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

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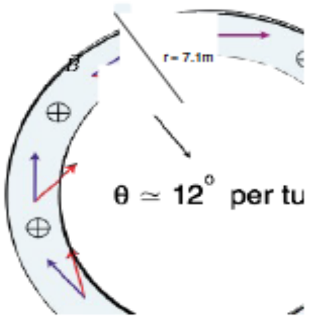
μ g–2

Principle of the Muon g-2 experiment

A tale of two frequencies

Polarized μ's are injected into the *(g-2)*μ storage ring where a strong (1.45T) 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 $\omega_s = \frac{geB}{2mc} + (1-\gamma)\frac{eB}{\gamma mc}$

The difference of these frequencies is independent of γ and proportional to the anomalous magnetic moment

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

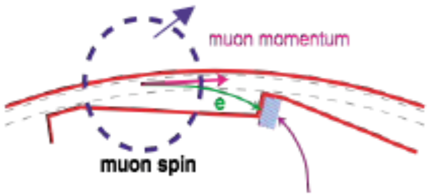
To measure a_μ, the task is to measure the difference frequency ω_a and the magnetic field *B*, which can be absolutely tied to the precession frequency of free protons ω_p.

Measuring ω_a

The parity-violating weak decay of the muon leads to a strong correlation between it's 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.

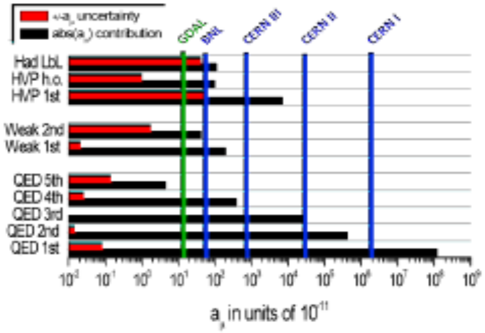
$$\mu^+ \rightarrow e^+ + \nu_e + \bar{\nu}_\mu$$

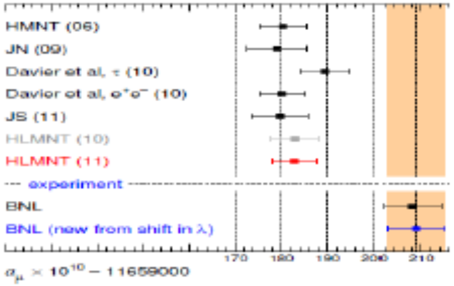


Measuring ω_p

Precise knowledge of the magnetic field 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.

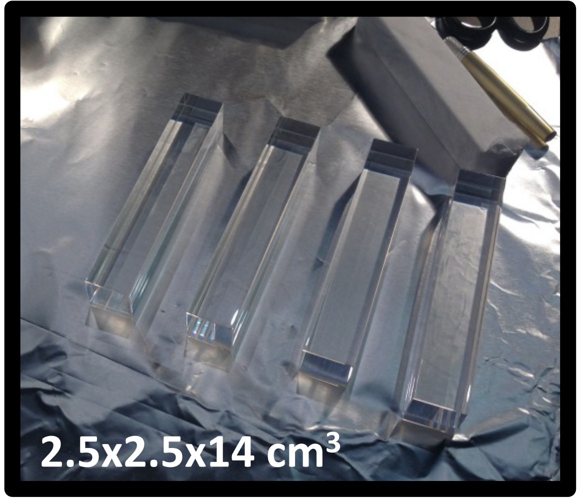
New Physics?

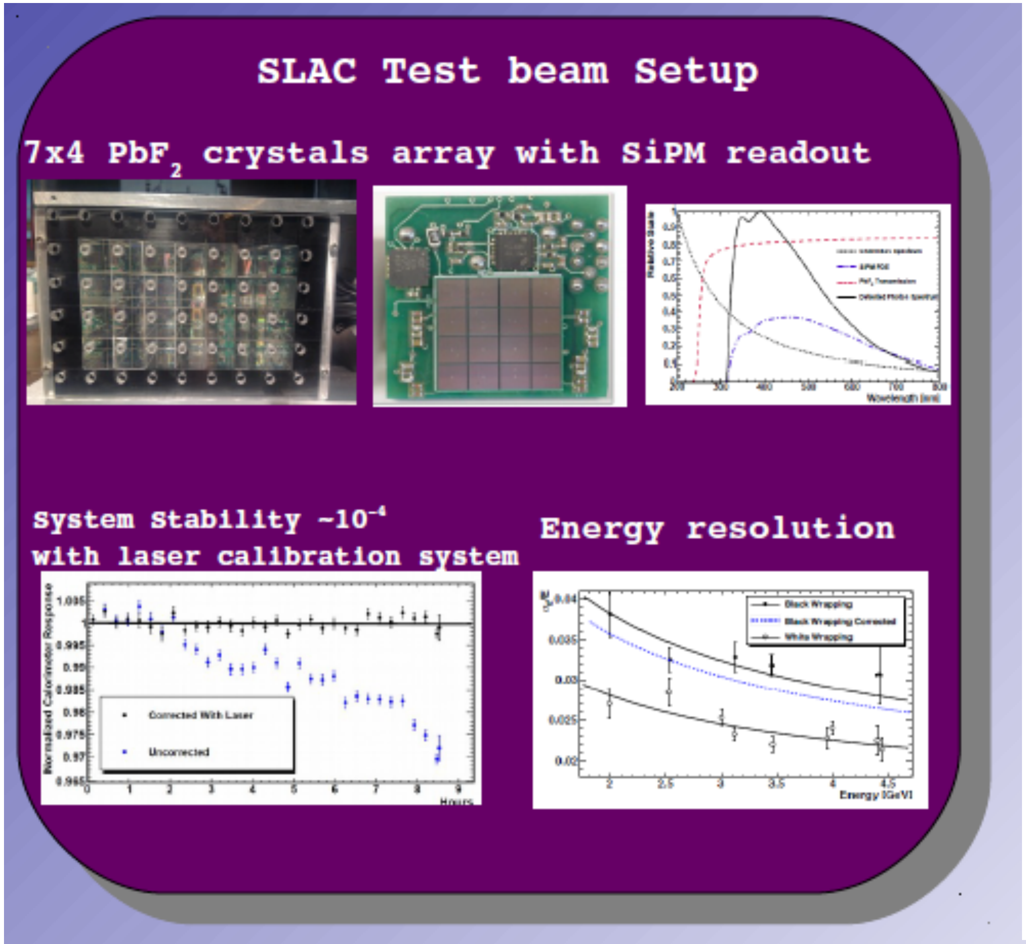




G-2 Calorimeter: PbF_2 crystals with SiPM readout

- Cherenkov light gives short pulse duration (few ns)
- High density (7.77 g/cm^3), small Molière radius (2.1 cm), short radiation length (0.93 cm)
- SiPMs unaffected by magnetic fields
- Segmentation reduces pileup
- Event rate in MHz range
- Few thousand pe per event (~1.5 pe/MeV)

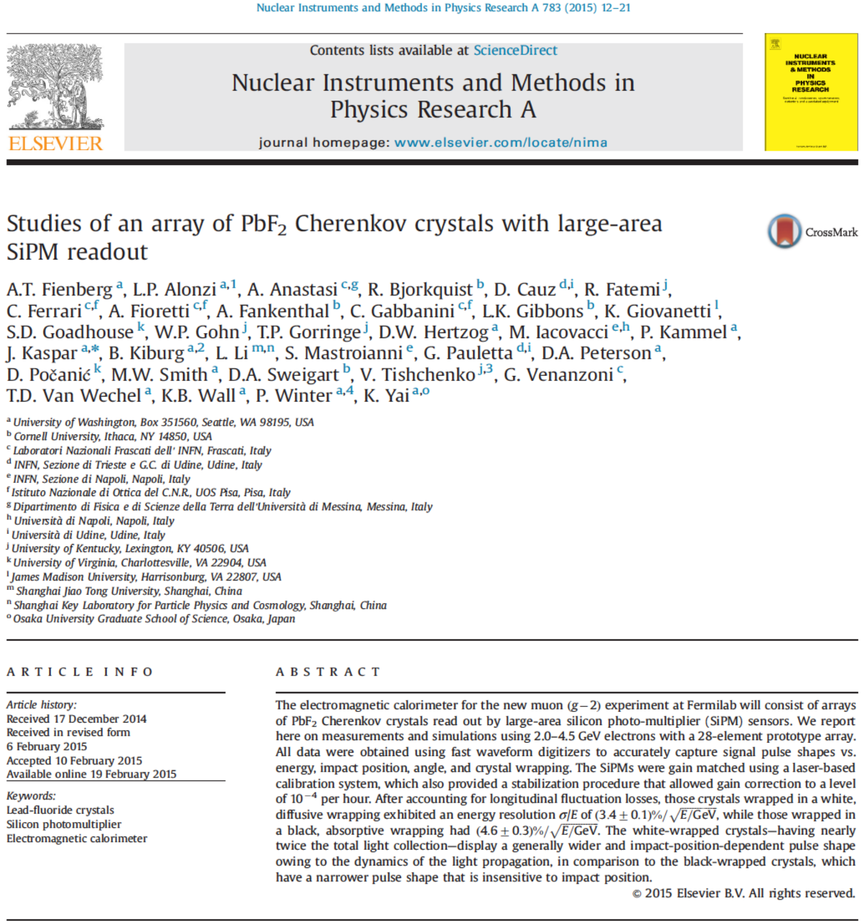

2.5x2.5x14 cm^3


SLAC Test beam Setup

7×4 PbF_2 crystals array with SiPM readout

System Stability ~10^{-4} with laser calibration system

Energy resolution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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. All data were obtained using fast waveform digitizers to accurately capture signal pulse shapes vs. energy, impact position, angle, and crystal wrapping. The SiPMs were gain matched using a laser-based calibration system, which also provided a stabilization procedure that allowed gain correction to a level of 10^{-4} per hour. After accounting for longitudinal fluctuation losses, those crystals wrapped in a white, diffusive wrapping exhibited an energy resolution σ/E of $(3.4 \pm 0.1)\%/\sqrt{E/\mathrm{GeV}}$, while those wrapped in a black, absorptive wrapping had $(4.6 \pm 0.3)\%/\sqrt{E/\mathrm{GeV}}$. The white-wrapped crystals—having nearly twice the total light collection—display a generally wider and impact-position-dependent pulse shape owing to the dynamics of the light propagation, in comparison to the black-wrapped crystals, which have a narrower pulse shape that is insensitive to impact position.