Muon *g* – 2 calorimeters

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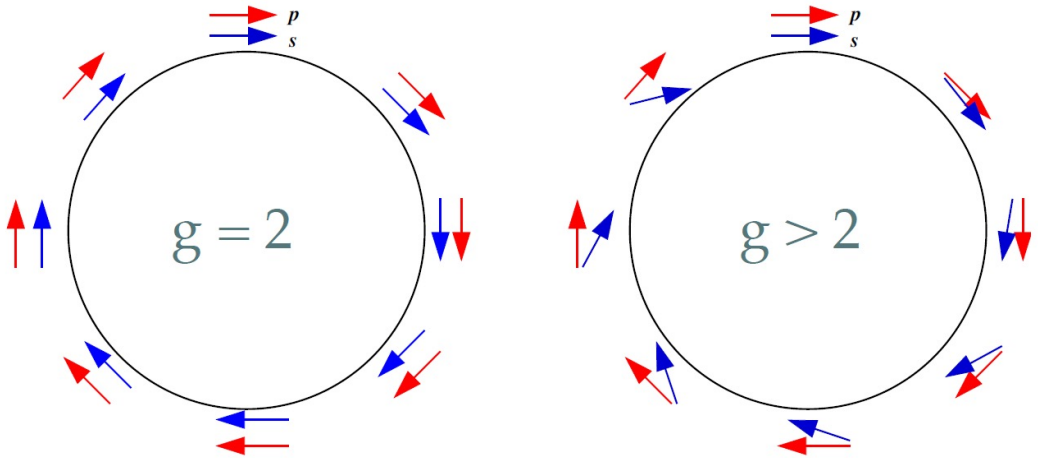
HEP Meeting

29 April 2021

Measuring ω_a

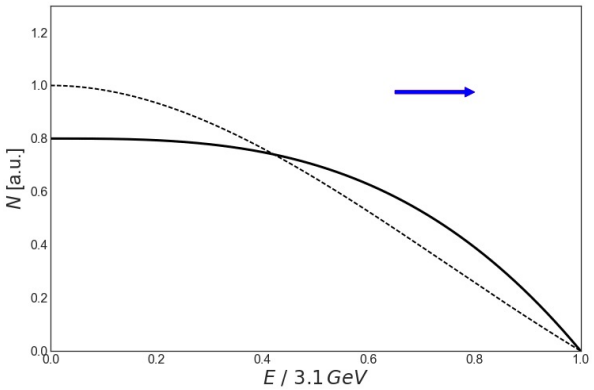
- Spin precesses relative to momentum in magnetic field
- Number of high-energy decay positrons oscillates as the spin precesses



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

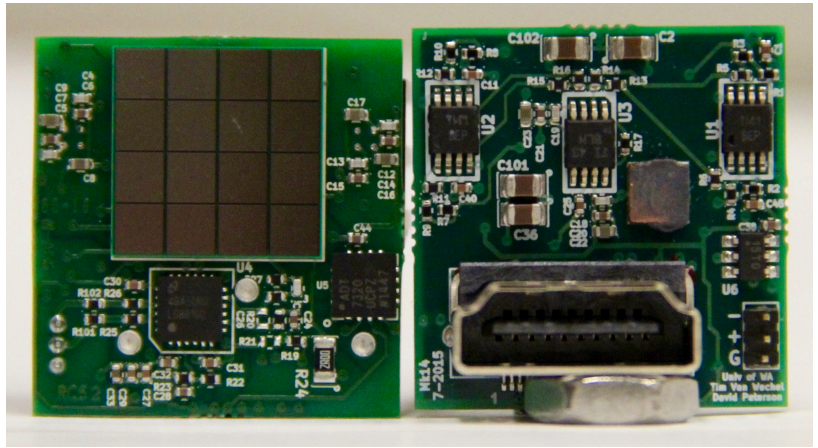
≈ 0 for motion transverse to magnetic field

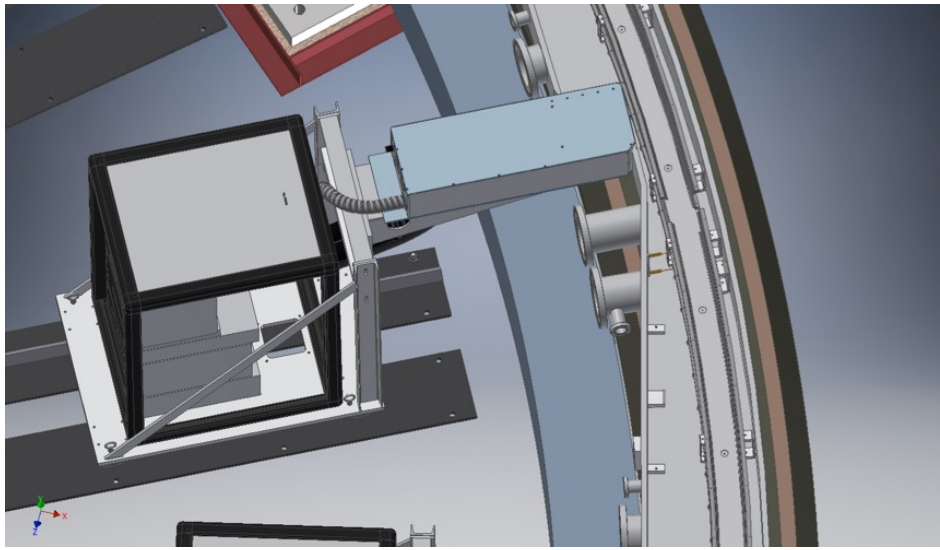
≈ 0 for muons at "magic" momentum 3.1 GeV / c or $\gamma = 29.3$



Calorimeters to measure spin precession

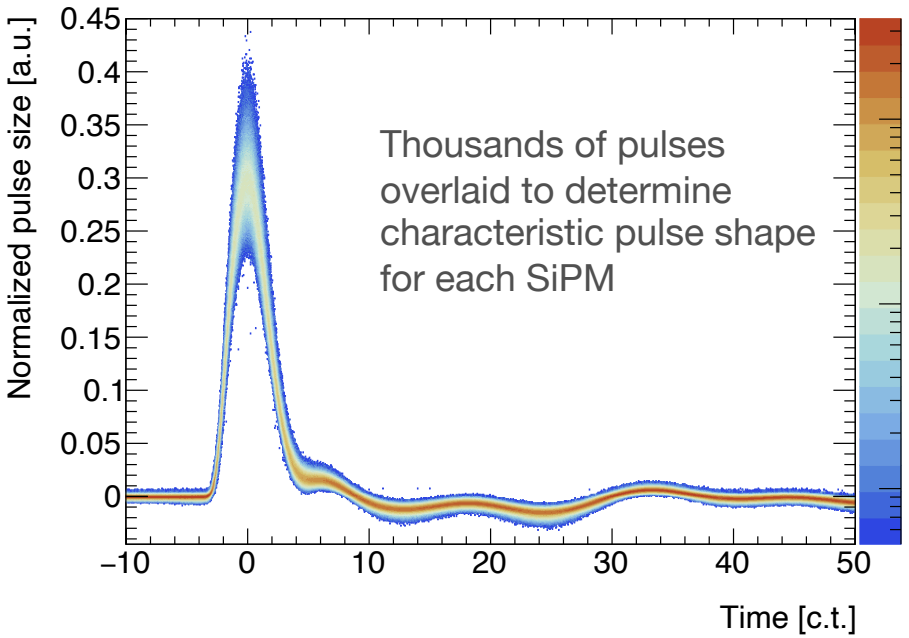
- 24 calorimeters equally spaced around the inner radius of the storage region
  - Each is a 6 high by 9 wide array of 25 x 25 x 140 mm^3 PbF_2 crystals
  - Large-area silicon photomulipliers (SiPMs, active area of 12 x 12 mm^2) to read out Cherenkov light
  - 2 immediately behind Liverpool-built straw trackers
- Laser distribution system to measure and correct for gain fluctuations

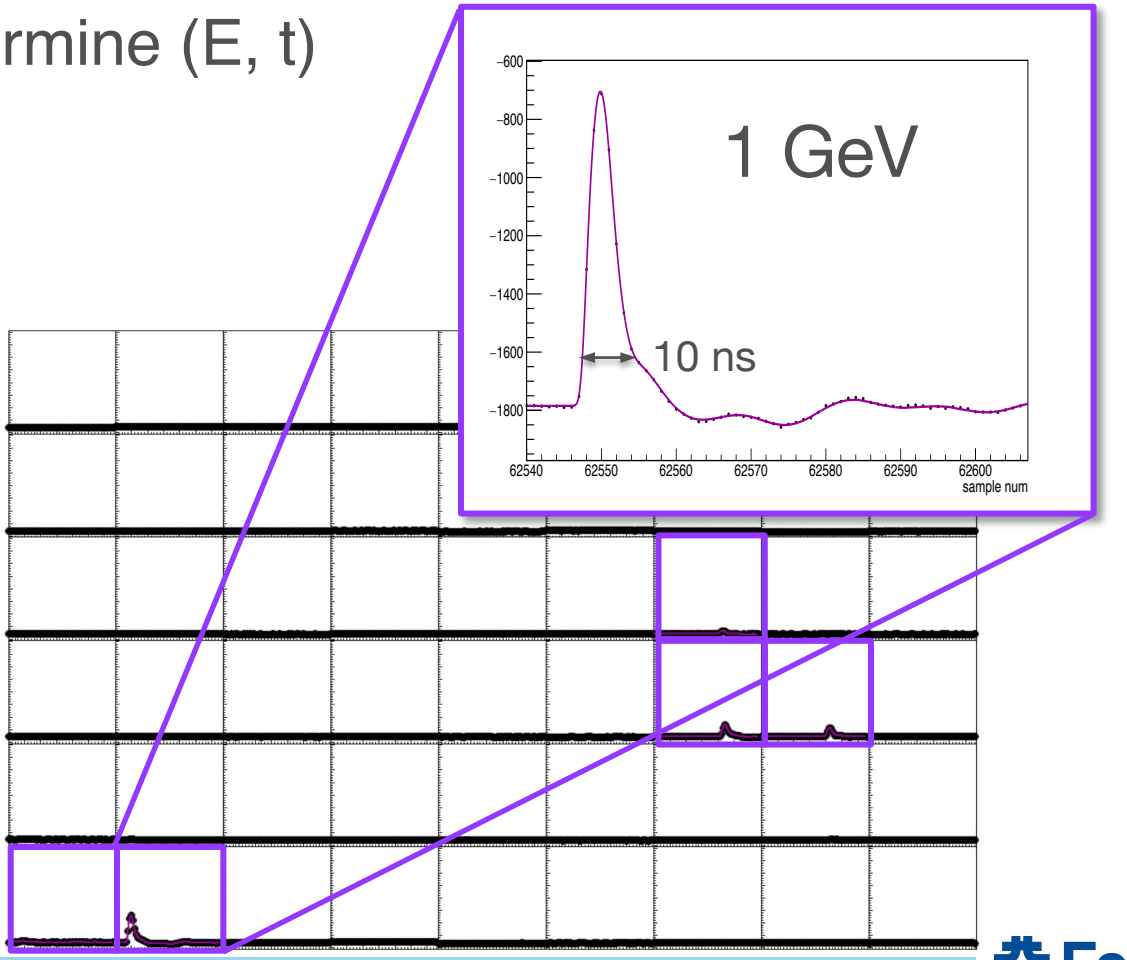




Positrons shower when striking a calorimeter

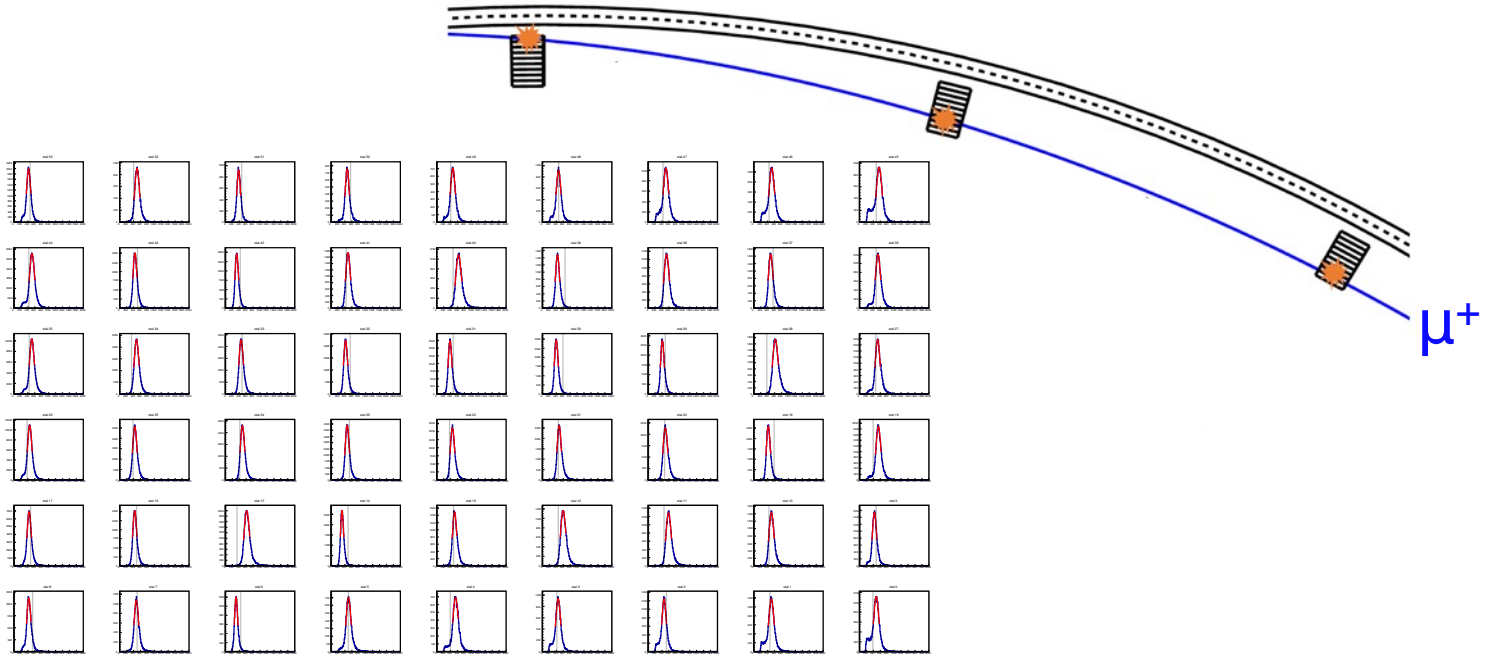
- Signals are digitized at ~800 mega-samples per second
  - True clock frequency is hardware blinded
- Fit using average pulse shape to determine (E, t)
  - Energy resolution of 3%
  - Timing resolution of 50 ps





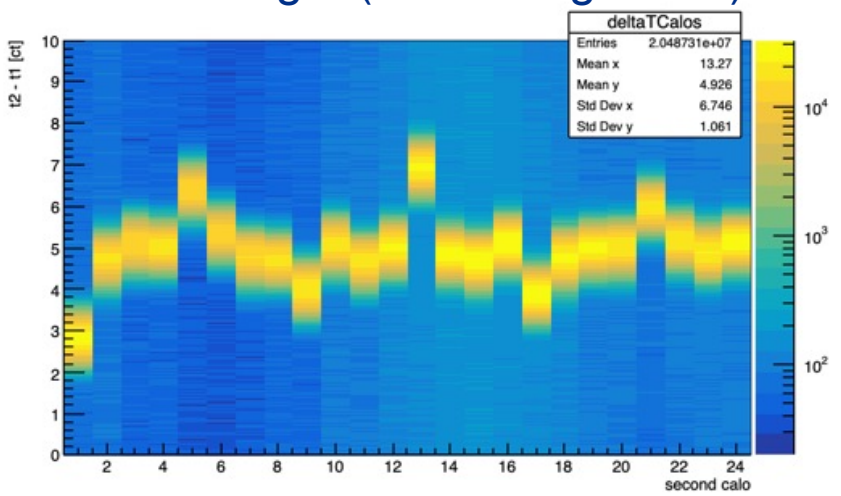
Calorimeter energy scale and timing alignment

- Muons that exit the storage region before decaying impact multiple detectors
  - Sharp energy peak (170 MeV) in single channel
  - Equally spaced detectors → consistent time of flight

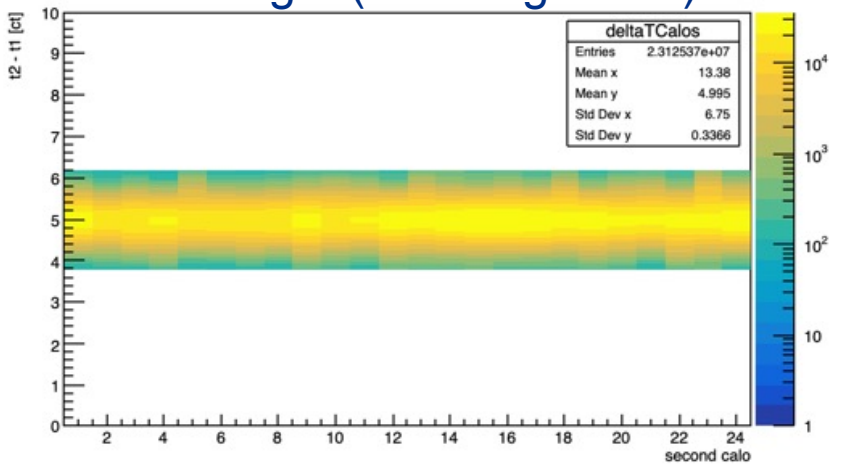


Energy peaks fit to determine calibration constants for the 54 channels in one calorimeter

Time of flight (before alignment)

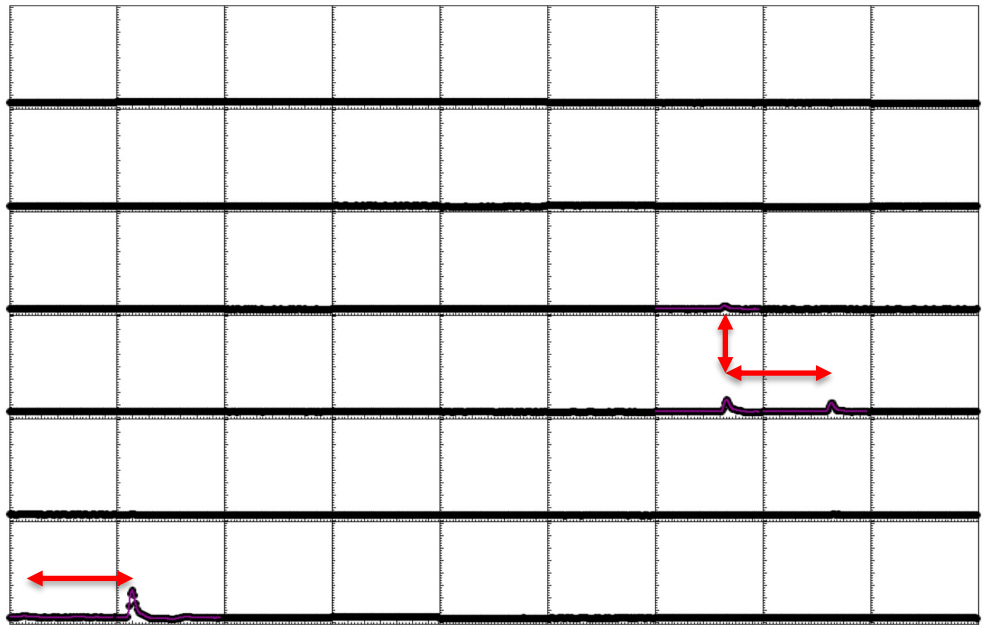


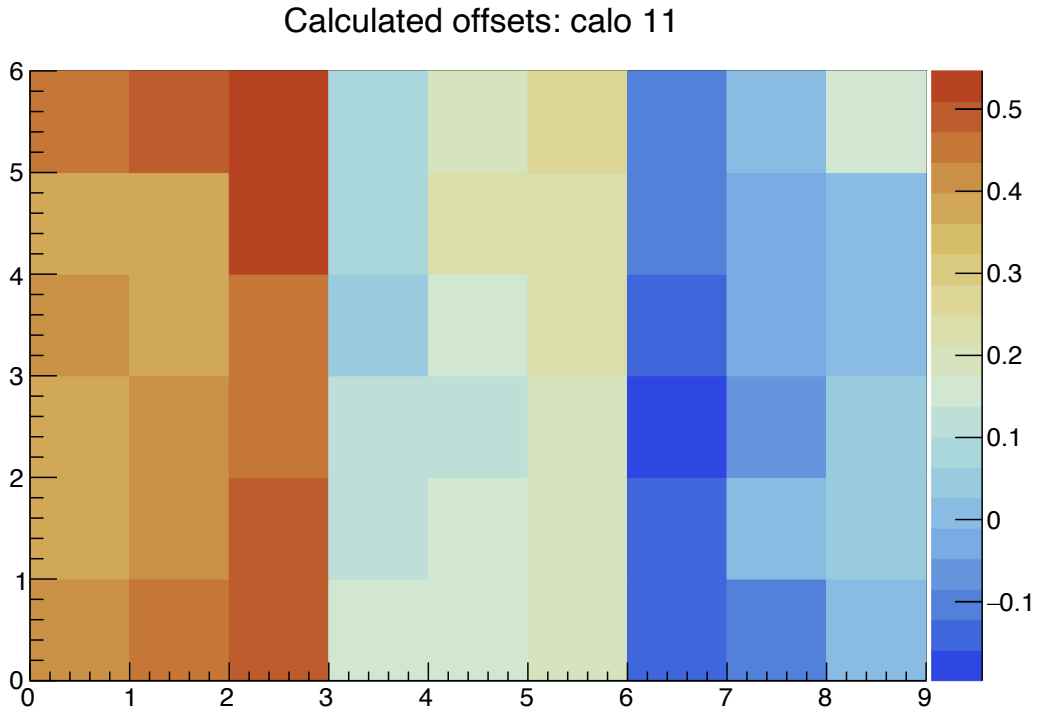
Time of flight (after alignment)



Timing alignment within a calorimeter

- Use positron showers shared between multiple channels
  - Each pair of horizontal/vertical neighbors
  - Set average time difference to 0

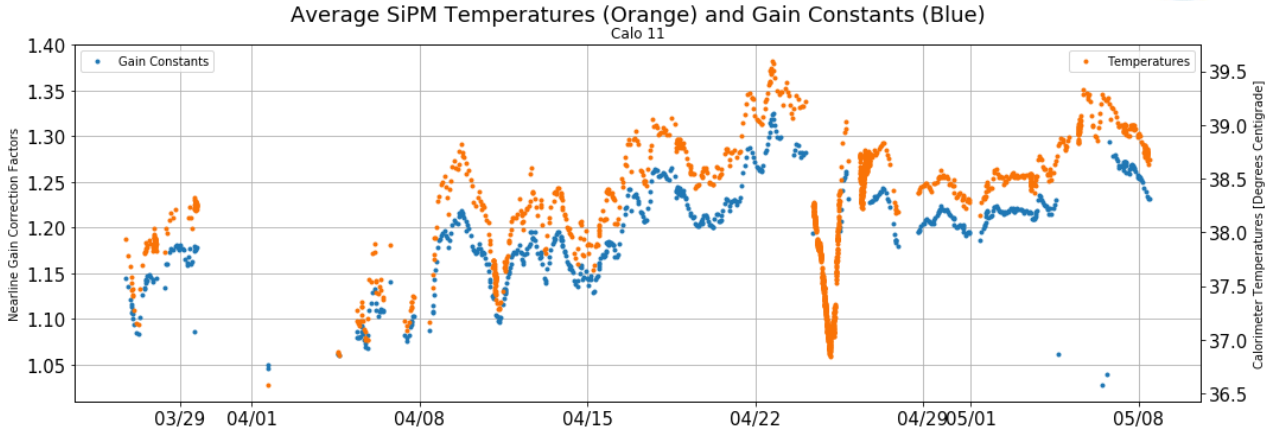


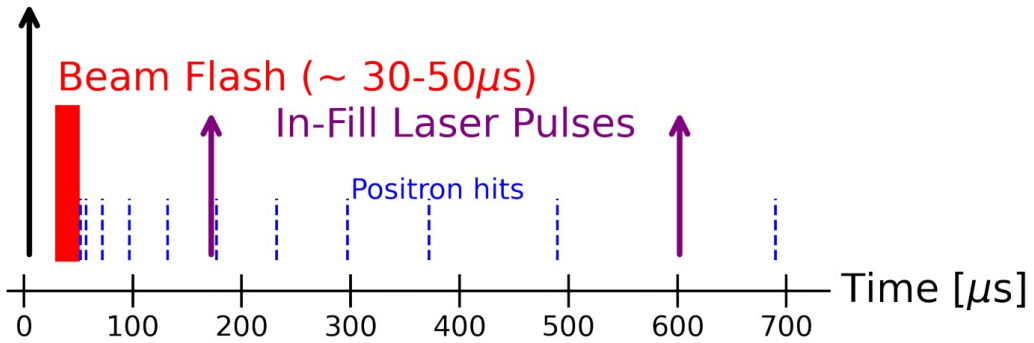


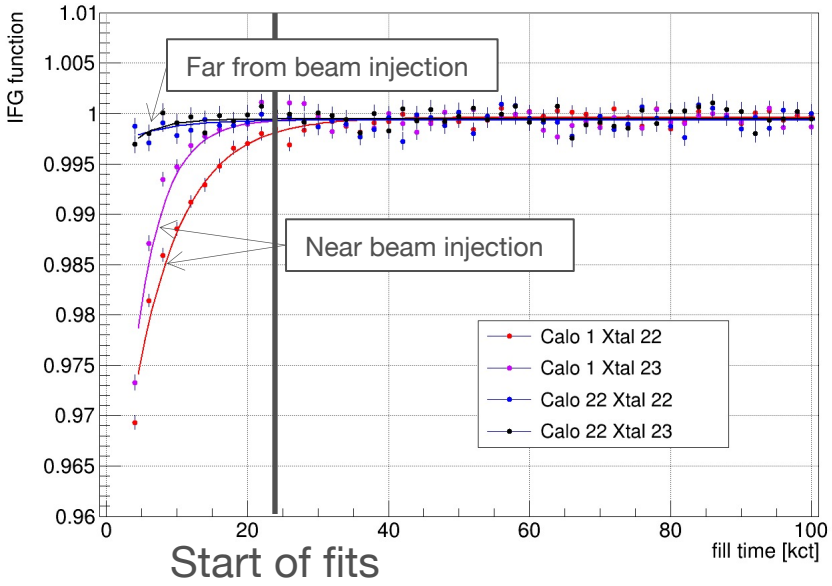
3 different fiber lengths to distribute laser light

Gain corrections

- Measured by the laser system
  - Corrections formed for each channel
- Long-term [hours]
  - Temperature drifts of the SiPMs
- In-fill [μs]
  - Splash of unstorable particles at beam injection depletes the SiPMs

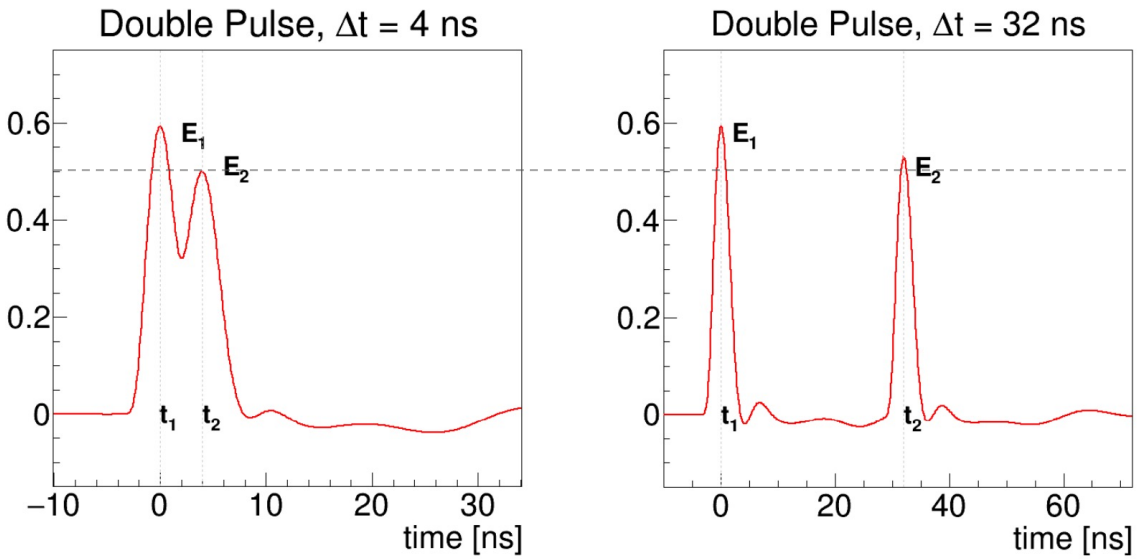


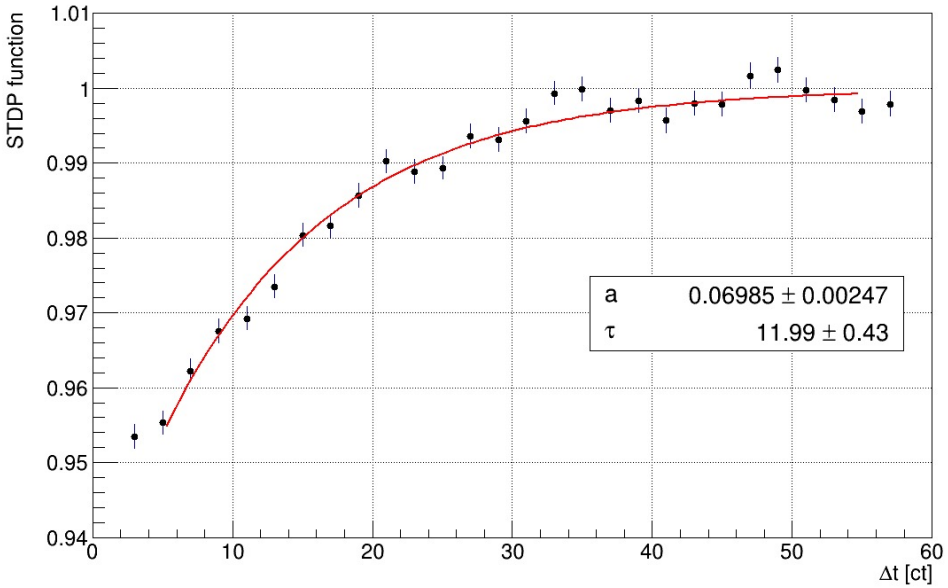




Gain corrections cont.

- Short term [ns]
  - SiPMs operated in Geiger mode
    - A pixel either fires or it doesn't
  - Recovery time of ~15ns after firing
  - Fewer pixels available → effective gain drop
  - Depends on time separation and number of pixels fired

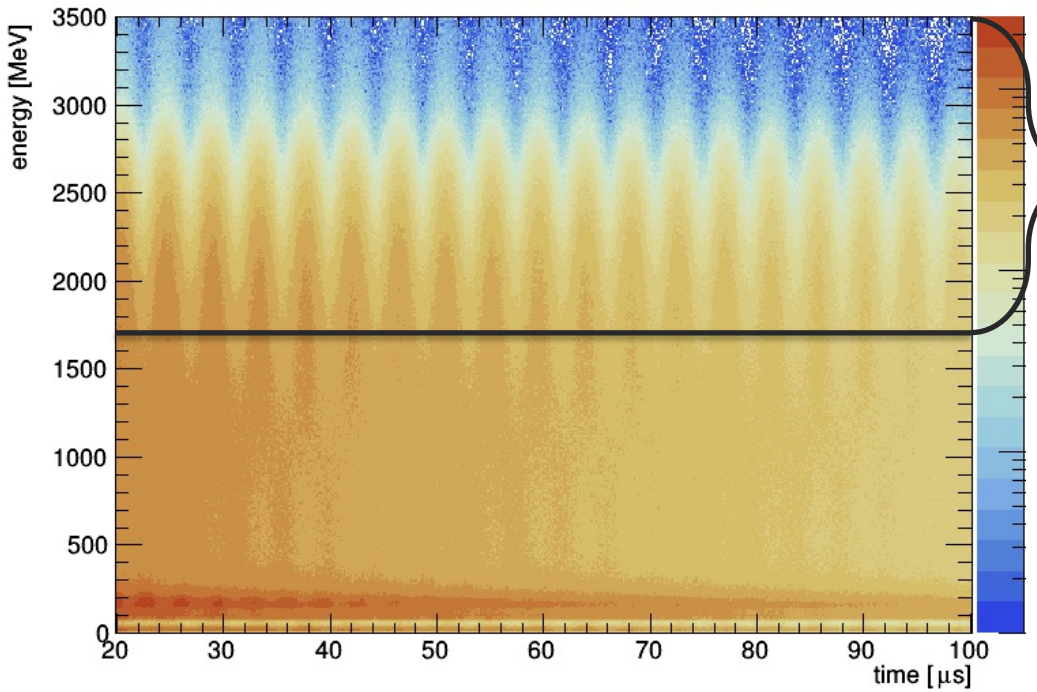


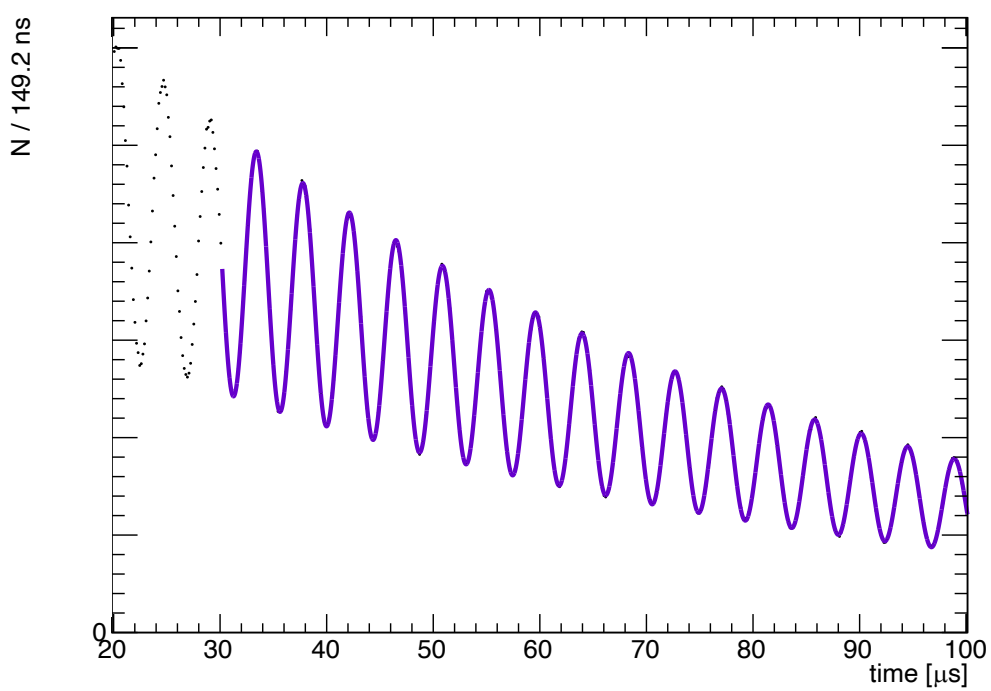


Fit function

- A typical histogram + fit
  - Cut on positron energy
  - Apply an energy-dependent weight

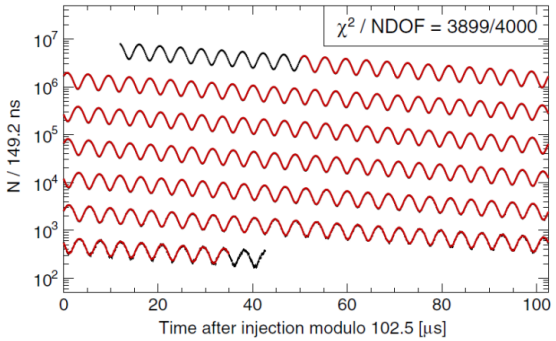
$$N(t) = N_0 \exp(-t/\gamma\tau_\mu)\left[1 + A\cos(\omega_a t - \phi)\right]$$

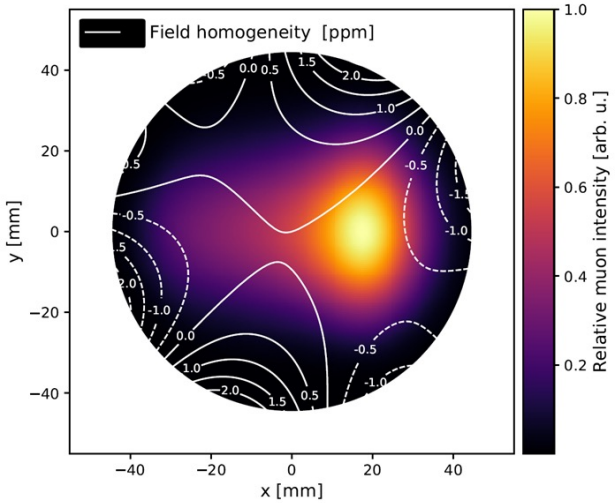


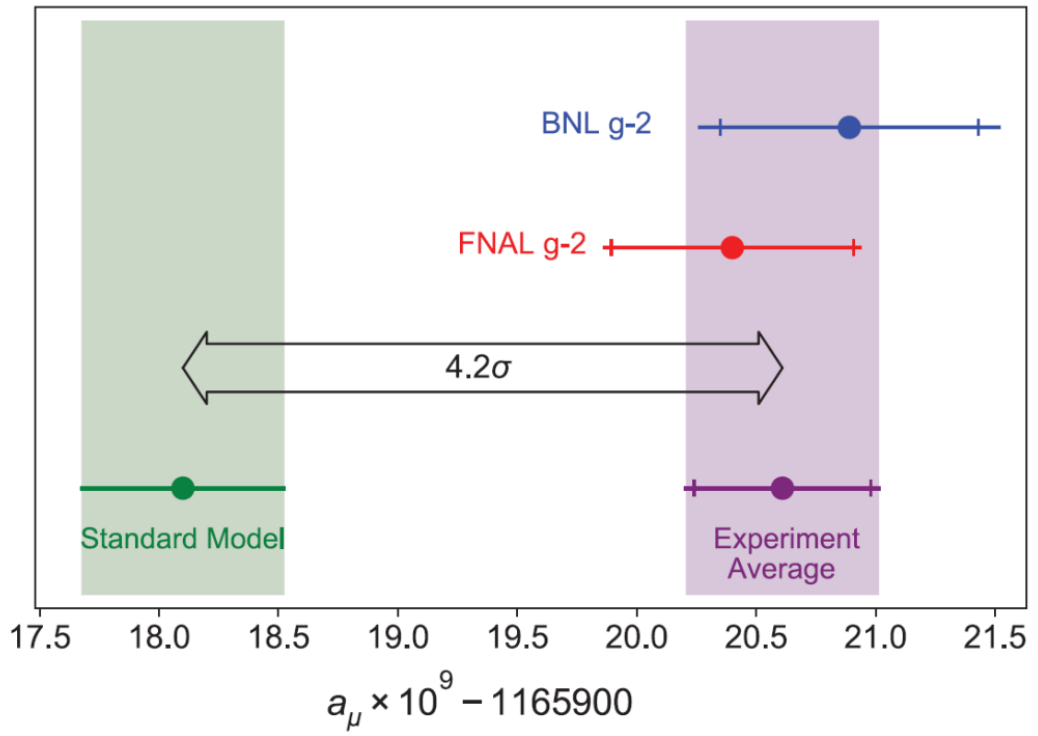


First results from E989

- Combined with knowledge of the magnetic field and location of the beam within the storage region (straw trackers)



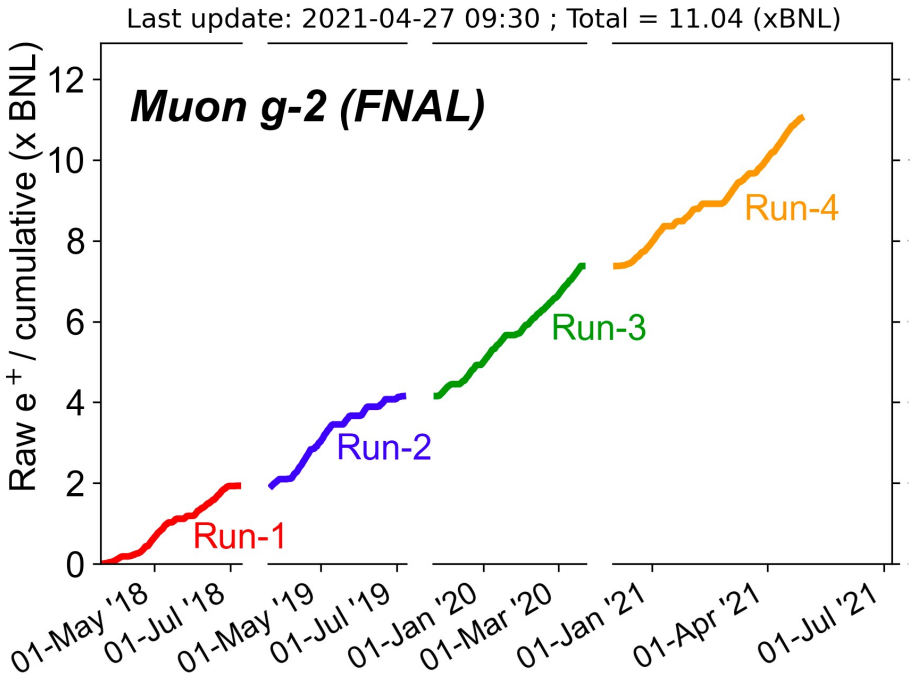




Conclusions and timeline

- $g-2$ in the middle of Run 4
  - Next result will combine Runs 2 and 3

- Transition to Mu3e this summer
  - Tracking software development and refinement
  - Outer tracker commissioning



Back-up slides

Further reading

- Calorimeters
  - Crystals: https://arxiv.org/abs/1412.5525
  - SiPMs: https://arxiv.org/abs/1611.03180
  - Test beam: https://arxiv.org/abs/1905.04407

- Laser system: https://arxiv.org/abs/1906.08432

- Run 1 result: https://arxiv.org/abs/2104.03281
- Measurement of ω_a: https://arxiv.org/abs/2104.03247
- Magnetic field: https://arxiv.org/abs/2104.03201
- Beam dynamics: https://arxiv.org/abs/2104.03240

Final ω_a fit

- Correct for pileup
- Additional terms in fit function
  - Changing acceptance due to beam motion
    - Taken from Liverpool-built straw tracker data
  - Normalization adjusted for muons that exit the storage region before decaying