Results of a MUonE scaled detector with 160 GeV muon beam

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The MUonE experiment

MUonE [1 − 4] is proposing an innovative method to measure the hadronic contribution to the muon $g-2$, a_μ^{HLO}, which is the main source of uncertainty for the Standard Model prediction, and is currently limiting the comparison with the experimental value.

The new method is based on the extraction of the hadronic running of the electromagnetic coupling constant, $\Delta\alpha_{\text{had}}(t)$, from the shape of the $\mu^+e^- \to \mu^+e^-$ differential cross section.

Fixed target experiment: 160 GeV μ^+ (M2 beam line at CERN) off a low-Z target ~ 1.5 cm thick.
Final apparatus foreseen after Long Shutdown 3:

- Measurement of incoming μ^+ momentum
- 40 tracking stations
- ECAL
- Muon ID system

Goal: $\sim 0.3\%$ statistical error on a_μ^{HLO} and similar systematics (competitive with the current results)

ECAL

5×5 PbWO$_4$ crystals, used in the CMS ECAL:

- 2.85×2.85 cm^2 area
- 23cm length (~25X$_0$)
- Readout: 10×10mm^2 APD

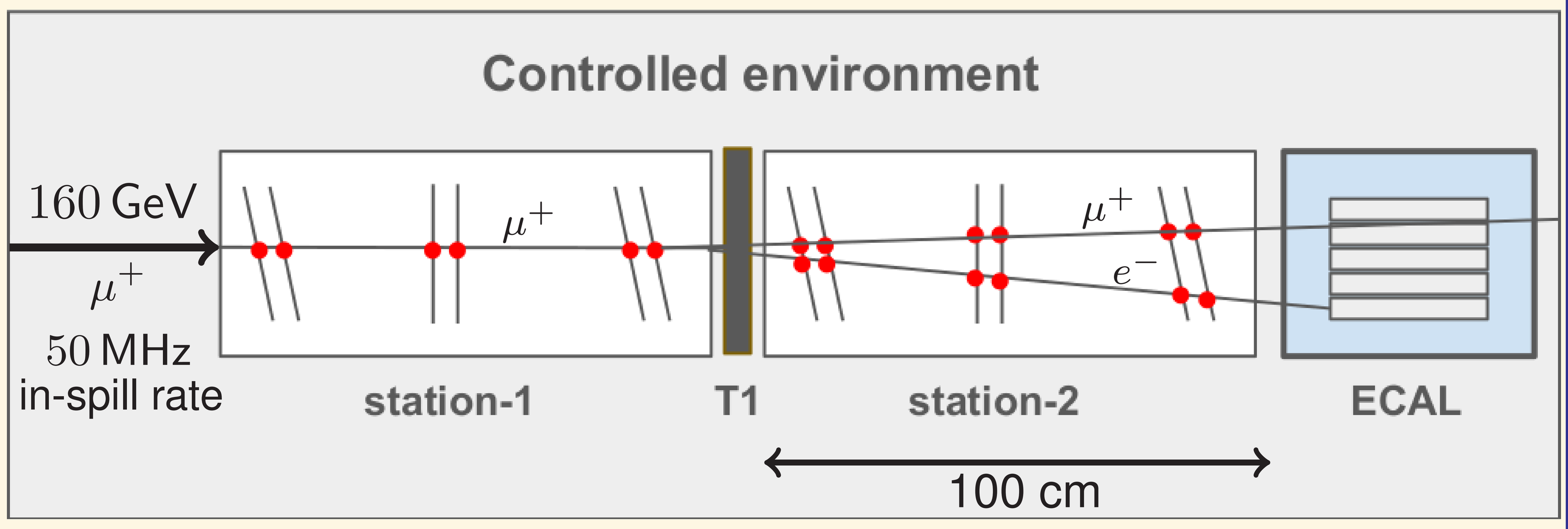
Total area: ~14×14 cm^2

Test Run 2023

3 weeks at the M2 beam line in September 2023

Apparatus:

- 2 tracking stations
- 1 graphite target (2 and 3 cm thickness used)
- ECAL



Achievements:

- Demonstrated continuous readout @ 40 MHz
- ECAL integrated in the main DAQ
- 350 TB raw data recorded to disk: ~ 1(2) × 10^8 elastic events with 3(2)cm target
- First tests of online tracking on FPGA

Analysis in progress:

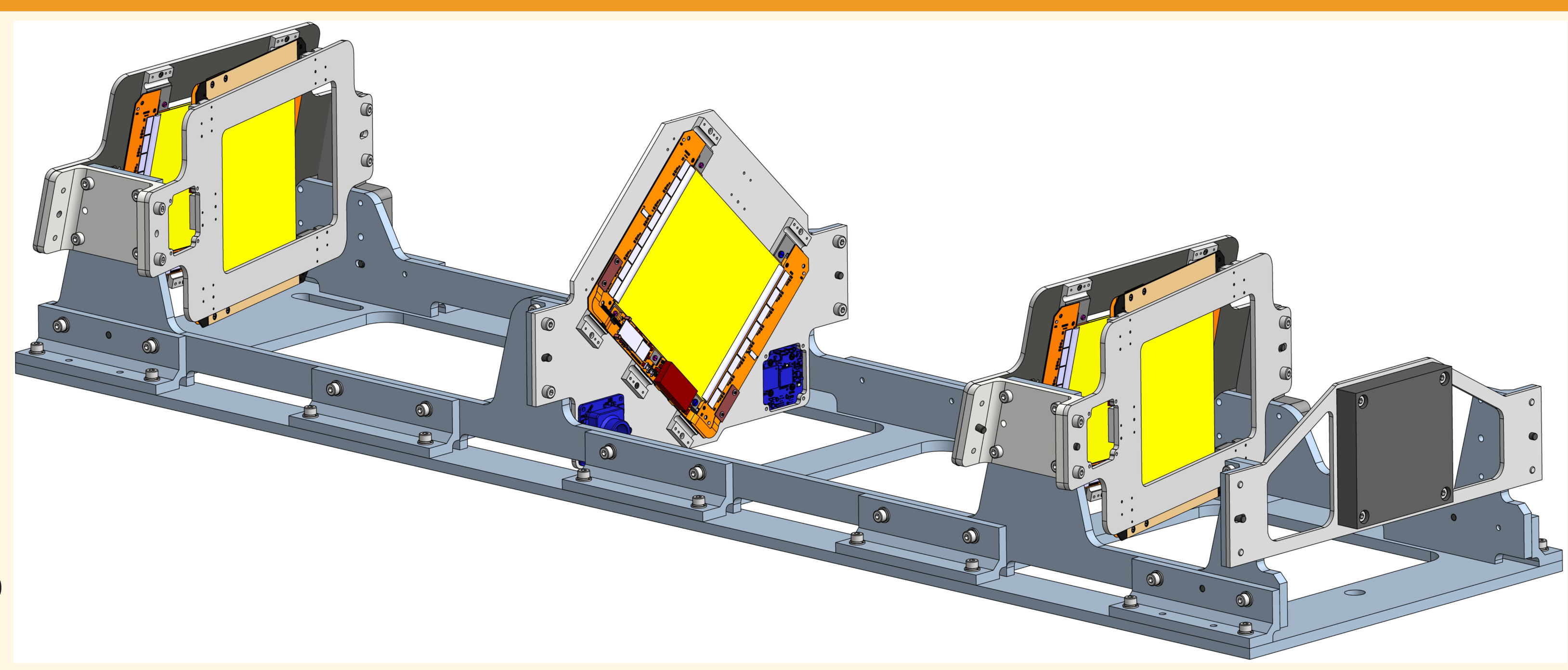
- Test the detector performance, the reconstruction algorithms and event selection
- Study systematics and background processes
- Final demonstration measurement: $\Delta\alpha_{\text{lep}}(t)$ with $O(10\%)$ statistical accuracy

The MUonE station

6×2S-modules (developed for the CMS-Phase2 upgrade [5]):

- 2×320 μm Si strip sensors
- Active area: ~10×10 cm^2
- 90 μm pitch
- Binary readout @ 40 MHz

Mechanical structure: INVAR (CTE ~1.2ppm/°C), to keep relative positions stable < 10μm.

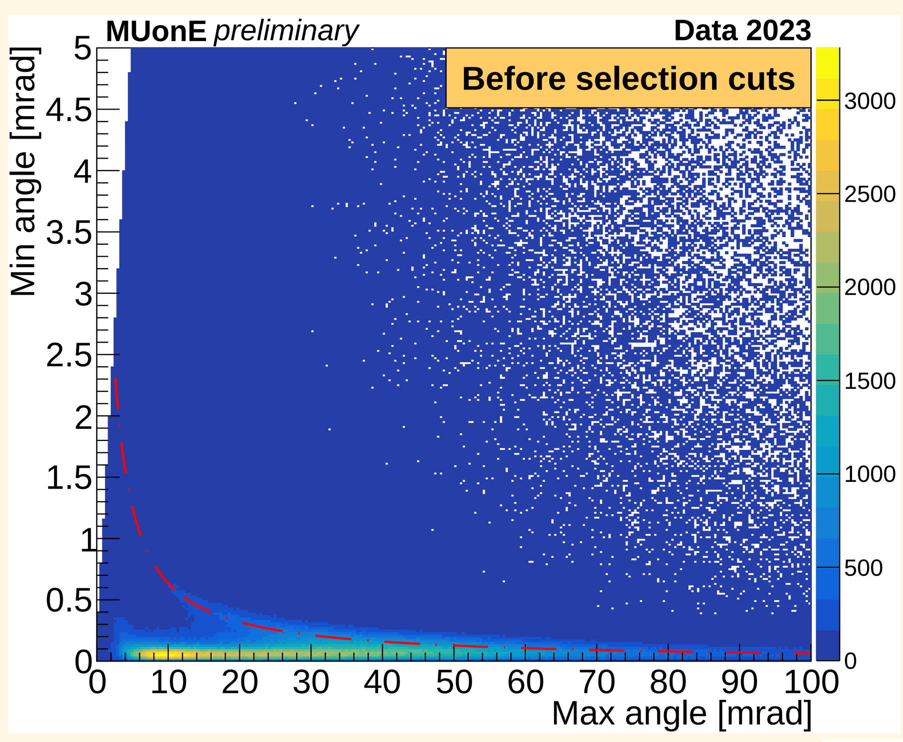


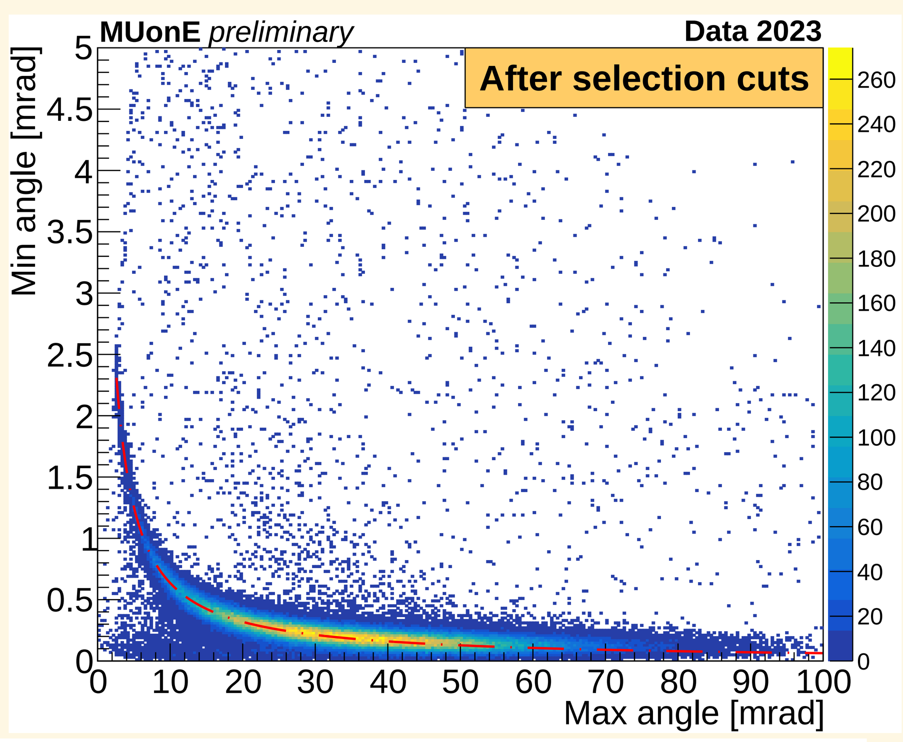
Event selection

- Signal: $\mu^+e^- \to \mu^+e^-$
  - Correlation between μ^+ and e^- scattering angles (red line below)
  - The event is planar
  - Cross section $\propto Z$
- Main background: $\mu^+N \to \mu^+Ne^+e^-$
  - Mimics the elastic scattering if an outgoing particle escapes detector acceptance
  - The event is not planar
  - Cross section $\propto Z^2$

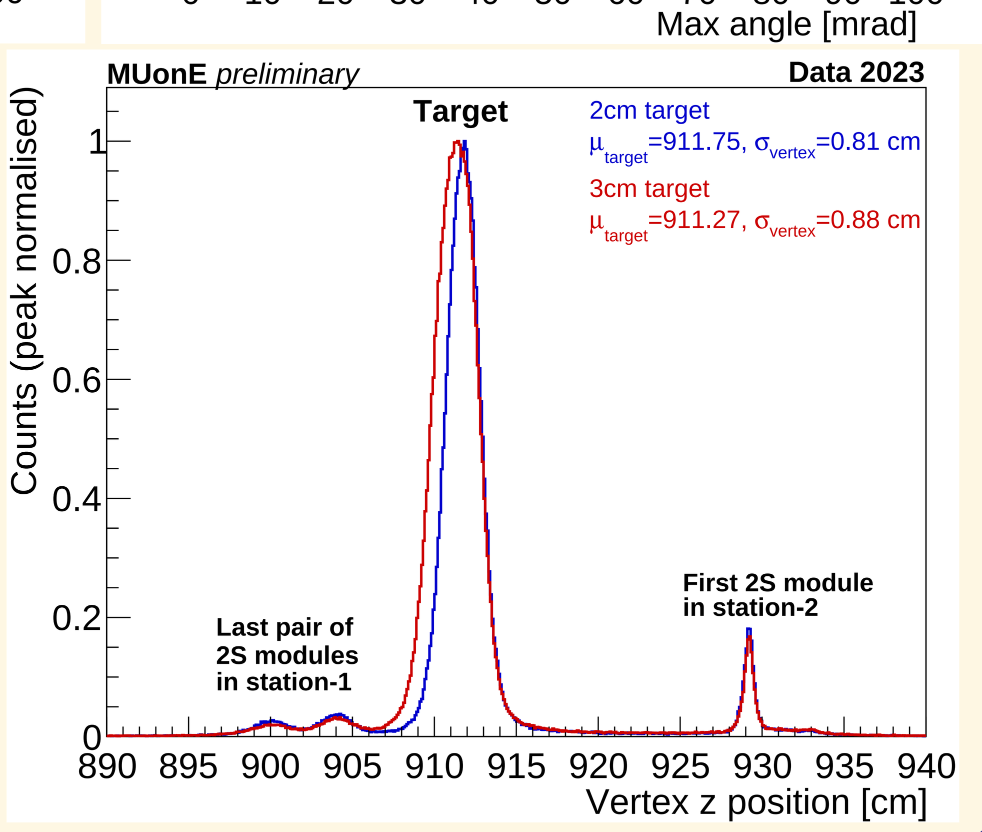
Effect of event selection on candidate elastic events (1 incoming track + 2 outgoing tracks):

- >= 1 hit per Si layer
- <= 14 hits in station-2
- acoplanarity cut
- $|z_{\text{vertex}} - z_{\text{target}}| \leq$ target thickness





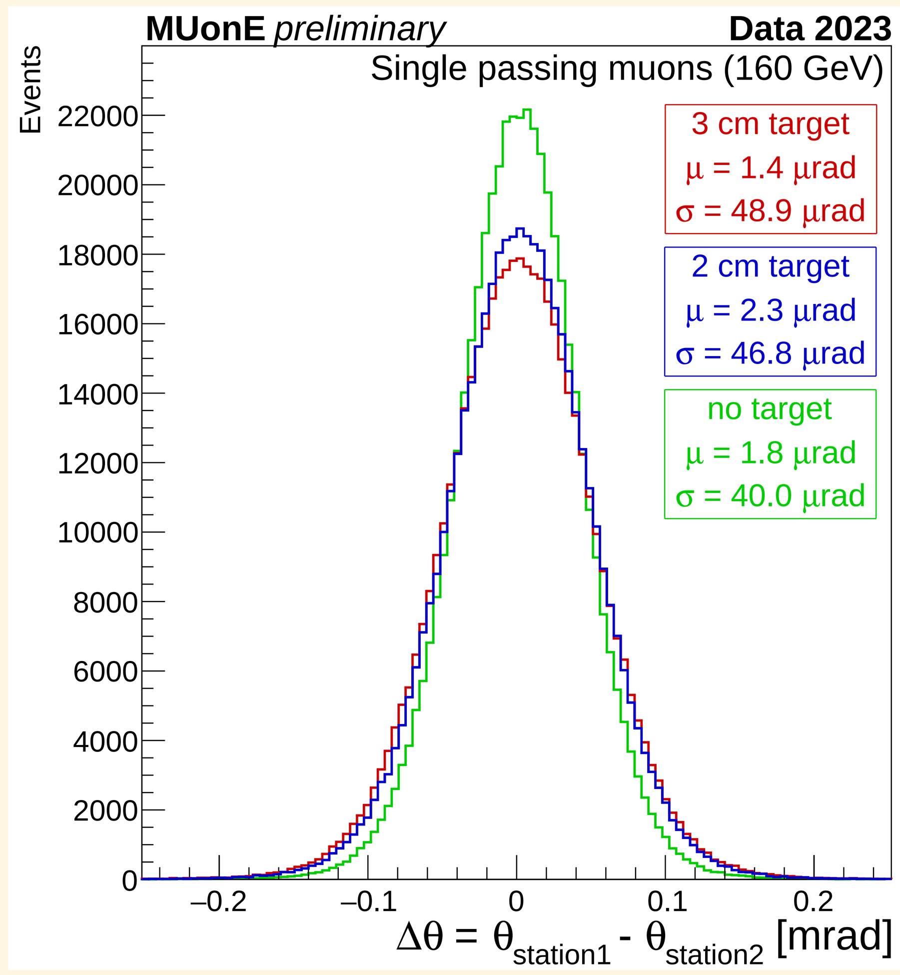
- Select candidate elastic events within angular acceptance: [0.2, 32] mrad
- The target center is shifted by 0.5 cm by changing between 3 cm and 2 cm thickness
- Interactions in the Si layers are visible
- Vertex resolution ~ 8 mm

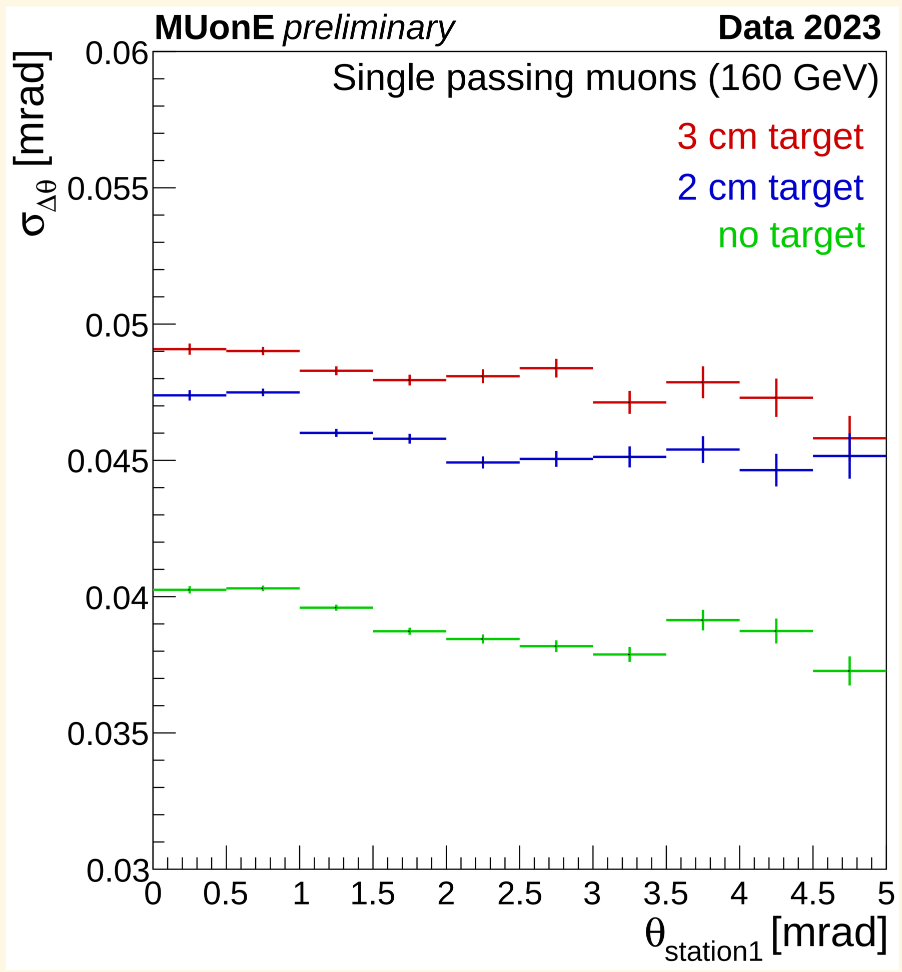


Target multiple scattering effects

Use events with single passing muons to study the angular resolution and the multiple scattering effects in the target.

The same muon is reconstructed separately in the two stations.





The multiple scattering effects of the target can be estimated as:

$$\sigma^2_{\text{MS}}(\text{target}) = \sigma^2_{\Delta\theta}(\text{target}) - \sigma^2_{\Delta\theta}(\text{no target})$$

target	$\sigma_{\Delta\theta}$ [μrad]	σ_{MS}(target) [μrad]	$\sigma_{\text{MS, expected}}$(target) [μrad]
3 cm	48.9 ± 2.1	28.1 ± 0.6	28.2
2 cm	46.8 ± 2.1	24.3 ± 1.4	22.6
no target	40.0 ± 2.2		

The main contribution to the uncertainties is due to residual misalignments.

The target multiple scattering effects are in good agreement with the expectations (Gaussian approximation for multiple scattering through small angles for 160 GeV muons).

References

[1] C. M. Carloni Calame *et al.*, Phys. Lett. B **746** (2015).
[2] G. Abbiendi *et al.*, Eur. Phys. J. C **77** (2017).
[3] G. Abbiendi *et al.* (MUonE Collaboration), MUonE Letter of Intent, CERN-SPSC-2019-026 (2019).
[4] G. Abbiendi *et al.* (MUonE Collaboration), Proposal for phase-1 of the MUonE experiment, CERN-SPSC-2024-015 (2024).
[5] CMS Collaboration, The Phase-2 Upgrade of the CMS Tracker, CMS-TDR-014 (2017).

Acknowledgments

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