Final Results from the BNL Muon g-2 Experiment

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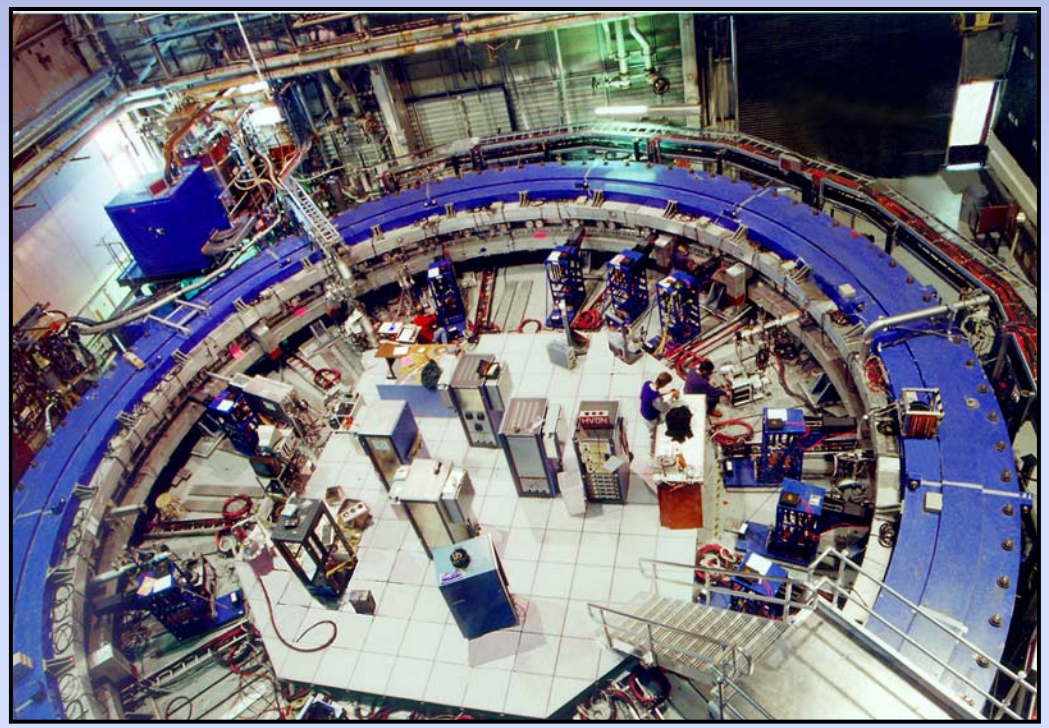
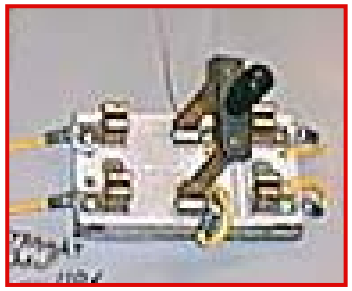


* ***Representing the E821 Collaboration*: Boston, BNL, Budker Inst., Cornell, KFI, Heidelberg, Illinois, KEK, Minnesota, Tokyo Tech, Yale**

Outline:

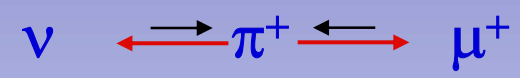
- Principle of the measurement
- New result with μ^-
- SM Theory
- BSM



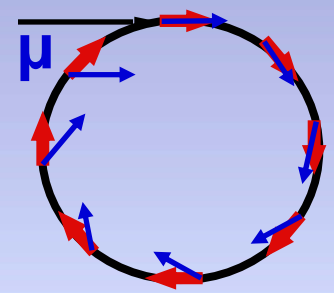
ASpen 2004

4 key miracles make it happen

- **P**olarized muons



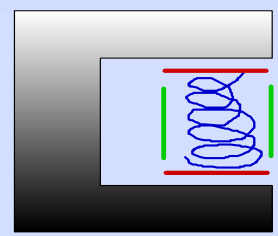
- **P**recession proportional to (*g*-2)



$$\omega_a = \omega_{spin} - \omega_{cyclotron}$$

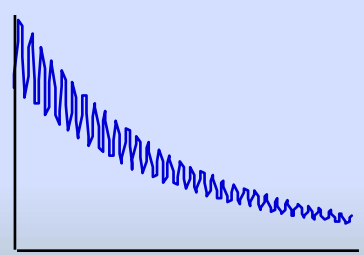
- **P**$_\mu$ The magic momentum

  E **field doesn't affect muon spin when** γ **= 29.3**



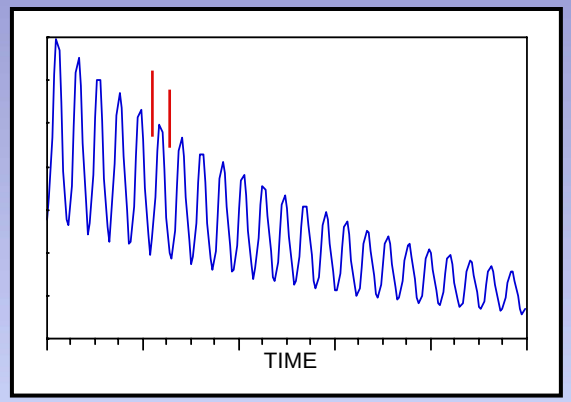
$$\vec{\omega}_a = \frac{e}{mc}\left[a_\mu \vec{B} - \left(a_\mu - \frac{1}{\gamma^2 - 1}\right)\vec{\beta} \times \vec{E}\right]$$

- **P**arity violation in the decay

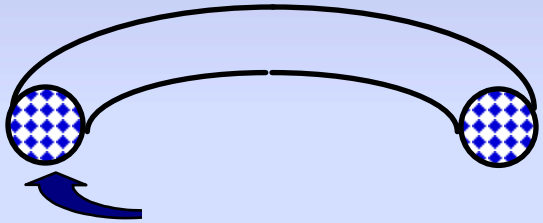


We measure

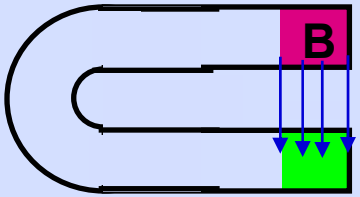
(1) Precession frequency



(2) Muon distribution



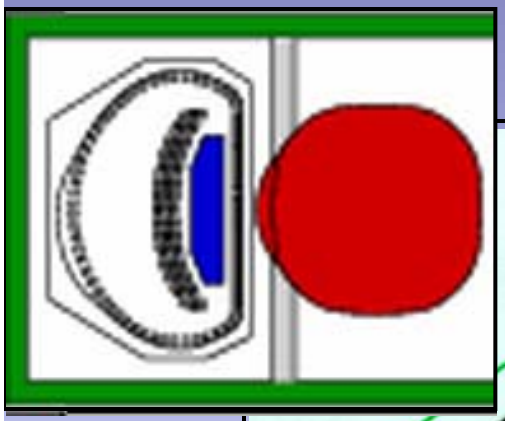
(3) Magnetic field map

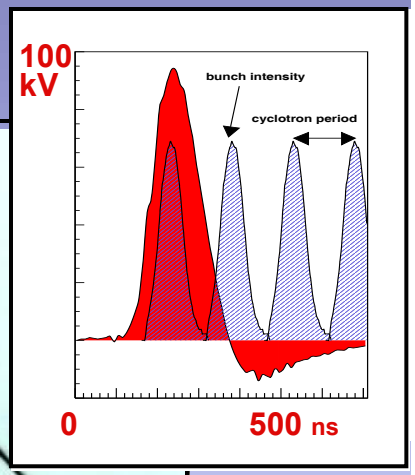


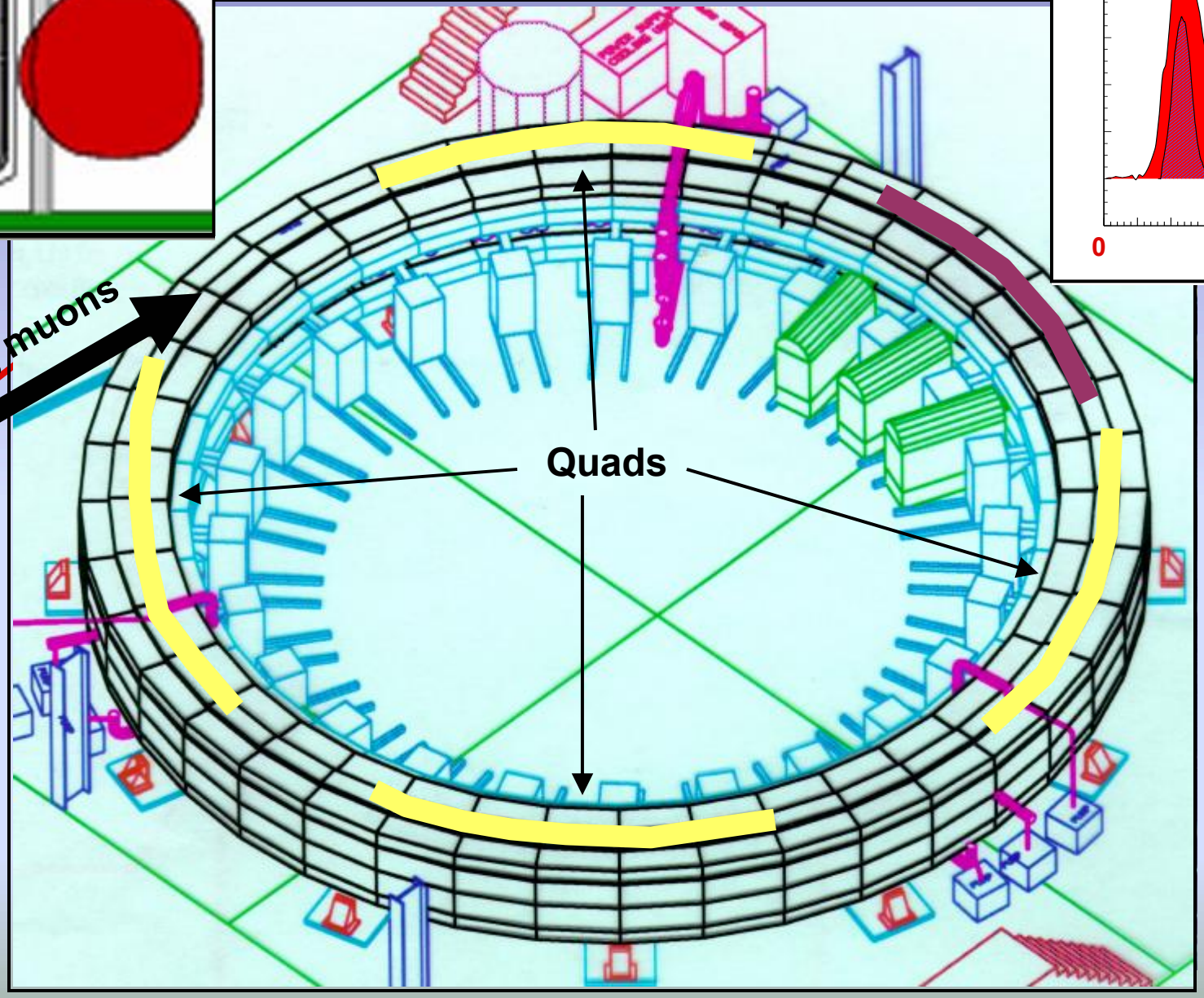
$$(g-2) \propto \frac{(1)}{\left\langle \int (2)(3) \right\rangle}$$

Double Blind Analysis

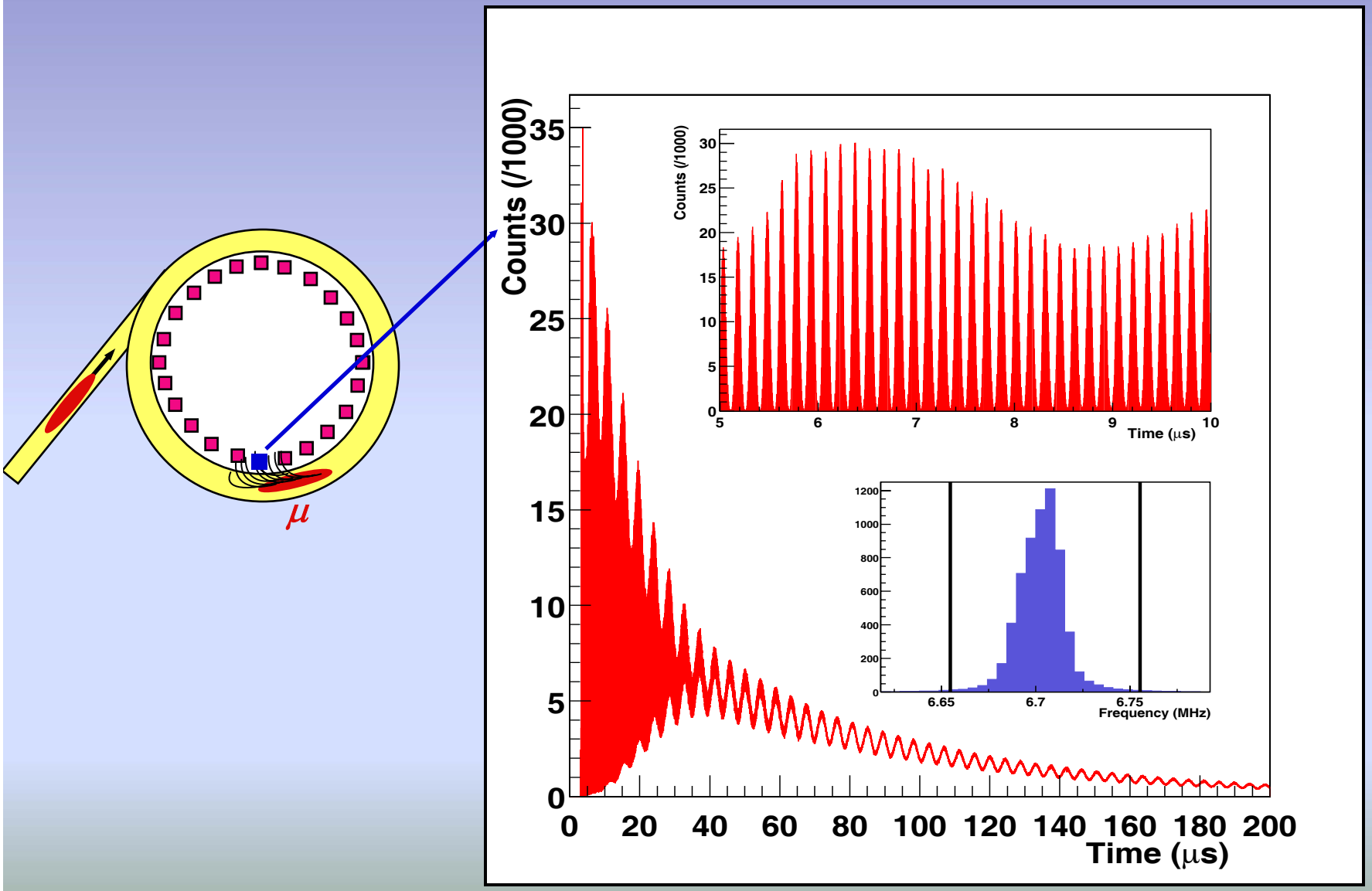
BNL Storage Ring



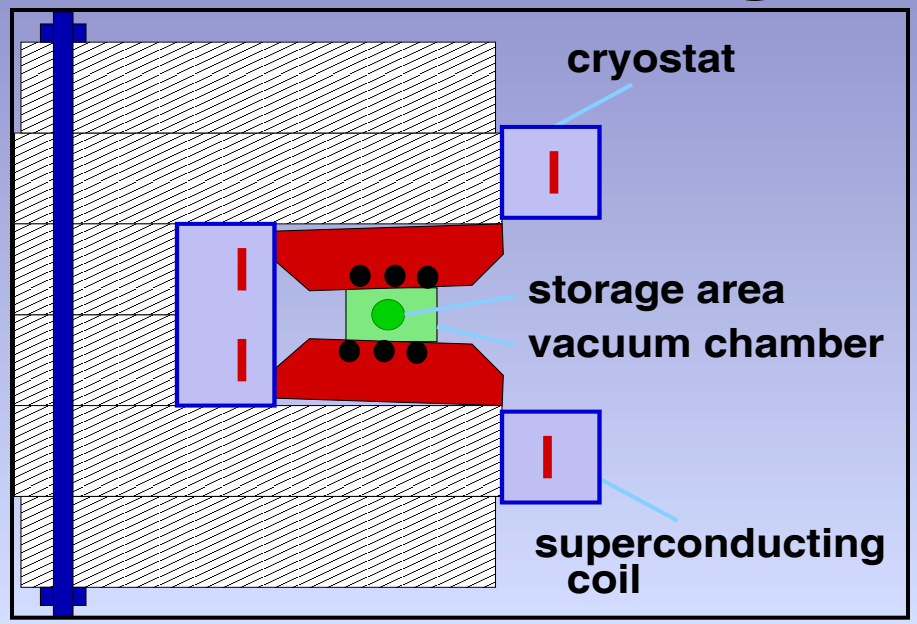




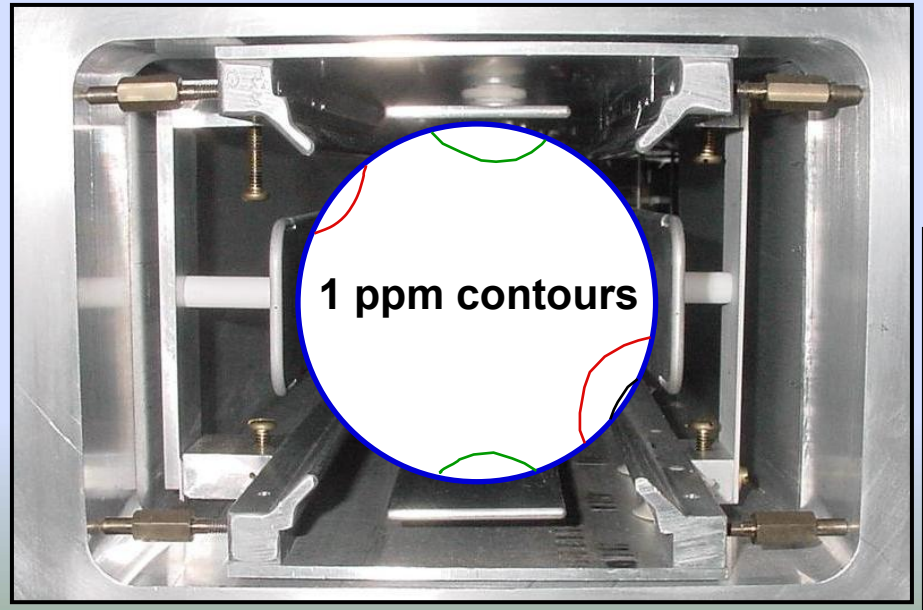
Fast Rotation



Magnetic Field



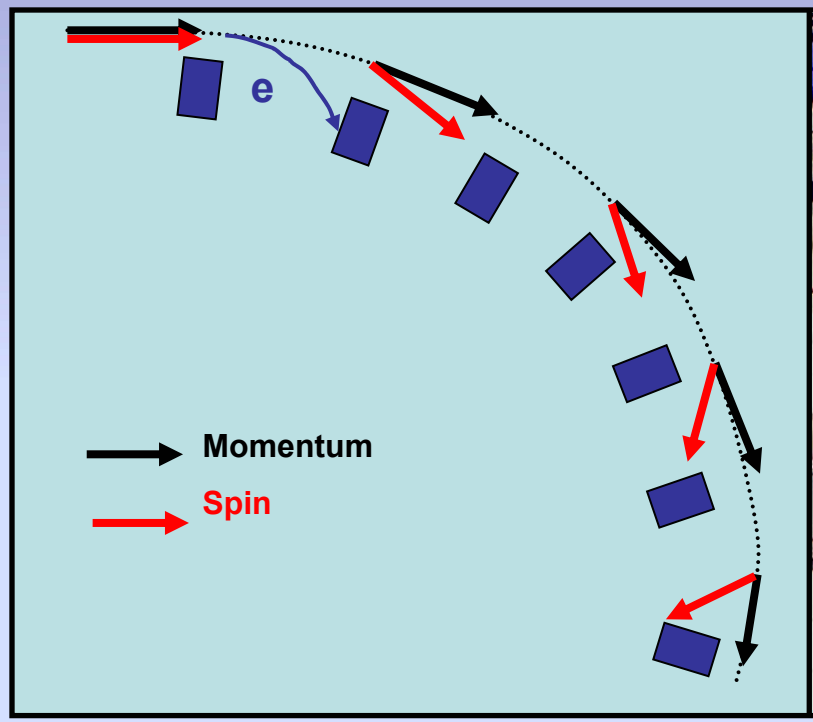
Measured *in situ* using an NMR trolley

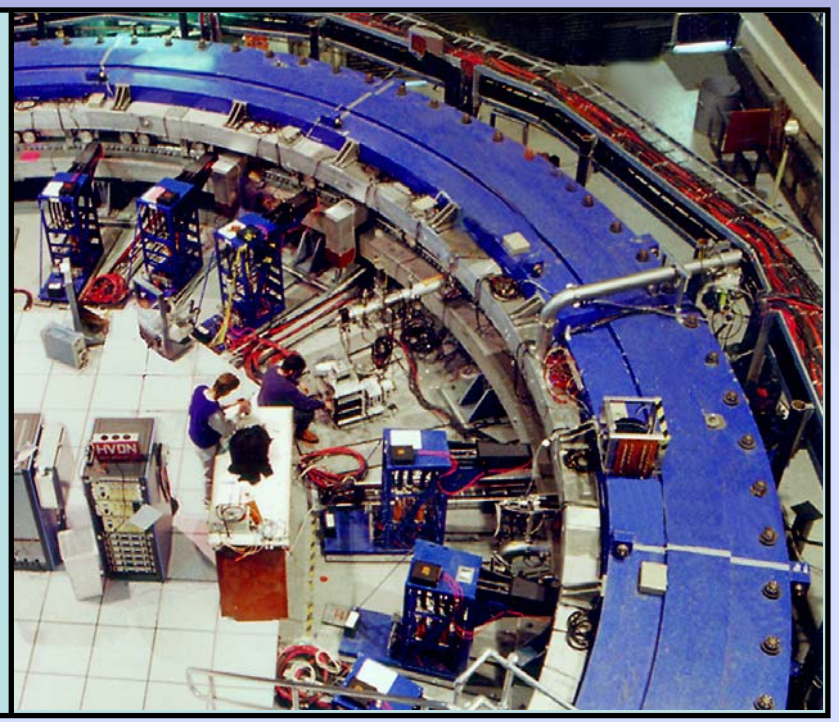


Continuously monitored using 150 fixed probes mounted above and below the storage region

Source of errors	Size [ppm]	2001
Absolute calibration of standard probe	0.05	0.05
Calibration of trolley probe	0.15	0.09
Trolley measurements of B_0	0.10	0.05
Interpolation with fixed probes	0.10	0.07
Uncertainty from muon distribution	0.03	0.10
Others†	0.10	0.17
Total systematic error on ω_p	0.24	

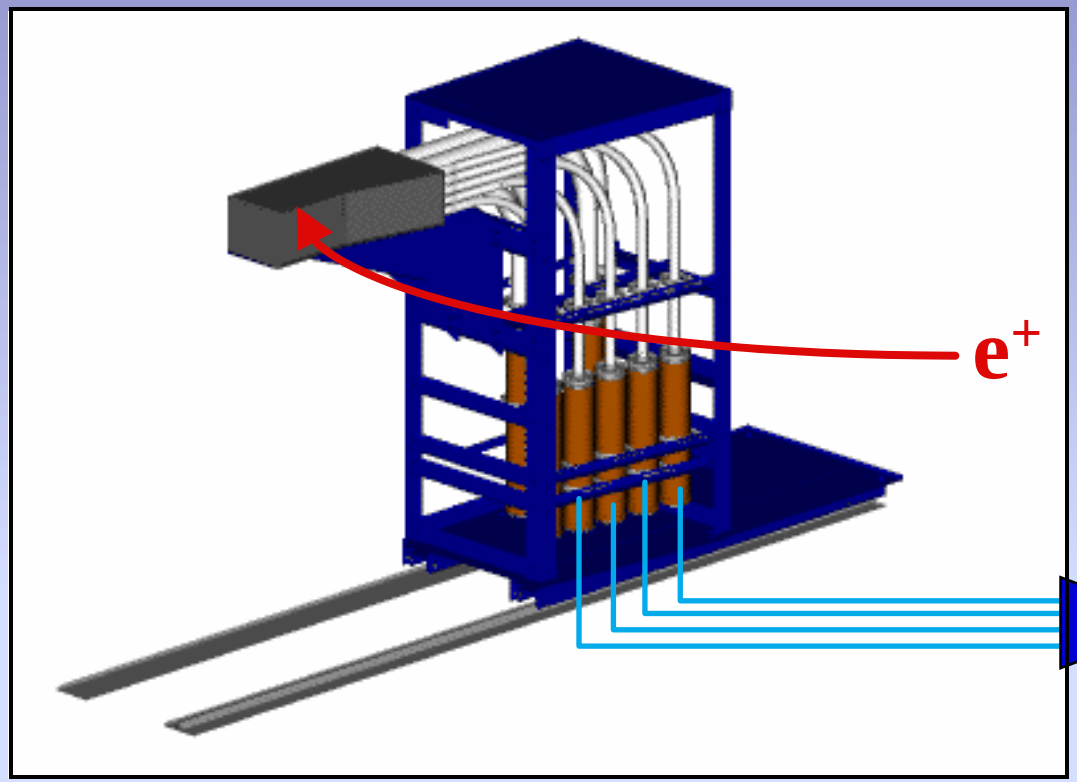
a_μ is proportional to the difference between the spin precession and the rotation rate

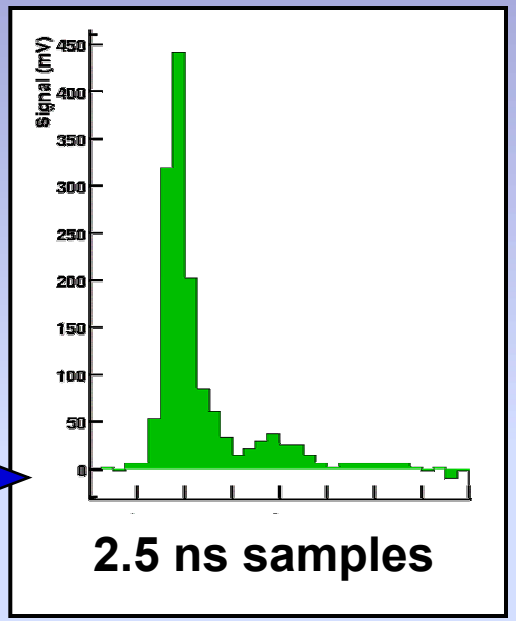




$$\Delta\omega = \omega_a = \left(\frac{g-2}{2}\right)\frac{eB}{mc}$$

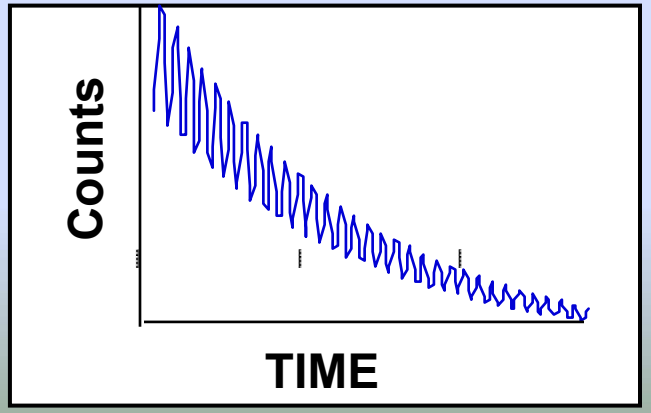
Measuring the difference frequency "ω_a"





< 20 ps shifts

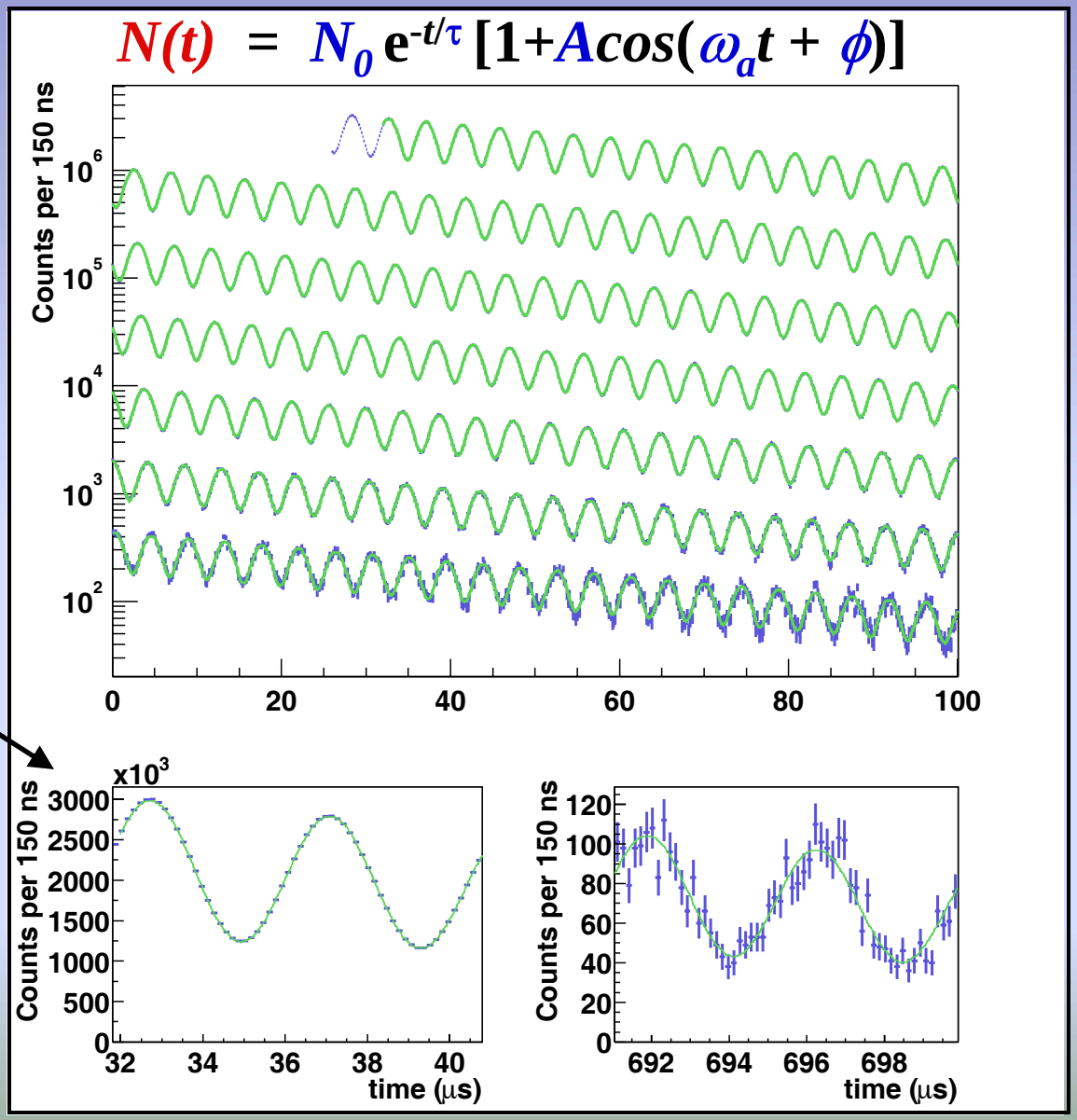
< 0.1% gain change



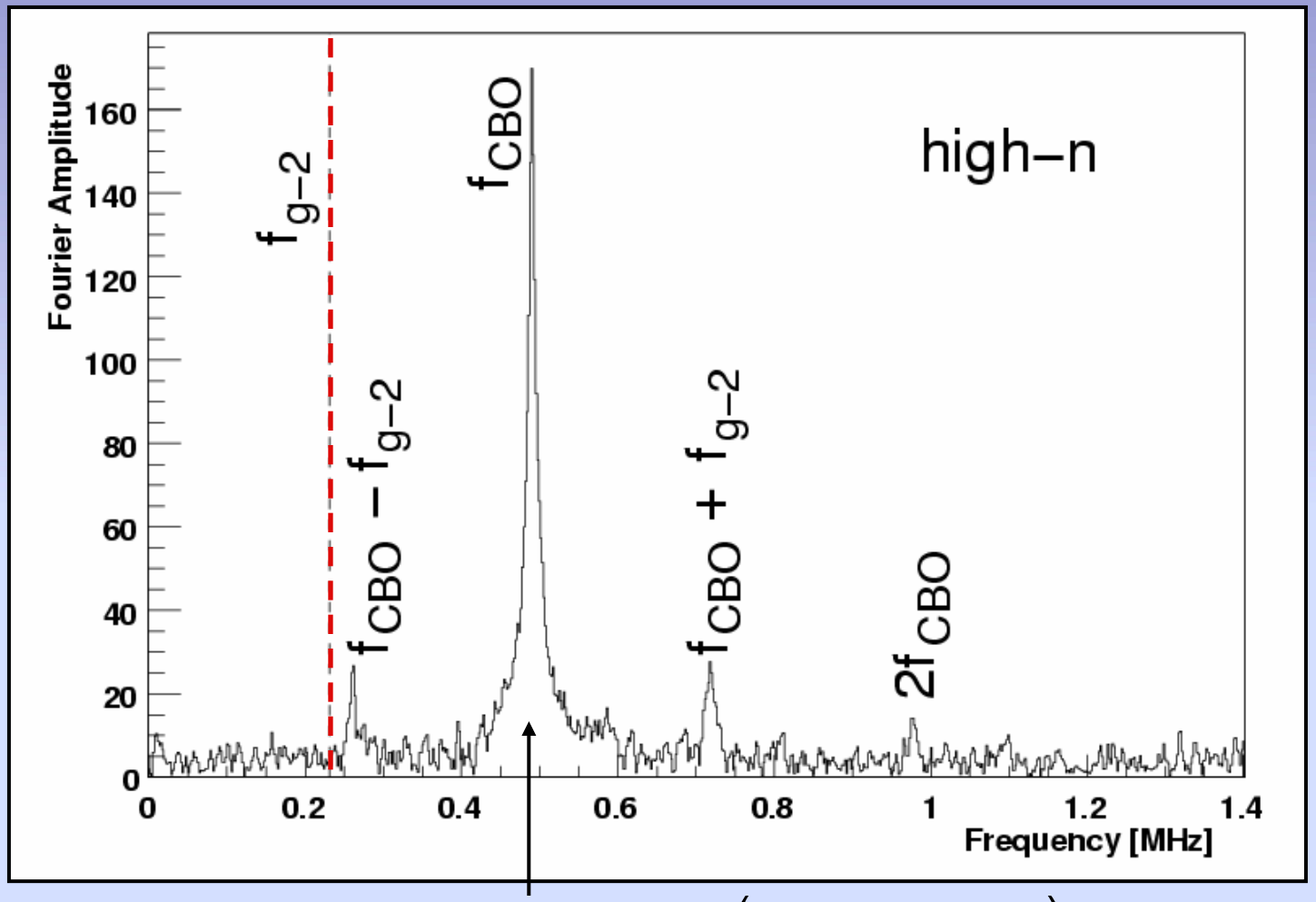
Fit to Simple 5-Par Function

Few billion events

Getting a good χ^2 is a challenge

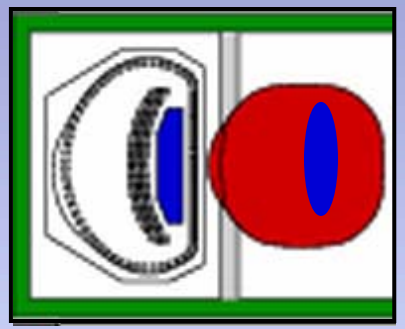


Fourier spectrum of residuals shows CBO, but in 2001, it's not hurting g-2



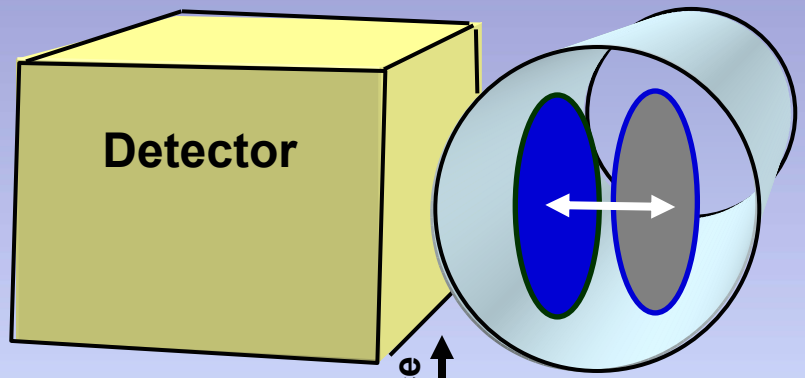
$$f_{CBO} \approx f_C\left(1-\sqrt{1-n}\right)$$

Coherent Betatron Oscillations

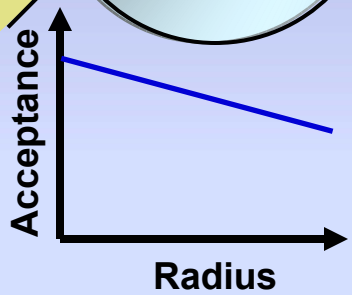


Inflector mapping to storage volume

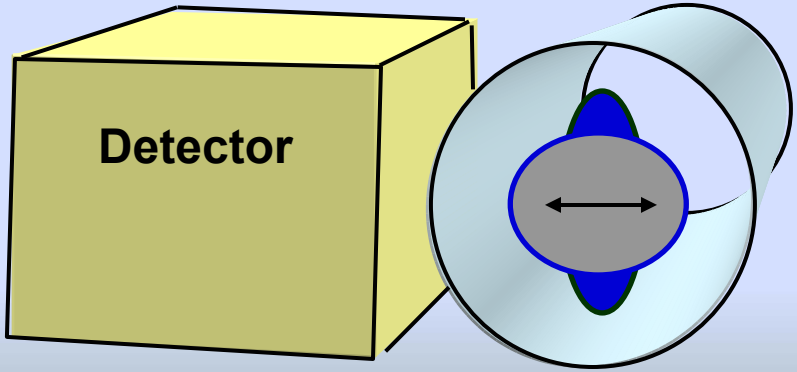
Beam into storage volume



"Swims"



Acceptance vs average radius

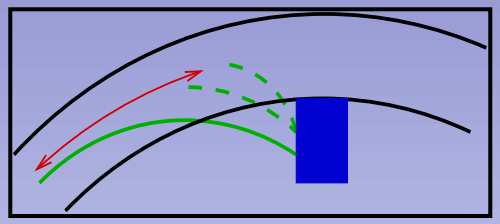


"Breathes"

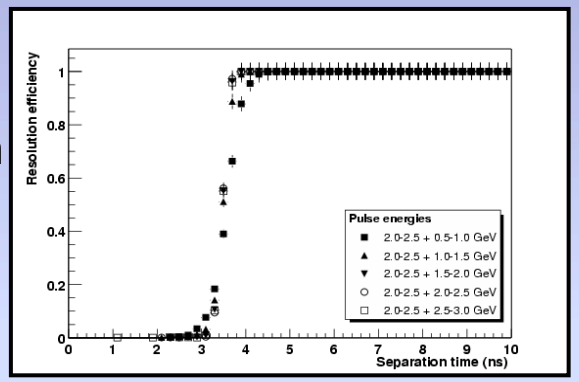
(smaller effect)

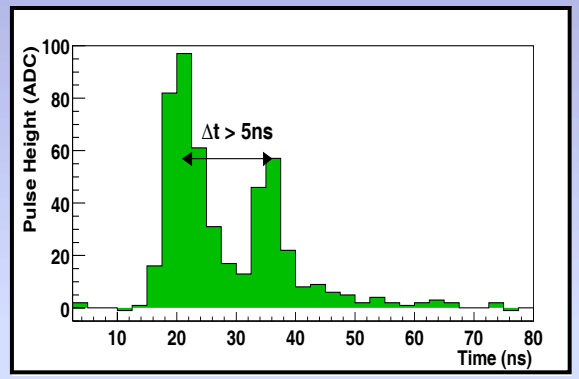
Pileup Subtraction

Phase shift possible



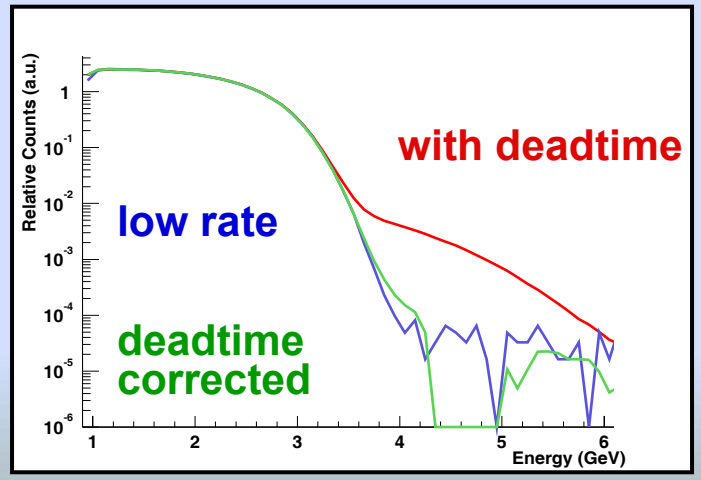
Separate when you can ...





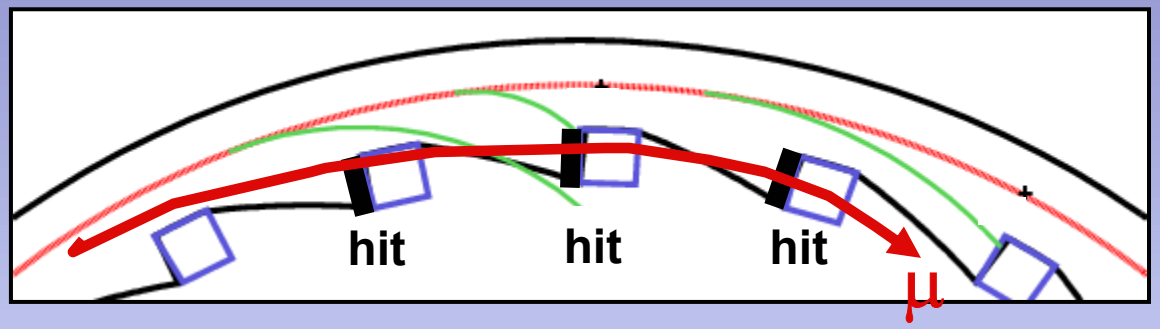
Extrapolate to zero deadtime on average using out-of-time resolved events

Build pileup-free histogram

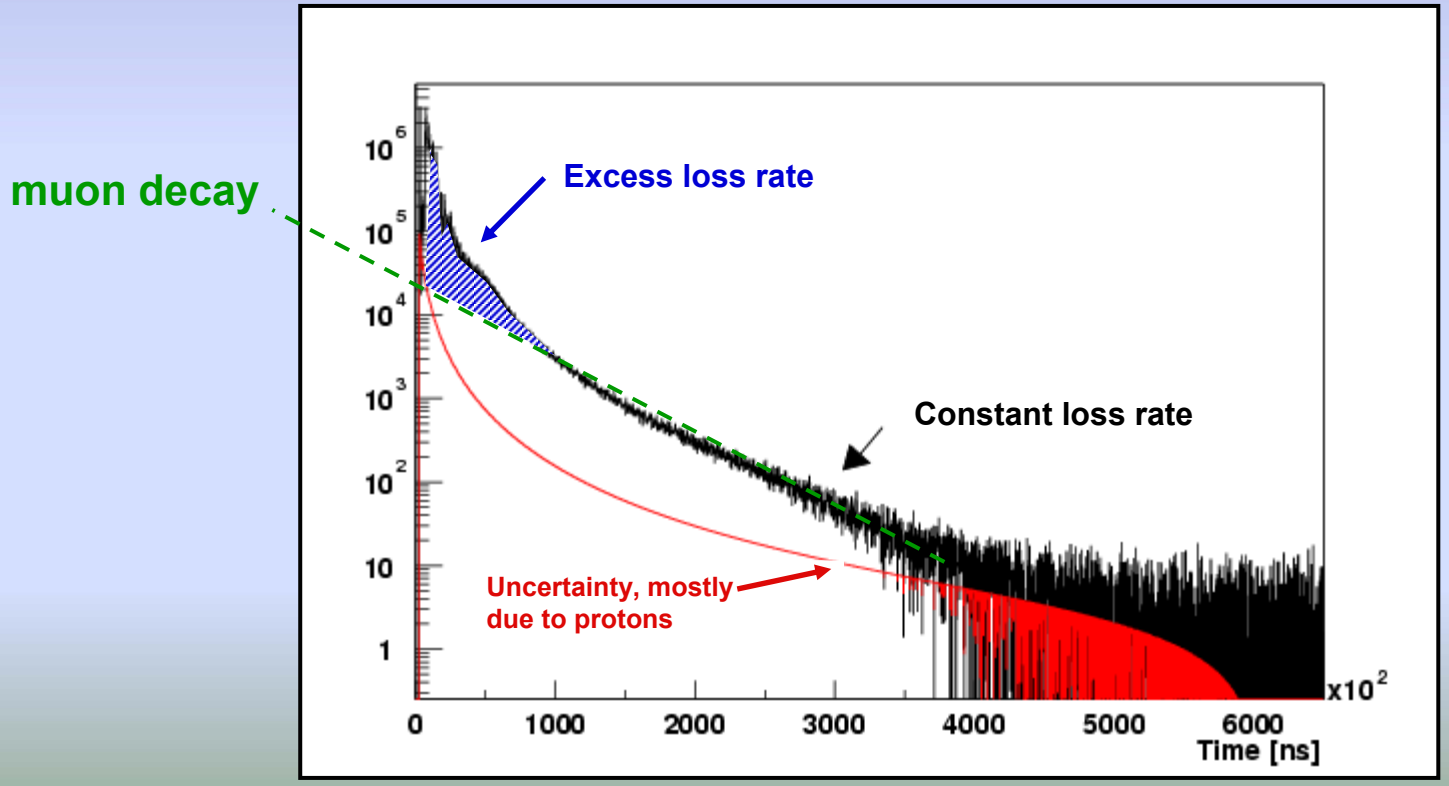


Energy of positrons

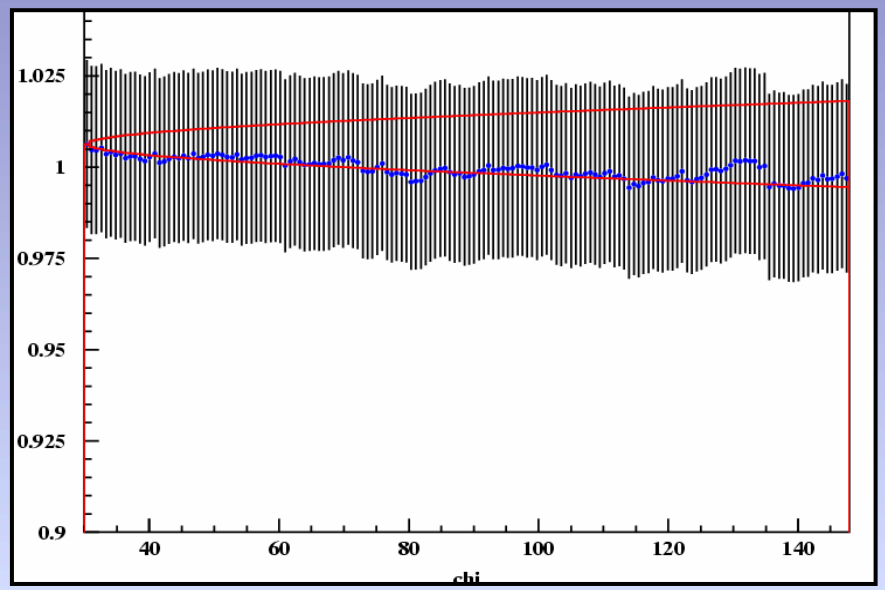
Muon Loss & Stored Protons

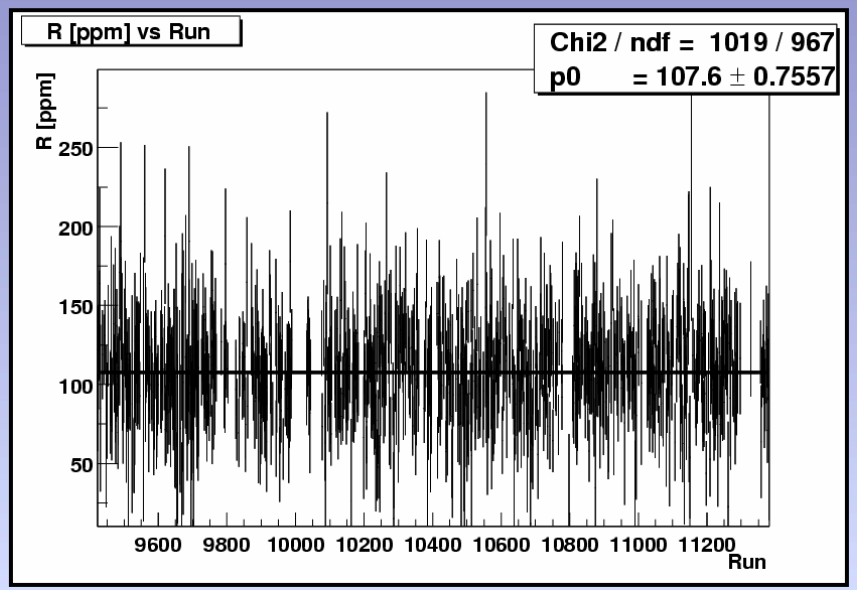


Account for "slow effects" by correction of muon flux in ring beyond exponential decay

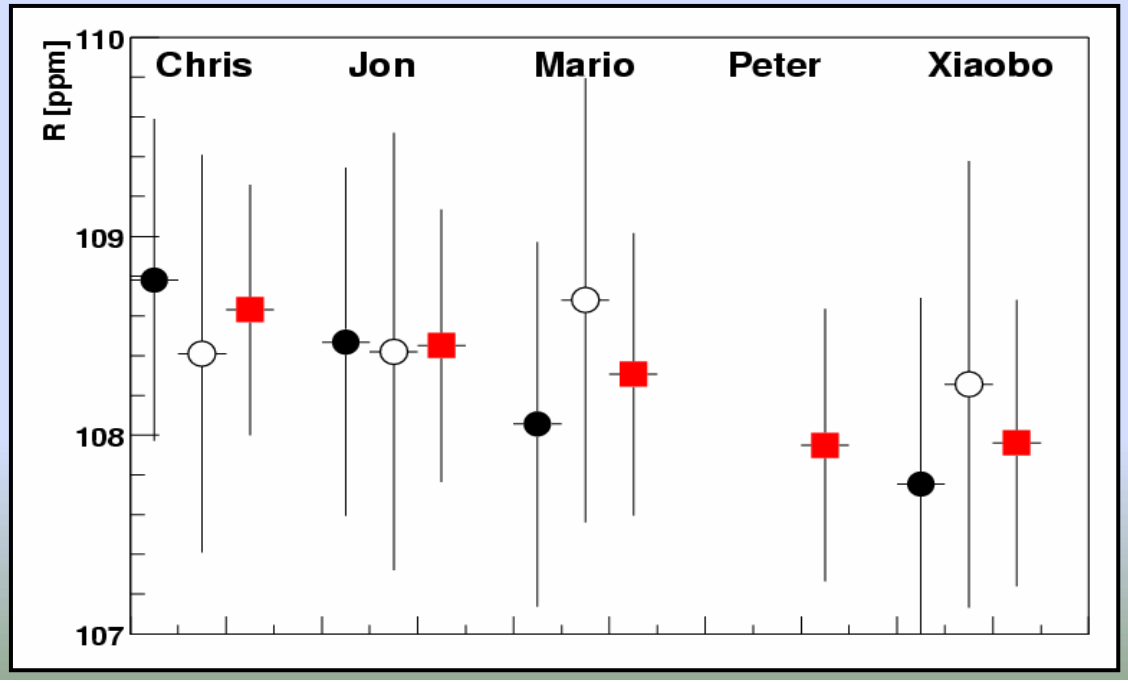


Internal Consistency: Chi-Sq, Run #, Analyzer

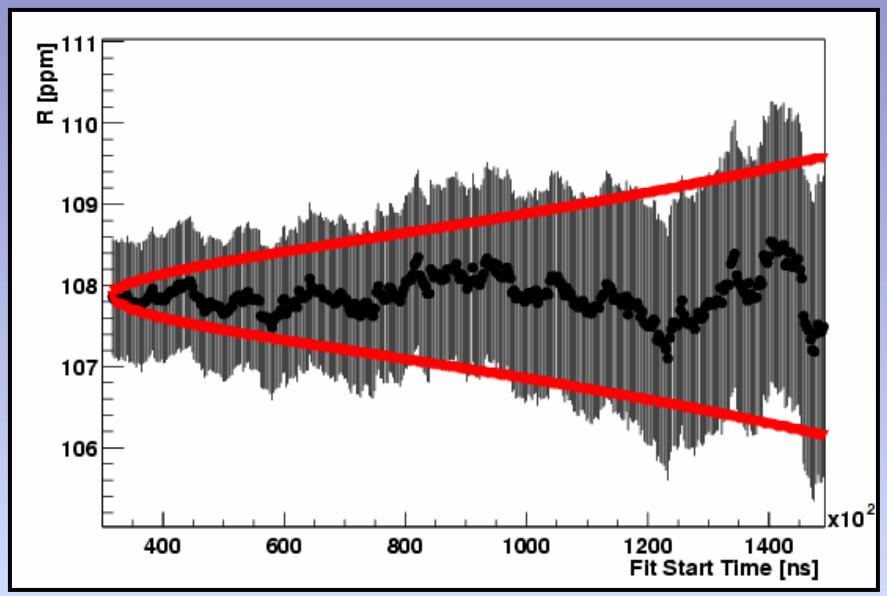


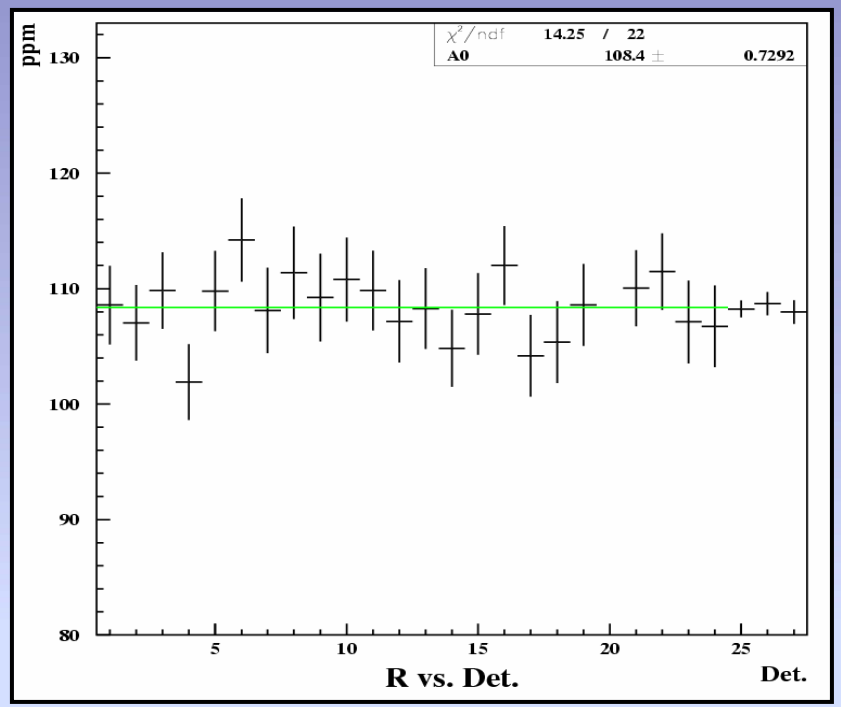


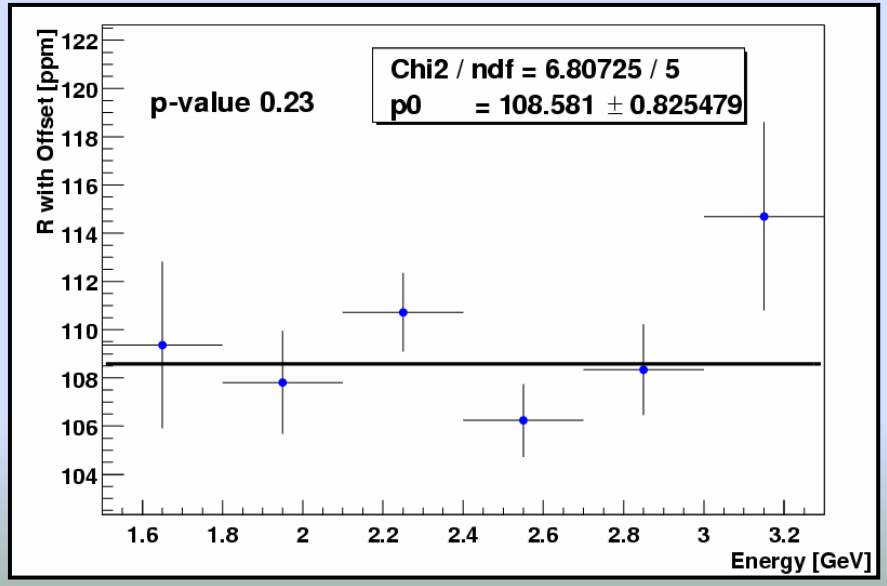
5
Independent Analyses



Internal Consistency: Start Time, Detector, Energy



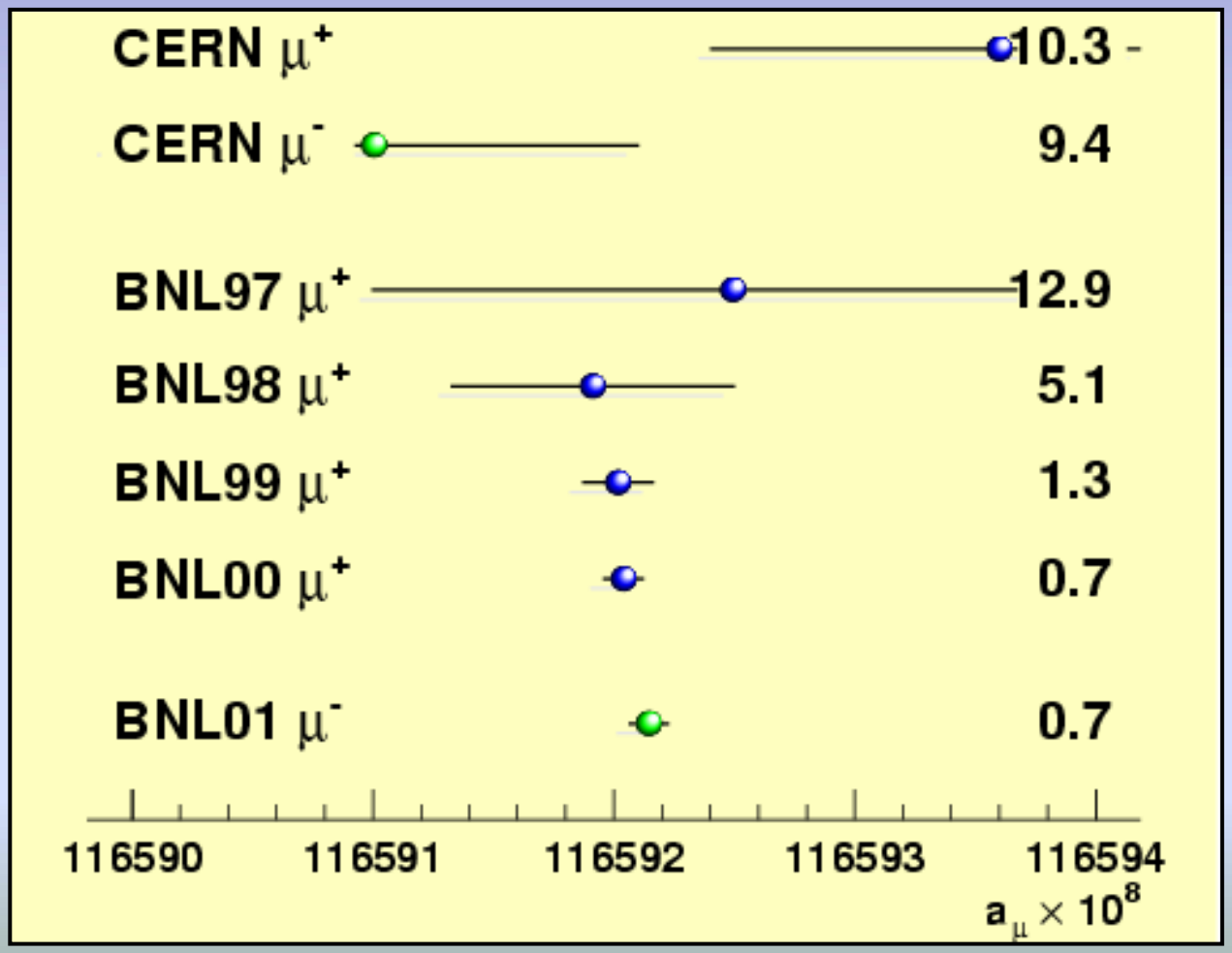




Issue	Uncertainty (ppm)
CBO	0.07
Pileup	0.08
Lost muons	0.09
Gain instability	0.12
Others	0.11
TOTAL ω_a	0.21

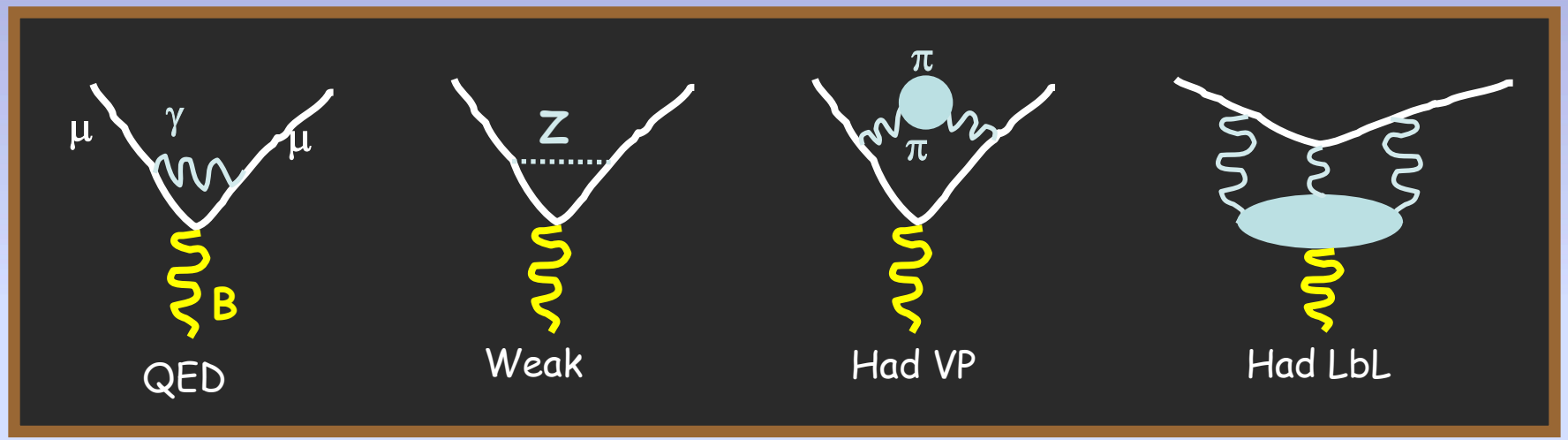
The new result is in excellent agreement with previous measurements on μ^+

$a_{\mu^-} = 11659214.0(8)(3) \times 10^{-10}$ (0.7 ppm)



g-2 Collaboration: hep-ex/0401008

g ≠ 2 because of virtual loops, many of which can be calculated very precisely

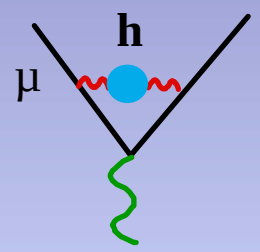


QED	Weak	Had VP	Had LbL
11 658 470.57(29)	15.4(3)	696.3(7) or 711.0(6)	+13.0(25)
(2003: +1.8 shift)			New: +50% shift ! Not agreed on yet

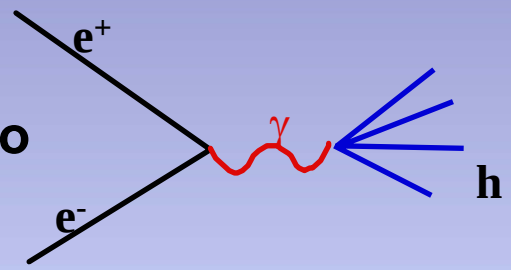
Units: $\times 10^{-10}$

Others cannot …

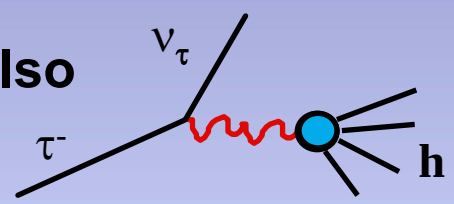
Hadronic vacuum polarization is obtained from data



is related to



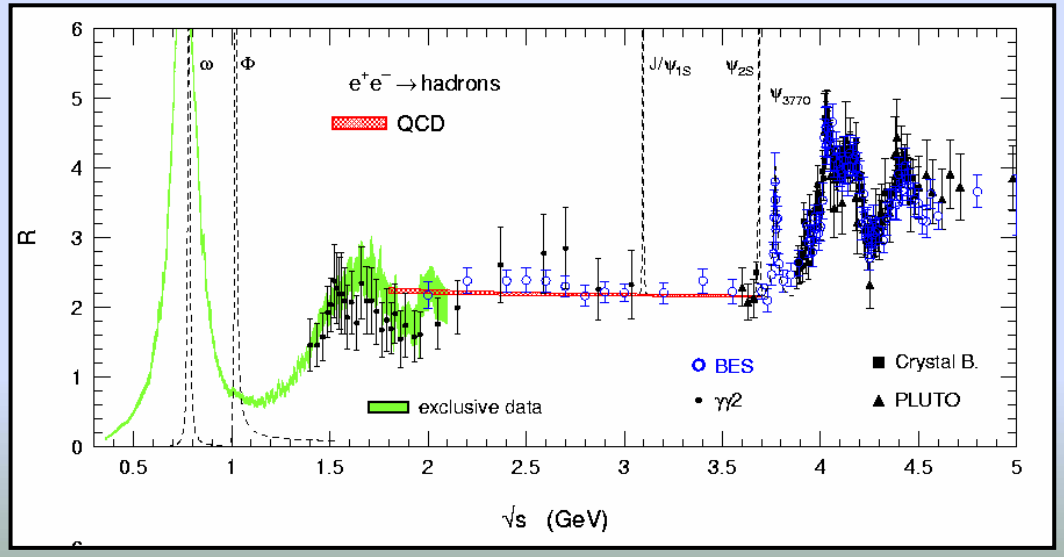
and also



$$a_{\mu}^{had,1} \propto \int_{2m_{\pi}}^{\infty} ds \frac{K(s)}{s} R(s)$$

$$K(s) \propto \frac{1}{s} + \ldots$$

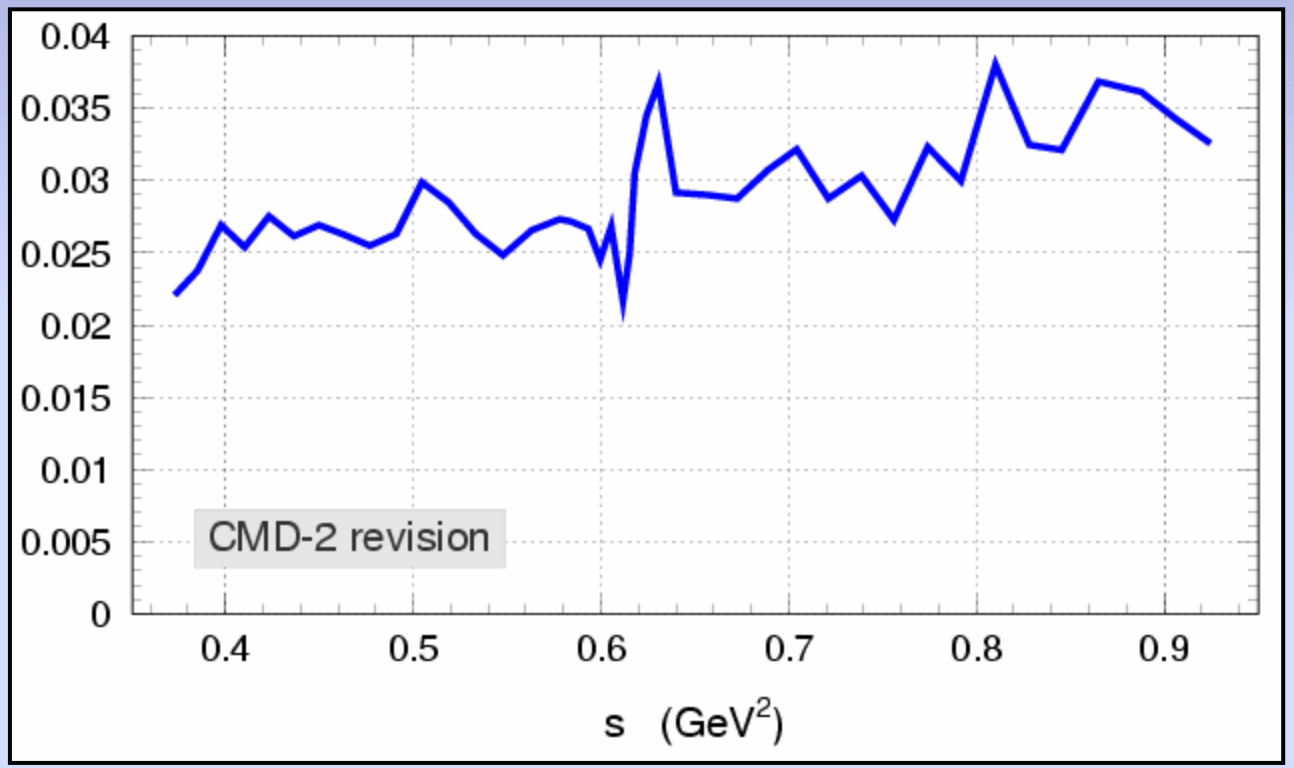
$$R(s) = \frac{\sigma\left(e^{+}e^{-} \rightarrow \text{hadrons}\right)}{\sigma\left(e^{+}e^{-} \rightarrow \text{muons}\right)}$$



In mid-2003, CMD corrected their data upward

The problem was a missing radiative correction in the normalization reaction

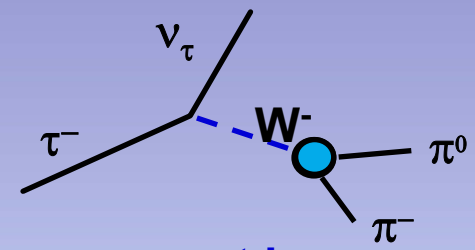
% Increase



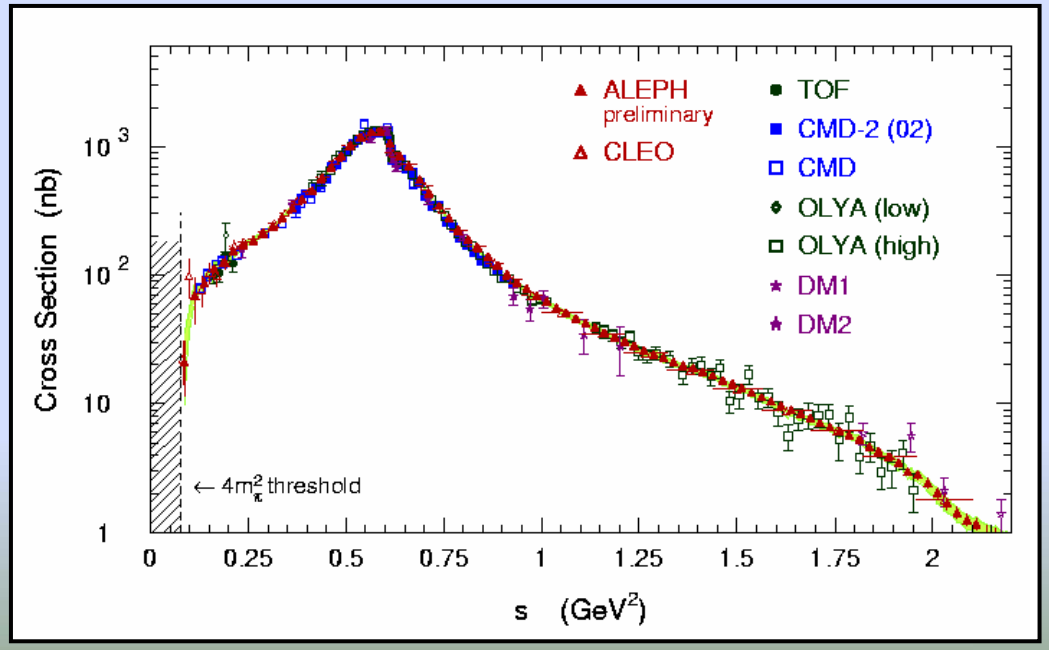
This reduced the Δ(Expt-Thy) significance from 3.0 $\rightarrow$ 1.9 σ

The τ - decay input to H-VP

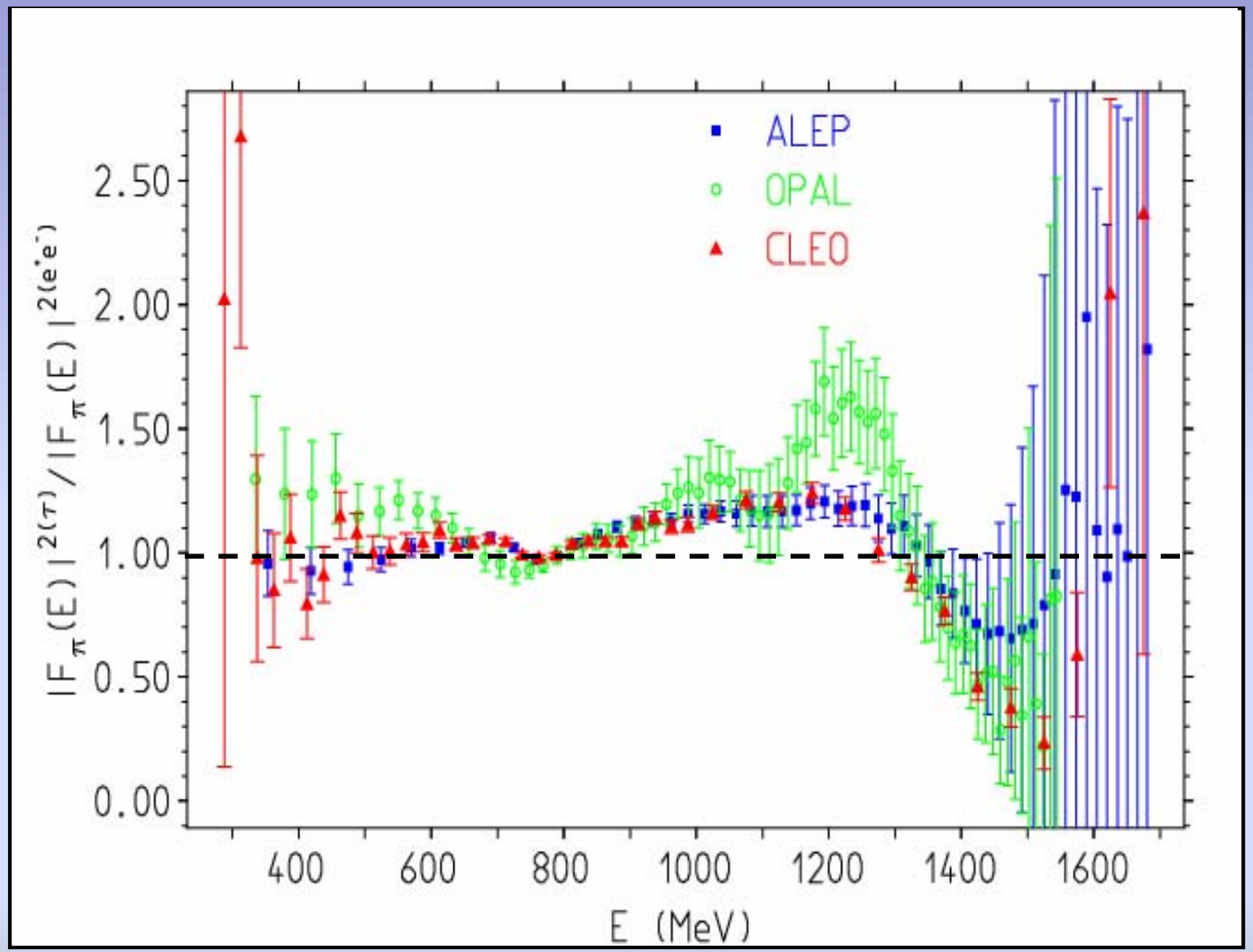
- Data precise
- Related by CVC with corrections
  - Isospin asymmetry ($\pi^+\pi^-$ *vs* $\pi^0\pi^-$)
  - Correction for $\rho^0 - \rho^-$ mass and width differences not in
  - Long-distance radiative corrections



- Bottom line, can the τ data contribute in the long run at sub % level?



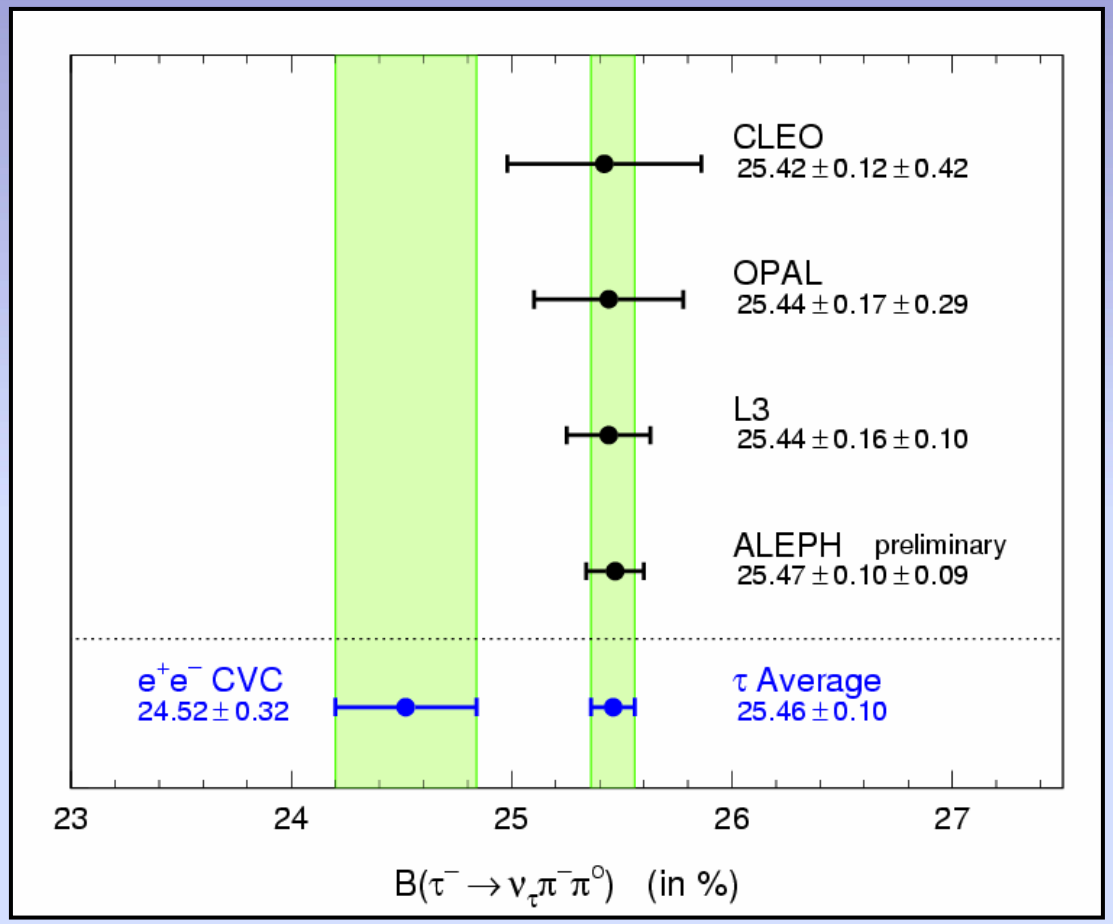
The τ - e^+e^- comparison



Difference is significant *AND* energy dependent

Davier, et al hep-ex/00308214 Jan 04

The *ee* – *tau*, directly compared are in worse agreement

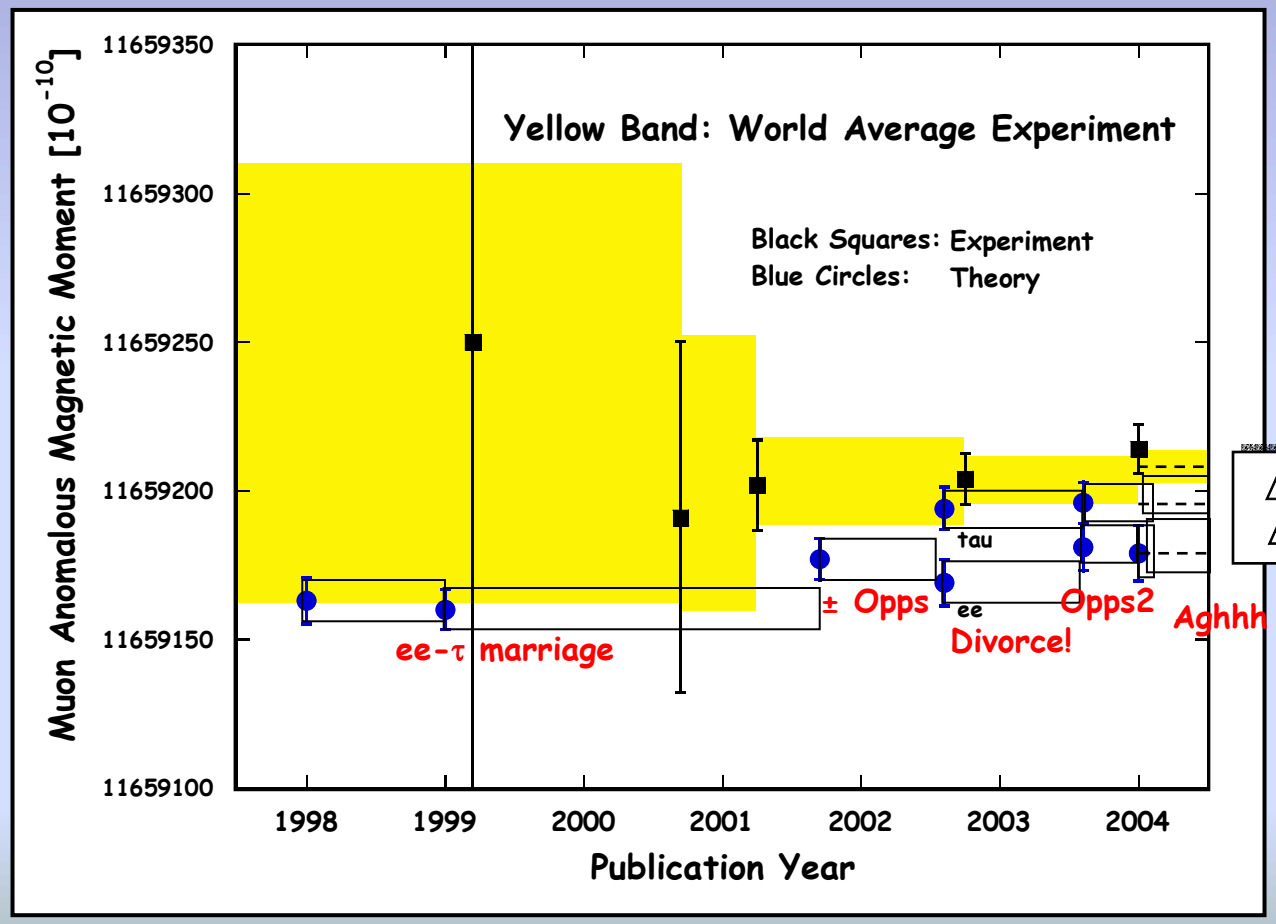


2.8 σ

So, we must quote both results …

Comparison of final results and theory

$$a_{\mu}(\text{world avg}) = 11\,659\,208(6) \times 10^{-10} \quad (0.5\ \text{ppm})$$



Includes new HLbL shift

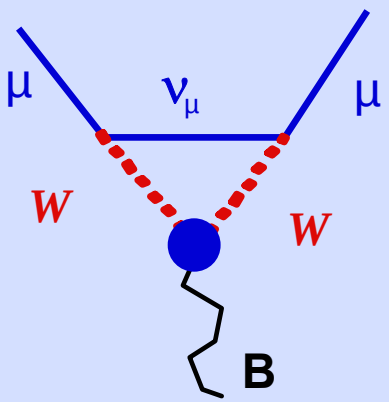
$\Delta(\text{tau})=10\pm9$
$\Delta(\text{ee})=23\pm9$

g-2 Collaboration: hep-ex/0401008

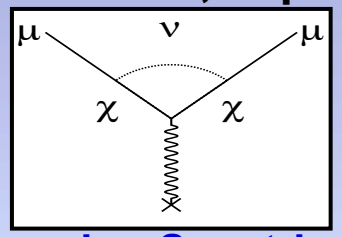
Why must this be resolved?

Non-zero Δa_μ appeals to a catalog of *SM Extensions*

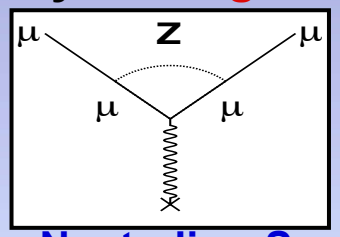
- **New physics …**
  - **SUSY**
  - **Leptoquarks**
  - **Muon substructure**
  - **Anomalous *W* couplings**



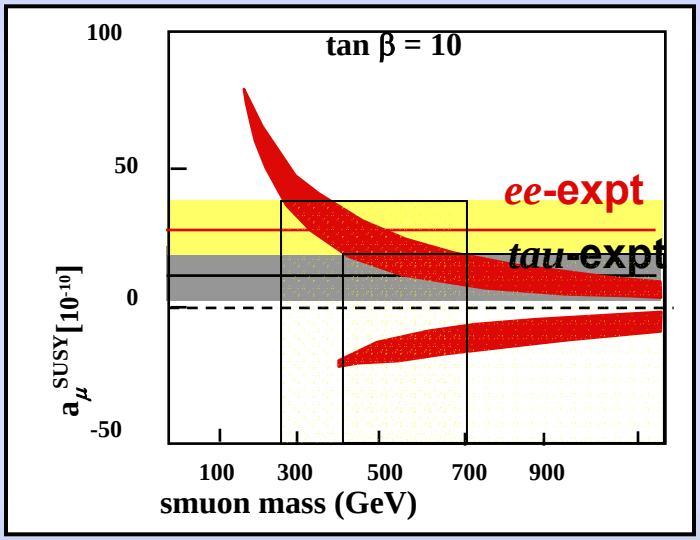
Sensitive for supergravity grand unification, especially for large tan β



Chargino-Sneutrino



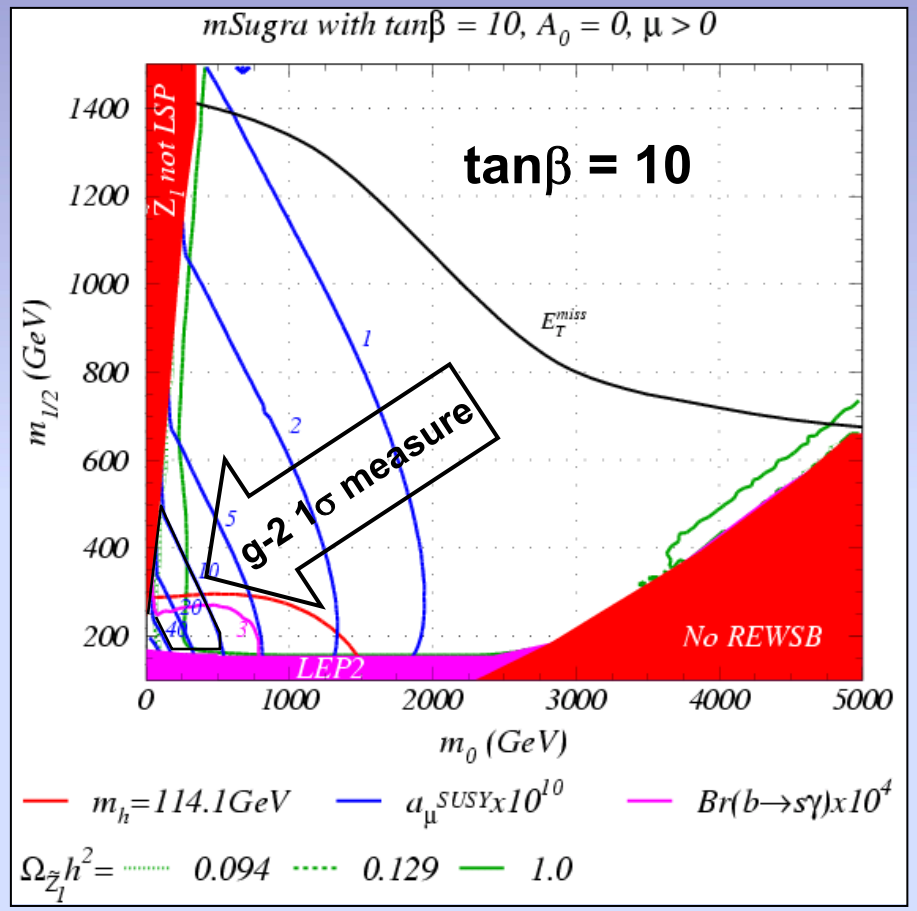
Neutralino-Smuon

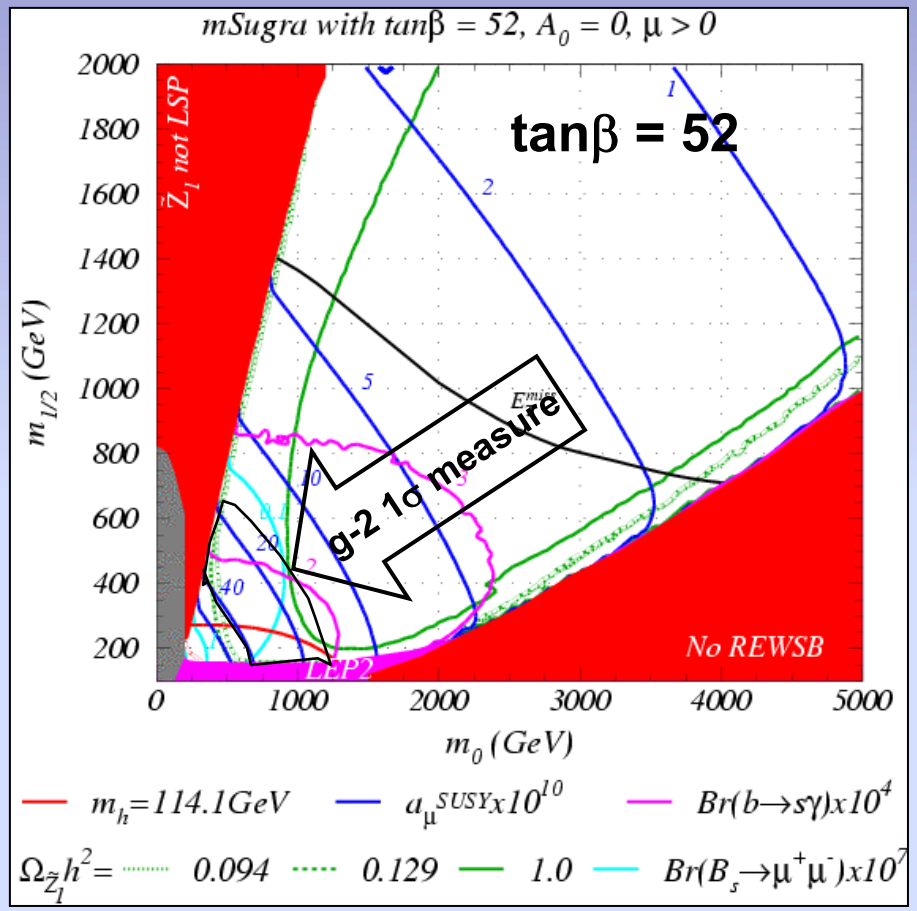


Aggressive approach, take the difference to be real.

Then you've got limits for SUSY particle masses.

mSUGRA Constraints – Selected tanβ (b→sγ, g-2, relic density)





Blue contours are g-2

Courtesy A. Belyaev

Because g-2 hasn't hit the systematic limit, let's go on … at BNL … to 0.2 ppm

- Main issue: get more muons into the ring
  - Open up the inflector
  - Improve beamline transmission
  - Install horn at target

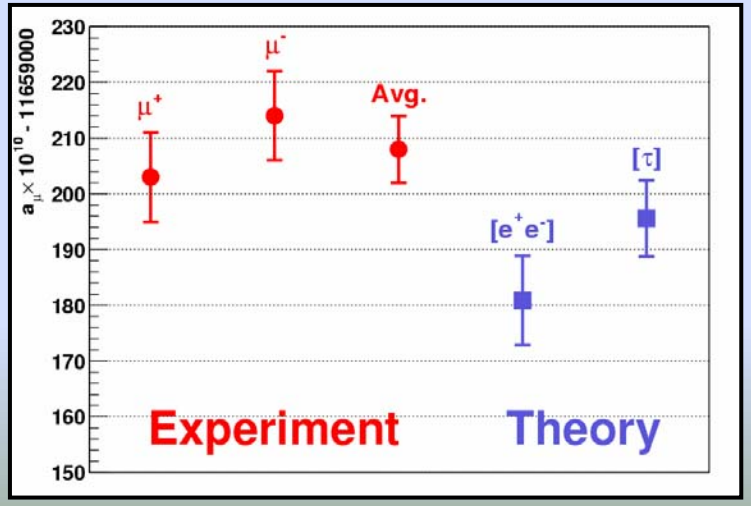
- Theory is active, improving and being checked

  (maybe some correction will even go the other way?)
  - Radiative return
  - VEPP—2000
  - Upgrades at KLOE
  - Radiative correction industry is active—expect they will keep up with data

- If SUSY particles are found at LHC, we measure tanβ

Conclusions

- All g-2 data published
  - Systematics lowered again
- Consistent results, consistently above theory
  - ee – tau controversy sill quite active
  - considerably more "ee" type data on the way
- The systematic limit is "far" away …we should go there



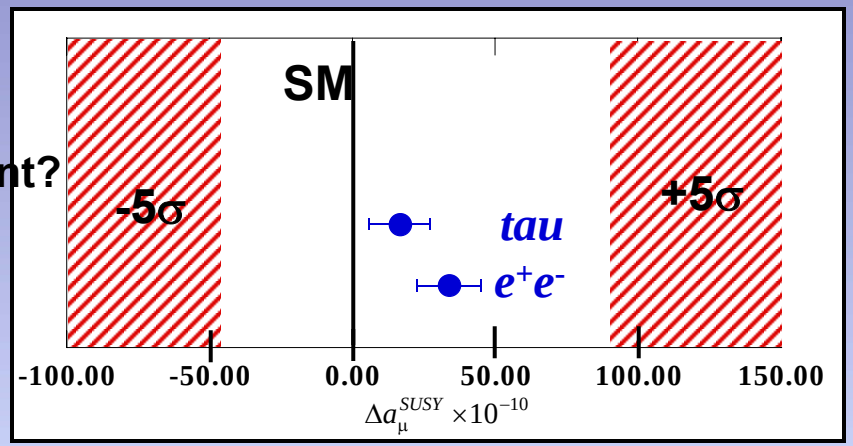
hertzog@uiuc.edu

Copy of talk: www.npl.uiuc.edu/~hertzog/ASPENg2.pdf

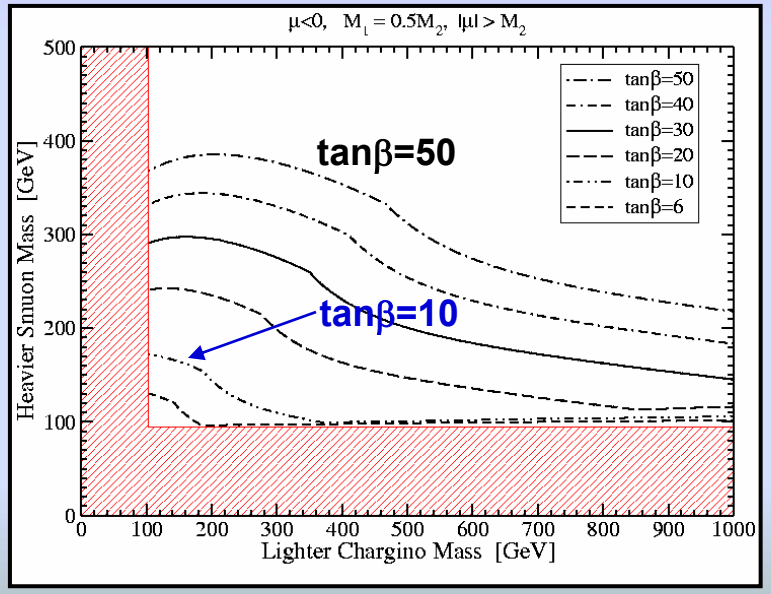
The End !

"Super-conservative" SUSY

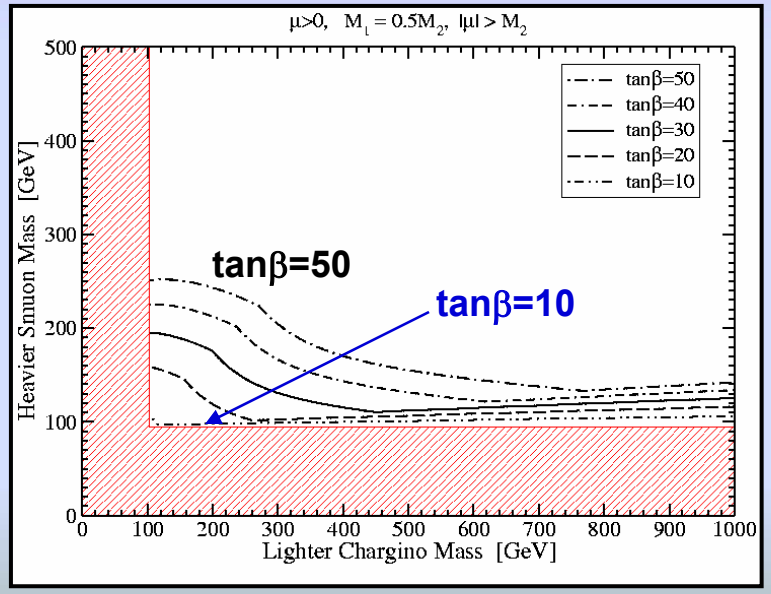
What's excluded by 5σ difference from experiment?



$\mu < 0$ solutions largely ruled out



$\mu > 0$ some constraints



Exclusion plots … below lines

Martin & Wells; hep-ph/0209309