Muon Source Based on GeV Electron on Target

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Motivation

- Muon is a sensitive probe for research in particle physics and condensed matter physics.
- Shanghai high repetition rate XFEL and extreme light facility (SHINE), which plans to complete its construction in 2026[1], creates the possibility of developing a muon source based on GeV electron on target
- Electron beam from SHINE[1] (8 GeV, 100 pC, 1 MHz) is an ideal one to drive muon source.
- Based on a totally different mechanism to generate muons, this muon source fills the blank of electron-driven muon source, exploring a new alternative for developing a muon source.

Muon from $\gamma \rightarrow \mu^+\mu^-$ process

I. Overview

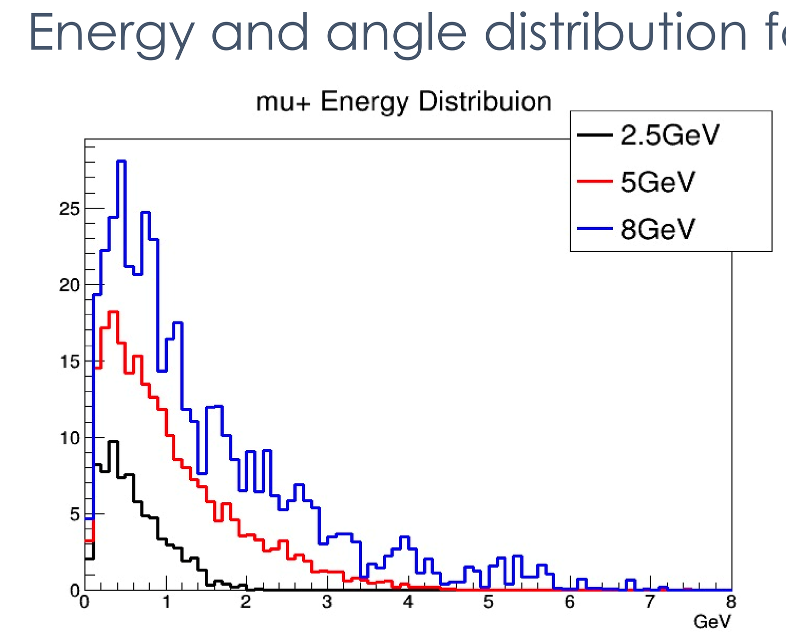
- $\gamma \rightarrow \mu^+\mu^-$ is an important process in producing muon with GeV energy.
- Using musrSim as a simulation software, we access the feasibility of a muon source based on $\gamma \rightarrow \mu^+\mu^-$ process.
- To match the beam charge in SHINE[1] (100 pC), we increase the cross section factor and then scale to the charge value.

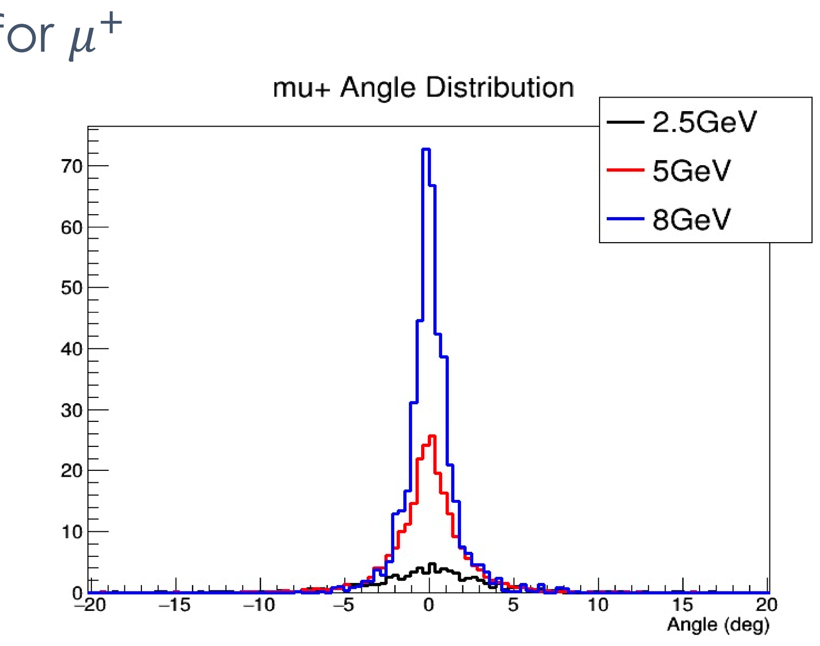
II. Simulation Parameter

- Beam charge:
  100 pC=10^6(events) × 10^4($\gamma \rightarrow \mu^+\mu^-$ factor) × 6.24 × 0.01(scale)
- Electron energy: 2.5 GeV, 5 GeV, 8 GeV
- Target: Tungsten, Variable thickness [0-40 mm]

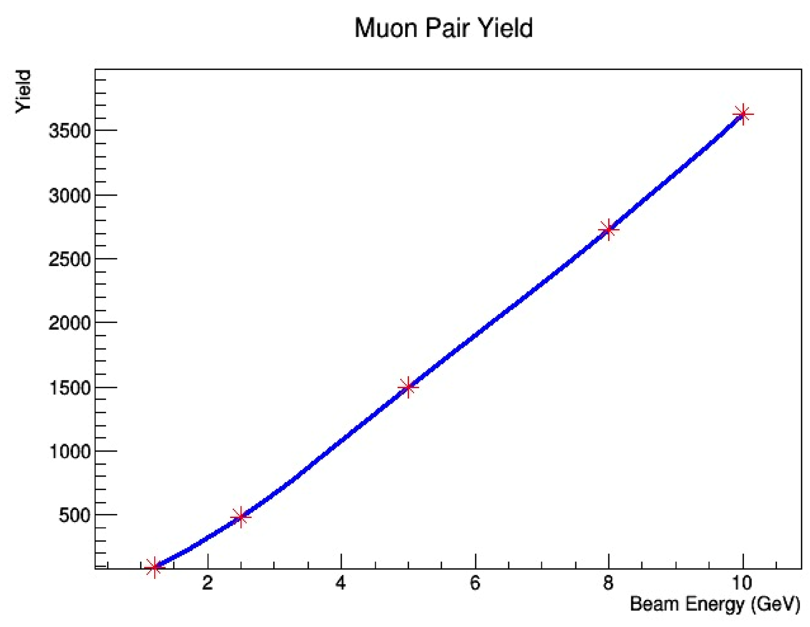
III. Muon distributions

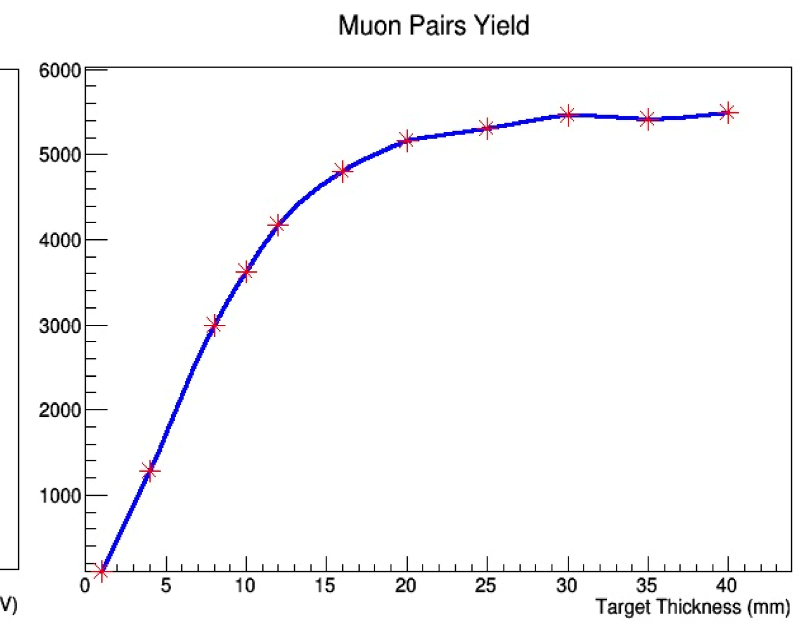
- Energy and angle distribution for μ^+





- Muon pair yield with respect to beam energy and target thickness





- Basically, our results are in agreement with the ones in Rao's paper[2].

IV. Potential Applications

- Muons from $\gamma \rightarrow \mu^+\mu^-$ process have such a low emittance that it is suitable for high-resolution muon radiography[2].
- Its high energy can also play a role in studies like neutrino oscillations and future muon colliders[2].

Nuclear process vs $\gamma \rightarrow \mu^+\mu^-$

I. Overview

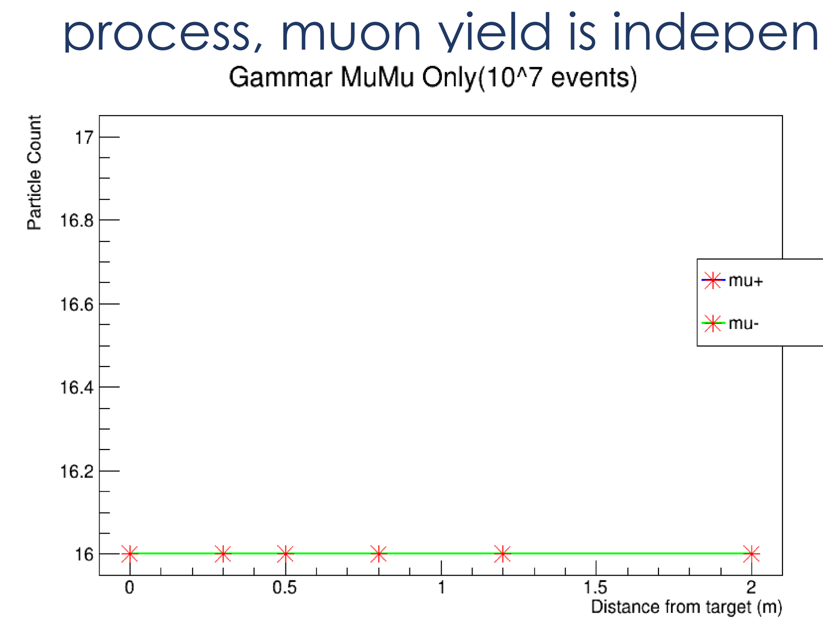
- However, most muons come from decays of π, K, which are produced by photonuclear and electronuclear process.
- Therefore, we need to compare the muon yield from $\gamma \rightarrow \mu^+\mu^-$ and nuclear process respectively.

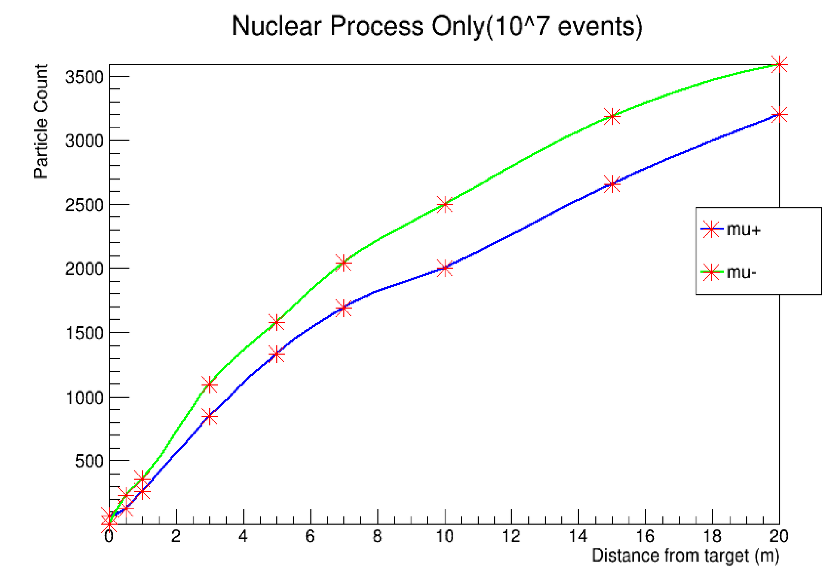
II. Nuclear process simulation

- In this section, we use 10 GeV electrons (10^7events) to hit 1 cm Tungsten target while turning off $\gamma \rightarrow \mu^+\mu^-$ process.
- As the distance increases, π and K will decay into muon. Therefore, we count muon number at different distances from the target using virtual sphere detectors with increasing radius.

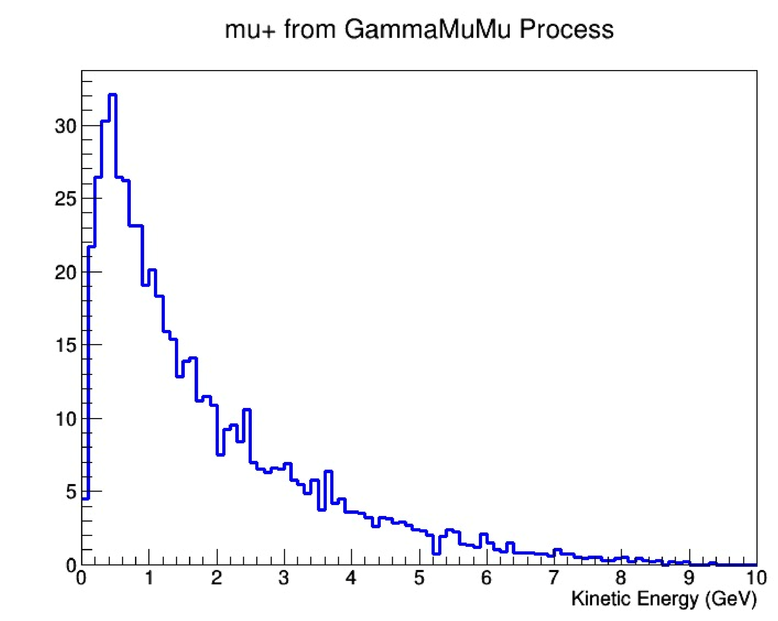
III. Nuclear process vs $\gamma \rightarrow \mu^+\mu^-$

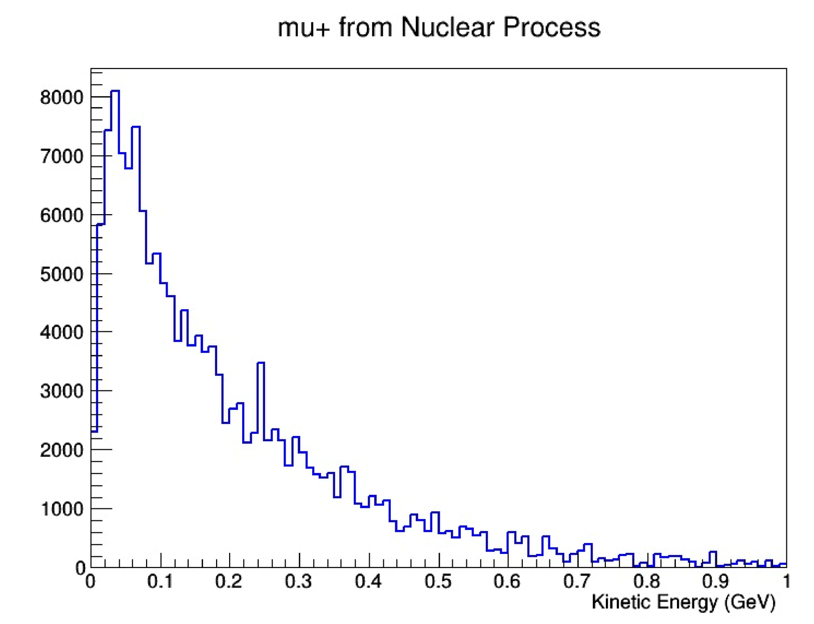
- Following picture shows output particles detected at different distances from the target. In nuclear process, the farther from the target, the more π and K decay into muon. In $\gamma \rightarrow \mu^+\mu^-$ process, muon yield is independent on the distance.





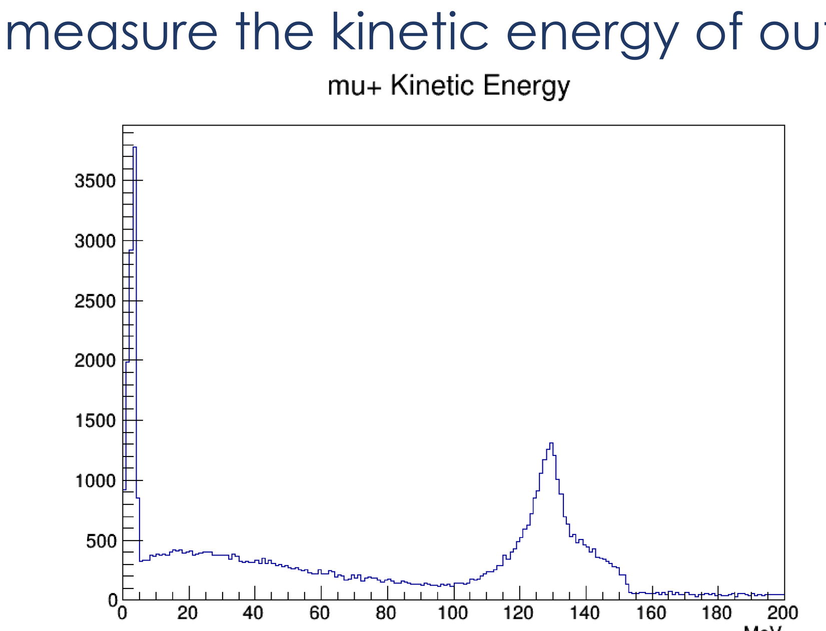
- Although nuclear process is 100 times the $\gamma \rightarrow \mu^+\mu^-$ process in cross section, it can only produce relatively low-energy muon, as following pictures show:





Surface muon

- A well-designed target size can stop π and K near its surface, producing surface muon.
- We use 10 GeV electron to hit 20 mm Tungsten target and measure the kinetic energy of output muon, which has 2 peaks:



Parent Particle	Peak 1	Peak 2
π^+	2689	2048
K^+	2	17432
Others	2	4
Total	2693	19484

- Peak 1 refers to muon with kinetic energy between 3.5-4.5 MeV, and peak 2 refers to 120-150 MeV.
- From the table, we know that muon in peak 1 comes mostly from π^+ decaying near target surface, while muon in peak 2 mostly from K^+ decaying near the target surface.

Conclusion

- With electron beam from SHINE[1] (8 GeV, 100 pC), each beam can produce around 10^3 muon pairs from $\gamma \rightarrow \mu^+\mu^-$ process, which is in agreement with Rao's paper[2]. Expected yield rate with SHINE beam is around $1\ \text{MHz} \times 10^3 \mu^\pm\ \text{pairs} = 10^9\ \mu^\pm\ \text{pairs/s}$.
- Compared with of $\gamma \rightarrow \mu^+\mu^-$ process, nuclear process has much larger cross section factor(100 times), but with softer energy spectrum.
- From photonuclear and electronuclear, surface muons from π and K decay close to the target surface can also be produced.

REFERENCE:
[1] SHINE: Z. T. Zhao, C. Feng and K. Q. Zhang, Nucl. Sci. Tech. 28, no.8, 117 (2017)
[2] Rao et al., Bright muon source driven by GeV electron beams from a compact laser wakefield accelerator, Plasma Phys.Control.Fusion 60 (2018) 095002