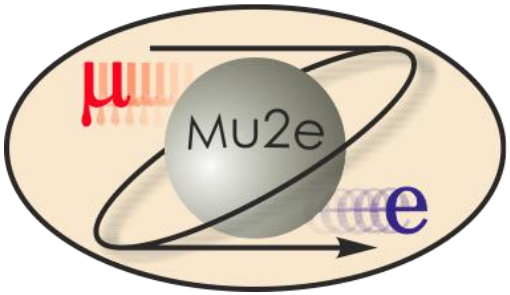
mu2e-doc-37983



Extinction Monitoring for Mu2e-II

April 28, 2021

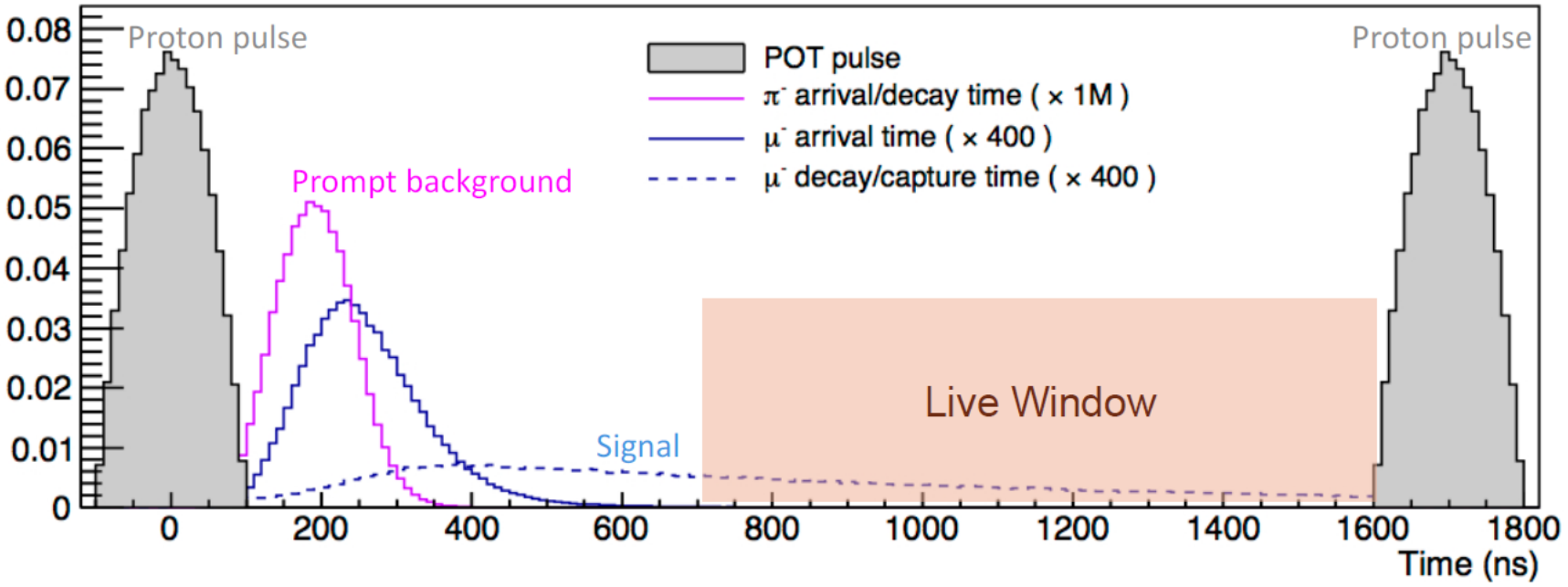
Matthew Jones

Previous Work

Author	Date	Mu2e-doc	Title
Paul Derwent	March 2, 2018	16226	PIP-II Mu2e and extinction
David Neuffer	August 31, 2018	19906	Mu2e →Mu2e-II proton beamline
Mu2e-II Workhop (ii)	July 29, 2020	indico	Eric's talk

Clearly, other people have thought about this more than I have, so I have some catching up to do…

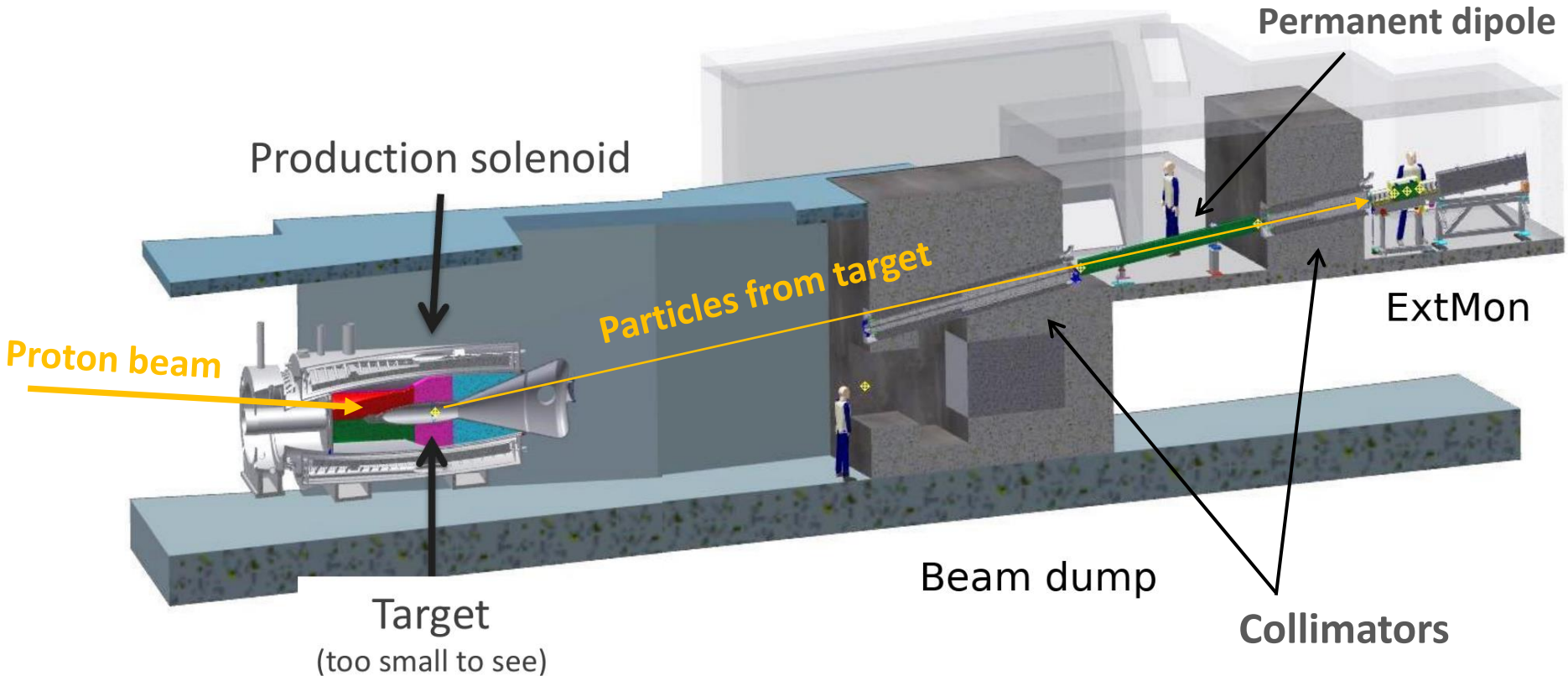
Mu2e Pulsed Proton Beam



- The Mu2e extinction monitor measures the time structure of particles from the pion production target
- Extinction is the fraction of protons arriving at the production target outside the proton pulse time window
- Required to be < 10^{-10} for Mu2e

Mu2e Extinction Measurement

- Relevant parameter to measure is the extinction of beam-on-target
- Continuously monitor particle production:



Mu2e Extinction Measurement

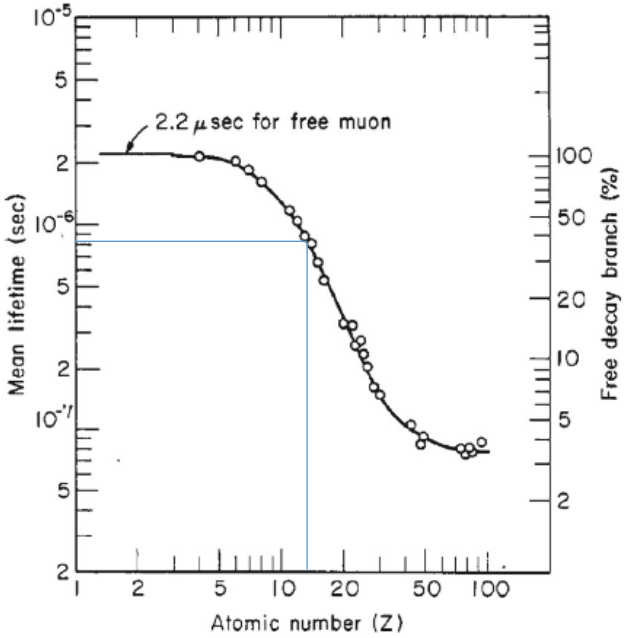
Main features:

1. A “filter” system (collimators and permanent magnet) to select a small fraction of particles from the production target (mostly protons)
2. A detector system that counts particles
   - Must be fully efficient for a single out-of-time charged particle (N')
   - Must accurately count the number of particles produced in-time with each beam pulse ($N_i \sim 40$)
   - Expect to set a limit in a time scale of hours:

$$\frac{N'}{\sum N_i} < 10^{-10} \text{ @ } 95\%\ C.L.$$

Bunch Structure in Mu2e-II

- PIP-II will provide 800 MeV protons (H^-) with high quality bunch structure
- Two scenarios to consider:
  1. Aluminum stopping target with a 1.7 μs cycle
  2. Other stopping target materials (eg, Au, Ti, Pb)

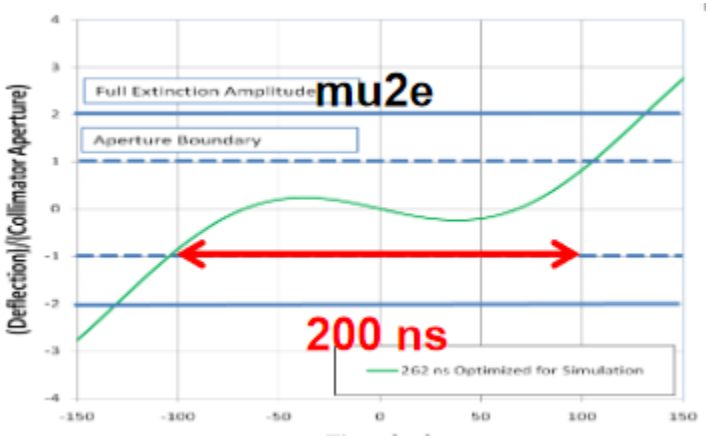


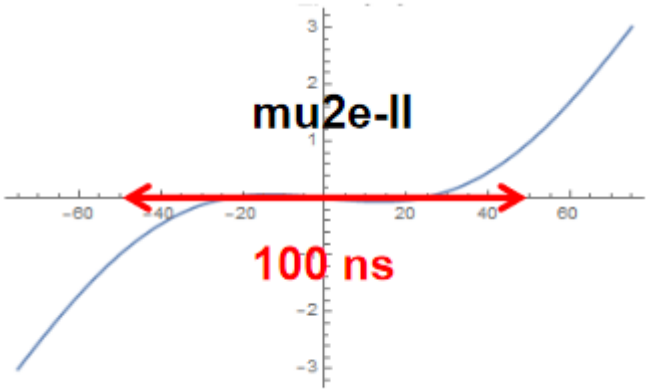
Eur. Phys. J. Plus (2020) 135:777
https://doi.org/10.1140/epjp/s13360-020-00777-y

T Yamazaki *et al* 1975 *Phys. Scr.* **11** 133

Mu2e-II with 1.7 μs cycle time

- Higher quality bunches: 250 ns → 100 ns pulse width
- Much smaller variation in pulse-to-pulse intensity
- Primary beam extinction should be better than 10^{-4}
  - Needs secondary extinction to achieve 10^{-11}
  - AC dipole should work with this time structure





(Mu2e-doc-19906)

Mu2e-II with 1.7 μs cycle time

- Beam delivery to the production target at 800 MeV will be quite different
  - An 800 MeV beam on the same axis as the 8 GeV beam would miss the target by 30 cm
  - Beam must enter the production solenoid at a different angle
  - Beam exits in a different direction ➔ new proton absorber needed
  - Sample of particles produced at the target will leave in a different direction ➔ Need to redesign filter system
- Rad hard pixel sensor and ASIC development for LHC experiments should work well for instrumentation

Mu2e-II with shorter cycle time

- Captured muon lifetime approaches 80 ns for Z > 40
- Fast cycle times needed to achieve high statistics
- Dispersion in the muon transport solenoid complications how one would use a beam extinction measurement
  - Time structure of particles arriving at stopping target is now quite different from particles produced at the production target
- Optimization of experimental sensitivity, considering rate limitations

Mu2e-II Extinction Monitoring Considerations

1. Time structure of 800 MeV beam on target
   - AC dipole design and performance studies
2. Simulation of 800 MeV beam on production target
   - Identify optimal filter system orientation for 1.7 μs cycle time
3. Identification of suitable HL-LHC instrumentation options
   - Newer pixel systems (RD53/C-ROC with thin planar sensors)
   - And/or precision timing?
4. Radiation environment and shielding design
   - Pixel system should be fine, but associated DAQ system might not be
5. Limits of beam extinction measurement for short cycle times?

Work Packages?

Survey of HL-LHC instrumentation development

Simulation of extinction channel for the production target

Models and measurements for primary beam extinction?

Simulation of proton transfer line and AC dipole

Simulation of extinction channel for the production target

Instrumented proton absorber?

High level model for experimental sensitivity optimization (including extinction)

Radiation studies (MARS, I guess)

Summary

- Achieving extinction of 10^{-11} or 10^{-12} seems plausible with a 1.7 μs cycle time
- Useful to verify this using simulations
  - Ideally, simulations should also satisfy other design requirements of the experiment
- Likely that new instrumentation options will become available
  - Unclear how well these will work with shorter cycle times
- Important to consider and evaluate different techniques for measuring extinction
  - Characterizing pulsed beam on target
  - Measure time structure/extinction closer to production target?
  - New ideas?
- Maybe we can make progress in at least some of the work package areas