APD test in Liquid Xe (2)

T. Tauchi, KEK, 18th July 2014

APD in CMS

K.Deiters et al., NIM A442(2000)193-197

Current version : S8664-55

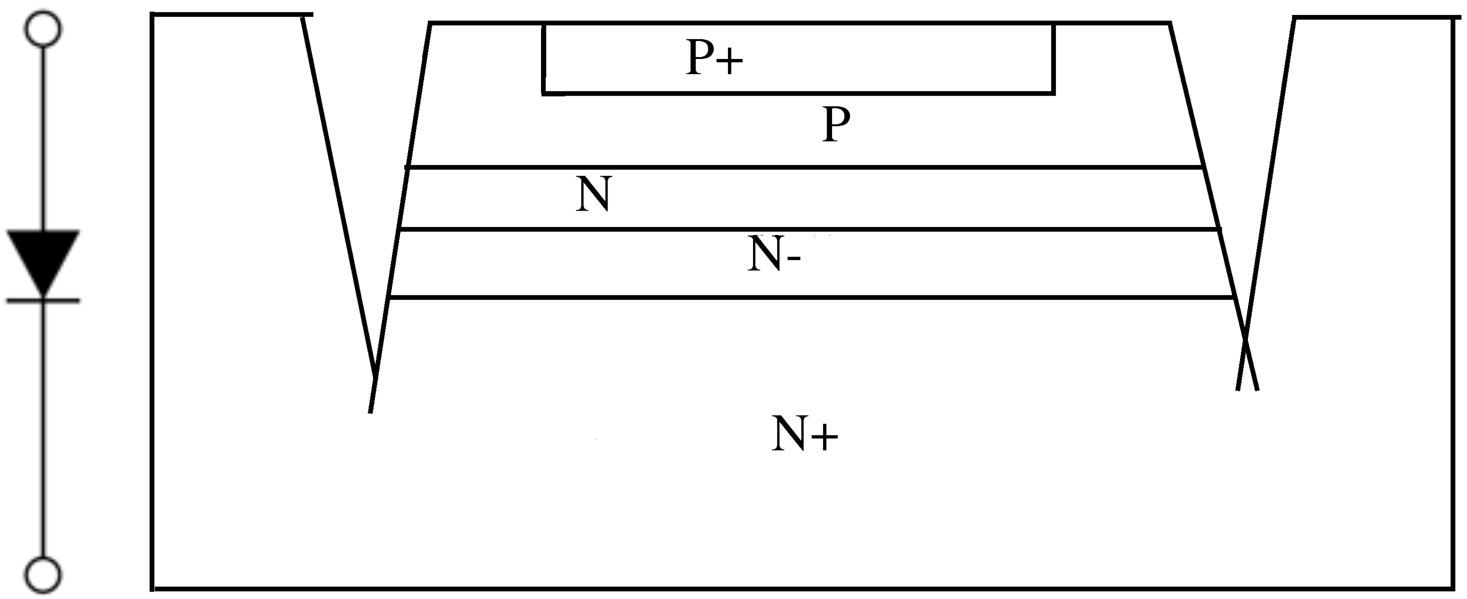


Fig. 1. Structure of an APD.

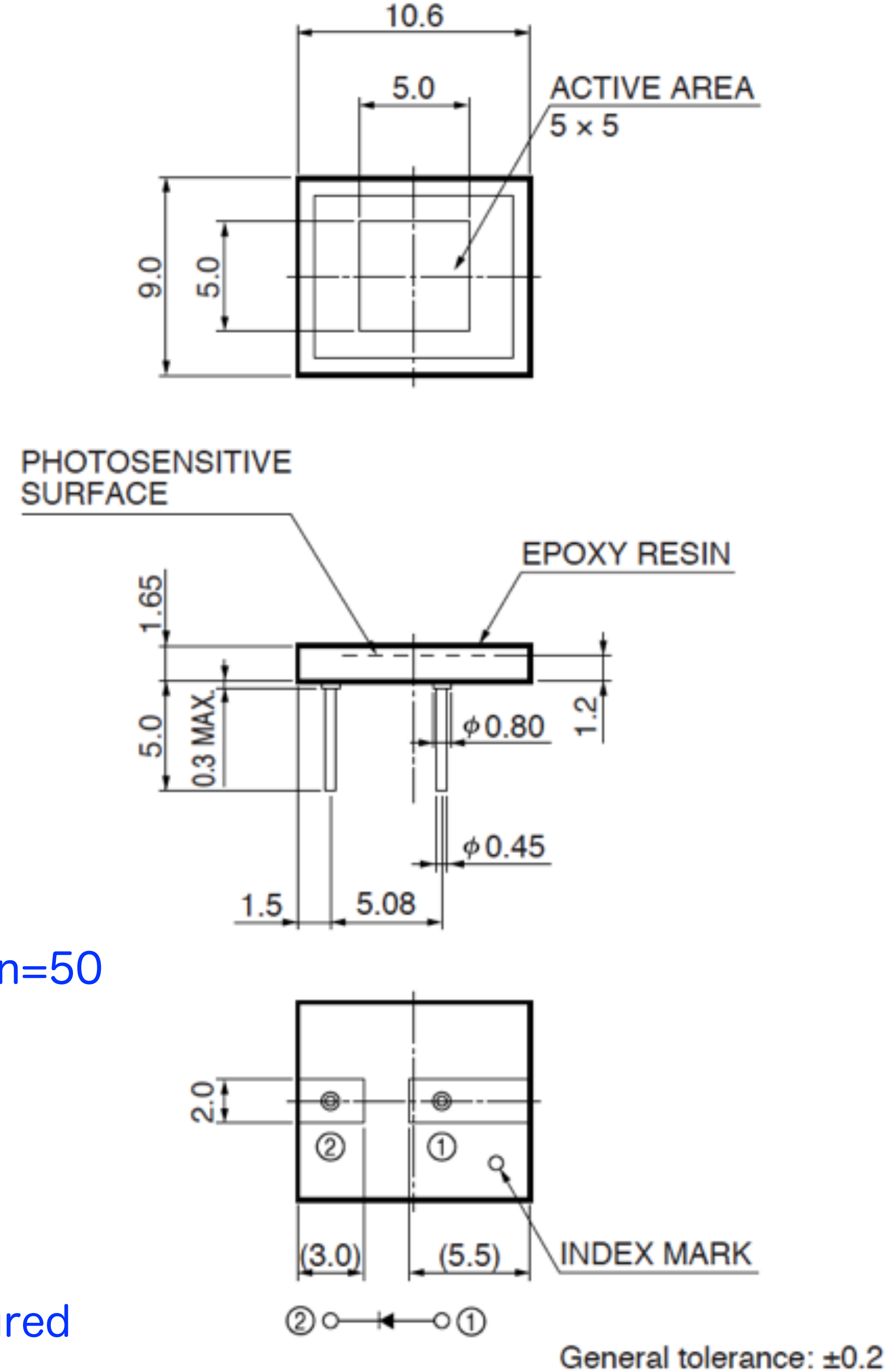
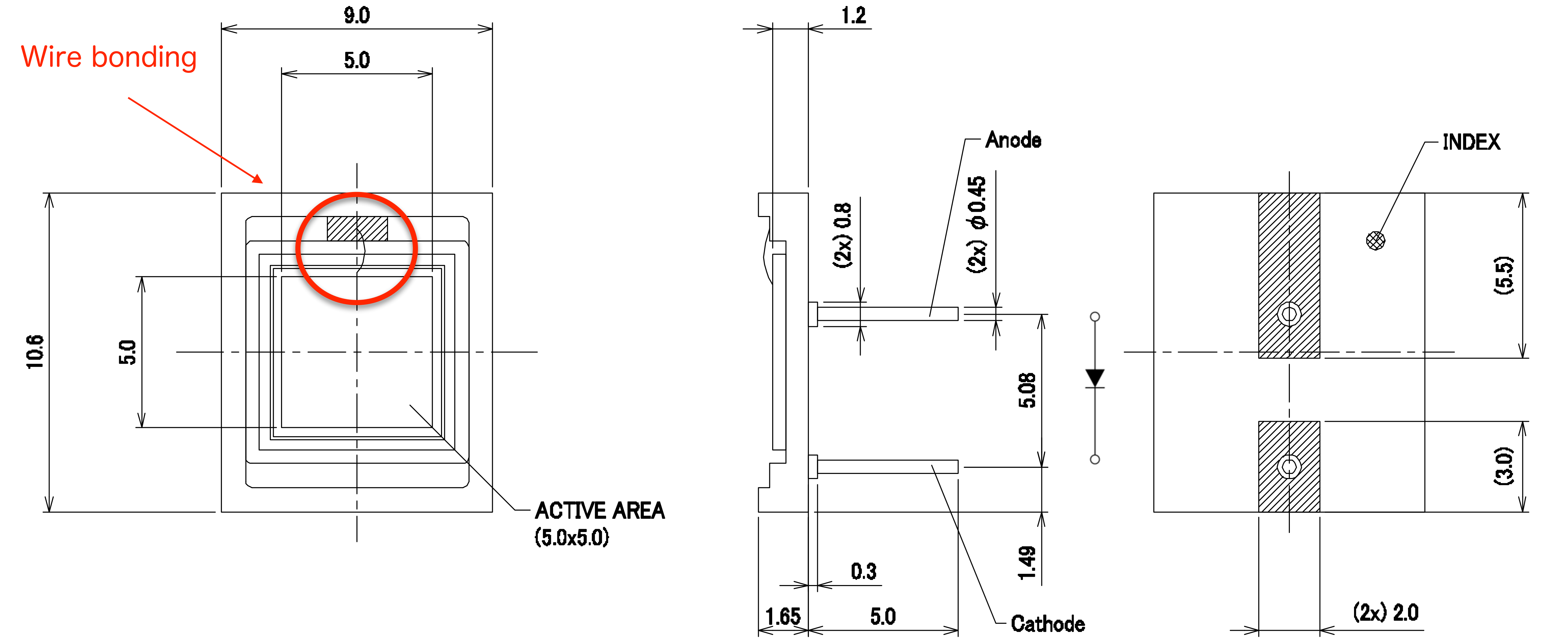


Table 1
Parameters of APDs

Active area	5×5 mm^2
Operating voltage	~ 330 V gain=50
Capacitance	75 pF
Series resistance	3 Ω
Dark current	< 10 nA
Quantum efficiency	70%@420 nm

Effective thickness, l_{eff} for direct interaction in APD   5.6um measured

Windowless APD



General Tolerance : ±0.2

c								SCALE 尺度	5/1	TITLE 名称	S10937-9390(X)
b											
a								UNIT 単位	mm	DWG.No 図番	REV 改訂
	FIRST ISSUE 初発行										
MARK 記号	CONTENTS 記 事	DATE 年月日	APPR 承認	CHCK 検図	CHCK 検図	DESN 設計	DRAW 製図	PROJ 三角法		HAMAMATSU PHOTONICS K.K. 浜松ホトニクス株式会社	

様式K03-0002 B

APD in CMS

K.Deiters et al., NIM A442(2000)193-197

CMS operation, 50 →

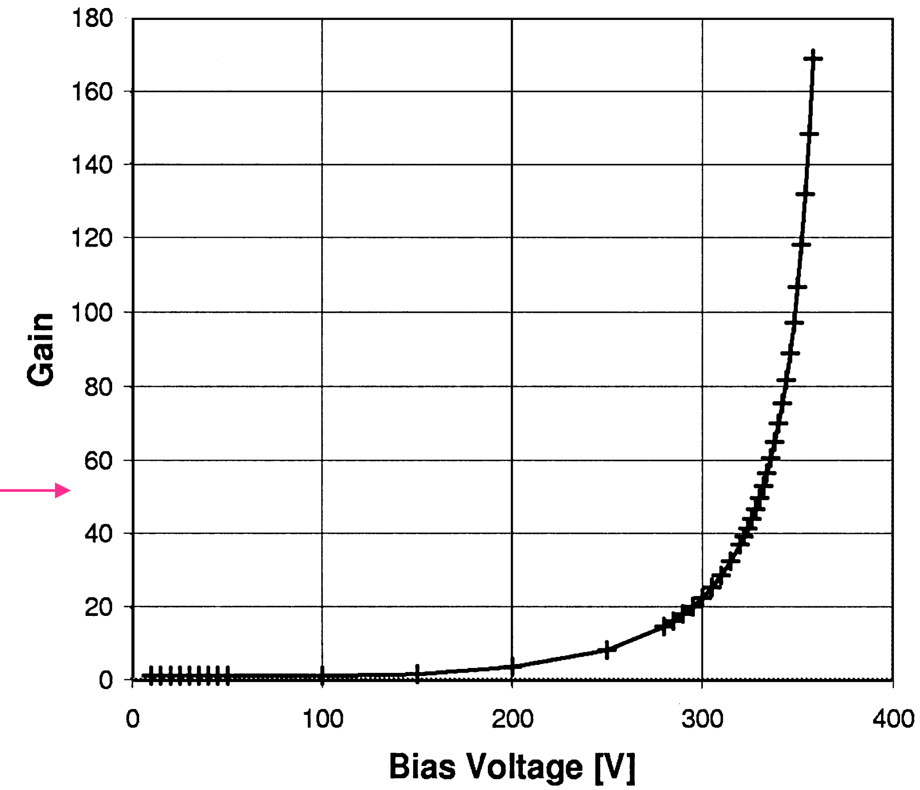


Fig. 3. Gain versus bias voltage.

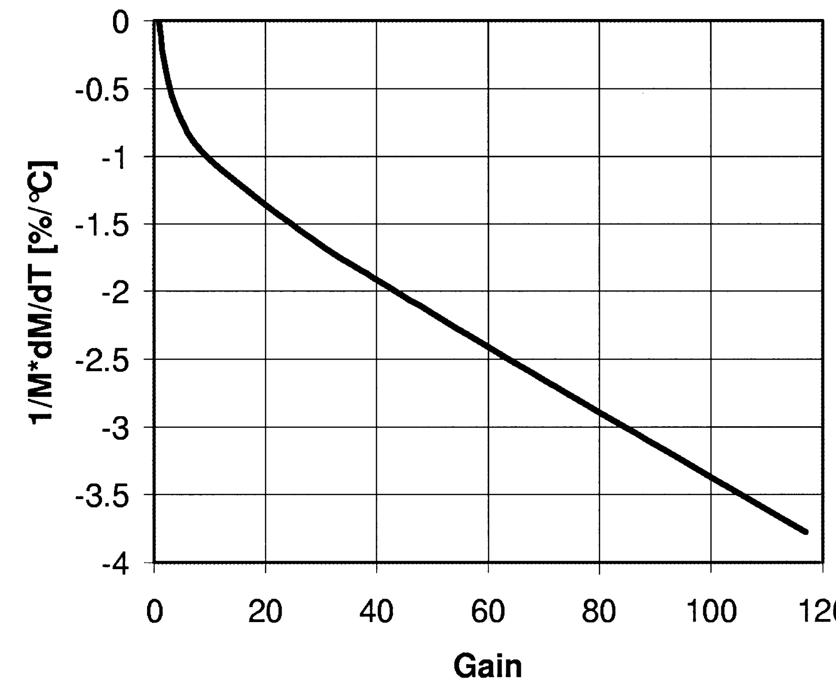


Fig. 5. Temperature coefficient of the gain versus gain.

Gain measured with a LED of 420nm at 25°C (DC mode)

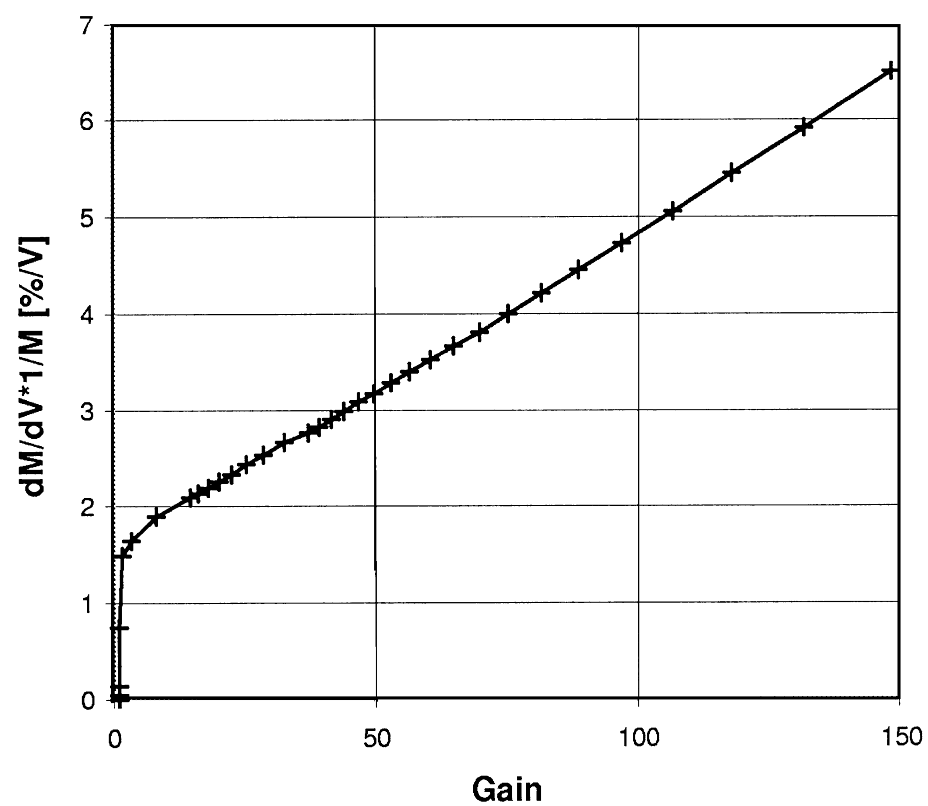


Fig. 4. Voltage coefficient of the gain versus gain.

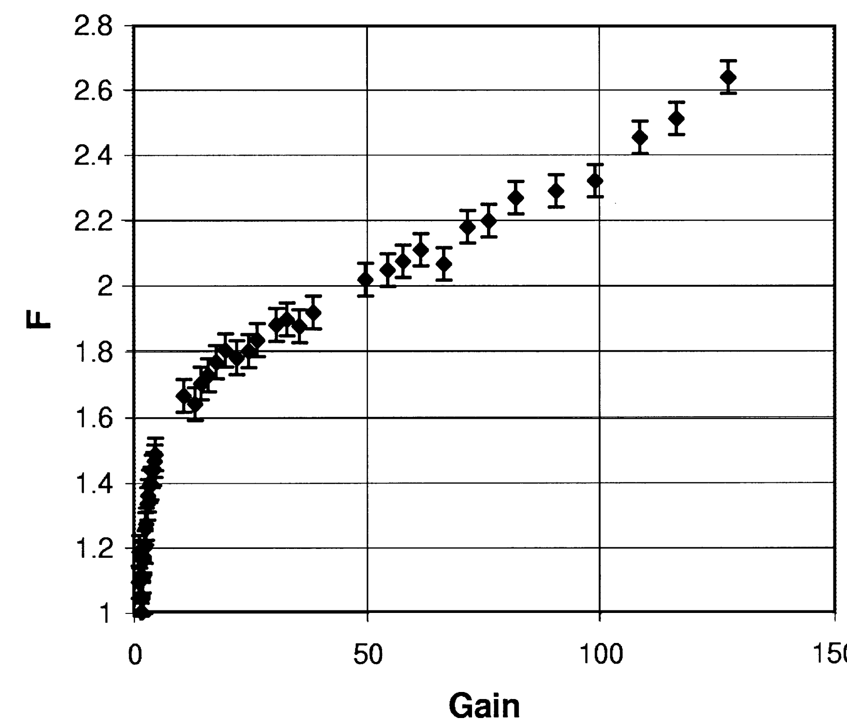


Fig. 6. Excess noise factor versus gain.

$$F = k \times M + \left(2 - \frac{1}{M}\right) \times (1 - k).$$

$k = \beta(\text{hole}) / \alpha(e^-)$

$$\frac{\Delta E}{E} = 2.355 \sqrt{\left(\frac{N_e}{N_0 M}\right)^2 + \frac{F-1}{N_0} + \delta^2},$$

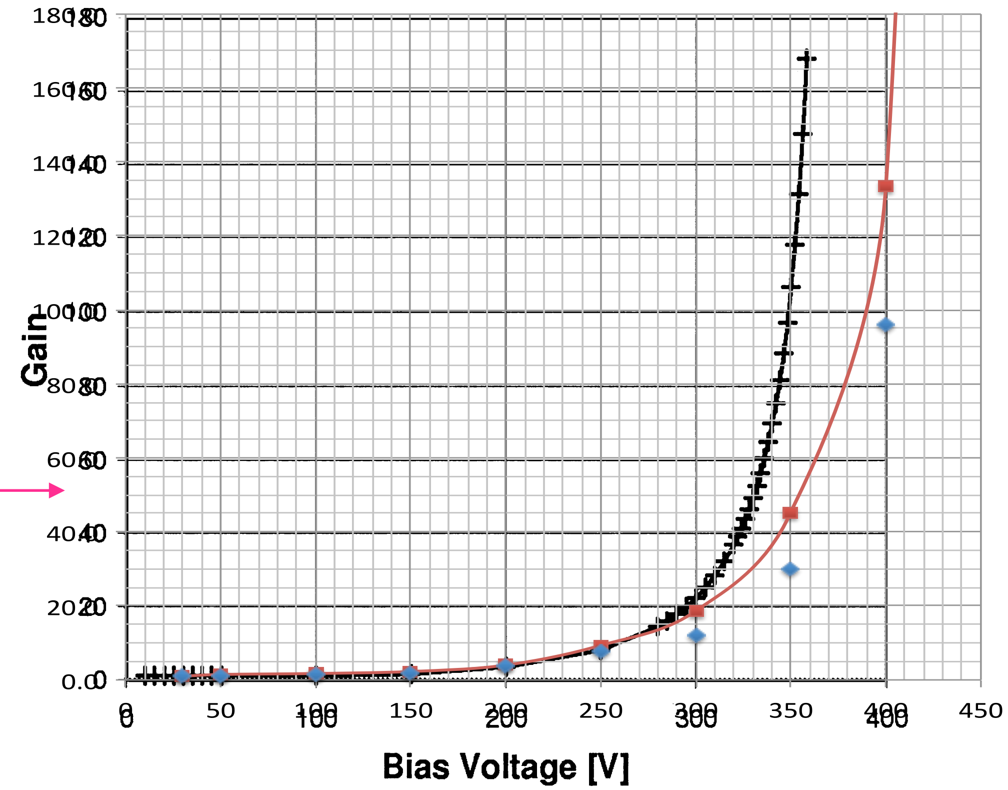
$F = \langle G^2 \rangle / \langle G \rangle^2$, G is a statistical variable that describes the multiplication gain, i.e. $M = \langle G \rangle$

S8664-55

APD in CMS

K.Deiters et al., NIM A442(2000)193-197

CMS operation, 50



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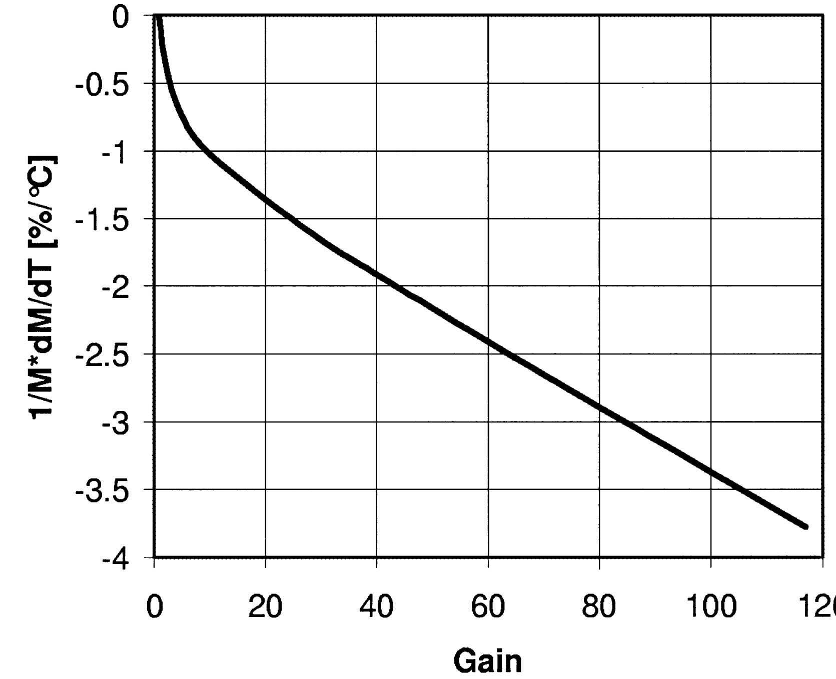

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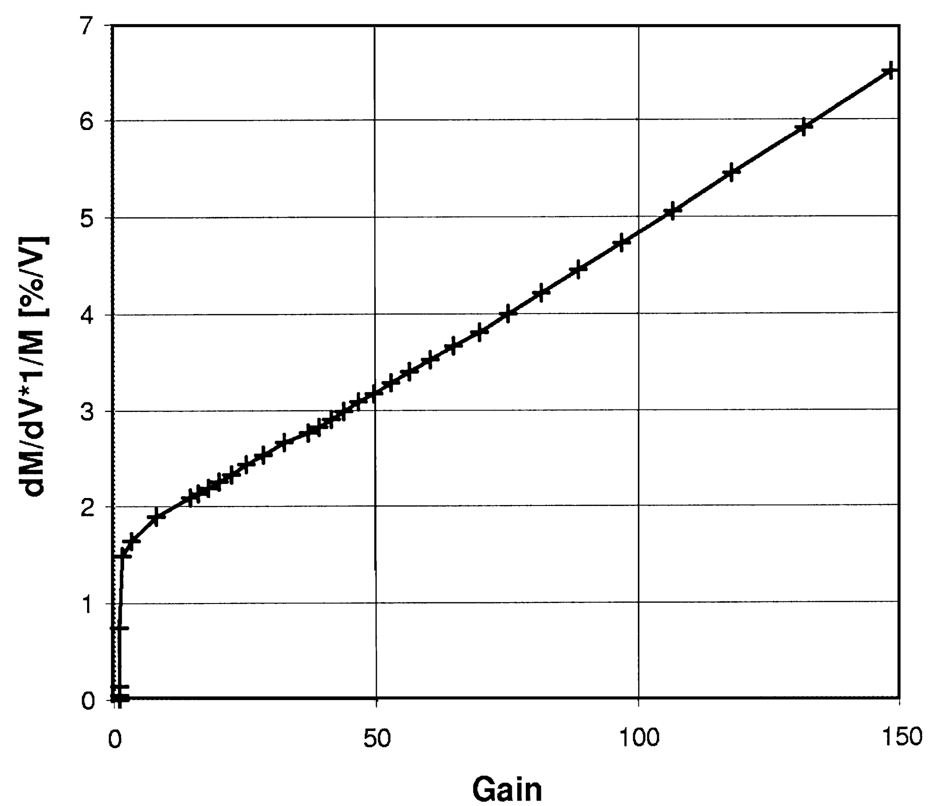

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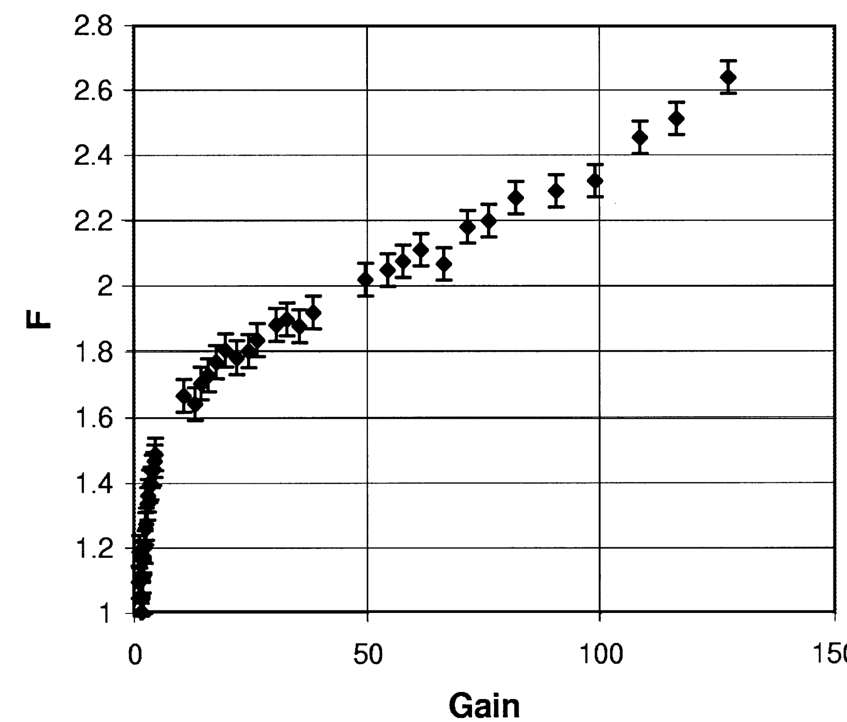

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$$\frac{\Delta E}{E} = 2.355 \sqrt{\left(\frac{N_e}{N_0 M}\right)^2 + \frac{F-1}{N_0} + \delta^2},$$

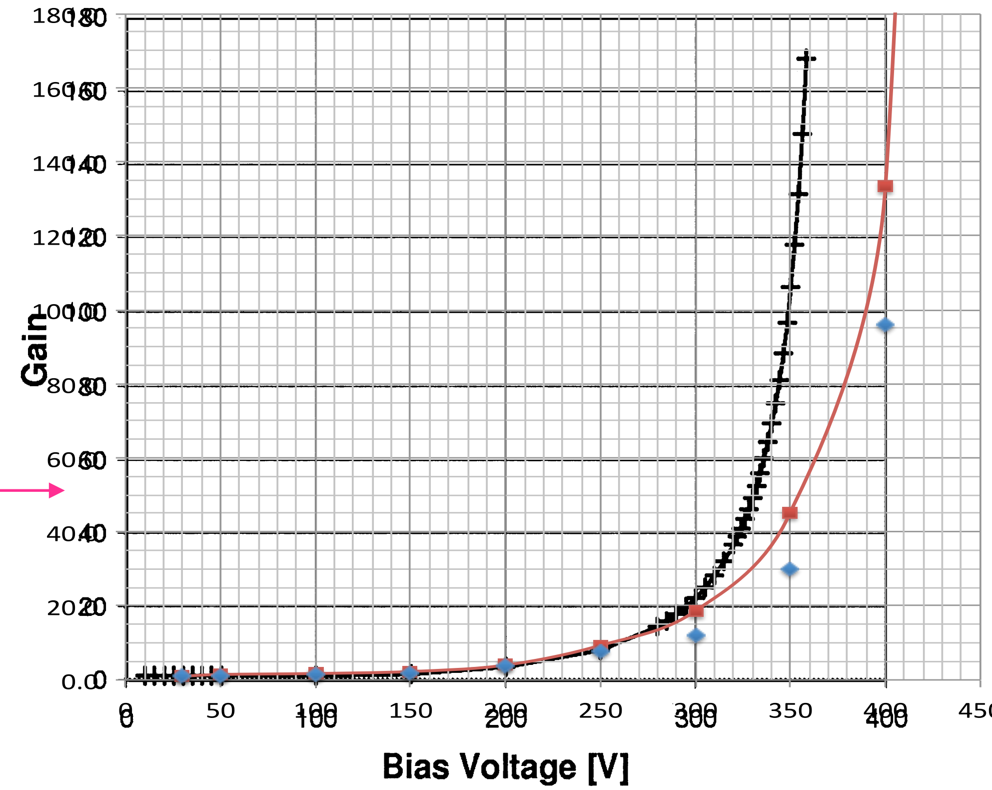
F=<G^2>/<G>^{2}, G is a statistical variable that describes the multiplication gain, i.e. M=<G>

APD in CMS

K.Deiters et al., NIM A442(2000)193-197

S8664-55

CMS operation, 50



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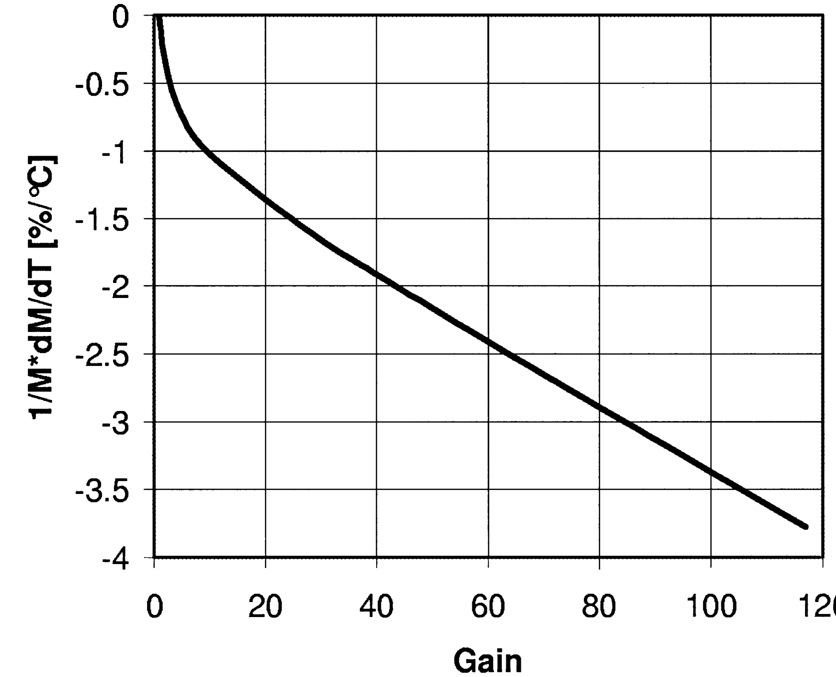

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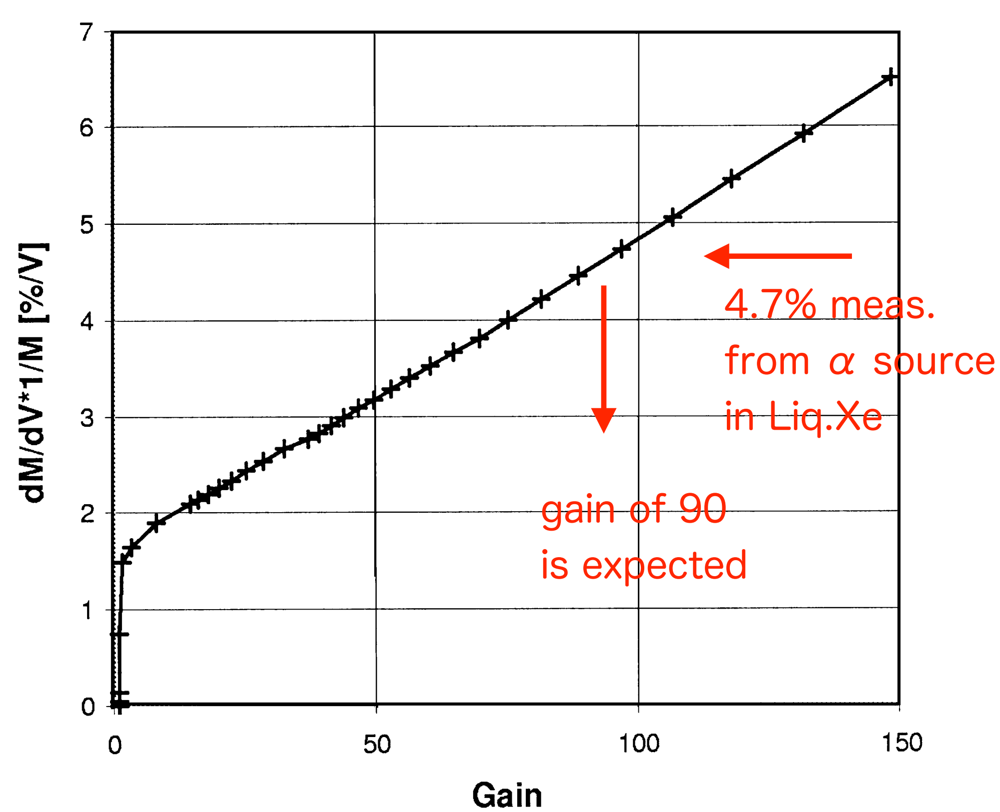
Gain measured with a LED of 420nm at 25℃ (DC mode)



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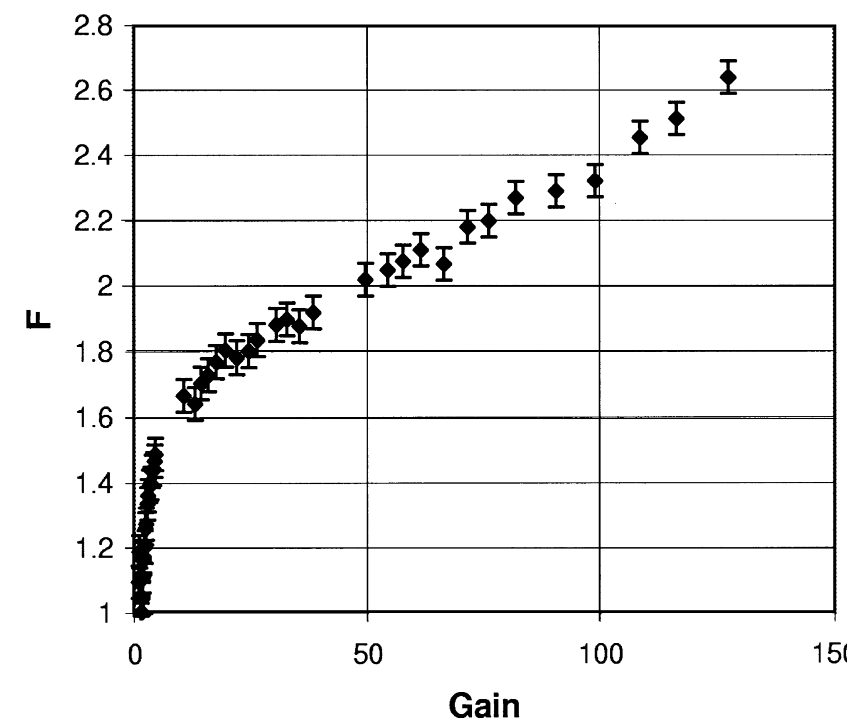

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$$\frac{\Delta E}{E} = 2.355\sqrt{\left(\frac{N_e}{N_0 M}\right)^2 + \frac{F-1}{N_0} + \delta^2},$$

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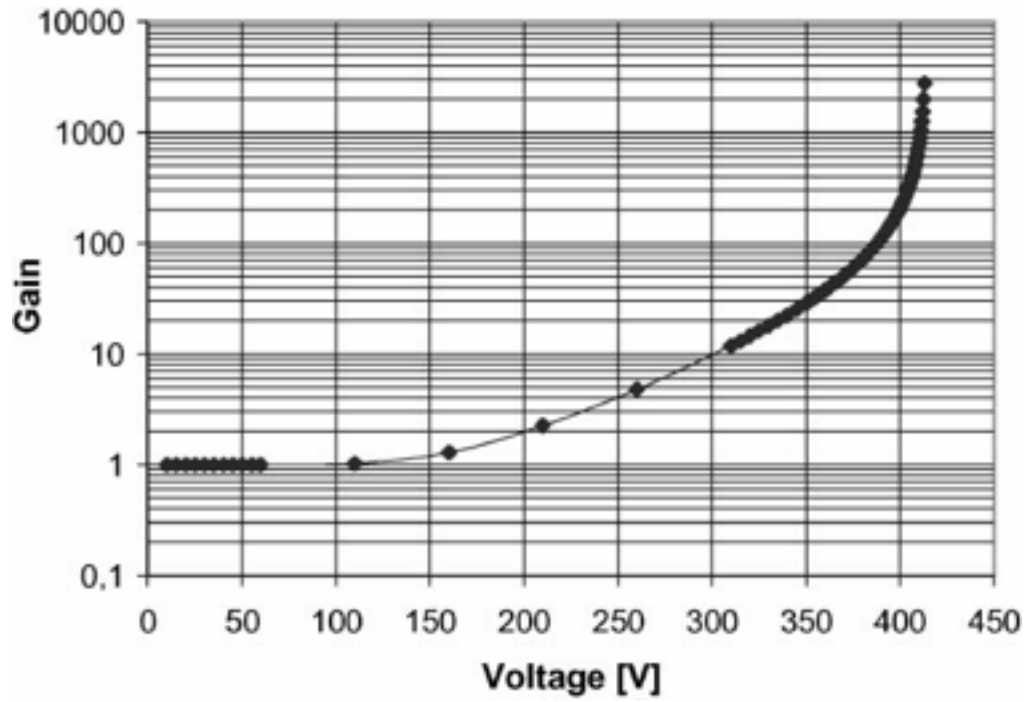
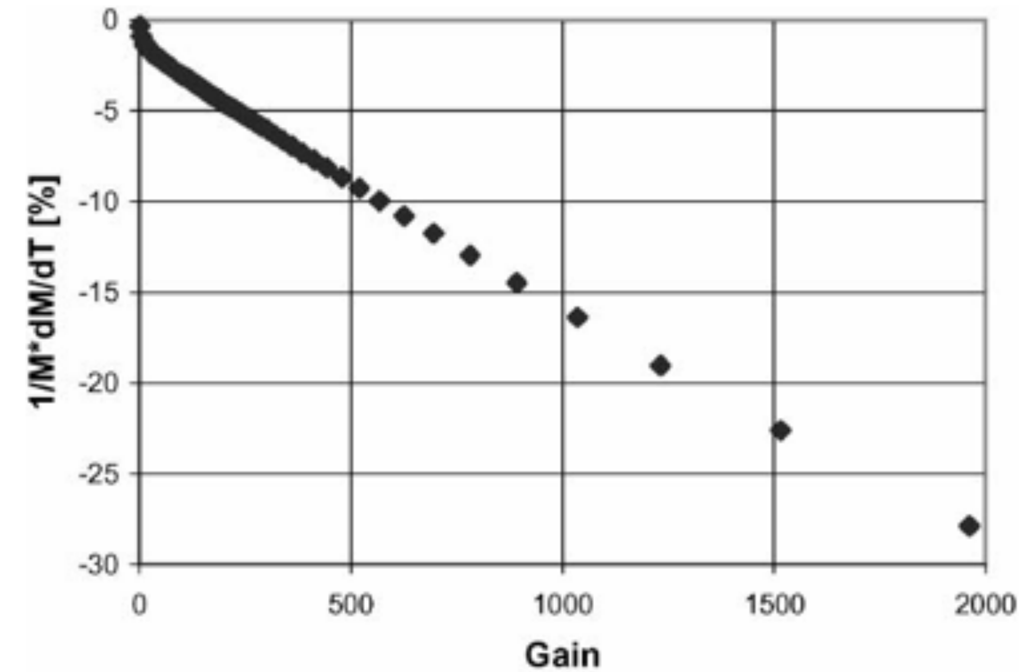
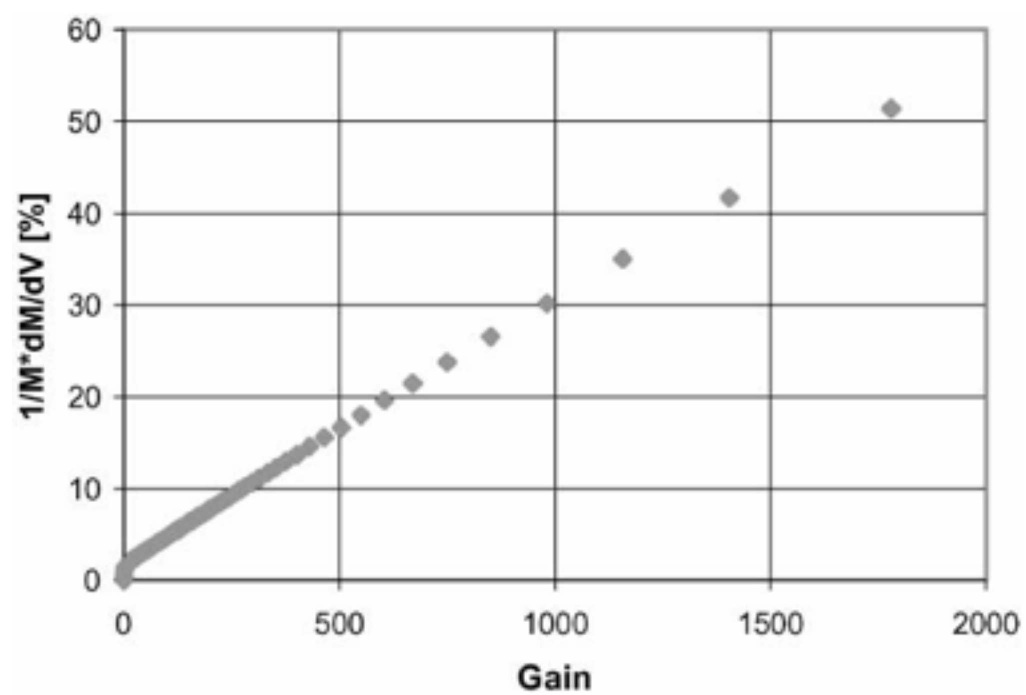
APD in CMS

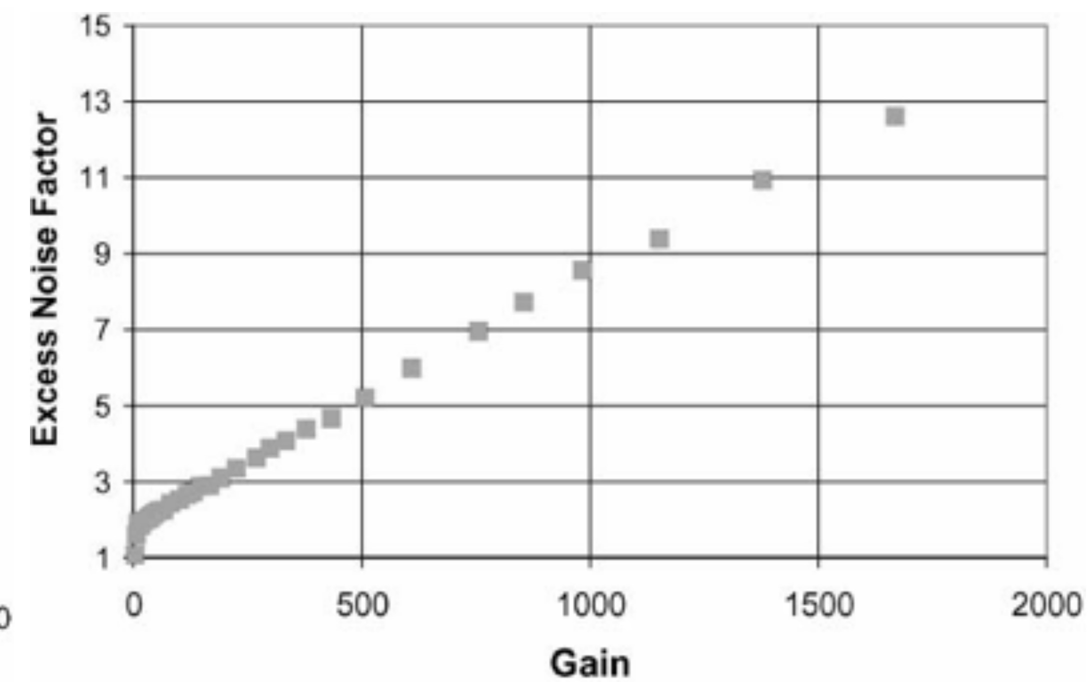
K.Deiters et al., NIM A461(2001)574-576





Gain measured with a LED of 430nm at 25℃ (DC mode)



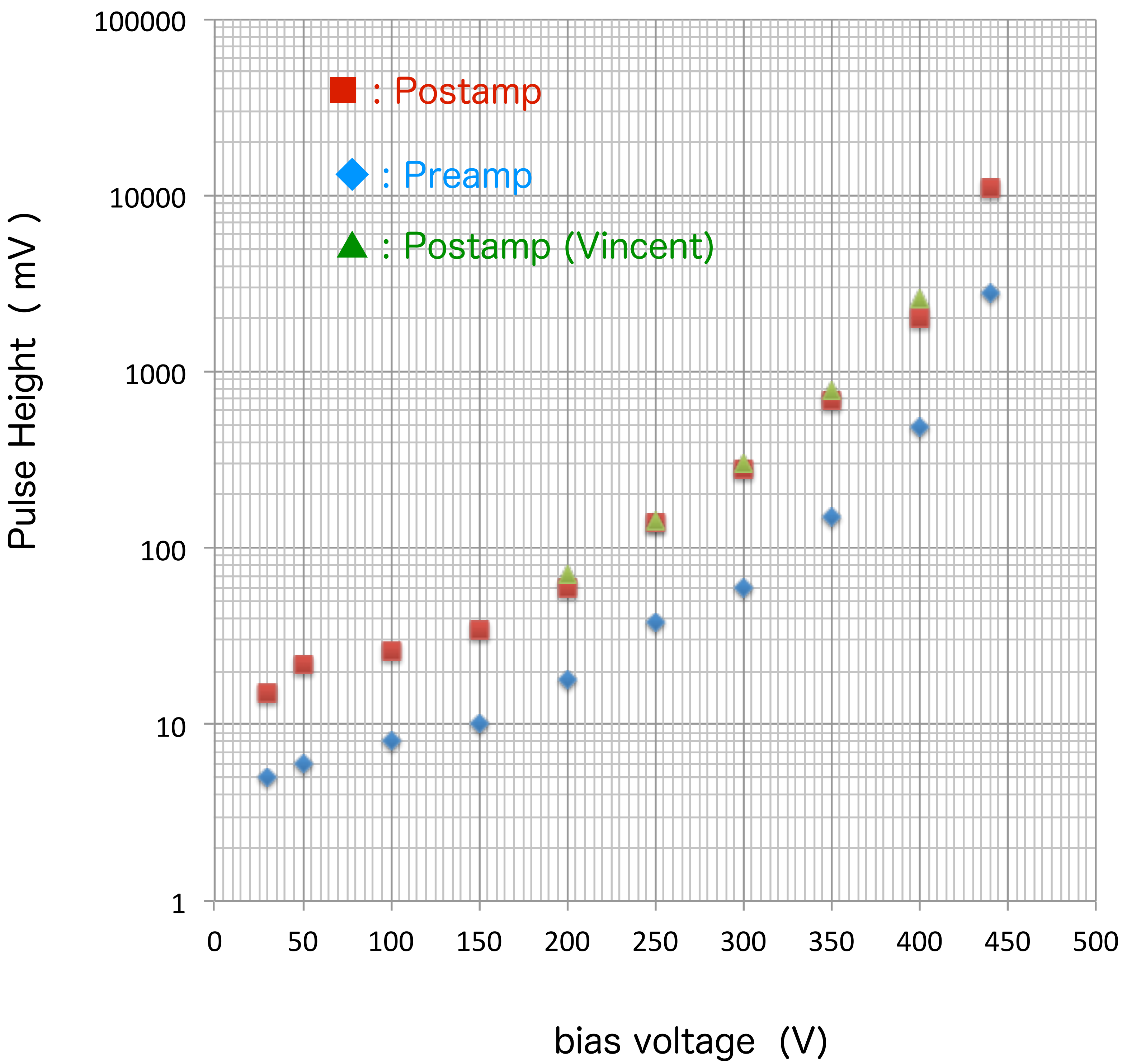


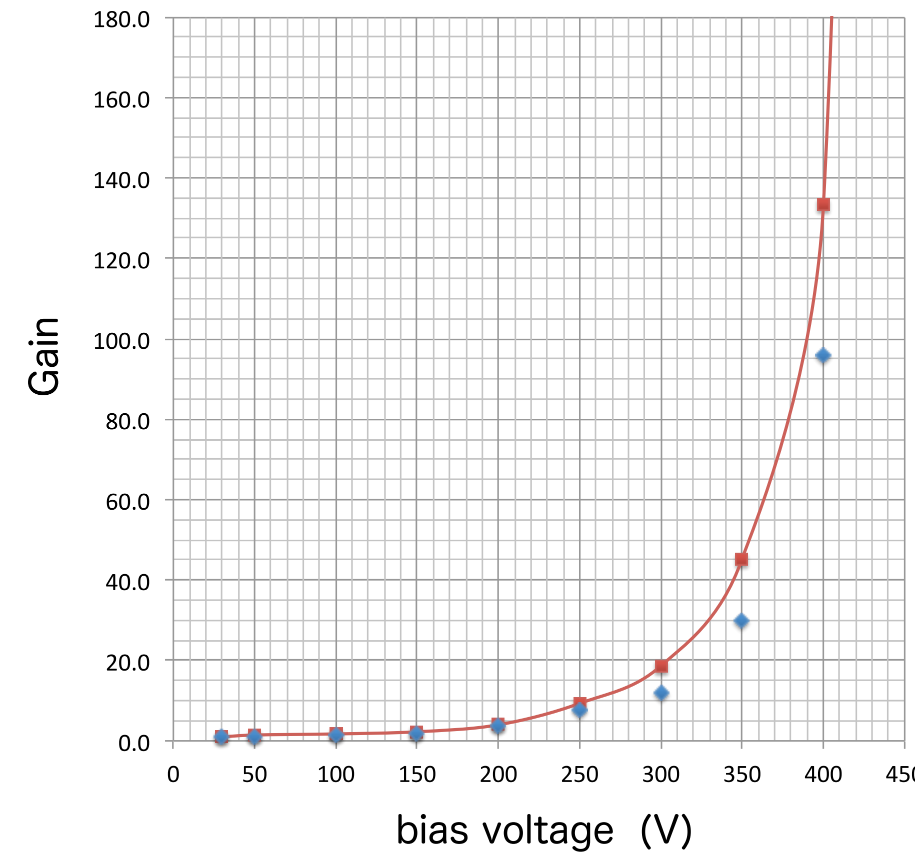
$$\frac{\Delta E}{E} = 2.355\sqrt{\left(\frac{N_e}{N_0 M}\right)^2 + \frac{F-1}{N_0} + \delta^2}\ , \quad \mathrm{F} = k \times M + \left(2 - \frac{1}{M}\right) \times (1-k).$$

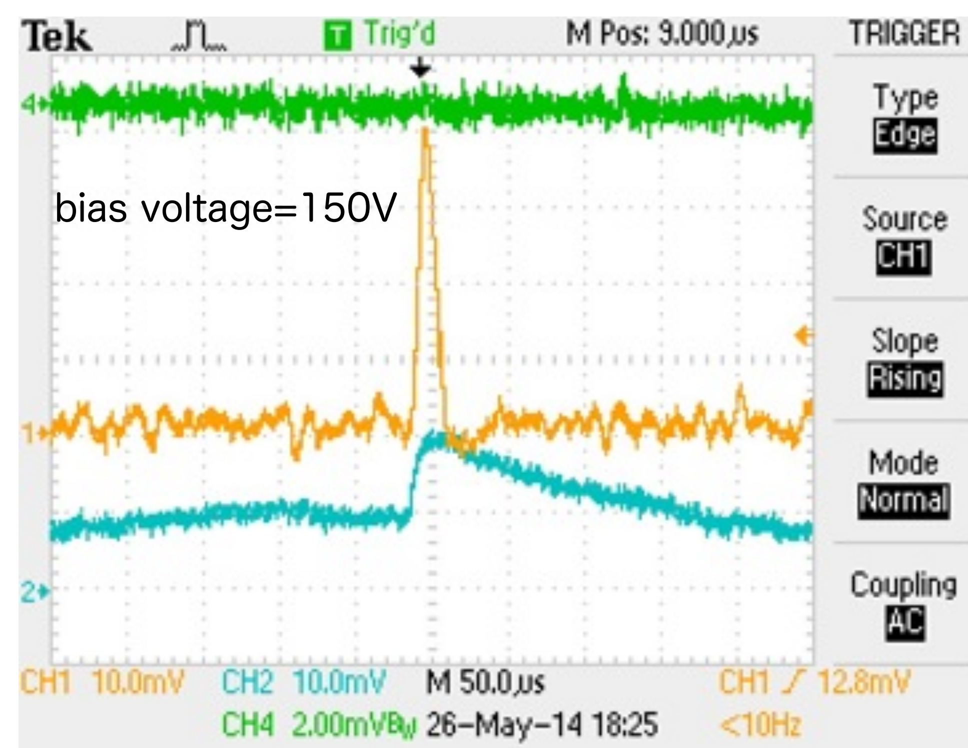
$F=\langle G^2\rangle/\langle G\rangle^2$, G is a statistical variable that describes the multiplication gain, i.e. $M=\langle G\rangle$

APD (S8664-55, short cable) with $^{241}A_m$NaI in room temperature

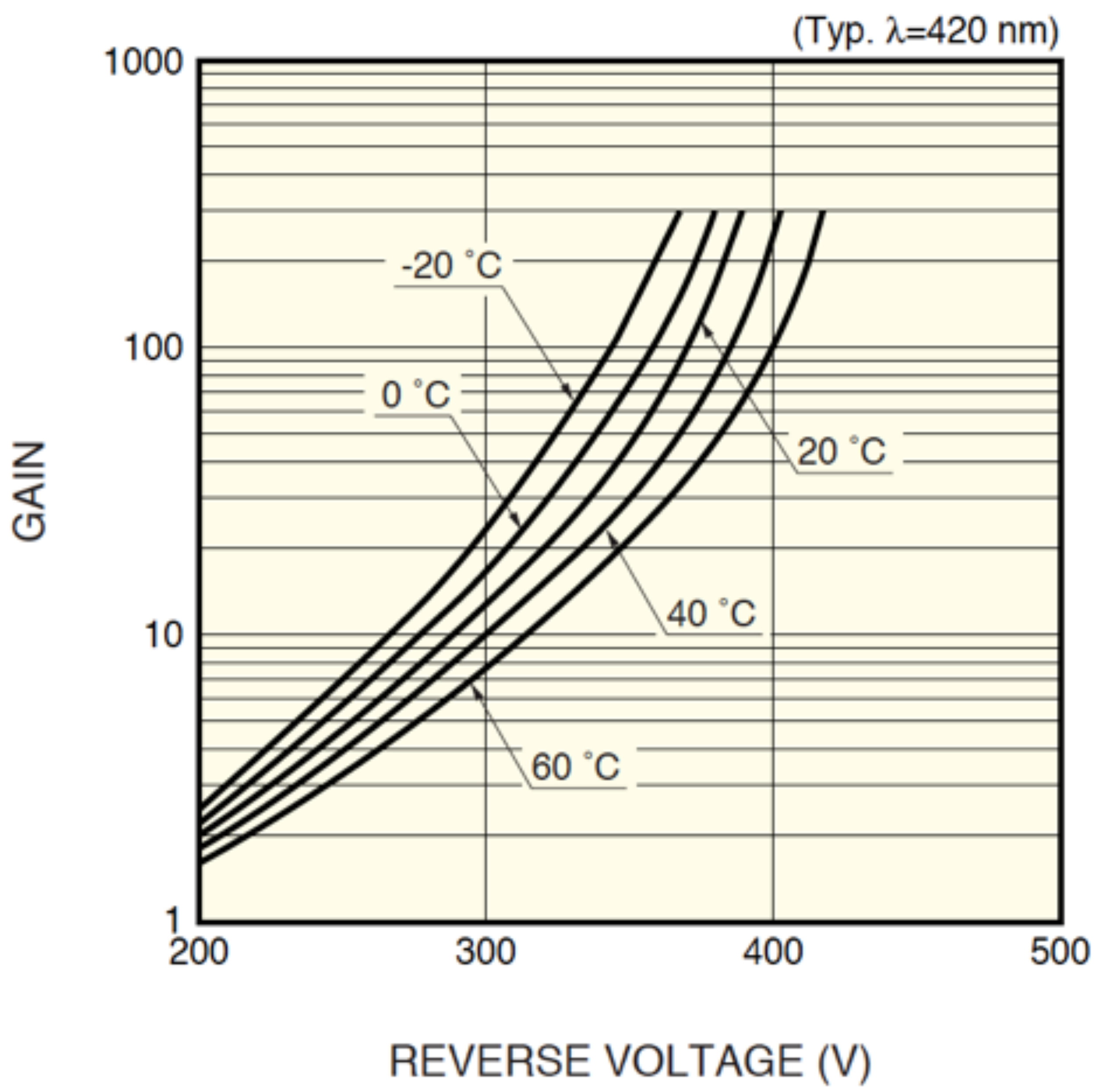
with the feedback capacitor of 0.1pF

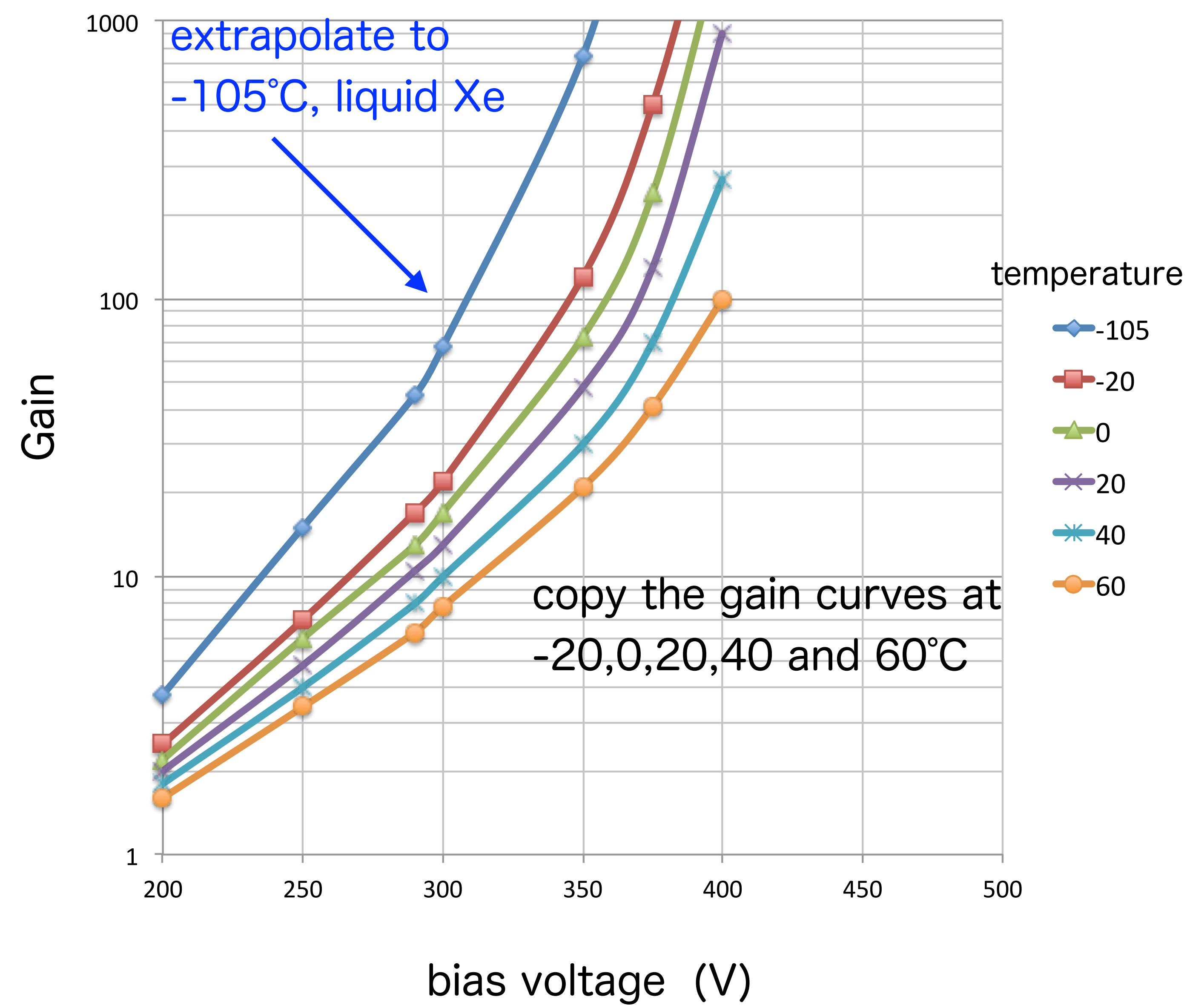


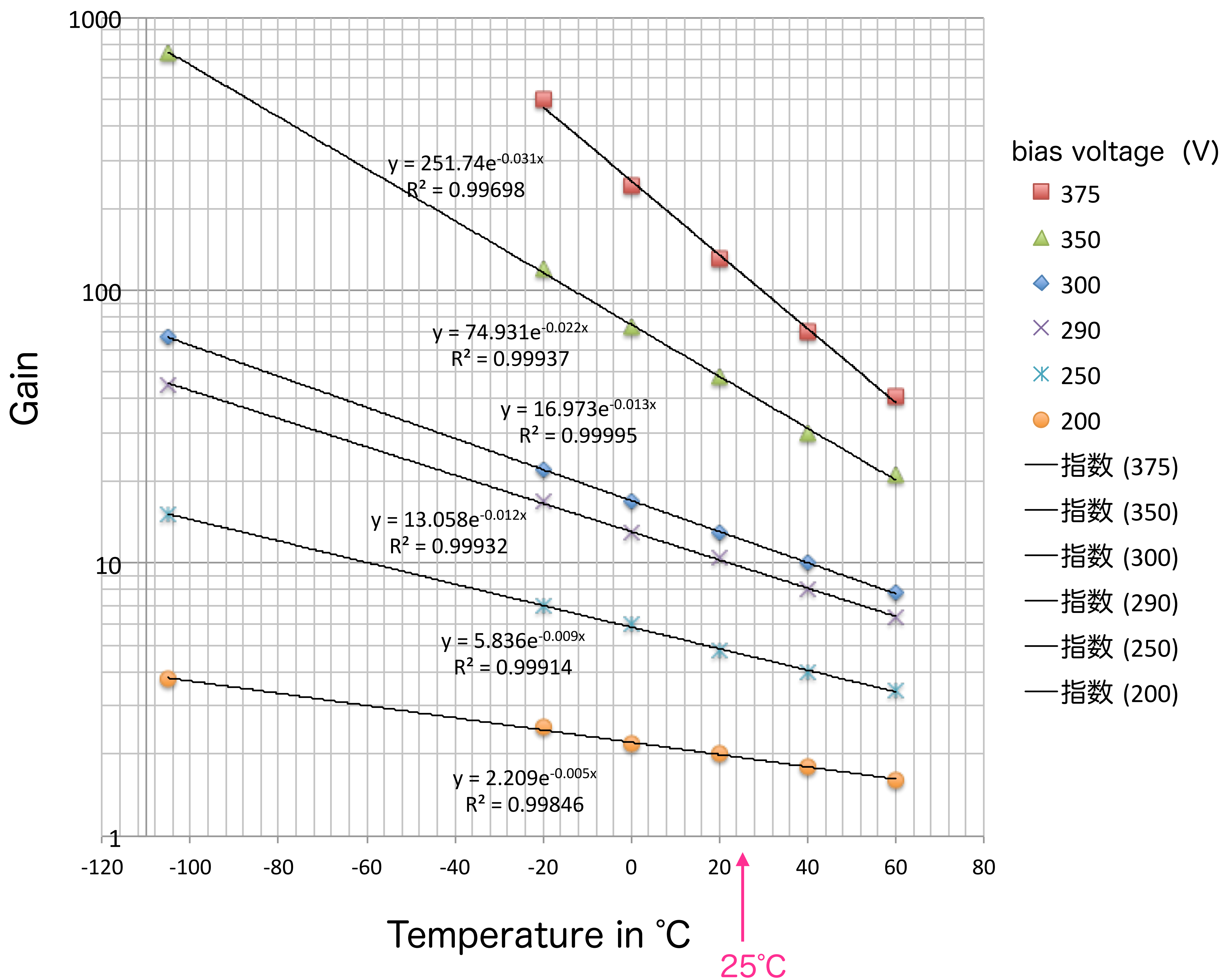




windowless APD : S10937-9390(X) (5x5mm^2)







Gain
1000
100
10
1
-120
-100
-80
-60
-40
-20
0
20
40
60
80
Temperature in ℃
25℃
y = 251.74e-0.031x
R² = 0.99698
y = 74.931e-0.022x
R² = 0.99937
y = 16.973e-0.013x
R² = 0.99995
y = 13.058e-0.012x
R² = 0.99932
y = 5.836e-0.009x
R² = 0.99914
y = 2.209e-0.005x
R² = 0.99846
bias voltage (V)
375
350
300
290
250
200
指数 (375)
指数 (350)
指数 (300)
指数 (290)
指数 (250)
指数 (200)

APD(S8148) in Liq.N_2

A.Dorokhova et al., NIM A504(2003)58-61

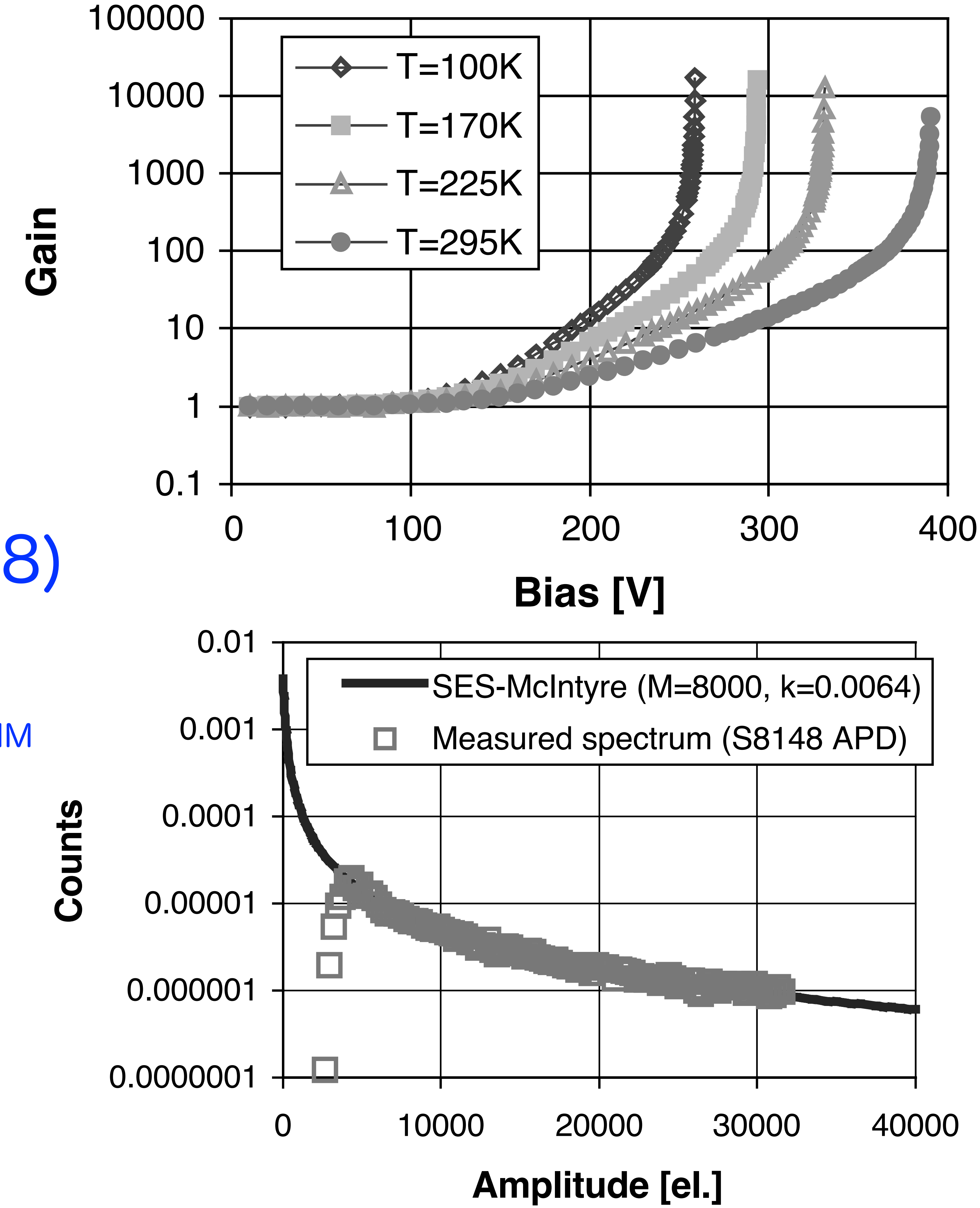
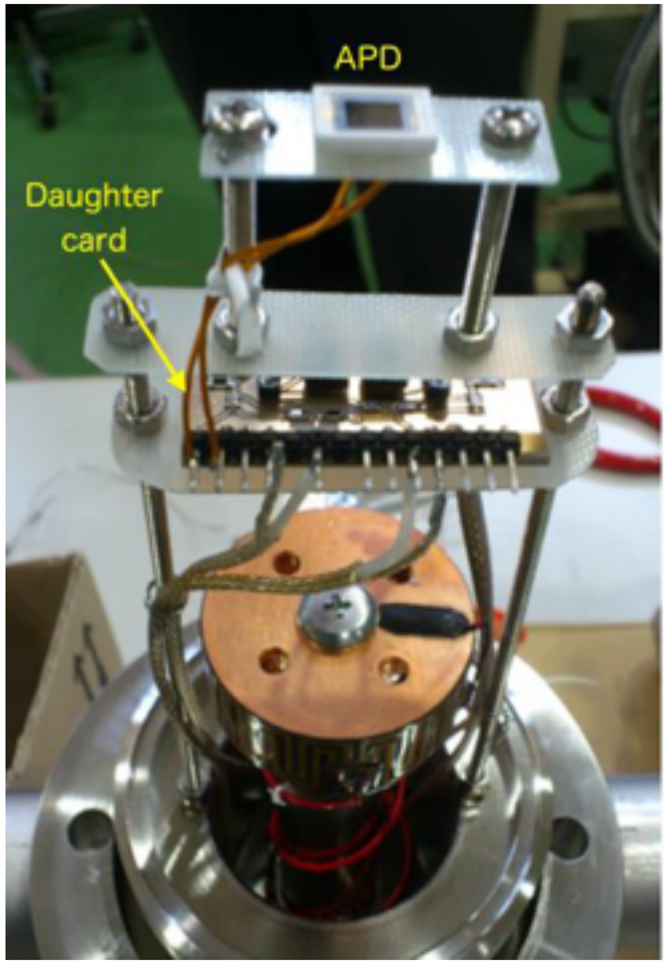
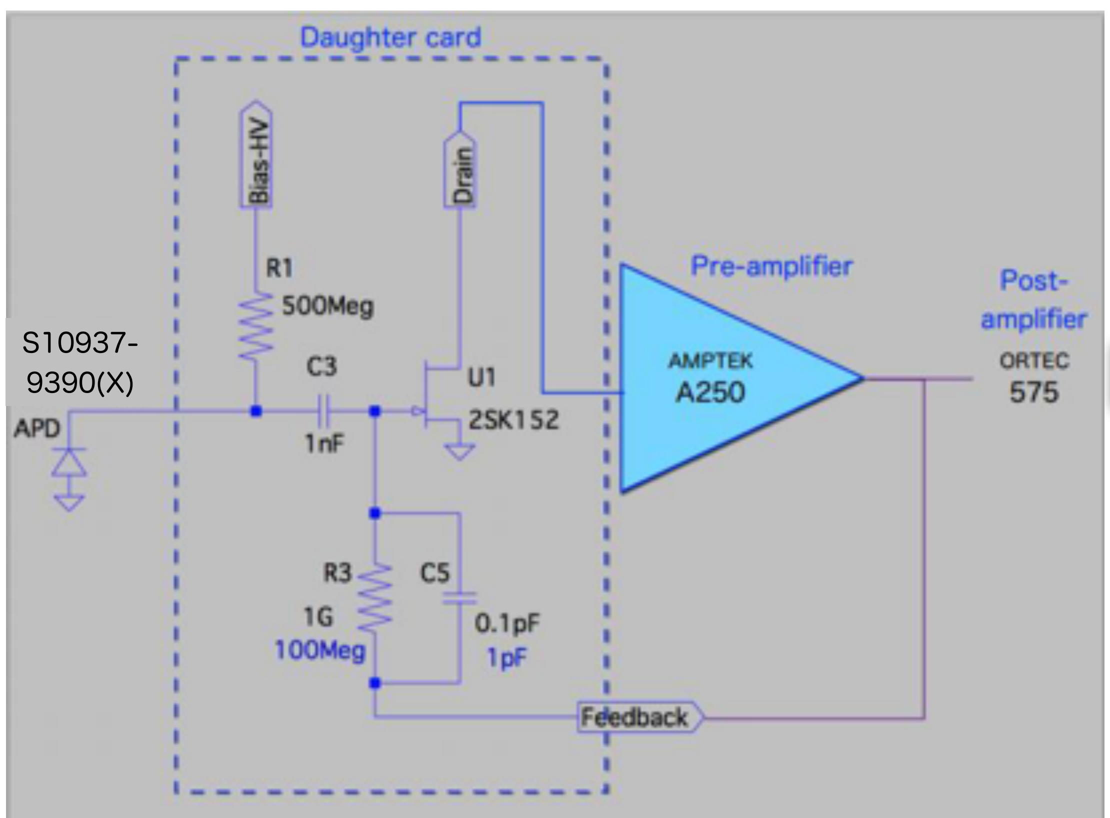


Fig. 6. APD single electron spectra (measured and calculated).

Measurement of γ ray spectrum



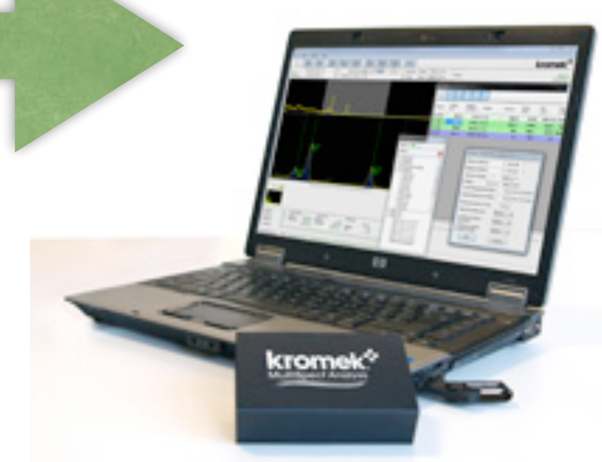
windowless APD
S10937-9390(X)
($5x5mm^2$)



APD($5x5mm^2$) and frontend electronics

Post-amplifier ORTEC 575A

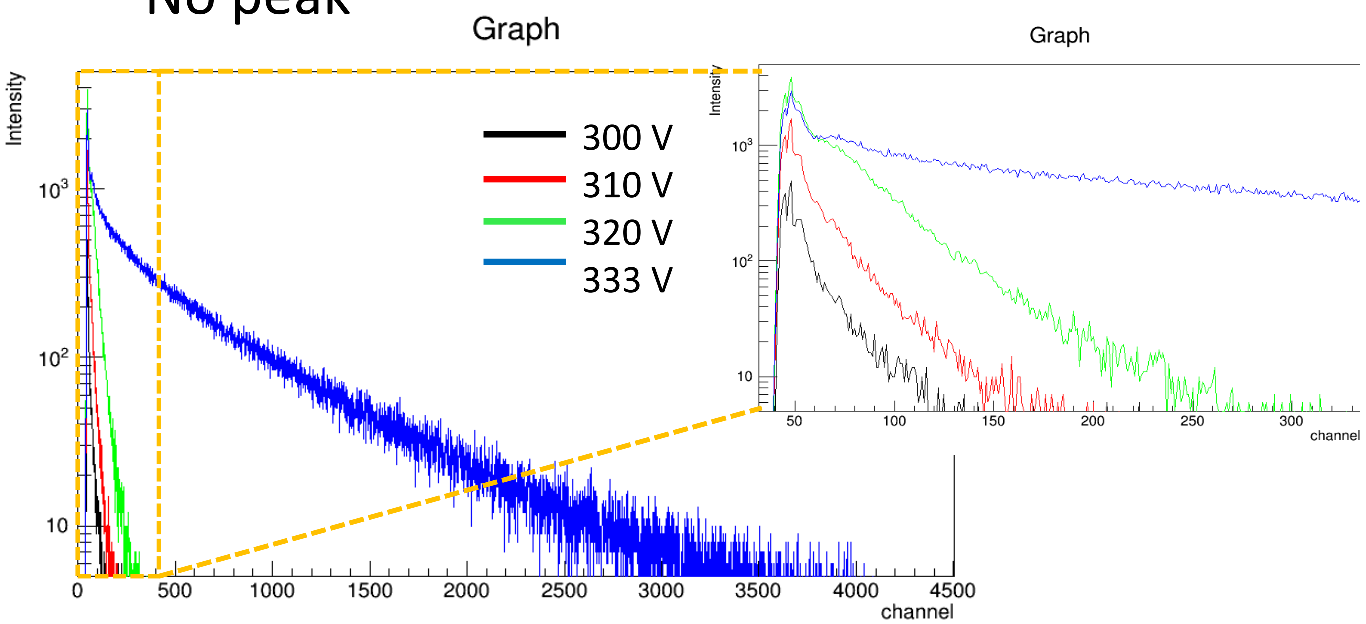
K102



Multichannel analyser

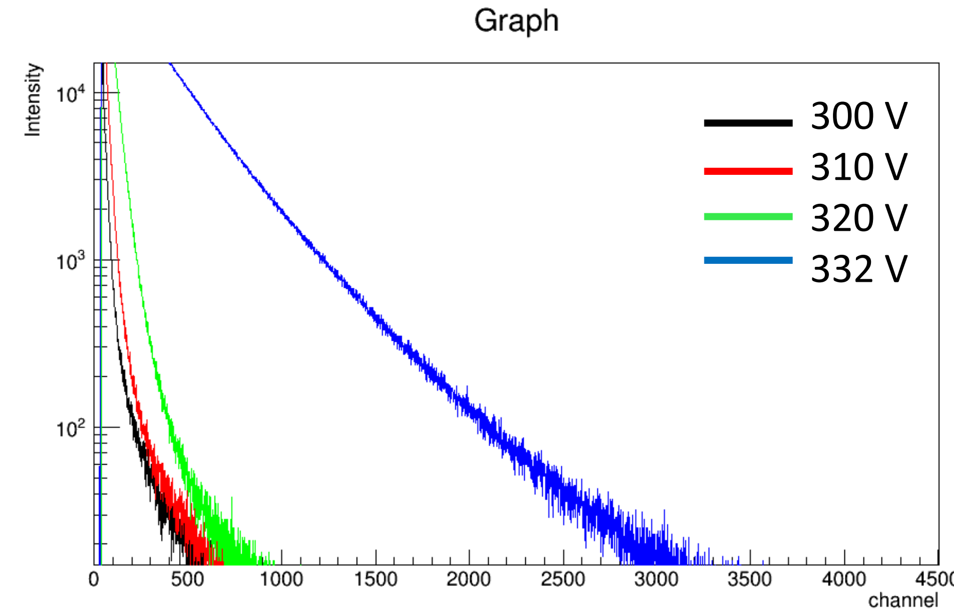
Measured results with a windowless APD : S10937-9390(X) (5x5mm^2)

- ^{137}Cs & LXe (time : 1800 s)
  - No peak



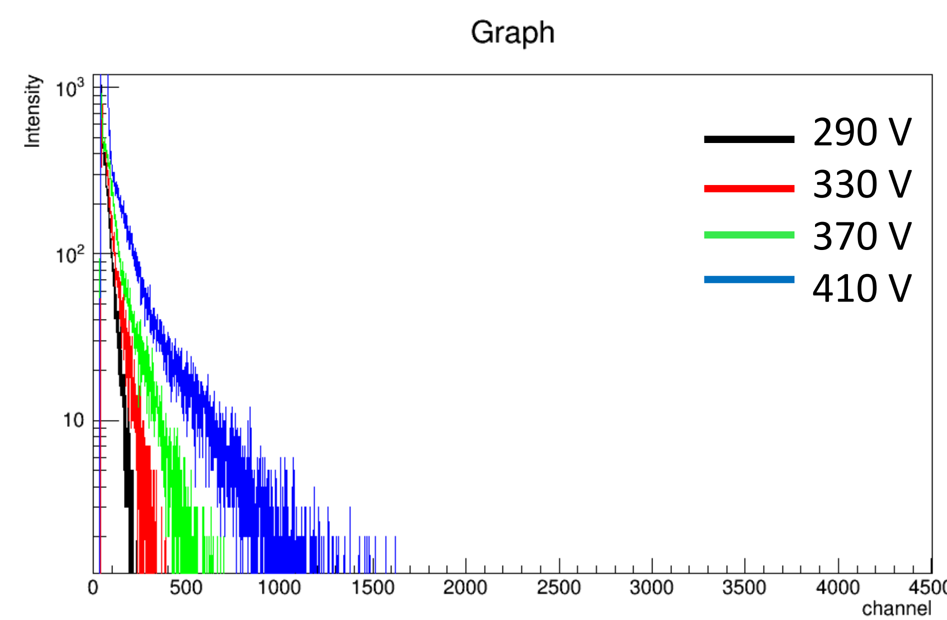
Number of photon is very low… ?

- ^{22}Na & LXe (time : 1800 s)
  - No peak



- Y-axis is set to log scale.
- It has almost same shape as ^{137}Cs case.

- ^{22}Na & GXe (time : 1800 s)
  - No peak



- Y-axis is set to log scale.
- It has almost same shape as ^{137}Cs case.

Compare to the PMT measurements (EDIT2013)

PMT 2” square R7600

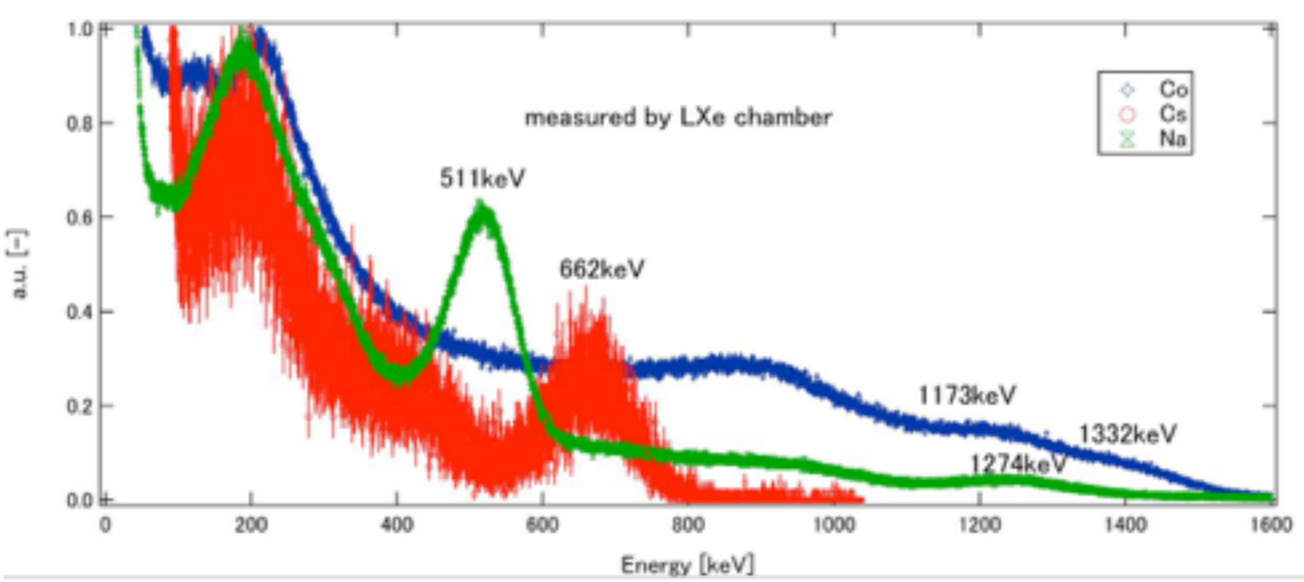


Fig5. Results of gamma(^{22}Na, ^{60}Co, ^{137}Cs) spectrum measurements

γ spectrum by the PMT and the same chamber during the EDIT2013

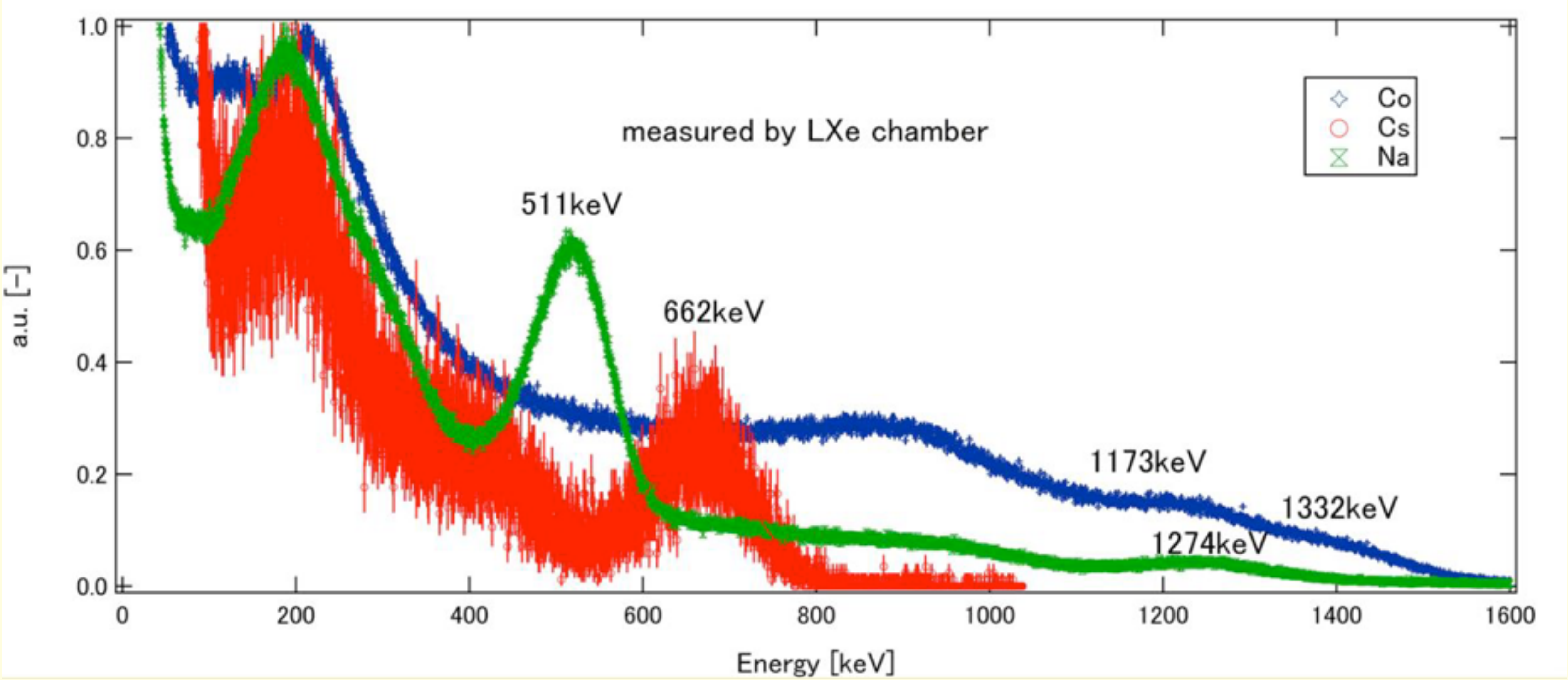
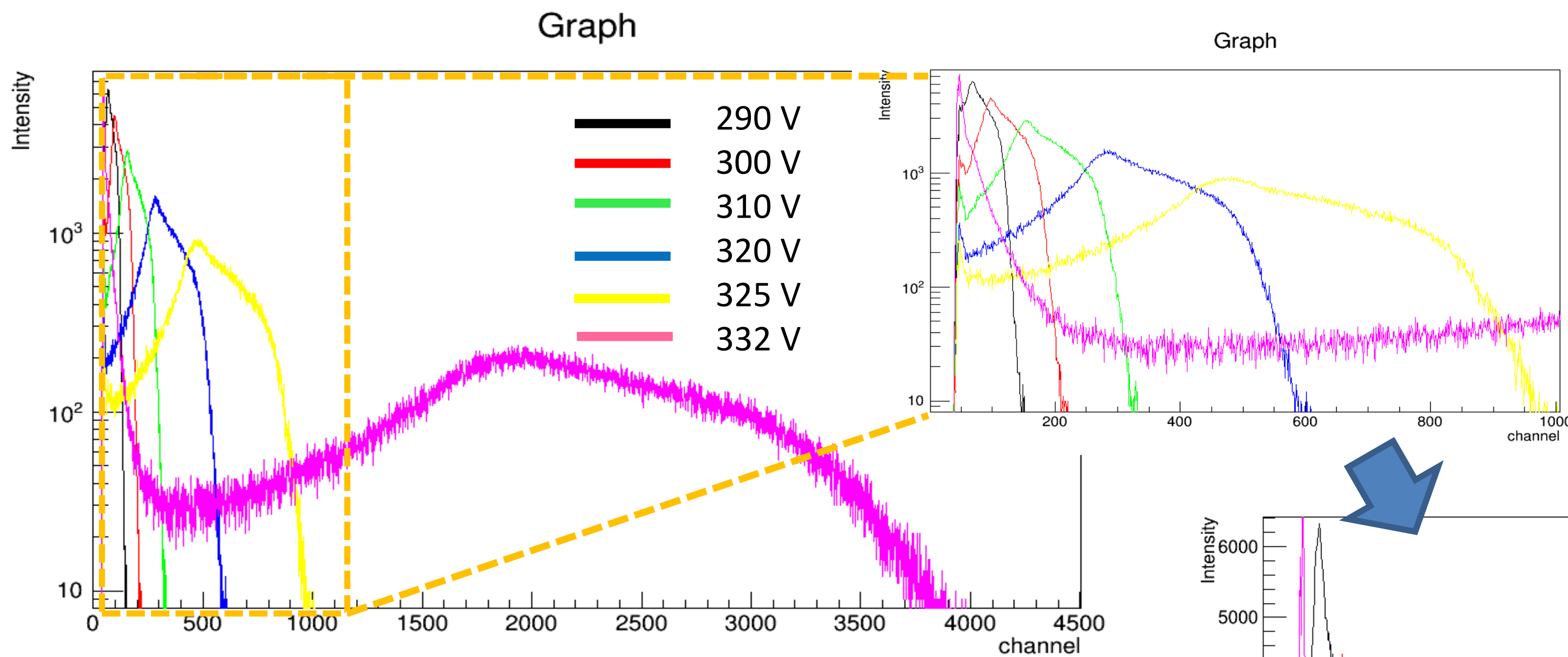


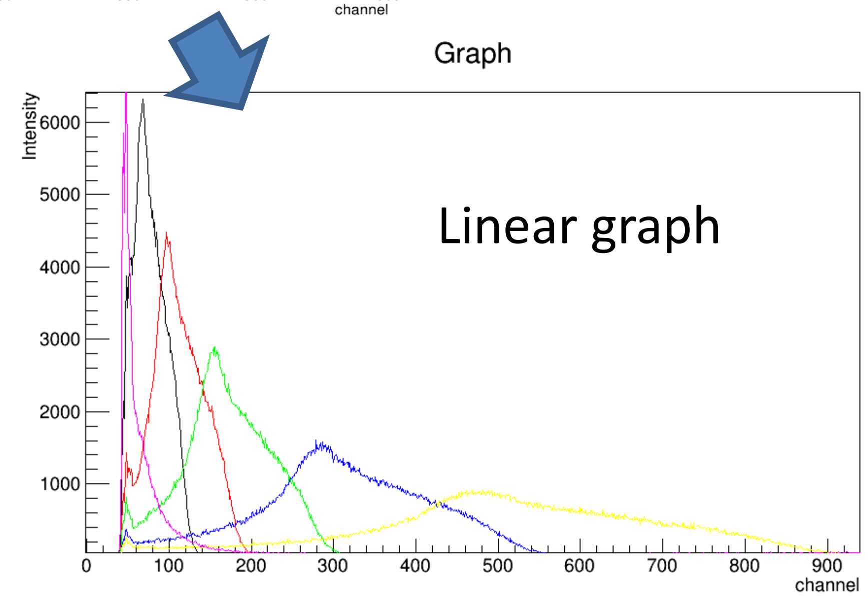
Fig5. Results of gamma(^{22}Na, ^{60}Co, ^{137}Cs) spectrum measurements

Table1. Energy Resolution FWHM

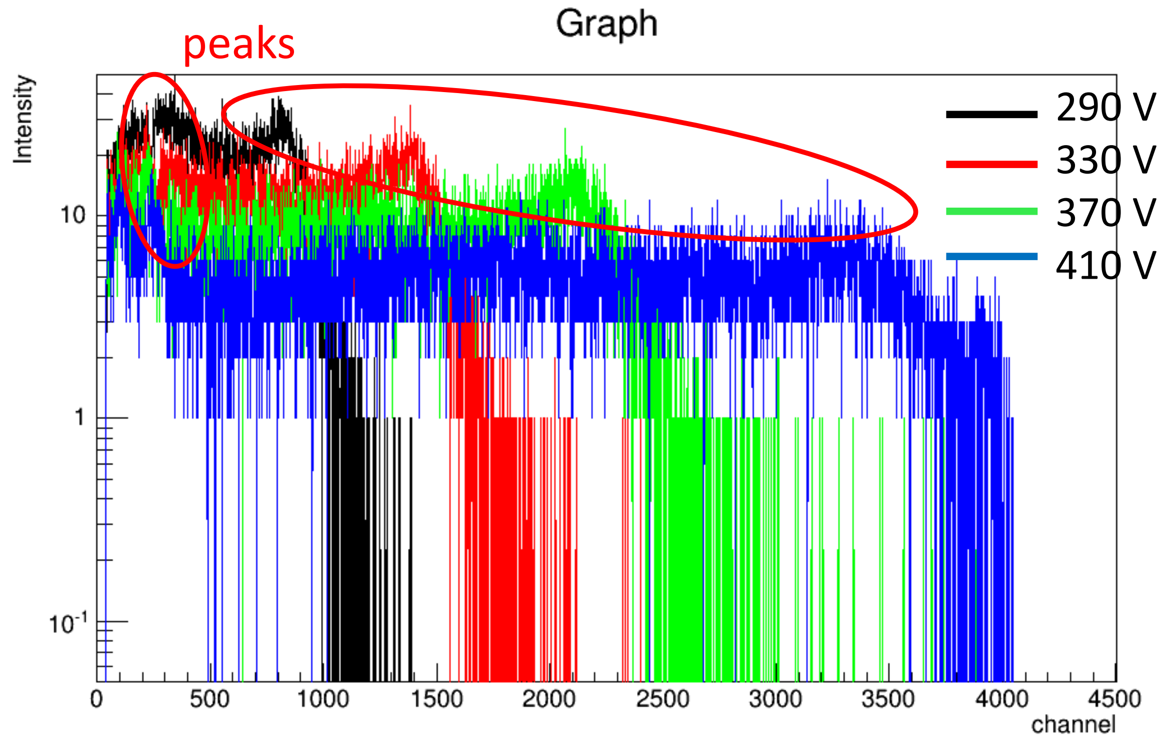
source	Energy	Energy Resolution	error
Na	511	14.3%	0.683%
	1274	19.7%	3.70%
Cs	662	20.3%	19.5%
Co	1173	28.9%	14.7%
	1332	14.6%	8.91%

- ^{241}Am & LXe (time : 1800 s)
  - One peak?





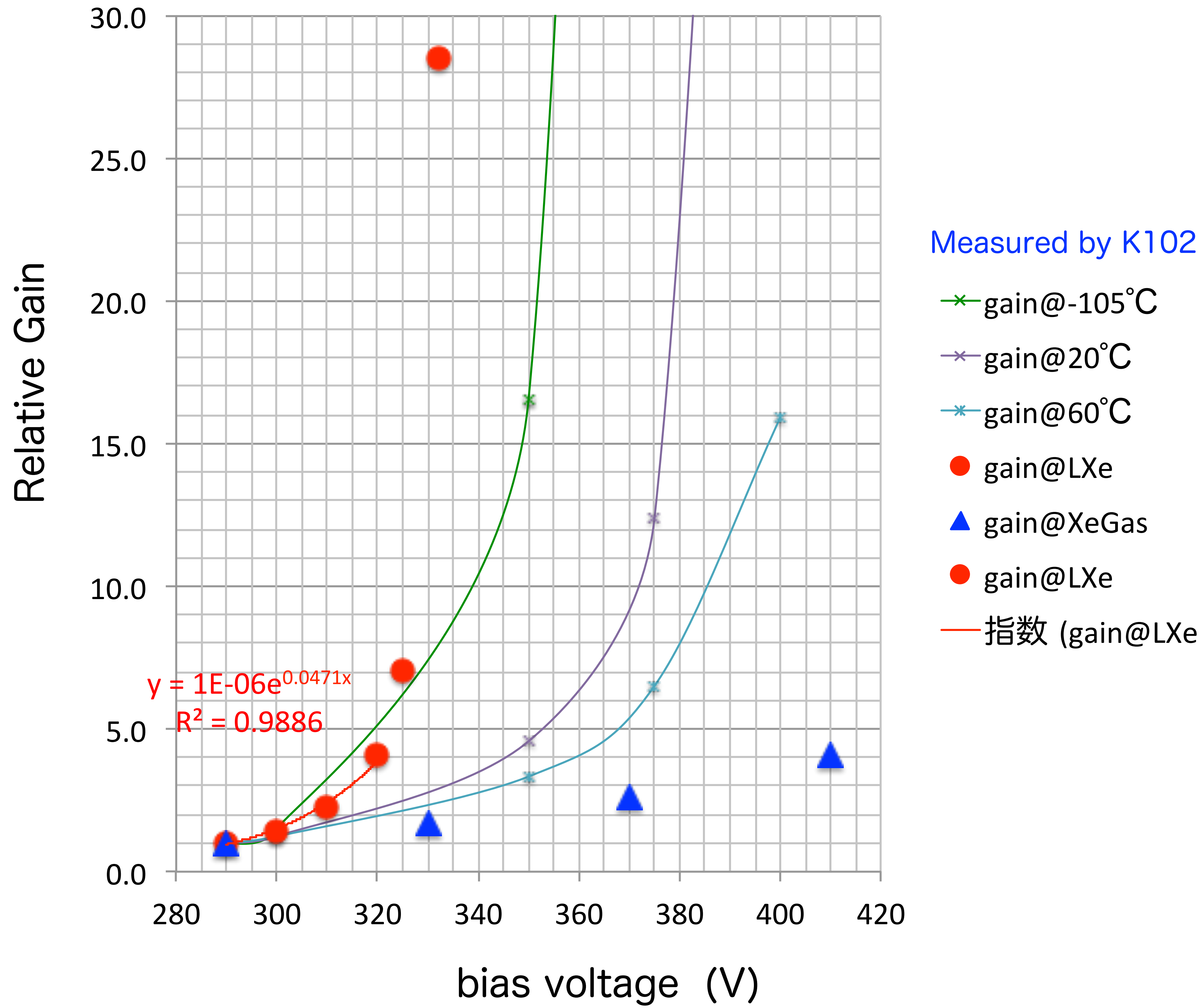
- ^{241}Am & GXe (time : 1800 s)



- Y-axis is set to log scale.
- Count rate is very low. (about ~10 cnt/s)

APD with $^{241}A_m$ in Xe at Liquid and Gas (P_{abs}=4atm) phases

with the feedback capacitor of 1pF



Rough Expectations

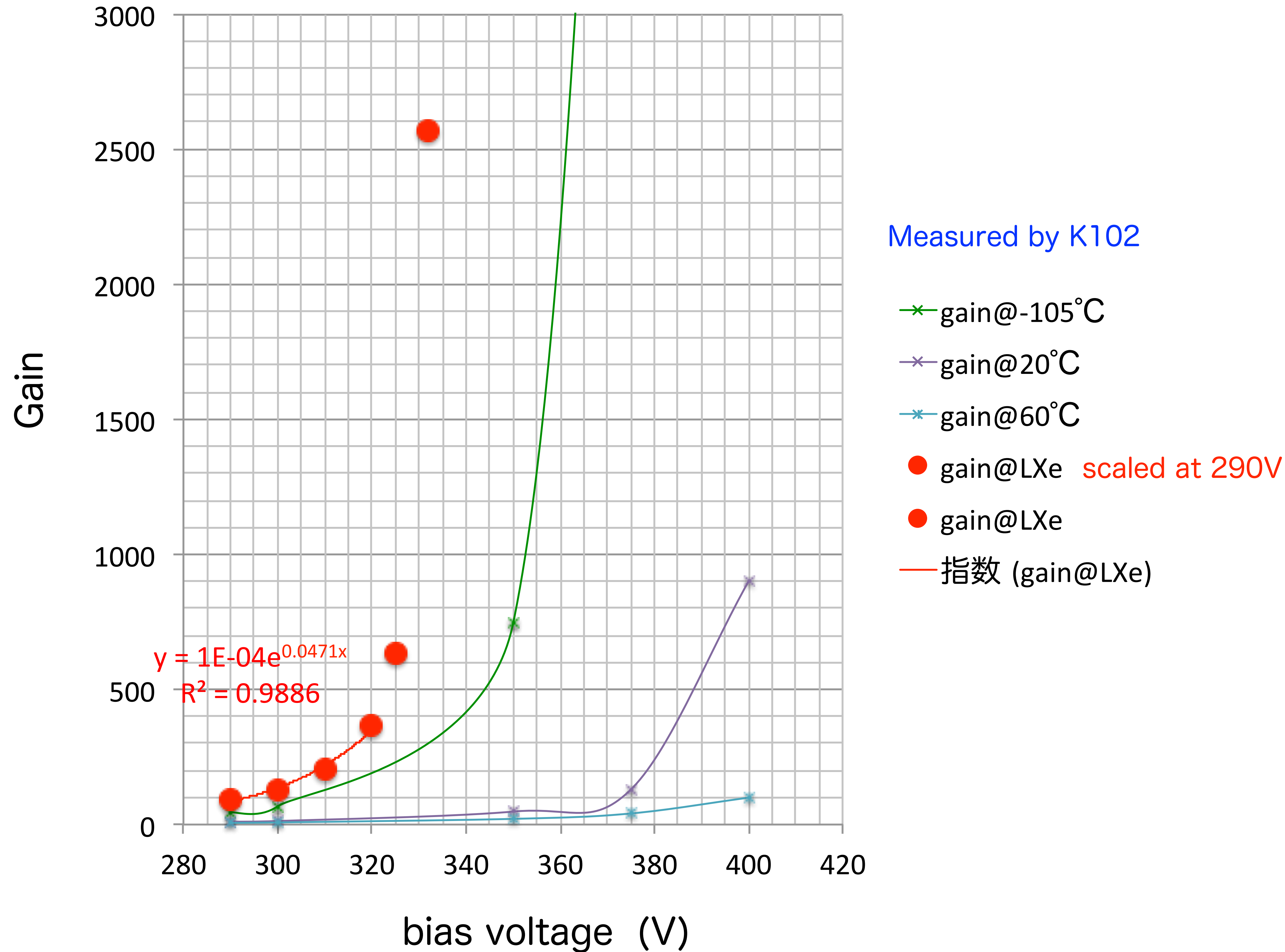
γ energy	photons in NaI/Xe	total photons	acceptance APD(s8664)		photons	quantum effiecincy	electrons N_0	charge	att. by 80+10pF	charge / 1pF	charge / 0.1pF	APD gain	APD PH	observed PH at preamp
MeV	/MeV		distance : d mm	η	in APD	by Catalog	in APD	1.6E-19/e	by Ltspice	mV	mV		mV	mV
5.5	40000	220000	6	0.055	12164	0.7	8515	1.362E-15	0.6	0.82	8.2	1	8.2	5
5.5	68027	374149	20	0.005	1862	0.7	1303	2.085E-16	0.6	0.13	1.3	90	11.3	14.0
0.66	68027	44898	10	0.020	894	0.7	626	1.001E-16	0.6	0.06	0.6	90	5.4	13.0

(1) APD gain is estimated by M=M(V=290V)・exp(bV) , b=4.7% and the gain corresponding in Fig.4, NIM A442(2000)193-197, K.Deiters et al. , assuming the same property of the APD expect for the quantum efficiency.

(2) Distance (d) is from the APD to the gamma ray source

(3) Acceptance η is a simple one defined by 5 x 5 mm^2 / $4\pi d^2$.

APD with ^{241}Am in Liquid Xenon



Measured by K102

Detection of Scintillation Light of Liquid Xenon with a LAAPD, V.N.Solovov et al., Nuclear Science Symposium Conference Record, 2000 IEEE (Volume:1) 7/58-7/62 vol.1, 15-20 Oct. 2000.

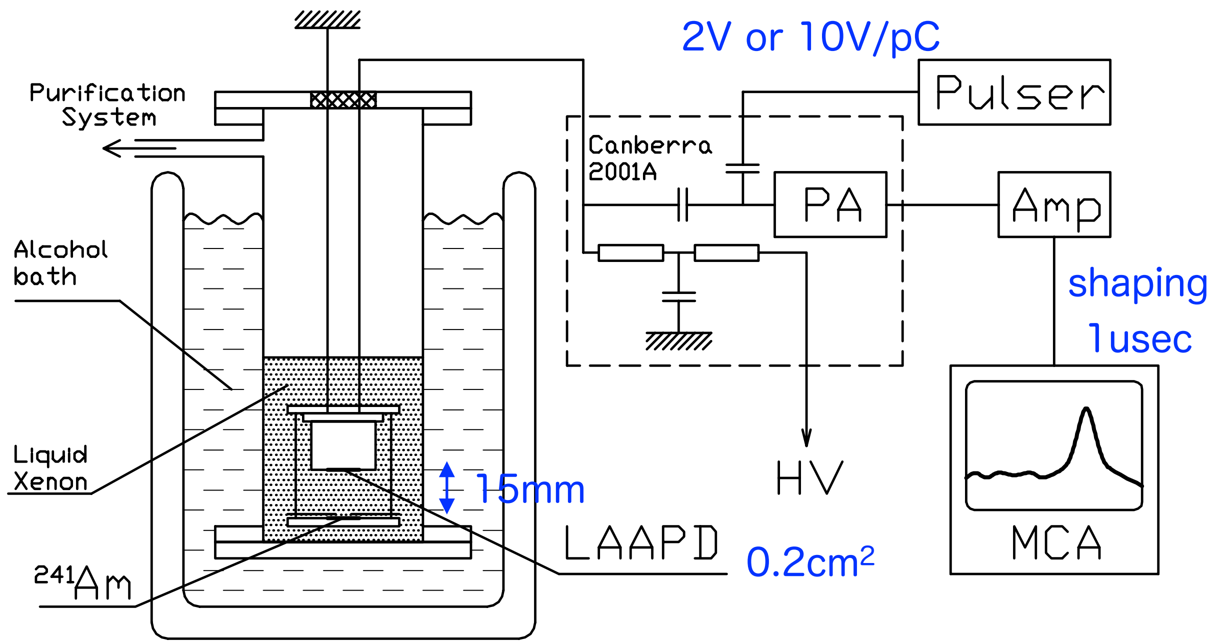


Figure 1: Set-up for energy resolution measurements: PA – charge sensitive preamplifier, Amp –spectroscopy amplifier, MCA – multichannel analyser.

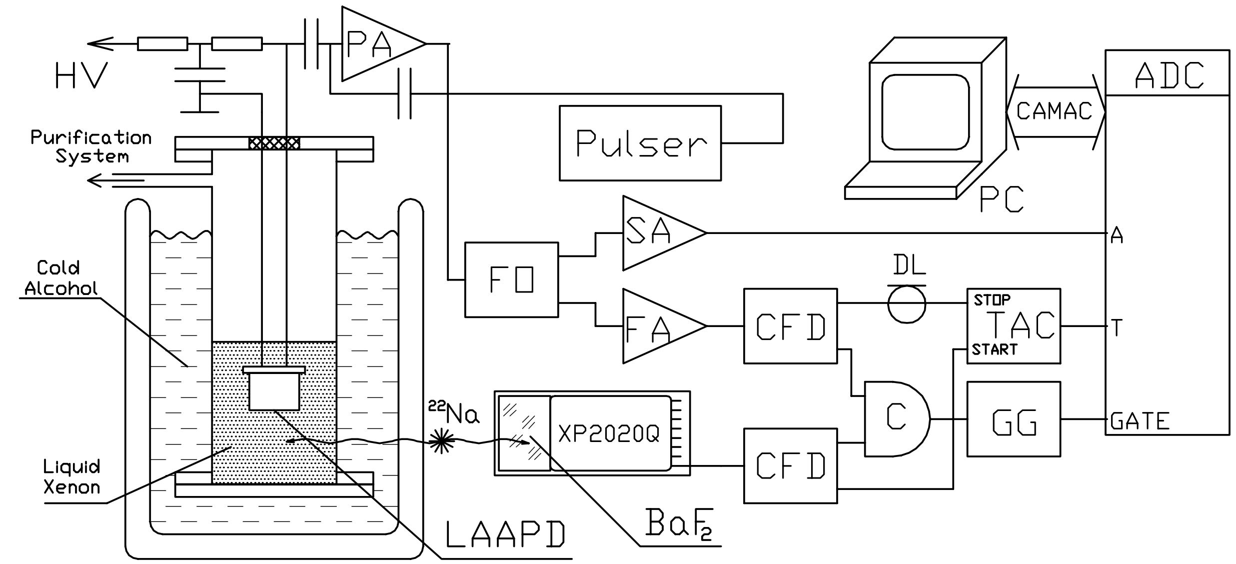


Figure 2: Set-up for time resolution measurements: PA – preamplifier, FO – linear fan-out, SA –shaping amplifier, FA – fast amplifier, CFD – constant fraction discriminator, C –coincidence unit, DL – delay line, TAC – time-to-amplitude converter, GG – gate generator.

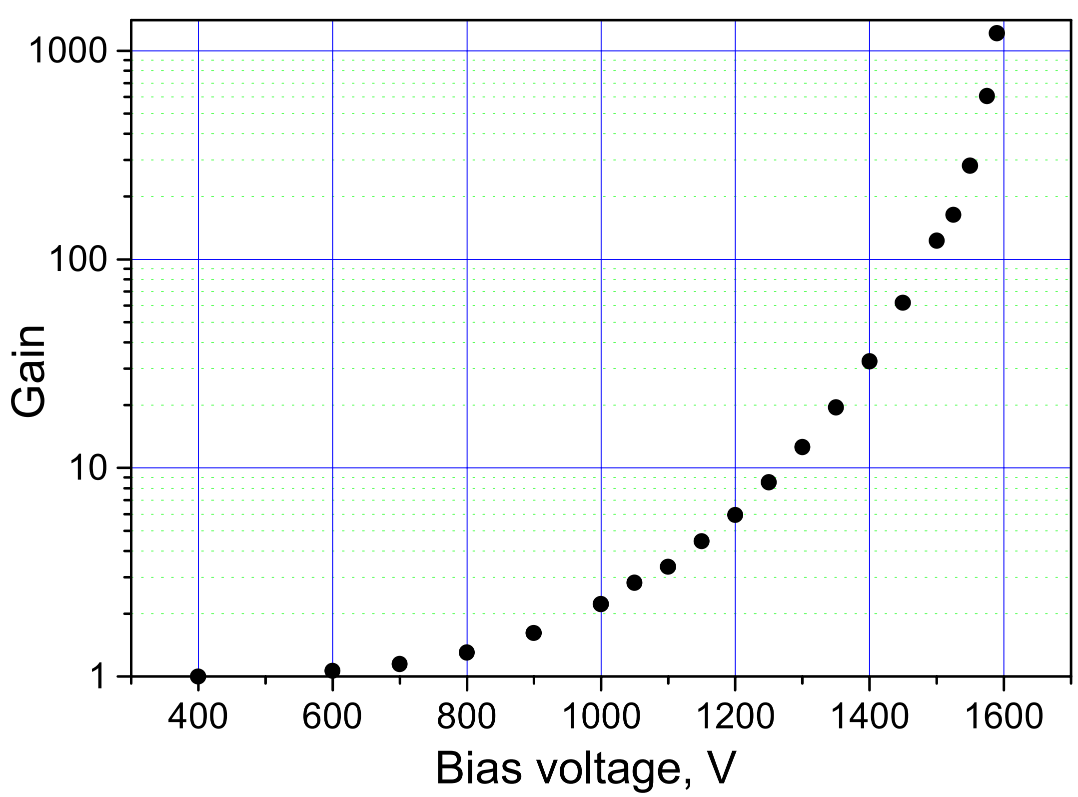


Figure 3: LAAPD gain as a function of bias voltage (T = -100ºC).

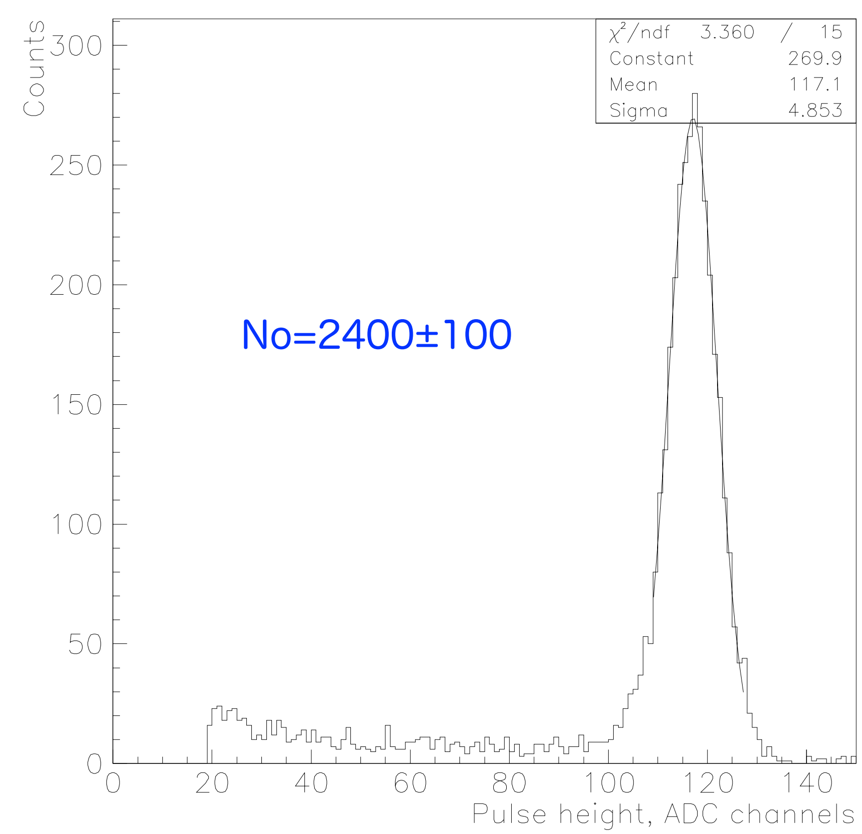


Figure 4: Typical pulse height spectrum of the scintillation due to 5.5 MeV α-particles. LAAPD gain is 120.

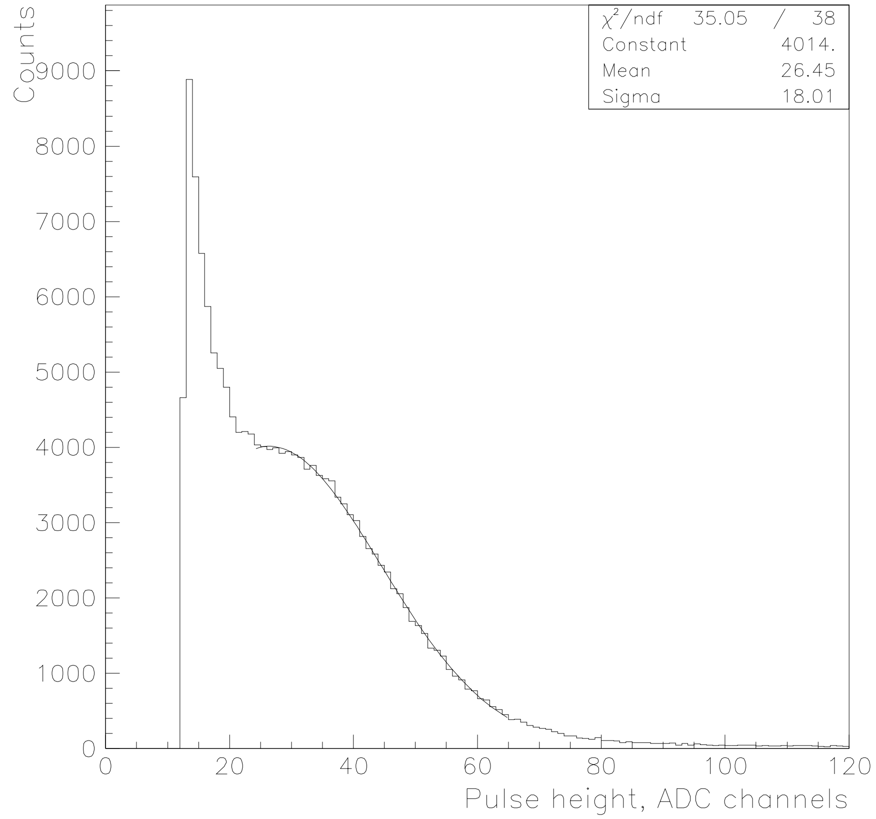
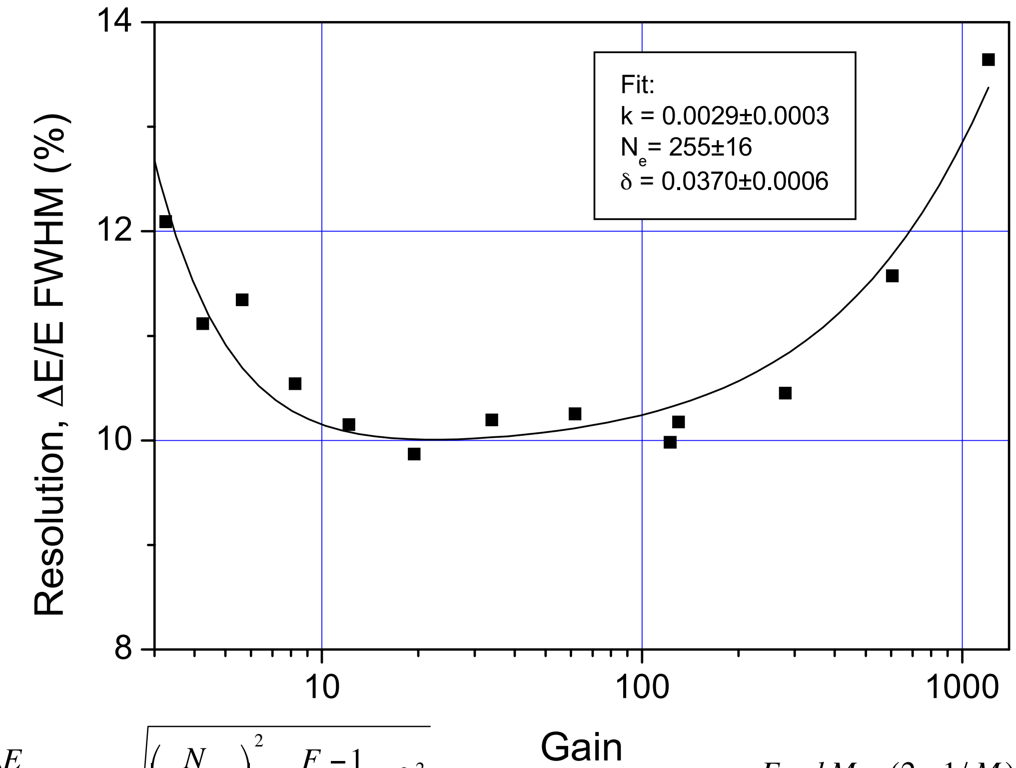


Figure 5: The pulse height spectrum obtained with the 241Am source placed at 5mm from the photodiode. A peak due to 60 keV γ-rays can be distinguished. The LAAPD gain is 150. The amplifier gain is 3 times higher than for the spectrum shown in Fig. 4.



$$\frac{\Delta E}{E} = 2.355\sqrt{\left(\frac{N_e}{N_0 M}\right)^2 + \frac{F-1}{N_0} + \delta^2}\,, \qquad F \approx kM + (2 - 1/M)(1-k)\,,$$

Figure 6: Energy resolution measured with α-particles as a function of gain. The squares are experimental points and the line is the best fit of eq. (1) to the experimental data.

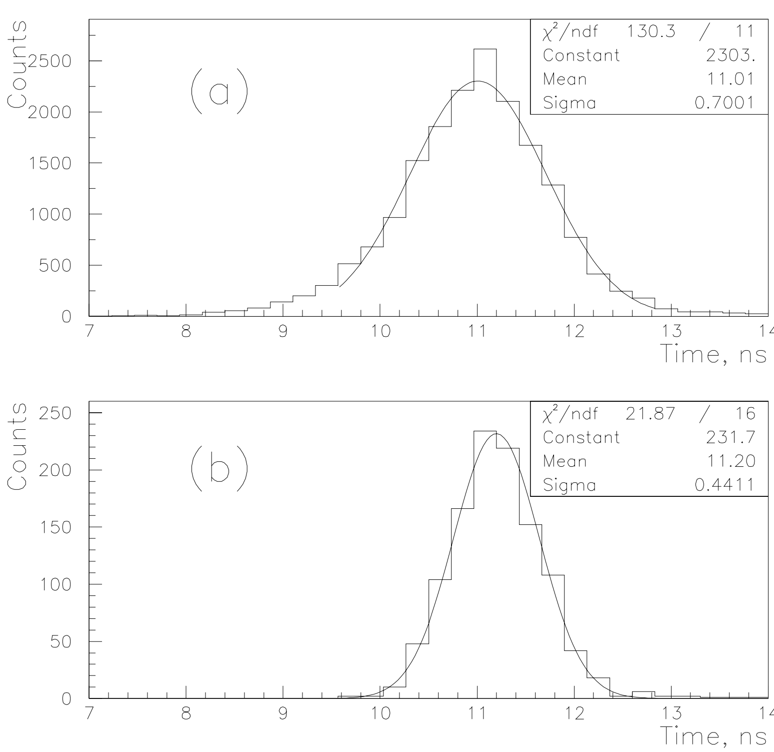


Figure 7: Time interval distributions, obtained with the LAAPD gain M=605 for N_0 above the threshold of 1,500 (a) and for N_0 in the range from 6,000 to 8,000 (b).

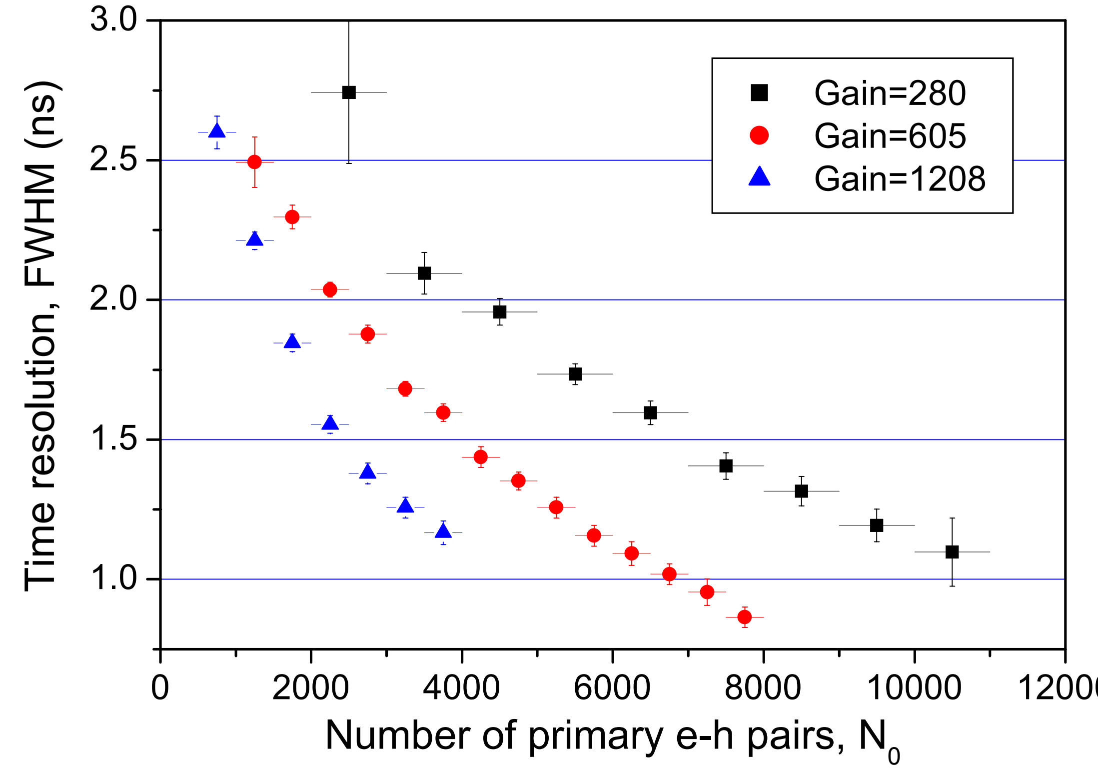


Figure 8: Time resolution as a function of the number of primary electron-hole pairs (N_0) for three values of the LAAPD gain.

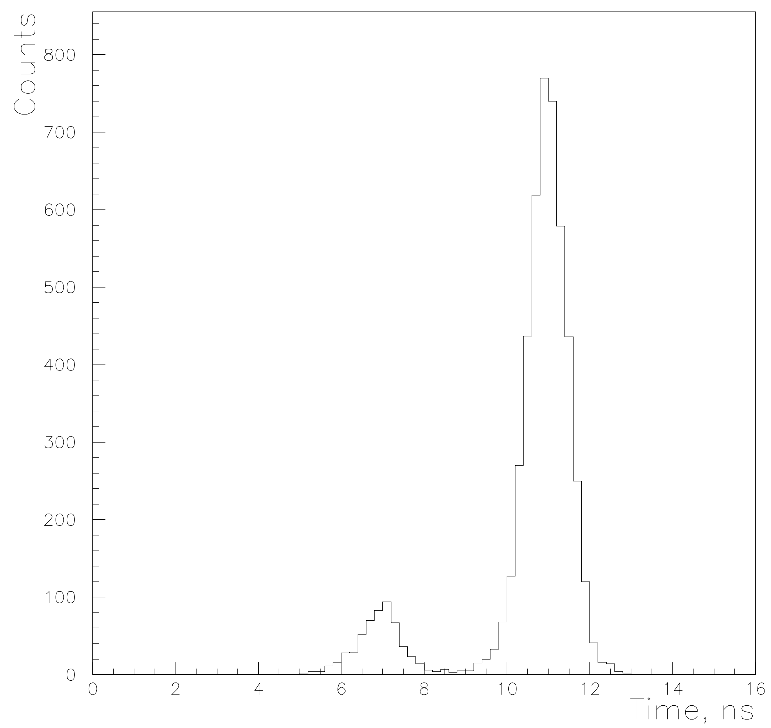


Figure 9: Time interval distribution including events involving direct interaction of γ-rays with the LAAPD (left peak) and those due to the scintillation produced in liquid xenon.

$$\frac{\Delta E}{E} = 2.355\sqrt{\left(\frac{N_e}{N_0 M}\right)^2 + \frac{F-1}{N_0} + \delta^2}\ , \qquad (1)$$

N_e is the number of noise electrons referred to the preamplifier input

Excess noise factor

$$F \approx kM + (2 - 1/M)(1-k)\ , \qquad (2)$$

k is a weighted average ratio of the hole ionization rate to that for electrons

Conclusions

A LAAPD was used for the detection of scintillation photons in liquid xenon. Immersed into the liquid, it has proven to be operational at T = -100 ℃.

An energy resolution of 10% (FWHM) was obtained with 5.5 MeV α-particles.

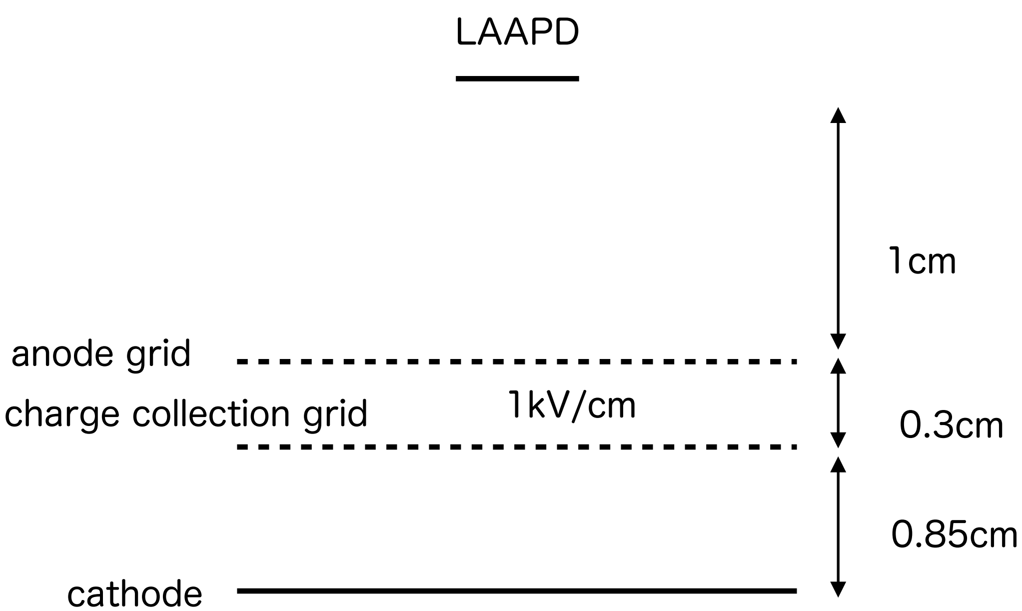
The coincidence time resolution, measured with 511 keV γ-rays, is similar to that reported for LSO and YAP scintillation crystals. The best value, obtained for the LAAPD gain of 605, is 0.9 ns (fwhm).

The estimated quantum efficiency for liquid xenon scintillation photons is about 100 %

Eq. (1) was fit to the experimental data with Ne, k and δ as free parameters. The best fit was obtained with N_e=255±16, k=0.0029±0.0003 and δ=0.0370±0.0006. The value for N_e is in good agreement with the measured one. The value found for k is significantly higher then that usually referred in the literature (k=0.0017) for this type of devices at room temperature. As for the δ value, according to our estimate, the solid angle variation contributes to δ with approximately 0.01. The photoelectron statistics, calculated under the assumption that a photon produces no more than one photoelectron, contributes an additional 0.02 ($1/\sqrt{N_0}$) . The missing fluctuations of about 0.029 (in order to obtain 0.037) may arise due to the fact that it is energetically possible for a VUV photon with the energy of 7.1 eV to produce two or more electron-hole pairs. In this case, the above estimate of the fluctuations in the number of photoelectrons is not valid. Eventual non-uniformity of VUV light reflection from the α-source surface may also contribute.

LAAPD Performance Measurements in Liquid Xenon

by David Day, 3 August 2004



LAAPD : pre-amplifier to an amplifier with a gain of 200, shaping pulse of 0.25 us, rise time of 0.2 us and a fall time of 0.2 ms.

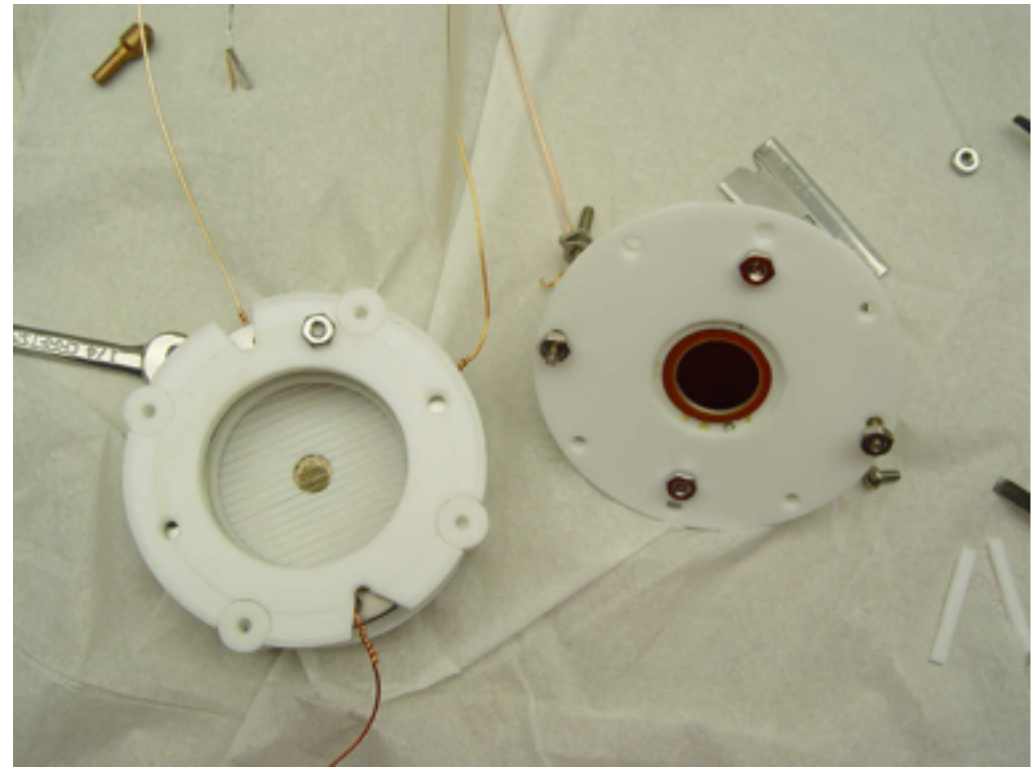


Fig. 2. Right- Teflon housing with LAAPD. Left- Charge Collection and Anode Grid in Teflon housing.

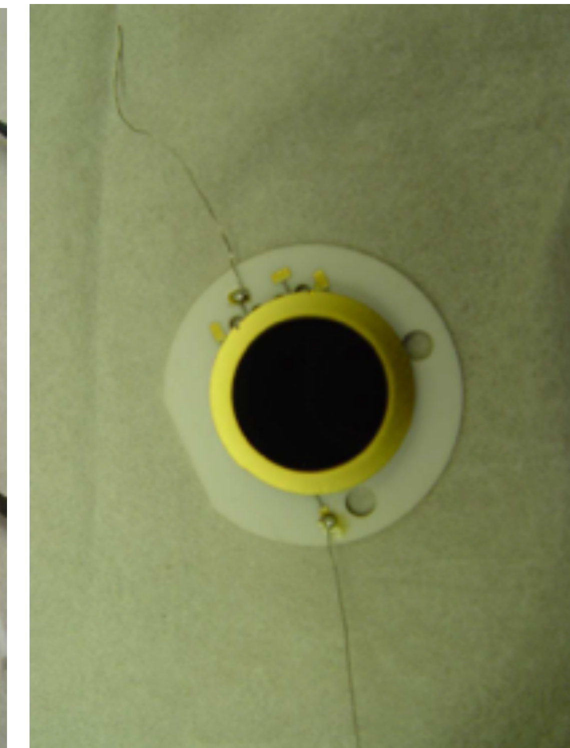


Fig. 1. 16mm diameter LAAPD from Advanced Photonix

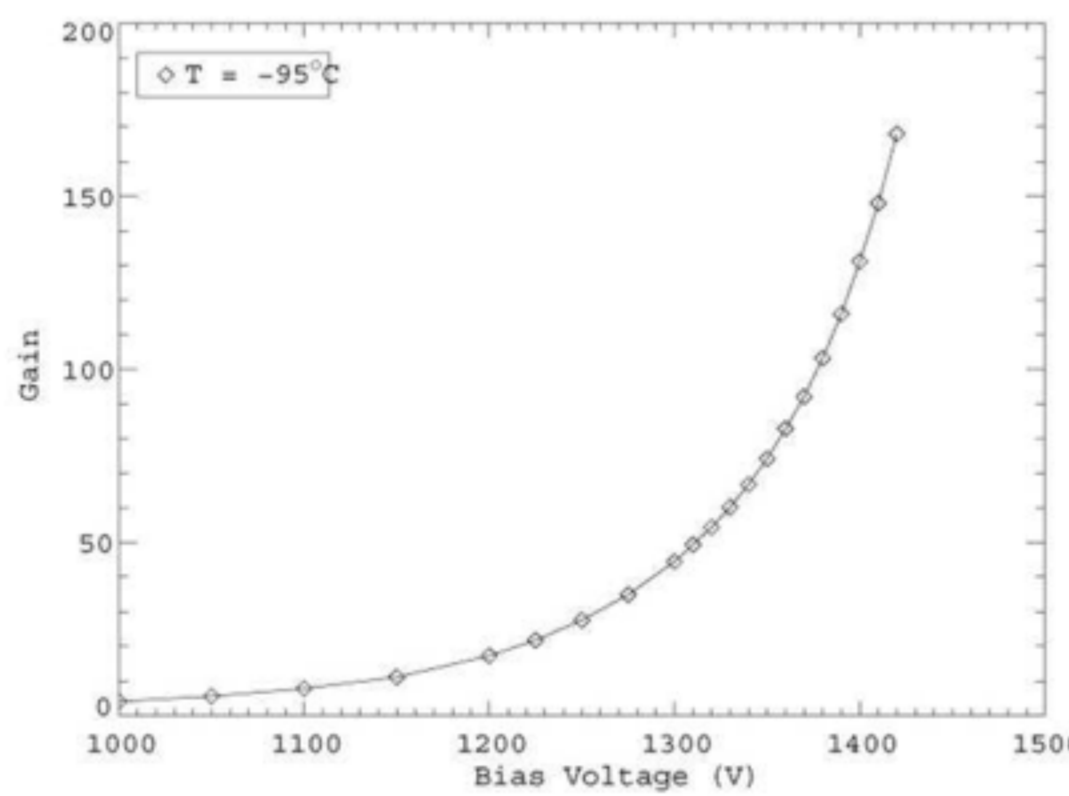
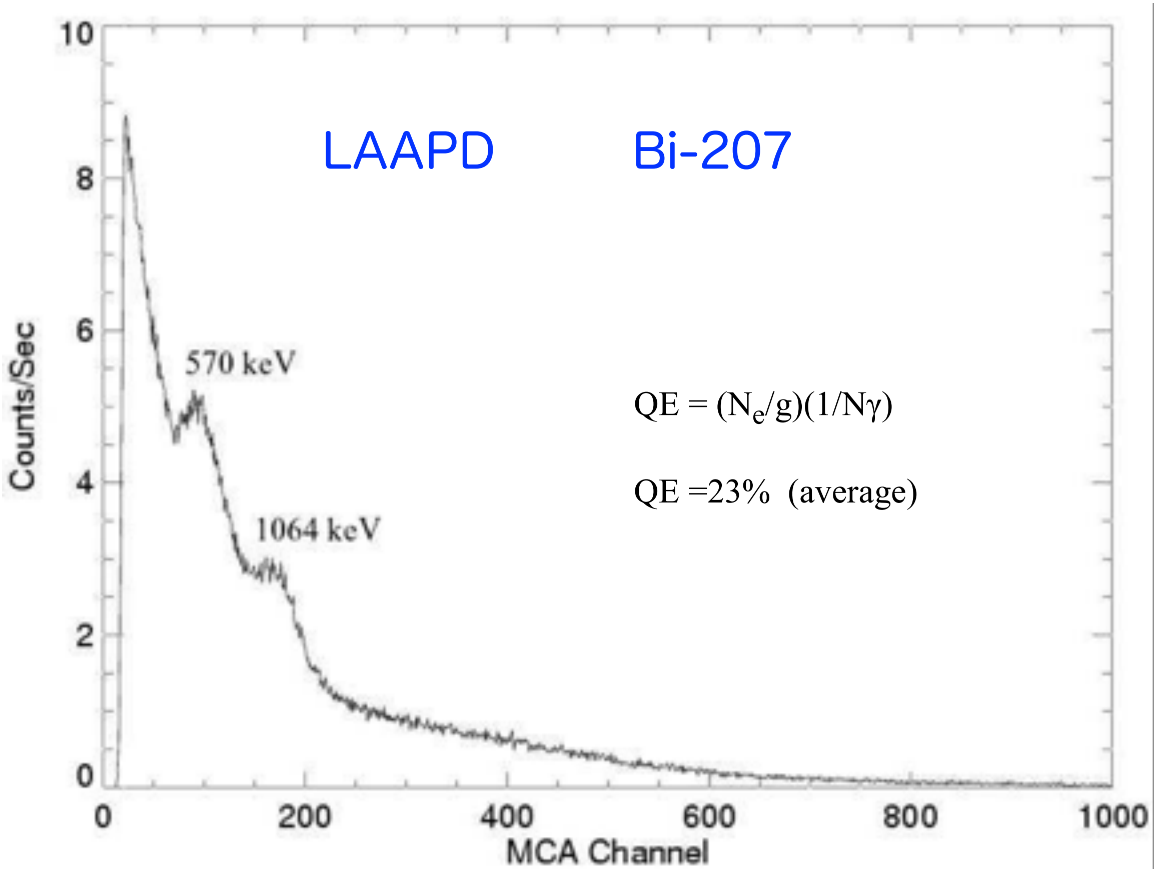
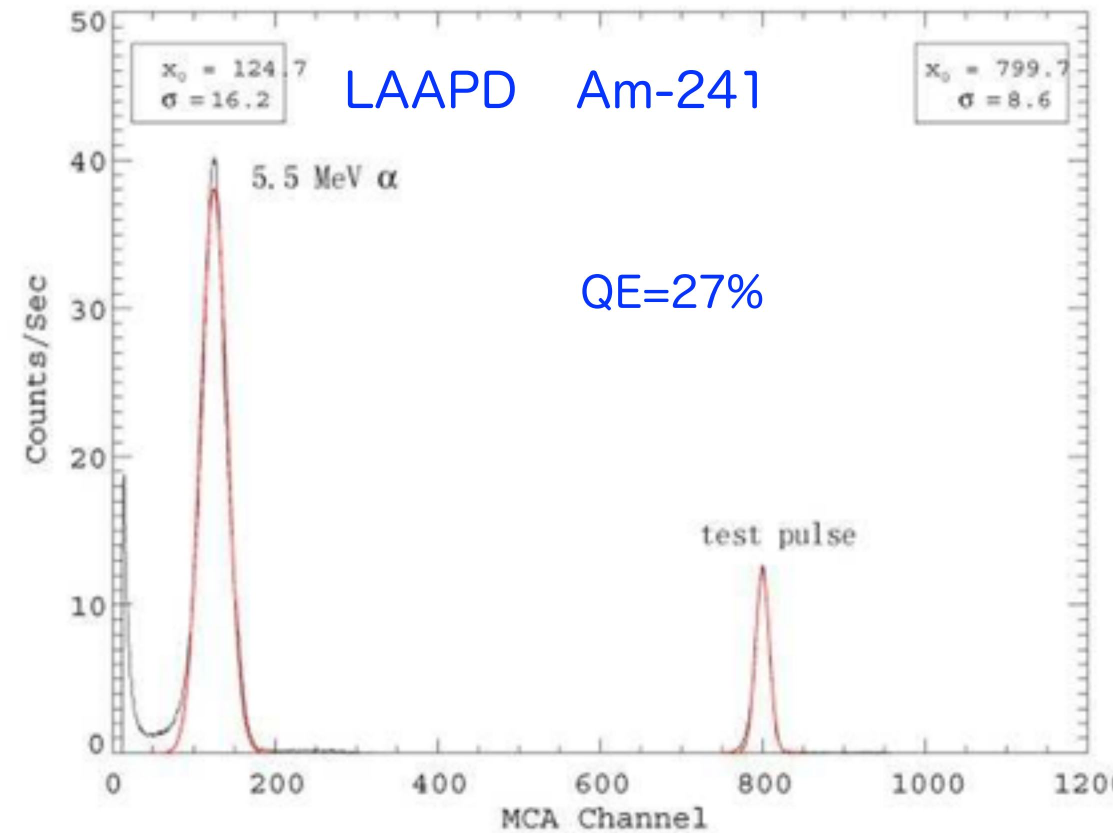
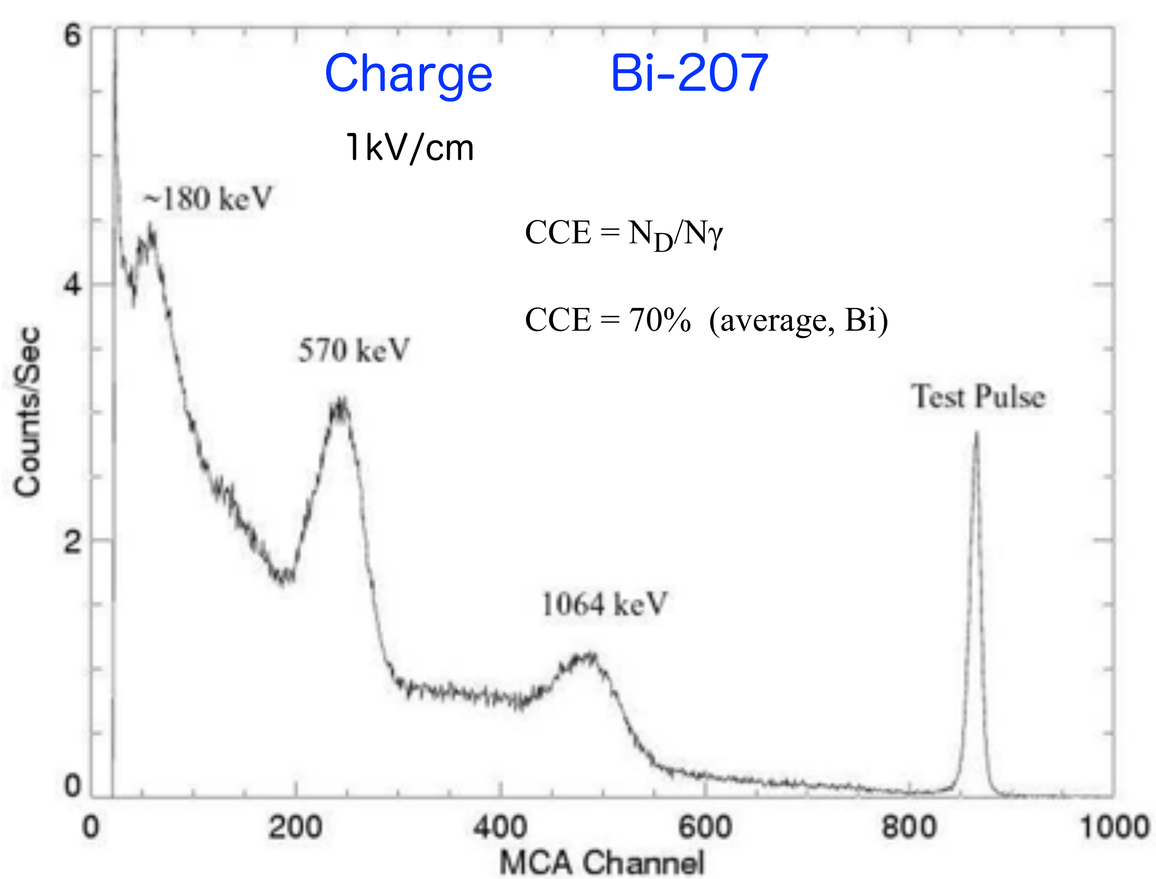
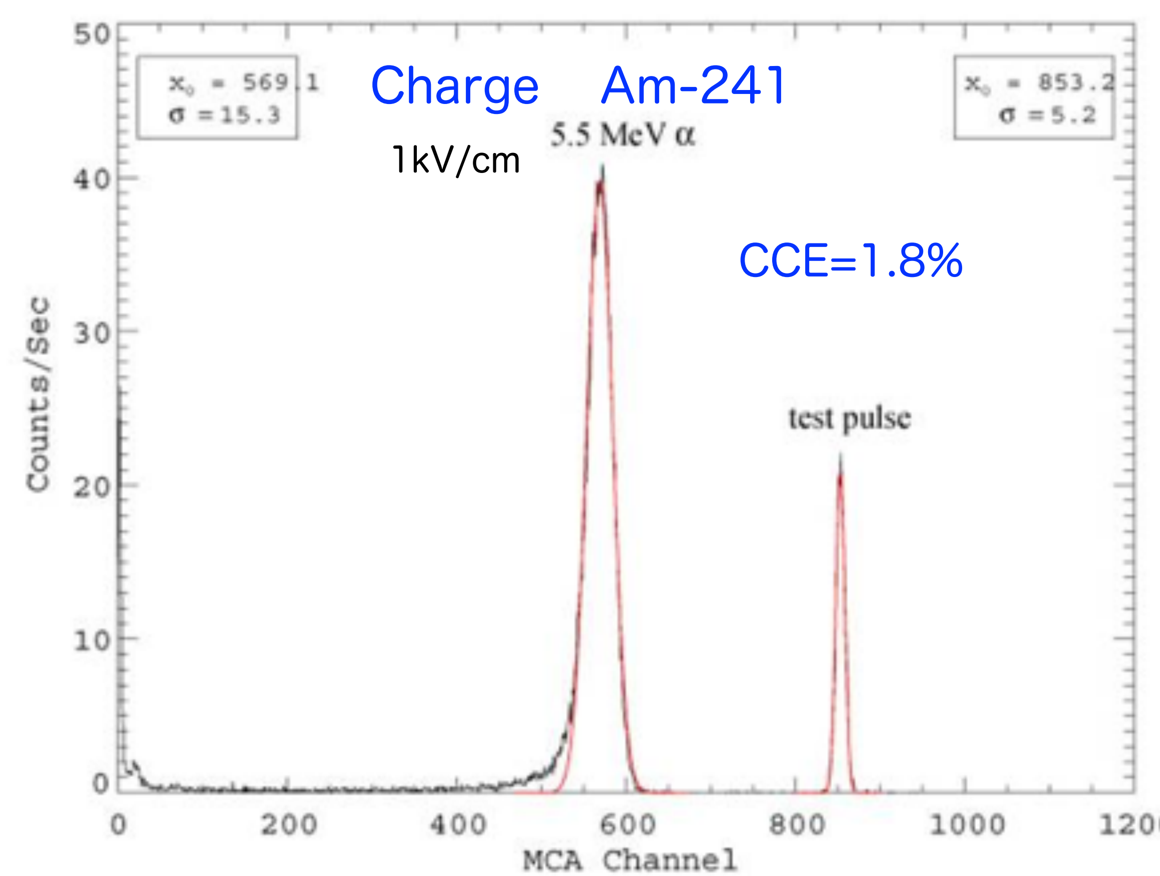


Figure 4. Gain versus bias voltage on LAAPD.


LAAPD
Bi-207
570 keV
1064 keV
QE = (N_e/g)(1/Nγ)
QE =23% (average)
Counts/Sec
MCA Channel
0
200
400
600
800
1000
2
4
6
8
10


LAAPD
Am-241
x₀ = 124.7
σ = 16.2
x₀ = 799.7
σ = 8.6
5.5 MeV α
QE=27%
test pulse
Counts/Sec
MCA Channel
0
200
400
600
800
1000
1200
10
20
30
40
50


Charge
Bi-207
1kV/cm
~180 keV
CCE = N_D/Nγ
CCE = 70% (average, Bi)
570 keV
Test Pulse
1064 keV
Counts/Sec
MCA Channel
0
200
400
600
800
1000
2
4
6


Charge
Am-241
1kV/cm
x₀ = 569.1
σ = 15.3
x₀ = 853.2
σ = 5.2
5.5 MeV α
CCE=1.8%
test pulse
Counts/Sec
MCA Channel
0
200
400
600
800
1000
1200
10
20
30
40
50

Proposal of study on the scintillation light in Xenon

Study in the test chamber

1. APD gain measurements as a function of the bias voltage from 20V to 320V
   in liquid Xe, where the feedback capacitance is 0.1pF replacing with 1pF and ^{241}Am source
   distance from APD to the α source = 1.5cm as precise as possible for acceptance calculation
   measurements by K102 (MCA)
   the gain estimated by the 5.5MeV peak

2. The same measurement by PMT, may be done in rehearsal of summer challenge
   comparison with the APD
   estimation of the APD quantum efficiency relative to the PMT
   assuming the PMT one in the data sheet and correction of acceptance

Study in the TPC chamber

1. Measurement of scintillation lights as a function of drift time in the TPC, 5cm drift
   as a function of drift electric field and the anode-grid electric field
   by using FADC (500MHz, 8k memory), current data in 5800 -6000 to be optimized
   purpose : detection of second scintillation lights in the anode-grid region
   as alternative method of the two phase Xe detector