The Calorimeter system of the new muon g-2 experiment at Fermilab

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Abstract

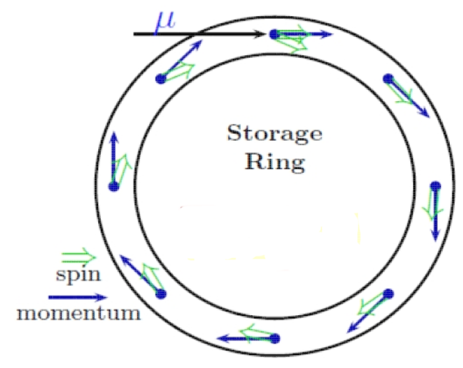
The electromagnetic calorimeter for the new muon *g-2* experiment at Fermilab will consist of arrays of PbF_2 Cherenkov crystals read out by large-area silicon photo-multiplier (SiPM) sensors. We report here the requirements for this system, the achieved solution and the results obtained from a test beam using 2.0–4.5 GeV electrons with a 28-element prototype array.

Principle of the Muon *g-2* experiment

A tale of two frequency.

Polarized muons are injected into the $(g-2)_\mu$ storage ring where a strong (1.45) magnetic field both traps the muons and causes their spin vector to precess.

The momentum turns at the cyclotron frequency while the spin rotates due to the combination of Larmor and Thomas precession.



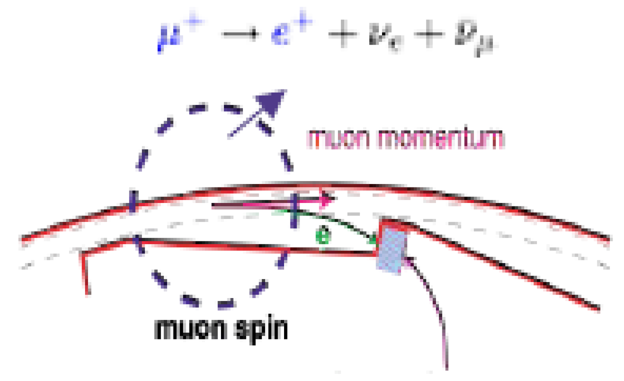
momentum rotation $\omega_c = \frac{eB}{\gamma mc}$

spin rotation $\omega_s = \frac{geB}{2mc} + (1-\gamma)\frac{eB}{\gamma mc}$

Measuring ω_a.

The parity violating decay of the muon leads to a strong correlation between its decay-time spin vector and the emitted positron direction.

24 calorimeter stations symmetrical around the storage ring measure the direction and energy of accepted positrons to observe ω_a over 10 muon lifetimes.



Measuring ω_p.

Precise knowledge of the magnetic field B measured by Nuclear Magnetic Resonance (NMR) probes can be related to the absolute field experienced by the muons through the precession frequency of free protons ω_p.

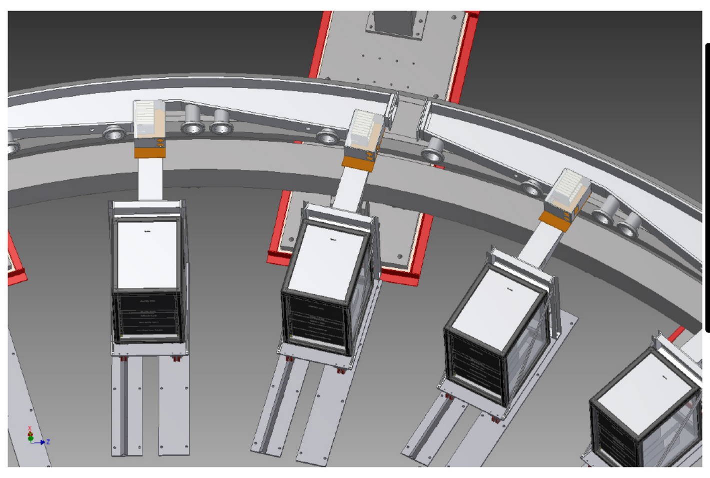
New Physics?

$\Delta a_\mu = a_\mu^{th} - a_\mu^{exp} \sim 3\sigma$

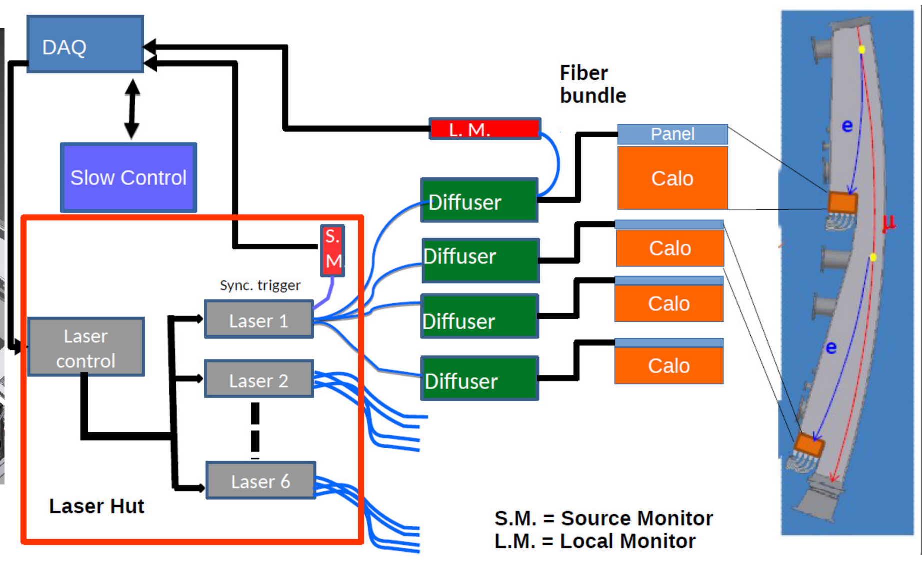
Main Requirements

1. Energy resolution 5%;
2. Timing resolution better than 100 ps for $e^+ > 100$ MeV.
3. 100% efficiency to resolve two showers for time separation ≥ 5 ns. 66% for time <5 ns.
4. Gain stability $\frac{dG}{G} < 0.1\%$ within 200 μs.
5. More relaxed long term Gain stability $\frac{dG}{G} < 1\%$.
6. Laser calibration must provide Gain monitoring with a precision $\sim 0.04\%$.

Calorimeter Layout

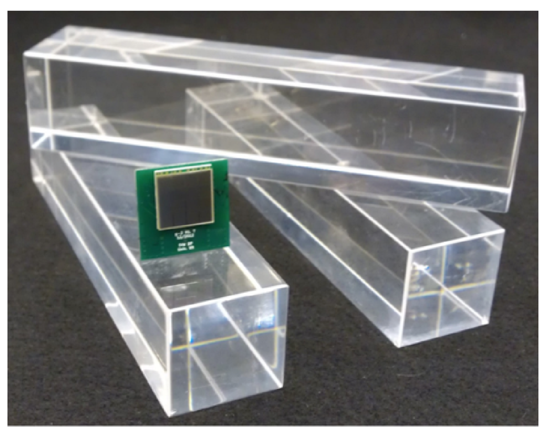


Calorimeter placement around the storage ring.



Scheme of the laser calibration system.

Calorimeter design

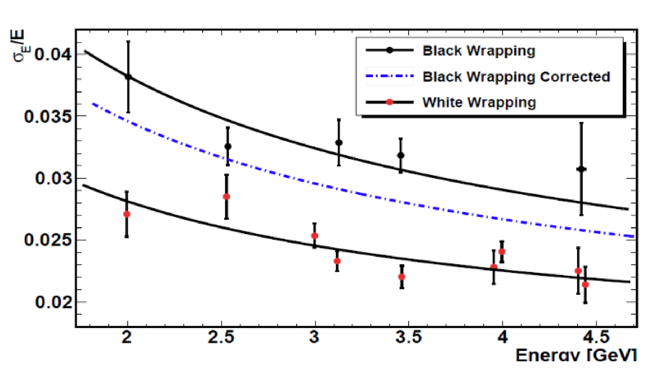


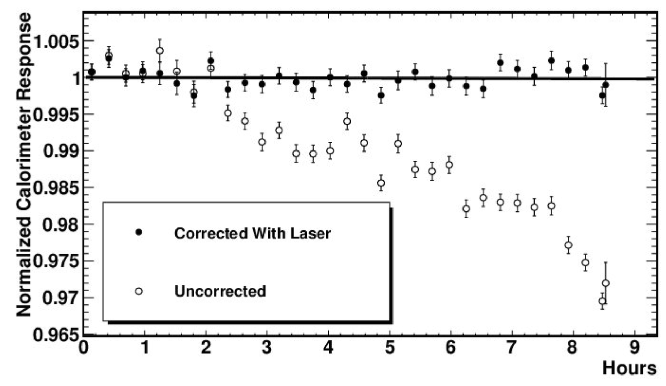
PbF_2 pure Cerenkov crystals, readout by large area Silicon Photomultiplier (SiPM).

Calorimeter prototype used at SLAC 4×7 crystal array. The final calorimeter is composed by a 6×9 crystals array. Segmentation is used to improve spatial resolution.

Results

Energy resolution & long term Gain stability





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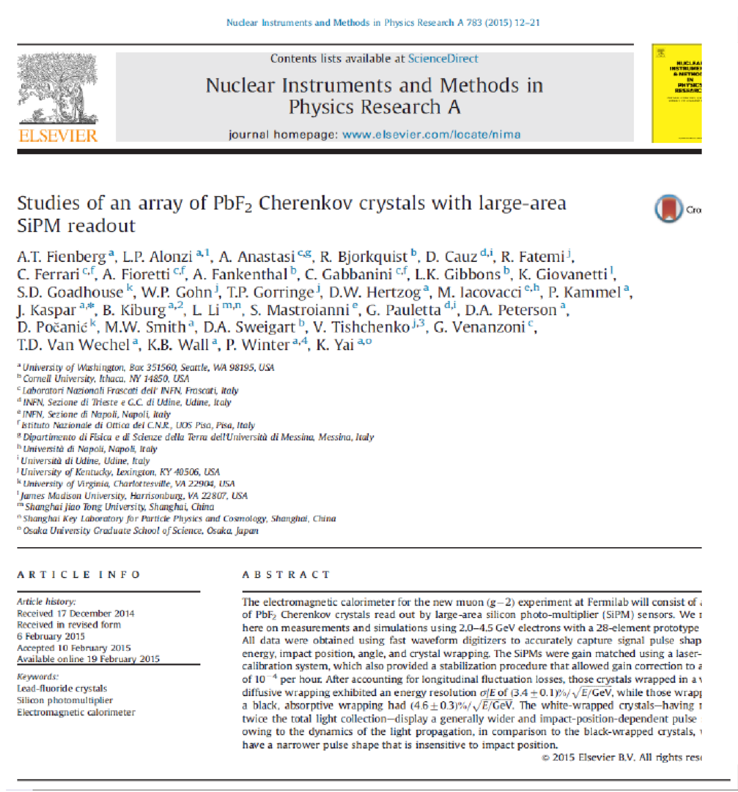
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Studies of an array of PbF_2 Cherenkov crystals with large-area SiPM readout

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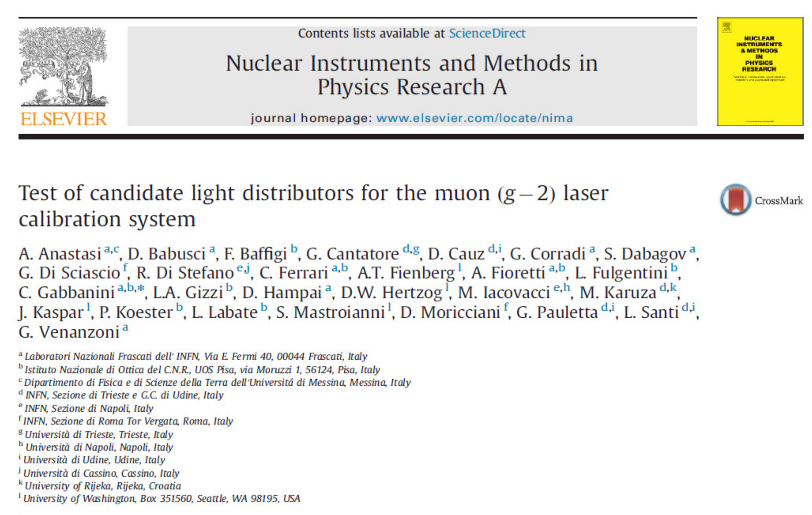
ABSTRACT

The electromagnetic calorimeter for the new muon (g−2) experiment at Fermilab will consist of arrays of PbF_2 Cherenkov crystals read out by large-area silicon photo-multiplier (SiPM) sensors. We report here on measurements and simulations using 2.0–4.5 GeV electrons with a 28-element prototype array.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Test of candidate light distributors for the muon (g−2) laser calibration system

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The new muon (g−2) experiment E989 at Fermilab will be equipped with a laser calibration system for