Status of QUPID, a novel photosensor for noble liquid detectors

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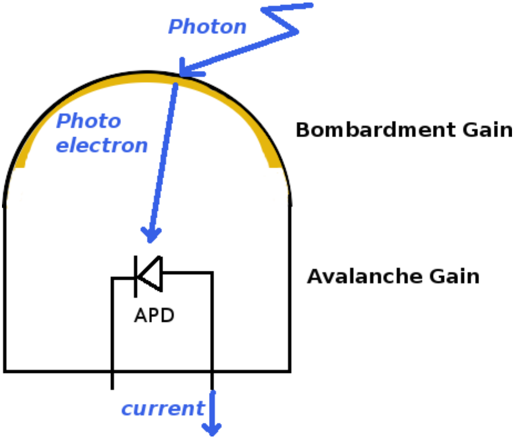
QUPID - QUartz Photon Intensifying Detector

- Hybrid photo sensor = photocathode + APD
- Developed for future noble liquid detectors
- First application in direct dark matter detector
- R&D jointly by UCLA and Hamamatsu



QUPID Motivation

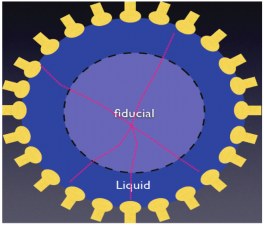
A need for ultra low radioactivity photosensor.

- Low background is crucial for the sensitivity of rare event searches such as Direct DM
- Liquid noble DM detector concept: LXe/LAr target for DM interaction + PMTs for detection of signal
- Dominant electromagnetic background originating from detector materials and shield comes from PMTs
- Metal package, stem pins, SS electrodes are dominant radioactive components of a PMT (arxiv/1103.5831)

SINGLE PHASE DETECTOR

XMASS radioactivity of PMTs contribute >70% to the total background rate of all detector materials

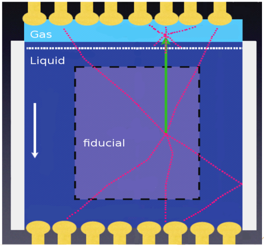
arxiv/1006.1473



DOUBLE PHASE DETECTOR

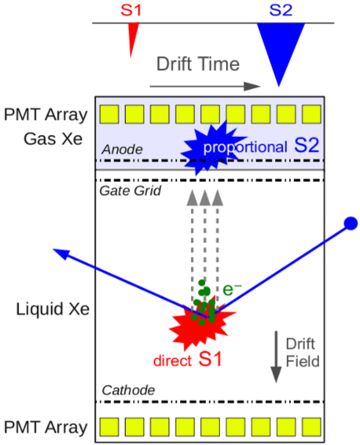
XENON100 radioactivity of PMTs contribute >60% to the total background rate of all detector materials

Phys. Rev. D 83, 082001 (2011)



Concept of dual phase liquid noble DM detector

- Both prompt scintill. signal (S1) and proportional scintill. signal (S2) recorded by the PMTs
- Energy region of interest for DM up to ∼40 keV (LXe), or ∼200 keV (LAr).
- Higher energy region for regular detector calibration up to few 100 keV.
- FAST S1 signal width scintillation decay time (∼ few ns to ∼ μs) shared among all PMTs.
- SLOWER AMPLIFIED S2 signal width 1-2μs and mainly localized on few top PMTs.
- Wavelength: UV to visible.

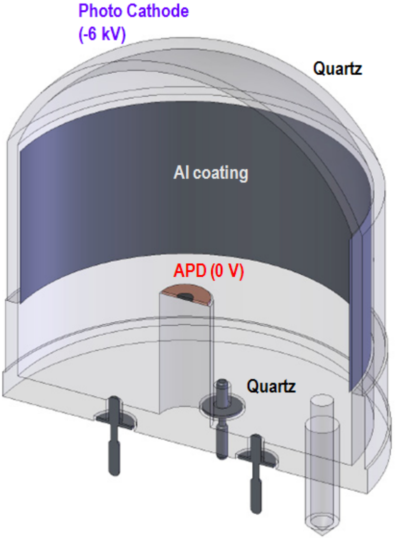


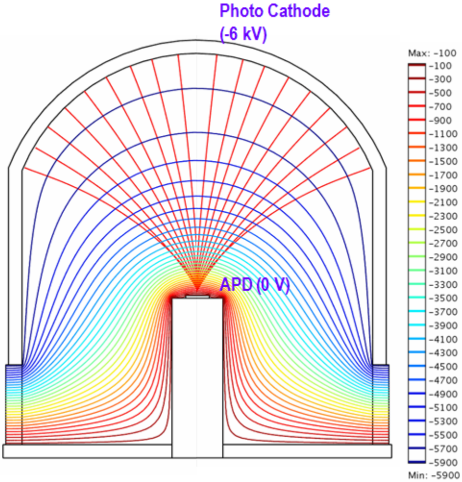
Photosensor for future liquid noble DM detectors

Photosensor requirements:
Better than current generation PMTs in all aspects (easy to write!)

- Ultra low intrinsic radioactivity
- High quantum and collection efficiency >30% at 178nm/420nm.
- Single photon sensitivity i.e total gain $>10^6$.
- Wide dynamic range $>10^4$ ($>10^6$ DBD).
- Good charge resolution.
- Good time resolution and pulse width <10ns.
- Simple structure&relatively large sensitive area $\sim$ few tens of cm^2
- Good uniformity across sensitive area.

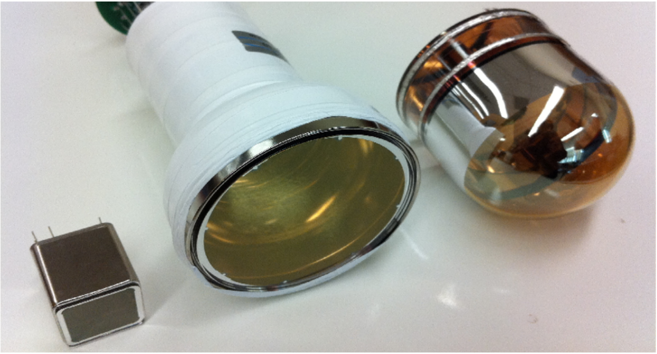
QUPID Design





QUPID

Radioactivity comparison



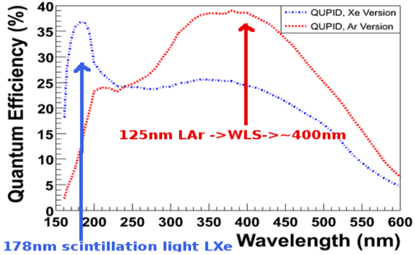
QUPID- overall lowest radioactivity per area.

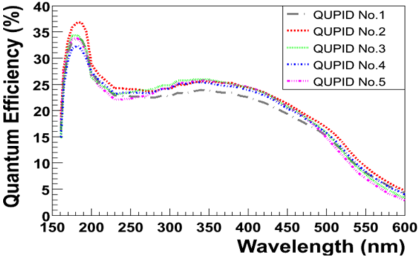
Radioactivity measured by University of Zuerich (arxiv:1103.3689, 1103.5831).

Phototube	Eff.Area	Units	^{238}U	^{226}Ra	^{232}Th	^{40}K	^{60}Co
R8520	6.4cm^2	mBq/cm^2	$<$2.3	$<$0.056	$<$0.070	2.2	0.10
R11410mod	32cm^2	mBq/cm^2	$<$2.9	$<$0.076	$<$0.082	0.42	0.11
QUPID	32cm^2	mBq/cm^2	$<$0.54	0.010	0.012	0.17	$<$0.0056

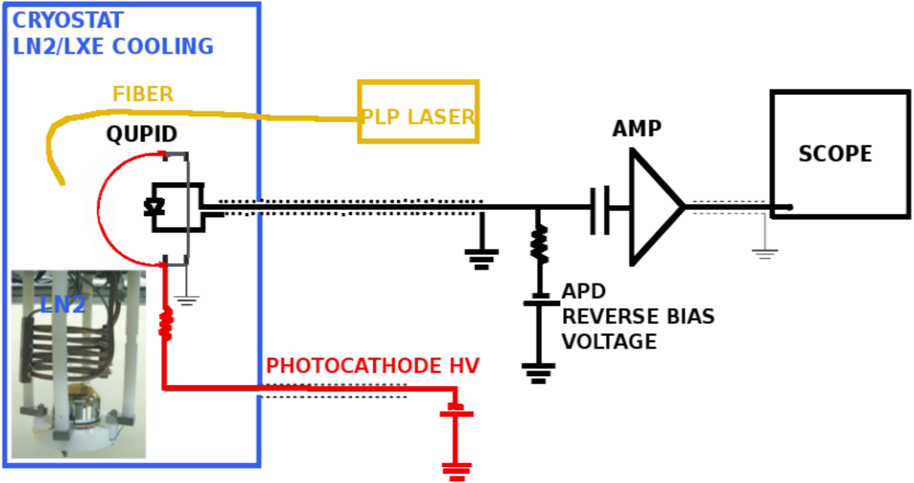
Photocathode quantum efficiency

- Ar and Xe version of QUPID developed.
- >30% QE for 178nm = LXe scintillation light.
- >30% QE for ~ 400nm, wavelength shifted LAr scintillation light.
- First tests done on QUPIDs for LXe.



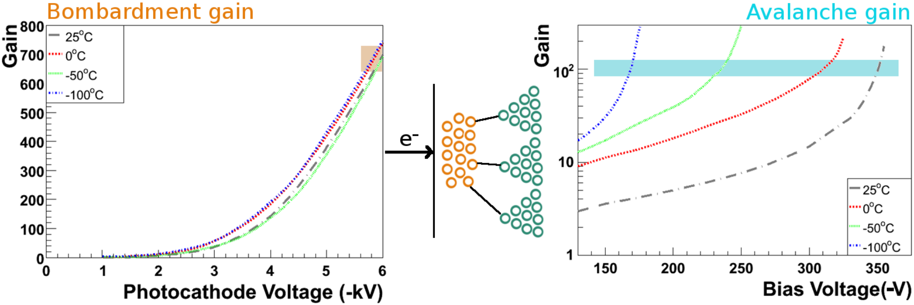


QUPID Readout schematics

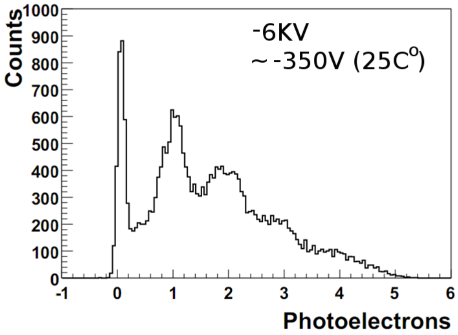


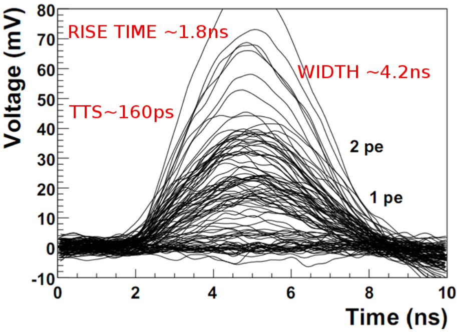
QUPID: Total gain

- Bombardment gain $\neq f(T)$ with max gain $\sim$750;
- Avalanche gain shows strong temperature dependence with max gain $\sim$200. Leakage current from 100nA (25C°) to 0.5nA (-100C°)
- Total gain $\sim 10^5$.

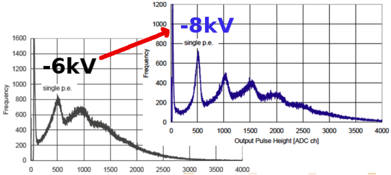


QUPID: Single photon sensitivity

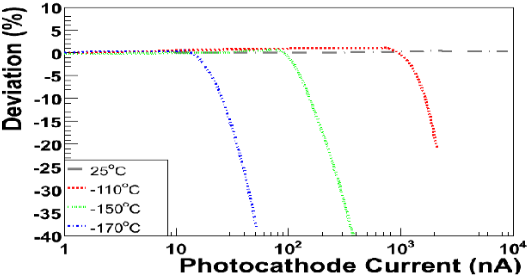


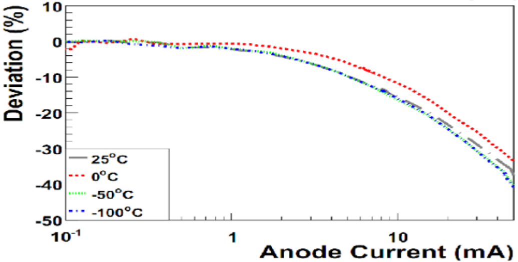


- Clear 1, 2, .. p.e. peaks.
- Good time resolution (3x3mm APD).
- Future improvements !



QUPID: Linearity





Photocathode DC

linearity up to 1 μA (LXe) few tens nA (LAr).

Anode pulse (1μs)

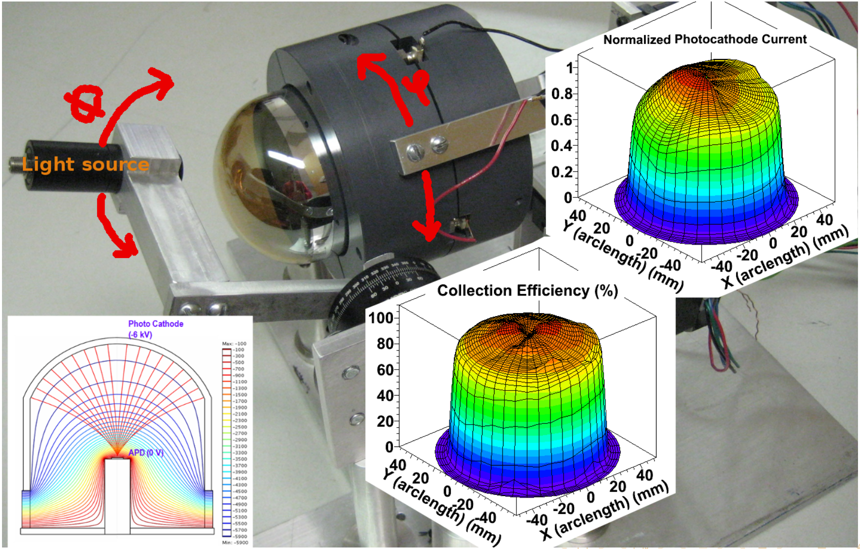
linearity $\neq$f(T).
5% deviation at $\sim$3 mA peak anode current for a gain of 10^5.

QUPID

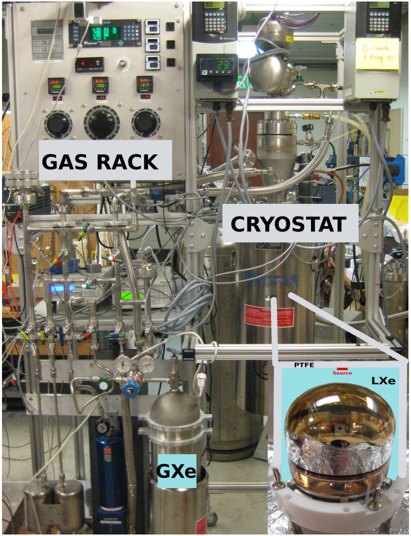
Input of $\sim 10^5$pe for a pulsed $\sim 1\mu$s.

QUPID: Uniformity

Photocathode response uniform within 20% and collection eff. >80%.

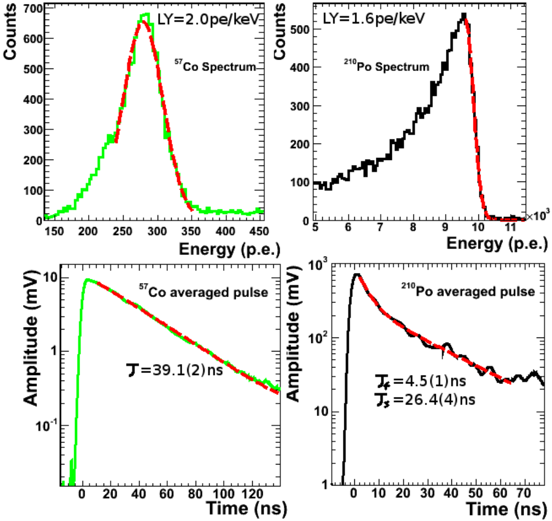


QUPID: Operation in LXe



- QUPID fully immersed in LXe.
- T = -100C°. P=1.6bar.
- Stable operation for $\sim$ 2 weeks.
- Continuous purification of LXe through hot getter.
- Gain calibration via optical fiber.
- Calibration sources.

QUPID: First measurements of LXe scintillation light



^{57}Co

$LY = 2.0 \pm 0.2$ pe/keV.
$\sigma/\mu = 10.4 \pm 1.2\%$.

^{210}Po

$LY = 1.6 \pm 0.2$ pe/keV.
$\sigma/\mu = 2.5 \pm 0.5\%$.

- LY limited by impurities and out-gassing
- Decay profiles similar to previously published values.

QUPID: Ongoing R&D

QUPIDs are proposed photosensors for future liquid noble DM detectors: XENON1T (LXe) and DarkSide (LAr).

Production @ Hamamatsu

- back-illuminated APD with breakdown V >full depletion V@LAr temp.
- QUPIDs with higher max photocathode HV.
- QUPIDs optimized for LAr scintillation.

Screening within XENON1T&DarkSide and at Hamamatsu

- continue to screen QUPIDs in low background germanium detector facilities.
- screen all building material individually.

Readout @ UCLA/Fermilab/Gran Sasso

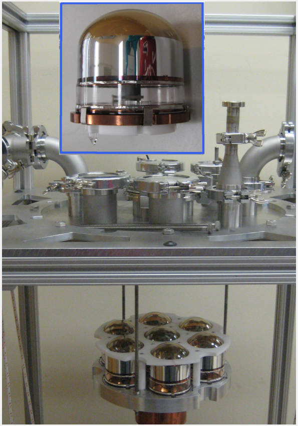
- Development of multichannel QUPID readout systems.
- Different approaches being investigated.

QUPID: Ongoing R&D

QUPIDs are proposed photosensors for future DM detectors: XENON1T (LXe) and DarkSide (LAr).

Characterization @ UCLA

- building several cryogenic systems to test 7 (or more) QUPIDs at once.
- characterization at low temperatures in vacuum/GN2.
- Operation in GAr, LAr, GXe, LXe. Crucial for deployment in future DM detectors.
- We want to study: long term stability, performance in the strong electric field, afterpulsing and cross-talks.



Summary

- QUPIDs are particularly promising candidates for replacement of PMTs in future ton-scale liquid noble detectors.
- Outstanding features: low intrinsic radioactivity, high quantum and collection efficiency, good charge resolution, high gain, wide linear dynamic range, satisfactory gain uniformity. good timing response.
- QUPID operation in the liquid noble environment was successfully demonstrated at UCLA.
- Further developments on QUPID continue.

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

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arXiv:1103.3689

Performance		25° C	-100° C
Photocathode	Material	Bialkali-LT	
	Quantum Efficiency at 178 nm	$34 \pm 2\%$	–
	Linearity (5% limit)	$> 10\ \mu A$	$> 1\ \mu A$
Electron Bombardment	Acceleration Voltage	6 kV	
	Typical Gain	750	
	Maximum Gain	800	
APD -3mm diameter	Capacitance	11 pF	
	Leakage Current	200 nA	0.3 nA
	Breakdown Voltage	360 V	180 V
	Typical/Max Gain	200/300	
Anode Output	Typical Total Gain	1.5×10^5	
	Maximum Total Gain	2.4×10^5	
	Linearity^0	3 mA	
Timing Properties	Rise Time (10%-90%)	1.8 ± 0.1 ns	
	Fall Time (90%-10%)	2.5 ± 0.2 ns	
	Pulse Width (50%-50%)	4.20 ± 0.05 ns	
	Transit Time Spread (FWHM)	160 ± 30 ps