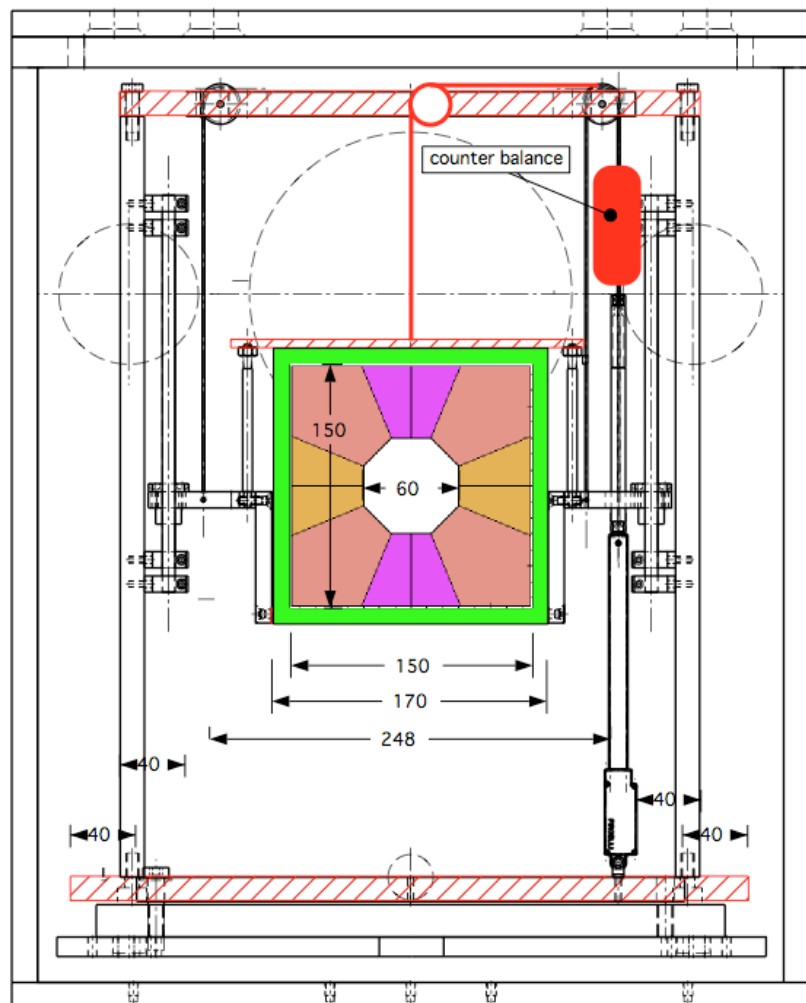


Fig. 9 Modification of the magnet holder to install 150 x 150 x 70 magnet.

well). This prevent us to make a corner magnet from single ingot and multiple ingots are required, which raises the cost. A minor modification that limits the sizes would avoid this situation. Figure 10 shows a possible modification for such a purpose: the excess parts of the magnets are removed and replaced by iron. The resulted magnetic flux density 0.88T is slightly less compared with 0.89T. The cost of the magnet is currently estimated as about \$17000 with the fabrication time of 65 days. In order to finalize and confirm the design, some more cost

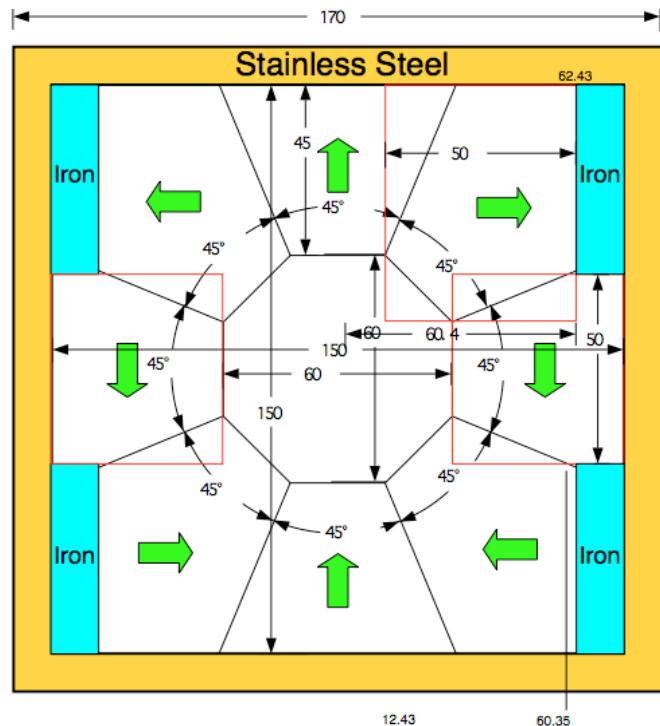


Fig. 10 Modified magnet configuration taking account the ingot size.

would be added, which may include an inspection at a factory. The fabrication time does not include detailed designing

process, such as the jigs for the assemblage of the magnet pieces into the holder, a fixing mechanism of the magnets, the transportation overhead and so on. The total delivery time would be three months and the decision of the order of the magnet should be as early as possible.

RADIA version 4.29 [3,4] is used for the magnetic field calculations, which also can generate a field map data for a particle tracking code. It should be noted that the generated values are merely based on an assumption of the simplified structure and cannot reflect real magnets such as imperfect shapes, non-uniformity in the magnets, and so on. The magnetic field values for these type of magnets would be about 5% less empirically. We also have to care the fact that severe neutron radiation may cause a demagnetization of magnet material. This may be evaluated through the magnetic field measurement of the current weak magnet at when the beam stops.

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