Scintillation light collection with SiPM and Artg4tk simulations for interactions in Liquid Argon

Summer student work at LArIAT - PPD - FNAL

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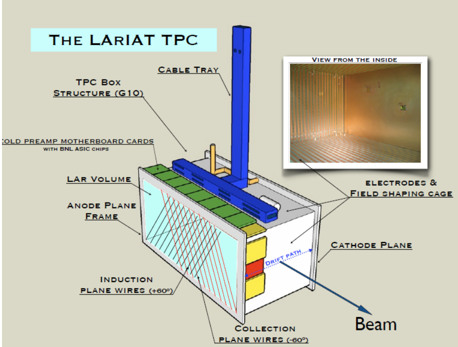
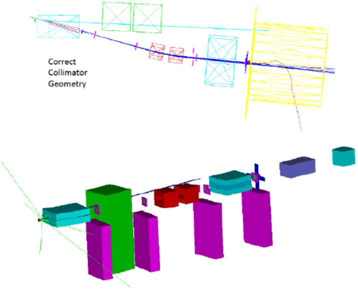
  - Mu plus and muminus interactions in Liquid Argon: analysis and discrimination

Introduction to LArIAT

LArIAT: Liquid Argon in A Testbeam

This experiment is part of the US Intensity Frontier Neutrino Program with LArTPC, Liquid Argon Time Projections Chambers. LArIAT program consist in a calibration of the Argon TPC in a dedicated beam line.





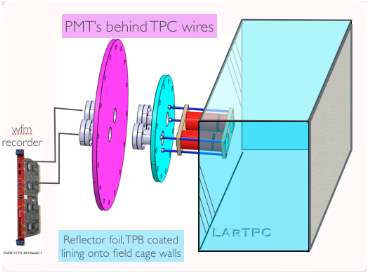
The tertiary beam layout from G4BeamLine MC simulation. Upstream and downstream collimators are in cyan, bending magnets in red, wire chambers and their stands in purple, the liquid argon TPC volume in violet. In the top view, the cryostat is shown in yellow. The green block is for shielding.

Hardware: Scintillation light collection with SiPM and readout

Liquid argon scintillation light readout:

- Trigger / t_0
- Calorimetric energy reconstruction

The readout is now composed by an array of two PMT's for cryogenic applications; two Silicon Photomultiplier Detectors (SiPM) are going to be added.

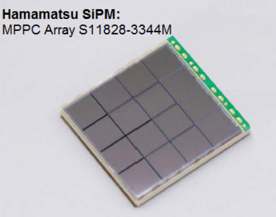


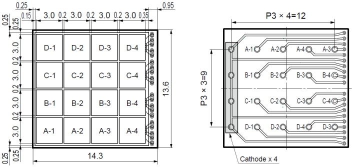
Scintillation light collection with SiPM and readout

SiPM for detection of scintillation light in LArIAT: Hamamatsu MPPC Array S11828-3344M

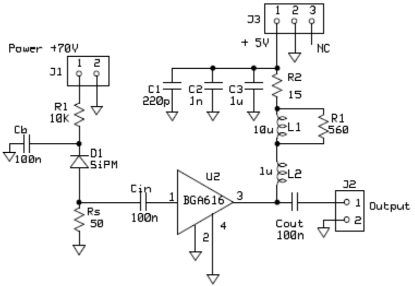
- Array of 16 channels anode output; each channel connected to 3600 pixels.
- Effective photosensitive area: 3x3 mm^2.
- Reverse breakdown voltage $V_{bk} \simeq +70$ V.
- FF=61.5%, PDE=50%
- Gain $\simeq 7.5 * 10^5$.

The SiPM voltage bias circuit and one stage of PreAmp had to be designed, produced and tested.

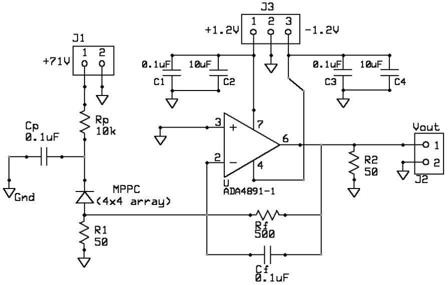




Design the bias and preamp circuit for Hamamatsu SiPM:
Express Software

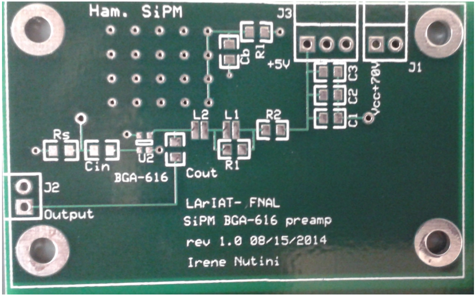


Irene's SCH circuit: opamp BGA616 (Infineon Technologies)



Will's SCH circuit: opamp ADA4891 (Analog Devices)

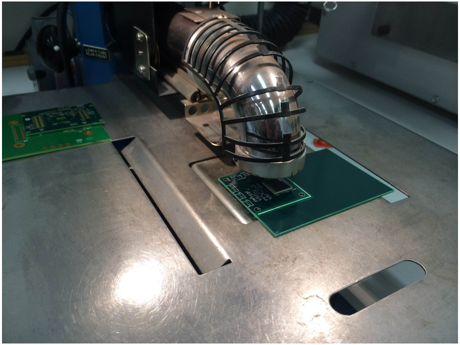
4-Layers PCB Miniboard for bias and preamp circuit for SiPM: my spare board



Thanks to Ed Kearns for his suggestions for the design on PCB

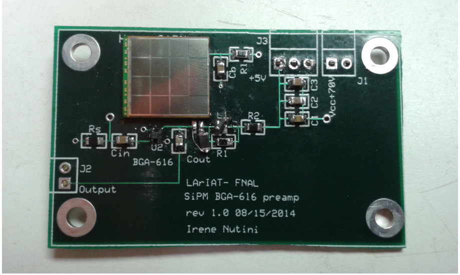
Scintillation light collection with SiPM and readout

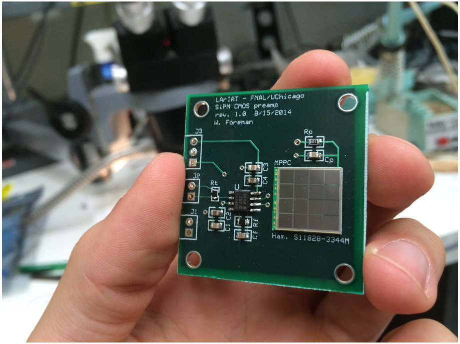
Mounting the components on the Miniboards: SiPM reflow:



Thanks to Albert Dyer for his suggestions for the reflow and the soldering.

The Miniboards are ready to be tested!:





Powering the Miniboards:

- Power supply for the SiPM: *HP 6645A System DC Power Supply* -> Inverse polarization: V_{cc}=+71.5 V (GAPD region of operation)
- Power supply for opamp BGA616: *HP6236B Triple output Power Supply*-> + 3.7 V (maximum +4.5V)

Scintillation light collection with SiPM and readout

Testing the boards:

1) Test of goodness of SiPM reflow with a blue LED

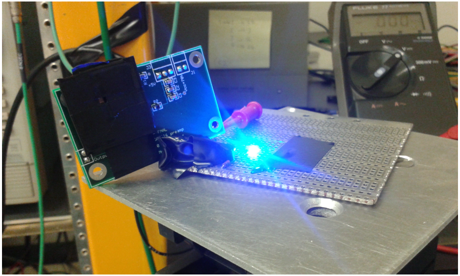
To test the goodness of the connection of each anode of the SiPM with the pads on the board done with the reflow:

- Cover the SiPM with a black mask with a little hole with the dimensions of a single channel; select a single channel.
- Light the SiPM with LED and measure the difference in output voltage and in the output dynamic resistance between cathodes and anodes

2) Coupling the SiPM boards with BC408 plastic scintillator

- Cover BC408 with Al-Mylar and then with black tape, leaving opened only two windows for the SiPMs
- Match the SiPM on the window with siliconic optical grease and then cover all
- Seeing signals from scintillation photons reaching the SiPMs

1) Test of goodness of SiPM reflow with a blue LED



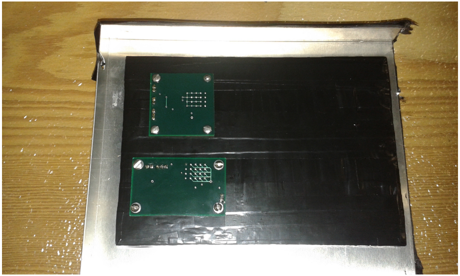
Emission wavelength of blue SMD LED: λ_{LED}= 470nm
Peak sensitivity wavelength for the SiPM: λ_{best}= 440nm (PDE= 50%)

V_{out}= -1.1 mV (room light, no LED), -0.8 /-0.4 mV (with mask, only one channel fired with LED)

R_d= 50Ω (no LED, is R_s), less than 50Ω (with mask, only one channel fired with LED)

Scintillation light collection with SiPM and readout

2) Coupling the SiPM boards with BC408 plastic scintillator:



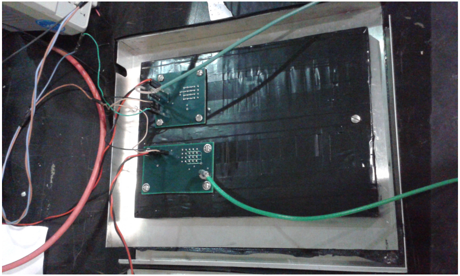
- Scintillator BC408:
  - Dimensions: 17 x 12 x 1 cm^3
  - LY(% Anthracene) = 64 (Anthracene,16500 $\frac{\gamma}{MeV}$)
  - λ =425 nm, scintillation light wavelength
  - λ_{att} =210 cm,attenuation lenght
- Reflective Al-Mylar covering: Reflectivity $R_M = 94\%$

$$LY_{Scint+SiPM} \approx 300 \ \frac{pe}{MeV}$$

(average extimated)

SiPM signals from cosmic rays crossing the scintillator:

Powering the two boards together coupled with the scintillator:



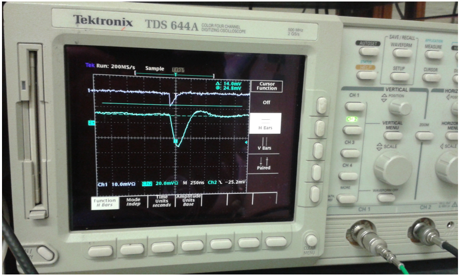
SiPM +71.5V; my opamp (BGA616) +3.7 V ; Will's opamp (ADA4891) +1.2V and -1.2 V.

Experimental setup (Asic Test Lab, WH 14th)

Scintillation light collection with SiPM and readout

SiPM signals from cosmic rays crossing the scintillator:

Coincidence signals from the two boards



Ch.1 Irene's board signal
Ch.2 Will's board signal.

Irene's board: opamp BGA616

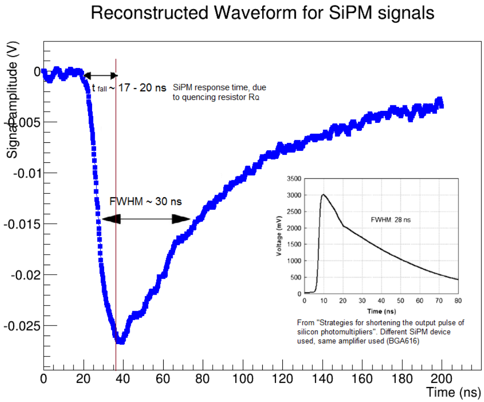
- less gain than Will's
- no offset
- low noise band on signal (less than 1mV)

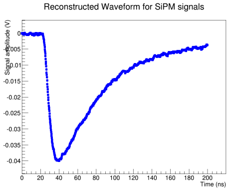
Will's board: opamp ADA4891
used with inverse feedback:

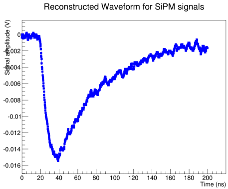
- higher gain
- +10 /+15mV baseline offset
- noise band of almost 5mV
- overshot on the rising tail

(Now Will is working to improve his circuit to fix this problem.)

SiPM signals from cosmic rays crossing the scintillator:
Triggering on Will's board. The signals I saw on the scope from my board came from coincidences, so they should be due to CR.

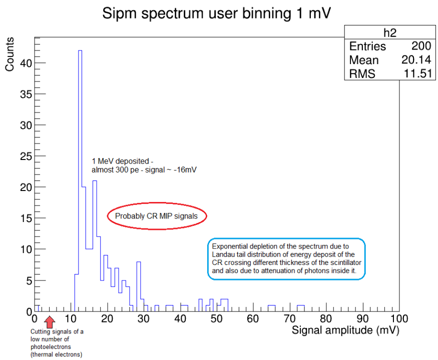




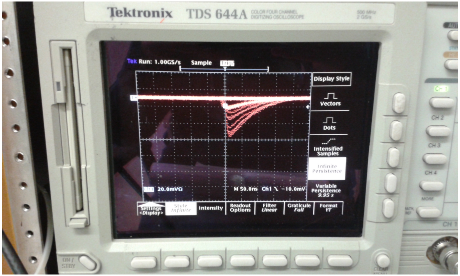


Characterization of SiPM signals:

Spectrum of amplitudes @Tamb with trigger level: - 10 mV



SiPM signals on the scope with *Infinite Persistence* display mode.



Scintillation light collection with SiPM and readout

Characterization of SiPM signals:

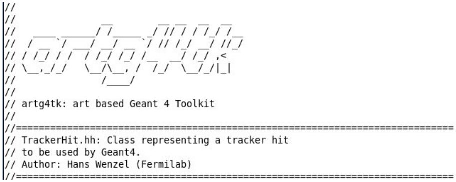
Next to do:

- See CR signal using an external trigger (coincidence of two PMTs coupled with scintillators) (maybe Thursday!)
- Setup a ADC system for acquiring signals from the boards and making spectra of amplitude/charge (maybe also need a shaping step?!)
- Cold test of the SiPM boards: Put the scintillator coupled with the SiPM boards in a dewar with Liquid N_2
- Put the SiPM boards in their sides on the LArTPC PMTs support, cabling and acquiring data

Software: Artg4tk simulations of interaction processes in Liquid Argon

Artg4tk simulation toolkit, principles of work

Artg4tk is a modular Art+Geant4 framework.



- Geant4:
  - .gdml file: detector description (geometry, material, sensitive detector...)
  - .fcl file: physics list (diffferent models for interaction processes) and user actions
- Art:
  - Created geant "products" stored in the Art Event
- Analisys modules

Artg4tk simulations of interaction processes in Liquid Argon

Simulations of particle interactions in Liquid Argon

MC study of physical processes of charged particle interaction on Ar target.

- muon capture vs muon decay
- hadron (proton, pion) interactions (features of spallation processes)
- pions and kaons interaction processes

Liquid Argon Detector in Geant4 (.gdml file) :
- Tracker Sensitive Detector
- Physical and geometrical proprieties of the LarTPC experiment: Cylinder of Liquid Argon (G4_lAr) with 300cm radius and 600 cm height(z).

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    </solids>

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        </volume>  . . . .
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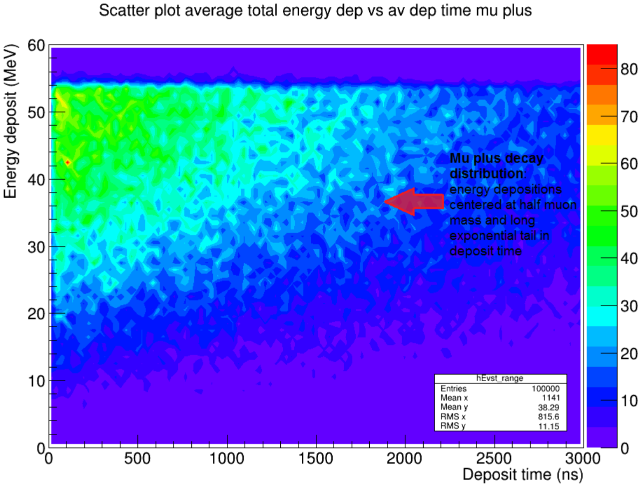
Mu plus (μ_+) and muminus(μ_-) interactions in Liquid Argon: analysis and discrimination

- μ_+ only **decay** after loosing all kinetic energy by ionization processes in Liquid Argon. (τ_d= 2.2μs)
  μ_+ -> $e^+ + \nu_e + \overline{\nu_\mu}$
- μ_- after lossing kinetic energy are captured in orbit of Ar nuclei and then can undergo either decay (d) or capture inside the nucleus(c). ($\tau_{tot} \simeq$ 570 ns, $\frac{1}{\tau_{tot}} = \frac{1}{\tau_d} + \frac{1}{\tau_c}$)
  - **Decay** (BR= 26 %)
  μ_- -> $e^- + \overline{\nu_e} + \nu_\mu$
  - **Capture by ^{40}Ar nucleus** (BR= 74 %):

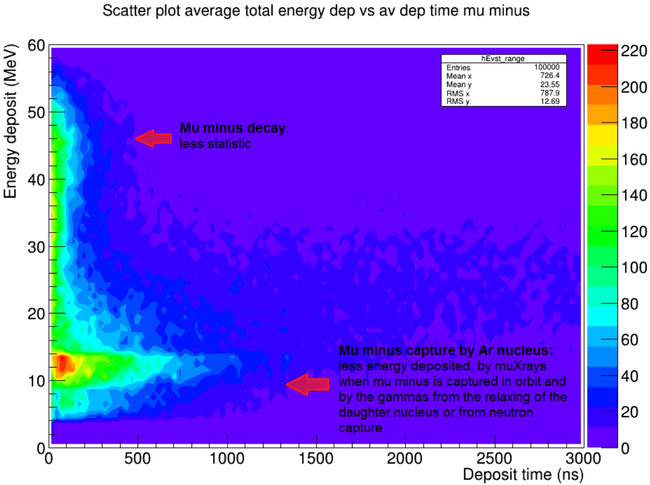
- $^{40}Ar + \mu_-$ -> $^{40}Cl + \nu_\mu$
- $^{40}Ar + \mu_-$ -> ^{39}Cl + n +ν_μ (principal)
- $^{40}Ar + \mu_-$ -> ^{38}Cl + 2n + ν_μ
- $^{40}Ar + \mu_-$ -> ^{39}S + p + ν_μ
- $^{40}Ar + \mu_-$ -> ^{38}S + d + ν_μ

μ_+ at 1GeV, Scatter Plot Deposit time vs Residual energy deposited (after having released all kinetic energy)

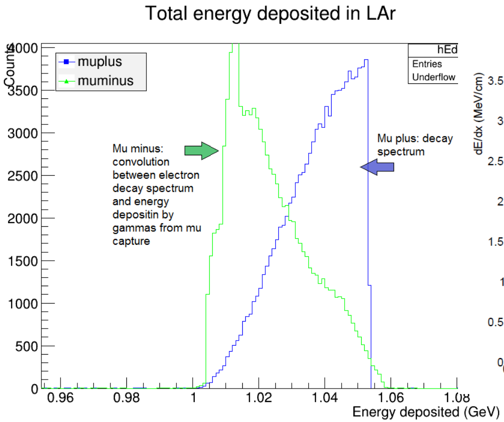


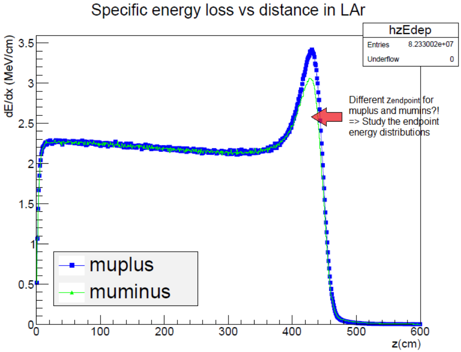
Artg4tk simulations of interaction processes in Liquid Argon

μ_{-} at 1GeV, Scatter Plot Deposit time vs Residual energy deposited (after having released all kinetic energy)

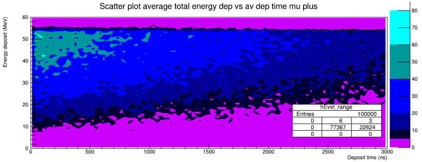


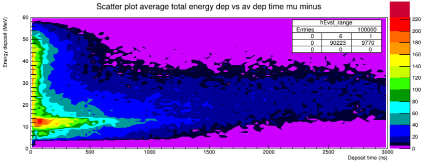
Comparison 1 GeV μ_+ and μ_-.





Comparison 1 GeV μ_+ and μ_-. Discriminating between μ_+ and μ_-





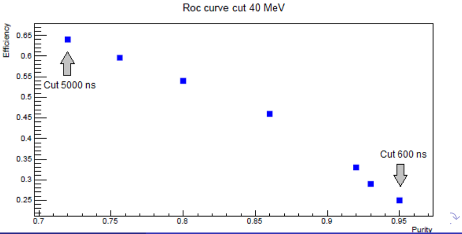
Cuts in (E,t) to select μ_- capture ev.
Residual energy deposited:
E < 40 MeV (fixed)
Deposit time: t < 600, 800,1000, 2000, 3000, 4000, 5000 ns

Efficiency of selection:

$$\epsilon = \frac{\int_0^{t_{cut}} mu_{-}counts}{Nevents}$$

Purity:

$$P = \frac{\int_0^{t_{cut}} mu_{+}counts}{Nevents}$$



Artg4tk simulations of interaction processes in Liquid Argon

Next to do:

- Can we discriminate from μ_+ to μ_- from endpoint informations? - > Extimate of the endpoint position x_{end} for each event, make distribution of x_{end}s and endpoint energy distributions (integrating from x_{end} to $x_{end} + \delta$ (fixed) for each event) for μ_- and μ_+
- Study spallation processes for protons and neutrons
- Treating Liquid Argon detector as a Sensitive Calorimeter, dividing the whole volume in sheets of 2mm thickness (spatial TPC resolution)

Conclusion

I had a great experience in Fermilab - LArIAT! I've learnt new things and worked on interesting projects with nice and kind people.

Thanks to:
My supervisors Flavio Cavanna and Jennifer Raaf,
Hans Wenzel, who helped me becoming confident with Artg4tk simulations and with whom I've worked on muons discrimination,
Ed Kearns, who gave suggestions for the PCB design of the SiPM boards,
Will Foreman with whom I've worked trying to operate the SiPM boards,
Albert Dyer, who helped me and Will soldering the little components on the SiPM boards and doing the reflow of the SiPM,
Rob Acciarri, Jason St.John and all the people of LArIAT collaboration that made me feel part of their group even if I was the last arrived member,
All of my friends here in Fermilab that supported me when I was struggling with the SiPM board and with whom I share nice days here in the US.