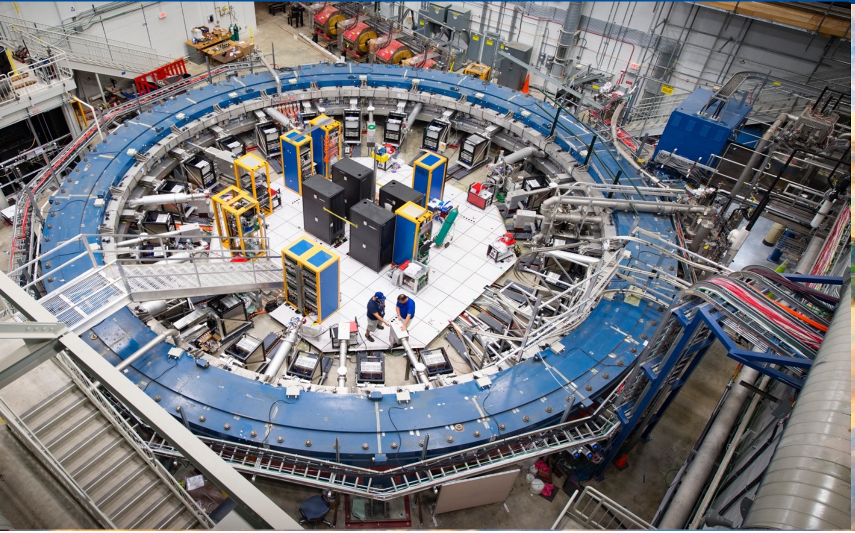


Wishlist for g-2 at Tau 2025

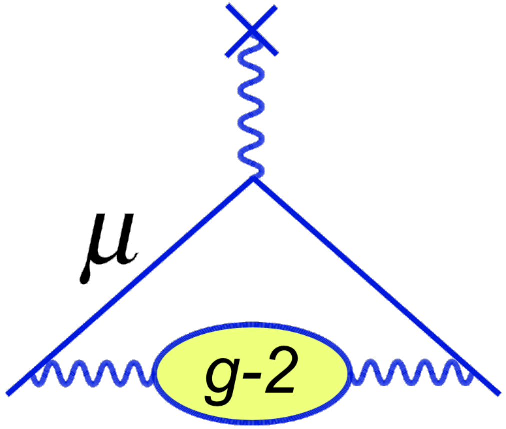
Brendan Kiburg

Fermi National Accelerator Laboratory

Technical Publication Number: FERMILAB-SLIDES-23-407-PPD

Tau 2023, Dec 4-8, Louisville Kentucky

Wishlist for g-2 at Tau 2025 Outline



- Tau g-2
- Muon g-2 Status
  - Experimental Status
    - Recent Results
    - Future Outlook
  - Theoretical Prediction
    - Dispersive Calculation
    - Prospects for Data Improvement
    - Tau Data
    - Lattice QCD
- Where Else to Look
  - Additional Analyses within Fermilab Muon g-2 (EDM, CPT/LV, DM)
  - JPARC g-2
  - MUonE
  - And beyond…
- Summary

Legend:

Content inside red boxes featured at Tau2023

g-2 Motivation (Tau)

Magnetic and Electric Tau Dipole Moments Revisited

1. Tau lepton DM

Why are we interested in Tau dipole moments?

- m = 1777 MeV
- Lifetime = 290 x 10^{-15} sec
- Tau lepton decays into hadrons
- Lepton universality

- Sensitivity to NP $(m_\tau/\Lambda)^n$
- $\left(\frac{m_\tau}{m_e}\right)^2 \approx 10^7$; $\left(\frac{m_\tau}{m_\mu}\right)^2 \approx 3 \cdot 10^2$

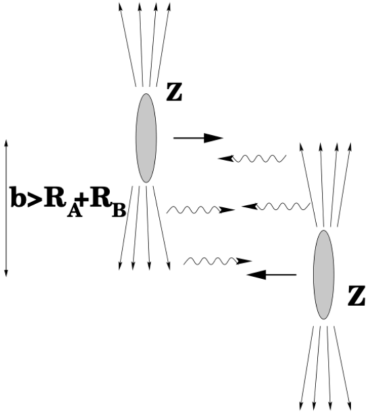
G.González- Sprinberg Louisville, 17th TAU 2023 3

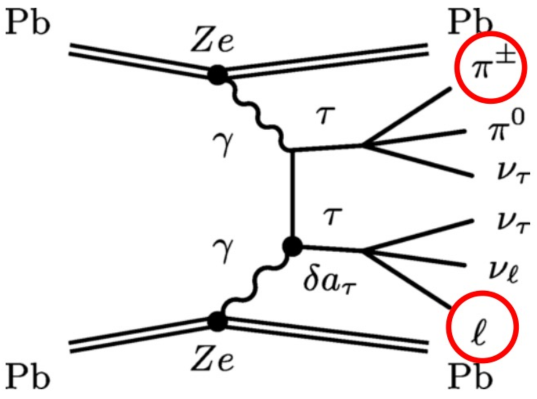
Magnetic and Electric Tau Dipole Moments Revisited Monday *Prof. Gabriel González-Sprinberg* 11:40 - 12:05

- New Physics (NP) can show up in the anomalous magnetic moment, a_τ
- m^2 enhancement
- Possible additional enhancements in Lepton non-universality models

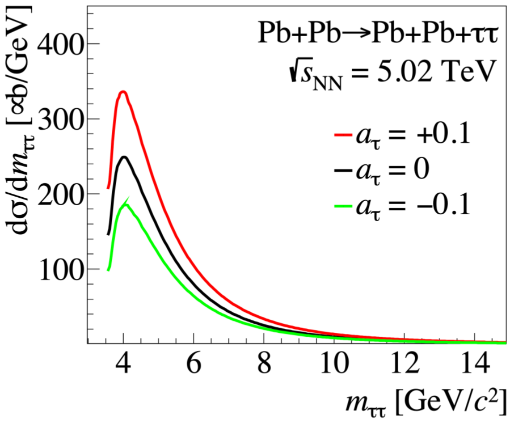
g-2 Tau Techniques

- Lifetime too short to store / track
- Instead, examining ultra peripheral Pb-Pb collisions, **coupling sensitive to a_τ**





N. Burmasov et al arxiv:2111.11383



Measurement of the tau-lepton pair production from photons and tau g-2	Quentin Buat
Wednesday	14:50 - 15:10

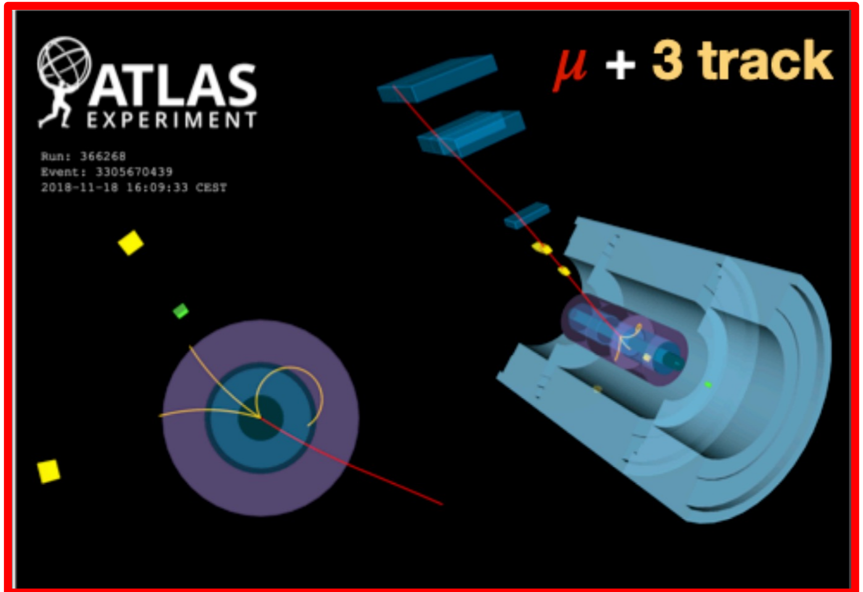
Measurement of the anomalous magnetic moment in ultraperipheral collisions with ALICE at the LHC	Paul Alois Buhler
Wednesday	15:10 - 15:30

Fermilab

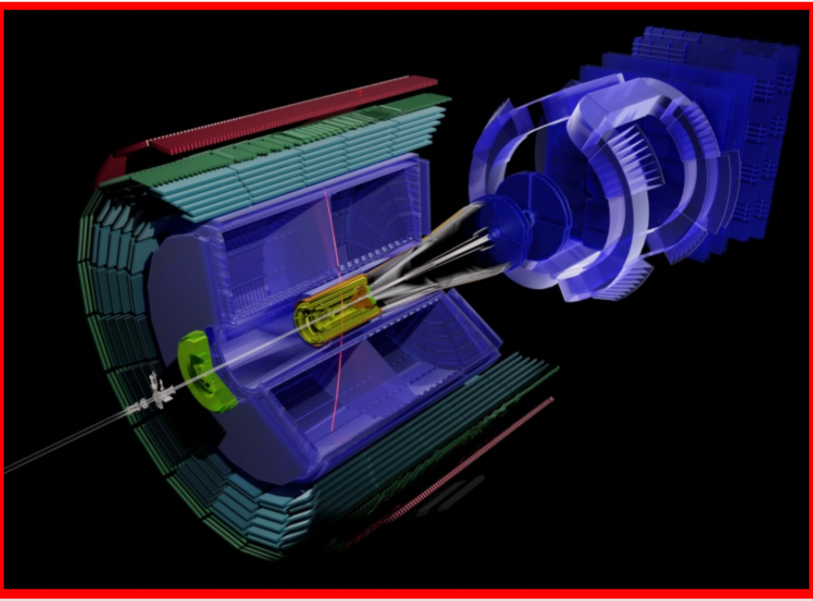
Event selection

- ATLAS: Focus on events with muon in final state μ +1 track or μ + 3 track

- ALICE: electron or muon and charged particle track
- Particle-ID capabilities → enhanced sensitivity



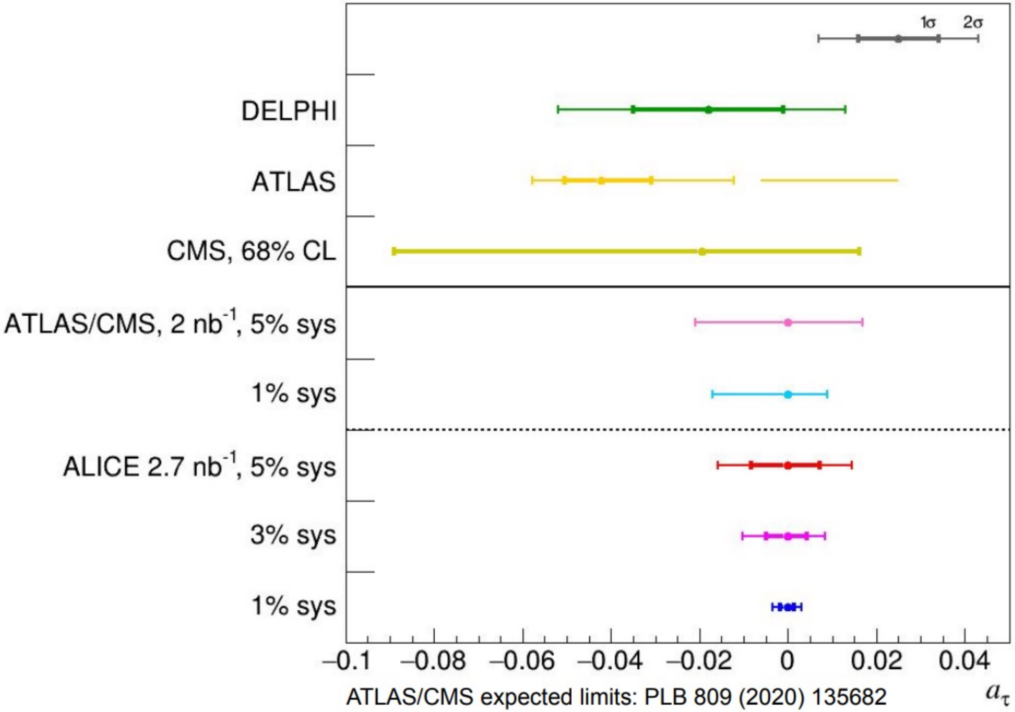
Measurement of the tau-lepton pair production from photons and tau g-2 *Quentin Buat* 14:50 - 15:10



Measurement of the anomalous magnetic moment in ultraperipheral collisions with ALICE at the LHC *Paul Alois Buhler* 15:10 - 15:30

LHC Run 3 will improve sensitivity to a_τ

- Current results competitive with LEP
- Significant improvements coming in Run 3 analyses
- From this morning (Chiral Belle Upgrades – M. Roney) "Approaches the precision regime in tau that starts to be sensitive to Minimal Flavour Violation equivalent of muon g-2 anomaly"

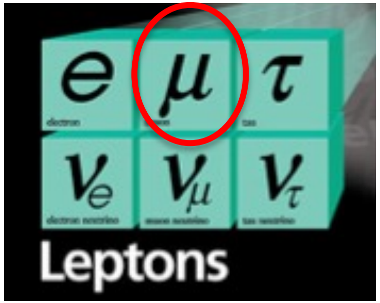


ATLAS/CMS expected limits: PLB 809 (2020) 135682
ATLAS results: arXiv:2204.13478
CMS results: DIS 22' talk and CDS: CMS-PAS-HIN-21-009

Measurement of the anomalous magnetic moment in ultraperipheral collisions with ALICE at the LHC *Paul Alois Buhler*
Wednesday 15:10 - 15:30

Fermilab

The muon



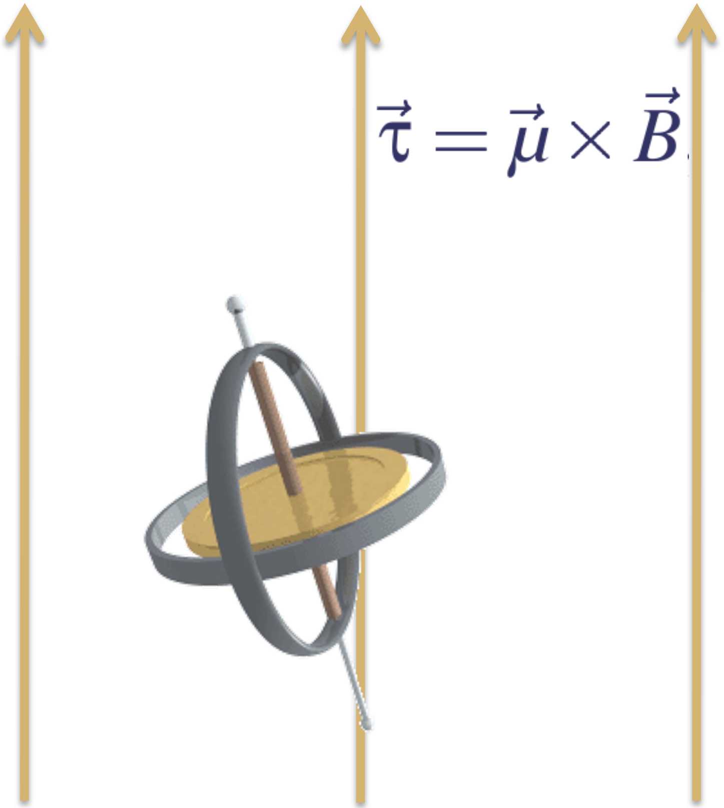
- Spin ½, encodes information about spin in its decay

$$\vec{\mu} = g \frac{q}{2m} \vec{S}$$

- g= 2 + contributions from virtual particles

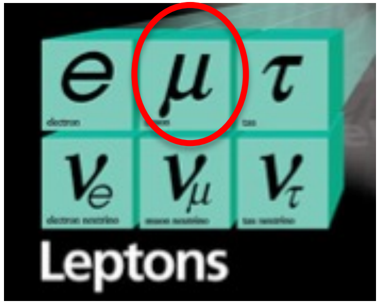
Magnetic Field

$$\vec{\tau} = \vec{\mu} \times \vec{B}$$



Fermilab

The muon



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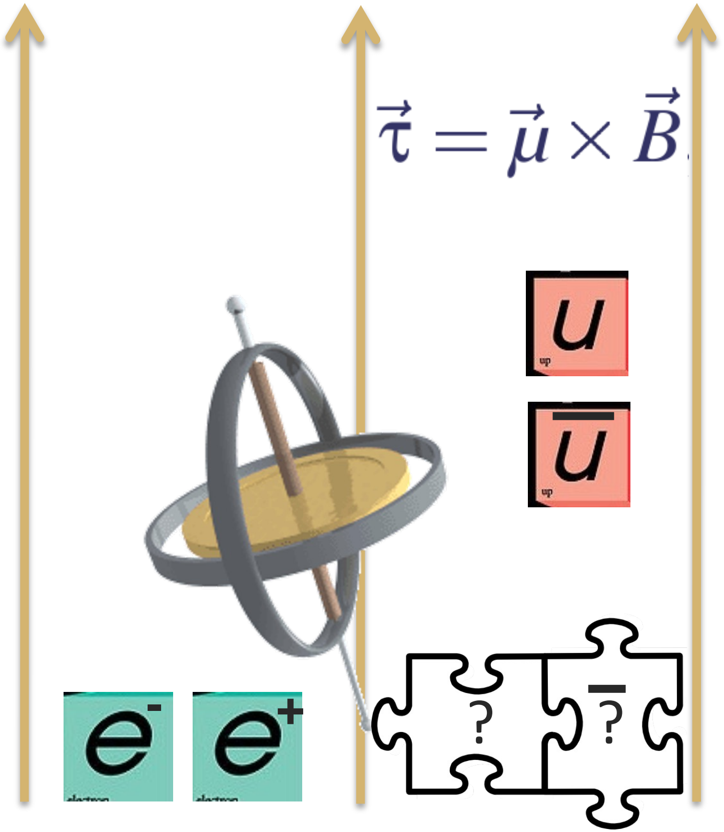
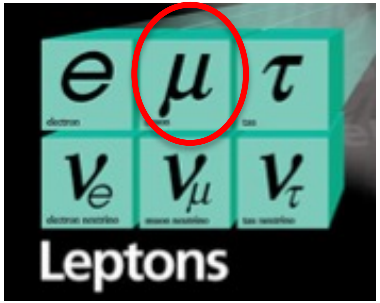
Magnetic Field



The muon



- Spin ½, encodes information about spin in its decay

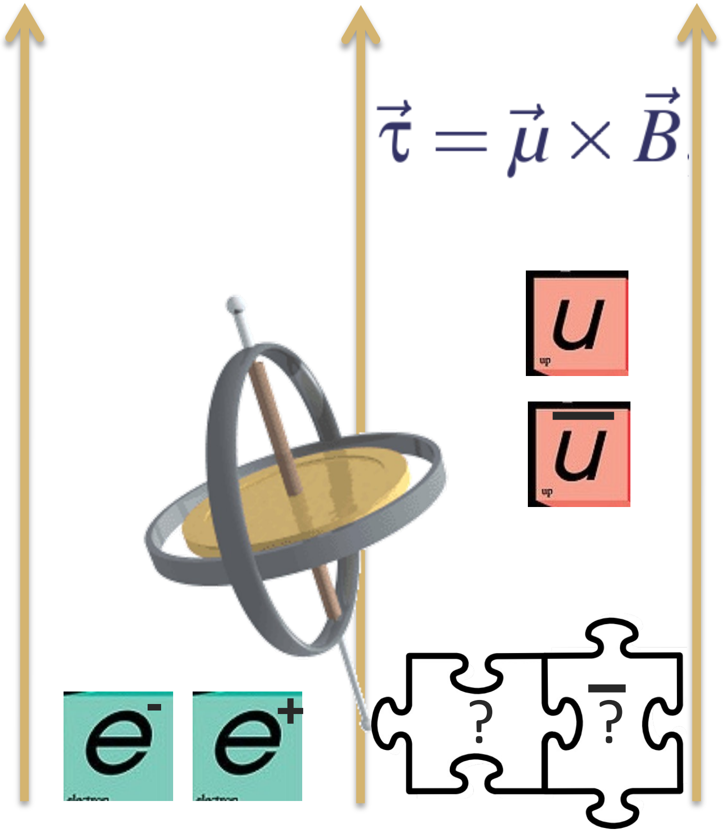
$$\vec{\mu} = g \frac{q}{2m} \vec{S}$$

- g= 2 + contributions from virtual particles

$m_\mu \sim 207\ m_e$; $m_\mu \sim 0.06\ m_\tau$
$2.2\ \mu s\ \tau_\mu \sim 8\times10^6\ \tau_\tau$
Goldilocks mass and lifetime to have sensitivity and store

Magnetic Field

$$\vec{\tau} = \vec{\mu} \times \vec{B}$$

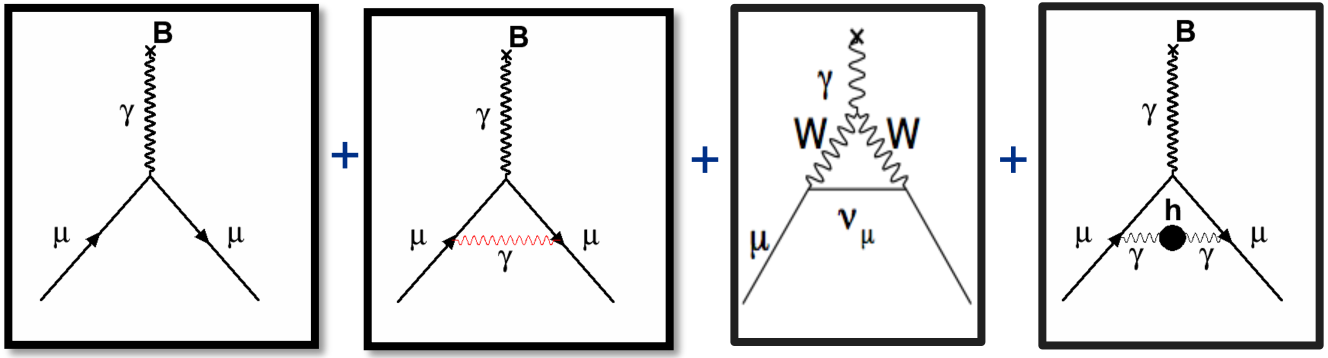


Fermilab

Muon g-2: Motivation

$$\vec{\mu} = g \frac{q}{2m} \vec{S}$$

g =



+ ?

$$g = 2 + \Delta g^{QED} + \Delta g^{EW} + \Delta g^{QCD} + \Delta g^{NP}$$

- a_μ is the anomalous magnetic moment (i.e the part that differs from 2)

$$a_\mu^{SM} = (g_\mu^{SM}-2)/2 = a_\mu^{QED} + a_\mu^{EW} + a_\mu^{QCD} + a_\mu^{NP}$$

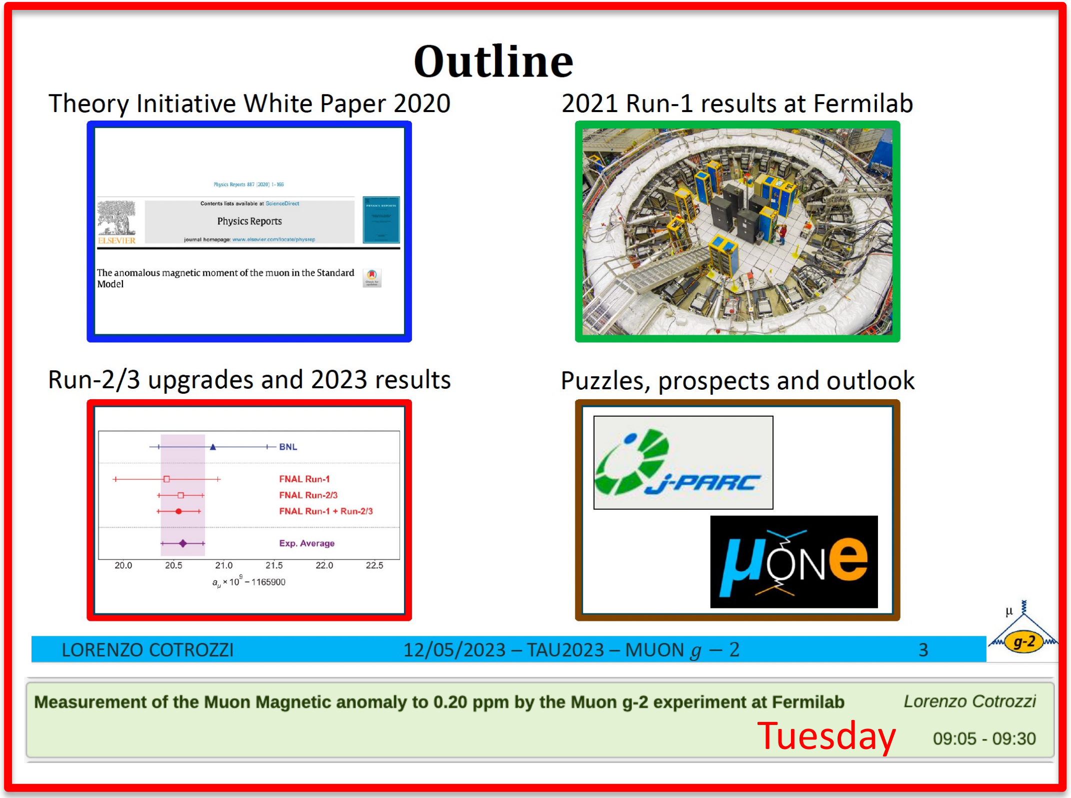
Fermilab

Determining a_μ from experiment

$$a_\mu^{exp} = \frac{m\omega_a}{eB}$$

Storage ring experiment

- Uniform, precisely measured B-field
- Measure muon precession in that field
- Weight by how muons sample that field in space and time



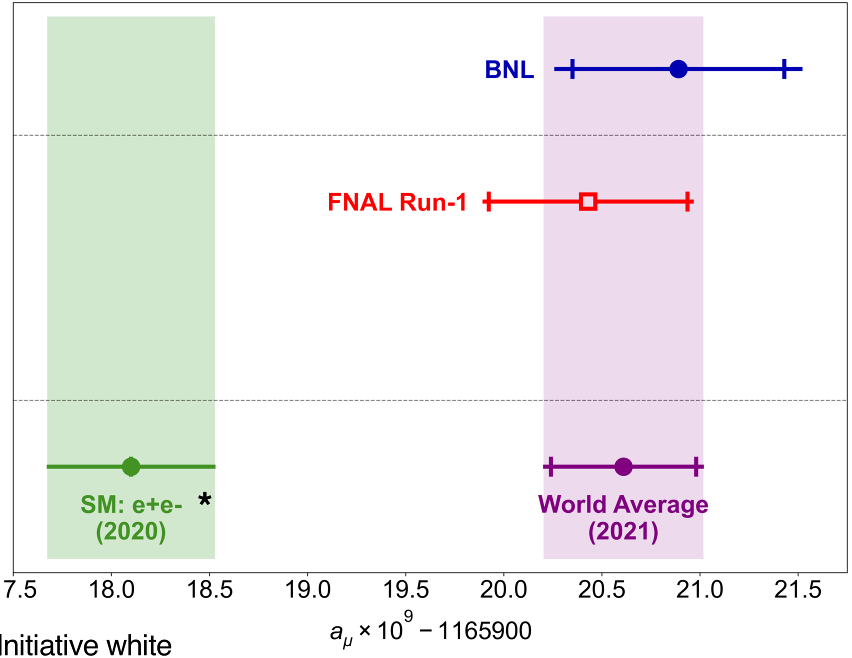
Fermilab

Starting Point: Run-1 Result

a_μ(FNAL; Run-1) = 0.00 116 592 040(54) [463 ppb]

a_μ(Exp) = 0.00 116 592 061(41) [350 ppb]

Complex theory situation → interpretation details later

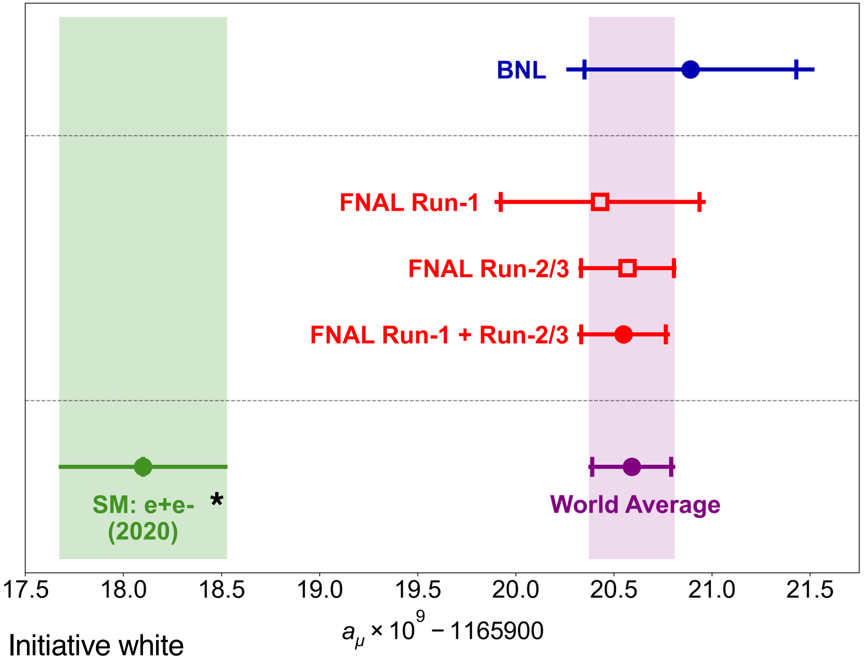


- 3.7σ discrepancy between BNL and WP 2020
- 4.2σ discrepancy between World Average 2021 and WP 2020

*Muon g – 2 Theory Initiative white paper (WP) value
https://doi.org/10.1016/j.physrep.2020.07.006

Run-2/3 Result: FNAL + BNL Combination

a_μ(FNAL) = 0.00 116 592 055(24) [203 ppb]



- FNAL combination: **203 ppb** uncertainty
- Both FNAL and BNL dominated by statistical error
- Combined world average **dominated by FNAL** values.

*Muon g – 2 Theory Initiative white paper (WP) value
https://doi.org/10.1016/j.physrep.2020.07.006

a_μ(Exp) = 0.00 116 592 059(22) [190 ppb]

Run-2/3 a_μ Uncertainties: Final Values

- Total uncertainty is **215 ppb**

[ppb]	Run-1	Run-2/3	Ratio
Stat.	434	**201**	2.2
Syst.	157	**70**	2.2

Quantity	Correction [ppb]	Uncertainty [ppb]
ω_a^m (statistical)	–	201
ω_a^m (systematic)	–	25
C_e	451	32
C_p	170	10
C_{pa}	-27	13
C_{dd}	-15	17
C_{ml}	0	3
$f_{\text{calib}}\langle\omega'_p(\vec{r}) \times M(\vec{r})\rangle$	–	46
B_k	-21	13
B_q	-21	20
$\mu'_p(34.7°)/\mu_e$	–	11
m_μ/m_e	–	22
$g_e/2$	–	0
Total systematic	–	70
Total external parameters	–	25
Totals	622	215

- Systematics of 70 ppb surpasses proposal goal (100 ppb)
- No dominant uncertainties to attack
- Modest improvements to field & beam dynamics possible

Wishlist : No surprises that cause systematic evaluation to increase

We can rewrite a_μ : our observables plus external measurements

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

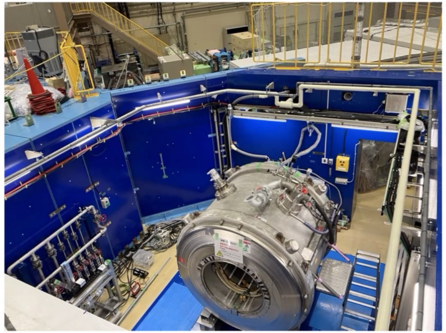
Quantities FNAL g-2 measures

Determined externally to 25 ppb,
Largest term is

$\frac{m_\mu}{m_e}$ Known to 22 ppb from muonium hyperfine splitting
Phys. Rev. Lett. **82**, 711 (1999)

MuSEUM in J-PARC

- Muonium Hyperfine splitting measurement



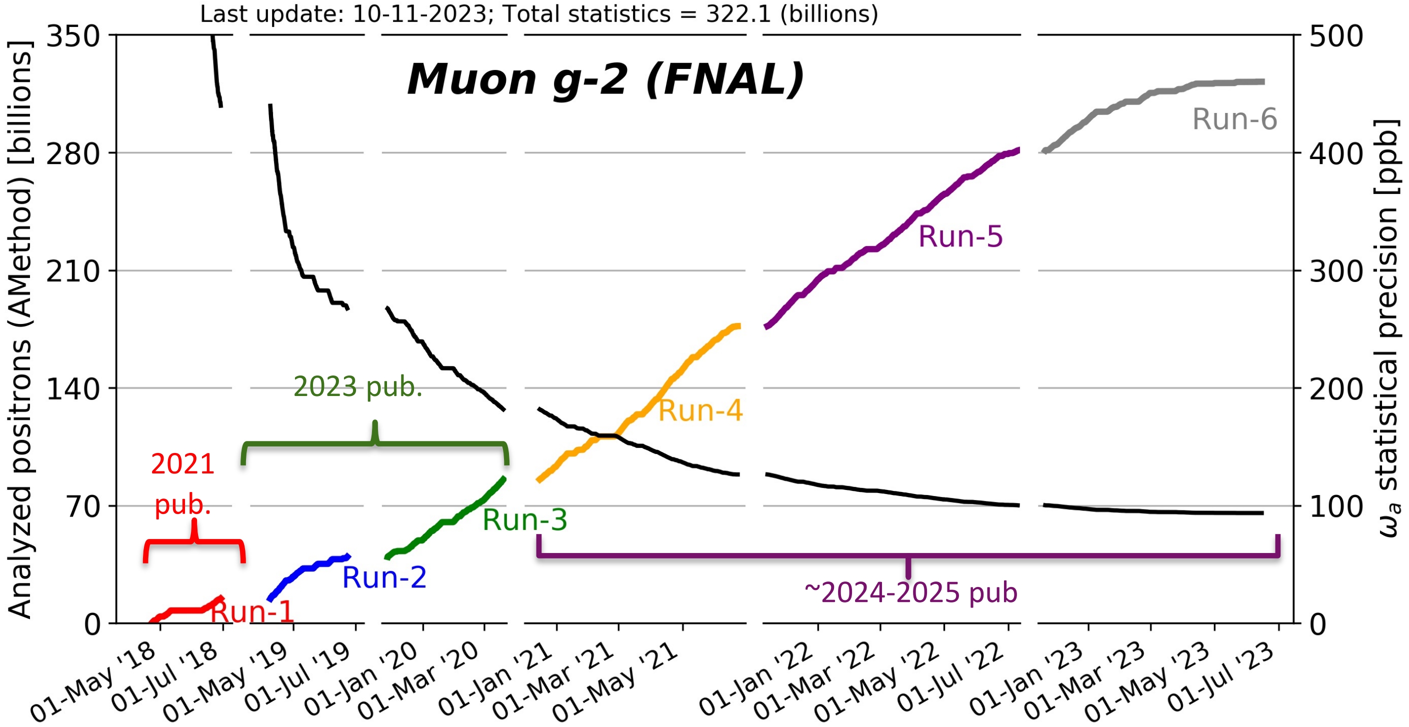
- MRI magnet moved to experimental area

- Feb. 2024: Shimming
- Mar. 2024: Beam Run (?)

Ken-ichi Sasaki

Wishlist for 2025: Maximize precision on inputs

FNAL Muon g-2 Data Summary



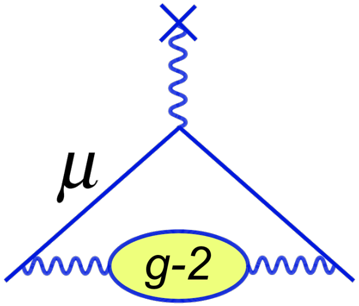
Wishlist for 2025:

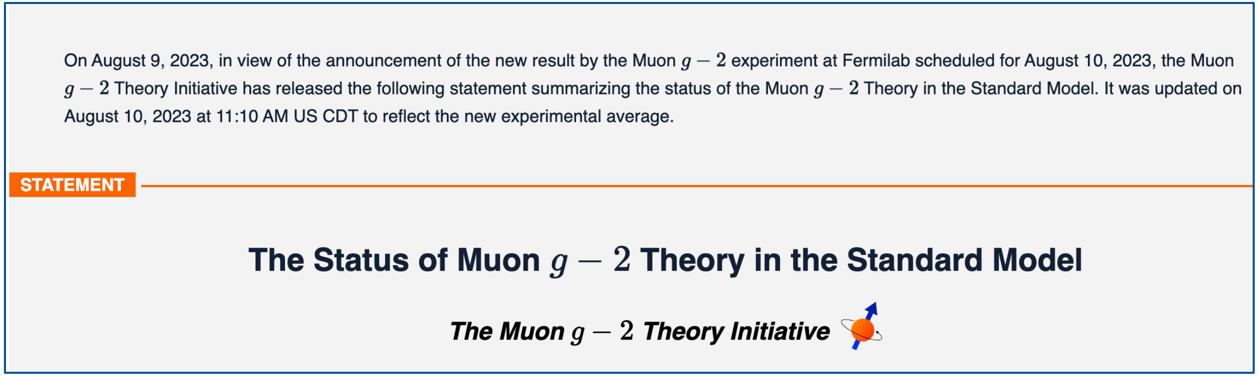
- Publish Run 4-6 analysis
- Maintain systematic unc. of 70 ppb
- Reduce total unc. by 35% (190 → 120 ppb)

- Statistical uncertainty should reach <100 ppb, the original proposal goal

Ultimate Projected Precision ~ 120 ppb = <100 ppb (stat) ⊕ 70 ppb (syst)

Theory Initiative (TI)





On August 9, 2023, in view of the announcement of the new result by the Muon $g-2$ experiment at Fermilab scheduled for August 10, 2023, the Muon $g-2$ Theory Initiative has released the following statement summarizing the status of the Muon $g-2$ Theory in the Standard Model. It was updated on August 10, 2023 at 11:10 AM US CDT to reflect the new experimental average.

STATEMENT

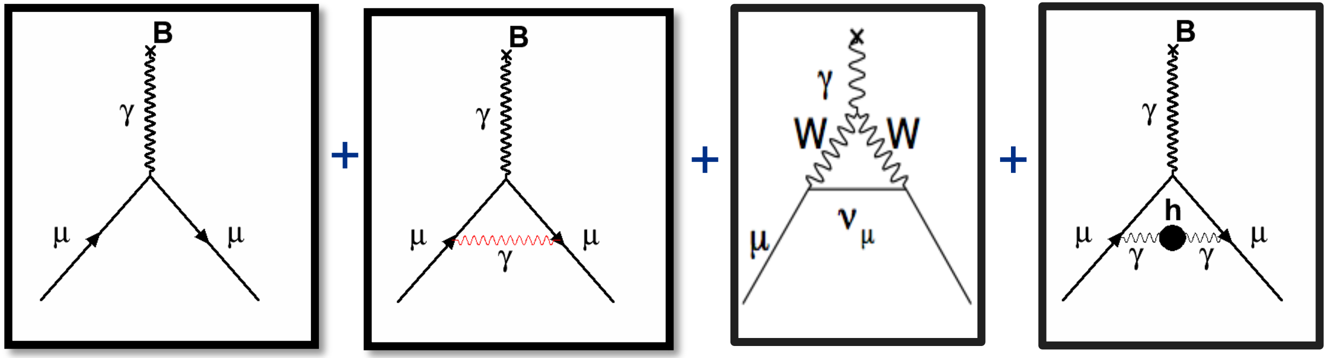
The Status of Muon $g-2$ Theory in the Standard Model

The Muon $g-2$ Theory Initiative

https://muon-gm2-theory.illinois.edu/

Muon g-2 calculation

g =



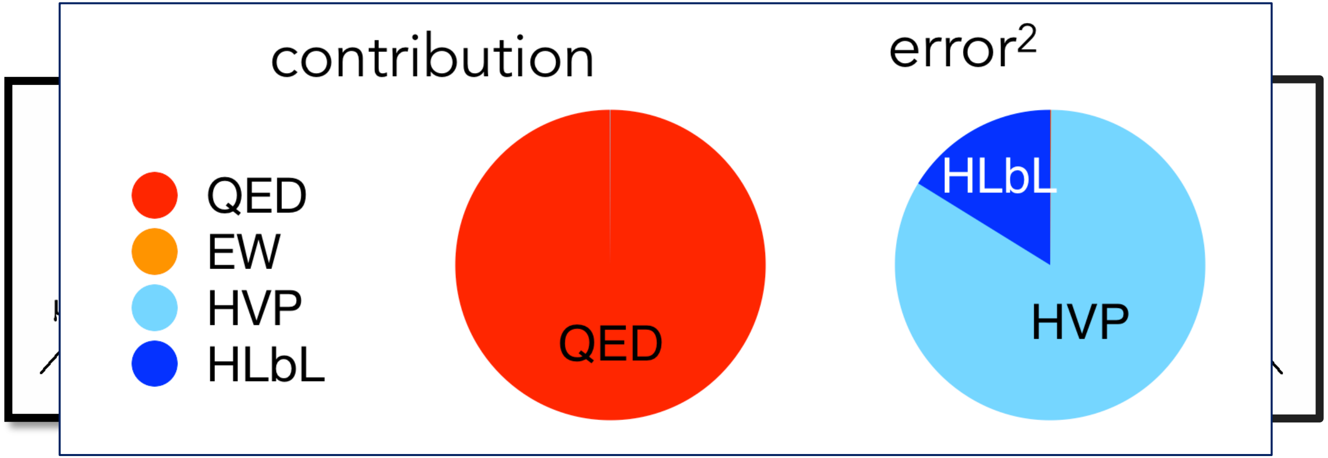
Value $g = 2 + O(10^{-3})_{QED} + O(10^{-9})_{EW} + O(10^{-7})_{QCD}$

Uncertainty (ppm) 0.001 , 0.01 , 0.34 (HVP)& 0.15(HLBL)

Relative Uncertainty ~1% (HVP) ~20%(HLBL)

Muon g-2 calculation

g =



Value $g = \quad 2 \quad + O(10^{-3})_{QED} \quad + O(10^{-9})_{EW} \quad + O(10^{-7})_{QCD}$

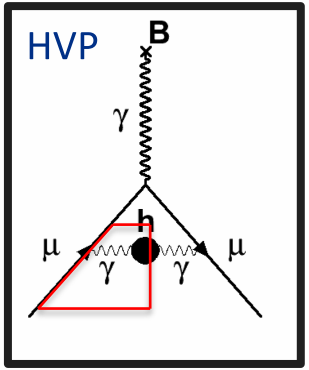
Uncertainty (ppm) 0.001 , 0.01 , 0.34 (HVP)& 0.15(HLBL)

Relative Uncertainty ~1% (HVP) ~20%(HLBL)

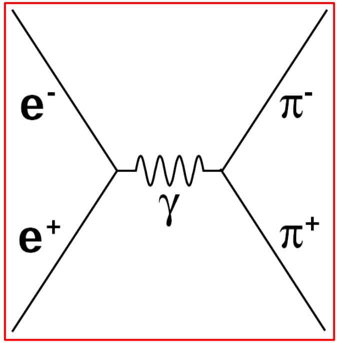
- Dominated by hadronic contributions → study those calculations in more detail

Dispersive Theory Calculation is Driven by Experimental Input

Relates these terms



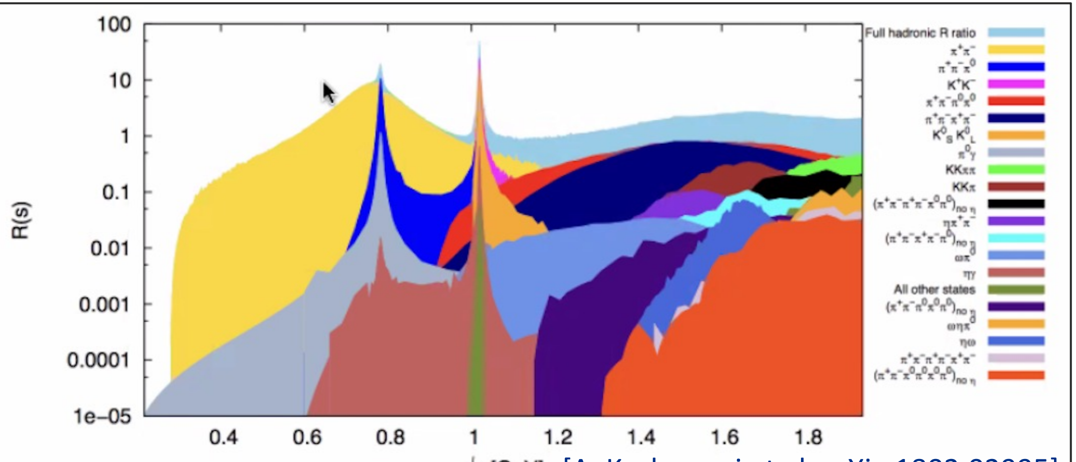
To observable processes like



$$\left(a_\mu^{\mathrm{HAD,LO}}\right) \propto \int_{4m_\pi^2}^{\infty} ds \frac{K(s)}{s} R(s)$$

$$R(s) \equiv \frac{\sigma_{\mathrm{tot}}(e^+e^- \to \mathrm{hadrons})}{\sigma_{\mathrm{tot}}(e^+e^- \to \mu^+\mu^-)}$$

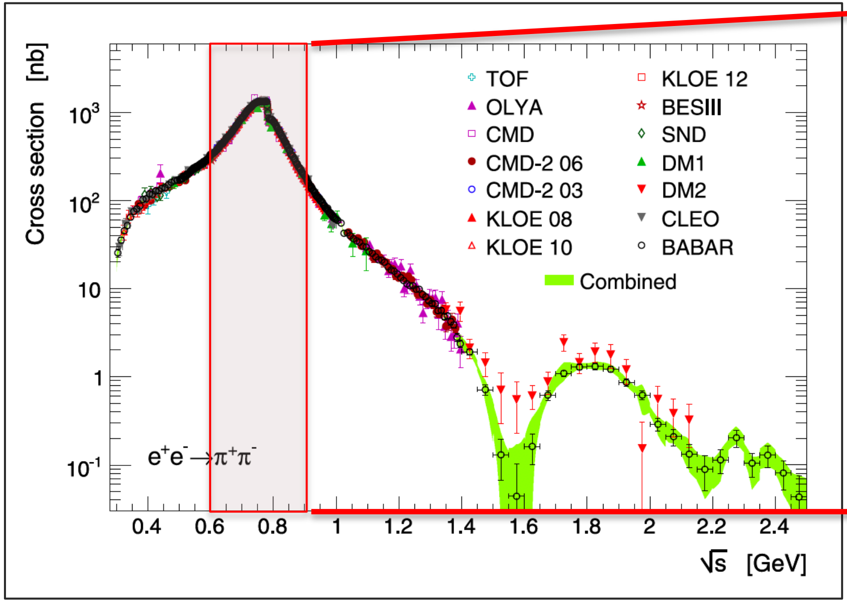
- Low-energy region dominates

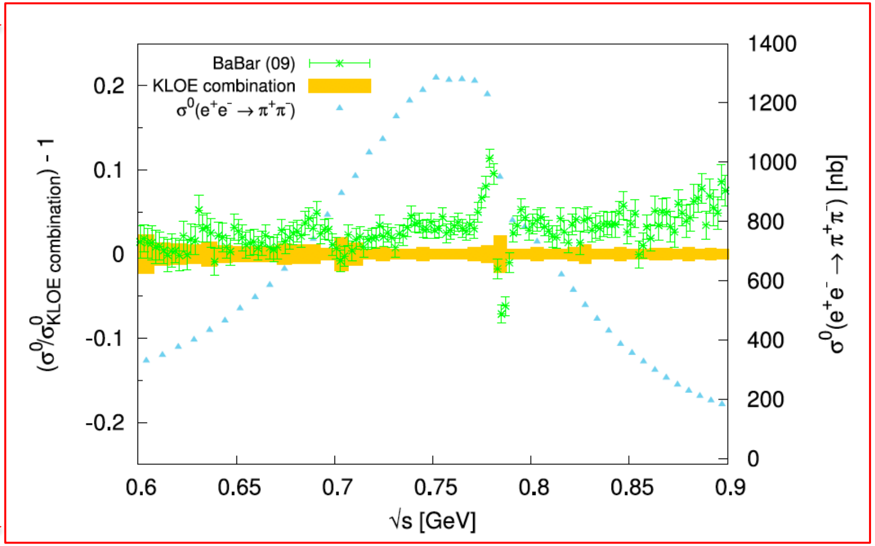


[A. Keshavarzi et al, arXiv:1802.02995]

Dispersive Theory Calculation is Driven by Experimental Input

Many detailed measurements of $e^+e^- \rightarrow \pi^+\pi^-$



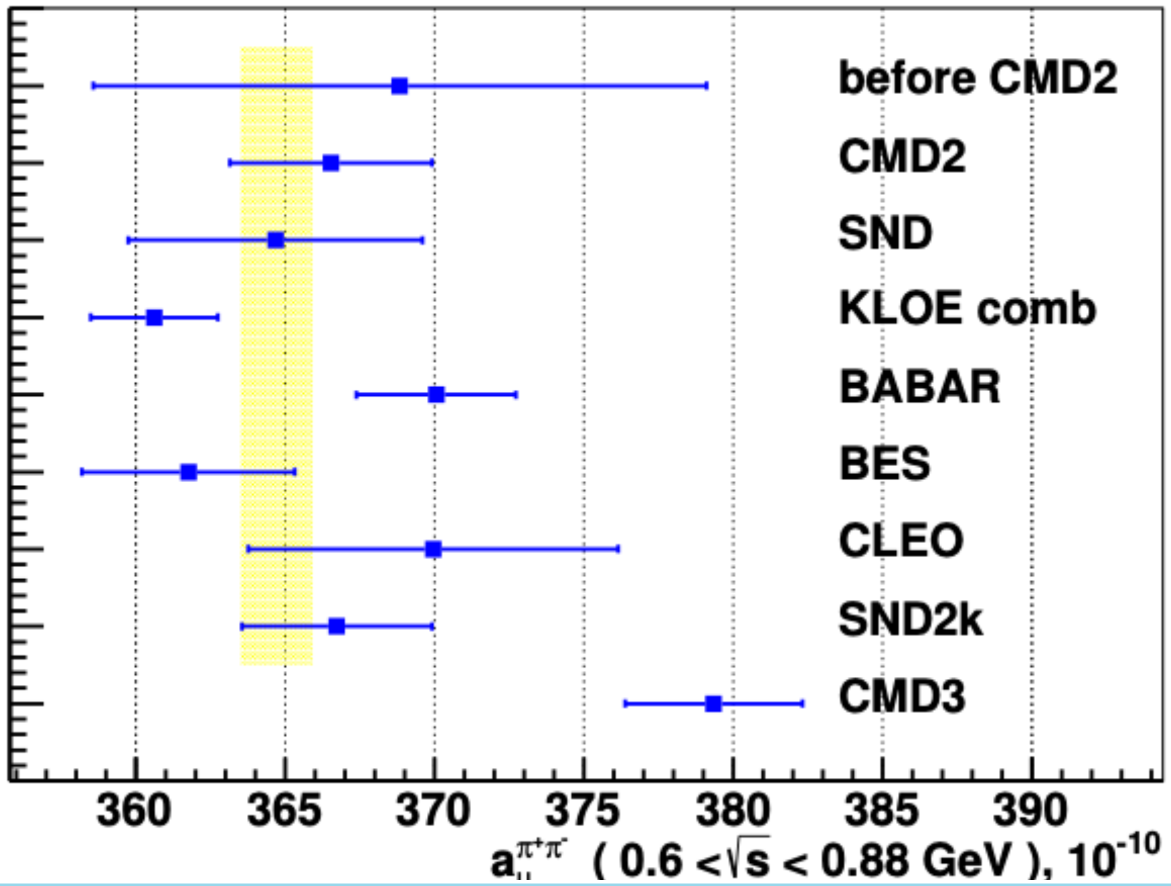


Spectral differences have limited the combination (recall, need percent level precision)

Evaluations inflate uncertainties to account for the tension → has limited e+/e- prediction

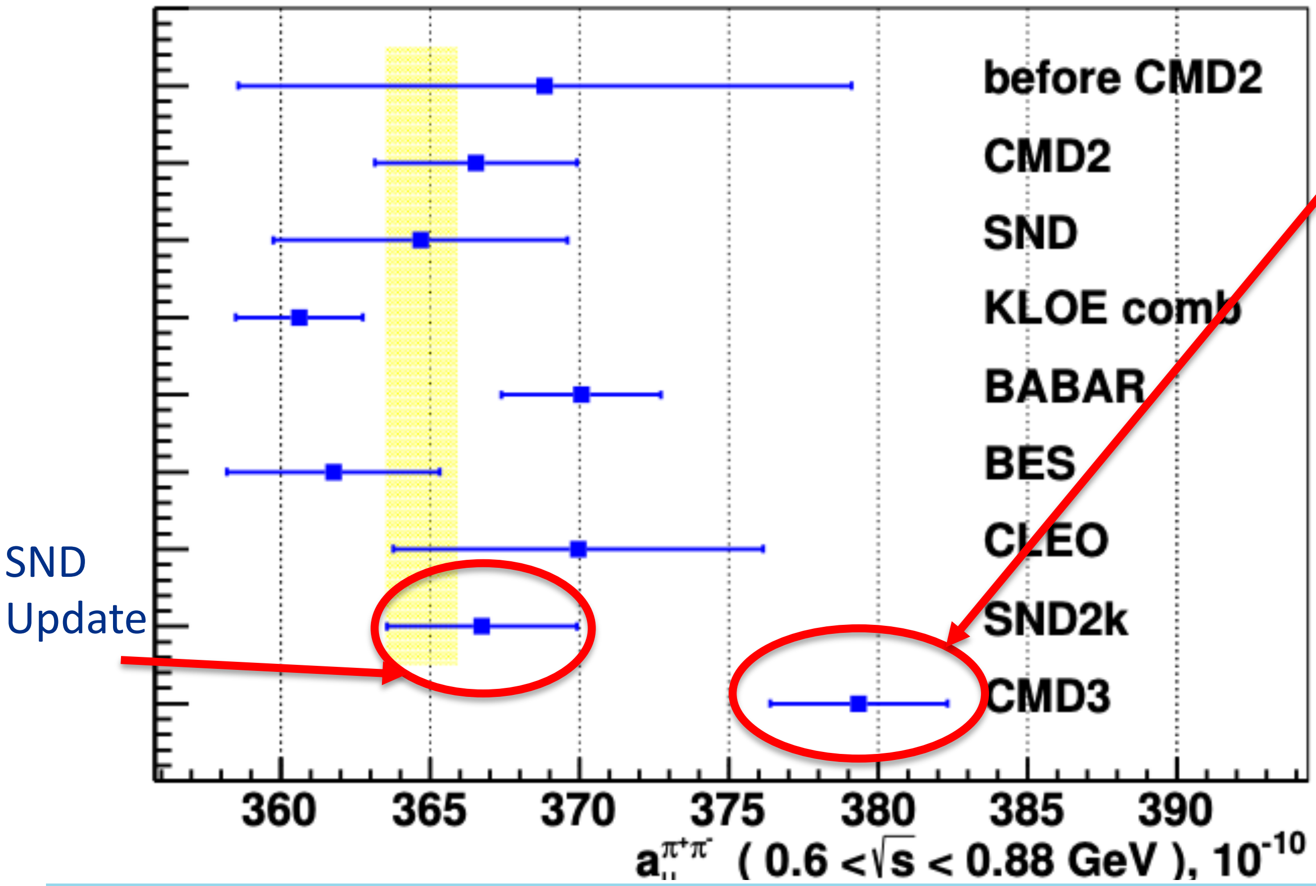
Wishlist for 2025: Understand spectral differences in $e^+e^- \rightarrow \pi^+\pi^-$

Various Evaluations of 2-pion contributions



Fermilab

New data further clouds interpretation



New from CMD-3
arXiv:2302.08834

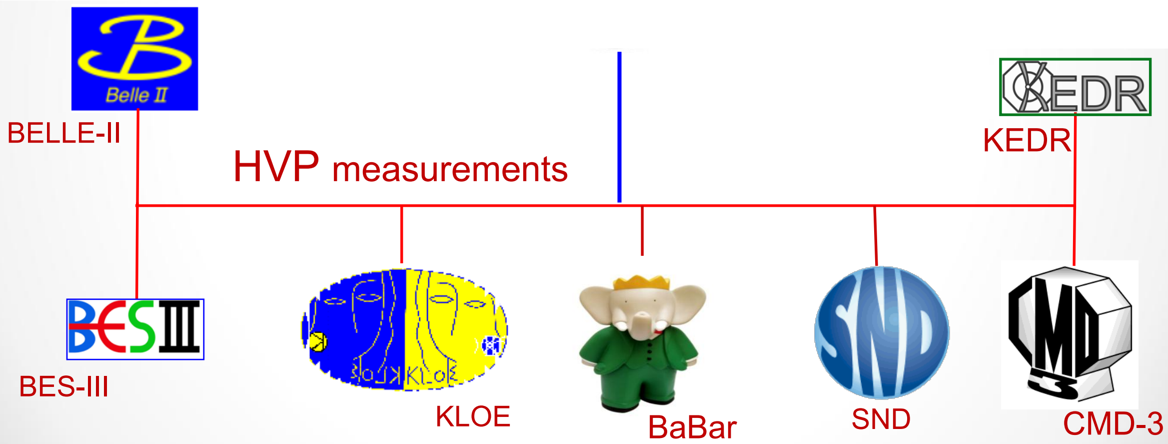
- Disagrees with others by 2.5-5 σ!
- Common facility w/ SND; some detector upgrades
- Analyzer seminar, community panels to investigate → No smoking gun

Wishlist for 2025:
Understand why CMD normalization so different

Improved e+/e- Prospects

Many machines/exp pushing to improve to sub % precision

BELLE-II:
362 /fb on tape → publish 2025



CMD-3:
continues to investigate differences

BESIII:
Pub: 2.9/fb
Data: 17.1 /fb 2024

KLOE: 7x larger data set on tape.
Blinded analysis

BaBar:
New analysis, full data set in 2024

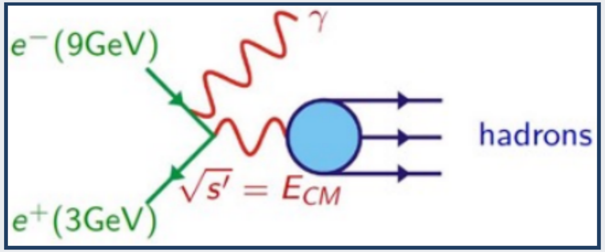
SND:
Pub 10% of data.
Full stats analysis in prep

Wishlist for 2025: Use larger e^+e^- data sets to study tensions

Understanding NNLO ISR corrections in e+/e- data from BaBar

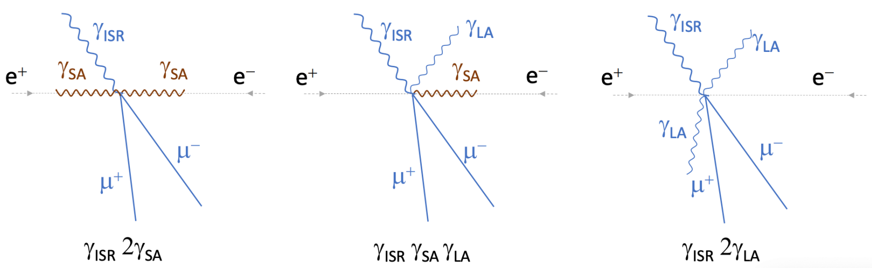
- *BaBar* measured $\sigma[e^+e^- \to \pi^+\pi^-(\gamma)]$ in 2009 with ISR technique and is working on $\sigma]e^+e^- \to \pi^+\pi^-(\gamma)]/\sigma]e^+e^- \to \mu^+\mu^-(\gamma)]$ with μ/π separation without PID

ISR technique



- measure $\sigma(e^+e^- \to \text{hadrons})(s)$ by measuring $\sigma(e^+e^- \to \gamma_{ISR} + \text{hadrons})[\Upsilon(4s)]$

NNLO

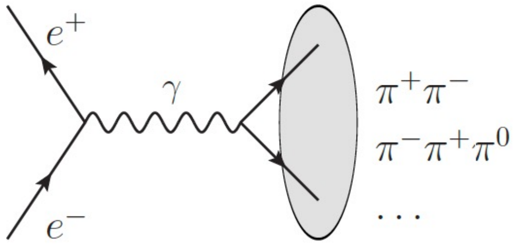


- NNLO radiation with ISR photon plus two additional radiation photons observed for the first time fraction $= (3.47 \pm 0.38)\%$ for muons and $(3.36 \pm 0.39)\%$ for pions
  - permits subtracting NNLO feed-through contributions to NLO samples

Study of additional radiation in the initial-state-radiation processes e+e−→μ+μ−γ and e+e−→π+π−γ in the BABAR experi…
Alberto Lusiani Friday

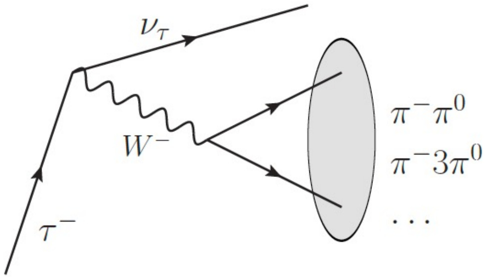
Fermilab

Tau Data inputs to a_μ^{HVP}



EM current

Final states $I = 0, 1$ neutral



$V - A$ current

Final states $I = 1$ charged

LEP and b-factories provide high-statistic tau decay samples
Can relate $\tau^- \rightarrow \pi^0 \pi^- \nu$ to $e^+e^- \rightarrow \pi^+ \pi^-$ with difficult isospin corrections

Tau hadronic decay input for Muon g-2	Friday	*Taku Izubuchi* 11:15 - 11:40

Tau Data inputs to a_μ^{HVP}

a_μ^{HVP} in the SM: Our τ-data based prediction

Miranda-Roig'20

$$a_\mu^{HVP,LO} = \frac{1}{4\pi^3}\int_{s_{thr}}^{\infty} ds\, K(s)\sigma^0_{e^-e^+\to hadrons}(s)$$

Both K & σ go as 1/s enhancing low-E contributions

(Alemany, Davier, Höcker '97)

Alternative evaluation possible using semileptonic tau decay data, specifically 2π (4π) channel. Requires isospin breaking (IB)

$$\sigma^0_{\pi\pi} = \left[\frac{K_\sigma(s)}{K_\Gamma(s)}\frac{d\Gamma_{\pi\pi[\gamma]}}{ds}\right]\frac{R_{IB}(s)}{S_{EW}},$$

$$R_{IB}(s) = \frac{FSR(s)}{G_{EM}(s)}\frac{\beta^3_{\pi^+\pi^-}}{\beta^3_{\pi^+\pi^0}}\left|\frac{F_V(s)}{f_+(s)}\right|^2$$

Kinematics & global cts. — Measurement — Short-distance EW RadCor — Final-state Rad — Kinematics

(Cirigliano-Ecker-Neufeld '01)

Highlighted challenging isospin breaking term

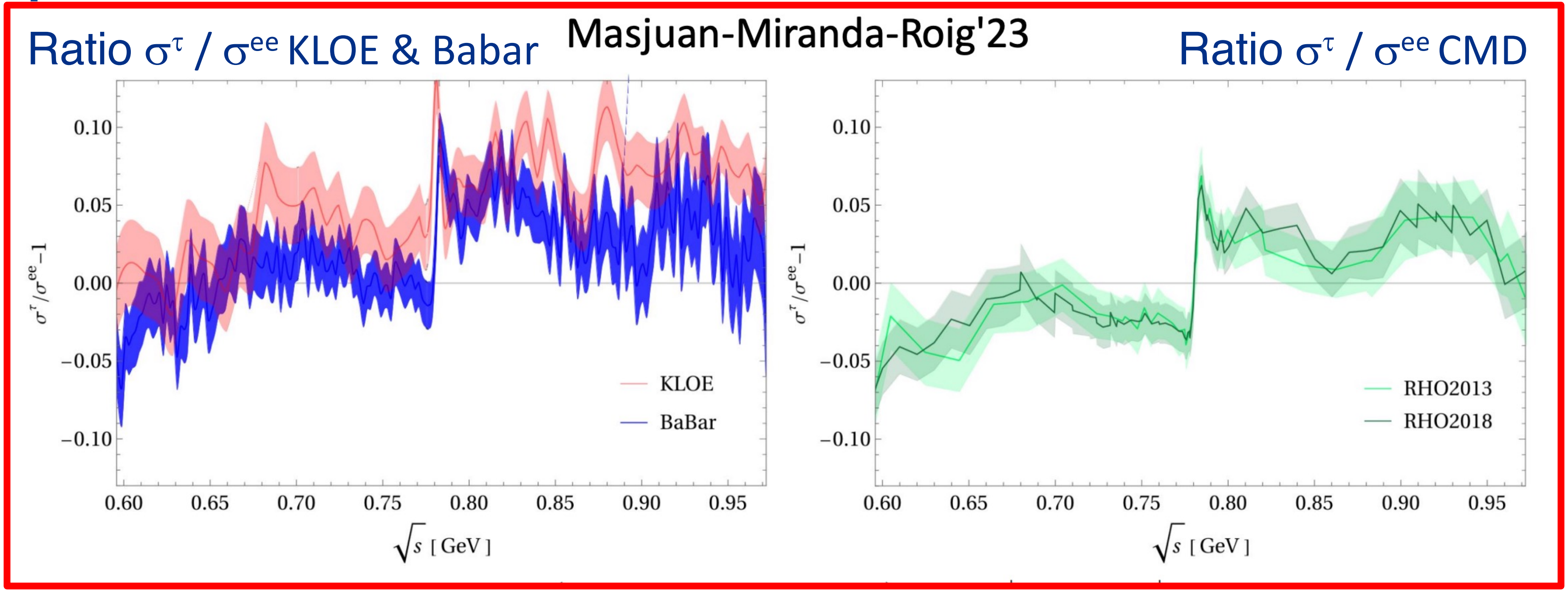
The ratio of neutral to charged current di-pion form factors (F_V/f_+) and the long-distance em RadCor (G_{EM}) are challenging.

Pablo Roig (Cinvestav, Mexico City)

Tau Data-Based Evaluation of hadronic vacuum polarization contribution to muon g–2 *Pablo Roig Garcés*

Tuesday 11:15 - 11:40

Spectral ratios of $\sigma^\tau / \sigma^{ee}$ show tension



Need to determine integral of these σ to percent-level

Shape of the isospin-breaking correction shows up in CMD + BaBar ratios

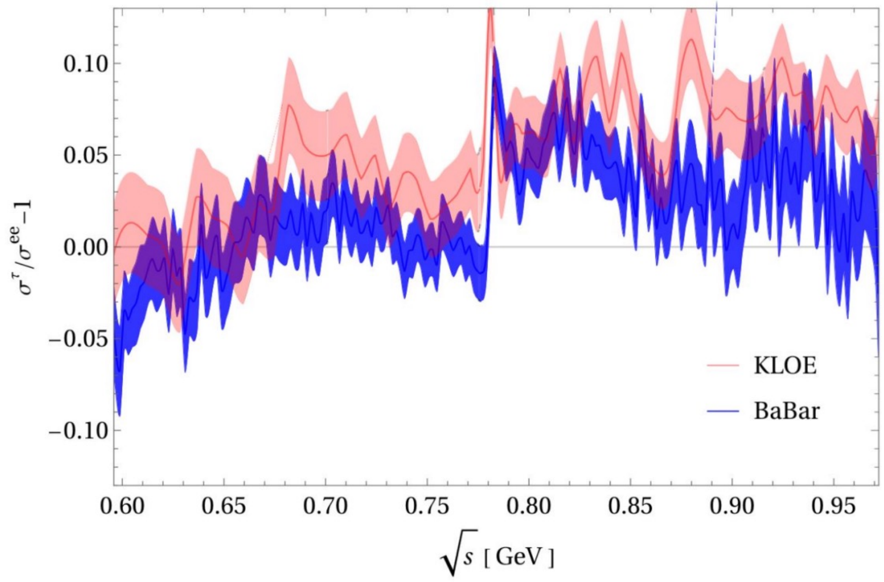
Fermilab

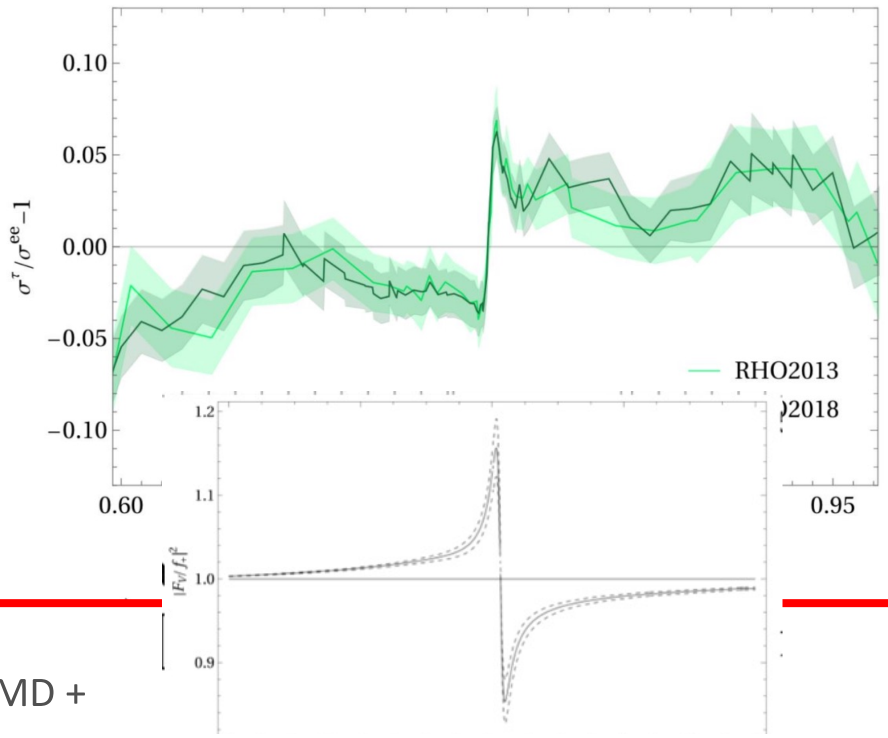
Spectral ratios of $\sigma^\tau / \sigma^{ee}$ show tension

Ratio $\sigma^\tau / \sigma^{ee}$ KLOE & Babar

Masjuan-Miranda-Roig'23

Ratio $\sigma^\tau / \sigma^{ee}$ CMD





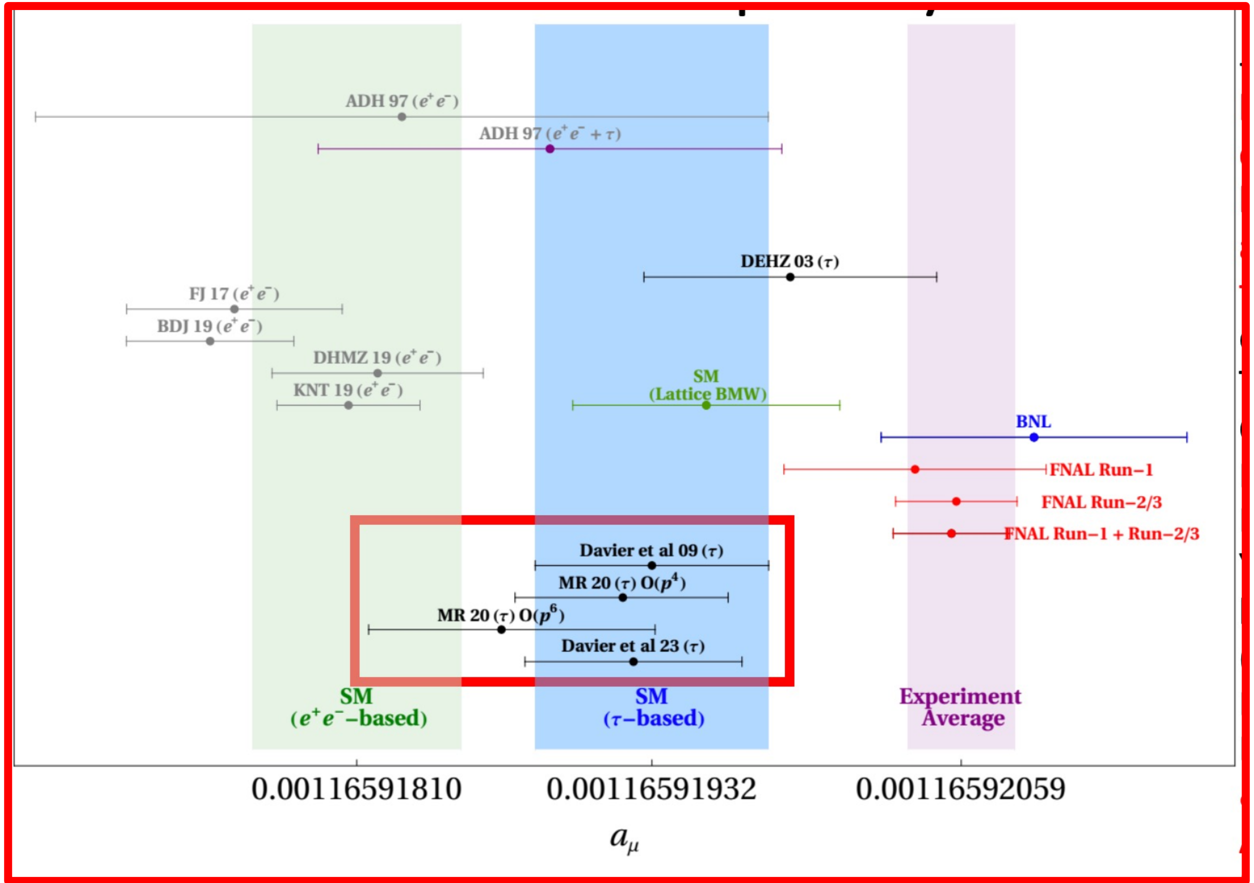
Need to determine integral of these σ to percent-level

Shape of the isospin-breaking correction shows up in CMD + BaBar ratios

Wishlist for 2025: Understand impact of isospin corrections on spectral shape above/below rho-omega mixing ... can Lattice QCD weigh in?

Tau Data inputs to a_μ^{HVP}

- Landscape of a_μ^{HVP} in flux
- Lots to understand in terms of spectral and absolute variations in $e^+ e^-$, and τ data



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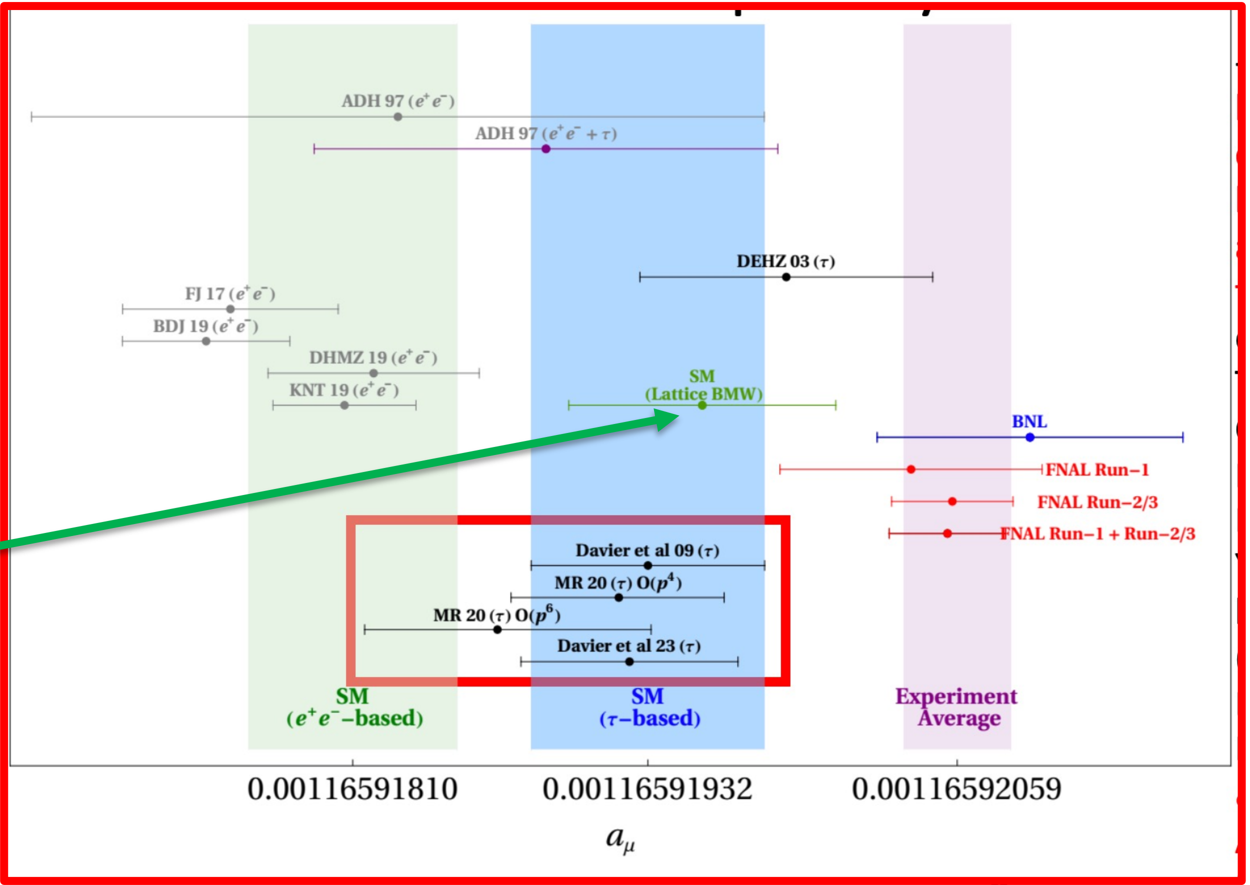
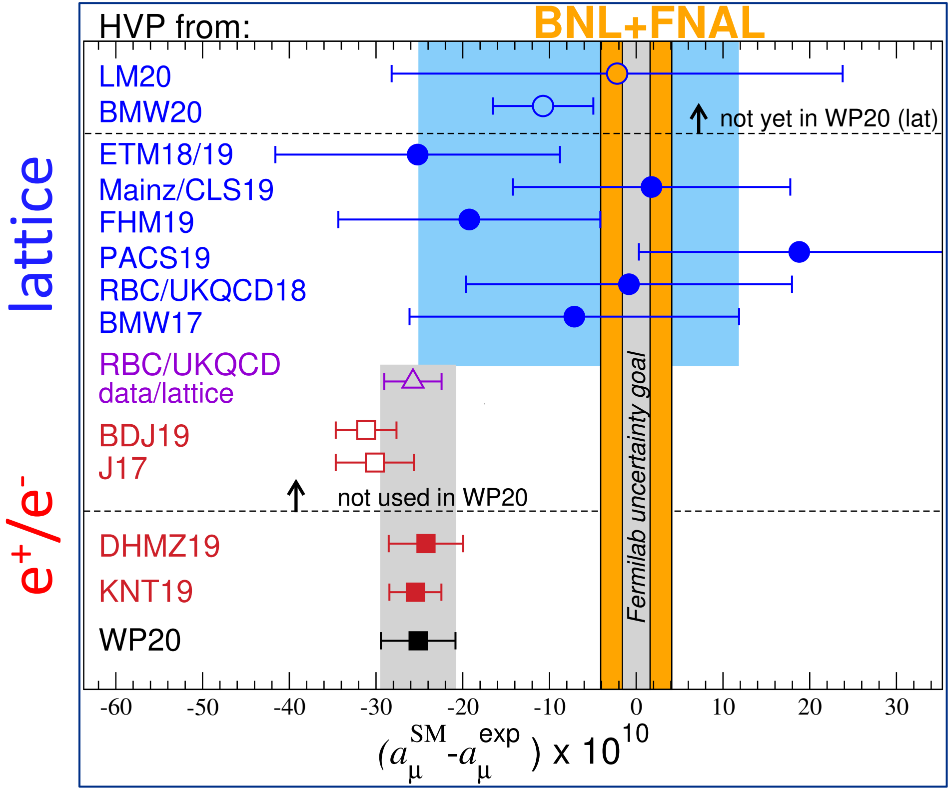
Tau Data inputs to a_μ^{HVP}

- Landscape of a_μ^{HVP} in flux
- Lots to understand in terms of spectral and absolute variations in $e^+ e^-$, and τ data … **as well as lattice…**



a_μ^{SM} determined using HVP from lattice QCD or dispersive calc

- In 2020 the first high-precision lattice QCD result came out: BMW
- Showed significant tension with e^+/e^- evaluation, much closer to experiment



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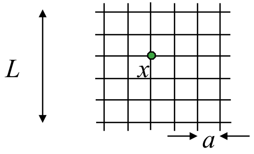
Lattice QCD Introduction

- Provides alternative method of calculating hadronic contributions
- Maps Minkowski spacetime ←→ Euclidean space

- Direct calculation using Euclidean Lattice QCD



Approximations:
discrete space-time (spacing a)
finite spatial volume (L), and time extent (T)
…

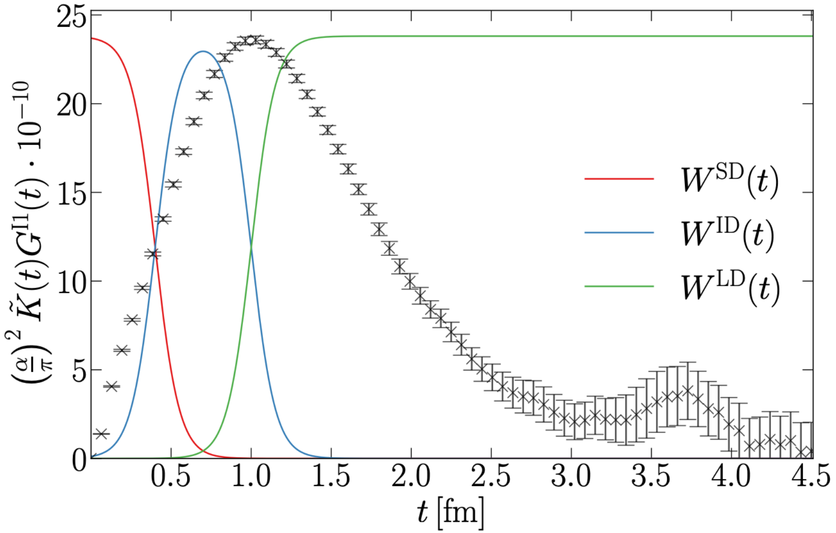
Integrals are evaluated numerically using Monte Carlo methods.

A. El-Khadra P5 town hall, 21-24 Mar 2023 X

Extrapolate:

- Lattice spacing a→0
- Finite volume, time: L→ ∞, T>L
- Quark masses, m → physical masses

Different windows in Euclidean time are sensitive to different systematics



Hadronic vacuum polarization contribution to the muon g–2 from lattice QCD — Friday — *Simon Kuberski* — 10:50 - 11:15

- Enables comparisons between groups in each window
- Short Distance (SD) t: 0 → t_0
- Intermediate (W) t: t_0 → t_1
- Long Distance (LD) t: t_1 → ∞

- Systematics vary for different windows
  - SD → discretization
  - LD → finite volume / stats

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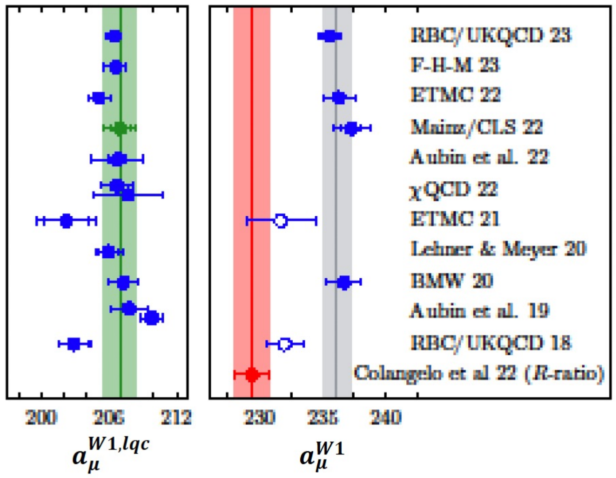
Intermediate Window Benchmark

- **Contributes 1/3** of the LO HVP contribution
- Systematic uncertainties are smaller
- Dispersive data can be mapped to the Euclidean space

- **The full intermediate window a_μ^{W1}**

H. Wittig, EW Moriond 2306.04165



Data-driven determinations of light-quark-connected and strange-plus-disconnected window contributions to a_mu
Kim Maltman
Tuesday

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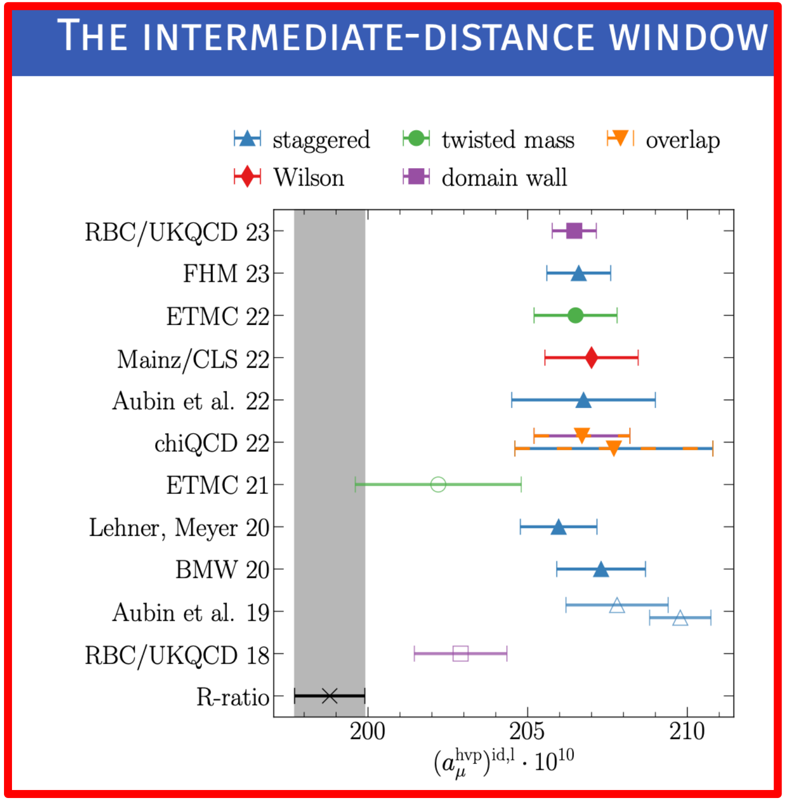
Status Intermediate window 2023



Hadronic vacuum polarization contribution to the muon g–2 from lattice QCD — Simon Kuberski — 10:50 - 11:15

Friday

- BY 2023, many groups have results in this window with <1% precision
- Several groups include sub-leading contributions to a_μ^{HVP}, all in good agreement
- ~4σ discrepancy with the r-ratio data
- Explains about 50% of the overall discrepancy between BMW and dispersive data
- In this window, where the lattice systematics are well-controlled, lattice QCD predicts significantly larger quark contribution to a_μ than the e+/e- data

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Lattice Wishlist for Tau 2025

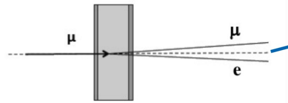
- Understand the 4σ discrepancy in the intermediate window between lattice QCD & $e^+e^- \rightarrow \pi^+ \pi^-$ r-ratio evaluation
- Develop multiple comparisons in the long-distance window
  - LD window contributes 2/3 of the total HVP
  - Has trickier finite-volume systematics
  - Statistically limited
- Achieve multiple, full evaluations of a_μ^{HVP}

Additional Experimental handle on HVP: MUonE at CERN

- A novel approach to determine the leading hadronic contribution via a high-precision shape measurement of the differential cross section of μe elastic scattering

$$a_\mu^{HLO} = \frac{\alpha_0}{\pi} \int_0^1 dx(1-x)\Delta\alpha_{had}[t(x)]$$

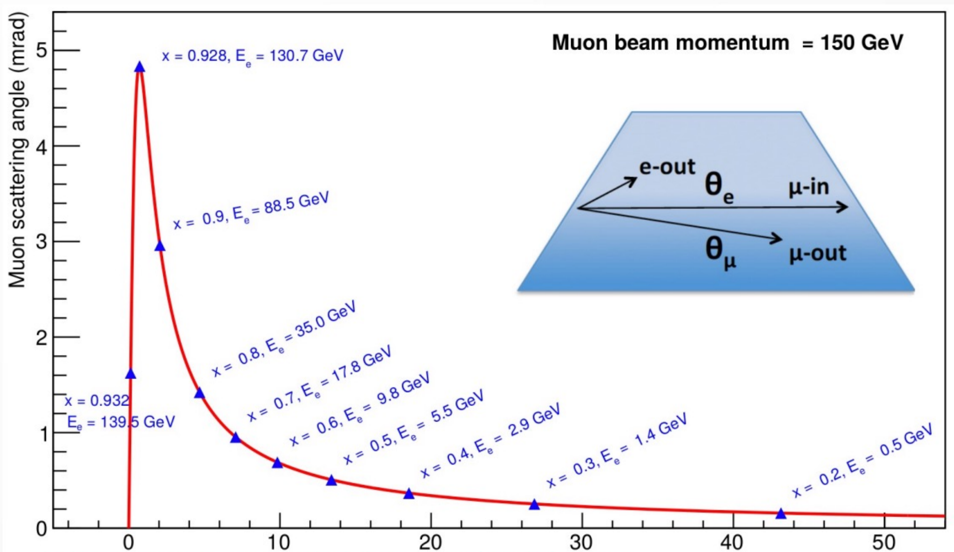
Extraction of $\Delta\alpha_{had}(t)$ from the ***shape*** of the $\mu e \rightarrow \mu e$ differential cross section



$$\frac{d\sigma_{\text{data}}(\Delta\alpha_{\text{had}})}{d\sigma_{\text{MC}}(\Delta\alpha_{\text{had}}=0)} \sim 1 + 2\Delta\alpha_{\text{had}}(t)$$

From theoretical calculation — To be measured

- Precision tracking off of target via silicon strip detectors
- Correlation between muon and electron angle
- Compute a_μ^{HLO} from 1 experiment
- Final Goal: 3 years of running → 0.3% precision on a_μ^{HLO}



Abbiendi et al, Eur. Phys. J. C 77.3 (2017), 139

An alternative evaluation of the leading-order hadronic contribution to the muon g-2 with MUonE — *Riccardo Pilato* — Tuesday 09:55 - 10:20

MUonE

- 3 weeks Test Run 2023: proof of concept of the experimental proposal. Data analysis ongoing.
  Request for a longer commissioning run in 2025 instrumenting more tracking stations.
- Full apparatus (40 stations) after CERN Long Shutdown 3 (2026-28) to achieve the target precision (~0.3% stat and similar syst).
- Alternative method to calculate a_μ^{HLO} with MUonE data:
  less sensitive to the parameterization chosen to model $\Delta\alpha_{had}(t)$ in the MUonE kinematic range.
  Comparable uncertainty to the space-like integral method.

23

Wishlist for Tau2025

- Full proposal developed
- Commissioning run (2025) with scaled down detector

An alternative evaluation of the leading-order hadronic contribution to the muon g-2 with MUonE *Riccardo Pilato*

Tuesday 09:55 - 10:20

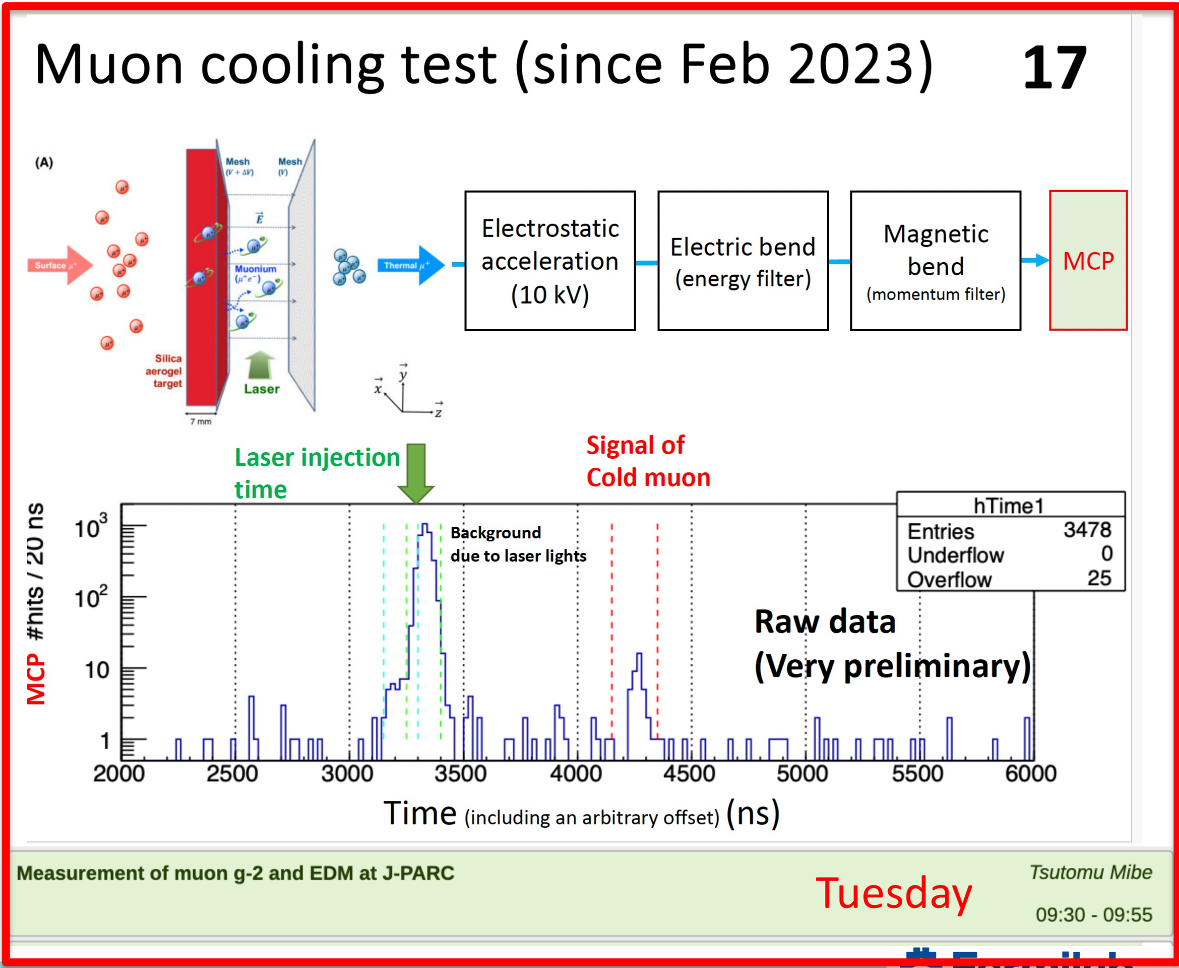
Fermilab

JPARC Muon g-2 & EDM

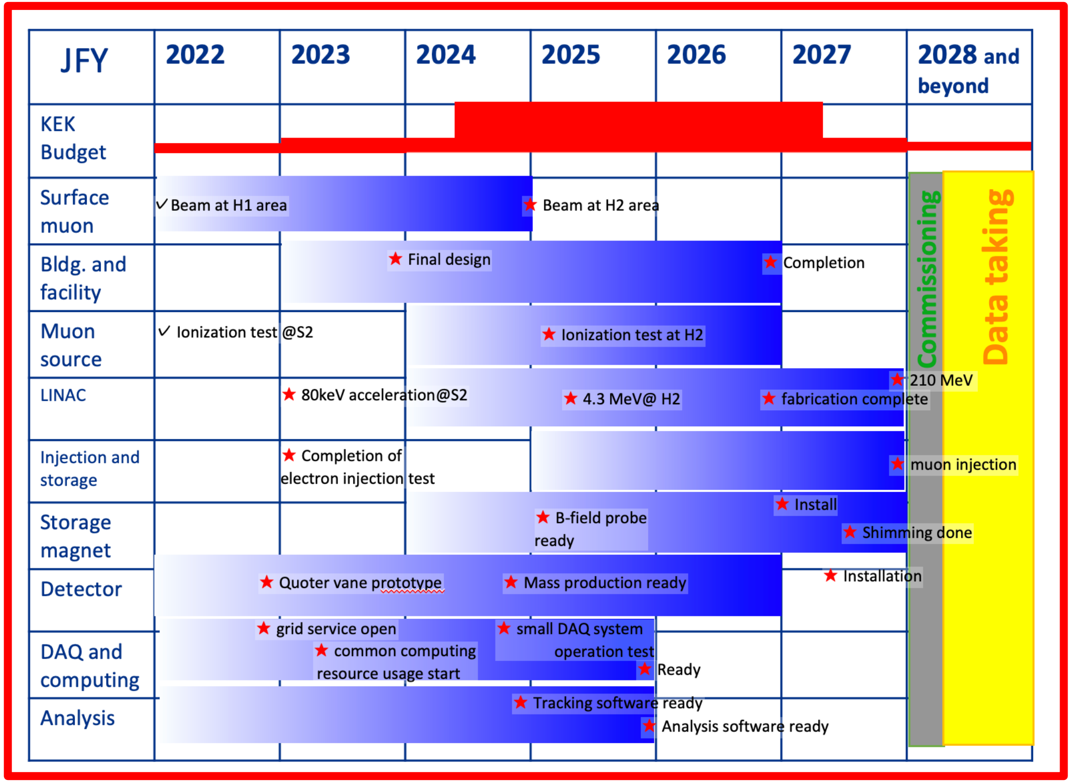
Novel g-2 approach
Ideal for pushing Muon EDM limits

Experiment adopts new method (different systematics):

- Low-emittance beam (cooling+ acceleration)
- Compact storage ring
- Very weak magnetic focusing



JPARC Muon g-2 & EDM



Measurement of muon g-2 and EDM at J-PARC

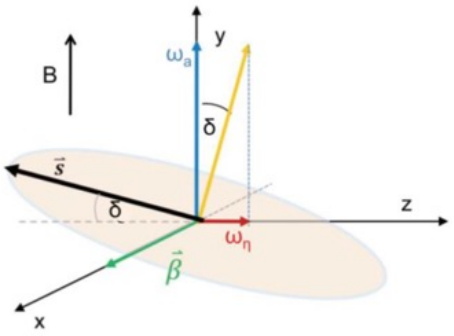
Tsutomu Mibe

Tuesday 09:30 - 09:55

Wishlist for Tau2025:

- Continued ramp up of JPARC support
- Progress on the muon source, cooling, accelerator and detectors!

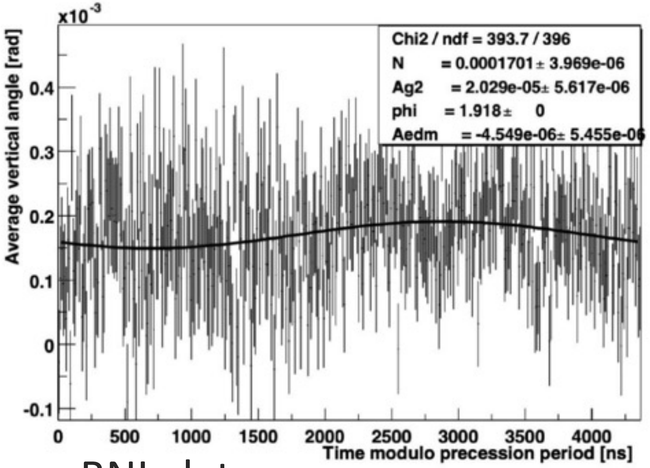
Searching for NP within Fermilab Muon g-2 (Muon EDM)



- Presence of a muon EDM would tilt precession plane

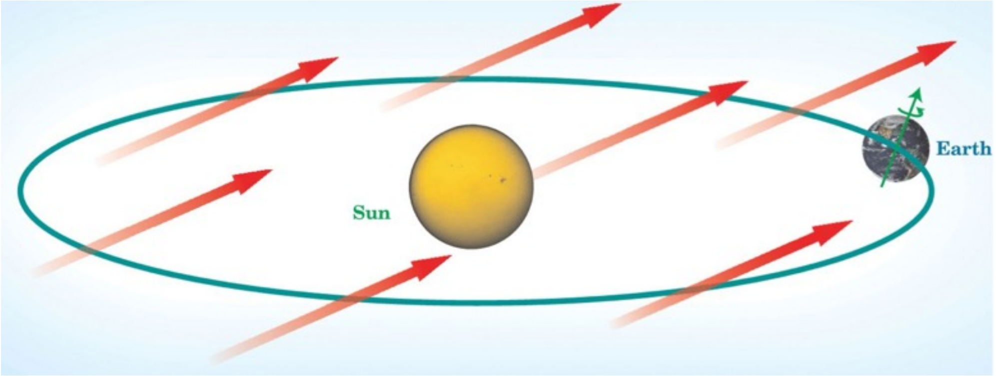
$$\vec{\omega}_{a\eta} = a_\mu \frac{e}{m}\vec{B} + \eta \frac{e}{2m}\left[\frac{\vec{E}}{c} + \vec{\beta}\times\vec{B}\right]$$

- Look for a rotation of muon precession out of the plane, oscillating out of phase with the g-2 wiggle. Requires:
  - precision pitch angle of decay electron
  - Tracker alignment and acceptance
  - Knowledge of vector components of the magnetic field
- Run 1/2/3 analysis nearing completion (still blind)
  - Statistical error dominated
  - Anticipated sensitivity $|d_\mu| \sim 5\times10^{-20}$ e·cm
  - ~4x better than current BNL limit of $|d_\mu| < 1.9\times10^{-20}$ e·cm
- At least 4x statistics on tape → $\sim 2\times10^{-20}$ e·cm ultimate limit

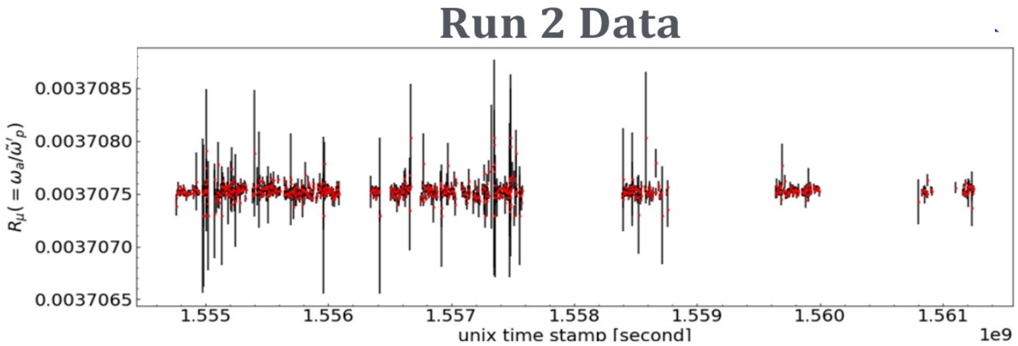


BNL data

Searching for NP within Fermilab Muon g-2 data (CPT/LV)



$$\mathcal{L}' = -a_\kappa \overline{\psi}\gamma^\kappa\psi - b_\kappa\overline{\psi}\gamma_5\gamma^\kappa\psi - \frac{1}{2}H_{\kappa\lambda}\overline{\psi}\sigma^{\kappa\lambda}\psi + \frac{1}{2}ic_{\kappa\lambda}\overline{\psi}\gamma^\kappa \overleftrightarrow{D}^\lambda\psi + \frac{1}{2}id_{\kappa\lambda}\overline{\psi}\gamma_5\gamma^\kappa \overleftrightarrow{D}^\lambda\psi$$



- Lorentz-violating extensions (e.g. Kostelecký et.al.)to the SM include terms with CPT/Lorentz violating signatures for our data
- Signals
  - Sidereal oscillation in ω_a (T = 23hr 56min)
  - a(μ+) – a(μ-)
  - Global fits to BNL/FNAL
- Improvements/complementarity to BNL
  - >20 x statistics w/ reduced systematics
  - Longer lever arm (ran for ~36 mos over 6 years compared to ~9 mos over 3 at BNL)
  - Different latitude
- Expecting > 4x improvement

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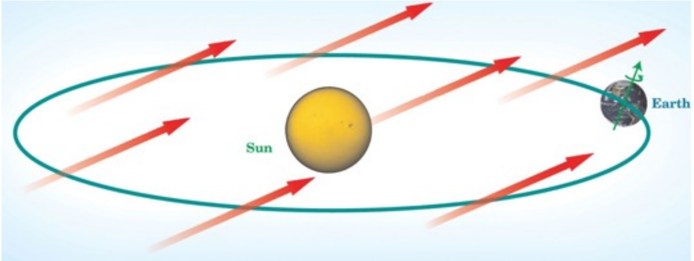
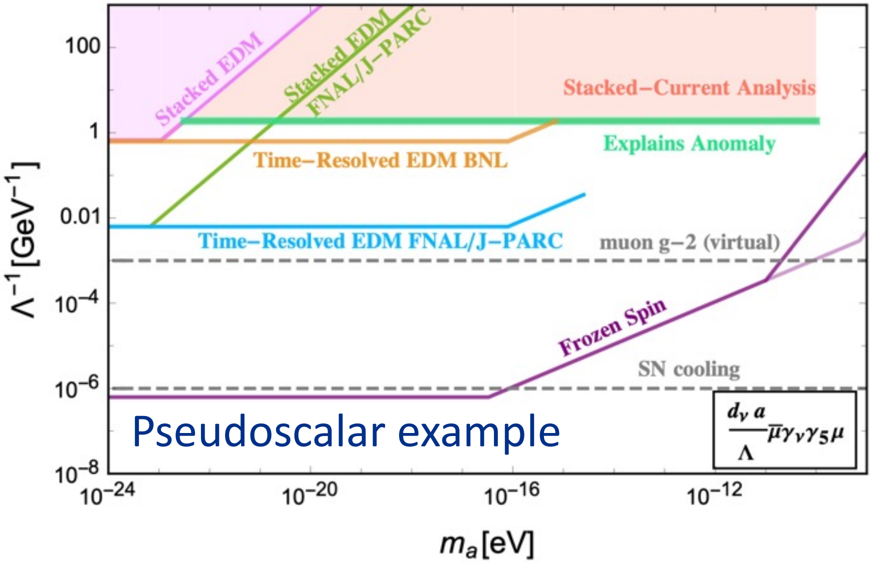
Searching for NP within Fermilab Muon g-2 data (Dark Matter)





- Coherent DM interactions can exert a spin torque and cause an oscillation in a_μ or the EDM signal
- Similar to sidereal variation analysis but the period now depends on the m_{DM}

$$\vec{\omega}_a(t) = \omega_{\rm sm}\hat{z} + \vec{\omega}_{\rm dm}(t) \qquad \vec{\omega}_{\rm dm} \approx -\frac{a_0}{\Lambda} m_a \vec{v} \sin(m_{\rm dm} t)$$

- Stacked plots are sensitive to overall shift in ω_a, but time-resolved analysis needed for ultimate sensitivity
- Precision analyses underway of a_μ vs time (t=100ms → 5 years)

Ryan Janish, Harikrishnan Ramani
PRD **102**, 115018 (2020)

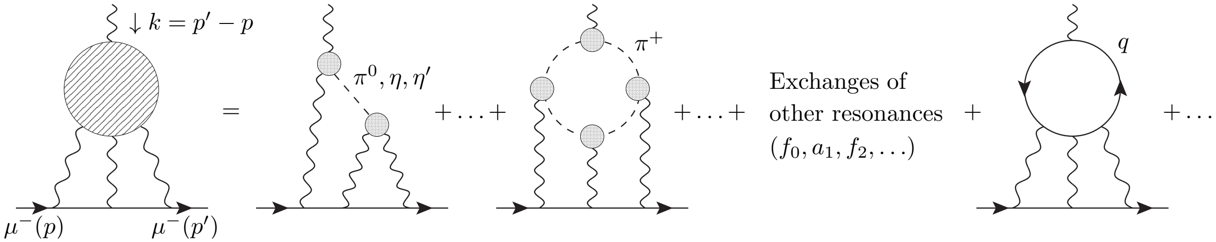
Wishlist Summary for Tau 2025

- **Muon g-2 Experiment**
  - Publish Run 4-6 analysis
  - Maintain systematic uncertainty of 70 ppb (No suprises!)
  - Reduce total uncertainty on a_μ^{exp} by 35% (190 ppb→ 120 ppb)
  - Publish companion EDM + CPT/LV & DM searches
- **MUonE**
  - Complete a fully developed proposal for physics run after long shutdown
  - Achieve first commissioning run (2025) w/ scaled down detector
- **JPARC g-2 / EDM effort**
  - Develop novel experimental method to determine a_μ with different systematic effects
  - Achieved demonstration of mature muon source, cooling, acceleration with launch of detector production

Wishlist Summary for Tau 2025

- **Theory**
  - Understand spectral differences in $e^+e^- \rightarrow \pi^+\pi^-$
  - Understand why CMD-3 normalization so different from KLOE/BaBar/CMD-2
  - Update results from KLOE, BABAR, BELLE-II, CMD,… and the corresponding dispersive evaluations
  - Understand impact of isospin corrections on spectral shape of τ data above and below the rho-omega mixing: Can lattice QCD weigh in and provide model-independent calculations for the isospin corrections?
  - Understand the 4σ discrepancy in the intermediate window between lattice QCD & $e^+e^- \rightarrow \pi^+\pi^-$ r-ratio evaluation
  - Develop multiple comparisons in the long-distance window, which contributes 2/3 of the total HVP, as well as full evaluations
  - Utilize blinding methods whenever possible to reduce unintentional biases

Hadronic Light by Light



- This difficult problem previously caused quite some stress!
- HLBL has smaller contribution that HVP, but relative uncertainty is larger
- After some excellent work in the last 5 years, multiple current HLbL lattice results and dispersive approaches are compatible with uncertainties ~20% .
- Corresponds to 0.15 ppm uncertainty on a_μ
- TI Outlook: We expect that ongoing work on both approaches will yield reduced uncertainties in 2024-2025, down to the 10% level.

Wishlist: Converge on HLbL calc. with ~10% rel uncertainty

Recent publication

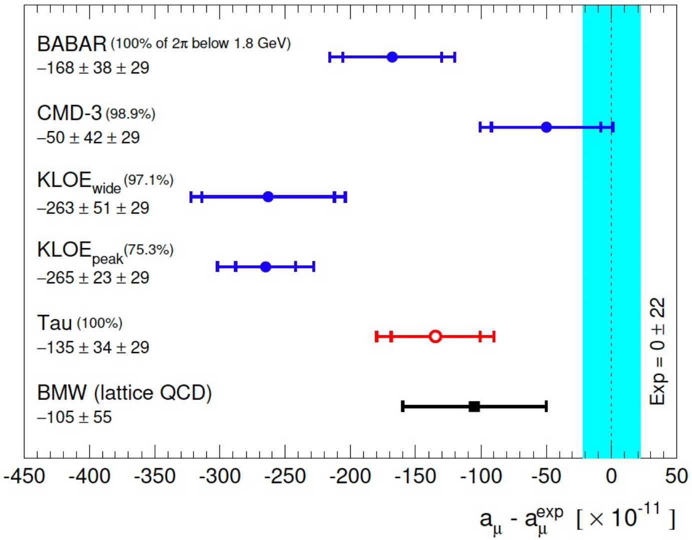


Fig. 11. Compilation of a_μ predictions subtracted by the central value of the experimental world average [2]. The

Note: Similar plots for the intermediate window

Davier et al: arXiv:2312.02053

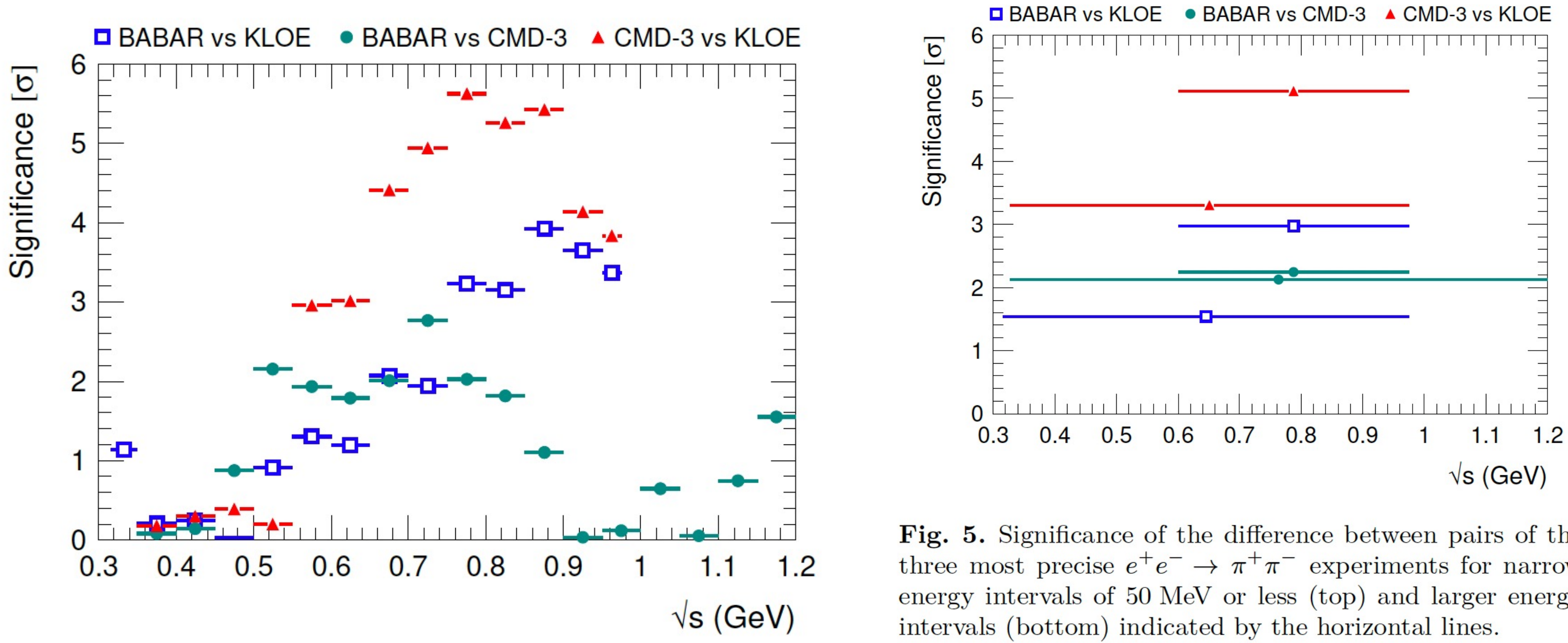


Fig. 5. Significance of the difference between pairs of the three most precise $e^+e^- \to \pi^+\pi^-$ experiments for narrow energy intervals of 50 MeV or less (top) and larger energy intervals (bottom) indicated by the horizontal lines.

Lepton Universality connections

If anomaly persists, potential explanation include things like $U(1)L_{\mu}-L_{\tau}$ extension of the SM

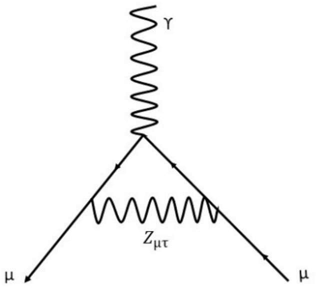
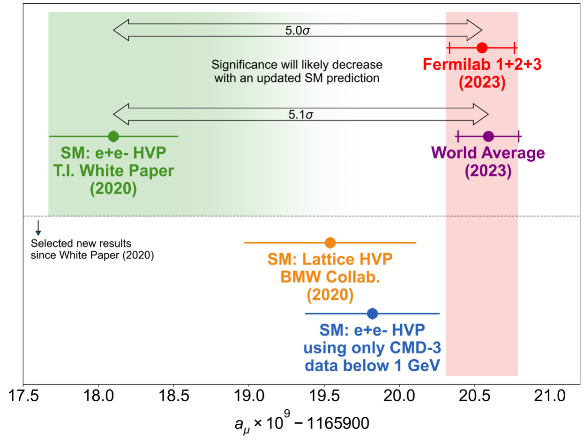


Figure 2: One loop contribution to muon $(g-2)$ mediated by neutral gauge boson $Z_{\mu\tau}$.

Muon g-2 (Lepton Universality)



Anyway, muon g-2 gives us some hint to violate the lepton universality.
For example, Lμ-Lτ model explains this discrepancy. So, muon g-2 may
Indicates deep relation between τ and μ.
We may need to consider tau g-2 more seriously.

04/Dec/2023 TAU2023 2

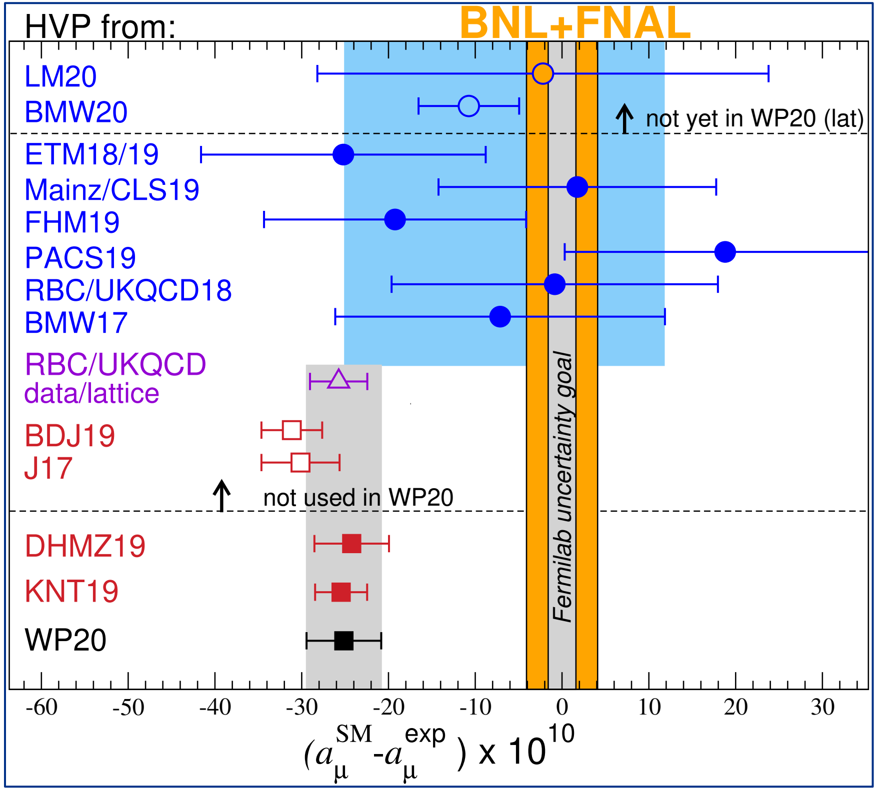
Overview of Tau Physics *Kiyoshi Hayasaka*

Monday

09:15 - 09:55

Summary: New Precise Lattice Calculations are in tension with Dispersive Calculations for a_μ

- Important to see how story evolves
  - Will need to see how other windows compares
  - There are several tensions within the dispersive calculations, within lattice and between dispersive and lattice contributions for HVP
- ***Critical*** to support efforts to understand these discrepancies and develop a firm theoretical calculation



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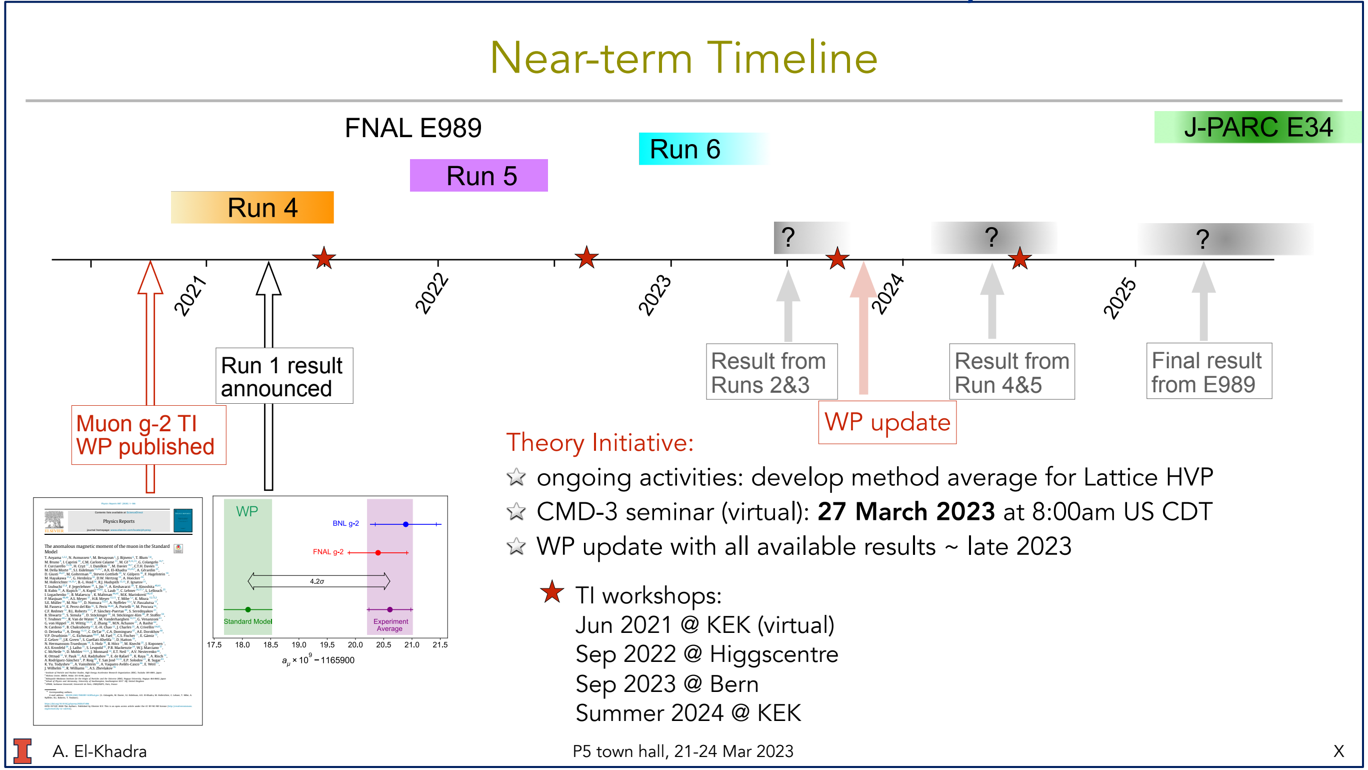
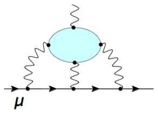
Overall Timeline & Summary

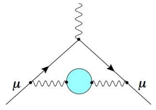
- Major exp & theory updates planned in 2023
- Both exp & theory planning significant updates by 2025
- Open questions on theory-theory & theory-exp anomalies will be addressed on this timeline

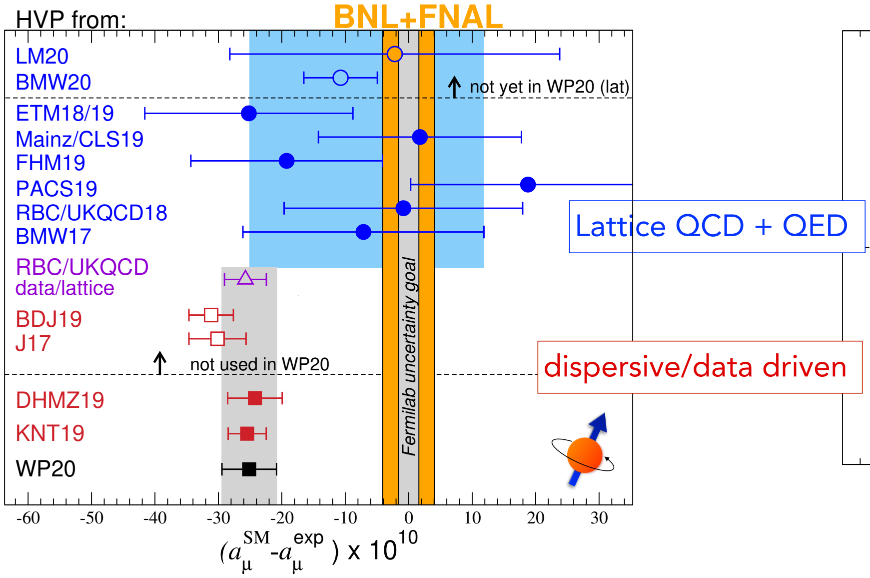
A. El-Khadra's talk at P5 town hall, March 2023

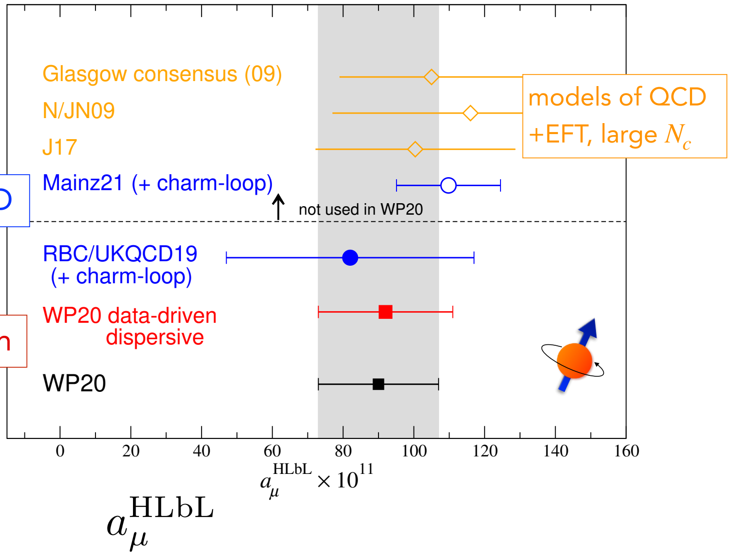




Hadronic Corrections: Comparisons







$$a_\mu^{SM} = a_\mu^{HVP} + \left[a_\mu^{QED} + a_\mu^{Weak} + a_\mu^{HLbL}\right]$$

A. El-Khadra   P5 town hall, 21-24 Mar 2023   X

Simultaneous measurements: g-2, EDM

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

Expected time spectrum of e^+ in $\mu \rightarrow e^+\nu\nu$ decay