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MUON STORAGE*

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I. Muon Storage in the main ring, using the ED/S at 10^3 GeV.

Protons are accelerated to 10^3 GeV/c in the ED/S. They are extracted, targeted, and pions are collected in the main ring at an energy of ~ 100 GeV/c. The pions decay (τ_{lab}^{π} at 100 GeV/c $\approx 20 \mu\text{s}$), giving birth to a muon beam. This muon beam can be extracted (low intensity!) or bumped onto an internal target (polarized?).

How many muons can one expect? (I follow Lou Hand's 1973 summer study note on antiprotons -- SS-73/210). The half aperture of the main ring is 1×2 cm at a β of 70 m. Thus,

$$\frac{\epsilon_v}{\pi} = \frac{a^2}{\beta} = 1.4 \text{ mm-mrad}$$

$$\frac{\epsilon_H}{\pi} = \frac{b^2}{\beta} = 5.6 \text{ mm-mrad.}$$

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For variable β at the injection point:

$$\Delta\Omega = \frac{\sqrt{\epsilon_H \epsilon_v}}{\beta} = \frac{8.8 \mu\text{sr}}{\beta \text{ (meters)}}$$

Hand calculates a $\frac{\Delta p}{p}$ of $\sim .18\%$. I will assume a larger value $\frac{\Delta p}{p} = .5\%$ (Private communication from L. Teng). From the curves of note M-3 -- "Meson Lab at Present"

$$\frac{d^2 N(\pi^+)}{dp d\Omega} \approx 40 \pi^+ / \text{int proton/GeV/c/SR.}$$

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Thus the yield for 2×10^{13} interacting protons is

$$N(\pi^+) = \frac{3.5 \times 10^9}{\beta_{\text{target}} \text{ (meters)}}$$

Using the low β solution of proposal 491, let $\beta_{\text{target}} = 3.5$. Then

$$N(\pi^+) = 10^9.$$

Once again, assuming a momentum acceptance of .5%, approximately 1% of the muons from the π decay will be trapped in the ring. So

$$N(\mu^+) = 10^7/\text{pulse}.$$

Assuming a repetition rate for the ED/S of 1 pulse per minute, the time averaged muon intensity is $1.7 \times 10^5 \mu^+/\text{sec}$. The μ^- rate is around $\frac{1}{2}$ of this. Contamination levels are

$$\left(\frac{p}{\mu^+}\right) \sim 5-10 \quad \left(\frac{p}{\mu^-}\right) \sim 10^{-2}.$$

At 100 GeV/c, $\tau_{\text{lab}}^{\mu} \sim 2\text{ms}$.

II. Muon Storage in the ED/S, using the main ring at 500 GeV.

The cross section for pion production is decreased by a factor of 2.

$$\frac{d^2 N(\pi^+)}{dp d\Omega} = 20 \pi^+/\text{interacting proton/GeV/c/sr}.$$

The half aperture of the ED/S is 2.8 cm. Thus (assuming $\beta = 70 \text{ m}$).

$$\frac{\epsilon_v}{\pi} = \frac{\epsilon_H}{\pi} = 11.2 \text{ mm-mrad}.$$

For variable β_{target} (β at the target)

$$\Delta\Omega = \frac{35 \mu\text{sr}}{\beta_{\text{target}} \text{ (meters)}}$$

(~ 4 x that of the main ring!)

Assume $\frac{\Delta p}{p} \approx 1\%$ for acceptance of pions. This implies $\sim 2\%$ of the muons from the pion decay will be accepted by the ring. For 2×10^{13} interacting protons, for $\beta_{\text{target}} = 2.5$ meters and 100 GeV/c muons:

$$N(\mu^+) = 1.1 \times 10^8 \mu^+/\text{pulse}.$$

For a repetition rate of 1 pulse/12 sec, this is a time averaged intensity of $10^7 \mu^+/\text{sec}$.

Comments

M. Month tells me I should multiply the above numbers by $\sim 1/3$ for reasons of target efficiency. He also comments that the momentum acceptance for the coasting (pion, muon) beam in the storage ring is greater than that of the bunched beam. There will be some increase in the flux of muons due to off momentum pions whose decay muons are accepted by the ring. H. Frisch has proposed a technique (See his note, this summer study) to take advantage of pion production by hadronic cascade processes, which may increase the flux of pions by a factor of 3 - 10 !!

In considering this possibility for ISABELLE, I have calculated what the g-2 precession does to the muon polarization (BNL 50486). Since the pions are decaying at different times, the polarization is diluted. For times $\gg \tau_{\pi}^{\text{lab}}$, $P = (1 + \omega^2 \langle \phi \rangle^2)^{-1/2}$ where $\omega = \gamma_{\mu} (g/2 - 1)$; $\langle \phi \rangle$ is the decay time of the parent pions, expressed in terms of radians of azimuth, $\langle \phi \rangle = \frac{\beta_{\pi} \gamma_{\pi} c \tau_{\pi}}{R}$ (R is the radius of the ED/S. Thus, for 100 GeV/c, $P \sim .11$.

Note that the muons decay, giving birth to a relatively pure ν_e (or $\bar{\nu}_e$) beam. If one can accept neutrinos from $\sim 1/30$ of the ED/S circumference, a time average ν_e flux of as high as $3 \times 10^5 \nu_e/\text{sec}$ may be possible.

Conclusions

The large aperture of the ED/S may allow a time averaged flux of as high as $10^7 \mu^+$ /sec to be achieved. More detailed study of various portions of this proposal should be done -- e.g. Frisch proposal, off momentum π decay, momentum acceptance.