The Detector for the MUonE Experiment at CERN.

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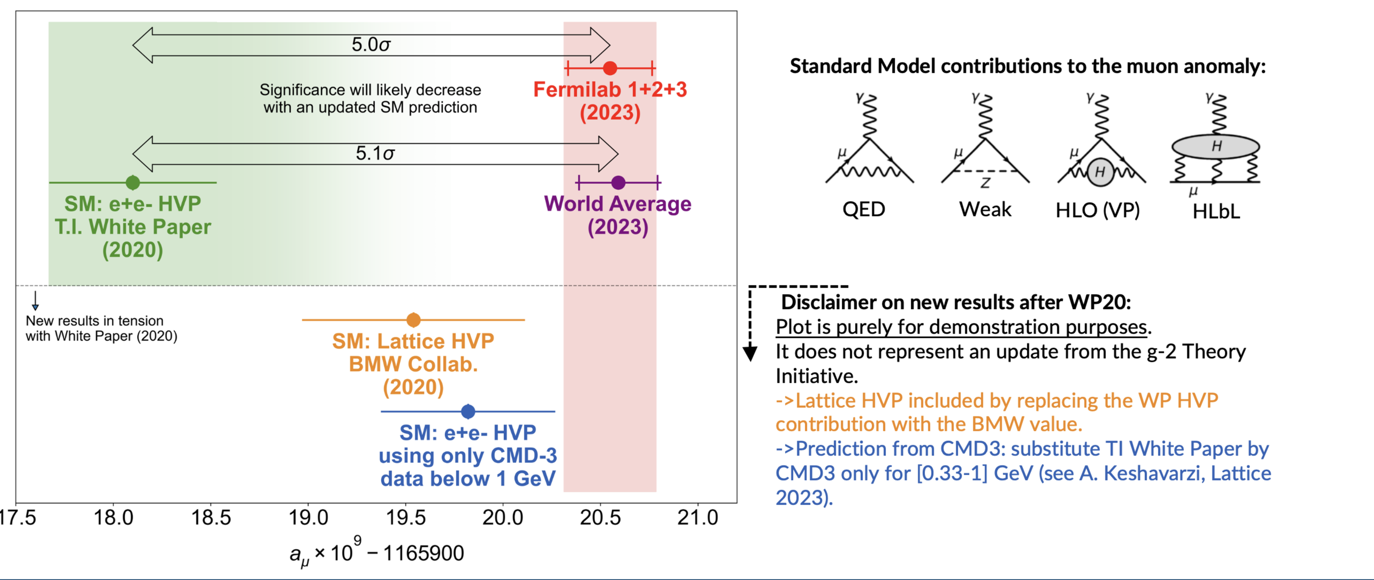
Abstract

The comparison between the measurement and the Standard Model prediction of the anomalous magnetic moment of the muon (a_μ) is a way to search for new physics. Recently, the Fermilab Muon g–2 experiment measured a_μ with a precision of 200 parts per billion (ppb) [1]. The theoretical prediction of a_μ is limited by the uncertainty in the leading-order hadronic-vacuum-polarization contribution (a_μ^{HLO}) as the two calculation methods, namely the dispersive approach and the lattice QCD, yield different results [2].

The MUonE experiment proposes an alternative and independent way to precisely measure a_μ^{HLO} through a unique direct measurement, which can be used to cross-check the theoretical value [3,4,5].

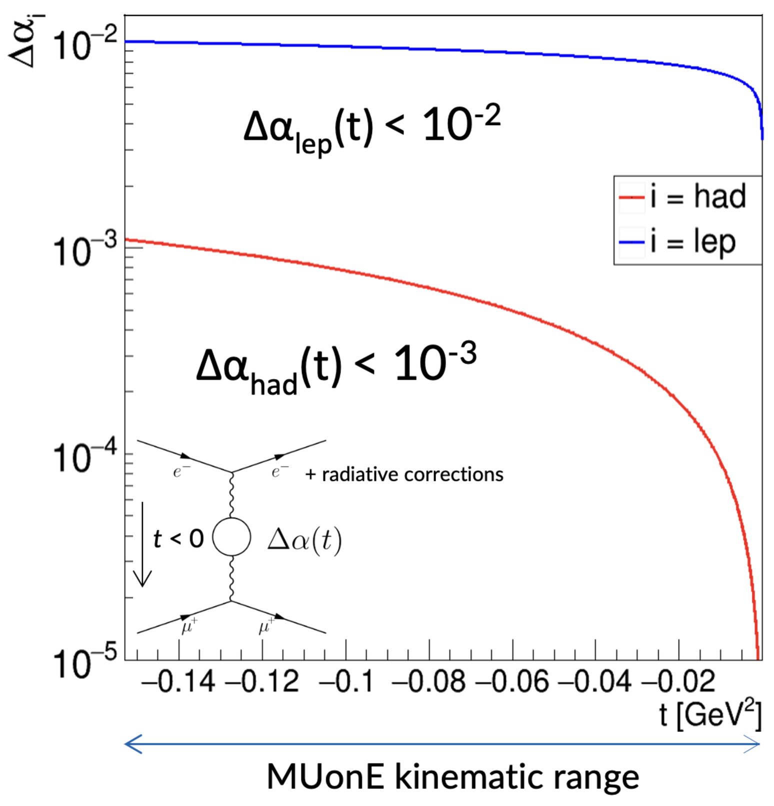


The MUonE Experiment

$$a_\mu^{HLO} = \frac{\alpha}{\pi}\int_0^1 dx(1-x)\Delta\alpha_{had}\left[t(x)\right]$$

$\Delta\alpha_{had}\,[t(x)]$ is the hadronic contribution to the running of α in the space-like region $t<0$ to be extracted from the shape of the **elastic scattering $\mu e \to \mu e$ differential cross section**.

Goal on a_μ^{HLO}: $\sim 0.3\%$ statistical uncertainty (same level of systematic uncertainty to be competitive with current results)

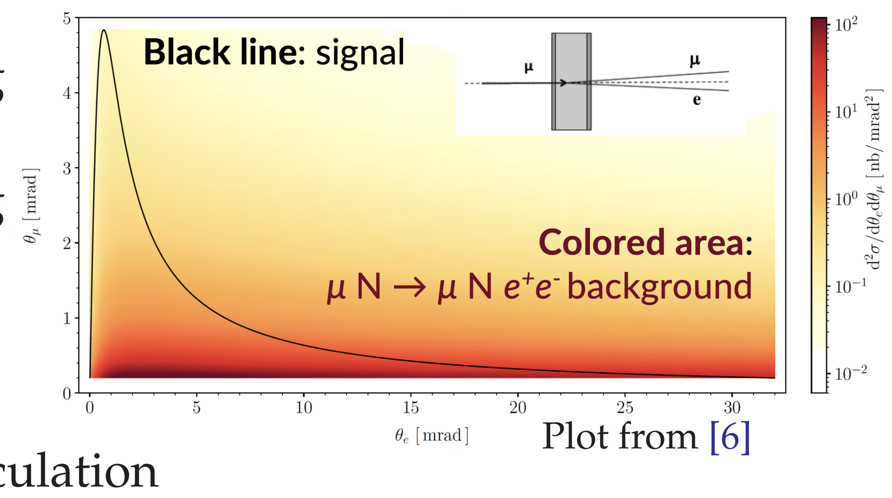


Extracting $\Delta\alpha_{\rm had}$ from μe elastic scattering:

$$\frac{d\sigma_{\rm data}(\Delta\alpha_{\rm had})}{d\sigma_{\rm MC}(\Delta\alpha=0)} \sim 1+2\Delta\alpha_{had}(t)$$

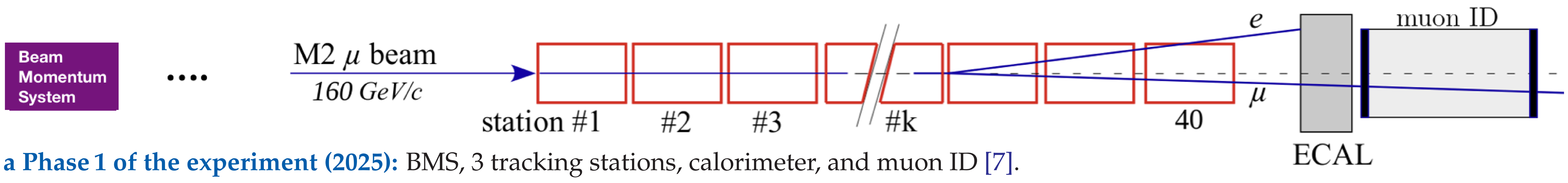
Error on $\Delta\alpha_{had}(t) \sim 1\%$
$\Rightarrow$ syst. unc. on $d\sigma/\sigma$: 10 ppm

- $d\sigma_{\rm data}$ from colliding muons into low-Z fixed target:
  - angular measurement of outgoing $e\mu$ angles: θ_e and θ_μ
  - selection of elastic events using correlation between θ_e and θ_μ
  - boosted kinematics: $\theta_\mu < 5$ mrad; $\theta_e < 32$mrad.
- $d\sigma_{\rm MC}$ from NNLO theoretical calculation



Plot from [6]

The experimental apparatus (planned for after the CERN long shutdown 3) comprises 40 stations:

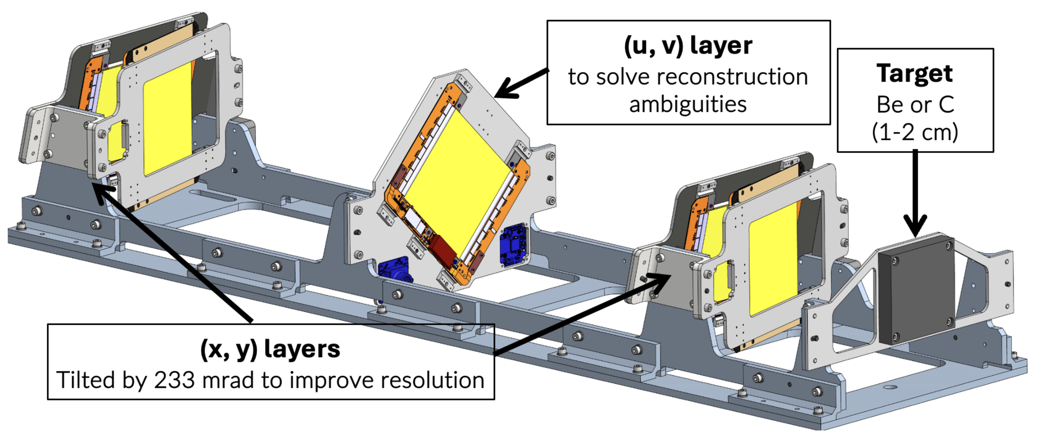


Proposal for a Phase 1 of the experiment (2025): BMS, 3 tracking stations, calorimeter, and muon ID [7].

The Detector

Tracking Station:

– 6 2S-modules (developed for the CMS-Phase2 upgrade [8]):



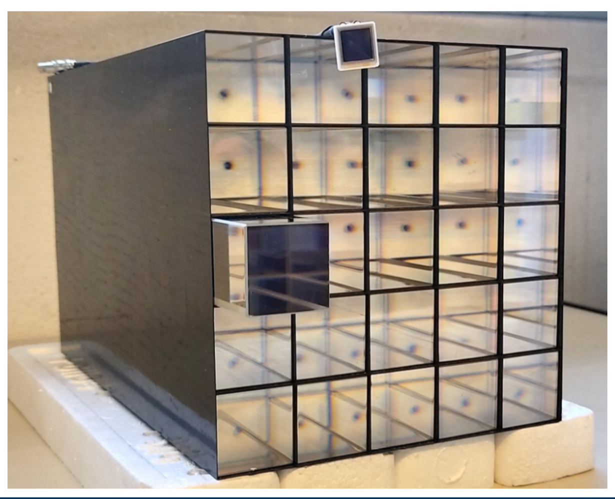
- two close-by 320 μm thick silicon micro-strip sensors
- readout by shared front-end ASICs (rate 40 MHz)
- total area $10\times 10\,\mathrm{cm}^2$
- 90 μm pitch ($\sim 26\,\mu$m resolution)

– Support structure made of INVAR (CTE$\sim$ 1.2 ppm/°C) to maintain relative position within a station stable at $<10\,\mu$m
– Stability monitored by a laser holographic system

Electromagnetic Calorimeter (ECAL):

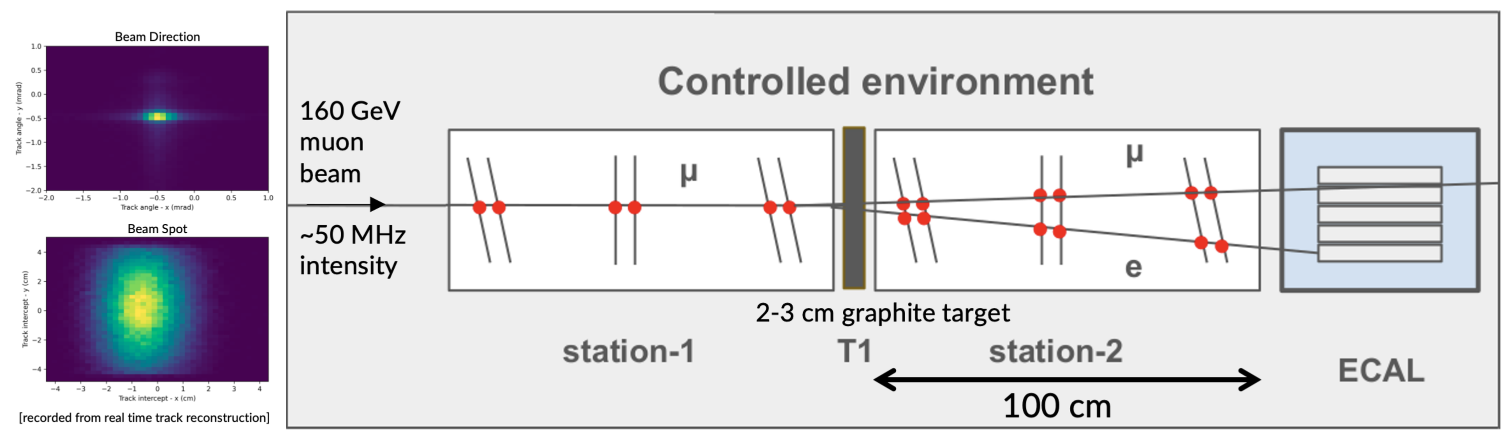
– 5×5 $PbWO_4$ CMS ECAL crystals:
- area: $2.85\times 2.85\,\mathrm{cm}^2$
- length: 23 cm ($\sim 25\,X_0$)

– Total area: $\sim 14\times 14\,\mathrm{cm}^2$
– Readout: $10\times 10\,\mathrm{mm}^2$ APD
– Energy and space resolution to be precisely assessed in dedicated beam tests.

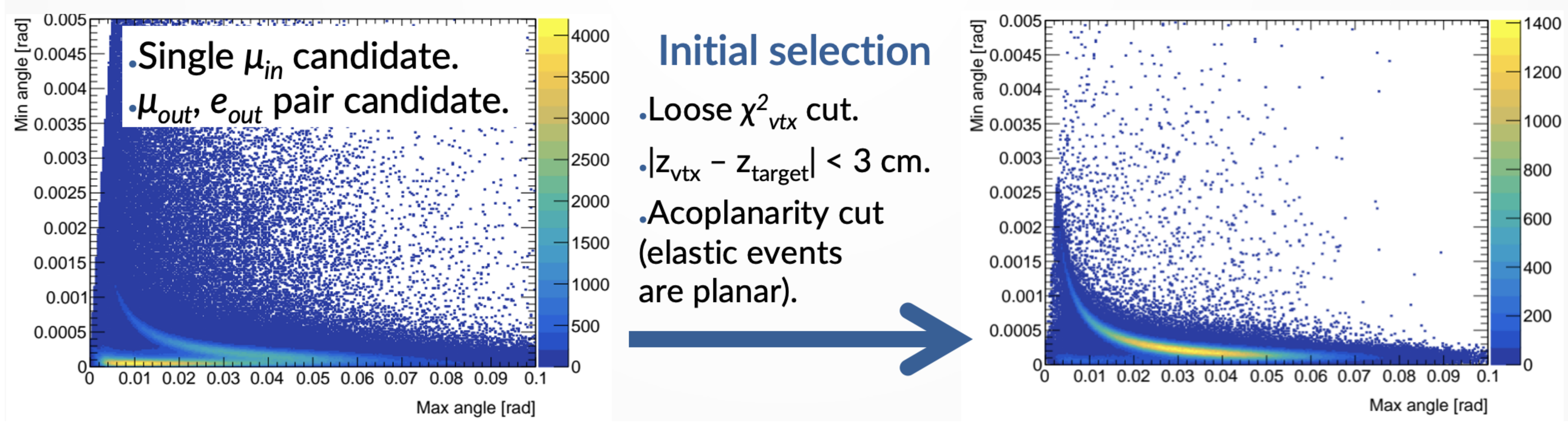


The 2023 Test Run

Tested a small version of final apparatus in the CERN M2 beamline [7]:



– Demonstrated continuous readout at 40 MHz and ECAL integration
– Recorded 350 TB raw data $\sim 1\,(2)\cdot 10^8$ elastic events with 3 (2) cm target
– Achieved online tracking on FPGA
– Tracking performance: $\sim$90% efficiency and $\sim$0.02 mrad angular resolution
– Data analysis is in progress. Observation of elastic scattering:



Conclusions

The MUonE experiment proposes to evaluate the leading order hadronic contribution to the anomalous magnetic moment of the muon by precisely measuring the μ-e differential cross section. The experimental apparatus includes a system of tracking stations and an electromagnetic calorimeter. A test with these two detectors was carried out in fall 2023 at the CERN M2 beamline in collaboration with CMS. While the analysis of the data is ongoing, the initial results demonstrate the capability of the system to handle the muon beam rate and the successful identification of μ-e elastic events. For 2025, the MUonE Collaboration has submitted a proposal for a Phase 1 of the experiment to further assess systematic uncertainties and background under realistic conditions and to make a preliminary measurement of $\Delta\alpha_{had}(t)$.

References

[1] Muon g-2 Collaboration, Phys. Rev. Lett. **131**, no.16, 161802 (2023)
[2] T.I. White Paper: Phys. Rept. **887**, 1-166 (2020) [https://muon-gm2-theory.illinois.edu]
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[6] Phys. Lett. B **854** (2024) 138720
[7] MUonE Phase 1 Proposal CERN-SPSC-2024-015 (SPSC-P-370)
[8] CMS-TDR-014 (2017)

Acknowledgements

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