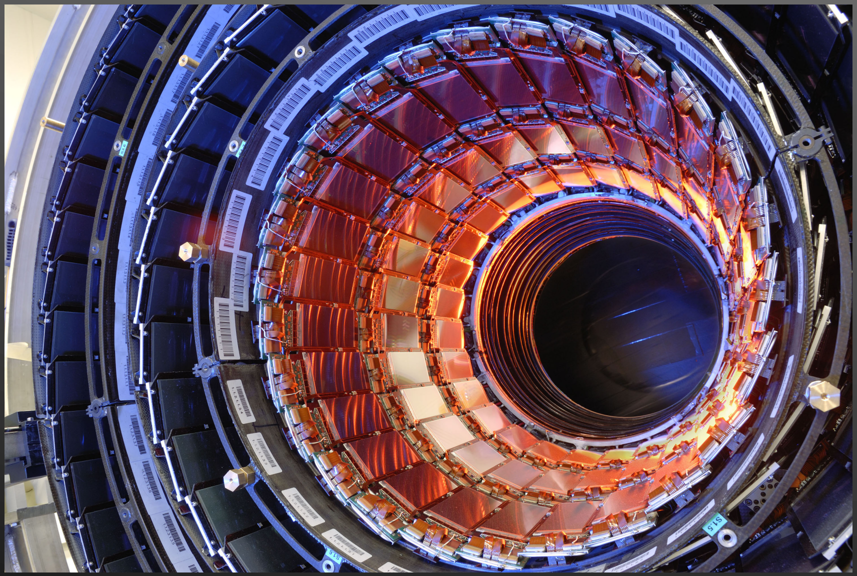
Software Implementation for the Characterization of Silicon Pixel Detectors at CMS

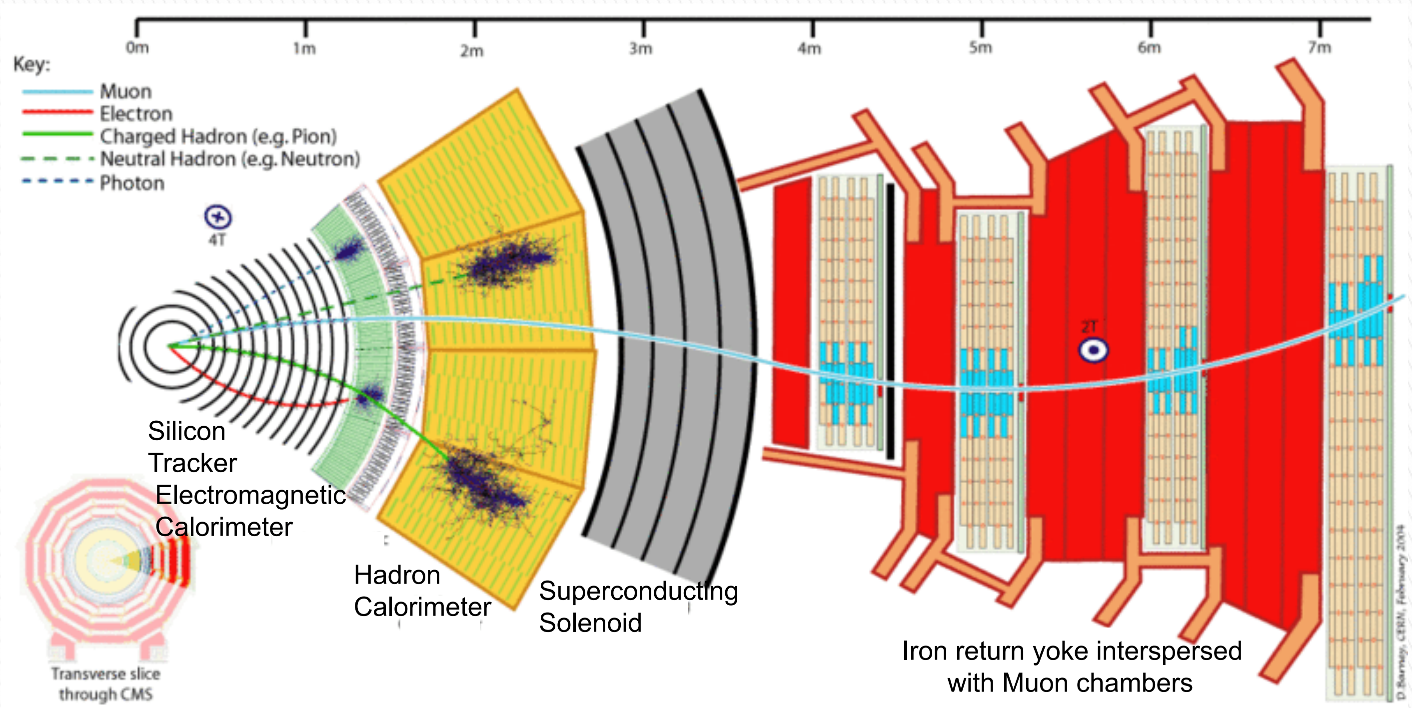
K.A. Miller, Florida A&M University
R. Eusebi, Texas A&M University

Why Do We Need CMS?

- CMS was built to explore:
  - The Higgs boson
  - Extra dimensions
  - Black holes
  - Supersymmetry
  - Dark matter

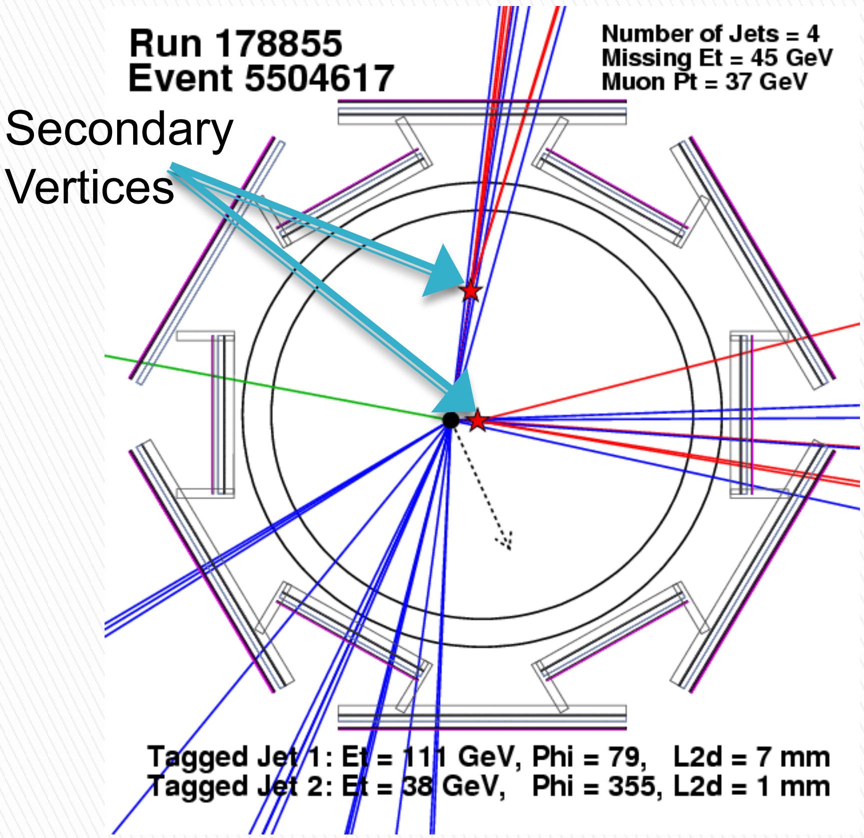


How Does CMS Track Particles?



- Particles are detected as they pass through successive layers of detectors
- Particles come out of the collision and bend according to a magnetic field
- The path of a particle is reconstructed from where the particles passed through the detectors

Why Are Pixel Detectors Important?



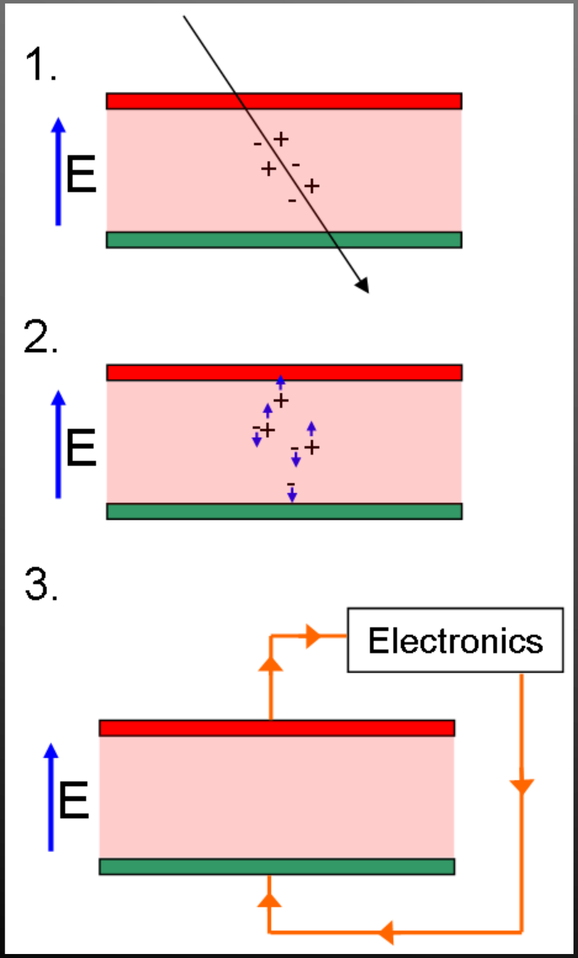
- B mesons decay close to the collision point, creating secondary vertices
- Pixel detectors are closest to the collision and allow determination of secondary vertices with greater accuracy
- B mesons are a main component of the Higgs boson decay products

Why Do We Need to Test Pixel Detectors?

- Pixel detectors are the closest to the beam line and are exposed to large amounts of radiation
  - Radiation changes the properties of the pixels
  - Radiation damages the detectors, necessitating frequent replacement
- Research is constantly being done to make detectors that can better withstand the radiation and thus last longer
- Pixels must be well-suited to the task of detecting particles

Detection of Particles

- When a particle passes through matter, it creates free electron-hole pairs
- The free charges move according to the applied bias
- The charges are detected by electronics, indicating a particle passed through that pixel

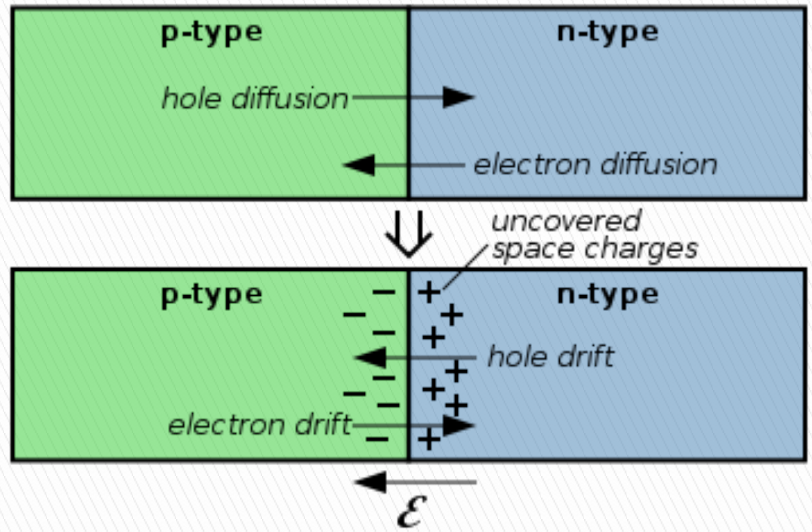


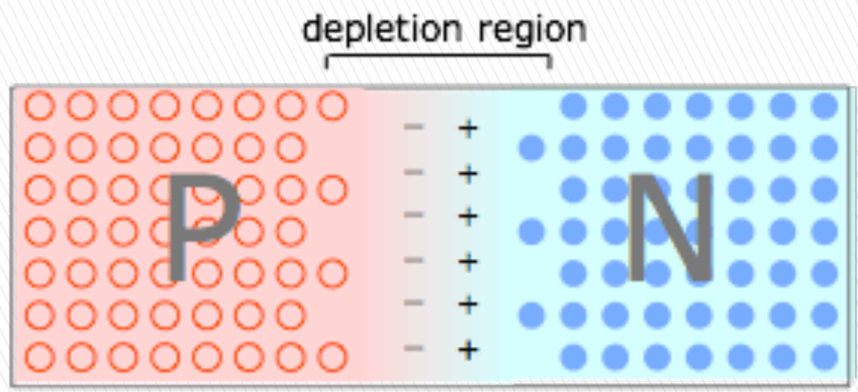
Construction of Pixel Detectors

- Pre-existing free charges would make it difficult to detect charges freed by passing particles
- The pixel detectors at CMS are doped silicon detectors
- Pixel detectors are made of either small p-type pixels imbedded in a larger n-type semiconductor, or vice-versa
  - N-type semiconductors have an excess of loosely-bound electrons
  - P-type semiconductors have an excess of electron holes

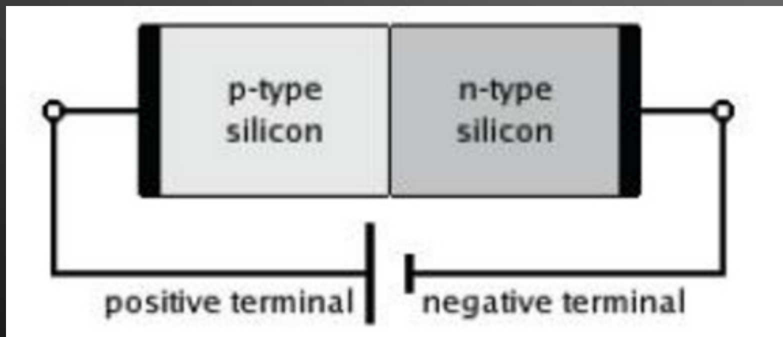
The Creation of a Depletion Region

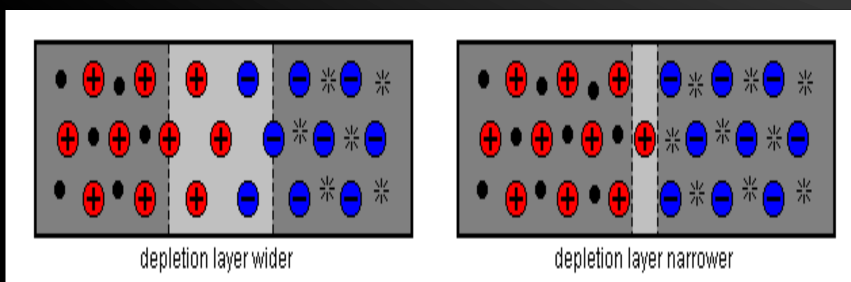
- Particles are tracked by the number of free charges, so no free charges must be present when there are no particles
- At the junction of n- and p-type semiconductors, the electrons in the n-type eliminate the holes in the p-type, creating a charge-free region
- This leaves positive charges along the junction in the n-type and negative charges along the junction in the p-type





Widening of the Depletion Region

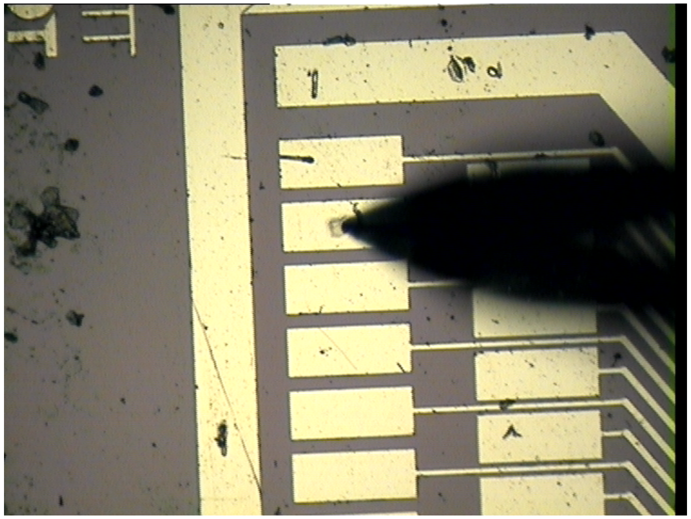




- The depletion region should ideally occupy the entire semiconductor to leave as few free charges as possible
- By applying a reverse bias (see figure at left), holes and electrons move away from the junction
- More neutral atoms are left surrounding the junction, widening the depletion region
- The reverse bias at which the depletion region spans the whole semiconductor is called the *depletion voltage*

Objectives of the Test

- We want to characterize the pixel sensors
  - Are the sensors good enough?
- For each pixel, we want to:
  - Test a pixel at a range of voltages for:
    - Current
    - Resistance
    - Capacitance
- Determine the depletion voltage

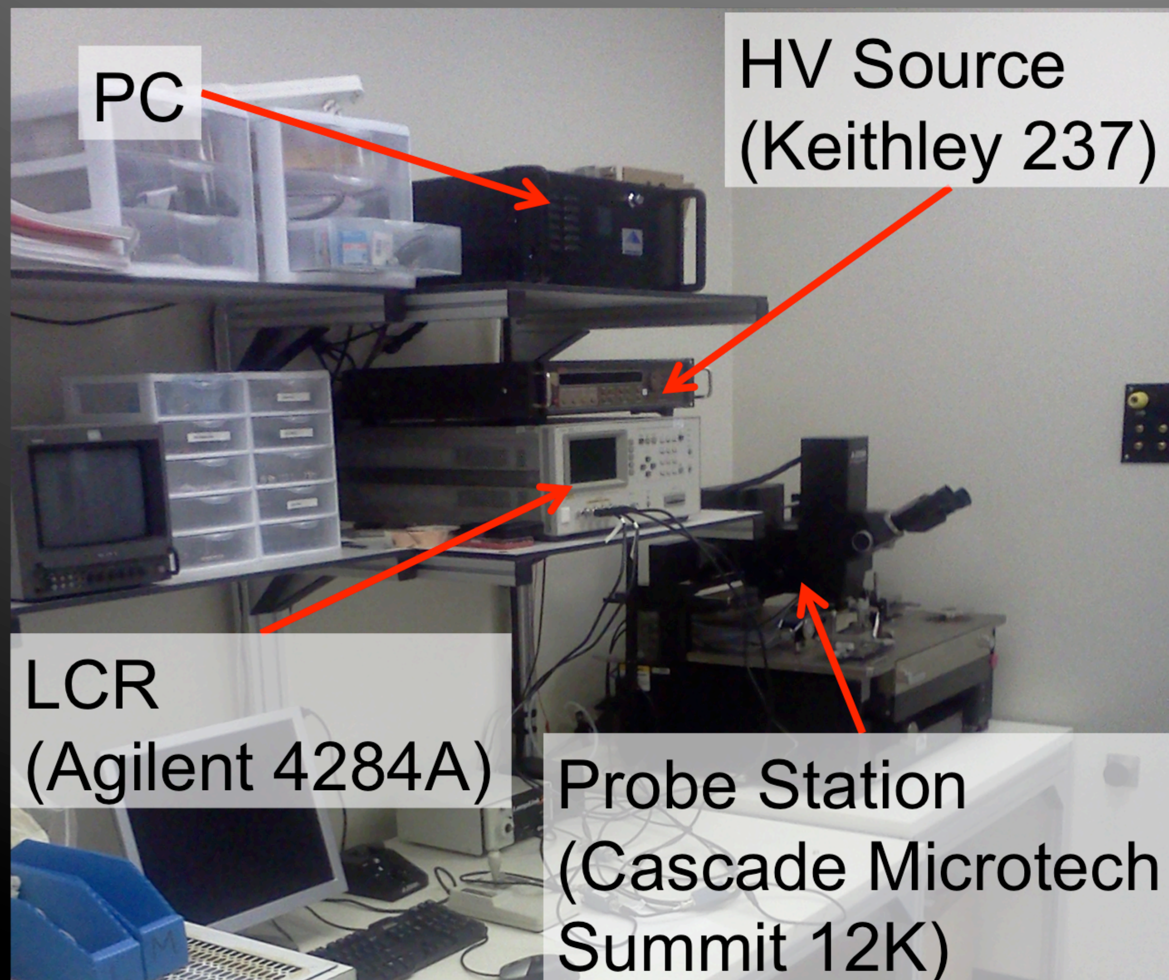


What Does Characterization Tell Us?

- Current and resistance:
  - Let us determine how much power is being dissipated and how much heat is being generated
  - Aid in the design of an appropriate cooling method
  - Determine the optimal temperature at which to run the system
- Capacitance:
  - Is related to the size of the depletion region, and allows us to determine the depletion voltage
  - Helps determine what sort of electronics are needed to amplify and interpret the data

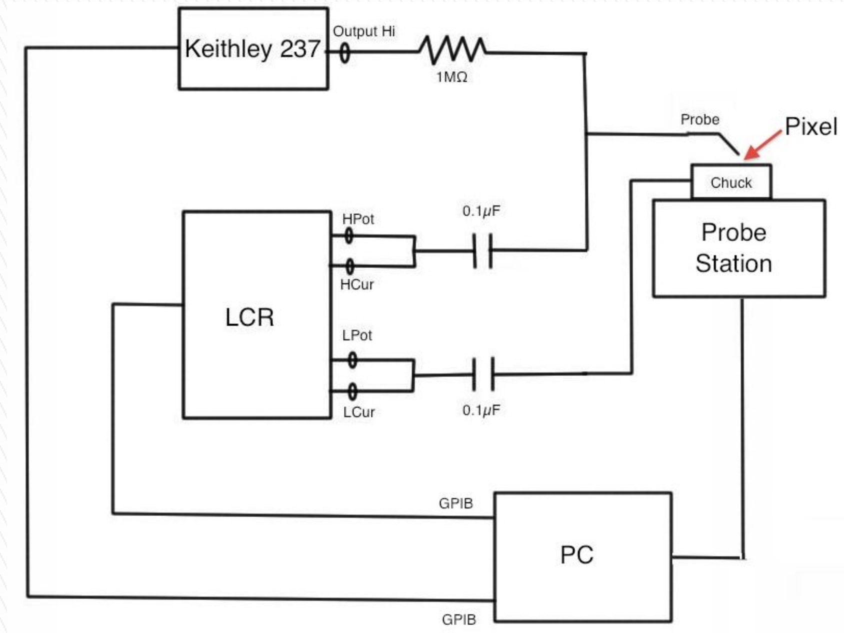
The Test Stand

- Recently purchased equipment
- Consists of a voltage source, LCR meter, and probe station connected to a PC



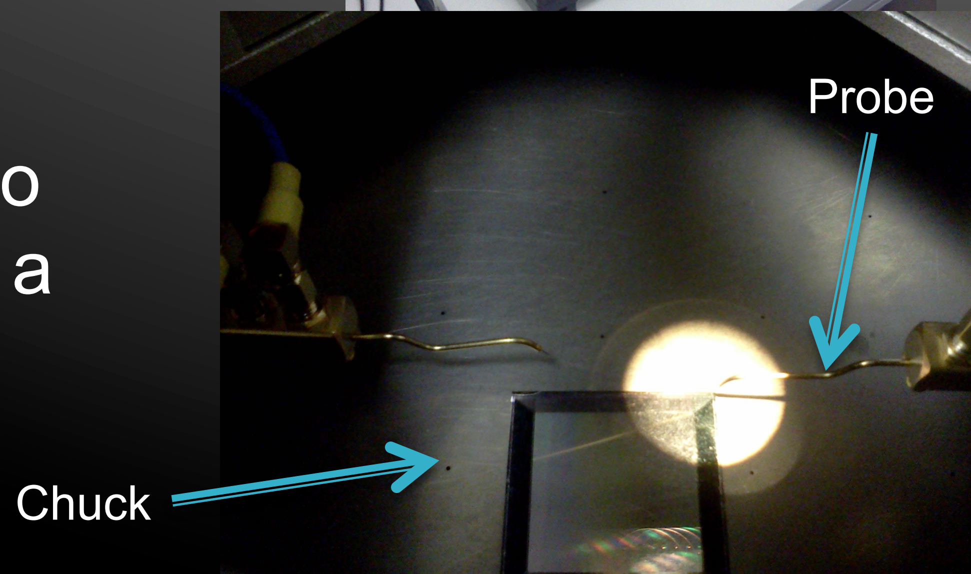
My Job

- Learn how to operate all of the instruments
- Interface each of the instruments with the PC
- Make a program in LabVIEW to control each instrument and perform an automated series of tests
- Make a C++ program that works in ROOT to analyze the data gathered by the tests



The Probe Station

- Cascade Microtech Summit 12K
- Has a resolution of a few microns
- Can be moved remotely
- Allows for voltage to be applied through a probe and at the chuck

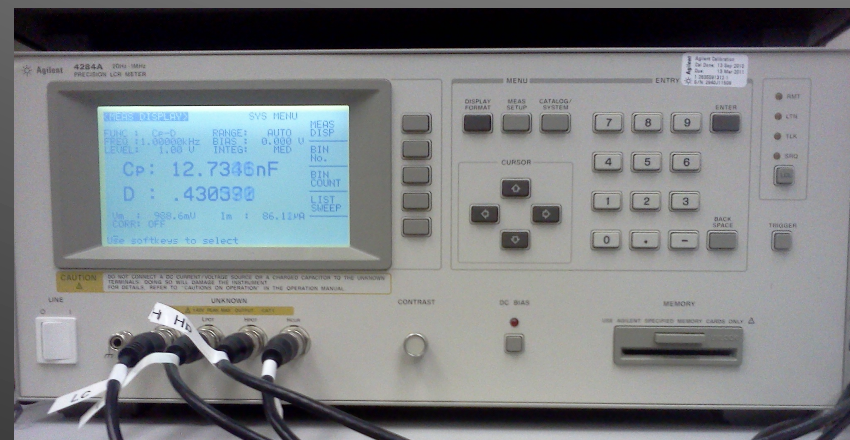


The Voltage Source

- Keithley 237
- Capable of sourcing voltages up to 1100V
- Has the option of sourcing voltage and reading current or sourcing current and reading voltage
- Interfaces with the PC using GPIB

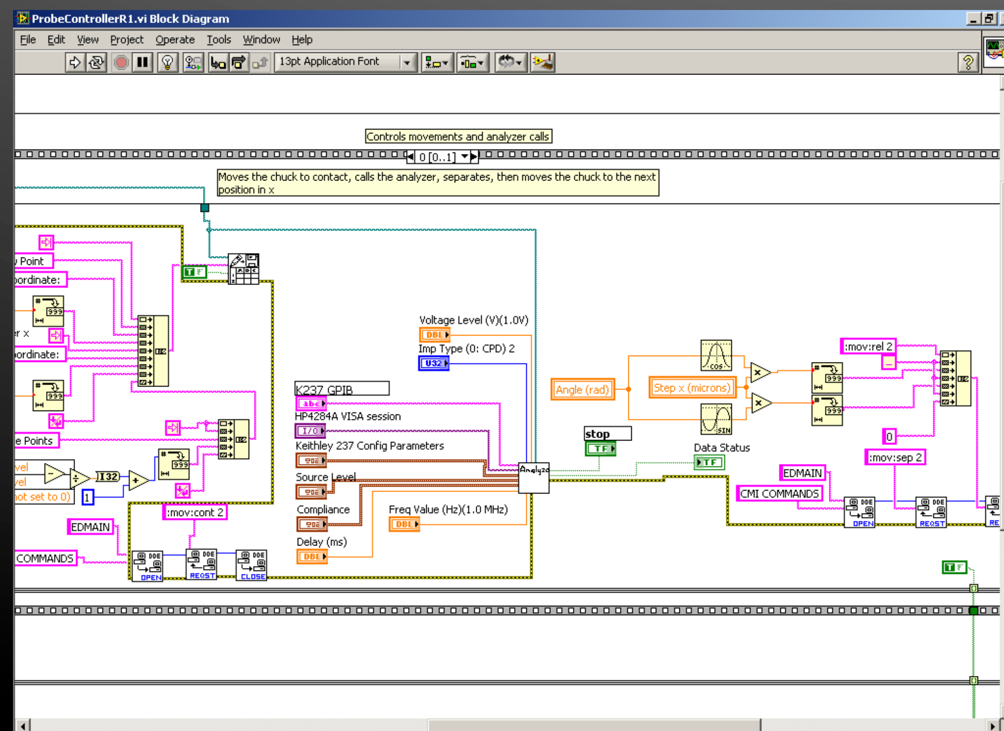
The LCR meter

- Agilent 4284A
- Measures inductance (L), capacitance (C), and resistance (R)
- Measures the impedance at a given frequency
- Connected to the probe and the chuck
- Using four-terminal configuration to minimize noise



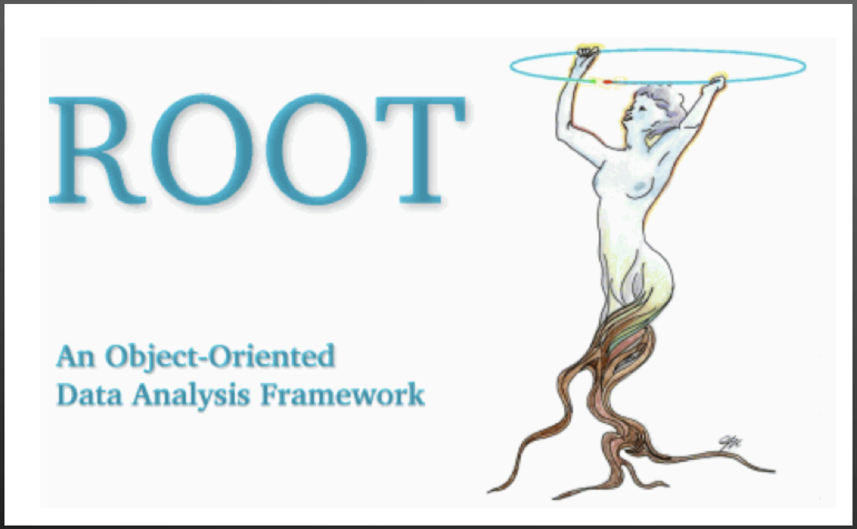
The LabVIEW VI

- The LabVIEW virtual instrument (VI) controls the voltage source, the LCR meter, and the probe station
- The main VI calls a measurement VI at each pixel in a user-defined grid
- The VI prints measurements to a database
- Consists of 5 VI's
  - Control VI
  - Measurement VI
  - VI Controlling Keithley 237
  - VI Controlling LCR meter
  - Calibration
    - Program can be calibrated to operate when the detector is not inserted with its edges parallel with the motion coordinate system of the probe station



Analyzing the Data

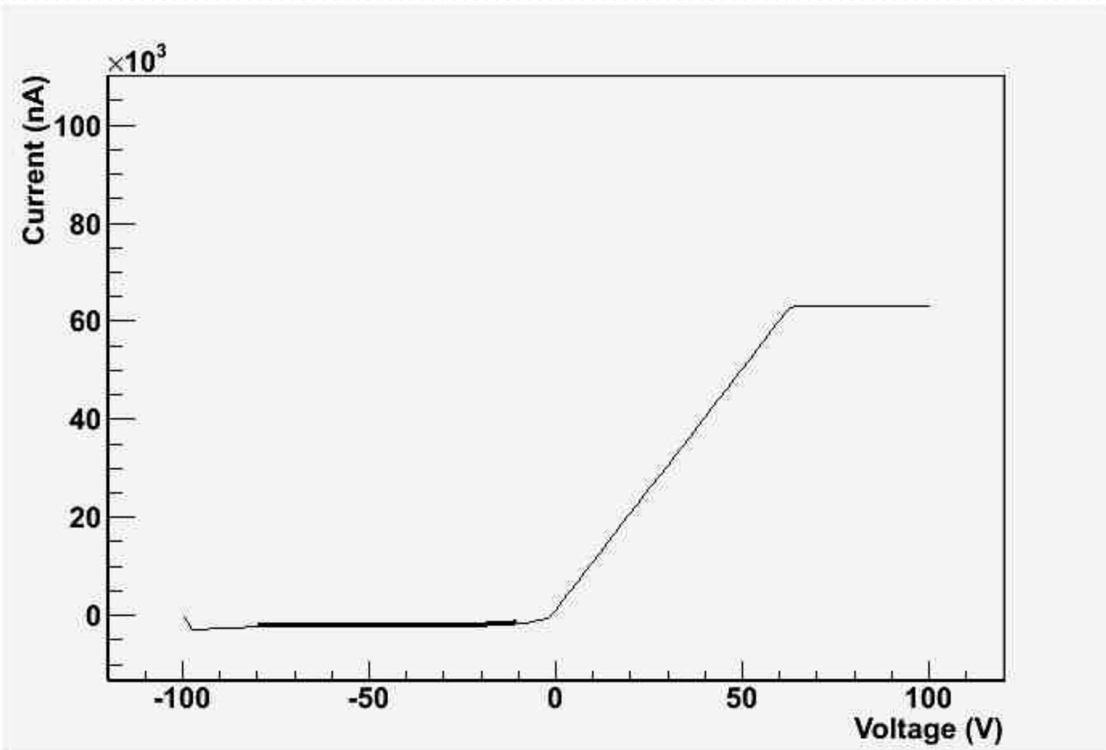
- ROOT is a C++ framework put out by CERN to facilitate data handling and analysis for particle physics
- Capable of creating the necessary graphs, histograms, and fits using C++



The Custom-made Data Analysis Program

- Reads the data file created by the LabVIEW code
- Stores operation settings and measurements to various class objects
- Creates curves for current or capacitance with respect to voltage
- Creates a map of the different quantities with respect to the pixel position
  - Quantities such as capacitance, depletion voltage, etc.

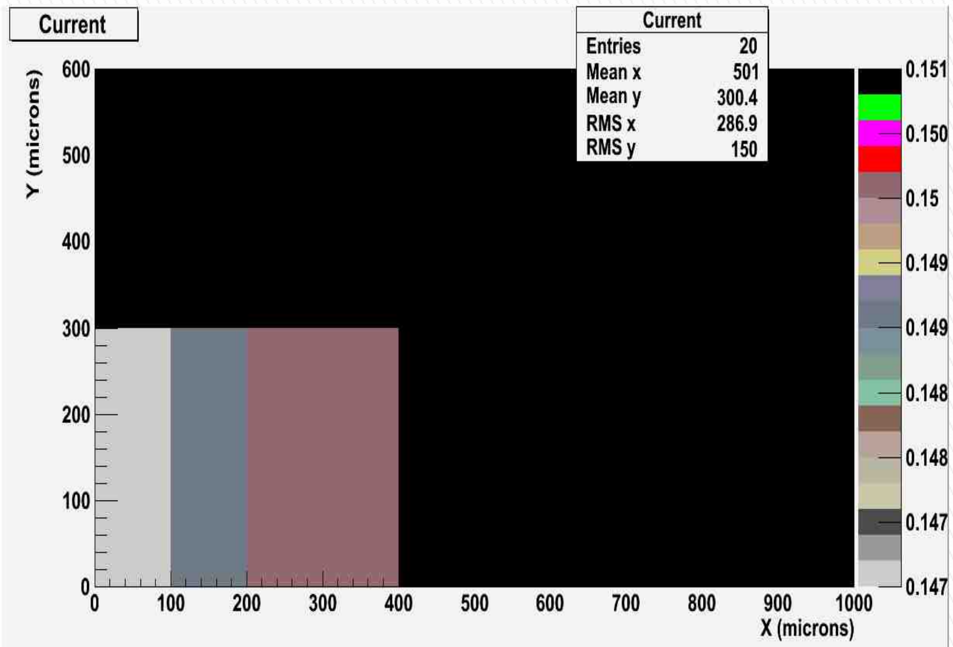
Results



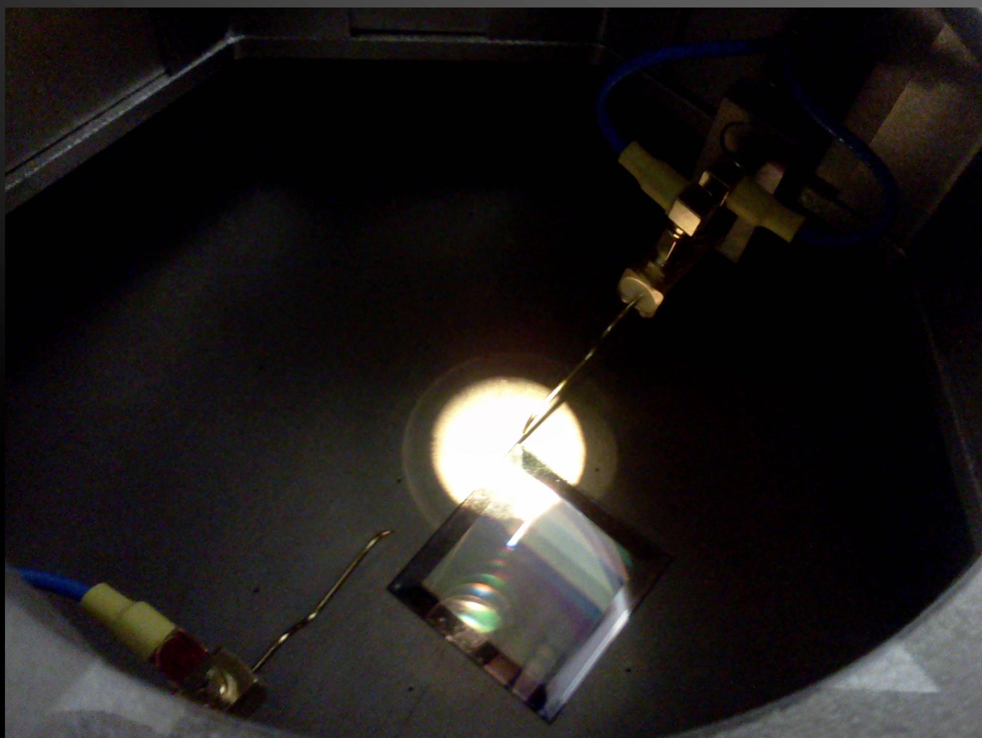
- The C++ program compiles in ROOT and is able to store all relevant data from the data file into class objects
- Can generate I-V, C-V, and R-V curves
- Still working on obtaining an appropriate fit for I-V and C-V curves

Results (cont…)

- Generation of histograms of various parameters with respect to pixel position (see right)



Summary



- We have a full setup ready to test silicon pixel detectors
- Each step in the data analysis chain has been successfully automated
  - LabVIEW can control all aspects of the testing devices
  - There is a program in place to automate the measurement and data storage process
  - The data analysis package can create any of the desired maps, curves, etc.