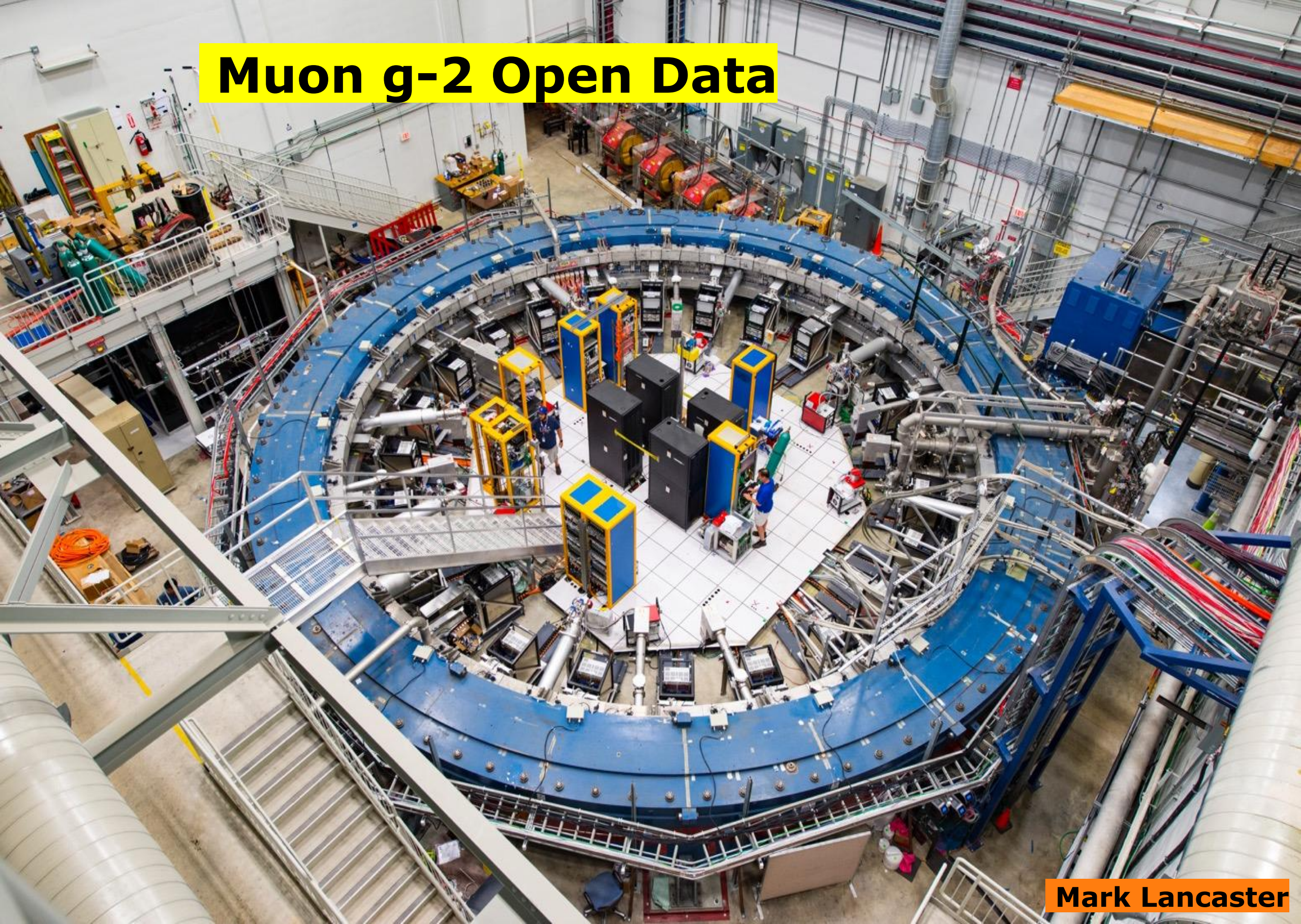
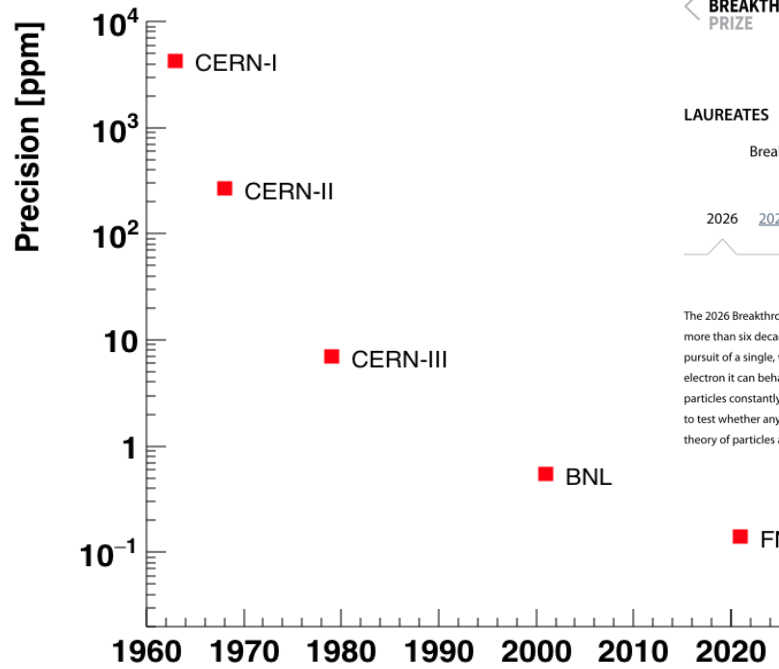


# Muon g-2 Open Data



Mark Lancaster

# Long Road To Open Data ...



FUNDAMENTAL PHYSICS BREAKTHROUGH PRIZE

MISSION BOARD TROPHY EVENTS NOMINATIONS NEWS CONTACTS MANIFESTO  
COMMITTEE PRIZES LAUREATES RULES

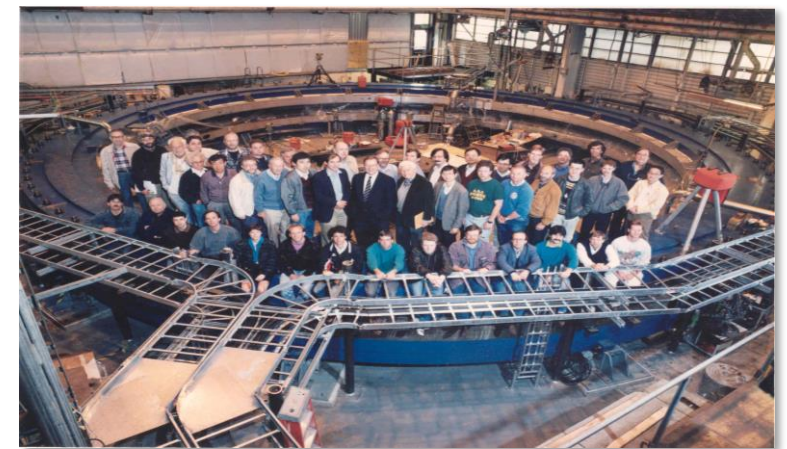
Search

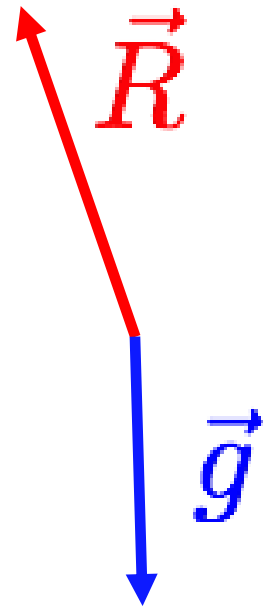
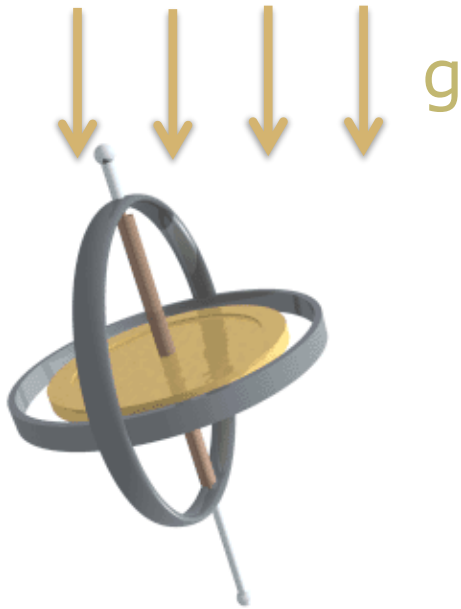
LAUREATES

Breakthrough Prize [Special Breakthrough Prize](#) [New Horizons Prize](#) [Vera Rubin New Frontiers Prize](#)  
[Physics Frontiers Prize](#)

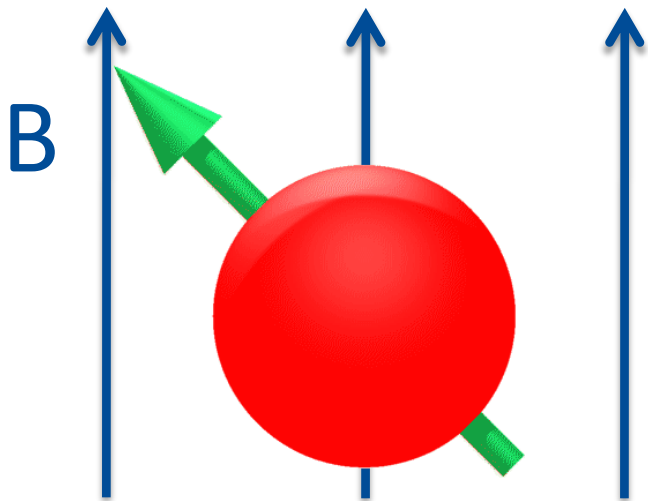
2026 2025 2024 2023 2022 2021 2020 2019 2018 2017 2016 2015 2014 2013 2012

The 2026 Breakthrough Prize in Fundamental Physics is awarded to the Muon g-2 collaborations at CERN, Brookhaven National Laboratory, and Fermilab. Across more than six decades, scientists and engineers from three collaborations representing dozens of institutions have pushed experimental precision ever higher in pursuit of a single, very significant number: the anomalous magnetic moment of the muon. The muon is a heavy, unstable cousin of the electron, and like the electron it can behave like a tiny magnet. The physicists are looking to capture how the muon's magnetic strength is subtly affected by the "foam" of virtual particles constantly popping in and out of empty space around it. Measuring the muon's magnetism and comparing it to theoretical predictions allows physicists to test whether any unknown particles or forces are hidden in this foam. In other words, to probe for new physics beyond the Standard Model, our most successful theory of particles and forces.



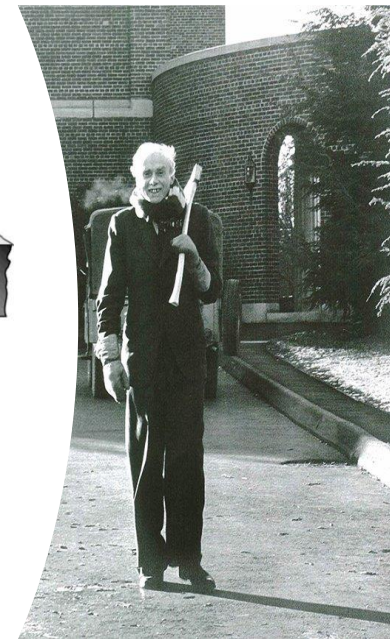
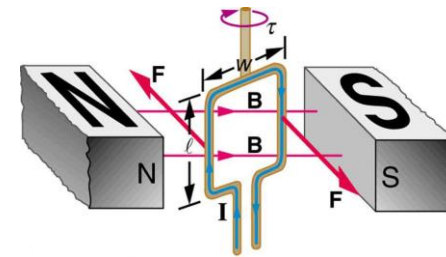


$$\vec{\tau} = m(\vec{R} \times \vec{g})$$

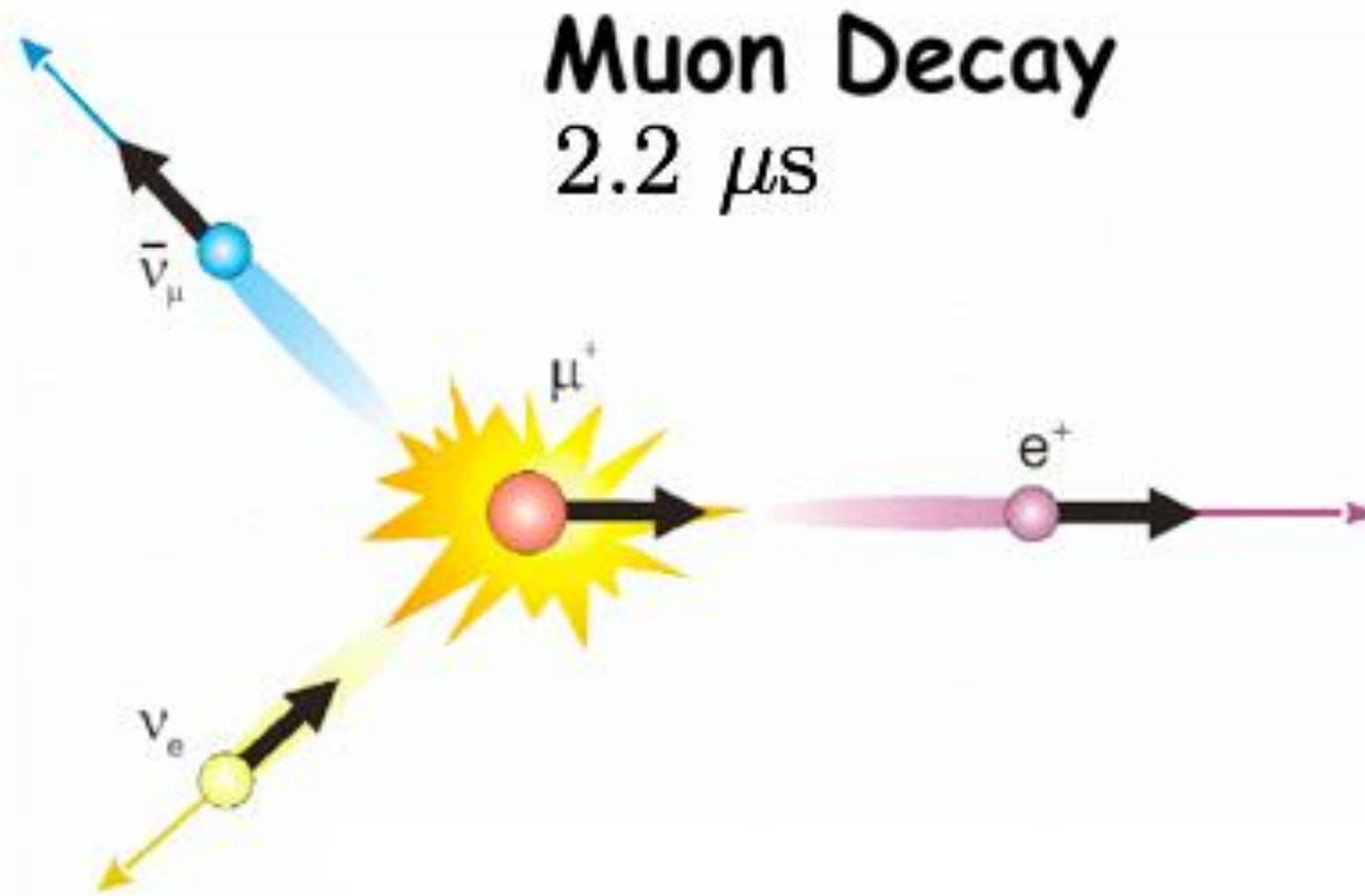


$$\vec{\mu} = g_S \frac{q}{2m} \vec{S}$$

$$\vec{\tau} = \vec{\mu} \times \vec{B} = \frac{d\vec{\mu}}{dt}$$



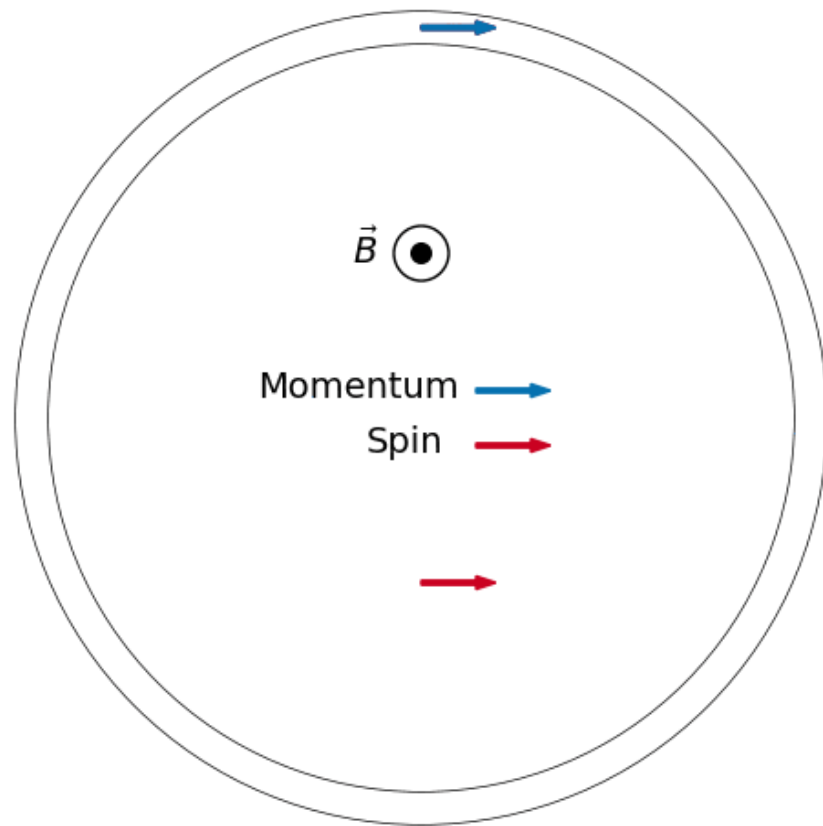
Axis of rotation not parallel to force  
Torque means axis of rotation (spin) "precesses"



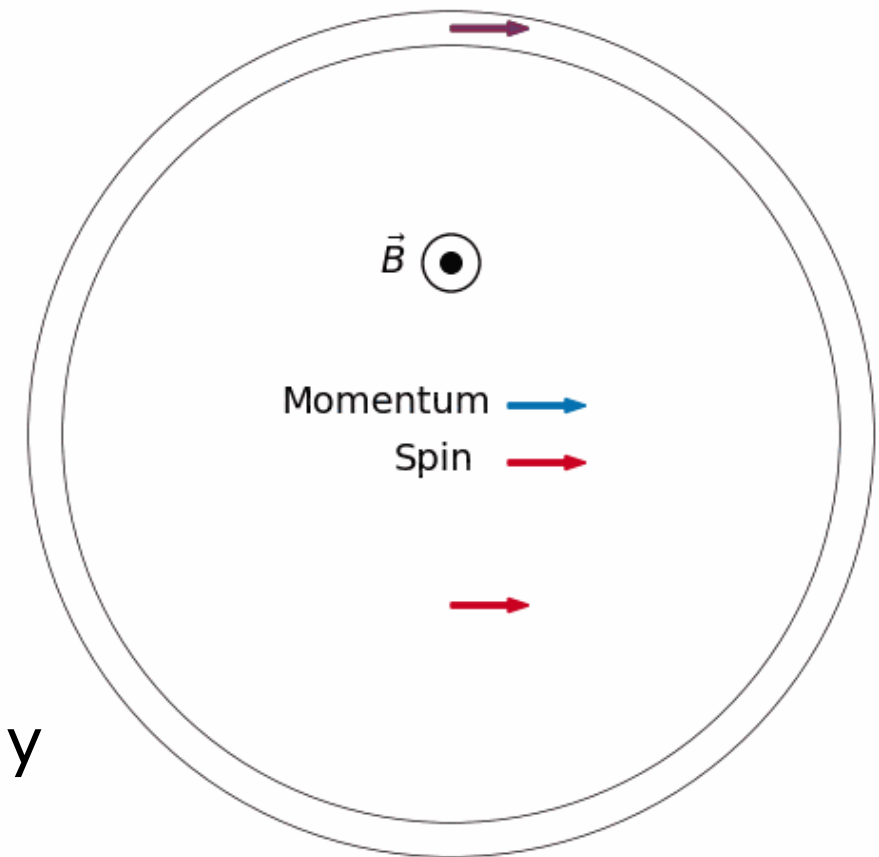
Property of weak decay means that the positrons of the highest energy are emitted along the direction of the muon spin

So we know muon spin direction from direction of highest energy decay  $e^+$

We know muon spin precesses in B-field and hence so should direction of highest energy decay  $e^+$

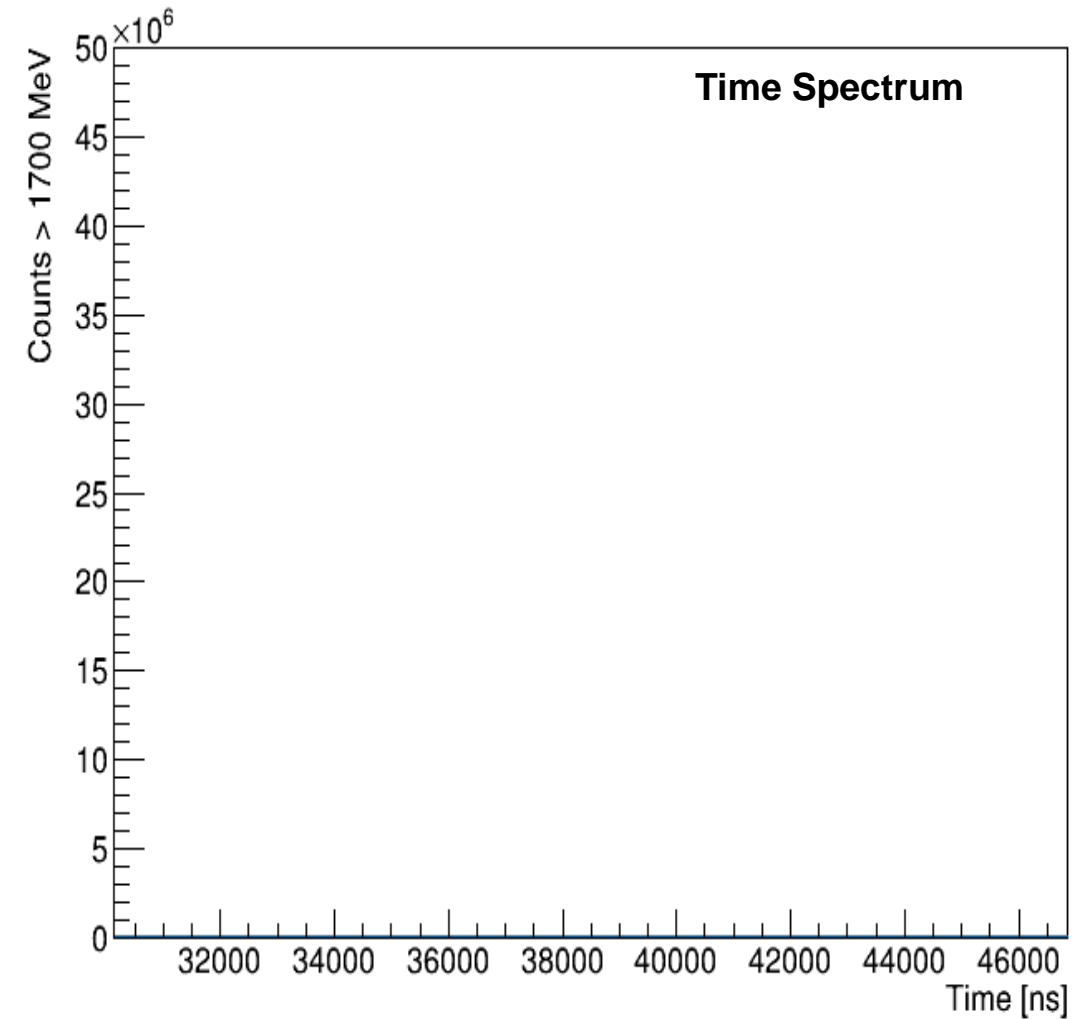
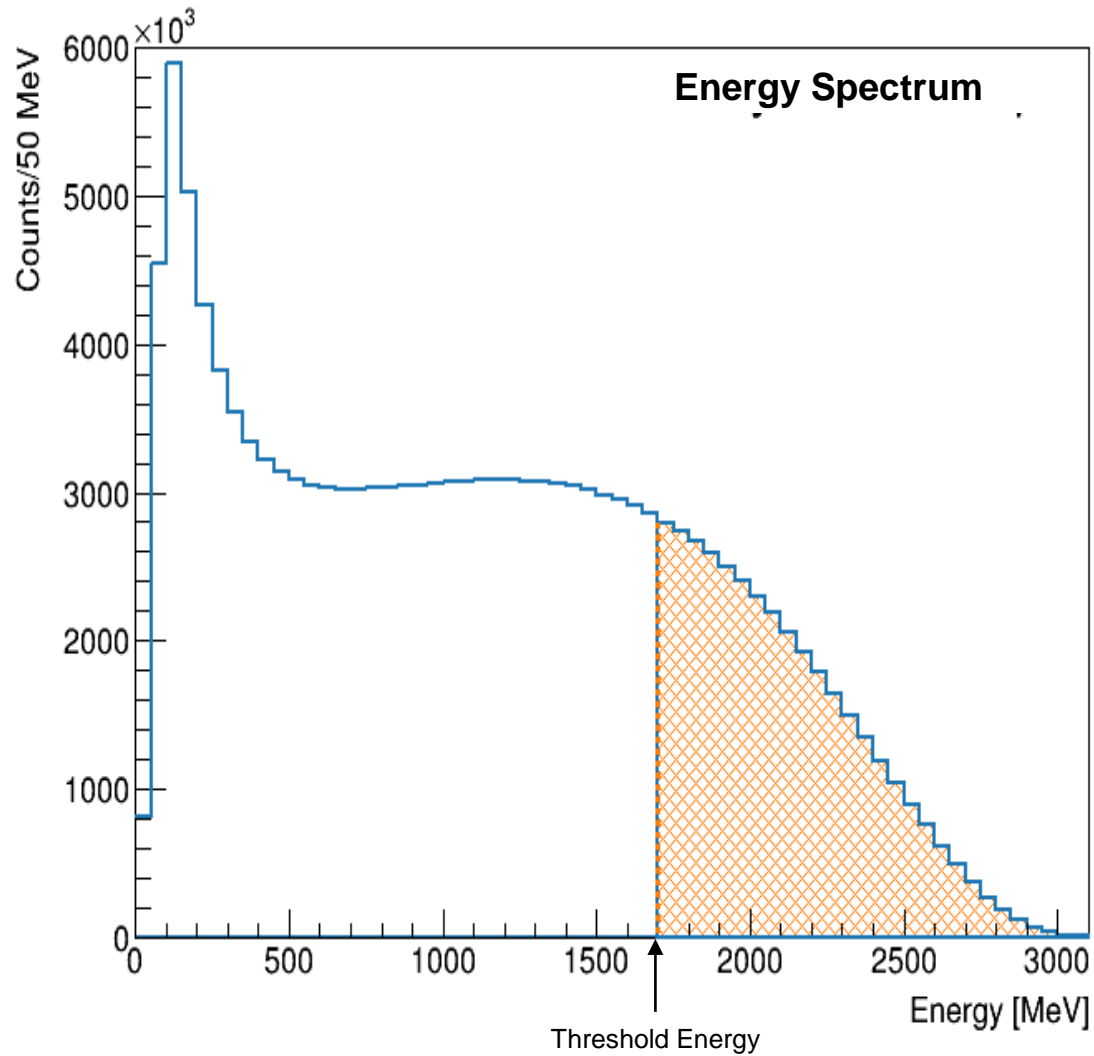


$$\omega_a = \omega_s - \omega_c = a_\mu \frac{eB}{m}$$

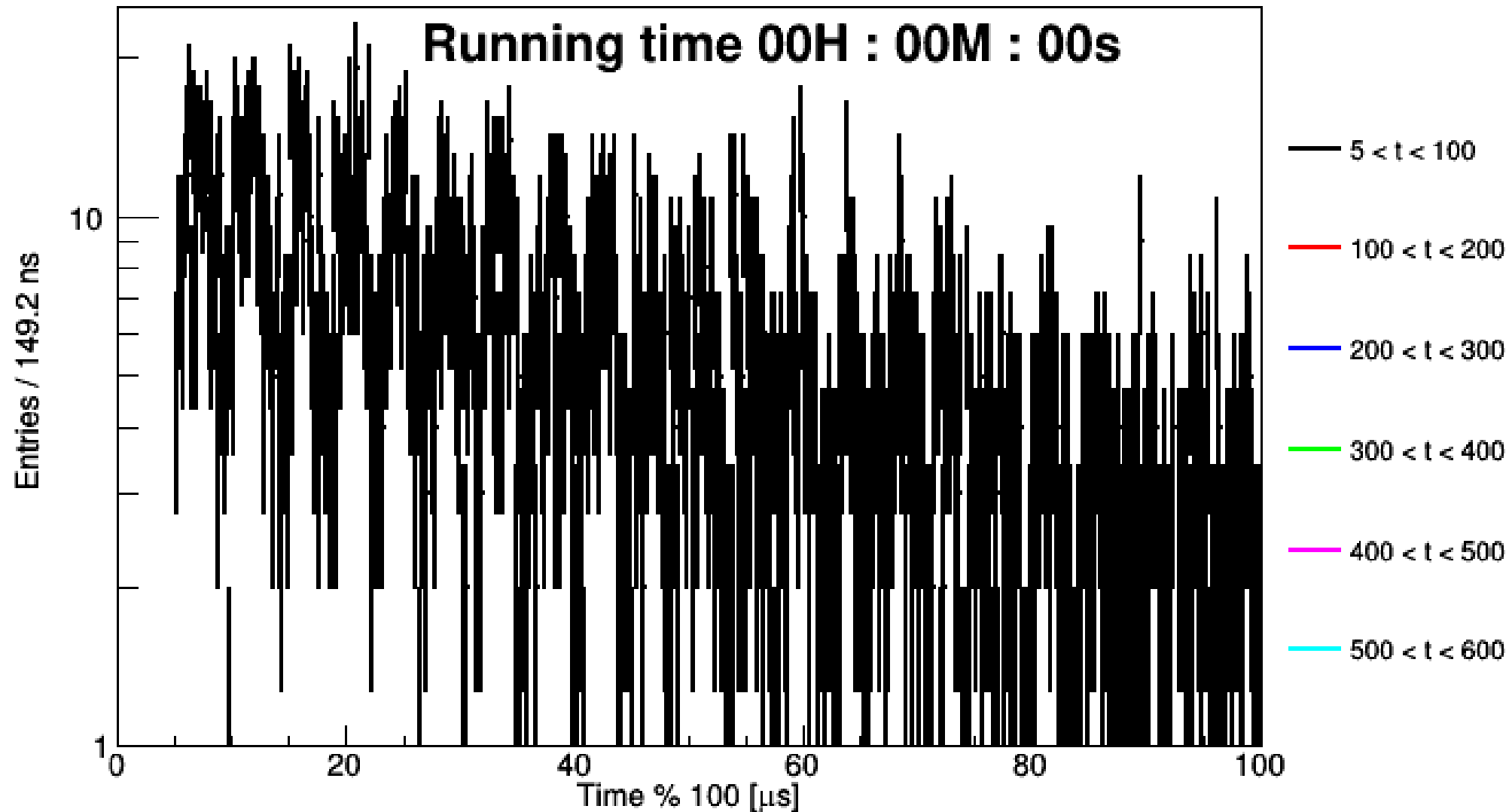


We expect to see the number of highest energy positrons rising and falling with time

# Highest energy e<sup>+</sup> population oscillates...

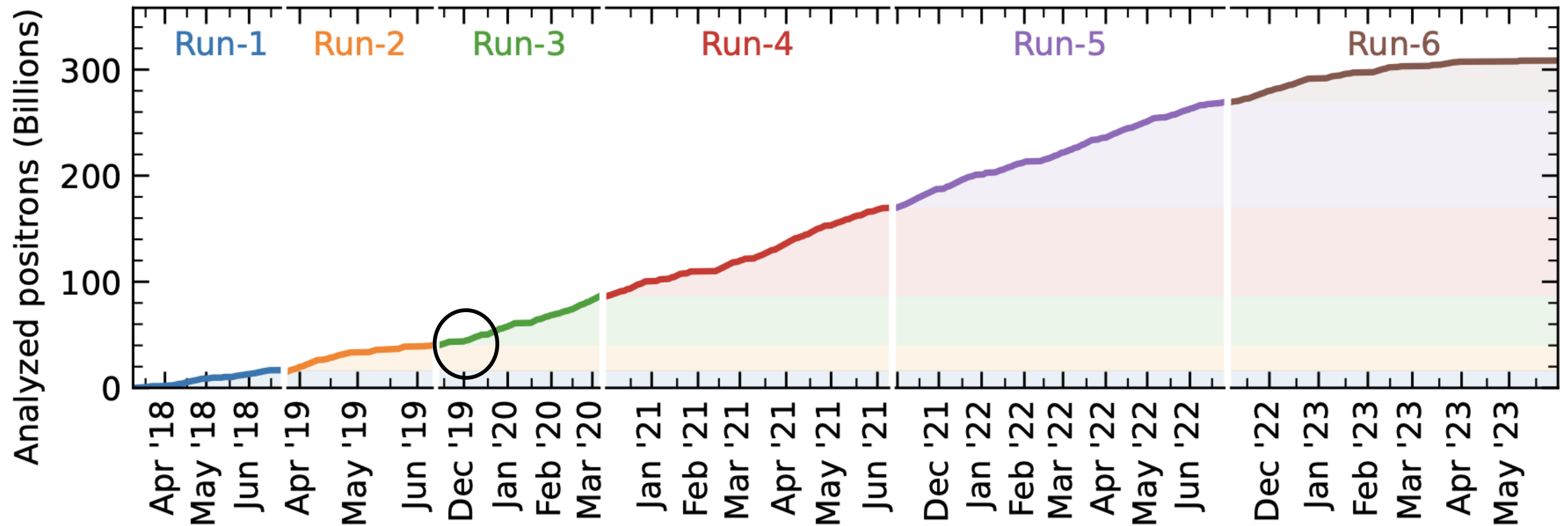


# Highest energy $e^+$ population oscillates...



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

# g-2 data was collected over 5 years



308.5B positrons recorded

Prototyping with (0.3%) 1.69B positrons from Nov/Dec 2019

The aim is largely educational (I have a teacher who has offered to help)

The entire open data team on the experiment is me ...

zenodo Search records... Communities My dashboard

Published April 17, 2026 | Version v1

Dataset Open

## Fermilab Muon g-2 3B dataset from Run-3a

Fermilab Muon g-2 Collaboration (Data collector)

This dataset is a summary file of the 3B dataset from the Run-3a data-taking period in November/December 2019, recorded by the Fermilab Muon g-2 Collaboration. The experiment records the time and energy of positrons from the decay of positive muons. These positive muons are confined by magnetic and electric fields to circulate in a cyclotron until they decay, and on average, it takes 149.2 ns for the muons to complete one revolution of the cyclotron. The 3B dataset recorded 1.69 billion positrons over a period of 15 days. Rather than have 1.69 billion records, the data is instead histogrammed. The number of positrons in each 149.2 ns interval is recorded in this dataset. The data has two columns: the first is the time (in ns), relative to when muons were injected into the cyclotron, of the start of the interval, and the second is the number of positrons (above a certain energy) recorded in that 149.2ns time interval. There are 4188 intervals recorded every time muons are injected into the cyclotron. The first interval occurs approximately 25 microseconds after the muons are injected, and the last interval occurs 650 microseconds after the muons are injected. The dataset thus records the number of positrons observed over a duration of approximately 625 microseconds. Approximately 80000 muons are injected into the cyclotron every 1.4 seconds, and the number of positrons is recorded in these intervals each time. The number is summed over all these injections for each interval, and this is what is recorded in the dataset.

### Files

Files (67.2 kB)		
Name	Size	
Fermilab_Muon_gm2_Run3B.npy	67.2 kB	Download
md5:7e3e9ee4d5b85770bef2133f201918ef		

The raw data of this 0.3% snapshot is 110 Tb... and requires a lot of expert massaging to analyse

Histogram the data into 4188 (149.2 ns) time bins with # positrons in each bin

Numpy binary file

Muon-gm2Data / outreach Public

<> Code Issues Pull requests Actions Projects Security and quality Insights

main 1 Branch 0 Tags Go to file Code

File	Commit Message	Time
src	Create wiggler-interactive.py	2 hours ago
.gitignore	Initial commit	2 days ago
CITATION.cff	Create CITATION.cff	2 days ago
LICENSE	Update LICENSE	2 days ago
README.md	Update README.md	2 days ago
requirements.txt	Created requirements.txt	21 minutes ago

mlancaster1953 Created requirements.txt 9074230 · 21 minutes ago 13 Commits

README MIT license

## Fermilab Muon g-2 Outreach Example Code and Data

This repository contains example python code and instructions for accessing the publicly available data of the Fermilab Muon g-2 experiment

### Contents

- src/ — Python example scripts for loading and analysing the data
- docs/ — supporting notes
- requirements.txt — Python package requirements

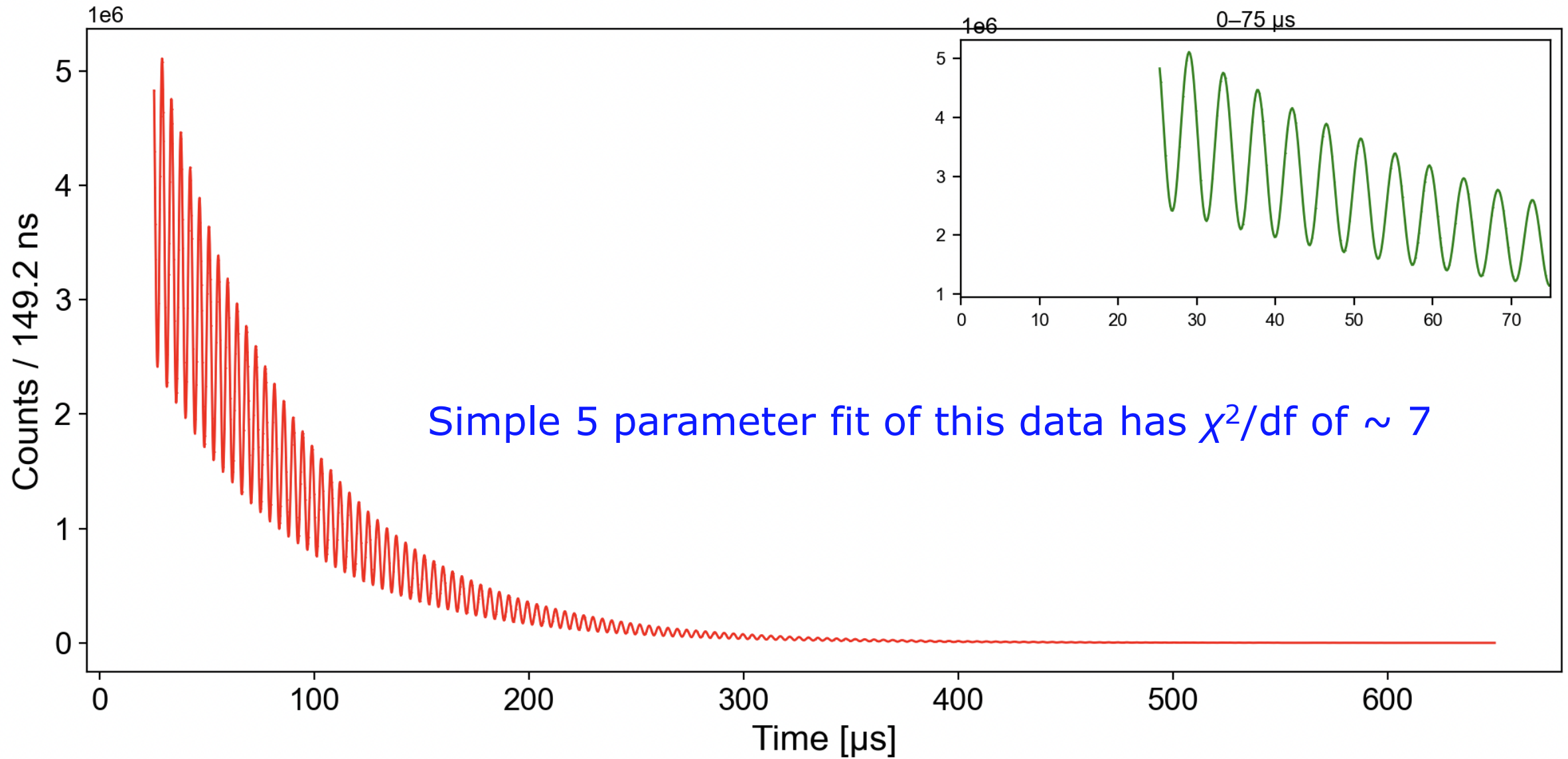
### Quick start

Create and activate a Python environment (recommended)

Install Python dependencies:

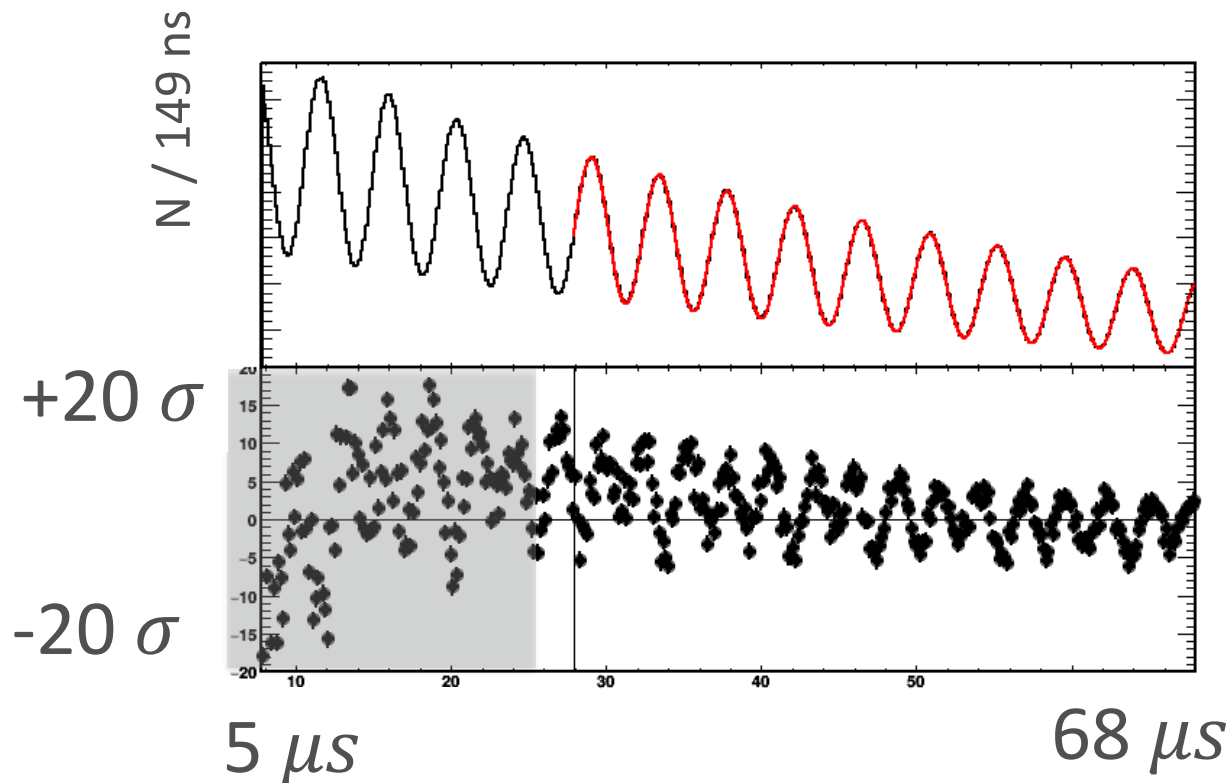
```
pip install -r requirements.txt
```

Screenshot

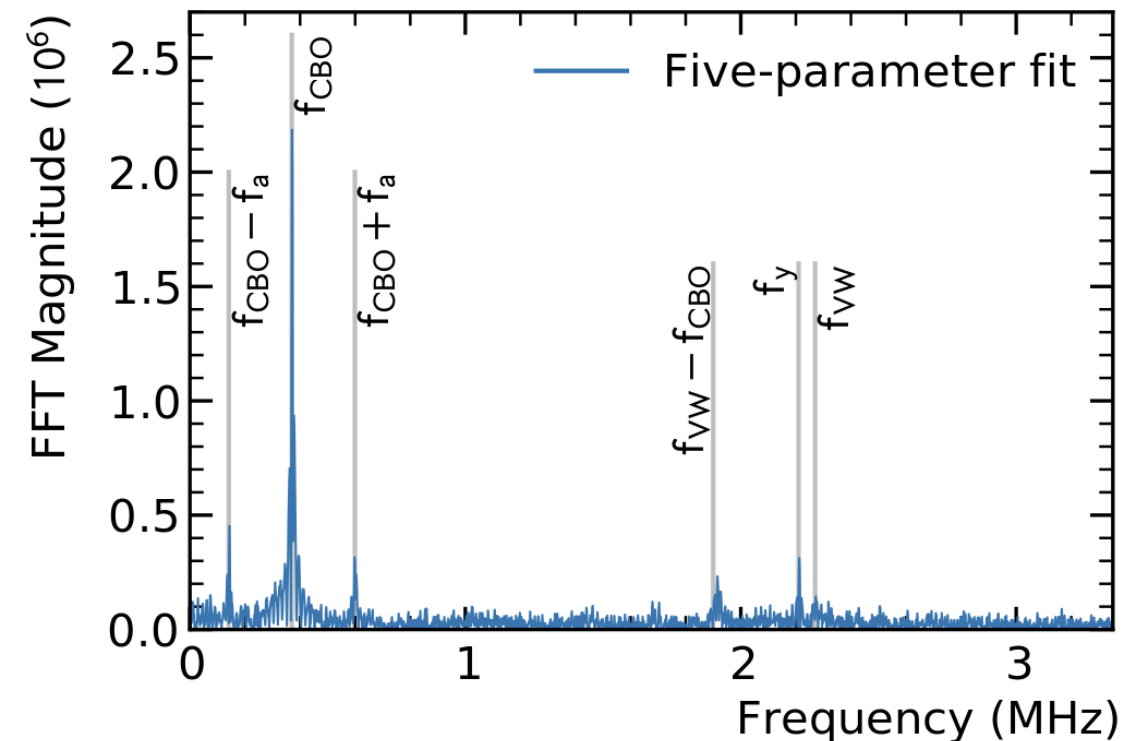


$$N_e(t) \simeq N_0 e^{-\frac{t}{\gamma\tau}} \left[ 1 - A \cos(\omega_a t + \phi_a) \right]$$

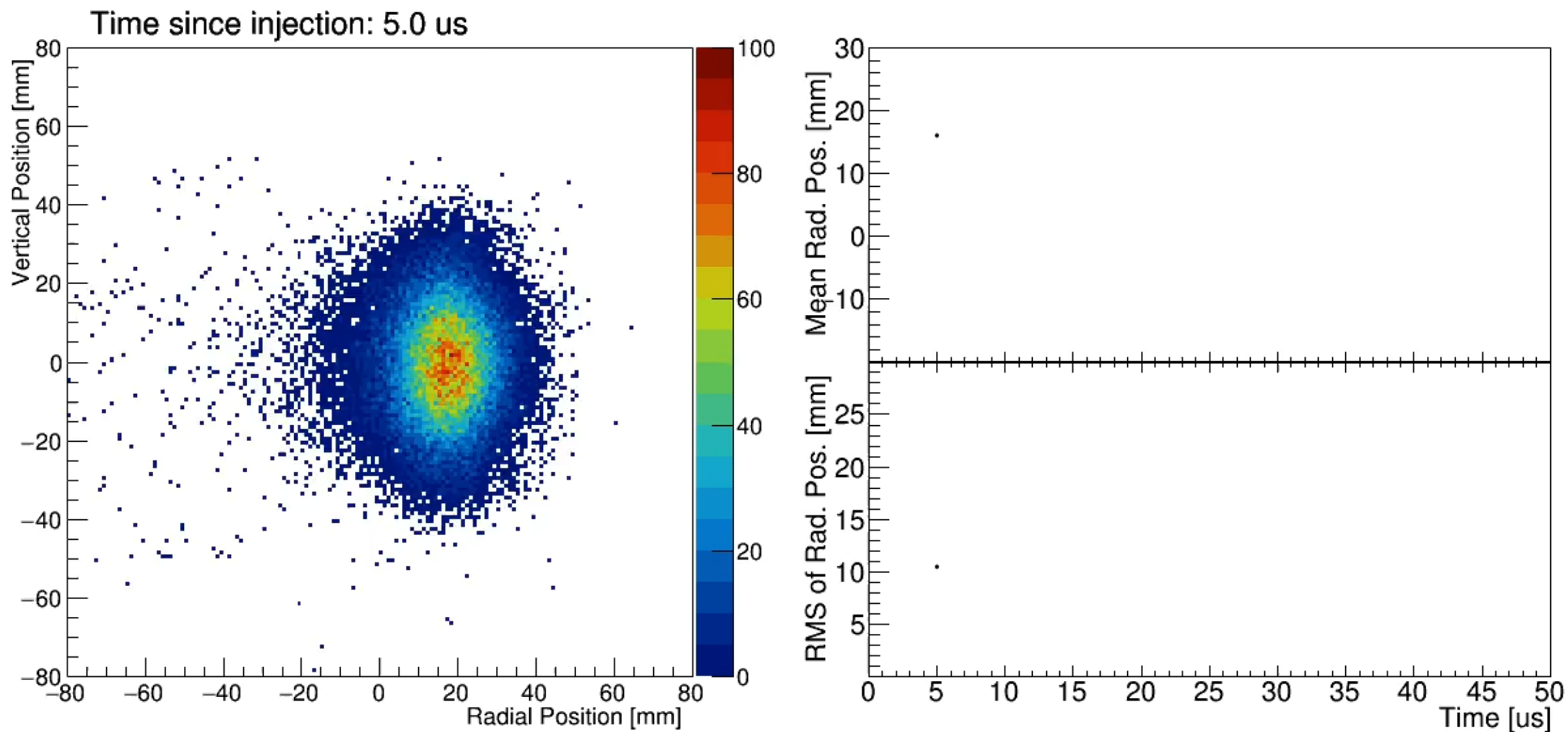
Residuals of 5-parameter fit (in frequency space) show the Wiggles / motion expected from the 2D-SHM of the beam



Fit and pulls for  $\sim 1$  lifetime



Fourier Transform of fit residuals



# Result of large parameter fit

$$N_0 e^{-\frac{t}{\tau}} (1 + A \cdot A_{BO}(t) \cos(\omega_a t + \phi \cdot \phi_{BO}(t))) \cdot N_{CBO}(t) \cdot N_{VW}(t) \cdot N_y(t) \cdot N_{2CBO}(t) \cdot J(t)$$

$$A_{BO}(t) = 1 + A_A \cos(\omega_{CBO}(t) + \phi_A) e^{-\frac{t}{\tau_{CBO}}}$$

$$\phi_{BO}(t) = 1 + A_\phi \cos(\omega_{CBO}(t) + \phi_\phi) e^{-\frac{t}{\tau_{CBO}}}$$

$$N_{CBO}(t) = 1 + A_{CBO} \cos(\omega_{CBO}(t) + \phi_{CBO}) e^{-\frac{t}{\tau_{CBO}}}$$

$$N_{2CBO}(t) = 1 + A_{2CBO} \cos(2\omega_{CBO}(t) + \phi_{2CBO}) e^{-\frac{t}{\tau_{CBO}}}$$

$$N_{VW}(t) = 1 + A_{VW} \cos(\omega_{VW}(t)t + \phi_{VW}) e^{-\frac{t}{\tau_{VW}}}$$

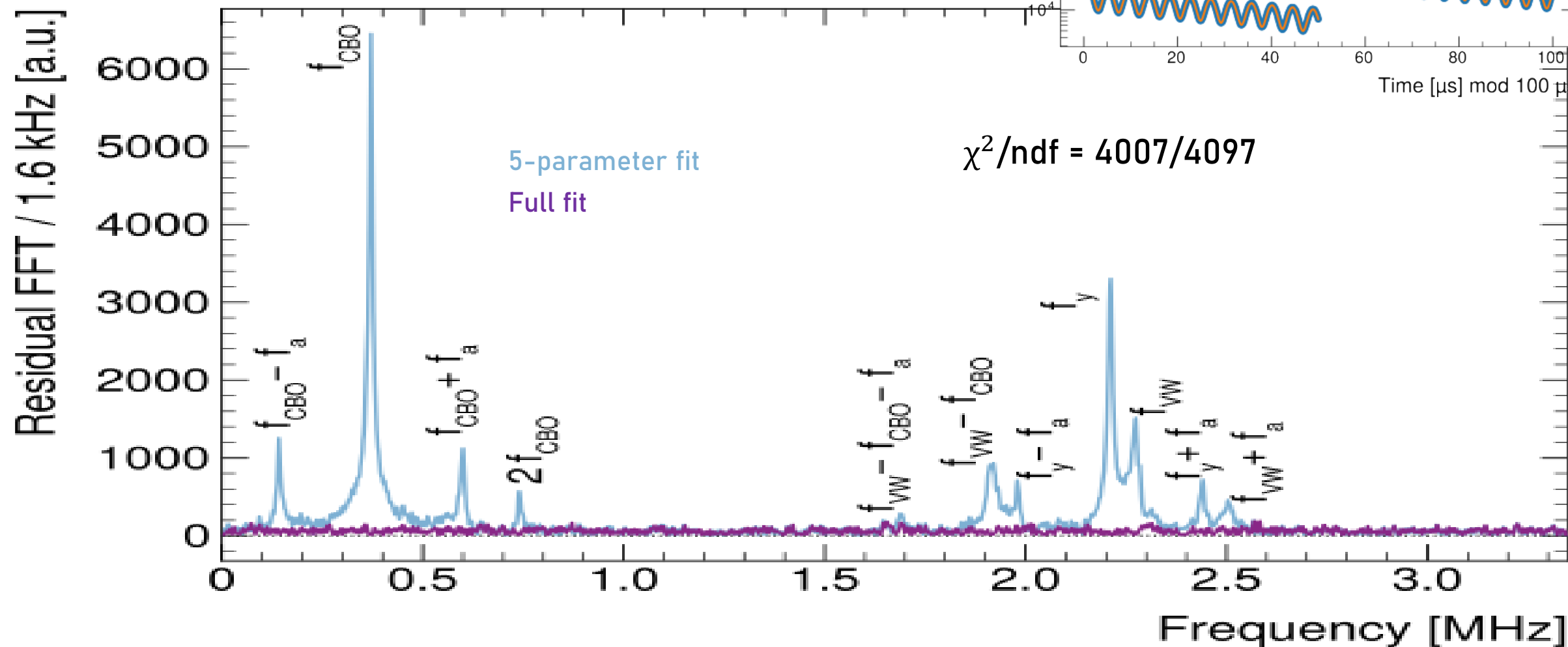
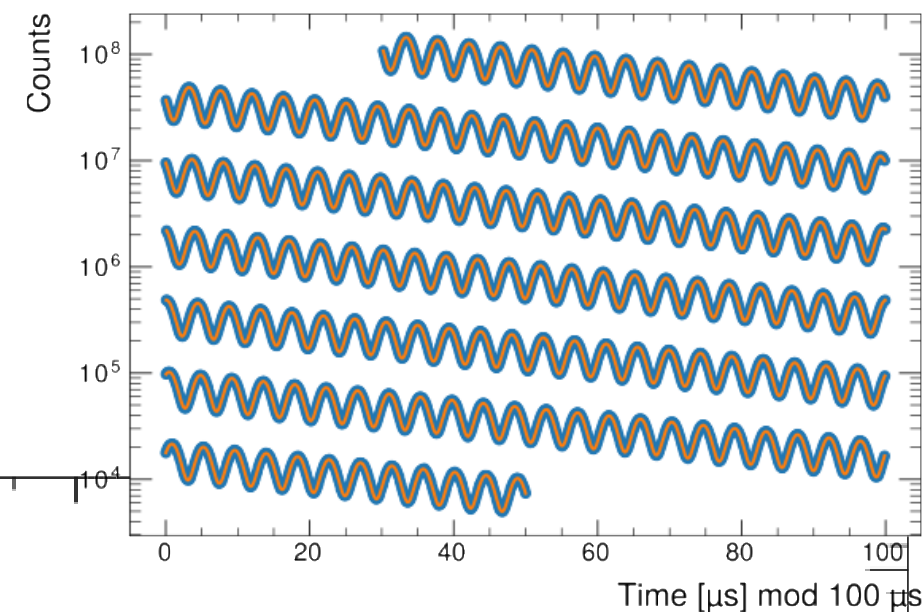
$$N_y(t) = 1 + A_y \cos(\omega_y(t)t + \phi_y) e^{-\frac{t}{\tau_y}}$$

$$J(t) = 1 - k_{LM} \int_{t_0}^t \Lambda(t) dt$$

$$\omega_{CBO}(t) = \omega_0 t + A e^{-\frac{t}{\tau_A}} + B e^{-\frac{t}{\tau_B}}$$

$$\omega_y(t) = F \omega_{CBO}(t) \sqrt{2\omega_c / F \omega_{CBO}(t) - 1}$$

$$\omega_{VW}(t) = \omega_c - 2\omega_y(t)$$



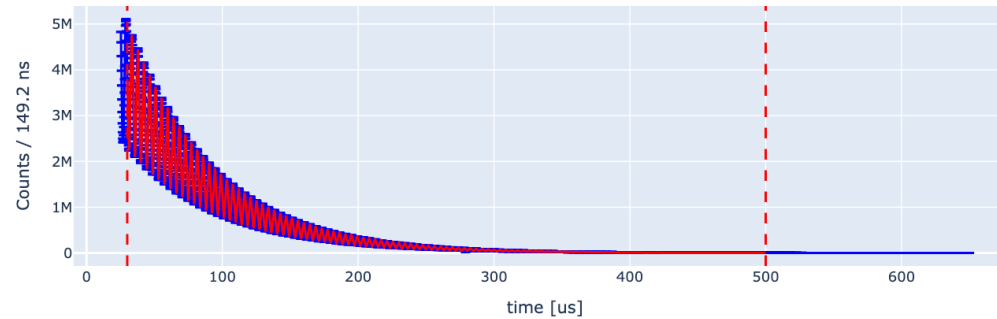
## Interactive Wiggle Fit

dash,plotly,flask

### Histogram Options

Set y-axis to log scale

Wiggle plot



### Fit Options

Fit start time [us]:

Fit end time [us]:

N0:

tau [us]:

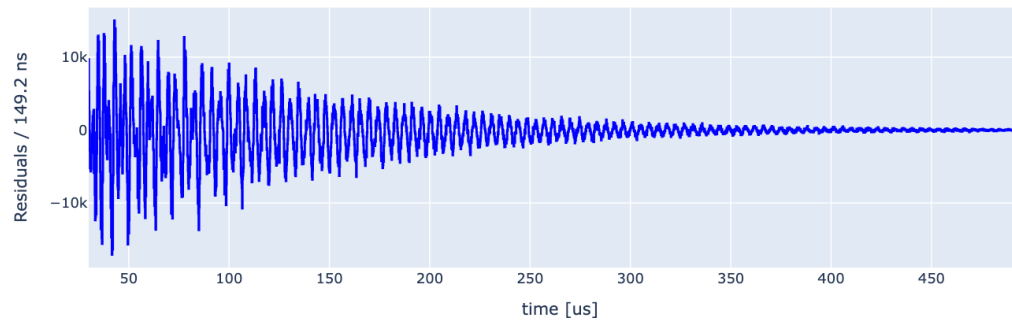
A:

R [ppm]:

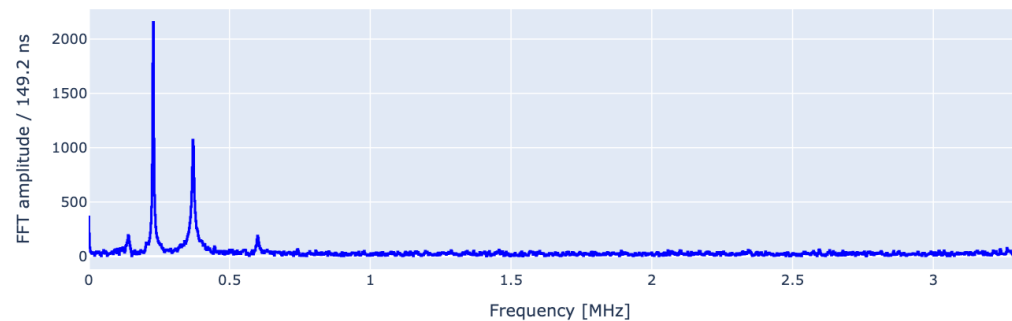
phi [rad]:

Do the Fit!

Residuals = Data - Fit



Fast Fourier Transform (FFT) of the Residuals



### Fit Results

Parameter Name	Value	Uncertainty
chi2	32753.1	0.0
ndf	3145.00	0.0
p-value	0.00000	0.0
N	5.82500e+6	0.0
tau	64.4400	0.0
A	0.374581	0.0
R	0.00000	0.0
phi	2.16682	0.0

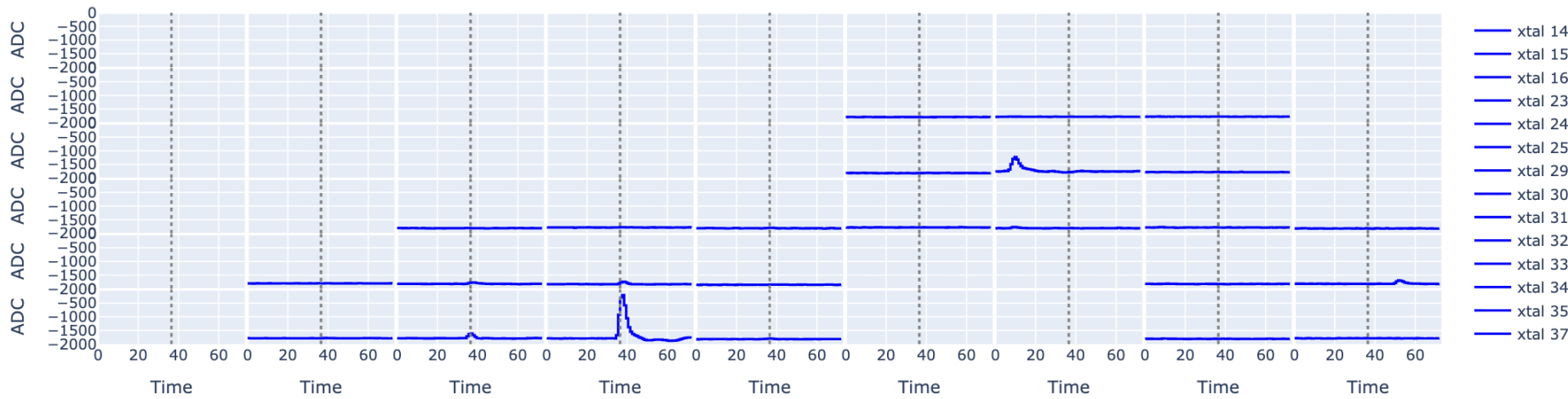
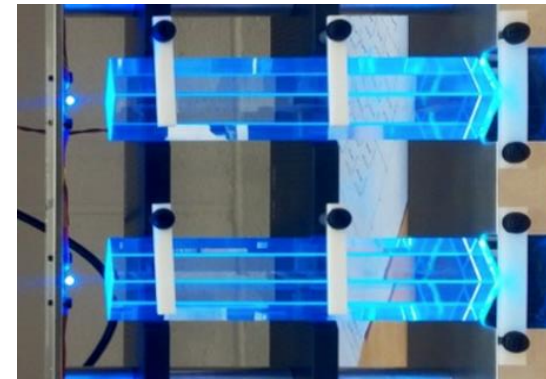
Good enough  
for a sub 1% (10000 ppm)  
measurement of g-2

With tweaks --> few ppm  
enough to see QED correction

Many aspects can be taught with this data

- Exponential formula for a decay
- Special relativity: time dilation
- Magnetic Moment
- Torques and precession
- Motion of charged particle in a magnetic field
  
- Fitting of data : importance of residuals
- Fourier transforms
- Simple Harmonic motion

Also looking into template fitting /calibrating raw calorimeter data to show how you go from raw data to the histogram...



## Fit Options

Is pile-up

Event Time [us]:



## Event Info

Run	30252
Subrun	263
Event	2
Island	53
Calorimeter	1
First Sample Time	133837.5
<input type="button" value="←"/> <input type="button" value="Save"/> <input type="button" value="→"/>	



“If you enjoy doing difficult experiments, you can do them, but it is a waste of time and effort because the result is already known” : **Pauli**



“No experiment is so dumb, that it should not be tried” : **Gerlach**

“You do less damage if you let the thing fall than if you try to catch it” : **Stern**

“the Muon obeys QED.  $g-2$  is correct to 0.5%. In my opinion, it will be right to any accuracy. **So it's not worth doing the experiment**” : *Head of CERN Theory*

“would you like to predict the result ?” : *Francis Farley*