Simulation of the Muon Flux Produced by 1.6 GeV Electrons in a Beam Dump

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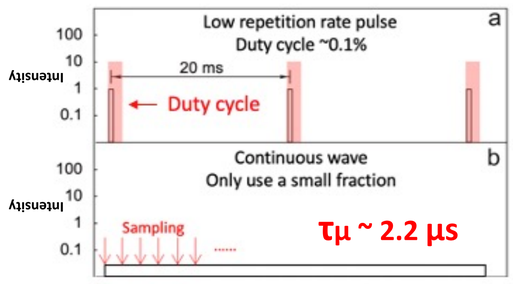
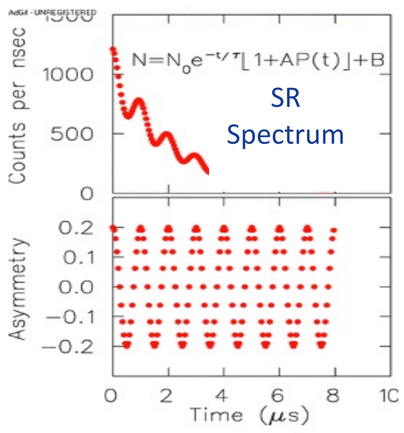
Current Muon Source Limitations

Two types of muon sources

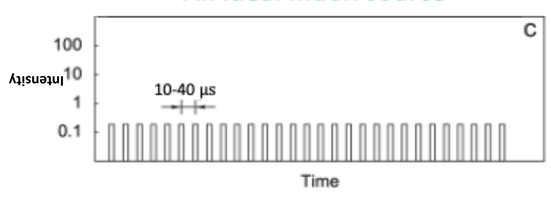




Measurement Duration ~ 10 μs

- Optimal measurement duration for μSR[1]: 10 μs ~ 20 μs (~ 5 to 10 muon lifetimes)
- Low Rep-Rate Pulsed muon source (e.g. J-PARC[2], Bunch frequency = 25 Hz)
  - Low duty cycle (10 μs out of 40 ms)
  - Detector dead time limitation
- DC muon source (e.g. PSI[3], Beam frequency = 50 MHz)
  - Allows 1 muon per 10 μs
  - Only utilize 0.1% of all muons

An ideal muon source



An ideal pulsed muon source would be like[4]:

- Increase bunch frequency: 25-100 kHz
  - Higher duty cycle (>50%)
- Less muon per bunch
  - Less pileup (~10^3 μ^+ /pulse)
- Closest beam: Mu2e[5] at FNAL (600 kHz)

A High Rep–Rate Pulsed EOT Muon Source

Electron-on-Target (EOT)

Photo-nuclear process

$$e^- + Z_1 \rightarrow Z_1 + \gamma$$
$$\gamma + Z_2 \rightarrow \pi^{\pm} + Z_3$$

Electro-nuclear process

$$e^- + Z_1 \rightarrow (e^-)' + Z_1 + \pi^{\pm} + Z_2$$

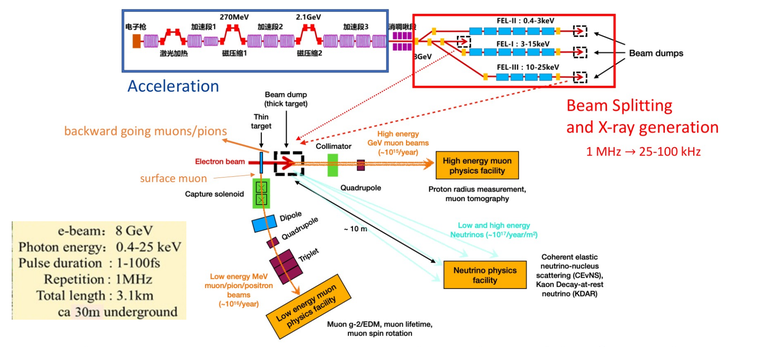
Bethe-Heitler process

$$e^- + Z_1 \rightarrow Z_1 + \gamma$$
$$\gamma + Z_2 \rightarrow \mu^+ + \mu^- + Z_2$$

Proton-on-Target (POT)

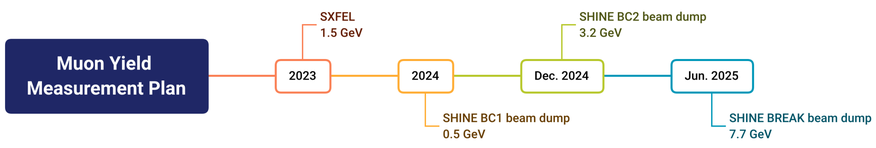
$$p + p \rightarrow p + n + \pi^+$$
$$\pi^+ \rightarrow \mu^+ + \nu_\mu$$

- **SHINE facility**, at Zhangjiang, Shanghai, aims at producing X-rays using high-energy electron beam[6].
- Beam parameters:
  - 8 GeV, 1 MHz frequency, 100 pC per bunch
- A muon source driven by EOT can be built by utilizing the electron beam from SHINE.

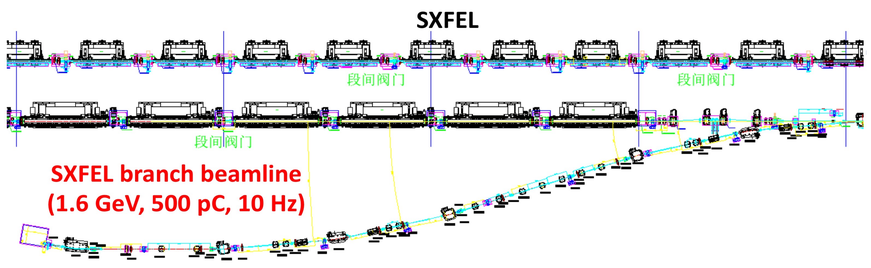


- A thin tungsten target can be placed before the dump to produce surface muon.
- The solenoid can be put very close to target for its lower radiation comparing to POT.

Feasibility Study: To Compare Simulated and Experimental Muon Yield



[Fig. 1 The Muon Yield Measurement Plan based on SHINE Project]



[Fig. 2 The Branch Beam Line of SXFEL]

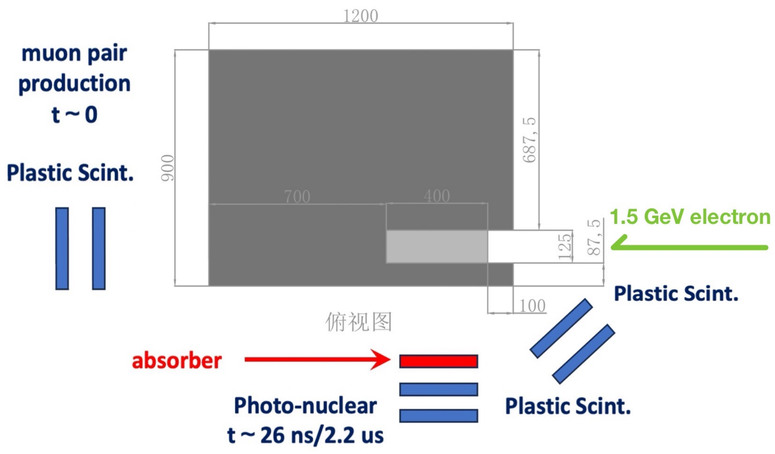
- Beam parameters of SXFEL:
  - Energy: 1.6 GeV
  - Bunch frequency: 10 Hz
  - Charge per bunch: 500 pC

Motivation of the Experiment:

- As the world's first EOT muon source based on the SHINE facility, it is crucial to conduct a feasibility test at the SXFEL to verify the compatibility between simulation results (based on Geant4) and experimental muon yield.

Methodology of the Experiment:

- Electrons will be injected into the SXFEL dump after producing soft X-ray.
- Scintillators will be set around the dump as detectors.
- Iron absorbers in front of the scintillators will block certain low-energy particles, while also producing muonic x-ray emissions from muonic atoms.

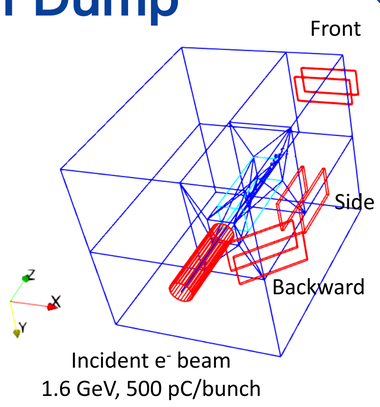


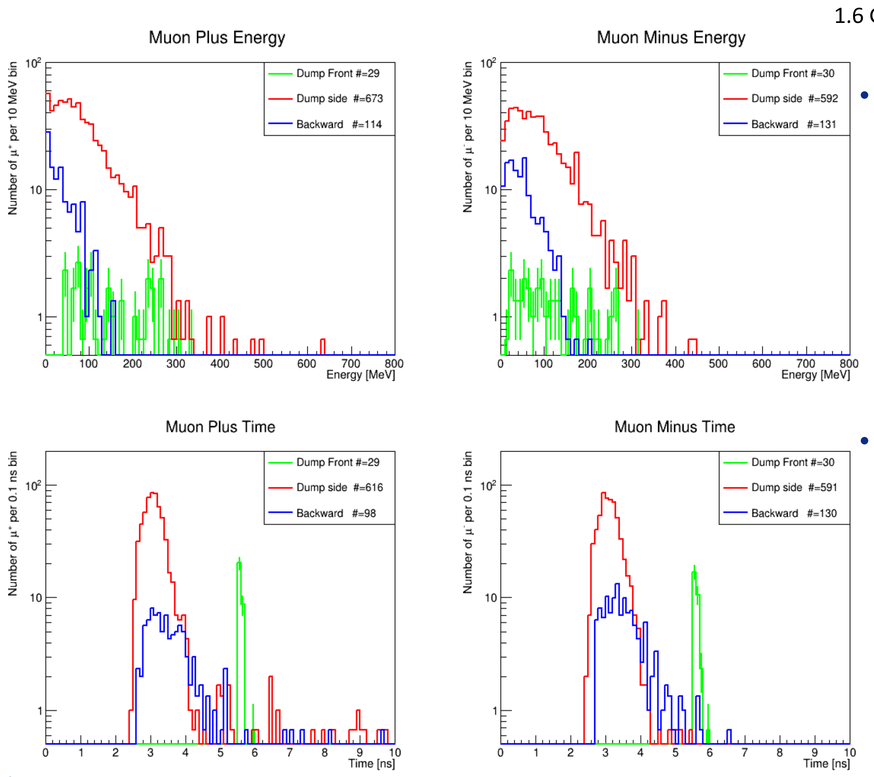
[Fig. 3 A Schematic View of the SXFEL Beam Dump and Detector Settings (Top View)]

- Different energy distribution can be measured by superimposing fixed thickness absorbers.
- Use multiple measurements to reconstruct the entire energy distribution.

Simulation Study: Beam Dump

- Three virtual detector doublets are placed around the beam dump in the simulation.
- There is no absorber in simulation.
- Muon yield per bunch (~3 x 10^9 EOT) , energy and time distributions have been studied in detail as follows.

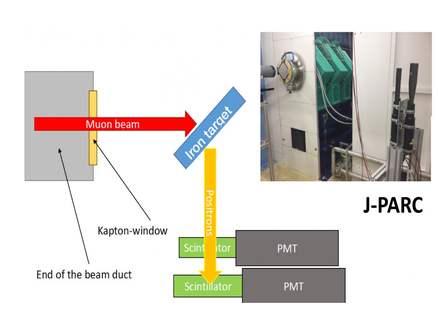




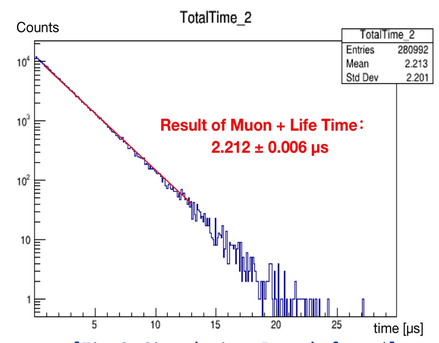
Particle yield/bunch

- The dump shielding is thickest at Front and thinnest at Side, which is responsible for the energy distribution and particle flux.
- This energy distribution result can help us determine the thickness of iron absorbers.

Experimental Strategy: Muon Detection

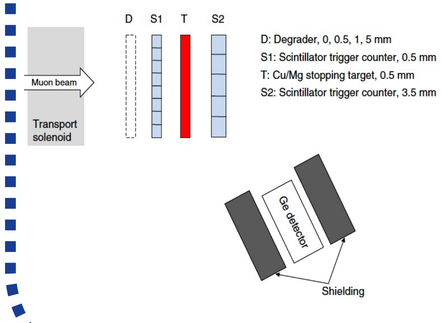


[Fig 4. Positive Muon Detection]

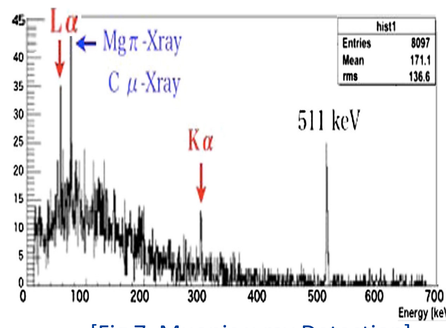


[Fig 6. Simulation Result for μ^+]

- μ^+ detection [8] is based on lifetime measurement. Iron degrader stops μ^+ and scintillators accept positron signals.



[Fig 5. Negative Muon Detection]



[Fig 7. Muonic x-ray Detection]

- μ^- detection [9] is based on characteristic muonic x-rays produced in the stopping target.

Conclusion

- Current proton-driven muon sources are either low-repetition-rate pulsed sources or DC sources, which are not optimal for various types of muon experiments ;
- A 25-100 kHz pulsed muon source can be built utilizing the to-be-dumped electron beam in the SHINE facility ;
- Our simulation and the upcoming experiment at SXFEL will prove the feasibility of constructing EOT muon source based on SHINE facility, and also verify the reliability of Geant4 simulation.

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