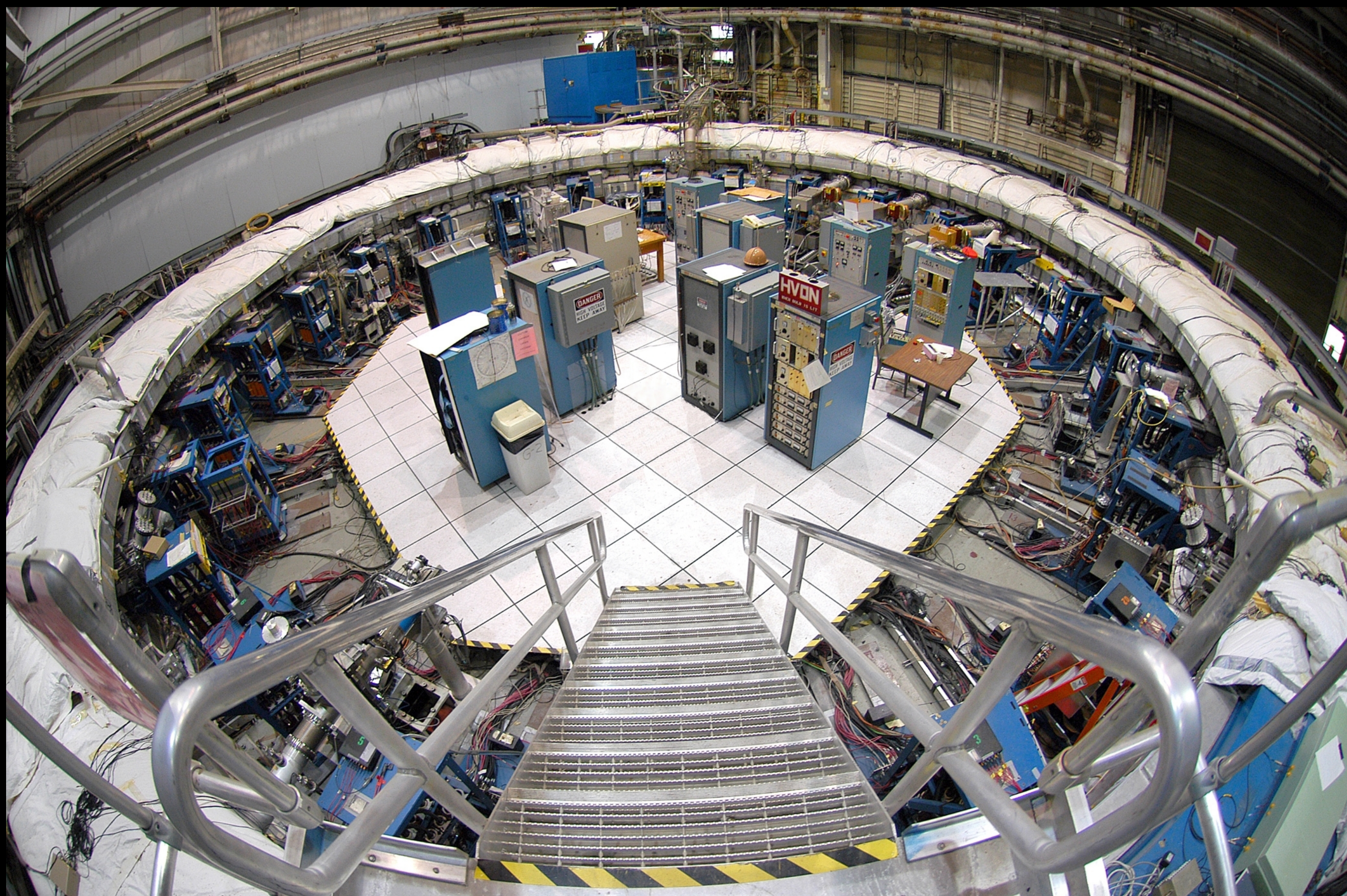
Muon g-2 over the next 5 years

Chris Polly, Fermilab



Taking muon g-2 into the next era

- The history of electron/muon g-2 is a brilliant example of how experiment and theory have intertwined in an interdependent march to higher precisions
  - Without the experiment, no motivation to pursue difficult calculations
  - Without the theory, no way to extract physics from the experiment

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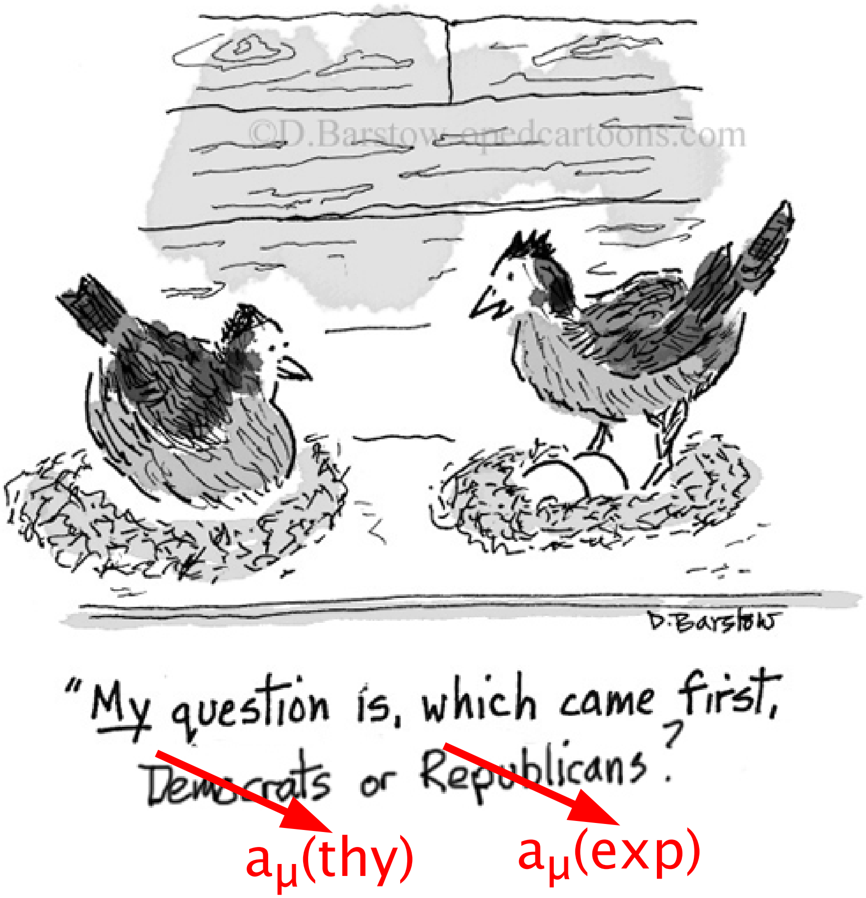
  - Bit of a chicken and egg problem...



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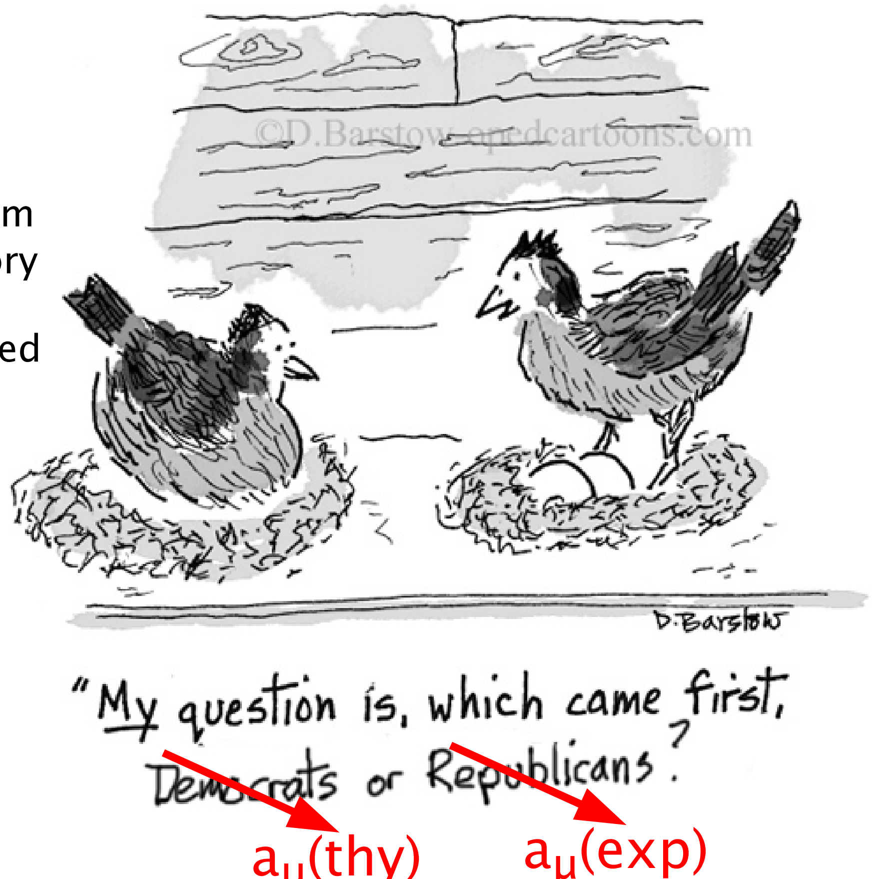
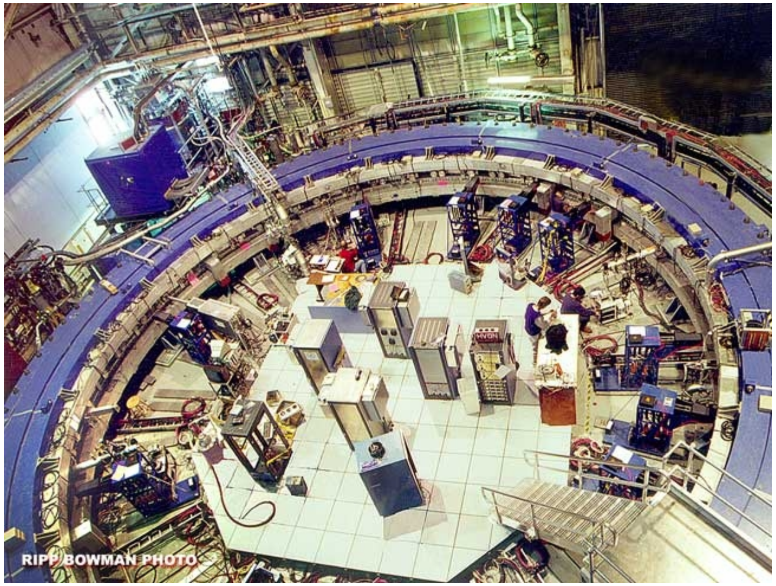
- Future outlook very promising
  - BNL muon g-2 ended with a precision of 0.54 ppm in a_μ and an intriguing 3σ discrepancy with theory
  - Theory error now at 70-80% of exp error, expected to improve to ~0.3 ppm in next 5 years
  - Equipment from BNL and infrastructure at FNAL allow a 0.14 ppm measurement over same time



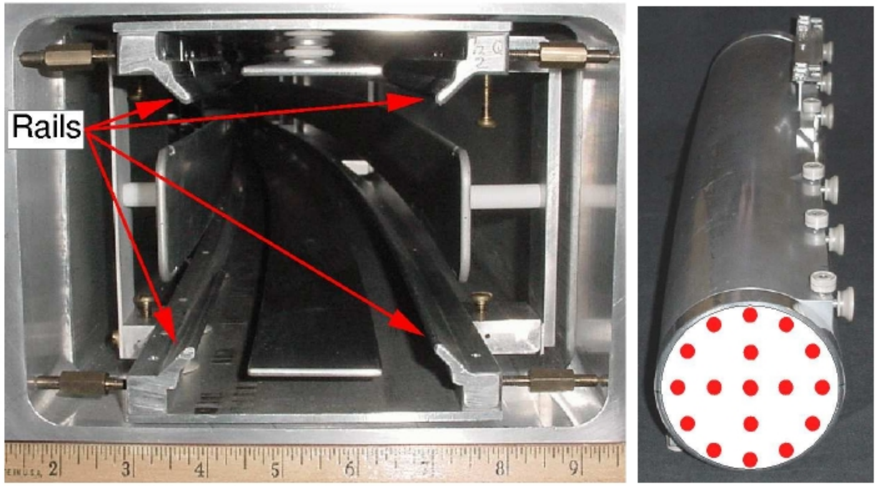
Lattice QCD could be THE critical theory development over the next 5 years!

Basics of the Brookhaven experiment



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

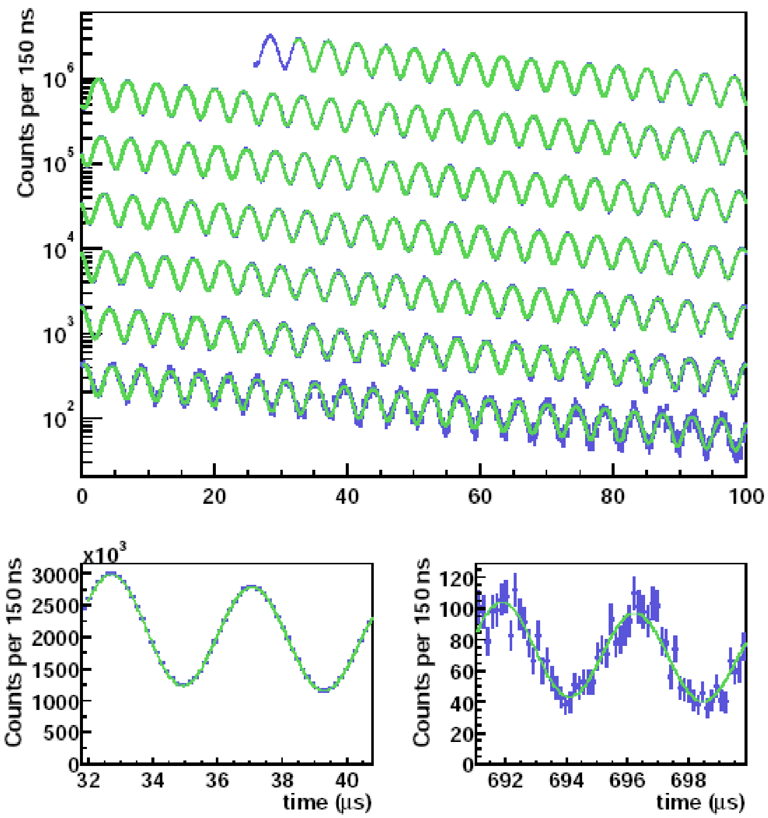
- Store polarized muons in storage ring
  - Measure ω_a, the precession of the muon spin relative to the momentum vector
  - Measure ω_p, the Larmor precession of free protons in the same magnetic field
  - Muon-to-proton magnetic moment ratio determined from muonium hyperfine spectroscopy

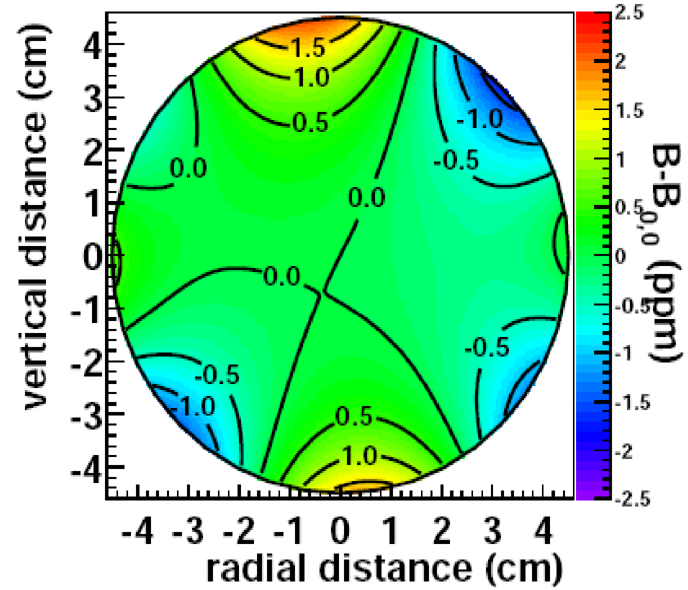


(a) Vacuum chamber cross section (b) Trolley

Final result from the BNL experiment

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





	2001 [ppm]	2000 [ppm]
Total Syst Error	0.27	0.39
Statistical Error	0.66	0.62
Total Error	μ^- 0.71	μ^+ 0.73

$$a_\mu^{exp} = 116\,592\,089(63) \times 10^{-11} \ \ (0.54\,\text{ppm})$$

Final result from the BNL experiment

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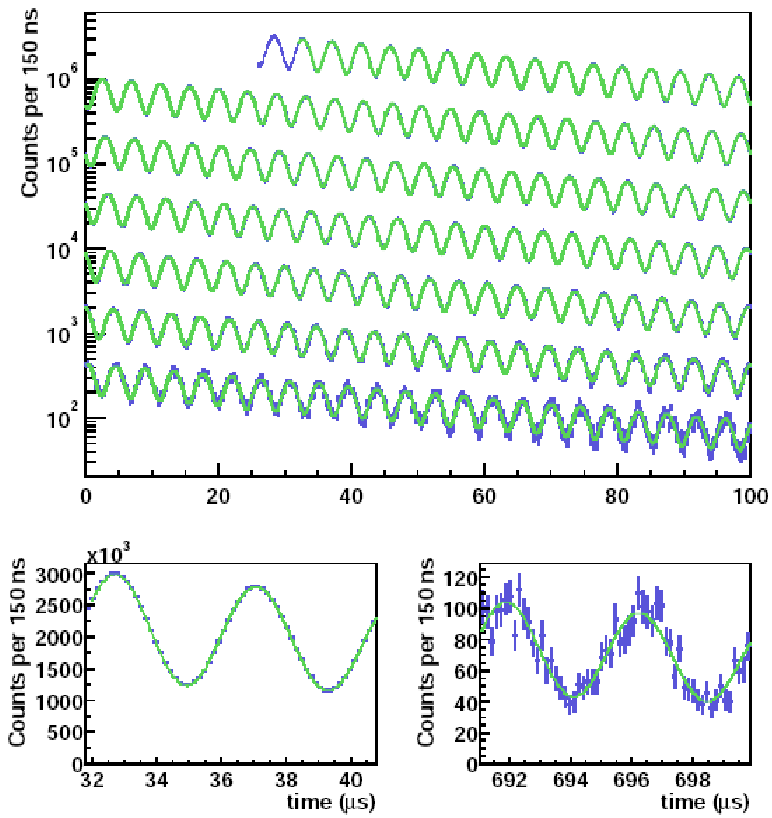
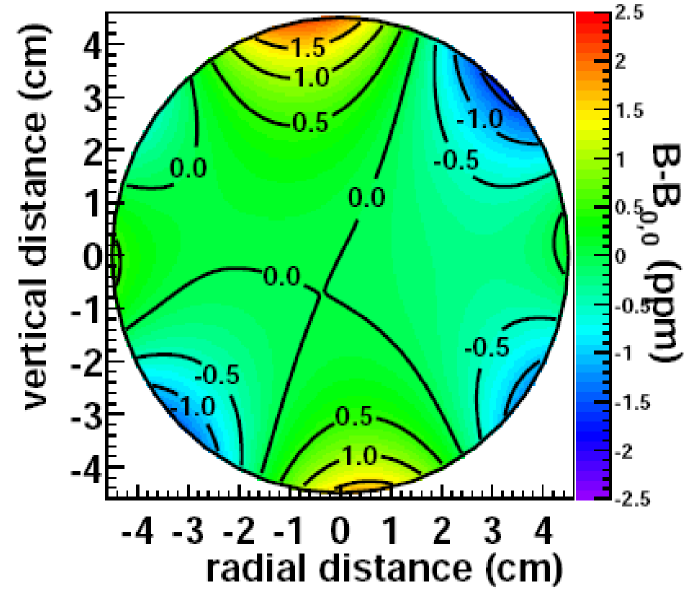


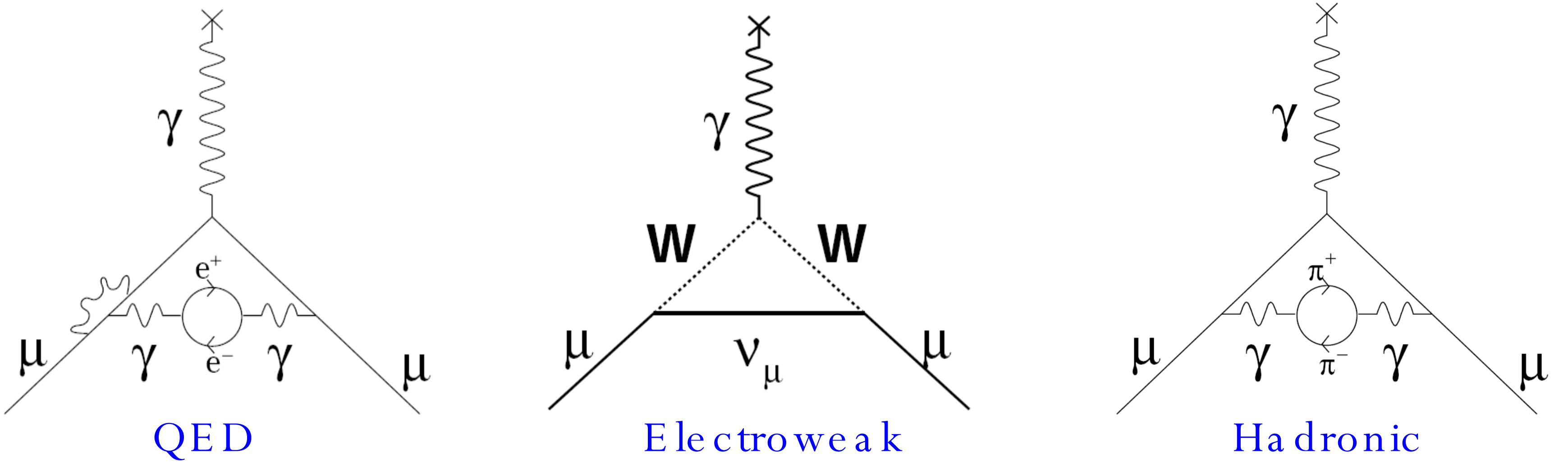


	2001 [ppm]	2000 [ppm]
Total Syst Error	0.27	0.39
Statistical Error	0.66	0.62
Total Error	μ^- 0.71	μ^+ 0.73

Stat error dominates!

$$a_\mu^{exp} = 116\,592\,089(63) \times 10^{-11} \;\; (0.54\,\text{ppm})$$

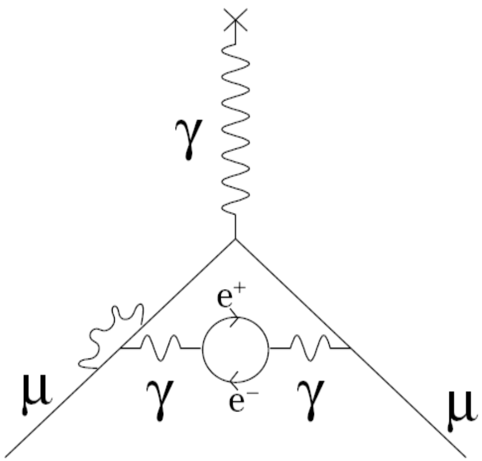
Theory of the muon anomaly $a_\mu = \frac{g-2}{2}$



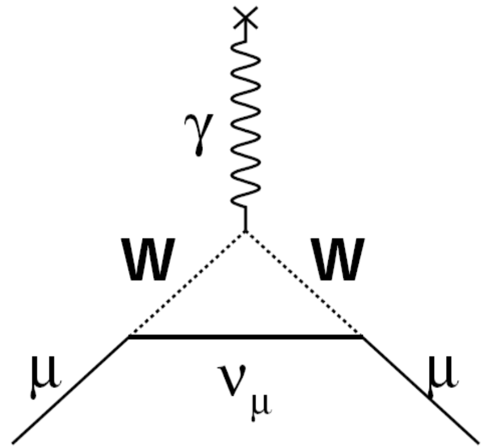
- It is common to break the SM contribution into various sources

$$a_\mu^{SM} = a_\mu^{QED} + a_\mu^{EW} + a_\mu^{HLBL} + a_\mu^{HVP} + a_\mu^{HOHVP}$$

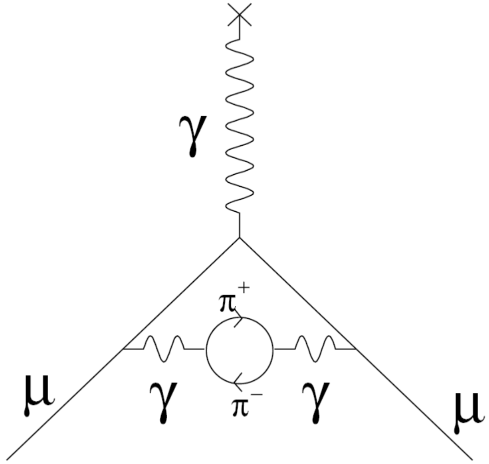
Theory of the muon anomaly $a_\mu = \frac{g-2}{2}$



QED



Electroweak

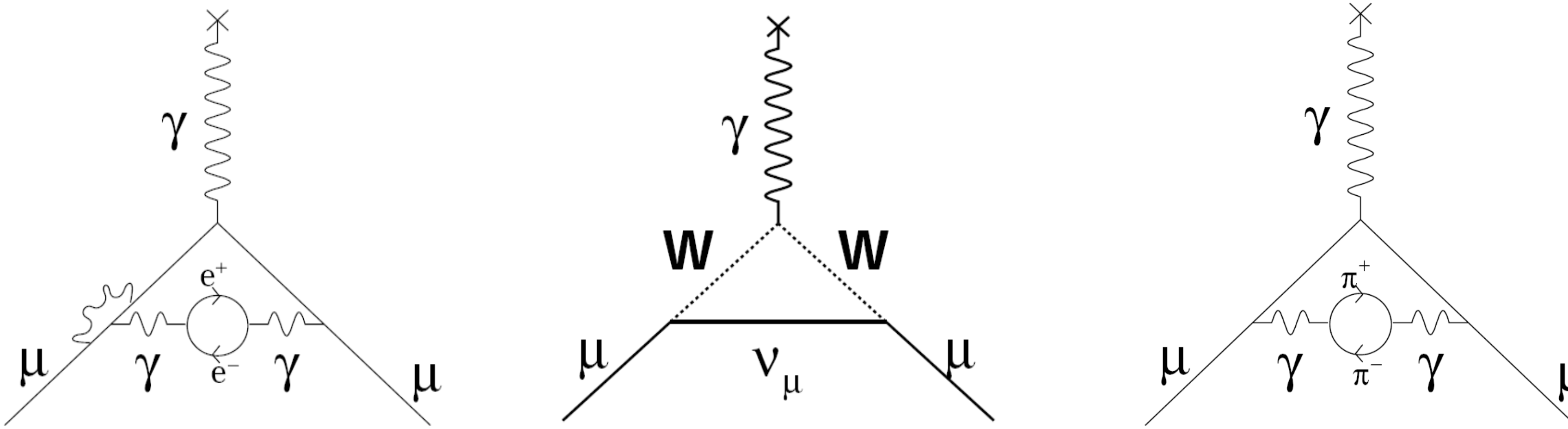


Hadronic

- It is common to break the SM contribution into various sources

$$a_\mu^{SM} = a_\mu^{QED} + a_\mu^{EW} + a_\mu^{HLBL} + a_\mu^{HVP} + a_\mu^{HOHVP} + a_\mu(NP)$$

Theory of the muon anomaly $a_\mu = \frac{g-2}{2}$



- It is common to break the SM contribution into various sources

$$a_\mu^{SM} = a_\mu^{QED} + a_\mu^{EW} + a_\mu^{HLBL} + a_\mu^{HVP} + a_\mu^{HOHVP} + a_\mu(NP)$$

- Provides an EXTREMELY SENSITIVE and GENERAL probe of higher mass exchanges

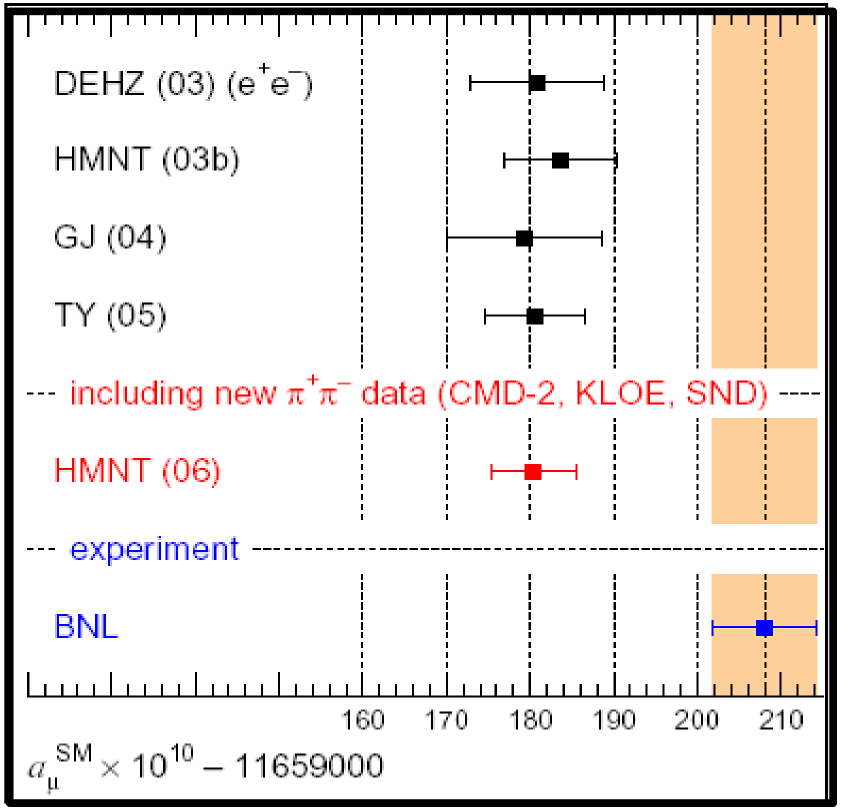
$$\lambda_{sens} \propto \left(\frac{m_\mu}{m_e}\right)^2 \approx 40,000$$

*Makes up for x1000 better precision of a_e

Muon g-2 is uniquely sensitive among all elementary particles.

Theory evaluations 2003-2008

Theory evaluation stable!



K. Hagiwara, A.D. Martin, Daisuke Nomura, T. Teubner

(De Rafael arXiv:0809.3205)

Contribution	Result in 10^{-11} units
QED (leptons)	$11\ 6584\ 718.09 \pm 0.14 \pm 0.04_\alpha$
HVP(lo)	$6\ 908 \pm 39_{\rm exp} \pm 19_{\rm rad} \pm 7_{\rm pQCD}$
HVP(ho)	$-97.9 \pm 0.9_{\rm exp} \pm 0.3_{\rm rad}$
HLxL	105 ± 26
EW	$152 \pm 2 \pm 1$
Total SM	$116\ 591\ 785 \pm 51$

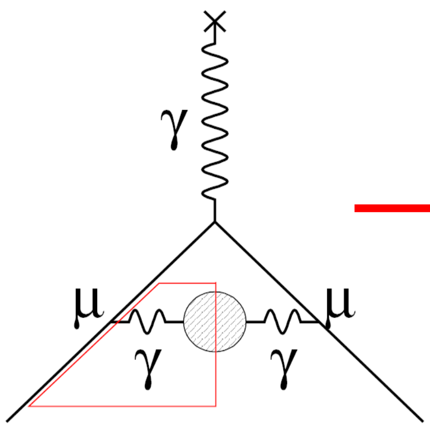
- Largest contribution from QED
- Largest error from hadronic terms
- Circa 2008 Δa_μ(exp-thy) evaluation, units of a_μ in 10^{-11}
  - Rafael (2008) 295 ± 81 (3.6σ)
  - HMNT (2008) 276 ± 81 (3.4σ)
  - Jeger. (2008) 267 ± 96 (2.8σ)
  - DEHZ (2006) 277 ± 84 (3.3σ)

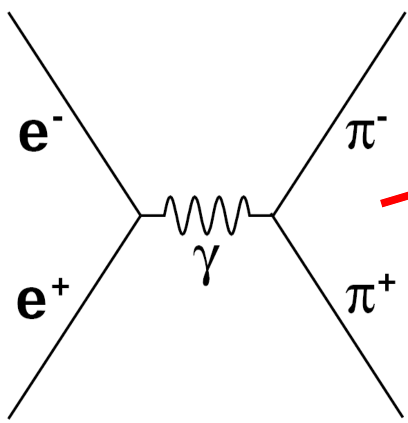
Most difficult part of theory comes from hadronic sector

Contribution	Result in 10^{-11} units
QED (leptons)	$11\,6584\,718.09 \pm 0.14 \pm 0.04_{\alpha}$
HVP(lo)	$6\,908 \pm 39_{\text{exp}} \pm 19_{\text{rad}} \pm 7_{\text{pQCD}}$
HVP(ho)	$-97.9 \pm 0.9_{\text{exp}} \pm 0.3_{\text{rad}}$
HLxL	105 ± 26
EW	$152 \pm 2 \pm 1$
Total SM	$116\,591\,785 \pm 51$

*Courtesy E. De Rafael, arXiv 0809.3025

- Common to divide hadronic loops into 3 categories...
  - $a_{\mu}(\text{had,LO}) = 6908 \pm 44$
  - $a_{\mu}(\text{had,HO}) = -98 \pm 1$
  - $a_{\mu}(\text{had,LBL}) = 105 \pm 26$



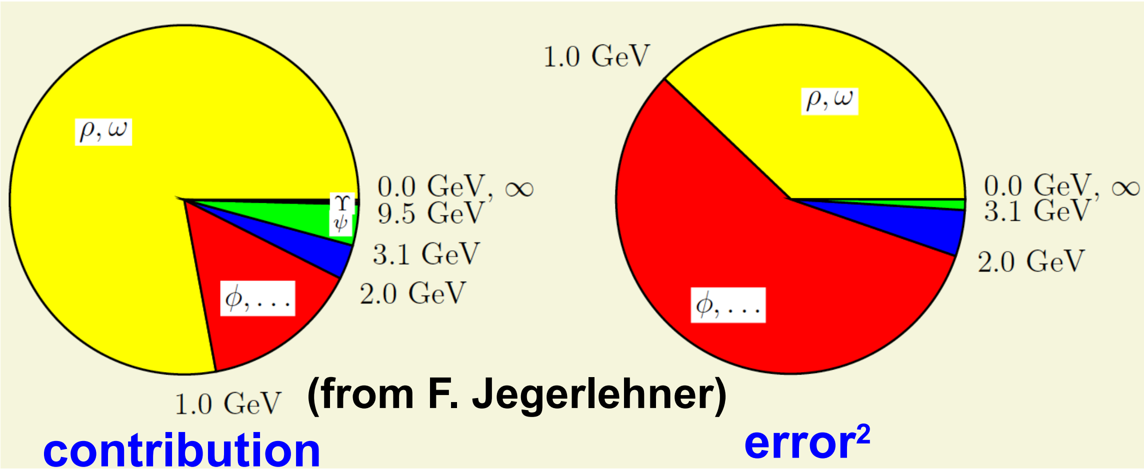


$$a_{\mu}^{had,1} \propto \int_{2m_{\pi}}^{\infty} ds \frac{K(s)}{s} R(s)$$

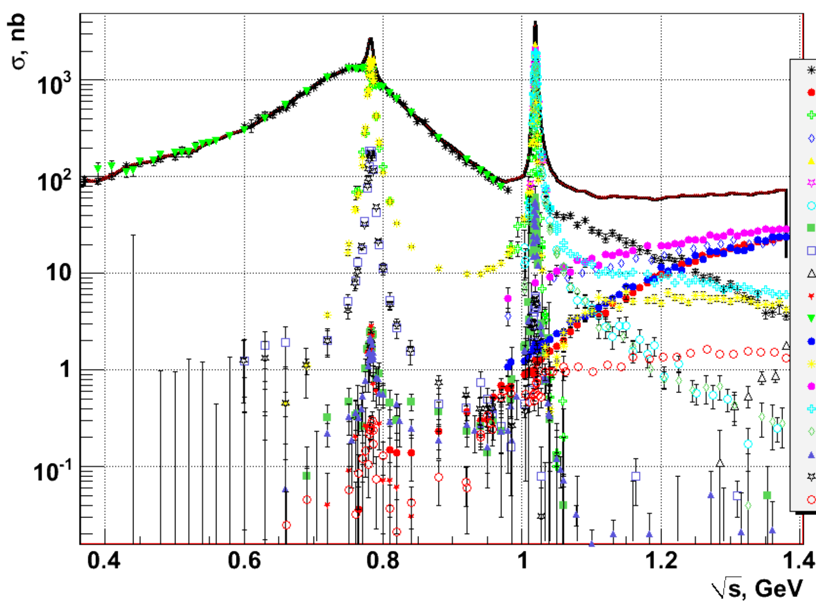
$$R(s) = \frac{\sigma(e^+e^- \to \text{hadrons})}{\sigma(e^+e^- \to \text{muons})}$$

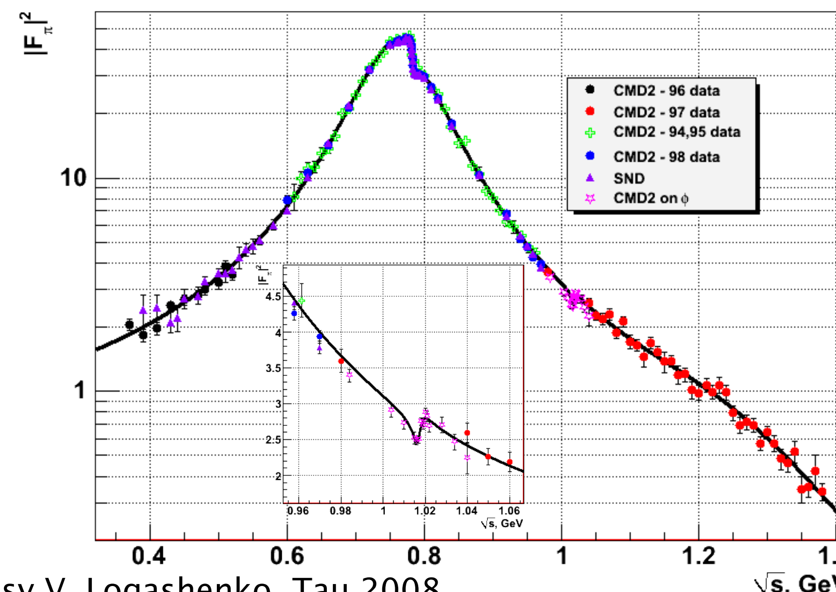
Current theory error dominated by e+e- --> hadrons, will likely no longer be the case in 5 years without progress on HLBL

Improvements in δa_μ(had,LO) from e+e- -> hadrons



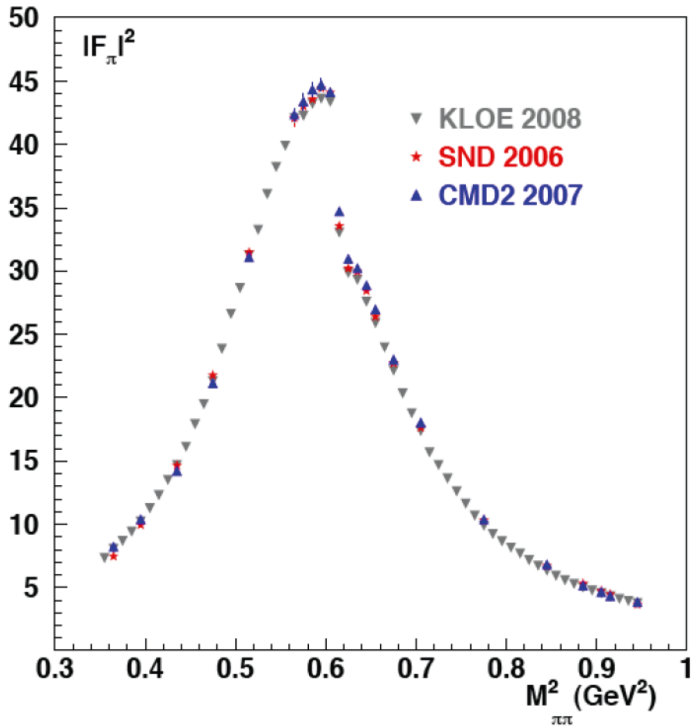
- Experiments have reduced error such that 2π region no longer dominates error
- Data from Novosibirsk (CMD2 and SND)
  - For 2π, ratio N(2π)/N(ee), form factor to 1-2%
  - All modes but 2π, luminosity measured using Bhabha scattering

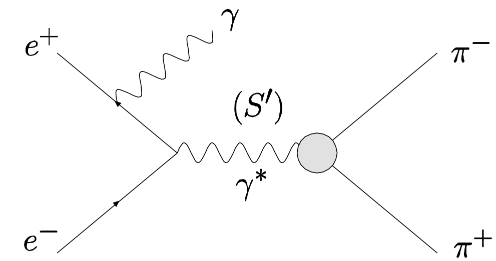


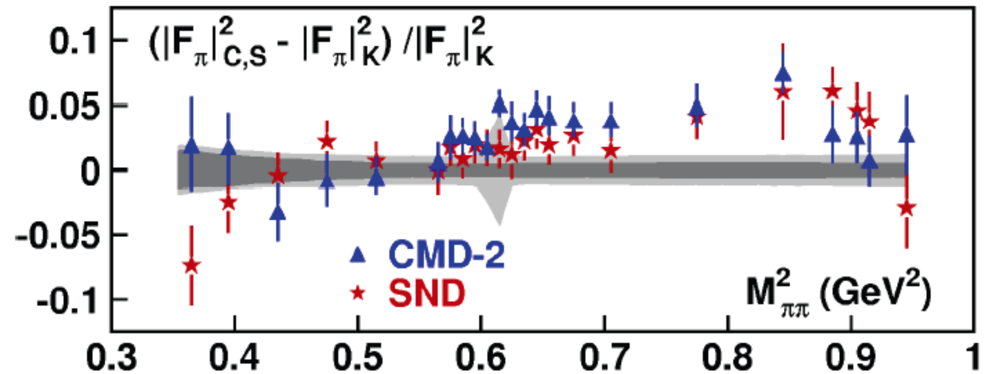


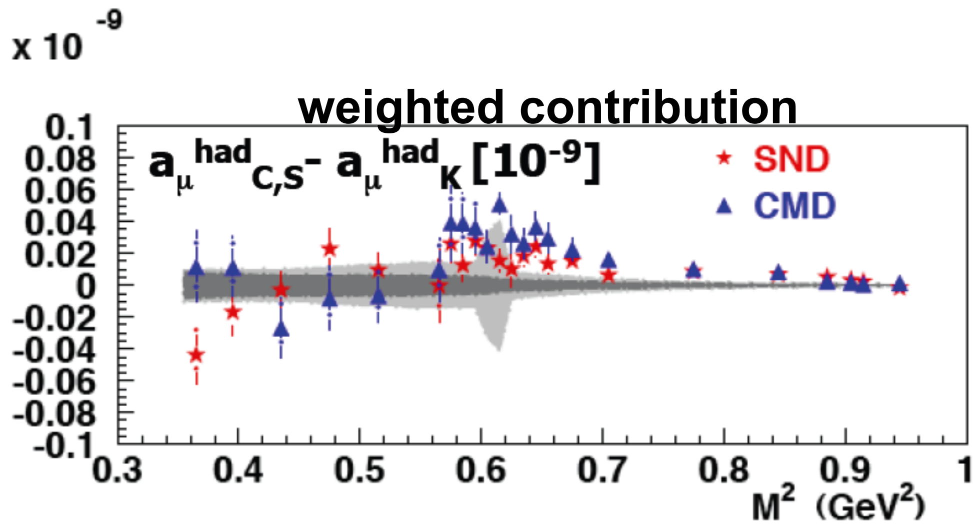
*Courtesy V. Logashenko, Tau 2008

KLOE has pioneered use of ISR for a_μ





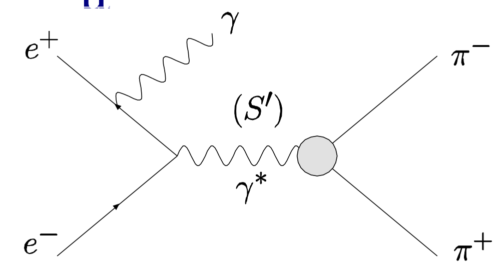




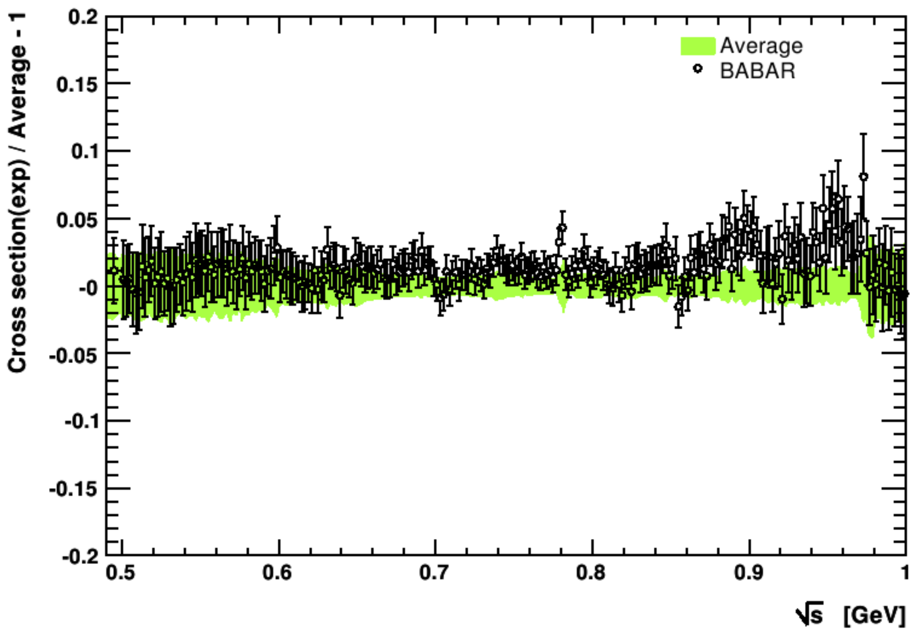
$$\sigma_{e^+e^-\to\pi^+\pi^-} = \frac{\pi\alpha^2}{3s}\beta_\pi^3|F_\pi|^2$$

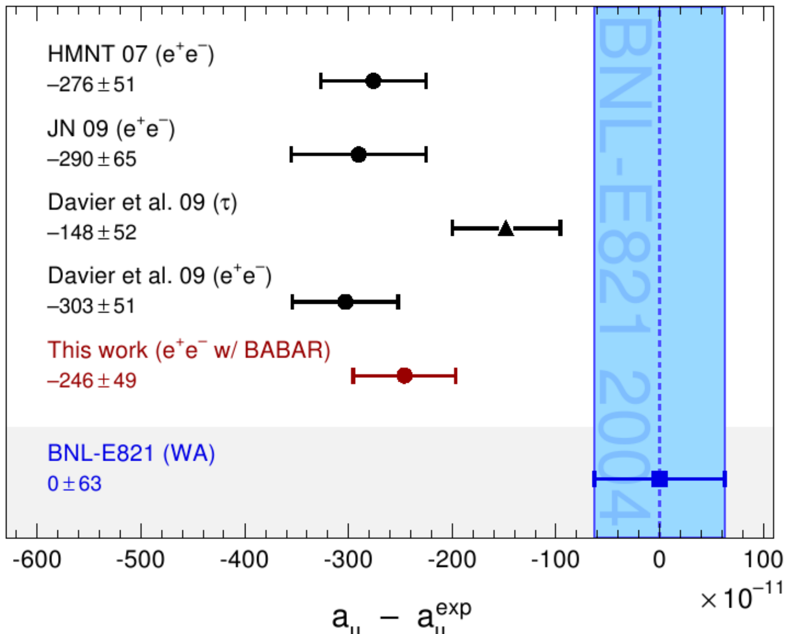
- Fantastic statistical precision
- KLOE agrees with direct CMD2 & SND

New results from Babar! Also using ISR for a_μ



- Very interesting new result
- Only 2nd expt to use ISR for muon g-2 input



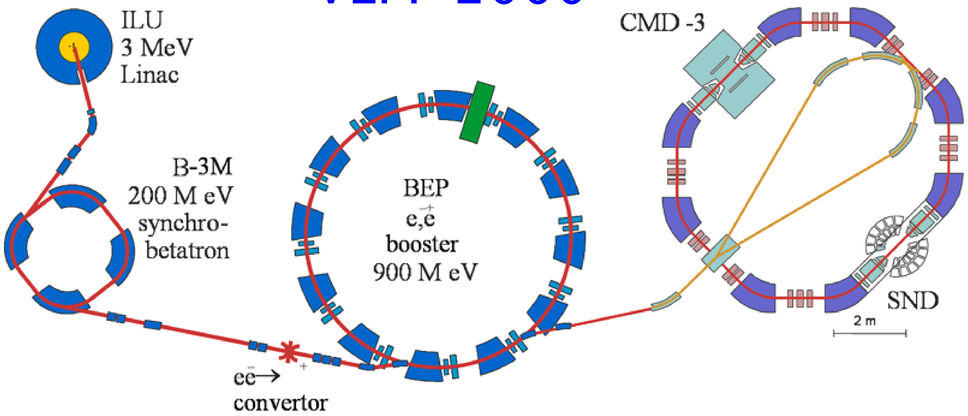


So now Babar had provided a 4th independent vote of confidence in theory...good, need that to extract new physics

$$a_\mu^{had} = 6955(41) \times 10^{-11}$$

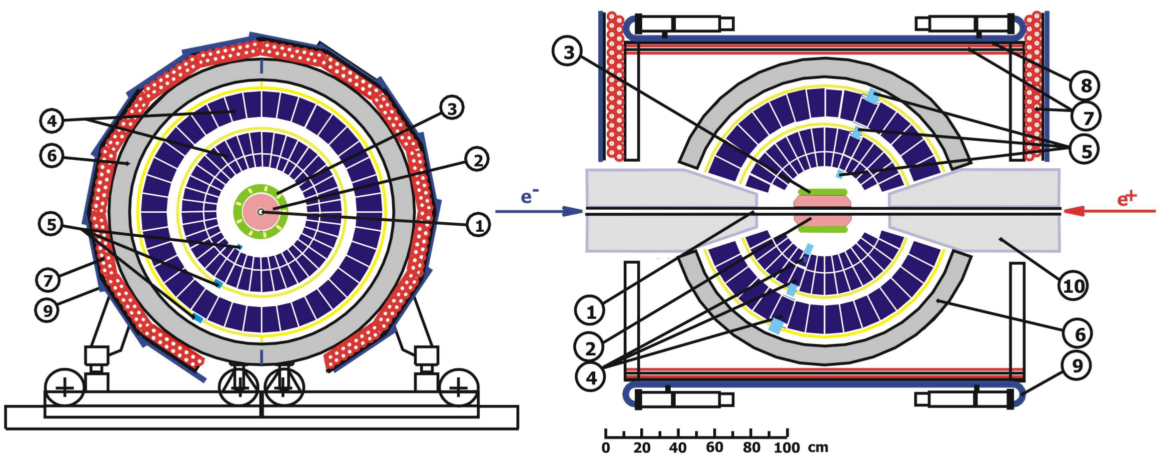
Future of LOHVP...upgraded facility VEPP-2000

VEPP-2000

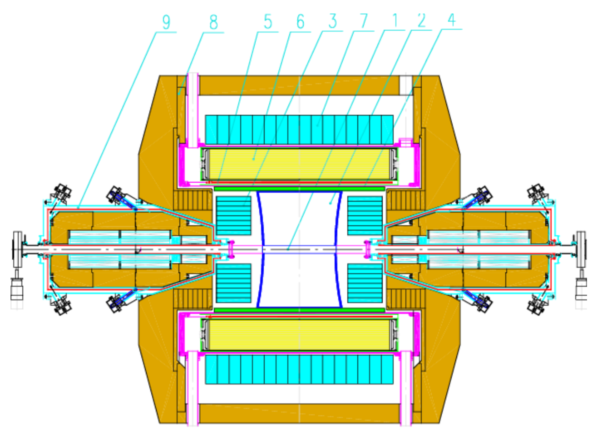


- Novosibirsk upgrades
  - Factor of 10-100 in stats, > 10 from luminosity alone
  - Energy extend range up to 2 GeV
  - Starting this year!!!
- More ISR results from KLOE & Babar, maybe Belle
- Note a 40% reduction in LOHVP will make HLBL the largest theory error

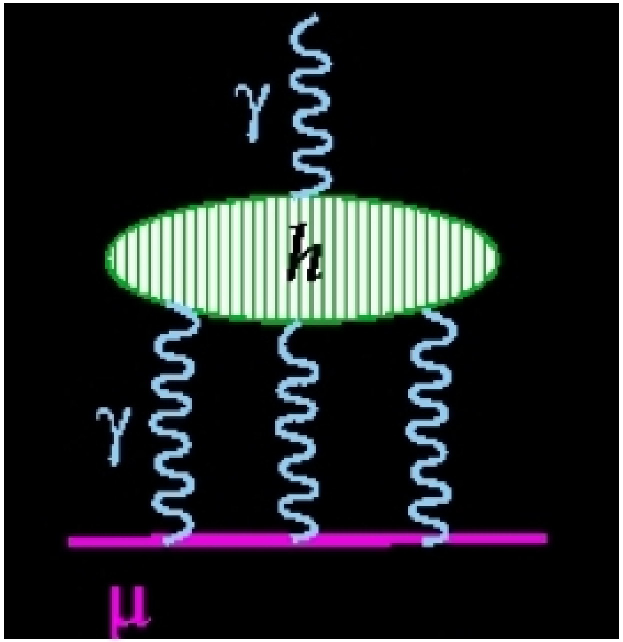
SND2000



CMD3



Hadronic light-by-light scattering



- More difficult as it can't be related to e+e- -> hadrons
- Requires a calculation within the context of a model
  - extended Nambu-Jona-Lasinio model
  - hidden local symmetry model
  - large N_c QCD
  - AdS QCD
- Dozen or so theorists working on the problem agree

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

$$a_\mu^{SM} = 116\,591\,834(49) \times 10^{-11} \;\; (0.42\,\mathrm{ppm})$$

$$a_\mu^{exp} = 116\,592\,089(63) \times 10^{-11} \;\; (0.54\,\mathrm{ppm})$$

$$\Delta a_\mu \equiv a_\mu^{exp} - a_\mu^{SM} = (255 \pm 80) \times 10^{-11}$$

Next two talks will focus HLBL inputs from lattice QCD (Tom Blum),
and experimental data (Dario Moricciani).

We are proposing to move the muon g-2 apparatus to FNAL

- Why?
  - Because the experiment ended stat-limited...magic γ method still has potential
  - Because for five years theory has been stable and indicating a 3σ diff with the experiment
  - Because we all are hoping for new information to come from direct production at the LHC, and muon g-2 will have enormous resolving power for new physics
  - FNAL uniquely equipped to deliver required beam

- How much better?
  - Theory error is already 80% of experimental and poised to come down to 50% in foreseeable future
  - Need at least a factor of 2 to match theory, but would like to get a factor 4 to be safely ahead
  - Factor of 4 will also start to hit the limitations of the experiment

With realistic assumption on systematic errors, we need a factor of 21 in statistics for total exp error to be quartered.


(Photo credit Marty Murphy)

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Where would we be with these assumptions on experimental and theoretical errors?

$$a_\mu^{SM} = 116\,591\,834(49) \times 10^{-11} \quad (0.42\,\text{ppm})$$

$$a_\mu^{exp} = 116\,592\,089(63) \times 10^{-11} \quad (0.54\,\text{ppm})$$

$$\Delta a_\mu \equiv a_\mu^{exp} - a_\mu^{SM} = (255 \pm 80) \times 10^{-11}$$

(49) → **30**; (63) → **16**

If the central value remain unchanged the significance of the current discrepancy would be 7.5σ!
(5σ with no theory improvements)

One problem...the ring's in Brookhaven!!!

- Ring built in 12 sections and can be disassembled. Moving 600 tons of steel in yoke and subsytems 'easy' part
- Monolithic 14 m diameter cryostats with superconducting coils inside are a little harder

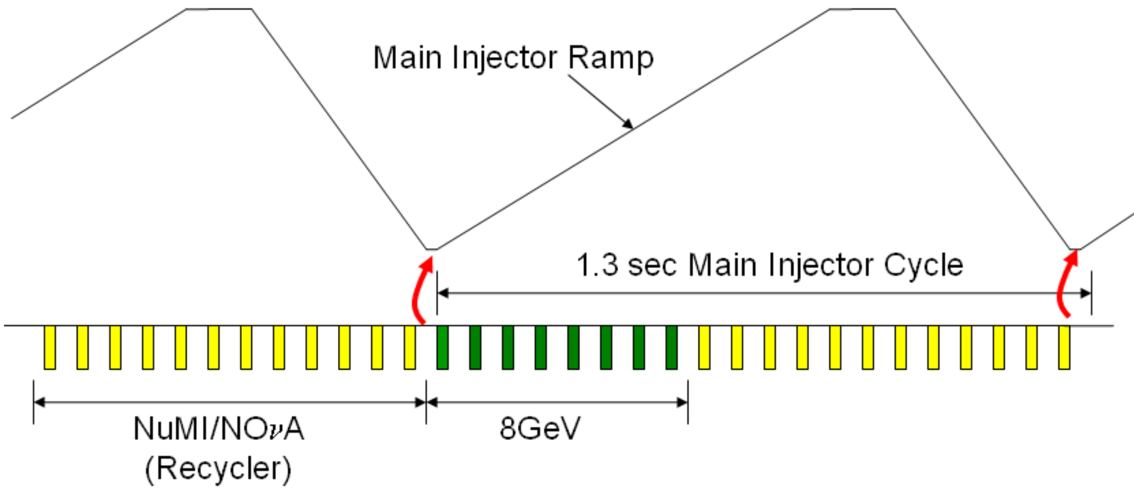
No problem

- Transport coils to and from barge via Sikorsky S64 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.

FNAL Plan--Booster

- 8 batches available in NOvA era, plan to use 6
  - 6 batches/1.3s = 4.6 Hz
- MiniBooNE experience 1 HZ -> 1.1e20 POT/yr
- Potentially 5e20 POT/yr available, but heavily depends on controlling losses in Booster
- For planning purposes, assume 4e20 POT/yr

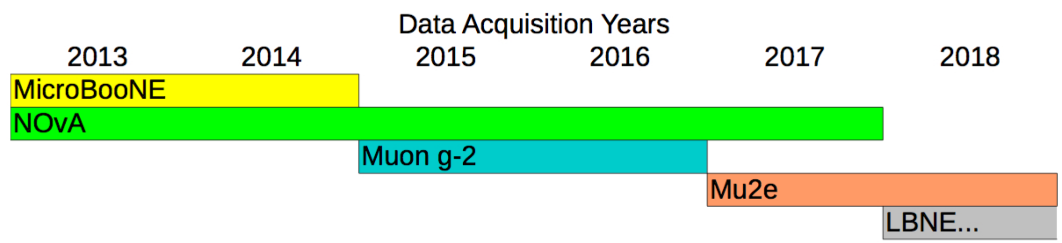
NOνA Time Line



FNAL Plan--Booster

- For planning purposes, assume 4e20 POT/yr
  - Compatible with other 8 GeV demands

Experiment	Total Beam Request
MicroBooNE	6.7×10^{20} POT
$g-2$	4.0×10^{20} POT
Mu2e	7.2×10^{20} POT

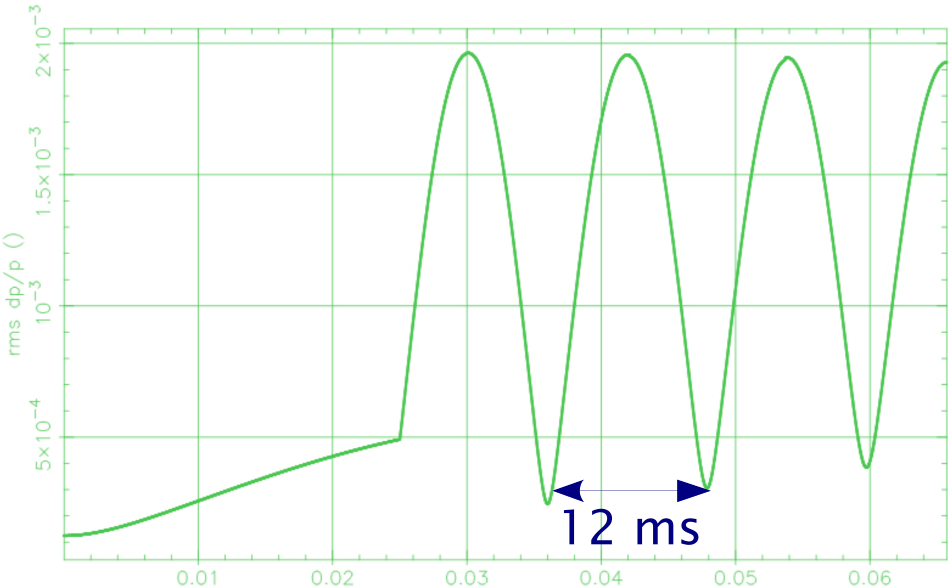


FNAL Plan--Booster to Recycler

- Use same transfer into the Recycler as NOvA

FNAL Plan--Recycler

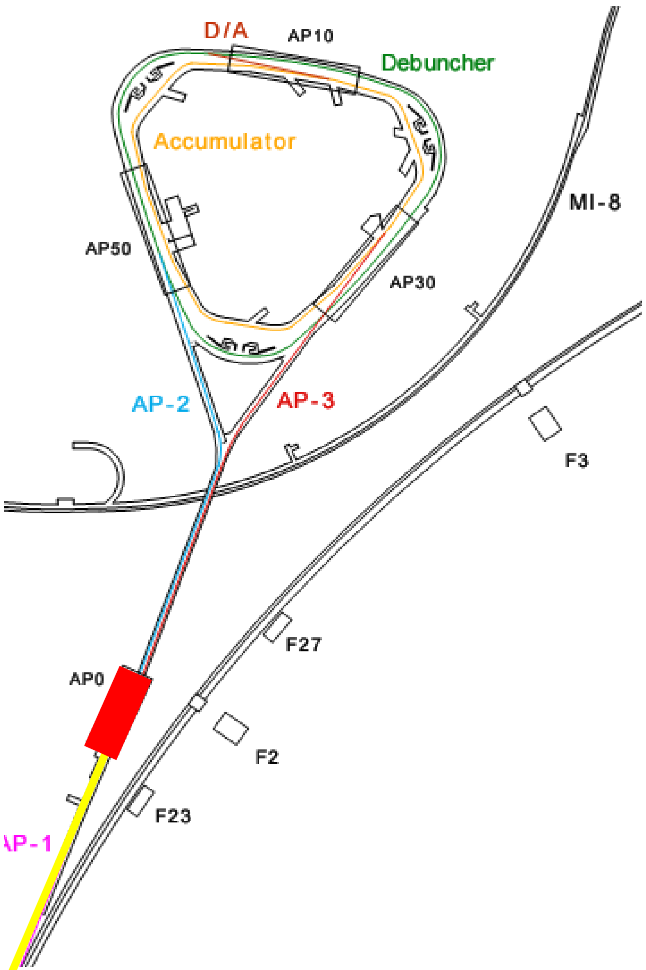
- To control rate-dependent systematics, need to rebunch each Booster batch into 4 bunches in the Recycler, 400 ns spacing
    - implies average rate of ~18 Hz into exp., compared to 4.5 Hz at BNL E821
- Need to move 2.5 and 5.0 MHz RF systems from MI to Recycler, possibly need to increase voltage by 10-30%
- Extract bunch every 12 ms



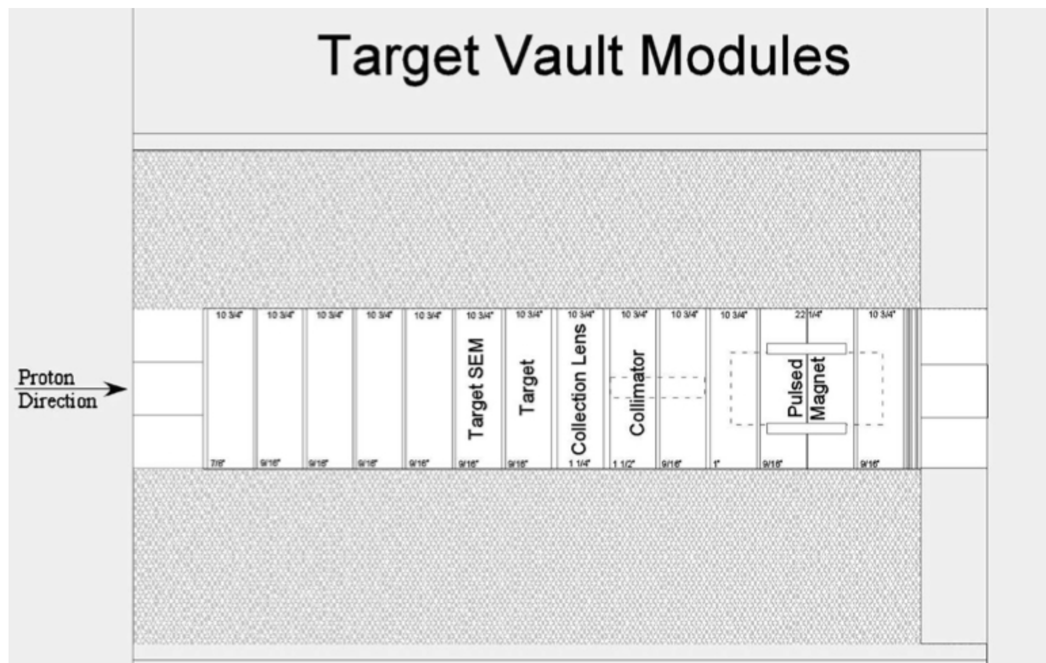
FNAL Plan--Extraction to AP1

- Very similar to NOvA injection line
- Connects Recycler to P1line --> P2 --> AP1
- Need a kicker to eject bunch every 12 ms
  - Average rate of 18 Hz
  - Rise time 180 ns, flat top 50 ns, back down in 5 s, ready to kick again in 12 ms
- Reduce losses in P1/P2 to handle 25 MW, 8 GeV beam

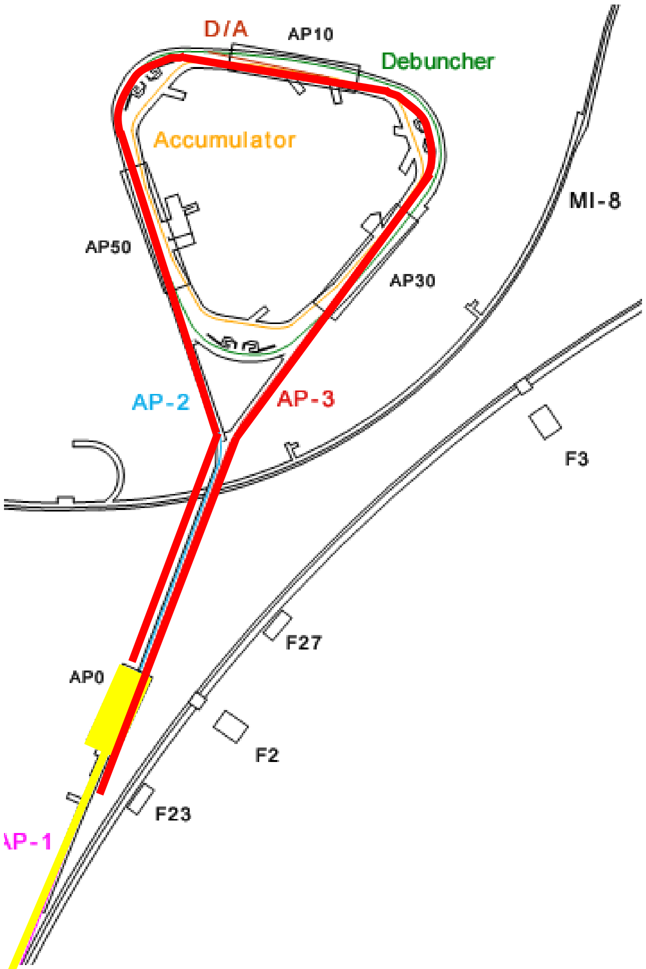
FNAL Plan--AP0 Target Station



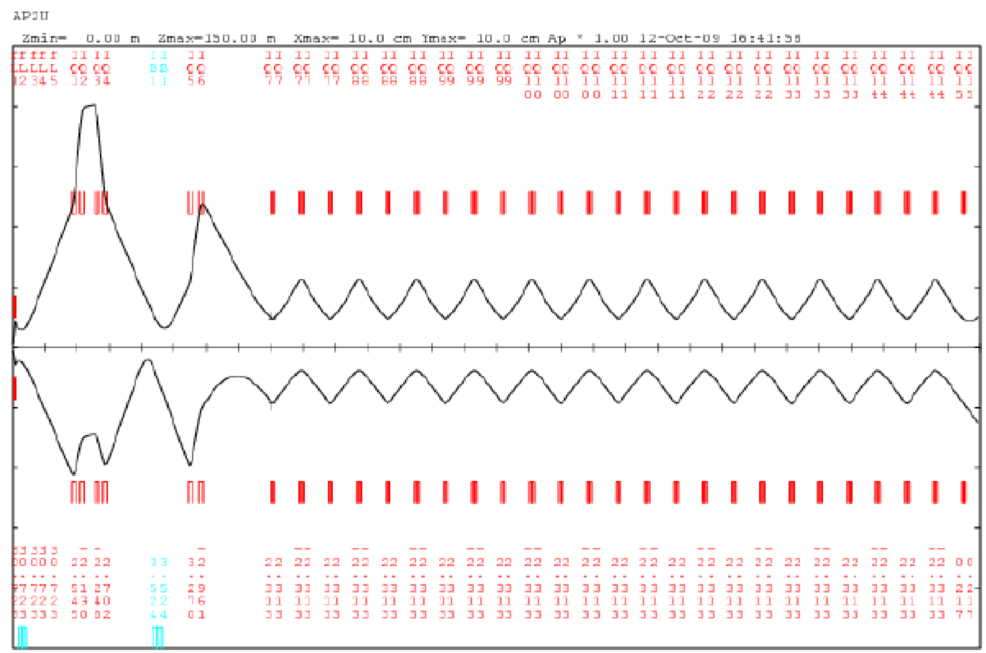
- Plan A: Use conventional rad-hard quads
  - Solution used in BNL E821
- Plan B: Reuse current target & Li lens
  - Have to evaluate if Li lens can operate at higher rate with reduced current
- Also looking at a multi-turn, DC PMAG design



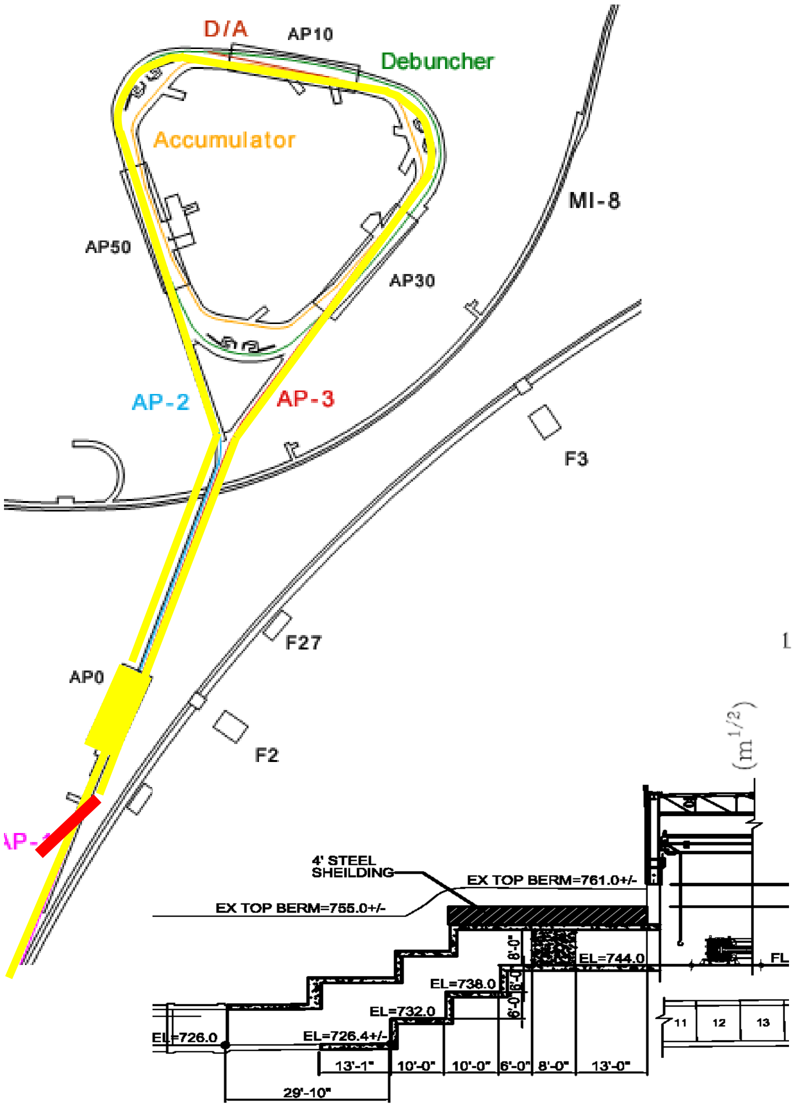
FNAL Plan--Pion decay line



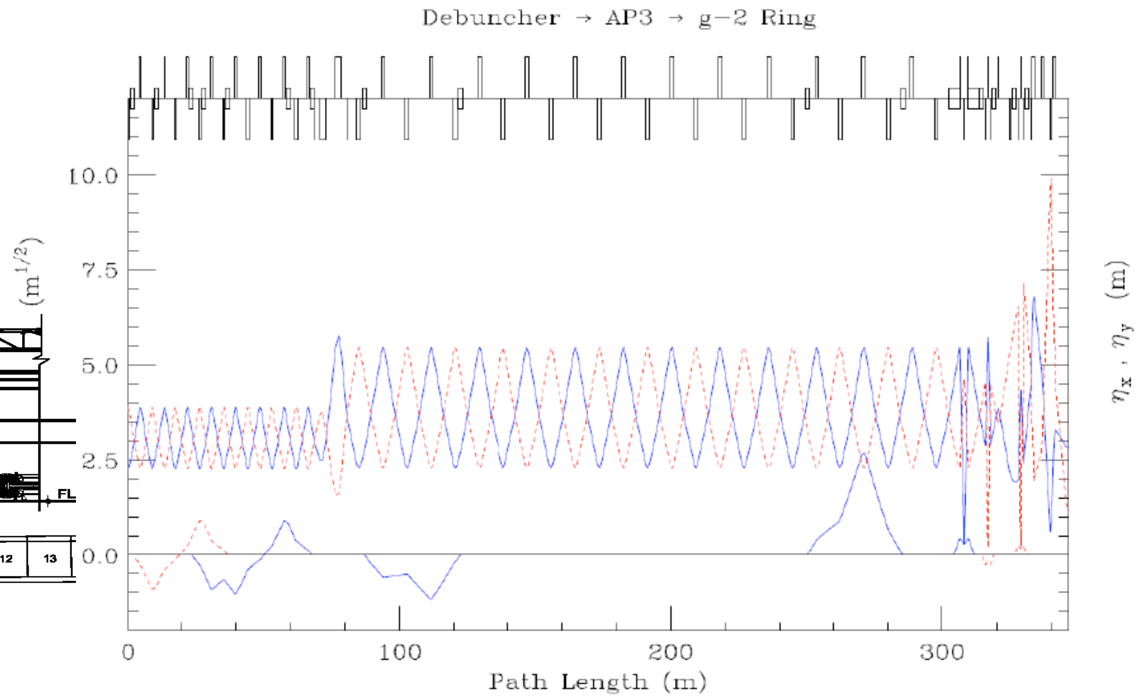
- Critical to the experiment is an 800 m or longer decay line (+--> +)
- Plan to use AP2 --> Debuncher --> AP3
  - New connection DEB-->AP3
  - Denser quad spacing in AP2/AP3



FNAL Plan--New tunnel to surface building

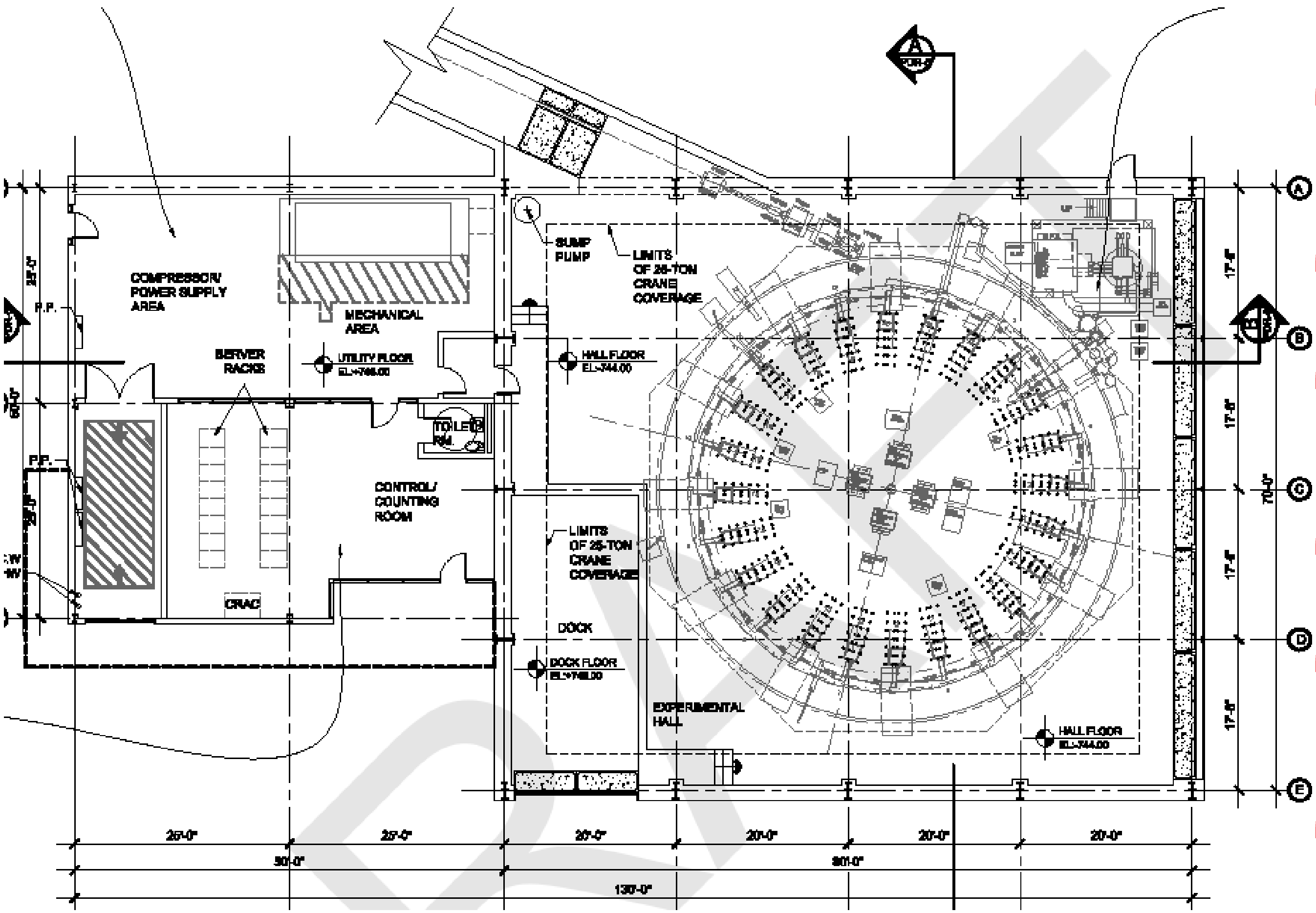


- Need to bring beam up to surface building
- Complicated optics
  - Horizontal and vertical bends keeping dispersion controlled
  - Match final optics into ring



Muon beam delivered to new building

Overhead view of new building design

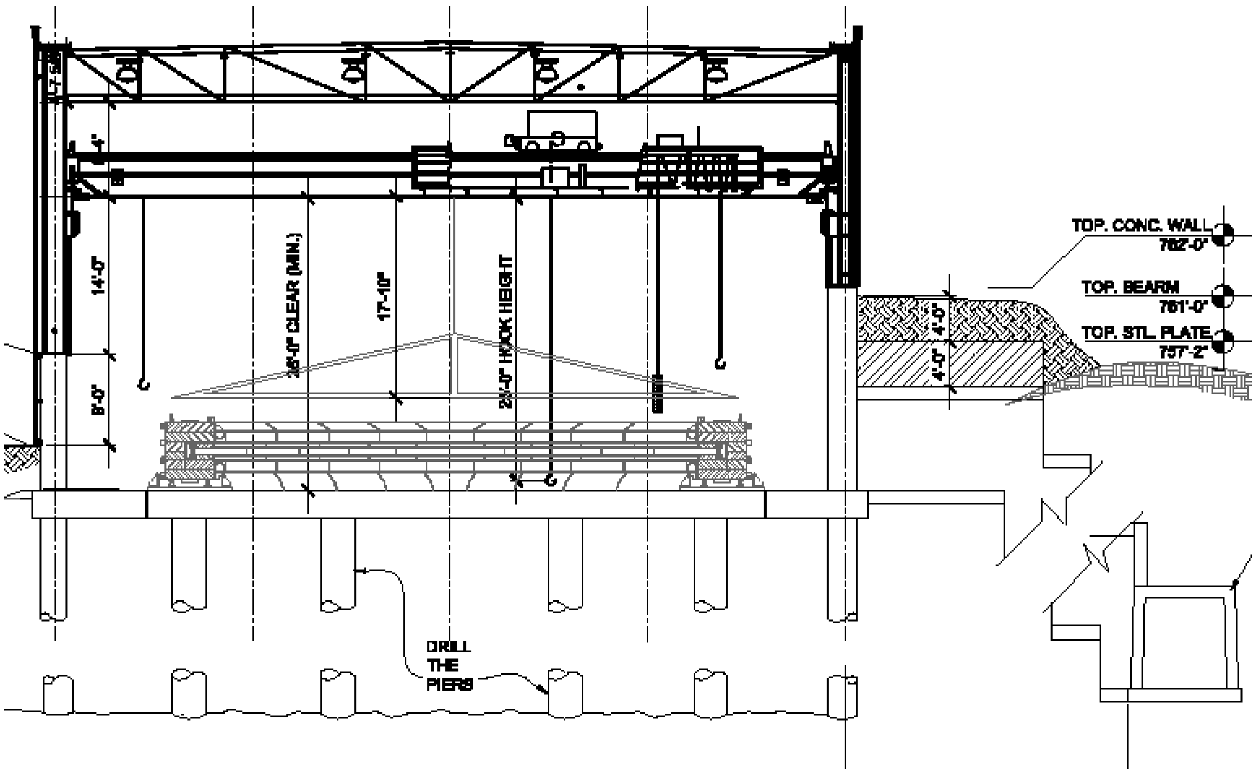


(Alber, Contreras, Huedem, Hunt, Niehoff, Stoica)

- Floor supports 650 tons via caissons down to bedrock
- Ring floor isolated from building
- Ring 4' below grade with 2'x8' additional shielding wall
- Temperature stability to +/- 2 F
- Includes new beam enclosure to bring beam up 18'
- Detailed total bldg cost $6.5M

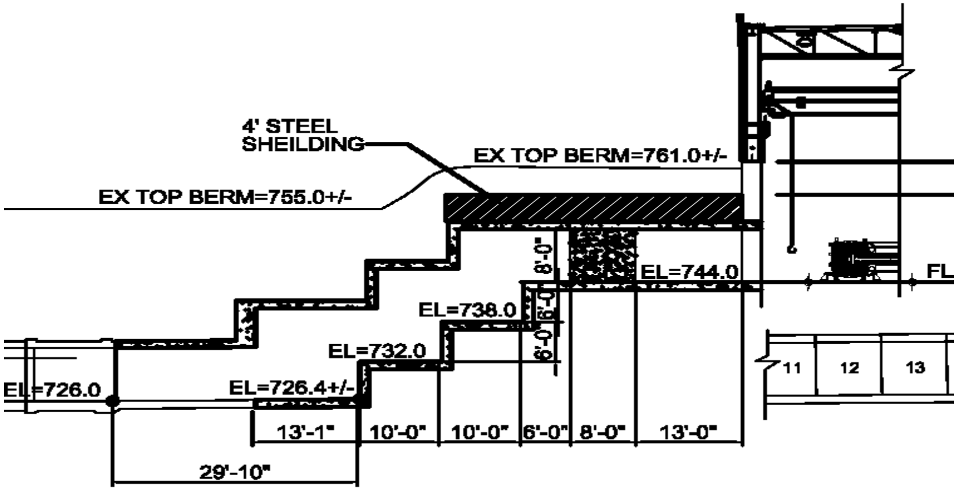
Muon beam delivered to new building

Elevation view of new building design

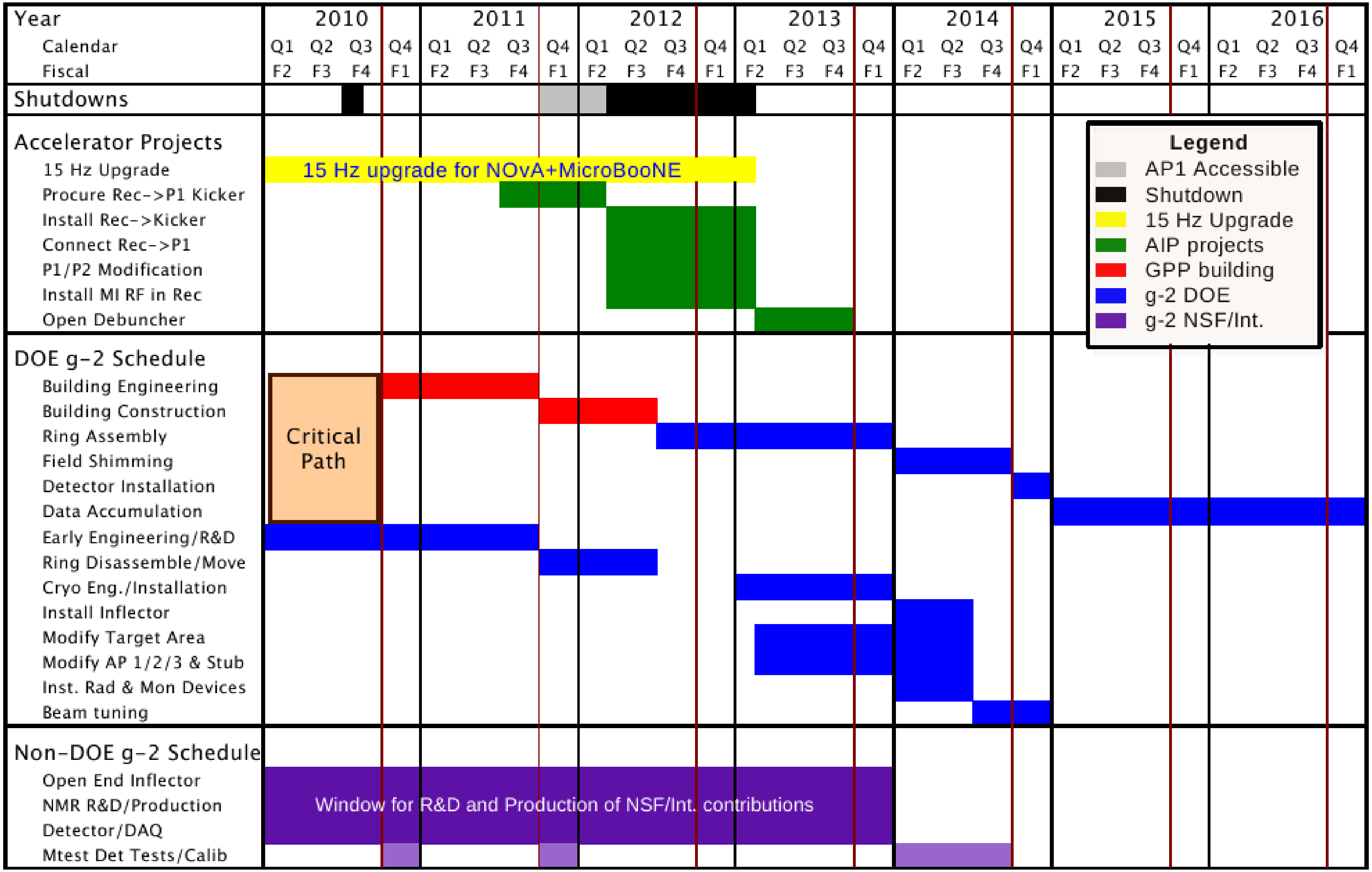


- Floor supports 650 tons via caissons down to bedrock
- Ring floor isolated from building
- Ring 4' below grade with 2'x8' additional shielding wall
- Temperature stability to +/- 2 F
- Includes new beam enclosure to bring beam up 18'
- Detailed total bldg cost $6.5M

How it might look on-site at FNAL

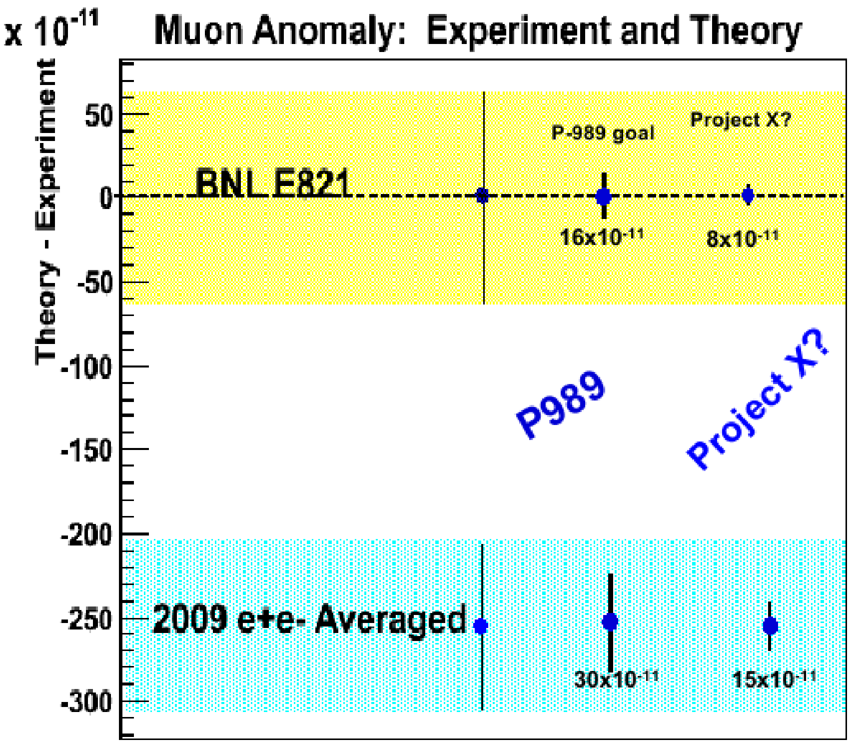


Project Timeline



In conclusion...

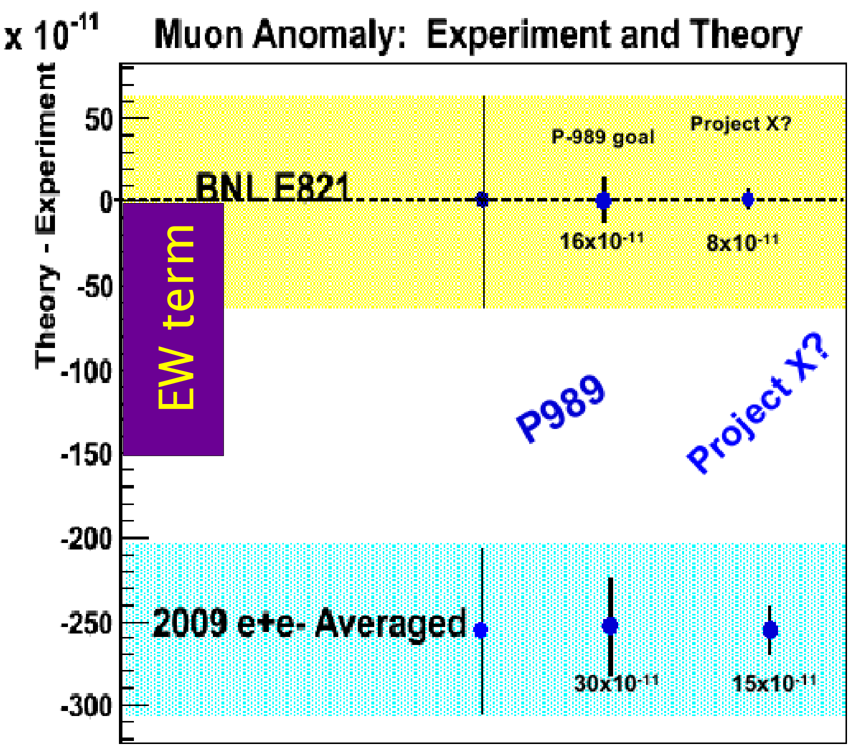
- Future of muon g-2 looks very promising over the next 5 years with gains in theory and experiment testing the BNL discrepancy at >7σ
- Improvement of our understanding of HLBL critical in the future
  - Extra confidence in existing theory estimation
  - FNAL experiment would end with HLBL as dominant error in a_μ(exp-thy)
  - Large potential for lattice to contribute significantly
- Project X era musings
  - plenty of beam power (25kW in P989, 2 MW then)
  - ICD2 design could provide storage ring fills at 1kHz (5 Hz in P989)
  - limit storage ring aperture to mag field 'sweet spot'
  - Motivation in this era critically relies on a path forward in reducing HLBL



In conclusion...

- Future of muon g-2 looks very promising over the next 5 years with gains in theory and experiment testing the BNL discrepancy at $>7\sigma$
- Improvement of our understanding of HLBL critical in the future
  - Confidence in existing theory estimation
  - FNAL experiment would end with HLBL as dominant error in a_μ(exp-thy)
  - Large potential for lattice to contribute significantly

For the first time since the development of the Standard Model, we have once again crossed into the unknown. The QED, QCD, and EW terms have all been tested...there are no other quantum field components left. Any residual difference is now by definition new physics!!!

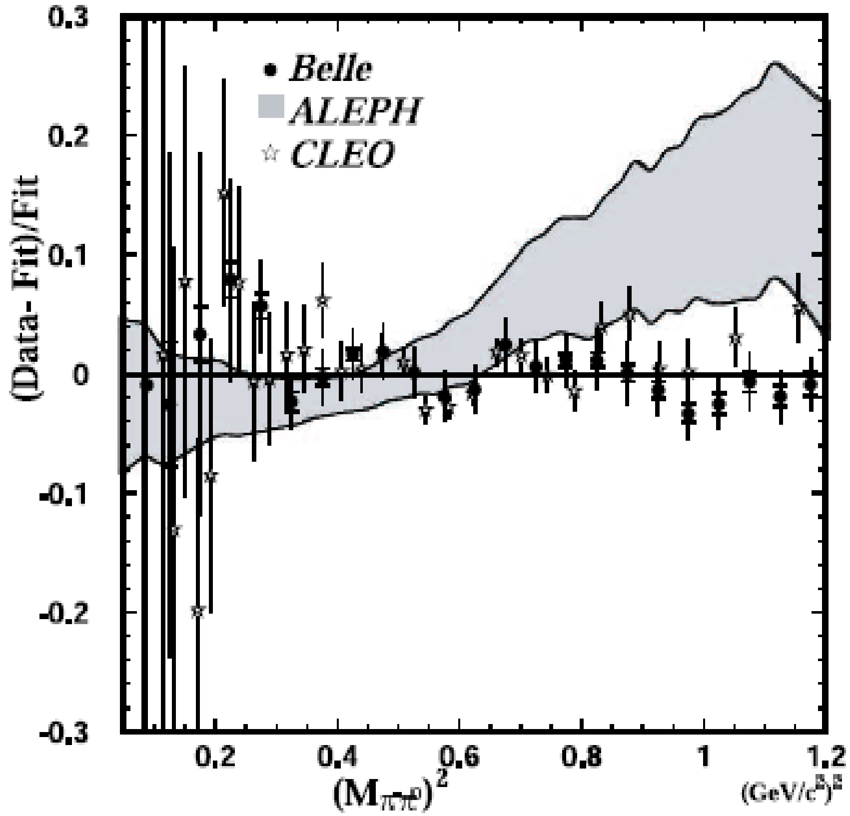


Backup slides

http://gm2.fnal.gov for more information, incuding full DOE proposal submitted this month

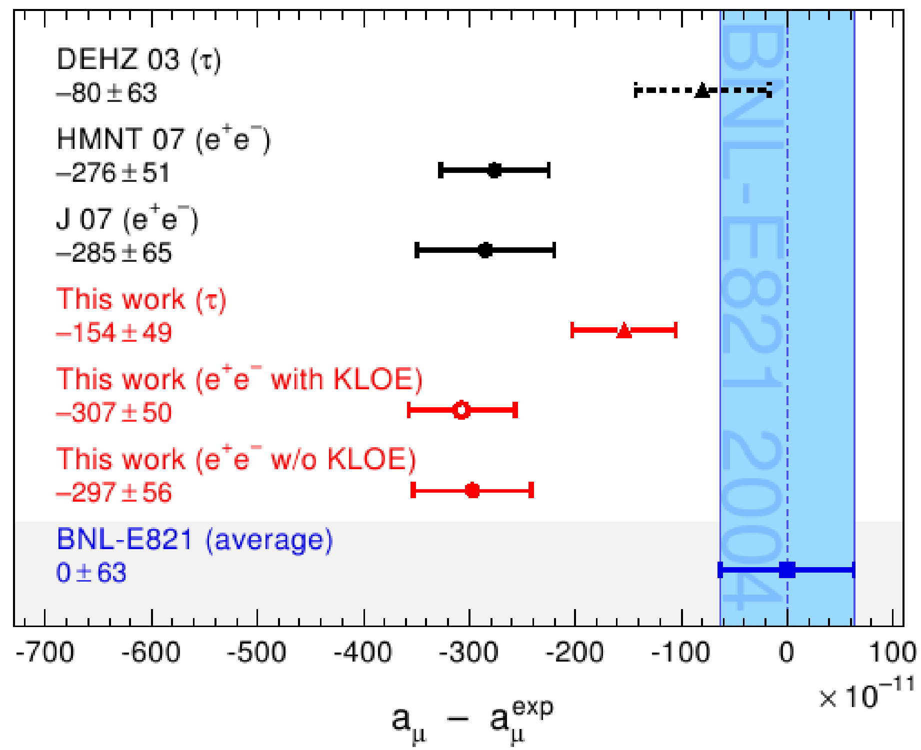
- Boston – electronics, beam dynamics simulations
- Brookhaven – quads, storage ring expertise
- Cornell – beam dynamics
- Fermilab – kicker, storage ring, straws, host institute, proton beams
- Illinois – beamlines, calorimeters, field quenching
- James Madison – calibration
- Kentucky – data acquisition
- Massachusetts – field shimming
- Michigan – simulations, field measurement
- Regis – fiber harp monitors
- Virginia – hodoscopes, simulations
- KVI Groningen – field team leadership, NMR systems
- LNF Frascati – calorimeter readout
- Novosibirsk BINP – beam dynamics, assembly
- St. Petersburg PNP – precision tracker
- KEK – electronics, inflector
- Osaka – detector contribution

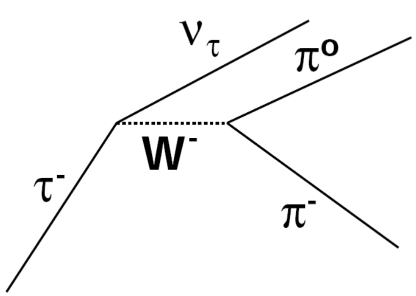
What about the τ?



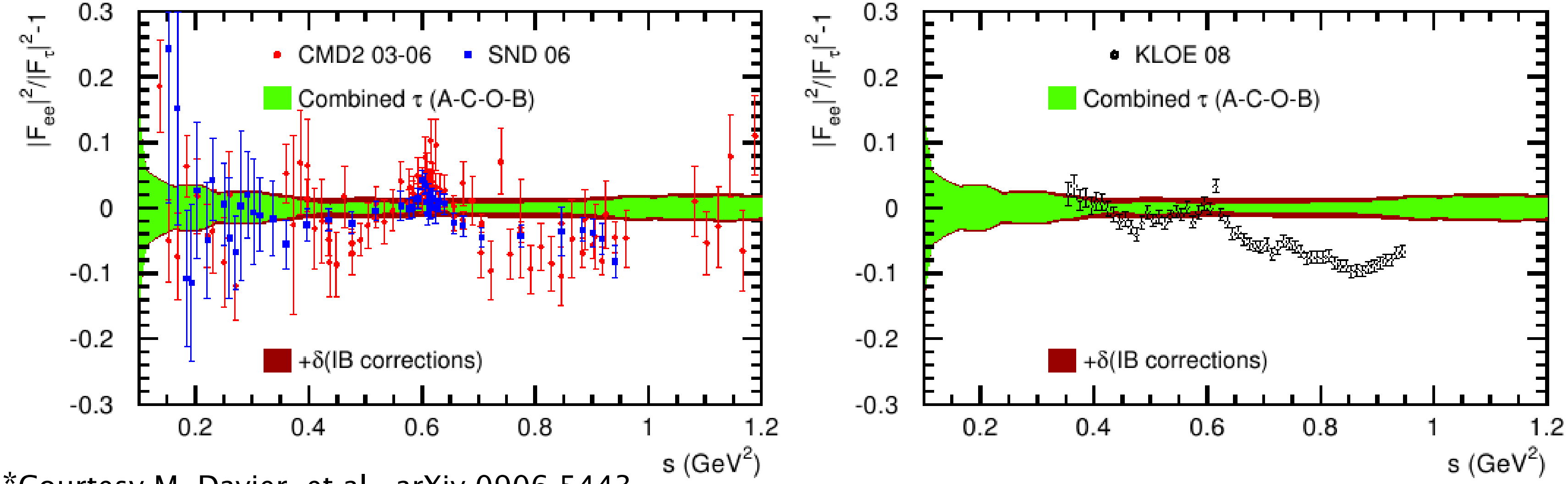
- Belle data in tension with ALEPH
- Direct prediction for N(2π) off by 4σ
- Original proponents think τ not usable until these discrepancies understood

*Courtesy M. Davier, et al., arXiv 0906.5443





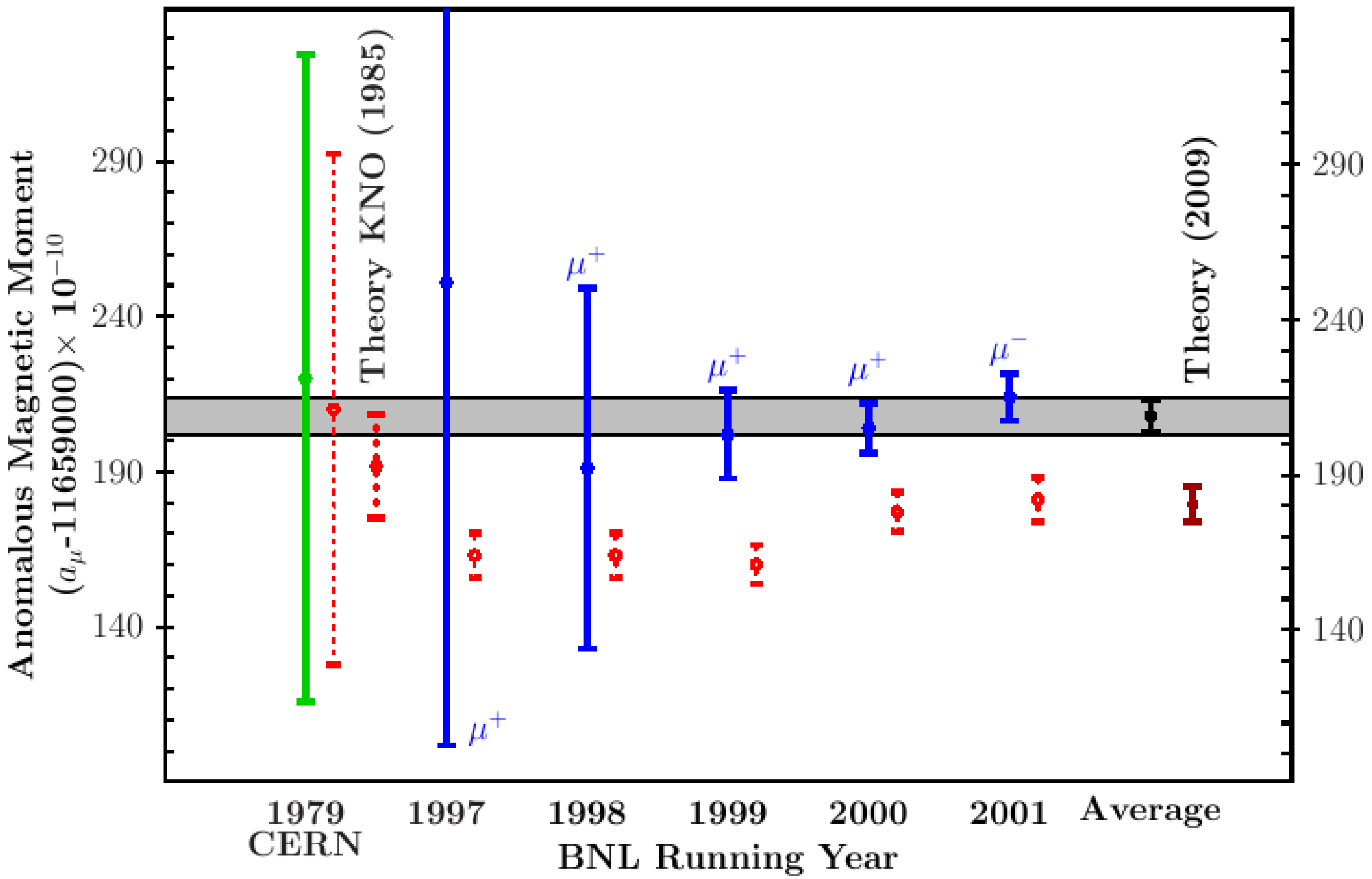
τ data systematically higher in 0.6-1.0 GeV



*Courtesy M. Davier, et al., arXiv 0906.5443

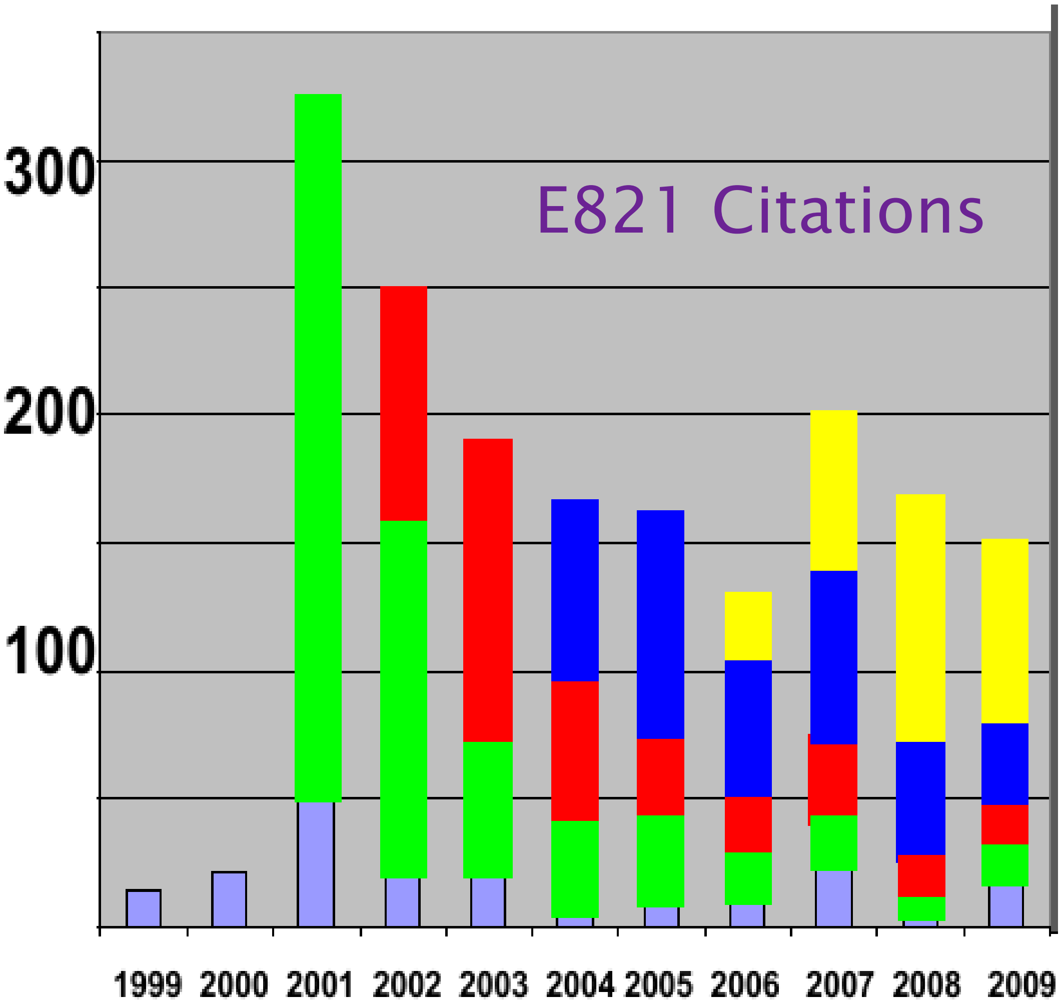
- Same region where region where Belle data in tension with ALEPH

Theory stable for decades (modulo 1 sign error)

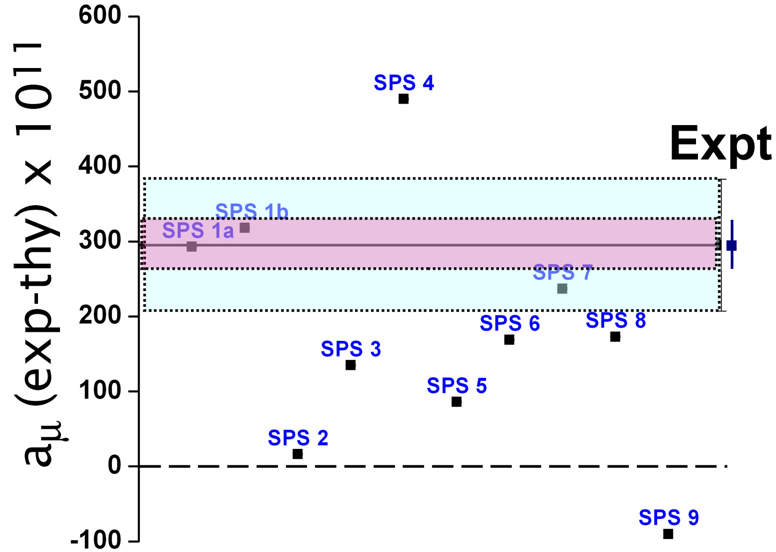


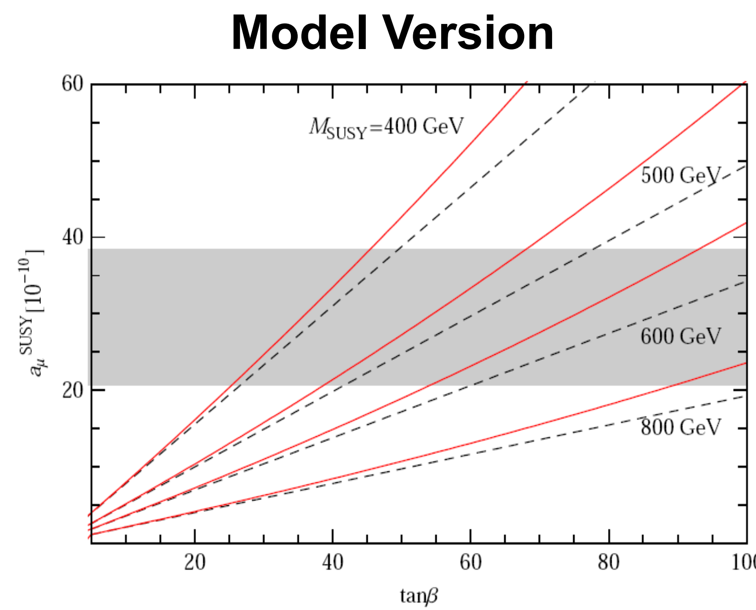
*Courtesy F. Jergerlehner, arXiv:0902.3360

This 3σ difference particularly relevant in LHC era..



continually confronted by g-2...general



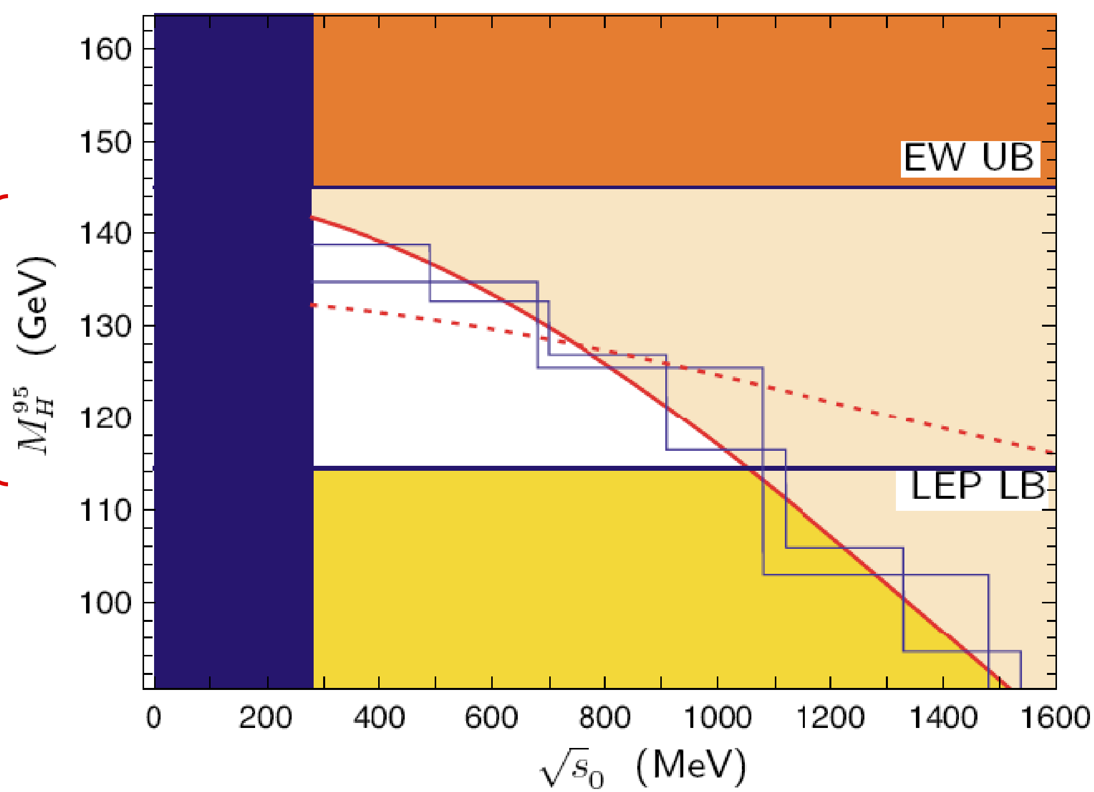


Marchetti, Mertens, Nierste, Stockinger (0808.1530)

What if the error was in σ(s)?

- How much does the M_H upper bound change when we shift σ(s) by Δσ(s) [and thus $\Delta\alpha_{had}^{(5)}(M_Z)$ by Δb] to accommodate Δa_μ ?

Higgs allowed



"where" to make the cross section change

Passera et al

This 3σ difference particularly relevant in LHC era..

- Imagine SUSY is proven to be reality…

  But which model is correct?

  - Huge resolving power between various scenarios
  - Current discrepancy consistent with more common Snowmass points

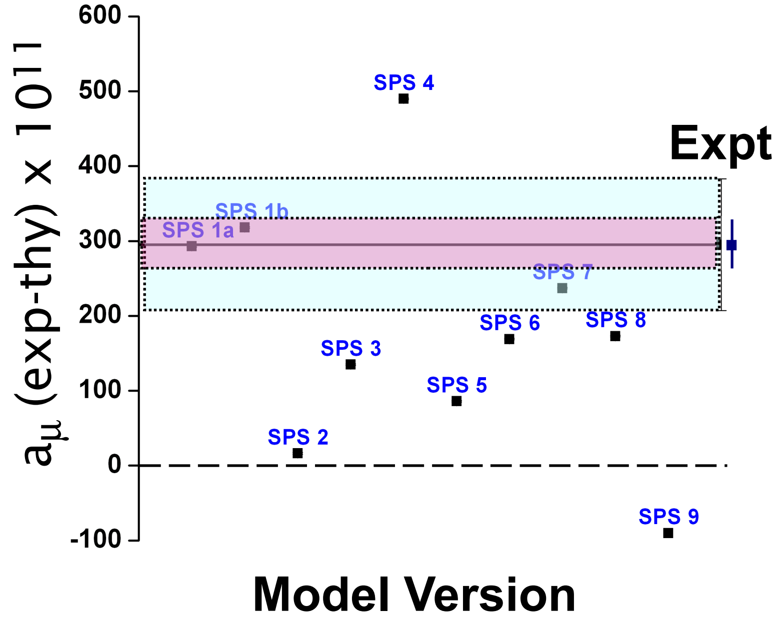
- Kaluza-Klein states or MSSM?

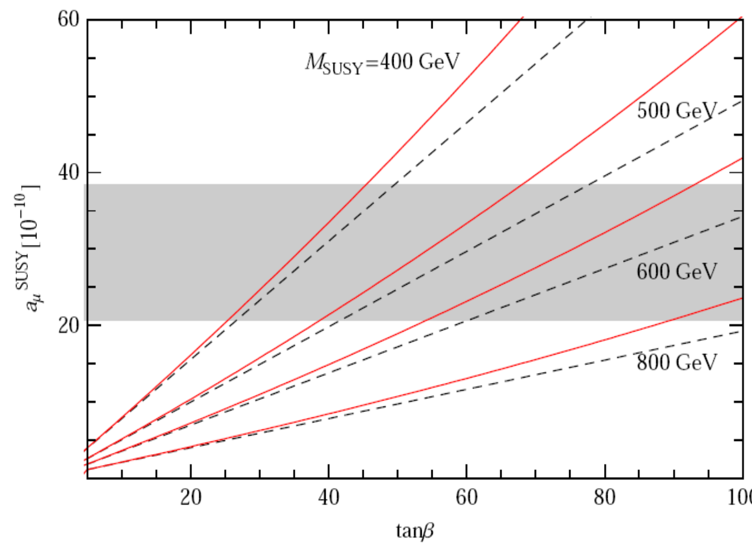
  a_μ (UED) = -13×10^{-11}

  a_μ (MSSM) = 298×10^{-11}

- tan β hard at LHC, g-2 much stronger

- Lots of other models (besides SUSY) continually confronted by g-2…general



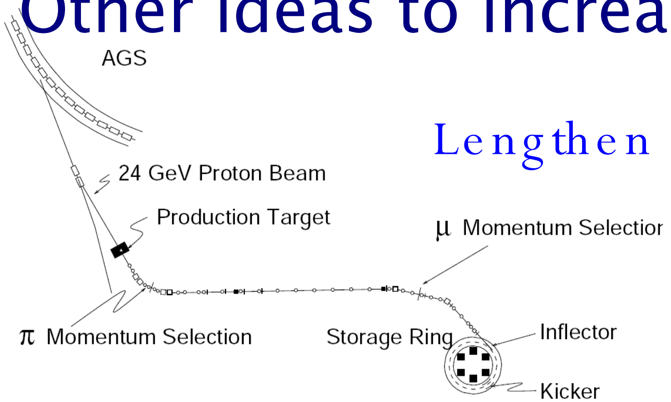


Marchetti, Mertens, Nierste, Stockinger (0808.1530)

Load not an issue and coils moved before

- Erickson Aircrane: Sikorsky S-64F specs
  - Rotor diameter 22.7 meters...compare to 14.5 meter diameter coils
  - Max hook weight 12.5 tons...compare to max coil weight of 8 tons
- Craned in past with lifting fixture shown
- Total in helicopter opearations <$380k

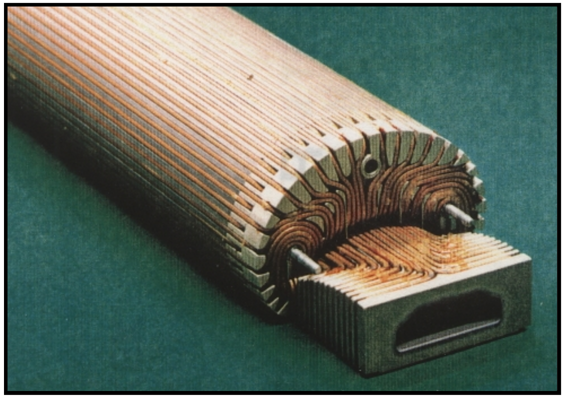
Other ideas to increase stored muons (and reduce errors)



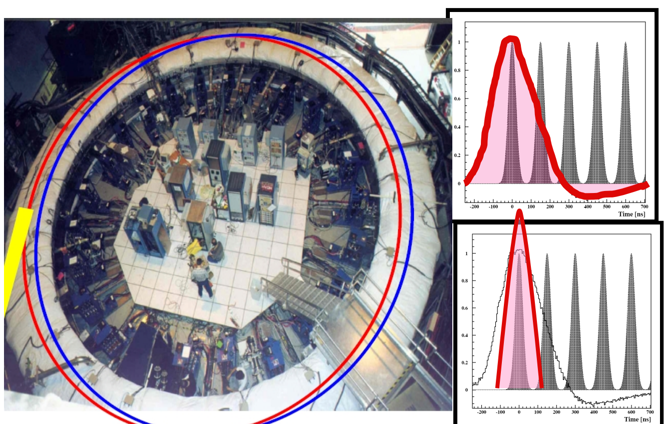
Lengthen π decay channel

Effect	2001 [ppm]	2000 [ppm]
CBO	0.07	0.21
Pileup	0.08	0.13
Gain changes	0.12	0.13
Lost muons	0.09	0.10
Others	0.08	0.08
Total ω_a Syst Error	0.21	0.31

Goal: total sys error < 0.1 ppm



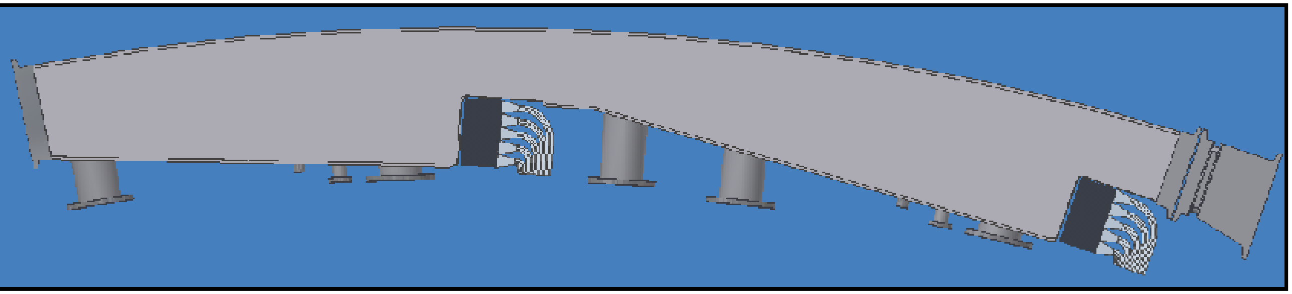
Open inflector

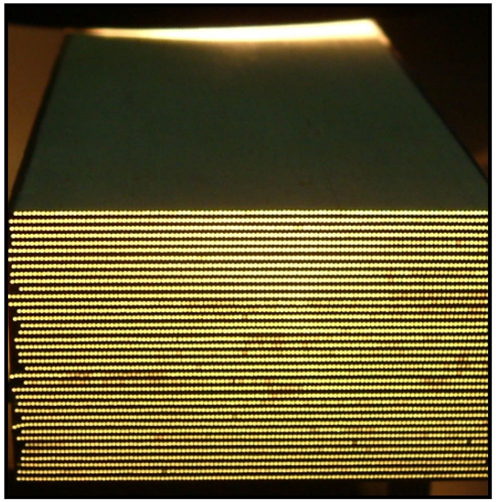


Better kicker waveform

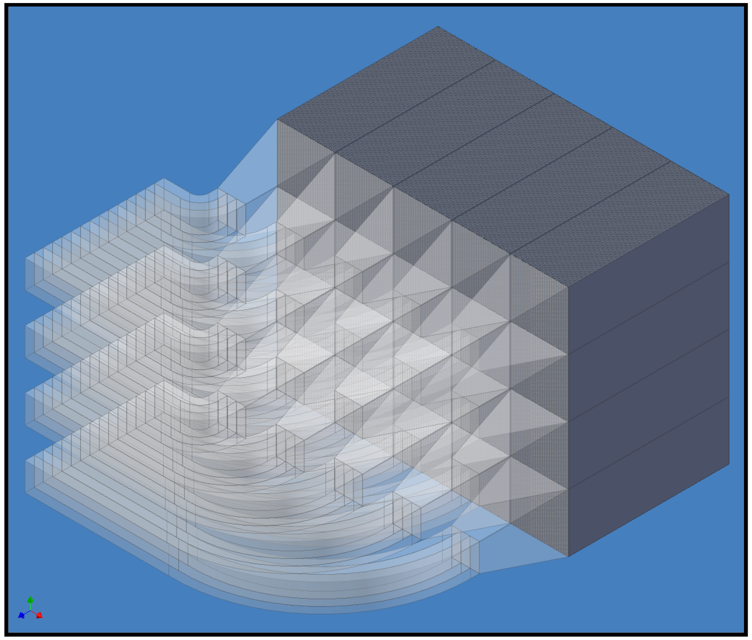
- Many other ideas to reduce errors, lots of interesting work to be done
  - Monitor muons with chambers in vacuum
  - Reduce pileup syst. with lower threshold

Spatial resolution of pileup

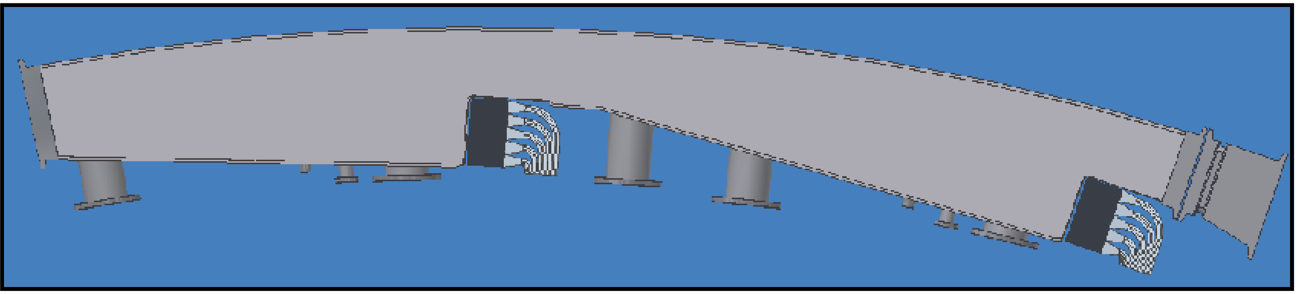


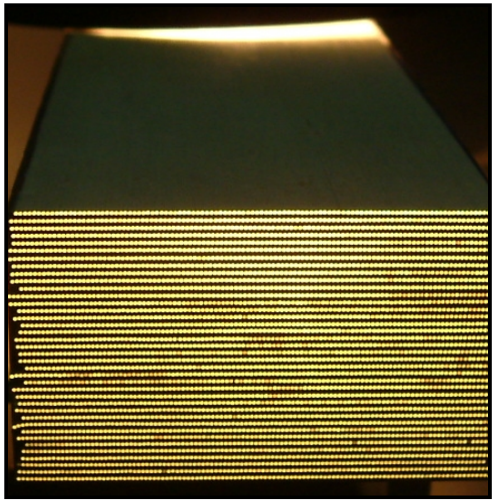


- Segmented W-SciFi calorimeter to provide ~35 cells of spatial resolution
  - Consistent with Moliere radius
  - BNL calorimeters had no segmentation
- R&D continues on SiPM readout (A. Para)
- 400-500 MHz WFDs to be mounted directly on each detector station
- First block constructed at Urbana and tested at FNAL MTest facility
- Next MTest run May 12-25 (A. Meyhoefer)



Spatial resolution of pileup





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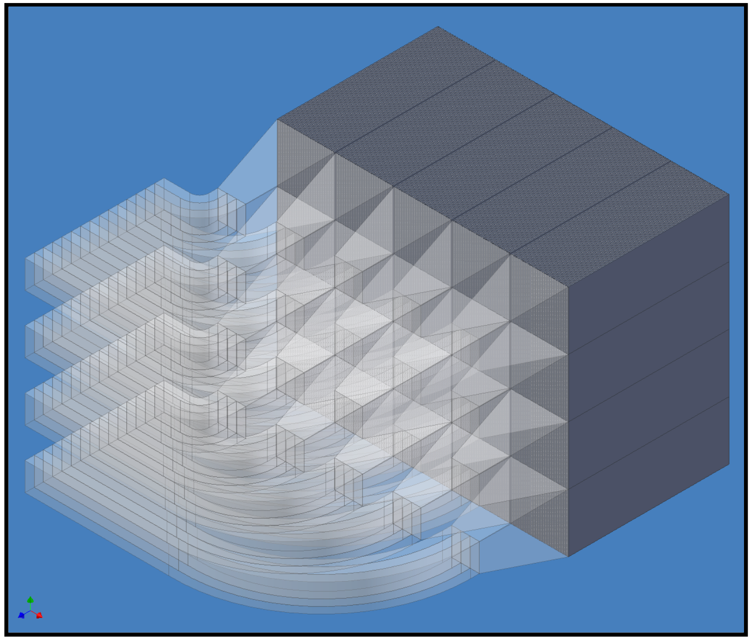
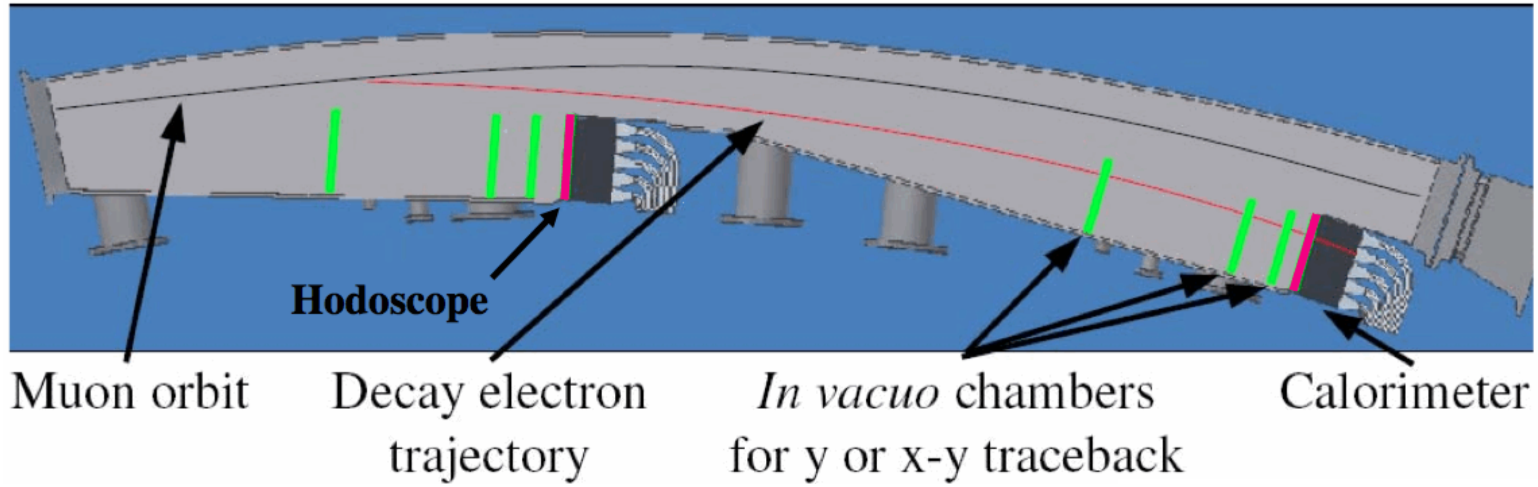
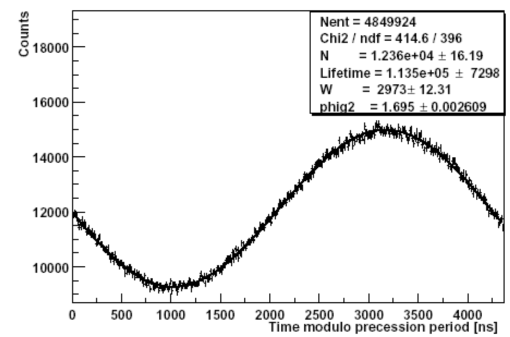


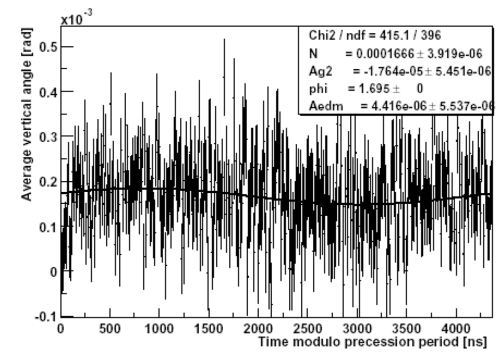
Measuring the electric dipole moment



- Best limit on μ EDM comes from single straw system (outside vacuum) in BNL g-2
  - Collected 10^7 tracks
  - Statistics limited

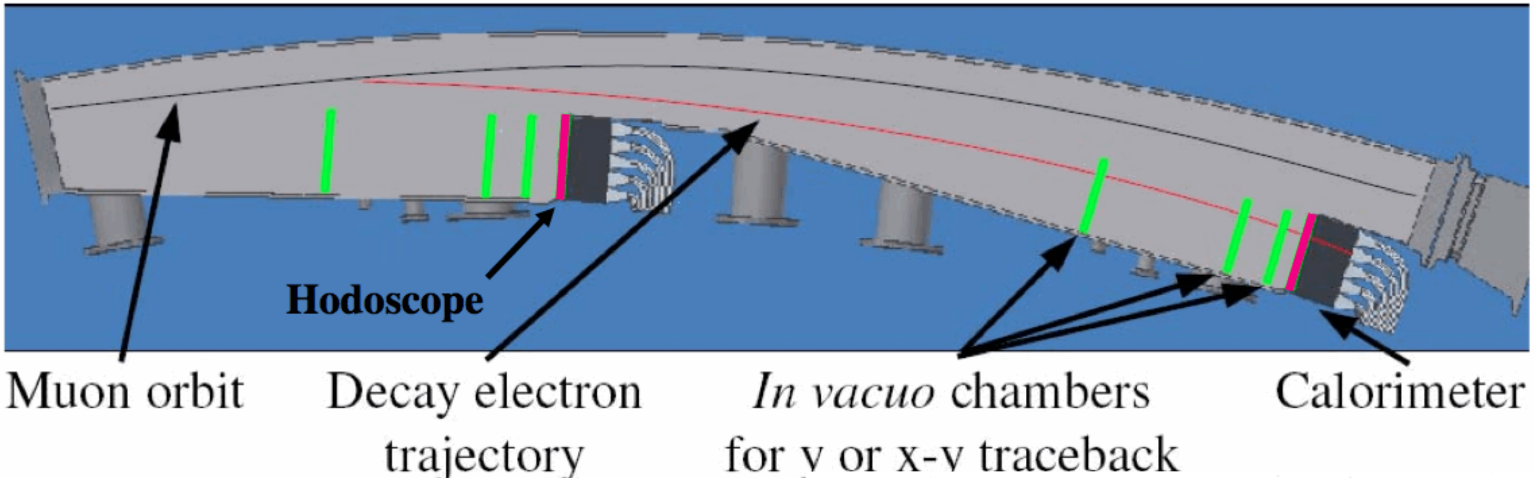
$$|d_{\mu^+}| < 3.2 \times 10^{-19}\ (e \cdot \mathrm{cm})\ (95\%\ \mathrm{C.L.})$$

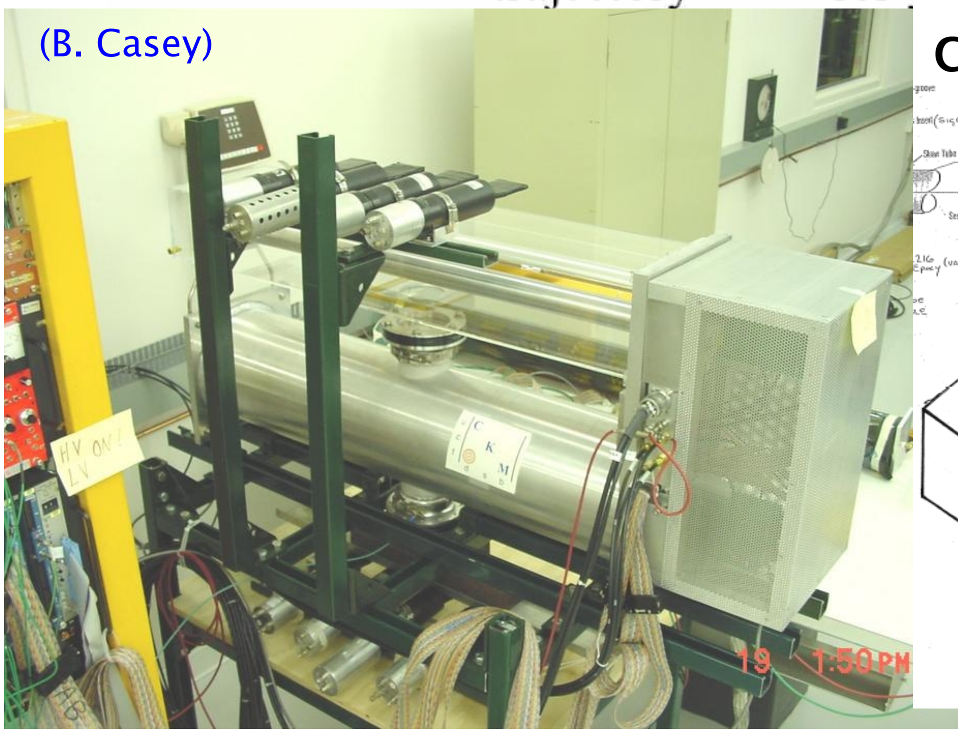


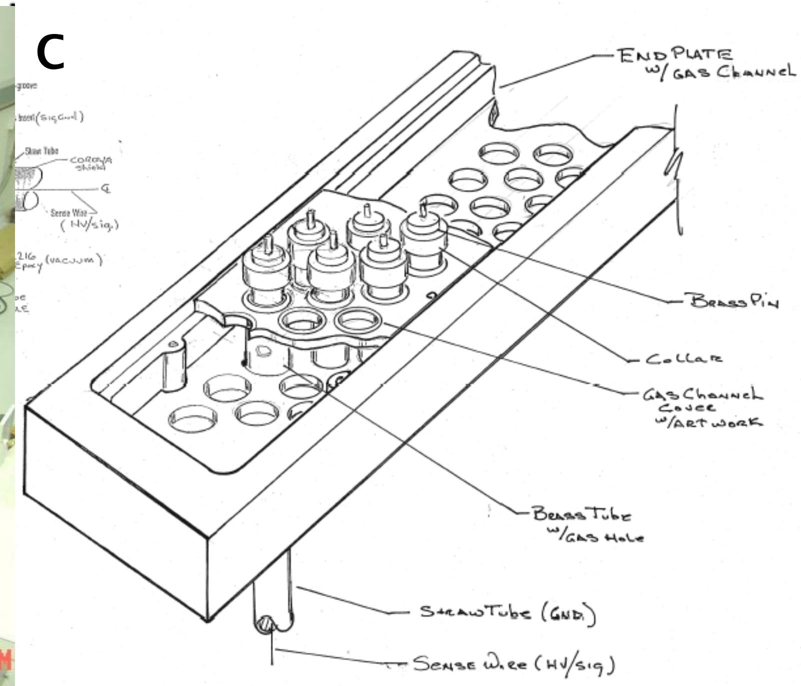


- Looking at installing 9 in-vacuo straw systems
  - Can collect >10^{10} tracks
  - Minimal factor of 30 improvement in d_μ

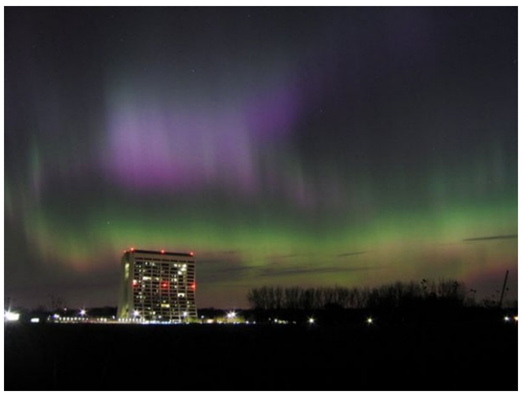
In-vacuo straw test stand at FNAL







OK, but why move to Fermilab?



- Brookhaven AGS: Hard to get more than about a factor of 10 in stored muons over original expt
- Even if we could get to x21, the instantaneous rates will make systematics difficult (many scale w/ rate)
  - Best rep rate at AGS...24 bunches in 2.7s
  - At FNAL Booster (after 15 Hz upgrade) we can use 6x4 (maybe even 8x4) bunches every 1.3s without interfering with NovA
  - If NovA is off we can go to 20x4 in 1.3s
- Additionally, since NovA is a >5 year program, there is not pressure to get the data all in 4 months
- Fits perfectly with the intensity/precision frontier that FNAL is hoping to establish over the next decade
- Perhaps even more ideas in a 2-4MW era
- From a cost perspective, really not that much more expensive due to repurposing existing infrastructure

Improvements at FNAL/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 ± 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

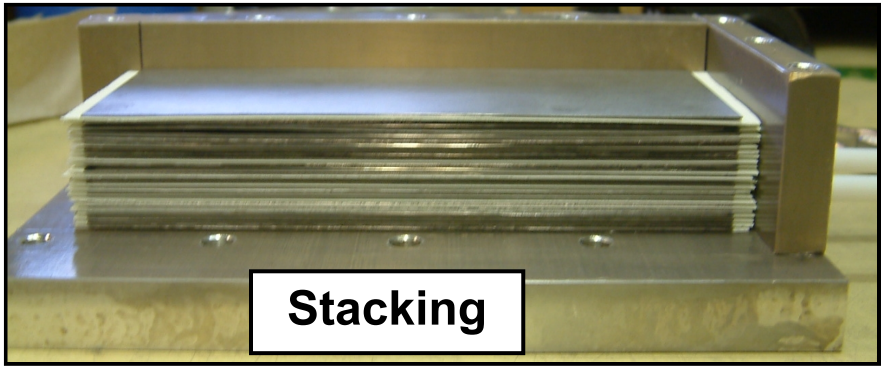
E821 Error	Size [ppm]	Plan for the New $(g-2)$ Experiment	Goal [ppm]
Gain changes	0.12	Better laser calibration and low-energy threshold	0.02
Lost muons	0.09	Long beamline eliminates non-standard muons	0.02
Pileup	0.08	Low-energy samples recorded; calorimeter segmentation	0.04
CBO	0.07	New scraping scheme;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

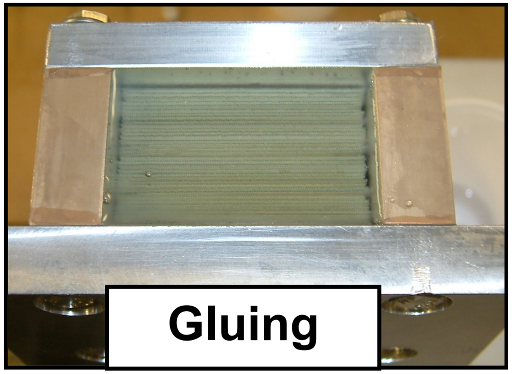
Source of errors	Size [ppm]				
	1998	1999	2000	2001	future
Absolute calibration of standard probe	0.05	0.05	0.05	0.05	0.05
Calibration of trolley probe	0.3	0.20	0.15	0.09	0.06
Trolley measurements of B_0	0.1	0.10	0.10	0.05	0.02
Interpolation with fixed probes	0.3	0.15	0.10	0.07	0.06
Inflector fringe 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

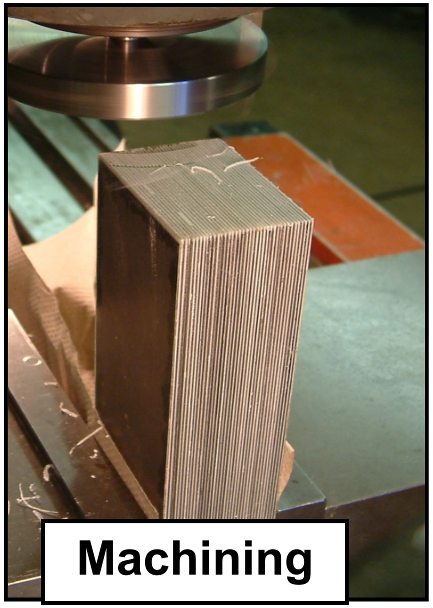
Improvements in B field determination

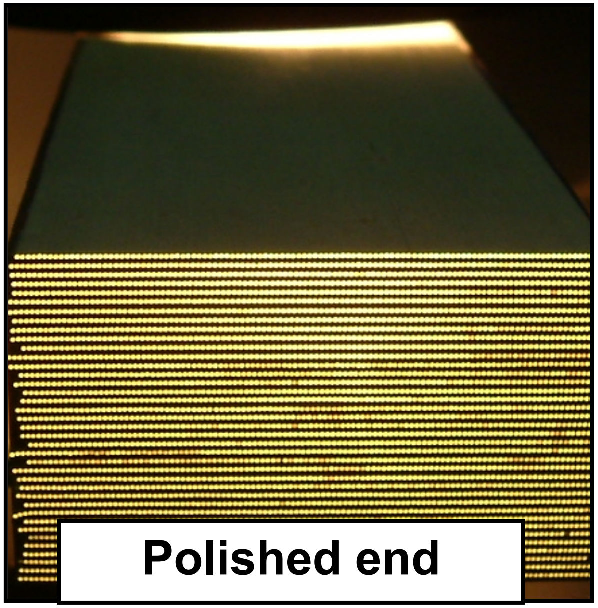
Source of Uncertainty	1998	1999	2000	2001	
Absolute Calibration	0.05	0.05	0.05	0.05	0.05
Calibration of Trolley	0.3	0.20	0.15	0.09	0.06
Trolley Measurements of B0	0.1	0.10	0.10	0.05	0.02
Interpolation with the fixed probes	0.3	0.15	0.10	0.07	0.06
Inflector fringe field	0.2	0.20	-	-	
uncertainty from 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

Fabrication test calorimeter block

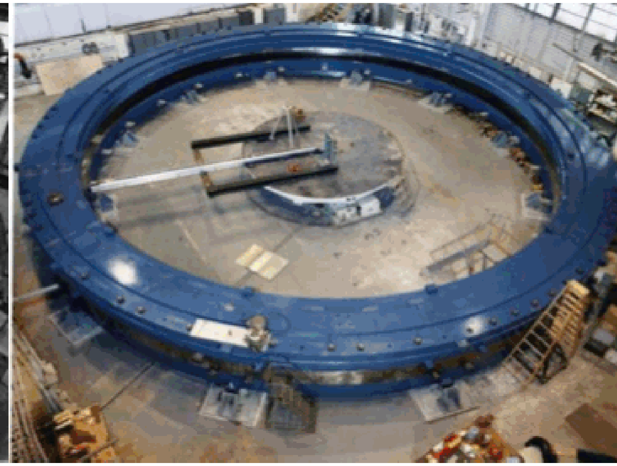


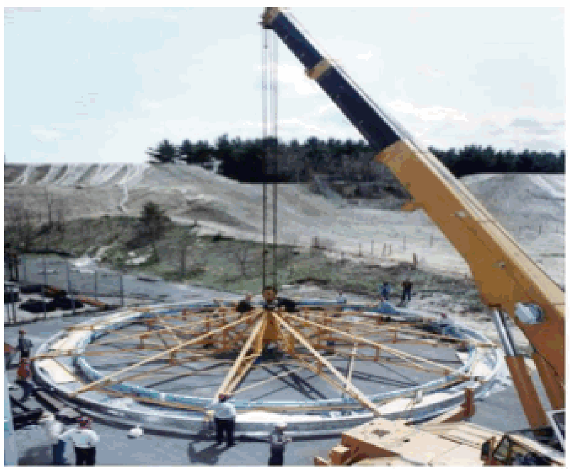
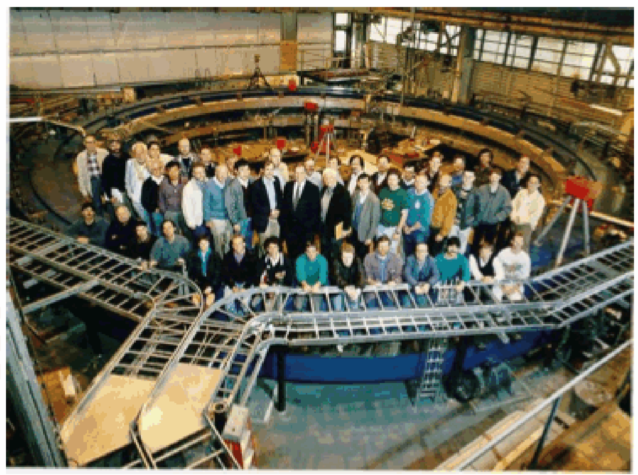
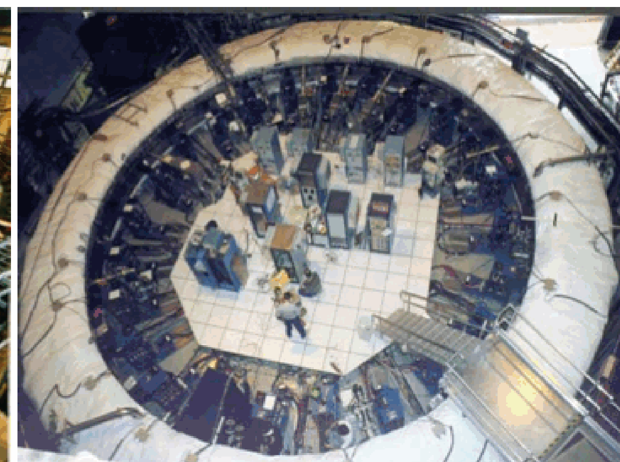


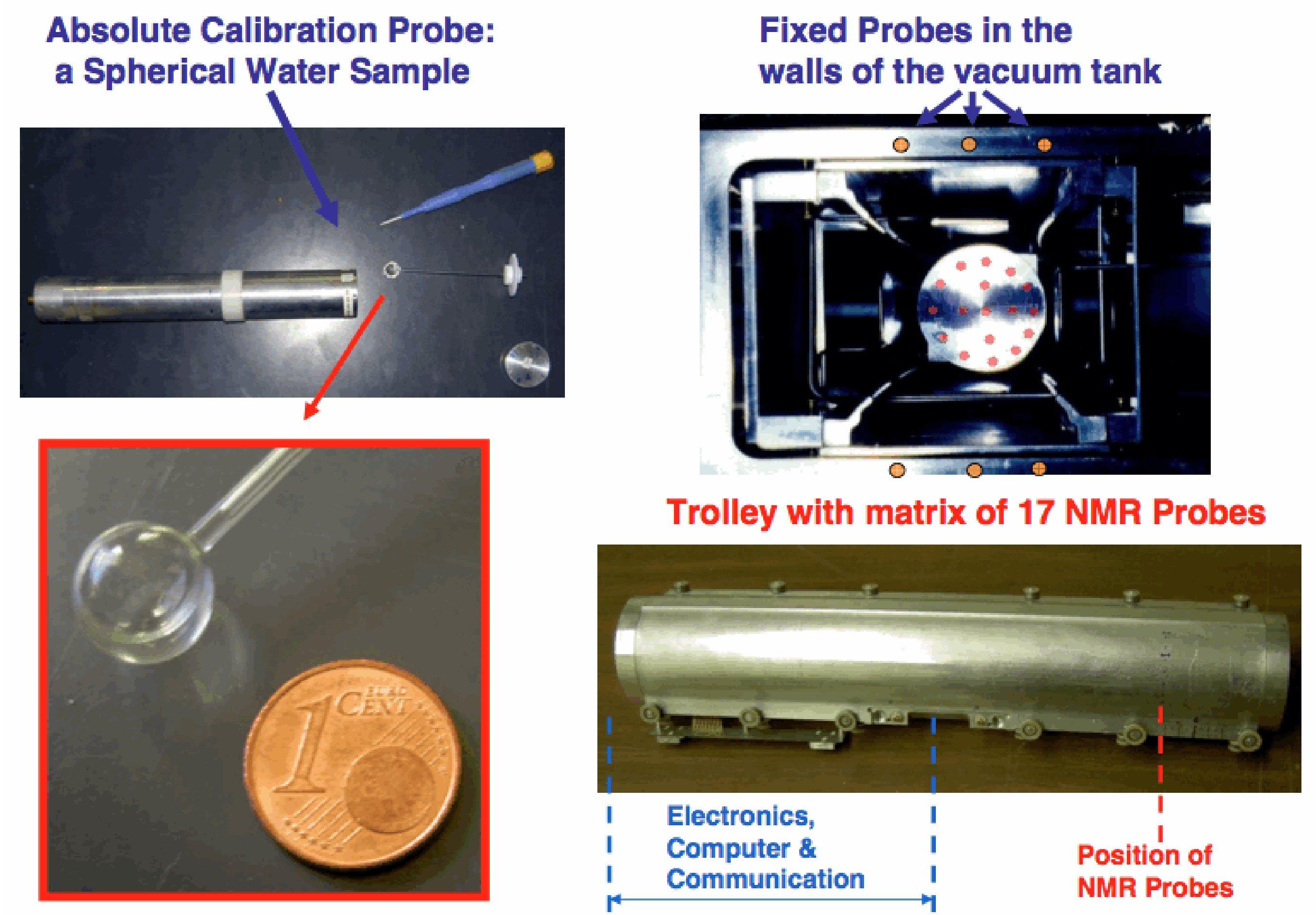




- Uses 0.5 mm thick tungsten plates without grooves, interleaved with 0.5 mm fiber ribbons


Scale document down



Absolute Calibration Probe:
a Spherical Water Sample
Fixed Probes in the
walls of the vacuum tank
Trolley with matrix of 17 NMR Probes
Electronics,
Computer &
Communication
Position of
NMR Probes

What about the muon mass?

VOLUME 82, NUMBER 4 PHYSICAL REVIEW LETTERS 25 JANUARY 1999

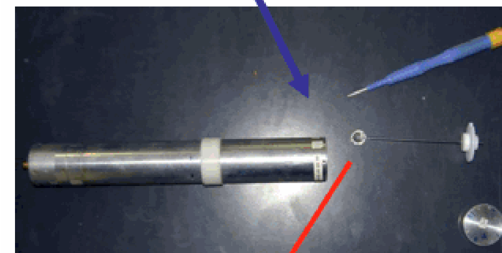
High Precision Measurements of the Ground State Hyperfine Structure Interval of Muonium and of the Muon Magnetic Moment

W. Liu,[1] M.G. Boshier,[1] S. Dhawan,[1] O. van Dyck,[2] P. Egan,[3] X. Fei,[1] M. Grosse Perdekamp,[1] V.W. Hughes,[1] M. Janousch,[1,4] K. Jungmann,[5] D. Kawall,[1] F.G. Mariam,[6] C. Pillai,[2] R. Prigl,[1,6] G. zu Putlitz,[5] I. Reinhard,[5] W. Schwarz,[1,5] P.A. Thompson,[6] and K.A. Woodle[6]

[1]*Department of Physics, Yale University, New Haven, Connecticut 06520-8121*
[2]*Los Alamos National Laboratory, Los Alamos, New Mexico 87545*
[3]*Lawrence Livermore National Laboratory, Livermore, California 94550*
[4]*ETH Zürich, Institute for Particle Physics, CH-5232 Villigen-PSI, Switzerland*
[5]*Universität Heidelberg, Physikalisches Institut, D-69120 Heidelberg, Germany*
[6]*Brookhaven National Laboratory, Upton, New York 11973*
(Received 21 August 1998)

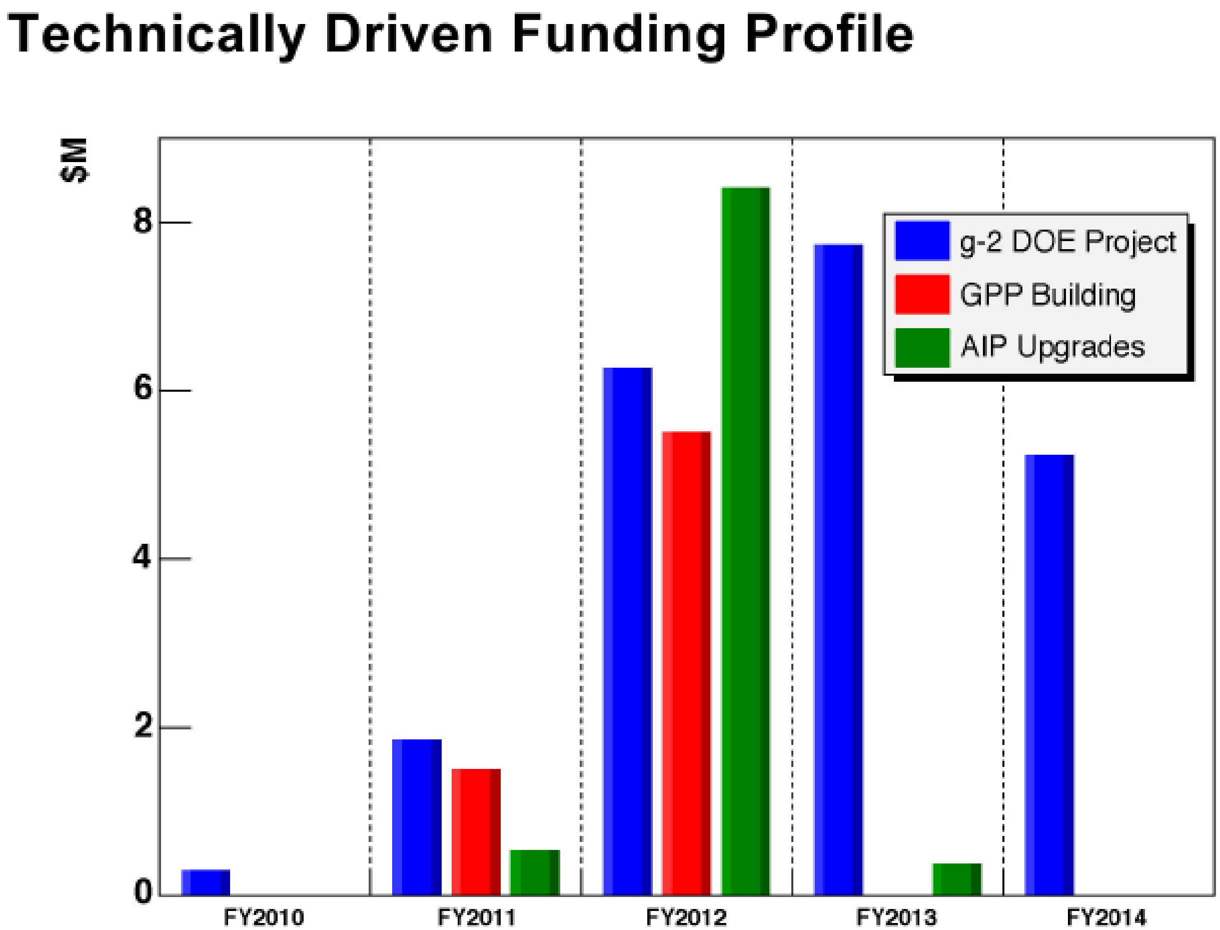
High precision measurements of two Zeeman hyperfine transitions in the ground state of muonium in a strong magnetic field have been made at LAMPF using microwave magnetic resonance spectroscopy and a resonance line narrowing technique. These determine the most precise values of the ground state hyperfine structure interval of muonium $\Delta\nu = 4\,463\,302\,765(53)$ Hz (12 ppb), and of the ratio of magnetic moments $\mu_\mu/\mu_p = 3.183\,345\,13(39)$ (120 ppb), representing a factor of 3 improvement. Values of the mass ratio m_μ/m_e and the fine structure constant α are derived from these results. [S0031-9007(98)08281-7]

Absolute Calibration Probe: a Spherical Water Sample



Fortuitous Physics Fact #3: Can use muonium hyperfine spectroscopy to eliminate dependence on muon mass measurement.

How much? TPC* of $42M



* $5M from NSF/international/D&D, $5M common to Mu2e ⇒ $32M incremental cost to DOE HEP to add g–2 to the existing program