Radiation resistant Hi-QE MCP-PMT detectors for space applications

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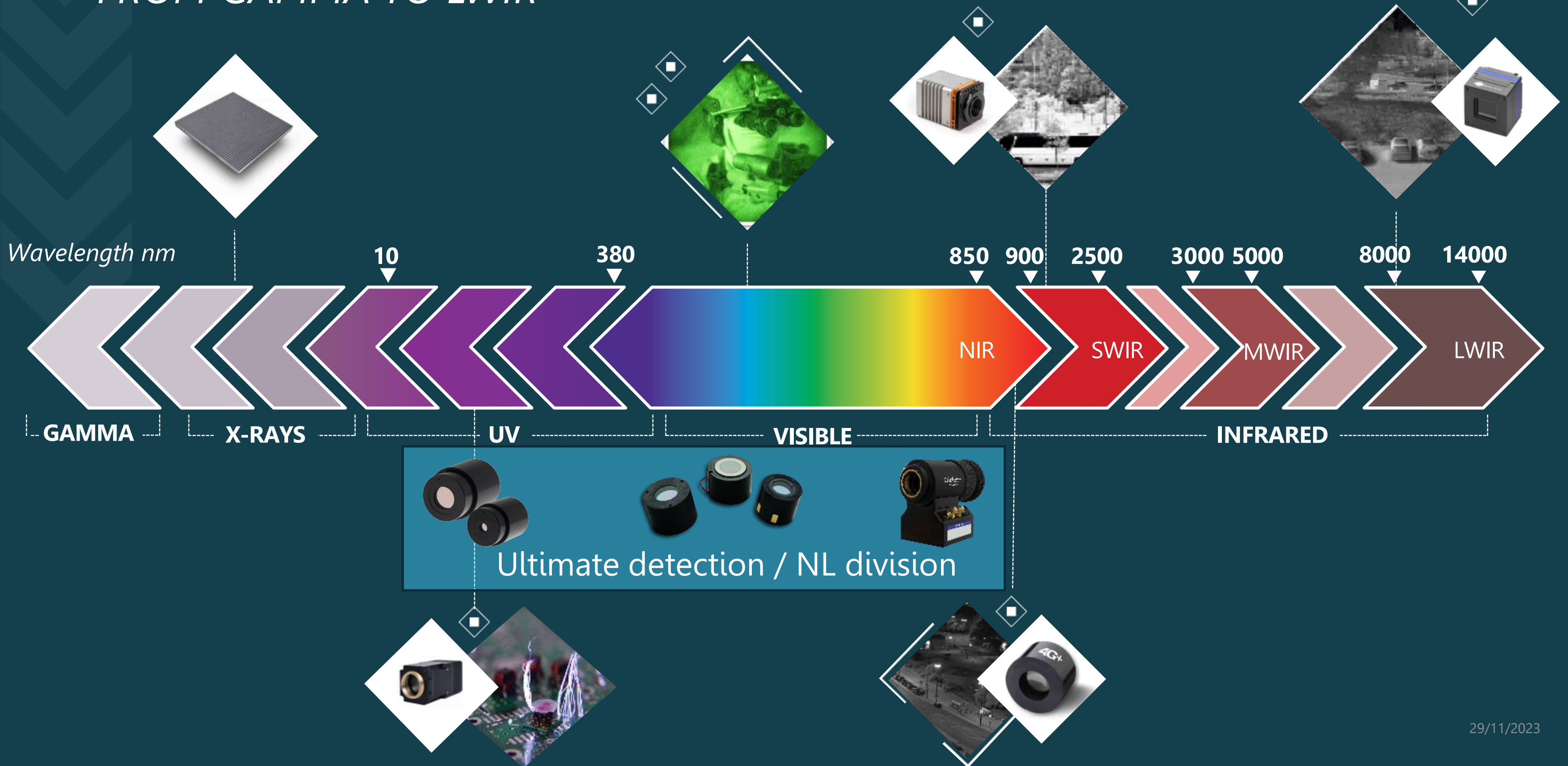
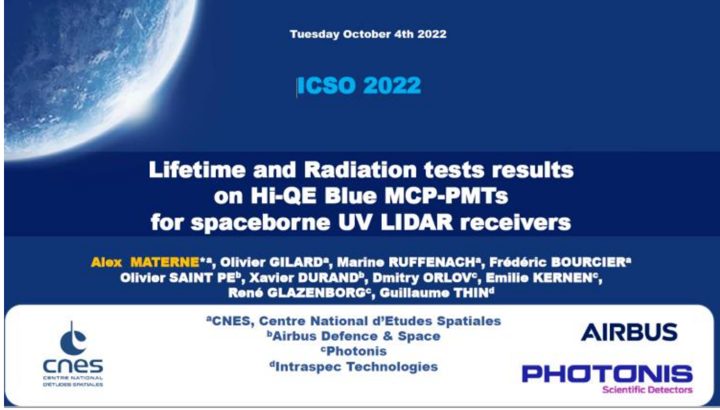
FROM GAMMA TO LWIR



MCP-PMT Single Photon Detectors for MESCAL mission



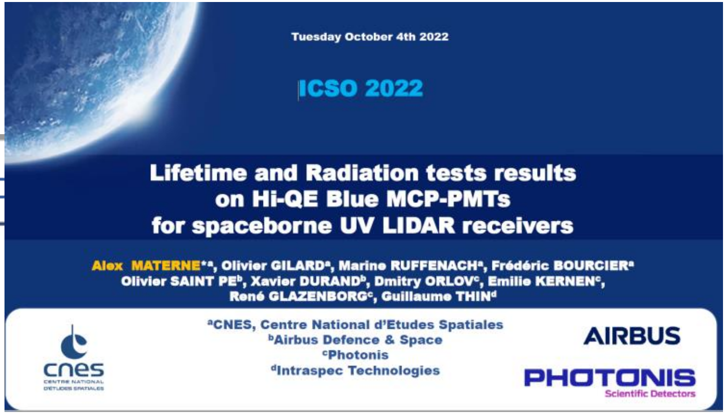
The UV Channel for MESCAL

- Cloud-aerosol lidar mission concept promoted by a French Laboratory (LMD/IPSL, Université Pierre et Marie Curie), to ensure data correlation between CALIOP (for green and NIR) and EarthCARE (for UV) as well as better speciation of aerosol types.
- Contribution to the MESCAL (Monitoring the Evolving State of Clouds and Aerosol Layers) project in the frame of the A-CCP (Aerosols and Cloud- Convection Precipitation) NASA study
- French contribution studies for the development of a HSRL UV receiver from 2018 until the abandonment decided by NASA LaRC of the 355 nm channel in 2021.

CONCLUSION

- **Novel design of Hi-QE Blue MCP-PMT Hi Linearity and Long Life** with stability of quantum efficiency up to 20 C of charge generation at the photocathode.
- Proton radiation proved no significant changes for LEO missions over more than 10 years equivalent fluences.
- Results improve TRL of the MCP-PMT technology and consolidates the position of Photonis MCP-PMTs for future space LIDAR missions.

Back to the future



Lifetime and Radiation tests results on Hi-QE Blue MCP-PMTs for spaceborne UV LID

LITE LIDAR On board Discovery — ICESat1 GLAS — CALIOP — ADM AEOLUS ALADIN — EarthCARE ATLID

1994 → 2003 → 2006 → 2018 → 2023 → Next

1994: Photomultiplier Tubes (355 nm ; 532 nm); Si APD (1064 nm)

2003: Si APD (532 nm)

2006: Photomultiplier Tubes (532 nm); Si APD (1064 nm)

2018: Accumulation CCDs (355 nm)

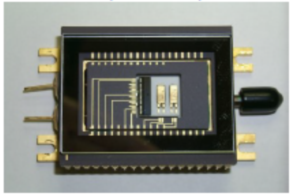
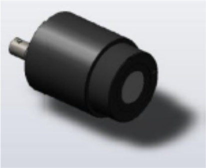


Photo courtesy of Airbus Defence & Space

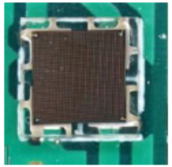
2023: MCCDs (355 nm)

Next:

MCP-PMT



Si-PM



APD MCT

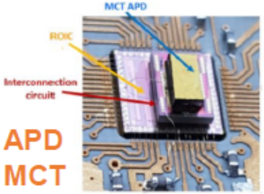
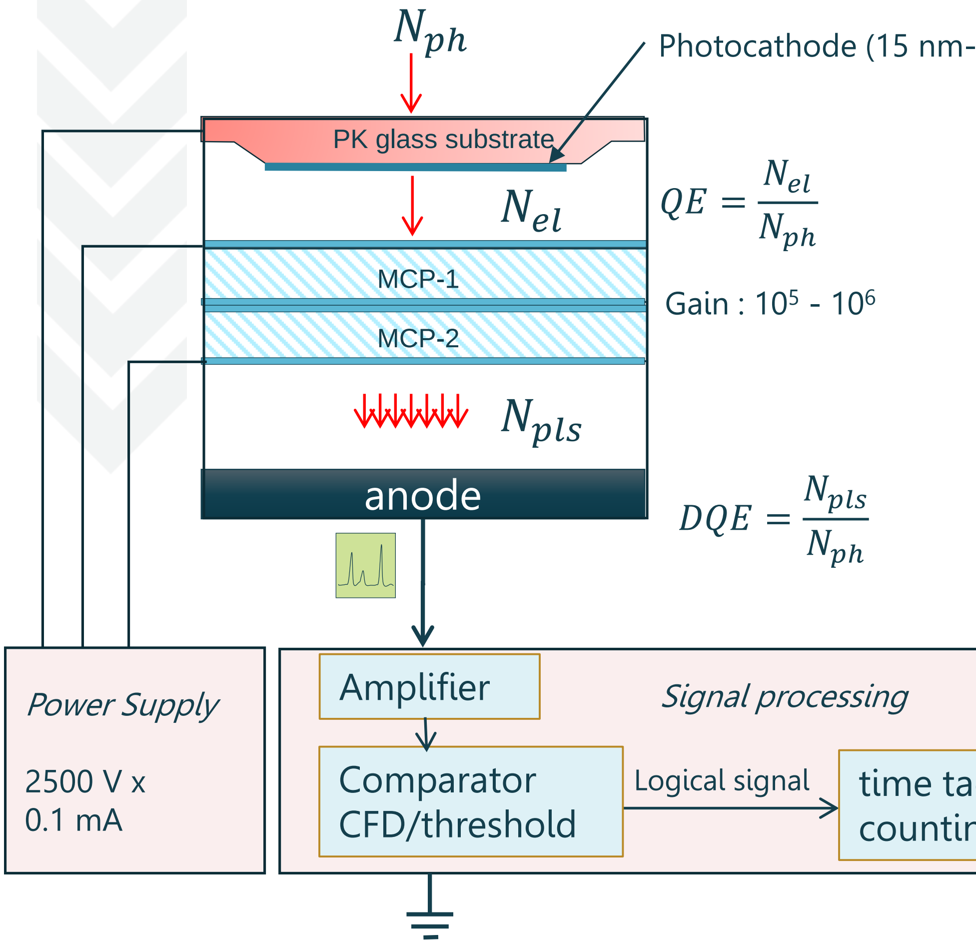


Photo courtesy of Airbus Defence & Space

VERTICAL SAMPLING FREQUENCY

MCP-PMT detector for photon counting/timing



Useful area 18 mm *(optional 8 mm)*
UV-VIS Quantum Efficiency (QE)
Detection QE (DQE).
MCP Collection Efficiency (CE)
Dark rate
Gain
Output linearity (MCP defined)
PHD shape with high P/V ratio
Dead time / afterpulsing
Pulse waveform (rise time, FWHM)
Time resolution
Life time
Radiation resistance

NewGen Fast Timing MCP-PMT detectors

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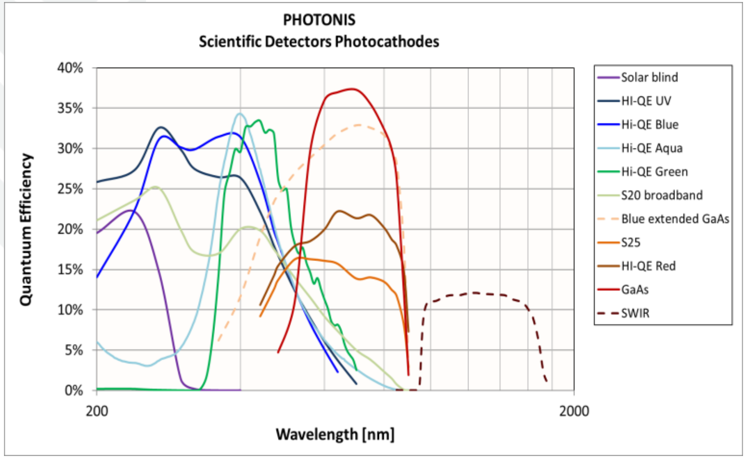
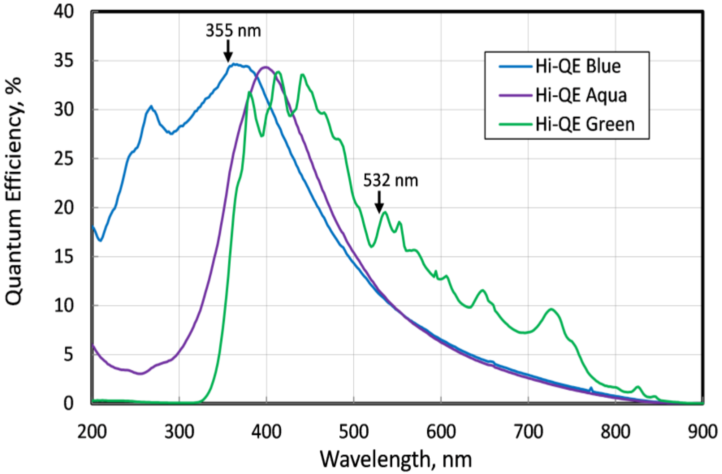
Quantum efficiency & Dark rates





DQE ≈ QE

- Large panel of available wavelength
- State-of-the-art sensitivities
- Further development in progress

- LOW DARK RATE (typical: <50 Hz/cm^2)
- Hi-QE Blue and is the best choice for 355nm LIDAR with QE>30 % (typical 35%)
- Hi-QE Green for 532 nm LIDAR with improved QE up to 22-25 %.

Orlov D. A., DeFazio J., Duarte Pinto S., Glazenborg R. and Kernen E., "High quantum efficiency S-20 photocathodes in photon counting detectors", Journal of Instrumentation 11, C04015 (2016).

NewGen Fast Timing MCP-PMT detectors

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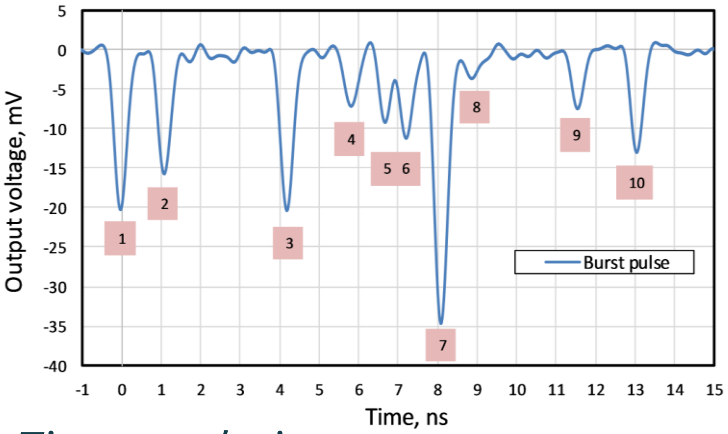
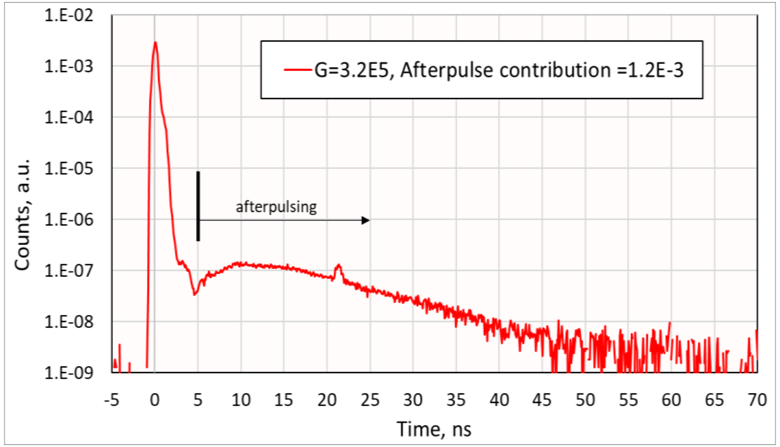
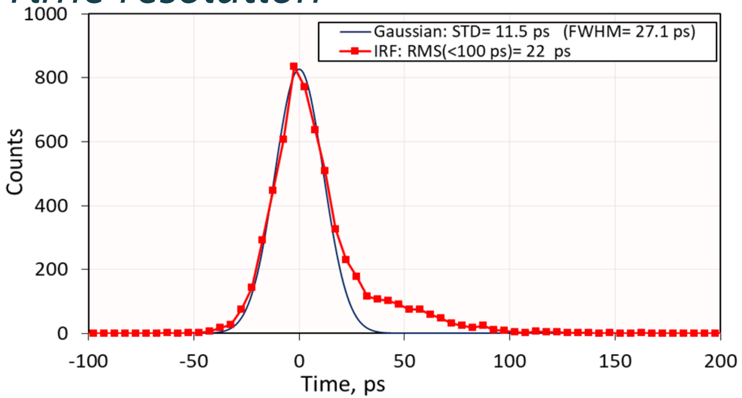
WFs for Burst mode illumination



Afterpulsing



Time resolution

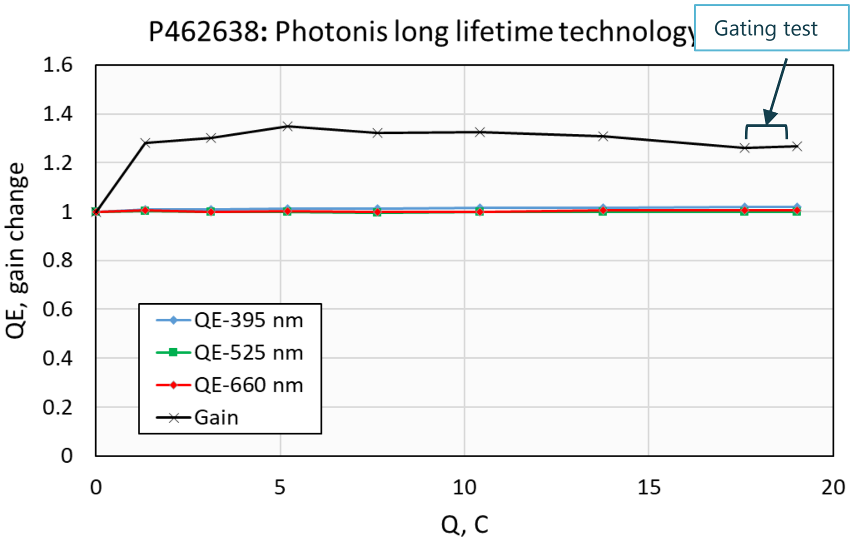


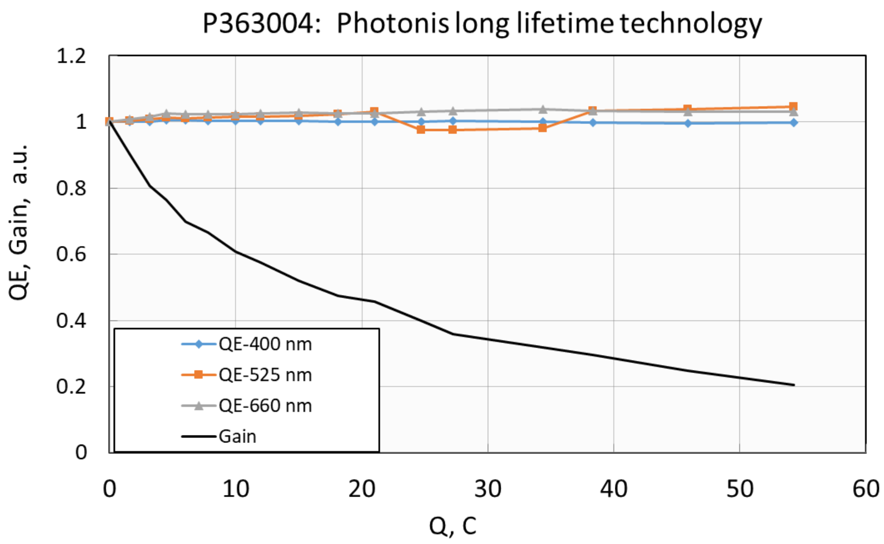
Results:

- Thanks to excellent WF the pulses separated of about 500 ps can be resolved.
- Excellent time resolution down to10 ps (sigma)
- Low afterpulsing contribution (no additional increase of dead time)

NewGen Fast Timing MCP-PMT detectors

lifetime





QEL NO degradation (also CE, and DR) up to about 20 C (P462638)
and 55 C (P363004)

Operational lifetime >> 10 years

Gain variation (less critical) – to be stabilized

NewGen Fast Timing MCP-PMT detectors

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Counting unit LinPix

> 100 MHz detector unit

In collaboration with Photonscore


High-Througput Single-Photon-Counting

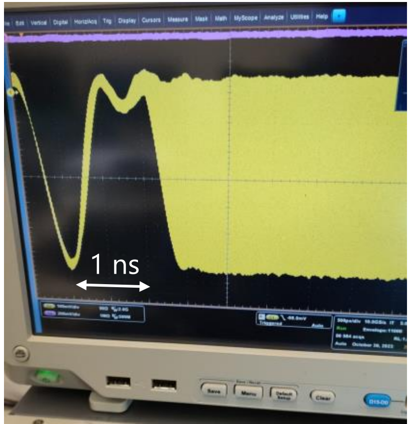
LINPix is the solution for ultra-fast single photon counting. The heart of the detector is a micro-channel plates based photomultiplier tube enabling a dead time below **2 ns** and sustainable count-rates above **100 MHz** and burst-rates of up to **1 GHz**. The combination of high throughput with timing resolution below **35 ps** makes LINPix a perfect photon detector for your application. A large **ø8 mm** sensitive area can have one of four highly sensitive photocathodes matching the spectral range you are interested in.

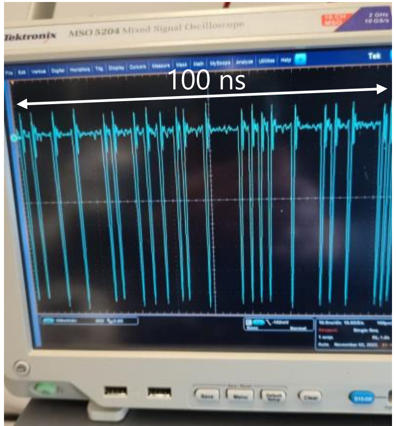
Dead time decreased down to 1.4 ns

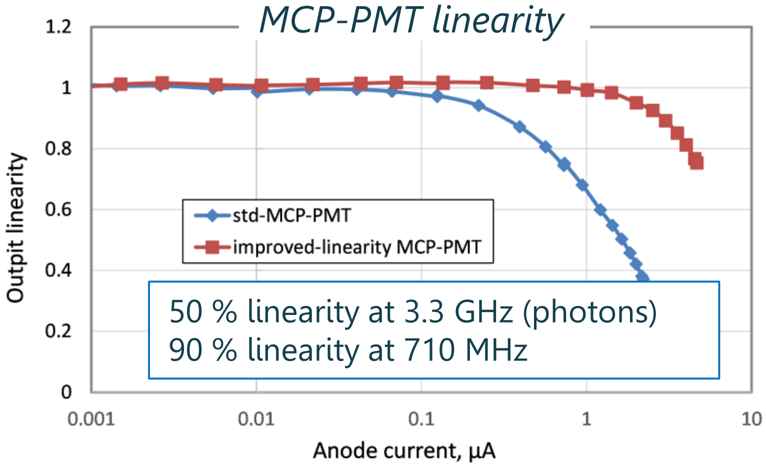
Counting rate above 240 MHz for FT8 (with > 3 times dropped amplitude!)

Jitter (sigma):
15 ps (@ 1 MHz),
< 20 ps (@ 10 MHz)
< 32 ps (@ 100 MHz)

Detector unit improvement







Proton radiation

Specification for LEO MESCAL mission:

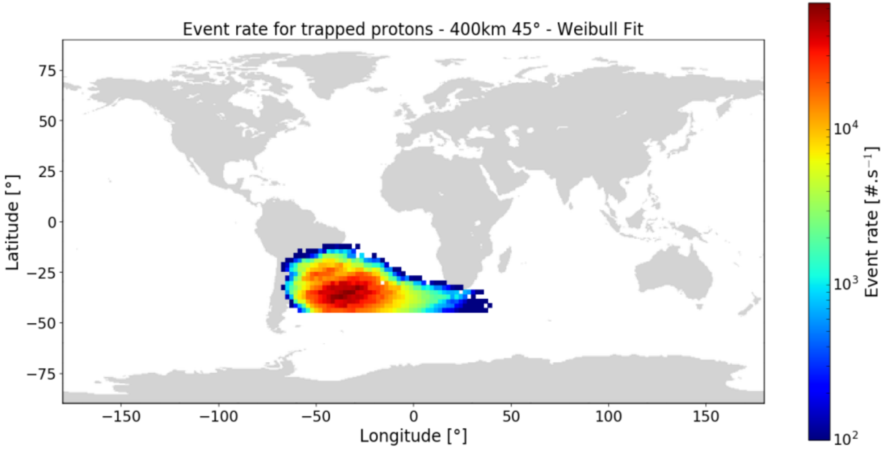
Mission Lifetime 10 years

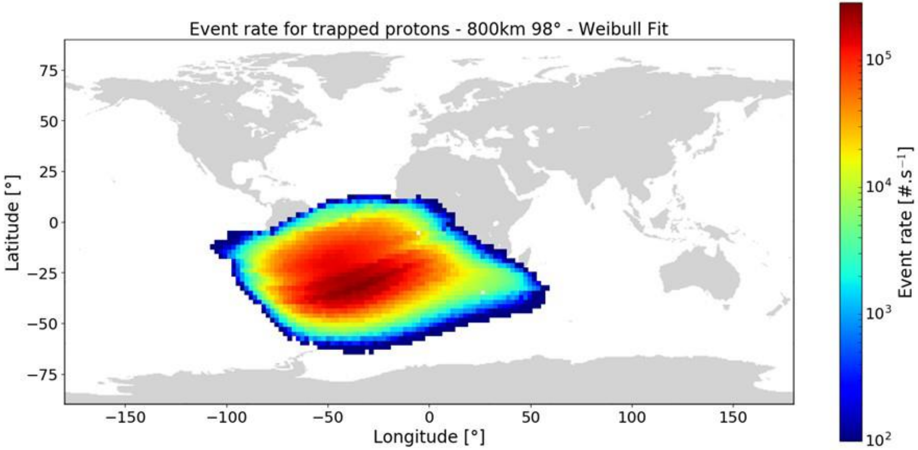
Orbit: 80 km (worse case)

Shielding: 4 mm AL

Total ionizing dose (TID) of 20 krad (Si)

Corresponds to TNID with an equivalent proton fluence of 1.8E11 p/cm^2 for 60 MeV protons.





Proton radiation tests

KVI facility in Groningen

1st Beam time: Surviving test

MCP-PMTs (x2) + PK-substrates

Proton energy: 60 keV

Beam direction: Normal to the detector surface (0^0)

Flux density: ~2E8 p/s/cm^2

Fluences: up to 5e11 p/cm^2

2nd Beam time: Radiation induced counts/proton

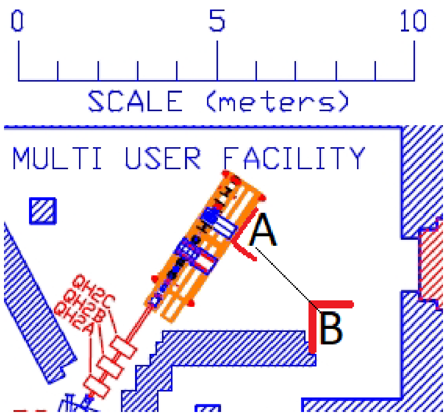
MCP-PMTs (x2)

Energy: 30, 60, 100, 184 keV protons

Beam direction: 0^0, 45^0, 60^0

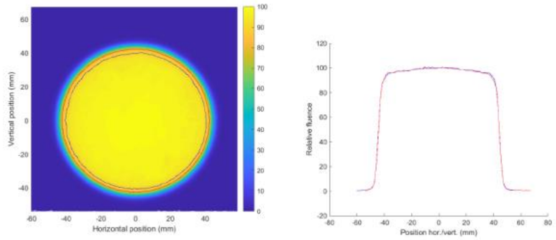
Flux density: ~ 1E8 p/s/cm^2

Fluences: 3E10 p/cm^2 (x12 measurements)



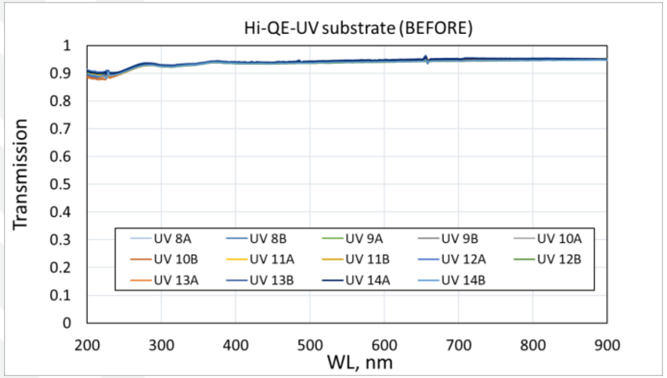
59.8 MeV 80 mm diameter field collimator

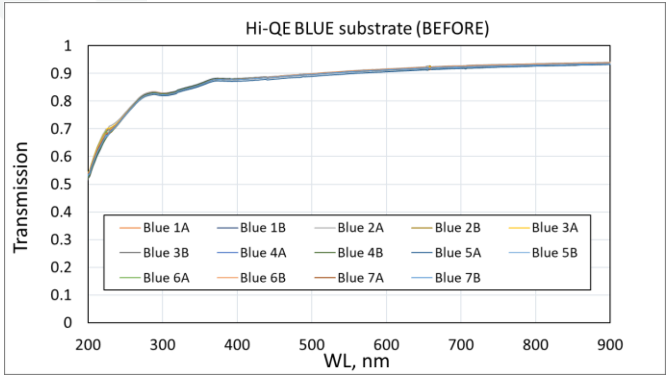
Left side: 2D profile, Right side: profile on Horizontal (blue) and Vertical (red) axis

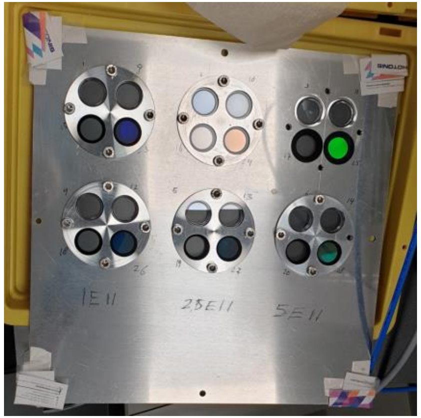


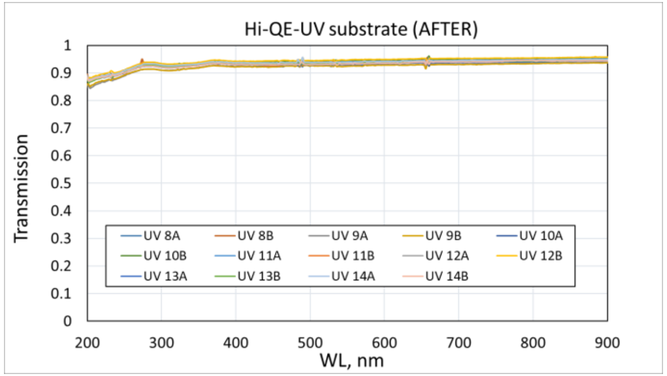
Proton radiation tests: substrate transmission

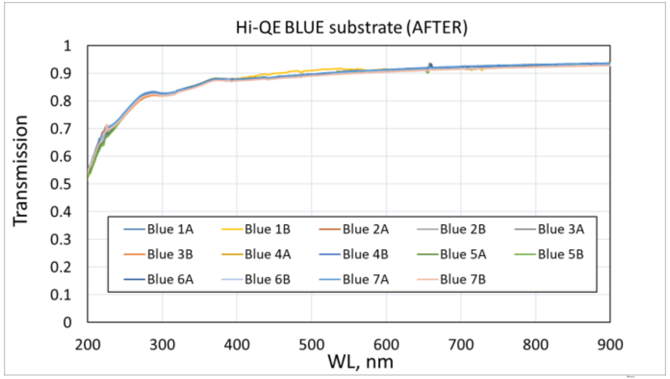
Quartz based substrate









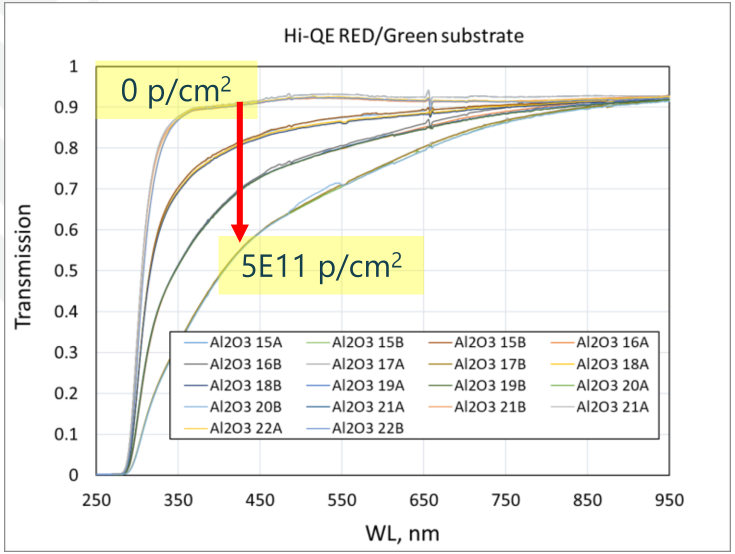


NO transmission change after 60 MeV proton radiation with fluences up to 5E11 p/cm^2 for quartz based Hi-QE UV and BLUE substrates

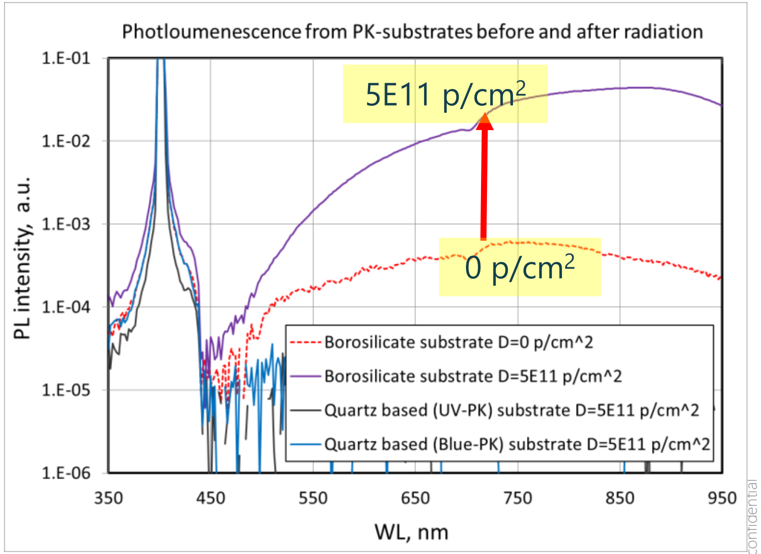
Proton radiation tests: substrate transmission

Borosilicate based substrate

Transmission



Photoluminescence



* Inline with cathodoluminescence data from CNES

Radiation induced transmission degradation mostly in UV and VIS part of the spectra for borosilicate based Hi-QE Green and Red photocathode substrate.

Proton radiation tests:

FT-18 MCP-PMT before and 7-8 wks after 60 MeV proton radiation D=5e11 p/cm^2

#938130	BEFORE	AFTER
QE_max, %	35.9	36.4
QE at 400 nm, %	32.9	33.5
Reference MCP voltage	1500	1500
Gain at reference voltage	2.25E5	2.27E5
P/V	4.9	4.8
DR (counts > 0.3 of mean energy, in few hours in dark), cps	150	480
MCP- DR (counts > 0.3 of mean energy), cps	0.15	1.4
Collection Efficiency	0.928	0.923
0.75 linearity range (full area), µA	3.1	2.9
0.5 linearity range (full area), µA	4.9	4.9
Transit Time Spread (dia 7 mm): sigma of Gaussian fit	23	24
Transit Time Spread (dia 7 mm): RMS for counts <200 ps	36	36
Waveform: Risetime, ps	256	239
Waveform: FWHM, ps	750	732
Afterpulsing (amp=10, threshold=30 mV)	6.1E-4	7.7E-4

#9452281	BEFORE	AFTER
QE_max, %	35.7	36.2
QE at 400 nm, %	32.7	33.3
Reference MCP voltage	1525	1525
Gain at reference voltage	2.11E5	2.11E5
P/V	3.8	3.7
DR (counts > 0.3 of mean energy, in few hours in dark), cps	215	540
MCP- DR (counts > 0.3 of mean energy), cps	29	27
Collection Efficiency	0.925	0.924
0.75 linearity range (full area), µA	3.2	3.0
0.5 linearity range (full area), µA	5.2	5.1
Transit Time Spread (dia 7 mm): sigma of Gaussian fit	21	21
Transit Time Spread (dia 7 mm): RMS for counts <200 ps	38	41
Waveform: Risetime, ps	305	292
Waveform: FWHM, ps	487	477
Afterpulsing (amp=10, threshold=30 mV)	7.2E-4	7.0E-4

MCP-PMT

NO change in MCP-PMT behavior before and after radiation.

Only small increase in dark rates is left due to small traces of radioactivity of the detector body.

Proton radiation tests: Electron/Proton yield

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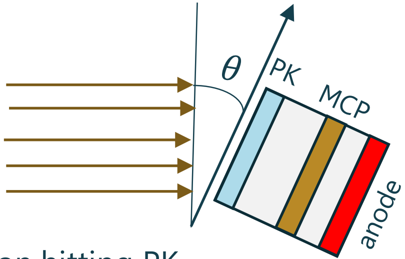
FD_{proton}: Proton flux density (proton/s/cm2)

S: PK area (cm^2)

$Np = F_d \times S \times \cos(\theta)$ – p-flux to PK window (proton/s)

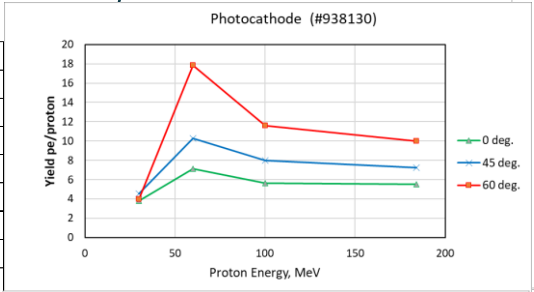


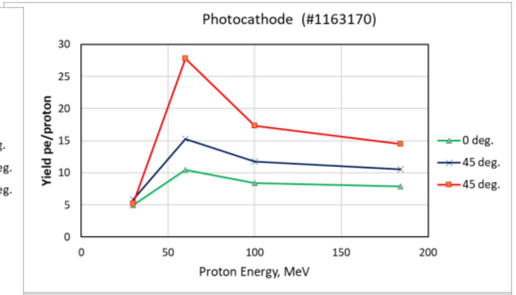
J_{el}: proton induce PK electron current
G0: MCP gain
J_{anode}: anode current (measured)

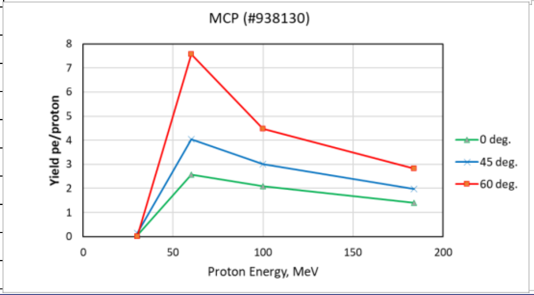
$$N_{el} = \frac{J_{anode}}{G_0 \times q} \text{ (electrons/s)}$$

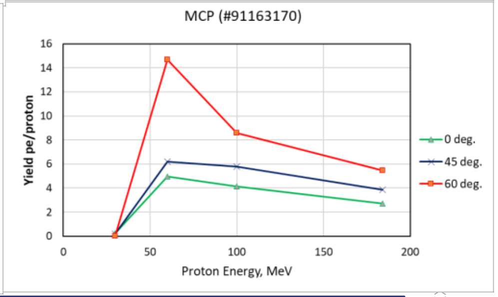
$\frac{N_{el}}{N_p}$ number of electrons (from PK generated by single photon hitting PK

		9383130 with conventional MCP			1163170 with long-lifetime MCP		
		Nel_eff / proton			Nel_eff / proton		
Energy, MeV	Angle	Total	PK	MCP	Total	PK	MCP
30	0	3.9	3.8	0.1	5.2	5.0	0.2
	45	4.7	4.5	0.1	6.0	5.8	0.2
	60	4.0	4.0	0.0	5.2	5.2	0.0
60	0	9.7	7.1	2.6	15.4	10.5	5.0
	45	14.3	10.3	4.0	21.5	15.3	6.2
	60	25.4	17.8	7.6	42.5	27.8	14.7
100	0	7.7	5.6	2.1	12.6	8.4	4.1
	45	11.0	8.0	3.0	17.5	11.7	5.8
	60	16.1	11.6	4.5	25.9	17.4	8.6
184	0	6.9	5.5	1.4	10.7	7.9	2.7
	45	9.2	7.3	2.0	14.4	10.6	3.9
	60	12.8	10.0	2.8	19.9	14.5	5.4









Electrons induced by single proton will be detected with sub-ns time as one pulse. Using correct threshold high energy proton induced unwanted pulses can be removed.

CONCLUSION & OUTLOOK

- *Radiation hardness proven up to TID of 55 krad (Si)*
  (60 MeV 5e15 protons/cm^2).
  > 30 years in space

- *Proton induced yield of false pulses (counts/proton) were derived for different proton energies and incident hitting angles.*

- *Excellent timing properties, long-lifetime, high linearity and very high radiation resistance consolidates position of new-generation MCP-PMT detector within LIDAR detectors.*

- *NEW: Counting electronics with dead time < 1.5 ns is developed.*

Thank you for your attention

Contact:

scientificdetectors@exosens.com