#### Estimating Target Performance for Negative Muon Production

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Eremey Valetov SJTU, TDLI, and MSU (Work supported by NSFC and DOE.)

Potential Fermilab Muon Campus & Storage Ring Experiments

### Section 1

### Introduction

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- We compared **pion**, **muon**, and **positron/electron** production in the Muon Campus **target station APO**
- **Simulations** were done using **G4beamline 3.06** with variance reduction and using **MARS15(2019)** 
  - The QGSP\_BERT\_HP physics list was used in G4beamline
- The **pion beam** was at **8 GeV**, and the lower energy cutoff was 2.75 GeV (based on minimum pion energy for production of muons at 0.98 · 3.094 GeV/c)
- The comparison was done for
  - **positive particles** in the **positive muon mode**
  - **negative particles** in the **negative muon mode**

### Introduction

- The comparison was done for
  - **all new particles** up to **1.2 m DS of the target** (122 mm DS of the collimator) with PMAG not included in the simulation
  - **particles** recorded **at 447.5 mm DS of the target** (123.5 mm US of the collimator, i.e., between the lithium lens and the collimator)
  - particles recorded at the US end of the first quadrupole Q801 in the M2 beamline



#### Muon Campus beamlines

#### Target station models Up to quadrupole Q801 in the M2 beamline

#### G4beamline





#### Particle production in the target station



Most pions (and muons) are created in the target, with another peak in the Li lens [GM2-doc-19979]

#### Optimal PMAG field magnitude



Maximize transmission to the US end of Q801 (first quadrupole in M2): MARS:  $B_{opt} = 0.55$  T G4beamline:  $B_{opt} = 0.54$  T

Maximize transmission to the US end of CMAG (at the end of M3): G4beamline:  $B_{opt} = 0.53 \text{ T}$ 

(A new PMAG optimization study is near completion.)

### Section 2

# Particle production results using G4beamline 3.06

## G4beamline: All pions produced in the target station up to 1.2 m DS from the target

 $\pi^+$  and  $\pi^-$ 

 $\pi^+$  to  $\pi^-$  ratio



G4beamline has a known discrepancy in production of  $e^+$ , with a factor of 4.18 compared to MARS [GM2-doc-23822].

### G4beamline: Pions recorded in the target station 447.5 mm downstream from the target

 $\pi^+$  and  $\pi^-$ 

 $\pi^+$  to  $\pi^-$  ratio



G4beamline has a known discrepancy in production of  $e^+$ , with a factor of 4.18 compared to MARS [GM2-doc-23822].

# G4beamline: Pions recorded in the M2 beamline at the US end of Q801 quadrupole

 $\pi^+$  and  $\pi^-$ 

 $\pi^+$  to  $\pi^-$  ratio



G4beamline has a known discrepancy in production of  $e^+$ , with a factor of 4.18 compared to MARS [GM2-doc-23822].

### Section 3

# Particle production results using MARS15(2019)

# MARS: All pions produced in the target station up to 1.2 m DS from the target



## MARS: All muons produced in the target station up to 1.2 m DS from the target



MARS: All  $e^+/e^-$  produced in the target station up to 1.2 m DS from the target



Most  $e^+/e^-$  are produced in pairs in EMS induced by photons from  $\pi^0$  decay.

### MARS: Pions recorded in the M2 beamline at the US end of Q801 quadrupole



### MARS: Muons recorded in the M2 beamline at the US end of Q801 quadrupole



MARS:  $e^+/e^-$  recorded in the M2 beamline at the US end of Q801 quadrupole



### Future Studies

- Study the reason for the discrepancy between
  G4beamline and MARS particle production results
  - Implement variance reduction for FTFP\_BERT\_HP (new "starting point") physics list in G4beamline; try using it instead of QGSP\_BERT\_HP
- Perform and compare full simulations of the Muon Campus beamlines for positive and negative muon running
- Analytically compare the relevant cross sections directly from a database for positive and negative muon running