Detector systems for the Muon g–2 experiment

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magnetic dipole moment of muon

- torque experienced in external magnetic field
- spin → intrinsic magnetic dipole moment
- experiment measures the anomalous part of magnetic dipole moment
$g - 2$ experiment at BNL

E821 (1999 - 2006):

$$a_{\mu} = 0.00116592089 (63) (\pm 0.54 \text{ ppm})$$

And a hint of New Physics?
Standard Model prediction

Status: summer 2011 (published results shown only)

- JN 09 (e^+e^- based)
  - $-299 \pm 65$
- DHMZ 10 ($\tau$ based)
  - $-195 \pm 54$
- DHMZ 10 (e^+e^-)
  - $-287 \pm 49$
- HLMNT 11 (e^+e^-)
  - $-261 \pm 49$

- BNL-E821 (world average)
  - $0 \pm 63$

BNL-E821 2004

3.6σ

3.3σ

Experiment E821

Muon g-2 exp. at FNAL
4 fold improvement

Talk by Polly, C. & Swanson, E. The Muon g-2 Experiment at Fermilab
Poster by Kiburg, B. Maximizing Magnetic Field Uniformity in the 1.45-Tesla Muon g–2 Storage Ring
principles of $\omega_a$ measurement

1. source of polarized muons (parity violating pion decay)
2. precession proportional only to the anomalous part of magnetic dipole moment ($g-2$)
3. magic momentum gets rid of $\beta \times E$ term
4. parity violating decay (positron reports on spin)
   Lorentz boost maps spin direction onto energy
a lighthouse riding a carousel
what does a calorimeter see

- Hit time [µsec]
- Positron energy [GeV]

- Energy threshold
- Muon decay
- Anomalous precession frequency
- Boosted Michel spectrum
beam profile changes, lost muons

pile-up

gain fluctuation
Calorimeter design goals

1. Positron **hit time** measurement with accuracy of (100 psec above 100 MeV)

2. **Deposited energy** measurement with resolution better than 5 \% at 2 GeV

3. **Energy scale** (gain) **stability** in 1e−3 range, over the course of 700 \(\mu\)sec fill where rate varies by 1e4.

4. 100 \% **pile-up separation** above 5 nsec, and 66 \% below 5 nsec.
lead fluoride crystals

laser light calibration system

SiPMs

24 calorimeter stations around ring
positron detection in calorimeter

PbF2 - pure Cherenkov radiator
SiPM - counts photons; magnetic field compatible

• based on a trans-impedance amplifier (no shunt resistor) PMT-like pulse shape

• programmable gain amplifier to equalize 1400 boards

• DC coupled differential signal to digitizers

• temperature sensor on board for offline gain calibration
custom made 800MHz digitizer

- 5ch, 800 MSpS
- 12 bit, TI ADS5401
- 1 V dynamic range
- <1 mV noise
- μTCA format

Poster by Sweigart, D. A new μTCA-based waveform digitizer for the Muon g-2 experiment
Talk by Gohn, W. Data Acquisition with GPUs: The DAQ for the Fermilab Muon g-2 Experiment
calorimeter at SLAC test beam
energy resolution 3% at 3GeV

both from data, and understanding of photo statistics and electronics contributions

Poisson comb of hit energies, 3 GeV electron beam
timing resolution 25ps at 3GeV

1. time differences within digitizer channels
2. time differences across channels

800 MSps, 1 tick is 1.25nsec
hit time extracted from leading edge
using a template fitter
relies on stability of pulse shape,
and uniformity of SiPM boards
pileup separation: double bunches
4.5 nsec separation

Pileup toolbox:
1. double-pulse fitter
2. spatial pattern of dep. energy
3. temporal pattern of hit times
4. pulse shape
energy scale stability

Three different timescales:
1. months, 2. muon fill of 700 µsec, 3. pileup ~10 nsec

load using laser:
~100 times more photons than a regular muon fill,
64 µsec exp decay in intensity, factor 1e4 over muon fill

probe with beam, specs: 1e-3, met.
laser calibration system

- gain stability of 0.04% in “offline” mode,
- 405 nm, same pulse shape and path as physics,
- laser monitors with Am/NaI reference,
- and local calorimeter monitors
pulse shape comparison

crystals wrapped in black Tedlar, to limit photon propagation to total internal reflection only
Beam related systematics, and EDM

Calorimeter acceptance is a function of decay vertex position, and positron momentum;

- coherent betatron oscillations
- muon momentum spread
- muons escaping storage region
- other early to late effects

Talk by Tishchenko, V. Muon storage for the Muon g-2 Experiment at Fermilab

Poster by Bjorkquist, R. Evaluating the Muon g-2 calorimeters as a beam diagnostic tool
Straw tracker design

- At 3 points around ring,
- 8 modules per station
- high-gain Ar:Ethane

Large azimuthal acceptance with low material (15µm Mylar)
Swiss-knife of Muon $g-2$ experiment

Measures stored **muon profile** and its time evolution. Addresses **pile-up** systematics, measure positron momentum. Detects **lost muons** escaping storage region. Measures **vertical pitch** of decay positrons $\rightarrow$ EDM measurement.

Determines area of **magnetic field map** seen by the muons. Limits the size or **radial and longitudinal** magnetic **fields**.

Makes an independent measurement of **positron momentum**.
Poster by Mott, J.  The readout system for the Fermilab Muon g-2 straw tracking detectors

Poster by Epps, A.  The construction and quality assurance testing of the Fermilab Muon g-2 straw tracking detectors

Poster by McEvoy, M.  The slow control system for the Fermilab Muon g-2 experiment
Test run at FNAL MTest beam

120 GeV protons, Silicon telescope, MWPC

Single straw radial resolution = 200 µm

Reconstructed hit radial resolution = 100 µm

Reconstructed hit vertical resolution = 750 µm

Confirmed by comparing to silicon tracks
Tracker performance met goals

hit position compared to wire chamber
drift time compared to silicon detector

Poster by Stuttard, T. The track reconstruction software and performance studies of the Fermilab Muon g-2 straw tracking detectors
Conclusions

Four fold improvement in determination of Muon g-2 requires new instrumentation.

Calorimeters and trackers are in production.

Detector installation in ring begins in Fall 2016

First beam arrives in Spring 2017.

Thank you very much!