

## LEPTONS AS POINT PARTICLES

REPEATEDLY STATED THAT LEPTONS

ELECTRONS

MUONS

(TAUS)

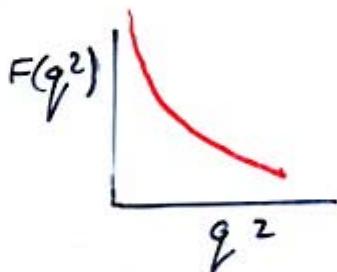
ARE POINT PARTICLES — NO EXTENSION  
IN SPACE

THIS IS A BIZARRE NOTION.

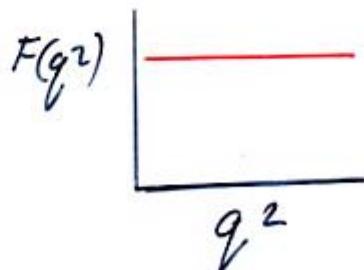
WHAT IS THE EXPERIMENTAL EVIDENCE?

ONE COULD LOOK FOR A FORM FACTOR  
IN ELECTRON-ELECTRON SCATTERING

EXTENDED OBJECT



POINT PARTICLE



UNTIL RECENTLY THIS WAS NOT A  
PRACTICAL EXPERIMENT — SHALL CROSS  
SECTION

WE KNOW THAT FOR A  
DIRAC POINT PARTICLE

$$\bar{\mu} = g \mu_0 \frac{J}{\hbar}$$

$$\mu_0 = \frac{e\hbar}{2mc}$$

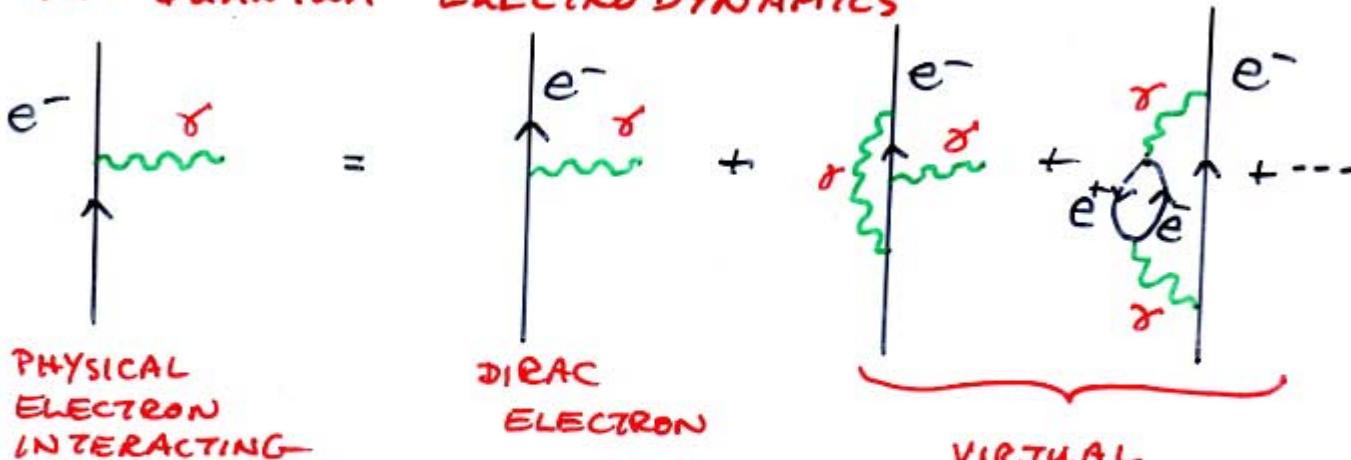
WHERE  $g=2$   $\rightarrow$  TWICE "CLASSICAL"  
EXPECTATION

FOR A -VE ELECTRON  $g=-2$

ANY DEVIATION FROM  $g=-2$  WOULD BE  
AN INDICATION OF SPATIAL EXTENT FOR  
THE ELECTRON

IN FACT ONE DOES MEASURE  $g \neq -2$   
BUT IT IS NOT INTERPRETED AS AN  
INDICATION OF SPATIAL EXTENT.

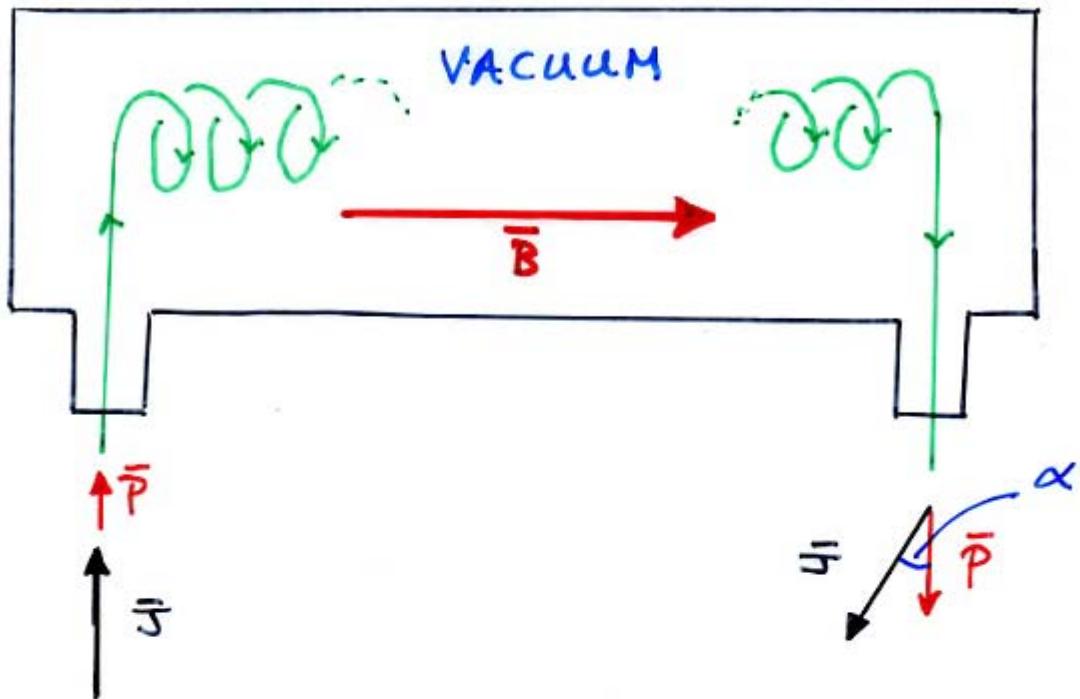
### IN QUANTUM ELECTRODYNAMICS



$$a = \frac{|g|-2}{2} = \frac{1}{2} \left( \frac{\alpha}{\pi} \right) - 0.328478966 \left( \frac{\alpha}{\pi} \right)^2 + 1.176 \left( \frac{\alpha}{\pi} \right)^3 + \dots$$

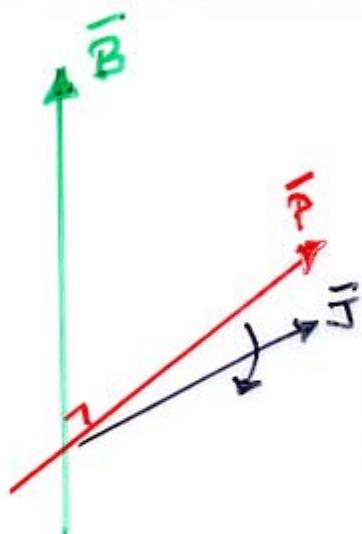
$\alpha = e^2/\hbar c$

PRECISE MEASUREMENT OF ELECTRON 191-2



MOMENTUM VECTOR WILL PRECESS  
WITH CYCLOTRON FREQUENCY

$$\omega_c = \frac{e}{mc} \cdot B$$



IN ADDITION TO THE  $\vec{B}$  FIELD CAUSING THE LINEAR MOMENTUM TO PRECESS, IT WILL ALSO CAUSE THE SPIN ANGULAR MOMENTUM TO PRECESS AT THE LARMOR FREQUENCY

- CLASSICALLY  $\omega_c = \frac{e}{mc} \cdot B$

$$\begin{aligned}\omega_L &= g \cdot \frac{e}{2mc} \cdot B \\ &= 1 \text{ CLASSICAL} \\ &= 2 \text{ DIRAC}\end{aligned}$$

← SPIN  $\frac{1}{2}$

FOR A DIRAC POINT PARTICLE  $e$

$$\omega_L - \omega_c = g \cdot \frac{e}{2mc} \cdot B - \frac{e}{mc} \cdot B$$

$$\omega_L - \omega_c = \frac{e}{mc} \cdot B \left( \frac{|g| - 2}{2} \right)$$

$$v_h - \omega_c = \frac{e}{mc} \cdot B \left( \frac{|g| - 2}{2} \right)$$

CLEARLY, FOR A DIRAC POINT PARTICLE,  
THE MOMENTUM AND SPIN VECTORS  
WILL ALWAYS BE PARALLEL

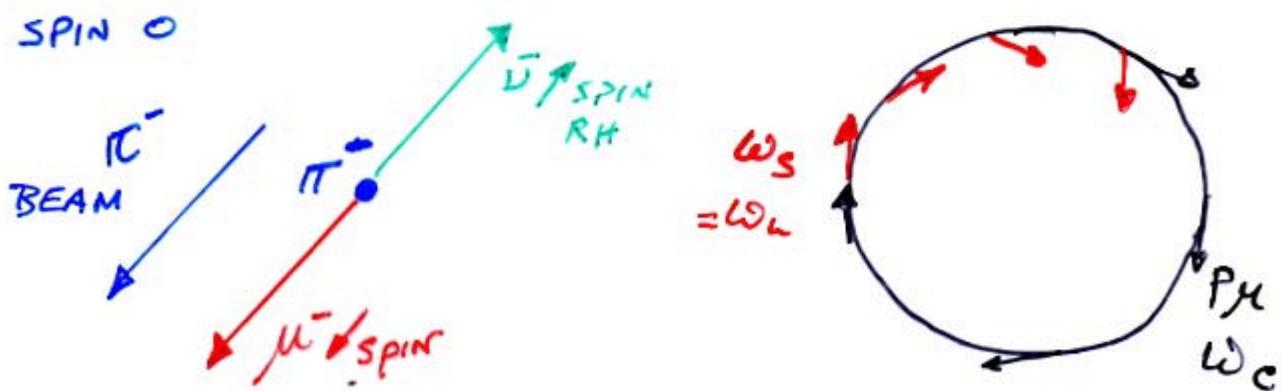
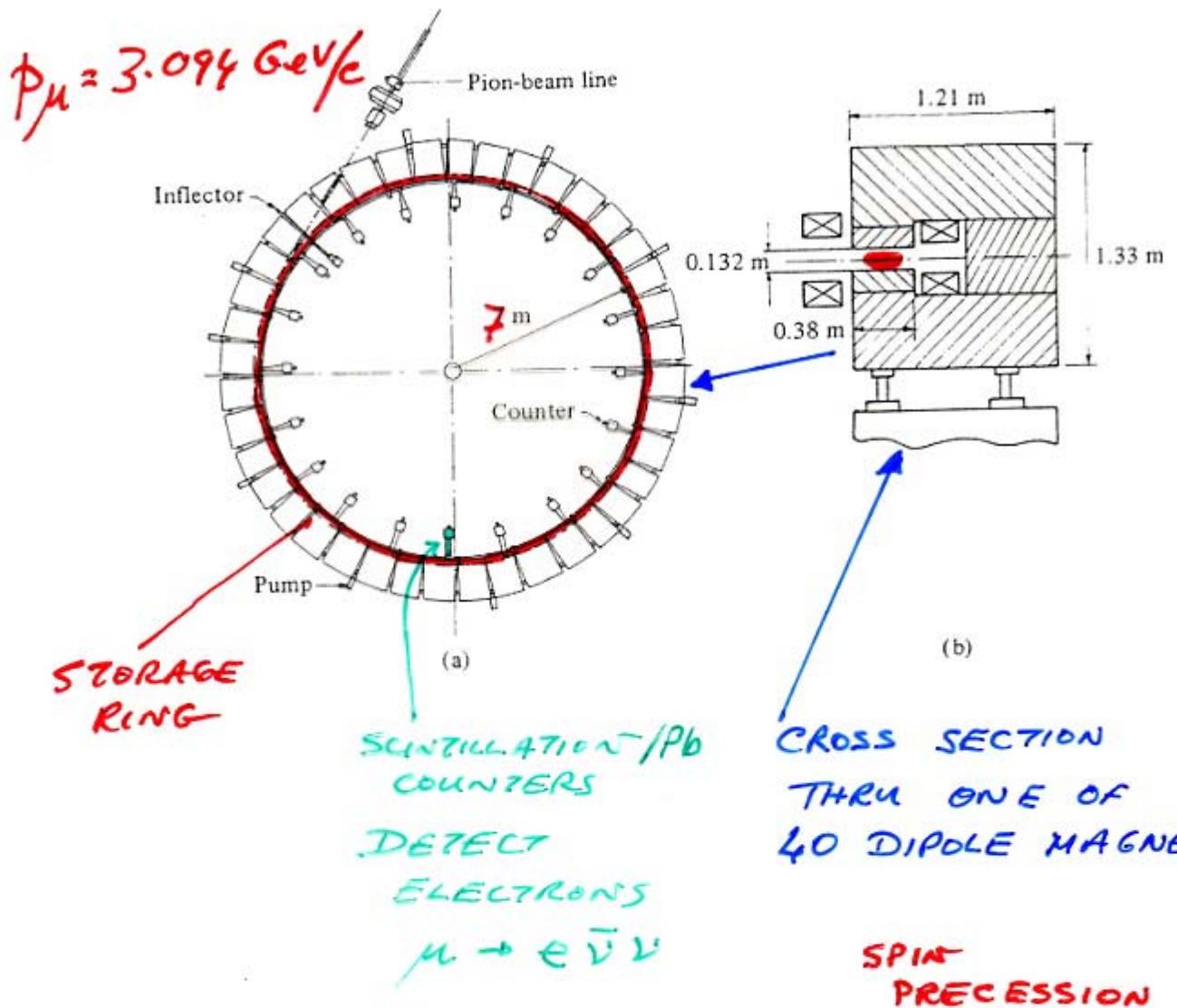
IF  $|g| \neq 2$ , AFTER A TIME  $t$ , THE  
ANGLE BETWEEN THE TWO VECTORS  
WILL BE

$$\alpha = \frac{e}{mc} \cdot B \left( \frac{|g| - 2}{2} \right) \cdot t$$

IF  $Bt$  IS LARGE  $\Rightarrow \alpha$  IS LARGE  
 $\Rightarrow$  VERY ACCURATE

FOR  $\mu$ ;  $\mu \rightarrow e\gamma\gamma$

SOLVE THIS BY STORING HIGHLY RELATIVISTIC  
MUONS IN A STORAGE RING.



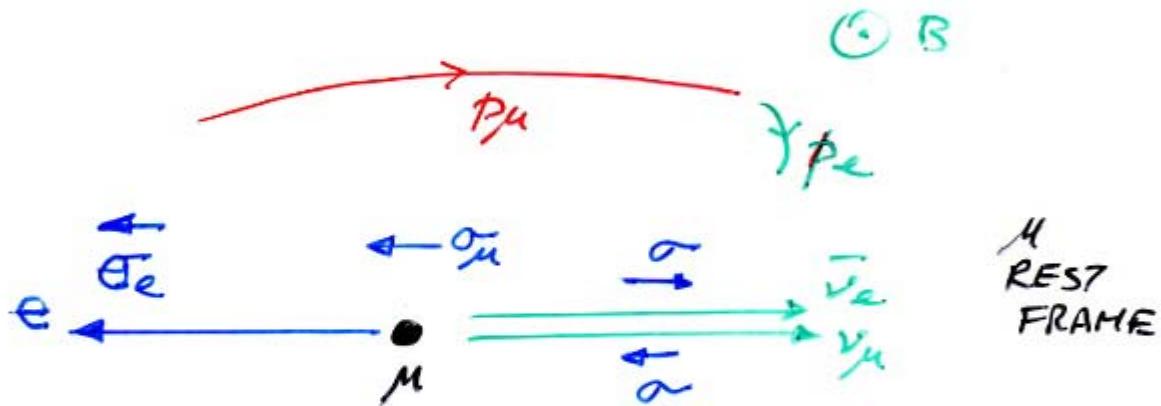
$\mu$  POLARIZATION  
 97%

$$\pi^- \rightarrow \mu^- \bar{\nu}_\mu$$

$$\mu \rightarrow e \bar{\nu}_e \nu_\mu$$

$$p_e < p_\mu$$

ELECTRONS EMERGE  
FROM STORAGE RING

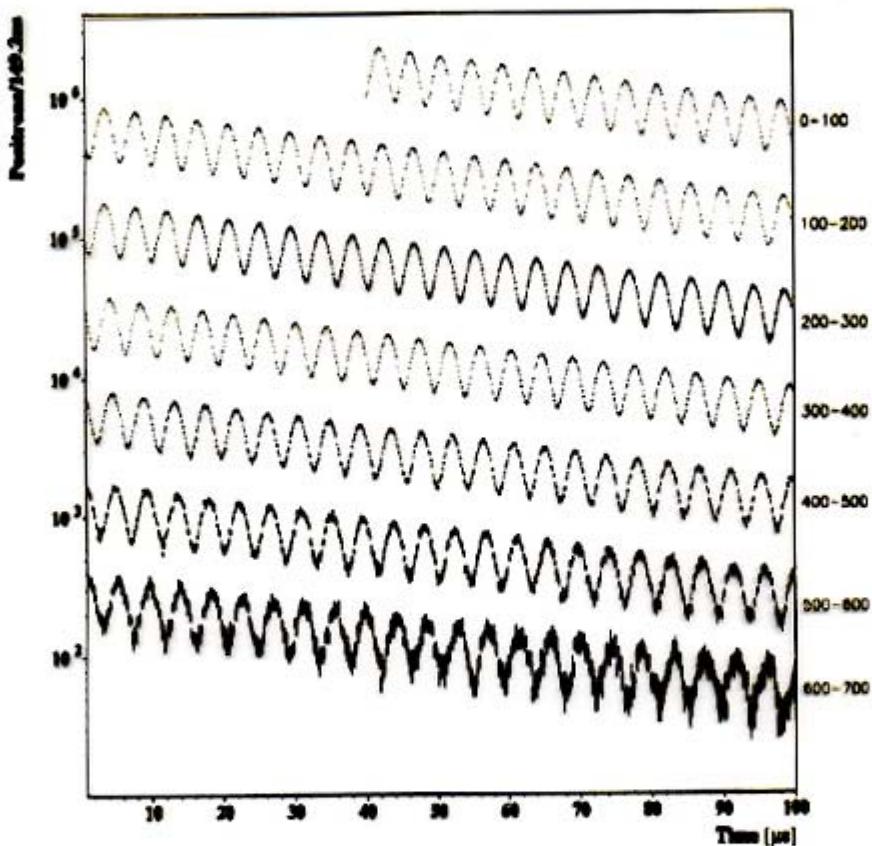


ELECTRON SPIN / MOMENTUM

DETERMINE WHAT WAS

MUON SPIN DIRECTION ON DECAY

## A Sample of 1999 data



**- 750 Million Positrons**

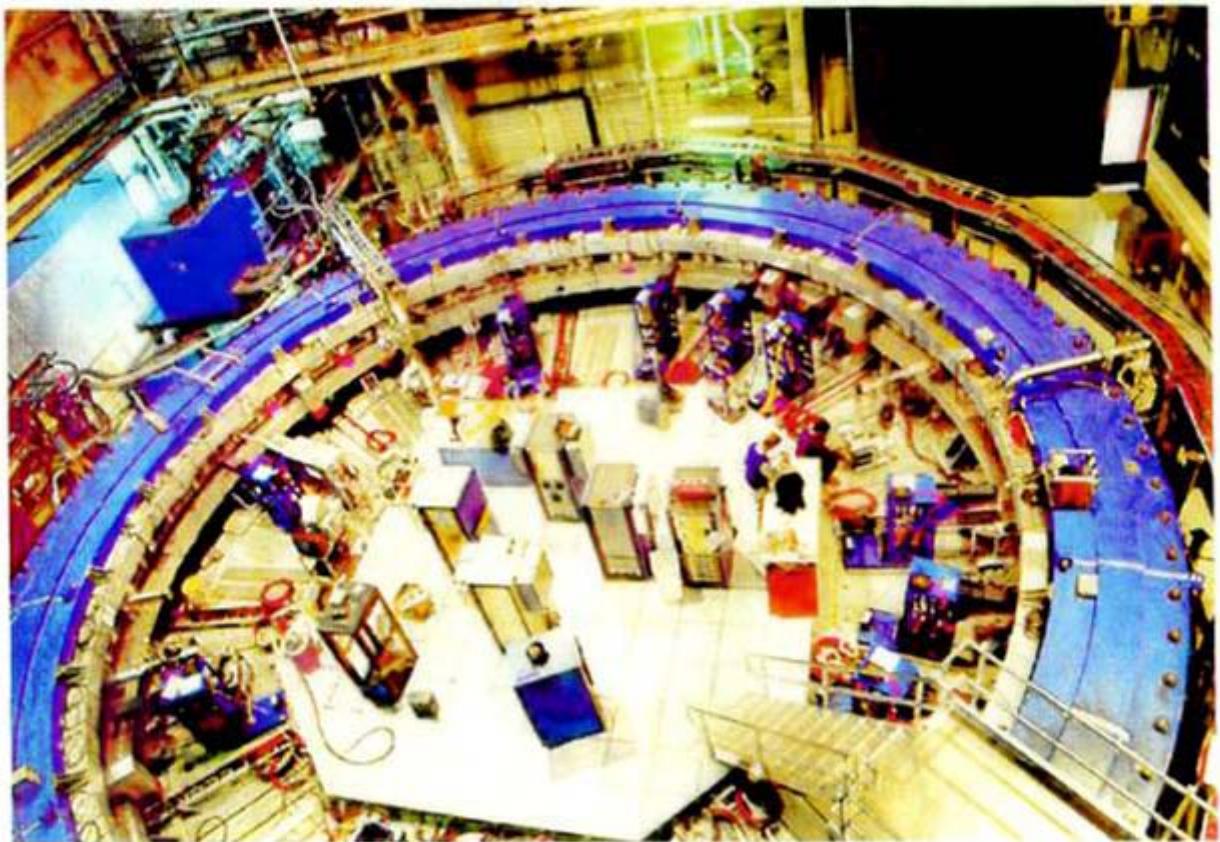
$$\text{Fit to } N(t) = N_0 e^{-t/\tau} (1 + A \cos(\omega t + \phi))$$

W<sub>a</sub> error goal : 0.1 ppm

## BNL E821 Muon (g-2)

$$a_\mu = 11659191(59) \times 10^{-10} (\pm 5 \text{ ppm})$$

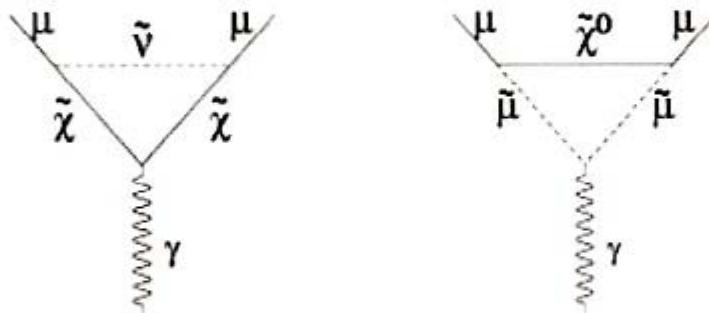
June 26 2000 Preprint



## Physics Beyond The Standard Model

Many speculative theories predict deviations from the standard model value for  $a_\mu$ . These include supersymmetry, muon substructure, and anomalous  $W$  couplings.

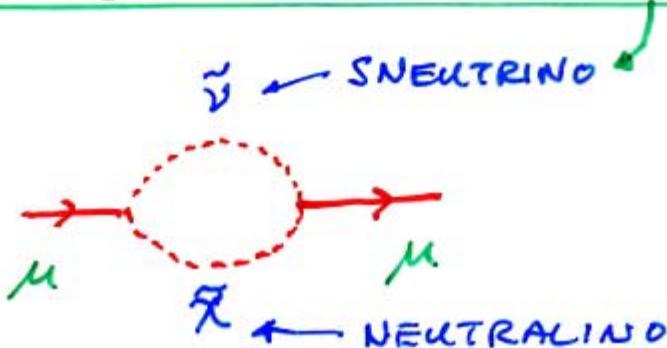
The muon anomalous  $g$  value is particularly sensitive to supersymmetry whose contributions to  $a_\mu$  come from smuon-neutralino and sneutrino-chargino loops.



In the limit of large  $\tan\beta$ , which is the ratio of the vacuum expectation values of two Higgs doublets, and for a degenerate spectrum of superparticles with mass  $\tilde{m}$ ,

$$a_\mu(\text{SUSY}) \approx 140 \times 10^{-11} \left( \frac{100 \text{ GeV}}{\tilde{m}} \right)^2 \tan\beta.$$

If we ascribe the difference  $a_\mu(\text{exp}) - a_\mu(\text{SM})$  to  $a_\mu(\text{SUSY})$ , for  $\tan\beta$  in the range 4 – 40, then  $\tilde{m} \approx 120 - 400 \text{ GeV}$ .



December 2001  
KEK-TH-793  
hep-ph/0112102

# Comment on the sign of the pseudoscalar pole contribution to the muon $g - 2$

Masashi Hayakawa \* and Toichiro Kinoshita †

\*Theory Division, KEK, Tsukuba, Ibaraki 305-0801, Japan

†Newman Laboratory, Cornell University, Ithaca, New York 14853

## Abstract

We correct the error in the sign of the pseudoscalar pole contribution to the muon  $g - 2$ , which dominates the  $\mathcal{O}(\alpha^3)$  hadronic light-by-light scattering effect. The error originates from the fact that the algebraic manipulation program FORM treats  $\epsilon$ -tensor so as to satisfy  $\epsilon_{\mu_1 \mu_2 \mu_3 \mu_4} \epsilon_{\nu_1 \nu_2 \nu_3 \nu_4} \eta^{\mu_1 \nu_1} \eta^{\mu_2 \nu_2} \eta^{\mu_3 \nu_3} \eta^{\mu_4 \nu_4} = 24$ , as opposed to the expected value  $-24$  when Minkowski space-time metric  $\eta^{\mu\nu}$  is specified (at least in the version available before 1995). Replacing the part  $\epsilon_{\mu_1 \mu_2 \mu_3 \mu_4} \epsilon_{\nu_1 \nu_2 \nu_3 \nu_4}$  by  $-\eta_{\mu_1 \nu_1} \eta_{\mu_2 \nu_2} \eta_{\mu_3 \nu_3} \eta_{\mu_4 \nu_4} \pm \dots$  in the FORM-formatted programs, we obtained a positive value for the pseudoscalar pole contribution, which agrees with the recent result obtained by Knecht *et al.*

---

\*e-mail address : haya@post.kek.jp

†e-mail address : tk@mail.lns.cornell.edu

## Results

(H.N. Brown et al., Phys Rev Lett. 86 (2001) 2227)

$$a_\mu('99) = 11\,659\,202(14)(6) \times 10^{-10} \text{ (1.3 ppm)}$$

$$a_\mu(\text{SM}) = 11\,659\,\underline{160}(7) \times 10^{-10} \text{ (0.6 ppm)}$$

$$a_\mu('99) - a_\mu(\text{SM}) = 42(17) \times 10^{-10}$$

