

dRICH Simulation Meeting : 1/10/2026

Understanding the time distribution of dRICH Hits

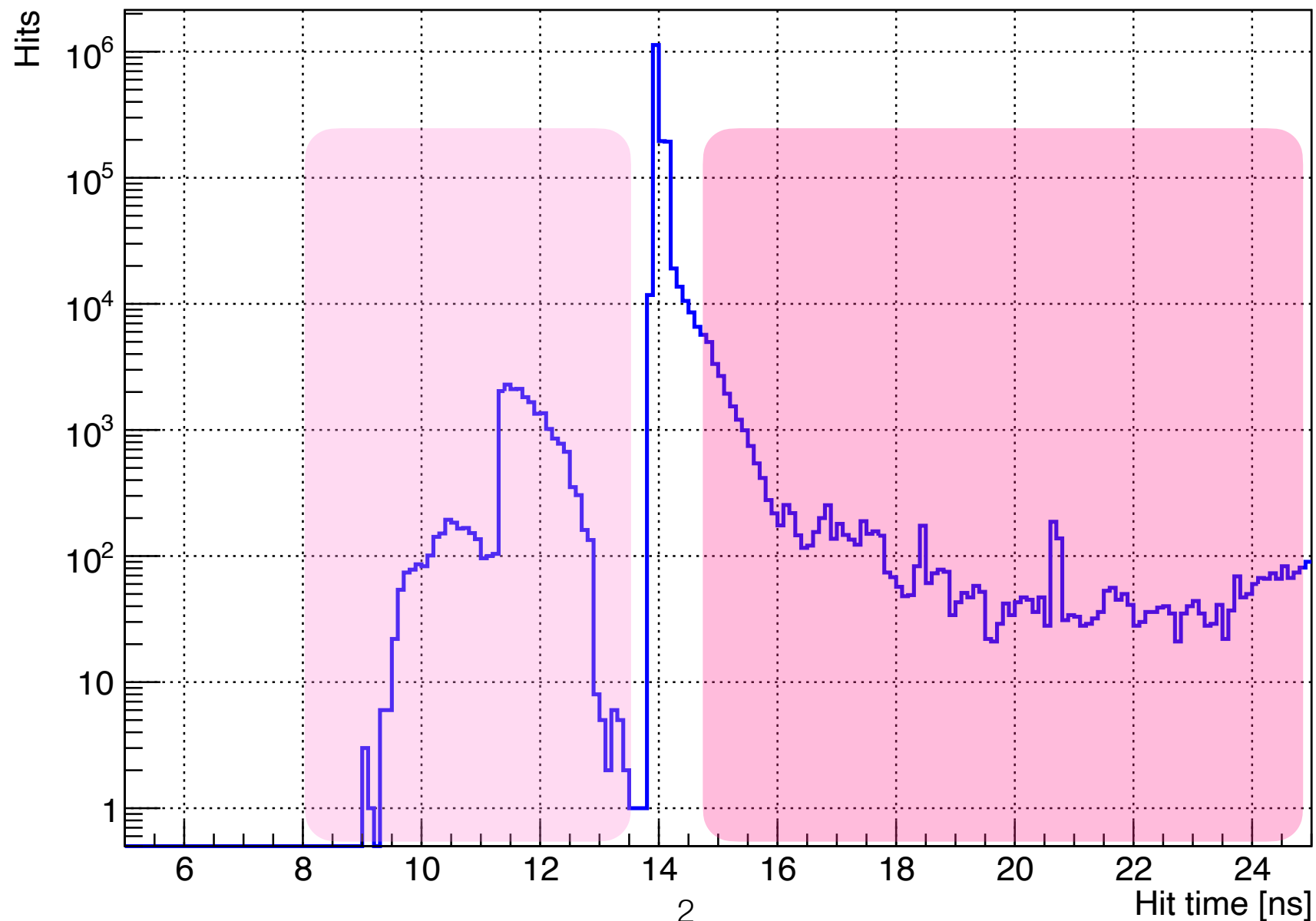
Anjali Sharma
INFN Trieste

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/>)

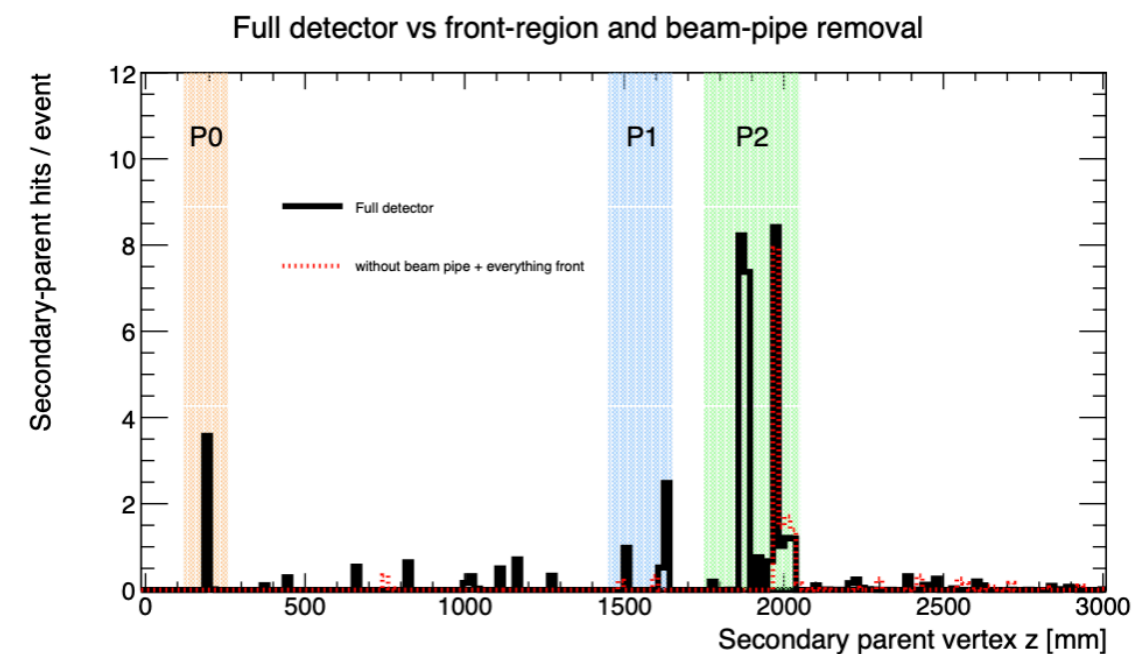
Simulation Sample:

- 30 GeV/c π^+
- $\eta = 2.5, \phi = 90^\circ$
- 5000 events



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/>)

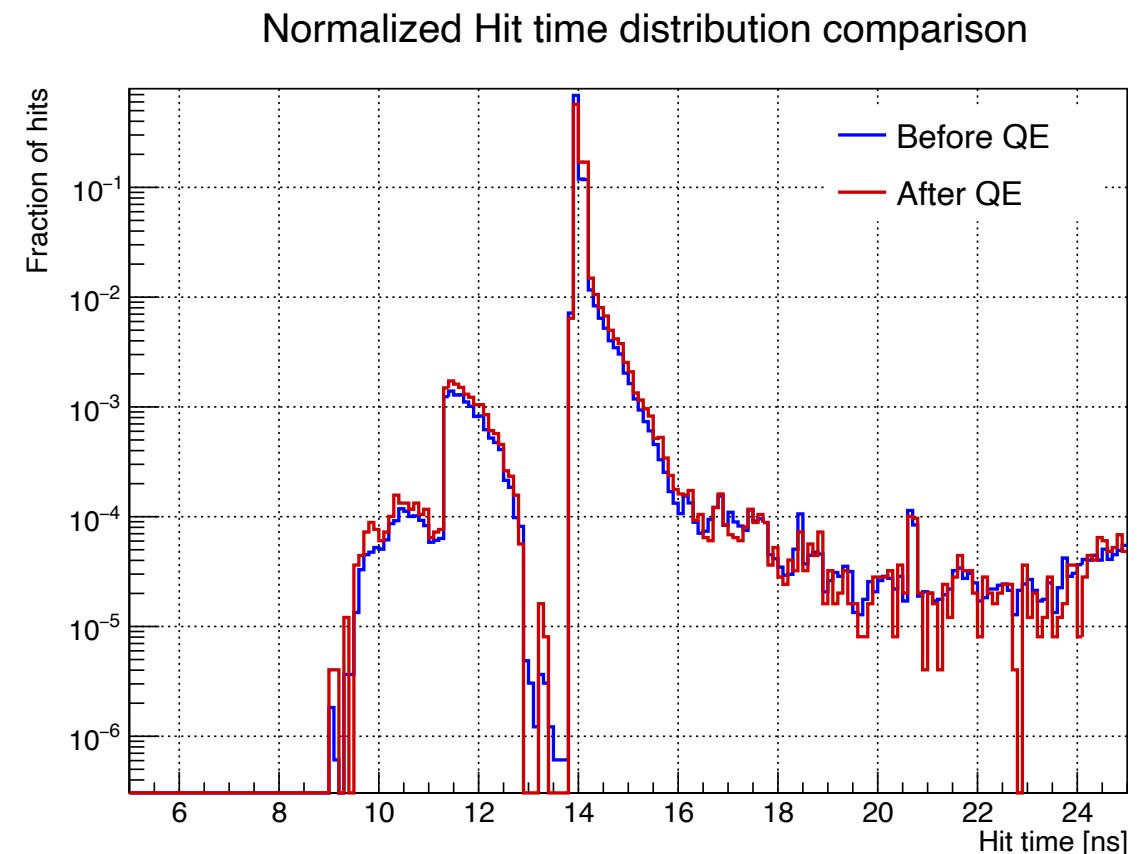


Main conclusion from Part I:

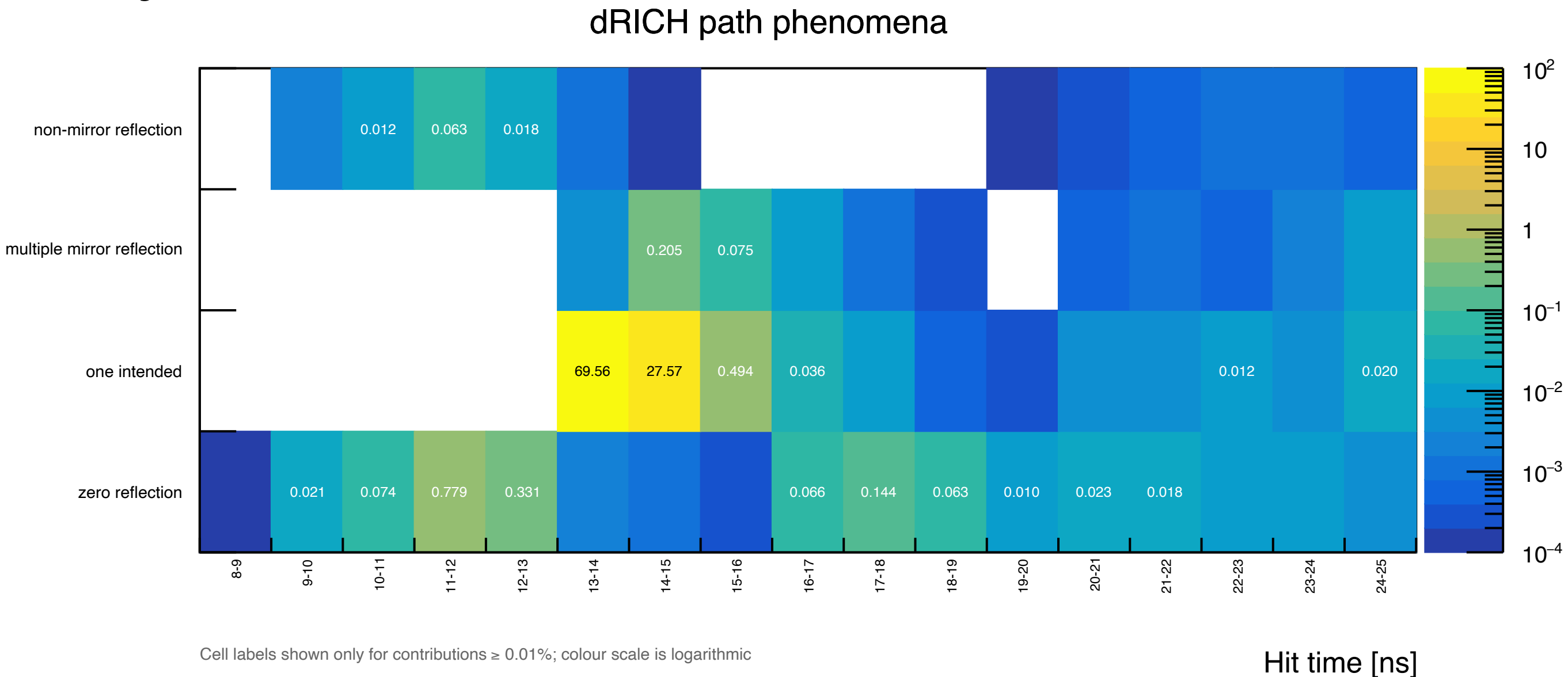
The late-hit secondary-parent population is not produced uniformly along z . It is concentrated in specific detector-material regions, with the dominant contribution near the TOF region.

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- ✓ QE implementation does not remove the tail. (10/Sep/2026 - <https://indico.bnl.gov/event/34302/>)



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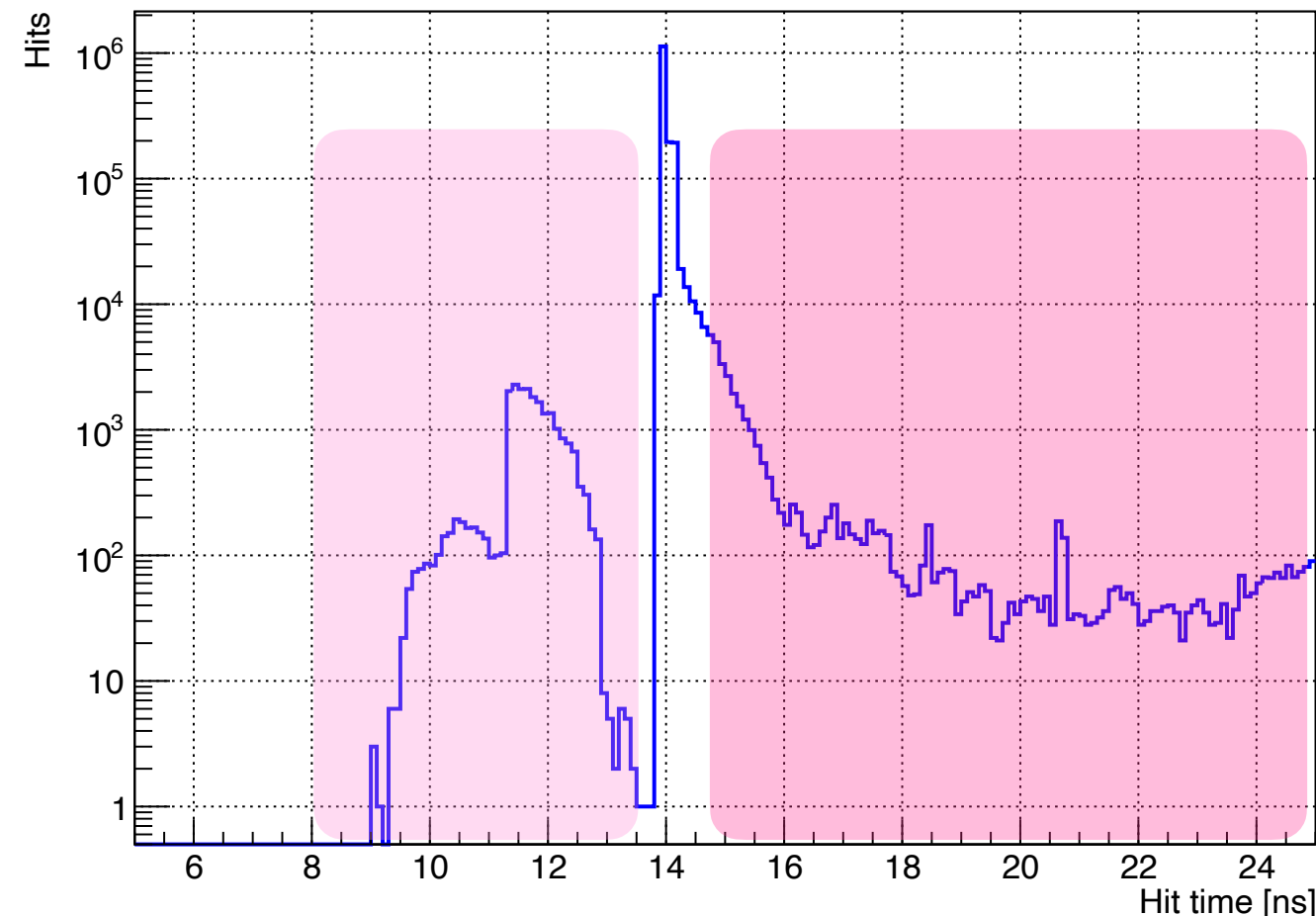


We combine the in-hand information (SIMULATION FILE) with the optical information (from GEANT4 superpowers) of the hits to get the path phenomena of optical photons

- 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.

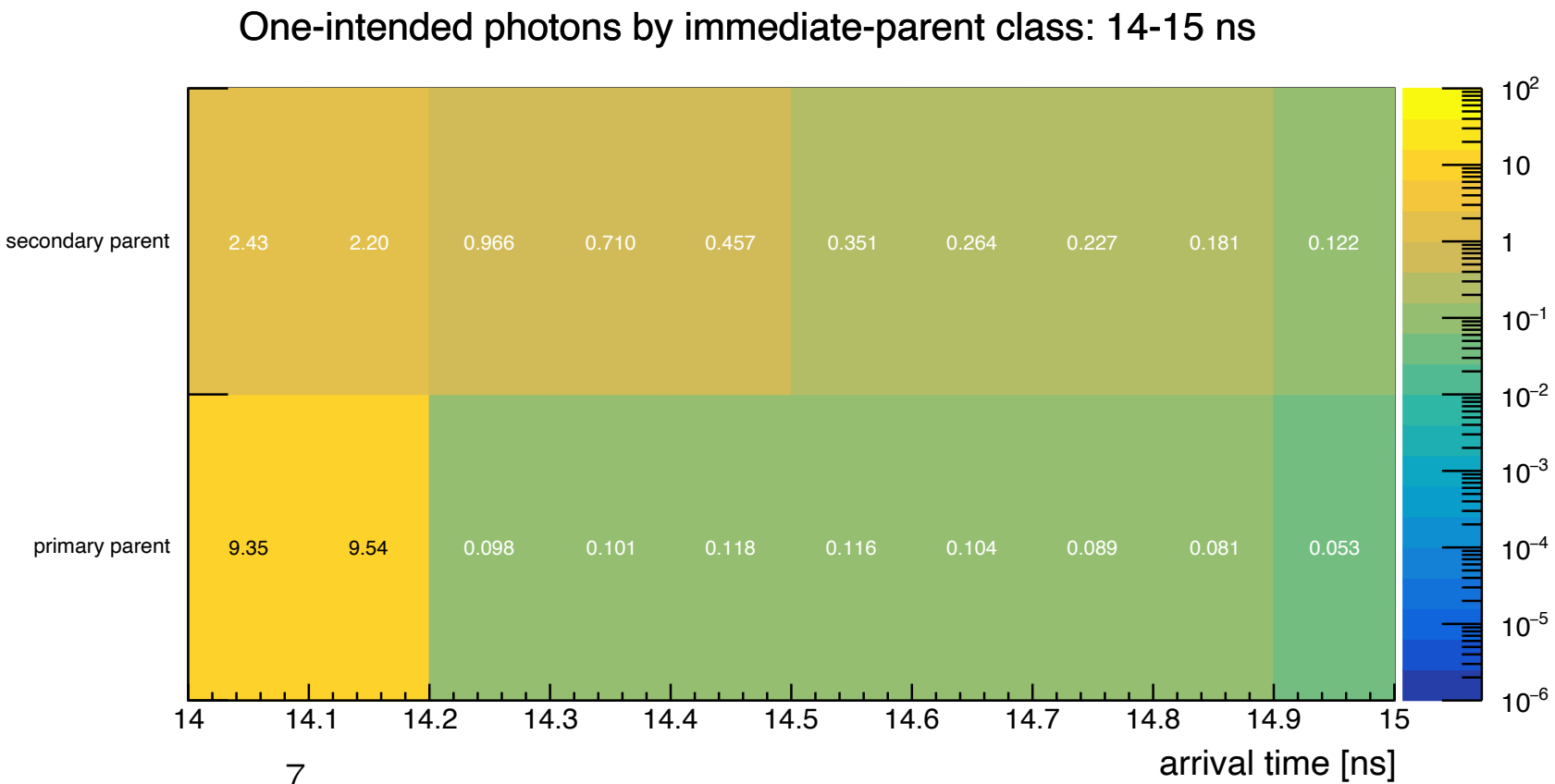
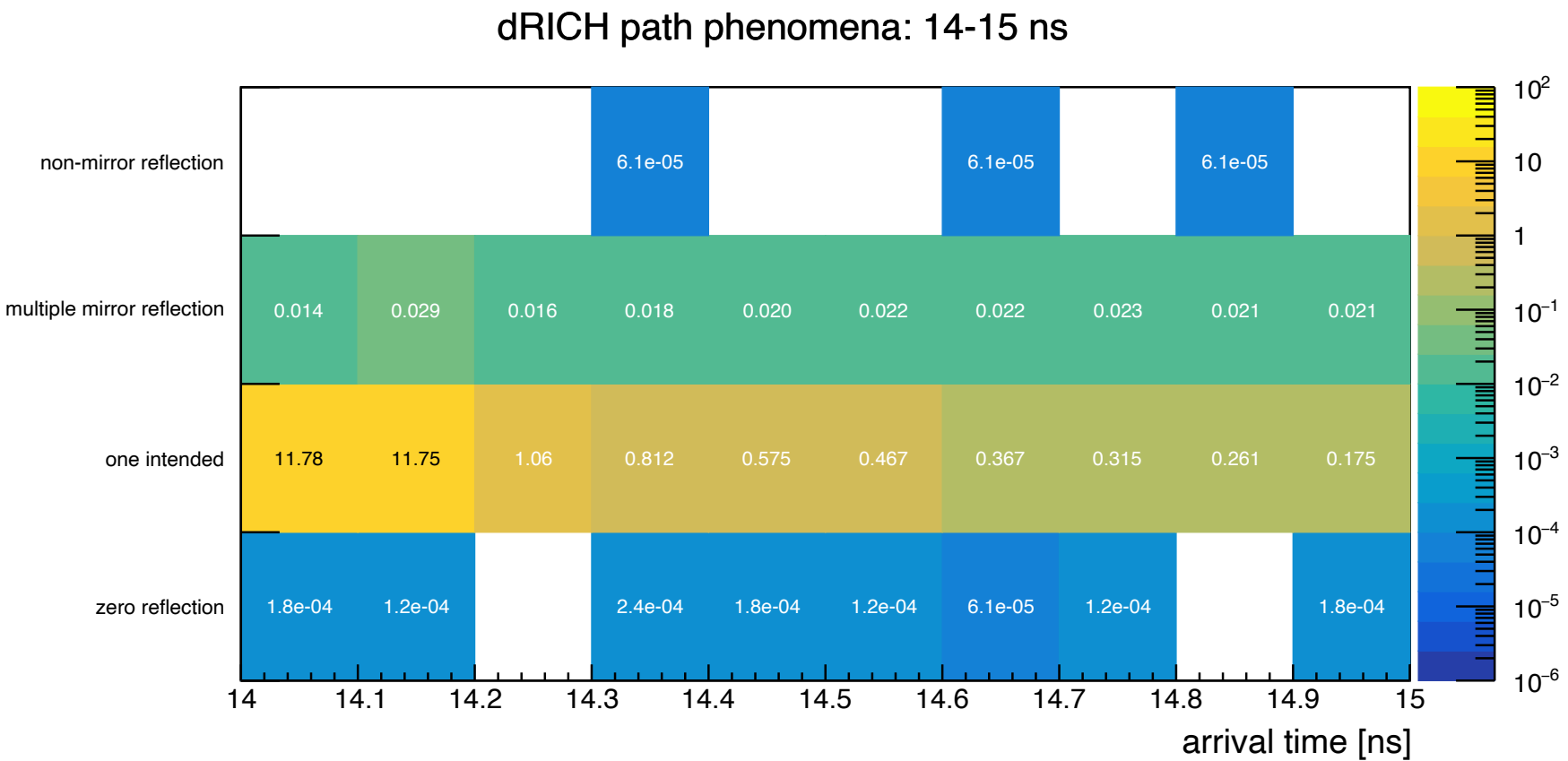
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- ✓ QE implementation does not remove the tail. (10/Sep/2026 - <https://indico.bnl.gov/event/34302/>)
- ✓ **Early hits:** predominantly direct, zero-reflection photons. **Nominal peak:** primary-parent photons with one intended mirror reflection. **Late tail:** predominantly secondary-parent photons. (10/Sep/2026 - <https://indico.bnl.gov/event/34302/>)



Story till now : Fine Timing Structure: 14–15 ns

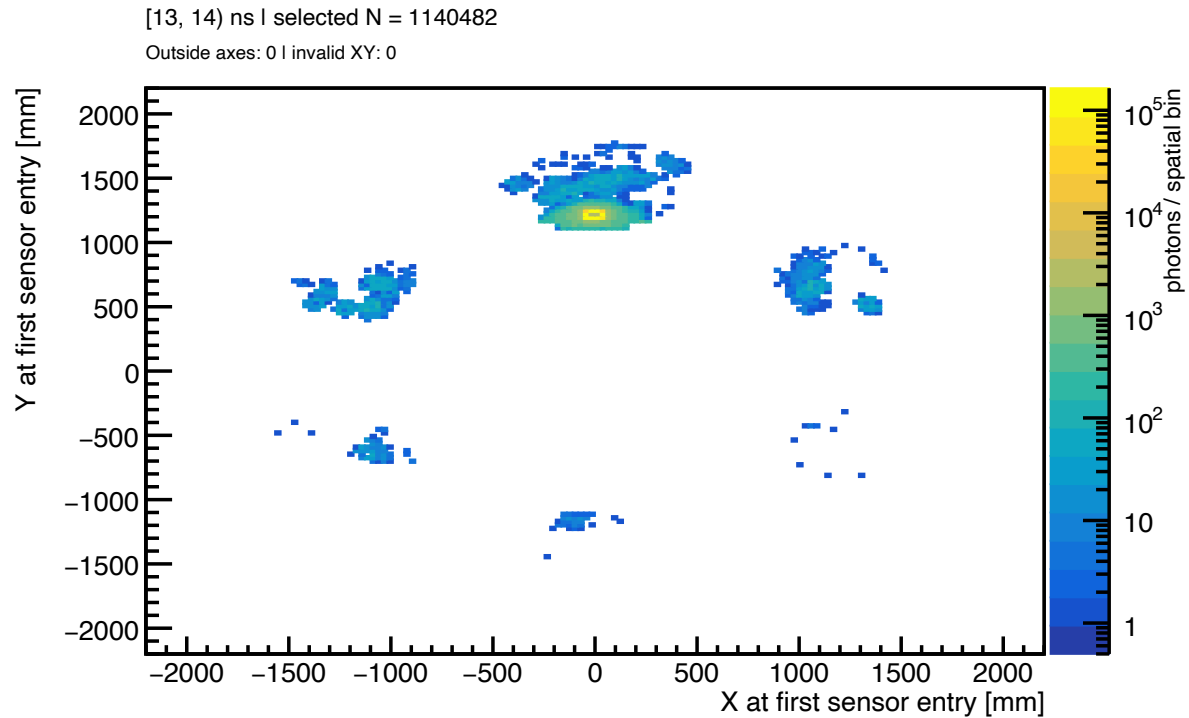
- The beginning of the late tail is caused mainly by a change in photon parentage, not by a change to multiple-reflection optical paths.
- The one-intended population transitions from primary-dominated near the nominal peak to secondary-dominated in the late region, with the crossover occurring around 14.2 ns.



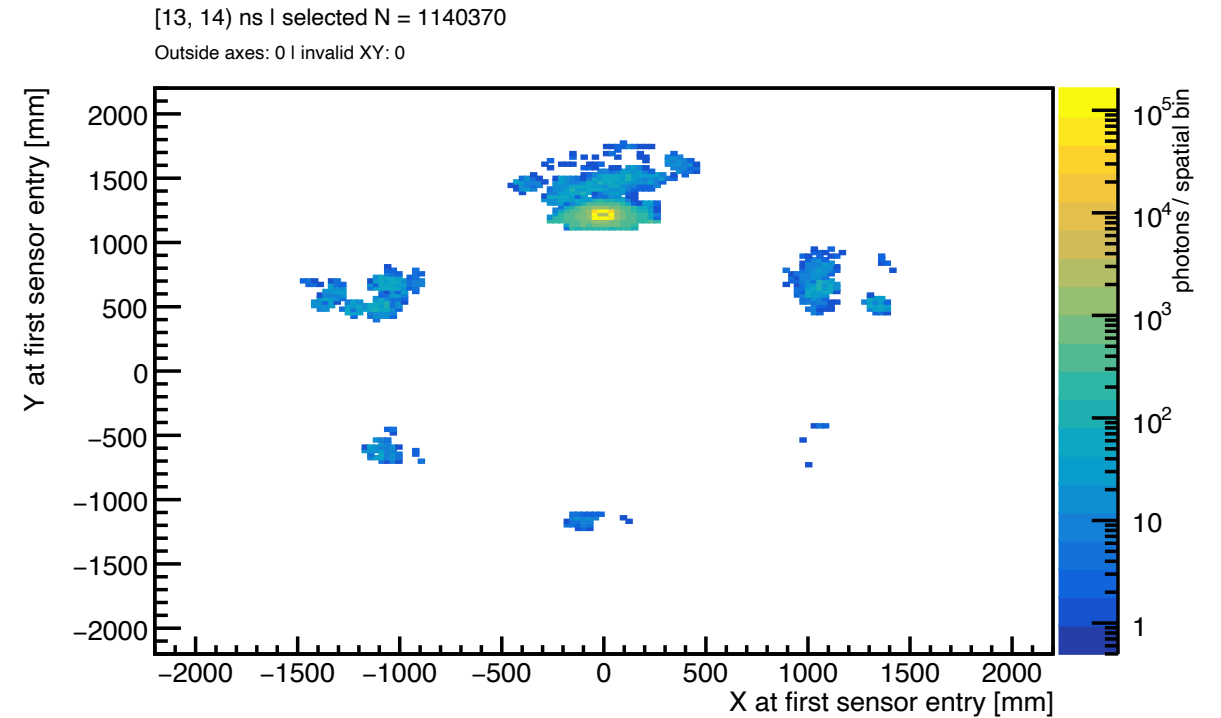
Cell values: percentage of the complete accepted sample.

Sensor-plane distribution near the nominal peak: 13-14 ns

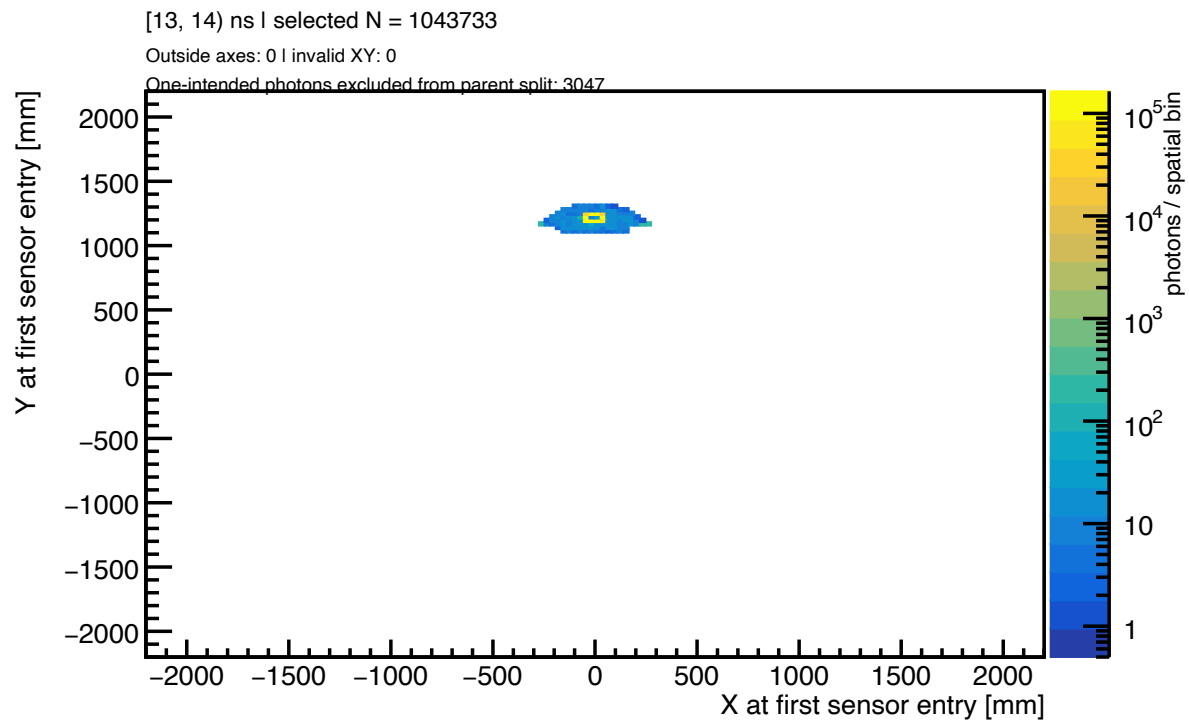
All accepted dRICH photons



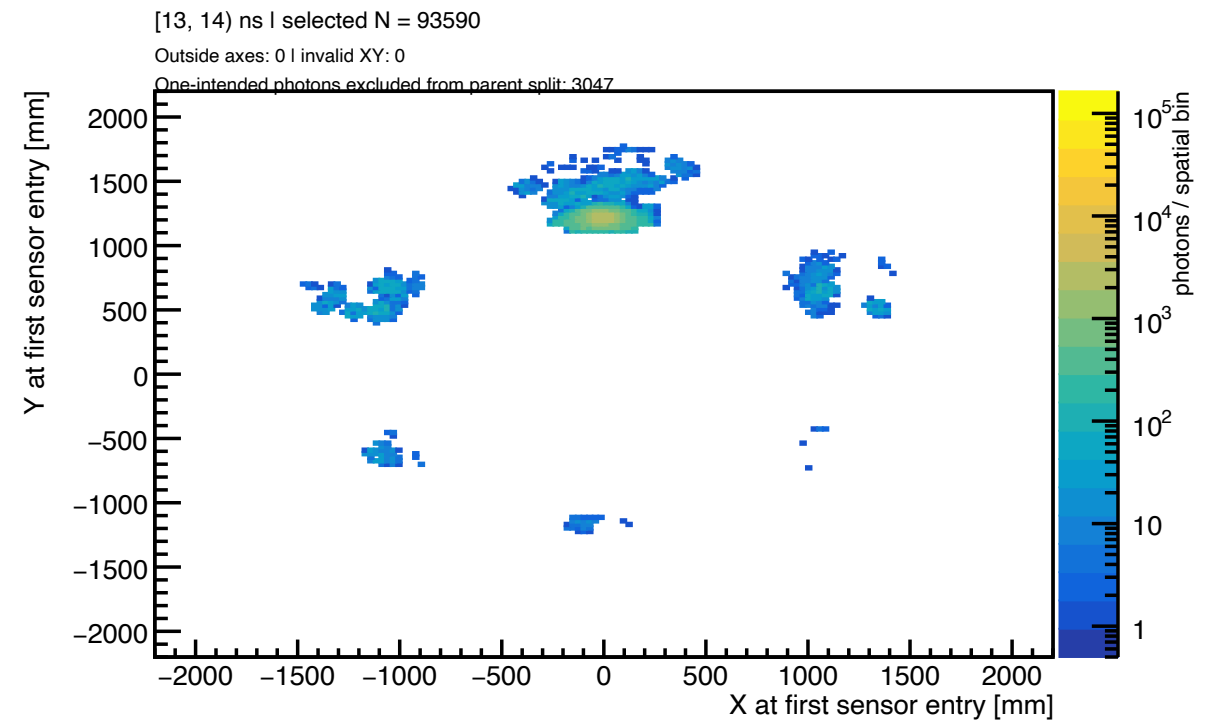
Exactly one intended mirror reflection



One intended: primary parent



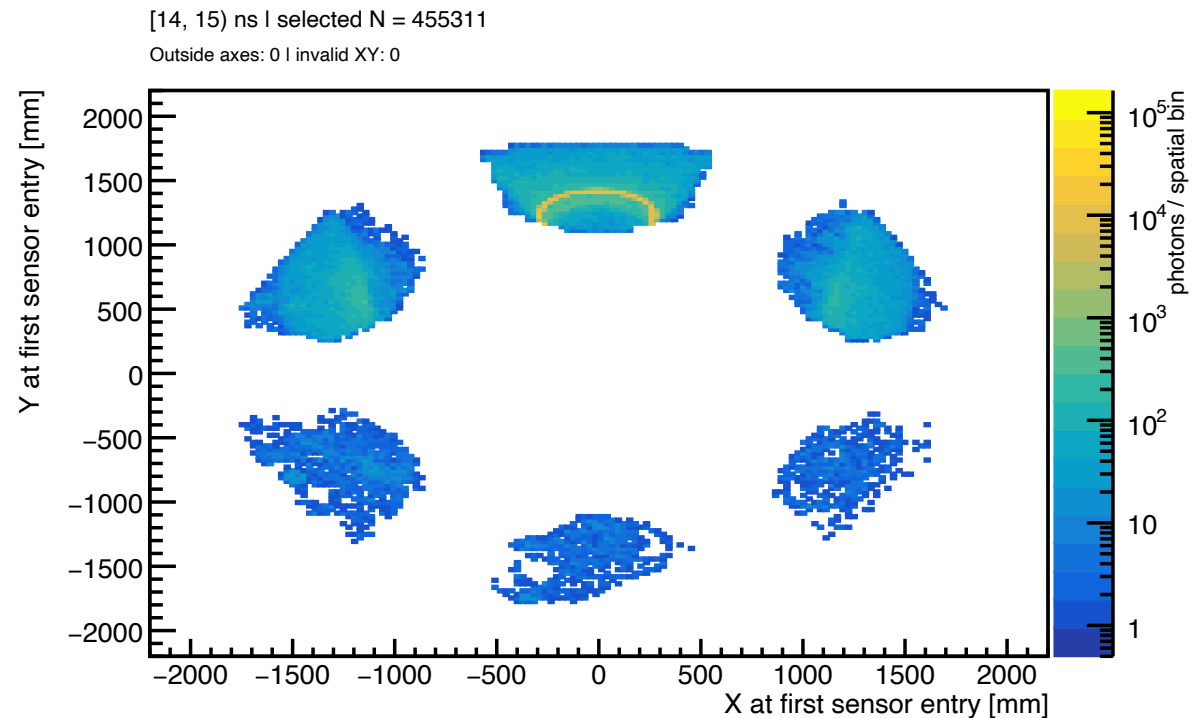
One intended: secondary parent



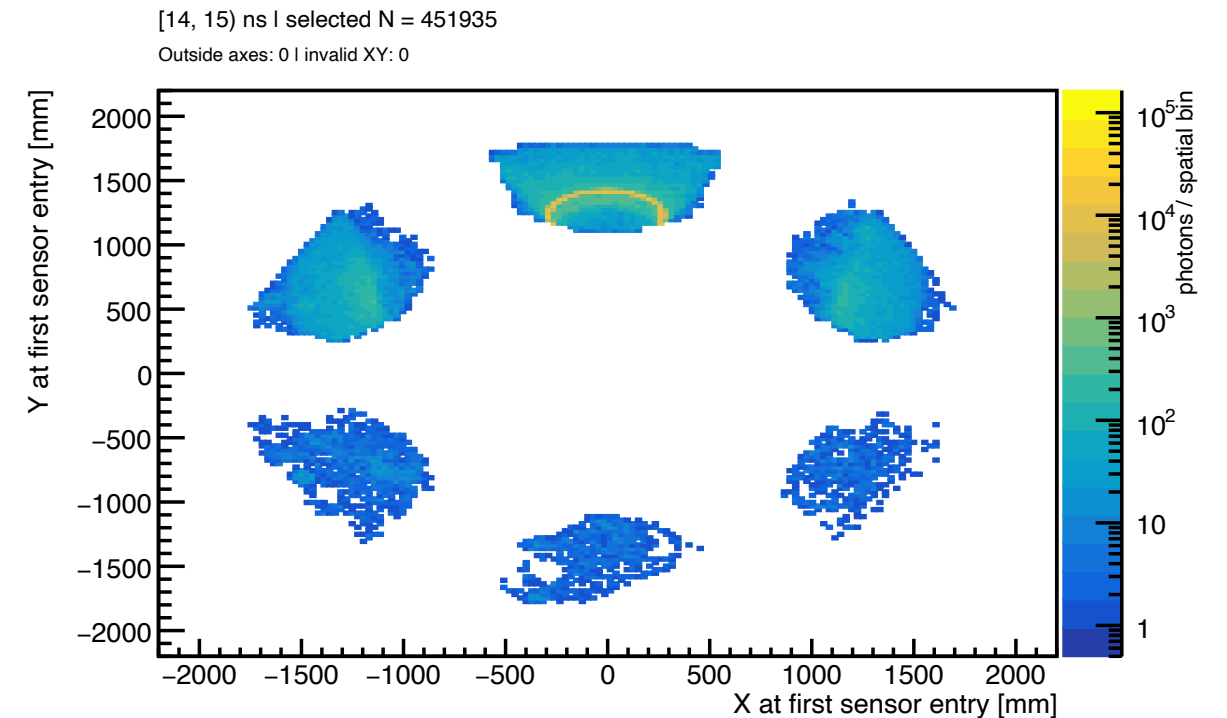
- Primary-parent photons form a compact population in the expected sensor region.
- Secondary-parent photons populate several sensor regions.

Sensor-plane distribution near the nominal peak: 14-15 ns

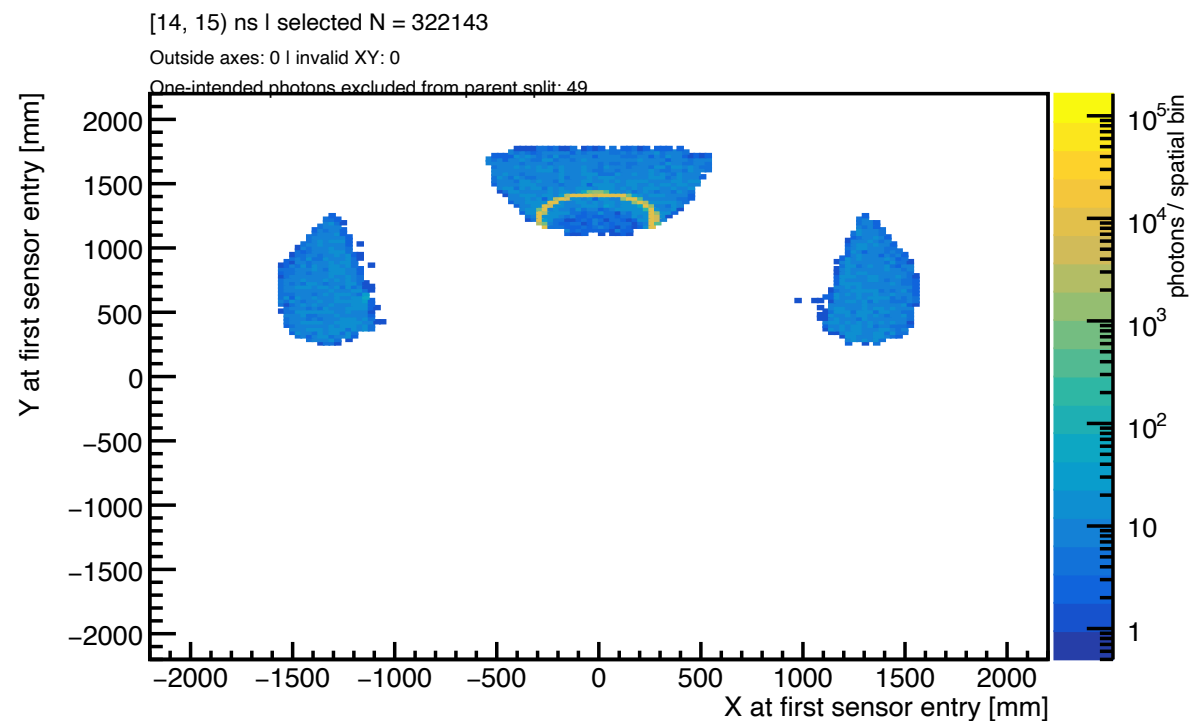
All accepted dRICH photons



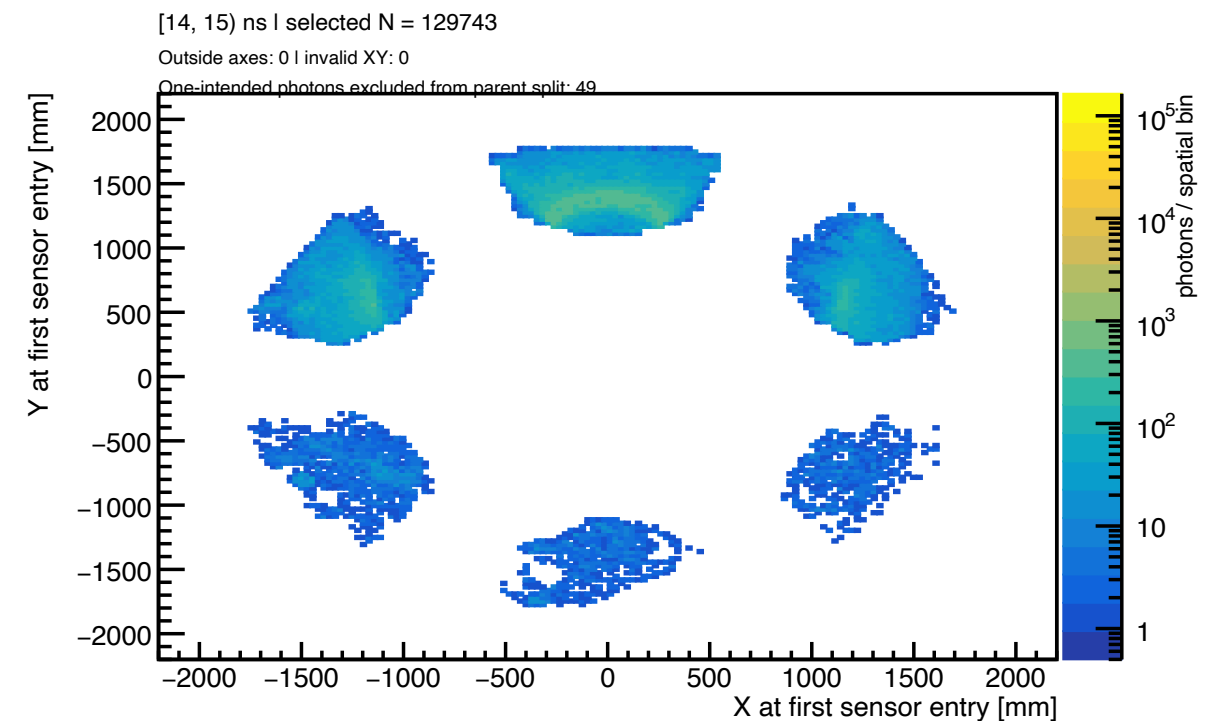
Exactly one intended mirror reflection



One intended: primary parent



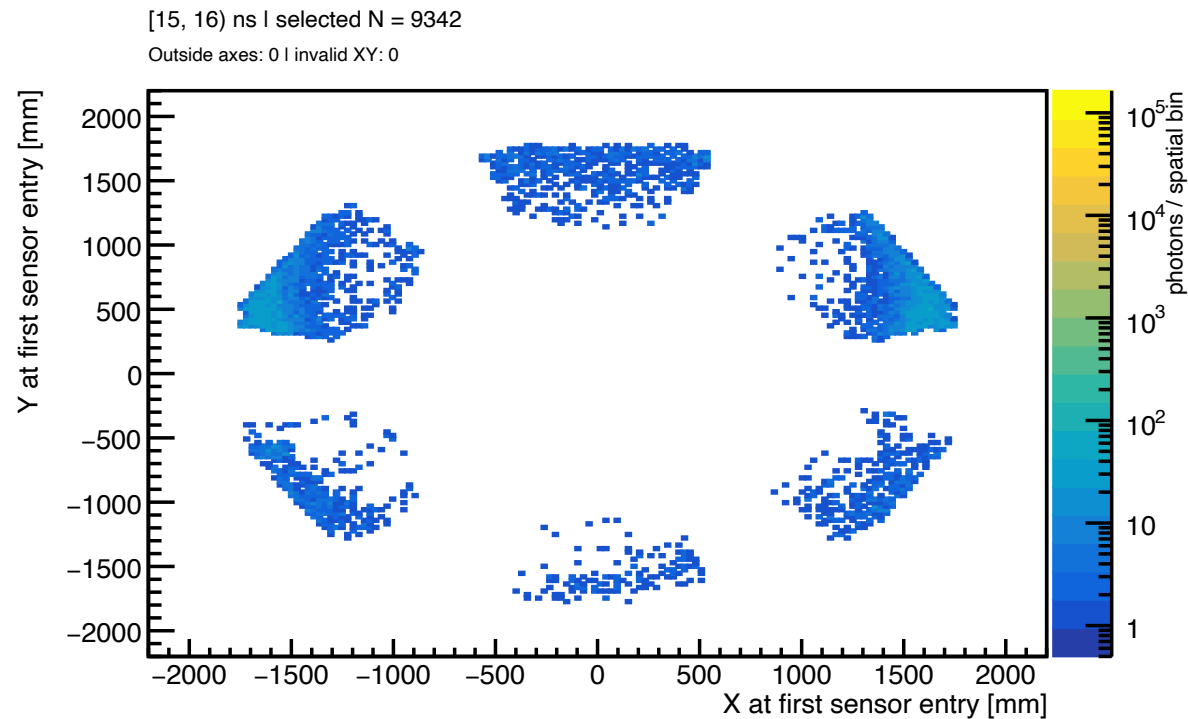
One intended: secondary parent



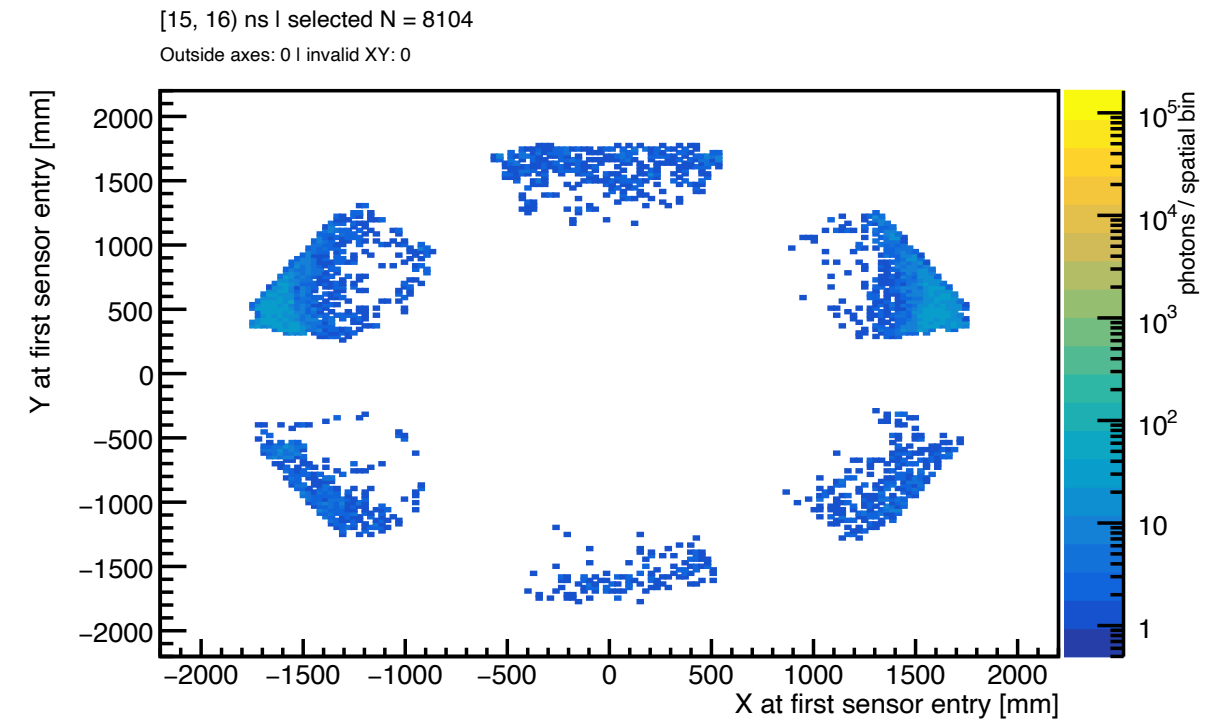
- The relative secondary contribution increases strongly.
- The primary population is less confined to the compact nominal pattern.
- Spatial broadening accompanies the transition into the timing tail.

Sensor-plane distribution near the nominal peak: 15-16 ns

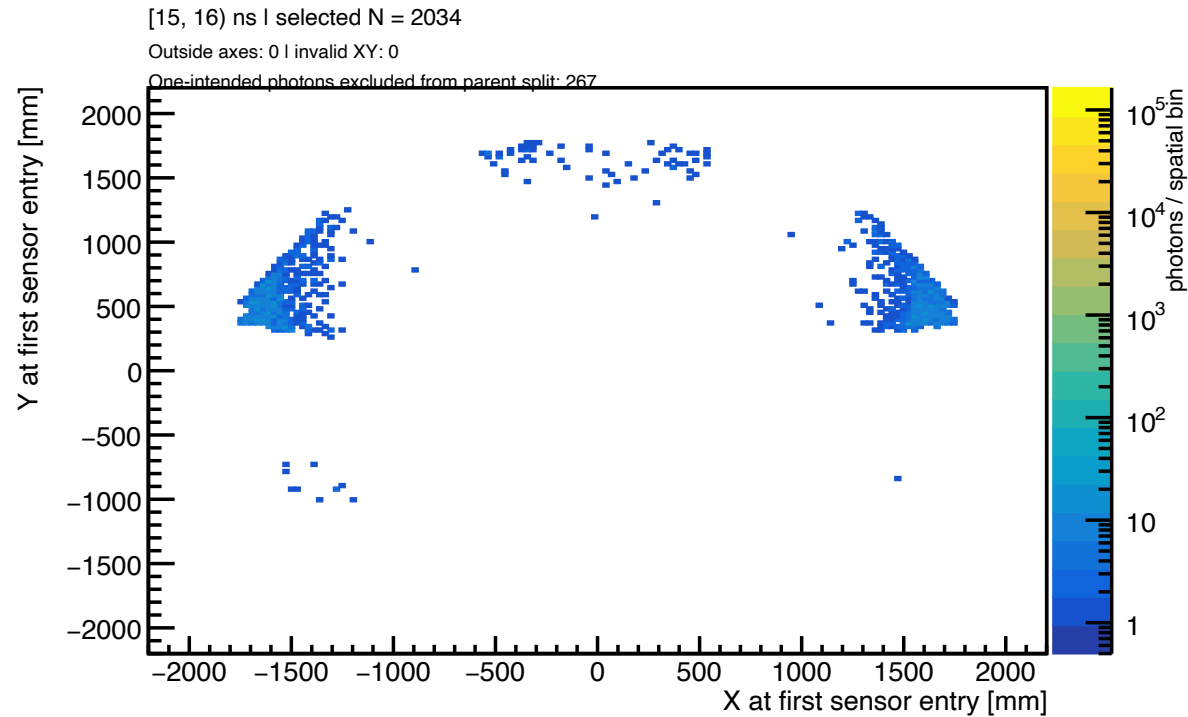
All accepted dRICH photons



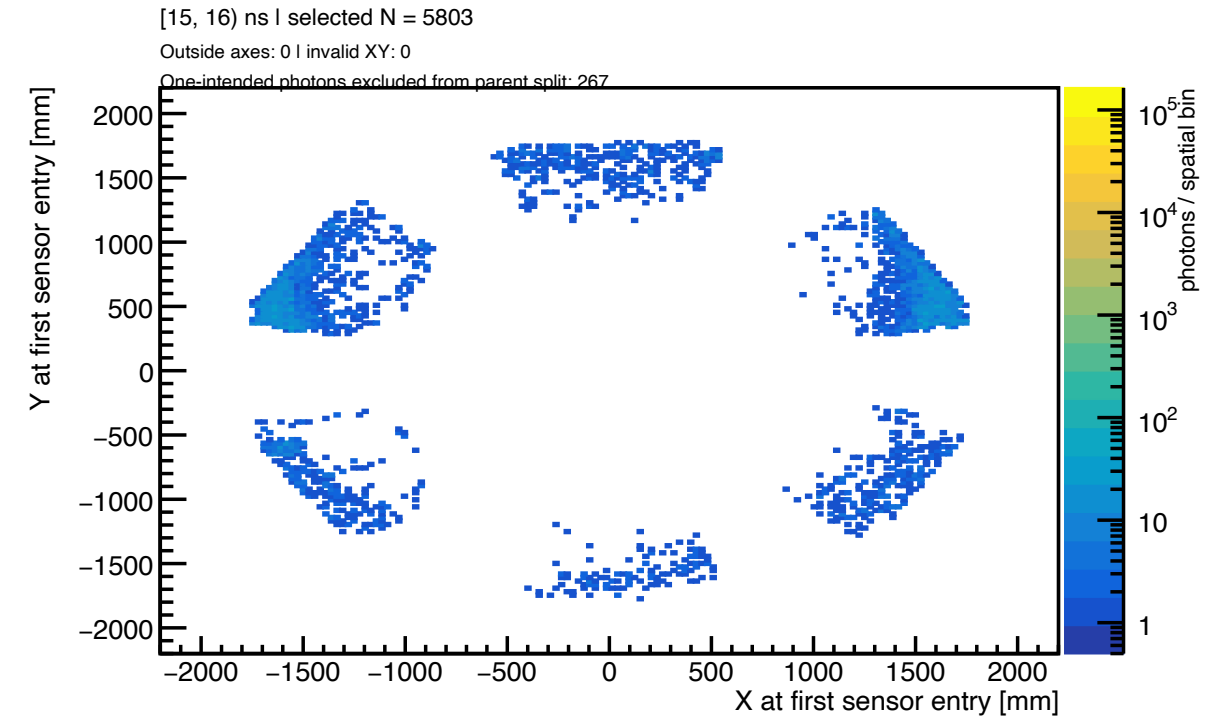
Exactly one intended mirror reflection



One intended: primary parent

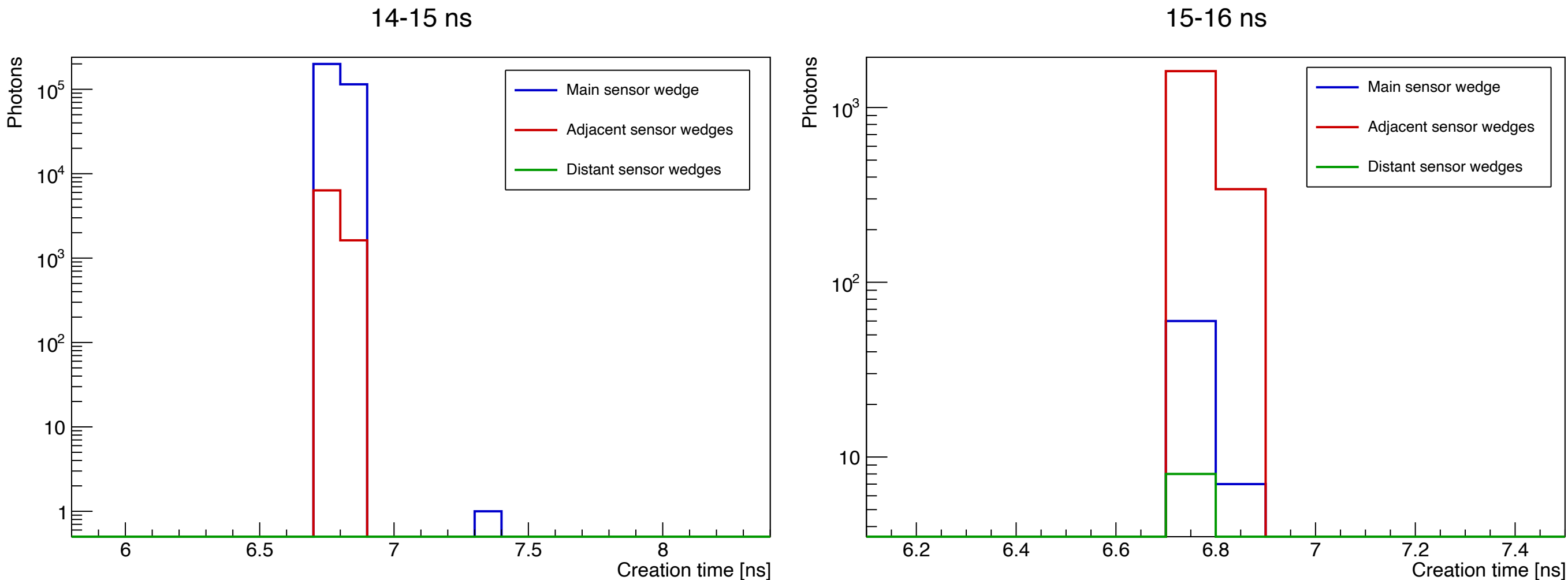


One intended: secondary parent



- Secondary-parent photons dominate the one-intended population and residual primary-parent photons are sparse.
- Late photons appear across sensor regions rather than following only the compact nominal pattern.

Creation time of Optical Photons:

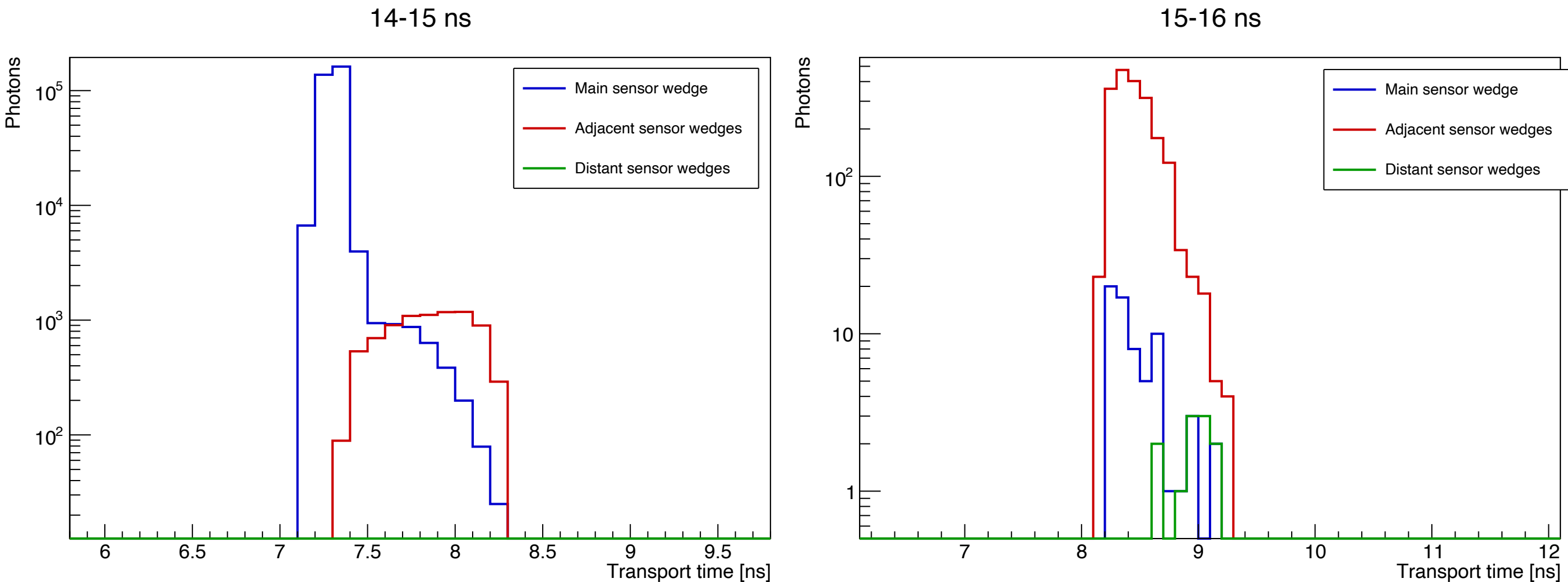


Creation-time comparison

- Primary photons reaching the **main, adjacent and distant sensor wedges are produced within a similar creation-time region.**
- Moving from 14–15 ns to 15–16 ns does not reveal a corresponding large shift in photon creation time.

The additional delay must arise predominantly during photon transport rather than at photon creation.

Transport time of Optical Photons:



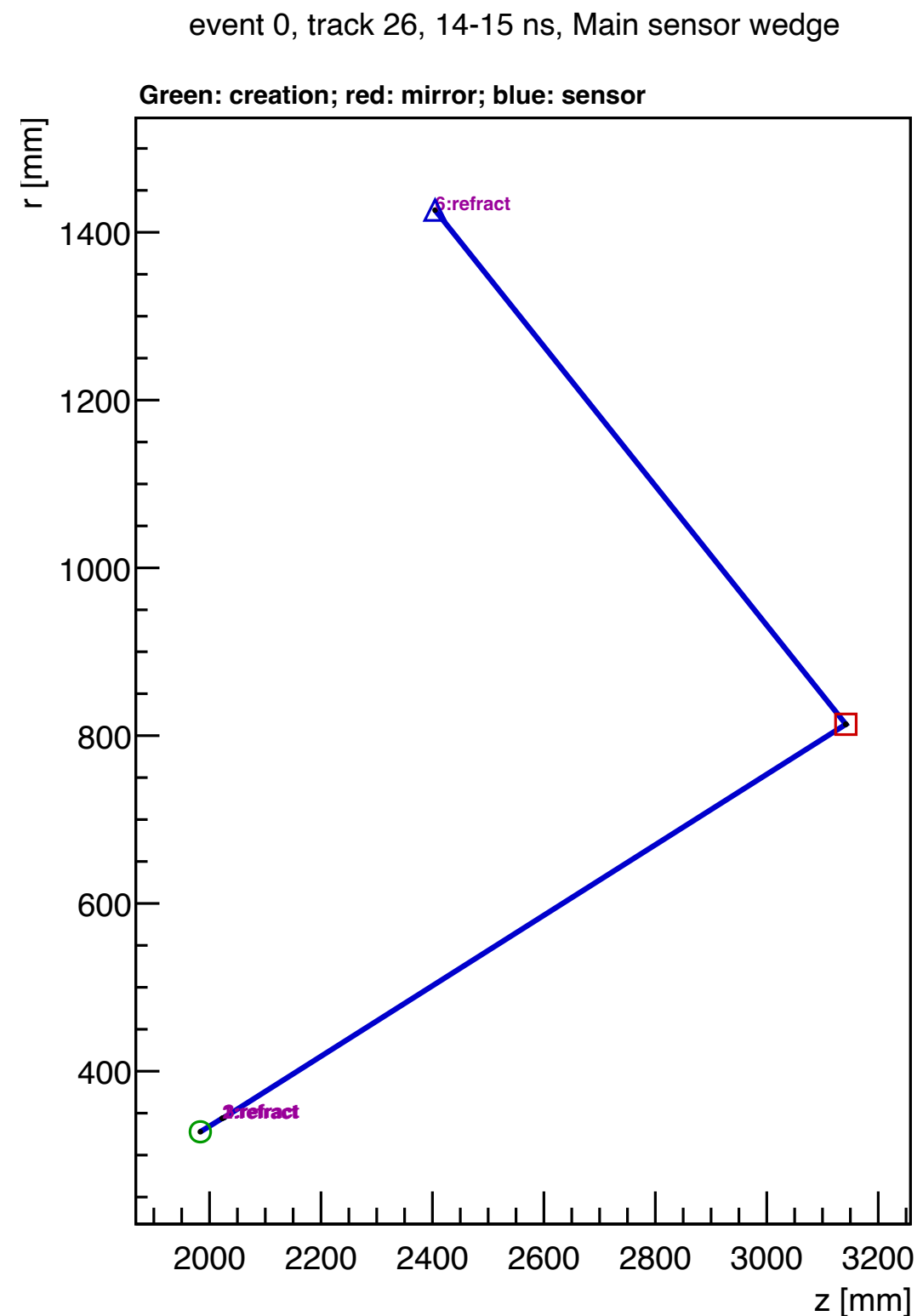
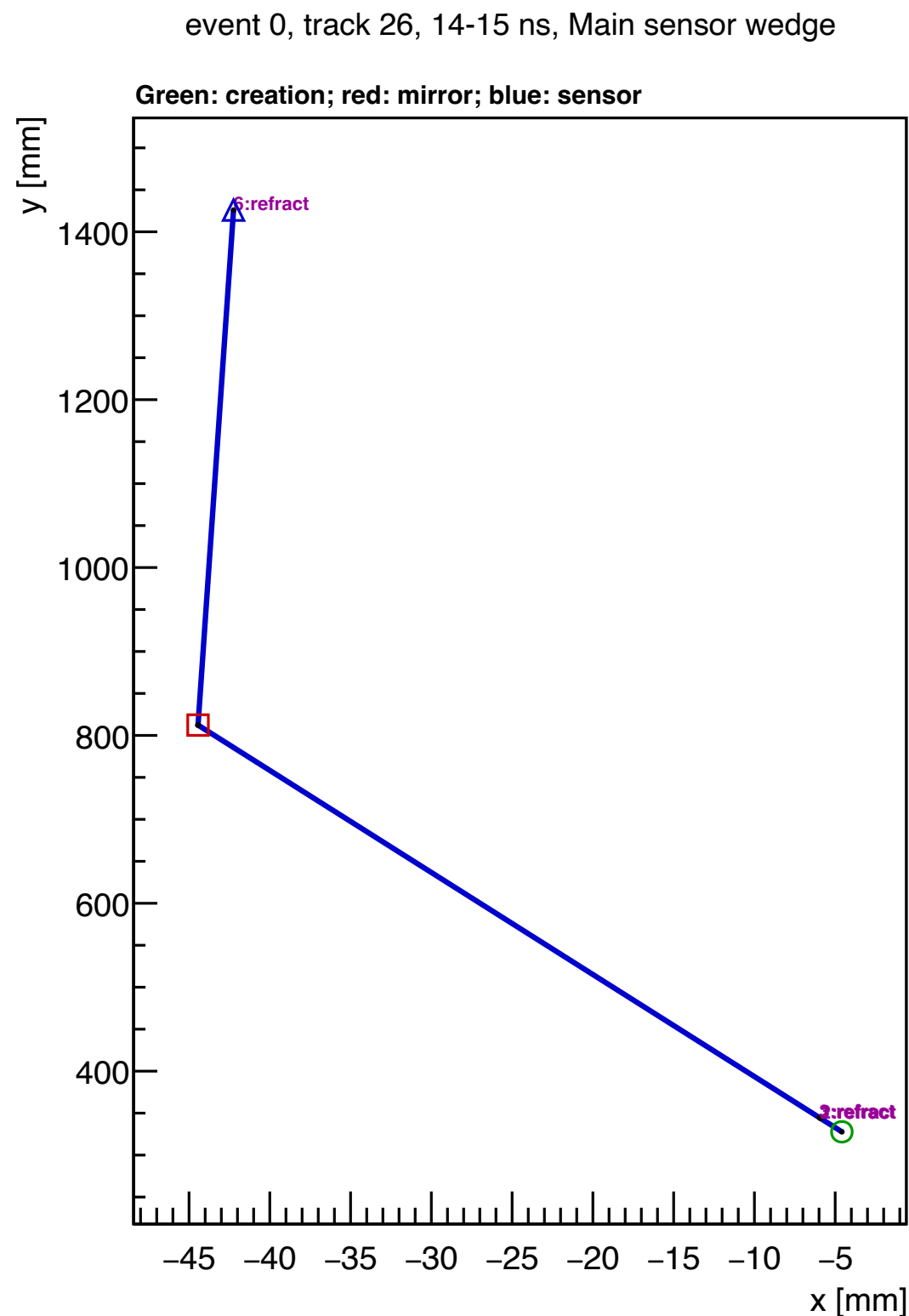
Transport-time comparison

- In the 14–15 ns region, photons reaching the nominal/main sensor wedge are concentrated toward the shorter transport-time population and the photons reaching adjacent wedges extend toward longer transport times.
- In the 15–16 ns tail, the surviving population is shifted toward still longer photon-transport times. The very small distant-wedge component also appears only within this delayed transport population.

Sector migration and late arrival are correlated with prolonged photon transport.

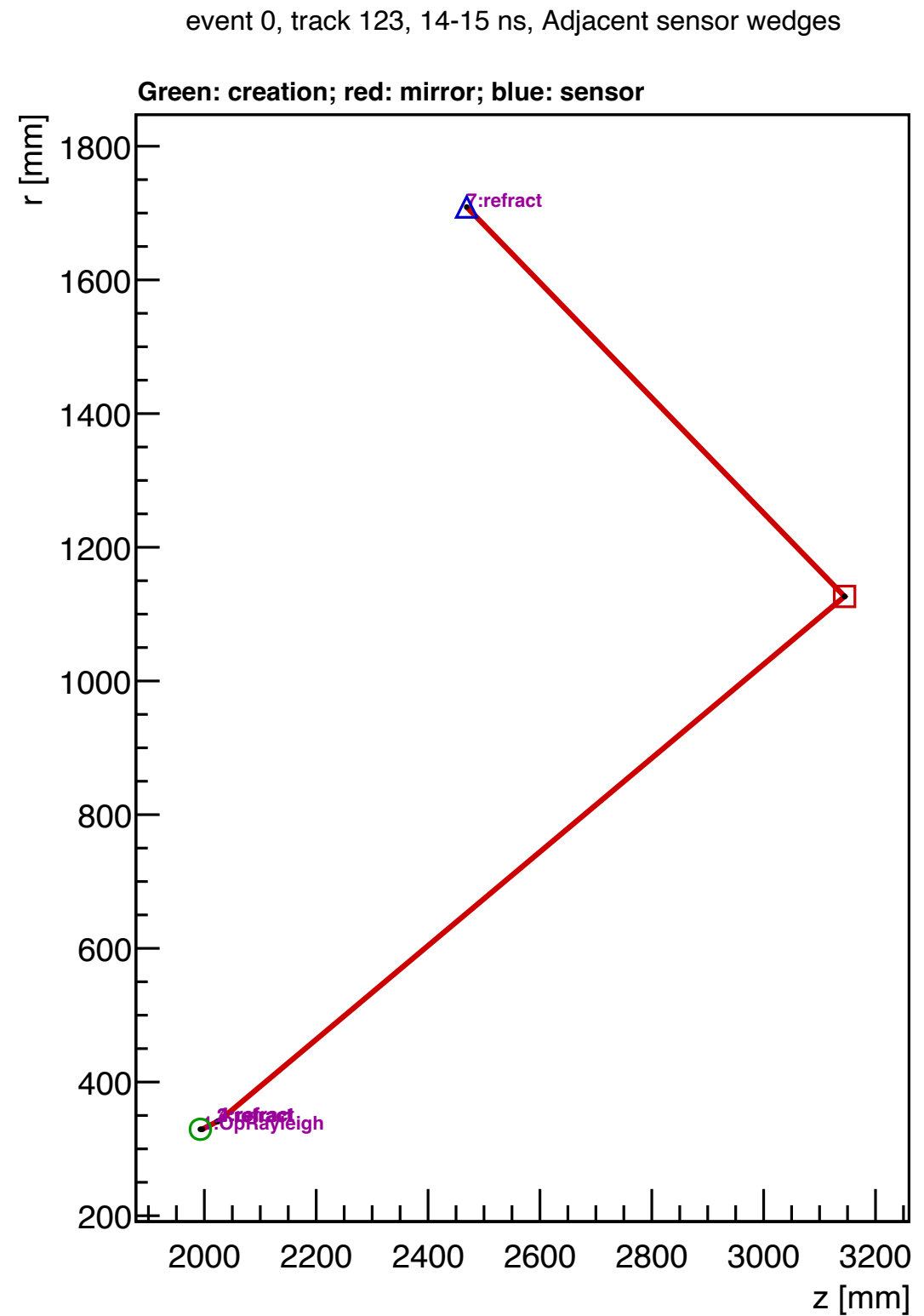
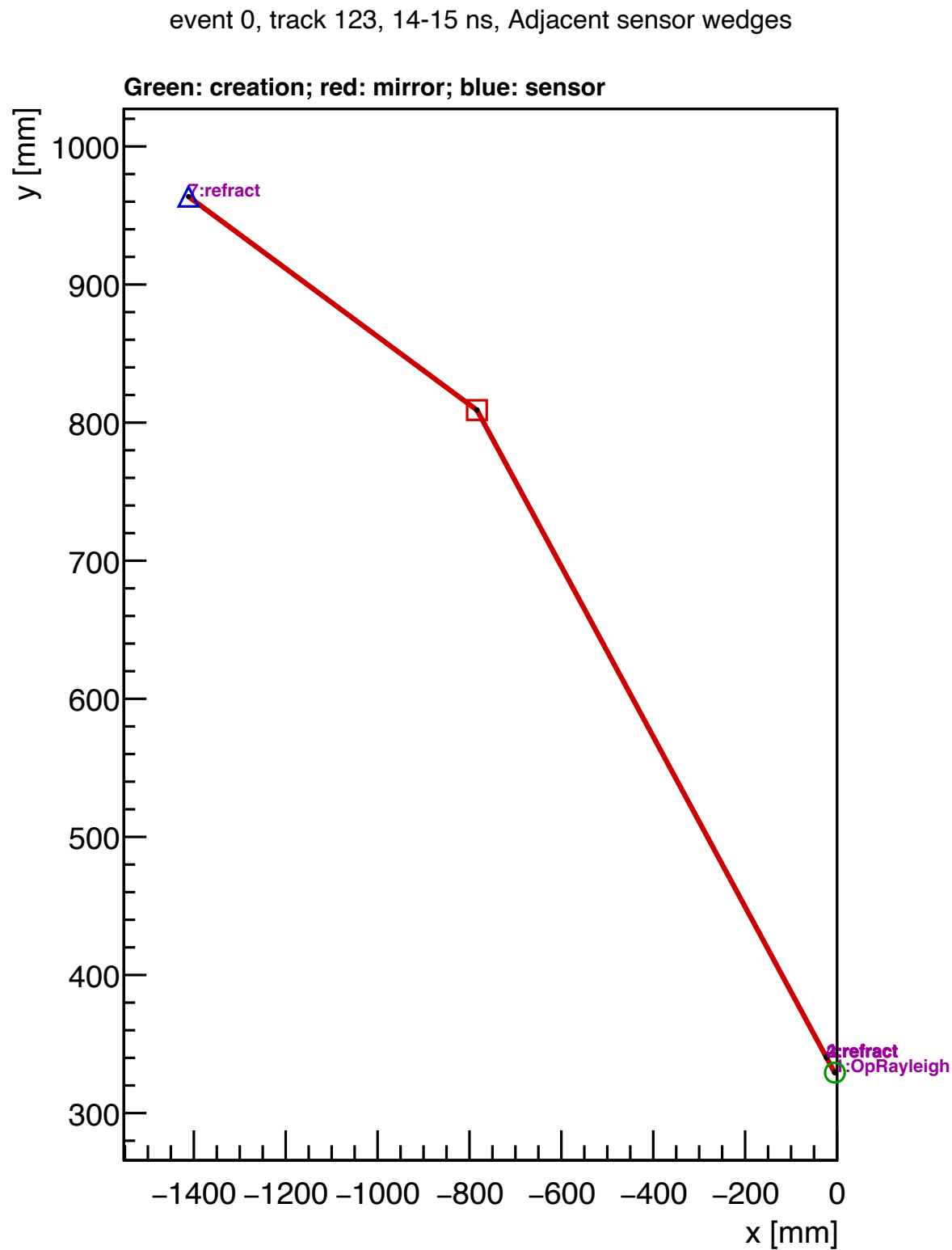
But what happens to the photon trajectory during this additional transport?

Nominal/main-sector example 14-15ns:



- This represents the comparatively regular optical transport associated with the nominal sensor sector.

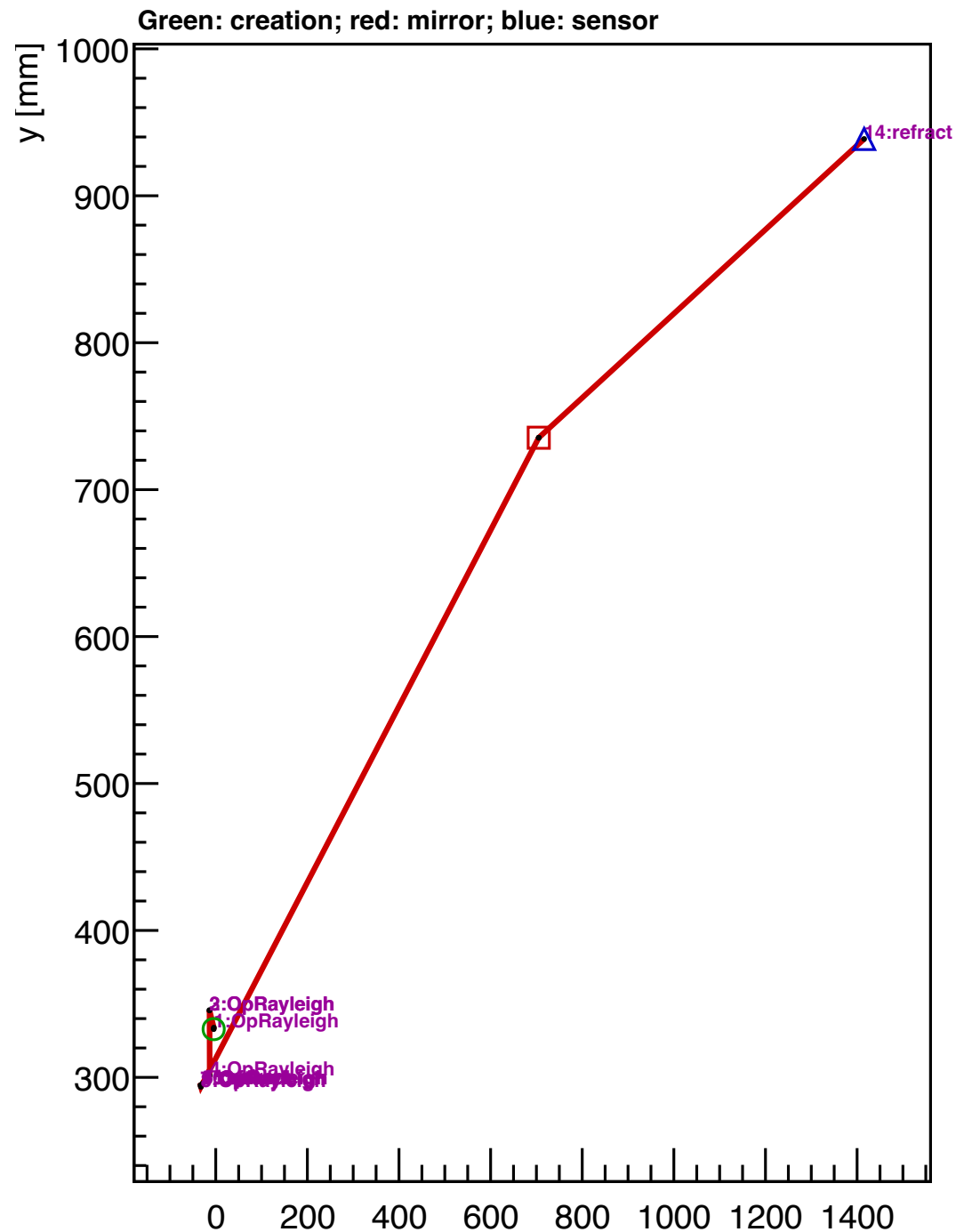
Migrated-sector example 14-15ns :



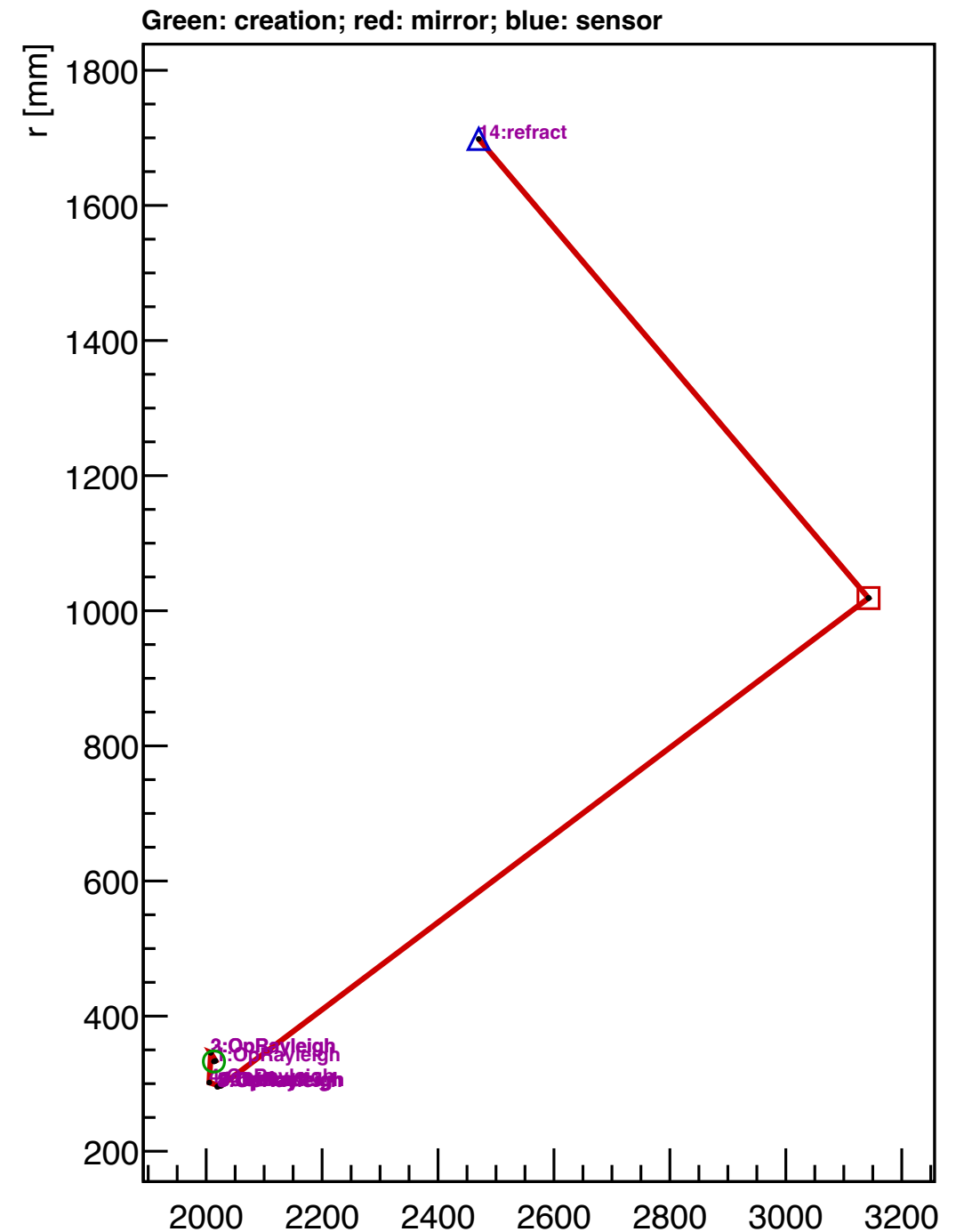
- Recorded Geant4 history contains an **OpRayleigh interaction** before the subsequent optical transport. Thus, one intended mirror reflection does not imply an undisturbed nominal trajectory

Migrated-sector example 15-16ns :

event 3, track 305, 15-16 ns, Adjacent sensor wedges



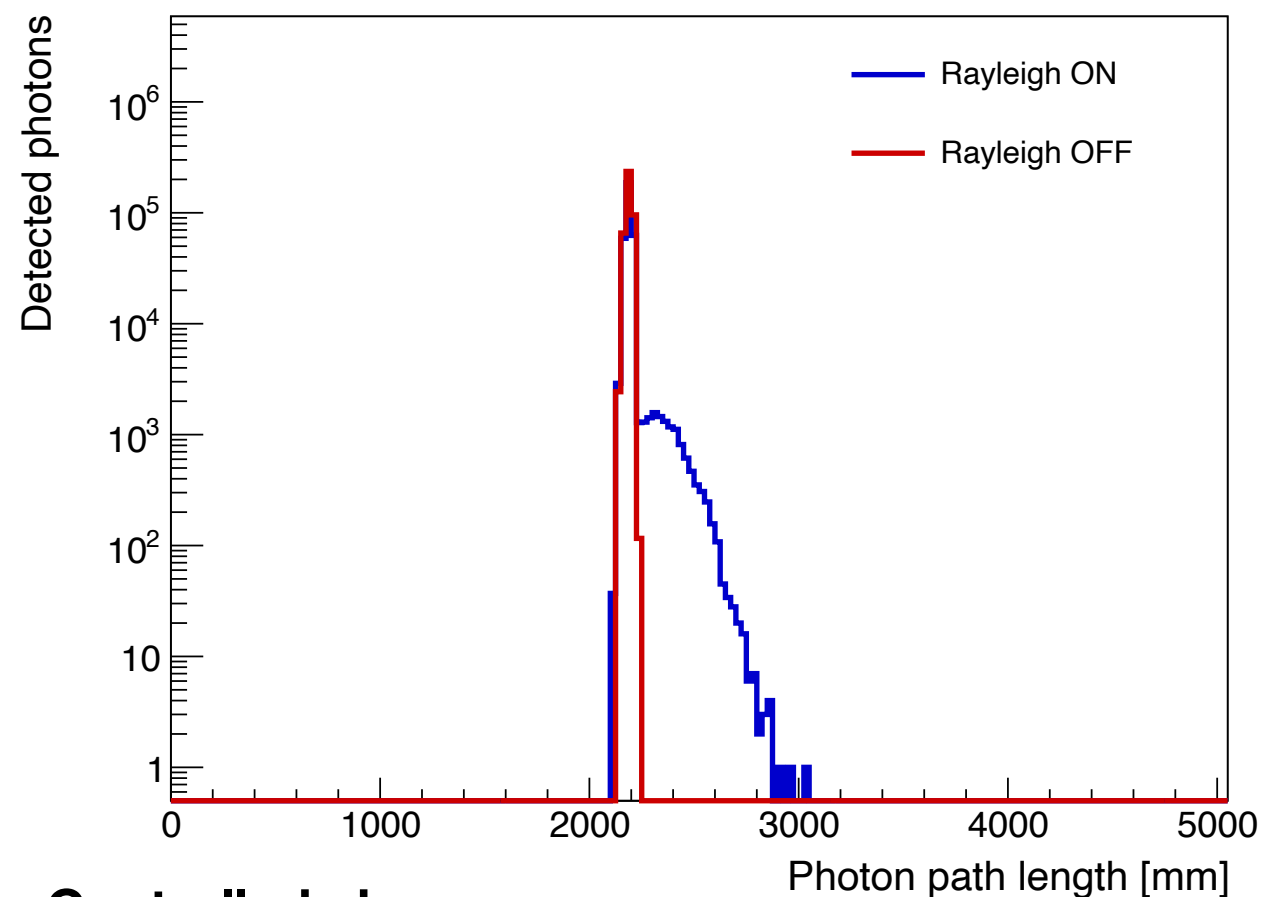
event 3, track 305, 15-16 ns, Adjacent sensor wedges



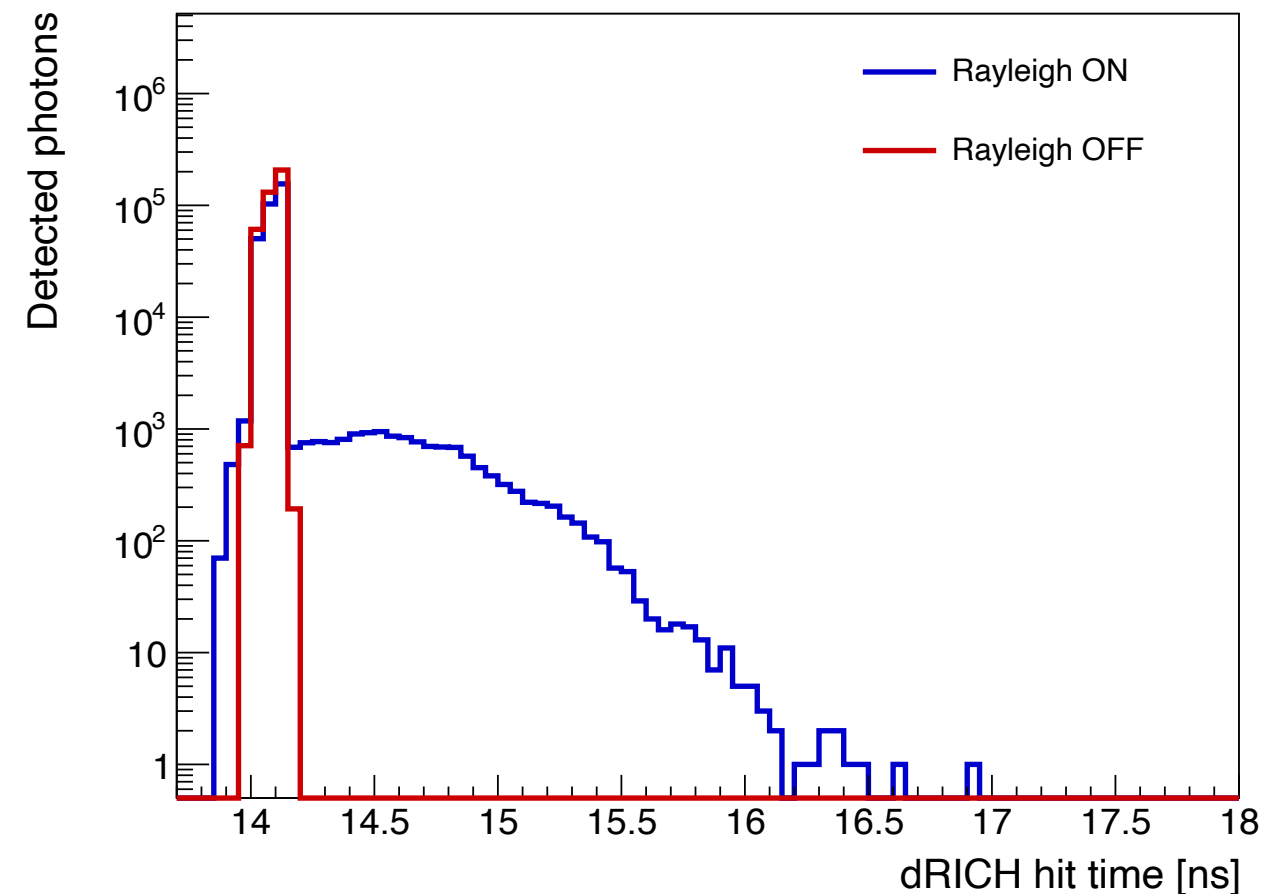
The optical histories therefore suggest that Rayleigh scattering is a plausible origin of the residual late-primary population and its sector migration.

Controlled optics test: switch Rayleigh scattering OFF in Aerogel

Aerogel primary-parent photons: One intended mirror



Aerogel primary-parent photons: One intended mirror



Controlled change

- same event configuration, geometry and optical setup
- Rayleigh scattering in aerogel: ON vs OFF (by commenting the Rayleigh property dRICH Aerogel in optical_materials.xml)

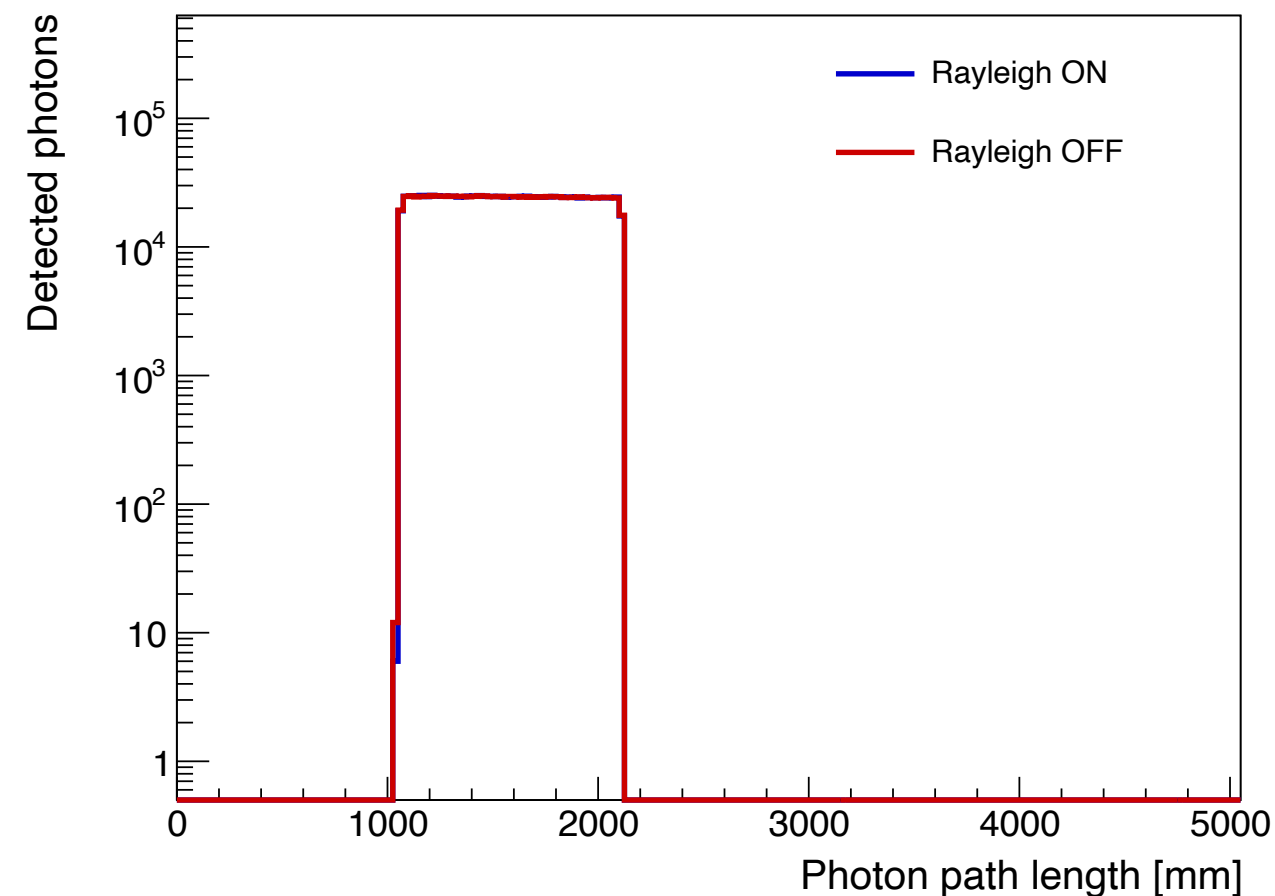
Observation

- With Rayleigh ON, a long-path population extends beyond the nominal path length.
- A corresponding late-time primary population is present.
- When Rayleigh scattering is disabled, the long-path and late-time populations are strongly suppressed.

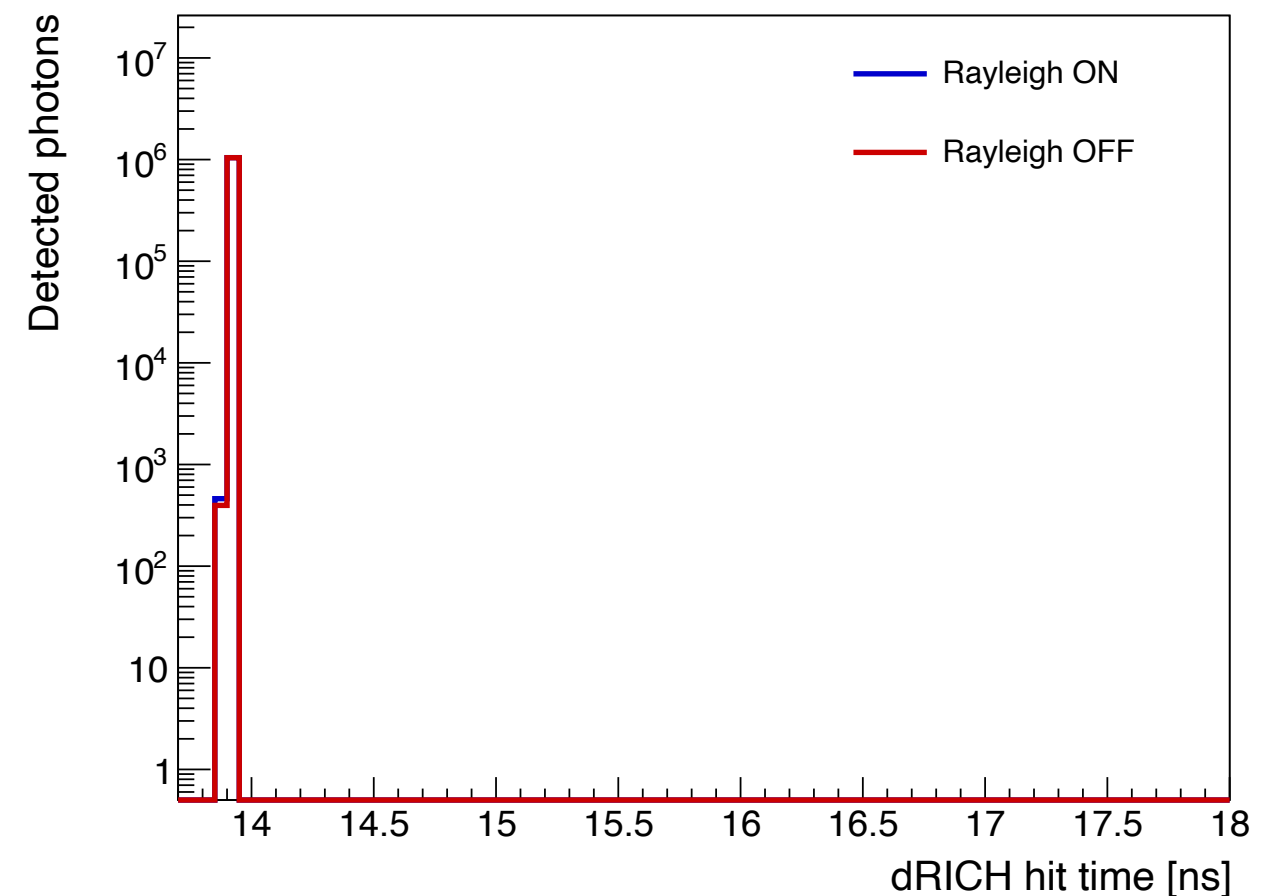
This identifies Rayleigh scattering as the main origin of the anomalous late primary-parent aerogel component in this controlled test.

Controlled optics test: switch Rayleigh scattering OFF for Gas

Gas primary-parent photons: One intended mirror



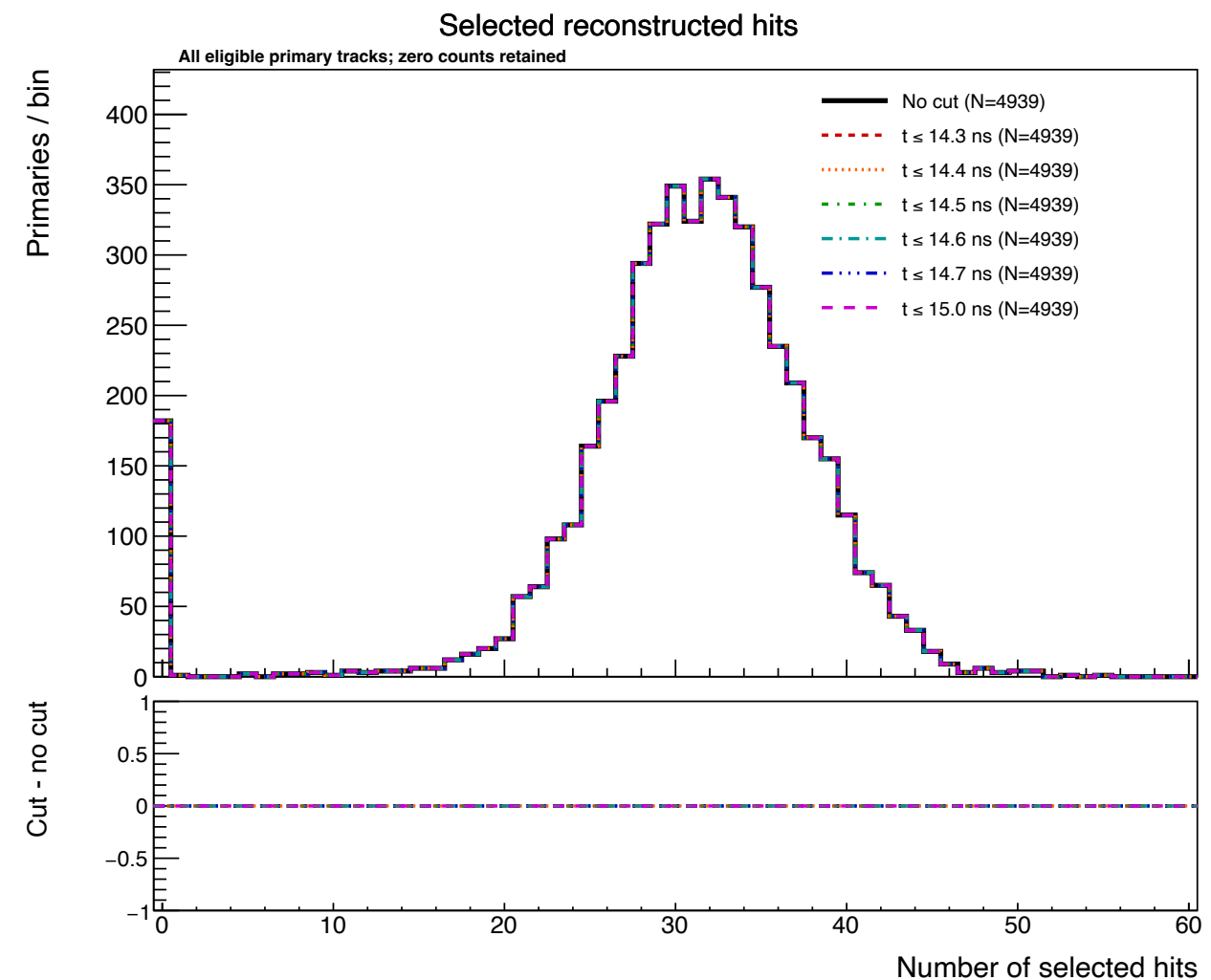
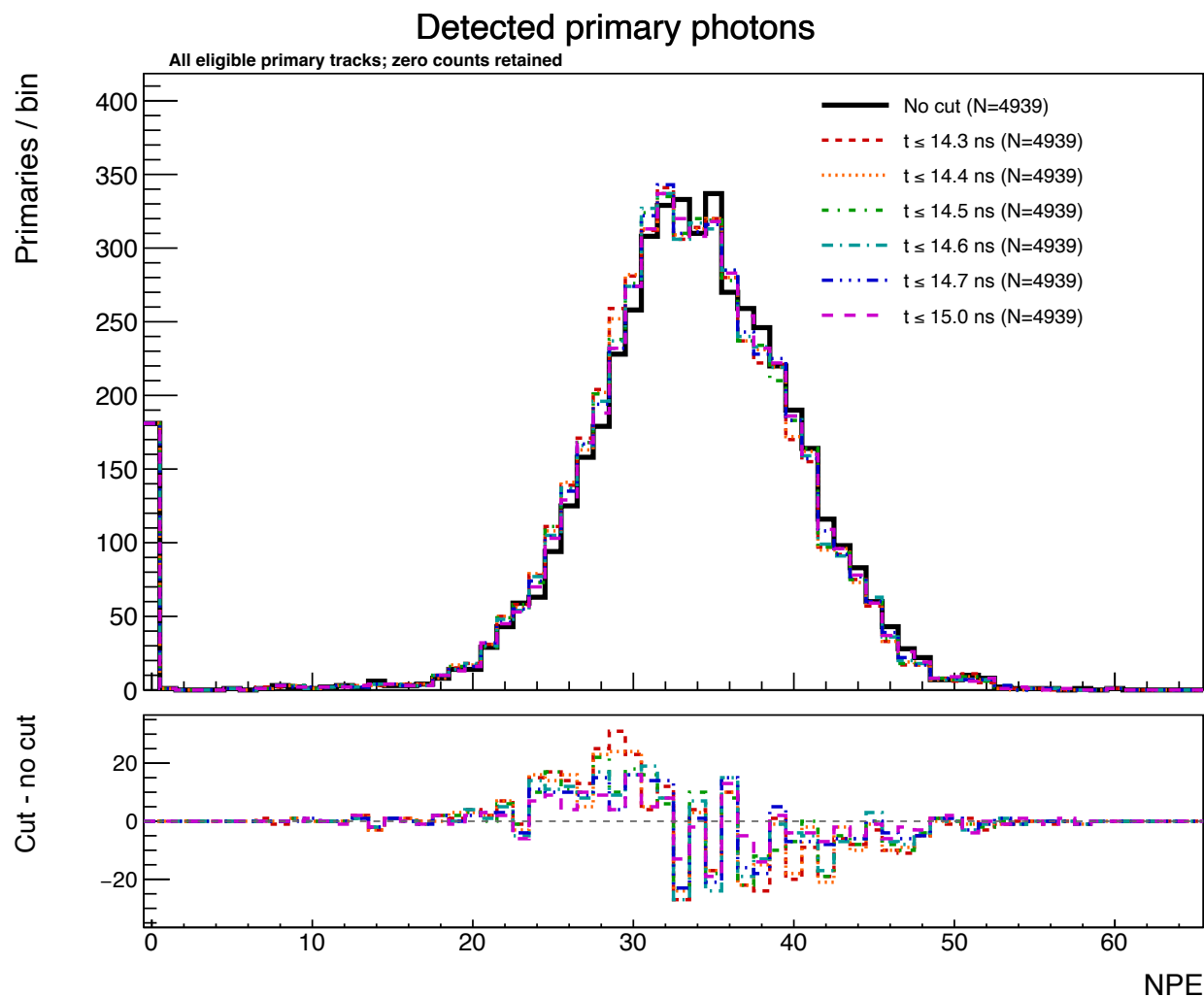
Gas primary-parent photons: One intended mirror



- The gas primary population does not exhibit the same strong long-path extension.
- Switching the tested Rayleigh contribution does not produce the dramatic change observed for aerogel.
- The anomalous primary late population is therefore associated specifically with aerogel photon transport.

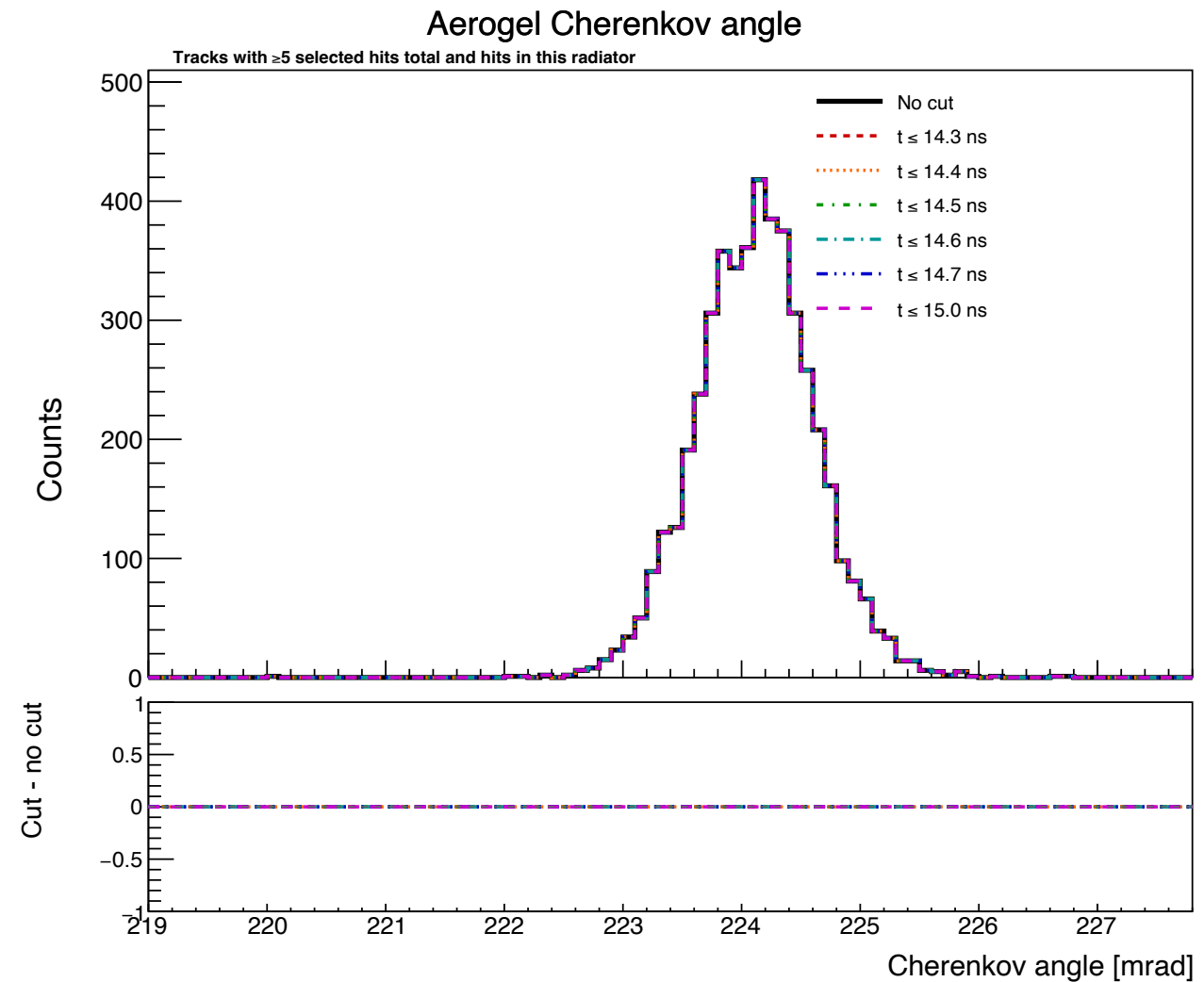
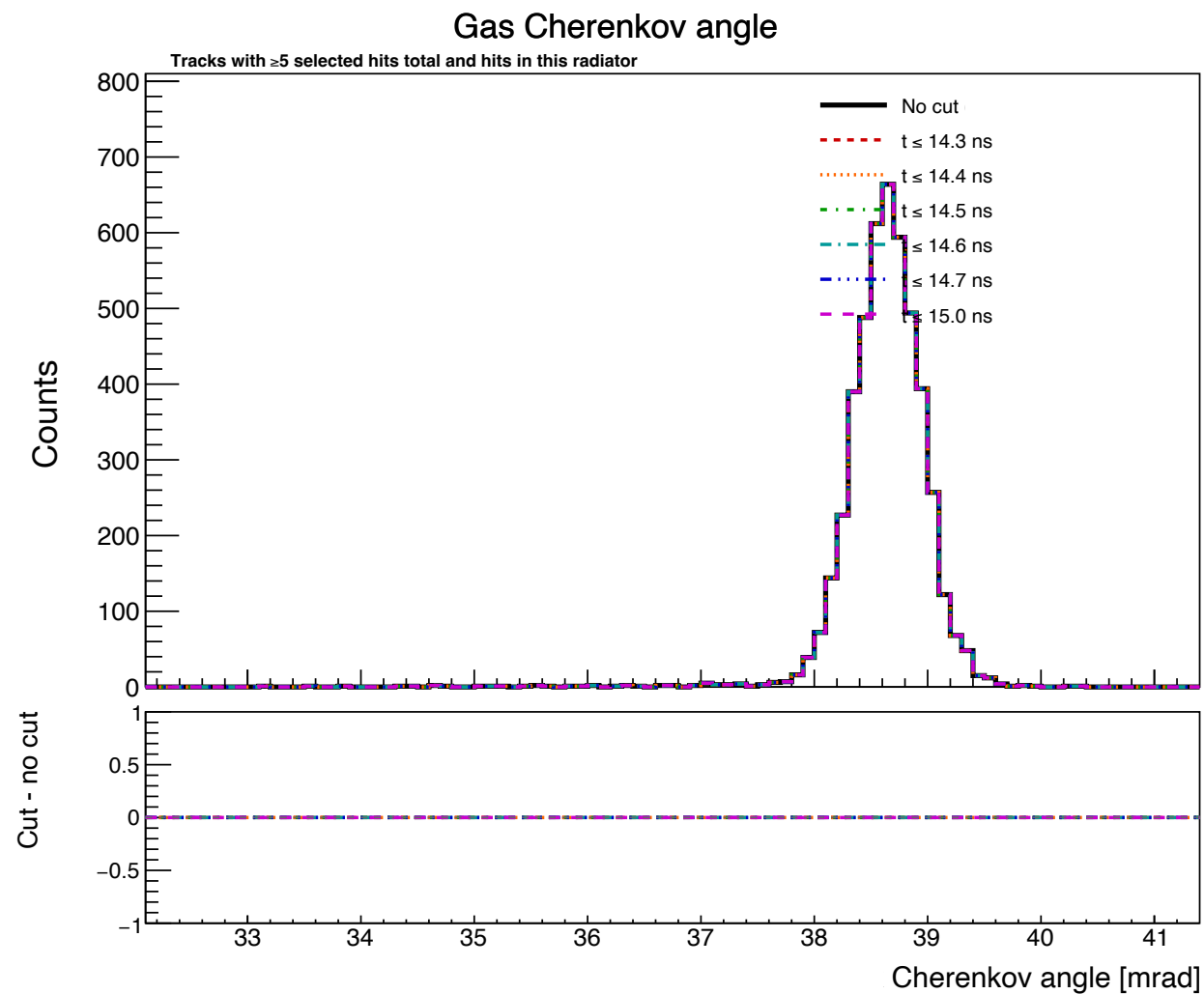
Reconstruction impact of Timing Selection :

IRT2 reconstructs the primary charged particle and uses its associated dRICH photon hits for the Cherenkov fit.



- The timing cuts probe the impact of late photons on primary-particle reconstruction.
- NPE shows only small differences relative to the full sample.
- The reconstructed-hit distribution is essentially unchanged.
- Late-hit rejection has only a small effect on the available photon statistics for this sample.

Reconstruction impact of Timing Selection :



- No visible systematic displacement of the reconstructed angle.
- Late-hit rejection has only a small effect on the available photon statistics for this sample.

For the studied 30 GeV/c pion sample, removing late hits down to ≤ 14.3 ns does not visibly degrade the reconstructed Cherenkov-angle distributions.

Conclusion :

EARLY

Short / non-nominal optical transport

- * zero-reflection/direct photons
- * non-mirror optical interactions
- * shorter-than-nominal propagation



Early arrival

NOMINAL

Expected Cherenkov photon transport

- * primary-parent photons
- * exactly one intended dRICH mirror reflection
- * nominal optical path
- * expected sensor-sector localization



Main timing peak

LATE

Two distinct physical components

Secondary-parent component

- * increasingly dominant with hit time
- * often still exactly one intended mirror reflection
- * spatially distributed across several sensor regions

Residual primary-parent component

- * strongest near the beginning of the tail
- * predominantly associated with aerogel
- * longer optical paths
- * sensor-sector migration
- * strongly reduced in Rayleigh-OFF control

Back-up

Optical History Check : Overall View

npsim \

--compactFile "\${DETECTOR_PATH}/epic.xml" \

\\geometry etc.

--inputFiles "pion_30g_eta2p5_phi90.hepmc" \

\\input

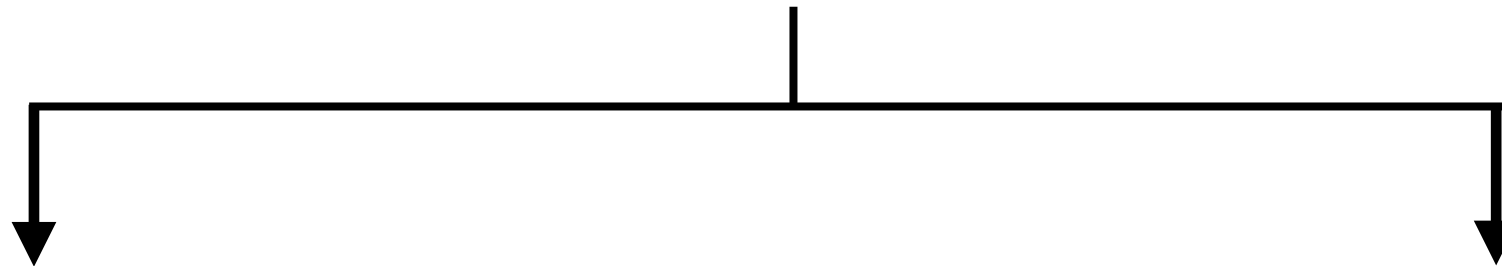
--outputFile "sim_pion_30g_90_2p5_history_5k.root" \

\\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

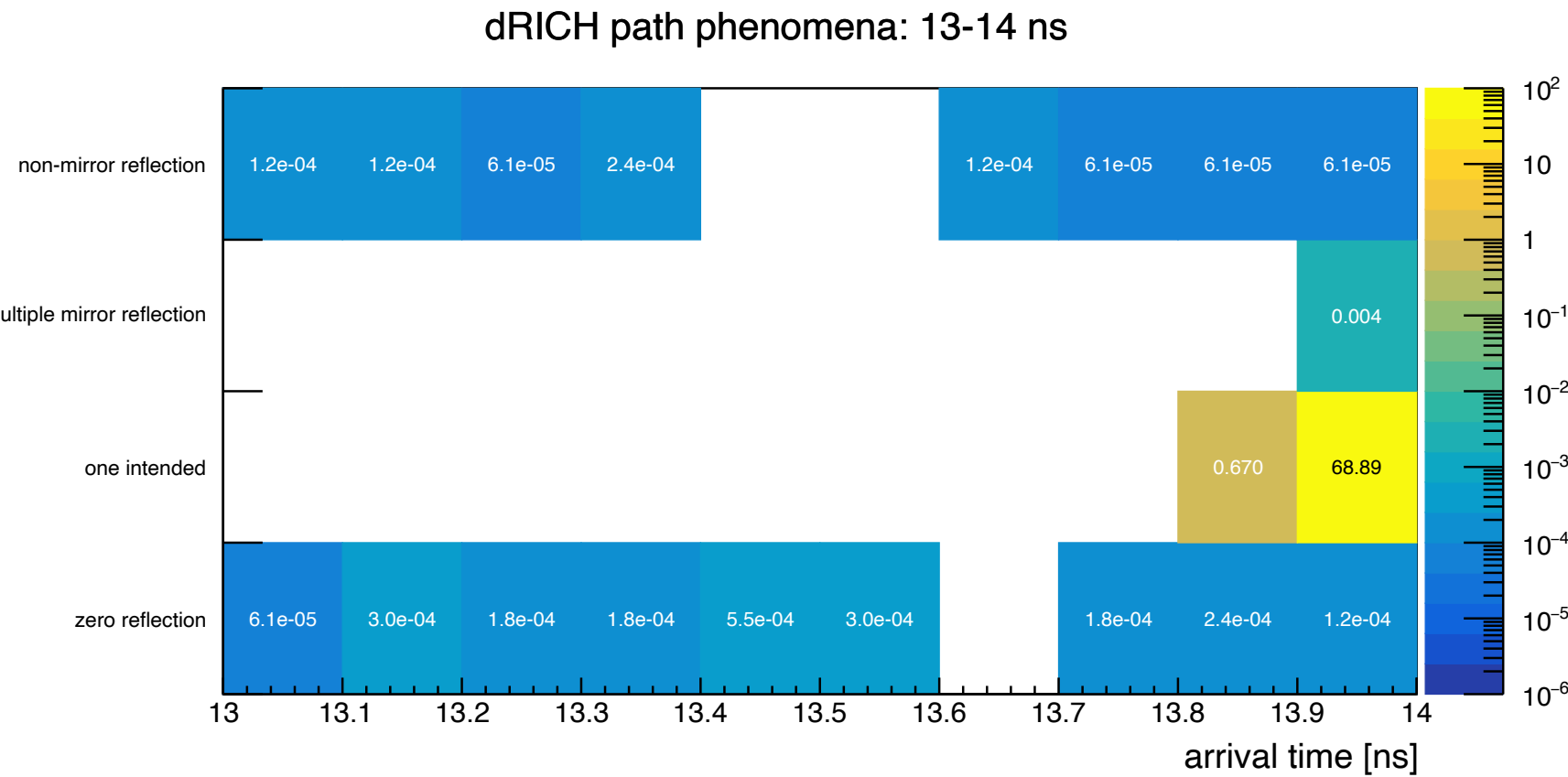


The standard simulation preserves detector hits and Monte Carlo relations, while the custom DDG4 observer actions independently preserve the step-by-step GEANT4 history of detected optical photons, allowing the measured hit time to be traced back to photon creation time, propagation path and optical-boundary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

Story till now : Fine Timing Structure: 13–14 ns

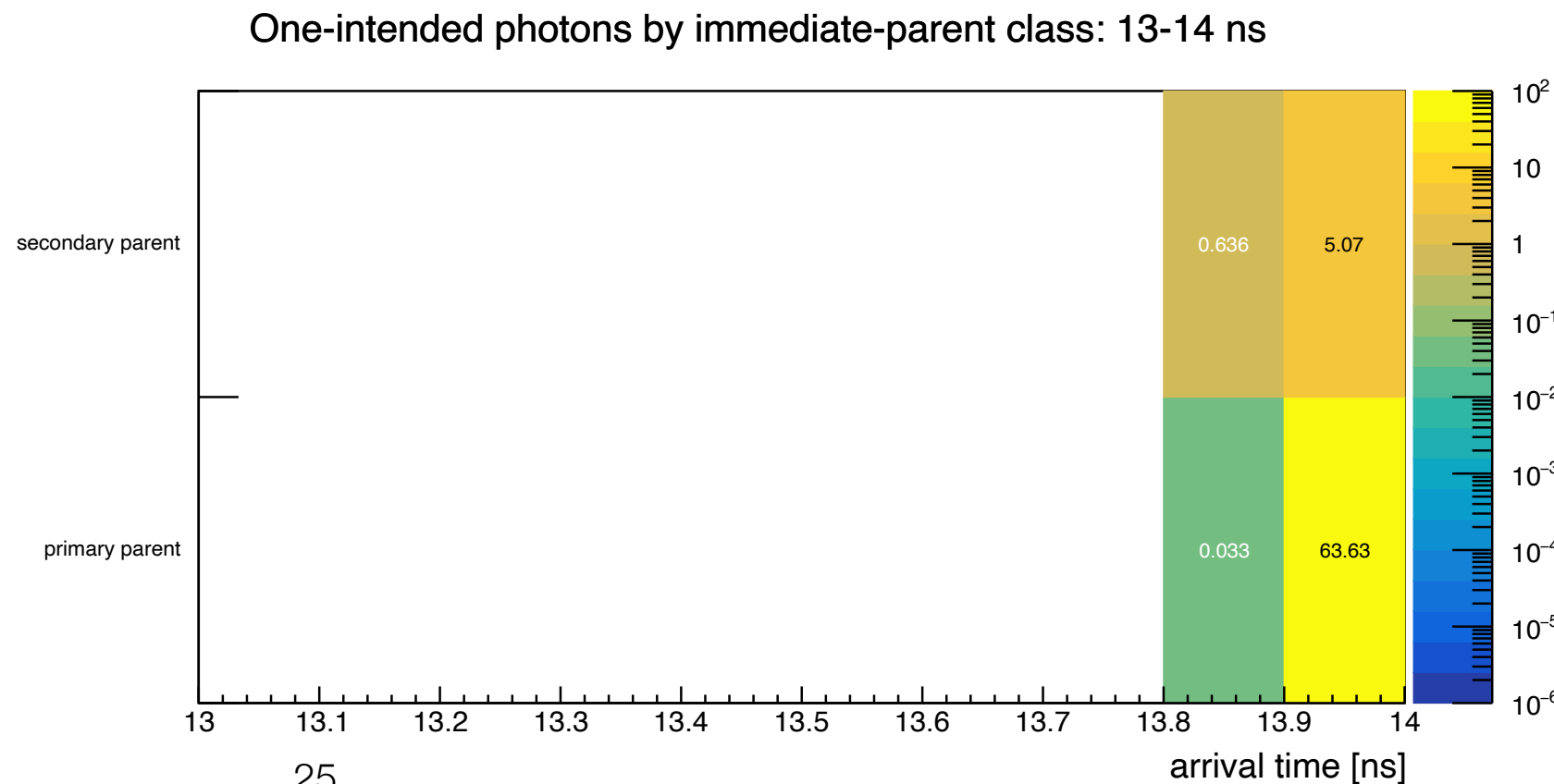
Upper plot — Optical-path classification

- 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.

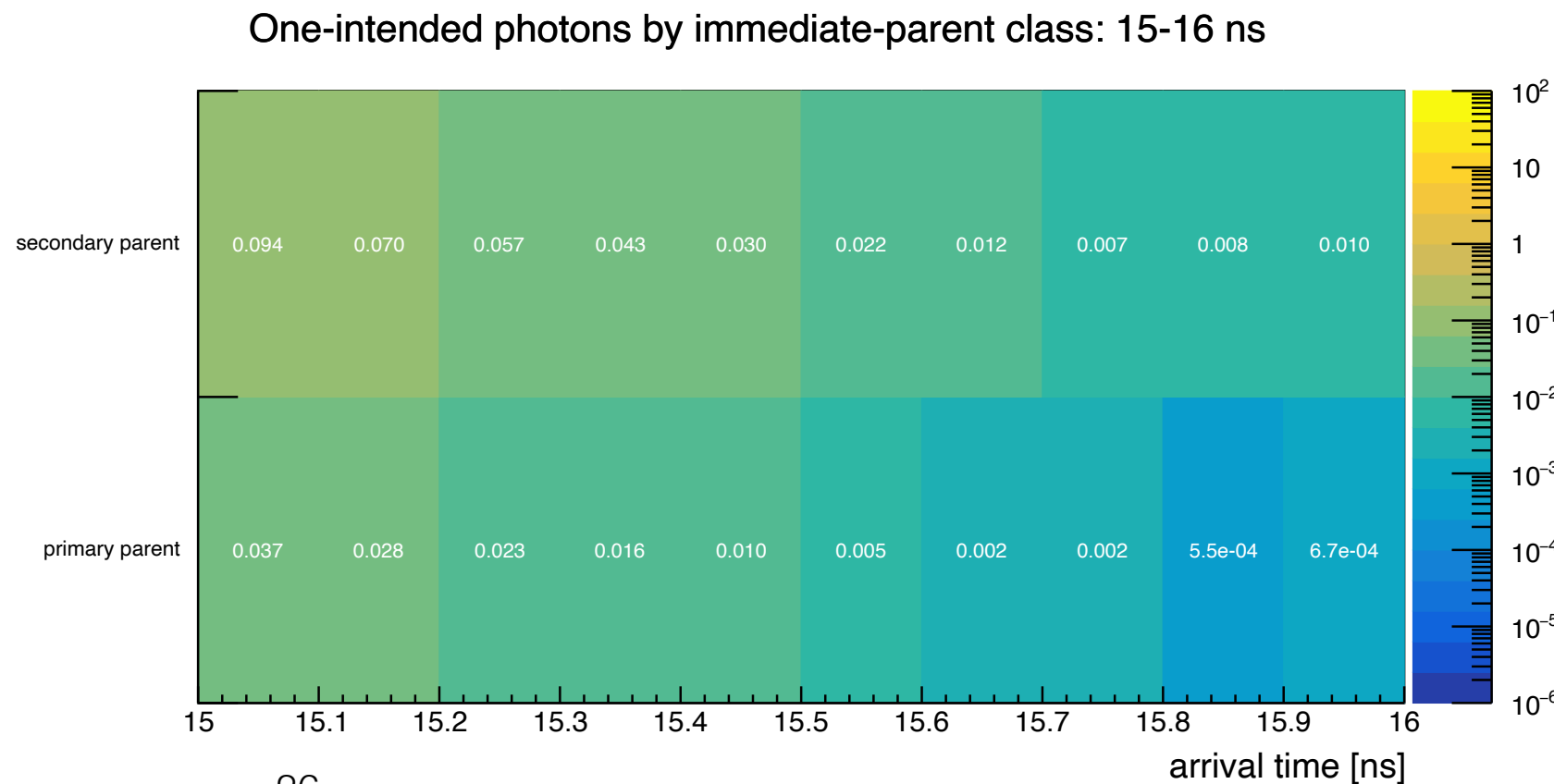
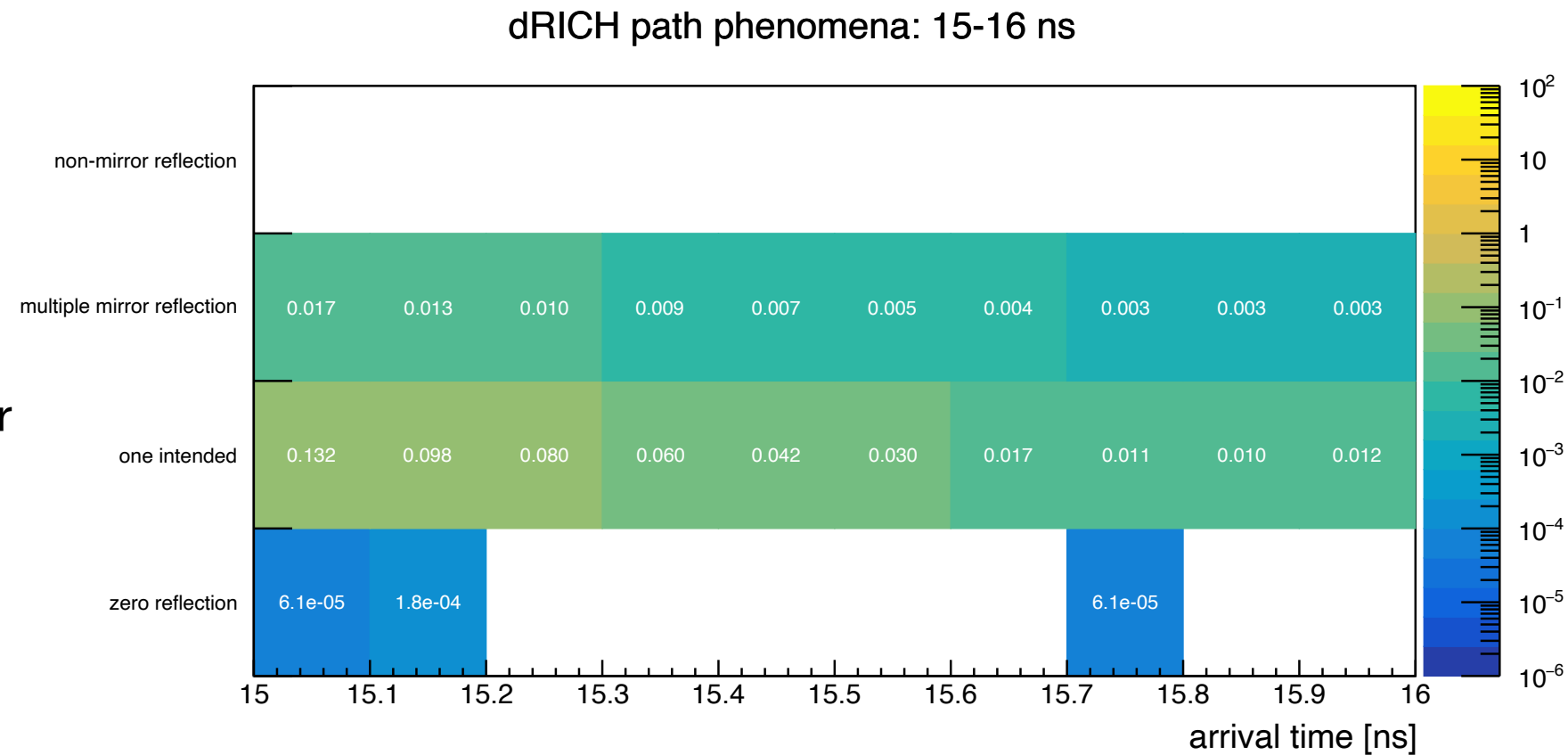


Cell values: percentage of the complete accepted sample.

Story till now : 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.



Cell values: percentage of the complete accepted sample.