



# Colloquium

## From Eikonal to Entanglement:

### A Unified Framework for Classical and Quantum Photonic Systems

**Dr. Jyh-Long Chern (陳志隆)**

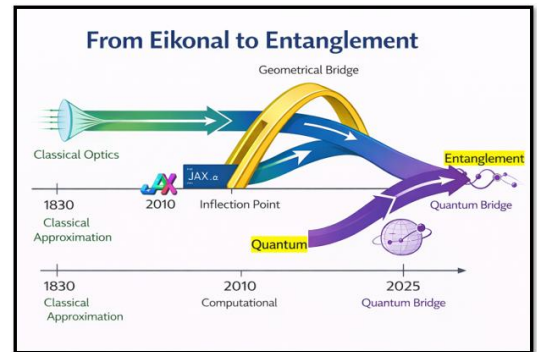
Formerly Professor, Institute of Electro-Optical Engineering, NCTU

Formerly Professor, Department of Physics, NCKU

**Date: 2026/04/28 (Tue)**

**Venue: S4-625**

**Time: 14:00**



#### Abstract :

A single photon traversing a quantum sensor encounters three distinct physical domains: it propagates through refractive optics, is transduced into a measurable signal at the detector, and deposits waste heat into the lattice. Conventionally, these three domains— propagation, detection, and energy management—are engineered by separate communities using separate tools. This talk presents a unified framework that connects them through exact mathematical bridge identities.

The central result is that the classical Strehl ratio and the quantum state fidelity are the *same* overlap integral:  $S = F$ . This single identity, rooted in the eikonal equation  $|\nabla W|^2 = n^2(\mathbf{r})$ , creates a continuous bridge from consumer lens design to quantum gate engineering—a span requiring a 45× tightening of the same wavefront specifications. Three bridge equations form a closed constraint triangle, and a *triangle closure test* reveals that cross-domain constraints can dominate single-domain budgets by factors of 8–70×. For NV-diamond quantum sensors, the thermal stability required by quantum fidelity (10 mK) is 8.5× tighter than what an optical designer working in isolation would specify—a constraint invisible without the integrated analysis.

The framework introduces *orthogonality* as the operating condition for independent design: when the Hessian condition number is small, each domain can be engineered separately; when it grows, co-design becomes mandatory. The identity  $S = F$  admits *six independent derivations* (D1–D6, spanning Huygens overlap, cumulant expansion, mode-resolved Fraunhofer coupling, Wigner purity, vector Richards–Wolf focusing, and quantum Fisher information) and is validated across *eleven canonical problem cases* (PC1–PC11) that tile the classical–quantum continuum from tolerance allocation through yield, dephasing, and mode-coupling design. Diagnostic ratios detect orthogonality breakdown before it reaches the laboratory, demonstrated throughout using nitrogen-vacancy diamond quantum magnetometry as the running example.

**Three Showcases.** The talk is accompanied by three experimentally-anchored demonstrations optimized for distinct audiences: a **teaching** showcase proving  $S = F$  numerically to machine precision across 104 random Zernike wavefronts; a **research** showcase computing the NV-diamond triangle closure ratio  $\kappa \approx 8.5$  and identifying three unfilled joint-measurement gaps in the current literature; and an **engineering** showcase mapping the 45× span from  $\sigma W = \lambda/14$  (Rayleigh, consumer) to  $\sigma W = \lambda/630$  (quantum gate) onto directly importable tolerance coefficients for commercial optical-design and photonic-simulation software.

**Open-Source Resources.** The three source volumes underlying this framework are freely available:

- **The Eikonal Bridge** — Classical to quantum optics via differentiable ray tracing.
- **Quantum Field Imaging** — Quantum metrology extended to computational imaging.
- **Thermal Photonics** — Unified conduction–radiation thermal engineering.