Muon $g-2$ session

USQCD All Hands Meeting, BNL

April 30, 2016

Background

E821 at BNL measured relative precession of muon spin to it's momentum $\omega_a = \frac{g-2}{2}\frac{eB}{m} = a_\mu \frac{eB}{m}$

The rate of detected electrons oscillates with ω_a, fit to $N(t) = Be^{-\lambda t}(1 + A\cos\omega_a t + \phi)$

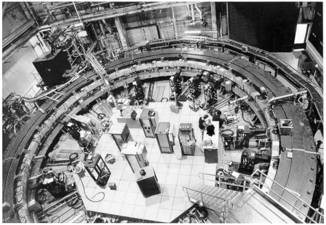


Figure 12. The storage-ring magnet. The cryostats for the inner-radius coils are clearly visible. The kickers have not yet been installed. The racks in the center are the quadrupole pulsers, and a few of the detector stations are installed, especially the quadrant of the ring closest to the person. The magnet power supply is in the upper left, above the plane of the ring. (Courtesy of Brookhaven National Laboratory)

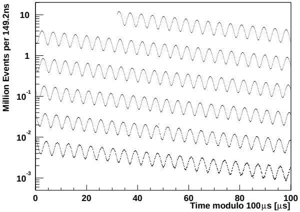
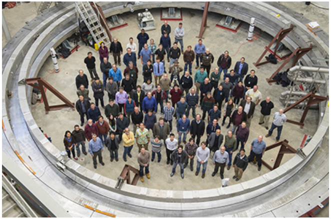


Figure 26. Histogram of the total number of electrons above 1.8 GeV versus time (modulo 100 μ s) from the 2001 μ^- data set. The bin size is the cyclotron period, $\approx$ 149.2 ns, and the total number of electrons is 3.6 billion.

$a_\mu(\mathrm{Expt}) = 11\,659\,208.0(5.4)(3.3) \times 10^{-10}$ 0.54 ppm!

Storage ring moved to FNAL for E989, beginning in 2017

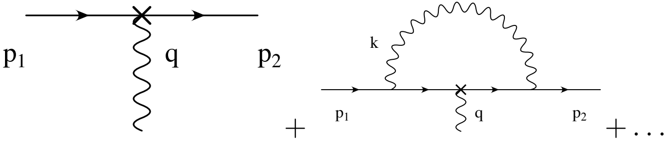


which is aiming for 0.14 ppm, $4\times$ improvement!

Priority for DOE

In Japan at J-PARC, the E34 experiment will measure a_μ using ultra-cold muons in a "table-top" experiment ($\sim$ 2020)

In interacting quantum field theory g gets corrections



$$\langle \mu(p') | J^\mu | \mu(p) \rangle \;=\; \bar{u}(p') \left(\gamma^\mu F_1(q^2) + i \frac{[\gamma^\mu, \gamma^\nu]\, q^\nu}{2} \frac{F_2(q^2)}{2m} \right) u(p)$$

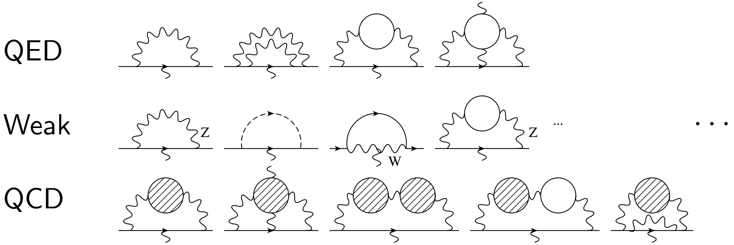
which results from Lorentz invariance and charge conservation when the muon is on-mass-shell and where $q = p' - p$

$$F_2(0) \;=\; \frac{g-2}{2} \equiv a_\mu \qquad (F_1(0) = 1)$$

(the anomalous magnetic moment, or anomaly)

Compute corrections order-by-order in perturbation theory by expanding $\Gamma^{\mu}(q^2)$ in QED coupling constant

$$\alpha \quad = \quad \frac{e^2}{4\pi} = \frac{1}{137} + \ldots$$

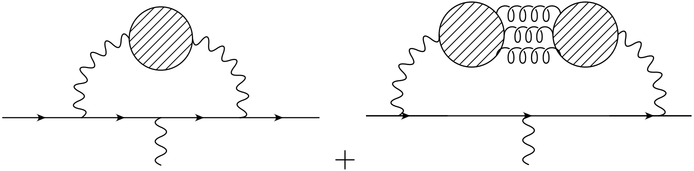


Corrections begin at $\mathcal{O}(\alpha)$; Schwinger term $= \frac{\alpha}{2\pi} = 0.0011614\ldots$

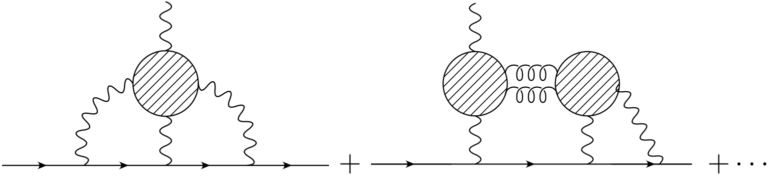
hadronic contributions $\sim 6 \times 10^{-5}$ smaller, dominate theory error.

Hadronic contributions

$O(\alpha^2)$: hadronic vacuum polarization (HVP)



$O(\alpha^3)$: hadronic light-by-light (HLBL)



Experiment - Standard Model Theory = difference

SM Contribution	Value $\pm$ Error ($\times 10^{11}$)	Ref
QED (5 loops)	116584718.951 ± 0.080	[Aoyama et al., 2012]
HVP LO	6923 ± 42	[Davier et al., 2011]
	6949 ± 43	[Hagiwara et al., 2011]
HVP NLO	-98.4 ± 0.7	[Hagiwara et al., 2011]
		[Kurz et al., 2014]
HVP NNLO	12.4 ± 0.1	[Kurz et al., 2014]
HLbL	105 ± 26	[Prades et al., 2009]
HLbL (NLO)	3 ± 2	[Colangelo et al., 2014]
Weak (2 loops)	153.6 ± 1.0	[Gnendiger et al., 2013]
SM Tot (0.42 ppm)	116591802 ± 49	[Davier et al., 2011]
(0.43 ppm)	116591828 ± 50	[Hagiwara et al., 2011]
(0.51 ppm)	116591840 ± 59	[Aoyama et al., 2012]
Exp (0.54 ppm)	116592080 ± 63	[Bennett et al., 2006]
Diff (Exp − SM)	287 ± 80	[Davier et al., 2011]
	261 ± 78	[Hagiwara et al., 2011]
	249 ± 87	[Aoyama et al., 2012]

New experiments+new theory=new physics

- Fermilab E989 early 2017, aims for 0.14 ppm
- J-PARC E34 late 2010's-2020, aims for 0.3-0.4 ppm
- Today $a_\mu(\mathrm{Expt})$-$a_\mu(\mathrm{SM}) \approx 2.9 - 3.6\sigma$
- If both central values stay the same,
  - E989 ($\sim 4\times$ smaller error) $\rightarrow \sim 5\sigma$
  - E989+new HLBL theory (models+lattice, 10%) $\rightarrow \sim 6\sigma$
  - E989+new HLBL +new HVP (50% reduction) $\rightarrow \sim 8\sigma$
- Good for discriminating models if discovery of BSM at LHC

  [Stckinger, 2013]
- Lattice calculations important to trust theory errors
- Lattice calculations Priority for DOE

Proposals

- Hadronic contributions to the muon $g-2$ using staggered fermions

  (PI: Christopher Aubin). Request: 40.2 M JPsi core-hours, 96 TB disk, 96 TB tape

- Muon $g-2$ Hadronic Vacuum Polarization from 2+1+1 flavors of sea quarks using the HISQ action

  (PI: Jack Laiho). Request: 15% ZPT on Mira, 0.35 M K40 gpu-hours at FNAL

- QCD + QED studies using Twist-Averaging

  (PI: Christoph Lehner). Request: 33.2 M Jpsi core-hours

- Continuum limit of Hadronic Vacuum Polarization contributions for $(g-2)_\mu$ and inclusive τ decay analysis on physical point Mobius-DWF ensemble

  (PI: Tom Blum). Request: 64.5 M Jpsi core-hrs on Pi0, 76 TB disk, 1.5 PB tape

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