Update on Silicon Photomultipliers

Yi Qiang

DOE S&T Review

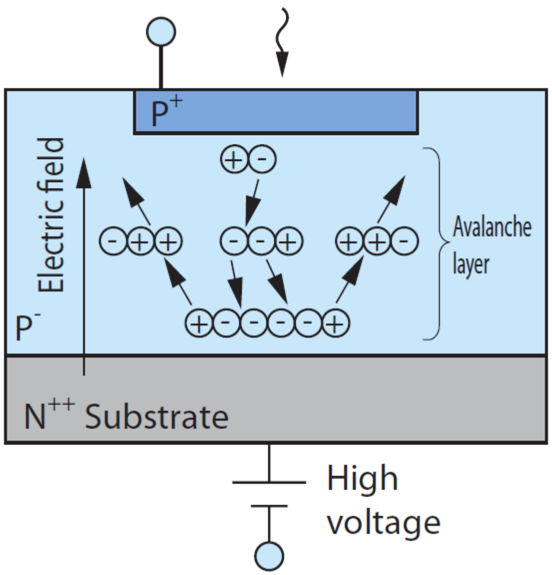
May 10, 2012

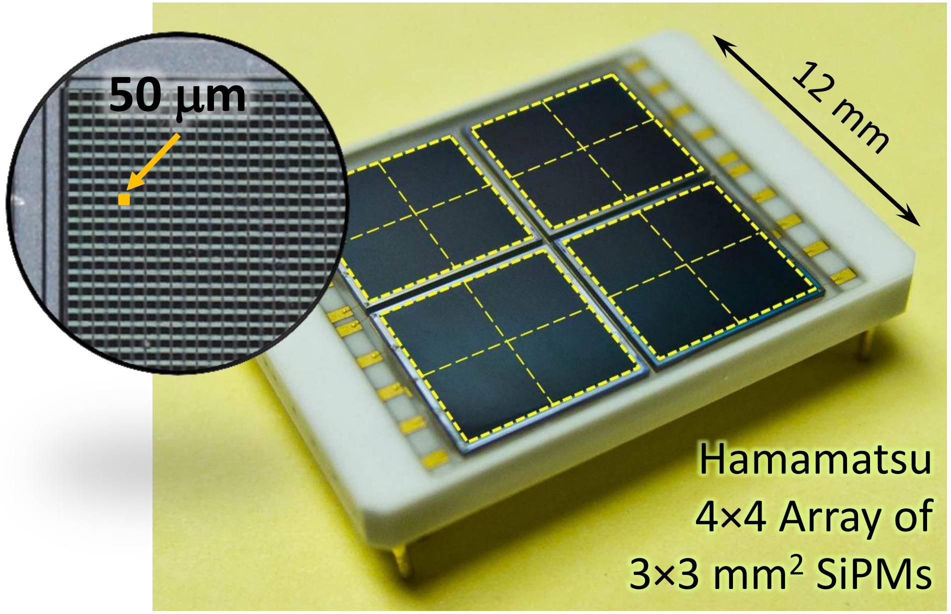
Bio – Yi Qiang

- MIT – Ph.D. (2007)
  - Search for pentaquarks in Hall-A at Jefferson Lab
- Duke University – Post. Doc. (2007 – 2010)
  - 6 GeV neutron transversity in Hall-A at Jefferson Lab, in charge of polarized ^{3}He target
  - Co-spokesperson of a 12 GeV SoLID SIDIS experiment using a longitudinal polarized ^{3}He target
- Jefferson Lab Hall-D – Staff Scientist (2010 – present)
  - In charge of photon beam radiator
  - Silicon photo multipliers, particularly for the Barrel Calorimeter

Introduction

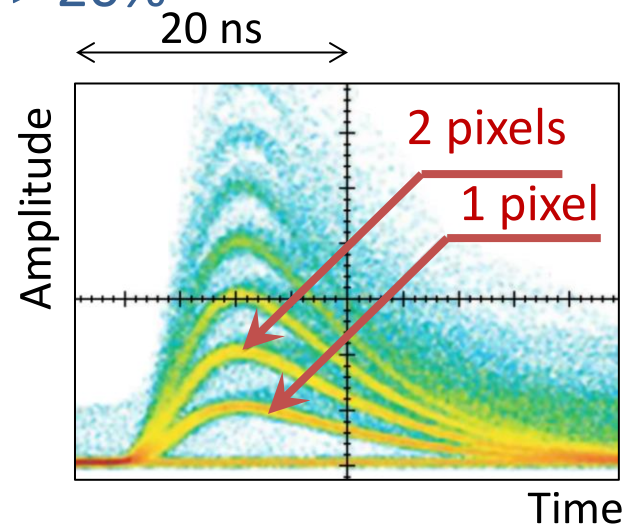
➢ **Silicon Photo Multiplier (SiPM)** is a new type of photon-counting device made up of multiple Avalanche Photo-Diode (APD) pixels operating in Geiger mode. Each APD pixel outputs a pulse signal when it detects one or more photons, and the output of the SiPM is the total sum of all these pulses.

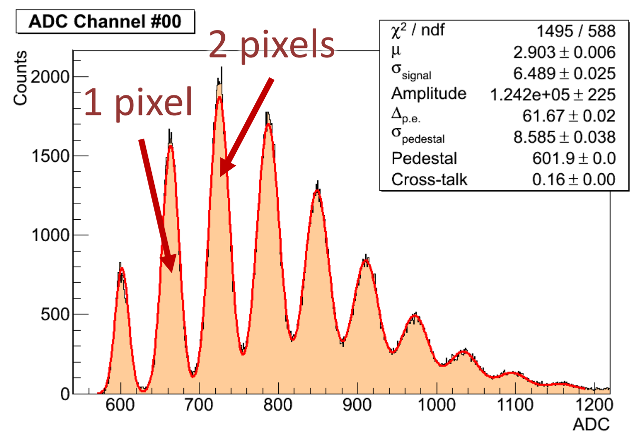




Features of SiPM

- Immune to strong magnetic field: few Tesla
- Good photon detection efficiency (PDE) : > 20%
- High gain: ~ $\times 10^6$
- Compact size
- No HV needed
- Photon counting for weak light
- Some disadvantages
  - Noise rate
    - can be reduced by cooling the sensor
  - Cross talk and after pulses: 10 ~ 20%
  - Limited range of gain:
    - strong corr. between gain and PDE
  - **Radiation hardness**

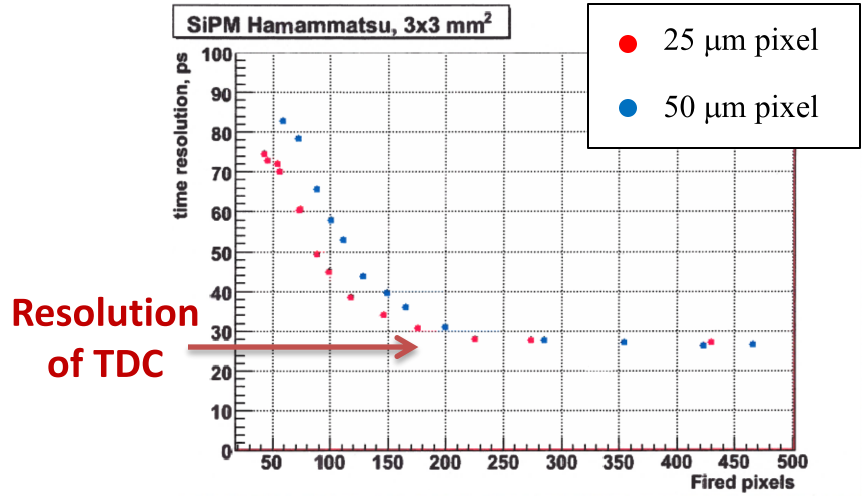


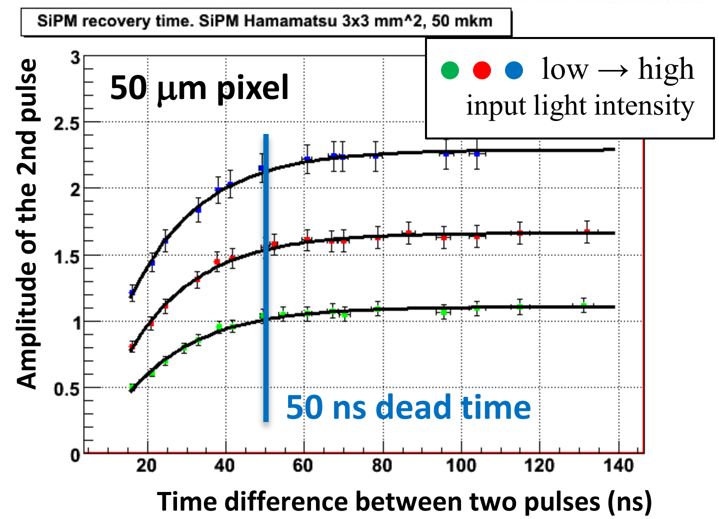


Time Resolution and Recovery Time

- PLP-10 Picosecond Light Pulser from Hamamatsu:
  - Pulse width < 70 ps
  - Repetition rate up to 100 MHz
- Intrinsic time resolution
  - < 30 ps
  - Good enough for most of the TOF applications
- Pixel recovery/dead time
  - 10 ~ 50 ns, depends on pixel size, smaller size → shorter recovery
  - Can handle MHz level input rate

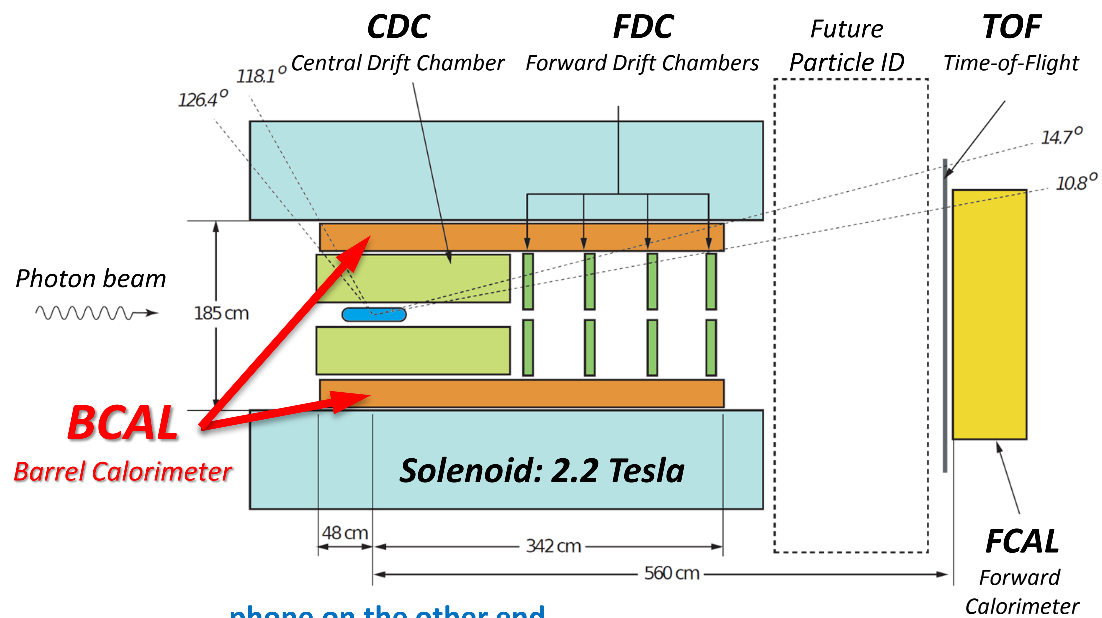
A NIM article is being prepared

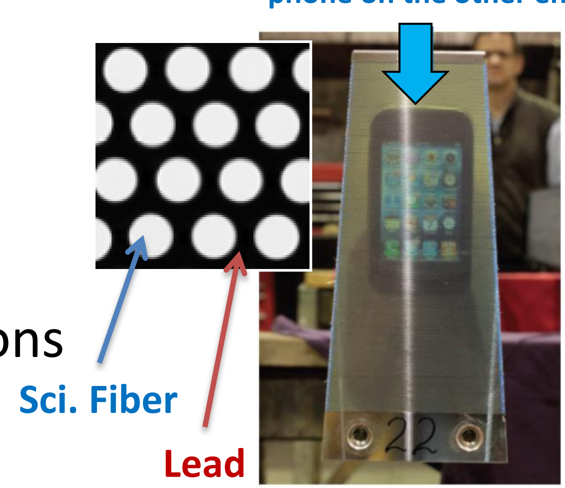


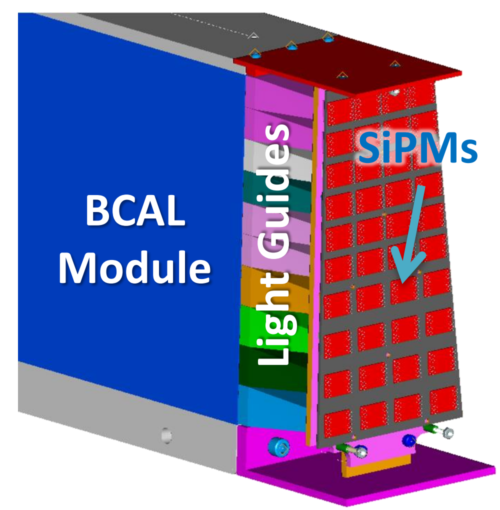


SiPM for Hall-D Barrel Calorimeter

- Barrel Calorimeter (BCAL)
  - Scintillator fiber – Lead
  - 48 trapezoidal modules
  - Photon energy and position
- Reasons to use SiPM
  - Strong magnetic field: > 1 T
  - Tight space for readout
  - Similar cost as fine-mesh PMTs
  - Good time resolution
- Additional benefits
  - Natural radial segmentations for additional PID



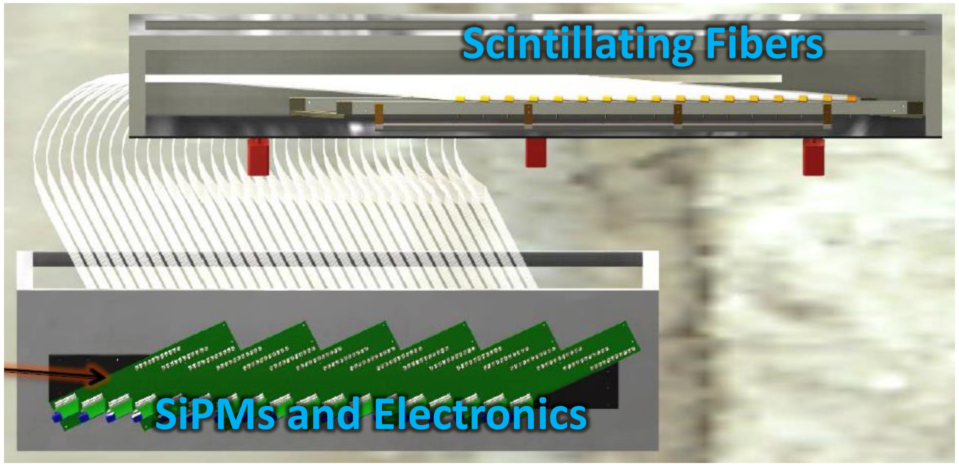


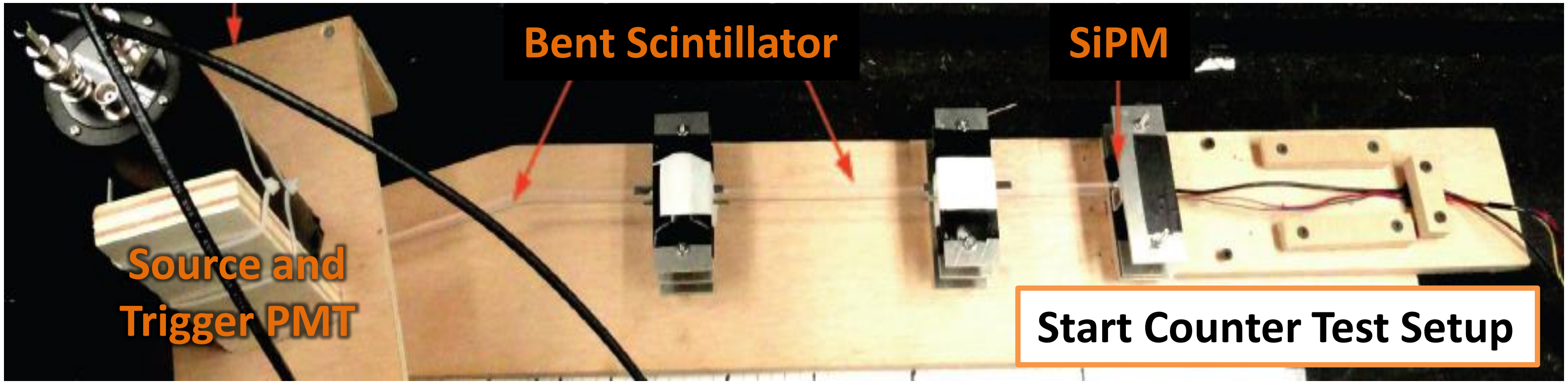


Applications for Scintillating Counters in Hall-D

- Beam line hodoscopes: tagger microscope and pair spectrometer
  - Small size to couple to thin fibers
  - Capability to handle high rates, short recovery time
- Start Counter:
  - Small size
  - Good time resolution

Photon Tagger Microscope

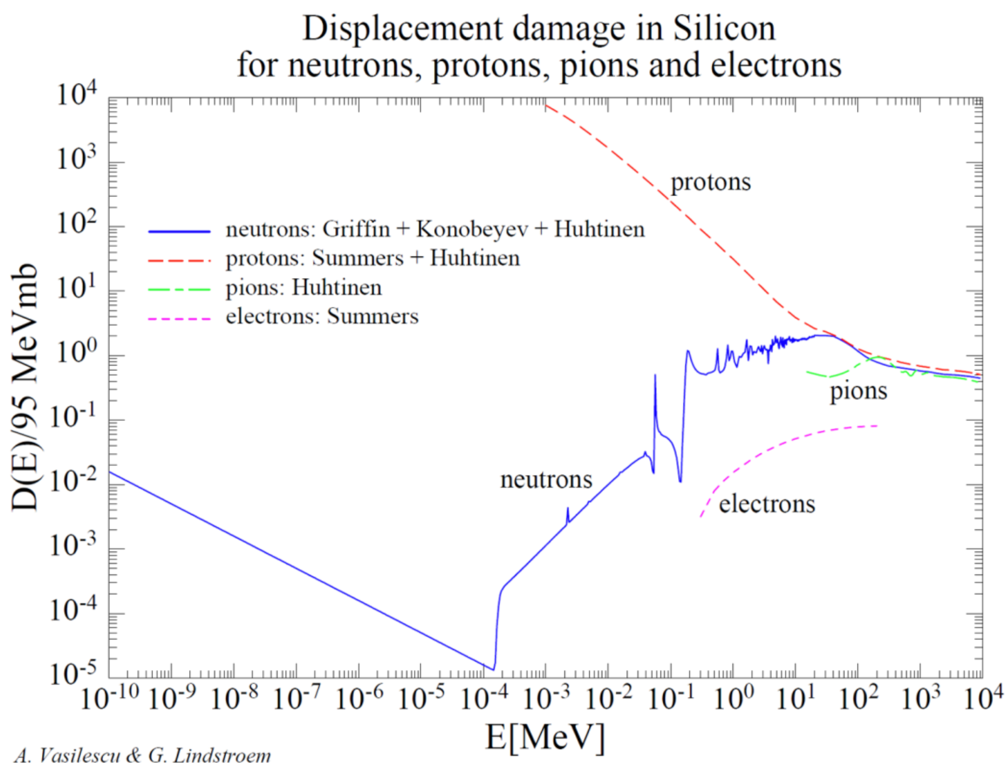




Start Counter Test Setup

Radiation Damage to Silicon Detectors

- Bulk radiation damage in silicon detectors is primarily due to displacing a **Primary Knock on Atom** out of its lattice site.
- Proportional to The **Non-Ionizing Energy Loss** (NIEL).
- Heavier particles induce greater damage.
- Neutron damage is the major concern for SiPMs in Hall D:
  - > 90% damage
  - 10 years running: $2.5\times10^{9} n_{eq}/cm^{2}$
  - Requires dark rate < 100 MHz for each SiPM array

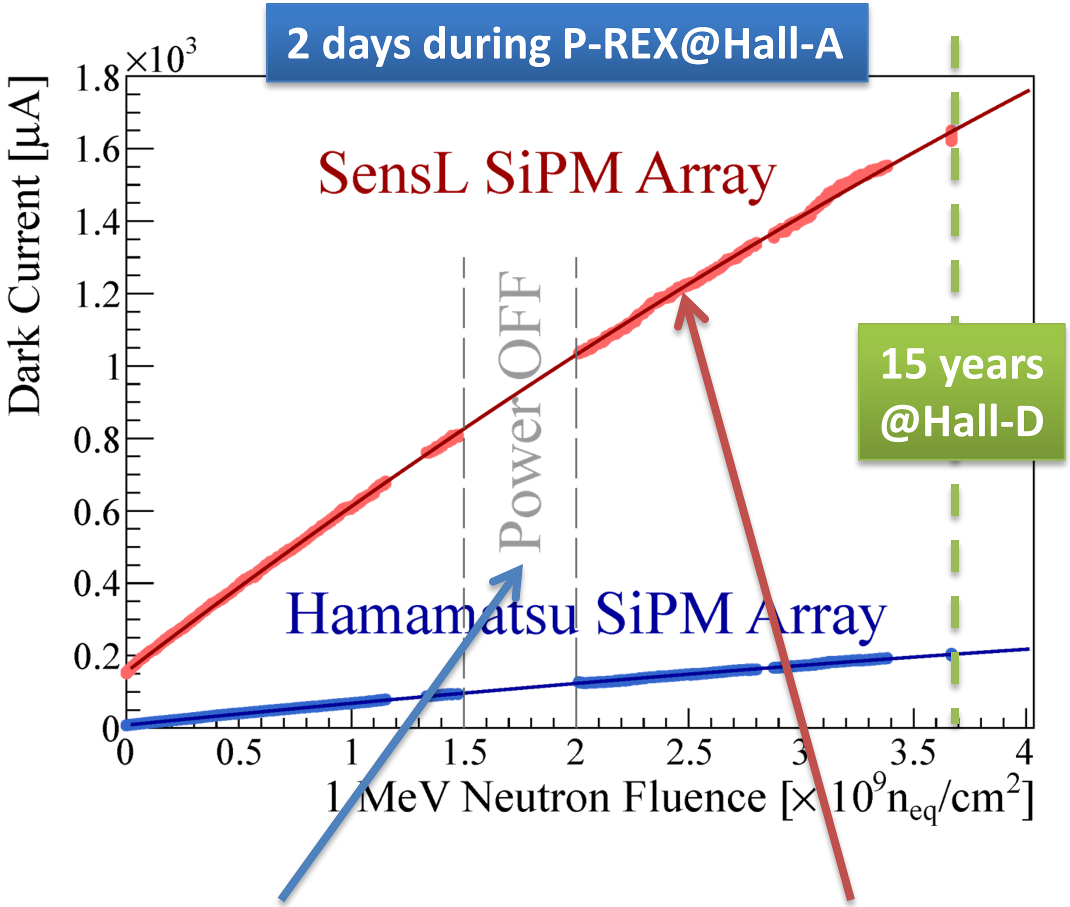


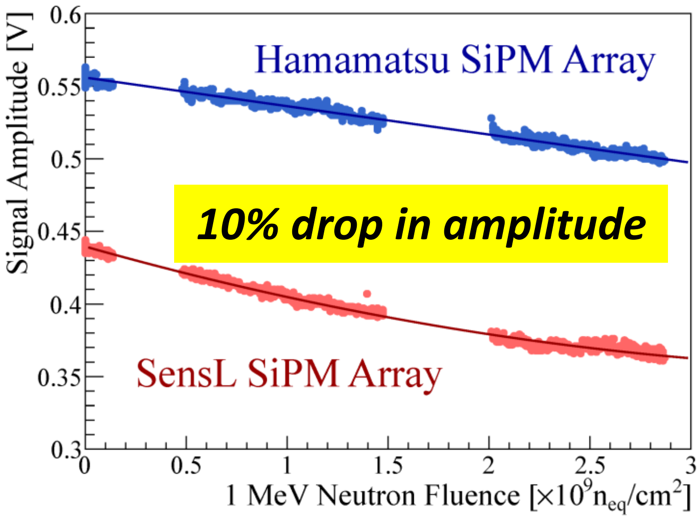
Neutron Radiation Tests at JLab

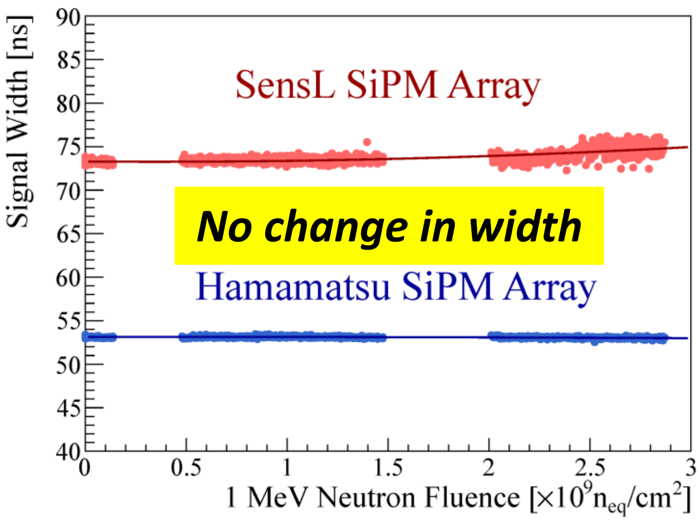
- Test using neutron background during P-REX in Hall-A
  - 12×12 mm^2 SiPM arrays from Hamamatsu and SenSL, 1×1 mm^2 and 3×3 mm^2 SiPMs from Hamamatsu (50 μm)
  - Self-annealing at room temperature
  - Need to cool these devices during GlueX operation
- Test using JLab RadCon AmBe source
  - 1×1 mm^2 SiPMs from Hamamatsu (50 μm)
  - Measure temperature dependence
    - Radiation damage
    - Self-annealing
    - Impact of radiation damage on the dark rate temperature dependence
  - Accumulated radiation damage with annealing

NIM paper being submitted

First Look at the Radiation Damage



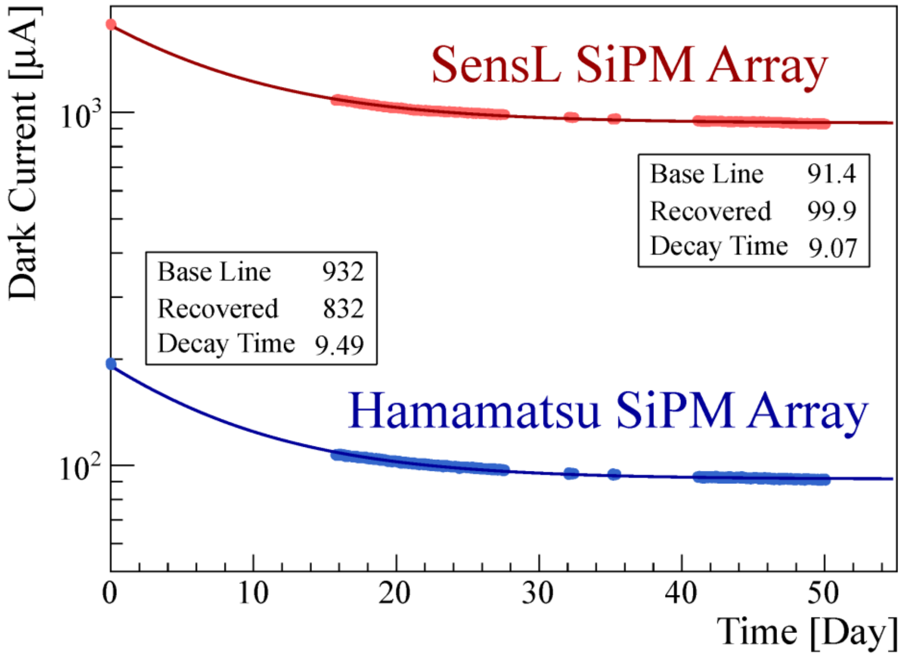




Damage independent on bias voltage

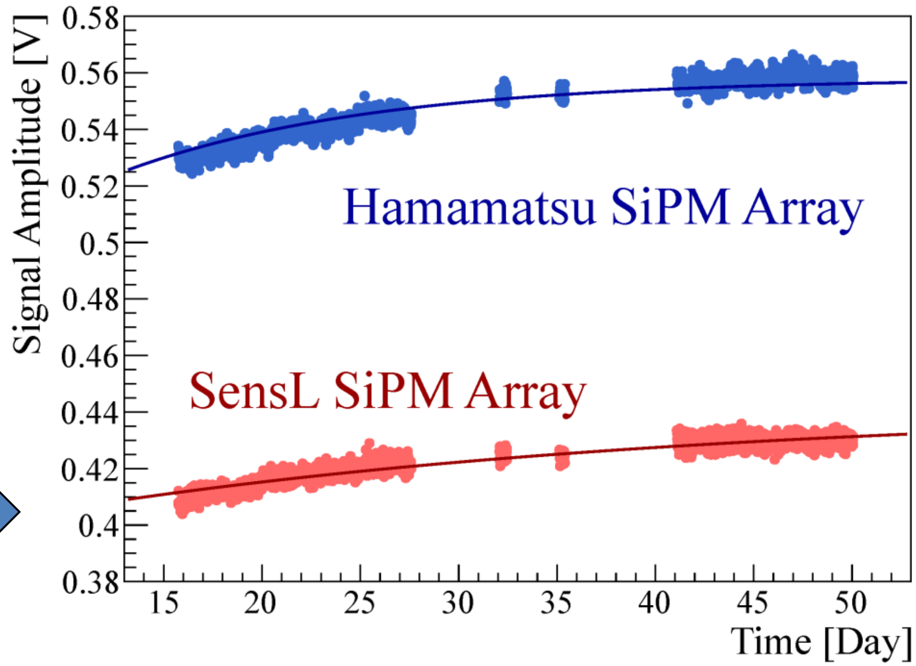
Approximate Linear damage curve

Annealing at Room Temperature



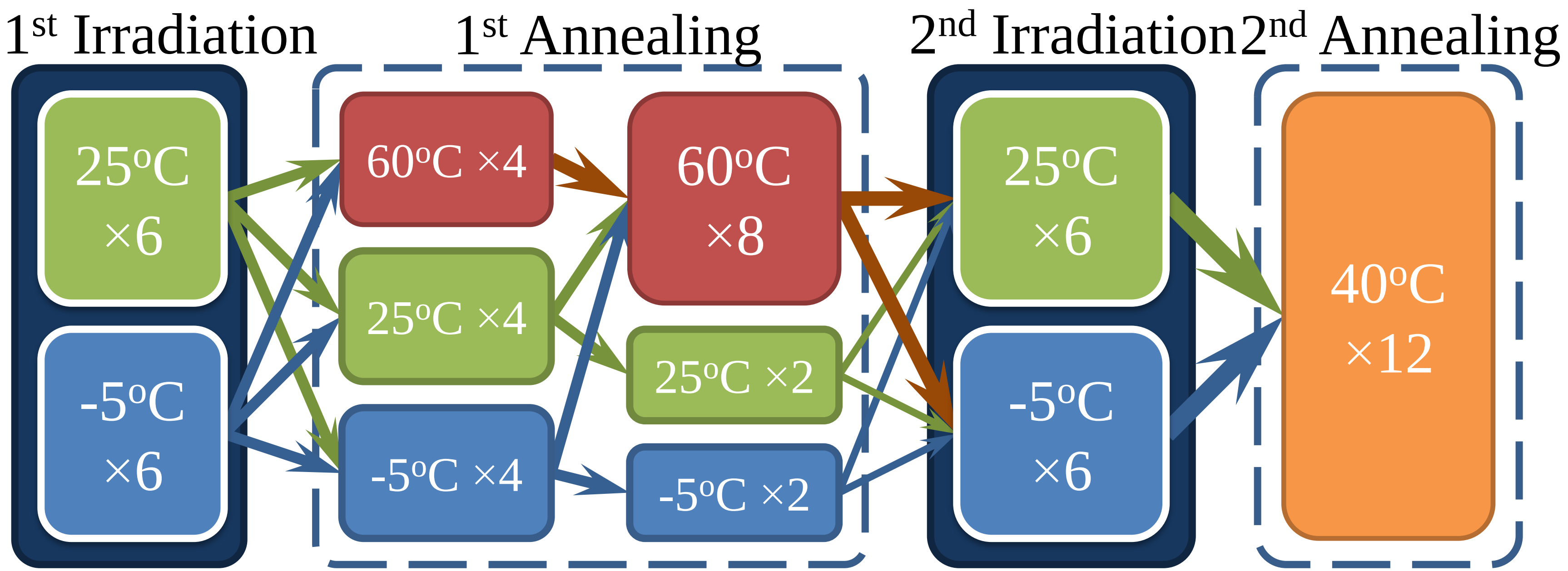
- About **half** of the increase of the dark current caused by radiation damage recovered
- Decay time ~ **10 days**

- Drop in amplitude fully recovered



Test Sequence using AmBe Source

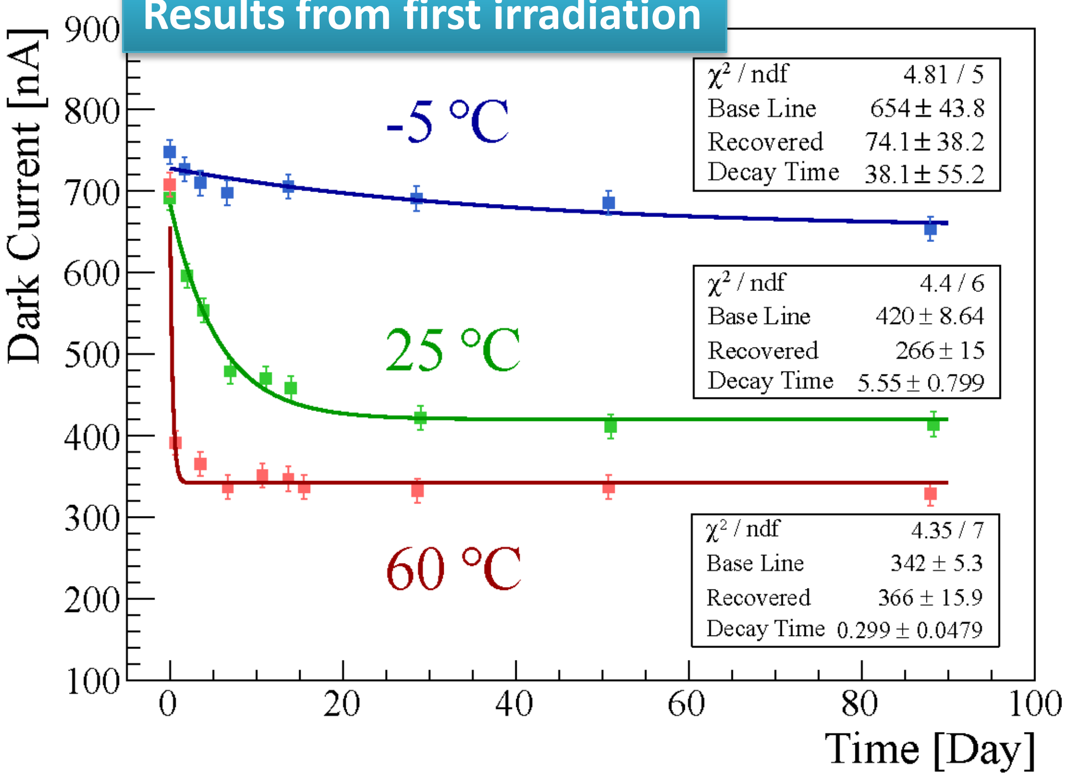
- 12 1×1mm^2 Hamamatsu SiPM (50 μm)
- Different temperature conditions/combinations
- Two irradiations and two annealings
- Total fluence ~ 13 years of high intensity running of GlueX

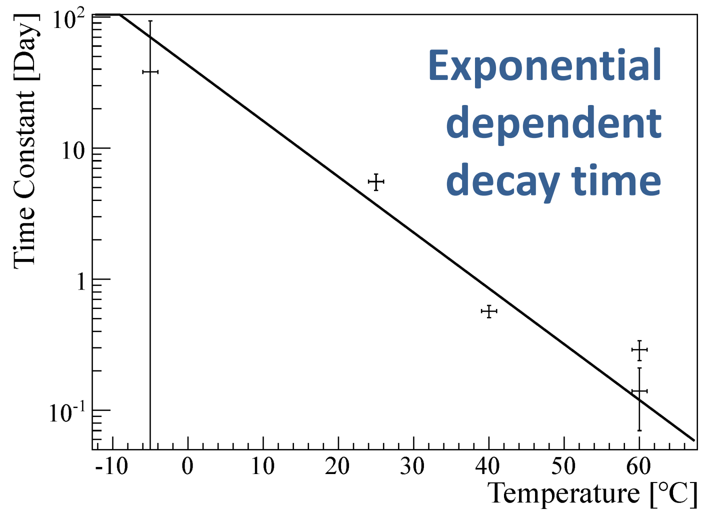


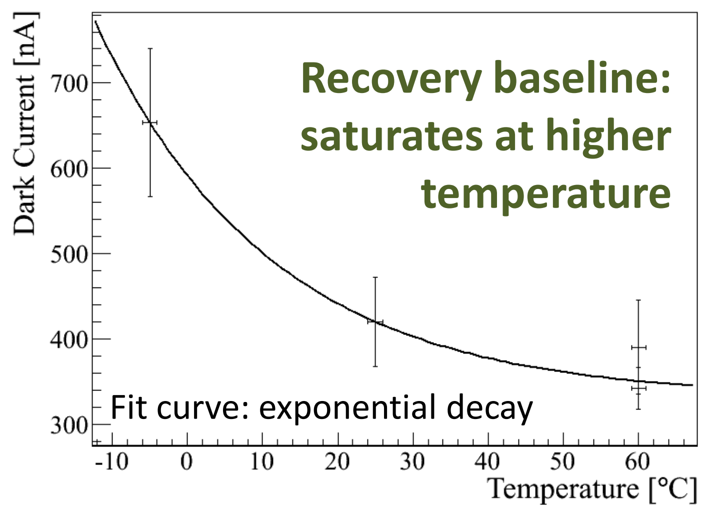
Numbers of units tested at different temperatures are shown in the blocks

Recovery at Different Temperatures

Results from first irradiation



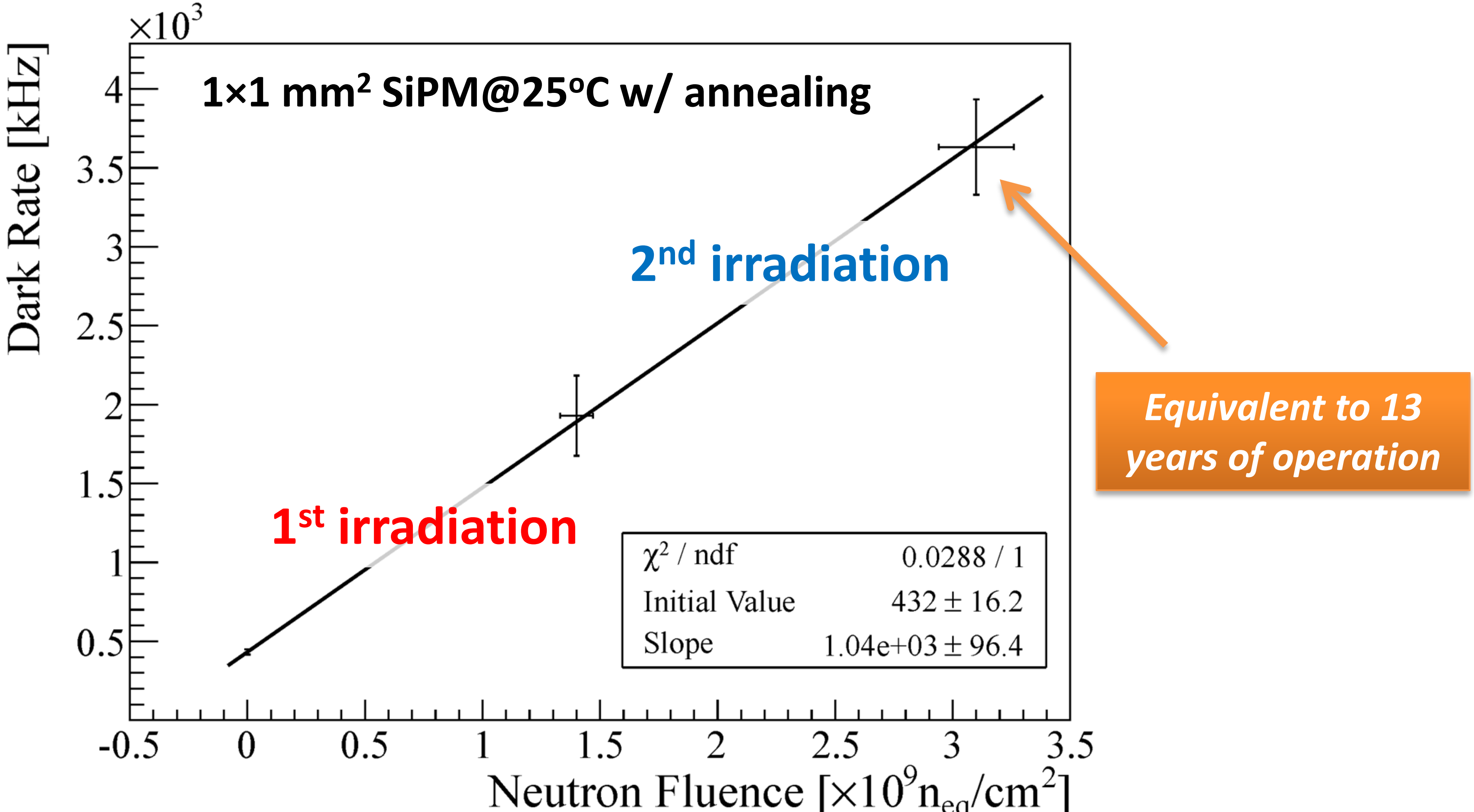




- Higher Temperature brings faster and stronger self-annealing

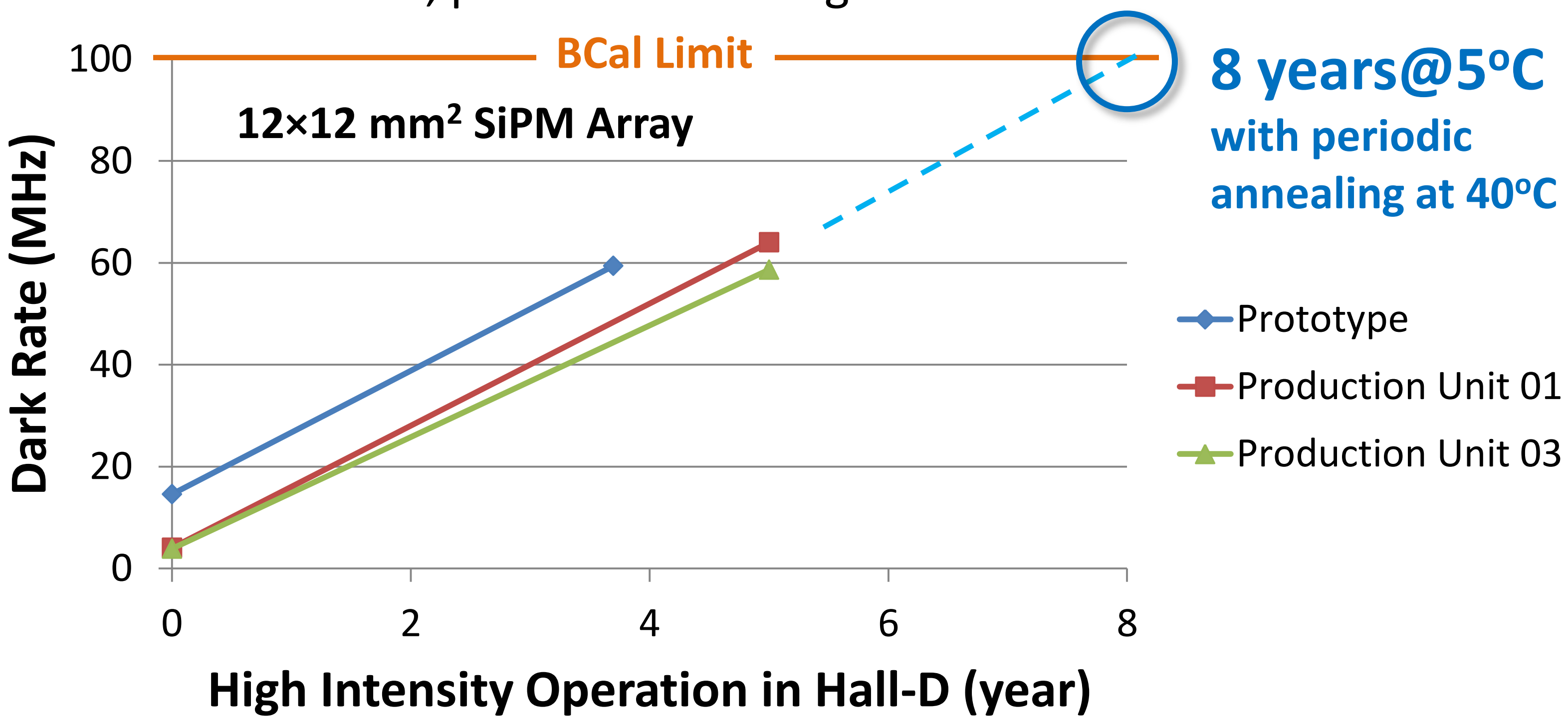
Damage Curve

- Radiation damage does NOT depend on temperature
- Radiation damage does NOT depend on previous irradiations



Expected Lifetime in Hall-D

- Hamamatsu improved initial dark rate of the production units, still same damage rate as prototype samples.
- Life time in Hall-D ~ 8 years with high intensity beam:
  - 10^8 γ/s on a 30 cm LH_2 target, 30% running efficiency
  - SiPMs cooled to 5°C, periodic annealing at 40°C



R&D for Electron-Ion Collider

- Except for the radiation hardness, SiPMs are ideal for future high energy detector systems, such as EIC:
  - High gain, compact form factor, good photon detection efficiency and immunity to magnetic field.
- An R&D proposal "*to test improved radiation tolerant Silicon Photomultipliers*" for EIC has been approved:
  - Collaborate with JLab detector group and Hamamatsu. Perform bench tests on samples with varied manufacturing parameters, then give feedbacks to Hamamatsu and continue the loop.
  - Received the first group of samples in April, test is ongoing.

Summary and Outlook

- Silicon photo multiplier is a novel photo detector with many desirable features.
- We thoroughly studied its performance including radiation hardness, time resolution and dead time.
- Applications in Hall-D:
  - Barrel Calorimeter
  - Beam line hodoscopes
  - Start counter
- Future applications in EIC
  - Many possibilities
  - R&D with Hamamatsu on the radiation hardness

Acknowledgement

➢ Hall-D

- ❑ Elton Smith (Scientist)
- ❑ Alexander Somov (Scientist, SiPM timing measurement)
- ❑ Ivan Tolstukhin (Grad. Student, SiPM timing measurement)

➢ Detector Group

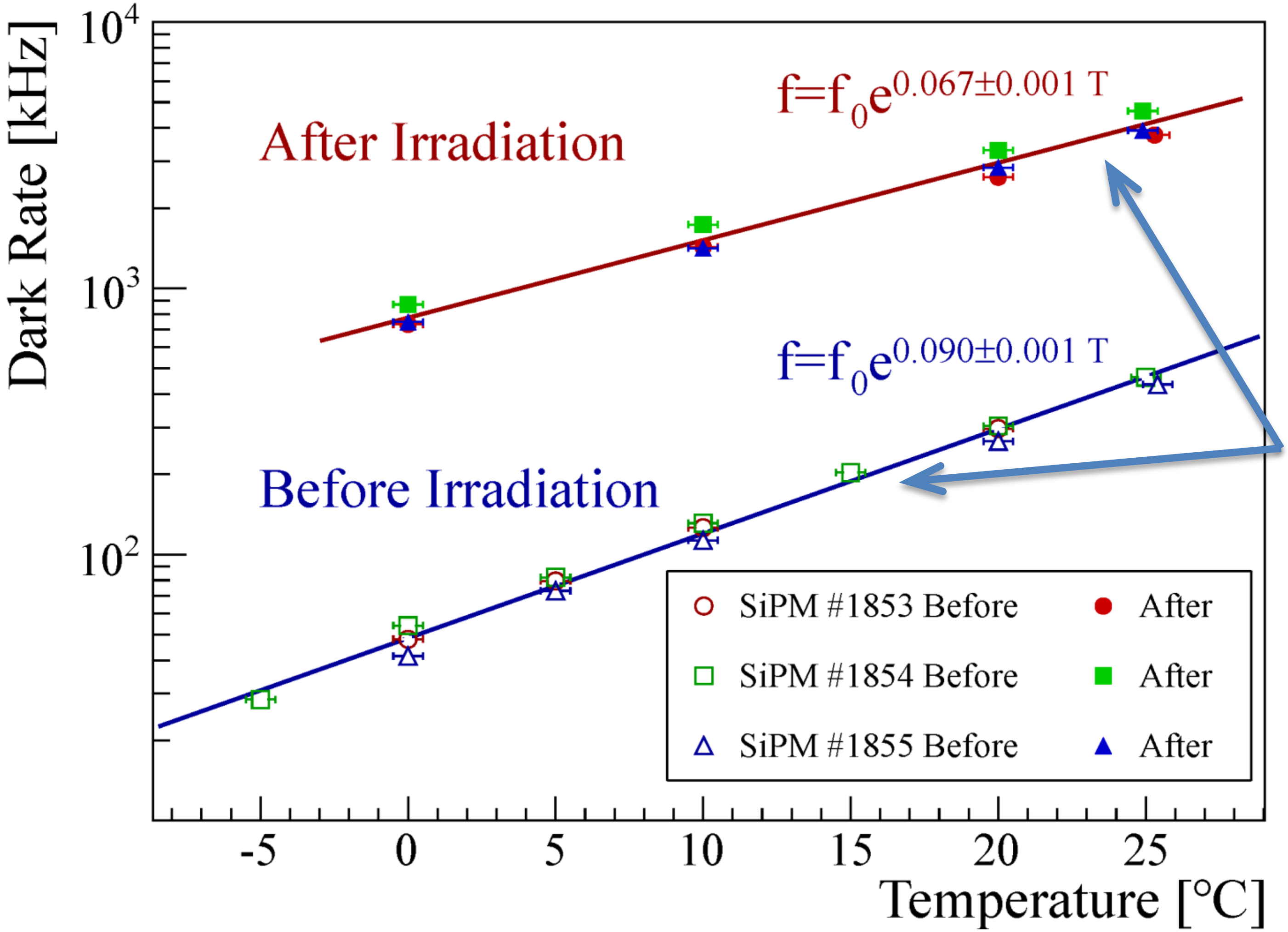
- ❑ Carl Zorn (Scientist, SiPM characterization and radiation measurements)

➢ Radiation Control Group

- ❑ Pavel Degtiarenko (Scientist, Flux simulation)
- ❑ Melvin Washington (Radiation monitoring)
- ❑ John Jefferson (AmBe source)

BACKUP SLIDES

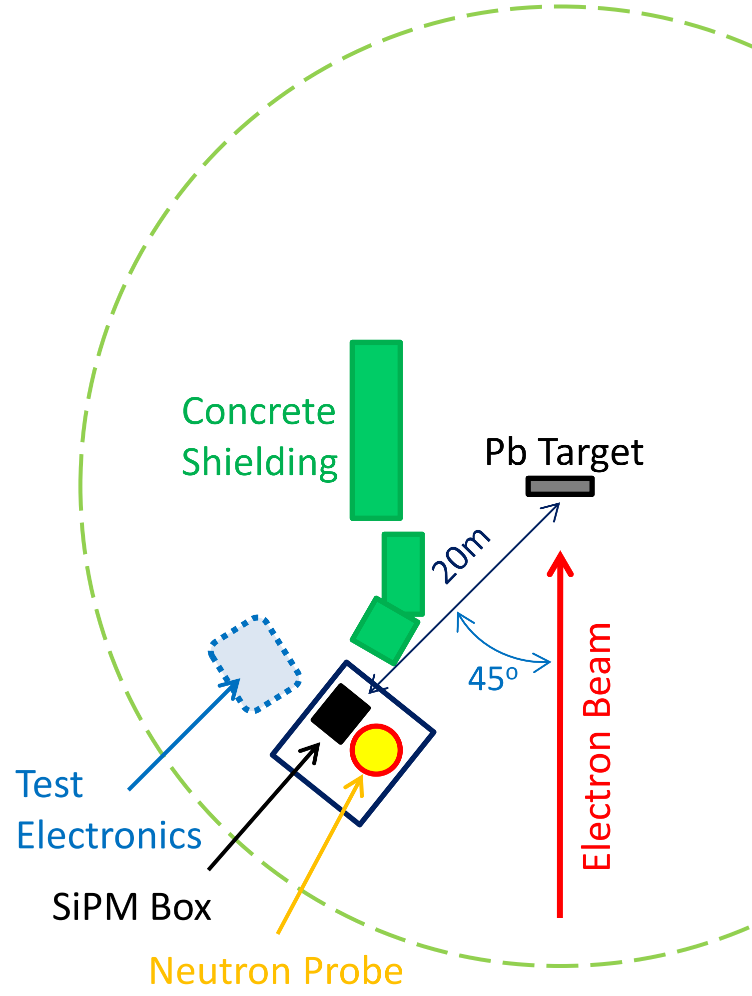
Temperature Dependence of Dark Rate



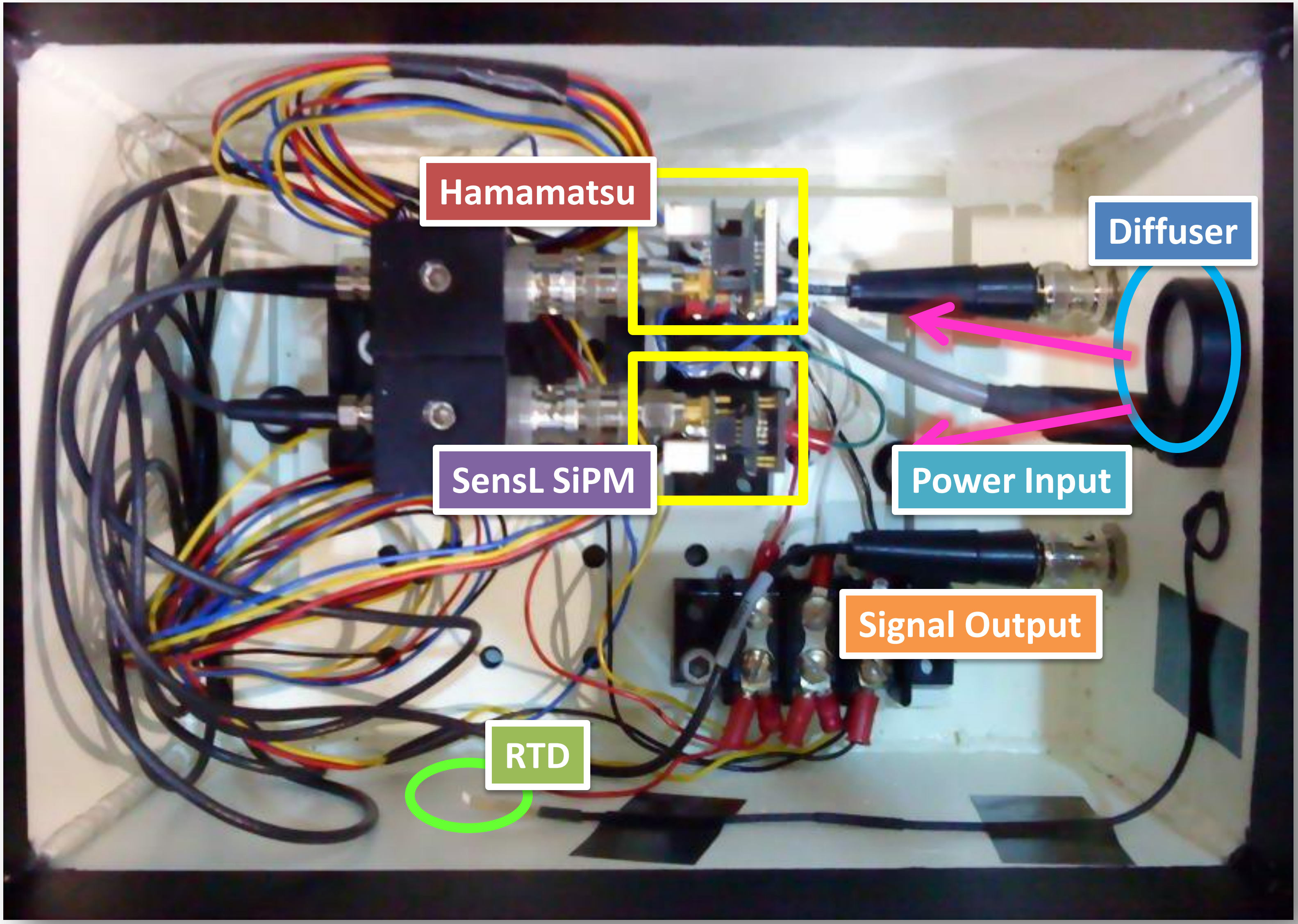
Similar Temperature dependence before and after irradiation

Test Configuration in Hall A during P-REX

- SiPM Test Box was put on a platform with direct view of the scattering chamber, 20 m away from the Pb target with an angle of 135º.
- A real time BF_3 neutron dose monitor was put next to the SiPMs.
- Electronics was shielded by the concrete blocks, additional shielding added later.

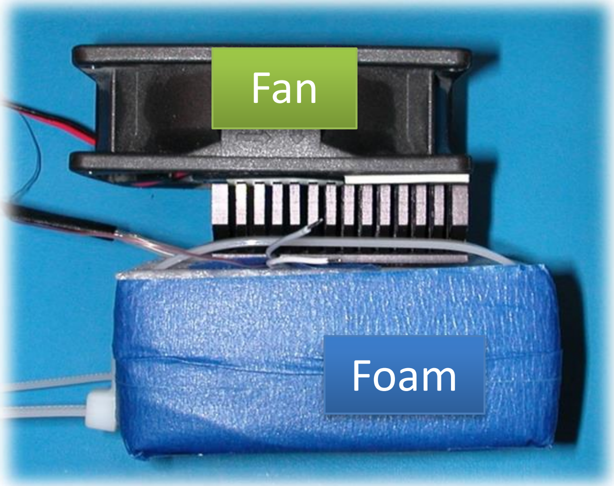


Inside the SiPM Box

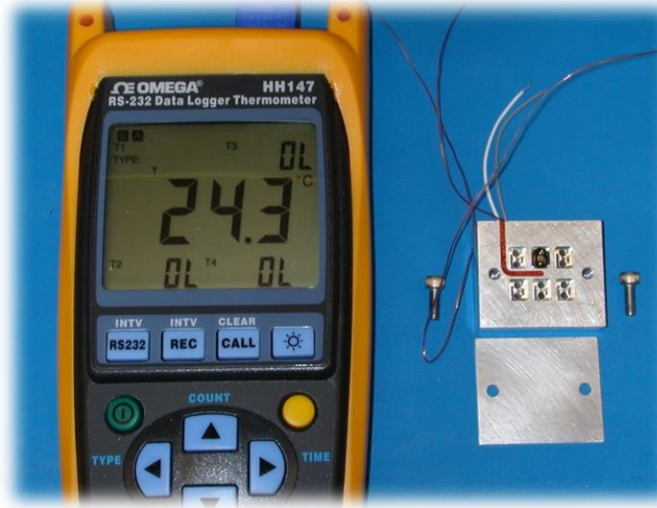


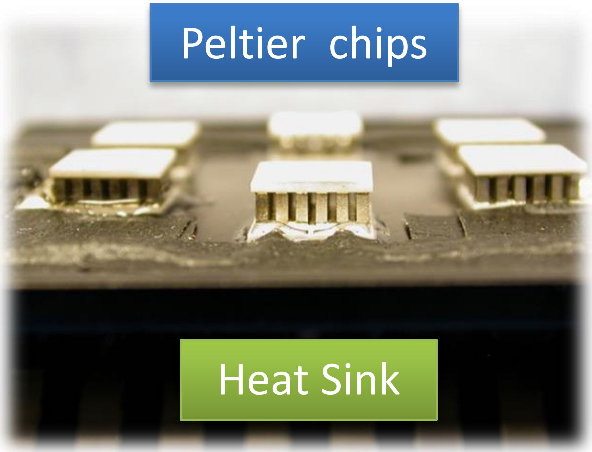
Instruments in the Hall

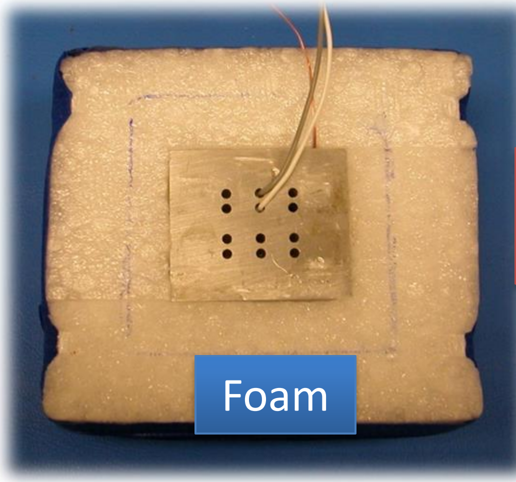
The Cooling Device

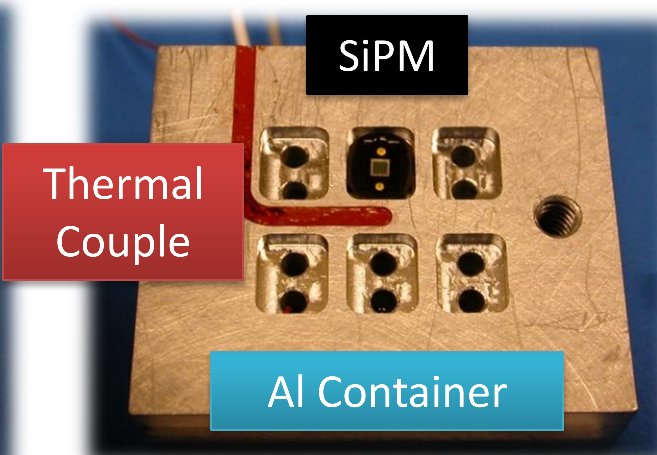


With six Peltier effect chips, the device can cool six SiPMs to -10^{o}C at 25^{o}C room temperature.

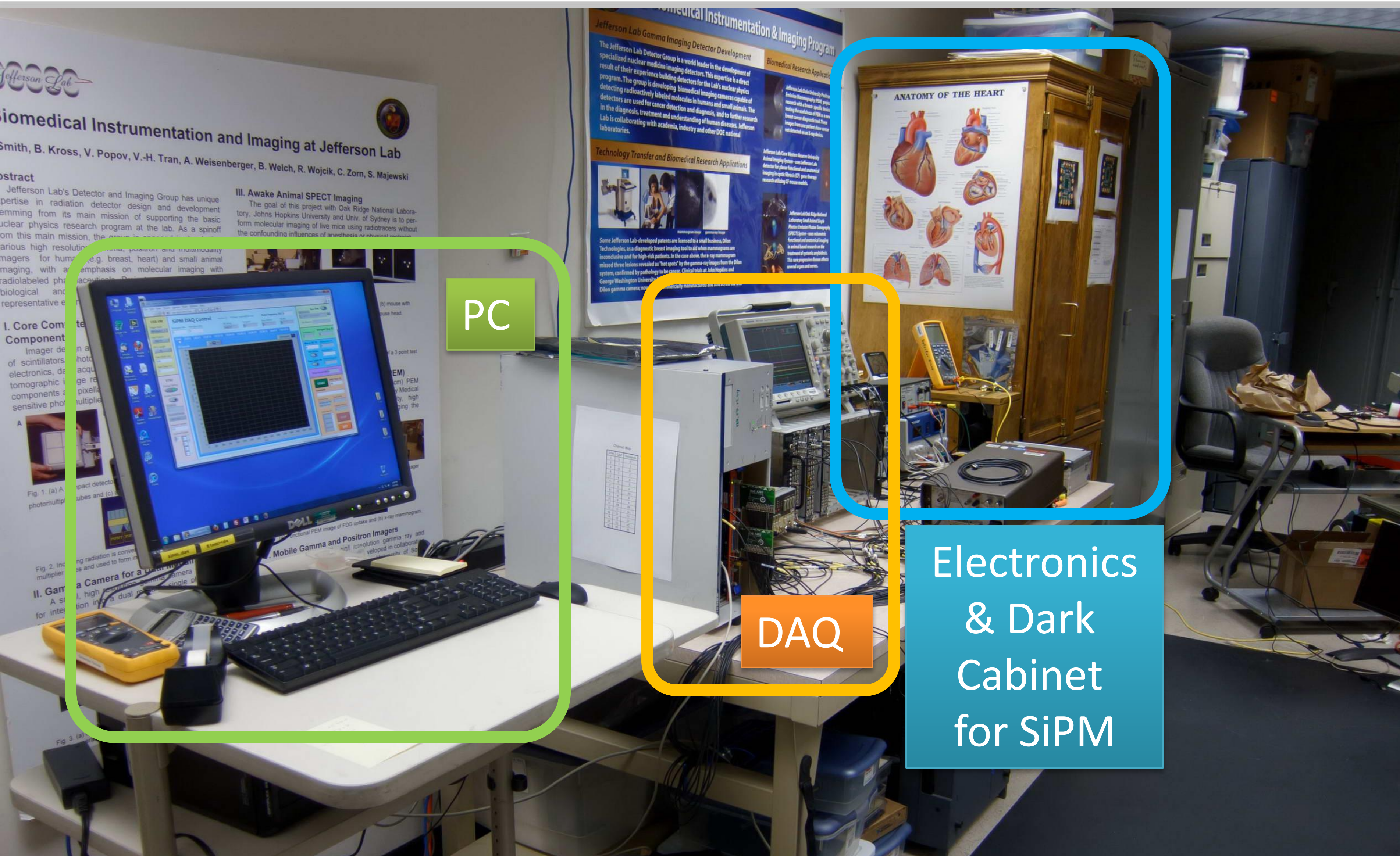




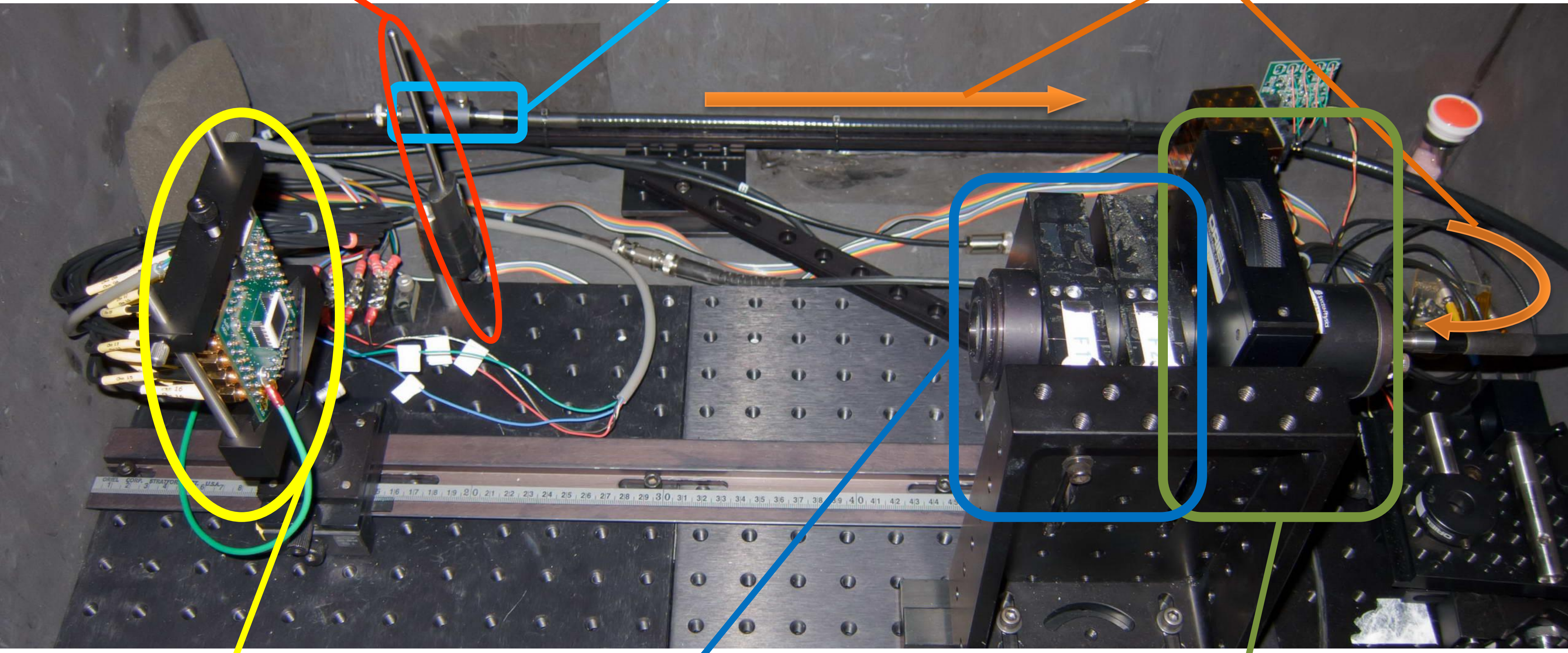




Test Setup

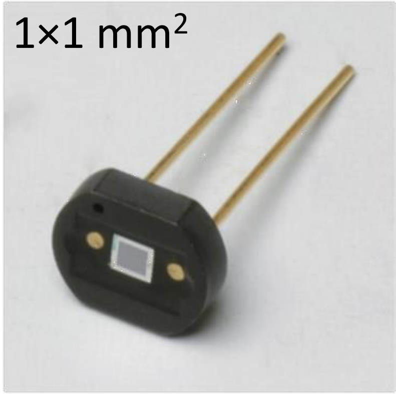

PC
DAQ
Electronics & Dark Cabinet for SiPM
ANATOMY OF THE HEART

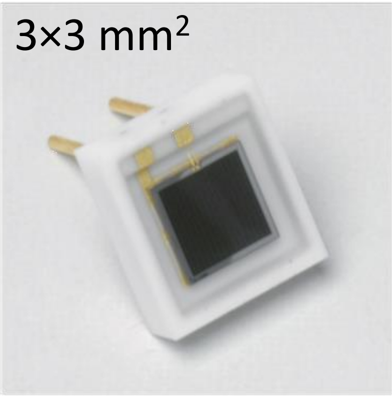
Inside the Dark Cabinet

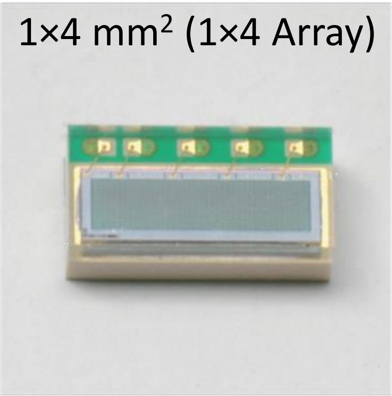


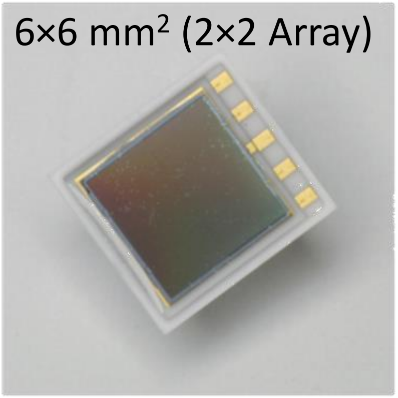
Introduction (cont.)

- Available in various dimensions and pixel sizes
  - Individual SiPM covers a few mm^2
  - SiPM Array for larger coverage
  - 25, 50, 100 μm pixel size available









- Electrical properties (Hamamatsu SiPMs)
  - Capacitance: 0.1 pF for 50 μm pixel
  - Breakdown Voltage: ~ 70 V

GlueX at Jefferson Lab Hall-D

- Study the QCD in the gluonic degree of freedom by searching for **mesons with exotic quantum numbers** in photo-production