Comprehensive Characterization of Photomultiplier Tubes for Next-Generation Neutrino Detectors at the CAPACITY Laboratory

A. De Benedittis[1,2], P. Migliozzi[1], C.M. Mollo[1], **A. Simonelli**[1], D. Vivolo[1,2]

[1]INFN - Sezione di Napoli, Laboratorio CAPACITY, Caserta
[2]Università degli Studi della Campania "Luigi Vanvitelli"

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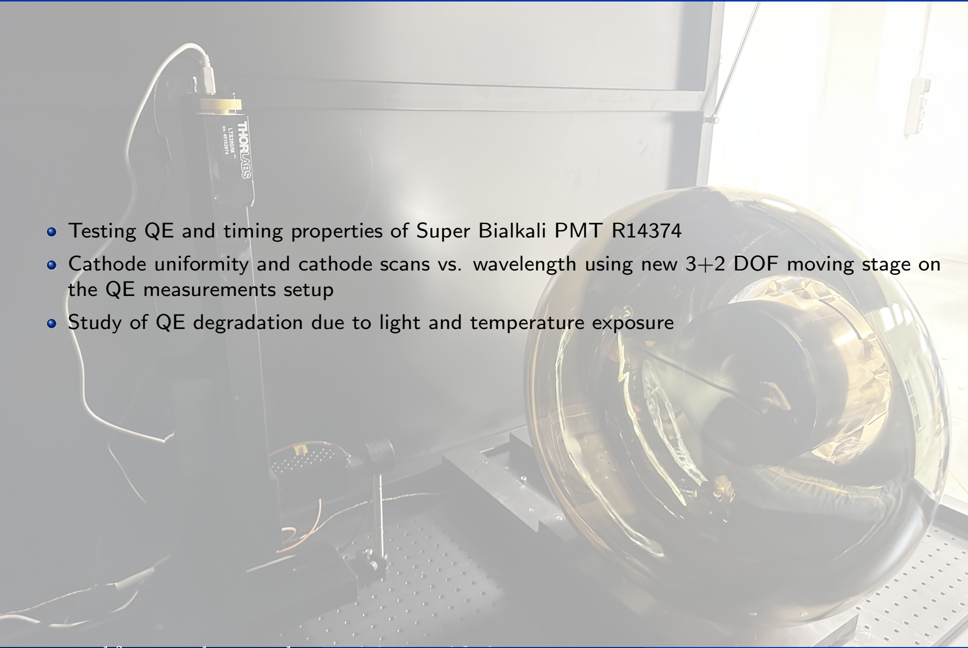
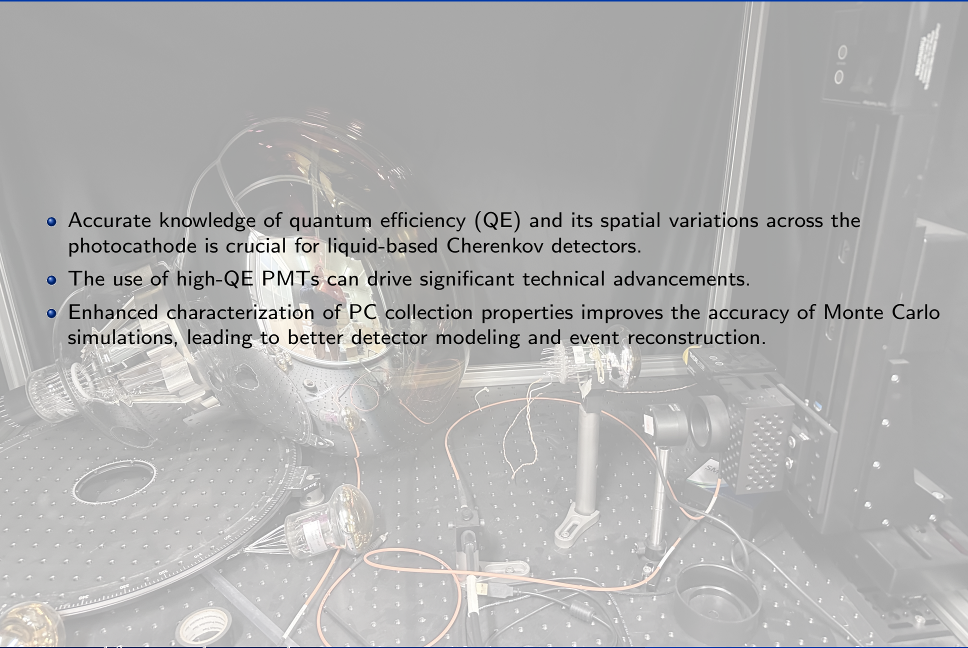
Overview



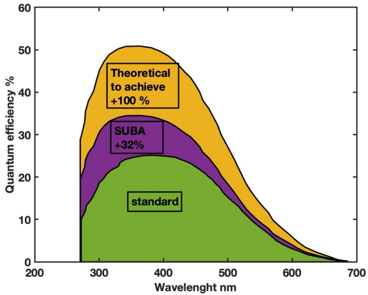
- Testing QE and timing properties of Super Bialkali PMT R14374
- Cathode uniformity and cathode scans vs. wavelength using new 3+2 DOF moving stage on the QE measurements setup
- Study of QE degradation due to light and temperature exposure

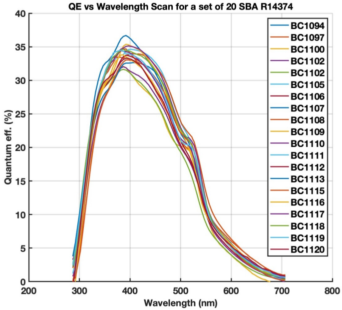
Importance of Quantum Efficiency and Cathode Uniformity



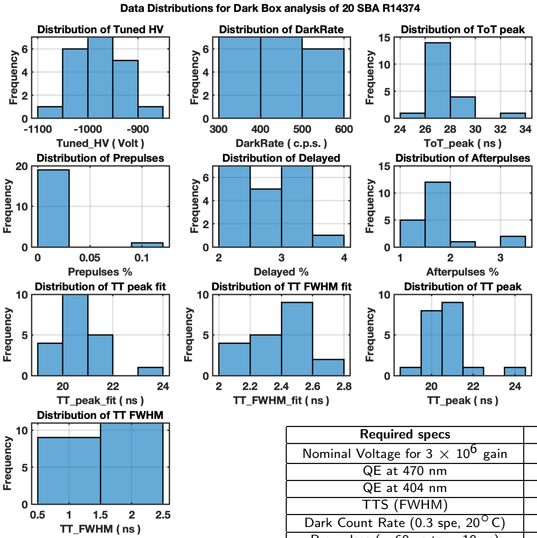
- Accurate knowledge of quantum efficiency (QE) and its spatial variations across the photocathode is crucial for liquid-based Cherenkov detectors.
- The use of high-QE PMTs can drive significant technical advancements.
- Enhanced characterization of PC collection properties improves the accuracy of Monte Carlo simulations, leading to better detector modeling and event reconstruction.

From standard to super and ultra bialkali specs for QE



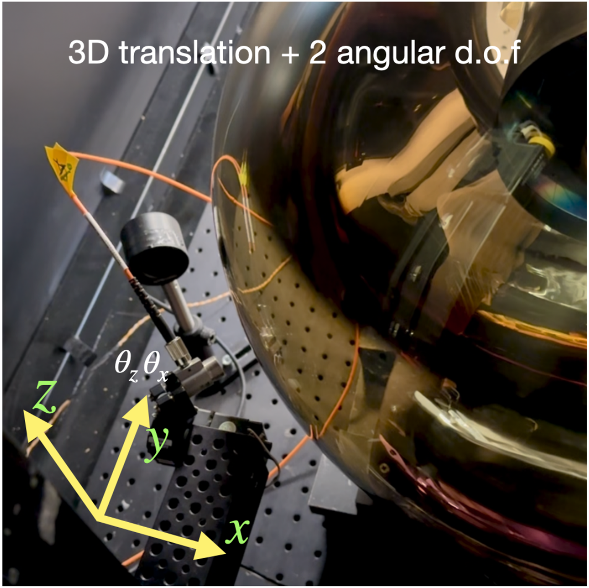


- The improvements in the production of bialkali metal photocathodes are ensuring values up to 45% in the Cherenkov light emission window in water.
- We are testing 20 units of 3" R14374 PMTs for a possible upgrade of the KM3NeT neutrino telescope.
- The enhancement in this technology appears to be strongly dependent on a lattice of Sb, where it is present (industrial secret).



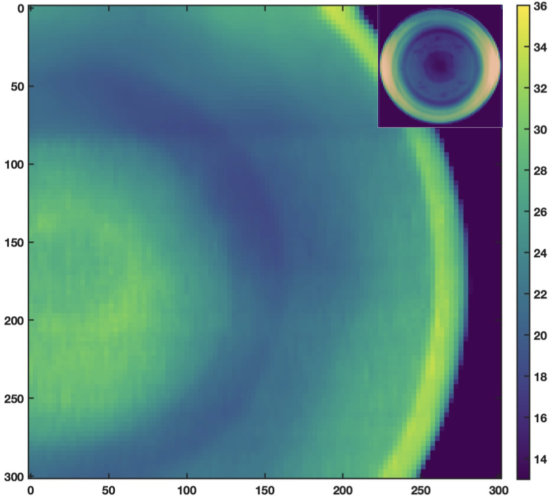
Required specs	Value
Nominal Voltage for 3 $\times$ 10^6 gain	900–1300 V
QE at 470 nm	$\geq$ 18%
QE at 404 nm	$\geq$ 25%
TTS (FWHM)	$\leq$ 5ns
Dark Count Rate (0.3 spe, 20°C)	2000 cps max
Pre-pulses (-60 ns to -10 ns)	1.5% max
Delayed Pulses (15–60 ns)	5.5% max
Late Afterpulses (100 ns–10 μs)	15% max

Latest upgrades: a 5-Axis Stage for PMT Testing



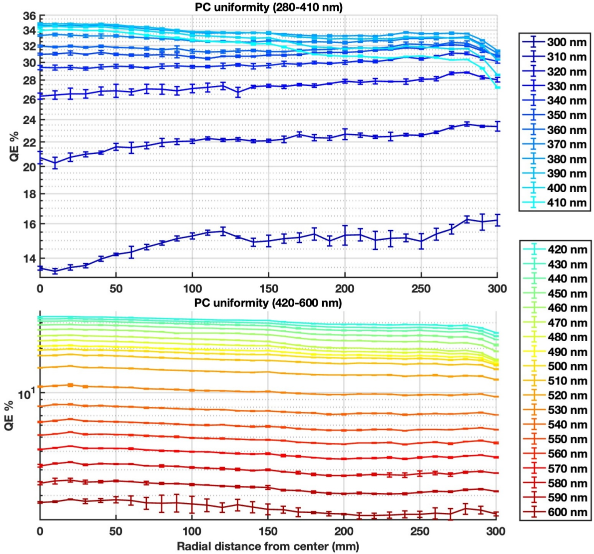
- 3 translational movements: X, Y, and Z
- 2 rotational movements: Tilt and Rotation
- Enables precise positioning of the beam probe
- Used for accurate QE and uniformity measurements
- Uses a spectral source covering from 250 to 1100 nm
- Can be equipped with picosecond pulsed laser source with continuosly tunable rep. rate at 369, 402, 453, 483, 509, 635, 720 nm

Scanning of 20" PMT Photocatode with 5 spatial degrees of freedom



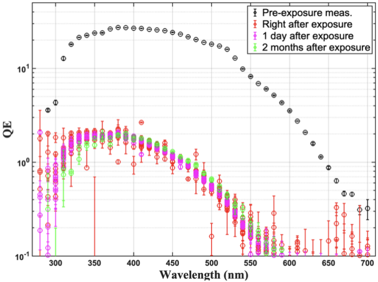
- **Description of the Image:**
  - The image shows a real-scale comparison of a QE map obtained at 410 nm.
  - The light incidence is parallel to the axis of symmetry of the PMTs.
- **Comparison of PMTs:**
  - In the small top-right image, a standard R14374 PMT is shown.
  - In the large section, a 20-inch PMT is displayed.
- **Coverage Area and Setup Potential:**
  - The displayed area represents the covered region with the current stages.
  - This highlights the potential of our experimental setup.

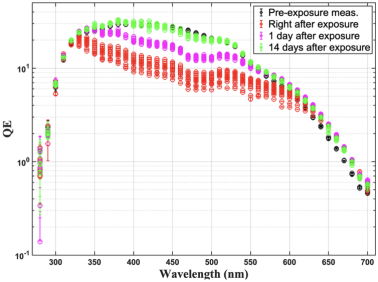
Cathode Uniformity vs. Wavelength



- The setup upgrades permits beam steering features.
- It enables a cathode scan to be performed at any angle between $\pm$ 160 deg.
- In this scan the probe light is maintained at the middle of the dynode structure, this minimizes backscattering.
- Reduced backscattering prevents a second photoelectric emission.
- This avoids biased measurements.
- The plot presented shows a radial cathode homogeneity scan of a 20" PMT.

QE Degradation Analysis



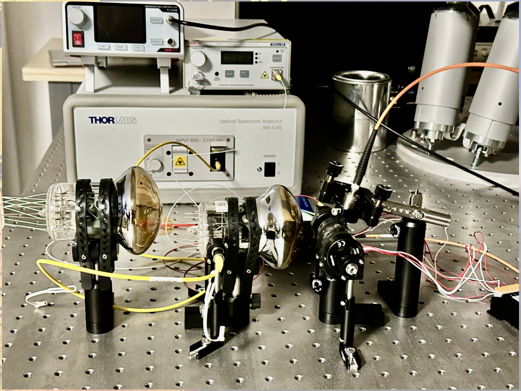


- **Light Stress Exposure:**
  - PMTs were exposed to Xe lamp light for 3, 23, and 70 hours.
  - This simulates exposure to sunlight for 5, 40, and 120 days (solar irradiance: 85.35 mW/cm² at $\lambda = 555$ nm).
  - No PMTs sustained permanent damage.
  - For prolonged exposure (23 and 70 hours):
    - Temporary QE degradation observed in 300–500 nm range.
    - The dark current showed alterations:
    - Recovery followed a power law (23 hours exposure).
    - Recovery followed a logarithmic law (70 hours exposure).
- **Thermal Stress Exposure:**
  - PMTs exposed to temperatures from 50°C to 210°C for varying durations.
  - No QE degradation observed up to 70°C, even for prolonged exposure.
  - Temporary QE decrease observed after:
    - 2 days at 90°C + 1 day at 180°C.
  - Irreversible damage observed only in:
    - 5 days at 180°C + 1 day at 210°C.

Conclusion

- The INFN CAPACITY Photosensors Lab is conducting extensive characterization of PMTs for next-generation neutrino telescopes. .
- The newly developed 5-axis scanning stage enables high-precision QE mapping and cathode analysis.
- Absorption spectroscopy techniques provide a novel approach for monitoring QE degradation in real-time.
- The lab's work contributes directly to detector optimization for projects like KM3NeT, improving detection efficiency and overall performance.

BACKUP: QE Degradation Analysis- Cesium diffusion investigation using absorption spectroscopy



- An absorption spectroscopy setup was created for the 852 nm line of Cesium.
- Purpose: Assess and monitor real-time QE degradation.
- The setup can be replicated for Potassium in the case of Bialkali metal coatings.
- Provides a quantitative analysis of the QE degradation process.