A new method of measuring the muon g-2

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Four ways to measure the muon anomalous moment

\[ a_\mu = \frac{\nu - 2}{2} \]

Three have been shown to work

Fourth not yet tried ...... might be best of all

Trap muons in a magnetic field ..... many turns

If \( g = 2 \) the spin turns with the momentum

If spin turns faster, you measure the difference \( g - 2 \)

Tests a fundamental prediction of the standard model
Henry, Shrank & Swanson  1969

Measured $a_\mu$ to 6%

Below theory .... but if one applies pitch correction it is close
No pulse magnets .... muons make 1600 turns and emerge spontaneously at the other end

Charpak et al. 1961, 1962

Measured $a_\mu$ to 0.4 % agree with theory
Bailey et al. 1968, 1972

Measured $a_\mu$ to 270 ppm
14m diameter muon storage ring

pion injection

pulsed inflector

uniform field zero gradient

g-2 frequency is same at all radii

vertical focus by electric quadrupoles

“magic energy” 3.1 GeV
radial electric field does not affect g-2 frequency
\( \tau = 64 \ \mu\text{sec} \)
Muon storage rings

CERN 1.2 GeV gradient field, weak focusing

M uon storage rings

CERN 3.1 GeV uniform field, electric focusing

BNL 3.1 GeV uniform field, electric focusing

τ 27 proton injection

64 pion injection

27 muon injection
Blind analysis ...
  magnetic field evaluated by one group
  $g$-2 frequency evaluated by another group
  take ratio to calculate $a_\mu$

3 separate runs $\mu^+$ & $\mu^-$ agree with each other

Overall mean $a_\mu = 0.001165 \pm 0.000082 \ (55) \ 0.47 \ \text{ppm}$

Comparison with theory

DEHZ 03 (e^+e^-Based)
180.9 ± 8.0

DEHZ 03 (τ-Based)
195.6 ± 6.8

HMNT 03 (e^+e^-Based)
176.3 ± 7.4

J 03 (e^+e^-Based)
179.4 ± 9.3 (preliminary)

TY 04 (e^+e^-Based)
180.6 ± 5.9 (preliminary)

DEHZ 04 (e^+e^-Based)
182.8 ± 7.2 (preliminary)

including KLOE

BNL-E821 04
208 ± 5.8

\[ a_\mu = 11,659,000 \ (10^{-10}) \]

Exp - th = 25.2 ± 9.2 \times 10^{-11} 2.7 sigma

from Hoecker
hep-ph/0410081 v2
The future

Plans at Brookhaven
aim to halve the error using same superconducting ring magnet
more muons by improving pi - mu decay channel
larger aperture inflector
subdivide the detectors to reduce signal overlap
data taking in 2009 - 2010

To go further you need more g-2 cycles to measure
higher magnetic field B ... impossible with electric focusing ... breakdown

OR

go to higher energy ..... increase lifetime
say goodbye to the magic energy 3.1 GeV
cannot use electric focusing ..... need an AG ring
AG muon storage ring

Increase energy to 15 GeV

- muon lifetime $\rightarrow$ 320 μsec
- 5 x more g-2 cycles to measure
- ? increase $B$ to 3 - 4 T? 10 x more cycles to measure

Use AG focusing

- need $B$ independent of orbit radius
  - momentum compaction factor $\alpha = dR / dp = 1$

To calibrate the magnetic field

- abandon static NMR
- use horizontally polarized protons in flight
  - i.e. use proton g-2 to calibrate muon g-2
  - $a = 1.789284739$ (30 ppb)
  - polarized proton source and polarimeter in use in RHIC
Ring design

Momentum compaction factor  \( \alpha = \frac{dR}{dp} = 1 \)

Well-known formula  \( \alpha = \frac{1}{Q_h^2} \)

Courant & Snyder, Annals of Physics (1958)

Example: weak focusing  \( Q_h = \sqrt{1 - n} \)

\( \alpha = \frac{1}{1 - n} \)

If  \( \alpha = 1, \)  \( Q_h = 1 \)

horizontal resonance
Uniform field independent of radius (momentum)

Vertical focusing from magnet edges

Horizontal focusing from bends

No limit on energy - longer muon lifetime
Figure 2 - 

\[ \text{Number of sectors} = 4 \]

\[ Q_v \quad \text{vs} \quad \text{open wedge angle} \quad \text{for 4 sector ring} \]
3 sector concept

\[ B = 4.5 \, T \quad \langle B \rangle = 3.8 \, T \]

bend radius 12 m
straight sections 4.3 m
momentum 15 GeV/c
\( Q_h = 1.025 \)
\( Q_v = 0.4 \)
muon lifetime 320 \( \mu s \)

need 10 billion recorded
decay electrons
say 50 billion injected muons
Advantages

no electric quadrupoles
no trolley
  calibration
  correction for diamagnetism in water
  paramagnetism in surrounding materials

no inflector to cancel the field in the magnet at injection
simple kicker using ferrite

higher energy ... e.g. 15 GeV
  increased accuracy
  longer lifetime reduces the counting rate
  less signal overlap
  less residual flash

higher magnetic fields
  increased accuracy
A new ring structure for muon g-2 measurements

Nuclear Instruments and Methods, A 523 (2004) 251

hep-ex/0307024
Reduce error in $a_\mu$ to 50 ppb ........... ! ! !

Is it worth it ??

uncertainty in theory is 500 ppb ...... but it will improve

hadronic contribution calculated by lattice QCD

when new physics is discovered it will have its effect on $a_\mu$

theorists will want to know if they are right

Historically experiment has often been ahead of theory
fine structure
  Zeeman effect
  Stern Gerlach
  Kusch & Foley
  Lamb shift
HAPPY BIRTHDAY LARRY

Bonne continuation