HEP annual meeting presentation

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Particle physics

MUonE and g-2

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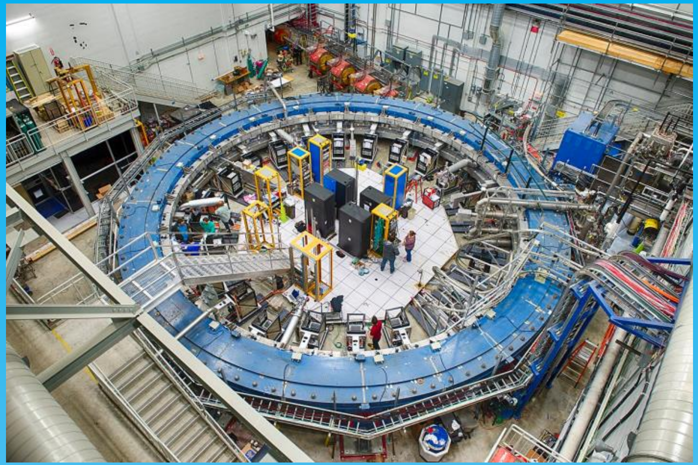
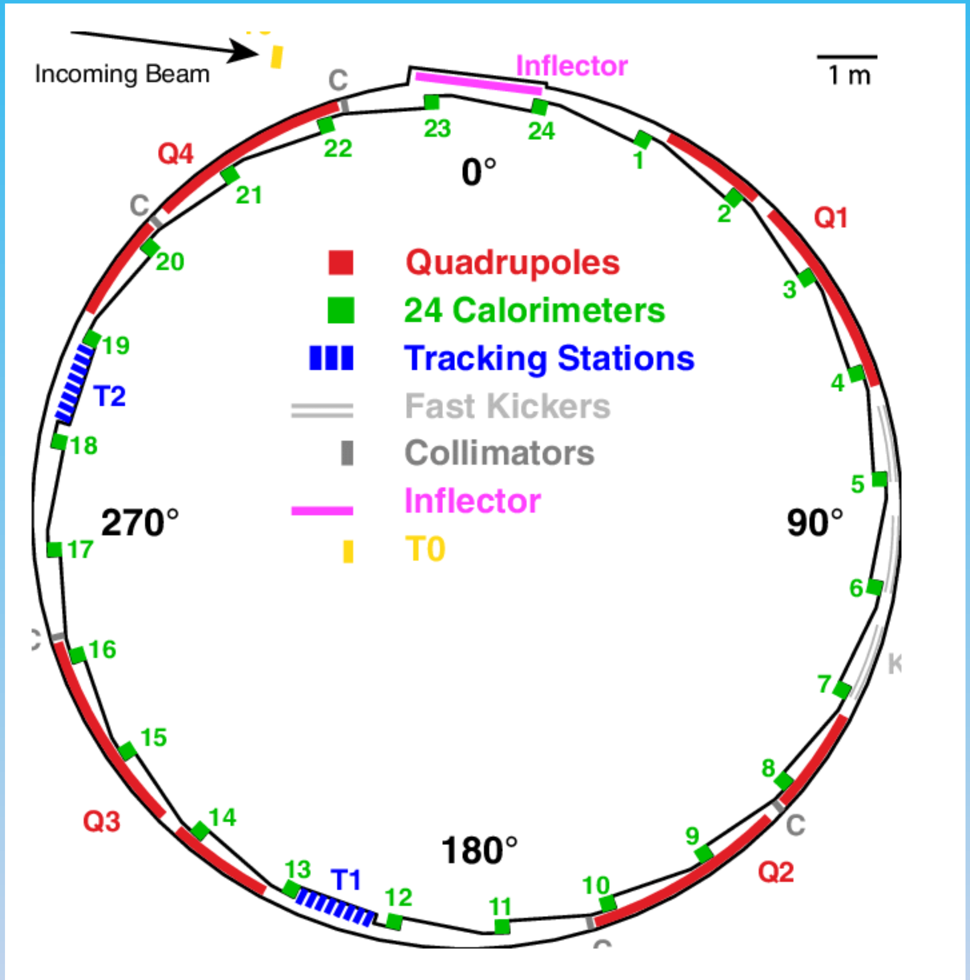
Theory of g-2 and MUonE

g-2 experiment

Muons orbit in the storage ring and decay into positrons. g-2 detects the positrons and counts them as a function of time.





The magnetic dipole moment is a measure of the strength of the muon's interaction with a B-field - $\vec{\mu} = g\frac{e}{2m}\vec{s}$

The g-factor relates the magnetic dipole moment of a particle to its spin.

Muon anomaly

$$a_\mu = \frac{g-2}{2}$$

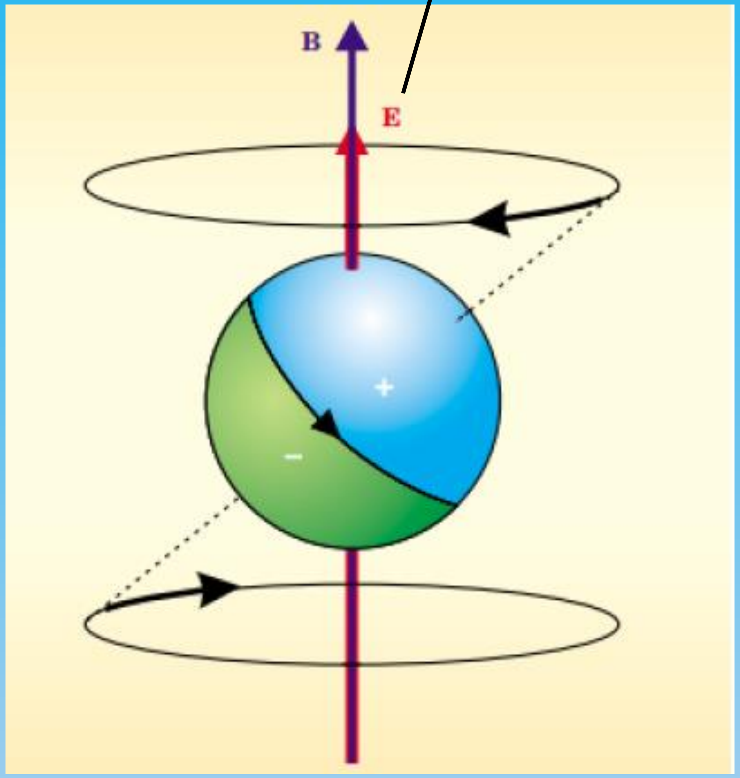
g is influenced by virtual particles

$$a_\mu = a_\mu^{QED} + a_\mu^{EWK} + a_\mu^{QCD} + \left(a_\mu^{BSM}?\right)$$

Muon EDM in g-2

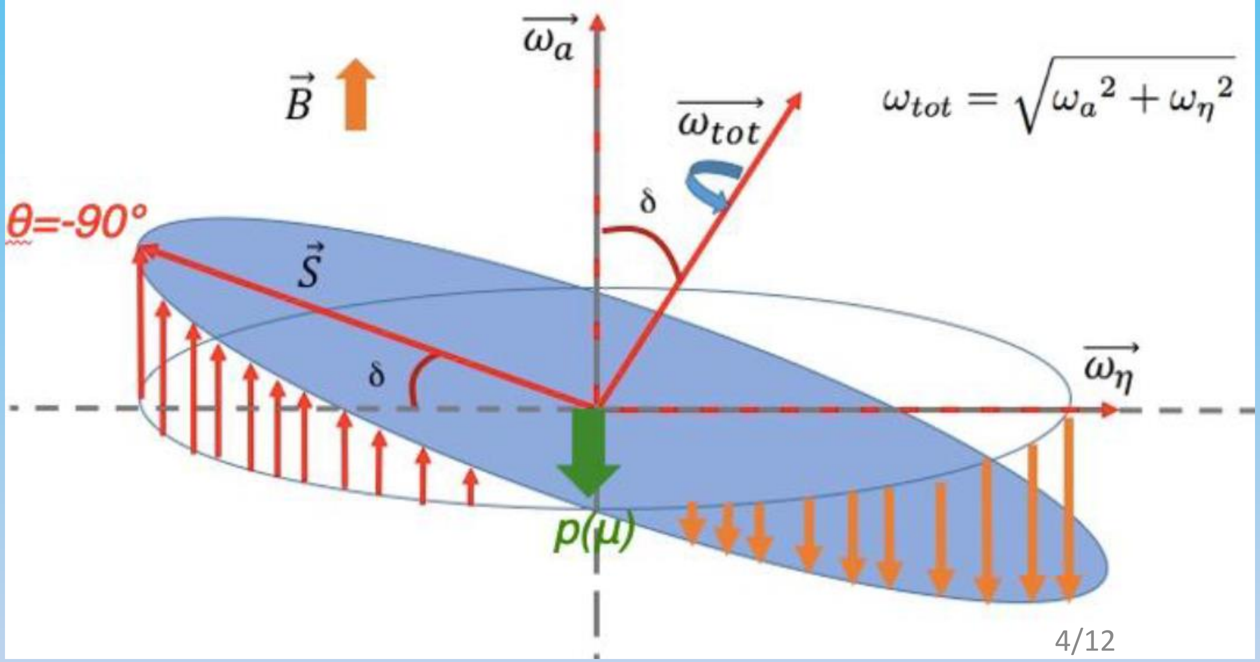
- The electric dipole moment (EDM) is a measure of the strength of the muon's interaction with a E-field - $\vec{d} = \eta \frac{Qe}{2mc} \vec{s}$
- Muon EDM causes the precession plane to tilt towards the centre of the storage ring.
- The average vertical angle of the positrons has an amplitude proportional to the EDM signal. We can use a ~sinusoidal fit function to calculate the tilt amplitude and therefore the EDM.

E-field induced by a Lorentz transformation of the B-field

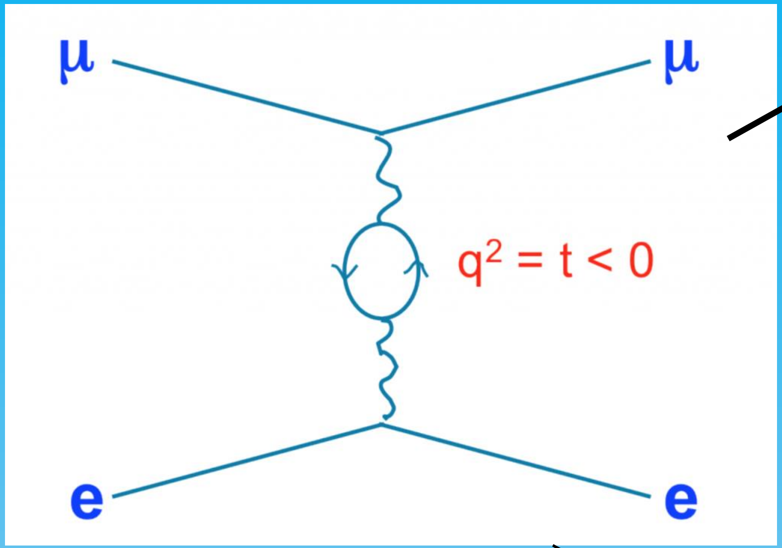


The EDM of a particle couples to an external E-field and produces a torque.

Torque ($\vec{\tau}$) = $\vec{d} \times \vec{E}$



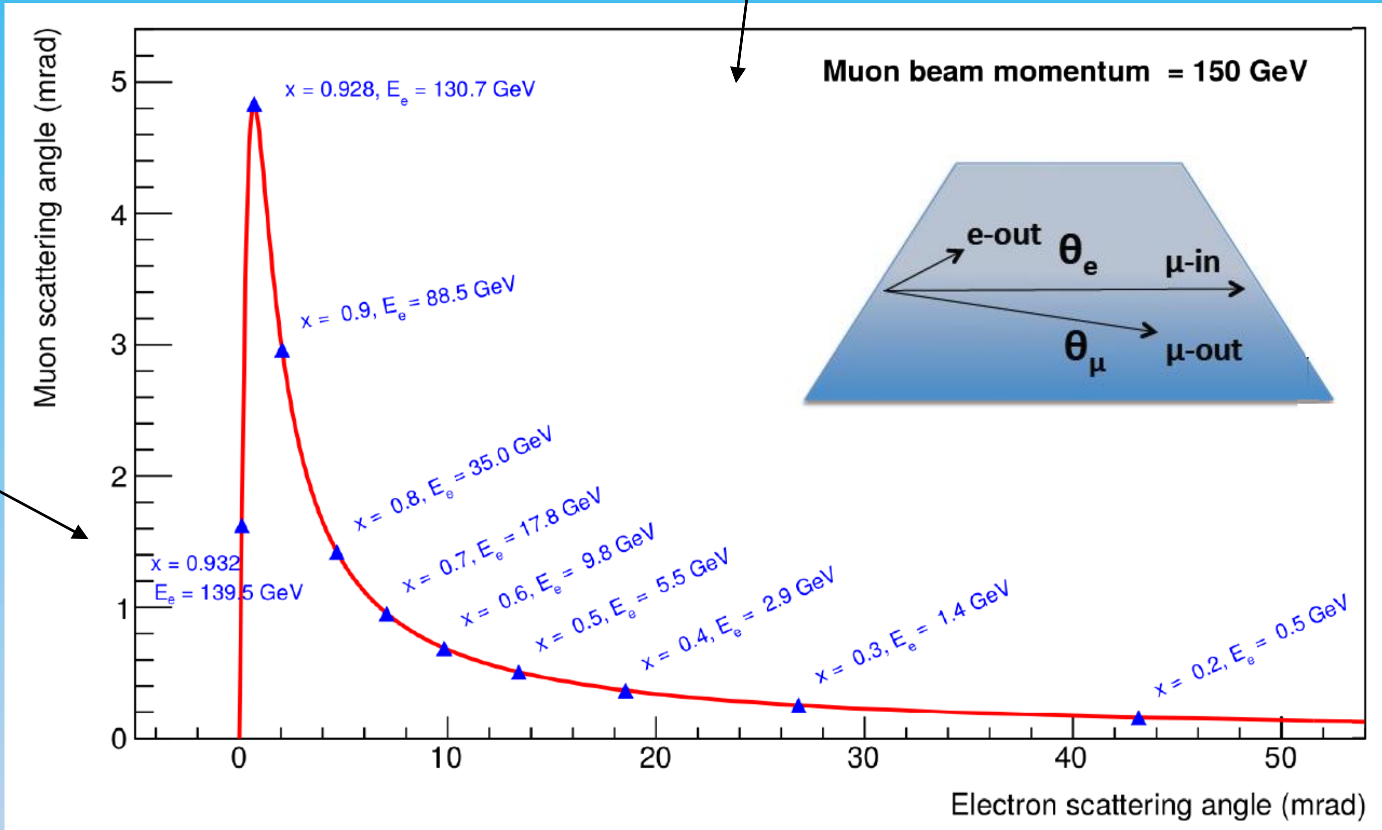
Goal of MUonE



MUonE is an electron-muon scattering experiment

$$a_\mu^{HLO} = \frac{\alpha_0}{\pi} \int_0^1 \mathrm{d}x\,(1-x)\Delta\alpha_{had}[t(x)]$$

MUonE will measure the number of muons and electrons as a function of the scattering angle

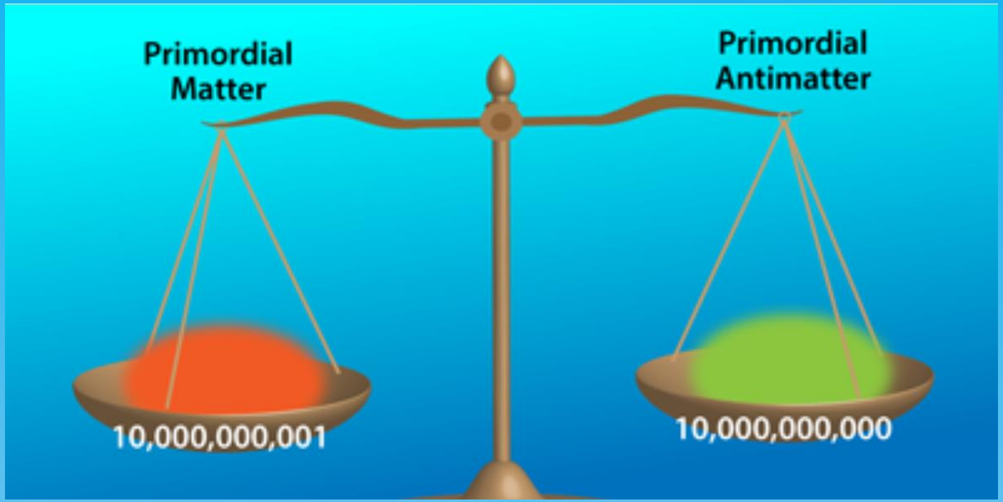


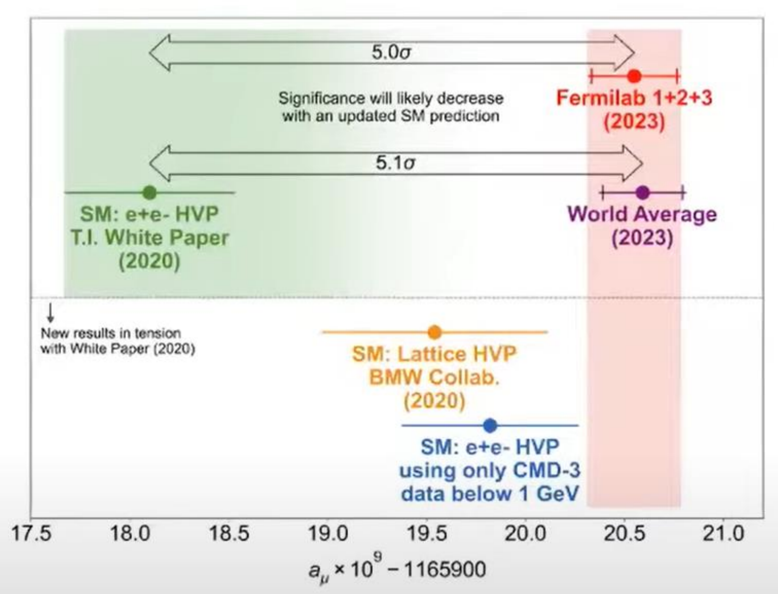
- It will provide a new independent determination of the hadronic vacuum polarisation contribution to the muon anomaly, a_μ^{HLO}.
- a_μ^{HLO} is the largest source of uncertainty on the theoretical determination of a_μ despite not being the largest contribution to a_μ.

Significance of the muon MDM and muon EDM

Muon EDM:

- Muons should not have a measurable EDM because particle EDMs violate CP symmetry.
- The matter antimatter asymmetry in the Universe can be explained with more sources of CP violation.
- If the muon has an EDM, this can help further probe and explain the asymmetry.





Muon MDM:

- MUonE will help “finalise” the theory value for the muon anomaly.
- If the muon anomaly remains, this is evidence for new physics and a flaw in the Standard Model.

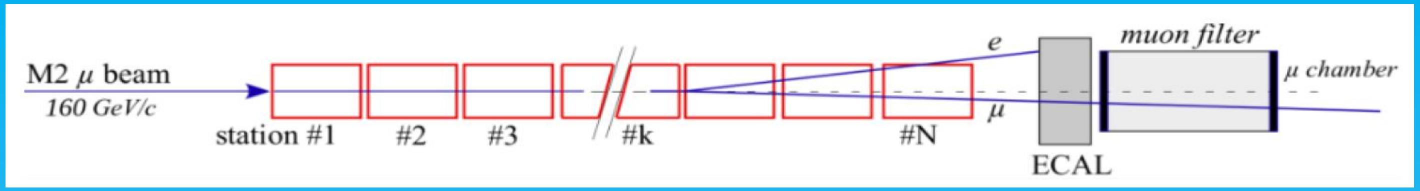
My analysis

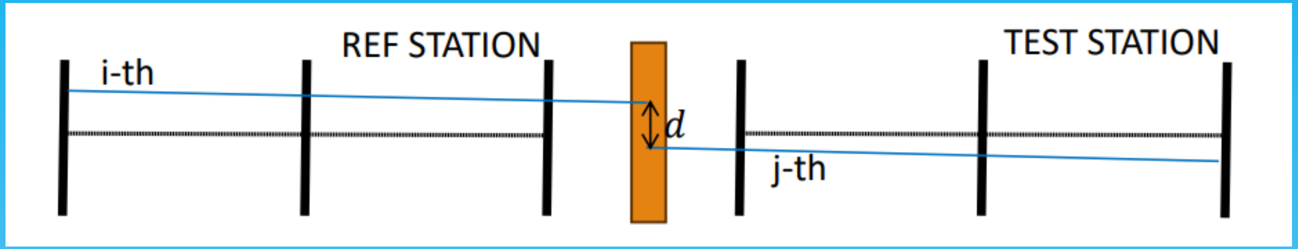
MUonE track reconstruction efficiency

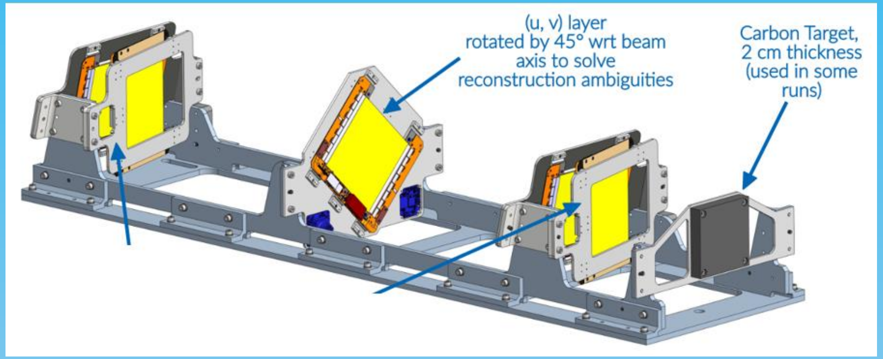
*Using data from the 2023 test beam with 2 detector stations (each made of 6 detector modules)

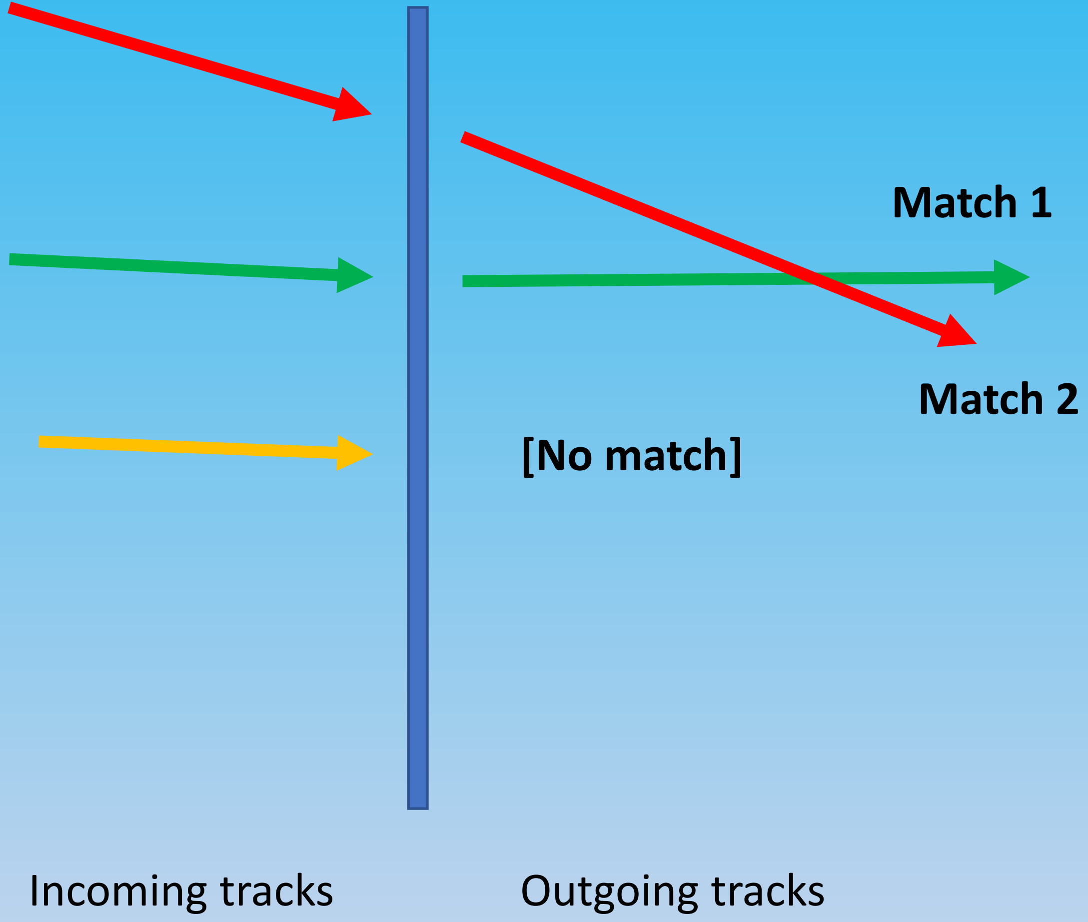
$$\textbf{Definition of track reconstruction efficiency} = \frac{\text{Number of good matches}}{\text{Total number of tracks in the first station}}$$

Track reconstruction efficiency in MUonE









$$d = \sqrt{(\Delta x)^2 + (\Delta y)^2}$$

Matching criteria: x and y

d/d_err < 2.7 for a good match

Track reconstruction efficiency in MUonE

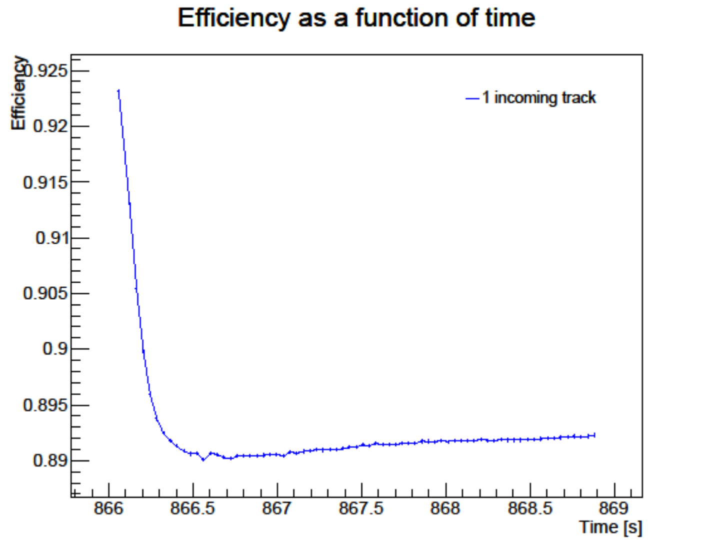
Example table

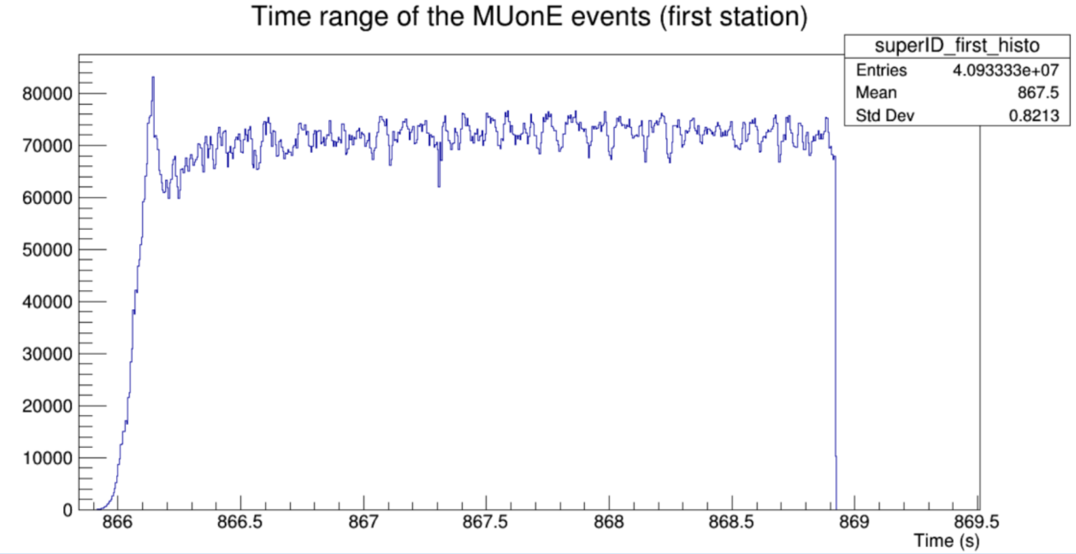
Example matching track table	Outgoing track #1	Outgoing track #2
Incoming track #1	d/d_err = 1.5	d/d_err = 1.0
Incoming track #2	d/d_err = 0.47	d/d_err = 5
Incoming track #3	d/d_err = 3	d/d_err = 4.2

- Incoming track #1 matches with outgoing track #2
- Incoming track #2 matches with outgoing track #1
- Incoming track #3 doesn't have a match

Smallest d/d_err = best match between the incoming and outgoing track

For 70 million events and only events with 1 incoming track:





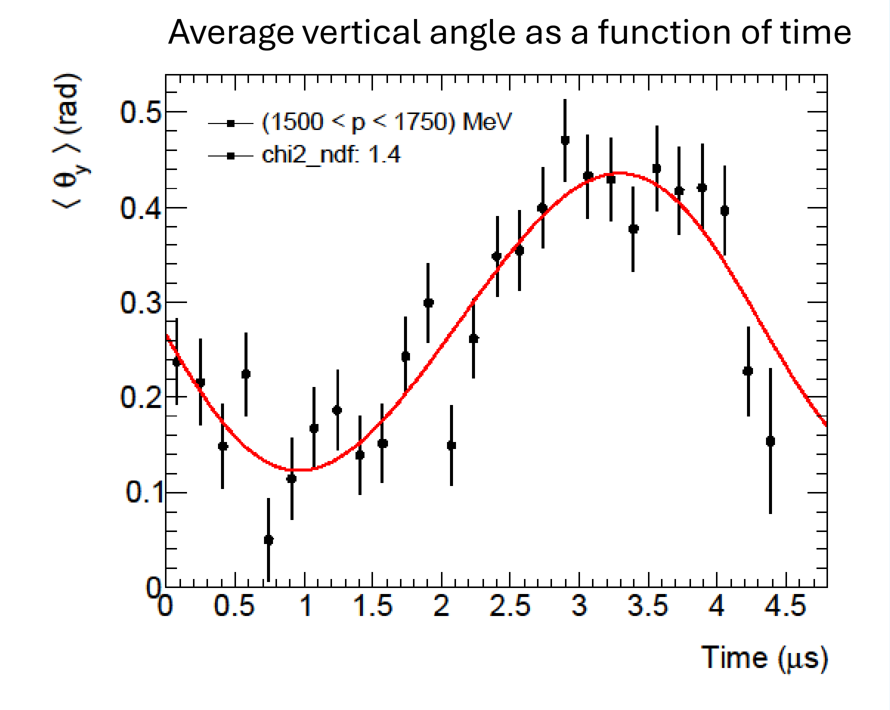
$\text{Efficiency} = 89\%$

P(track) = $\varepsilon^6 + 2\varepsilon^5(1-\varepsilon)$

P(track) = 0.89 (rounded) and therefore the individual module efficiency (ε) = 0.97 (rounded)

G-2

I am running run-1 data and MC files.
I analyse the vertical angle oscillation vs time and evaluate the impact of modifying the sinusoidal fit.



New fit:

$$\frac{A_0\cos(\omega_a t+\phi_1) + A_{\frac{\pi}{2}}\sin(\omega_a t+\phi_1)+c}{1+A'\cos(\omega_a t+\phi_2)}$$

- I'll be running the final analysis on the full dataset and help to determine the most sensitive EDM limit.

- Brookhaven measurement of the muon EDM limit in 2002: $\mathrm{d}_\mu < 1.8\times10^{-19}\mathrm{e.}\,cm$ [1]
- g-2 expects to set a muon EDM limit of: $\mathrm{d}_\mu < 1.0\times10^{-20}\mathrm{e.}\,cm$

[1[Papa, A. (2022). *muEDM at PSI: An attractive possibility to extend even further the intensity frontier program Motivations: Search for EDMs*. [online] Available at: https://indico.fnal.gov/event/22303/contributions/247108/attachments/157746/206536/muEDM_Snowmass_July22th_2022_Papa.pdf

Conclusion

- The track reconstruction efficiency for MUonE is 89% and the individual module efficiency is 97%. This has been seen in multiple analyses.
- g-2's latest result is a 5.1σ difference between the theoretical and experimental values for the muon anomaly.

- I help with the analysis for g-2 (EDM analysis), and I help with the analysis and hardware of MUonE (detector support structure, efficiencies and background studies).
- I will be working on the 2025 test beam for MUonE.
- I'll be going on a 6-month industrial placement (as part of LIV.INNO).

MuonE Hardware

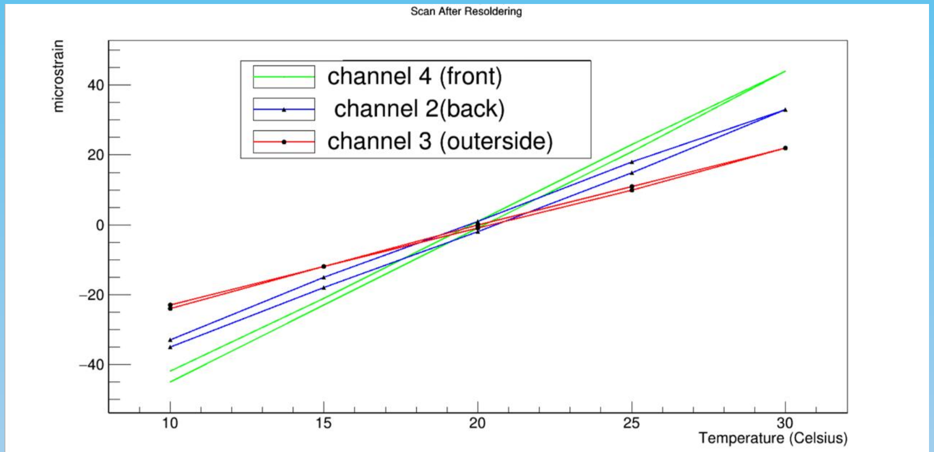
Giorgia and I are testing carbon fibres, including M55J/EX1515 (a carbon fibre/cyanate ester composite) to determine if it is good enough to replace invar as the detector support structure material in MUonE.

We're doing tests of the material's coefficient of thermal expansion (CTE) and investigating any deformation.

We're also confirming the validity of our methods by also investigating materials with known CTEs.

Detector support structure prototype

Carbon fibre CTE investigation



Testing the methods we use