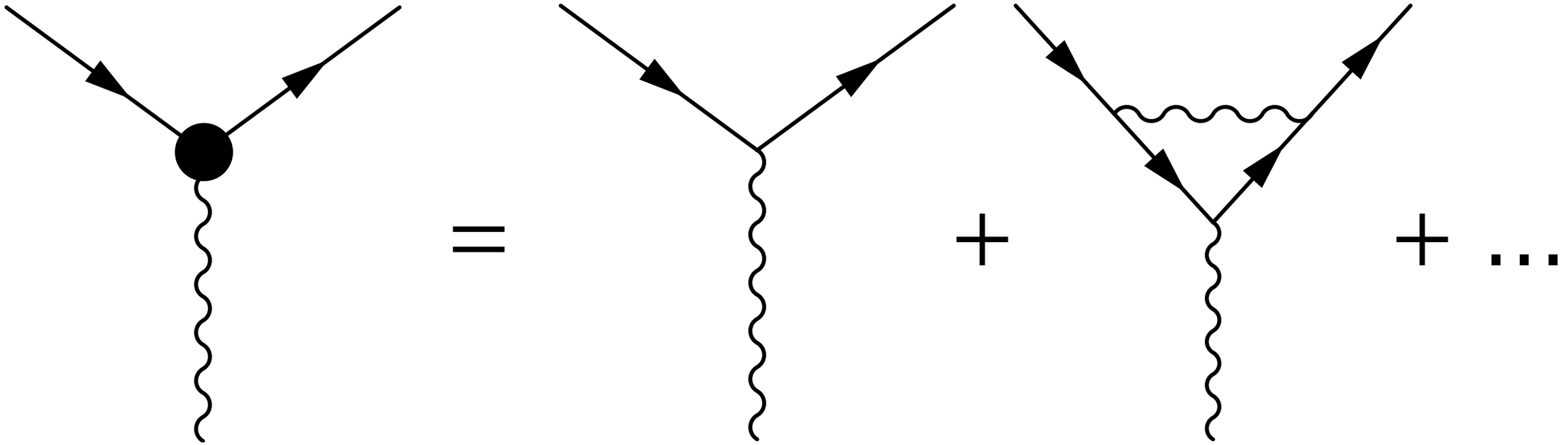
Anomalous Magnetic Moment

$$g = 2 + \alpha/\pi$$



Modification of j^μ leads to
modification of magnetic moment

Anomalous Magnetic Moment

Define:

$$a_e = \frac{1}{2}(g_e - 2)$$

"Anomaly"

$$a_e = \frac{\alpha}{2\pi} + C_2\left(\frac{\alpha}{\pi}\right)^2 + C_3\left(\frac{\alpha}{\pi}\right)^3 + C_4\left(\frac{\alpha}{\pi}\right)^4 + \ldots$$

1st order

2nd order

3rd order

4th order

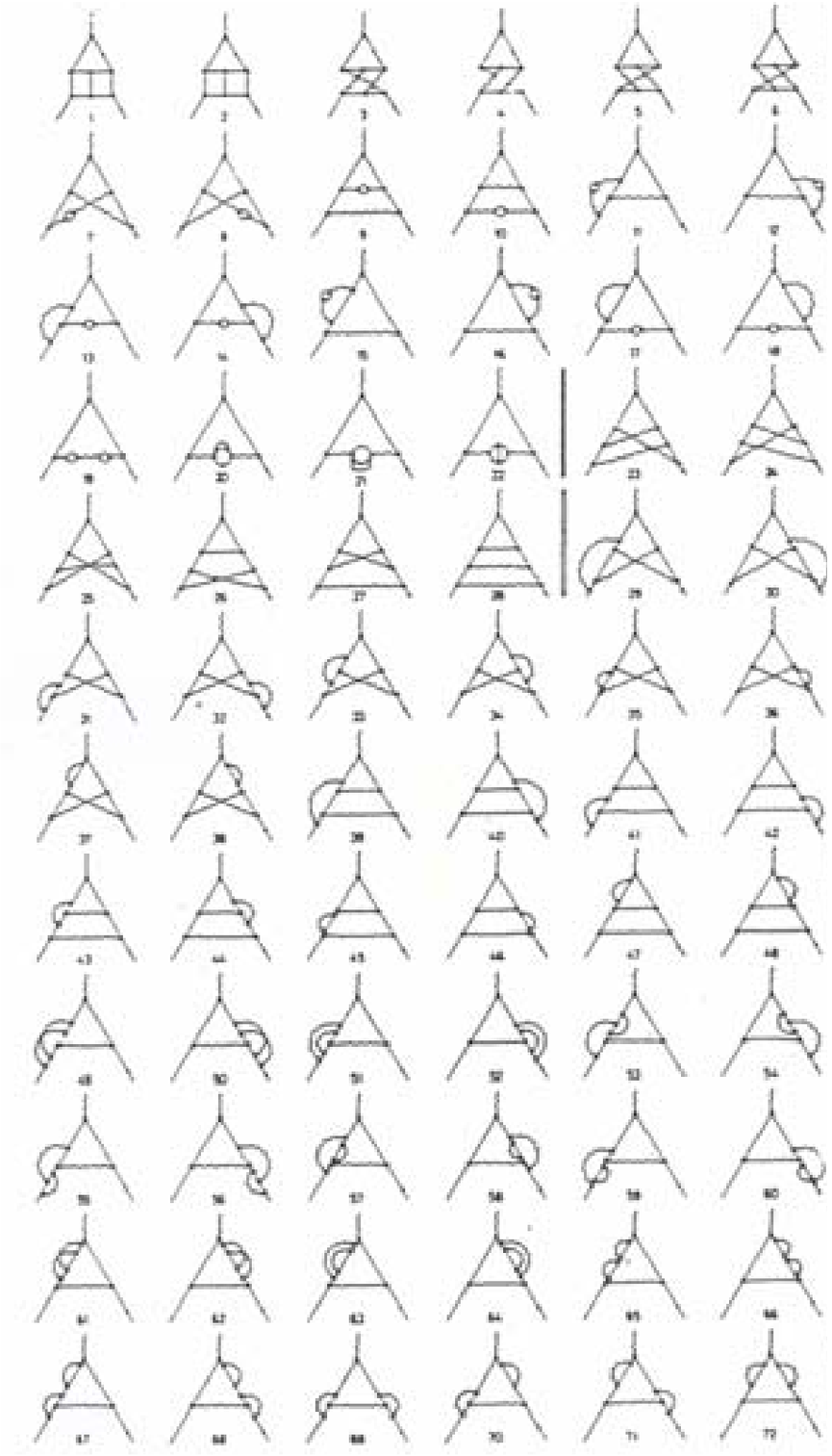
Anomalous Magnetic Moment

Radiative corrections to g-2

Corrections are nowadays calculated to 4-loop level

Feynman Graphs		
$O(\alpha)$		1
$O(\alpha^2)$		7
$O(\alpha^3)$	analytically	72
$O(\alpha^4)$	numerically	891
til $O(\alpha^4)$		971

Most precise calculations:
T. Kinoshita et al.



$O(\alpha^3)$ diagrams

Larmor Frequency

Classical:

$$\Delta\ell = \ell \ \sin\theta \ \omega\Delta t$$

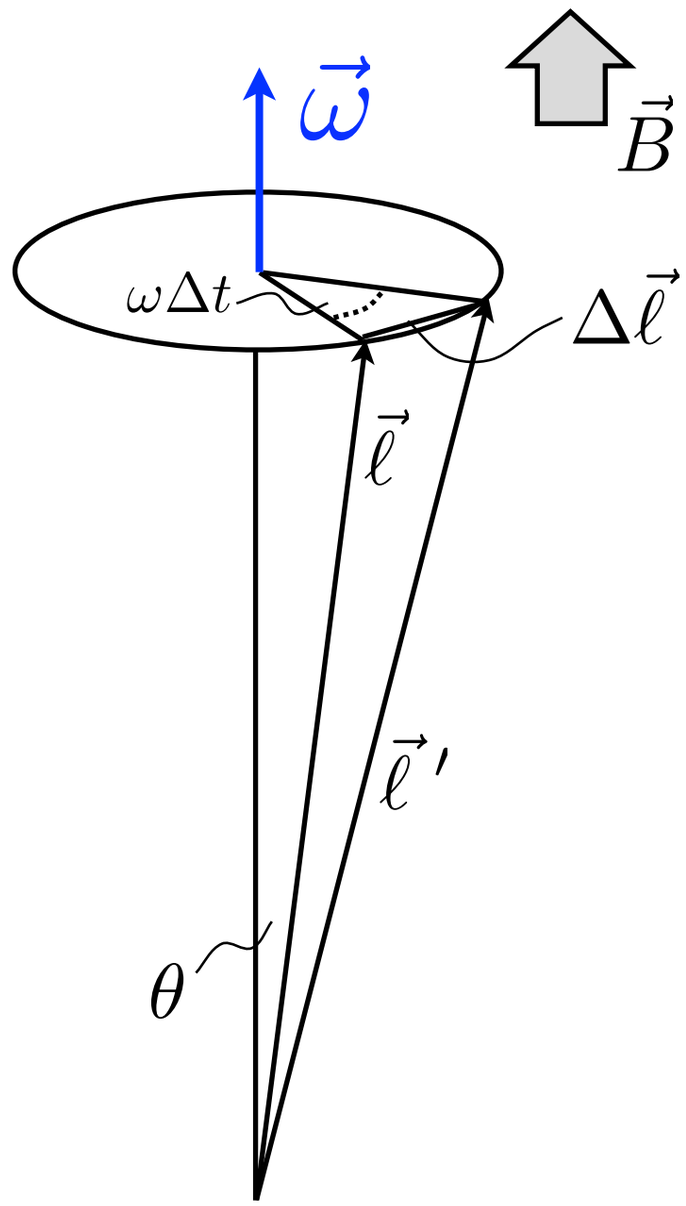
$$\frac{d\ell}{dt} = \omega\ell\sin\theta = \tau$$
$$= \mu B\sin\theta$$

$$\omega = \frac{\mu}{\ell}B$$

For
Spin:

$$\left.\begin{aligned}\ell &= s\\ \mu &= g_e\frac{e}{2m}s\end{aligned}\right\} \quad \omega = g_e\frac{e}{2m}B$$

[Larmor Frequency]



$\vec{\tau}$: Torque
$\vec{\ell}$: Angular Momentum

Cyclotron Frequency

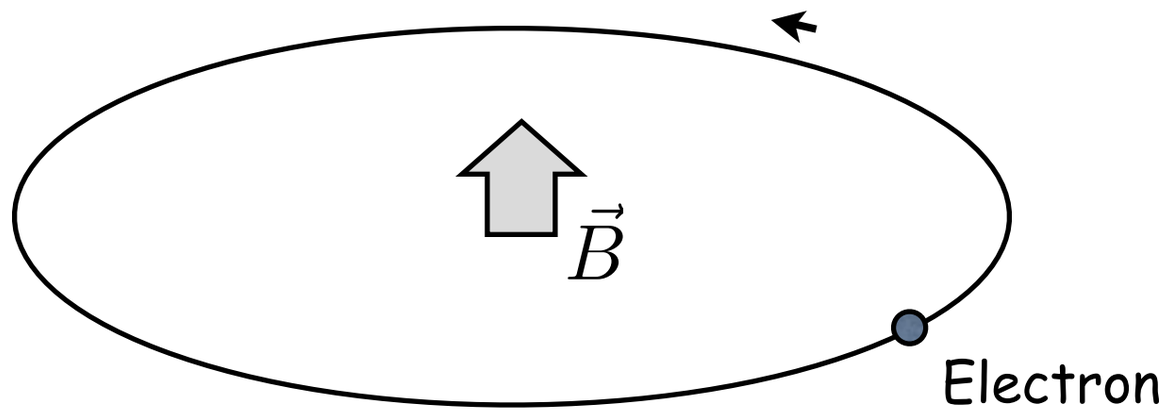
Classical:

$$m\omega^2 r = evB$$

$$= e\omega r B$$

$$\omega = \frac{e}{m}B$$

[Relativistic: $\omega = \frac{e}{m\gamma}B$]



For g=2:

$$\omega_c = \frac{e}{m}B$$

Cyclotron Frequency

$$\omega_s = \frac{e}{m}B$$

Larmor Frequency

Cyclotron Frequency
equal to
Larmor Frequency

Basic Idea for Measuring Anomaly

$$\omega_s = g\frac{e}{2m}B$$ — Larmor Frequency

$$\omega_c = \frac{e}{m}B$$ — Cyclotron Frequency

$$a = \frac{\omega_s - \omega_c}{\omega_c} = \frac{\omega_a}{\omega_c}$$

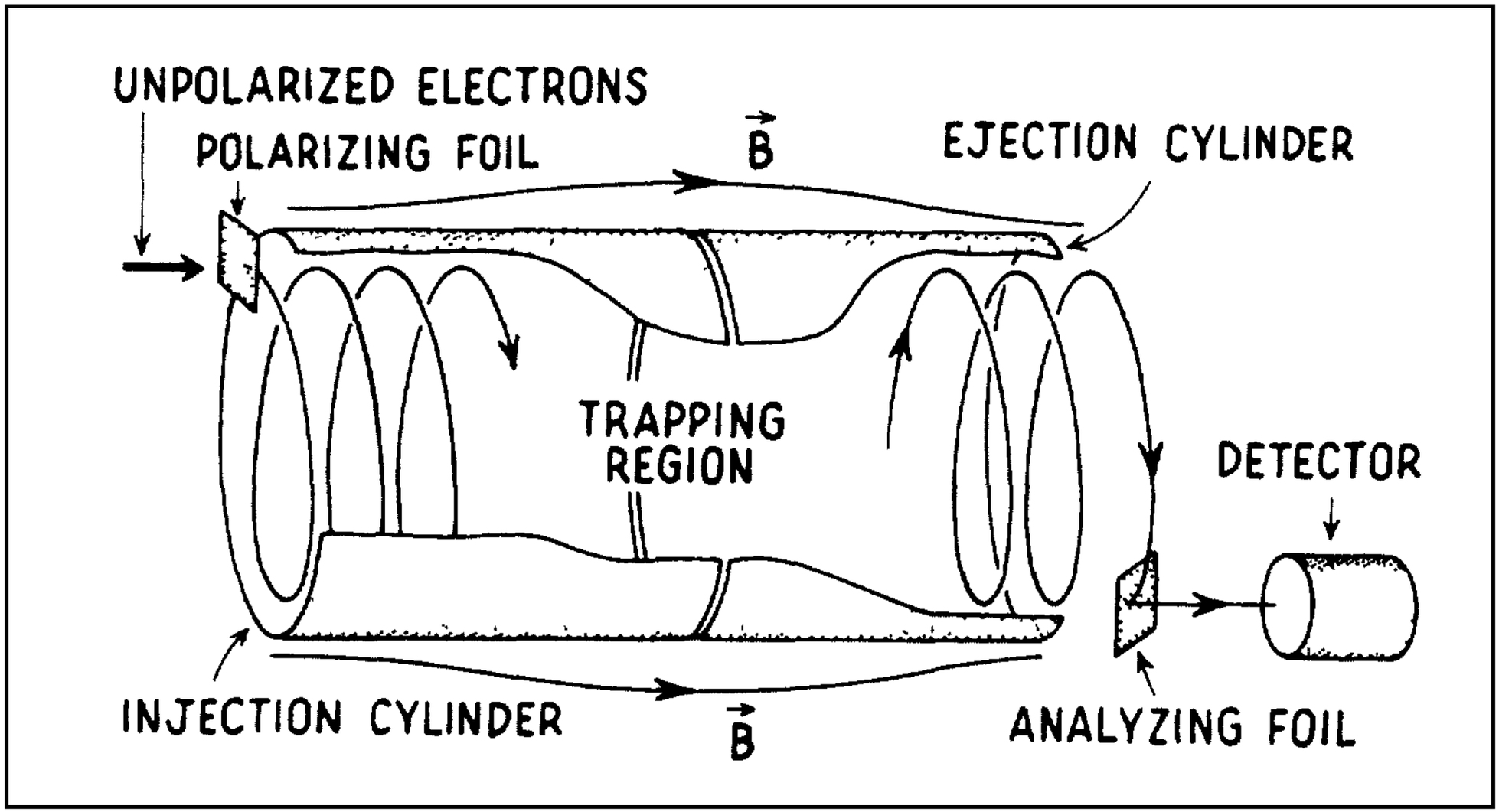
[non relativistic]

Relativistic:

$$a = \frac{\omega_a}{\omega_c \gamma}$$

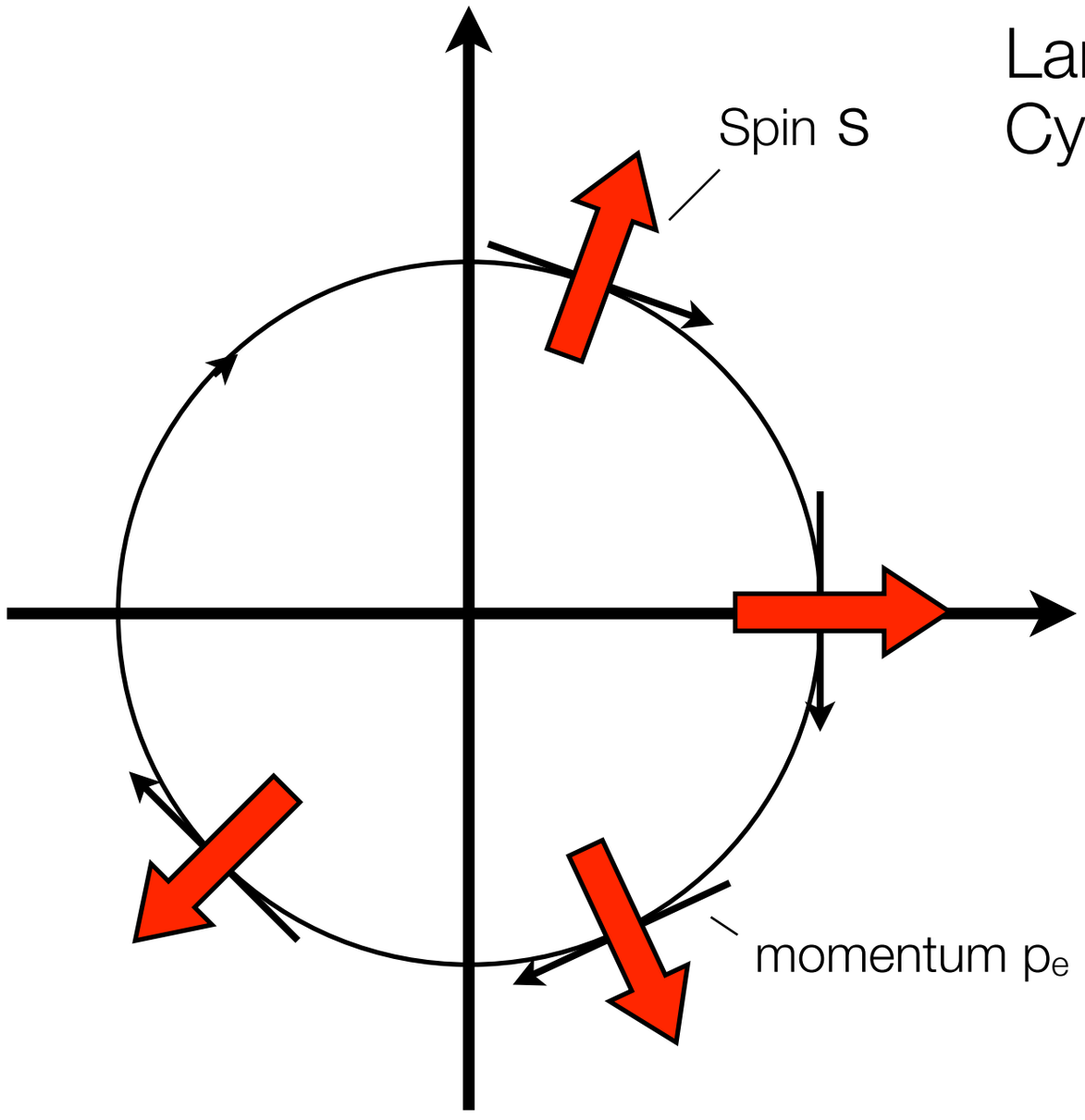
Electron (g-2)-Measurement

Polarization and polarization
detection via Mott Scattering



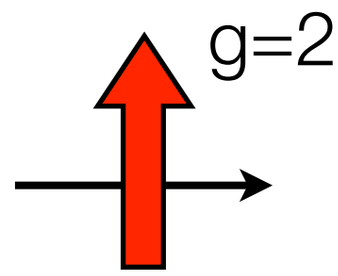
[Wesley & Rich, Phys. Rev. A4, 1341]

Electron (g-2)-Measurement



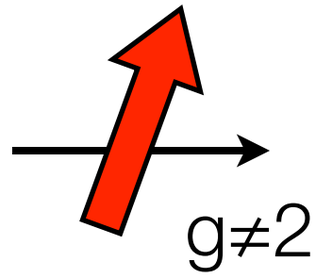
Lamor frequency equal Cyclotron frequency:

Polarization stays constant



otherwise:

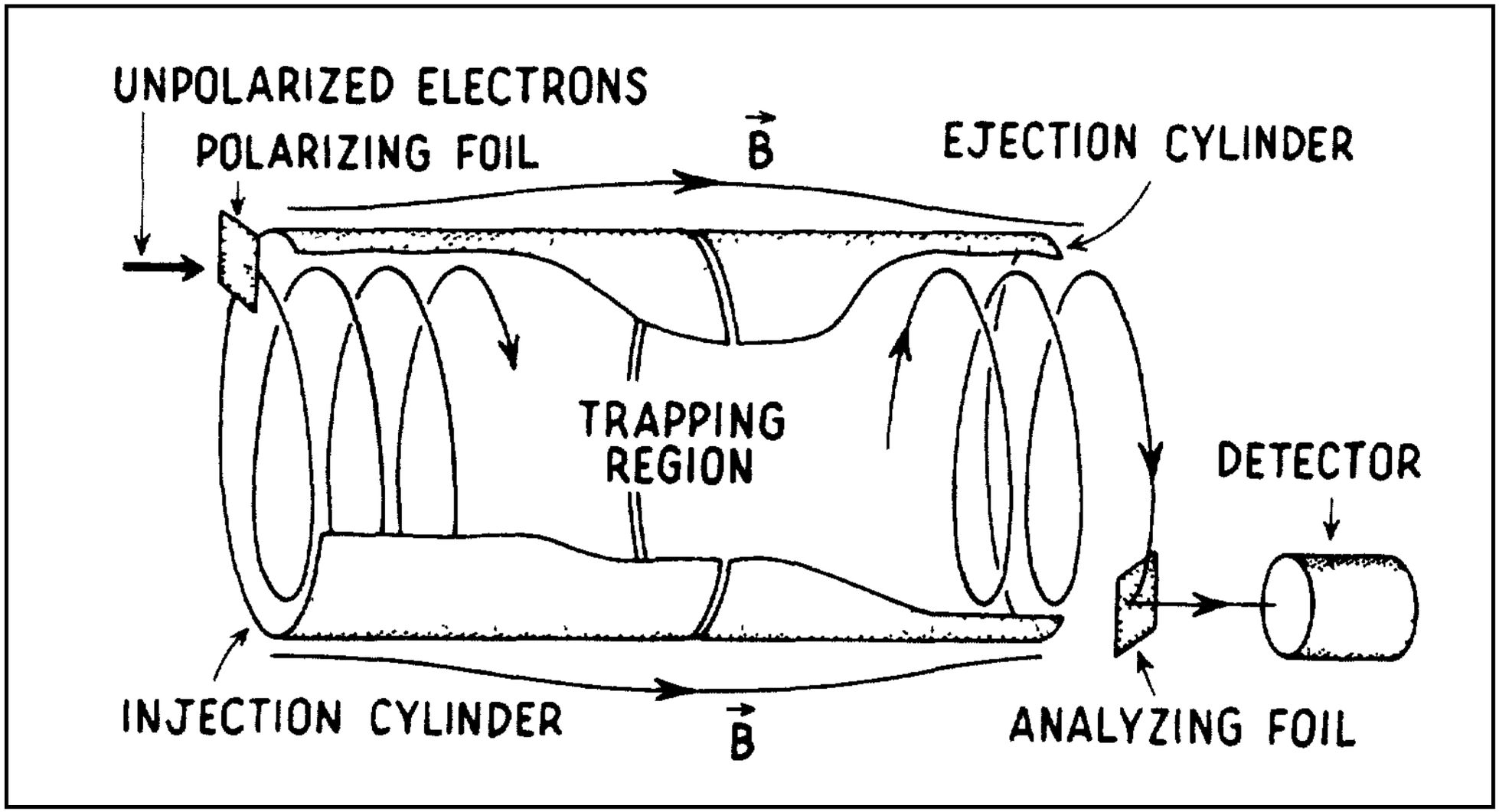
Polarization depends on number of turns



Measure Polarization!
[Here using Møller Scattering]

Electron (g-2)-Measurement

Polarization and polarization
detection via Mott Scattering



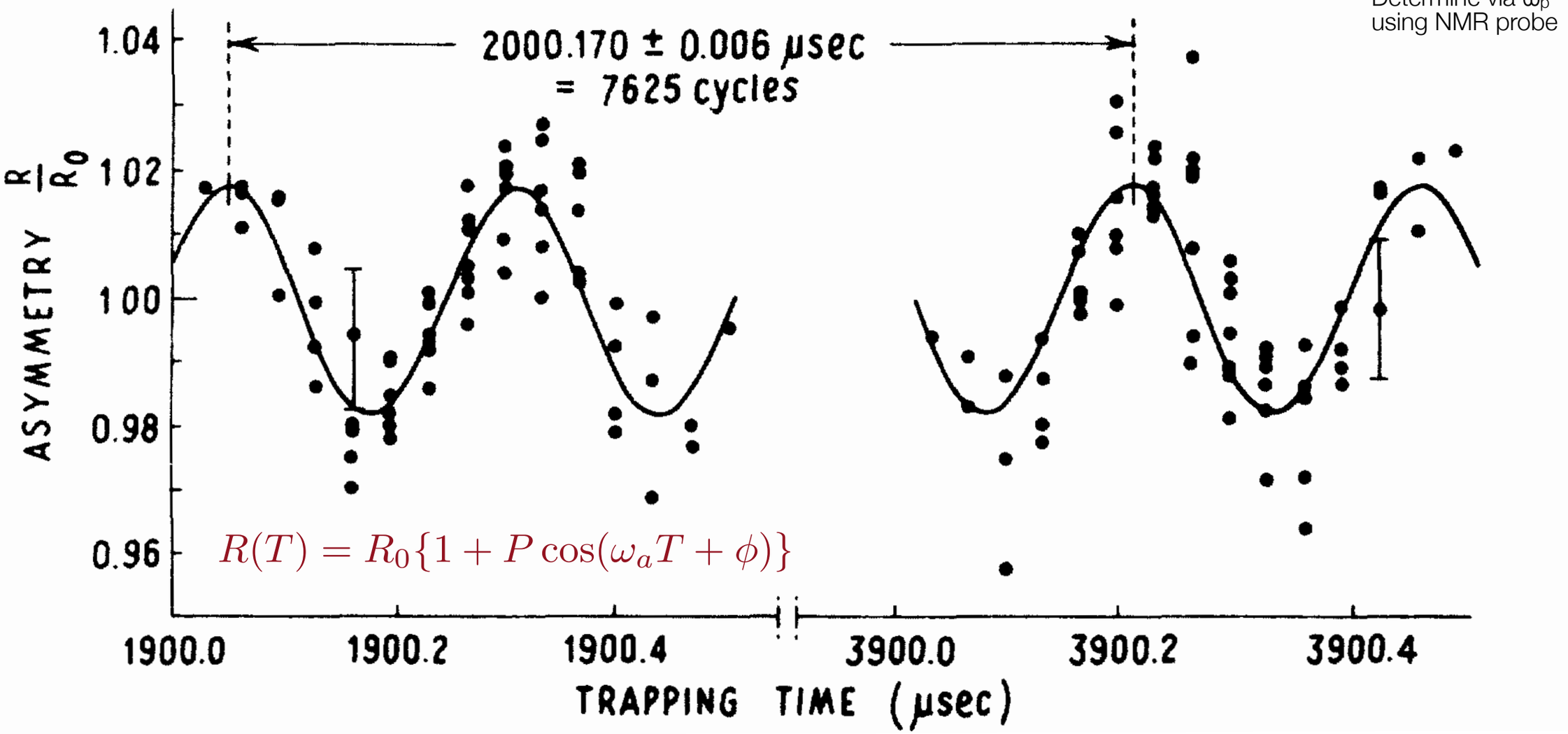
[Wesley & Rich, Phys. Rev. A4, 1341]

Electron (g-2)-Measurement

$\omega_s - \omega_c \sim 10^7$
$\omega_c \sim 10^{10}$
} $a \sim 10^{-3}$

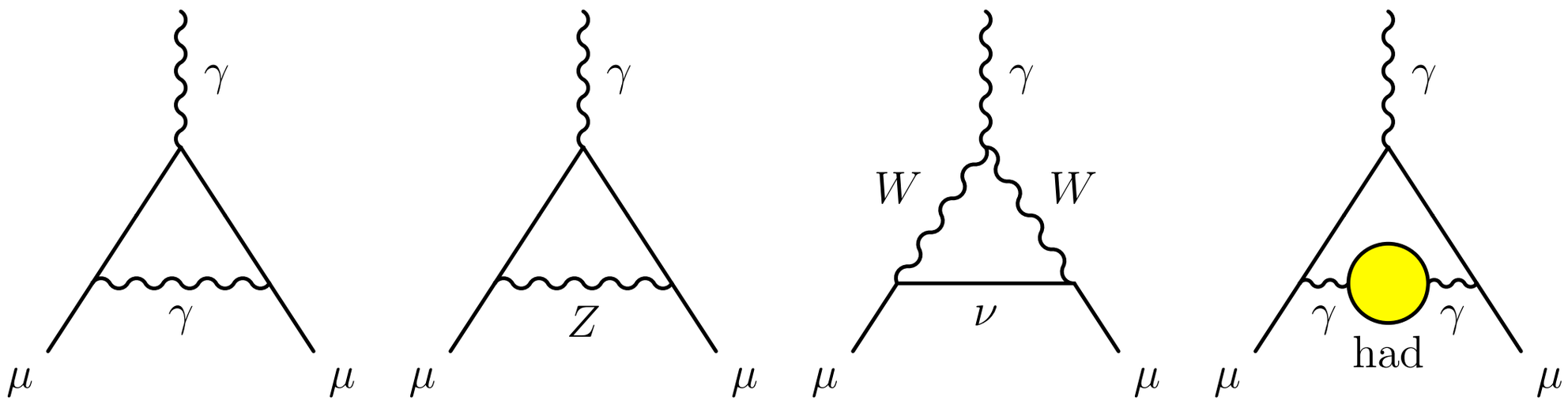
Determine via ω_p using NMR probe

Result:

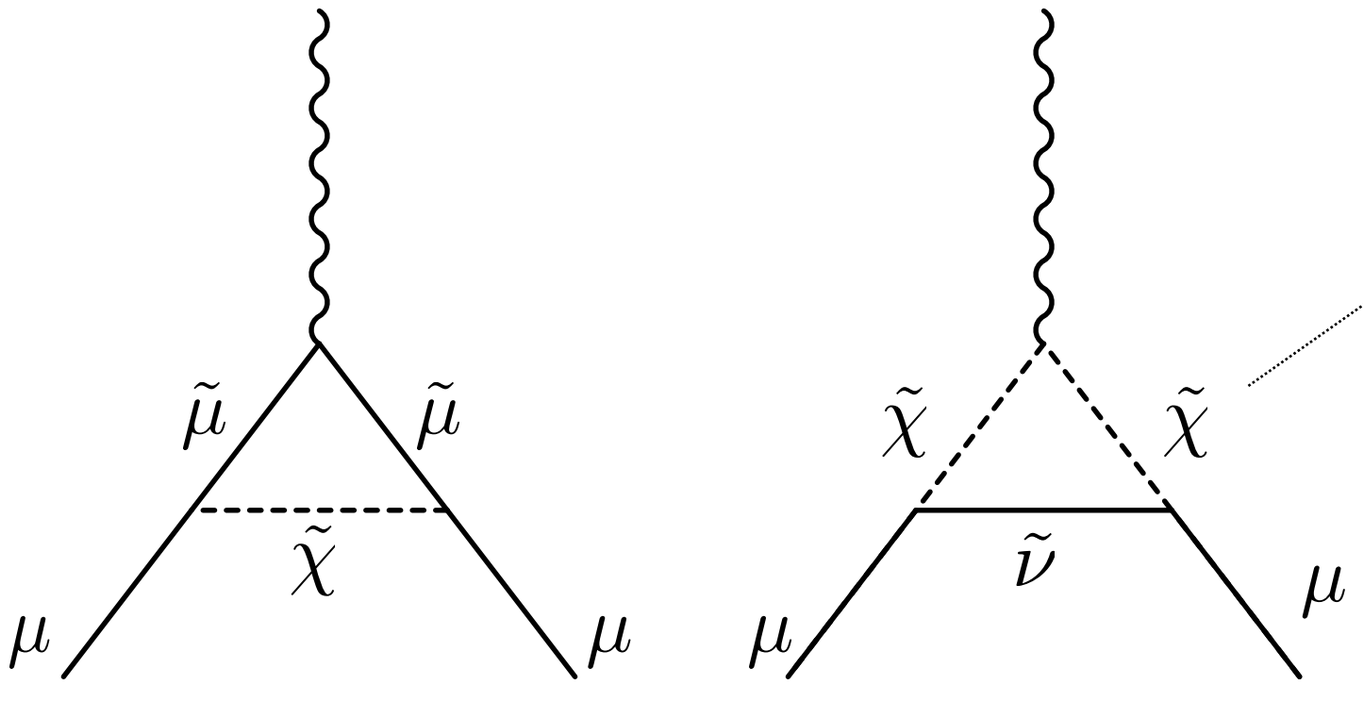


$$a_e = 11596577(35) \times 10^{-10}$$ [1971]

Anomalous Magnetic Moment



electroweak &
hadronic corrections



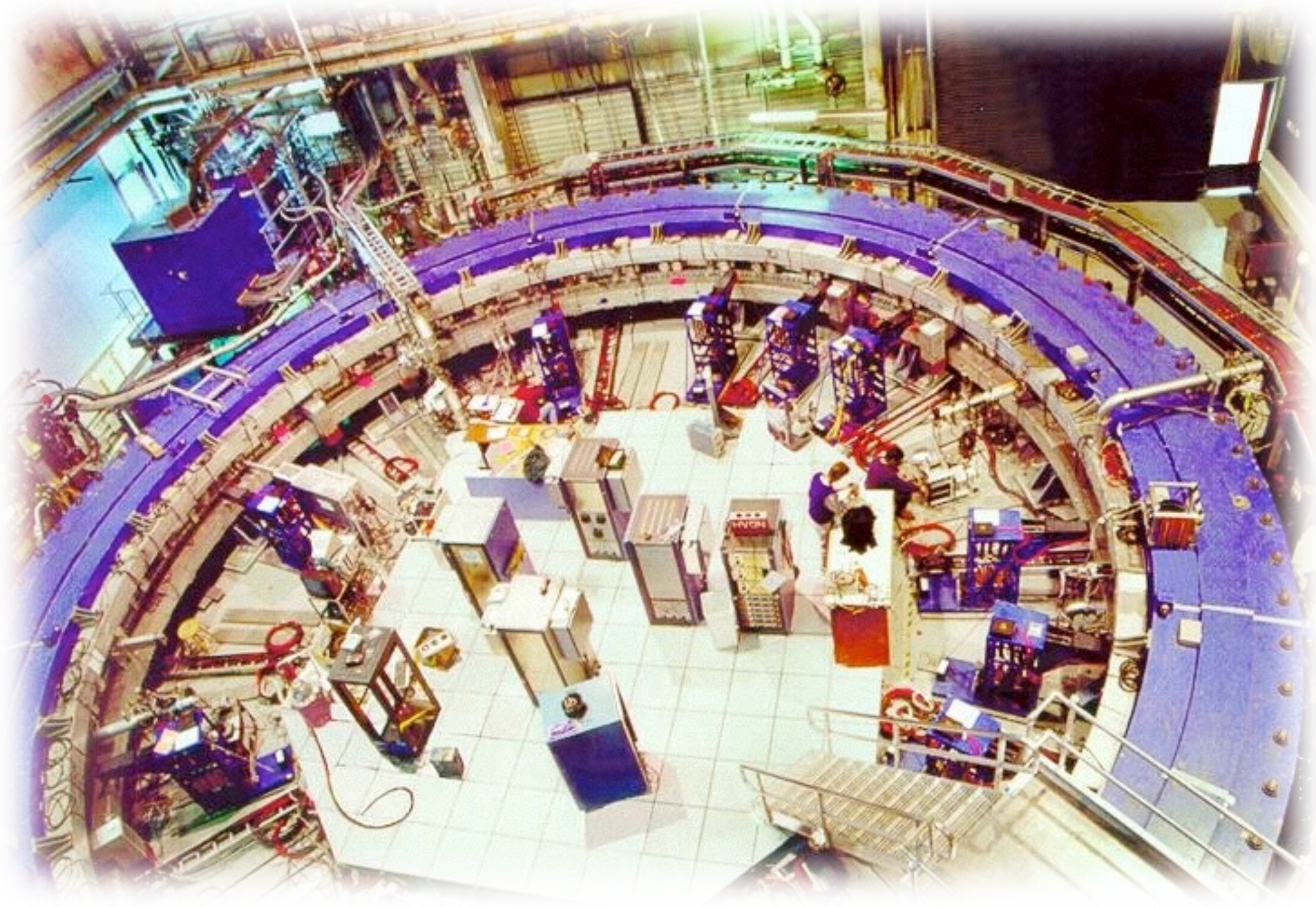
New physics
enters via loops

Corrections
proportional to:

$$\lambda_{\rm NP} = \left(\frac{m_\mu^2}{M_{\tilde{\chi}}^2} \right)$$

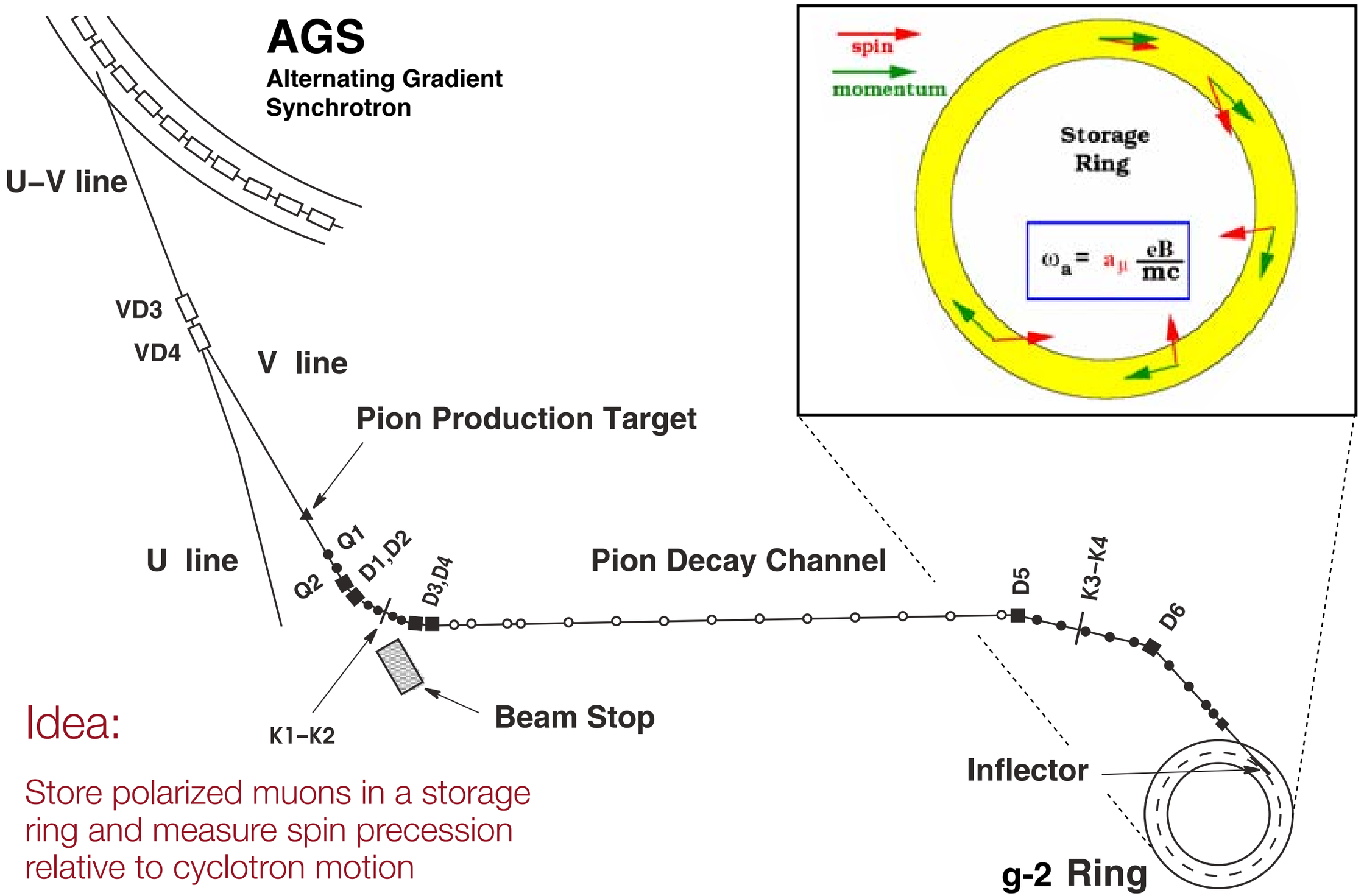
Use Muons !

Muon (g-2)-Measurement



Brookhaven, Muon Storage Ring

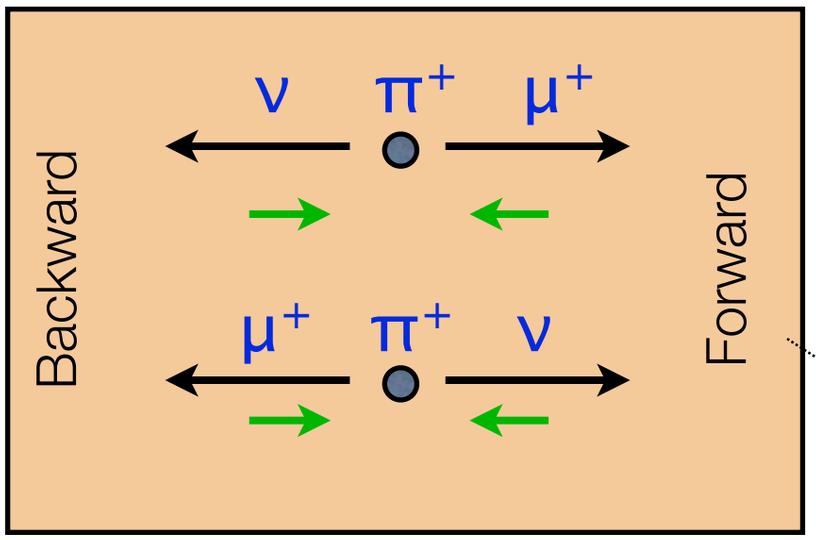
Muon (g-2)-Measurement



Idea:

Store polarized muons in a storage ring and measure spin precession relative to cyclotron motion

Muon (g-2)-Measurement



Only forward decays selected. [energy, mag. field]

Life of a muon:
The g-2 Experiment

Select forward muons

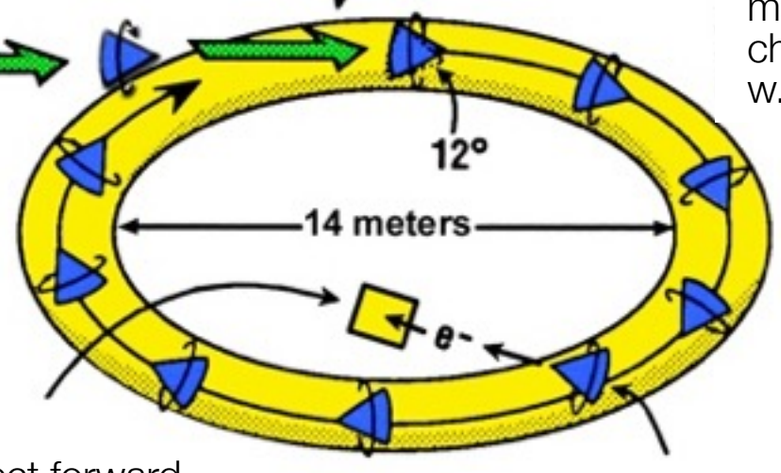
Target

Protons from AGS

Pions [3.1 GeV]

Muons from pion decay

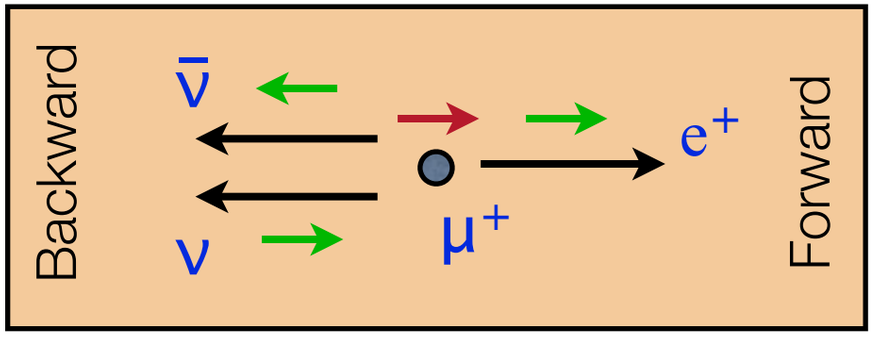
Muon injection



After each circle muon spin axis changes by ~12° w.r.t. momentum

24 detectors measure select forward μ-decays via electron energy [E>1.8 GeV]

Muon decay via $\mu^+ \rightarrow e^+ \nu_e \bar{\nu}_\mu$

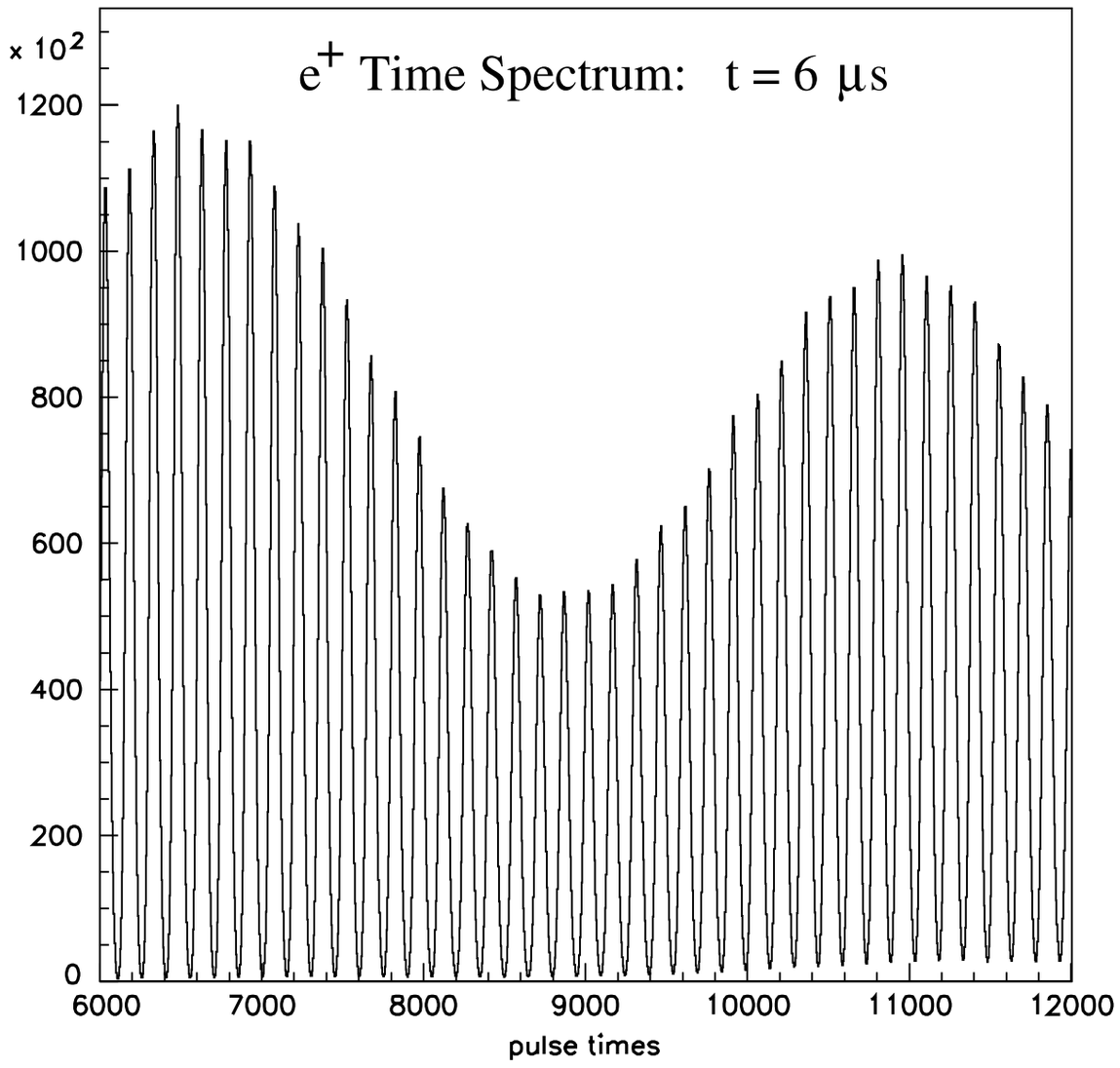


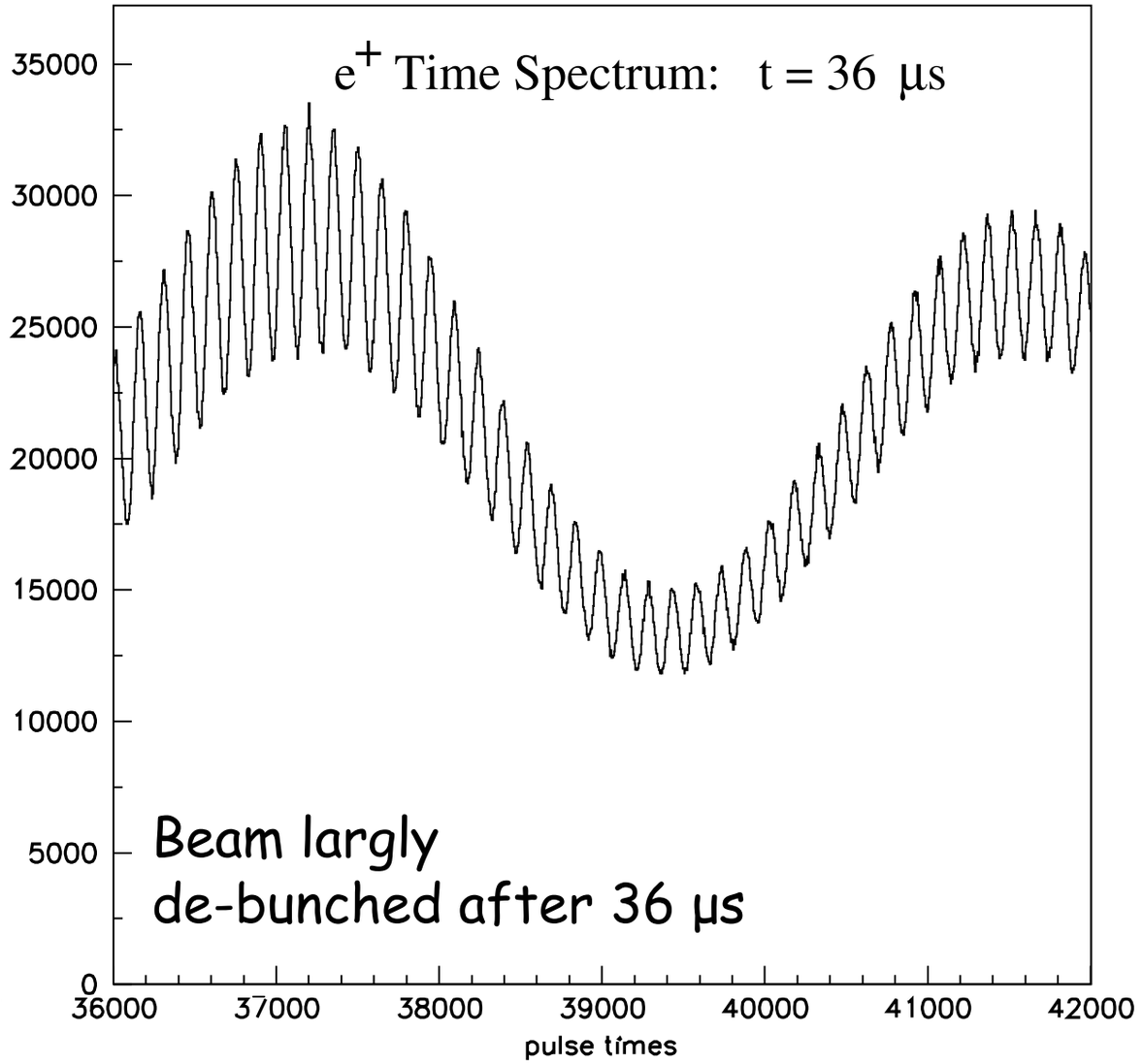
Polarization determines number of high energy e^+

Muon (g-2)-Measurement

Time Spectrum of single calorimeter

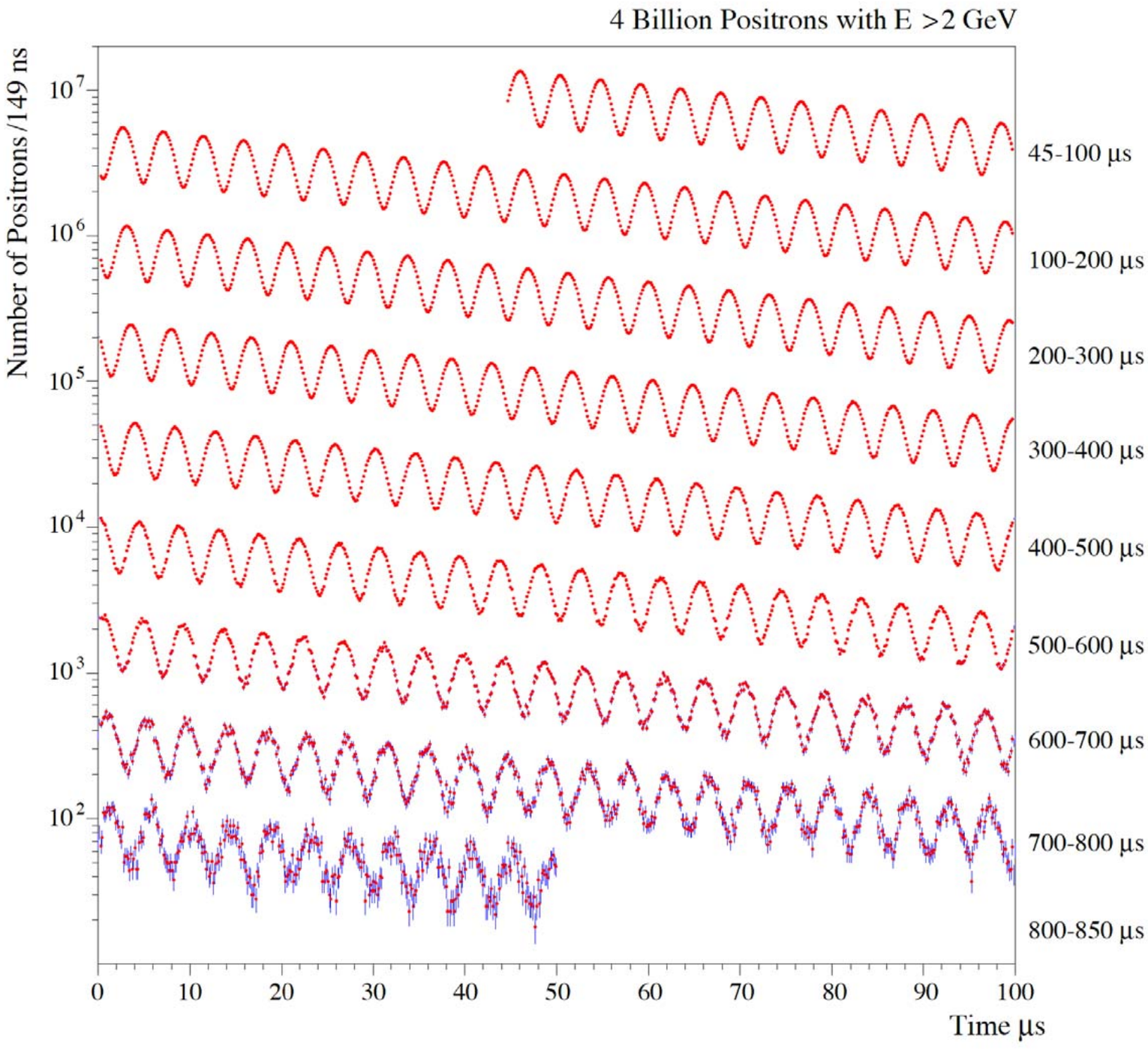
Puls hight





Time

Muon (g-2)-Measurement



Muon (g-2)-Measurement