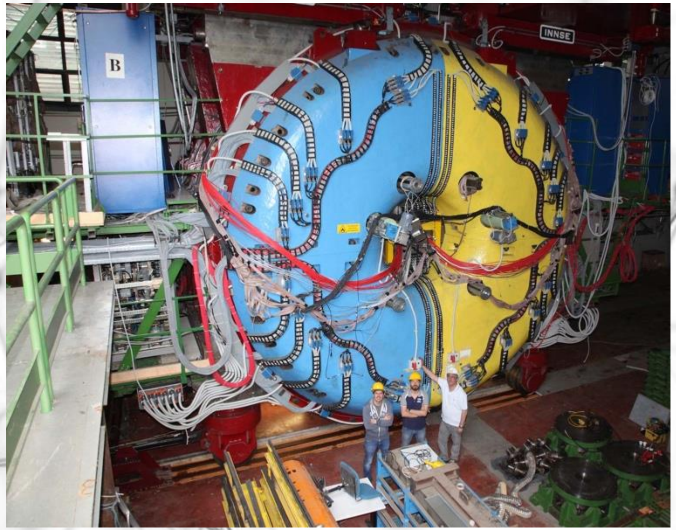
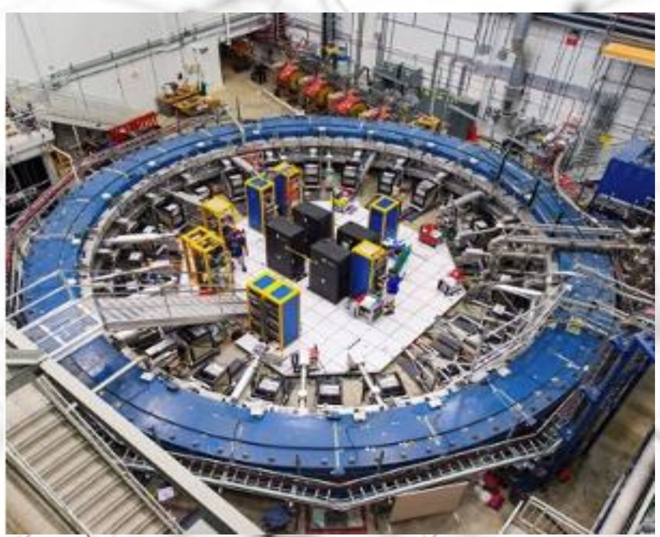
LEVERHULME TRUST

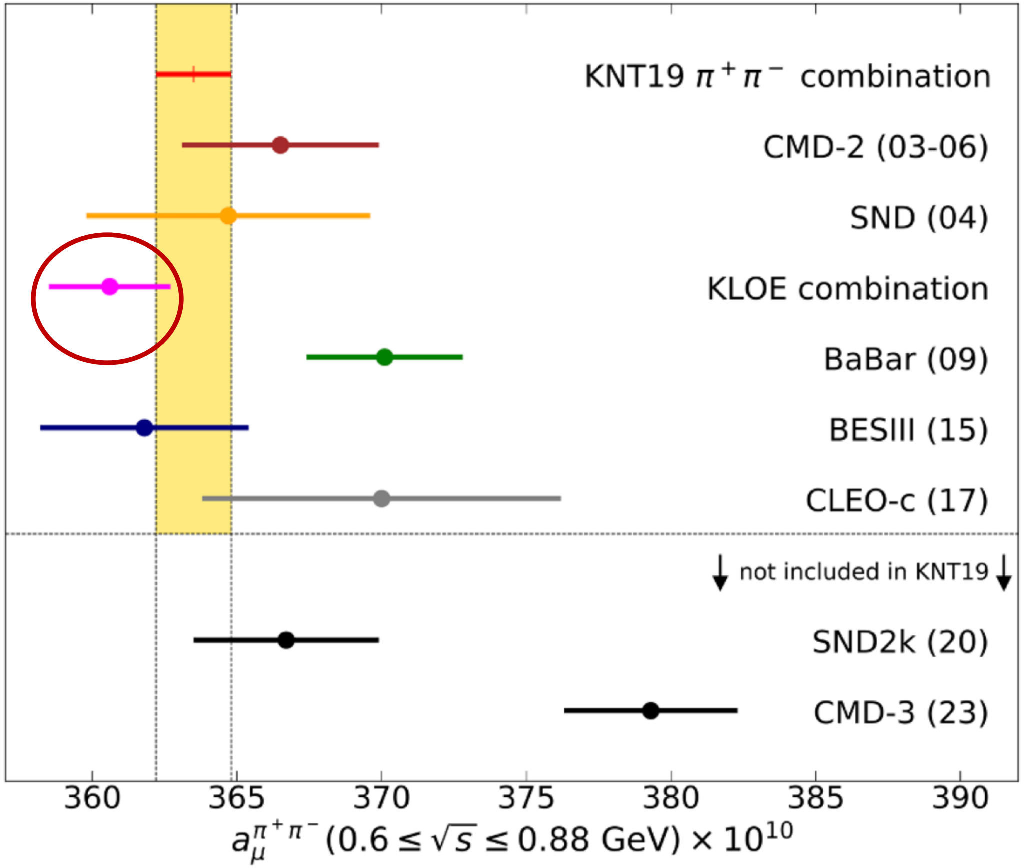


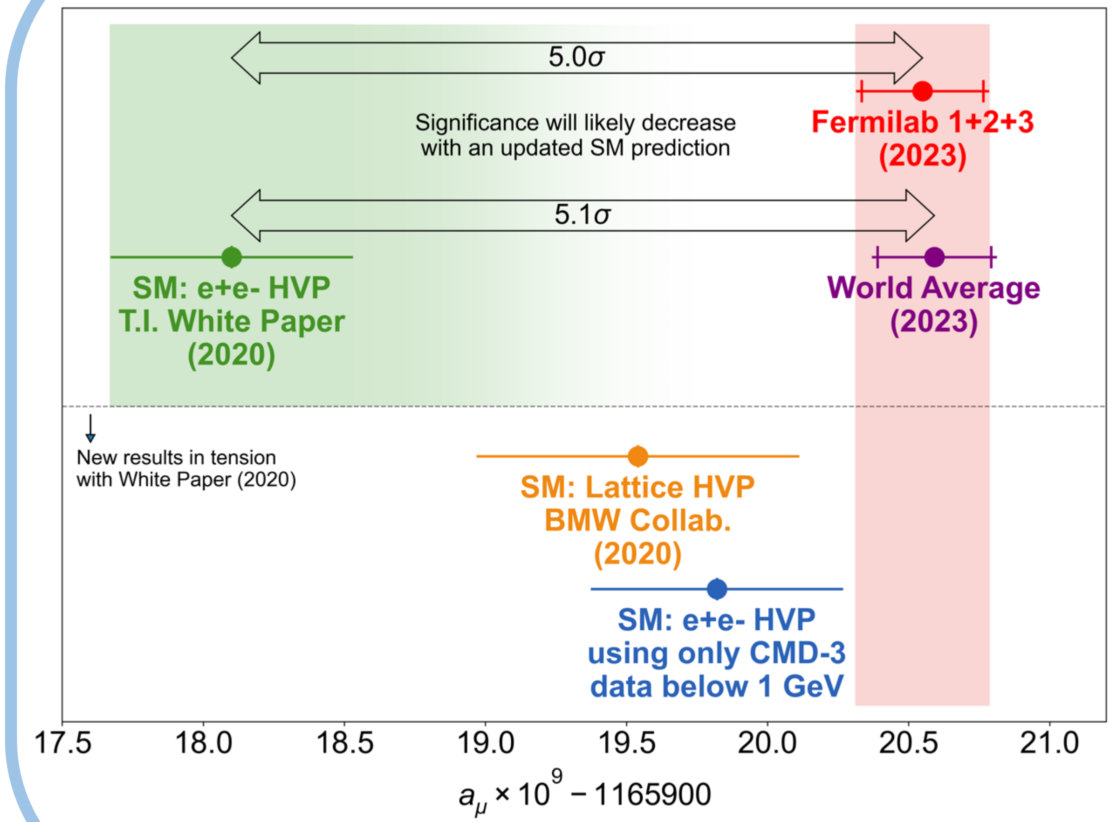


KLOE, MUON G-2 AND MU-EDM AT LIVERPOOL

ESTIFA'A ZAID ON BEHALF OF THE KLOE-2 COLLABORATION FNAL G-2 COLLABORATION

THE MUON G-2 LANDSCAPE





The KLOE measurements have been instrumental in shaping the current landscape of muon g-2.

IMPORTANT: THIS PLOT IS VERY ROUGH!

- TI White Paper result has been substituted by CMD-3 only for 0.33 → 1.0 GeV.
- The NLO HVP has not been updated.
- It is purely for demonstration purposes → <u>should not be taken as final!</u>

THE CURRENT EFFORT

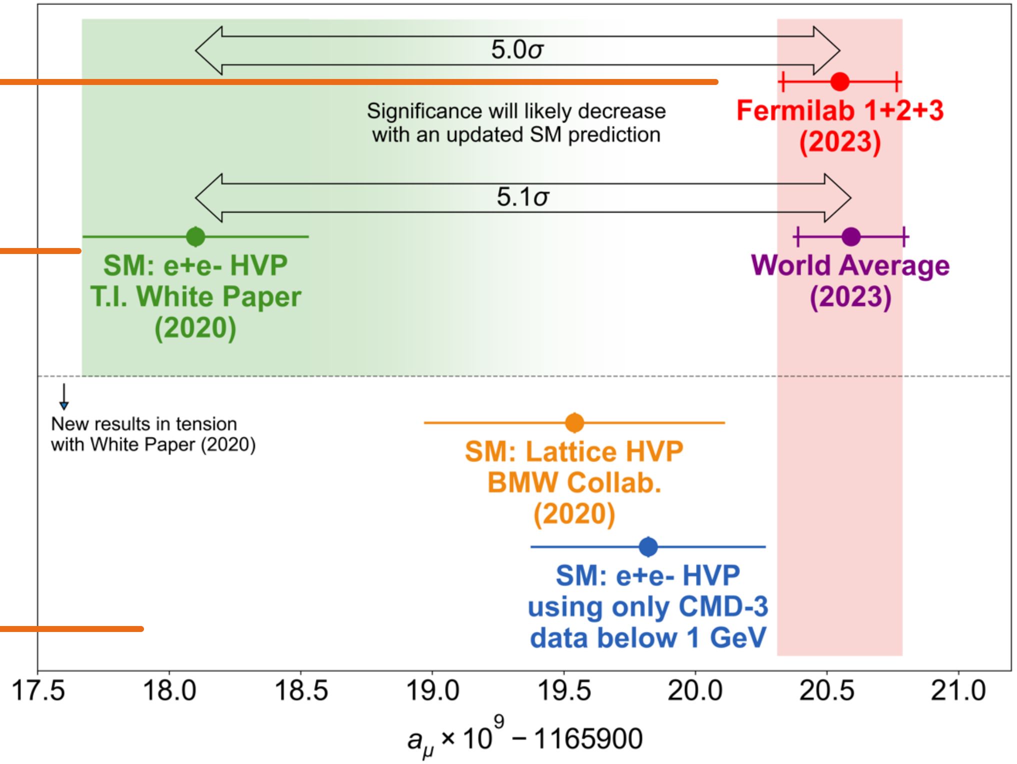
The Leverhulme Trust grant which was awarded to Graziano Venanzoni in 2022 has funded a large group in Liverpool (12 postdocs and 8 PhD students) with the aim of clarifying the muon g-2 puzzle.

LEVERHULME TRUST

Muon g-2 Experiment at Fermilab Run 4+5+6

New KLOE hadronic cross section measurement

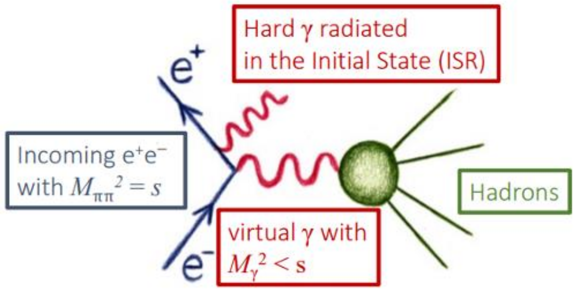
MUonE experiment: a new approach to determining a_μ^{HLO}

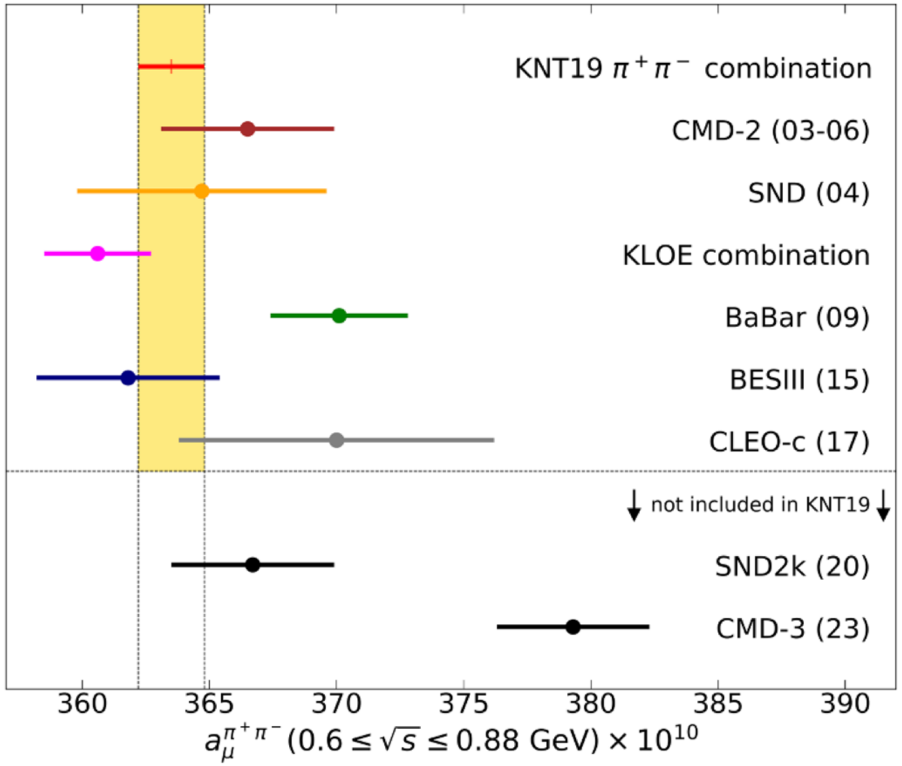


THE CURRENT EFFORT

There is a current experimental effort to **discern tensions in the dispersive approach** to determining the muon g-2 SM prediction

The main contribution to the evaluation of the hadronic contribution to the muon anomaly (a_μ^{HLO}) is taken from the $e^+e^- \to hadron$ cross section





A long-standing tension ($\simeq 2.8\sigma$) exists between KLOE cross section measurements and BaBar

The new CMD-3 $e^+e^- \to \pi^+\pi^-$ cross section measurement is in tension with both BaBar ($\simeq 2.3\sigma$) and KLOE ($\simeq 5.1\sigma$)

Combined theoretical prediction for the dispersive approach is limited by tensions between KLOE and BaBar measurements. Even without including CMD-3

THE CURRENT EFFORT

New KLOE hadronic cross section measurement

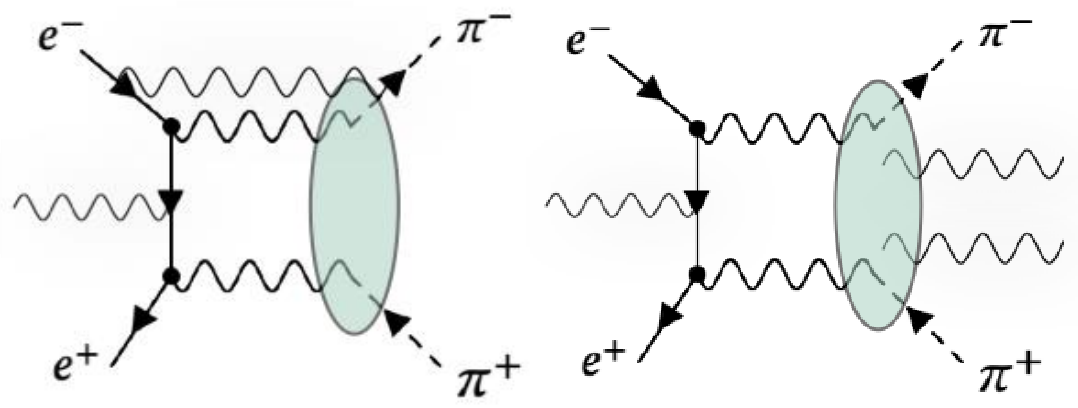
RadioMonteCarLow 2

Leading updated comparisons of Monte Carlo generators for low-energy physics.

Combined effort with theory members at Liverpool University to cross check Radiative Corrections for published analyses, calculate higher order radiative corrections and develop NNLO MC generators for the new analysis.

Large experimental group of 15 members at Liverpool University working on the KLOE analysis as well as collaborators from Pisa, Dresden and Krakow institutes.

THEORETICAL SUPPORT FOR THE KLOE EXPERIMENT



- Main focus on radiative return processes, $e^+e^- \to \pi^+\pi^-\gamma$ and $e^+e^- \to \mu^+\mu^-\gamma$
- Next-to leading (NLO) theoretical predictions currently available
- We are now improving these predictions:
  - Make use of soft-QED approximation
  - Improved theoretical precision to match KLOE-2 data needs

Why Low-Energy Physics, Why Now?

- Renewed interest in low-energy e^+e^- annihilation as a probe of hadronic effects
- Two Physical Review Letters publications highlight recent theoretical advances (including one from our group).

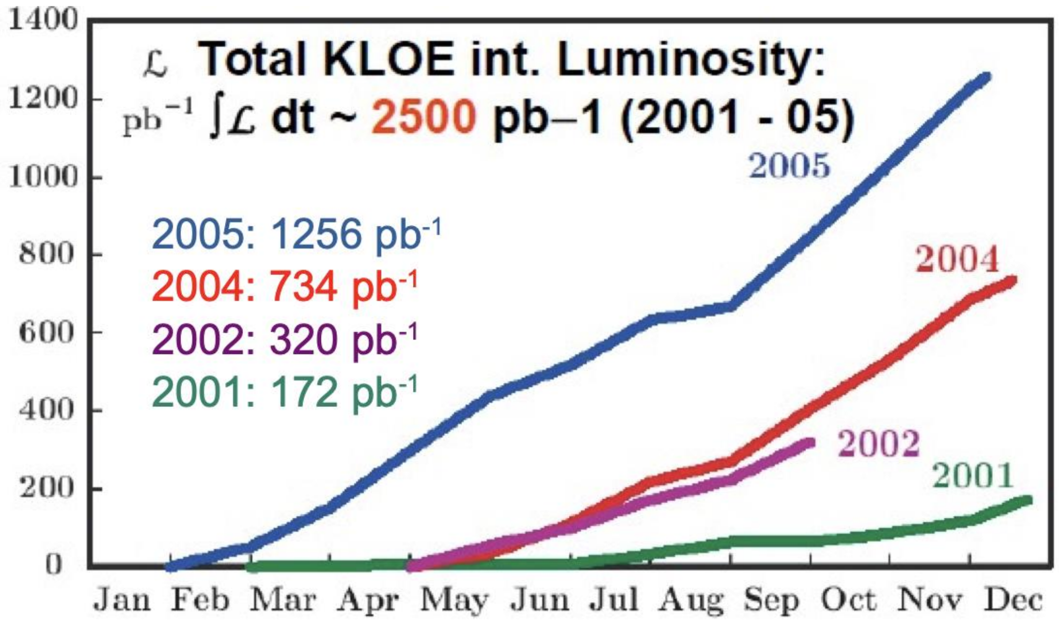
Phys.Rev.Lett. 128 (2022) 2, 022002,
Phys.Rev.Lett. 132 (2024) 23, 231904

Visibility, impact, and the need for support

- Our work is visible: two talks accepted at EPS-HEP 2025
- Precision improvements demand high-performance computing:
  - NNLO theoretical predictions will shed light on analysis of KLOE-next data
  - Tuning of Monte Carlo predictions
- Supporting this request means supporting cutting-edge theoretical input for hadronic physics

CURRENT KLOE HADRONIC CROSS SECTION ANALYSIS

Previous KLOE analyses were done on 240 pb^{-1} (~ 3.5 million $\pi\pi\gamma$ events) of data taken in 2002 and 232 pb^{-1} from 2006



This ongoing analysis aims to use **2004/2005 KLOE data** to carry out a new measurement. The ~1.7 fb^{-1} includes **~ 25 million $\pi\pi\gamma$ events** which have **never been used** before in such an analysis. 2006 off-peak data will be used for additional cross checks and systematic studies

CURRENT KLOE HADRONIC CROSS SECTION ANALYSIS

Syst Errors (%)	KLOE12 $a_\mu^{\pi\pi}$ ratio	KLOE-next (expected) $a_\mu^{\pi\pi}$ ratio
Background Filter (FILFO)	negligible	negligible
Background Subtraction	0.6	0.2
Trackmass	0.2	0.2
Particle ID	negligible	negligible
Tracking	0.1	0.1
Trigger	0.1	0.1
Unfolding	negligible	negligible
Acceptance ($\theta_{\pi\pi}$)	negligible	negligible
Acceptance (θ_π)	negligible	negligible
Software Trigger (L3)	0.1	0.1
Luminosity	-	-
$\sqrt{s}$ dep. of H	-	-
Total exp. systematics	0.7	0.3
Vacuum Polarisation	-	-
FSR treatment	0.2	0.2
Rad. function H	-	-
Total theory systematics	0.2	0.2
Total systematic error	0.7	0.4

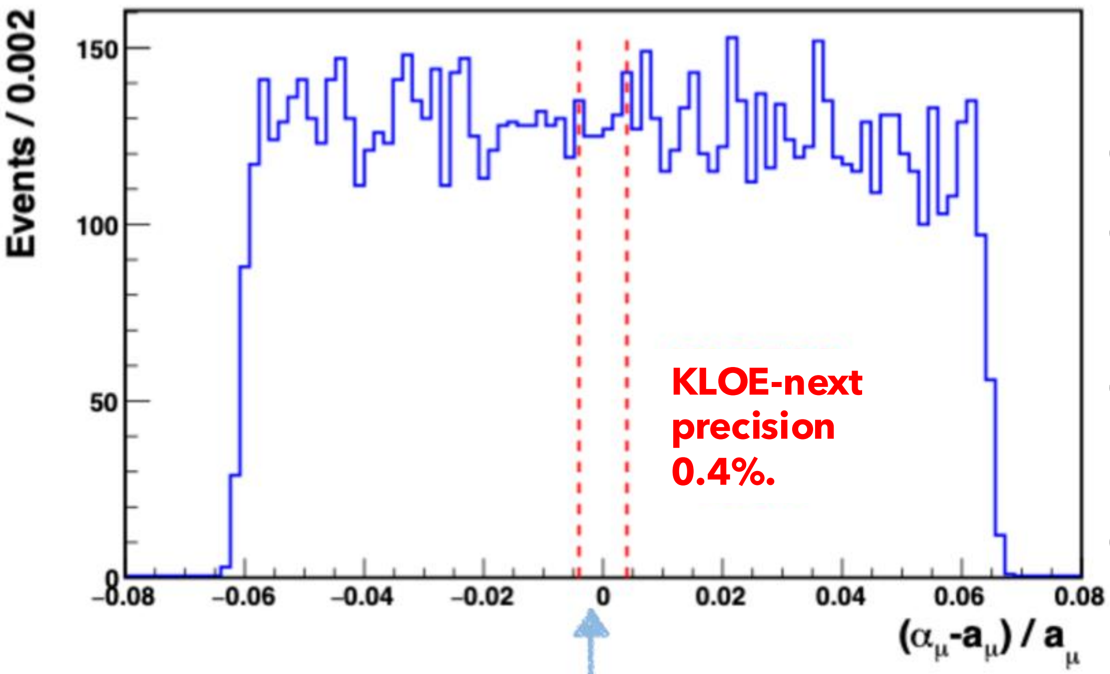
Analysis group is tackling different aspects using new techniques with the intention of reducing the larger systematic uncertainties.

KLOE12: $0.3\%_{stat} \oplus 0.2\%_{th} \oplus 0.7\%_{syst} \Rightarrow \sim 0.8\%_{tot}$

KLOE-next$_{(goal)}$: $0.1\%_{stat} \oplus 0.2\%_{th} \oplus 0.3\%_{syst} \Rightarrow \sim 0.4\%_{tot}$

There will be a factor 7 statistical improvement making the statistical uncertainty negligible wrt systematics. There will be dedicated work on the background. subtraction procedure to achieve a **x3 reduction of the background subtraction uncertainty**.

A BLINDED ANALYSIS

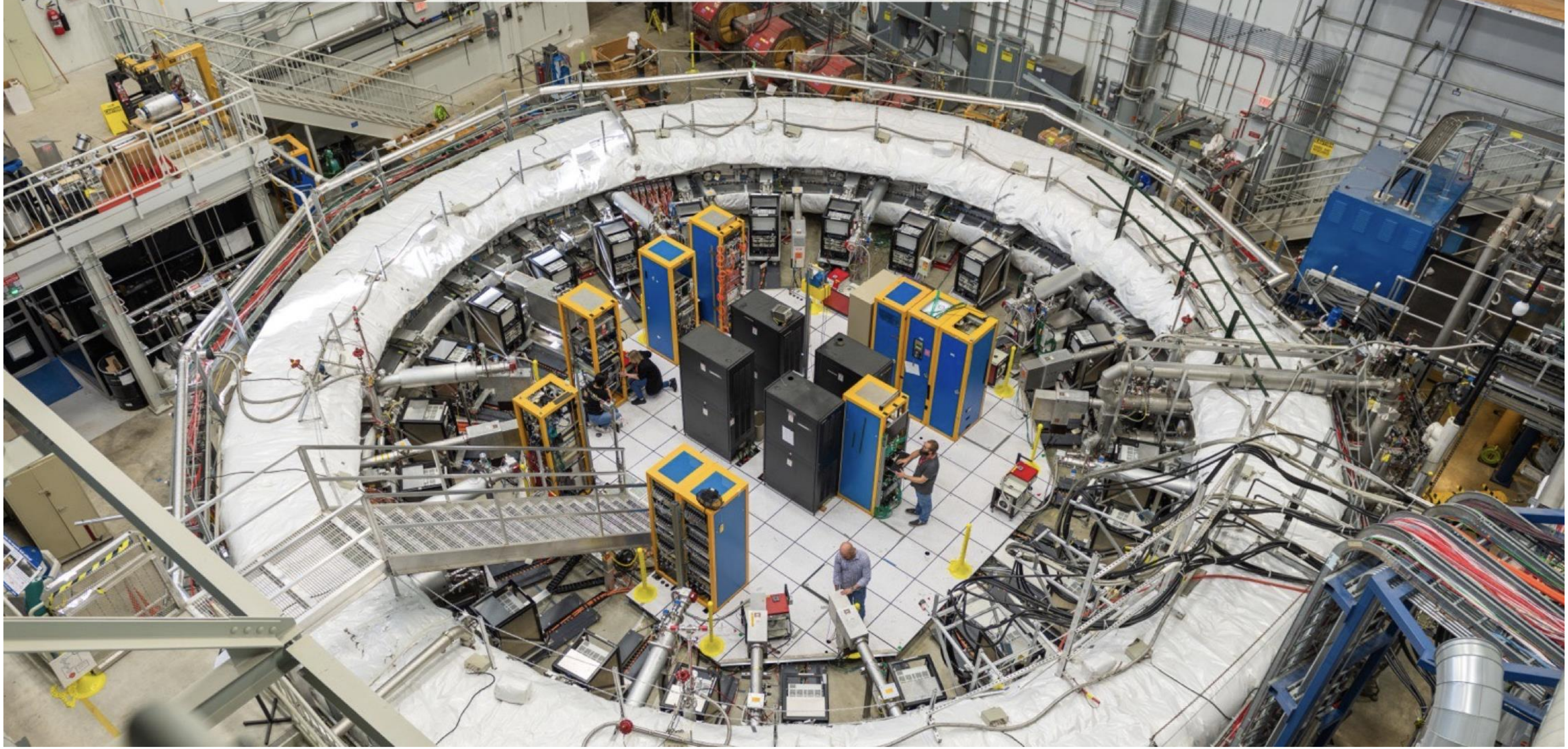


Blinded value of a_μ is $\pm 6\%$ with respect to true value in simulations. Blinded offset is much larger than KLOE-next precision

Blinding procedure has been documented and undergone an internal review process.

- The new KLOE analysis will be **conducted blindly** to ensure good practice and avoid bias throughout.
- This is not a trivial task and is the **first KLOE a_μ^{HLO} analysis to be blinded.**
- The aim of blinding is to shift the result of the analysis by a small amount without jeopardising the distributions of data and Monte Carlo.
- Two sets of root-tuples will be used in this analysis; **blinded and working (unblinded) root-tuples.**
- For the blinded root-tuples, proposed procedure is as follows:
  - **Removing a small, unknown (to the analysers) fraction of events from each $Q^2_{\pi\pi}$ or $Q^2_{\mu\mu}$ slice in data.**
  - This modifies the measured differential cross section and thus $a_{\pi\pi} \propto \int ds \ldots \sigma_{\pi\pi}(s)$ whilst having no affect on distributions at fixed Q^2 bins.
- Efficiencies are calculated on the working root-tuples ($|F_\pi|^2$ not accessible here).
- **Extraction of $|F_\pi|^2$ is done only on blinded root-tuples.**

Muon g-2 at Fermilab: MC-1



KEY PRINCIPLES OF MEASURING G-2

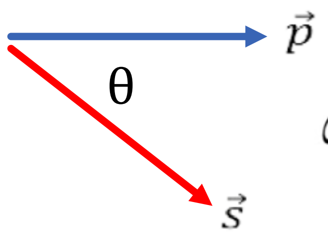
$$\omega_a = \omega_s - \omega_c = a_\mu \frac{e}{m_\mu c} B$$

To get this

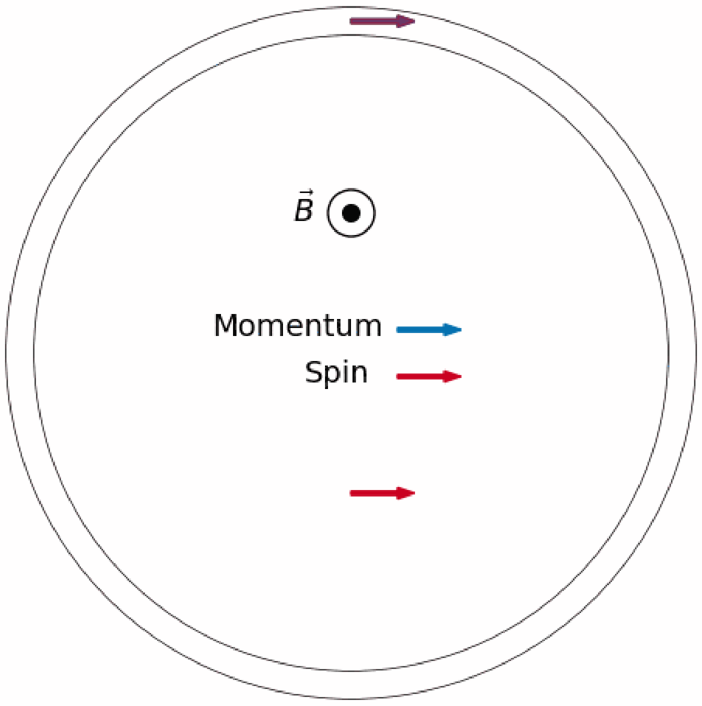
Measure these

Spin rotates ahead of momentum as muon orbits the ring.

At a given point in the ring spin rotates radially in and out with a frequency of ω_a



$$\omega_a = \dot{\theta}$$



MEASURING MUON G-2

$$\hbar\omega_p = 2\mu_p|\vec{B}|$$

We measure

From literature

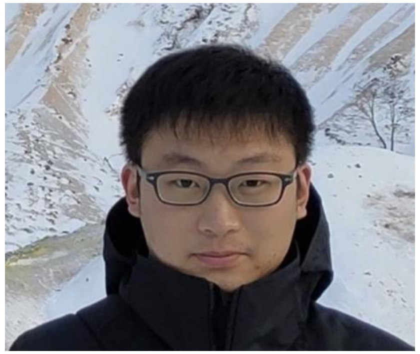
$$a_\mu = \frac{\omega_a}{\tilde{\omega}'_p(T_r)} \frac{\mu'_p(T_r)}{\mu_e(H)} \frac{\mu_e(H)}{\mu_e} \frac{m_\mu}{m_e} \frac{g_e}{2}$$

3 ppb

22 ppb

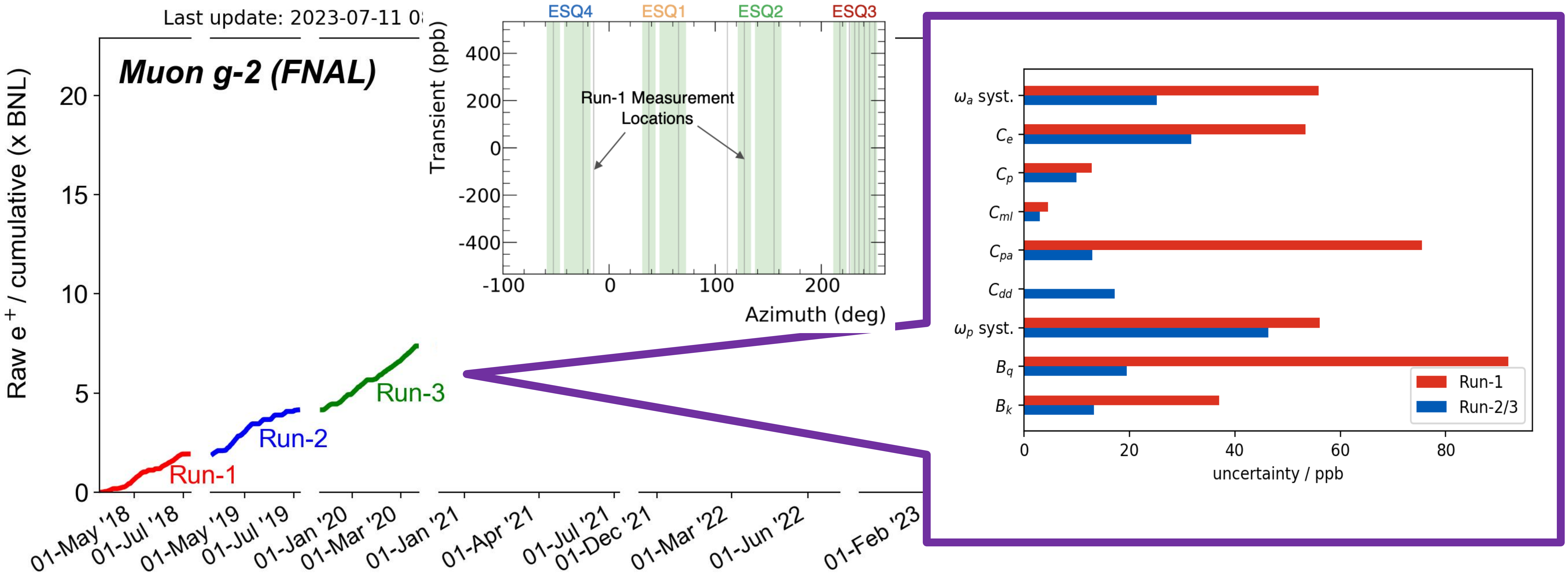
0.3 ppt

$$\frac{\omega_a}{\boxed{\tilde{\omega}'_p}} = \frac{f_{\text{clock}}\,\boxed{\omega_a^{meas}}\,(1 + \boxed{C_e + C_p + C_{ml} + C_{pa} + C_{dd}})}{f_{\text{calib}}\,\langle\, \omega'_p(x,y,\phi) \times M(x,y,\phi)\,\rangle\,(1 + B_k + B_q)}$$

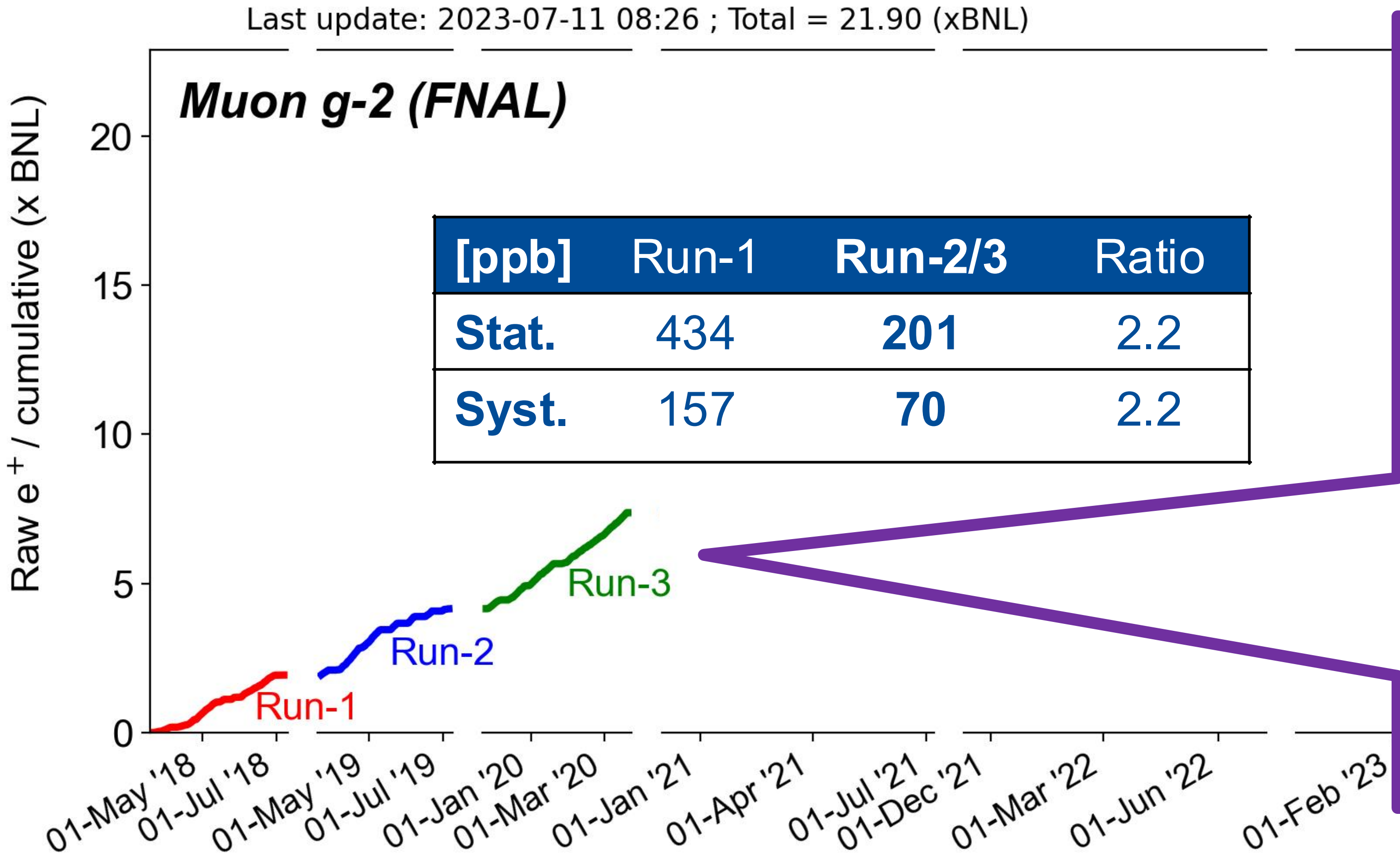


RUN 2 DATA COLLECTION AND RESULT

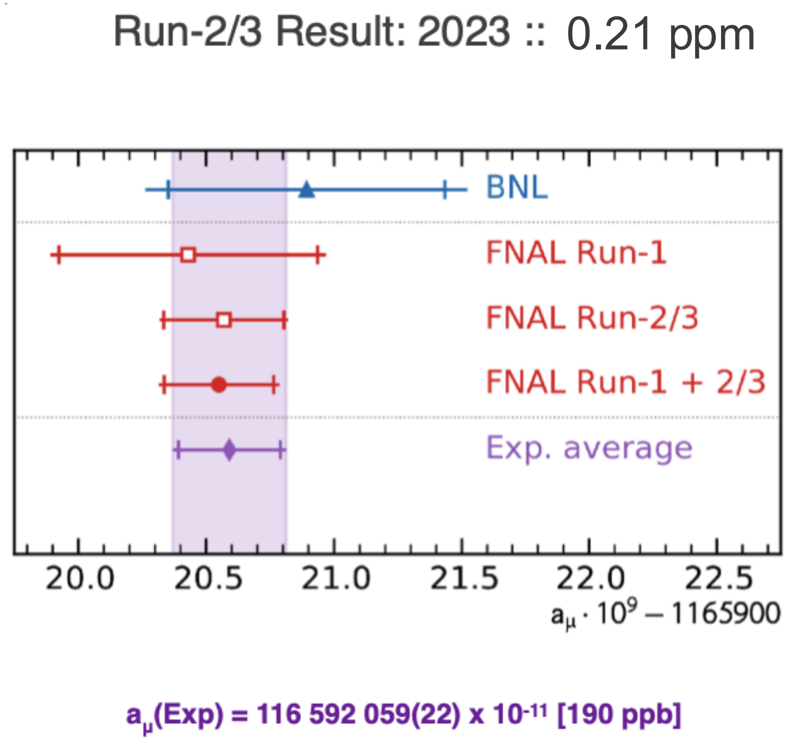


- **Damaged resistors in 2/3 quad plates redesigned and replaced. Beam oscillation frequencies are more stable C_{pa} reduced.**
- **The oscillating magnetic fields from vibrating quads measured with a new NMR probe and measurement positions increased. B_q reduced**

RUN 2/3 DATA COLLECTION AND RESULT

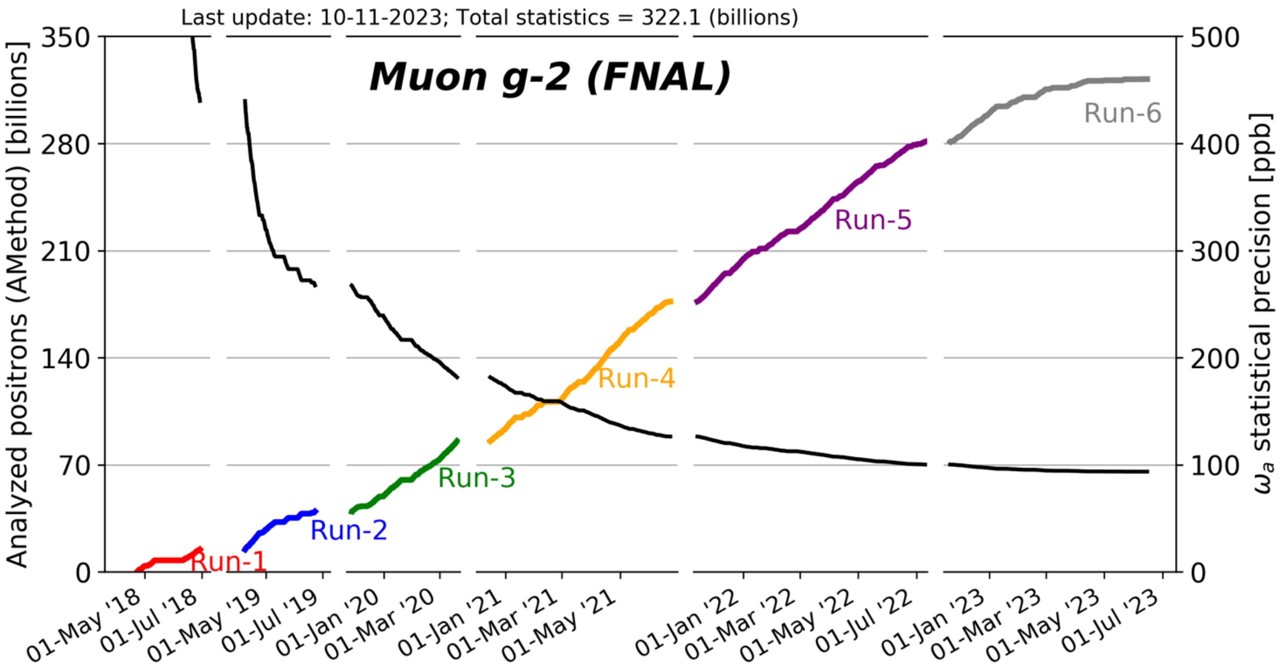


[ppb]	Run-1	**Run-2/3**	Ratio
Stat.	434	**201**	2.2
Syst.	157	**70**	2.2



Total Systematic: 70 ppb
Statistical uncertainty is still higher than systematic.

RUN 4/5/6 DATA COLLECTION AND FINAL RESULT !

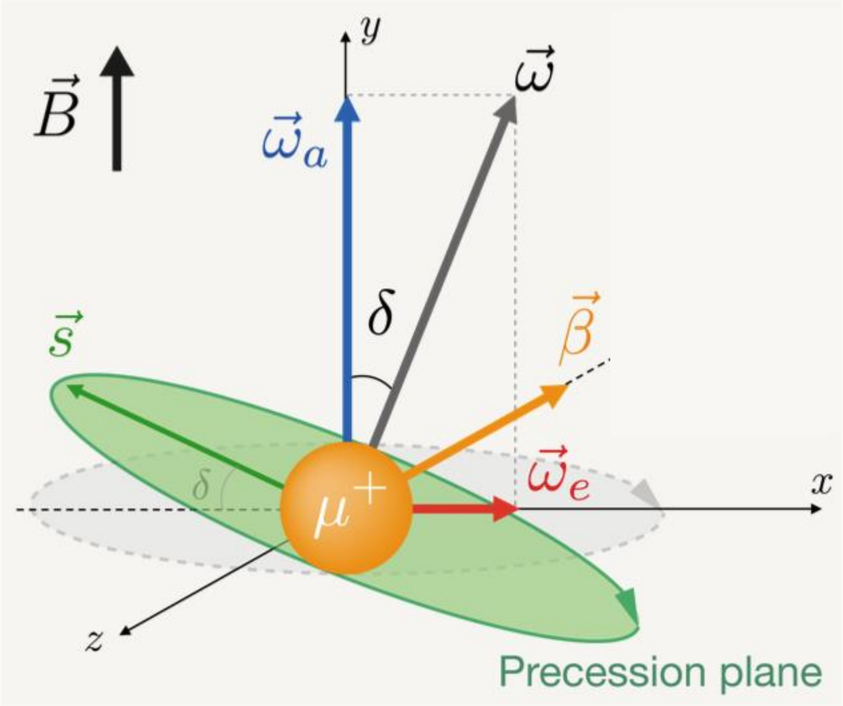


Still analysing full dataset of 322 billion positrons → Release talk scheduled for the 3rd of June 2025 (Save the Date !)

Statistical uncertainty: with Runs 1-6 we expect to surpass design goal of 100ppb statistical uncertainty

Running conditions: Quadrupole radio frequency switched on during Run 5 and 6. This reduced radial and vertical motion of muons giving a more stable beam and less muon losses.

Systematic uncertainty: Great efforts to understand and investigate the systematics better than run 2/3



Non-zero EDM introduces a tiny increase in the precession frequency

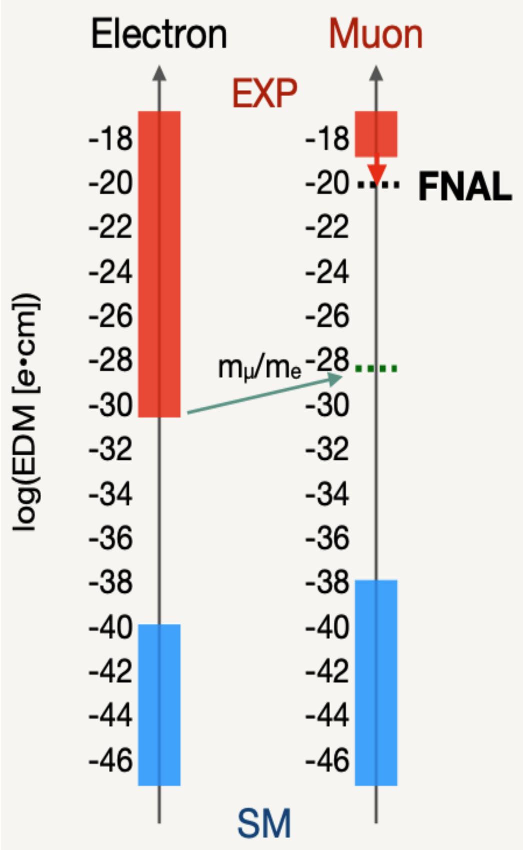
$$\omega = \sqrt{\omega_a^2 + \omega_e^2}$$

Where ω_a^2 is the horizontal precession and ω_e^2 is the vertical precession.

Search for an EDM by looking for a small tilt to the spin precession plane

FNAL muon EDM search focuses on the tracker-based approach, measuring vertical decay angle

Results expected summer 2025



THANK YOU VERY MUCH