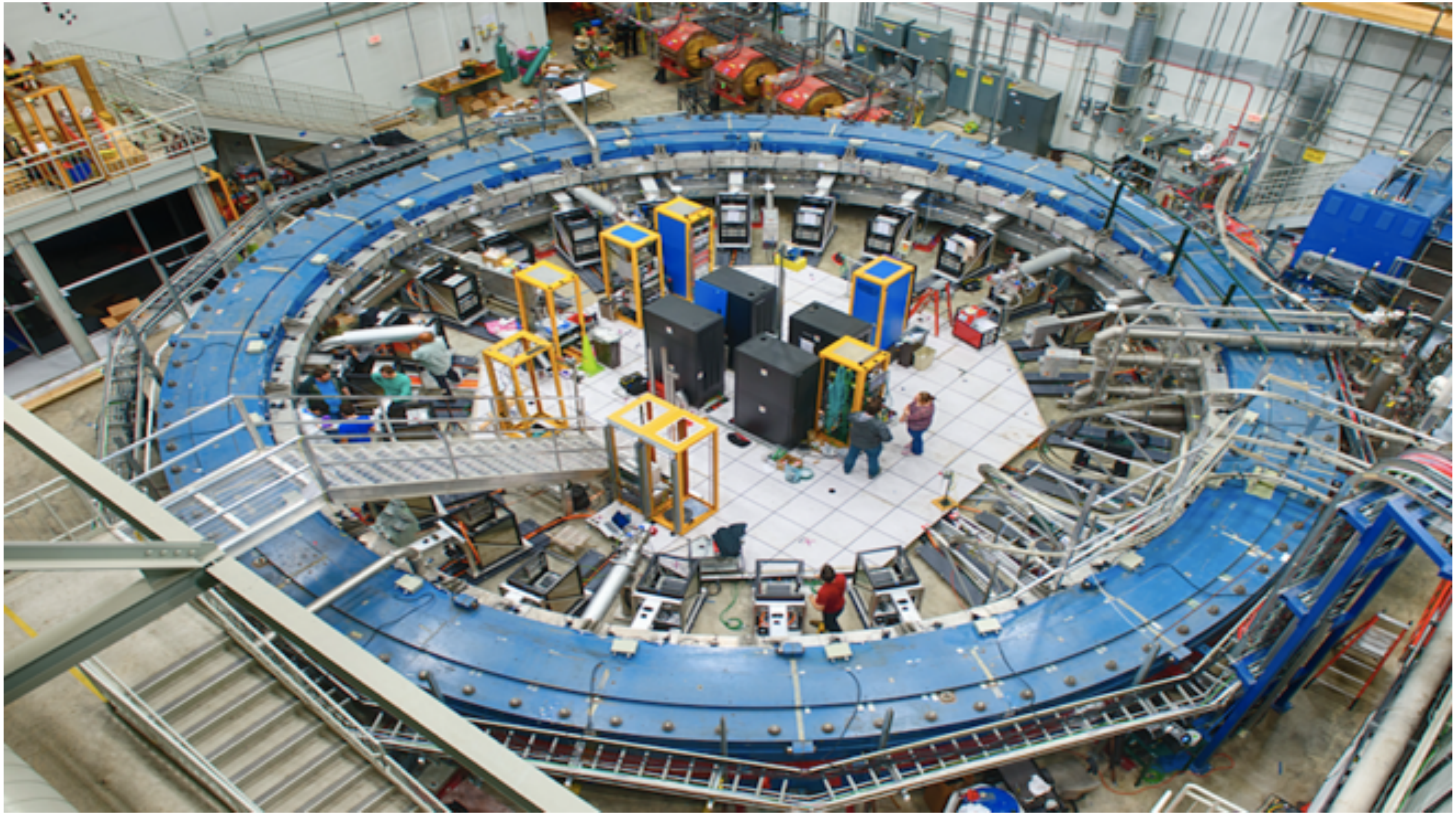
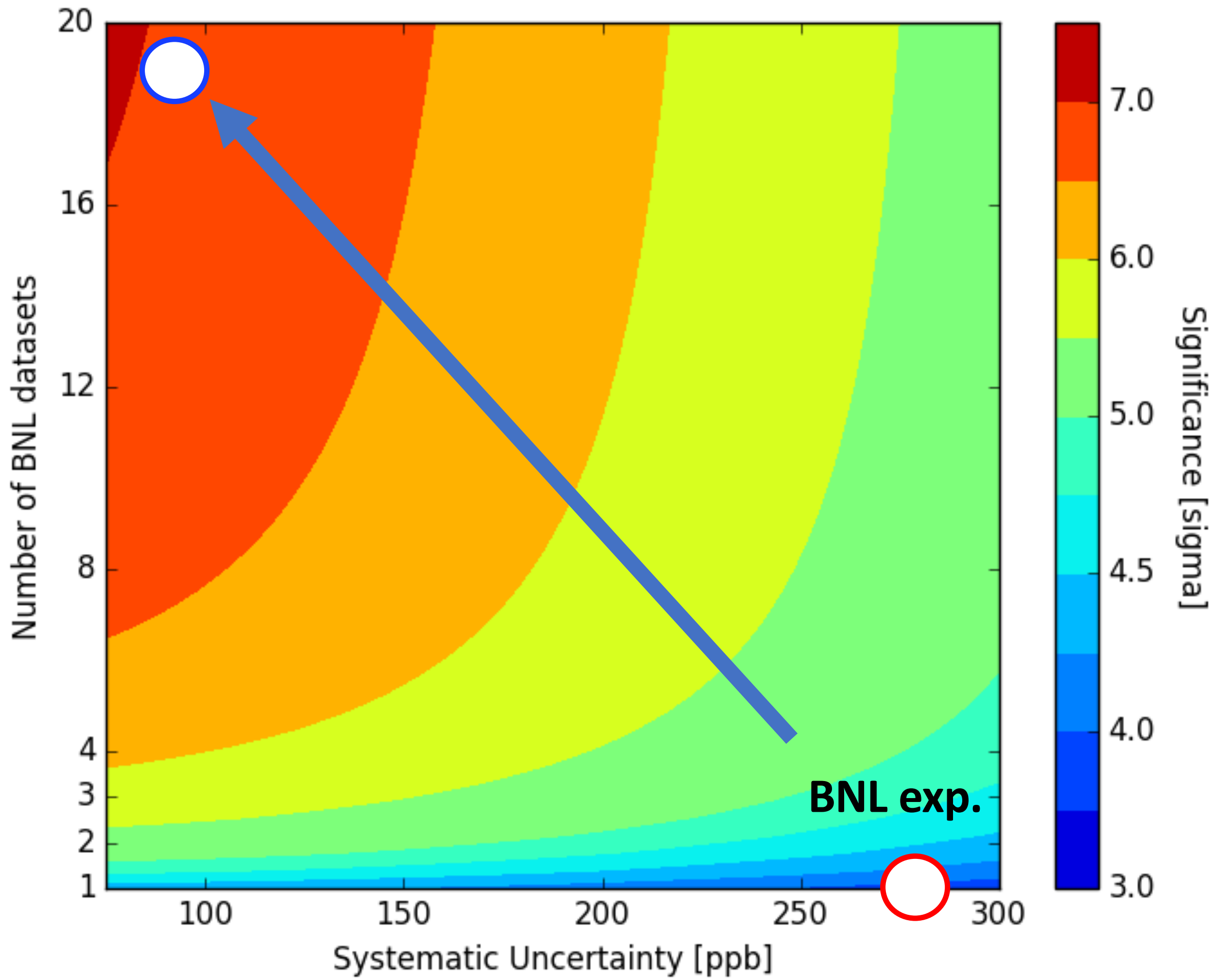


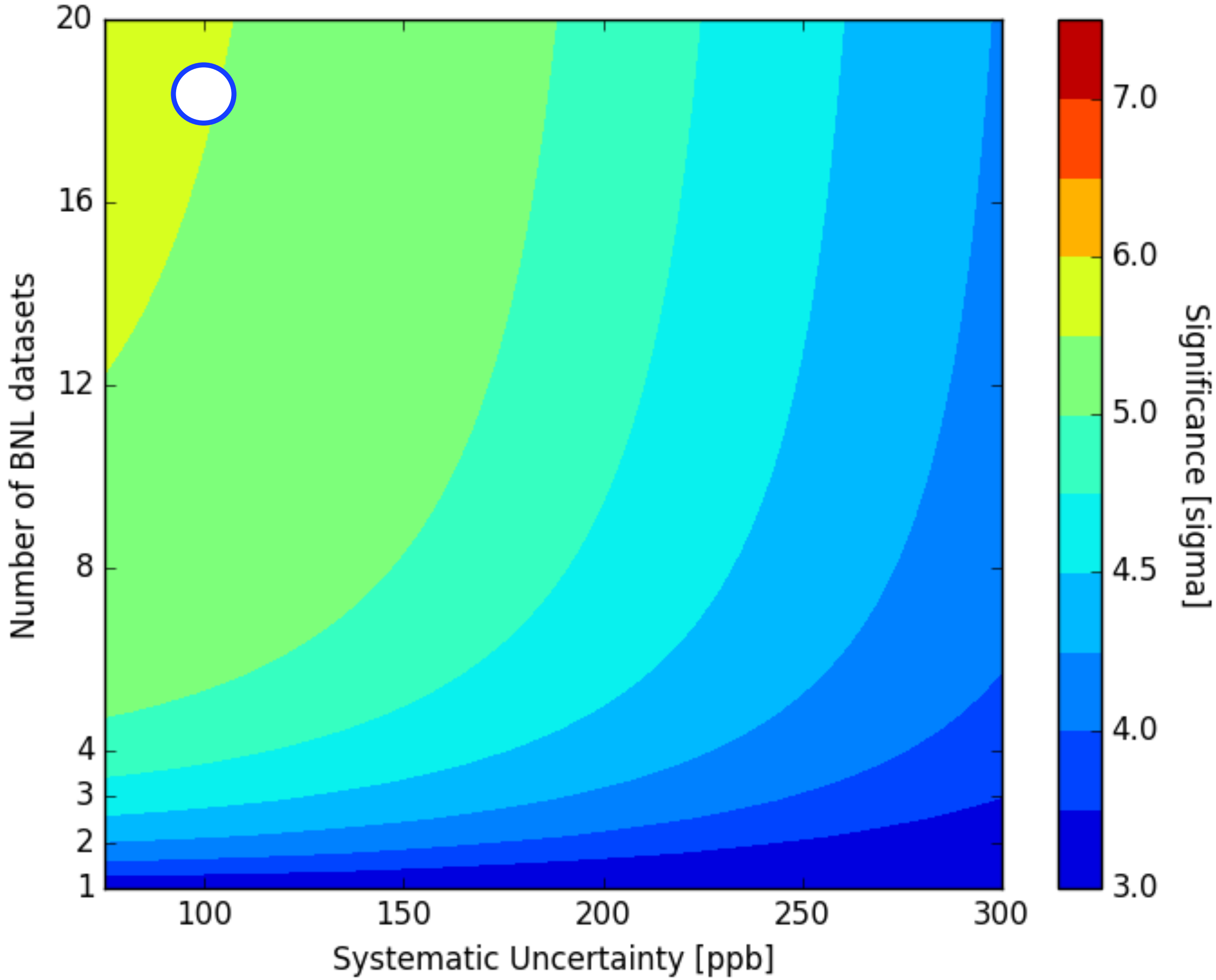
Muon g-2 Status

Mark Lancaster, NEWS General Meeting, November 4-5, 2019

Aim of experiment

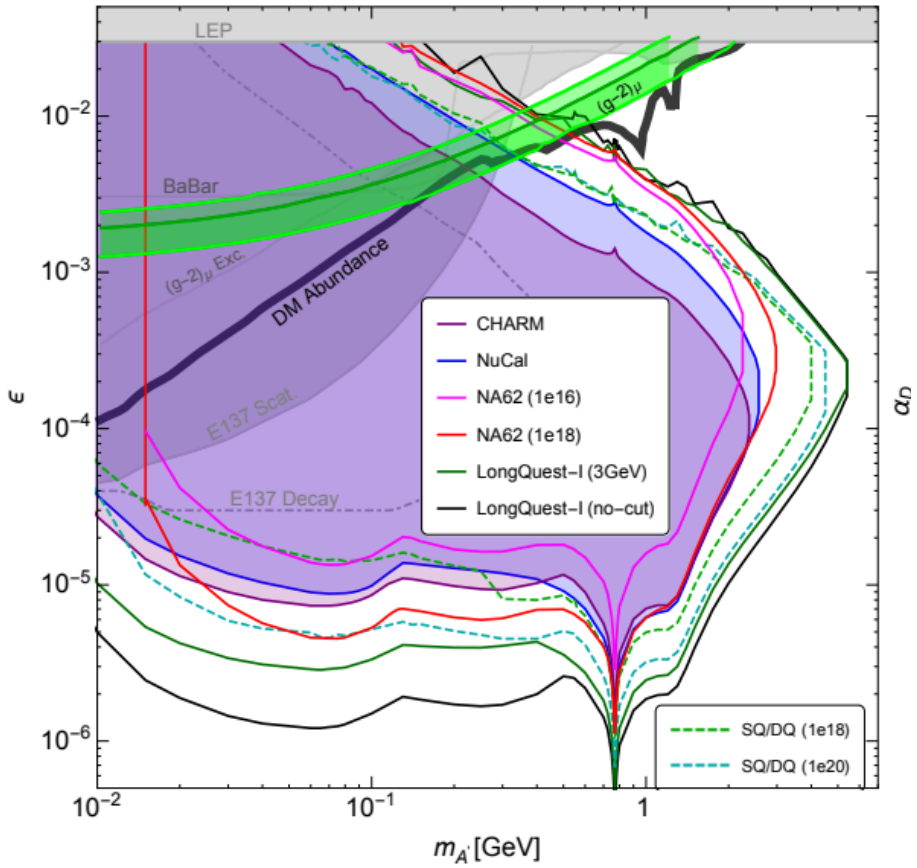


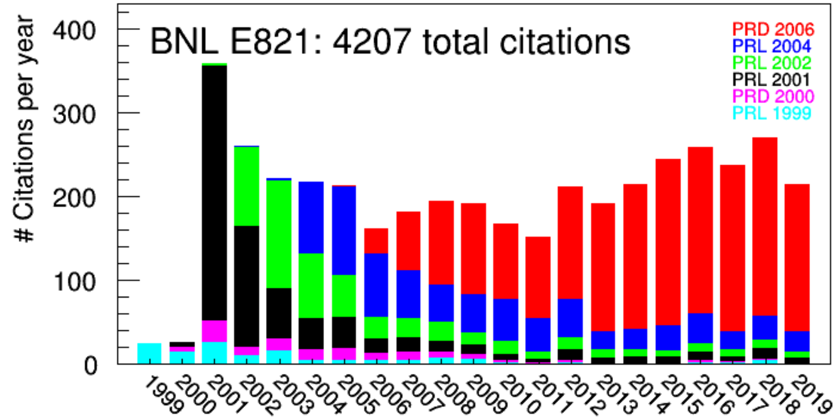
If measure 1σ below BNL value



Motivation

arXiv:1908.07525





".. it's extremely sensitive to new physics. It's still running, but if I were to put my money on something that would signal new physics, it's the g-2 experiment at Fermilab. I think it's really fascinating..."

$(g\text{-}2)_e$ vs $(g\text{-}2)_\mu$

arXiv.org > hep-ph > arXiv:1908.03607

High Energy Physics – Phenomenology

Explanation of electron and muon g-2 anomalies in the MSSM

Marcin Badziak, Kazuki Sakurai

(Submitted on 9 Aug 2019)

arXiv.org > hep-ph > arXiv:1907.08109

High Energy Physics – Phenomenology

$(g-2)_{\mu,e}$ and the ANITA anomalous events in a three-loop neutrino mass model

Mohammad Abdullah, Bhaskar Dutta, Sumit Ghosh, Tianjun Li

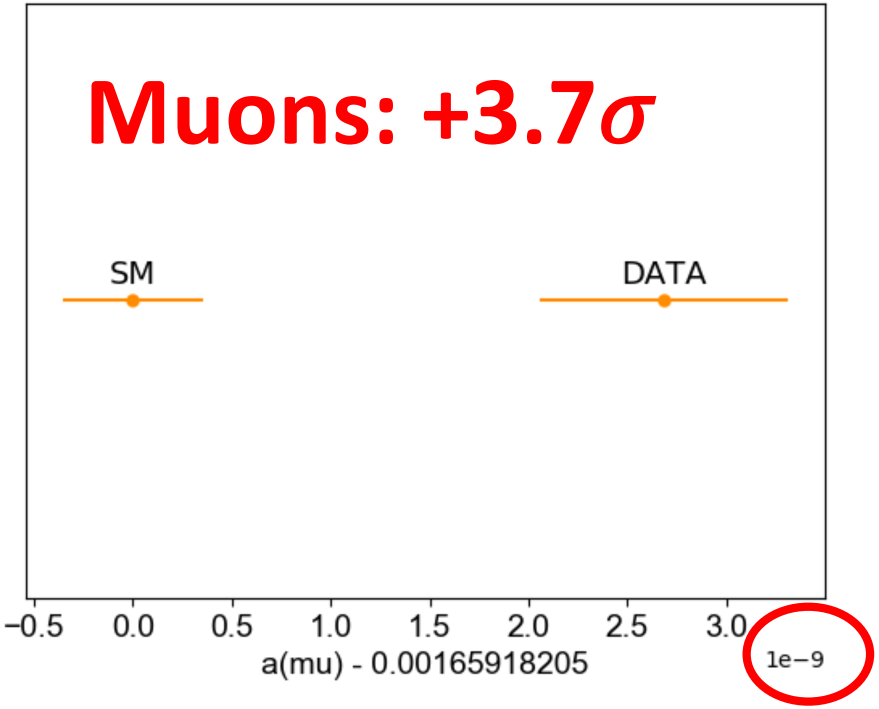
(Submitted on 18 Jul 2019)

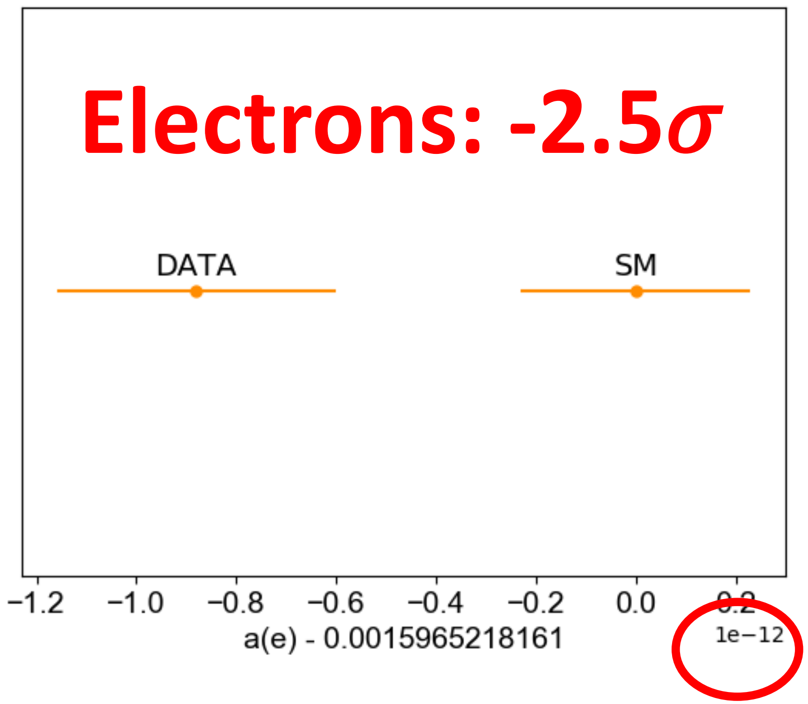
arXiv.org > hep-ph > arXiv:1905.03789

High Energy Physics – Phenomenology

Combined explanations of $(g-2)_\mu$, $(g-2)_e$ and implications for a large muon EDM

Andreas Crivellin, Martin Hoferichter



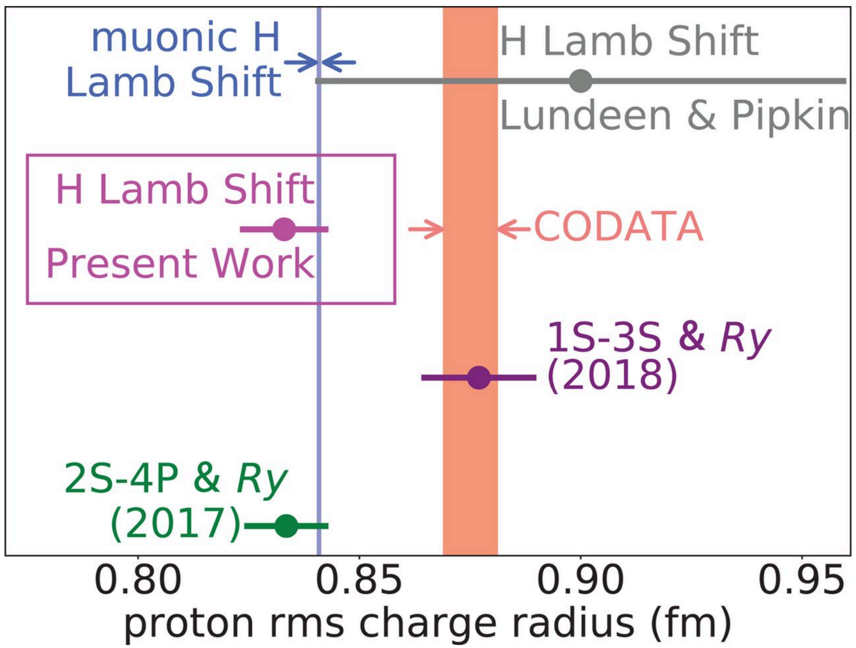


New physics in muon interactions ?

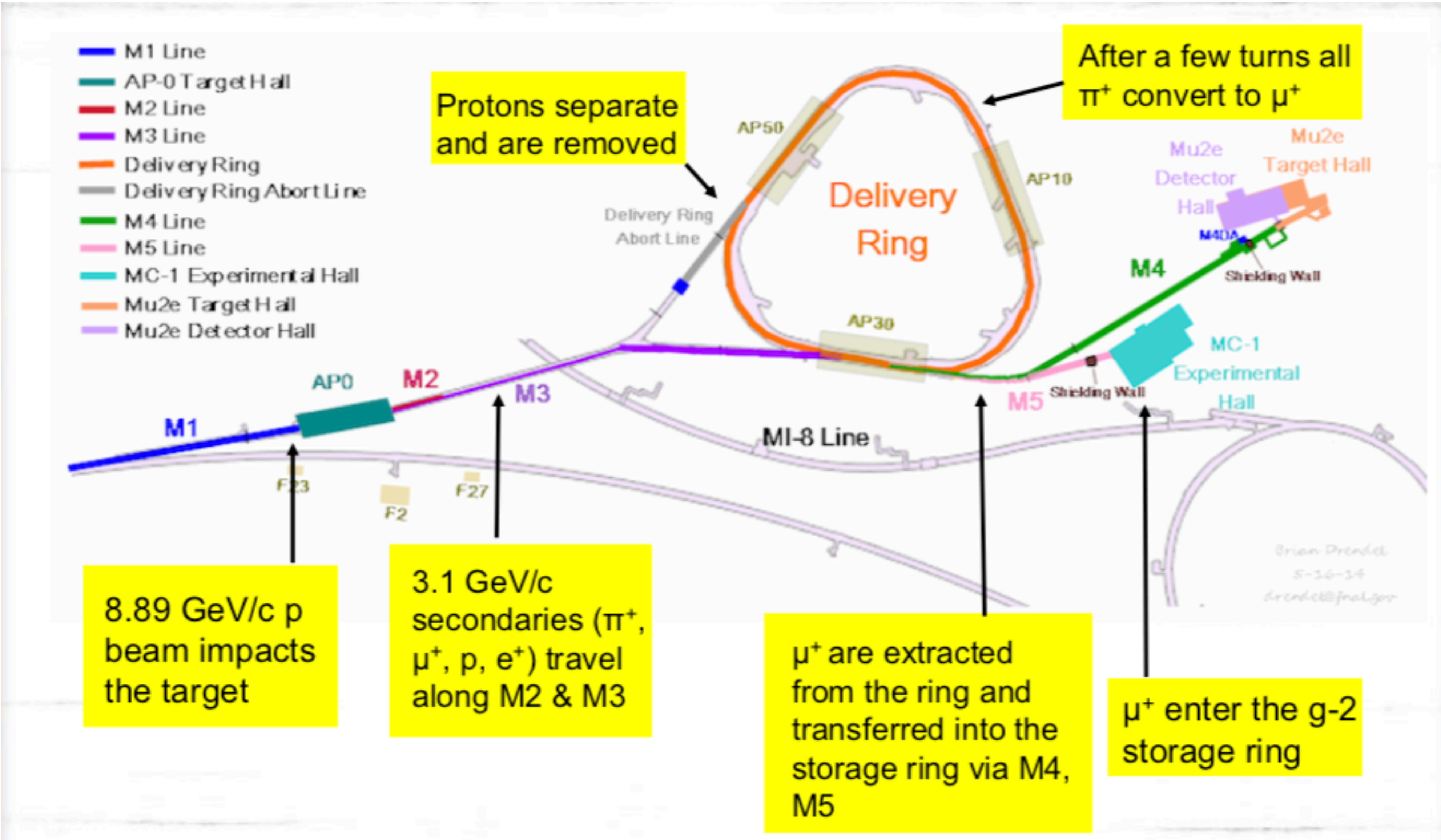
Physicists Finally Nail the Proton's Size, and Hope Dies

27

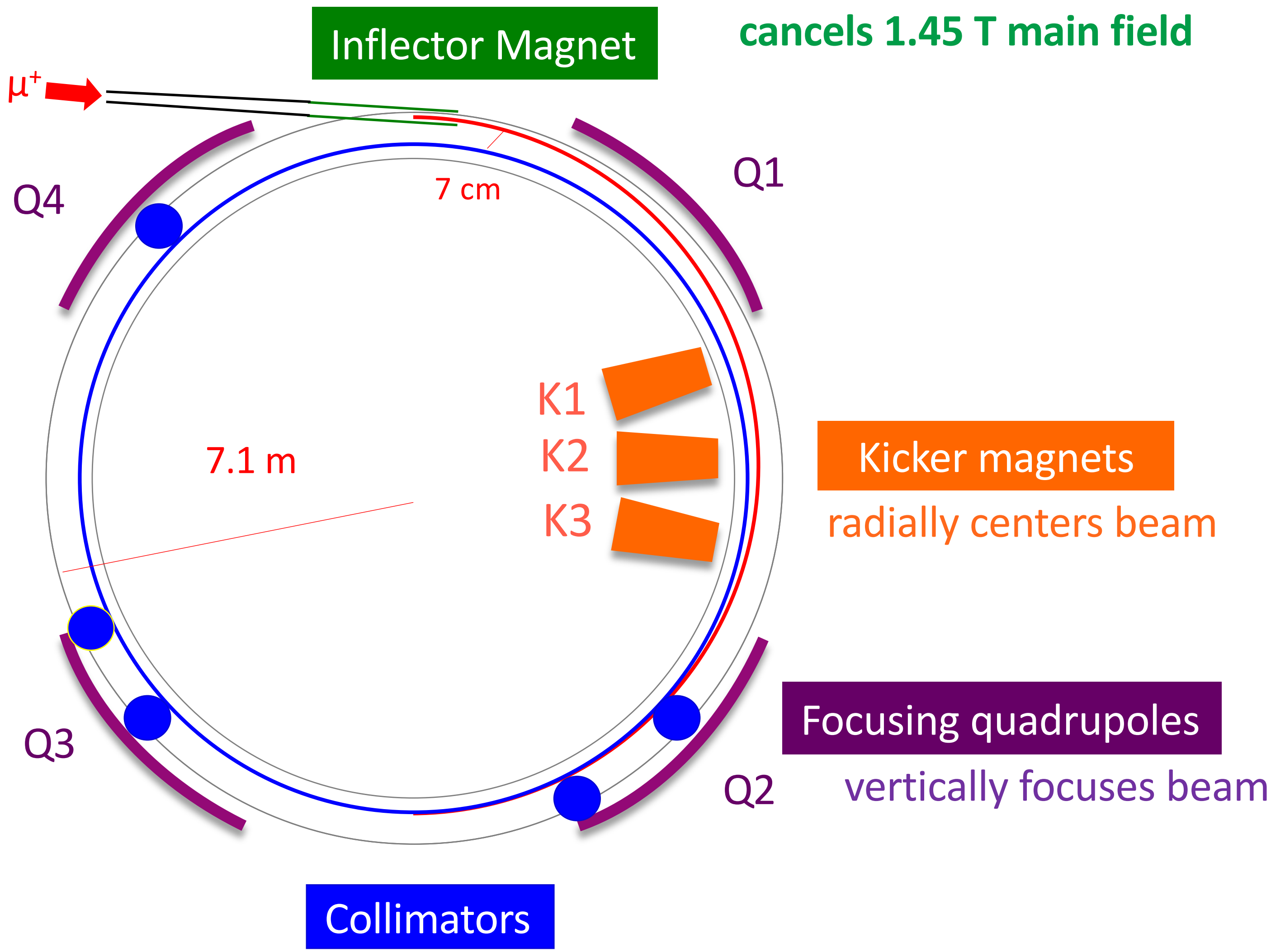
A new measurement appears to have eliminated an anomaly that had captivated physicists for nearly a decade.



Experiment Overview



Experiment Overview



Methodology

3 ppb : Hydrogen Maser

22 ppb : Muonium hyperfine splitting

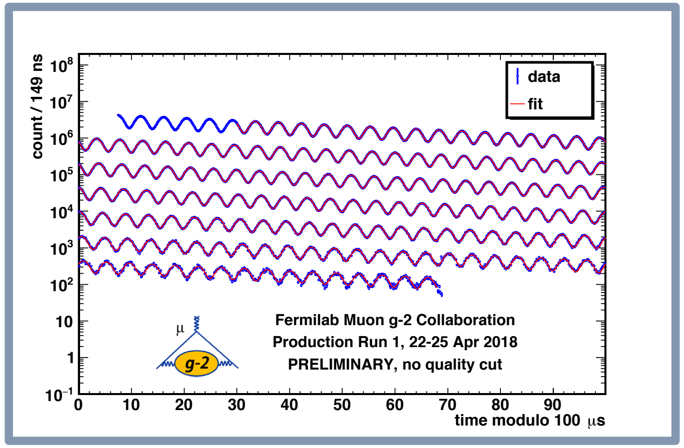
0.00026 ppb : Electron g-2/QED

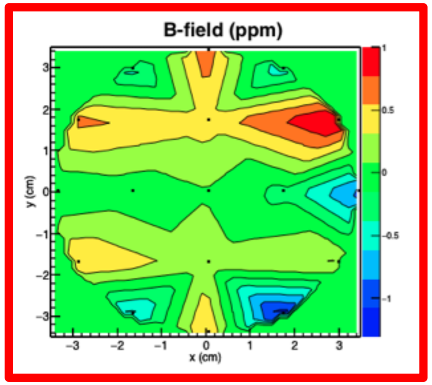
140 ppb

$$a_\mu = \frac{\omega_a}{\tilde{\omega}_p} \frac{\mu_p}{\mu_e} \frac{m_\mu}{m_e} \frac{g_e}{2}$$

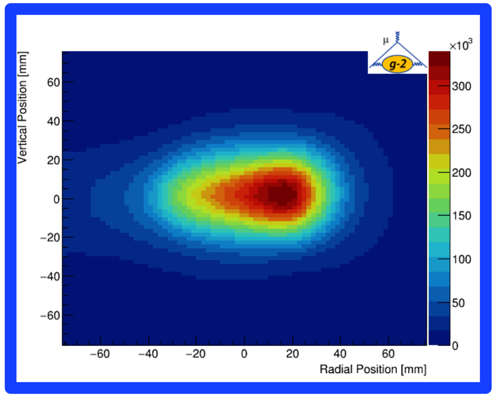
$$\Downarrow$$

$$\frac{\omega_a}{\omega_p \otimes \rho(r)} \Rightarrow$$



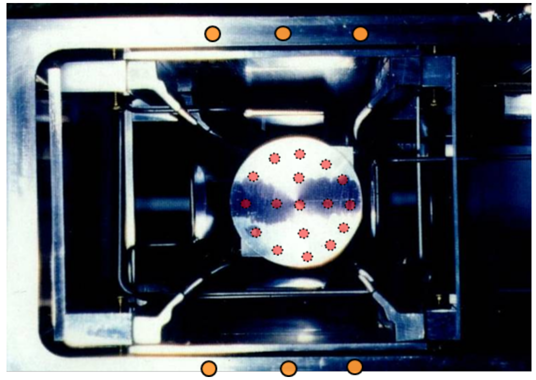


$\otimes$



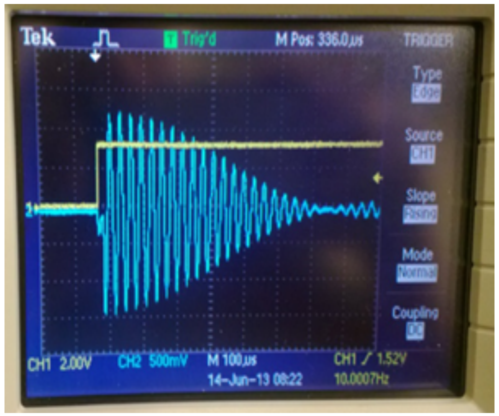
Monitoring the Field

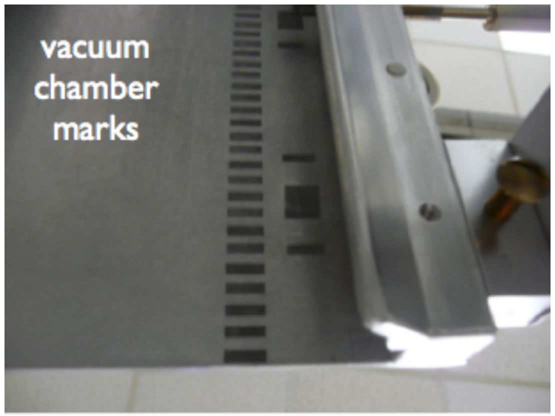
- Fixed probes track field at top/bottom of vacuum chamber monitor field 24/7



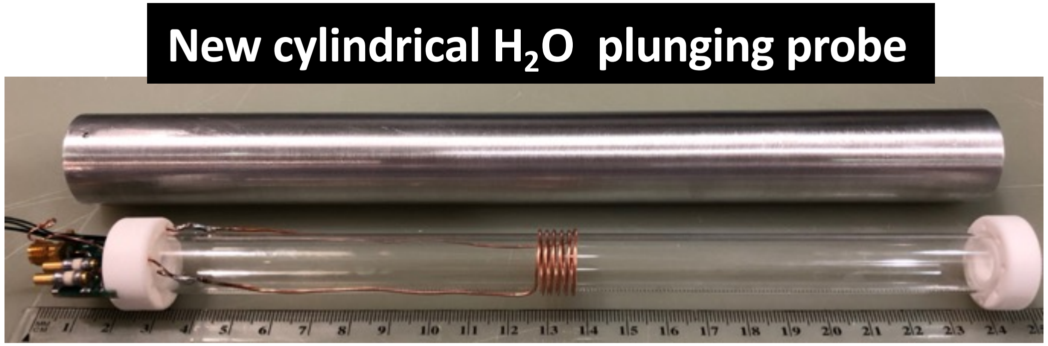
- NMR trolley maps field where muons traverse every 2-3 days

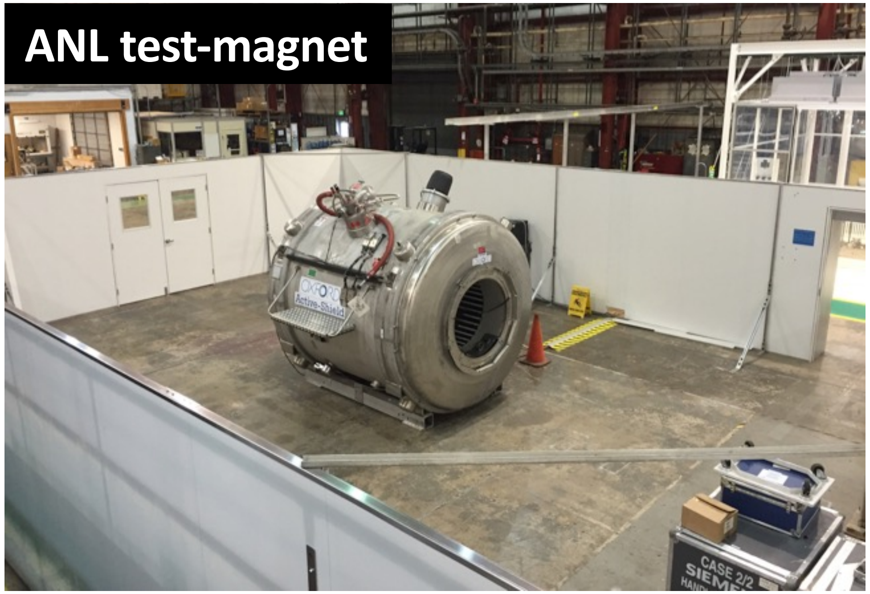
- Digitizing FID signals

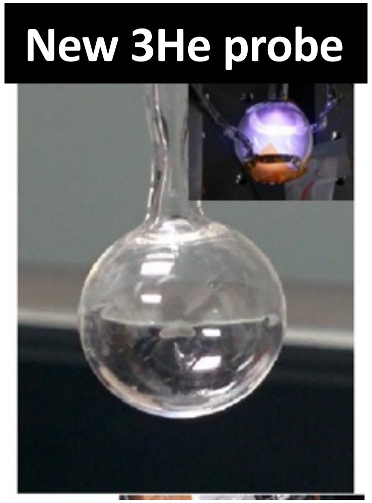




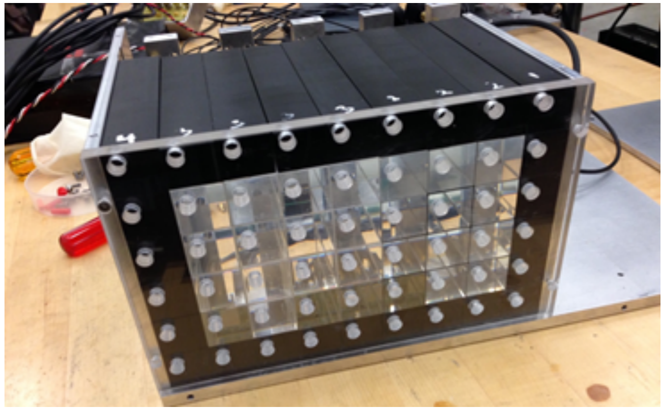
Absolute Field Calibration

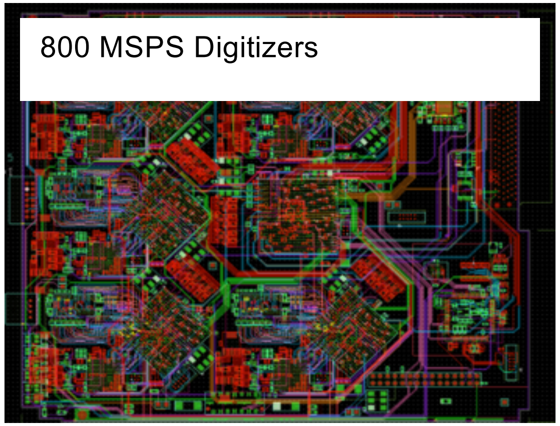


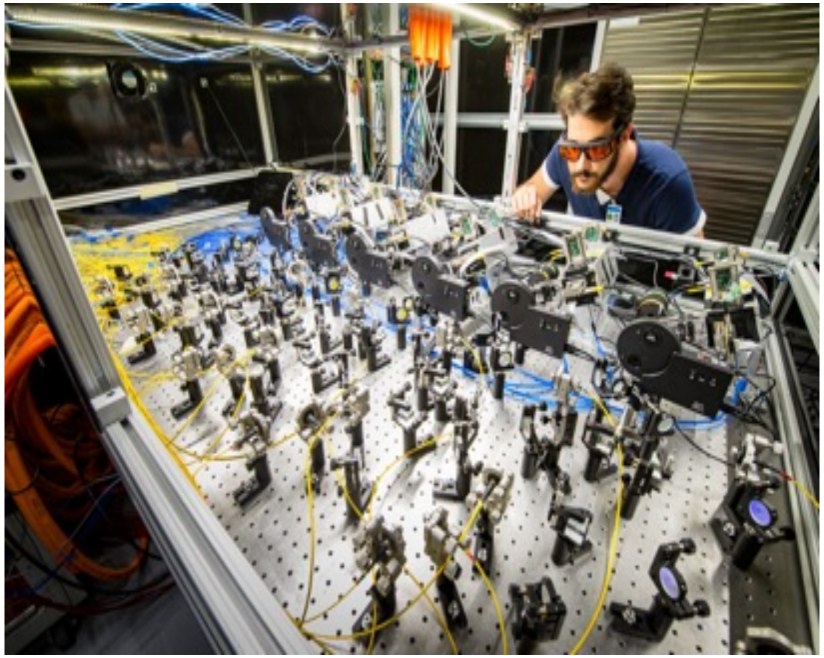


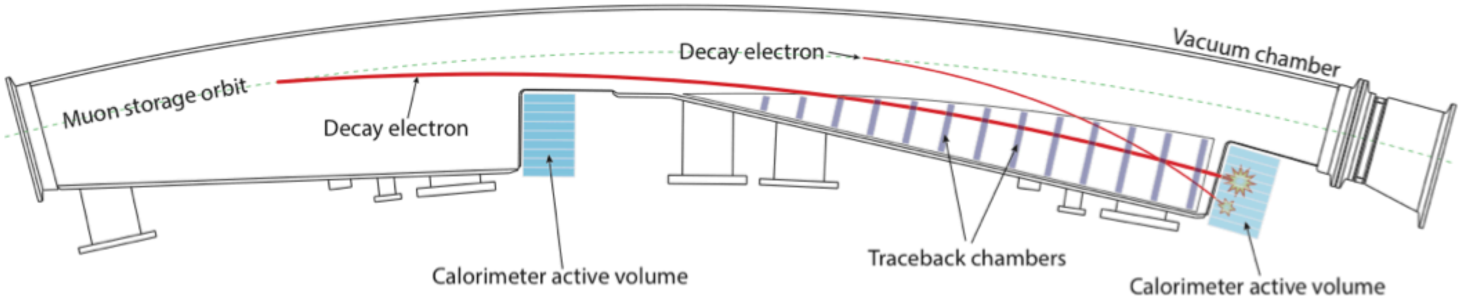


Calorimeters

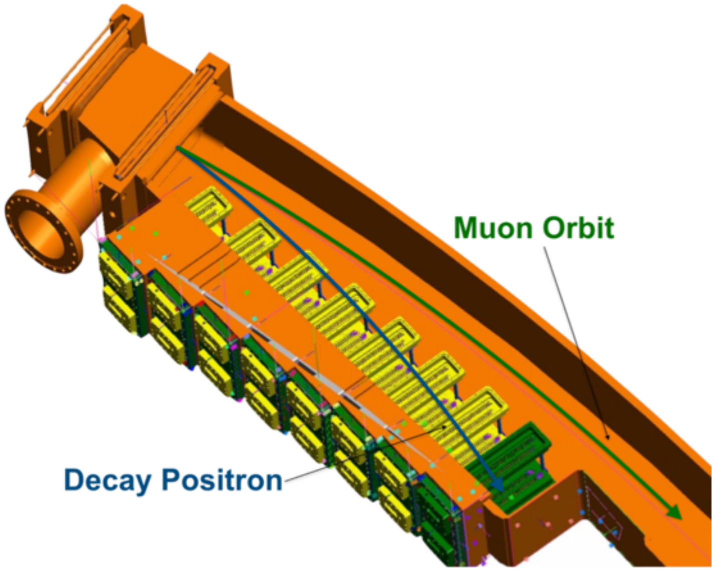


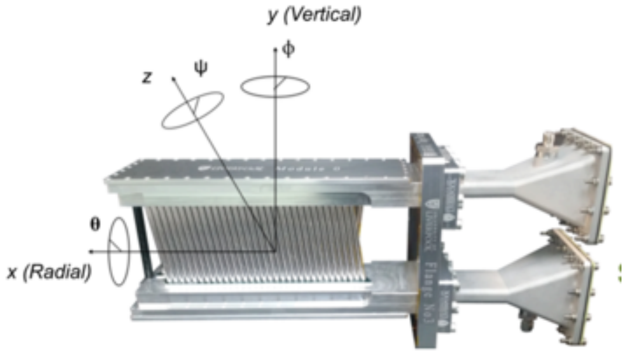


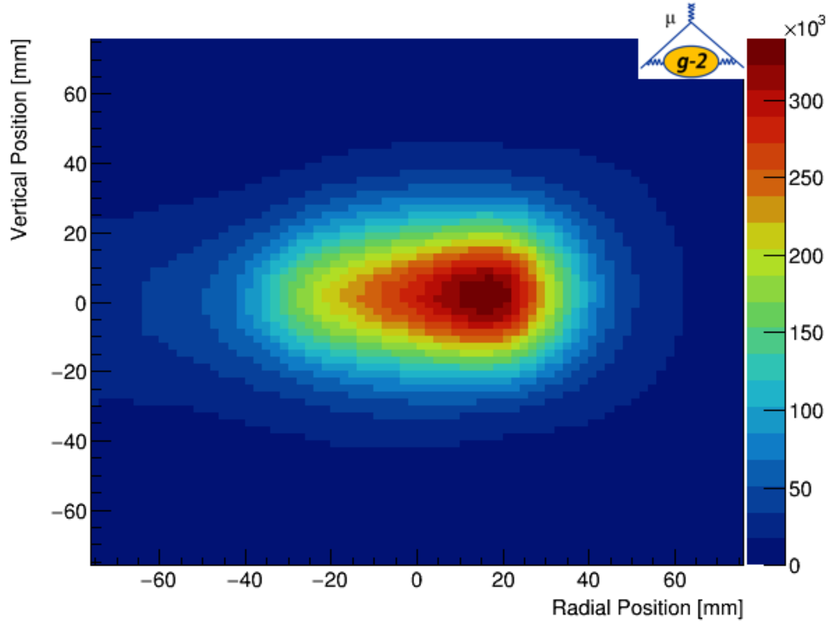


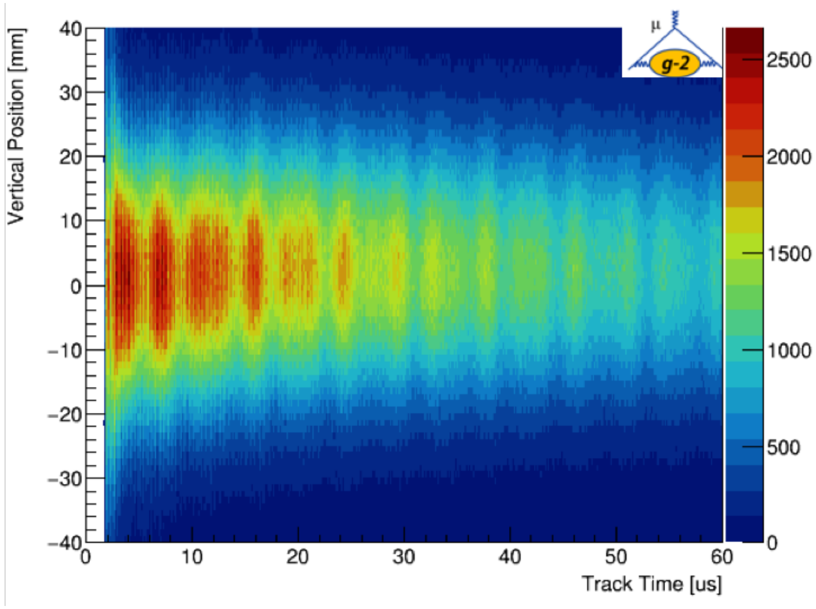


Straw Trackers

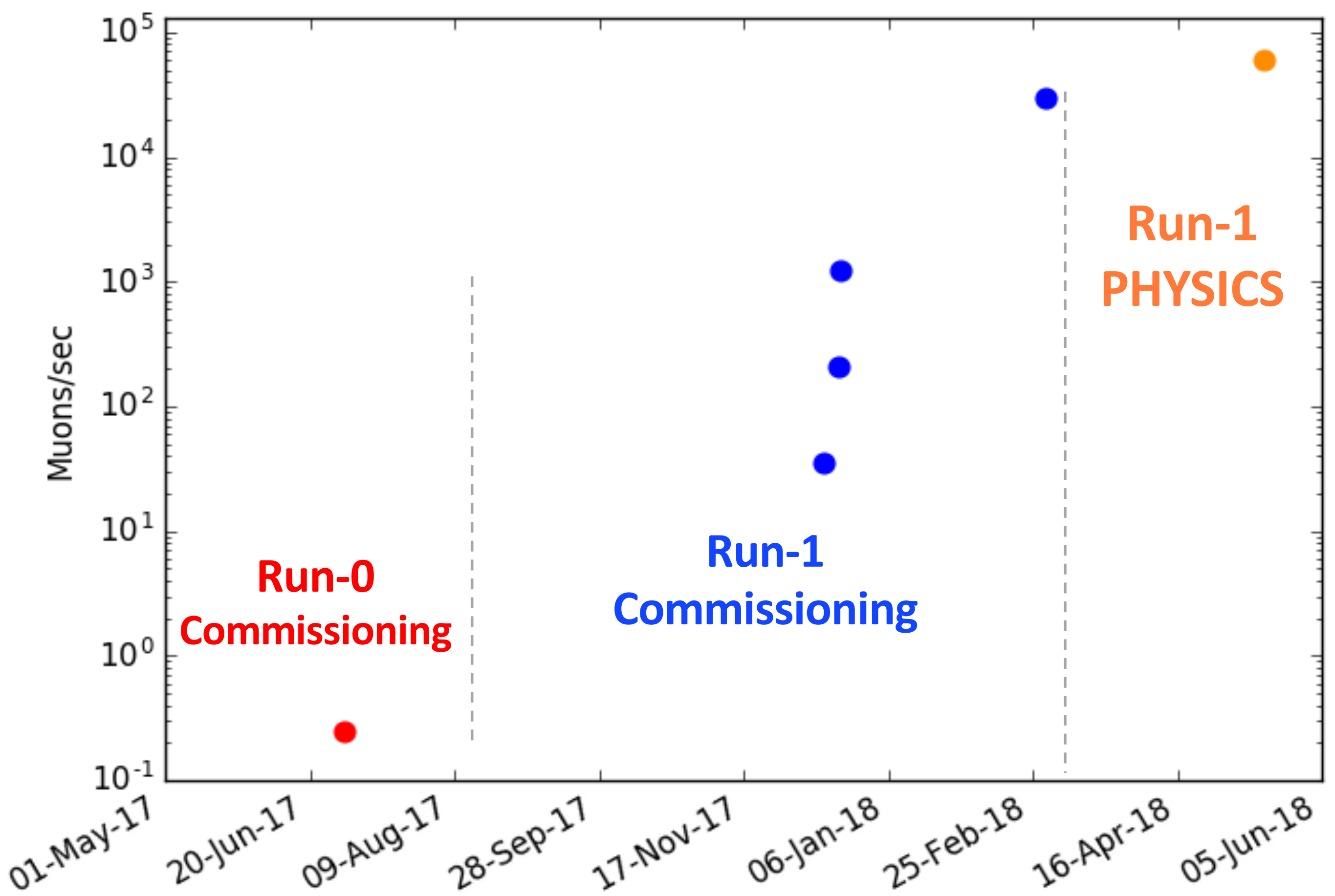








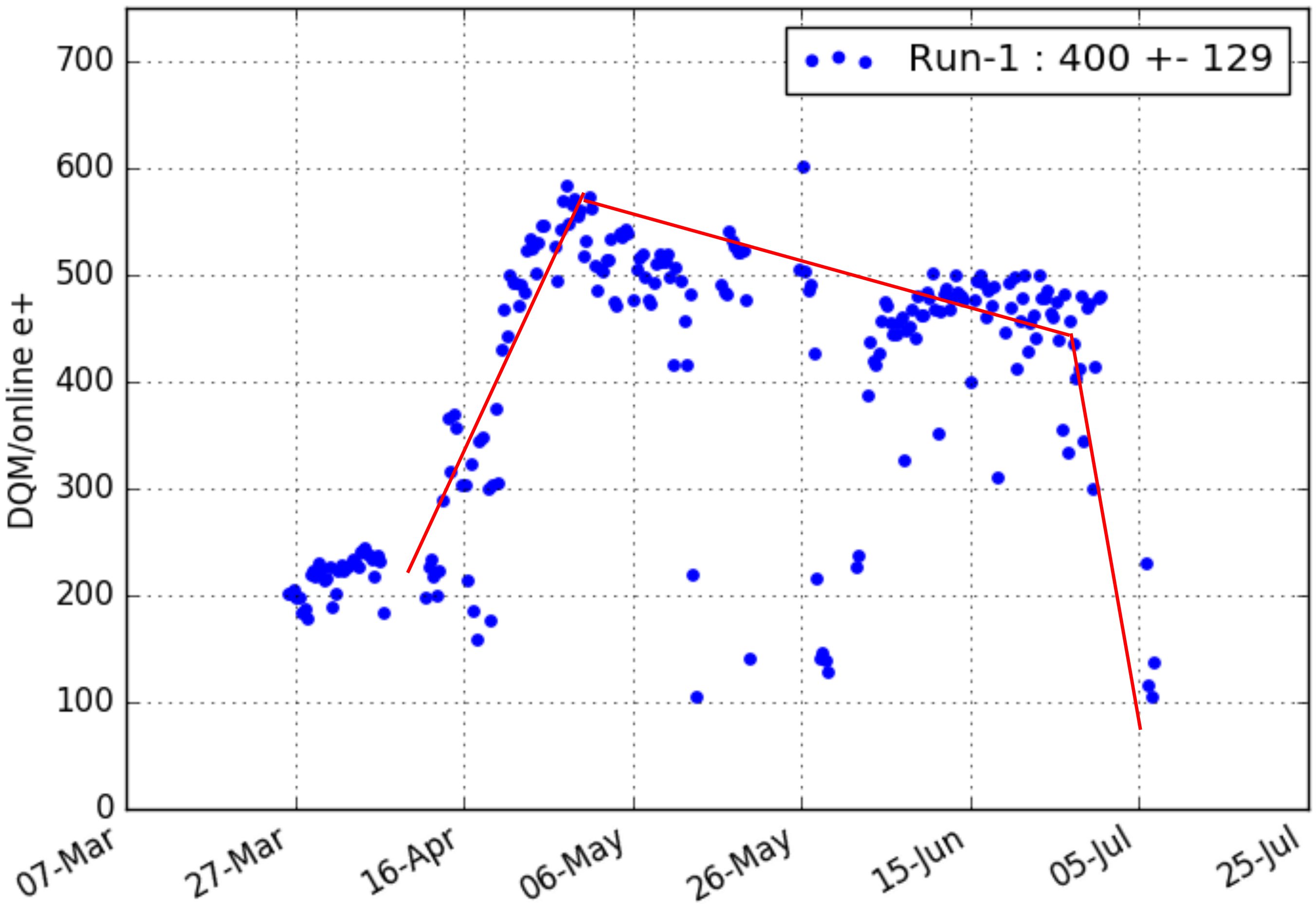
Commissioning Jun-17 → Mar-18



5 orders of magnitude improvement in muon flux

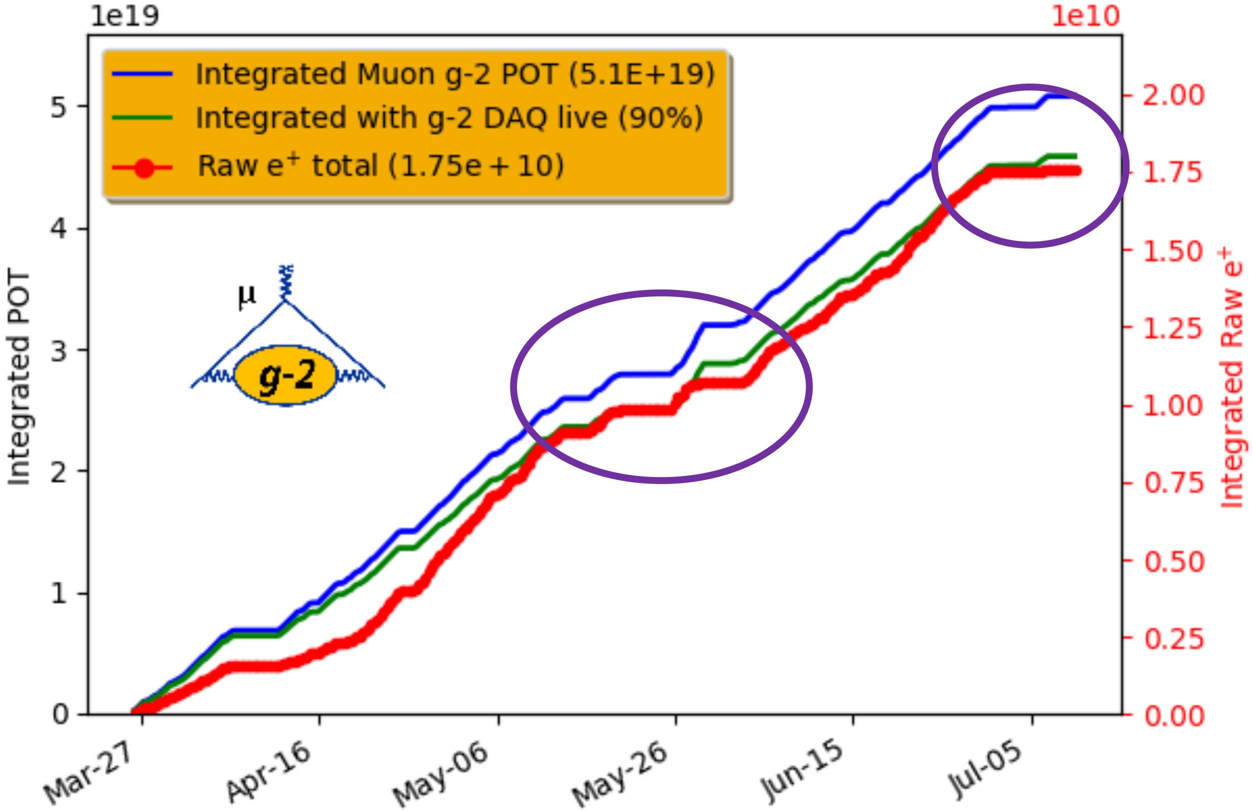
TDR envisaged 200 days of commissioning (June-17, Nov-17 → Mar-18)

Run-1



Run-1 : 400 +- 129
DQM/online e+
0
100
200
300
400
500
600
700
07-Mar
27-Mar
16-Apr
06-May
26-May
15-Jun
05-Jul
25-Jul

Run-1



Raw data: x2 BNL **but** several different quad/kicker settings.

Resulted in 7 datasets with approx. x1.4 BNL.

Run-2 aim: fewer datasets with constant conditions

Run-1 to Run-2

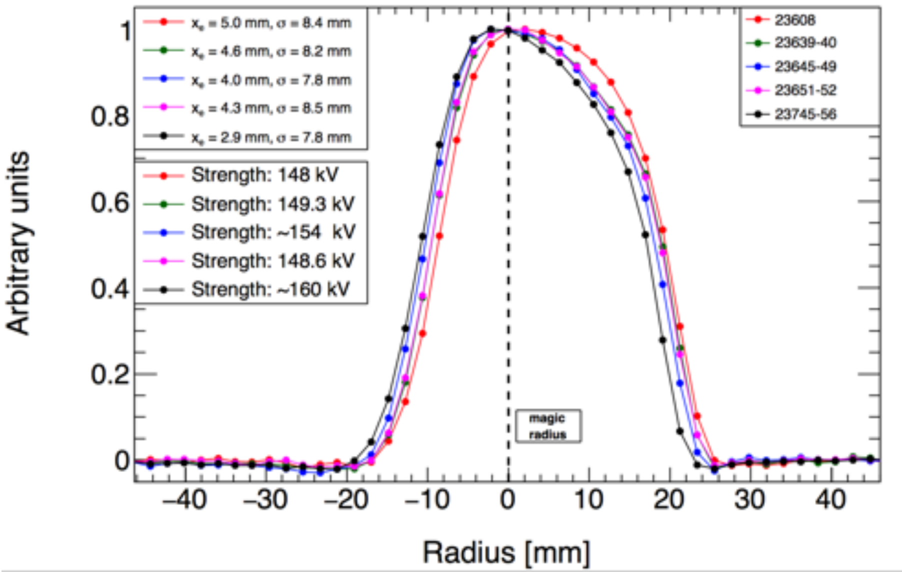
Run-1 issues affecting integrated stats (& systematics/ease of analysis)

- kick was too low
- kicker had significant downtime
- significant number of quad sparks
- magnet downtime due to cryo purity issues

Such that fraction of days with > 100M e+ was 57%.

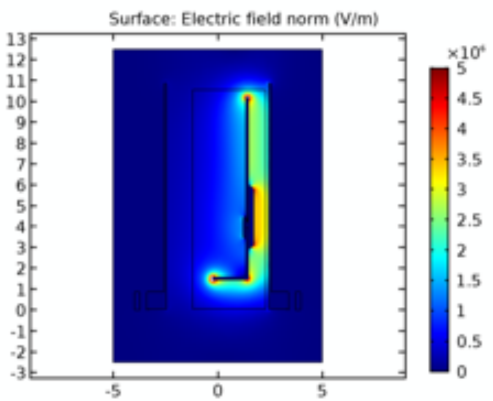
The run-1/2 shutdown addressed these issues

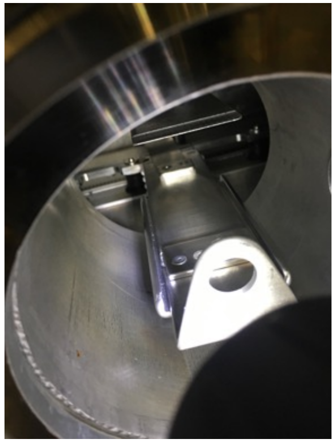
Kicker



Kicker ran very stably at 142 kV for 2 months.
Run-1 average was 124 kV.

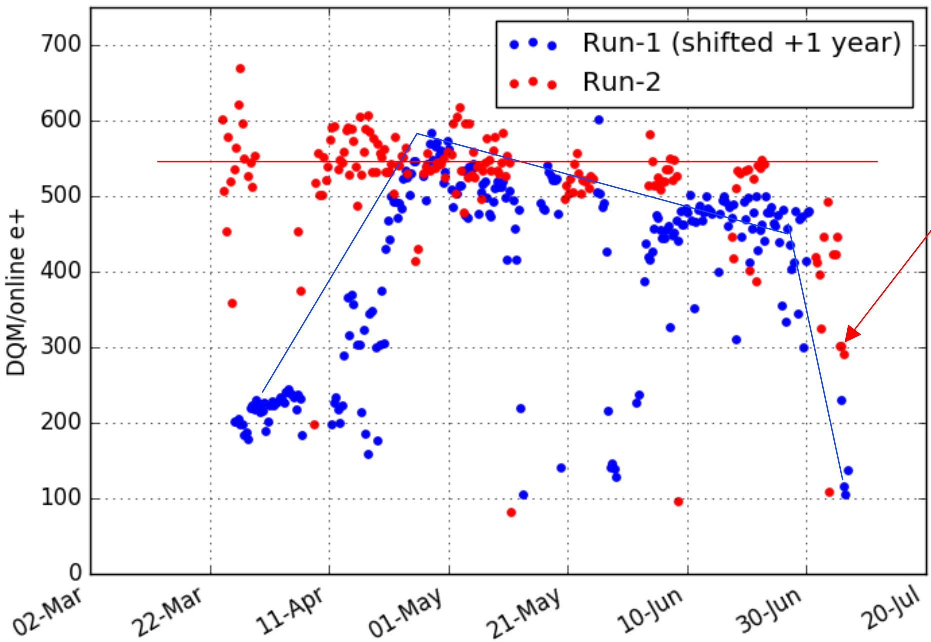
Much reduced sparking
Still some cable issues above 145 kV



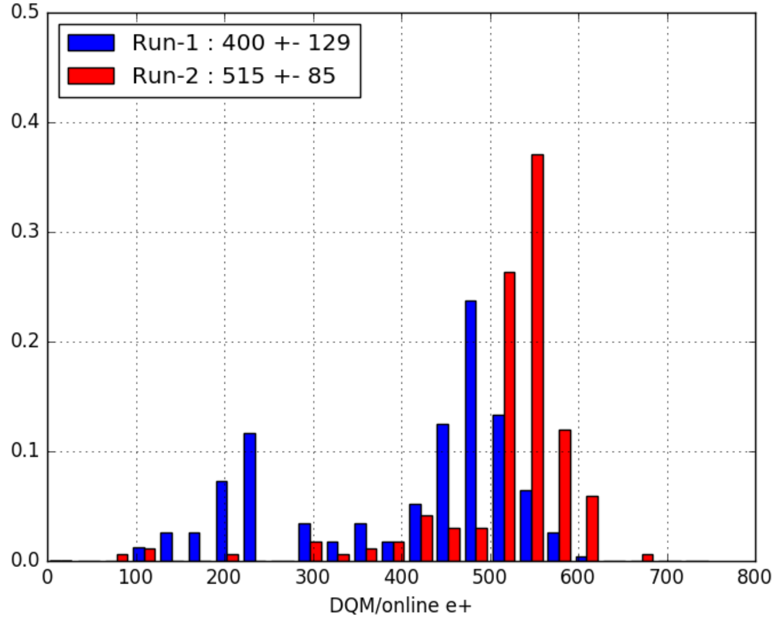


Run-1/2 e^+ per fill

systematic runs

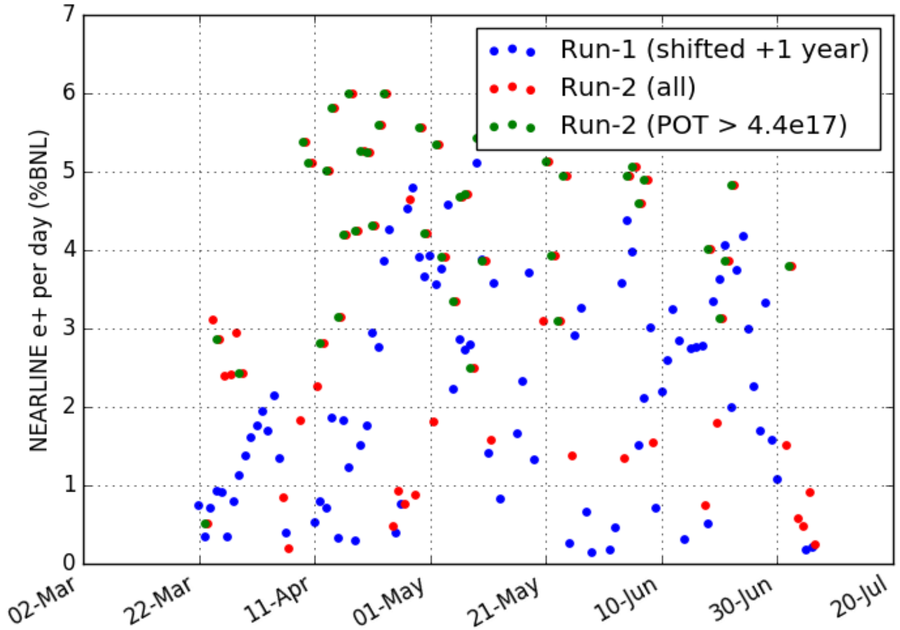


Run-2: 1.3 x Run-1



This despite a 19% reduction in intensity due to running the Li lens with 10% lower current

Run-1/2 : e^+ per day

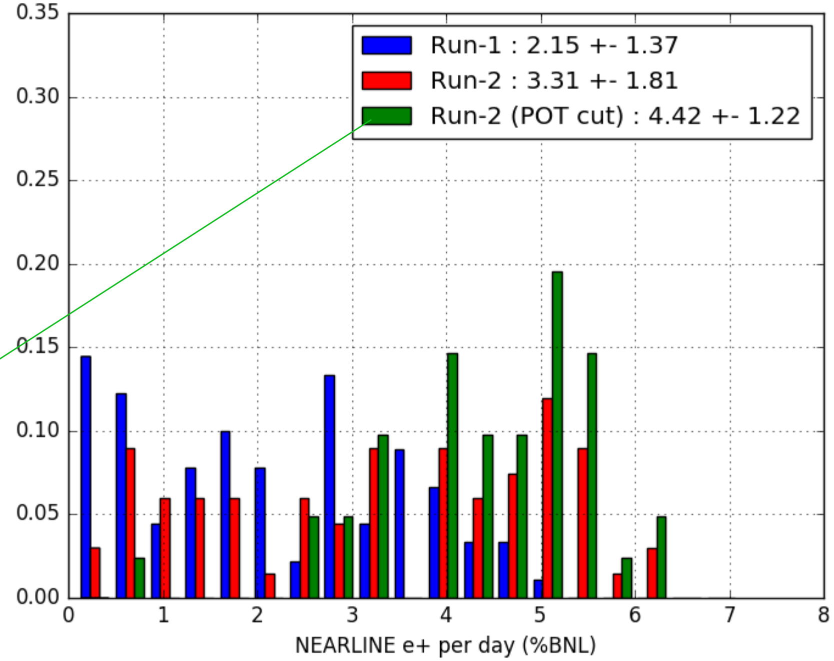


Average running was 3.3% BNL/day

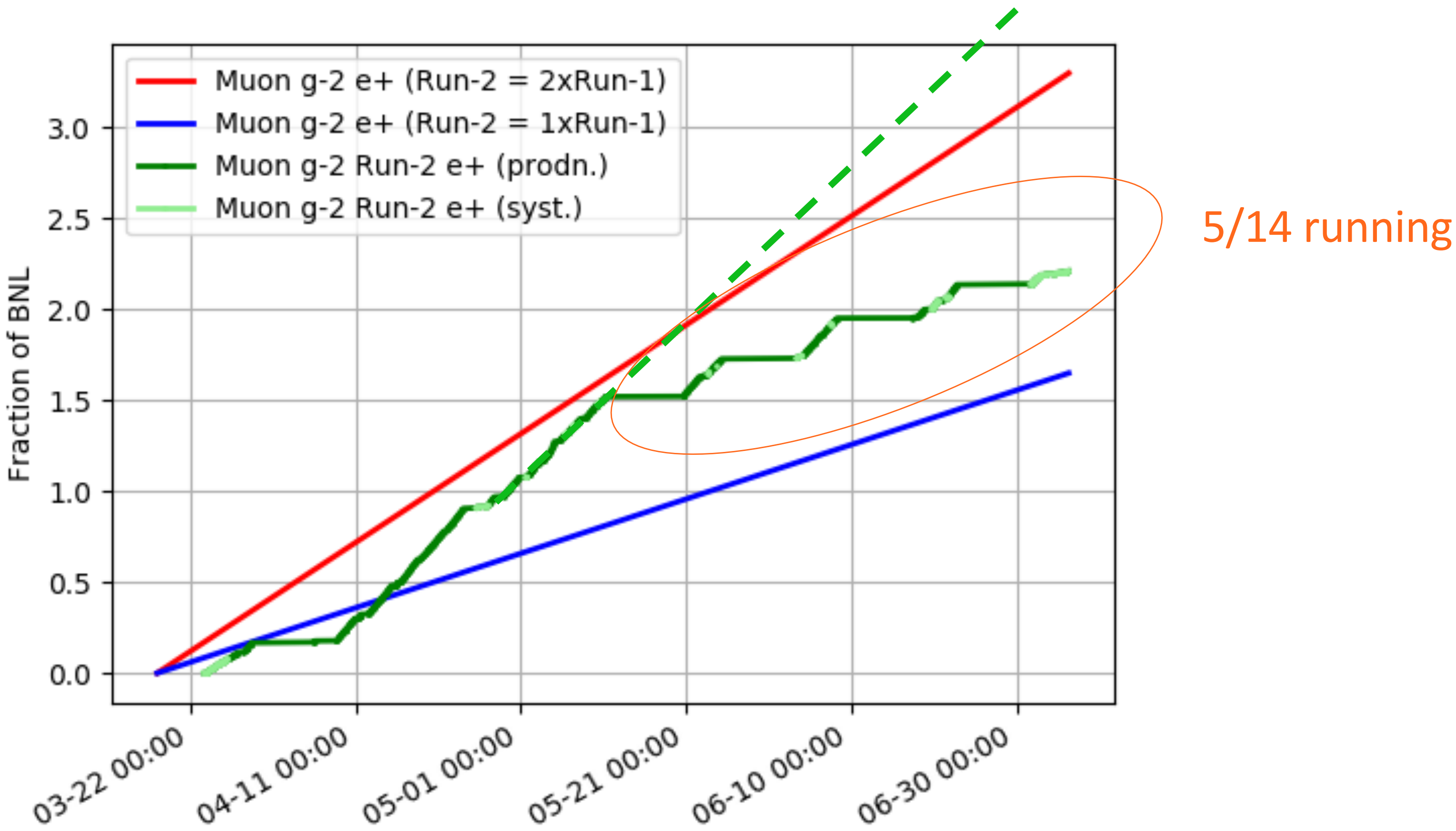
But when beam was available more than 12 hrs/day: 4.4% BNL/day

Run-2: 1.5 x Run-1 per day

When providing beam for more than 12 hrs in a day

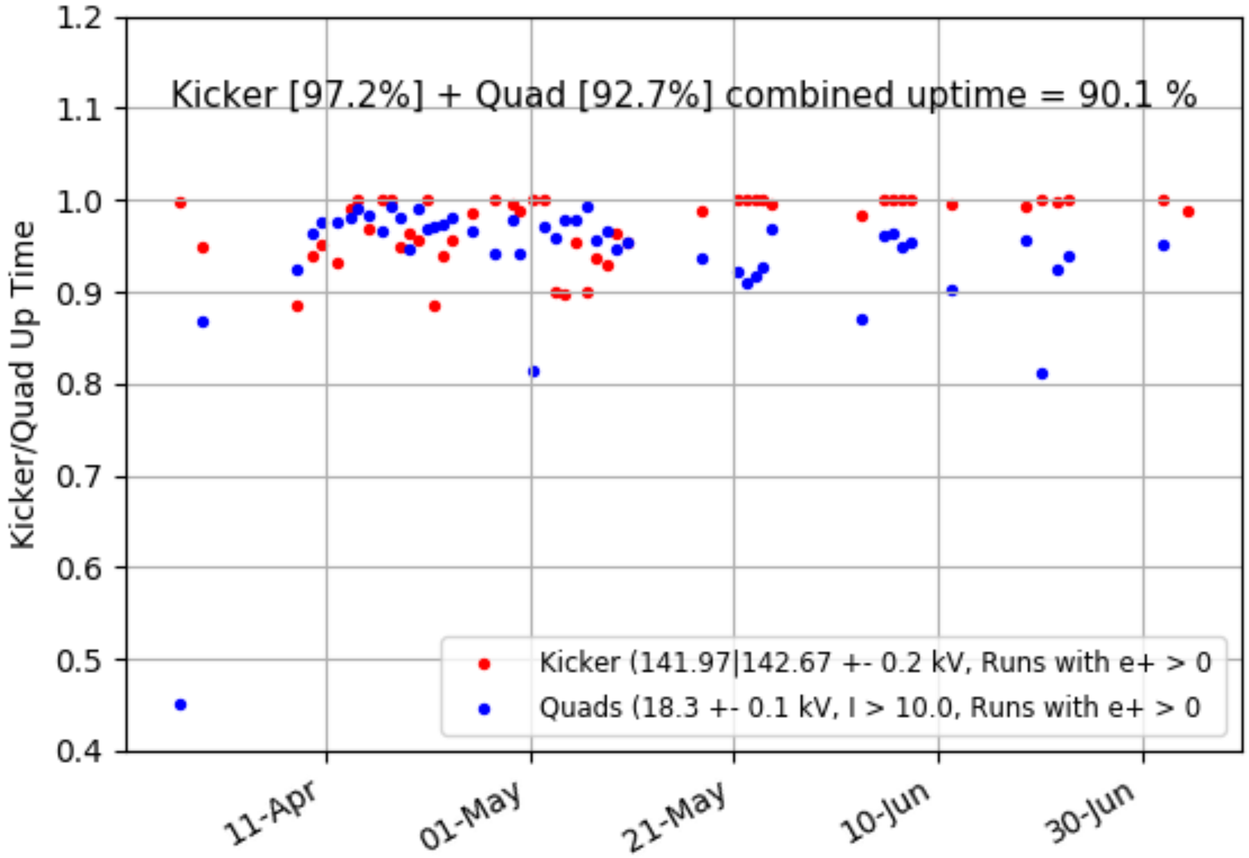


Impact of 5/14 running

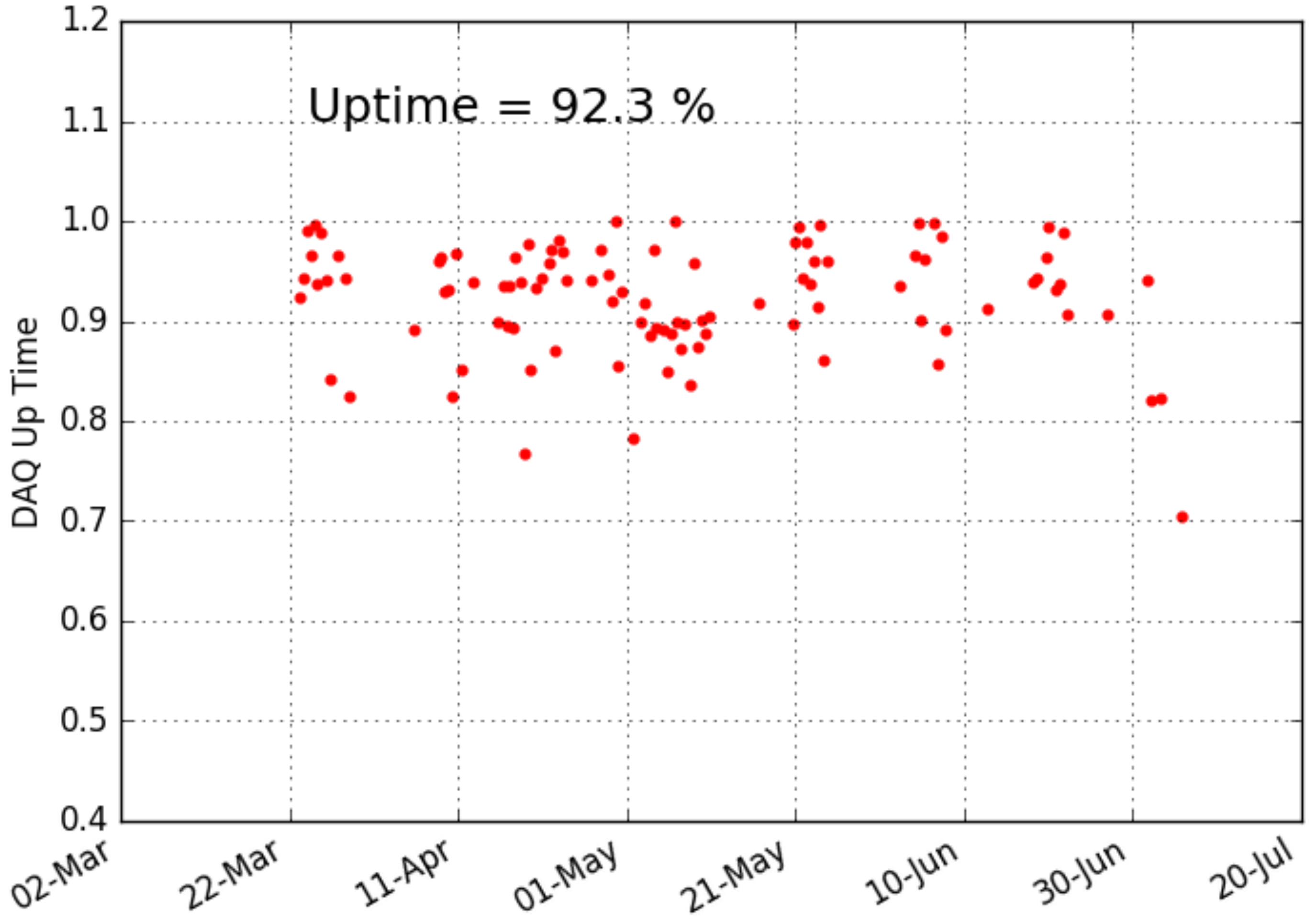


Quad/Kicker Run-2 Uptime

Combined uptime of kicker/quads was 90% : far better than Run-1



DAQ Uptime



Uptime = 92.3 %
DAQ Up Time
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
02-Mar
22-Mar
11-Apr
01-May
21-May
10-Jun
30-Jun
20-Jul

Reduced intensity per fill

	e+/fill	Effect	Factor
TDR	**1100**		
		Wedges	1.06
		Li Lens	0.81
		Kick (142 vs 155 kV)	0.84
		Quads (18 vs 28 kV)	0.92
		Actual beamline apertures	0.8
		TOTAL	**0.53**
RUN-2 Predicted			582
RUN-2 Actual			525 +/- 85*

*includes some systematic runs where rate was lower.

In physics running intensity is x0.5 that of TDR expectation.

Reduced uptime

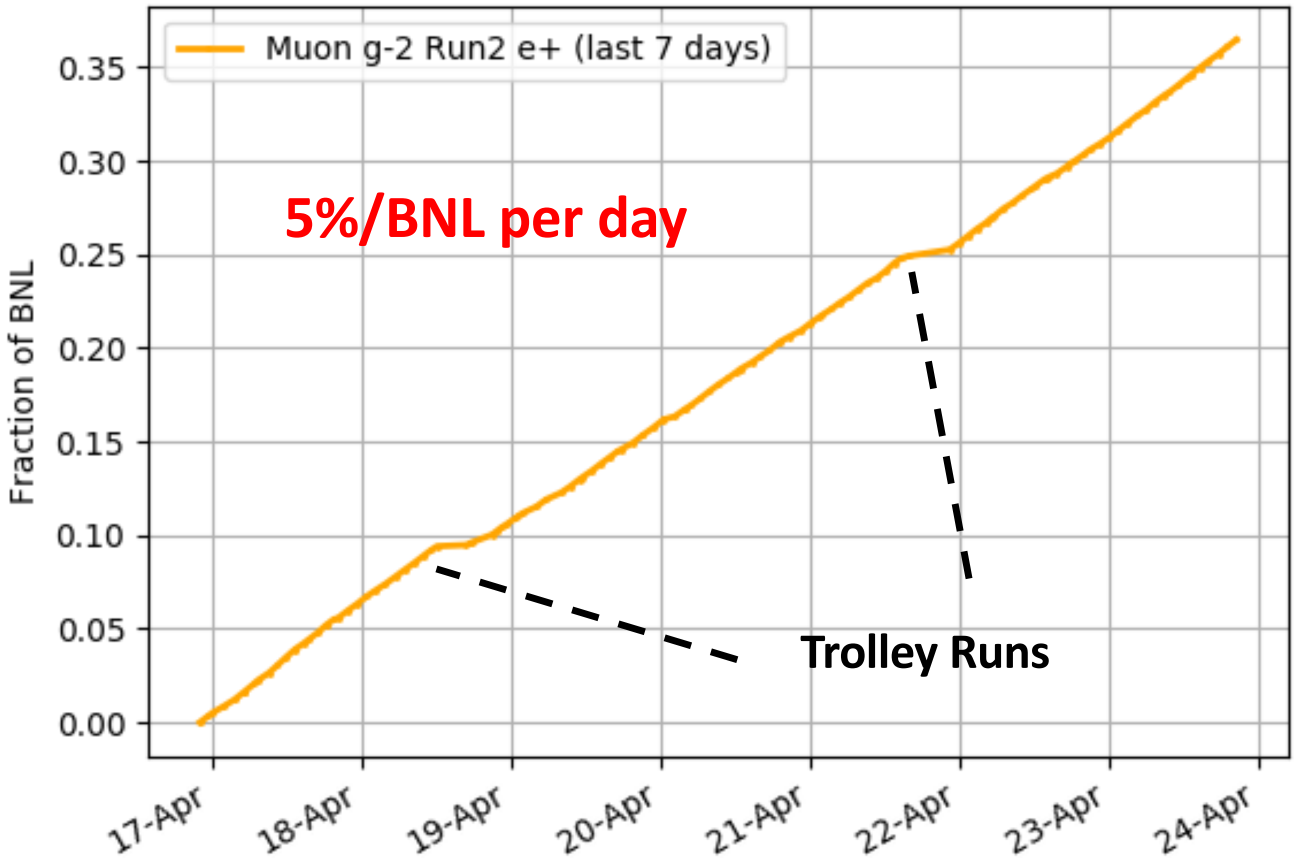
	TDR	Run-2
g-2 systems	0.9	0.77 *0.92 (DAQ), 0.90 (kicker/quad), 0.93 (cryo)*
MI Cycles 1.4 vs 1.33 sec		0.95
Trolley Runs	0.94	0.94
Testbeam Users		0.91
Accelerator uptime*	0.85	0.82
TOTAL	0.72	0.5

TDR expectation: 1,100 e+/fill and 72% uptime → 825M/day

Predicted Run-2 : x 0.5 (e+/fill) and x 0.7 (uptime) → 290M/day

Run-2 actual : 286M/day (3.3% BNL/day).

A good week…

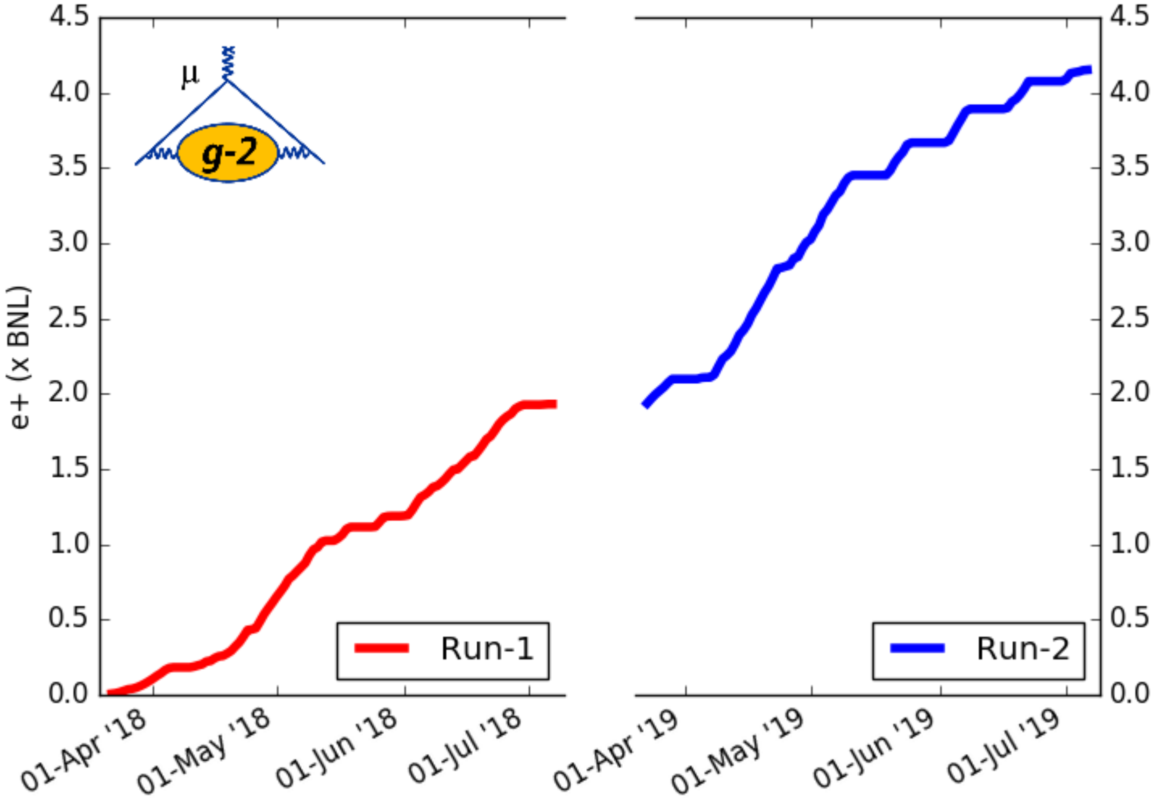


Anticipate Run-3 period to be more like this

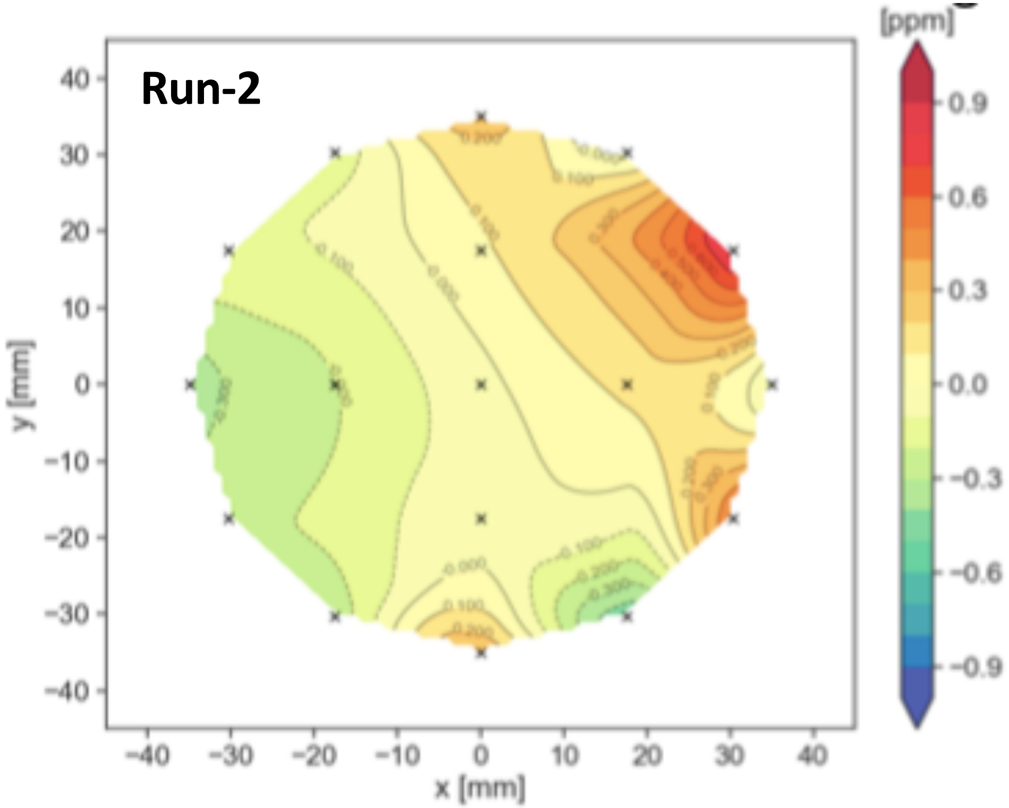
Run-1 & Run-2 Integrated

Over x4 BNL before data-quality cuts (DQC)

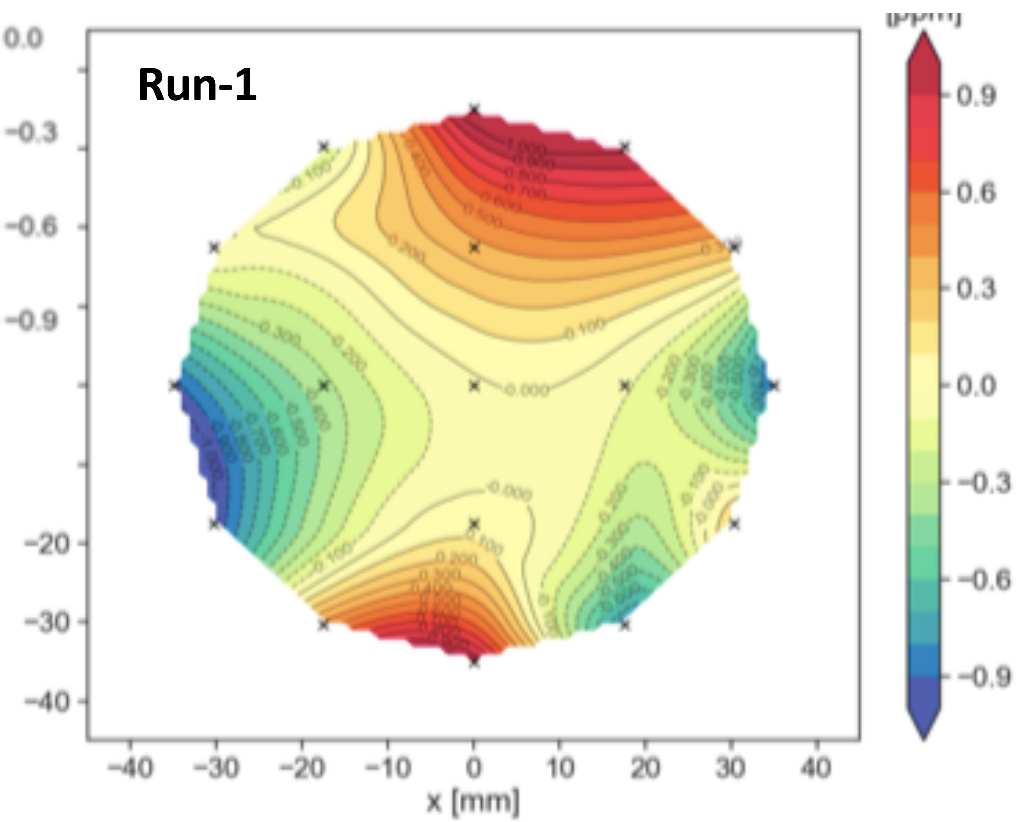
Due to smoother running expect Run-2 DQC impact to be modest and so Run-2 analysis will be on ~ x1.8 BNL vs ~ x1.4 BNL in Run-1



Quick Analysis Highlights



Everything is blinded !



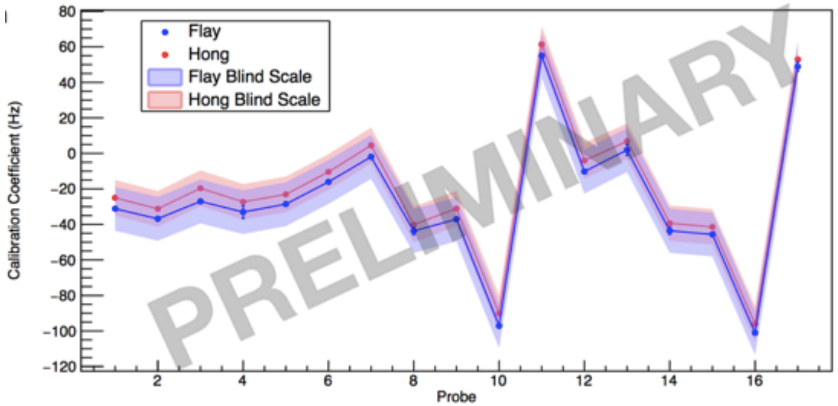
On average x2 better than BNL

Run-1 : Field Determination (ω_p)

Fixed probe → Trolley → Absolute (plunging probe)

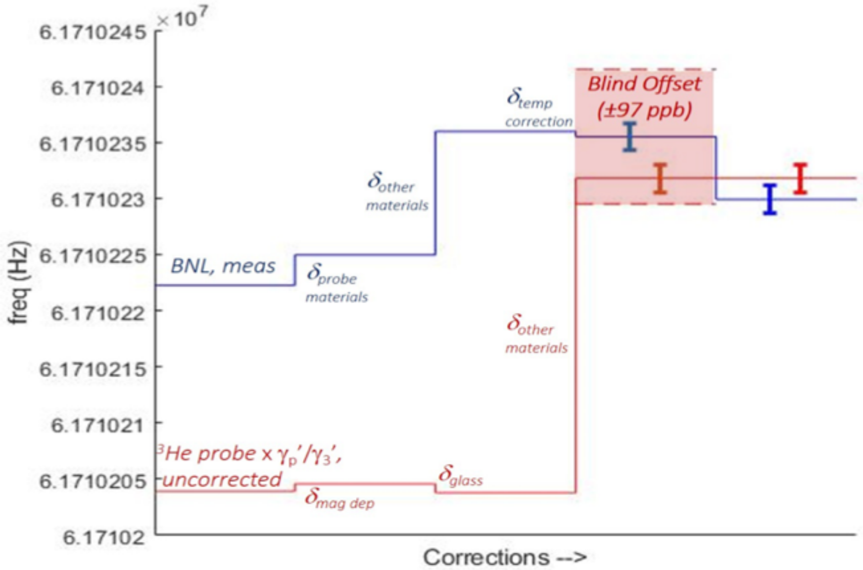
Comparison of trolley and plunging probe measurements in two independent analyses

Quantity	Uncertainty (ppb)
Material Perturbation	10
Probe Pitch	5
Radiation Damping	1
Water Sample Oxygen Contamination	1
Water Sample Container Geometry	1
Water Diamagnetic Shielding	14
Water Magnetic Susceptibility	3
Water Temperature	16
TOTAL	**24**



Also two independent analysis doing interpolation from fixed probe measurements to the trolley measurements.

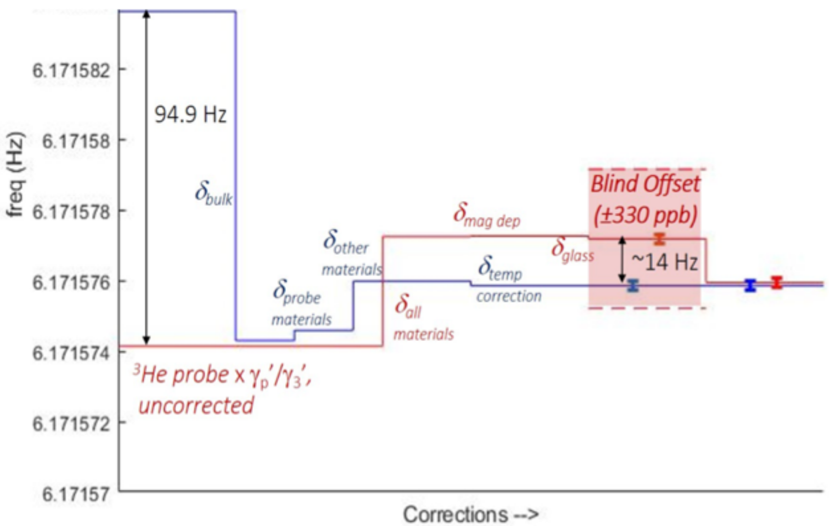
^3He cross calibration with H_2O probe



Sphere

1.24±2.29 Hz (20±37 ppb)

- Cross-calibration performed blind
- Analysis completed and unblinded
- Agreement with original BNL spherical probe and cylindrical plunging probe well within errors
- Difference also small relative to 540 ppb BNL error

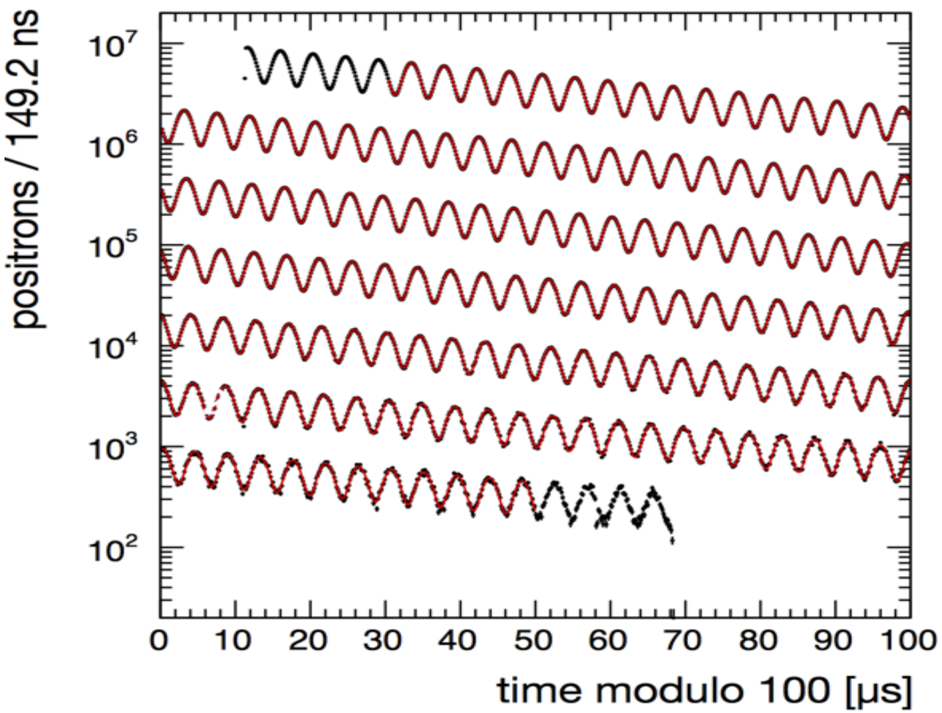


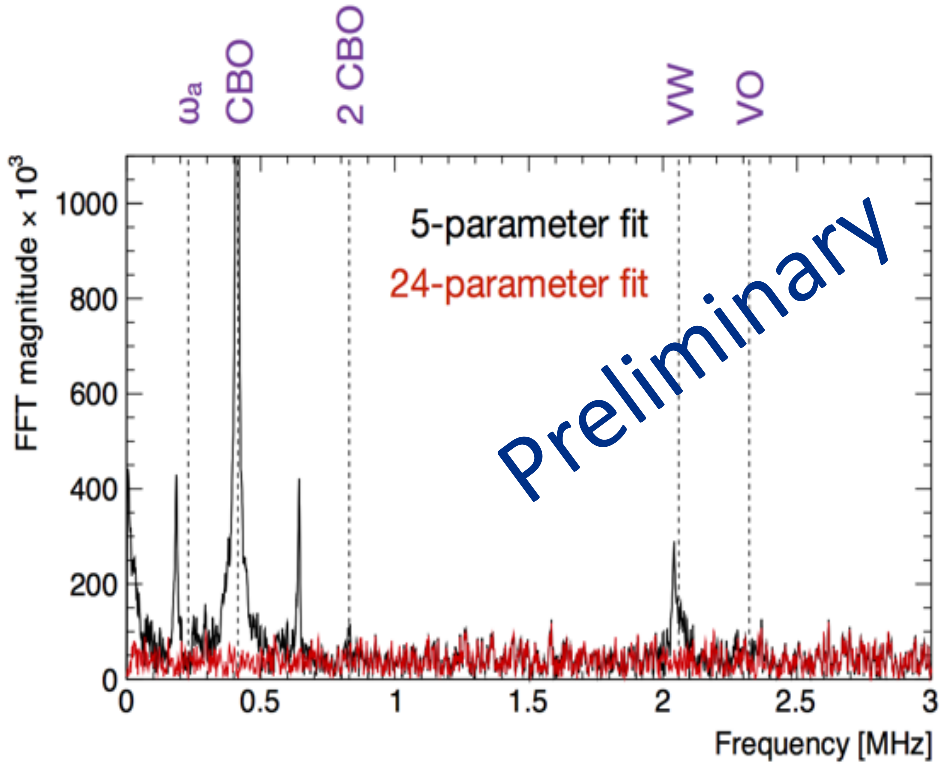
Cylinder

0.92±2.23 Hz (15±36 ppb)

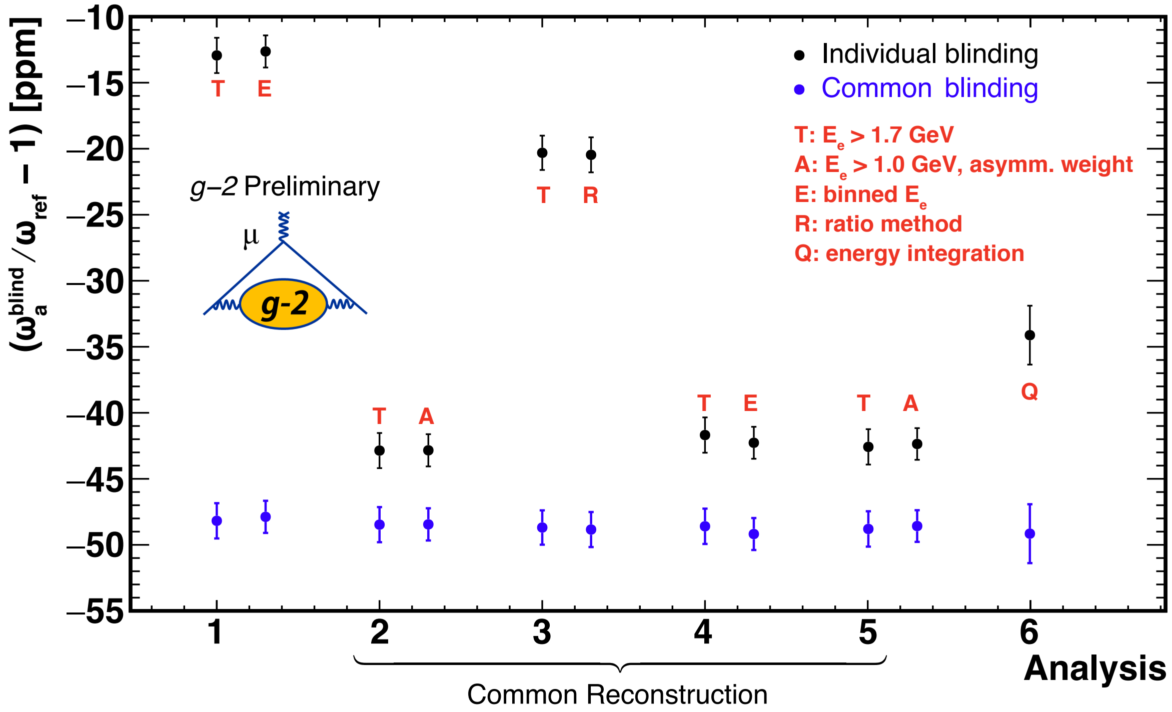
ω_a determination

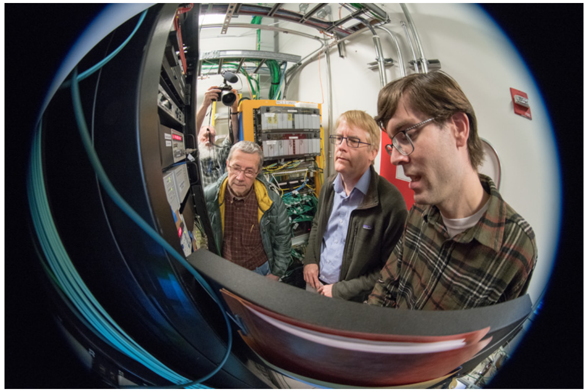
$$N(t) = N_0 \cdot \Lambda(t) \cdot N_{1\mathrm{CBO}}(t) \cdot N_{2\mathrm{CBO}}(t) \cdot N_{VW}(t) \cdot N_{VO}(t)$$
$$\cdot e^{-t/\tau}\left[1 + A_0 \cdot A_{1\mathrm{CBO}}(t) \cdot \cos(\omega_a(R) \cdot t + \phi_0 + \phi_{1\mathrm{CBO}}(t))\right]$$





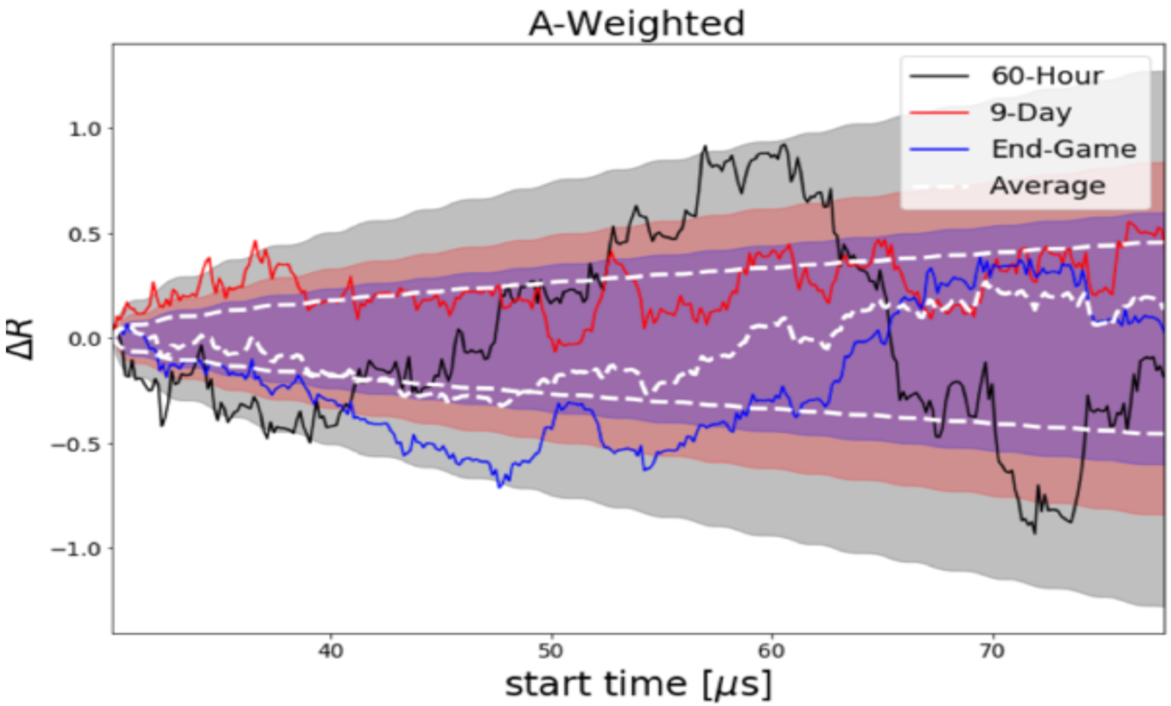
Run-1 Analysis Status





Hardware blinding : x10 size of the BNL discrepancy wrt SM

Present datasets have stat. uncertainty ½ BNL



410 ppb (stat) Run-1 vs 460 ppb (BNL).

With Run-2 data approach half the BNL stat. uncertainty

Run-1 sub-datasets have statistical variations within expectations

Expectations for Run-3/4

- Accelerator uptime to be closer to 90% not 80% assuming overtime restrictions don't exist in Run-3/4.
- Modest g-2 DAQ improvements: x0.92 → x0.95.
- Optimisation of upstream wedges: x1.06 → x1.15
- Moves average BNL/day from 3.3% to 4.0%.
- Improved temperature control (critical for field & calorimeter gain)

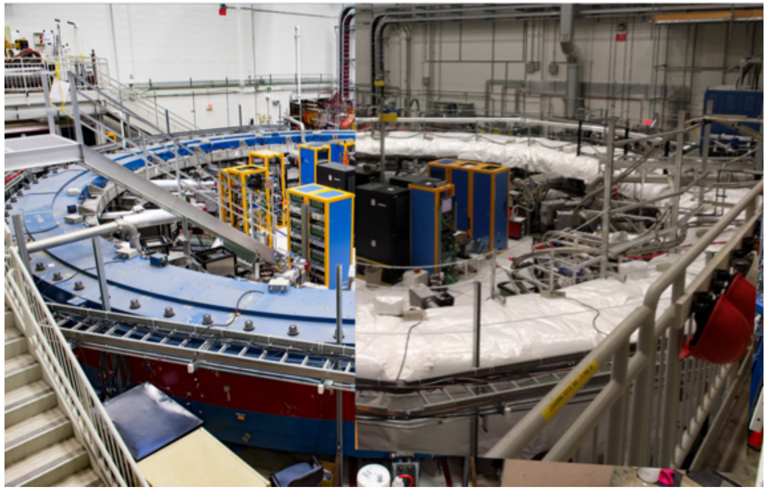
Other potential improvements:
- install new inflector: x1.4
- increase quad / kicker voltage : x1.1
- faster switching PS (mitigates testbeam) : x1.05

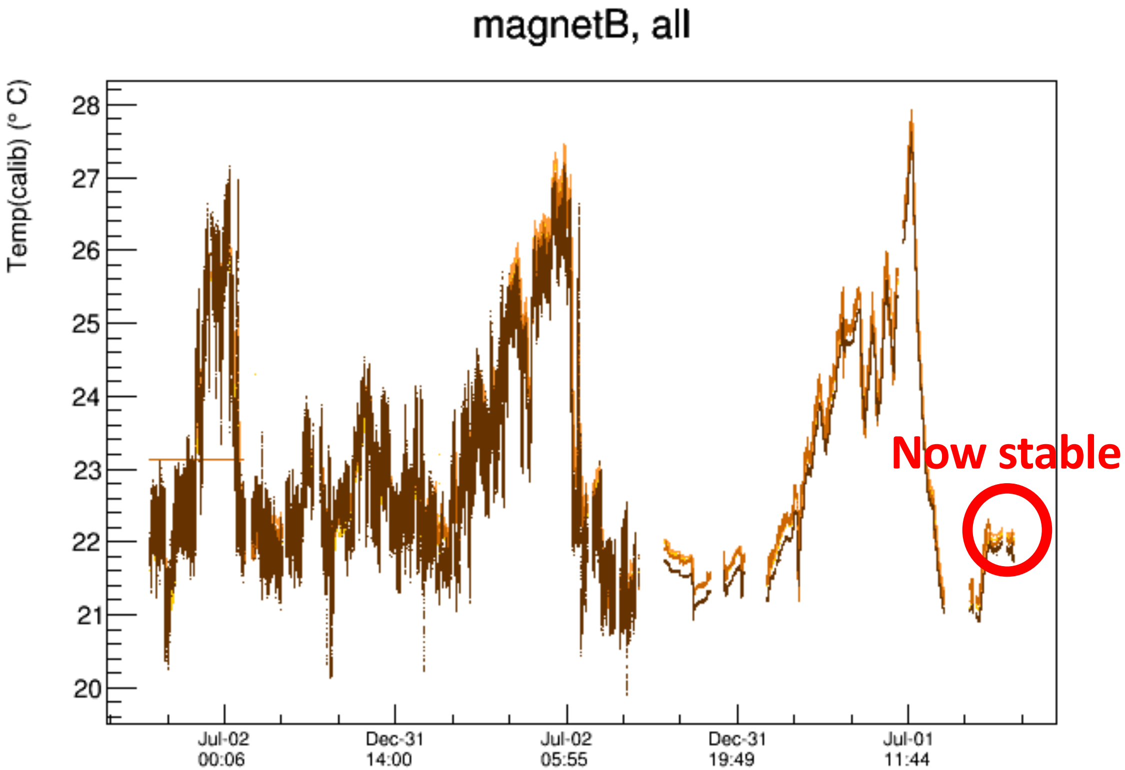
In projections we are assuming 4% of BNL per day

When had POT for > 12 hrs a day in Run-2 **we had 4.2% BNL/day**

Improved temperature control for Run-3

Before After

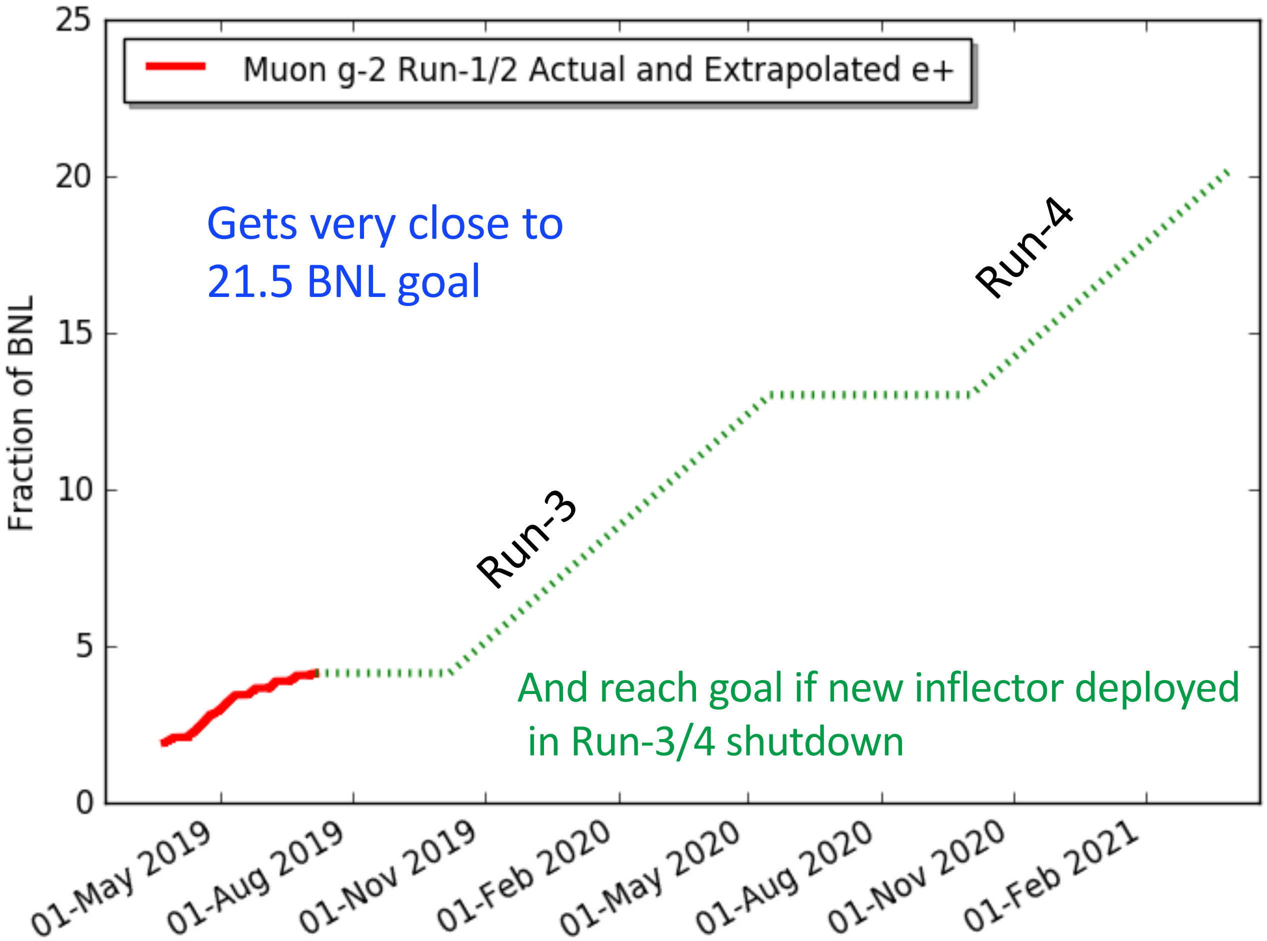




Large day/night oscillations

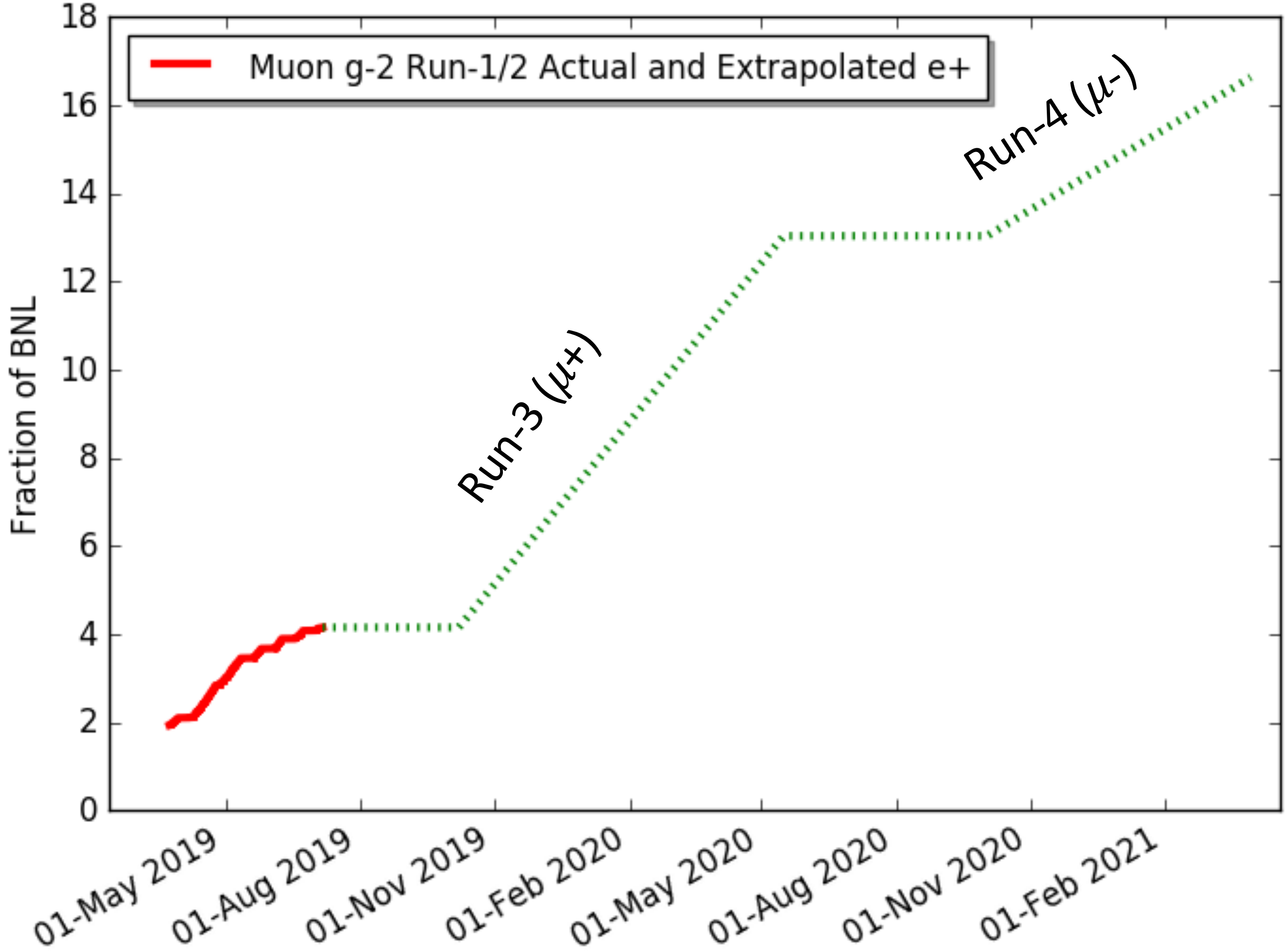
Significant overall rise over data taking period

Run-3/4


Muon g-2 Run-1/2 Actual and Extrapolated e+
Gets very close to
21.5 BNL goal
Run-3
Run-4
And reach goal if new inflector deployed
in Run-3/4 shutdown
Fraction of BNL
0
5
10
15
20
25
01-May 2019
01-Aug 2019
01-Nov 2019
01-Feb 2020
01-May 2020
01-Aug 2020
01-Nov 2020
01-Feb 2021

Possible Run-4 with μ-

Run-4 could alternatively accumulate x8.5 the BNL μ- sample
e.g. if becomes systematics limited with μ+ or μ+ result > 5σ



Requires extra work in Run-3/4 shutdown

- Cryo pumps
- Kicker standoffs

New inflector would give x12 BNL μ- sample.

Beyond Run-4

Beam time is prioritised for Mu2e but initial part of Run-5 is likely g-2 running.

Ideas presently being pursued for future use of g-2 ring

- dedicated muon EDM experiment : new Si trackers infront of each calo
- O(10 keV) ν_μ mass measurement

HEPAP/P5 is summer of 2021 i.e. as Run-4 concludes.

Conclusions

- Run-1 and Run-2 were challenging: several technical issues had to be resolved
- Run-1 data will by itself surpass BNL precision
- Early analysis allowed us to quickly understand where we most needed to make improvements to control systematics for Run-2
- Run 2 (1.8×BNL) was taken under much more stable and improved conditions
- Expect even higher quality data in Runs 3 & 4 with 1×BNL collected per month
- (Blinded) independent analyses making good progress