Stato dell'analisi e richieste di calcolo

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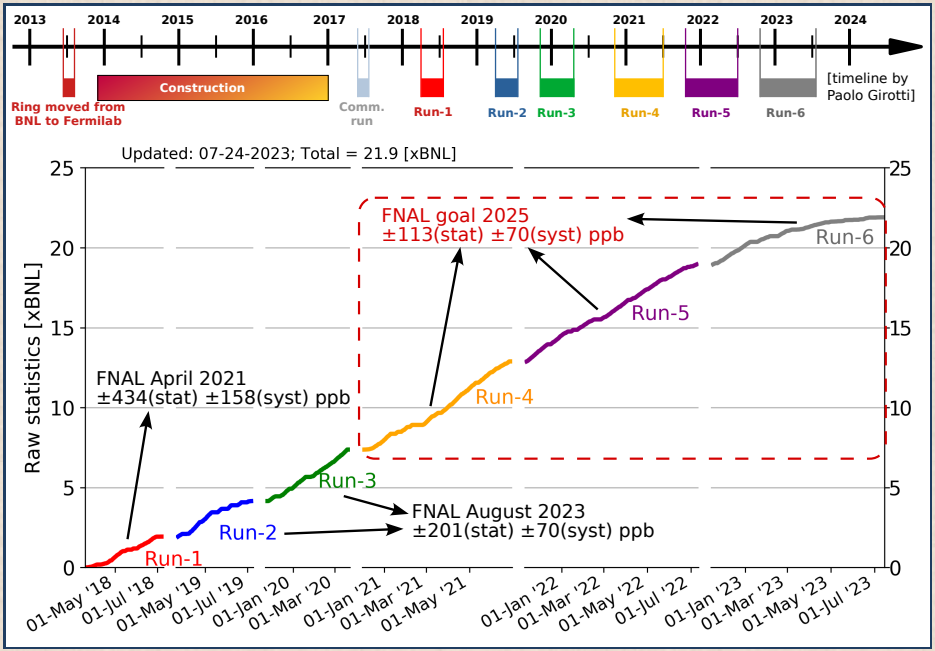
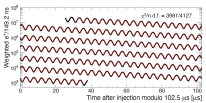
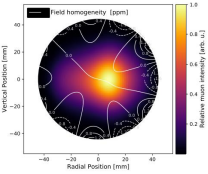
Gminus2 - riunione con i referee, 27 giugno 2024

Data recorded by FNAL Muon $g-2$ experiment







Master formula for a_μ

$$a_\mu = \frac{\omega_a}{\omega_p} \times \frac{\mu'_p(T_r)}{\mu_e(H)} \frac{\mu_e(H)}{\mu_e} \frac{m_\mu}{m_e} \frac{g_e}{2}$$

External factors, known to 25 ppb

Make spin precess slower

Make phase change over fill

$$\frac{\omega_a}{\omega_p} = \frac{\omega_a^m}{\omega_p^m} \frac{1 + C_e + C_p + C_{pa} + C_{dd} + C_{ml}}{1 + B_k + B_q}$$

Measured values

Transient magnetic fields

[taken from L.Cotrozzi, Sep 2023]

C_e	E-field
C_p	Up/Down motion
C_{pa}	Phase-Acceptance
C_{dd}	Differential Decay
C_{ml}	Muon Losses
B_k	Kicker Eddy current
B_q	Quad vibrations

Uncertainties on Run 2+3 a_μ measurement

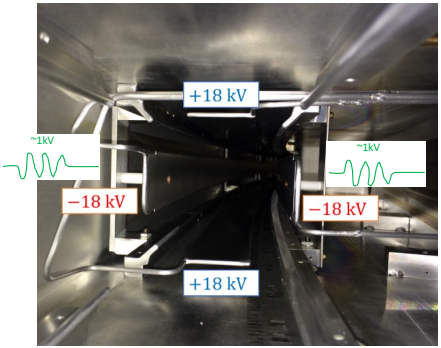
Quantity	Correction [ppb]	Uncertainty [ppb]
$\omega_a^{m,\mathbf{stat,Fit}}$	0.0	201.3
$\omega_a^{m,stat,\mathbf{Randomization}}$	0.0	0.8
$\omega_a^{m,\mathbf{stat}}$	0.0	201.3
$\omega_a^{\mathbf{Clock}}$	0.0	2.0
$\omega_a^{\mathbf{Times}}$	0.0	0.9
$\omega_a^{\mathbf{Gain}}$	0.0	4.7
$\omega_a^{\mathbf{Pileup}}$	0.0	7.0
$\omega_a^{\mathbf{Muon\ loss}}$	0.0	3.1
$\omega_a^{\mathbf{CBO\ model}}$	0.0	21.4
$\omega_a^{\mathbf{muon}\ p\ \&\ \tau}$	0.0	0.3
$\omega_a^{\mathbf{Residual\ Slow\ Term}}$	0.0	9.9
$\omega_a^{m,\mathbf{syst}}$	0.0	25.3
ω_a^m	0.0	202.9
$C_\mathbf{e}$	451.2	31.7
$C_\mathbf{p}$	170.3	10.0
$C_\mathbf{ml}$	0.0	3.0
$C_\mathbf{pa}$	-27.3	13.0
$C_\mathbf{dd}$	-14.5	17.2
...		

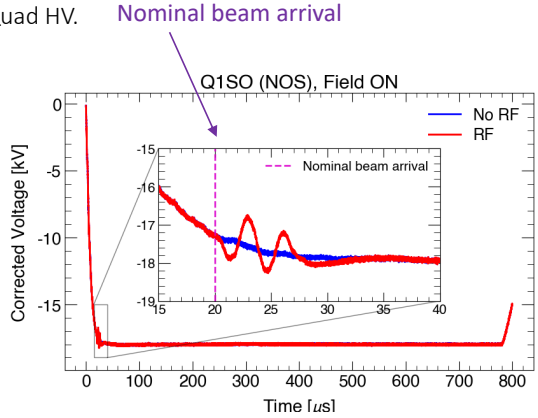
Quantity	Correction [ppb]	Uncertainty [ppb]
...		
$\tilde{\omega}_p'(T)^{m,\mathbf{stat}}$	0.0	7.9
$\tilde{\omega}_p'(T)^{m,\mathbf{syst}}$	0.0	45.8
$\tilde{\omega}_p'(T)^{m}$	0.0	46.4
B_k	21.4	13.3
B_q	21.0	19.5
$R_\mu^{\mathbf{stat}} = [\omega_a/\tilde{\omega}_p'(T)]^{\mathbf{stat}}$	0.0	201.5
$R_\mu^{\mathbf{syst}} = [\omega_a/\tilde{\omega}_p'(T)]^{\mathbf{syst}}$	622.1	69.8
$R_\mu = \omega_a/\tilde{\omega}_p'(T)$	622.1	213.2

- aim to confirm and possibly improve Run 2+3 systematics estimates for Run 4+5+6
- on-going Italian contributions to several areas:
  - calorimeter gain monitoring
  - CBO modeling in ω_a fit
  - electric field correction to ω_a
  - kicker transient field

Damping of horizontal oscillations with RF on quadrupoles (Run ≥5B)

- We apply the RF voltage on top of the Quad HV.

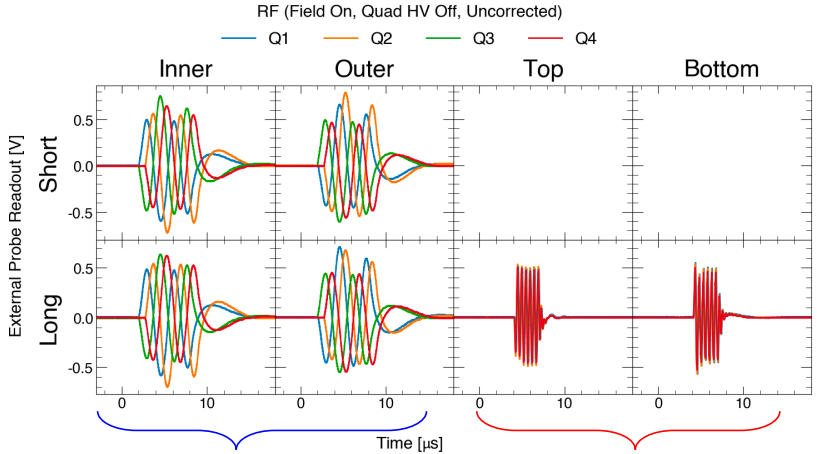




[On Kim, Mar 2024]

Added damping of vertical oscillations with RF on quadrupoles (Run $\geq$5M)

RF Waveforms



[On Kim, Mar 2024]

Three ω_a data samples

datasets	RF	fills
4A-U, 5A	noRF	82 M
5B-L	xRF	54 M
5M-U, 6A-N	xyRF	112 M

Studies to improve CBO modeling in ω_a fit

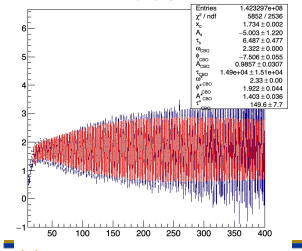
- Run 2+3: CBO systematics from varying model of varying amplitude and frequency
- Run 4+5+5: working on fitting CBO in time slices to get empirical time dependencies
  - fit CBO separately in each calorimenter (cancellation when summing on all)
  - fit CBO using traker and reconcile with calorimeter CBO fits
  - [Elia Bottalico, Daniele Boccanfuso (student)]

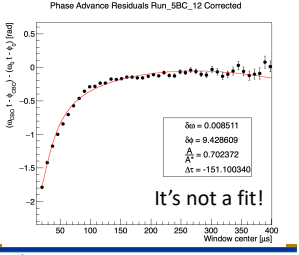
Modelling the phase advance

Thanks to this model, we can use parameters from x(t) fit to plug into it and describe the phase advance:

$$x(t) = A_{CBO}\, e^{-t/\tau_{CBO}} \cos(\omega_{CBO} t - \phi_{CBO}) + A^{*}_{CBO}\, e^{-t/\tau^{*}_{CBO}} \cos(\omega^{*}_{CBO} t - \phi^{*}_{CBO})$$

$$\phi(t) = \omega_0 t - \phi_0 + \tan^{-1}\left(\frac{\sin(\delta\omega t - \delta\phi)}{\cos(\delta\omega t - \delta\phi) + \frac{A_{CBO}}{A^{*}_{CBO}} e^{-\frac{t}{\tau_{CBO}} + \frac{t}{\tau^{*}_{CBO}}}} \right)$$





Computing and data production

- co-coordinator Paolo Girotti
- main production of ω_a data completed in 2023
- reprocessing of tracker data (Run 2,3,4,5,6) to get much improved efficiency, 36% done now
- reprocessing of ω_a data for reconstruction fix, almost complete
- reprocessing fast rotation analysis Run 4+5+6, 57% done
- processing of Run 6 mini-scifi data, done

ω_a measurement

- 6 independent groups, total of 20 analyses with different methods
  - strong Italian contribution to Europa analysis group (Lorenzo Cotrozzi, A.L.)
- [done] blinded preliminary fits on all 3 data samples
  - more detailed fit models, fit parameters from $\sim$27 to $\sim$37
- [on-going] task force on CBO modeling
  - above mentioned contributions by Elia Bottalico, Daniele Boccanfuso
- [on-going] task force on slow term in ω_a fit
- [on-going] study on calorimeter leakage correction [Paolo Girotti, Giorgia Tassone]
- [starting] ω_a measurements consistency checks [A.L.]
- [starting] systematics estimation
  - calorimeter gain systematics, responsibles Lorenzo Cotrozzi, Paolo Girotti
  - first pileup scans completed [Lorenzo Cotrozzi]
- [future] combination of different analyses measurements [A.L.]
- several months of work ahead, optimistically most work might be completed by end 2024

Beam dynamics corrections to ω_a

- co-coordinator Elia Bottalico
- [on-going] important refinement on fast rotation fit for the E-field correction [Elia Bottalico]
- expect months of work ahead (large improvements for Run 2+3, one of last items to be completed)
- expect other corrections not on critical path
- [done] first estimate of phase acceptance correction [Elia Bottalico]

ω_p measurement

stationary field

- issues with position determination from the trolley barcode reader
- ML code has been developed to recover, works well
- full analysis chain for muon weighting tested and working well
- consistency checks may be ready by July
- several months needed before completing uncertainty estimates

transient fields

- separate presentation by Paolo Girotti on kicker transient field measurement
- unsure about status of estimate of quad transient fiels – expect not in critical path

Computing in Italy

- have asked in 2023 and obtained in 2024 some computing resources at CNAF
  - 64 standard CPU cores (10 HEPSPEC06 each) for analysis
  - 160 TB of online, hot, disk space
  - 1.2 PB of tape
- have completed on-boarding in June
- disk not available right now, but expected to be in some months
- in the process of getting access to resources and learning how to use them
- no new computing request for 2025, we just ask to keep already granted resources

FNAL will close for two weeks at end of August

From Chief Operating Officer Greg Stephens: Two-week lab closure and low-tempo period

Inbox × fnal ×

Fermilab News
to allhands, all-users

5:08 PM (1 hour ago)

Message from the Chief Operating Officer

Two-week lab closure and low-tempo period

Dear colleagues,

As discussed in the recent all-hands meeting, Fermilab will be closed the weeks of Aug. 26 and Sept. 2, 2024, which coincides with the Labor Day holiday. This closure period is one of the measures to help align the lab's budget spending with available funding. We are finalizing a plan to help minimize the impact on employees with insufficient vacation accrual to cover the closure period. As Lia mentioned in the all-hands meeting, we are making provisions so that no employee will have to take leave without pay.

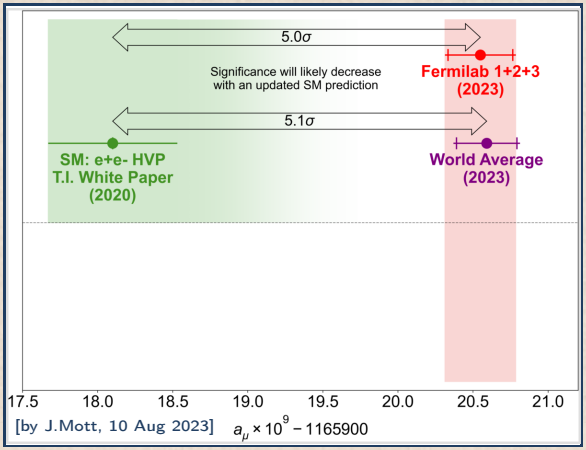
During the closure, Fermilab operations and activities not related to the safe operations of DOE O 413.3B projects or necessary to safeguard lab facilities will be suspended. Personnel will not be allowed to perform any onsite or remote work unrelated to the laboratory's reduced operational status and DOE O 413.3B project activities. In case of unexpected issues or emergencies, normal supervisory call-in processes will be followed, and repair/restoration activities will be coordinated with senior leadership.

- confirms our concerns, we are eager to transfer data to CNAF and use CNAF computing

Thanks for listening

Backup Slides

Comparison with theory



- large discrepancy with WP2020 prediction
- but new measurements not included in WP2020 expected to decrease significance of discrepancy

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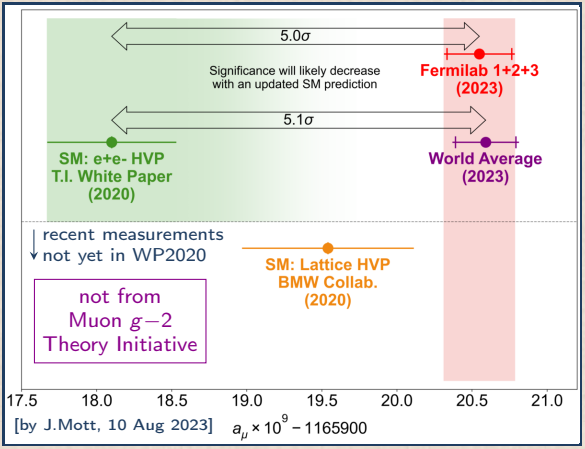

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- replace WP2020 $a_\mu^{\mathrm{HVP,LO}}(\pi^+\pi^-)$ in $[0.33, 1.0]$ GeV interval with CMD-3 $\sigma(e^+e^- \to \pi^+\pi^-)$ measurement [A. Keshavarzi, Lattice 2023] (this is a visual exercise, not an updated SM prediction)

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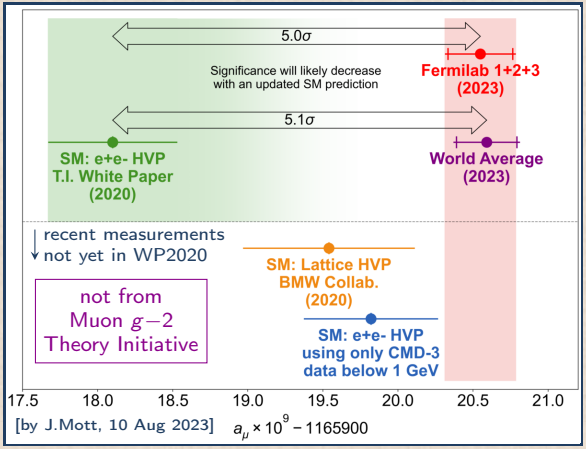

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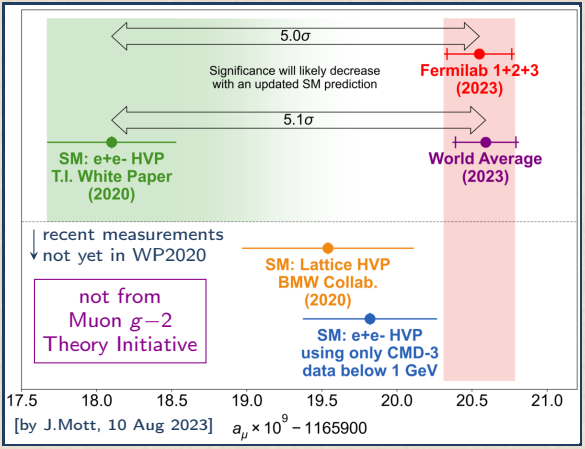

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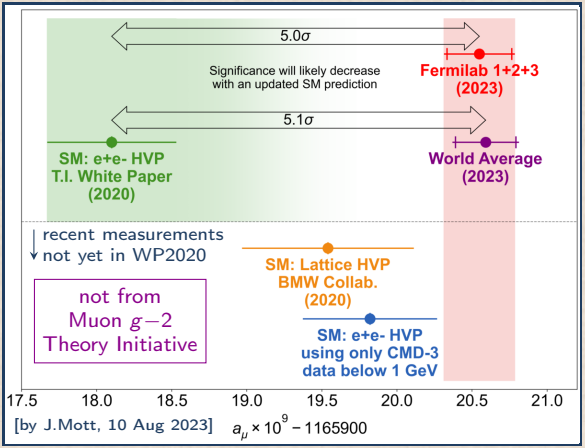

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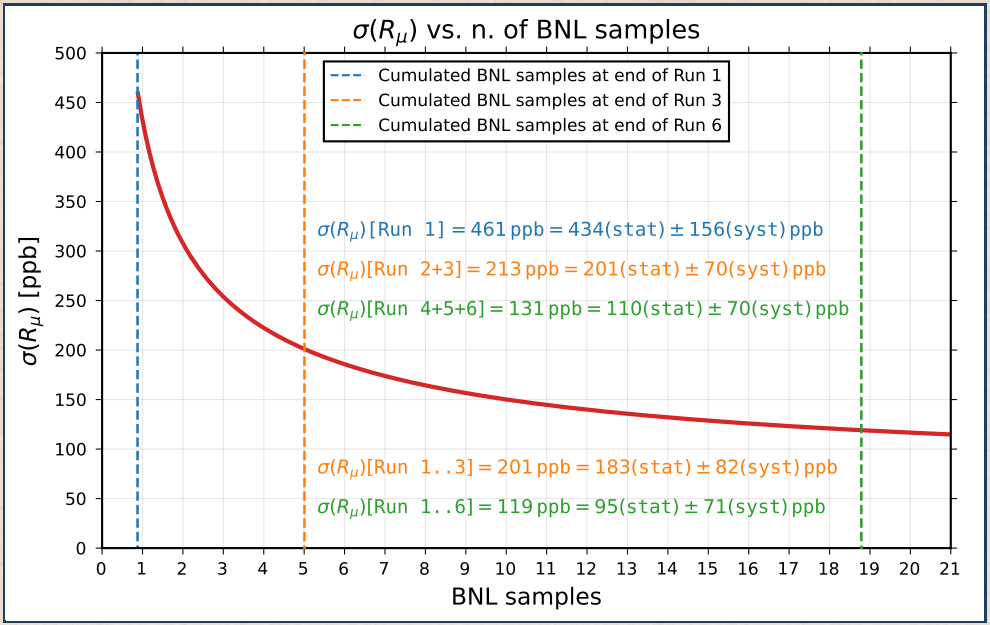
- large ongoing effort to understand present poor consistency of theory predictions based on different inputs

Expected future precision of FNAL Muon $g-2$ measurement



Introduction

- prompted by the Fermilab request to Muon g-2 collaborators to be prepared to possible shutdons of Fermilab computing caused by financial constraints, we have investigated the costs and benefits of having a backup of Muon g-2 data in Italy with the ability to analyze them
- given the cost structure of INFN computing resources at CNAF, i.e. pay once to have 5 years of use for disk and CPU, and 10+ years of use for tape, we believe that we can get valuable benefits for 5 years (and more, for tape) by requesting a relatively small amount of funds in the coming year
- the requested computing resources funding would insure that
  - we will have storage and CPU for 5 years to complete our planned data analysis program effectively
  - we would be protected from Fermilab computing shutdowns
  - we would be resilient from Fermilab shifting focus to other experimental programs (Mu2e, DUNE)

Some strategy details

- provide CPU and storage to do the muon precession frequency (ω_a) analysis in Italy, using the Root skims of the "Europa" analysis group (composed of collaborators from Italy and UK), with minimal requirements of software setup
- provide a tiny amount additional resources, compared to the above task, for other activities (magnetometer, simulation, analysis of vertex detector data for beam dynamics corrections)
- acquire cheap tape storage to backup the Muon g-2 collaboration reconstructed skims, performing a backup of the official dataset, from which ω_a-related reprocessing is possible, for improvements and systematics studies, requiring the availability of the ART software

Funding requests

- 160 TB of online, hot, disk space
  - 19.2 k€ (120 €/TB for 5 years at CNAF/T2-Pisa)
  - store all Run 1-6 ω_a Root skims (112 TiB $\simeq$ 123 TB, for Europa analysis by Italy / UK)
  - additional 37 TB for working space, magnetometer, simulation datasets, vertex detector data for beam dynamics studies
- 200 TB of tape
  - 2.0 k€ (10 euro/TB for 10+ years at CNAF/T2-Pisa)
  - keep a backup copy of all Run 1-6 ω_a Root skims, possibly free additional working space on disks
- 64 standard CPU cores (10 HEPSPEC06 each) for analysis
  - 6.4 k€ (100 €/core at CNAF/T2-Pisa for 5 year)
  - same cost for CPU batch, CPU interactive, grid
- total: 27.6 K€

sub-judice

- 1.0 PB of tape storage
  - if there is an explicit request from the collaboration to provide data backup
  - or if there is evidence that Fermilab computing will be poorly reliable
  - 10.0 k€ (10 euro/TB for 10+ years at CNAF/T2-Pisa)
  - backup copy of all recon skims, assuming expected reduction from 1.4 PiB $\simeq$ 1.54 PB to $<$1.0 PB

Possible locations of computing resources

- CNAF (checked with Daniele Cesini)
- Pisa (Tier 2, checked with Enrico Mazzoni)
  - T2-Pisa hosting disks and computing, with tape at CNAF (as done by Belle II and CMS)
  - past collaboration with Pisa on Grid production job submissions