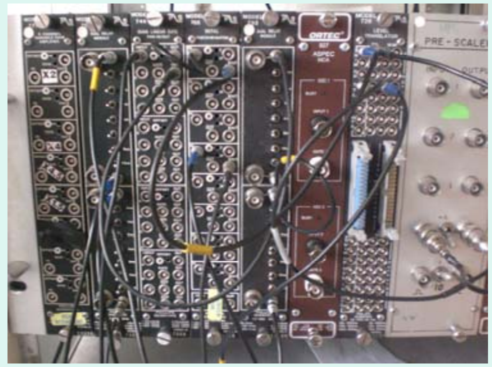
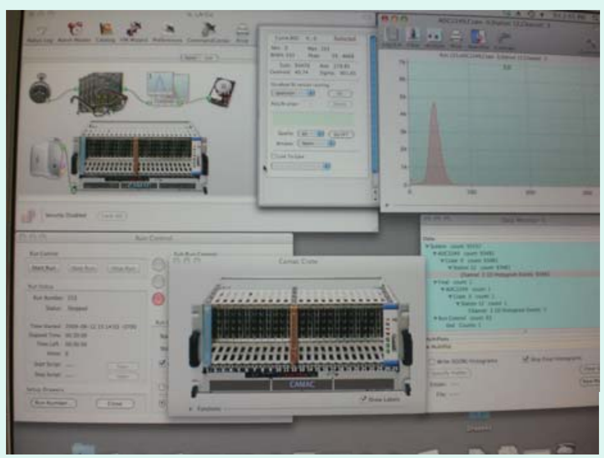


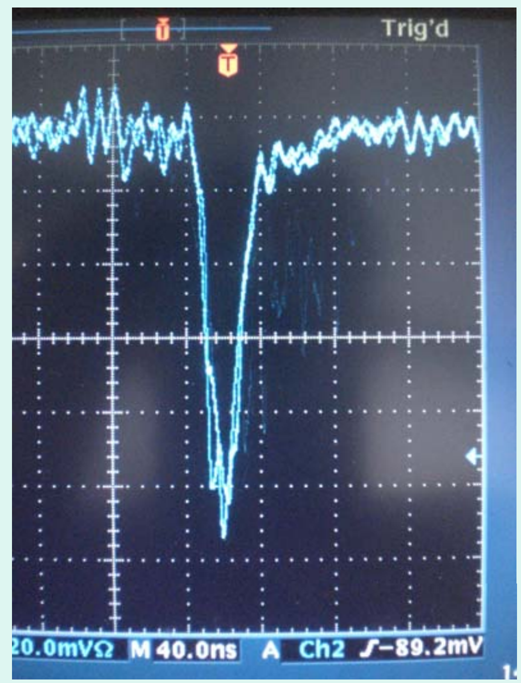

# A Summer at LArGe

*Josh Eby, IU South Bend*
University of Washington
REU Progam
8/21/09

MY REFLECTION!

MY HAND!





# Outline

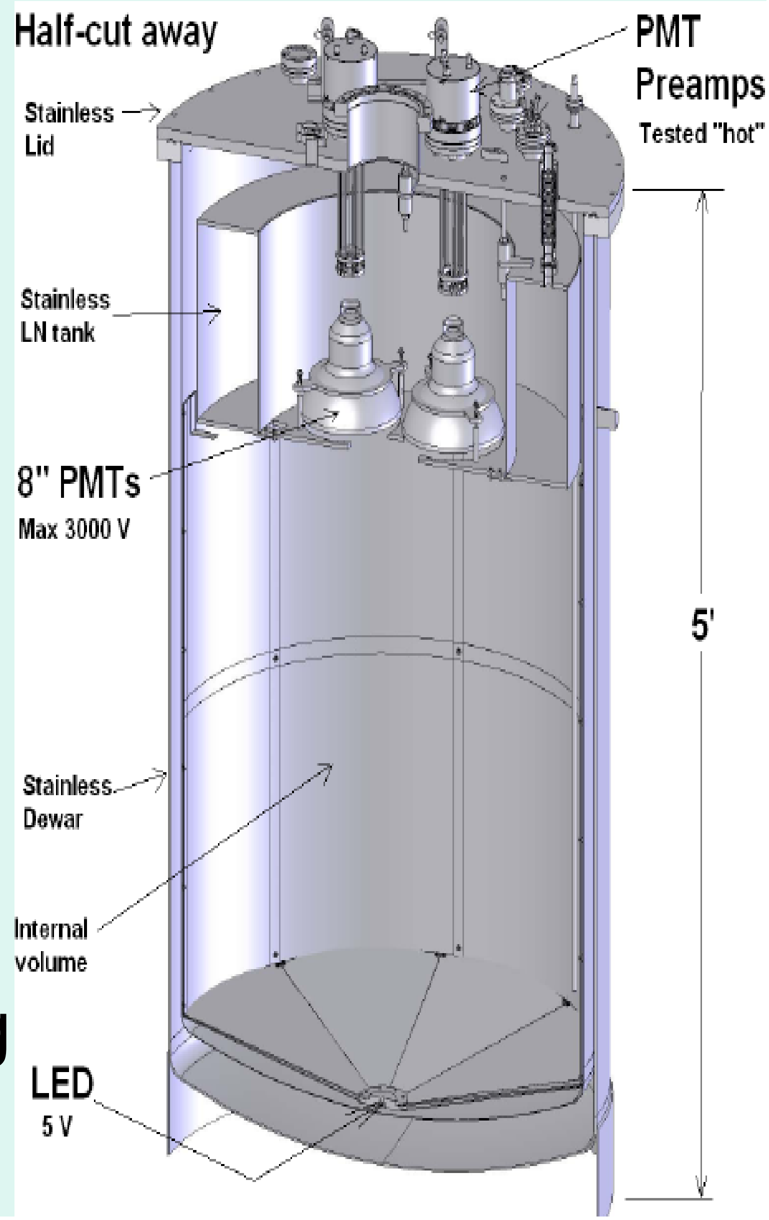
- Scientific motivation: dark matter
- Photon interactions in matter
- Scintillators and phototubes
- LArGe: Overall goals; summer goals
- My summer with LArGe:
  - Photomultiplier tube tests
  - Gas scintillation test

# Scientific Motivation: Dark Matter

- One of the hottest questions in the physical sciences
- Very compelling astrophysical evidence for DM composing nearly 25% of the universe
- We don’t know what it is for sure, but many suppose that it is some new particle that interacts very weakly.
- The detection of such a particle would require a very sensitive detector, but also one that is not bogged down by extraneous or undesirable signals.

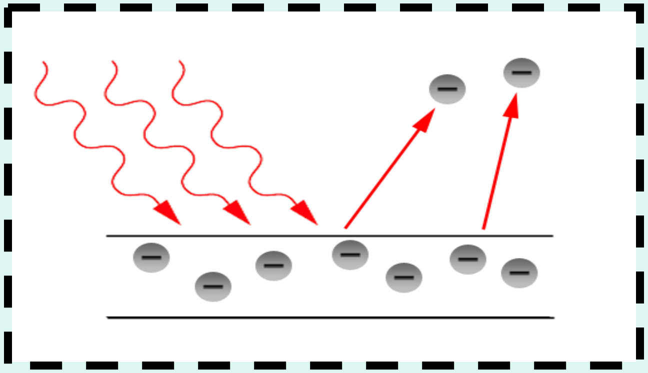
# LArGe Detector

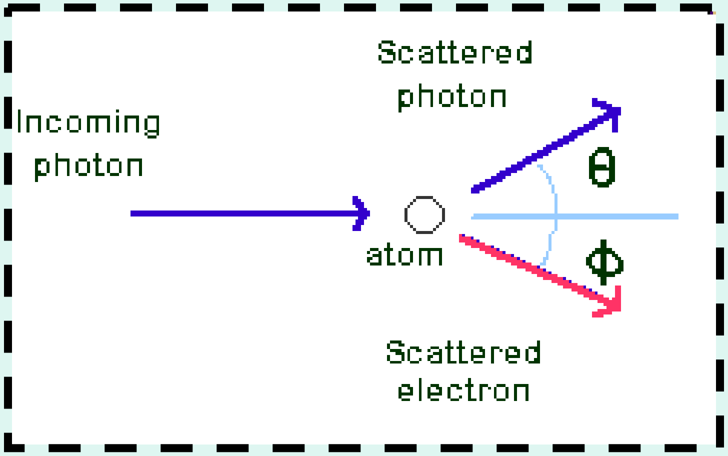
- Goal:
  - Immerse sensitive DM detector in liquid Argon
  - Active Argon veto
- Applications:
  - DM searches
  - Neutrinoless double-beta decay experiment (0νββ)
  - Any experiment requiring very low background counting



# Photon Interactions in Matter

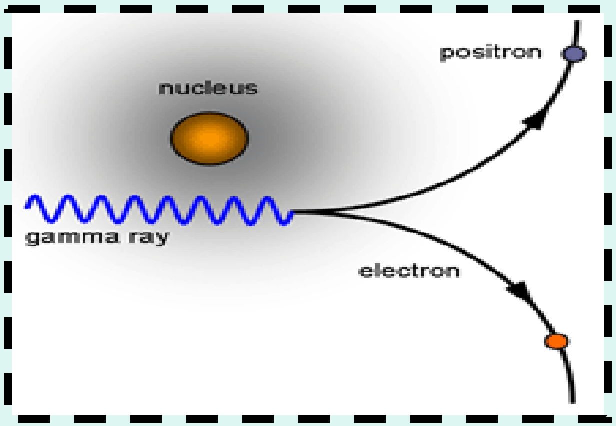
- Photoelectric absorption
  - All photon energy deposited into liberated electron
  - Sharp peak at full photon energy



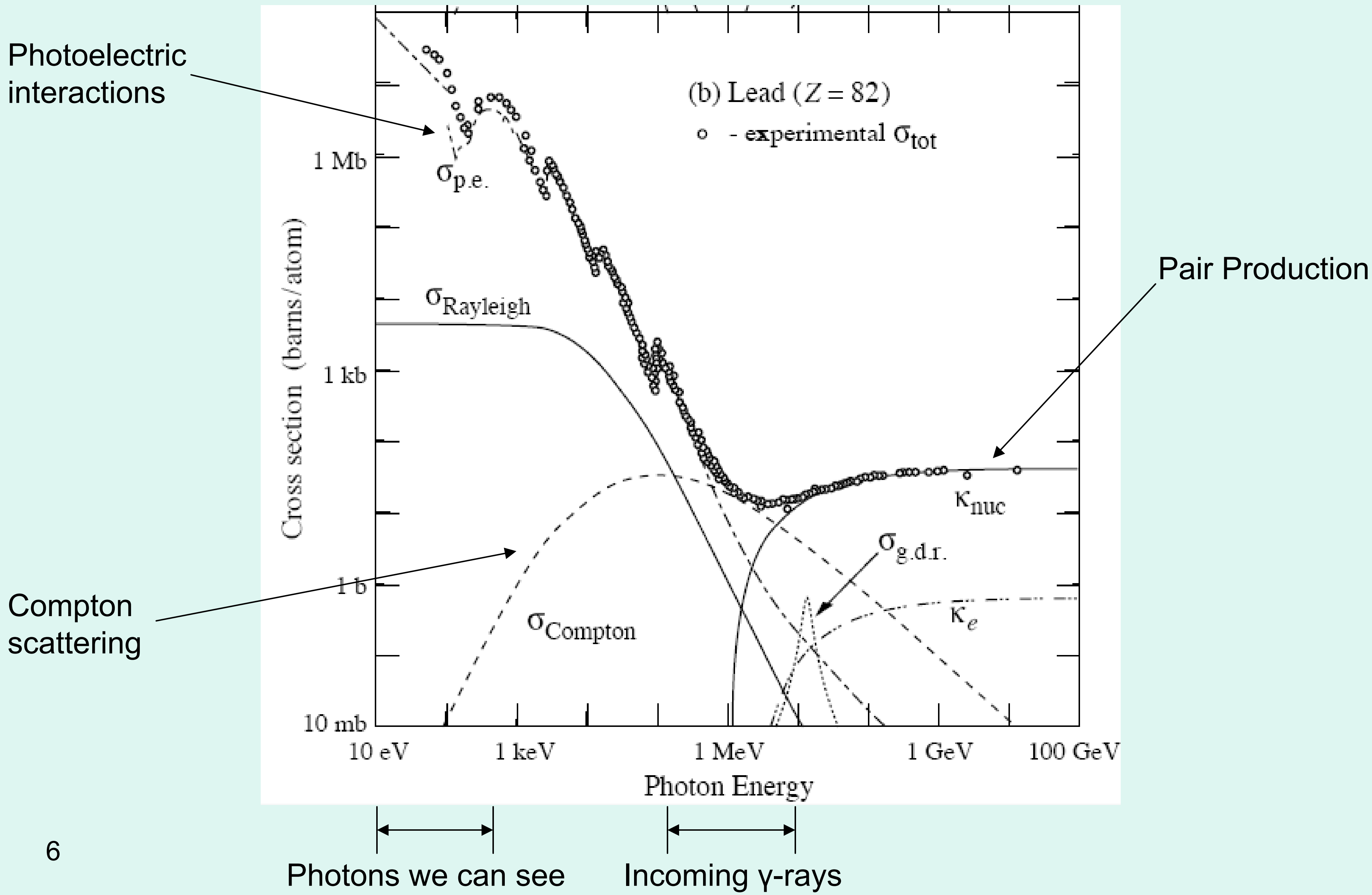



- Compton scattering
  - Electron liberated; photon is scattered at lower energy
  - Scattering angles from 0 to π are observed, producing a continuous energy distribution

- Pair production
  - Electron/Positron pair produced; photon disappears
  - Sharp peak at $2m_ec^2$ below full photon energy

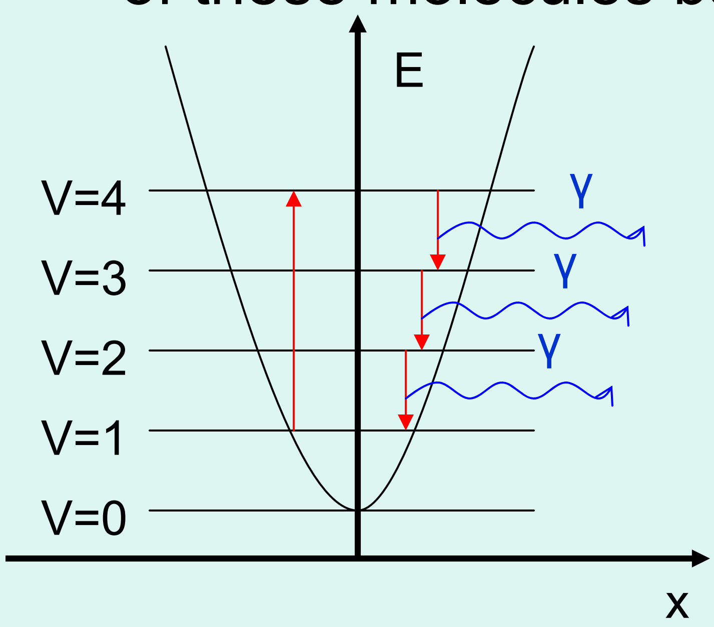


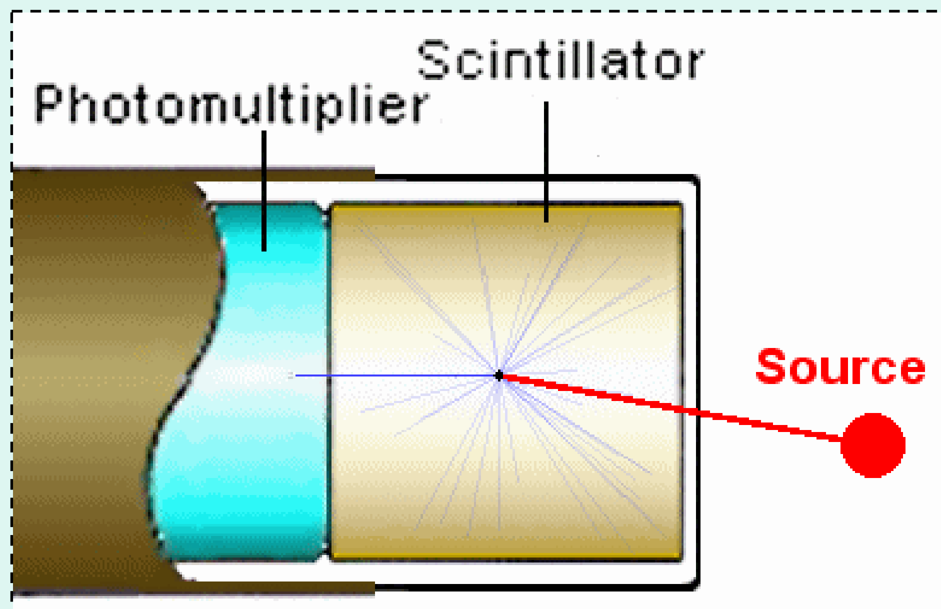
# Photon Interactions in Matter



# Scintillators

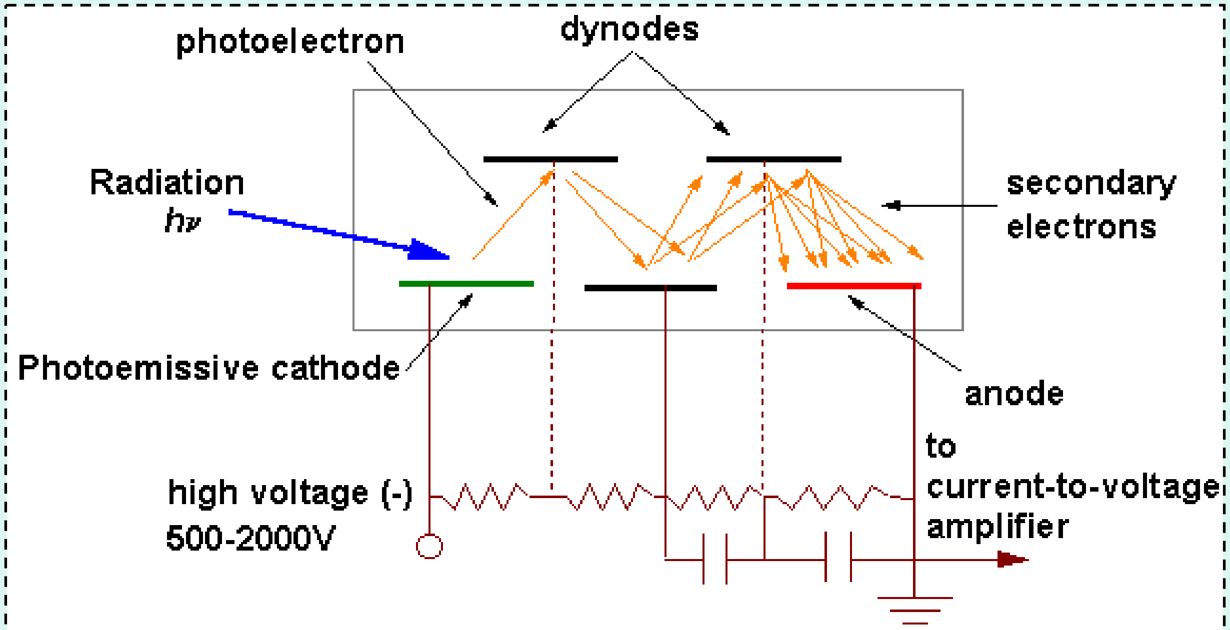
1. Charged particles (e.g. electrons) in motion transfer energy to molecules of the scintillation material.
2. These molecules are raised into higher energy vibrational or electronic states.
3. Photons are produced as a result of the de-excitation of these molecules back into lower energy states.



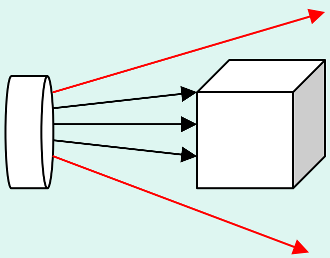
# PhotoMultiplier Tube

1. Photoemission in the photocathode
2. Electron multiplication in the dynodes
3. Absorption and detection of the electrons in the anode as an electrical pulse

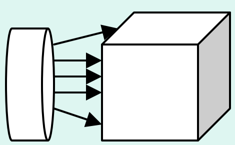


# Background and Unwanted Counts

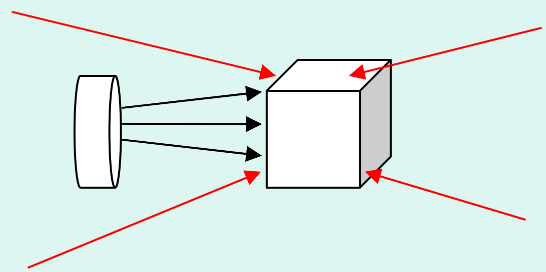
Lost counts between detector and source



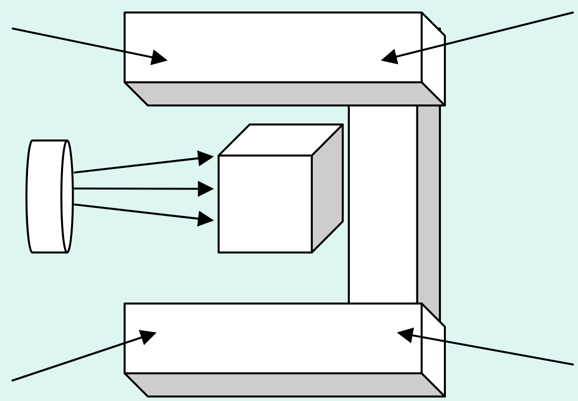
**Solution: Less distance**



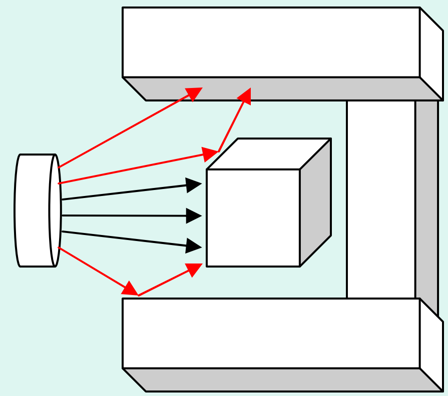
Counts from undesired outside sources



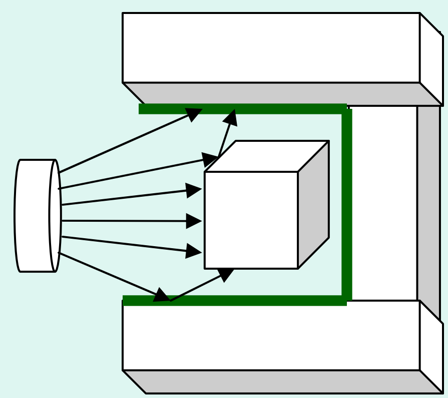
**Solution: Passive Shield**



Compton scattering

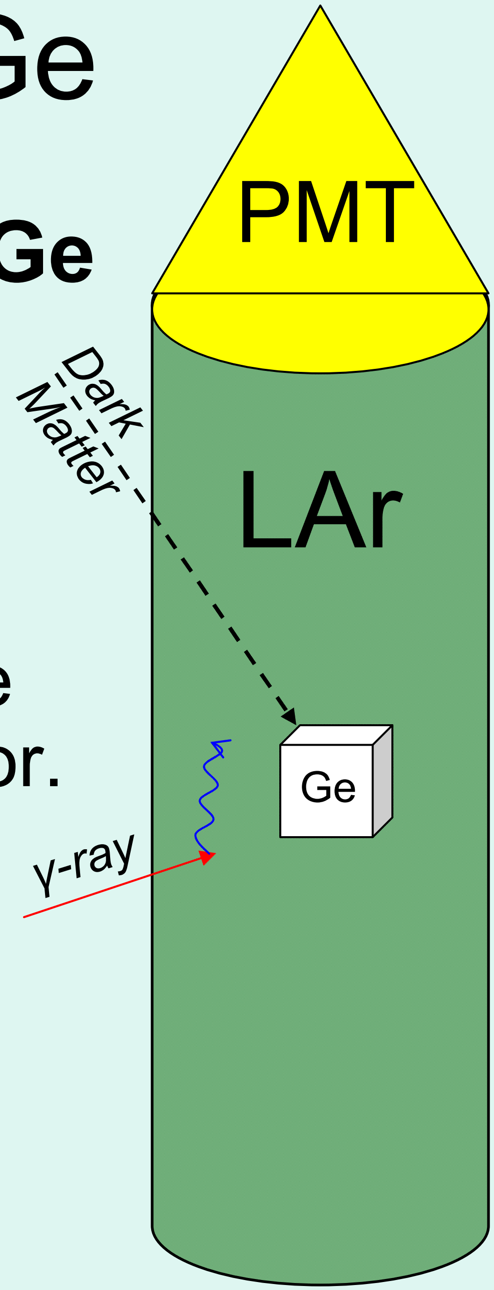


**Solution: Active Veto**



# Motivation for LArGe

- **L**-iquid **Ar**-gon **Ge**-rmanium = **LArGe**
- Immersion of Germanium detector (or other type) into LAr scintillator
  - LAr cools detector.
  - LAr acts as a shield, stopping outside radiation from interacting with detector.
  - LAr acts as an active veto, catching compton scattered photons and emitting, through scintillation, energy that would be lost otherwise.



# LArGe Detector: Timeline

1. Test PMTs and bases *outside* the cryostat

Summer '09

2. Test PMTs and bases *inside* the cryostat using simple gas scintillator and β-source

3. Input LAr cryogen and test with β-source

The Future!

4. Immerse detector in LAr to detect dark matter or rare physical processes

# PMT Tests

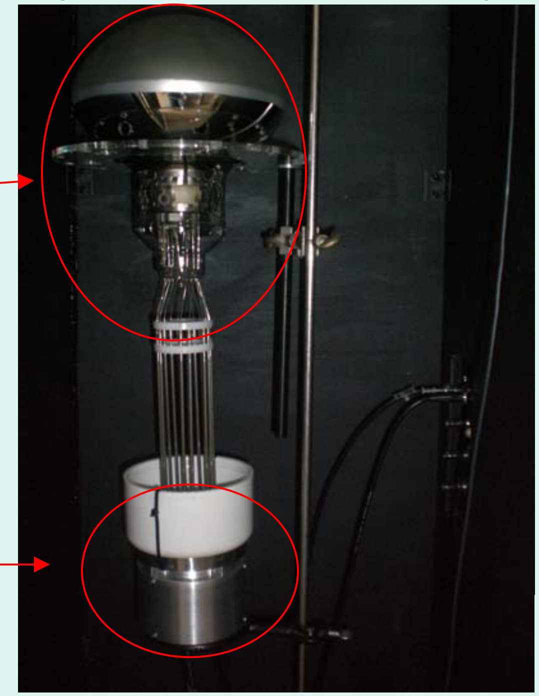
**Photomultiplier Tube**

•KB 9357

•8’’ diameter

•Operates at cryogenic temperatures

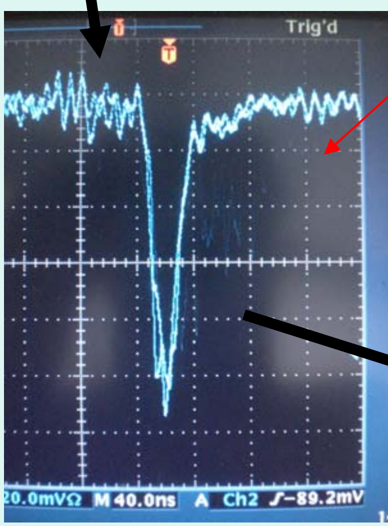
(REFLECTIVE FOIL)



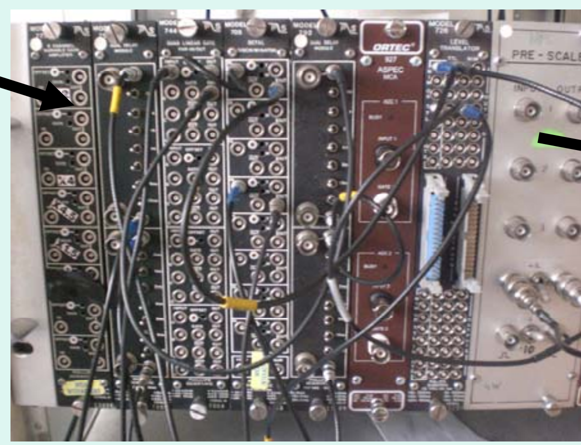
**Preamp (base)**

(PULSER HERE)

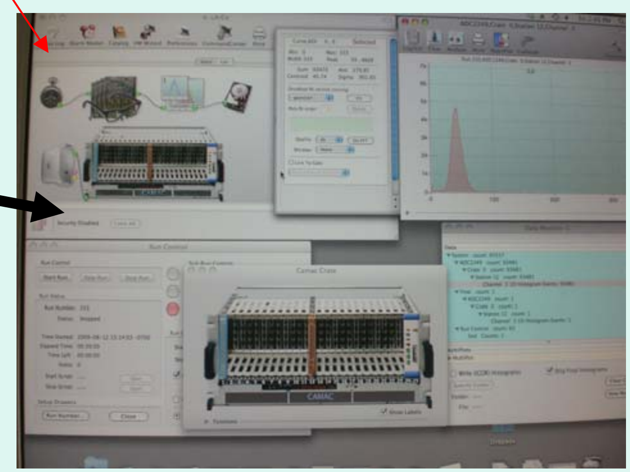
**Pulse**




**Data Acquisition System**

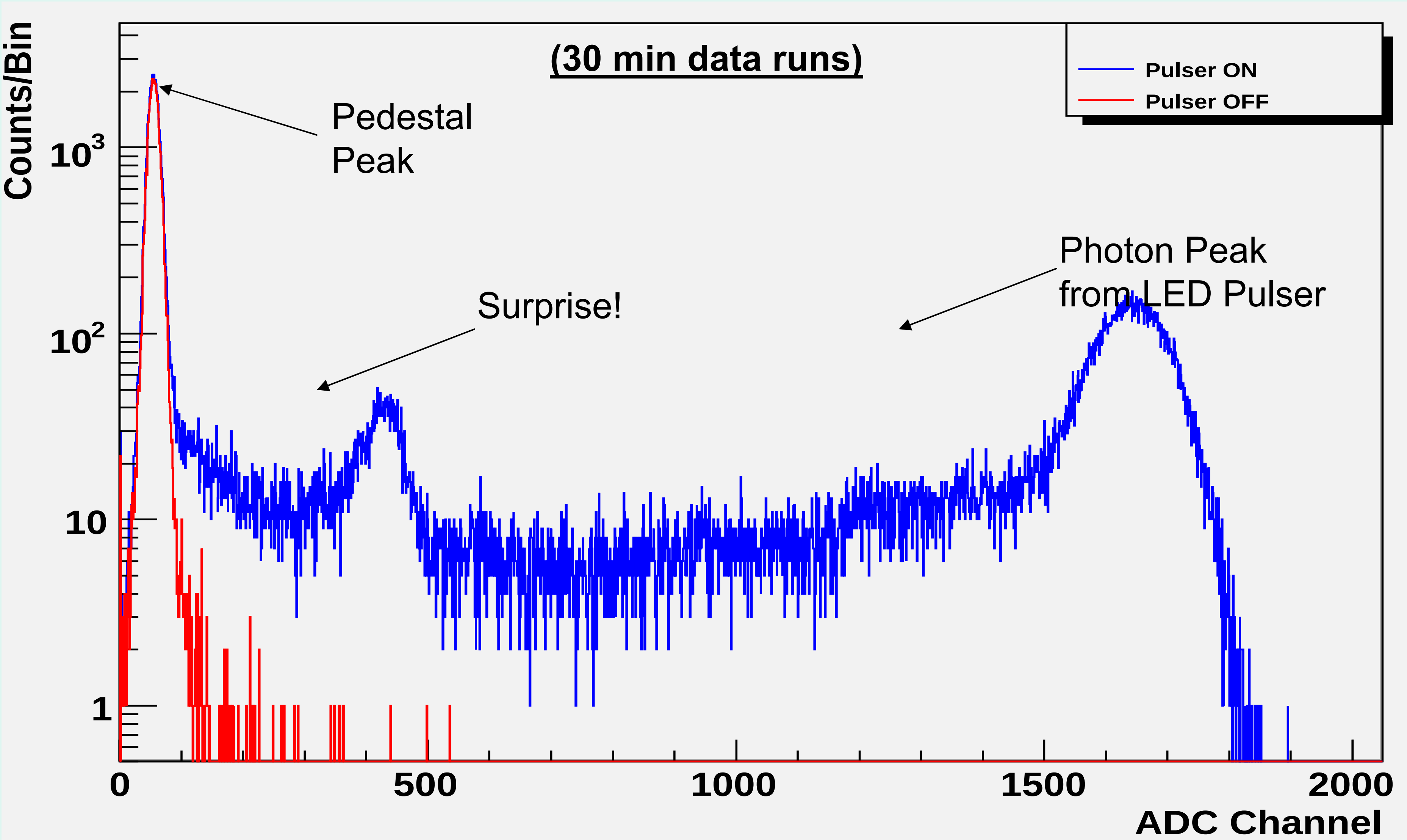



**ORCA Software**



PMT 2/3, Base1

# PMT Tests




*Counts/Bin (log scale) vs. ADC Channel (arb. Units) for PMT "3/3" with Base 1*



*BLUE: LED Pulser ON* *RED: LED Pulser OFF*

# Gas Scintillation Tests

- Before working with LAr cryogen, we sought to test PMT/base setup with a gas scintillator.
- Commonly used:
  - Noble gases (He, Ne, Ar, Kr, Xe)
  - Nitrogen gas ($N_2$)
- Criteria for choosing gas scintillator:
  - PMT Specs
    - 9357 KB sensitivity: λ=275-630nm light
    - QE maximum: 350nm< λ<400nm
  - Ability to stop β-particles
  - High light output
  - Inexpensive, if possible

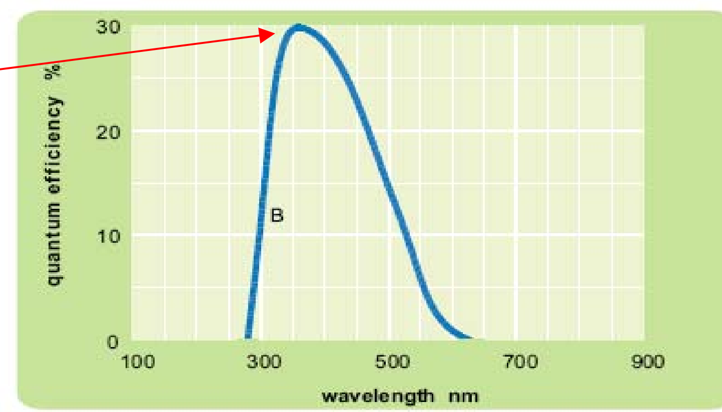
**PMT Specifications**

4 envelope characteristics

| | 9357 KB borosilicate |
|---|---|
| spectral range*(nm) | 275 - 630 |
| refractive index ($n_d$) | 1.49 |
| K (ppm) | 60 |
| Th (ppb) | 30 |
| U (ppb) | 30 |

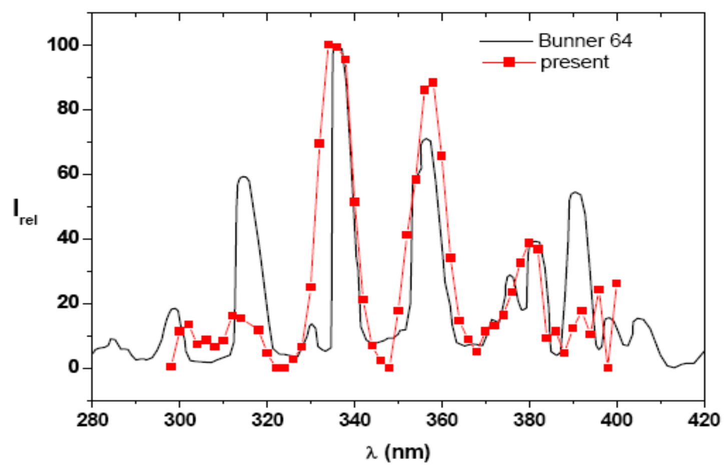
* wavelength range over which quantum efficiency exceeds 1 % of peak

5 typical spectral response curves



# Gas Scintillation Tests: Ar vs. $N_2$

Nitrogen scintillation




P = $10^5$ Pa; T = 296 K; Δλ = 9 nm

Noble Gas scintillation

| Gas | Emission Wavelength | Decay Times Fast/Slow | Light Yield | Price/kg |
|---|---|---|---|---|
| $^4$He | 80 nm | 10 ns / 1.6 μs | ~50 γ/keV [5] | 5 $ |
| $^{20}$Ne | 77 nm | 10 ns / 3.9 μs | 30 γ/keV [3] | 60 $ |
| $^{40}$Ar | 128 nm | 4 ns / 1.6 μs | 40 γ/keV [3] | 2 $ |
| $^{131}$Xe | 175 nm | 4 ns / 22 ns | 42 γ/keV [3] | 1'000 $ |

| | **Scintillation Wavelength** | **Light Yield** | **$E_γ$** | **Stopping Power** |
|---|---|---|---|---|
| **$N_2$** | 340 nm | 140 γ/MeV | 3.6 eV | Low |
| **Ar** | 128 nm | 40,000 γ/MeV | 9.7 eV | High |

# The Future of LArGe

- Further tests, including gas scintillation, will confirm whether LArGe is ready for full-scale LAr scintillation experiments.
- Ultra low-background experiments like LArGe may provide the tools for detecting new weakly interacting particles or reactions with very long lifetimes.
- The future is bright…

# Special Thanks To:

- Mike Miller and Jonathan Diaz
- The entire CENPA team
- The UW REU Program directors, participants and affiliates

# References


- pdg.lbl.gov
- "Radiation Detection and Measurement" (3rd edition) by Glenn Knoll
- See Final Paper for full citations


# Pictures/Graphs


- http://www.easypedia.gr/el/articles/p/h/o/%CE%95%CE%B9%CE%BA%CF%8C%CE%BD%CE%B1~Photoelectric_effect.png_68da.html
- http://astroa.physics.metu.edu.tr/lece/compton_scatter.html
- http://www.hepweb.org/activity/education/Projects/Teaching%20Advanced%20Physics/Atomic%20and%20Nuclei/Particles%20and%20antiparticles/page_5442.html
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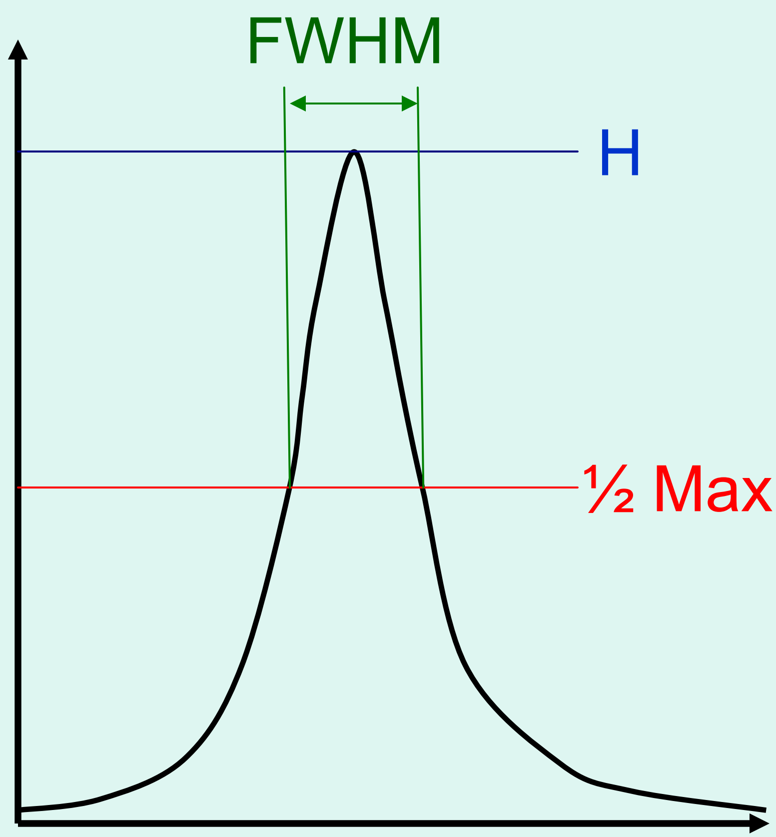
- http://www.auger.de/events/air-light-03/talks/Fraga.pdf
- http://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=04178987

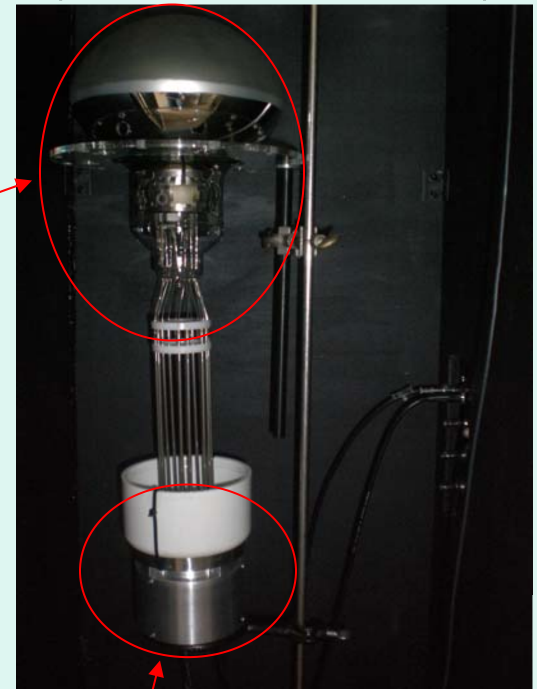
# Potential Problems: Energy Resolution

- Ideally, energy peaks are narrow, sharp lines, but in practice, they have some finite width.
- **R ≡ (FWHM)/H**
- Contributors to resolution loss include:
  - Statistical fluctuations
  - PMT characteristics
  - Intrinsic crystal resolution



# PMT Tests

(REFLECTIVE FOIL)



**Photomultiplier Tube**

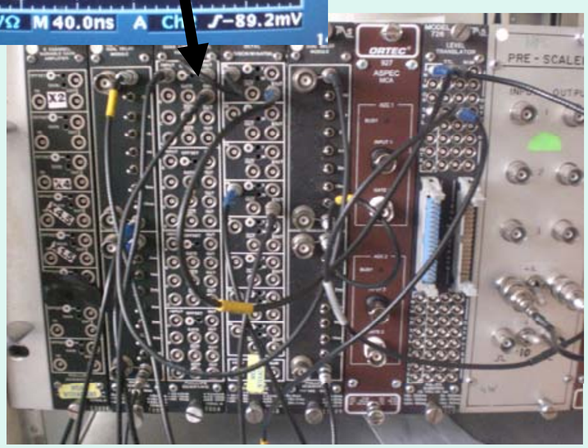
- KB 9357
- 8'' diameter
- Operates at cryogenic temperatures


**Pulse**

**Preamp (base)**

(PULSER HERE)

**Data Acquisition**

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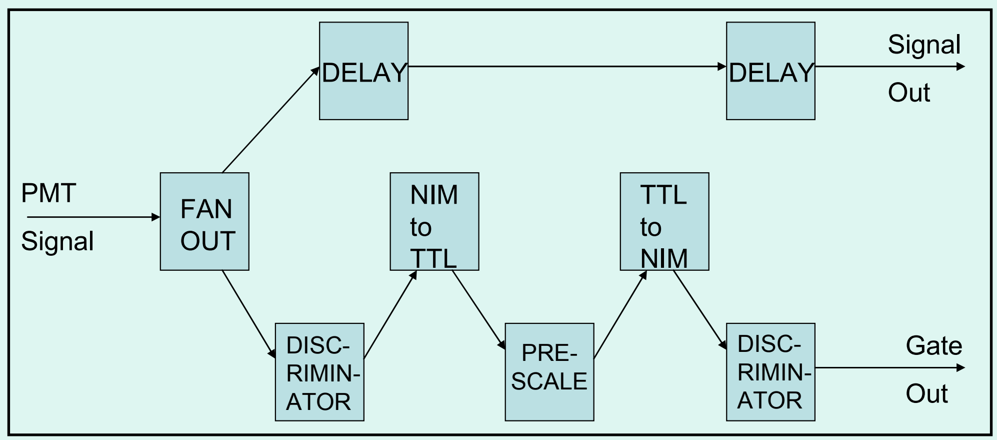

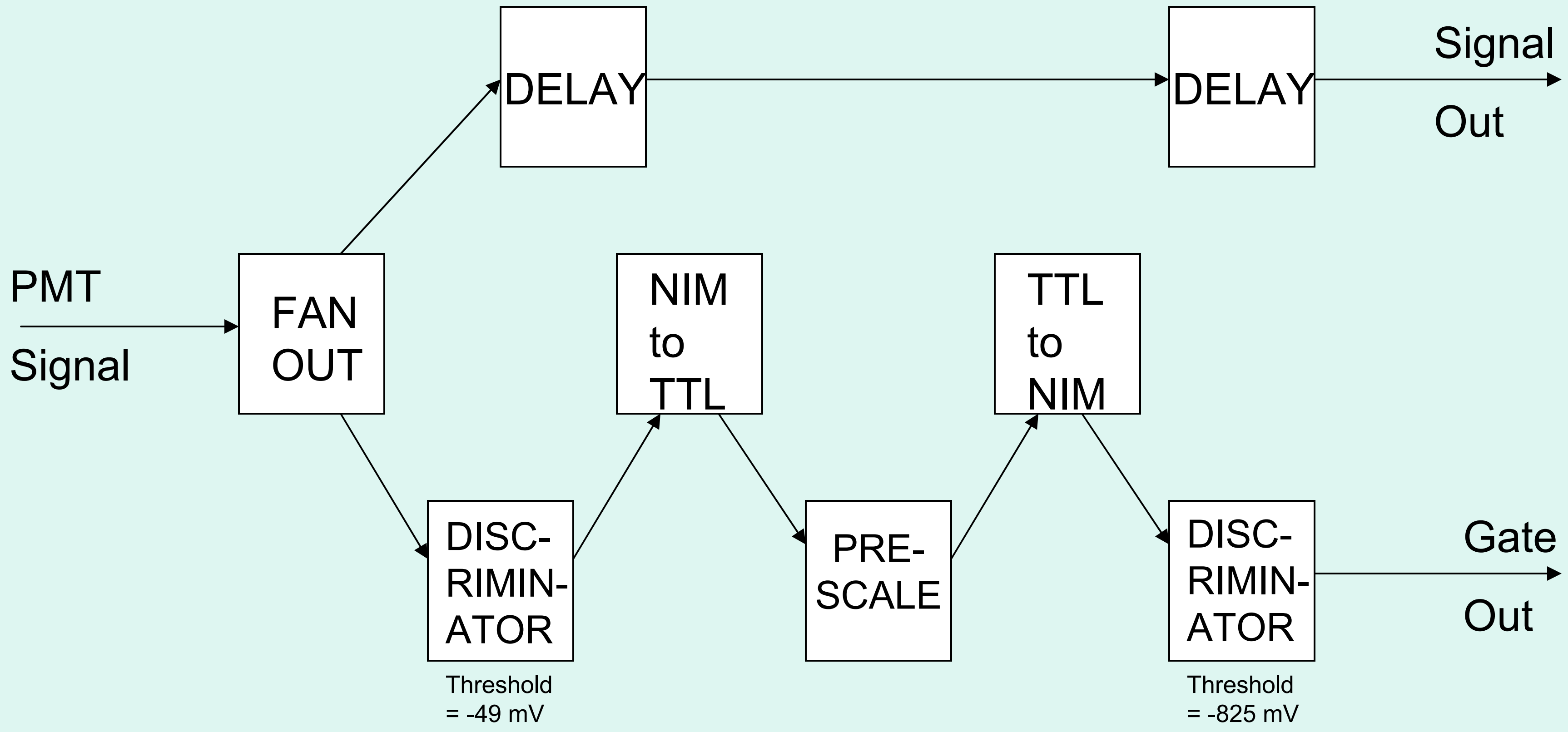
PMT
Signal
FAN
OUT
DELAY
DELAY
Signal
Out
NIM
to
TTL
TTL
to
NIM
DISC-
RIMIN-
ATOR
Threshold
= -49 mV
PRE-
SCALE
DISC-
RIMIN-
ATOR
Threshold
= -825 mV
Gate
Out