Liquid Argon Scintillation

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Adapted: Noah Hood

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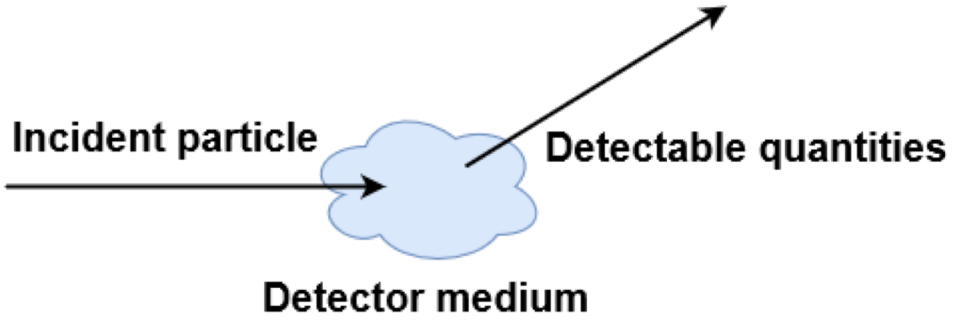
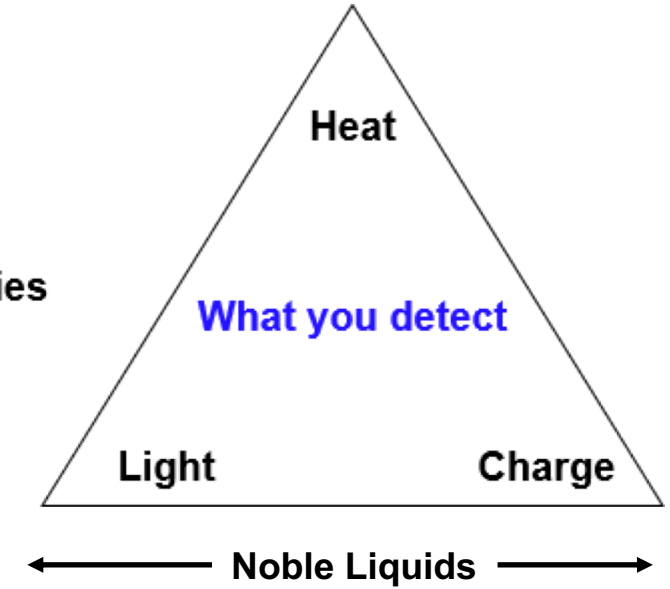
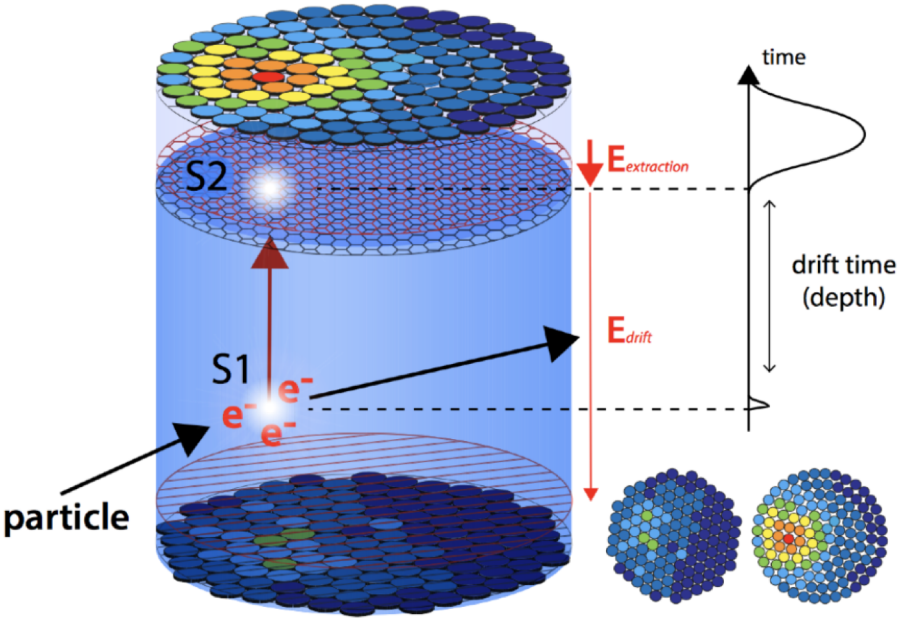
How do we detect interactions?





Why noble liquids?

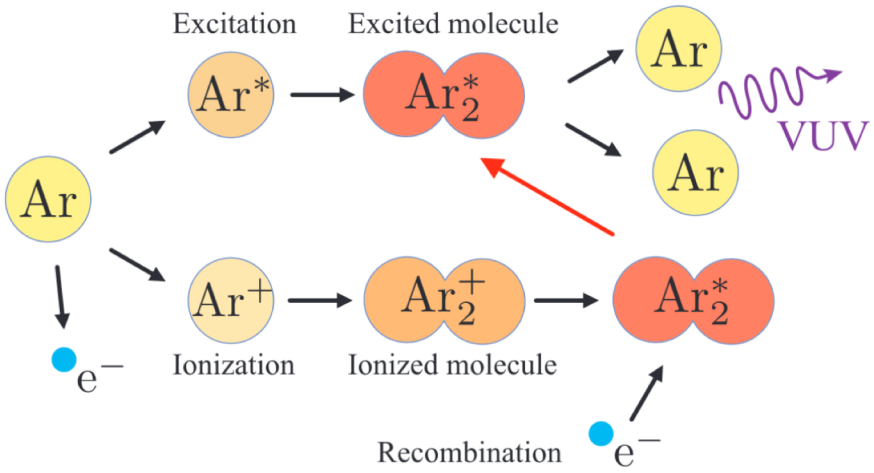
- Detects light *and* charge (at an applied **E** field)
  - Light + charge gives depth of interaction (time projection chamber)
- Particle identification
  - Charge to light ratio in liquid xenon
  - Pulse-shape discrimination in liquid argon
- Scalable
  - Several tons of liquid xenon (LZ, XENONnT, PandaX-4T)
  - Several kilotons of liquid argon (Darkside-20k)



Credit: XENON Collaboration

Liquid argon scintillation mechanism

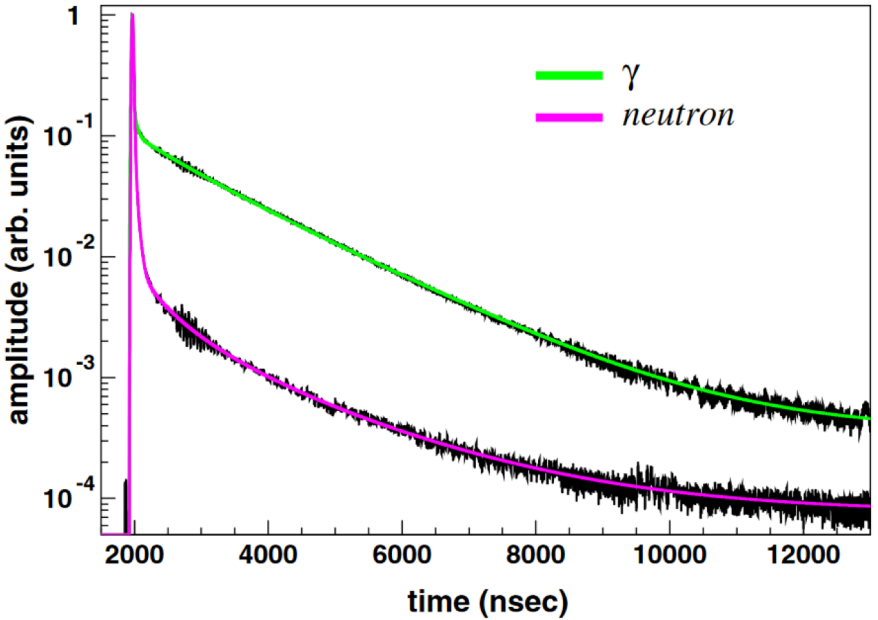
- Deposited energy does two things
  - Excitation: Forms Ar_2^* excimer
  - Ionization: Forms Ar_2^+ molecule
  - If no **E** field: electrons recombine
- De-excitation gives off light
  - ~128 nm VUV
  - Often needs wavelength shifters to detect
  - New SiPMs are sensitive to LAr light



Source: V Boccone, ArDM Collaboration. DOI 10.1088/1742-6596/160/1/012032

Pulse-shape discrimination

- Two states: singlet and triplet
  - Singlet decay: 6-7 ns
  - Triplet decay: ~1.6 μs
  - Different particles produce different singlet to triplet ratios
  - Can be used to distinguish between nuclear and electronic recoils
- Pulse shape discrimination parameter: $\frac{\int_0^{t_1} P(t)dt}{\int_0^{\infty} P(t)dt}$

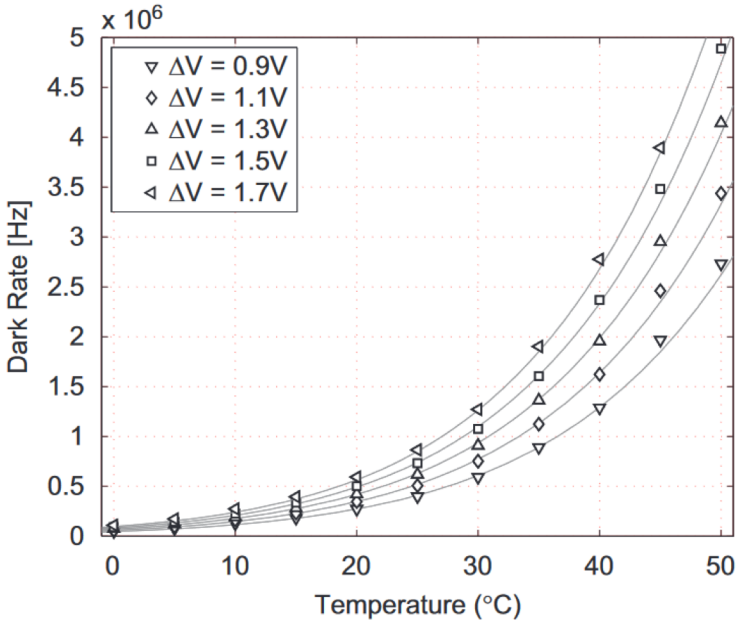


Average waveforms for neutrons and gammas
Source: Ettore Segreto, Phys. Rev. D 103, 043001

Light Detection with VUV-Sensitive Silicon Photomultipliers (SiPMs)

- Liquid argon is cold ⇒ can see single photons!
- Which SiPM will be used?
  - Hamamatsu S13370 SiPM
  - ~15% PDE at Ar scintillation light wavelength (~128 nm)
- SiPM dark count:

$$R_{DN}(\Delta V, T) = A(V - V_0)\left(\frac{T}{298}\right)^{3/2} e^{-(E/2kT - E/2k\cdot 298)}$$



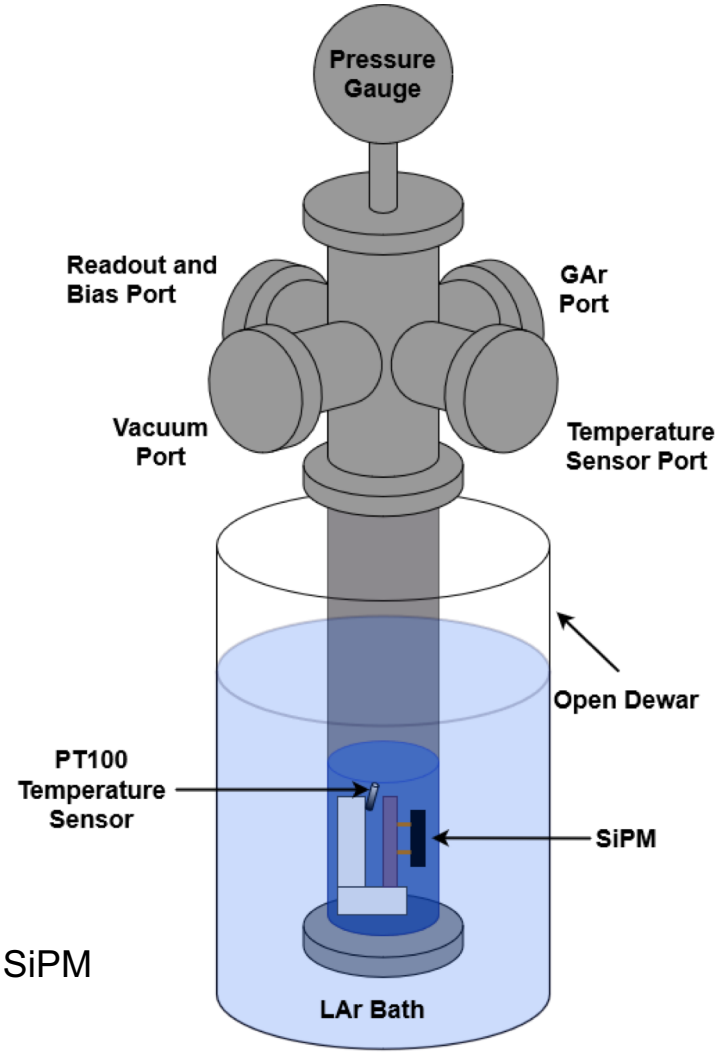
SiPM dark count with temperature

Liquid Argon Module

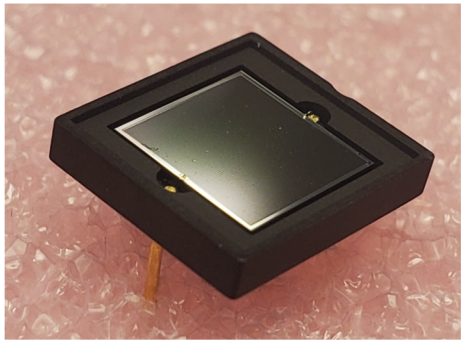
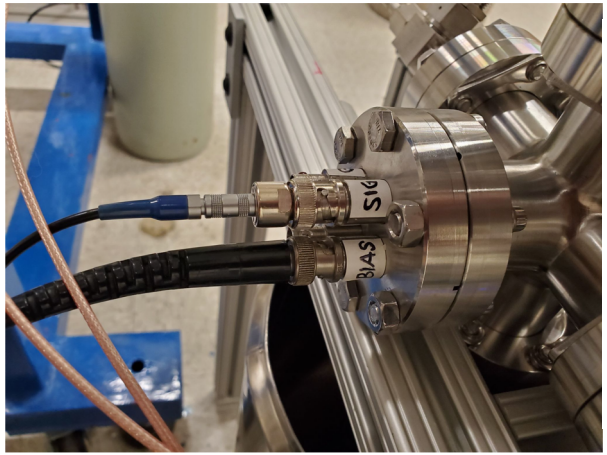
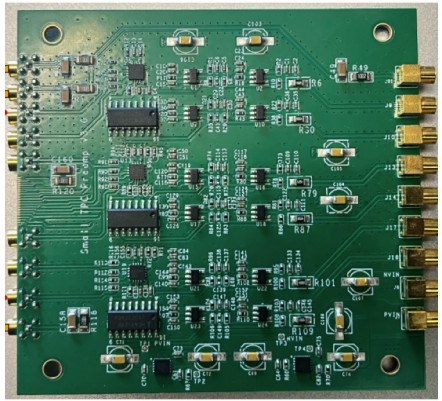
- A bare-minimum setup for scintillation light detection with liquid argon
  - SiPM to detect the ~128 nm scintillation photons
  - High-purity gas argon
  - Vacuum environment
  - (Impure) liquid argon to condense the gas argon
  - A temperature sensor to ensure the gas argon is cooled
- Main tasks
  - Experiment setup
  - Data acquisition
  - Data analysis

Module Setup

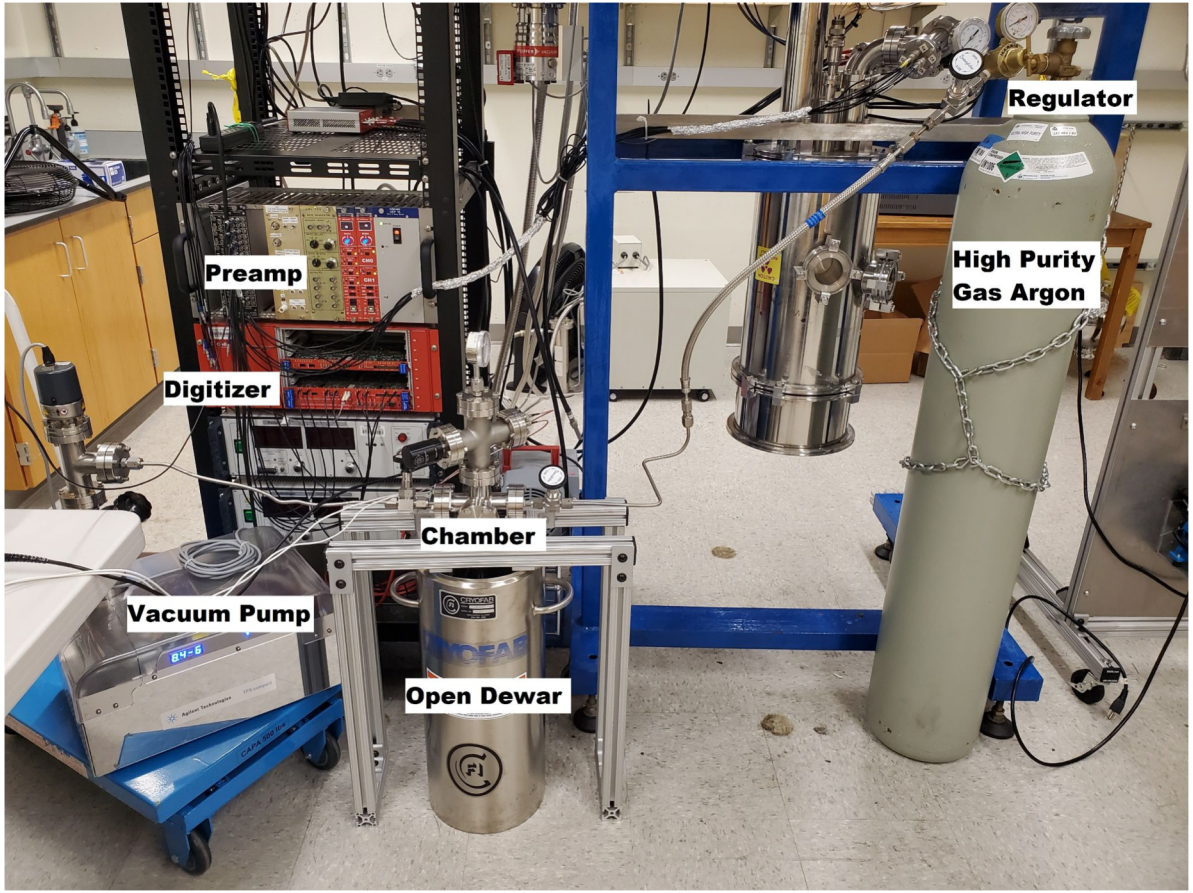
- SiPM
  - Located at the bottom of the chamber
  - Bias voltage needed
  - Readout and get amplified
- Vacuum
  - Pump connected through the vacuum port
- Gas
  - High-purity gas argon, with regulator
  - Fill the chamber through the GAr port
- Cryogenic
  - LAr bath to condense the gas argon
  - PT100 sensor to monitor the temperature above the SiPM



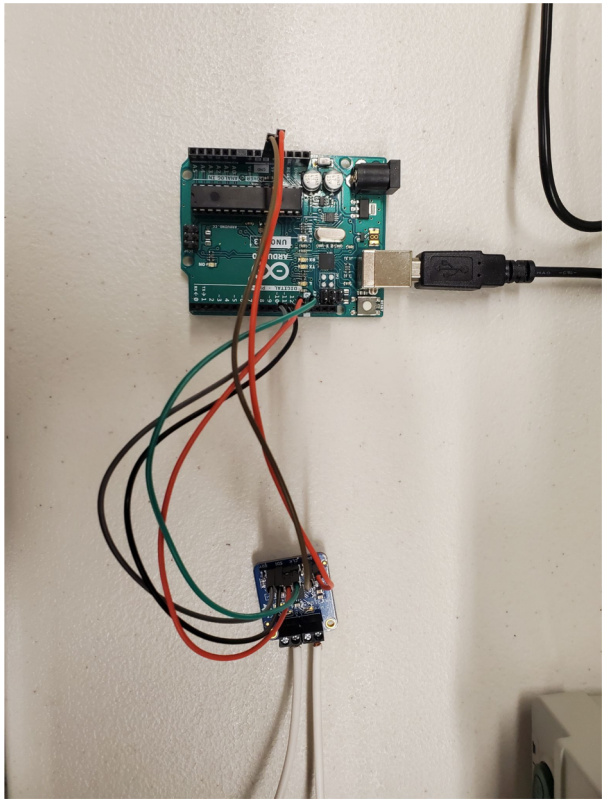
SiPM Setup

		
S13370 SiPM	Bias and signal feedthrough	Amplifier

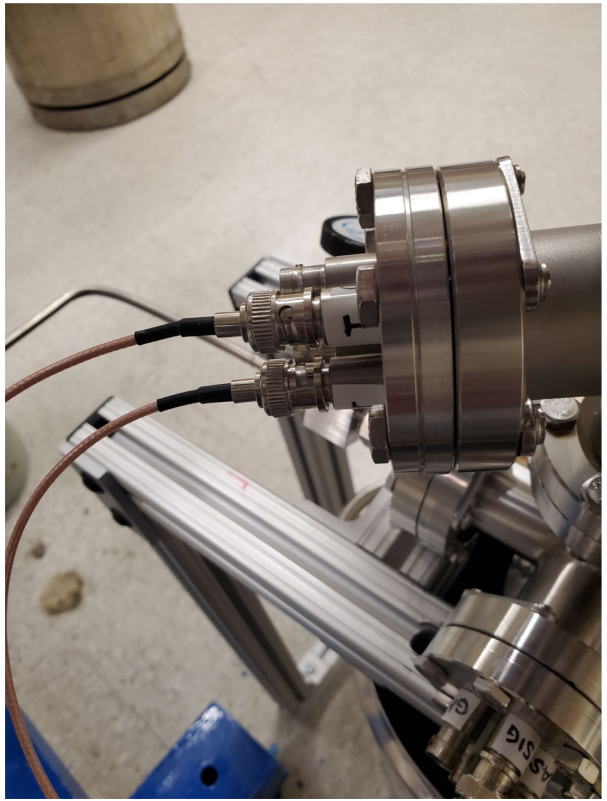
Vacuum, Gas and Cryogenics



Temperature Monitoring



Temperature sensor feedthrough



Arduino readout of temperature sensor

What will be Explored

- Experiments
  - Simple gas system and cryogenics
  - Observe SiPM signals with oscilloscope
  - Data taking
- Analysis
  - Area spectrum
  - Pulse shape discrimination