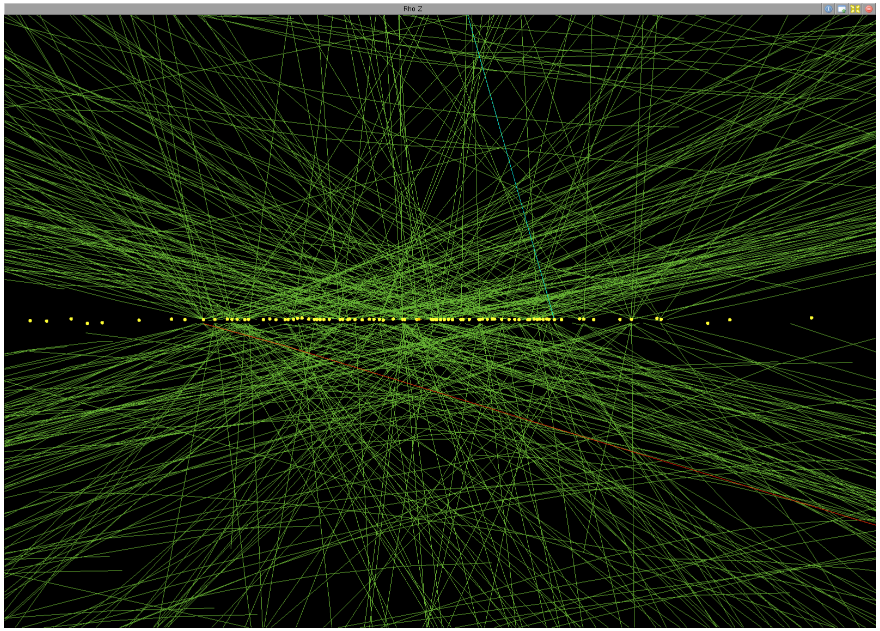
CMS Pixel Detector

Noise Calibrations

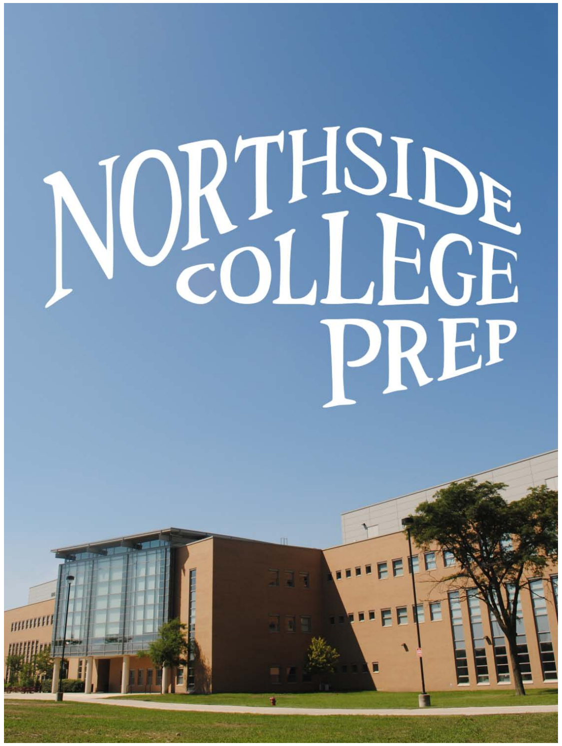
Kiriakos Hilbert
Northside College Prep
Quarknet 2013

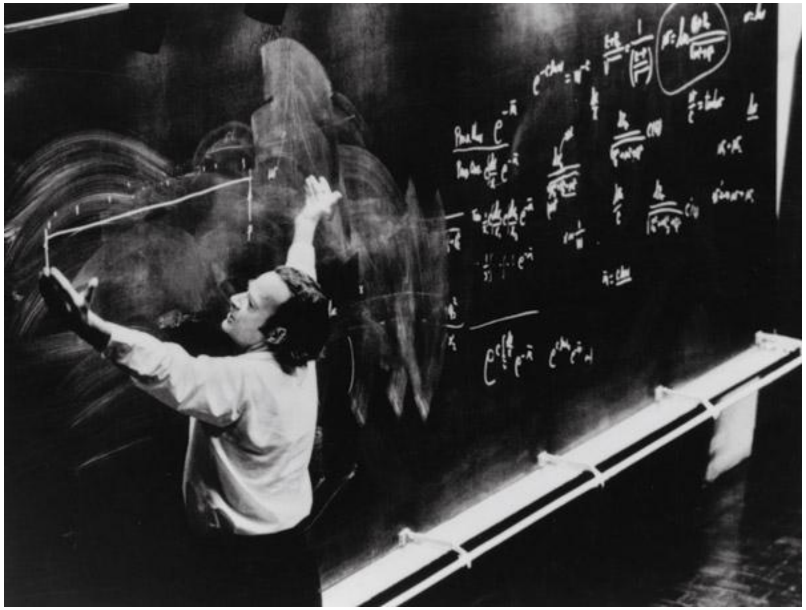
Mentored by Dr. Marco Verzocchi



Introduction

- Kiriakos “Kerry” Hilbert
- Rising Senior
- Northside College Prep
  Chicago, IL
- 100% Physics Major





Outline

- **Large Hadron Collider**
- **Compact Muon Solenoid Detector**
- **Pixel Detector**

  Structure / Layout

  Readout

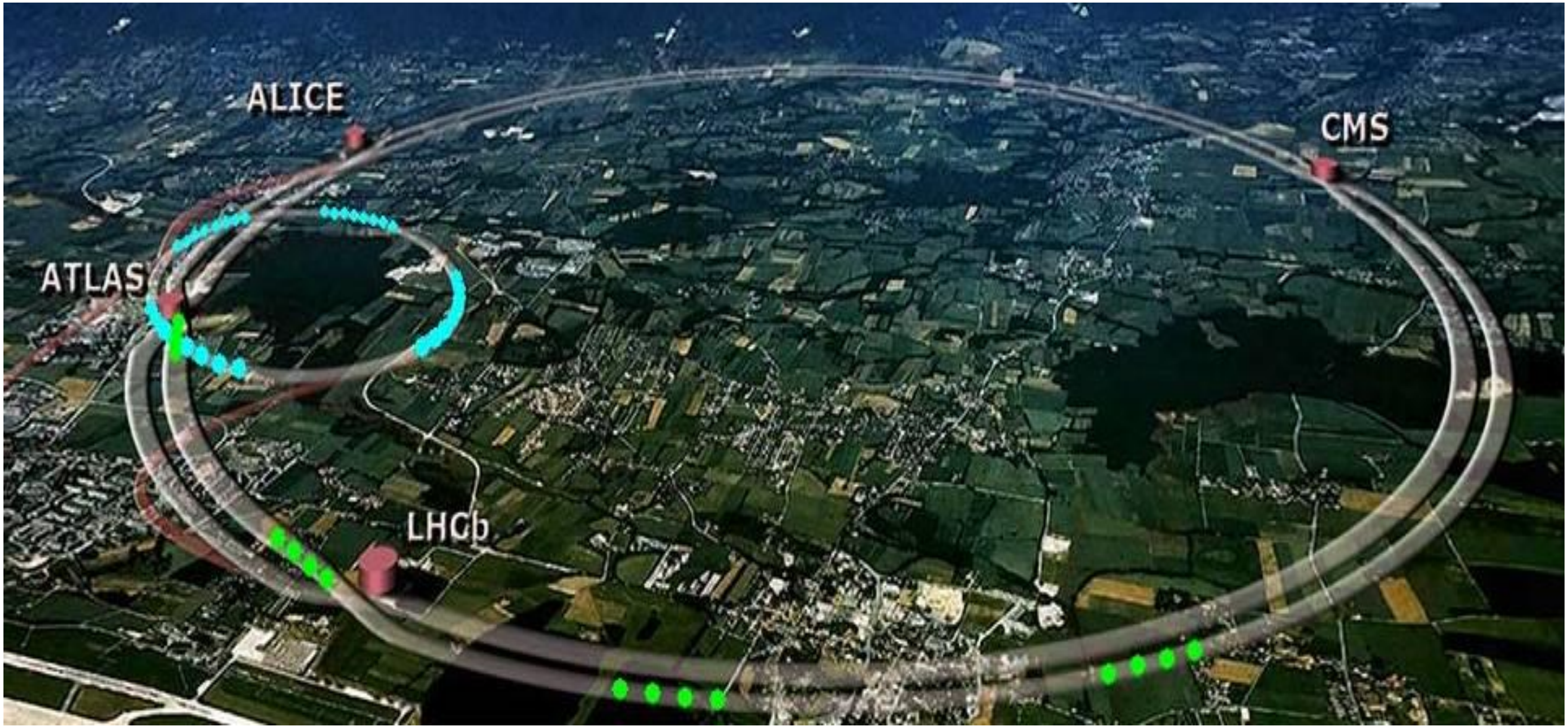
  Electronics

  Testing

  Calibration

  Radiation Damage

LHC: Large Hadron Collider

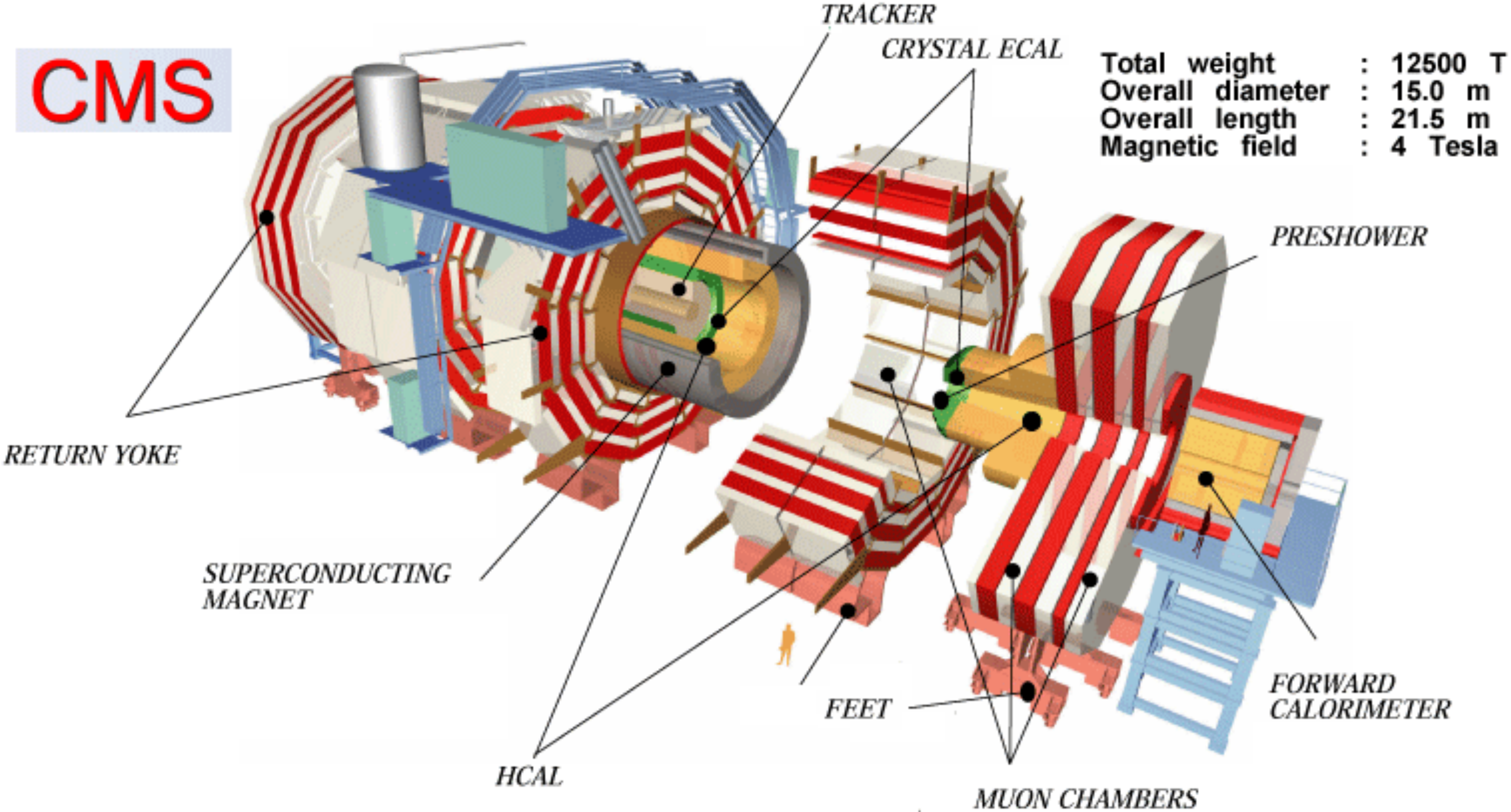


- Used to study known particles and their interactions
- Looks for new particles and interactions

LHC

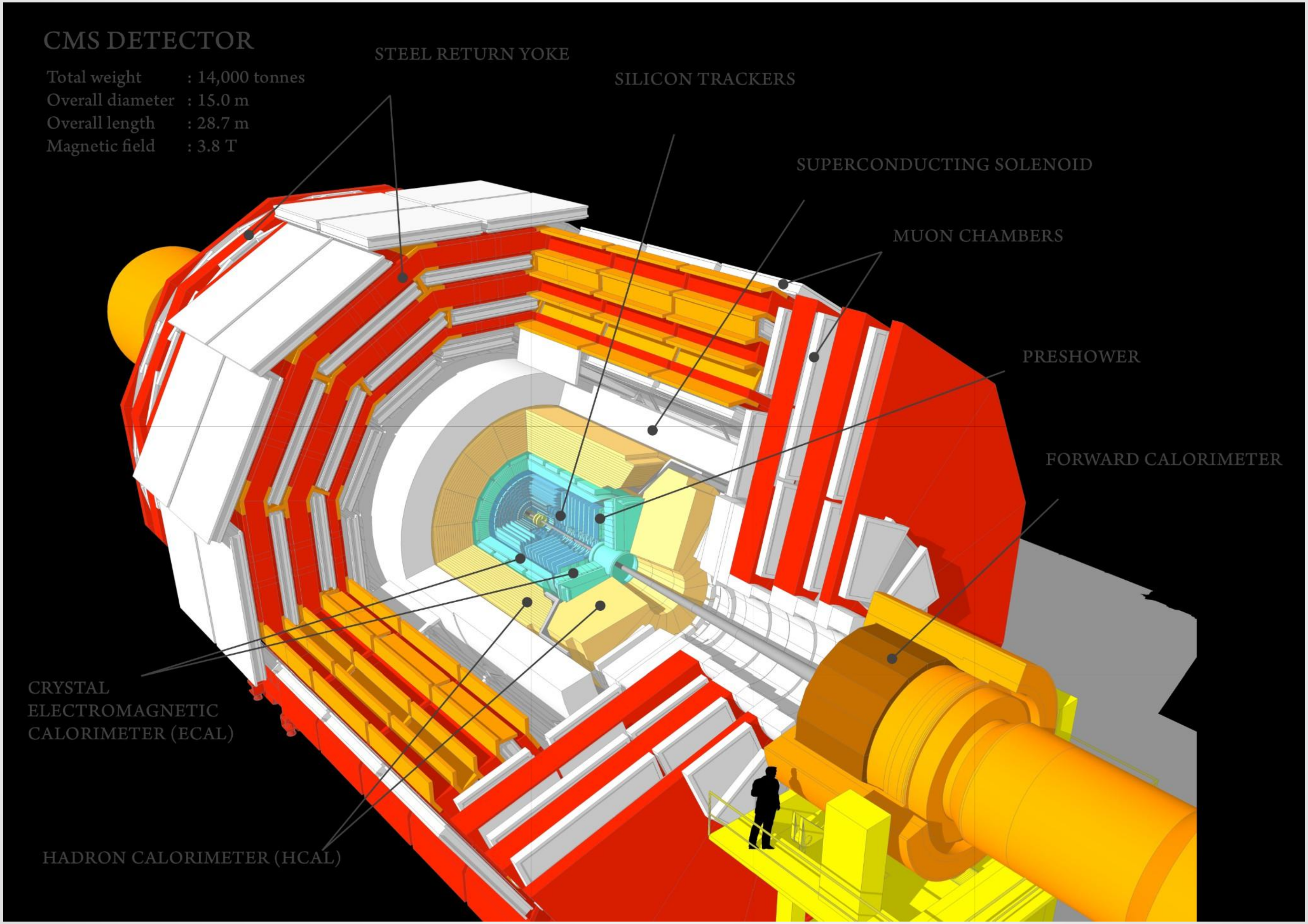
- Studies proton-proton collisions
- Peak collisions occur 40 million times per second
- Bunches cross every 25 nanoseconds

Compact Muon Solenoid



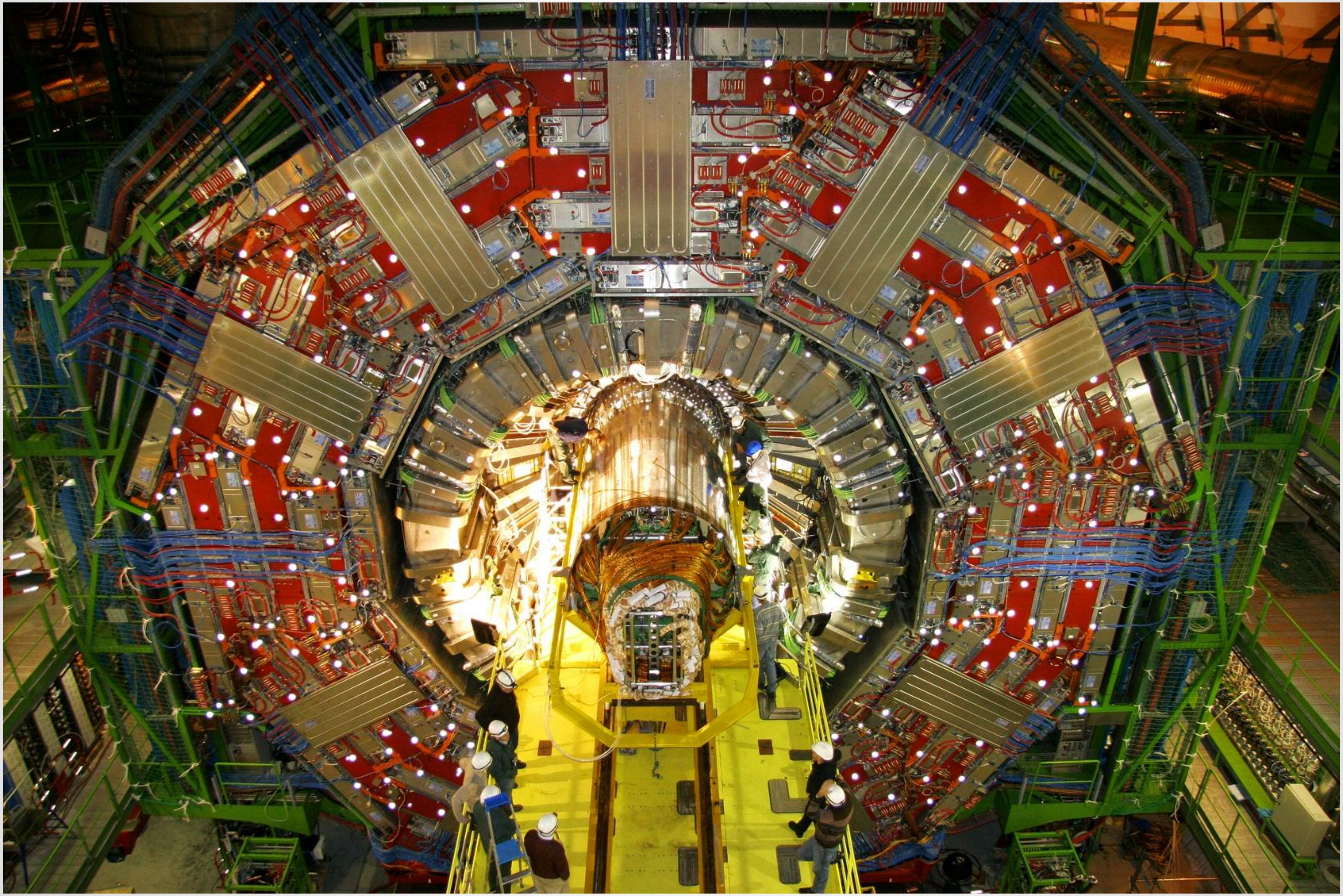
- General purpose detector: Higgs, Standard Model, Heavy Ions
- 4T solenoidal magnetic field - 100,000 times stronger than Earth's magnetic field
- Proton - Proton interaction chamber
- 8 Tera Electron Volts

Elements of the CMS

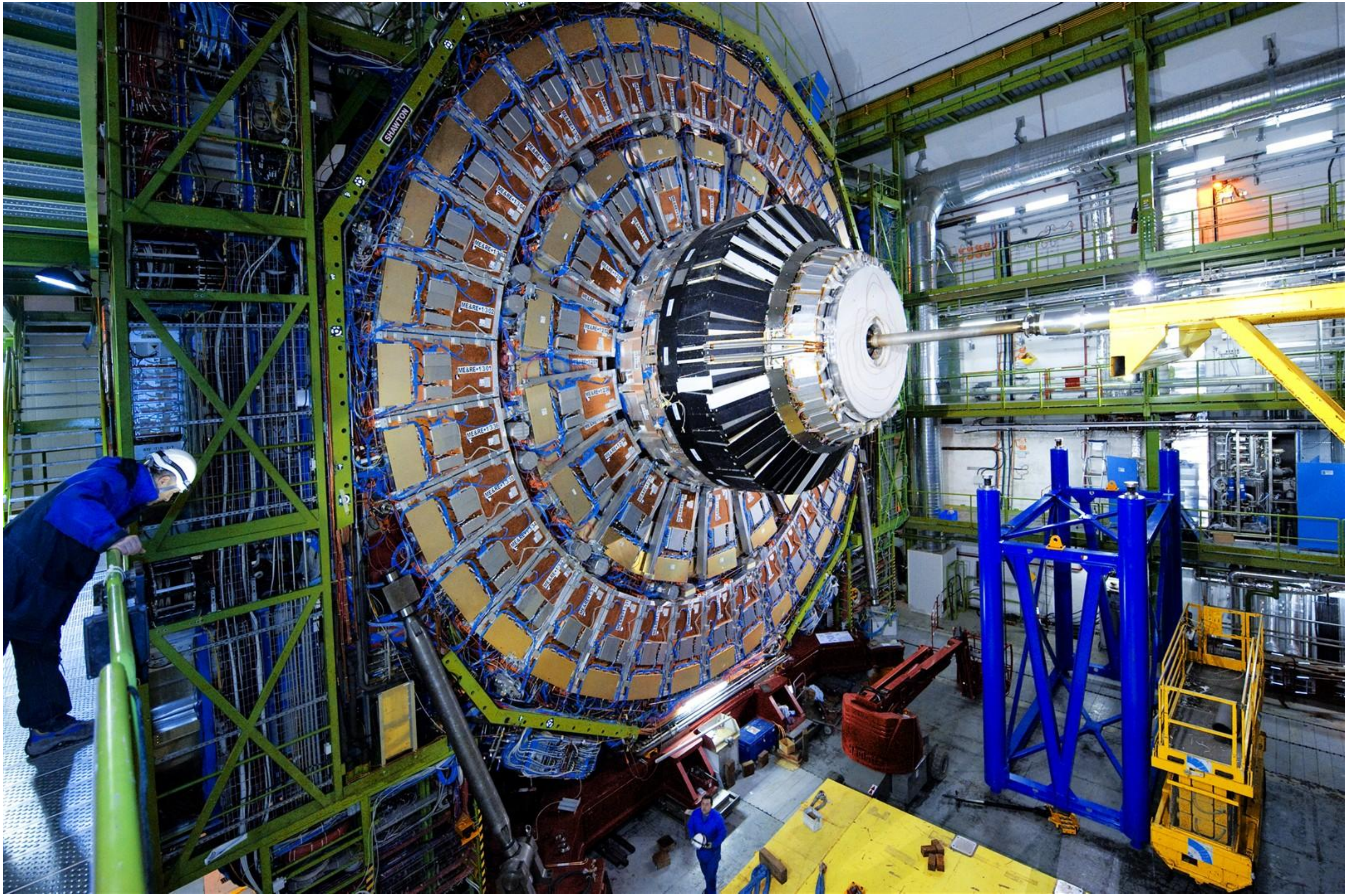


Underground Cavern

Head On View



Side View



CMS Pixel Detector

Pixel Size: 100 x 150 microns

Silicon sensors - Ideal Properties

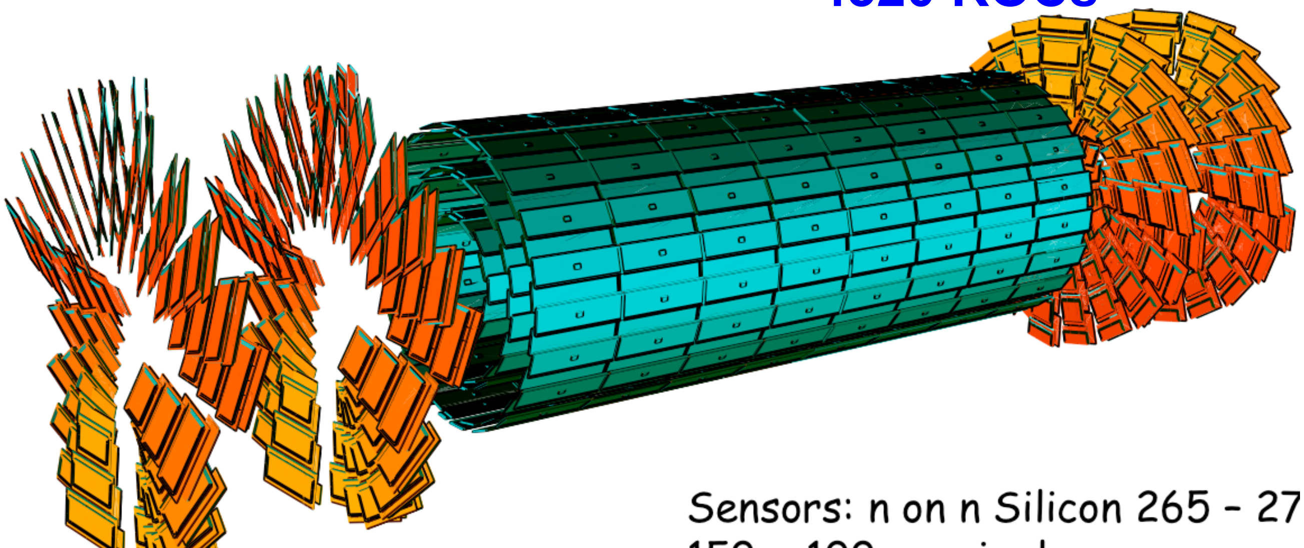
Bump-bonded to PSI 46 Read Out Chips (ROCs)

Barrel Pixels

- 3 layers at radii 4.3, 7.2, and 11 cm
- 48 million pixels
- 11520 ROCs

Forward Pixels

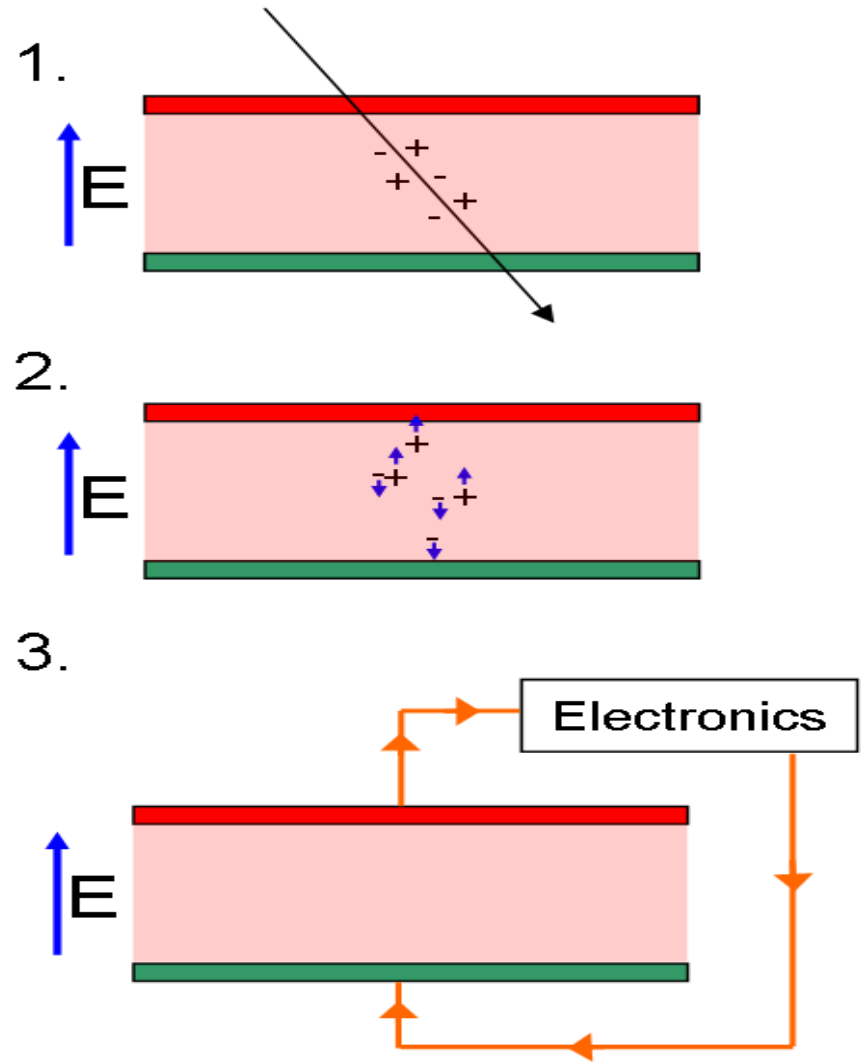
- 4 disks at 34.5 and 46.5 cm from interaction point
- 18 million pixels
- 4320 ROCs



Sensors: n on n Silicon 265 - 27
150 x 100 μm pixels

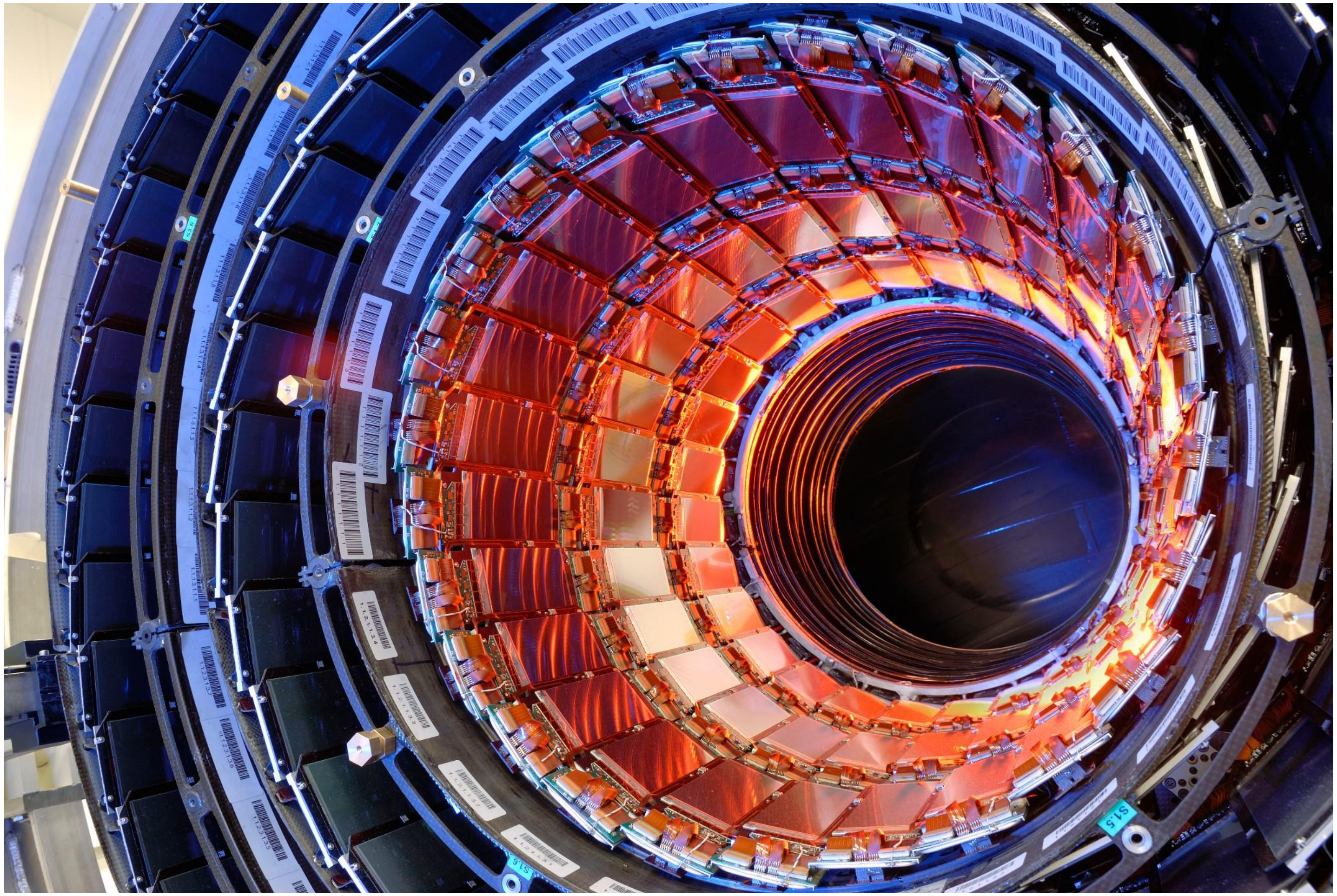
What Happens During a Hit?

- Particle passes through pixel
- If ionizing radiation, electrons knocked loose and "holes" created
- Electron/ "Hole" pairs are proportional to intensity of radiation
- Pulse measured in outer circuit
- Diode Structure - Threshold Voltage

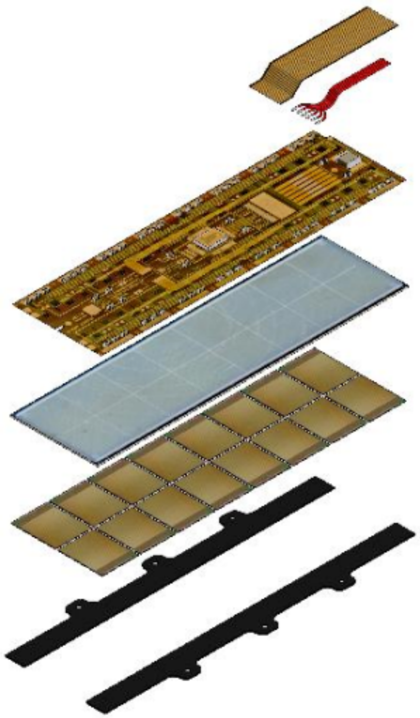


CMS Pixel Detector

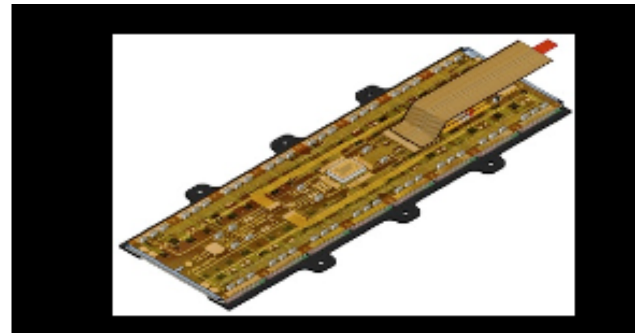
- Provides high resolution 3D space point required for track pattern recognition and reconstruction
  - 1.06 m^2 area
  - 66 million channels

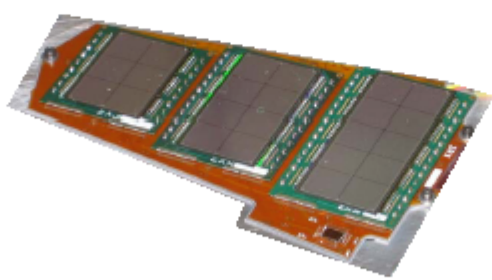


Modules of the Pixel Detector

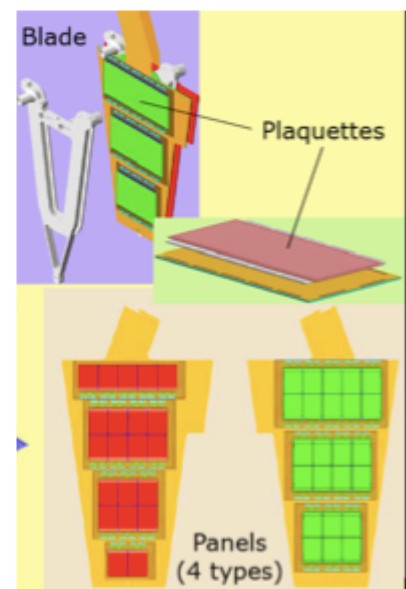


BPIX (Barrel Pixel Detector) has 768 modules

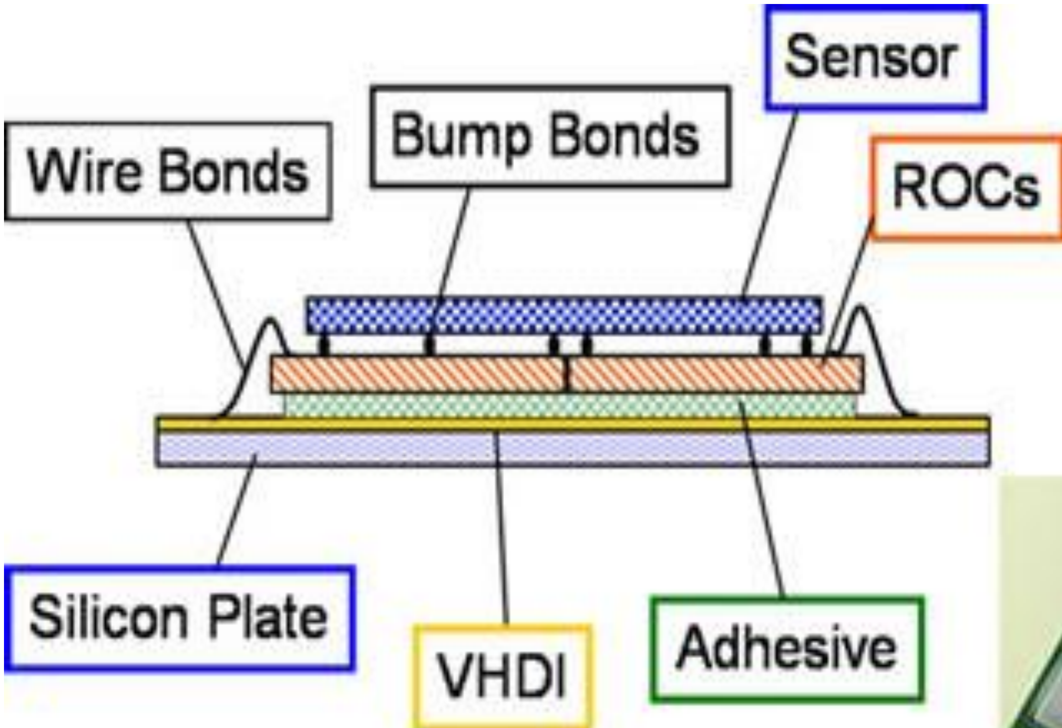


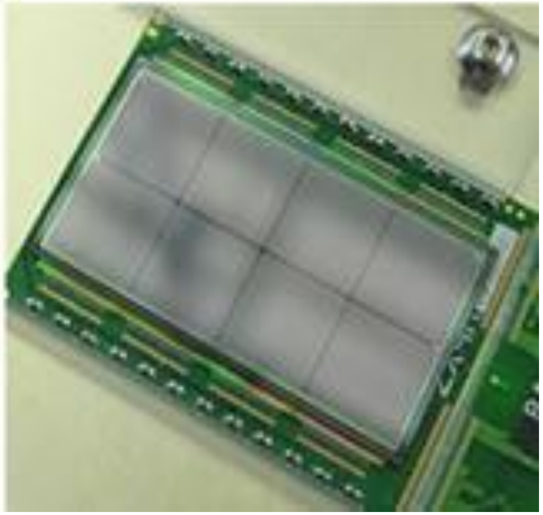


FPIX (Forward Pixel Detector) has 672 modules



Bump Bonding

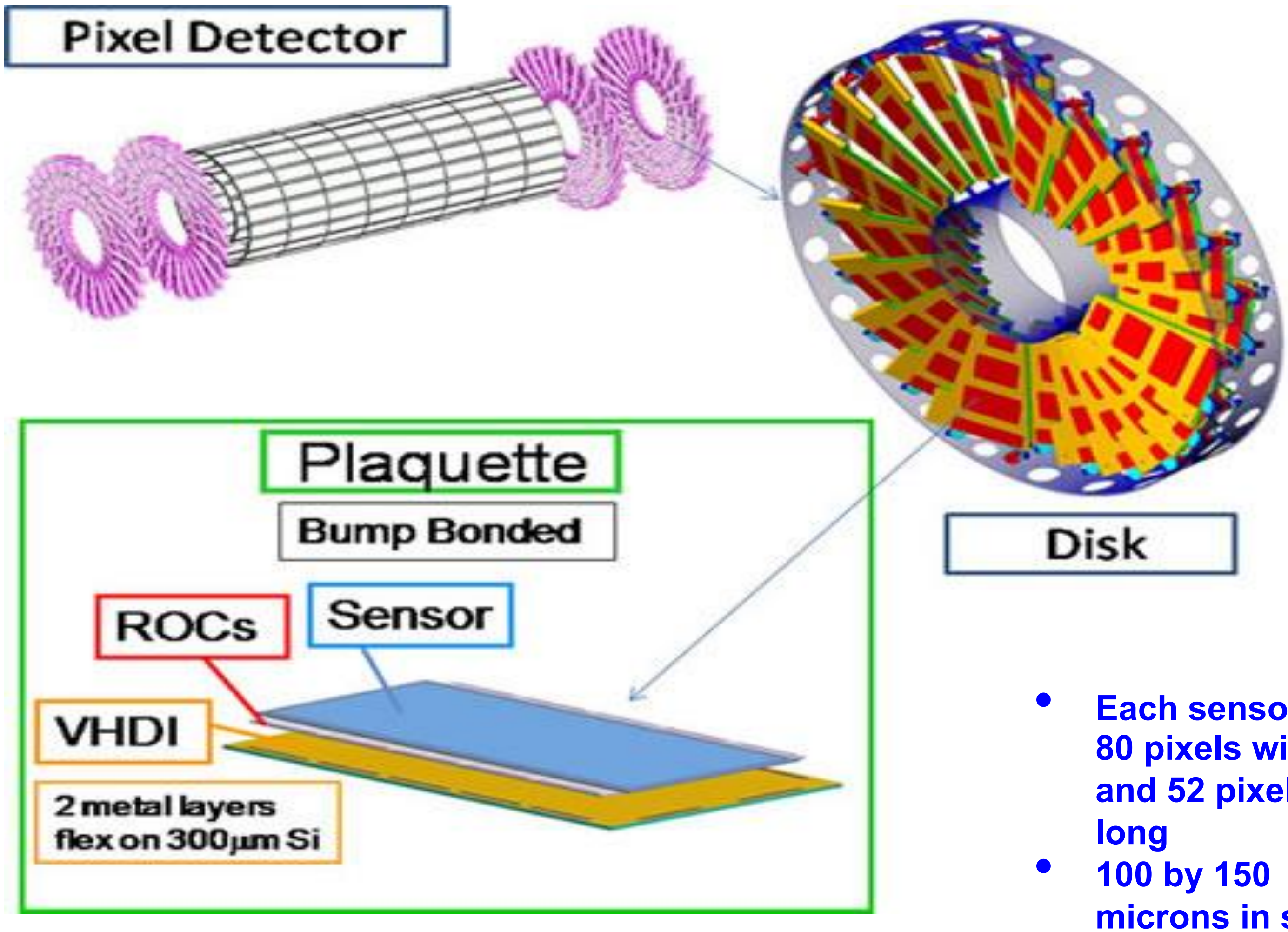




- **Small amounts of solder connect the actual sensor to the ROC**

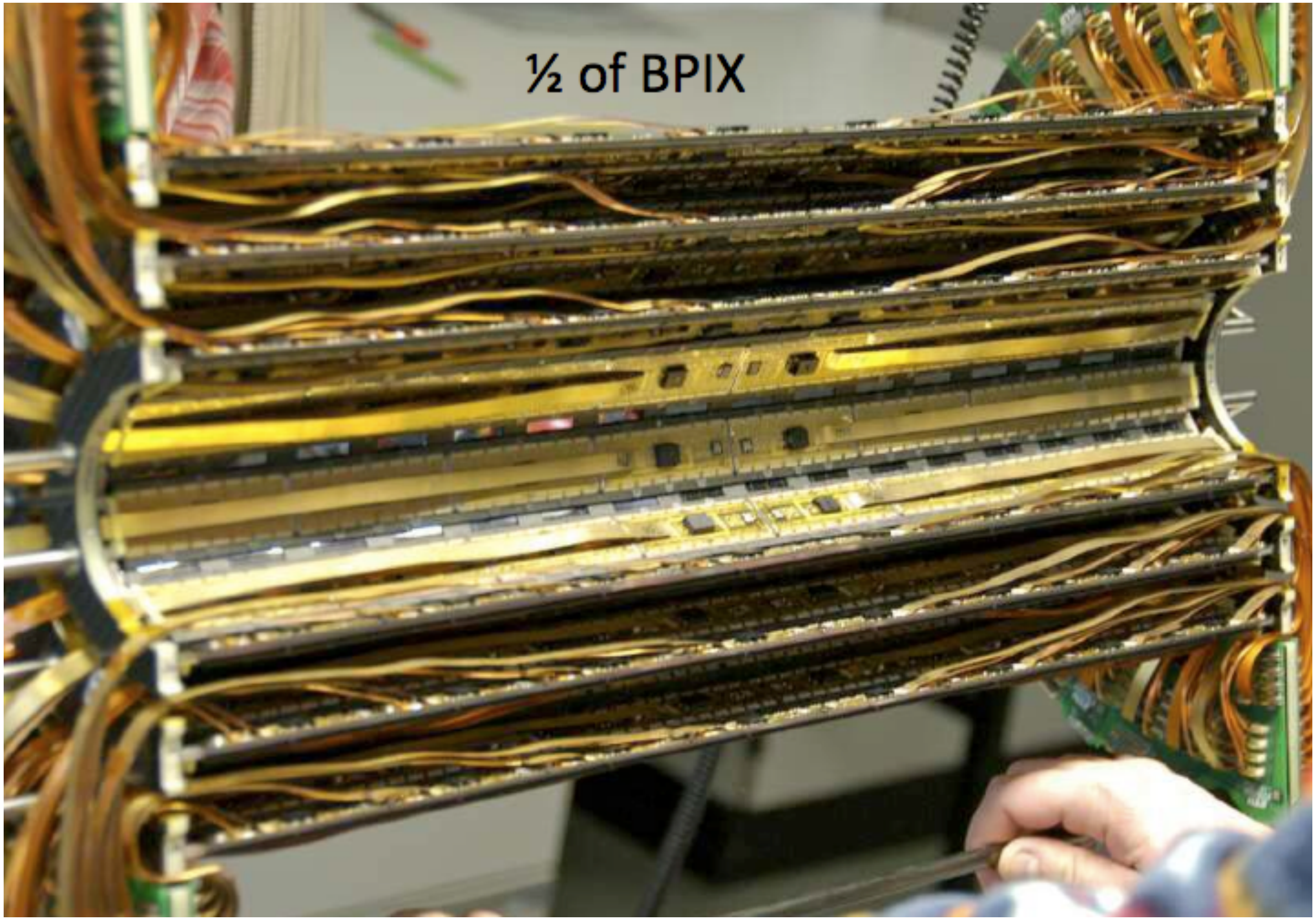
Pixel Readout Chip

- PSI design
- Manufactured by IBM
- 15,840 ROCs on whole detector
- 4,160 pixels per ROC

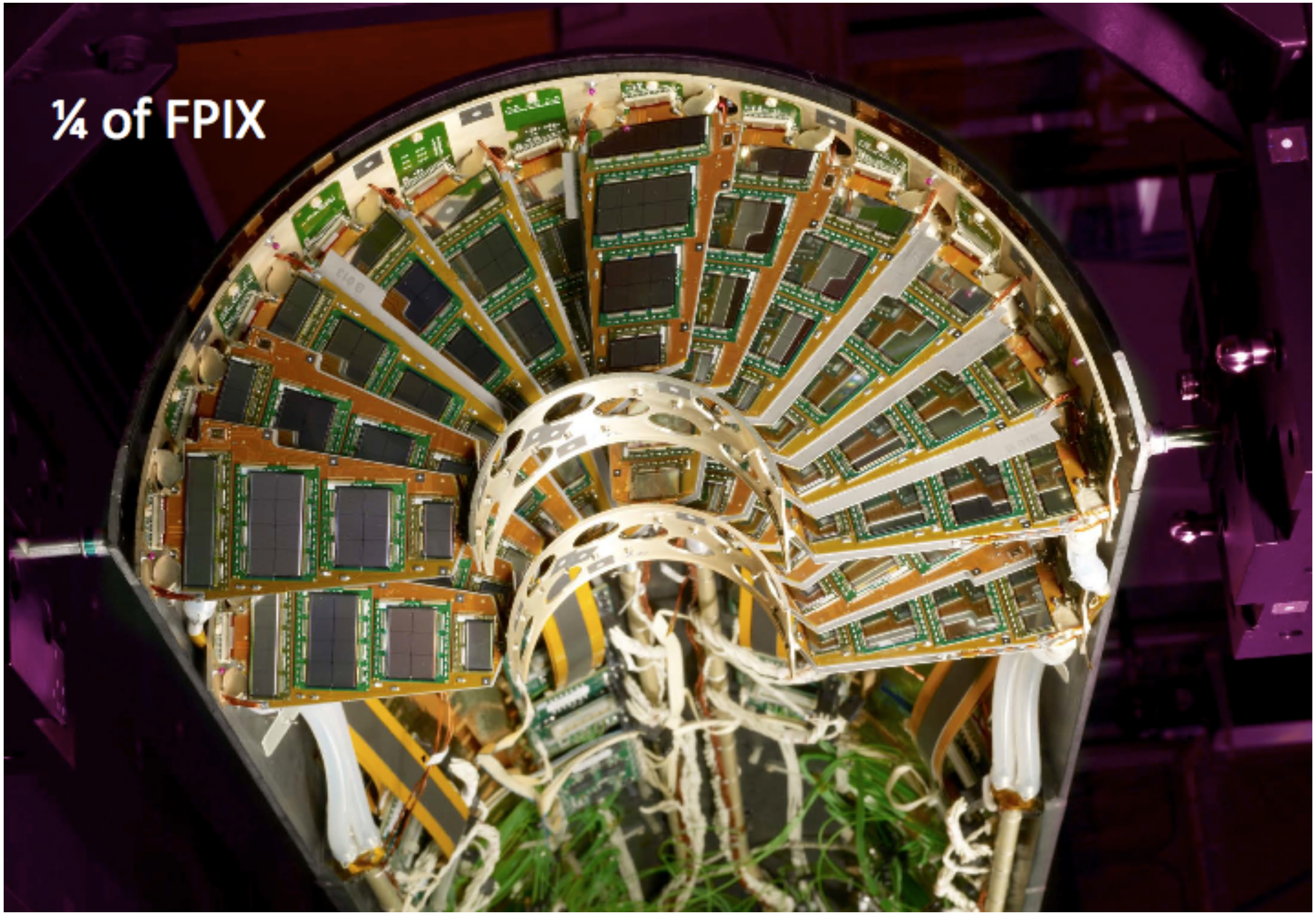


- Each sensor is 80 pixels wide and 52 pixels long
- 100 by 150 microns in size

Barrel Pixel (BPIX)



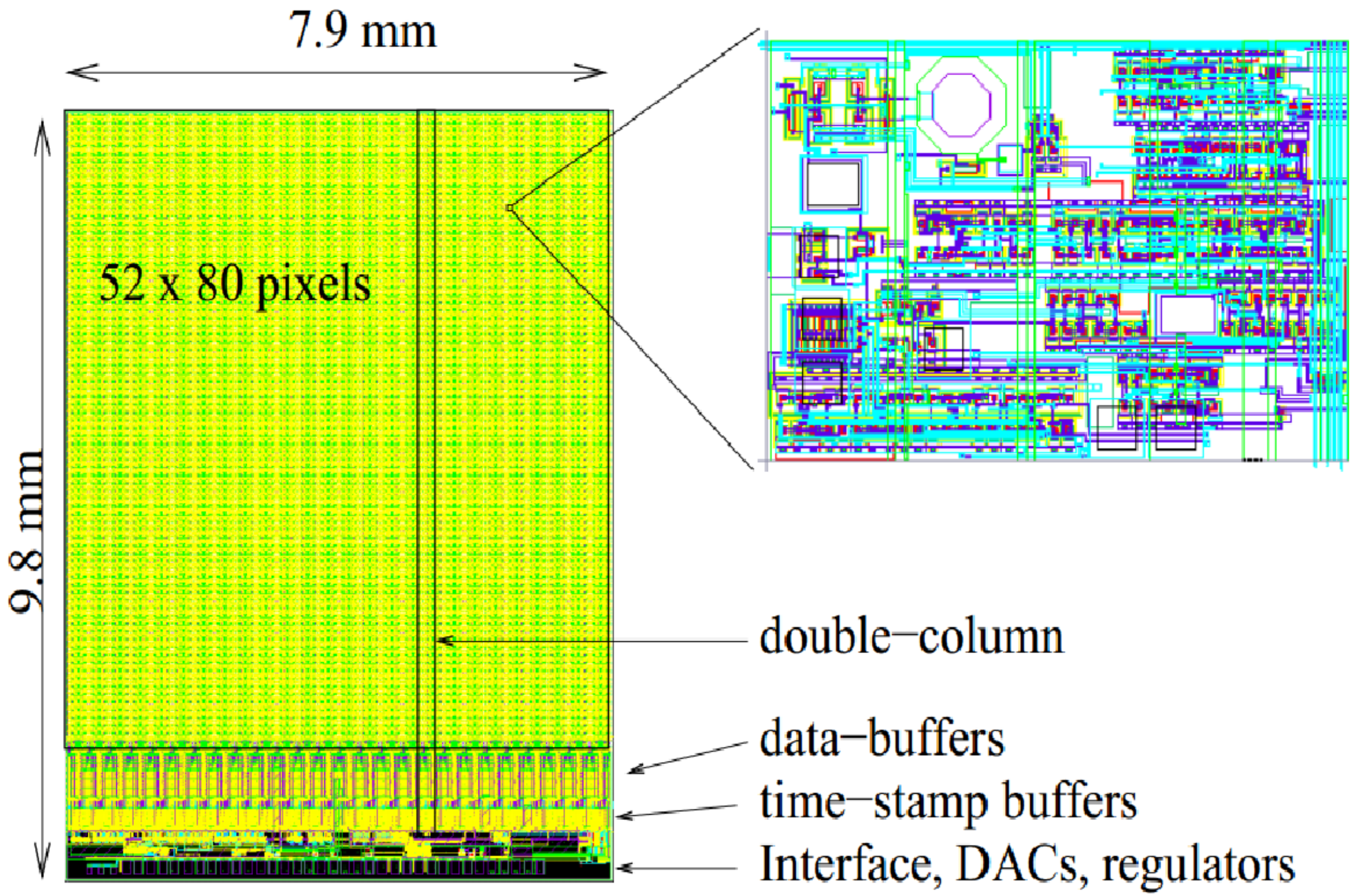
Forward Pixel (FPIX)



Read Out Electronics Goals

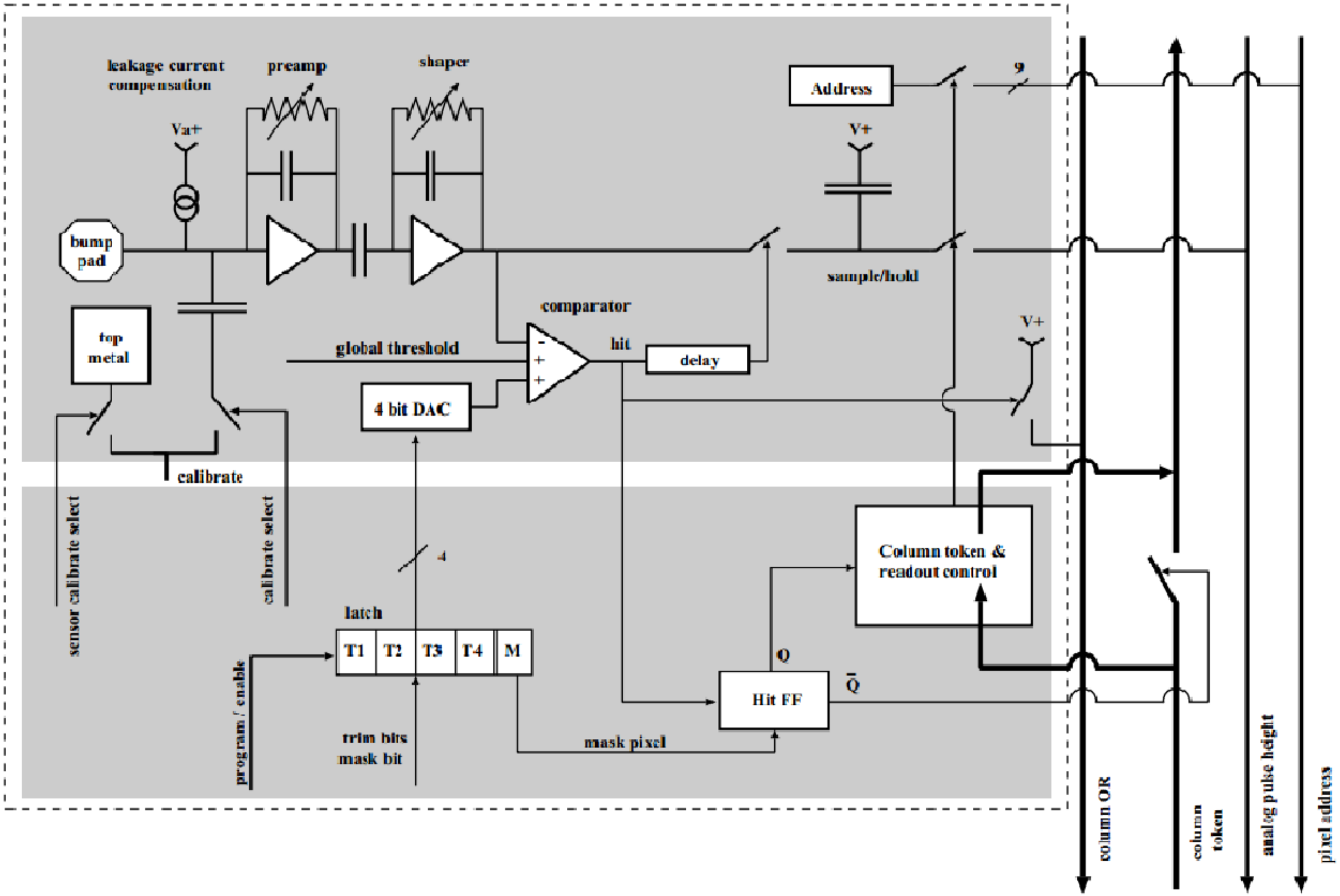
- Register signals produced in sensor
- Store the time, position, and charge of all channels
- Send out the data for bunch crossings as selected by first trigger

ROC Layout



- Double Column Architecture
  - 1.3 million transistors

ROC Circuitry

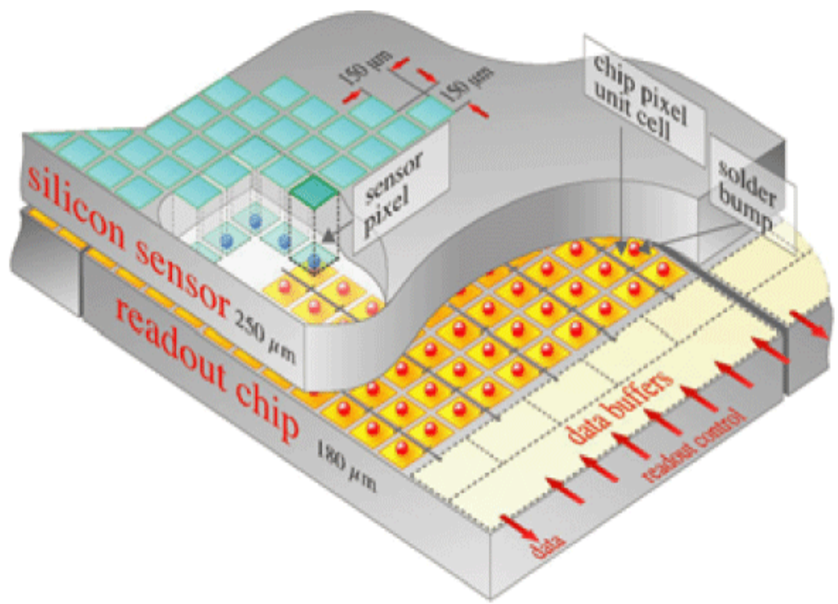


40 MHz Analog Readout

Reads out:

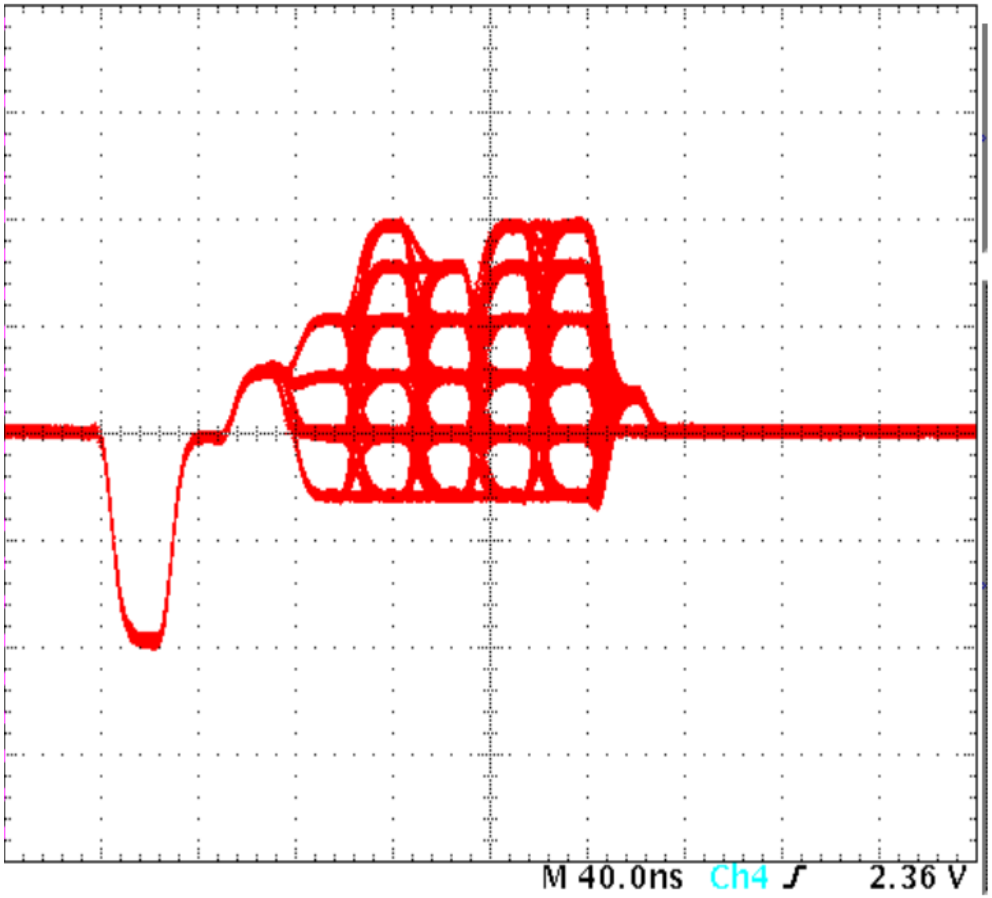
- **Analog Pulse Height**
- **Pixel Address**

Hit pixel address coded in base-6



Analog Readout

- Six discrete analog levels are used to encode hits
- 2 pieces of information correspond to the double column
- 3 pieces of information for the row



Senary Encoding

Senary readout encodes the pixel's address and pulse height in a base 6 numbering system

There was a hit on "row" 425 and column 46

This is the information that the ROC will relay, but what does that mean?

Counting in base 6, break down what 425 really means

Each digit corresponds to a component of base 6

4 * *36* **2** * *6* **5** * *1*

144 **12** **5**

Sum: 159

425 in base 6 is referring to Row 159

Time Stamps and Hits

- **Time stamps must be precise**
- **Correlation between stamps and hits must be completely correlated**
- **Absolutely crucial**

Digitizer and Data Readout

The signal sent through the ROC, at this point, is electrical and analog. It encodes the ROC #, row and column and charge collected of each pixel hit.

The electrical signal from the ROC is then converted to an optical signal. This signal makes its way to the FED (Front End Driver) where it is truly digitized and given level thresholds for decoding.

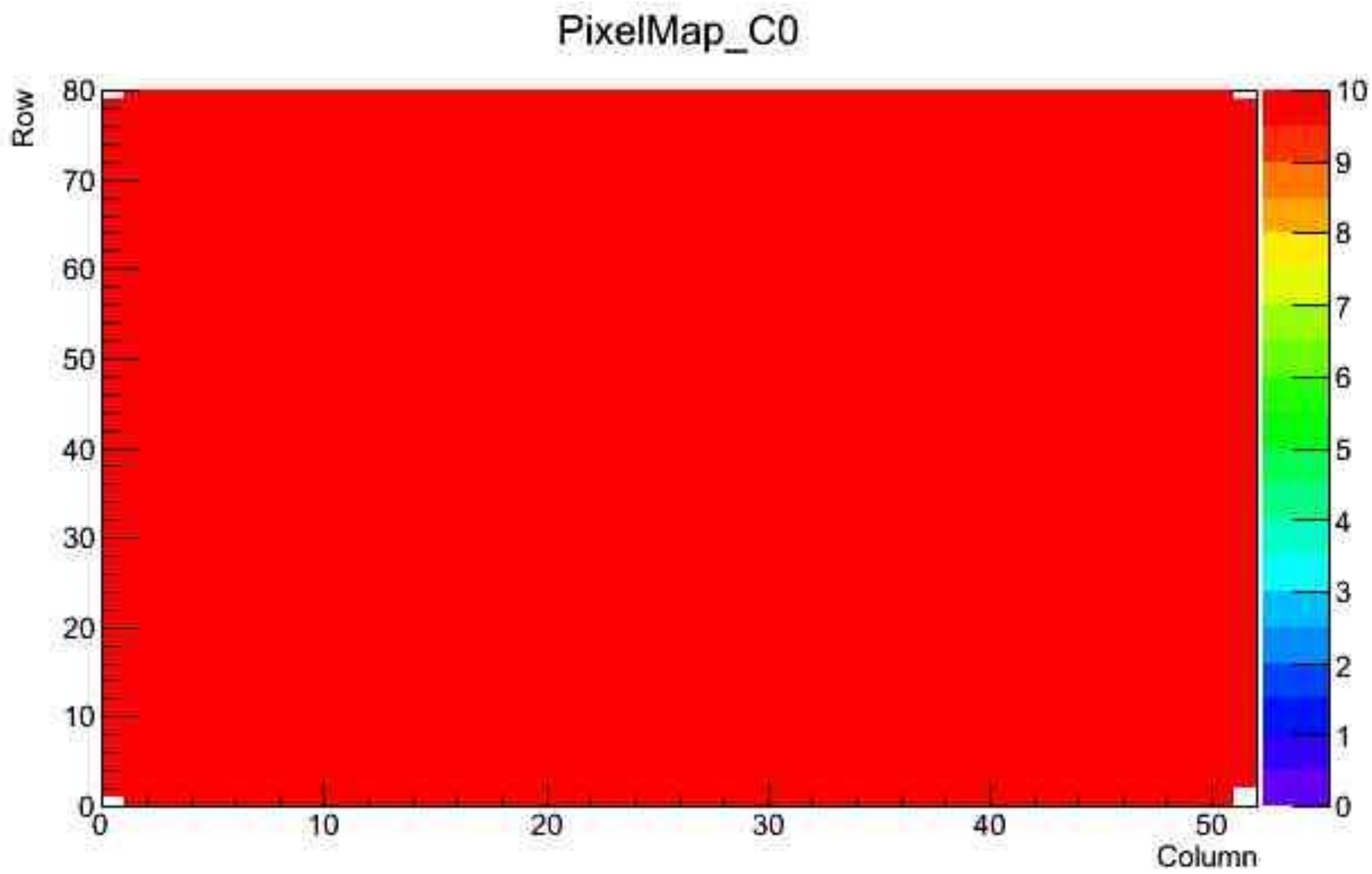
FEDs send digitized data down to the Data Acquisition System (DAQ).

Testing and Calibration Overview

- A large portion of module testing consists of DAC registers programming.
- All of the 26 DACs are set to their default value for each Readout-Chip.
- Running module testing allows individual calibration of crucial DACs.
- Pixel electronic connections and their readouts are tested for functionality.
- Calibration tests are in turn performed, including testing the responses of the noise, trim, and gain of each individual pixel.

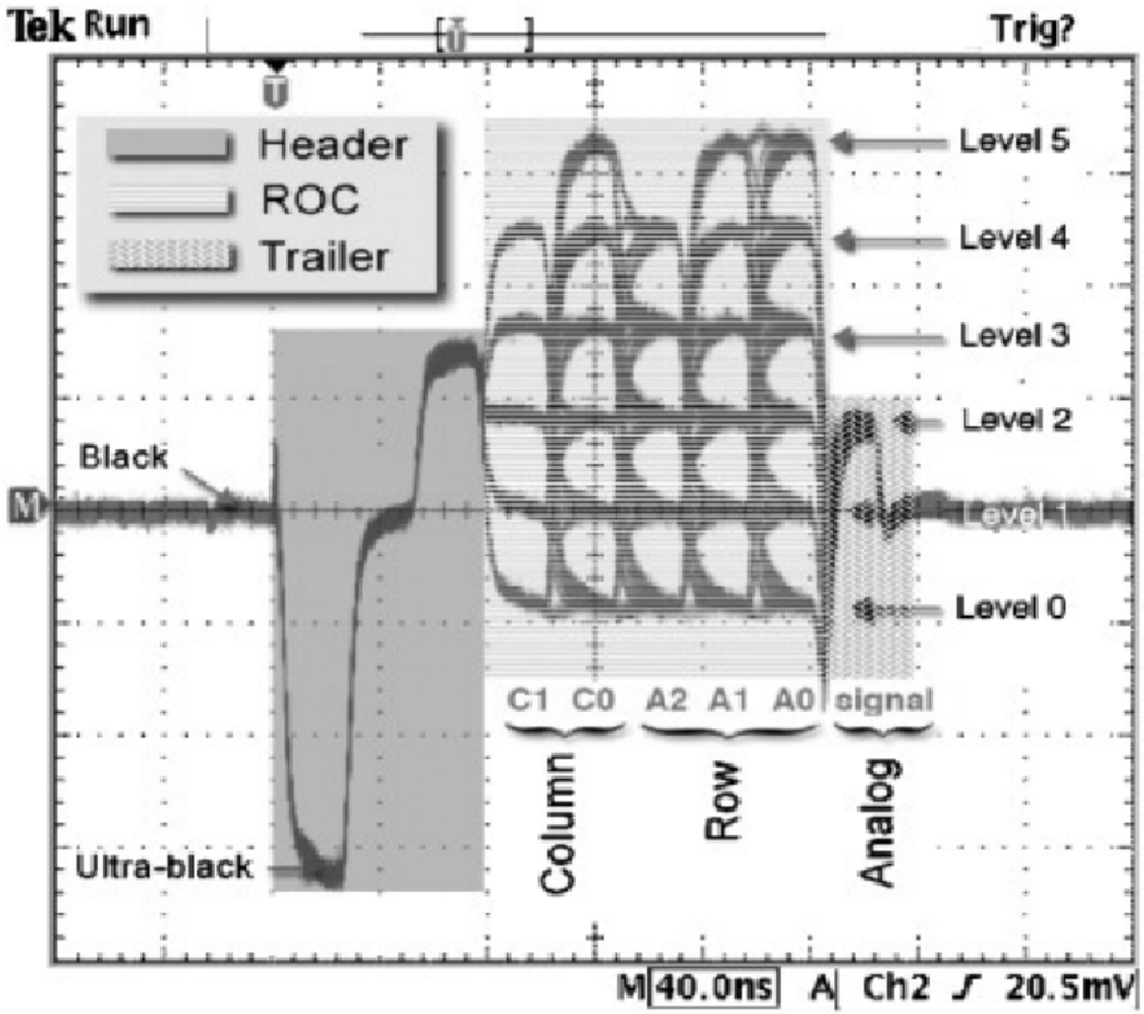
Pixel Map

- **Basic test performed to see pixel functionality**
- **"Dead" pixels in the four corners of the sensor**
- **Most pixels functioning perfectly fine**



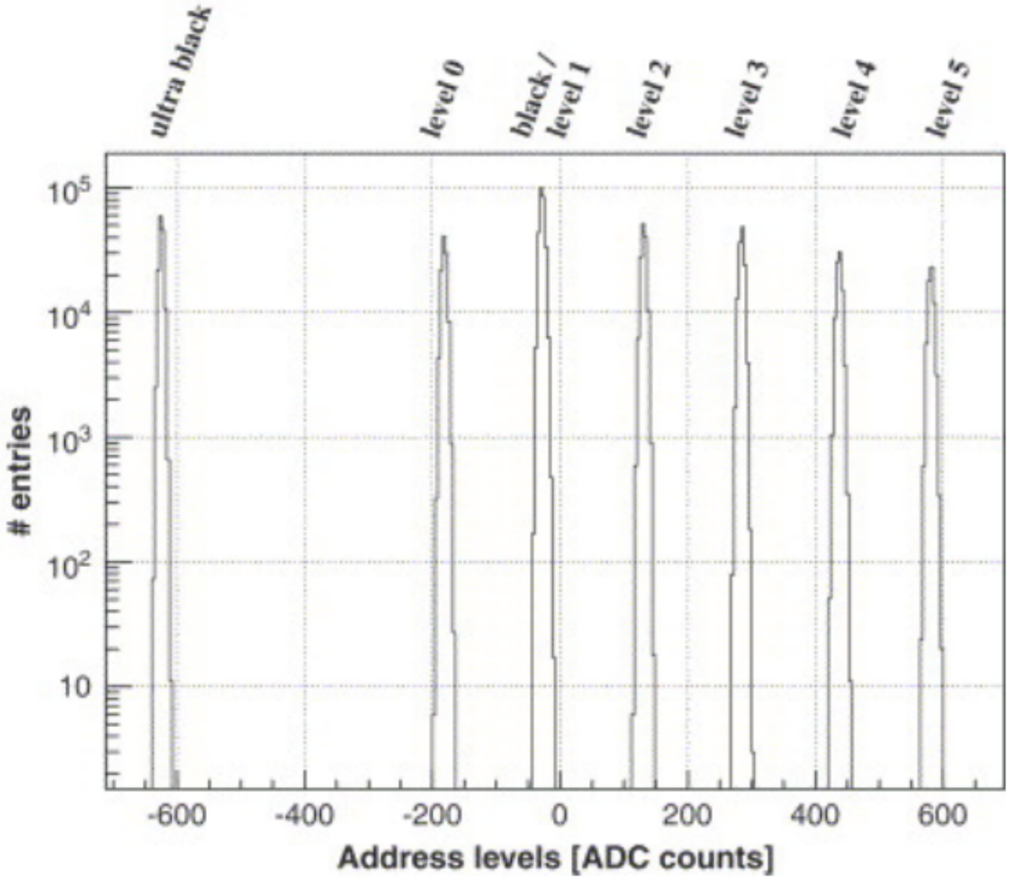
Baseline Calibration

- Calibrate so that "black" level is in middle of ADC
- Conveys that data will follow "ultra-black" level or signal



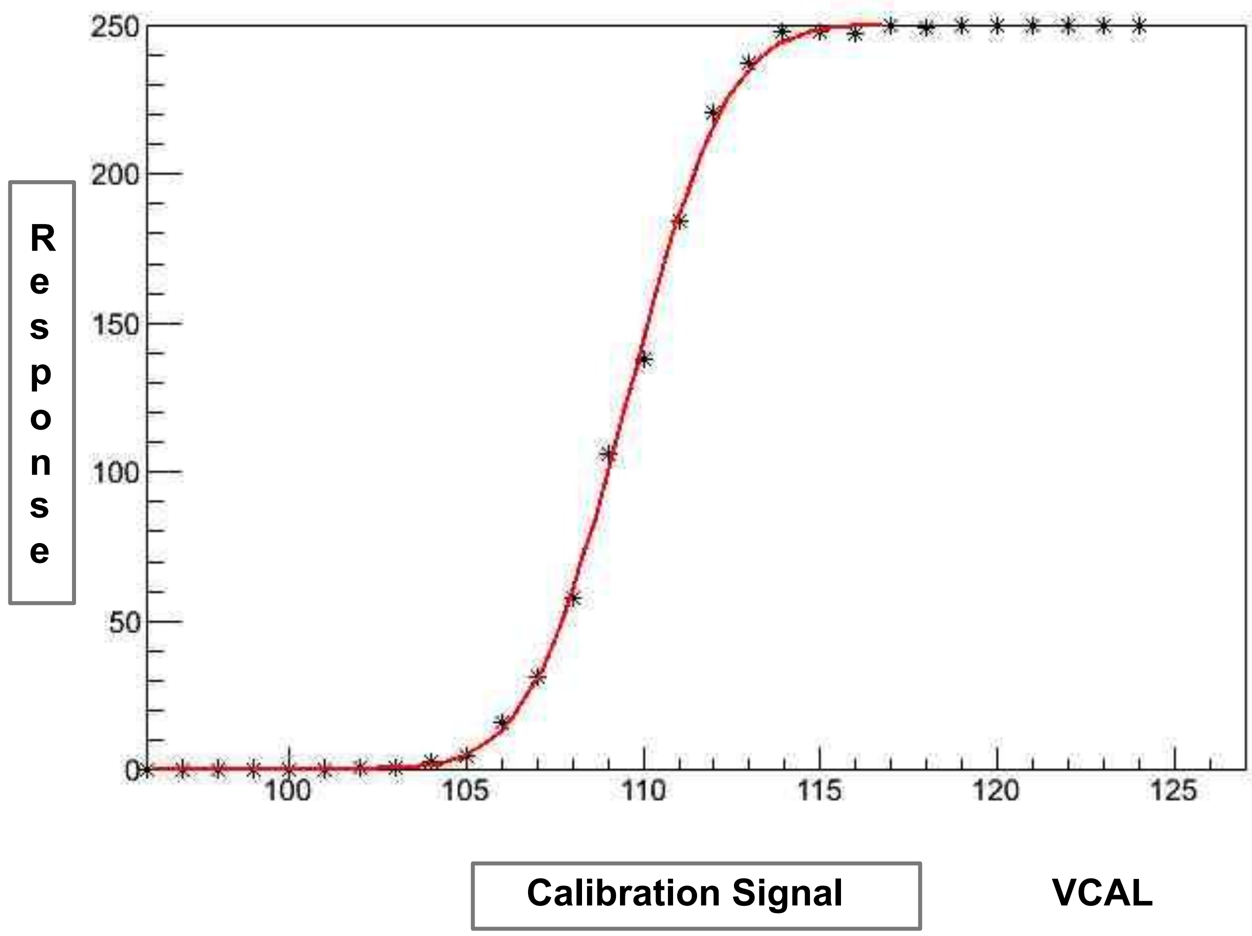
Address Level Calibration

- Distinguishes / separates between address levels



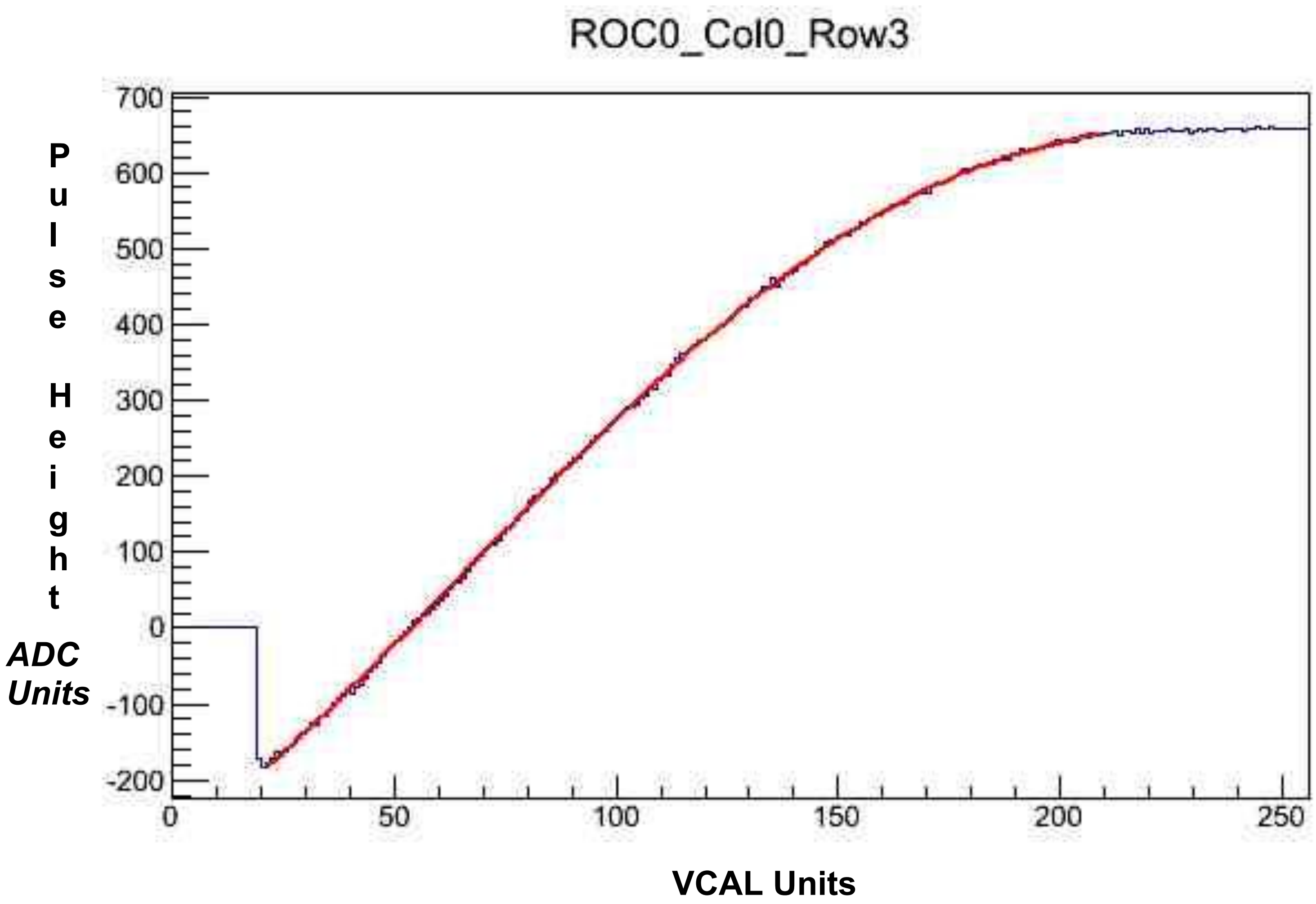
S-Curve Calibration

- Checks the efficiency vs. injected charge for sensors
- Response vs. Calibration signal
- Width between plateaus represents the amount of noise present in a pixel



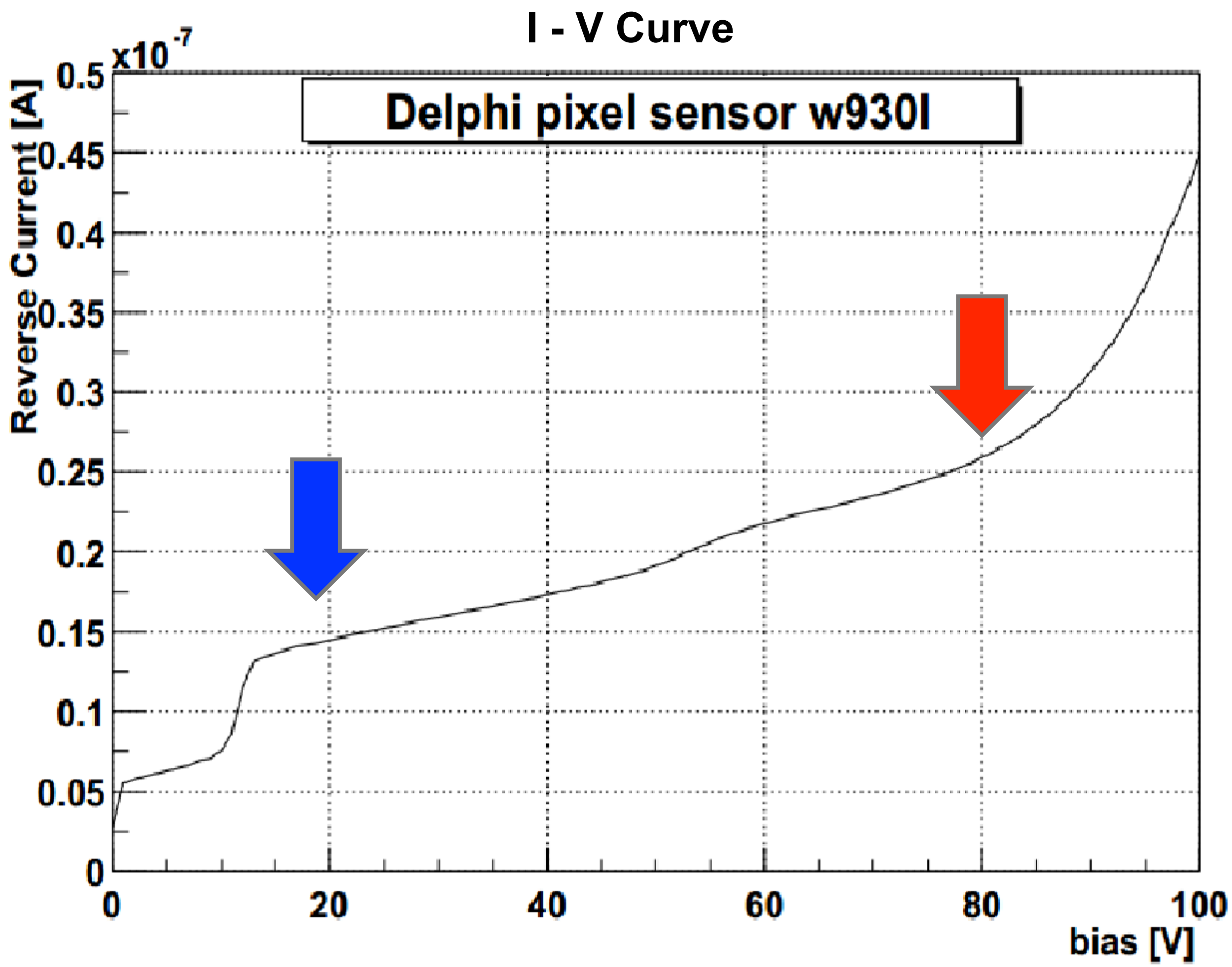
Gain Calibration

- ADC counts vs. Injected Charge
- Linear Pixel Response



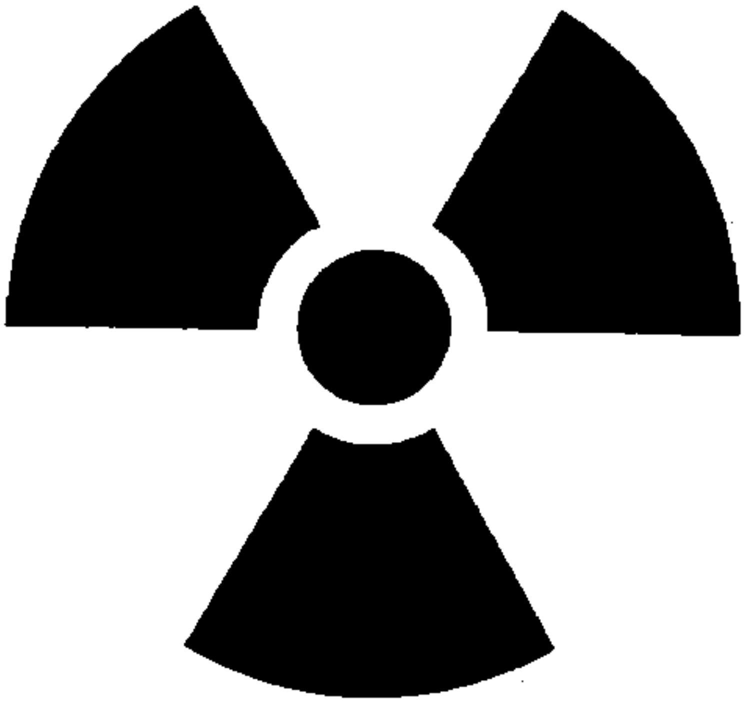
Probing the Pixel Detector

- **Instate a voltage from 0 to 600 V on the chip's readout components**
- **Response curve to ensure that the chip is predictable and reliable**
- ***Should* be plateau in the middle of the curve that reflects how efficient the chip is**



Impact of Radiation Damage

- Analog current increases with radiation damage
- Slower pre-amplifier run time
- Higher thresholds for pixels



Conclusion

- CMS's FPIX detector is functioning very efficiently and at an excellent resolution as had been planned
- Its operation takes much calibration to eliminate the effect noise may have
- Programming is an EXTREMELY valuable skill
- Many thanks to my mentor, Dr. Marco Verzocchi, for his endless patience and insightful explanations

  (I definitely needed them)