Fermilab, Batavia (IL) September 22, 2015

Characterization of a SensL C-30035-16P Silicon Photomultiplier array at cryogenic temperature

LArIAT - Neutrino division

OVERVIEW:
- -search for the best configuration for the front-end electronics
- -device testing
- -future aims

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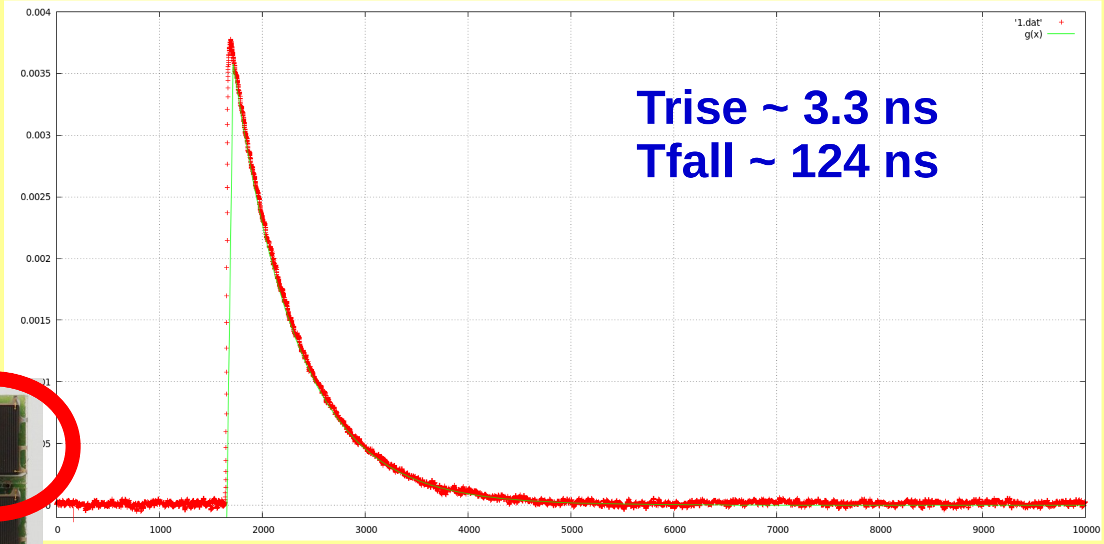
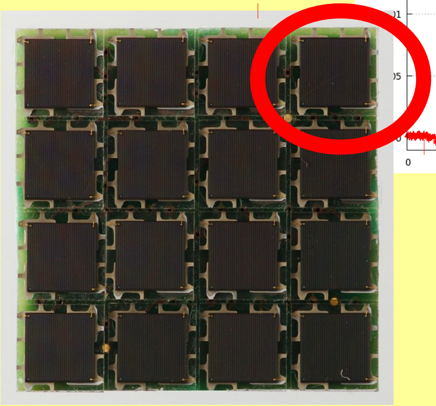
The best configuration

Before starting with the cryogenic test, we have compared several configurations in order to find the one which will have the smallest alterations at low temperature

First of all, we have taken as reference a SensL evaluation board. On it there is installed a single SMT (surface mount technology) SiPM with the same characteristics of one of our 16 SMT SiPM of the Array.

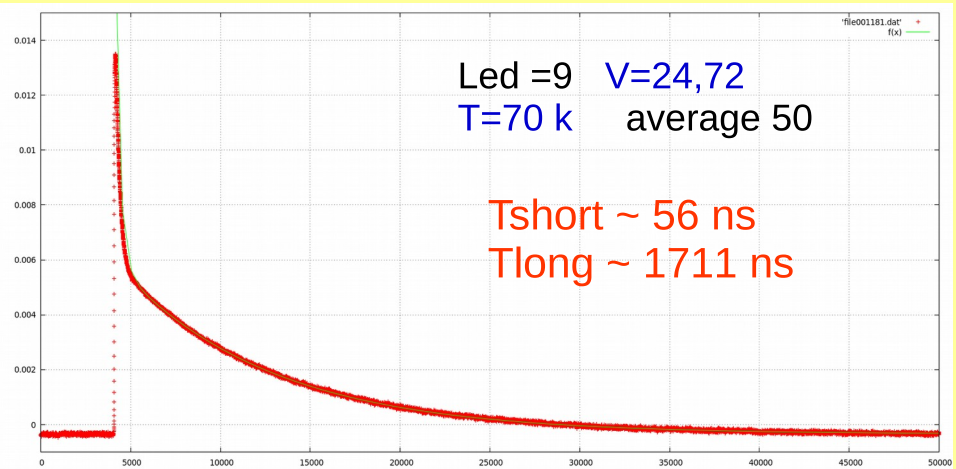
The MicroFC-SMA board: 3mm SMT version.

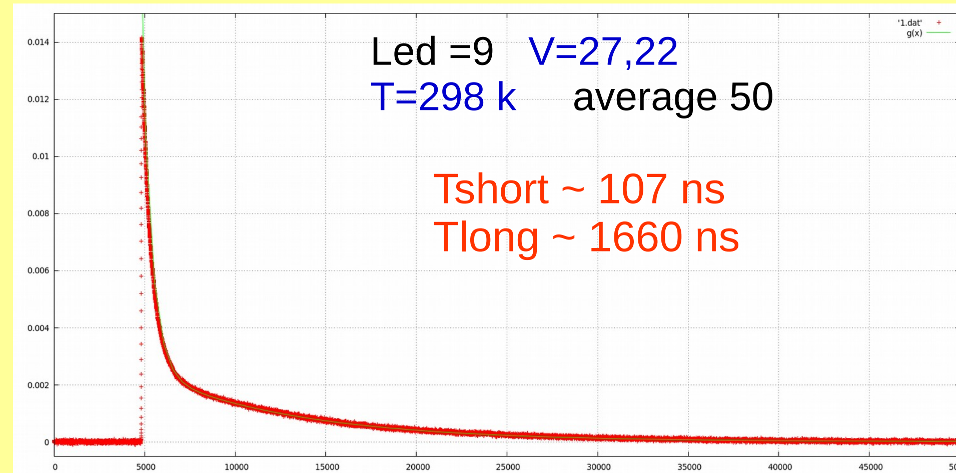




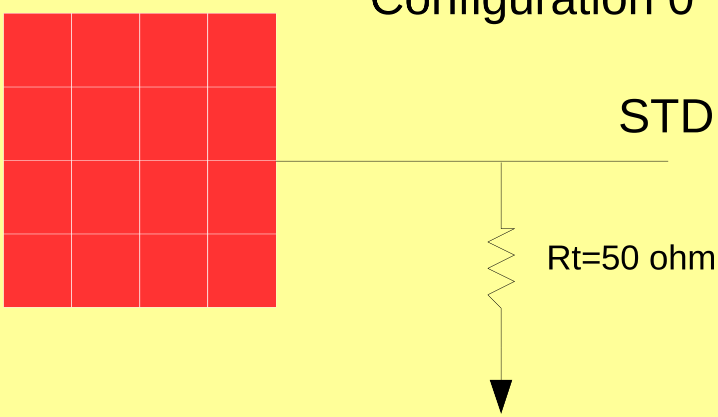
Our ArrayC-30035-16P-PCB comprised of 16 individual 3mm SMT sensors arranged in a 4x4 array

The first step with our board has been building a configuration similar to the evalutation board: “Configuration 0”





“Configuration 0”



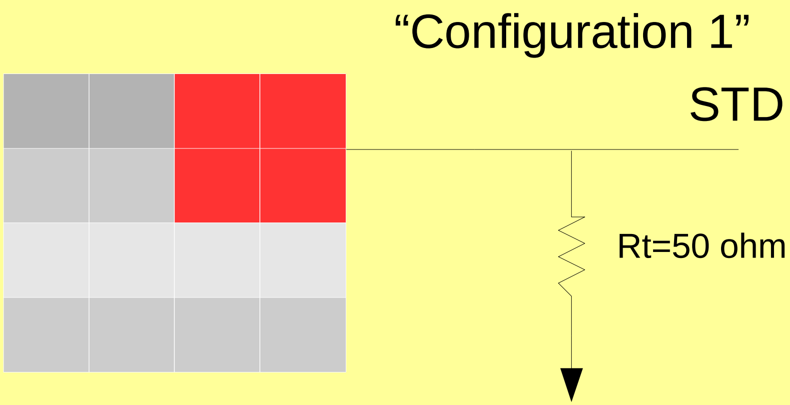
In this configuration all 16 the SMT are connected together.
This causes a stretching of the discharge time due to the intrinsic capacity of each SMT, that here are connected in parallel

Tfall_long=R_load*C_tot

R_load=Rt C_tot=16*C_SMT

C_SMT= 850 pF (from SensL data sheet)

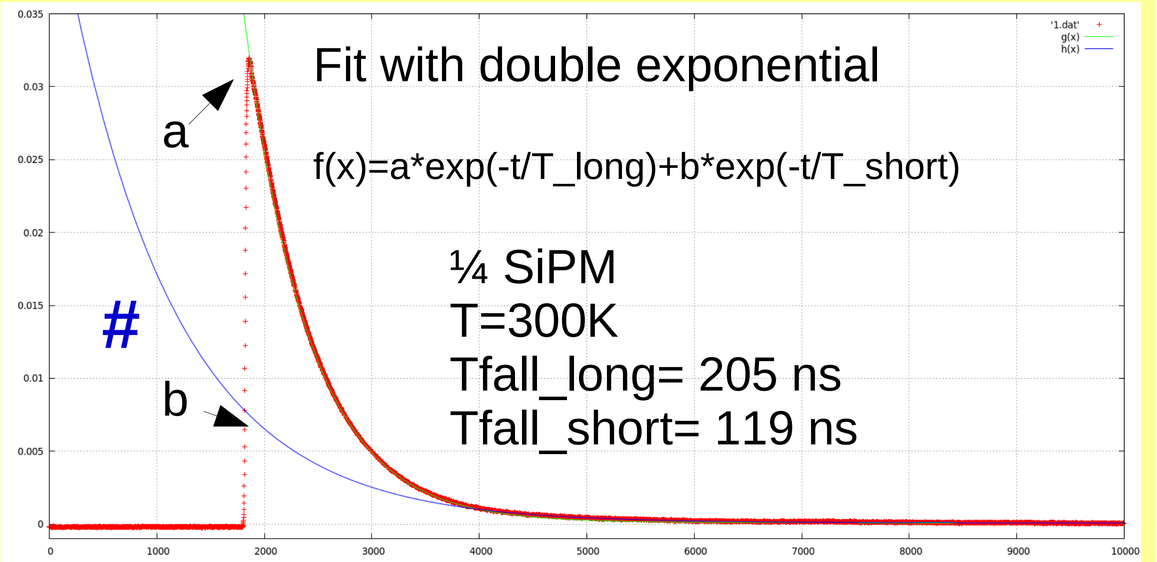
To solve the tau fall problem we set a new configuration, in which the 16 SMT are connected 4 by 4 to a R_load of 50 Ohm. “Configuration 1”

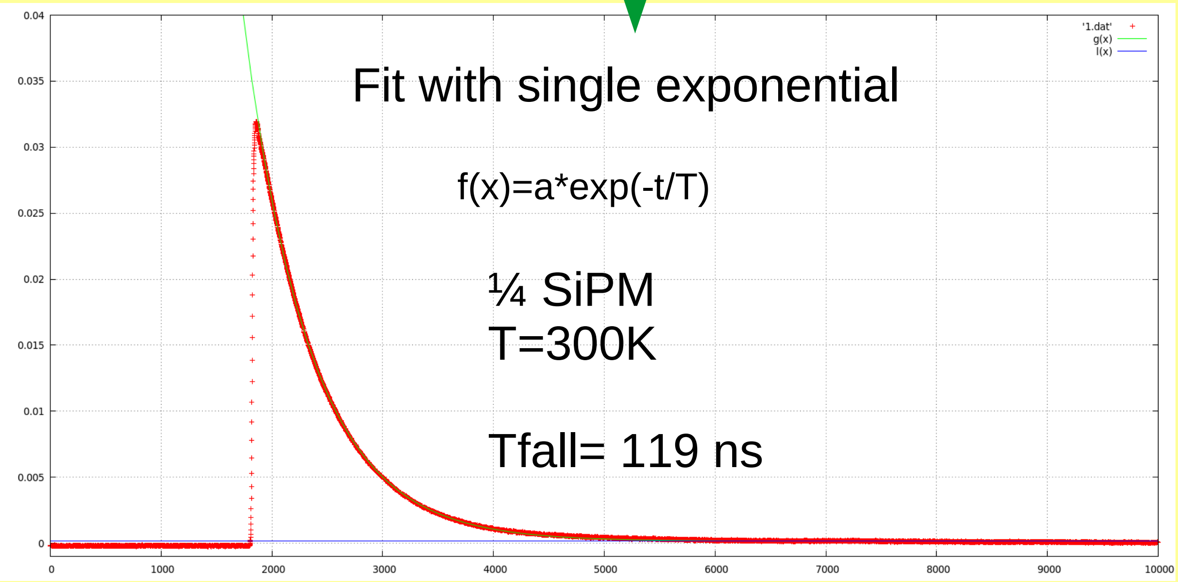


In this case(as in the evaluation board) the Tfall_long ~ Tfall_short and the multiplication factor of the exponential is << (#), so we can approximate the fall with a unique exponential.

This approximation will not cause us any problem at cryogenic temperature because only the Tfall_short is sensible to T.

(See “PhotoDet 2012 LAL Orsay, June 2012 - The SiPM Physics and Technology - a Review **G.Collazuol** - Department of Physics and Astronomy, University”)



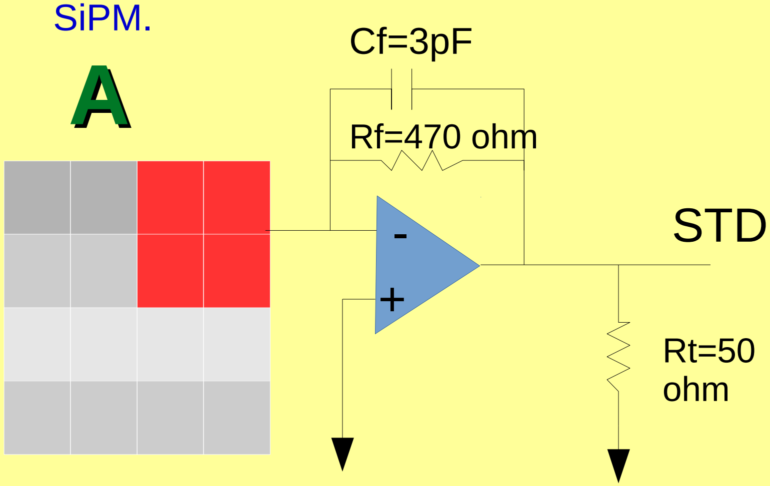


The amplification stage.

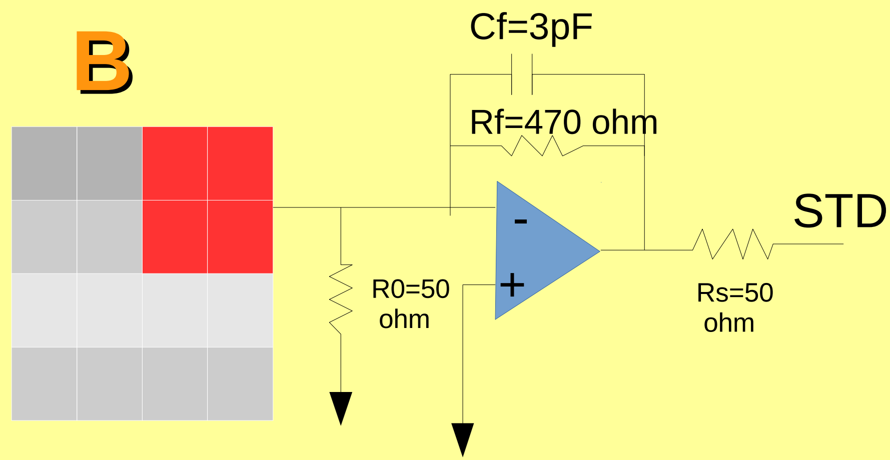
We have choosen a configuration with Rf and Cf, which ,in addition to amplify, integrates the signal, in order to detect all the charge. This makes our device able to analyze signals produced by LAr scintillation.

Like for the previous configurations, we start to test the one recommended on the SensL data sheet, but there was a lot of noise so we test various configurations.
In these first tests we connected only 4 SMT to reduce the effects due to the connection of more SMT SiPM.

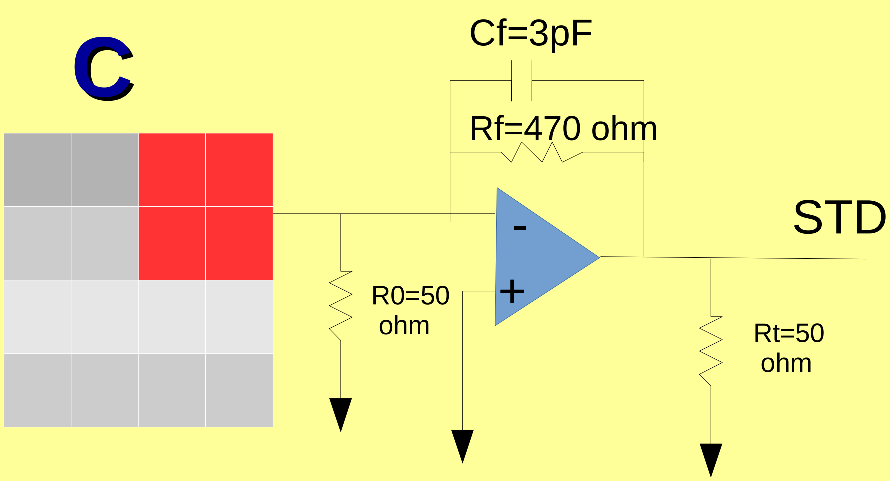
A



B



C

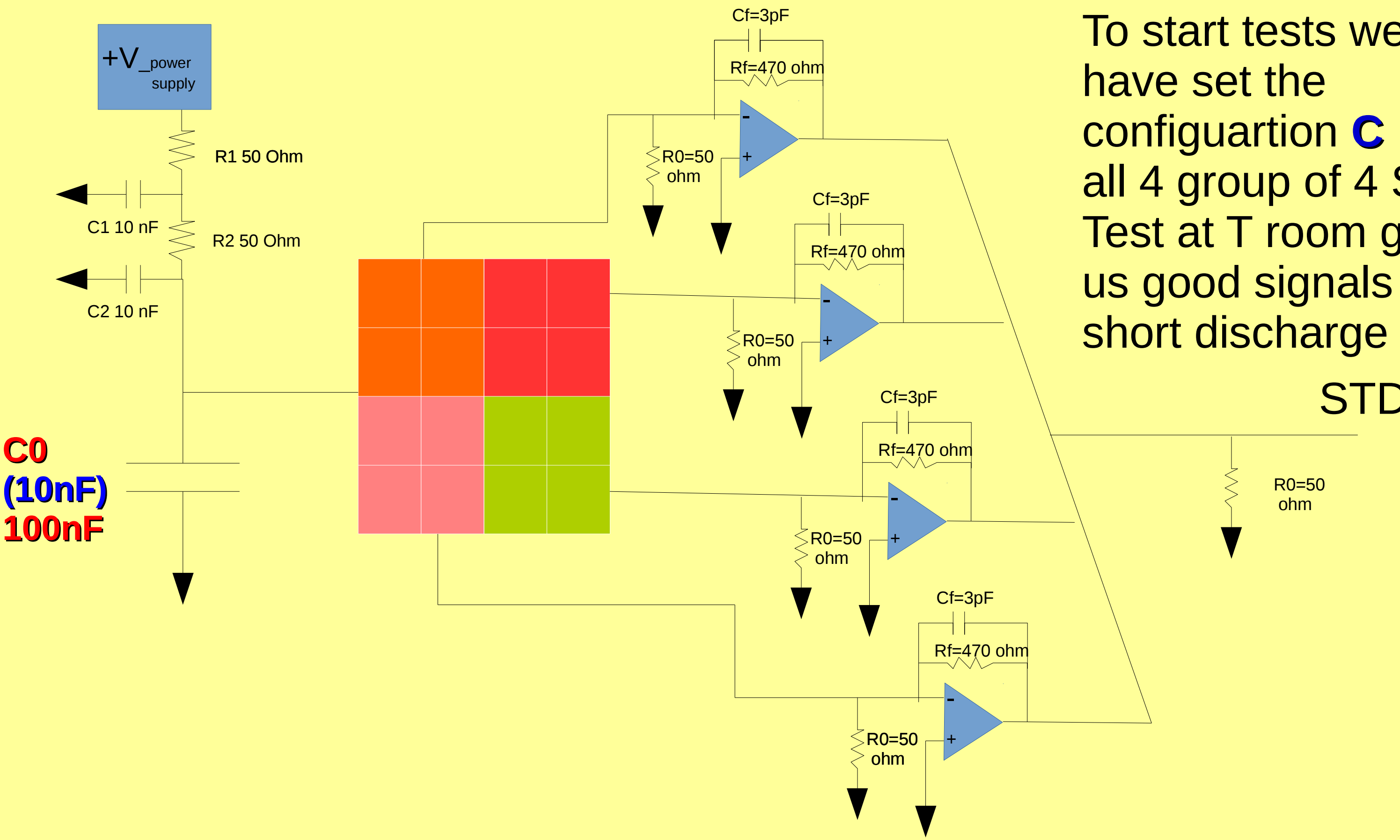


The configuration **C** has been found the best because:

-has a R0 connected directly to the 4 SMT, that allow to have a T_recovery independent from the number of SMT connected and independent on R_quenching

-has a good impedence for the oscilloscope reflection: Rt=50 ohm. The best impedence should be a R of 50 ohm in series, like Rs in conf **B**, but it can't be possible for the Rf on the OpAmp, which cause an increase of impedence seen by oscilloscope.

5- Test of SiPM with all 16 SMT connected 4 by 4, T=300K and T=70K. A new noise source: C0.



To start tests we have set the configuartion **C** for all 4 group of 4 SMT. Test at T room gives us good signals with short discharge time.

When we started to take cryogenic measures with all 16 SMT of SiPM connected, came out a new kind of noise.

I (with Albert' help) have measured each single electronic component in liquid nitrogen (77.35 K) and came out that the capacitances lose half of their value. The resistences are the same (+2 ohm).

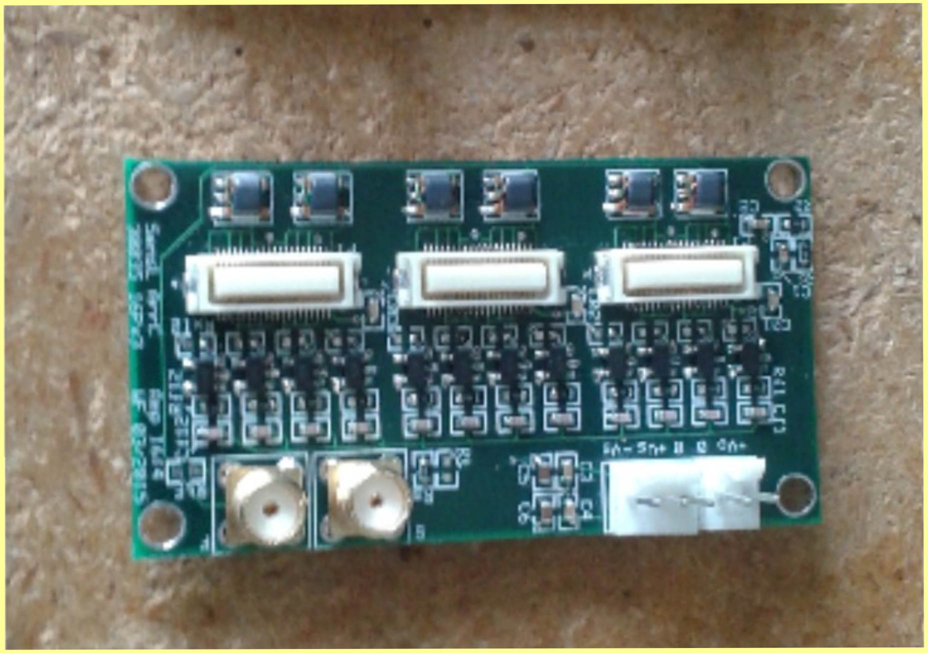
4 Sep 2015	Test C e R	Cryio T
Nominale	T room	T cryo
Ohm	R/C + wire in cool	R/C + wire in cool
66,5	66,9	68,9
49,9	50,2	52,3
470	471,6	473,6
604	606	612
3 pF	5,6 pF	26pF
10 nF	10,6 nF	4,85 nF
		Dante

So we have replaced

C0=10nF → C0=100nF

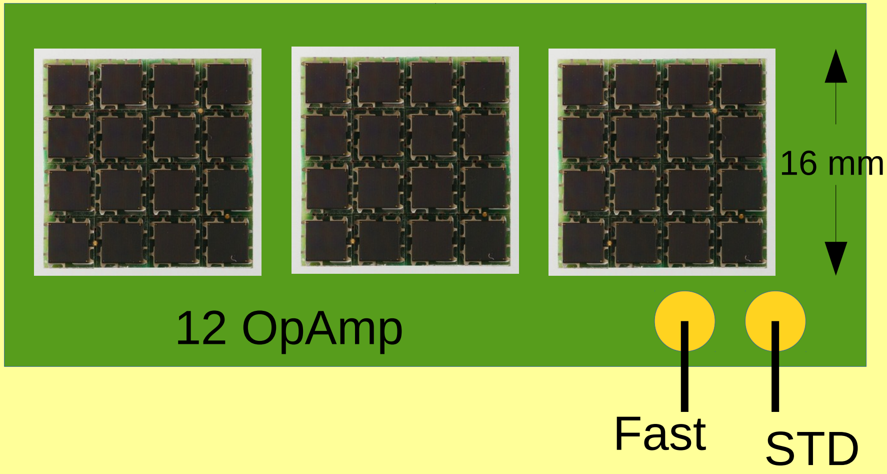
To be sure that the condition
C0>>C_SiPM aren't violated

(Light detection in nEXO - F. Retiere on behalf of the nEXO collaboration and in particular the photo-detector group 8/28/2015 pg.19)



Board designed by Irene Nutini, INFN (Fermilab summer student 2014 and Fermilab graduating 2015)

At this point we have a good configuration for the board which will lodge
THREE ArrayC-30035-16P-PCB



Below there are some exemple of fitted wave form and test on how:

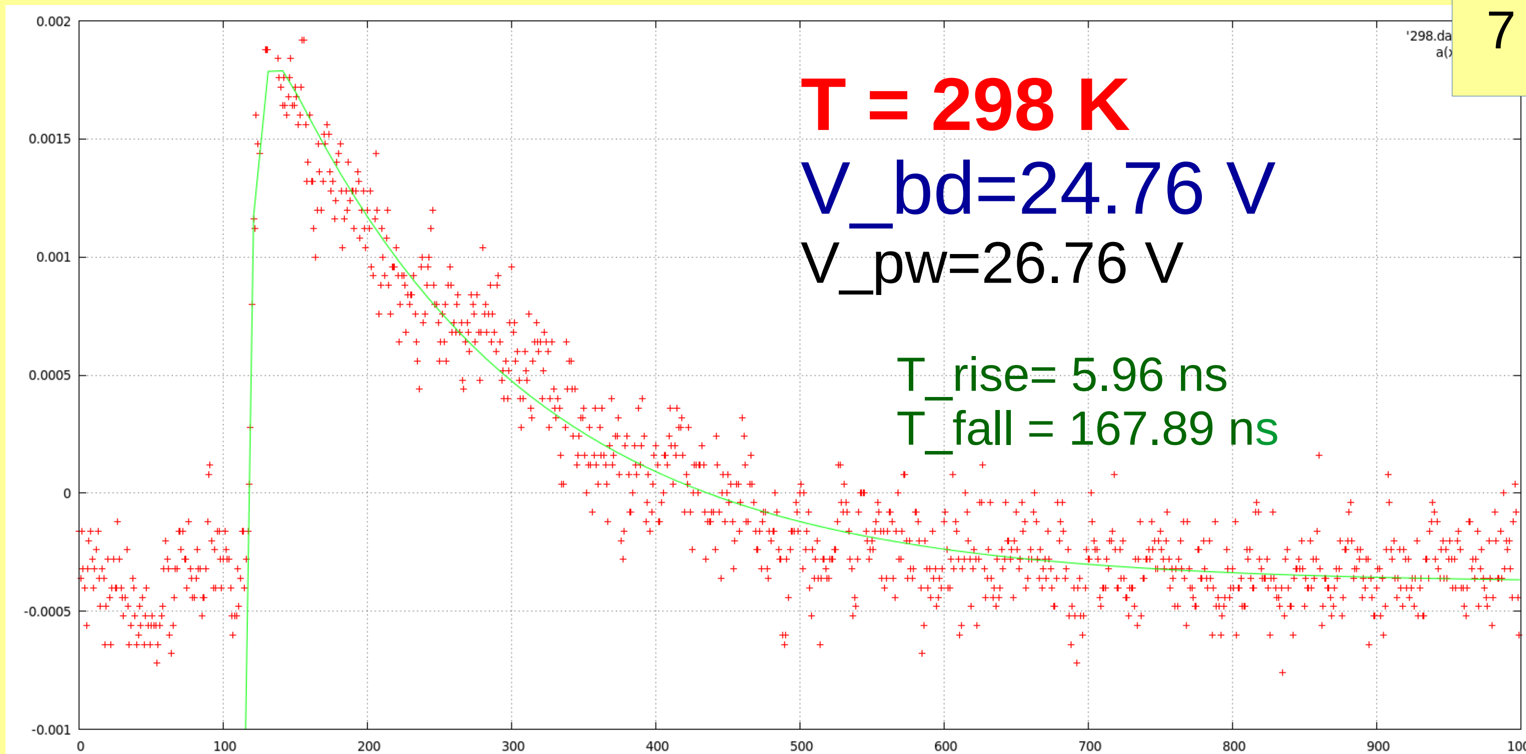
-response of the amplifier stage
- breakdown voltage
- single photoelectron response
- gain vs Vbias
- gain

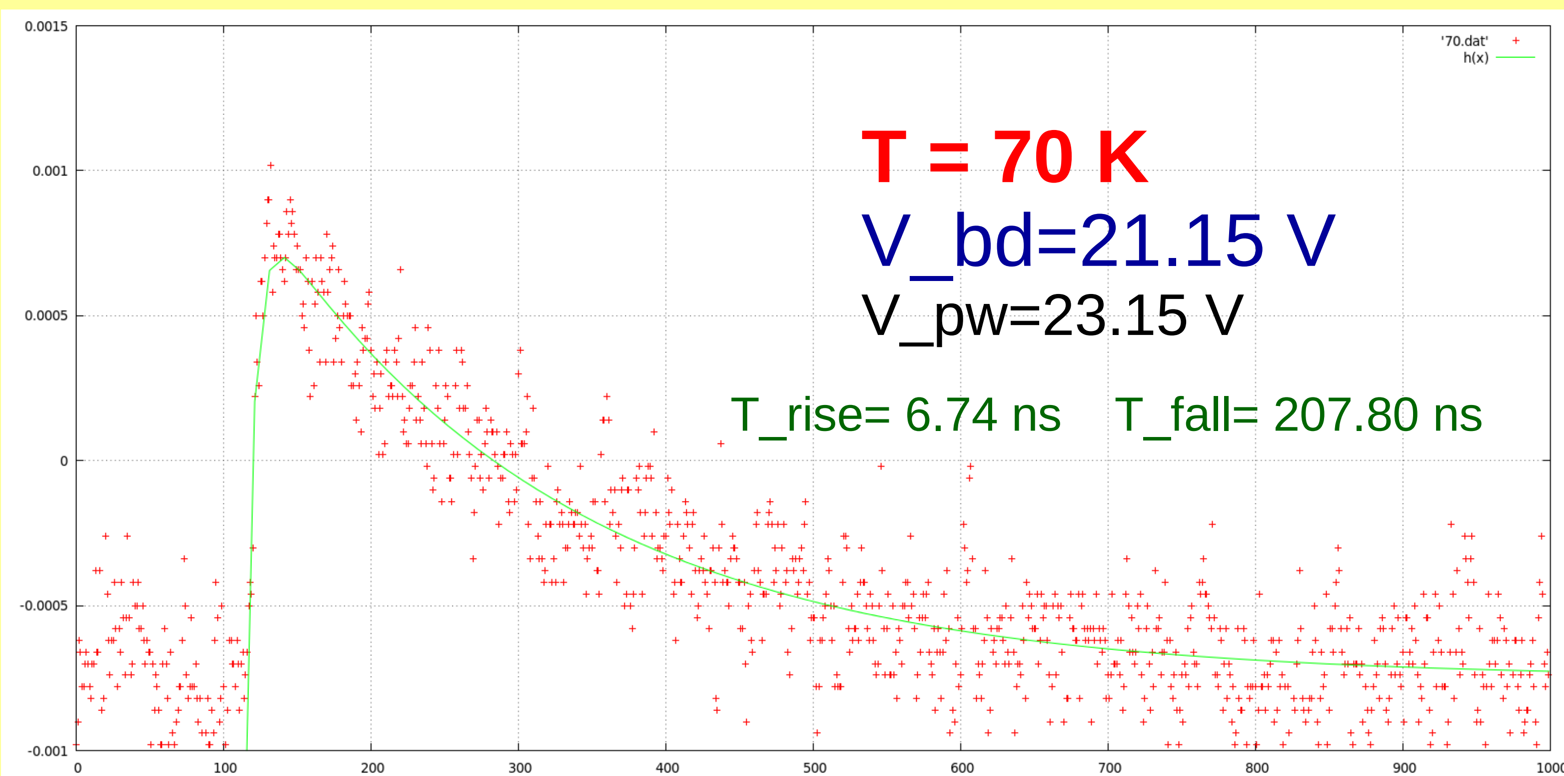
change as a function of temperature , in cryogenic range

The wave form below are the response of our device to an impulsive signal which come from a LED.
This signal is ~ 1 ns wide and monochrome: $\lambda \sim 400$ nm

SiPM direct signal

We can immediately see that, with our configuration, the signal shape doesn't change a lot from T_room to T~T_Lar

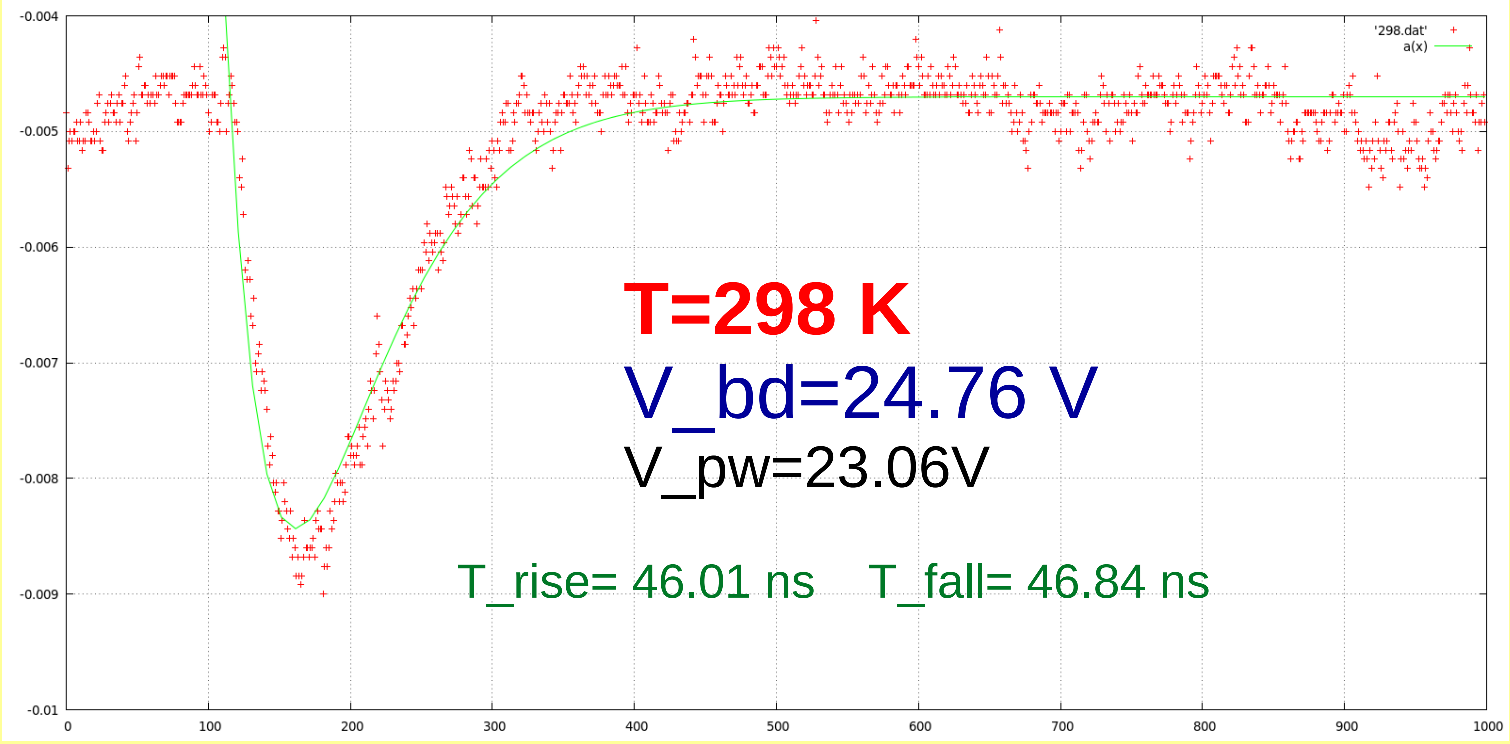




OpAmp off;
LED = 10.0;
deltaV=2V

Integrated SiPm pulse signal through preamp

When we amplify the signal,
the differences from T_room to T_Lar
are even less

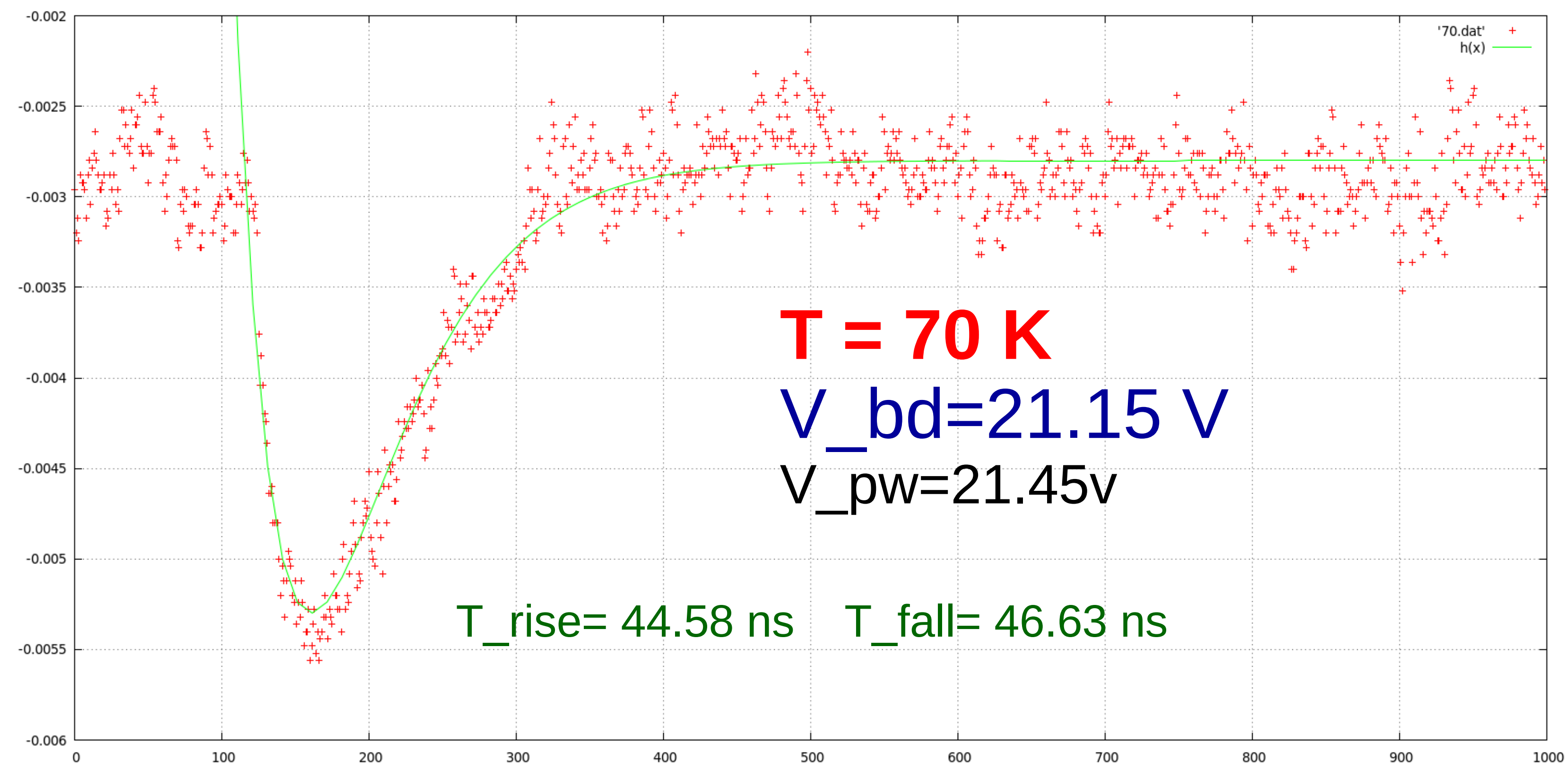


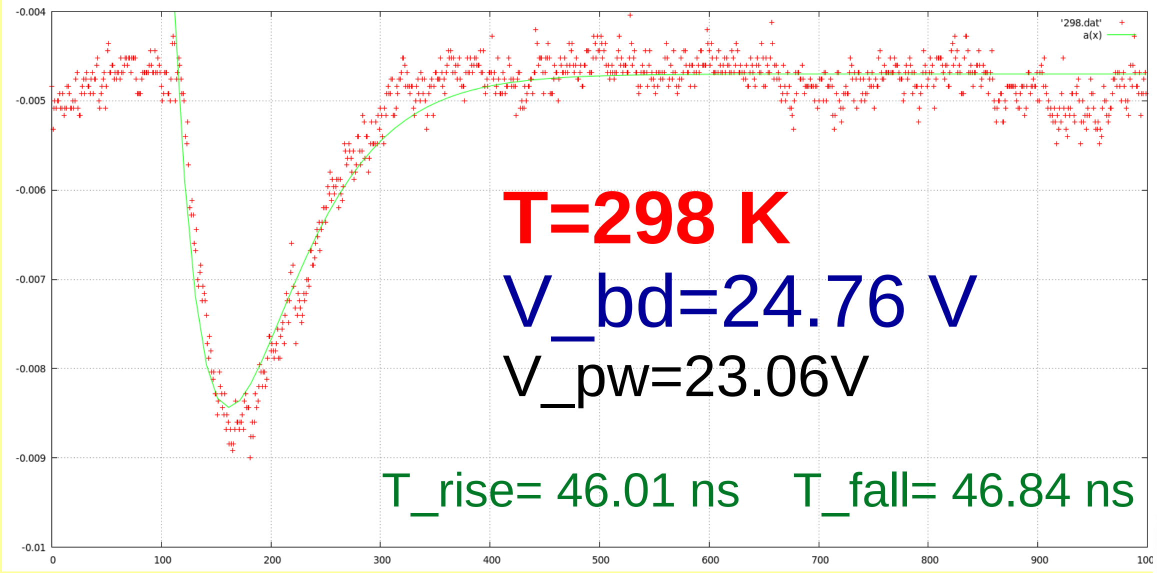
OpAmp on

deltaV = 0.30 V

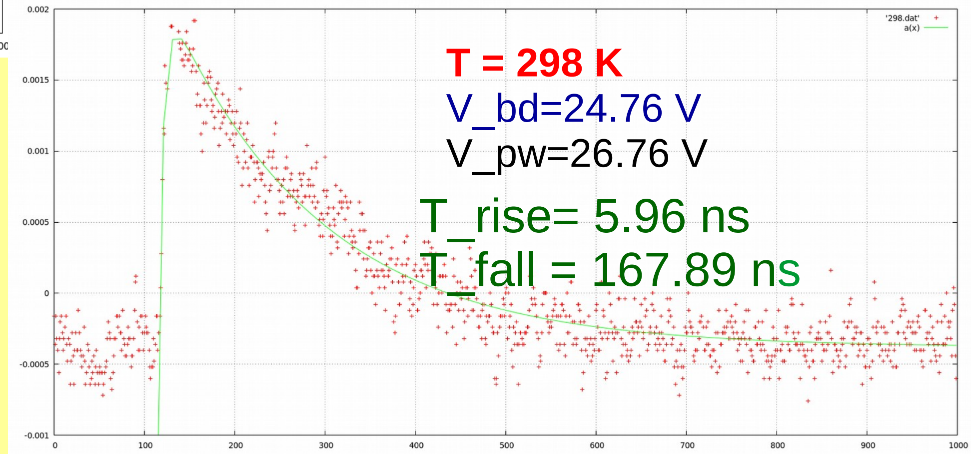
LED = 10.0

V_OpAmp = +/- 1.80 V





OpAmp on
deltaV = 0.30 V
LED = 10.0
V_OpAmp = +/- 1.80 V

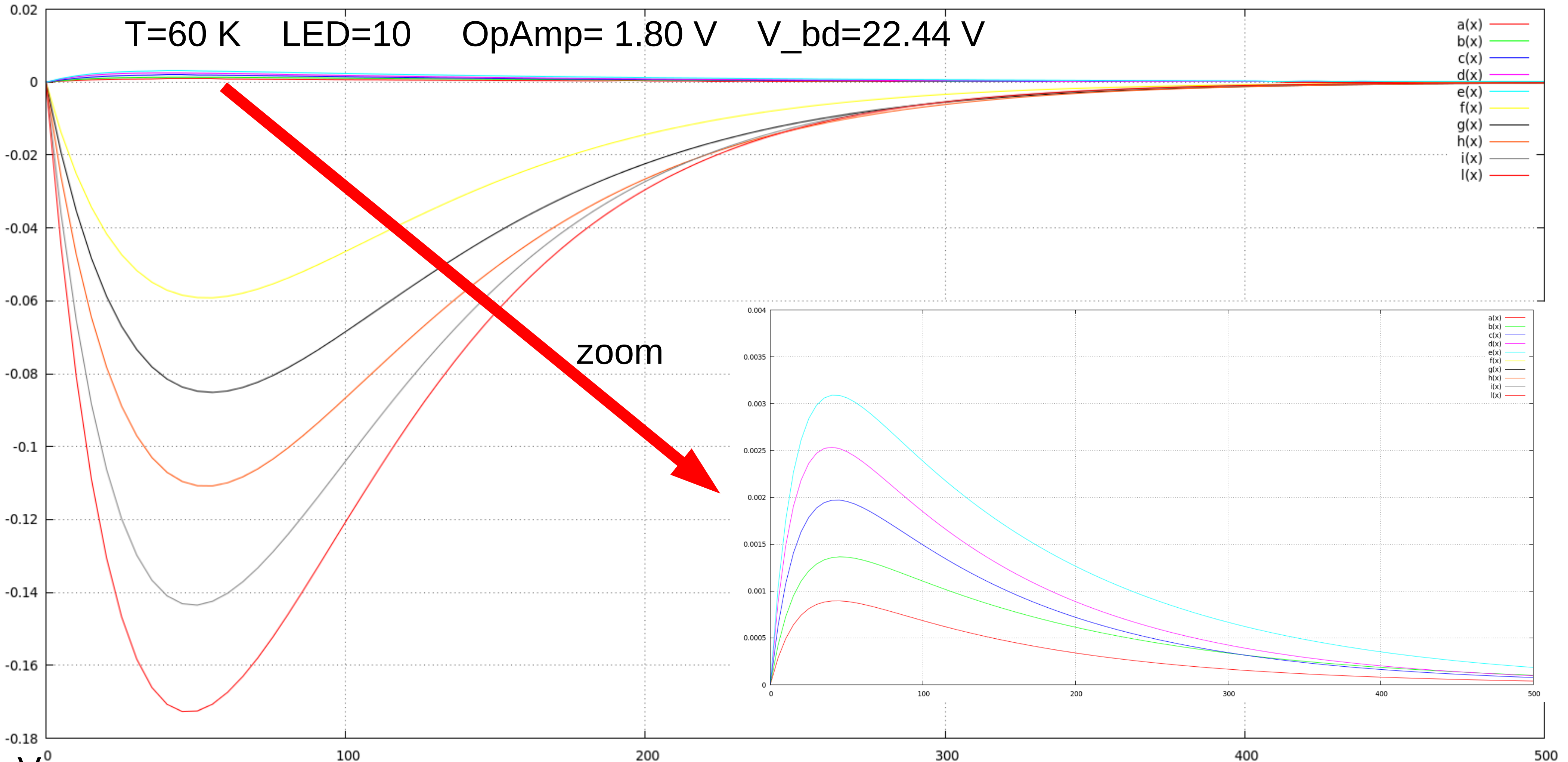


In the amplified signal we have to note that rise time is longer then in the direct signal. We think that this is due to the OpAmp performance.
From the data sheet we know that our OpAmp: "ADA4891-1" has a bandwidth of 220 Mhz → ~5 ns that is the same rising time of our signals.

One of the next steps for the future is to replace our OpAmp with someothers faster and at the same time with a good response at cryogenic temperature

STD(OpAmp off) vs STD(OpAmp on)

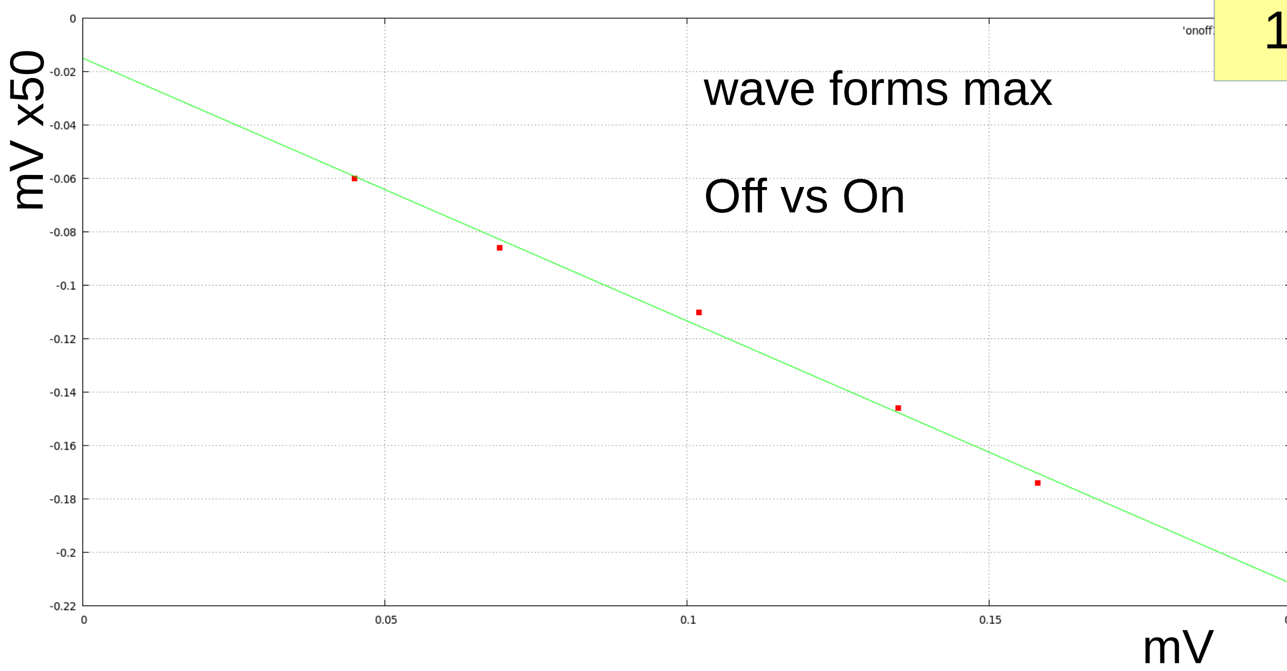
STD=standard output from the SiPM



$V_{\_pw}$ (V)	Picco OpAmp Off (mV)	Picco OpAmp On (mV)	Op Amp off Int (V*ns)	Op Amp on Int(V*ns)
23,86	0.045/50	-0.060	0.172	-8.6233
24.23	0.069/50	-0.086	0.301	-12.767
24.66	0.102/50	-0.110	0.367	-16.062
25.00	0.135/50	-0.146	0.461	-19.203
25.40	0.158/50	-0.174	0.633	-22.344

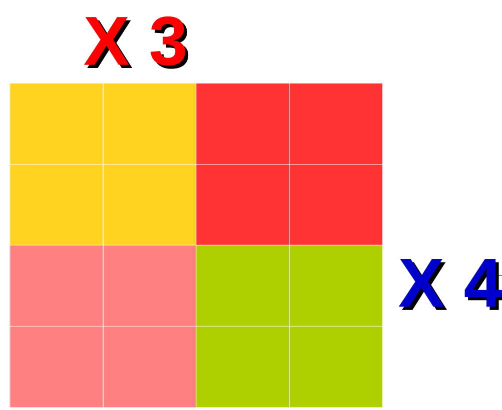
V_pw (V)	Max OpAmp Off (mV)	Max OpAmp On (mV)
23,86	0.045/50	-0.060
24.23	0.069/50	-0.086
24.66	0.102/50	-0.110
25.00	0.135/50	-0.146
25.40	0.158/50	-0.174

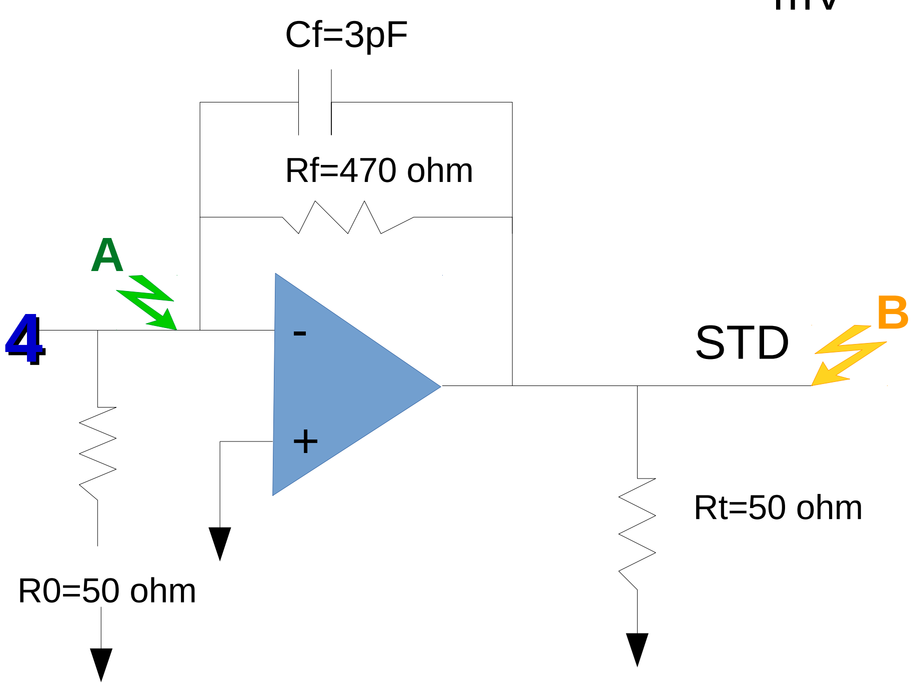
f(x)=-0.015-0.98323*x



$$\frac{\text{Amplified signal}}{\text{No amplified signal}} \approx 50$$

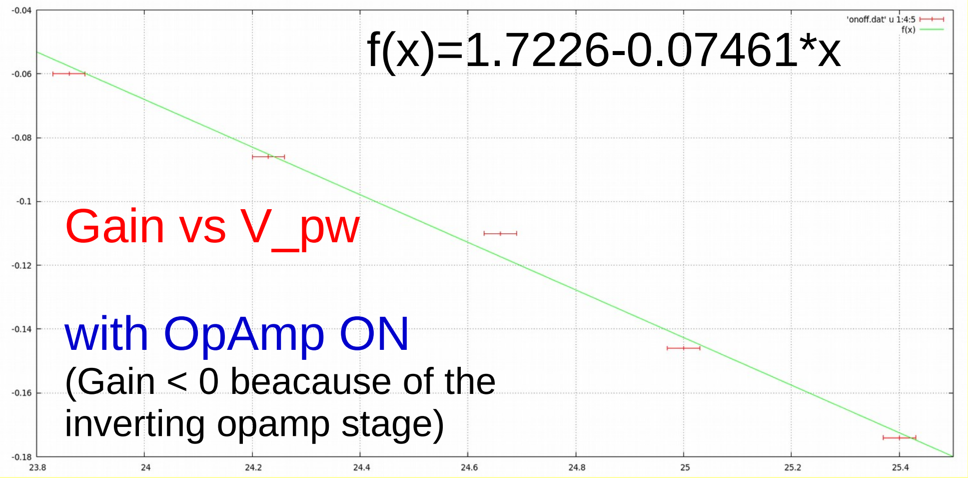
But this doesn't mean that our OpAmp gain is 50. The signal before the amplification stage isn't the same of that we see with the Op Amp off.

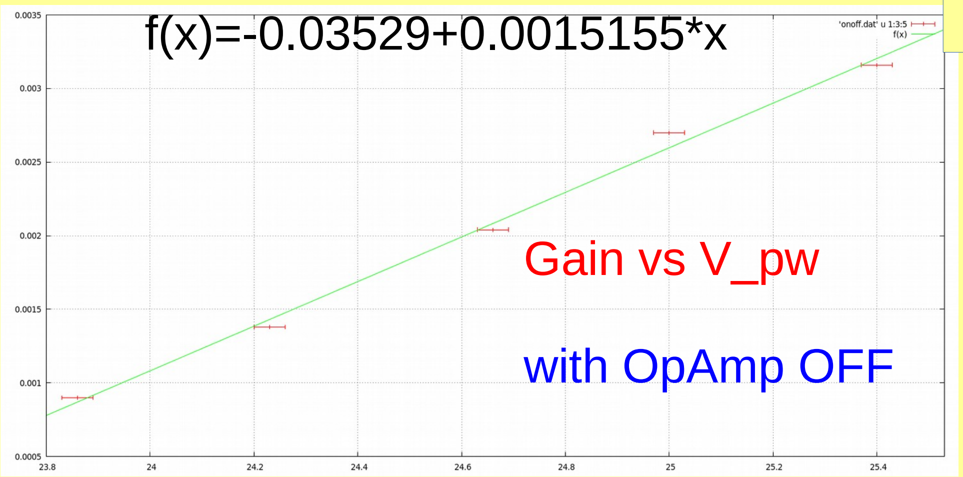




The true gain is: $\frac{\text{Signal A}}{\text{Signal B}}$ with the OpAmp on

The signal in **B** with the OpAmp off, differs from **A** because the current flows in the resistance Rf of 470 ohm.





V_pw (V)	Peak OpAmp Off (mV)	Peak OpAmp On (mV)	Op Amp off Int (V*ns)	Op Amp on Int(V*ns)
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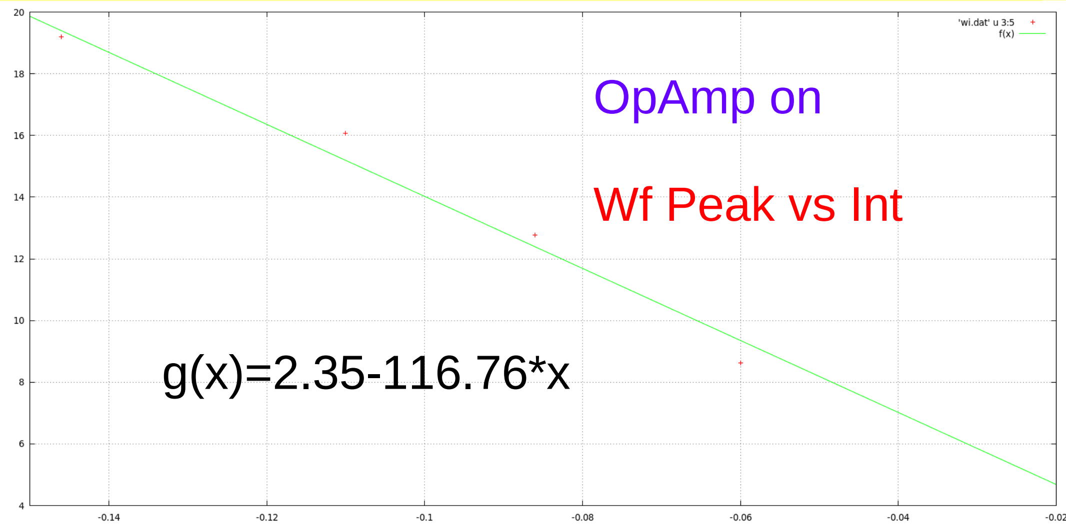
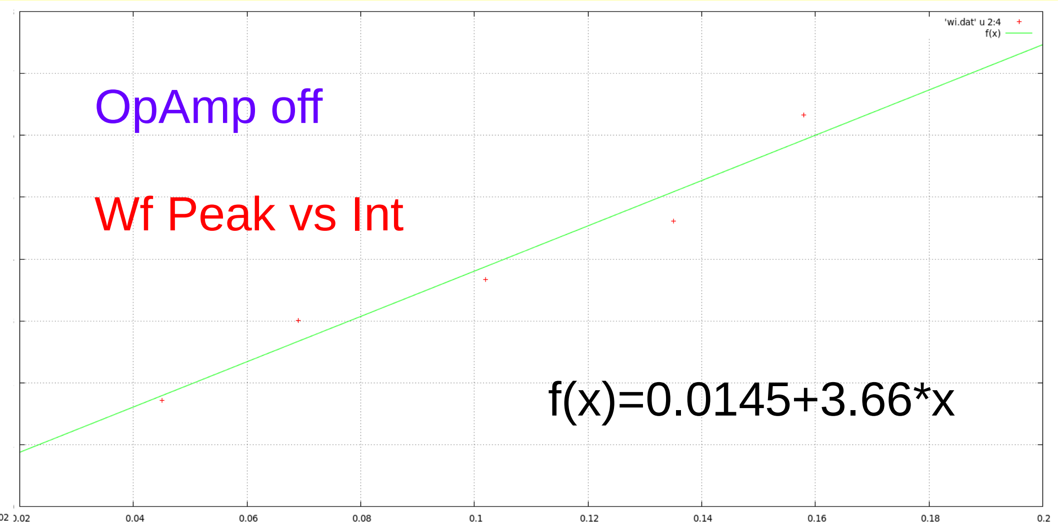
25.00	0.135/50	-0.146	0.461	-19.203
25.40	0.158/50	-0.174	0.633	-22.344

In this graphics Gain is the signal integral. It is proportional to the number of photons that cause an avalanche in the SiPM.

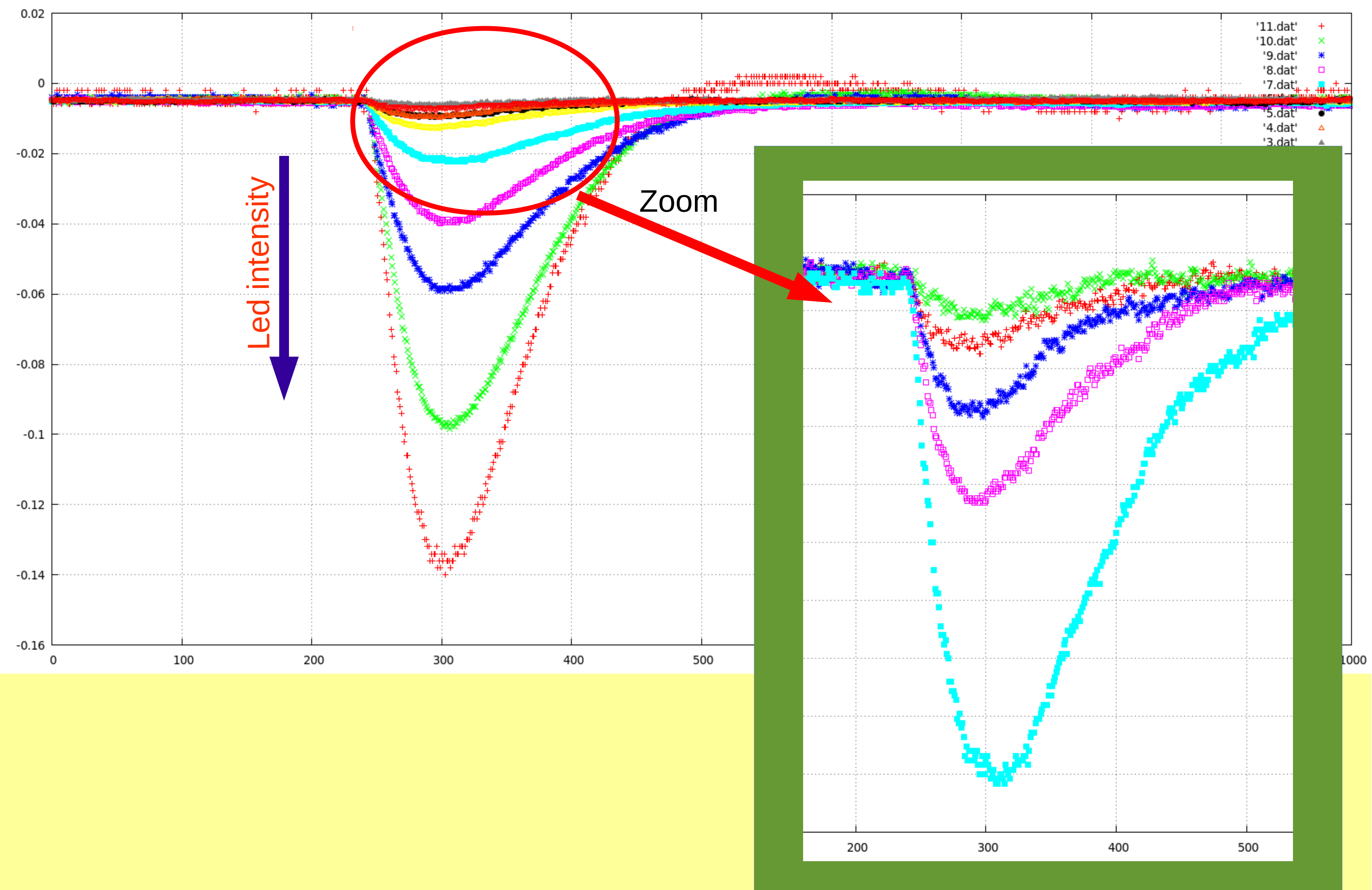
Gain = Q/q_e = $\Delta V\,(C_q + C_d)/q_e$ = $(1/q_e R_{load}) \cdot \int V\,dt$

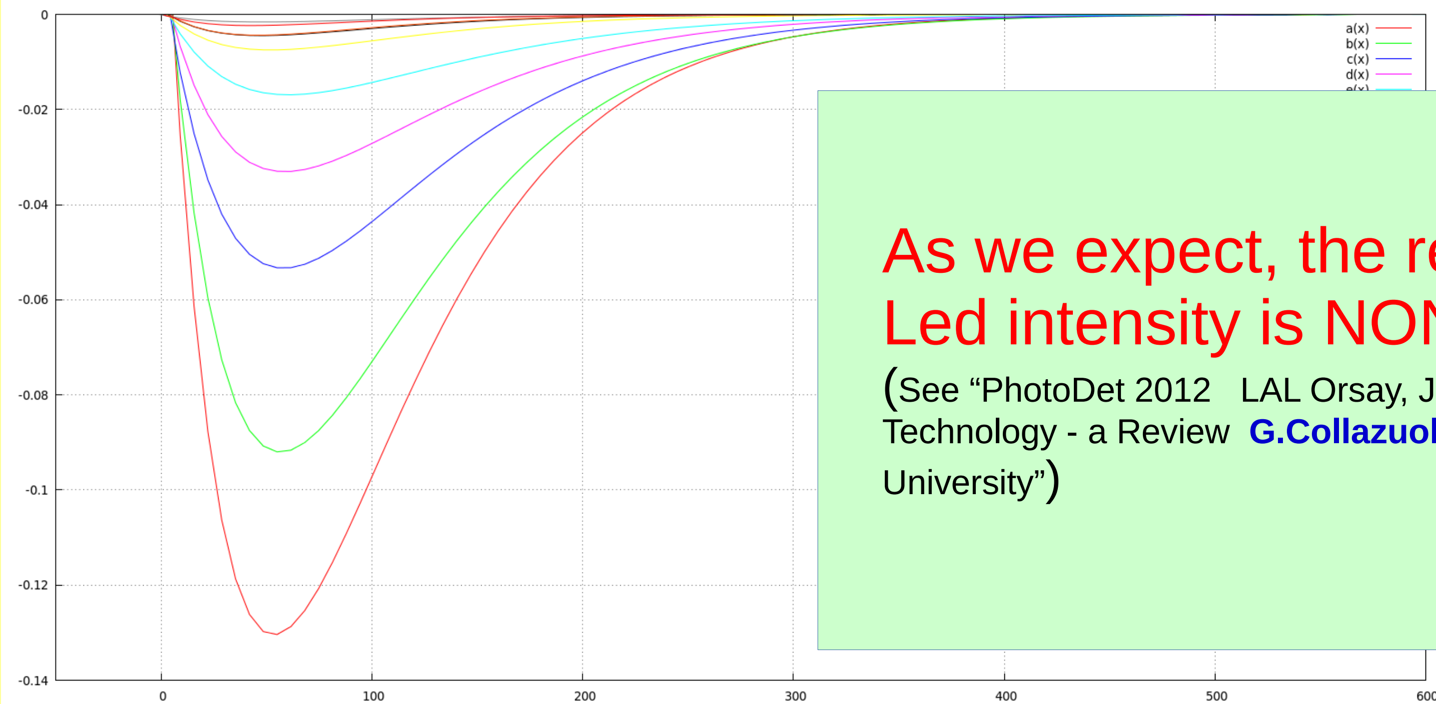
q_e =eleelectron charge
Q =flowing charge as output signal





Gain vs LED Intensity

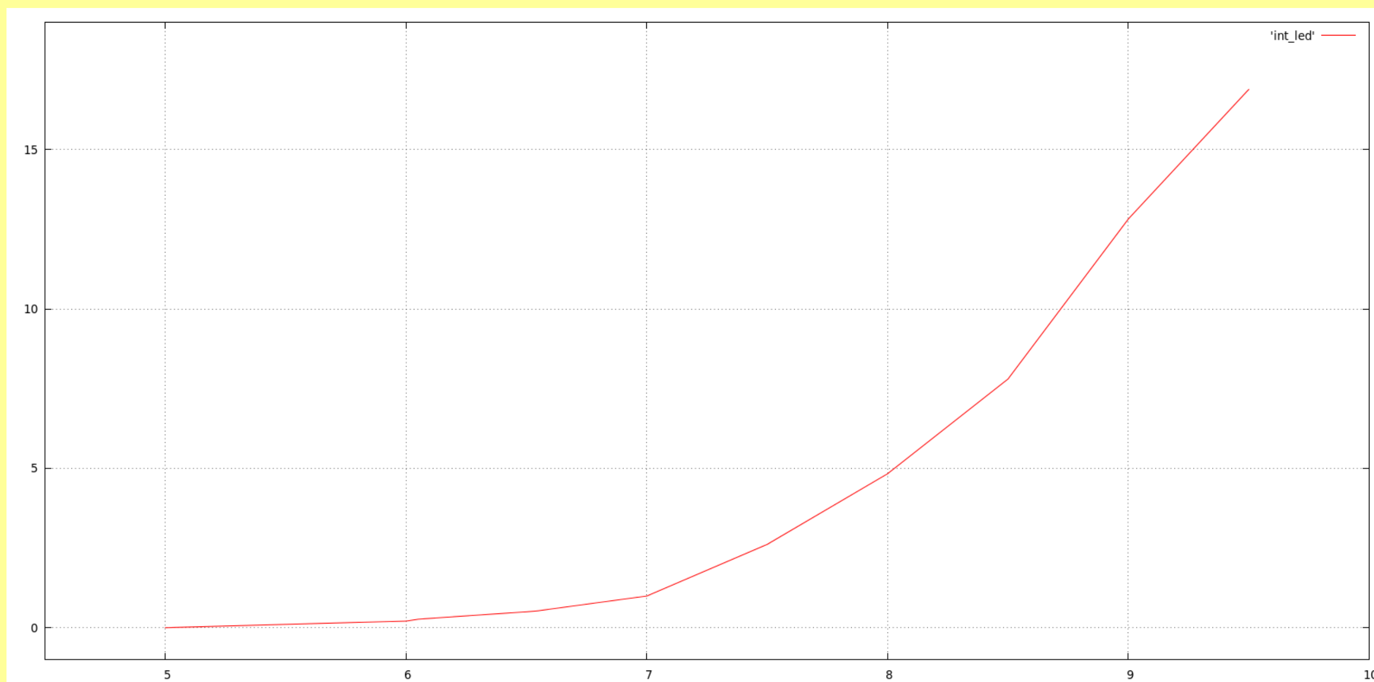




As we expect, the response of Gain to Led intensity is NON-linear

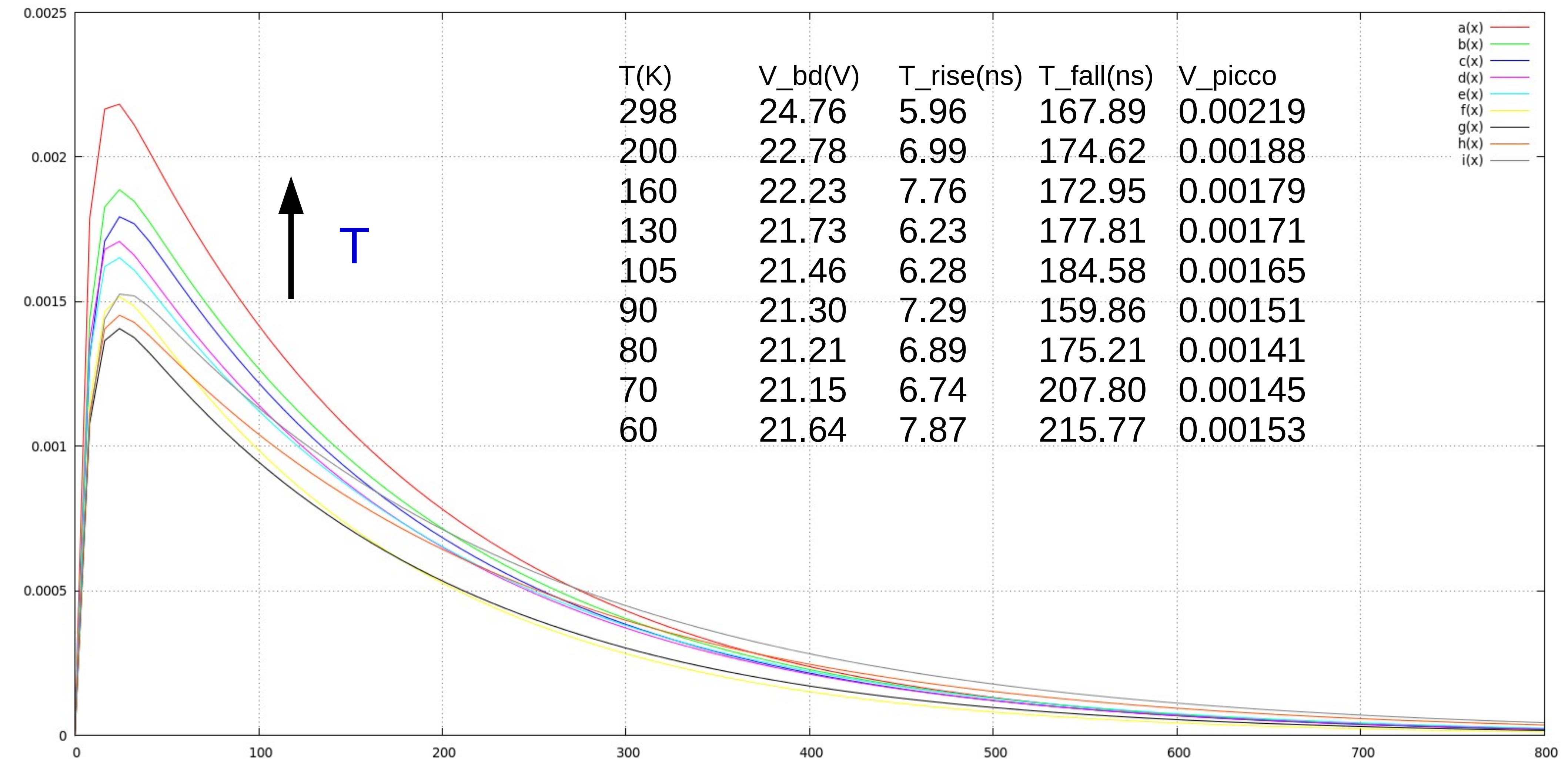
(See “PhotoDet 2012 LAL Orsay, June 2012 - The SiPM Physics and Technology - a Review **G.Collazuol** - Department of Physics and Astronomy, University”)

LED Intensity	Int (V*ns)
9.5	16.8927
9.0	12.8266
8.5	7.80432
8.0	4.83257
7.5	2.61637
7.0	0.995064
6.55	0.533115
6.5	0.500127
6.05	0.267186
6.0	0.208458
5.0	0



Tau (Signal Time constants) vs T from T_room to T_LAr

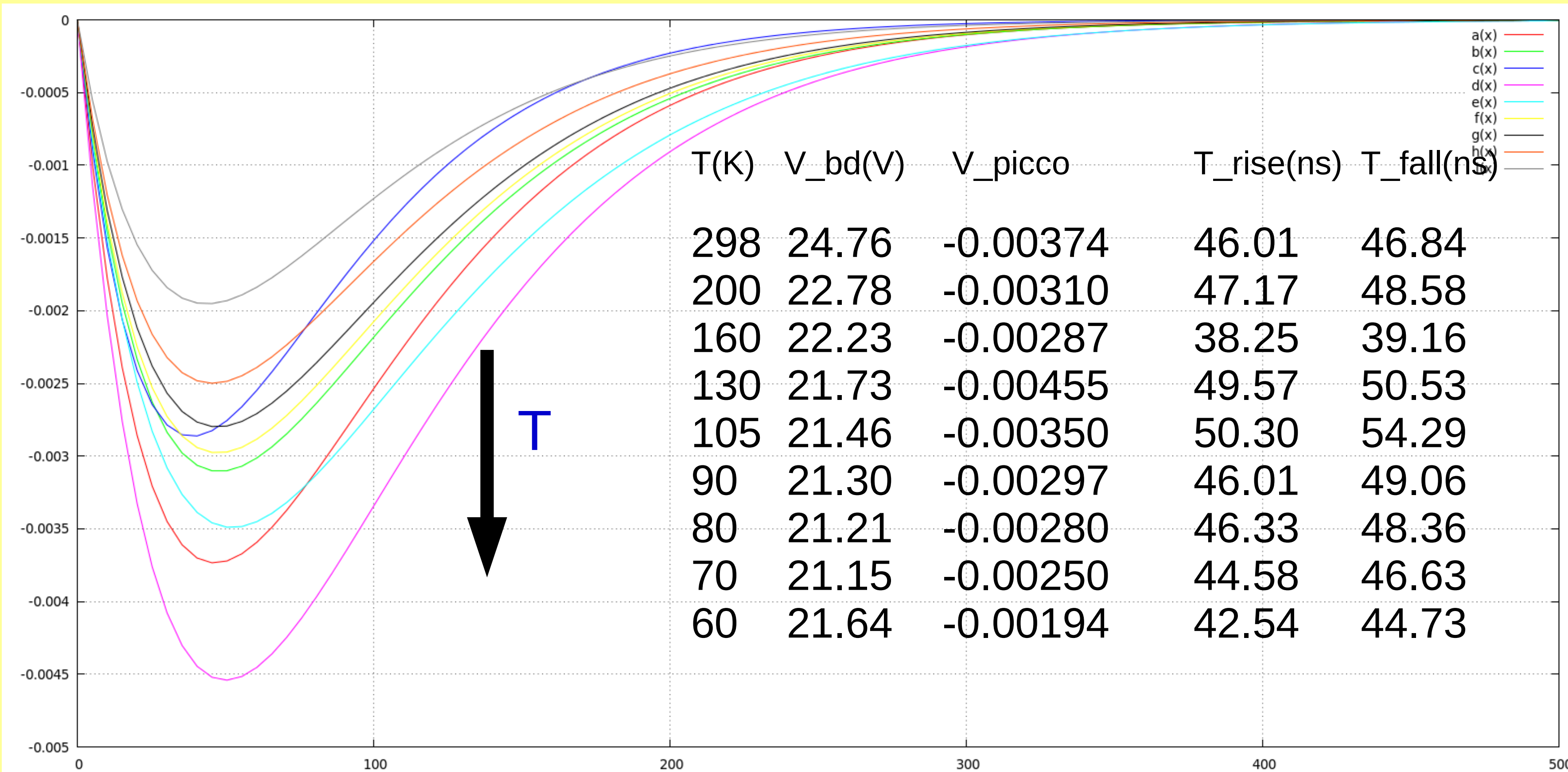
OpAmp off, V_ps – V_bd = 2.00 V, LED = 10.0



T(K)	V_bd(V)	T_rise(ns)	T_fall(ns)	V_picco
298	24.76	5.96	167.89	0.00219
200	22.78	6.99	174.62	0.00188
160	22.23	7.76	172.95	0.00179
130	21.73	6.23	177.81	0.00171
105	21.46	6.28	184.58	0.00165
90	21.30	7.29	159.86	0.00151
80	21.21	6.89	175.21	0.00141
70	21.15	6.74	207.80	0.00145
60	21.64	7.87	215.77	0.00153

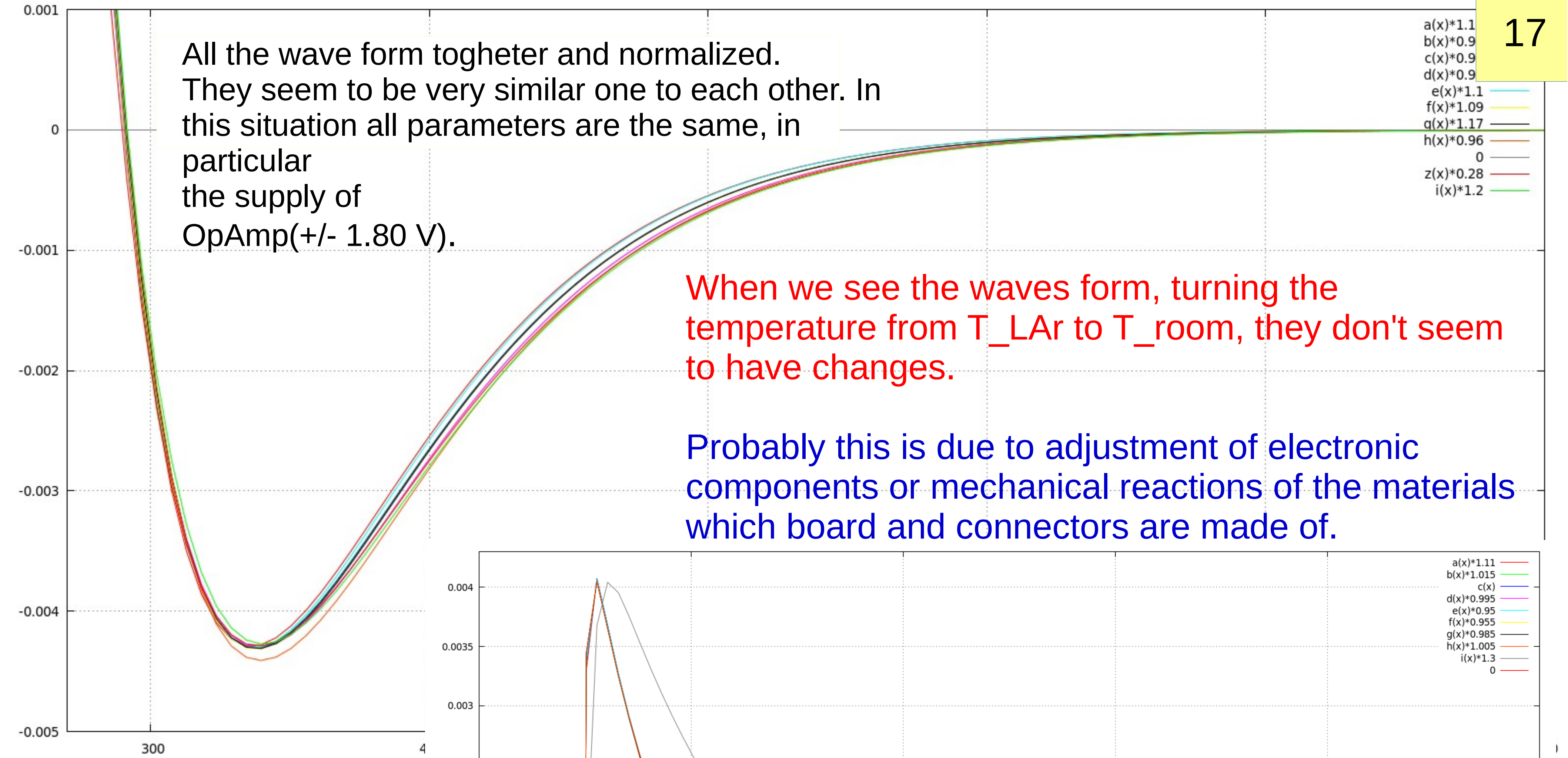
Tau vs T from T_room to T_LAr

OpAmp on; V_OpAmp=+/- 1.80 V;   (V_ps – V_bd) = 0.30 V;   LED = 10.0



T(K)	V_bd(V)	V_picco	T_rise(ns)	T_fall(ns)
298	24.76	-0.00374	46.01	46.84
200	22.78	-0.00310	47.17	48.58
160	22.23	-0.00287	38.25	39.16
130	21.73	-0.00455	49.57	50.53
105	21.46	-0.00350	50.30	54.29
90	21.30	-0.00297	46.01	49.06
80	21.21	-0.00280	46.33	48.36
70	21.15	-0.00250	44.58	46.63
60	21.64	-0.00194	42.54	44.73

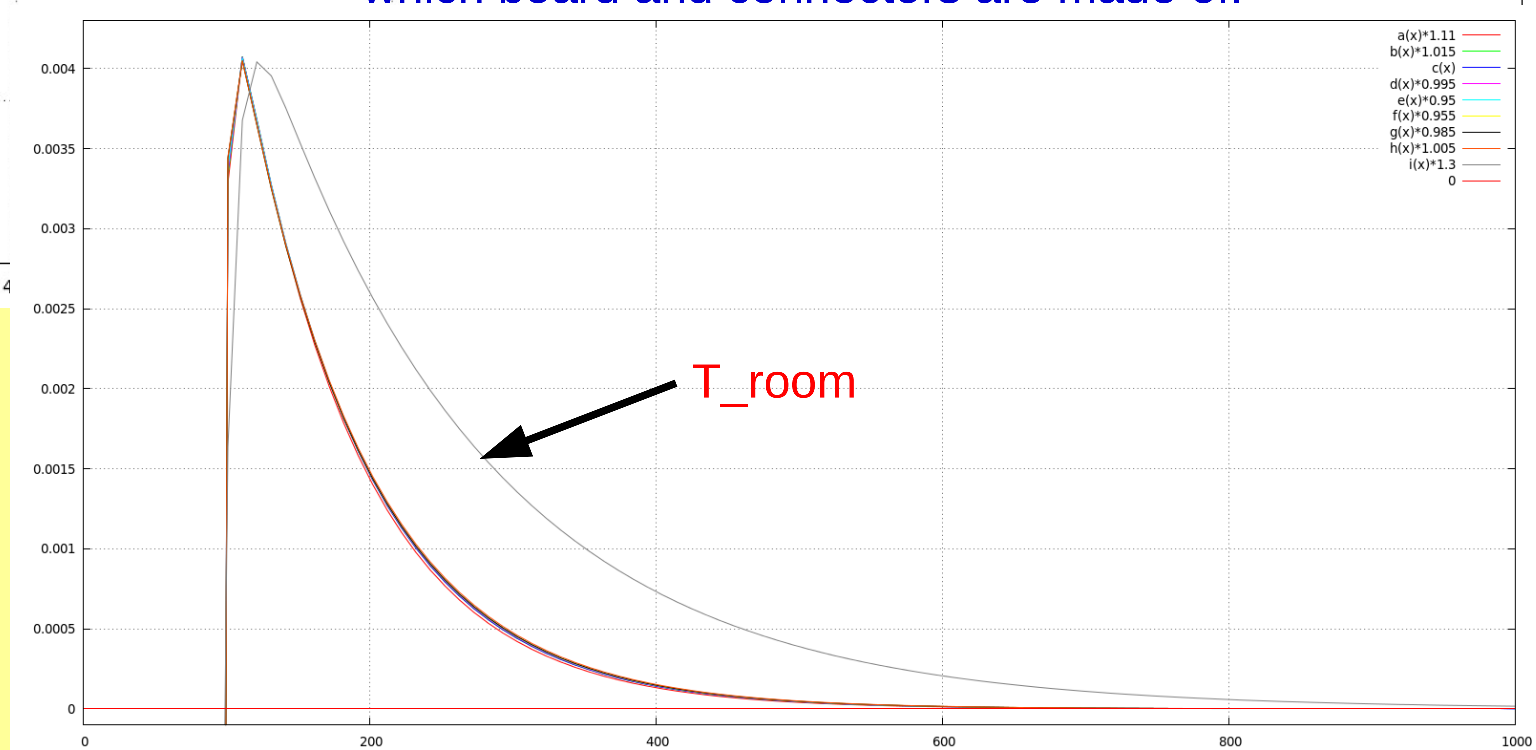
The dipendence of Tau from T have to be studied and understood better because we have detected an anomaly in his behavior. When we see the same trend from T_Lar to T_room, the situation is a bit different...



All the wave form togheter and normalized.
They seem to be very similar one to each other. In this situation all parameters are the same, in particular
the supply of
OpAmp(+/- 1.80 V).

When we see the waves form, turning the temperature from T_LAr to T_room, they don't seem to have changes.

Probably this is due to adjustment of electronic components or mechanical reactions of the materials which board and connectors are made of.



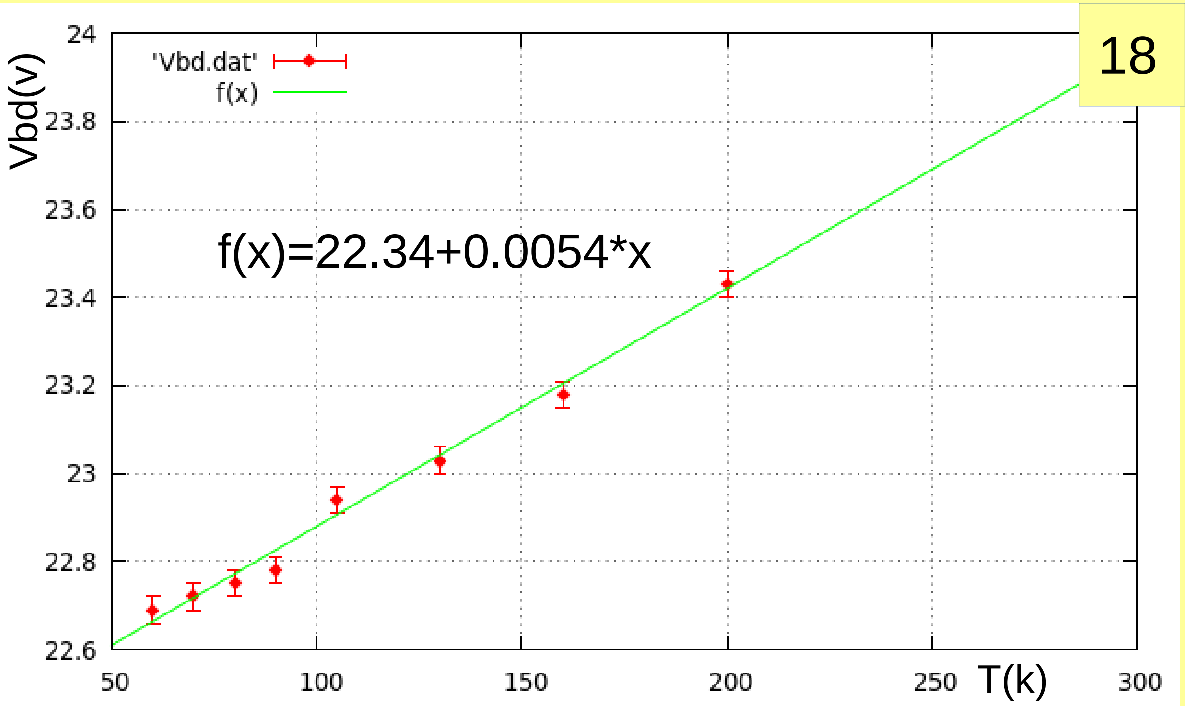
...however
we see the
expected tred

T(k)	Vbd(V)
60	22.69
70	22.72
80	22.75
90	22.78
105	22.94
130	23.03
160	23.18
200	23.43
298	24.85

Errorbar is due to power supply incrementing step (0.03 V)

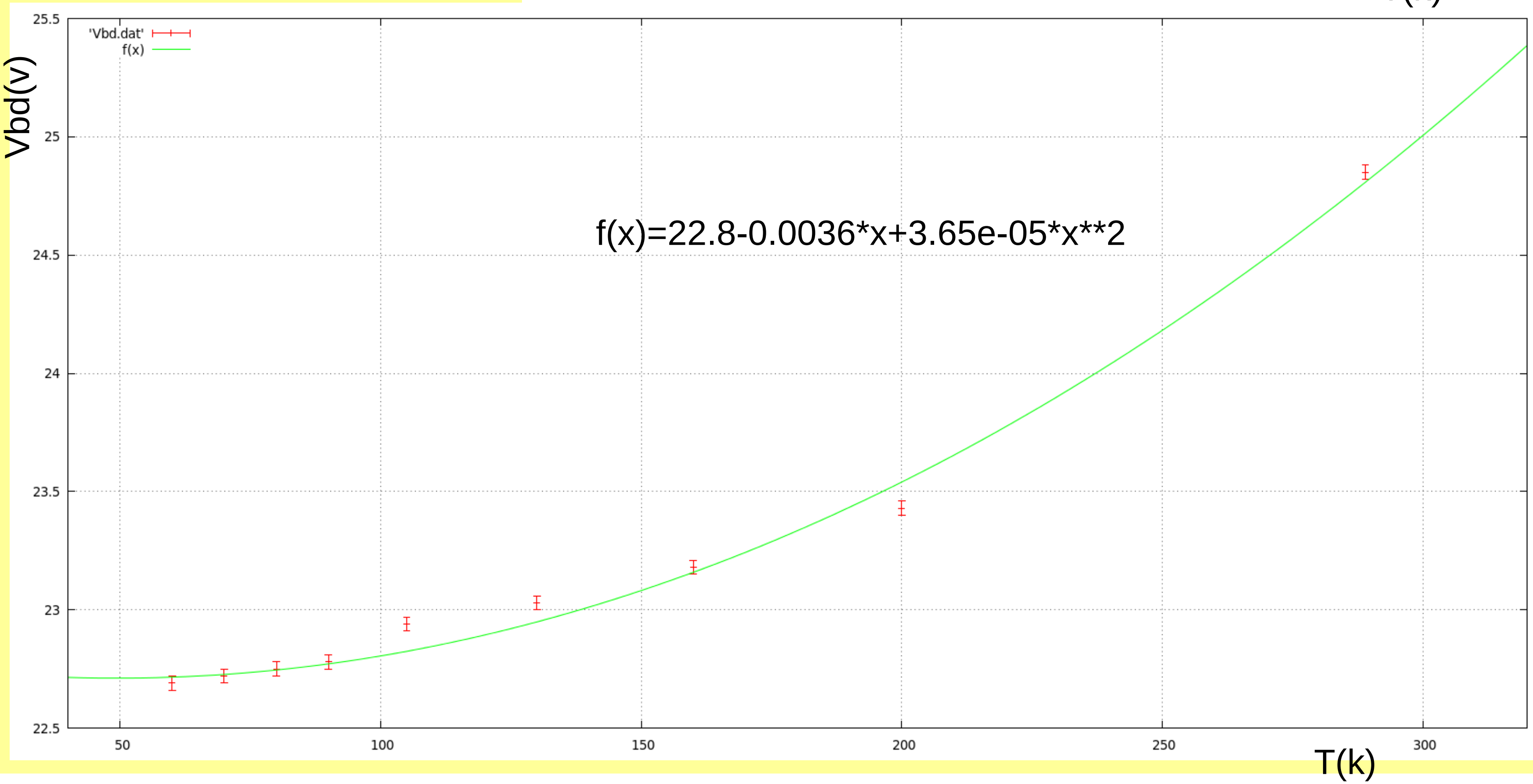
V(OpAmp)=+/-1.80 V
Led=10

Vbd = Vbd' +5.4 mV/K

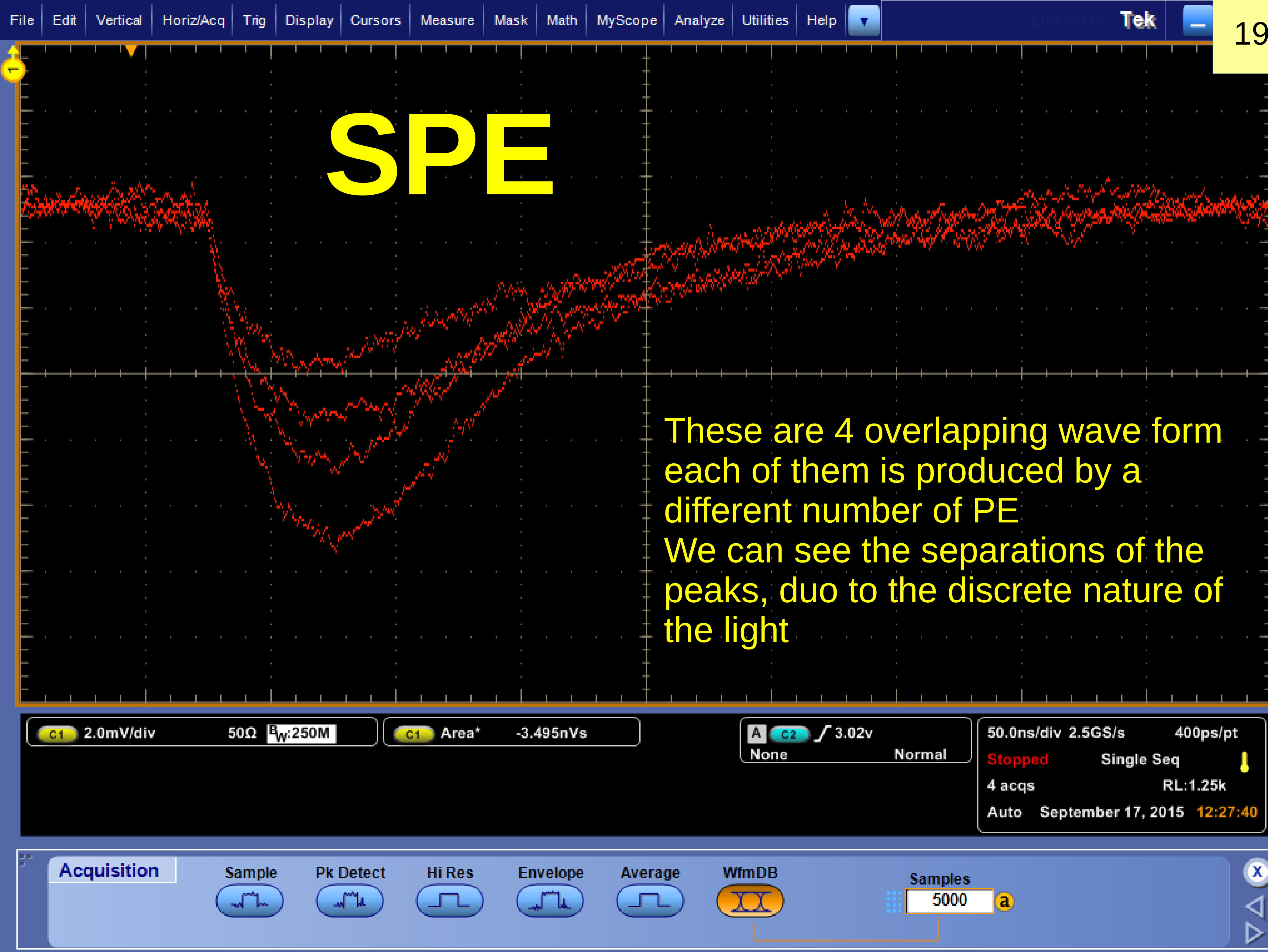


V_bd dependence on T is linear +quadratic

See: G.Collazuol pg.22



SPE

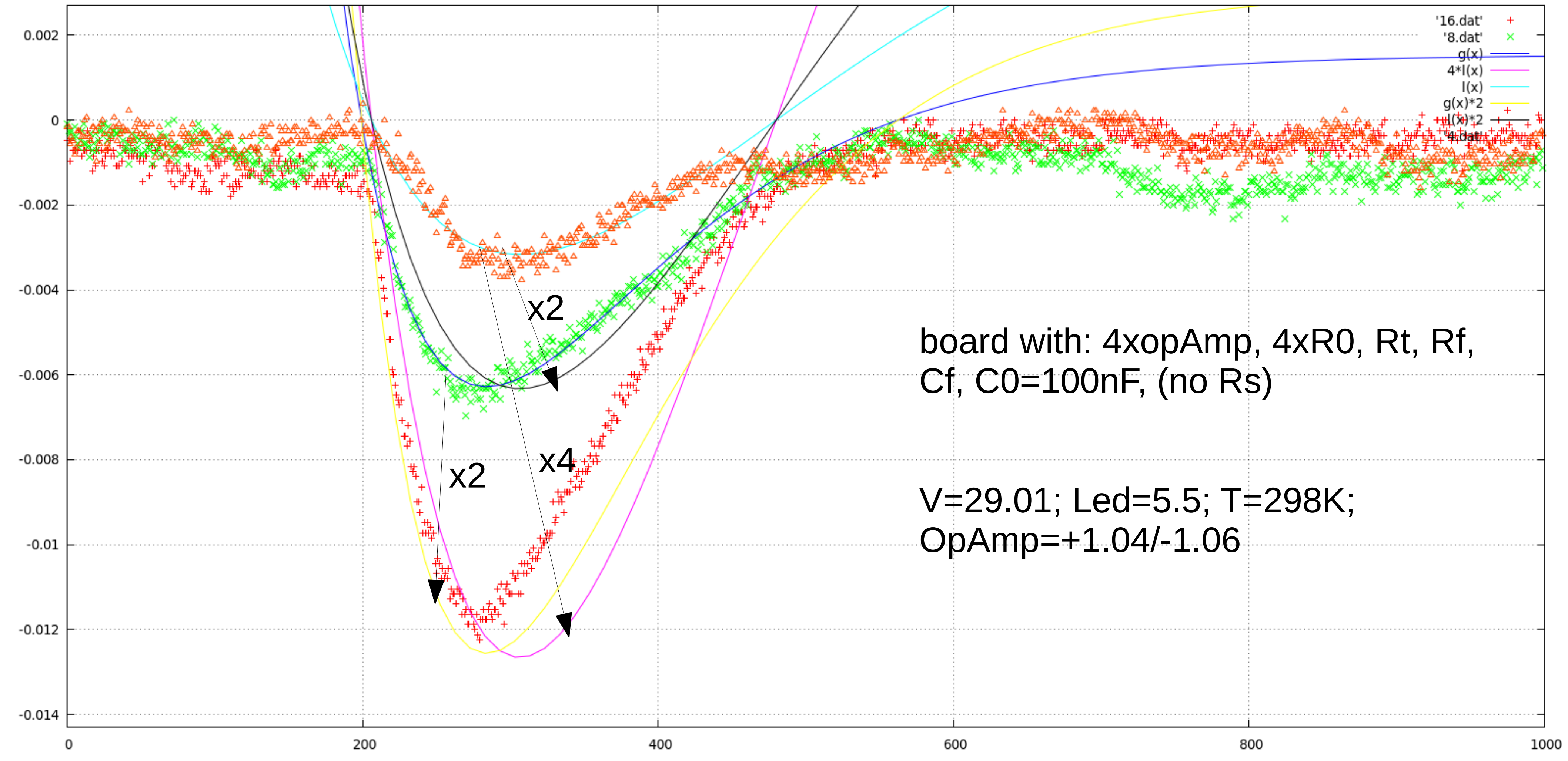


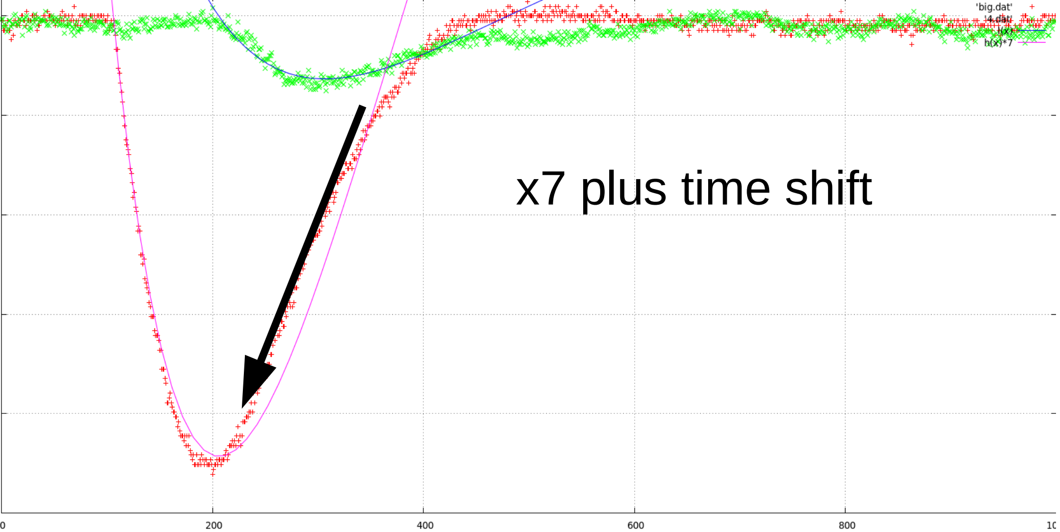
These are 4 overlapping wave form each of them is produced by a different number of PE

We can see the separations of the peaks, duo to the discrete nature of the light

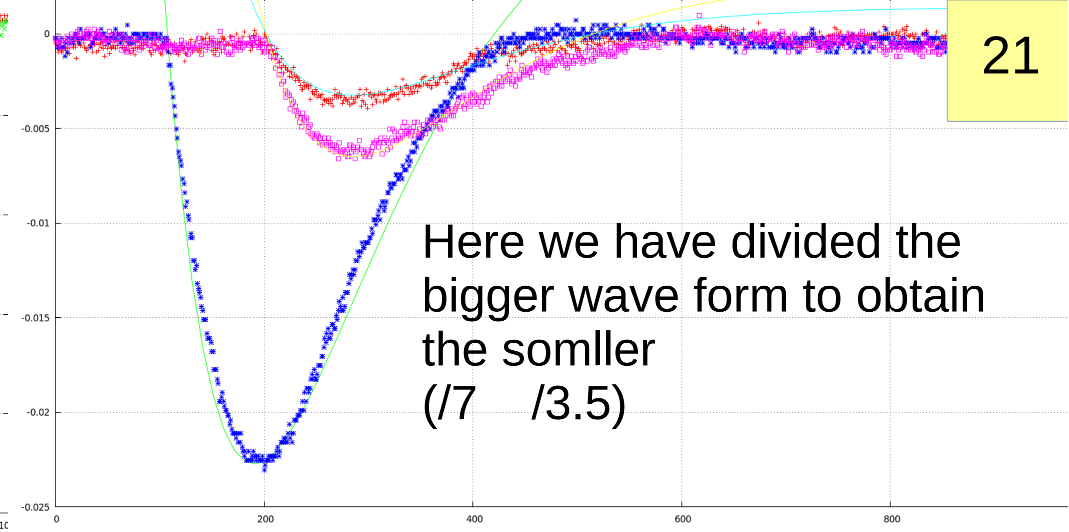
At the moment we aren't able to make a good characterization of the single photoelectron signals(SPE) with the board configuration with 3 SiPM Array and 12 OpAmp (4 for SIPM). But, from the board with only one SiPM Array and 4 OpAmp, we have beautiful exemples of SPE and few SPE wave form.

Limitation due to the noise that comes out using 12 OpAmp together

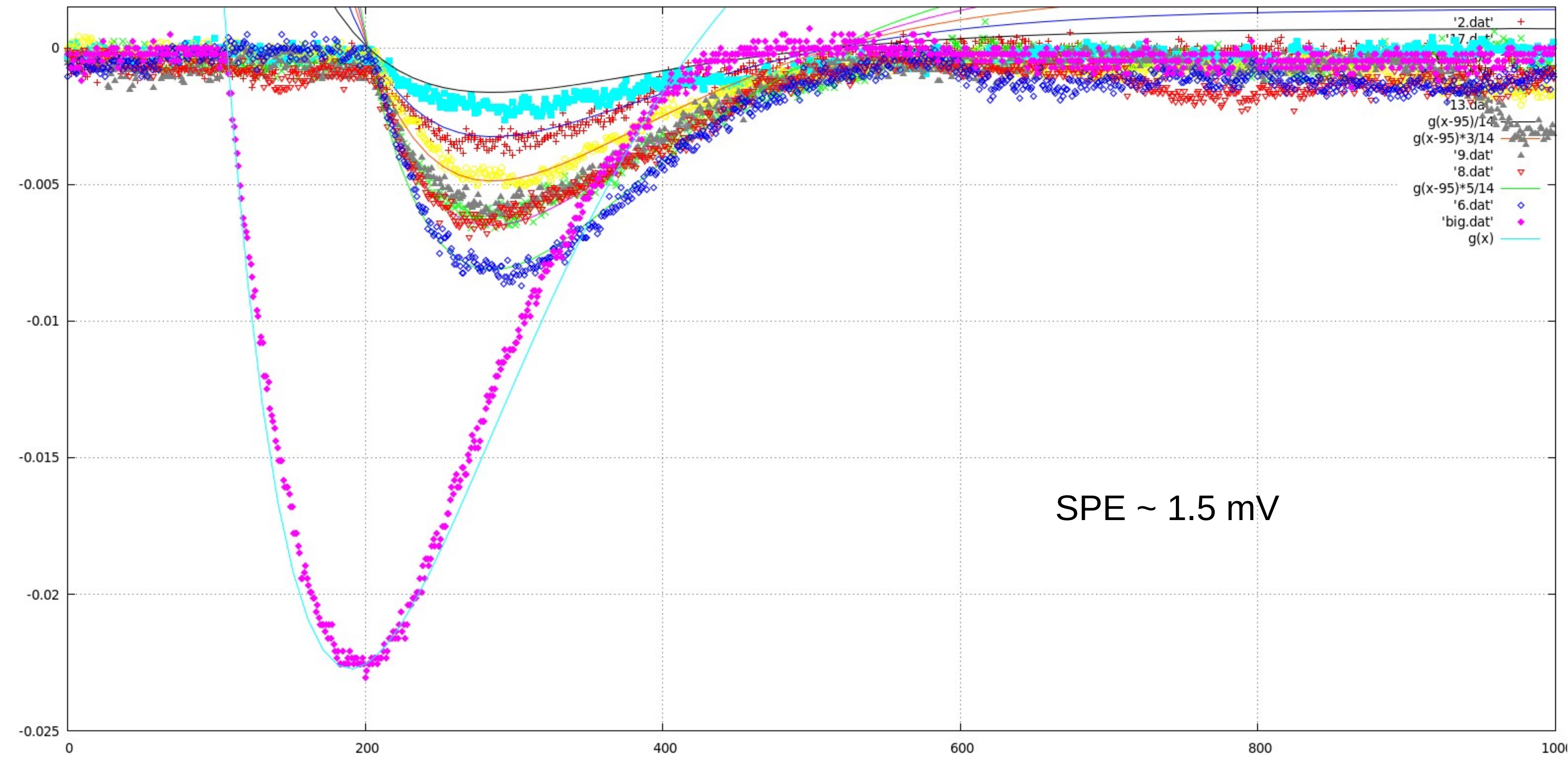




x7 plus time shift
0
200
400
600
800



Here we have divided the
bigger wave form to obtain
the somller
(/7 /3.5)
0
-0.005
-0.01
-0.015
-0.02
-0.025
0
200
400
600
800



SPE ~ 1.5 mV
'2.dat'
'13.dat'
g(x-95)/14
g(x-95)*3/14
'9.dat'
'8.dat'
g(x-95)*5/14
'6.dat'
'big.dat'
g(x)
0
-0.005
-0.01
-0.015
-0.02
-0.025
0
200
400
600
800

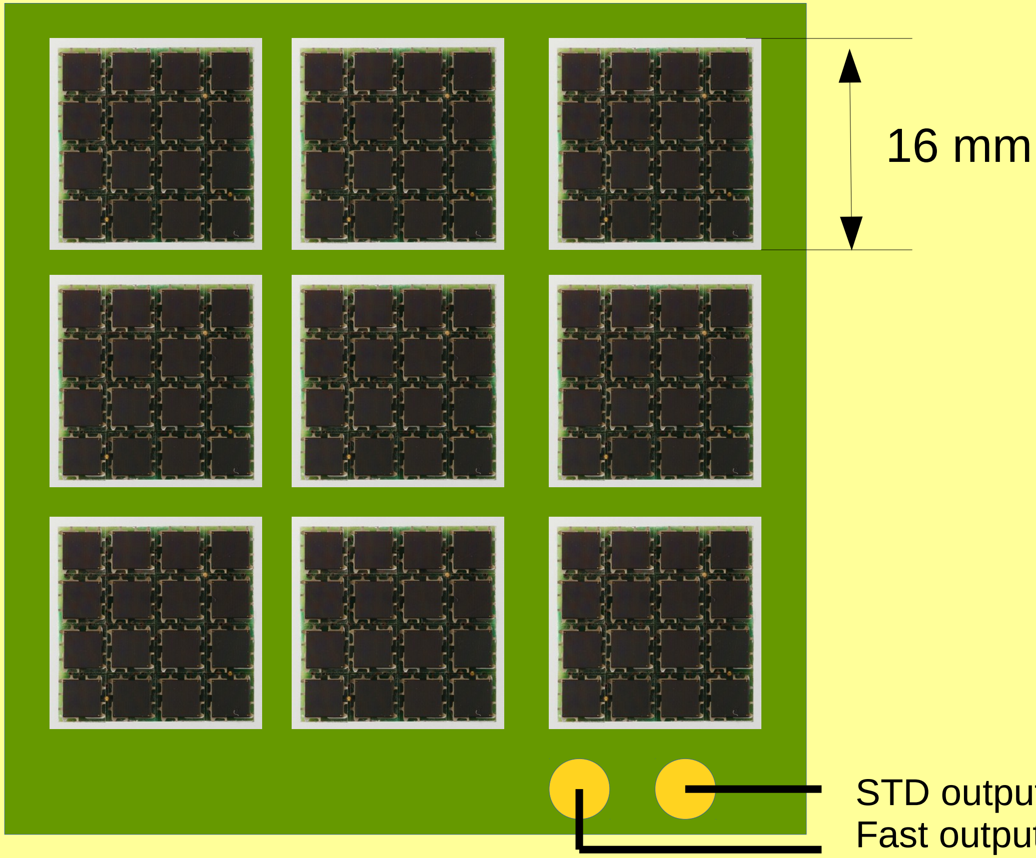
Future aims:

-develop a technique which allows us to reconstruct events from Liquid Argon scintillation light.

Our idea: try to reconstruct a packet of photons with a known time distribution, for example generated by a Monte Carlo, and then, doing the reverse process, from any wave form go back the structure in term of photon

-build a bigger device, in order to reach a size comparable to those of a traditional PMT, able to work at cryogenic temperature and sensible to the single photoelecrton, with the same characteristics of a single SMT SiPM

OUR IDEA:



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