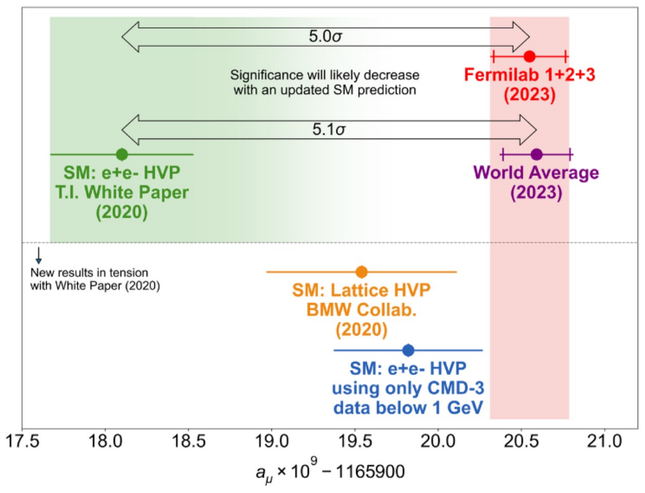
# Development of a muon spin polarization monitor for the J-PARC Muon g-2/EDM experiment

Meng Lyu*, Xintong Cai, Fangyuan Yu, Siyuan Chen, Kim Siang Khaw
Shanghai Jiao Tong University

## Introduction to J-PARC Muon g-2/EDM Experiment

- There is a large discrepancy in the muon g-2 value ($a_\mu = \frac{g_\mu - 2}{2}$) between the experiment result (Fermilab 2023[1]) and theoretical calculation in 2020
- J-PARC at KEK, Japan plans to measure both muon g-2 and EDM using ultra-slow muon[2] to provide an independent measurement of $a_\mu$
- The muon spin polarization monitor is designed to make sure the polarization of the thermal muon converted from the surface muon is near 50%




Muon g-2 Puzzle in 2023[1]

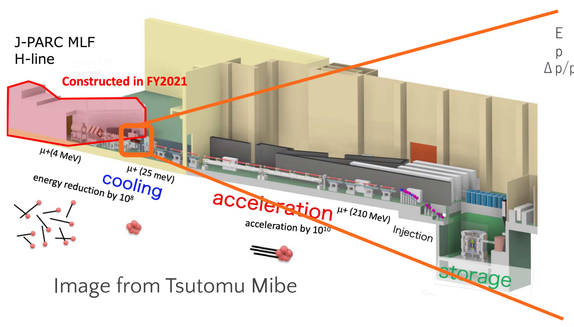
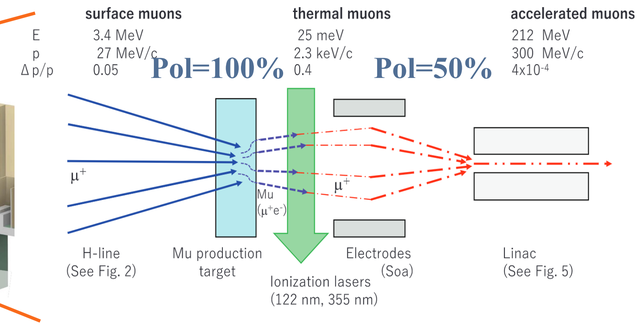



Image from Tsutomu Mibe



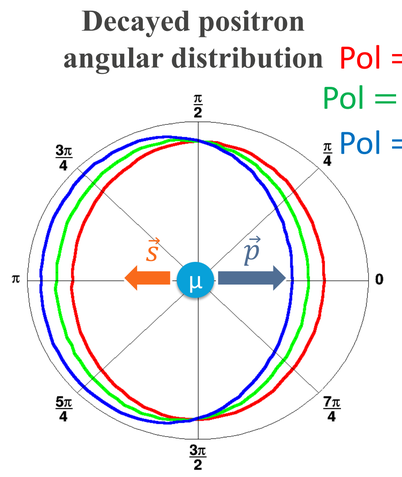

## The Muon Spin Polarization Monitor

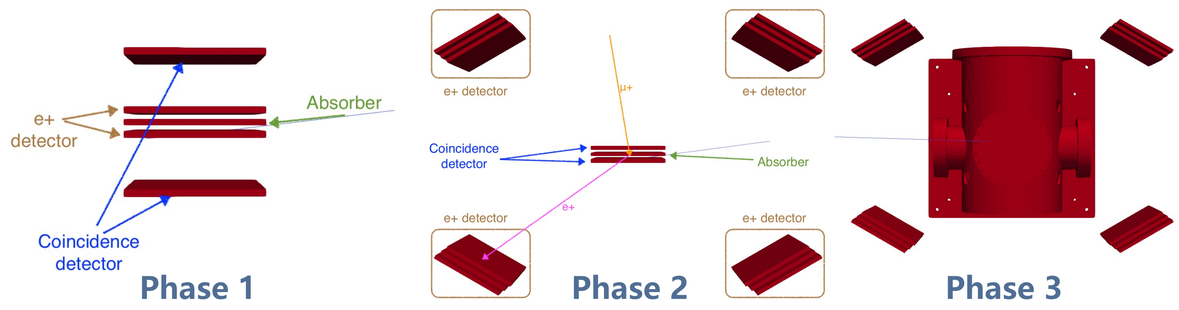
- $\mu^+ \to e^+ + \nu_e + \overline{\nu_\mu}$ decay shows asymmetry with regard to muon spin direction due to the parity violation of weak interaction
- Polarization is obtained from measuring muon decay asymmetry $A$:

$$A = \frac{F - B}{F + B}$$

$F$ = #Forward decay, $B$ = #Backward decay

- Phase 1&2: validate asymmetry-based polarization measurement and optimize design using atmospheric muon
- Phase 3: Apply our design to the J-PARC experiment



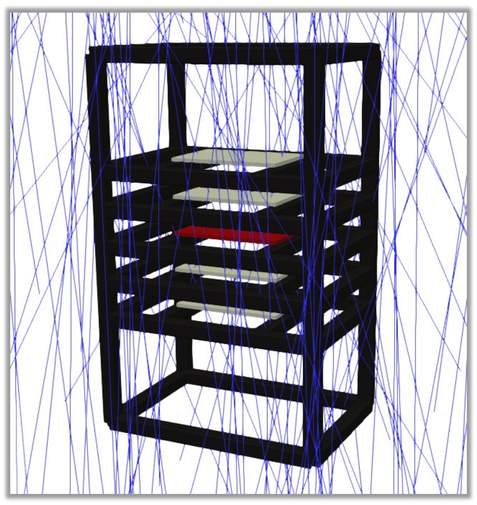




## Monte Carlo Simulation

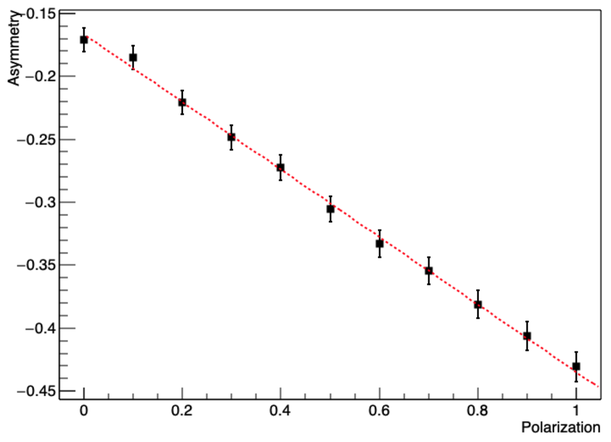
- A model for the atmospheric muon flux distribution[3] (energy and angle) and the optimized geometry setup are imported to the MC simulation based on Geant4

$$\frac{dI_\mu}{dE_\mu} = 0.14\left[\frac{E_\mu}{GeV}\left(1+\frac{3.64GeV}{E_\mu(\cos\theta^*)^{1.29}}\right)\right]^{-2.7} \times\left[\frac{1}{1+\frac{1.1E_\mu\cos\theta^*}{115GeV}}+\frac{0.054}{1+\frac{1.1E_\mu\cos\theta^*}{850GeV}}\right]$$

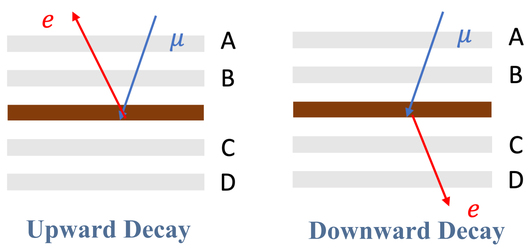
- A series of algorithms is developed to select muon decaying in the absorber and determine the flying direction of decayed positrons



Atmospheric Muon Visualization

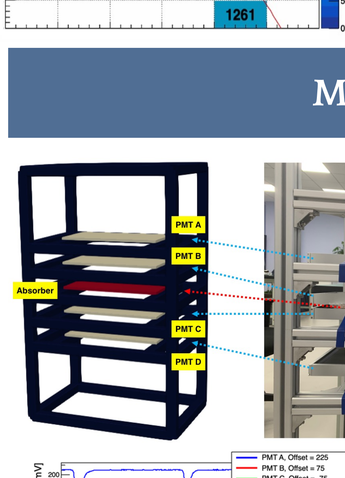


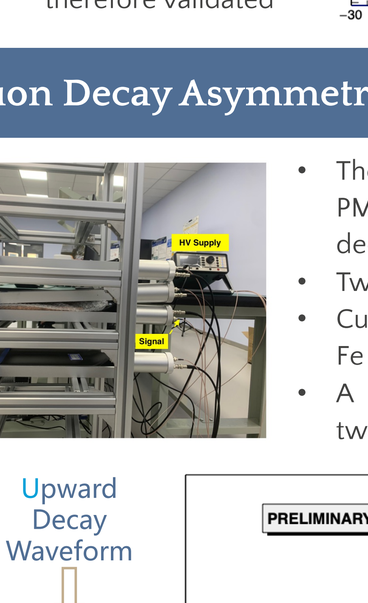

$$A = (-0.268 \pm 0.010)\,P - (0.167 \pm 0.005)$$



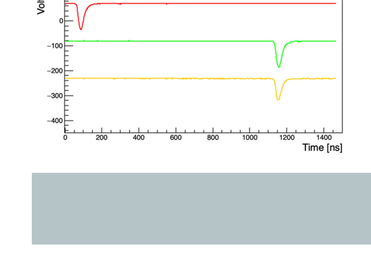

- Obtain decay asymmetry for a given polarization fraction from MC simulation
- The Phase 1 Asymmetry-Polarization curve shows good linearity
- The polarization of atmospheric muon can be derived from decay asymmetry

## Muon Angular Distribution (MAD)

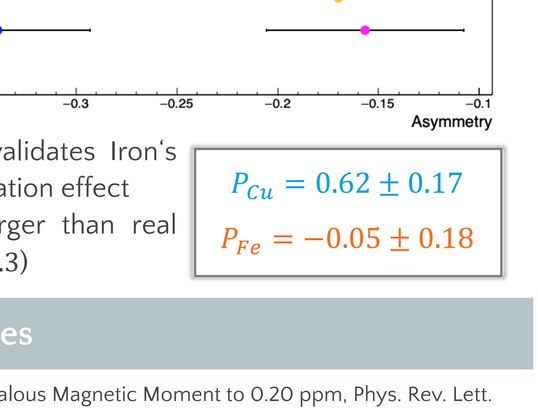





- A 6×4 scintillator bar array is constructed to measure the angular distribution of the atmospheric muon
- Photons produced when muon passes through scintillators are converted into electric signals for data analysis




- The zenith angle is reconstructed from scintillator positions
- The measured distribution agrees with MC simulation
- The atmospheric muon model is therefore validated




## Muon Decay Asymmetry (MDA)


- The combination of scintillator and PMT is used to detect muons and decayed positrons/electrons
- Two absorbers (Cu and Fe) are used
- Cu absorber merely stops muon while Fe absorber also depolarizes muon
- A difference in the measurement of two asymmetries is expected




Upward Decay Waveform

$$A = \frac{D - U}{D + U}$$

Downward Decay Waveform




- $P_{Fe} \approx 0$ validates Iron's depolarization effect
- $P_{Cu}$ is larger than real value (~0.3)

$$P_{Cu} = 0.62 \pm 0.17$$
$$P_{Fe} = -0.05 \pm 0.18$$

## Conclusion & Future Prospects

- A comprehensive study of Phase 1, including MC simulation, MAD and MDA, has been performed
- The MC simulation includes a realistic atmospheric muon distribution for the design and optimization of the apparatus, and provides the Asymmetry-Polarization relationship
- The angular distribution measured by the Muon Angular Distribution (MAD) apparatus agrees with the MC simulation
- From the measurement of the Muon Decay Asymmetry (MDA) apparatus, $P_{Fe}$ agrees with simulation and validates the depolarization effect of Iron, while $P_{Cu}$ is twice larger than real value, and the reason is under investigation
- Development of Phase 2 is in progress, and a prototype Phase 2 apparatus is currently in data taking mode



Phase 2 MDA structure

## References

[1] Muon g-2 collaboration, Measurement of the Positive Muon Anomalous Magnetic Moment to 0.20 ppm, Phys. Rev. Lett. 131 161802(2023)
[2] Abe, M. et al. A New Approach for Measuring the Muon Anomalous Magnetic Moment and Electric Dipole Moment, https://doi.org/10.48550/arXiv.1901.03047 (2019)
[3] Guan, M., Chu, M., Cao, J., Luk, K., & Yang, C. A parametrization of the cosmic-ray muon flux at sea-level. https://doi.org/10.48550/arXiv.1509.06176 (2015)

***Email:** meng.lv@sjtu.edu.cn

This work is supported by National Natural Science Foundation of China (Grant No. 1211101353) and Zhiyuan Scholars Program (Grant No. 2022-09)