dRICH Simulation Meeting : 10/09/2026

Understanding the time distribution of dRICH Hits

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Quantum Efficiency (QE) Implementation :

Simulation Sample:

- 30 GeV/c π^+
- η = 2.5, ϕ = 90°
- 5000 events

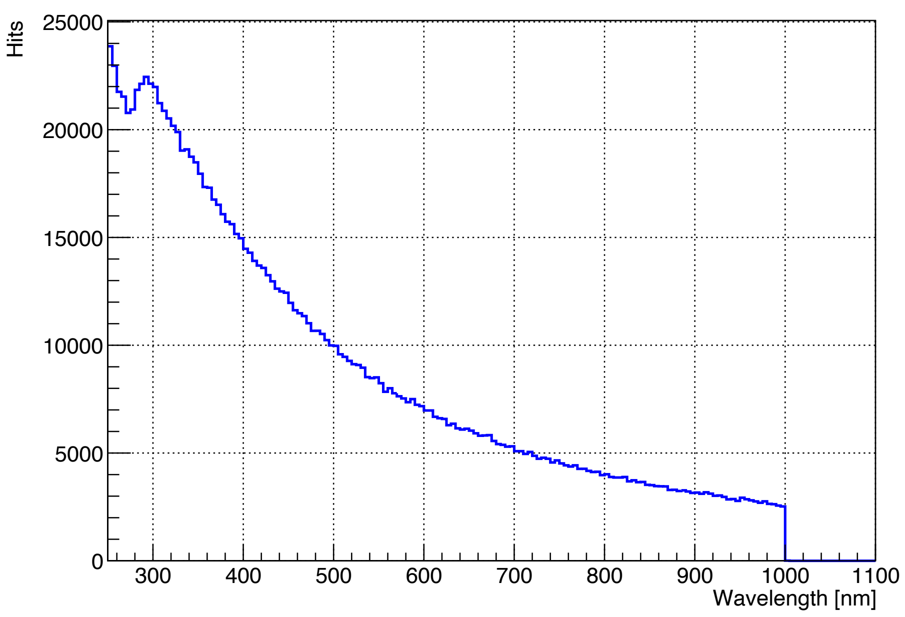
QE workflow :

DRICHHits → Linked optical photons → λ → $QE(\lambda)$ → Accept/Reject

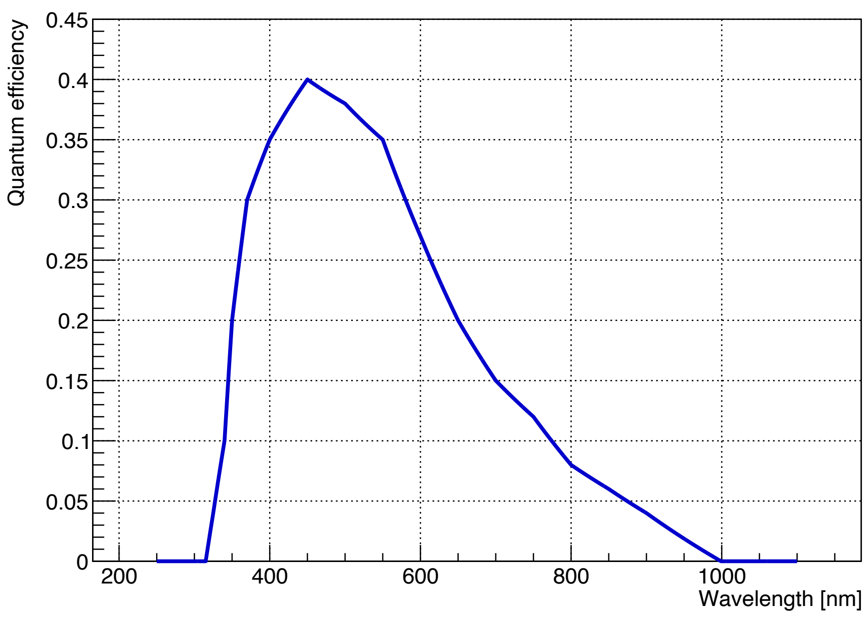
Accept if r < $QE(\lambda)$; where r ~ U(0,1) (random number b/w 0-1)

QE input: λ dependent QE table taken from the digitization configuration

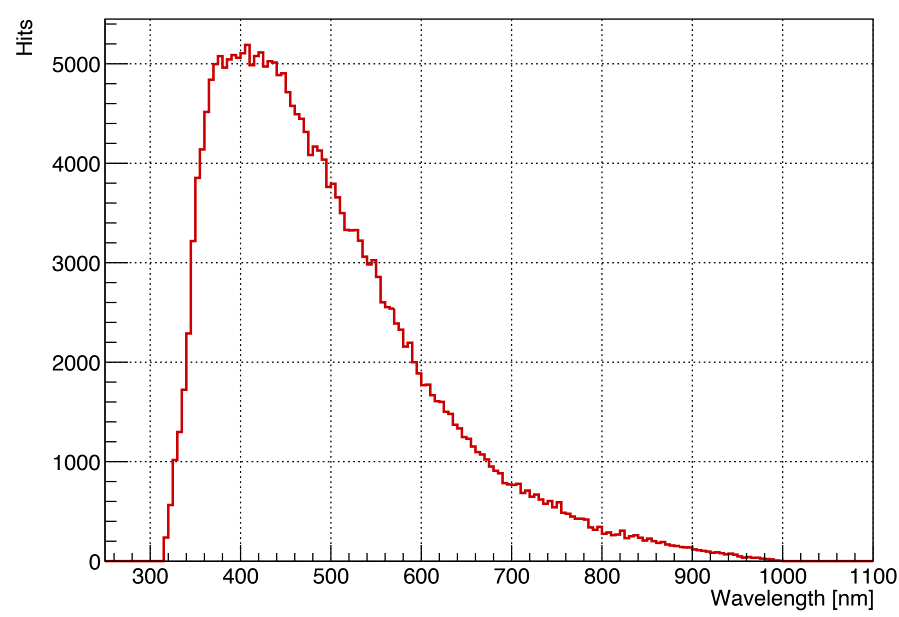
Wavelength distribution before QE



Interpolated QE table used in simulation



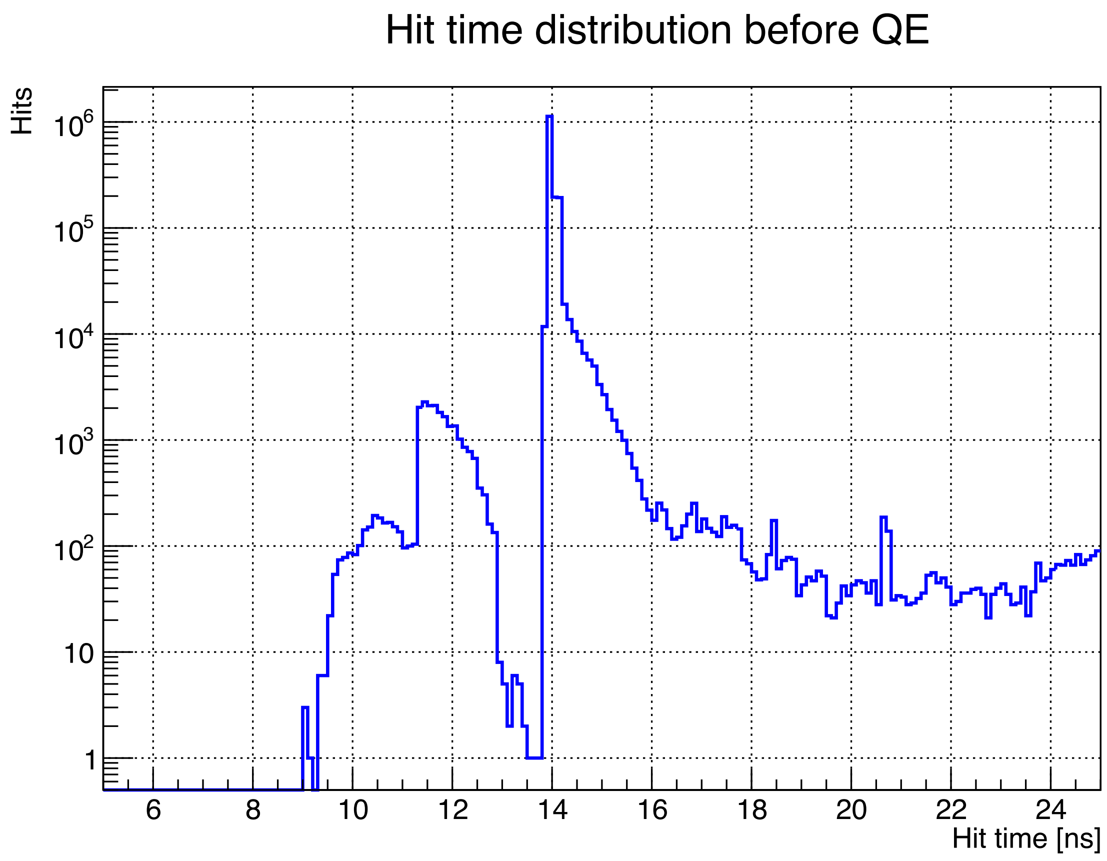
Wavelength after QE

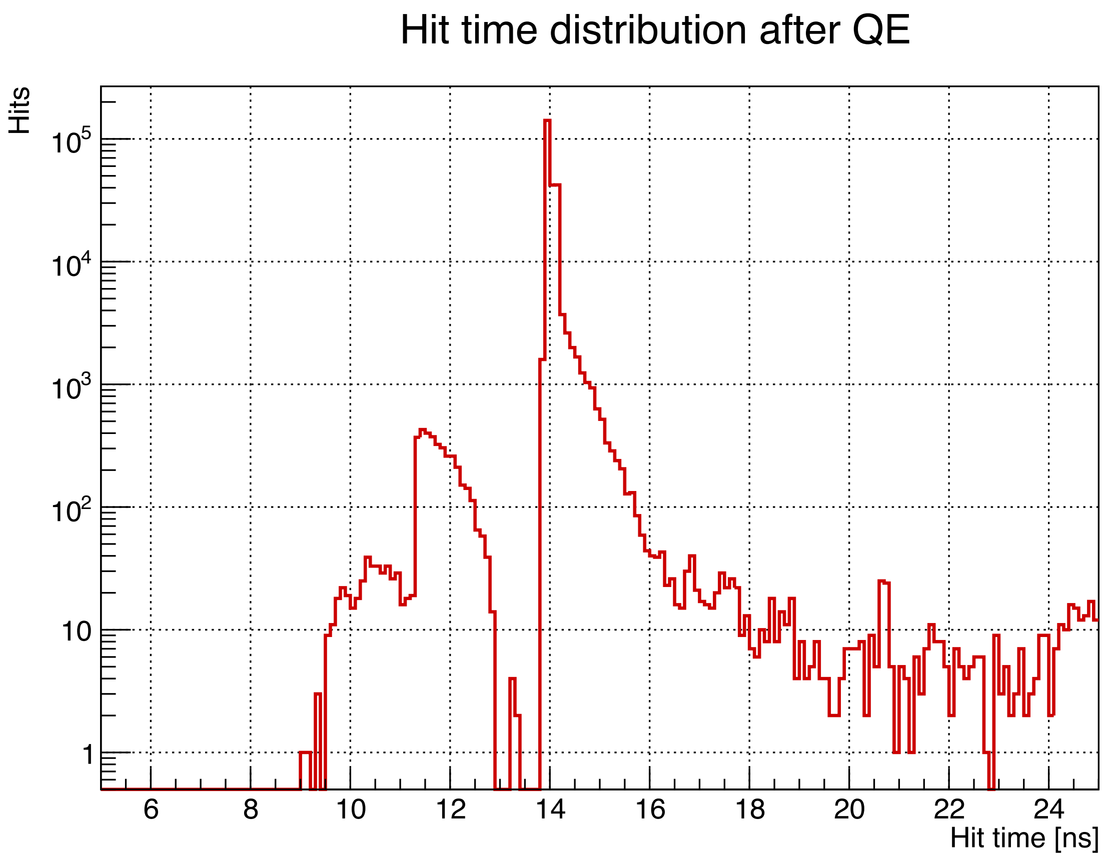


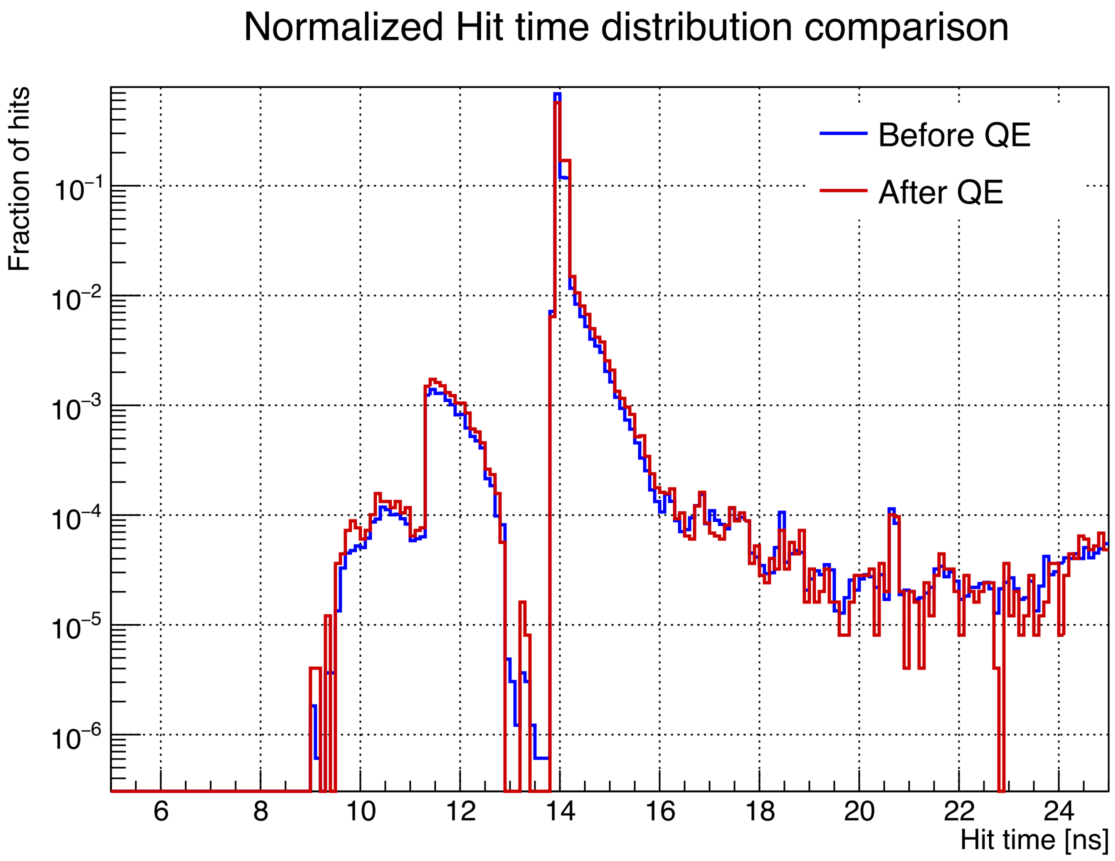
Takeaway :

The wavelength-dependent QE selection converts the incident-photon-hit sample into a statistically expected photoelectron-level sample.

Impact of QE on Timing:

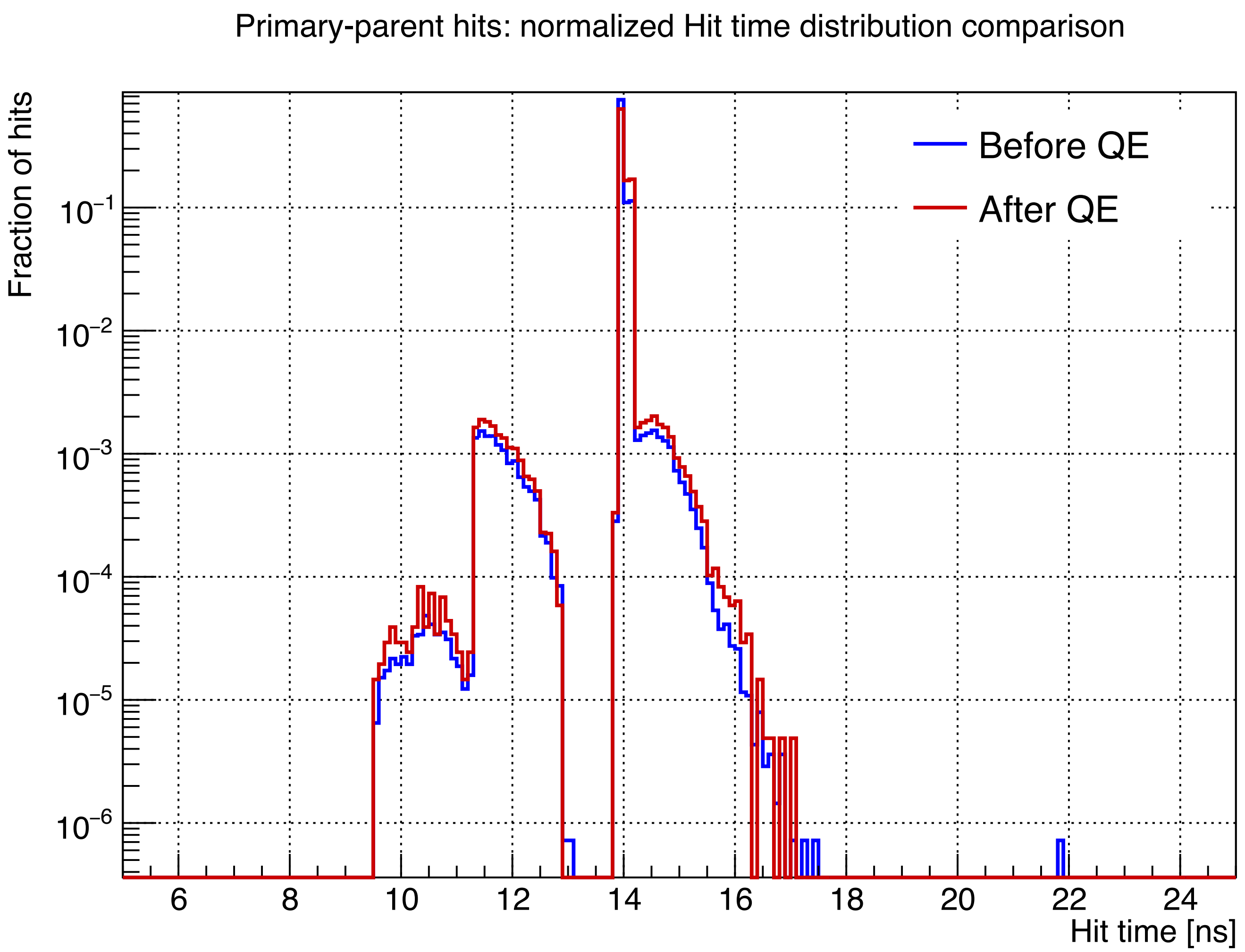


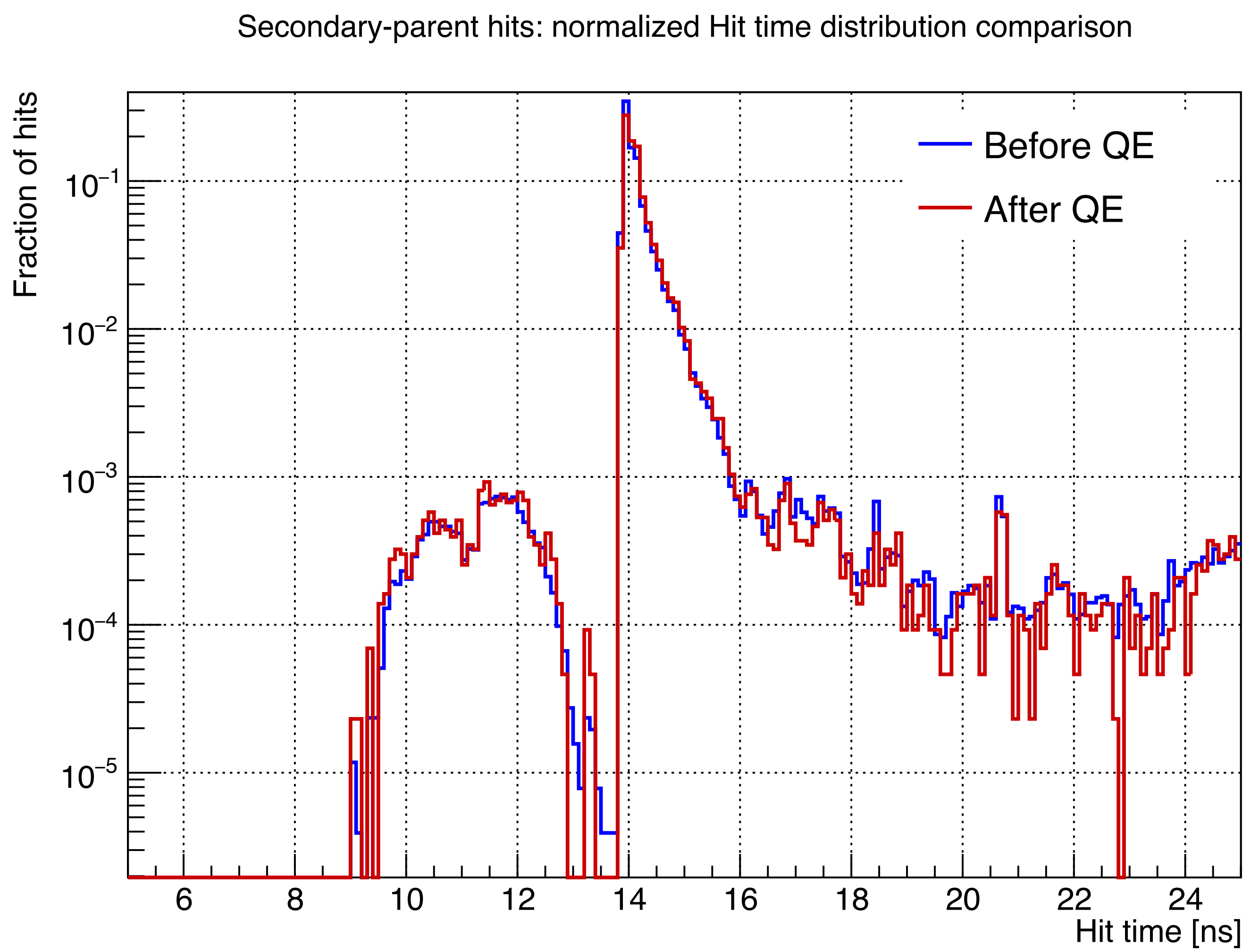




- QE primarily affects the hit statistics rather than the timing position or distribution.

Impact of QE on Timing:





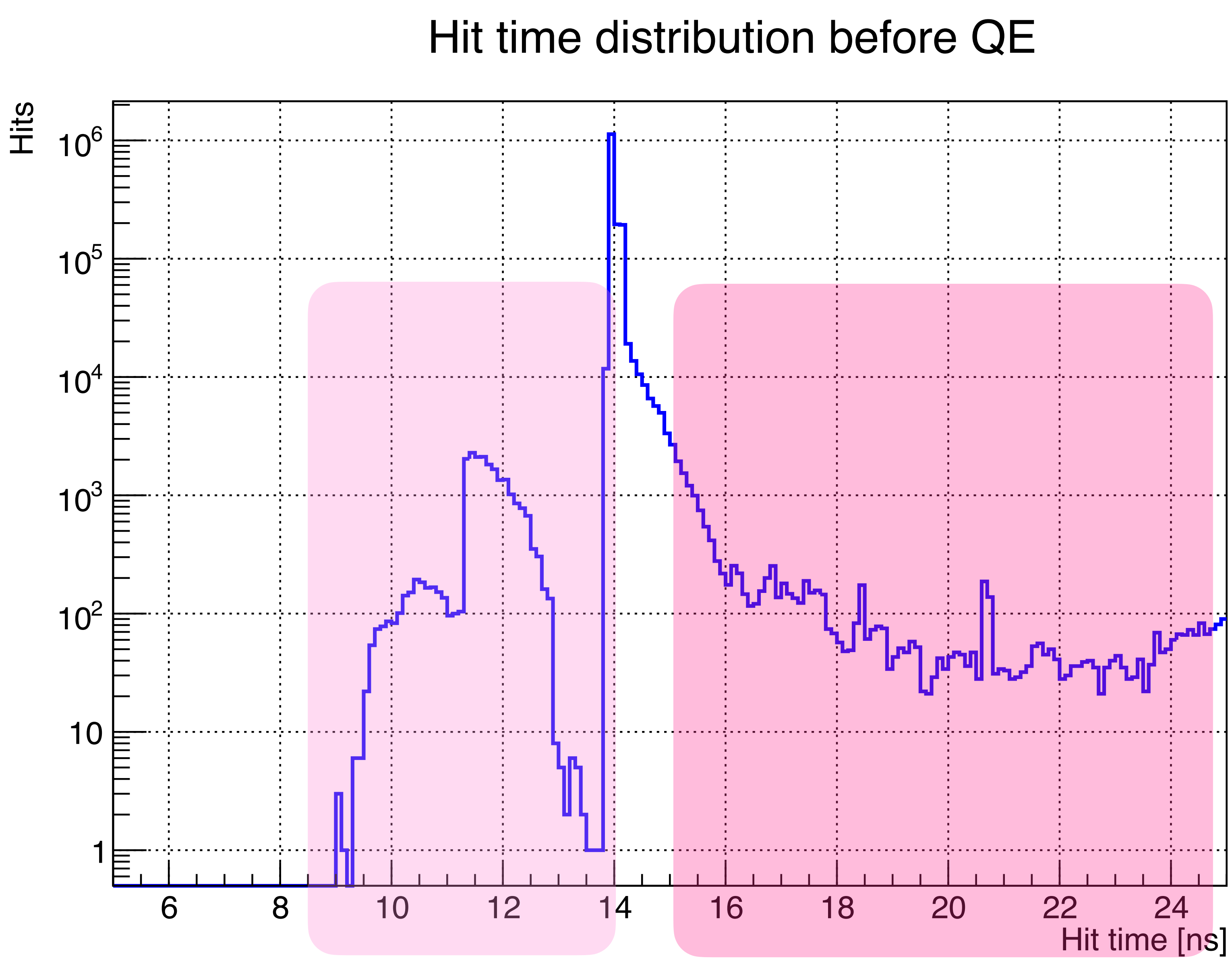
- The same behavior is observed for photons produced by primary and secondary particles: QE reduces the accepted yield, while the main timing structures remain.
- The late-time component therefore cannot be explained as a consequence of sensor QE.

Story till now :

- ☑ A clear late-time component beyond the prompt dRICH photon-hit peak.
- ☑ The tail is not purely gas or aerogel driven; both radiator configurations contribute.
- ☑ Late hits are mainly linked to photons whose immediate parent is a secondary particle, especially e^-/e^+.
  (26/March/2026 - https://indico.bnl.gov/event/32183/)
- ☑ Full-detector simulation enhances the late-time region compared with dRICH-only.
  (7/May/2026 - https://indico.bnl.gov/event/32811/contributions/124233/attachments/70018/120012/PG_vs_HEPMC_DRICHOnly_AllDet.pdf)
- ☑ Detector-removal scans indicate contribution from upstream sub-detectors.
- ☑ Species, momentum and η scan still has late-time component.

  (28/May/2026 - https://indico.bnl.gov/event/33070/); (23/July/2026 - https://indico.bnl.gov/event/33619/)
- ☑ QE implementation does not remove the tail.

Full Picture (HOPEFULLY !!) :



Extending the Study Beyond the Tail

- So far, our focus has mainly been on the tail part of the distribution, particularly the late-arriving hits. However, there are also early-arriving hits.
- We already have kinematic information, their parent composition.
- The key question is: Do the early hits follow the nominal dRICH optical path, or do they reach the sensor through direct or otherwise non-nominal routes?

- To answer this, we combine the already in-hand information with the optical information of the hits.
- We currently do not have this optical information directly, but fortunately, GEANT4 provides the possibility to obtain it.
- This gives us a way to cross-check the early hits and determine whether they have a physical origin.

Optical History Check : Overall View

```
npsim \
  --compactFile "${DETECTOR_PATH}/epic.xml" \                      \\geometry etc.
  --inputFiles "pion_30g_eta2p5_phi90.hepmc" \                     \\input
  --outputFile "sim_pion_30g_90_2p5_history_5k.root" \             \\output
  --numberOfEvents 5000 \
  --steeringFile "drich_photon_history.py"                         \\custom
```

sim_pion_30g_90_2p5_history_5k.root
└──── Standard EDM4hep output:
MCParticles, DRICHHits and hit-particle relations

drich_photon_history.root
└──── Custom diagnostic output:
photonSteps tree

drich_photon_history.py is a configuration layer. It:

- registers the event, tracking and stepping actions;
- instantiates the custom C++ action;
- specifies the diagnostic ROOT output file;
- enables the required history-recording configuration.
- does not calculate reflection, refraction or absorption. These outcomes are simulated by Geant4.

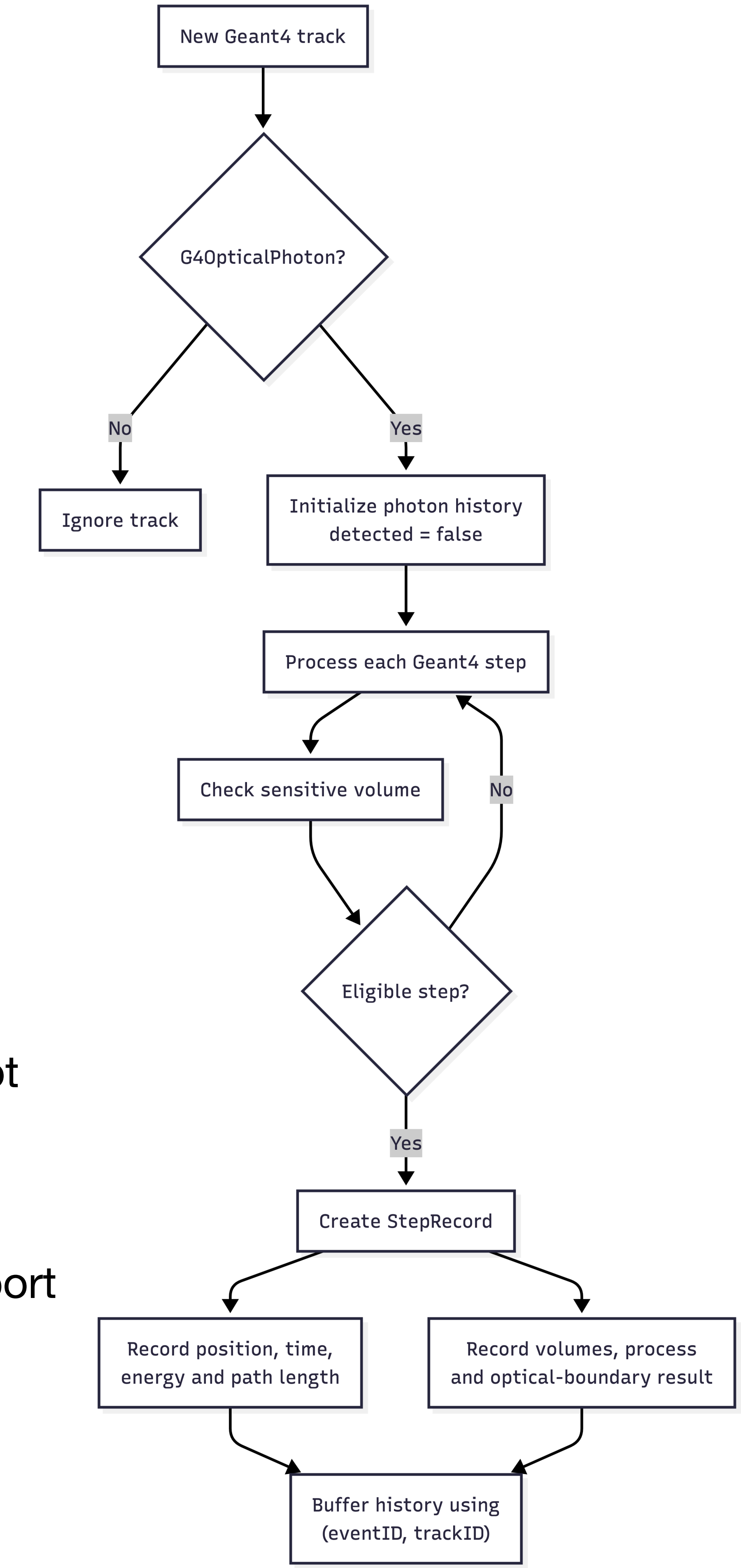
Optical History Check : information recorded by the custom C++ action

Information written for every eligible step:

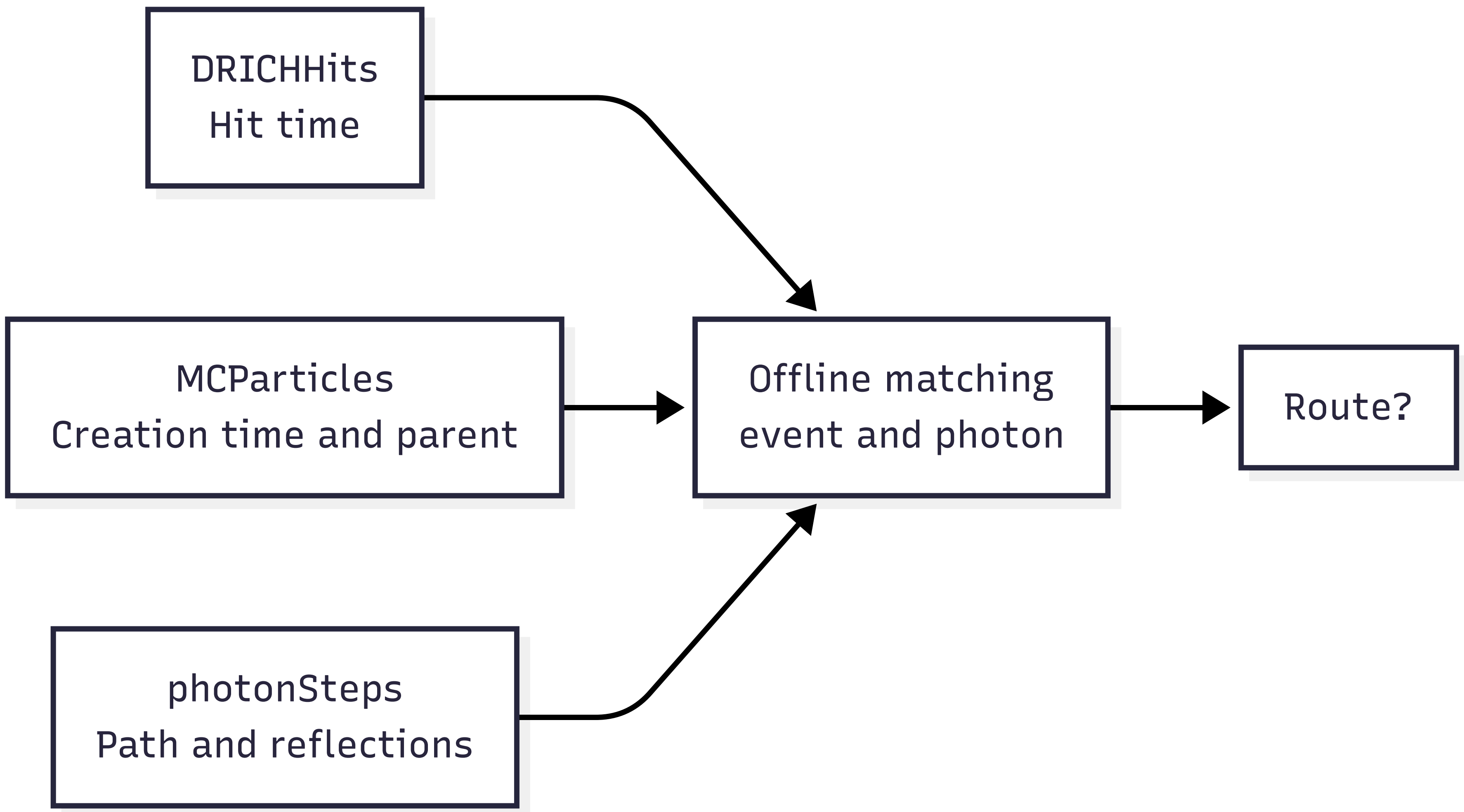
- eventID, trackID, parentTrackID, stepNumber;
- pre-step and post-step position;
- pre-step and post-step global time;
- step length and cumulative track length;
- photon kinetic energy;
- pre-step and post-step volume names;
- process defining the step;
- GEANT4 optical-boundary status;
- sensitive-volume encounter flag.

Important interpretation:

- Only photons that encounter a sensitive volume are retained.
- Photons absorbed or lost before reaching a sensitive detector are not written.
- The standard simulation output and diagnostic history are produced independently.
- The custom actions observe Geant4; they do not alter photon transport or create DRICHHits.

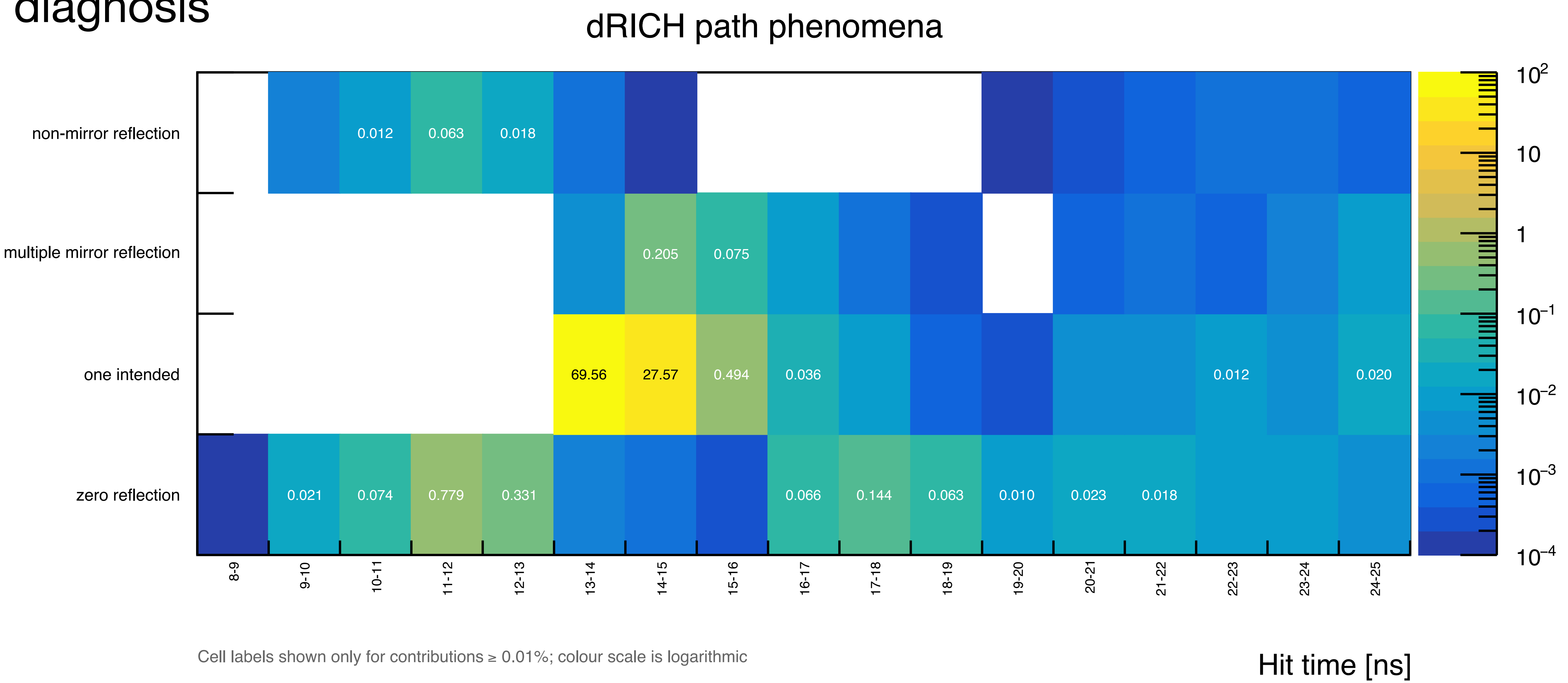


Optical History Check : From recorded information to timing diagnosis



The standard simulation preserves detector hits and Monte Carlo relations, while the custom DDG4 observer actions independently preserve the step-by-step GEANT4 history of detected optical photons, allowing the measured hit time to be traced back to photon creation time, propagation path and optical-boundary interactions. Photons touching DIRC or pfRICH volumes are excluded.

Optical History Check : From recorded information to timing diagnosis



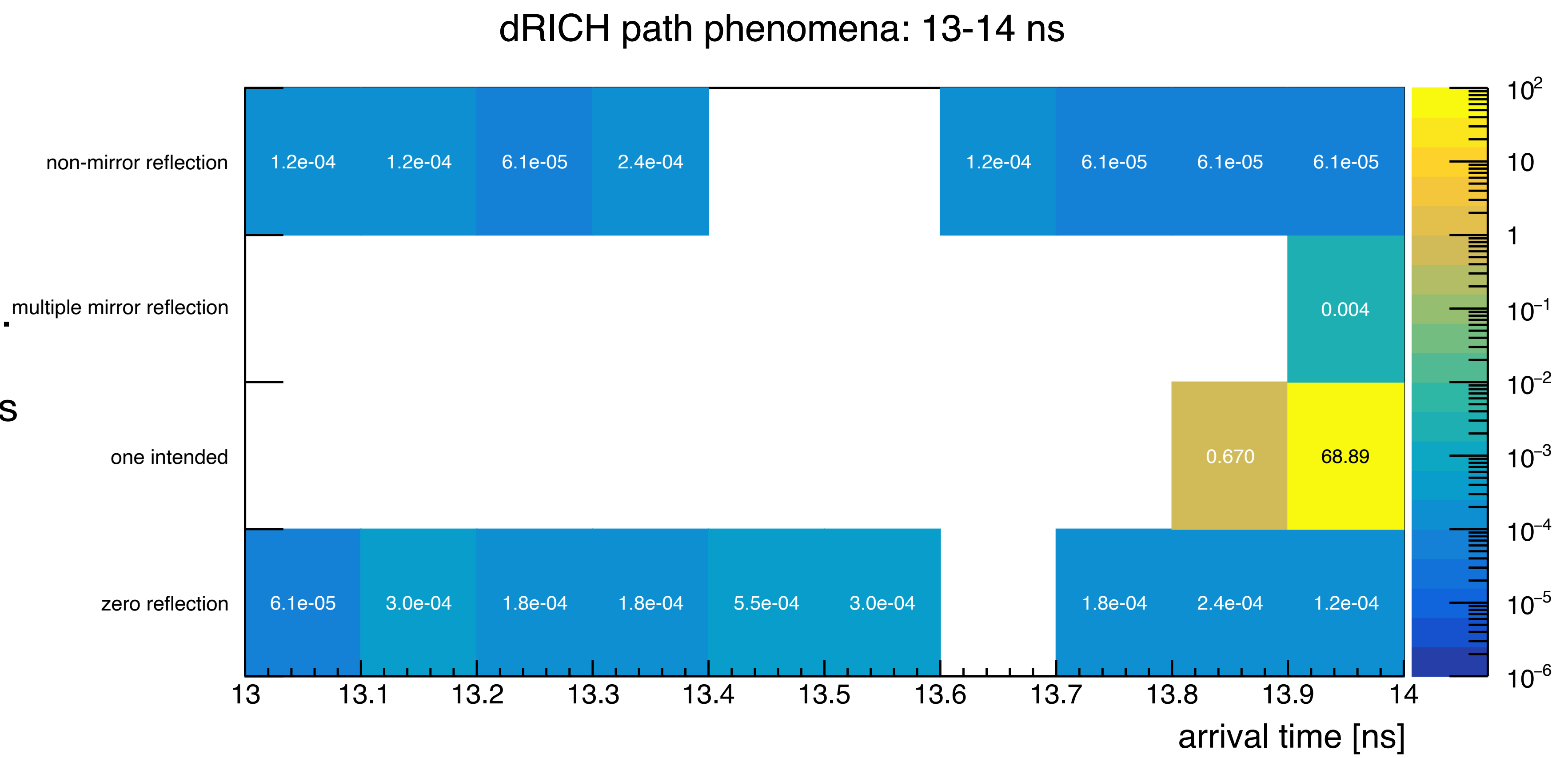
- The main timing peak is dominated by one intended dRICH-mirror reflection.
- Early hits are mainly zero-reflection + non-mirror reflection photons.
- Late hits remain dominated by one intended reflection.
- Multiple-mirror reflections increase at late times but remain subdominant.

Cell values: percentage of the complete accepted dRICH photon sample.

Optical History Check : Fine Timing Structure: 13–14 ns

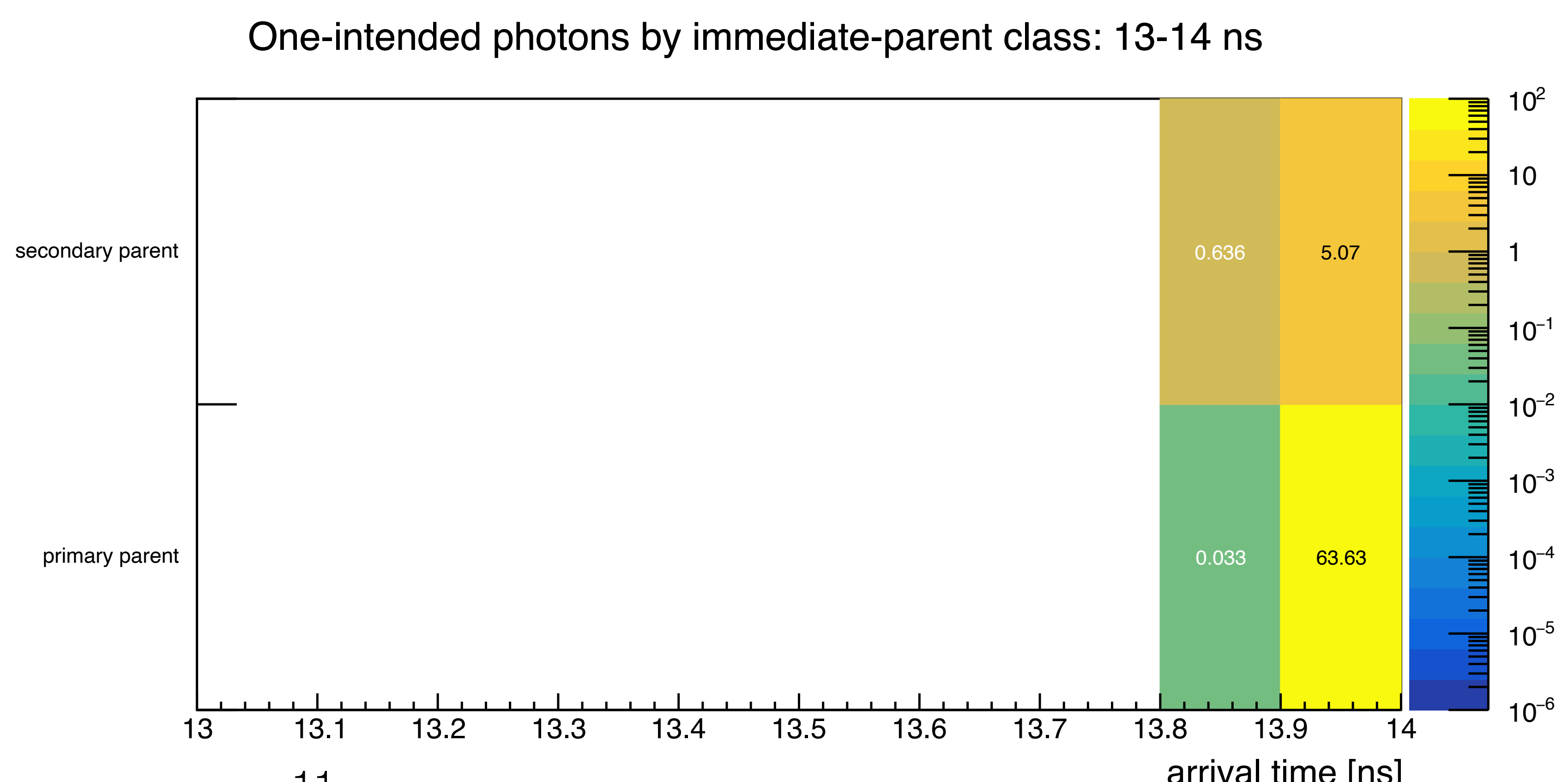
Upper plot — Optical-path classification

- Arrival time is divided into fine 0.1 ns bins.
- The prompt peak between 13.8 and 14.0 ns is almost entirely composed of photons with one intended mirror reflection.



Lower plot — Parent classification of one-intended photons

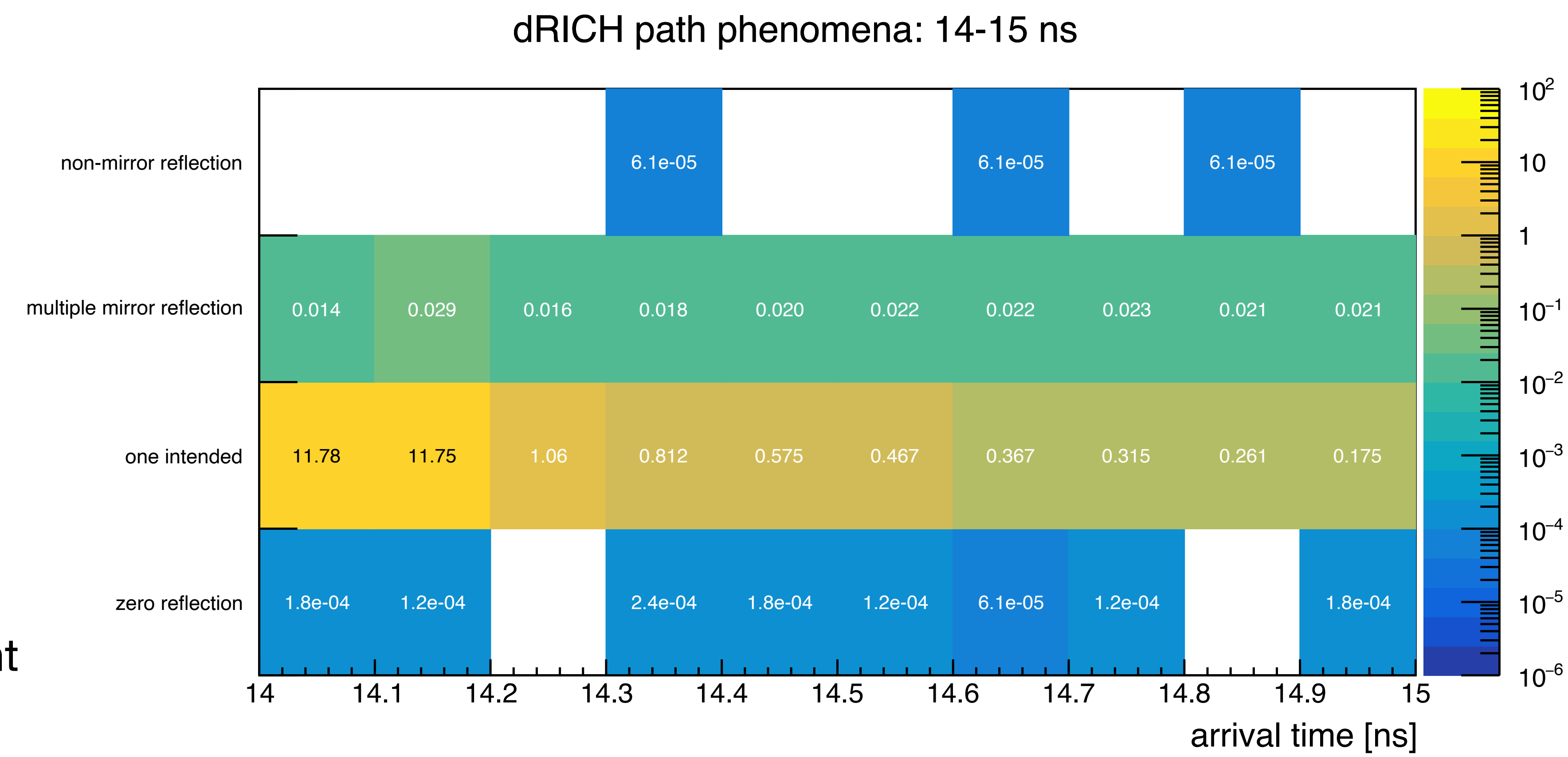
- Selects only photons with exactly one intended dRICH-mirror reflection from the upper plot.
- Separates them according to their immediate parent:
  - Primary parent
  - Secondary parent
- The 13.8–13.9 ns rise has a larger secondary-parent contribution.
- The main 13.9–14.0 ns peak is strongly dominated by primary-parent photons.

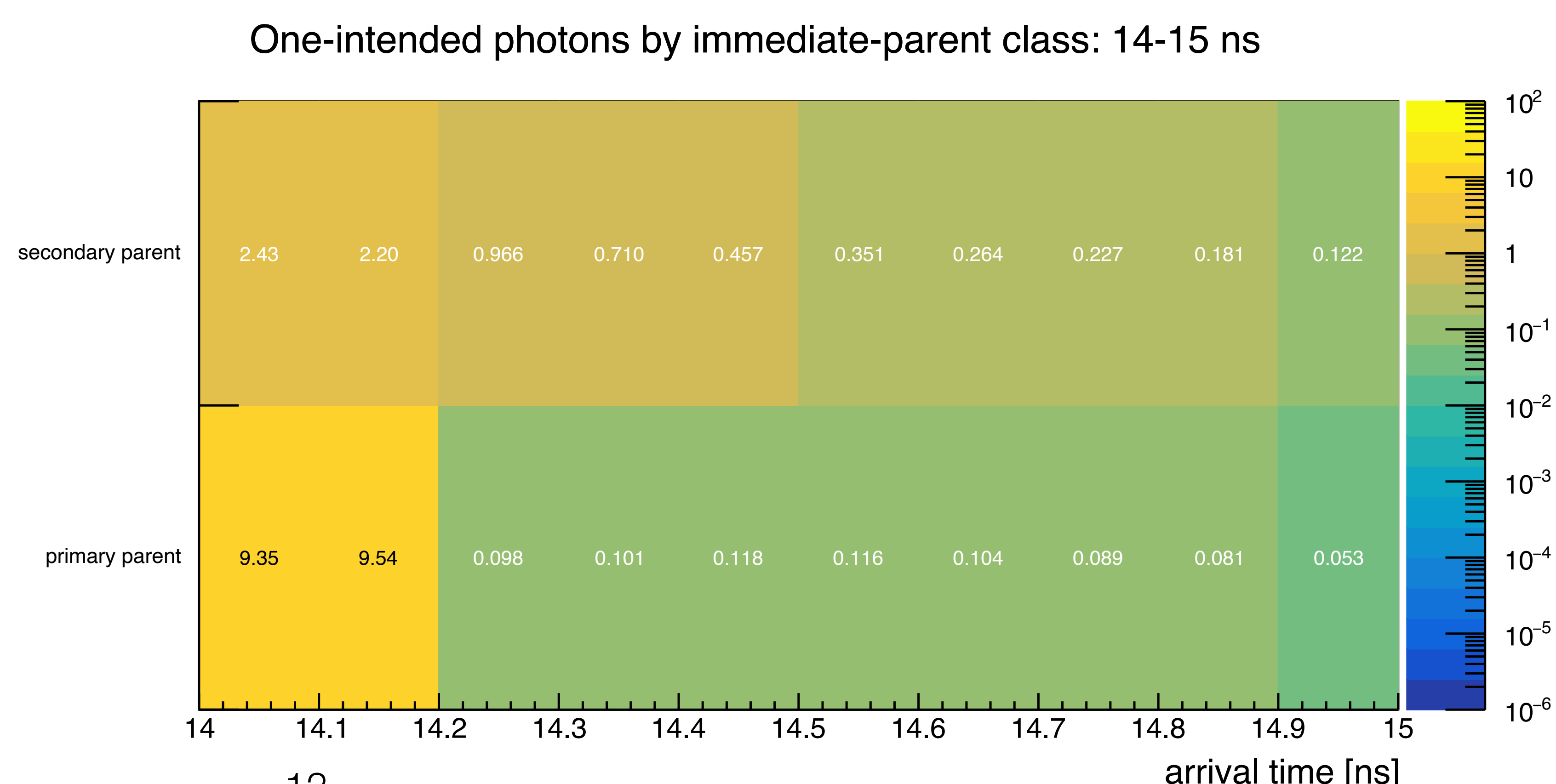


Cell values: percentage of the complete accepted sample.

Optical History Check : Fine Timing Structure: 14–15 ns

- The nominal primary-parent population continues up to approximately 14.2 ns.
- Beyond 14.2 ns, the one-intended-reflection contribution decreases continuously.
- Multiple-mirror reflections are present but remain a small contribution.
- Secondary-parent photons dominate the one-intended category after 14.2 ns.





Conclusion: The beginning of the late tail is dominated by secondary-parent photons—not by additional reflections.

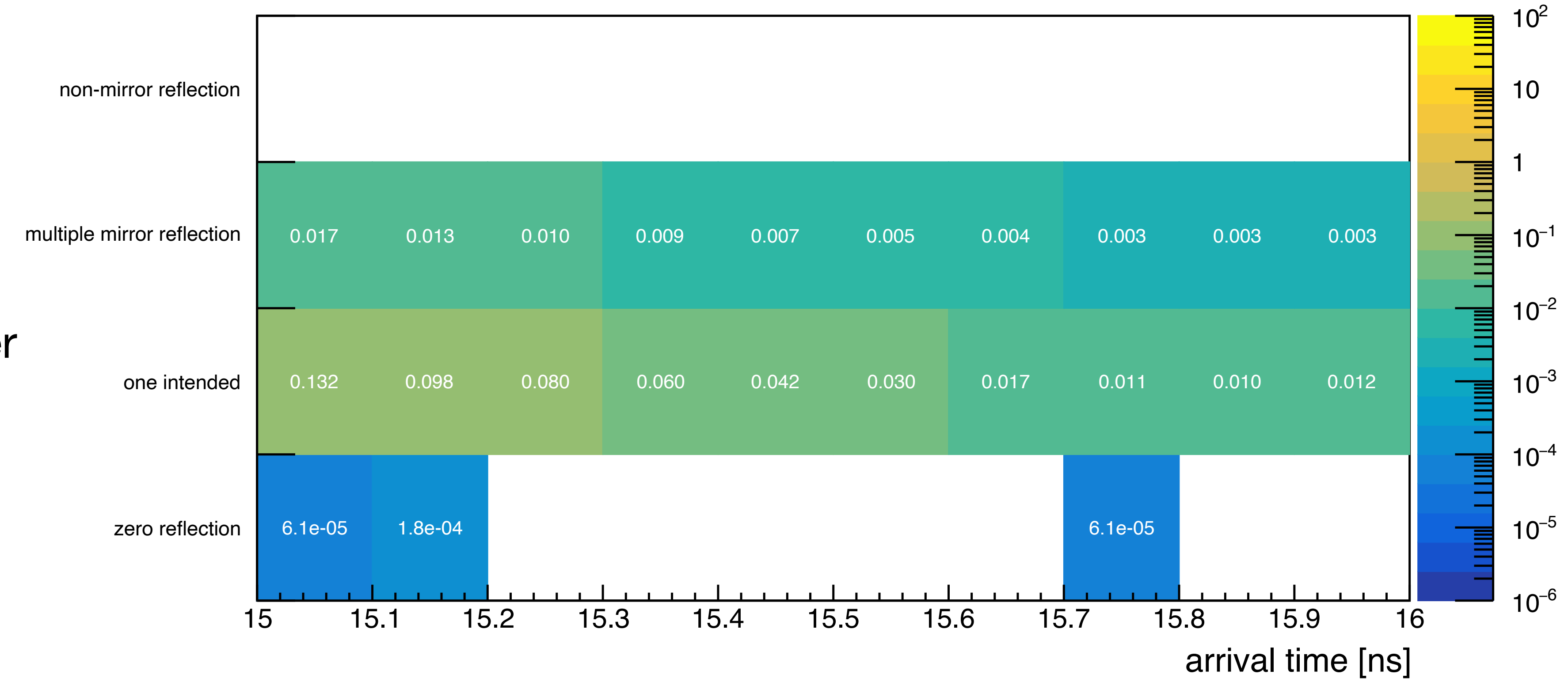
Cell values: percentage of the complete accepted sample.

Optical History Check : Fine Timing Structure: 15–16 ns

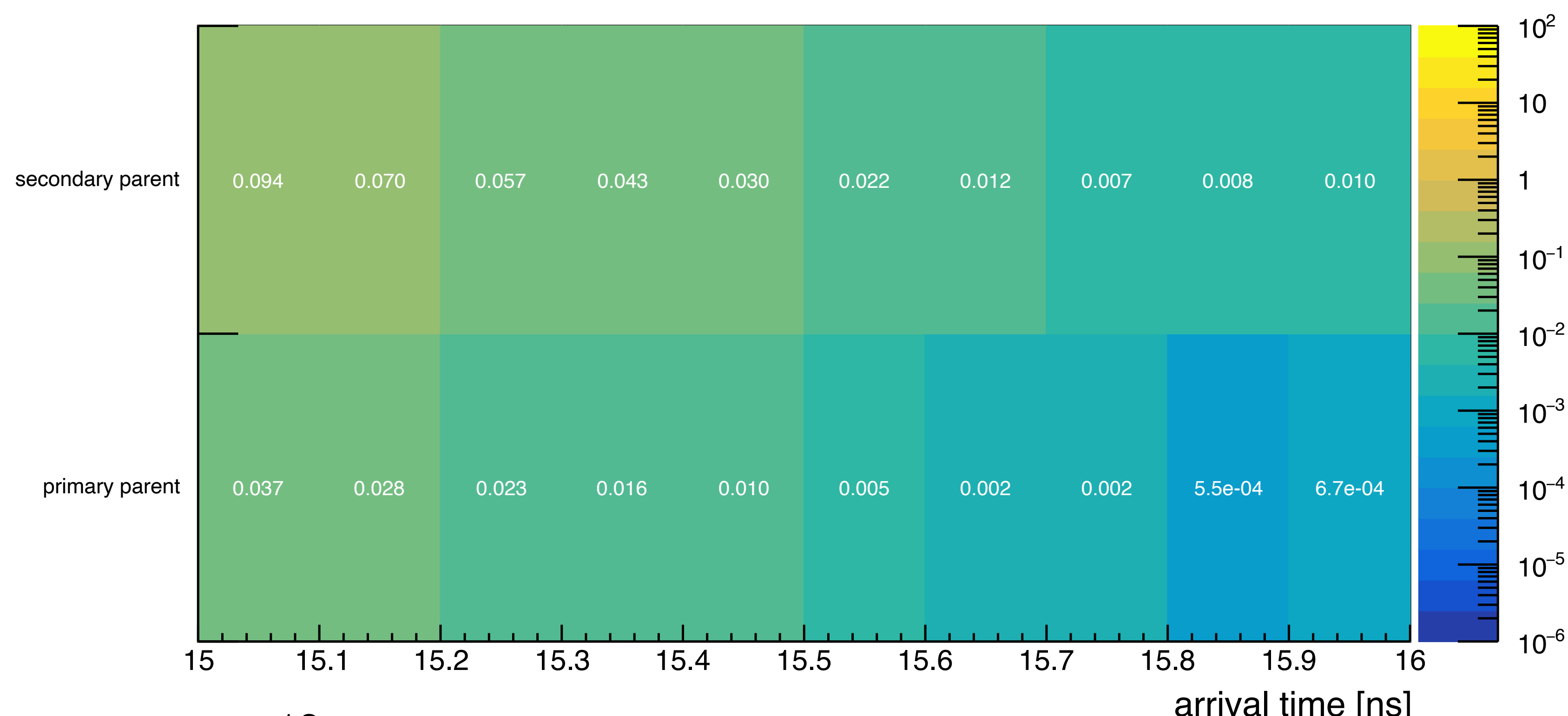
- One intended reflection remains the largest optical category.
- Multiple-mirror photons form a smaller late-time contribution.
- Secondary-parent photons dominate every fine-time bin.
- Beyond approximately 15.8 ns, primary-parent photons are nearly absent.

Conclusion: The extended tail is predominantly produced by secondary particles following apparently valid one-mirror paths.

dRICH path phenomena: 15-16 ns



One-intended photons by immediate-parent class: 15-16 ns



Cell values: percentage of the complete accepted sample.

Conclusion :

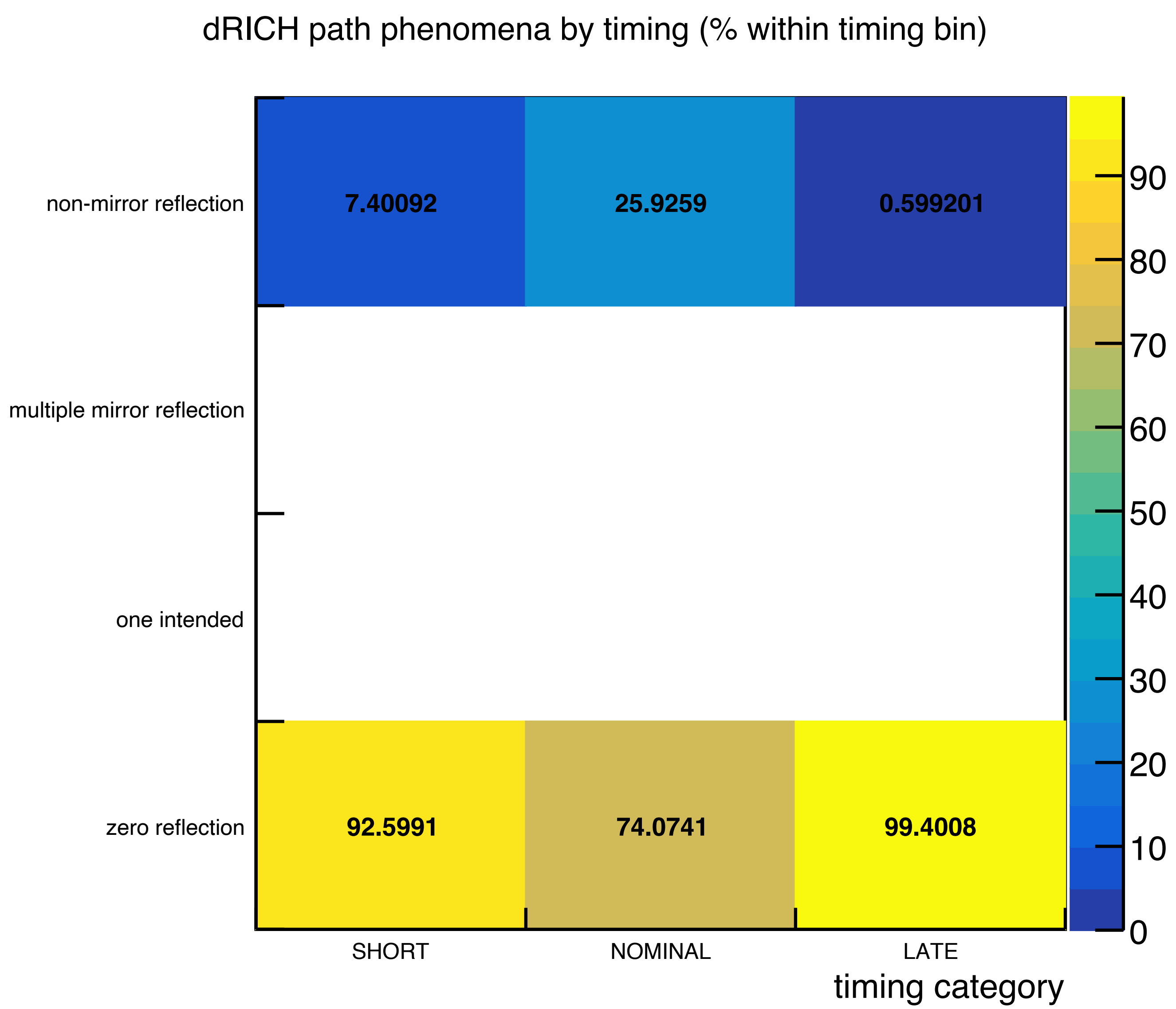
- **Early hits:** predominantly direct, zero-reflection photons.
- **Nominal peak:** primary-parent photons with one intended mirror reflection.
- **Late tail:** predominantly secondary-parent photons.
- Most late photons have one mirror reflection.
- QE changes the detected yield but not the timing structure.

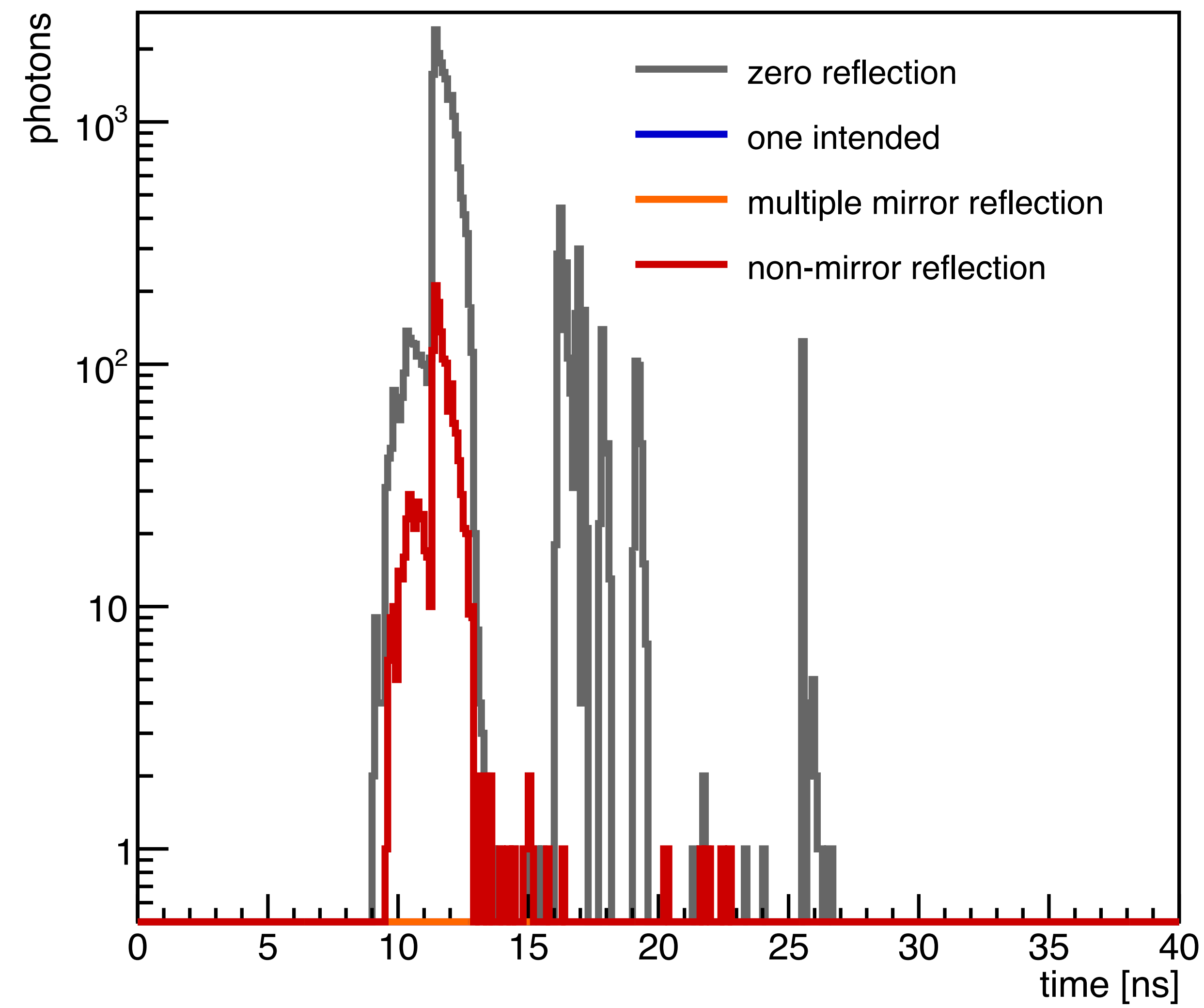
Back up

Optical History Check :

Control test - dRICH mirror reflectivity set to R=0

SHORT - <13ns ; Nominal - 13-14.2 ns ; LATE - >14.2ns

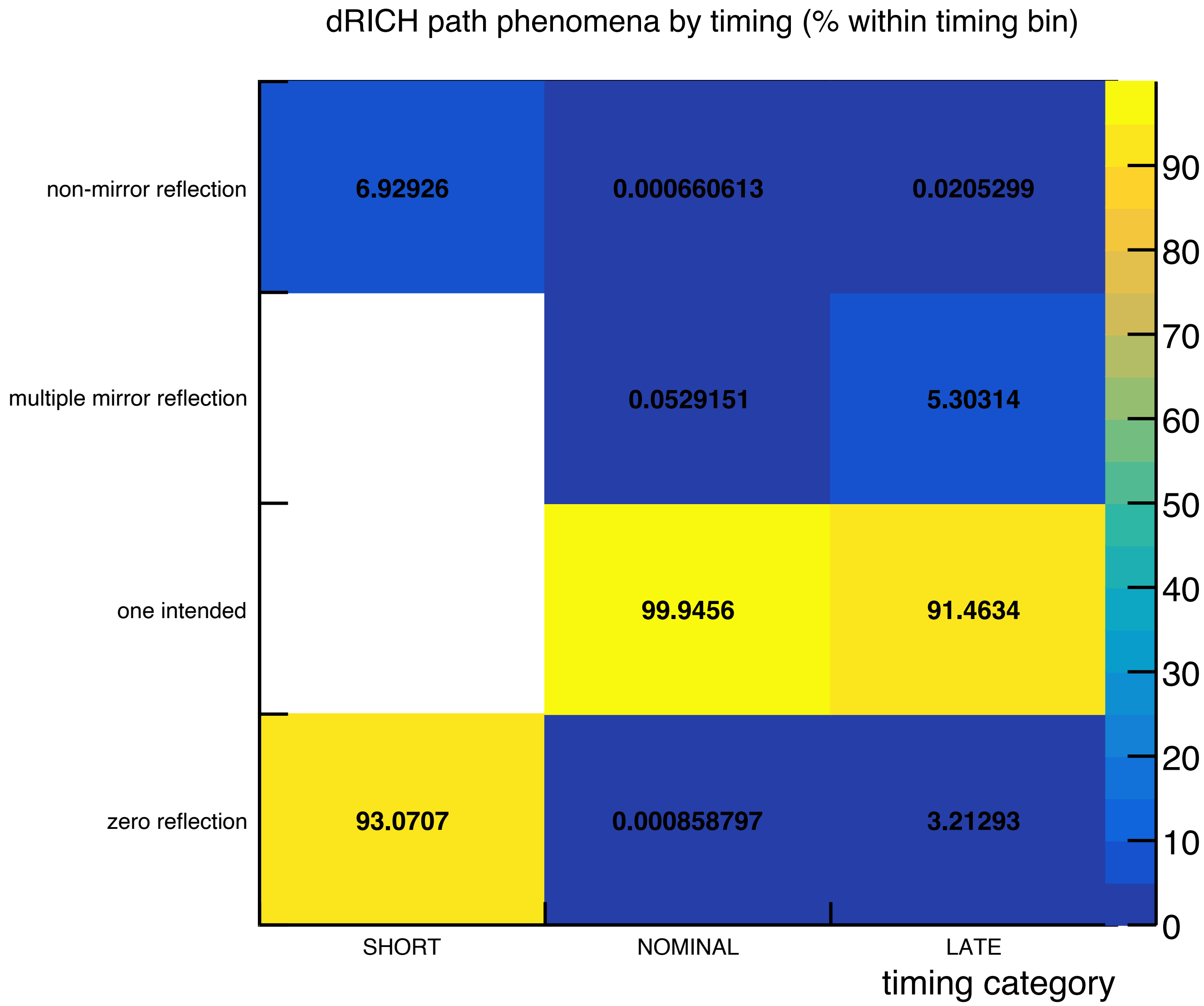


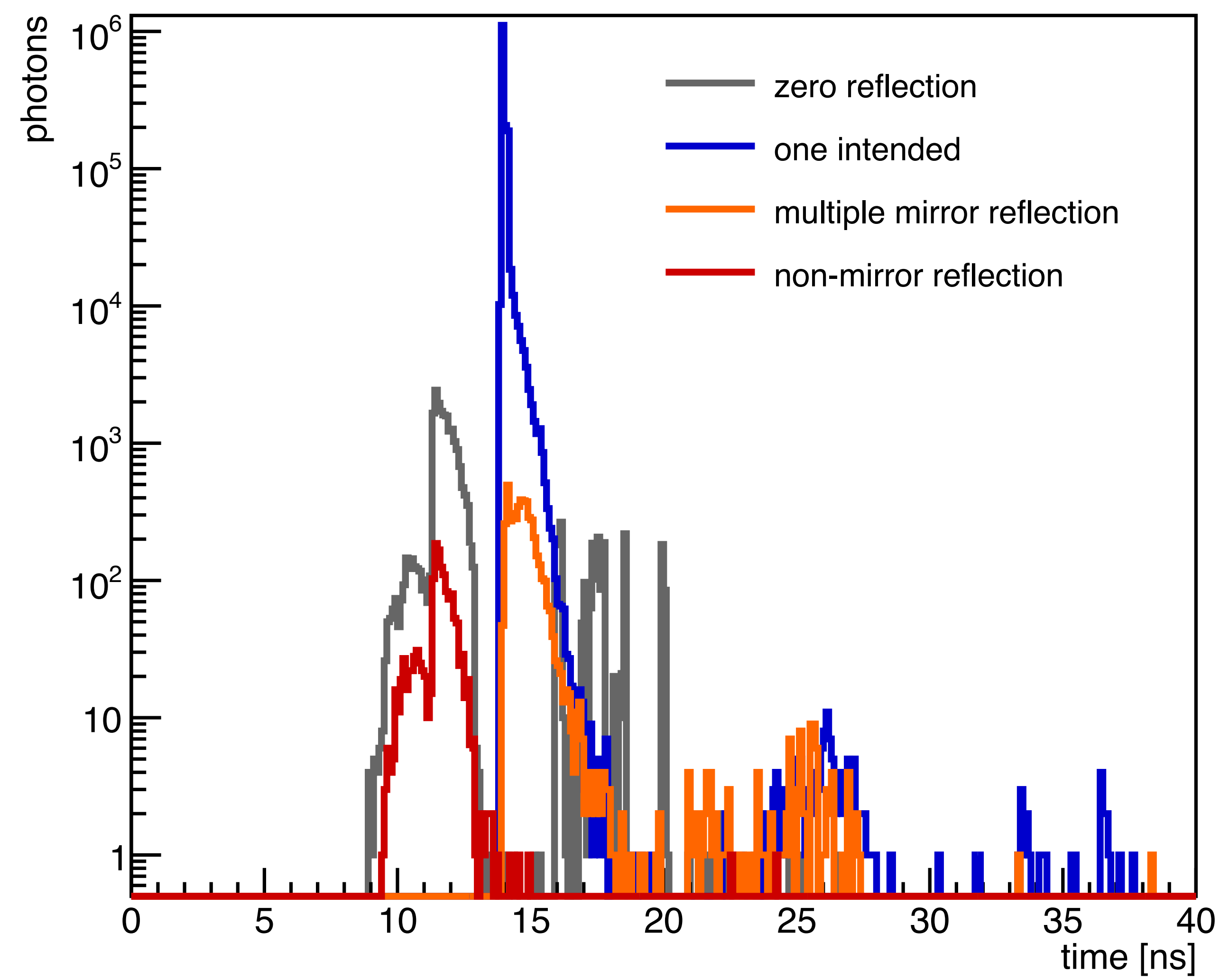


Takeaway: As expected, the one-mirror and multiple-mirror categories disappear. The remaining detected photons reach the sensor without reflecting from the dRICH mirror, validating the reflection-identification logic.

Optical History Check :

Nominal simulation: standard dRICH mirror reflectivity

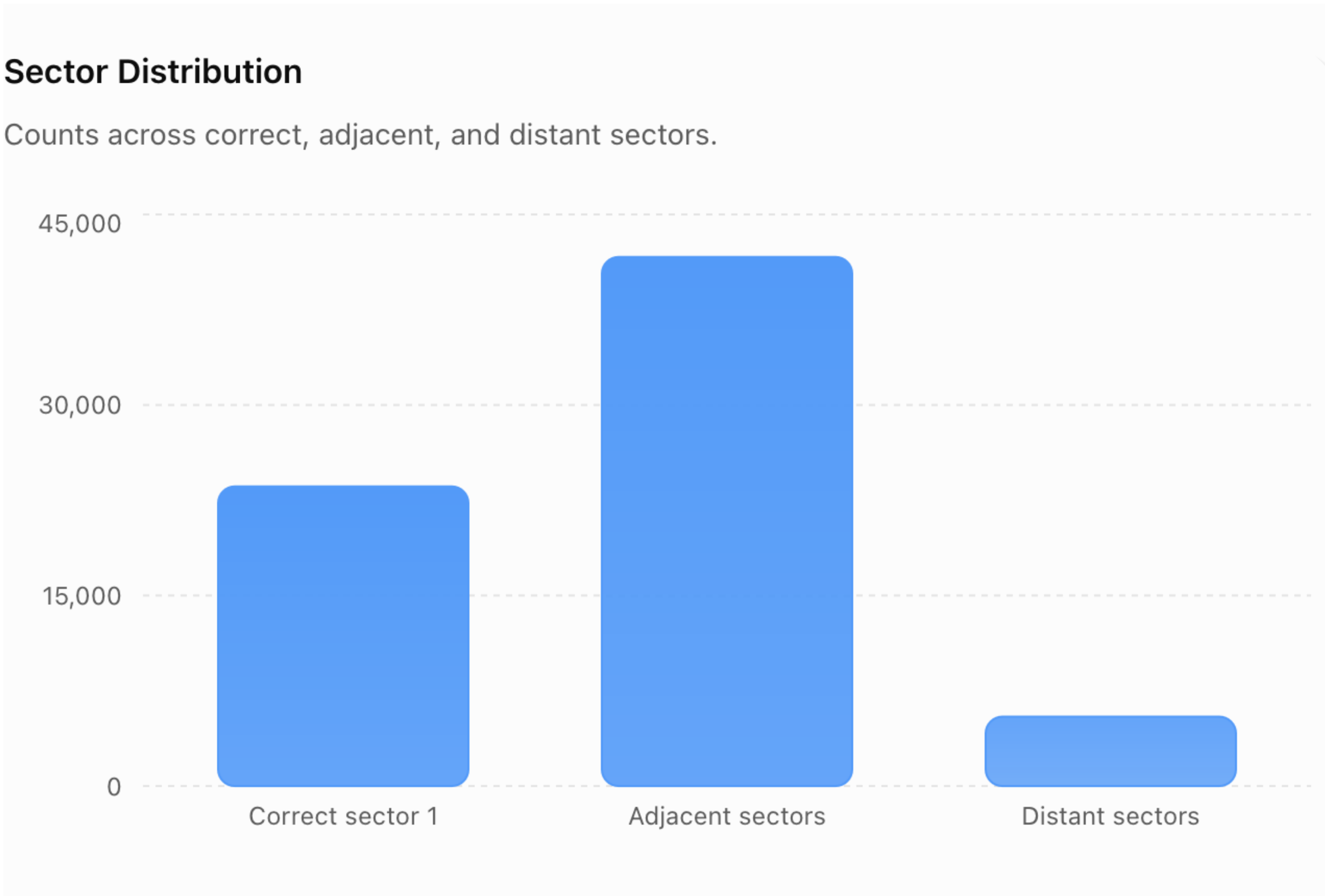




Restoring mirror reflection recovers the expected optical topology: 99.95% of nominal photons undergo exactly one dRICH-mirror reflection.

Optical History Check :

Origin of late photons with exactly one dRICH-mirror reflection



Exactly one mirror reflection” describes the reflection count—not compatibility with the primary-pion optical path. Around 66% of late, exactly-one-mirror photons reflect from sectors other than the nominal primary-track sector.

Mirror group	Primary parent	Secondary parent
Correct sector 1	20.70%	79.30%
Adjacent sectors 0/2	23.28%	76.72%
Distant sectors 3–5	0.55%	99.45%