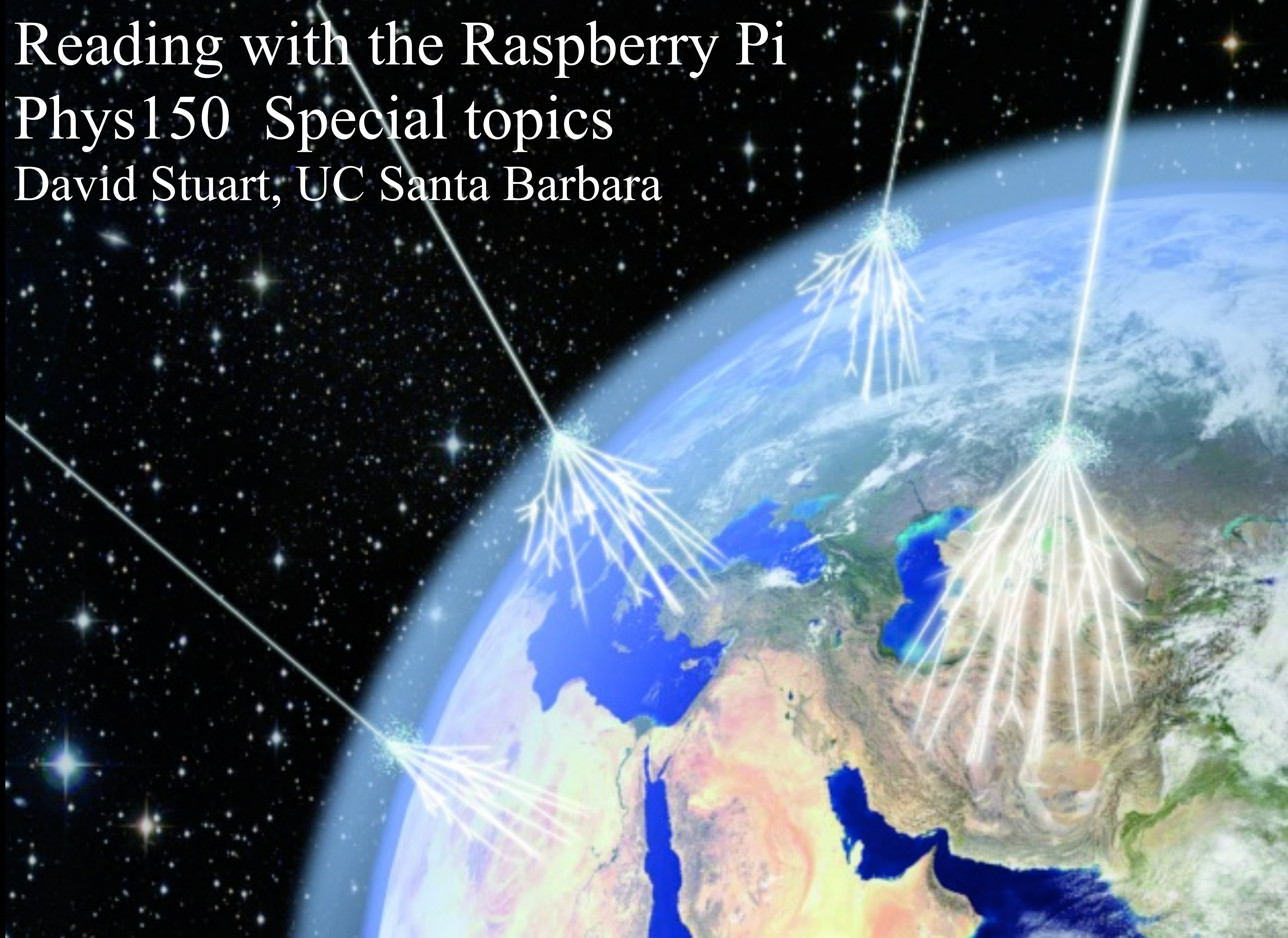
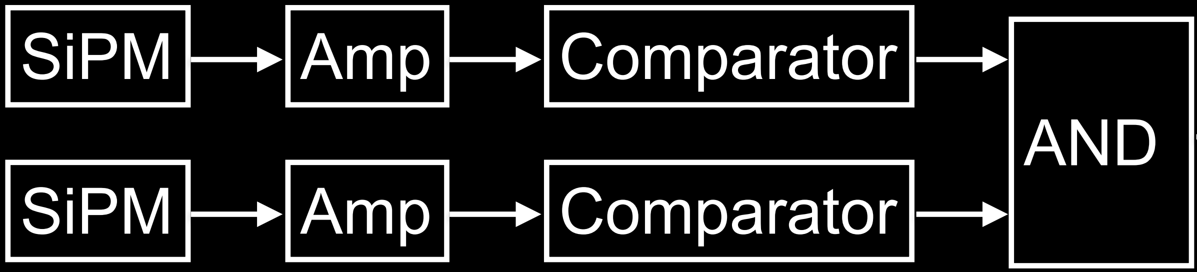
Reading with the Raspberry Pi

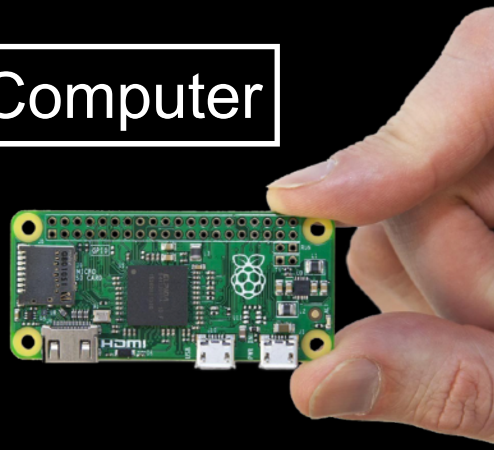
Phys150 Special topics

David Stuart, UC Santa Barbara



Review: Electronics for the detector

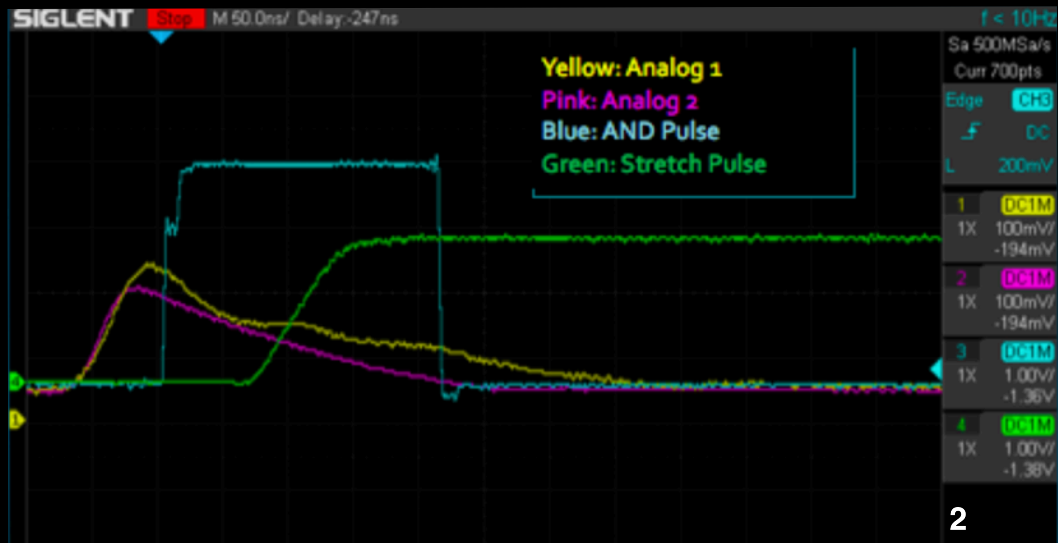




The "stretched pulse" should last for about 100 μs, which is plenty of time for the RPi to detect it.

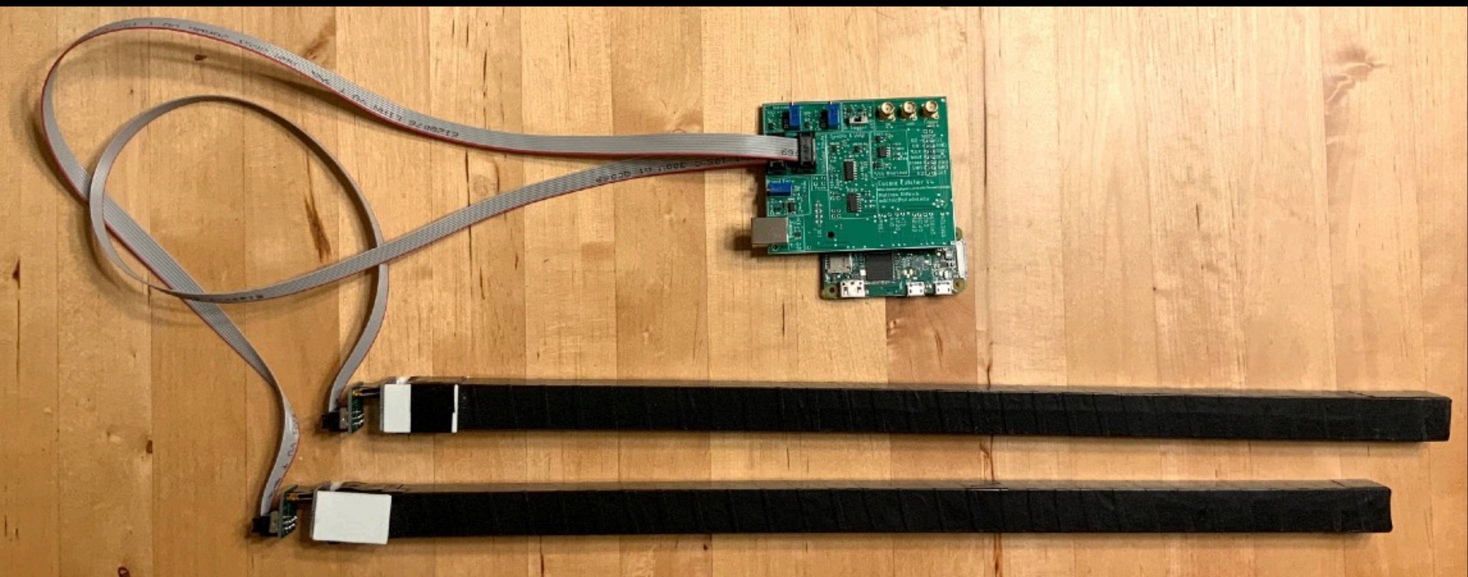
We'll go through how to do that today.

First I'll discuss the homework and before that the schedule for picking up equipment.



Picking up equipment

You will each get one set to use throughout the quarter, but return after.
I can ship to you if you aren't local — email me.
A socially distanced pickup outside Broida, south side, on the following times:
Friday 11:30 - 12:30
Friday 4:30 - 5:00
Monday 12:00 - 1:00



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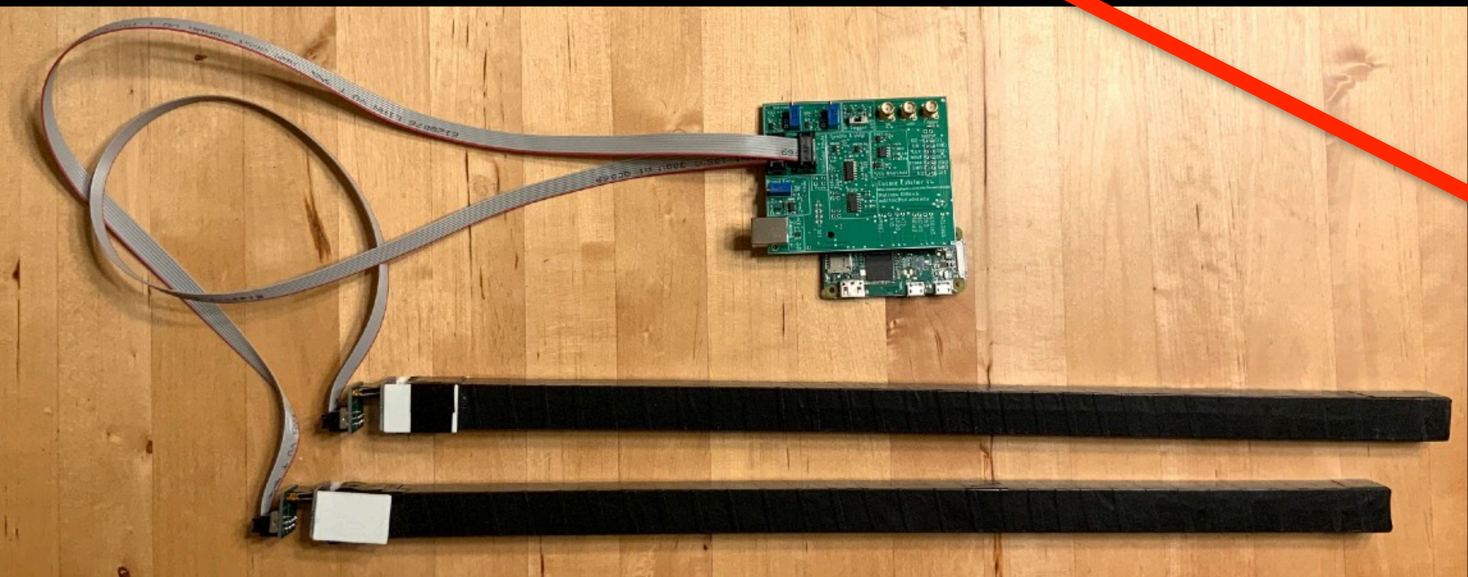
Small things like adapters, jumpers, LEDs, resistors, SD cards, in drawer on Broida loading dock.



Homework

But first, let's discuss the homework questions:
1). Why the shoulder at 120 mV and the filler in between peaks?

Some answers considered lower energy photons producing a different response.

Key idea of photons is that they are discrete quanta.

In photoelectric effect, there is a minimum wavelength; above that no electrons, and below that only one electron. Not 1.2 electrons.
Often called "photo-electrons" to indicate their origin (cf beta, delta, auger).

In SiPM, it is similar although it is an electron-hole pair, rather than an ejected electron and remaining positive charge.

So really, the discrete photons cause integer number of electrons.

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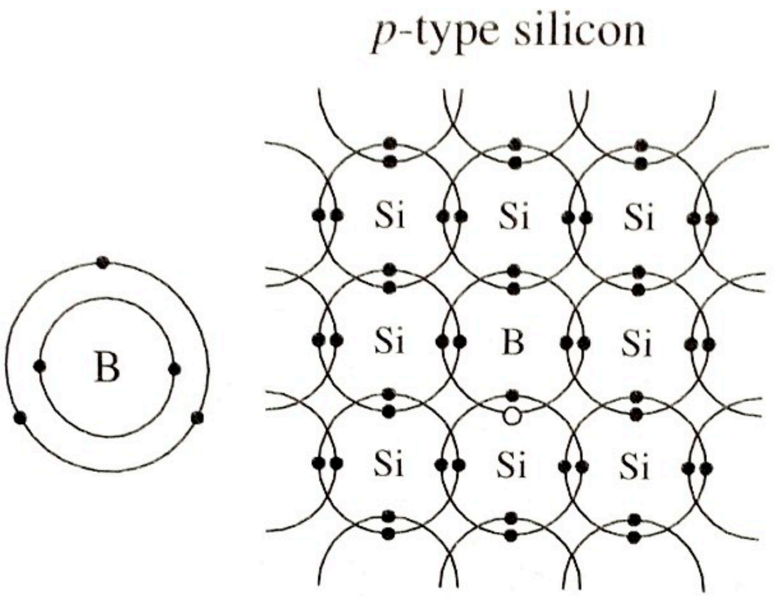
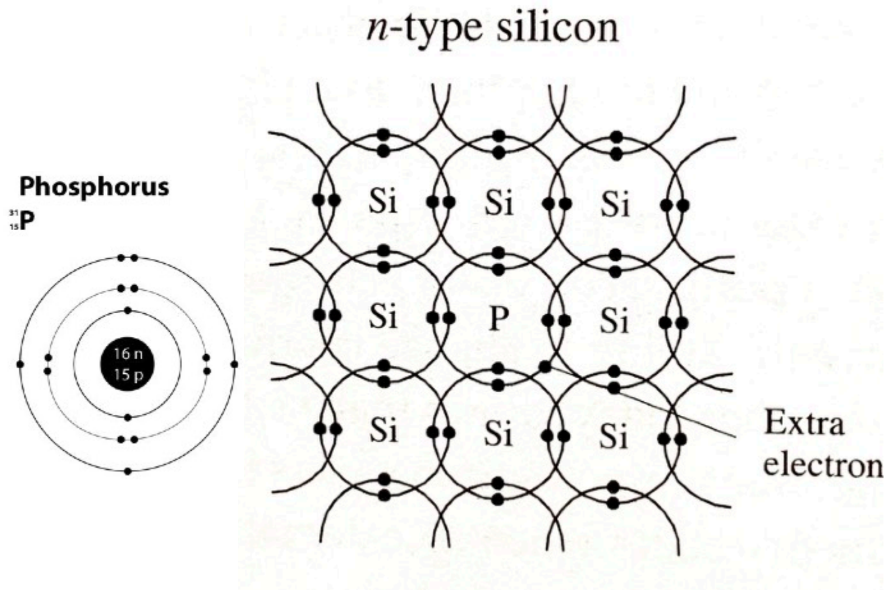
So really, the discrete photons cause integer number of electrons.
Suspect that the response to the electrons is varying somehow.

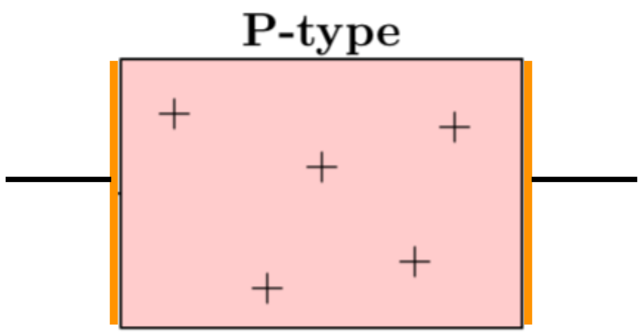
Let’s build some deeper understanding about SiPMs

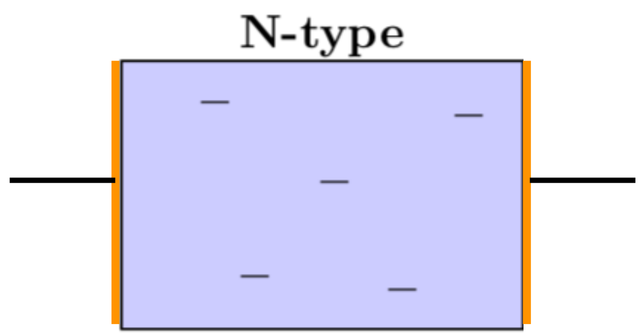
They are just photodiodes operating in avalanche mode (aka geiger mode). So let’s review how diodes work. Silicon crystals can be doped with an excess of charge carriers, either n-type or p-type.

Pure silicon is an insulator, but doping with impurities adds “free charge carriers”. $I = n A q v_d$ We can adjust n to control conductivity and hence resistivity.







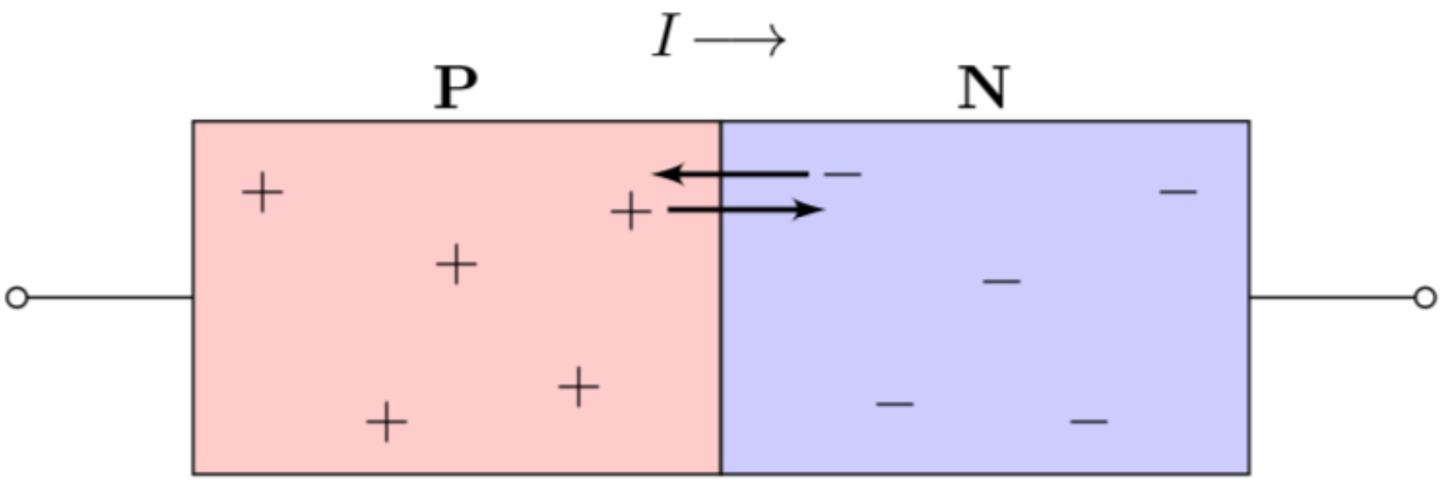


A diode is made with a p-n junction

If I put a p-type piece in contact with an n-type piece, the opposite signed charge carriers can move to cancel either other.

As they do so, they will leave a region on either side of the junction that is *depleted* of charge carriers.

The bulk is charge neutral throughout, but the carriers are no longer *free charge carriers*.



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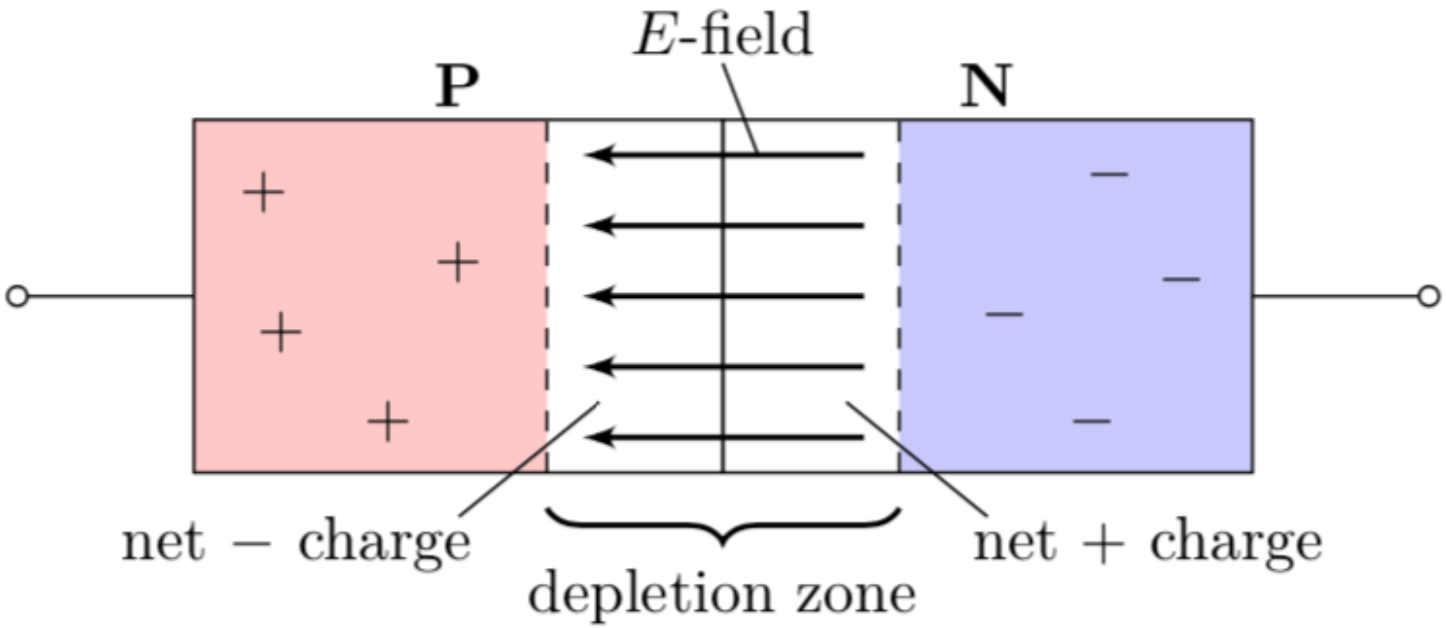
And an intrinsic electric field develops in the depletion region.

$V \cong 0.7$ Volts



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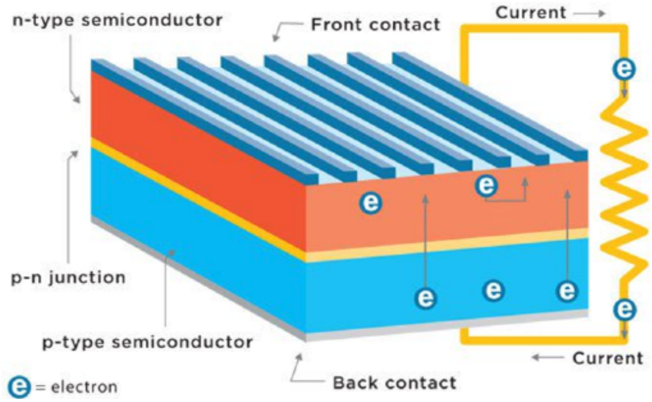
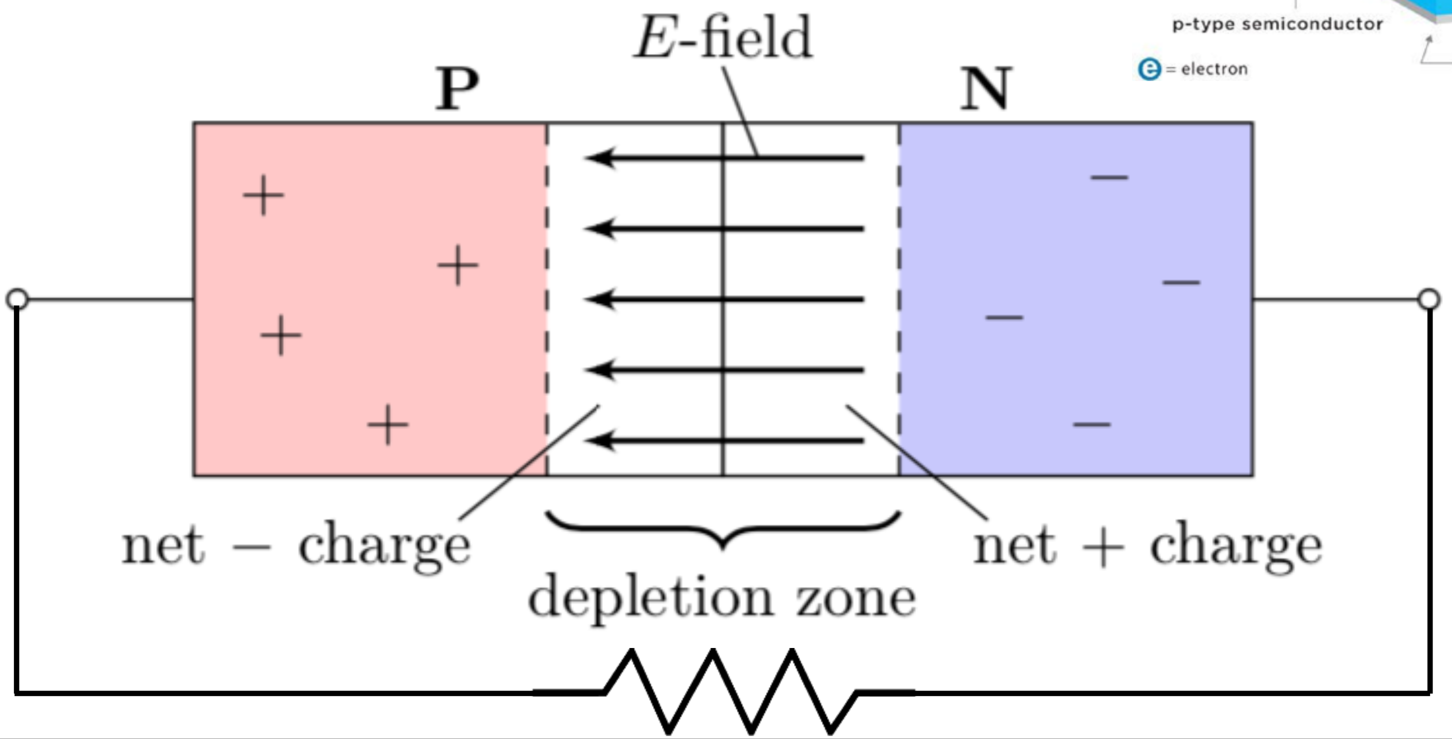
An intrinsic electric field develops in the depletion region. V ≅ 0.7 Volts

If we put a resistor across this, no current would flow because the depletion region has high resistivity (n=0).

Voltage, but no current, so no power. Unless we freed a charge carrier.

This is a photocell.





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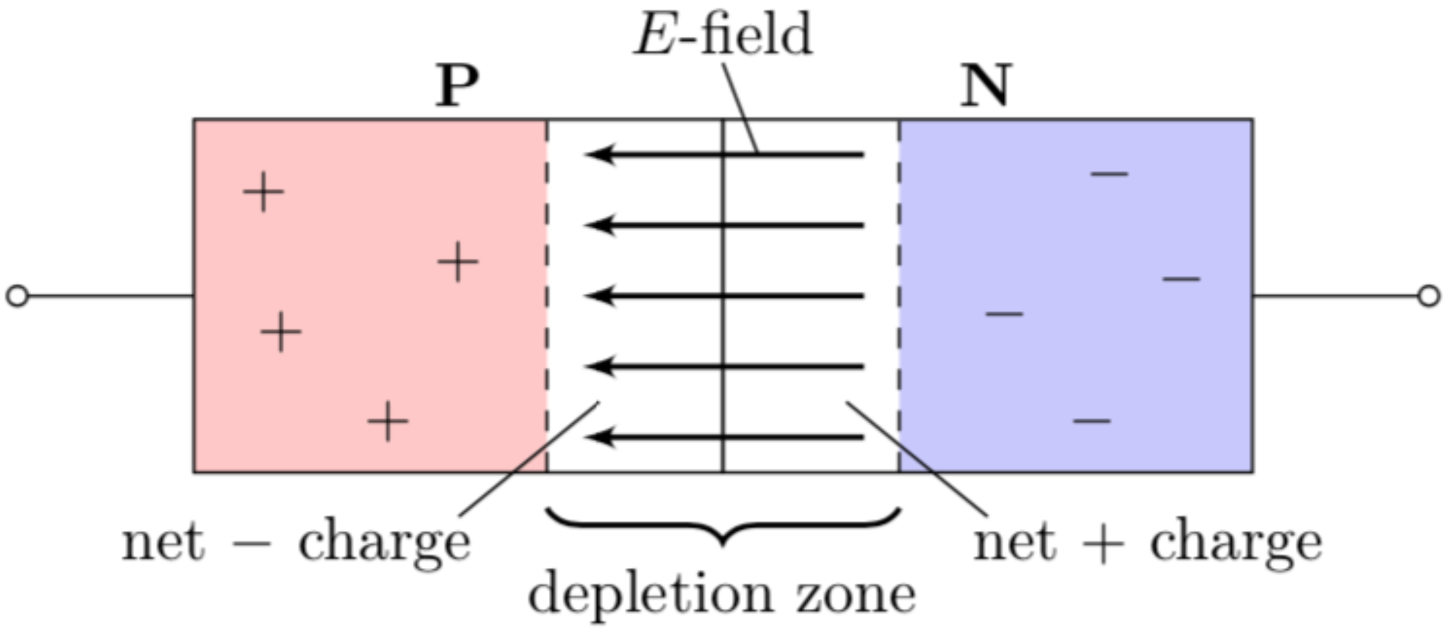
This is a pn-diode, and its symbol matches that of a one-way valve.



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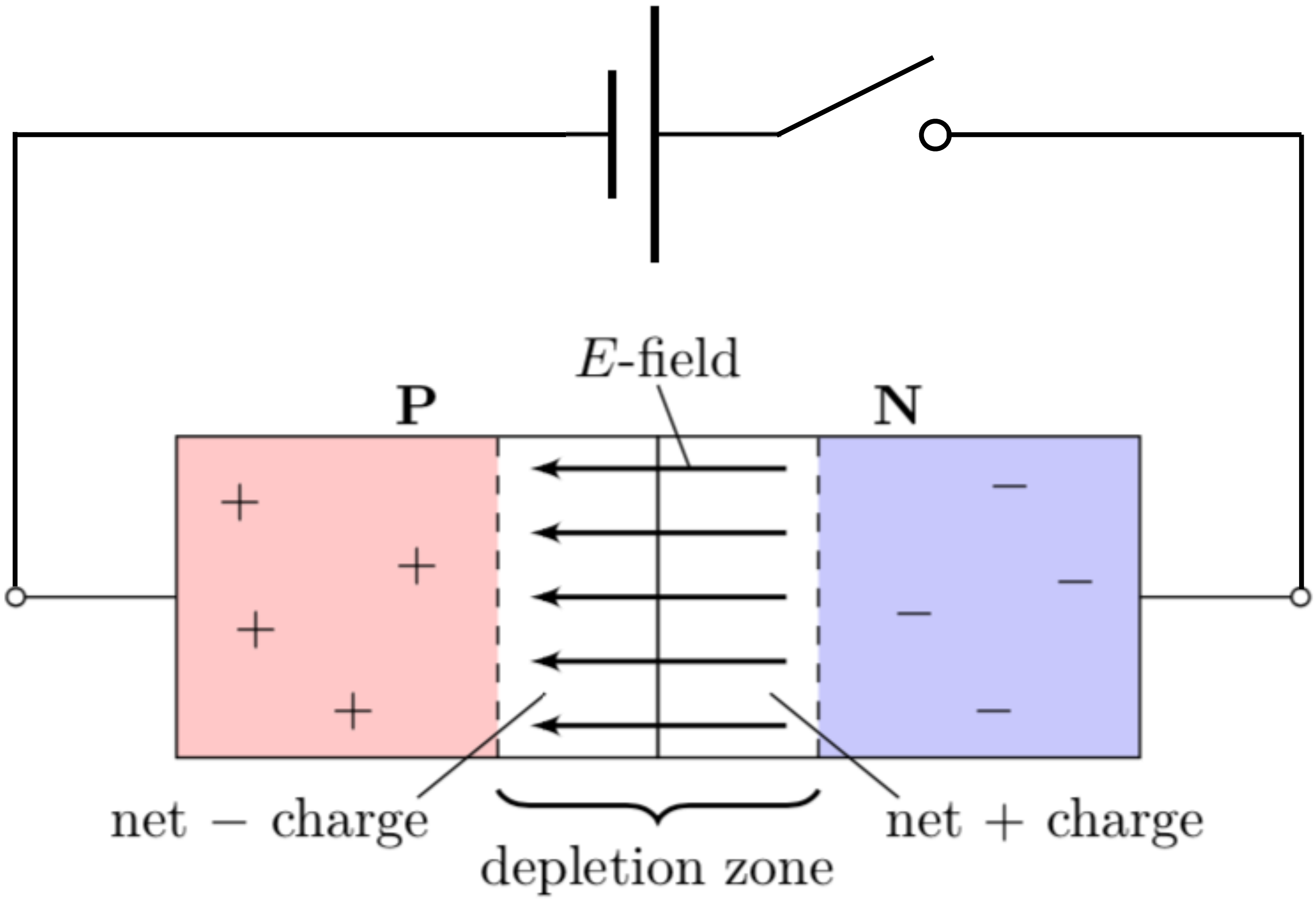
We can see that one-way current behavior by applying an external voltage.



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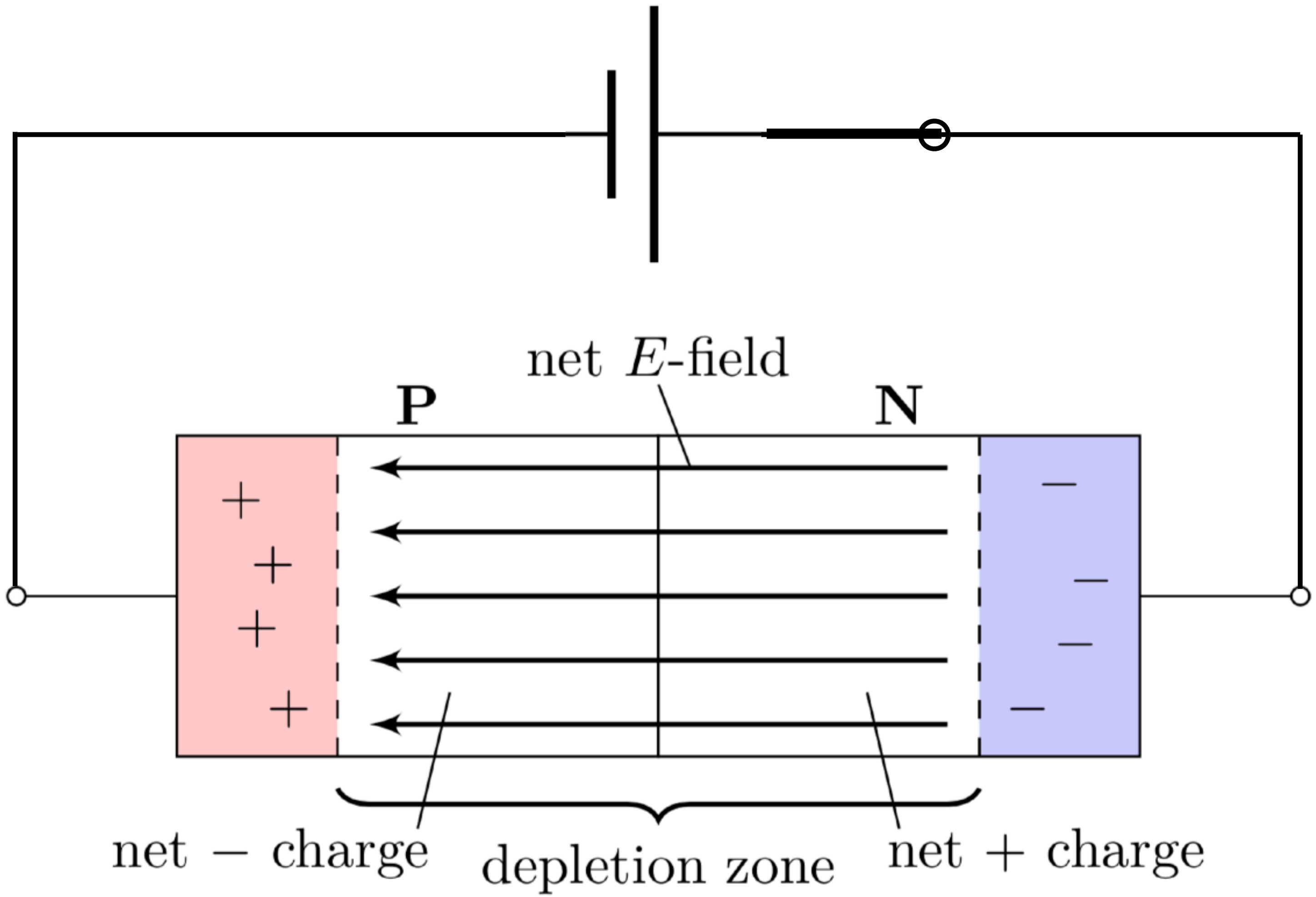
That widens the depletion region but current still won't flow through it.



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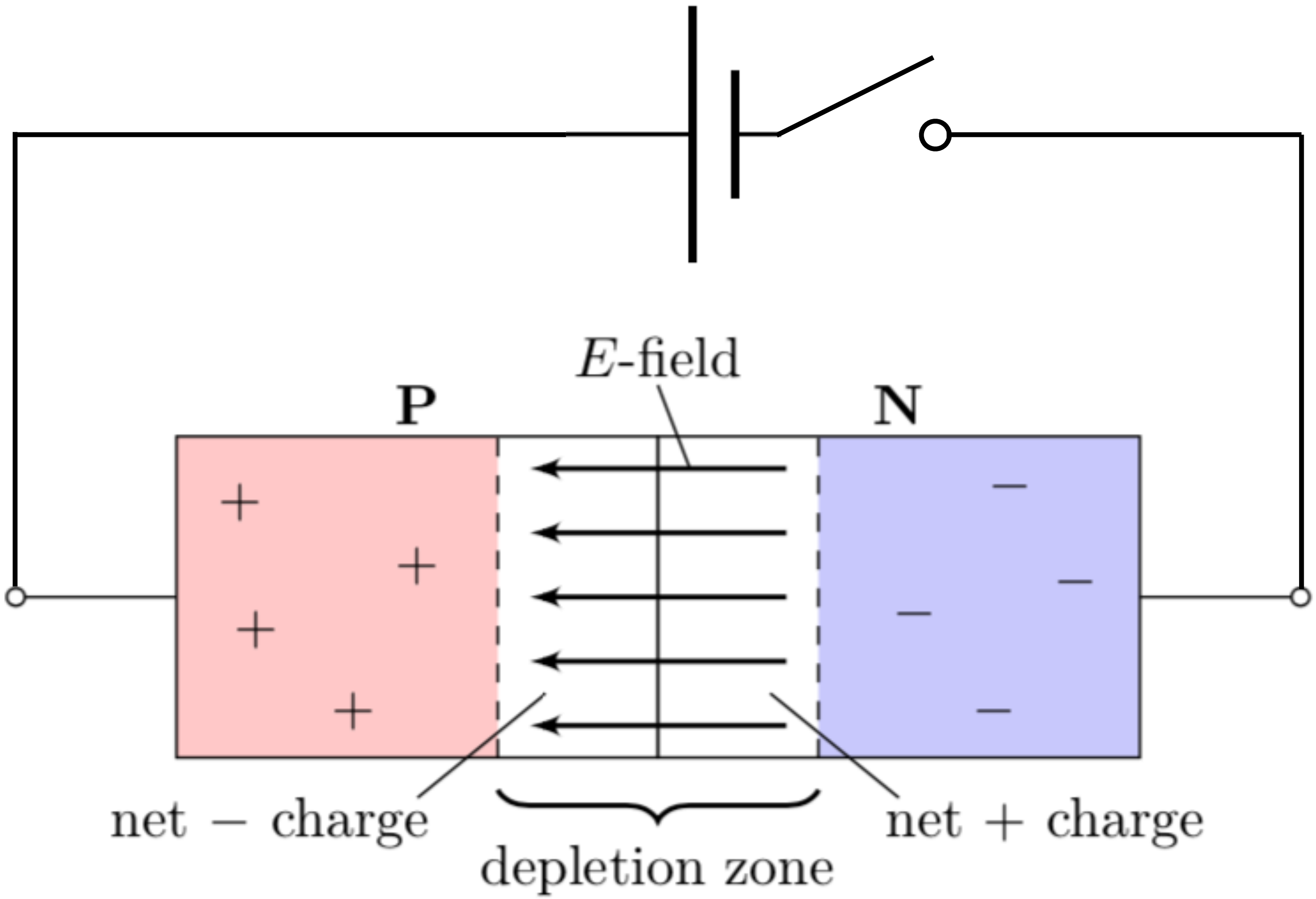

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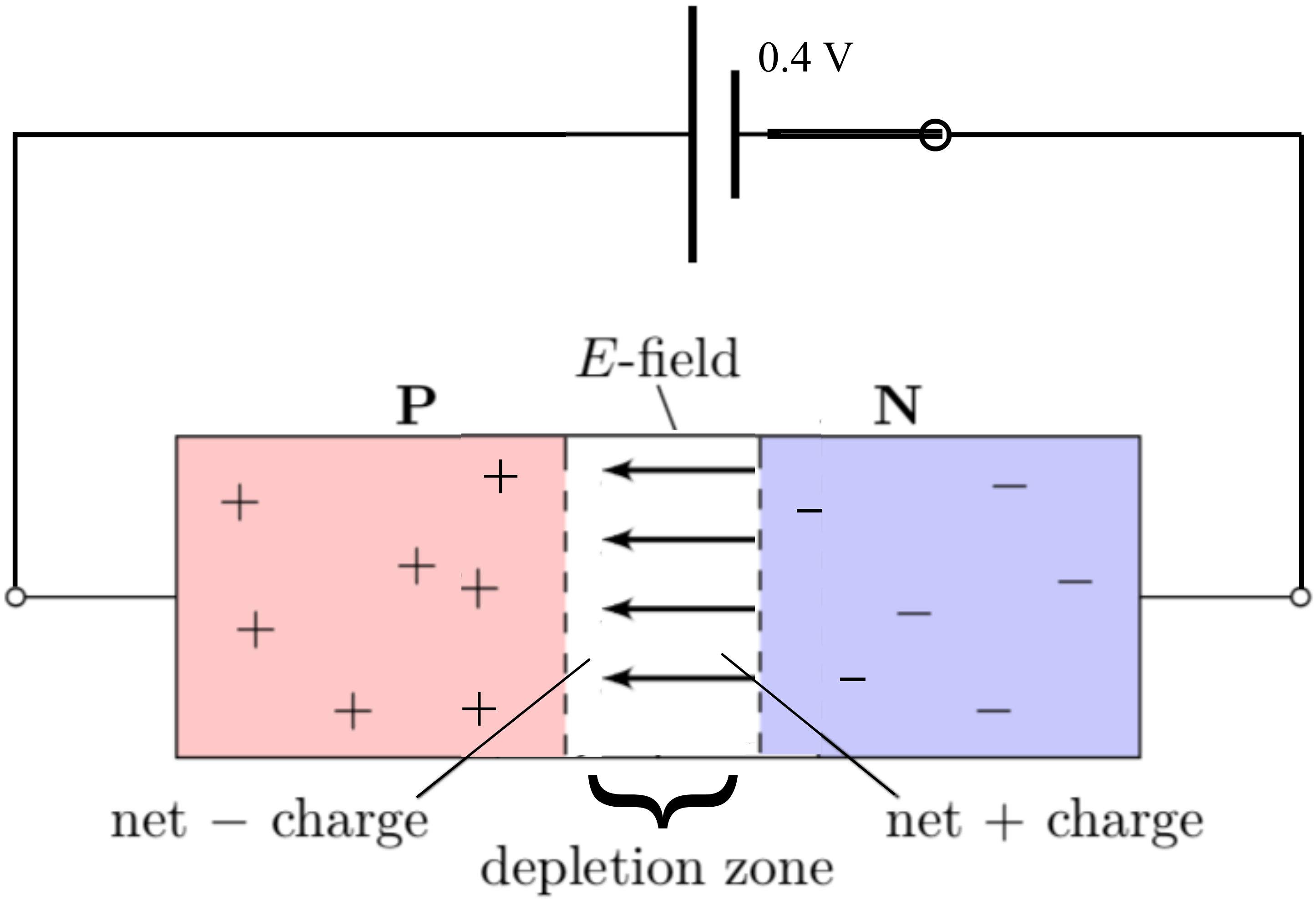

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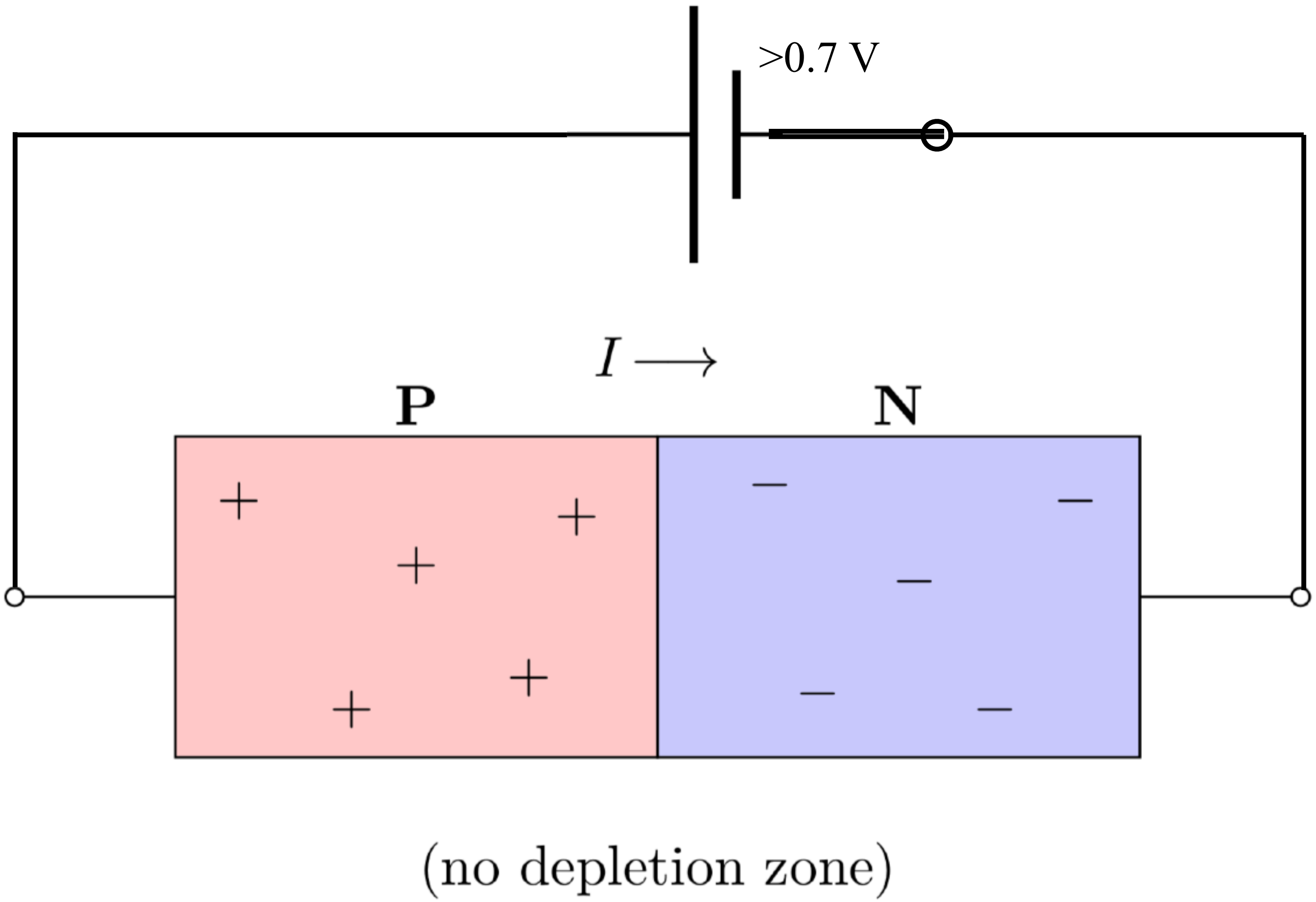
We can see that one-way current behavior by applying an external voltage.

Flip the battery’s polarity. Once we overcome the 0.7 V internal voltage, current flows through continuous charge carriers.



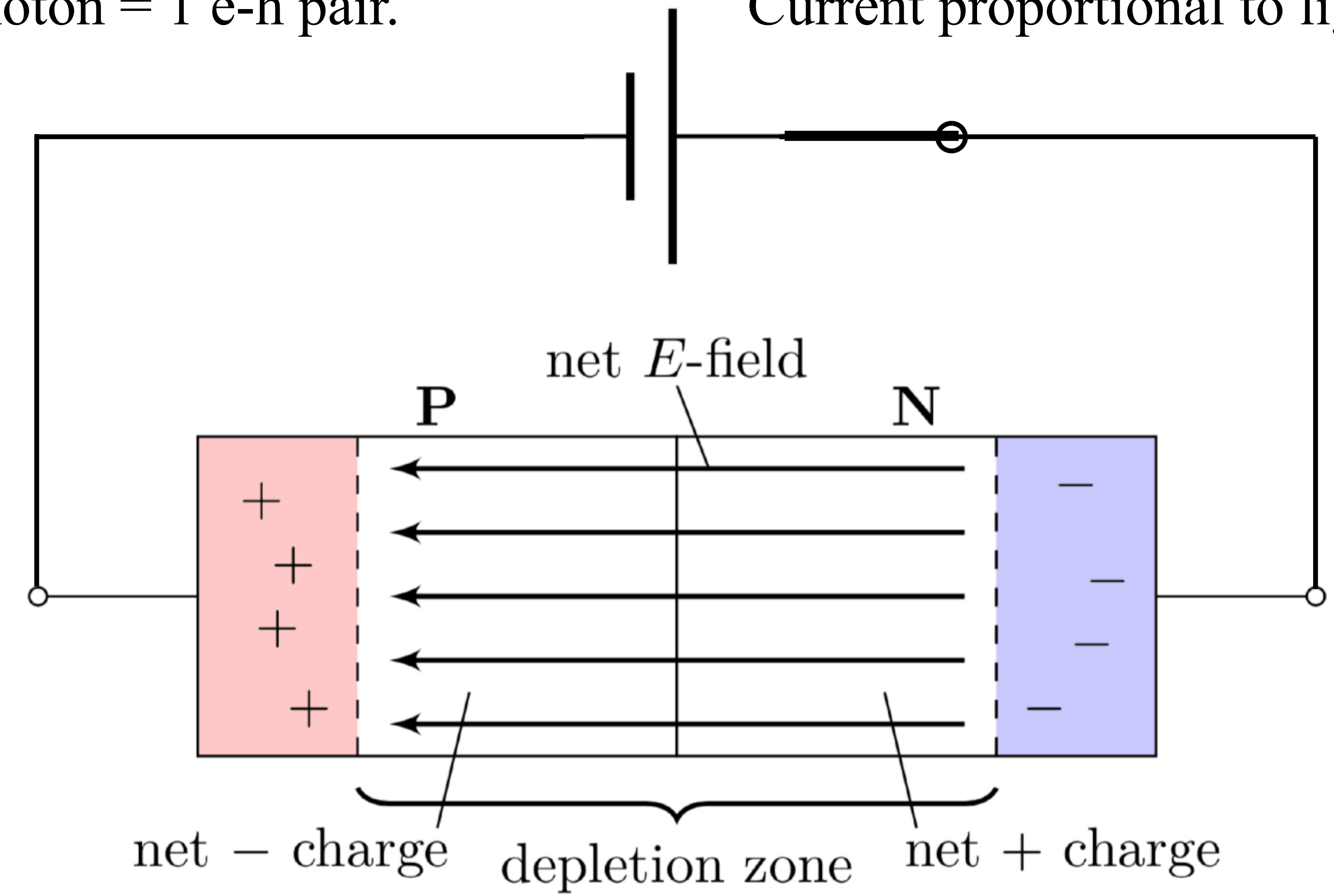
A diode is made with a p-n junction

If we go back to the reversed bias setup, we should get no current, so “off”.

But if a photon is absorbed in the depletion region, it can “ionize” an electron-hole pair. They are then free to move apart in the field and cause a (small) current. The photon just needs to have an energy E = hc/λ high enough to ionize.

If so, 1 photon = 1 e-h pair.

Current proportional to light intensity.



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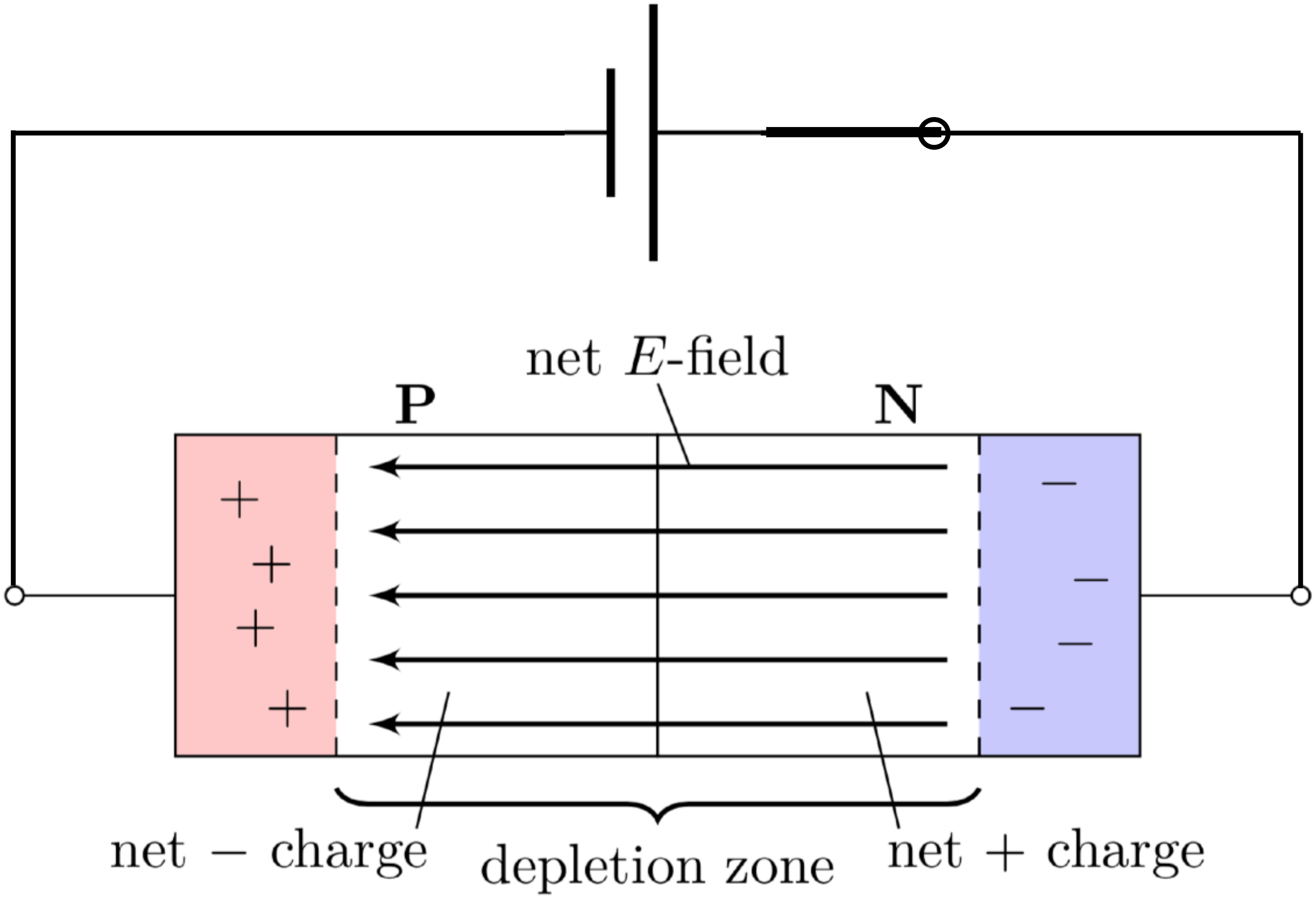
But the "ionization energy" of the crystal (better called the band-gap) is only about 1 eV, so even IR photons can generate e-h pairs. We will see "dark counts".

Alternatively thermal fluctuations in the crystal itself will generated e-h pairs.

This causes a "dark current".



Diode IV curve

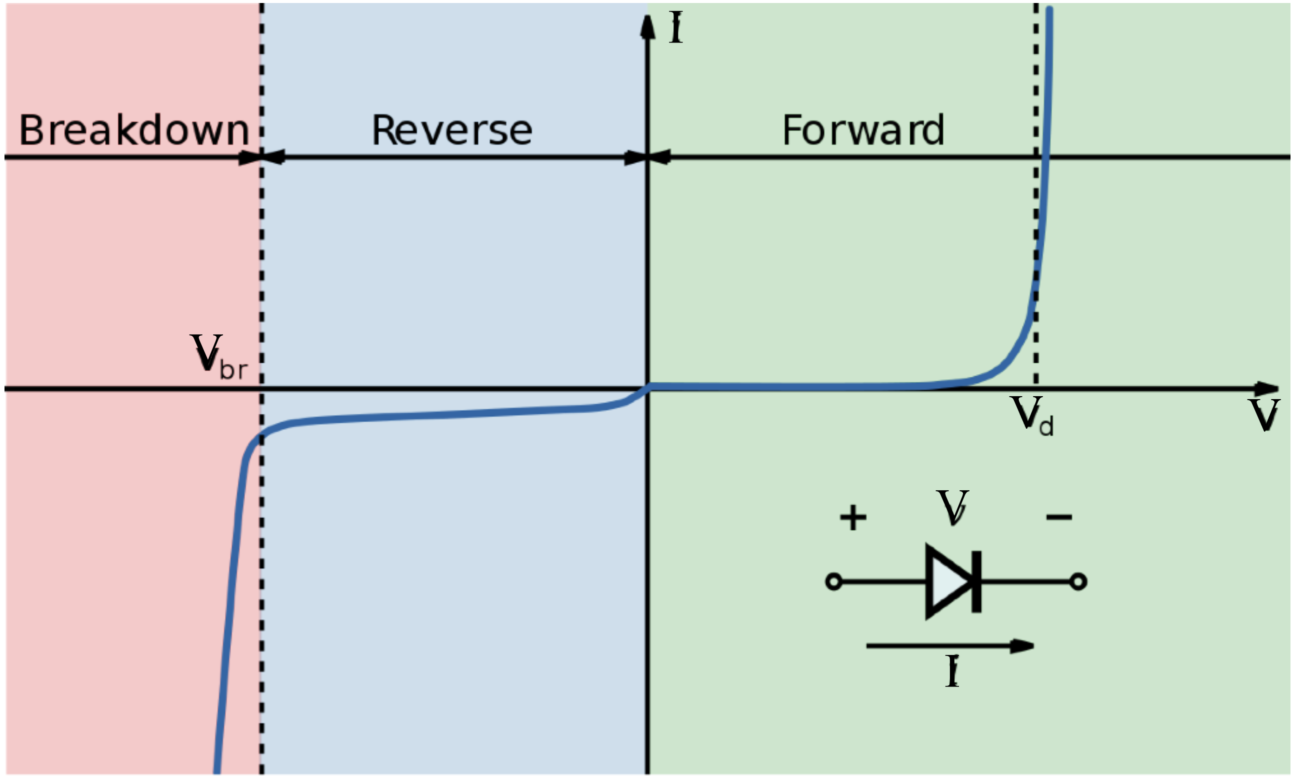
This behavior is characterized in the IV curve.

Forward voltage to overcome depletion region.

Large current when forward biased beyond intrinsic depletion voltage.

Dark current when reverse biased.

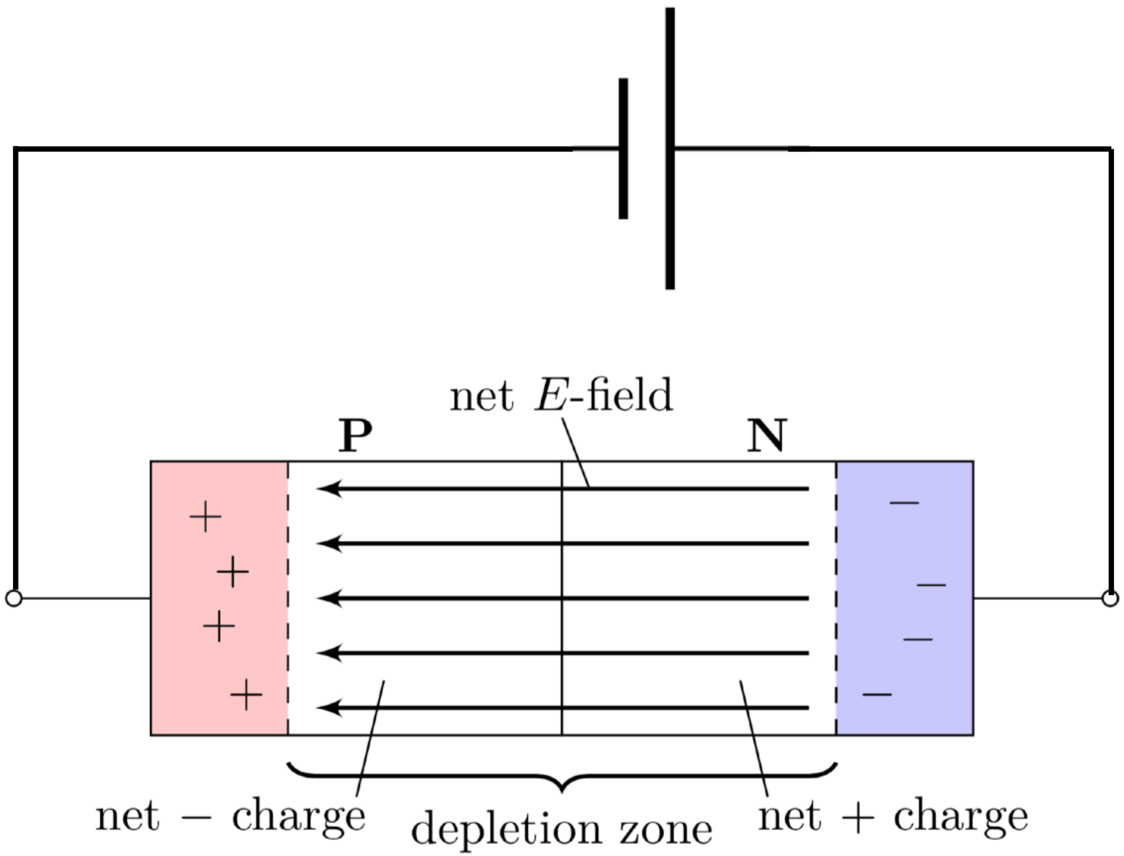
Then breakdown…

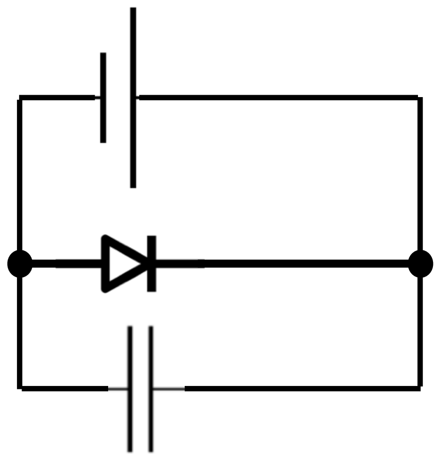


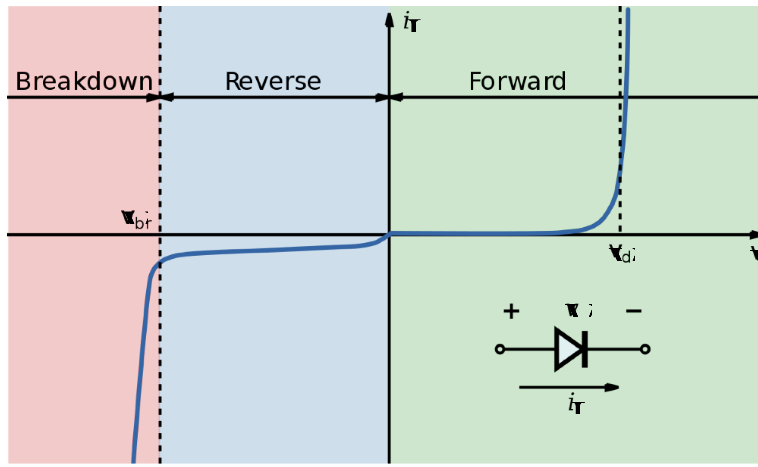
Reverse breakdown

A large enough reverse voltage makes it go into breakdown, where any e-h pair (thermally or optically generated) is accelerated enough in the field to cause secondary "ionization" and hence an avalanche.

At high enough reverse voltage, this avalanche just shorts across the diode.







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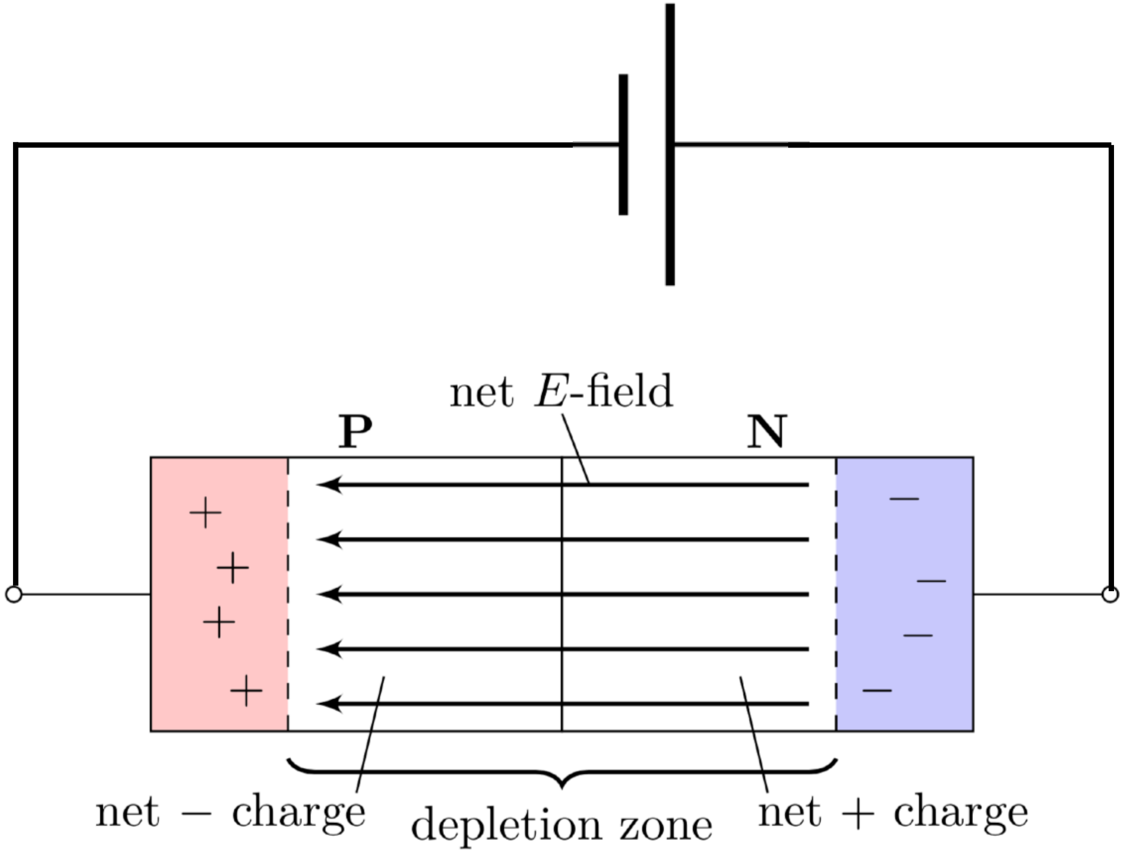
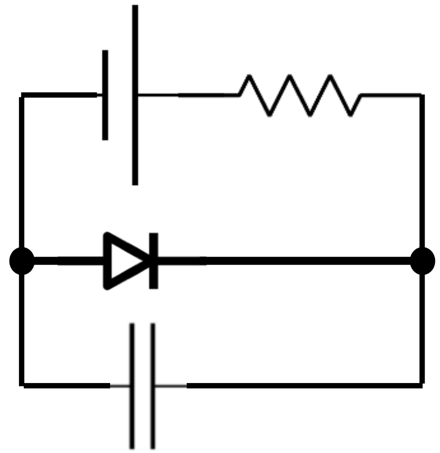
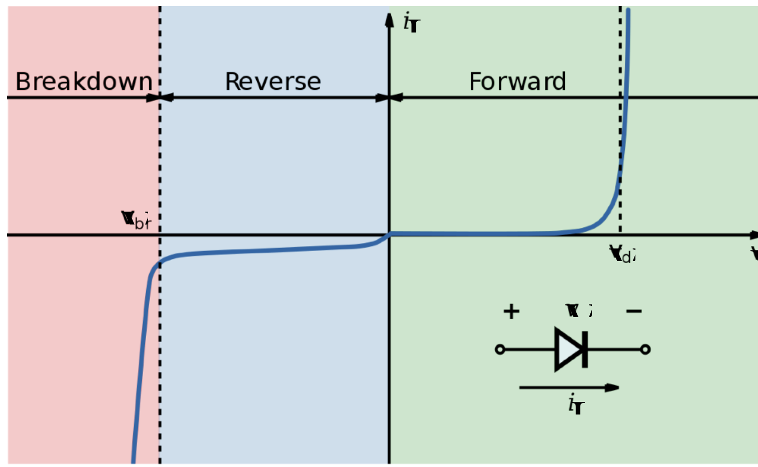
Quench with a resistor…







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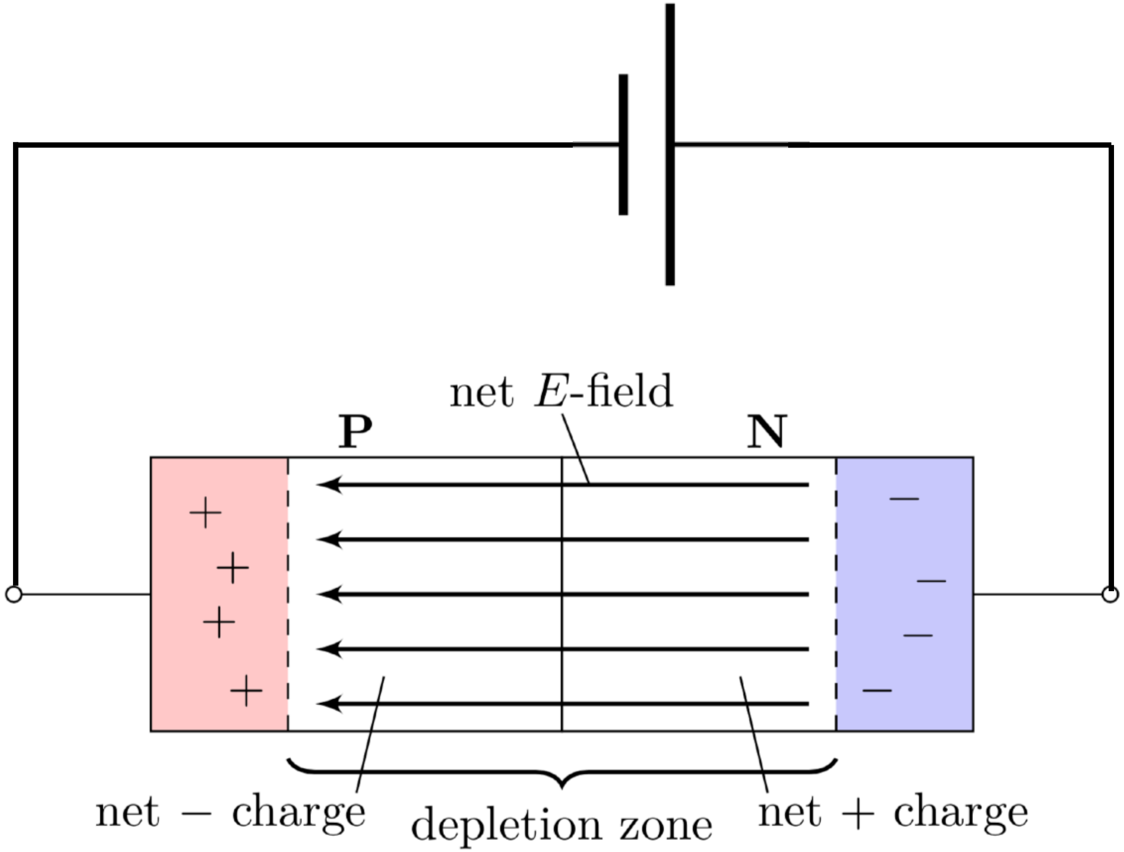
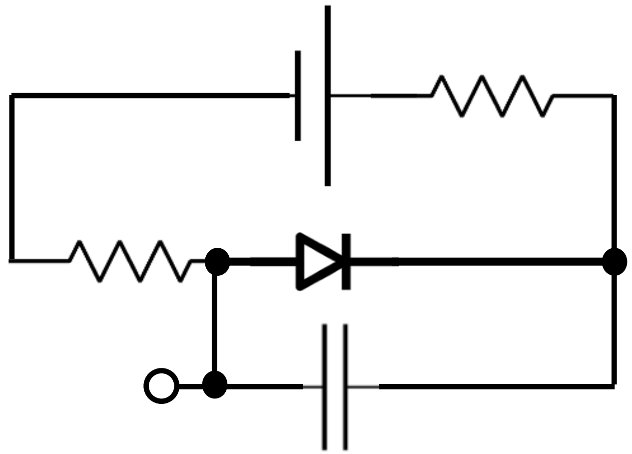
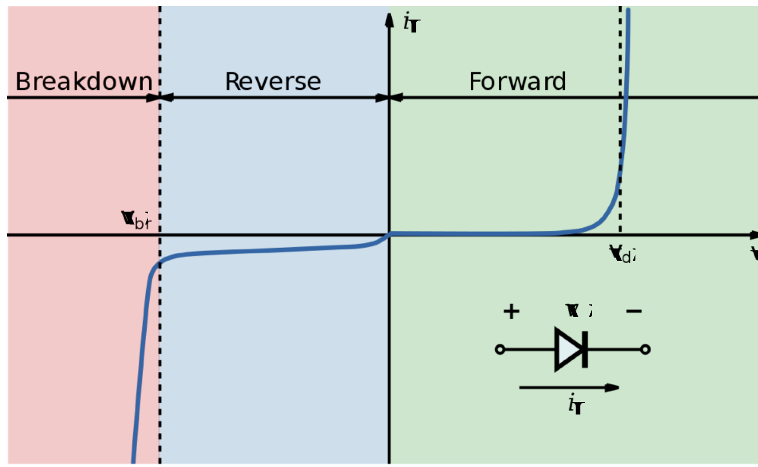
Quench with a resistor… measure output voltage across another resistor.



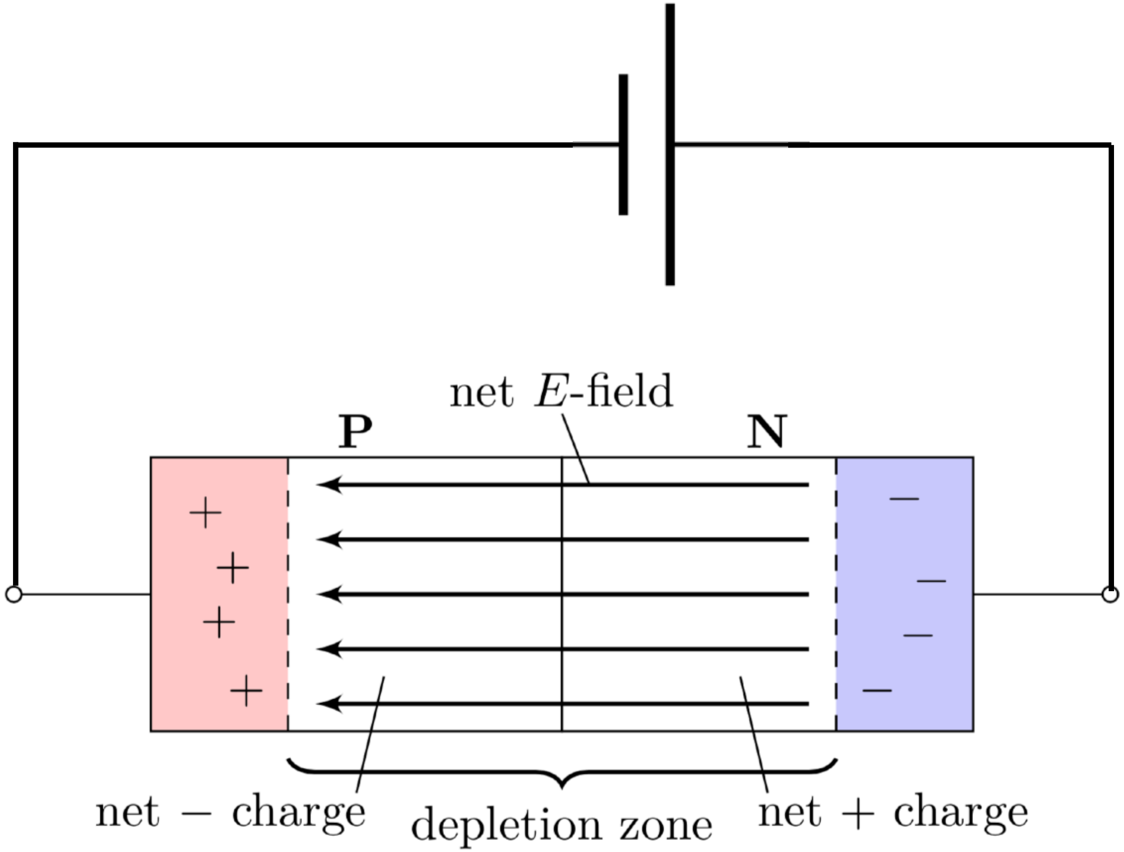


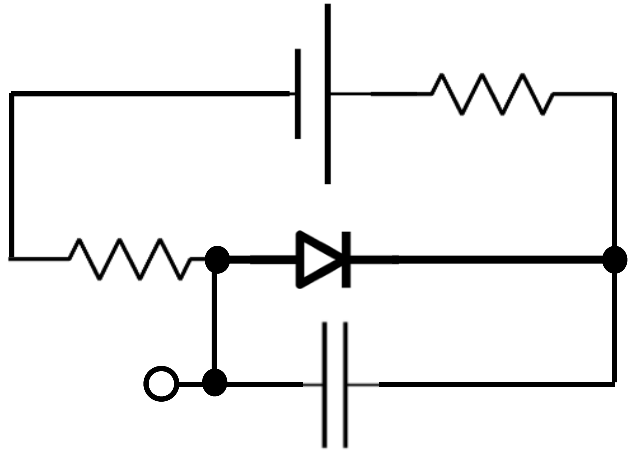


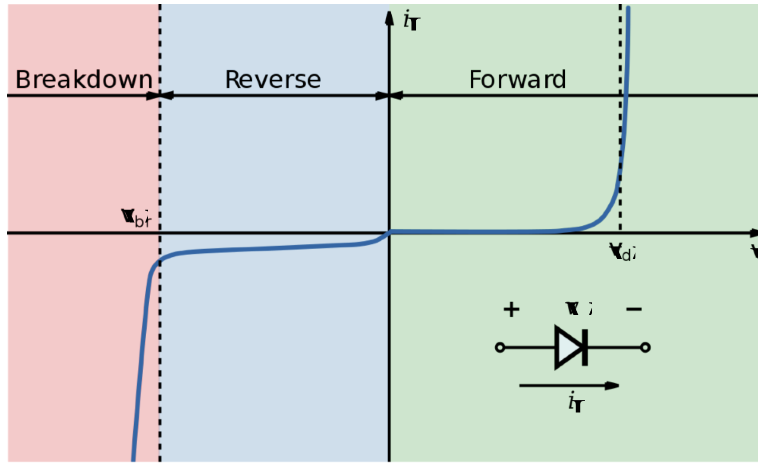
Reverse breakdown

This dumps the full charge from the capacitor through the resistor and makes a voltage pulse that is the same for any photon (as long as C and R are unchanged).

The bias voltage drops, reducing the reverse voltage so the diode recovers. Eventually the power supply reestablishes the bias to regain photon sensitivity.







Counting photons

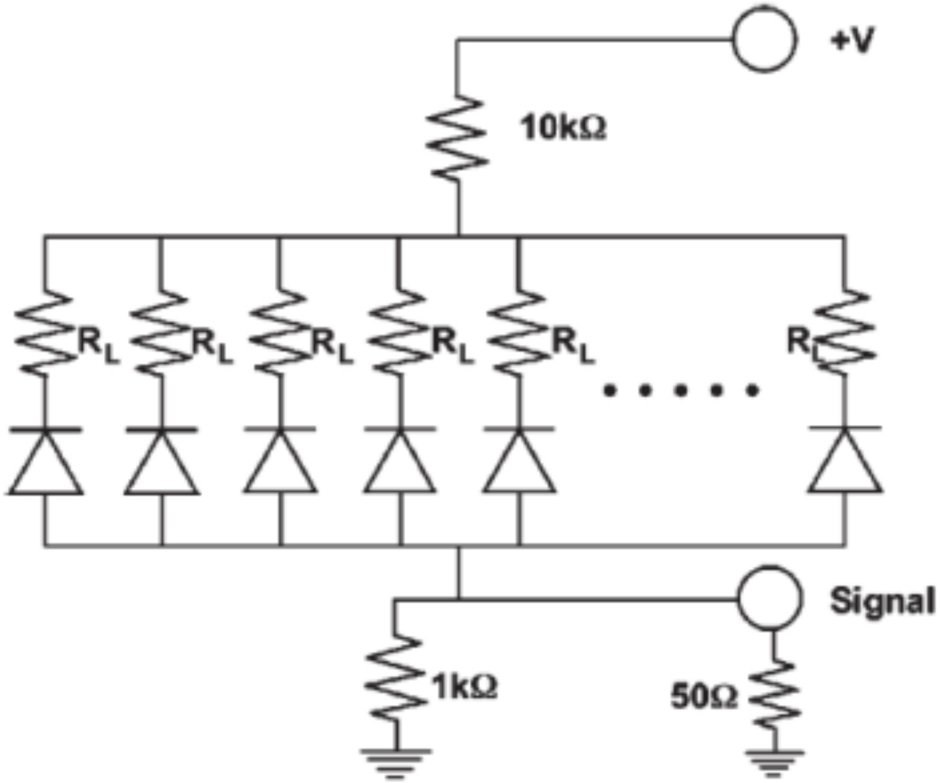
To count more than one photon we need multiple diodes in parallel.

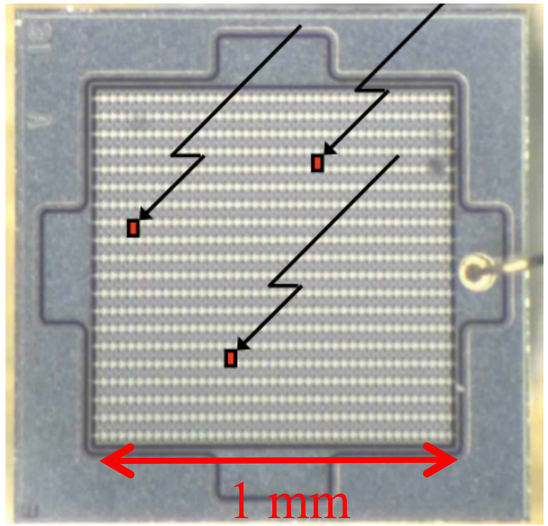
A SiPM is just an array of reverse biased diodes.

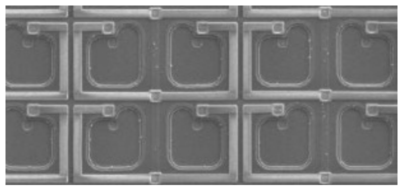
Each one gives a specific pulse if ≥1 photon hits it.

Multiple photons counted as multiple diodes breaking down. (MPPC).

Quench resistors built into each ~40x40 μm pixel.







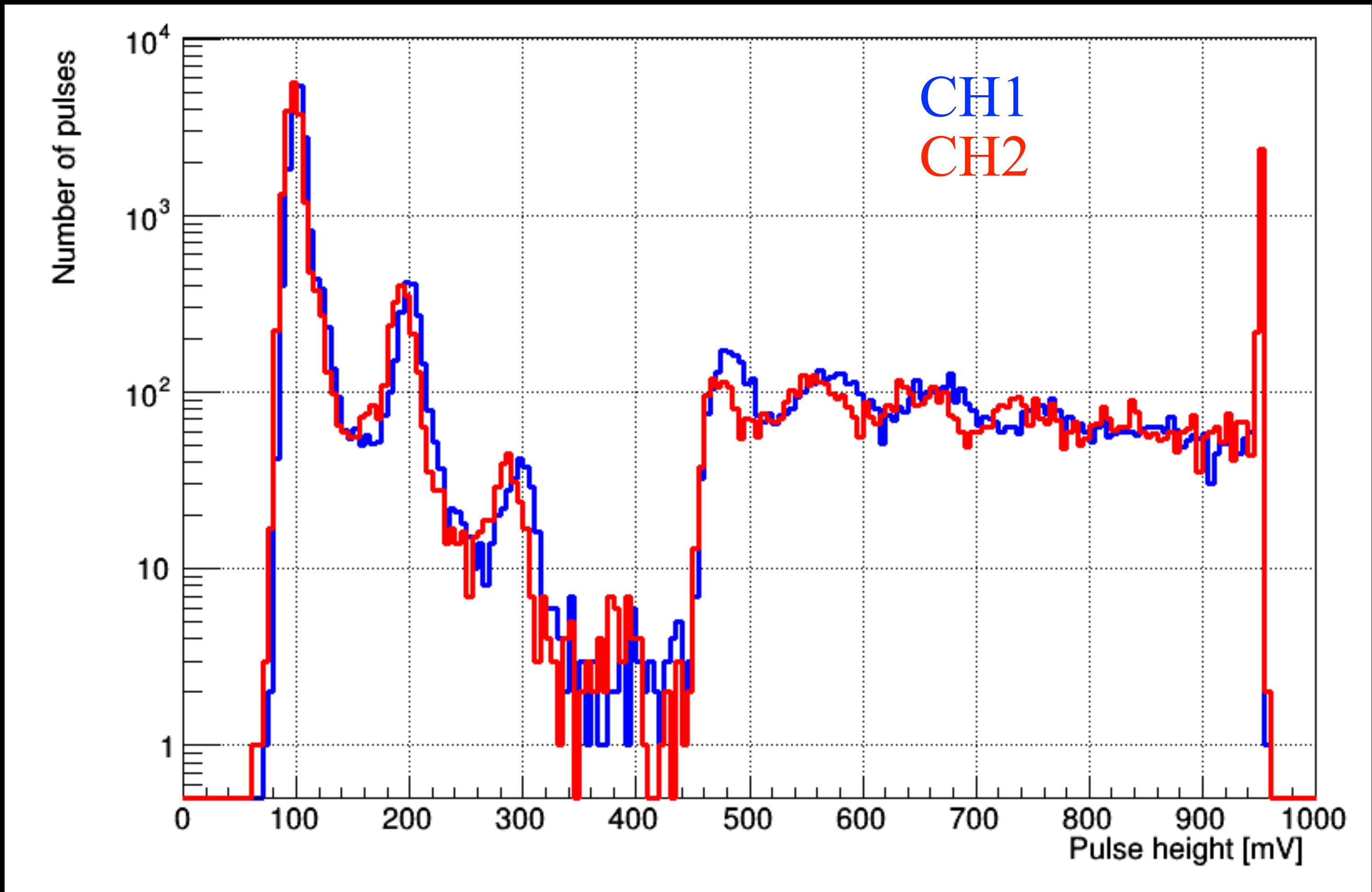
Homework

But first, let's discuss the homework questions:

1). Why the shoulder at 120 mV and the filler in between peaks?

1a). Why isn't the distribution a series of delta functions?

Electronic noise, different capacitance for different pixels, different gain for different devices, different "pedestal offset".



Maybe question 2 is just about 1a? Or at least, that may be part of it.

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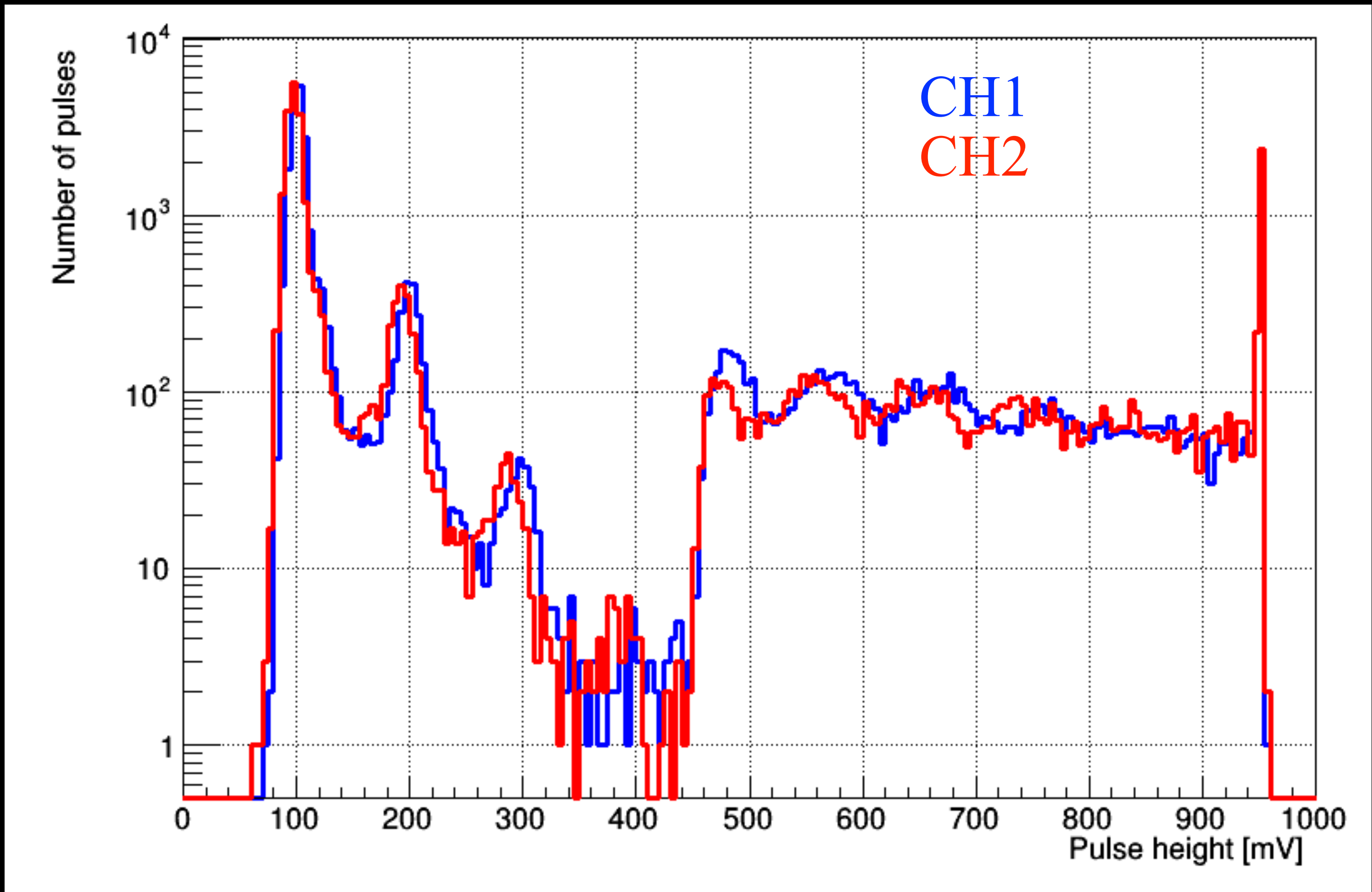
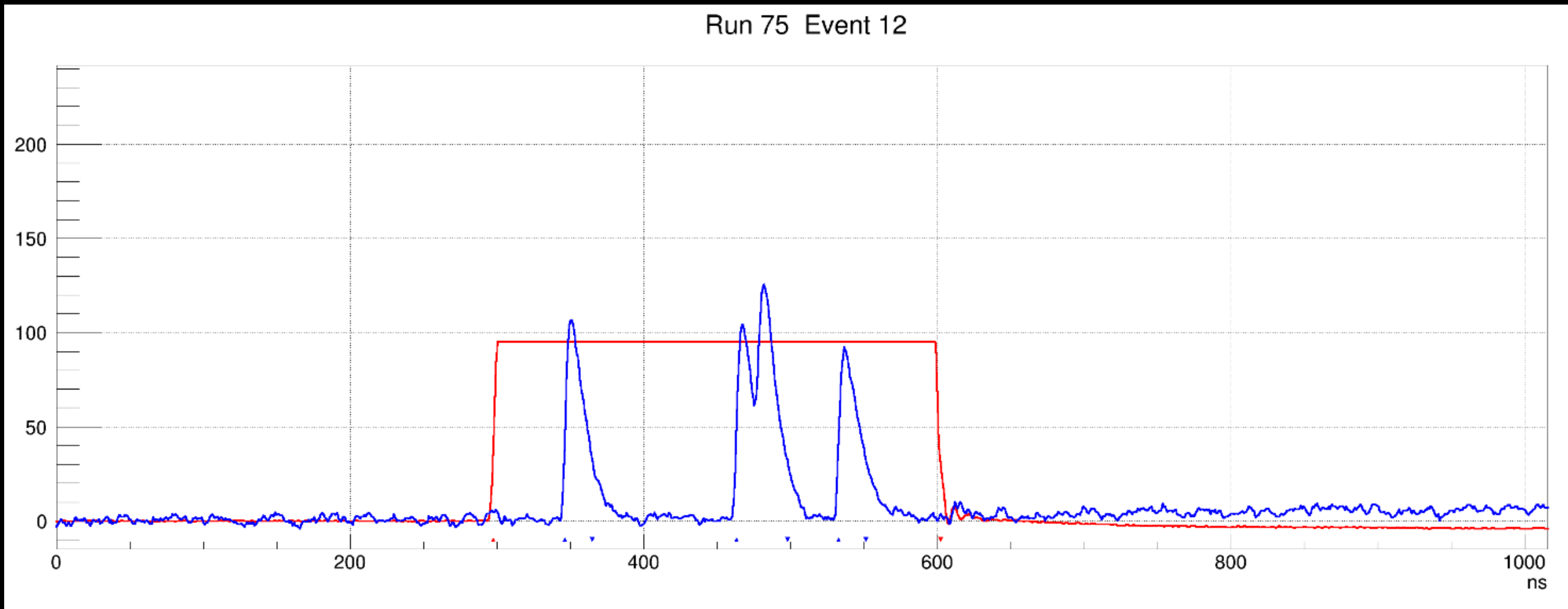
OK, not a series of delta functions, but a series of gaussians.
But, this doesn't explain a shoulder or filler in between.



Homework

So let's look at some waveforms…

Pulse 1 and 3 are consistent with gaussian fluctuations.
More than the noise, so maybe pixel variation.
Pulse 2 is really two pulses, ie 2 photons hitting two different cells causing two different capacitor dumps.



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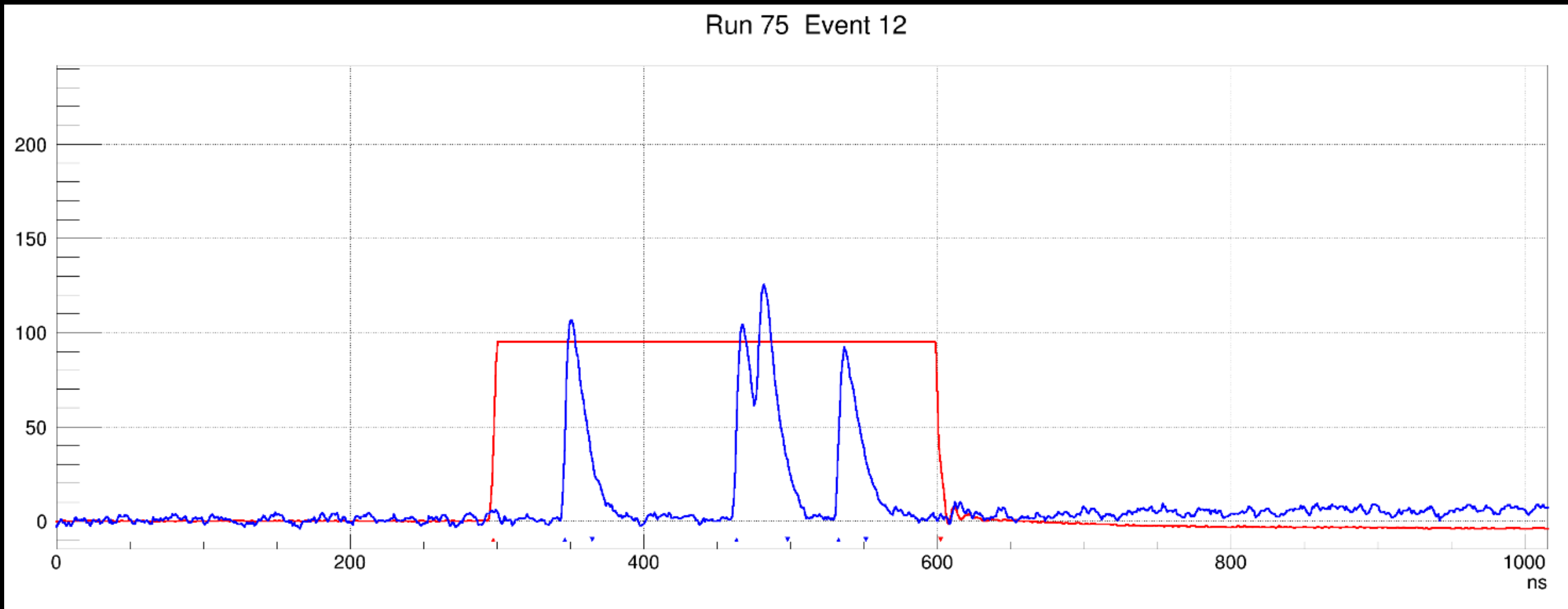
If they were exactly coincident they would double the pulse height, if not they will have a max height somewhere between 100 and 200 mV.



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The filler is random overlap of two photons, but not exactly coincident.

$\Rightarrow$It should be larger in bright times and smaller in dark times.

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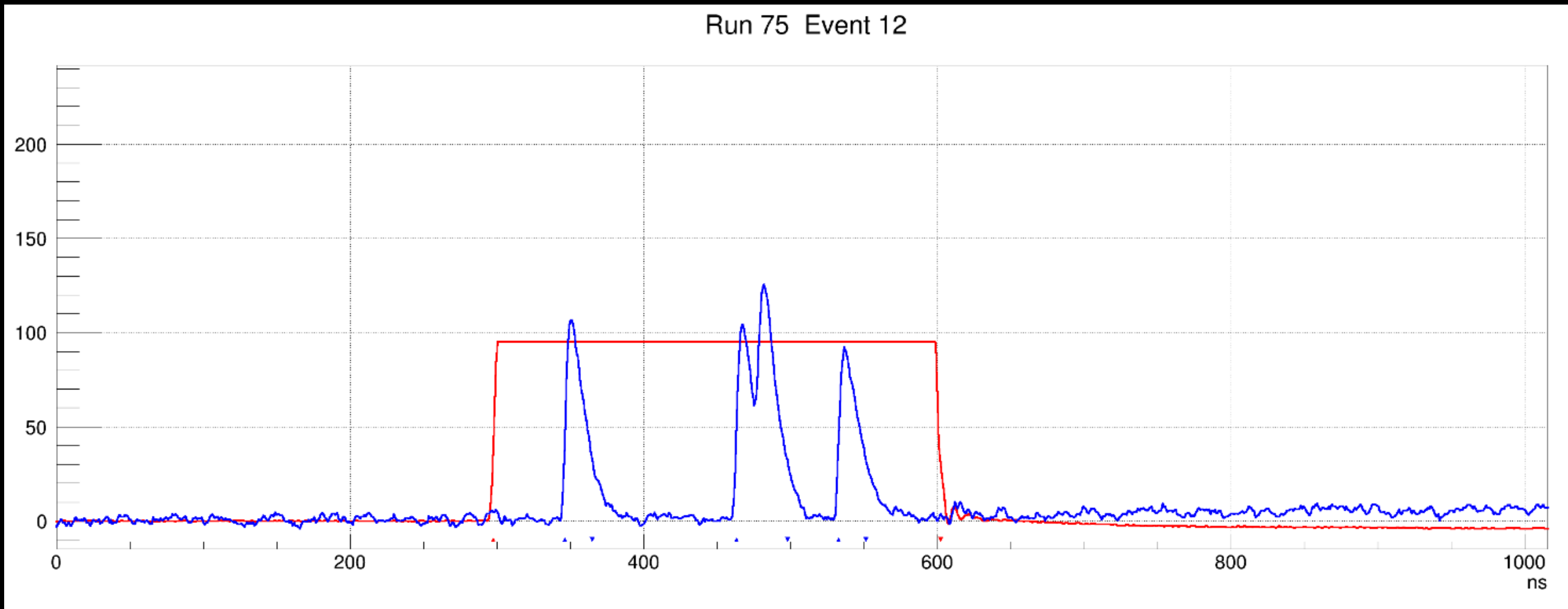
The filler is random overlap of two photons, but not exactly coincident.
⇒It should be larger in bright times and smaller in dark times.

The shoulder is when they are just far enough apart in time to be resolved as a peak on a peak.



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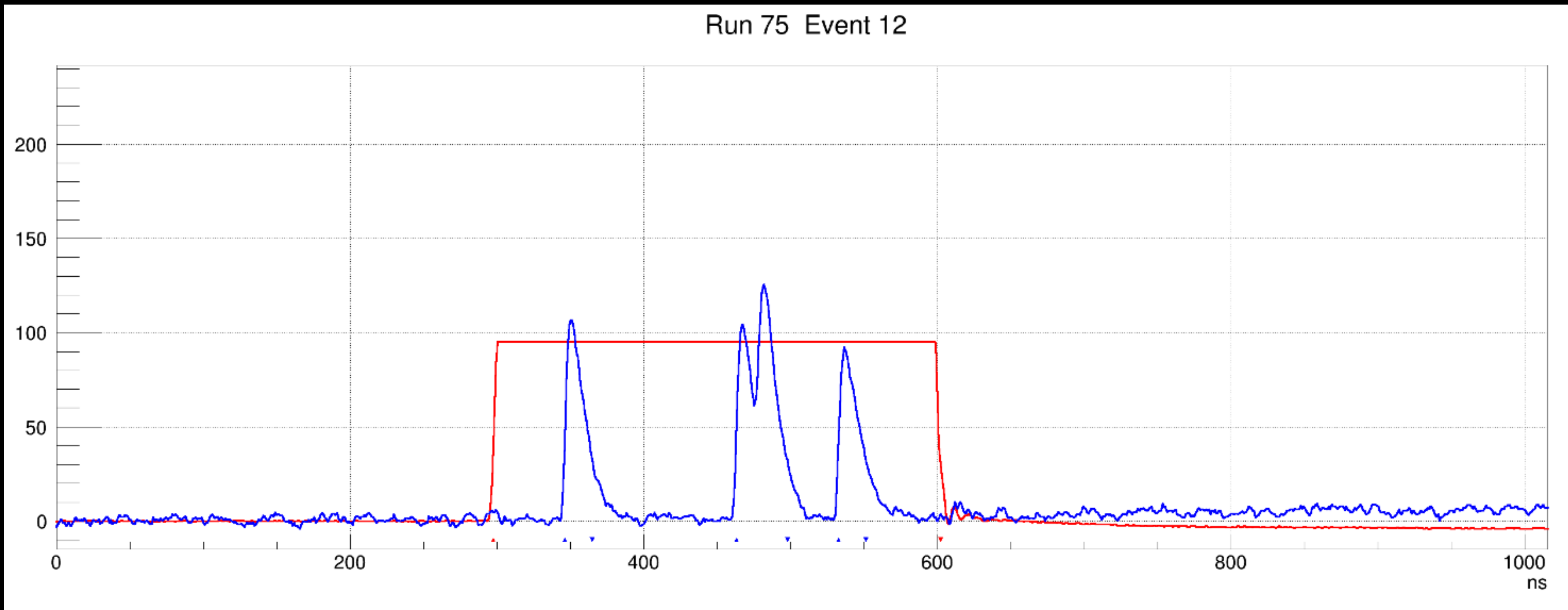

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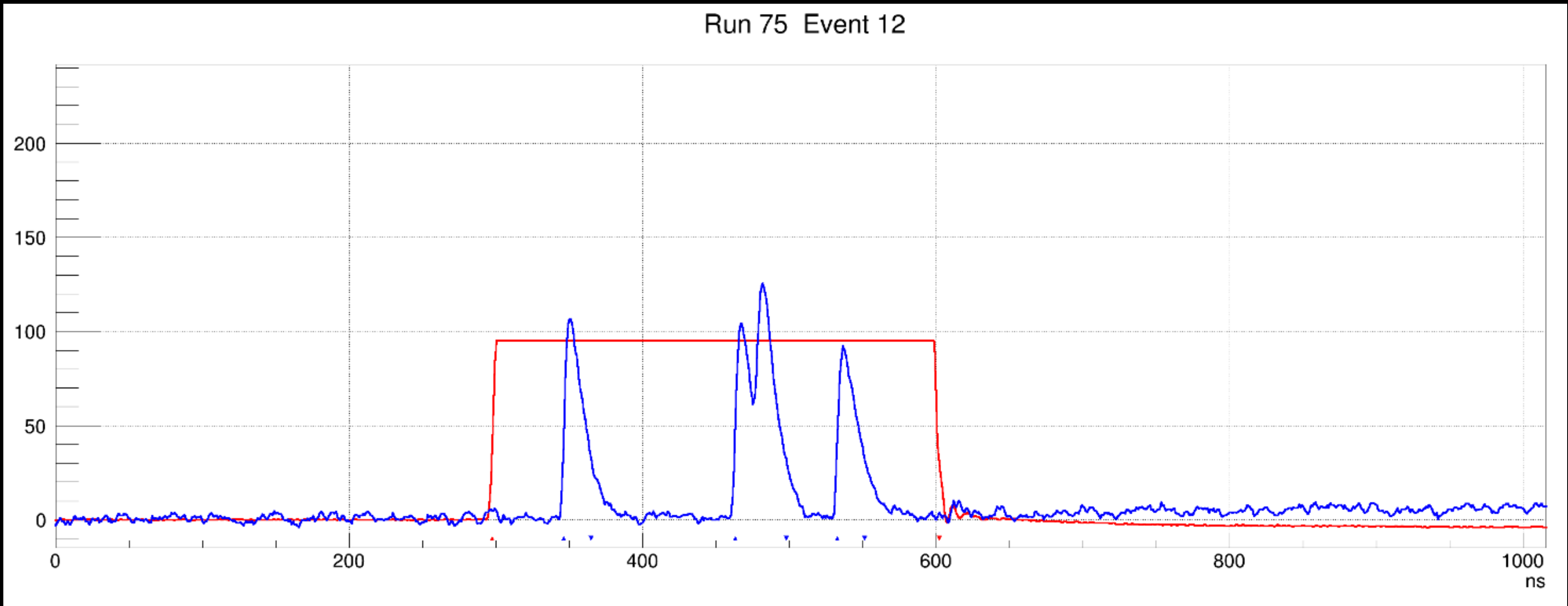

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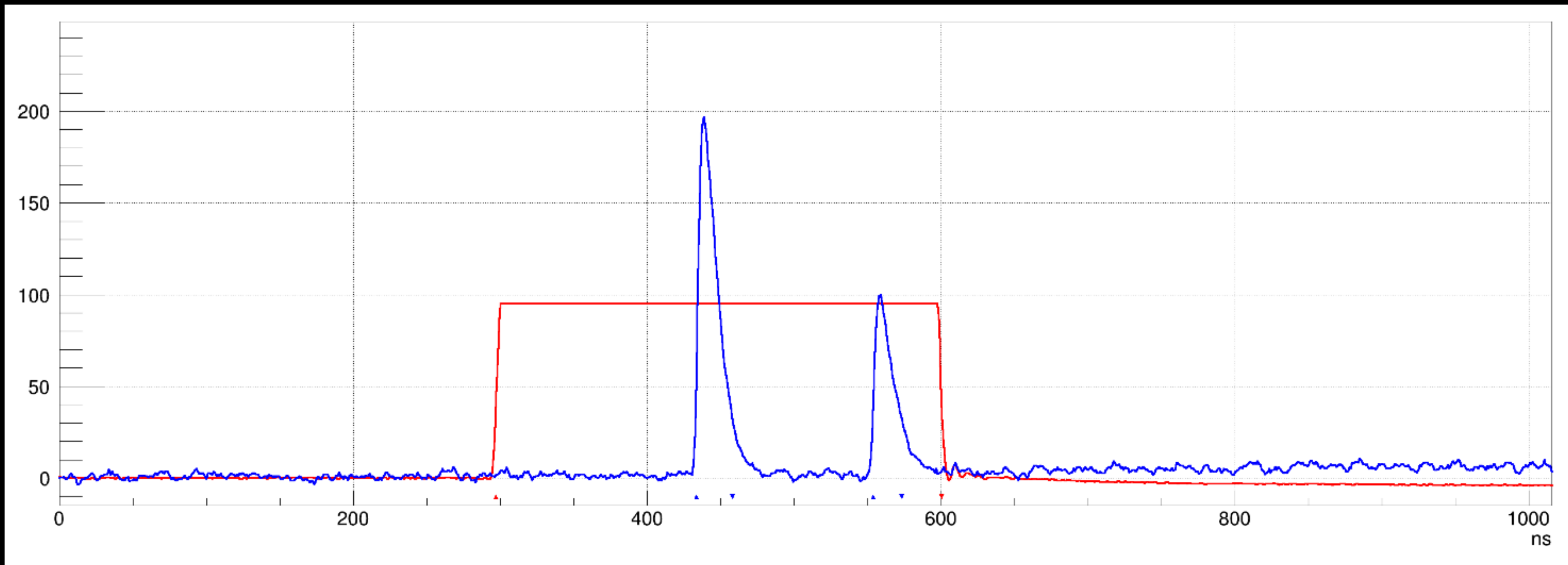
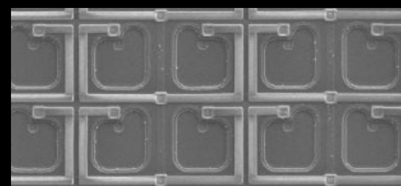
But, then we do we get 2 photon peaks in the "dark times" when the thermal excitations are very rare? The odds of two thermal excitations exactly overlapping is too small!



Ah, but the diode becomes an LED during breakdown
And illuminates the neighboring cells → "cross-talk".



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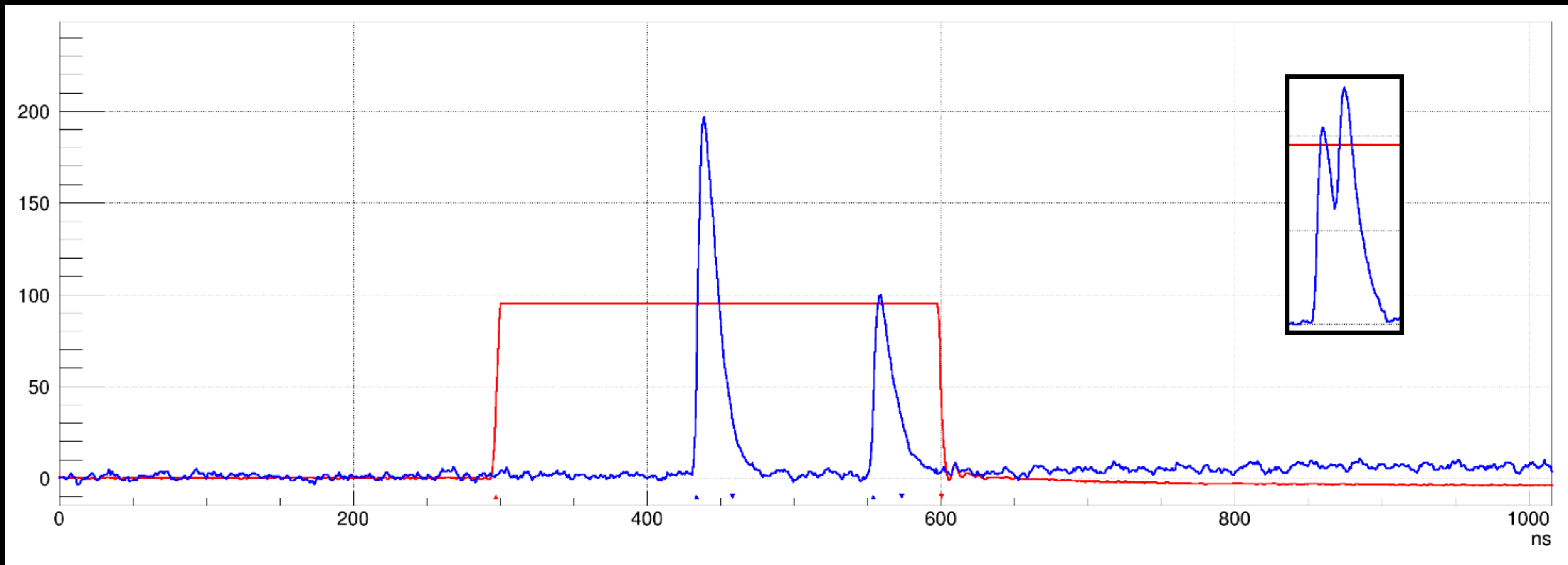
If there is any delay in the cross-talk process, it will make the second photon pulse be slightly later and contribute to the falling edge of the first pulse so they add to less than twice the single photon pulse.



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How to test the new hypothesis for (2)?

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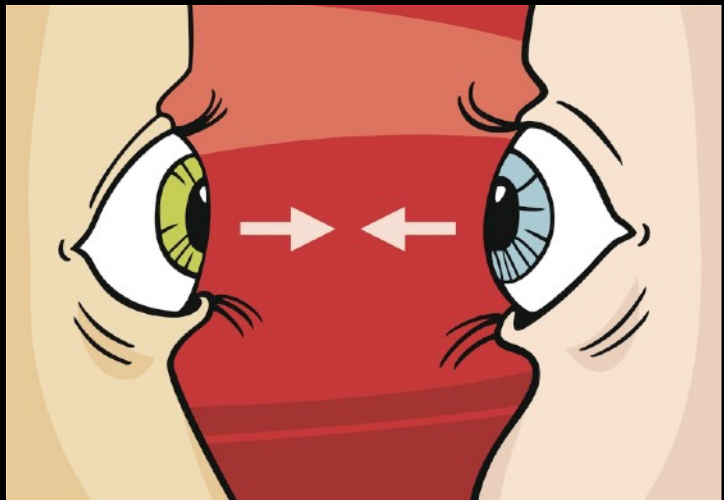
Look for those cross-talk photons with another photo detector.



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"An hour in the library can save an afternoon in the lab."

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The explanation for (1) is strongly supported by the waveform views.
How to test the new hypothesis for (2)?

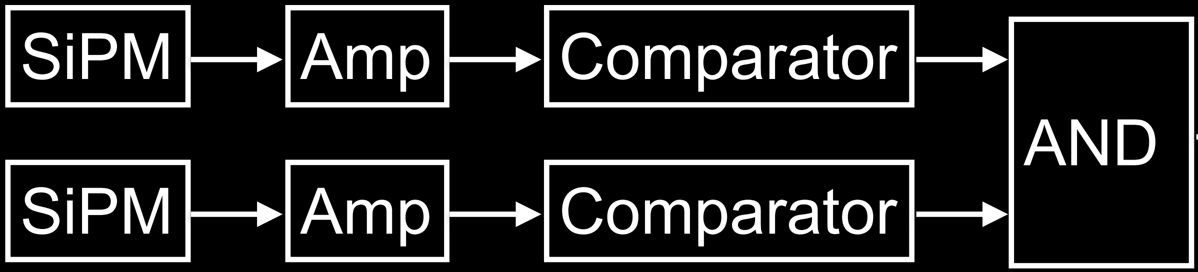
Look for those cross-talk photons with another photo detector.

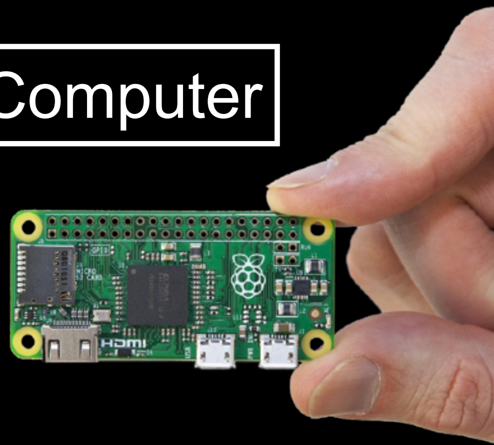
Or we could go read the manual for the device, where it will explain all of this and show us calibration measurements for all of it.

"An hour in the library can save an afternoon in the lab."

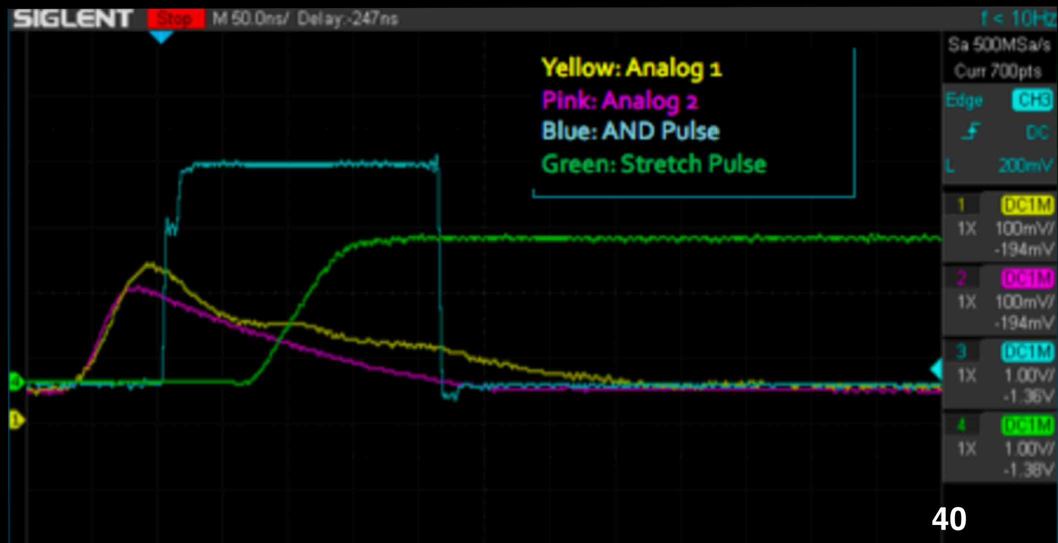
But I prefer the lab!

Review: Electronics for the detector



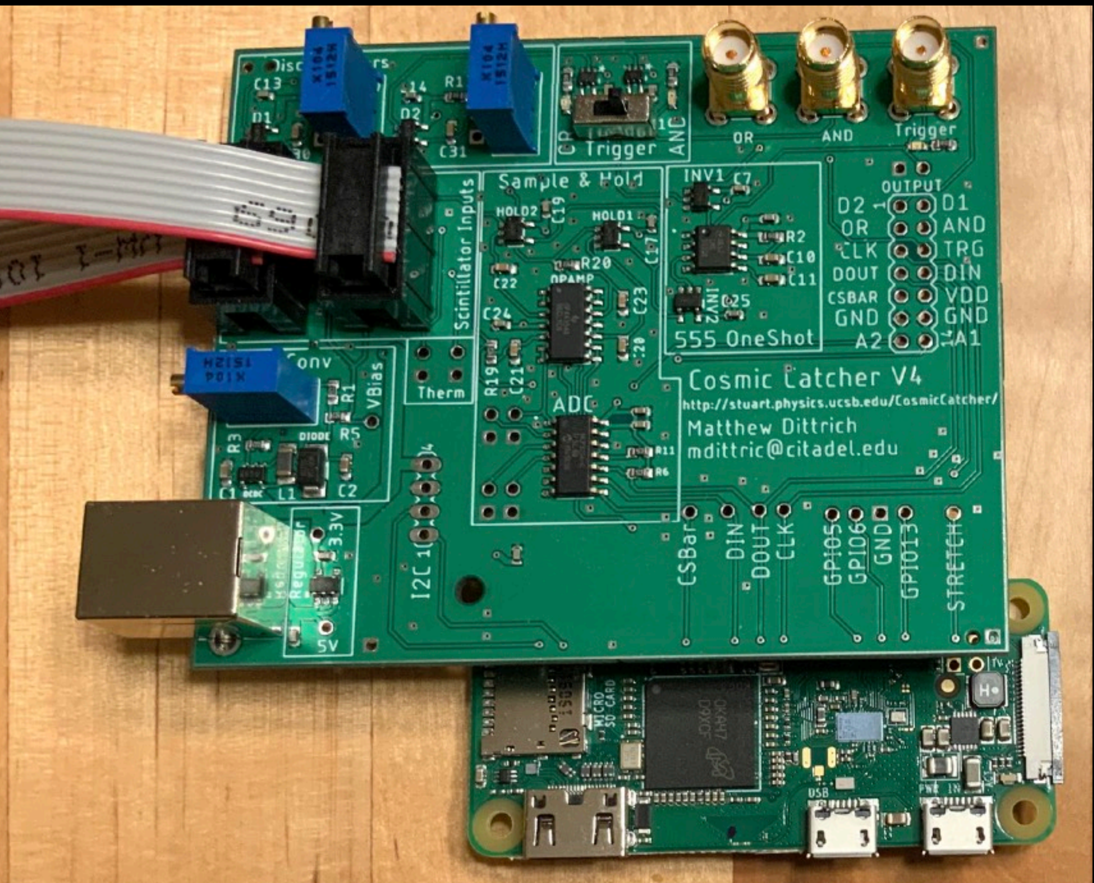


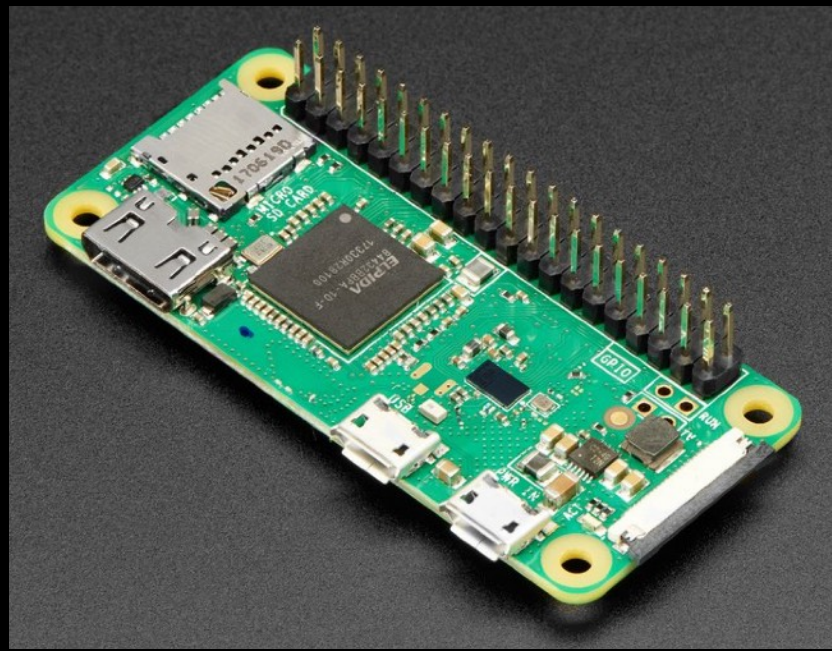
Use the RPi to read “Stretch” as an input digital signal and record the time when it is seen to go high.



Pi overview

Embedded linux with GPIO pins





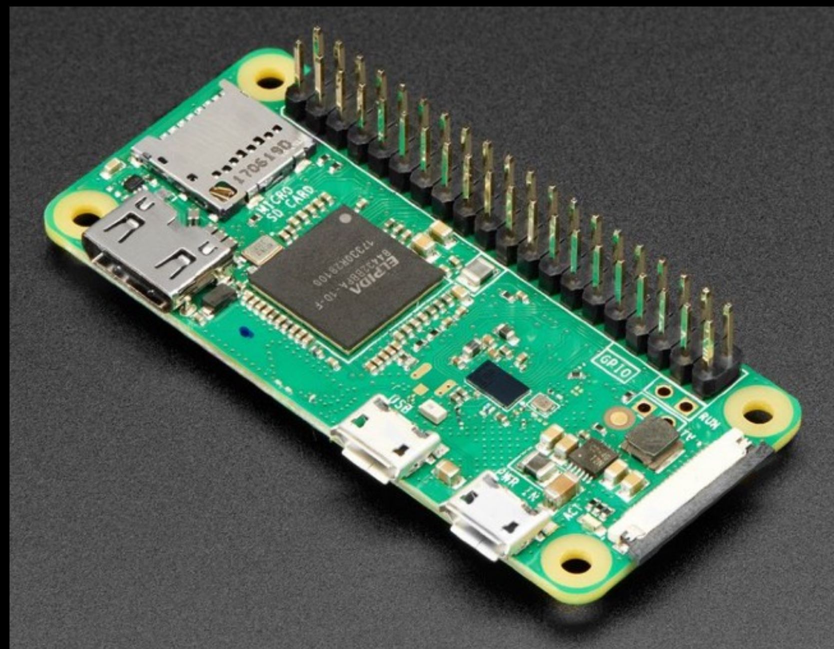
Pi overview

Embedded linux with GPIO pins

Pi Zero W is smaller but fussy,
with WiFi Micro-USB and Mini-HDMI.
We will try to run it “headless”.

But first, lets run it,
see what it looks like,
and learn a bit of Unix

Open terminal
ssh pi@phys150default.local
default150password



Pi overview

Embedded linux with GPIO pins

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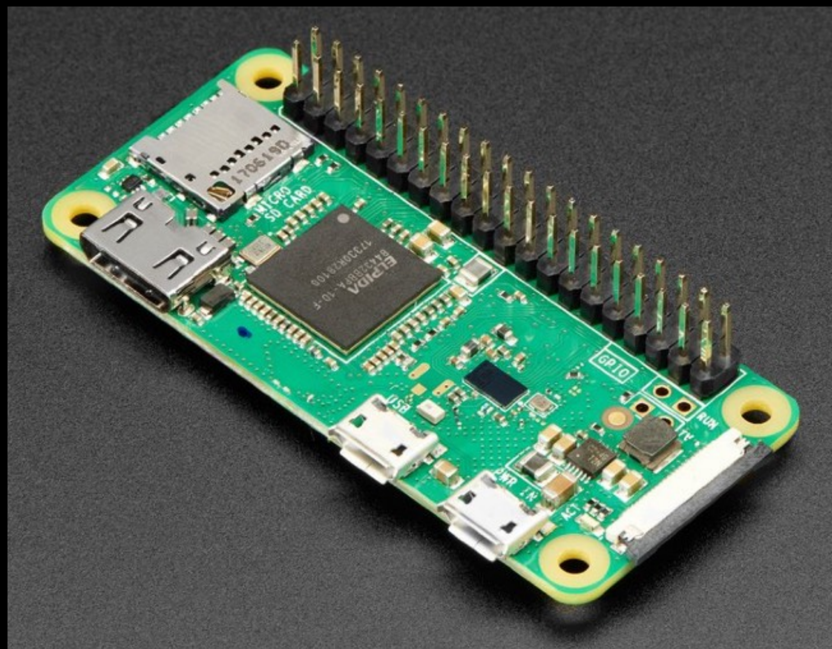


Demo login…
Ramble about rsa keys…

Pi GPIO pins

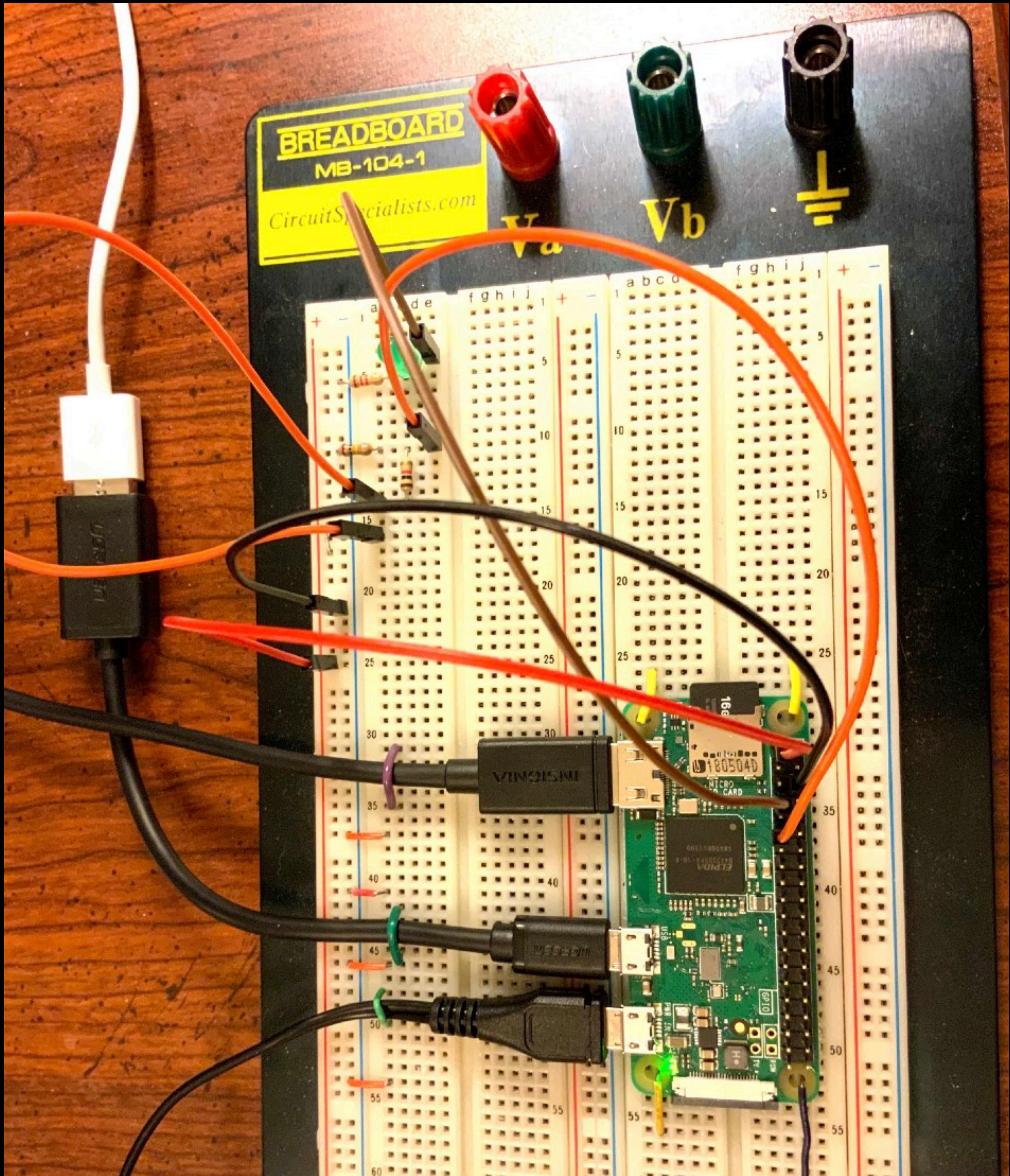
The GPIO pins can be used for either INPUT or OUTPUT
But you have to specify it.

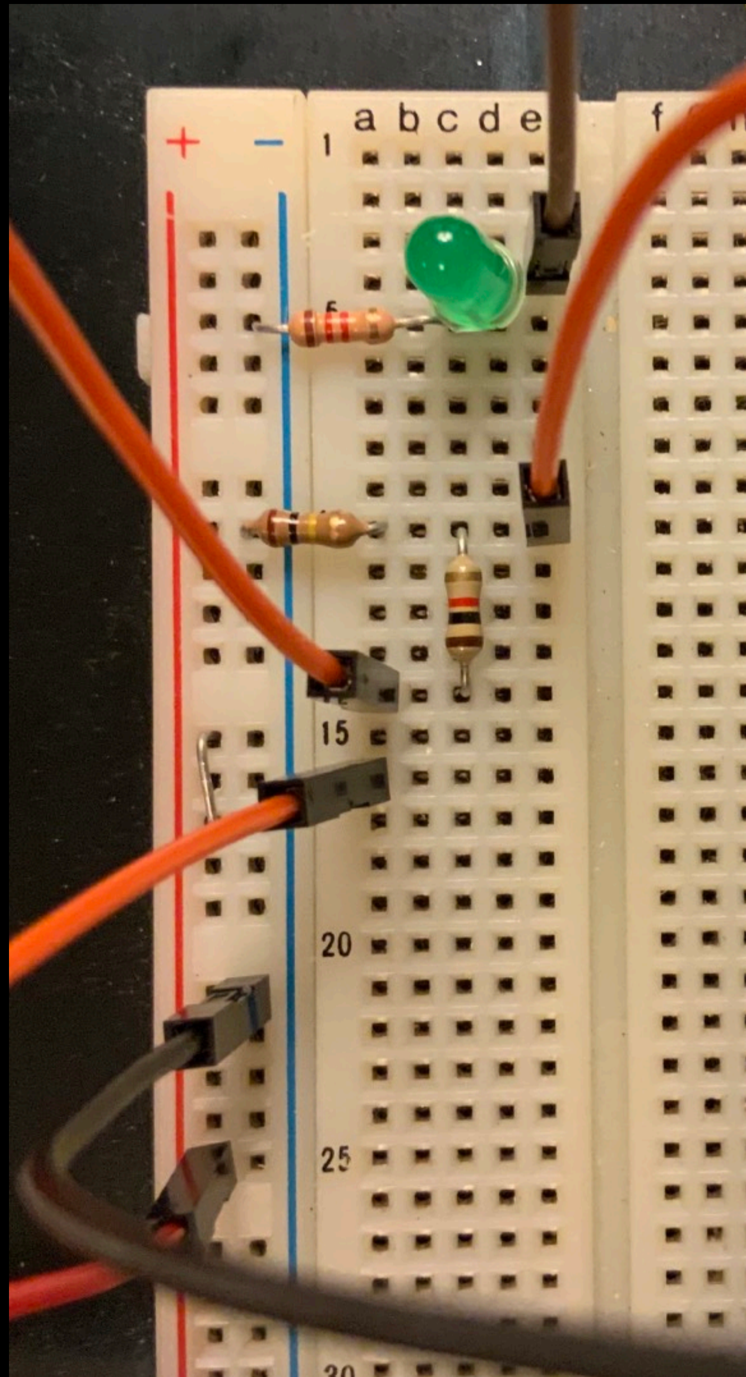
Python example flashing LED and reading input.

Python example reading input with time stamp.

Source code in ~/150/

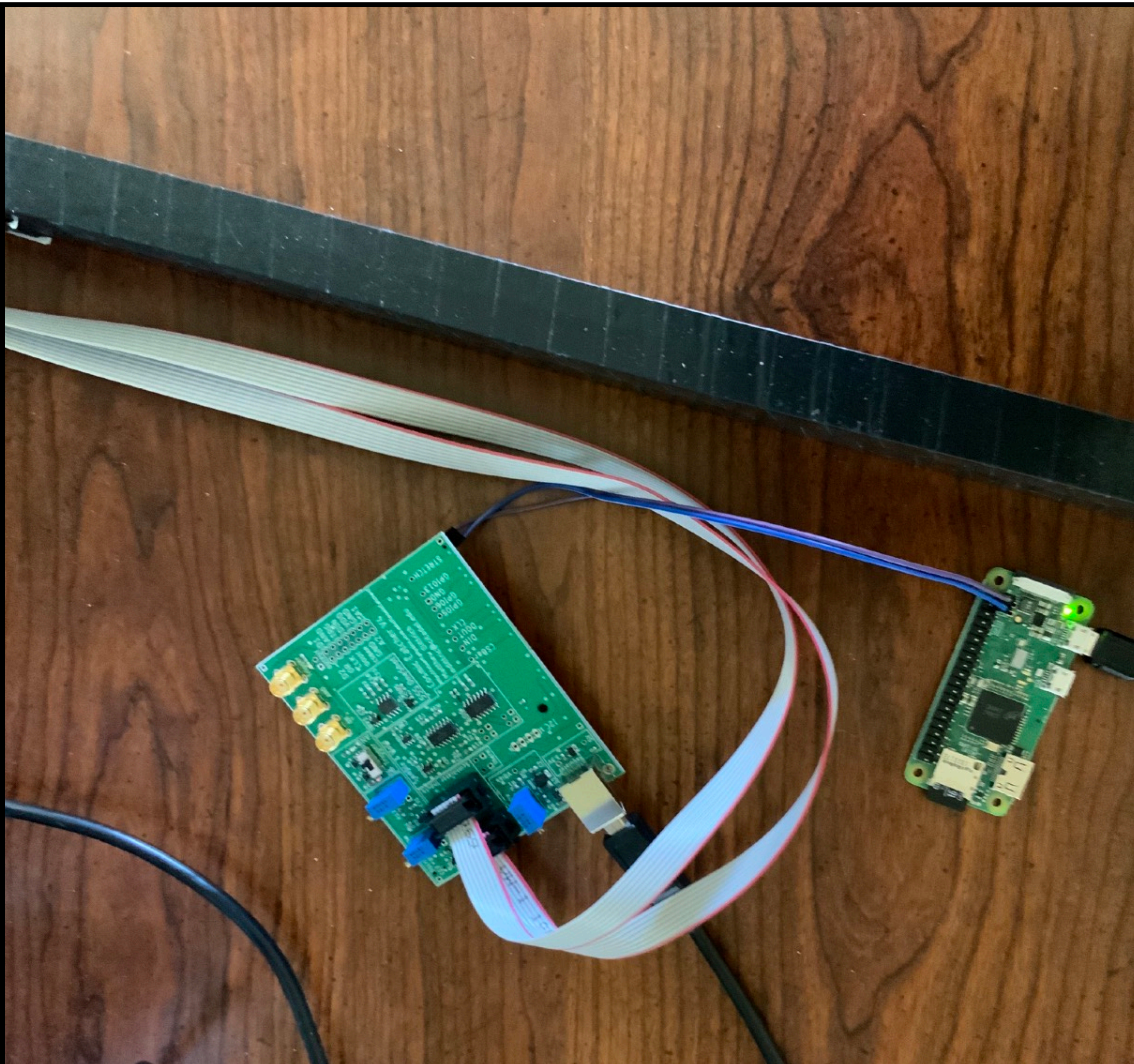
Pi GPIO pins





Pi GPIO pins


Pi Model B/B+
3V3 Power
1
2
5V Power
GPIO2 SDA1 I2C
3
4
5V Power
GPIO3 SCL1 I2C
5
6
Ground
GPIO4
7
8
GPIO14 UART0_TXD
Ground
9
10
GPIO15 UART0_RXD
GPIO17
11
12
GPIO18 PCM_CLK
GPIO27
13
14
Ground
GPIO22
15
16
GPIO23
3V3 Power
17
18
GPIO24
GPIO10 SPI0_MOSI
19
20
Ground
GPIO9 SPI0_MISO
21
22
GPIO25
GPIO11 SPI0_SCLK
23
24
GPIO8 SPI0_CE0_N
Ground
25
26
GPIO7 SPI0_CE1_N
ID_SD I2C ID EEPROM
27
28
ID_SC I2C ID EEPROM
GPIO5
29
30
Ground
GPIO6
31
32
GPIO12
GPIO13
33
34
Ground
GPIO19
35
36
GPIO16
GPIO26
37
38
GPIO20
Ground
39
40
GPIO21
Pi Model B+



Saving data

We will want to save the data in a format that allows later offline correlation. So, I will define an output file format as a text file with each line corresponding to one measurement or other data point.

DataType PiID Date Values

DataType=1 is for a hit detection. The value is the dead time required to record the entry.
DataType=0 is used for a comment, e.g., change state or start run.
DataType=2 is used for a pulse height measurement.
DataType=3 is used for an altitude measurement.
DataType=4 is used for a title angle measurement. (It has 3 values.)
DataType=5 is used for a temperature measurement.
Other values are reserved for future use.

PiID is the ID# of the pi making the measurement. This will be used for correlation.

Saving data

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DataType PiID Date Values

But, you are free to design your own, just document it.

Lab assignment this week

Use a raspberry pi to read the digital output of a detector (pick it up).
Make some kind of interesting measurement with it, e.g.:

- Is the rate different during the day and night?

Save the data on the pi and then copy it to your laptop using scp or the web server and analyze it offline.