# Muon Anomalous Magnetic Moment
# --a harbinger of new physics

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Physics 564

# Outline

- Introduction
- Experimental Approach
  - Generate and Store Muons
  - Measure Anomalous Spin Precession Frequency
- Theoretical Approach
  - QED
  - Hadronic
  - Electroweak
- Comparison
- New Physics?

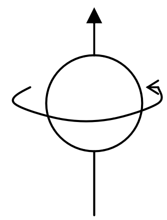
# Anomalous Magnetic Moment

- Spin Angular Momentum: $\vec{\mu}_s = \frac{ge\vec{S}}{2m_e c}$

Dirac Equation predicted $g = 2$ for spin-1/2 particle w/o substructure

--1928

- However,
  - Proton $g_p = 5.8$
  - Neutron $g_n = -3.8$



Evidence of Quark Model!

--1960s

Definition of Anomalous Magnetic Moment: $a = \frac{g-2}{2}$

Which can be theoretically calculated very accurate!

Thus it is a good choice for experimentalists to examine theoretical correction.

# Brookhaven E821 Experiment

Anomalous spin precession frequency: $\dfrac{ea_\mu B}{m_\mu c}$

Larmor frequency: $geB/2m_\mu c$

Anomalous magnetic moment: $\dfrac{\omega_a}{\omega_L - \omega_a}$

Both frequencies are measured in units of the the free proton precession frequency (by NMR).

## Blind Data Analysis Philosophy:

Independent analyses of the two parameters were made by different groups.

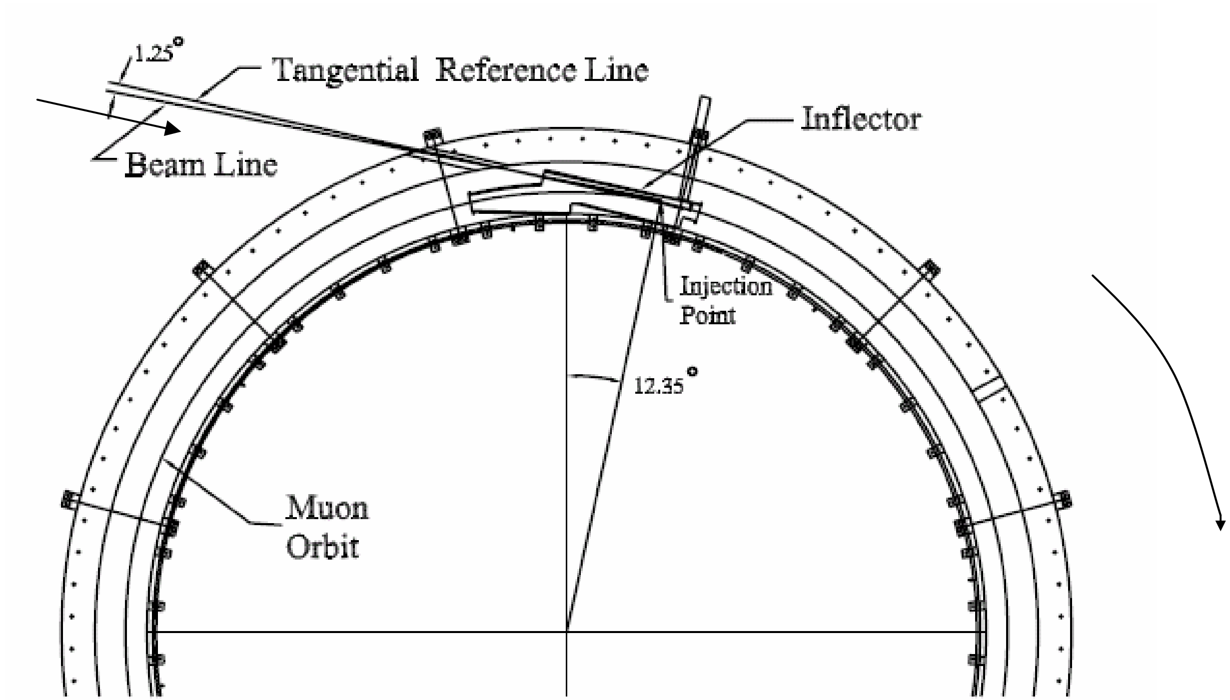
No one knows information to compute the final result before completion.

# Generate and Store Muons

Protons+ nickel target ⟶ pions ⟶ secondary muons

The charge of muons can be selected by adjusting experimental parameter.

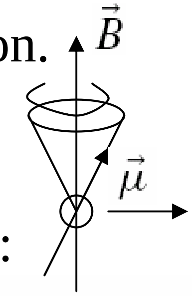
Muons were polarized and injected to the muon storage ring.



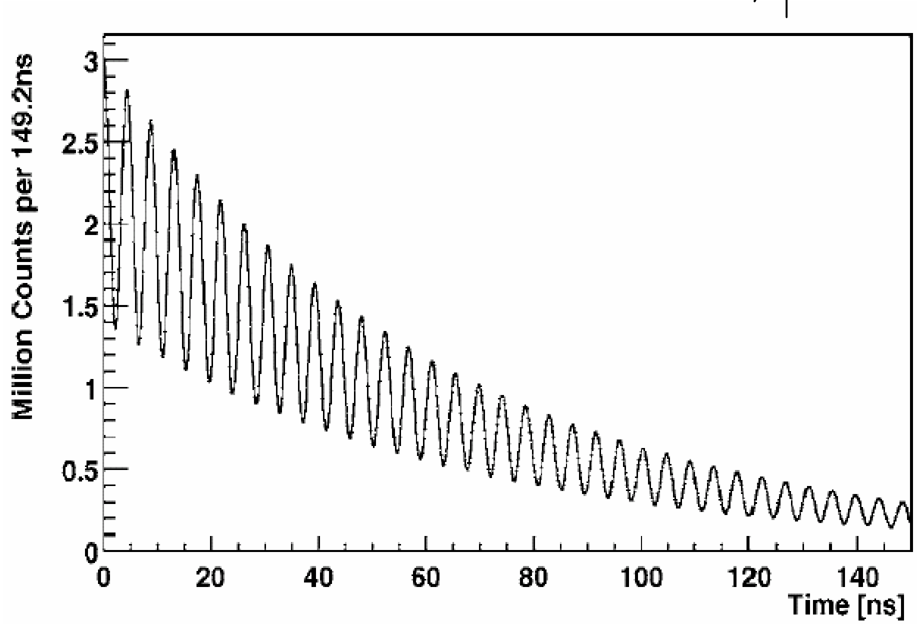

Inflector and Storage Ring

# Measure The Anomalous Magnetic Moment

- Muons will decay in the storage ring $\mu^- \rightarrow e^- \bar{\nu}_e \nu_\mu$
- Energy of the electron is related to the polarized direction of muon.
- If spin is aligned with momentum, it's LESS likely to get high-energy electron.
- If spin is opposite to momentum, it's MORE likely to get high-energy electron.
- The rate of detected electrons above a specified threshold energy:




$$\frac{dN(t; E_{\rm th})}{dt} = N_0 e^{-t/\gamma\tau_\mu}\left[1 + A\cos(\omega_a t + \phi)\right]$$

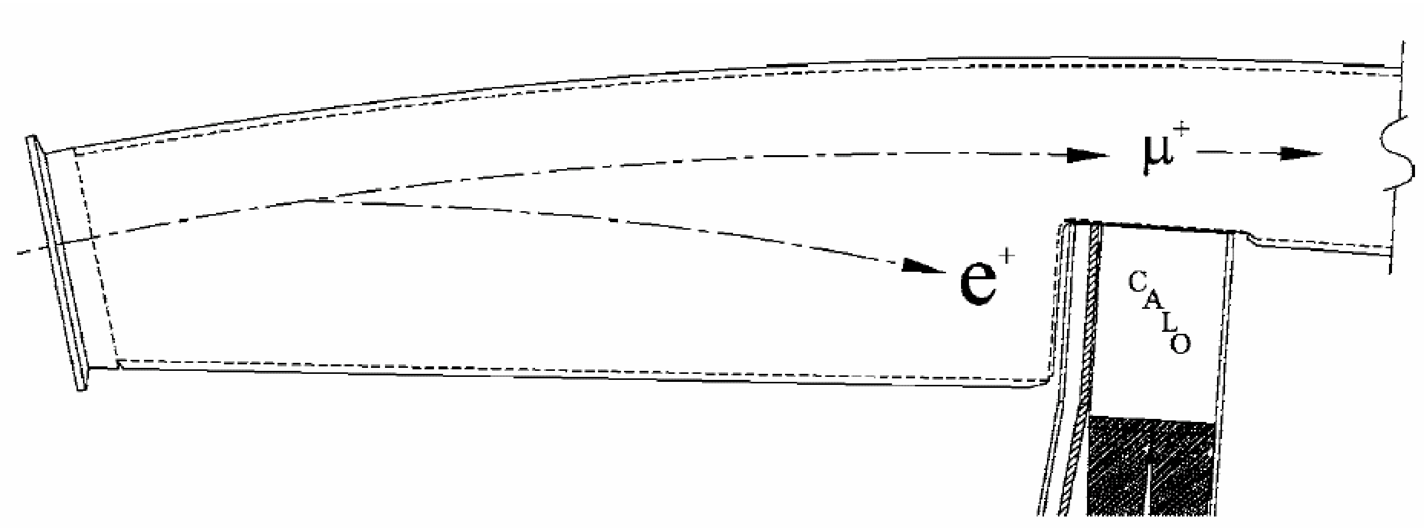



If we can get the time spectrum of detected electrons, then we can get anomalous spin precession frequency!

## Need to Measure: electron energy

as following…

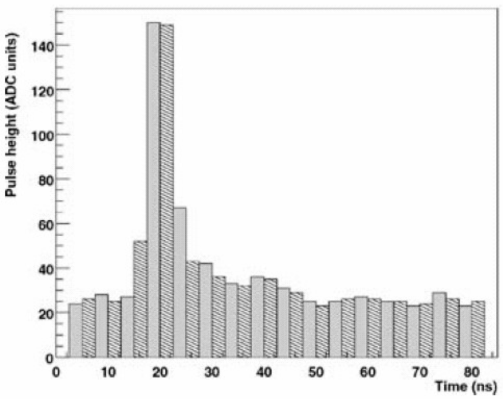
# Electron Detector System



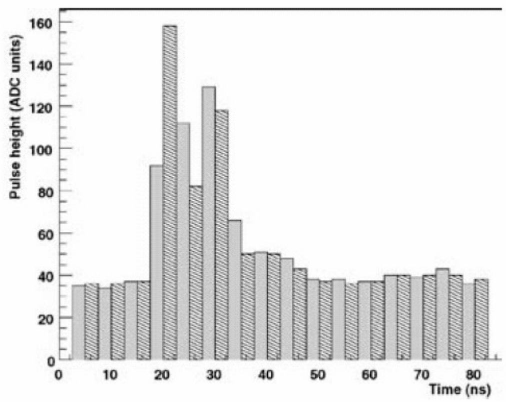

Top view of the chamber and calorimeter.

The energy of the decay positron was detected by the calorimeter.

# Data Analysis




One Pulse




Two Close Pulses

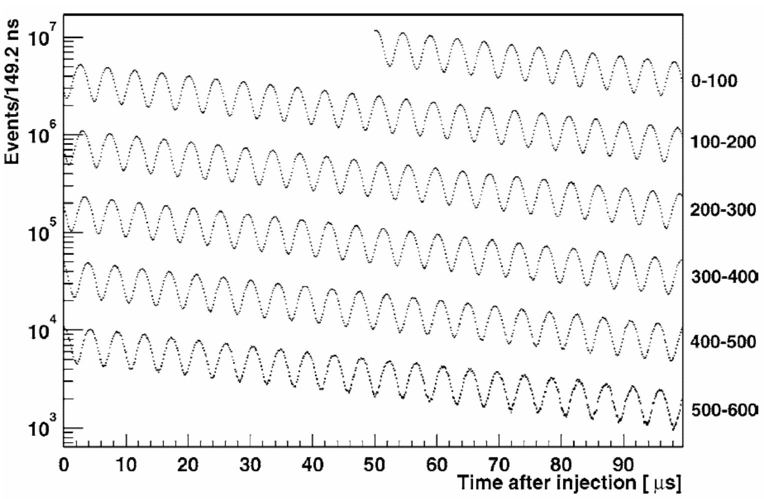
Pile-Up

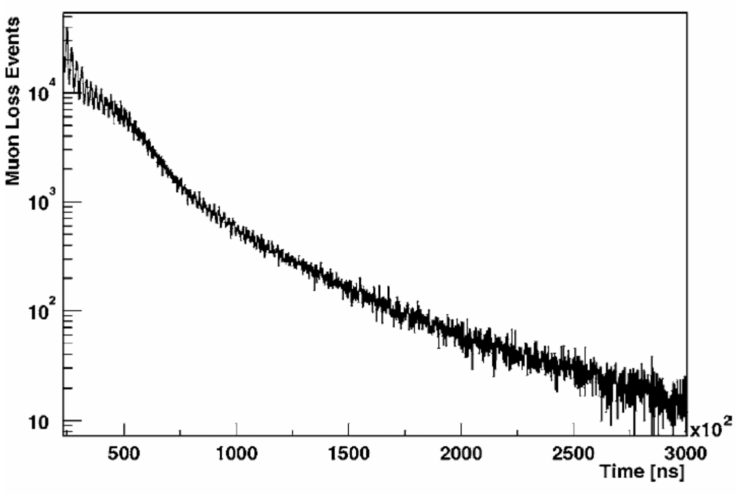
Pulses separated by >3.5-5ns are resolved reliably and recorded as individual events.

▪The injected ~50-ns-long muon bunches expand all over the ring after about 0.025ns.

▪Pileup-subtracted histograms are created for each detector and run and now are ready for fitting.

# Data Analysis




Histogram of 4 billion decay electrons from the 2000 run.

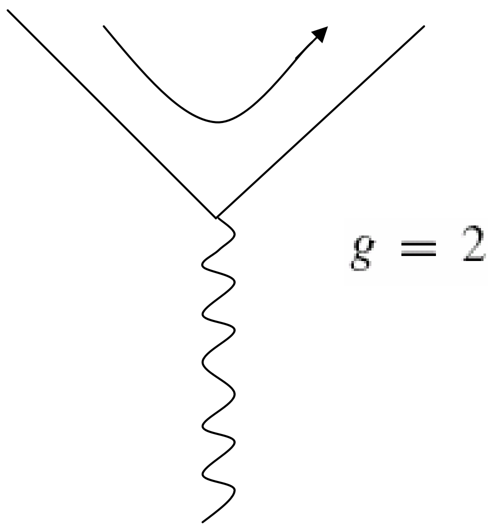
Muon loss events vs. time after injection.

In principle, these data can be fitted to the function we introduced previously.

In fact, more data analysis techniques are used.

# Theory

The first Order is:

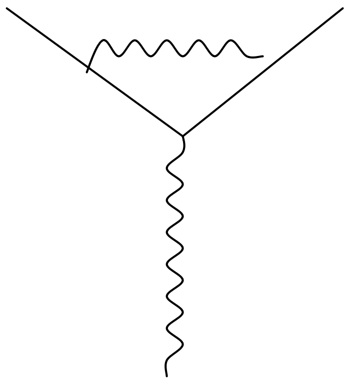


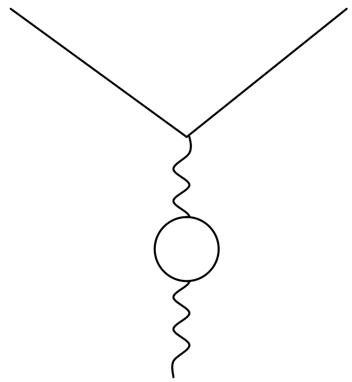

There are also other known or unknown contributions:

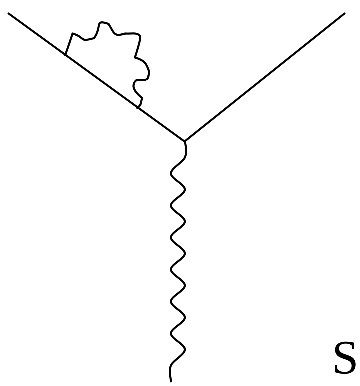
QED, Hadronic, Electroweak, and so on.

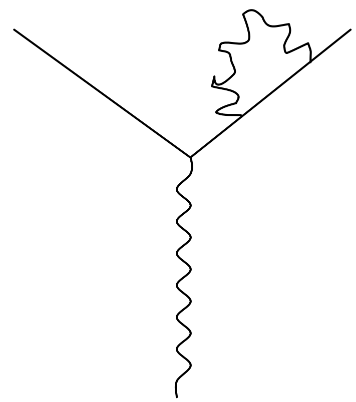
Need to Calculate higher order Feynman Diagram.

# QED Contribution





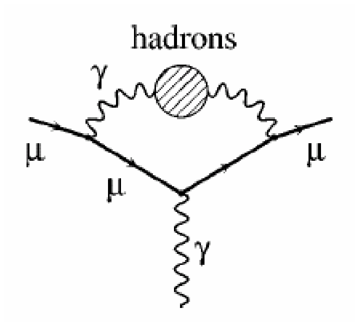




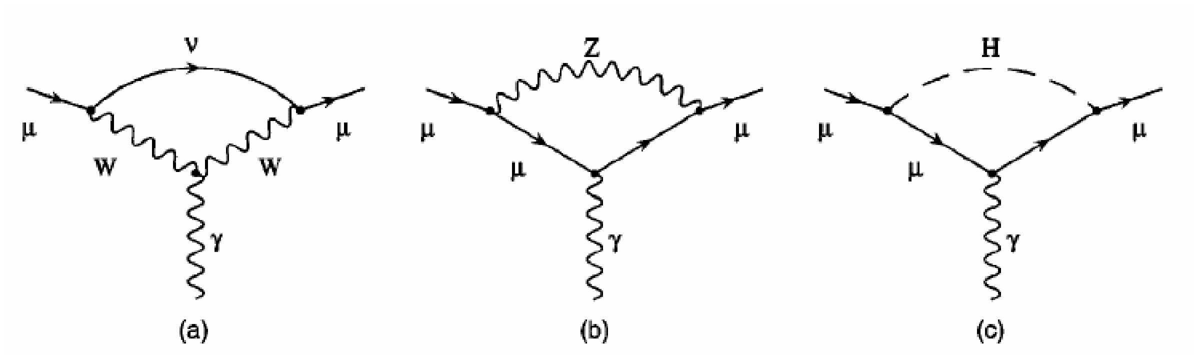
Second order diagrams

# Hadronic and Electroweak Contribution

Hadronic Effects:




Electroweak Effects:



# Comparison

Experimental value: $a_{\mu^\pm}(\text{expt.}) = 11659208(6) \times 10^{-10} \quad [0.5\,\text{ppm}]$

QED: $a_\mu^{\text{QED}} = 116\,584\,705.7(2.9) \times 10^{-11}$

Hadronic: $a_\mu^{\text{Had}}(\text{vac. pol.}) = 6924(62) \times 10^{-11}$

Electroweak: $a_\mu^{\text{EW}} = 152(4) \times 10^{-11}$

Standard Model Value: $116\,591\,597(67) \times 10^{-11}$

Room for new physics:

$$215 \times 10^{-11} \leqslant a_\mu(\text{new physics}) \leqslant 637 \times 10^{-11}$$

# New Physics?

- ➢ IF THE NEW PHYSICS IS,
- SUperSYmmetry (SUSY)

  New SUSY particles are expected to be discovered soon at Fermilab and LHC.
- Minimal SUperGRAvity (mSUGRA)

The branching ratio of $B_s \to \mu^+\mu^-$ will be largely enhanced and can be detected by Tevatron.

- Anomalous W boson properties

  Not so likely, it have been ruled out because of contradiction to existing data.
- New gauge bosons, muon compositeness, extra Higgs bosons, leptoquarks ,bileptons, compact extra dimensions,
- And many many…

The parameters of new physics can be narrowed and determined with the development of more accurate experiments for muon anomalous magnetic moment and other effects.