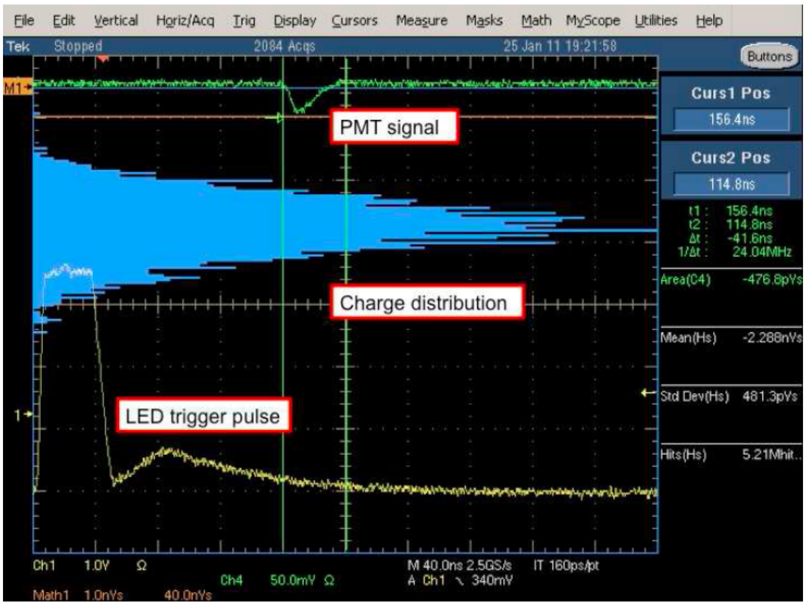
# Radiation Detector 2018/19 (SPA6309), Homework 4


Name:
ID:

**Problem (10 points)**




The picture is the data from the cryogenic photo-multiplier tube (PMT) test (JINST8(2013)T07005 http://arxiv.org/abs/1304.0821 (http://arxiv.org/abs/1304.0821)), taken by an oscilloscope terminated with 50 Ohm impedance. A PMT is illuminated by a LED in a liquid nitrogen bath. The yellow line shows the LED light is on, and then the green line shows the signal pulse from the PMT. The duration from the rising edge to the falling edge is roughly 40ns, and the height is roughly 25 mV, so the collected charge is around 500 ns·mV.

[1] How much charge from this single green pulse is collected in Coulombs?

[2] Assuming 5 photo-electrons are produced by this PMT at this moment, estimate the gain of this PMT.

Since the number of photo-electrons varies, we cannot assume that for each event to estimate gain. Instead, we use the fact that the photon-electron distribution obeys Poisson distribution with mean $\mu$ and variance $\sigma^2$ (or width $\sigma$). Here, the blue histogram is the distribution of the collected charge (mean $\hat{\mu}$, width $\hat{\sigma}$), which is proportion to the photo-electron distribution times factor $K$ ($\hat{\mu} = K \cdot \mu$, $\hat{\sigma} = K \cdot \sigma$). The measured mean of this distribution is 2.288 nV·s and the width of the distribution is 481 pV·s. Although this is not shown here, the pedestal of this measurement is 122 pV·s.

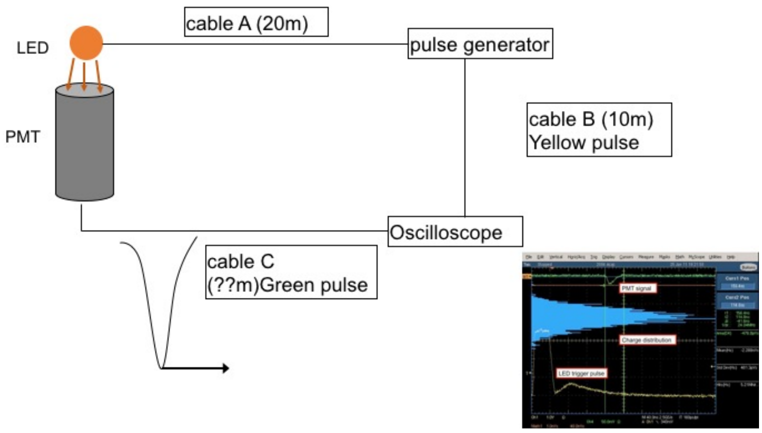
[3] What is the averaged collected charge without noise?

[4] Show this distribution has the mean number of detected photo-electrons around 20, and estimate the gain of this PMT.

In this measurement, the LED is triggered by a pulse generator. The yellow curve represents the trigger pulse for LED, where the cable length from the pulse generator to LED is 20m (cable A), but the pulse generator to the oscilloscope is 10m (cable B). The PMT pulse propagates along the cable C with unknown length to the oscilloscope. The LED is triggered by the rising edge of the trigger pulse (=the earliest part of the yellow pulse). Here, the LED is located in front of the PMT and we neglect the time for photons to propagate from the LED to the PMT. We also neglect the time for the PMT to produce the signal pulse from the detected photons.

[5] What is the length of cable C?

**solution**




[1] $I \cdot R = V \rightarrow Q \cdot R = s \cdot V = 500 \times 10^{-12}$s·V. Thus, $Q = 1 \times 10^{-11}C$. Since each electron carries $1.602 \times 10^{-19}C$

In [1]:
```
C=1.602E-19
e=1.0E-11/C
print e
```

```
62421972.5343
```

[2] There are 62.422 million electrons. Since this number of electrons are produced from 5 photo-electrons, the gain of this PMT is $1.248 \times 10^7$.

[3] 2.288-0.122=2.166 nV·s, so this is the averaged collected charge without noise.

[4] Since $2.166 = K \cdot \mu$ and $\sigma = K \cdot \sqrt{\mu} = 0.481$, thus $\left( \frac{K \cdot \mu}{K \cdot \sqrt{\mu}} \right)^2 = (4.502)^2 = 20.3$, so indeed LED intensity is tuned to produce 20 photo-electrons in this PMT. Thus, the gain of PMT is $2.166/50/1.602$

In [3]:
```
charge=2.166E-9
coulomb=1.602E-19
impedance=50
photoelectron=20.0
print "gain of the PMT is", charge/coulomb/impedance/photoelectr
```

```
gain of the PMT is 13520599.2509
```

The gain of PMT is $1.35 \times 10^7$

[5] The speed of light in the coaxial cable is roughly 20cm/ns (or 2/3 of speed of light), thus it takes 100ns to propagate 20m long cable A. Since cable A is 10m shorter than cable B, this means when we see the trigger pulse on the oscilloscope, the trigger pulse hasn't arrived yet to the LED, and it takes another 50ns. On the other hand, on the oscilloscope, there is a 160ns separation between the LED trigger pulse and PMT pulse. So the real separation of time between LED on and PMT signal arriving oscilloscope is 110ns, thus the length of cable C is 22m.