The Fermilab Muon g-2 Experiment



Becky Chislett

Aim of Experiment

Make a 0.14 ppm measurement





Anomalous Contribution



Additional "loop" interactions give a non g=2 contribution

$$a_{\mu} = \left(\frac{g-2}{2}\right)$$

This is the so-called anomalous contribution

These interactions <u>flip the chirality</u> of the muon but conserve flavour and CP.

$$a_{\mu} = \frac{\alpha}{2\pi} = 0.00116 \ 140980$$
$$= 0.00116 \ 591792 \ (\text{SM all loops})$$



Theory consensus

Comparison of SM & BNL Measurement



Present measurement is at odds with SM at 3.5σ level and now broad consensus on SM value

A 0.14 ppm measurement moves this to more than 5σ irrespective of theory.



Theory consensus



SM estimate from e⁺e⁻ data is now being independently verified from lattice calculations.





BSM Landscape

Measurement probes much of the same TeV-scale BSM landscape as LHC.

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Complements LHC



LHC cannot probe all of phase space e.g. small mass slepton/neutralino mass differences, high tanβ.

In event of LHC BSM observation g-2 measurement can resolve degeneracy in model pars & improve their determination e.g. tanβ.



Muon : Electric Dipole Moment

Essentially zero in SM : any observation is new physics



Muon is the only 2nd flav. gen. measurement. and it's free of nuclear / molecular effects

BNL limit is 1.8 x 10⁻¹⁹

Can quickly be improved by x10 and ultimately x100 to 10⁻²¹

Needs non mass-scaling BSM effects to see anything given e⁻ EDM limit



FNAL g-2 Experimental Technique



24 calorimeters and 3 straw-trackers (UK) measure e⁺ for O(1 ms) for spills separated by 10ms.

16,000 stored 3.09 GeV muons from 10¹² protons per spill.



Storage ring at BNL







Fermilab Muon g-2 Experiment

Storage Ring At FNAL











Seven FNAL g-2 improvements





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Muon Campus at FNAL









75% of beam/accelerator work complete. Remaining infrastructure work in 2016 summer shutdown

First beam Q2 2017.







Improvements to injection system





Magnet on : shimming almost done



Magnet has been on OK at 1.45T (4.5k) for 10 months.

Shimming of magnet has been going on for 10 months

Improved field uniformity by a factor of 100.

Now well below required uniformity of 25 ppm azimuth average

These shims are thinner than a human hair....



Field Uniformity is excellent



> to 10 microns

Tilt to 5

YOKE

26 tons to 125 microns





Field Uniformity

Map of the Storage Field



Field uniformity in storage region < 0.1 ppm



Muons are distributed over storage volume

B-field is not uniform over this volume

Need to convolute the two : **use trackers**



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New Detectors





Calorimeter (PbF₂ + SiPMT)

- more segmented.
- x2 sampling (800M/s) vs BNL
- quicker response (5 ns)
- improved energy resolution



Straw Trackers (UK)

- authenticate pileup
- measure muon profile
 - identify lost muons
 - calibrate calorimeter
 - measure EDM



Straw Trackers



UK building 24 trackers + spares

Funding for 2 RAs + techs. £1M PPRP.

And off detector electronics, DAQ DQM & offline tracker software.







Performing as expected in three testbeams at FNAL







Straw Trackers

Mass production well underway at Liverpool and trackers arriving every 2 weeks at FNAL.



1st 8 station tracker will be installed in November. $2^{nd}/3^{rd}$ trackers before beam in June 2017.



Schedule & Competition

Project has remained on-budget and on-schedule since 2013.

UK deliverables on track : project grant ends April 2017.

1st data-taking in 2017 when expect stats similar to BNL.

x20 BNL stats to be accumulated in 2018-2019.

RAs, M&O funded by STFC CG through to Sep 2019 - expect analysis to be conclude in subsequent CG-period.

Competition: J-PARC g-2

Still in R&D phase and not yet fully approved. Will ultimately provide very valuable orthogonal measurement using a very different (and challenging !) technique



Conclusion





g-2 is a critical measurement in establishing (or not) integrity of BSM models in concert with LHC: particularly the non-colour sector

UK making most significant contribution to experiment outside of US.

We need to cast the BSM-search net wide: if the current anomaly persists then FNAL g-2 would establish BSM at 9σ









Fermilab Muon g-2 Experiment

	-		
E821 Error	Size	Plan for the E989 $g-2$ Experiment	Goal
	[ppm]		[ppm]
Absolute field	0.05	Special 1.45 T calibration magnet with thermal	
calibrations		enclosure; additional probes; better electronics	0.035
Trolley probe	0.09	Absolute cal probes that can calibrate off-central	
calibrations		probes; better position accuracy by physical stops	
		and/or optical survey; more frequent calibrations	0.03
Trolley measure-	0.05	Reduced rail irregularities; reduced position uncer-	
ments of B_0		tainty by factor of 2; stabilized magnet field during	
		measurements; smaller field gradients	0.03
Fixed probe	0.07	More frequent trolley runs; more fixed probes;	
interpolation		better temperature stability of the magnet	0.03
Muon distribution	0.03	Additional probes at larger radii; improved field	
		uniformity; improved muon tracking	0.01
Time-dependent	_	Direct measurement of external fields;	
external B fields		simulations of impact; active feedback	0.005
Others	0.10	Improved trolley power supply; trolley probes	
		extended to larger radii; reduced temperature	
		effects on trolley; measure kicker field transients	0.05
Total	0.17		0.07



ω_a systematics





Competition: J-PARC Muon g-2



Unlike FNAL/BNL approach. This technique has yet to be proven to work





μ **g-2**

J-PARC g-2 : Several Challenges 🗍 🗌 🗲

Getting a sufficient rate of ultra cold muons (require 10⁶ /sec and 10¹² e⁺

Avoiding pile-up issues in detector with the 1 MHz rate

Achieving v. small vertical beam divergence : $\Delta p_T/p_T = 10^{-5}$

Requires advances in "muonium" production

- target materials e.g. nano-structured SiO₂
- lasers (pulsed 100 μJ VUV) to ionise muonium (x100)



Complementarity with Mu2e

For BSM dipole interactions e.g. SUSY

Â $\sqrt{\tilde{e}} \tilde{\mu} \underline{e} \mu$



But no theoretical motivation for any particular θ_{eu} value.

 $a_{\mu} \sim g^2 \times \left(\frac{m_{\mu}}{\Lambda}\right)^2$

Need **both** measurements to resolve model degeneracy