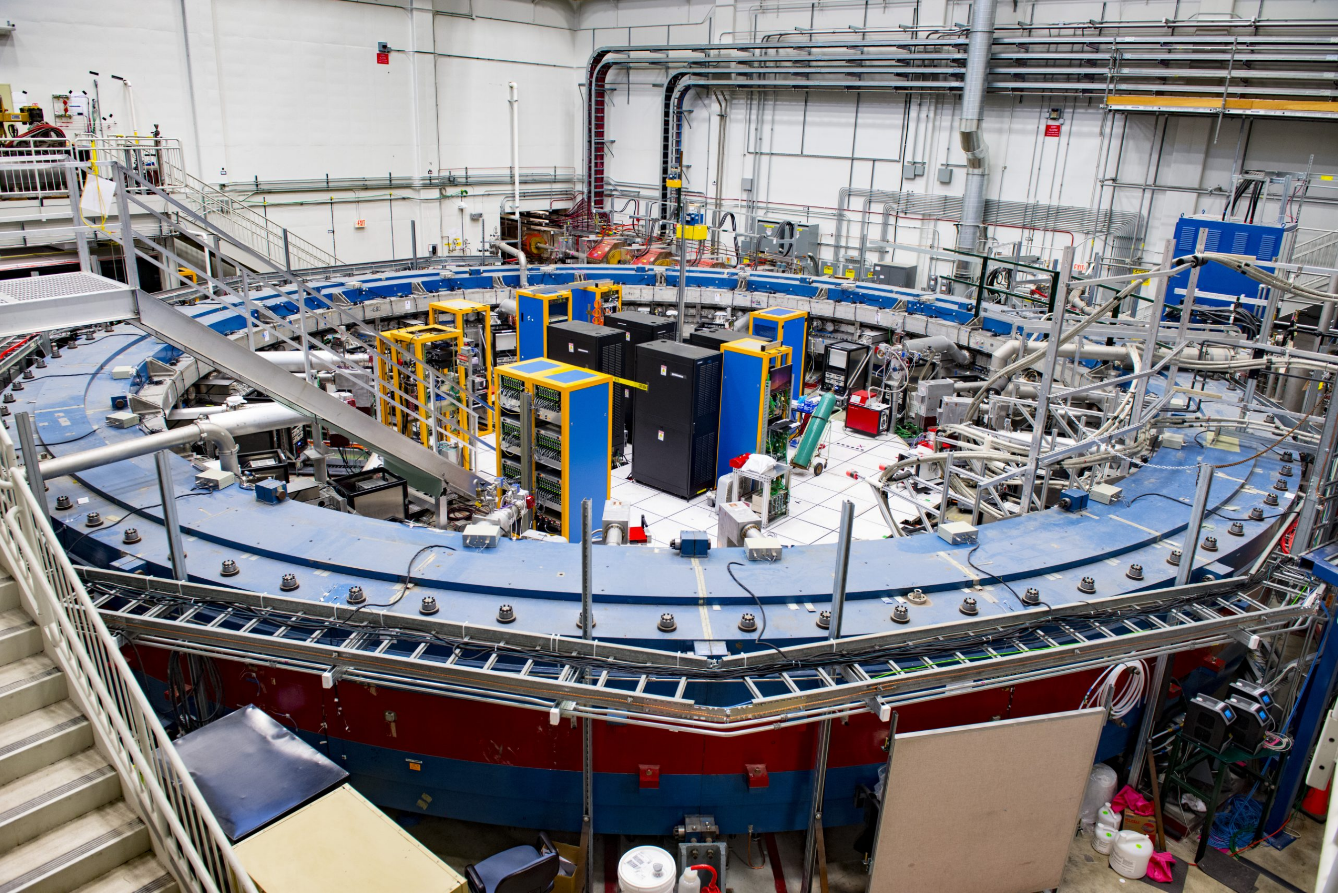


The precession frequency measurement in the Muon g-2 experiment at Fermilab

Matteo Sorbara *on behalf of the Muon g-2 collaboration*

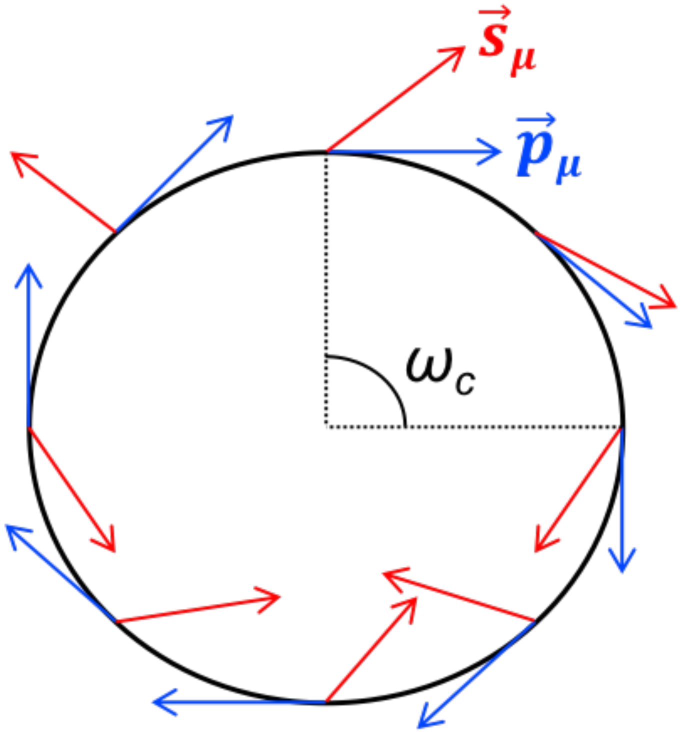
Congresso SIF 2020

14^{th} – 18^{th} of September 2020

Muon g-2 in a nutshell

The measure is based on the anomalous spin precession frequency of a muon in a uniform magnetic field. For relativistic particles:

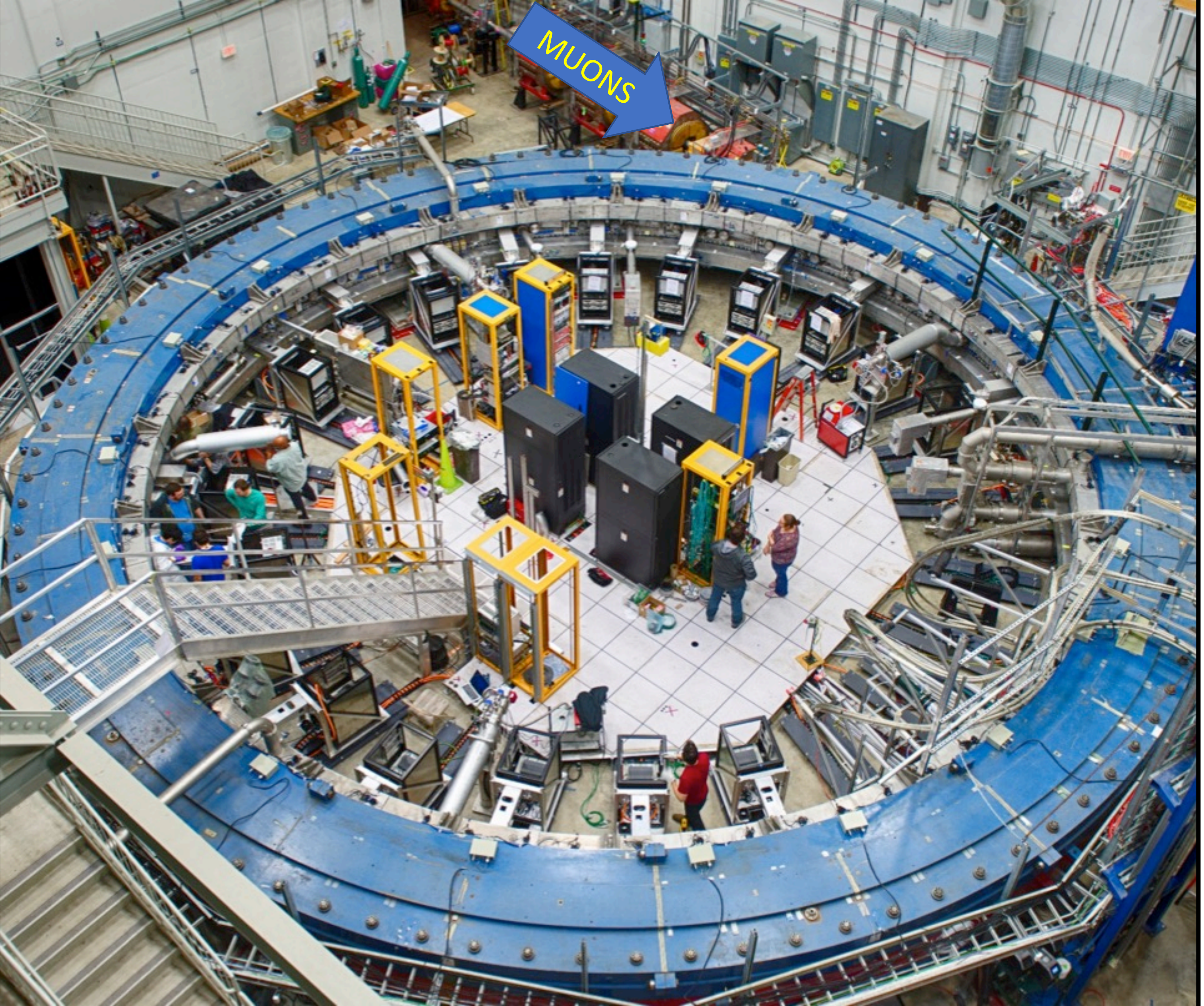
$$\vec{\omega}_a = \vec{\omega}_s - \vec{\omega}_c$$
$$= -\frac{e}{mc}\left[a_\mu \vec{B} - \left(a_\mu - \frac{1}{\gamma^2 - 1}\right)\vec{\beta}\times\vec{E} - a_\mu\left(\frac{\gamma}{\gamma+1}\right)(\vec{\beta}\cdot\vec{B})\vec{\beta}\right]$$



Where the E-field term is caused by focussing electrostatic quadrupoles (more later). For $\gamma = 29.3$ (CERN III) the E-field term vanishes, and using a magnetic field perpendicular to the beam $\vec{\beta}\cdot\vec{B} = 0$, so the expression becomes:

$$\vec{\omega}_a = -\frac{e}{mc} a_\mu \vec{B} \rightarrow \mathrm{a}_\mu = \frac{g_e}{2}\frac{m_\mu}{m_e}\frac{\mu_p}{\mu_e}\frac{\omega_a}{\omega_p}$$

We need to measure precisely ω_a and the B-field (ω_p).



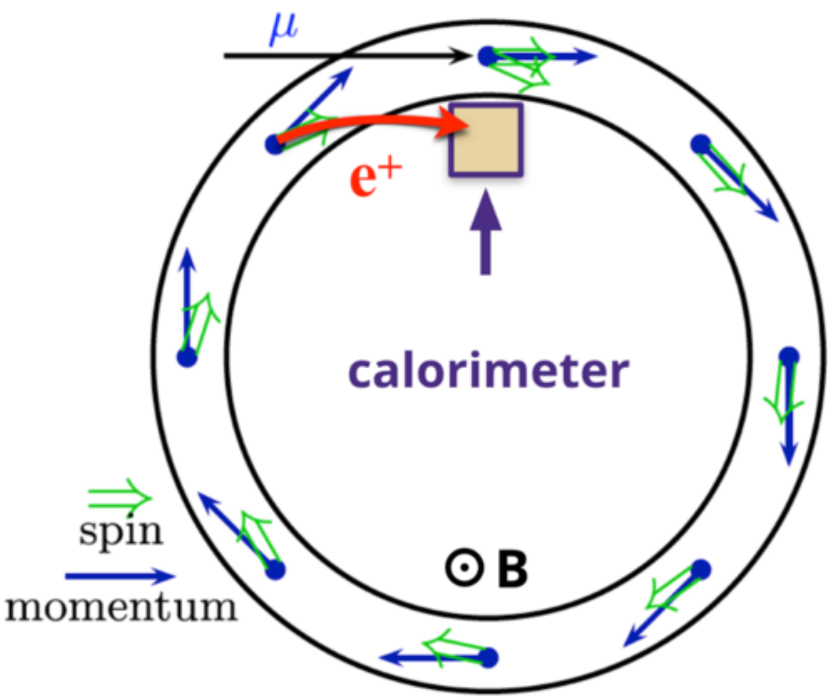
- 1.45 T storage ring
- 24 calorimeters (1296 crystals)
- 2 trackers
- 4 quadrupoles for vertical focussing
- 3 kickers for beam positioning
- 378 NMR probes to monitor the magnetic field
- 6 lasers to measure the SiPMs gain

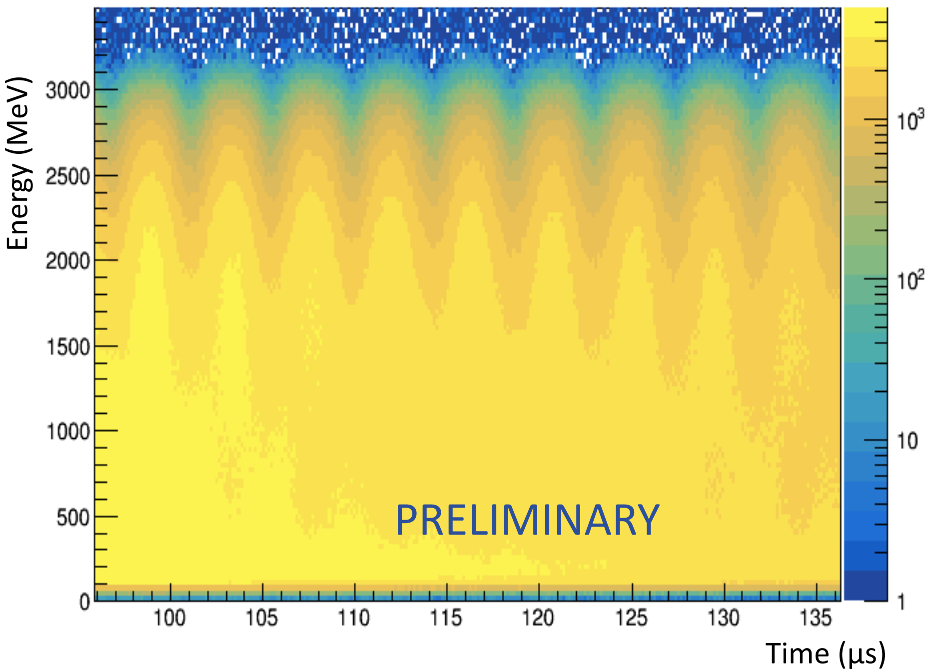
ω_a Measure

- Muon's spin is correlated to high energy positron's momentum
- The number of positrons is modulated by the anomalous precession frequency

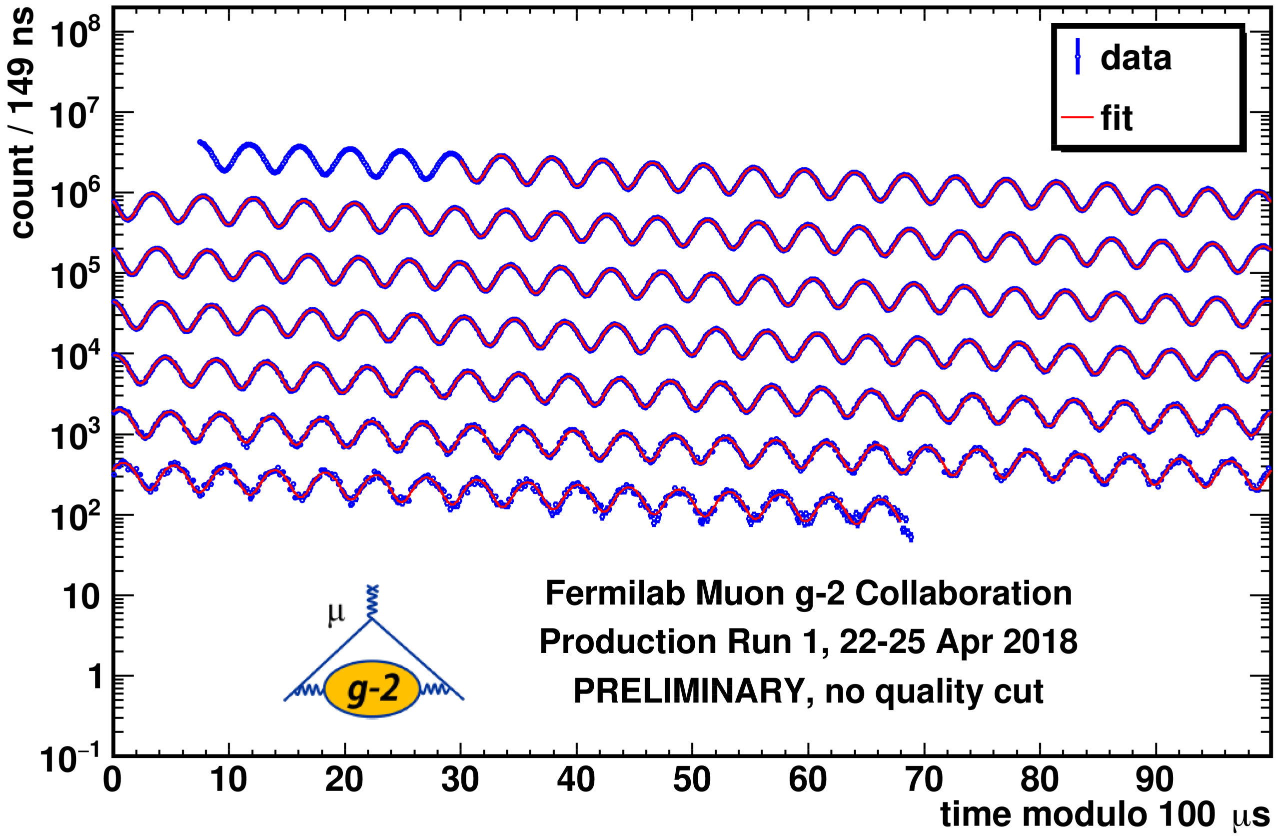
$$N_0 e^{-t/\tau}[1 - A\,cos(\omega_a t + \phi)]$$

- The data are corrected for gain drops in the SiPMs using the laser calibration system
- Pileup subtraction is applied to the histograms before the fitting procedure





T-method Wiggle Plot



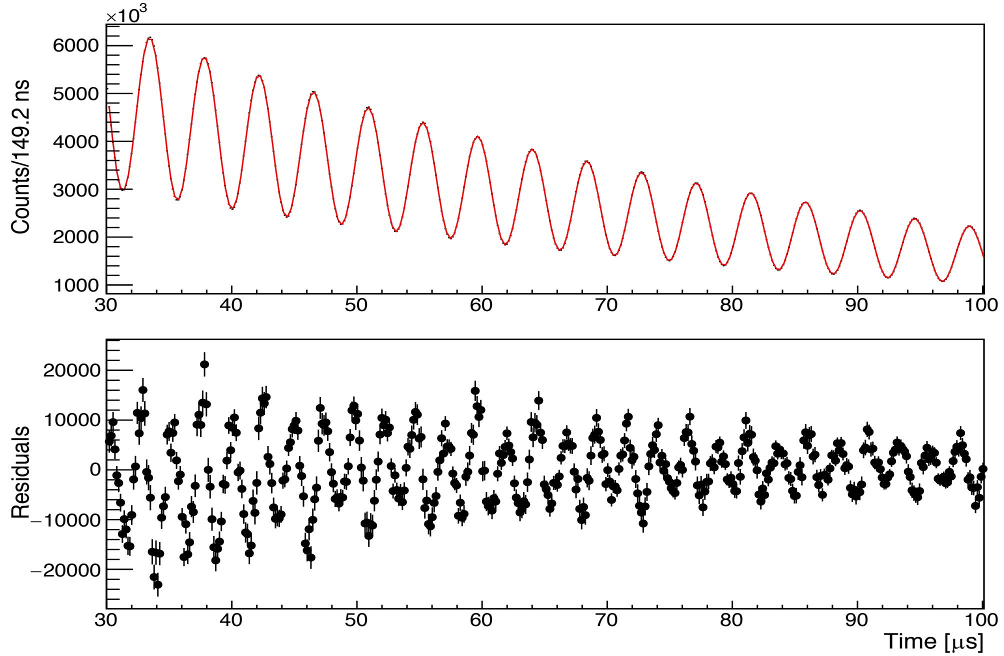
- 4 different analysis methods:
  - T: integrate all positrons above 1.7 GeV
  - A: weight the positrons with A(E) function and integrate above 1.1 GeV
  - R: randomly split dataset in 2 subsets shifted by ±half a g-2 period, build combinations of the 2 subsets to remove slow terms (exponential, gain…)
  - Q: No clustering: just integrate energy above threshold (in theory no threshold should be applied) for each crystal

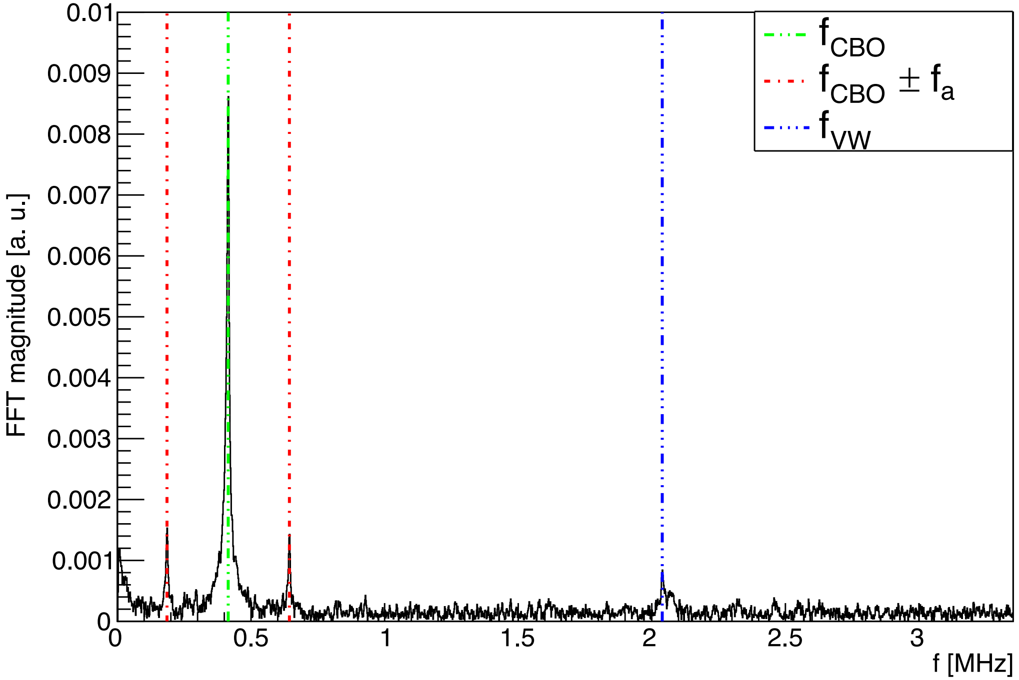
The ω_a fit

- The wiggle plot is fitted with a decay exponential modulated by the precession frequency:

$$f_5(t) = N_0 e^{-t/\tau}[1 - A\,cos(\omega_a t + \phi)]$$

- The 5 parameters function presents peaks in the residuals FFT due to beam dynamics effects
- Increasing the number of corrections in order to remove peaks from the FFT residuals





The fit equation

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

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

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

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

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

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

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

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

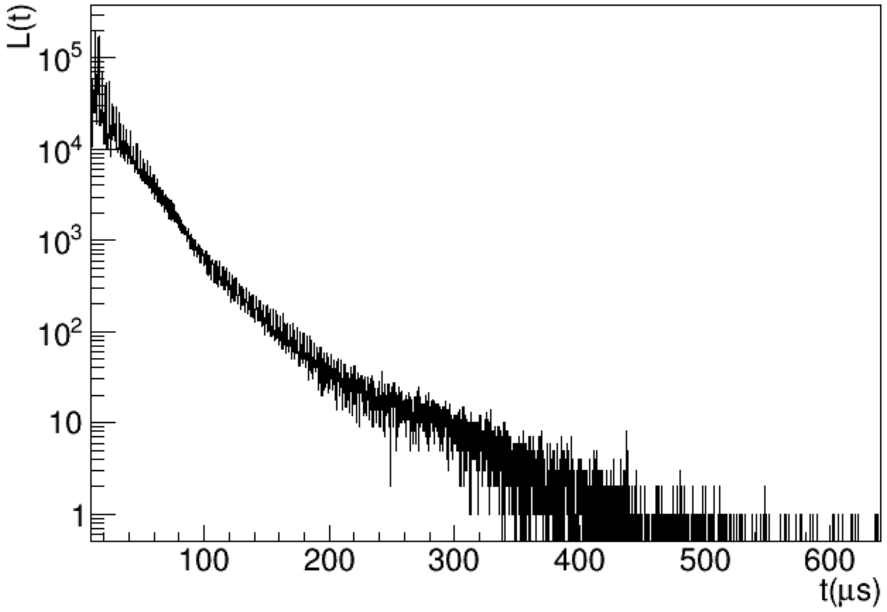
$$\omega_{\mathrm{CBO}}(t) = \omega_0 t + Ae^{-\frac{t}{\tau_A}} + Be^{-\frac{t}{\tau_B}}$$

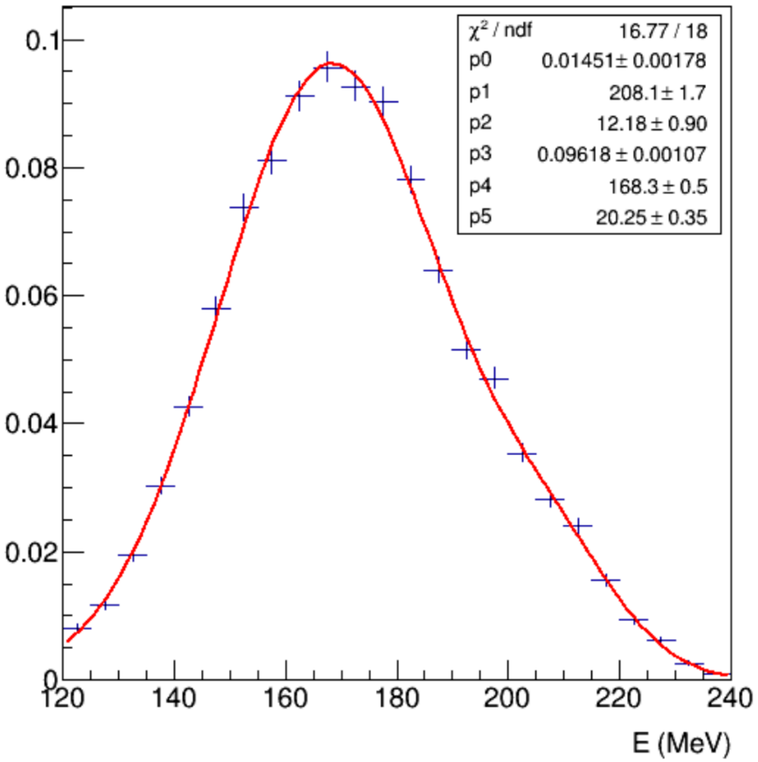
$$\omega_y(t) = F\omega_{\mathrm{CBO}(t)}\sqrt{2\omega_c/F\omega_{\mathrm{CBO}}(t) - 1}$$

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

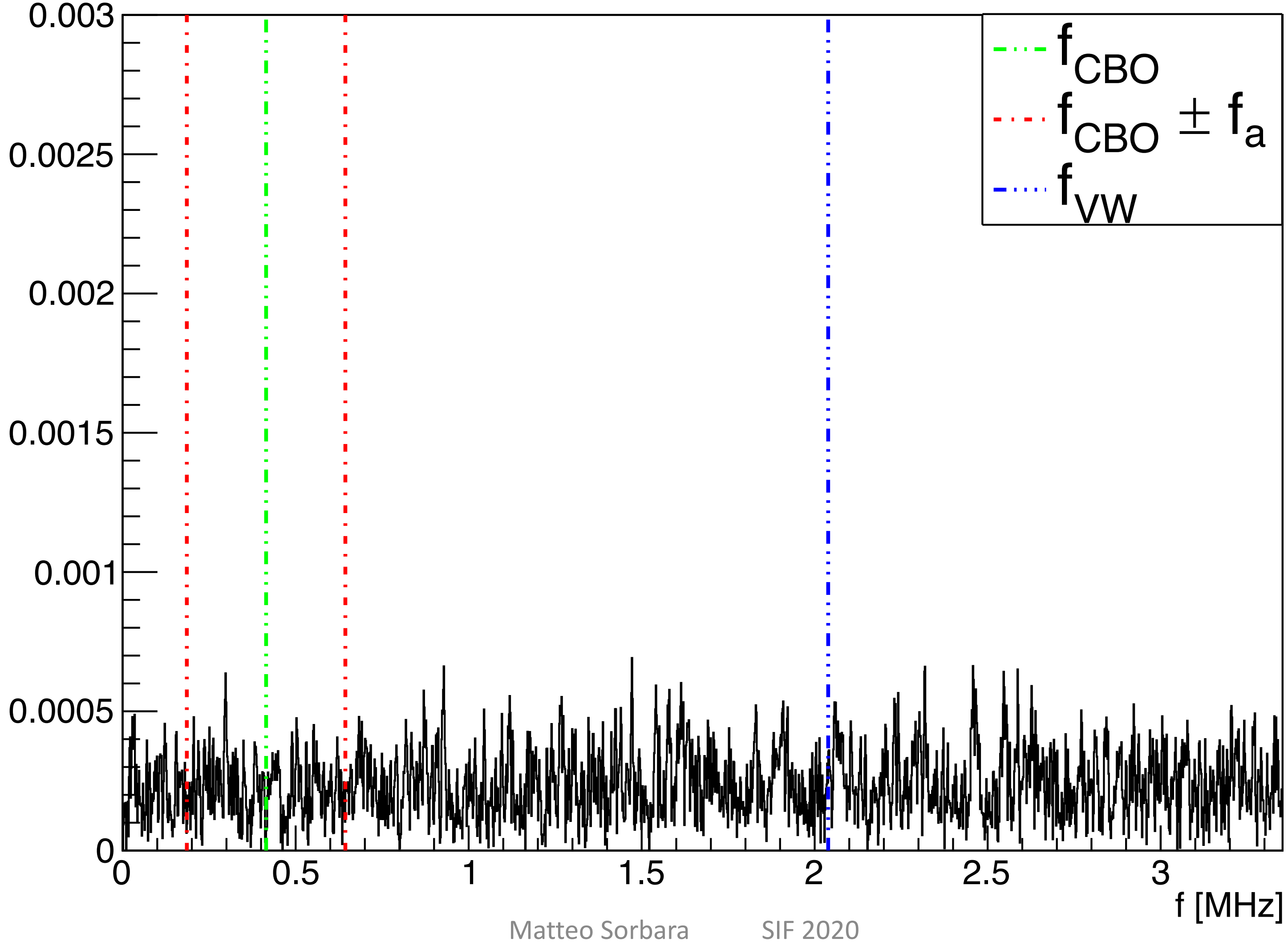
Lost Muons

- Muons lost from the storage ring distorts the measured lifetime
- $J(t) = 1 - K_{LM} \int_0^t e^{\frac{t'}{\tau}} L(t')dt'$
- $L(t)$ measured from data
- Based on the detection of Minimum Ionizing Particles in the calorimeters
- Triple (+ 4 + 5) coincidences in consecutive calorimeters with timing $\Delta t = 6.25\ ns$
- Tracker identification is used to identify the lost muons using their momentum





Final Fit



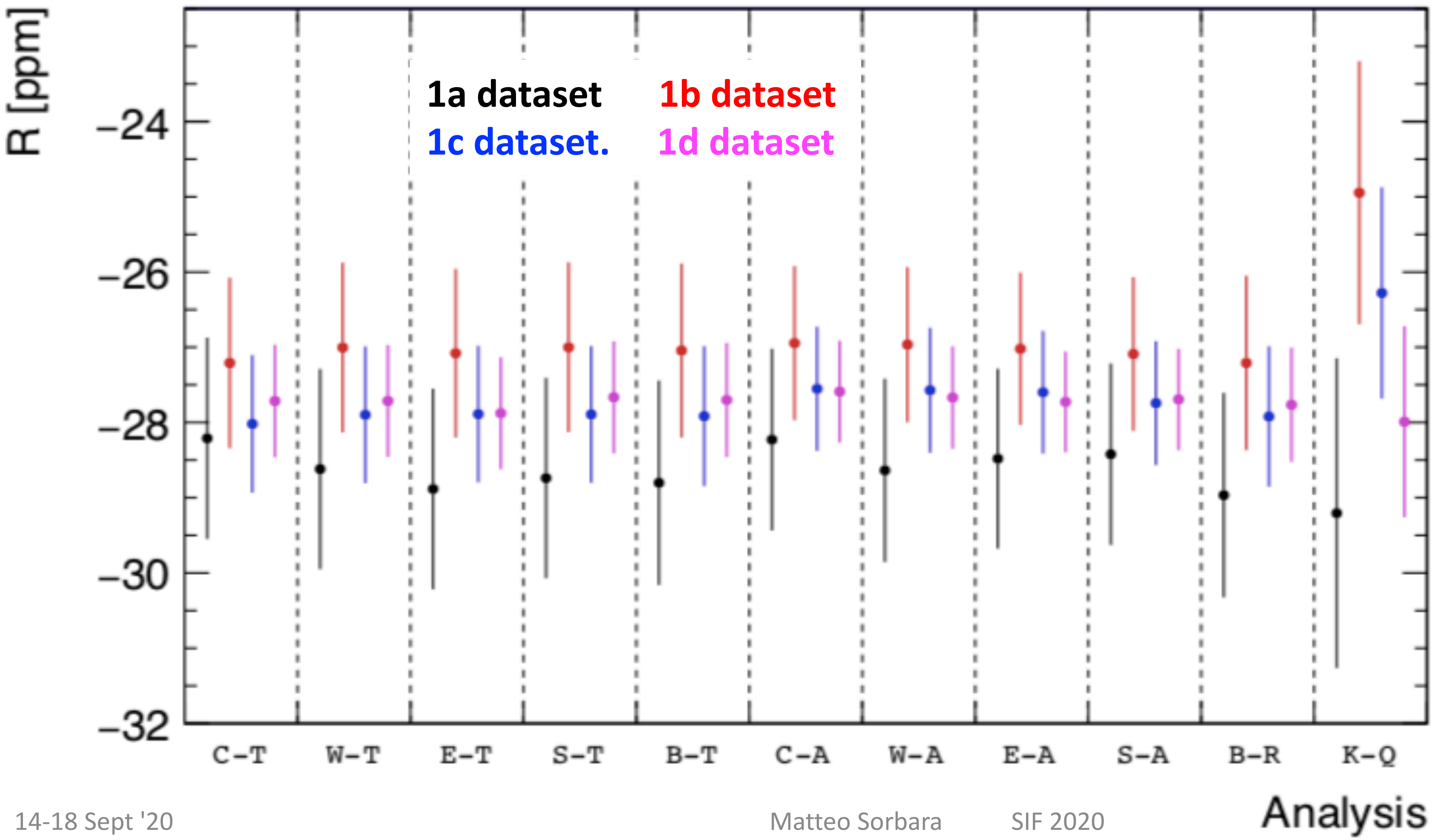
0.003
0.0025
0.002
0.0015
0.001
0.0005
0
0
0.5
1
1.5
2
2.5
3
f [MHz]
f_{CBO}
$f_{CBO} \pm f_a$
f_{VW}

Run 1 Datasets

Run 1 collected in spring 2018. Identified 4 datasets based on the storage parameters (quadrupoles field index, kickers voltage)

Dataset	Nickname	Acquisition	Quad n	Kicker [kV]	Positrons
1a	60 hour	22 – 25 Apr	0.108	128-132	1.0B
1b	High Kick	26 Apr – 2 May	0.120	136-138	1.2B
1c	9 day	4 – 12 May	0.120	128-132	2.4B
1d	End Game	6 – 29 Jun	0.108	122-127	4.0B

Run 1 (relative) Unblinding



Note: error bars are the statistical uncertainty only

Conclusions

- Full Run 1 analysis is almost complete
- The total statistical power of the dataset is about the same as the BNL result
- The expected statistical uncertainty is $\mathcal{O}(450\ ppb)$ and the systematic uncertainty $\mathcal{O}(300\ ppb)$
- Unblinded result expected before the end of 2020
- Run2 analysis started with qualitatively better beam conditions (reduced beam related systematics)