Characterization of the QUartz Photon Intensifying Detector (QUPID)

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Characterization of the QUartz Photon Intensifying Detector (QUPID) for use in Noble Liquid Detectors

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Dark Matter and Double Beta Decay experiments require extremely low radioactivity within the detector materials. For this purpose, the University of California, Los Angeles and Hamamatsu Photonics have developed the QUartz Photon Intensifying Detector (QUPID), an ultra-low background photodetector based on the Hybrid Avalanche Photo Diode (HAPD) and entirely made of ultraclean synthetic fused silica. In this work we present the basic concept of the QUPID and the testing measurements on QUPIDs from the first production line.

Screening of radioactivity at the Gator facility in the Laboratori Nazionali del Gran Sasso has shown that the QUPIDs safely fulfill the low radioactive contamination requirements for the next generation zero background experiments set by Monte Carlo simulations.

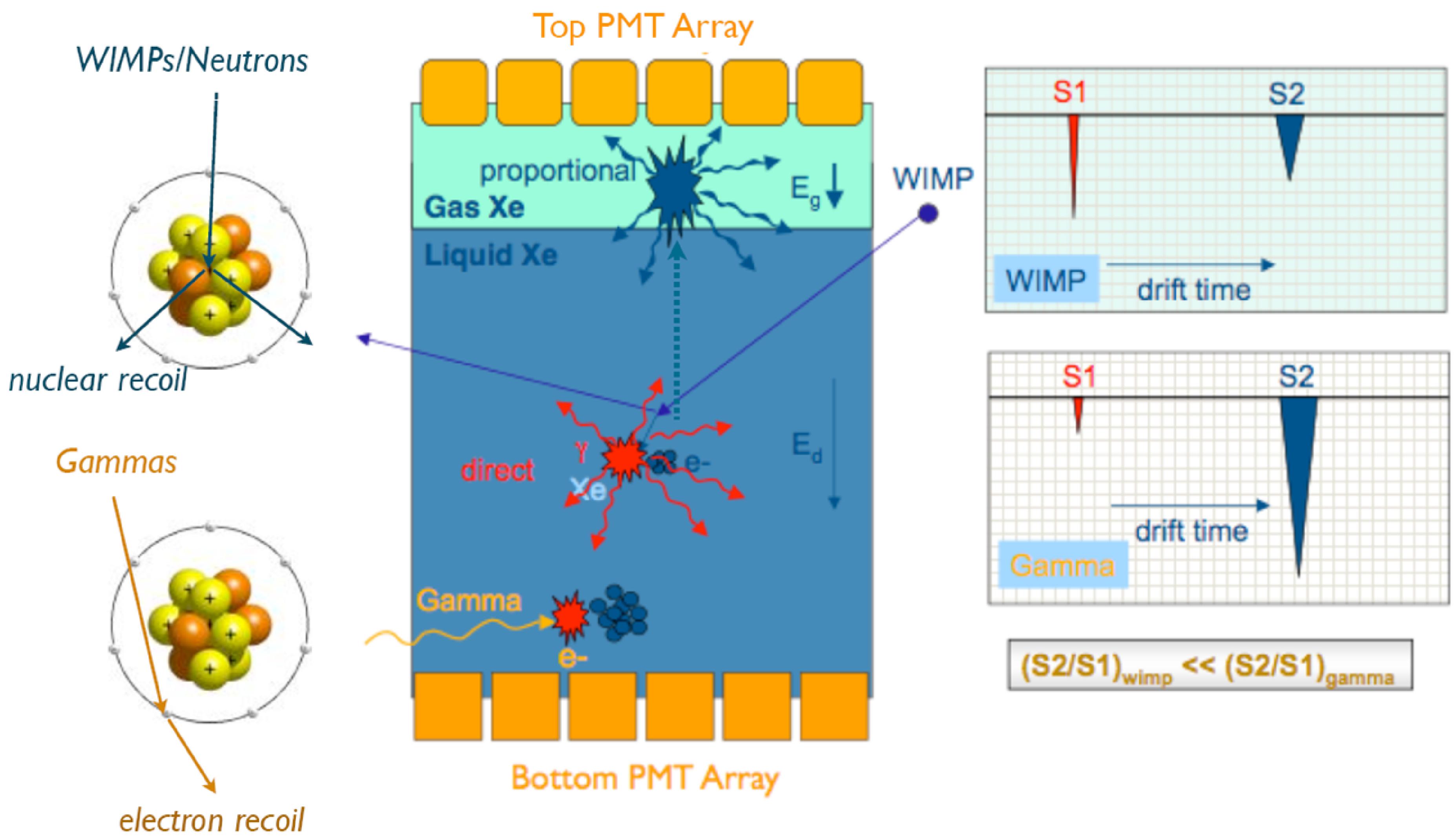
The quantum efficiency of the QUPID at room temperature is $> 30\%$ at the xenon scintillation wavelength. At low temperatures, the QUPID shows a leakage current less than 1 nA and a global gain of 10^5. In these conditions, the photocathode and the anode show $> 95\%$ linearity up to 1 μA for the cathode and 3 mA for the anode. The photocathode and collection efficiency are uniform to 80% over the entire surface. In parallel with single photon counting capabilities, the QUPIDs have a good timing response: 1.8 ± 0.1 ns rise time, 2.5 ± 0.2 ns fall time, 4.20 ± 0.05 ns pulse width, and 160 ± 30 ps transit time spread.

The QUPIDs have also been tested in a liquid xenon environment, and scintillation light from ^{57}Co and ^{210}Po radioactive sources were observed.

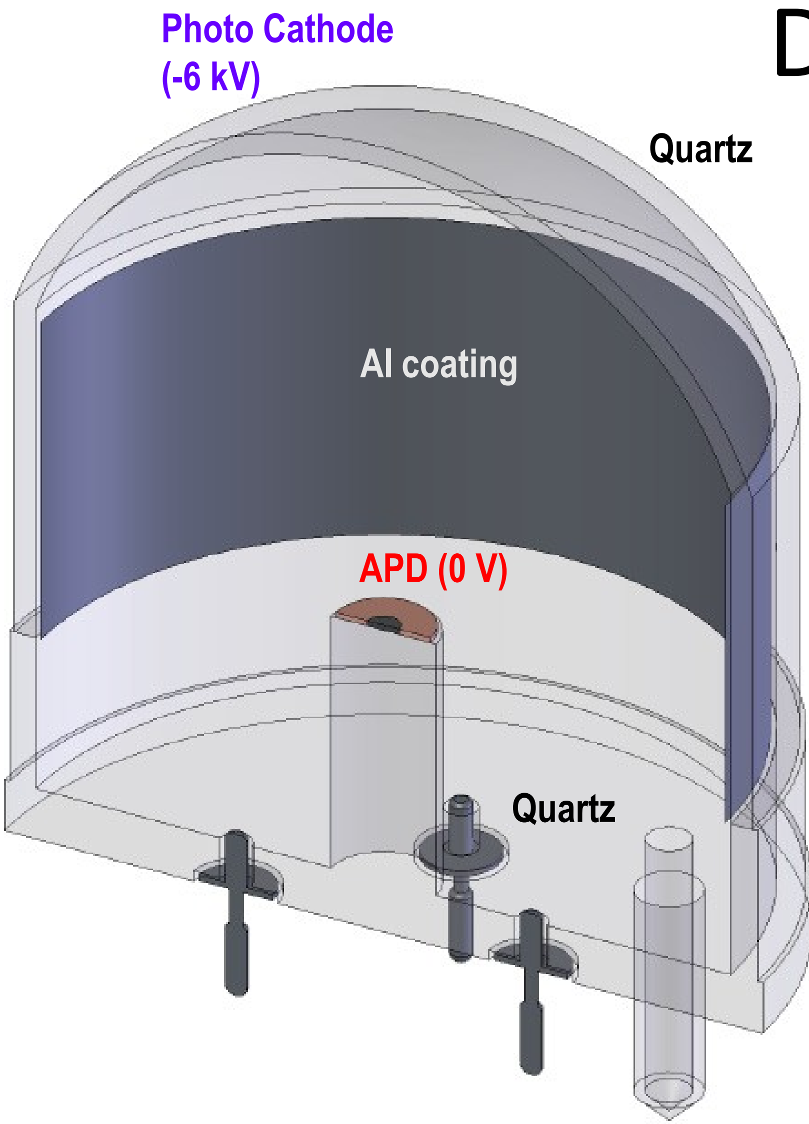
Overview

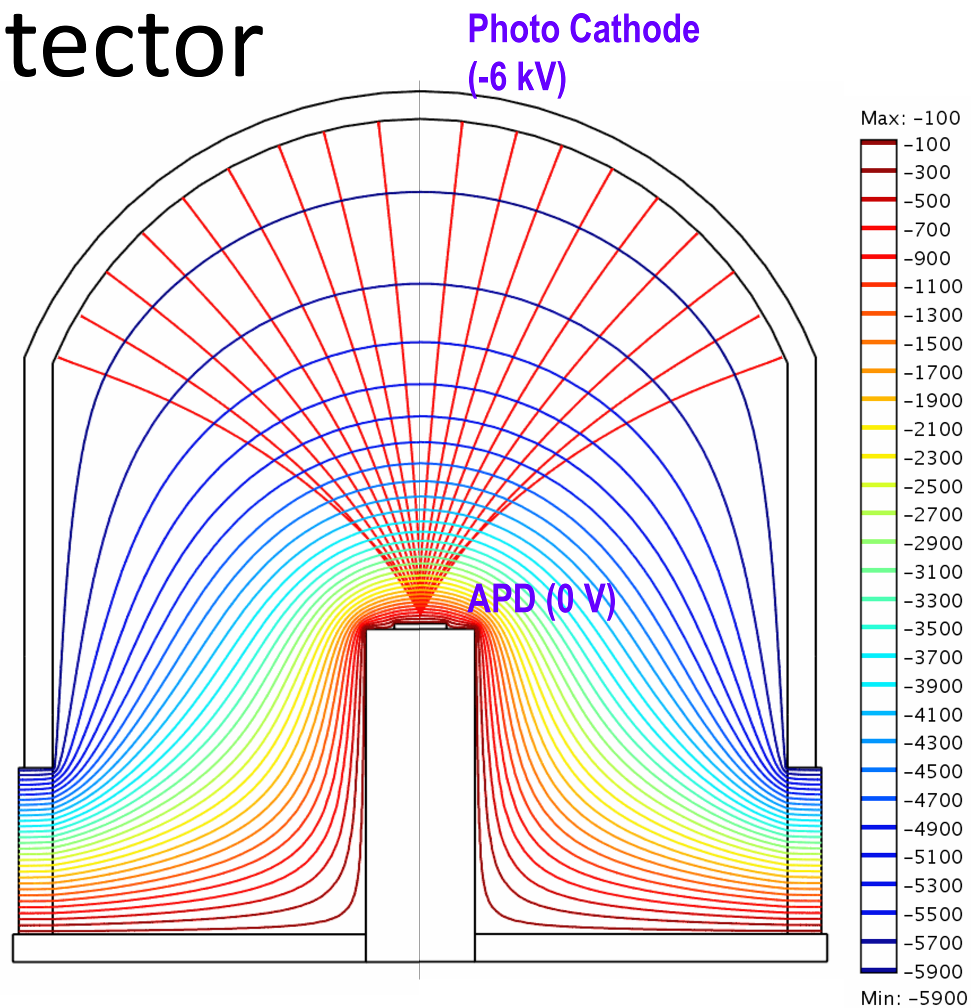
- Dual Phase TPC
- QUPID Concept
- QUPID Design Goals
- Test Systems/Results
- Support Structure
- Future DM Experiments
- Conclusion

Dual Phase TPC



QUPID, The QUartz Photon Intensifying Detector

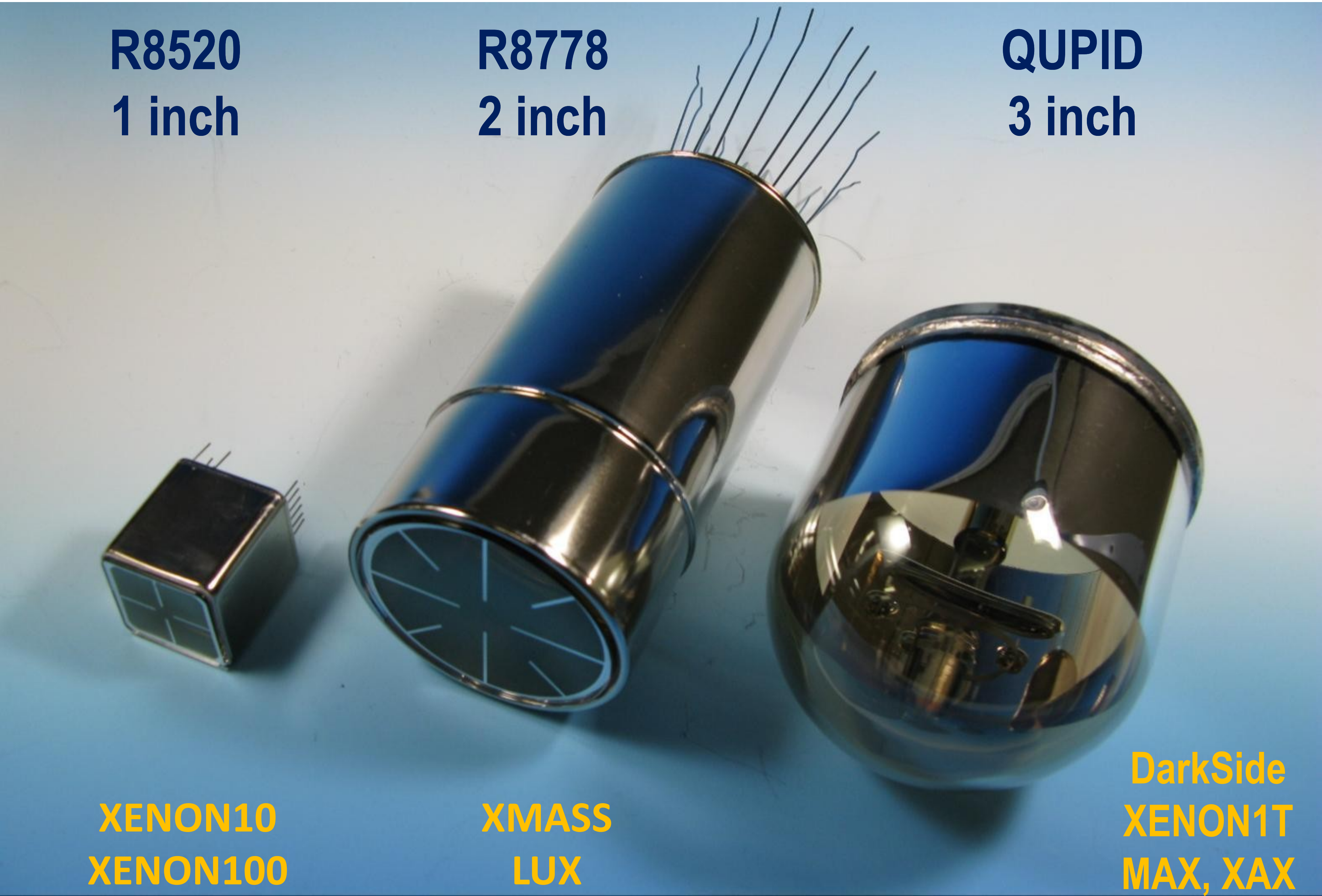




Made by Synthetic Silica only.

Actual QUPID

Comparison of Low-radioactive Photon Detectors from Hamamatsu



QUPID Design Goals

The QUPID should be better than standard PMTs in all aspects

	R8520
Radioactivity	<4.7 mBq/cm^2
Quantum Efficiency	>30%
Total Gain	>10^6
Pulse Width	~10 ns
Transit Time Spread	~1 ns

In addition:

- Photon Counting Capabilities
- Good Photocathode Uniformity
- Good Collection Efficiency

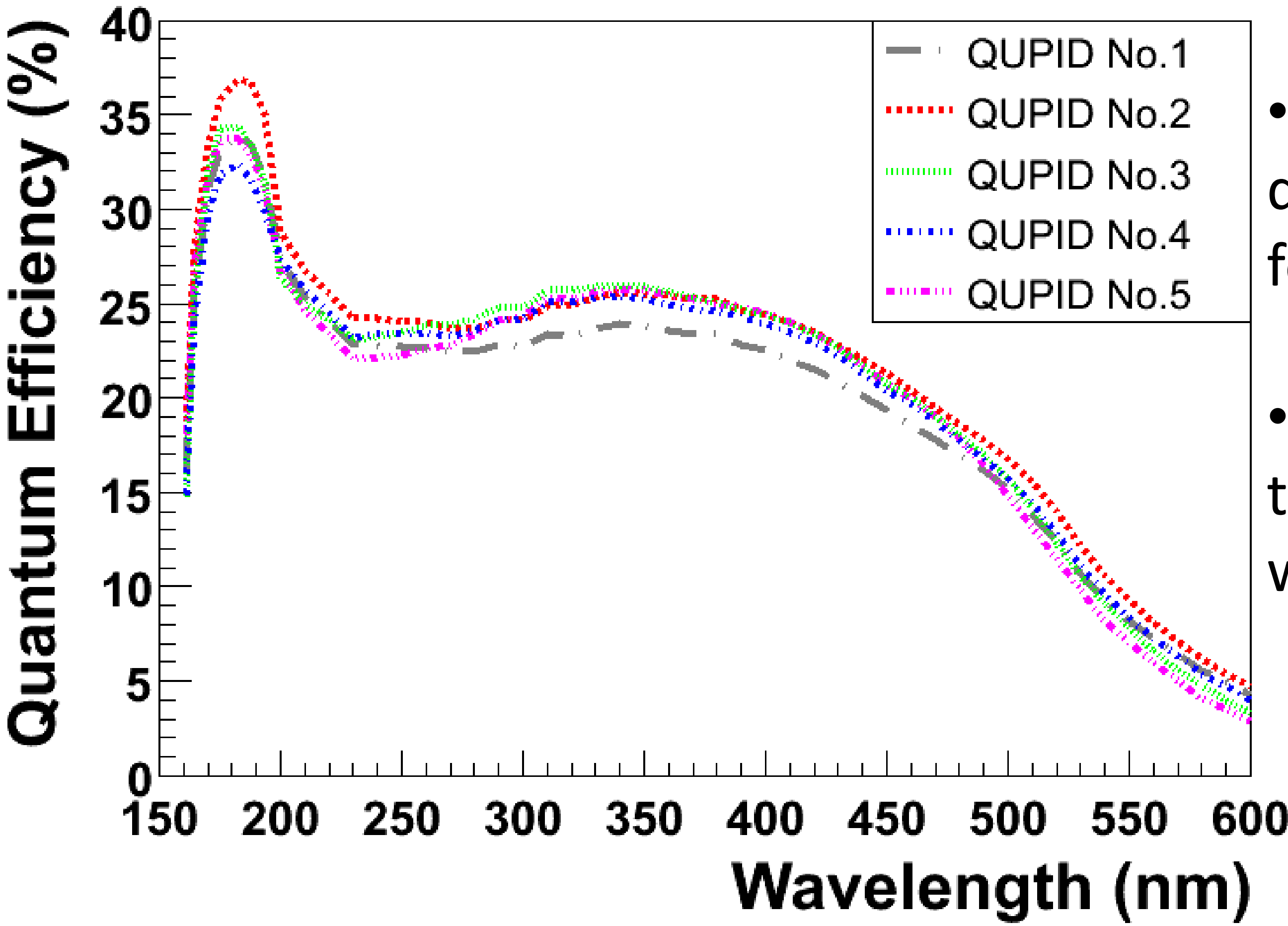
Radioactivity

Phototube	Effective Area	Units	^{238}U	^{226}Ra	^{232}Th	^{40}K	^{60}Co
R8520	6.5 cm^2	mBq/cm^2	<2.3	<0.056	<0.070	2.2	0.10
R11410-MOD	32 cm^2	mBq/cm^2	<2.9	<0.076	<0.082	0.42	0.11
QUPID	32 cm^2	mBq/cm^2	<0.54	0.010	0.012	0.17	<0.0056

- Radioactivity measured at the Gator screening facility in LNGS, operated by University of Zurich
- R8520 is a 1" square PMT used in Xenon10 and Xenon100
- R11410-MOD is a 3" Circular PMT being considered for future DM detectors
- The radioactivity of the QUPIDs are far better than the others per unit area
- ^{60}Co and ^{40}K emits γ's that penetrate particularly far and is of greatest concern for large DM detectors

arXiv:1103.3689, arXiv:1103.5831

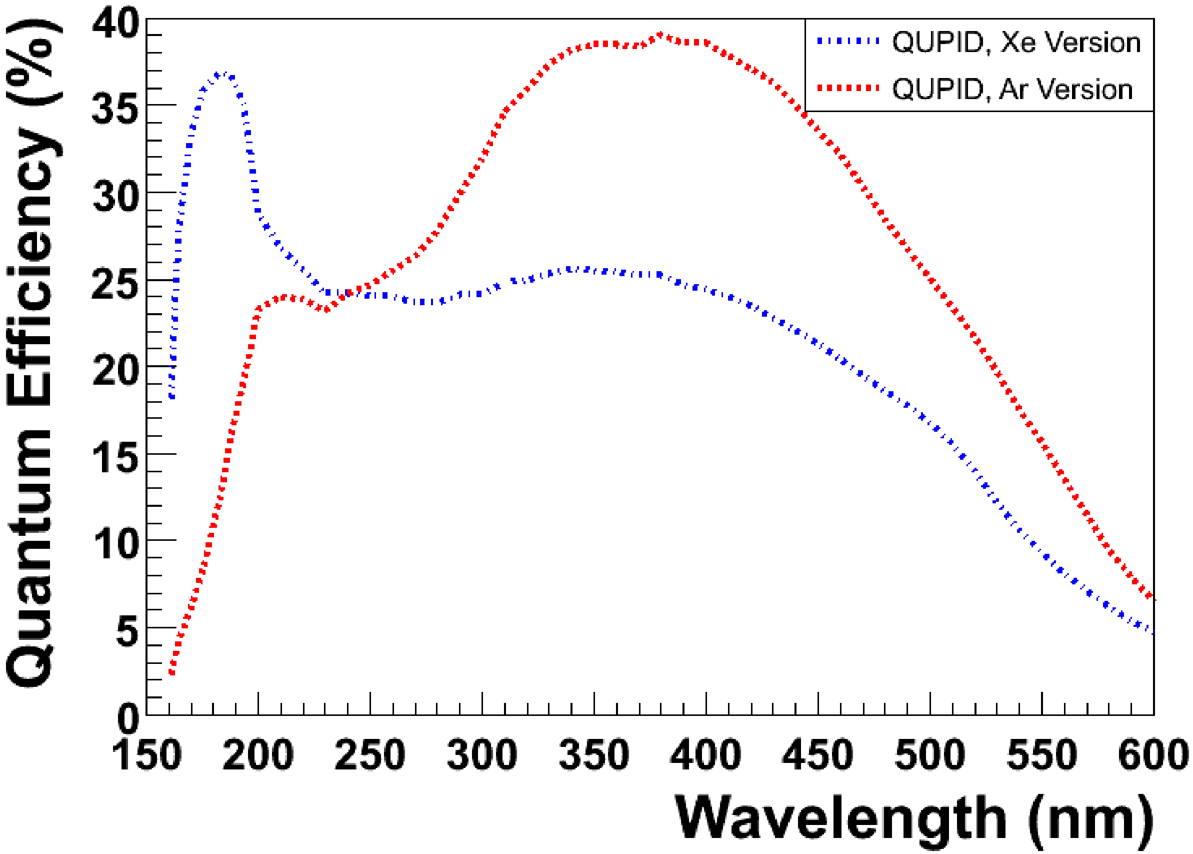
Quantum Efficiency



- Photocathode developed specifically for operation in Xenon
- >30% QE at 178 nm, the scintillation wavelength of Xenon

Data taken at Hamamatsu

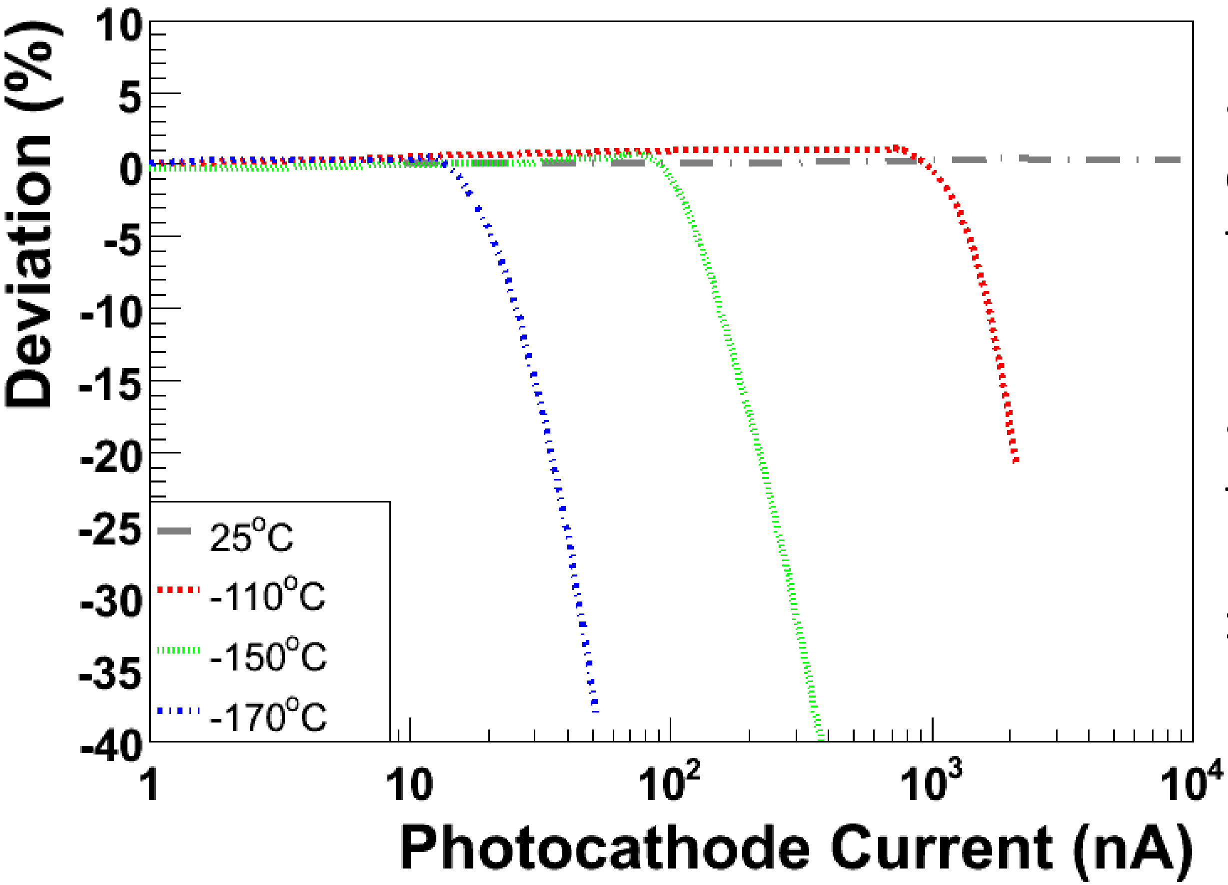
Argon and Xenon Versions of the QUPID



- The photocathode can be optimized for Argon operation, quartz is not transparent to Argon scintillation wavelength, so a WLS must be used to bring it to visible wavelengths
- The Quantum Efficiency of the Argon version peaks at ~40% near 400 nm
- TPB can be used to wavelength shift Ar scintillation light to the visible wavelengths

Data taken at Hamamatsu

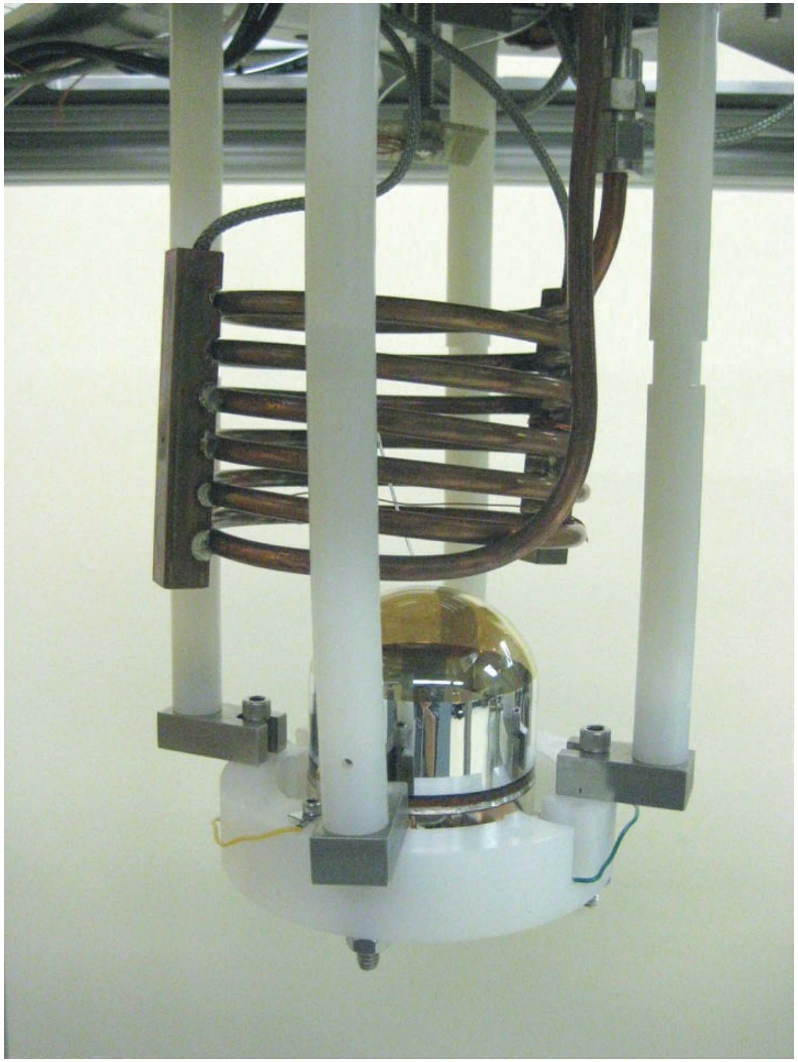
DC Cathode Linearity

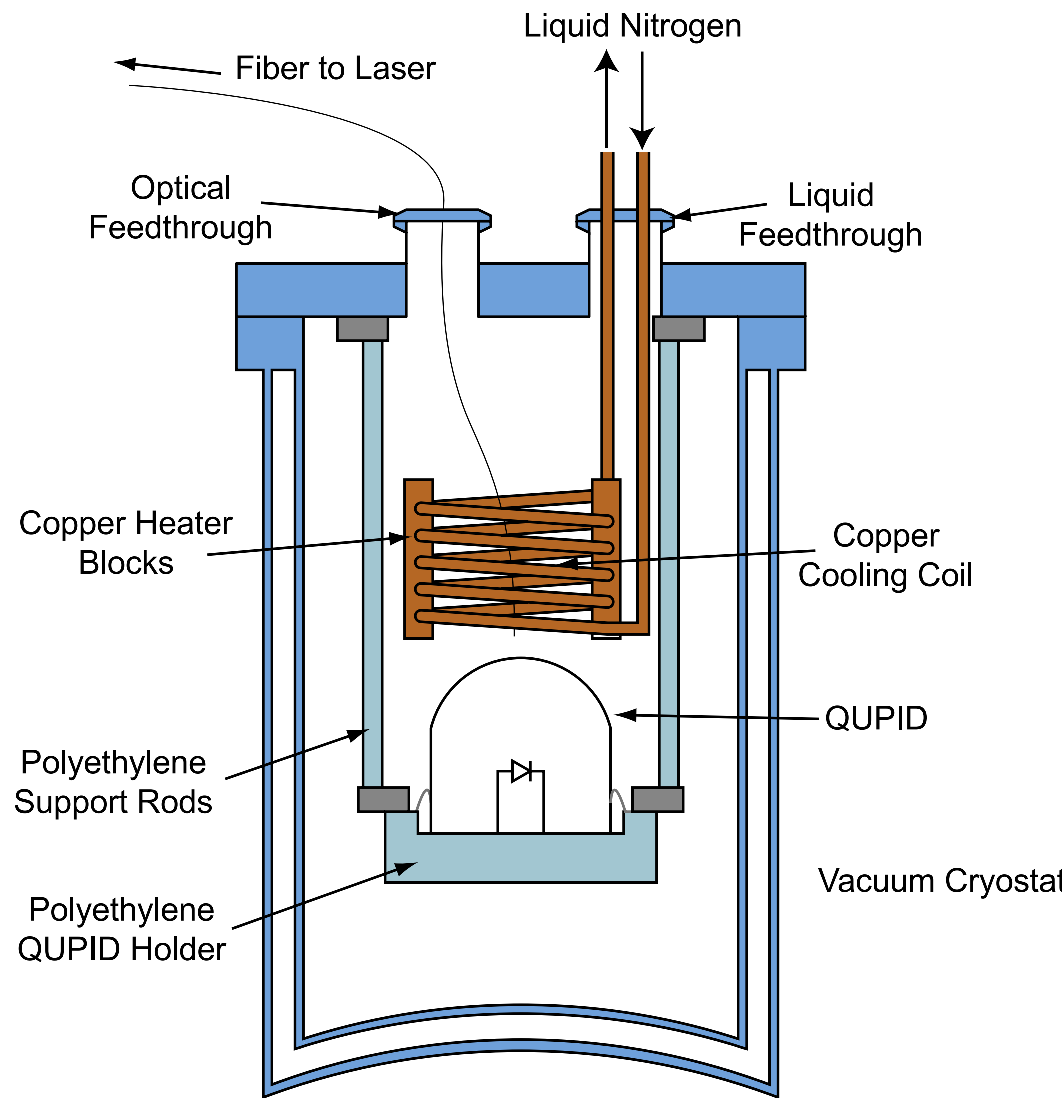


- Photocathode also developed to withstand low temperatures with good linearity
- At Liquid Xenon temperature, the photocathode is linear up to >1μA

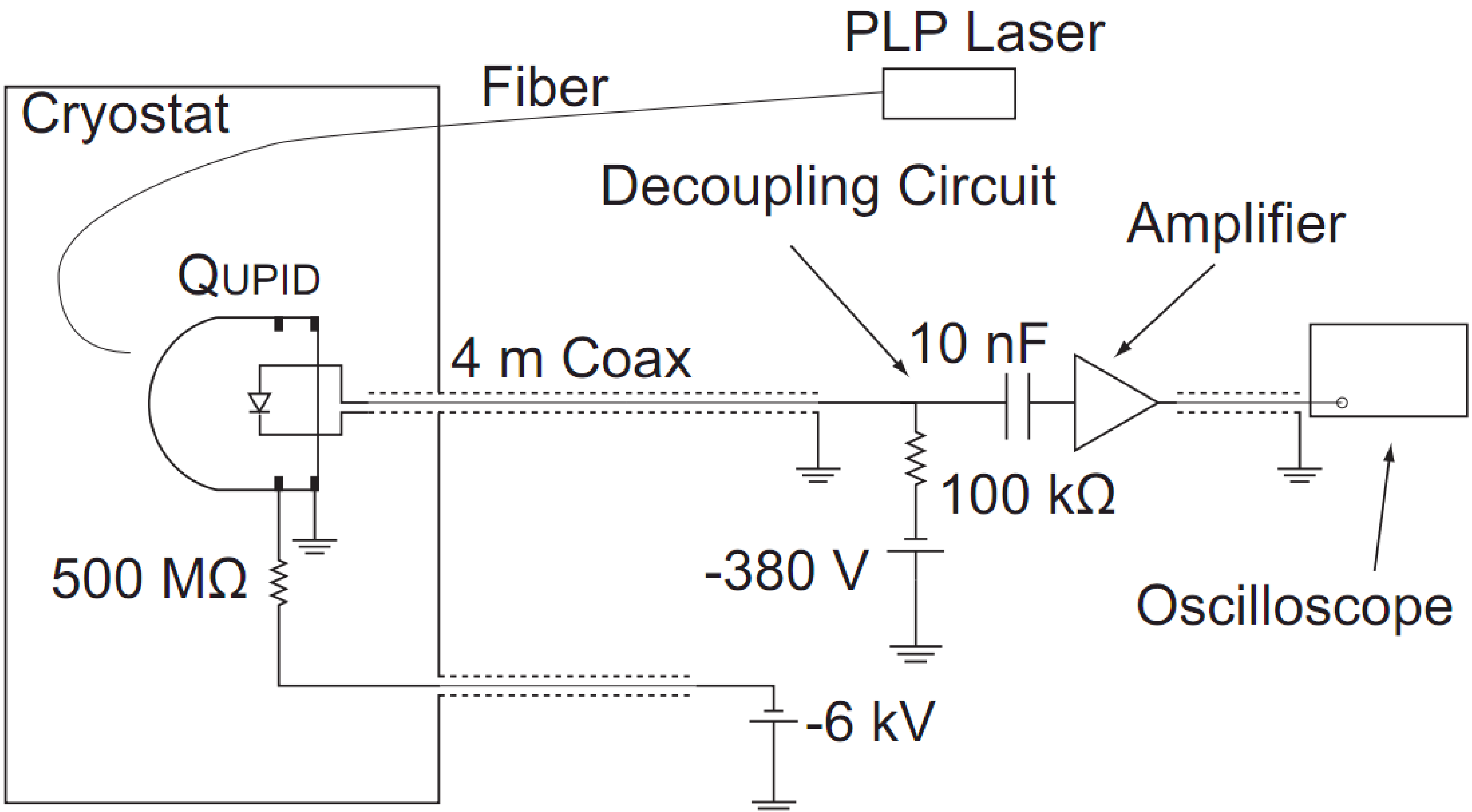
Data taken at Hamamatsu

Liquid Nitrogen Cooling System

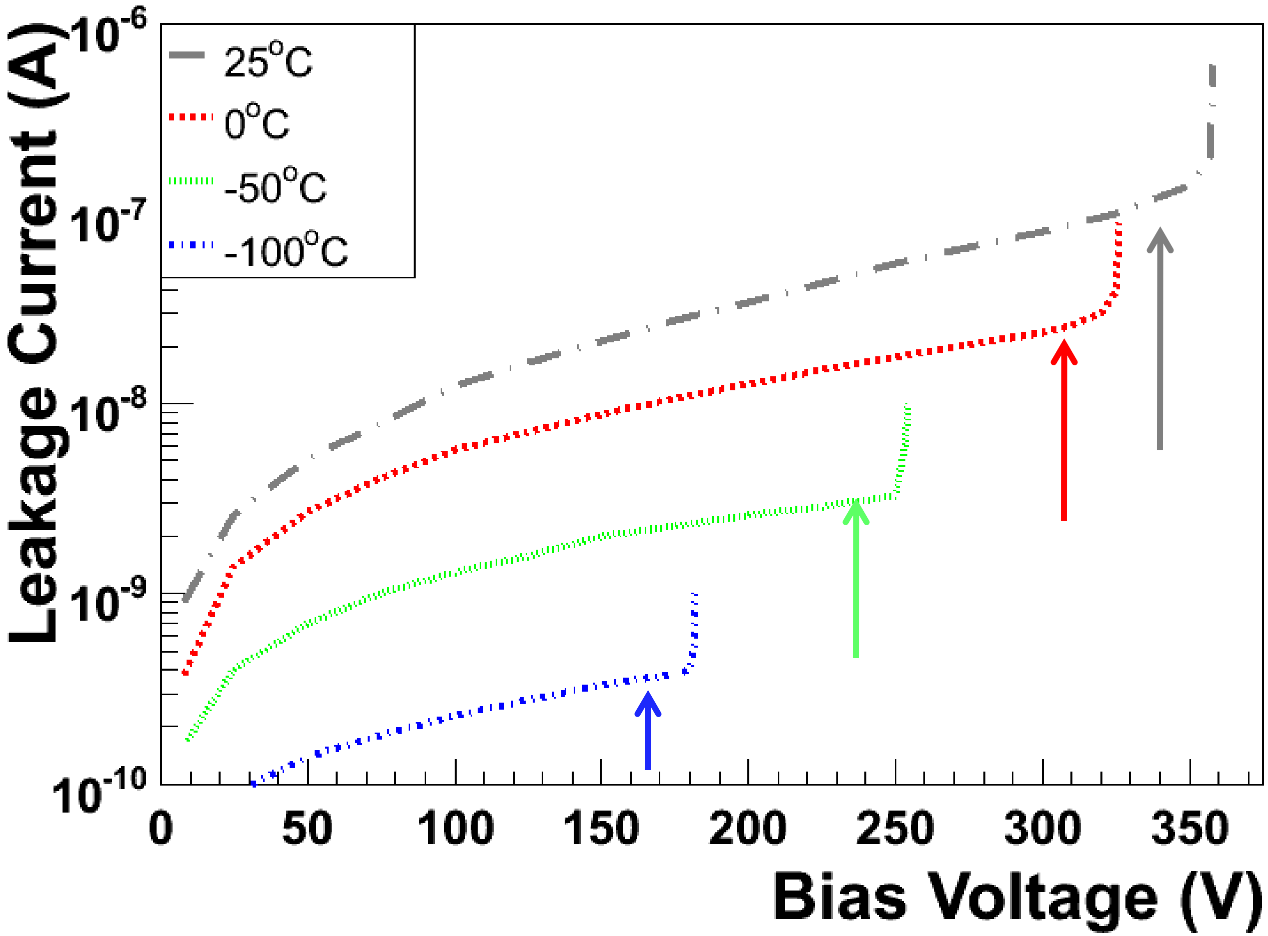




Readout Schematic



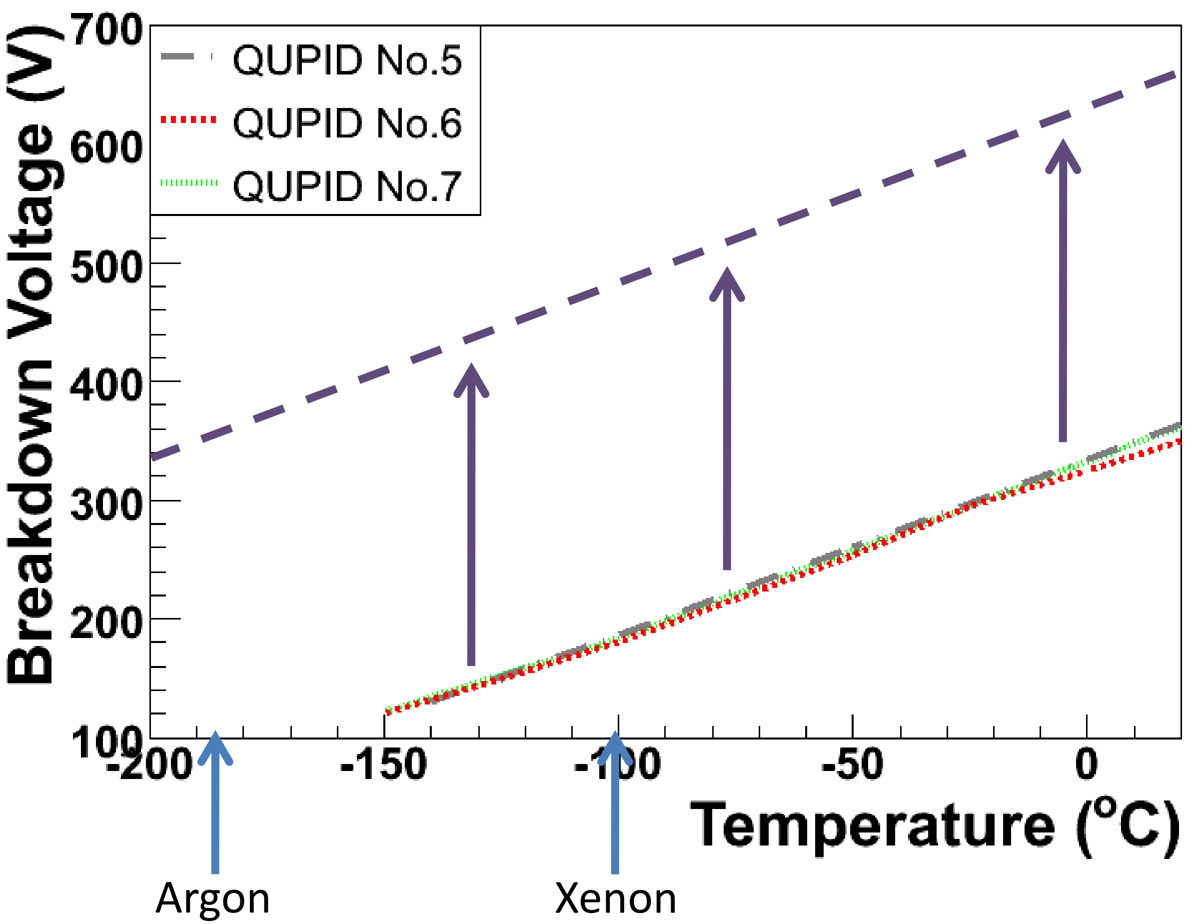
Leakage Current



- Strong temperature dependence of Leakage Current

- Want to operate before breakdown to maximize gain

Leakage Current for Argon Operation

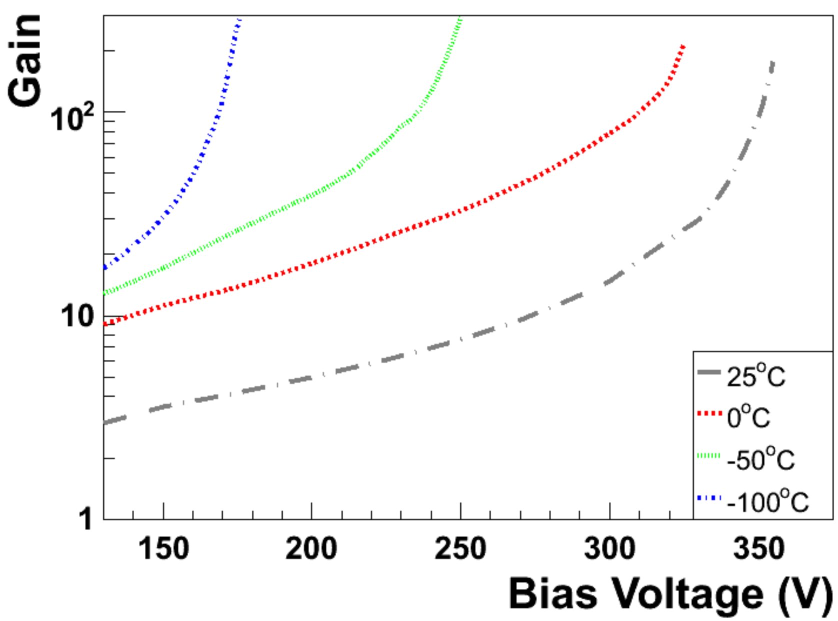


- APD is inoperative below 120V bias
- At liquid xenon temperatures, the APD is still operative
- APD for liquid argon operation has been developed by Hamamatsu and is being integrated in the QUPID for Liquid argon temperature

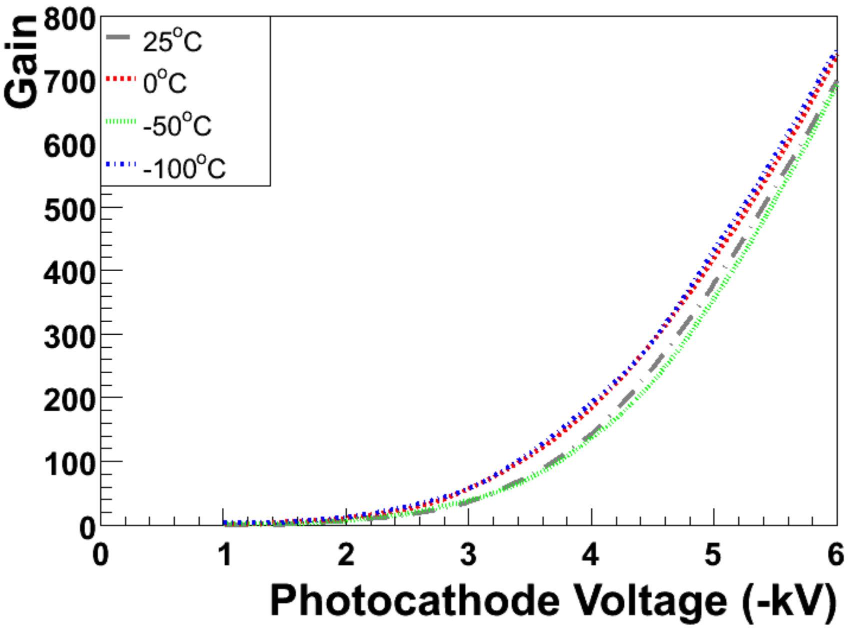
Avalanche and Bombardment Gain

- Avalanche Gain shows strong temperature dependence, Bombardment Gain does not
- Maximum Avalanche Gain ~200, maximum Bombardment Gain ~750
- Total Gain ~10^5

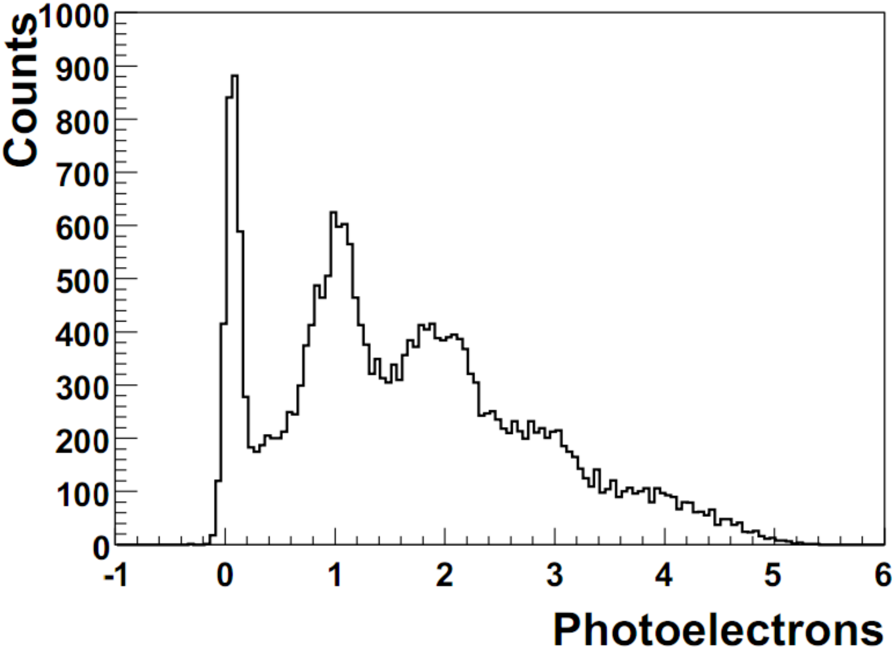
Avalanche Gain

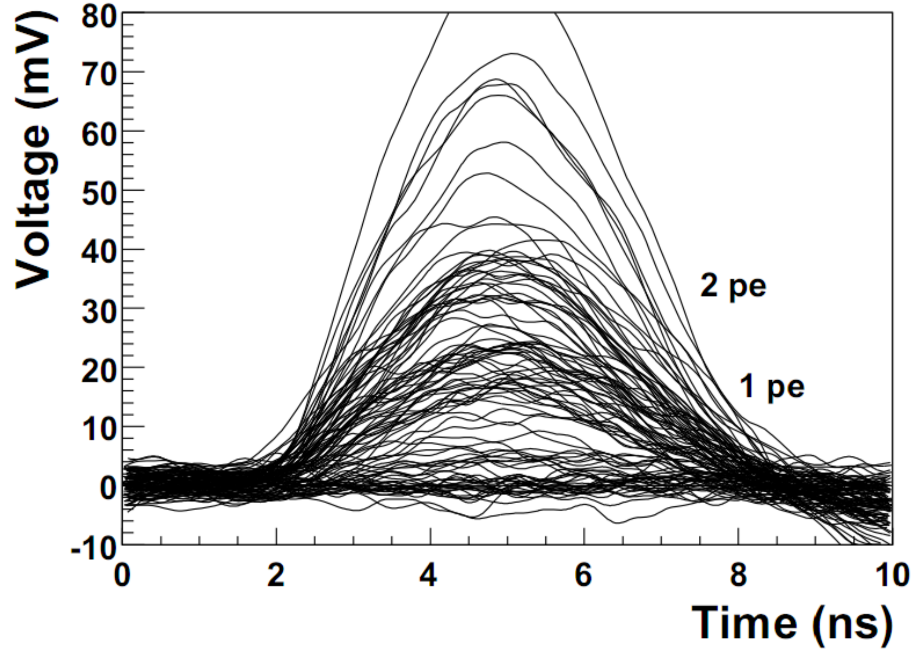


Bombardment Gain

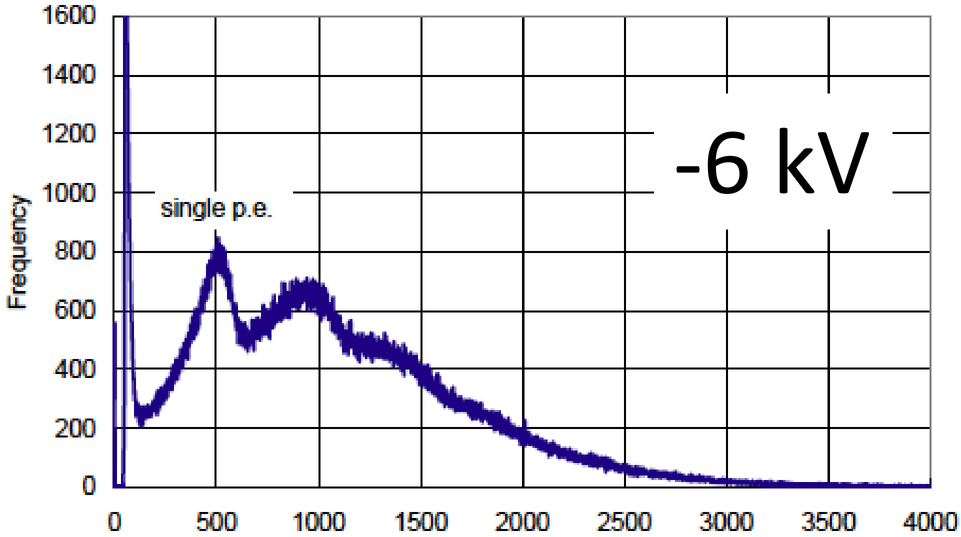


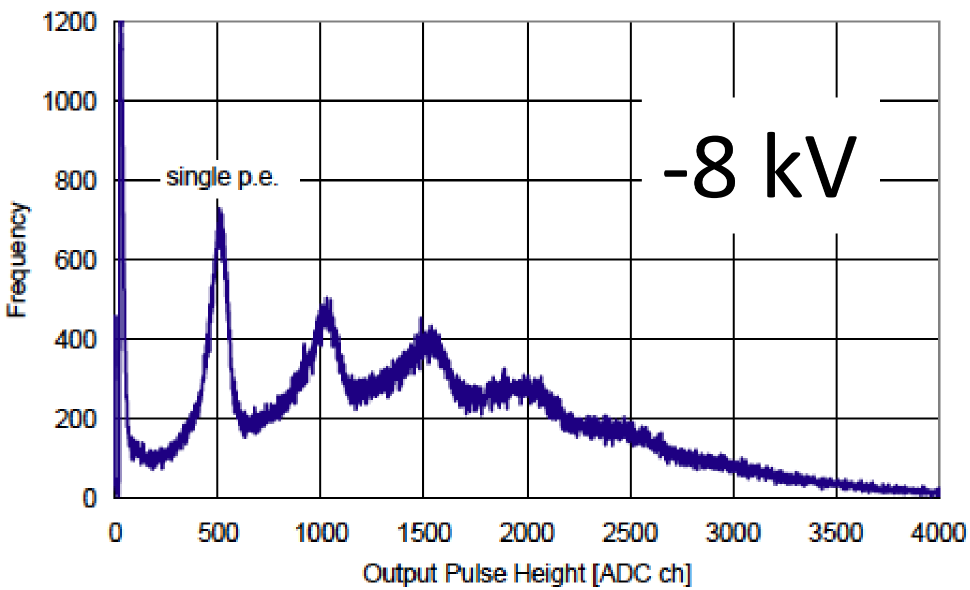
Photon Counting Capabilities and Pulse Shape





	ns
Rise time	1.8 ± 0.1
Fall time	2.5 ± 0.2
Pulse width	4.20 ± 0.05
Transit time spread	0.16 ± 0.03

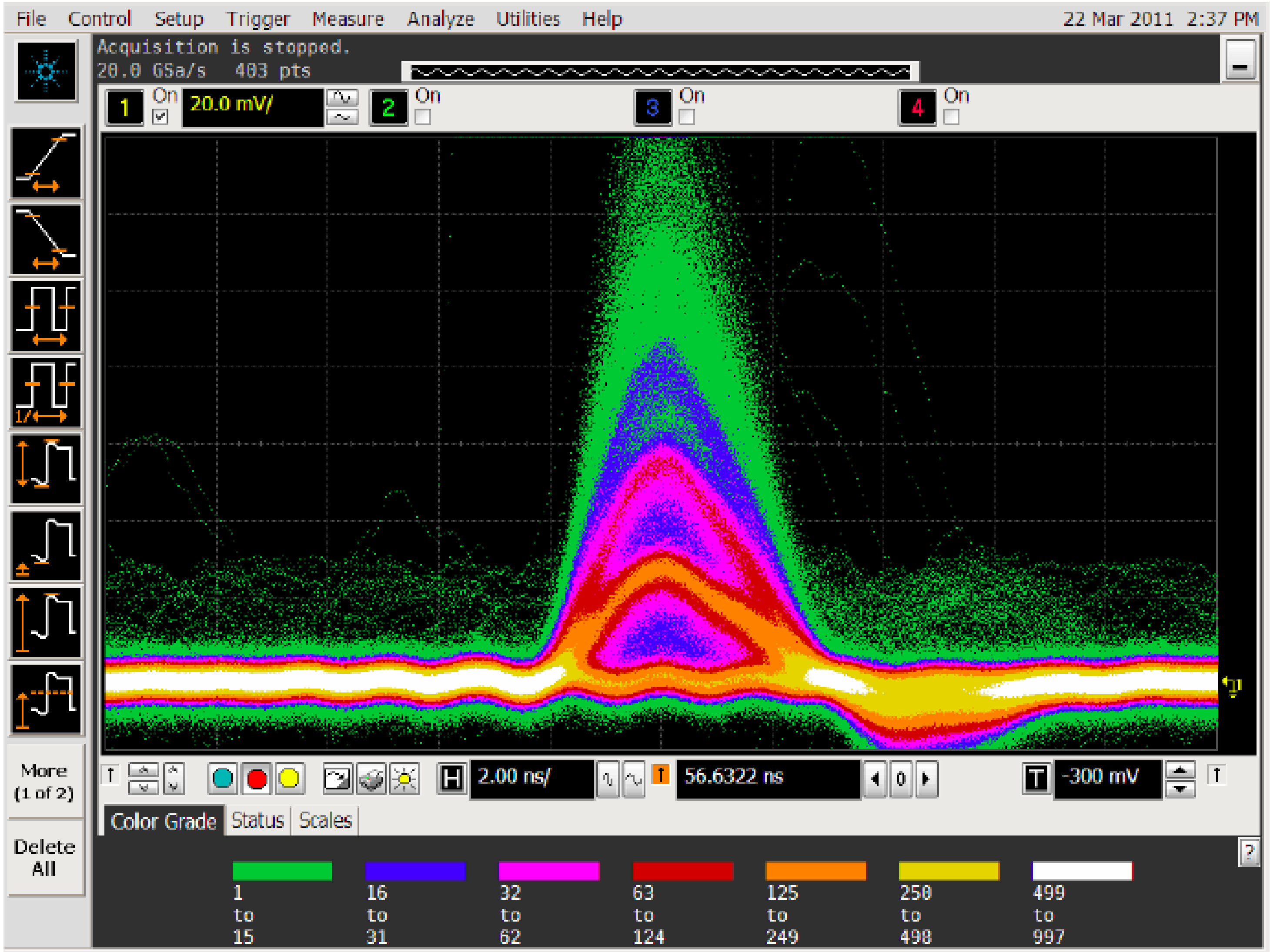




- A new version of the QUPID is being made
- Operation will be possible up to -8 kV
- Much better photon counting is possible

Data taken at Hamamatsu

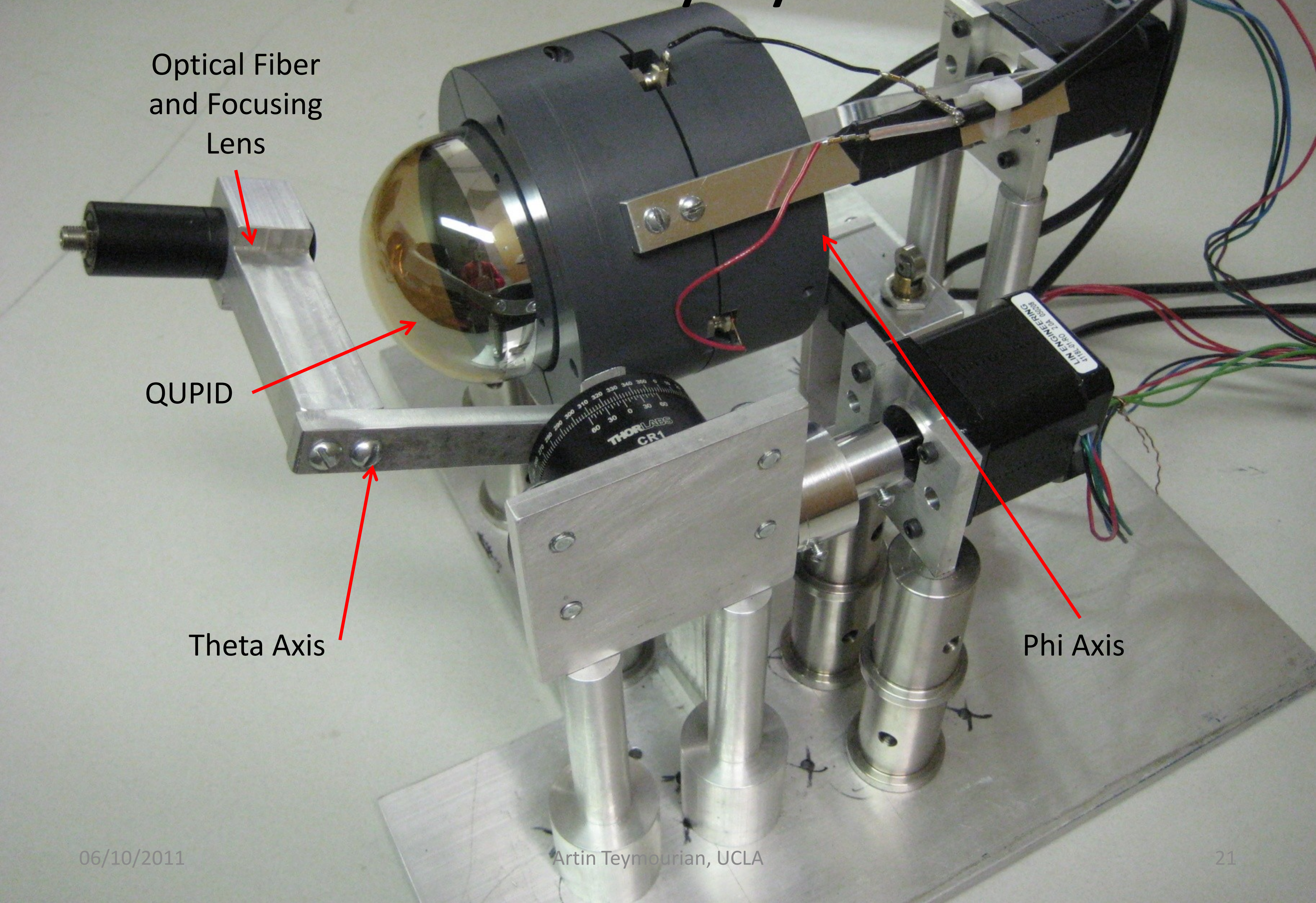
Preliminary -8 kV Operation



-8kV, 335V, C5594 amp., PLP 405nm, 20mV/div, 2ns/div

Data taken at Hamamatsu

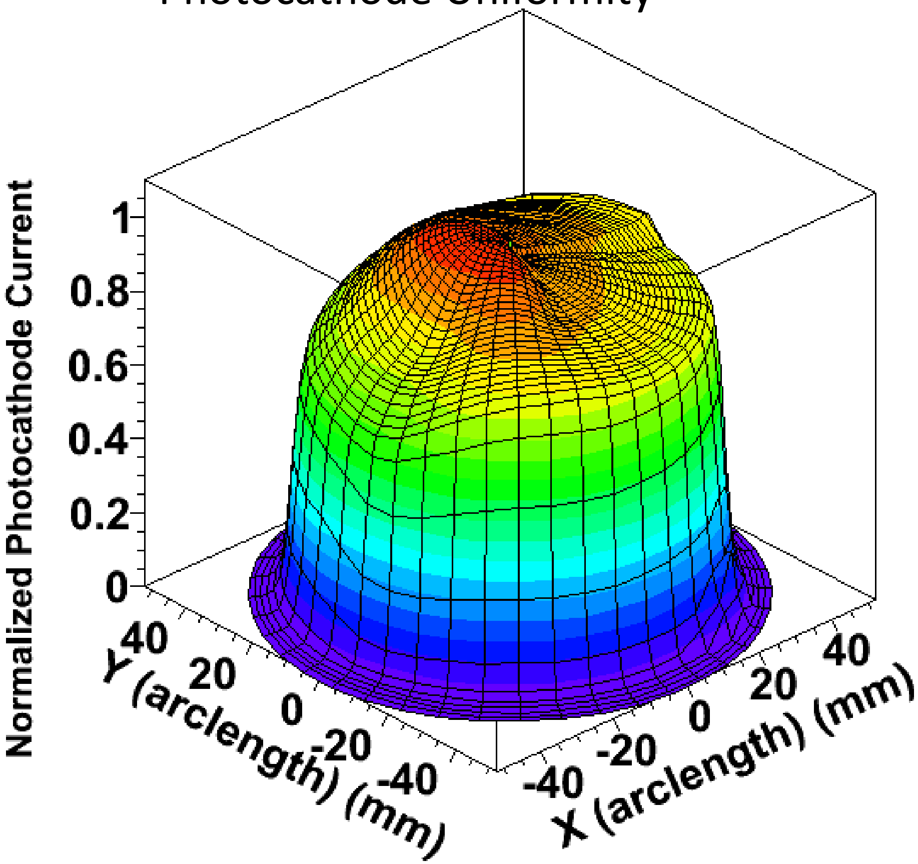
Uniformity System



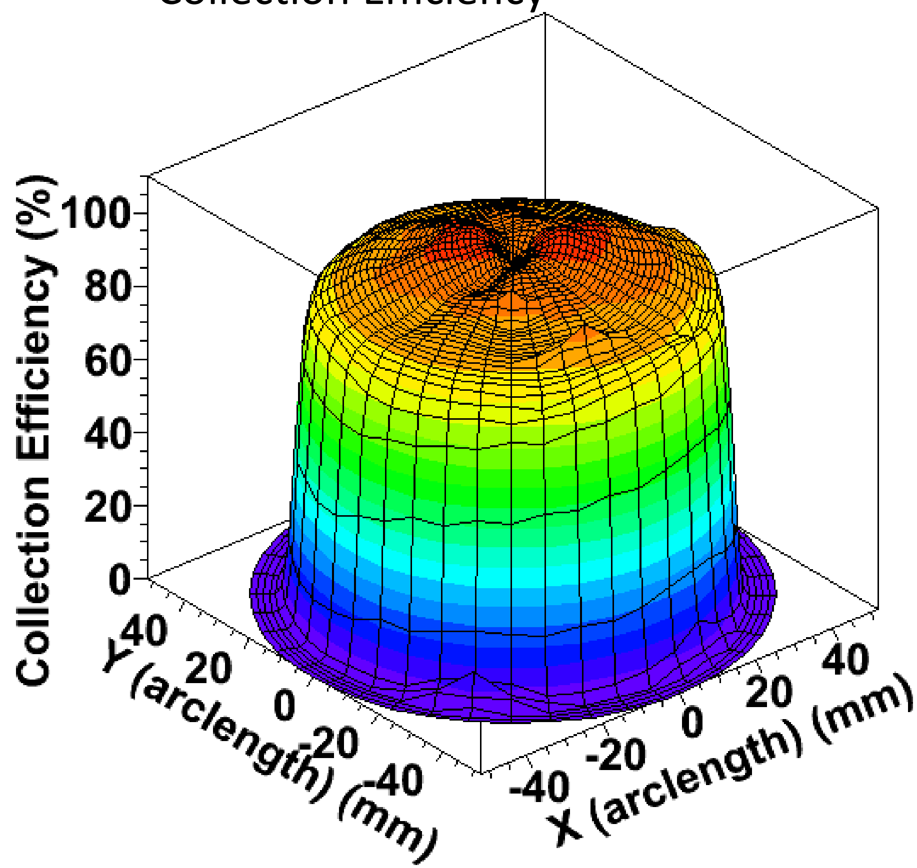
Uniformity

- Uniform photocathode response (within 20%) and collection efficiency

Photocathode Uniformity



Collection Efficiency



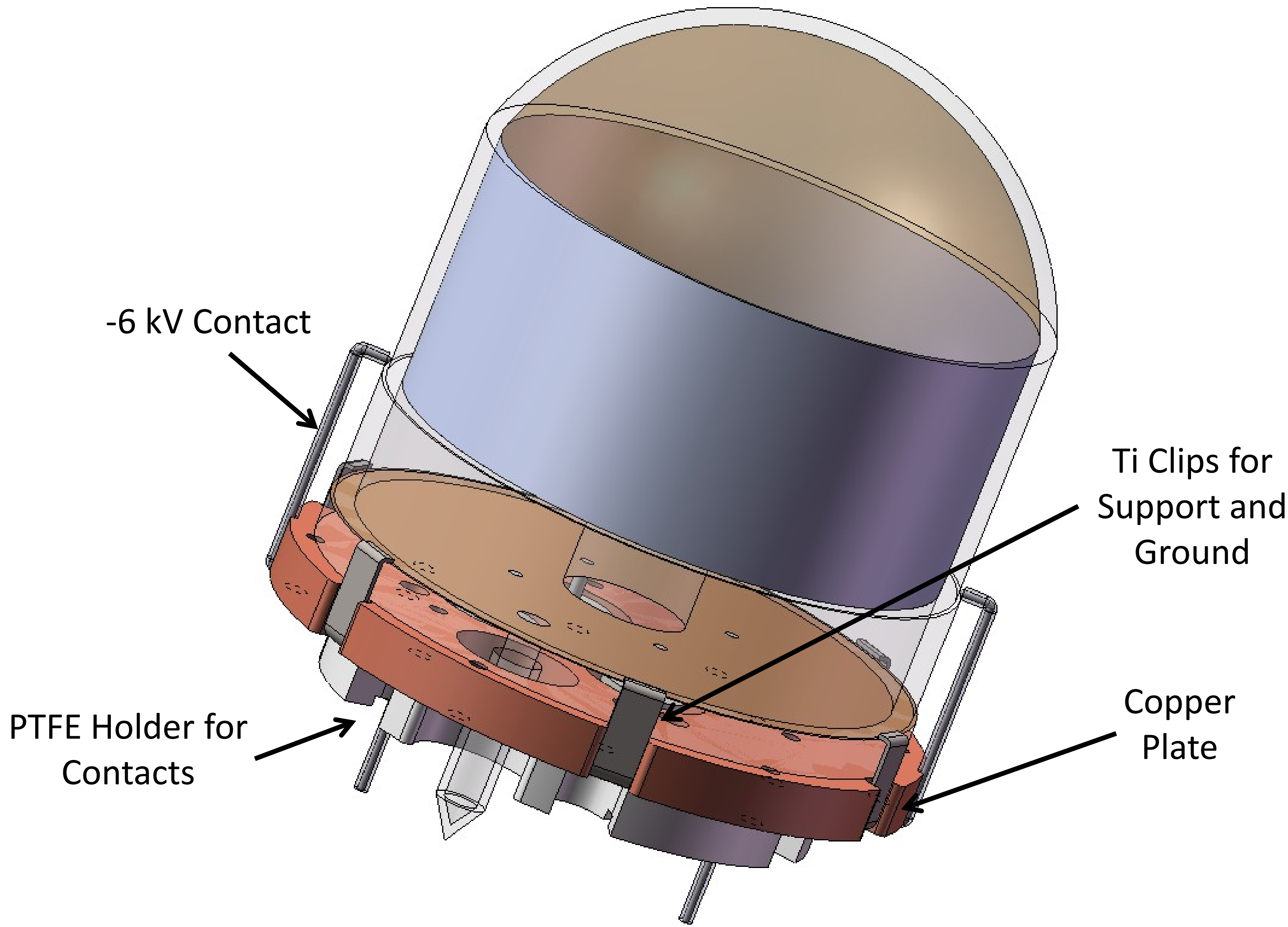
QUPID Characteristics Summary

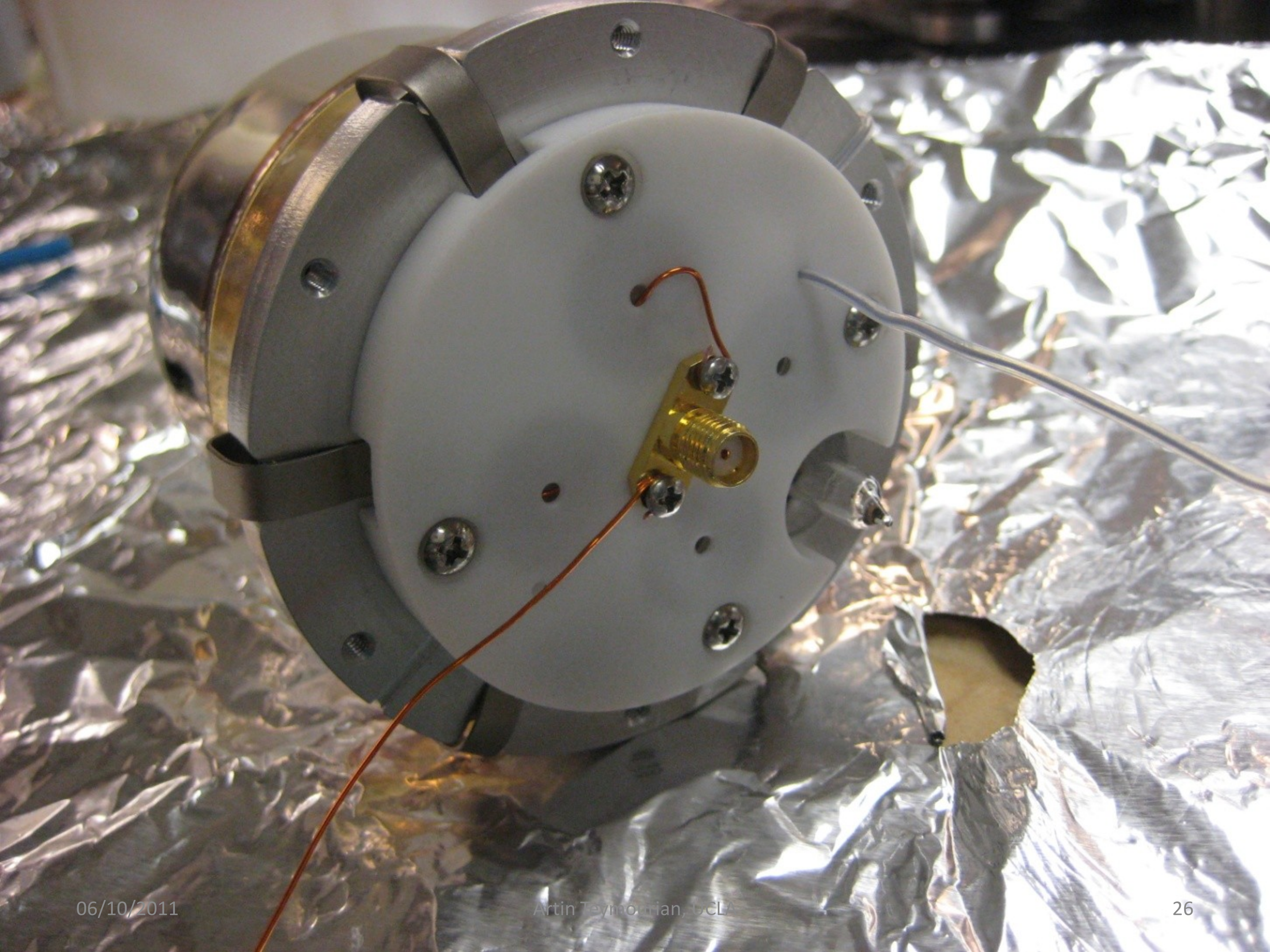
	R8520	QUPID
Radioactivity	<4.7 mBq/cm^2	<0.59 mBq/cm^2
Quantum Efficiency	>30%	>30% at 178nm
Photocathode Linearity @ -100^{o}C	0.1 nA	>1μA
Total Gain	>10^6	>10^5 (>10^6 with amplifier)
APD Leakage Current	---	<1 nA at -100^{o}C
Pulse Width	~10 ns	4.2 ns
Transit Time Spread	~1 ns	160 ps

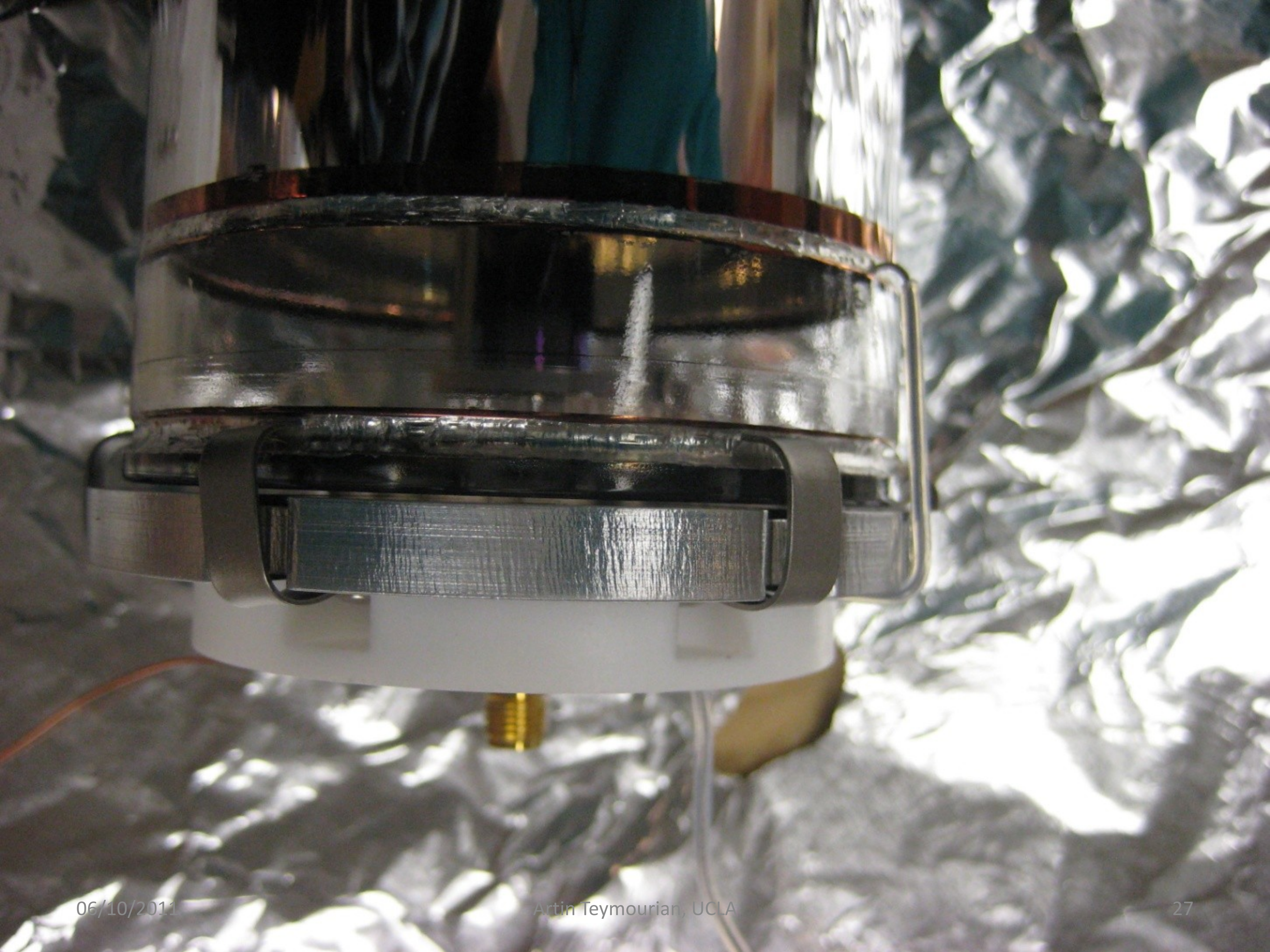
- 1, 2, 3 photoelectron peaks seen clearly
- Good photocathode uniformity
- Excellent collection efficiency over the entire photocathode

Operation in Liquid Xenon

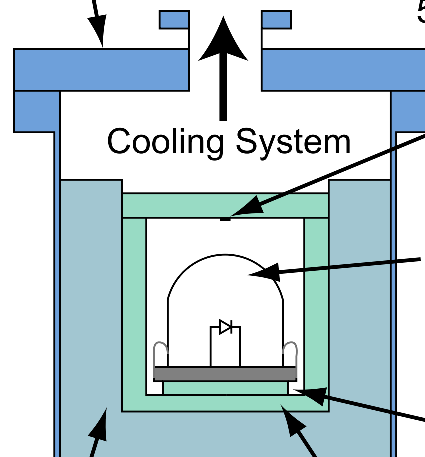
Single QUPID Holder



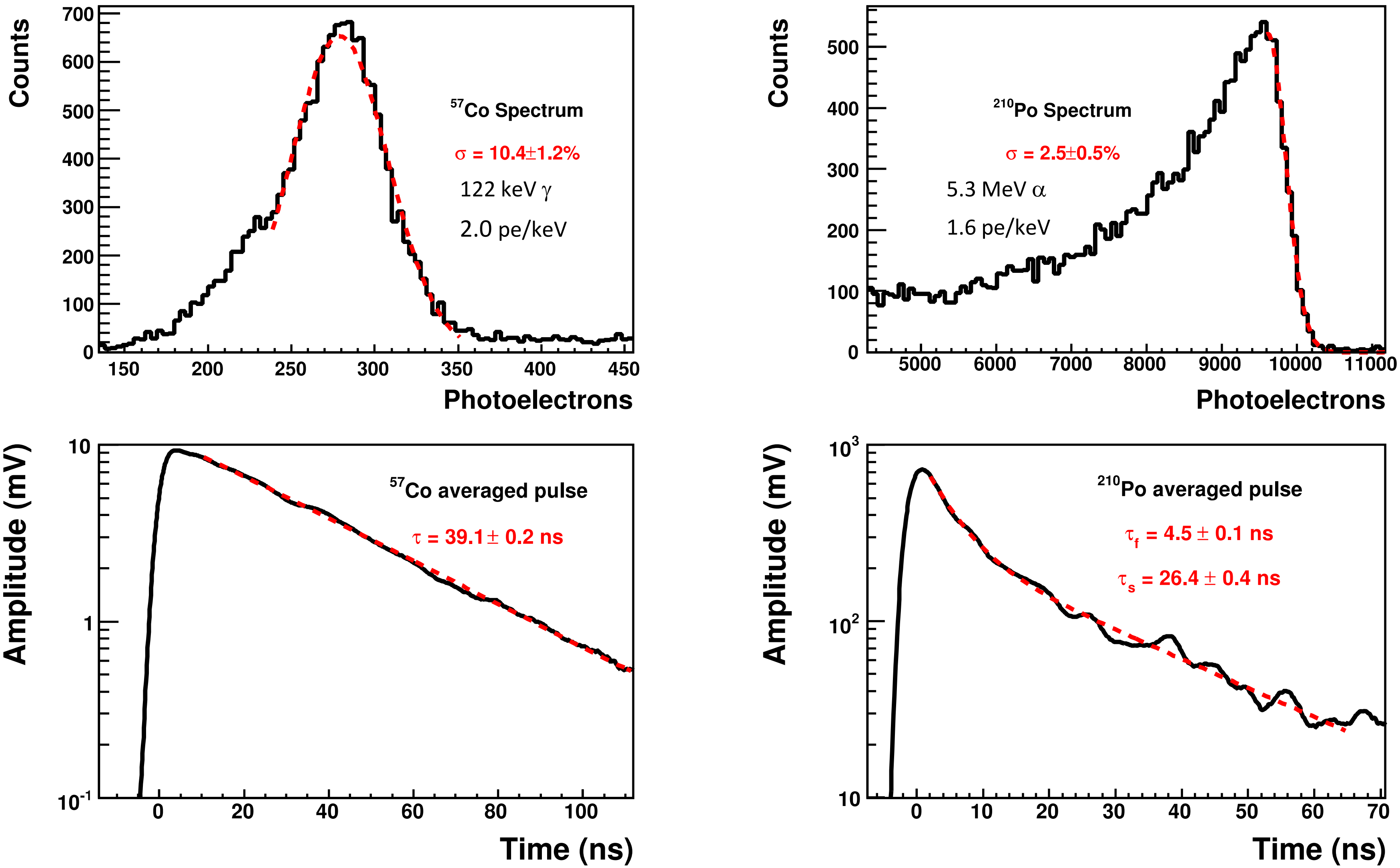




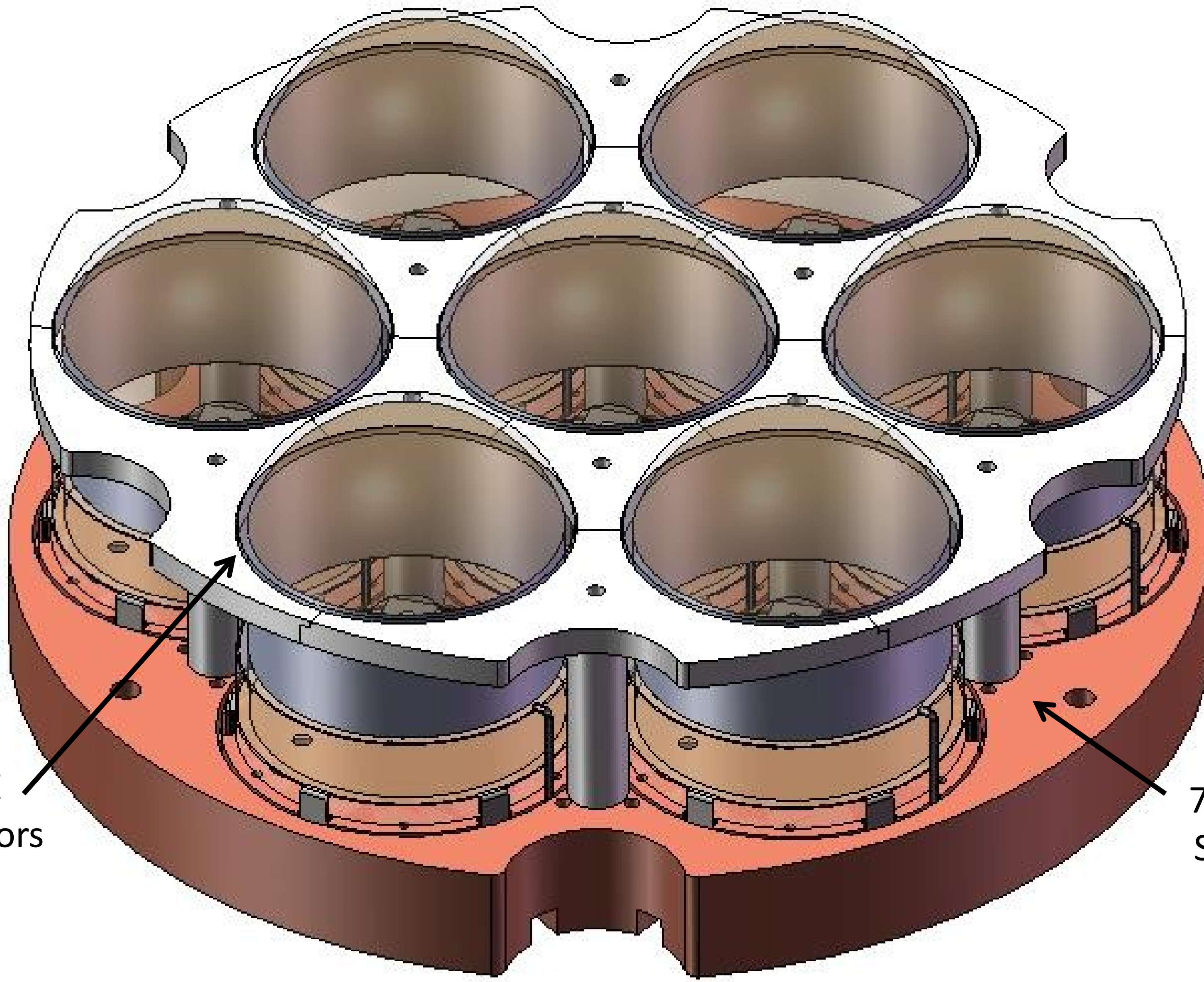
QUPID Operation in Liquid Xenon



Scintillation Light of Xenon Observed

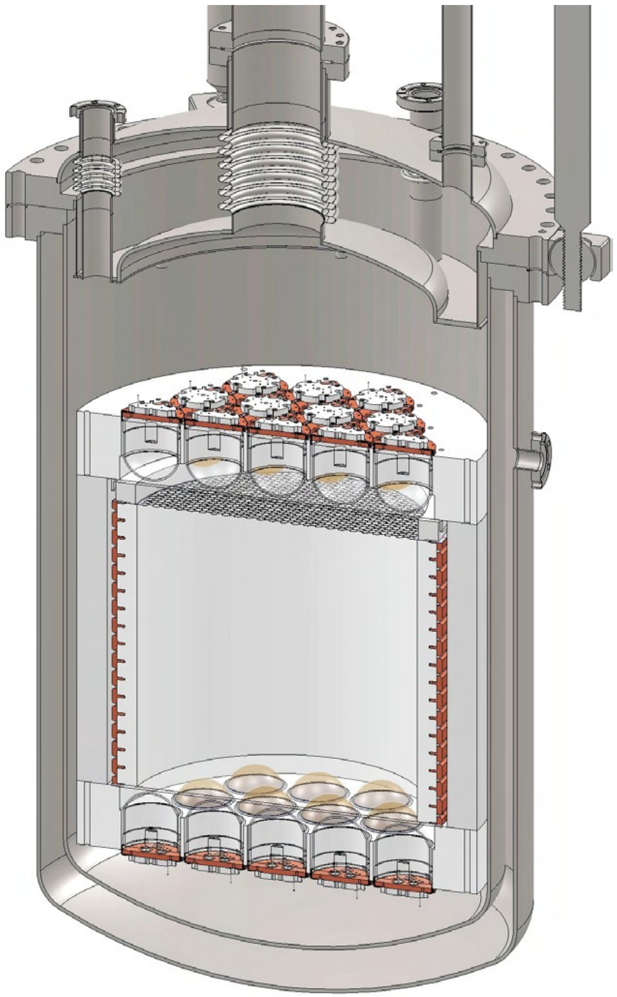


7 QUPID Holder

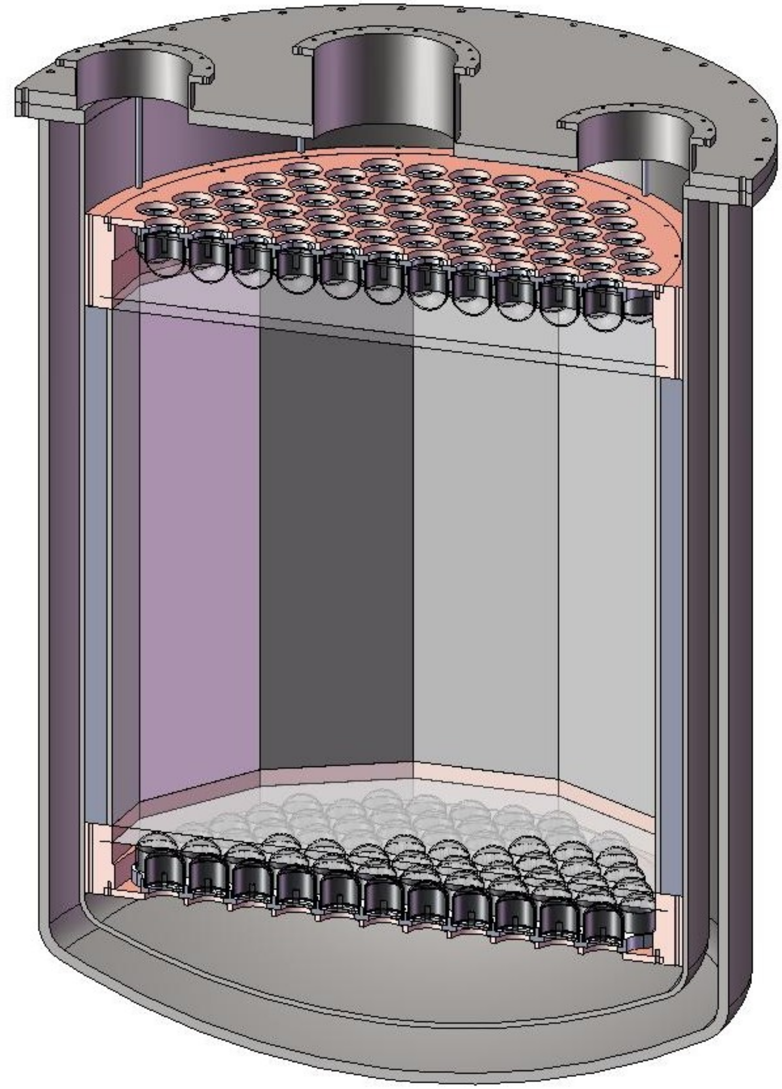


Future Detectors

DarkSide50



Xenon1Ton



Conclusion

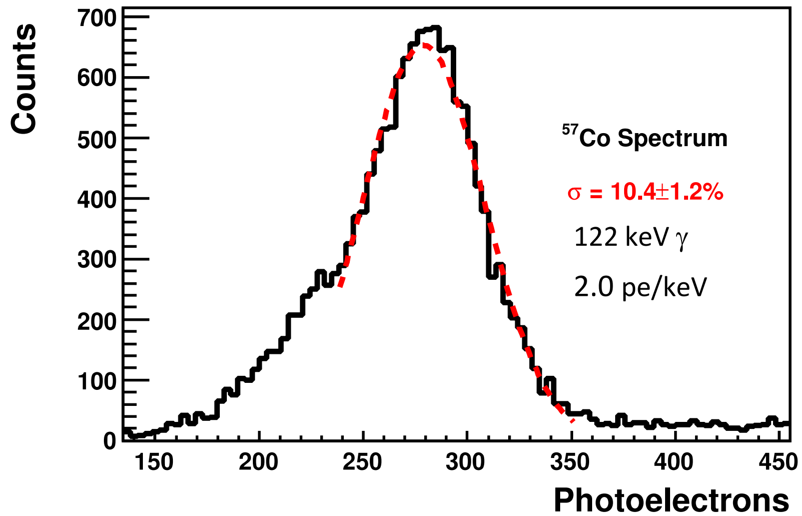
- QUPIDs are a new, low radioactivity phototube for future DM experiments
- Excellent photon counting, uniformity, quantum efficiency, and photocathode linearity
- Has been operated in cryogenic temperatures and in Liquid Xenon, with scintillation light being observed
- Will be used in DarkSide50 and Xenon1Ton

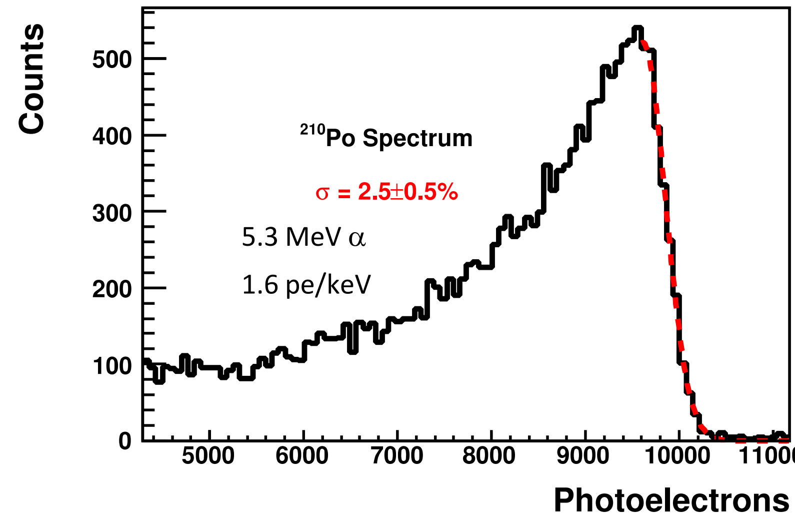
Acknowledgements

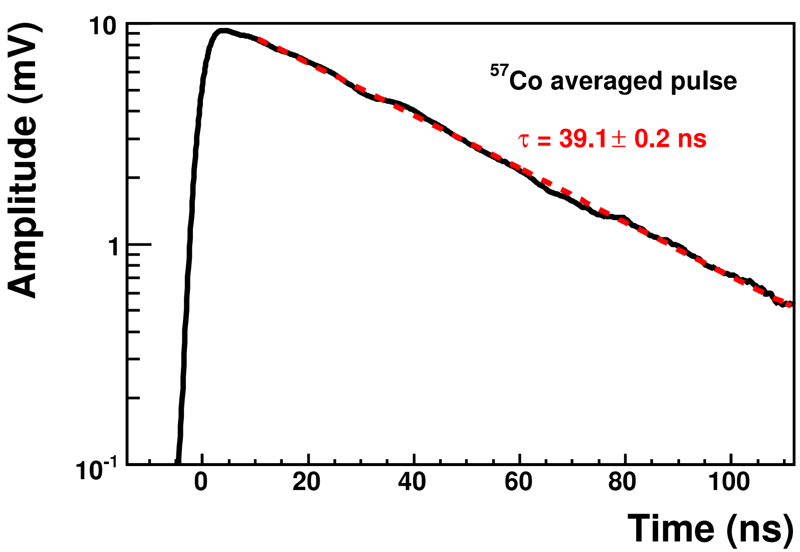
- XENON100 Collaboration
- DarkSide50 Collaboration
- MAX Collaboration
- Hamamatsu Photonics
- "Characterization of the QUartz Photon Intensifying Detector (QUPID) for use in Noble Liquid Detectors" arXiv:1103.3689
- "Material screening and selection for XENON100" arXiv:1103.5831

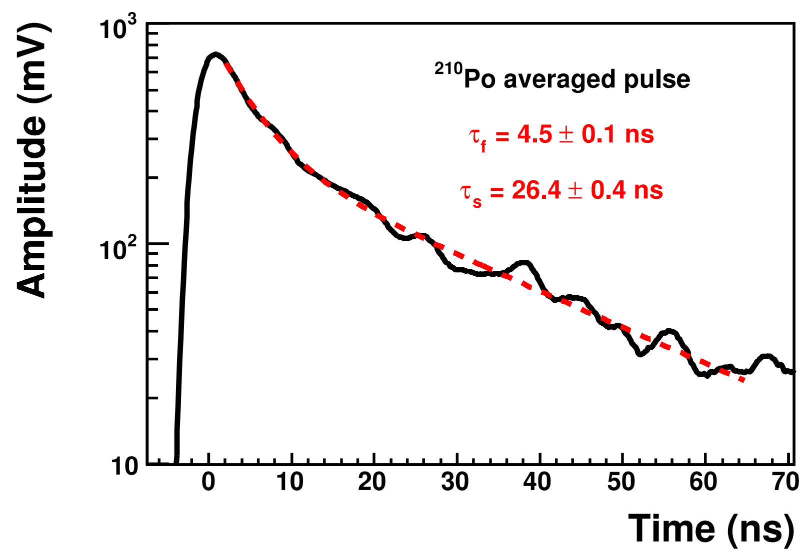
Extra Slides

Scintillation Light of Xenon Observed

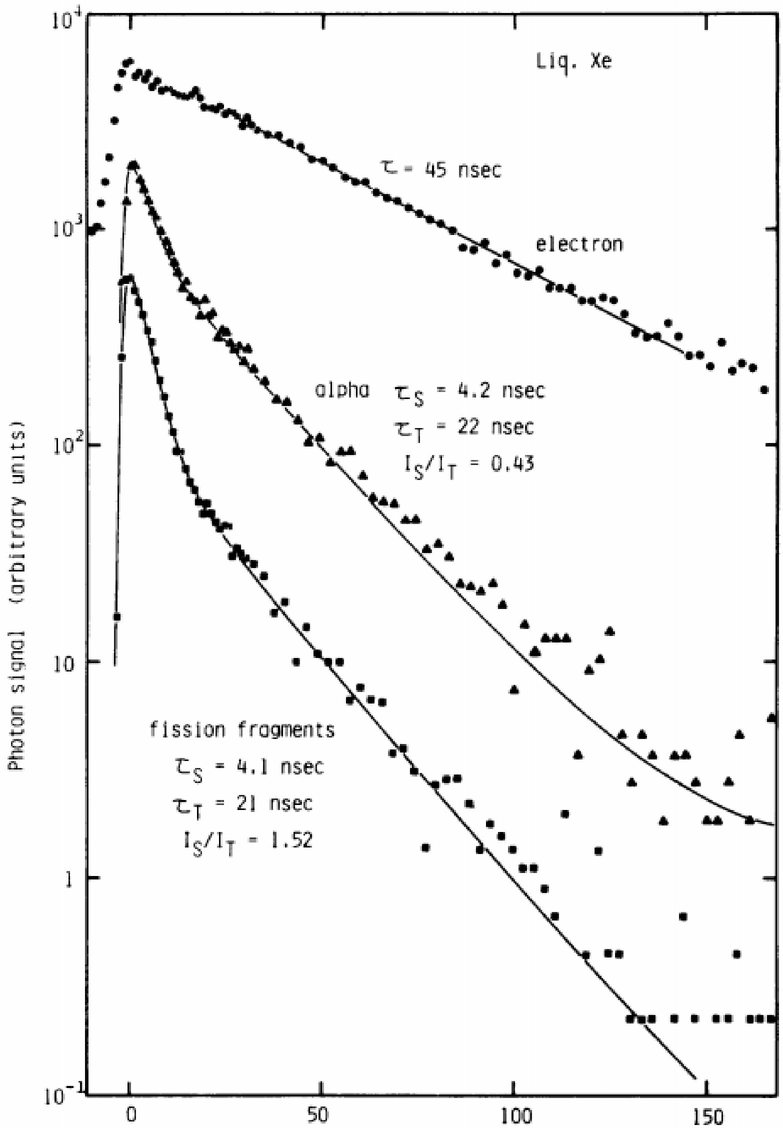








Published Decay Times



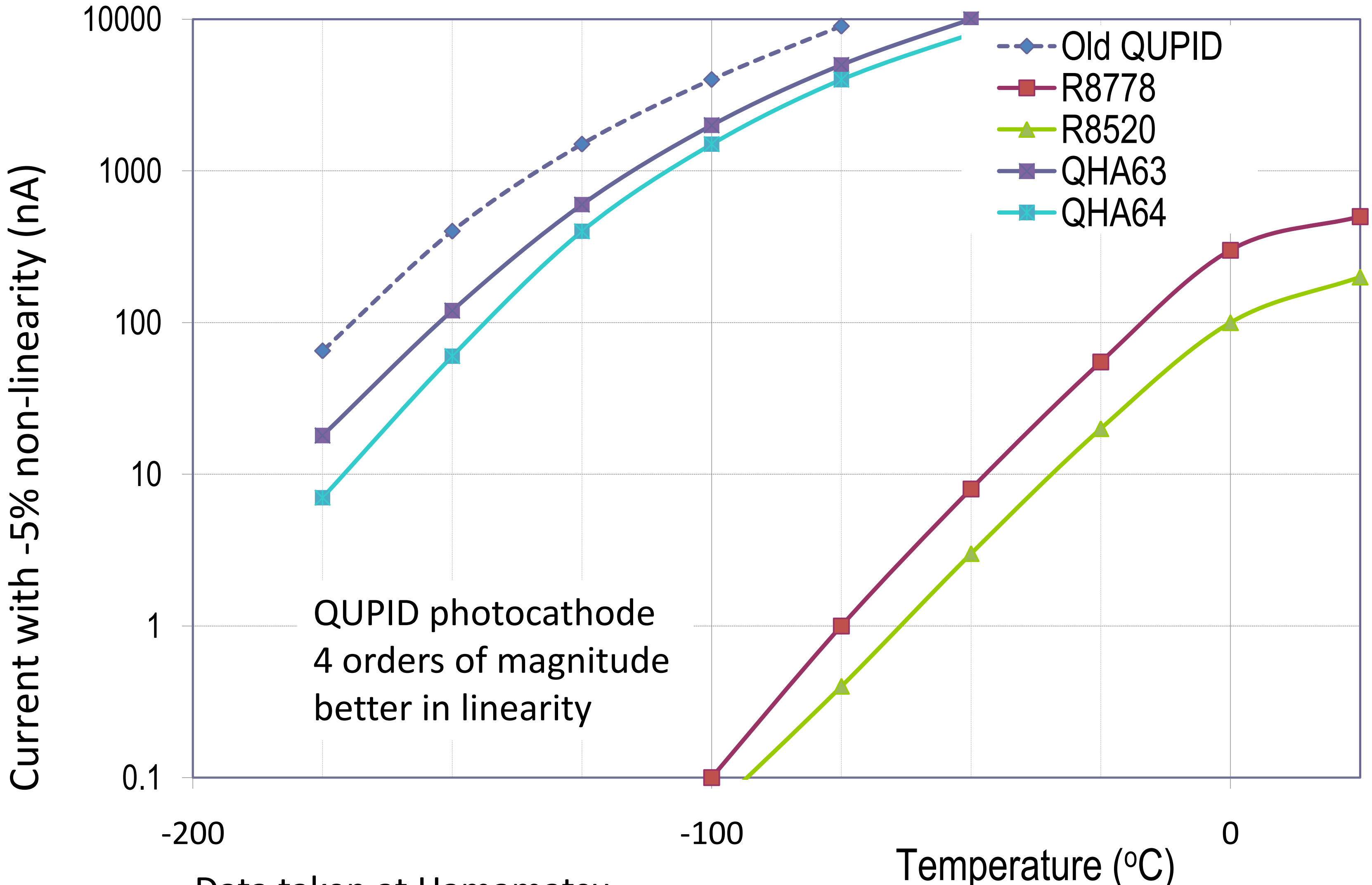
Hitachi, et al.

- The values for the decay times and proportion of fast and slow components are comparable to published values

Scintillation Characteristics

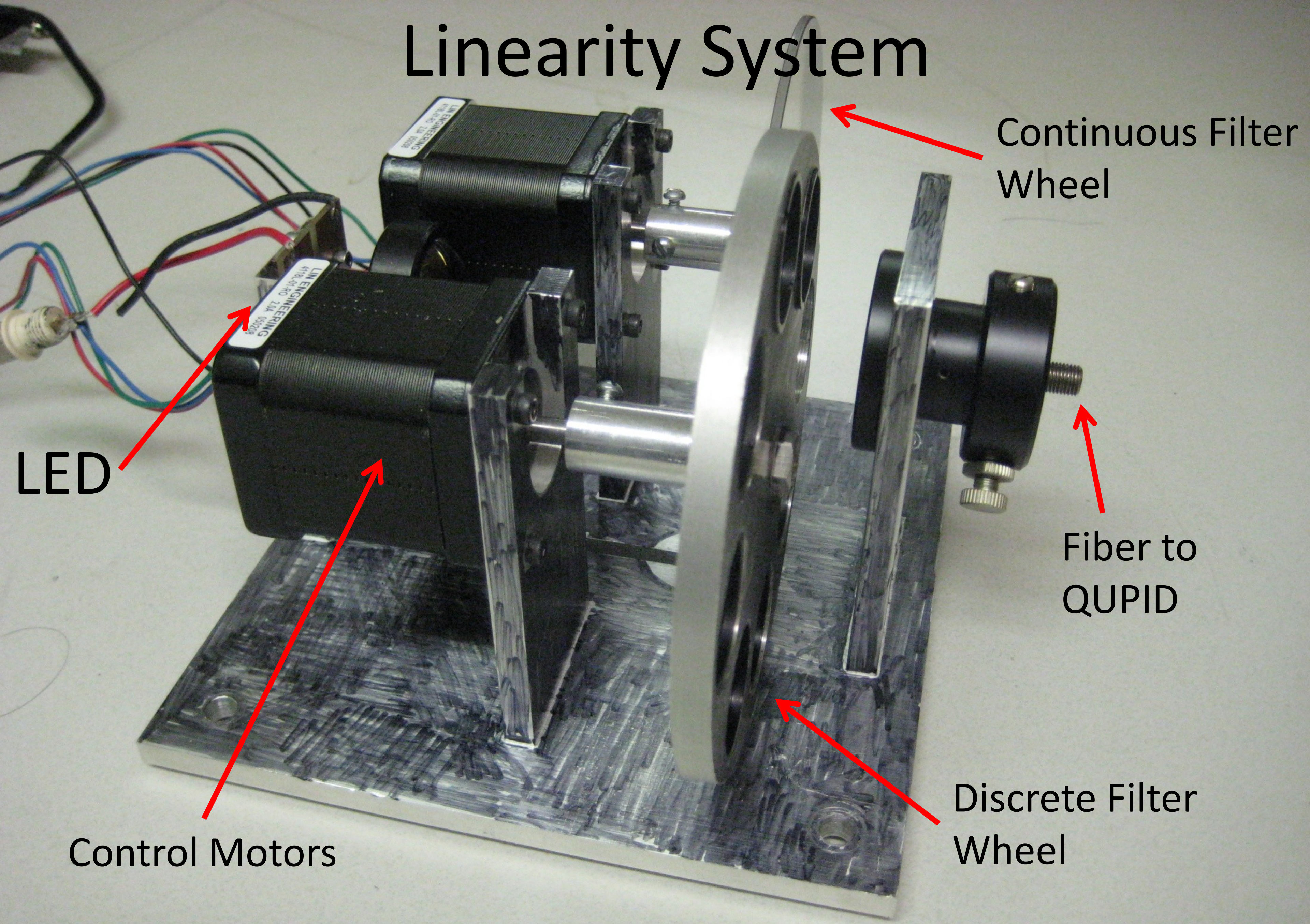
Source	Type	Enery	Light Yield	Resolution	Decay Time	Previously Published Decay Times
^{57}Co	γ	122 keV, 86% 136 keV, 11%	2.0 ± 0.2 pe/keV	10.4 ± 1.2%	39.1 ± 0.2 ns	34 ± 2 ns (Kubota, et al.) 45 ns (Hitachi, et al.)
^{210}Po	α	5.3 MeV	1.6 ± 0.2 pe/keV	2.5 ± 0.5%	4.5 ± 0.1 ns, fast (71%) 26.4 ± 0.4 ns, slow (29%)	4.3 ± 0.6 ns, fast (69%) 22.0 ± 2.0 ns, slow (31%) (Hitachi, et al.)

DC Cathode Linearity

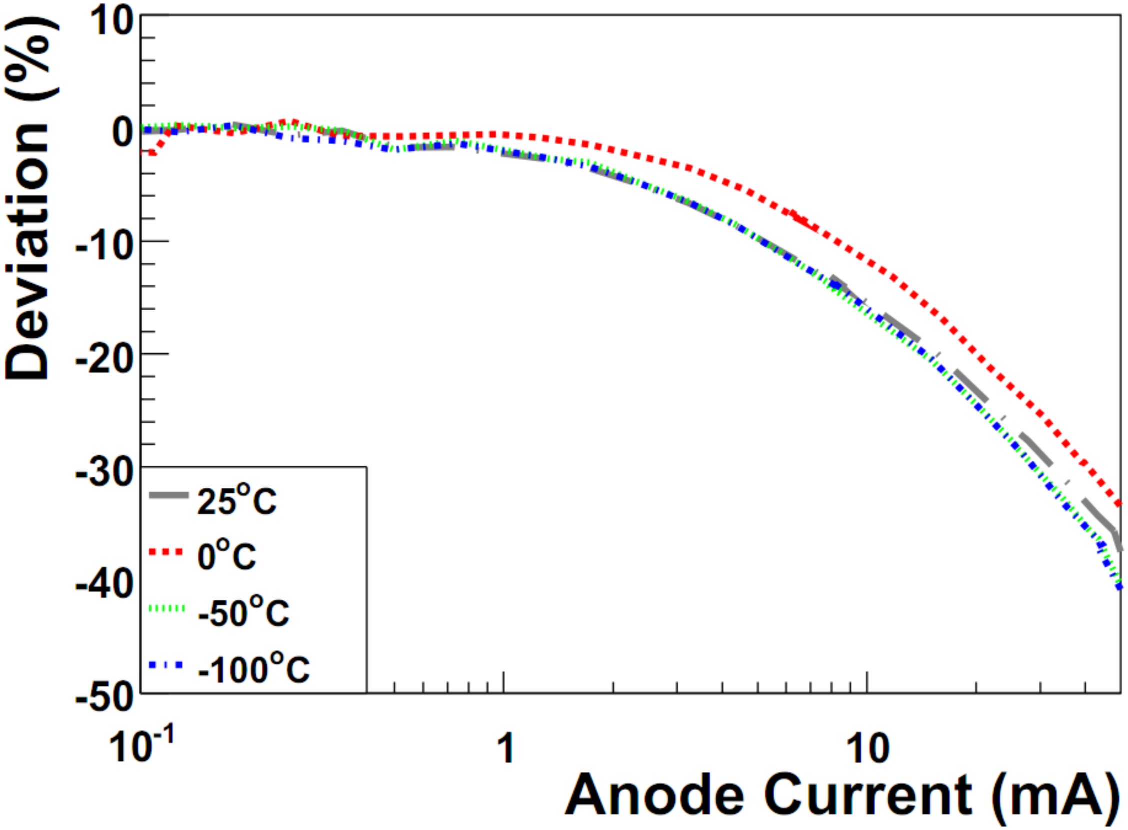


Data taken at Hamamatsu

Linearity System



Anode Linearity



- Anode linear up to ~2 mA at 10^5 gain
- Anode linearity independent of temperature
- Gradual non-linearity can be characterized and applied as a correction