Why do we need magnetic shielding for PMTs?

Tolerance ~ 1 G
SUPPLY VOLTAGE \( E \) IS ACROSS A VOLTAGE DIVIDER PROVIDING 1/6 OF \( E \) BETWEEN CATHODE AND DYNOE No.1; 1/12 OF \( E \) FOR EACH SUCCEEDING DYNOE-STAGE; AND 1/12 OF \( E \) BETWEEN DYNOE No.10 AND ANODE.

PHOTOCATHODE IS FULLY ILLUMINATED. TUBE IS ORIENTED IN MAGNETIC FIELD AS SHOWN BELOW:

\[
F = qv \times B
\]

(1) and (2) -> electron scanning on dynodes
(3) -> electron reflected/bent away from dynodes
How does magnetic shielding work?

$$\nabla^2 \Phi_m = 0$$

magnetic scalar potential

$$S = \frac{H_{\text{out}}}{H_{\text{in}}} = \frac{3t\mu}{4r}$$

Infinitely long cylinder

• High $\mu$ materials
• The thicker, the better (large $t$)
• Bring the shielding closer to the target (small $r$)
Saturation Effect of the shielding materials

Relative permeability: $\mu_r = B / H$ (cgs)

Some units:
Magnetic strength (H) 1 Oe = 80 A/m
Magnetic flux density (B) 1 Gauss = $10^{-4}$ Tesla

$\mu = B / H.$

In cgs, $\mu_0 = 1.$

$S = \frac{H_{out}}{H_{in}} = \frac{3t\mu}{4r}$

PMT handbook, Hamamatsu Photonics, 2007. page 116
Edge Effect

- Extension of magnetic shielding is necessary to maintain the shielding factor

Figure 5-43: Edge effect of a magnetic shield case

PMT handbook, Hamamatsu Photonics, 2007. page 119
Comparing the shielding effect along three axis

- X-axis: parallel with dynodes
- Y-axis: transverse to dynodes
- Z-axis: parallel with c-axis of PMT

- Magnetic shielding is most effective along x and y direction
- Avoid magnetic fluxes along the c-axis of PMT.
AESOP magnet

AESOP-lite magnet?

Smaller magnet blocks
Smaller field strength around the magnets

Inside the ring, the field strength is around 4000 G

Top view scheme

KNOW YOUR ENEMY! ‘The evil source’
AESOP-lite CAD design (PMT orientation and positions)

Vertical: T1, T3, Guard and T4 (minimize Hz)

Horizontal: T2 (minimize Hr)
AESOP magnet angle dependence study

measurement was done at a position 4 inch above the top surface of the ring magnet and 6 inch away from the center.

angle '0' indicates the primary direction of the magnetic field inside the ring magnet sets.
Magnetic field strength (upper limit) at T1 position.

With the shielding similar to PMTs for AESOP, can we survive this much magnetic field?
PMT working condition
HV: 1100 V
Light source: Pulse LED

Oscilloscope setting:
Vertical 20 mV/Ω
Horizontal 25 ns/div
Measurement/snap

External magnetic field was applied *parallel to the c-axis* of the PMTs, generated by a set of Helmholtz coils.

Magnetic shielding:
Co-Netic/Netic 22P70 (RCA)
Co-Netic/Netic 22P90 (Hamamatsu)
B // c-axis of PMT

$T1$ will be totally Fine.
<table>
<thead>
<tr>
<th># of stages</th>
<th>Tube diameter (inch)</th>
<th>Maximum supply voltage</th>
<th>Current amplification/Gain</th>
</tr>
</thead>
<tbody>
<tr>
<td>RCA 6342A</td>
<td>10</td>
<td>2</td>
<td>1500 V</td>
</tr>
<tr>
<td>Hamamatsu</td>
<td>12</td>
<td>2</td>
<td>2700 V</td>
</tr>
</tbody>
</table>

- With only co-netic/netic material as shielding, both PMTs retain 90% of the pulse amplitude up to 30 Gauss (B/\).  

- Cut-off field is 45 Gauss for Hamamatsu and 60 Gauss for RCA at 1100 V excitation.  

- FWHM (~13.5 ns for RCA and 9.5 ns for Hamamatsu) remains the same up to 40 Gauss. (The decrease of FWHM above 40 Gauss for RCA was probably due to measurement of unstable waveforms on the oscilloscope. Vertical scale was kept at 20 mVΩ throughout the entire measurement)
Hamamatsu R329 @ 1200 V (136 mV)
RCA 6342A @ 1100 V (222 mV)

No obvious change in PMT pulse height or width.

We might have to use 35P70 (combined with 22P70) instead of a single 22P90 to achieve such a 2 inches extension of shielding for CK.
This 2 inches extension (possibly filled with light pipe?) has two roles:

- Set the PCI further away from the magnet, reducing the magnetic field strength
- Avoid the edge effect of the magnetic shielding. (retain the maximum shielding factor)

Tested using pulse LED. No obvious change in PMT pulse height or width.
Summary and future work

• Based on current CAD design (mainly the positions/orientations of the PMTs), proper shielding can be achieved using single Co-Netic/Netic tubes (22P90) with a 2-inch extension.

• As for plan A (no plan B yet), Hamamatsu PMTs will be replacing the RCAs in LEE. Magnetic shielding (22P90 with 2-inch extension) will be employed.

• T1, T2 (CK), T3 and Guard will be assembled together according to the design. Ground test will be performed in the presence of AESOP magnet.

• Meanwhile, LEE circuit board (ADC) will also be tested with Hamamatsu PMTs.