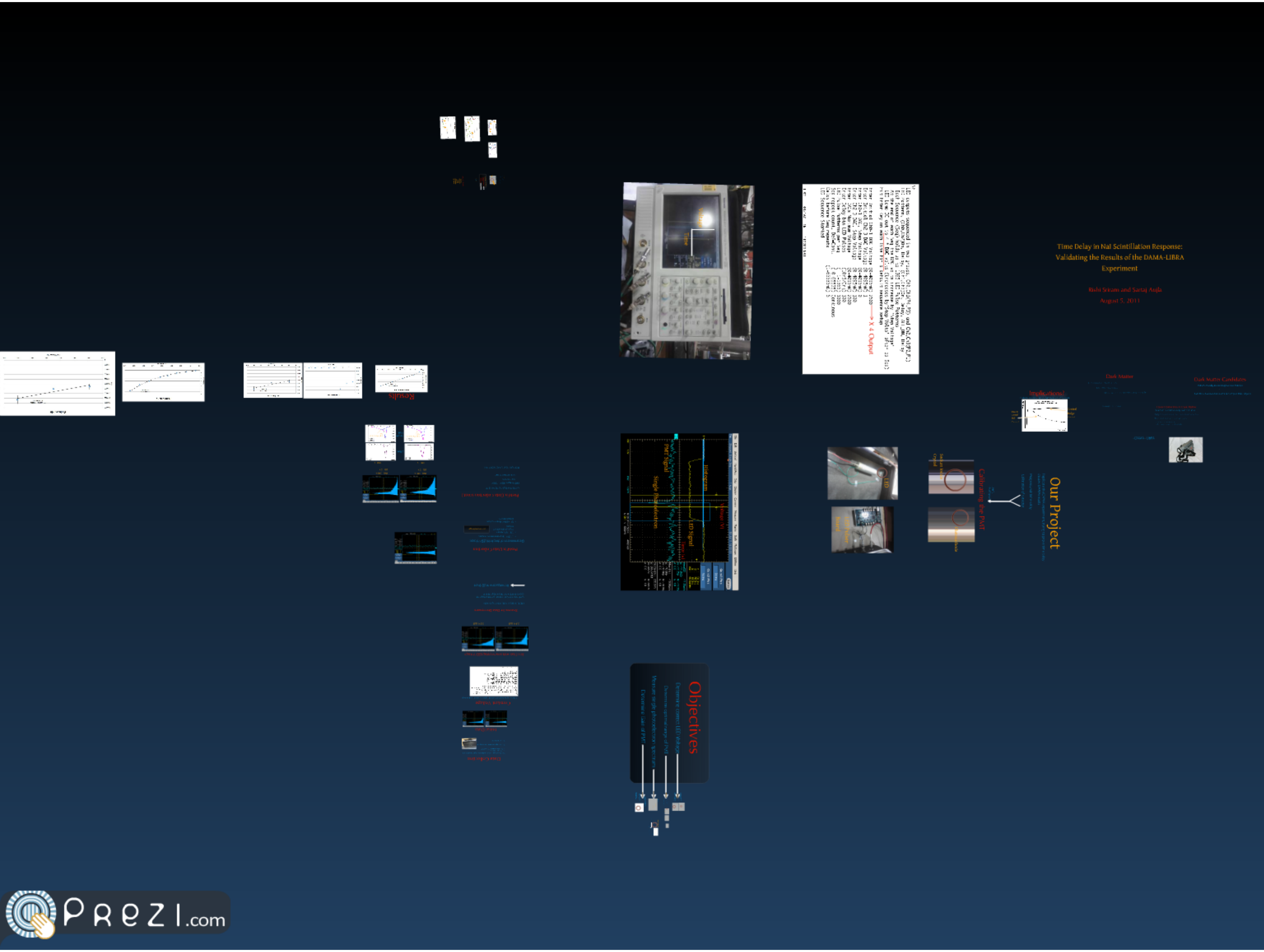


Time Delay in NaI Scintillation Response:
Validating the Results of the DAMA-LIBRA Experiment
Rishi Sriram and Sartaj Aujla
August 5, 2011
Our Project
Calibrating the PMT
Objectives
Results
Histogram
PMT Signal
LED Signal
Single Photodetection
X 4 Output
Dark Matter
Dark Matter Candidates
Implications
LED
Prezi.com

Time Delay in NaI Scintillation Response: Validating the Results of the DAMA-LIBRA Experiment

Rishi Sriram and Sartaj Aujla

August 5, 2011

Dark Matter

Matter composed of "invisible" particles

Used to explain missing mass

83% of all matter in the universe- Ordinary matter only 17%

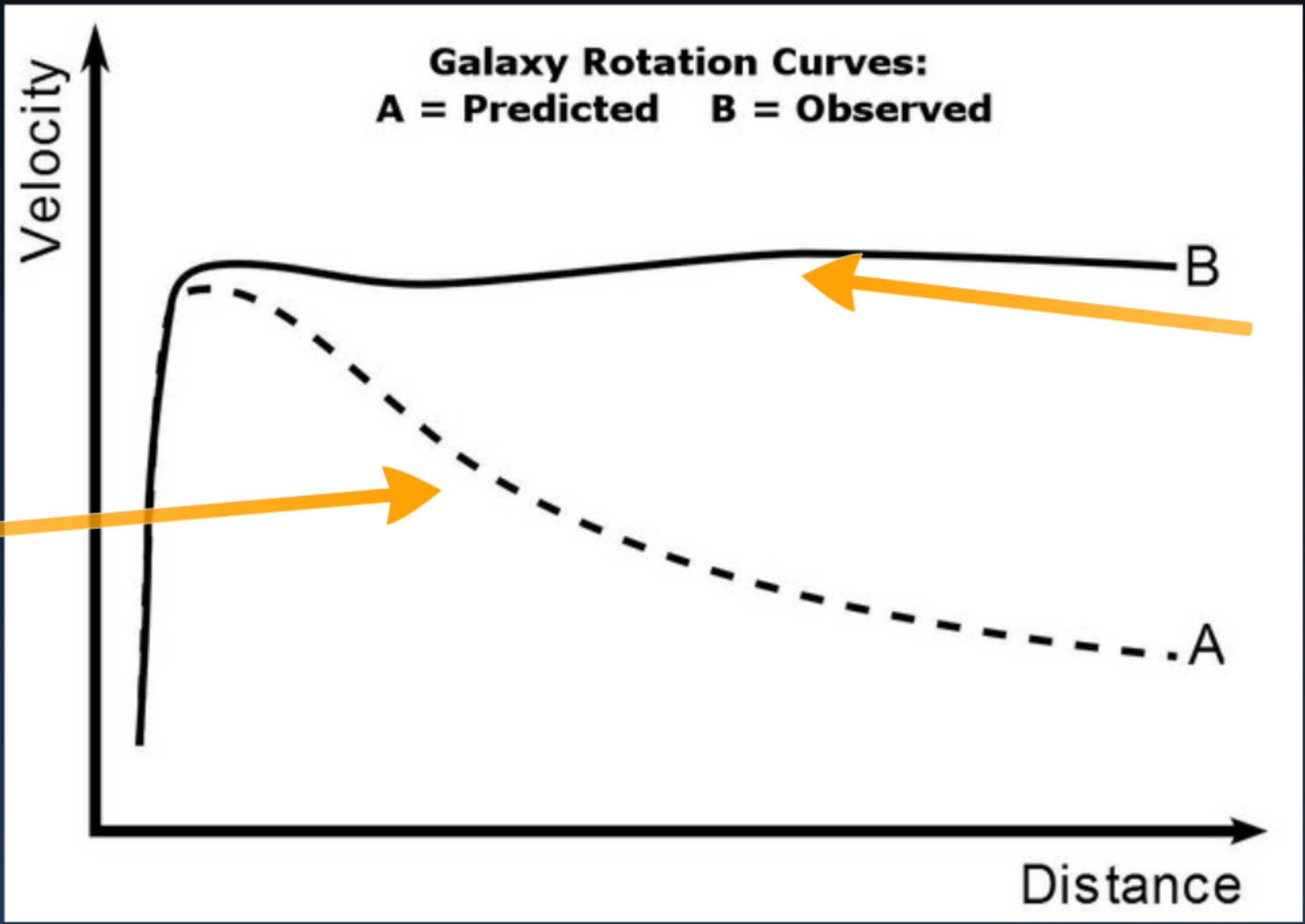
Extremely difficult to detect

Implications?

Galactic rotation curves- luminance to mass ratio

Mass in Central Disk

(Predicted)



Central Bulge

(Observed)

Extremely difficult to detect

Dark Matter Candidates

WIMPs- Weakly Interacting Massive Particles

MACHOs- Massive Astronomical Compact Halo Objects

Matter

ntillation

ed substances

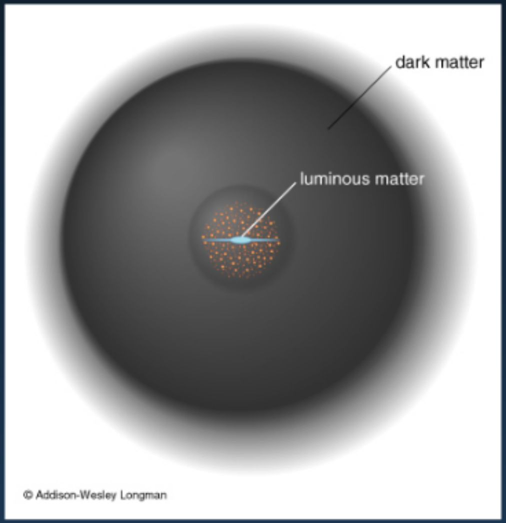
WIMPs

Theoretical particles that make up dark matter

Interaction Strength with matter ≈ Weak Force

Detectable interaction with gravity

No radiation or light emitted



Dark Matter Candidates

WIMPs- Weakly Interacting Massive Particles

MACHOs- Massive Astronomical Compact Halo Objects

Matter

ntillation

ed substances

MACHOs

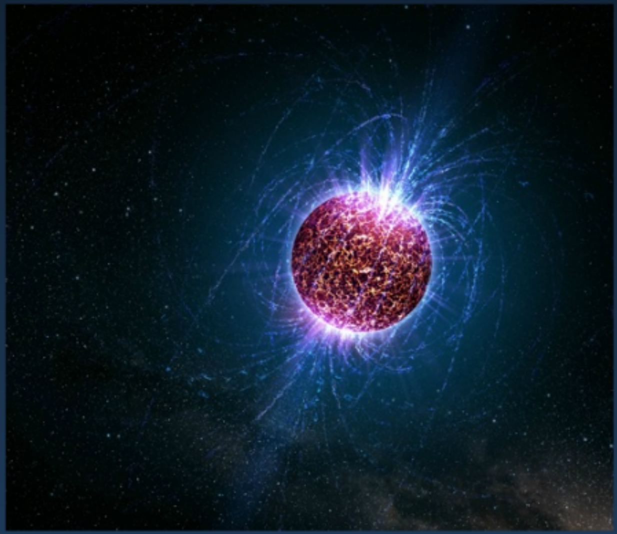
Massive Astronomical Compact Halo Objects

Astronomical Bodies explaining dark matter

Black Holes

Large baryonic matter

- Neutron Stars, Brown Dwarfs, etc.



Direct Detection of Dark Matter

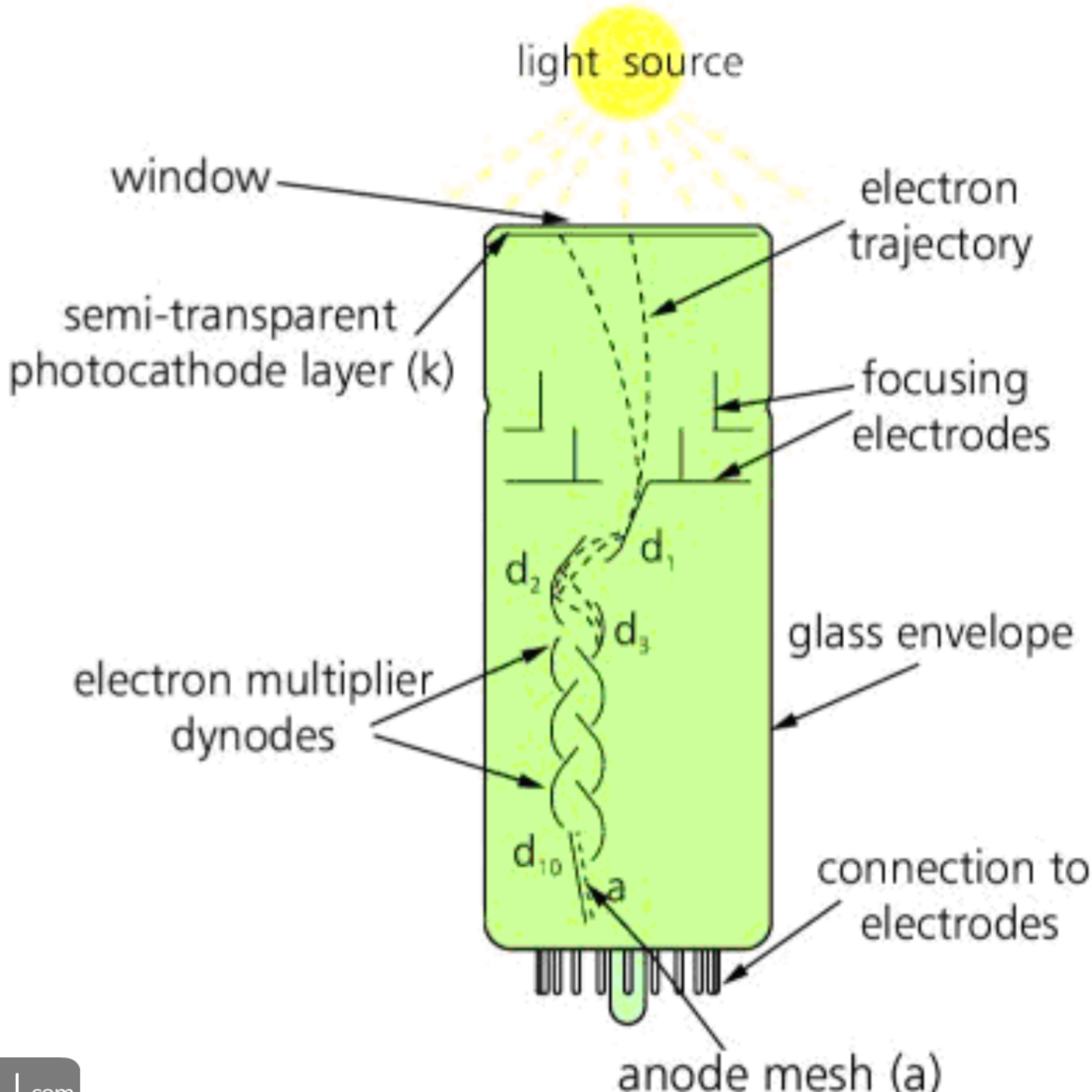
Interactions in ionization energy, heat, scintillation

Cryogenic Detectors: Detect heat in supercooled substances

Noble Liquid: Detect scintillation light flashes

Further scintillation detection

- Scintillators, Photo Multiplier Tubes (PMTs)


light source
window
electron
trajectory
semi-transparent
photocathode layer (k)
focusing
electrodes
d_1
d_2
d_3
glass envelope
electron multiplier
dynodes
d_{10}
a
connection to
electrodes
anode mesh (a)

- DAMA - LIBRA

The DAMA-LIBRA Collaboration

Carried out in 2003, first results reported 2008

Used a NaI crystal as scintillator, with Tl impurity activator

Detected an annual change in modulation- ~2-6 keV

- Rate change in earth's speed relative to dark matter winds

Problem: Modulation signal/WIMP detection not replicated by other experiments

Proposed Explanation for the DAMA Results

NaI Crystal Time Delay in Scintillation Response

- Energy absorbed, emitted again as light
- Small amount of energy left within crystal, emitted later

Our Project

Replicate the DAMA experiment, trying to prove time delay caused DAMA results

Progress, not time delay

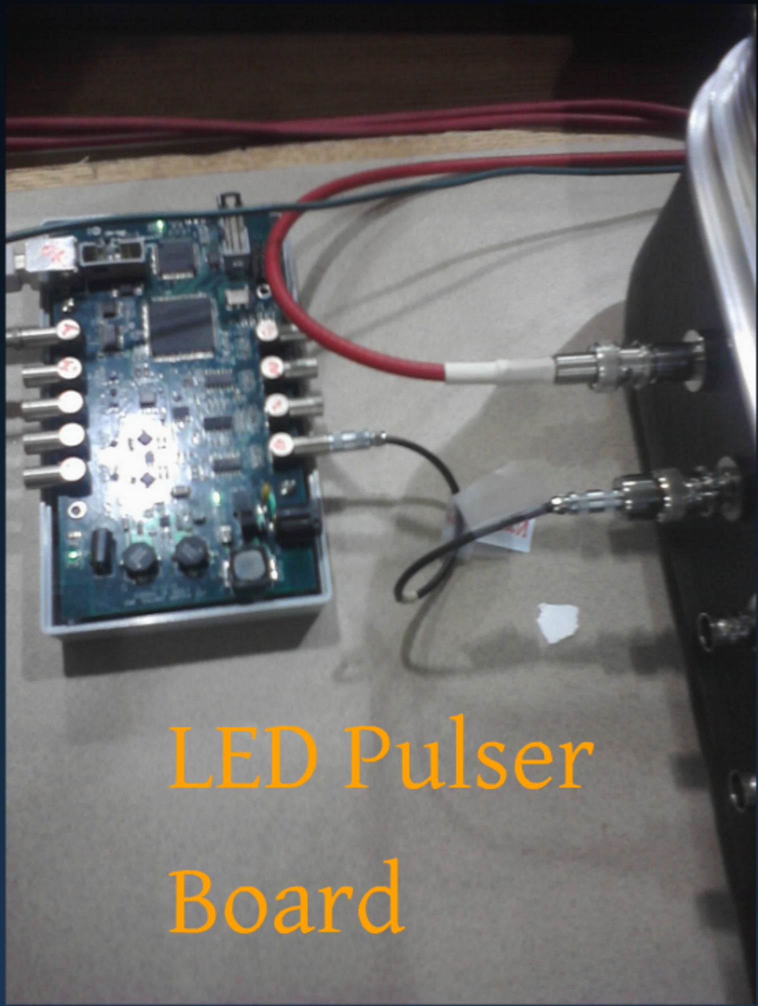
Calibration of detector

- PMTs
- NaI Crystal

Calibrating the PMT

Prezi.com


LED

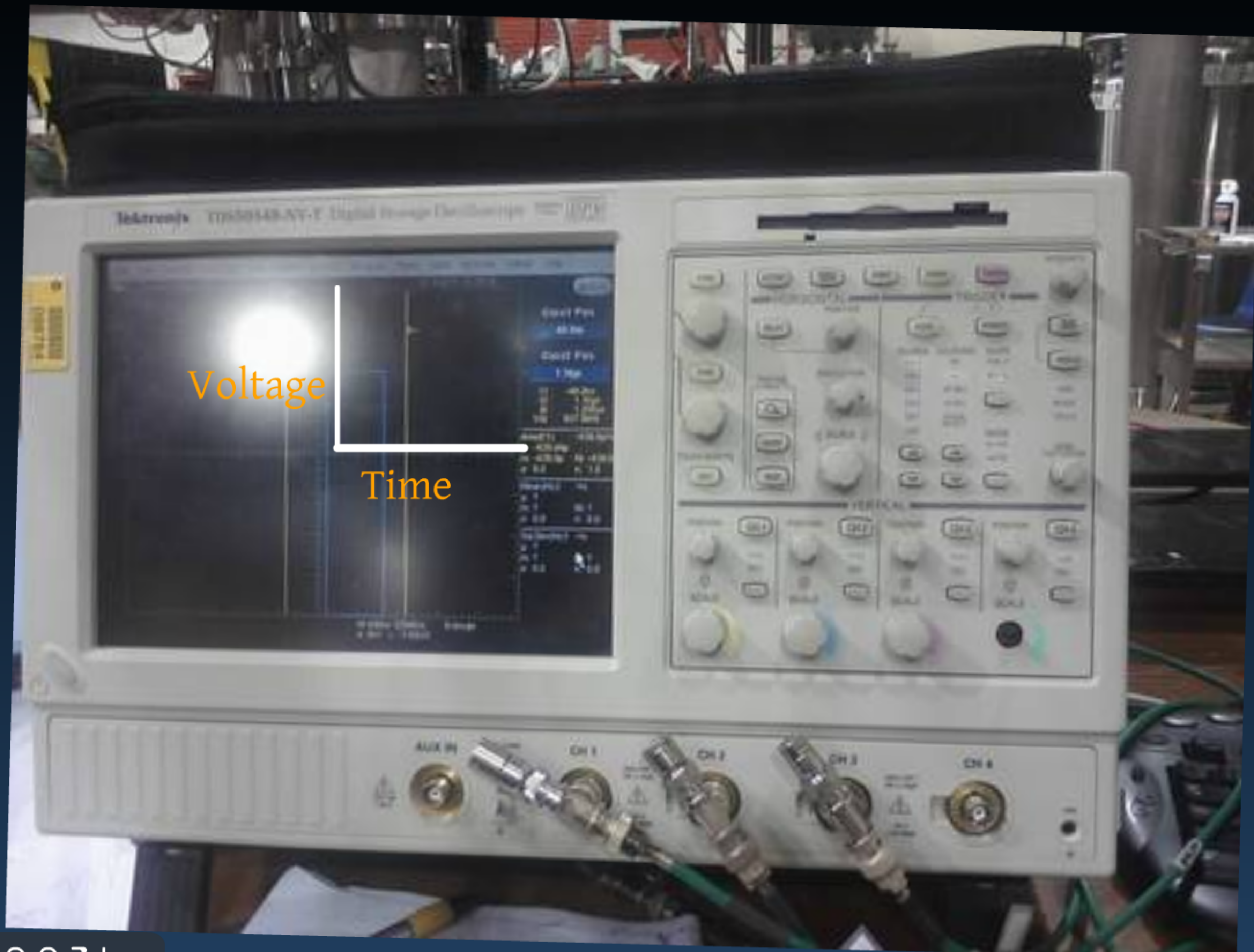

LED Pulser
Board

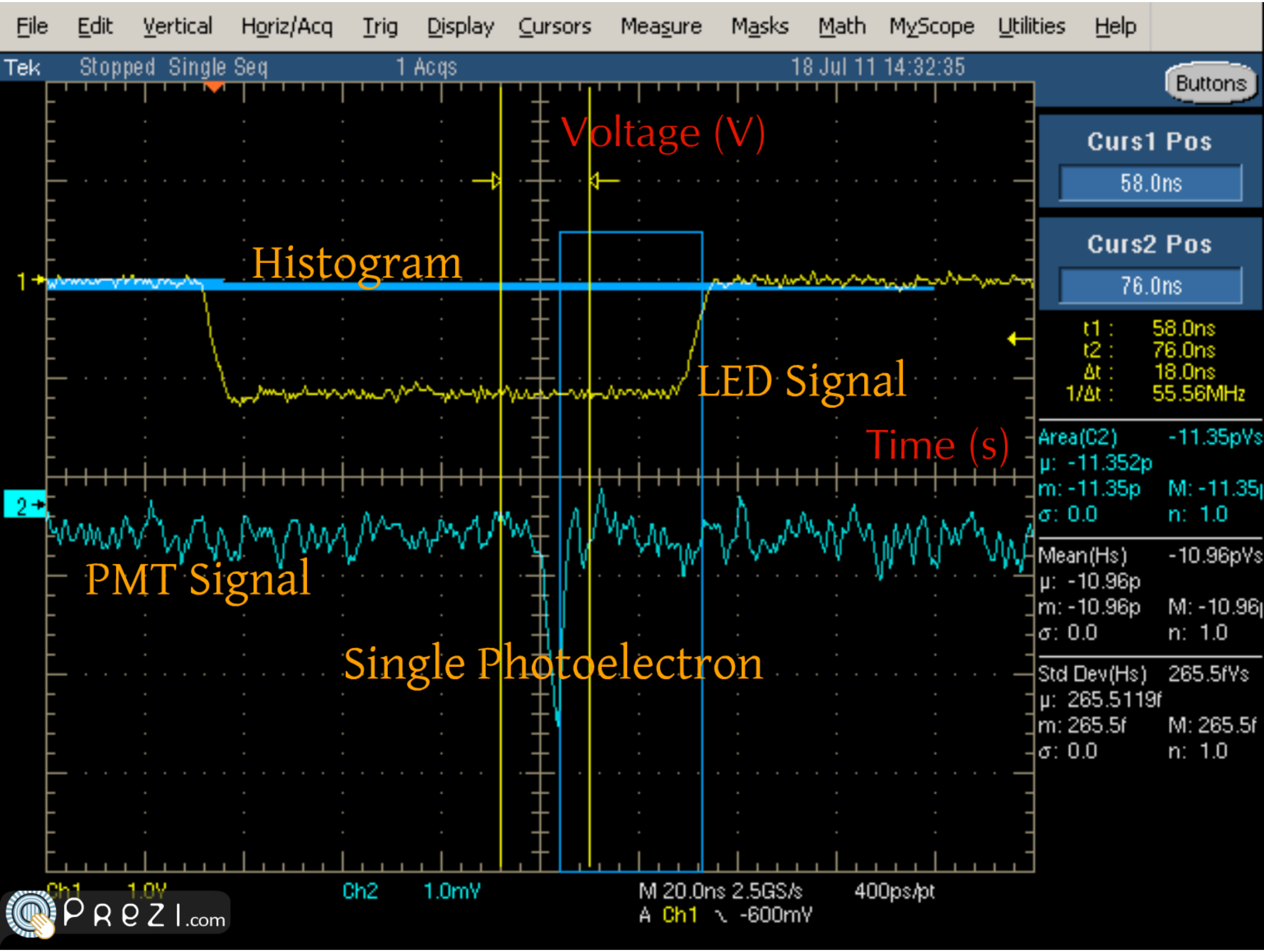
```
SE
 LED outputs sequenced in two groups, Ch0,Ch1(P4,P3) and Ch2,Ch3(P2,P1)
 LED Pattern, (Ch0,Ch2)On, Delay, (Ch1,Ch3)On, Delay, ALL_ON, Delay
  Each Sequence (Seq) holds up to 1365 LED Pulse Patterns
  At the end of each Seq the DAC volts increase by 'Step Voltage'
  LED Lemo DC out is 4 * DAC volts (increases by'Step Volts' after ea Seq)
 Hit Enter Key on each line for a default sequence setup

 Enter Initial Ch0-1 DAC Voltage (0-4095mV) 2500
 Enter Initial Ch2-3 DAC Voltage (0-4095mV) 1
 Enter Ch0-1 DAC, Step Voltage   (0-4095mV) 0
 Enter Ch2-3 DAC, Step Voltage   (0-4095mV) 100
 Enter DACs Maximum Voltage      (0-4095mV) 2500
 Enter Delay btw LED Pulses      (10nS/Cnt) 100
 LED Pulse Patterns per Seq      (  1-1365) 1000
 Seq repeat count, Def=Cont.     ( 0-65535) Continous
 Delay before Seq repeats      (1-65535mS) 5
 LED Sequence Started
```

X 4 Output

1:32 43x160 1k 115200 N81


Voltage
Time


File Edit Vertical Horiz/Acq Trig Display Cursors Measure Masks Math MyScope Utilities Help
Tek Stopped Single Seq 1 Acqs 18 Jul 11 14:32:35
Buttons
Voltage (V)
Histogram
LED Signal
Time (s)
PMT Signal
Single Photoelectron
Curs1 Pos
58.0ns
Curs2 Pos
76.0ns
t1 : 58.0ns
t2 : 76.0ns
Δt : 18.0ns
1/Δt : 55.56MHz
Area(C2) -11.35pVs
μ: -11.352p
m: -11.35p M: -11.35
σ: 0.0 n: 1.0
Mean(Hs) -10.96pVs
μ: -10.96p
m: -10.96p M: -10.96
σ: 0.0 n: 1.0
Std Dev(Hs) 265.5fVs
μ: 265.5119f
m: 265.5f M: 265.5f
σ: 0.0 n: 1.0
Ch1 1.0V
Ch2 1.0mV
M 20.0ns 2.5GS/s 400ps/pt
A Ch1 ⟍ -600mV
PREZI.com

Objectives

Determine correct LED Voltage

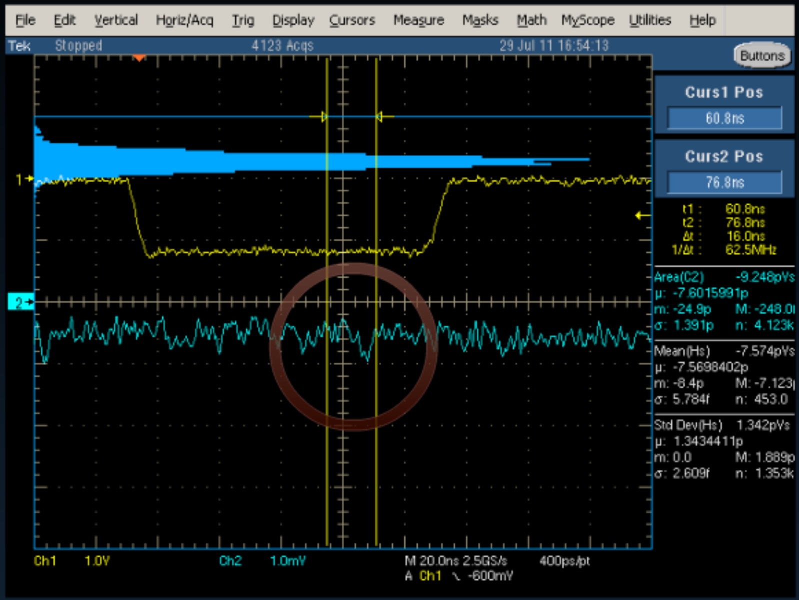
Determine optimal range of PMT

Measure single photoelectron spectrum

Determine Gain of PMT

Minimum- Below threshold
(no photoelectrons)

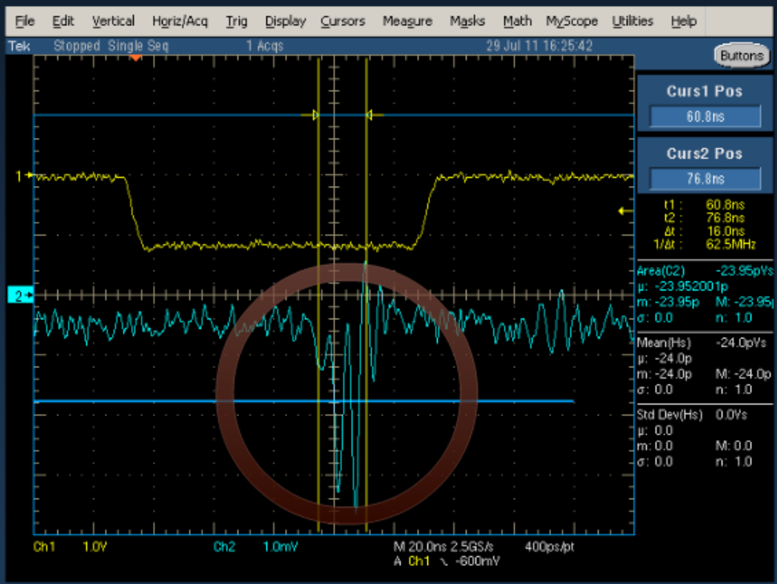
1.1 V LED Input)



LED Voltage

Maximum- Above threshold
(Mostly 2+ photoelectrons)

4.096 V LED Input)



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Objectives

- Determine correct LED Voltage
- Determine optimal range of PMT
- Measure single photoelectron spectrum
- Determine Gain of PMT

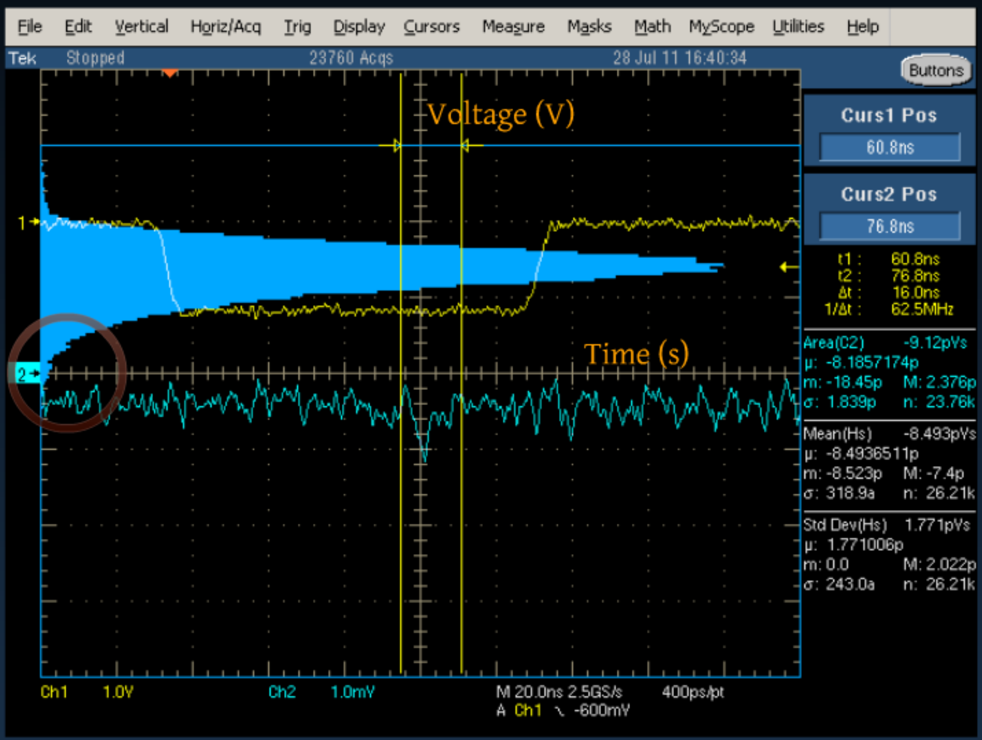
Optimal Range

Range of High Voltages

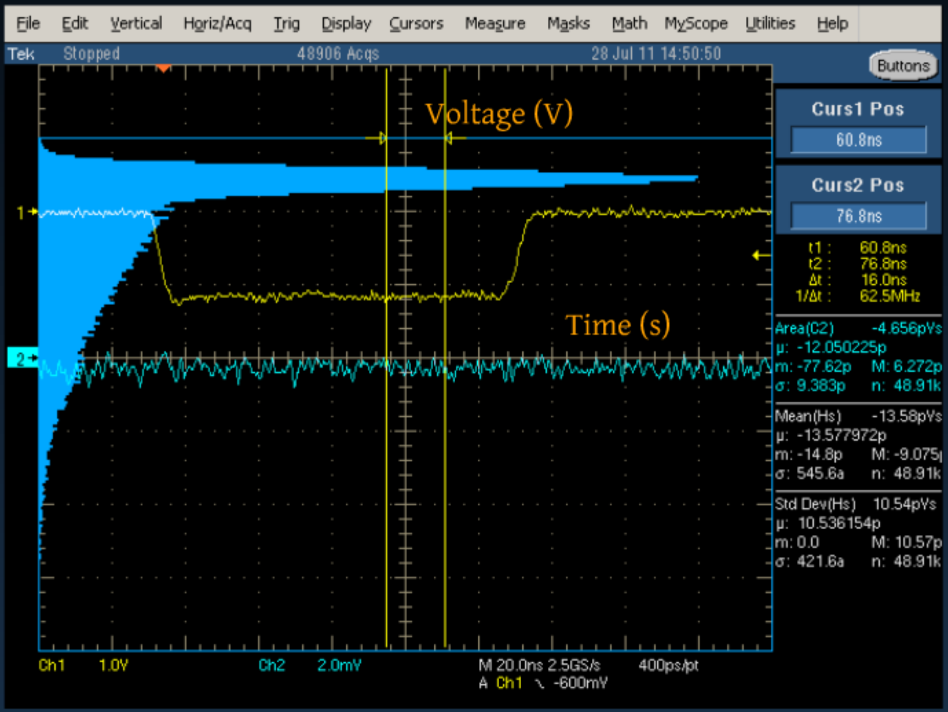
900 V (Distributor Recommended) -
1251 V (Noise dominated)

Optimization

Point maximizing separation between single photoelectron peaks and noise distribution



PMT- 900 V



PMT- 1251 V

Objectives

Determine correct LED Voltage

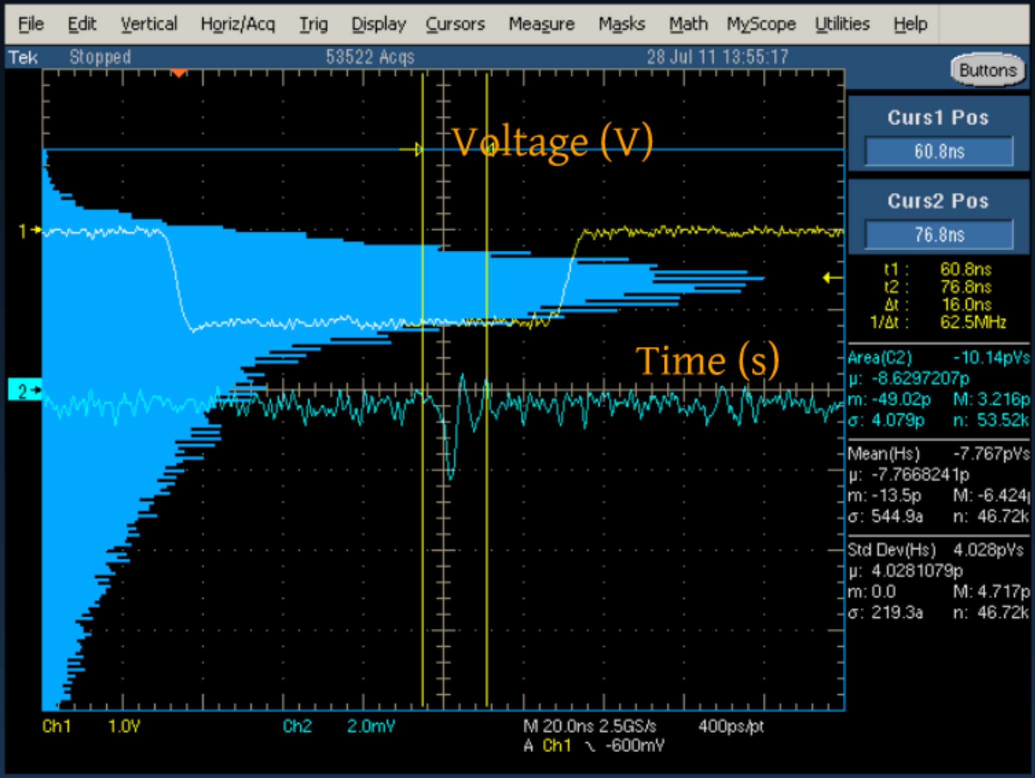
Determine optimal range of PMT

Measure single photoelectron spectrum

Determine Gain of PMT

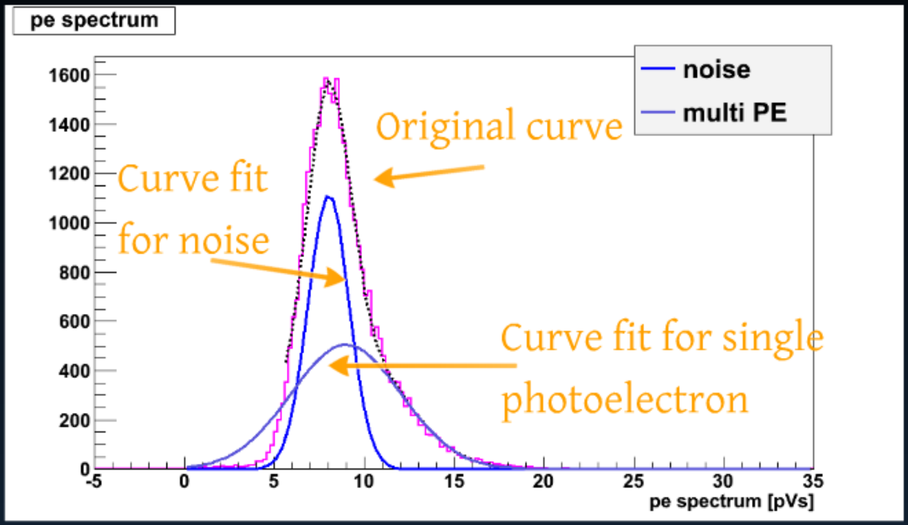
Histograms

Single Photoelectron Peak



Conversion factor between initial photoelectron and number of final

Fit curves to histograms



Mean of single photoelectron peak

- measured in pVs -

Radioactive Source Data: Correlate gamma peaks (pVs) to known energy values (keV) -- Stage 2 of full project

Convert mean of area (pVs) to charge (C)

Conversion factor between number of photoelectrons released (pVs) and energy intensity (keV)

Objectives

Determine correct LED Voltage

Determine optimal range of PMT

Measure single photoelectron spectrum

Determine Gain of PMT

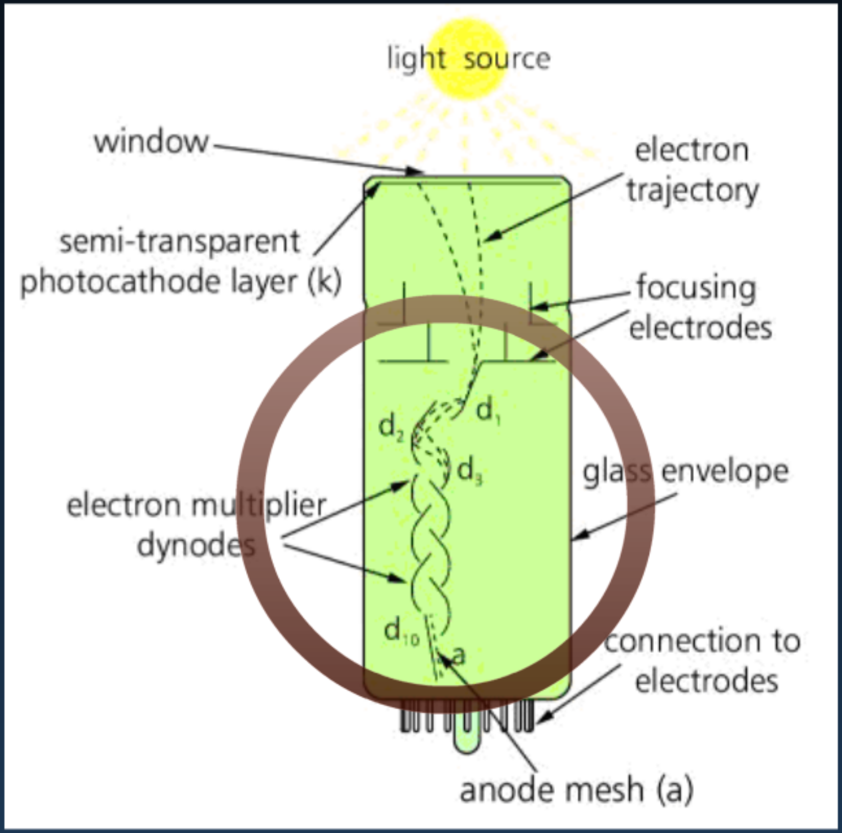
Ch1 1.0V Ch2 2.0mV M 20.0ns 2.5GS/s 400ps/pt
A Ch1 ↘ -600mV

Conversion factor between initial photoelectron and number of final electrons

PMT Gain

Area of peaks -> charge -> number of electrons

Gain factor across multiple high voltages



Data Collection

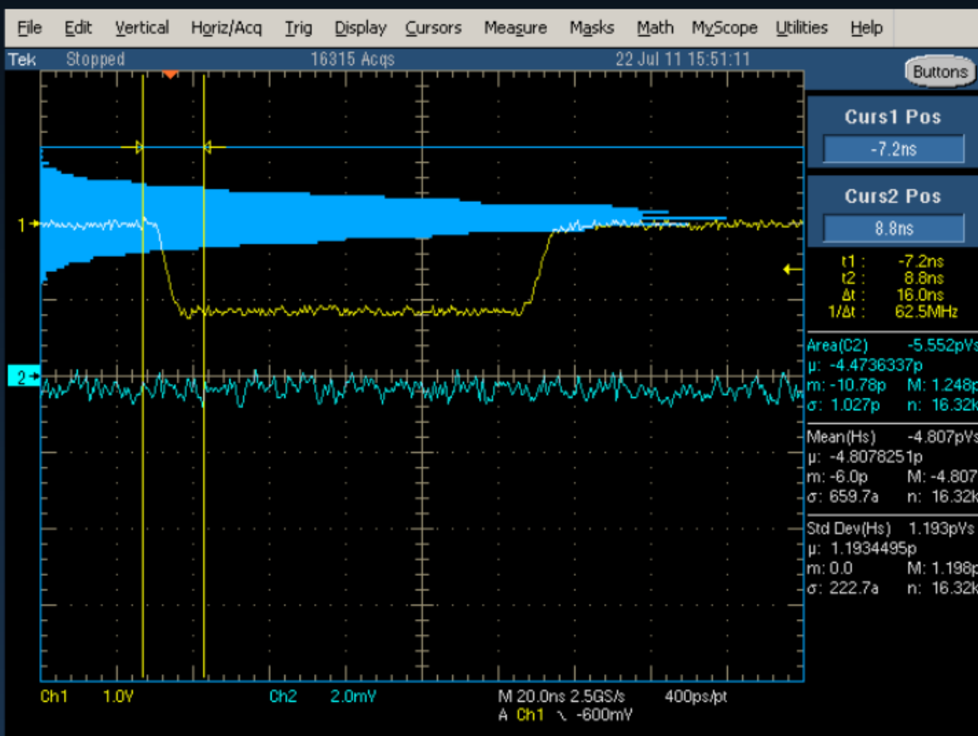
Black Box configuration to produce only single photoelectrons

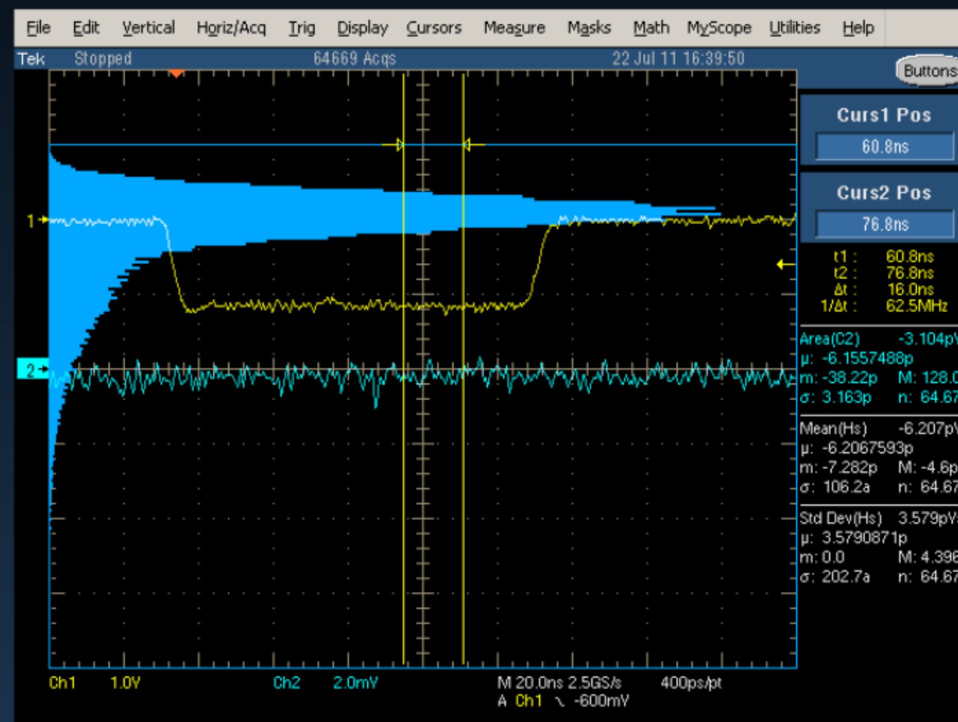
- LED light intensity
- Distance between LED and PMT

Data for single photoelectron histograms

Data for noise offset

Initial Data





onstant Voltage

Constant Voltage

LED- Stepping voltage (default setting) vs. constant input voltage

```
SE
 LED outputs sequenced in two groups, Ch0,Ch1(P4,P3) and Ch2,Ch3(P2,P1)
 LED Pattern, (Ch0,Ch2)On, Delay, (Ch1,Ch3)On, Delay, ALL_ON, Delay
  Each Sequence (Seq) holds up to 1365 LED Pulse Patterns
  At the end of each Seq the DAC volts increase by 'Step Voltage'
  LED Lemo DC out is 4 * DAC volts (increases by'Step Volts' after ea Seq)
 Hit Enter Key on each line for a default sequence setup

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 Enter Ch0-1 DAC, Step Voltage [ (0-4095mV) 0   ]
 Enter Ch2-3 DAC, Step Voltage [ (0-4095mV) 100 ]
 Enter DACs Maximum Voltage      (0-4095mV) 2500
 Enter Delay btw LED Pulses      (10nS/Cnt) 100
 LED Pulse Patterns per Seq      (  1-1365) 1000
 Seq repeat count, Def=Cont.     ( 0-65535) Continous
 Delay before Seq repeats       (1-65535mS) 5
 LED Sequence Started


 1:32      43x160    1k      115200 N81
```

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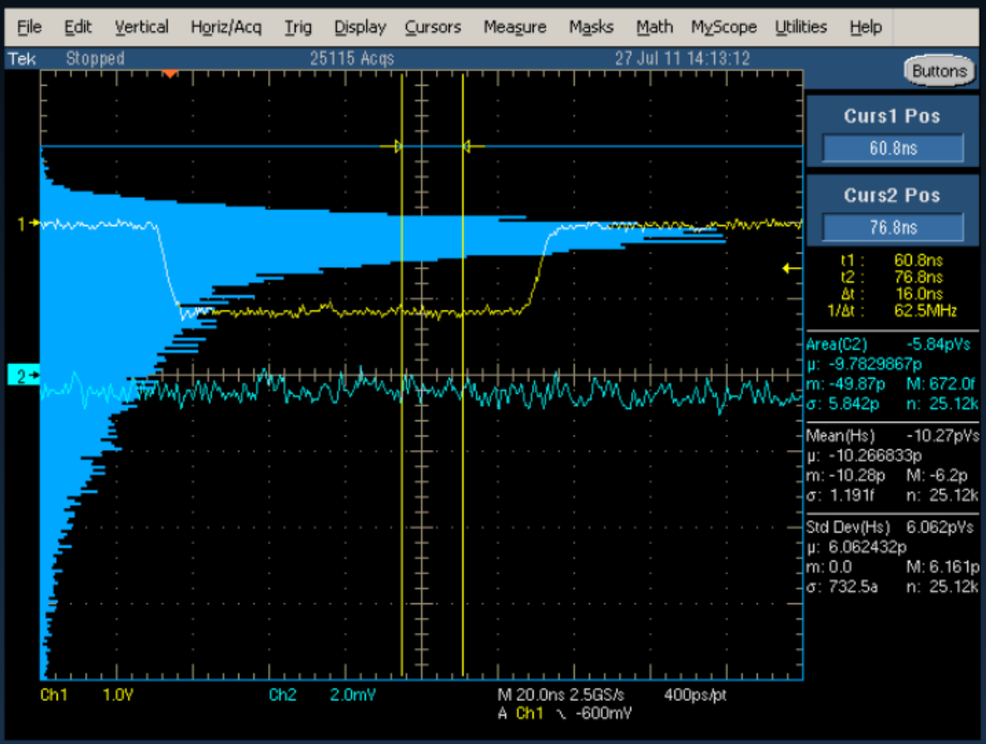
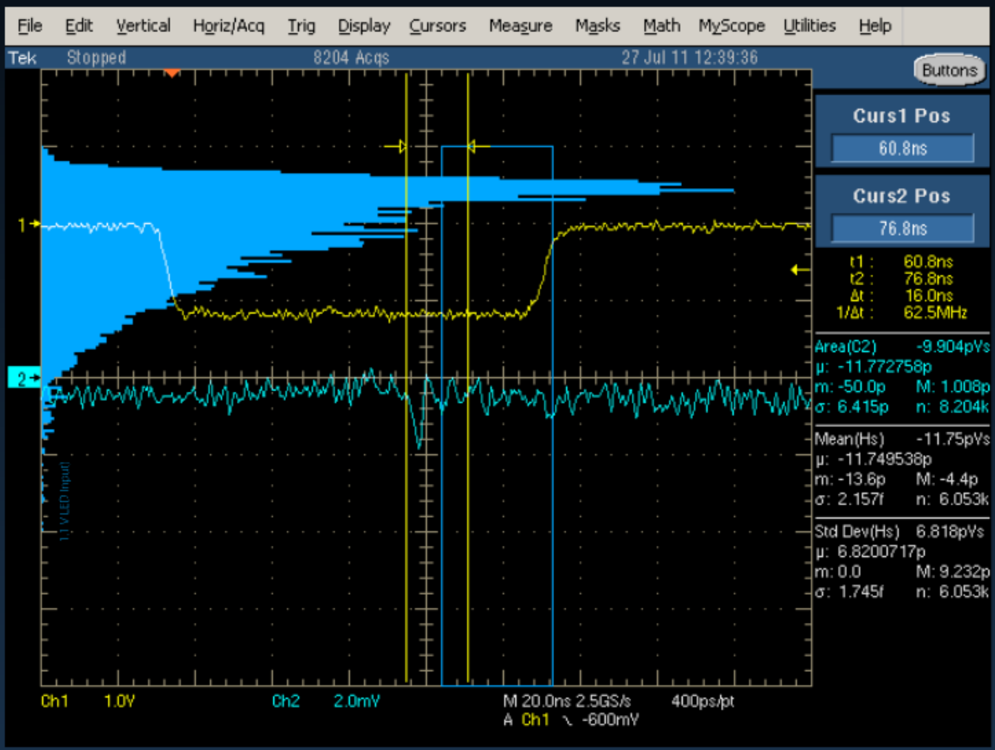
First Trials with non-Stepping LED Voltage



2.5 V LED



3.3 V LED

2.5 V LED 3.3 V LED

Reasons for Data Discrepancy

LED Pulser Board not functioning correctly

Confirmed with Oscilloscope- Correct voltage not applied to LED when step voltage set to 0

→ Reconfiguration of LED Board

Post-Fix Data Collection

Determination of threshold LED Voltage:

- < 1.75 V- No photoelectrons released
- 1.75 - 2.5 V: Mostly single photoelectrons released
- 2.5 - 4.096 V: Mostly multiple photoelectrons

1.75 V: Threshold Voltage

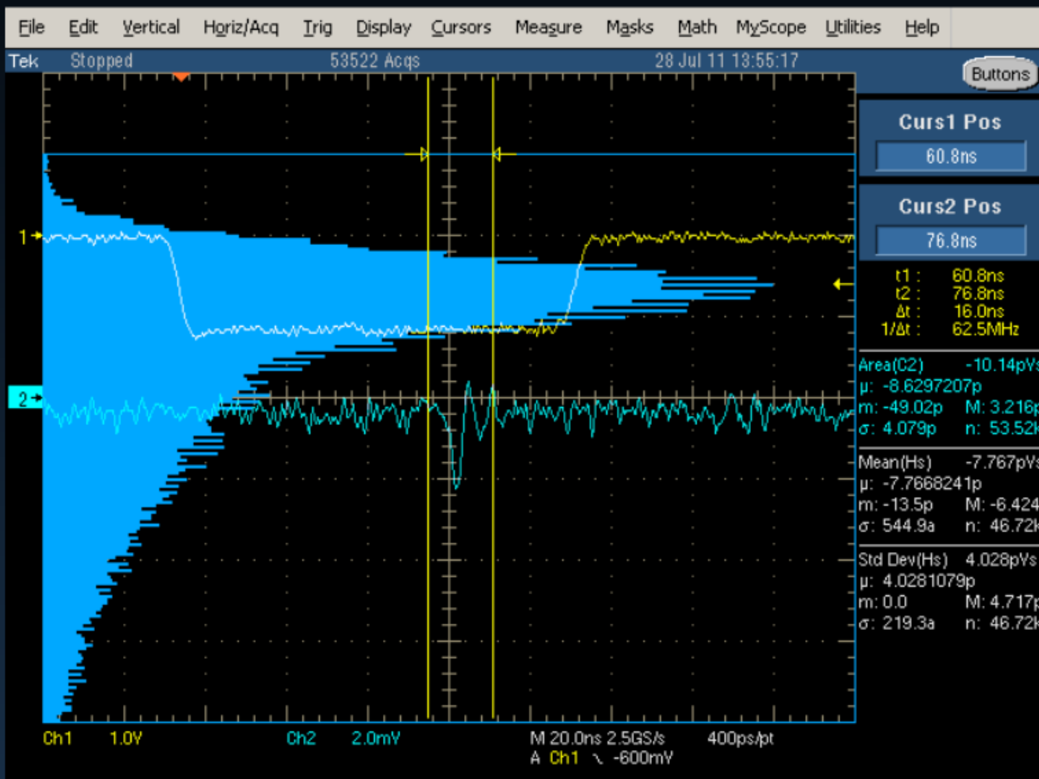
Post-Fix Data Collection (cont.)

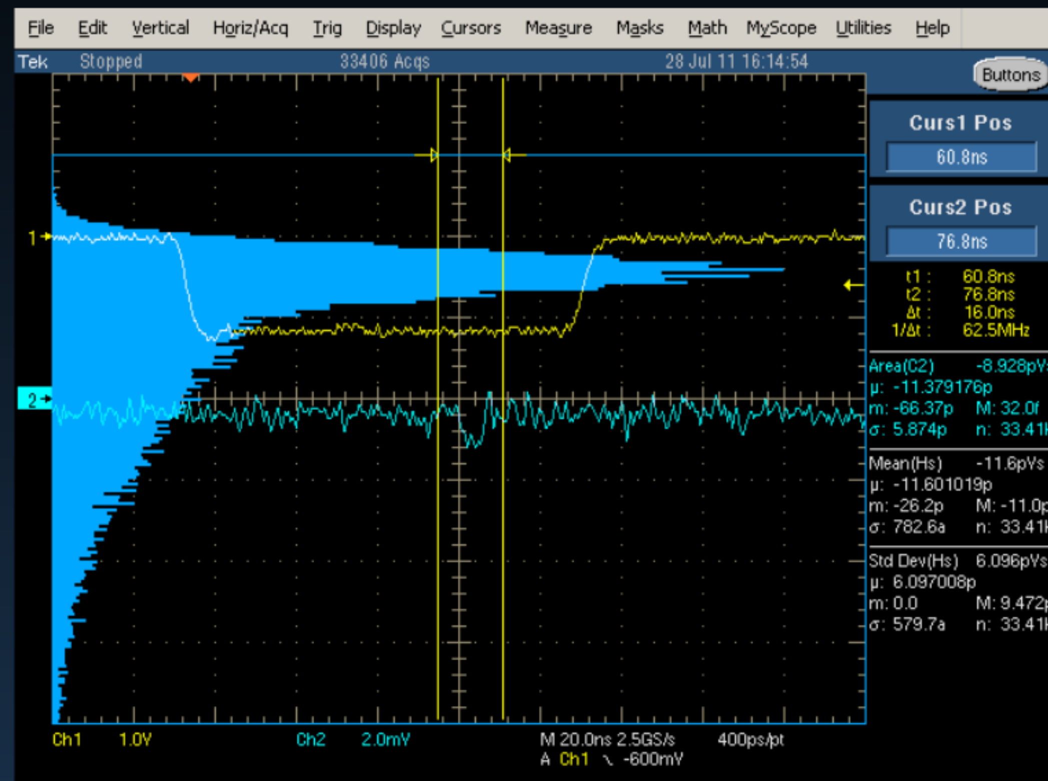
Constant voltage maintained at 2V

PMT Voltages: 900 V - 1250 V

- 50 V increments
- Noise Tests taken for each

Testing to make sure calibration held





PMT- 1001 V

LED- 2 V

PMT- 1049 V

LED- 2 V

1001 V

1049 V

pe spectrum

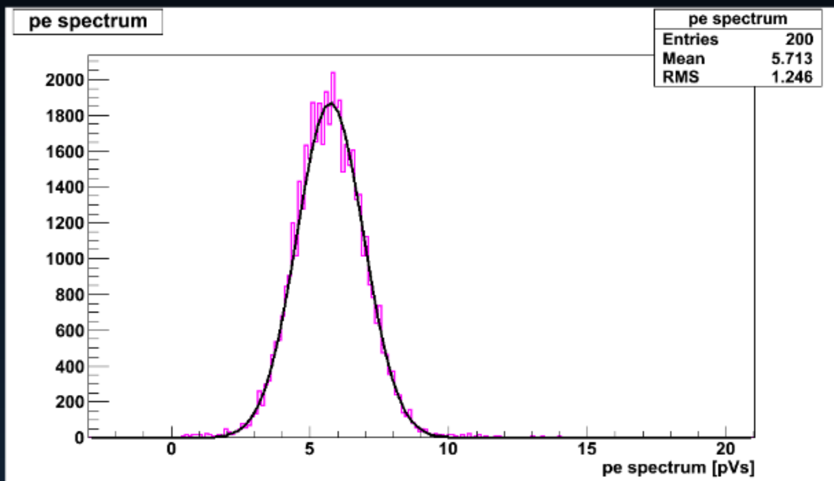
pe spectrum

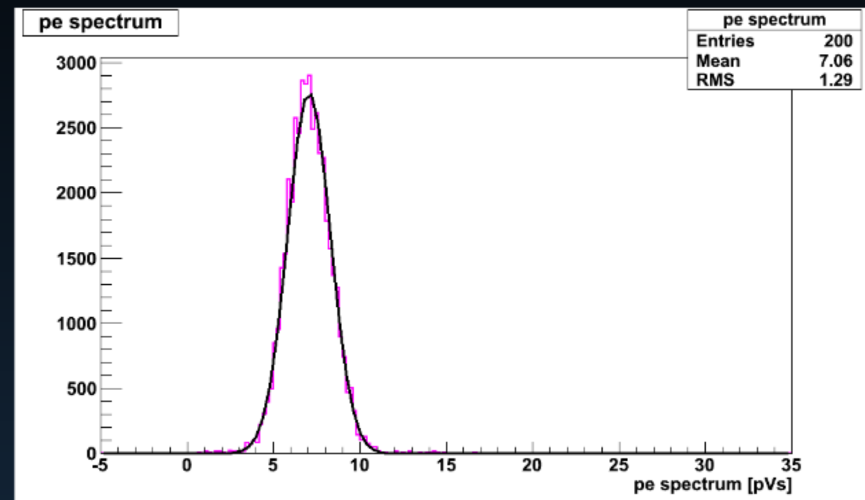
LED- 2 V

1001 V

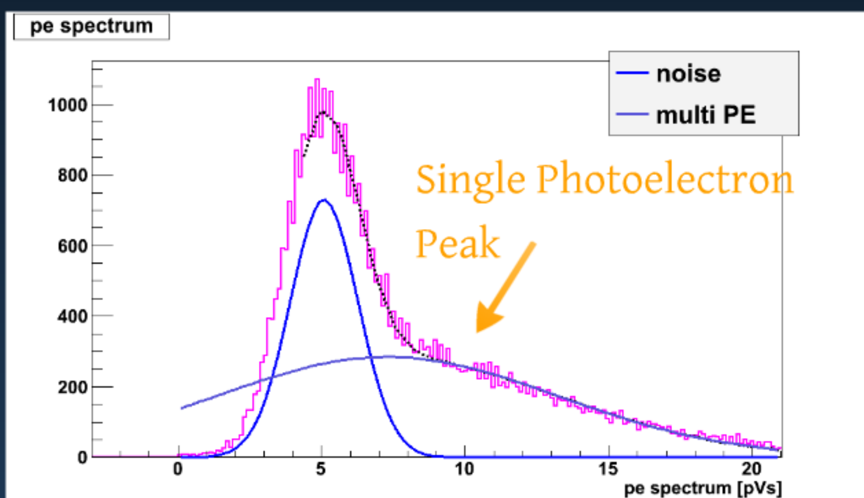
LED- 2 V

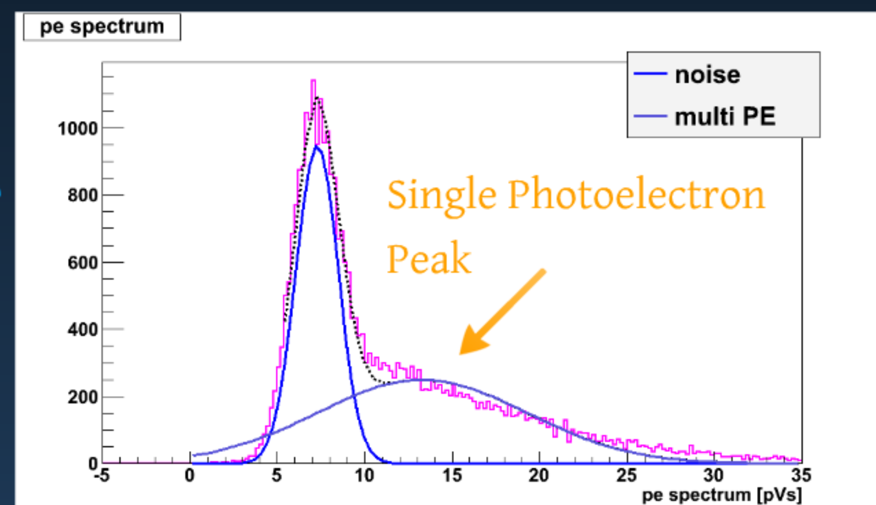
1049 V





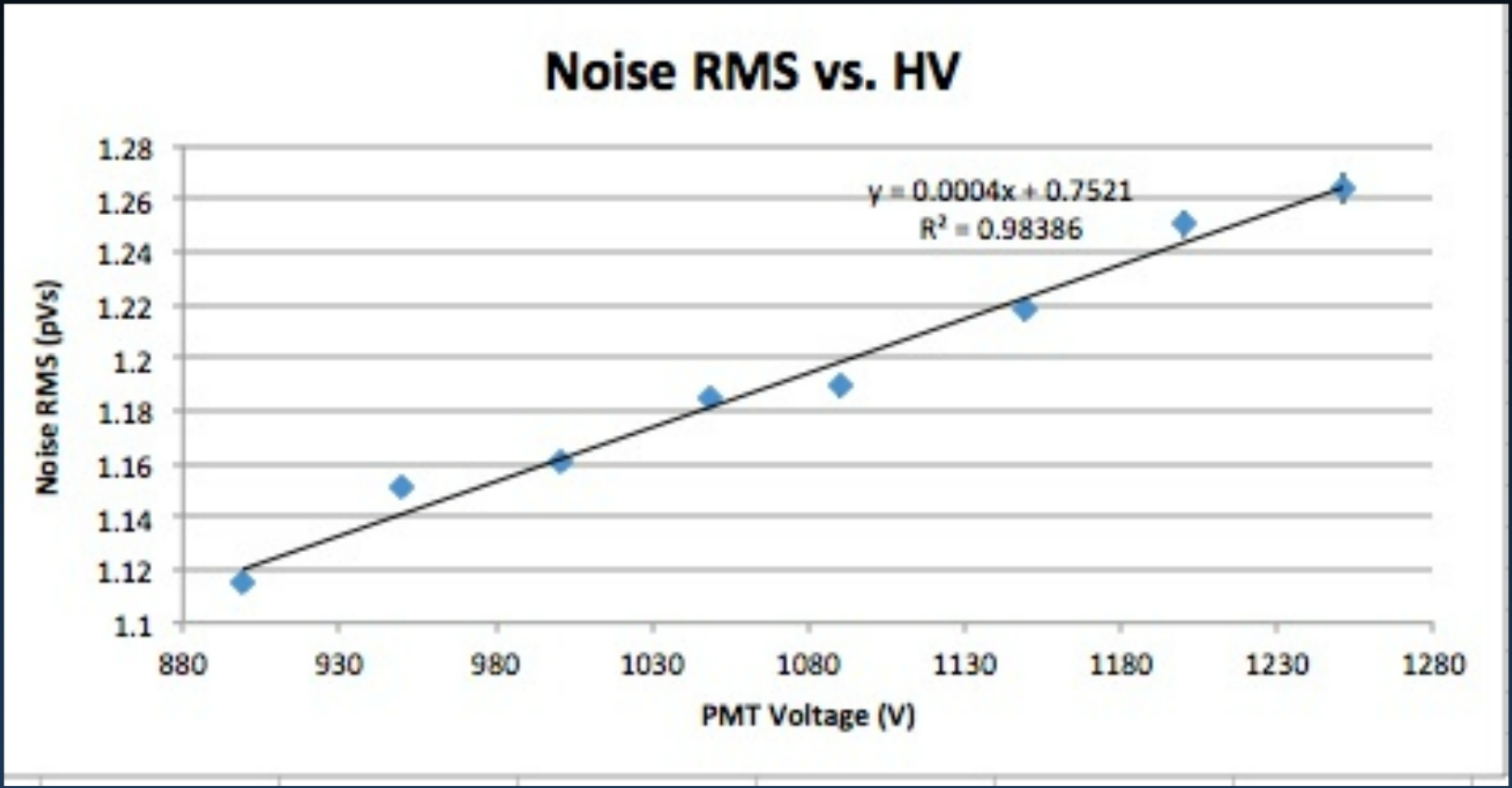
Offset

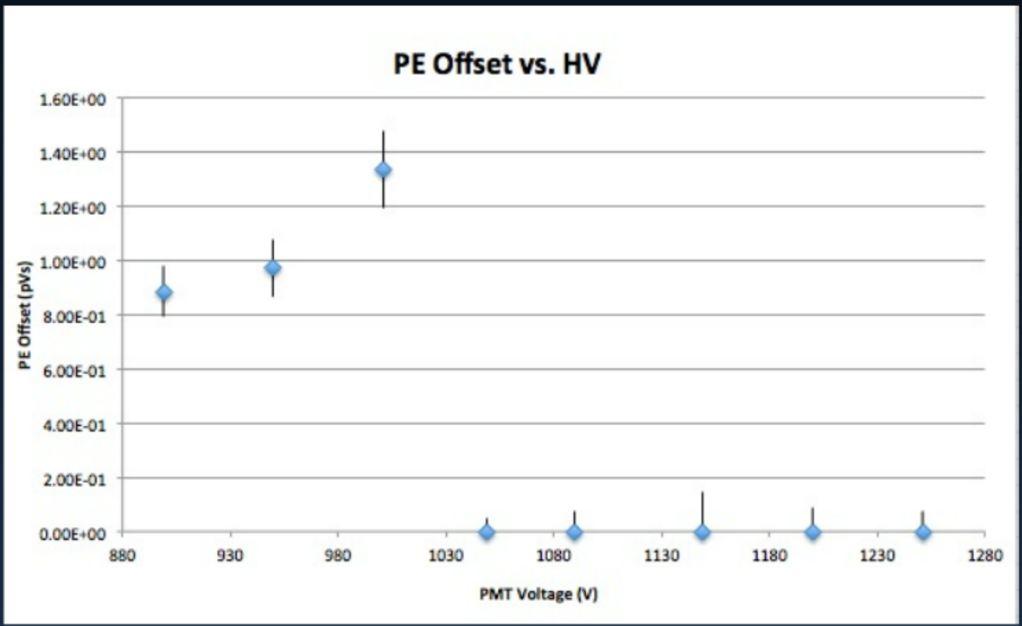




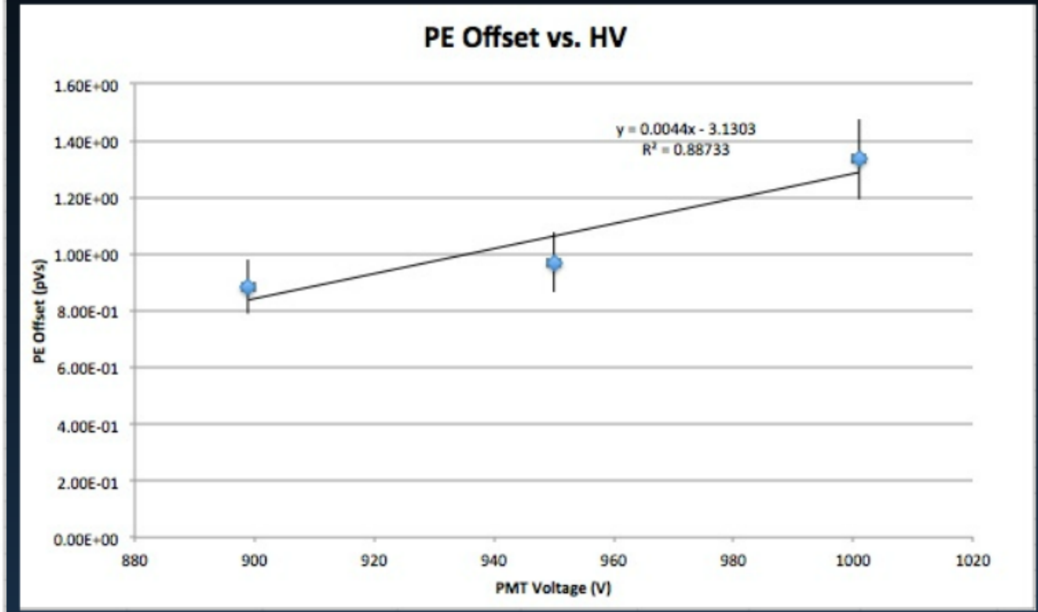
Single Peak

Results

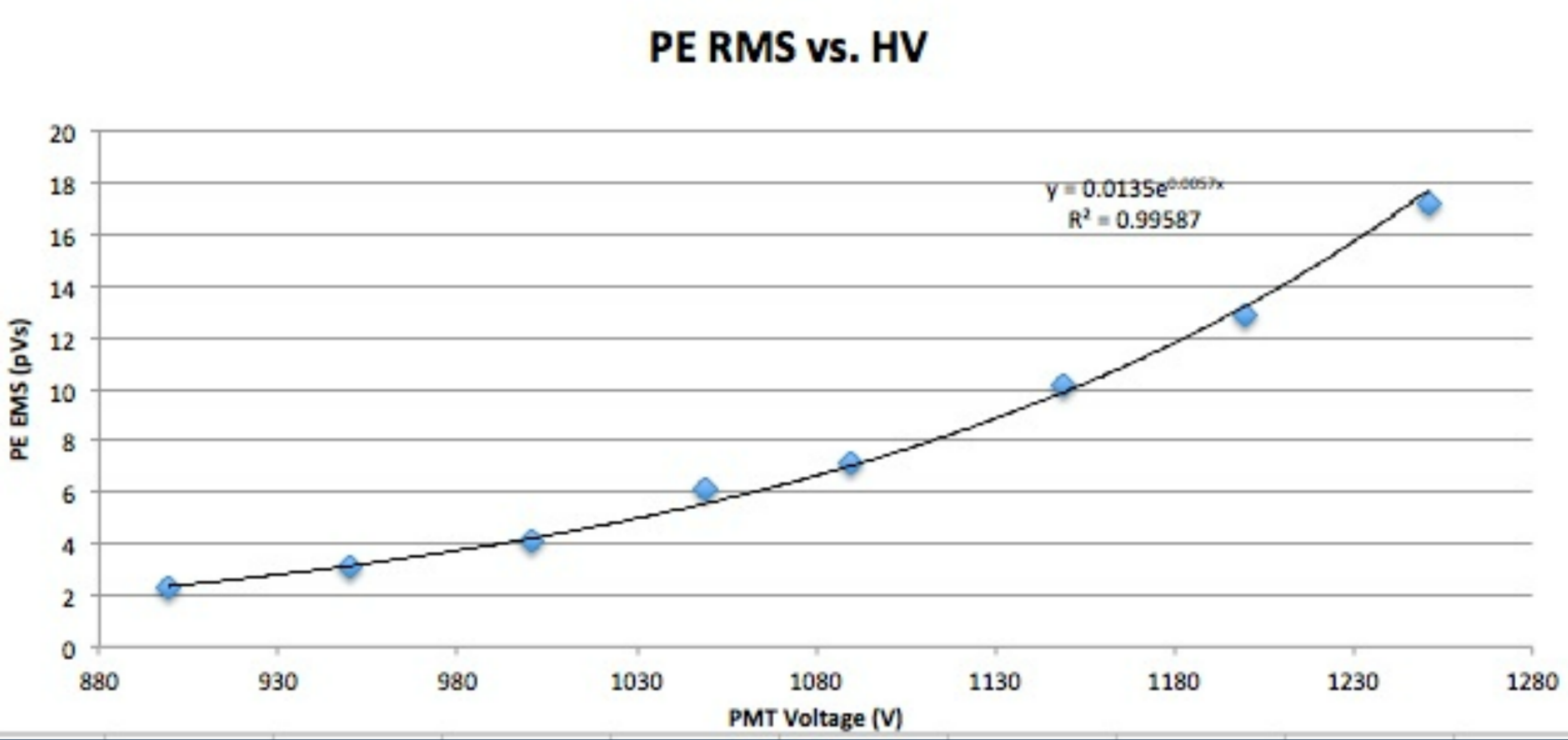

Noise RMS vs. HV
y = 0.0004x + 0.7521
R² = 0.98386
Noise RMS (pVs)
1.28
1.26
1.24
1.22
1.2
1.18
1.16
1.14
1.12
1.1
880
930
980
1030
1080
1130
1180
1230
1280
PMT Voltage (V)



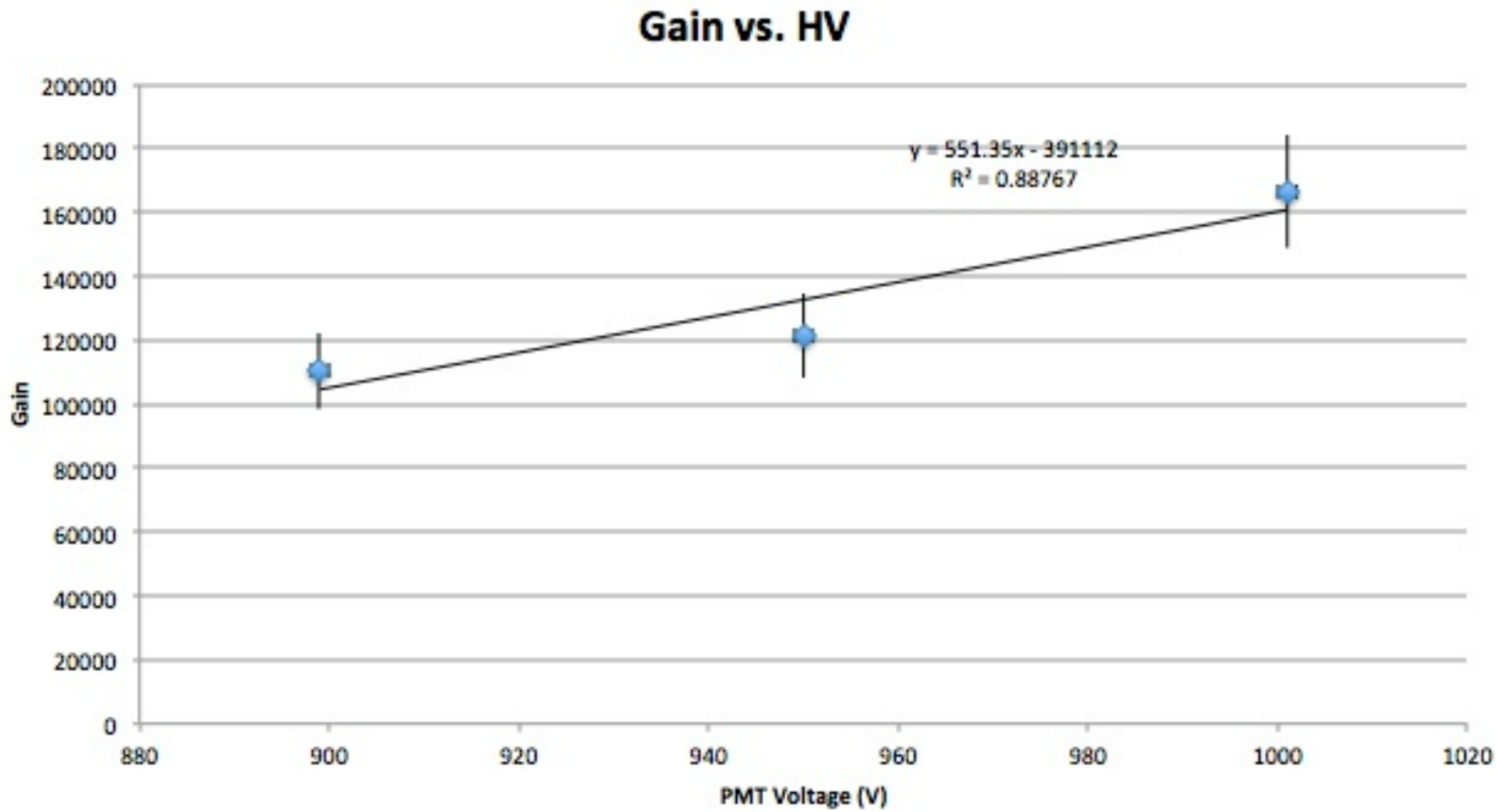
PE Offset vs. HV
PE Offset (pVs)
PMT Voltage (V)



PE Offset vs. HV
y = 0.0044x - 3.1303
R² = 0.88733
PE Offset (pVs)
PMT Voltage (V)



PE RMS vs. HV
y = 0.0135e^0.0057x
R² = 0.99587
PE EMS (pVs)
0
2
4
6
8
10
12
14
16
18
20
880
930
980
1030
1080
1130
1180
1230
1280
PMT Voltage (V)


Gain vs. HV
y = 551.35x - 391112
R² = 0.88767
Gain
200000
180000
160000
140000
120000
100000
80000
60000
40000
20000
0
880
900
920
940
960
980
1000
1020
PMT Voltage (V)

Phase 2: Coupling with Radioactive Sources

NaI crystal reattached to PMT

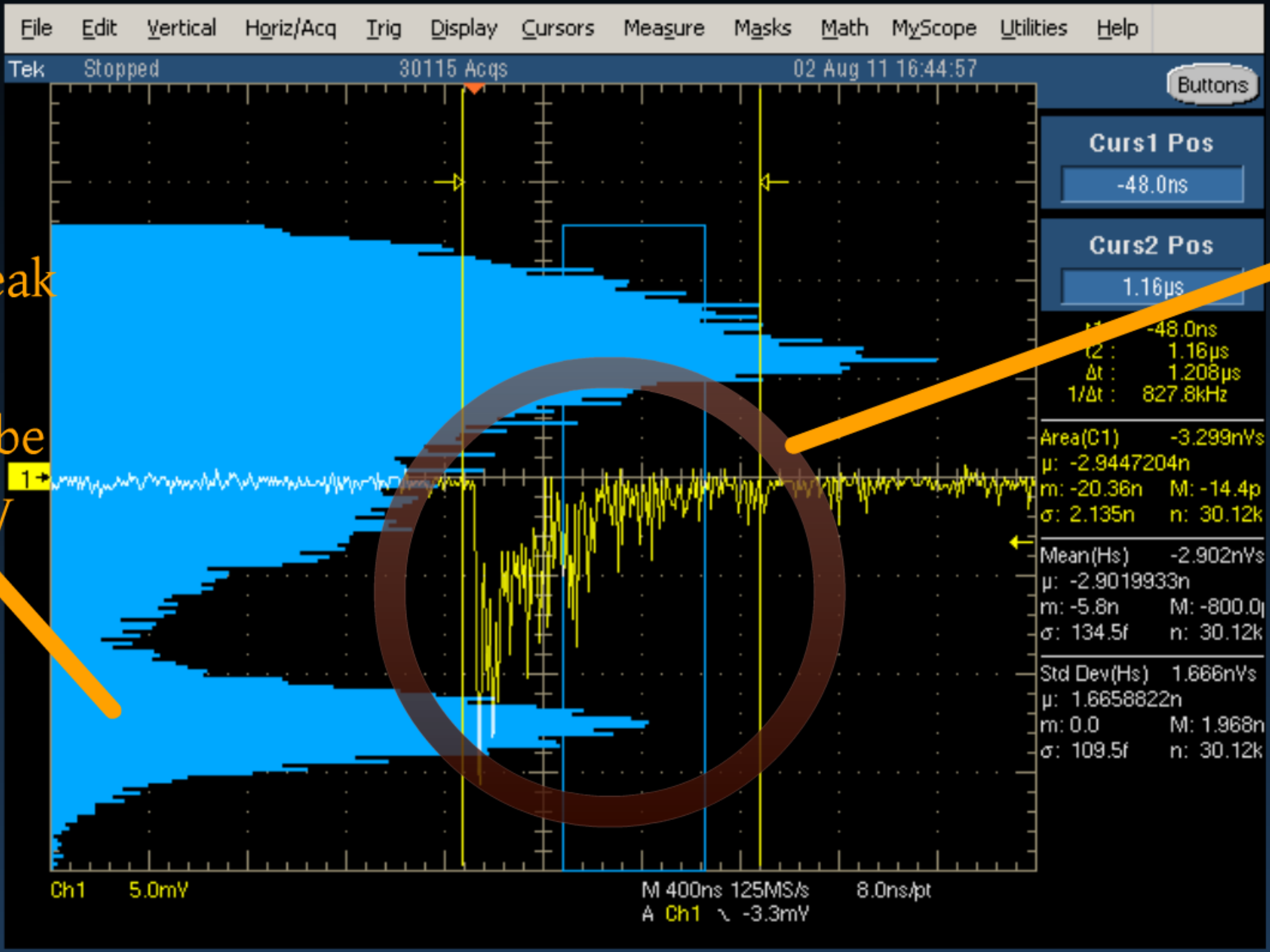
Low-intensity radioactive sources

- Cs-137, Na-22, Co-57

Gamma Peaks

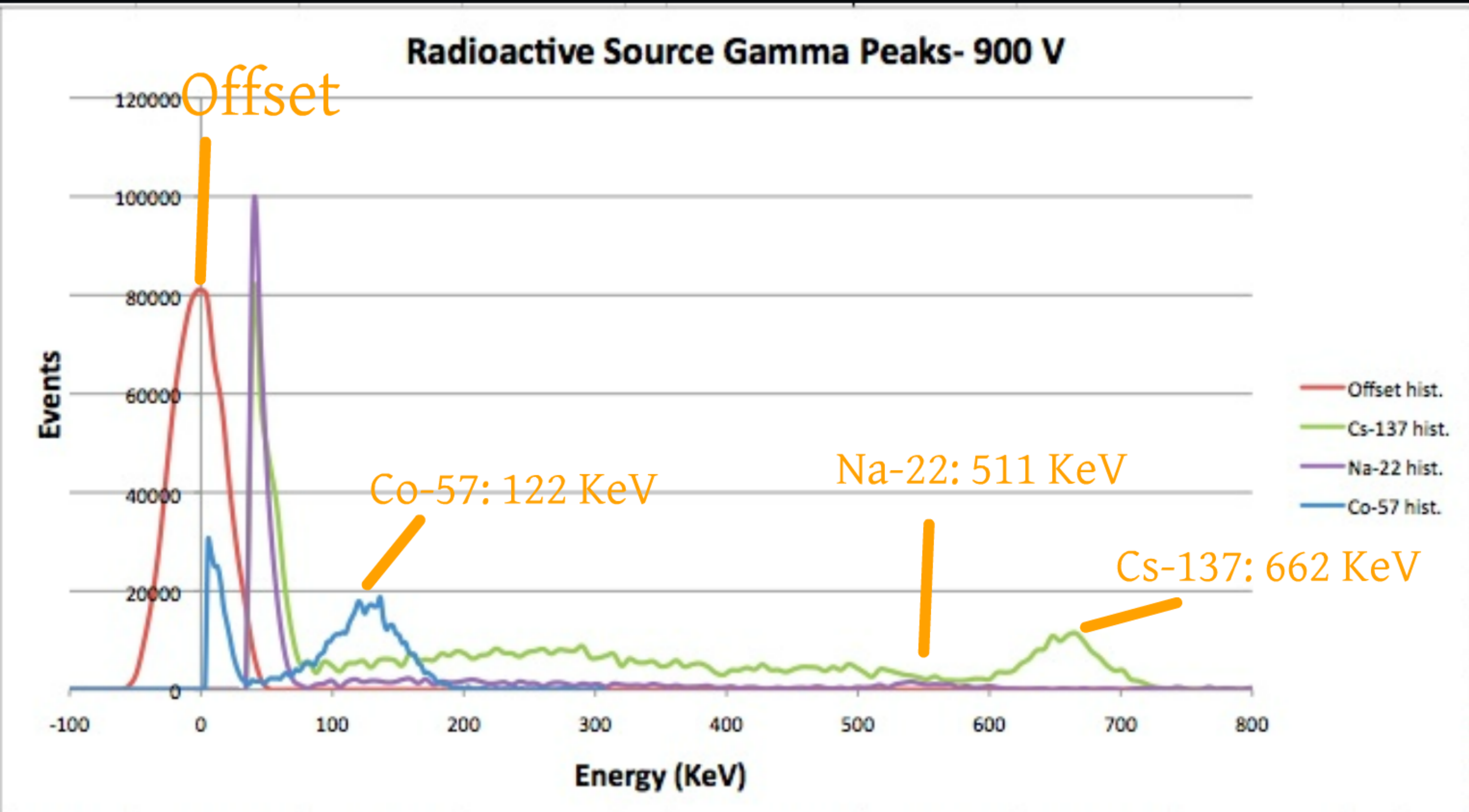
Correlation from area of gamma peaks (pVs) to energy (KeV)

Cs-137, 1000 V PMT

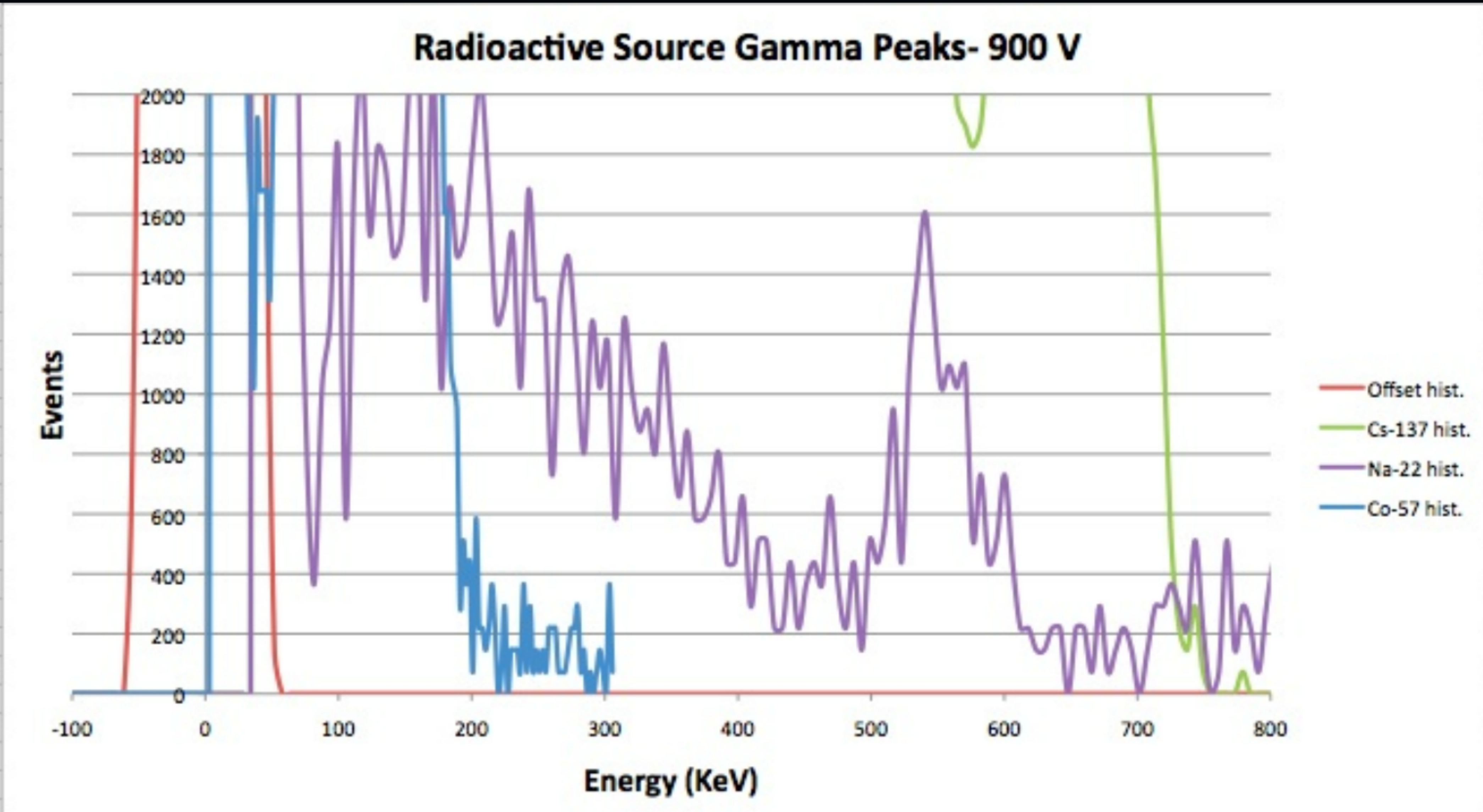


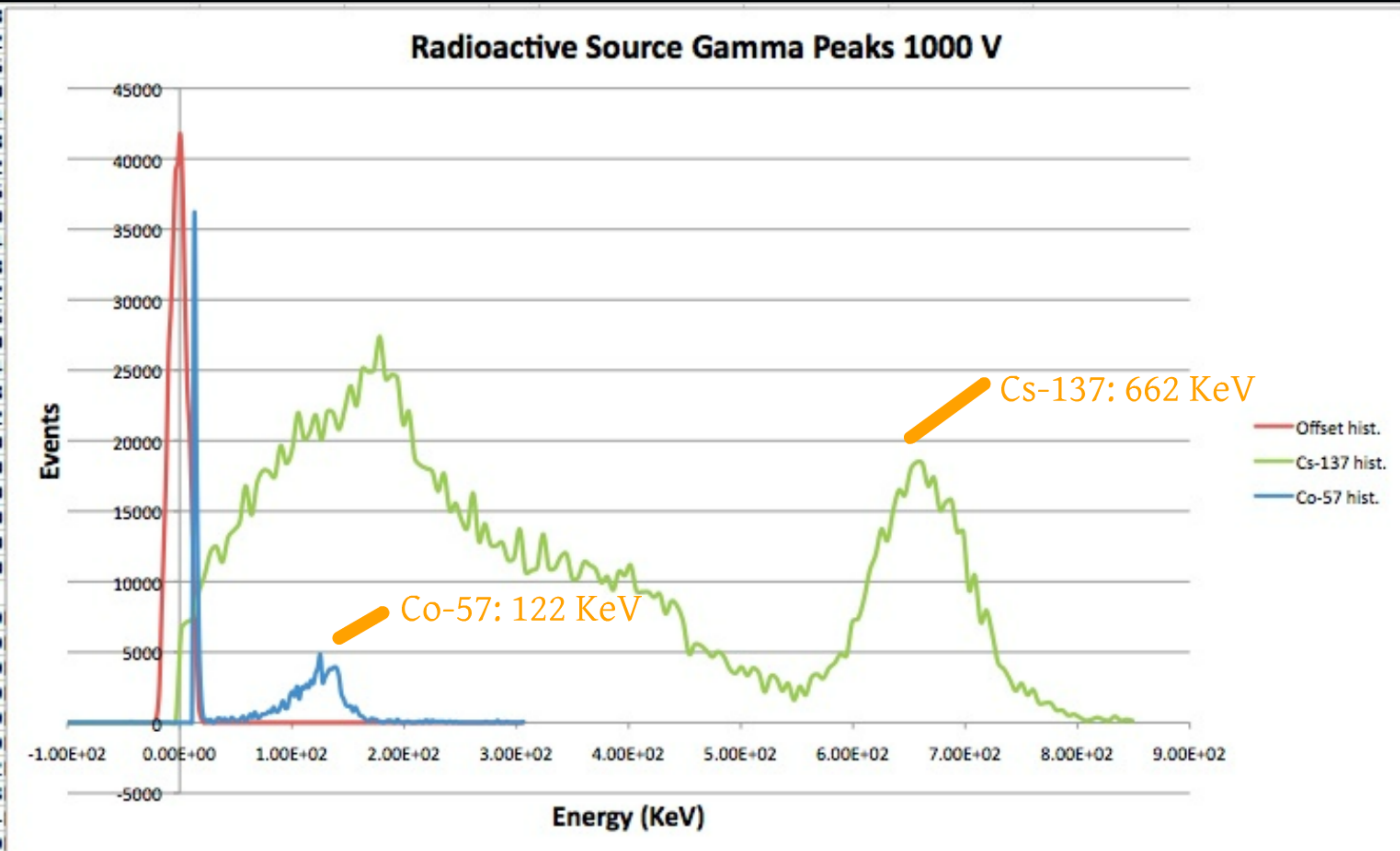
Gamma peak in pVs- known to be 661.64 KeV

Gamma spectrum given by source

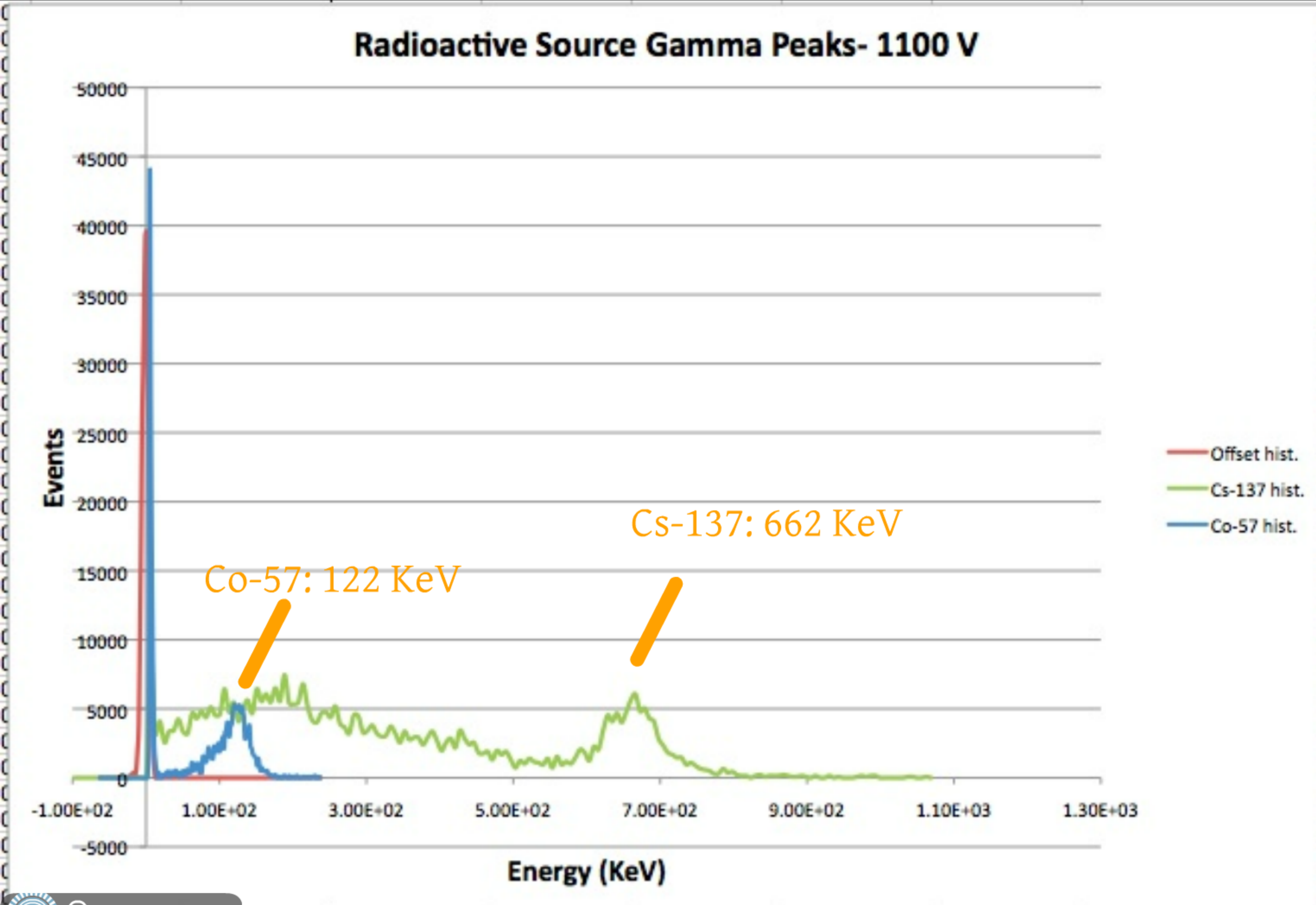


Radioactive Source Gamma Peaks- 900 V
Offset
Co-57: 122 KeV
Na-22: 511 KeV
Cs-137: 662 KeV
Events
120000
100000
80000
60000
40000
20000
0
-100
0
100
200
300
400
500
600
700
800
Energy (KeV)
Offset hist.
Cs-137 hist.
Na-22 hist.
Co-57 hist.


Radioactive Source Gamma Peaks- 900 V
Events
2000
1800
1600
1400
1200
1000
800
600
400
200
0
-100
0
100
200
300
400
500
600
700
800
Energy (KeV)
Offset hist.
Cs-137 hist.
Na-22 hist.
Co-57 hist.



Radioactive Source Gamma Peaks 1000 V
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
-5000
Events
-1.00E+02
0.00E+00
1.00E+02
2.00E+02
3.00E+02
4.00E+02
5.00E+02
6.00E+02
7.00E+02
8.00E+02
9.00E+02
Energy (KeV)
Cs-137: 662 KeV
Co-57: 122 KeV
Offset hist.
Cs-137 hist.
Co-57 hist.


Radioactive Source Gamma Peaks- 1100 V
Events
50000
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
-5000
-1.00E+02
1.00E+02
3.00E+02
5.00E+02
7.00E+02
9.00E+02
1.10E+03
1.30E+03
Energy (KeV)
Offset hist.
Cs-137 hist.
Co-57 hist.
Co-57: 122 KeV
Cs-137: 662 KeV

Finding the Time Delay

Determine Background Radiation

Final Exposure

Background

With crystal/PMT setup, determine backround spectrum

- Environmental factors -- cosmic rays, environmental radioactivity

Finding the Time Delay

Determine Background Radiation

Final Exposure

Final Exposure

1) Expose crystal to high intensity radioactive sources

2) Immediately remeasure background spectrum after stopping exposure

Background changed?

Which is, essentially....

- More money
- More data

Special Thanks

Lauren Hsu

James Browne

Terry Kiper

Sten Hansen

George Dzuricsko

Chris Stoughton