Multi-Anode PMTs

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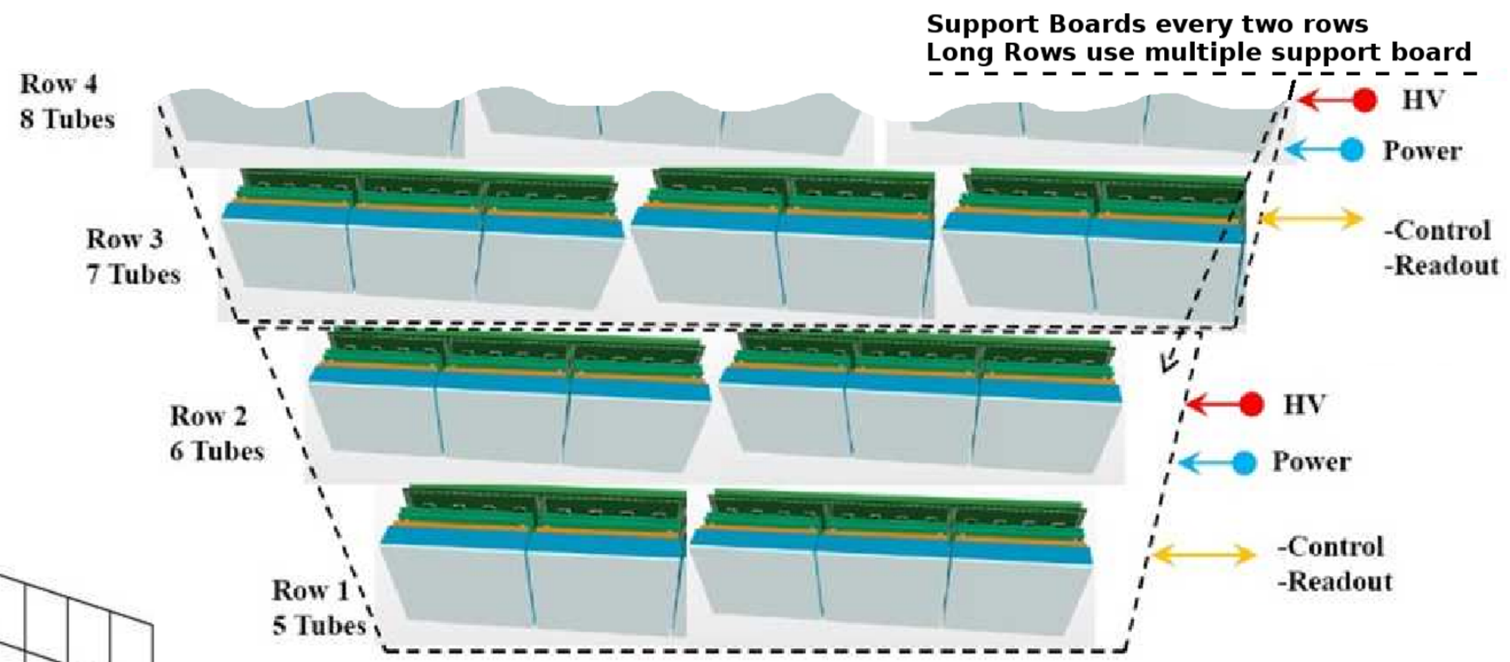
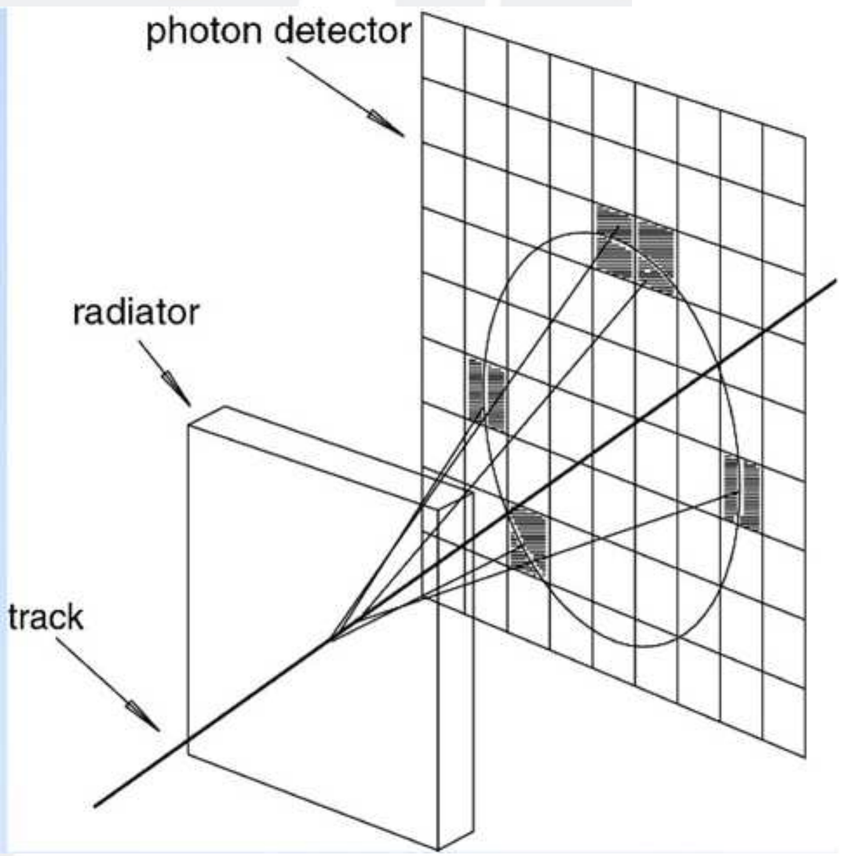
CLAS12 RICH review
October 2015

Photon Detector



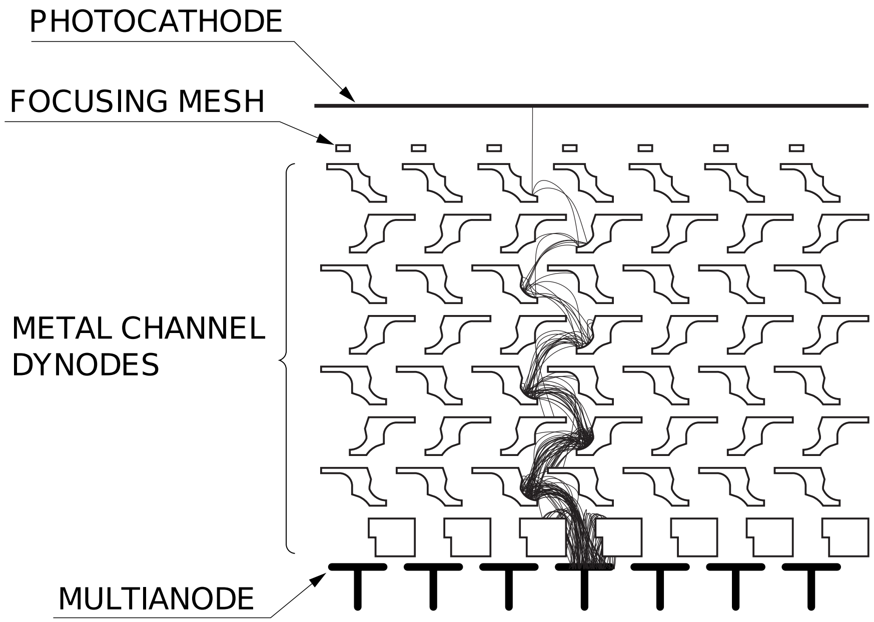


FEATURES

- ~400 Multi-Anode PMTs for single RICH sector
- ~25000 PMT channels
- Position sensitive <1cm resolution
- Efficient single photon detection

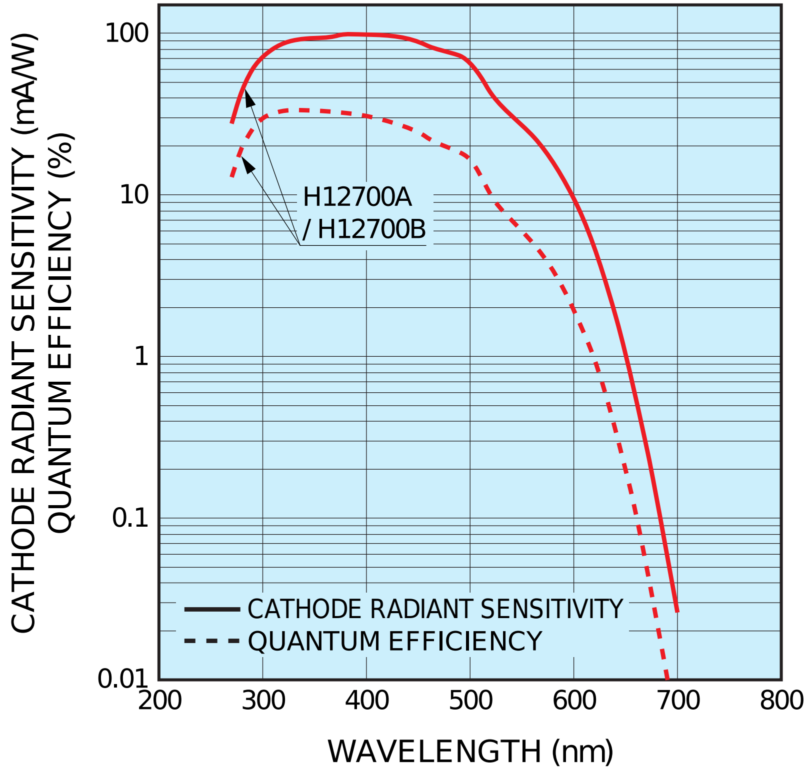
Multi-Anode PhotoMultiplier Tube

HAMAMATSU H12700



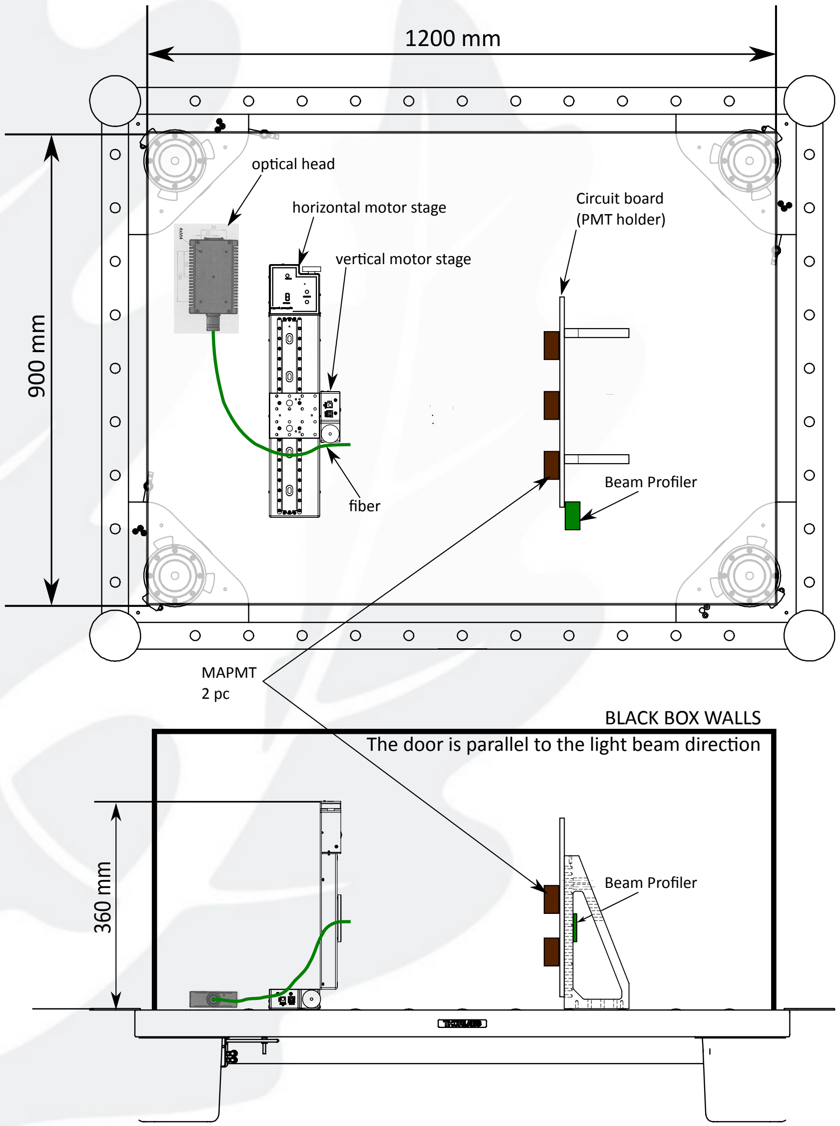
FEATURES

- **Large Effective Area: 48.5mm x 48.5mm**
- **Packing Density: 87%**
- **8x8 Multianode, Pixel size: 6mm x 6mm**
- **High Quantum Efficiency: 33%**

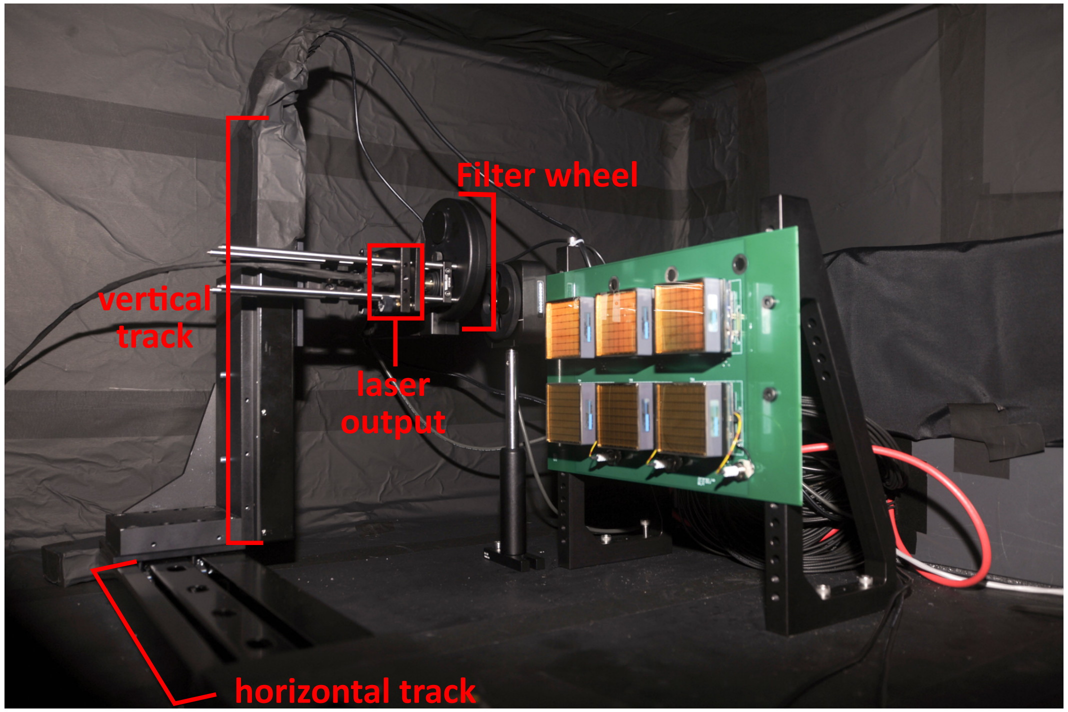


Experimental Setup Assembly

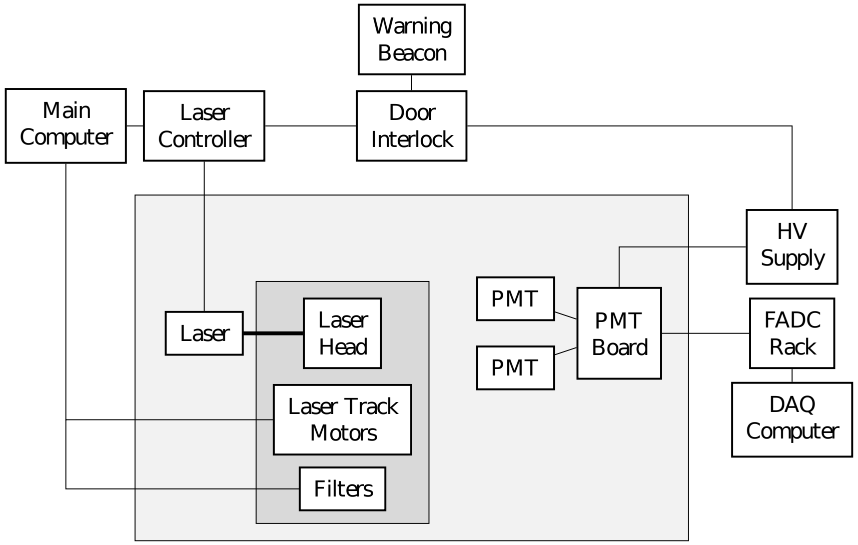
Setup Schematic



Inside the Black Box



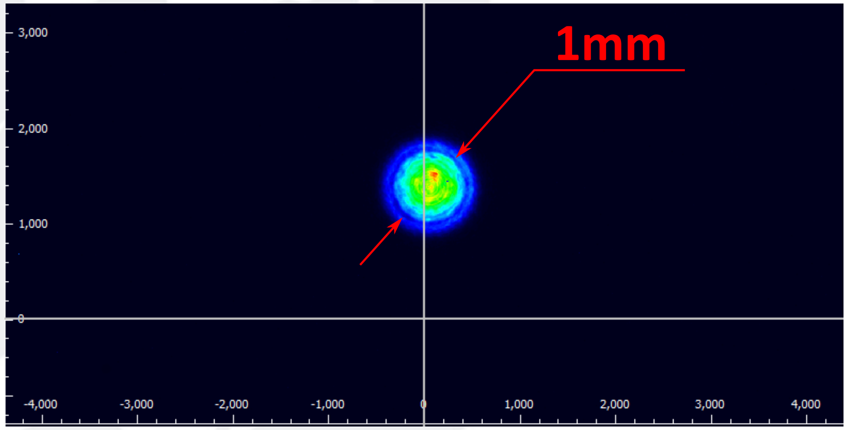
Setup Diagram



Optical System

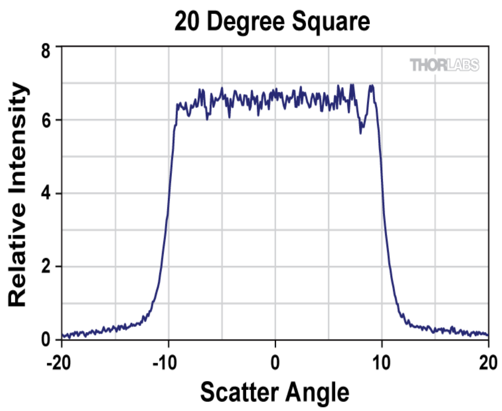
- Picosecond Diode Laser
- Monochromatic light 470nm
- Short pulse width: 15-50ps
- Pulse frequency: up to 1 MHz
- Beam attenuation: ND filters

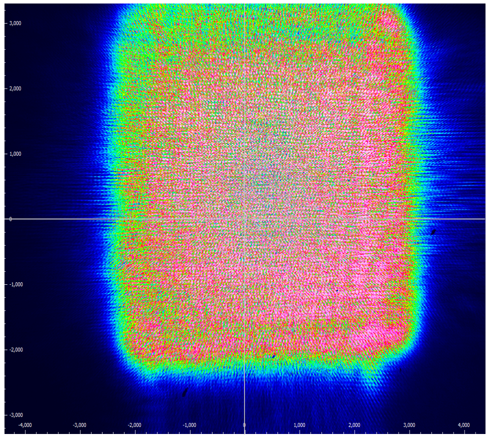
Individual pixel illumination



- **Individual pixel characterization**
- **Scan pixel surface: photocathode uniformity test**

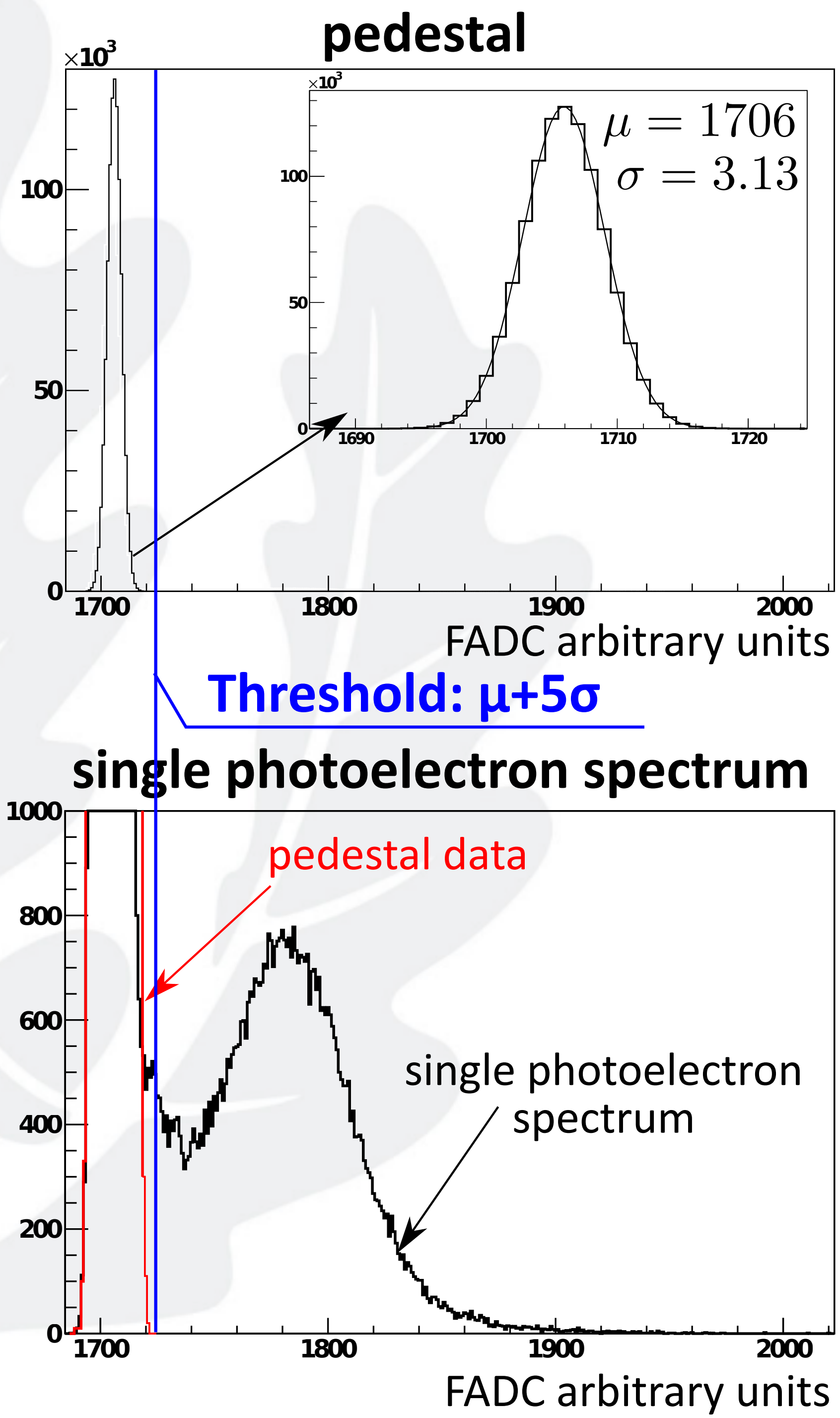
Full face illumination





- **Simultaneous illumination of all 64 pixels**
- **Full coverage of MAPMT surface**

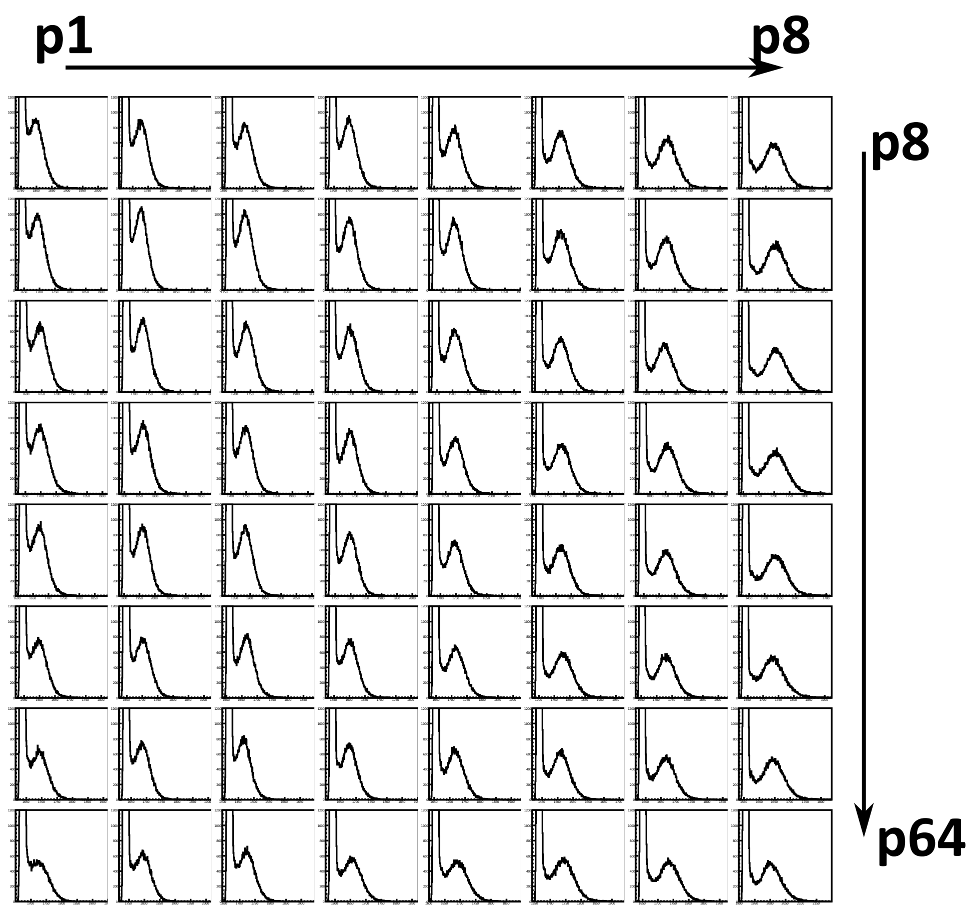
Experimental technique



- **Pedestal - Data collected without laser light**
- **SPE spectum - collected using the laser light attenuated by Neutral Density filters**

attenuation factor≈10^6

$$n_{eff} = \frac{N_{5\sigma}}{N_0}$$



Experimental observables

laser characteristic:
FIXED and CONSTANT for all runs

$$\alpha = \boxed{f} * \eta * \epsilon = \frac{N_{5\sigma}}{N_0}$$

NUMBER OF EVENTS over 5σ of pedestal

TOTAL NUMBER OF EVENTS

f - light source intensity

- our light source (laser) characteristic. It is specific to experimental setup. **We assume it is stable and constant for all our measurements.**

η - photocathode efficiency

- PMT photocathode characteristic, probability of the photoelectron emission.

ϵ - photoelctron multiplication efficiency

- PMT dynodes characteristic, efficiency of the electron multiplier section. Require the "knowledge" of **single photoelectron** signal shape.

α - global efficiency

- "final" and most important criteria that is the convolution of all eficiencies.

Hamatsu PMT Characteristics

measured and reported by Hamamatsu for each MAPMTS

Serial Number	(1) Cathode Luminous Sens. µ A/lm	(2) Anode Luminous Sens. A/lm	(3) Anode Dark Current nA	(4) Anode Dark Current nA	(5) Cathode Blue Sens. Index	(6) Gain x10^6
GA0206	80. 5	125. 0	0. 52	5. 93	11. 40	1. 55
GA0208	78. 5	324. 0	1. 18	3. 34	11. 30	4. 13
GA0224	82. 3	168. 0	0. 65	2. 54	11. 80	2. 04
GA0226	76. 2	96. 2	0. 56	3. 20	11. 50	1. 26
GA0237	78. 4	177. 0	0. 98	2. 82	11. 20	2. 26
GA0259	82. 6	128. 0	0. 15	0. 56	11. 70	1. 55
GA0261	87. 8	226. 0	0. 34	1. 58	11. 80	2. 57
GA0291	101. 0	138. 0	0. 83	7. 86	11. 90	1. 37
GA0293	92. 0	273. 0	0. 32	1. 08	12. 00	2. 97
GA0297	102. 0	320. 0	2. 11	6. 65	12. 10	3. 14
GA0300	111. 0	176. 0	1. 45	3. 41	12. 10	1. 59
GA0302	118. 0	219. 0	1. 40	3. 55	12. 30	1. 86
GA0303	99. 3	149. 0	0. 86	2. 29	12. 10	1. 50
GA0308	86. 7	139. 0	0. 56	1. 11	11. 90	1. 60
GA0310	94. 4	140. 0	0. 51	0. 57	12. 80	1. 48
GA0319	99. 5	185. 0	0. 25	0. 71	13. 20	1. 86
GA0328	92. 3	116. 0	0. 60	5. 68	12. 30	1. 26
GA0330	107. 0	166. 0	1. 38	4. 35	12. 20	1. 55
GA0331	94. 9	212. 0	0. 97	4. 52	12. 50	2. 23
GA0342	76. 4	95. 3	0. 78	1. 82	11. 20	1. 25
GA0345	78. 1	125. 0	1. 58	4. 95	10. 70	1. 60
GA0355	70. 2	136. 0	0. 22	0. 70	11. 10	1. 94
GA0357	72. 5	148. 0	0. 51	1. 09	11. 00	2. 04
GA0358	83. 7	278. 0	0. 88	5. 75	11. 00	3. 32
GA0361	69. 1	154. 0	1. 60	3. 60	10. 80	2. 23

Cathode Luminous Sensitivity

- ➤ defines photocathode performance

Cathode Blue Luminous Sensitivity

- ➤ defines photocathode performance for wavelength shorter than 450 nm

Gain (amplification)

- ➤ performance of the multiplication system (collection efficiency, dynode secondary electron emission)

Anode Luminous Sensitivity

- ➤ defines MAPMT performance of photoelectron emission and multiplication system (convolution of cathode lumious sensitivity and gain) **directly related to measured efficiency!**

Anode Uniformity

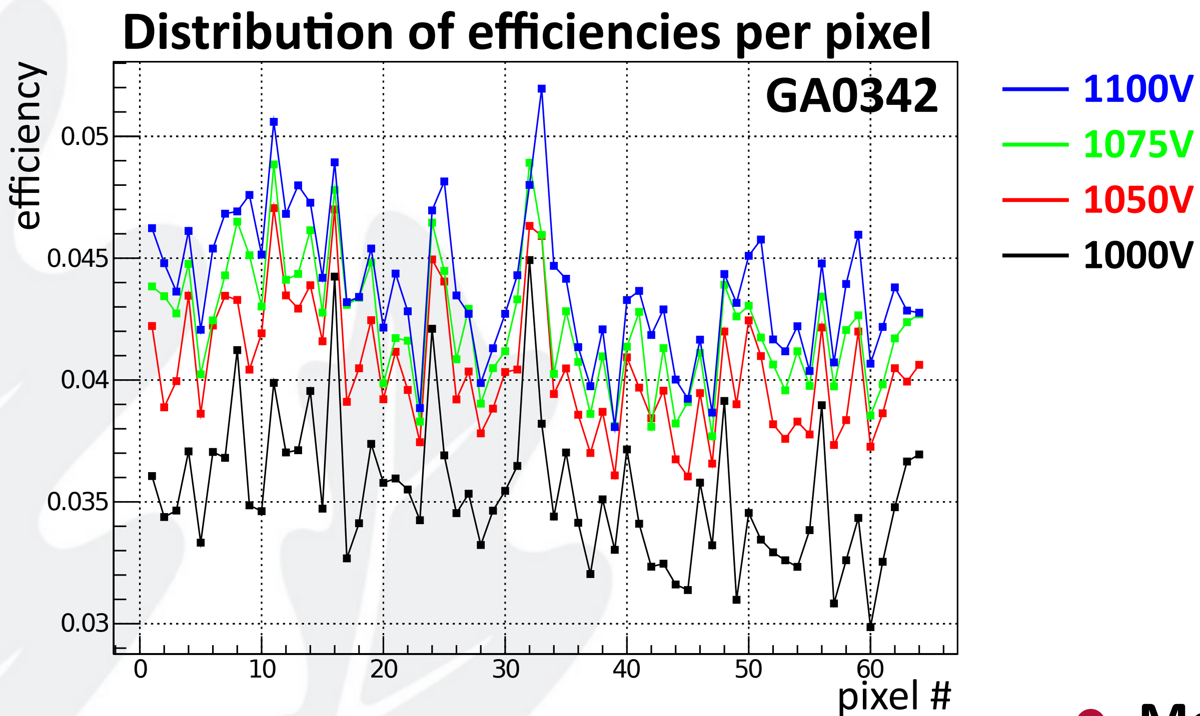
Ratio of Anode Output = 1 : 1.7

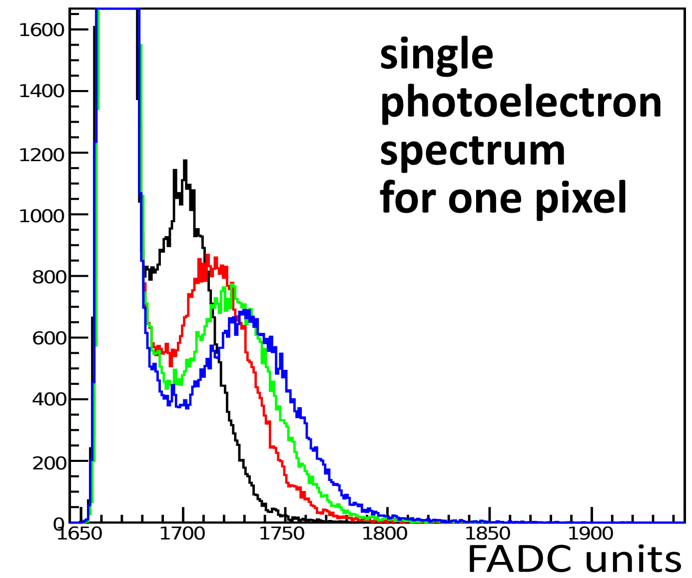
P1 67	P2 71	P3 76	P4 72	P5 69	P6 74	P7 69	P8 67
P9 69	P10 66	P11 70	P12 66	P13 61	P14 65	P15 66	P16 71
P17 72	P18 66	P19 66	P20 64	P21 60	P22 62	P23 67	P24 74
P25 75	P26 67	P27 67	P28 67	P29 62	P30 63	P31 69	P32 75
P33 76	P34 65	P35 67	P36 67	P37 64	P38 65	P39 70	P40 75
P41 74	P42 64	P43 65	P44 67	P45 65	P46 67	P47 71	P48 76
P49 70	P50 65	P51 68	P5 72	P53 68	P54 71	P55 72	P56 77
P57 81	P58 89	P59 94	P60 100	P61 94	P62 98	P63 94	P64 83

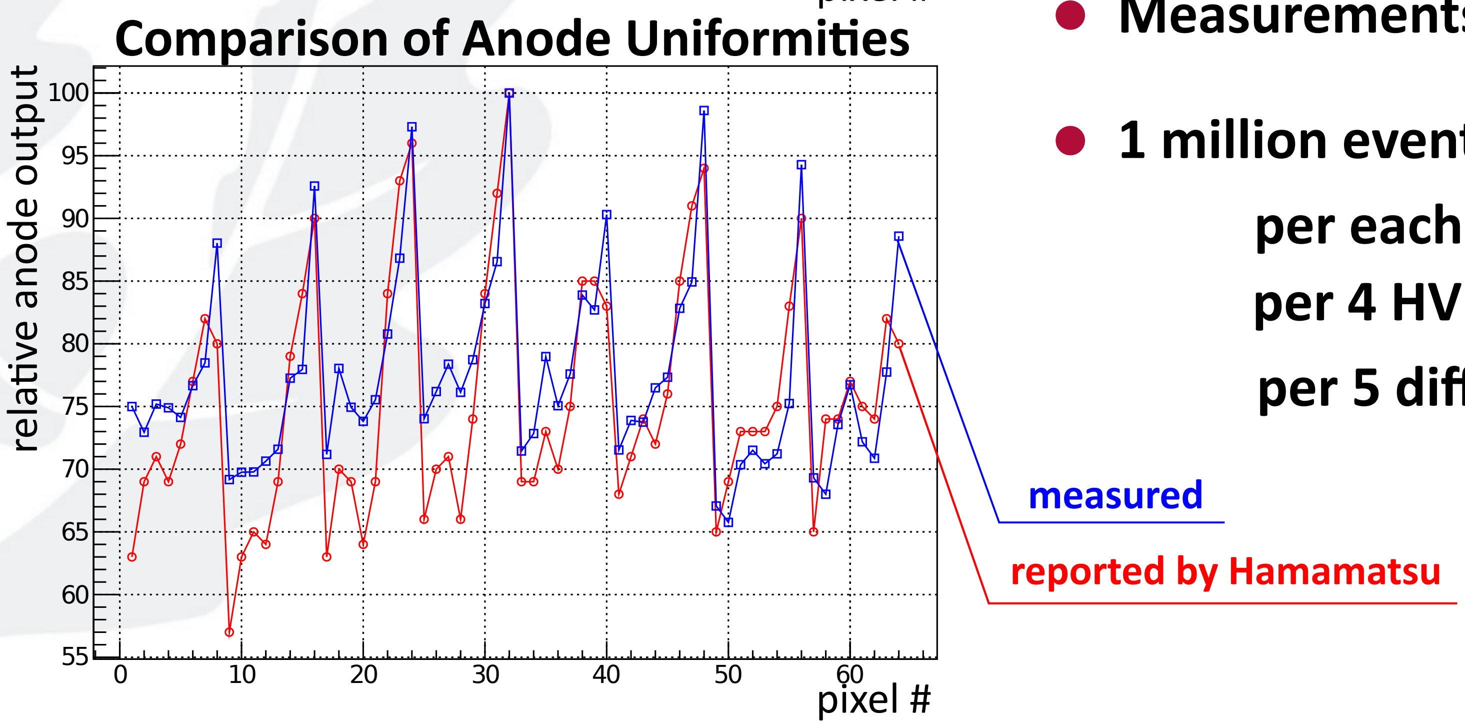
Top View

typical uniformity data obtained from each anode probably originates from gain variations in the secondary electron multiplier

Experimental measurements







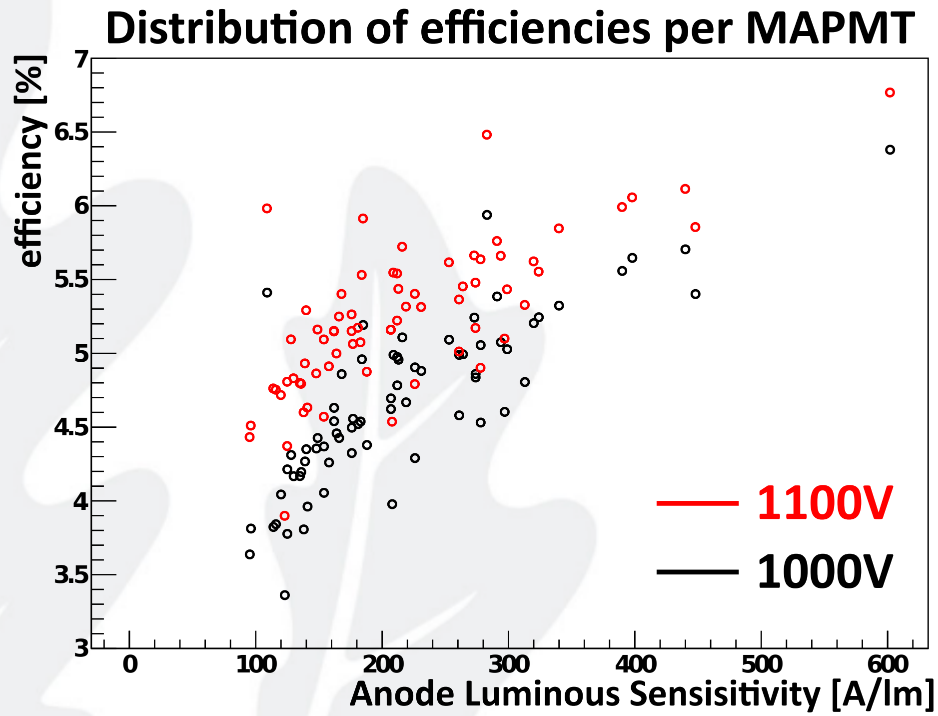
- Measurements performed for 4 HV
- 1 million events are collected

  per each pixel

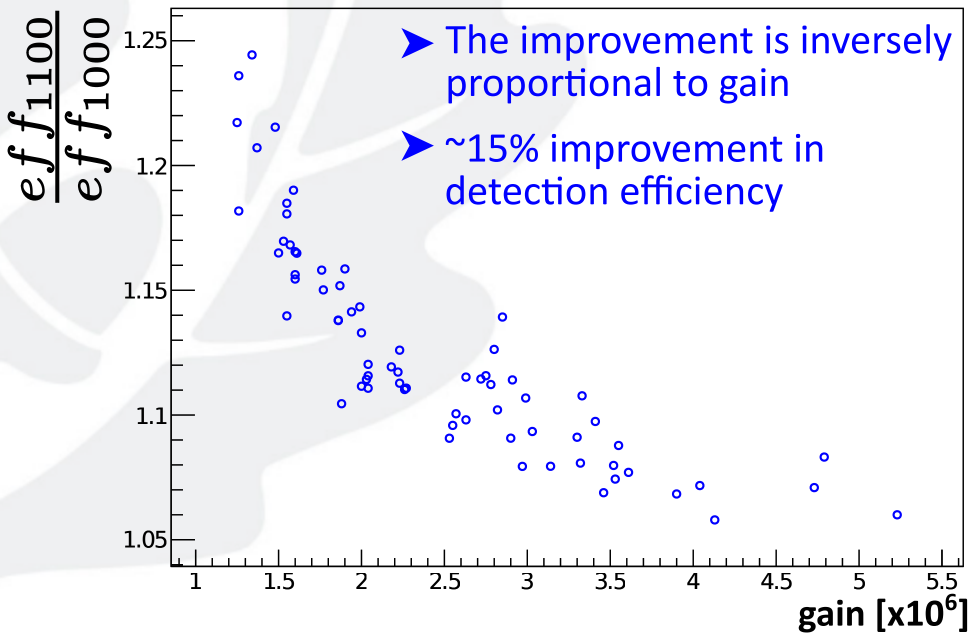
  per 4 HV

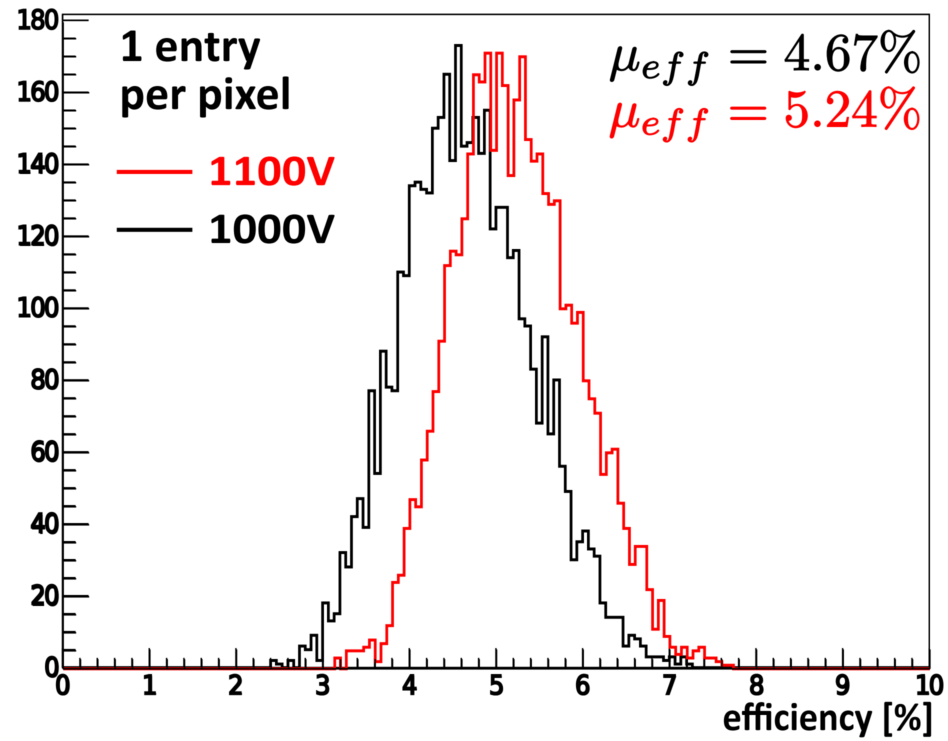
  per 5 different light intensities

Experimental measurements



- Each point corresponds to 1 MAPMT
- The correlation between efficiencies and anode luminous sensitivities [as expected]
- The efficiency of single photon detection is clearly superior at higher supply voltage

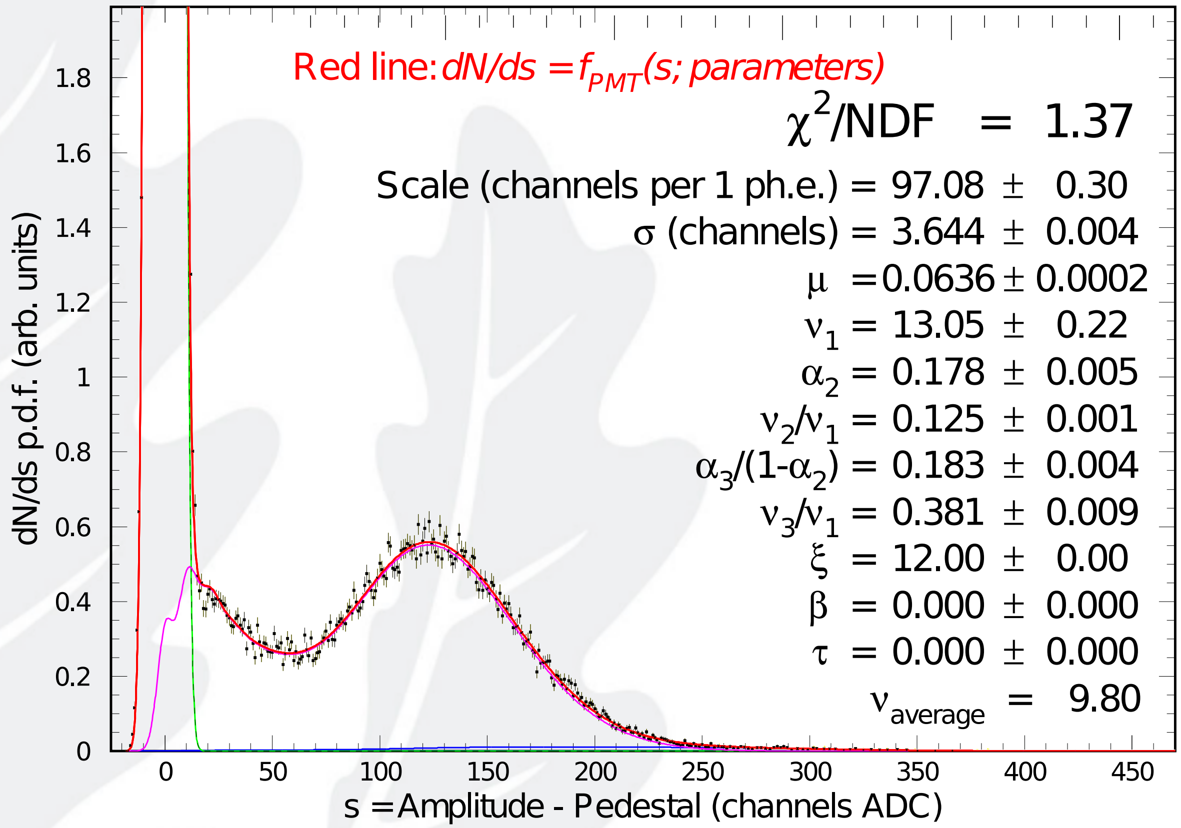




SPE Spectrum Analysis

model by Pavel Degtiarenko

Typical fit of single photoelectron spectrum



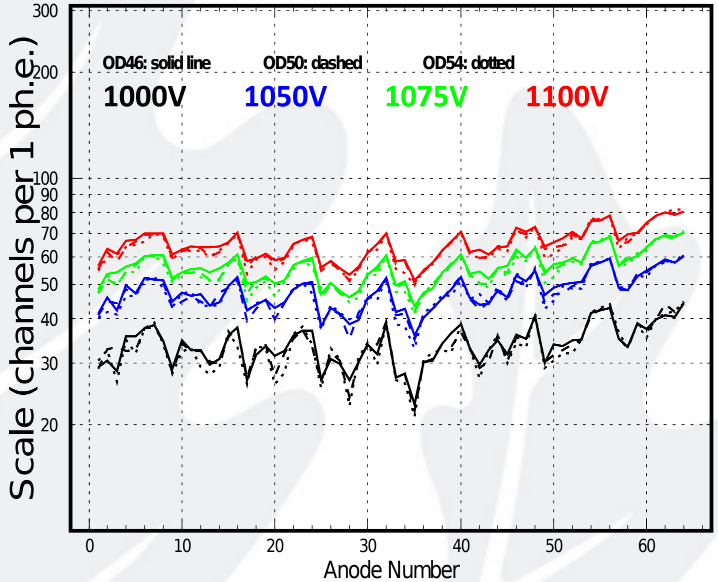
- **new mathematical model for description of SPE developed at JLab (to be published in NIM) provides the most realistic description of MAPMT response.**
- segmentation of the first dynode into areas with different multiplicities of secondary electrons ν_1, ν_2, ν_3
- average number of photoelectons per one event μ (could be converted to quantum efficiency with calibrated light source)
- gain is calculated as an average of the single photoelectron peak **Scale**

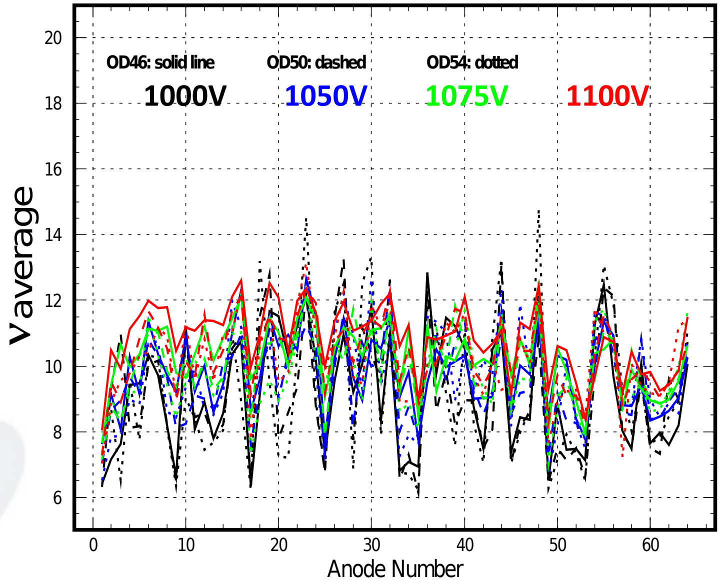
- **approximate the true single-photoelectron spectra**
- **disentangle the characteristics of photocathode and multiplier system can provide quantum efficiency and collection efficiency within model framework**
- **parameterized form is well suited for future simulation of detector response**

SPE Spectrum Analysis

model by Pavel Degtiarenko

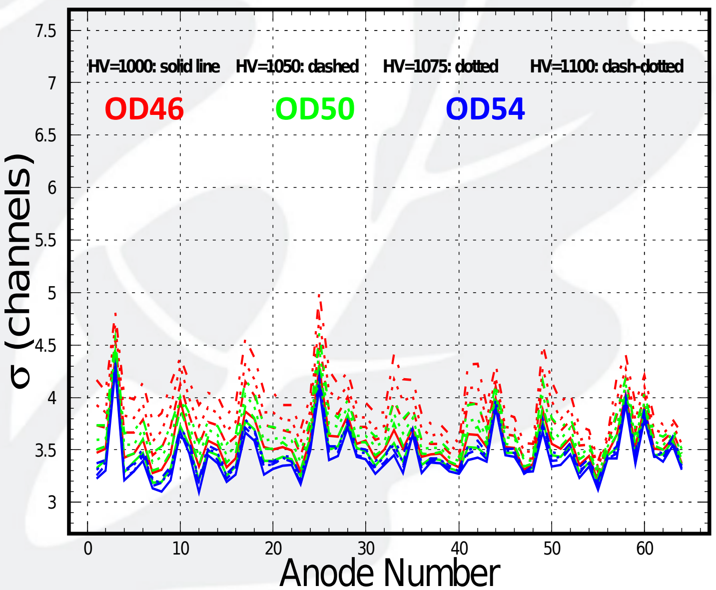
OD - optical density filters used for laser attenuation
OD46 = $10^{-4.6}$ attenuation
OD54 = $10^{-5.4}$ attenuation

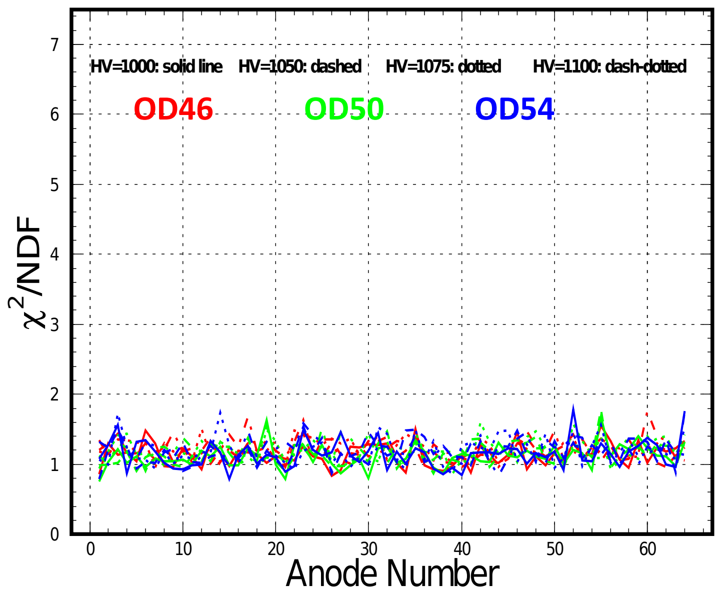


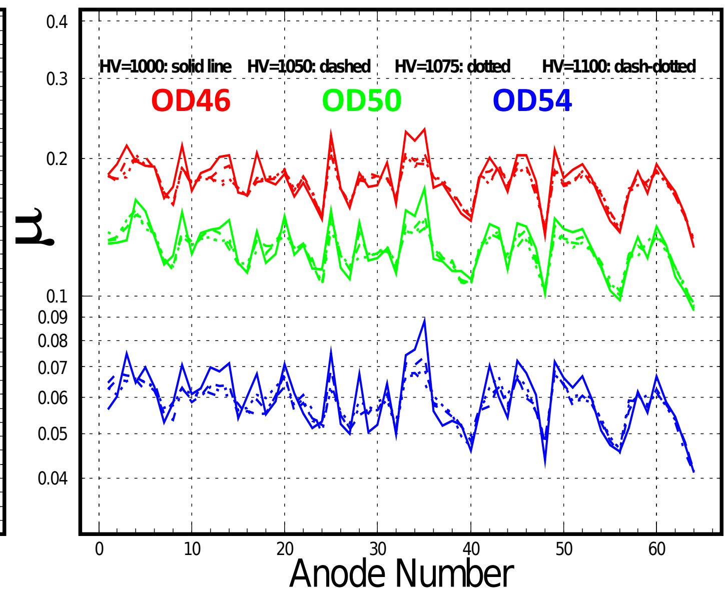


FEATURES

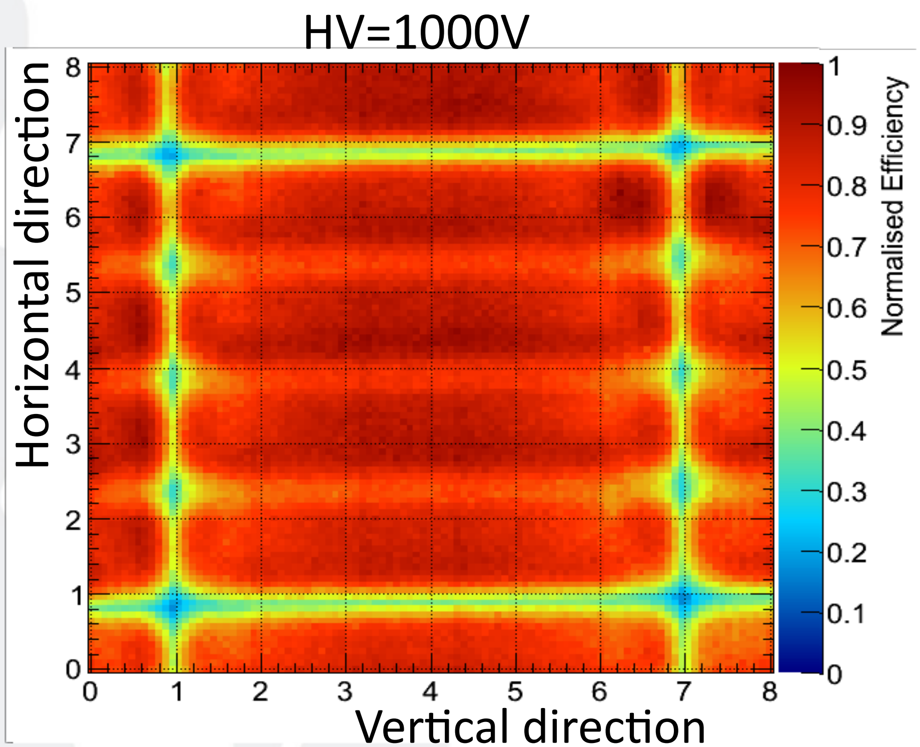
- **Scale** - independent of Light Intensity (PMT dynode system characteristic)
- **μ** - independent of High Voltage (PMT photocathode characteristic)

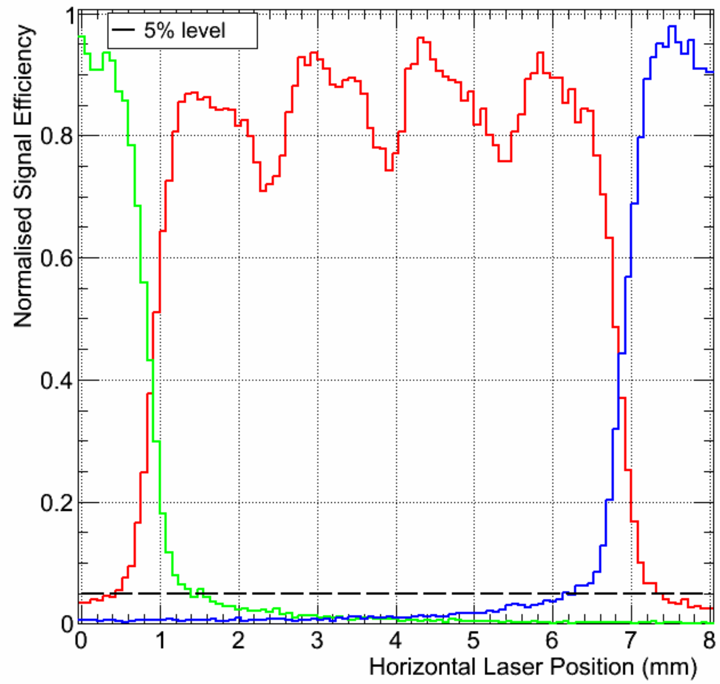


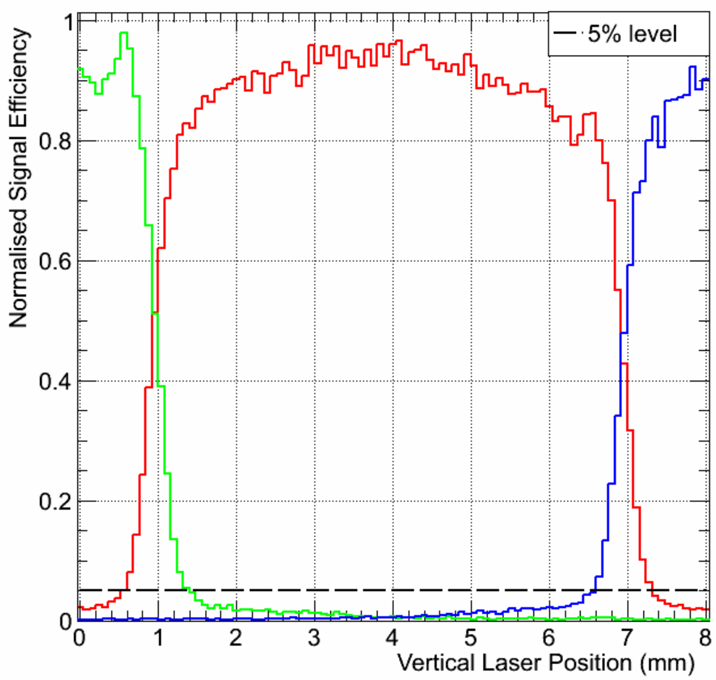




Pixel surface uniformity



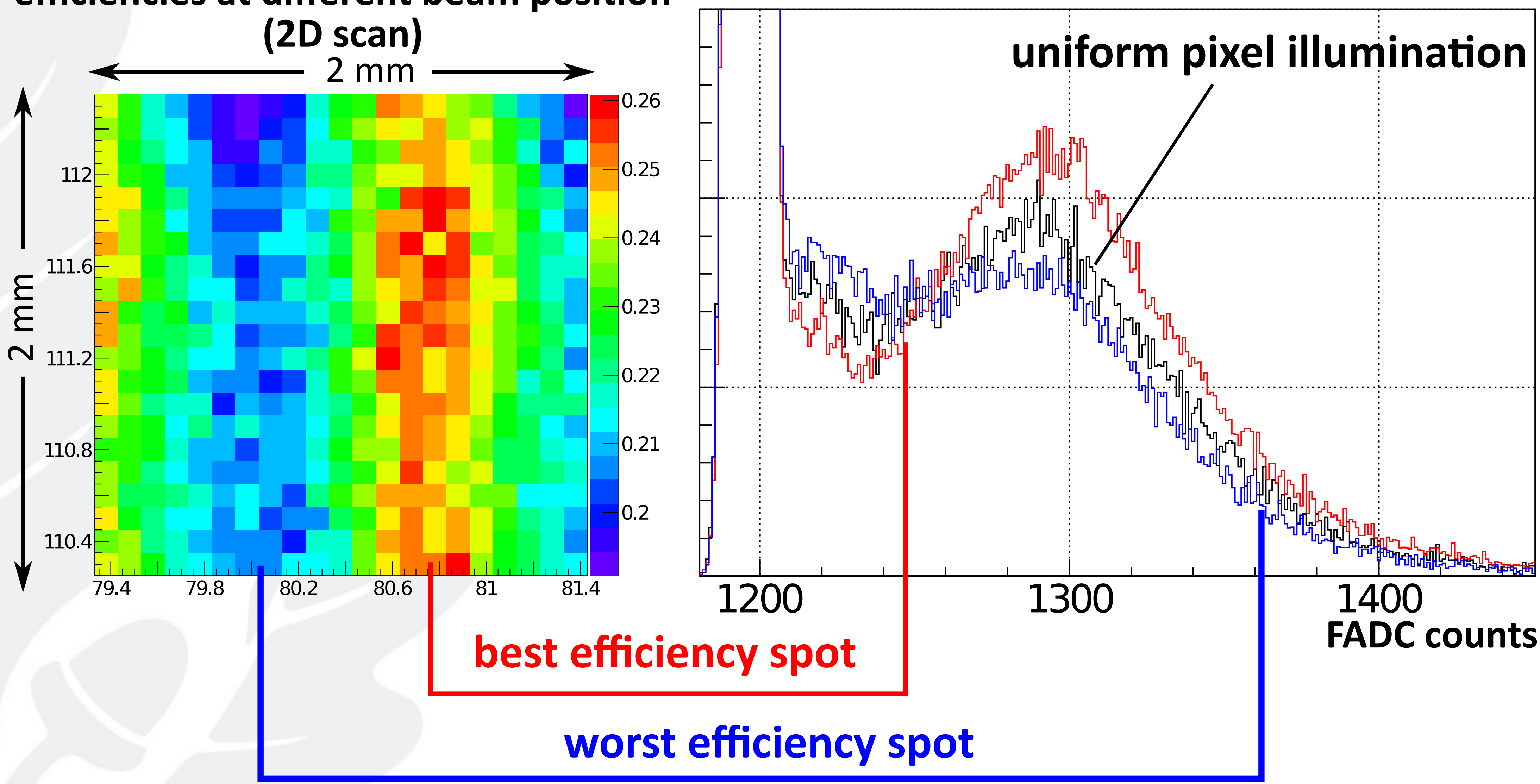




- **Response segmentation depending on dynode mesh structure in horizontal direction**
- **Uniform response in vertical direction**
- **Signal strength drops in deadspace are 40-50% relative to the signal maximum values**

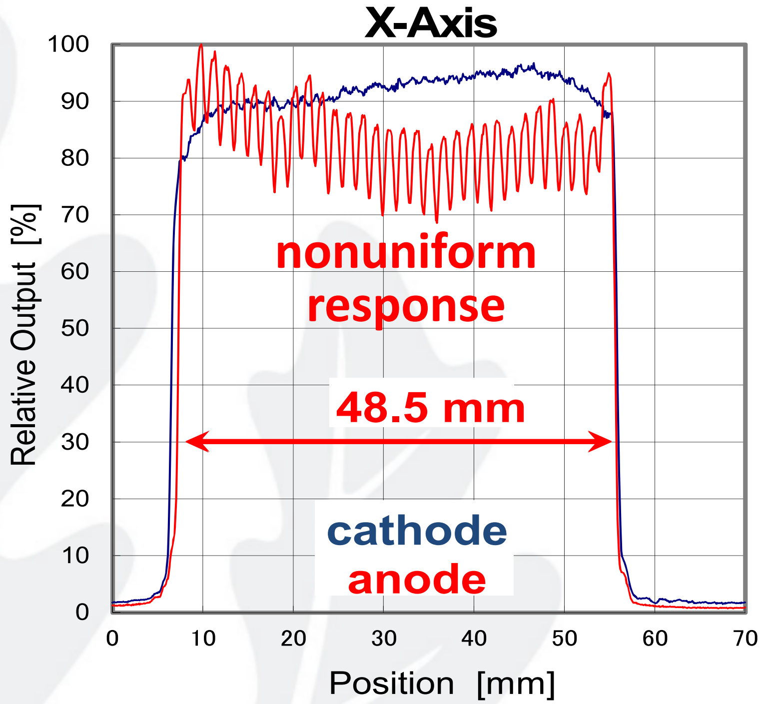
Pixel surface uniformity

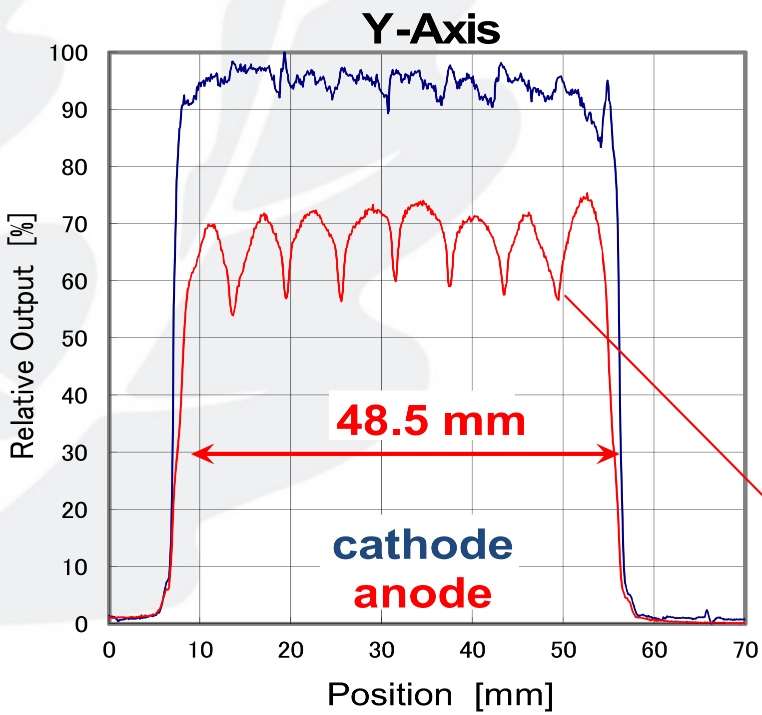
efficiencies at different beam position (2D scan)

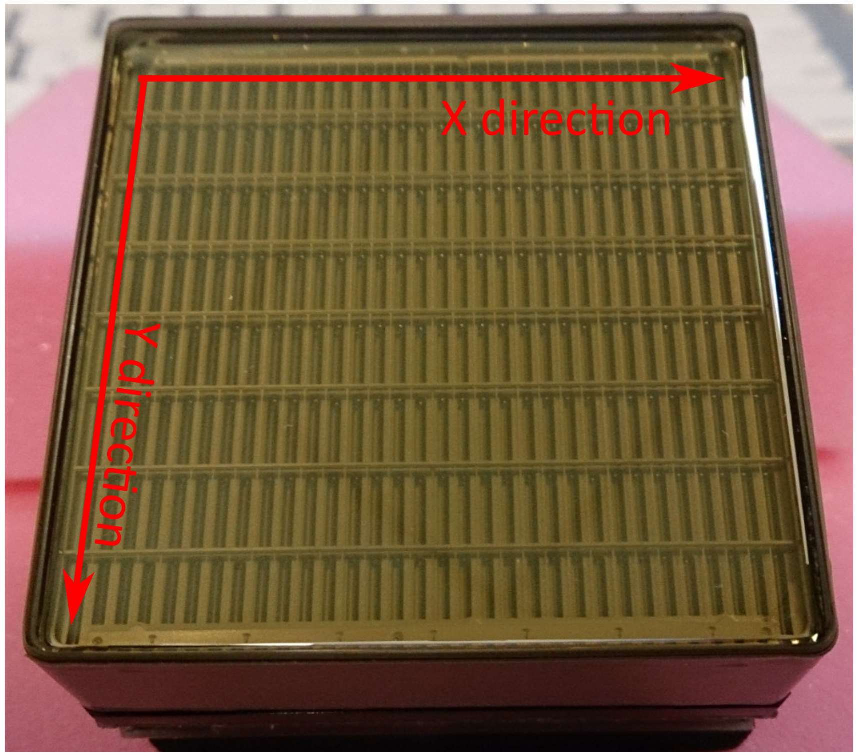


Illuminate the whole surface of the pixel to obtain average characteristics!

Pixel surface uniformity: Hamamatsu response





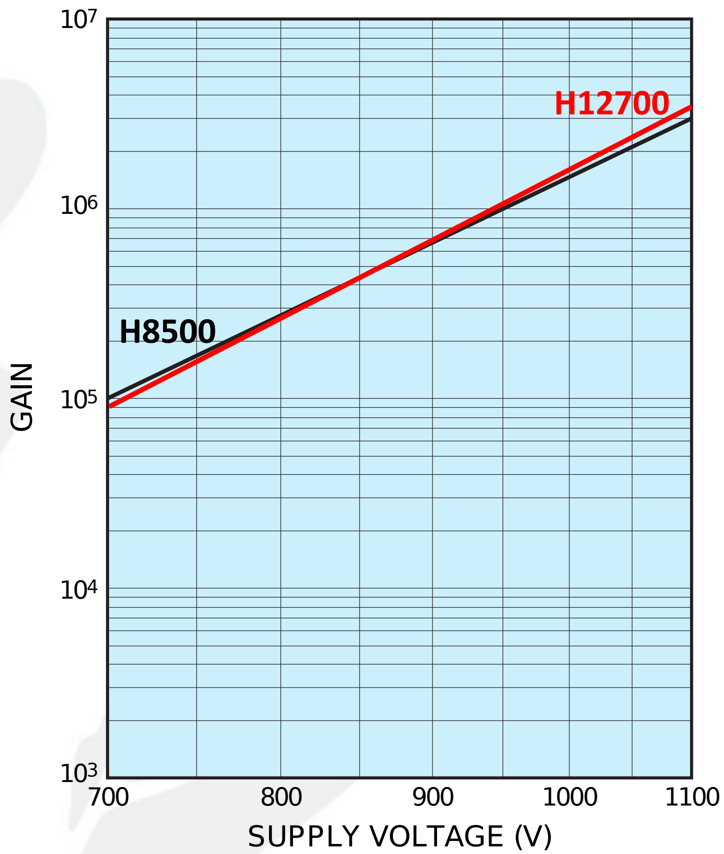


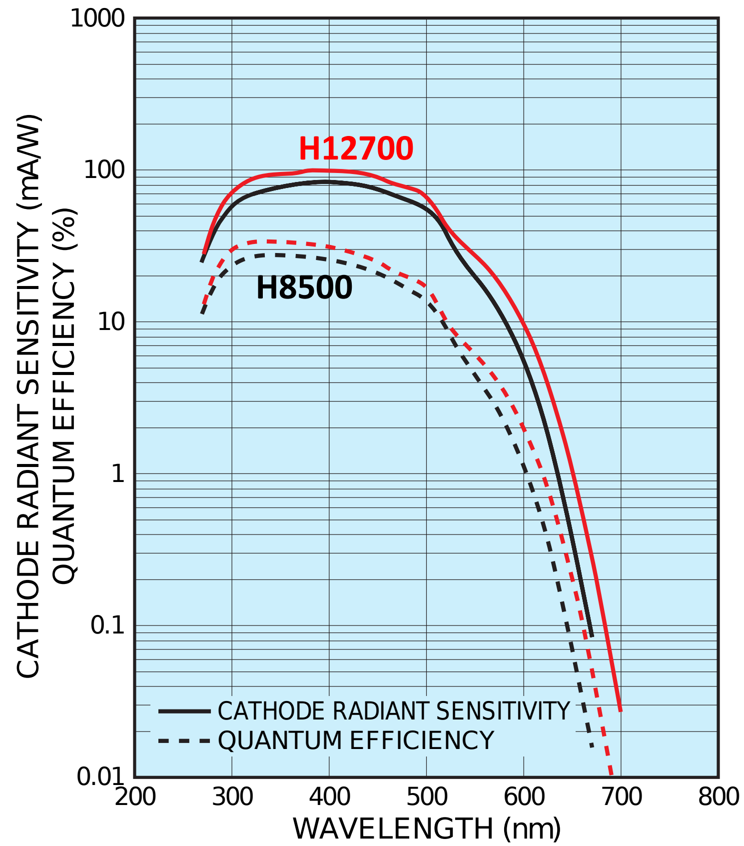
- continuity in dynode surface along Y direction
- gaps between dynode in X directions
- uniform photocathode performance

deadspace between pixels

H8500 to H12700 comparison

- **H8500 is an older model of MAPMT**





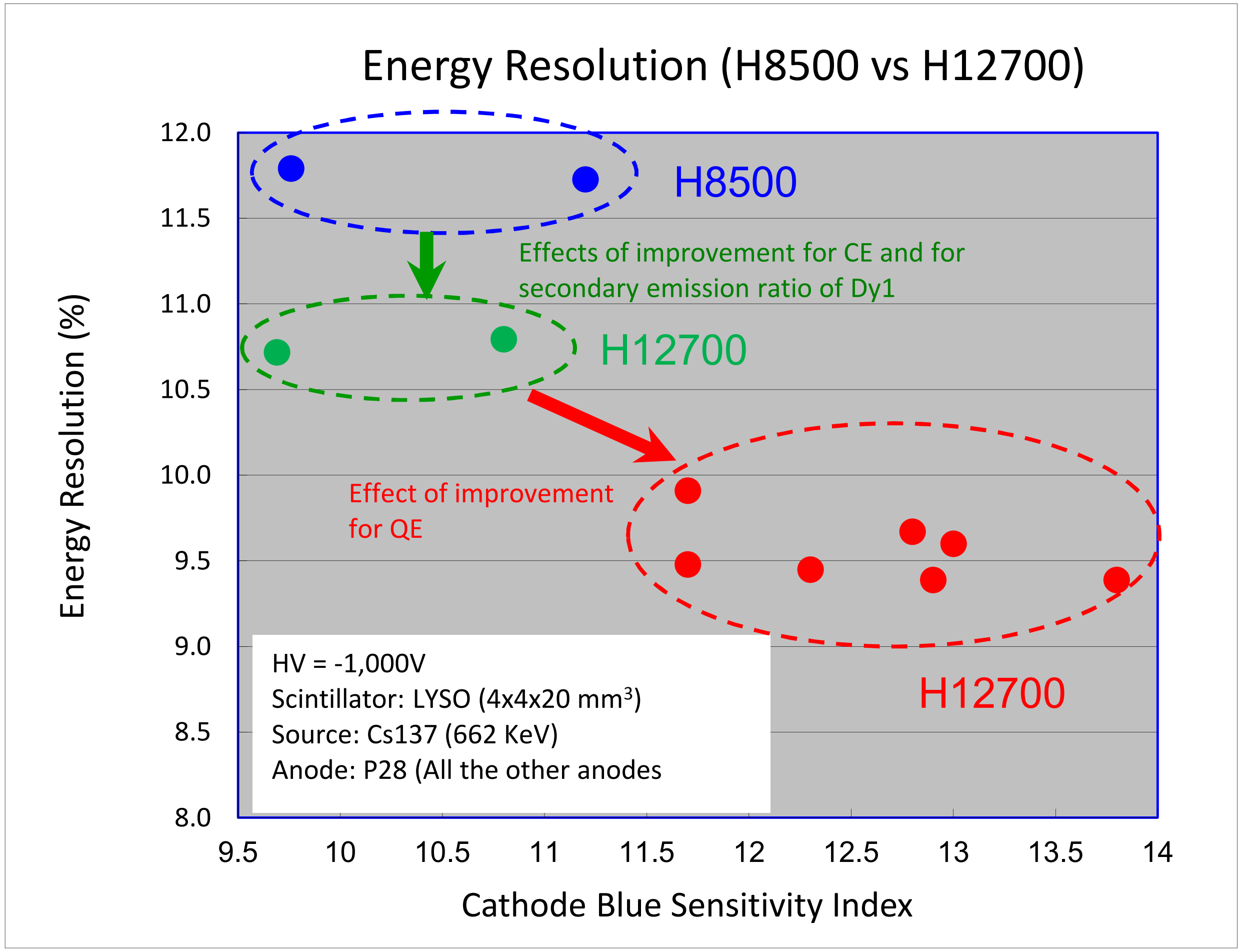
- H12700 is designed for better detection of single photon
- H12700 has better cathode sensitivity: better quantum efficiency
- H12700 has less dynode stages: **10** vs **12** (H8500)
  but it has similar gain

H8500 to H12700 comparison

Energy Resolutions of Flat Panel PMTs

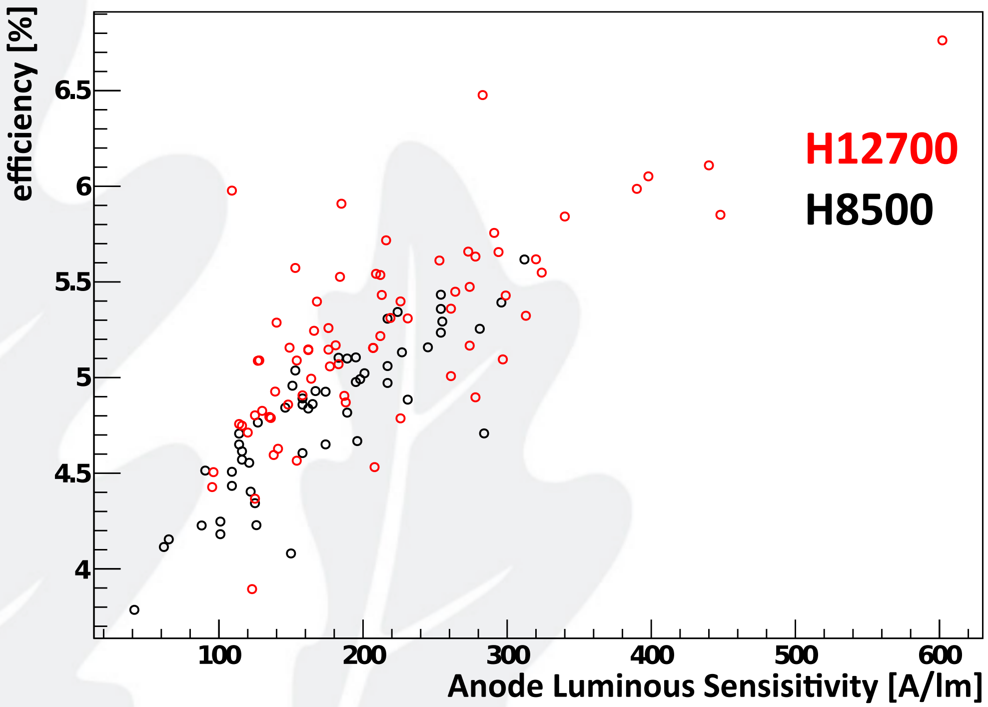
Supply Voltage : -1,000 V
Scintillator : LYSO (4 x 4 x 20 mm^3)
Source : Cs-137 (662 keV)
Measured anode pixel : P28 (all the other anodes are grounded.)

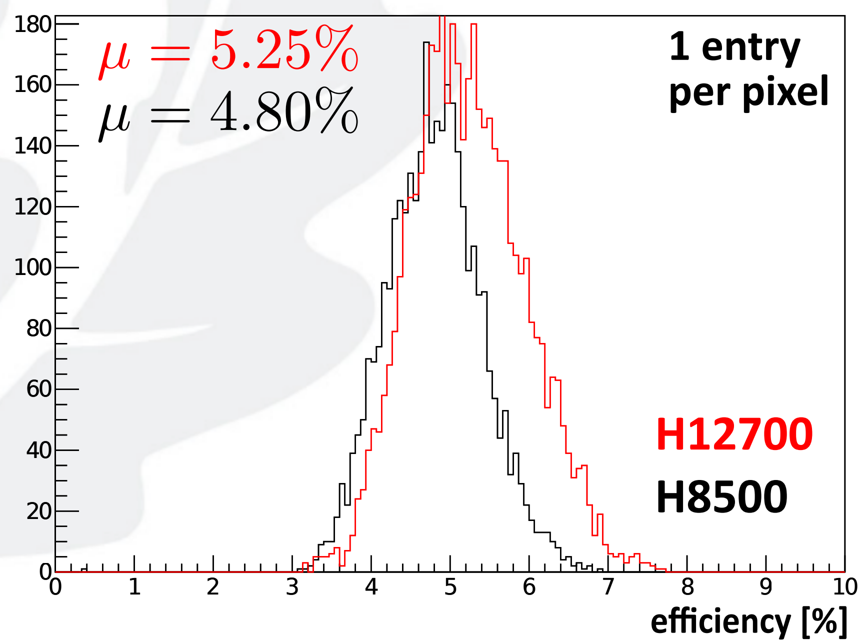
Type	S/N	Sk (uA/lm)	Skb	E-Reso (%)
H12700	ZA0126	61.2	11.7	9.9
	ZA0195	103	13.8	9.4
	ZA0246	90.3	12.3	9.5
	ZA0257	78.4	11.7	9.5
	ZA0263	85.4	12.9	9.4
	ZA0264	80.2	12.8	9.7
	ZA0269	86.3	13	9.6
	Ave.	**83.5**	**12.6**	**9.6**
H12700	ZA0001	54.8	9.69	10.7
	ZA0002	69.2	10.8	10.8
	Ave.	**62.0**	**10.2**	**10.8**
H8500	CA7105	66.6	11.2	11.7
	CA7109	52.1	9.76	11.8
	Ave.	**59.4**	**10.5**	**11.8**



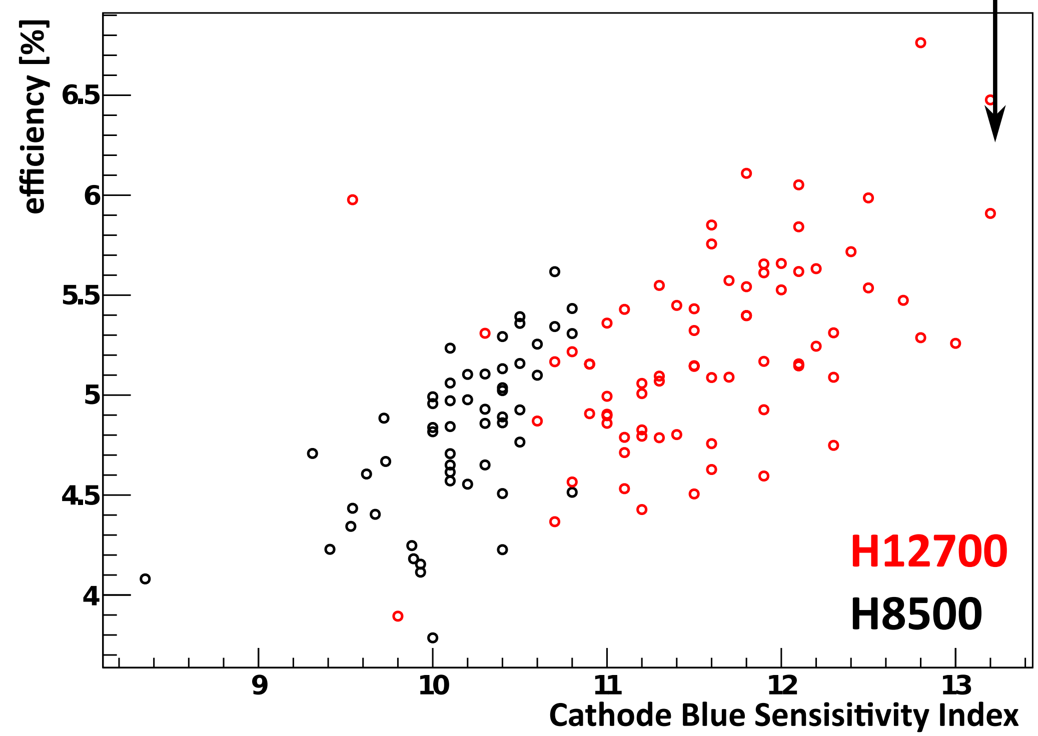
- H12700 has higher QE photocathode - better alkali metal application due the lower number of dynode stages
- H12700 has better secondary emission ratio for first dynode due to the higher supply voltage

H8500 to H12700 comparison

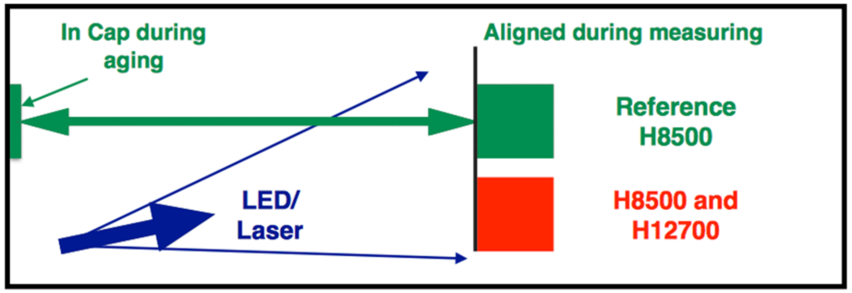




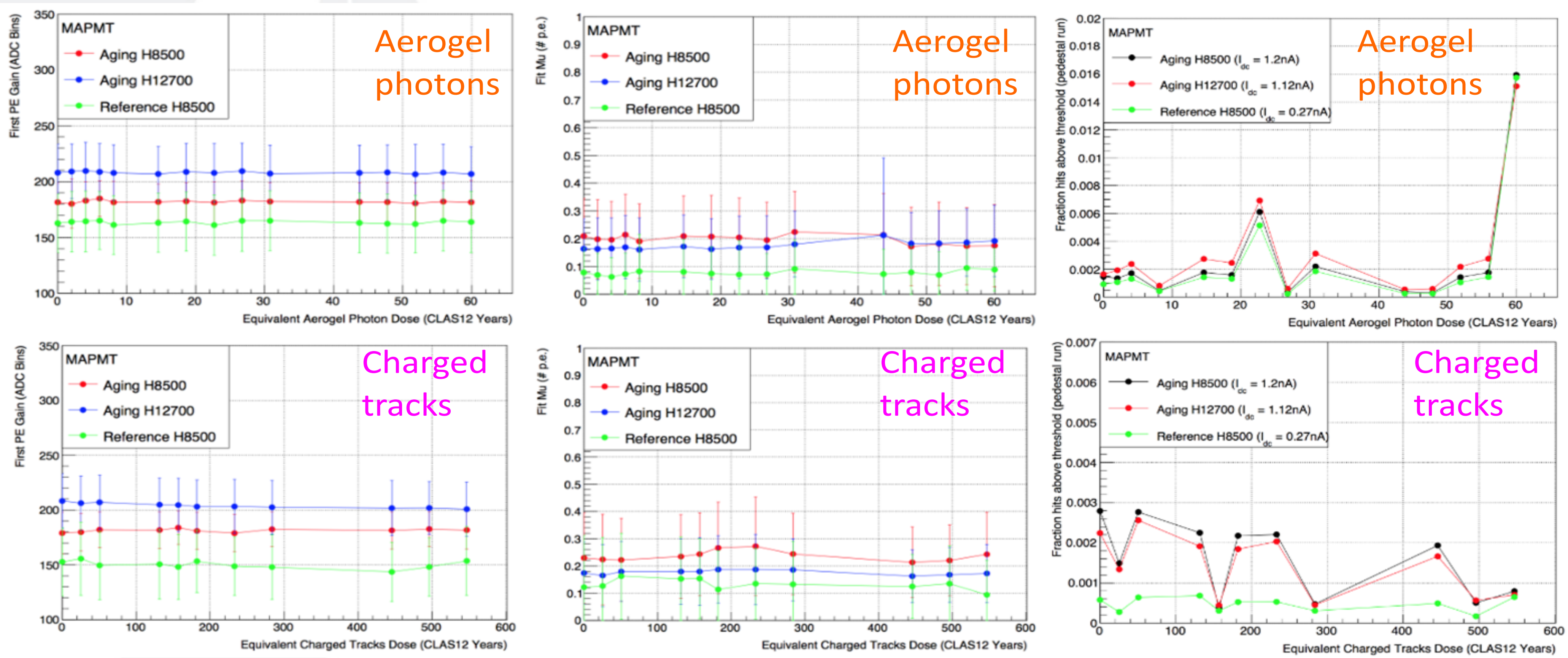
- Full face illumination
- The H12700 single photon detection capabilities are superior to H8500 and in agreement with specifications
- The SPE detection efficiency is better due to the decisively higher quantum efficiency



MAPMT Ageing Studies

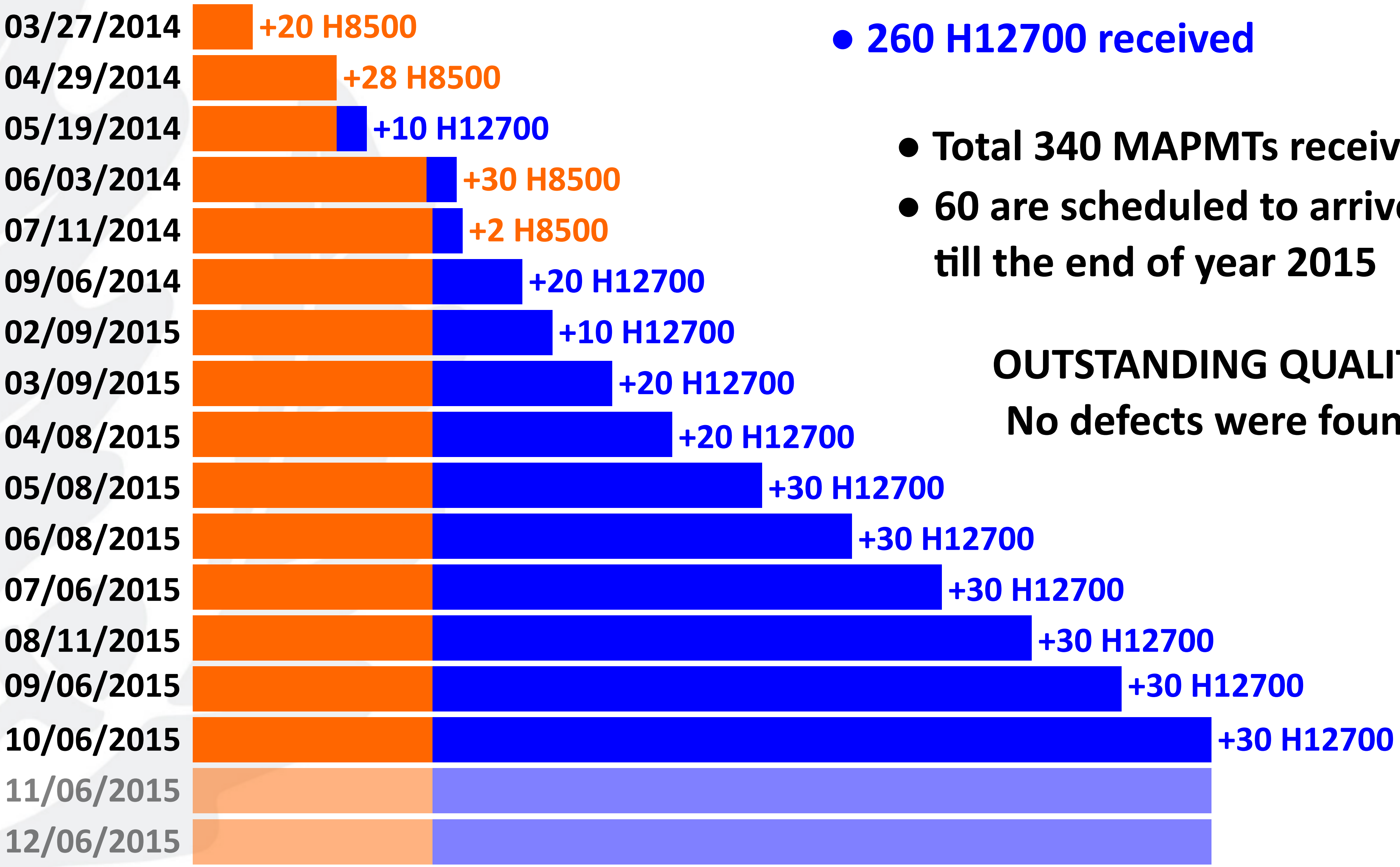


- Main ageing contributions from aerogel photons and charged tracks in MAPMT windows
- Ageing: by multi-p.e. LED to simulate charged tracks; by few p.e. laser to simulate aerogel photons
- Single p.e. laser measurements to monitor performance
- Estimated doses calculated from expected event rate of 50kHz (conservative numbers)



- No significant systematic effect in signal gain or mean number of p.e. detected
- Any variations comparable with reference PMT fluctuations
- No increase in dark currents observed during pedestal runs

MAPMT delivery timeline



- 80 H8500 received
- 260 H12700 received

- Total 340 MAPMTs received
- 60 are scheduled to arrive till the end of year 2015

OUTSTANDING QUALITY!
No defects were found!

Conclusion

- 80 H8500, 260 H12700 MAPMTs received: no defects were found
- The new H12700 MAPMTs have better performance
- The MAPMTs characterization setup is able to test 10 (12-14 if necessary) MAPMTs per day with high statistics and different configuration of high voltage supply and light intensities
- The model to describe SPE is implemented and found to be well suitable for description of MAPMTs SPE response
- The MAPMTs characterization measurements are in agreement with Hamamatsu specs
- We expect to receive remaining MAPMTs till the end of this year and we are ready for them....