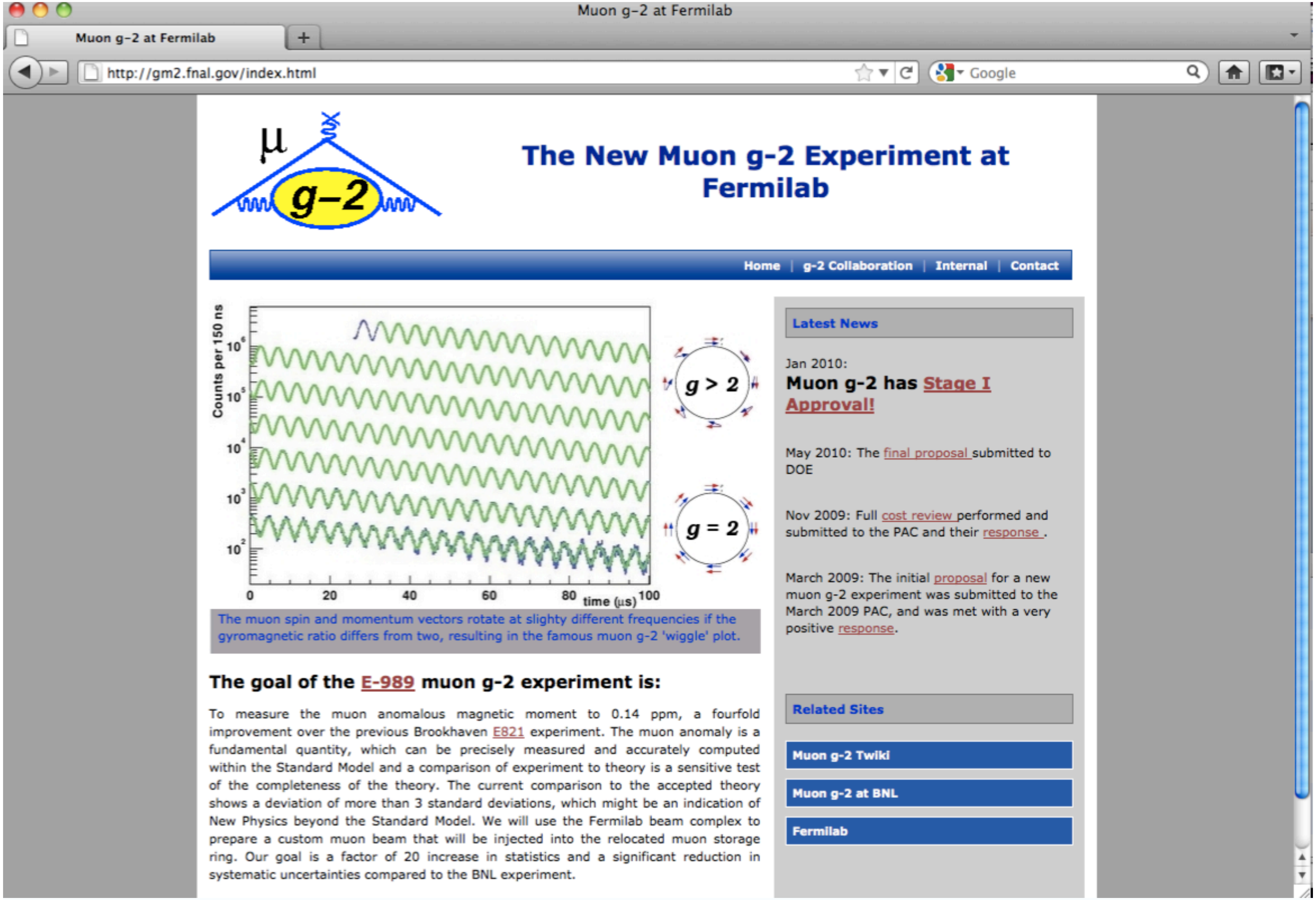


The New Muon g-2 Experiment at Fermilab

The muon spin and momentum vectors rotate at slighty different frequencies if the gyromagnetic ratio differs from two, resulting in the famous muon g-2 'wiggle' plot.

The goal of the E-989 muon g-2 experiment is:

To measure the muon anomalous magnetic moment to 0.14 ppm, a fourfold improvement over the previous Brookhaven E821 experiment. The muon anomaly is a fundamental quantity, which can be precisely measured and accurately computed within the Standard Model and a comparison of experiment to theory is a sensitive test of the completeness of the theory. The current comparison to the accepted theory shows a deviation of more than 3 standard deviations, which might be an indication of New Physics beyond the Standard Model. We will use the Fermilab beam complex to prepare a custom muon beam that will be injected into the relocated muon storage ring. Our goal is a factor of 20 increase in statistics and a significant reduction in systematic uncertainties compared to the BNL experiment.

Latest News

Jan 2010:

Muon g-2 has Stage I Approval!

May 2010: The final proposal submitted to DOE

Nov 2009: Full cost review performed and submitted to the PAC and their response .

March 2009: The initial proposal for a new muon g-2 experiment was submitted to the March 2009 PAC, and was met with a very positive response.

Related Sites

RMCLWG meeting, Mainz 28 September 2012

Fermilab Today

Wednesday, Sept. 19, 2012

Feature

Second muon experiment receives Mission Need approval from DOE

This rendering shows the location of the proposed Muon Campus at Fermilab. The arrow points to the proposed site of the planned Muon g-2 experiment. Click to enlarge. *Image: Muon Department/FESS*

Fermilab's plans for creating a Muon Campus with top-notch Intensity Frontier experiments have received a big boost. The Department of Energy has granted Mission Need approval to the Muon g-2 project, one of two experiments proposed for the new Muon Campus. The other proposed experiment, Mu2e, is a step ahead and already received the next level of DOE approval, known as Critical Decision 1.

"We now are officially on DOE's roadmap," said Lee Roberts, professor at Boston University and co-spokesperson for the roughly 100 scientists collaborating on the Muon g-2 (pronounced gee minus two) experiment. "This should make it easier to increase the size of our collaboration and foster international participation. Potential collaborators supported by the National Science Foundation or foreign funding agencies will be happy to see that we now have DOE's official Mission Need approval."

At present, the Muon g-2 collaboration includes scientists from institutions in China, Germany, Italy, Japan, the Netherlands and Russia as well as 16 institutions in the United States. Physicists from several institutions in the United Kingdom are in the process of joining the collaboration.

CDO received last week!

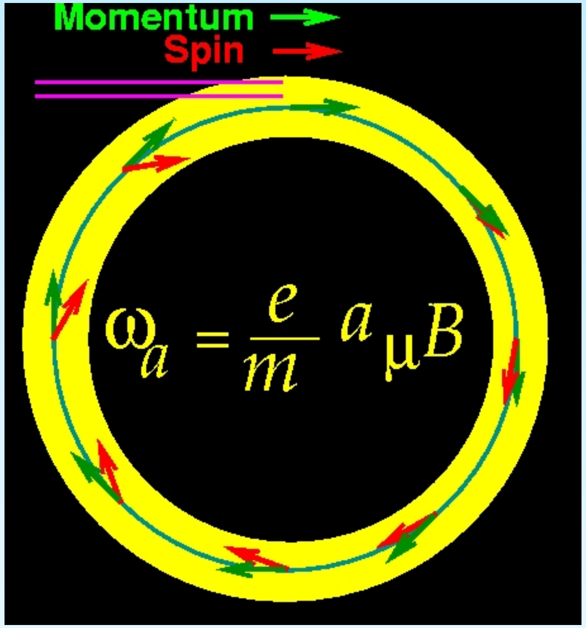
The a_μ Experiment:

- Place polarized muons in a B field
  - spin precession frequency (q = ± e)

$$\vec{\omega}_S = -g\frac{q\vec{B}}{2m} - \frac{q\vec{B}}{\gamma m}(1-\gamma)$$

  - cyclotron frequency

$$\vec{\omega}_C = -\frac{q\vec{B}}{m\gamma}$$



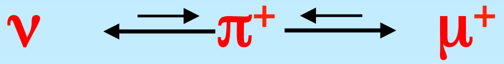
$$\vec{\omega}_a = \omega_S - \omega_C = -\frac{e}{m}a_\mu\vec{B}$$

Since g > 2, the spin gets ahead of the momentum

Measuring ω_a and B → $a\mu$

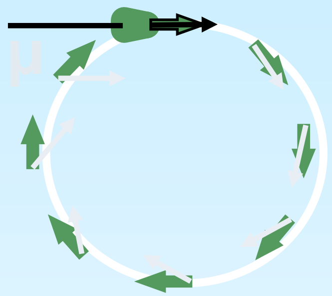
4 Key elements of modern storage-ring g-2 measurements

(1) Polarized muons



~97% polarized for forward decays

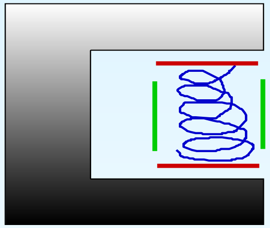
(2) Precession proportional to (*g*-2)



$$\omega_a = \omega_{spin} - \omega_{cyclotron} = \left(\frac{g-2}{2}\right)\frac{eB}{mc}$$

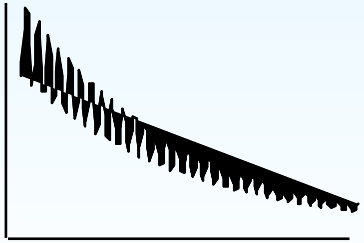
(3) P_μ magic momentum = 3.094 GeV/c

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



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

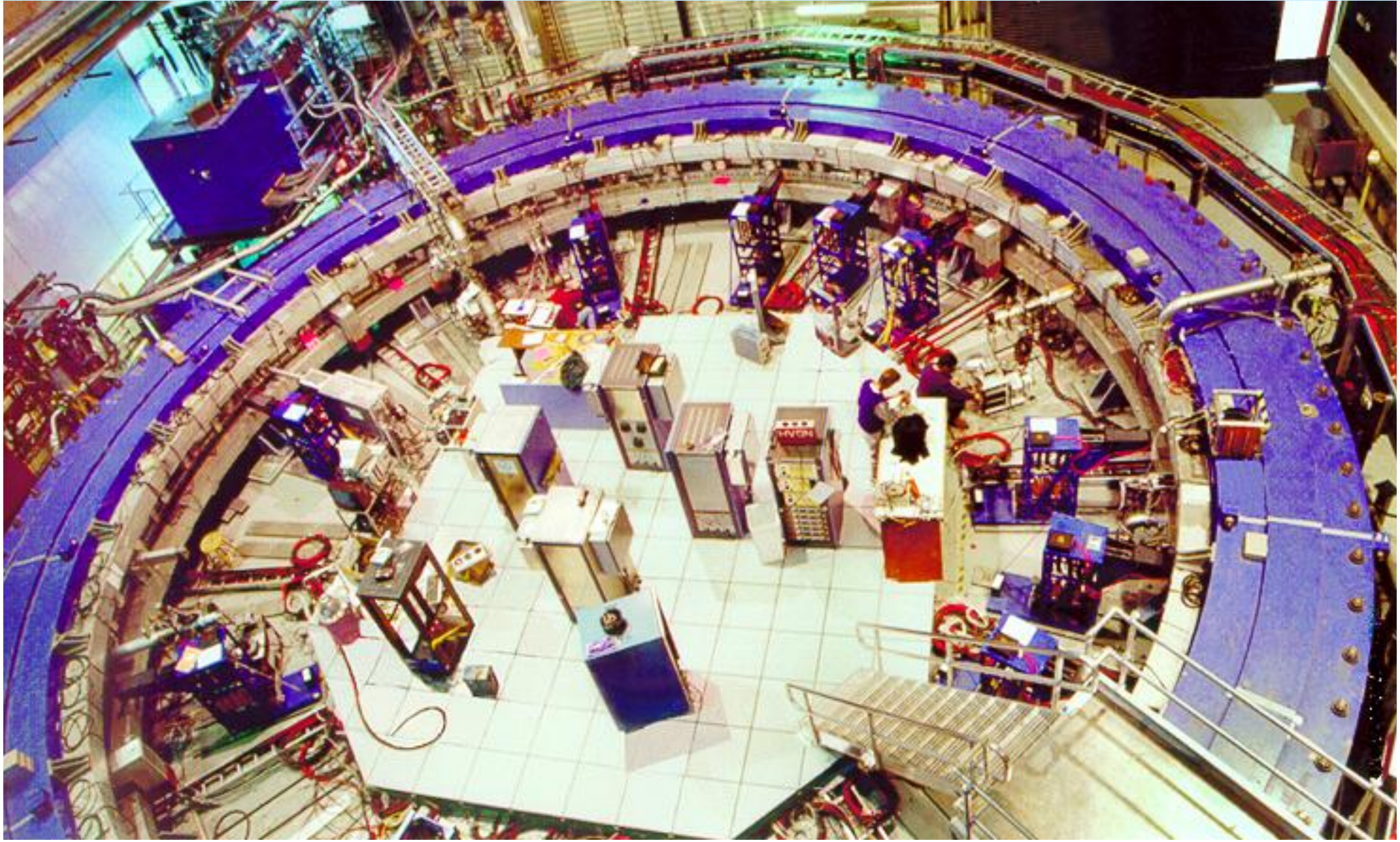
(4) Parity violation in the decay gives average spin direction



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

*Note: this carries a tiny systematic error of < 0.05 ppm in past experiment

E821 exp at BNL: Muon (g-2) storage ring



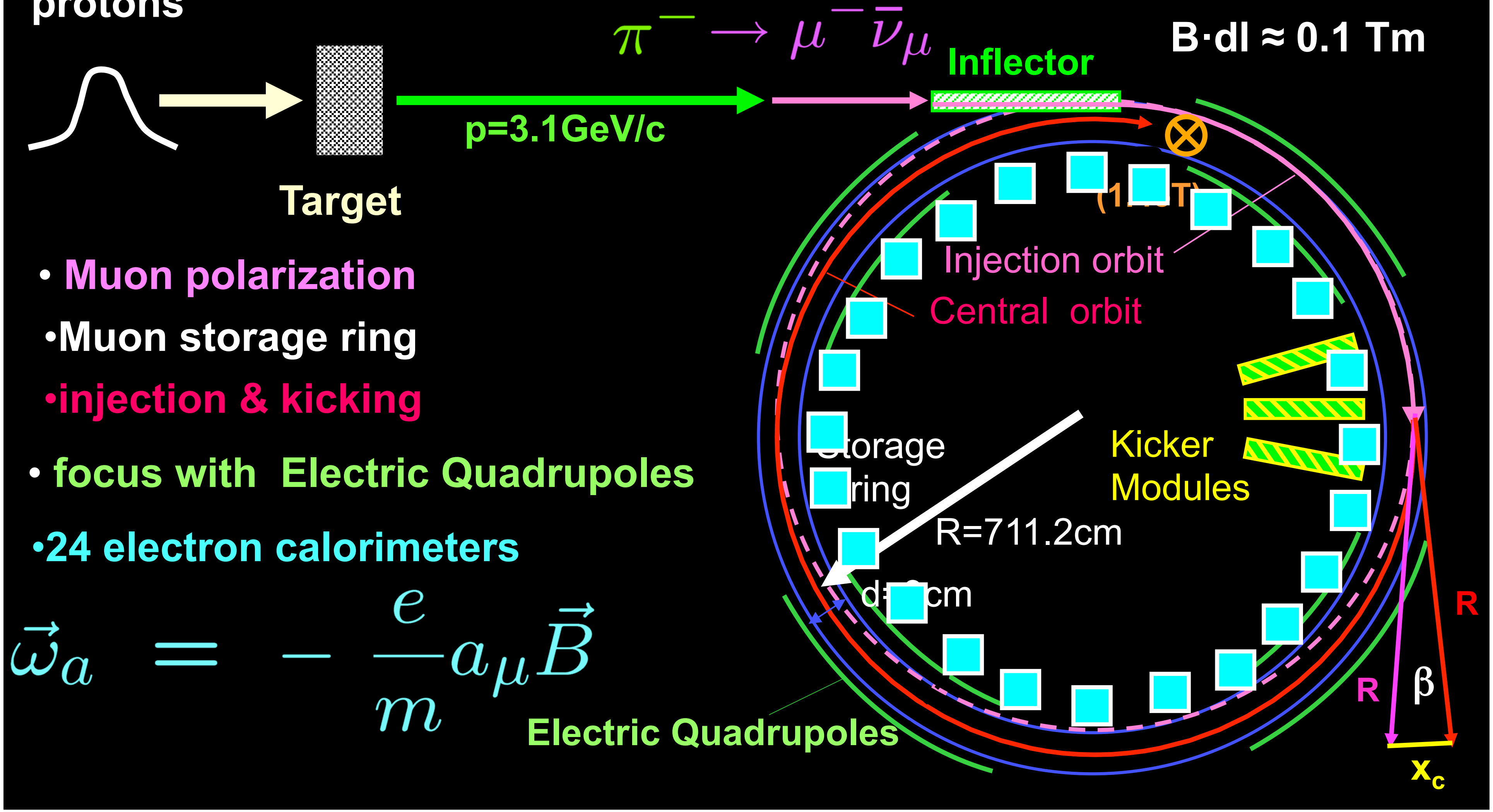
Experimental Technique

25ns bunch of
$\geqslant$ 1 X 10^{12}
protons

$x_c \approx 77$ mm

$\beta \approx 10$ mrad

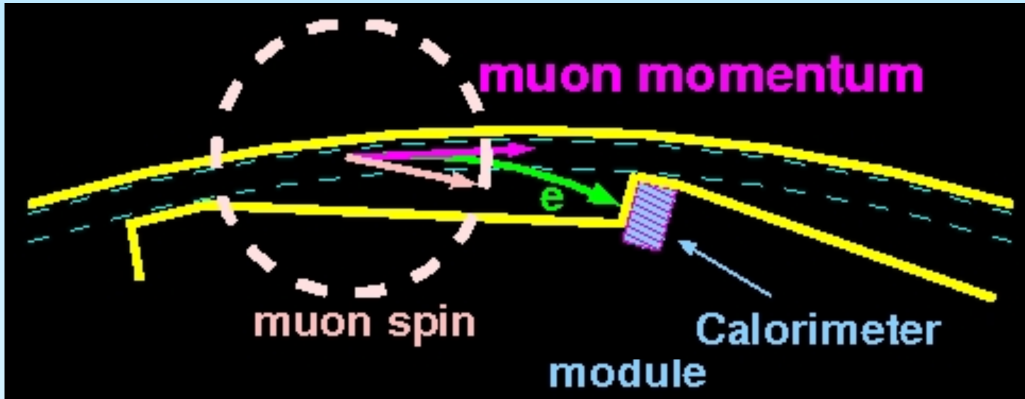
B·dl ≈ 0.1 Tm



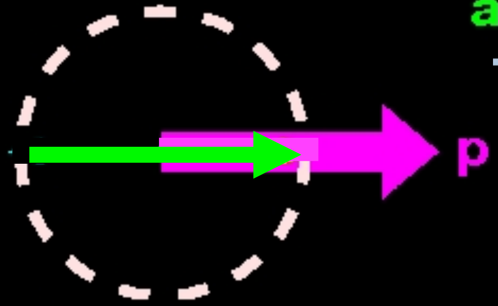
- **Muon polarization**
- **Muon storage ring**
- **injection & kicking**
- **focus with Electric Quadrupoles**
- **24 electron calorimeters**

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

$e^{\pm}$ from $\mu^{\pm} \to e^{\pm} \nu \bar{\nu}$ are detected

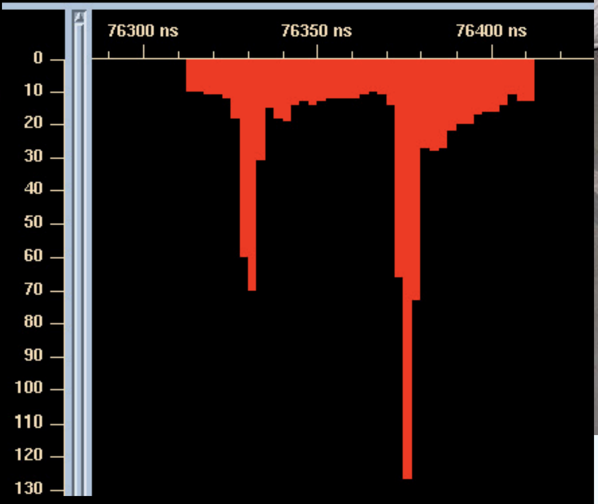


Measures Energy and time

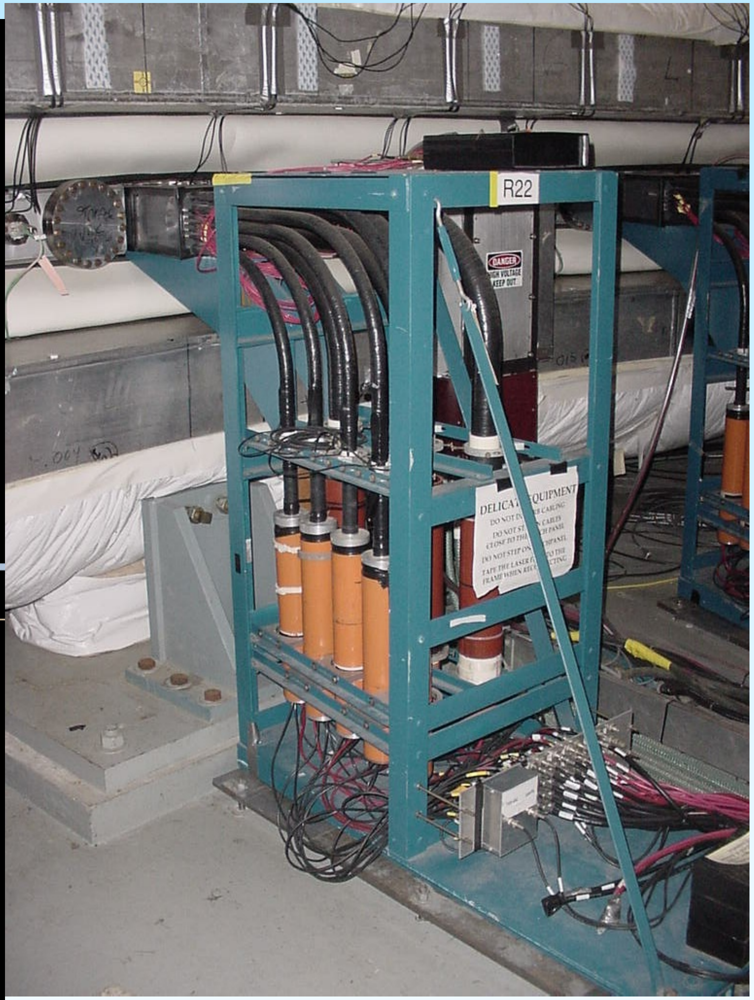


spin forward, more high energy e

spin backward, less high energy e



Waveform digitizer gives t, E



Picture of a Lead-Scifi Calorimeter from E821

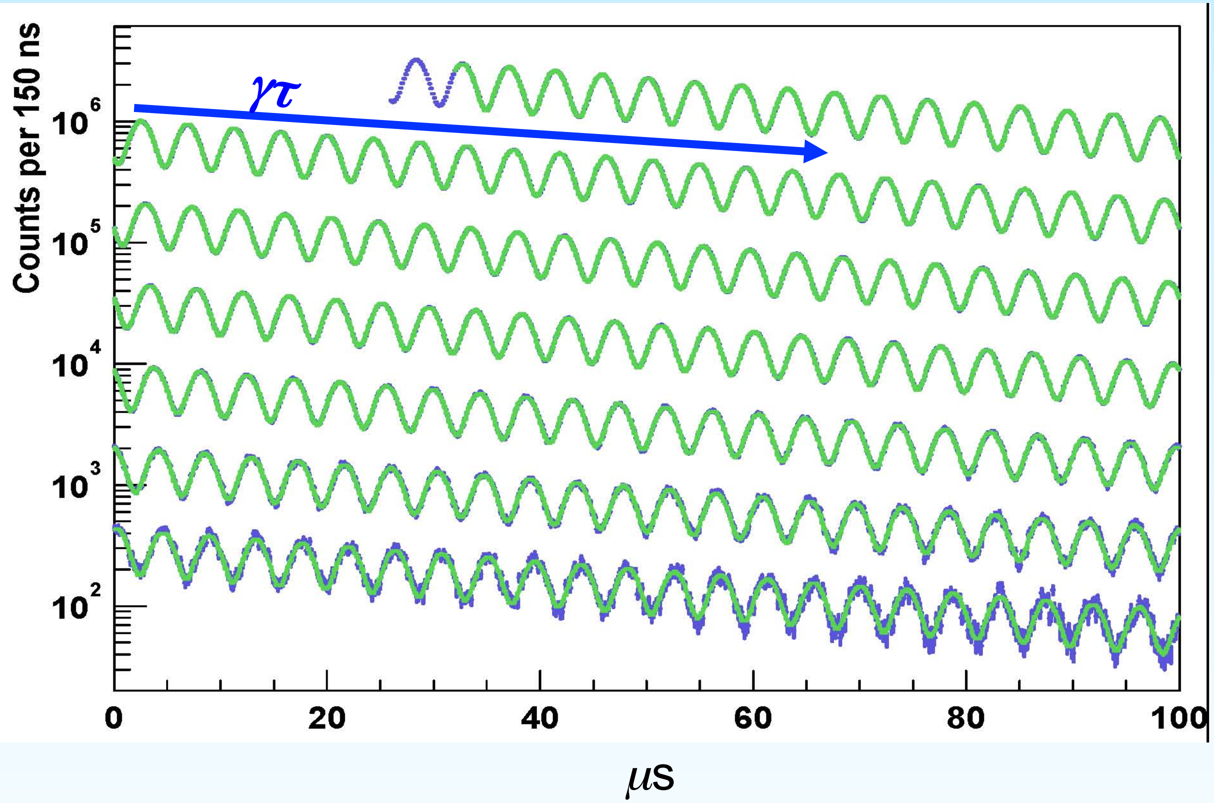
The arrival time spectrum of high-energy e$^-$ ω_a

$$f(t) \simeq N_0 e^{-\lambda t}[1 + A \cos \omega_a t + \phi)]$$

$$3.6 \times 10^9 \; e^-$$

$E_e \geq 1.8$ GeV

$\gamma\tau_\mu$ = 64.4 μs;
(g-2): τ_a = 4.37 μs;
Cyclotron: t_C = 149 ns



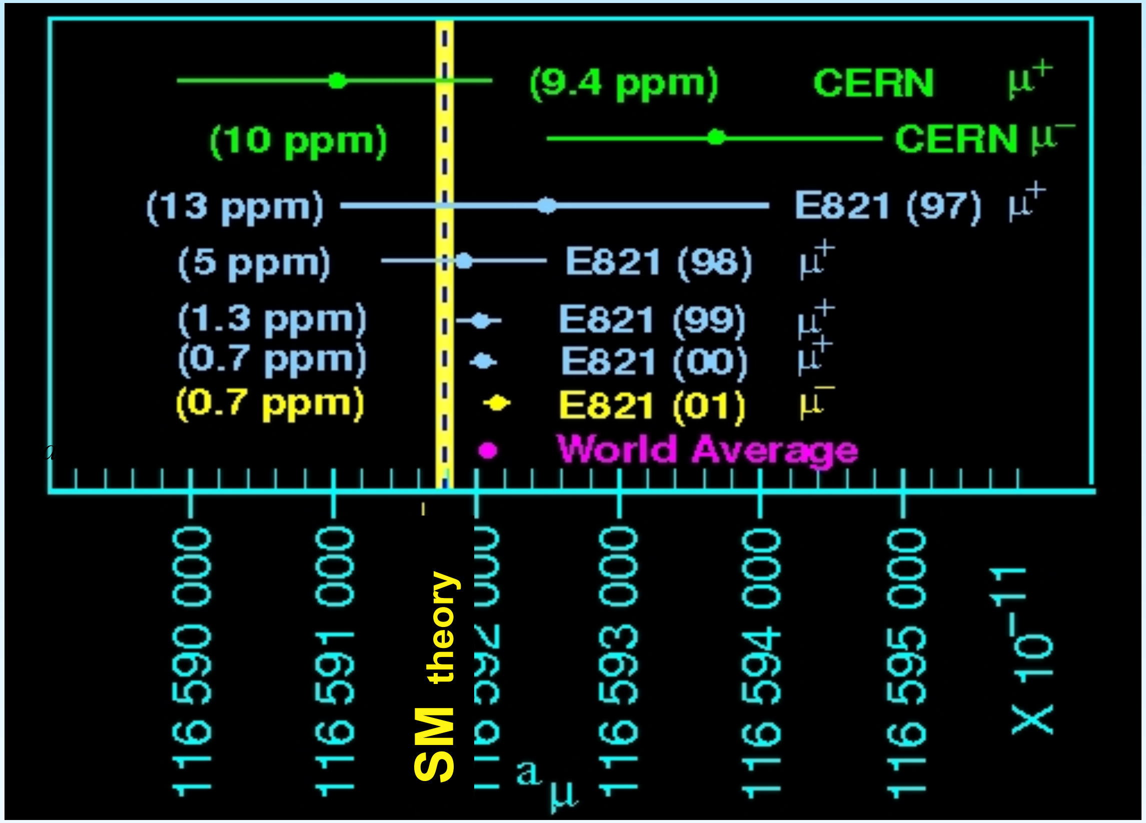
$$a_\mu^{E821} = 116\,592\,089(54)_{stat}(33)_{sys}(63)_{tot}\times 10^{-11}$$

(0.54 ppm!)

A factor 15 improvement in accuracy respect to CERN!

~3.5 “standard deviations” with SM

Error dominated by experimental uncertainty!

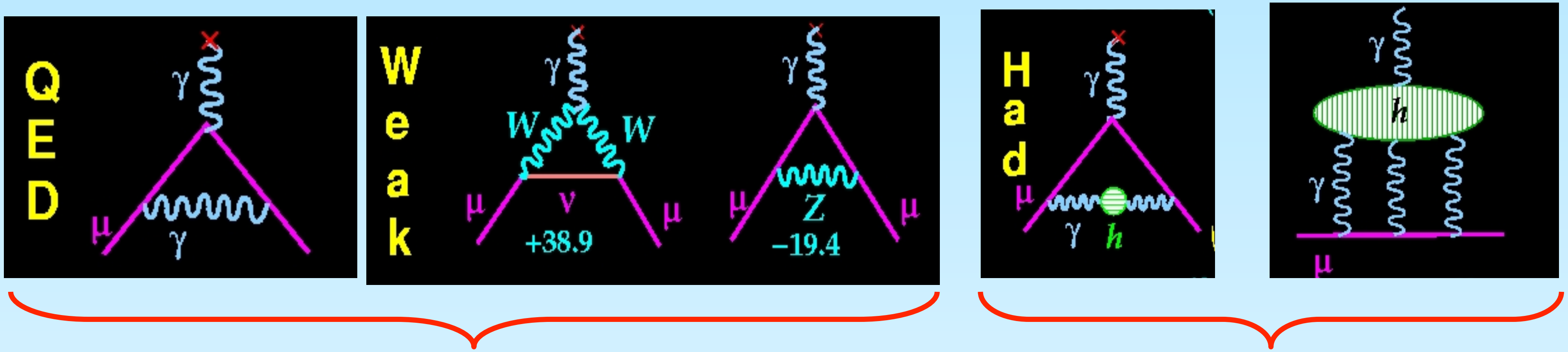


$$a_\mu^{SM} = 116\,591\,802 \pm 49 \times 10^{-11}$$ **M. Davier et al. 2011**

$$a_\mu^{E821} - a_\mu^{SM} = (287 \pm 80) \times 10^{-11} \ (3.6\,\sigma)$$

Hint of new physics?

The SM Value for a_μ



well known

significant work ongoing

CONTRIBUTION	RESULT $(\times 10^{-11})$ UNITS
QED (leptons)	$116\ 584\ 718.09 \pm 0.14 \pm 0.04_\alpha$
HVP(lo)	$6\ 923 \pm 42$
HVP(ho)	-97.9 ± 0.9
HLxL	105 ± 26
EW	$154 \pm 2_{Higgs} \pm 1_{had}$
Total SM	$116\ 591\ 802 \pm 42 \pm 26 \pm 2 (49_{tot})$

We have reached a 0.6 ppm accuracy!

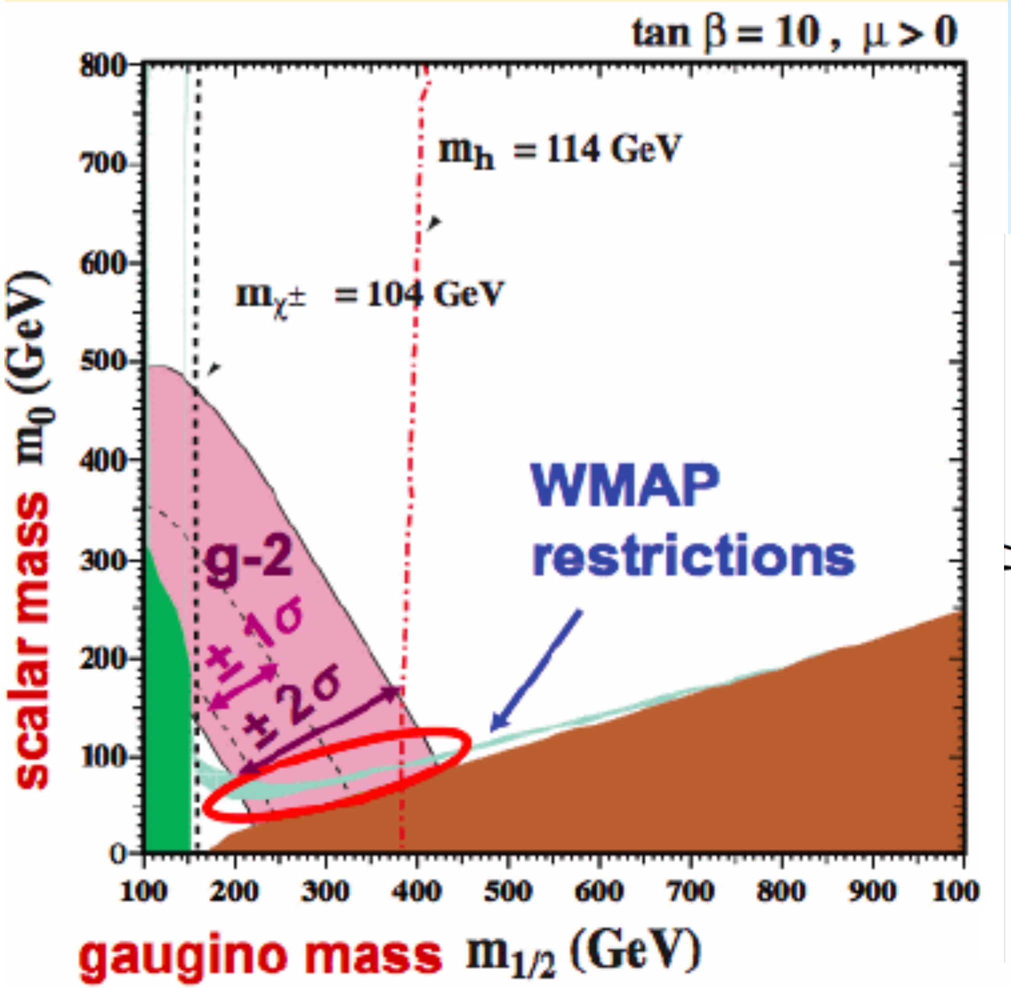
(E821 @ BNL)

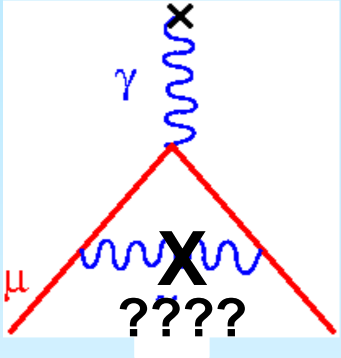
$\sigma_{\mathrm{exp}} = \pm 63$

New Physics?

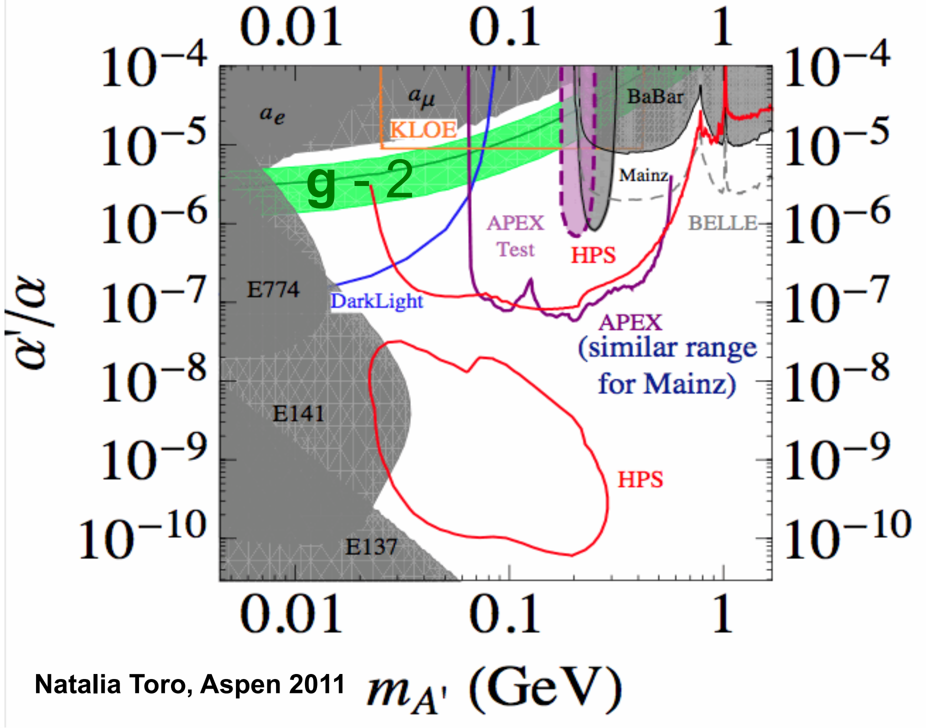
$$a_\mu^{TH} = a_\mu^{QED} + a_\mu^{HAD} + a_\mu^{Weak} + a_\mu^{???}$$

SUSY?





Dark Photons?

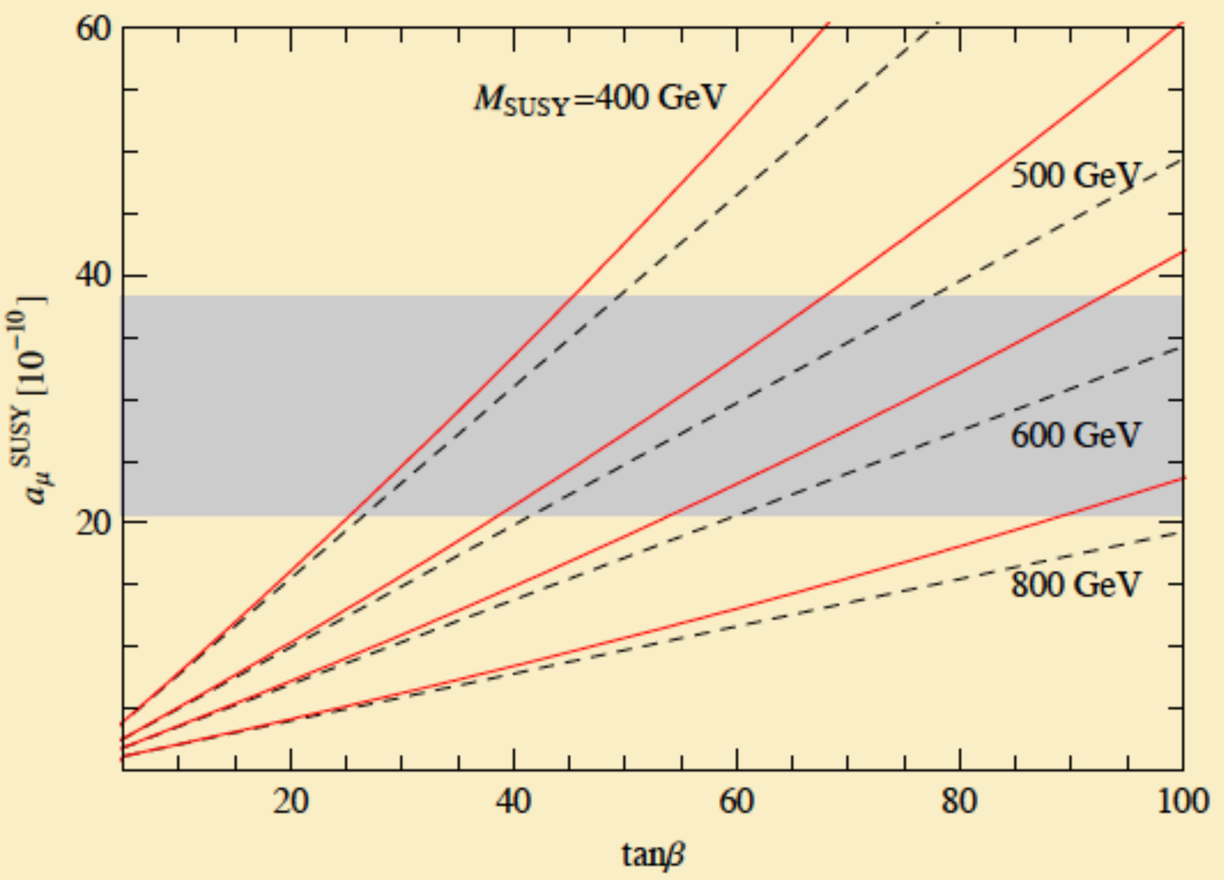


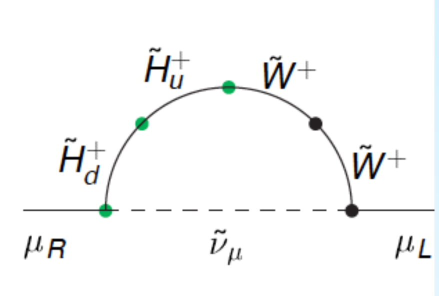
Natalia Toro, Aspen 2011

SUSY?

SUSY with mass scale of several 100 GeV is consistent with discrepancy

$$\Delta a_\mu^{SUSY} \approx 13 \cdot 10^{-10} (\mathrm{sgn}\,\mu) \tan\beta \left(\frac{100\ GeV}{M_{SUSY}} \right)^2$$





Large tanβ, μ>0 prefer

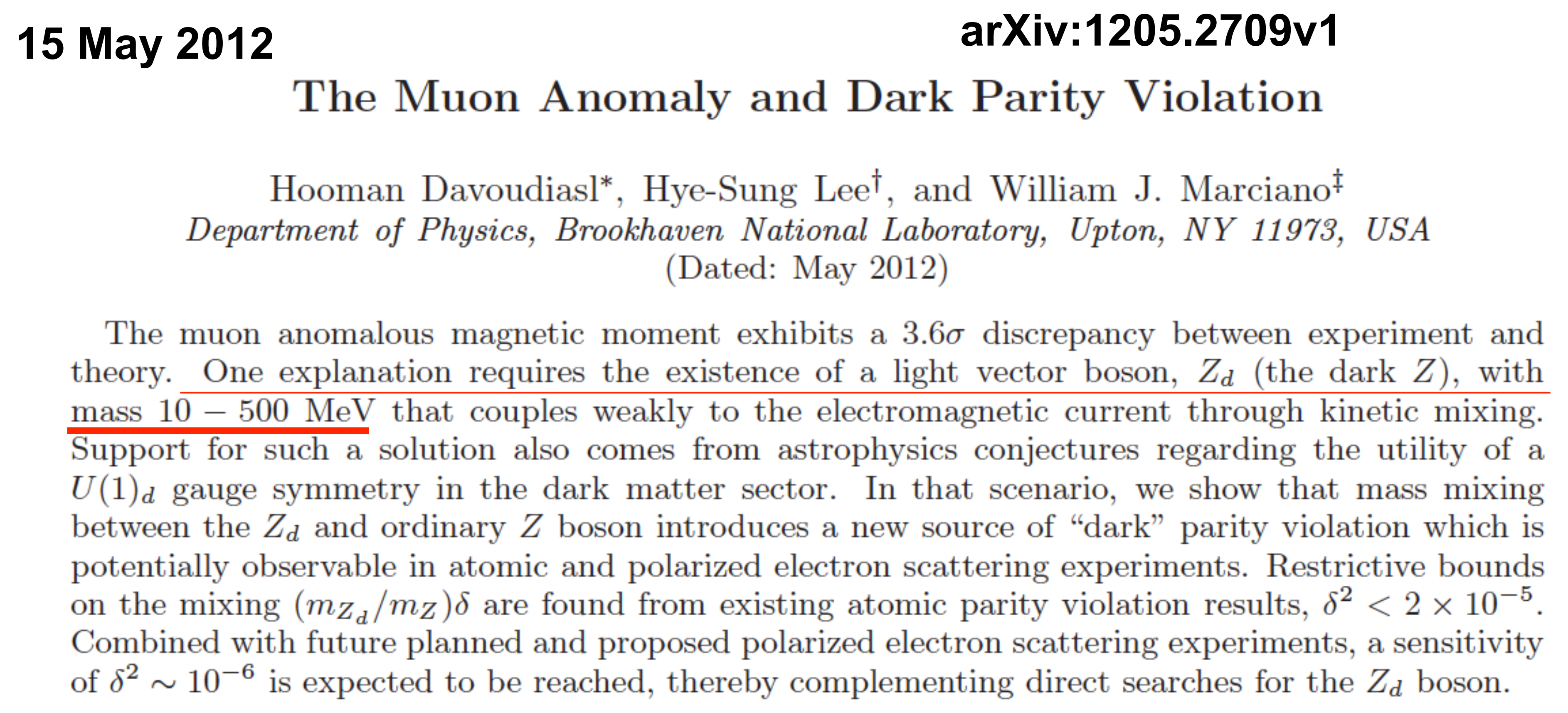
strong limit on M_{SUSY}

Important constraint for interpretation of BSM physics searches at LHC

Dark Photons?

15 May 2012

arXiv:1205.2709v1

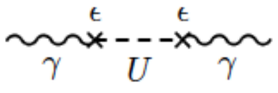


The Muon Anomaly and Dark Parity Violation

Hooman Davoudiasl*, Hye-Sung Lee†, and William J. Marciano‡
Department of Physics, Brookhaven National Laboratory, Upton, NY 11973, USA
(Dated: May 2012)

The muon anomalous magnetic moment exhibits a 3.6σ discrepancy between experiment and theory. One explanation requires the existence of a light vector boson, Z_d (the dark Z), with mass 10 – 500 MeV that couples weakly to the electromagnetic current through kinetic mixing. Support for such a solution also comes from astrophysics conjectures regarding the utility of a $U(1)_d$ gauge symmetry in the dark matter sector. In that scenario, we show that mass mixing between the Z_d and ordinary Z boson introduces a new source of "dark" parity violation which is potentially observable in atomic and polarized electron scattering experiments. Restrictive bounds on the mixing $(m_{Z_d}/m_Z)\delta$ are found from existing atomic parity violation results, $\delta^2 < 2 \times 10^{-5}$. Combined with future planned and proposed polarized electron scattering experiments, a sensitivity of $\delta^2 \sim 10^{-6}$ is expected to be reached, thereby complementing direct searches for the Z_d boson.

$$\mathscr{L}_{\text{mix}} = -\frac{\epsilon}{2} F^{\text{em}}_{\mu\nu} F^{\mu\nu}_{\text{DM}} \qquad (\epsilon \ll 1)\ .$$



Searches for dark photons are currently underway at e^+e^- colliders (B-,tau/charm-, ϕ-factories)and fixed target experiments (JLAB, MAMI, etc…)

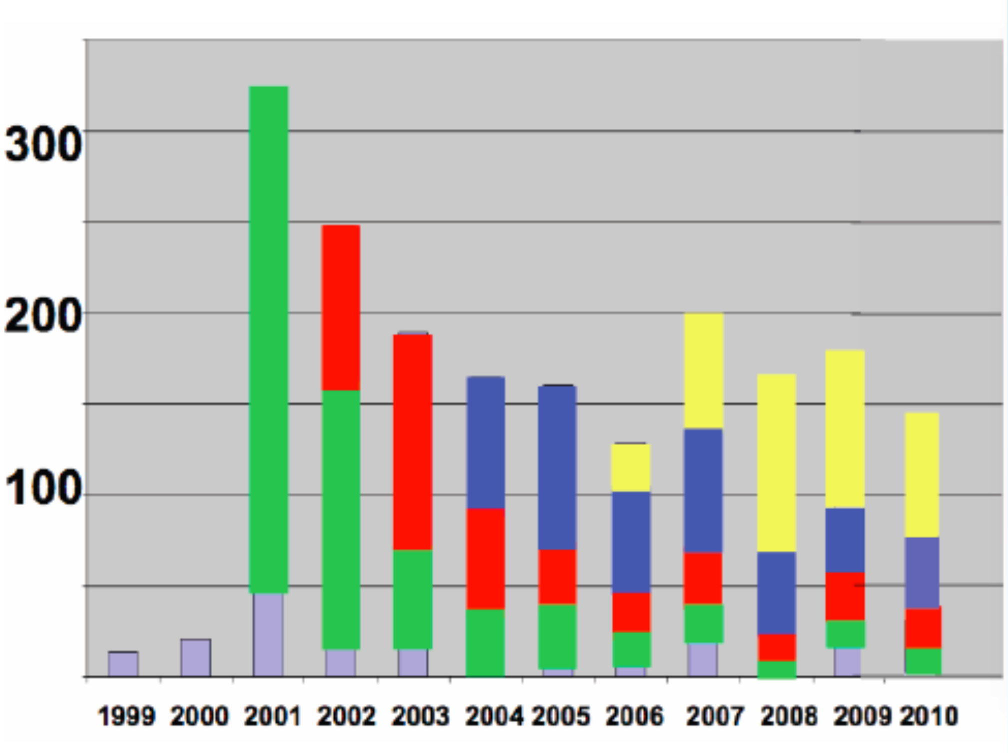
Summary of present status

E821 experiment at BNL has generated enormous interest

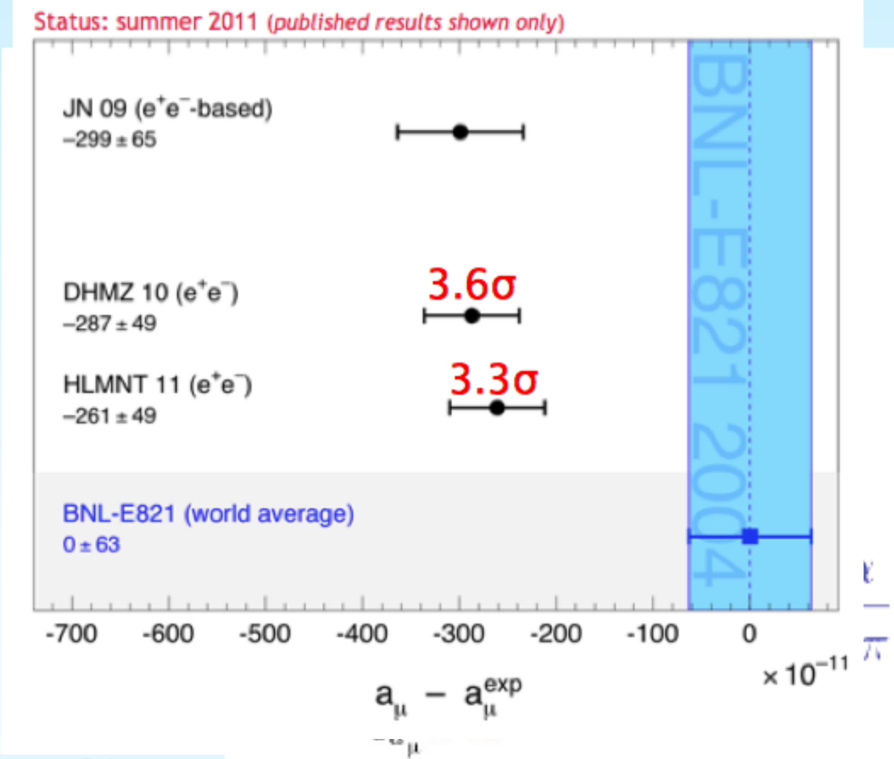
Tantalizing deviation with SM (although persistent since 10 years) is ~3σ

Current discrepancy limited by experimental uncertainty (BNL)

BNL E821 citations



Present



>1850 total citations to our results

We need a new experiment!

New experiment at FNAL (E989)

- New experiment at FNAL (E989) at magic momentum, consolidated method. **20 x** μ w.r.t. E821. Relocate the BNL storage ring to FNAL.

- **E821 at Brookhaven**

$$\left.\begin{aligned}\sigma_{\text{stat}} &= \pm 0.46\ \text{ppm}\\ \sigma_{\text{syst}} &= \pm 0.28\ \text{ppm}\end{aligned}\right\}\ \sigma = \pm 0.54\ \text{ppm}$$

- **E989 at Fermilab**

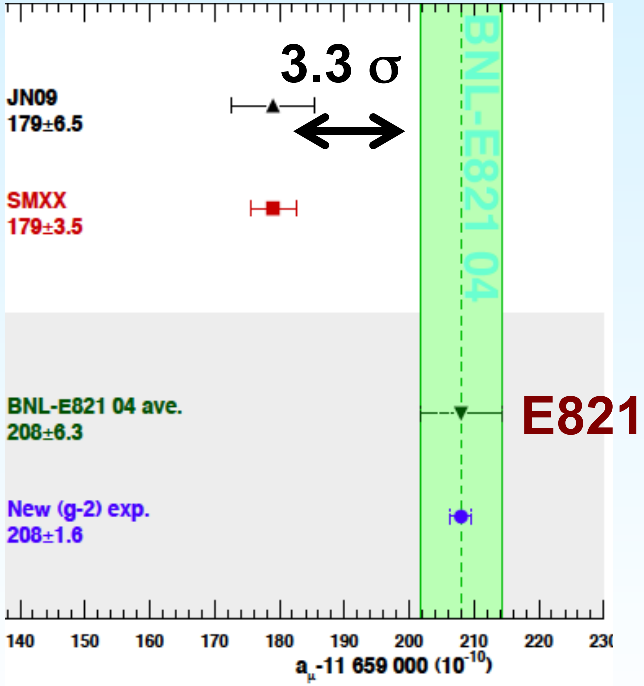
$$\left.\begin{aligned}\sigma_{\text{stat}} &= \pm 0.1\ \text{ppm}\\ \sigma_{\text{syst}} &= \pm 0.1\ \text{ppm}\end{aligned}\right\}\ \sigma = \pm 0.14\ \text{ppm}$$

New experiment at FNAL (E989)

- New experiment at FNAL (E989) at magic momentum, consolidated method. **20 x** μ w.r.t. E821. Relocate the BNL storage ring to FNAL.

Precision target ~ 16×10^{-11} (0.14 ppm) . If the central value remains the same ⇒ 5-8σ from SM* (enough to claim discovery of New Physics!)

***Depending on the progress on Theory**



New experiment at FNAL (E989)

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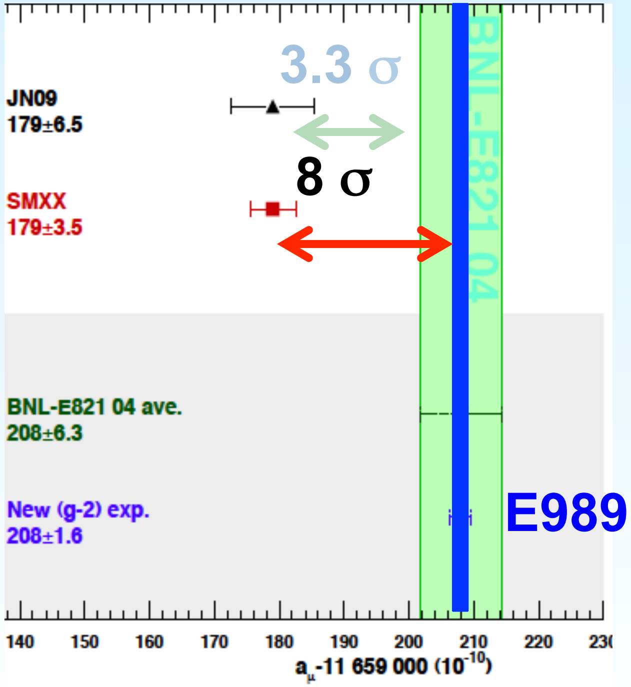
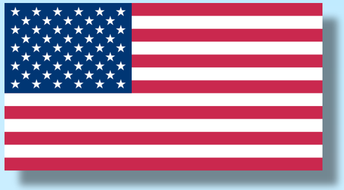


***Depending on the progress on Theory**

Fermilab E989 Experiment (July 12):



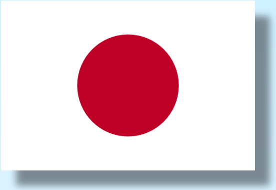
Argonne
Boston University
Brookhaven
CUNY Queens
Cornell
Fermilab
Illinois
James Madison
Kentucky
Massachusetts
Michigan
Muons Inc.
Northwestern
NIU?
Regis
Virginia
Washington

Shanghai

Dresden

KVI

Frascati
Rome



KEK
Osaka

Dubna
Novosibirsk
PNPI

UK Consortium?

>100 Collaborators,

~30 Institutions

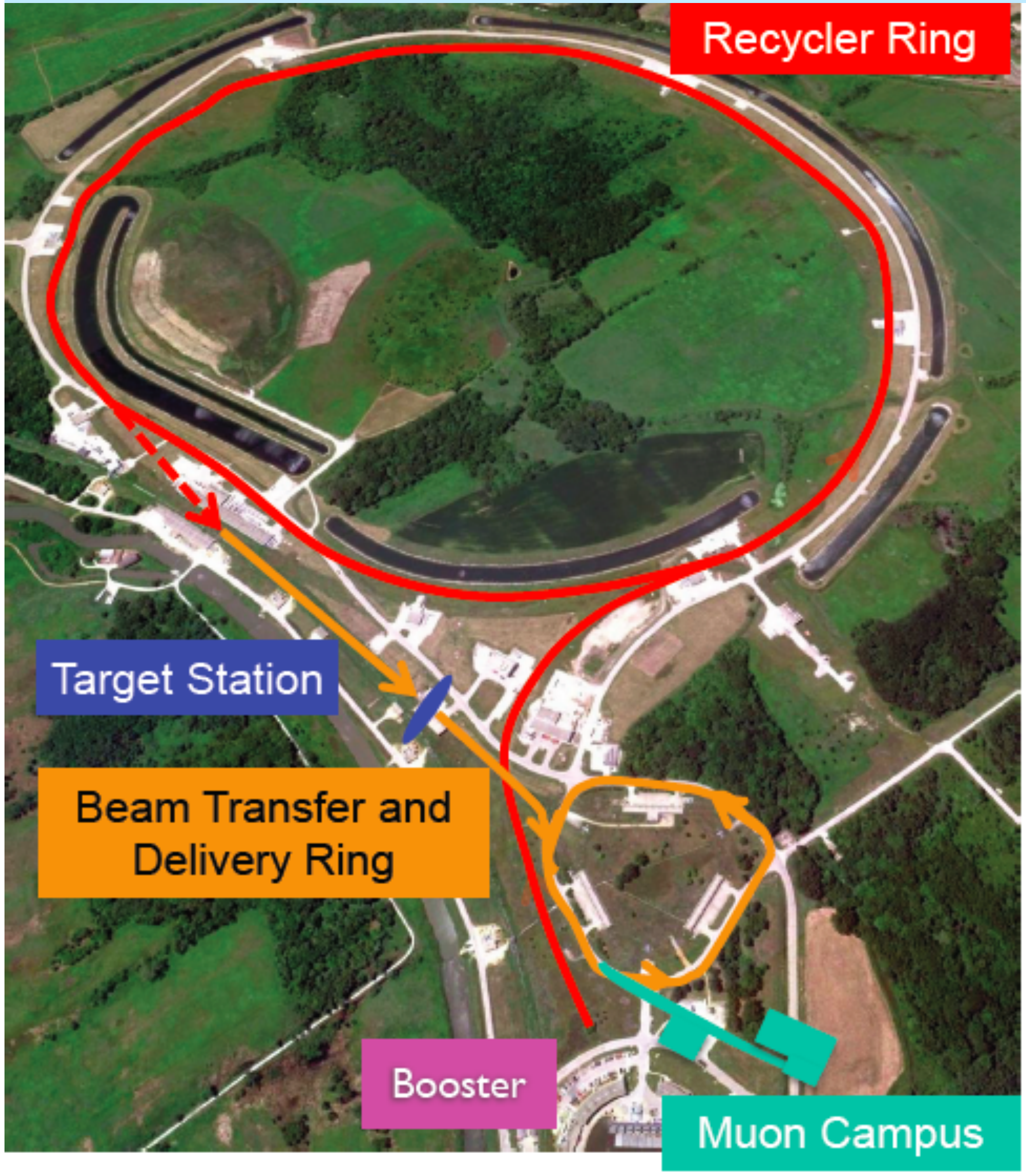
"Collaboration has attained critical mass…have to put all this expertise to good use by matching tasks onto interests and capabilities"

C. Polly, Project Manager, June 12

Why Fermilab?

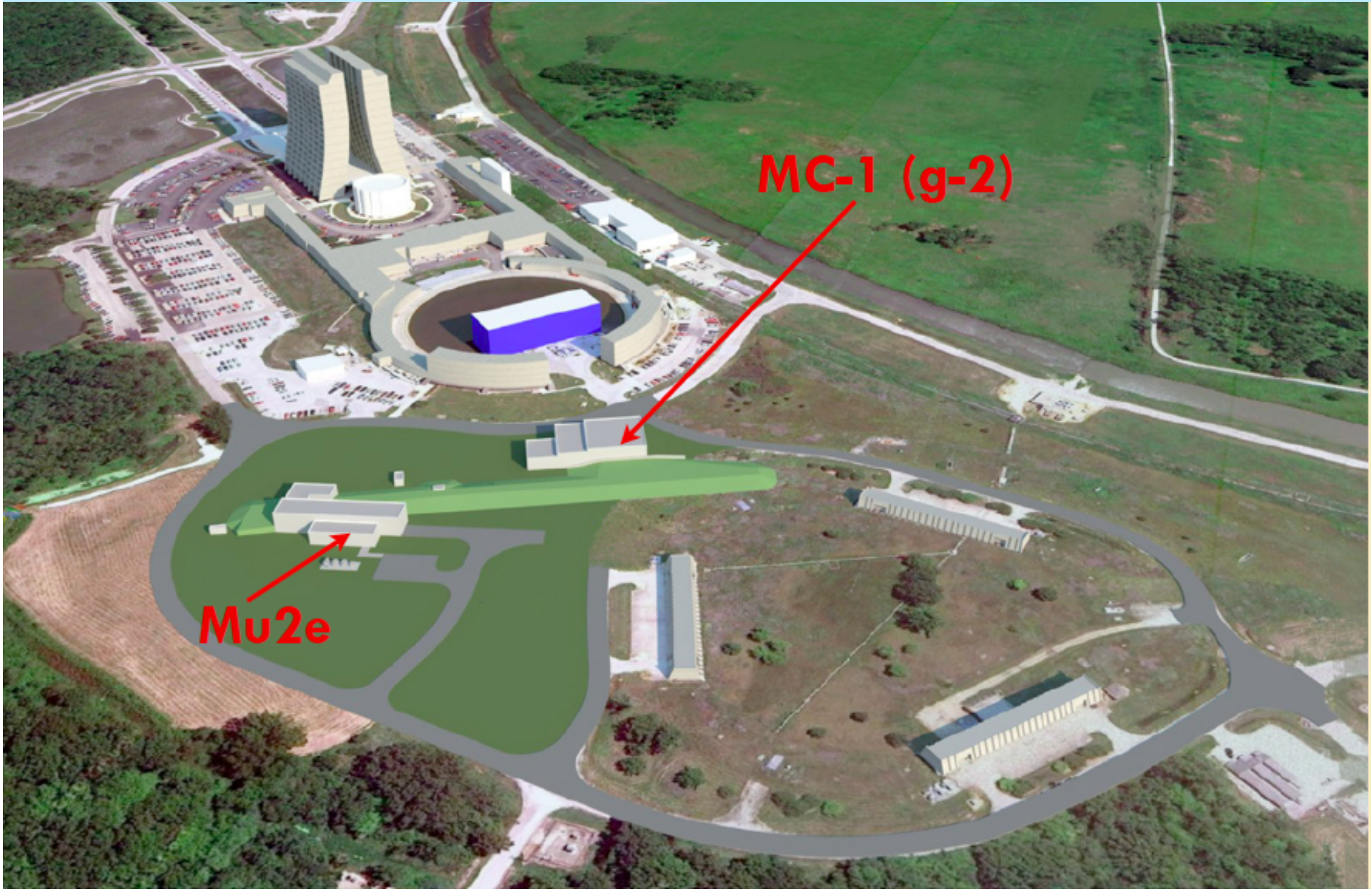
- The existence of many storage rings that are interlinked permits us to make the "ideal" beam structure.
  - proton bunch structure:
    - BNL 4 X 10^{12} p/fill: repetition rate 4.4 Hz
    - FNAL 10^{12} p/fill: repetition rate 15 Hz
  - using antiproton rings as an 900m pion decay line
    - 20 times **less** pion flash at injection than BNL
  - 0^o muons
    - ~5-10x increase μ/p over BNL
  - Can run parasitic to main injector experiments (e.g. to NOVA) or take all the booster cycles
- Expected data taking in 2016

Beam delivery to g-2



- Recycler
  - 8 GeV protons from Booster
  - Re-bunched in Recycler
  - New connection from Recycler to P1 line (existing connection is from Main Injector)
- Target station
  - Target
  - Focusing (lens)
  - Selection of magic momentum
- Beamlines / Delivery Ring
  - P1 to P2 to M1 line to target
  - Target to M2 to M3 to Delivery Ring
  - Proton removal
  - Extraction line (M4) to g-2 stub to ring in MC1 building

Fermilab Muon Campus



Total cost of Muon Program

Muon Campus

- MC-1 Building GPP
- MC Beamline Enclosure GPP
- MC Site Prep GPP
- MC Cryo Plant AIP
- Recycler AIP
- Delivery Ring AIP

Total cost ~$50M

Muon g-2 Project

- g-2 Accelerator
- Ring Reassembly/Upgrades
- E821 Equipment Transfer
- Project Management

Total cost ~$30M

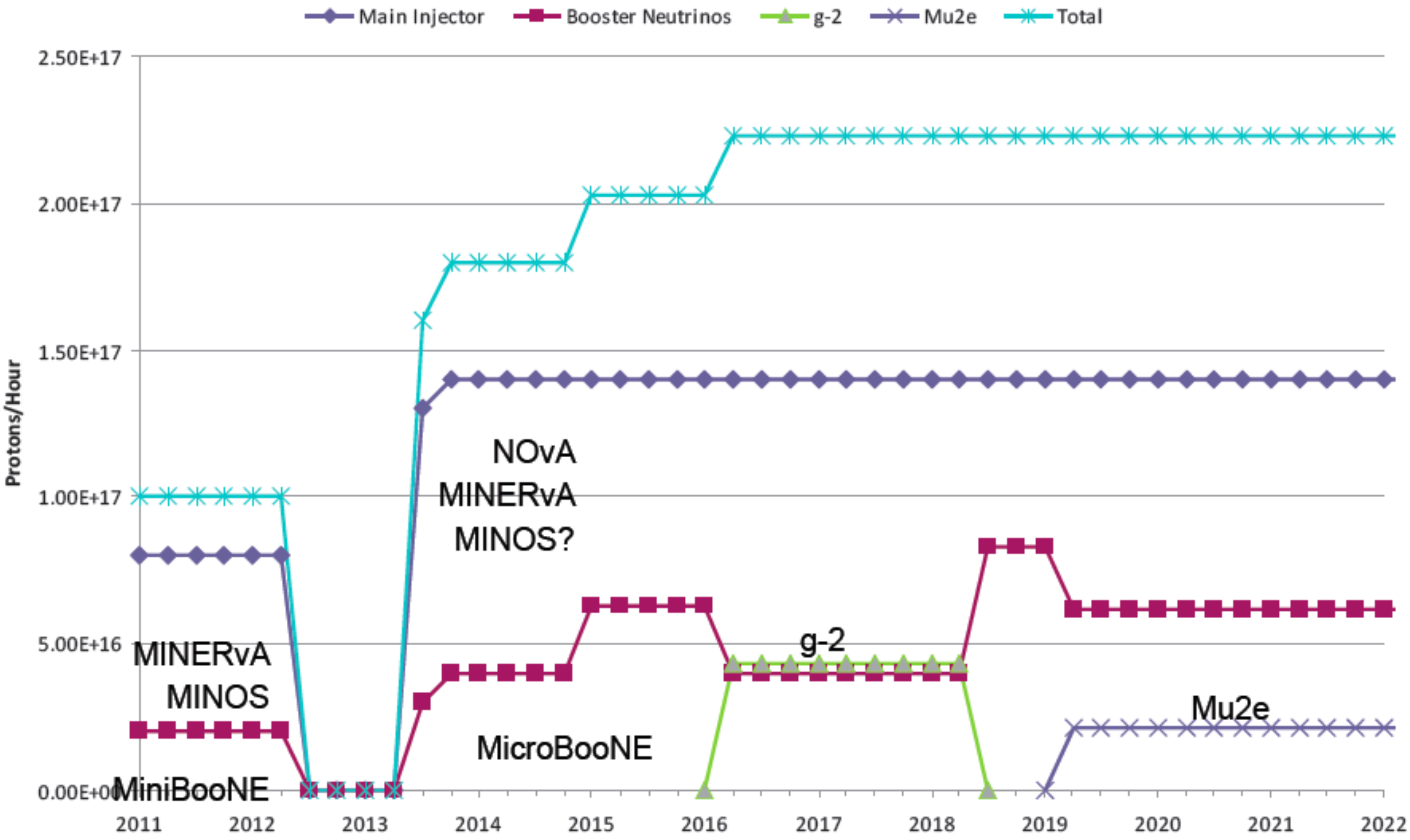
Mu2e Project

- Accelerator
- Civil Construction
- Solenoids
- Muon Channel
- Tracker
- Calorimeter
- CRV
- DAQ
- Project Management

Total cost ~$230M

Total muon program $310M
spread over 2012-19

Who gets beam when?



Upgrades at Fermilab

- New segmented detectors to reduce pileup
  - PbF2 Crystals?
  - W-scifi prototype under study X_0 = 0.7 cm?
  - SiPM or PMT?
- New electronics
  - 500 MHz 12-bit WFDs, with deep memories
- Improvements in the magnetic field calibration, measurement and monitoring.

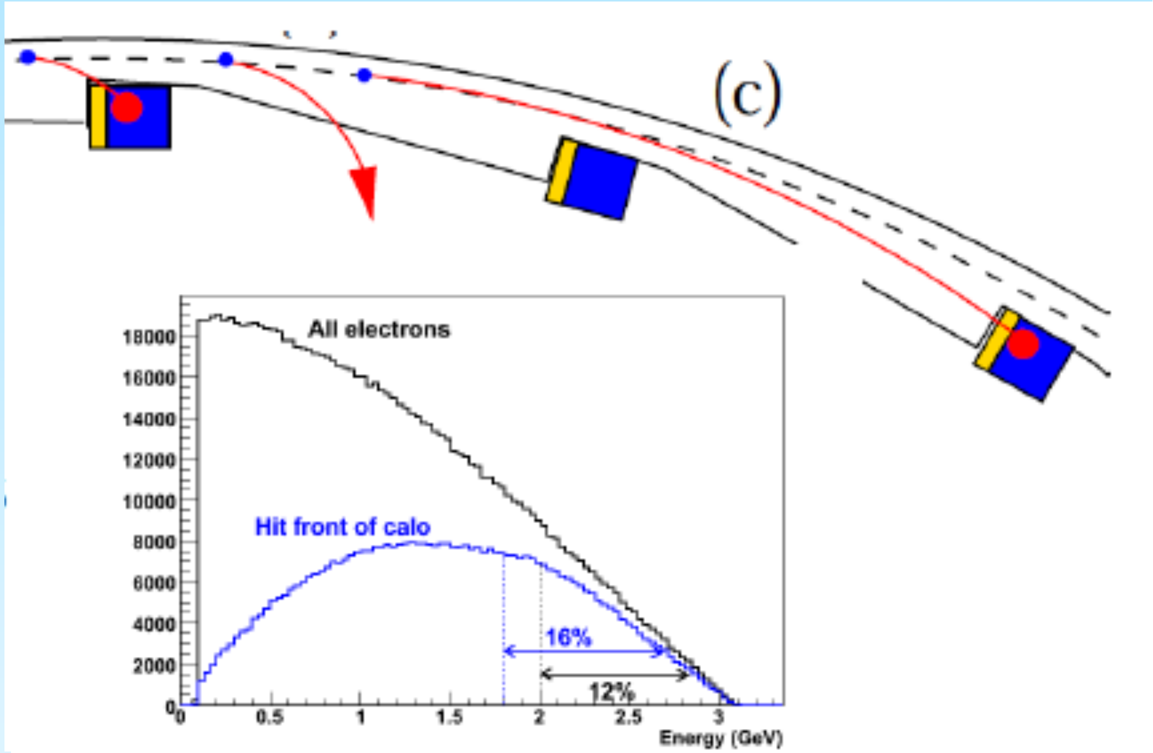
Calorimeters

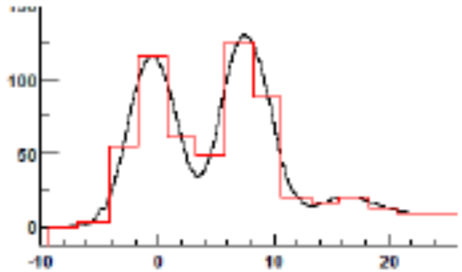
ω_a is determined from e+ arrivals with E>1.8 GeV.

Non magnetic, compact (to separate two pulse in space), fast (to separate two pulse in time) and with moderate energy resolution.

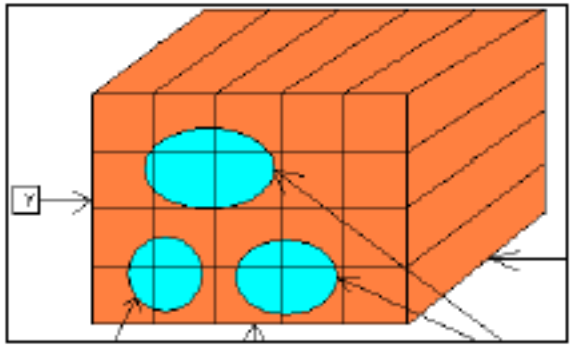
Present design:

- 24 stations
- 35 crystals (5x7 array)/ station
- 3x3x14 cm3 PbF2 crystals (Cherenkov)
- $\sigma E/E \sim$ 3-5%/sqrt(E)
- SiPM readout with optimized pulse shape





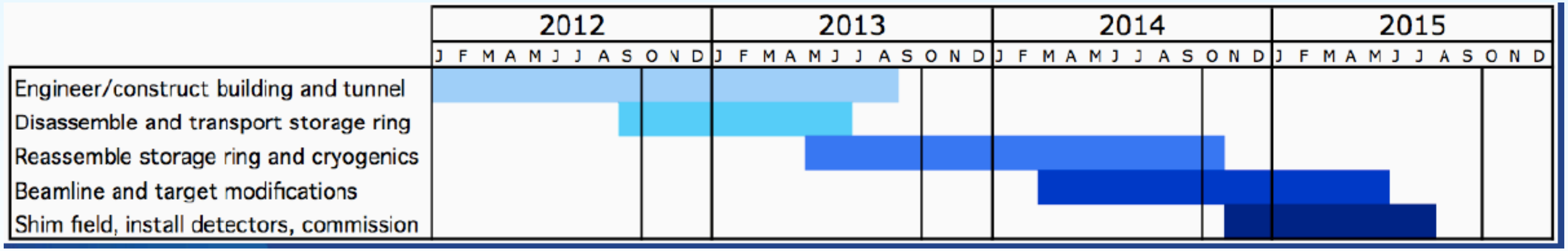
(b) $\Delta t = 8$ ns



E989 Status and Timeschedule

- Fermilab Stage 1 approval on 2011
- CD0 received on Sep 12
- Conceptual Design Report being prepared
- CD-1 expected in early 2013

Goal is to be ready for data in 2016



Conclusion

- During the last ten years the muon (g-2) provided one of the strongest tests of the SM, thanks to the impressive accuracy of BNL experiment (δa_μ^{EXP} = 0.54 ppm). Important interplay with LHC!

- The SM prediction has steadily improved thanks to precise e^+e^- data (worldwide effort): δa_μ^{SM} = 0.43 ppm

- At present a discrepancy of more than 3 “standard deviations” between SM and Experiment; uncertainty dominated by BNL experiment

- New $(g-2)_\mu$ experiment at Fermilab with a fourfold reduction δa_μ^{EXP} = 0.14 ppm . First results could be available around 2017/18

- Theoretical uncertainty will improve thanks to current and planned experimental activities (as well as theoretical ones)

Stay Tuned!

Why Fermilab?

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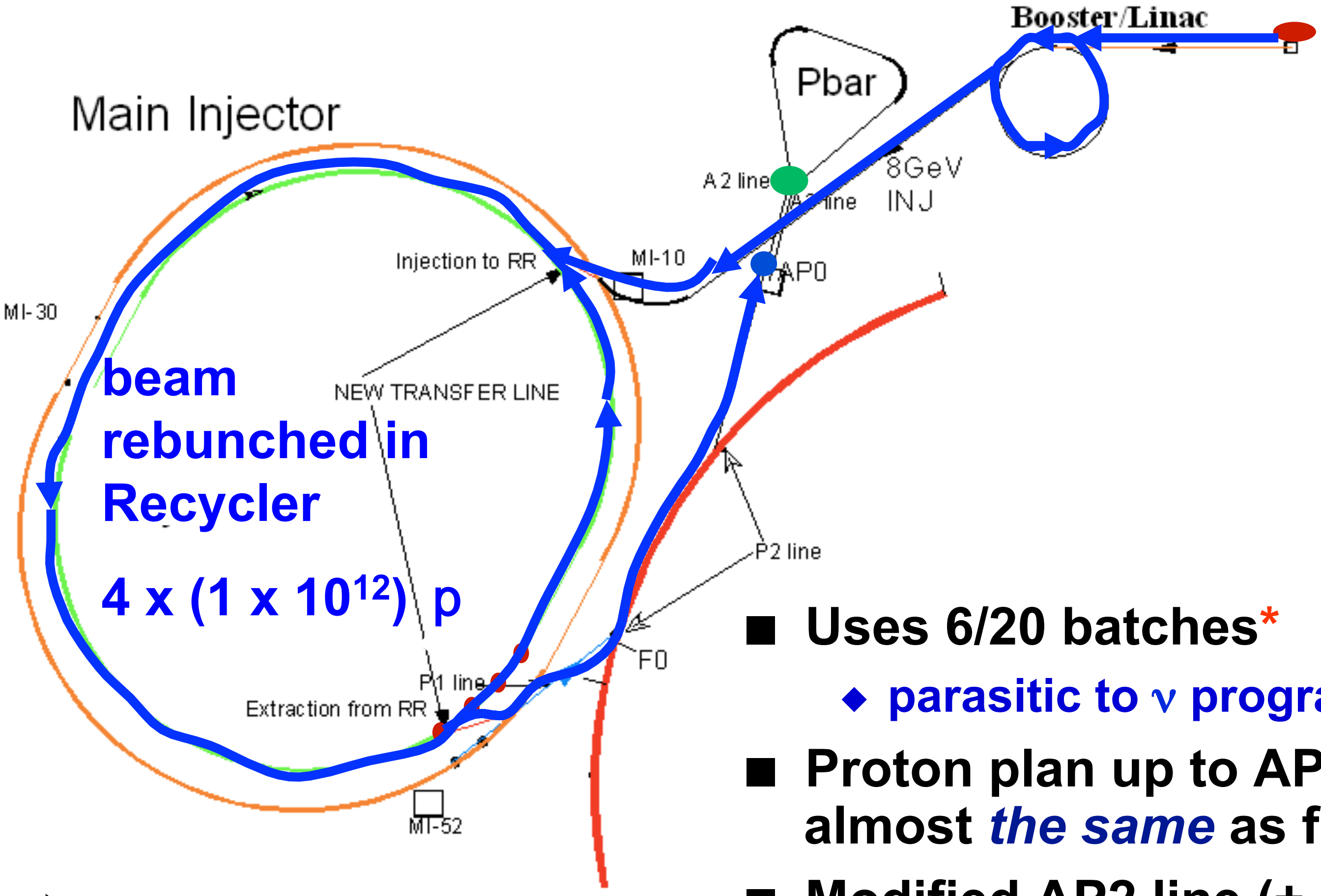
  - 0^o muons
    - ~5-10x increase μ/p over BNL
  - Can run parasitic to main injector experiments (e.g. to NOVA) or take all the booster cycles
- Expected data taking in 2016

Polarized muons delivered and stored in the ring at the magic momentum, 3.094 GeV/c



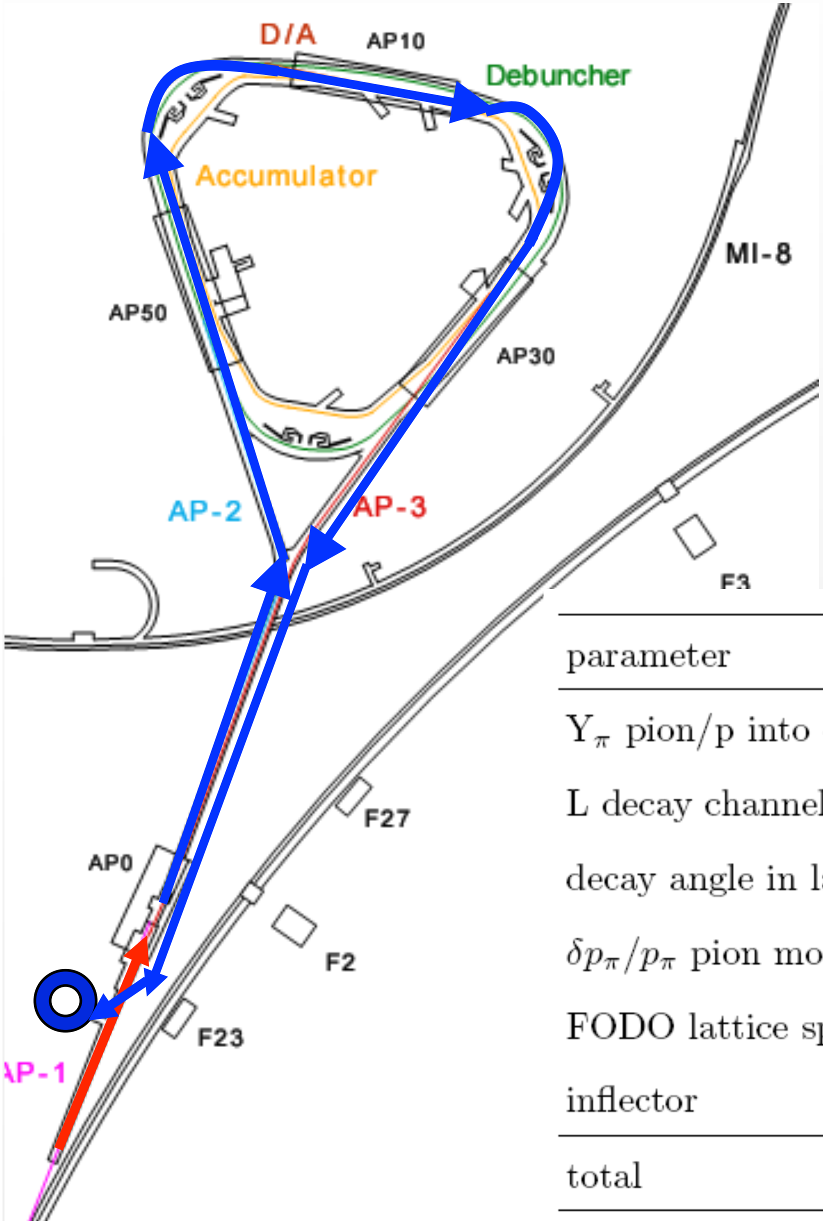
beam rebunched in Recycler

$4 \times (1 \times 10^{12})$ p

- **Uses 6/20 batches***
  - **parasitic to ν program**
- **Proton plan up to AP0 target is almost *the same* as for Mu2e**
- **Modified AP2 line (+ quads)**
- **New beam stub into ring**

***Can use all 20 if MI program is off**

The 900-m long decay beam reduces the pion "flash" by x20 and leads to 6 – 12 times more stored muons per proton (compared to BNL)



Flash compared to BNL

parameter	FNAL/BNL
p / fill	0.25
π / p	0.4
π survive to ring	0.01
π at magic P	50
Net	0.05

Stored Muons / POT

parameter	BNL	FNAL	gain factor FNAL/BNL
Y_π pion/p into channel acceptance	$\approx$ 2.7E-5	$\approx$ 1.1E-5	0.4
L decay channel length	88 m	900 m	2
decay angle in lab system	3.8 $\pm$ 0.5 mr	forward	3
$\delta p_\pi / p_\pi$ pion momentum band	$\pm 0.5\%$	$\pm 2\%$	1.33
FODO lattice spacing	6.2 m	3.25 m	1.8
inflector	closed end	open end	2
total			11.5

Upgrades at Fermilab

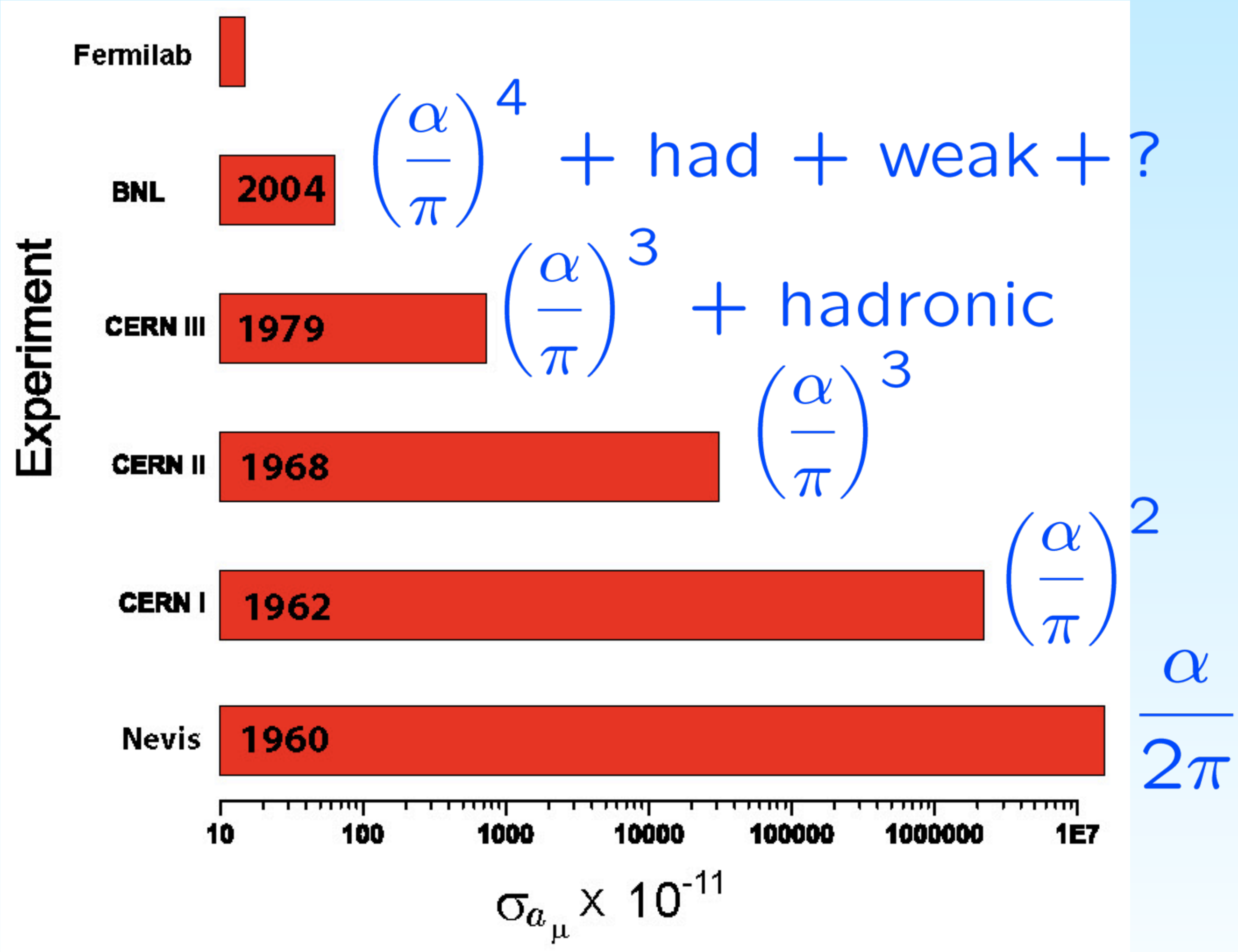
- **New segmented detectors to reduce pileup**
  - **W-scifi prototype under study X_0 = 0.7 cm**
  - **NIM A602 :396-402 (2009).**
- **New electronics**
  - **500 MHz 12-bit WFDs, with deep memories**
- **Improvements in the magnetic field calibration, measurement and monitoring.**

Muon (g-2) storage ring to be relocated to FNAL

- Transport coils to and from barge via Sikorsky aircrane
- Ship through St Lawrence -> Great Lakes -> Calumet SAG
- Subsystems can be transported overland, but probably more cost effective to ship steel on barge as well.

Sikorsky S64F 12.5 T hook weight (Outer coil 8T)

Thank you for your attention!

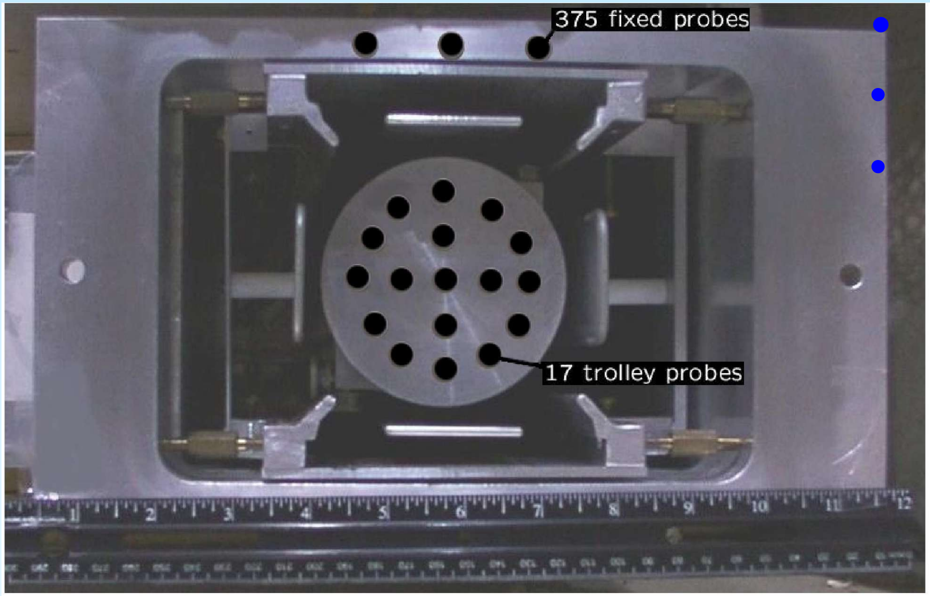


Many thanks to Lee Roberts and Dave Hertzog for helping me with the presentation

SPARES

The magnetic field is measured and controlled using pulsed NMR and the free-induction decay.

ω_p

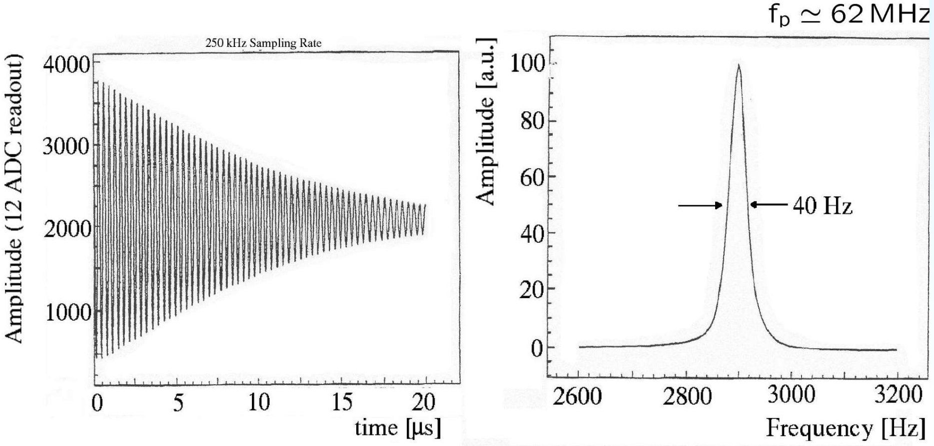


- ω_p= Larmor frequency of the free p
- We measure ω_a and ω_p independently
- Use $\lambda = \mu_\mu/\mu_p$ as the "fundamental constant"

Blind analysis

$$\boxed{a_\mu = \frac{\frac{\omega_a}{\omega_p}}{\frac{\mu_\mu}{\mu_p} - \frac{\omega_a}{\omega_p}}}$$

Free induction decay signals:



Systematic uncertainty on ω_p expected to be reduced by a factor 2 thanks to **better** shimming (uniformity of B), **relocations** of critical NMR probes, and **other** incremental changes

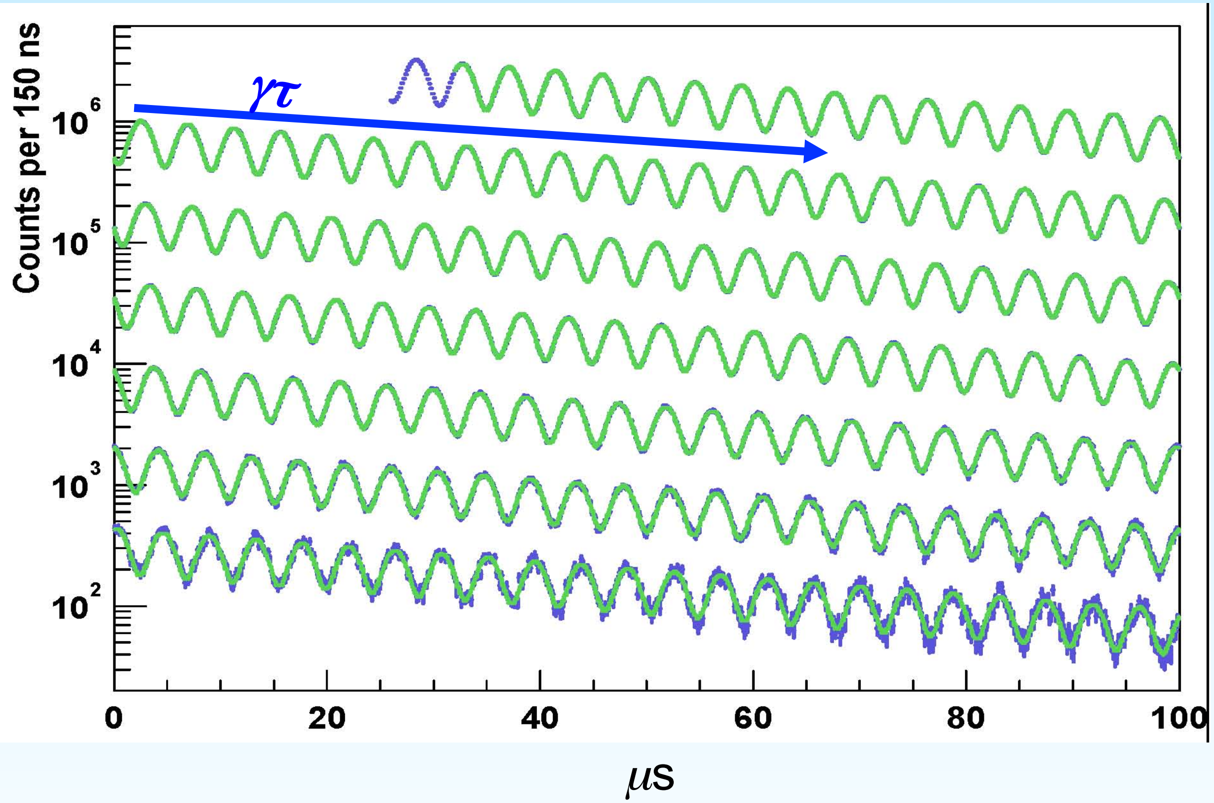
The arrival time spectrum of high-energy e$^-$ ω_a

$$f(t) \simeq N_0 e^{-\lambda t}[1 + A\cos\omega_a t + \phi)]$$

$3.6 \times 10^9\ e^-$

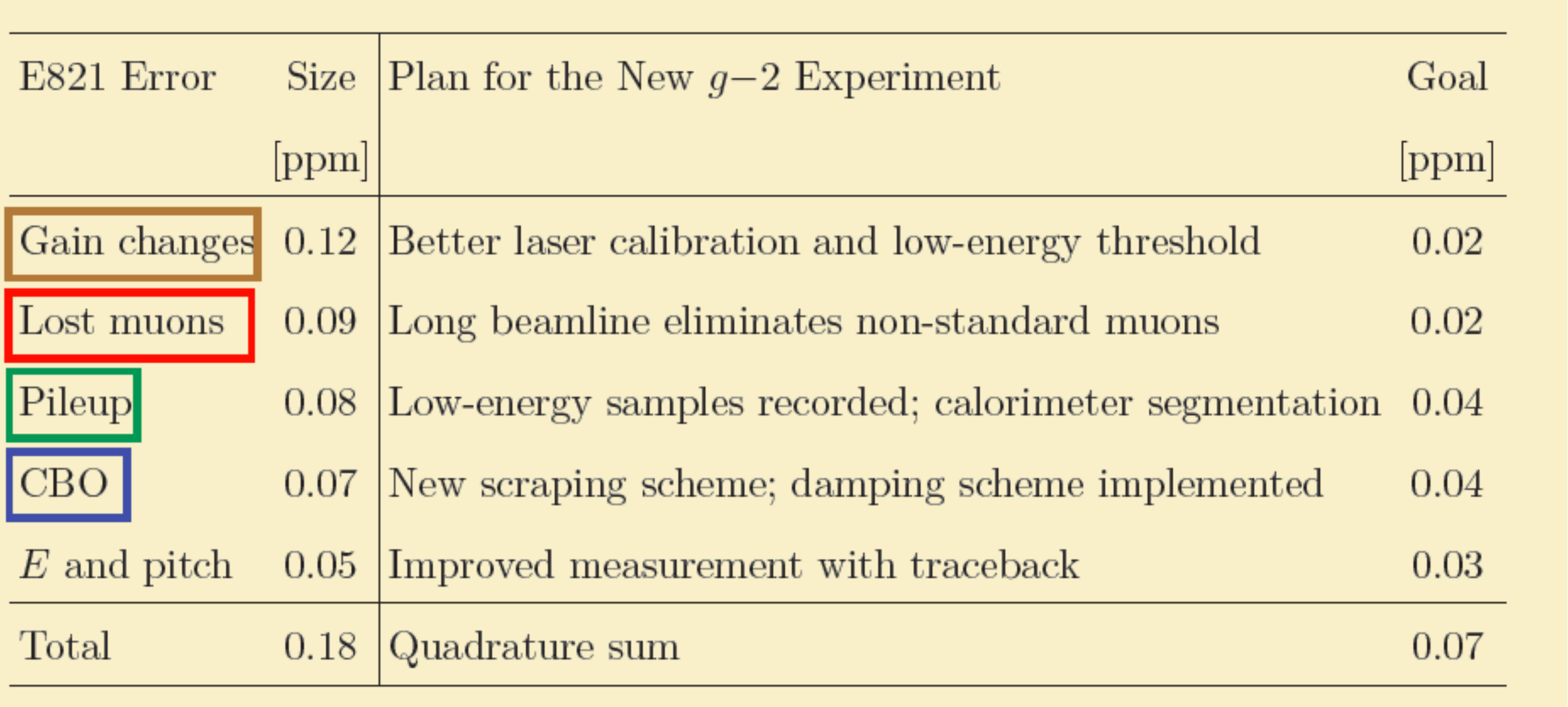
$E_e \geq 1.8$ GeV

$\gamma\tau_\mu$ = 64.4 μs;
(g-2): τ_a = 4.37 μs;
Cyclotron: t_C = 149 ns



Systematic uncertainty on ω_a expected to be reduced by 1/3 at E989 (compared to E821) thanks to **reduced** pion contamination,the **segmented** detectors, and an **improved** storage ring kick of the muons onto orbit.

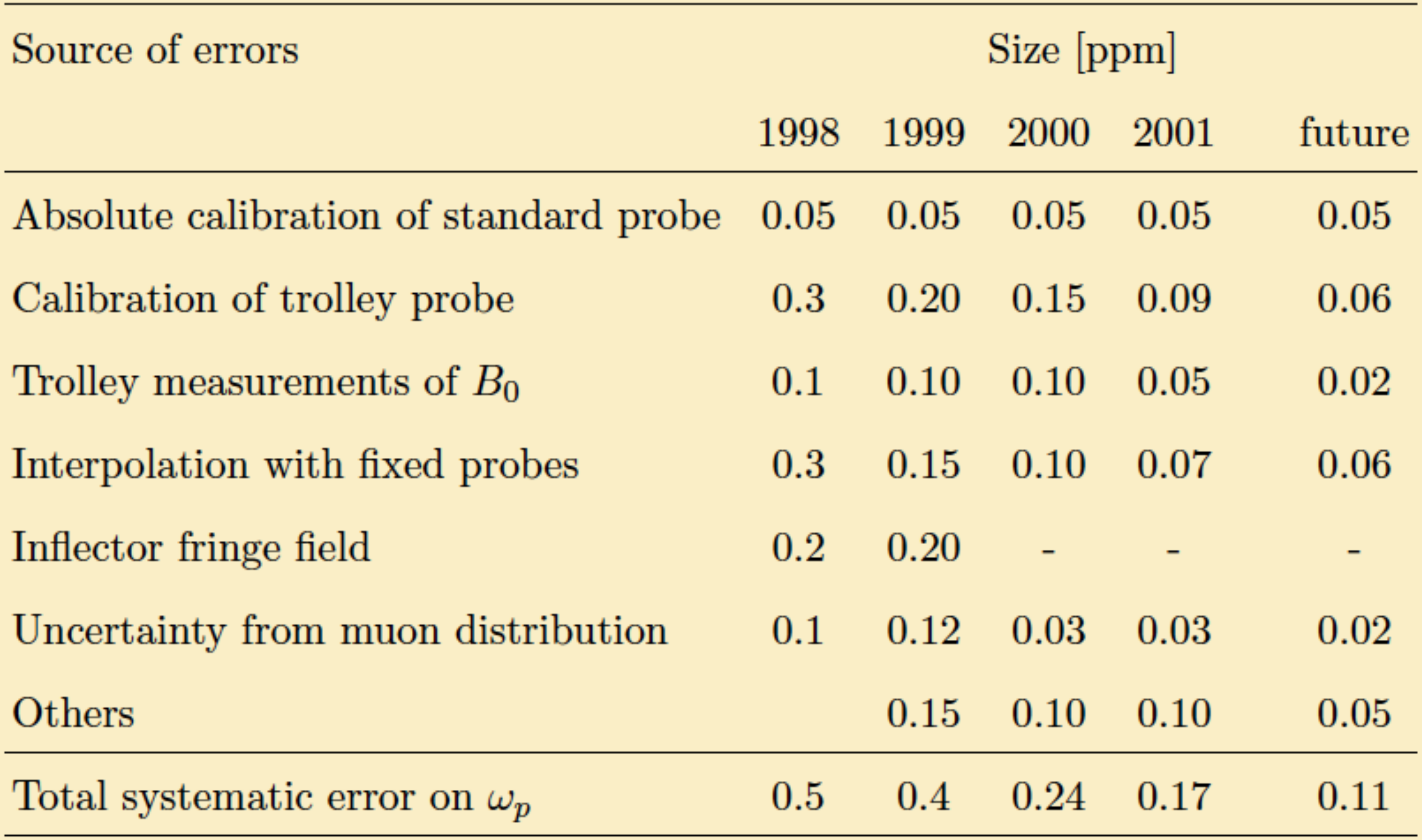
Improving ω_a



E821 Error	Size [ppm]	Plan for the New $g-2$ Experiment	Goal [ppm]
Gain changes	0.12	Better laser calibration and low-energy threshold	0.02
Lost muons	0.09	Long beamline eliminates non-standard muons	0.02
Pileup	0.08	Low-energy samples recorded; calorimeter segmentation	0.04
CBO	0.07	New scraping scheme; damping scheme implemented	0.04
E and pitch	0.05	Improved measurement with traceback	0.03
Total	0.18	Quadrature sum	0.07

Systematic uncertainty on ω_a expected to be reduced by 1/3 at E989 (compared to E821) thanks to **reduced** pion contamination,the **segmented** detectors, and an **improved** storage ring kick of the muons onto orbit.

Improving ω_p



Source of errors	Size [ppm]				
	1998	1999	2000	2001	future
Absolute calibration of standard probe	0.05	0.05	0.05	0.05	0.05
Calibration of trolley probe	0.3	0.20	0.15	0.09	0.06
Trolley measurements of B_0	0.1	0.10	0.10	0.05	0.02
Interpolation with fixed probes	0.3	0.15	0.10	0.07	0.06
Inflector fringe field	0.2	0.20	-	-	-
Uncertainty from muon distribution	0.1	0.12	0.03	0.03	0.02
Others		0.15	0.10	0.10	0.05
Total systematic error on ω_p	0.5	0.4	0.24	0.17	0.11

Systematic uncertainty on ω_p expected to be reduced by a factor 2 thanks to **better** shimming (uniformity of B), **relocations** of critical NMR probes, and **other** incremental changes

Muon g-2 project received CD-0 this week!

Fermilab *Today*

Wednesday, Sept. 19, 2012

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Feature

Second muon experiment receives Mission Need approval from DOE

This rendering shows the location of the proposed Muon Campus at Fermilab. The arrow points to the proposed site of the planned Muon g-2 experiment. Click to enlarge. *Image: Muon Department/FESS*

Fermilab's plans for creating a Muon Campus with top-notch Intensity Frontier experiments have received a big boost. The Department of Energy has granted Mission Need approval to the Muon g-2 project, one of two experiments proposed for the new Muon Campus. The other proposed experiment, Mu2e, is a step ahead and already received the next level of DOE approval, known as Critical Decision 1.

"We now are officially on DOE's roadmap," said Lee Roberts, professor at Boston University and co-spokesperson for the roughly 100 scientists collaborating on the Muon g-2 (pronounced gee minus two) experiment. "This should make it easier to increase the size of our collaboration and foster international participation. Potential collaborators supported by the National Science Foundation or foreign funding agencies will be happy to see that we now have DOE's official Mission Need approval."

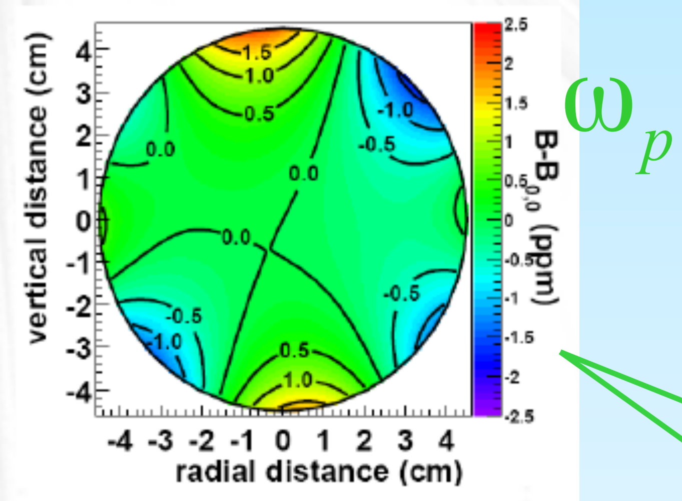
At present, the Muon g-2 collaboration includes scientists from institutions in China, Germany, Italy, Japan, the Netherlands and Russia as well as 16 institutions in the United States. Physicists from several institutions in the United Kingdom are in the process of joining the collaboration.

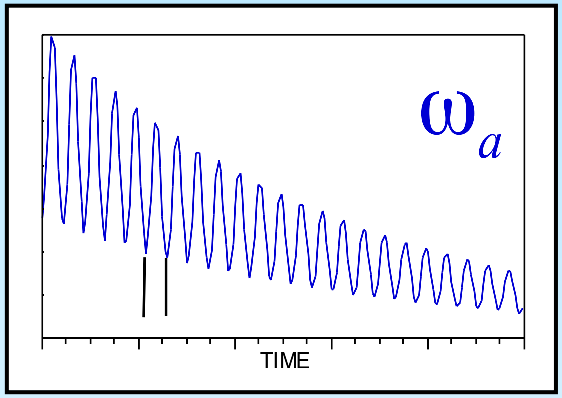
The new Muon Campus at Fermilab will consist of the reconfigured Antiproton Source, which will provide high-intensity muon beams, and two new buildings, which will host the Muon g-2 and Mu2e experiments. The new buildings will be located south of Wilson Hall, between the Booster accelerator and the former Antiproton Source.

"The design of the buildings has progressed a lot," said Chris Polly, project manager for the Muon g-2 experiment. "We hope to break ground for the Muon Campus by the end of the calendar year."

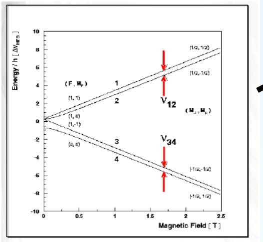
CD-0 is a necessary first step for a project within the DOE where it is officially placed on the roadmap and given a 'Mission Need' status

The anomaly is obtained from three well-measured quantities





$$a_\mu = \frac{\dfrac{\omega_a}{\omega_p}}{\dfrac{\mu_\mu}{\mu_p} - \dfrac{\omega_a}{\omega_p}}$$



μ_μ/μ_p = 3.183 345 24(37) (120 ppb)

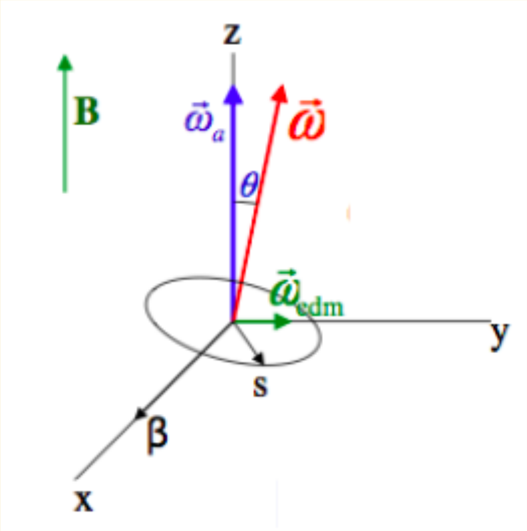
= *3.183 345 39(10) (31 ppb)*

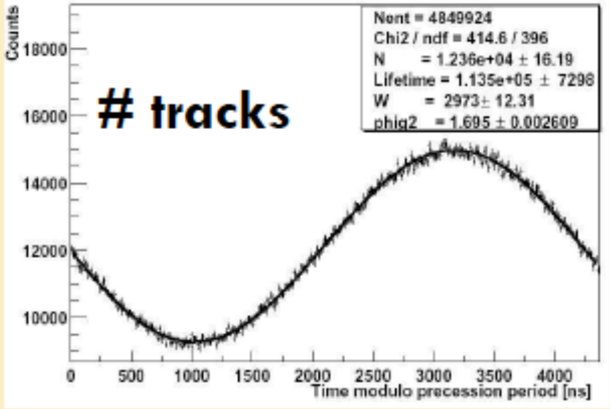
The error budget for a new experiment represents a continuation of improvements already made during E821

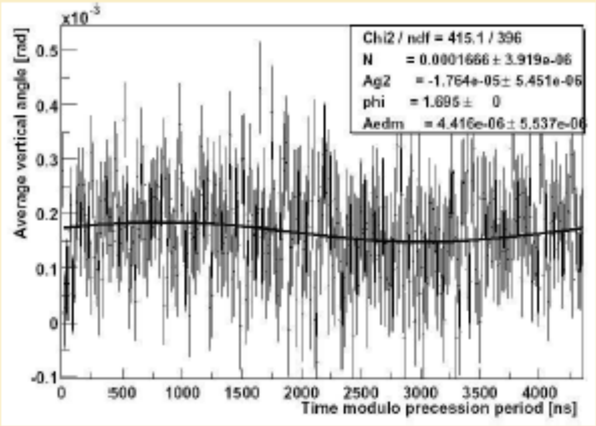
Systematic uncertainty (ppm)	E821 final	E989 Goal
Magnetic field – ω_p	0.17	0.07
Anomalous precession – ω_a	0.18	0.07

Statistical uncertainty (ppm)	0.46	0.1
Systematic uncertainty (ppm)	0.28	0.1
Total Uncertainty (ppm)	0.54	0.14

Muon EDM





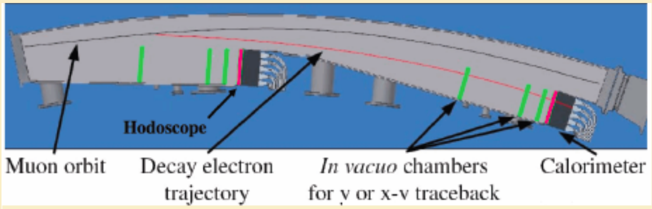


vertical angle of tracks

Precession plane tilted, vertical out of phase oscillation of ω_a

Current best limit from E821

$$|d_\mu| < 1.8 \times 10^{-19}\, e\ \mathrm{cm}\ (95\%\ \mathrm{C.L.})$$



Expect 10-30x better in new experiment

Muon anomaly as precision test of the SM

$$a_\mu = \frac{(g_\mu - 2)}{2}$$

- Long established discrepancy (>3σ) between SM prediction and BNL E821 exp.

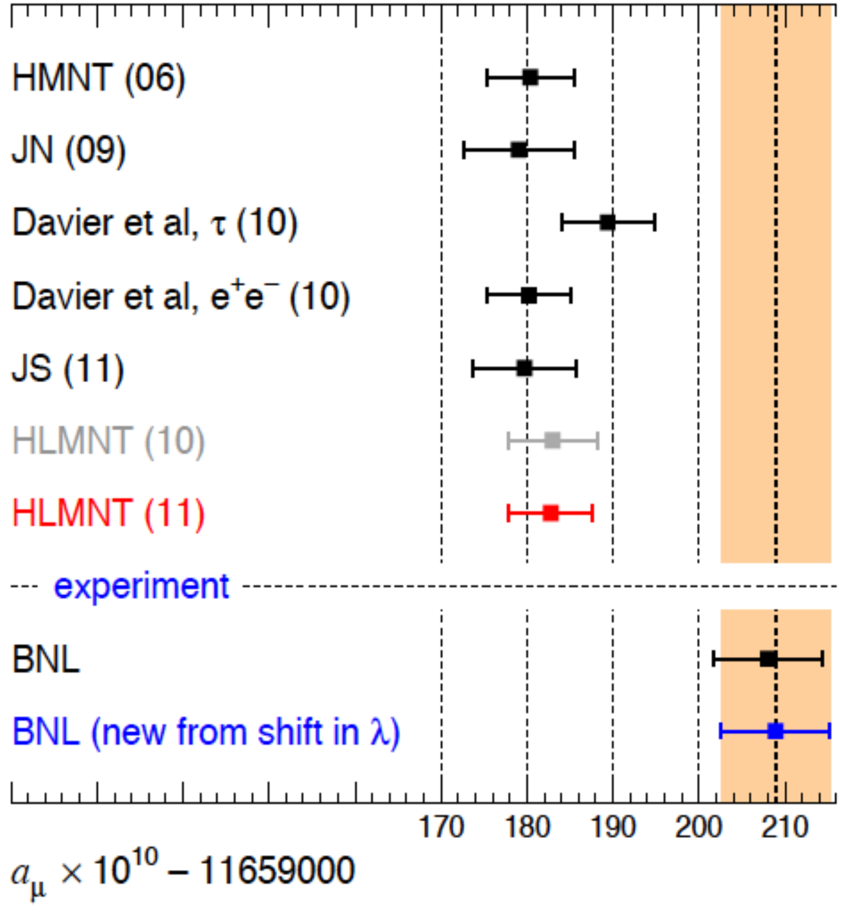
•A twofold improvement on $\delta a_\mu^{\text{TH-EXP}}$ from 2001 (thanks to BNL and new e^+e^- measurements)!

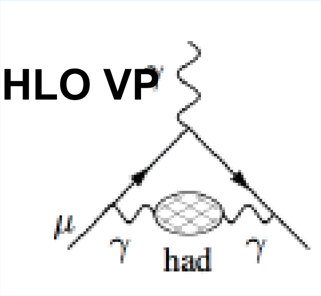
In 2001 a_μ^{EXP}-a_μ^{TH}=(23±16)•10^{-10}

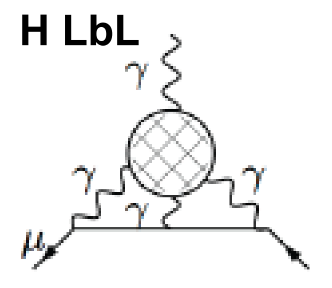
•Theoretical error δa_μ^{SM} (5÷6x10^{-10}) dominated by HLO VP (4÷5x10^{-10}) and HLbL (2.5÷4x10^{-10}).

•Experimental error δa_μ^{EXP} =6.3 x10^{-10} (0.54 ppm), E821. Plan to reduce it to 1.6 10^{-10} (0.14 ppm) by the new g-2 experiments at FNAL (E989) and J-PARC.

Hagiwara et al. arxiv:1105.3149







a_μ^{HLO} = (690.9±4.4)10^{-10}

[S.Eidelman, TAU08]

δa_μ^{HLO} ~0.6%

a_μ^{HLbL} =(10.5±2.6)10^{-10} [P. dR&V. 08]

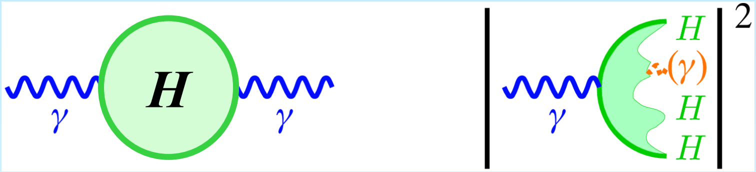
(11 ±4)10^{-10} (J.N.)

δa_μ^{HLbL} ~25-40%

$$a_\mu^{\rm EXP} - a_\mu^{\rm TH} = (27.6 \pm 8.1)\cdot 10^{-10}, \ \sim 3.4\sigma$$

a_μ^{HLO}:

L.O. Hadronic contribution to a_μ can be estimated by means of a dispersion integral



$$a_\mu^{had} = \left(\frac{\alpha\ m\mu}{3\pi}\right)^2 \int_{4\,m_\pi^2}^{\infty} ds\, \frac{R(s)\,\hat{K}(s)}{s^2}$$

1 / s^2 makes low energy contributions

$$e^+e^- \longrightarrow \pi^+\pi^-$$

especially important:

in the range < 1 GeV

contributes to 70% !

$$R(s) = \frac{\sigma_{tot}(e^+e^- \to \gamma^* \to q\,\bar{q} \to hadrons)}{\sigma_{tot}(e^+e^- \to \gamma^* \to \mu^+\mu^-)}$$

- K(s) = analytic kernel-function

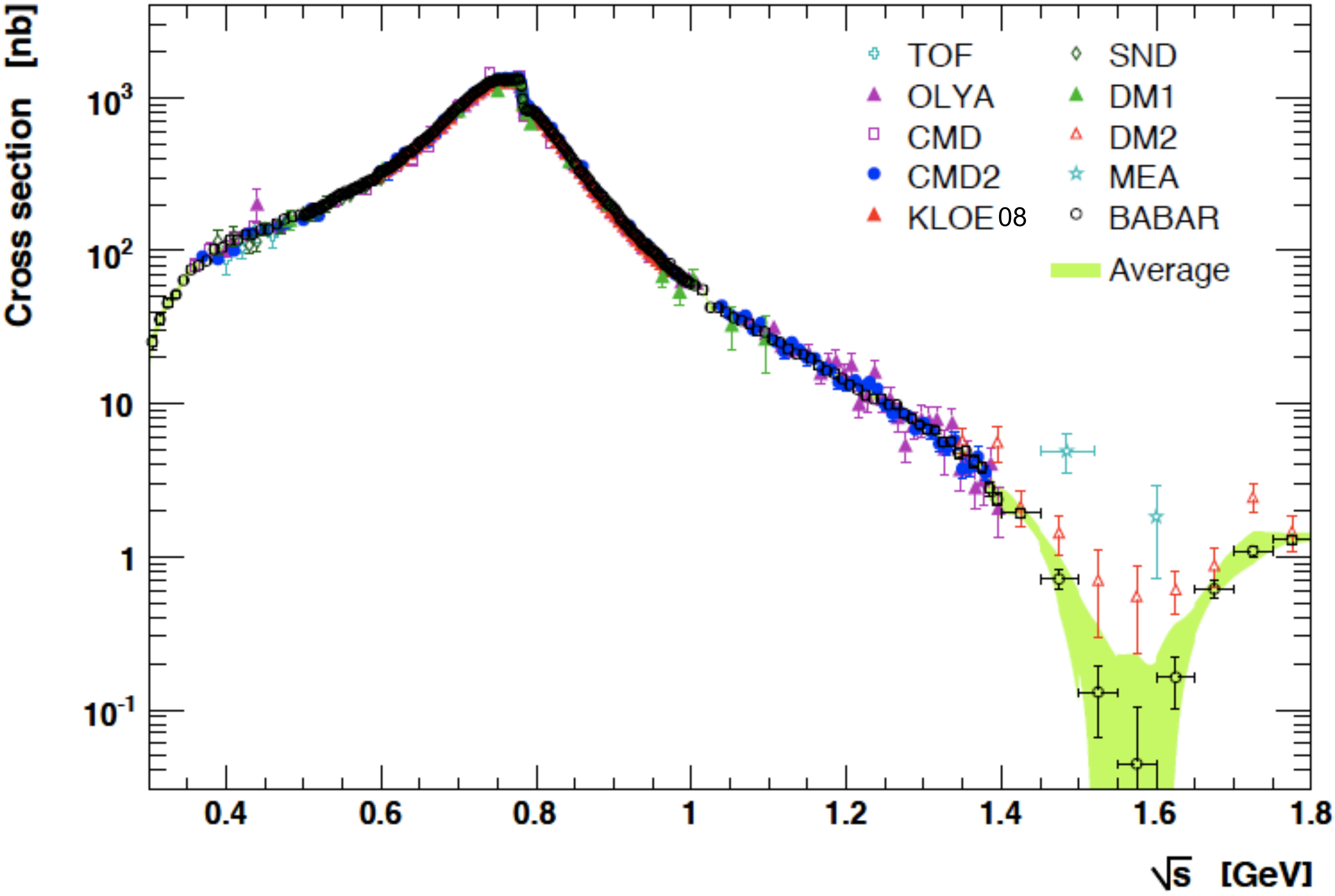
- above sufficiently high energy value, typically 2…5 GeV, use *pQCD*

Input:

a) hadronic electron-positron cross section data **(G.dR 69, E.J.95, A.D.H.'97,….)**

b) hadronic τ- decays, which can be used with the help of the CVC-theorem and an isospin rotation (plus isospin breaking corrections) **(A., D., H. '97)**

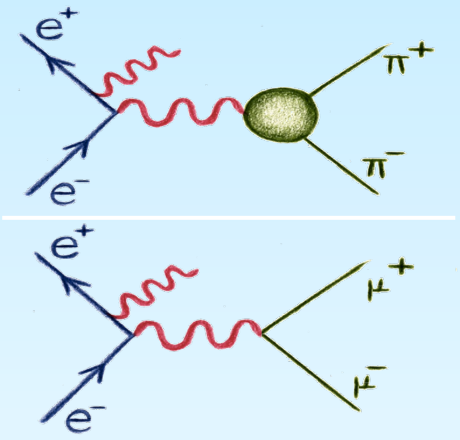
Measured Cross section for $e^+e^- \to \pi^+\pi^-$



New KLOE result on $e^+e^- \to \pi^+\pi^-$ by $\pi\pi\gamma/\mu\mu\gamma$ ratio (ISR)

An alternative way to obtain $|F_\pi|^2$ is the bin-by-bin ratio of pion over muon yields (as done by BaBar).

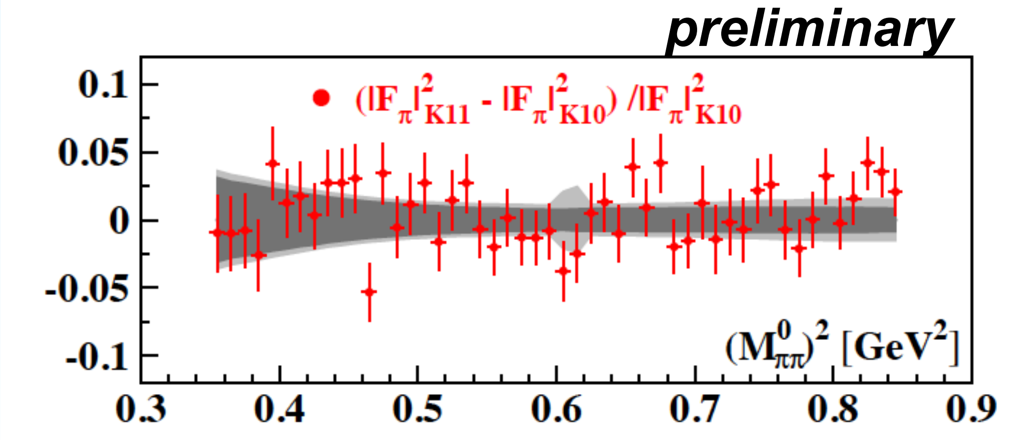
$$|F_\pi(s')|^2 \approx \frac{4\left(1+2m_\mu^2/s'\right)\beta_\mu}{\beta_\pi^3} \underbrace{\frac{d\sigma_{\pi\pi\gamma}/ds'}{d\sigma_{\mu\mu\gamma}/ds'}}_{\text{meas. quantities}}$$



Many radiative corrections drop out:

- *radiator function*
- *int. luminosity from Bhabhas*
- *Vacuum polarization*

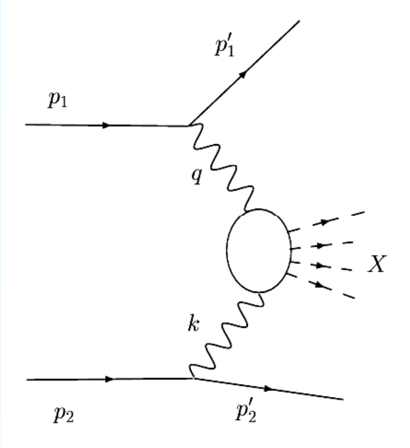
See Mandaglio's talk

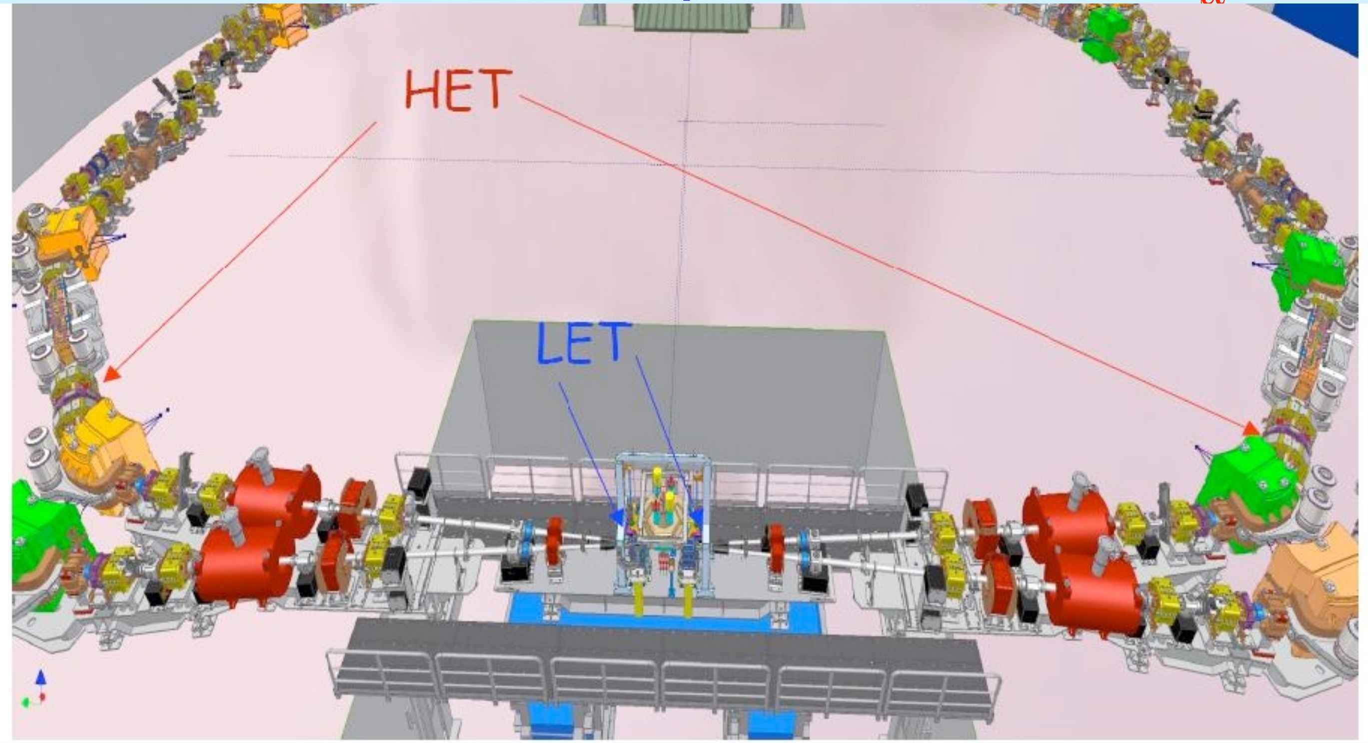


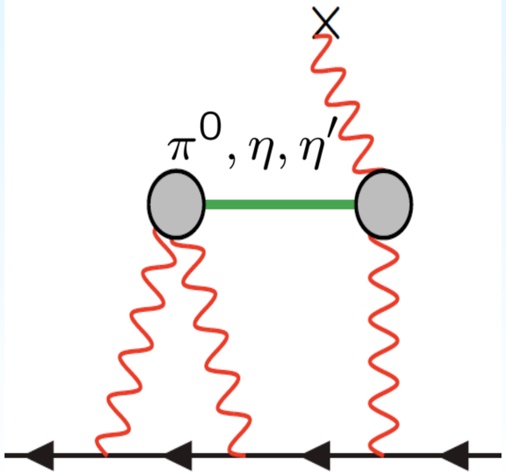
Good agreement with previous measurement!

KLOE-2 to measure $\gamma\gamma^* \rightarrow$ *hadrons* to constrain HLBL

- Constrain the on-shell amplitudes and remove a significant portion of the theoretical uncertainty on the HLBL
- A reasonable improvement on $a_\mu^{\pi 0}$



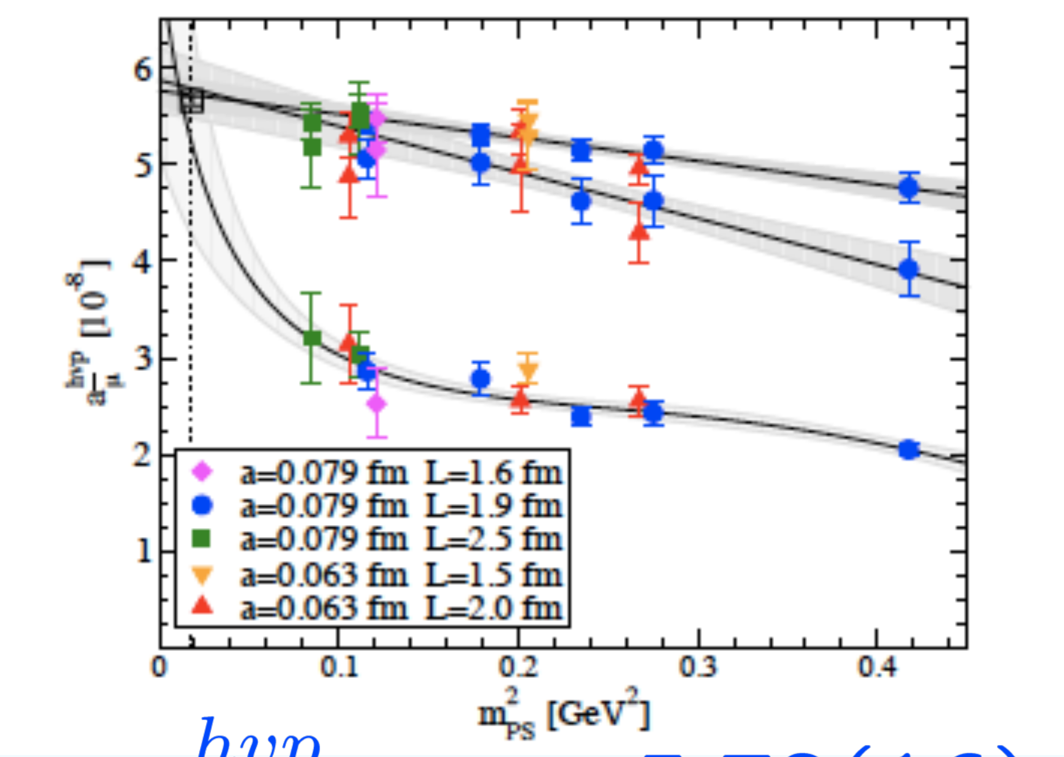




For more details see Moricciani's talk

What about the lattice?

- A new 2-3% lattice result for the lowest-order hadronic (u,d quarks only)contribution:



Very promising results!

Prospects for HLBL?

See Jansen's talk

$$a_{\mu,N_f=2}^{hvp} = 5.72(16) \times 10^{-8}$$

Feng, Jansen, Petschlies, Renner, arXiv:1103.4818v1 [hep-lat]

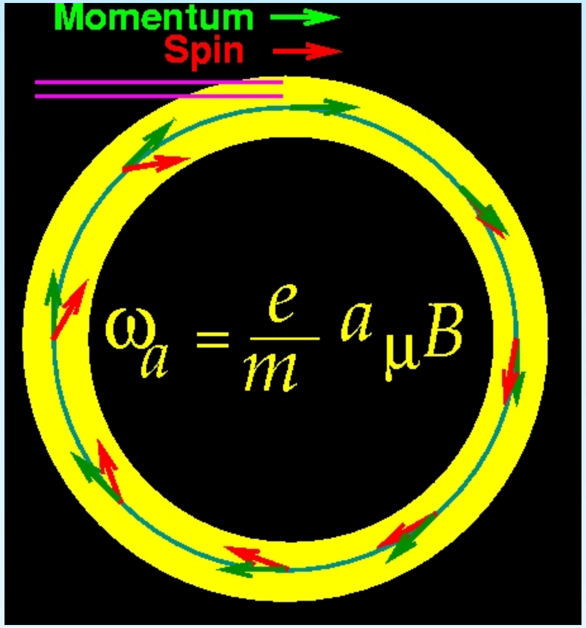
The a_μ Experiments:

- Place polarized muons in a B field
  - spin precession frequency (q = ± e)

$$\vec{\omega}_S = -g\frac{q\vec{B}}{2m} - \frac{q\vec{B}}{\gamma m}(1-\gamma)$$

  - cyclotron frequency

$$\vec{\omega}_C = -\frac{q\vec{B}}{m\gamma}$$



$$\vec{\omega}_a = \omega_S - \omega_C = -\frac{e}{m}a_\mu\vec{B}$$

Since g > 2, the spin gets ahead of the momentum

Spin Motion: Use Electric Field for Vertical Focusing

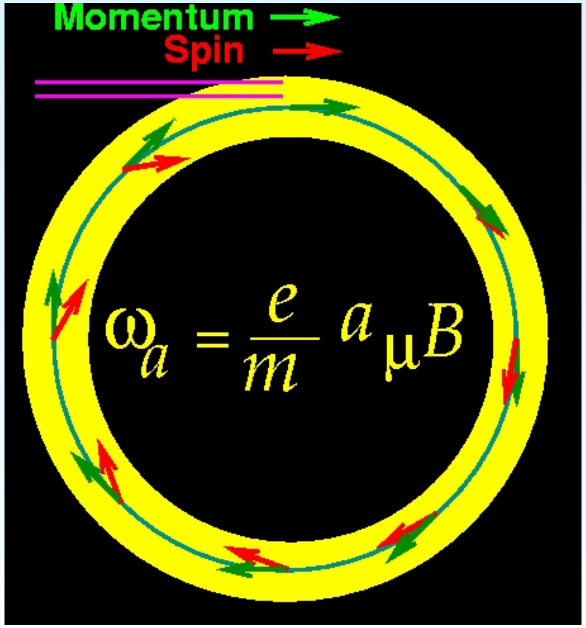
$$\begin{aligned}\vec{\omega}_a &= \omega_S - \omega_C \\ &= -\frac{q}{m}\left[a_\mu \vec{B} - \cancelto{0}{\left(a_\mu - \frac{1}{\gamma^2 - 1}\right)} \frac{\vec{\beta} \times \vec{E}}{c}\right]\end{aligned}$$

$\gamma_{\text{magic}} = 29.3$

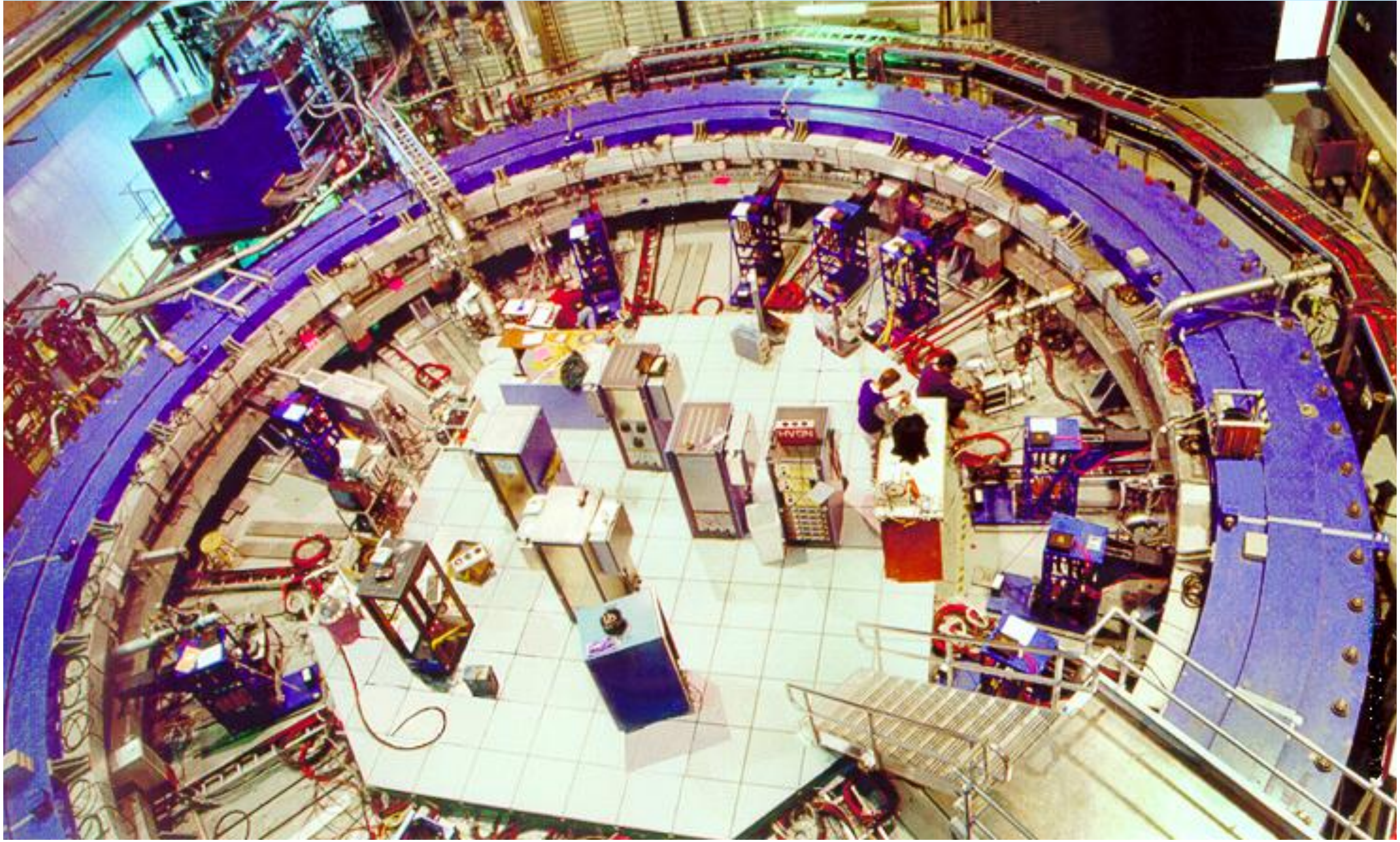
$p_{\text{magic}} = 3.09\ \text{GeV/c}$

Electrostatic quadrupoles cover 43% of ring

Small (< 1ppm) correction for muons not at the magic γ.



Muon (g-2) storage ring to be relocated to FNAL



The error budget for a new experiment represents a continuation of improvements already made during E821

Systematic uncertainty (ppm)	1998	1999	2000	2001	E821 final	P989 Goal
Magnetic field – w_p	0.5	0.4	0.24	0.17		0.07
Anomalous precession – w_a	0.8	0.3	0.31	0.21		0.07
Statistical uncertainty (ppm)	4.9	1.3	0.62	0.66	0.46	0.1
Systematic uncertainty (ppm)	0.9	0.5	0.39	0.28	0.28	0.1
Total Uncertainty (ppm)	5.0	1.3	0.73	0.72	0.54	0.14

Summary (g-2)

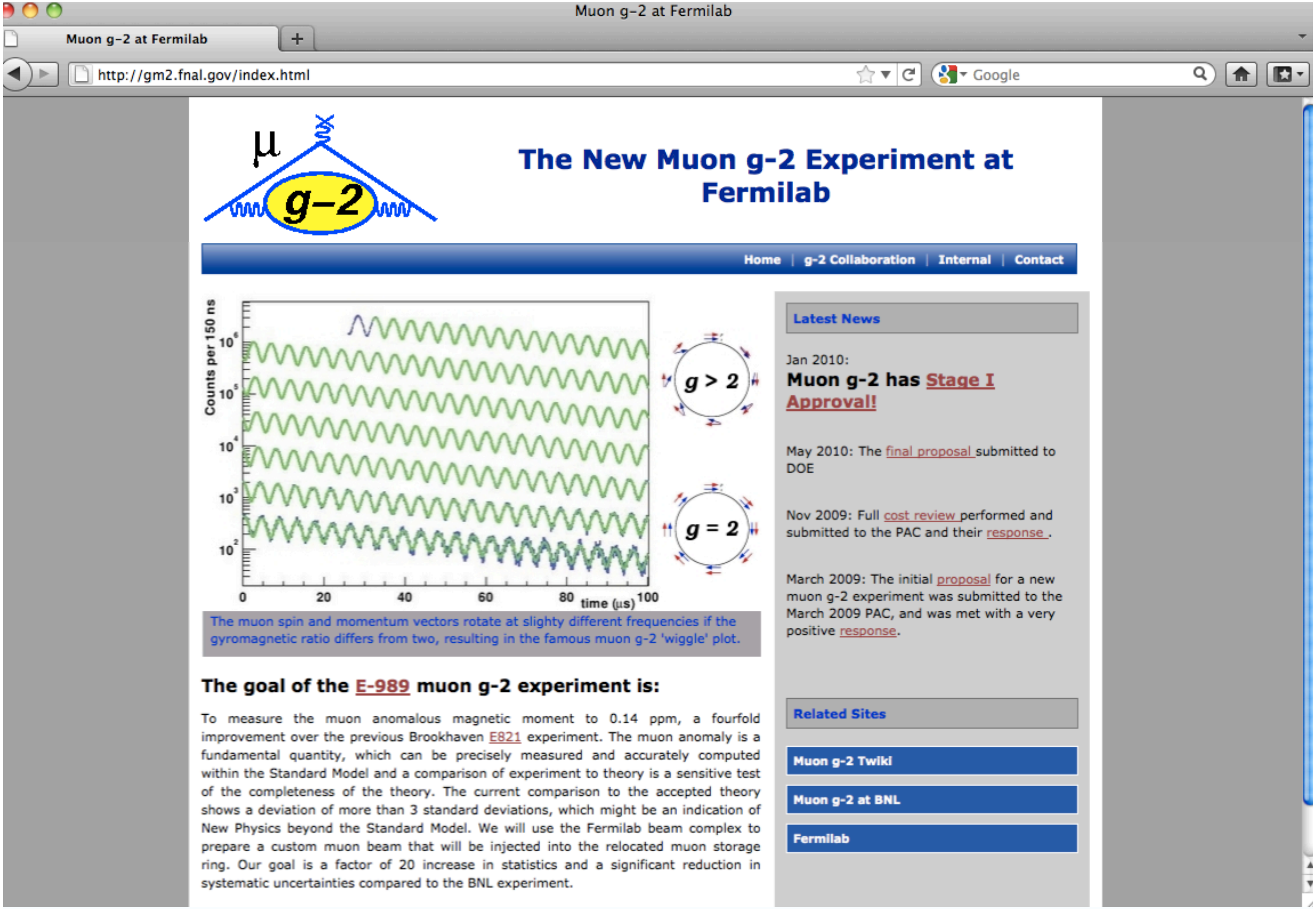
- The measurements of $e^{\pm}$ and $\mu^{\pm}$ magnetic dipole moments have been important benchmarks for the development of QED and the Standard Model.
- At present there appears to be a > 3 σ difference between a_{μ} and the SM prediction.
  - if confirmed it would fit well with SUSY expectations, but LHC data will play a role in the interpretation.
- A worldwide effort continues to improve the SM value.
- a_{μ} has been particularly valuable in restricting physics beyond the standard model. It will continue that role in guiding the interpretation of the LHC data.
- The Fermilab experiment, E989, will improve the error on a_{μ} by a factor of ≥4.
- First results could be available around 2017/18

Goal is to be ready for data in 2016 with the magnet shimmed

We expect CD0 this fall/Winter

– Conceptual Design Report being prepared

- FY2011 Funding began this June
- FY12 and beyond is being discussed between DOE and Fermilab



The New Muon g-2 Experiment at Fermilab

The muon spin and momentum vectors rotate at slighty different frequencies if the gyromagnetic ratio differs from two, resulting in the famous muon g-2 'wiggle' plot.

The goal of the E-989 muon g-2 experiment is:

To measure the muon anomalous magnetic moment to 0.14 ppm, a fourfold improvement over the previous Brookhaven E821 experiment. The muon anomaly is a fundamental quantity, which can be precisely measured and accurately computed within the Standard Model and a comparison of experiment to theory is a sensitive test of the completeness of the theory. The current comparison to the accepted theory shows a deviation of more than 3 standard deviations, which might be an indication of New Physics beyond the Standard Model. We will use the Fermilab beam complex to prepare a custom muon beam that will be injected into the relocated muon storage ring. Our goal is a factor of 20 increase in statistics and a significant reduction in systematic uncertainties compared to the BNL experiment.

Latest News

Jan 2010:

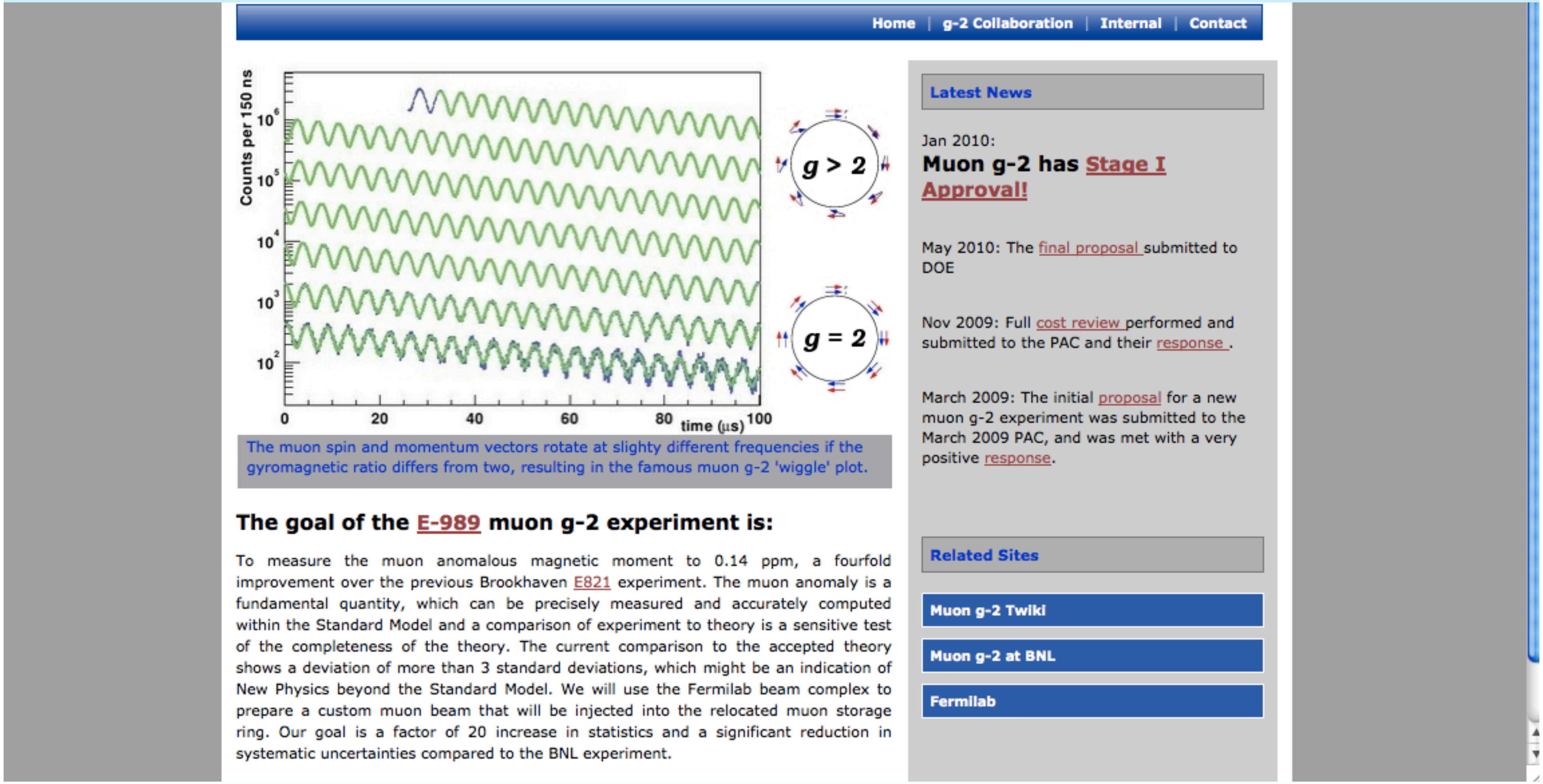
Muon g-2 has Stage I Approval!

May 2010: The final proposal submitted to DOE

Nov 2009: Full cost review performed and submitted to the PAC and their response .

March 2009: The initial proposal for a new muon g-2 experiment was submitted to the March 2009 PAC, and was met with a very positive response.

G. Venanzoni for the New G-2 Collaboration,



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Related Sites

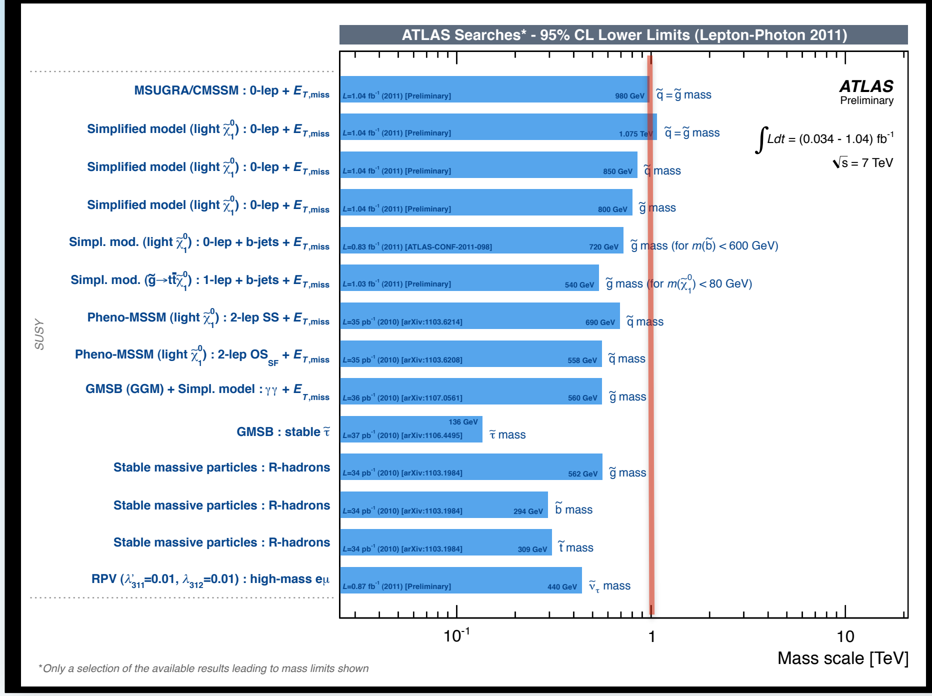
G. Venanzoni for the New G-2 Collaboration,

What could a $\Delta a_\mu \approx 30\times10^{-10}$ Deviation Tell Us?

Amount of discrepancy in ballpark of SUSY with mass scale of several 100 GeV

Δa_μ^{SUSY} $+13\cdot10^{-10}$

But strong m_{SUSY} limits from LHC require large tanβ

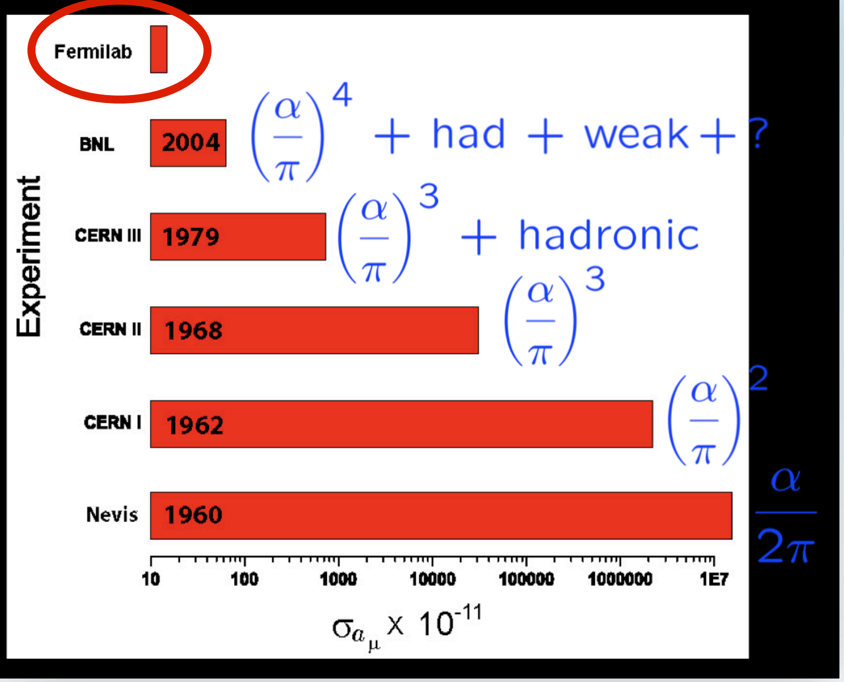


*Only a selection of the available results leading to mass limits shown

Proposals for new experiments E989 at FNAL (similar technique as E821) and at J-PARC (new: ultra-slow muons) with target of σ ~ 1.6 10^{-10}

Final E989 proposall:
http://gm2.fnal.gov/public_docs/proposals/Proposal-APR5-Final.pdf

LOI: KEK_J-PARC-PAC2009-06
See also, e.g., Naohito SAITO (KEK), Seminar at DESY 2011



$\left(\frac{\alpha}{\pi}\right)^4 + \text{had} + \text{weak} + ?$

$\left(\frac{\alpha}{\pi}\right)^3 + \text{hadronic}$

$\left(\frac{\alpha}{\pi}\right)^3$

$\left(\frac{\alpha}{\pi}\right)^2$

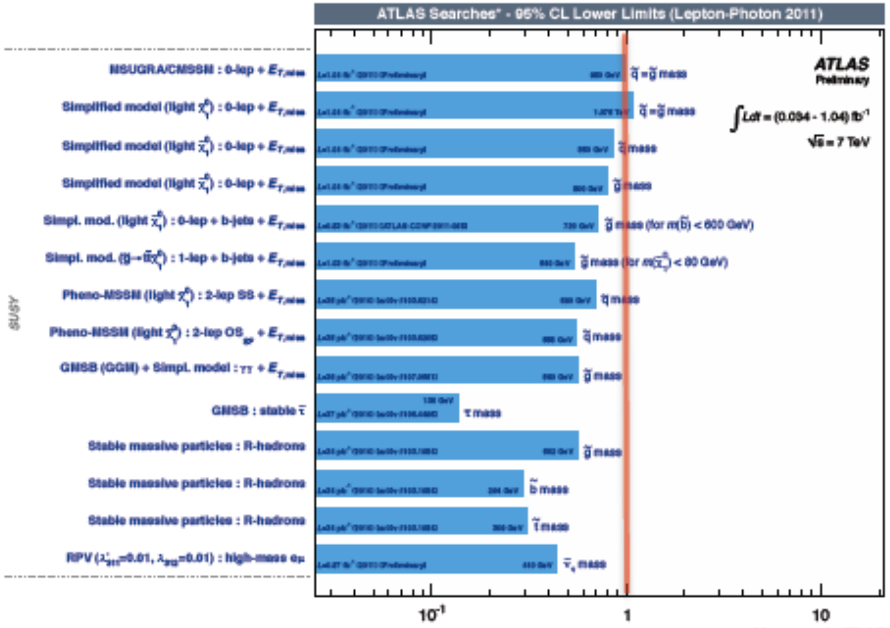
$\frac{\alpha}{2\pi}$

What could a $\Delta a_\mu \approx 30\times10^{-10}$ Deviation Tell Us?

Amount of discrepancy in ballpark of SUSY with mass scale of several 100 GeV

$$\Delta a_\mu^{\text{SUSY}} \approx +13\cdot10^{-10}\,\text{sgn}(\mu)\left(\frac{100\text{ GeV}}{m_{\text{SUSY}}}\right)^2\tan\beta$$

But strong m_{SUSY} limits from LHC require large $\tan\beta$



*Only a selection of the available results leading to mass limits shown

Alternative recent scenario involves "dark photons"

→ Light vector boson from dark matter sector coupling to SM through mixing with photon

Coupling to charged particles with strength **$\varepsilon\cdot e$**

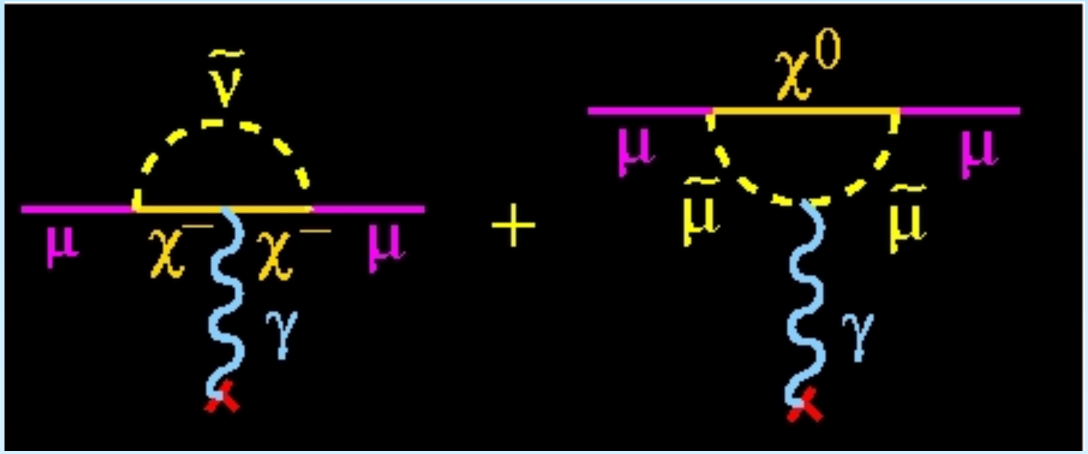
$$\Delta a_\mu^{\text{dark }\gamma} \approx \frac{\alpha}{2\pi}\varepsilon^2\cdot F\left(\frac{m_{\text{dark }\gamma}}{m_\mu}\right)$$

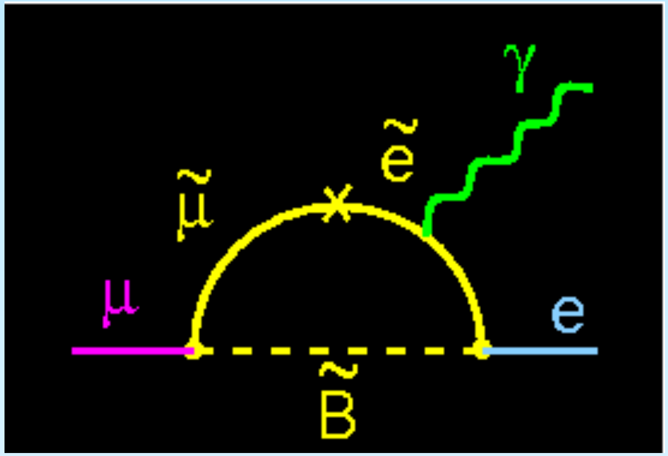
which, for ε ≈ 0.001–0.002 and $m_{\text{dark }\gamma} \approx$ 10–100 MeV, can provide a solution for the discrepancy

Searches for the dark photon in that mass range are currently underway at Jefferson Lab, USA, and MAMI in Mainz, Germany

Pospelov, PRD 80, 095002 (2009)
Tucker-Smith and Yavin, PRD 83, 101702 (2011)

a_μ is sensitive to a wide range of new physics, e.g.SUSY





$$a_\mu(\mathrm{SUSY}) \simeq (\mathrm{sgn}\mu)\, 130\times10^{-11}\, \tan\beta \left(\frac{100\ \mathrm{GeV}}{\tilde{m}}\right)^2$$

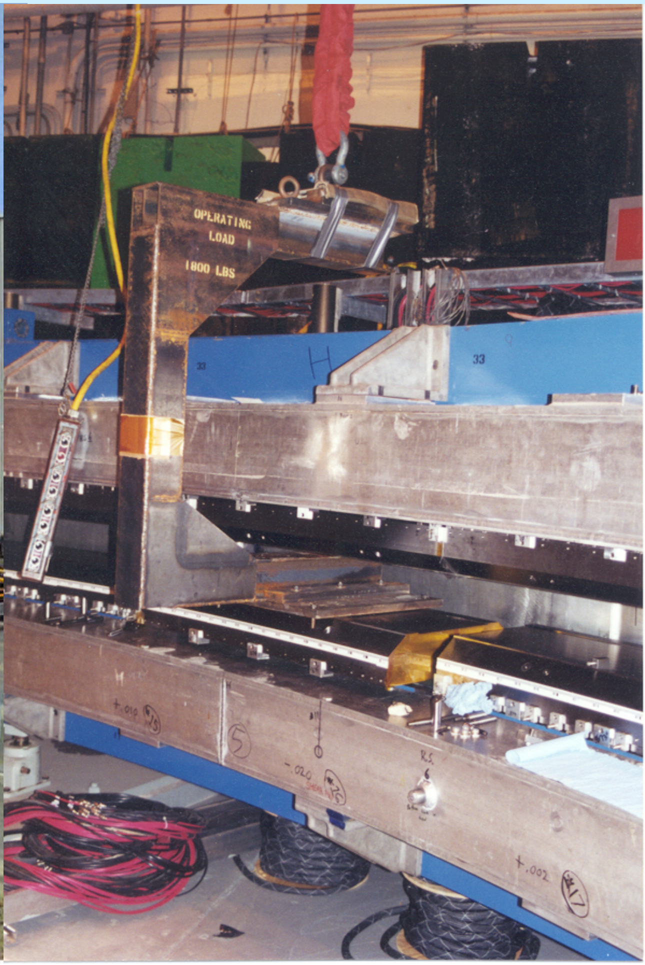
difficult to measure at LHC

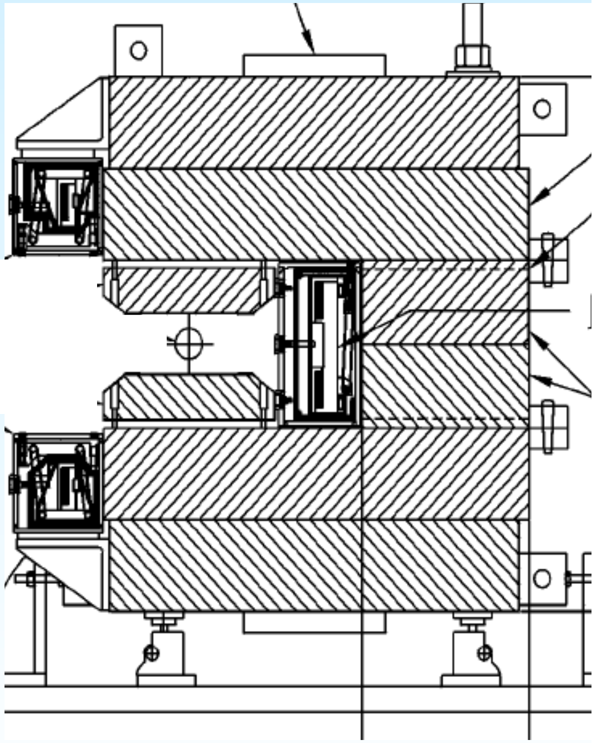
Related processes in SUSY

$$\mu^+ \to e^+\gamma;\ \ \mu^- + \mathcal{N} \to e^- + \mathcal{N}$$

Ring relocation to Fermilab

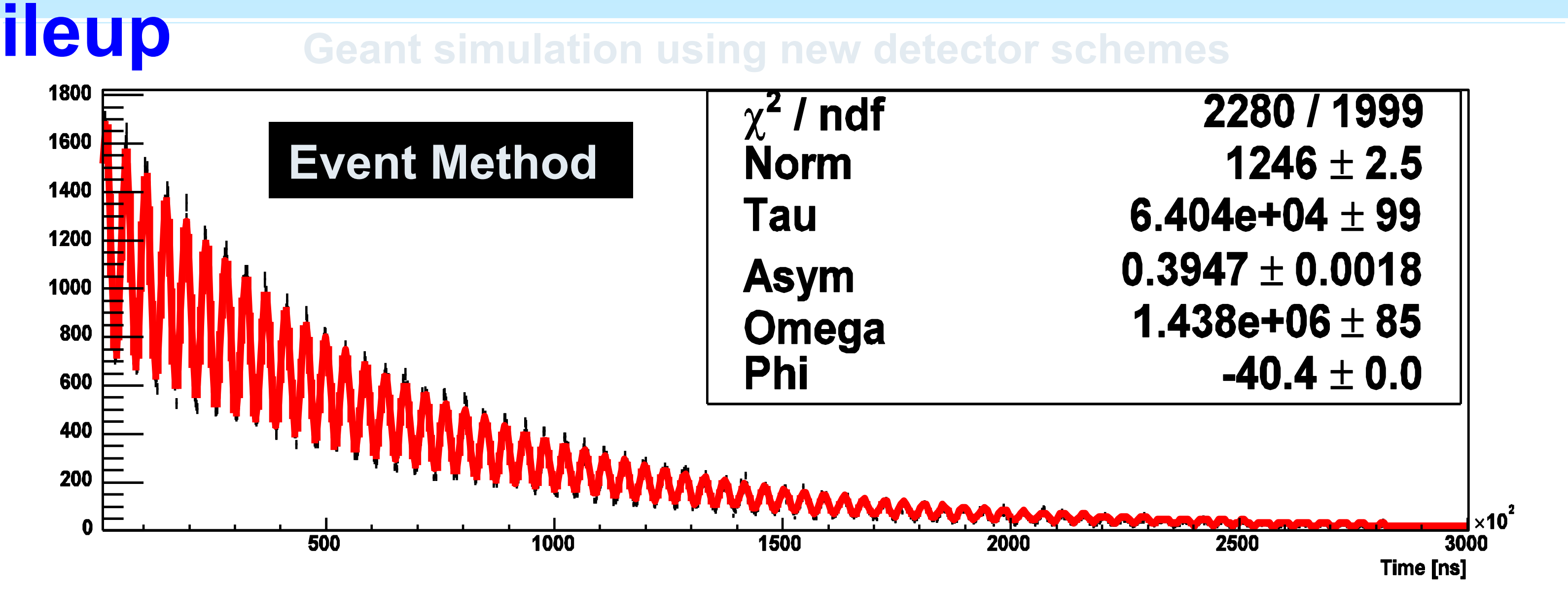
- Heavy-lift helicopters bring coils to a barge
- Rest of magnet is a “kit” that can be trucked to and from the barge



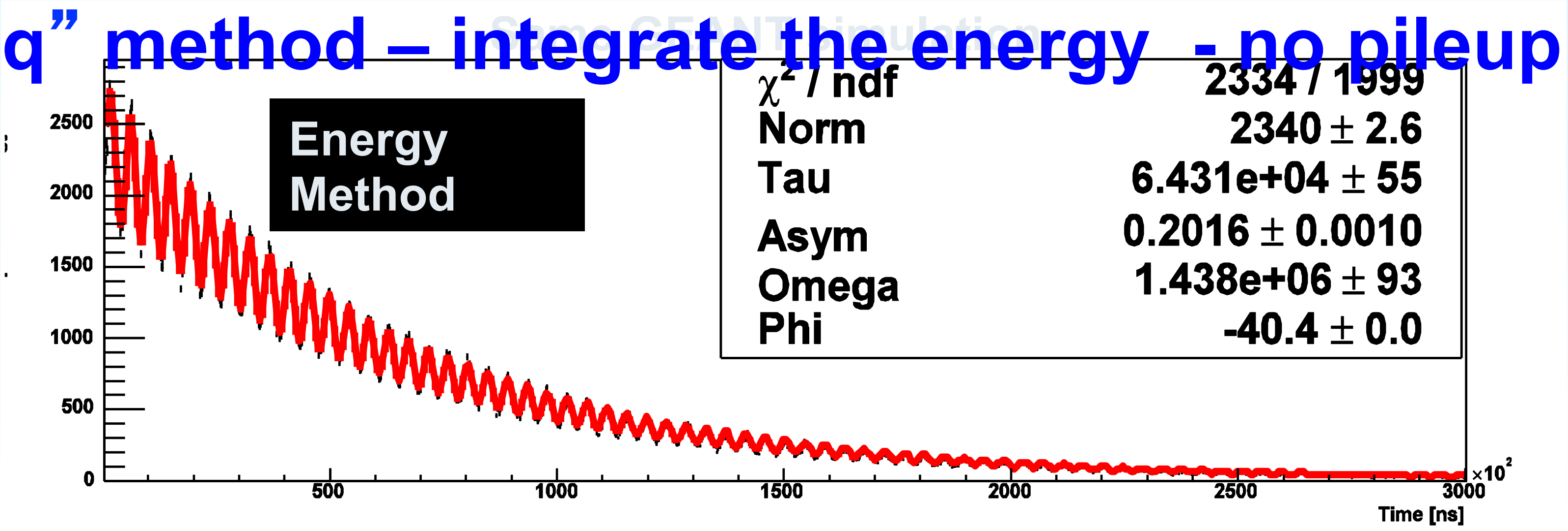


Complementary ways to collect data

- “t” method – time and energy of each event - pileup

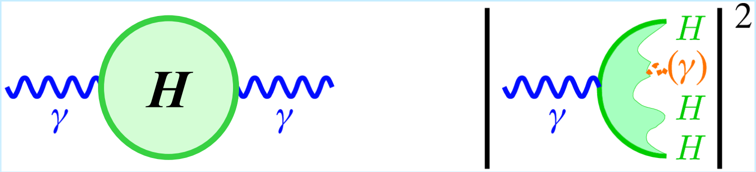


- “q” method – integrate the energy - no pileup



a_μ^{HLO}:

L.O. Hadronic contribution to a_μ can be estimated by means of a dispersion integral



$$a_\mu^{had} = \left(\frac{\alpha\ m\mu}{3\pi}\right)^2 \int_{4\,m_\pi^2}^{\infty} ds \frac{R(s)\,\hat{K}(s)}{s^2}$$

1 / s^2 makes low energy contributions

$e^+e^- \to \pi^+\pi^-$ ortant:

in the range < 1 GeV

contributes to 70% !

$$R(s) = \frac{\sigma_{tot}(e^+e^- \to \gamma^* \to q\,\bar{q} \to hadrons)}{\sigma_{tot}(e^+e^- \to \gamma^* \to \mu^+\mu^-)}$$

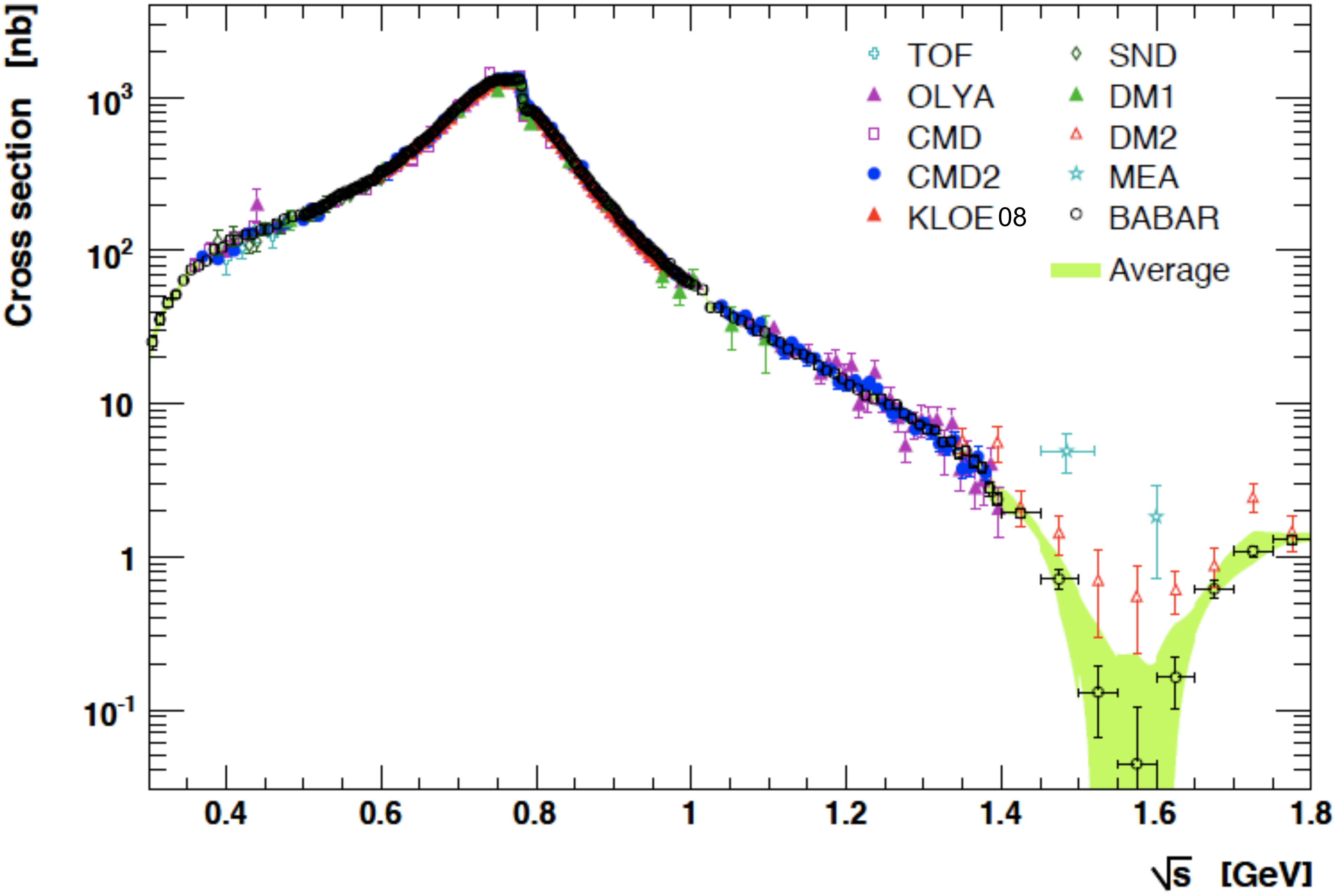
- K(s) = analytic kernel-function
- above sufficiently high energy value, typically 2…5 GeV, use *pQCD*

Input:

a) hadronic electron-positron cross section data (G.dR 69, E.J.95, A.D.H.'97,….)

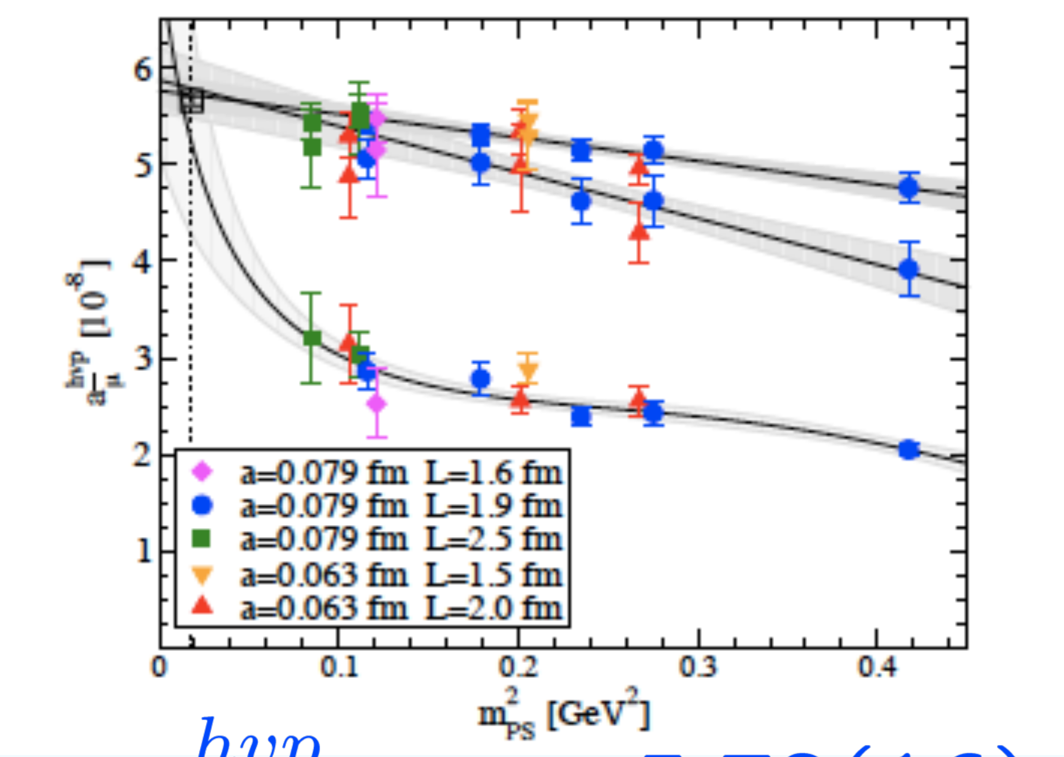
b) hadronic τ- decays, which can be used with the help of the CVC-theorem and an isospin rotation (plus isospin breaking corrections) (A., D., H. '97)

Measured Cross section for $e^+e^- \rightarrow \pi^+ \pi^-$



What about the lattice?

- At the INT Workshop on the Hadronic Light-by-Light contribution in February, Karl Jansen presented a new 2-3% lattice result for the lowest-order hadronic (u,d quarks only)

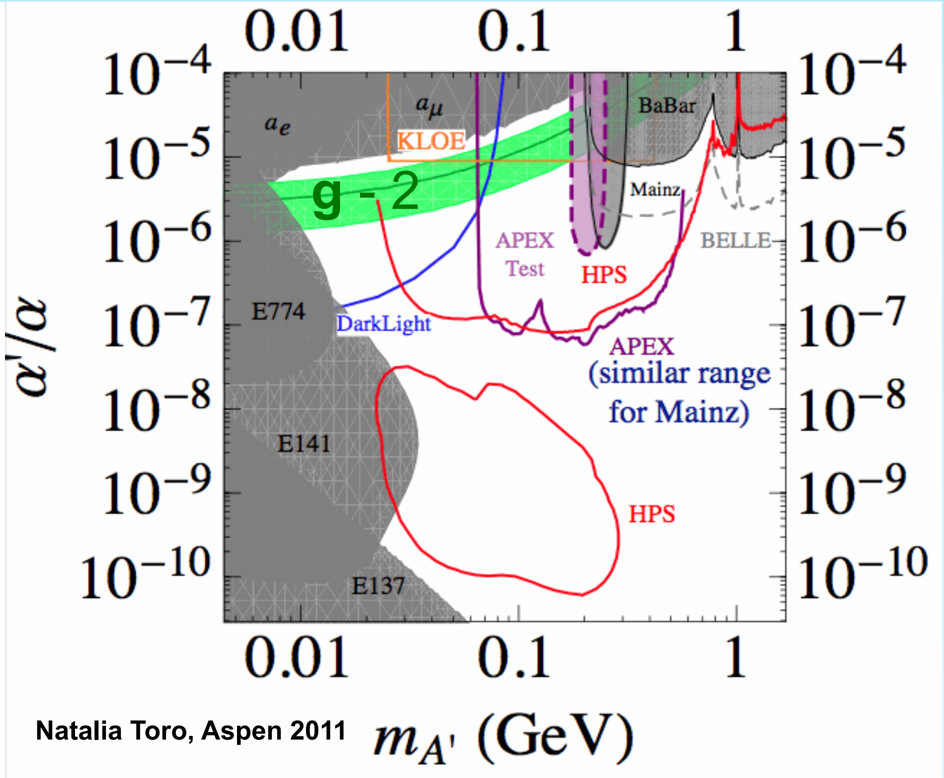


We can look forward to results from the other lattice groups!

$$a_{\mu,N_f=2}^{hvp} = 5.72(16) \times 10^{-8}$$

Feng, Jansen, Petschlies, Renner, arXiv:1103.4818v1 [hep-lat]

Other Models



Natalia Toro, Aspen 2011

- Technicolor
  - small Δa_μ
- Littlest Higgs with T-parity
  - small Δa_μ
- Universal Extra Dimensions
  - small Δa_μ
- Randall Sundrum
  - could accommodate large Δa_μ
- Two Higgs doublets, shadow Higgs
  - small Δa_μ
- Additional light bosons that can affect EM interactions (difficult to study at LHC)
  - secluded U(1),etc., could have significant Δa_μ

The error budget for a new experiment represents a continuation of improvements already made during E821

Systematic uncertainty (ppm)	1998	1999	2000	2001	E821 final	P989 Goal
Magnetic field – w_p	0.5	0.4	0.24	0.17		0.07
Anomalous precession – w_a	0.8	0.3	0.31	0.21		0.07

Statistical uncertainty (ppm)	4.9	1.3	0.62	0.66	0.46	0.1
Systematic uncertainty (ppm)	0.9	0.5	0.39	0.28	0.28	0.1
Total Uncertainty (ppm)	5.0	1.3	0.73	0.72	0.54	0.14

Systematic errors on ω_a (ppm)

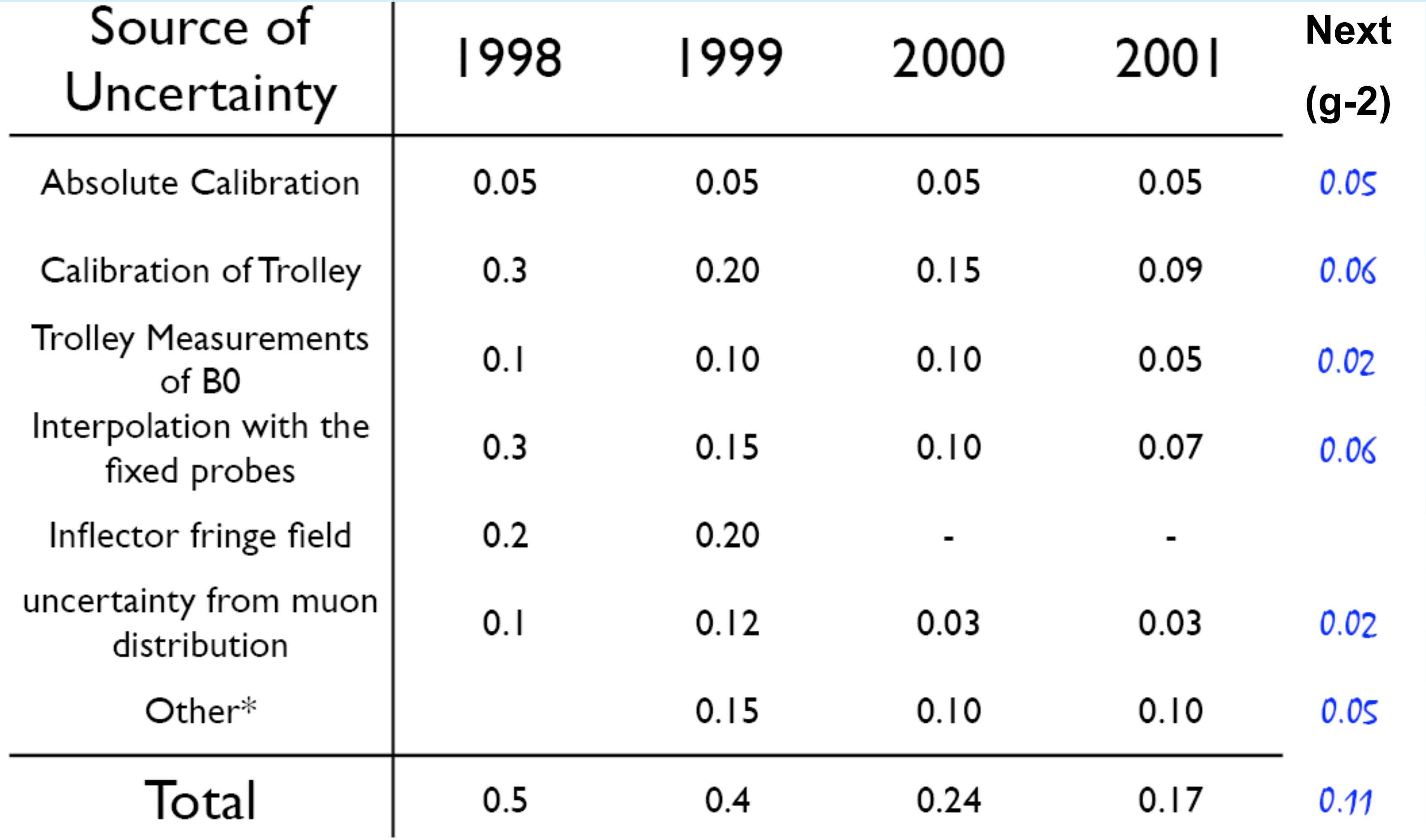
$\sigma_{systematic}$	1999	2000	2001	Future
Pile-up	0.13	0.13	0.08	0.04
AGS Background	0.10	0.10	0.015*	
Lost Muons	0.10	0.10	0.09	0.02
Timing Shifts	0.10	0.02	0.02	
E-Field, Pitch	0.08	0.03	0.06*	0.03
Fitting/Binning	0.07	0.06	0.06*	
CBO	0.05	0.21	0.07	0.04
Beam Debunching	0.04	0.04	0.04*	
Gain Change	0.02	0.13	0.13	0.02
total	0.3	0.31	0.21	~0.07

better with Fermilab beam structure and improved detectors/electronics

Σ* = 0.11

The Precision Field: Systematic errors

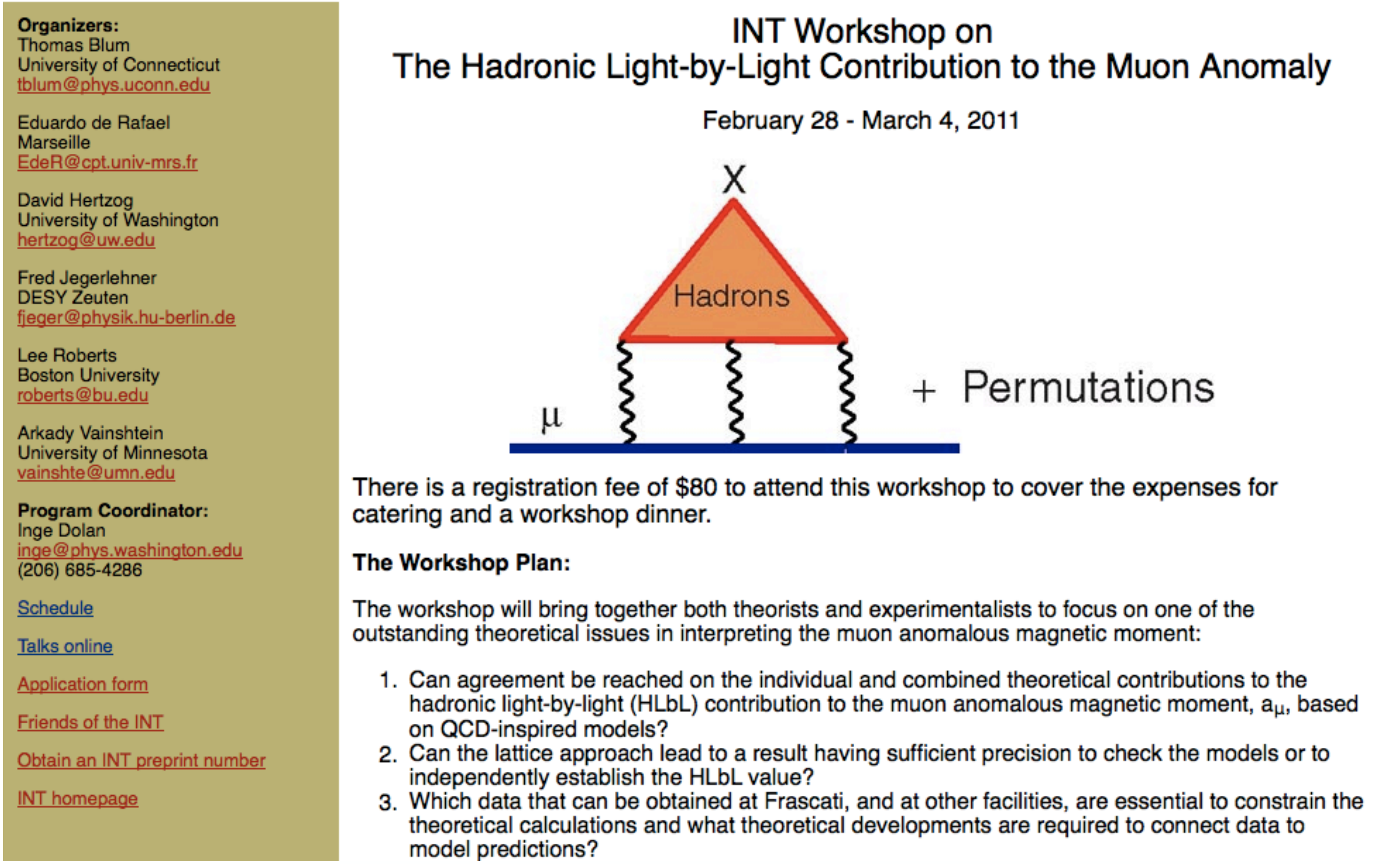
- Why is the error 0.11 ppm?
  - That’s with *existing* knowledge and experience
    - with R&D defined in proposal, it will get better



Source of Uncertainty	1998	1999	2000	2001	**Next (g-2)**
Absolute Calibration	0.05	0.05	0.05	0.05	0.05
Calibration of Trolley	0.3	0.20	0.15	0.09	0.06
Trolley Measurements of B0	0.1	0.10	0.10	0.05	0.02
Interpolation with the fixed probes	0.3	0.15	0.10	0.07	0.06
Inflector fringe field	0.2	0.20	-	-	
uncertainty from muon distribution	0.1	0.12	0.03	0.03	0.02
Other*		0.15	0.10	0.10	0.05
Total	0.5	0.4	0.24	0.17	0.11

Hadronic Light-by-Light Contribution

see: http://www.int.washington.edu/PROGRAMS/11-47w/



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Schedule

Talks online

Application form

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INT Workshop on
The Hadronic Light-by-Light Contribution to the Muon Anomaly

February 28 - March 4, 2011

There is a registration fee of $80 to attend this workshop to cover the expenses for catering and a workshop dinner.

The Workshop Plan:

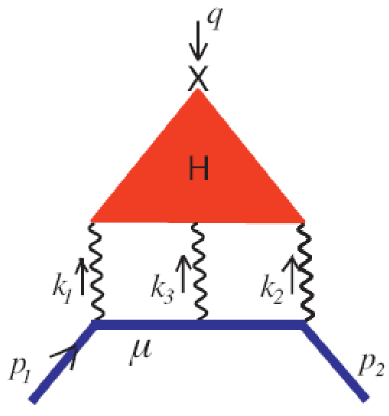
The workshop will bring together both theorists and experimentalists to focus on one of the outstanding theoretical issues in interpreting the muon anomalous magnetic moment:

1. Can agreement be reached on the individual and combined theoretical contributions to the hadronic light-by-light (HLbL) contribution to the muon anomalous magnetic moment, a_μ, based on QCD-inspired models?
2. Can the lattice approach lead to a result having sufficient precision to check the models or to independently establish the HLbL value?
3. Which data that can be obtained at Frascati, and at other facilities, are essential to constrain the theoretical calculations and what theoretical developments are required to connect data to model predictions?

Hadronic Light–by–Light Scattering Contribution to the Muon Anomalous Magnetic Moment

arXiv:0901.0306v1

Joaquim Prades[a], Eduardo de Rafael[b] and Arkady Vainshtein[c]



$$a^{\rm HLbL}(\pi\,,\eta\,,\eta') = (11.4 \pm 1.3) \times 10^{-10}$$

$$a^{\rm HLbL}({\rm scalars}) = -(0.7 \pm 0.7) \times 10^{-10}$$

$$a^{\rm HLbL}(\pi{-}{\rm dressed\ loop}) = -(1.9 \pm 1.9) \times 10^{-10}$$

$$a^{\rm HLbL}({\rm pseudovectors}) = (1.5 \pm 1) \times 10^{-10}$$

Dynamical models with QCD behavior

$$a_\mu^{\rm HLBL} = 105\ (26) \times 10^{-11}$$

Note, with Δa_μ = 295 x 10^{-11} … If HLBL is the source of the difference with SM, it would need to increase by 11 σ ….

The π^0 (Goldstone) contribution fixes sign of the contribution **From χpt and large N_c QCD**

$$a_\mu^{[\chi pt]} = \left(\frac{\alpha}{\pi}\right)^3 \left\{ \frac{N_c^2}{48\pi^2}\frac{m_\mu^2}{F_\pi^2}\ln^2\left(\frac{\mu}{m}\right) + \mathcal{O}\left[\ln\left(\frac{\mu}{m}\right) + \kappa(\mu)\right]\right\}$$

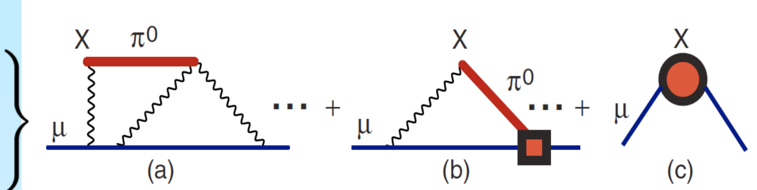
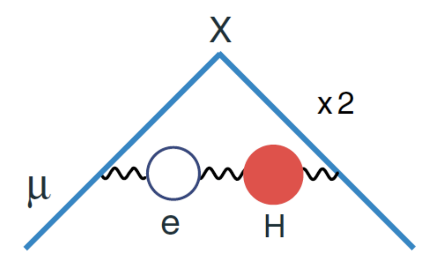
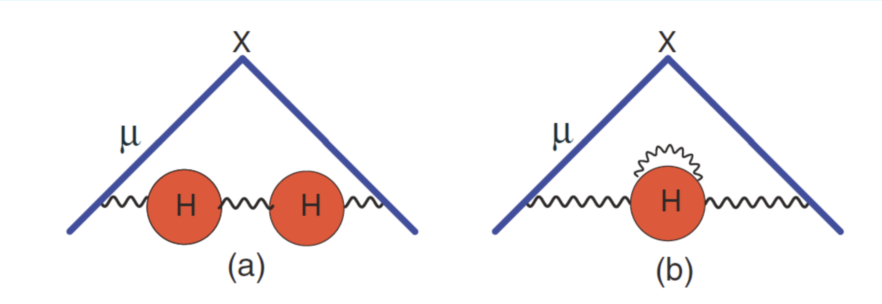


Figure 53. One Goldstone reducible diagrams in chiral perturbation theory.

Examples of other 3-loop hadronic contributions:



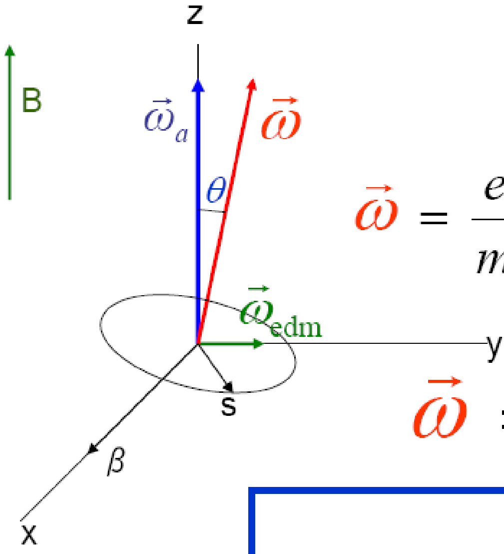


$$a_\mu^{H6} = -97.9\ (.9) \times 10^{-11}$$

- The magnitude of the HLBL is about the same as the magnitude of the 3-loop HVP which can be calculated from the dispersion relation.
- It's hard to believe that the HLBL would be huge compared to the other 3-loop contributions.

EDMs in Storage Rings: E821@ BNL

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



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

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

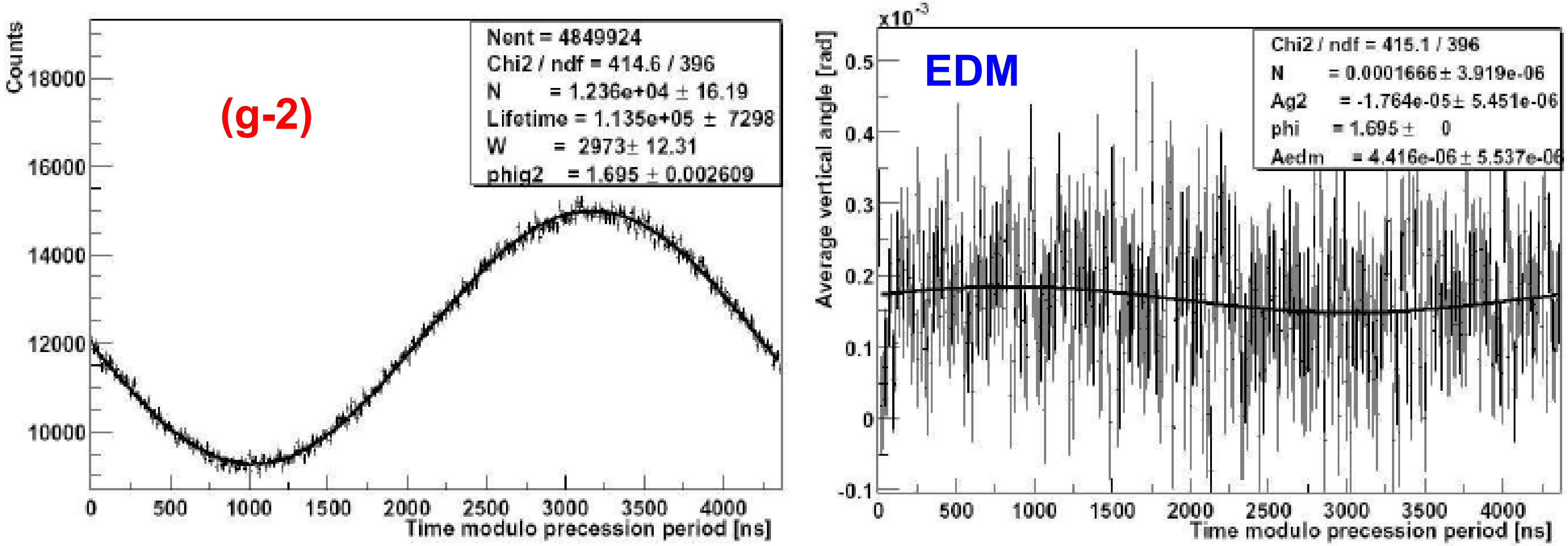
$$\boxed{\tan\theta = \frac{\omega_{edm}}{\omega_a}}$$

$$\vec{d} = \eta\left(\frac{Qe}{2mc}\right)\vec{s}$$

$$\omega_{\rm edm} <<<<<< \omega_{\rm a}$$

Muon EDM in the BNL E821 Storage Ring

E821 Data



Vertical Oscillation out of phase with ω_a

$$N^{\pm}(t) \propto 1 + A_\mu \cos(\omega t + \phi) \mp A_{EDM} \sin(\omega t + \phi)$$

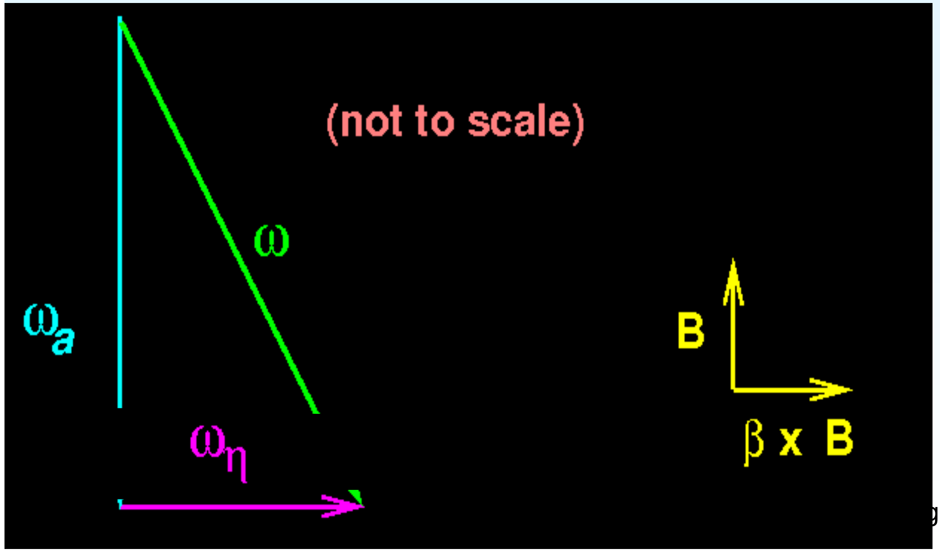
$$d_\mu < 1.8 \times 10^{-19} \text{ (95\% CL)}$$

How do we get rid of the (g - 2) signal?

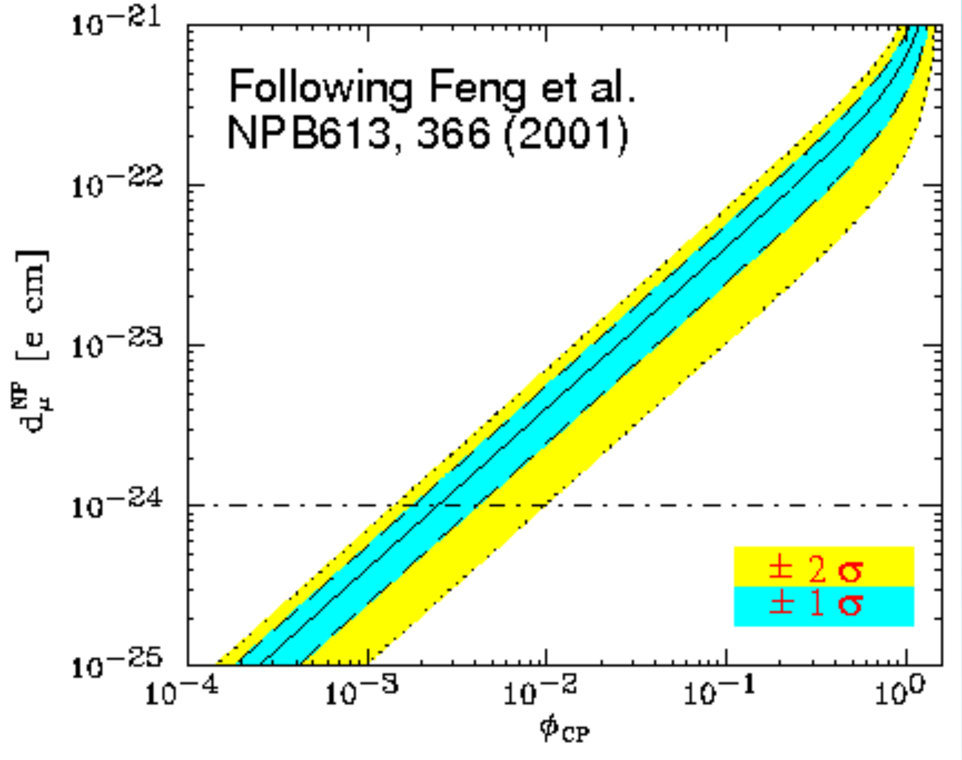
- Y. Semertzidis idea of the “frozen spin”
  - Use a radial **E** field to turn off the ω_a precession

$$\vec{\omega} = -\frac{e}{m}\cancelto{0}{\left[a_\mu \vec{B} - \left(a_\mu - \frac{1}{\gamma^2 - 1}\right)\frac{\vec{\beta}\times\vec{E}}{c}\right]}$$

$$+\frac{e}{m}\left[\frac{\eta}{2}\left(\frac{\vec{E}}{c} + \vec{\beta}\times\vec{B}\right)\right]$$



a_μ implications for the muon EDM assuming same New Physics participates **(recall that (Δ^{today}=255(80) X10^{-11})**



Assuming that

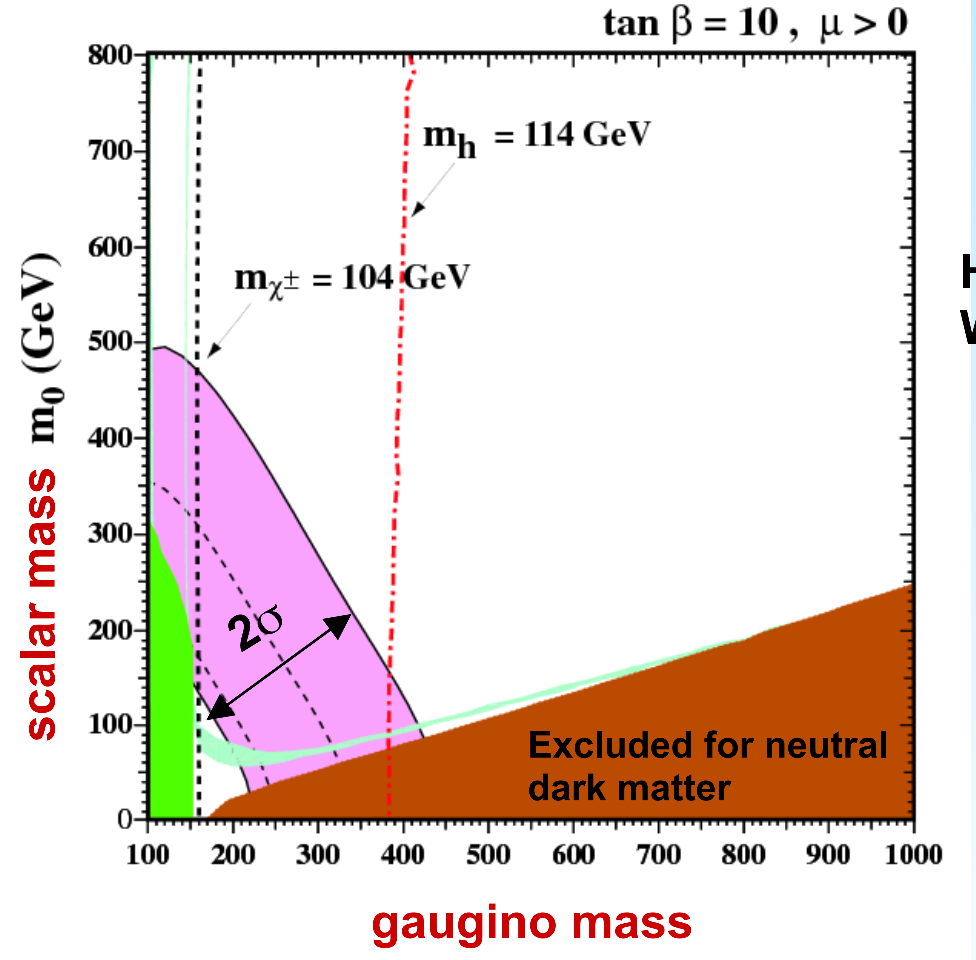
$$a_\mu^{\mathrm{NP}} = 300(100) \times 10^{-11}$$

$$d_\mu^{\mathrm{NP}} \simeq 3 \times 10^{-22} \left(\frac{a_\mu^{\mathrm{NP}}}{3 \times 10^{-9}} \right) \tan \phi_{CP} \quad \mathrm{e \cdot cm}$$

where ϕ_{CP} is a CP violating phase.

Either d_μ is **of order 10^{-22} e cm**, or the CP phase is strongly suppressed!

Typical CMSSM 2D space showing g-2 effect (note: NOT an exclusion plot)



Present:
$\Delta a_\mu = 295 \pm 88 \times 10^{-11}$

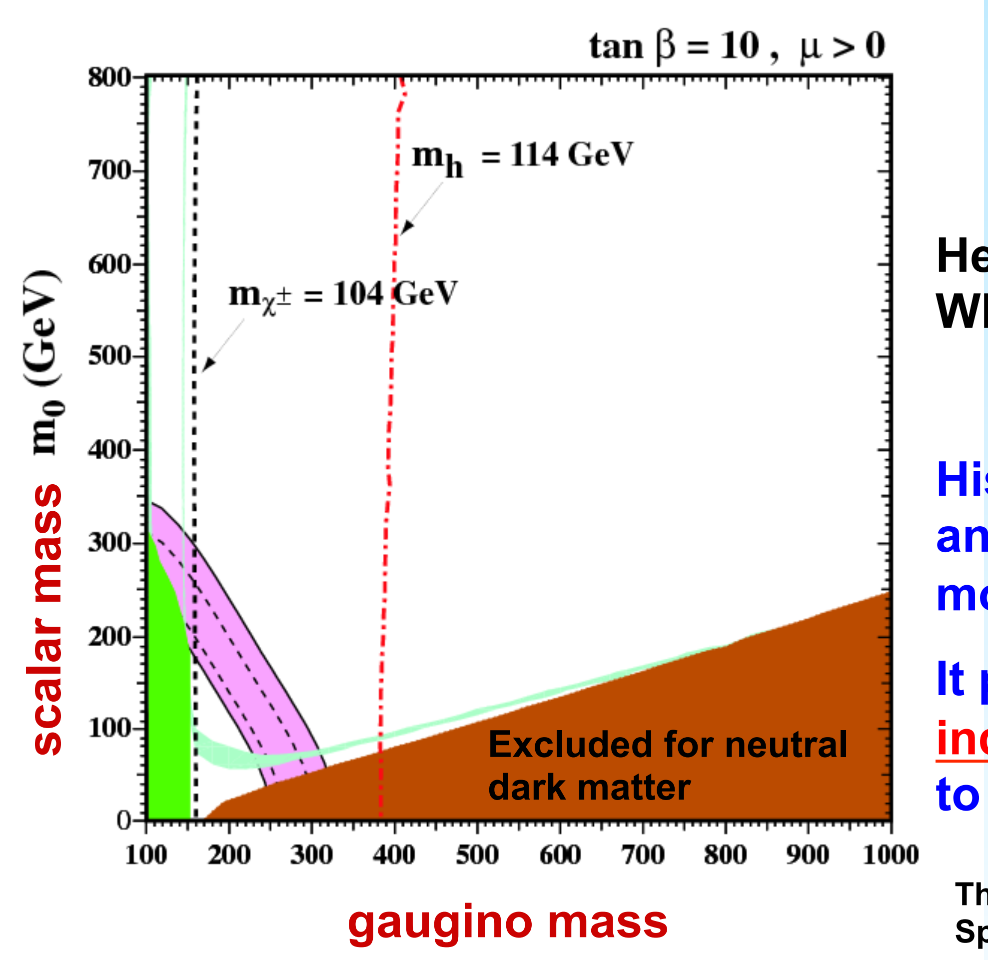
Here, neutralino accounts for the WMAP implied dark matter density

courtesy Keith Olive

This CMSSM calculation: Ellis, Olive, Santoso, Spanos. Plot update: K. Olive

Typical CMSSM 2D space showing g-2 effect (note: NOT an exclusion plot)

Back



Future
$\Delta a_\mu = 295 \pm 34 \times 10^{-11}$

Here, neutralino accounts for the WMAP implied dark matter density

Historically muon (g-2) has played an important role in restricting models of new physics.

It provides constraints that are independent and complementary to high-energy experiments.

This CMSSM calculation: Ellis, Olive, Santoso, Spanos. Plot update: K. Olive

With new experimental and theoretical precision and same Δa_μ

courtesy Keith Olive

Cross section data:

At low energies (< 2 GeV) only measurements of exclusive channels, two approaches:

Energy scan (CMD2, SND):

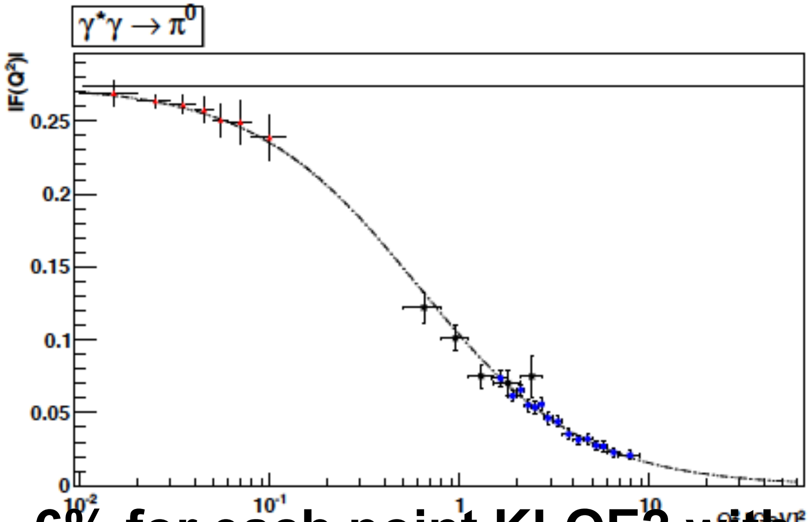
- **energy of colliding beams is changed to the desired value**
- **"direct" measurement of cross sections**
- **needs dedicated accelerator/physics program**
- **needs to measure luminosity and beam energy for every data point**

Radiative return (KLOE, BABAR, BELLE):

- **runs at fixed-energy machines (meson factories)**
- **use initial state radiation process to access lower lying energies or resonances**
- **data come as by-product of standard physics program**
- **requires precise theoretical calculation of the radiator function**
- **luminosity and beam energy enter only once for all energy points**
- **needs larger integrated luminosity**

KLOE-2 contribution to $F_{\pi^0\gamma^*\gamma}(q_1^2,0)$ and $a_\mu^{LbL,\pi 0}$

By including KLOE-2→a reduction of a factor 2 in the error of $a_\mu^{\pi 0}$!

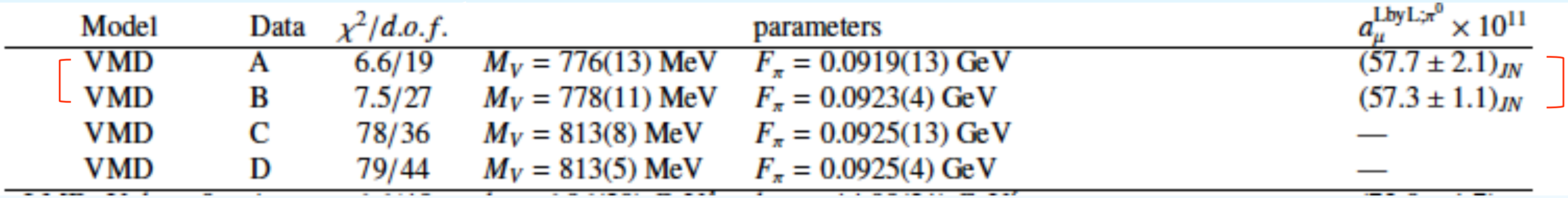


On the possibility to measure the $\pi^0 \rightarrow \gamma\gamma$ decay width
and the $\gamma^*\gamma \rightarrow \pi^0$ transition form factor
with the KLOE-2 experiment
(D. Babusci et al. to be submitted to journal)

$q^2 = -2EE'(1-\cos\theta)$

6% for each point KLOE2 with 5 fb^{-1}

See the talk of Ivashin

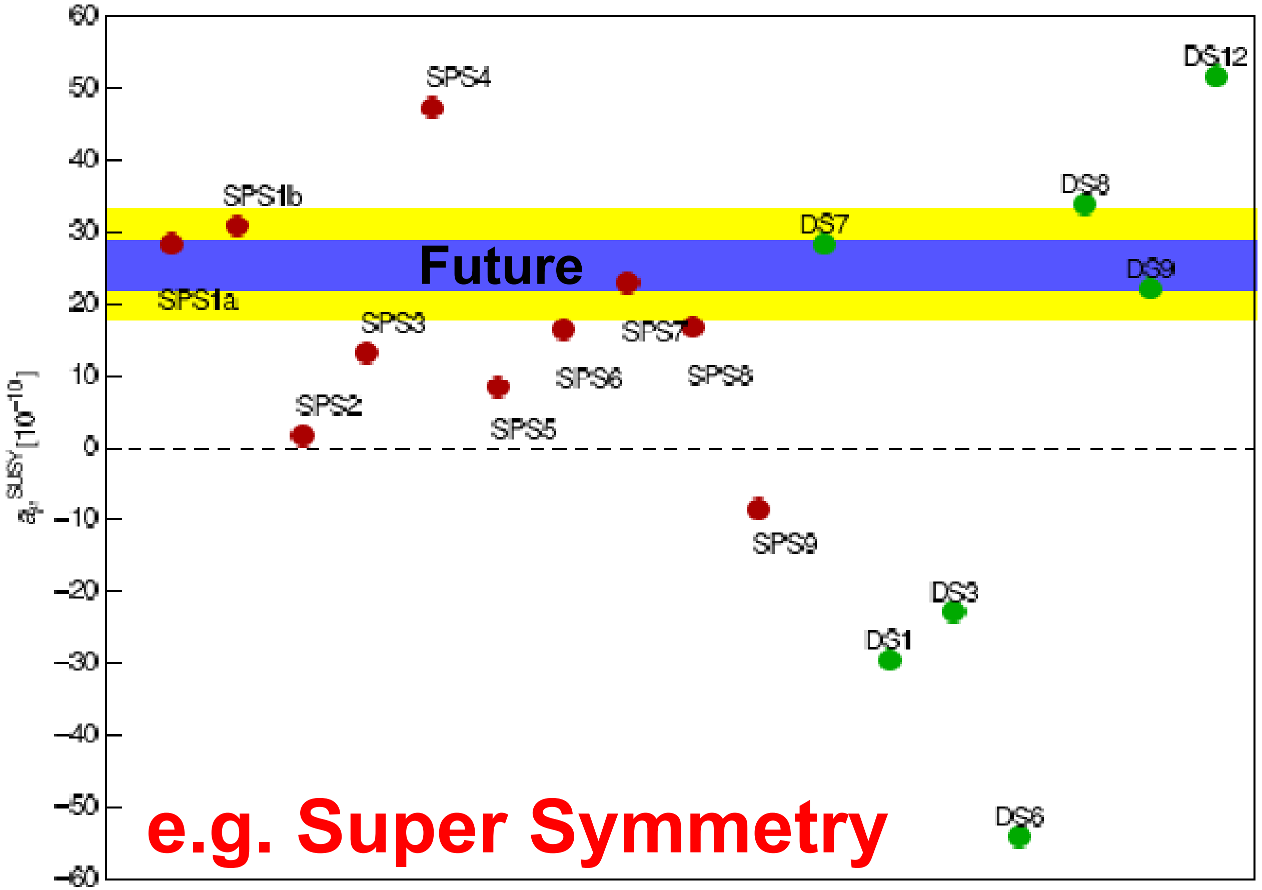


Model	Data	$\chi^2/d.o.f.$		parameters	$a_\mu^{\mathrm{LbyL};\pi^0} \times 10^{11}$
VMD	A	6.6/19	$M_V = 776(13)$ MeV	$F_\pi = 0.0919(13)$ GeV	$(57.7 \pm 2.1)_{JN}$
VMD	B	7.5/27	$M_V = 778(11)$ MeV	$F_\pi = 0.0923(4)$ GeV	$(57.3 \pm 1.1)_{JN}$
VMD	C	78/36	$M_V = 813(8)$ MeV	$F_\pi = 0.0925(13)$ GeV	—
VMD	D	79/44	$M_V = 813(5)$ MeV	$F_\pi = 0.0925(4)$ GeV	—

A : CLEO, CELLO, PrimEx;
B : CLEO, CELLO, PrimEx, KLOE-2;
C : CLEO, CELLO, BaBar, PrimEx;
D : CLEO, CELLO, BaBar, PrimEx, KLOE-2;

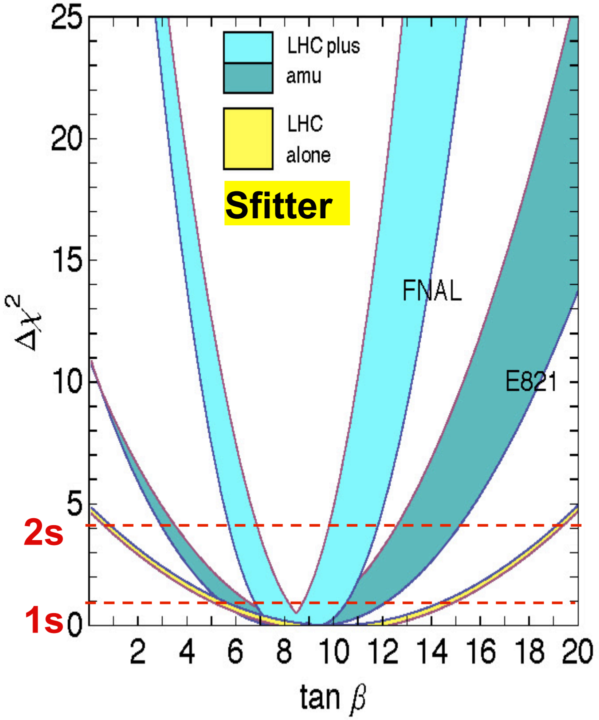
In addition the measurement of $\Gamma(\pi^0 \rightarrow \gamma\gamma)$ will constrain $F_{\pi 0}(q^2=0)$ (which is now obtained by WZW model $1/4\pi f_\pi$ w/o error)

Muon g-2 is a powerful discriminator between models; chiral-changing, flavor and CP conserving interaction.



e.g. Super Symmetry

tan *b* sensitivity



SPS1a; LHC 100 fb-1 at 14 TeV

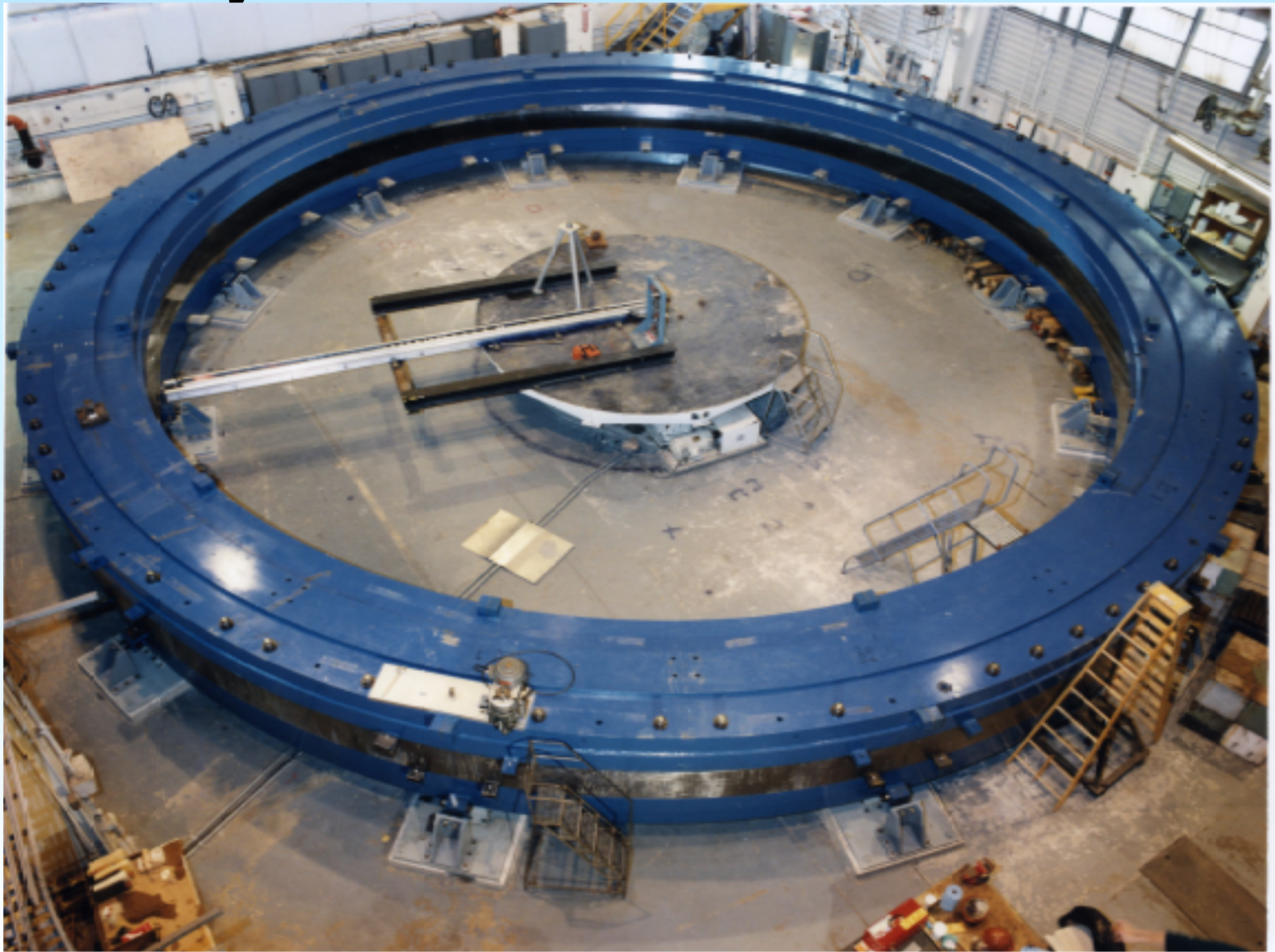
Snowmass points and slopes (SUSY)

from D. Stöckinger

LHC Inverse Problem (300fb^{-1})

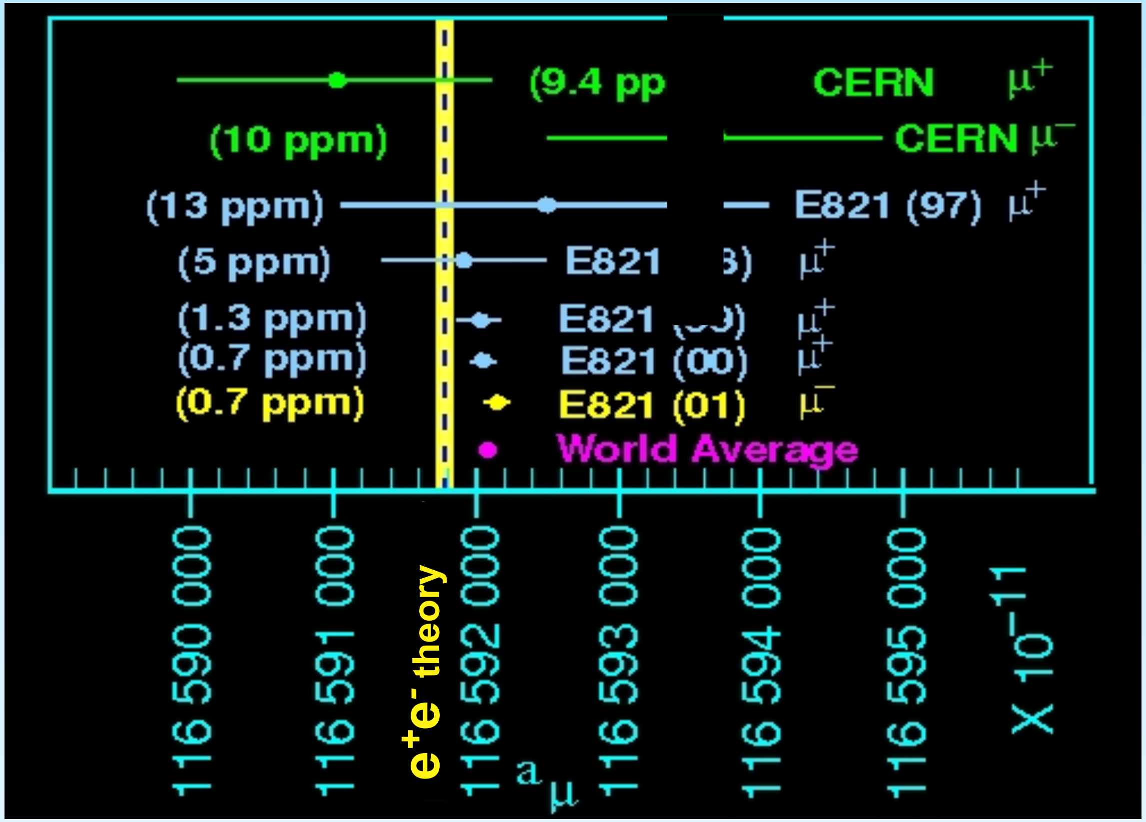
can't be distinguished at LHC [Sfitter: Adam, Kneur, Lafaye, Plehn, Rauch, Zerwas '10]

Yoke fully assembled



E821 achieved 0.54 ppm; e^+e^- based theory 0.49 ppm Hint is 3.2 – 3.6 σ

Theory: Davier, et al., Eur. Phys. J. C (2011) 71: 1515



$$a_\mu^{SM} = 116\,591\,802 \pm 49 \ \ (0.42\,\text{ppm})$$

$$a_\mu^{E821} = 116\,592\,089(54)_{stat}(33)_{sys}(63)_{tot} \times 10^{-11}$$

$$\Delta a_\mu^{(\text{today})} = (287 \pm 80) \times 10^{-11}$$

~3.5 "standard deviations"

Hint of new physics?

Systematic errors on ω_a (ppm)

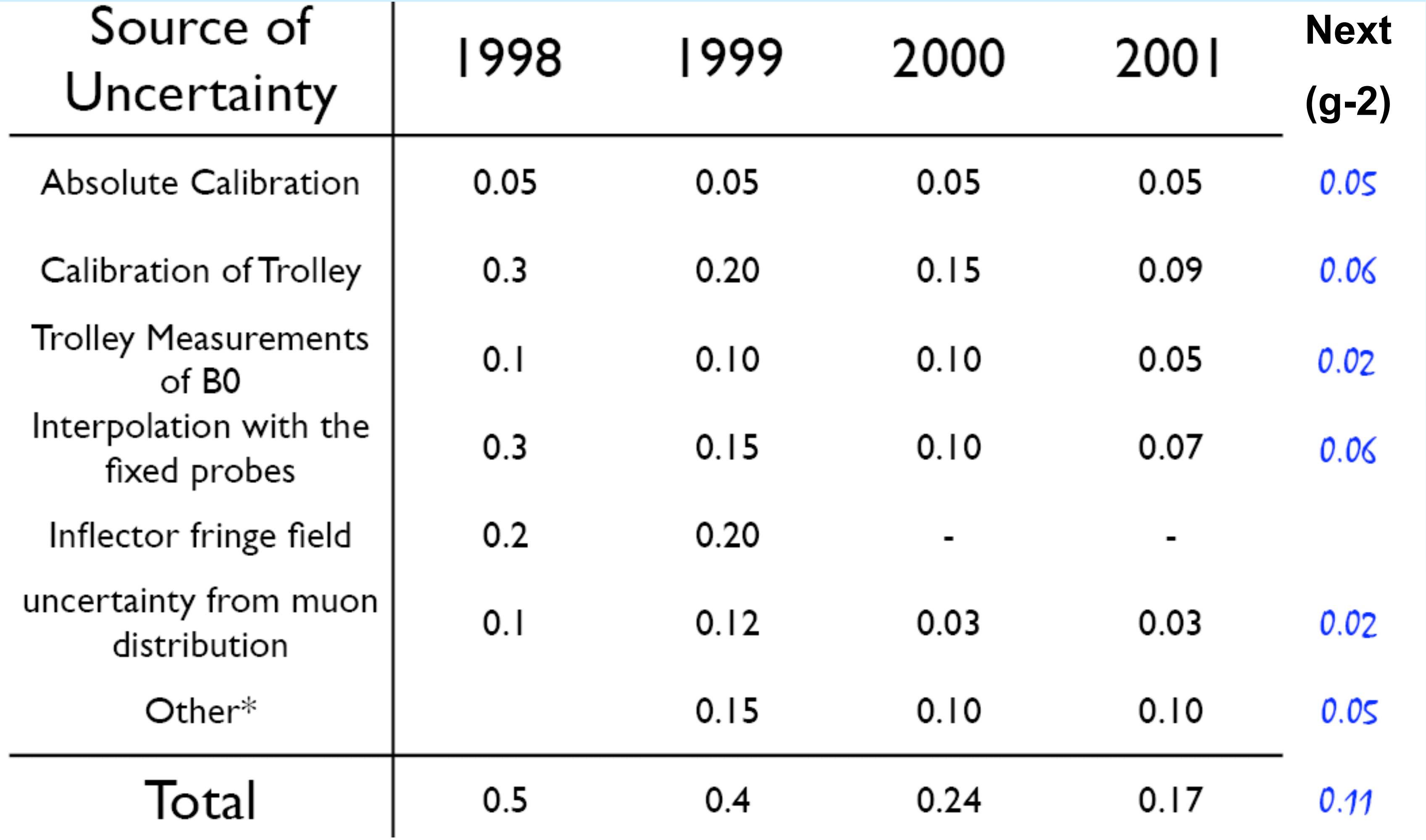
$\sigma_{\text{systematic}}$	1999	2000	2001	Future
Pile-up	0.13	0.13	0.08	0.04
AGS Background	0.10	0.10	0.015*	
Lost Muons	0.10	0.10	0.09	0.02
Timing Shifts	0.10	0.02	0.02	
E-Field, Pitch	0.08	0.03	0.06*	0.03
Fitting/Binning	0.07	0.06	0.06*	
CBO	0.05	0.21	0.07	0.04
Beam Debunching	0.04	0.04	0.04*	
Gain Change	0.02	0.13	0.13	0.02
total	0.3	0.31	0.21	~0.07

○ **better with Fermilab beam structure and improved detectors/electronics**

Σ* = 0.11

Systematic errors on ω_p (ppm)

- Why is the error 0.11 ppm?
  - That's with *existing* knowledge and experience
    - with R&D defined in proposal, it will get better



Source of Uncertainty	1998	1999	2000	2001	**Next (g-2)**
Absolute Calibration	0.05	0.05	0.05	0.05	0.05
Calibration of Trolley	0.3	0.20	0.15	0.09	0.06
Trolley Measurements of B0	0.1	0.10	0.10	0.05	0.02
Interpolation with the fixed probes	0.3	0.15	0.10	0.07	0.06
Inflector fringe field	0.2	0.20	-	-	
uncertainty from muon distribution	0.1	0.12	0.03	0.03	0.02
Other*		0.15	0.10	0.10	0.05
Total	0.5	0.4	0.24	0.17	0.11