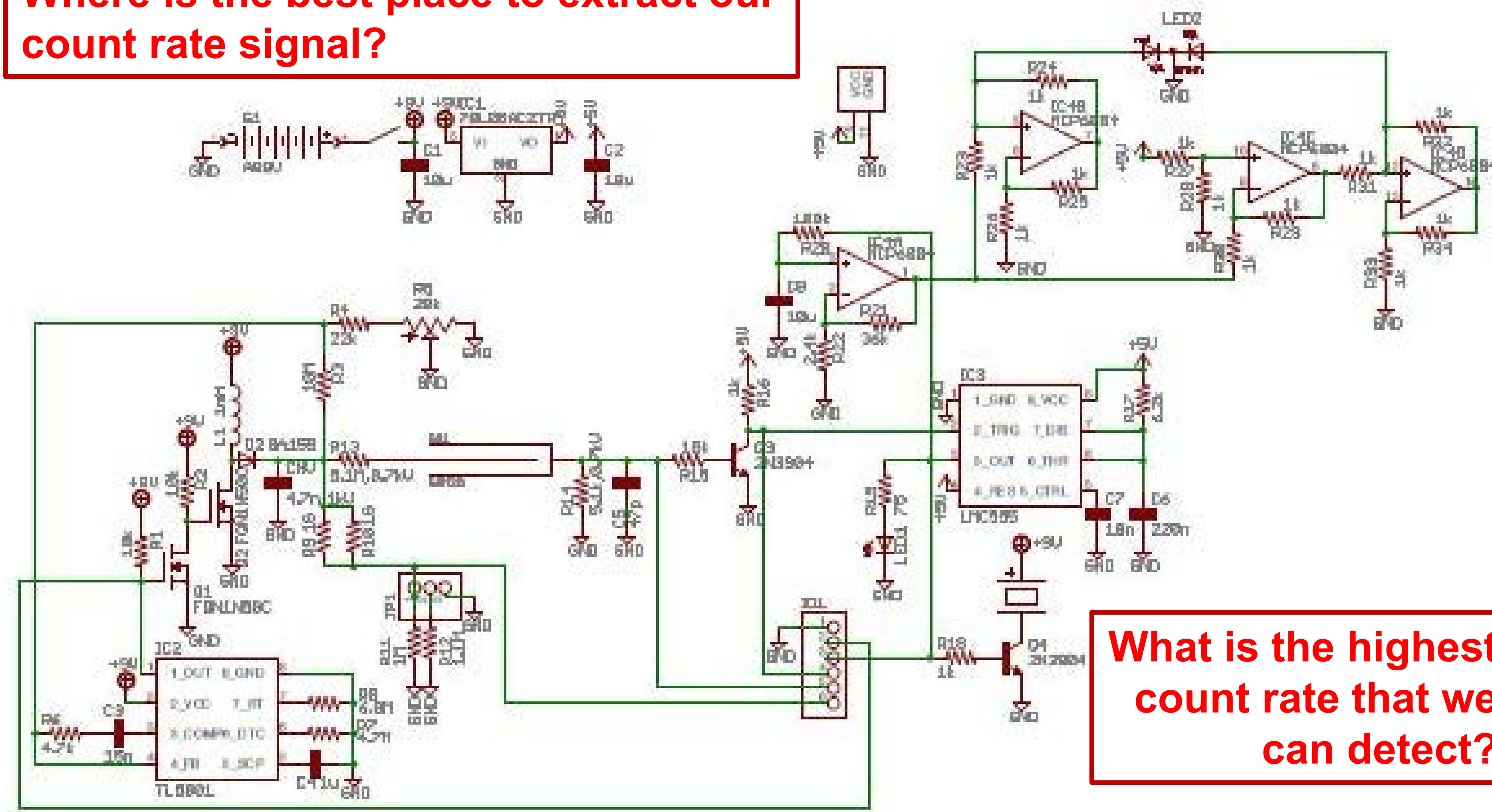
Geiger Tube Theory, Dead Time

22.S902 – DIY Geiger Counters

Prof. Michael Short

Questions to Start

Where is the best place to extract our count rate signal?



What is the highest count rate that we can detect?

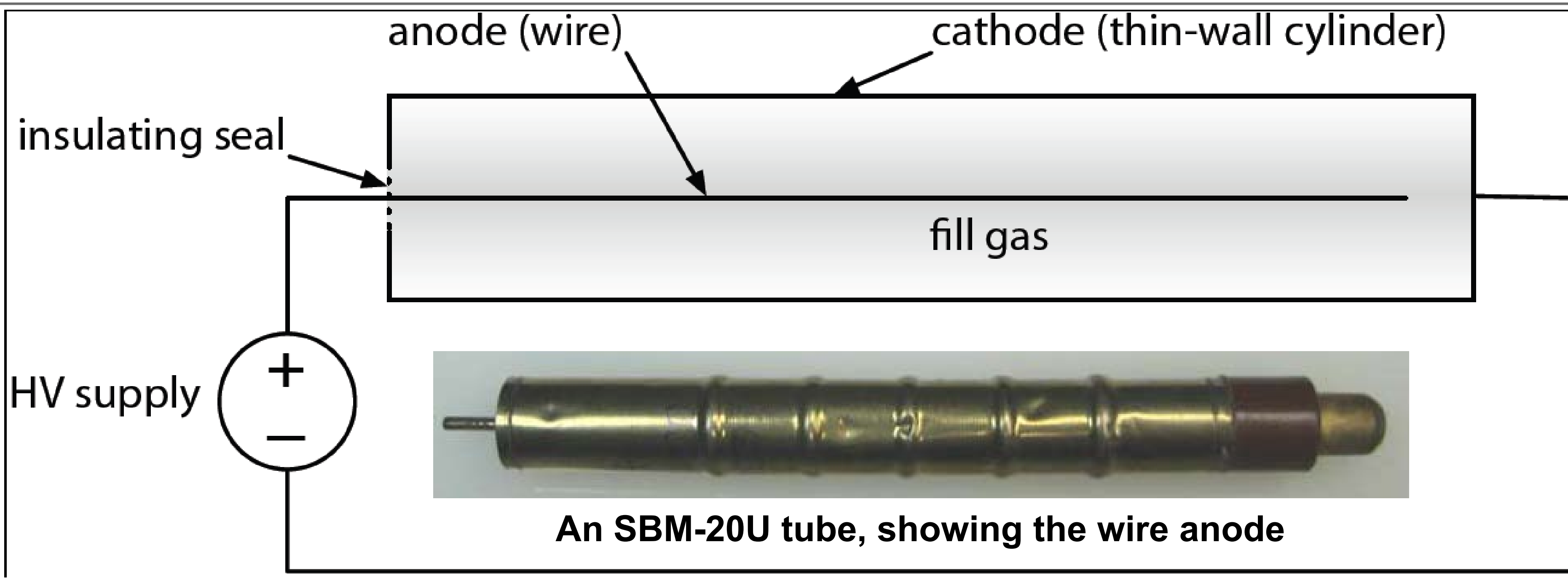
Courtesy of Mark Chilenski. Used with permission.

Motivation

- Understand how ionization chambers, and specifically Geiger tubes, function
- Learn the mechanism of “dead time” in detectors, and how it limits them
- Characterize detectors as paralyzable or not
- Predict how dead time will affect counting output and statistics

Geiger-Müller Tubes

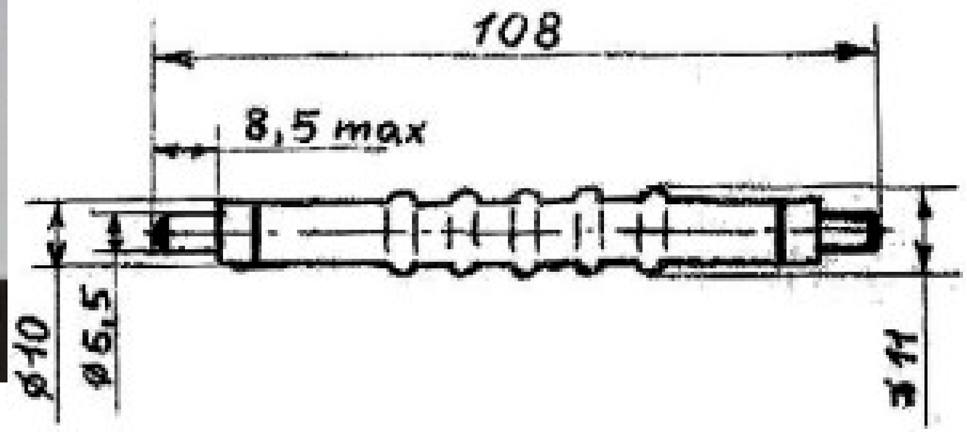
http://www.imagesco.com/geiger/gmt-03.jpg



An SBM-20U tube, showing the wire anode

Our SBM-20 Geiger tubes

Our SBM-20 Geiger-Müller Tubes



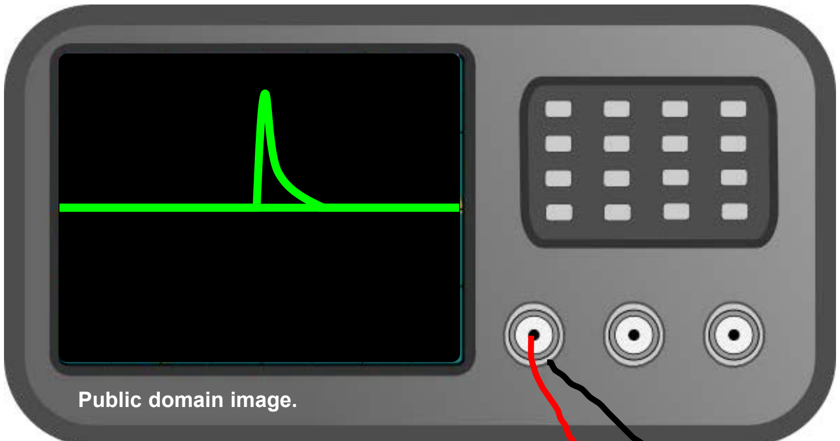
<u>Wall thickness:</u> 50μm steel

<u>Wall Density:</u> 8 g/cm^3

<u>Assume 1 atm equal gas mixture</u>

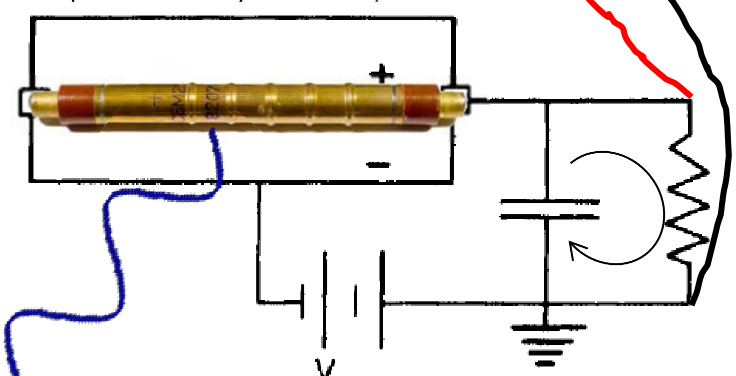
For more information, see:
http://www.gstube.com/data/2398/

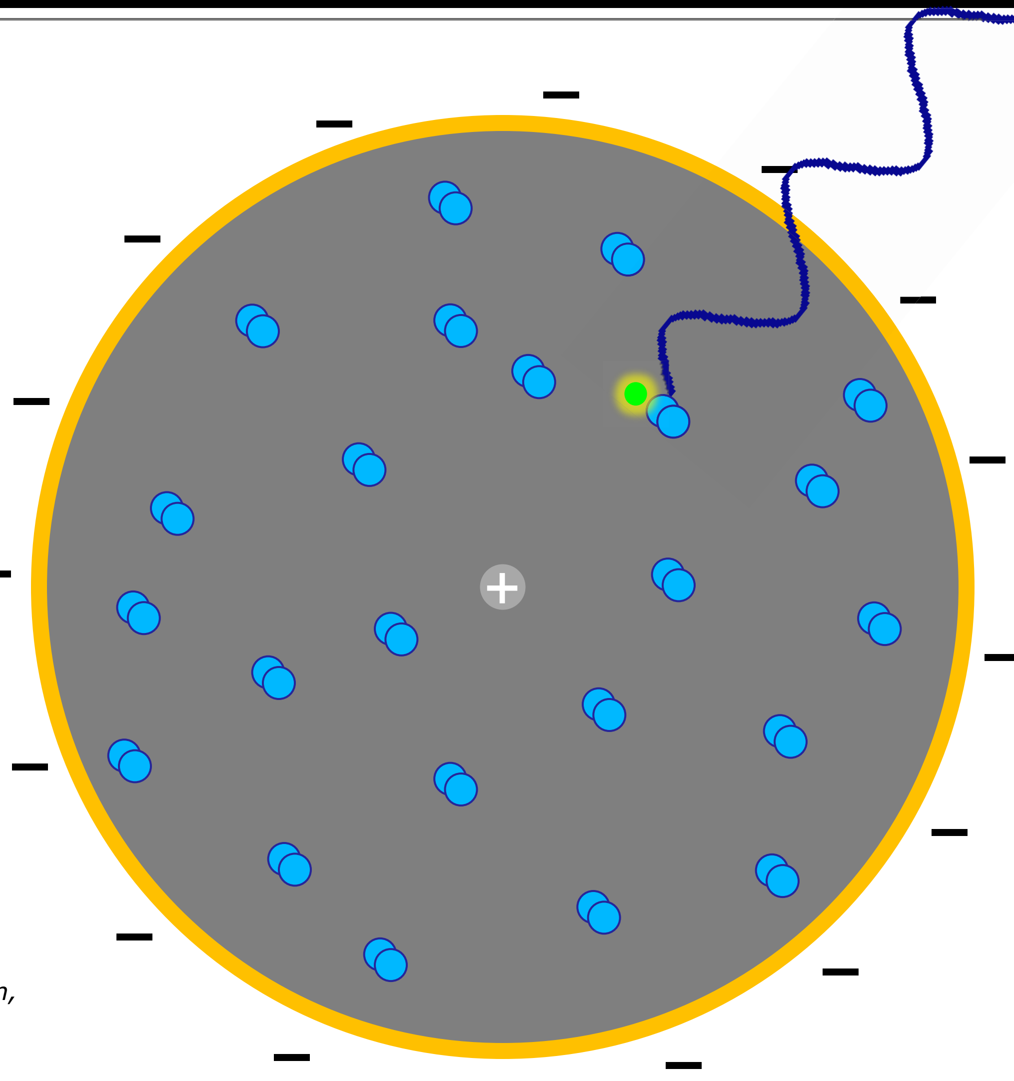
Ionization Chambers



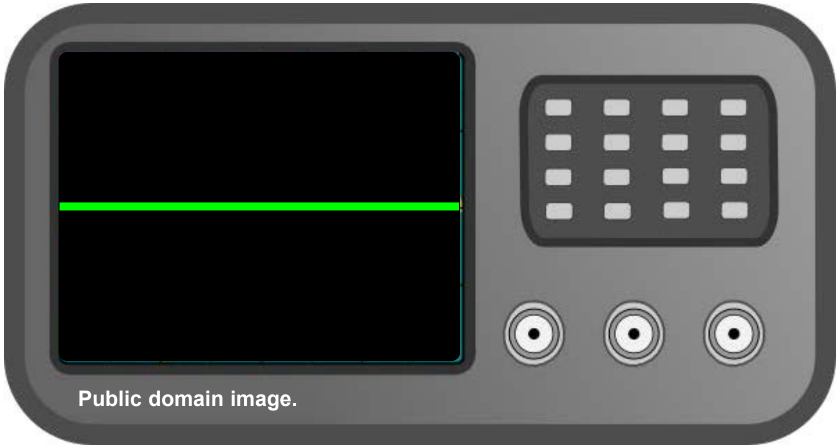
Public domain image.

Geiger tube photo courtesy of Jeff Keyzer on Flickr.

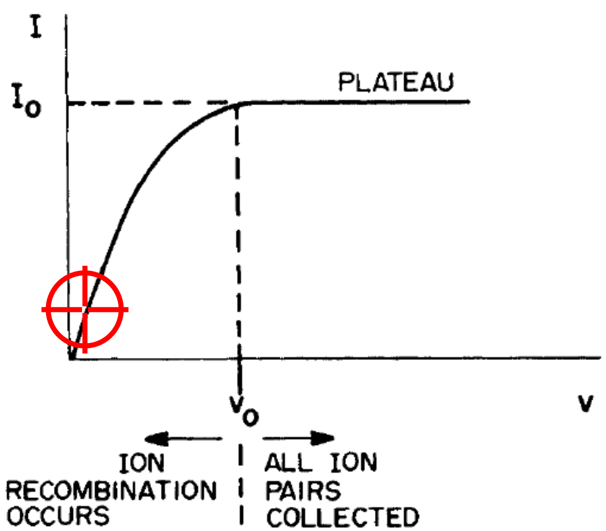


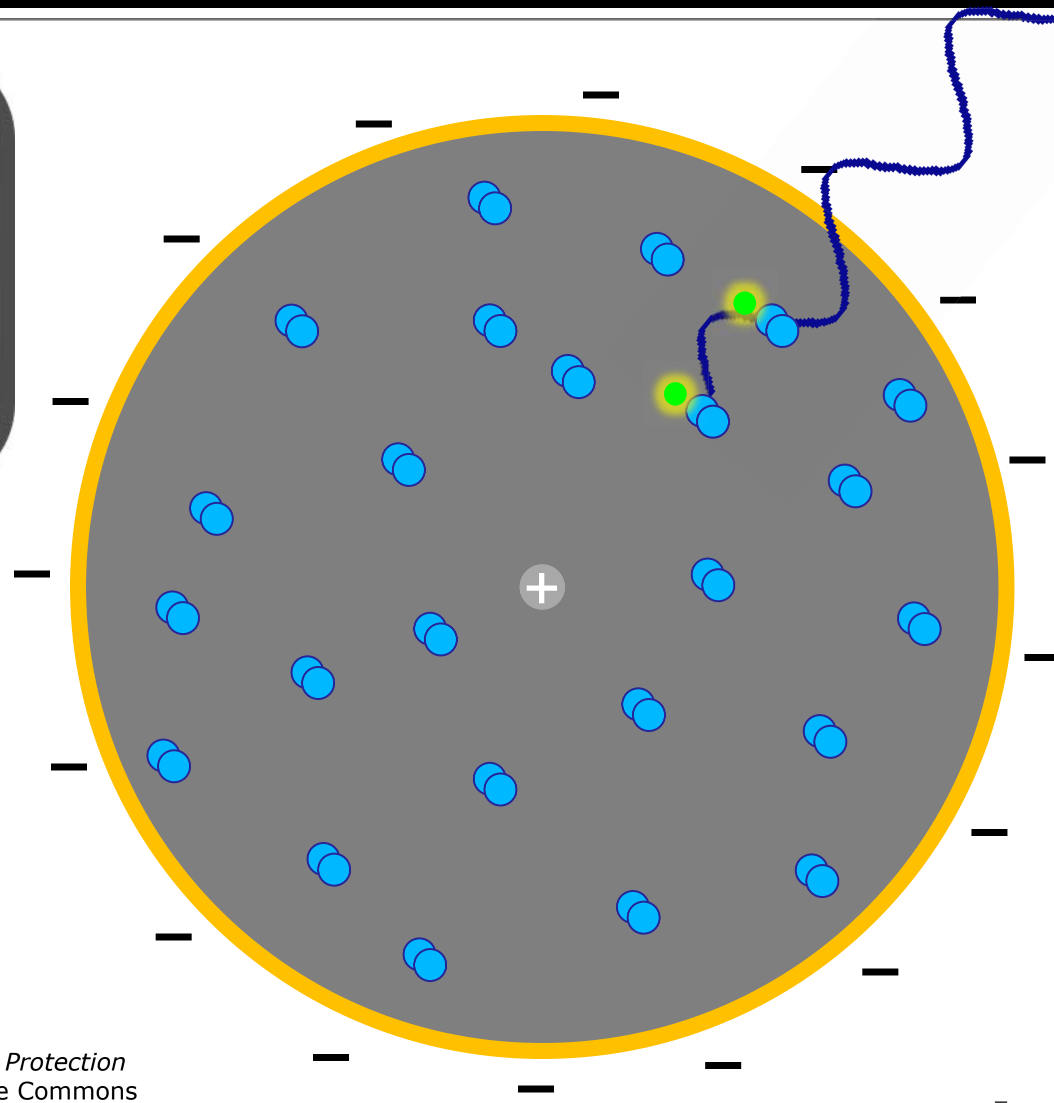


The Ionization Plateau (Low-V)

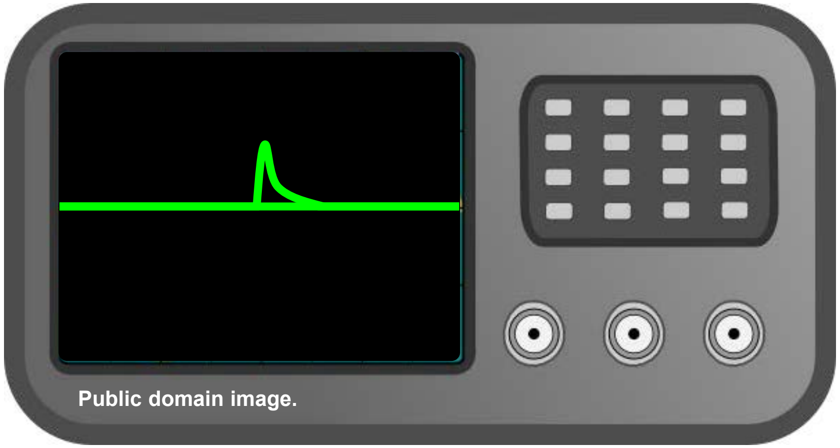


Public domain image.

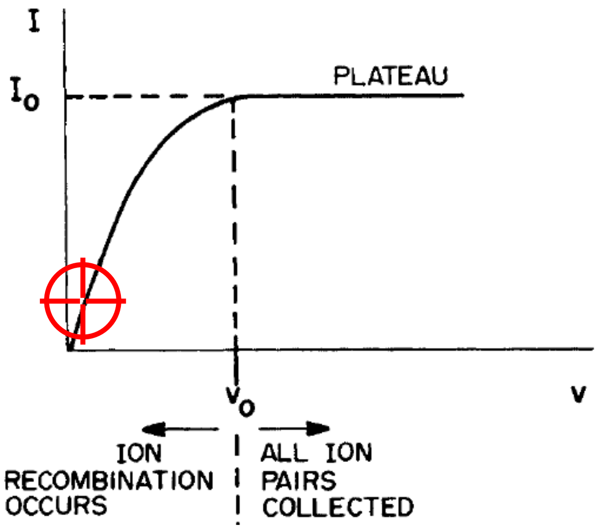


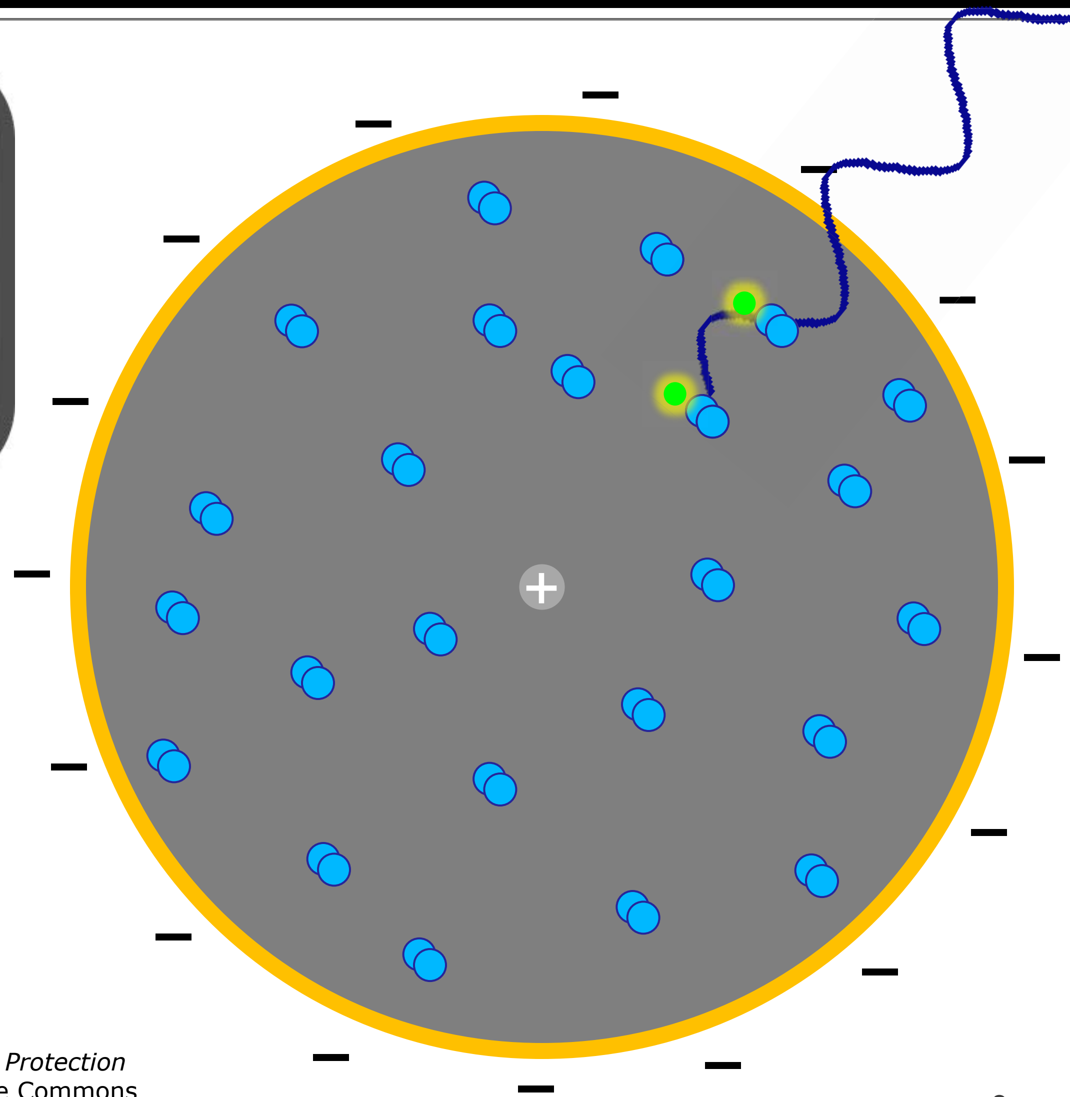


The Ionization Plateau (Med-V)

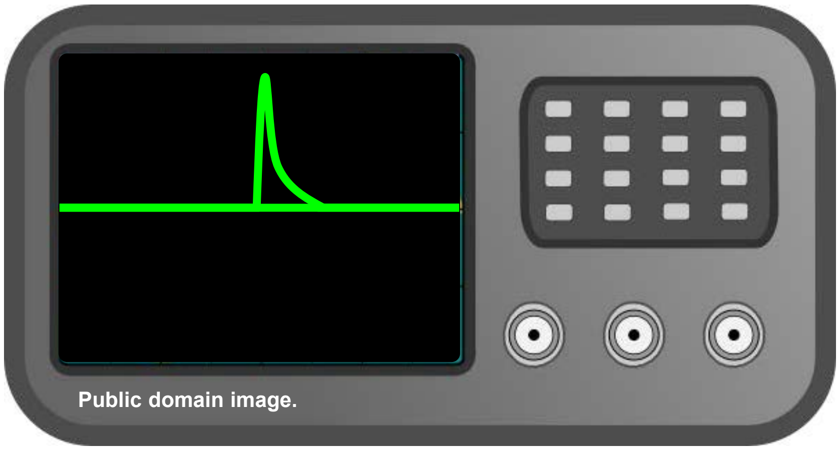


Public domain image.

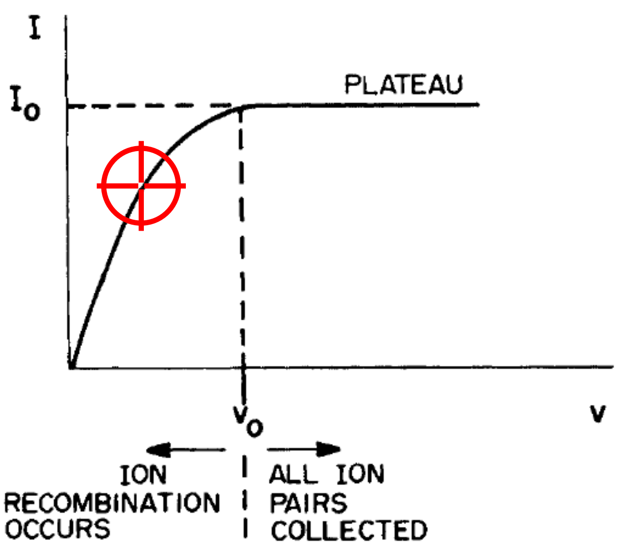


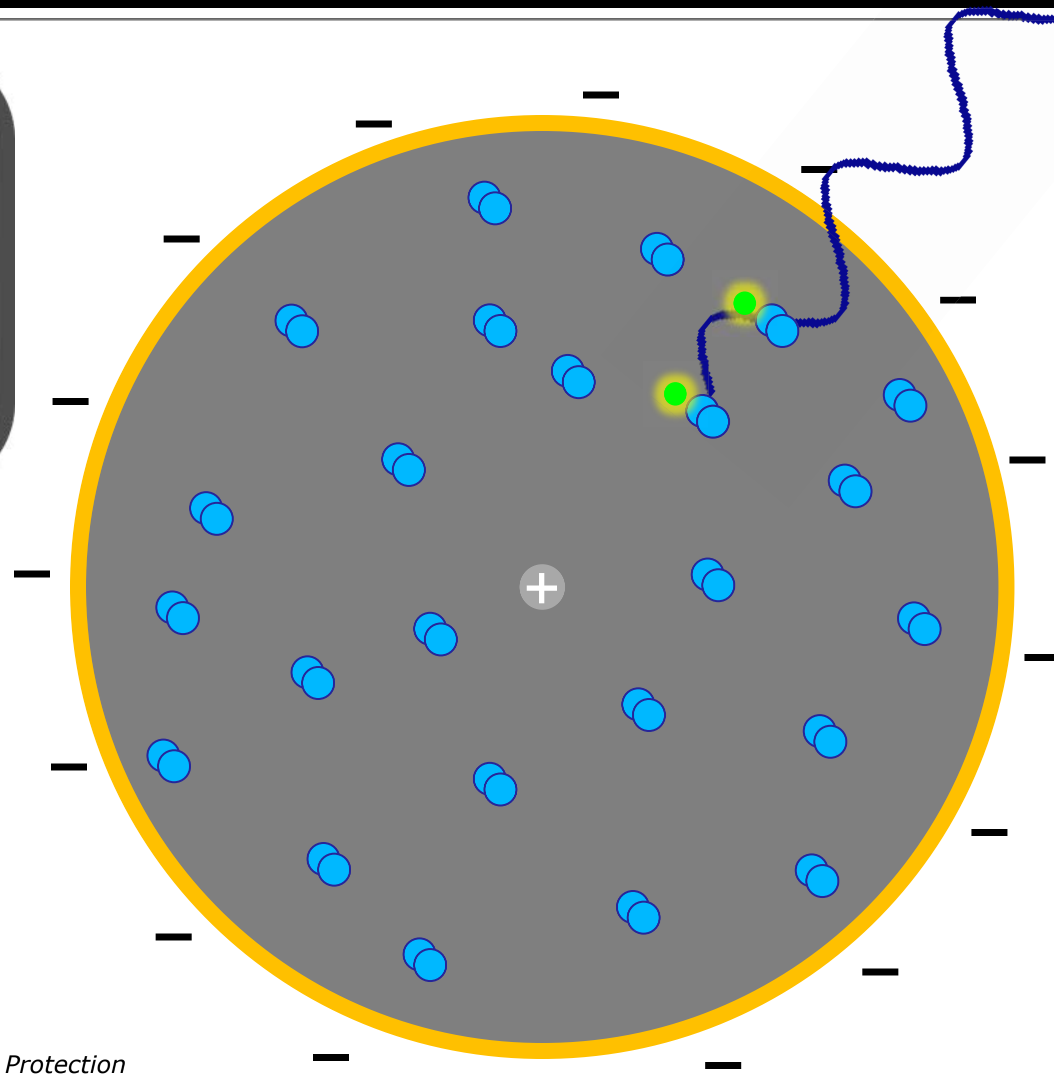


The Ionization Plateau (High-V)

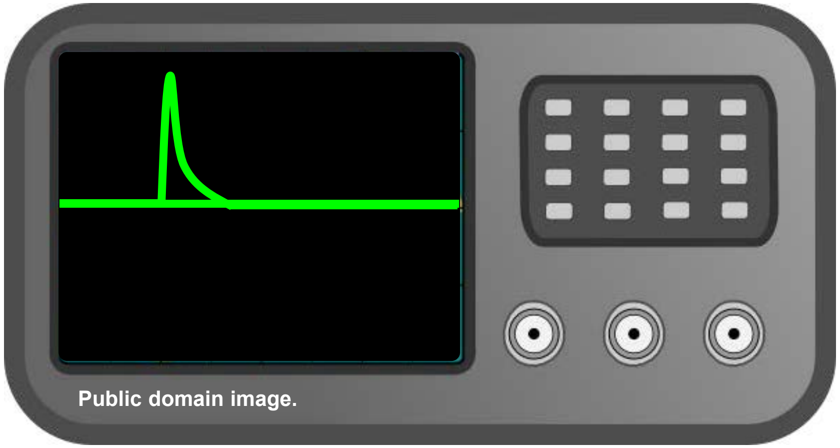


Public domain image.

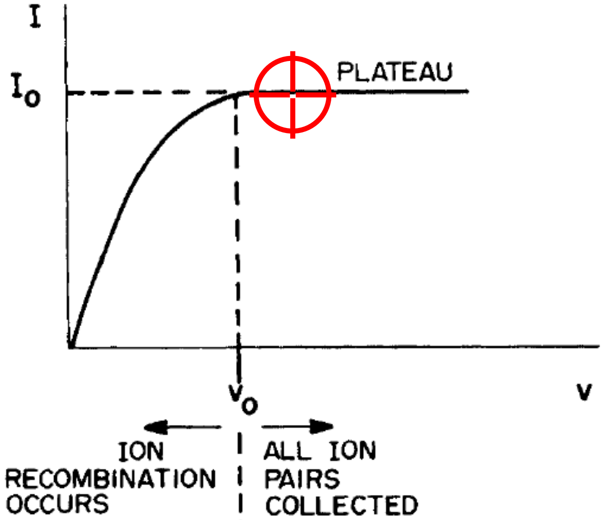


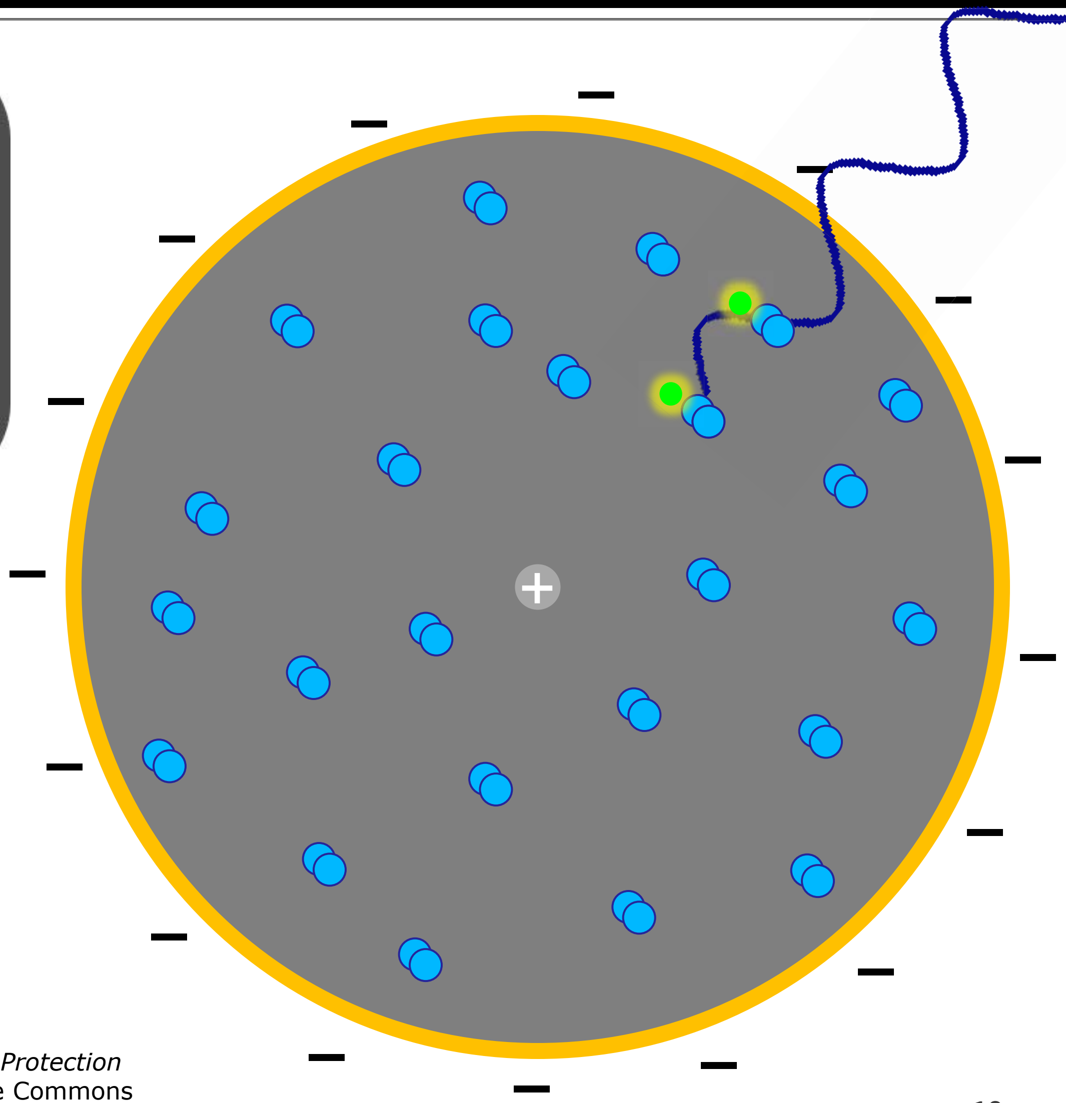


The Ionization Plateau (HIGH-V)



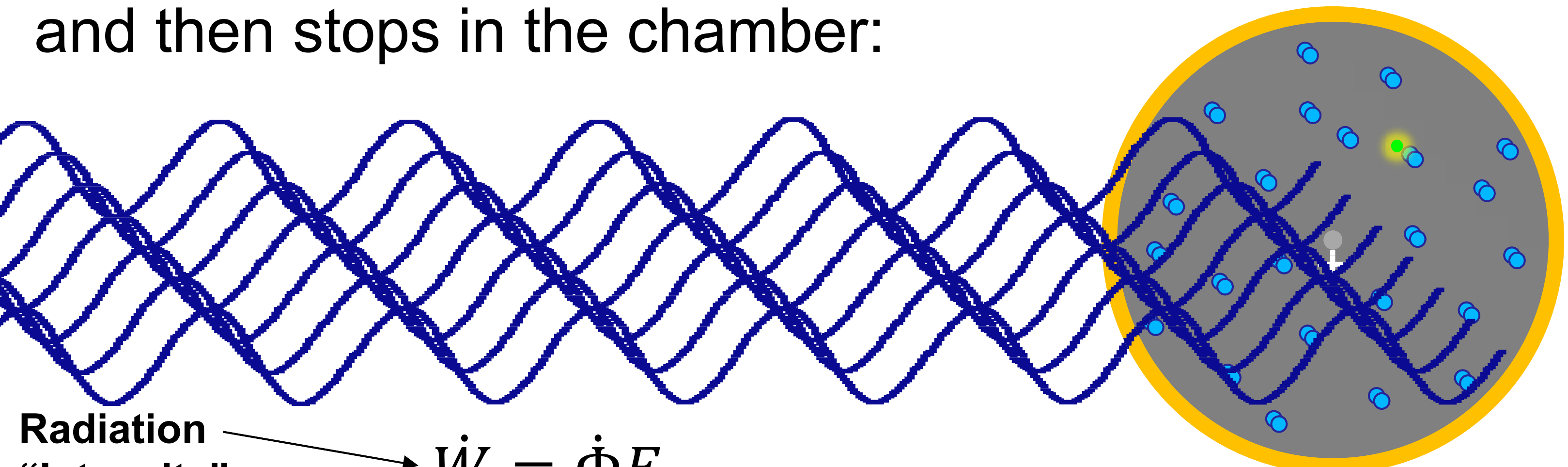
Public domain image.





Now for the Math…

Let's say a gamma flux of $\dot{\Phi}\left(\frac{\#}{cm^2-s}\right)$ enters a chamber of area *A*. Each makes *N* ion pairs, each with a charge of *e* and energy *W*, and then stops in the chamber:



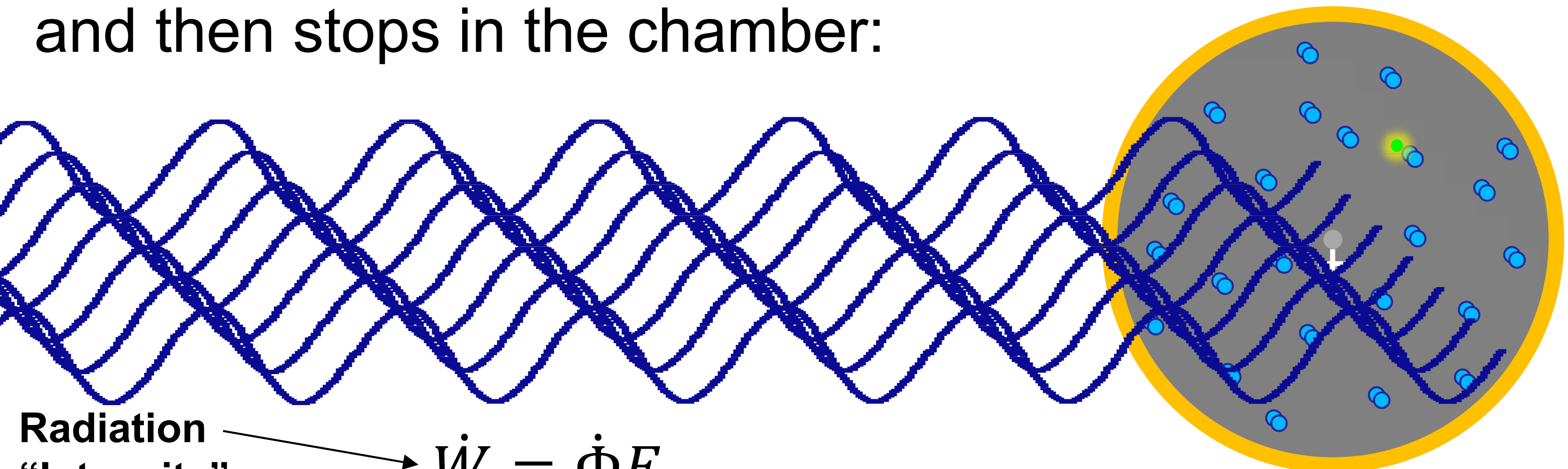
Radiation "Intensity" → $\dot{W} = \dot{\Phi}E_\gamma$

The charge produced per particle is Ne, and the number of particles entering per second is $\dot{\Phi}A$. That makes the current *I*:

$$I = \dot{\Phi}ANe$$

Now for the Math…

Let's say a gamma flux of $\dot{\Phi}\left(\frac{\#}{cm^2-s}\right)$ enters a chamber of area *A*.
Each makes *N* ion pairs, each with a charge of *e* and energy *W*, and then stops in the chamber:



Radiation "Intensity" → $\dot{W} = \dot{\Phi} E_\gamma$

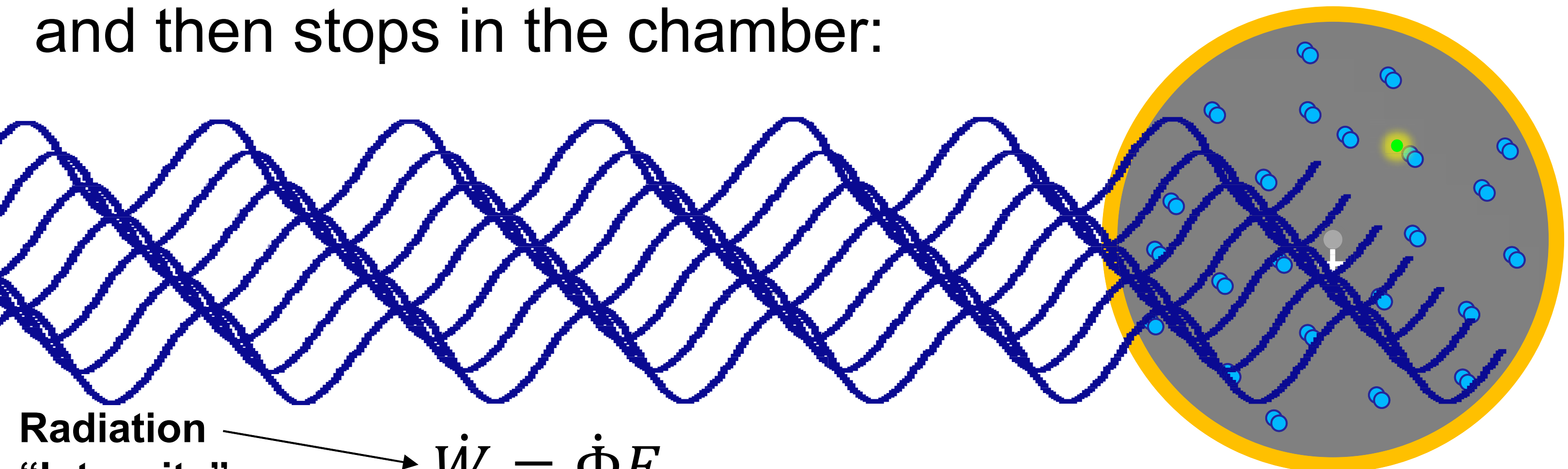
Now use the radiation intensity:

$$I = \dot{\Phi} A N e \Rightarrow \frac{I}{ANe} = \dot{\Phi} \Rightarrow \dot{W} = \frac{I}{ANe} E_\gamma = \frac{IW}{AE_\gamma e} E_\gamma = \frac{IW}{Ae}$$

Now for the Math…

Let's say a gamma flux of $\dot{\Phi}\left(\frac{\#}{cm^2-s}\right)$ enters a chamber of area *A*.

Each makes *N* ion pairs, each with a charge of *e* and energy *W*, and then stops in the chamber:

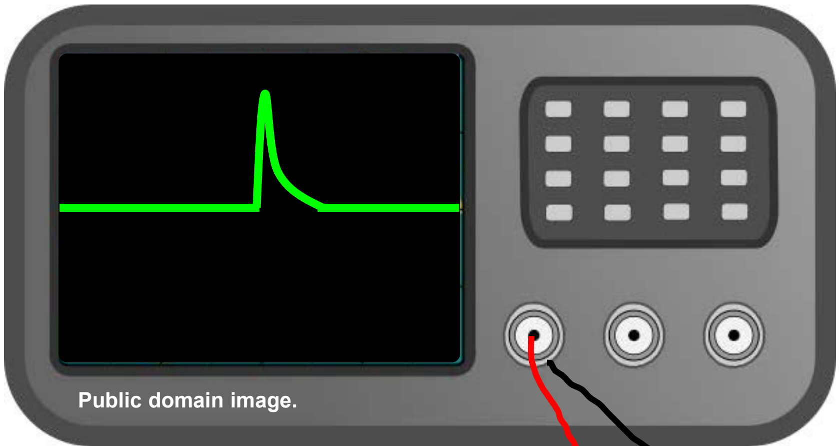


Radiation "Intensity" → $\dot{W} = \dot{\Phi} E_\gamma$

The absorption rate of energy in the chamber is $\dot{E}_{abs} = \dot{W} A$

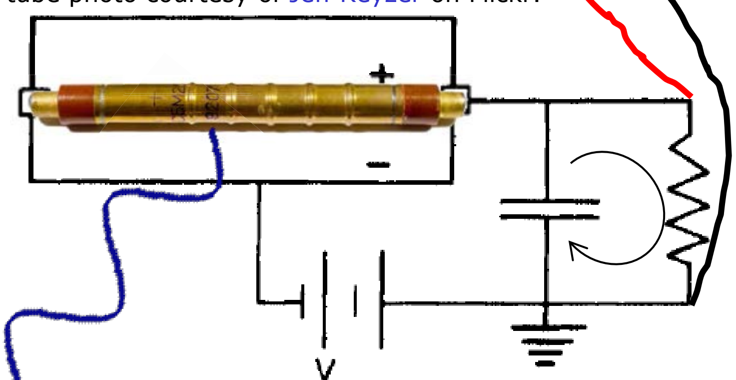
These can be used to measure gamma ray energy, proportional to the measured current!

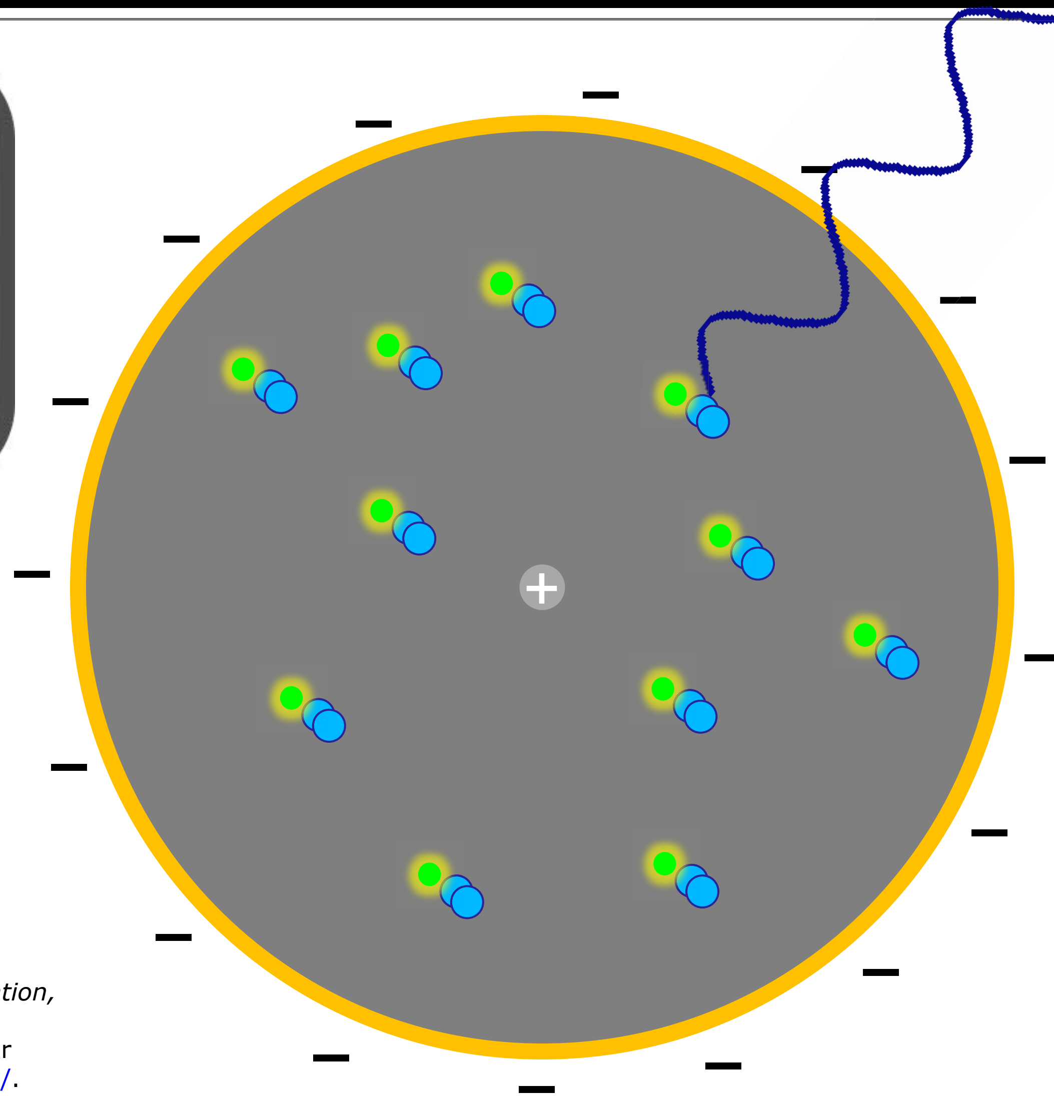
Our Use: A Simple Counter



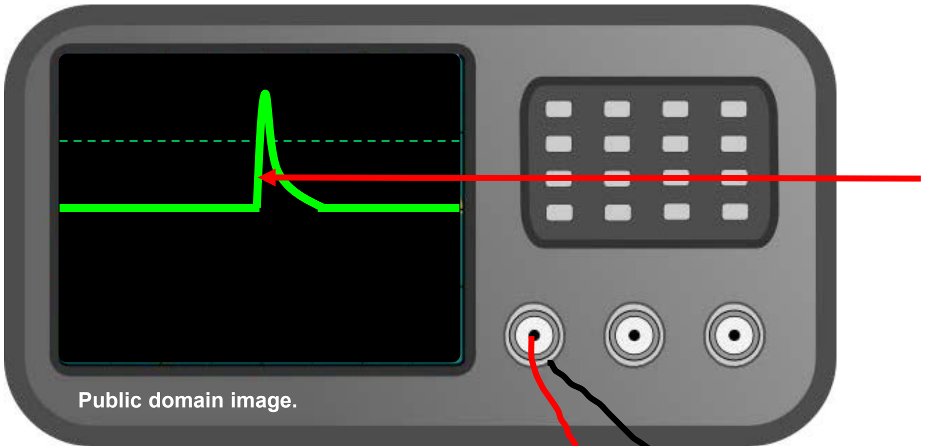
Public domain image.

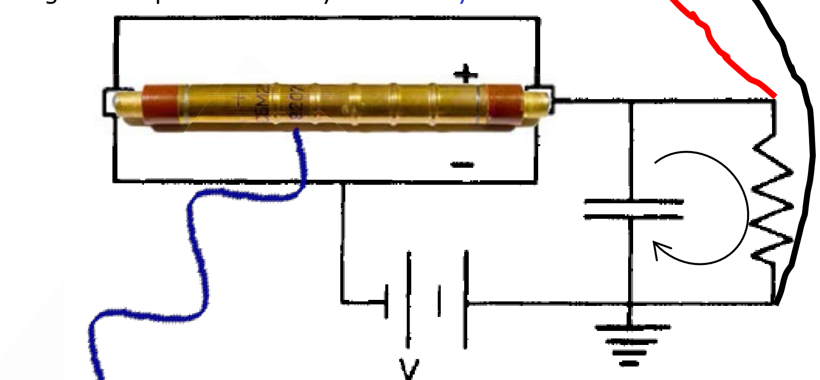
Geiger tube photo courtesy of Jeff Keyzer on Flickr.





Our Use: A Simple Counter



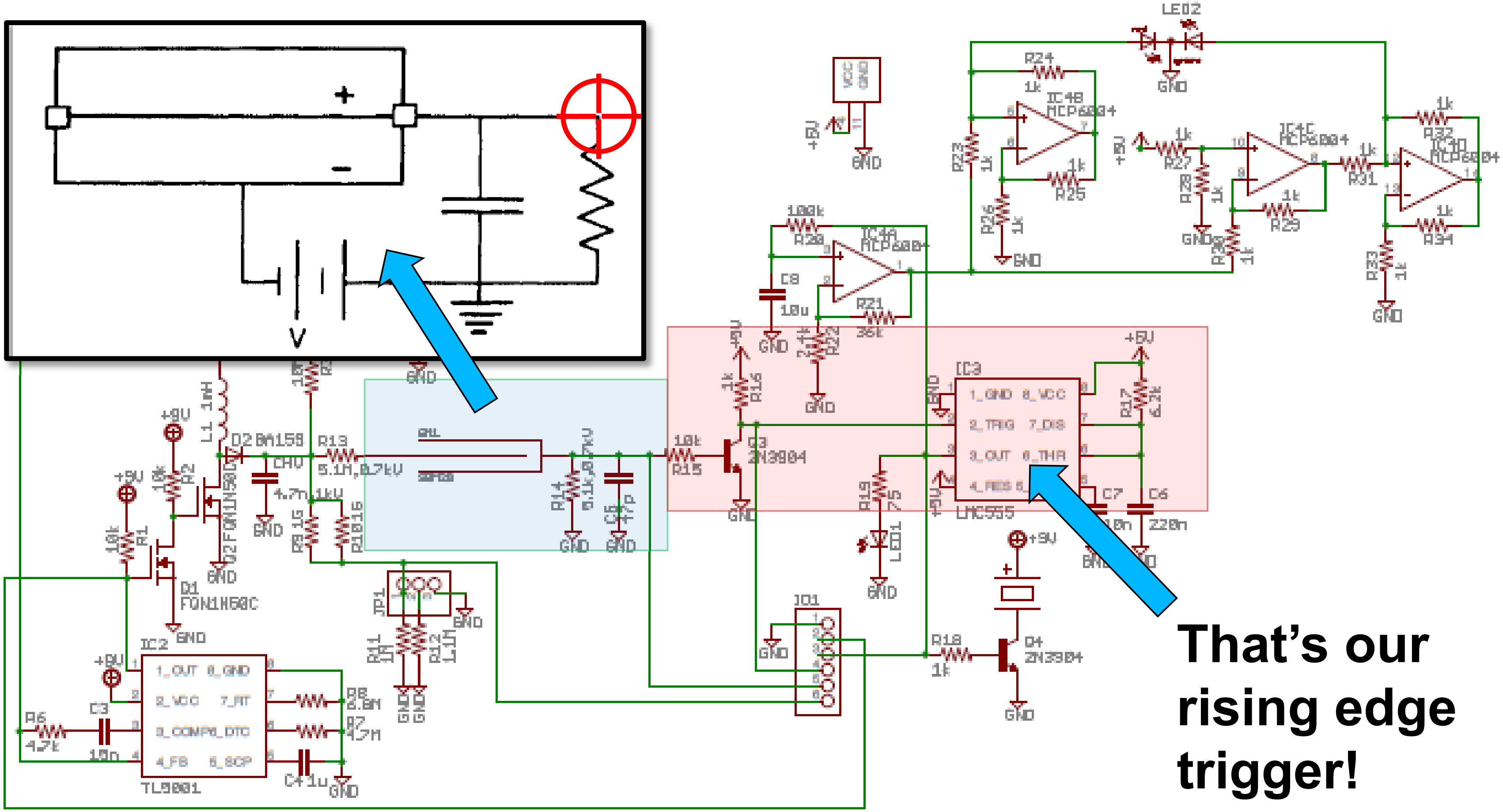


We use circuitry to detect the *rising edge* of the pulse from the Geiger tube

Set some threshold to call the edge *risen*

Send this (now digital) signal to our LEDs and the speaker to make light and nose!

Let’s Re-Examine Our Circuit

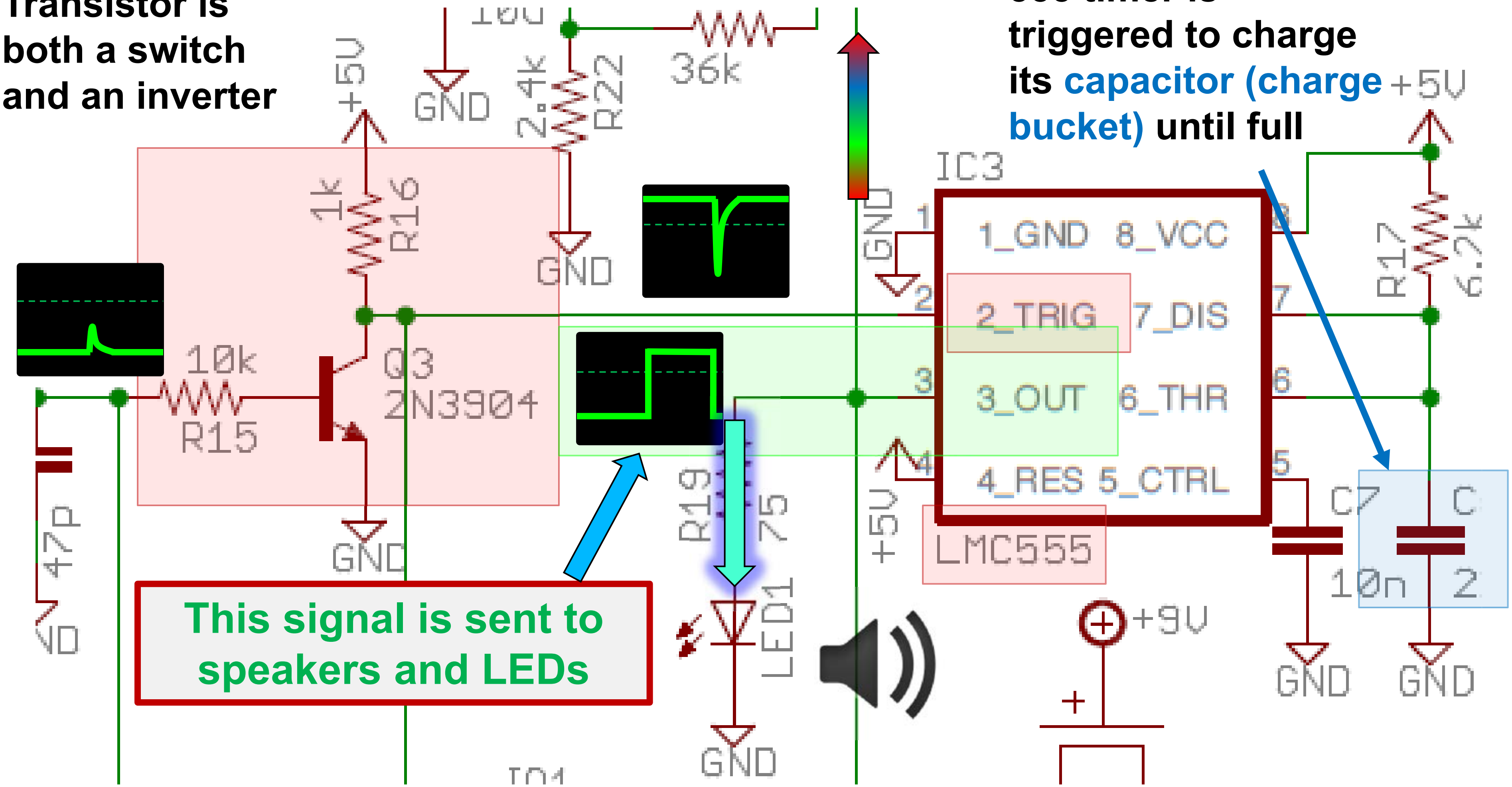


That’s our rising edge trigger!

Look Closer: Rising Edge Trigger

Transistor is both a switch and an inverter

555 timer is triggered to charge its capacitor (charge bucket) until full

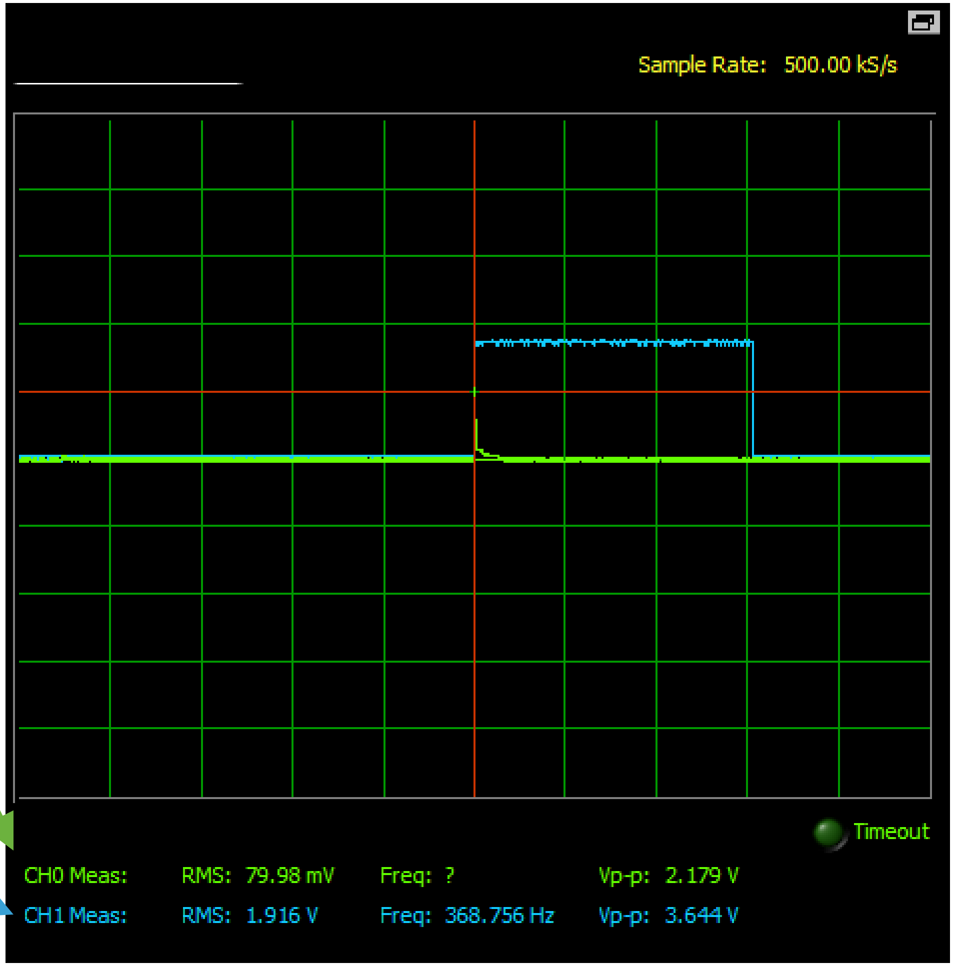


This signal is sent to speakers and LEDs

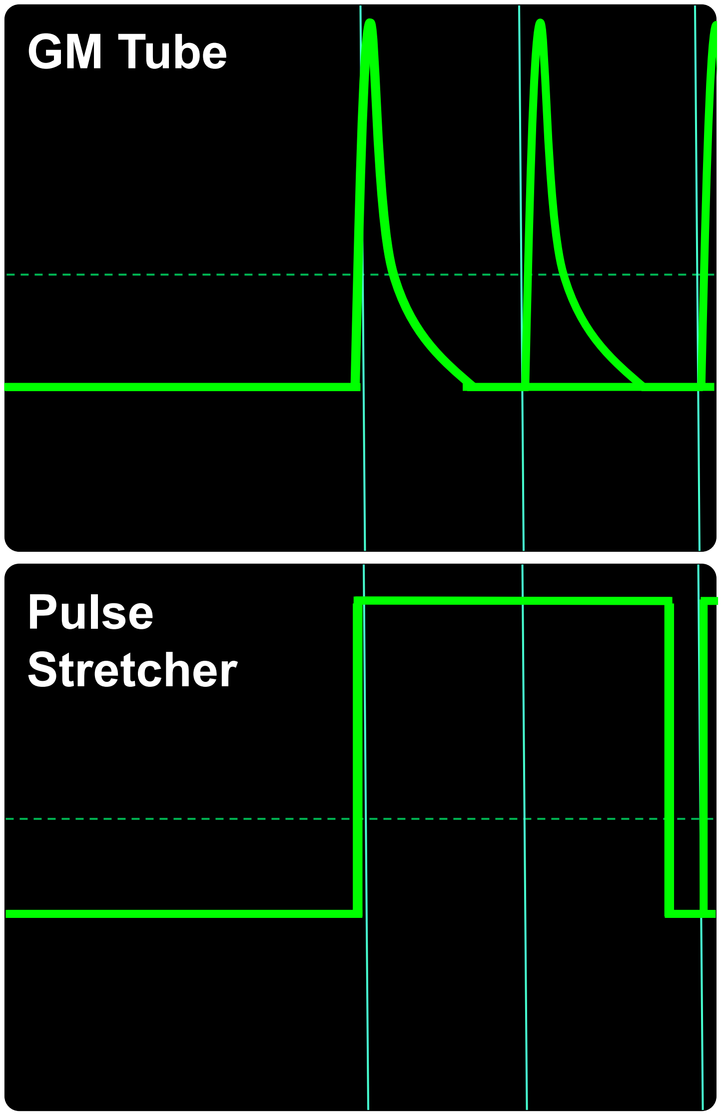
Our Measured Waveforms

Actual SBM-20 Geiger tube waveform

Pulse stretcher (sound and light) waveform



Limiting Cases: High Signal



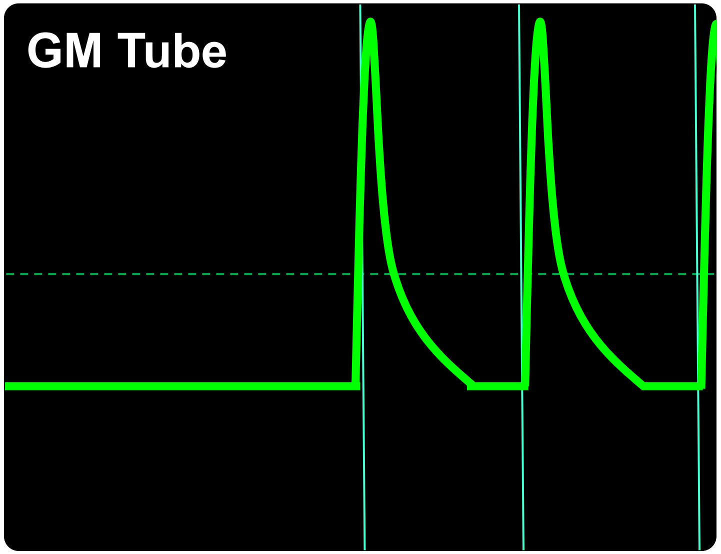
No problem!

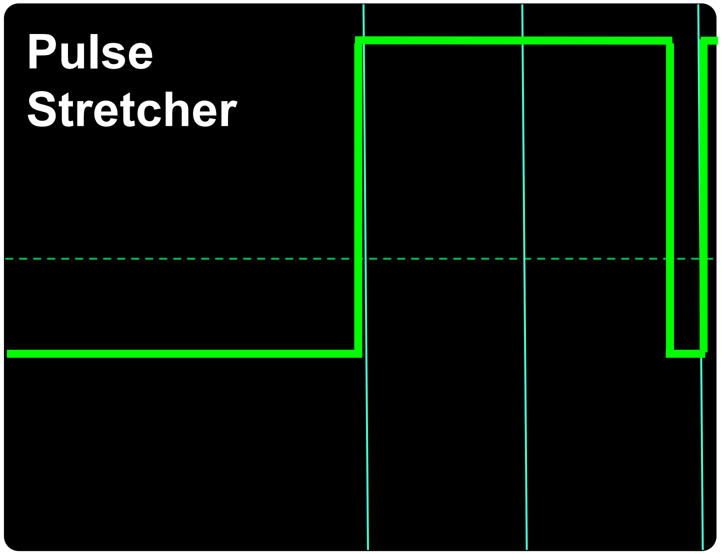
What happens if LOTS of counts come in at once?

This is known as “dead time,” a period when the detector is unresponsive

Missed count!

Paralyzable vs. Non-Paralyzable





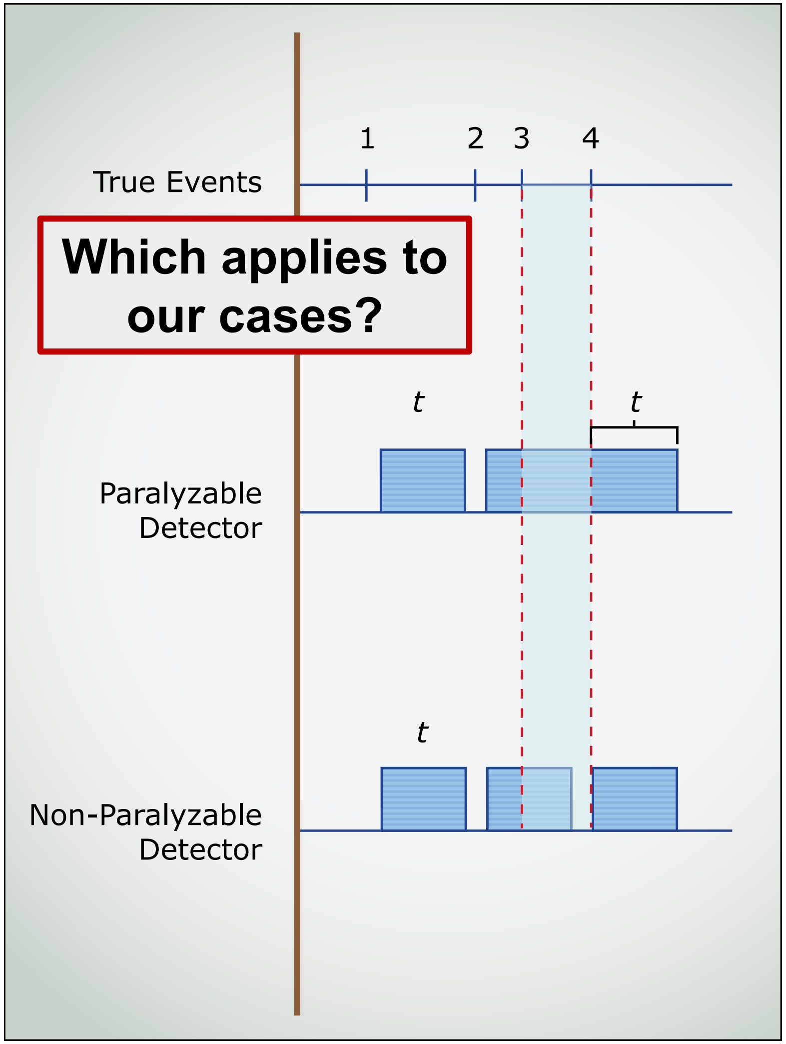
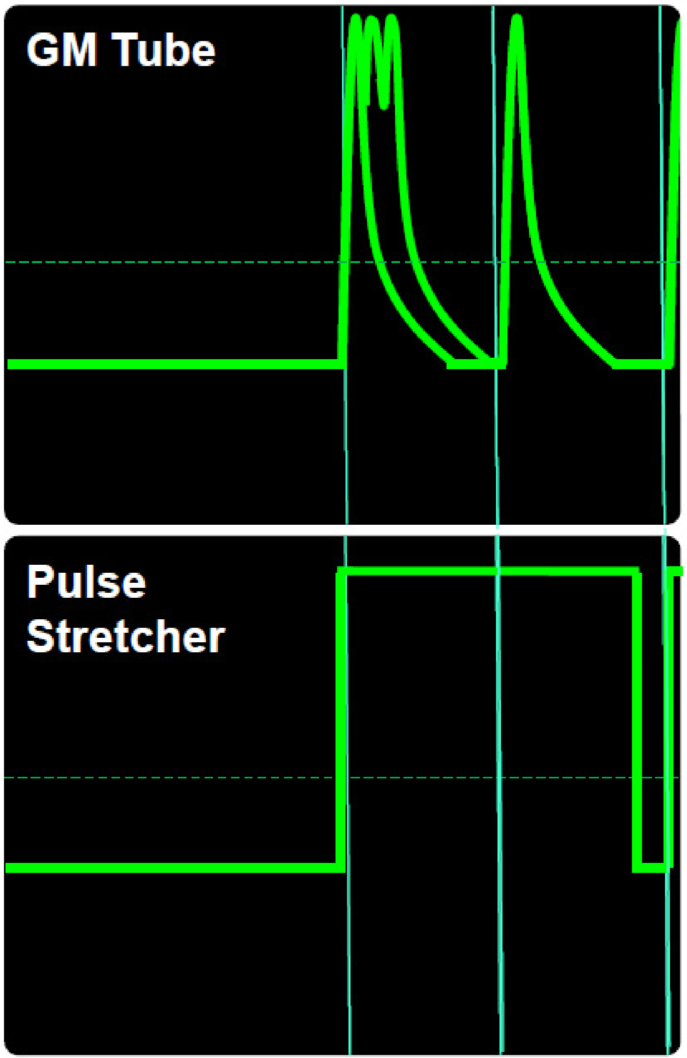
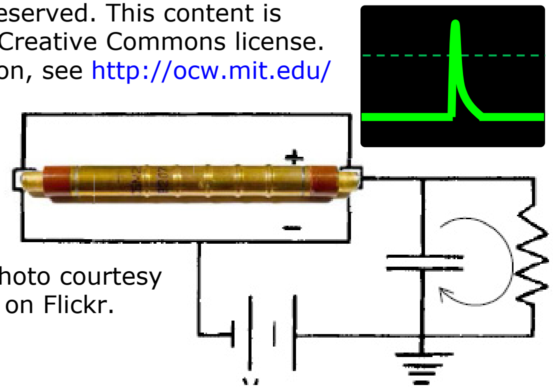


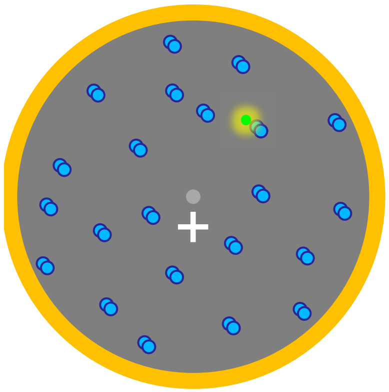
Image by MIT OpenCourseWare.

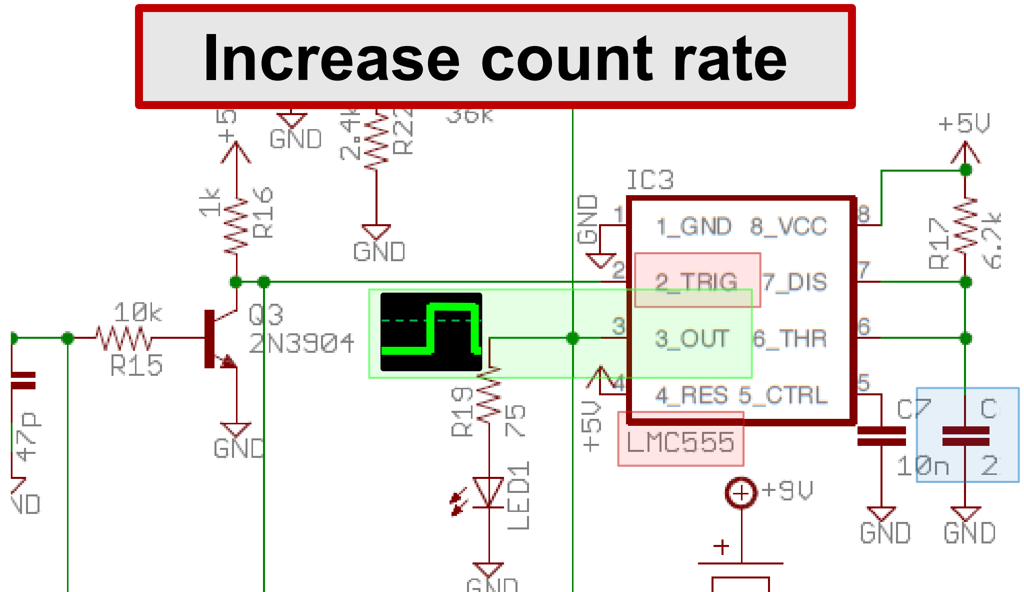
Paralyzable vs. Non-Paralyzable



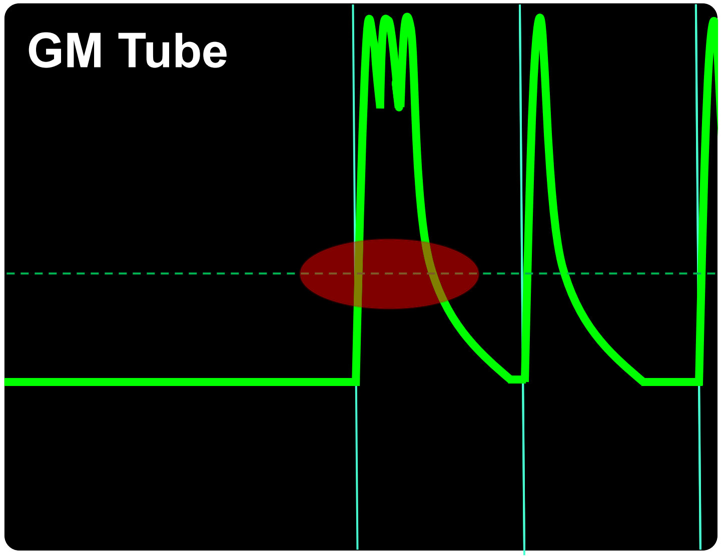


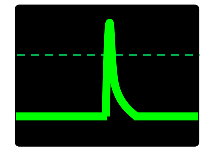
Geiger tube photo courtesy of Jeff Keyzer on Flickr.

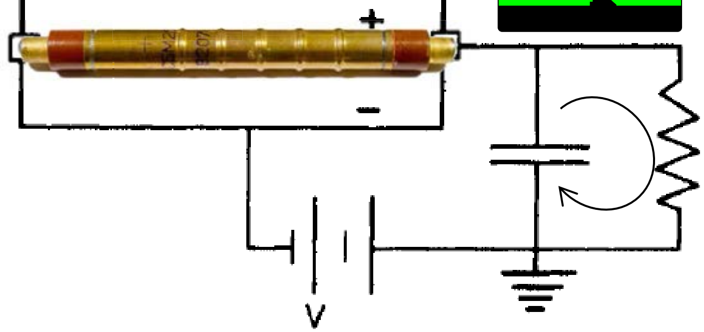


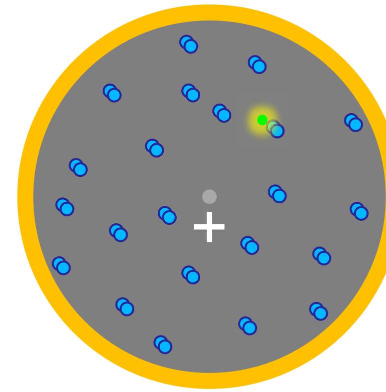


Paralyzable vs. Non-Paralyzable









Very rapid radiation events keep the ion current high

This maintains the circuit voltage
above the rising edge trigger threshold

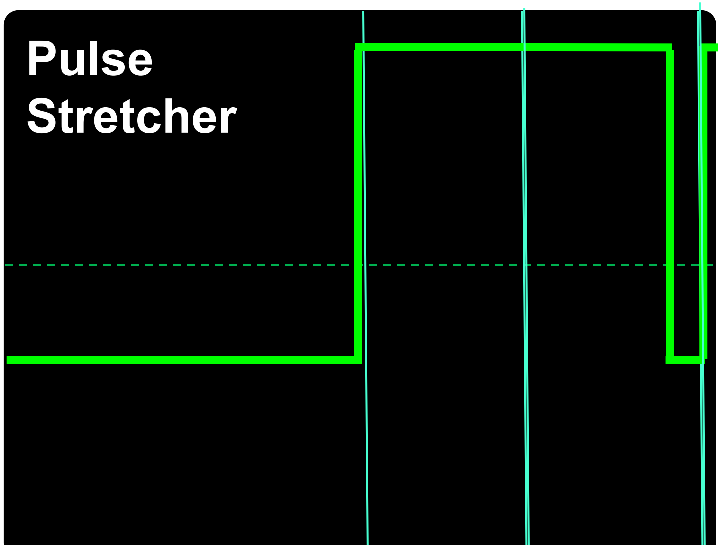
The GM tube is therefore **paralyzable**,
but its dead time is very **low** (<1μs)

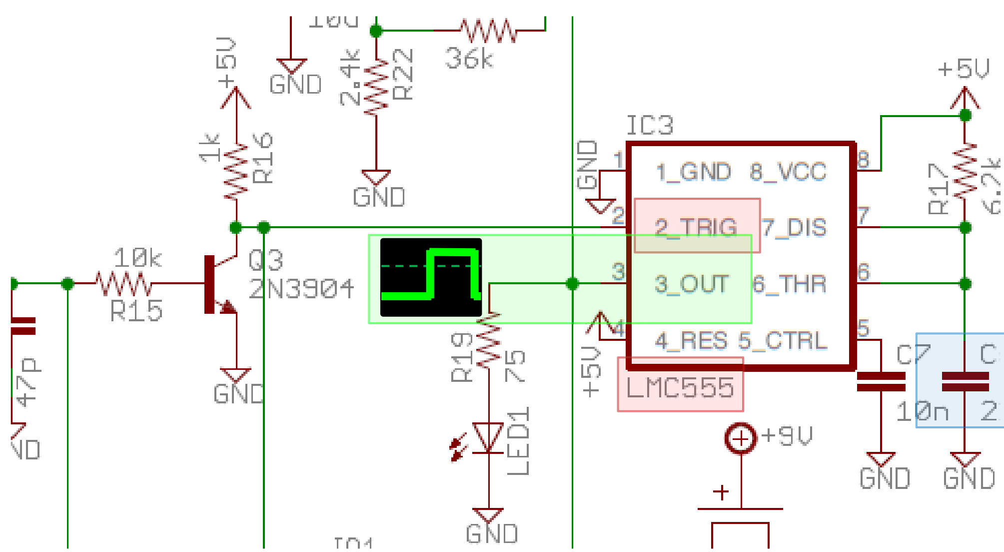
Paralyzable vs. Non-Paralyzable

Very rapid radiation events
don't re-trigger capacitor discharge

No additional time is spent at logic high voltage

The pulse stretcher is therefore **non-paralyzable**,
but its dead time is very **high** (~1.5ms)





Thinking Ahead for the Lab

- How will you characterize GM dead time?
- How will you characterize pulse stretcher dead time?
- Where on your circuit will you connect the computer to measure counts?
- What other sources of dead time exist in the system? *Hint: There are some!*

Questions?

22.S902 Do-It-Yourself (DIY) Geiger Counters
January IAP 2015