BACKGROUNDS IN THE MAIN RING TUNNEL

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This note is prompted by an attempt to assess the background difficulties in the main ring tunnel at beam currents of $5 \times 10^{13}$ protons/pulse. The results may be useful when considering electron targets for the main ring, p-p collisions, or experiments at C0.

**What is An Acceptable Background?**

1. At the ISR the quoted beam loss (at the San Francisco Accelerator Conference) is $1.6 \times 10^{-7}$. We know that experiments are clean at the ISR. Assuming that backgrounds are spread uniformly around the ring, the larger NAL circumference implies that a loss rate of $10^{-5}$ is acceptable. The acceptable lifetime from this limit is

$$\tau = 10^5 \text{ sec.}$$

2. We can estimate the acceptable beam loss assuming 10 particles/m$^2$/µsec is an acceptable background rate. We assume that a detector might see 1% of the main ring, a multiplicity of 10 and that all of these particles go into a 10 m$^2$ area. The number of protons lost in the entire ring is

$$N_p = \frac{10^6}{0.01} \times \frac{10}{10} \times \frac{1}{10} = 10^9 \text{ protons/sec.}$$

The loss rate is $10^9/5 \times 10^{13} = 2 \times 10^{-5}/\text{sec.}$ The corresponding acceptable lifetime from this calculation is

$$\tau = 5 \times 10^4 \text{ sec.}$$

**What is the Present Background?**

1. The "Procedures for Experiments" handbook quotes 50 minimum ionizing particles/cm$^2$/sec/10$^{10}$ protons measured 5 ft from the beam at 300 GeV in C0. This number has been remeasured and is quoted in Proposal 231 as $16/\text{cm}^2/\text{sec}/10^{10}$ p at 300 GeV and 3.5 ft from the beam line. Assuming 1% of the main ring is effective, a multiplicity of 10, and 10m$^2$ effective area, we find

$$I = \frac{16 \times 10 \times 10^4}{10 \times 0.01 \times 10} = 1.6 \times 10^{-3}/\text{sec.}$$
or a lifetime of

\[ \tau = 0.6 \times 10^4 \text{ sec.} \]

2. NAL beam lifetimes have been measured at low energy. The data are as follows:

<table>
<thead>
<tr>
<th>E (GeV)</th>
<th>\tau (sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>2.8</td>
</tr>
<tr>
<td>25</td>
<td>5.3</td>
</tr>
<tr>
<td>30</td>
<td>11.3</td>
</tr>
<tr>
<td>35</td>
<td>15</td>
</tr>
<tr>
<td>40</td>
<td>24</td>
</tr>
<tr>
<td>45</td>
<td>33</td>
</tr>
<tr>
<td>50</td>
<td>41</td>
</tr>
</tbody>
</table>

These data were taken at an average pressure \( p = 2 \times 10^{-6} \) Torr.

Empirically this curve fits \( \tau \propto E^{2.68} \). Extrapolating to 300 GeV and at \( 3 \times 10^{-7} \) Torr gives

\[ \tau = 44 \left( \frac{300}{50} \right)^{2.68} \left( \frac{20}{3} \right) \]

\[ \tau = 1.3 \times 10^4 \text{ sec}, \]

although this extrapolation has no theoretical validity and may be optimistic.

**What Limits the Present Beam Lifetime?**

The NAL vacuum is currently about \( 3 \times 10^{-7} \) Torr. We can estimate the beam loss due to this vacuum and its effect on the circulating protons. We consider the following effects:

1. **Beam-gas interactions.** We assume the gas to be nitrogen with a cross section of 280 mb as taken from the ISA grey book design report. They also give the conversion formula

\[ 3.3 \times 10^6 \text{ molecules/cm}^3 \text{ corresponds to } 10^{-10} \text{ Torr.} \]

The NAL circumference is taken as \( 6 \times 10^5 \text{ cm} \) and its frequency as 50 Kc. The loss is then

\[ L < 2 \times 3.3 \times 10^6 \times 3 \times 10^{-7} \times 50 \times 10^3 \times 280 \times 10^{-27} \times 6 \times 10^5 \times 10^{-10} = 1.66 \times 10^{-5} \text{ /sec.} \]

The lifetime is nearly energy-independent and is

\[ \tau = 0.6 \times 10^4 \text{ sec (at } P = 3 \times 10^{-7}). \]

2. **Single coulomb scattering.** The cross section is

\[ \frac{d\sigma}{dt} = \frac{4\pi^2 m_e^2 e^2}{1^2}. \]
Integrate from $t = 0$ to some $t_{\text{min}}$
\[
\sigma = \frac{4\pi \frac{2}{3} \frac{\theta^2}{\theta_{\text{min}}}}{t_{\text{min}}} \cdot \frac{1.2 \times 10^{-29}}{t_{\text{min}}} \text{ cm}^2 \text{ for nitrogen.}
\]

Taking $t_{\text{min}}$ to be $(P_{\perp})^2 = p^2 \theta^2$, where $\theta = 2 \text{ cm/50 m} = 0.4 \text{ mrad}$ is the approximate physical machine aperture implies
\[
p_{\perp} = 100 \text{ MeV/c at 300 GeV}.
\]

This gives
\[
t_{\text{min}} = 1.6 \times 10^{-5} E^2 \text{ where } E \text{ is in GeV.}
\]

The lifetime is (using the previous conversion factors)
\[
\tau = 0.6 \times 10^{-3} \frac{E^2 (\text{GeV})^2}{P (\text{Torr})} \text{ sec.}
\]

At 300 GeV and $3 \times 10^{-7}$ Torr this is
\[
\tau = 1.8 \times 10^8 \text{ sec.}
\]

3. **Multiple coulomb scattering.** We use a formula taken from the ISA design report.

Scattering of 1 mm rms gives
\[
t = 4.4 \times 10^{-6} \frac{E^2 (\text{GeV})^2}{\beta_{\text{ave}} \beta_{\text{max}} P (\text{Torr}) (m^2)} \text{ sec.}
\]

Assuming 5 mm-rms scattering leads to beam loss implies a factor of 25, $\beta_{\text{ave}} \beta_{\text{max}} = 5000 \text{m}^2$ for NAL. The lifetime is therefore
\[
\tau = 2.2 \times 10^{-8} \frac{E^2 (\text{GeV})^2}{P (\text{Torr})} \text{ sec.}
\]

At 300 GeV and $3 \times 10^{-7}$ Torr this implies
\[
\tau = 6600 \text{ sec.}
\]

This latter lifetime is the shortest calculated at low energies and equals the nuclear lifetime at 300 GeV. Multiple scattering appears to be the dominant effect at low energy. The figure shows an $E^2$ extrapolation of the measured NAL lifetime; the data are not in violent disagreement with the calculation.
Conclusions

These calculations imply that one must be very careful when considering experiments using the main ring beam at design intensity of $5 \times 10^{13}$. Either the lifetime must be long or the losses must be arranged to occur on a scraper well-removed from the interaction region. Good (\(= 10^{-9}\) Torr) local vacuum is also necessary. The impact of the problem is most easily seen by the fact that the present Co background must be reduced by a factor of \(-400\) in order to do effective experiments at intensities of $5 \times 10^{13}$ protons per pulse.

\[ t_0 = 3 \times 10^6 \frac{E_{\text{GeV}}}{P_{\text{Torr}}} \text{ sec} \]