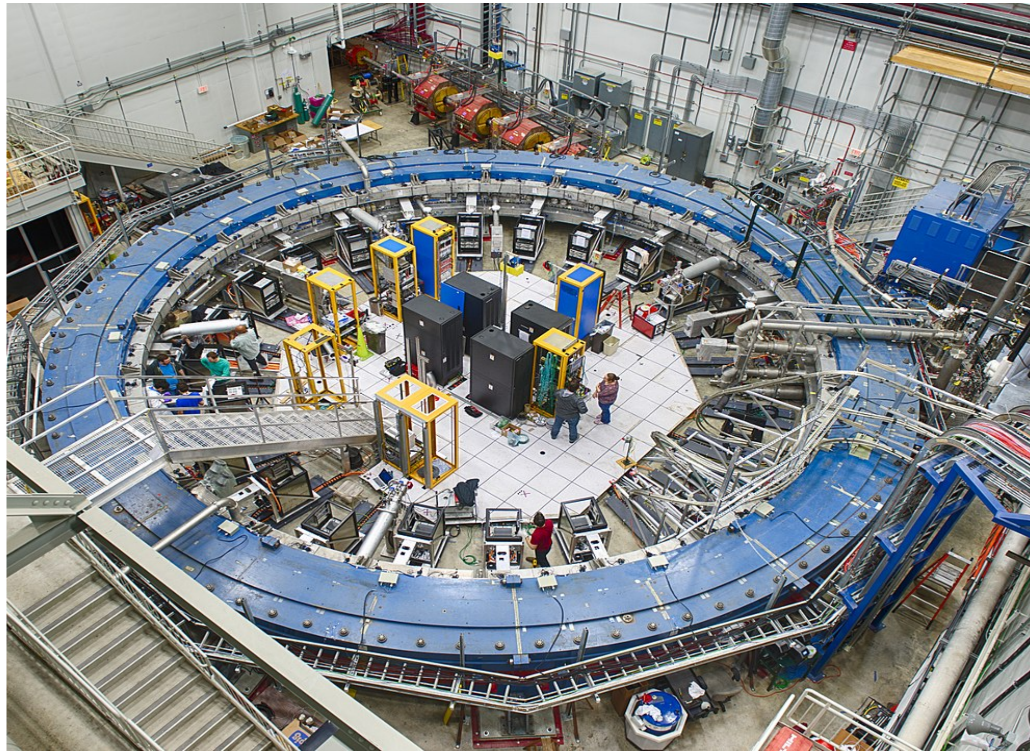


The Muon g-2 experiment

XXXII International Otranto School
11 June 2021

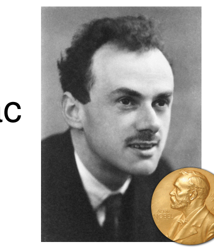
Paolo Girotti

The g-2

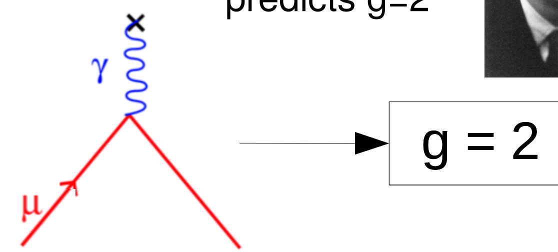
- Muon: elementary spin-1/2 particle with magnetic moment proportional to spin through the g-factor:

$$\vec{\mu} = g \frac{q}{2m} \vec{S}$$

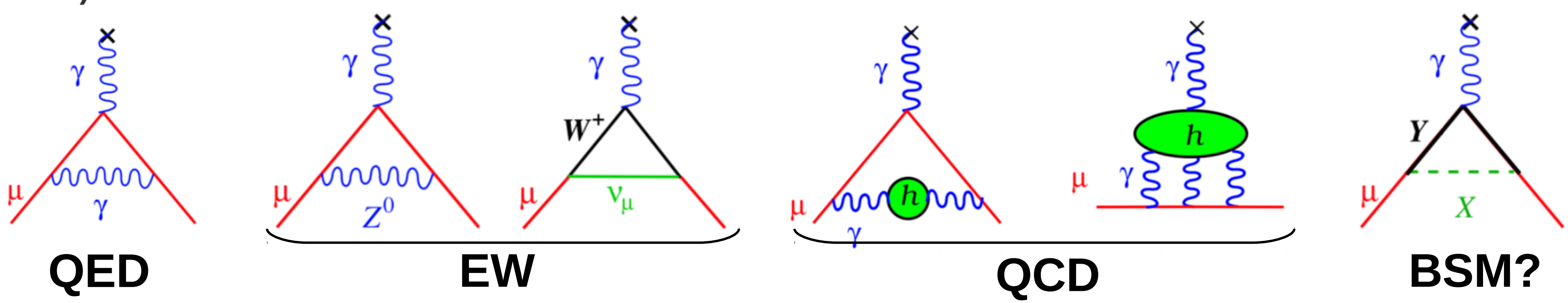
1928: Paul Dirac predicts g=2



- If there were no quantum loop corrections:



- With high-order corrections considered (from all particle physics!) :

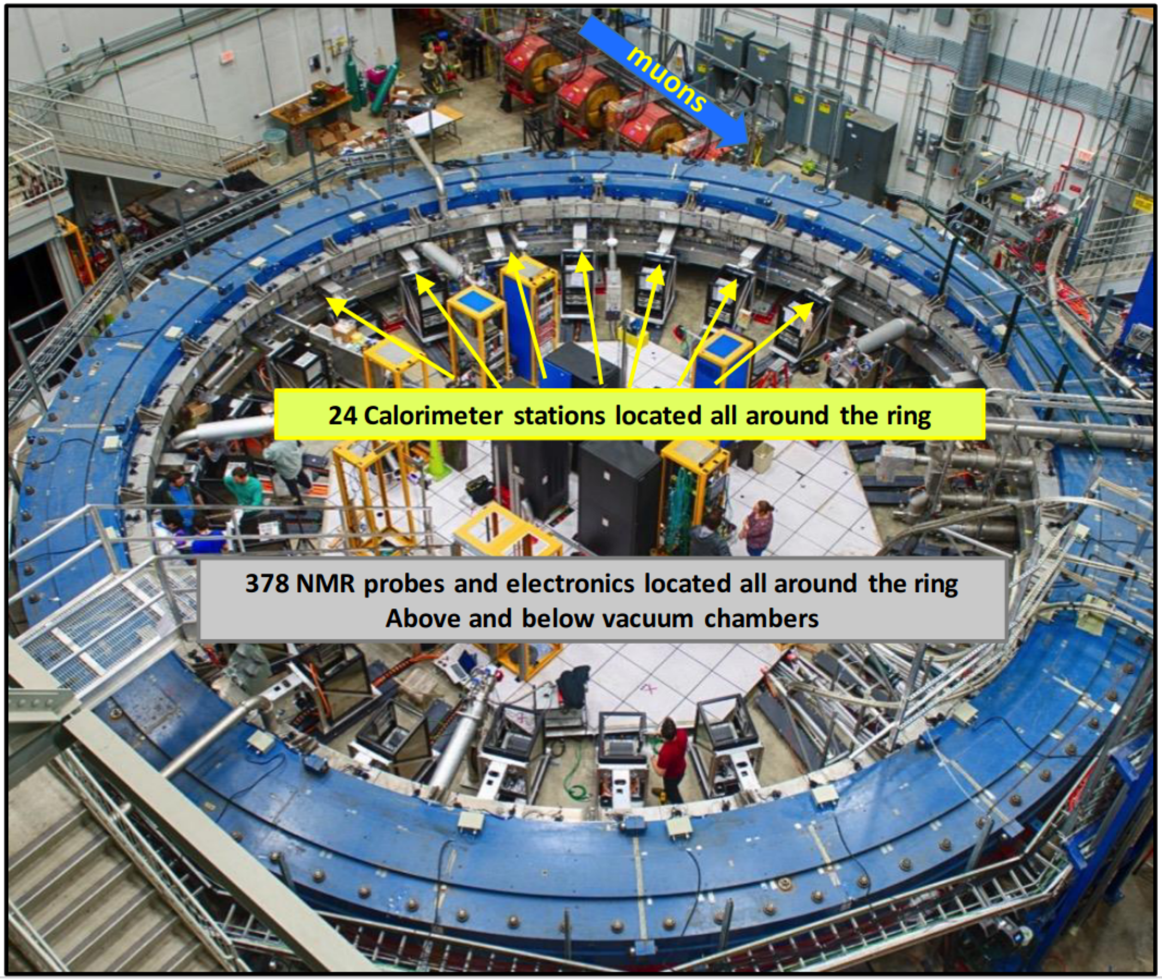


$a_\mu \equiv (g-2)/2$ = 0.0011658… +0.000000001536... +0.000000069383… **+?**

The experiment

$$a_\mu = \frac{\omega_a}{\tilde{\omega}'_p(T_r)} \frac{\mu'_p(T_r)}{\mu_e(H)} \frac{\mu_e(H)}{\mu_e} \frac{m_\mu}{m_e} \frac{g_e}{2}$$

$$\frac{\omega_a}{\tilde{\omega}'_p(T_r)} = \frac{f_{\mathrm{clock}}\,\omega_a^m (1 + C_e + C_p + C_{ml} + C_{pa})}{f_{\mathrm{calib}} \langle \omega_p(x,y,\phi) \times M(x,y,\phi) \rangle (1 + B_k + B_q)}$$



- Highly polarized muon beam @3.1 GeV
- Magnet ring with 1.45 T high-uniformity field (
- 24 PbF_2 calorimeters (1296 SiPMs) and 2 tracker stations to measure positrons (muon w_a)
- 378 fixed + 17 movable Nuclear Magnetic Resonance probes to measure w_p (B)

The muon decays

- V-A decay, positron follows spin direction, and highest energy positrons occur when spin and momentum vector are aligned

$$a_\mu \propto \frac{f_{\text{clock}}\ \omega_a^m\ (1 + C_e + C_p + C_{ml} + C_{pa})}{f_{\text{calib}}\ \langle \omega'_p(x,y,\phi) \times M(x,y,\phi) \rangle\ (1 + B_k + B_q)}$$

22 parameter fit function

$$N_0\, e^{-\frac{t}{\gamma\tau}} \left(1 + A \cdot A_{BO}(t) \cos(\omega_a t + \phi \cdot \phi_{BO}(t))\right) \cdot N_{\text{CBO}}(t) \cdot N_{\text{VW}}(t) \cdot N_y(t) \cdot N_{2\text{CBO}}(t) \cdot J(t)$$

$$A_{\text{BO}}(t) = 1 + A_A \cos(\omega_{\text{CBO}}(t) + \phi_A) e^{-\frac{t}{\tau_{\text{CBO}}}}$$

$$\phi_{\text{BO}}(t) = 1 + A_\phi \cos(\omega_{\text{CBO}}(t) + \phi_\phi) e^{-\frac{t}{\tau_{\text{CBO}}}}$$

$$N_{\text{CBO}}(t) = 1 + A_{\text{CBO}} \cos(\omega_{\text{CBO}}(t) + \phi_{\text{CBO}}) e^{-\frac{t}{\tau_{\text{CBO}}}}$$

$$N_{2\text{CBO}}(t) = 1 + A_{2\text{CBO}} \cos(2\omega_{\text{CBO}}(t) + \phi_{2\text{CBO}}) e^{-\frac{t}{2\tau_{\text{CBO}}}}$$

$$N_{\text{VW}}(t) = 1 + A_{\text{VW}} \cos(\omega_{\text{VW}}(t) t + \phi_{\text{VW}}) e^{-\frac{t}{\tau_{\text{VW}}}}$$

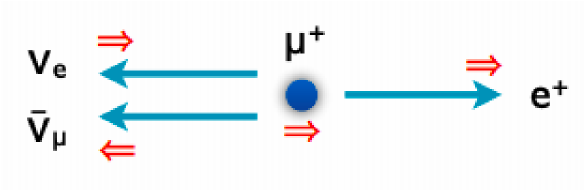
$$N_y(t) = 1 + A_y \cos(\omega_y(t) t + \phi_y) e^{-\frac{t}{\tau_y}}$$

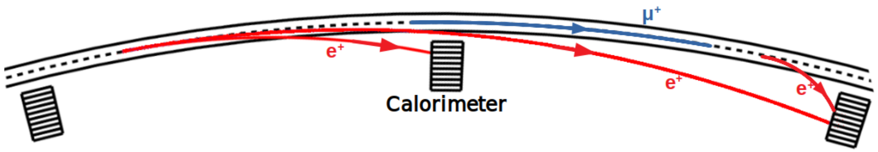
$$J(t) = 1 - k_{LM} \int_{t_0}^{t} \Lambda(t) dt$$

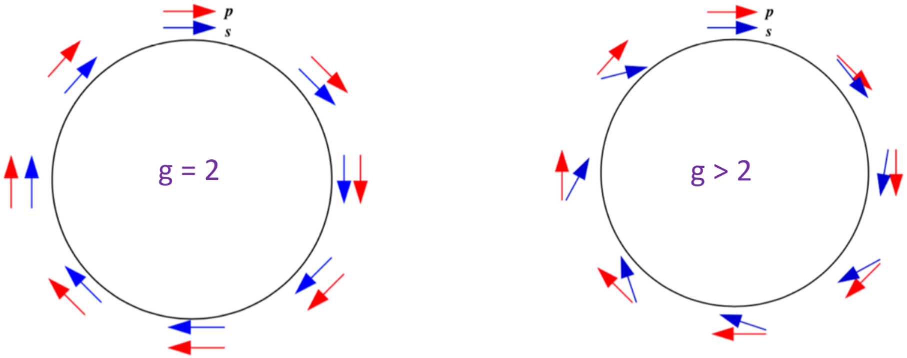
$$\omega_{\text{CBO}}(t) = \omega_0 t + A e^{-\frac{t}{\tau_A}} + B e^{-\frac{t}{\tau_B}}$$

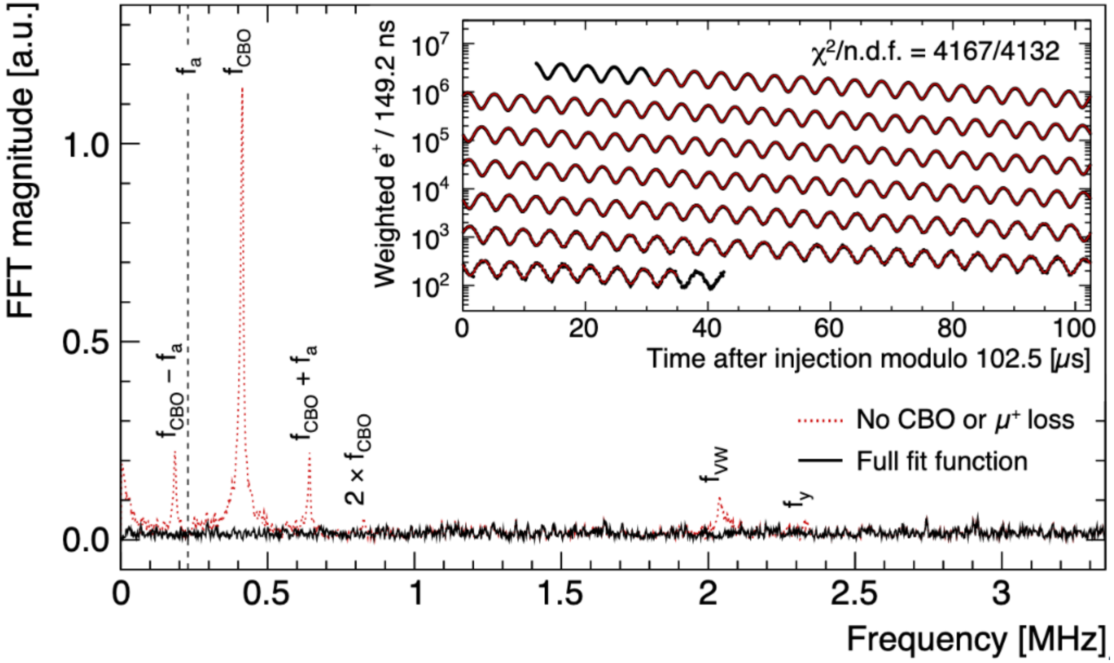
$$\omega_y(t) = F \omega_{\text{CBO}(t)} \sqrt{2\omega_c / F \omega_{\text{CBO}}(t) - 1}$$

$$\omega_{\text{VW}}(t) = \omega_c - 2\omega_y(t)$$



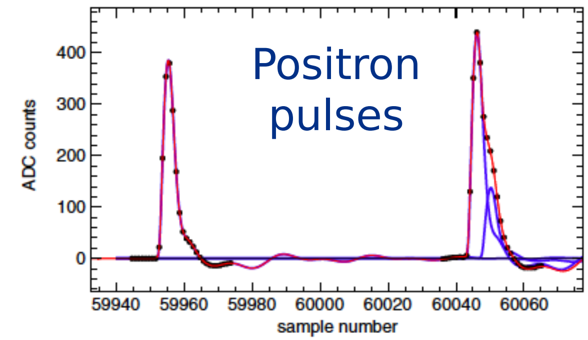


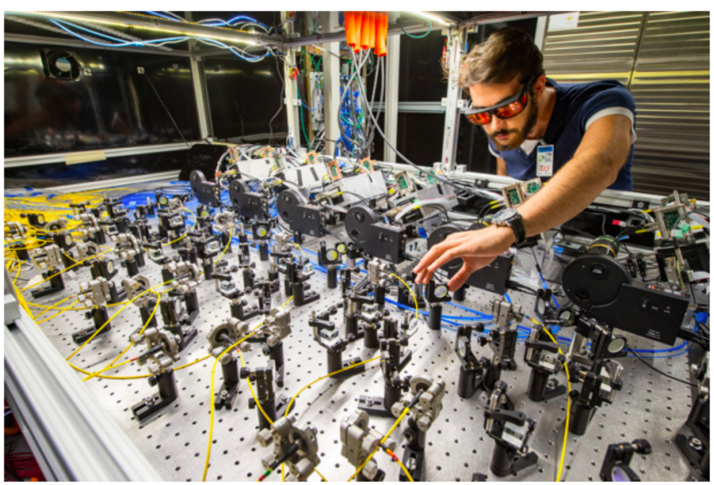




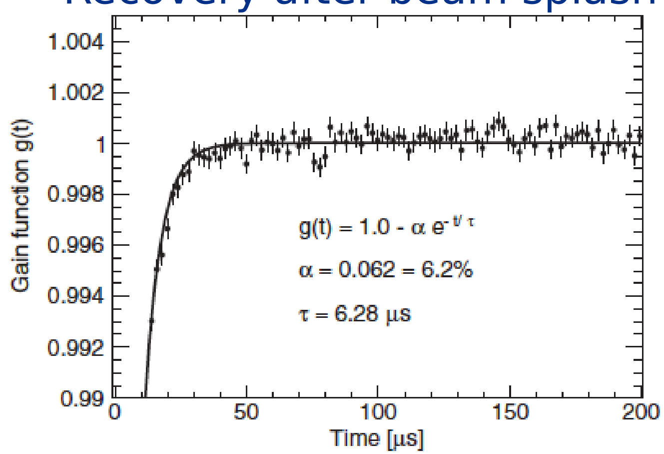
The Laser Calibration System

- Built by the Italian team (INFN-INO)
- 405 nm short laser pulses shot before, during, and after beam injection
- Channel time synchronization at 0.1 ns level
- Chanel gain calibration at 0.0001 level
- Pileup and gain systematics reduced from 180 ppb at BNL to 41 ppb

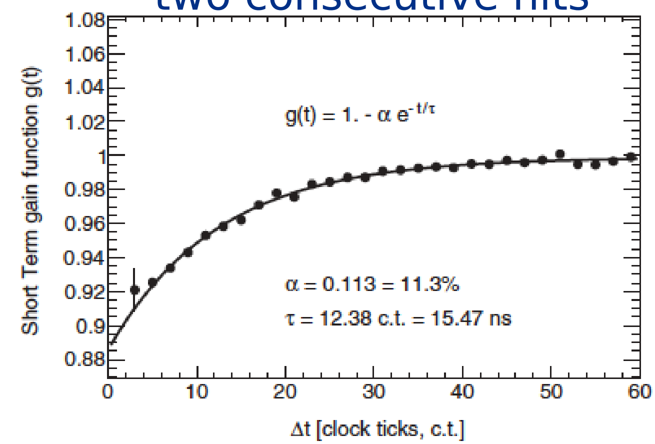




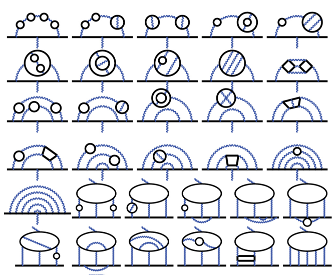
Recovery after beam splash



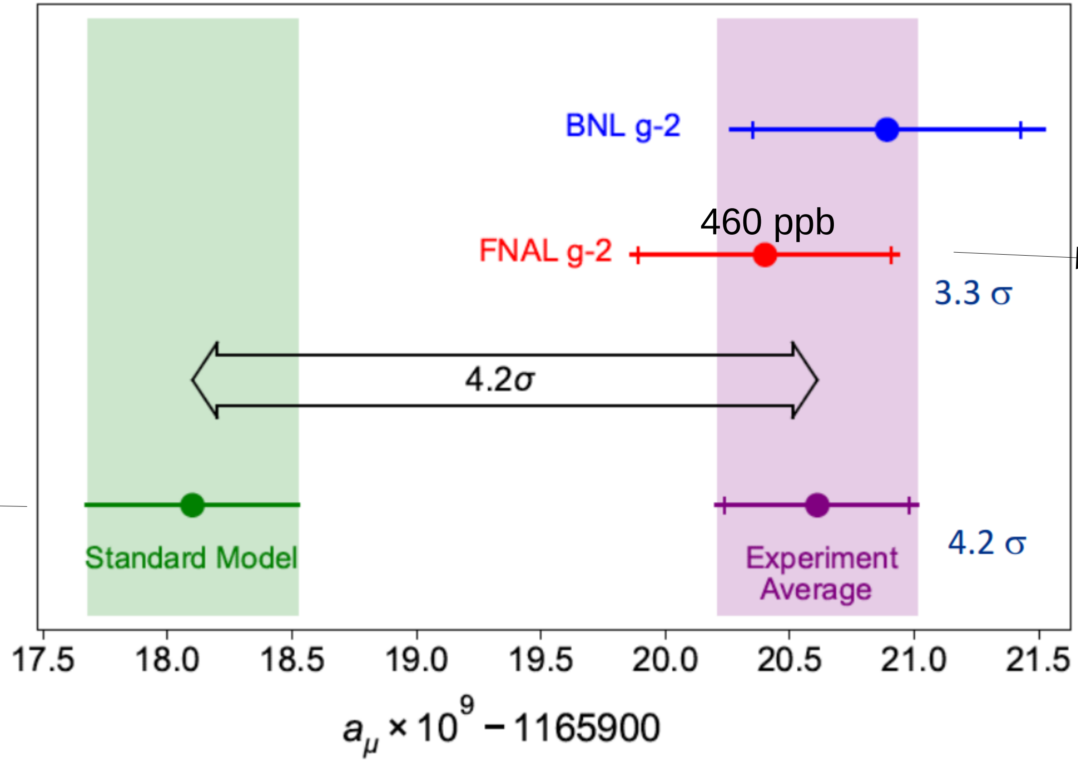
Recovery between two consecutive hits



Status



https://doi.org/10.1016/j.physrep.2020.07.006



3.7

3.3 σ

4.2 σ

Run1 7 April 2021

Quantity	Correction terms (ppb)	Uncertainty (ppb)
ω_a^m (statistical)	$\cdots$	434
ω_a^m (systematic)	$\cdots$	56
C_e	489	53
C_p	180	13
C_{ml}	−11	5
C_{pa}	−158	75
$f_{\text{calib}}\langle\omega_p(x,y,\phi) \times M(x,y,\phi)\rangle$	$\cdots$	56
B_k	−27	37
B_q	−17	92
$\mu'_p(34.7°)/\mu_e$	$\cdots$	10
m_μ/m_e	$\cdots$	22
$g_e/2$	$\cdots$	0
Total systematic	$\cdots$	157
Total fundamental factors	$\cdots$	25
Totals	544	462

https://doi.org/10.1103/PhysRevLett.126.141801
https://doi.org/10.1103/PhysRevD.103.072002
https://doi.org/10.1103/PhysRevA.103.042208
https://doi.org/10.1103/PhysRevAccelBeams.24.044002
https://doi.org/10.1088/1748-0221/14/11/P11025

a_μ = 0.001 165 918 108 ± 378 (theory)
a_μ = 0.001 165 920 610 ± 410 (experiment)

- High precision theory
- High precision experiment
- Current discrepancy suggests new physics
- Experiment continuing with 140 ppb goal