Bare PMT linearity measurement summary

1. linearity by Laser input (short pulse)
2. linearity by LED input (long pulse)
3. linearity fitting by Gen1 function with gain change

Jun 18, 2022

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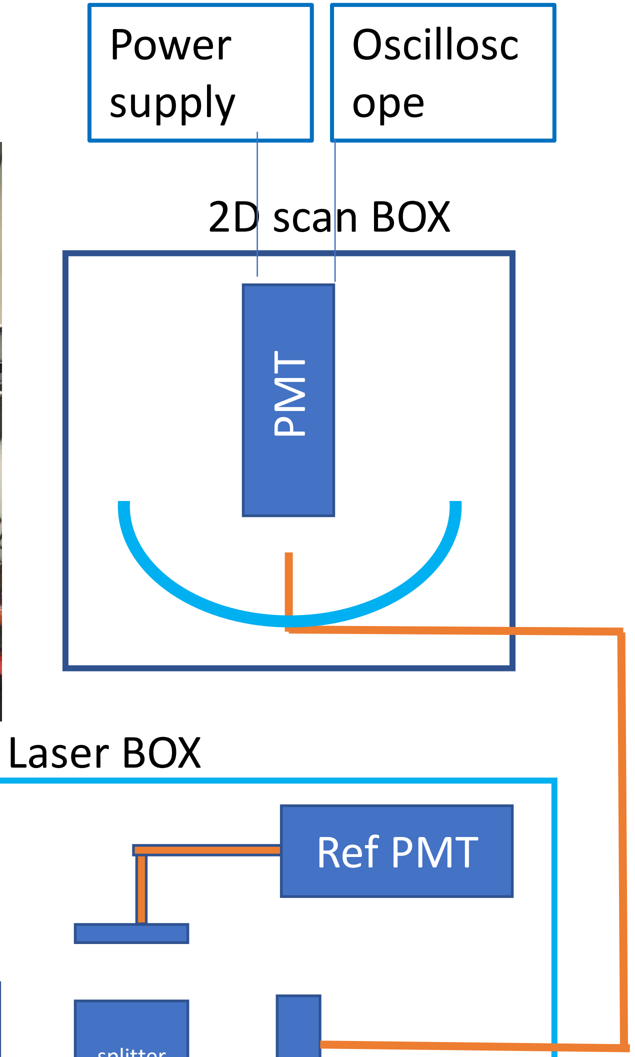
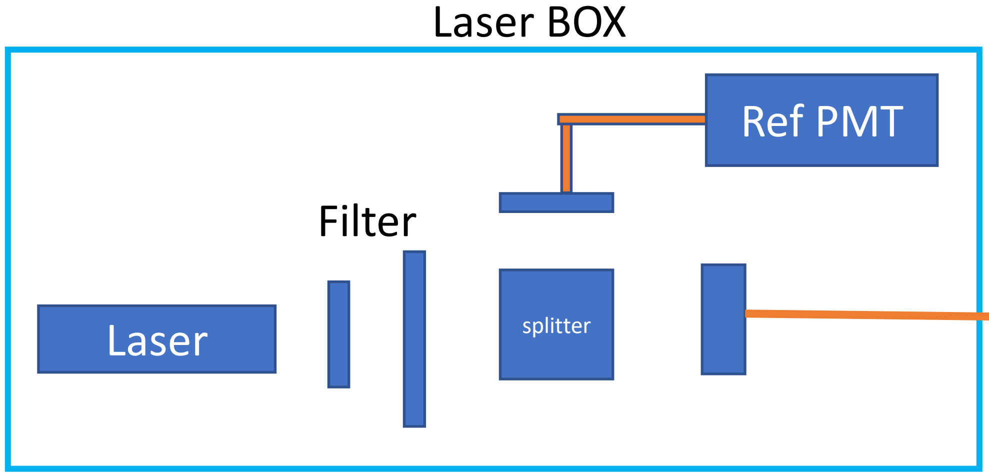
1. Linearity measurement by Laser
Measurement setup

Laser: Hamamatsu M10306 : pulse width 60ps
Filter: fix 1%
rotation{0.1%, 1%, 5%,10%,50%,100%}
Power supply: KEYSIGHT E3631A + HV board
Linearity measurement use 2D-scan box, laser output is center.
Repetition rate : 10Hz
Bare PMT at room temperature

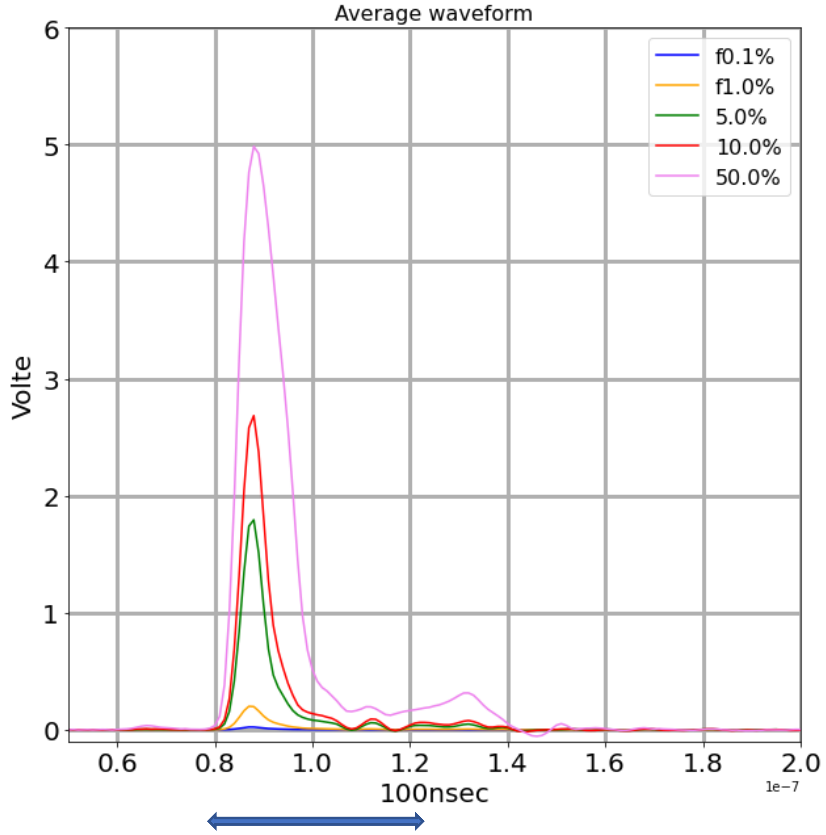




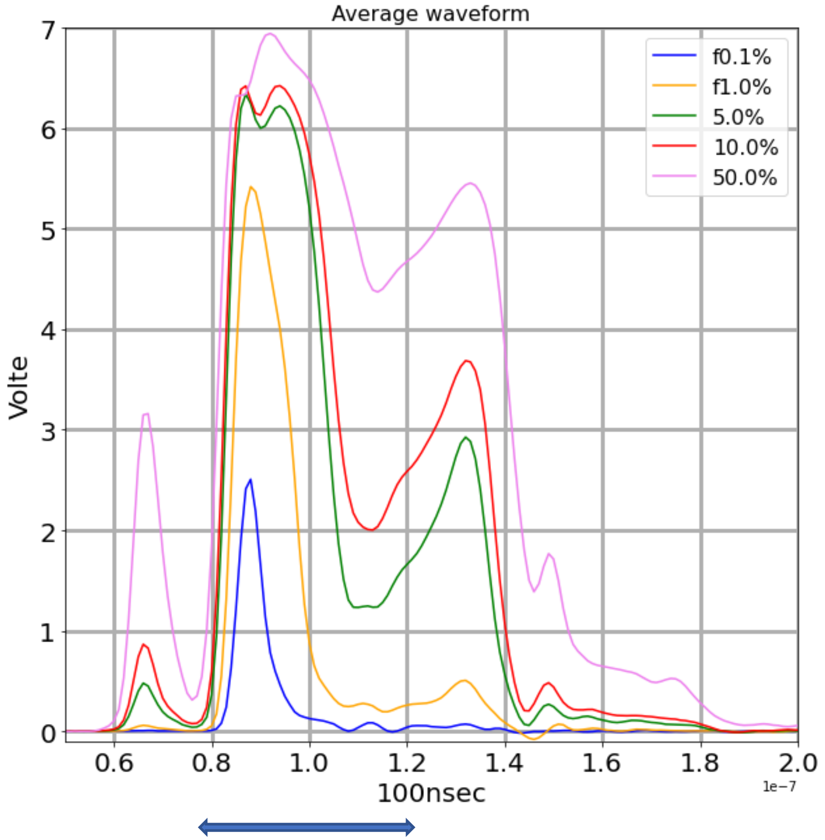
Linearity measurement

- Fix laser intensity, and change Filter 1%+{0.1%,1%,5%,10%,50%} , w/o 1%+{0.1%~50%}
- 1000 waveforms/one filter setting
- Averaged waveform example (sq0987)

with 1% filter



w/o 1% filter



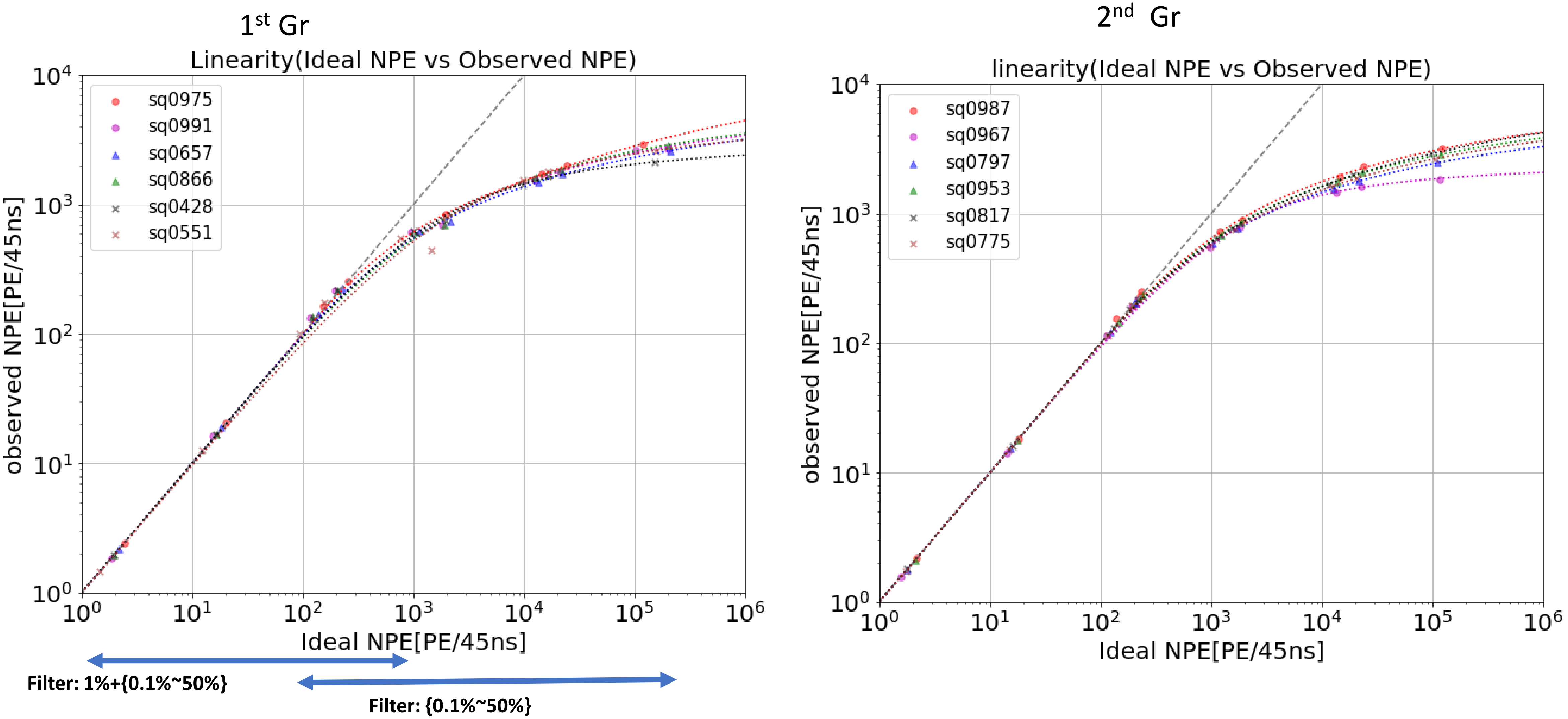
Charge integration :80ns~125ns. Not include pre-pulse and late pulse

Linearity measurement (Analysis)

- Calculate charge (NPE) and peak current each waveform in each filter setting.
- Create histogram of NPE and peak current for each filler, then get mean by gaussian fitting.
- Using filter 1%+1% data in the non-saturated region as a reference point, the ideal amount (NPE and peak current) are calculated by the ratio of the transmittance of the filter.
- Plot ideal amount and observed amount
- fit linearity curve by following function.
  I_{in} : ideal input NPE or peak current
  I_{ob} : observed NPE or peak current

$$I_{ob}^{-1} = I_{in}^{-1} + p_0 \frac{\ln(1 + (I_{in}/p_1)^3)}{\ln(1 + (I_{in}/p_2)^{0.5})}$$

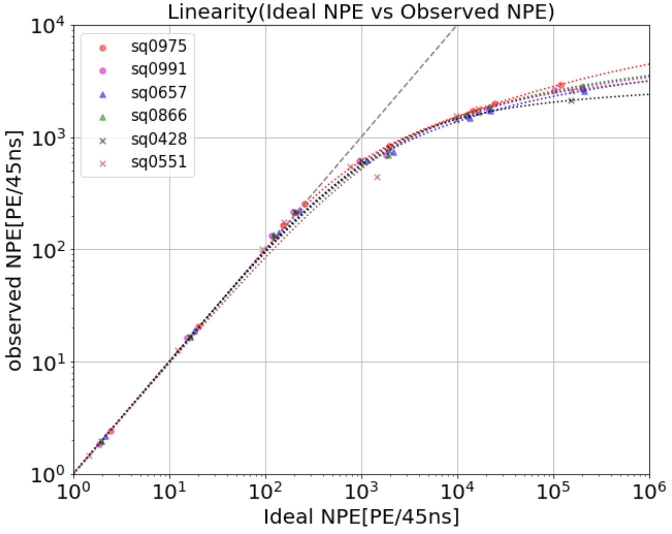
Linearity measurement (Golden PMT input Laser pulse)

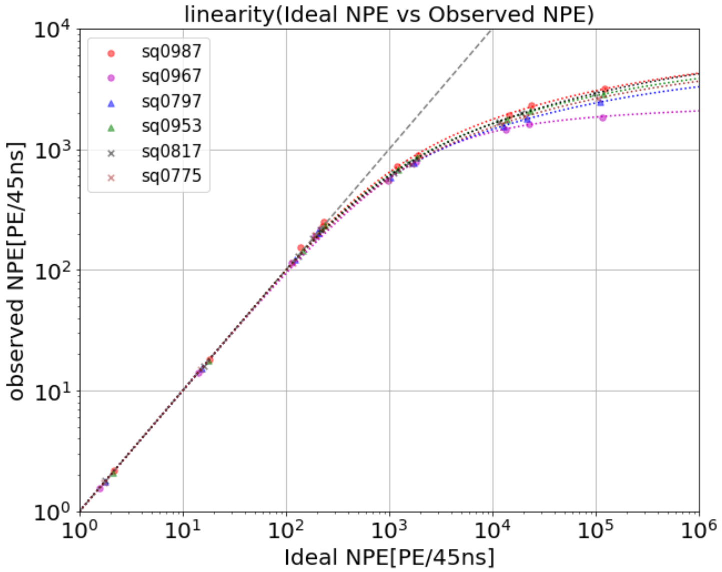


- All PMT is almost same curve, and good linearity below ~300PE
- sq0551(@~150PE) is dropped. Need to measure again.

Linearity fitting function (Golden PMT: input Laser)

(1./x + (1./p0) * np.log(1. + (x/p1)**3) /np.log(1. + (x/p2)**0.5)) ** -1

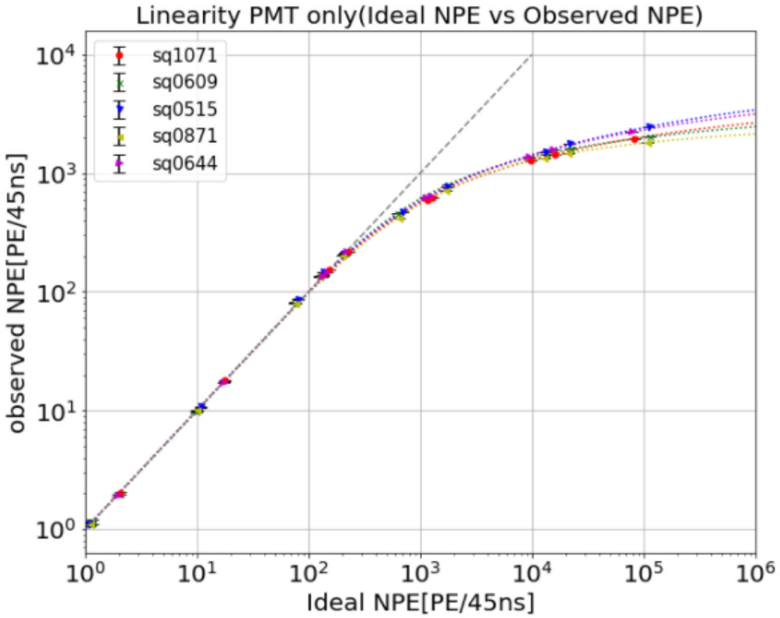


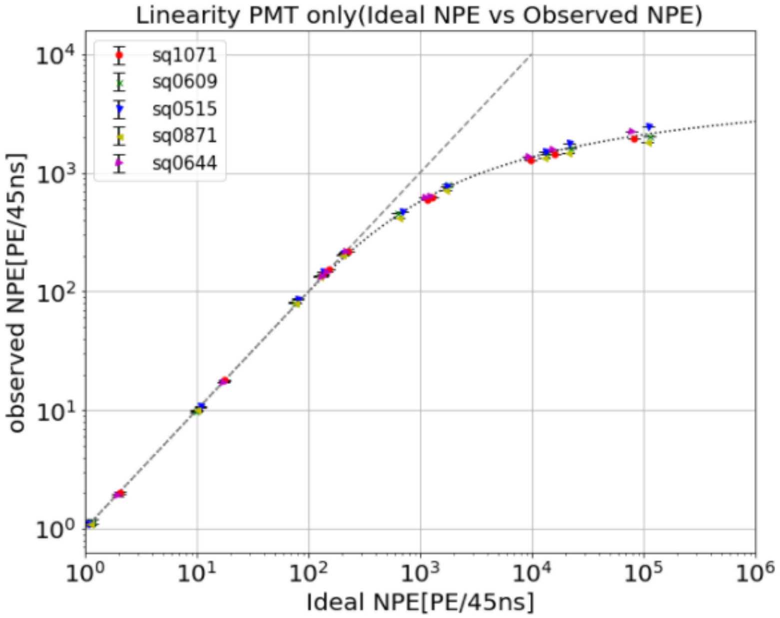


	p0	p1	p2
sq0975:	[87313	228	142644]
Sq0991:	[46472	74.8	19074]
Sq0657:	[43498	102.7	23332]
sq0866	[48345	46.5	15568]
Sq0428:	[22619	41.5	1698]
Sq0551:	[47479	0.015	794.5]

	p0	p1	p2
sq0987:	[59425	168.1	32187]
Sq0967:	[17632	21.20	505.6]
Sq0797:	[43643	136.5	23163]
Sq0953:	[53356	148.5	29210]
Sq0817:	[65054	133.9	44713]
Sq0775:	[51408	110.5	27154]

Linearity for charge(NPE) (different PMTs: input Laser)





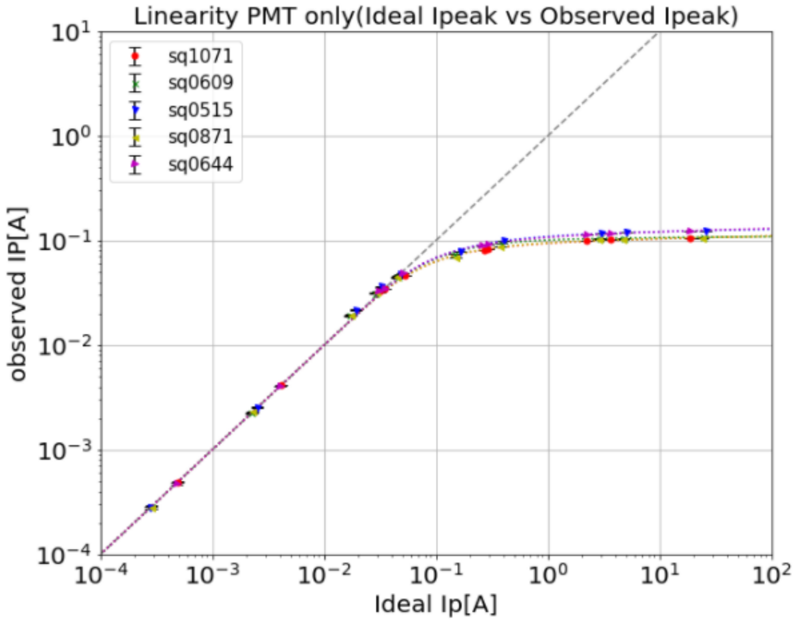
$$I_{ob}^{-1} = I_{in}^{-1} + p_0 \frac{\ln(1+(l_{in}/p_1)^3)}{\ln(1+(I_{in}/p_2)^{0.5})}$$

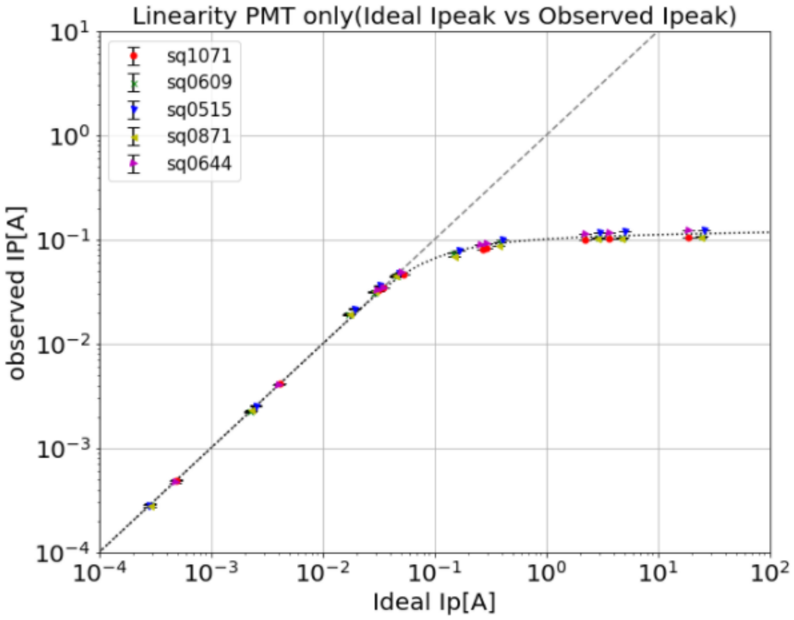
PMT	p_0	p_1	p_2
sq1071	32330 ± 999	147.0 ± 15.1	16160 ± 2286
sq0609	25672 ± 645	204.7 ± 18.9	8934 ± 1174
sq0515	49695 ± 1879	175.4 ± 20.1	40129 ± 6166
sq0871	20830 ± 800	87.1 ± 25.9	3439 ± 1034
sq0644	41570 ± 1606	161.7 ± 18.2	24891 ± 4038

fit by one function for 5 PMTs data (averaged parameter)

PMT	p_0	p_1	p_2
all	31645 ± 4145	149.5 ± 78.5	13268 ± 8737

Linearity of peak current (different PMTs: input Laser)





$$I_{ob}^{-1} = I_{in}^{-1} + p_0 \frac{\ln(1+(l_{in}/p_1)^3)}{\ln(1+(I_{in}/p_2)^{0.5})}$$

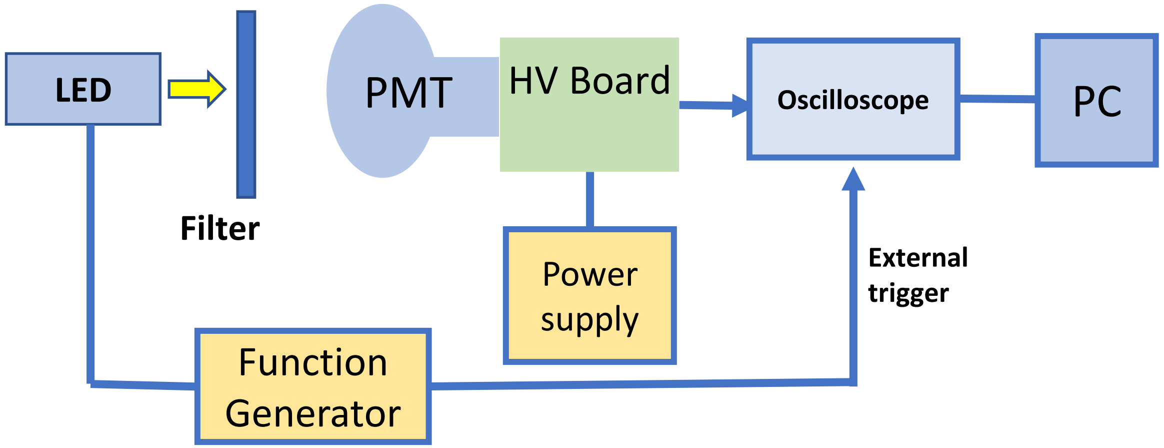
fit by one function for 5 PMTs data (averaged parameter)

PMT	p_0	p_1	p_2
sq1071	0.7884 ± 0.0483	0.04184 ± 0.00623	0.1583 ± 0.0622
sq0609	0.7149 ± 0.0611	0.04496 ± 0.00889	0.090 ± 0.0538
sq0515	0.9165 ± 0.0868	0.0460 ± 0.01050	0.1678 ± 0.1030
sq0871	0.7796 ± 0.0806	0.04062 ± 0.0102	0.1422 ± 0.0967
sq0644	0.9774 ± 0.0689	0.05002 ± 0.0078	0.2464 ± 0.1040

PMT	p_0	p_1	p_2
All PMT	0.8342 ± 0.0719	0.04466 ± 0.00913	0.1567 ± 0.0876

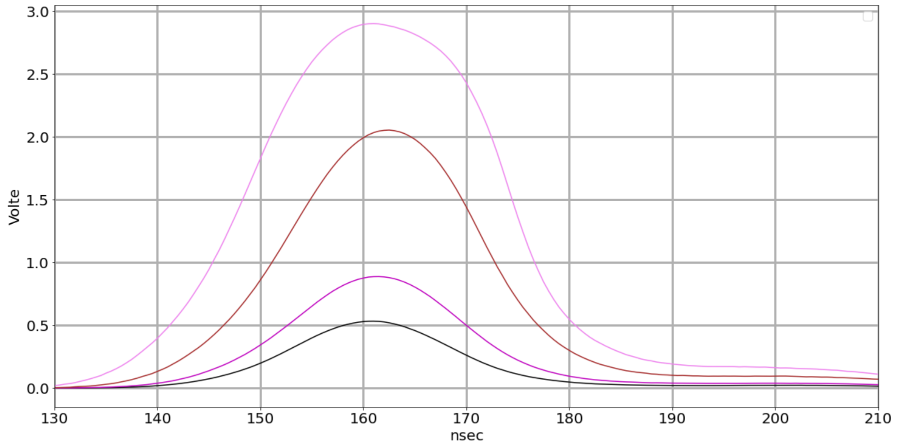
2. Linearity for long pule (Input : LED)

Measurement set up
LED & Filter set just before PMT in freezer box
Note: room temperature
Not use 2D box (too low by use optical fiber)
LED wavelength: 405nm
FG: REGOL DG4162
Oscilloscope : Rohde&Schwarz RTO1044
filter : rotational only (1% + 0.1% is too low)



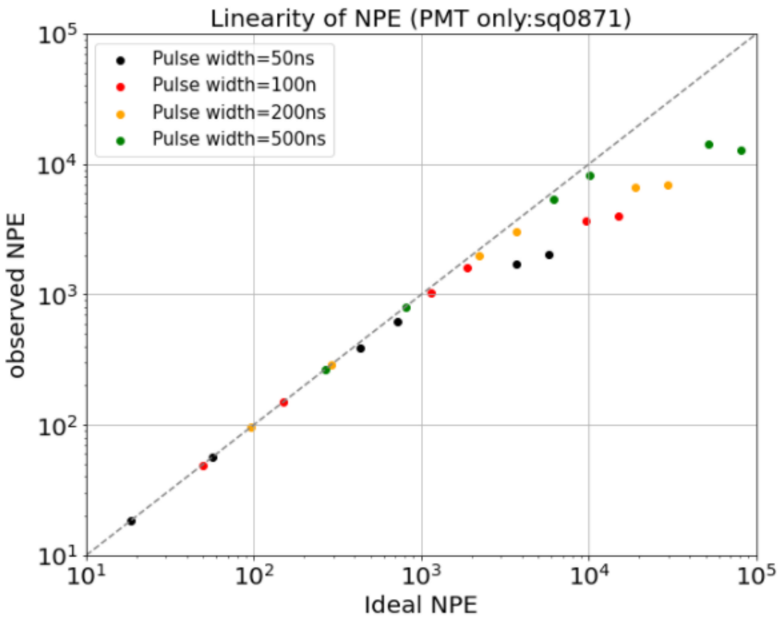
pulse width & peak height changed by FG waveform

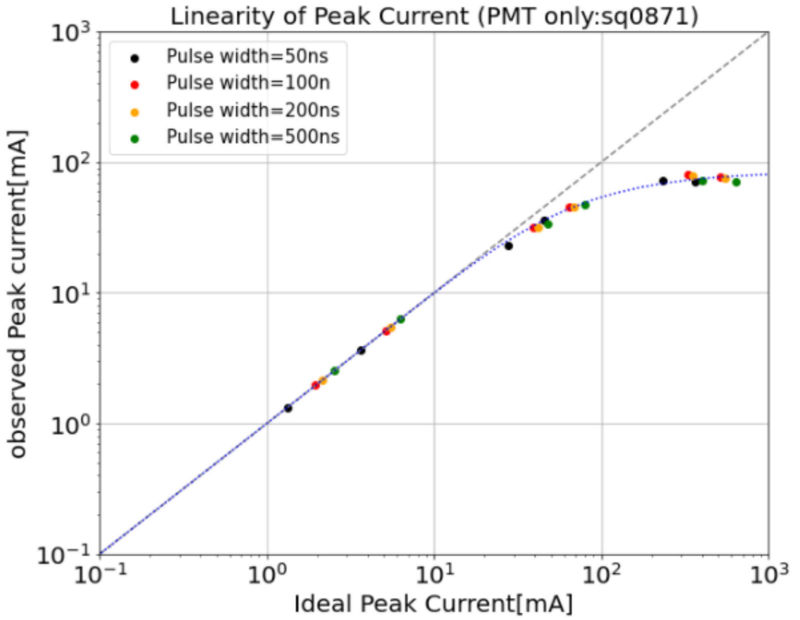
ex: averaged waveform pulse width 50ns



Linearity for long pule (Input : LED)

Peak current dose not depend on pulse width





no fitting
NPE increase with pulse width
saturation depends on not NPE but peak current

cannot fit by $$I_{ob}^{-1} = I_{in}^{-1} + p_0 \frac{\ln(1+(I_{in}/p_1)^3)}{\ln(1+(I_{in}/p_2)^{0.5})}$$

so use $$I_{\text{real}} = I_{ideal} \cdot \frac{\ln(1+\frac{A}{I_{ideal}})}{\ln(1+\frac{A}{I_{ideal}}) + \frac{A}{I_s} \cdot e^{-B/I_{ideal}}}$$

PMT	I_s	A	B
sq0871	84.85 ± 3.11	0.1419 ± 0.0520	32.47 ± 9.13

3. Linearity fitting by Gen1 function with gain change

This is Dom simulator function for linearity

$$I_{real} = I_{ideal} \cdot \frac{\ln(1 + \frac{A}{I_{ideal}})}{\ln(1 + \frac{A}{I_{ideal}}) + \frac{A}{I_s} \cdot e^{-B/I_{ideal}}}$$

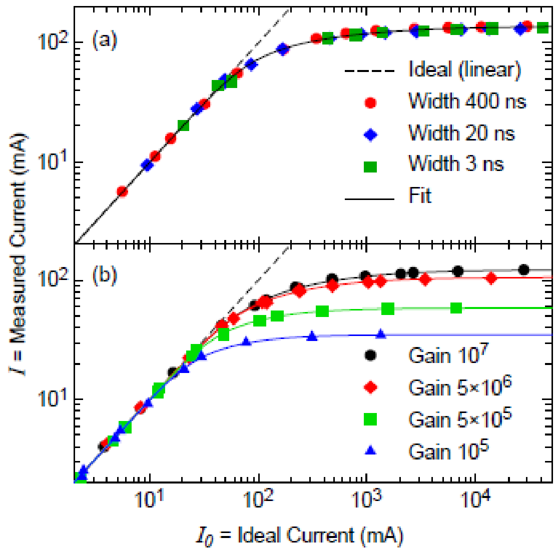
$$I_s = 10^{(a_1 + b_1 x + c_1 x^2)}$$

$$A = 10^{(a_2 + b_2 x + c_2 x^2)}$$

$$B = 10^{(a_3 + b_3 x + c_3 x^2)}$$

$$x = \log_{10}(gain)$$

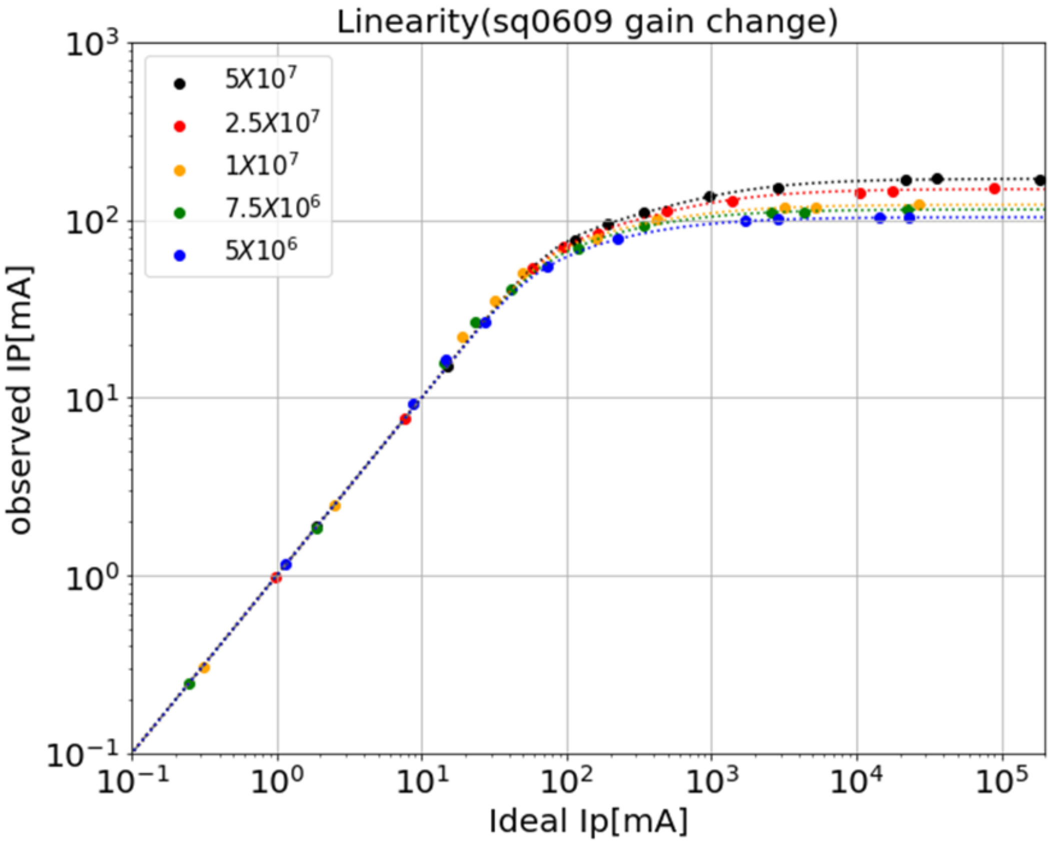
Gen1 DOM result

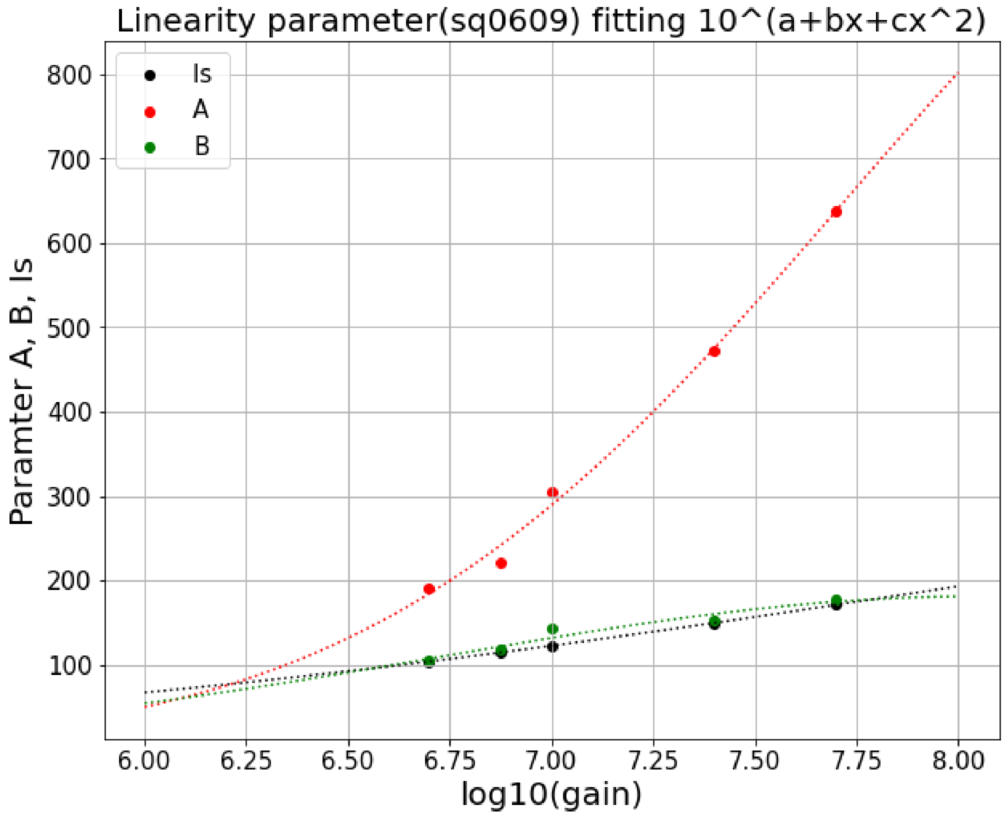


D-Egg dose not use for ice top detector, so no need low gain area (below $5X10^6$)
Measure linearity at $5X10^6$, $7.5X10^6$, $1X10^7$, $2.5X10^7$, $5X10^7$

Not completed, there are not good result.

linearity fitting by Gen1 function(sq0609:Gain range: $5X10^6$ ~ $5X10^7$)





Good result!

Fitting by following function and get parameter A, B, Is at each gain

$$I_{real} = I_{ideal} \cdot \frac{\ln(1+\frac{A}{I_{ideal}})}{\ln(1+\frac{A}{I_{ideal}}) + \frac{A}{I_s} \cdot e^{-B/I_{ideal}}} \quad (1)$$

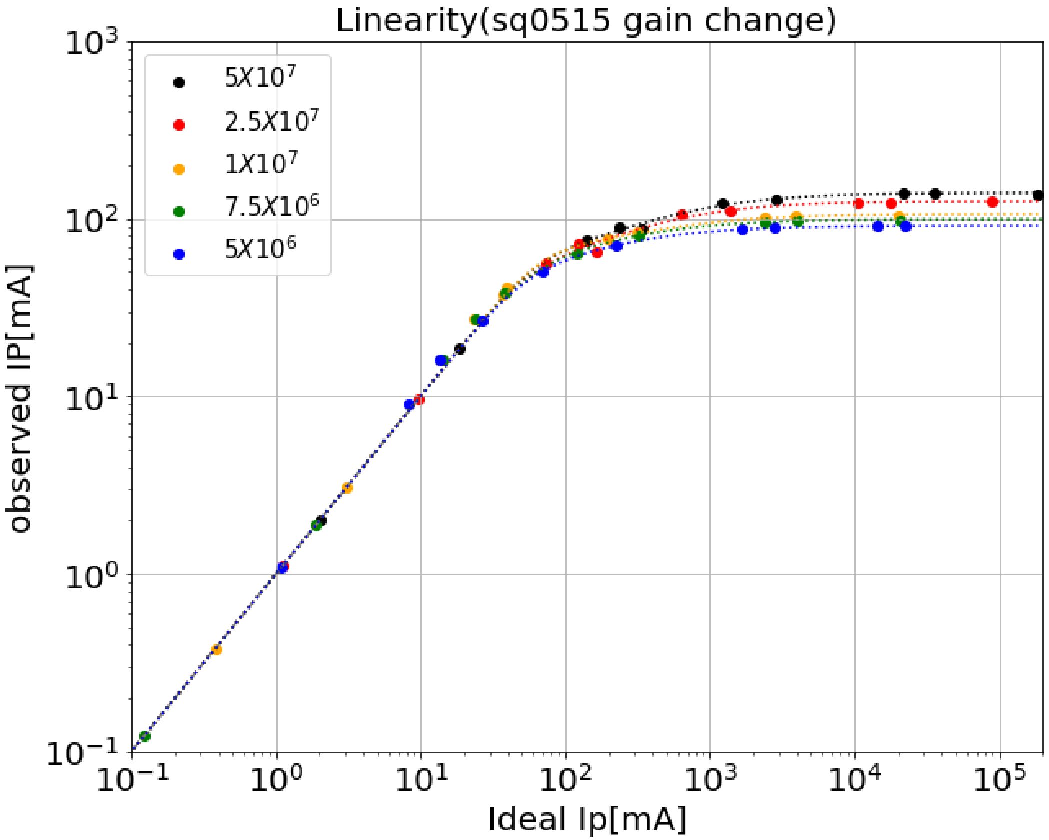
$$I_s = 10^{(a_1+b_1x+c_1x^2)}$$
$$A = 10^{(a_2+b_2x+c_2x^2)}$$
$$B = 10^{(a_3+b_3x+c_3x^2)}$$
$$x = \log_{10}(gain)$$

・・・(2)

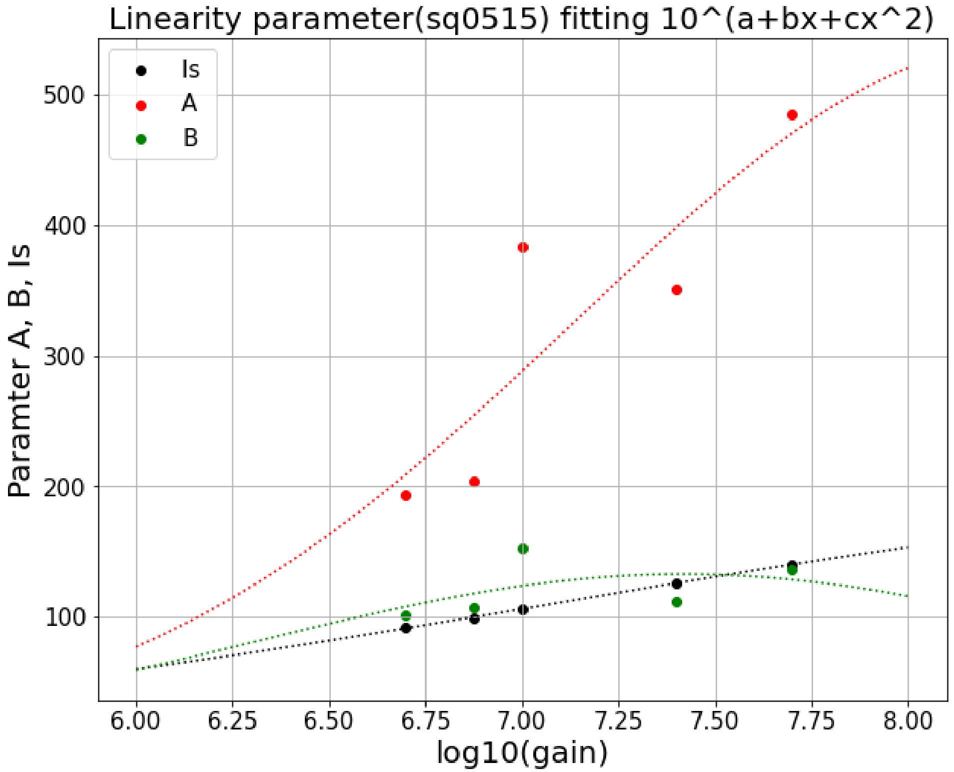
# sq0609 coefficent
Is_ce = [-1.093, 0.679, -0.0321]
A_ce =[-9.613, 2.846, -0.160]
B_ce = [-5.777, 1.994, -0.123]

linearity fitting by Gen1 function(sq0515:Gain range: $5X10^6$ ~ $5X10^7$)

Fitting by function (1), seems good



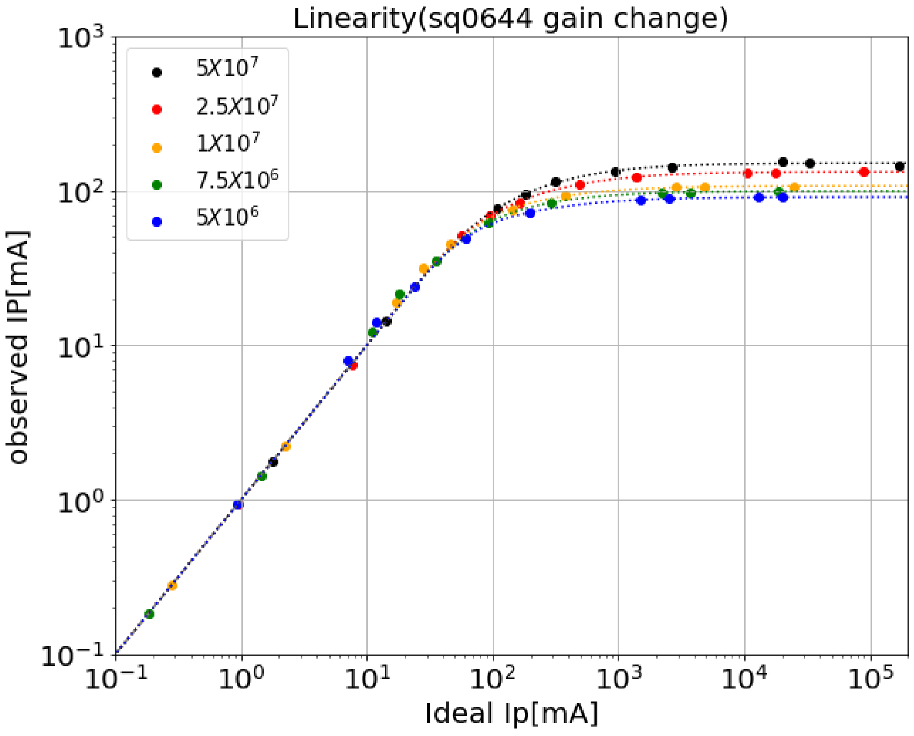
gain dependency of A and B are not good @ $1X10^7$



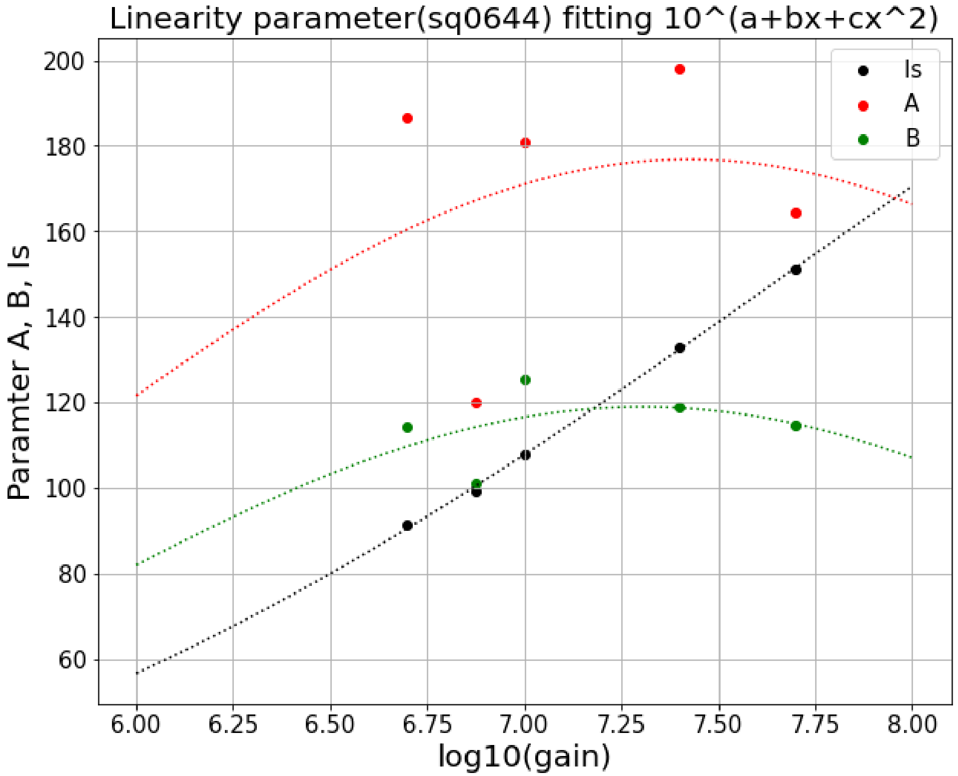
NG result!

Linearity fitting new function (sq0644) ($5X10^6$ ~ $5X10^7$)

Fitting by function (1), seems good



Parameter A, B are completely NG



NG result!

linearity (sq0644) fitting by coefficient from sq0609 as typical data

●: measurement data

----: calculate by the coefficient from sq0644

$a_1, a_2, a_3, b_1, b_2, b_3, c_1, c_2, c_3$

# sq0609 coefficent
Is_ce = [-1.093, 0.679, -0.0321]
A_ce =[-9.613, 2.846, -0.160]
B_ce = [-5.777, 1.994, -0.123]

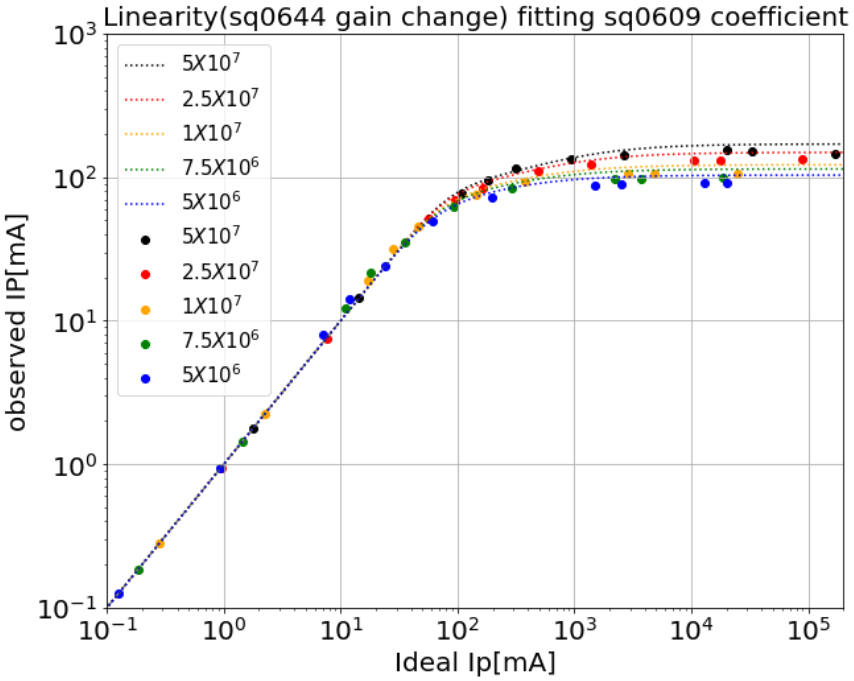
$$I_{real} = I_{ideal} \cdot \frac{\ln(1 + \frac{A}{I_{ideal}})}{\ln(1 + \frac{A}{I_{ideal}}) + \frac{A}{I_s} \cdot e^{-B/I_{ideal}}}$$

$$I_s = 10^{(a_1 + b_1 x + c_1 x^2)}$$

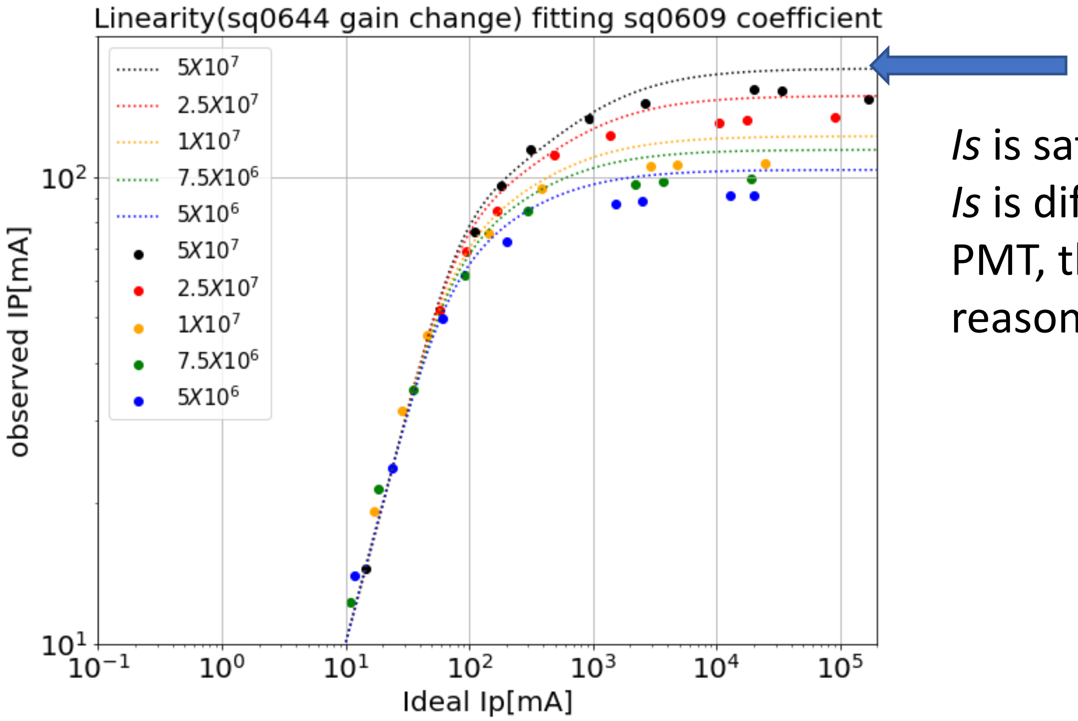
$$A = 10^{(a_2 + b_2 x + c_2 x^2)}$$

$$B = 10^{(a_3 + b_3 x + c_3 x^2)}$$

$$x = \log_{10}(gain)$$



expansion view

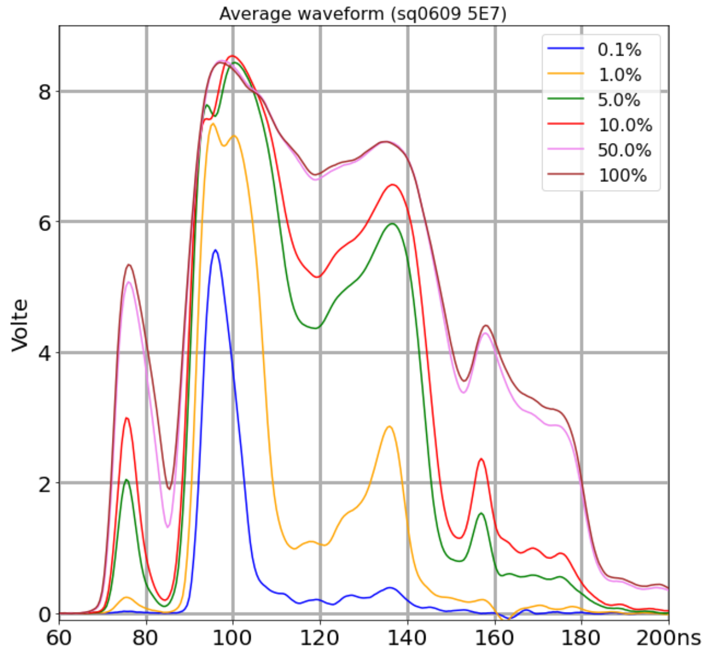


Is is saturated current.
Is is different from PMT by PMT, therefore it is not reasonable to use same *Is*.

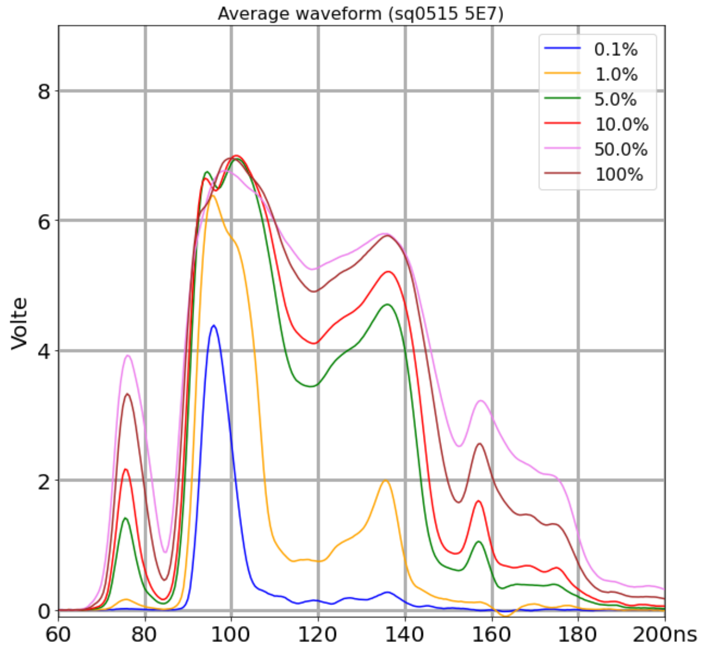
Saturated peak current *Is* (PMT by PMT)

Averaged waveform (High intensity) @ $5X10^7$ gain

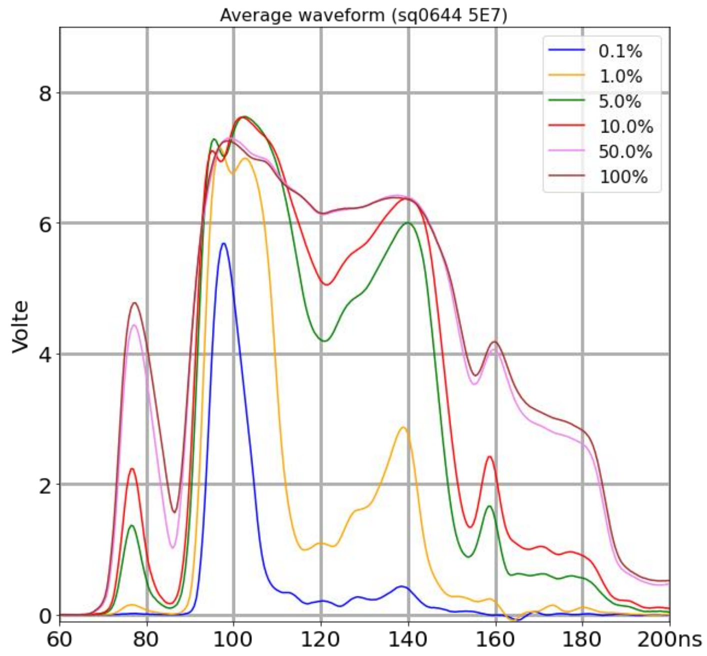
sq0609: 8.5V => 170mA



sq0515: 7.0V => 140mA



sq0644: 7.6V => 152mA



(170 – 140) / 140 = 0.21   21% difference