Status of R11410

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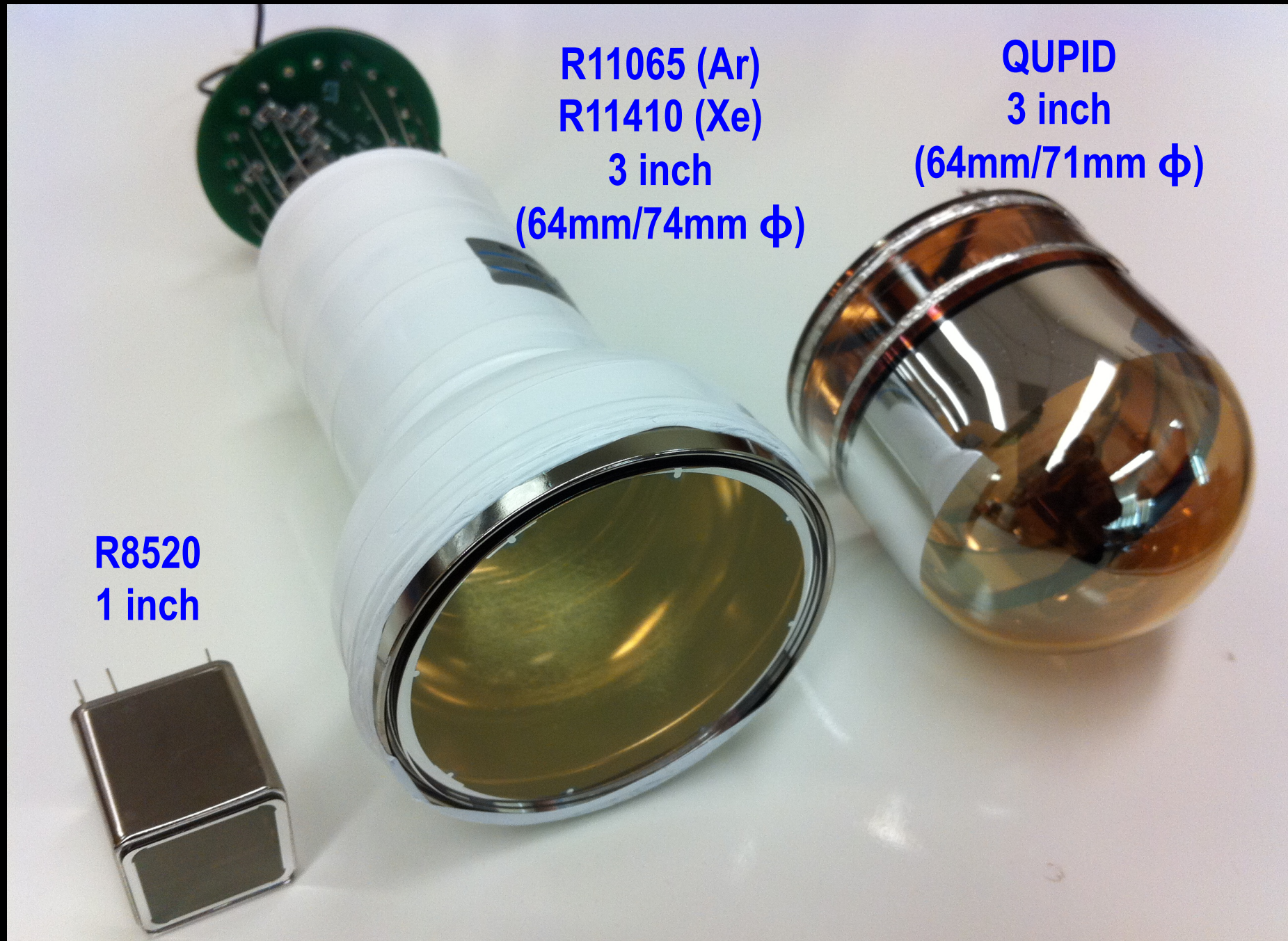
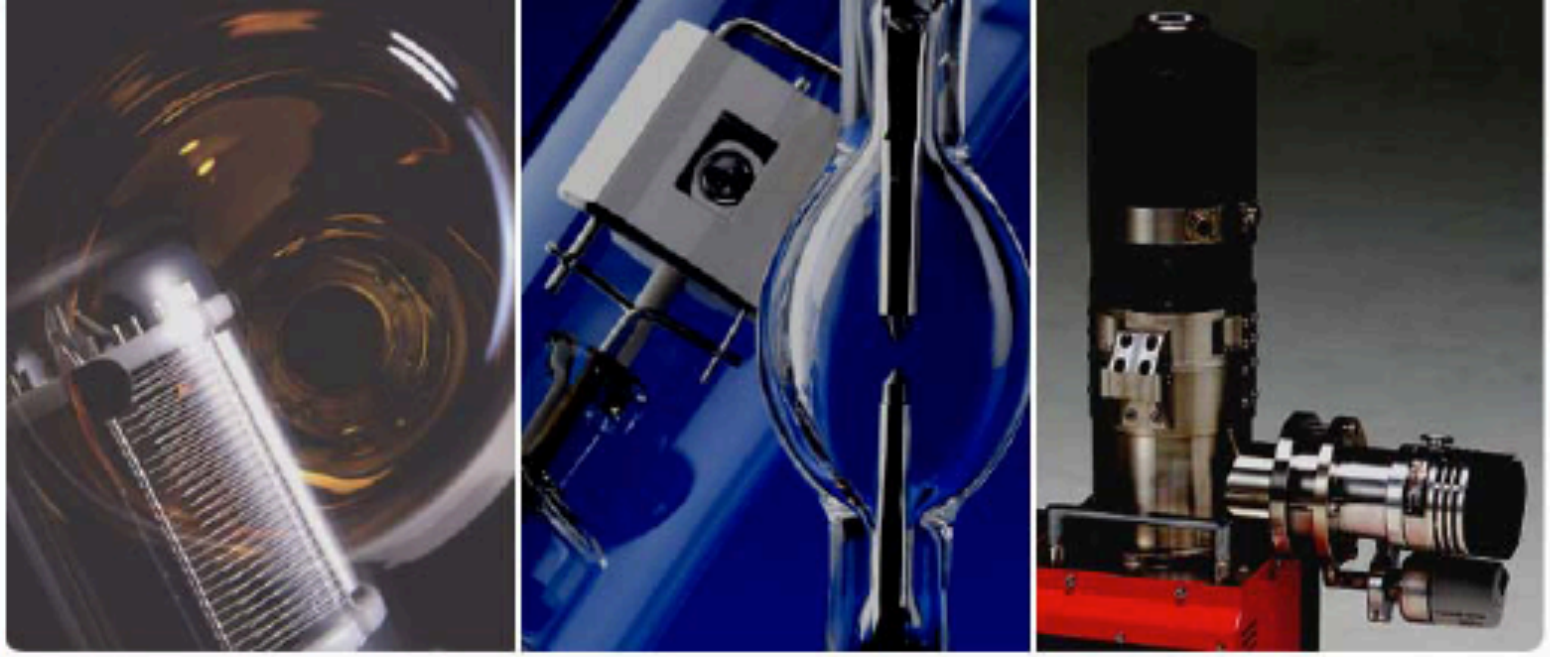
Specs from Hamamatsu

Comparison of Photon Detectors from Hamamatsu





HAMAMATSU

Development of PMT (R11410MOD) for Dark Matter Experiment

Mar.23.2010

Hamamatsu Photonics

Electrical Characteristics

Items	R11410	R11065
Suitable Experiment	**Liq. Xe**	**Liq. Ar**
Operating Temp.	**~ -110 deg C**	**~ -185 deg C**
Photocathode	Low Temp. Bialkali	Low Temp. Bialkali
Spectral response	160~650 nm	200~650 nm
QE at interest	**26% at 175 nm**	**25% at 420 nm**
Dynode Structure	Box & Line, 12-stage	
Gain	5E+06 typ. at 1500V	
Rise Time	5.5 ns typ.	
Transit Time	46 ns typ.	
TTS	6.5 ns typ.	
Pulse Linearity	20 mA typ. at +/- 2% dev.	

R11410-10 Official Data Sheet

HAMAMATSU

TENTATIVE DATA SHEET
Aug. 2011

PHOTOMULTIPLIER TUBE

R11410-10

For Low Temperature Operation down to -110 deg. C
Special Bialkali Photocathode (Bialkali LT), Low Radioactivity, 12-stage
76 mm (3 Inch) Diameter, Head-on Type, Synthetic Silica, Ceramic Stem Type

General

Parameter		Description / Value	Unit
Spectral response		160 to 650	nm
Wavelength of Maximum Response		420	nm
Window material		Synthetic silica	-
Photocathode	Material	Bialkali	-
	Minimum Effective Area	φ64	mm
Dynode	Structure	Box & Linear-focused	-
	Number of Stages	12	-
Suitable Socket		E678-20B (supplied)	-
Operating Ambient Temperature		-110 to +50	deg. C
Storage Temperature		-110 to +50	deg. C

R11410-10 Official Data Sheet

Maximum Ratings (Absolute Maximum Values)

Parameter		Value	Unit
Supply voltage	Between Anode and Cathode	1750	V
	Between Anode and Last Dynode	300	V
Average Anode Output		0.1	mA
Pressure-resistance (Gauge)		0.2	Mpa

Characteristics at 25 deg. C

Parameter		Min.	Typ.	Max.	Unit
Cathode Sensitivity	Luminous (2856K)	-	90	-	uA/lm
	Quantum Efficiency at 175 nm	-	26	-	%
	Blue Sensitivity Index (CS 5-58)	-	10	-	-
Anode Sensitivity	Luminous (2856K)	-	450	-	A/lm
Gain		-	5.0×10^6	-	-
Anode Dark Current (after 30 min. storage in darkness)		-	10	100	nA
Time Response	Anode Pulse Rise Time	-	5.5	-	ns
	Electron Transit Time	-	46	-	ns
	Transit Time Spread (FWHM)	-	6.5	-	ns
Pulse Linearity at +/-2% deviation		-	20	-	mA

NOTE : Anode characteristics are measured with a voltage distribution ratio and supply voltage shown below :

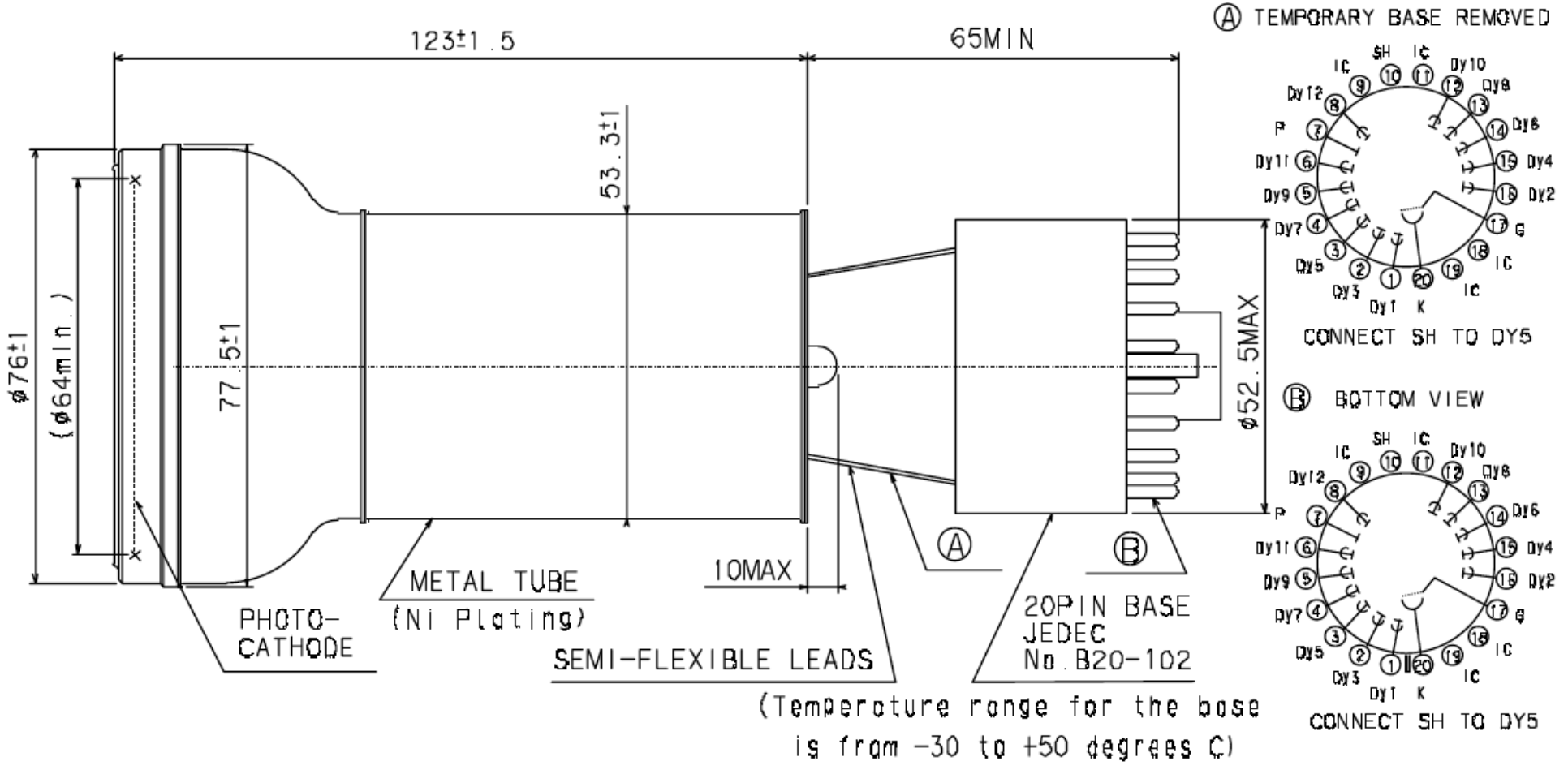
Voltage Distribution Ratio and Supply Voltage

Electrodes	K	Dy1/G	Dy2	Dy3	Dy4	Dy5	Dy6	Dy7	Dy8	Dy9	Dy10	Dy11	Dy12	P
Ratio	4	1.5	2	1	1	1	1	1	1	1	1	2	1	

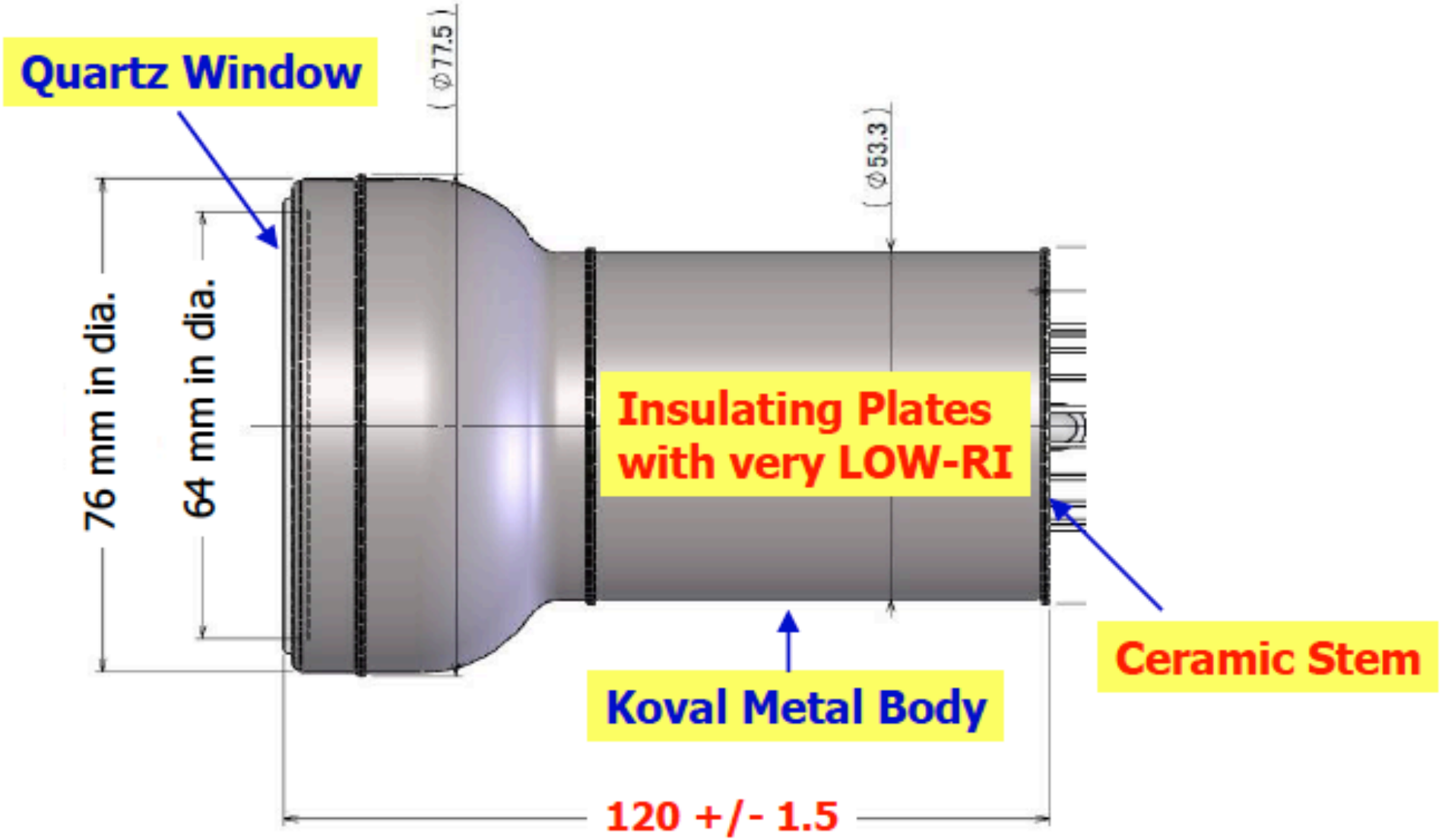
Supply Voltage : 1500 V K : Cathode G : Grid Dy : Dynode P : Anode

PMT Structure

Mechanical Structure

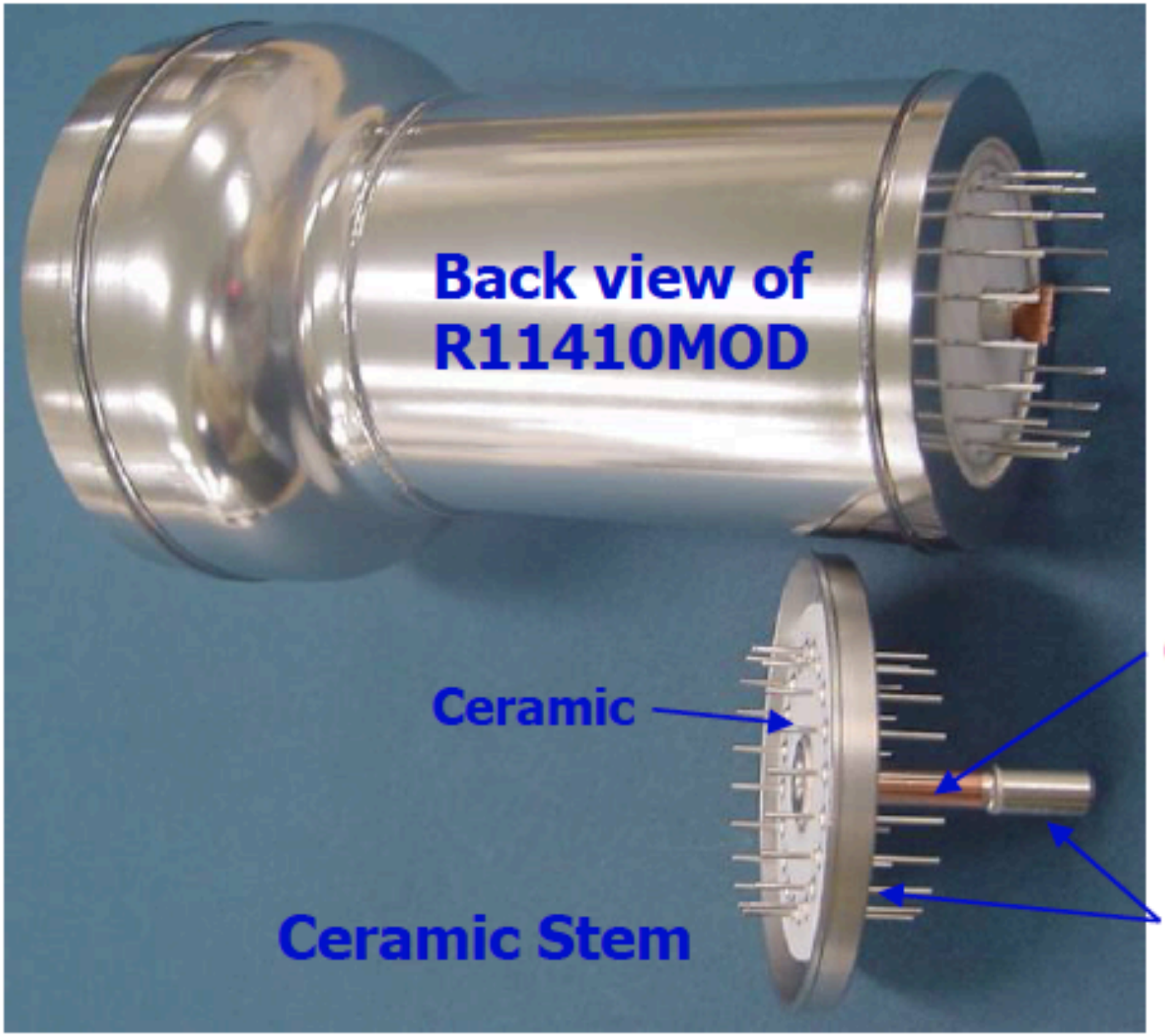


Development for R11410MOD



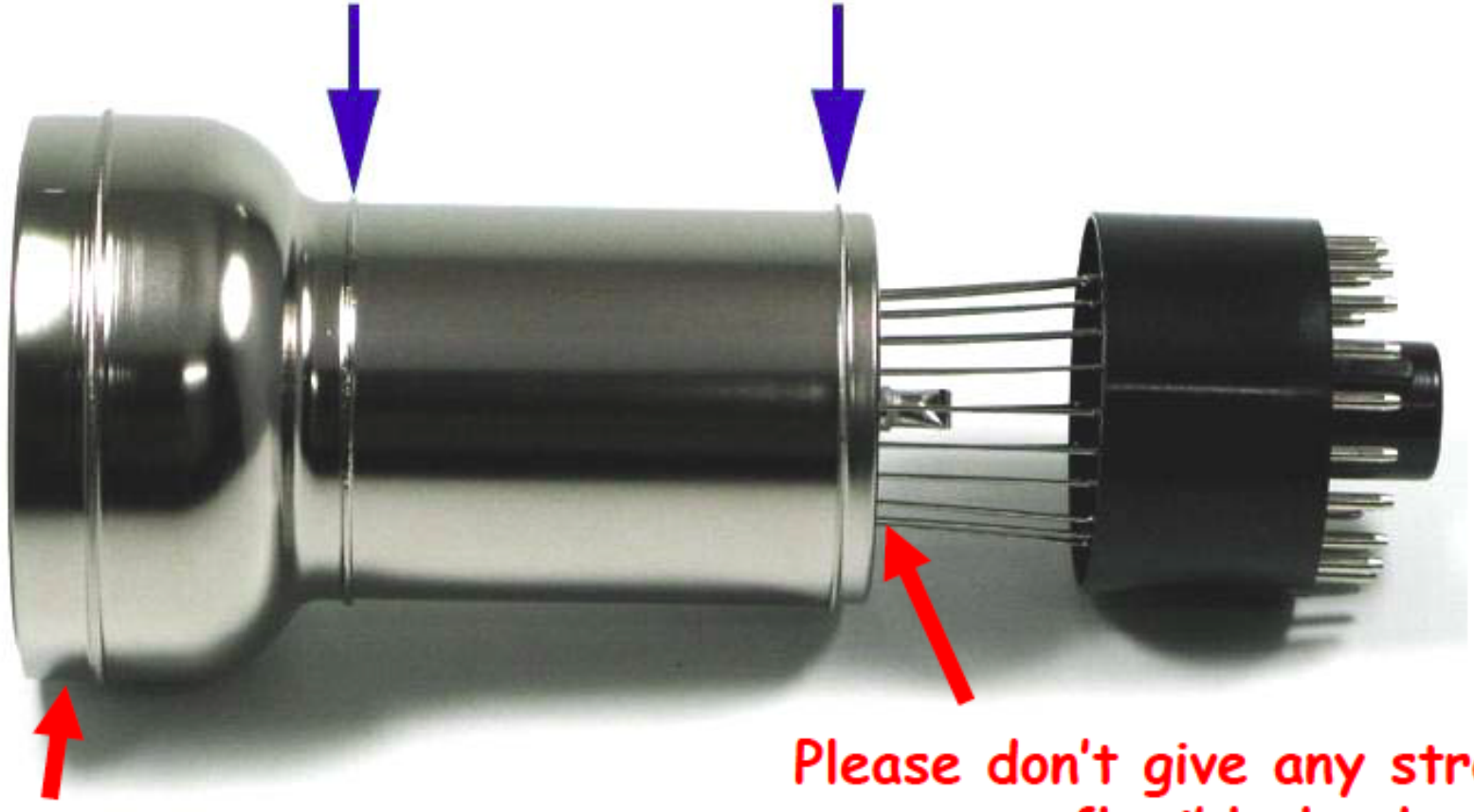
Comparison between 2 Types

Picture of R11410MOD (2)



How to support R11410

Please use these points for support of the PMT.



Top part is not suitable for supporting, because it might result in air leakage.

Please don't give any strong stress to flexible leads. It may damage the joint with stem plate and metal lead.

Radioactivity

RI Level for R11410MOD

Estimated RI level

< Unit : mBq/PMT >

Materials	Weight (g)	40K	U	Th	Co60	Sub Total
Quartz Faceplate	35	0.0	0.2	0.4	0.1	0.7
Metal Bulb	95	5.7	2.9	1.0	3.5	13.1
Stem (ceramic)	25	0.0	0.0	0.7	5.5	6.2
Insulating Plates	16	0.0	0.1	0.2	0.0	0.3
Electrodes	31	0.0	0.1	0.0	0.0	0.1
Total	202	5.7	3.3	2.3	9.1	20.4

Expected RI level : 10~30 mBq/PMT

QUPID gamma background

- Energy range [2 - 20] keVee
- Multiple hit cut
- S2/S1 cut at 99% rejection

Requirement: < 0.1 γ/y in [2 - 20] keVee from the QUPIDs

				QUPID	3" PMT R11410-MOD		
	5 cm (1.5 t)	10 cm (1.1 t)	15 cm (0.74 t)	GATOR	GATOR	Hamamatsu	SOLO
	mBq	mBq	mBq	mBq	mBq	mBq	mBq
U	0.5	5.5	54.5	<17	<95	3.3	0.4
Th	0.4	3.6	36.4	0.4(2)	<2.6	2.3	2.7
K	2.3	18	138.5	5.5(6)	13.4	5.7	8.3
Co	0.2	1.2	8.2	<0.18	3.5	9.1	2

- U contamination main issue
  => to keep 1 ton target mass U must be kept at the level of 5 mBq
- Other elements satisfy the specs for 1 ton target mass

QUPID gamma background

- Energy range [2 - 20] keVee
- Multiple hit cut
- S2/S1 cut at 99% rejection

	requirement (< 1 evt/y in [2.45 - 2.5] MeVee)			QUPID	3" PMT R11410-MOD		
	Natural Xe						
	10 cm (1.1 ton)	20 cm (0.46 t)	30 cm (0.13 t)	GATOR	GATOR	Hamamatsu	SOLO
	mBq	mBq	mBq	mBq	mBq	mBq	mBq
U	0.01	0.025	0.06	<17	<95	3.3	0.4
Th	0.1	0.5	5	0.4(2)	<2.6	2.3	2.7
Co	0.001	0.006	0.03	<0.18	3.5	9.1	2

	requirement (< 1 evt/y in [2.45 - 2.5] MeVee)			QUPID	3" PMT R11410-MOD		
	Enriched Xe						
	10 cm (1.1 ton)	20 cm (0.46 t)	30 cm (0.13 t)	GATOR	GATOR	Hamamatsu	SOLO
	mBq	mBq	mBq	mBq	mBq	mBq	mBq
U	0.1	0.25	0.6	<17	<95	3.3	0.4
Th	1	5	50	0.4(2)	<2.6	2.3	2.7
Co	0.01	0.06	0.3	<0.18	3.5	9.1	2

QUPID neutron background

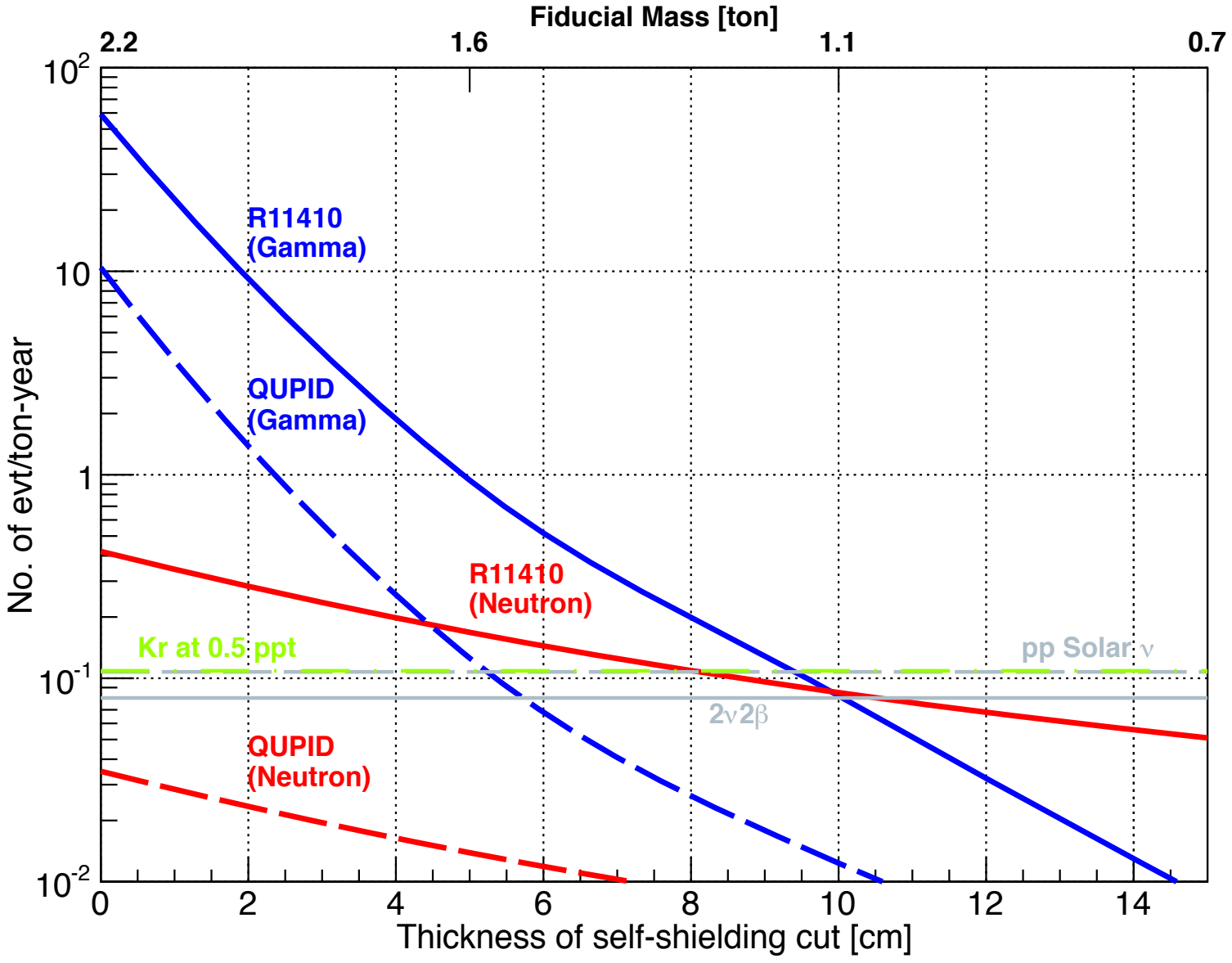
- **SOURCES-4C** assuming Th at 0.4(2) mBq
  - About a factor 6 lower than GATOR upper limit
- **Geant4**
  - Energy range [5 - 40] keVnr
  - Multiple hit cut
  - Assuming 2.7 mBq U and 0.6 mBq Th

Requirement: < 0.1 n/y in [5 - 40] keVnr from the QUPIDs

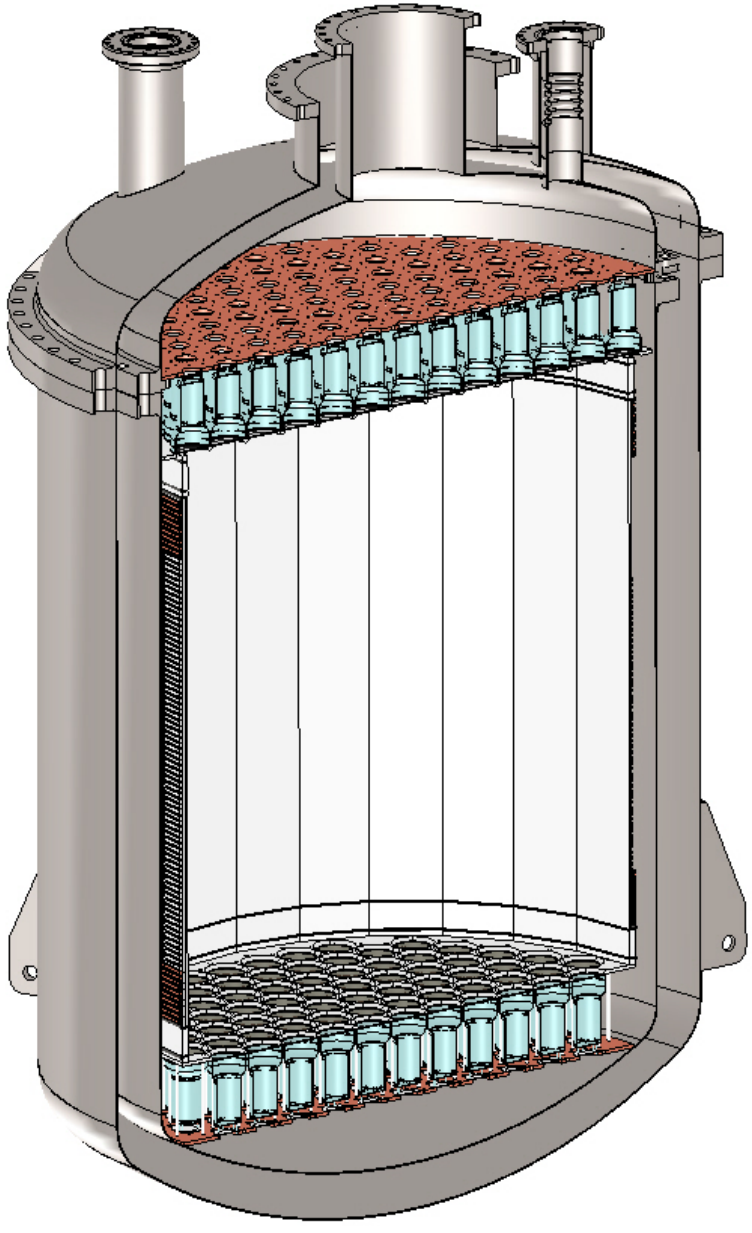
			QUPID	3" PMT R11410-MOD		
	10 cm (1.1 t)	20 cm (0.5 t)	GATOR	GATOR	Hamamatsu	SOLO
	mBq	mBq	mBq	mBq	mBq	mBq
U	9	27	<17	<95	3.3	0.4
Th	2	6	0.4(2)	<2.6	2.3	2.7

- Allowing 0.1 n/y in the signal phase space: U activity must be reduced to 9 mBq while Th already satisfy the specifications

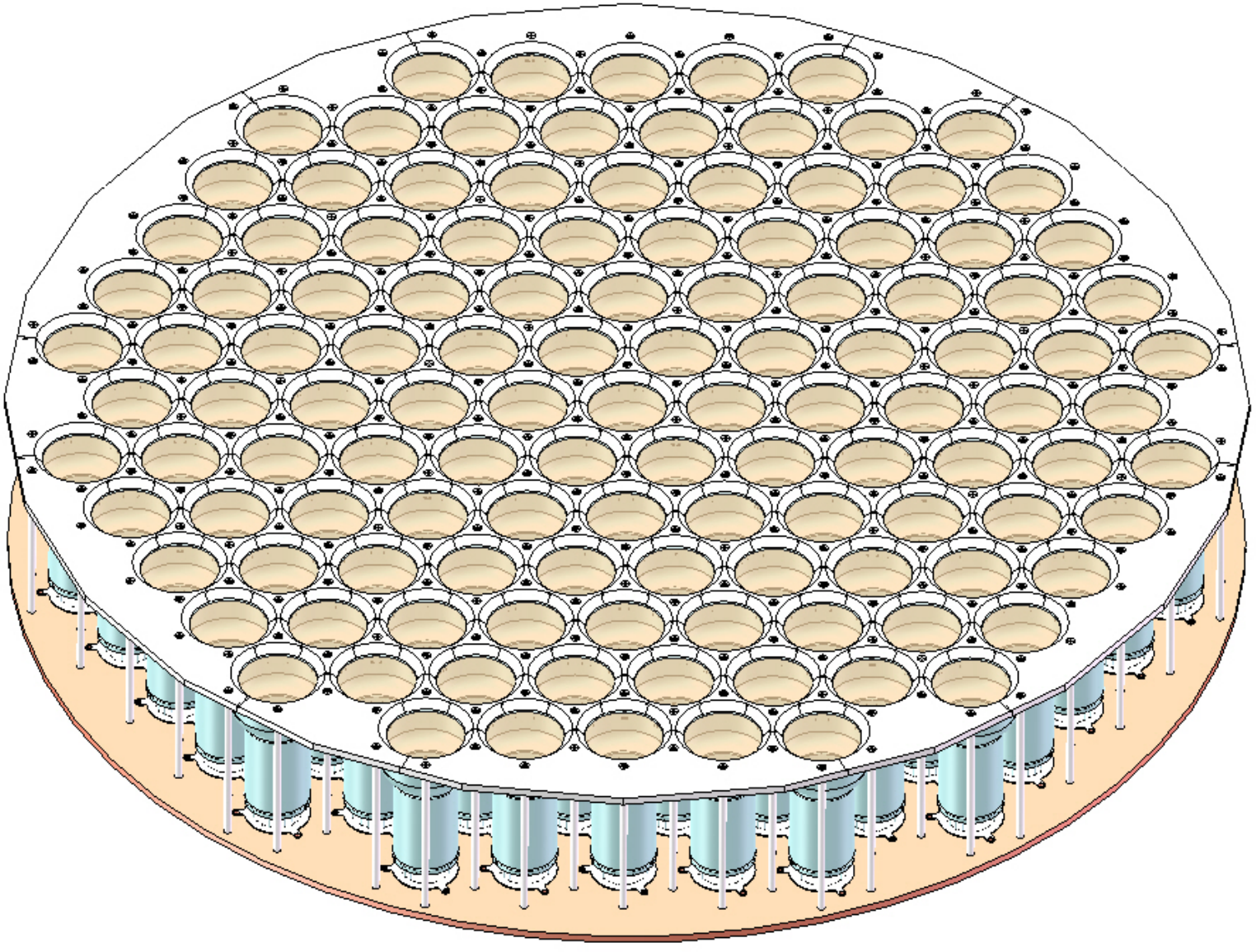
Photo-sensor background vs. fiducial



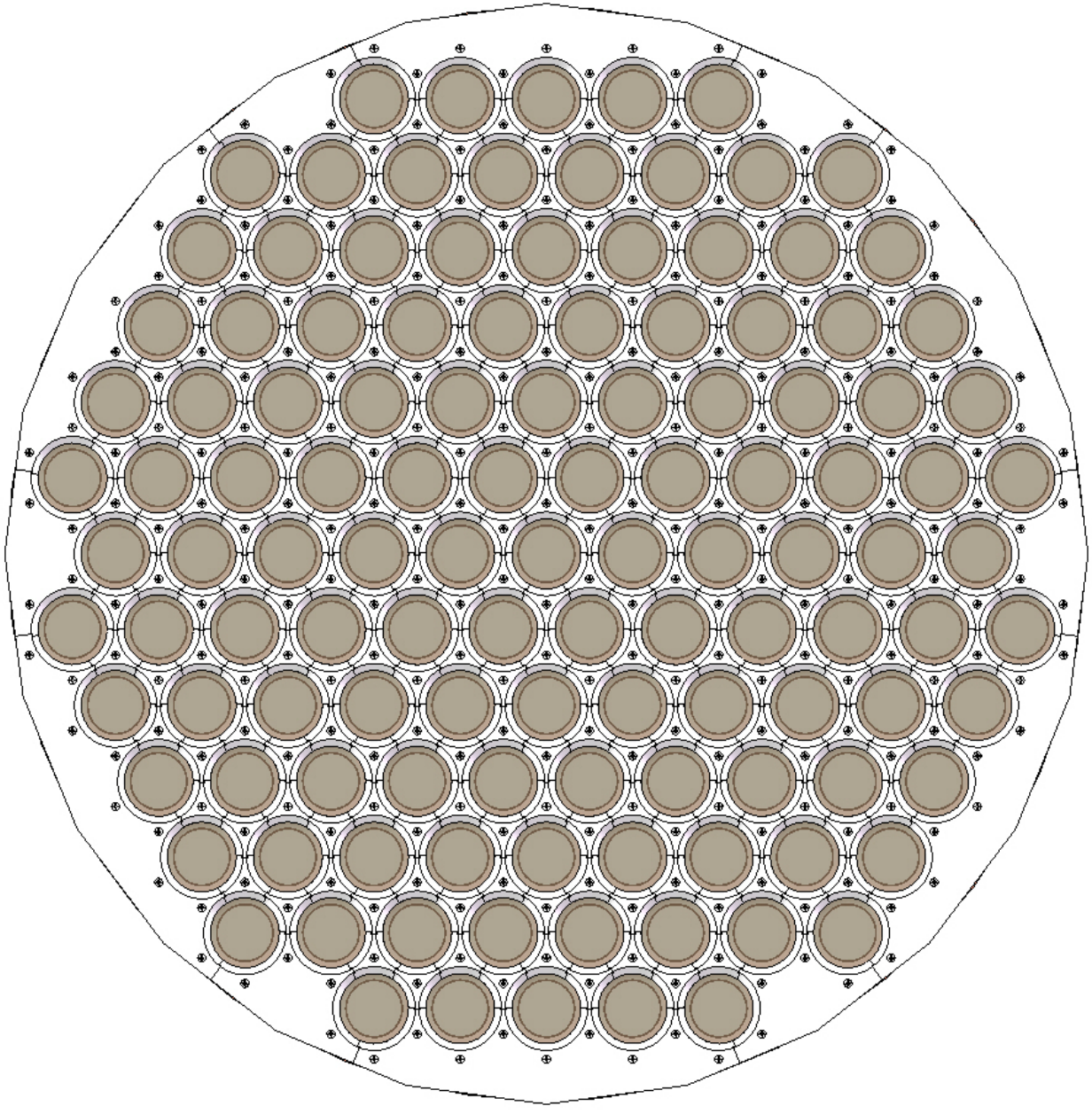
Mechanical Support



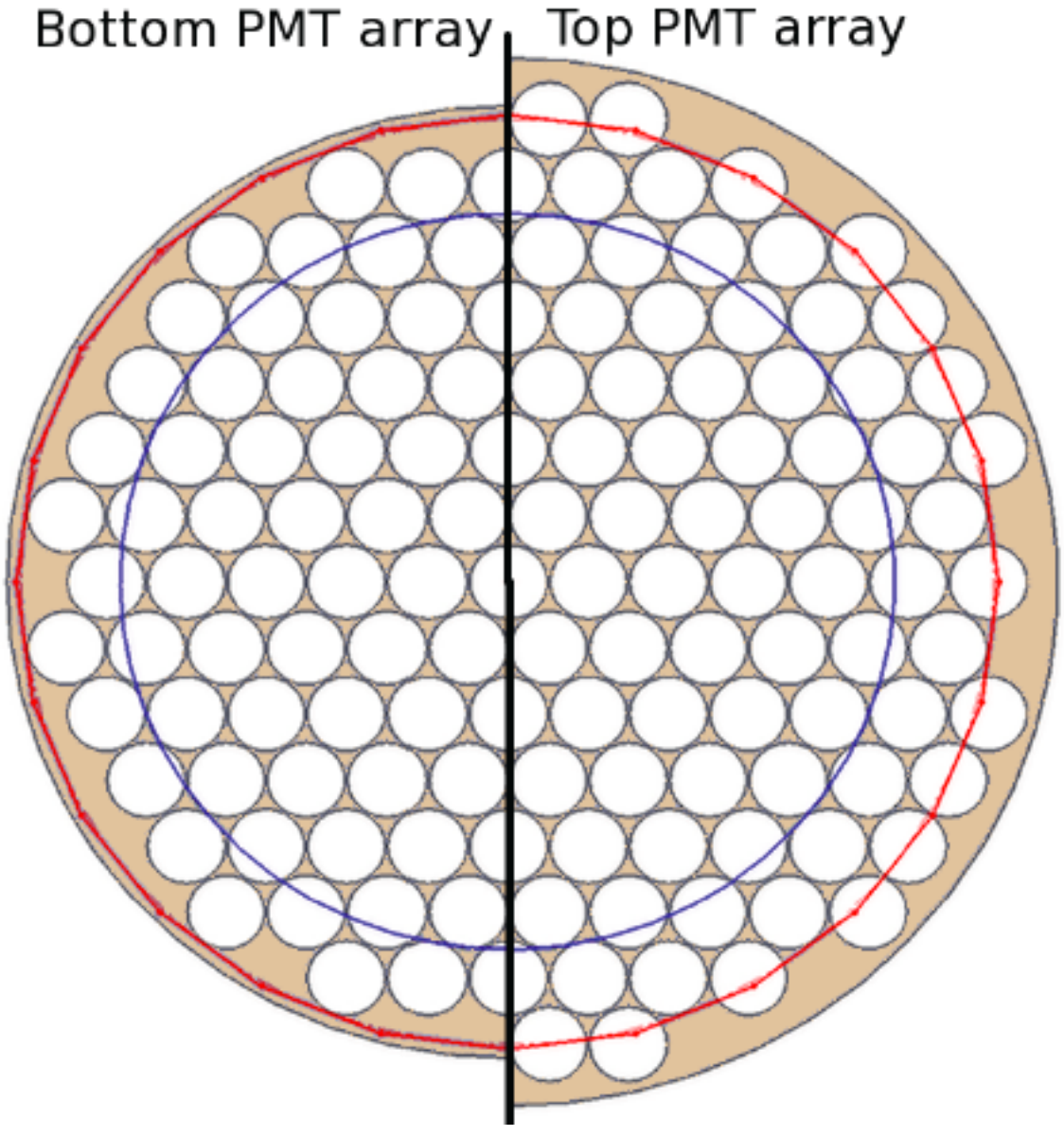
XENON1T PMT Array



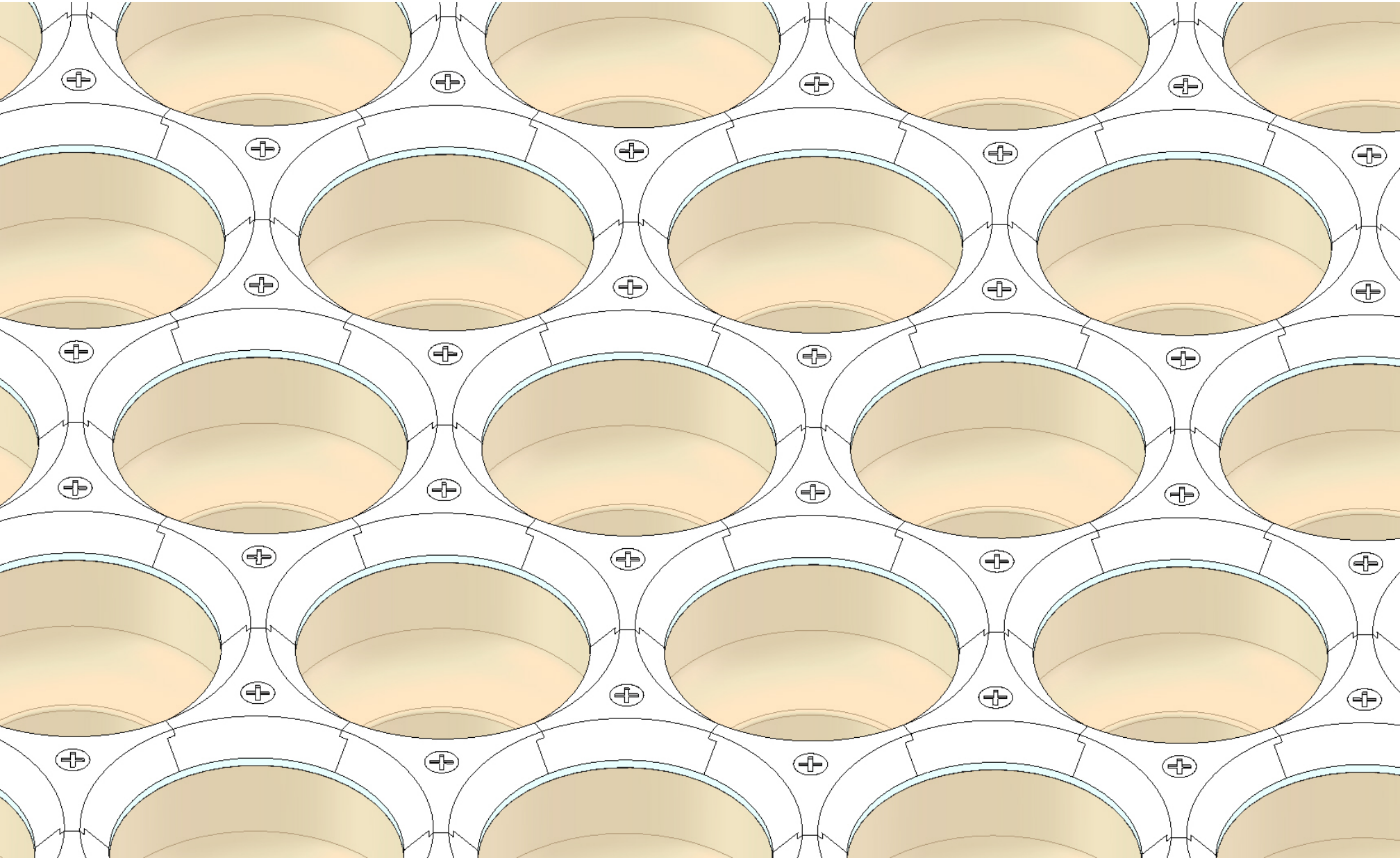
XENON1T PMT Array



XENON1T PMT Array

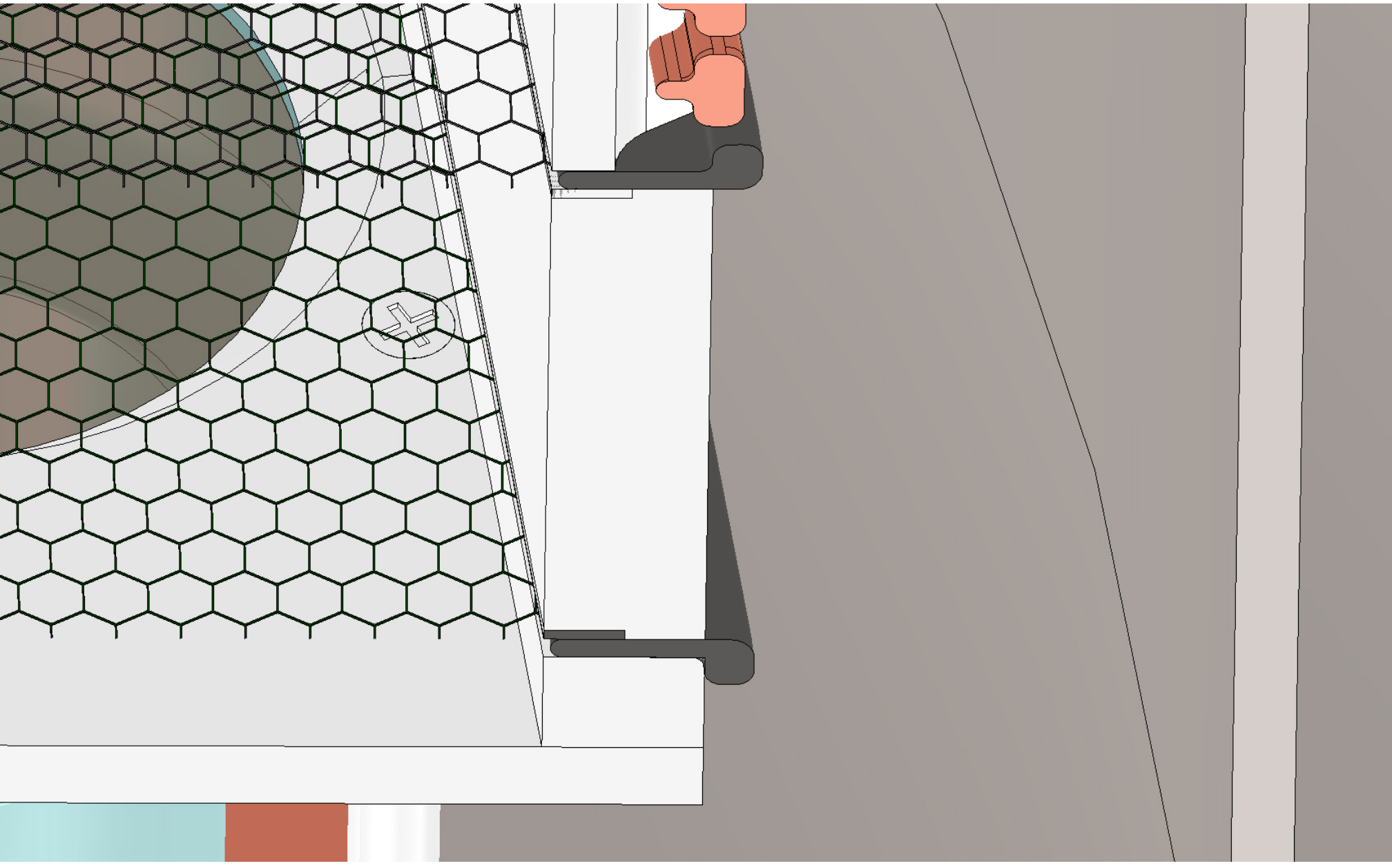


XENON1T PMT Array

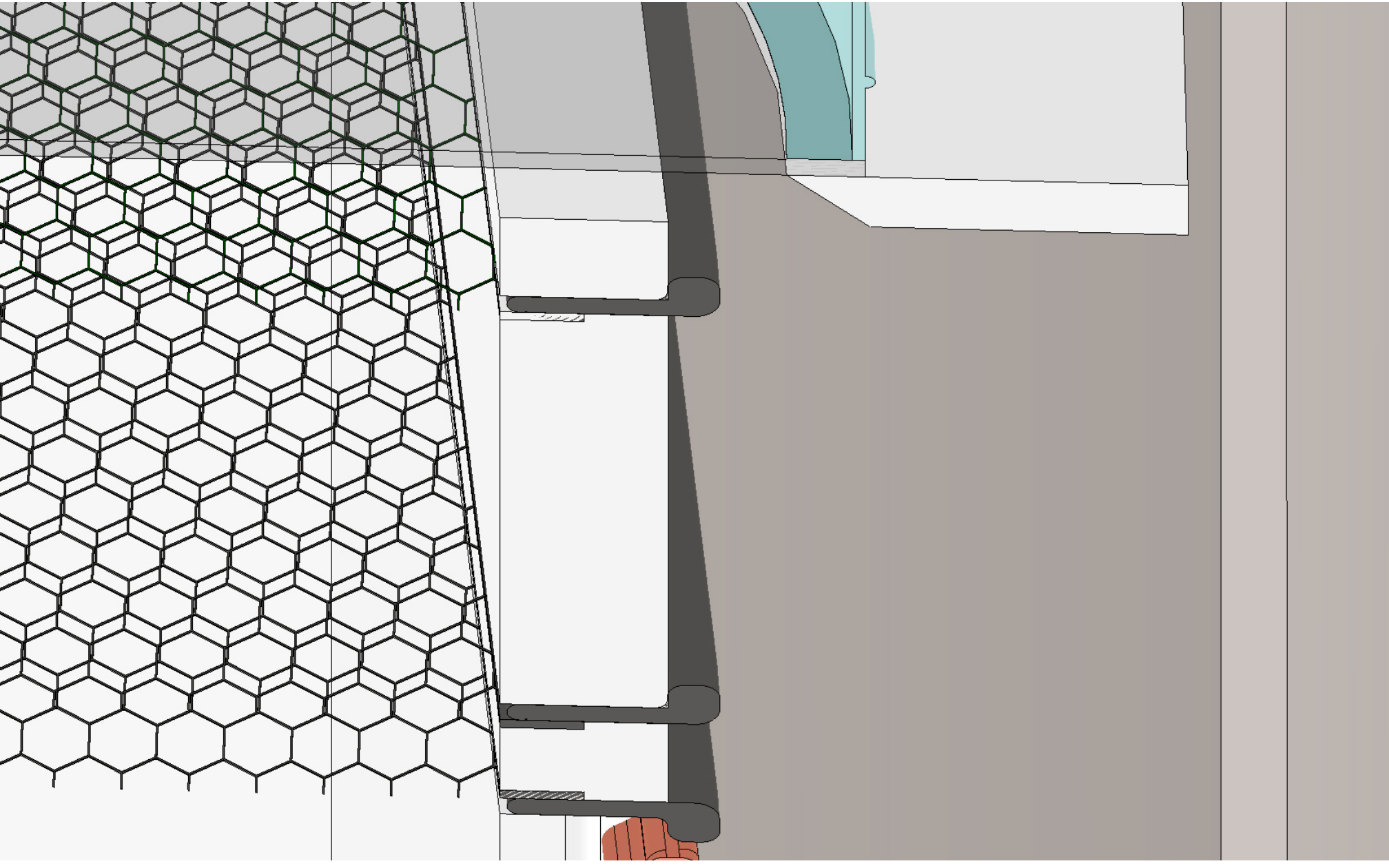


XENON1T PMT Array

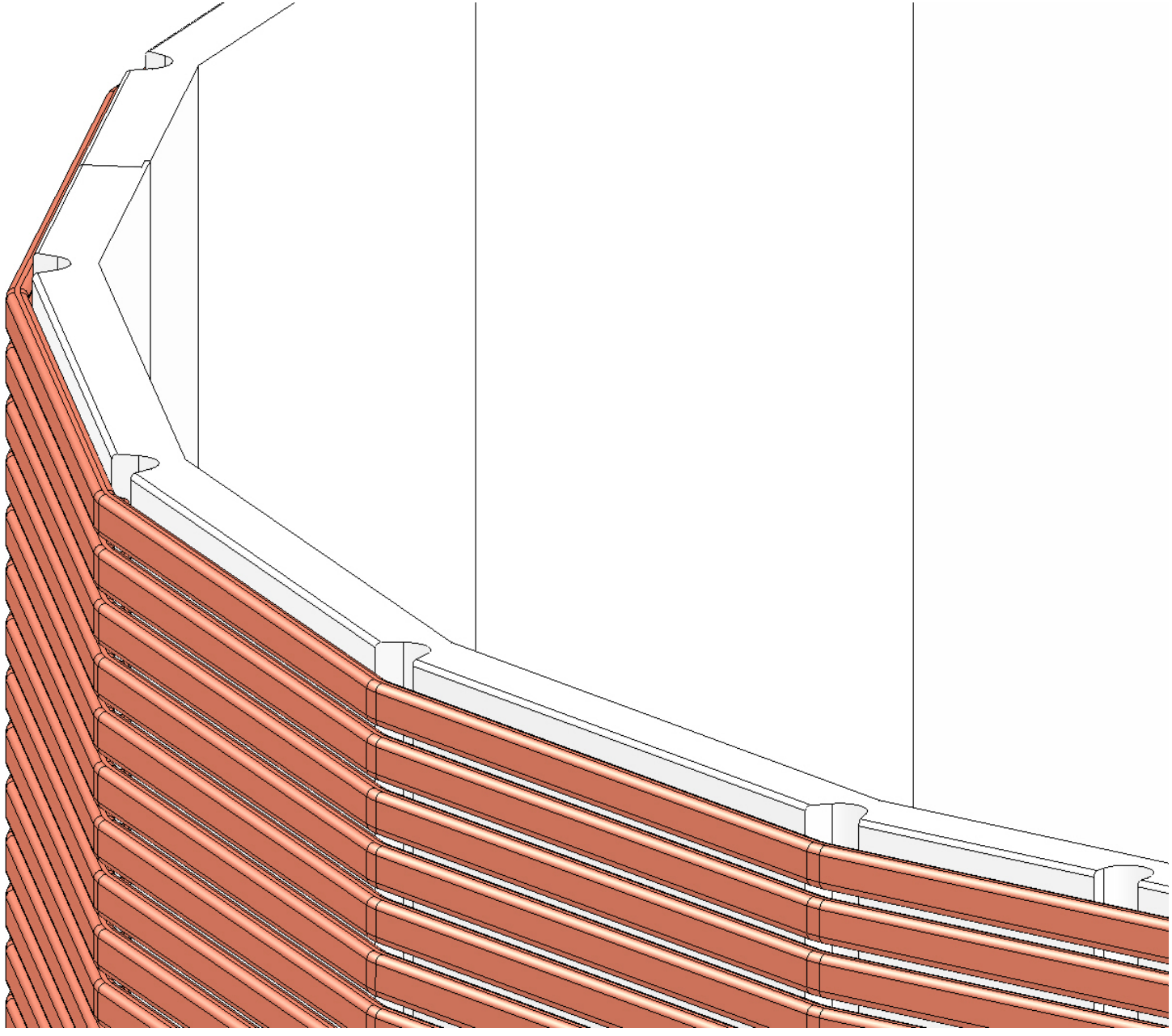
XENON1T TPC



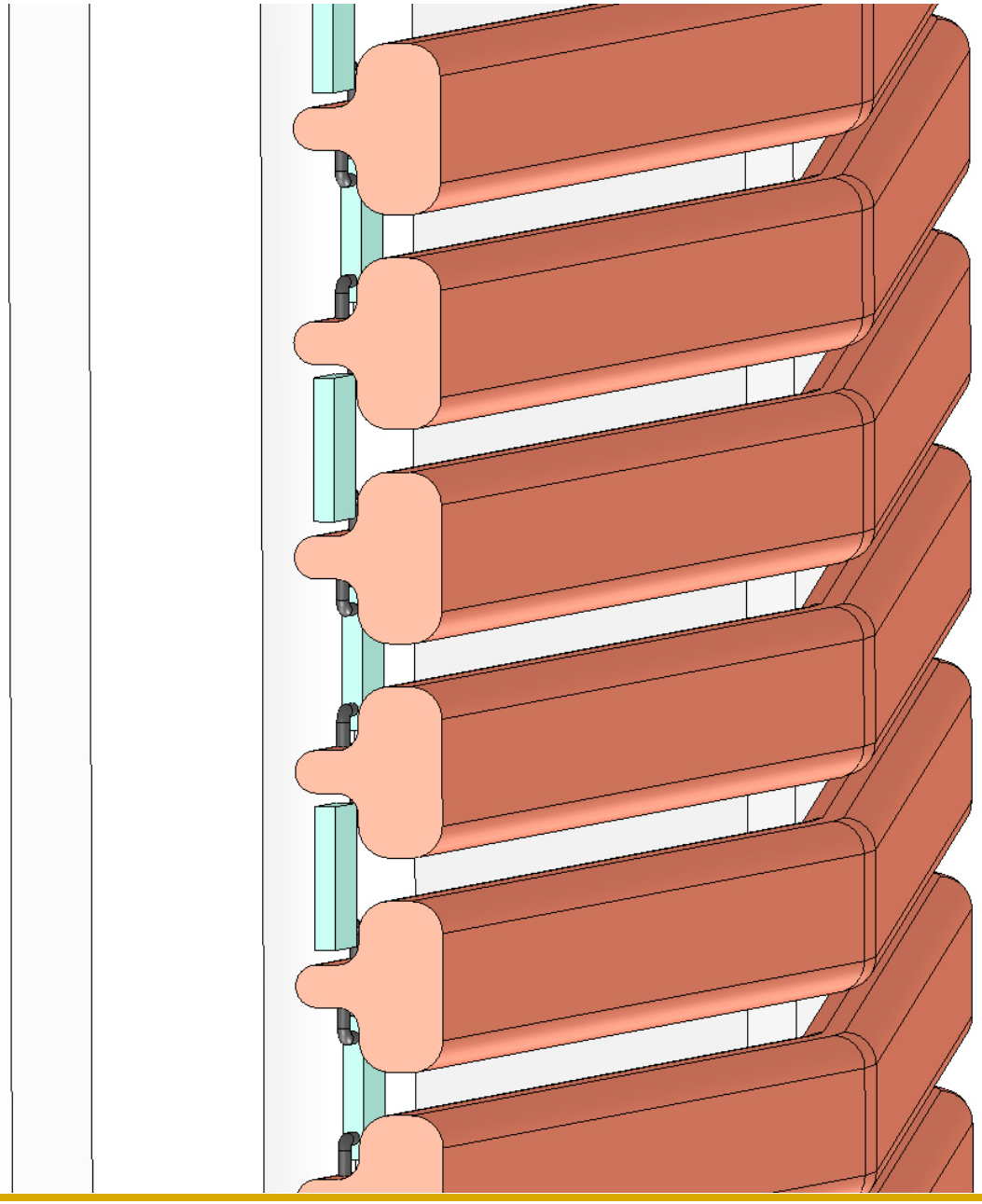
XENON1T TPC



XENON1T TPC

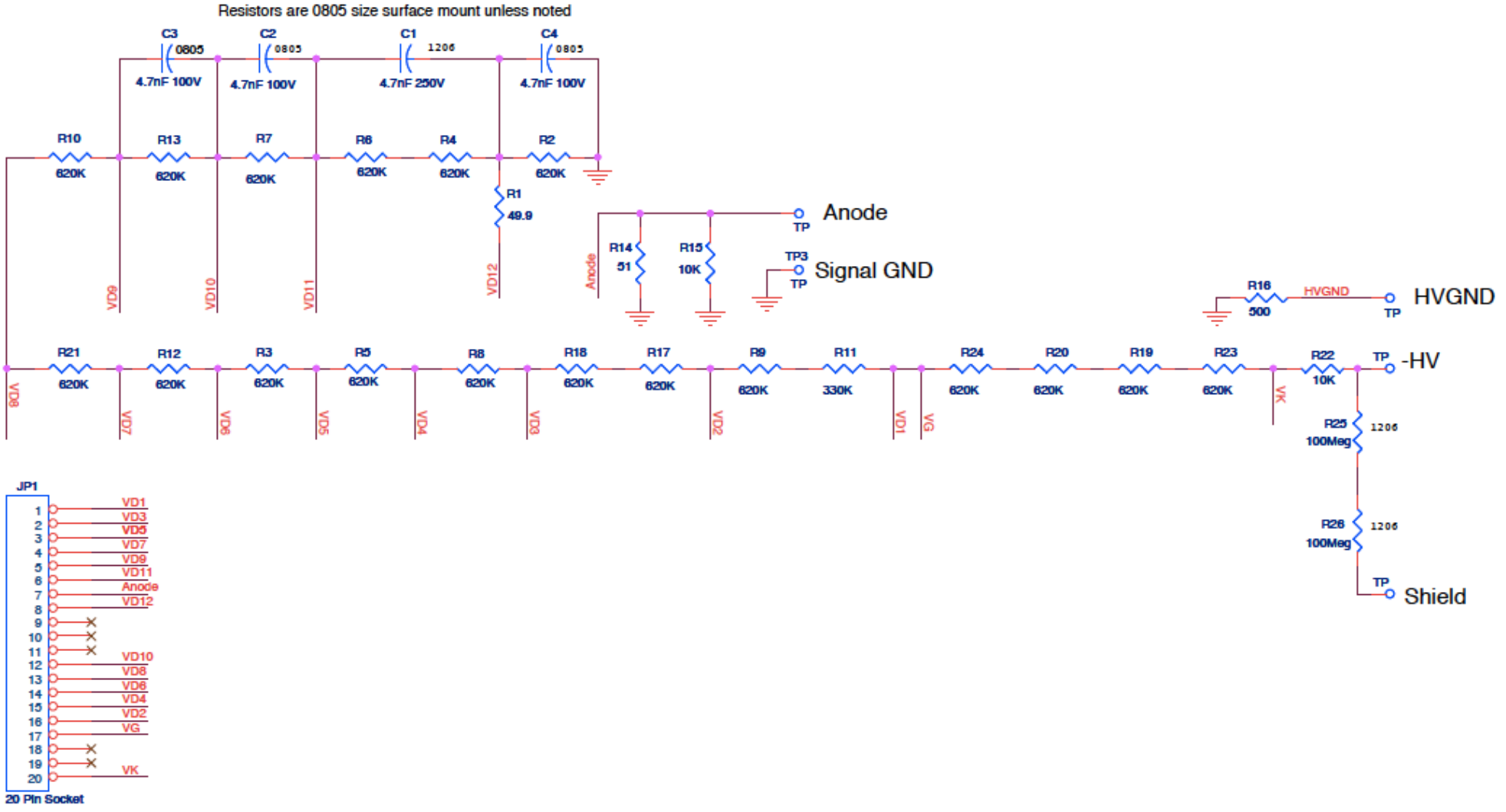


XENON1T TPC

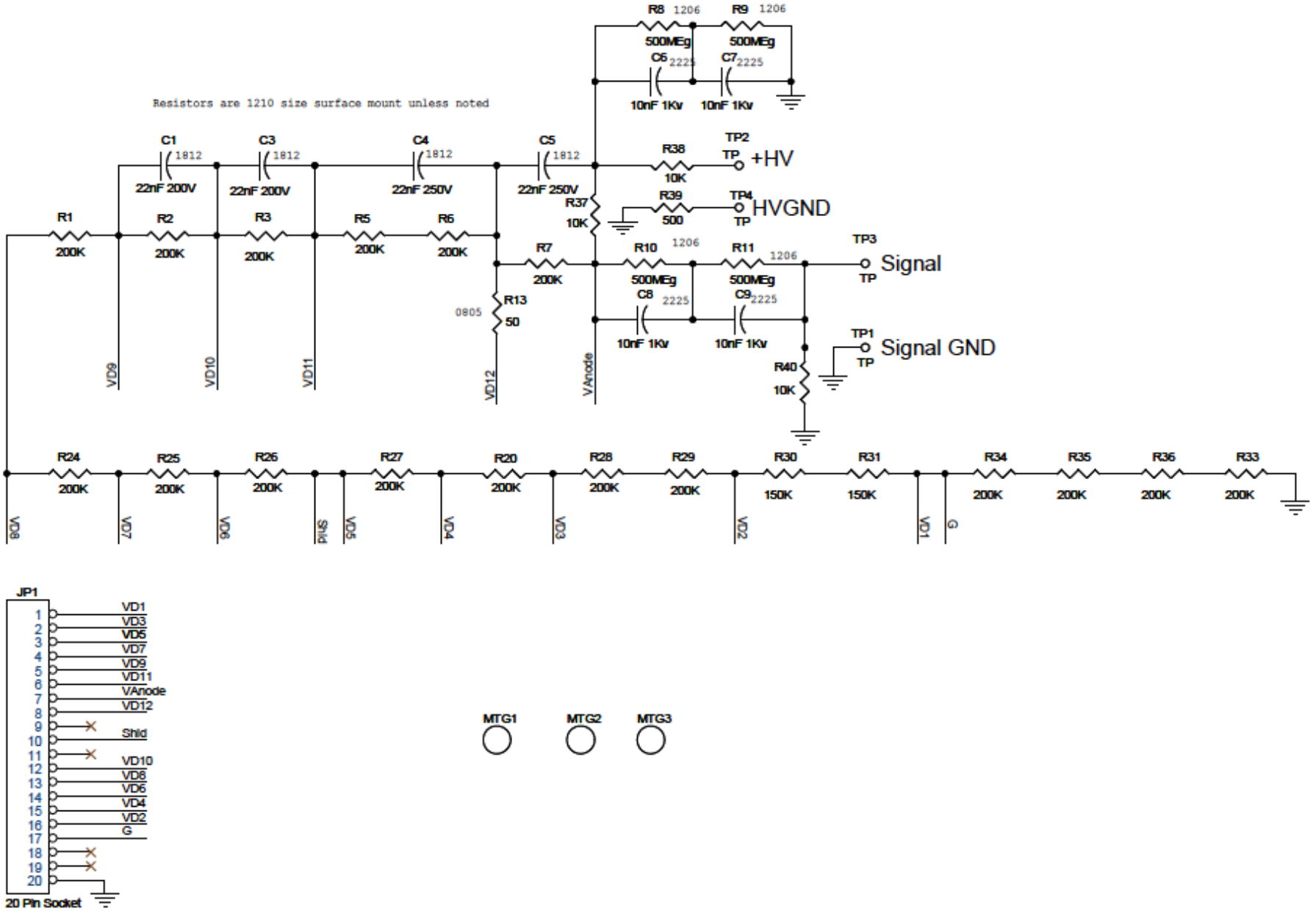


Base Design

Negative Base



Positive Base

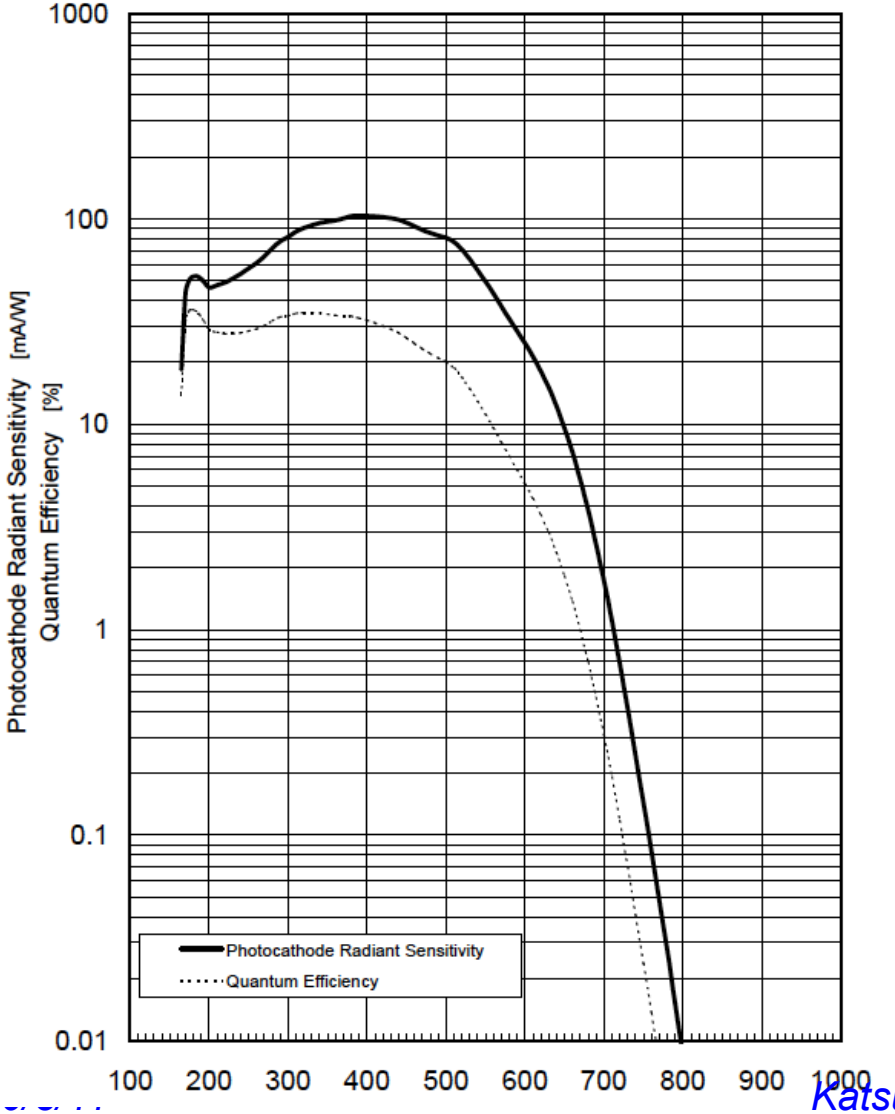


Quantum Efficiency

QE of ZK6340 and KA0001

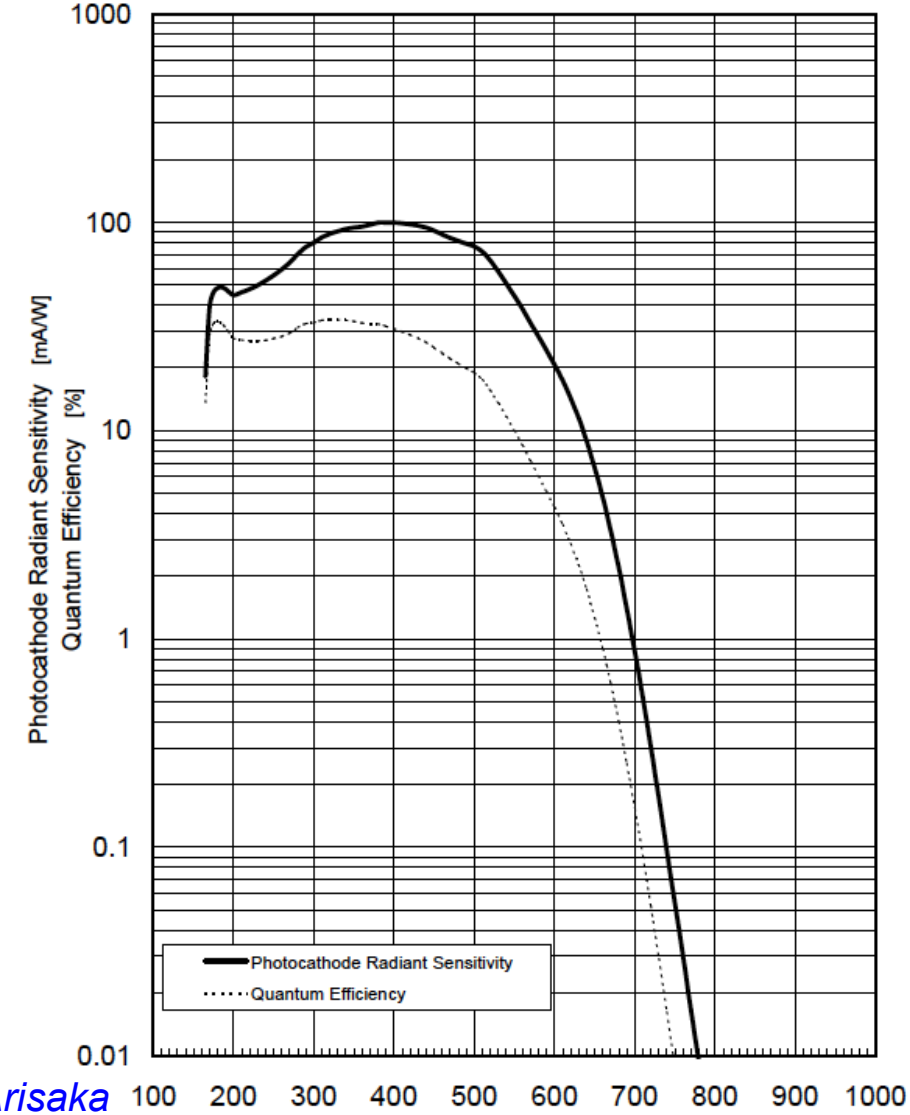
Spectral Response Characteristics

Tube Type	R11410-10	Max. Q.E.	34.9 %
Serial No.	ZK6340	Wavelength of max.	320 nm
Date	Aug.24, 2011		
Tested by	H.OISHI		
Note			

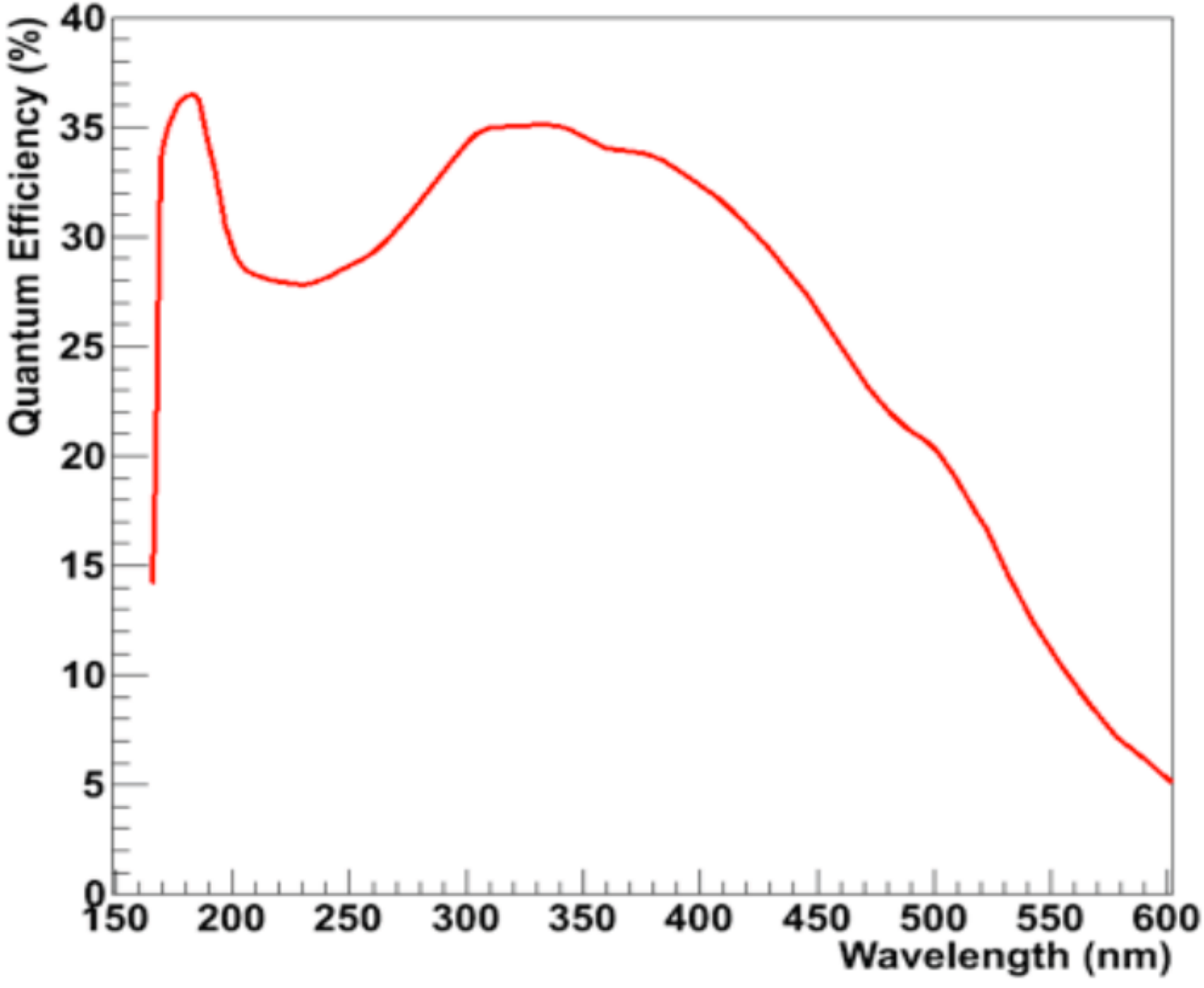


Spectral Response Characteristics

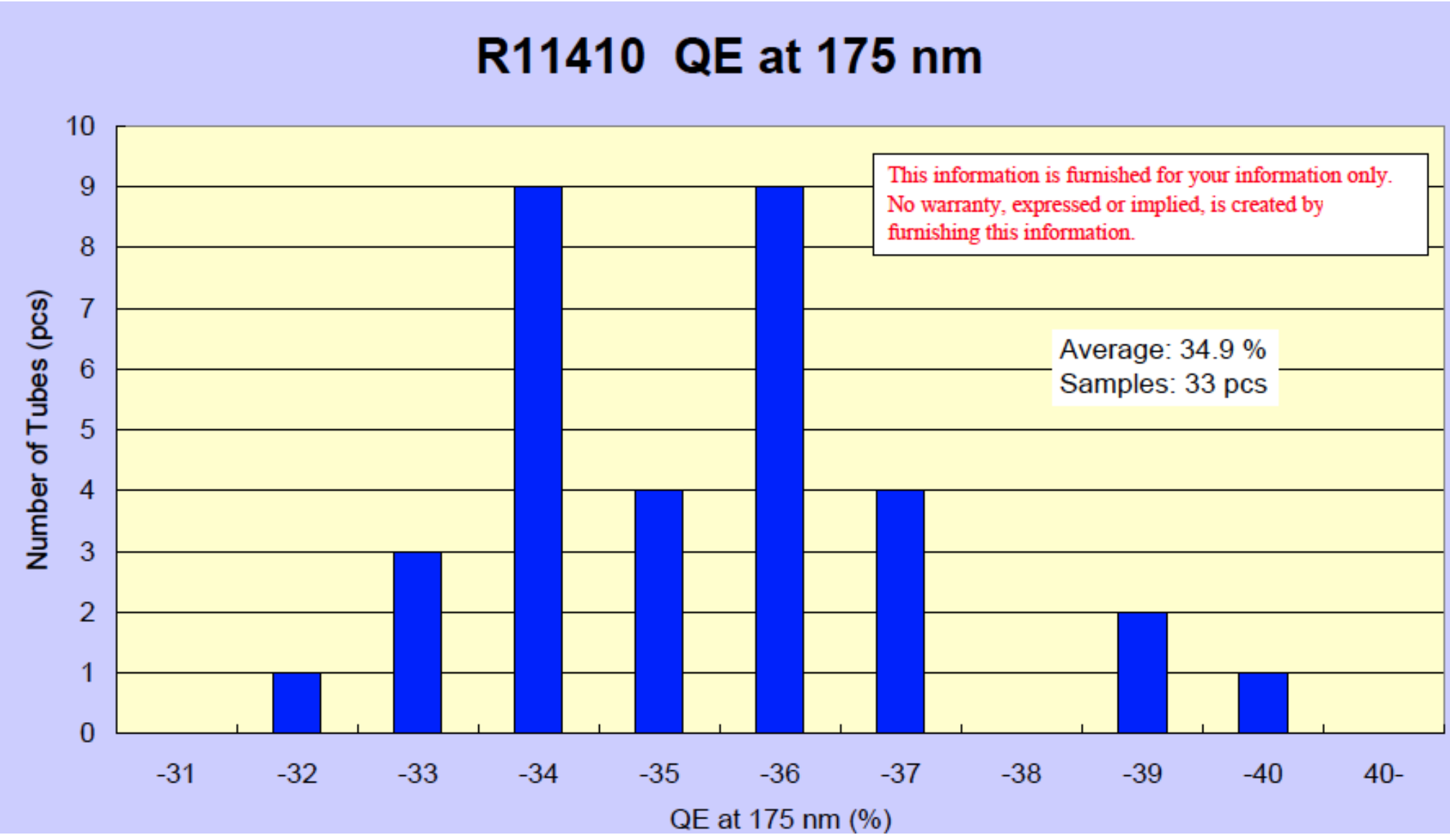
Tube Type	R11410-10	Max. Q.E.	34.0 %
Serial No.	KA0001	Wavelength of max.	320 nm
Date	Aug.24, 2011		
Tested by	H.OISHI		
Note			



QE of R11410


Quantum Efficiency (%)
40
35
30
25
20
15
10
5
0
150
200
250
300
350
400
450
500
550
600
Wavelength (nm)

R11410 QE Distribution



Gain, Dark current vs. HV

Two R11410-10 shipped to UCLA

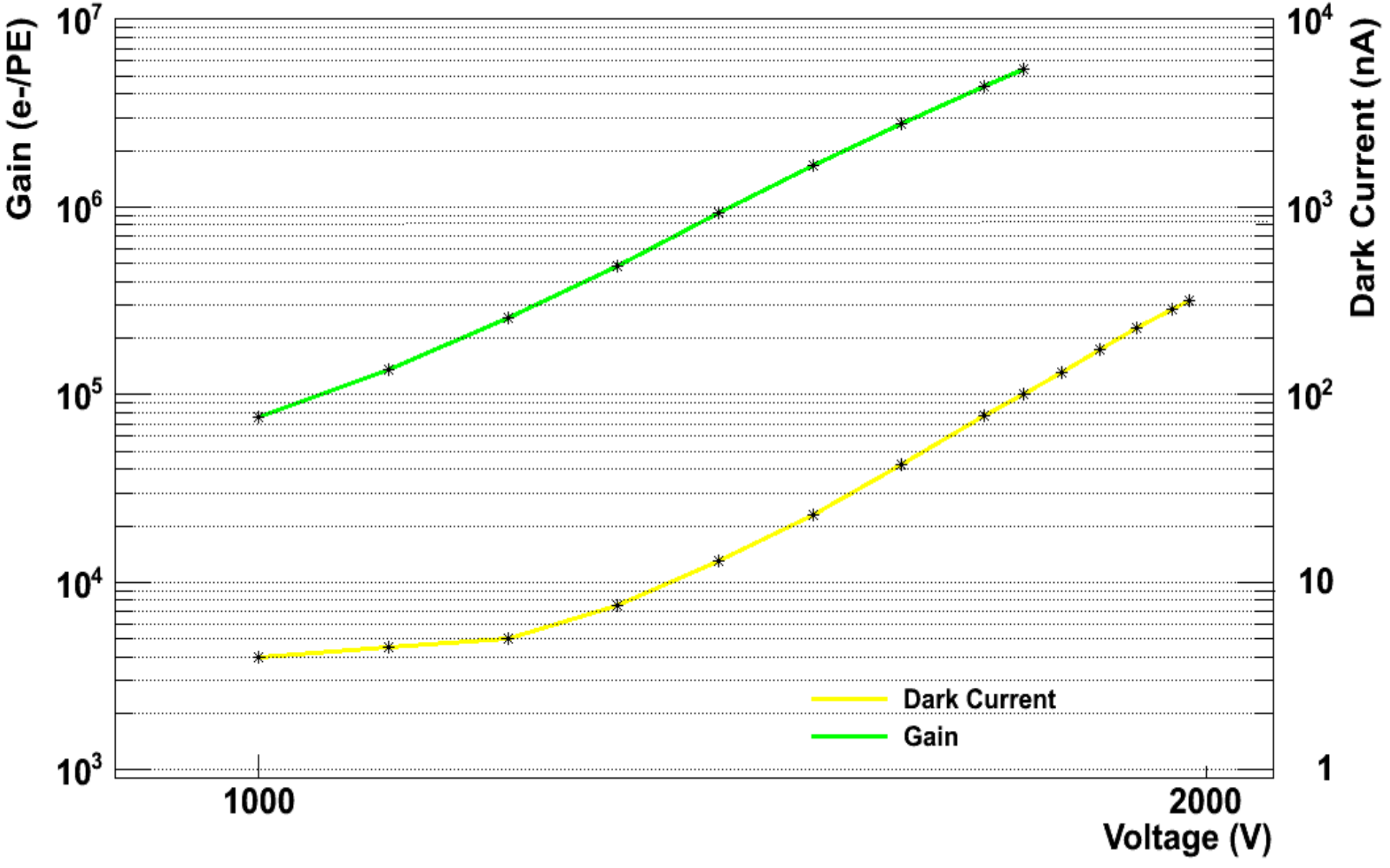
ZK6340 and KA0001

R11410-10 TEST DATA

August 31, 2011

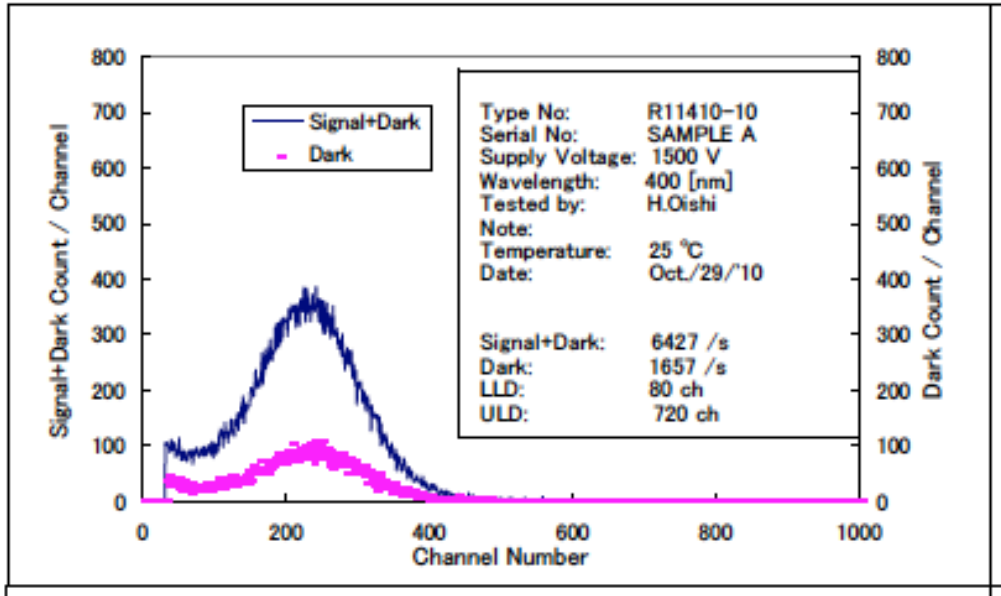
	SERIAL NUMBER	SK [uA/lm]	SKB	SP [A/lm]	GAIN				IDB [nA]			
				1500 V	1000V	1250V	1500V	1750V	1000V	1250V	1500V	1750V
1	ZK6340	142.0	13.10	391	1.04E+05	6.43E+05	2.75E+06	9.36E+06	0.48	2.90	12.0	40.0
2	KA0001	125.0	12.40	399	1.24E+05	7.57E+05	3.19E+06	1.05E+07	0.71	4.10	17.0	56.0

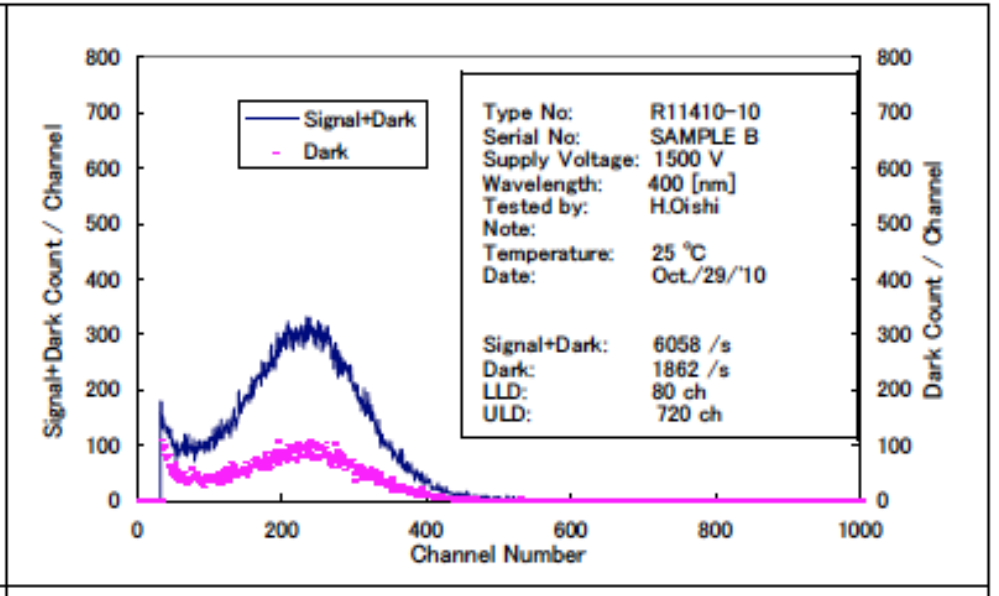
Gain and Dark Current

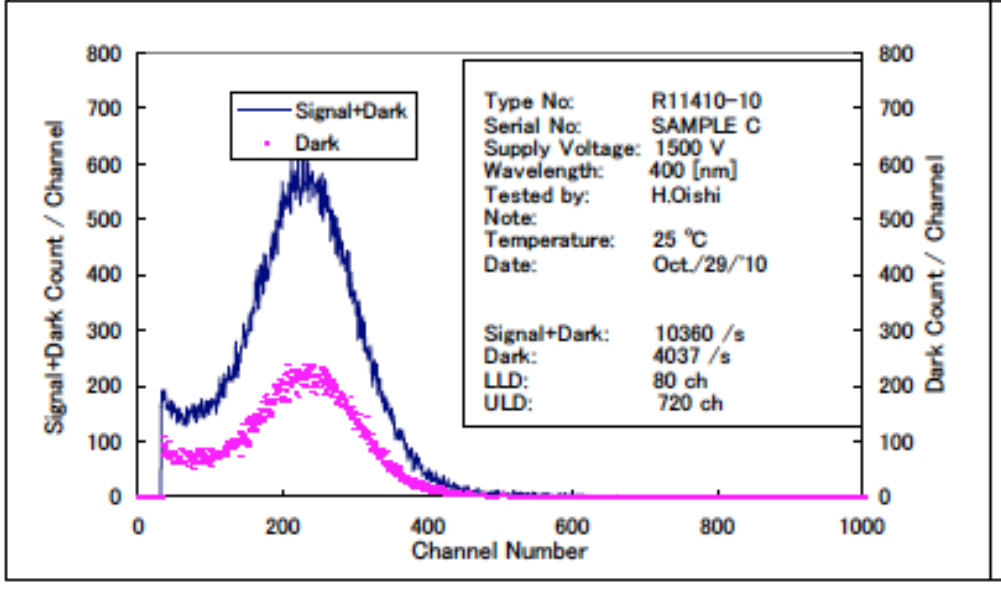


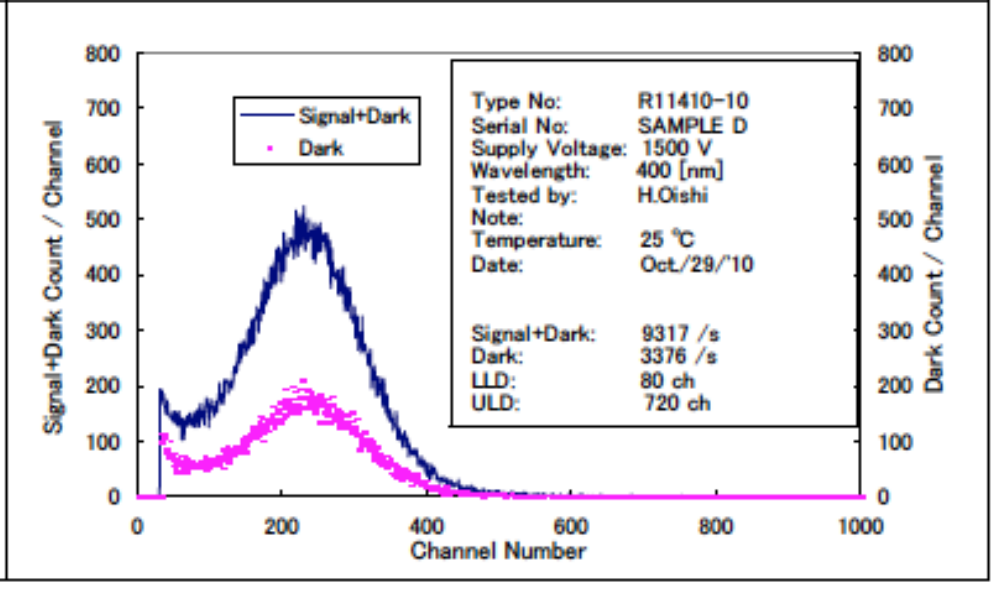
Single PE

R11410 Single PE Distribution



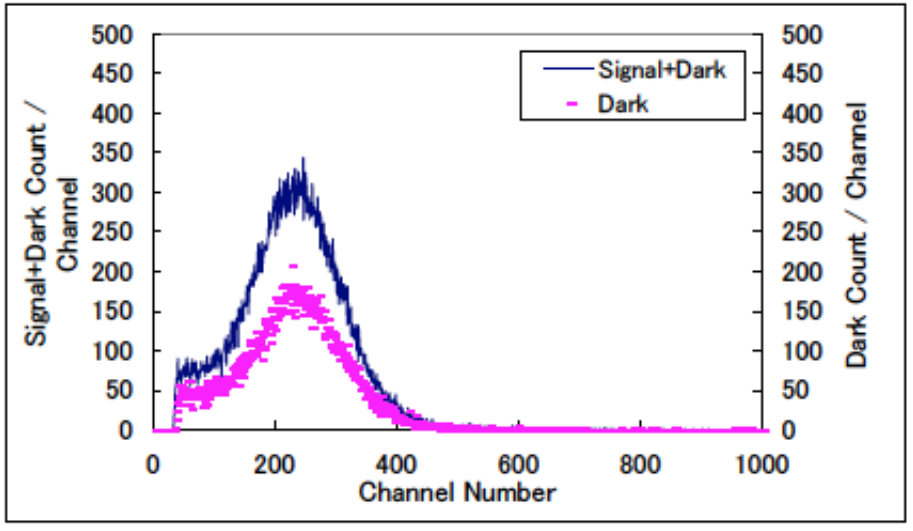




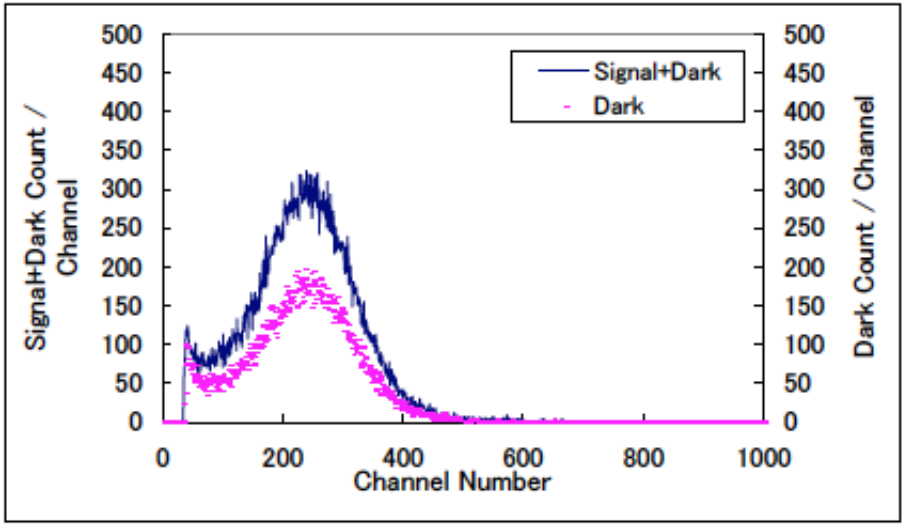


ZK6340 and KA0001

Single Photon Pulse Height Distribution

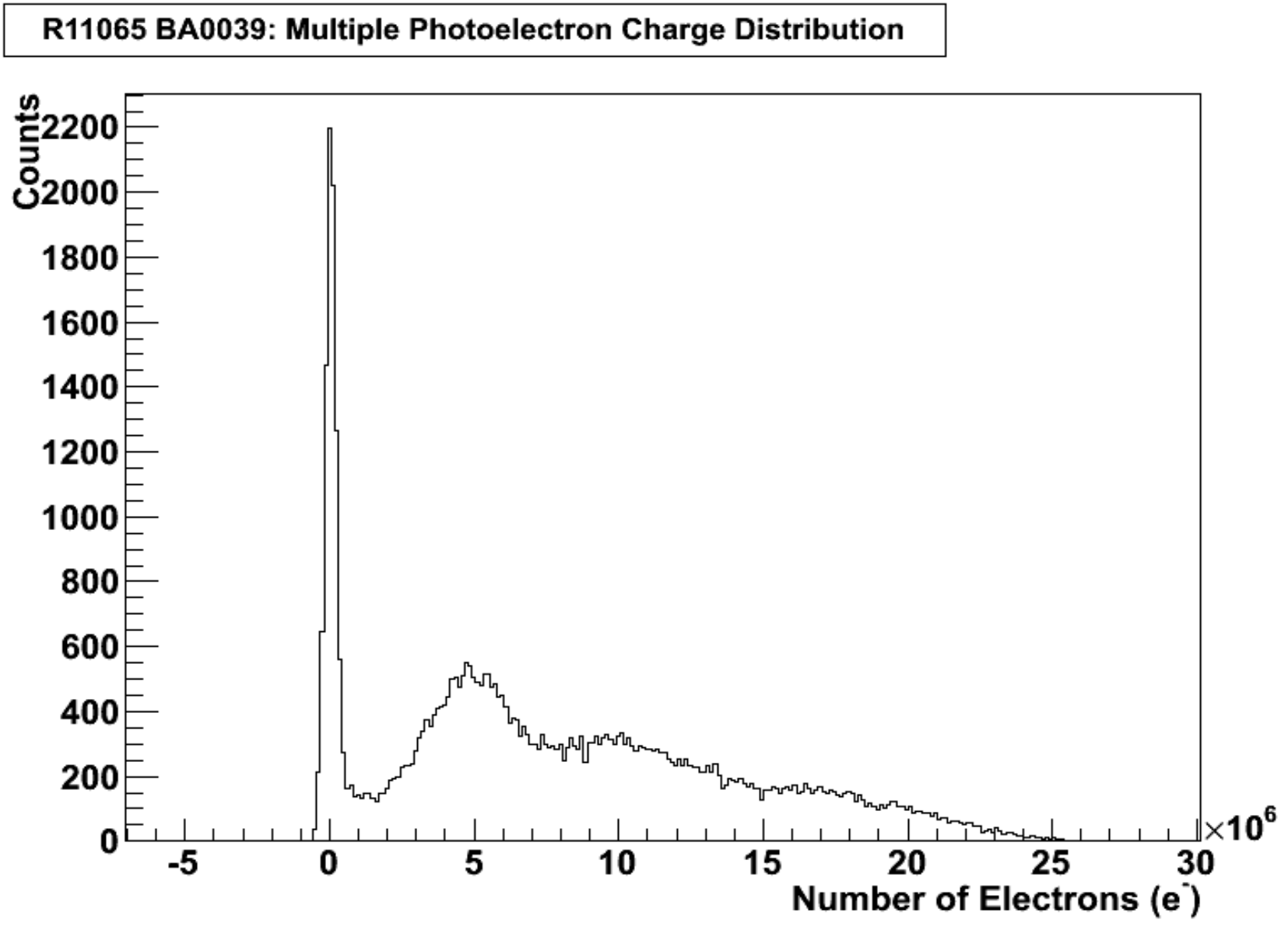


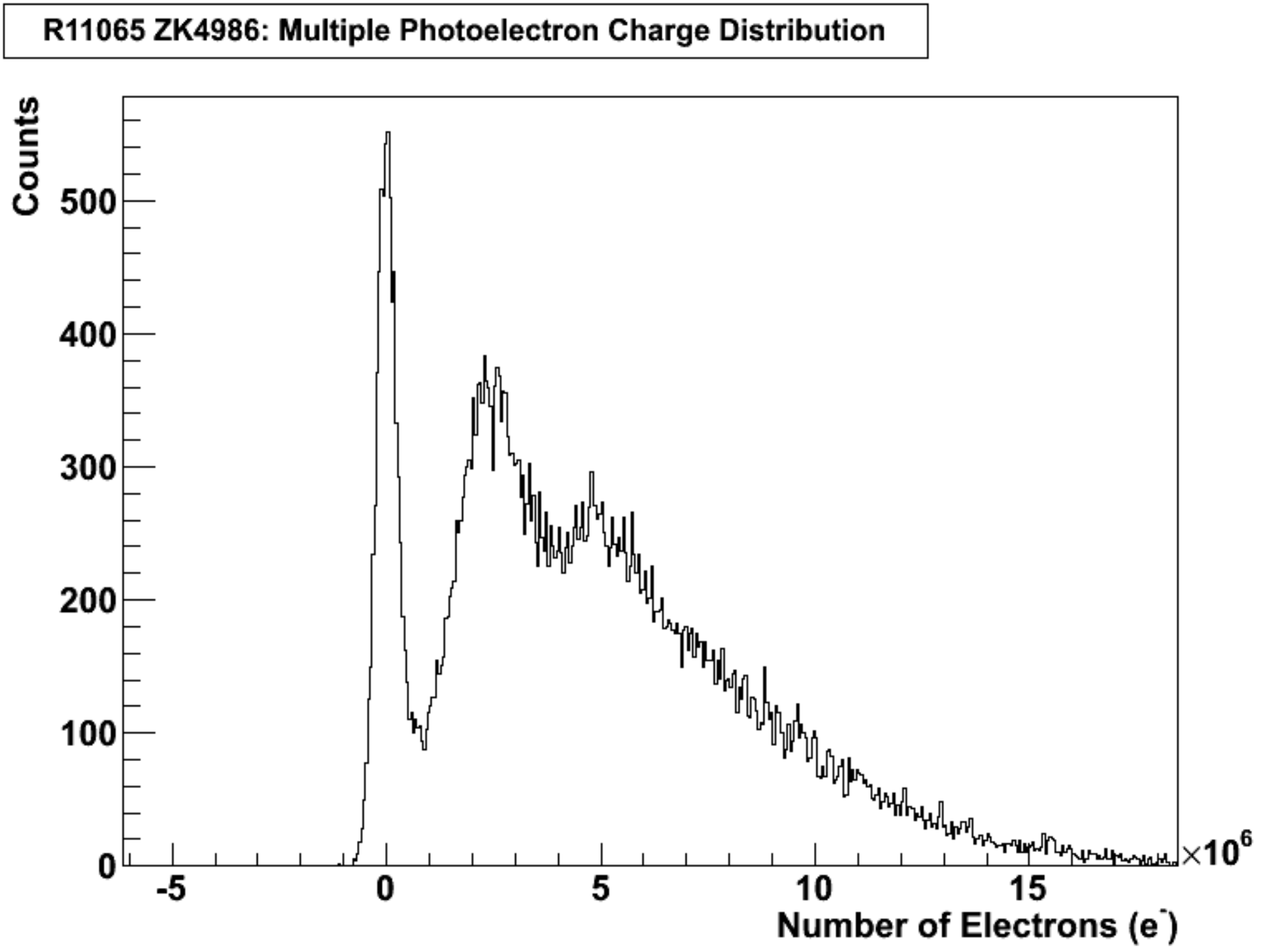
Type No:	R11410-10	Date:	AUG./01/'11
Serial No:	ZK6340	Note:	
Voltage:	1500 V	Signal+Dark:	5674 /s
Wavelength:	400 [nm]	Dark:	3107 /s
Temperature:	25 ℃	LLD:	77ch
Tested by:	H.OISHI	ULD:	693ch



Type No:	R11410-10	Date:	AUG./01/'11
Serial No:	KA0001	Note:	
Voltage:	1500 V	Signal+Dark:	5841 /s
Wavelength:	400 [nm]	Dark:	3387 /s
Temperature:	25 ℃	LLD:	78ch
Tested by:	H.OISHI	ULD:	702ch

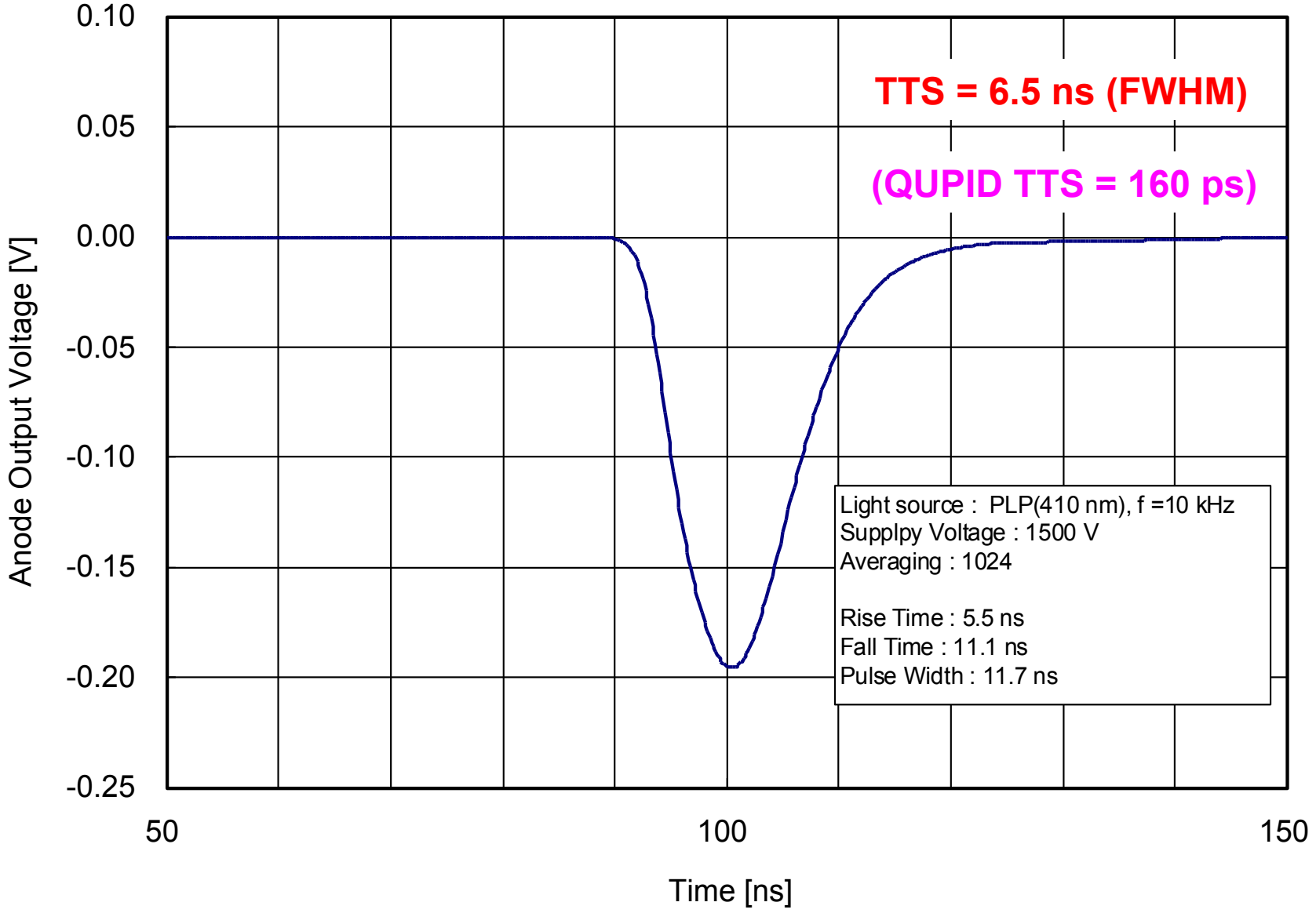
Multiple Photoelectron Charge Distribution (1500 V)



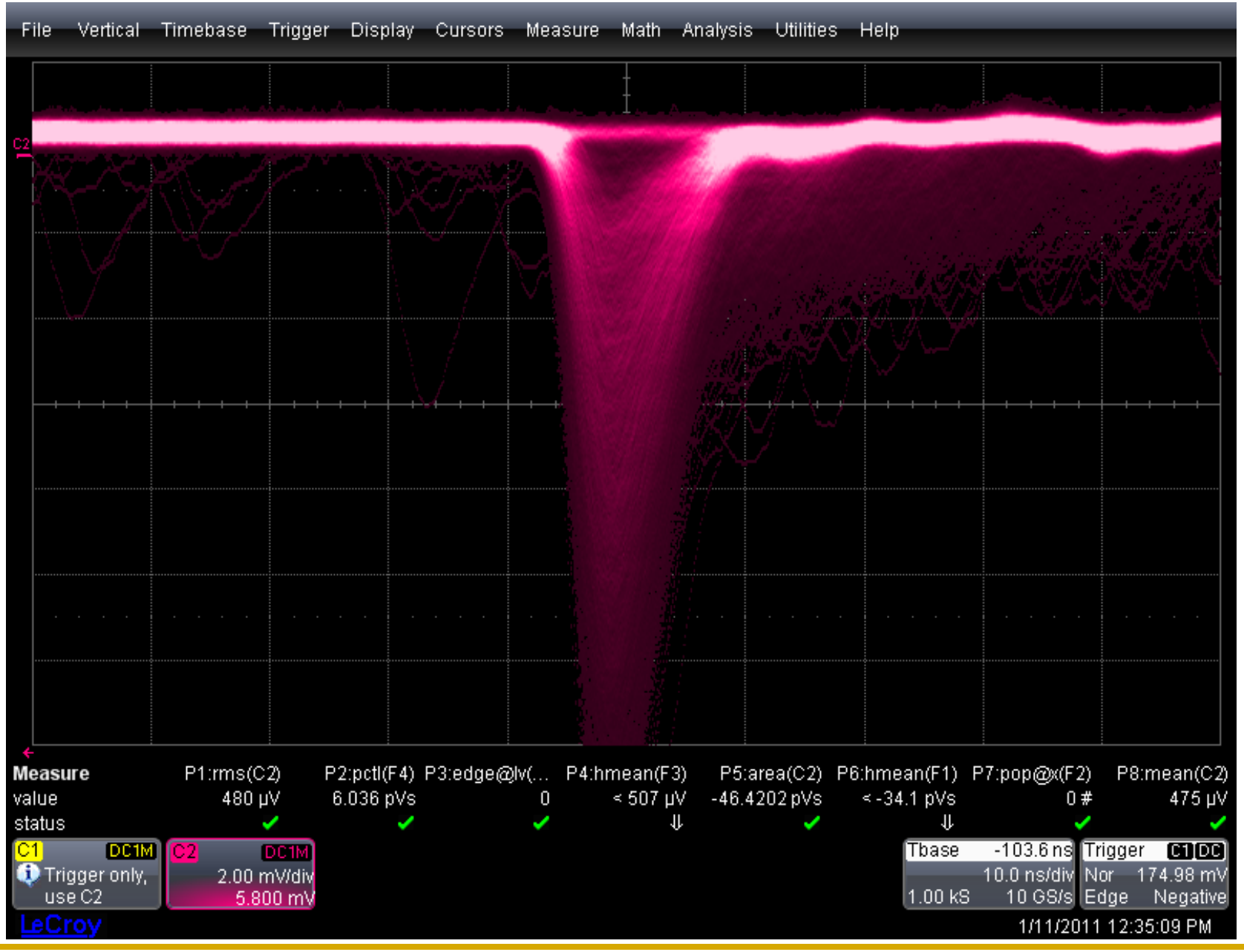

R11065 ZK4986: Multiple Photoelectron Charge Distribution
Counts
500
400
300
200
100
0
-5
0
5
10
15
×10^6
Number of Electrons (e^-)

Wave form
Time Properties

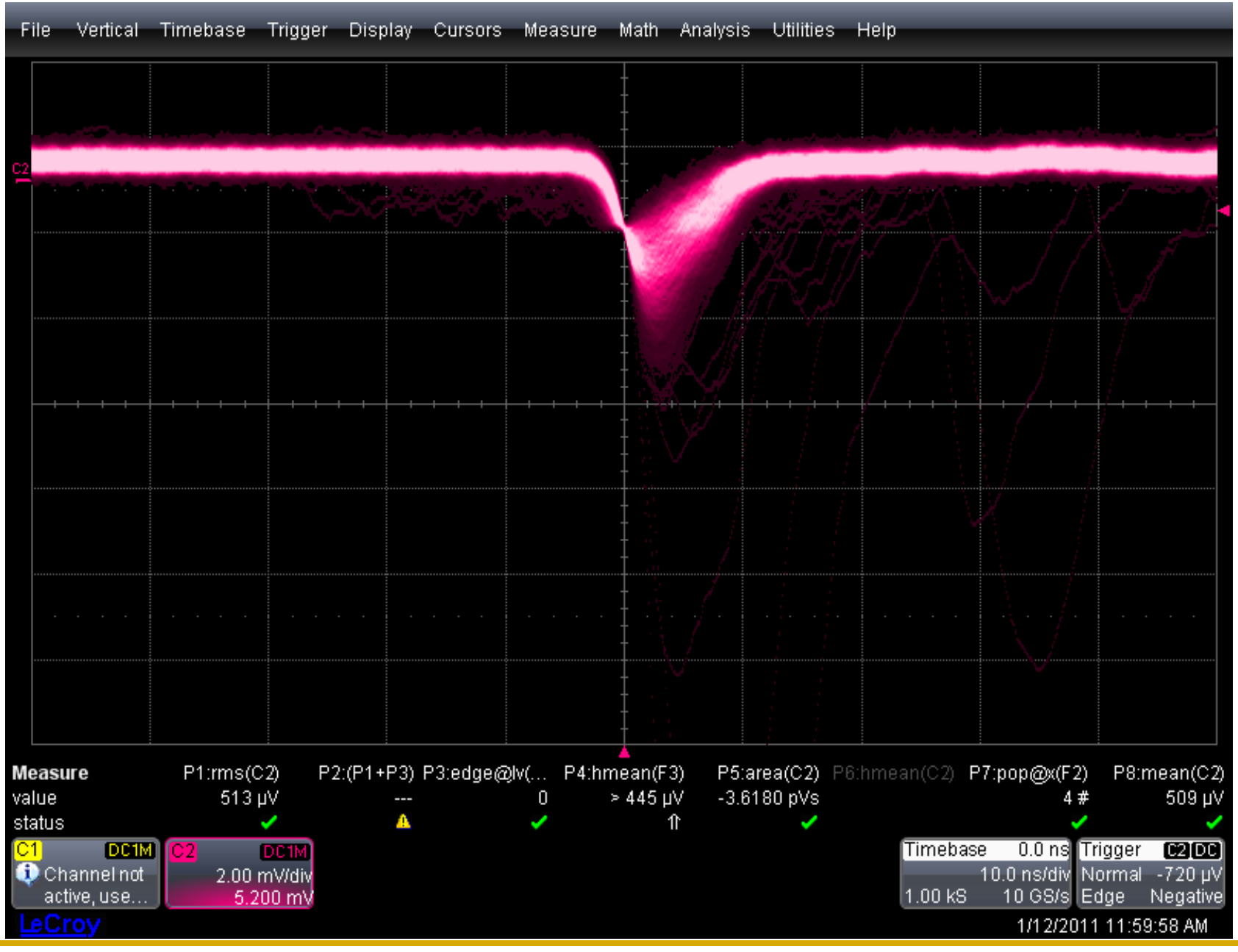
R11410 and R11065
ANODE OUTPUT WAVEFORM



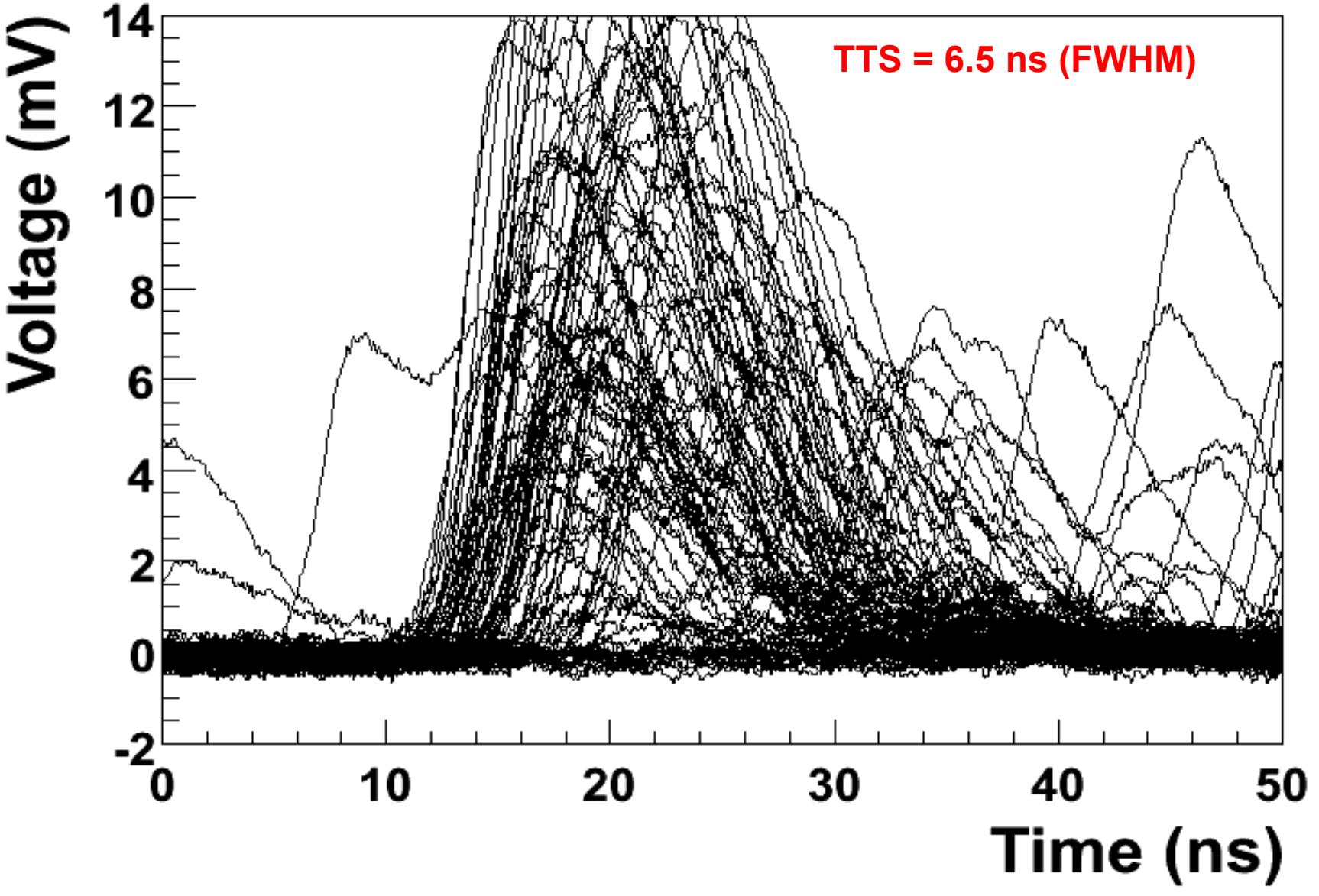
ZK4986 - Multiple Photoelectron Waveforms



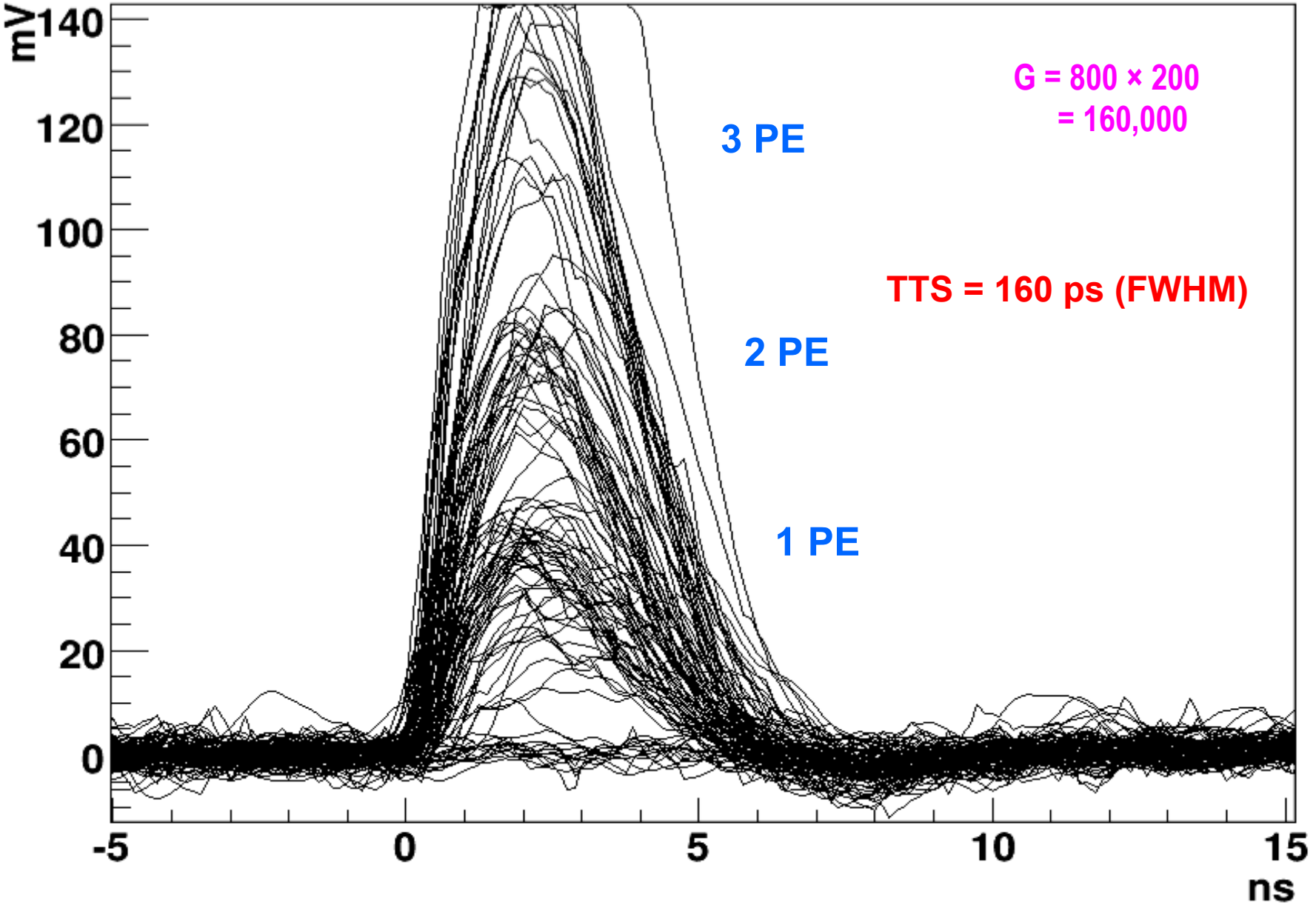
ZK4986 – Dark Count Waveforms (1 mV Threshold)



R11410 Multiple Photoelectron Waveforms



QUPID Multiple Photoelectron Waveforms



Timing Properties

- **Single Photoelectron timing properties of several phototubes**

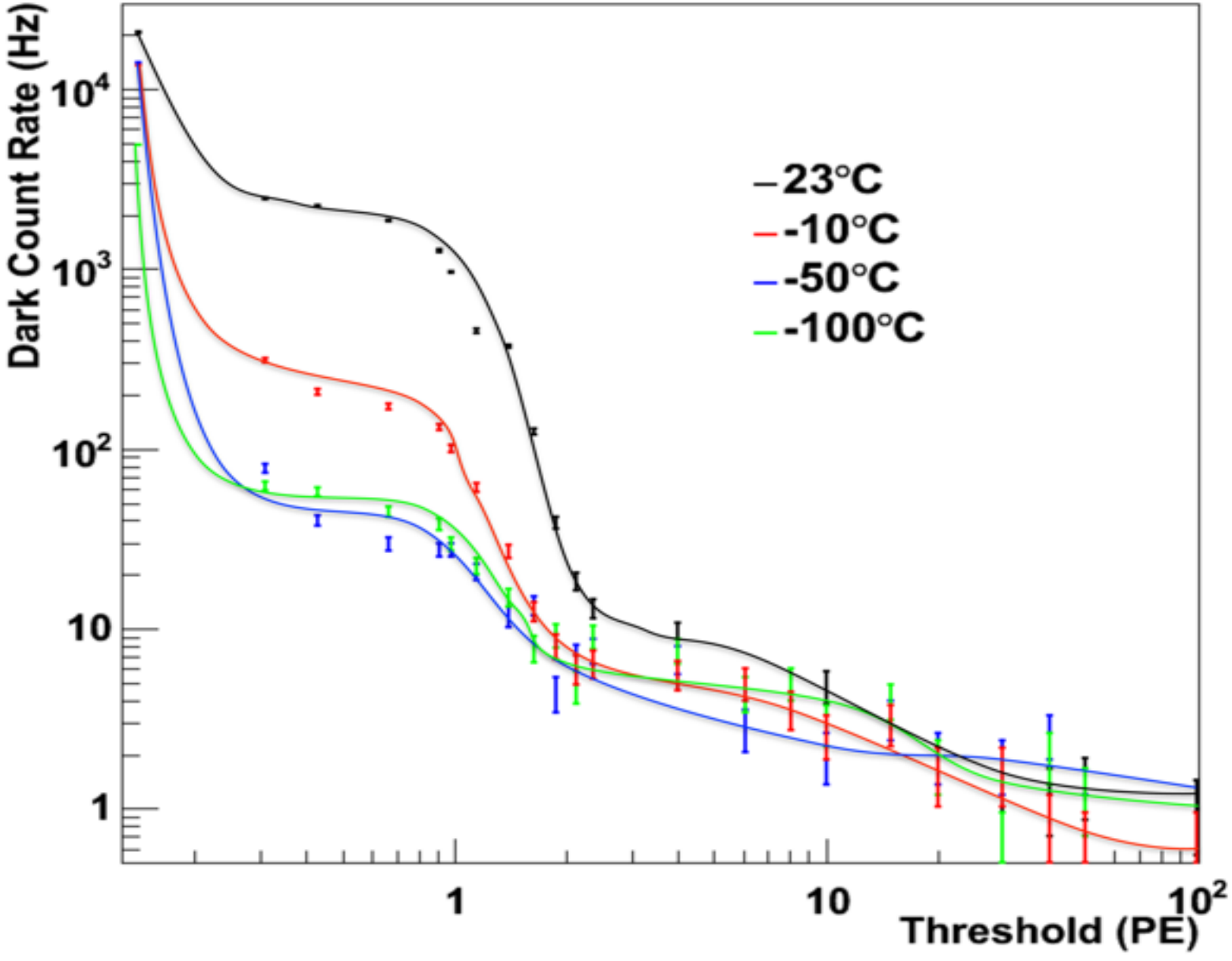
Phototube	Rise Time	Fall Time	Pulse Width	Transit Time Spread
R11065	4.2 ± 1.1 ns	10.0 ± 1.0 ns	8.0 ± 0.6 ns	7.4 ± 0.5 ns
R8520	1.9 ± 0.2 ns	2.9 ± 0.2 ns	4.4 ± 0.1 ns	1.1 ± 0.1 ns
QUPID	1.8 ± 0.1 ns	2.5 ± 0.2 ns	4.20 ± 0.05 ns	160 ± 30 ps

CTTD

- **CTTD here!**

Dark Count Rate

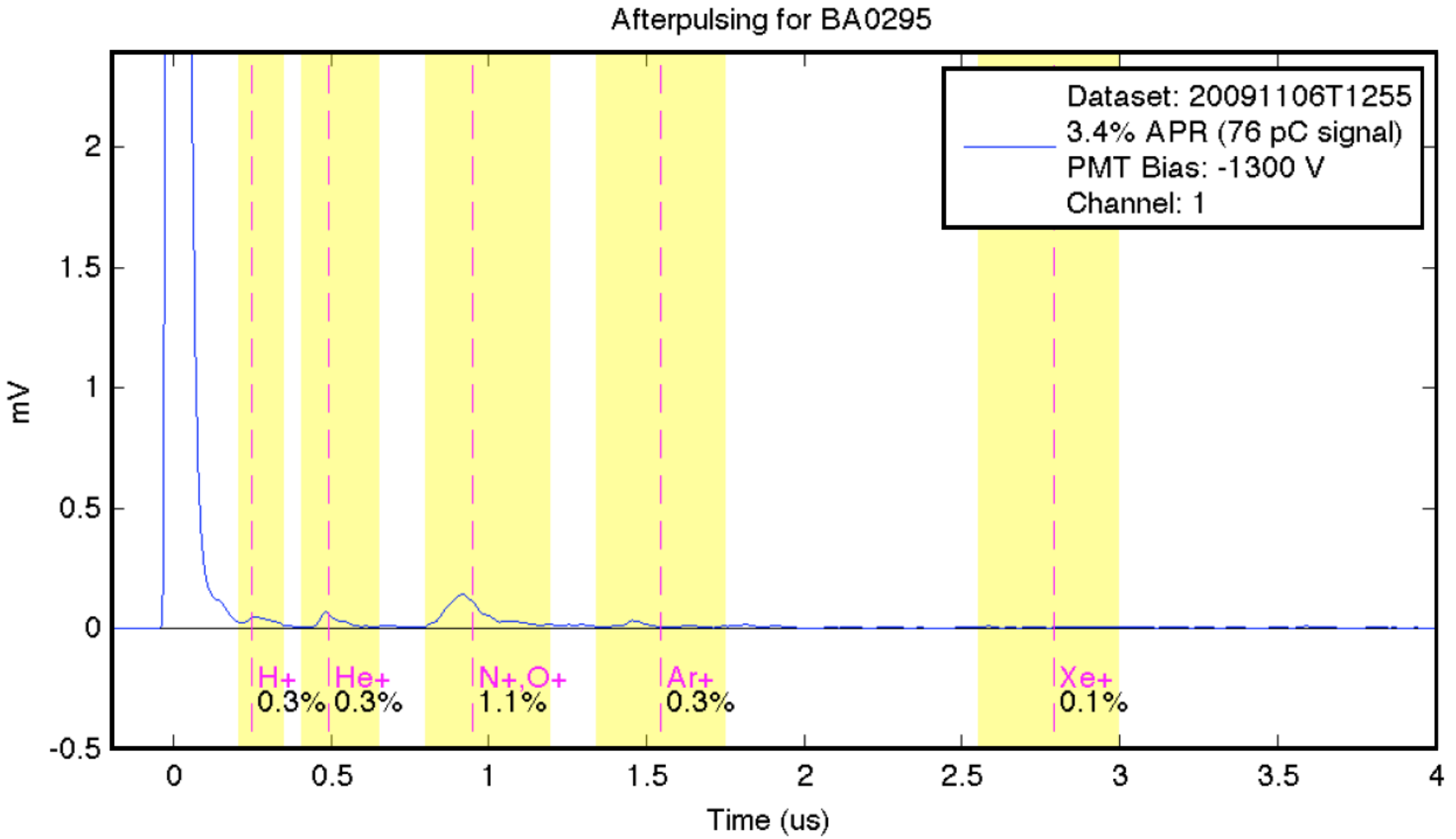
Dark Count Rate (R11410)



After Pulse

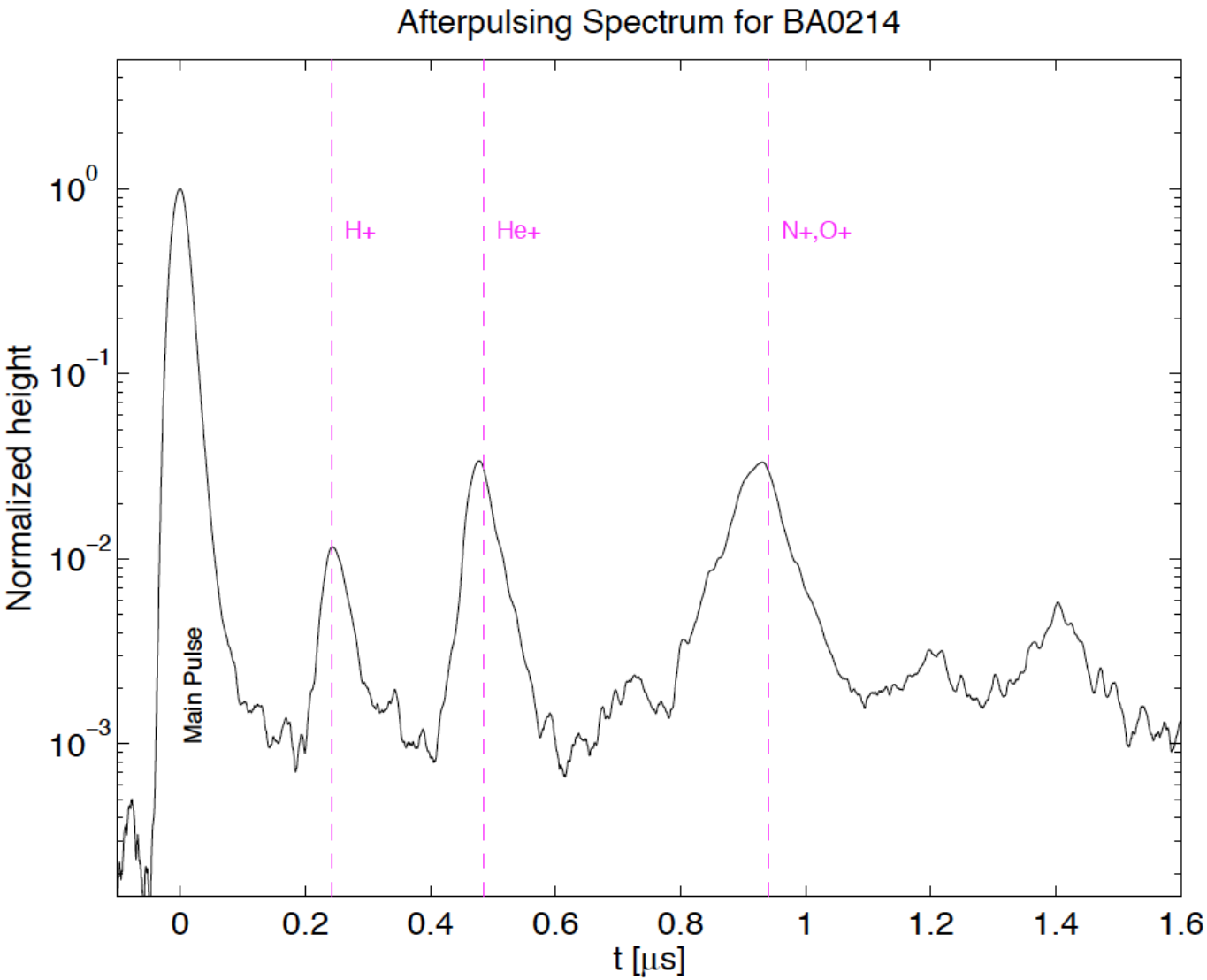
R8778 After Pulse

Healthy R8778 PMT Afterpulsing Spectrum



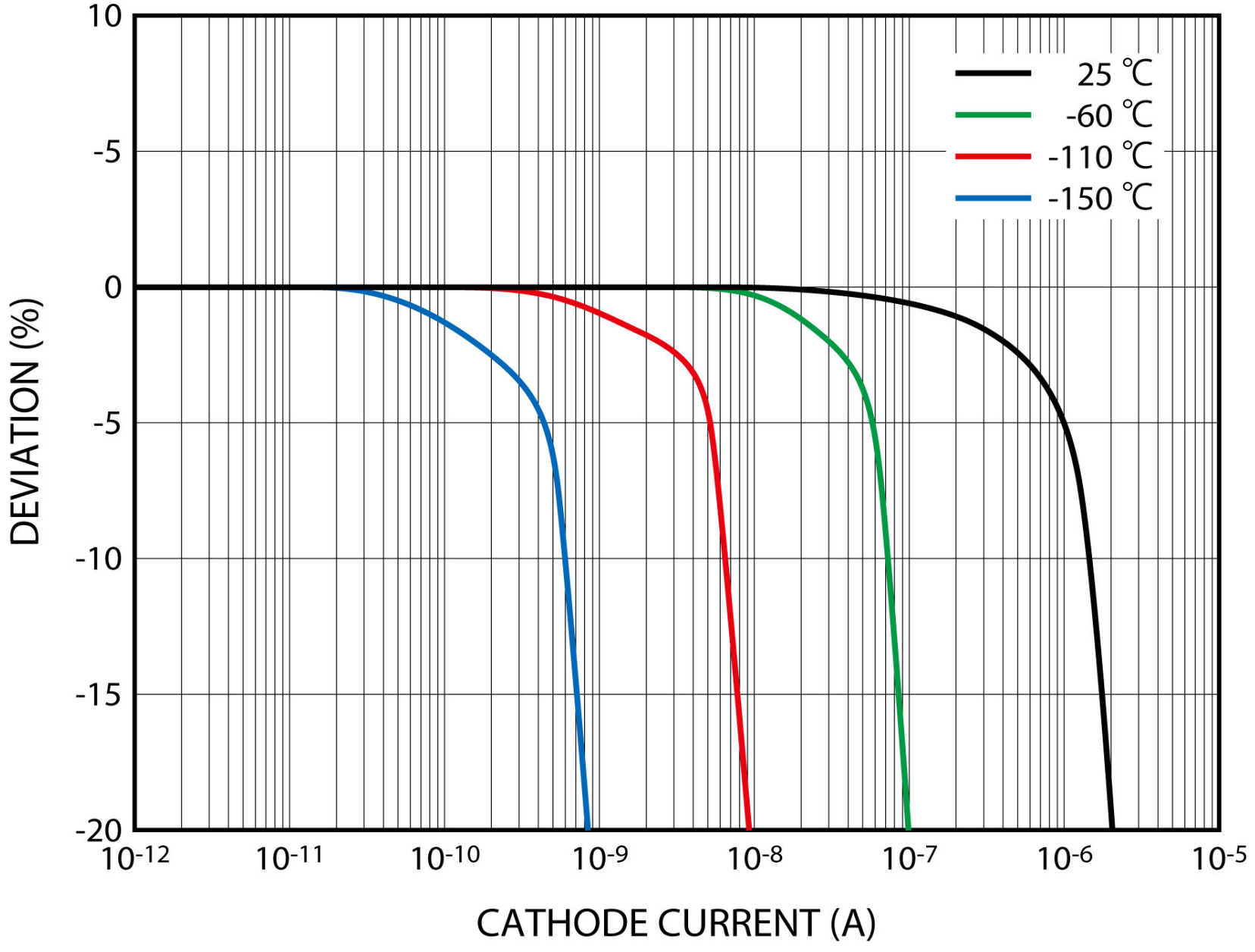
R8778 After Pulse

R8778 exposed to He, and having a small air leak

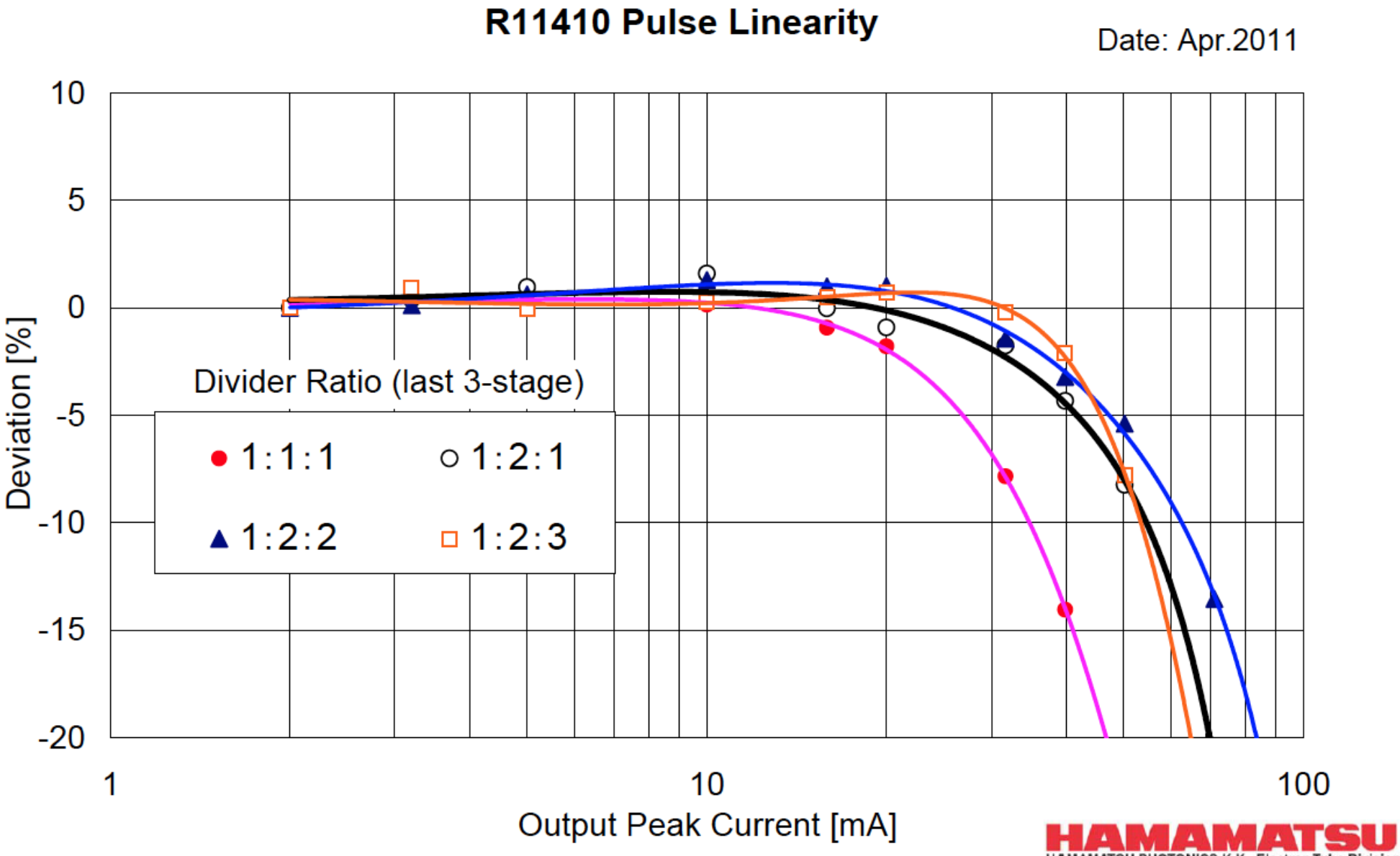


Linearity

R11410 and R11065
CATHODE CURRENT LINEARITY



Anode Pulse Linearity



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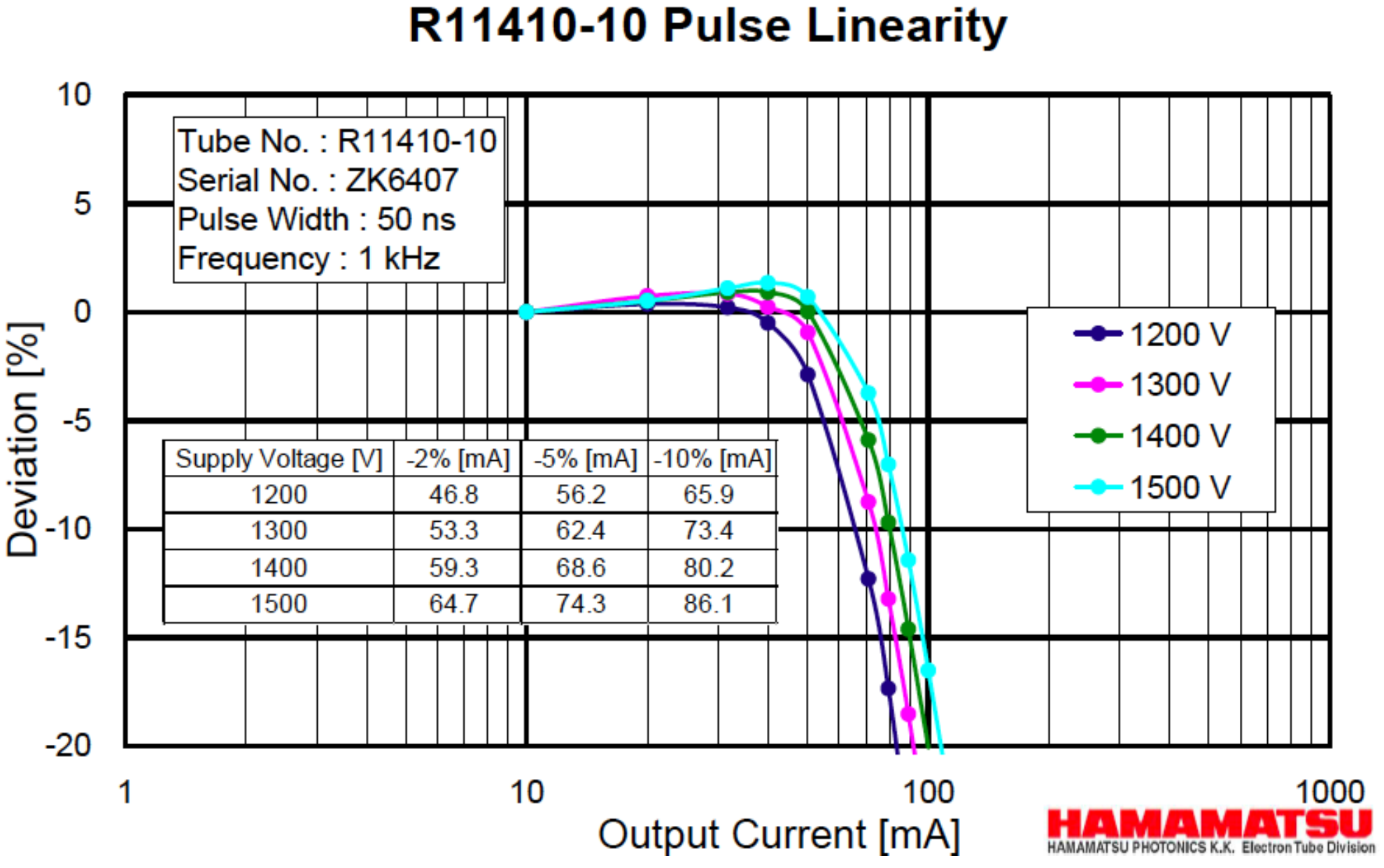
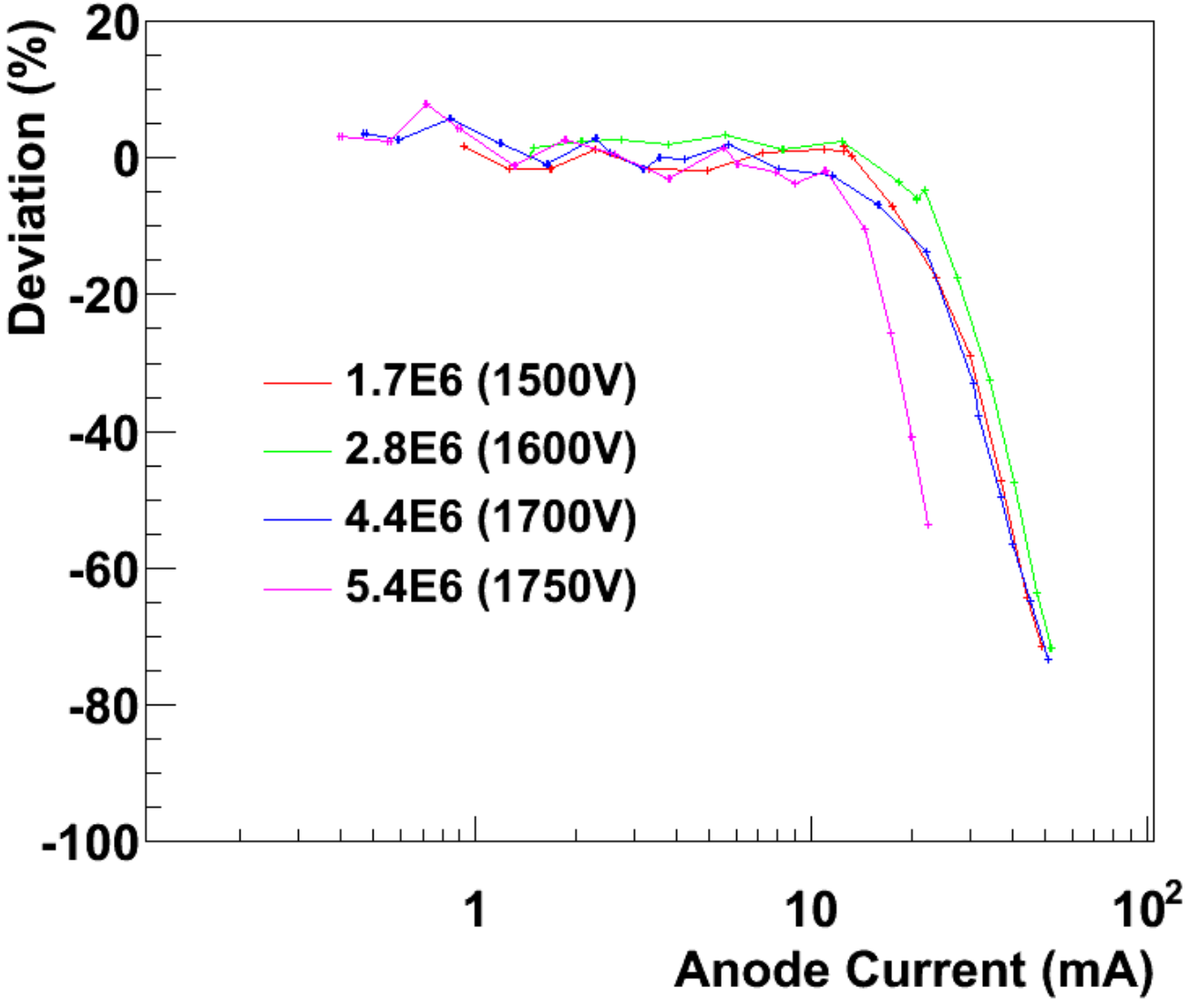
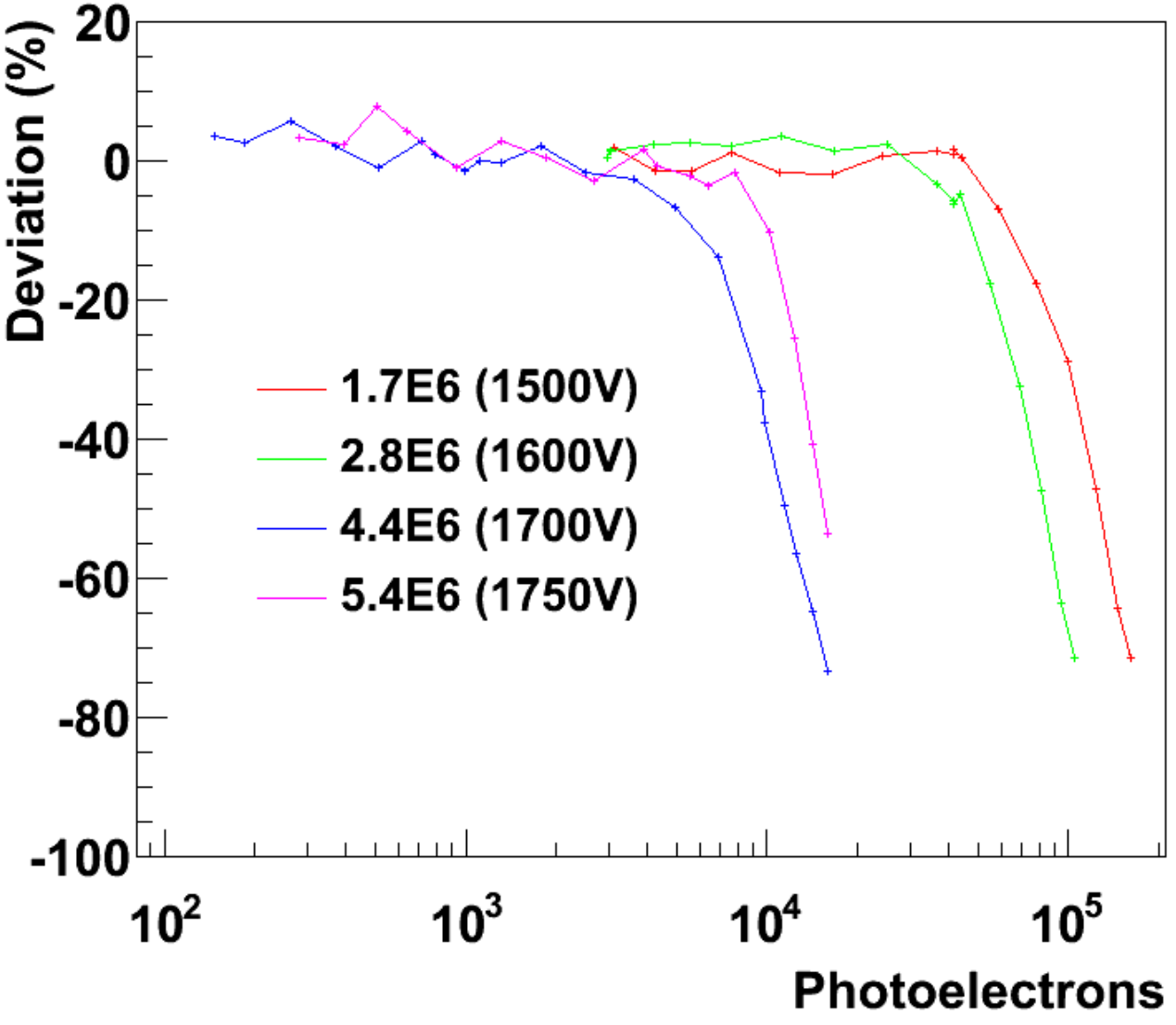
Pulse Linearity



Linearity (Anode Current)

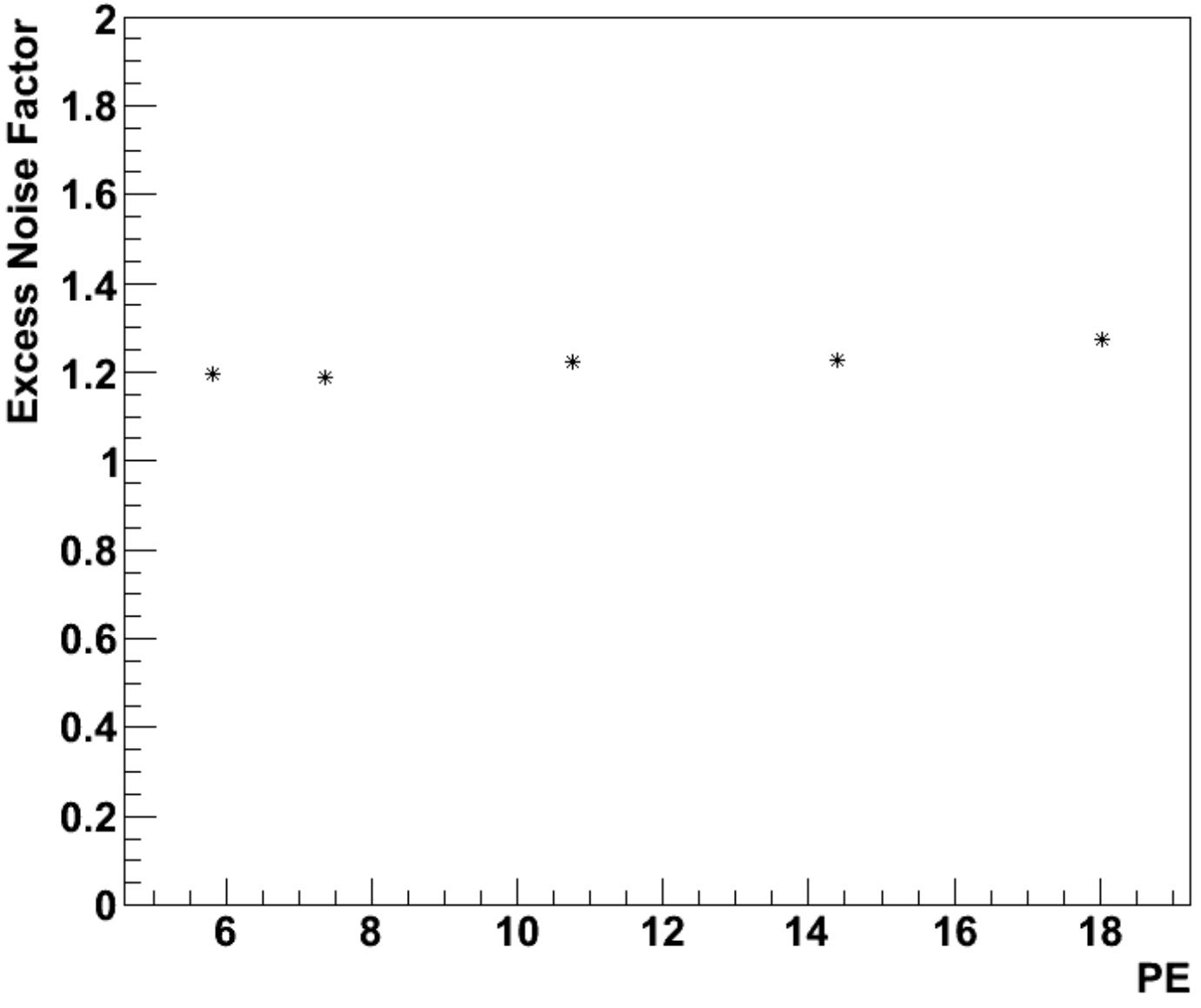


Linearity (PE)



Excess Noise Factor

Excess Noise Factor

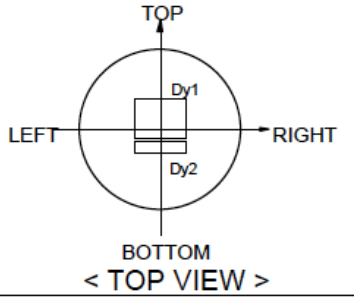


Uniformity

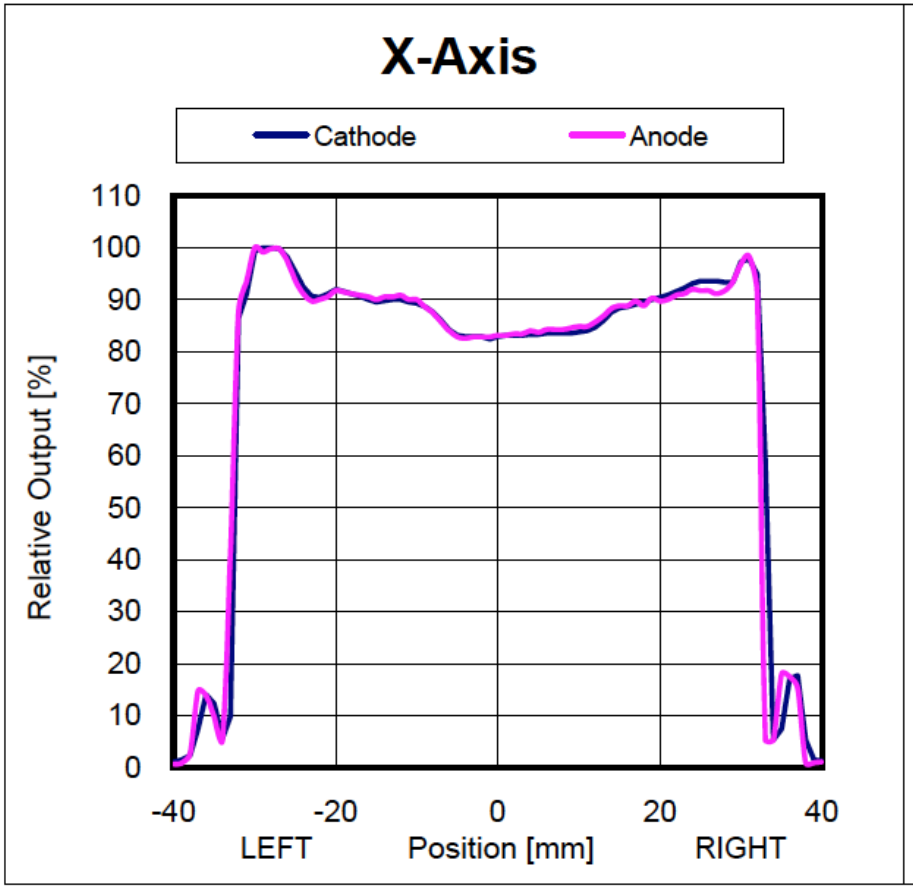
ZK6340

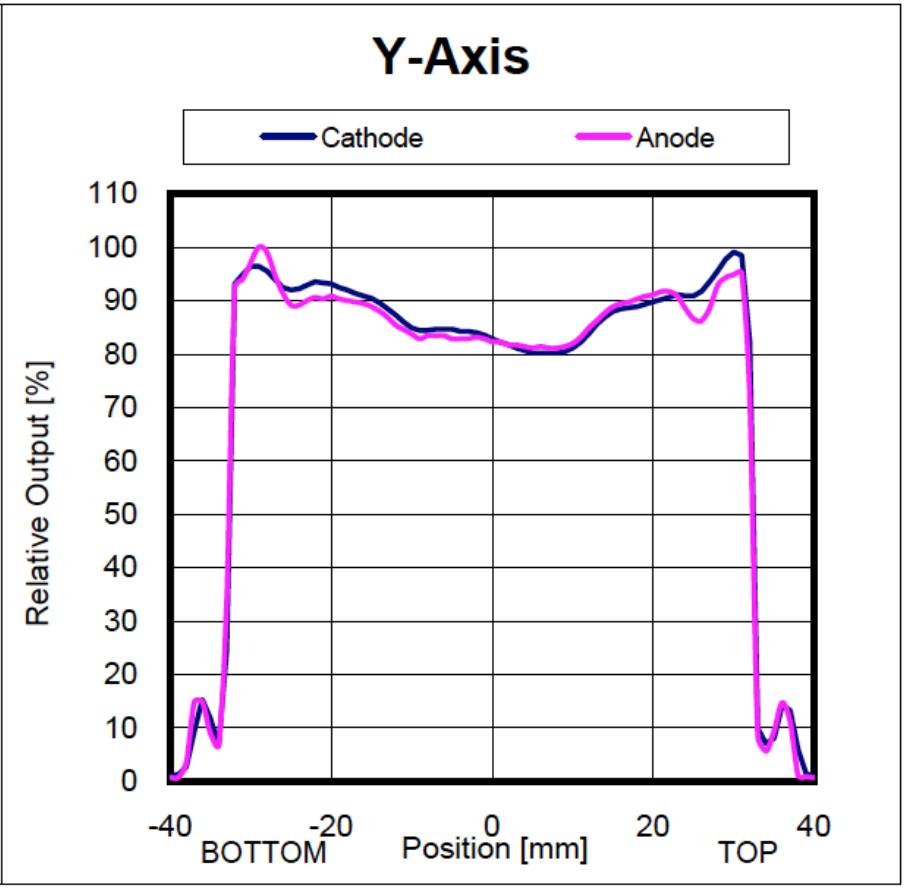
UNIFORMITY

Type No	: R11410-10	Spot Diameter	: 1 mm
Serial No	: ZK6340	Note	:
Supply Voltage	: 1500 V	Test Date	: 2011/8/26
Wavelength	: 400	Tested By	: S.Kasahara



< TOP VIEW >





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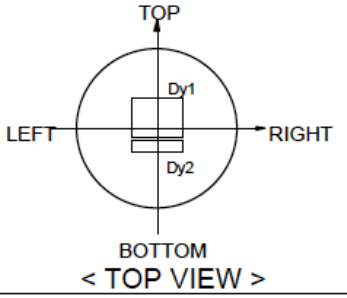
KA0001

UNIFORMITY

Type No	: R11410-10	Spot Diameter	: 1 mm
Serial No	: KA0001	Note	:
Supply Voltage	: 1500 V	Test Date	: 2011/8/26
Wavelength	: 400	Tested By	: S.Kasahara



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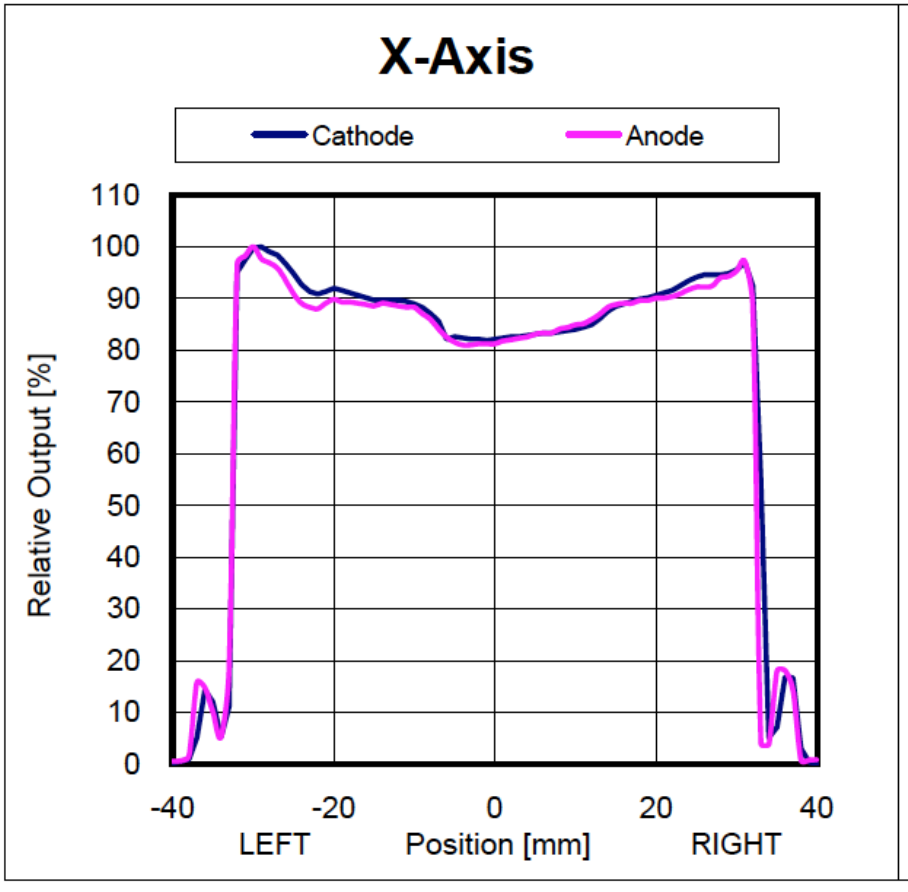

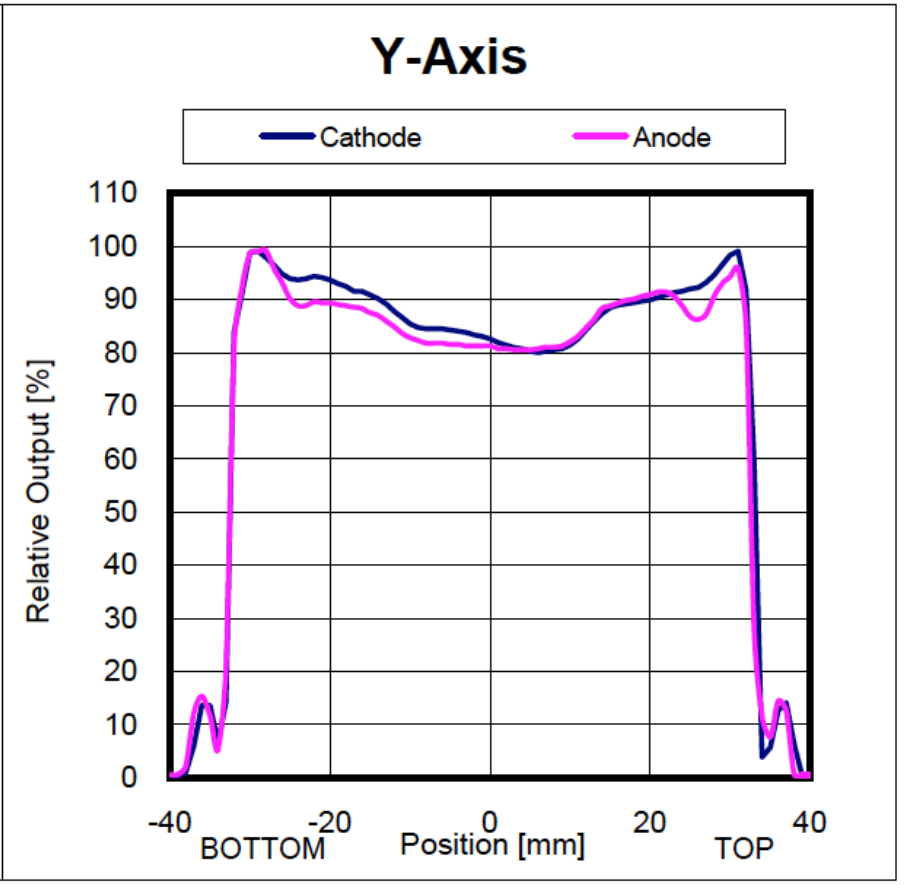

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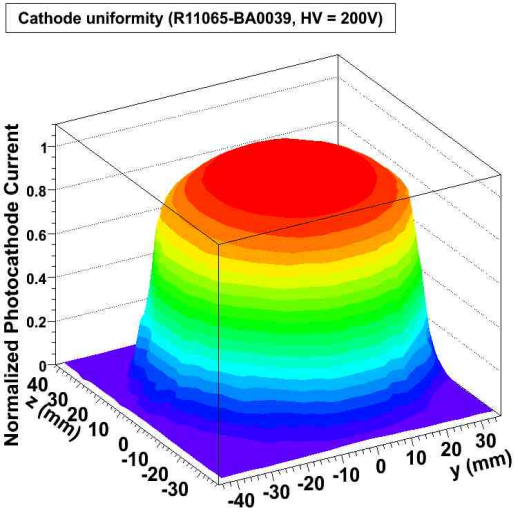
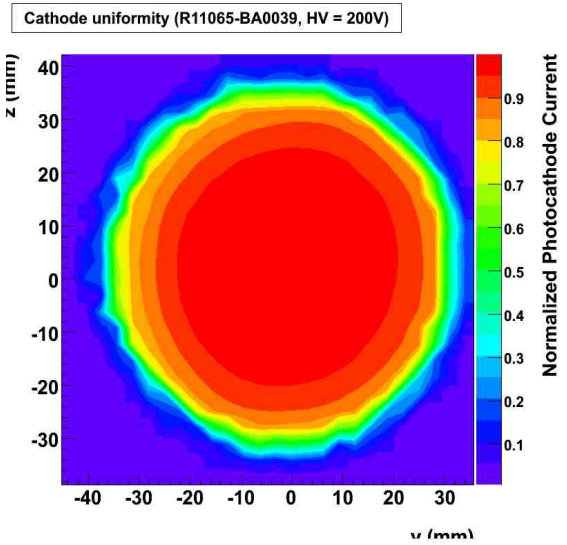
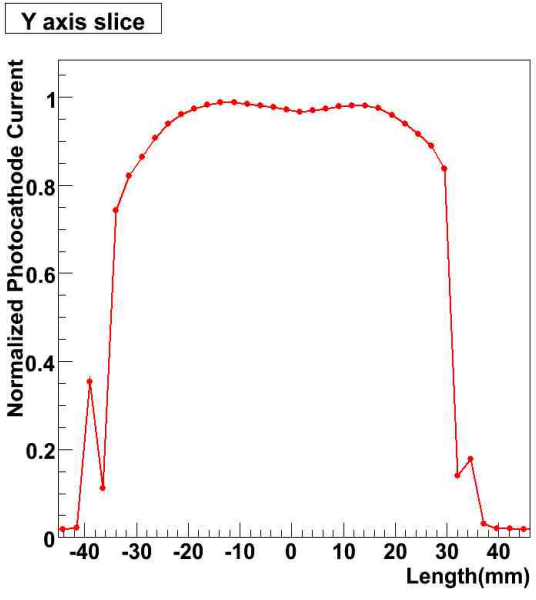
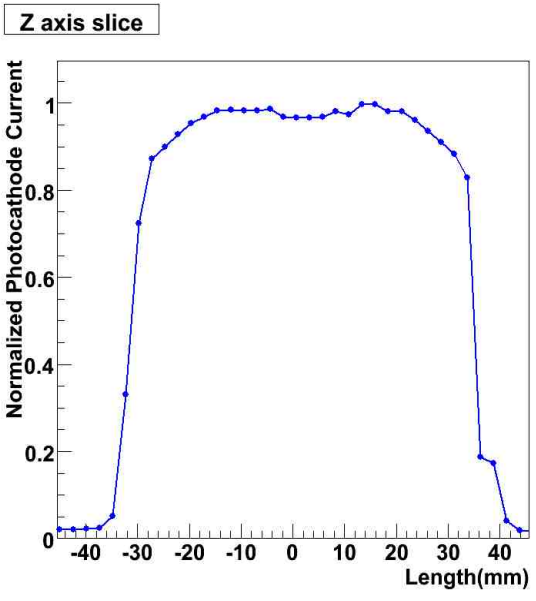
R11065 Cathode Uniformity

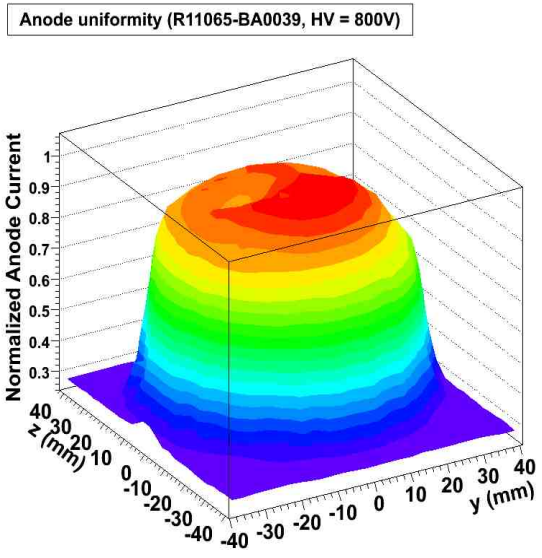


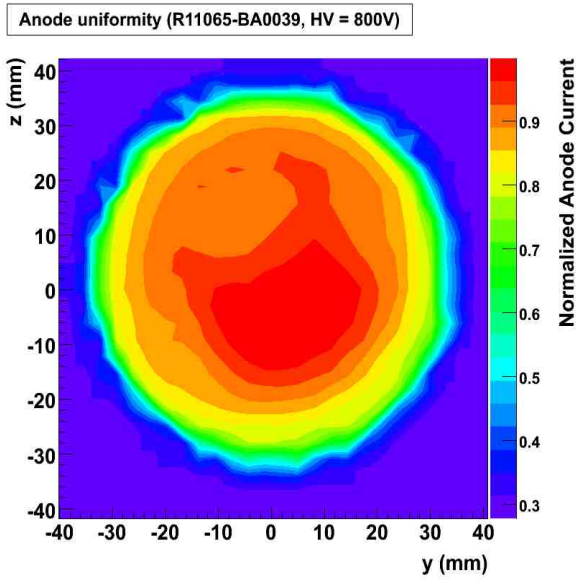


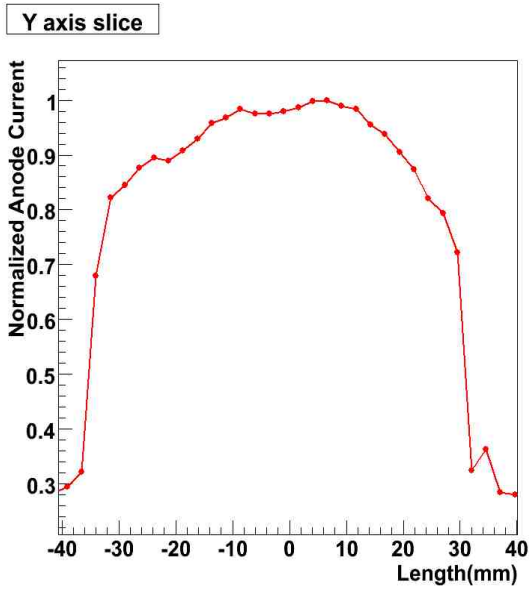


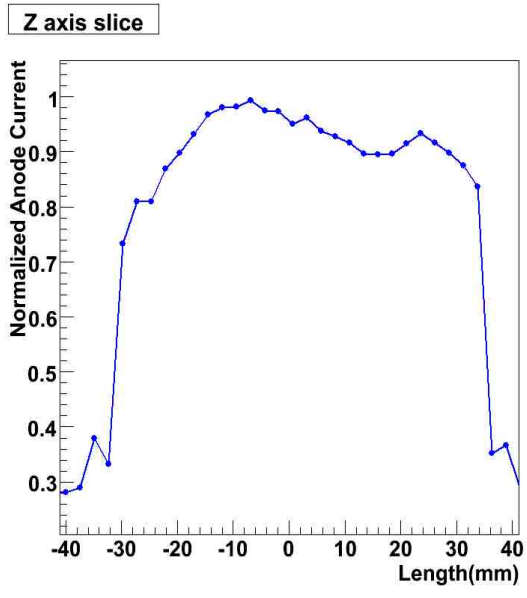


R11065 Anode Uniformity



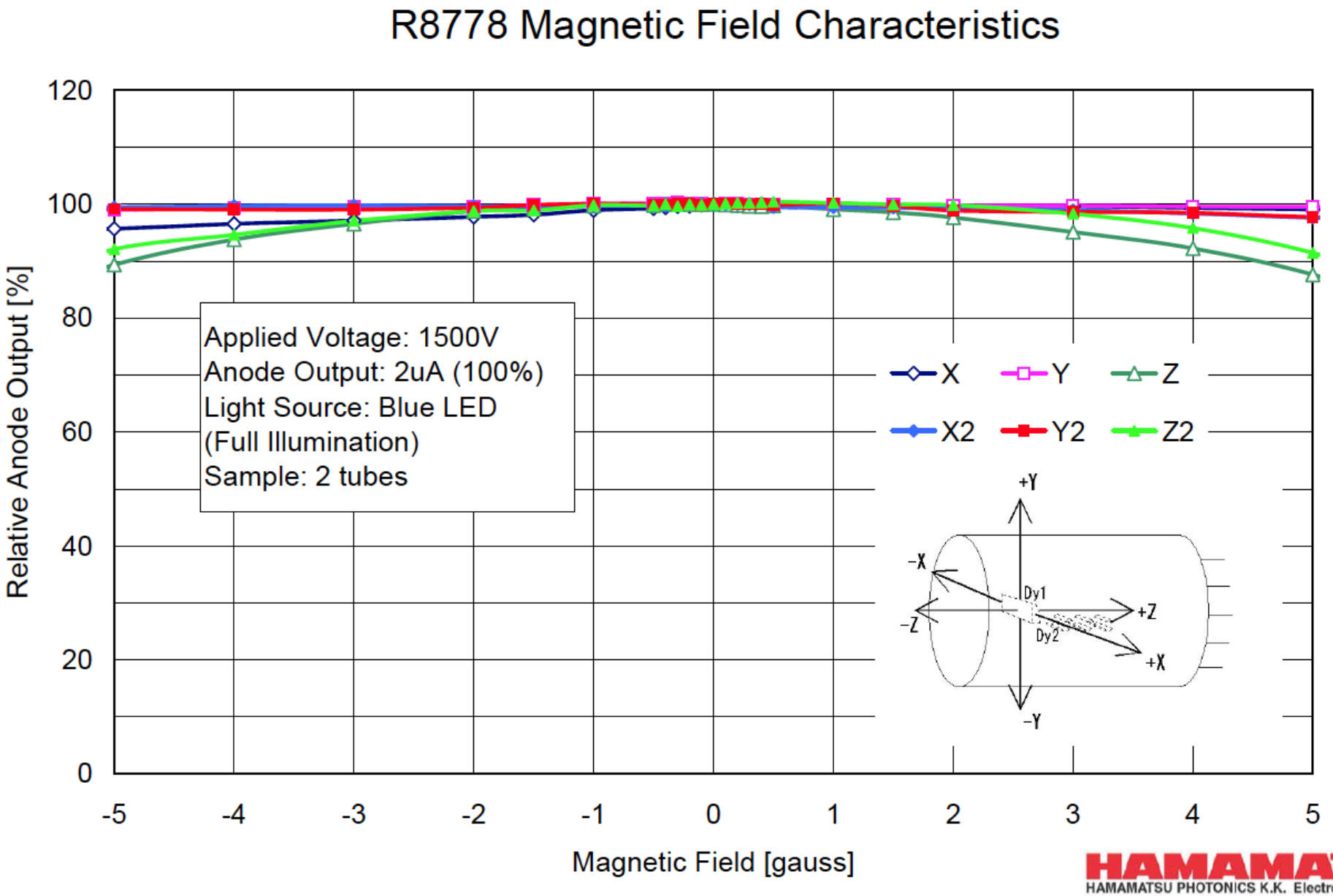






Effect of Magnetic Field

R8778 Magnetic Field Effect



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R11410 Magnetic Field Effect

- Waiting for Hamamatsu measurement in a week.

Pressure Tests

Pressure Tests

- So far two PMT tested
  - One broken at 8 atm.
  - The other broken at 15 atm.
- Long term tests done in a week.
  - 4 PMT
  - 2 – 3 days
  - 6 astmos

Summary

Main Concerns

- **Optimum Gain**
  - 5E6, higher or lower?
- **Anode Linearity**
  - Reduce #dynode?
  - Tapered bleeder?
- **5 atmosphere**
- **Effect of the earth magnetic field**
- **Radioactivity**
  - Reduce Cobalt from Metal tube
  - Mas Spectrometer and Neutron activation
- **QE**
  - Both Xe and Ar operation
  - Include Minimum in spec?
- **Waveform andTTS**

Immediate Action Items

- Purchase order of 10 R11410
- Radiation screening by
  - Mass Spectrometer
  - Neutron activation
- 300 R11410 for XENON 1 Ton
  - $6,817 per tube budgeted
  - 100 from Europe (MPI, Zurich)
  - 60 from NSF (Columbia)
  - 140 from DOE (UCLA)