Some comments on the tests done at Princeton on June 25.

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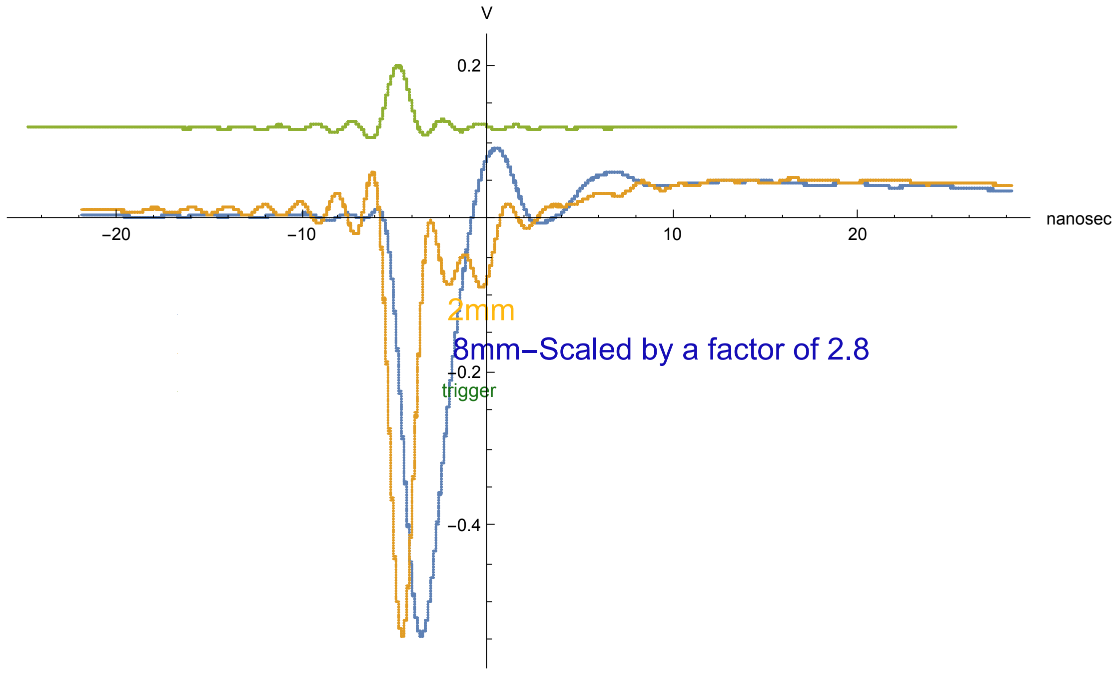
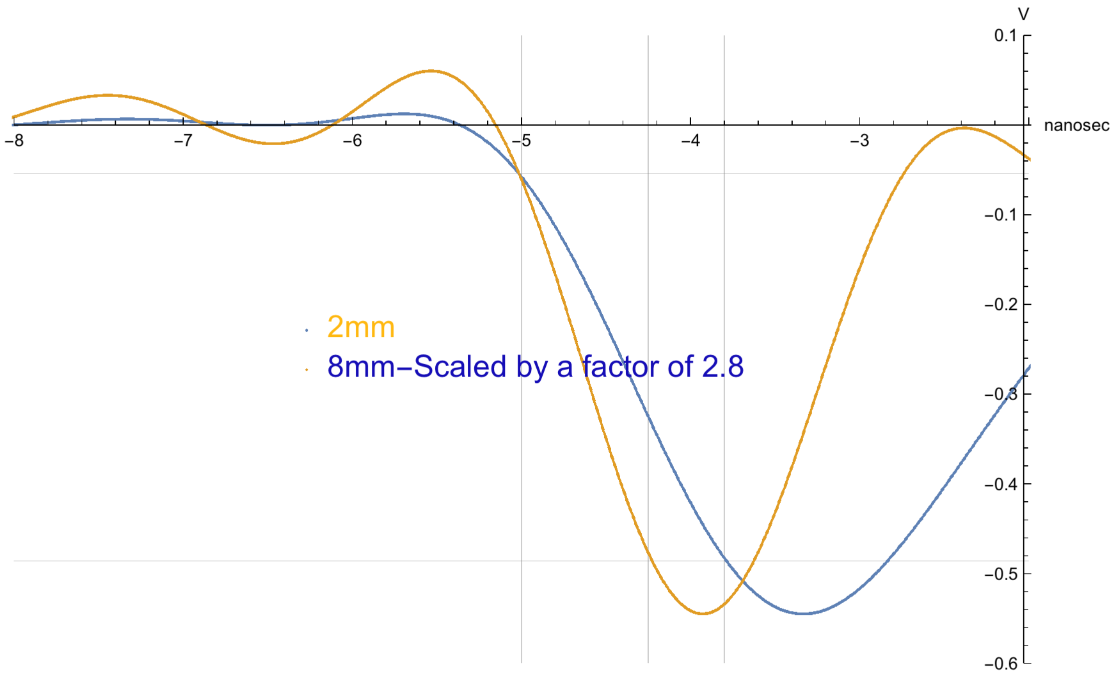
In the following I examine the waveforms that we took with Lu and argue that we have a fairly consistent picture of timing degradation due to detector capacitance.

```
ListPlot[{Transpose[{time, trace3 * 2.8 + .015}], Transpose[{time, trace1 + .015}], Transpose[{time - 3, (- (trace2) / 20 + .3)}]},
 AxesLabel → {"nanosec", "V"}, PlotRange → Full, ImageSize → Large,
 PlotLegends → Placed[{"                                                2mm",
    "                                                8mm-Scaled by a factor of 2.8",
    "                                               trigger"}, Center]]
```


V
0.2
−0.2
−0.4
−20
−10
10
20
nanosec
2mm
8mm−Scaled by a factor of 2.8
trigger

```
ListPlot[{Transpose[{time + .2, trace3 * 2.8 + .015}], Transpose[{time + 0.645, trace1 + .015}]},
 AxesLabel → {"nanosec", "V"}, PlotRange → {{-8, -2}, {-.6, .1}}, GridLines → {{-5, -4.25, -3.8}, {-.486, -.054}},
 ImageSize → Large, PlotLegends → Placed[{"2mm", "8mm-Scaled by a factor of 2.8"}, Center]]
```



The Above waveforms were taken using the Wenteq amplifier (Freq. Response 10 - 1000 MHz and gain of 50 db) and the full scope bandwidth (4 GHz). They clearly show that the peak amplitude with 8 x8 mm APD is a factor of 2.8 lower than for the 2 x2 mm APD. They also show a deterioration of risetime (10 - 90 %) from 0.75 nsec to 1.2 nsec .

The sensitivity to pickup noise from the Vcsel is higher in the second case but I do not believe that the intrinsic amplifier noise is different in the 2 cases (we should verify by taking many traces with a long baseline). If this is so then we are paying a price of 2.8*1.2/0.75 = 4.48 in time electronic noise limited time resolution

as a result of this "capacitance effect". This is really worth defeating and the best path still seems to be with Mitch' s lower input imedence amplifier. The other alternative we discussed is to try to alter the capacitance to the screen. We should also compare risetime of direct signal off the anode to that of the screen (we think the latter should be faster).

How well does this fit with the circuit model we did last year? I reproduce it below. As you can see, if the effective capacitance at the mesh terminal of the 8*8 mm^2 APD is 24pF, which gives an RC time constant into the 50 Ohm preamp impedance of 1.2 nanoseconds then we also account for the peak amplitude reduction by a factor of 2.8 in goinf rom nominal 4 pF to 24 pF.

So everything seems pretty consistent!

```
Q0 = 1.6 * 10^-19 * 6000. * 600.
```

5.76×10^{-13}

Input signal time distribution, approximate with an exponential. Start from Laplace transform of the signal, which gives a reasonable shape in time domain. Signal normalization (integral eq. to Q0). However as shown later the pulse shape at the preamp output is reproduced quite well assuming delta dirac signal from the detector.

```
Clear[taud, taui];
sigs = 1/(1 + taui s) 1/(1 + taud s);
sig = InverseLaplaceTransform[sigs, s, t]
taud = .5 × 10^-9; taui = 0.3 × 10^-9;
LogPlot[sig , {t, 0, 10 × 10^-9}, Frame → True]
```

$$\frac{e^{-\frac{t}{taud}}}{taud - taui} - \frac{e^{-\frac{t}{taui}}}{taud - taui}$$

Time domain response of the preamp (vo) to dirac delta signal to charge Qi. taup0 is determined by the amplifier bandwidth and we use 320 picosec for 500 MHz BW. ku is the amplifier voltage gain, which we take to be 10 (20 dB amp).

```
Clear[Qi, id, cd, ri, taud, taui, vin, vpo, vo, vot, ku, taup0];
```

$$\texttt{vin} = \texttt{id}\ \frac{\texttt{ri}}{1 + \texttt{s cd ri}}\ \texttt{Qi};$$

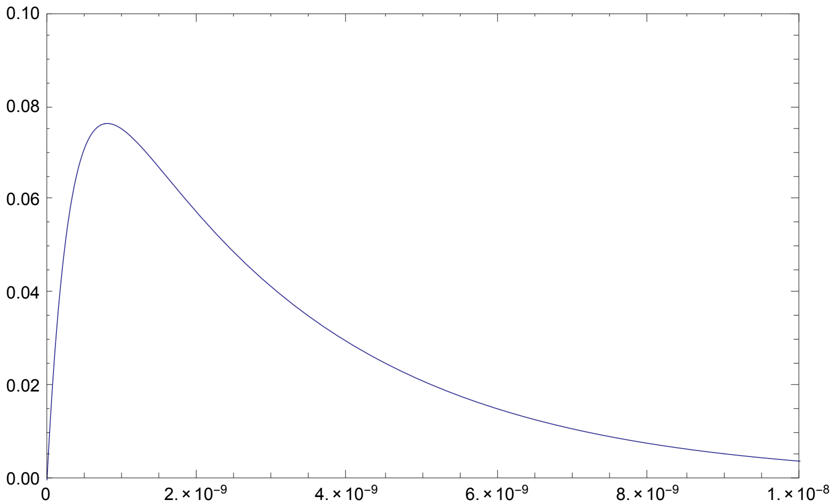
$$\texttt{vo} = \texttt{vin}\ \frac{\texttt{ku}}{1 + \texttt{s taup0}};$$

```
id = 1;
vot = InverseLaplaceTransform[ vo, s, t]
```

$$\text{ku Qi ri}\left(\frac{e^{-\frac{t}{\text{cd ri}}}}{\text{cd ri} - \text{taup0}} - \frac{e^{-\frac{t}{\text{taup0}}}}{\text{cd ri} - \text{taup0}}\right)$$

$$\texttt{Qi} = 0.6 \times 10^{-12};\ \texttt{cd} = 60 \times 10^{-12};\ \texttt{ri} = 50;\ \texttt{ku} = 10;\ \texttt{taup0} = 0.32 \times 10^{-9};$$

$$\texttt{Plot}\left[\texttt{vot},\ \left\{t, 0, 10 \times 10^{-9}\right\},\ \texttt{Frame} \rightarrow \texttt{True},\ \texttt{PlotRange} \rightarrow \left\{\left\{0, 10 \times 10^{-9}\right\}, \{0, .1\}\right\}\right]$$



Solve for the peak amplitude and plot it vs. Capaciatance of the detector.

```
Clear[Qi, id, cd, ri, taud, taui, vin, vpo, vo, vot, ku, taup0];
```

$$\text{resp}[t\_] := \text{ku Qi ri}\left(\frac{e^{-\frac{t}{\text{cd ri}}}}{\text{cd ri} - \text{taup0}} - \frac{e^{-\frac{t}{\text{taup0}}}}{\text{cd ri} - \text{taup0}}\right)$$

```
FullSimplify[D[resp[t], t]]
```

$$\frac{\text{ku Qi}\left(-\frac{e^{-\frac{t}{\text{cd ri}}}}{\text{cd}} + \frac{e^{-\frac{t}{\text{taup0}}}\,\text{ri}}{\text{taup0}}\right)}{\text{cd ri} - \text{taup0}}$$

```
Solve[D[resp[t], t] == 0, t]
```

Solve::ifun: Inverse functions are being used by Solve, so some solutions may not be found; use Reduce for complete solution information. >>

$$\left\{\left\{t \to \frac{\text{cd ri taup0 Log}\left[\frac{\text{cd ri}}{\text{taup0}}\right]}{\text{cd ri} - \text{taup0}}\right\}\right\}$$

$$\text{resp}\left[\frac{\text{cd ri taup0 Log}\left[\frac{\text{cd ri}}{\text{taup0}}\right]}{\text{cd ri} - \text{taup0}}\right]$$

$$\text{ku Qi ri}\left(-\frac{\left(\frac{\text{cd ri}}{\text{taup0}}\right)^{-\frac{\text{cd ri}}{\text{cd ri}-\text{taup0}}}}{\text{cd ri} - \text{taup0}} + \frac{\left(\frac{\text{cd ri}}{\text{taup0}}\right)^{-\frac{\text{taup0}}{\text{cd ri}-\text{taup0}}}}{\text{cd ri} - \text{taup0}}\right)$$

```
maxresp = ku Qi ri (-(cd ri/taup0)^(-cd ri/(cd ri-taup0))/(cd ri - taup0) + (cd ri/taup0)^(-taup0/(cd ri-taup0))/(cd ri - taup0))

Qi = Q0; ri = 50; ku = 10; taup0 = 0.32 × 10^-9;

LogPlot[maxresp , {cd, 4 * 10^-12, 100 × 10^-12}, AxesLabel → {  C_d[Farad], Peak Amplitude[V]},
 PlotRange → {{4 × 10^-12, 60 × 10^-12}, {.03, .5}}, LabelStyle → Directive[Bold, Larger]]
```

$$\text{ku Qi ri}\left(-\frac{\left(\frac{\text{cd ri}}{\text{taup0}}\right)^{-\frac{\text{cd ri}}{\text{cd ri}-\text{taup0}}}}{\text{cd ri}-\text{taup0}}+\frac{\left(\frac{\text{cd ri}}{\text{taup0}}\right)^{-\frac{\text{taup0}}{\text{cd ri}-\text{taup0}}}}{\text{cd ri}-\text{taup0}}\right)$$