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HPS experiment: current sensitive preamplifiers's modifications to fit to 2 APD sizes: 5×5 mm^2 10×10mm^2

1/ Introduction and physics data for engineers

The HPS calorimeter will consist of 442 PbWO4 crystals. The size of each crystal is 160mm×13mm×13mm. The energy of gamma or electrons in a crystal ranges from 10MeV up to 3 GeV. The 2 Hamamatsu APDs that we can use are: S8664-55 and S8664-1010.
The preamplifiers from the previous IC calorimeters (years 2004-2005) that we can modify for the tests are: N055, N076, N129 (out of order), N147, N318, N340, N346, N356, N363, N383, N402, 460, 465 and 466.
The preamplifiers from the new FT CLAS12 calorimeter that we can modify for the tests are: FT22, FT61, FT299, FT317, FT328 (Noisy, out of order), FT347 and FT396.

2/ Original scheme and layout used for the IC calorimeter (DVCS experiment)

The figure 1 gives the layout (top and bottom) of the original IC preamplifier.

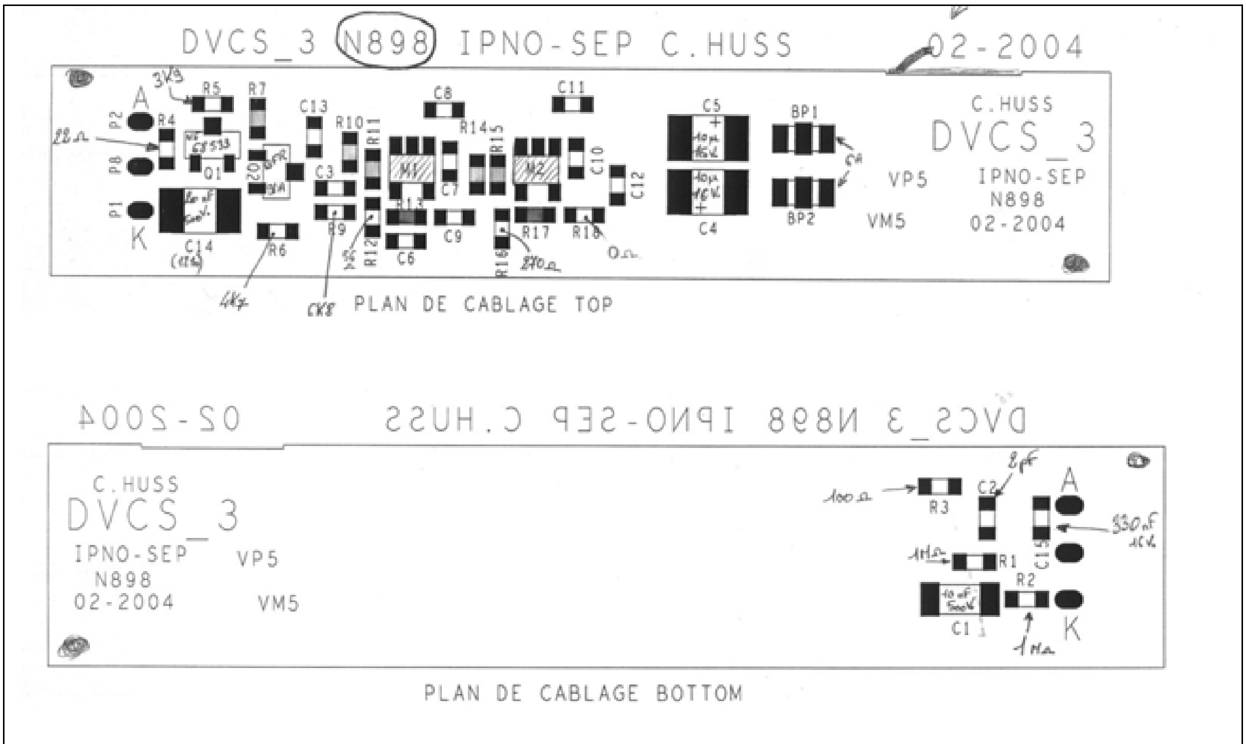

Figure 1: top and bottom views of the original IC preamplifier (DVCS experiment 2004-2005).

The figure 2 gives the original scheme.

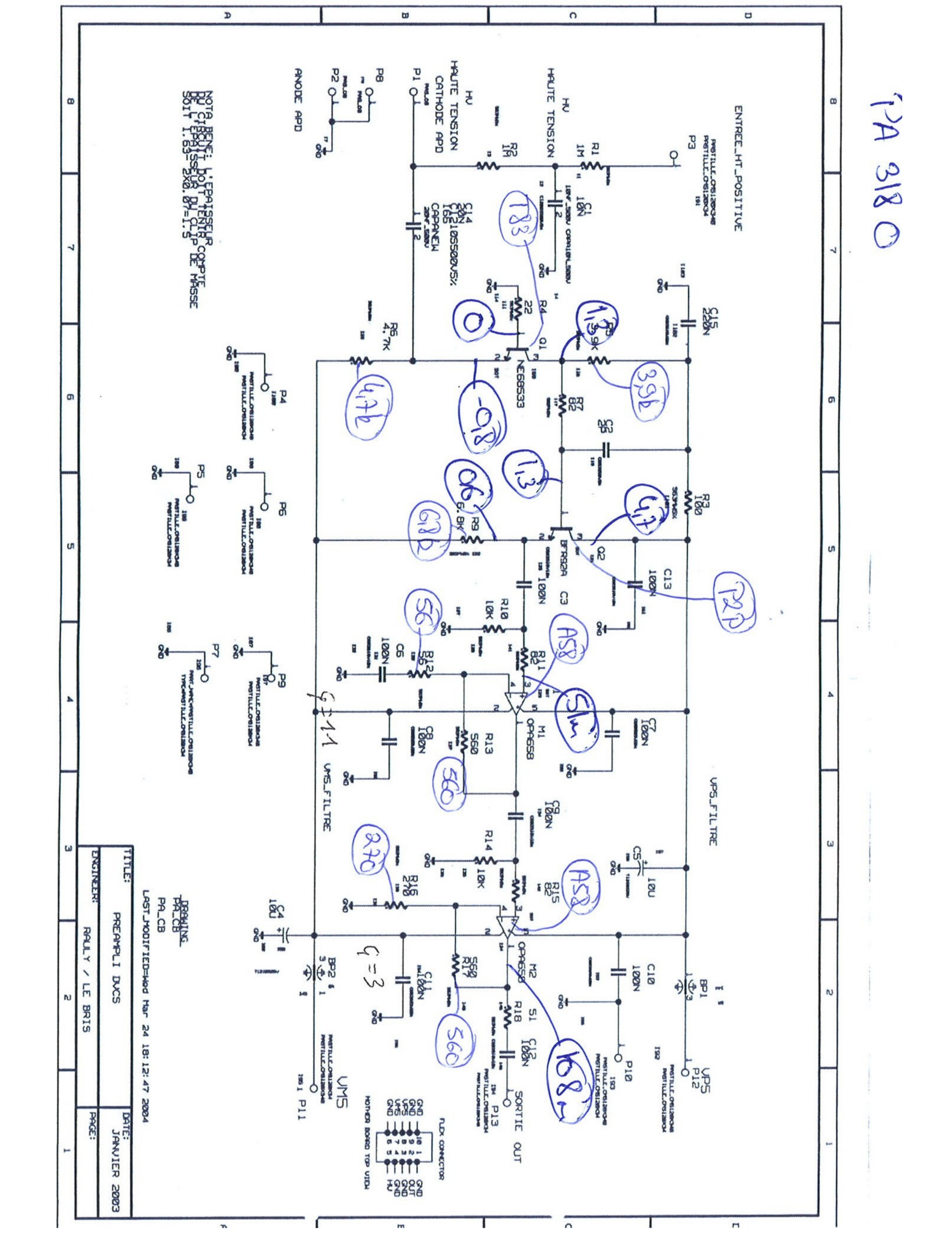

Figure 2: original scheme of the IC preamplifier (DVCS experiment).

The figures 3a (for Qin=0.6pC) and 3b (for saturation) give the output signals (yellow) for the preamplifier N318 and for 20ns input pulse-width. This 0.6pC input charge corresponds to about 3 GeV in the crystal for 5×5 mm^2 APD (assumptions: APD gain=200 and 6 photo-electrons/MeV).

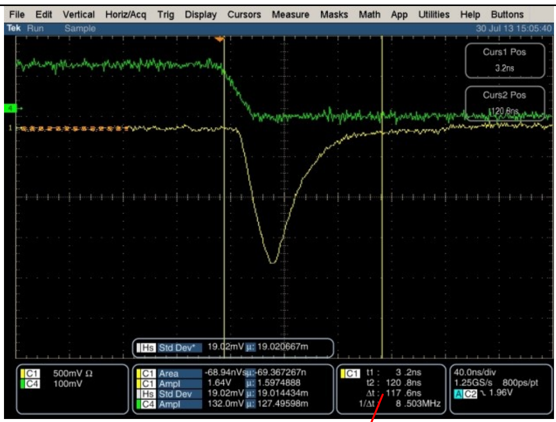

Figure 3a: output signal (yellow) of the N318 preamplifier and for 0.6pC input charge. The integration gate is about 120ns.

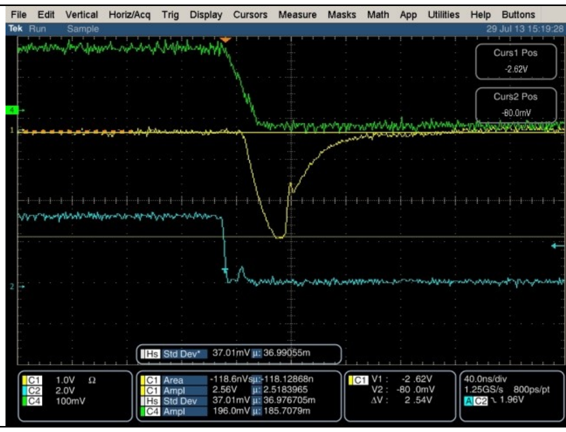

Figure 3b: saturated output signal (yellow) of the N318 preamplifier and for 0.85pC input charge.

It is worth noting that there is no saturation for 3GeV (or Qin=0.6pC). Furthermore, the integration gate is about 120ns.

The figures 4a and 4b give the linearity curves for the preamplifier N318 respectively for input charges and input energies.

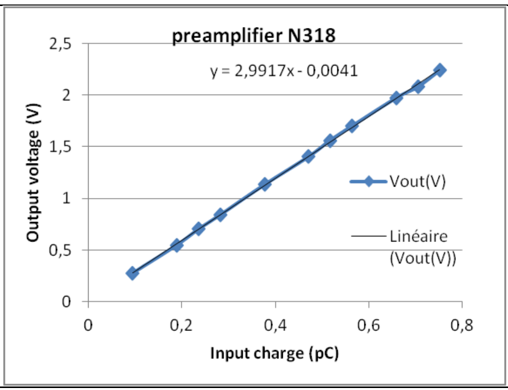

Figure 4a: output voltage (V) as a function of the input charge (pC) for the preamplifier N318. The input pulse width is 20ns. The gain is 3V/pC.

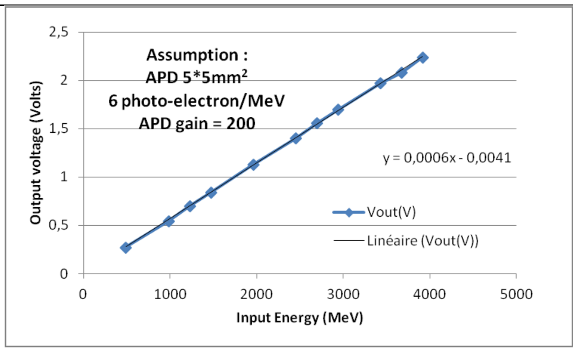

Figure 4b: output voltage (V) as a function of the input Energy in the crystal (MeV) for the preamplifier N318. The assumptions are: 5×5mm^2 APD, 6 photo-electrons/MeV and APD gain = 200. The input pulse width is 20ns.

The figures 3 and 4 can give the following characteristics/informations:

- the preamplifier gain (for 20ns input pulse width) = 3V/pC or 0.6mV/MeV
- the integration gate is about 120ns
- the output saturation is about 2.5V (for Qin=0.85pC)

The figures 5 give the output signal (preamplifiers N318) for 6fC as input charge (Vin = 1.36mV for 4.7pF) and for 20ns input pulse-width.

Figure 5: output signal (yellow trace) of the preamplifier N318 and for 6fC as input charge. Without input capacitance.

6fC corresponds to about 30MeV in the crystal (for 5×5 mm^2 APD). The minimum signal that could be detected is close to 30MeV.

The output noise is given on figures 6a (without input capacitance) and 6b (with 82pF input capacitance).

Figure 6a: output noise of the preamplifier N318 without input capacitance. The standard deviation is 2.2mV-RMS.

Figure 6b: output noise of the preamplifier N318 with 82pF input capacitance. The standard deviation is 4.2mV-RMS.

The output standard deviation is 2.2mV-RMS (without input capacitance). With a gain of 3V/pC, it corresponds to an input equivalent input noise of 0.00073 pC (=2.23mV/3000) or 0.73fC-RMS .

For 82pF input capacitance, the output noise is 4.2mV-RMS which corresponds to 1.4fC-RMS or 7.5 MeV as input noise.

The power consumptions are: 12mA for +5V and 12mA for -5V.

The aim of the modifications is:

- to increase the bandwidth to fit in a 50ns integration gate
- to detect 3GeV in the crystal for 2V output dynamic
- to detect the minimum energy of 10 MeV

In this paper, the reference preamplifier will be the N318 and we will modify the others N340, N346 and N363 and FT22.

3/ Use of Hamamatsu 5×5 mm² APD : preamplifiers modification

3.1/ Introduction

If we consider the coupling between the crystal and the 5×5 mm² APD (geometry, gluing and quantum efficiency), we assume that we have a transfer coefficient of 6 photo-electrons/MeV before multiplication (**to be confirmed**). The suggested APD gain is equal to 200 but can be modified (**to be confirmed**). The detector capacitance should be 80pF.

10MeV in the crystal corresponds to 1.9fC ($=10\times6\times200\times1.6\times10^{-19}$) at the preamplifier input.

3GeV in the crystal corresponds to 0.576pC ($=3000\times6\times200\times1.6\times10^{-19}$) at the preamplifier input.

3.2/ modification of the preamplifier N363

The proposed simple modification (preamplifier N363) consists to remove a compensation capacitance (M1=OPA658 and C2=NC). The figure 7 gives results for an input charge of 0.6pC and also for an equivalent input capacitance of 82pF.

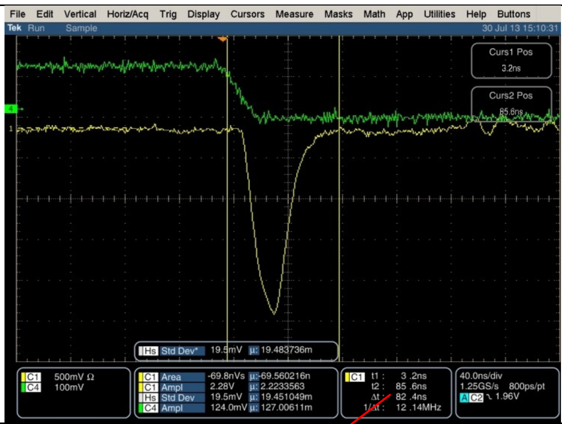

Figure 7: output signal for 0.6pC as input charge and for an equivalent input capacitance of 82pF. Preamplifier N363. The integration gate is close to 82ns.

The figures 8a and 8b give the differences in term of noise respectively for an input capacitance of 0pF and 82pF and for the modified N363 preamplifier (M1= OPA658 and C2=NC).

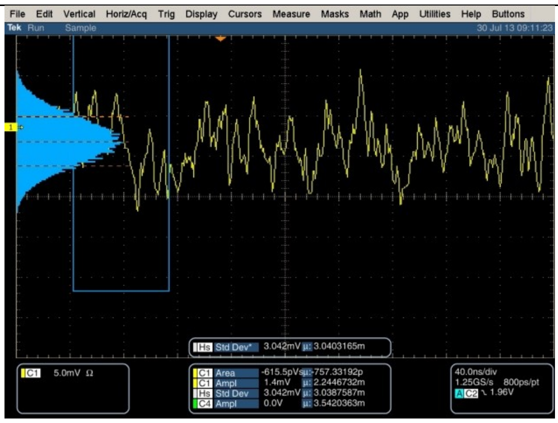

Figure 8a: output noise for the modified N363 preamplifier with M1=OPA658 and C2=NC and without input capacitance. The output noise is 3mV-RMS.

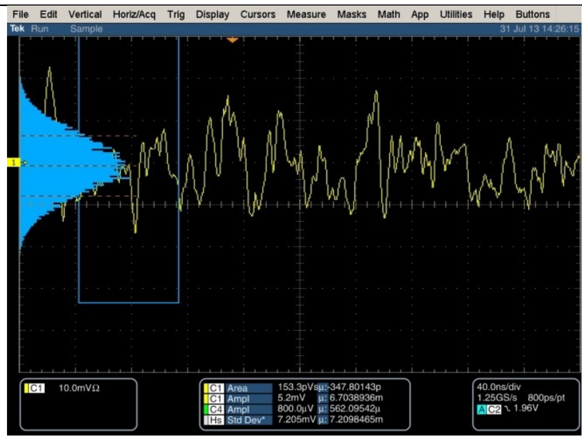

Figure 8b: output noise for the modified N363 preamplifier with M1=OPA658 and C2=NC for 82pF input capacitance. The output noise is 7.2mV-RMS.

The minimum estimated signal is given on figure 9. The minimum detected input charge corresponds to about 7.7fC or 40 MeV (APD gain =200 and 6 photo-electrons/MeV).

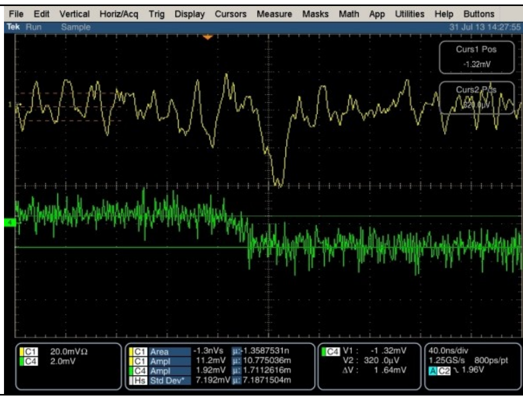

Figure 9: minimum estimated output signal for Qin= 7.7fC (Vin=1.64mV and 4.7pF).

3.3/ modification of the preamplifier N346

The modifications for the preamplifier N346 are the following (with respect to the scheme figure 2): Q1 = Q2 = BFR182, C2=NC, R6=4.7kΩ.

The main informations are given on figure 10a (integration gate = 75ns) and 10b (linearity curve).

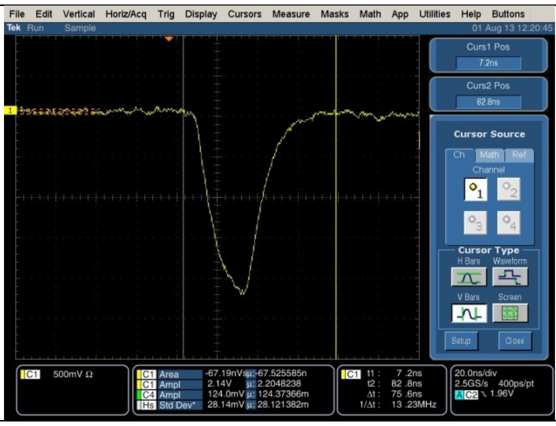

Figure 10a: output signal for an input charge of 0.6pC. The estimated integration gate is 75ns.

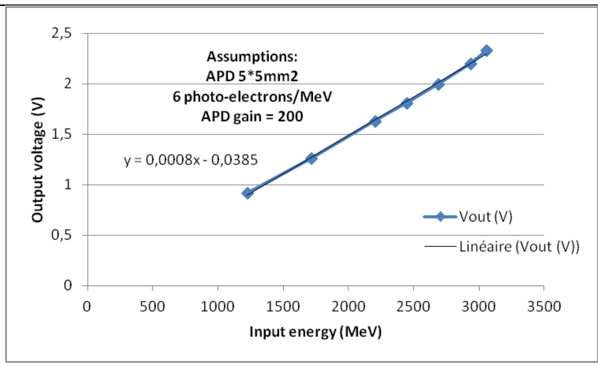

Figure 10b: output voltage as a function of the input energy. The gain is 0.8mV/MeV.

For an input capacitance of 82pF, the output noise is 6.6mV which corresponds to an estimated input noise of 8.2MeV.

4/ Use of Hamamatsu 10×10 mm^2 APD : FT22 preamplifier modification

If we consider the coupling between the crystal and the 10×10 mm^2 APD (geometry, gluing and quantum efficiency), we assume that we have a transfer coefficient of 25 photo-electrons/MeV before multiplication (**to be confirmed**). The suggested APD gain is equal to 150 but can be modified (**to be confirmed**). The APD capacitance should be 270pF.

10MeV in the crystal corresponds to 6fC ($=10\times25\times150\times1.6\times10^{-19}$) at the preamplifier input.

3GeV in the crystal corresponds to 1.8pC ($=3000\times25\times150\times1.6\times10^{-19}$) at the preamplifier input.

The aim is to use the characteristics close to FT CLAS12 preamplifiers.

The new scheme is given on figure 11 (as compared to the original scheme on figure 2).

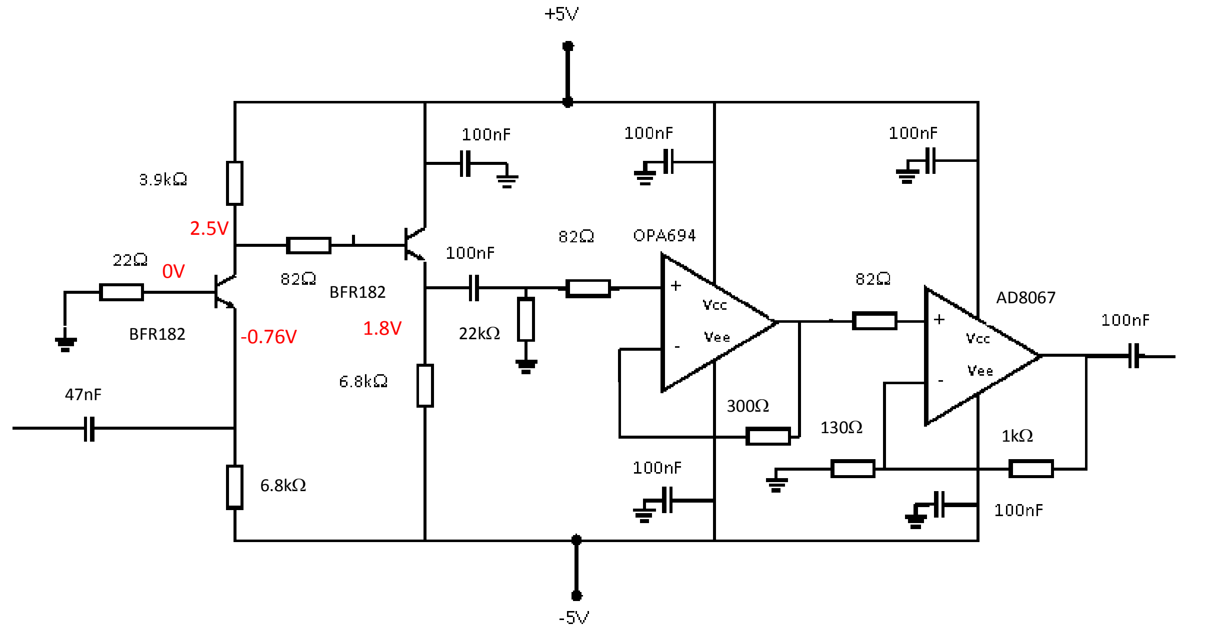

Figure 11: New scheme to fit to 10×10 mm^2 APD based on CLAS12 FT preamplifiers.

The main modifications are the following:

Q1=Q2=BFR182, M1=OPA694, M2=AD8067

R5=3.9kΩ (collector resistance of the input transistor)

R6=6.8kΩ (emitter resistance of the input transistor)

R10=22kΩ, R12=NC, R13=300Ω, R17=1kΩ, R16=130Ω, C9=0Ω, R14=NC, C2=NC

Some measured DC points are also written on the scheme.

We have modified the FT22 preamplifier. The figure 12 gives the output signal (yellow) for an input charge of 1.8pC. It corresponds to about 3GeV with the following assumptions: 25 photo-electrons, APD gain = 150.

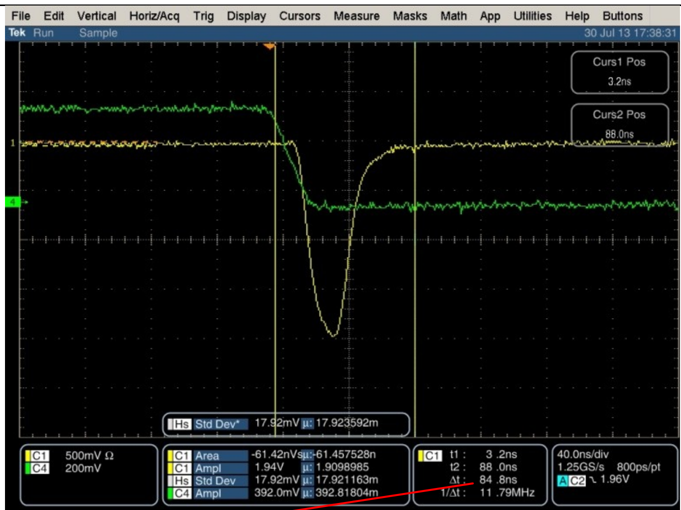

Figure 12: Output signal (yellow) for an input charge of 1.8pC. The peak voltage is 2V and the integration gate is 85ns. The input pulse width is 20ns

The peak voltage is about 2V for an input charge of 1.8pC. Then the estimated gain is about 1.1V/pC for 20ns input pulse width.
Furthermore, the estimated integration gate is 85ns.

The figure 13a gives the output noise without input capacitance whereas the figure 13b represents this noise with a 270pF input capacitance (close to the APD capacitance).

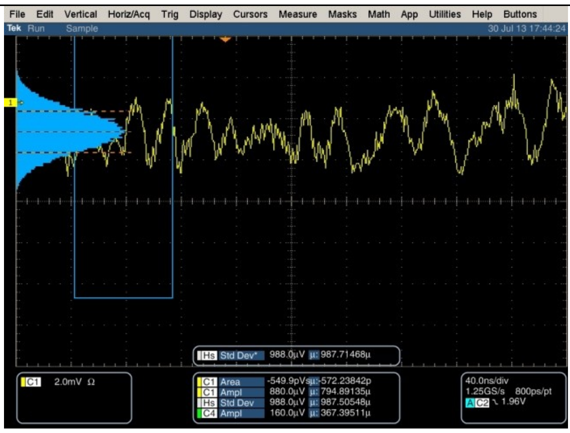

Figure 12a: output noise of the modified FT22 preamplifier without input capacitance. The output noise is 987µV-RMS.

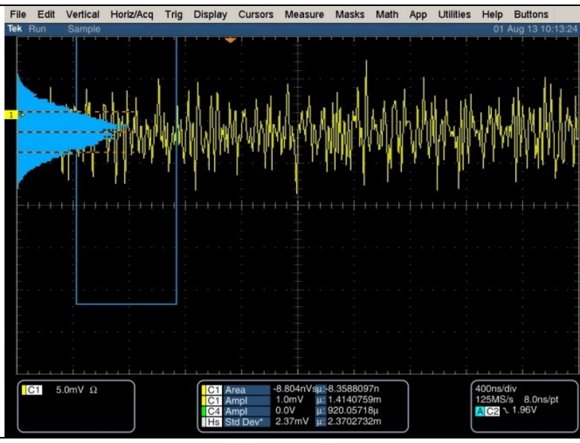

Figure12b: output noise of the modified FT22 preamplifier with 270pF as input capacitance. The output noise is 2.4mV-RMS.

The figure 13a and 13b give the linearity curves with respect to input charge and Energy.

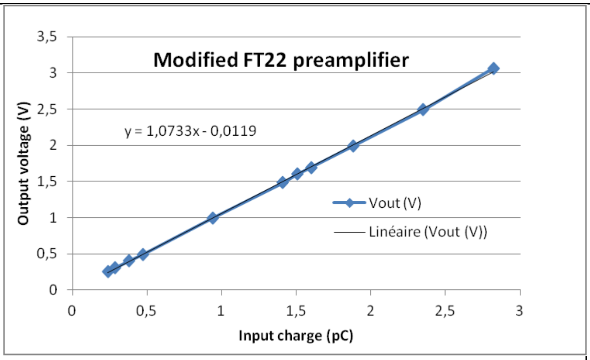

Figure 13a: output voltage as a function of the input charge for the modified scheme of figure 11. The gain is 1 V/pC.

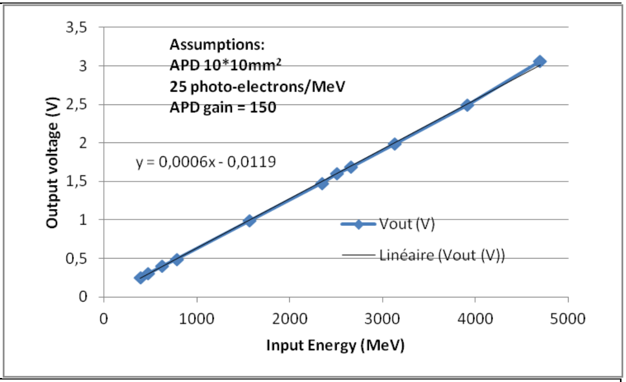

Figure 13b: output voltage as a function of the input energy for the modified scheme of figure 11. The gain is 0.6mV/MeV.

For a 270pF detector capacitance, the output noise is 2.4mV (figure 12b) which corresponds to an input noise of 3 MeV.

5/ Summary

5.1/ Summary for APD 5×5 mm^2 configuration

In the following chart, the assumptions are:

- Input pulse width = 20ns
- 6 photo-electron/MeV before multiplication
- APD gain =200

Preamplifier number	N318	N363	N346
Preamplifier modifications	No modification, cf figure 2 C2=2pF, Q1=NE68533 Q2=BFR92, M1=0PA658	Figure 2 with C2=NC	Figure 2 with C2=NC Q1=Q2 = BFR182 R6=4.7kΩ
Gain (V/pC) PW=20ns	3V/pC	3V/pC	4V/pC
Gain (mV/MeV) PW=20ns	0.6mV/MeV	0.6mV/MeV	0.8mV/MeV
Output voltage (V) for Ein=3GeV	1.7V	1.7V	2.2V
Estimated integration gate (ns)	120ns	82ns	**75ns** **See figure 10a, p10**
Measured RMS output noise without detector capacitance (mV)	2.2mV	3mV	3mV
Measured output noise with 82pF detector capacitance (mV-RMS)	4.2mV	7.2mV	6.6mV
Estimated RMS input noise without detector capacitance (MeV)	3.7MeV	5MeV	3.9MeV
Estimated RMS input noise with 82pF detector capacitance (MeV)	7.5 Mev	12MeV	**8.2MeV**
Estimated minimum input signal that can be detected in MeV	30MeV	40MeV	30MeV

5.2/ Summary for APD 10×10 mm^2 configuration

In the following chart, the assumptions are:
- Input pulse width = 20ns
- 25 photo-electron/MeV before multiplication
- APD gain =150

Preamplifier number	FT22	N055	
Preamplifier main modifications	C2=NC, Q1=Q2=BFR182, M1=0PA694, M2AD8067	Q1=Q2=BFR182 C2=NC R12=75Ω R16=NC	
Gain (V/pC) PW=20ns	1V/pC	1V/pC	
Gain (mV/MeV) PW=20ns	0.6mV/MeV	0.6mV/MeV	
Output voltage (V) for Ein=3GeV	1.9V	1.9V	
Estimated integration gate (ns)	85ns	85ns	
Measured output noise with 270pF detector capacitance (mV-RMS)	2.4mV	2.5mV	
Estimated RMS input noise with 270pF detector capacitance (MeV)	4MeV	4.2MeV	
Estimated minimum input signal that can be detected in MeV	20MeV	20MeV	

6/ Partial conclusion

- With the use of the APD 5×5mm^2, the modified preamplifier N346 (see chart paragraph 5.1/, page 9) seems to give the best characteristics: integration gate = **75ns** and estimated input RMS noise = **8.2MeV**.
- However, the desired integration gate of 50ns was not reached.
- Futhermore, the minimum input signal that can be detected is **30 MeV** and not 10 MeV.
- If desired, I can try to reach 50 ns (decreasing R5 on figure 2 and increasing the gain of the other stages).
- With the use of the APD 5×5mm^2, I think it will be not possible to detect 10MeV of input signal except if we increase the APD gain.
- With the use of the APD 10×10mm^2, the significantly modified preamplifier FT22 (see chart paragraph 5.2/ and figure 11, page 7) seems to give good characteristics: integration gate = **85ns** and estimated input RMS noise = **4MeV**.
- A lighter modification can be tested
- The input noise is the lowest if we use the APD 10×10mm^2