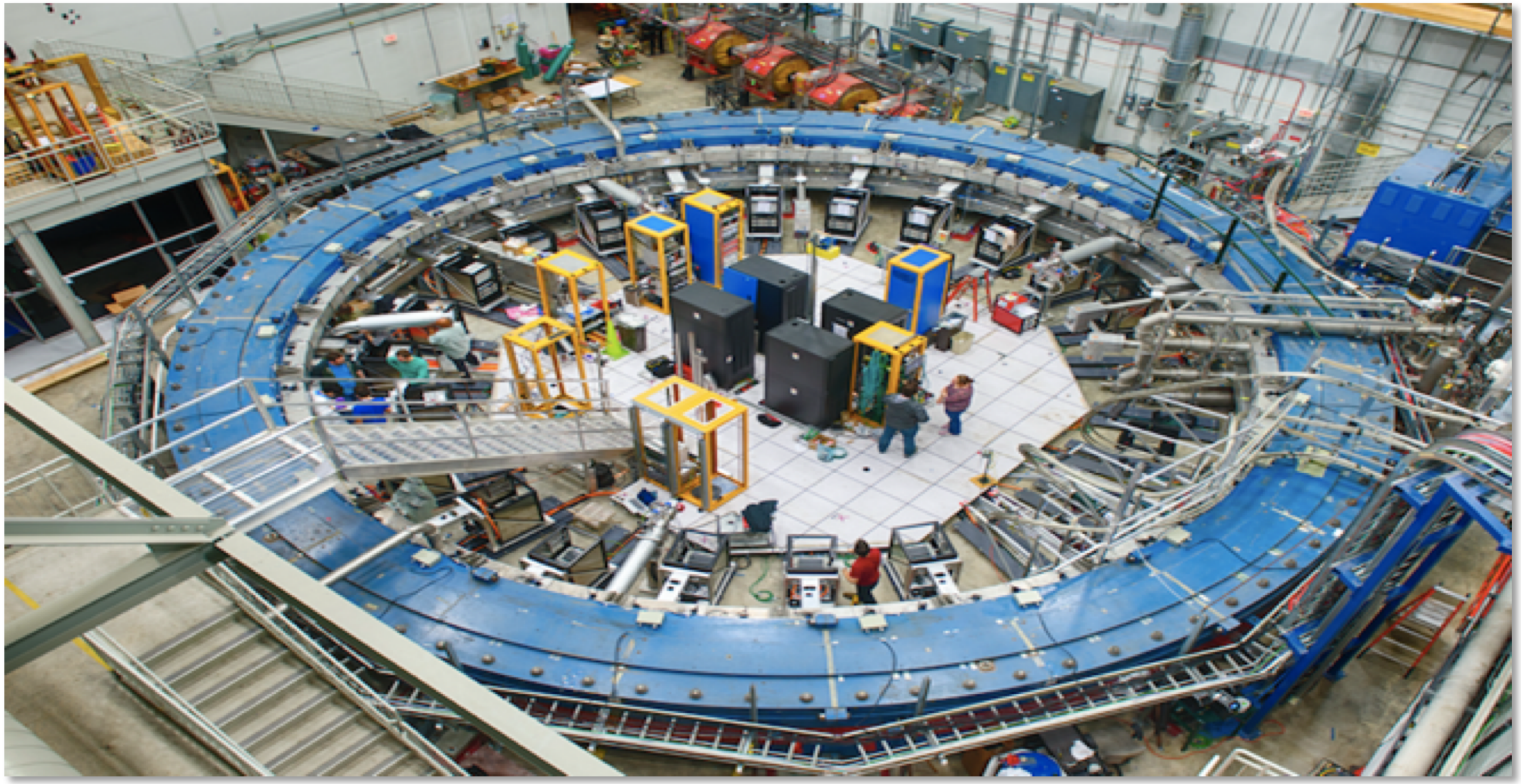
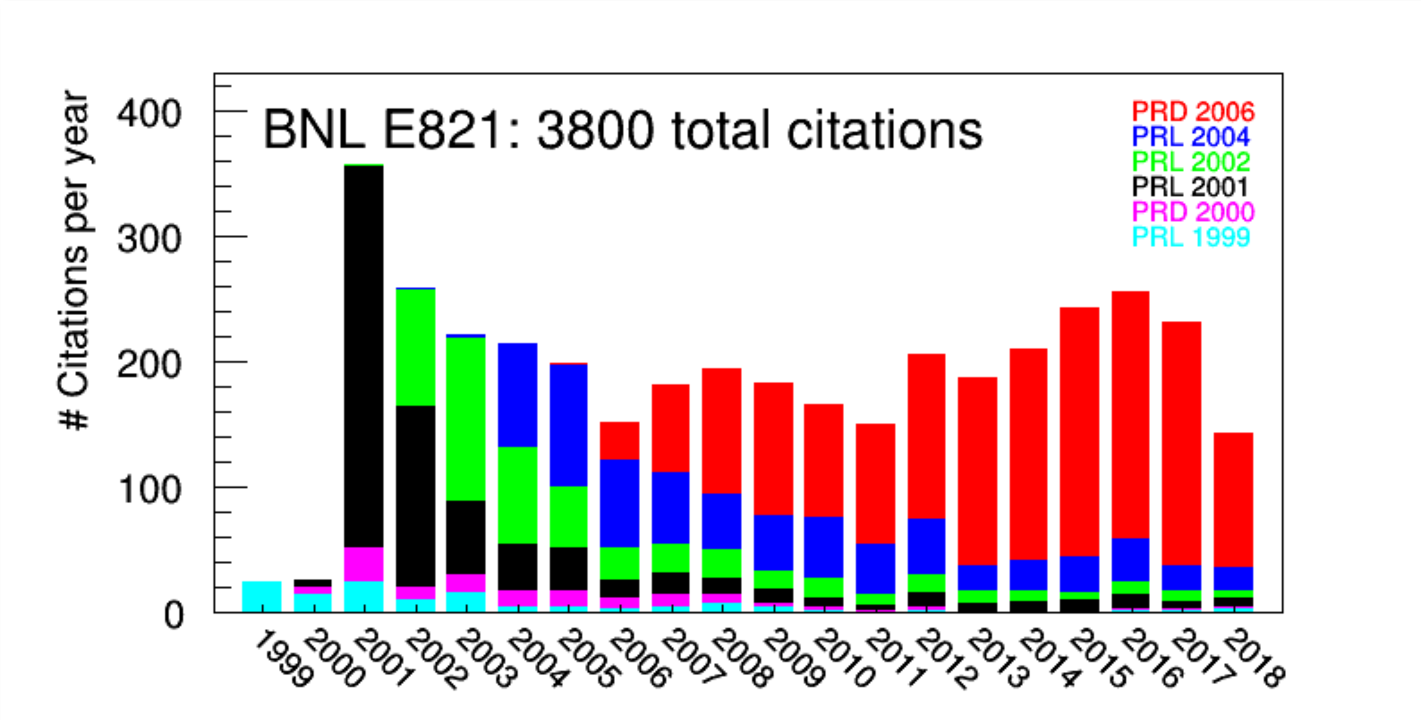


Muon g-2 overview

Mark Lancaster

MUSE

A topic of interest



CERN Courier September 2018

News

MUON G-2

Closing in on the muon's magnetic moment

arXiv.org > hep-ph > arXiv:1807.08167

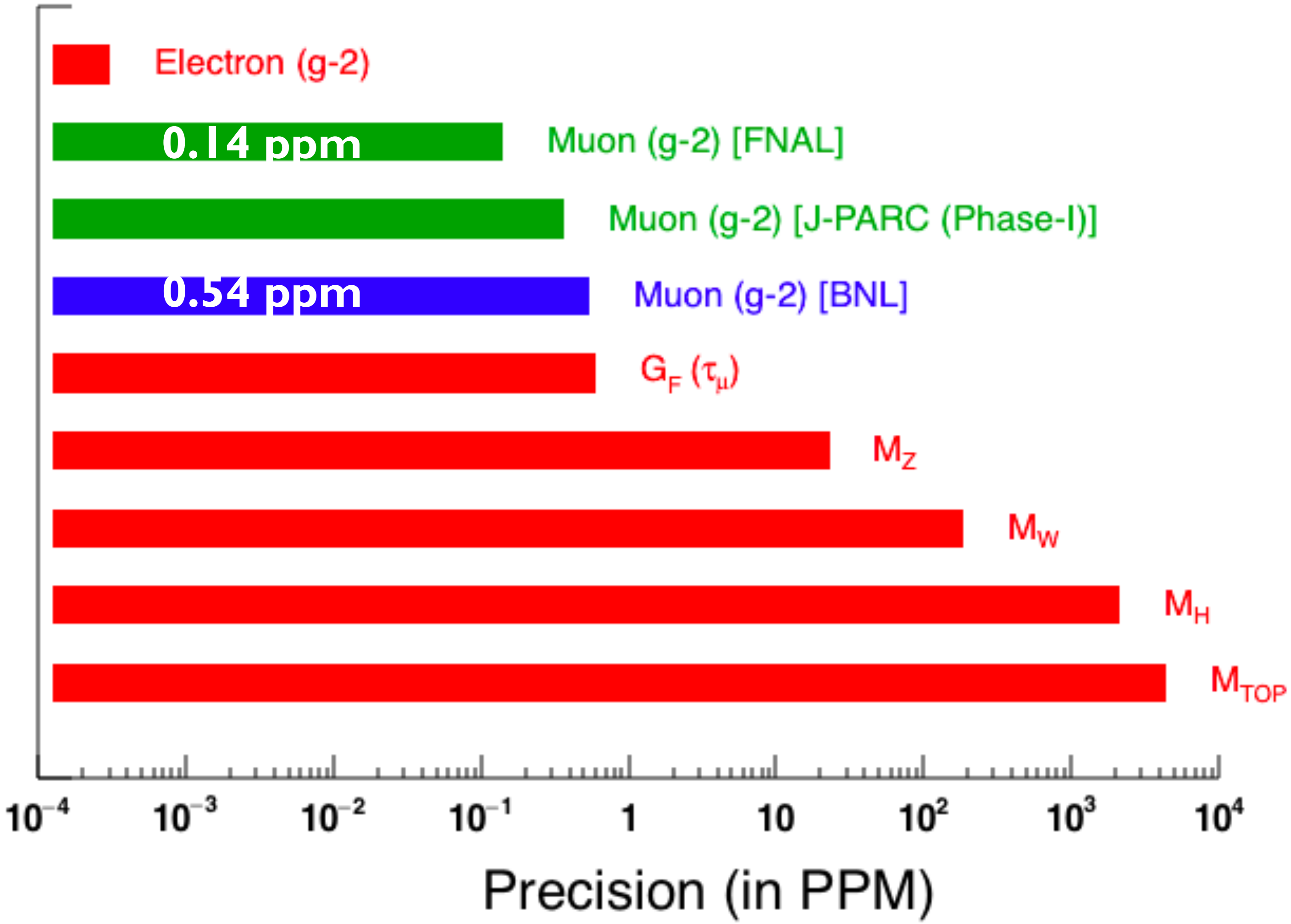
High Energy Physics – Phenomenology

Charged scalars confronting neutrino mass and muon g-2 anomaly

Nabarun Chakrabarty, Cheng-Wei Chiang, Takahiro Ohata, Koji Tsumura

(Submitted on 21 Jul 2018)

Aim of experiment : 0.14 ppm (stat. = syst.)



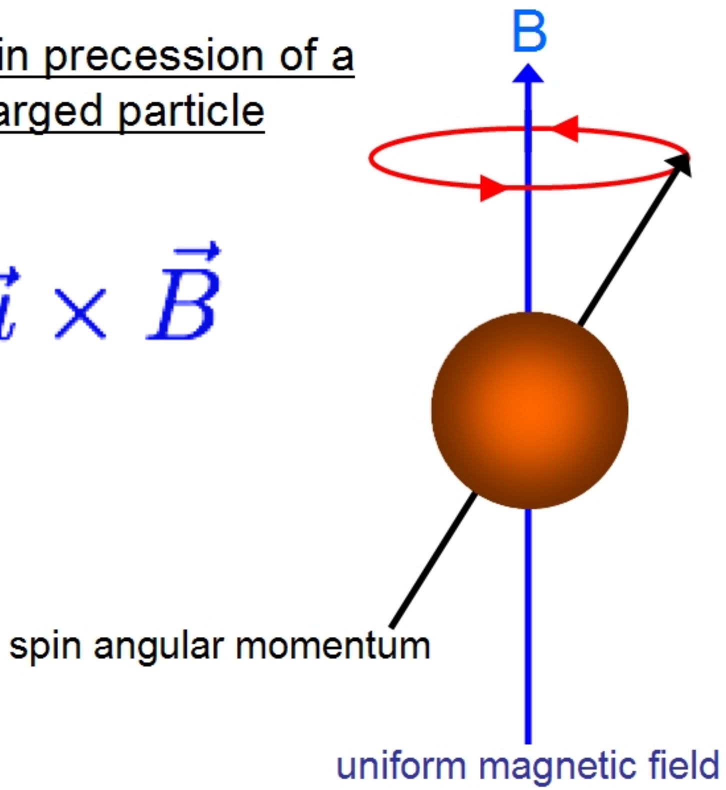
g-2 Basics

$$\vec{\mu} = g\frac{Qe}{2m}\vec{s}$$

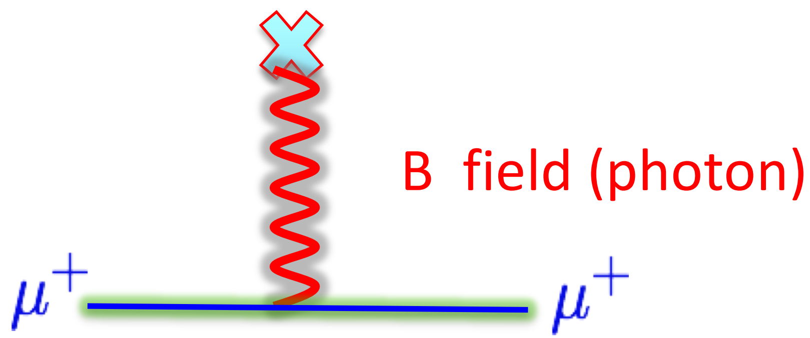
Interaction between
magnetic moment (spin) with B-field.

<u>Spin precession of a charged particle</u>

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



Spin **<u>precesses</u>** around B at
a frequency determined by “g”



Methodology

Particle in a circular storage ring (B-field): two frequencies:

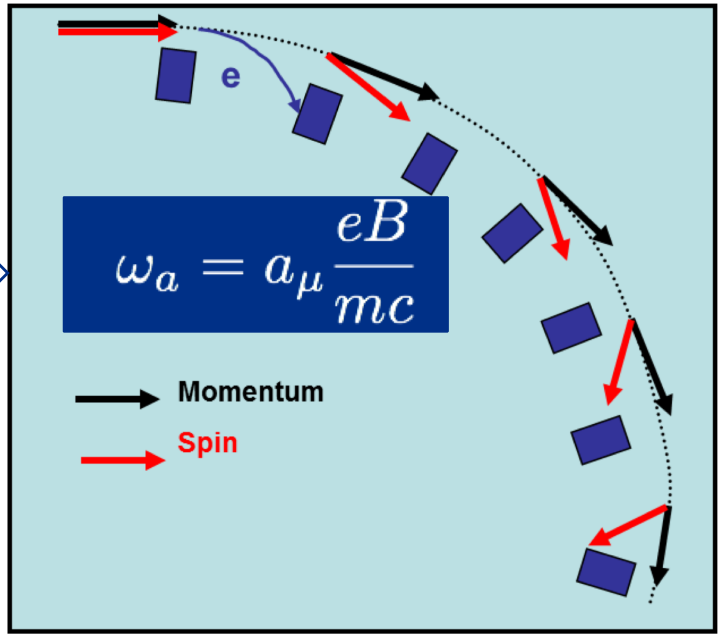
$$\omega_S = \frac{geB}{2mc} + (1-\gamma)\frac{eB}{\gamma mc} \qquad \omega_C = \frac{eB}{mc\gamma}$$

Spin vector of muon rotates slightly quicker than Momentum vector.

For a 1.5T field spin rotates in 144ns and momentum in 149ns.

$$\omega_a = \omega_S - \omega_C = \left(\frac{g-2}{2}\right)\frac{eB}{mc} = a\frac{eB}{mc}$$

$$f_a = 228 \text{ kHz}$$



Methodology

$$\omega_a = -\frac{e}{m}\left[a_\mu \vec{B} - \left(a_\mu - \frac{1}{\gamma^2 - 1}\right)\frac{\vec{\beta} \times \vec{E}}{c}\right]$$

FNAL: MAKE ZERO BY CHOOSING "MAGIC" γ

J-PARC: MAKE ZERO BY HAVING E=0

$$a_\mu = \frac{\omega_a}{B}\frac{m}{e}$$

Need to measure two quantities
- B field
- ω_a

To better than 0.1 ppm

We measure two frequencies : ω_a and ω_p

$$a_\mu = \frac{\omega_a}{B}\frac{m_\mu}{e} = \frac{\omega_a}{\omega_p}\frac{\mu_p}{\mu_e}\frac{m_\mu}{m_e}\frac{g_e}{2}$$

FNAL g-2: 140 ppb

8 ppb

25 ppb

0.0003 ppb

2.5 ppb
(J-PARC MuSeum expt)

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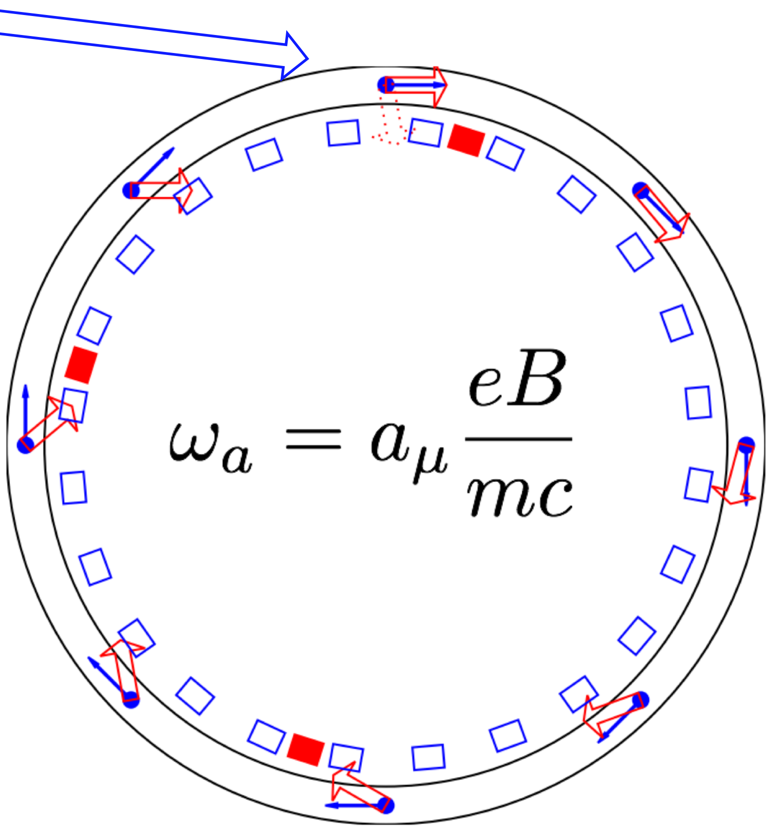
Methodology

Inject 3.09 GeV muons into a storage ring (B = 1.45 T)



$$\omega_a = a_\mu \frac{eB}{mc}$$

Exploit property that direction of e^+ from μ^+ decay is strongly correlated with μ^+ spin for highest energy e^+

24 calorimeters and 2 straw trackers measure e^+ for O(1 ms) in 16 spills separated by 10ms every 1.4 sec.
O(10,000) stored 3.09 GeV muons from 10^{12} protons per spill.

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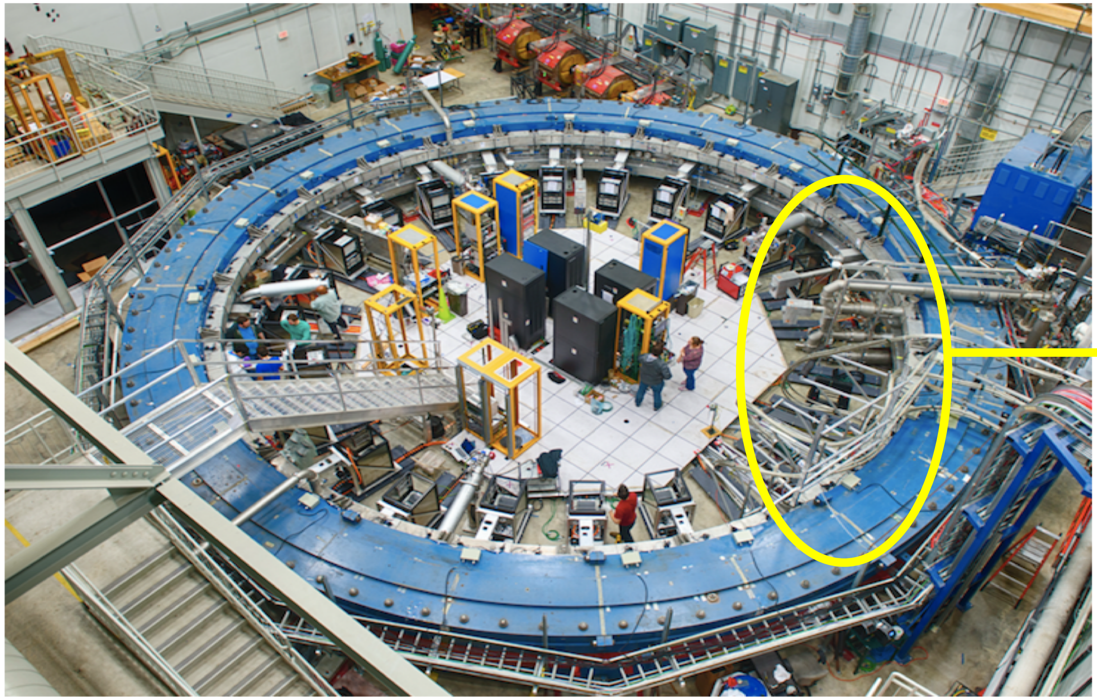
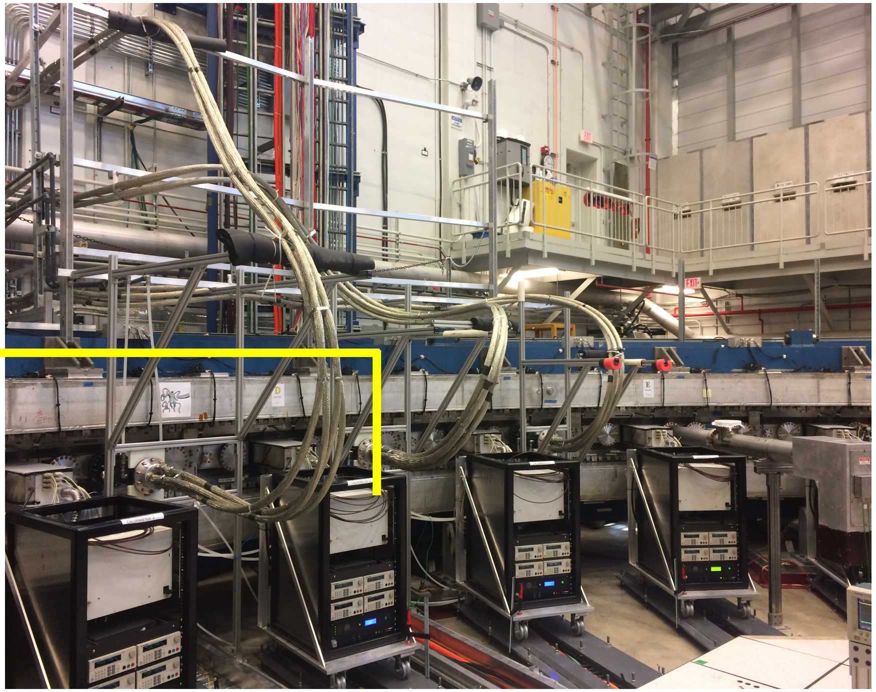
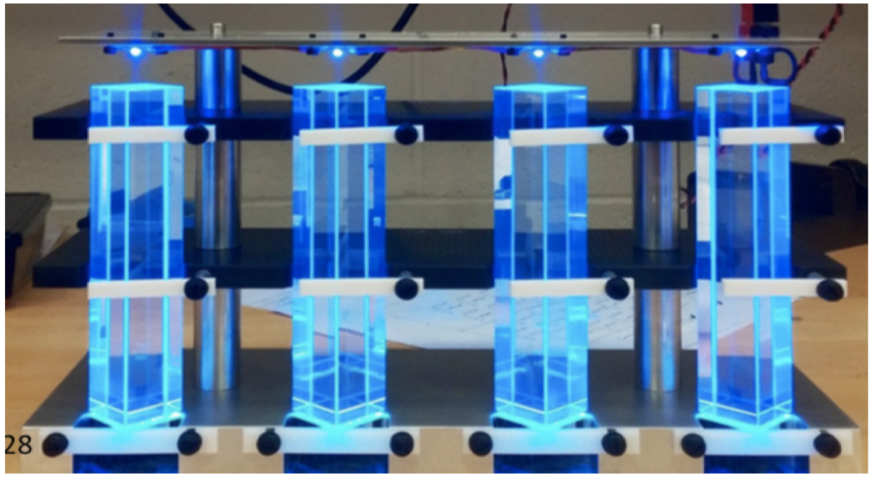
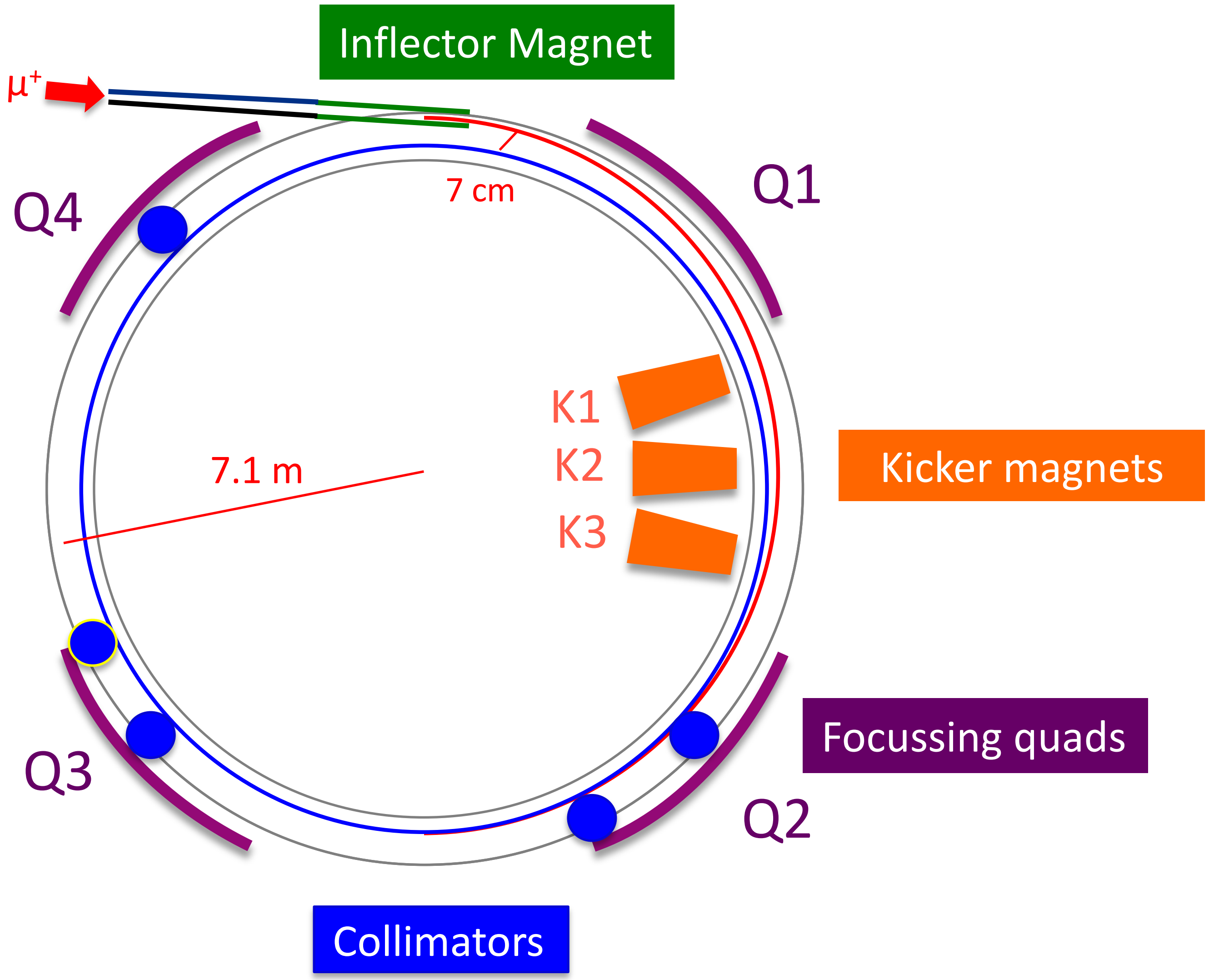
Realisation of this







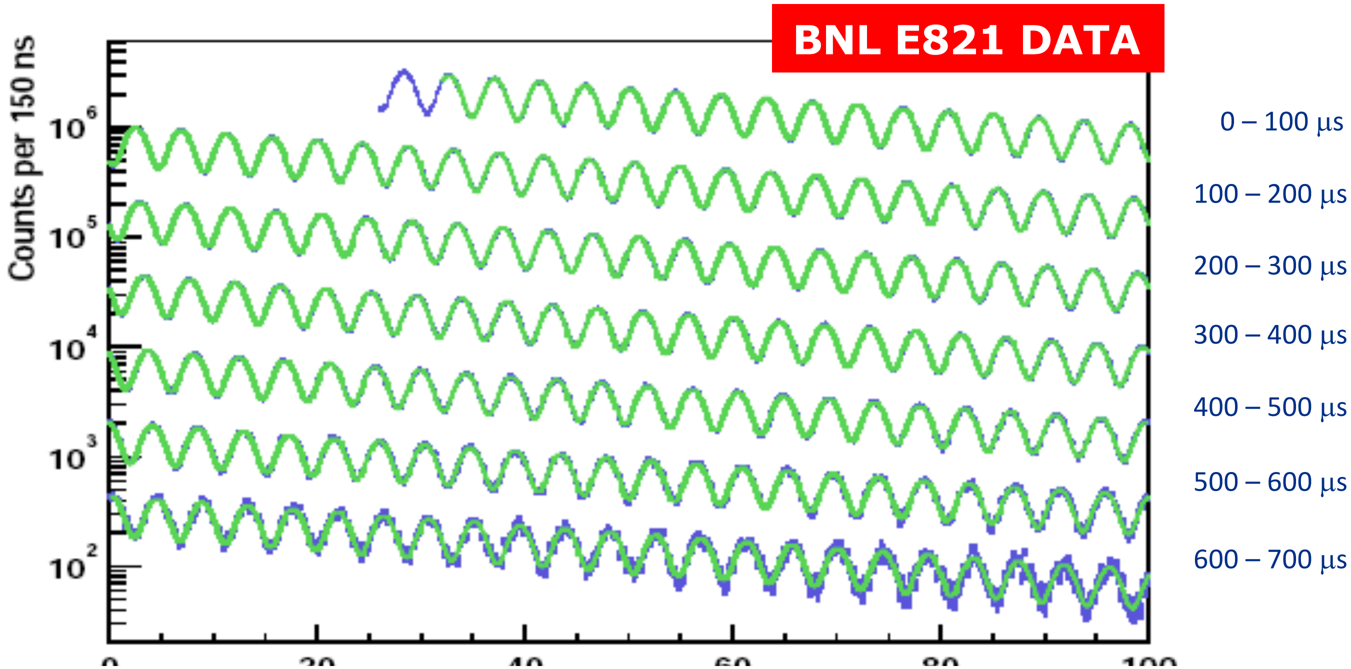
Injection/Storage



“Wiggle Plot”

$$N_e(t) \simeq N_0 e^{-\frac{t}{\gamma\tau}}[1 - A\cos(\omega_a t + \phi_a)]$$

$$E_{e+} > 1.8 \text{ GeV}$$



To get < 0.1 ppm statistical accuracy requires approx 180B decaying muons.

BNL analysed approx. 5B e^+ and 3.5B e^-

Two corrections to “Wiggle Plot”

$$\vec{\omega}_a = \frac{e}{mc}\left[a_\mu \vec{B} - \left(a_\mu - \frac{1}{\gamma^2 - 1}\right)\vec{\beta}\times\vec{E} - a_\mu\left(\frac{\gamma}{\gamma+1}\right)\left(\vec{\beta}.\vec{B}\right)\vec{\beta}\right]$$

Quad E-fields   Vertical Motion

1. E-field Correction : 0.25-0.5 ppm (depending on kicker voltage)

- position uncertainty / misalignment of quad plates
- deviation of beam from equilibrium radius / magic momentum

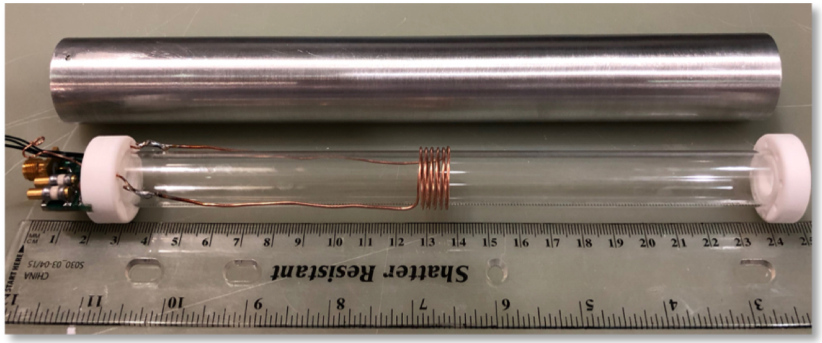
2. Pitch Correction : 0.25 ppm

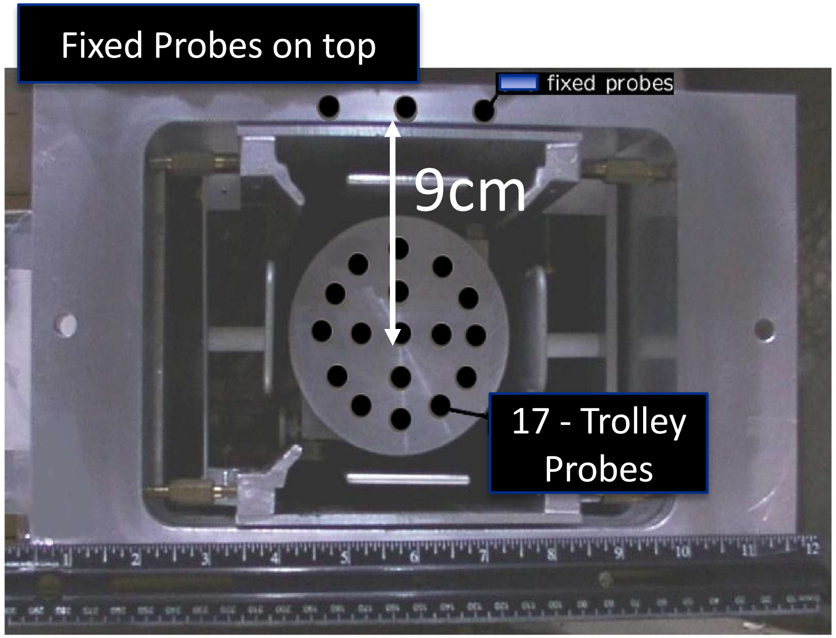
- due to (small) vertical betatron oscillation

BNL had O(10%) uncertainties on these corrections

ω_p : using pulsed NMR

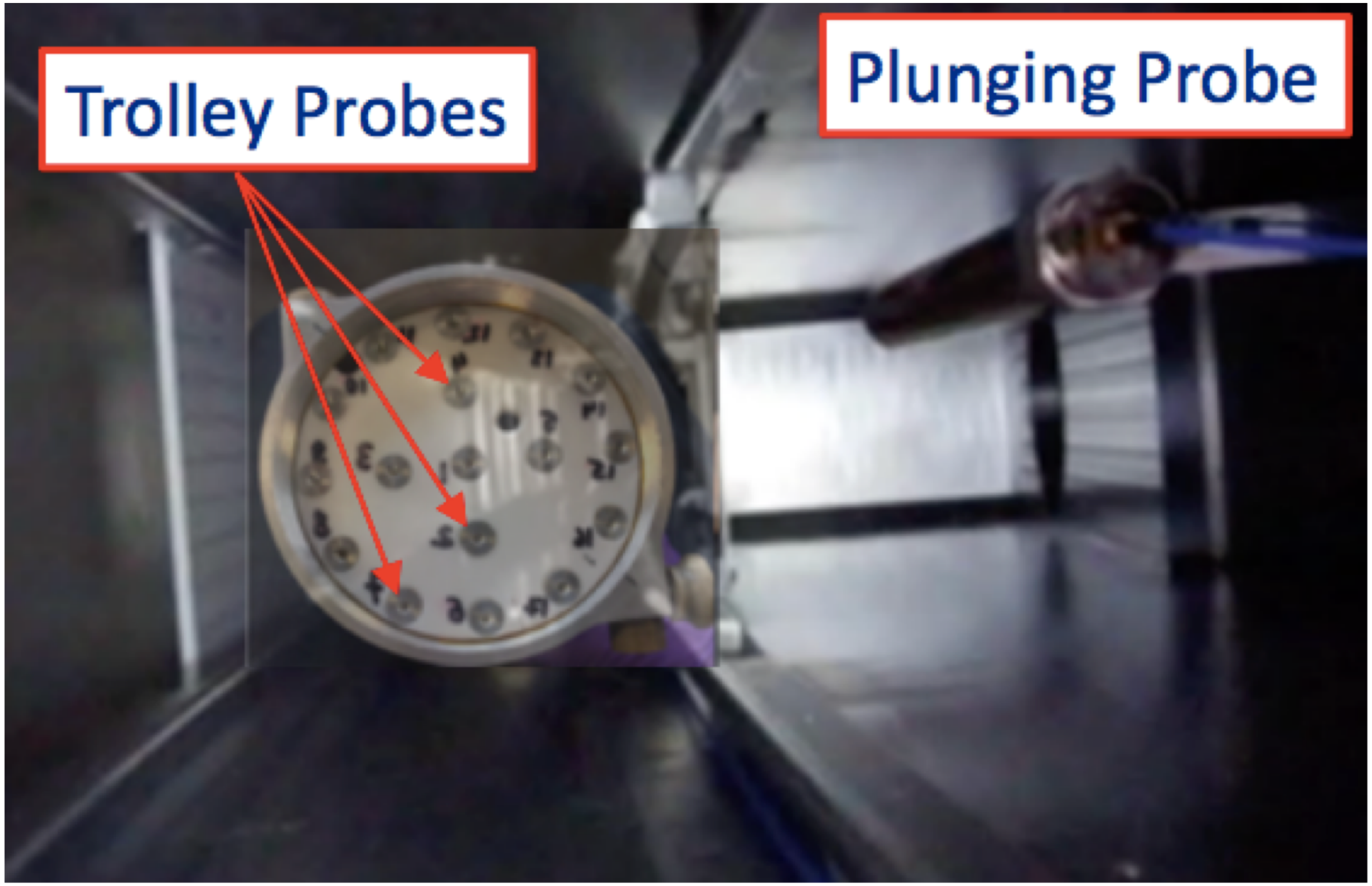
Without beam : measure using a "**trolley**" with 17 NMR probes
With beam : using 378 **"fixed probes"**





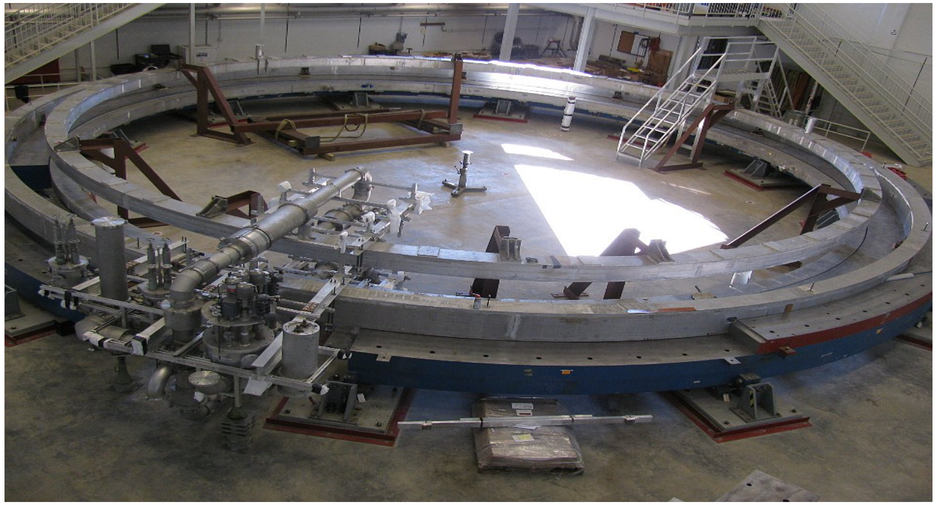
Calibrate "trolley" with absolute **"plunging probe"** & cross-check this with ^{3}He probe (and probes from J-PARC g-2 & MUSEUM expts)

ω_p : using pulsed NMR



How are we doing

We’ve come a long way in a short-time….



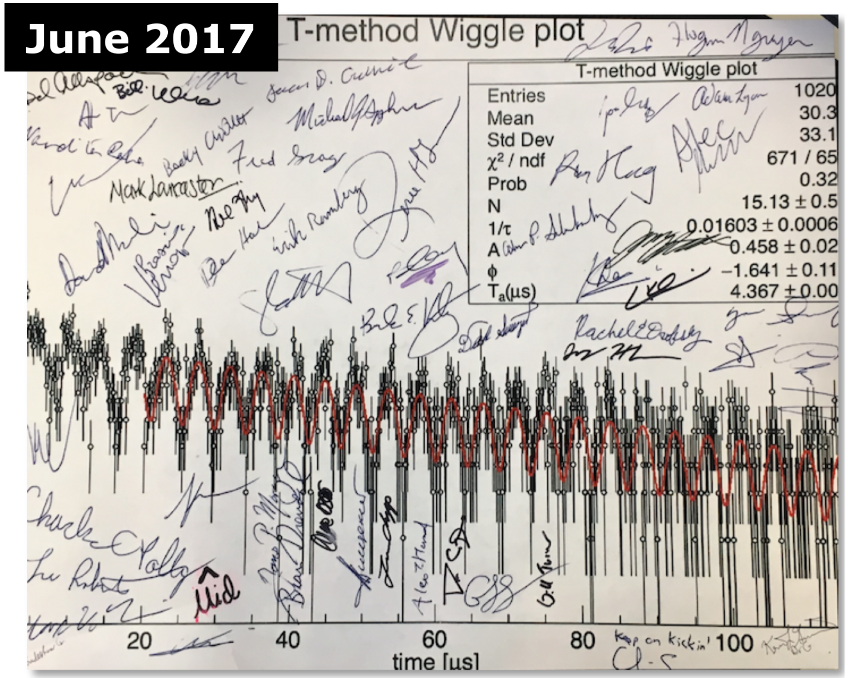
First Beam

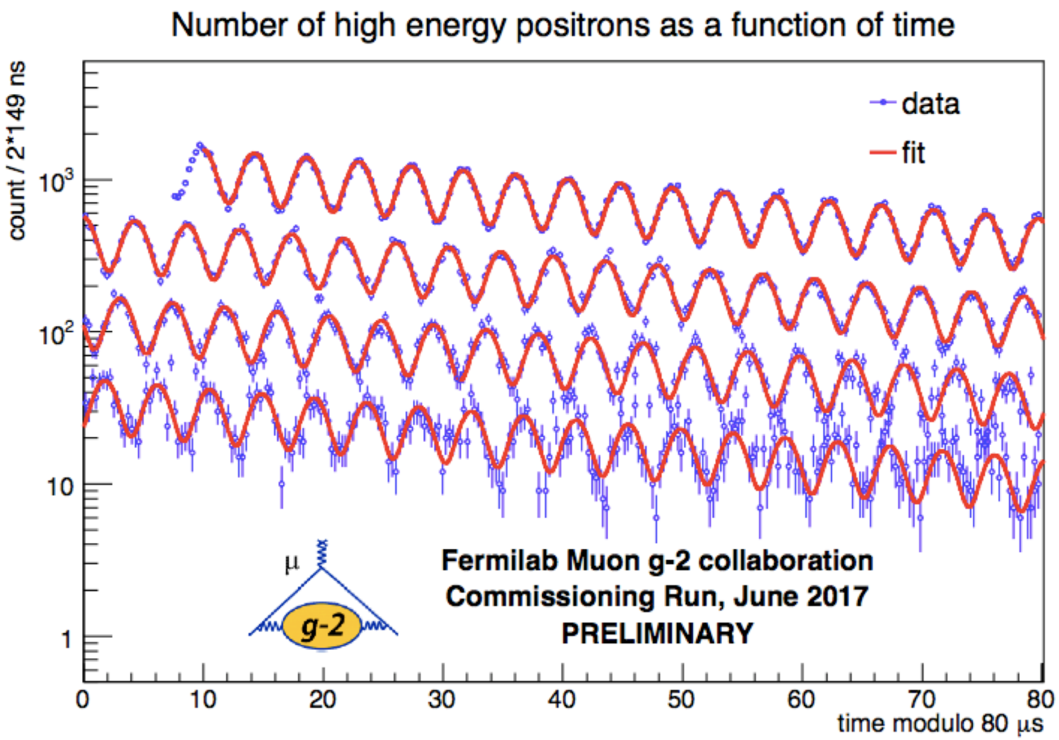
Within a couple of weeks we had verified that:

- detectors / DAQ worked to specification
- injection systems could store beam
- what we saw was broadly inline with predictions

First Wiggle Plot : Run-0 Commissioning Run

June 2017

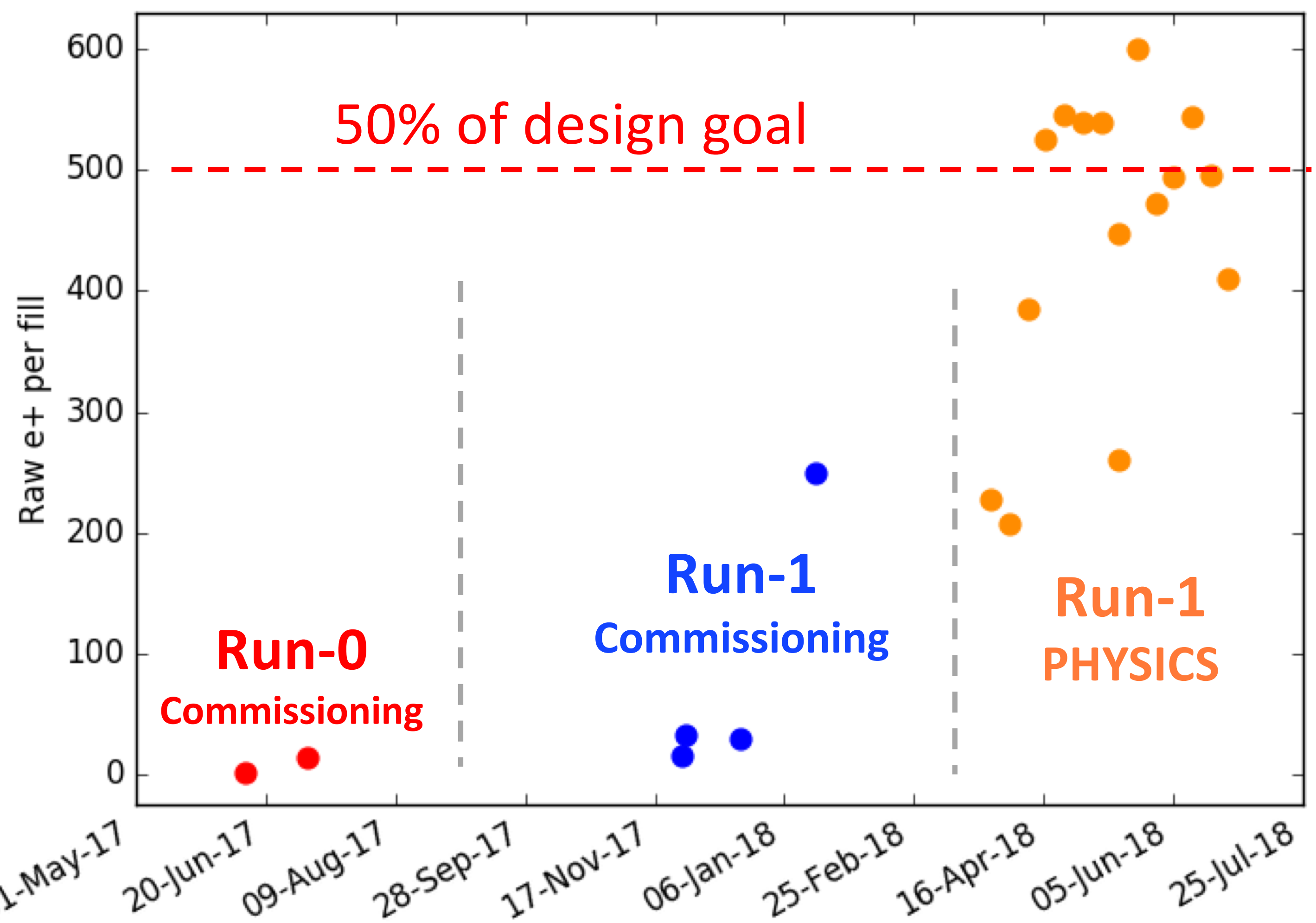




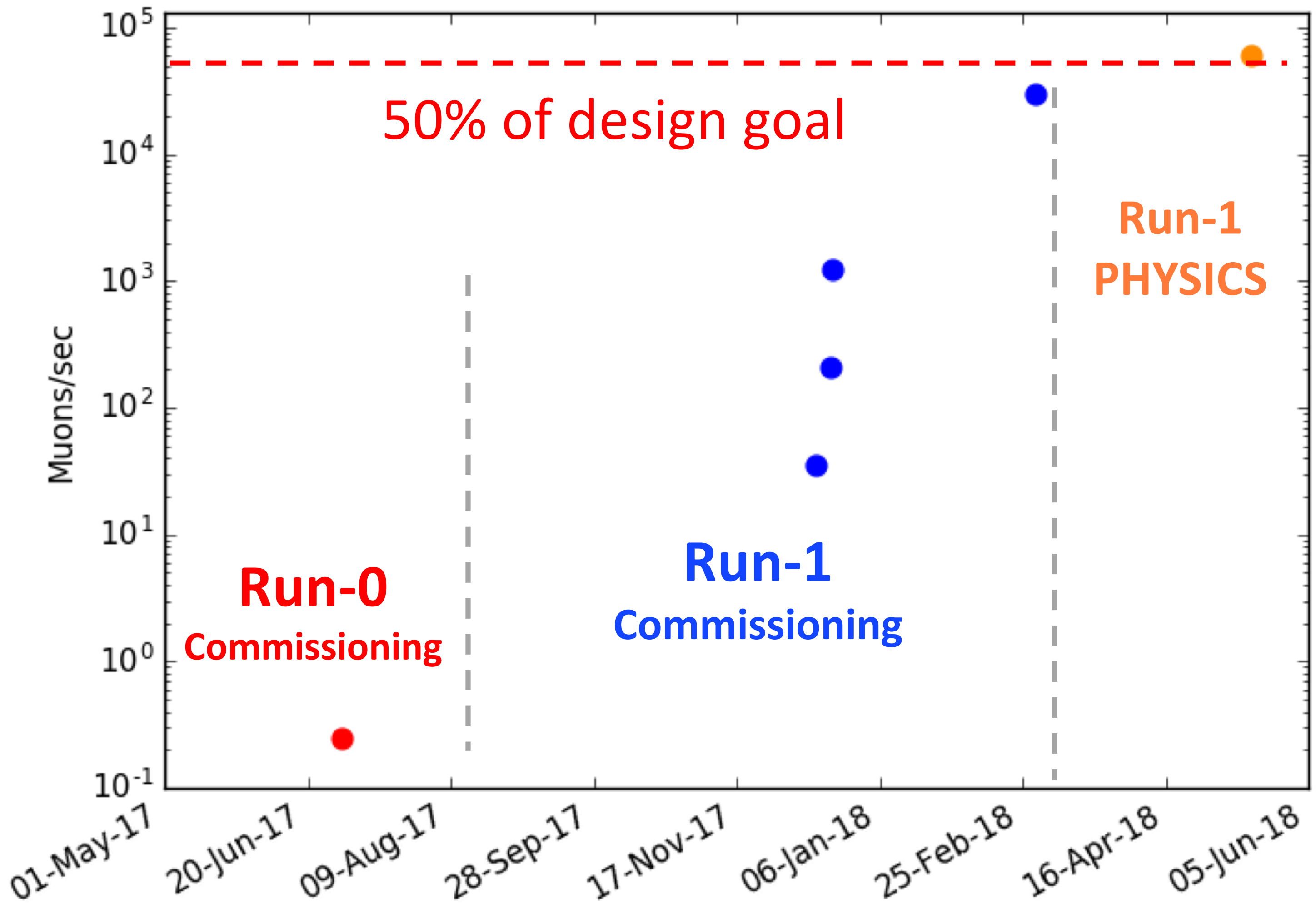
60 ppm (stat) measurement with a beam dominated by protons

Observed 1-20 e^+ per fill with 1-4 fills per minute

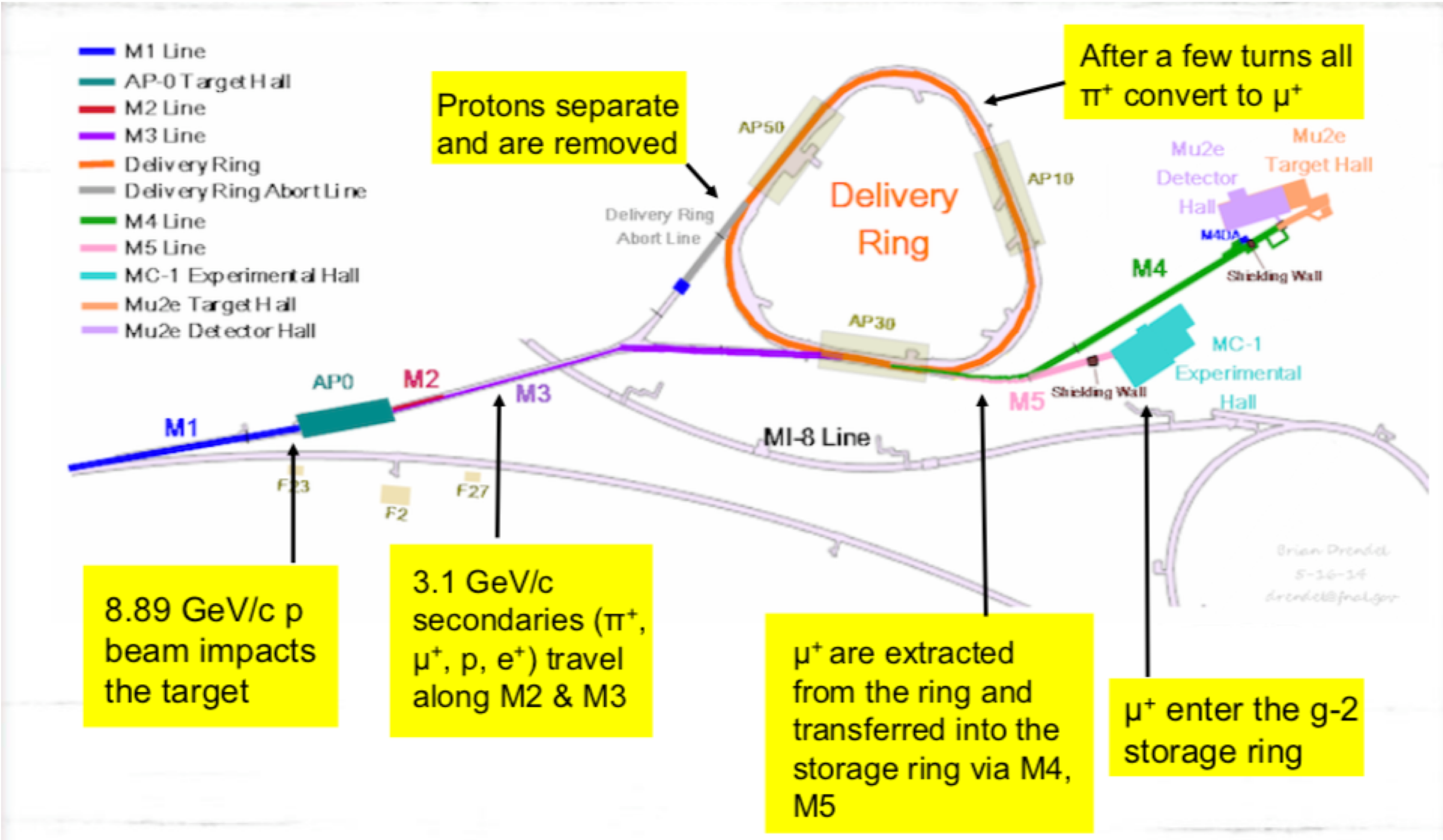
Commissioning : Jun 2017 – Mar 2018



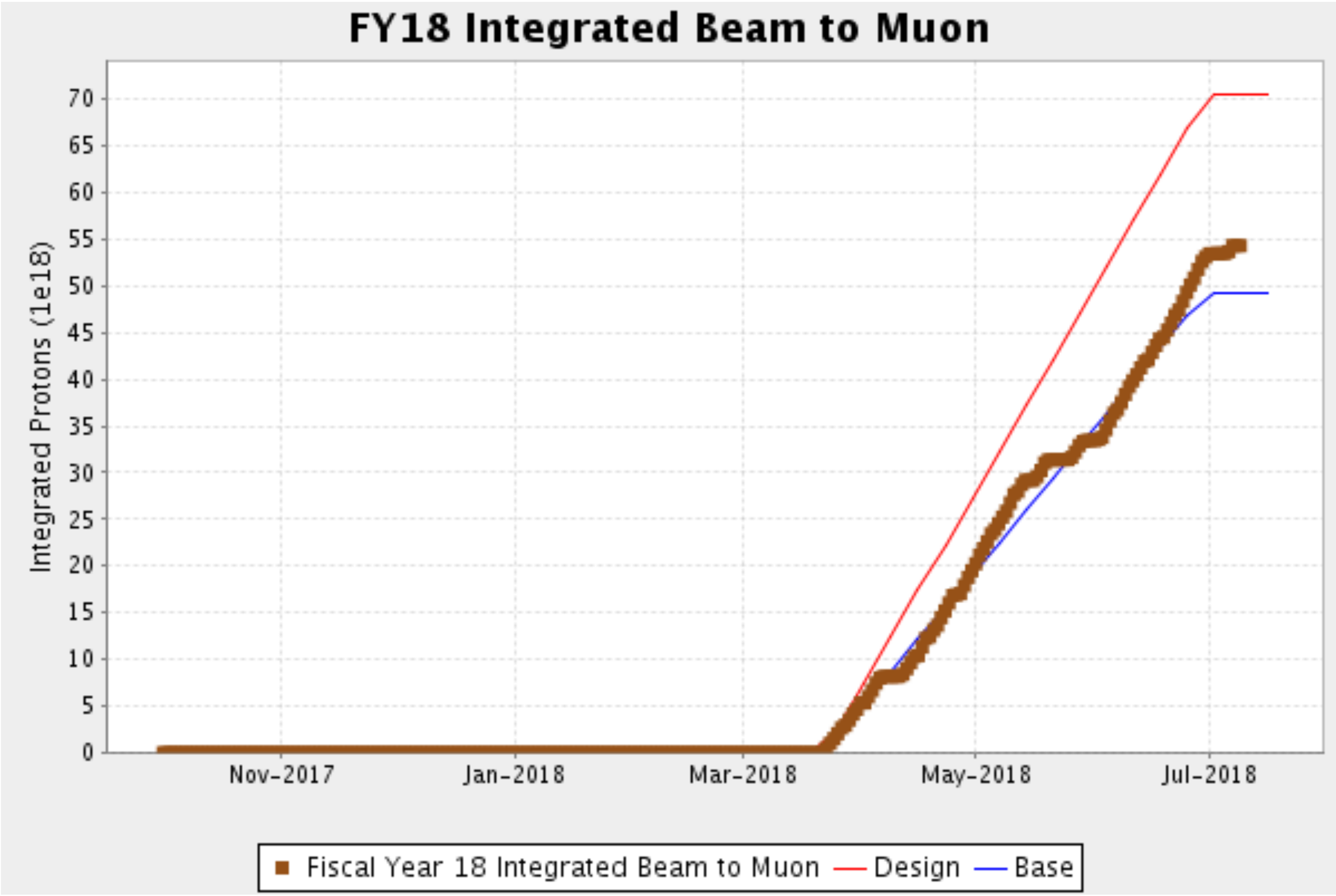
Commissioning : Jun 2017 – Mar 2018



Accelerator Performance

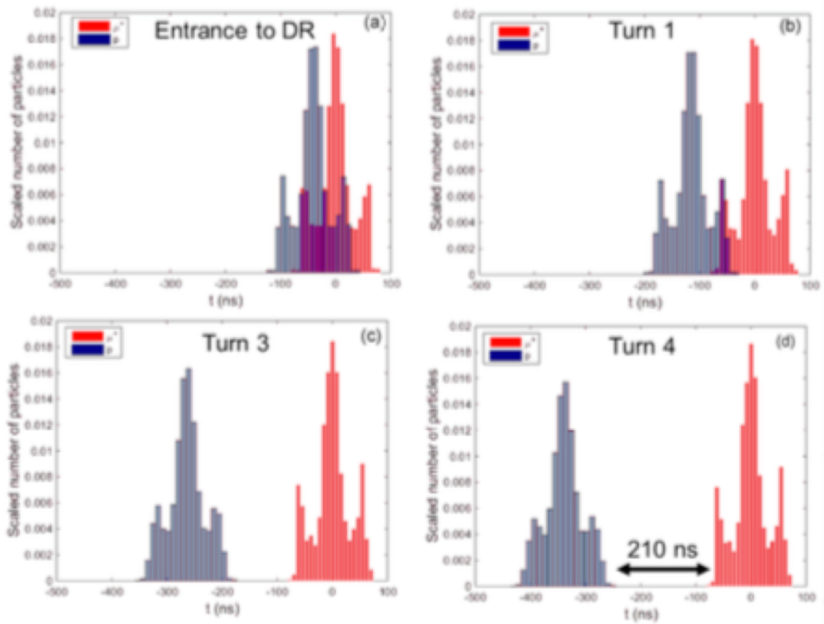


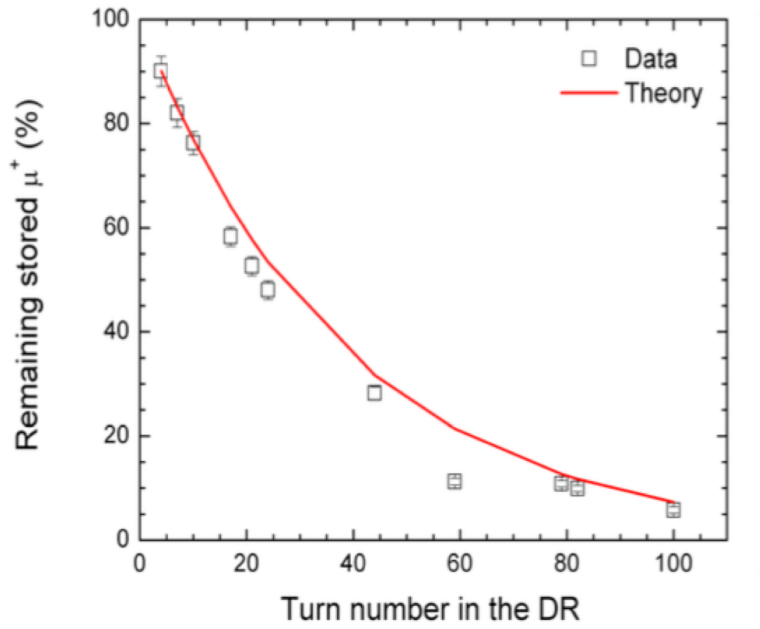
Accelerator Performance

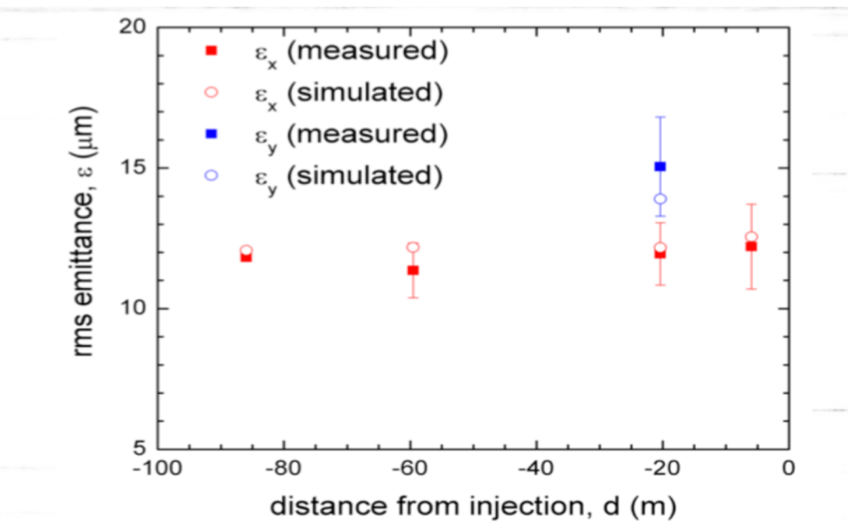


Achieved baseline goal for the year in terms of protons-on-target

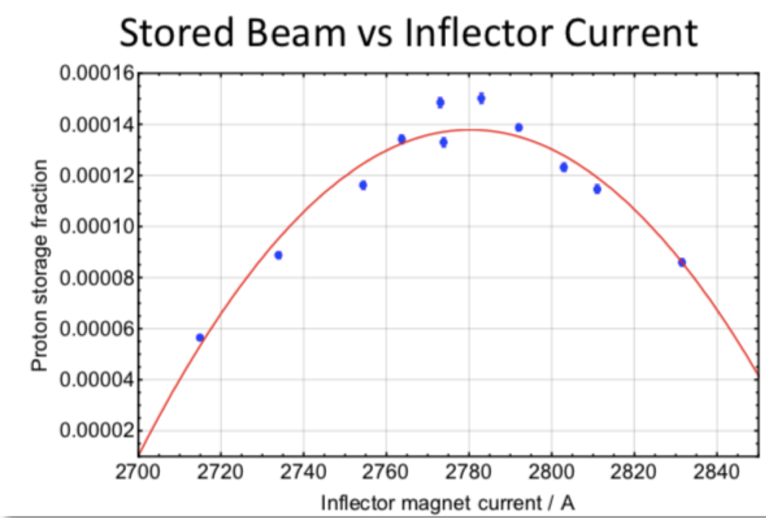
Accelerator Performance







Injection/Storage Performance

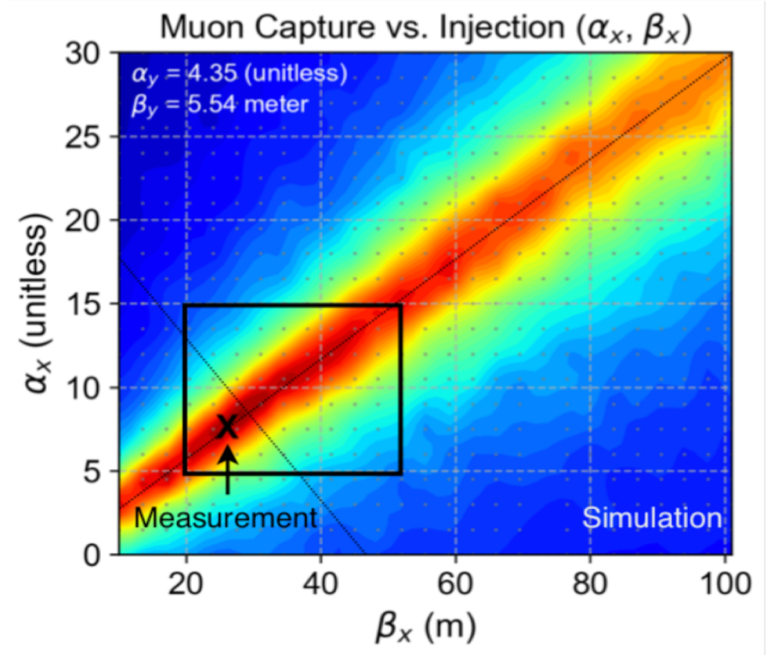


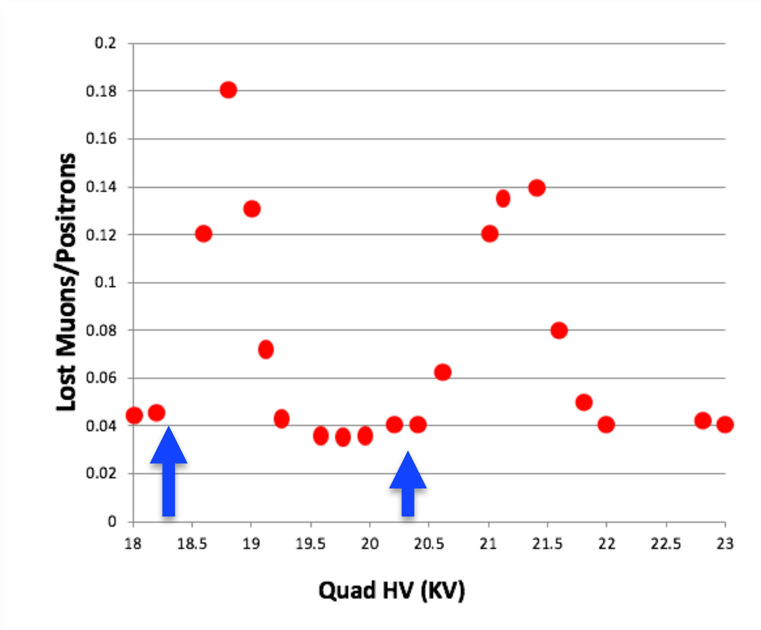
Kicker timing / voltage

Inflector current

Surface coils

Quad settings





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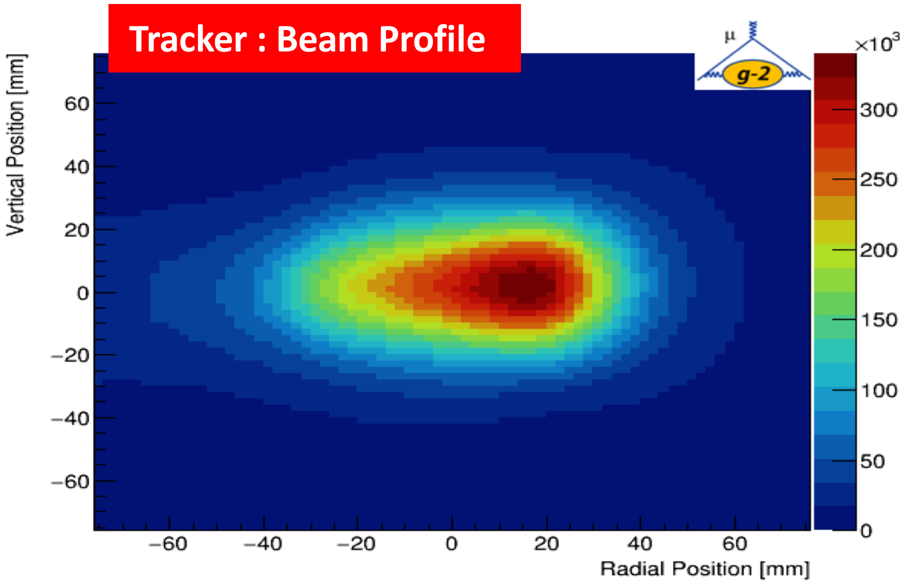
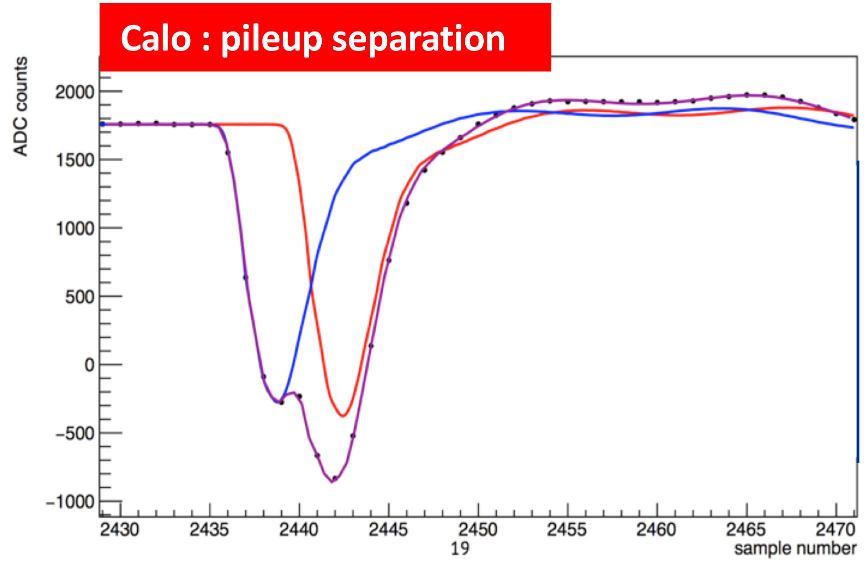
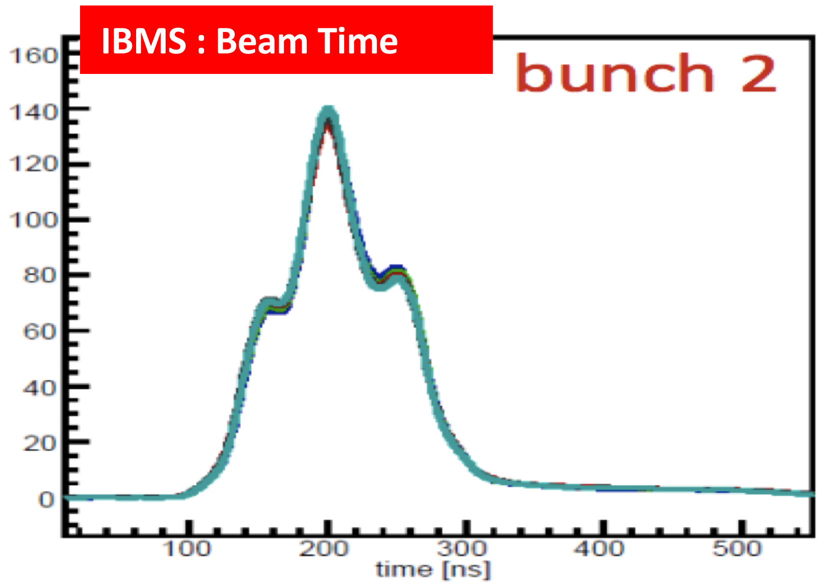
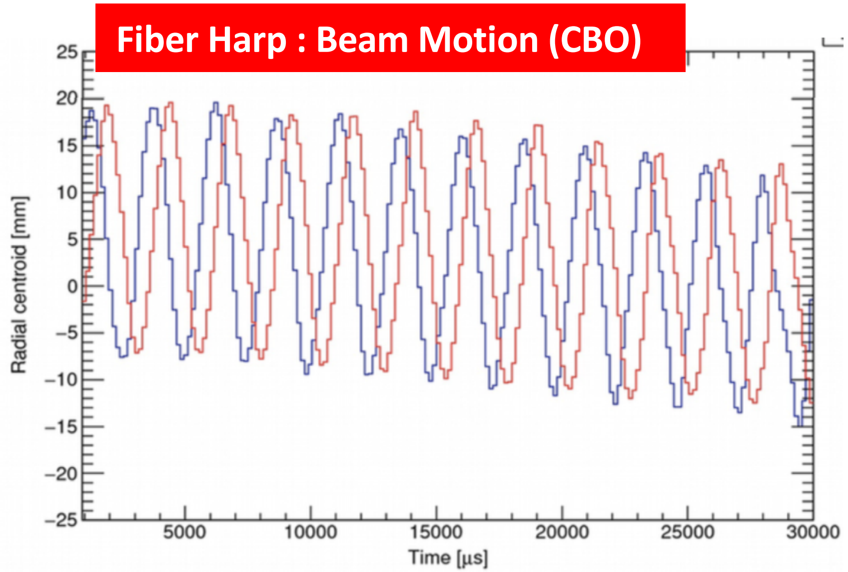
Detector Performance



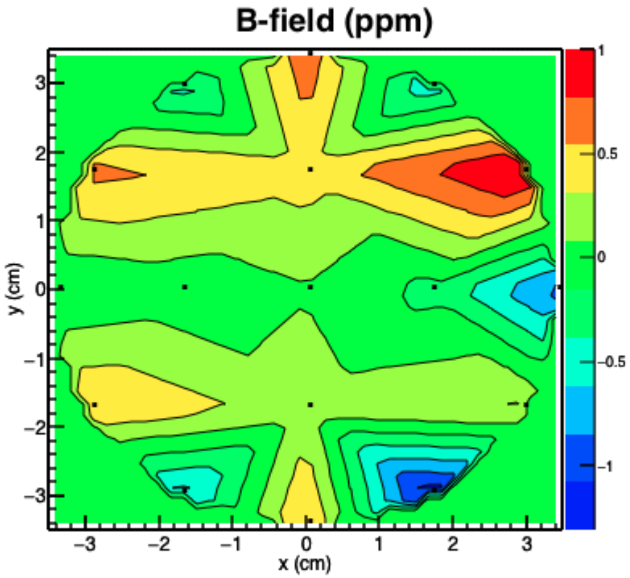






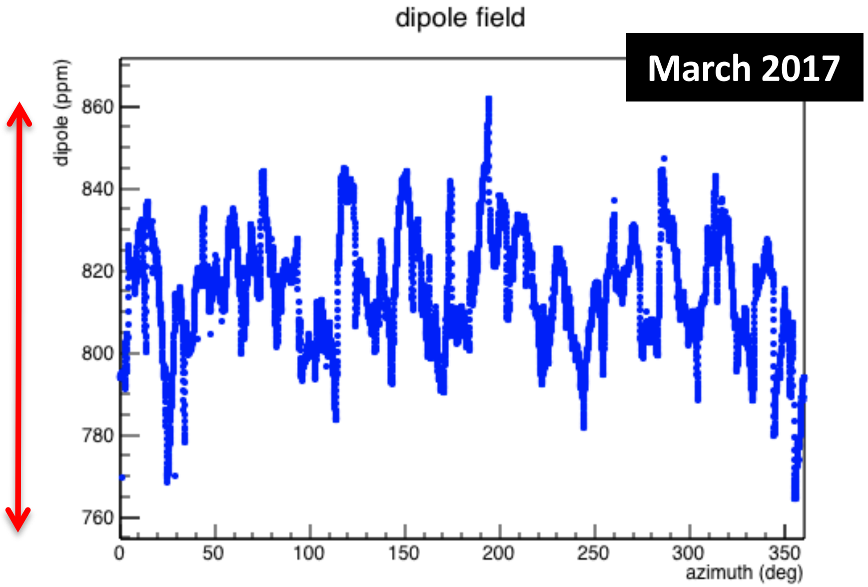
MUSE

Field Performance



	Norm	Skew
Quad	-0.19	0.28
Sext	0.05	0.27
Octu	-0.07	0.25
Decu	0.23	0.07
Dipole	-0.0	

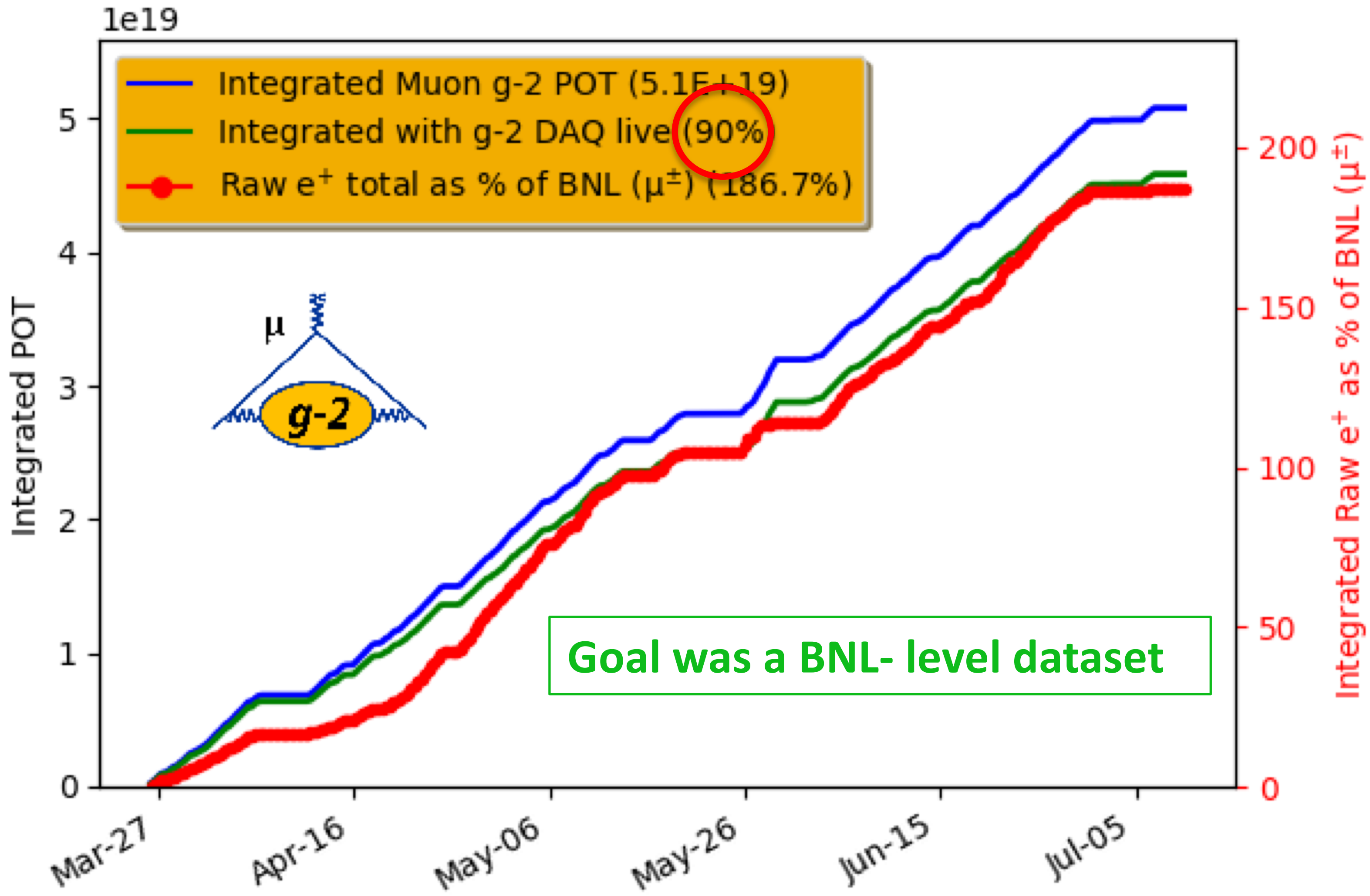
100 ppm



Moments: < 0.3 – 0.5ppm (Goal was 1/3 BNL: 0.5 ppm)

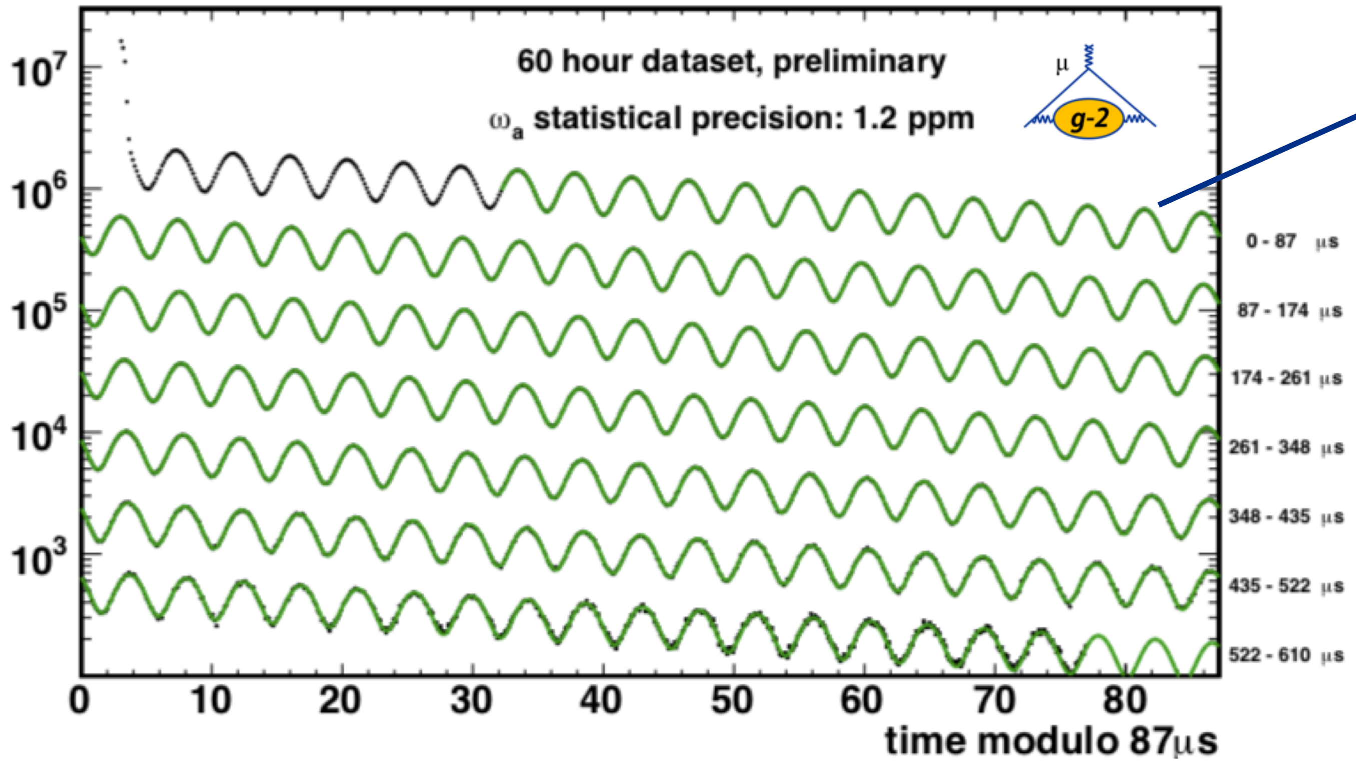
Dipole RMS: 14-21 ppm (Goal was 1/2 BNL: 15-20 ppm)

Dataset Accumulated



In 3 months recorded 17.5B e^+ (BNL recorded 9.4B e^+/e^-)

60hr data (1.2 ppm stat.)



$$\omega_a = a_\mu \frac{eB}{mc}$$

Full Run-1 dataset expect < 0.4 ppm stat. error (cf BNL 0.46 ppm)

Summary

We have had a very successful 18 months

- accelerator & g-2 injection/storage increased muon yield by 10^5
- now routinely operating at rate of approx. 0.5 of TDR goal.
- summer shutdown work is progressing well to increase the rate and improve the quality of the beam.
- analysis of a dataset with a statistical precision better than BNL is well underway and we expect to publish this in 2019.