PRECISION MONITORING OF RELATIVE BEAM INTENSITY FOR MU2E

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Abstract

For future experiments at the intensity frontier, precise and accurate knowledge of beam time structure will be critical to understanding backgrounds. The proposed Mu2e experiment will utilize ∼200 ns (FW) bunches of 3×10^7 protons at 8 GeV with a bunch-to-bunch period of 1695 ns. The out-of-bunch beam must be suppressed by a factor of 10^{-10} relative to in-bunch beam and continuously monitored [1]. I propose a Cerenkov-based particle telescope to measure secondary production from beam interactions in a several tens of microns thick foil. Correlating timing information with beam passage will allow the determination of relative beam intensity to arbitrary precision given a sufficiently long integration time. The goal is to verify out-of-bunch extinction to the level 10^{-6} in the span of several seconds. This will allow near real-time monitoring of the initial extinction of the beam resonantly extracted from Fermilabs Debuncher before a system of AC dipoles and collimators, which will provide the final extinction. The effect on beam emittance is minimal, allowing the necessary continuous measurement. I will present the detector design and some concerns about bunch growth during the resonant extraction.

MOTIVATION

The Mu2e experiment will search for the coherent conversion of a muon to electron in the field of a nucleus with an expected sensitivity to branching ratios on the order of 10^{-17} [2]. In order to achieve this improvement of 4 orders of magnitude over previous experiments [3, 4, 5] a pulsed proton beam must be delivered which meets requirements set by Mu2e analysis of backgrounds. By pulsing the beam and gating the detector off for ∼700 ns after the pulse, prompt backgrounds which can imitate the signal event are allowed to decay away. After ∼700 ns the experiment takes data until the next pulse. Because of the 864 ns lifetime of the muonic Al in the stopping target, a portion of the muonic atoms remain after the prompt backgrounds have decayed away. The pulsed structure must be formed in the accelerator complex and the Mu2e beam line and continuously monitored to ensure the longitudinal structure of the delivered beam meets requirements.

MU2E EXTINCTION REQUIREMENT

The restriction placed on the beam which ensures prompts backgrounds are reduced to acceptable levels for the desired sensitivity is referred to as the extinction condition. Simply stated, the extinction condition says that beam delivered to the experiment should consist of an in-time bunch window and out-of-time window. The integrated number of protons out of time should be suppressed relative to the integrated in-time protons by a factor of 10^{-10}. The integration can be done over all pulses delivered to the experiment, but as a diagnostic of beamline performance and to veto data during problematic periods the goal is to achieve integration times as short as possible.

Achieving Extinction

The gross structure of the beam is to be provided by the resonant extraction from the FNALs Debuncher ring. An h=4 RF system will be used to contain one bunch during a spill, which gives the beam a period equal to the 1.695 ns period of the Debuncher with an 8 GeV proton beam. The intensity of the beam is expected to be $3x10^7$ protons per pulse (ppp) with a 50% pulse-to-pulse variation. The pulse is 200 ns full width with a hard cutoff at the window edges[6]. The final 10-10 extinction will be achieved in two stages. Initially, extinction up to the level of $\sim 10^{-6}$ will be achieved in FNALs Accumulator and Debuncher rings. Beam formation in the Accumulator will use an h=4 RF system, along with higher harmonics, to create four 200 ns bunches, full width, from three momentum stacked Booster batches coasting as DC beam. Bunches will be transferred one at a time to an h=4 RF system in the Debuncher and resonantly extracted before the next bunch is transferred. The 1695 ns period of the Debuncher provides the main structure of the proton beam. The final extinction will be provided by an AC dipole which will sweep out-of-time beam onto collimators down stream of the bending magnet at half the frequency of the beam, allowing in-time beam to pass at the nodes of a driving sine wave. A schematic layout of the beamline is shown in Fig. 1.

Bunch Diffusion

The h=4 RF system in the Debuncher will create RF buckets of ∼425 ns, 225 ns larger than the Mu2e window. This means that beam can remain in the bucket, but diffuse out of the allowed Mu2e region. The slow spill will take on the order of 150 msec, during which the bunch will diffuse in longitudinal phase space. The level to which the beam will leak out of the Mu2e window is not known and is under investigation. This information is vital to monitoring accelerator performance with regards to extinction.

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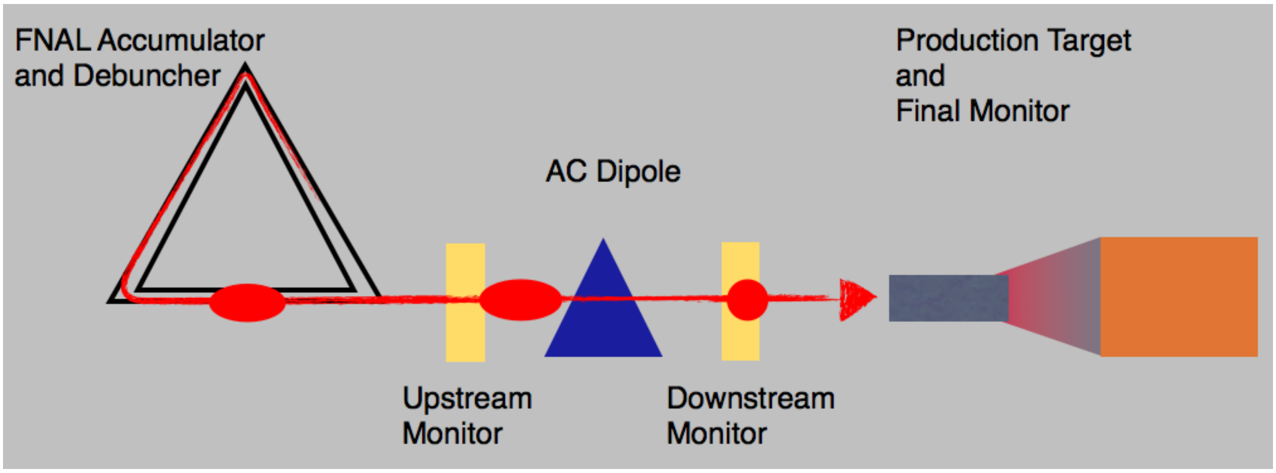

Figure 1: Schematic layout of Mu2e beamline. Both upstream and down stream monitor are foil/telesccope type discussed here.

EXTINCTION MONITORING

There will be a monitor at the Mu2e production target to monitor the protons striking the target up to the final extinction precision requirement. The final measurement will have an integration time of an hour or more and rely on the beam interaction in the target to provide a measurement of extinction. Because the final extinction monitoring device will rely on the production target and will be located downstream of the AC Dipole, another monitor is needed to measure extinction upstream of the AC Dipole and be used for beam tune-up.

Upstream Monitors

It will be necessary to monitor the performance of the accelerator system upstream of the AC dipole in establishing the initial bunch structure. Anywhere upstream of the production target, it is crucial that the monitor be continuously operable without degrading the proton beam. In order to meet the precision requirement the monitor must be sensitive over a dynamic range of $\sim 10^7$. We have decided to use a thin film scatterer, several microns of Ti, which will intersect the beams path and a telescope, located out of the path of the beam, to detect Cerenkov light from secondaries produced by beam-foil interactions. If the total foil thickness traversed by the beam is kept less to than $\sim$0.5mm, emittance increase will be tolerable [7]. In order to handle the dynamic range, the device will observe a small solid angle and integrate over a period large enough to build up an extinction measurement. Even an efficiency of 1 hit per 3×10^7 proton bunch could determine an extinction of 10^{-6} in several 10^6 bunches, or a few seconds. The detector will be composed of several Multi-Pixel Photon Counters (MPPCs) optically coupled to quartz bars which will be aligned to produce coincidence for secondaries originating at the beam. By optimizing the acceptance such that the probability of hits overlapping in the MPPC during the bunch passage is negligible we can increase the threshold for pixels per hit on the MPPCs and lower the noise [8]. It should be noted that requiring multi-pixel hits on a single MPPC we may reduce acceptance by placing a cut on the velocity of particles which will produce a hit. The number of detectors for coincidence and pixels per detector required to register a hit will likely be driven by the rate background noise from neutrons in the tunnel. A schematic of the foil setup and a detail of the detector are shown in Figs 2 and 3. Preliminary simulations have been done in FLUKA to verify that production of secondaries above Cerenkov threshold in quartz is sufficient with reasonable acceptance [9].

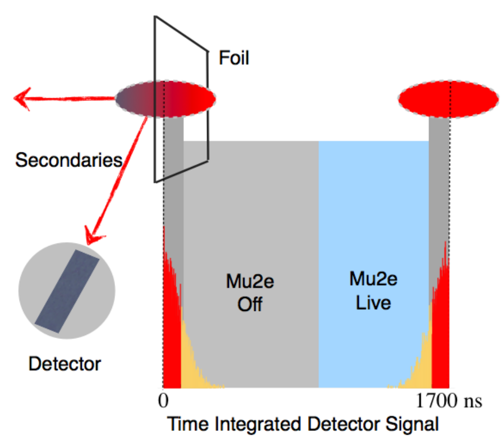

Figure 2: Relative placement of in-beam foil and detector. Mu2e timing windows are indicated. Red signal is in-time, yellow is out-of-time.

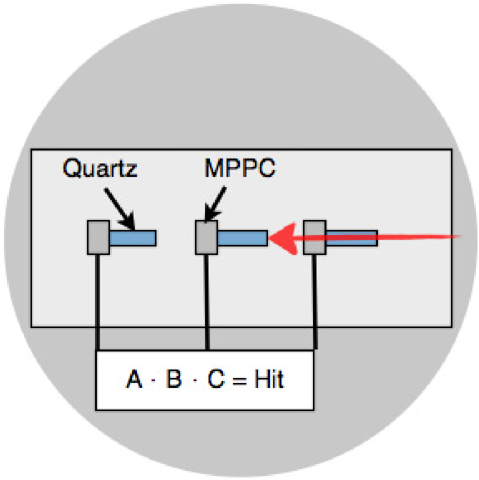

Figure 3: Detail of detector indicated in Fig 2. Quartz is optically coupled to MPPC.

CONCLUSION

A scheme for monitoring the extinction of out-of-time beam in the Mu2e beamline before the AC-Dipole as an intermediate check and aid in beam tune-up has been presented. Future work will focus on modeling the expected accelerator performance so that the detector discussed can be used to monitor the beam in near real-time.

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