50 channel FPGA based ADC and TDC Data Acquisition System for a Neutron Detector Experiment

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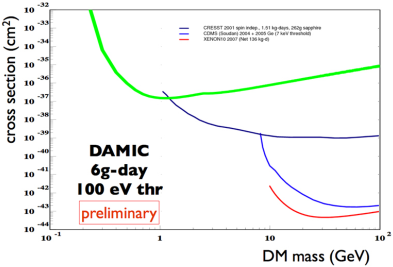
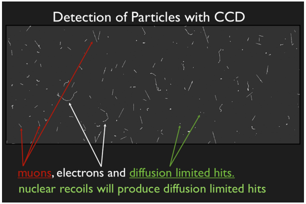
Summer Internship Program
Fermi National Accelerator Laboratory

September 27, 2013

DAMIC Experiment

DAMIC (Dark Matter In CCDs) is a Fermilab experiment that makes use of CCDs to search for **light dark matter candidates** with masses in the order of a few GeVs.





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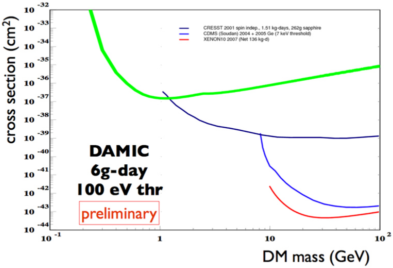
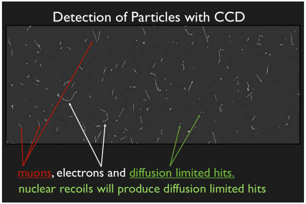
The new CCD technology allows us to set a **lower threshold** than other experiments have been able to do so far, making us more sensitive to lower mass dark matter particles.





Neutron Detector Experiment (1)

We are interested in designing and constructing a **scintillator neutron detector** in order to use neutron beams to make silicon quenching factor calibrations for the DAMIC experiment (University of Notre Dame).

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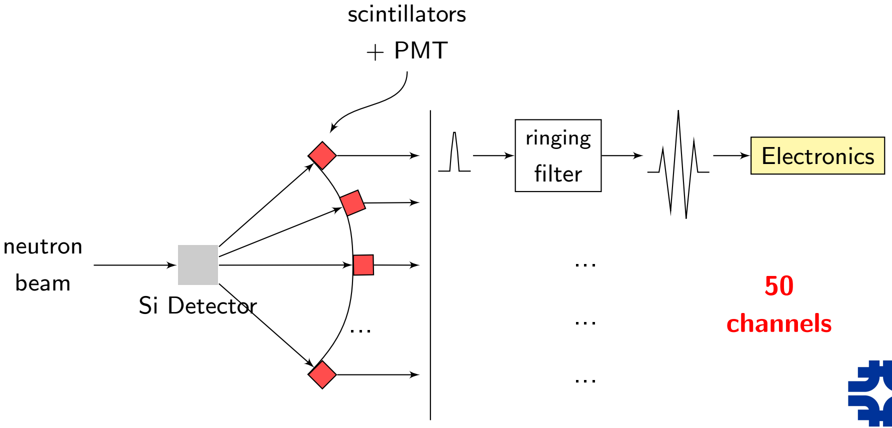

Neutron Detector Experiment (2)

My task @ Fermilab

Designing the Electronics for the DAQ and in particular:

- Programming the FPGA board using Simulink and ISE Design Suite;
- Acquiring data from the memory by means of the DOOCS interface;
- Analyzing the stored data using MATLAB.

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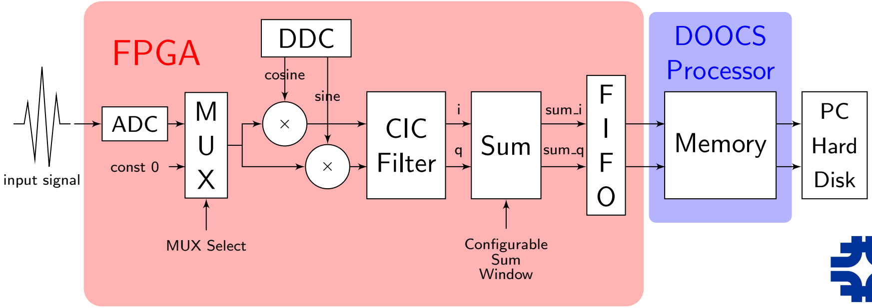

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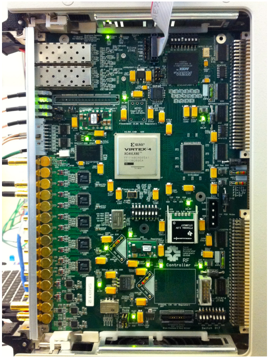

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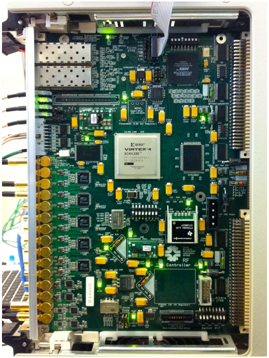

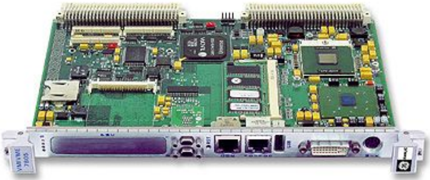

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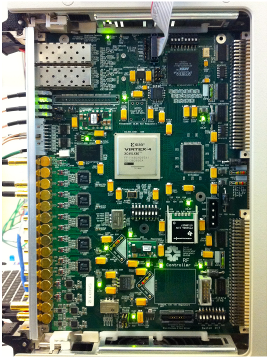
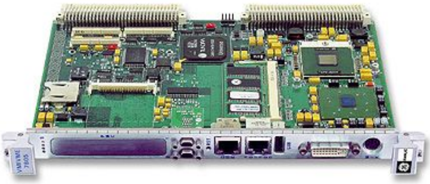




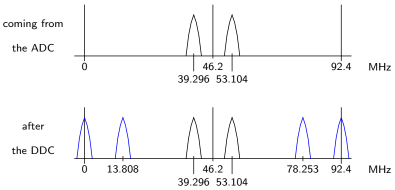
They were previously used for a cavity controller (ESE LLRF controller) for the ILC project.

ISE Design Project and Simulink Models (1)

Digital Down Converter (DDC)

The input real signal (centered at an IF $f_{IF} = 53.104$ MHz), is sampled at $f_s = 92.4$ MHz and digitized.

The DDC then converts it to a **baseband complex signal** centered at zero frequency.



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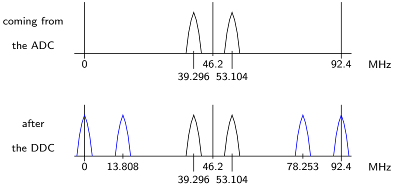
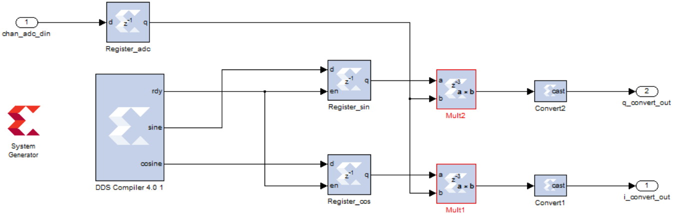
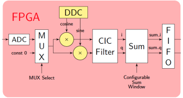


The Direct Digital Synthesizer (DDS) generates a complex sinusoid at the chosen frequency of $f_{DDS} = 39.296$ MHz.





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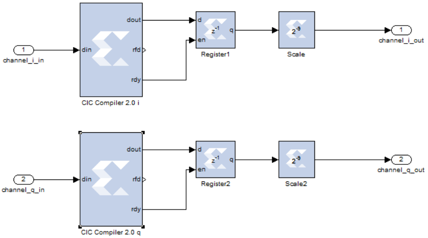
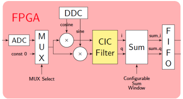
- Differential delay: $M = 2$;
- Sample rate change factor: $R = 16$.





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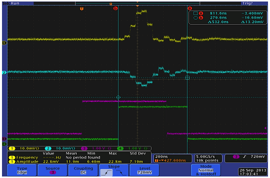

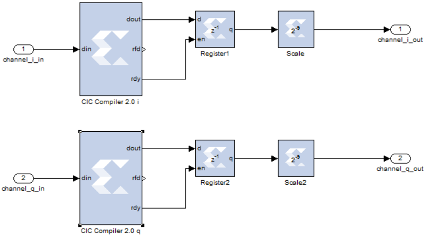

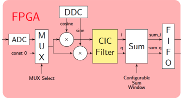

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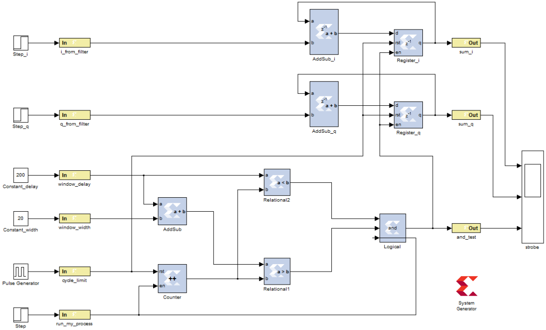

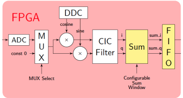

ISE Design Project and Simulink Models (3)

Sum Block and FIFO Register

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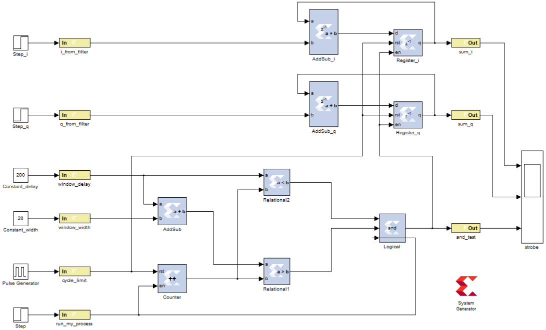
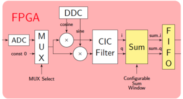


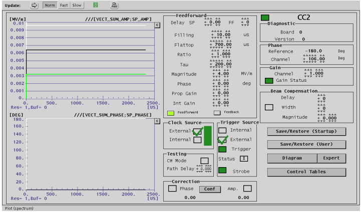


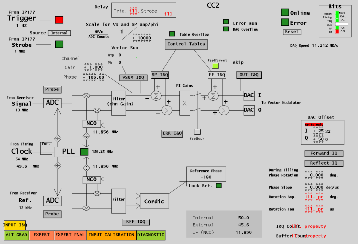
FIFO register: a FIFO is needed to decrease the sampling frequency to 5.775 MHz, which is compatible with DOOCS processor.

Data Acquisition and Analysis (1)

DOOCS Interface and Reflection

Reflection is the software that lets us interact with the processor.





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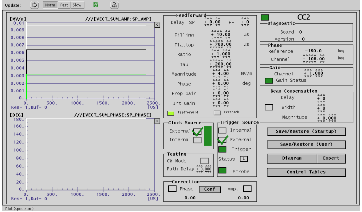

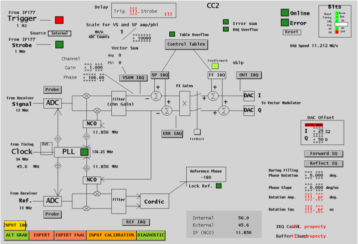

Through **DOOCS interface** we can:

- Check clock and trigger status;
- Modify delay and width of the configurable windows;
- Look at channel outputs that constantly update;
- Acquire the data and save them into a text file.

Data Acquisition and Analysis (2)

Data Analysis with MATLAB

We wrote several MATLAB scripts and functions to handle the acquired data and in particular to:

```
function [ ] = histograms( data_i2, data_q2, data_i3, data_q3 )

complex2 = complex(data_i2, data_q2); %calculates amplitude and phase for channel 2
ampl2 = abs(complex2);
phase2 = angle(complex2);

complex3 = complex(data_i3, data_q3); %calculates amplitude and phase for channel 3
ampl3 = abs(complex3);
phase3 = angle(complex3);

phase_diff = phase3 - phase2; %calculates phase difference between the two channels

figure;
s(1) = subplot(3,1,1);
s(2) = subplot(3,1,2);
s(3) = subplot(3,1,3);

hist(s(1),ampl2,300); %plots the histograms for ampl2
title(s(1), 'Amplitude (channel 2)');
xlabel(s(1), 'points');
ylabel(s(1), 'repetitions');

hist(s(2),ampl3,300); %plots the histograms for ampl3
title(s(2), 'Amplitude (channel 3)');
xlabel(s(2), 'points');
ylabel(s(2), 'repetitions');

[g, h] = hist(s(3),phase_diff,300);
%plots the histograms for phase_diff after rescalin the x axis on the basis of the TDC
m = 0.31002;
h_scaled = h / m;
stairs(h_scaled, g);
xlim([-10 10]);
title(s(3), 'Phase difference');
xlabel(s(3), 'ns');
ylabel(s(3), 'repetitions');

end
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- Plot them by means of **histogram bars** to compare the results with the expected behavior.

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We took several measurements on two channels using different input delays (0 to 7 ns) and plotted the difference in phase between them, obtaining a **linear relationship** as expected.

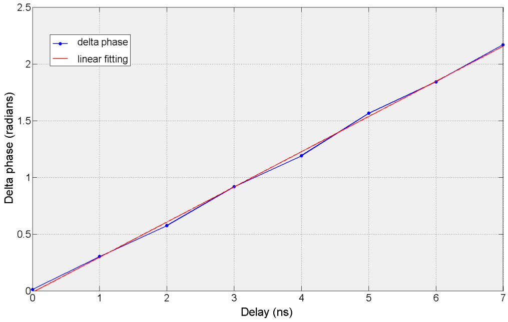
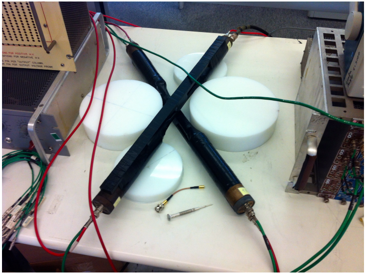


Photo Multiplier Tube Readout @ SiDet (1)

Equipment and setup

We tested the Data Acquisition and Analysis system at the Fermilab Silicon Detector Facility (SiDet) using **scintillators and Photo Multiplier Tubes** (PMTs) to detect muons.



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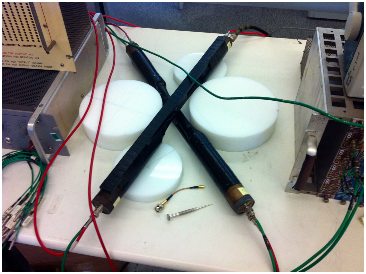

We chose **muons** for the test because there is plenty of them and because they are safer.

Photo Multiplier Tube Readout @ SiDet (2)

Data Acquisition and Analysis

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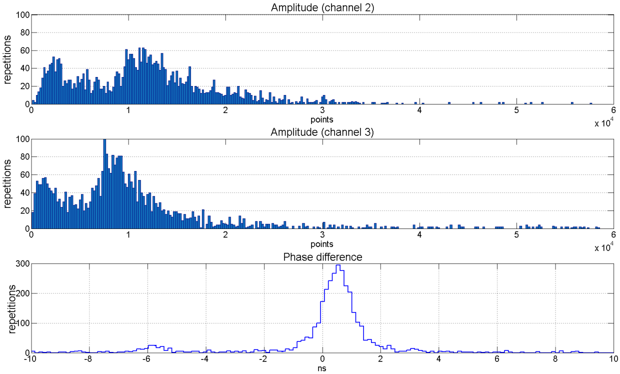


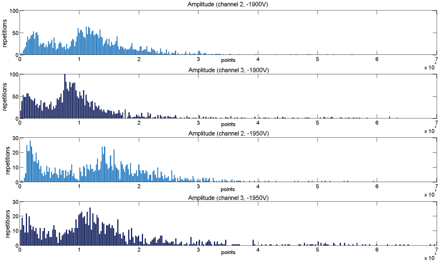
Amplitudes of channels 2 and 3 and phase difference (zero delay and input voltage of -1900 V)

FWHM $\simeq$ 1.5 ns

Photo Multiplier Tube Readout @ SiDet (3)

Data Acquisition and Analysis

Amplitudes of channels 2 (light blue) and 3 (dark blue) with input voltages of -1900 V and -1950 V



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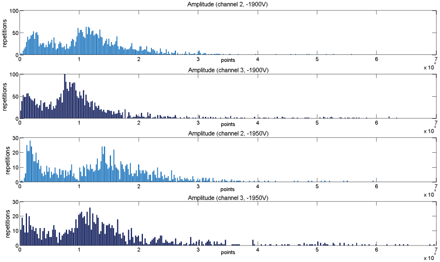

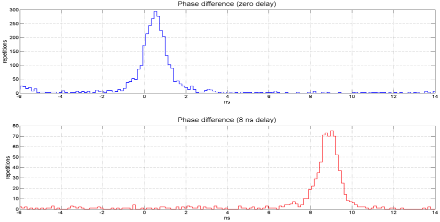

Phase difference with zero delay (blue) and 8 ns delay (red) between the two channels