Gain measurements of 4 replaced PMTs

- Single photo-electron method of measuring gains

- 2 replaced PMTs were originally measured in 2012 and used in TOF-I

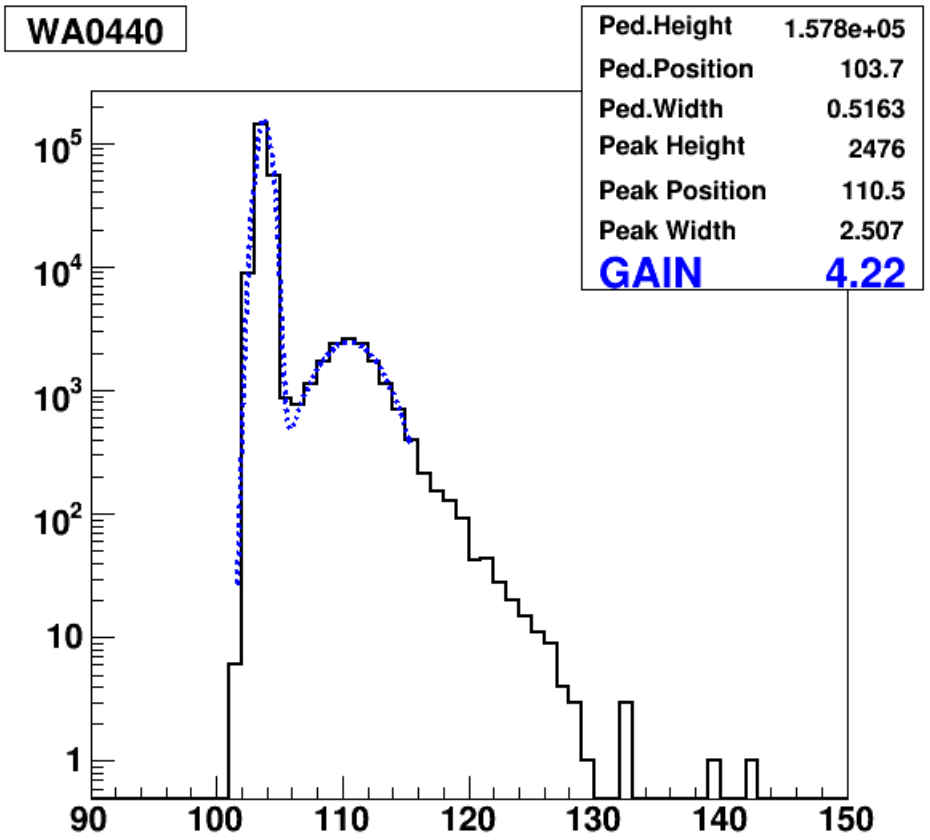
- 2 other PMTs were originally measured in 2017 and used in TOF-II

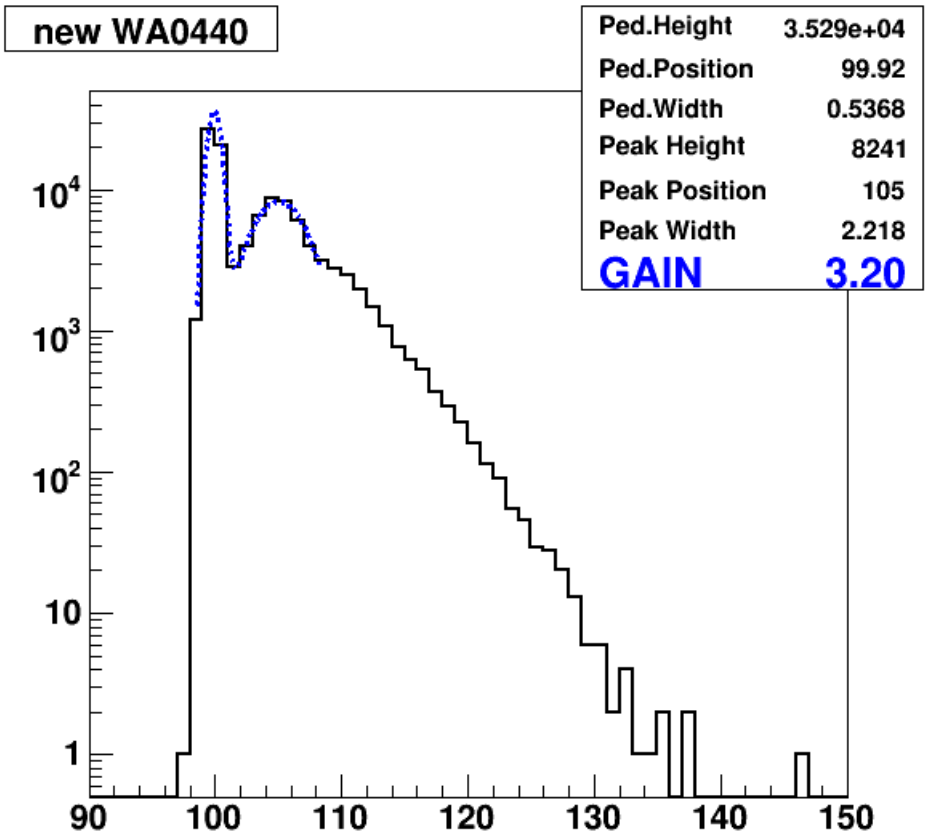
- Lab setup has changed over time (current CAEN V792 QDC vs. old CAEN V256 QDC, amplifiers, etc.)

- To check consistency of the measurements, a spare never used before PMT was remeasured again. Its old and new gains were measured to be 2.71 and 2.87 (in millions), reflecting a typical uncertainty of such measurements.

Comparison of the gains in 2019 and 2021

PMT WA0440 : TOF-N-20 Initially measured: October 2017

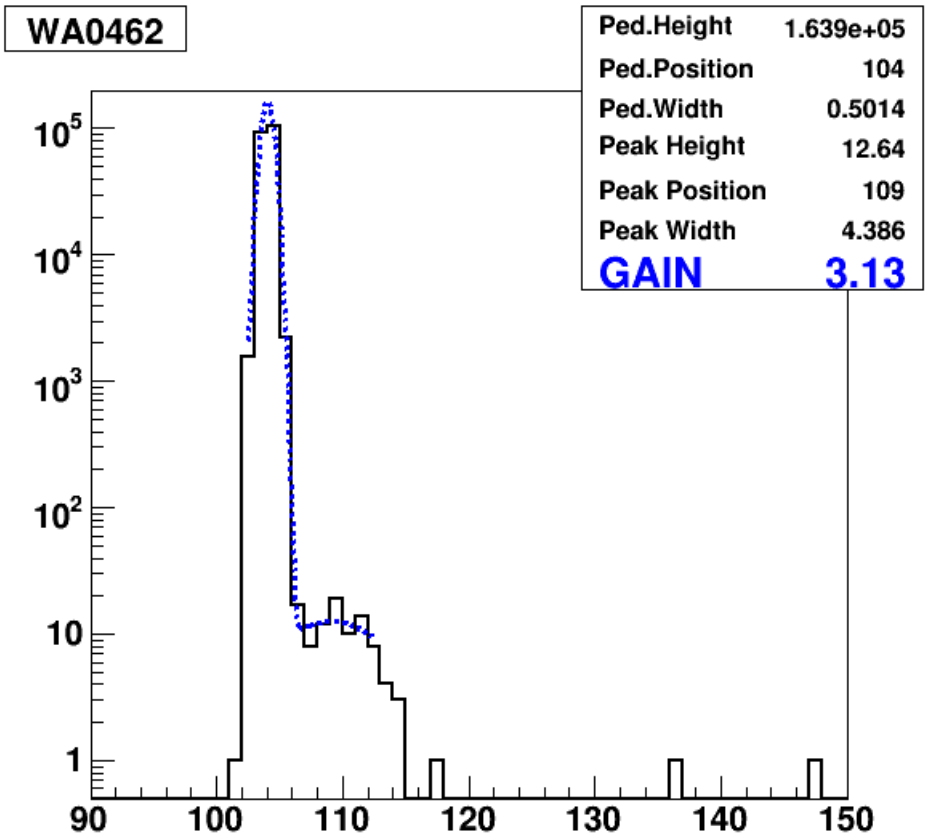


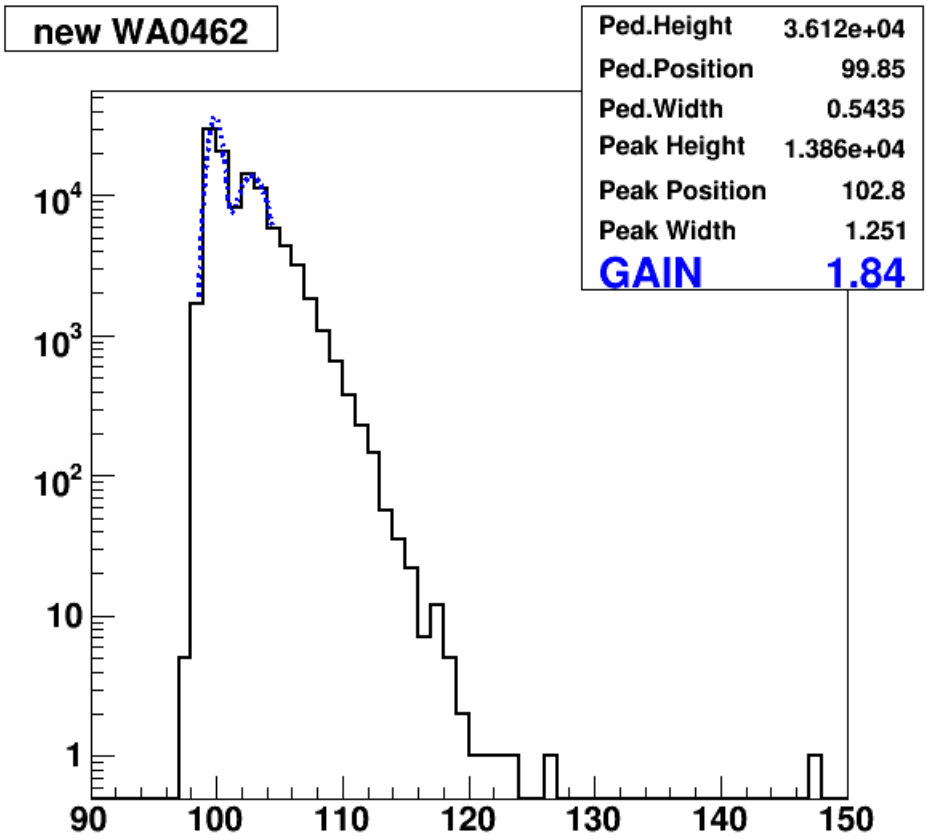


Old gain 4.22 **New gain 3.20**

Comparison of the gains in 2019 and 2021

PMT WA0462 : TOF-S-21 Initially measured: October 2017

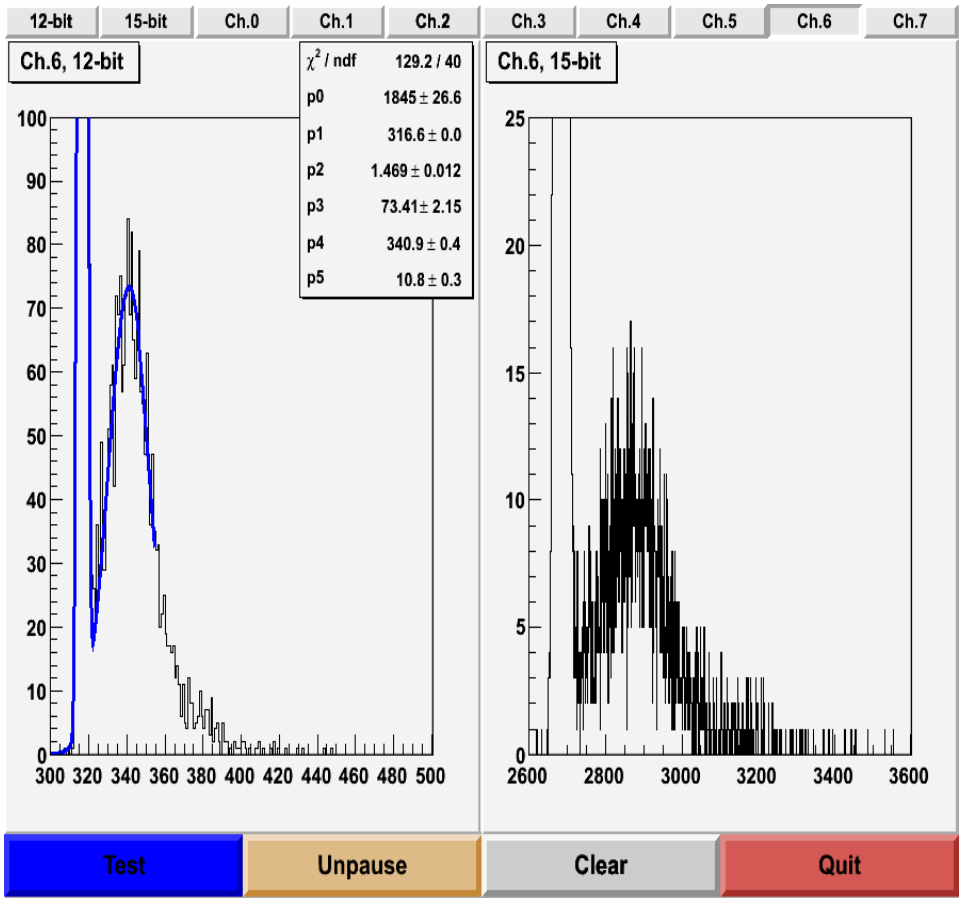


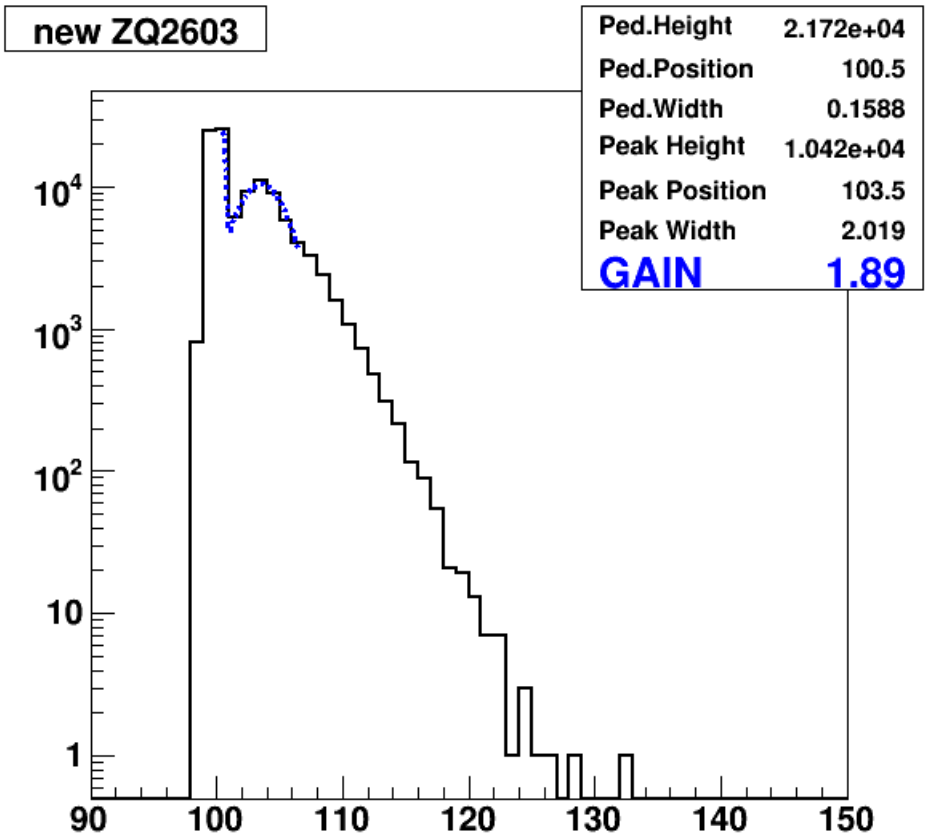


Old gain 3.13 **New gain 1.84**

Comparison of the gains in 2014 and 2021

PMT ZQ2603 : TOF-DW-24 Initially measured: November 2012

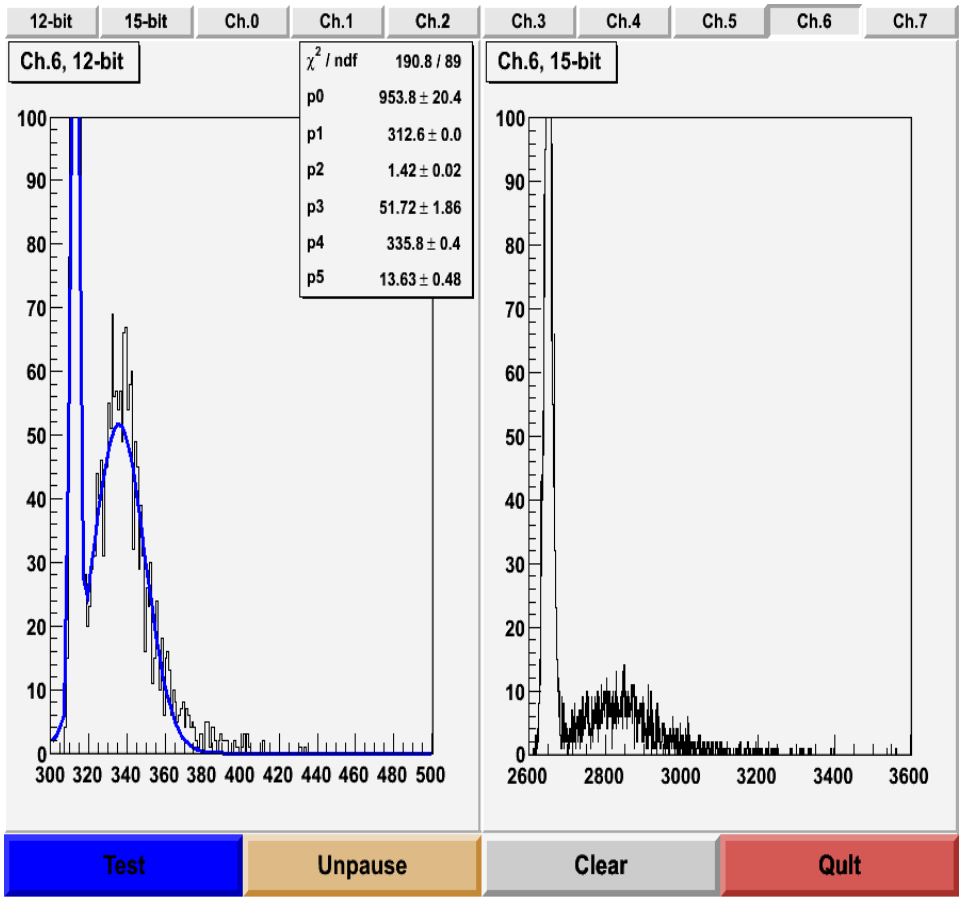


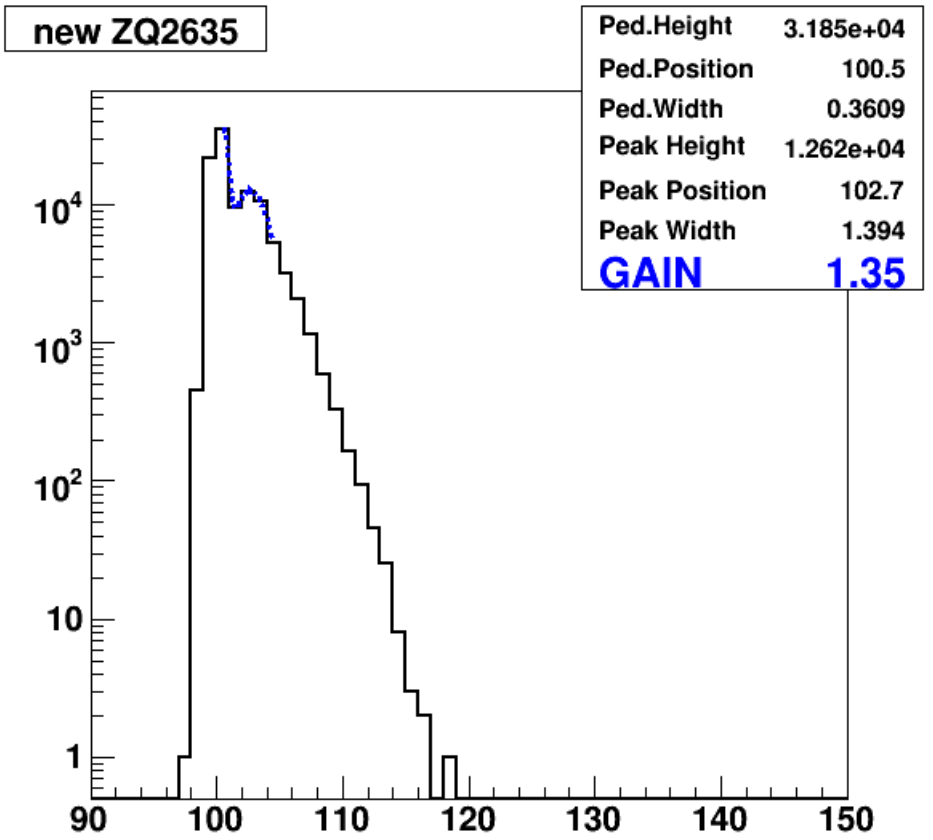


Old gain 3.79 **New gain 1.89**

Comparison of the gains in 2014 and 2021

PMT ZQ2635 : TOF-U-24 Initially measured: November 2012





Old gain 3.62 **New gain 1.35**

Gains of replaced PMTs

Replaced PMT	Location	Original gain	Final gain	Replaced with
ZQ2603	DW-24 (DW-25 in TOF-1)	**3.79**	**1.89**	5.77
ZQ2635	UP-24 (UP-25 in TOF-1)	**3.62**	**1.35**	7.16
WA0440	N-20	**4.22**	**3.20**	6.00
WA0462	S-21	**3.62**	**1.84**	7.48

- All 4 replaced PMTs are close to the beam.

- PMTs DW-24 and UP-24 were on the same bar and got the same beam exposure, and lost 50% and 62% of their gains from 2014 to 2021

- PMT S-21 was only slightly closer to the beam comparing with N-20 but lost 49% of gain in comparison with 24% loss of N-20 in less than 2 years of GlueX-II running.

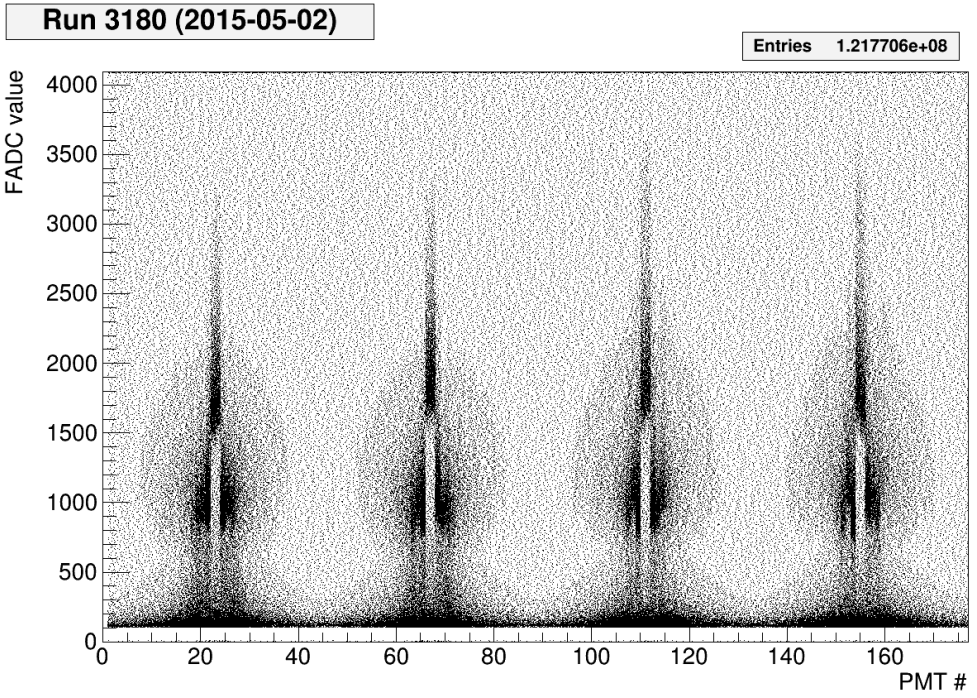
Gain degradation over time

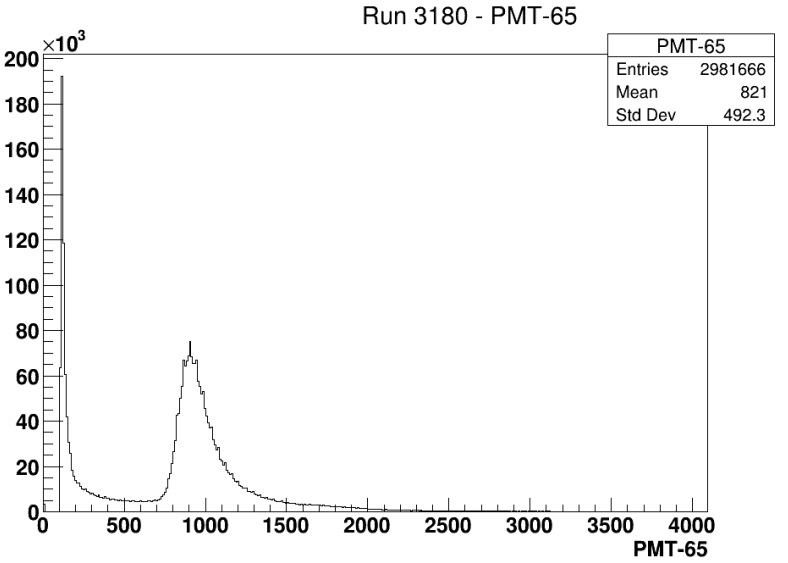
- Over 7+ years of GlueX running, PMT High Voltage has been adjusted a few times. Therefore, comparing FADC amplitudes or MPV peaks over the whole period doesn't make sense.

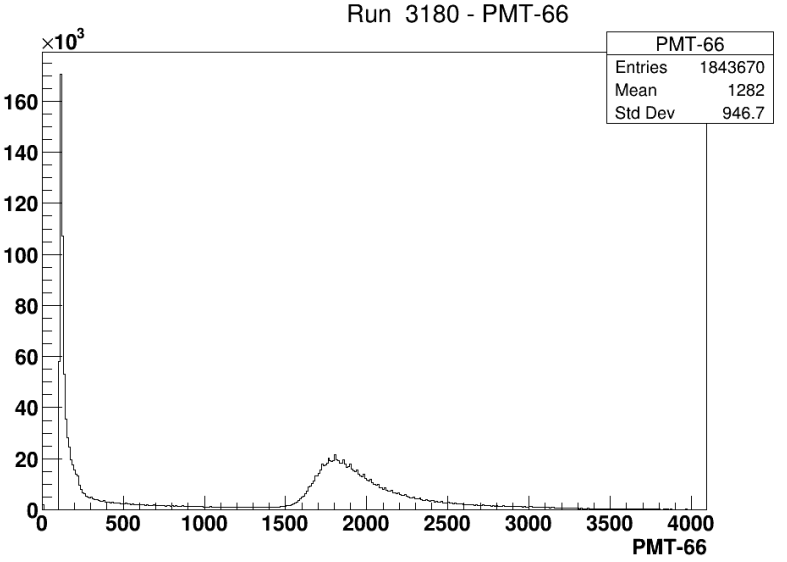
- Some secondary changes, especially in the earlier days, like changes in FADC NSA/NSB ; switch of dynamic range from 1V to 2V to 0.5V, etc., complicate analysis of FADC amplitudes.

- Fortunately, there were some long periods of stability, suitable for gain degradation analysis, i.e., Beni's analysis of Spring'17 run.

FADC peaks in engineering runs (2014-2016)

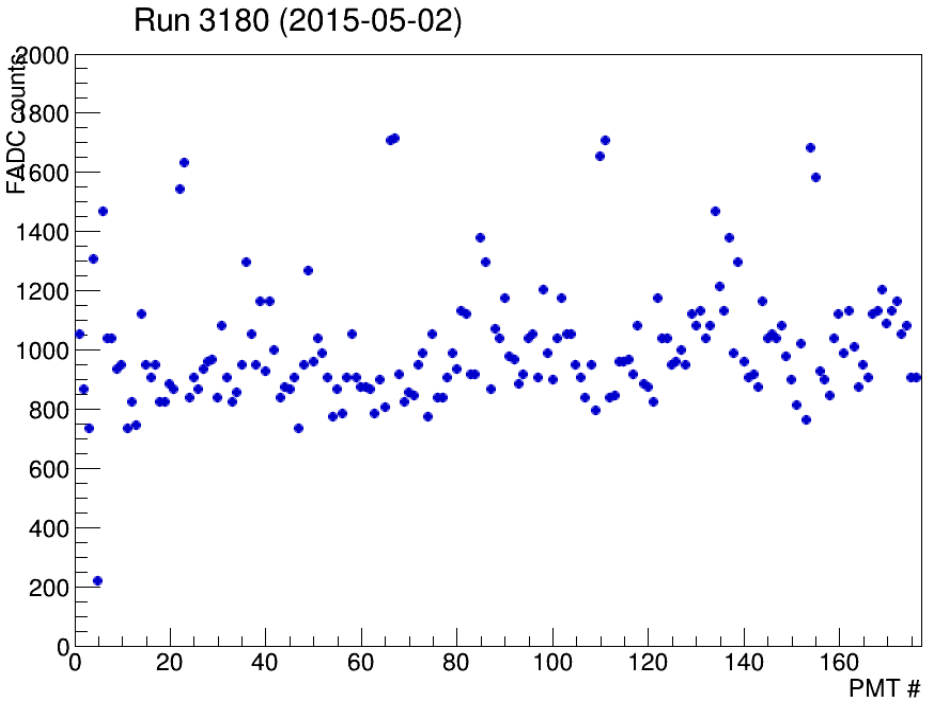


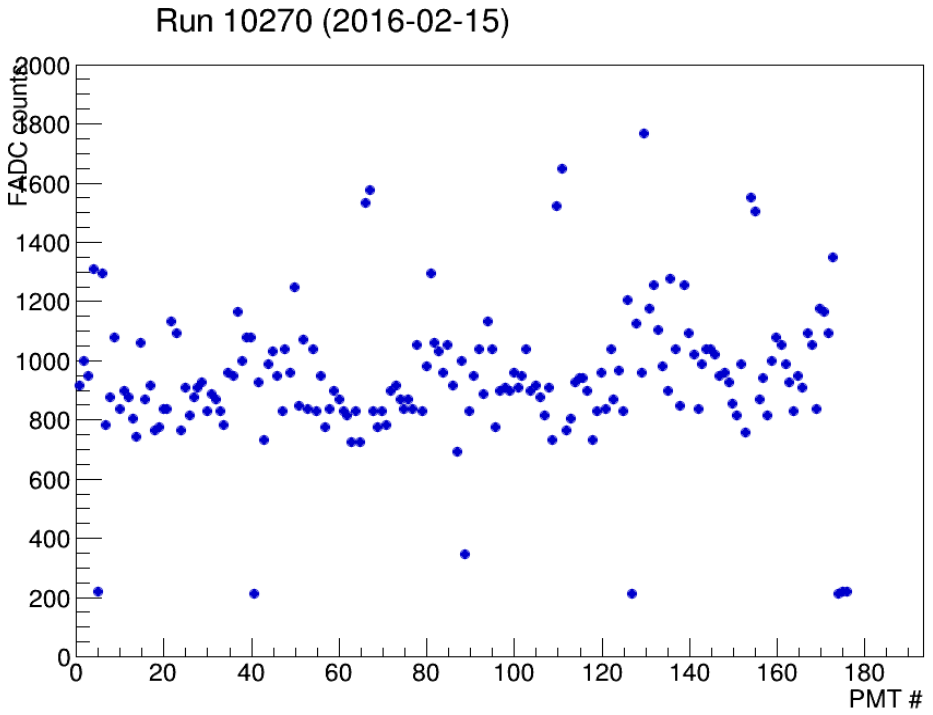




- Stable but relatively high HV (~1700 V);
- Beam current 10-50nA;
- Mostly unrecorded beam flux;
- Clear MPV peak mostly close to beam;
- Ignoring NSA/NSB changes, etc.

FADC peaks in engineering runs (2014-2016)

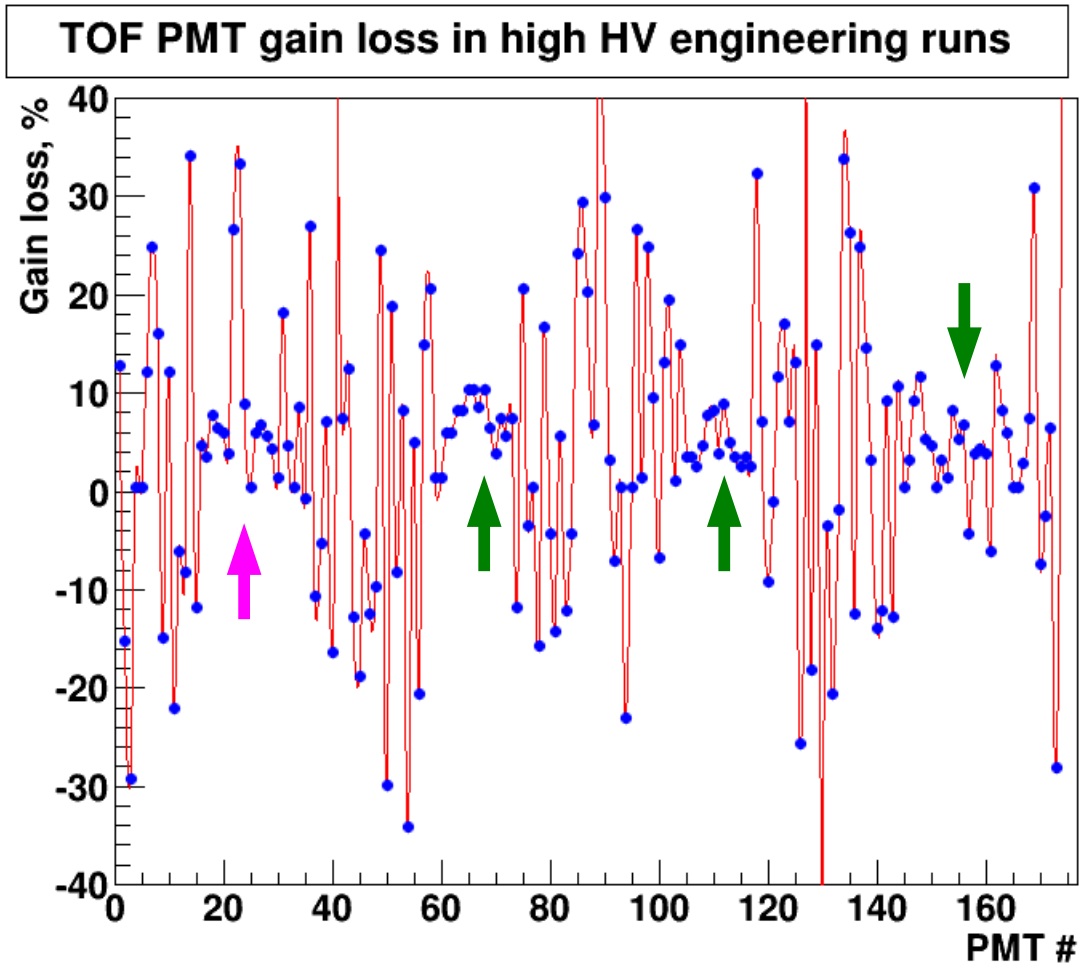




- Run 3180 in May 2015 was soon after FADC dynamic range switch from 1V to 2V

- Run 10270 in Feb 2016 was shortly before dynamic range switch from 2V to 0.5V and significant decrease of PMT HV settings.

Gain loss in engineering runs (2014-2016)



- Only central TOF bars have enough statistics to be reliable measured (marked with green arrows; magenta – bad FADC)

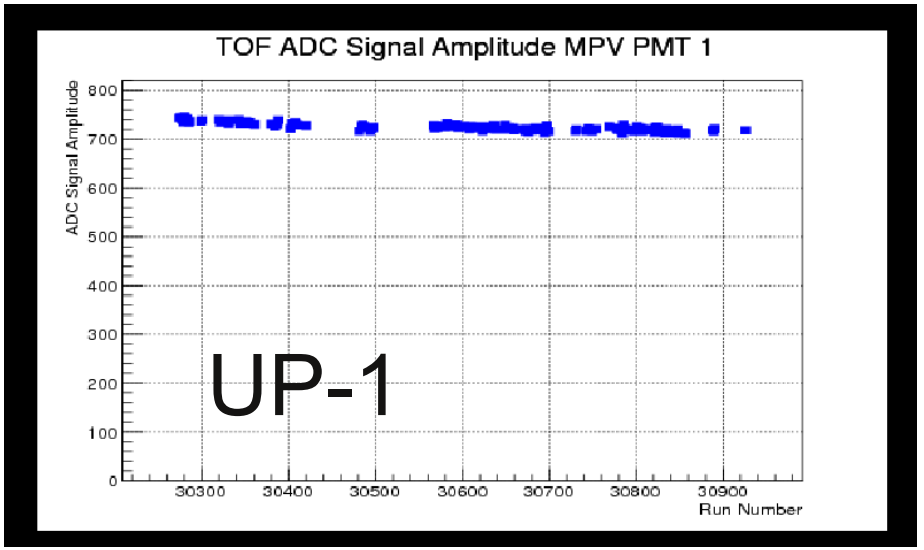
- Decrease of gain from run 3180 to run 10270 as percentage of gain in run 3180 is shown

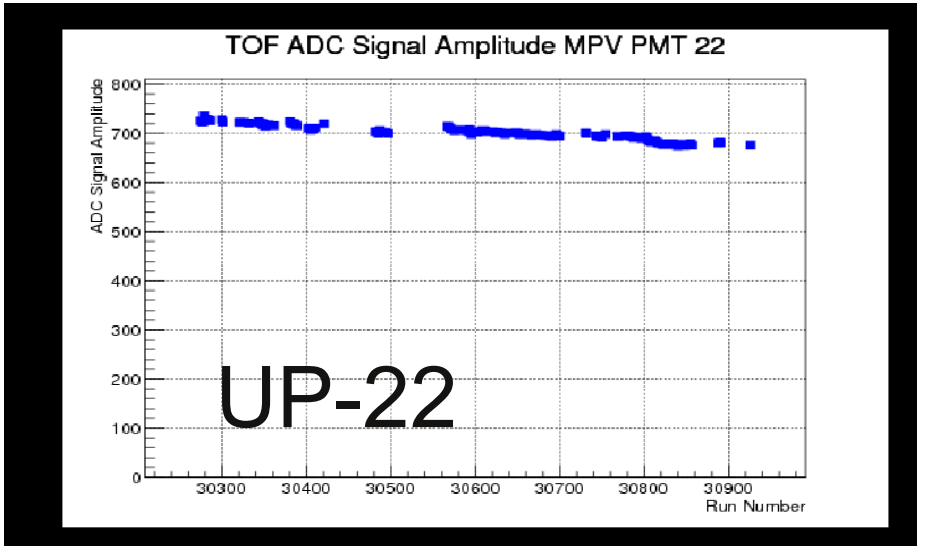
- Loss of gain close to beam region is estimated to be

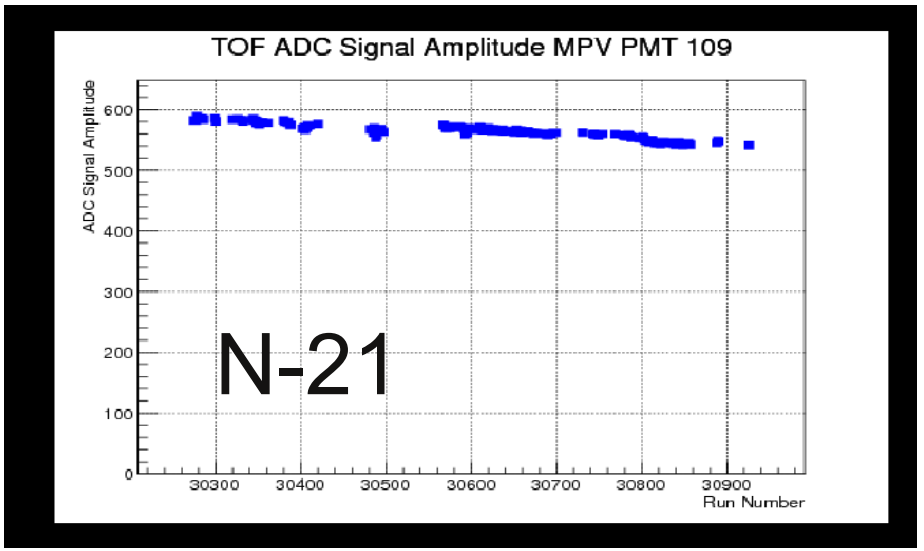
2%-10%

Gain degradation in Spring'17 run

- Beam current 100nA-150nA; same PMT HV







- Gain degradation over the whole Run Period: ~10%

- Actually, this is “MPV degradation”:
  1) gain degradation;
  2) photocathode degradation;
  3) optical joints degradation;
  4) scintillator degradation...

How to be a fortune teller

Spring 2017:

- About 40 days of running at 100-150nA
- MPV degradation in 2017 at 1250V: ~10%
- Beam flux in 2017 (ignoring BANU): 5.9×10^{13} beam photons

2017-2020:

- Estimated beam flux in 2017-2020 (ignoring BANU again): 62×10^{13} photons

- Estimated gain remaining at constant HV : $(\sim 90\%)^{(62/5.9)} \sim 33\%$ (2 replaced PMTs from TOF-1 has 38% and 50% of remaining gain)

- Projected gain degradation per 1 calendar month of running @350nA: $100\% - (\sim 90\%)^{(30 \text{ days} / 40 \text{ days}) * (350\text{nA} / 150\text{nA})} = 17\%$

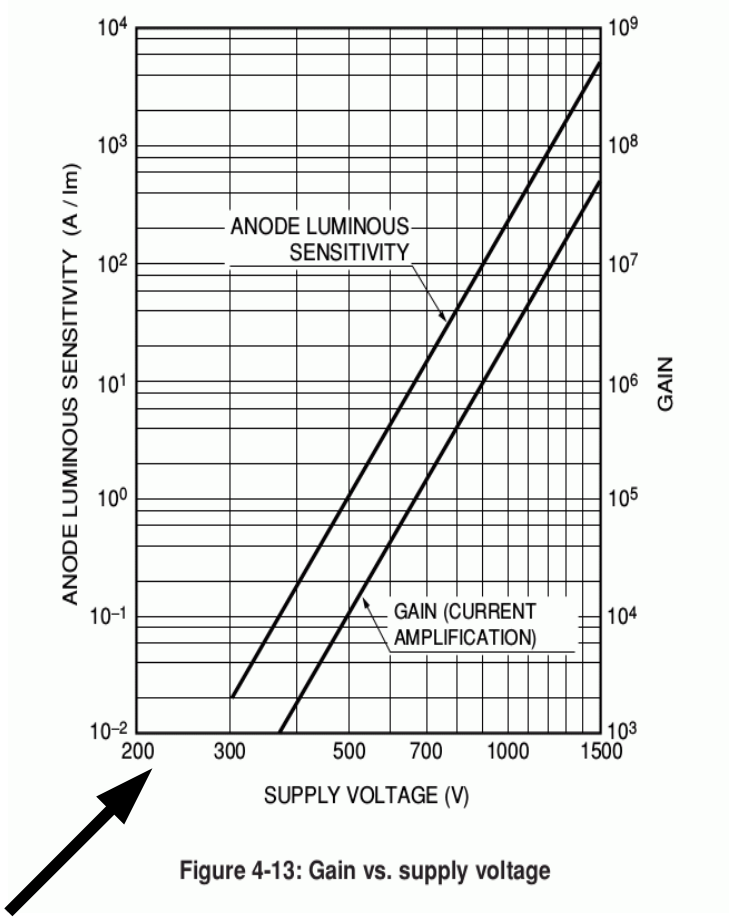


Figure 4-13: Gain vs. supply voltage

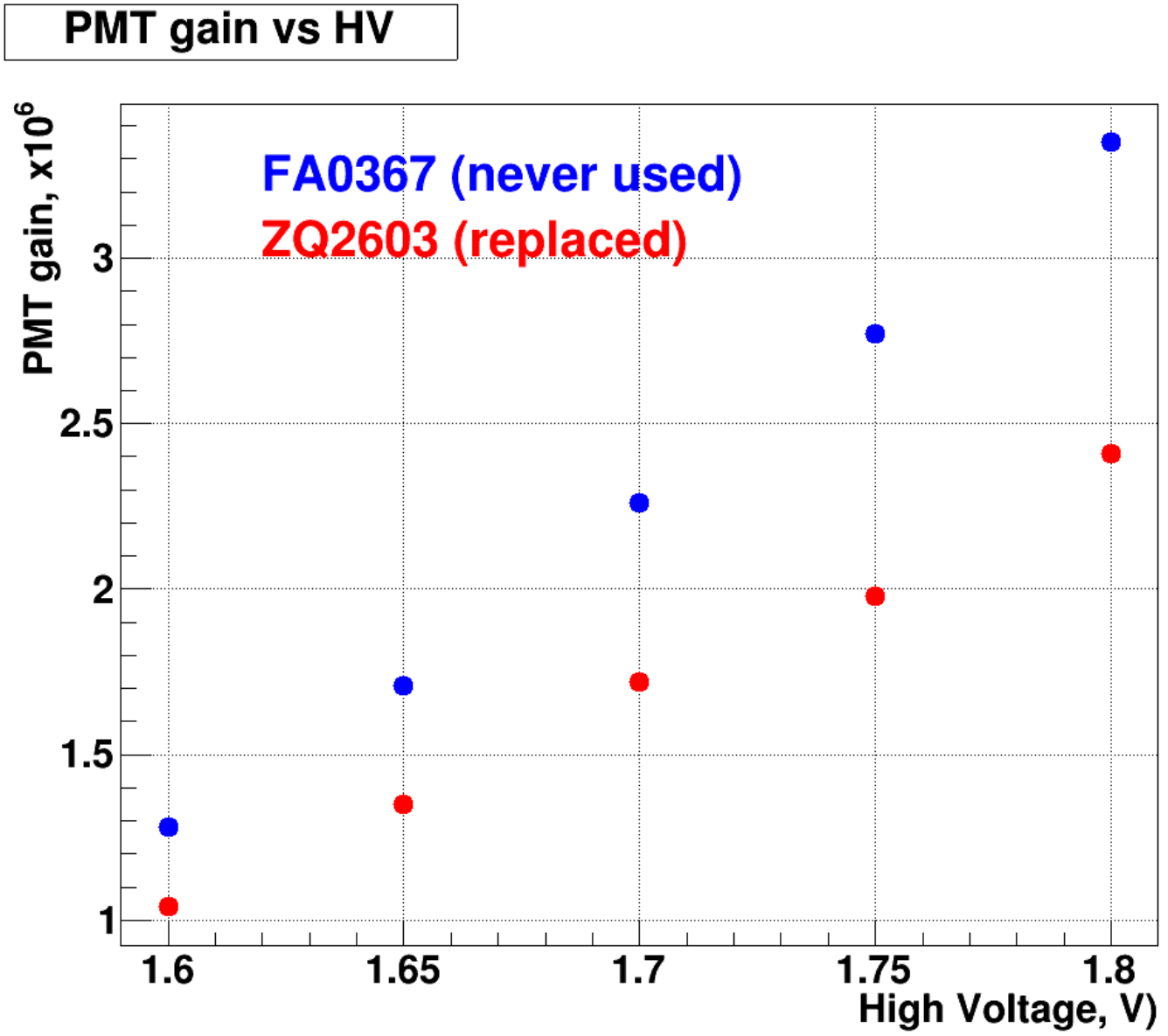
- Indeed, ~100V rise in HV compensates factor of 2-3 loss in gain at HV midrange (per Hamamatsu)

History of PMT HV changes:

Date	ZQ2603	ZQ2635	Mean for all	WA0449	WA0462
10 / 2014	1608	1601	1592		
07 / 2016	1250	1250	1250		
01 / 2017	1300	1300	1259		
12 / 2019	1351	1391	1313	1220	1254
01 / 2020	1351	1391	1318	1270	1254
02 / 2020	1351	1391	1372	1290	1296
06 / 2021	replaced	replaced		replaced	replaced

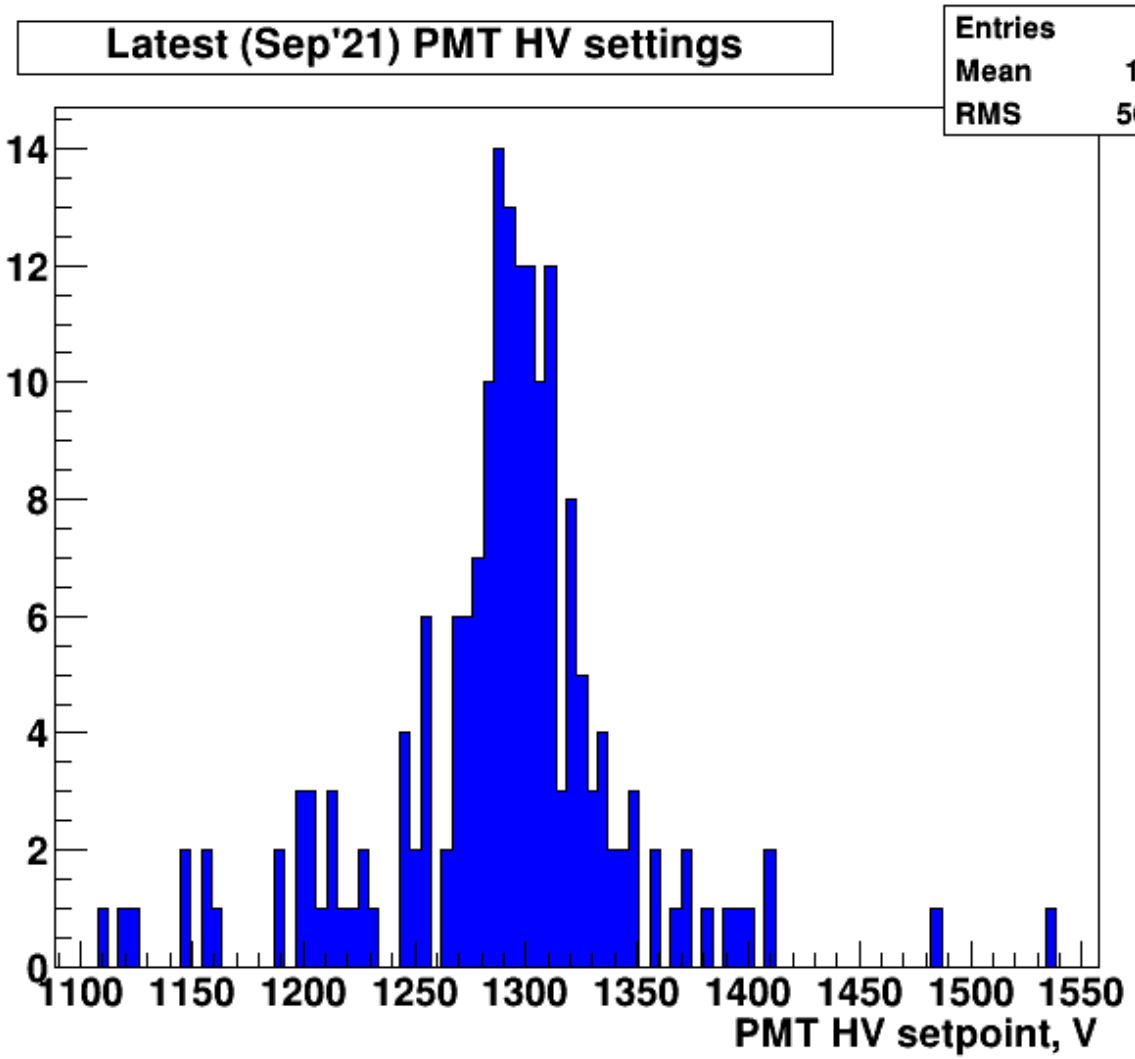
- Reason for replacement: relatively low gain, non-reactive to changes in HV

Lab measurement of gain response to HV



Somewhat shallow slope but nothing critical.

Current (Sep'21) HV settings



- After gain-balancing through HV adjusting by Beni

- After 7+ years of running, only 2 PMTs (from original TOF-I) have HV near 1500V. They are potential candidates for replacement in the future.

- Majority of PMTs are in the 1250-1350V range. They are ~100V above what they were set in 2016.

5 years of running → only ~100V of HV increase and 4 PMT replacement

Need to monitor: 1) high HV tubes; 2) Non-reactive to HV changes tubes.