Simulating the g-2 experiment by the laser control board

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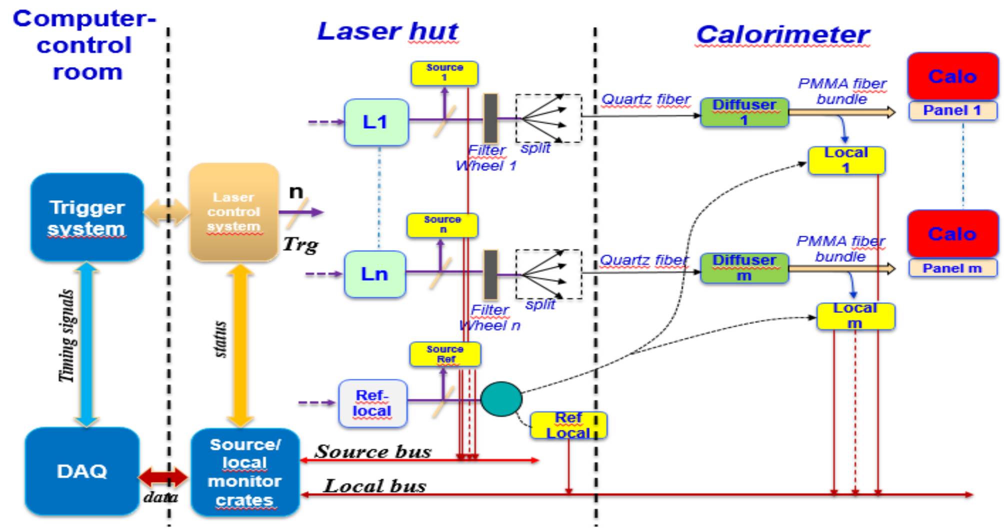
Outline

- The calibration system
- The functionalities of the laser control board
- The operation modes
  - During the real data
  - Simulating the g-2 experiment
- The architecture
- The implementation
- Tests and measurements
- Conclusions

The Calibration system

Calorimeter gain fluctuations and monitoring at the 10^{-4} level (both during in-beam & out of beam)



Calibration system: diode Laser and distribution system transmission

- ❑ **6 lasers Picoquant (750 pJ @ 405 nm) /** Average Power (@ 40 MHz): 28 mW
- ❑ **24 diffusers**
- ❑ **Monitor system**

S

Source monitor (signal input: ~150 pJ/pulse~$3\text{x}10^{8}$ γ)

- **2 PIN diodes and readout electronics**
- **1 PMT with Am/NaI pulser**
- **Light mixing chamber**

L

Local monitor (signal input: ~0.01 pJ/pulse~10^{4} -10^{5} γ)

- **2 PMT**

Required value at the output of each crystal 0.01 pJ/pulse (el. 2 GeV)

Systematics are measured with reference to a *Am/NaI "pulser" with rate of ~10Hz* → need ~ 3 hours for 0.01% statistical accuracy

The functionalities

- ***Interface with the Trigger system***
  - *Synchronization with the clock, control and command system (CCC)*
- ***Provides the calibration pulses according the following modes:***
  - Pulse train generation at programmable frequencies **superimposed** to the real data during 700 μs fill window;
  - Physics event **simulation** with "flight simulator" mode by triggering the laser according to an exponential function exp(-t/τ), as expected from muon decay:
    - Detector/electronics/DAQ test and characterization
  - Time reference signal for reset, synchronization and initialization of DAQ and electronics (Sync/RST)
    - Alignment between channels
    - Time measurements
  - Filter wheels managing for SiPM calibration:dynamic ~ 5
- ***Interface with the monitor system electronics***
  - Time reference signals for data processing and readout
  - Status and activity of the monitor system

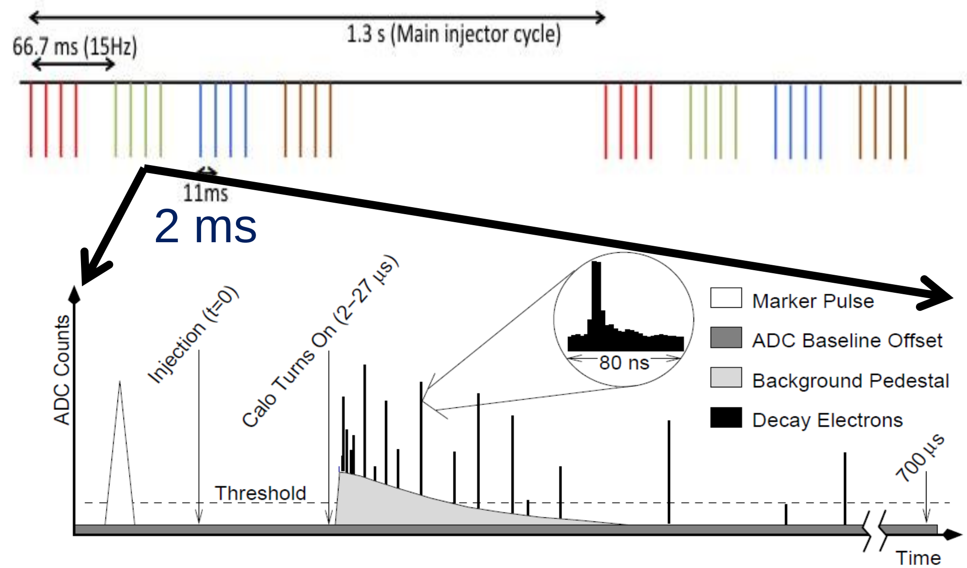
Operation mode during real data

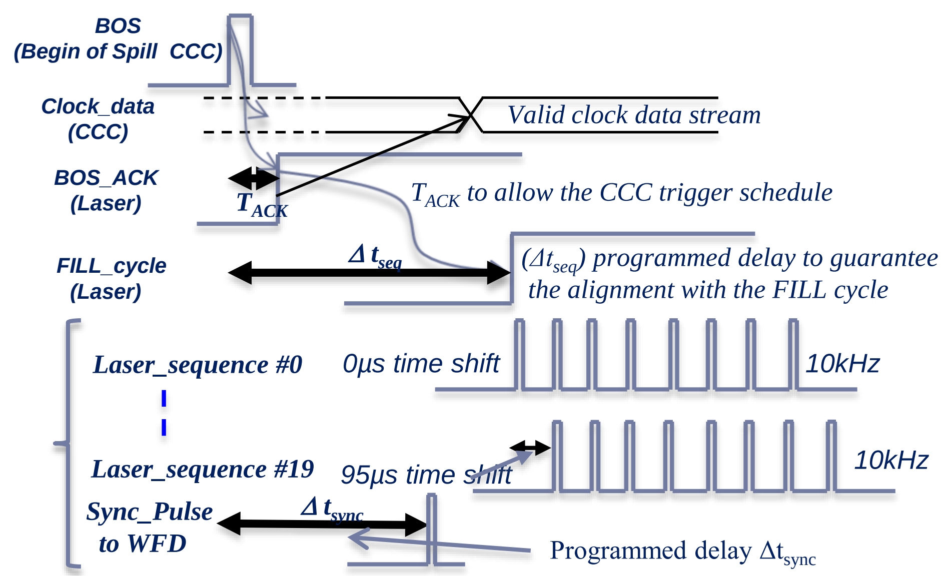
Required stability at 10^{-4} for a single point every a few μs:

- Sampling of G(t) in more than 100 points between 0 and 700μs
- Laser fired at fixed frequency
- Reduce pileup between muon signal and calibration signal
- Train pulse in fill is shifted cycle by cycle by a t_s

with 10 kHz laser frequency and with a t_s = 5μs → sampling of G(t) in 140 points → each calibration point has about 2000 samples in 30' with a pileup contained under 10^{-4} level

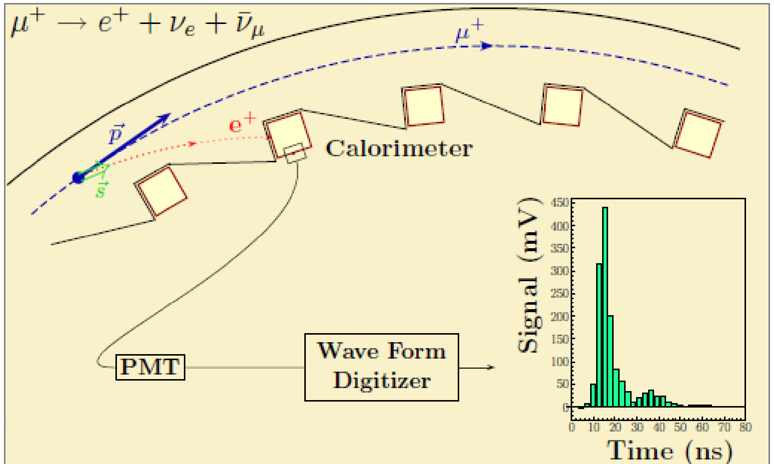
Frequency/time shift and time delays are programmable



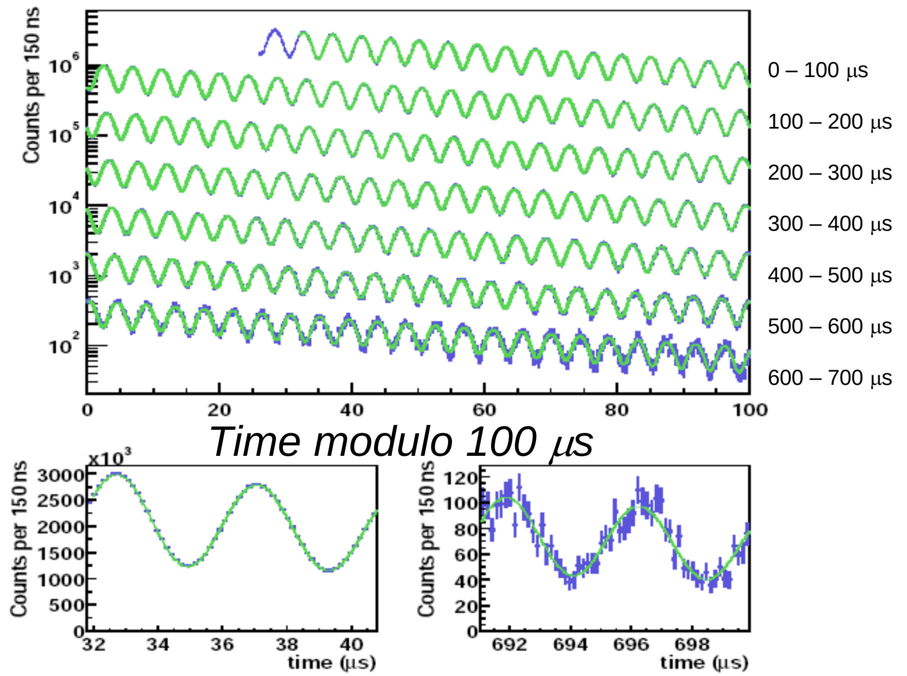


Simulating the g-2 experiment

Measuring ω_a



Muon lifetime	τ_μ = 64.4 μs
(g-2) period	τ_a = 4.37 μs
Cyclotron period	τ_C = 149 ns



The integrated number of positrons (above E_{th}) modulated at ω_a

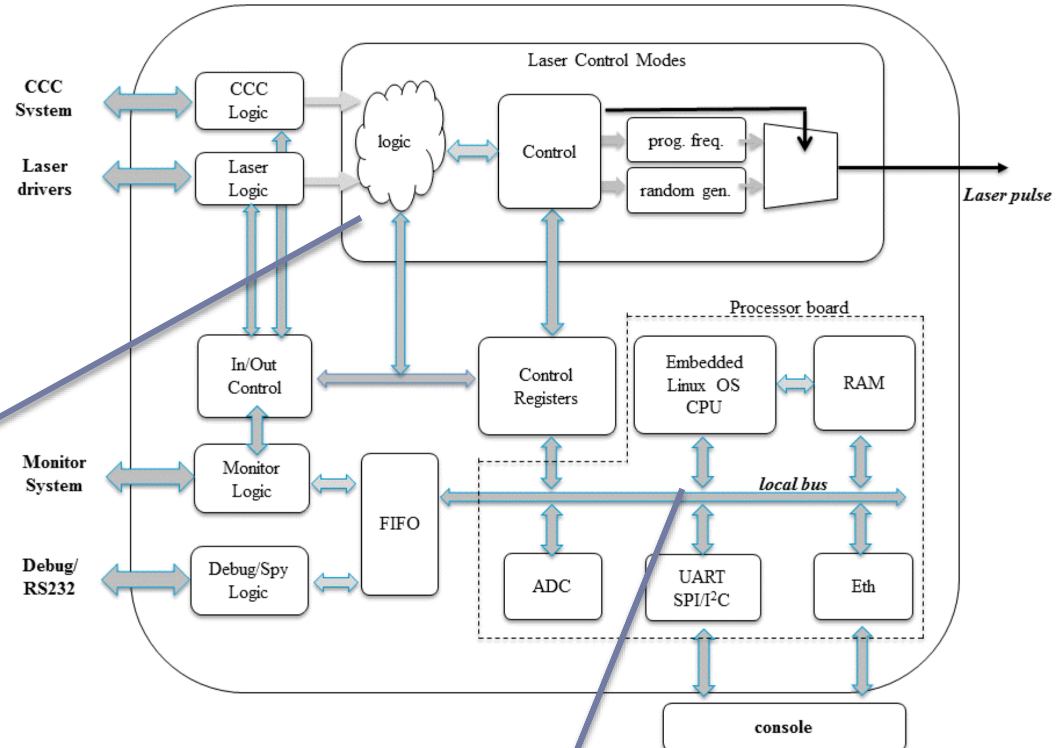
- Angular distribution of decayed positrons correlated to muon spin
- Five parameter fit to extract ω_a $$N(t) = N_0 e^{-t/\tau} [1 + A\cos(\omega_a t + \phi)]$$
- Challenging because of:
  - ***Pileup***
  - ***Gain changes***
  - ***Coherent Betatron***
  - ***Oscillations***
  - ***Muon Losses***

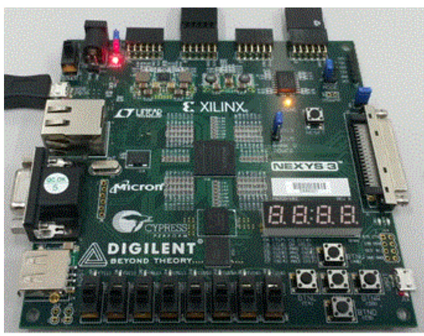
Full simulation to test the detector/DAQ under real conditions

The architecture

Platform for embedded applications:

- *Complete managing of the laser pulse generations*
- *Fully managed remotely*
- *Based on ARM8 board*
- *Running Linux OS*

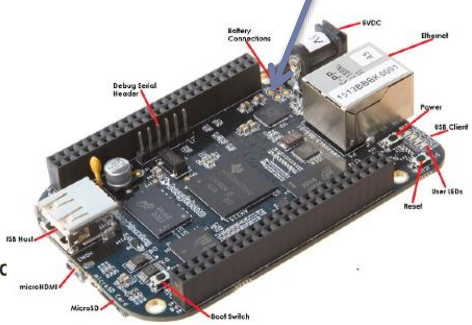


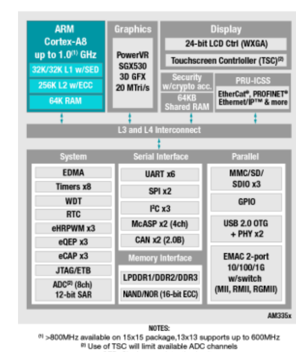


Xilinx Spartan-6 XC6LX16-CS324
16Mbyte Micron Cellular RAM
16Mbyte Micron Parallel PCM
16Mbyte Micron Quad-mode SPI PCM
100 MHz fixed-frequency oscillator
10/100 SMSC LAN8710 PHY
USB-UART

CPU: TI AM335x 1 GHz – ARM A8
RAM: 512 Mb
LAN: 10/100 Mbit
USB: 1 port
UART: up to 4 serial lines
I2C: up to 2 I2C bus
SPI: up to 2 SPI buses
ADC: up to 7 analog input @12bit
GPIO: up to 65 GPIO lines
STORAGE: 2Gb eMMC + uSD carc

Video output on microHDMI





BBB by TI

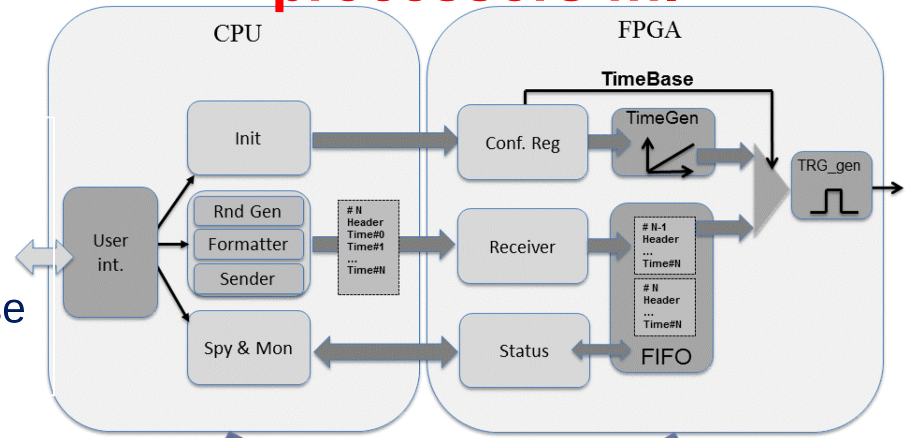
The random generator implementation

A random pulse generator is required to simulate the muon decay

- Used for SiPM detector stations studies and pileup measurements over a large dynamic range
- Check of electronics, DAQ and data processing in real conditions

Typically implemented in hardware but with powerful embedded processors ….

- N. of hits between 10 and 100
- Time resolution of pulse generator = 10 ns



Linux distribution:

- Full support for compilers and applications (packages management via APT repository)
- Kernels: major releases available – 3.x (up to 3.8.13 with Xenomai - Real-Time Linux support) – 4.x (up to 4.5.0)

Software processes:

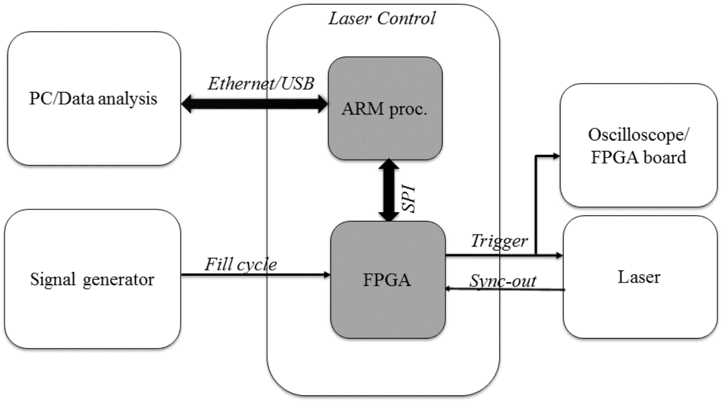
- **Configuration**
- random extraction of n. hits → Gaussian
- random extraction of time hits → exp(-t/τ)
- **Formatter**
- **Sender** on SPI link
- **Spy&Mon** for FIFO access

Hardware modules:

- **Receiver** from SPI and frame check
- **FIFO writer**
- **Digital comparator** of time hits
- **Trigger generation stage**

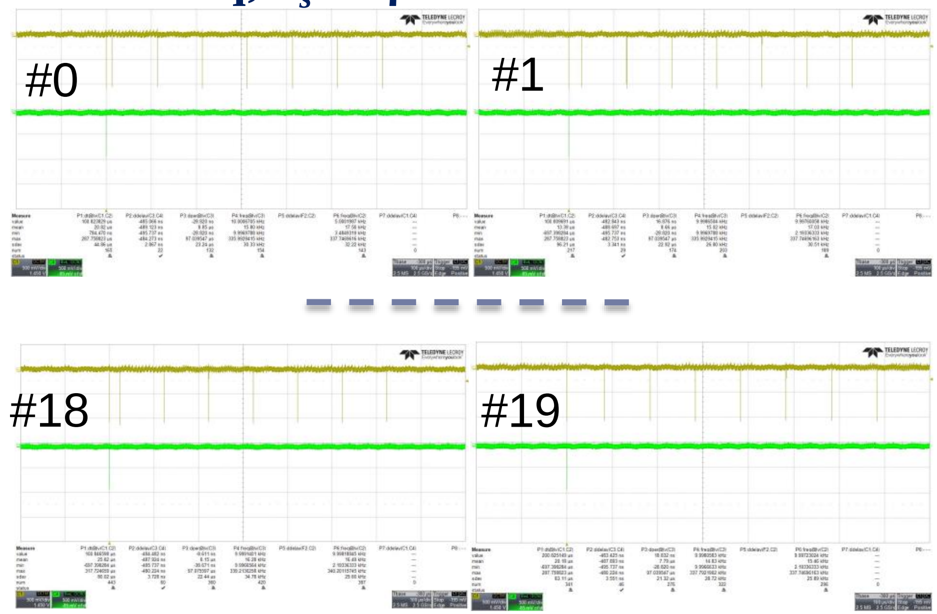
- SPI link = 5 MHz
- Sender process checks the FIFO status with a polling
- Timing characteristics of pulses defined in the final trigger generation

Test measurements: fixed frequency mode

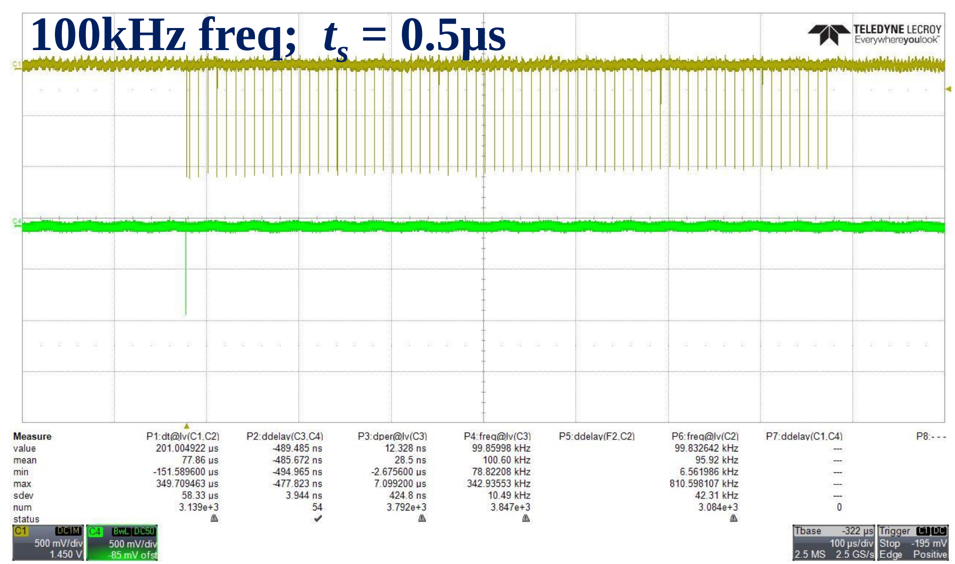


Test bench setup

10kHz freq; $t_s = 5\mu s$



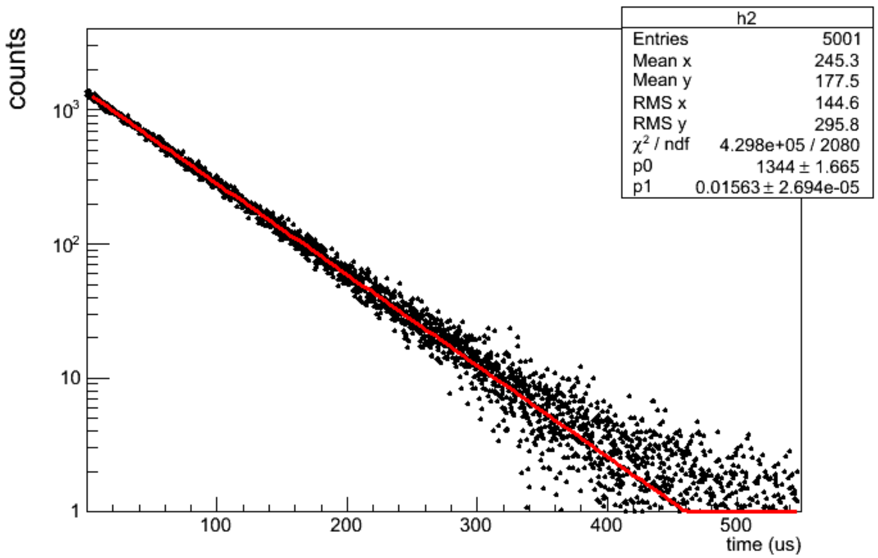
100kHz freq; $t_s = 0.5\mu s$

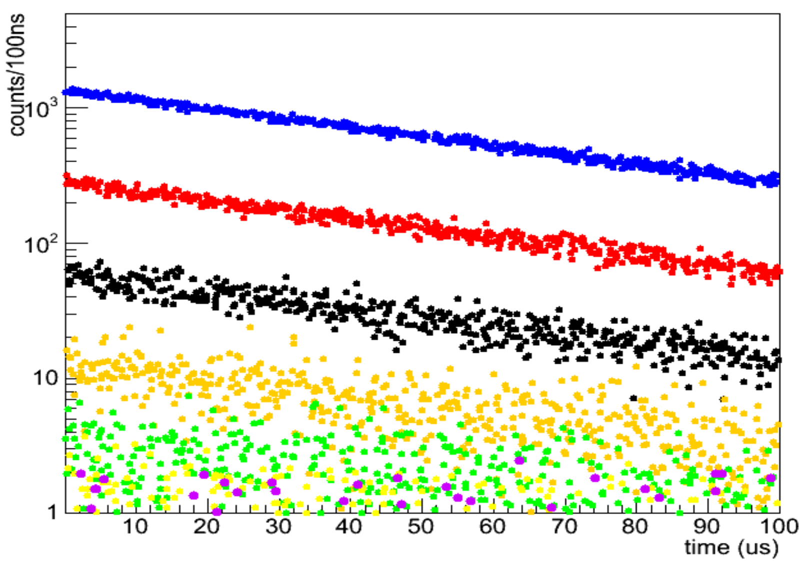


- A signal generator to replace the DAQ and the CCC system
- PicoQuant LDH-P-C405M pulsed diode laser for fully interface
- LeCroy oscilloscope for measurements
- PC for spy and data analysis

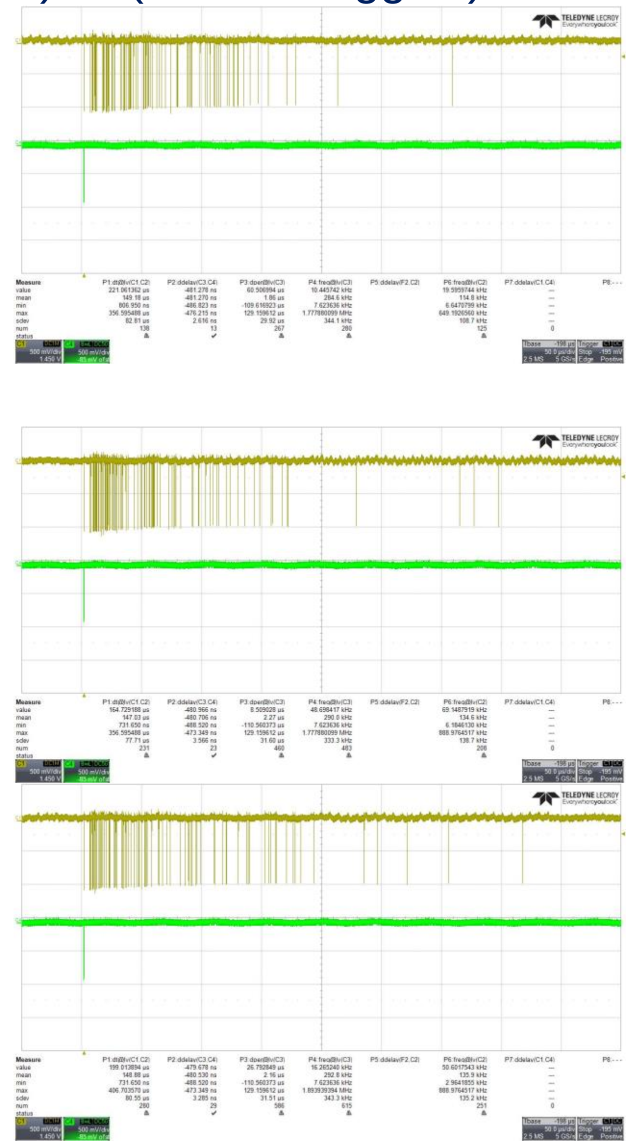
Test measurements: flight simulator

Laser control board used to simulate (g-2) fill (with no wiggles)





Average 96 hits; pulse width = 20ns



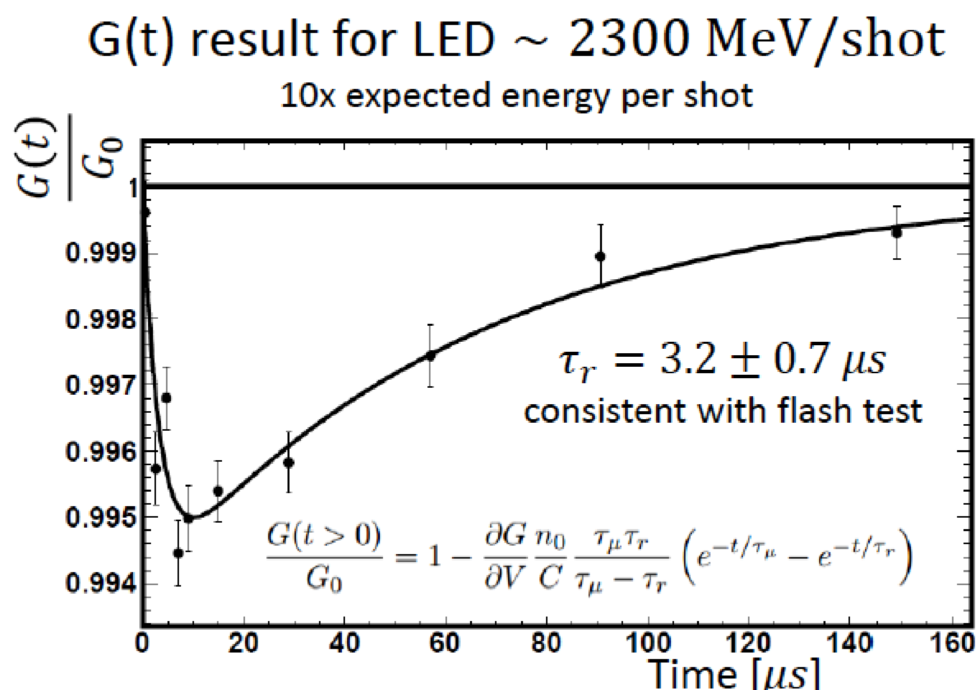
Test measurements (3)

- Flash at t = 0: detectors near injection site face saturation
- G(t) over fill: average current varies with muon lifetime, spans several orders of magnitude
- Short term G(Δt): (pileup / double pulse)

Tests @ LNF and SLAC during 2016

$$G(t)/G_0 = 1 - \frac{\partial G}{\partial V}\frac{n_0}{C}\frac{\tau_\mu \tau_r}{\tau_\mu - \tau_r}\left(e^{-t/\tau_\mu} - e^{-t/\tau_r}\right)$$

simulating Bias Voltage recovering curve

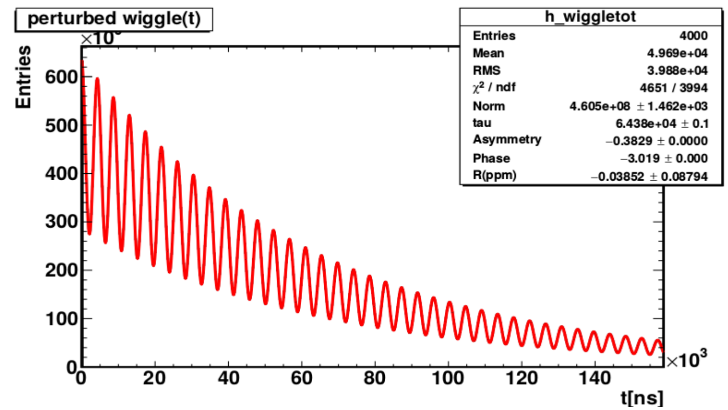


From Aaron presentation using a Led interfaced with a flight simulator board and a laser to fill at constant rate (http://gm2-docdb.fnal.gov:8080/cgibin/ShowDocument?docid=2708)

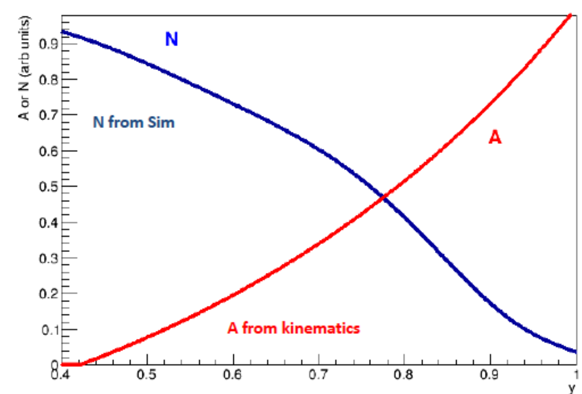
Next step: simulation with wiggle

Wiggle plot: 5-parameters fit function

$N(t) = N(y)[1+A(y)\cos(\omega_a(1+R)t+\phi(y))]\exp(-t/\tau)$



- $Y=E_e/E_{max}$ (E_{max}=3.1 GeV) $0<y<1$
- Normalization N(y), Asimmetry A(y) and phase $\phi(y)$ depend on the electron energy y



Simulation of the positron signal modulated by ω_a

- same system architecture for random generation
- different parametrization of the function

Needed tests for CPU resources in online processing

Conclusions

- The Laser control system manages the interface with the trigger system and the local DAQ system
- It provides the laser calibration pulses according to
  - Sync/RST for electronics initialization and synchronization
  - Pulse train at programmable frequency (kHz÷MHz) during the FILL
  - Muon decay simulation with “Flight simulator”
- The laser control is based on an hybrid platform with an FPGA and a embedded processor
  - The core is a random number generator
- The system is fully (re)configurable and managed remotely
- The laser control has been intensively tested at LNF/SLAC and in other test stands
- The system will be installed at FNAL by the end of this year
- Simulation with wiggle is under way