**MuCool Note 337**

# Dependence of Muon Capture on Initial Bunch-length in the Neutrino Factory

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**Abstract.** Following recent studies on the dependence of muon capture on initial proton bunch length, we explore that dependence for the version of the Neutrino Factory front end with gas-filled cavities. With the initial bunch length varied from 0 to 10 ns, a moderate dependence on initial bunch length is obtained, with a loss in μ/p of ~0.01 per ns of initial bunch length. The result is in reasonable agreement with other studies.

## Introduction

For a neutrino factory, short, intense bunches of protons are focused onto a target to produce pions, which decay into muons and are then accelerated into a high-energy storage ring, where their decays provide beams of high-energy neutrinos.[1, 2] The challenge is to collect and accelerate as many muons as possible. The pions (and resulting muons) are initially produced within a short bunch length and a broad energy spread, much larger than the acceptance of any accelerator. In the neutrino factory design study 2A,[3] the π's drift from the production target, lengthening into a long bunch with a high-energy "head" and a low-energy "tail", while decaying into μ's. Then the beam is transported through a buncher that forms the beam into a string of bunches, and an "rf rotator" section that aligns the μ bunches to (nearly) equal central energies, and then cooled in a ~200 MHz cooling channel with LiH absorbers. We have also considered using high-pressure gas-filled rf cavities in the rf rotator section to combine the phase-energy rotation and cooling into a single, more compact system. (see Fig. 1) [4, 5].

J. Gallardo et al. [6] have recently studied the dependence of the muon capture efficiency on the initial π/μ bunch length, which depends on the intial proton on target bunch length. The results were not inconsistent with previous studies,[7] but showed a possibly stronger dependence on initial bunch length then previously expected. In this note we consider changing the initial bunch length within the gas-cavity version of the neutrino factory front end, and compare the results with previous studies.

## Study Conditions and Results

The baseline scenario for this study was described in ref. [5]. This case had a target within a 20T solenoid that tapers down to 2T and a drift region that is 111m long, going into a "high-frequency adiabatic buncher" that is ~51m long. The adiabatic buncher was followed by a 54m long "phase-energy rotation region", in which high-energy bunches are decelerated and low-energy bunches accelerated, while the bunch structure is maintained. Within the phase-energy rotation cooling channel, the transport (rf cavities and drifts) were filled with a density of $H_2$ gas corresponding to 150A (at 295ºK) (dE/ds = 0.0517 MeV/cm). The rf gradient in the rf cavities was 24MV/m, with the transport cells consisting of 0.5m rf cavities with 0.25m drifts (for magnet coils).

As in previous studies, the simulation code ICOOL (version 2.96)[8] was used to calculate the acceptance at the end of the capture/cooling channel. The reference acceptance includes all muons within the reference transverse acceptances of $\varepsilon_x$ and $\varepsilon_y$ of 0.03m amplitude (normalized), and longitudinal rf acceptance of 0.15m, as measured by the ecalc9 program. A typical simulation would track 5000 particles.

The initial $\pi/\mu$ beam distribution was based on the Study 2 initial reference beam, which had an rms width of 3ns, and was based on MARS simulations of a 24 GeV proton beam on a Hg target. We obtained different initial beams by simply scaling the initial time coordinates of the particles. The remaining simulation parameters were not changed or reoptimized. (Effects from the finite target size and length limit the minimum realistic bunch length to ~1ns. The simulations with bunch lengths less than that are using initial distributions that are not completely practical.)

Figure 2 shows $\mu$/p within the reference acceptance at the end of the phase-energy rotator for different initial values of the initial beam width $\tau_{rms}$, with $\tau_{rms}$ varying from 0.1ns to 10 ns.

The results can be reasonably well approximated by a simple linear fit, which can be expressed as:

$$\mu/\mathrm{p} \cong 0.245 - 0.01\tau_{0,\mathrm{rms}},$$

where $\tau_{0,rms}$ is the bunch length at the target in ns.

The fit to the straight line fit is reasonably good. The data point for $\tau_{0,rms}$ = 1ns is anomalously high at 0.250 $\mu$/p. The difference is almost certainly simulation/statistics variation related. Increasing the data sample from 5000 to 8000 particles reduces this to ~ 0.235 $\mu$/p (exactly on the empirical line), while the 8000 particle $\tau_{0,rms}$ = 3ns simulation result increases to ~ 0.219 $\mu$/p from 0.211 at 5000 particles. (This is an increase in $\mu$/p to slightly over the line from slightly below the line)

Overall, this moderate variation in acceptance as a function of initial bunch length enables significant variation in neutrino factory parameters. The dependence of these results is somewhat intermediate between the dependences seen in reference 6 and 7. Increasing the bunch length from 1ns to 3ns reduces $\mu$/p by ~8.5±2%.

For bunch lengths greater than ~4ns the reduction in acceptance was accompanied by significant longitudinal emittance increases. The match into the capture buckets was somewhat degraded. It remains desirable to keep the rms bunch length < ~5ns, and shorter lengths are preferable.

# REFERENCES


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**Figure 1:** Layout of the modified μ capture and cooling section. Protons on target produce π's that decay to μ's and drift to a total of 111m. The muons are bunched within the 51m long buncher and the bunches are rotated to nearly equal energies within the rf rotator while being cooled transversely by absorbers within the rf rotator. In the Study 2A version the rotator was followed by a 80m long cooling section.

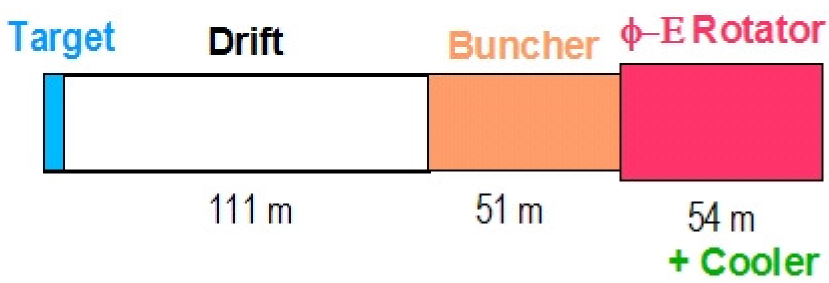


**Figure 2:** Simulations results for μ/p obtained at the end of the rotator (Study 2A criteria). Numerical results from ICOOL simulations with 5000 reference particles are shown as "data". The empirical fit displayed on the graph is $\mu/p = 0.245 - 0.01\tau$, where $\tau$ is the initial rms bunch length in ns.