**Oklahoma University**

**HEP Seminar, 25 March 2004**

# Muon g-2 and Electric Dipole Moments in Storage Rings: Powerful Probes of Physics Beyond the SM


Yannis K. Semertzidis

Brookhaven National Lab

**"Muon g-2 Collaboration"**

and

**"EDM in Storage Rings Collaboration"**


$$\frac{d\vec{s}}{dt} = \vec{\mu} \times \vec{B} + \vec{d} \times \vec{E}$$

# Muon g-2 Collaboration

G.W. Bennett[2], B. Bousquet[9], H.N. Brown[2], G. Bunce[2]‡, R.M. Carey[1], P. Cushman[9], G.T. Danby[2], P.T. Debevec[7], M. Deile[11], H. Deng[11], S.K. Dhawan[11], V.P. Druzhinin[3], L. Duong[9], F.J.M. Farley[11], G.V. Fedotovich[3], F.E. Gray[7], D. Grigoriev[3], M. Grosse-Perdekamp[11], A. Grossmann[6], M.F. Hare[1], D.W. Hertzog[7], X. Huang[1], V.W. Hughes[11]†, M. Iwasaki[10], K. Jungmann[5], D. Kawall[11], B.I. Khazin[3], F. Krienen[1], I. Kronkvist[9], A. Lam[1], R. Larsen[2], Y.Y. Lee[2], I. Logashenko[1,3], R. McNabb[9], W. Meng[2], J.P. Miller[1], W.M. Morse[2]#, D. Nikas[2], C.J.G. Onderwater[7], Y. Orlov[4], C.S. Özben[2,7], J.M. Paley[1], Q. Peng[1], C.C. Polly[7], J. Pretz[11], R. Prigl[2], G. zu Putlitz[6], T. Qian[9], S.I. Redin[3,11], O. Rind[1], B.L. Roberts[1]†, N. Ryskulov[3], Y.K. Semertzidis[2], P. Shagin[9], Yu.M. Shatunov[3], E.P. Sichtermann[11], E. Solodov[3], M. Sossong[7], L.R. Sulak[1], A. Trofimov[1], P. von Walter[6], and A. Yamamoto[8].

(Muon $(g-2)$ Collaboration)

[1] *Department of Physics, Boston University, Boston, Massachusetts 02215*

[2] *Brookhaven National Laboratory, Upton, New York 11973*

[3] *Budker Institute of Nuclear Physics, Novosibirsk, Russia*

[4] *Newman Laboratory, Cornell University, Ithaca, New York 14853*

[5] *Kernfysisch Versneller Instituut, Rijksuniversiteit Groningen, NL 9747 AA Groningen, The Netherlands*

[6] *Physikalisches Institut der Universität Heidelberg, 69120 Heidelberg, Germany*

[7] *Department of Physics, University of Illinois at Urbana-Champaign, Illinois 61801*

[8] *KEK, High Energy Accelerator Research Organization, Tsukuba, Ibaraki 305-0801, Japan*

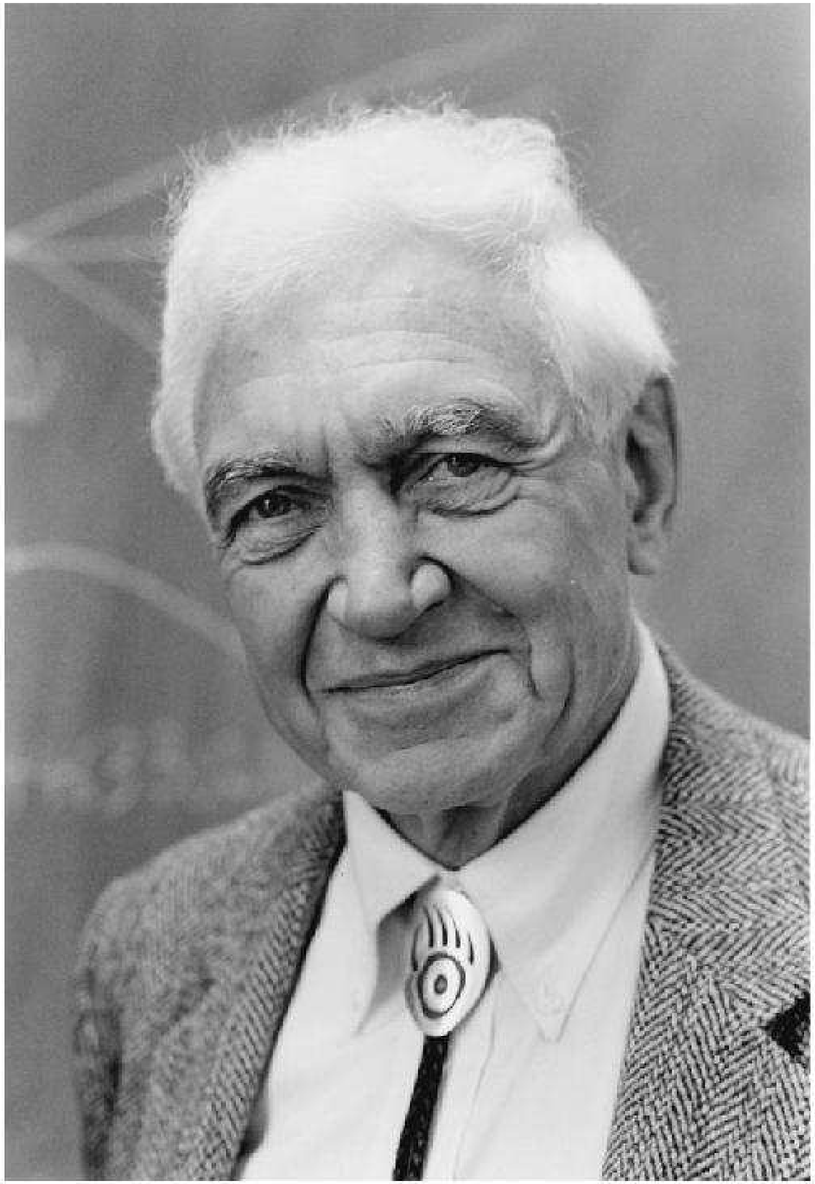
[9] *Department of Physics, University of Minnesota, Minneapolis, Minnesota 55455*

[10] *Tokyo Institute of Technology, Tokyo, Japan*

[11] *Department of Physics, Yale University, New Haven, Connecticut 06520*

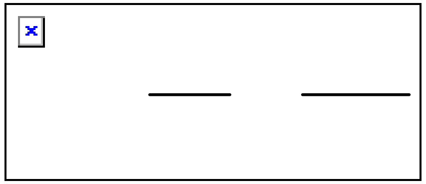
†Spokesperson ‡Project Manager # Resident Spokesperson

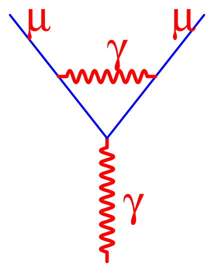
# Prof. Vernon W. Hughes (1921 – 2003)



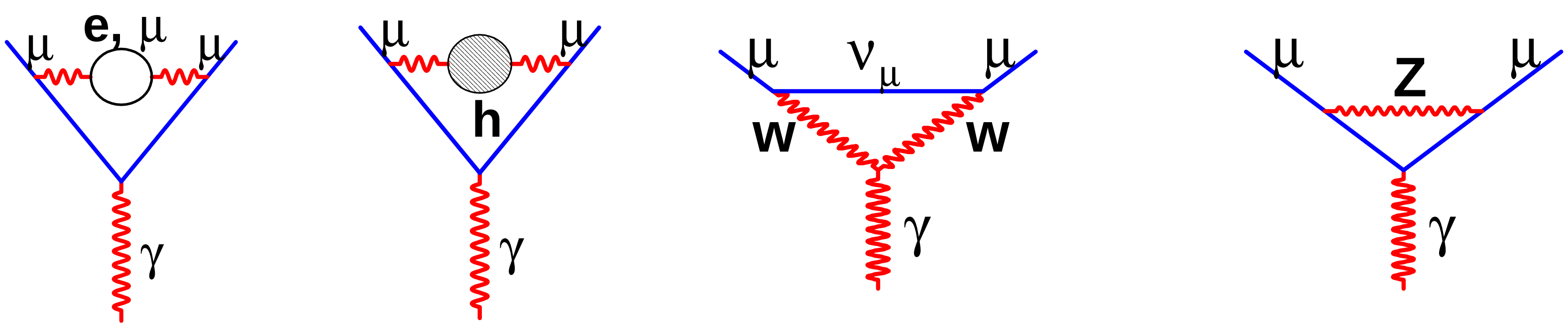
# *g* - *2* for the muon

Largest contribution :






Other standard model contributions :




QED hadronic weak

# Theory of $a_\mu$

- $a_\mu(\text{theo}) = a_\mu(\text{QED}) + a_\mu(\text{had}) + a_\mu(\text{weak})$
  $+ a_\mu(\text{new physics})$

- $a_\mu(\text{had}) \ = a_\mu(\text{had1}) + a_\mu(\text{had, HO}) + a_\mu(\text{had, LBL})$

  ? $\quad$ -10±0.6 $\quad$ + 8.6 ±3.5

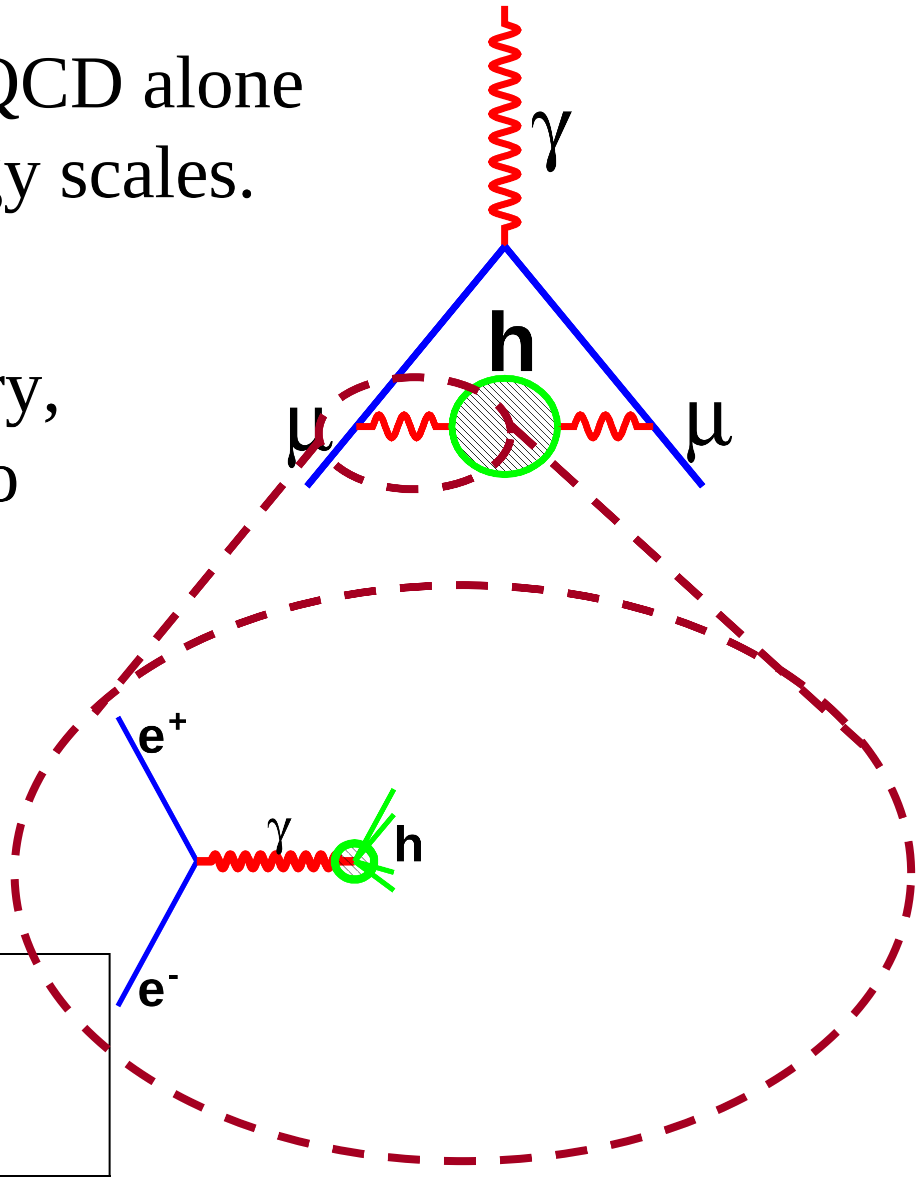
  in units of $10^{-10}$

# Hadronic contribution (had1)

Cannot be calculated from pQCD alone because it involves low energy scales.

However, by dispersion theory, this $a_\mu$(had1) can be related to

measured in $e^+e^-$ collisions.

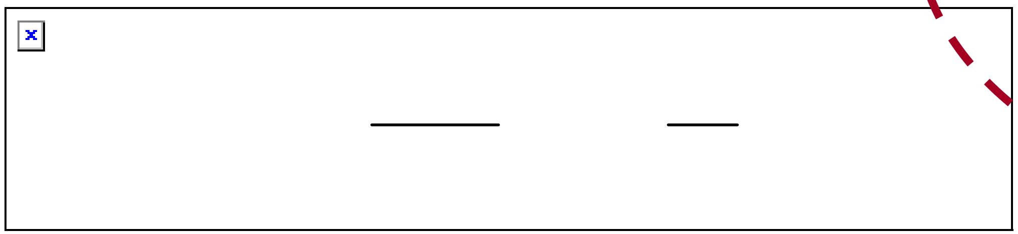


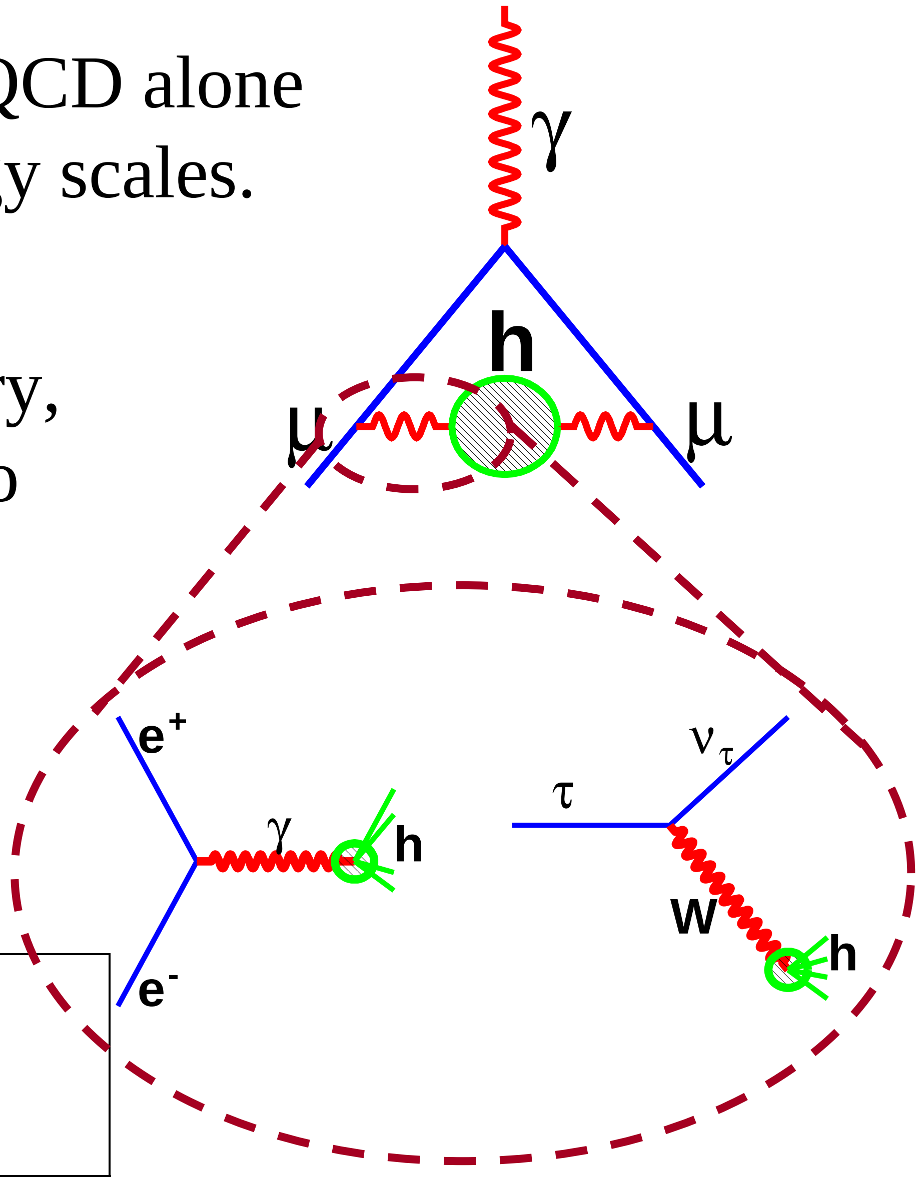
# Hadronic contribution (had1)

Cannot be calculated from pQCD alone because it involves low energy scales.

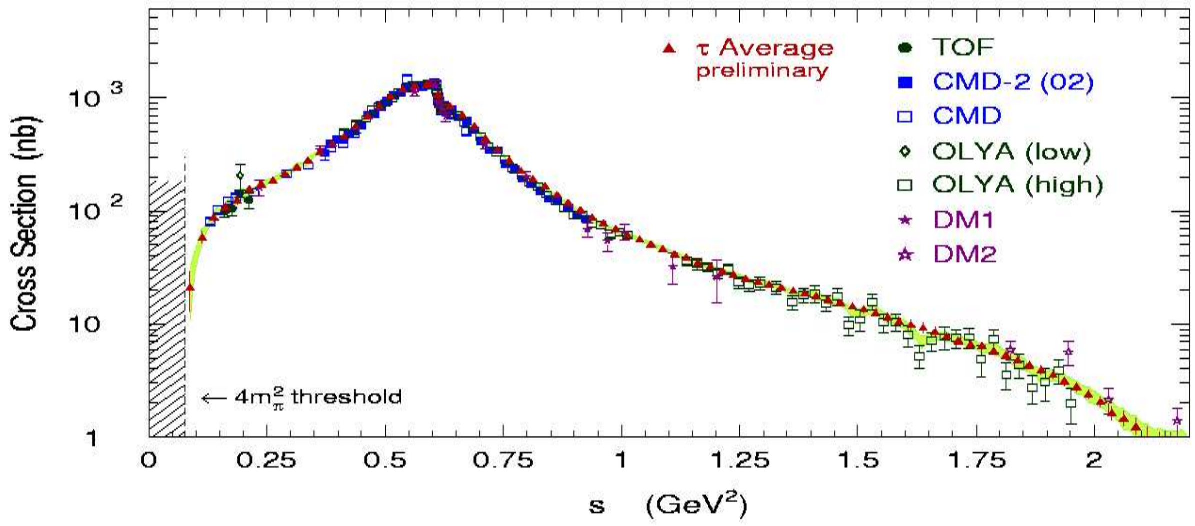
However, by dispersion theory, this $a_\mu$(had1) can be related to

measured in $e^+e^-$ collisions or $\tau$ decay (assuming CVC).

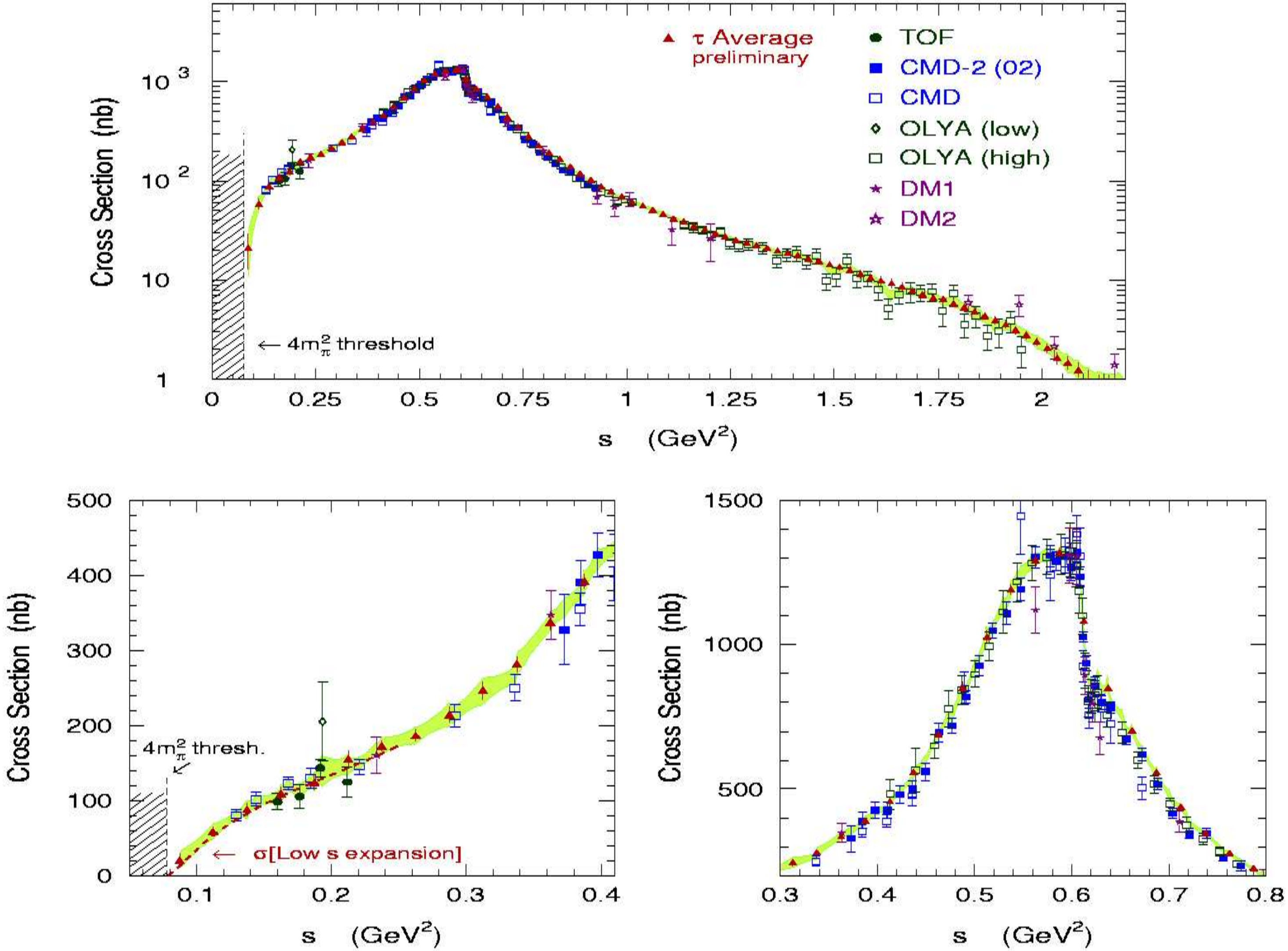




# Evaluation of R

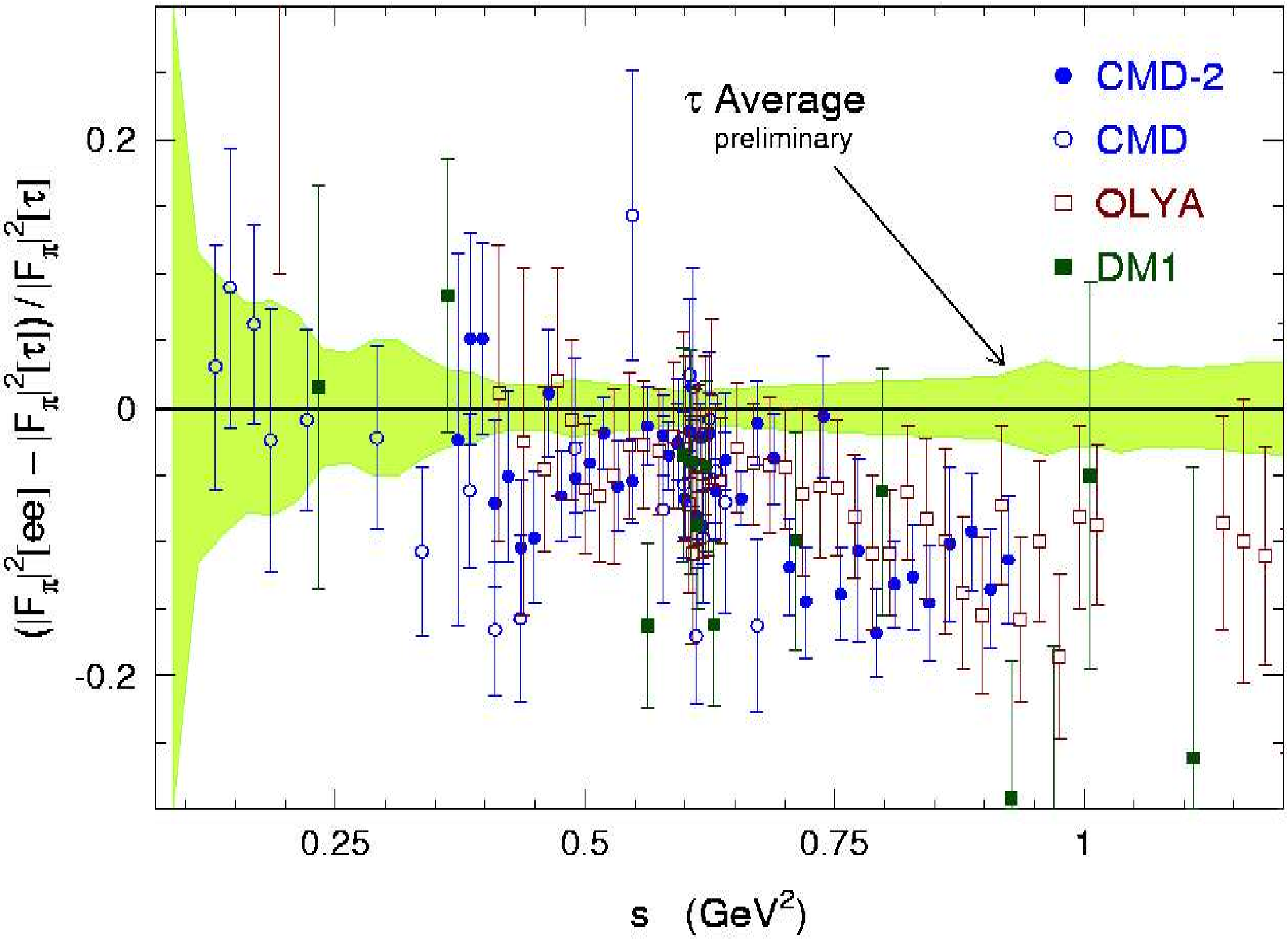


# Evaluation of R



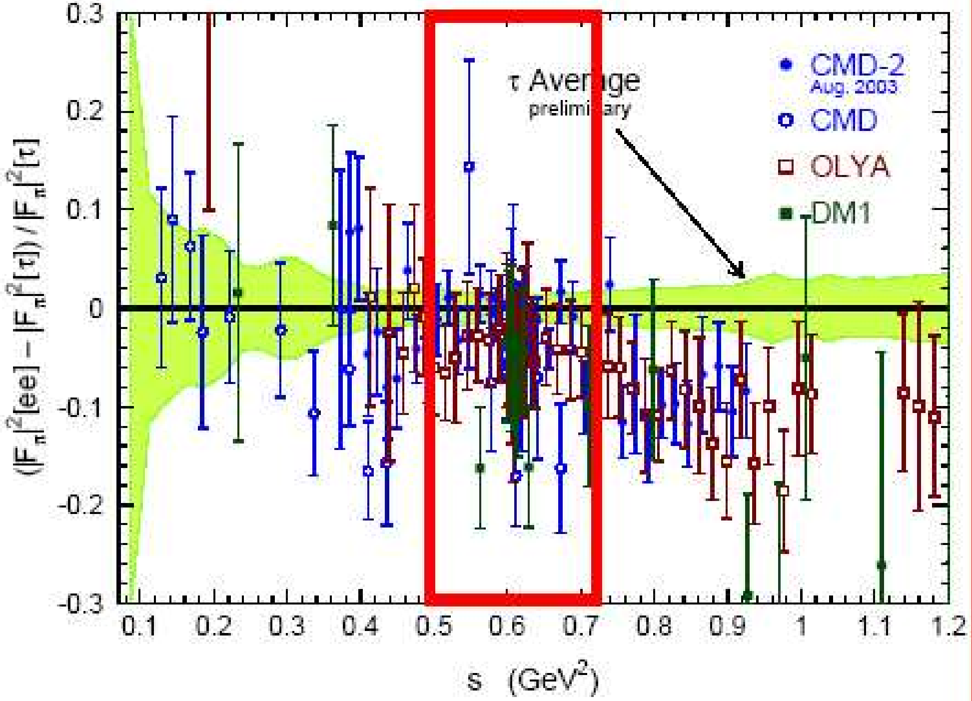

M. Davier *et al.*, hep-ph/0208177.v3

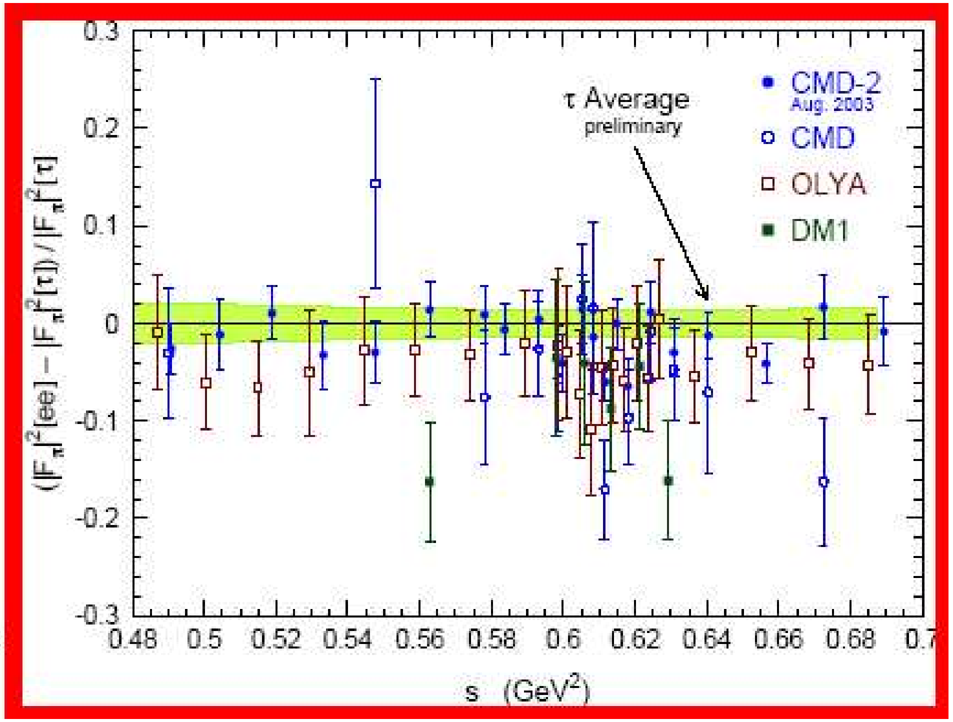
# Difference between $e^+e^-$ and $\tau$




M. Davier *et al.*, hep-ph/0208177.v3

# …Difference between $e^+e^-$ and $\tau$




M. Davier *et al.*, Eur. Phys. J. **C31**, 503 (2003)

M. Davier, hep-ph/0312065

- **$a_\mu$(had1,$e^+e^-$)=(696.3±7.)×$10^{-10}$**
- **$a_\mu$(had1,$\tau$) =(711.0±6.)×$10^{-10}$**

**Why?**

M. Davier, hep-ph/0312065

- $a_\mu$**(had1,$e^+e^-$)=(696.3±7.)×$10^{-10}$**
- $a_\mu$**(had1,τ)    =(711.0±6.)×$10^{-10}$**

| $e^+e^-$ based | τ based | |
|---|---|---|
| **Correct** | **Correct** | τ-data interpr. Wrong** |
| **Correct** | **Wrong** | |
| **Wrong*** | **Correct** | |
| **Wrong*** | **Wrong** | |

***Other ($e^+e^-$) collaborations are looking into it, e.g., the KLOE Collaboration is about to announce their result.**

**$e^+e^- \to \rho^0 \to \pi^+\pi^-$, whereas $\tau^- \to \rho^- \nu_\tau \to \pi^-\pi^0\nu_\tau$,
S.G., F.J., hep-ph/0310181

# Theory of $a_\mu$

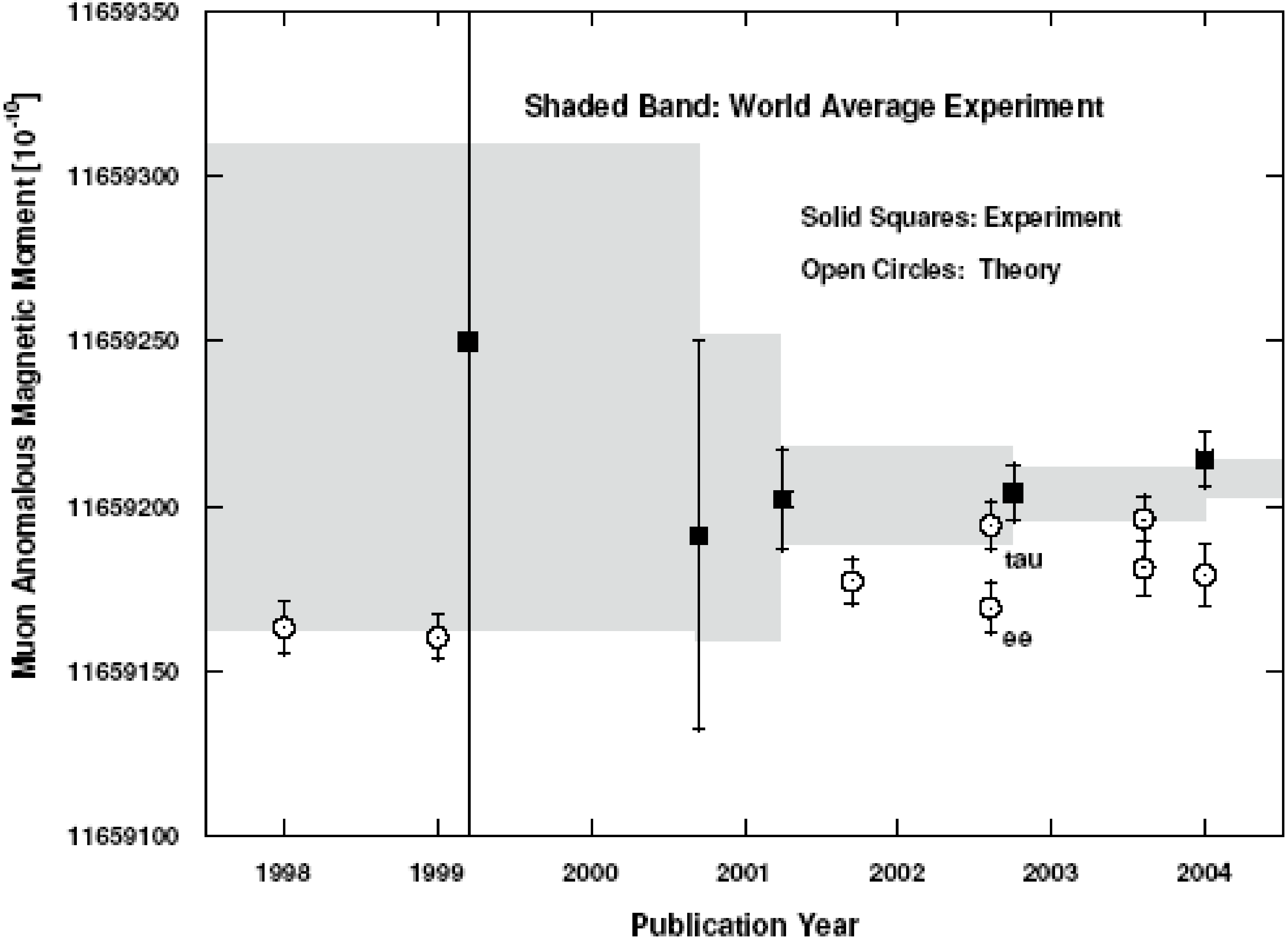
- $a_\mu(\text{theo}) = a_\mu(\text{QED}) + a_\mu(\text{had}) + a_\mu(\text{weak})$
  $+ a_\mu(\text{new physics})$

- $a_\mu(\text{QED}) = 11\ 658\ 470.6\ \ (0.3) \times 10^{-10}$
- $a_\mu(\text{had}) = 694.9\ \ (8.) \times 10^{-10}$ (based on $e^+e^-$)
- $a_\mu(\text{had}) = 709.6\ \ (7.) \times 10^{-10}$ (based on $\tau$)
- $a_\mu(\text{weak}) = 15.4\ \ (0.3) \times 10^{-10}$

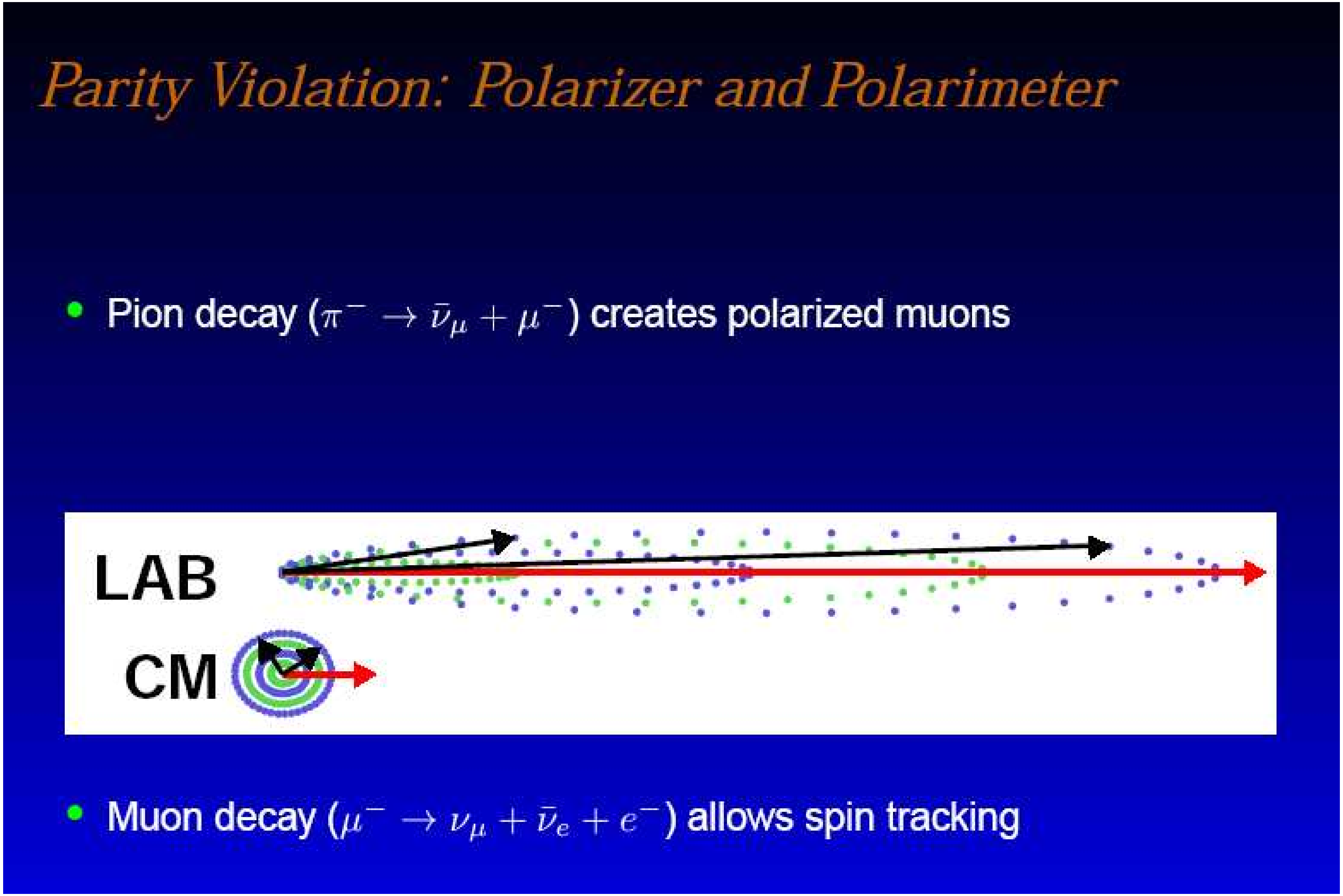
---

- $a_\mu(\text{SM}) = 11\ 659\ 181(8) \times 10^{-10}$ (based on $e^+e^-$)
- $a_\mu(\text{SM}) = 11\ 659\ 196(7) \times 10^{-10}$ (based on $\tau$)

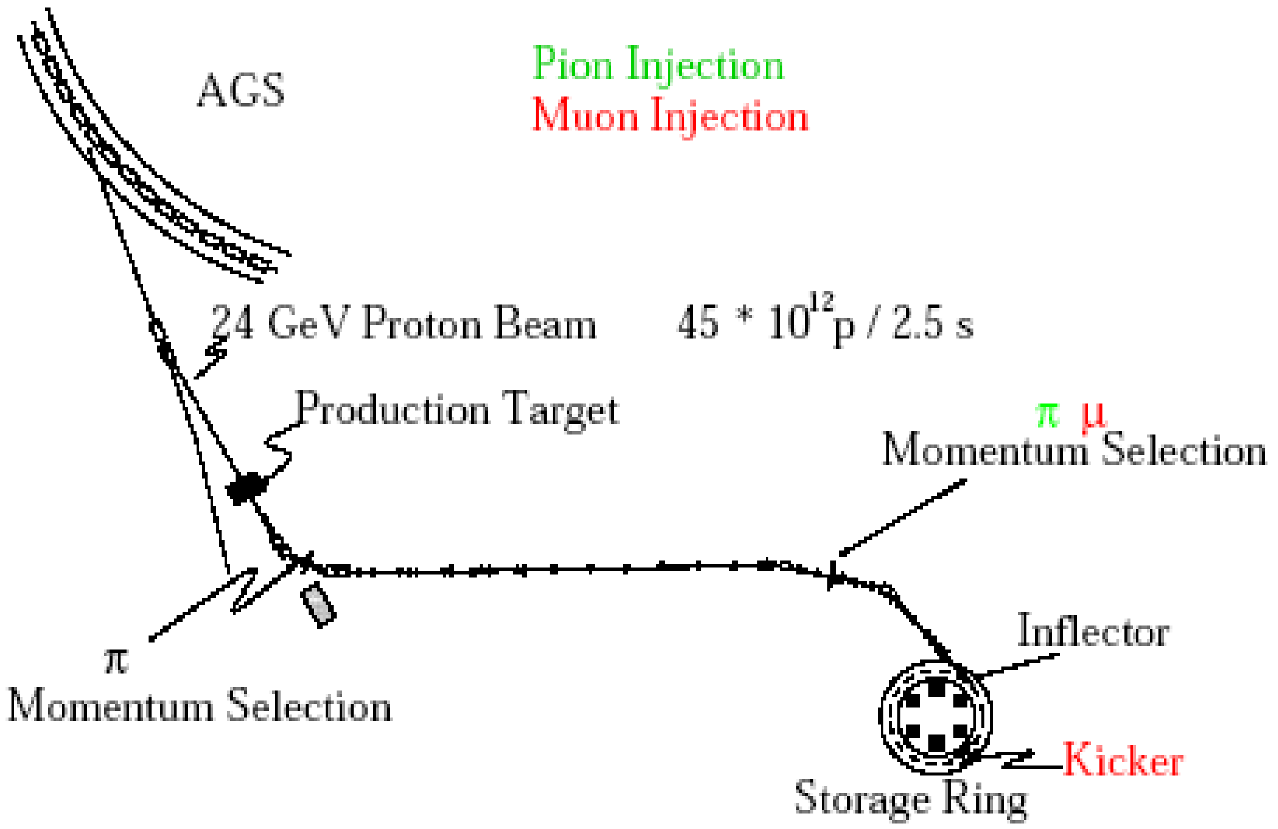
# Theory and Experiment vs. Year



# Experimental Principle



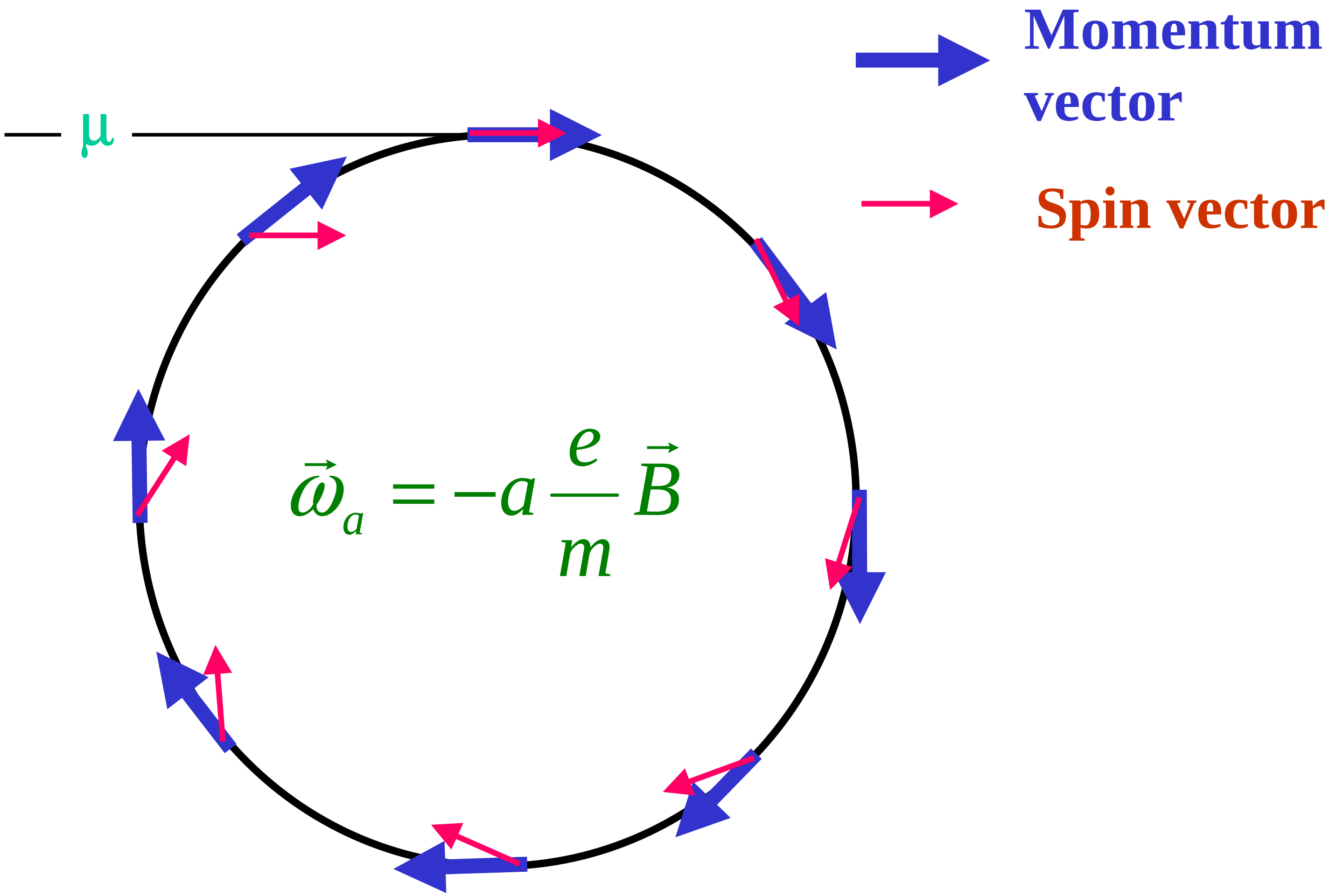
# Beamline:
# Polarized Muon Beam Production



- **The Muon Storage Ring:**
  **$B \approx 1.45T$, $P_{\mu} \approx 3.09$ GeV/c**
- **Inner Ring of Detectors**

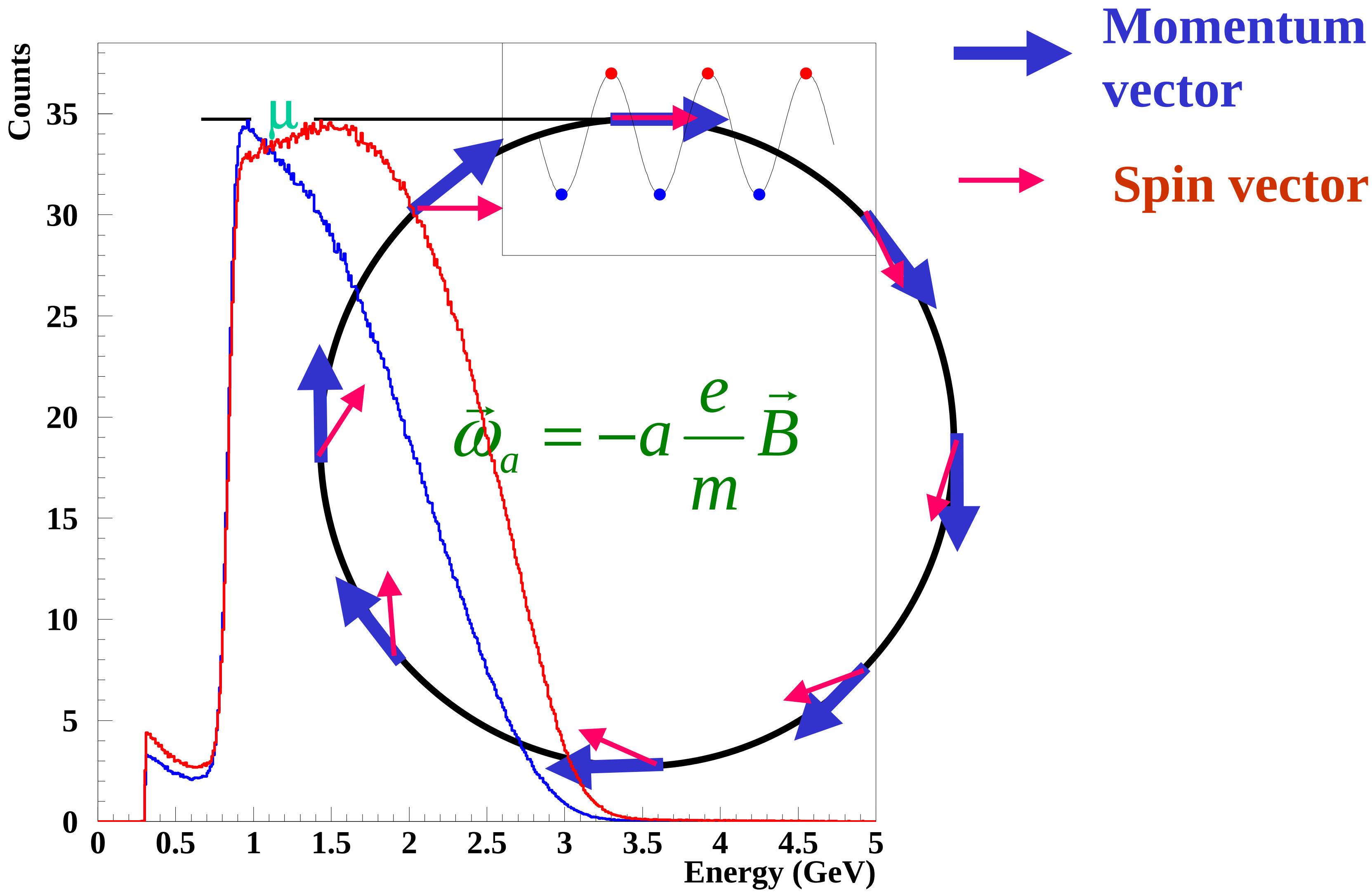

- **High Proton Intensity from AGS**
- **Muon Injection**

# Spin Precession in g-2 Ring
# (Top View)



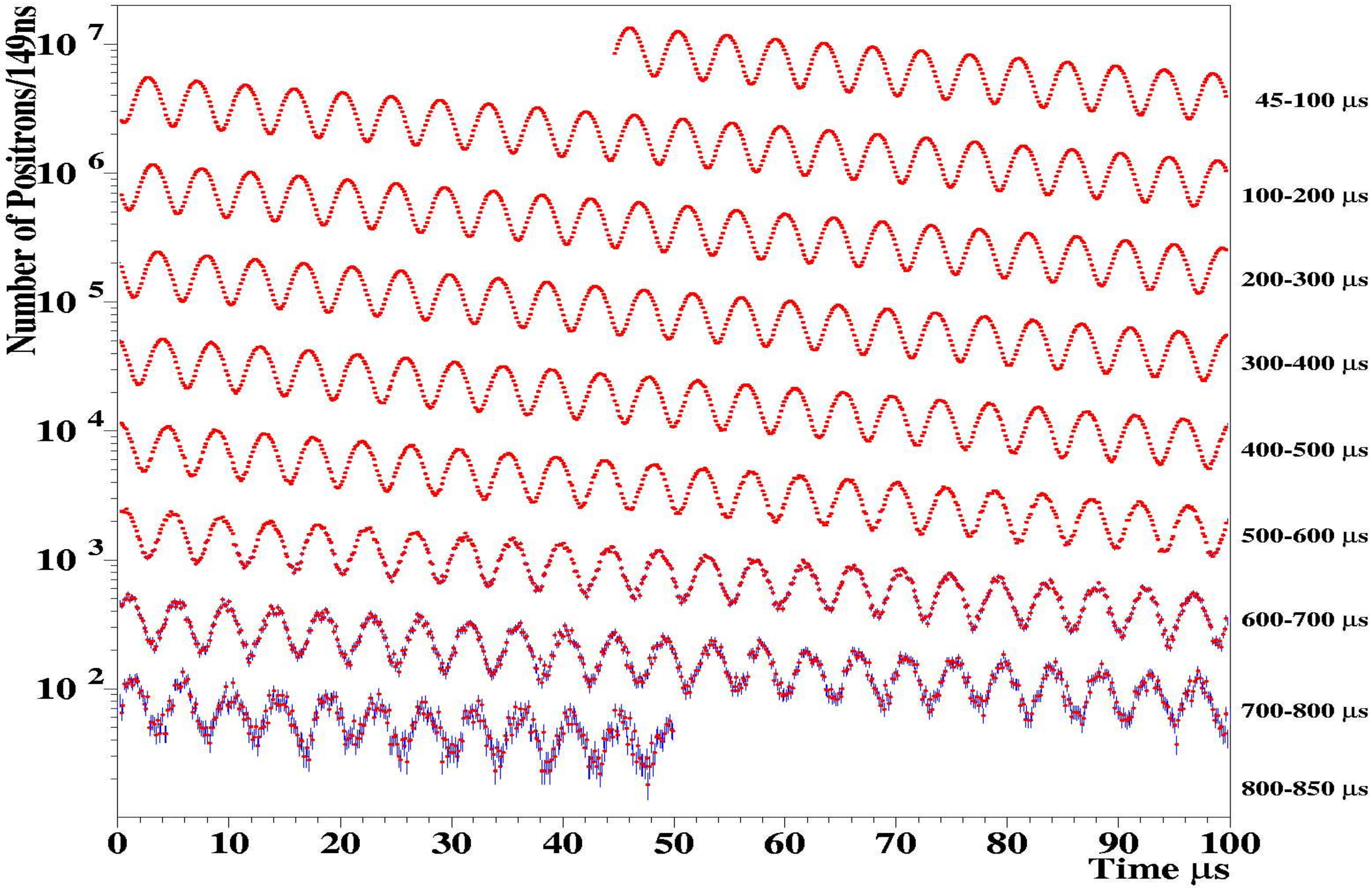

$$\vec{\omega}_a = -a \frac{e}{m} \vec{B}$$

# Spin Precession in g-2 Ring (Top View)

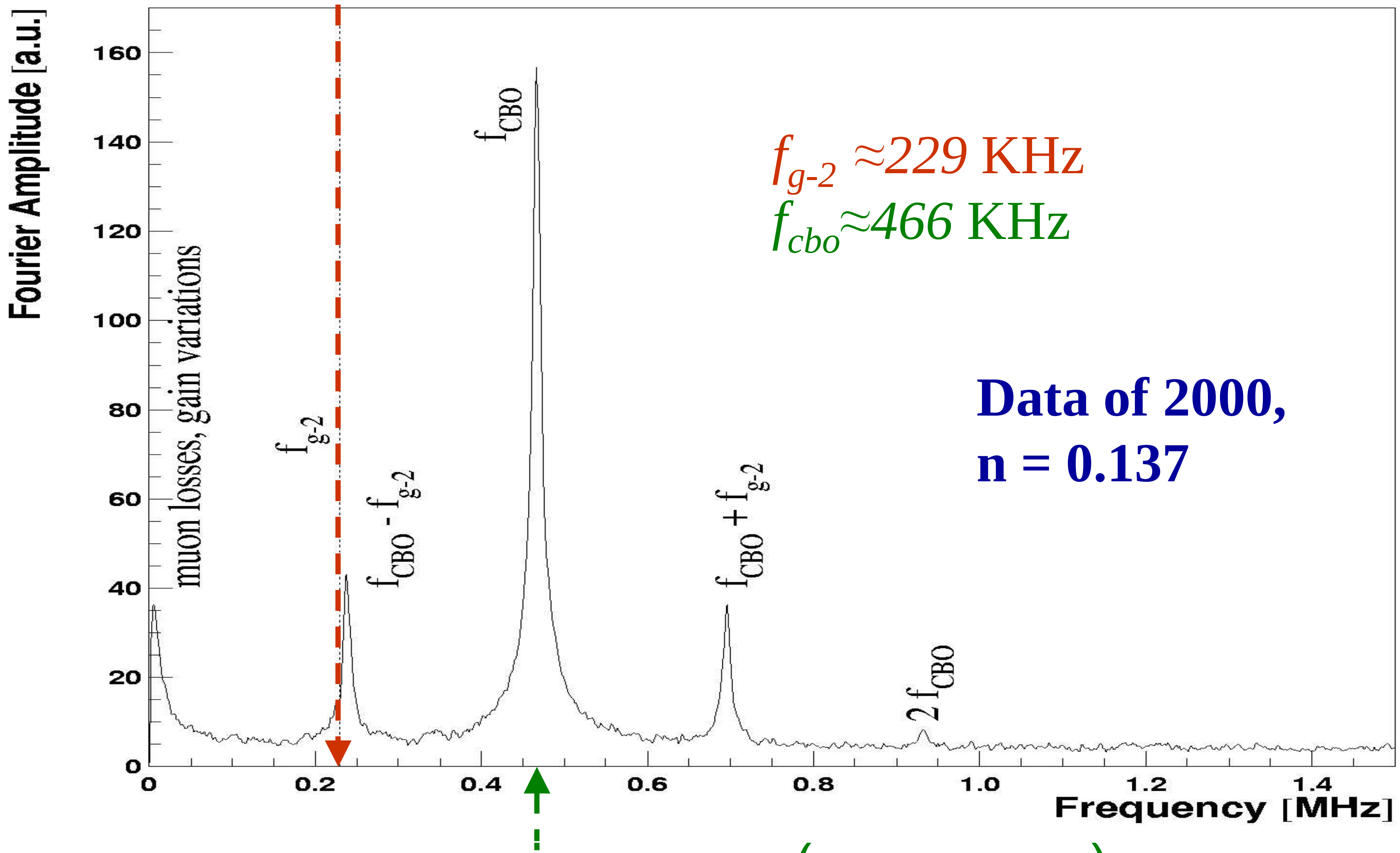


# 4 Billion $e^+$ with E>2GeV

$$dN / dt = N_0 e^{-\frac{t}{\tau}} [1 + A \cos(\omega_a t + \phi_a)]$$



# 5-parameter Function Not Quite Adequate. Fourier Spectrum of the Residuals:




$$f_{cbo} \approx f_C\left(1-\sqrt{1-n}\right)$$

# Modulation of $N_0$, $A$, $\phi_a$ with $f_{cbo}$:

$$dN/dt = N_0(t)e^{-\frac{t}{\tau}}\left[1 + A(t)\cos\left(\omega_a t + \phi_a(t)\right)\right]$$

$$N_0(t) = N_0\left[1 + A_N e^{-\frac{t}{\tau_{cbo}}}\cos\left(2\pi f_{cbo}t + \phi_N\right)\right]$$

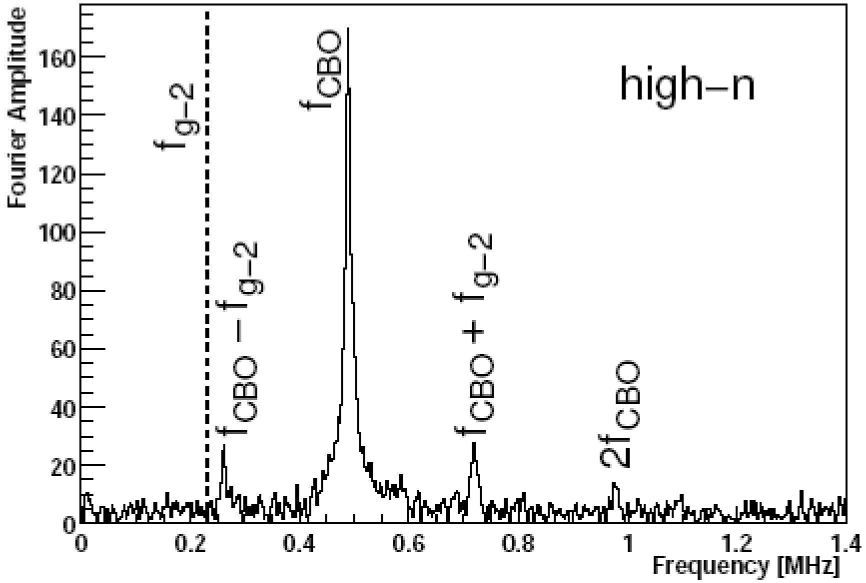
$$A(t) = A\left[1 + A_A e^{-\frac{t}{\tau_{cbo}}}\cos\left(2\pi f_{cbo}t + \phi_A\right)\right]$$

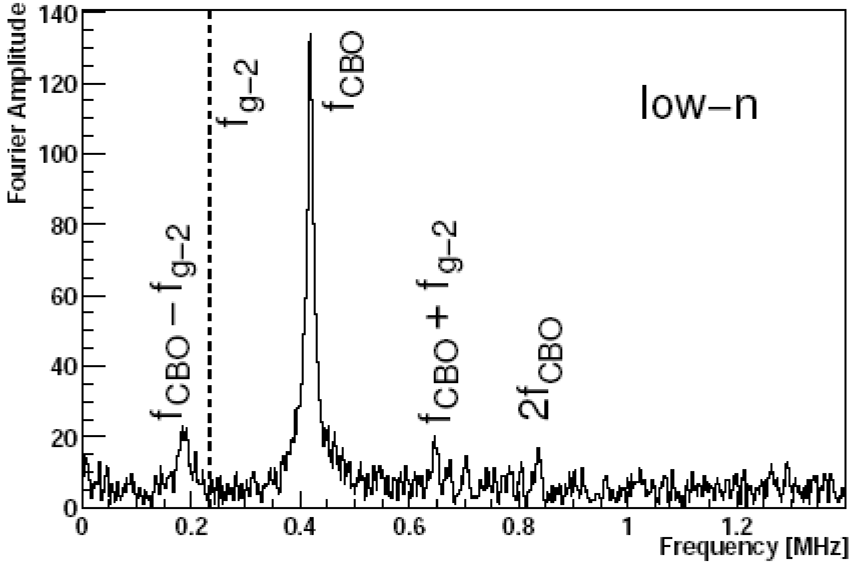
$$\phi_a(t) = \phi_a + A_\phi e^{-\frac{t}{\tau_{cbo}}}\cos\left(2\pi f_{cbo}t + \phi_\phi\right)$$

**Amplitudes of $A_N$, $A_A$, $A_\phi$, Consistent with Values from MC Simulations ($10^{-2}$, $10^{-3}$, $10^{-3}$ respectively)**

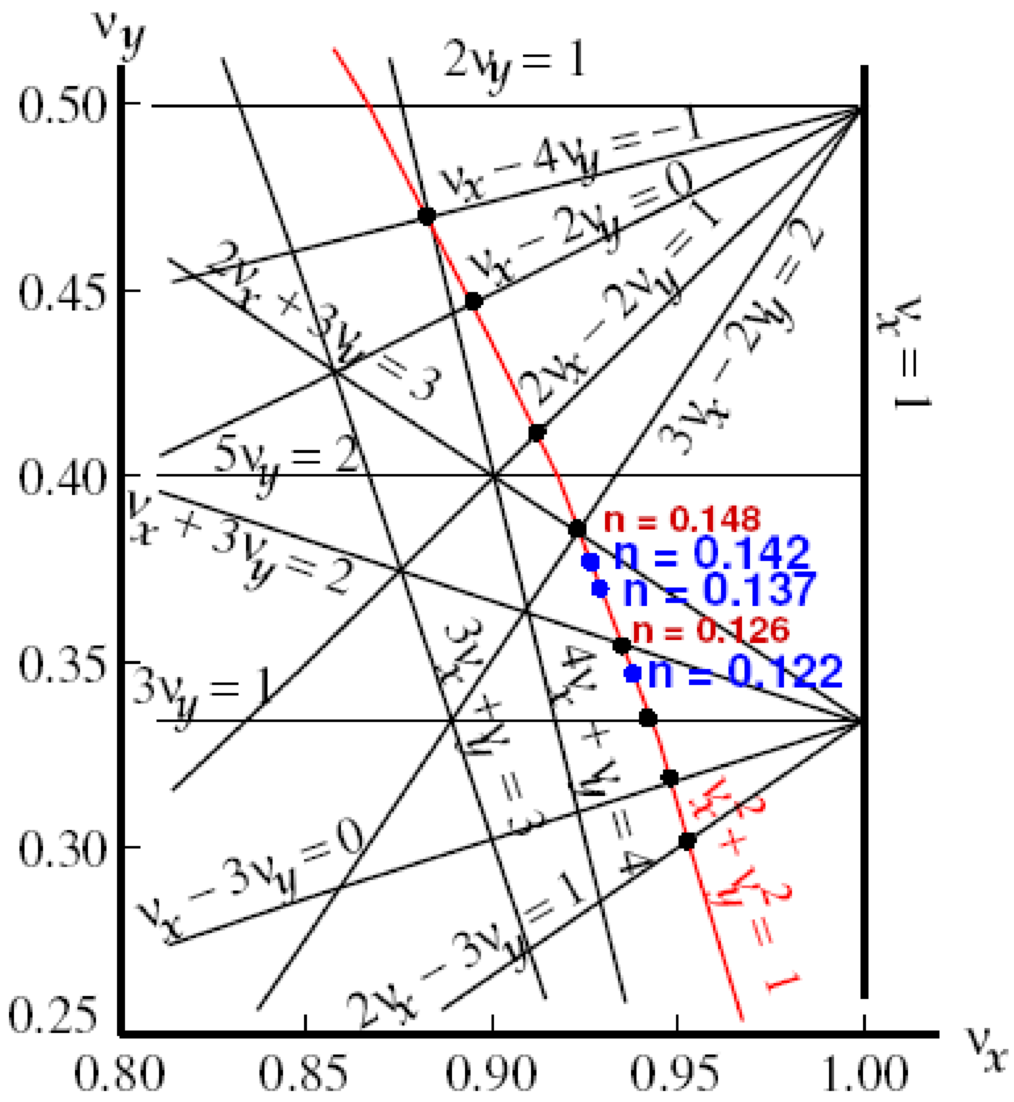
# 2001 Run with Negative Muons

- In 2001 we have collected 3.7 Billion electrons with E>1.8GeV from a run with negative muons ($\mu^-$). Run at n=0.122 and n=0.142.



# Vertical vs. Horizontal Tune

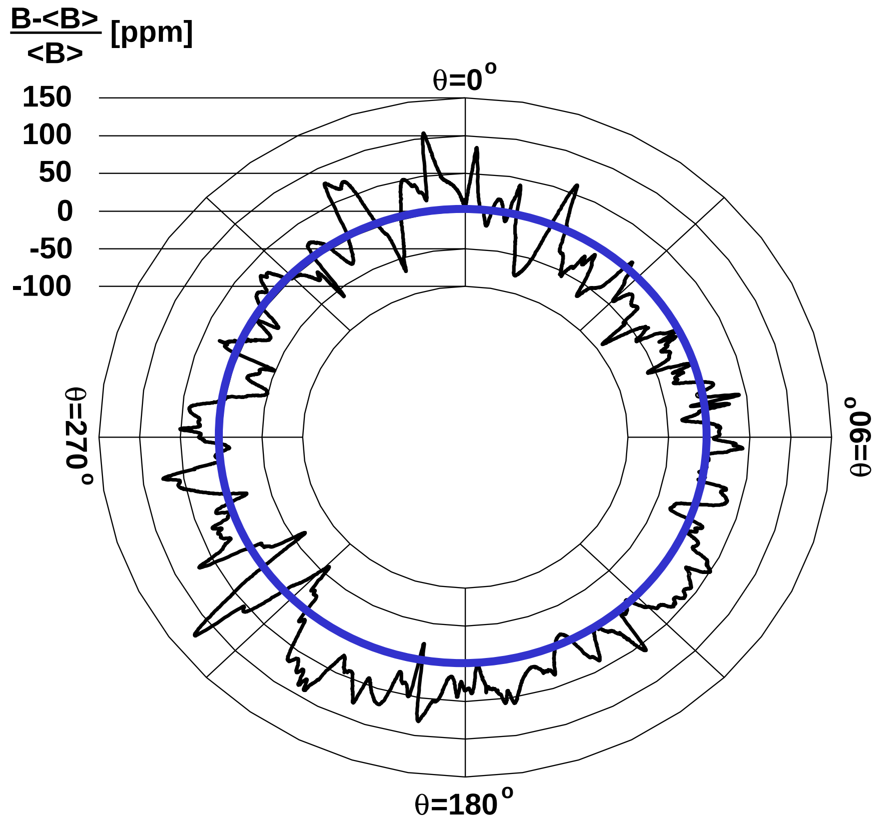


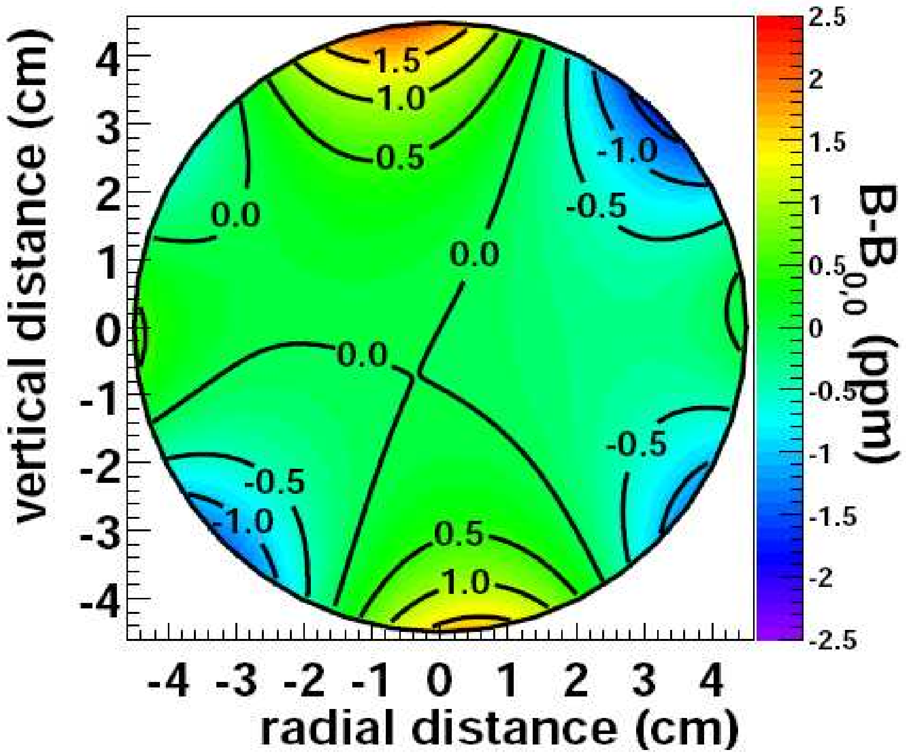
# Systematic/Statistical Uncertainties for the $\omega_a$ Analysis.

| | Size [ppm] | |
|---|---|---|
| **Systematic Uncertainties** | **2001** | **2000** |
| Coherent Betatron Oscillations (CBO) | 0.07 | 0.21 |
| Pileup (Overlapping Signals) | 0.08 | 0.13 |
| Gain Changes | 0.12 | 0.12 |
| Lost Muons | 0.09 | 0.10 |
| Others | 0.11 | 0.08 |
| Total Systematics | 0.21 | 0.31 |
| **Statistical Uncertainty** | 0.66 | 0.62 |

| | | |
|---|---|---|
| **Total Uncertainty:** | **0.7** | **0.7** |

# Magnetic Field measurement




The *B* field azimuthal variation at the center of the storage region. <B>≈1.45 T

The *B* field averaged over azimuth.

# Magnetic Field Measurement

**Systematic Uncertainties for the $\omega_p$ Analysis.**

| Source of Errors | Size [ppm] 2001 | 2000 |
|---|---|---|
| Absolute Calibration of Standard Probe | 0.05 | 0.05 |
| Calibration of Trolley Probe | 0.09 | 0.15 |
| Trolley Measurements of B-field | 0.05 | 0.10 |
| Interpolation with Fixed Probes | 0.07 | 0.10 |
| Uncertainty from Muon Distribution | 0.03 | 0.03 |
| Others | 0.10 | 0.10 |
| Total | 0.17 | 0.24 |

# Computation of $a_\mu$:

$$a_\mu = \frac{\omega_a}{\frac{e}{m_\mu}\langle B \rangle} = \frac{\omega_a / \omega_p}{\mu_\mu / \mu_p - \omega_a / \omega_p}$$

- *Analyses of $\omega_a$ and $\omega_p$ are Separate and Independent ("**Blind Analysis**"). When Ready, only then, Offsets are Removed and $a_\mu$ is Computed.*

# Computation of $a_\mu$:

$$a_{\mu^-} = \frac{\omega_a}{\frac{e}{m_{\mu^-}}\langle B\rangle} = \frac{\omega_a/\omega_p}{\mu_{\mu^-}/\mu_p - \omega_a/\omega_p} = \frac{R_{\mu^-}}{\lambda - R_{\mu^-}}$$

$$R_{\mu^-} \equiv \omega_a/\omega_p = 0.003\,707\,208\,3\,(26)$$

$$\lambda = \mu_\mu/\mu_p = 3.183\,345\,39\,(10)$$

W.L. *et al.*, PRL **82**, 711 (1999)

Data of 2001:

***$a_\mu$(exp)=11 659 214(8)(3)×$10^{-10}$*** **(0.7 ppm)**

# Average of $a_\mu$:

CPT? $\Delta R = R_{\mu^-} - R_{\mu^+} = (3.5 \pm 3.4) \times 10^{-9}$

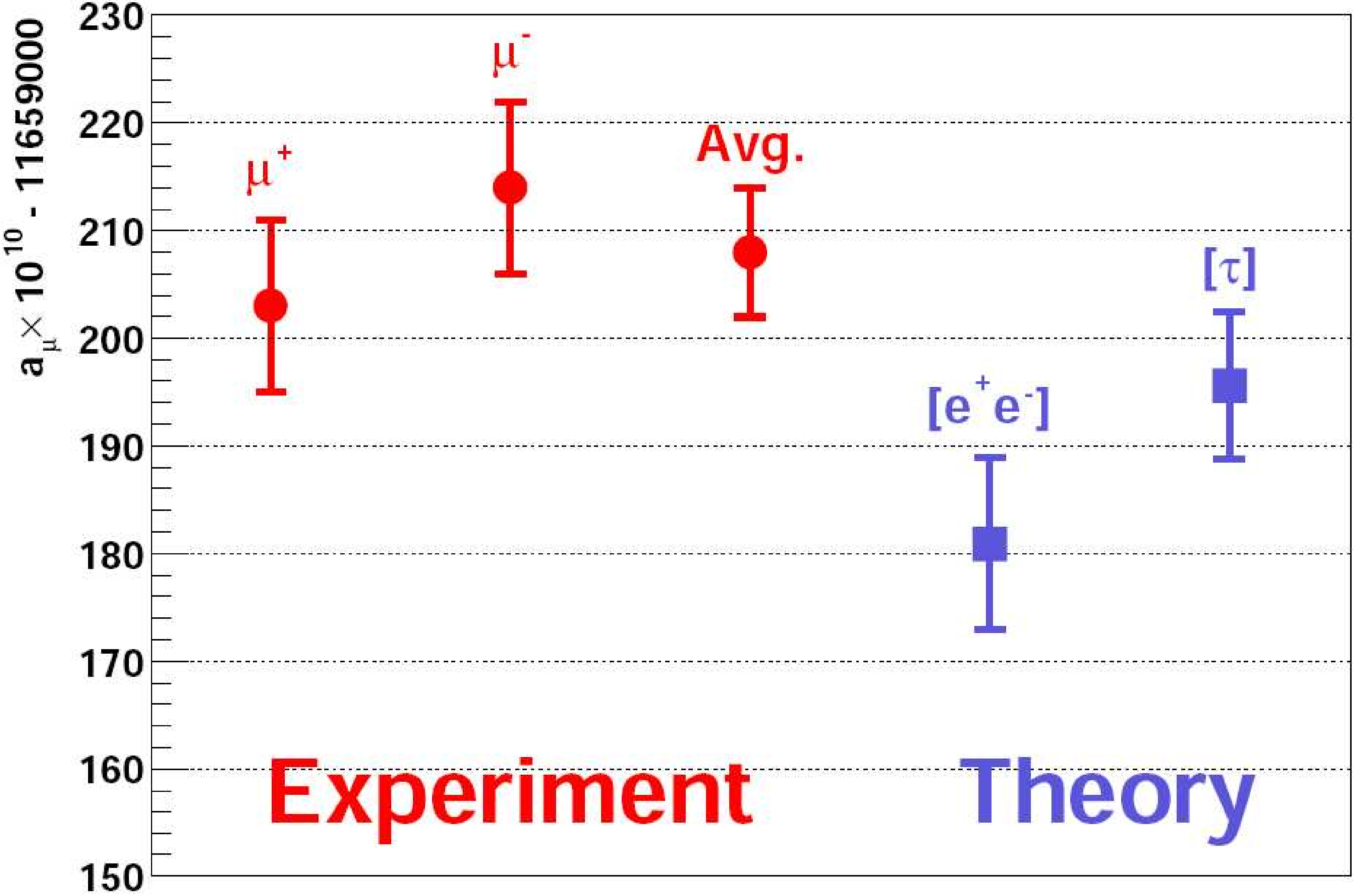
Exp. World Average:

***$a_\mu$(exp)=11 659 208(6)×$10^{-10}$* (0.5 ppm)**

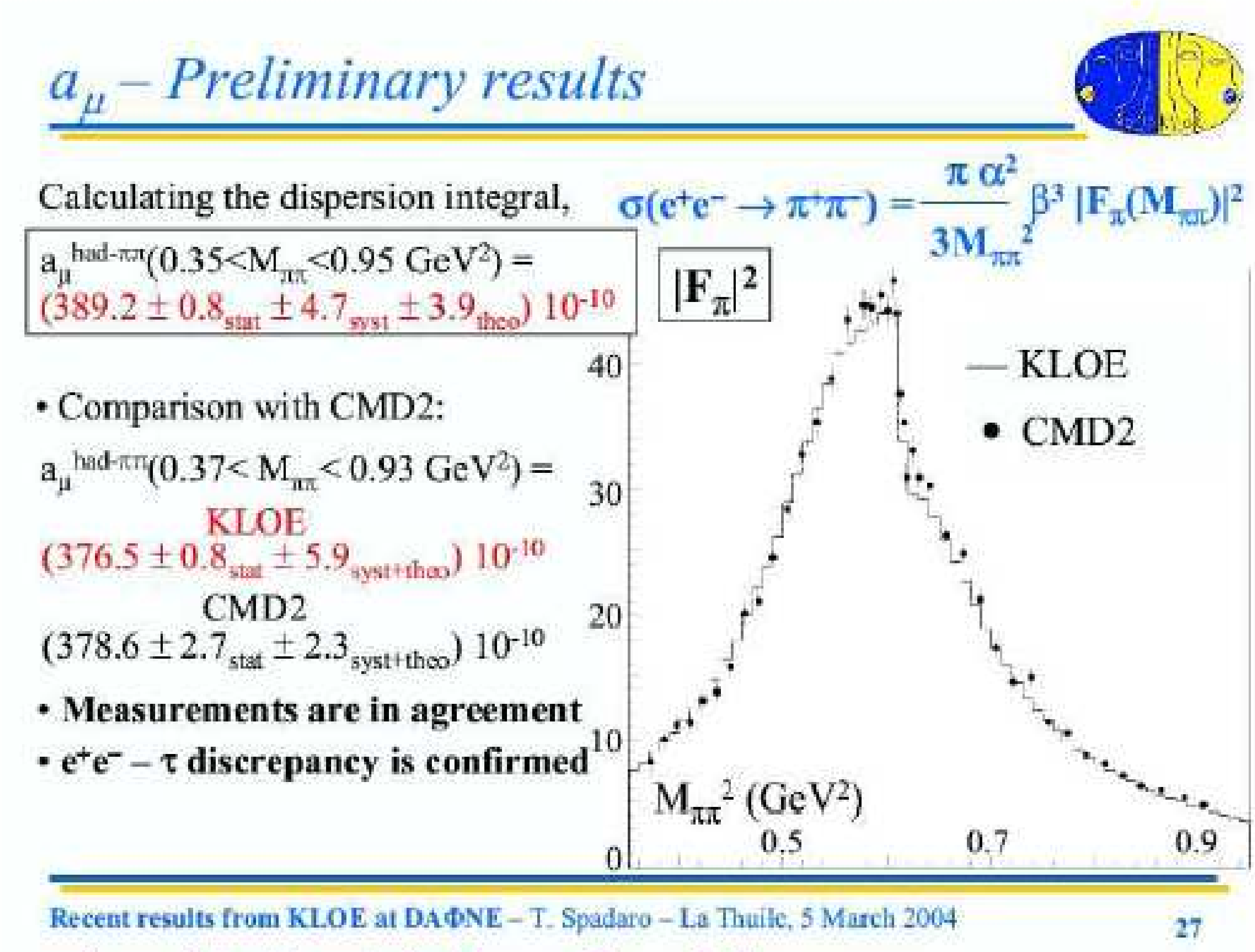
**$a_\mu$(exp)- $a_\mu$(SM) = 27 (10)×$10^{-10}$, 2.7σ, based on $e^+e^-$ data**

**$a_\mu$(exp)- $a_\mu$(SM) = 12 (9) ×$10^{-10}$, 1.4σ, based on τ-data**

G.B. *et al.*, hep-ex/0401008, PRL in Press



# Recent KLOE Results




(provided by Juliet Lee-Franzini)

# Recent Developments in Theory

- $a_\mu$(had, LBL) = +8.6(3.5)$\times 10^{-10}$ Large N QCD+Chiral
  +13.6(2.5)$\times 10^{-10}$ Melnikov + Vainshtein
  +11.1(1.7)$\times 10^{-10}$ Dubnicka *et al*
  +9.2(3.0)$\times 10^{-10}$ T+Ynd.
  +11.0(2.0)$\times 10^{-10}$ W. Marciano, prelim.

- Use +12.0(3.5)$\times 10^{-10}$ WM

- $a_\mu$(QED) = 11 658 472.07(0.04)(0.1)$\times 10^{-10}$ Recent Kinoshita Update

# Recent Developments in had1

- $a_\mu$(had,1) = 696.3(6.2)(3.6)$\times 10^{-10}$ DEHZ

  696.2(5.7)(2.4)$\times 10^{-10}$ HMNT

  694.8 (8.6) $\times 10^{-10}$ GJ

  692.4(5.9)(2.4)$\times 10^{-10}$ HMNT inclusive

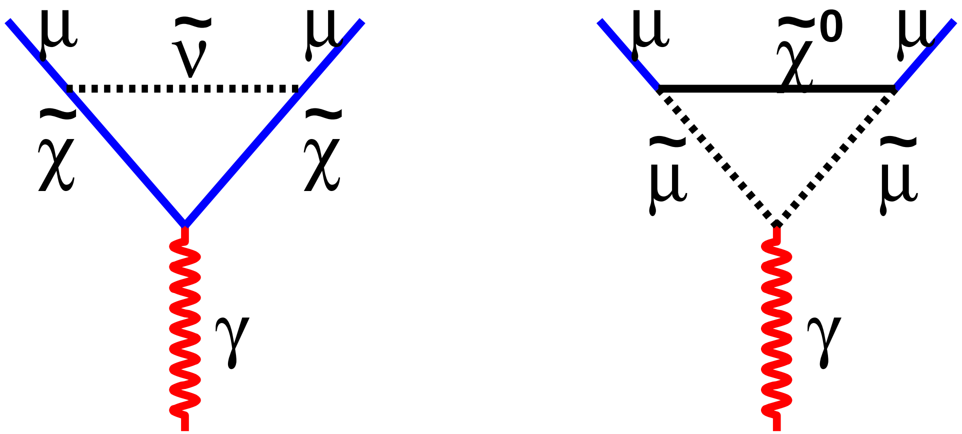
  693.5(5.0)(1.0)$\times 10^{-10}$ TY

- Use = 694.4 (6.2)(3.6)$\times 10^{-10}$ WM

- $a_\mu$(SM) = 11 659 184.1 $(7.2)_{VP}$ $(3.5)_{LBL}$ $(0.3)_{EW,QED}$ $\times 10^{-10}$
- $a_\mu$(Exp) = 11 659 208.0 (5.8)$\times 10^{-10}$

- $\Delta a_\mu = a_\mu$(Exp) - $a_\mu$(SM) = 23.9 (9.9)$\times 10^{-10}$ or 2.4 $\sigma$ deviation

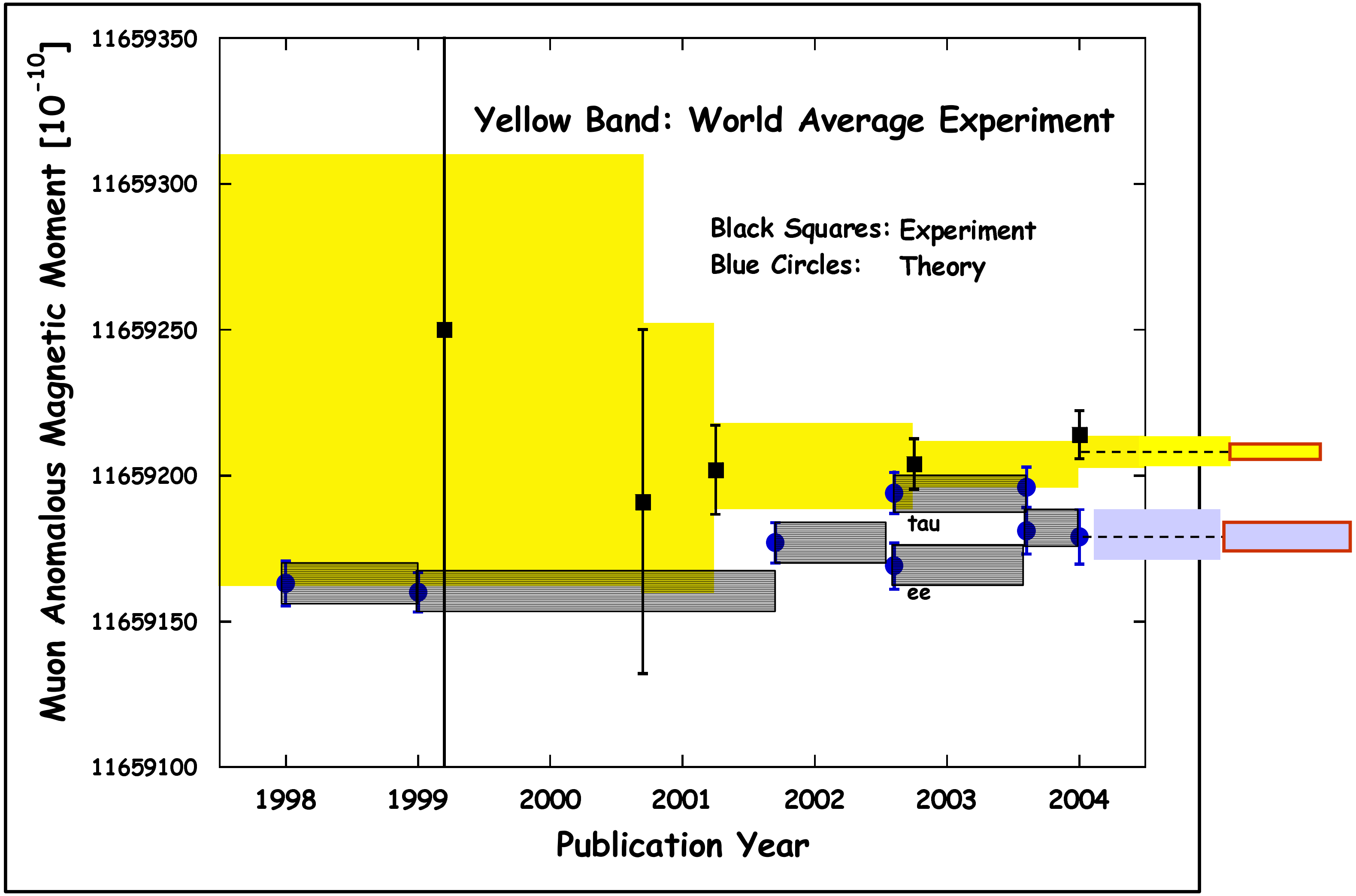
# Beyond standard model, e.g. SUSY



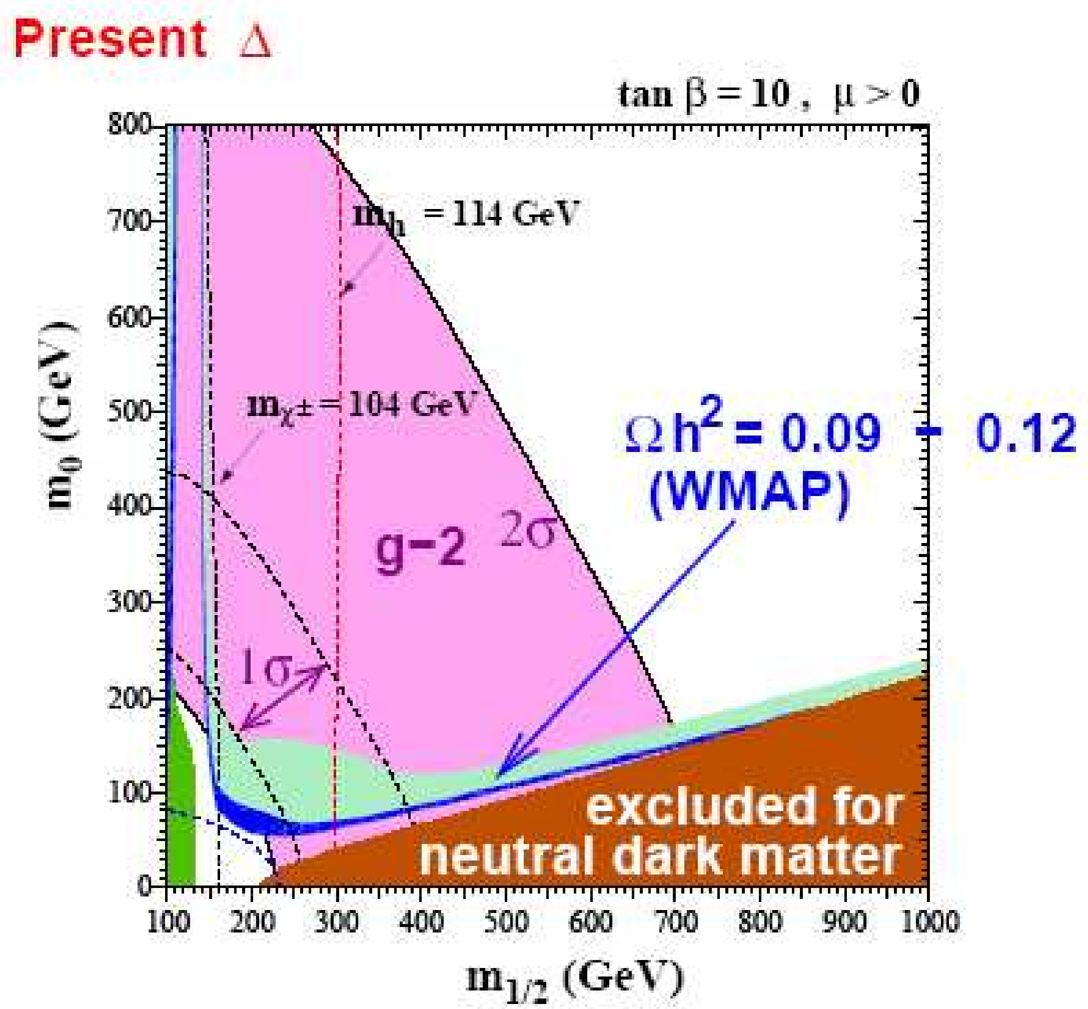

$$a_\mu^{\text{susy}} \cong \text{sgn}(\mu) \times 13 \times 10^{-10} \left( \frac{100\text{GeV}}{m_{\text{susy}}} \right)^2 \tan\beta$$

W. Marciano, J. Phys. G29 (2003) 225

# Current Status and Future Prospects

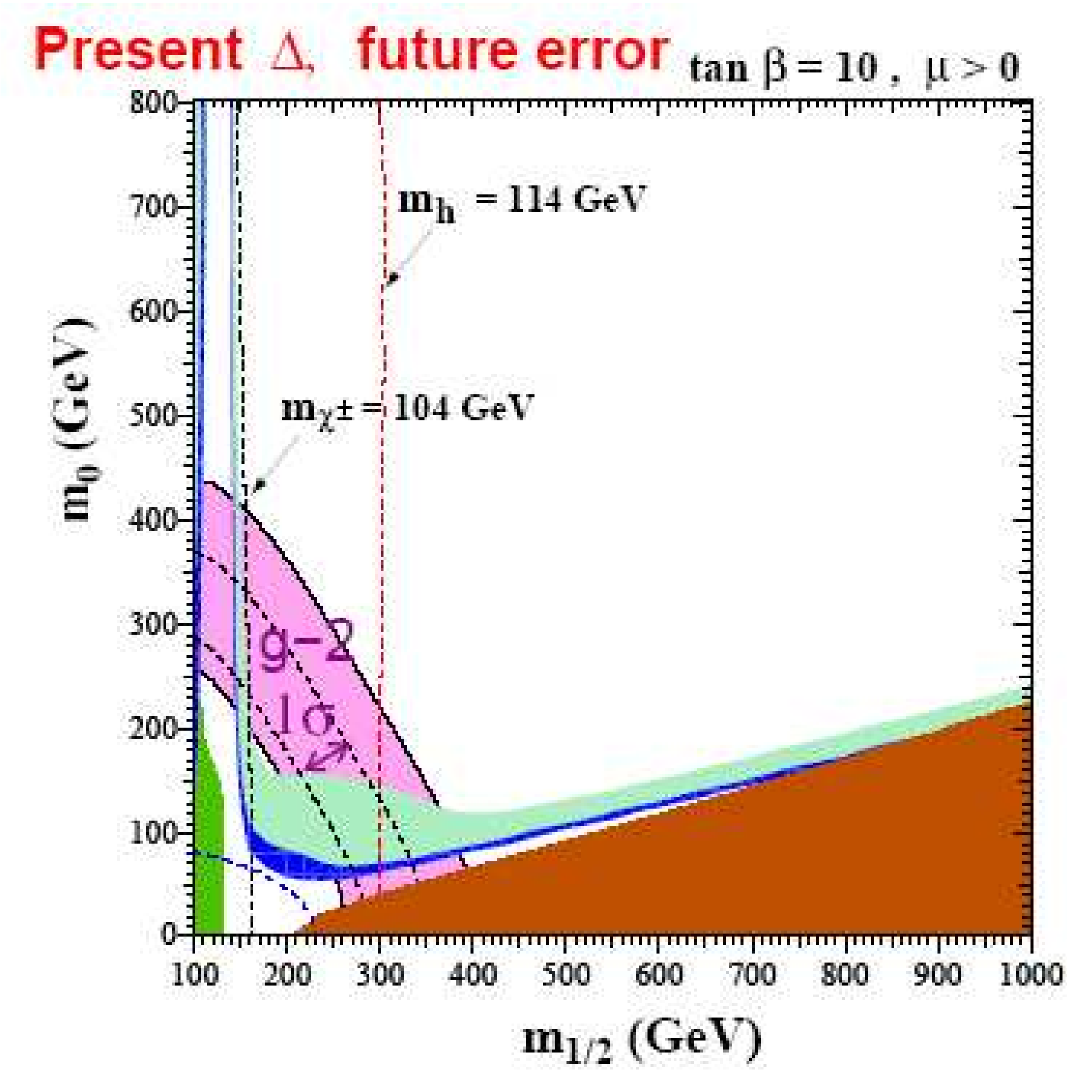


# SUSY Dark Matter




**Following Ellis, Olive, Santoso, Spanos.**
**Plot by K. Olive**

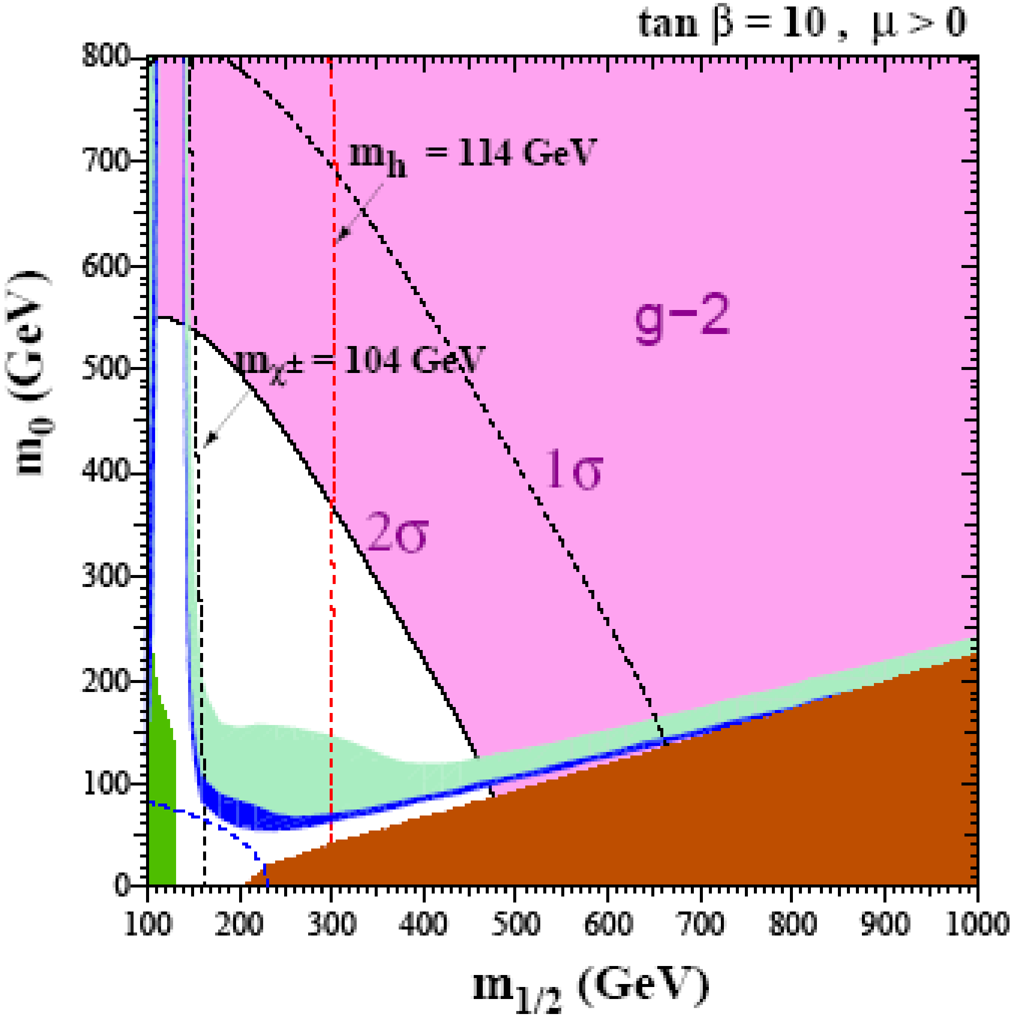
# SUSY Dark Matter




**Following Ellis, Olive, Santoso, Spanos.**
**Plot by K. Olive**

# SUSY Dark Matter

Δ=0 Future error




**Following Ellis, Olive, Santoso, Spanos.**
**Plot by K. Olive**

**Upper Limits on SUSY Mass Scales are set by Muon g-2**

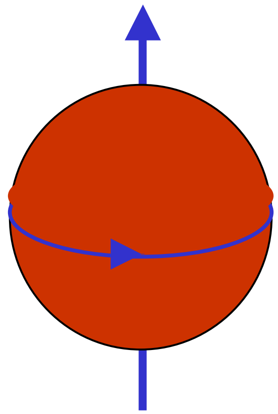
# Prospects and Summary

- Experimental measurement of the anomalous magnetic moment of negative muons to 0.7 ppm.
- Combined with the positive muon result:  0.5ppm
- More data from the theory front are/will be analyzed: Novosibirsk, KLOE, BaBar, Belle.
- The g-2 collaboration is working towards reducing the experimental error by a factor of 2.

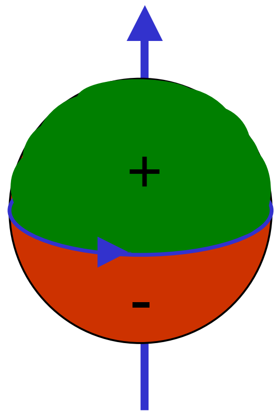
# Electric Dipole Moments in Storage Rings

- **EDMs: Why are they important?**
- **EDMs in Storage Rings**

# Spin is the only vector…

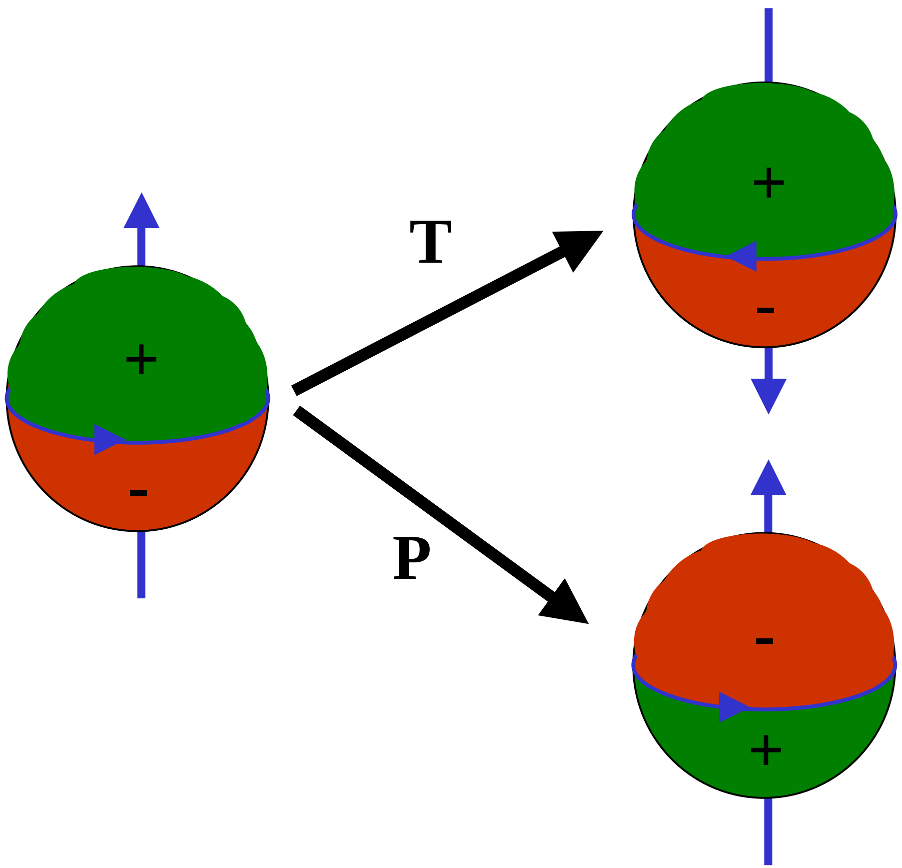


$$\vec{d} = 0$$




$$\vec{d} \propto d\vec{\sigma}$$

# A Permanent EDM Violates both T & P Symmetries:



**T-Violation** $\xrightarrow{\text{CPT}}$ **CP-Violation**

**<u>Andrei Sakharov 1967:</u>**

**CP-Violation is one of three conditions to enable a universe containing initially equal amounts of matter and antimatter to evolve into a matter-dominated universe, which we see today….**

# EDM Searches are Excellent Probes of Physics Beyond the SM:

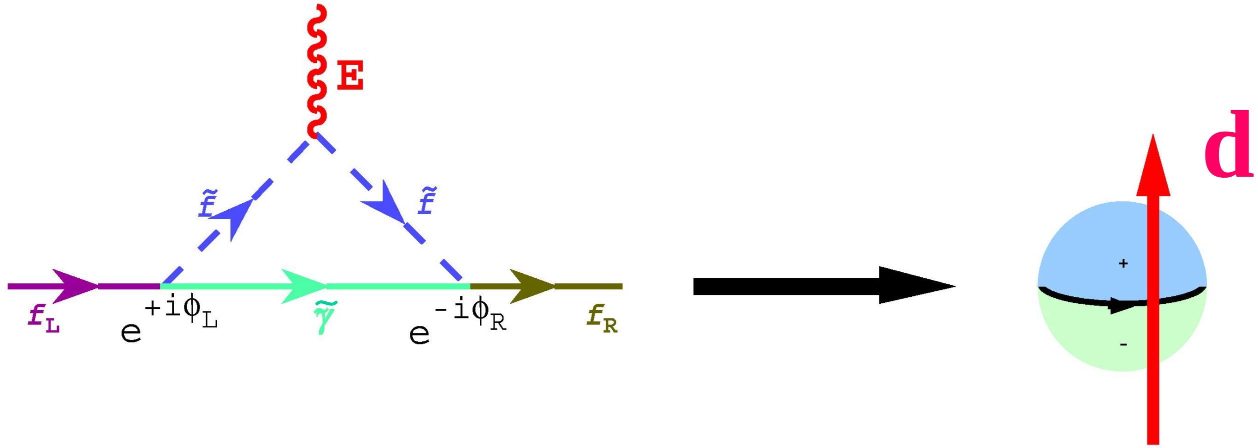
**SM:** **One CP-Violating Phase (CKM), Needs loops with all quark families for a non-zero result (Third Order Effect).**

**SUSY:** **42 CP-Violating Phases, Needs one loop for a non-zero result (First Order Effect).**

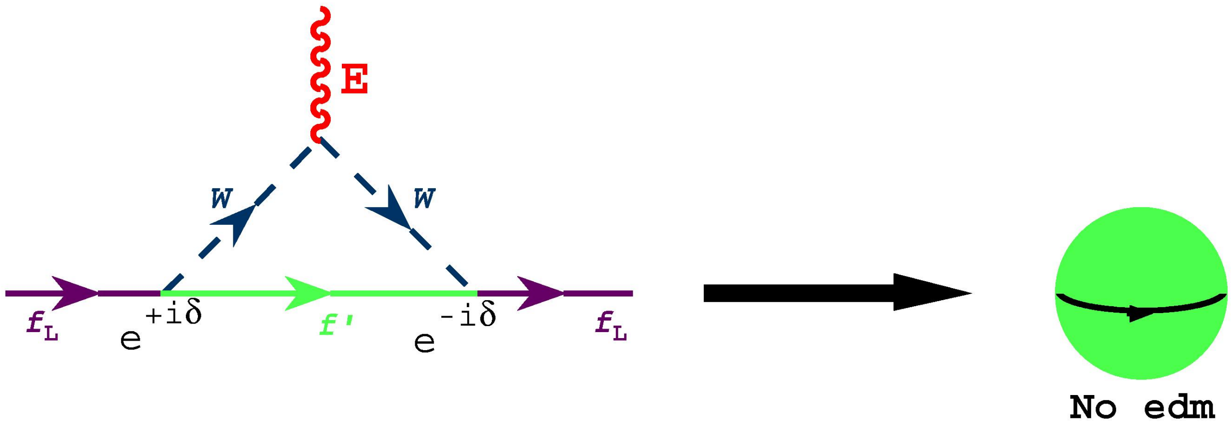
# Supersymmetry generates EDM naturally; Standard Model does not.

à la Fortson

(a) SUSY: Generates edm in virtual cloud.




(b) Standard Model: Edm cancels.

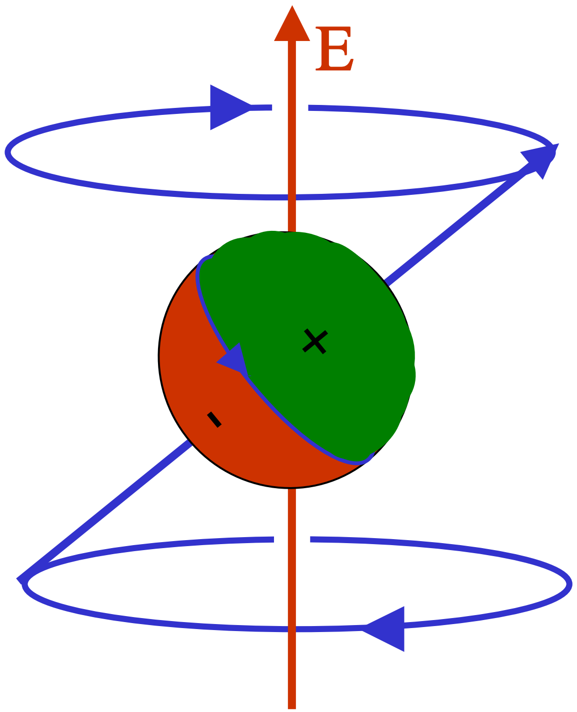


# Usual Experimental Method

$$\frac{d\vec{s}}{dt} = \vec{\mu} \times \vec{B} + \vec{d} \times \vec{E}$$

Carrier Signal

Small Signal




**Compare the Zeeman Frequencies When E-field is Flipped:**

$$\hbar(\omega_1 - \omega_2) = 4dE$$

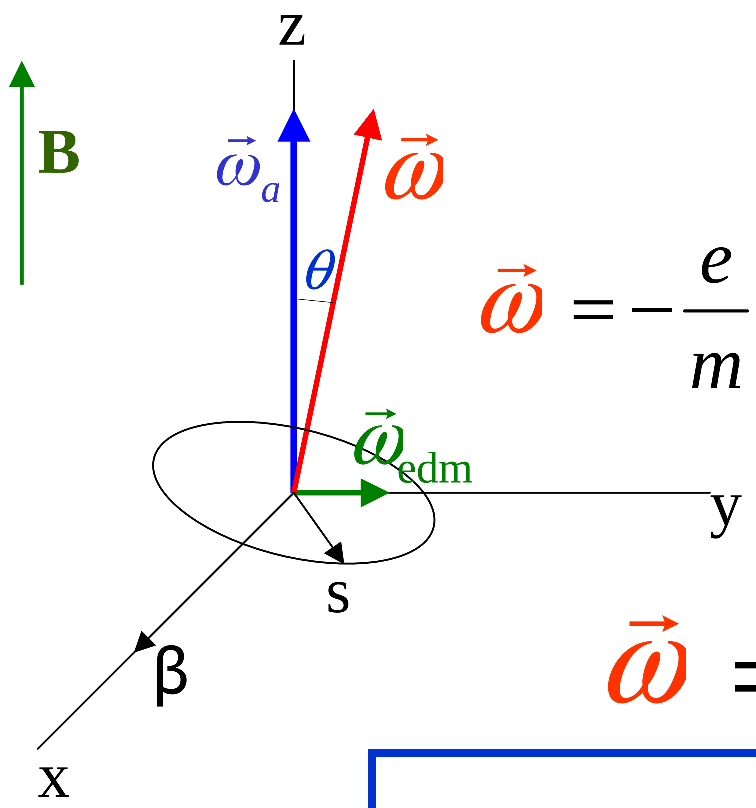
$$\sigma_d \propto \frac{1}{E}\frac{1}{\sqrt{N\tau T}}$$

# Electric Dipole Moments in Storage Rings

$$\frac{d\vec{s}}{dt} = \vec{d} \times \left( \vec{u} \times \vec{B} \right)$$

e.g. 1T corresponds to 300 MV/m!

# Indirect Muon EDM limit from the g-2 Experiment




$$\vec{\omega} = -\frac{e}{m}\left\{a\vec{B} + \frac{\eta}{2c}\left(\vec{u}\times\vec{B}\right)\right\}$$

$$\vec{\omega} = \vec{\omega}_a + \vec{\omega}_{edm}$$

$$\tan\theta = \frac{\omega_{edm}}{\omega_a}$$

Ron McNabb's Thesis 2003: $< 2.7\times 10^{-19}\,\mathrm{e\cdot cm}$ 95% C.L.

# Two Major Ideas:

- Radial E-field to Cancel the g-2 Precession
- Injecting CW and CCW

- Sensitivity: $10^{-24}$ e·cm statistical (1 yr, 0.75MW)
  $10^{-27}$ e·cm systematic error

- Muon EDM LOI: (http://www.bnl.gov/edm) to J-PARC.

# Parameter Values of Muon EDM Experiment

- Radial E-Field: $E \approx -aBc\beta\gamma^2$
- E=2MV/m
- Dipole B-field: B ~ 0.25T , R ~ 10m
- Muon Momentum: $P_\mu \approx 500$ MeV/c, $\gamma \approx 5$

- F. Farley et al., hep-ex/0307006

# Muon EDM Letter of Intent to J-PARC/Japan, 2003

J-PARC Letter of Intent: Search for a Permanent Muon Electric Dipole Moment at the $10^{-24}$ e · cm Level.


A. Silenko, **Belarusian State University, Belarus**

R.M. Carey, V. Logashenko, K.R. Lynch, J.P. Miller†, B.L. Roberts

**Boston University**

G. Bennett, D.M. Lazarus, L.B. Leipuner, W. Marciano,

W. Meng, W.M. Morse, R. Prigl, Y.K. Semertzidis†

**Brookhaven National Lab**

V. Balakin, A. Bazhan, A. Dudnikov, B. Khazin, I.B. Khriplovich, G. Sylvestrov

**BINP, Novosibirsk**

Y. Orlov, **Cornell University**

K. Jungmann, **Kernfysisch Versneller Instituut, Groningen**

P.T. Debevec, D.W. Hertzog, C.J.G. Onderwater, C. Ozben

**University of Illinois**

E. Stephenson, **Indiana University**

M. Auzinsh, **University of Latvia**

P. Cushman, Ron McNabb, **University of Minnesota**

N. Shafer-Ray, **University of Oklahoma**

K. Yoshimura, **KEK, Japan**

M. Aoki, Y. Kuno#, A. Sato, **Osaka, Japan**

M. Iwasaki, **RIKEN, Japan**

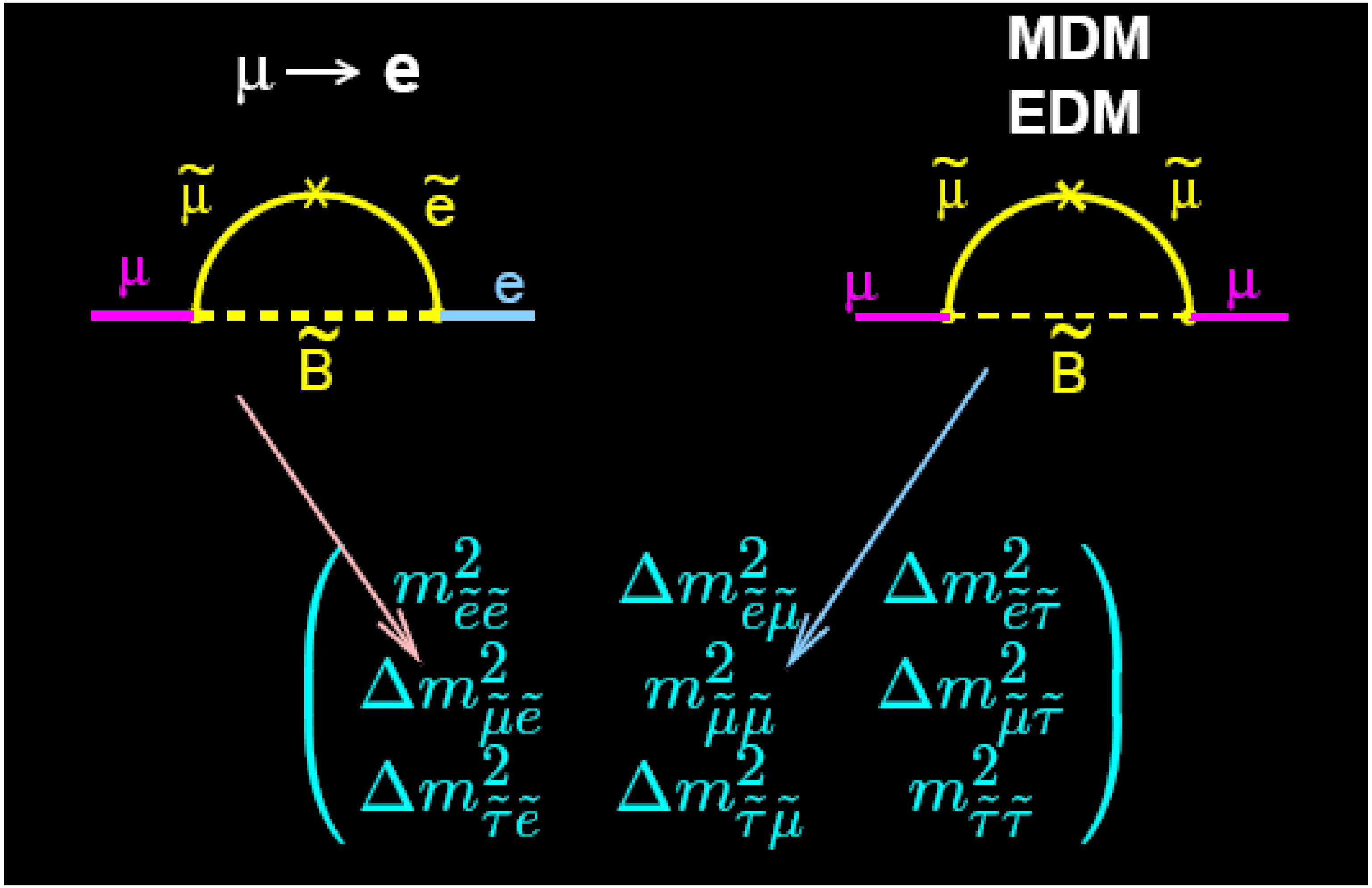
F.J.M. Farley, V.W. Hughes, **Yale University**


January 9, 2003

†Spokesperson

# Resident Spokesperson

# SUSY: EDM, MDM and Transition Moments are in Same Matrix



# Expected Muon EDM Value from $a_\mu$

$$L_{DM} = \frac{1}{2}\left[ D\bar{\mu}\sigma^{\alpha\beta}\frac{1+\gamma_5}{2} + D^*\bar{\mu}\sigma^{\alpha\beta}\frac{1-\gamma_5}{2}\right]\mu F_{\alpha\beta},$$

where $\sigma^{\alpha\beta} = \frac{1}{2}\left[\gamma^\alpha, \gamma^\beta\right]$ and

$$a_\mu \frac{e}{2m_\mu} = \Re D,$$

$$d_\mu = \Im D,$$

$$D^{SUSY} = \left|D^{SUSY}\right| e^{i\phi_{CP}}$$

$$d_\mu = 2\times 10^{-22}\ \mathrm{e}\cdot\mathrm{cm}\ \frac{a_\mu^{\mathrm{SUSY}}}{27\times 10^{-10}}\tan(\phi_{CP})$$

# Predictions in Specific Models

VOLUME 85, NUMBER 24 PHYSICAL REVIEW LETTERS 11 DECEMBER 2000

## Enhanced Electric Dipole Moment of the Muon in the Presence of Large Neutrino Mixing

K. S. Babu,[1] B. Dutta,[2] and R. N. Mohapatra[3]
[1]*Department of Physics, Oklahoma State University, Stillwater, Oklahoma 74078*
[2]*Center for Theoretical Physics, Department of Physics, Texas A & M University, College Station, Texas 77843*
[3]*Department of Physics, University of Maryland, College Park, Maryland 20742*

(Received 12 July 2000)

The electric dipole moment (edm) of the muon ($d_\mu^e$) is evaluated in supersymmetric models with nonzero neutrino masses and large neutrino mixing arising from the seesaw mechanism. It is found that if the seesaw mechanism is embedded in the framework of a left-right symmetric gauge structure, the interactions responsible for the right-handed neutrino Majorana masses lead to an enhancement in $d_\mu^e$ to values as large as $5 \times 10^{-23} e$ cm, with a correlated value of $(g - 2)_\mu \simeq 13 \times 10^{-10}$. This should provide a strong motivation for improving the edm of the muon to the level of $10^{-24} e$ cm as has recently been proposed.

**50σ effect at $10^{-24}$ e•cm Exp. Sensitivity!**

PACS numbers: 14.60.Pq,

It has long been recognized that e (edm) of fermions can provide a u[nique window to probe] into the nature of the forces that are responsible for $CP$ violation [1]. Experimental limits on the edm of neutron have

**The predicted value for the electron is 10 times less than the current experimental limit.**

hand, are much weaker, the present limit derived from the CERN $(g - 2)$ experiment [4] is $d_\mu^e \le 1.1 \times 10^{-18} e$ cm.

The effective theory that emerges from this model at scales below $v_R$ is a constrained MSSM with far fewer number of phases. In particular, it has a built-in solution to the

plings of the $\nu_R$ fields, as well as the associated trilinear $A$ terms, will affect the soft supersymmetry breaking pa-

# g-2 Values

| | | |
|---|---|---|
| • Electron | 0.00116 | done |
| • Muon | 0.00117 | doing |
| • Proton | 1.8 | ------ |
| • Deuteron | -0.15 | OK! |

# Deuteron Coherence Time

- E, B field stability
- Multipoles of E, B fields
- Vertical (Pitch) and Horizontal Oscillations
- Finite Momentum Acceptance $\Delta P/P$

**At this time we believe we can do $\tau_p \sim 10s$**

# Deuteron Statistical Error (200MeV):

$$\sigma_d \approx 6.5 \frac{\hbar a \gamma^2}{\sqrt{\tau_p} E_R \left(1 + a\gamma^2\right) AP \sqrt{N_c f T_{Tot}}}$$

$\tau_p$ : 10s. **Polarization Lifetime (Coherence Time)**

$A$ : 0.3. **The left/right asymmetry observed by the polarimeter**

$P$ : 0.55. **The beam polarization**

$N_c$ : $10^{11}$d/cycle. **The total number of stored particles per cycle**

$T_{Tot}$: $10^7$s. **Total running time per year**

$f$ : 0.01 **Useful event rate fraction**

$E_R$ : 3.5MV/m. **Radial electric field**

$$\sigma_d \approx 5 \times 10^{-28} \, \mathrm{e \cdot cm} \quad \text{per year}$$

# Deuteron EDM to $10^{-27}$ e·cm Sensitivity Level is 100 times better than $^{199}$Hg

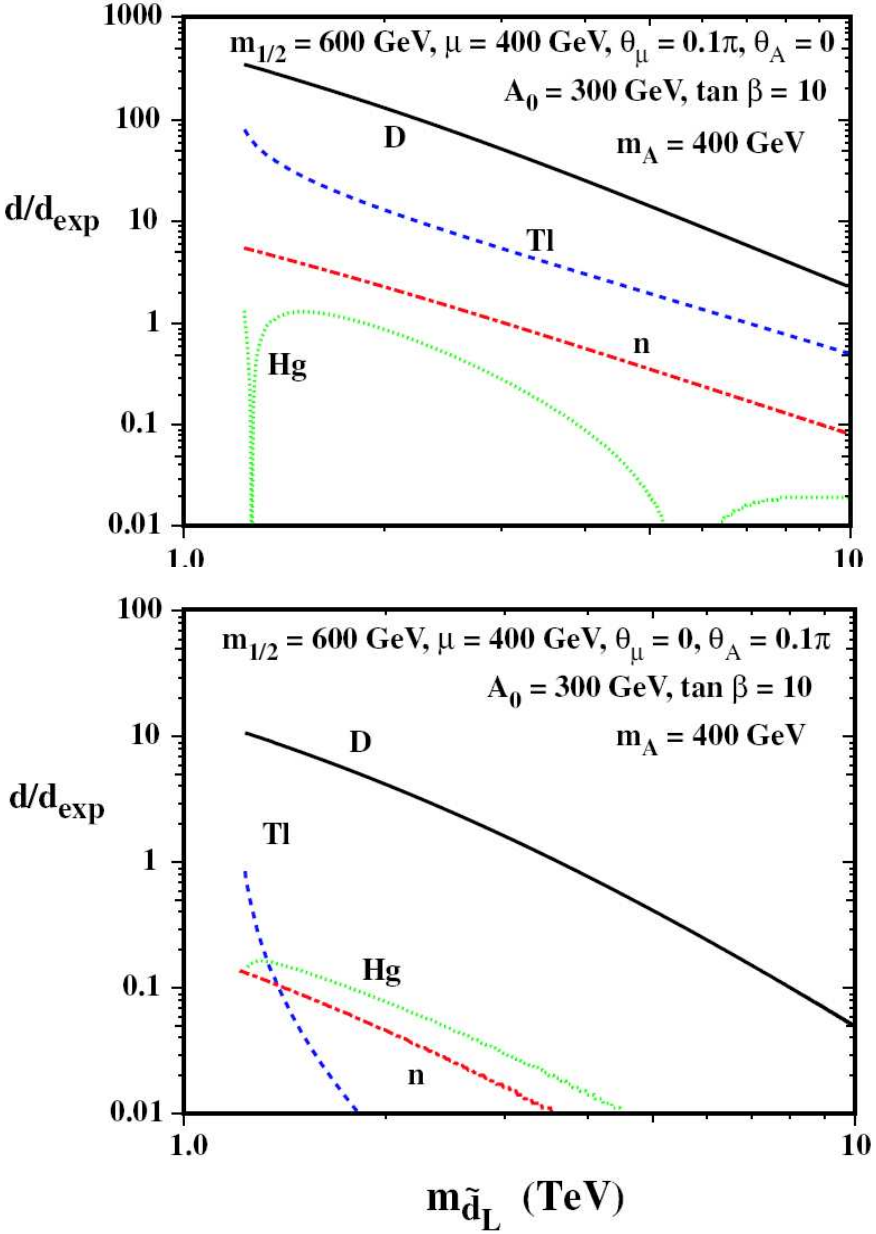
- T-odd Nuclear Forces: $\boldsymbol{d_d = 2\times10^{-22}\,\xi}$ **e·cm** with the best limit for $\boldsymbol{\xi < 0.5\times10^{-3}}$ coming from the $^{199}$Hg EDM limit (Fortson, *et al*., PRL 2001), i.e. $\boldsymbol{d_d < 10^{-25}}$ **e·cm.**

(Sushkov, Flambaum, Khriplovich Sov. Phys. JETP, **60**, p. 873 (1984) and Khriplovich and Korkin, Nucl. Phys. **A665**, p. 365 (2000)).

$d_d = d_p + d_n$ (I. Khriplovich)

It Improves the Current Proton EDM Limit by a Factor of ~10,000 and a Factor 60-100 on Neutron.

# Deuteron (D) EDM at $3\times10^{-27}$e·cm




Relative strength of various EDM limits as a function of left handed down squark mass (O. Lebedev,

K. Olive, M. Pospelov and A. Ritz,

hep-ph/0402023)

# Possible Locations for a Deuteron EDM Experiment:

- Brookhaven National Laboratory
- Indiana University Cyclotron Facility
- KVI/The Netherlands

} **$20-30M**

## Proposal This Year…

# Effect of Vertical Component of E

- Clock Wise and Counter-Clock Wise Injection:
  Background: Same Sign
  Signal: Opposite Sign

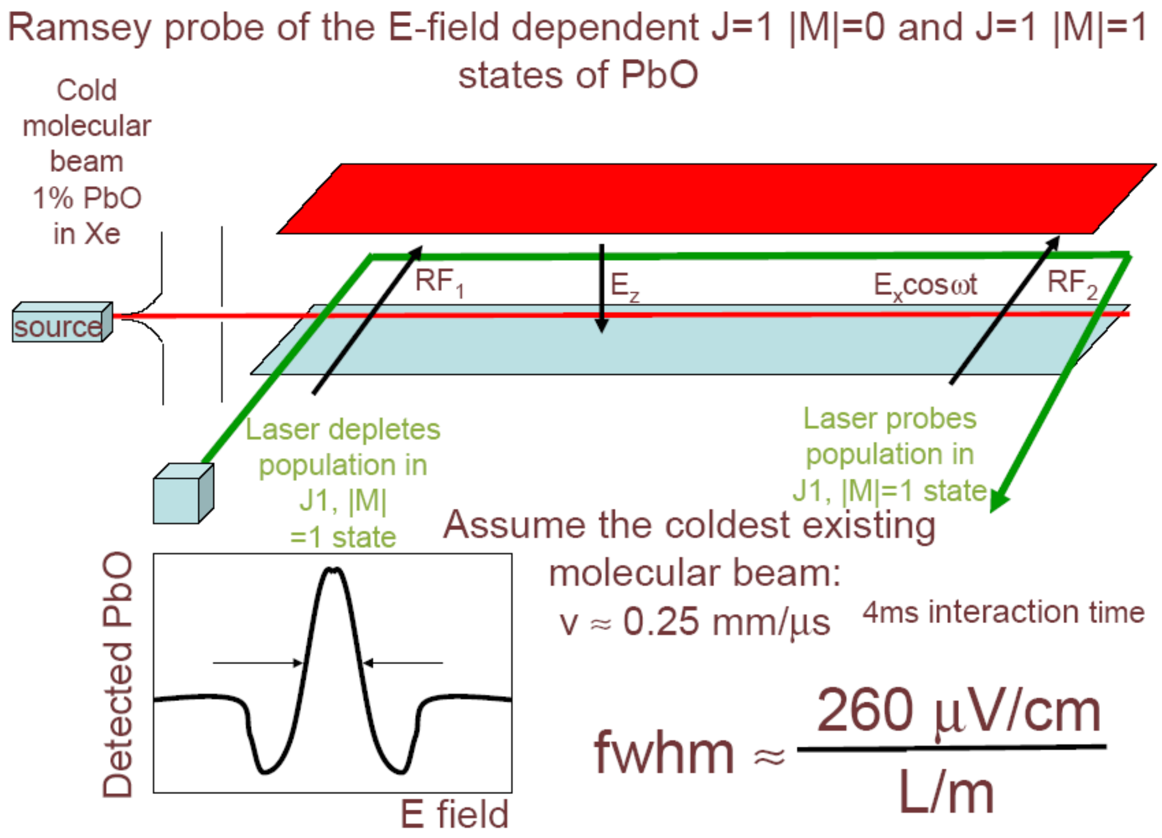
- Protons $\beta=0.15$, $\gamma=1.01$, $\omega=115\times10^5\times\theta_E$ rad/s
- Deuterons $\beta=0.2$, $\gamma=1.02$, $\omega=13\times10^5\times\theta_E$ rad/s
- Muons $\beta=0.98$, $\gamma=5$, $\omega=2\times10^5\times\theta_E$ rad/s

- Other Diagnostics Include Injecting Forward vs Backward Polarized Beams as well as Radially Pol.

# We are Studying

- Target and Polarimetry (Deuteron case)
- E-field Directional/Amplitude Stability
- Beam and Spin Dynamics

# E-field Stability: Major Breakthrough Idea by Neil Shafer-Ray




**E-field Stability of Order $10^{-8}$ to $10^{-9}$**

# Questions Physicists Ask:

EDMs

- Why Matter?

  CP Violation

- Why Mass?

  Higgs Field

- Why This Standard Model?

  SUSY or other extensions

# Summary

## Electric Dipole Moment Searches:

- Exciting Physics, Forefront of SUSY/Beyond SM Search.

- Revolutionary New Way of Probing EDMs, Muon and Deuteron Cases-Very Exciting.

- Sensitive EDM Experiments could bring the Next Breakthrough in Elementary Particle Physics.