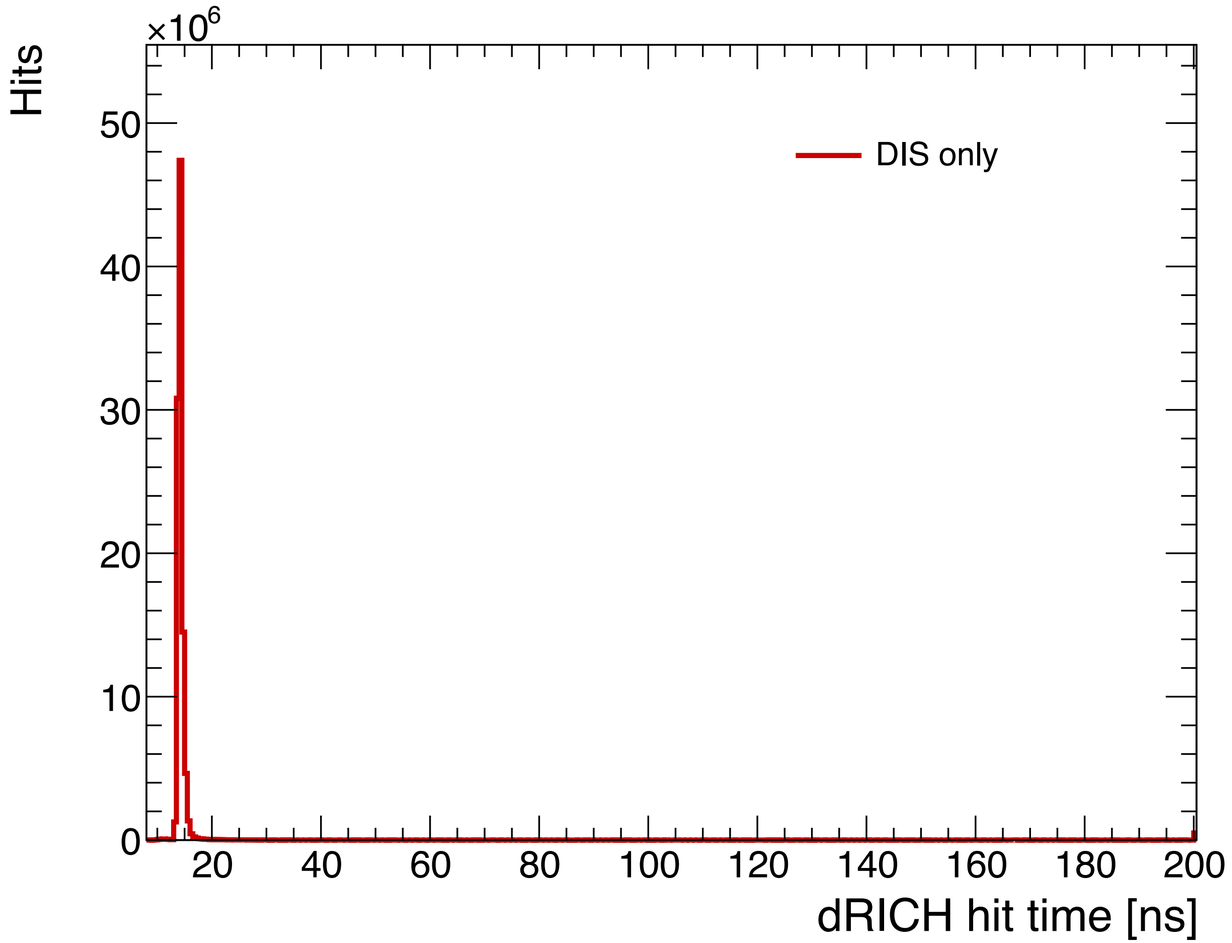
Understanding the Time Distribution of dRICH Hits

Simulation-level photon origins, optical transport, and then moving to Physics events

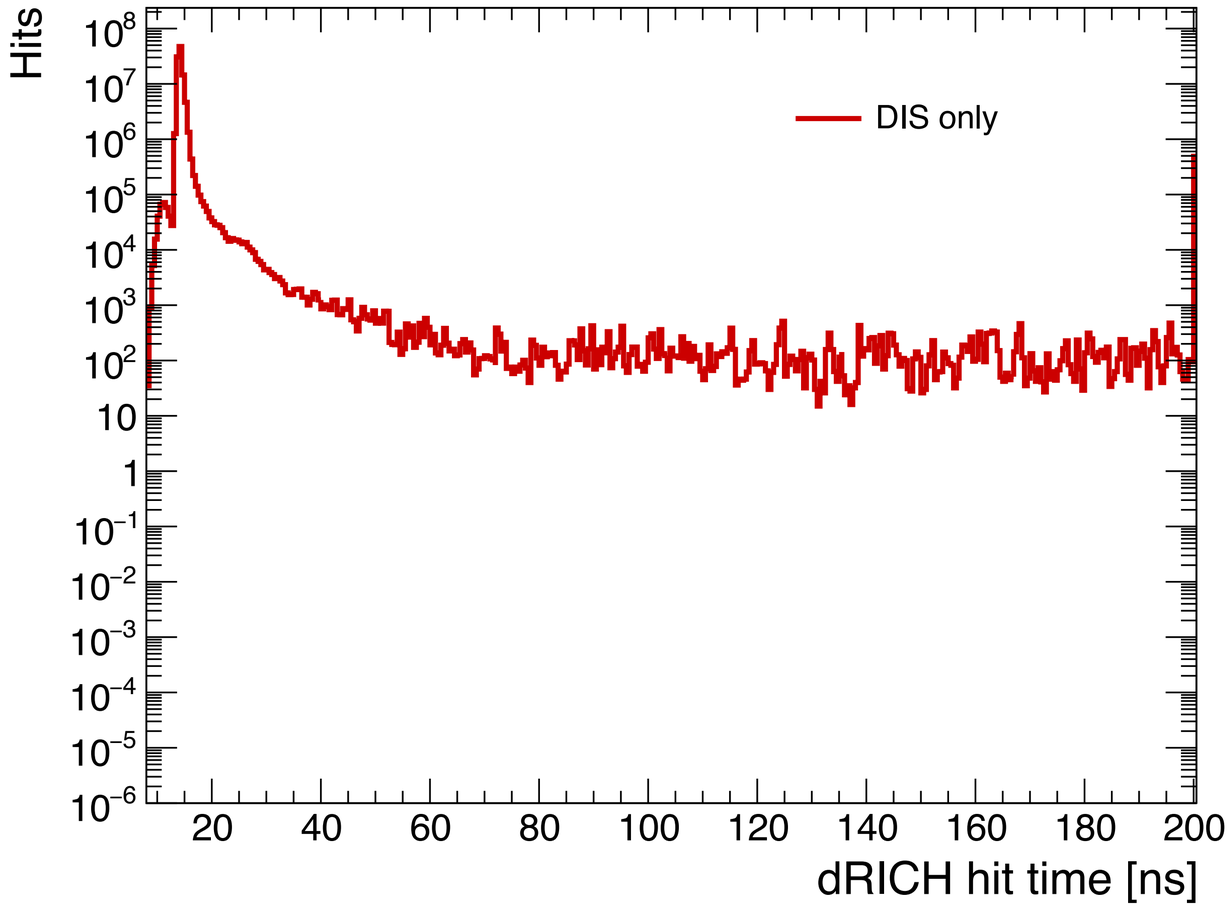
Anjali Sharma on behalf of INFN Trieste

DIS timing distribution



Peak at around 14ns and that is dRICH hit timing distribution : THAT IS IT !!!

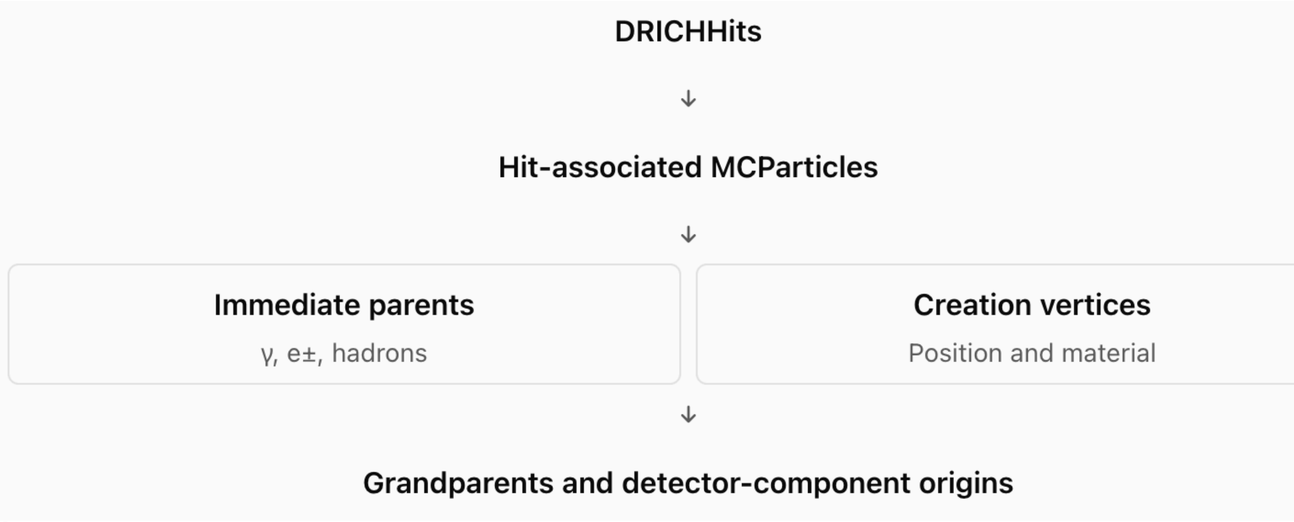
DIS timing distribution : BUT WAIT



Dataset and analysis method :

Process - Pythia8 neutral-current DIS minQ² = 1 GeV²
Beam config - 10 × 100 GeV
Geometry - epic_craterlake, version 26.02.0

DIS – `epic:/FULL/26.02.0/epic_craterlake/DIS/NC/10x100/minQ2=1`

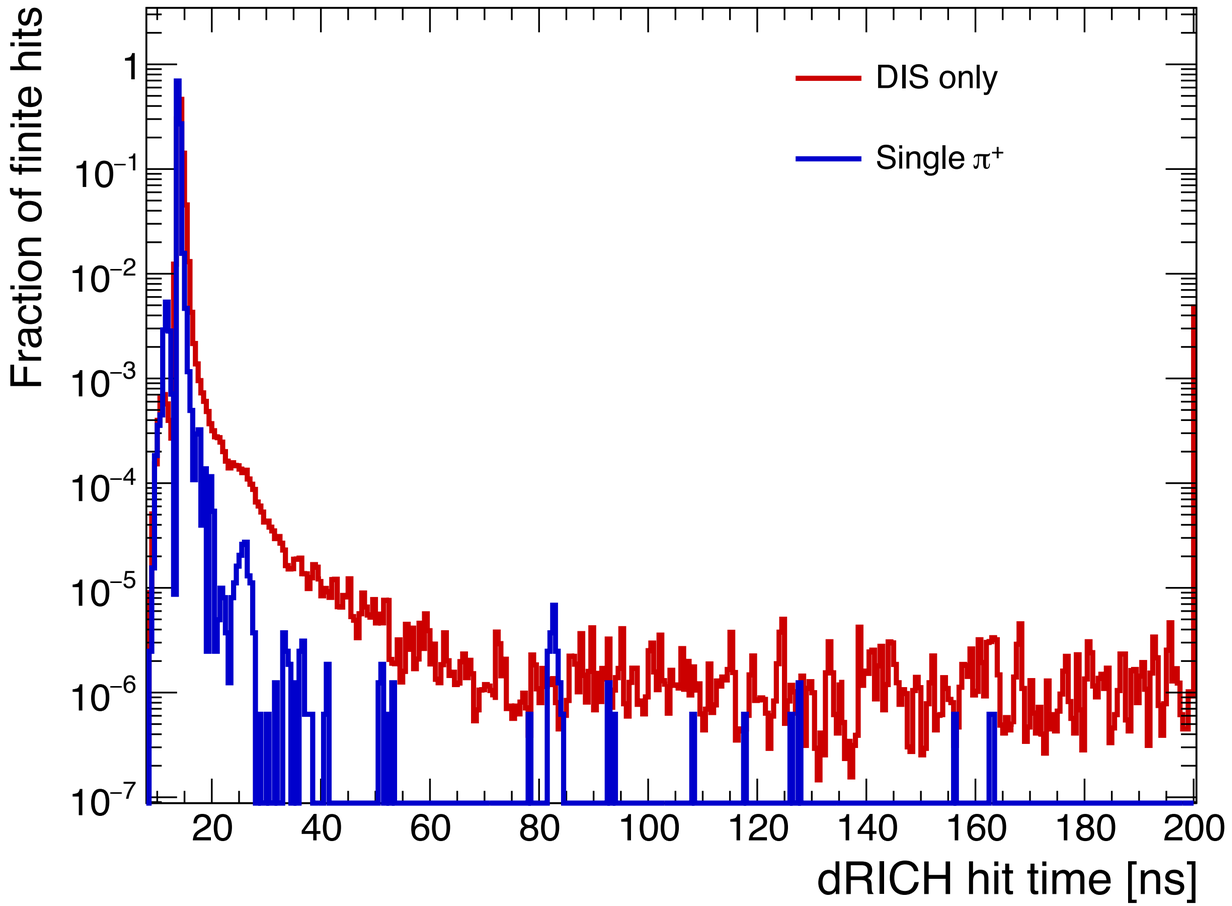


Data Sets :

Parameter	Single π^+	Eight-particle sample	DIS only
Generator	HepMC3 single-particle	Random 8-particle sample (π,K,P,e & their Anti-Part)	Pythia8 NC DIS
Particle	π^+	8 charged-particle species	DIS final-state particles
Momentum	30 GeV/c	5–50 GeV/c	Generated DIS spectrum
η	2.5	1.8–3.0	DIS kinematics
ϕ	90°	60°–120°	DIS kinematics
Events analyzed	5,000	5,000	~101x1083
Detector simulation	Geant4 (npsim)	Geant4 (npsim)	Geant4 (npsim)
Geometry	ePIC/dRICH	ePIC	ePIC Craterlake 26.02.0
Simulation output	EDM4hep ROOT	EDM4hep ROOT	EDM4hep ROOT

This presentation is SIMULATION LEVEL study only

DIS and single particle timing distribution



DIS:

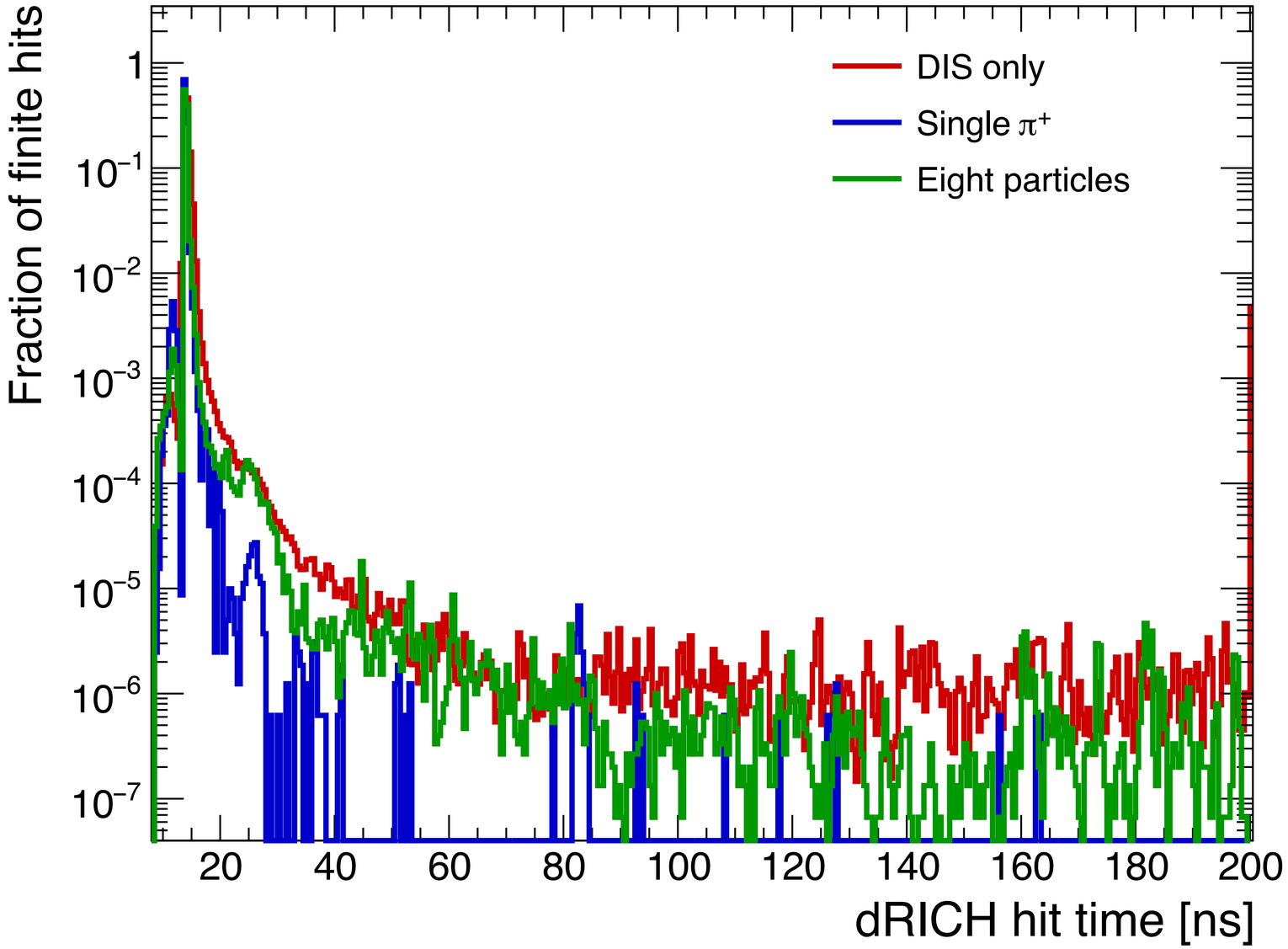
Process - Pythia8 neutral-current DIS minQ² = 1 GeV²
Beam config - 10 × 100 GeV
Geometry - epic_craterlake, version 26.02.0

DIS – `epic:/FULL/26.02.0/epic_craterlake/DIS/NC/10x100/minQ2=1`

Simulation Sample:

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

DIS and simulations timing distribution



Observations

- All three datasets exhibit a prominent timing peak, corresponding to the dominant photon-arrival population.
- The controlled single-pion sample shows a comparatively concentrated timing distribution, with a smaller extended-time population.
- The eight-particle sample retains the main timing structure but exhibits additional contributions outside the dominant peak.
- DIS events show a more pronounced and extended late-time population, reflecting the increased complexity of particle production and photon transport.

Conclusion

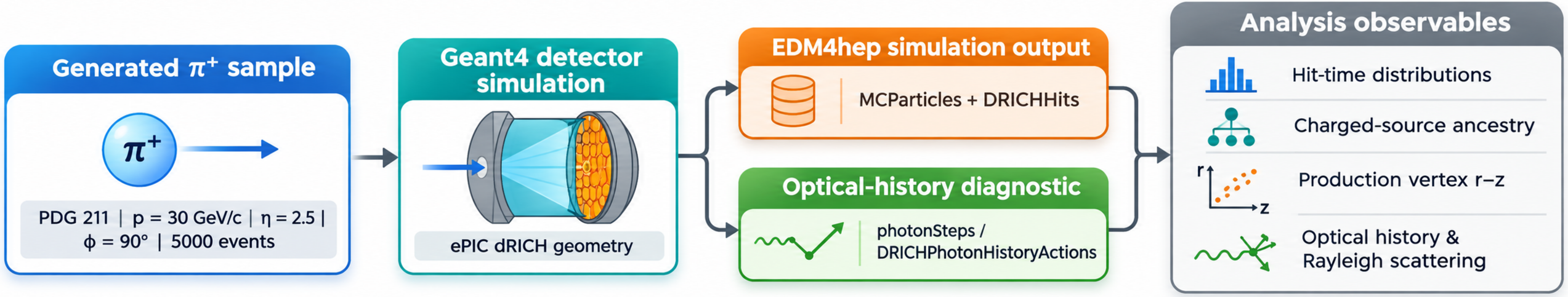
The three samples provide a progression from a controlled single-particle reference to complex DIS events, allowing the mechanisms responsible for the dRICH timing structures to be investigated systematically.

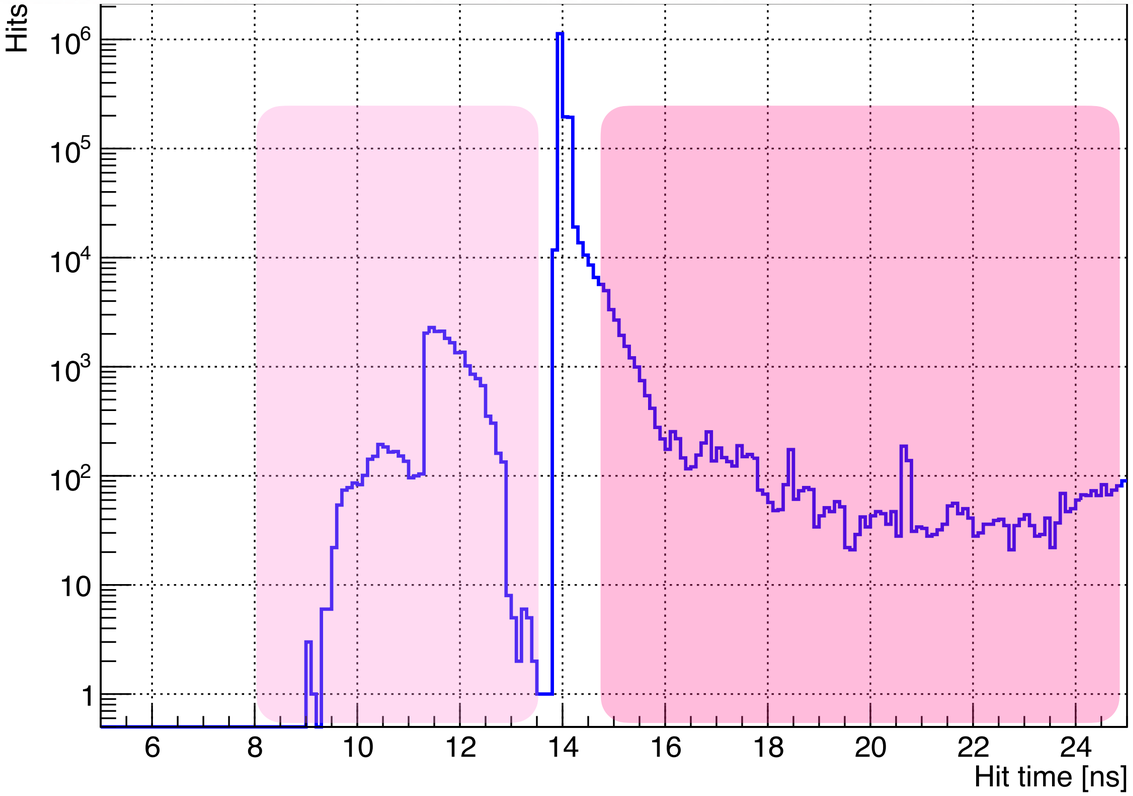
Single-particle pion:

Controlled simulation study of photon origin, optical transport

π^+, 30 GeV/c, η = 2.5 and 5,000 generated events

Controlled Single-Pion Simulation Workflow





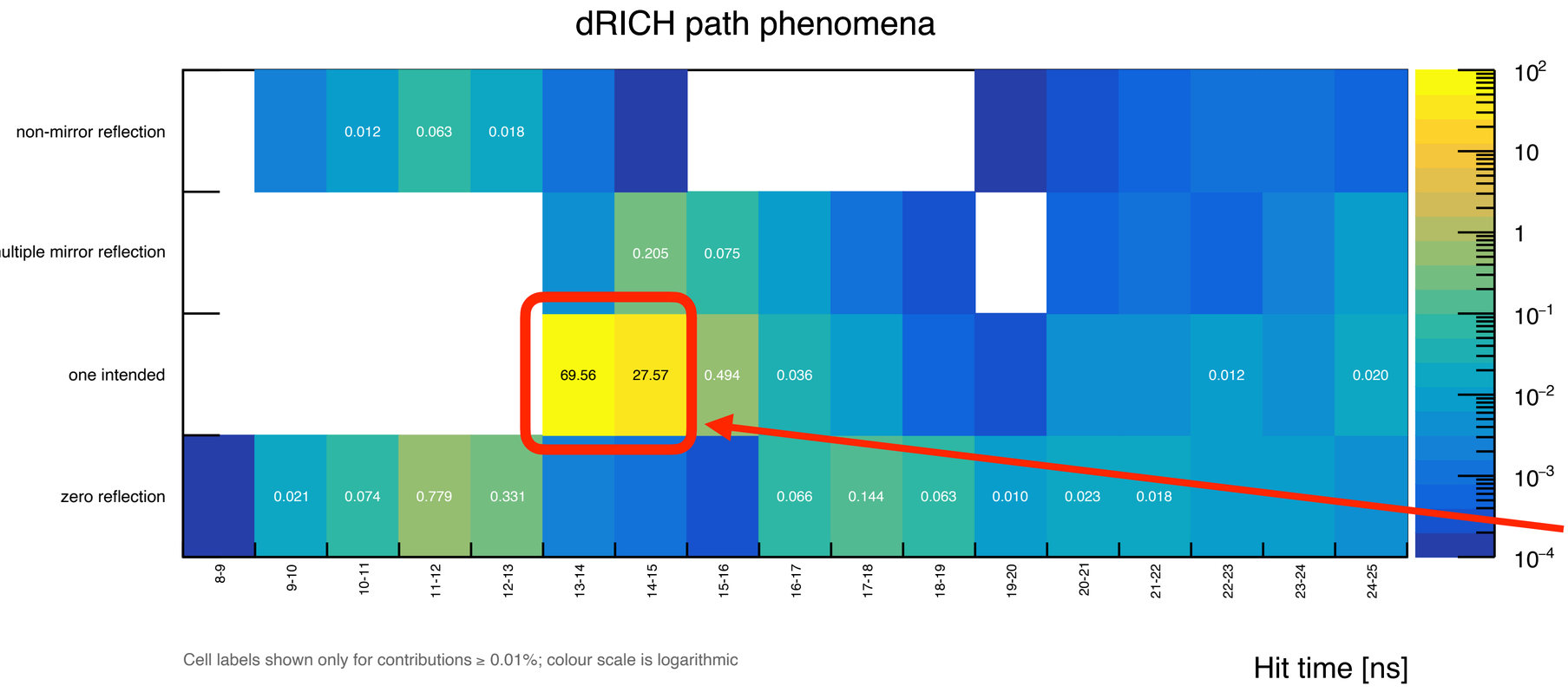
Observations :

- The detected photon-hit times exhibit a narrow dominant structure, together with additional earlier-arriving and extended-time populations.
- Although the linear representation highlights the dominant timing peaks but logarithmic representation reveals populations that are **much smaller** in absolute counts but extend across a broader time range.

Question: Do the additional timing components originate from the primary pion, secondary particles, or optical propagation effects?

Optical-Boundary History: How Do Photons Reach the Sensors?

*** The heat-map entries are percentages of all accepted photons, rather than percentages within each time bin**



Photons are classified into:

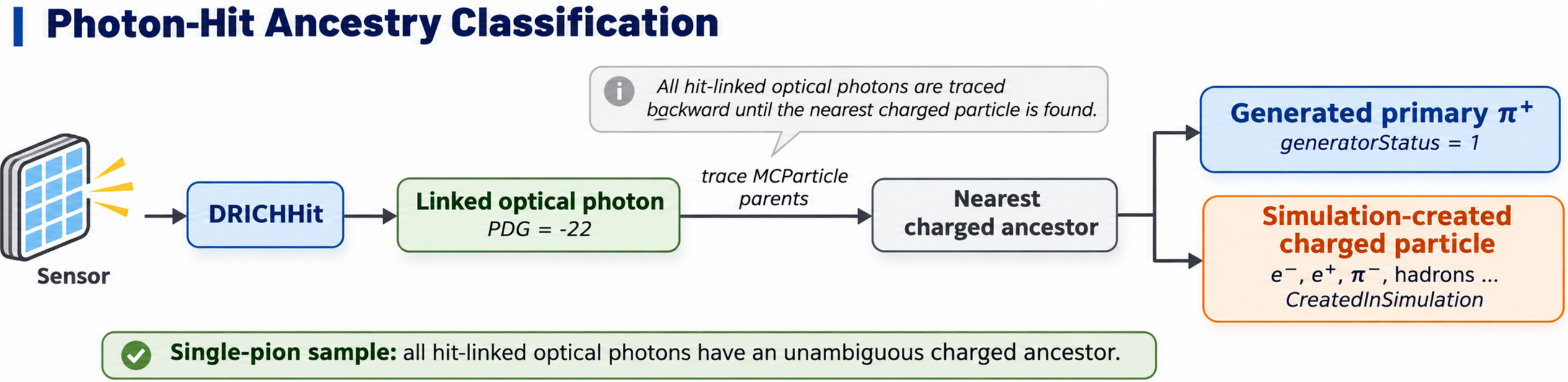
- Zero mirror reflections.
- Exactly one intended dRICH mirror reflection.
- Multiple intended mirror reflections.
- Non-mirror reflection categories.

~97% of Total dRICH hits

Observations

- The principal timing peak is overwhelmingly dominated by photons undergoing exactly one intended mirror reflection.
- Earlier photons include more direct and non-nominal optical trajectories.
- Delayed photons can still follow a one-intended-mirror path.

MCParticle ancestry and classification

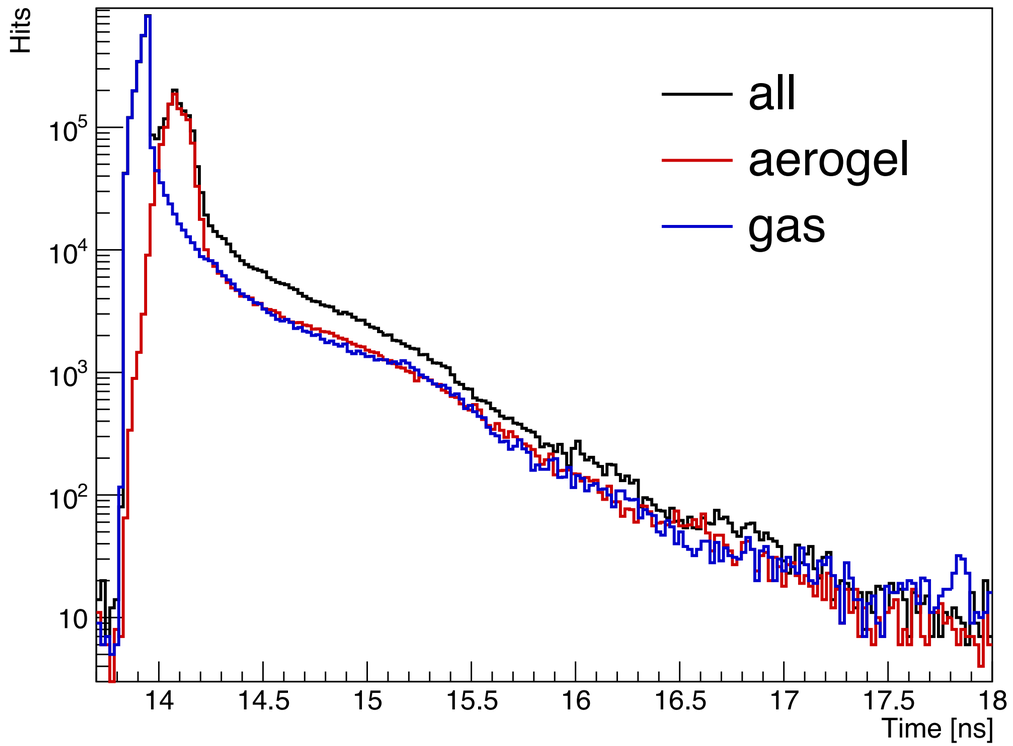


For each selected dRICH photon hit, the associated optical photon is identified through the MCParticle relation. The photon ancestry is traced backward to the nearest charged ancestor.

The charged ancestor is classified into two categories:

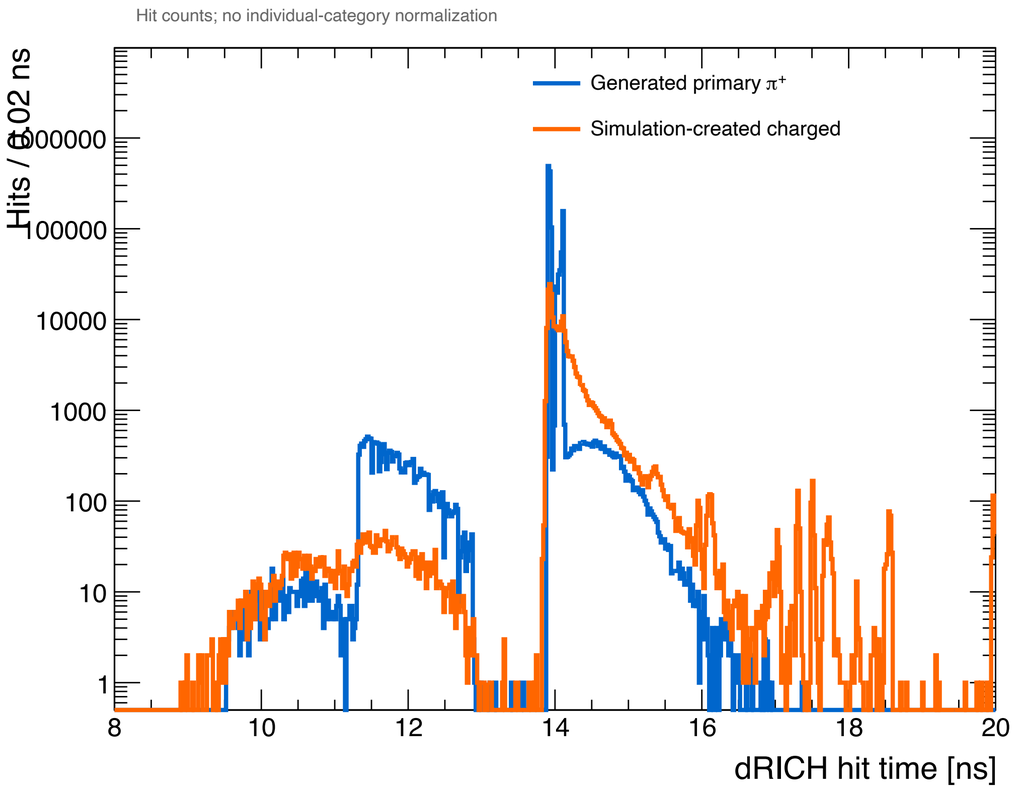
- Primary pion: Generated π^+ associated with the initial event, with generatorStatus = 1 and not created during simulation.
- Secondary charged particle: Simulation-created e^-, e^+, hadron or other charged particle identified through the CreatedInSimulation flag.

Disentangling Radiator and Charged-Particle Contributions



* legends' meaning :"all" means **aerogel and gas**;
:"gas" means **gas and vacuum**;
:"aerogel" means **vacuum and aerogel**;

✤ The observed tail is a combined effect of both radiators rather than a feature of only one radiator.

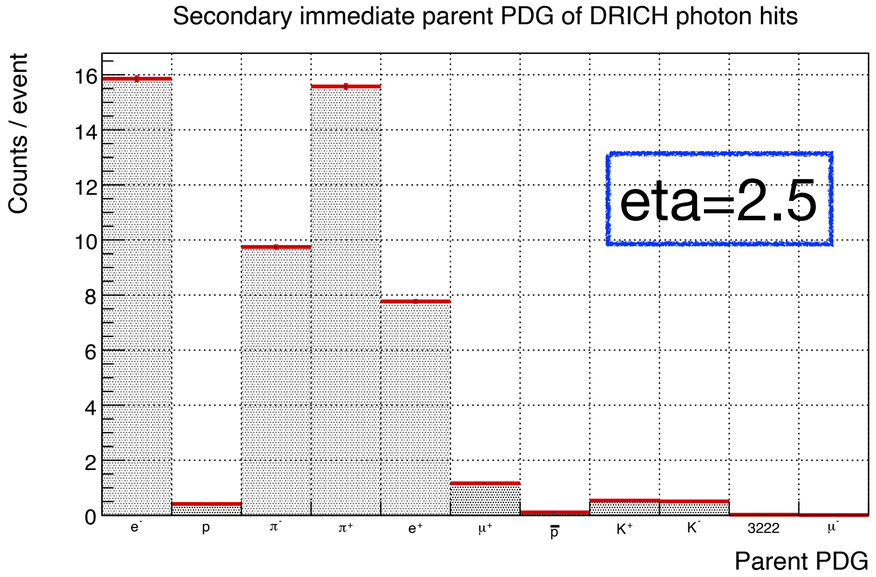


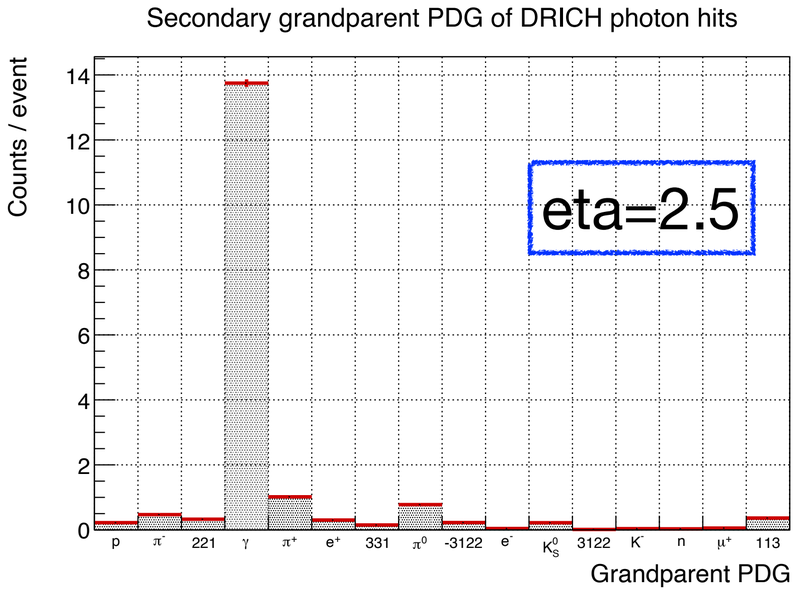
✤ Late-time photon hits are dominated by photons whose immediate parent is a secondary particle.

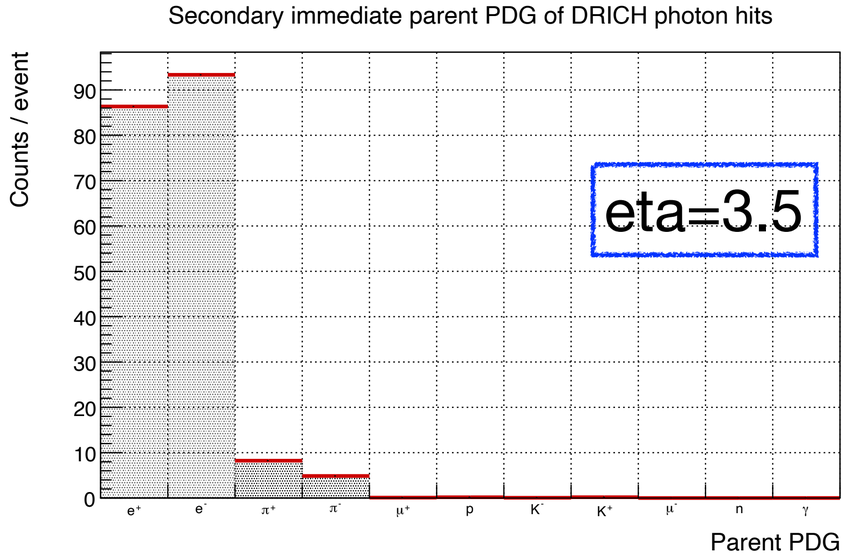
Conclusion

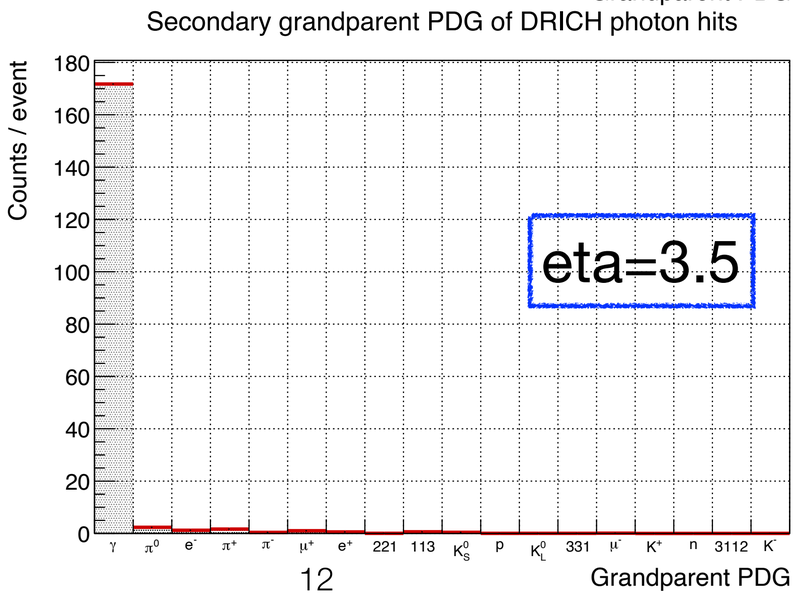
The radiator-configuration comparison tests the sensitivity of the timing distribution to radiator composition and optical conditions. Independently, charged-particle ancestry reveals an increasingly important secondary contribution outside the main peak.

Which Secondary Particles Contribute?



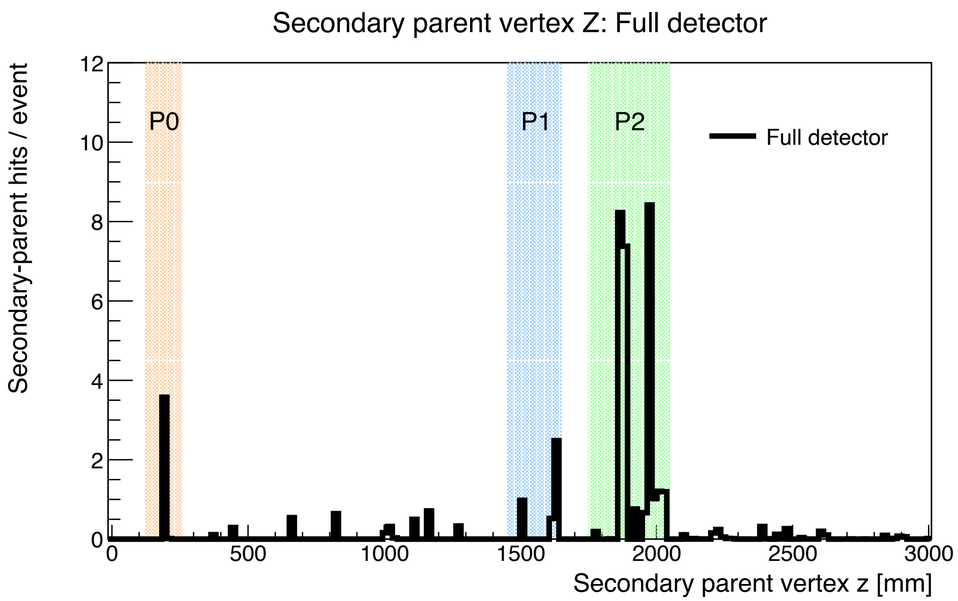




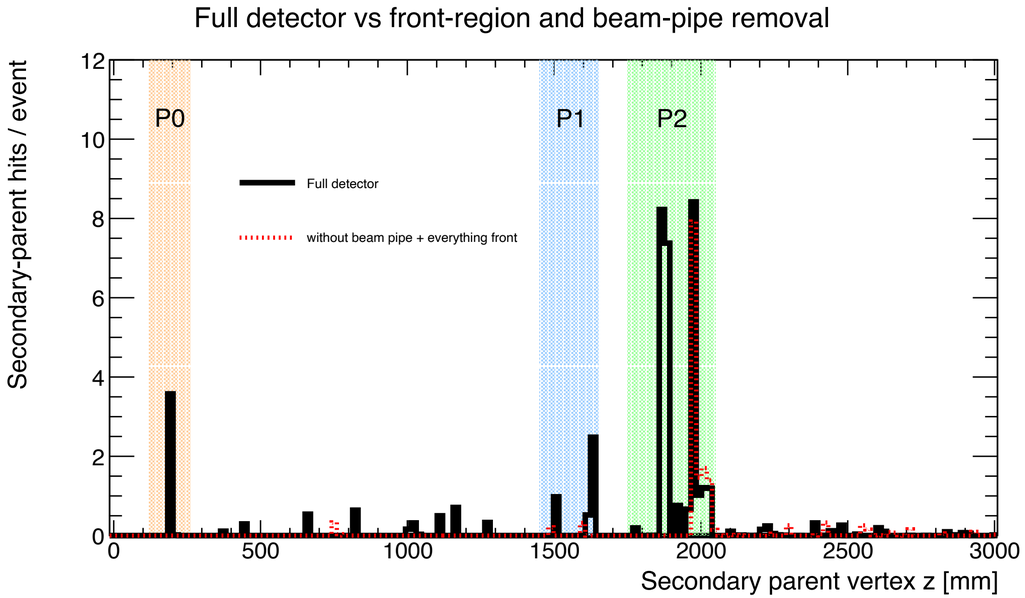


Electrons and positrons are major contributors among the secondary charged particles associated with dRICH photon hits. Their ancestry contains substantial photon and hadron contributions, indicating that secondary-particle production is an important part of the simulated detector response.

Where Do the Secondary Particles Originate?



P0: front/early-z material region
P1: intermediate material region
P2: TOF–dRICH transition / dominant peak cluster region



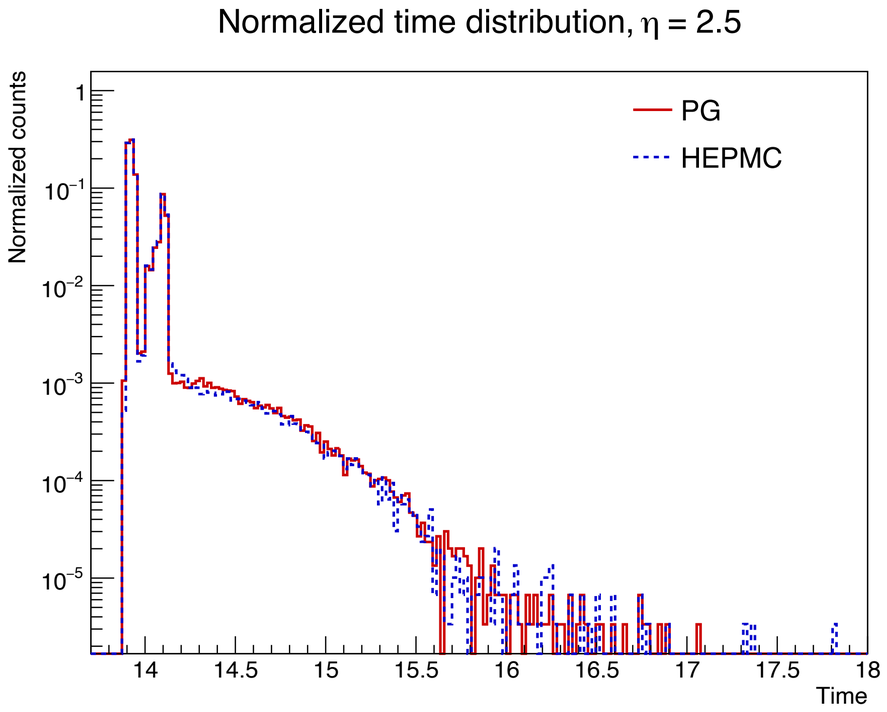
Observations

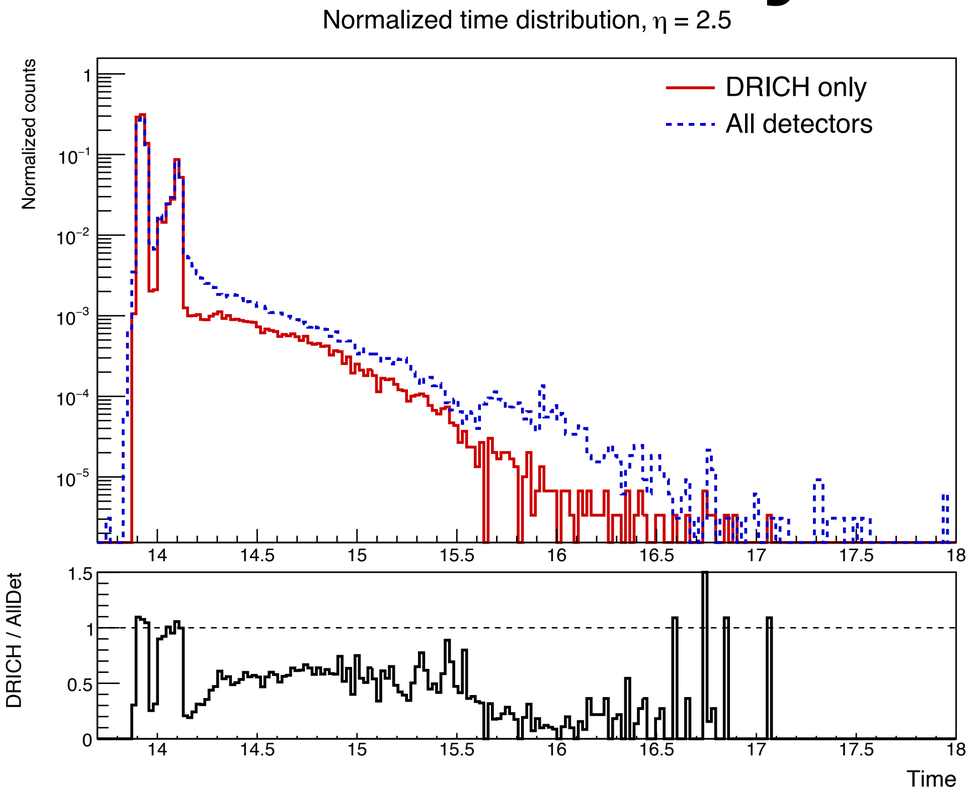
- The production vertices of secondary charged particles are not uniformly distributed along the detector z-axis.
- Distinct peaks appear in particular detector-material regions.
- The strongest cluster in the studied full-detector configuration appears near the downstream TOF–dRICH transition.
- Removing upstream components modifies particular production peaks, indicating sensitivity to detector material.

Conclusion

The enhanced late photon population is associated with secondary particles produced in specific detector-material regions, rather than uniformly throughout the detector.

Controlled Checks: Generator and Geometry





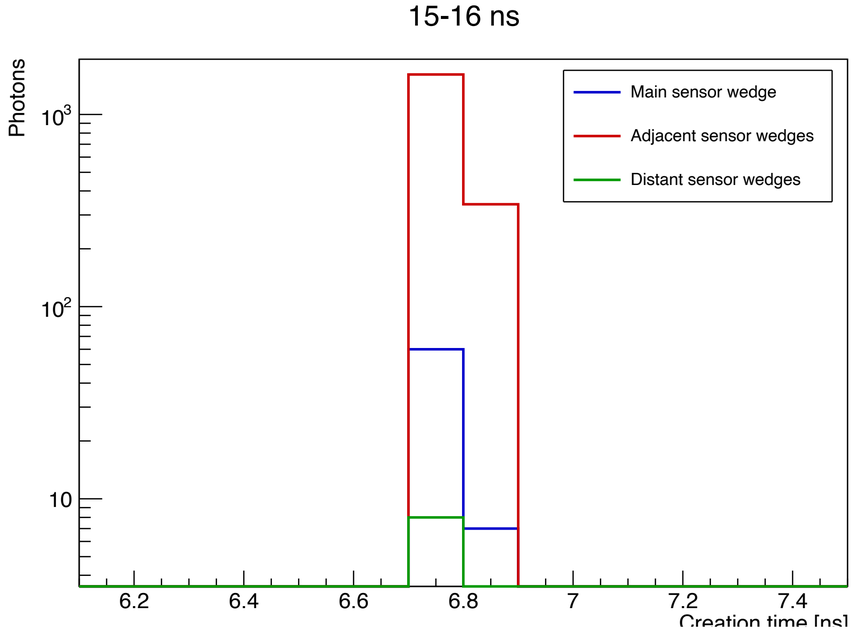
Observations

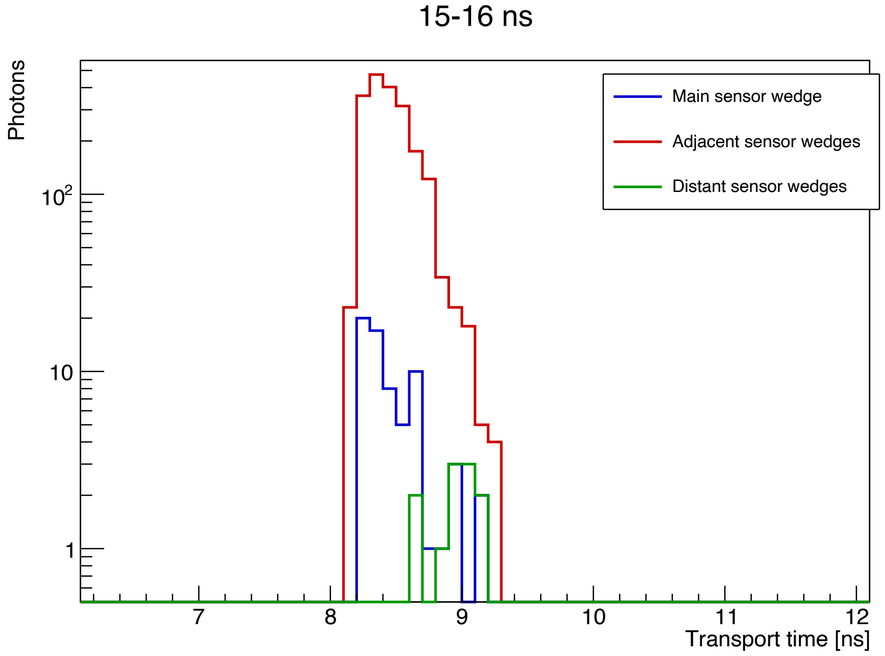
- The late component persists across different controlled simulation configurations.
- Agreement between Particle Gun (PG) and HepMC indicates that the effect is not primarily introduced by the event-input format.
- Including the surrounding ePIC detector increases the late-hit population, consistent with additional secondary-particle production.

Conclusion

The timing tail is a reproducible feature of the simulated detector response. Its amplitude and composition depend on radiator conditions and surrounding detector material.

Separating Photon Emission Time from Optical Transport Delay





Observations

Photon creation time

- Primary-parent photons reaching different sensor wedges are created within broadly similar time intervals.
- Comparing the 14–15 ns and 15–16 ns arrival windows does not reveal a correspondingly large change in creation time.

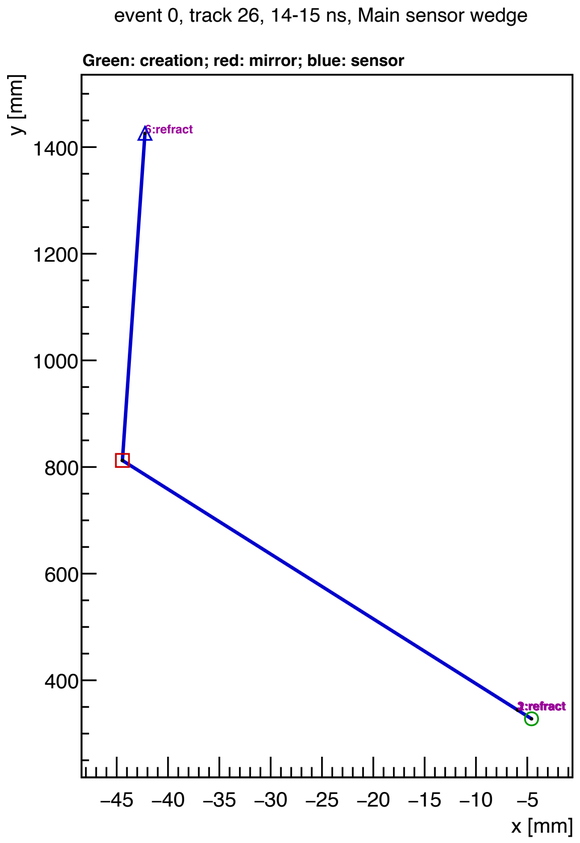
Photon transport time

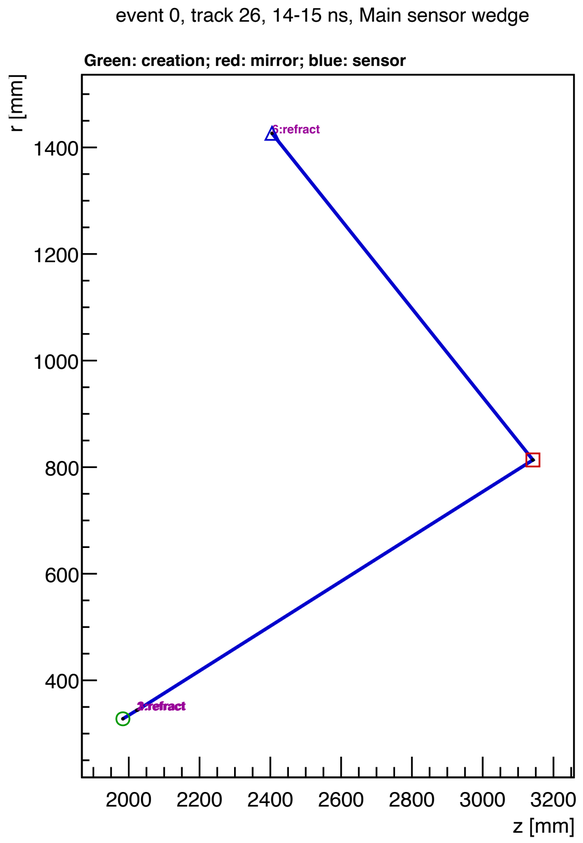
- The main sensor wedge contains a comparatively shorter transport-time population.
- Photons reaching adjacent or distant wedges extend toward longer transport times.
- The 15–16 ns arrival window contains photons with longer transport intervals than the 14–15 ns population.

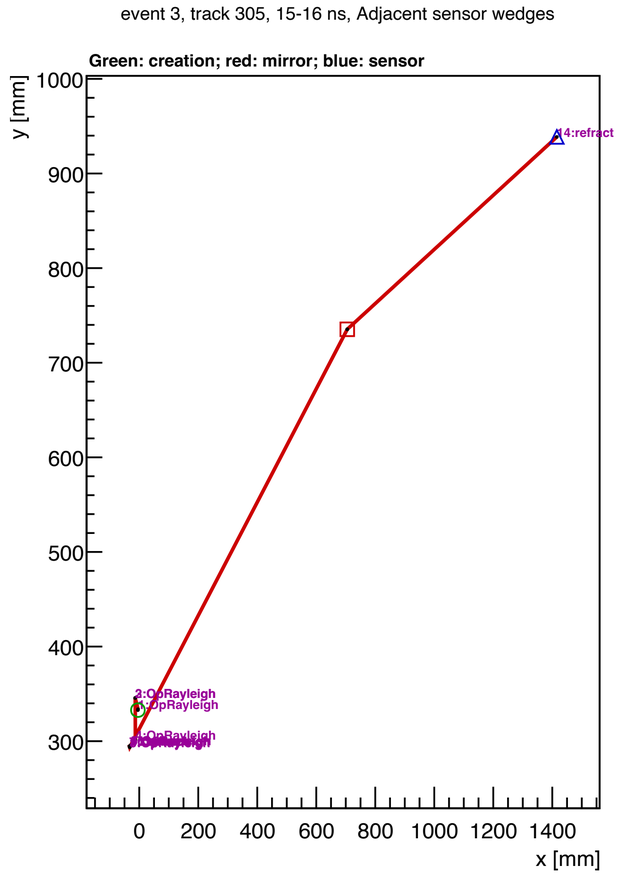
Conclusion

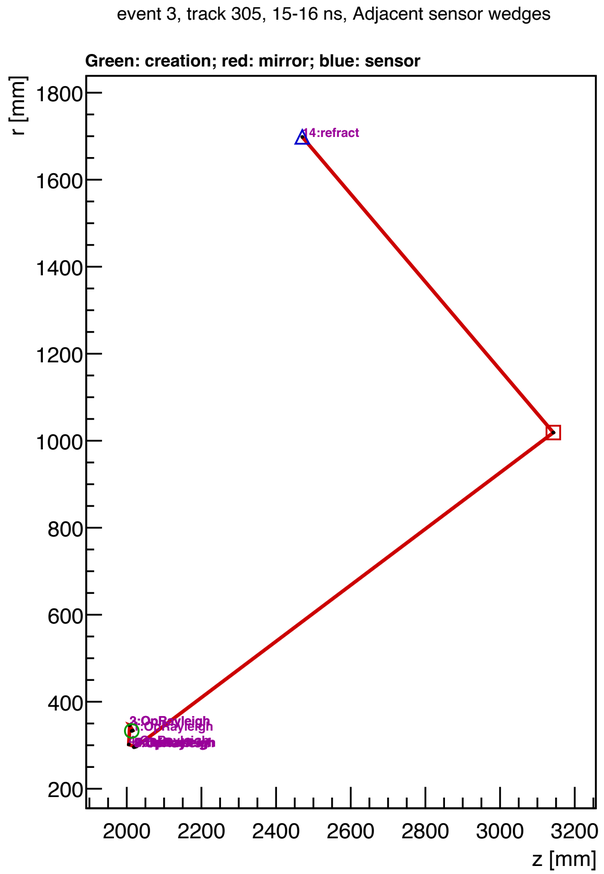
The additional delay and migration away from the nominal sensor wedge are correlated with prolonged optical transport, rather than a comparable shift in photon creation time.

Sensor-Sector Migration and Photon Trajectories





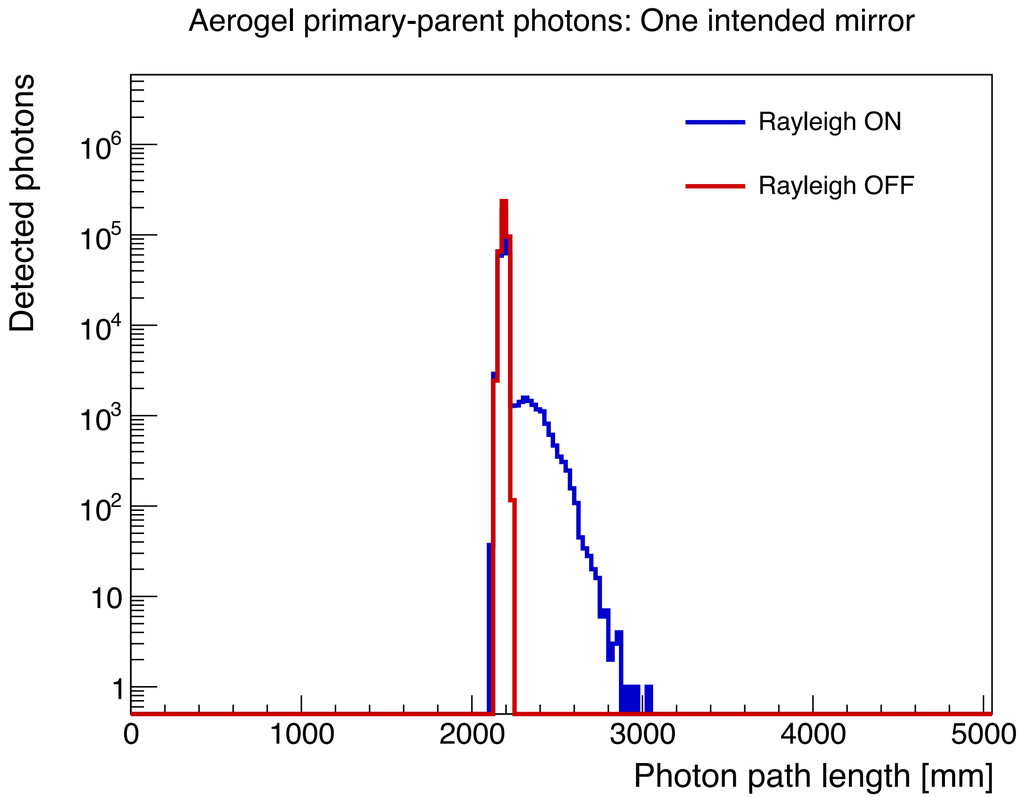


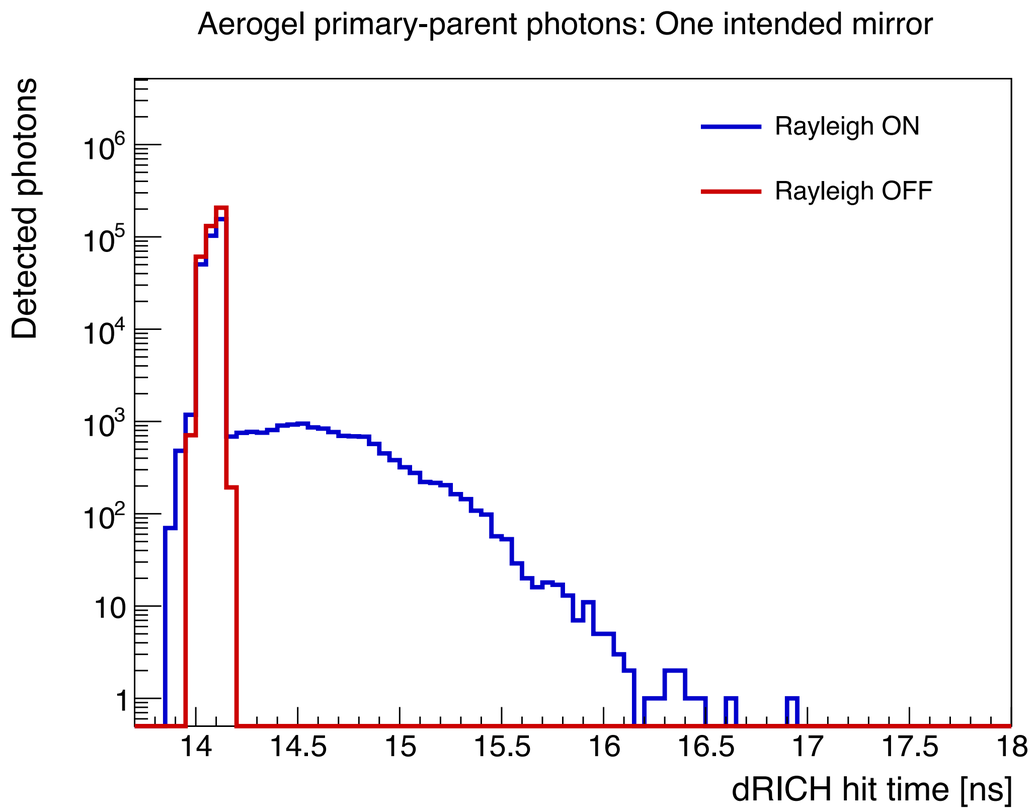


Observation

- Photon arrival in a different sensor wedge is not necessarily evidence of an additional mirror reflection.
- Rayleigh scattering can change the photon direction before it reaches the mirror.
- The altered trajectory may produce a longer transport interval and a later detector hit.

Controlled optics test: switch Rayleigh scattering OFF in Aerogel





Controlled change

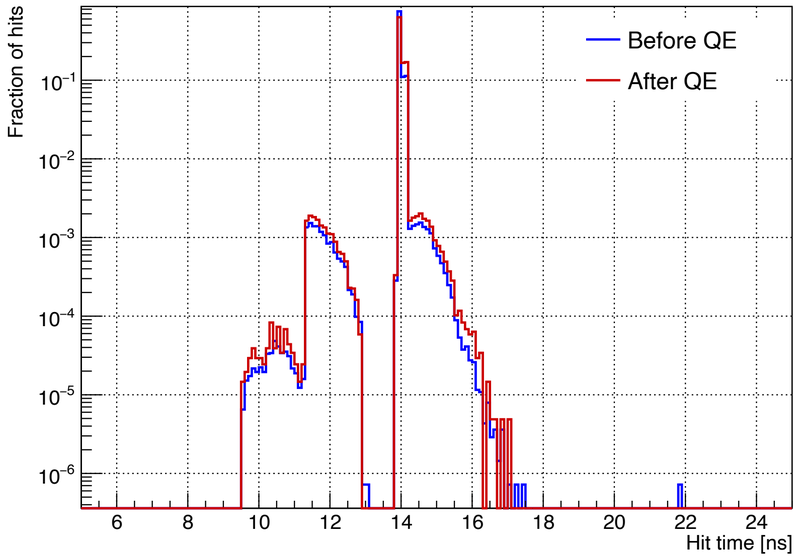
- same event configuration, geometry and optical setup
- Rayleigh scattering in aerogel: ON vs OFF (by commenting the Rayleigh property dRICH Aerogel in optical_materials.xml)

Observation

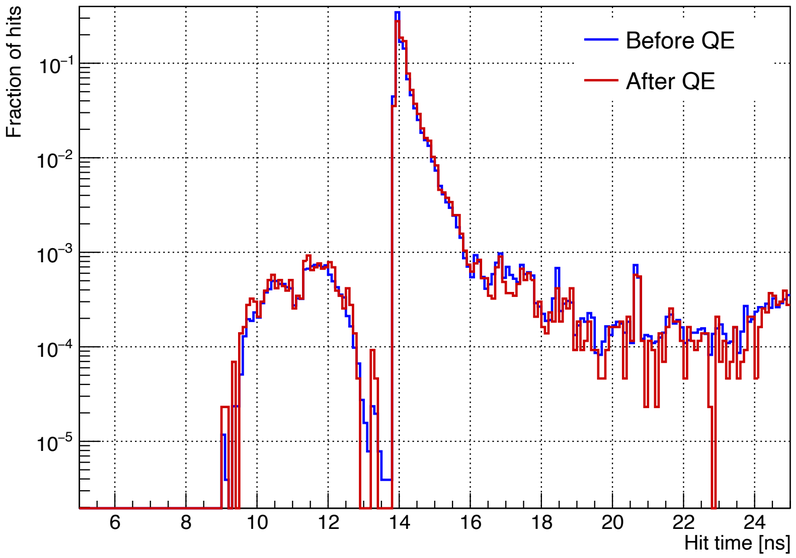
- With Rayleigh ON, a long-path population extends beyond the nominal path length.
- A corresponding late-time primary population is present.
- When Rayleigh scattering is disabled, the long-path and late-time populations are strongly suppressed.

Quantum Efficiency: Does Sensor Acceptance Change the Timing Structure?

Primary-parent hits: normalized Hit time distribution comparison



Secondary-parent hits: normalized Hit time distribution comparison



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

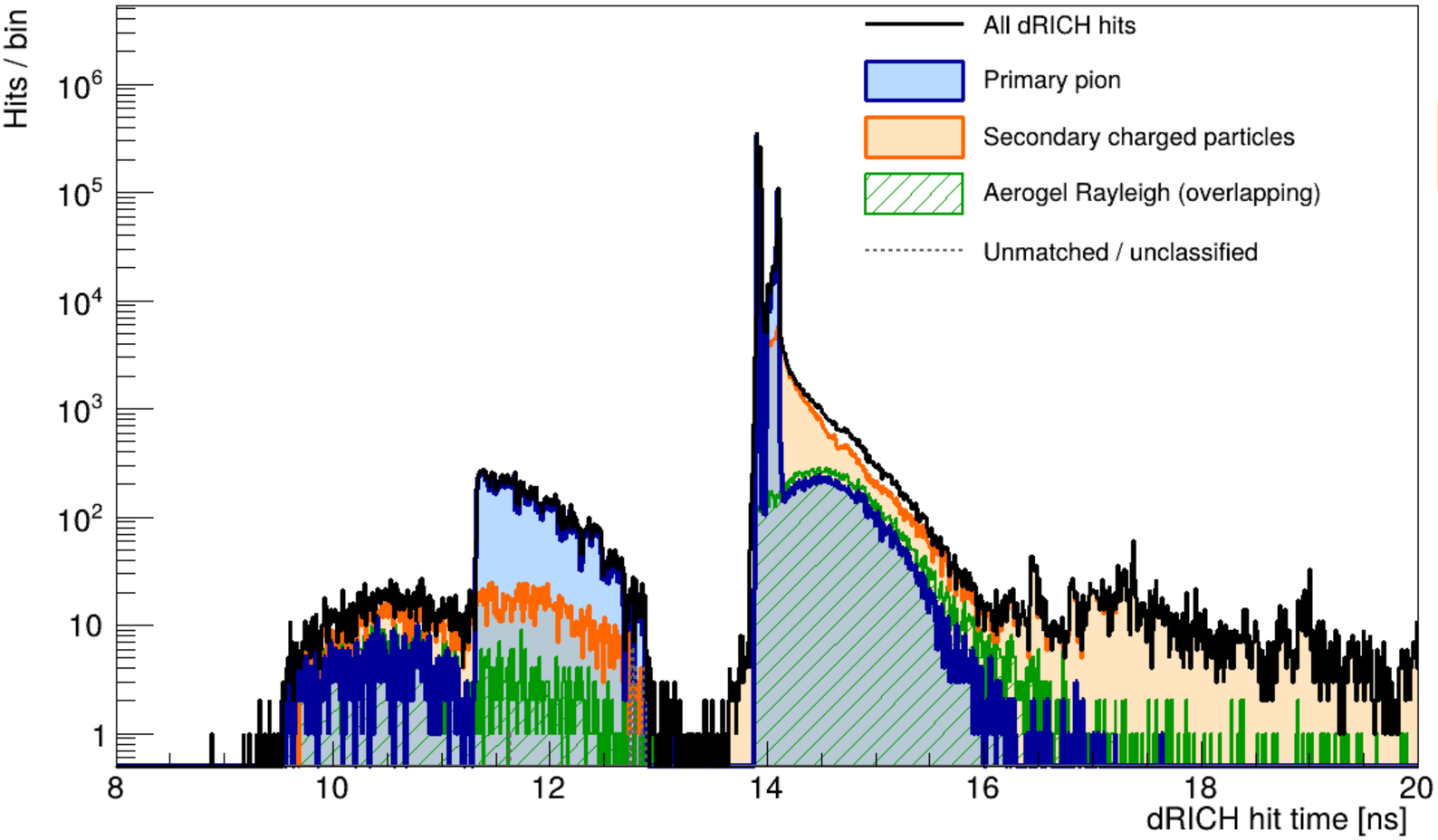
Observations

- QE reduces the number of accepted photons.
- The dominant peak position and the overall early/late timing structures remain.
- The same qualitative behavior is observed for primary-parent and secondary-parent photons.
- The extended timing population therefore cannot be attributed to QE alone.

Conclusion

QE mainly changes the accepted photon yield, while preserving the principal timing structures of this sample.

The Full Picture of single simulated particle



EARLY :

Shorter or non-nominal optical transport

Primarily direct/zero-reflection photons, along with contributions from other non-nominal optical interactions.

NOMINAL :

Expected Cherenkov photon transport

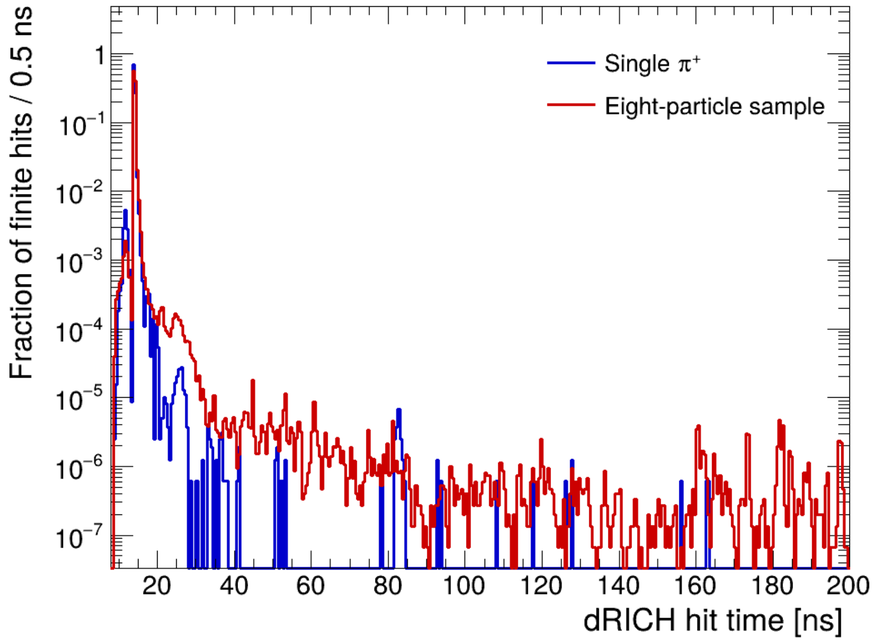
Dominated by primary-parent photons undergoing one intended dRICH mirror reflection, reaching the expected sensor region.

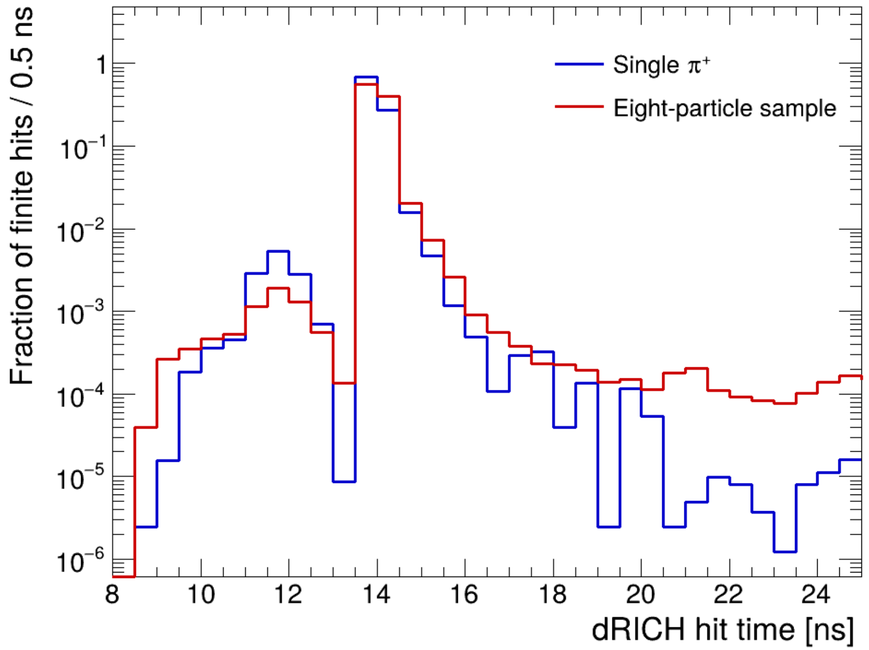
LATE :

Two physical contributions

Secondary-parent photons, increasingly dominant with arrival time, and a residual primary-parent population with prolonged optical transport, strongly linked to aerogel Rayleigh scattering in the controlled test.

From a Single Pion to a Mixed-Particle Environment





The single-pion study established that:

- The principal timing peak is dominated by photons following the intended dRICH optical path.
- Secondary charged particles contribute significantly to delayed photon populations.
- Rayleigh scattering in aerogel can prolong primary-photon optical transport.

Simulation Sample for Mixed Particles:

- 5 -50 GeV/c $pi^{\pm}$, $K, \bar{K}, P, \bar{P}, e^{\pm}$
- η = 1.8-3, ϕ = 60° - 120°
- 5000 events

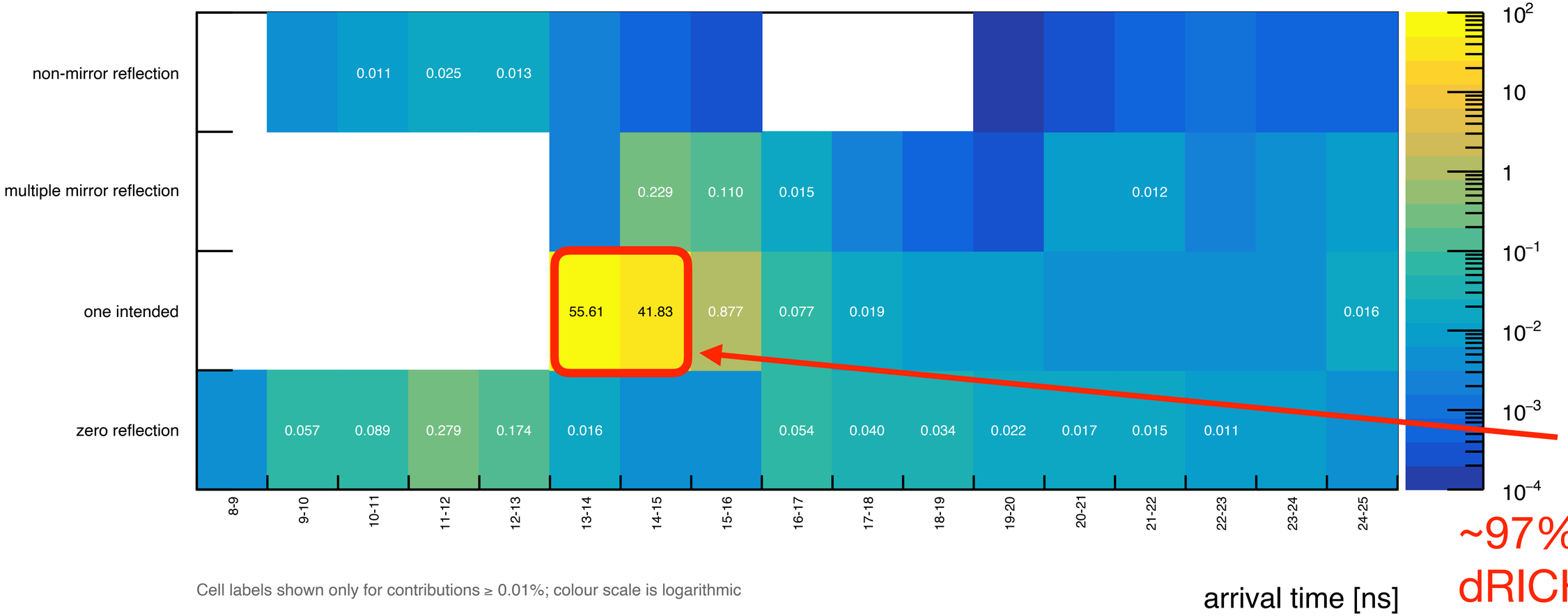
Observations:

- Both samples exhibit a prominent photon-arrival population near 14 ns.
- The eight-particle sample retains the general timing structure observed for the single pion.
- Differences become visible in the early-arrival region and in the extended late-time distribution.

Optical-Boundary History: Eight-Particle Events

* The heat-map entries are percentages of all accepted photons, rather than percentages within each time bin

dRICH path phenomena (% of all accepted dRICH photons)



Cell labels shown only for contributions ≥ 0.01%; colour scale is logarithmic

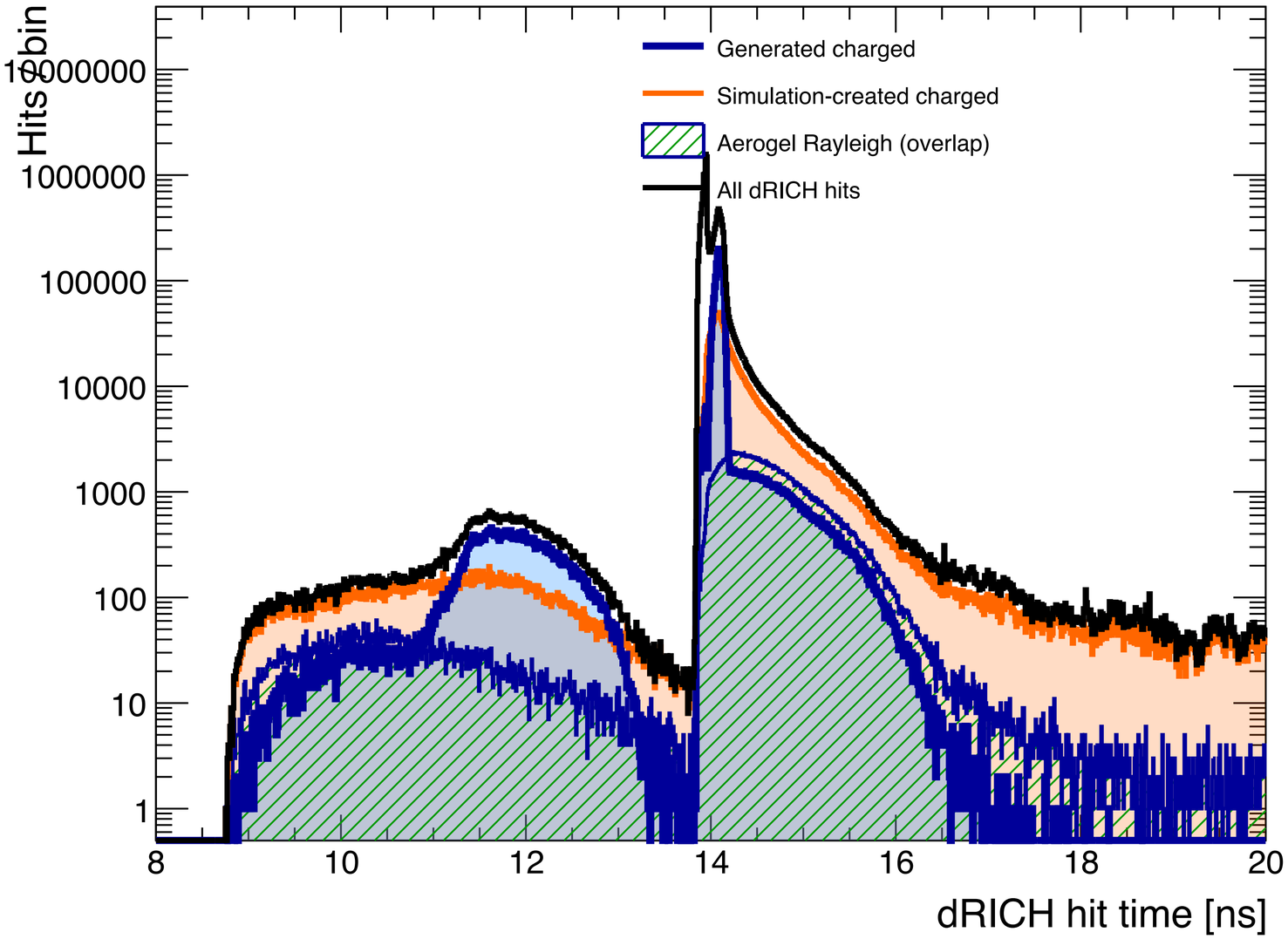
arrival time [ns]

~97% of Total dRICH hits

Observation :

- The principal timing region remains dominated by exactly one intended mirror reflection.
- Zero-reflection and other non-nominal trajectories contribute to earlier arrival times.
- Delayed photons can still belong to the one-intended-mirror category.
- Multiple-reflection contributions remain relatively small in the principal arrival-time region.

The Full Picture of 8 particle simulated particles



What Does the Eight-Particle Study Establish?

The Timing Mechanisms Remain Identifiable in a Mixed-Particle Environment

☑ **Persistence of the principal timing population**

The main photon-arrival structure survives the transition from a fixed single-pion configuration to mixed particle species and kinematics.

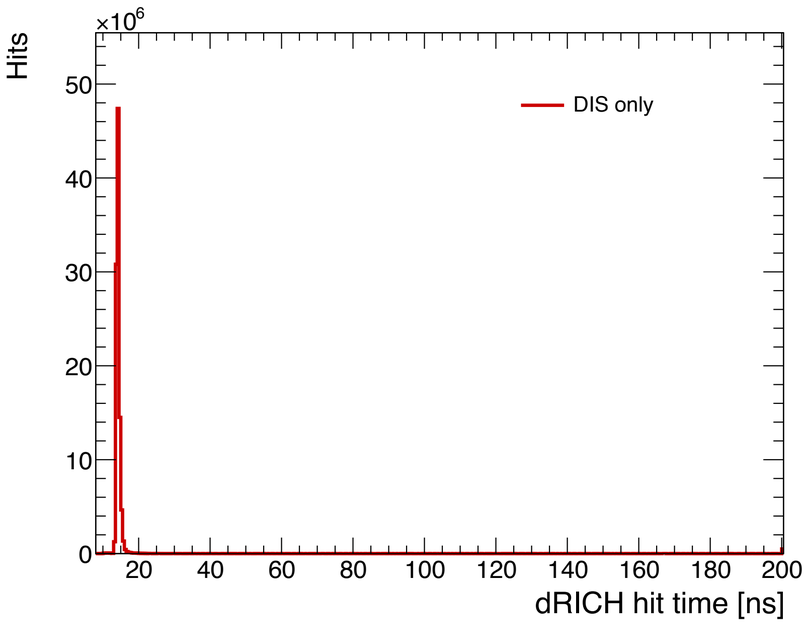
☑ **Consistent optical-transport classification**

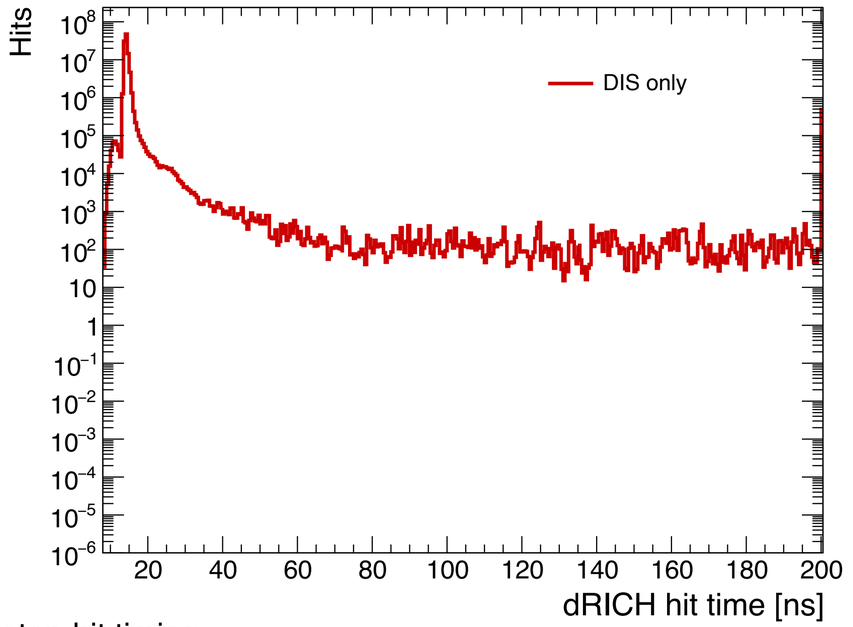
The one-intended-mirror photon population remains dominant around the main timing peak.

☑ **Charged-source and optical effects remain distinct**

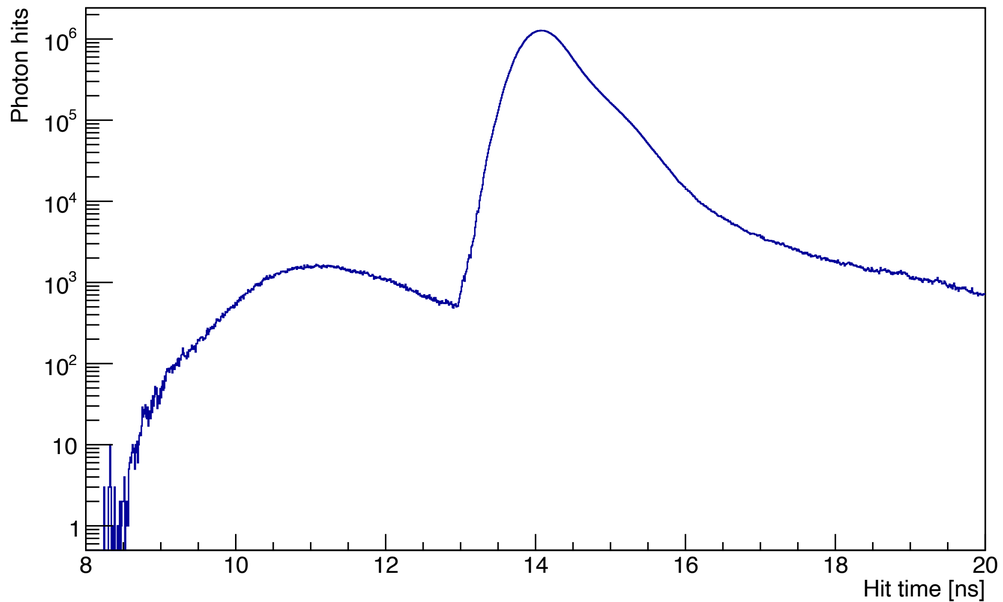
Secondary charged-particle production and Rayleigh scattering both contribute to the extended timing response.

From Controlled Particle Samples to Realistic DIS Events





DIS dRICH photon-hit timing



DIS:

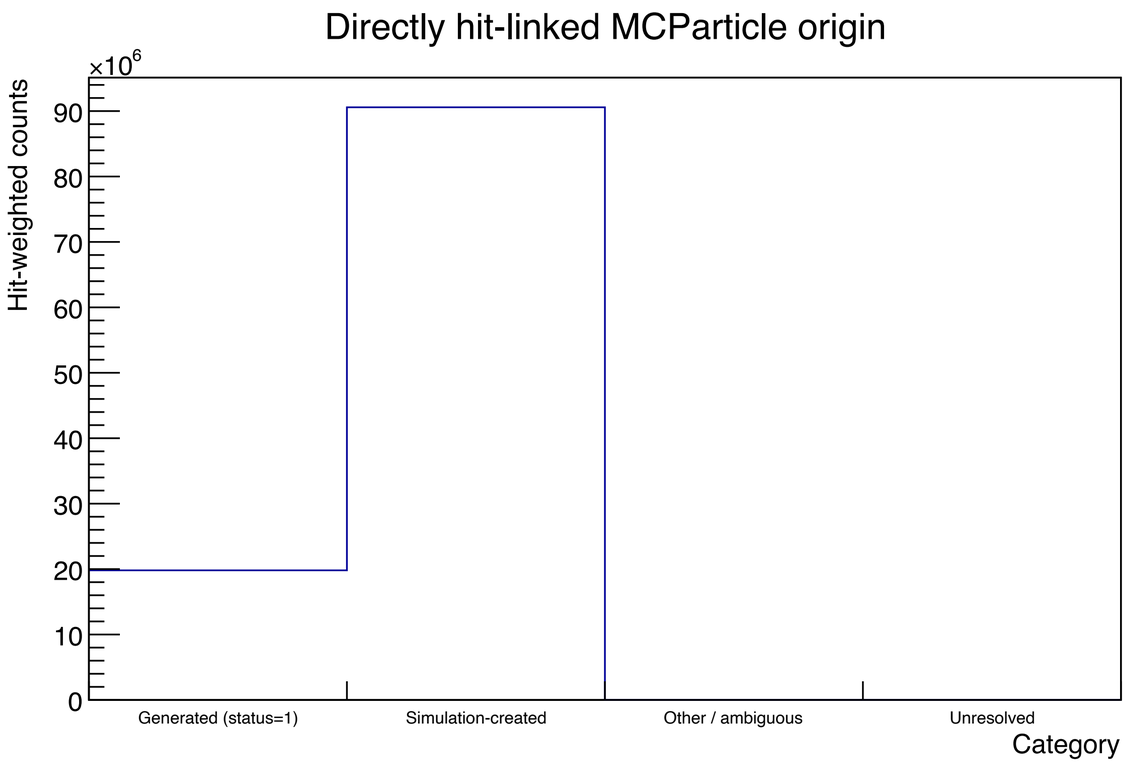
Process - Pythia8 neutral-current DIS minQ² = 1 GeV²
Beam config - 10 × 100 GeV
Geometry - epic_craterlake, version 26.02.0

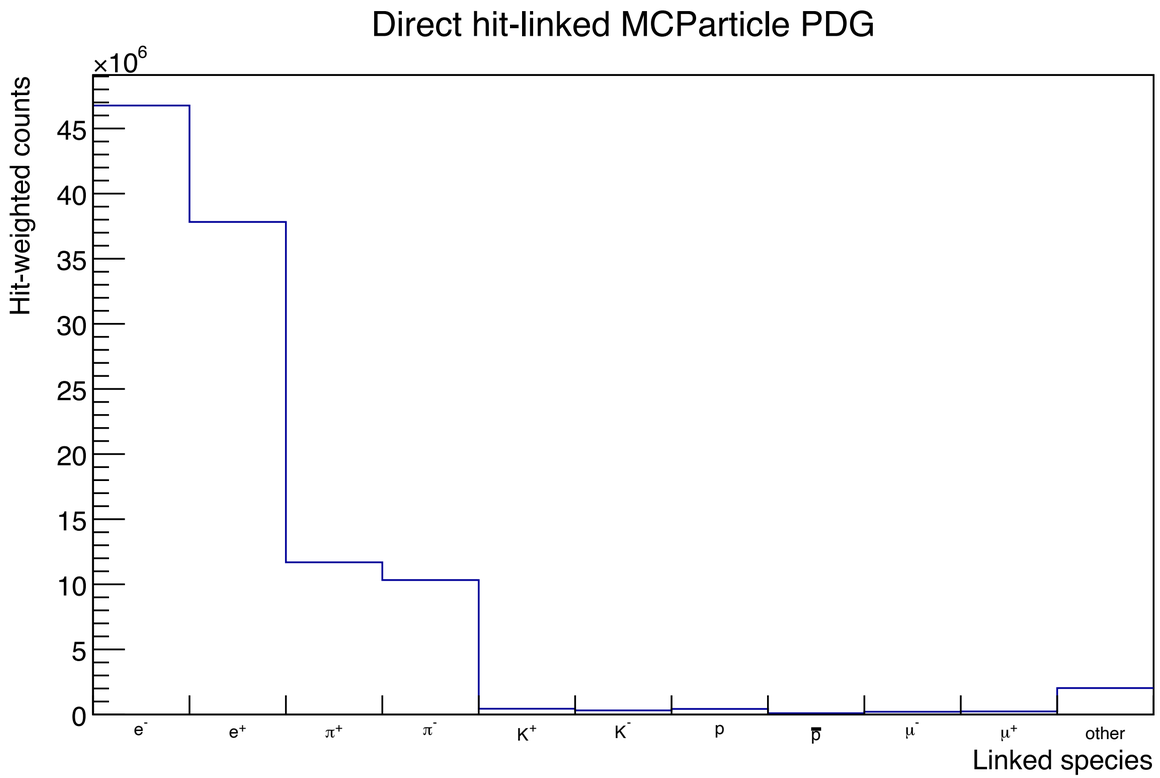
`DIS - epic:/FULL/26.02.0/epic_craterlake/DIS/NC/10x100/minQ2=1`

Observations

- The simulated DIS timing distribution exhibits a dominant photon-arrival peak near 14 ns.
- Earlier and delayed photon populations are also visible.
- The logarithmic representation reveals a broad, low-population timing structure beyond the main peak.
- The detailed 8–20 ns view resolves the timing components surrounding the principal peak.

Generated and Simulation-Created Contributions to dRICH Hits

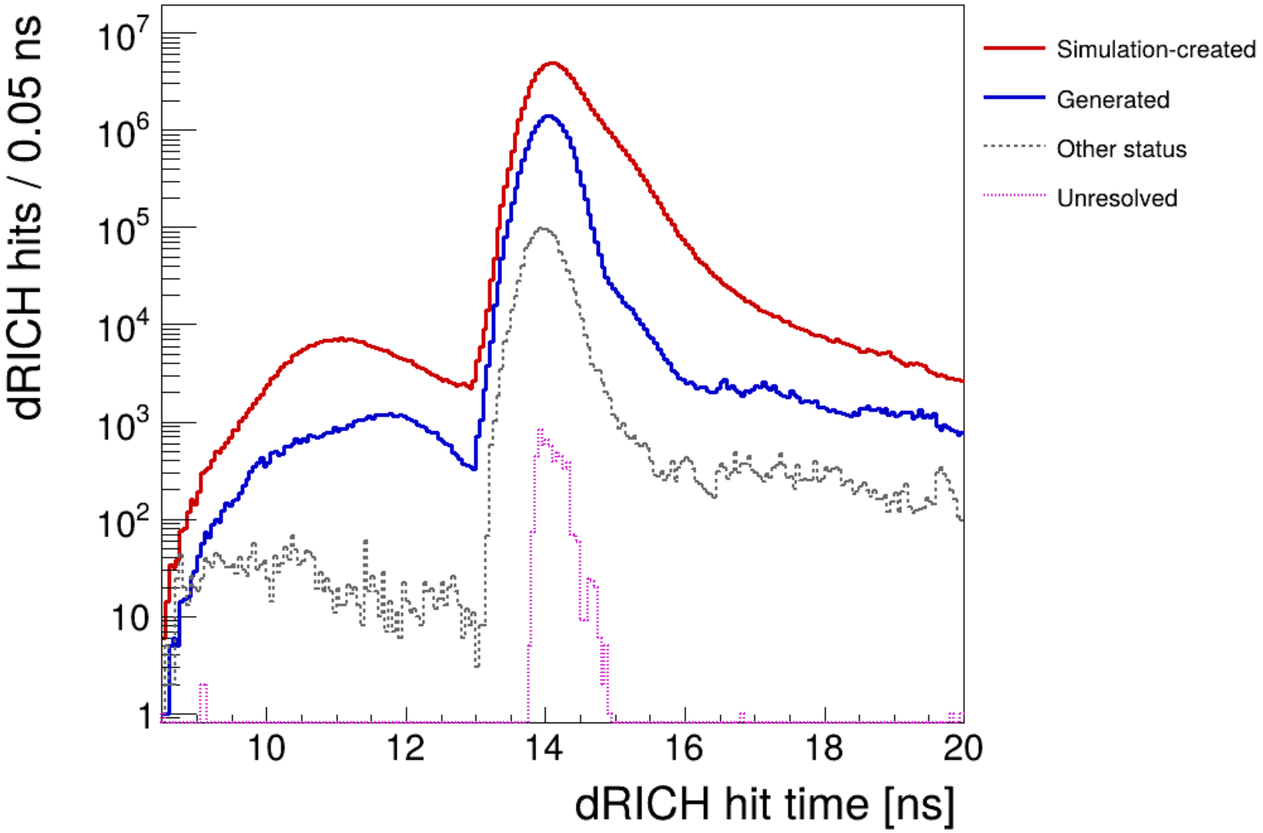


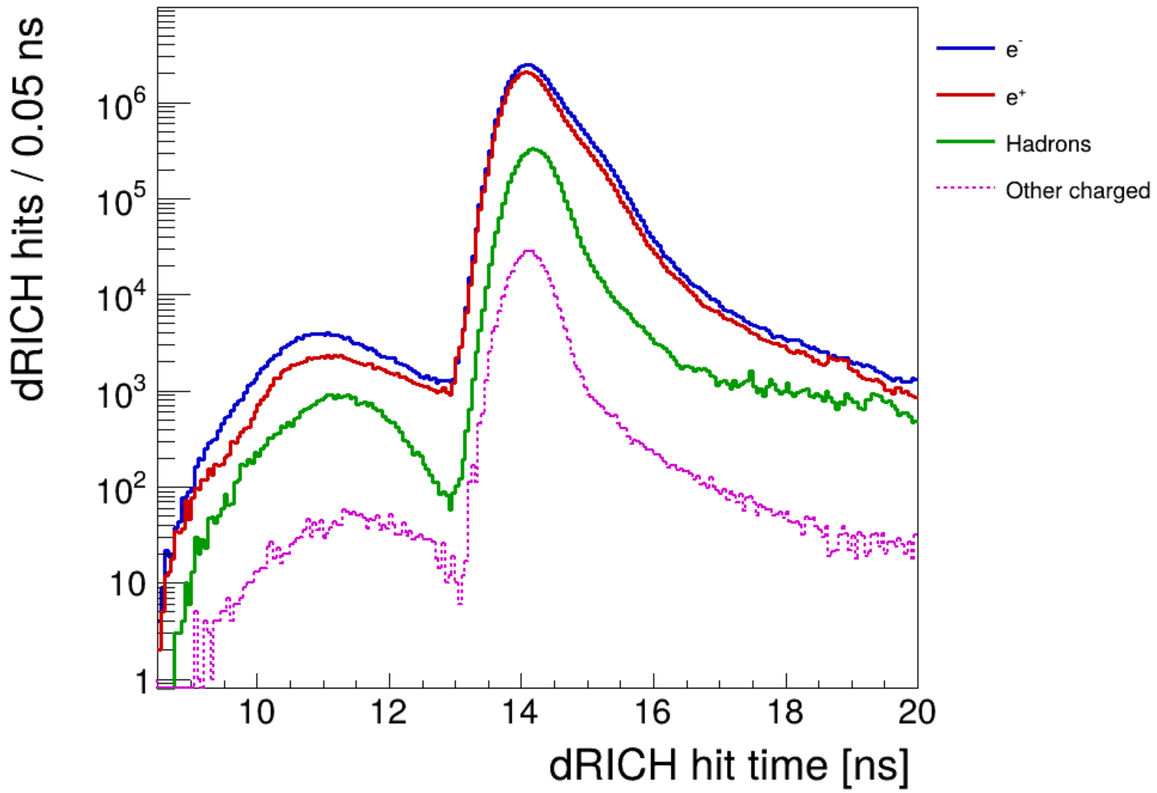


Observations

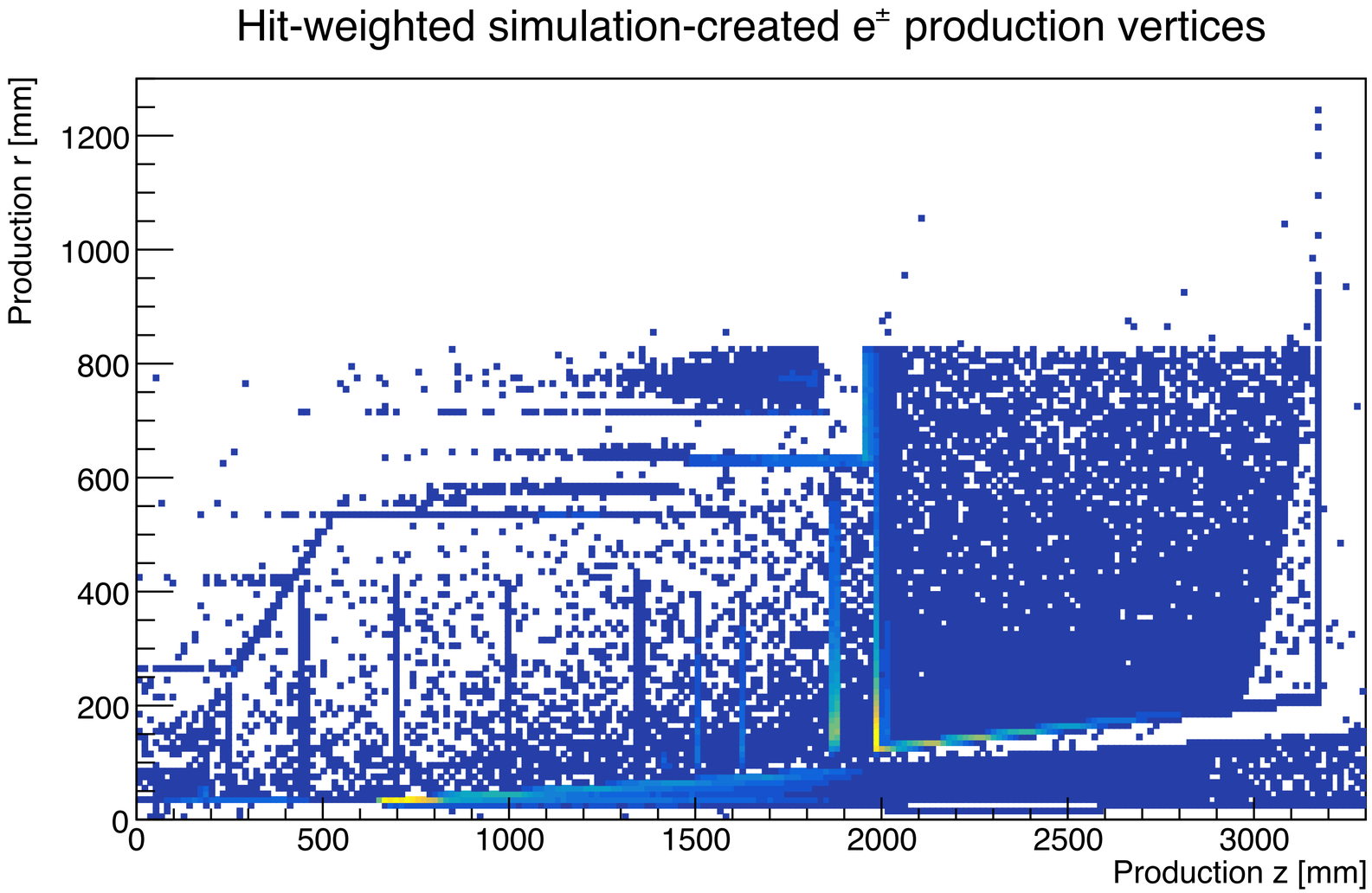
- The hit-associated particle population contains substantial contributions from simulation-created particles.
- Electrons and positrons are important among the charged-particle species associated with dRICH hits.

Timing Distribution by Particle Origin





Where Are Secondary Electrons and Positrons Produced?



Observations

- The production vertices of simulation-created electrons and positrons are spatially nonuniform.
- The hit-weighted distribution emphasizes production regions whose secondaries contribute strongly to recorded dRICH hits.

Conclusion: From Photon-Transport Physics to dRICH Timing Capability

1. Nominal photon transport: The principal arrival-time population is associated with the intended dRICH optical path.

2. Origin of additional timing components: Secondary charged-particle production and non-nominal optical propagation both contribute to extended photon-arrival distributions.

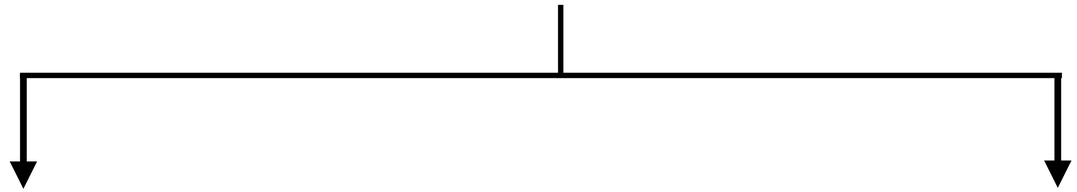
3. Controlled optical validation: Aerogel Rayleigh scattering is a major source of delayed primary-parent photons in the controlled single-pion test.

4. Progression to complex events: The principal timing structure remains recognizable in mixed-particle and DIS simulations, while secondary-particle contributions become important for interpretation.

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.

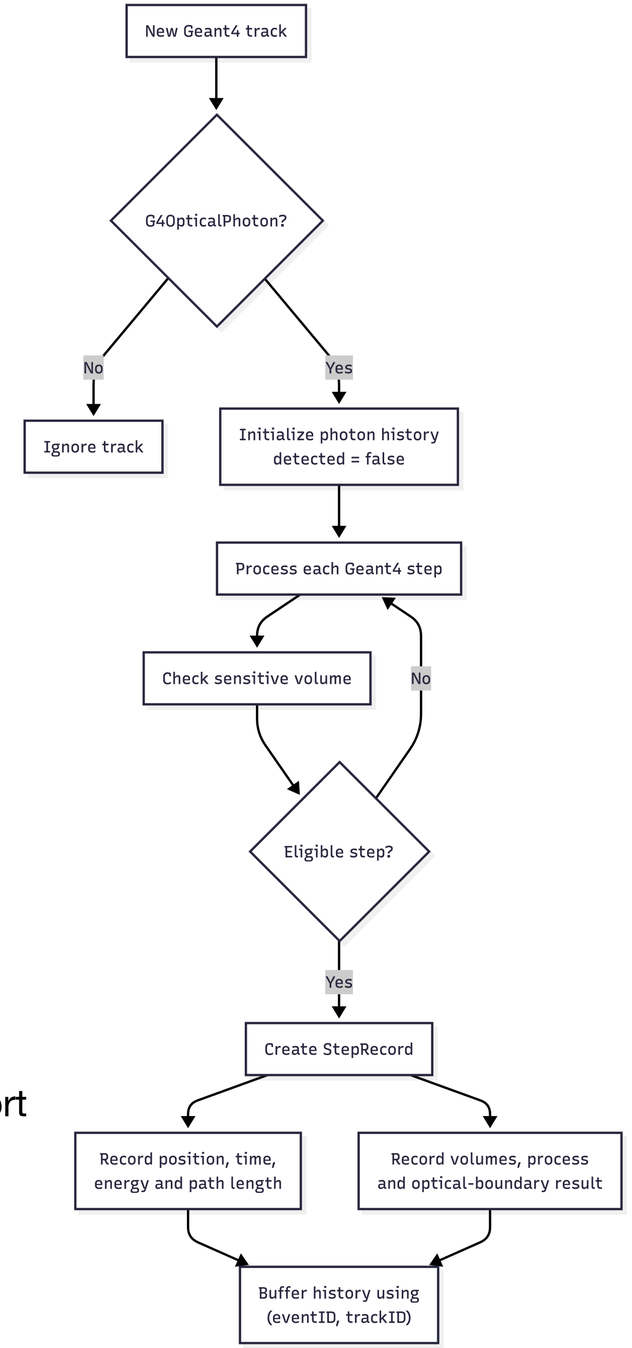
Optical History Check : information recorded by the custom C++ action

Information written for every eligible step:

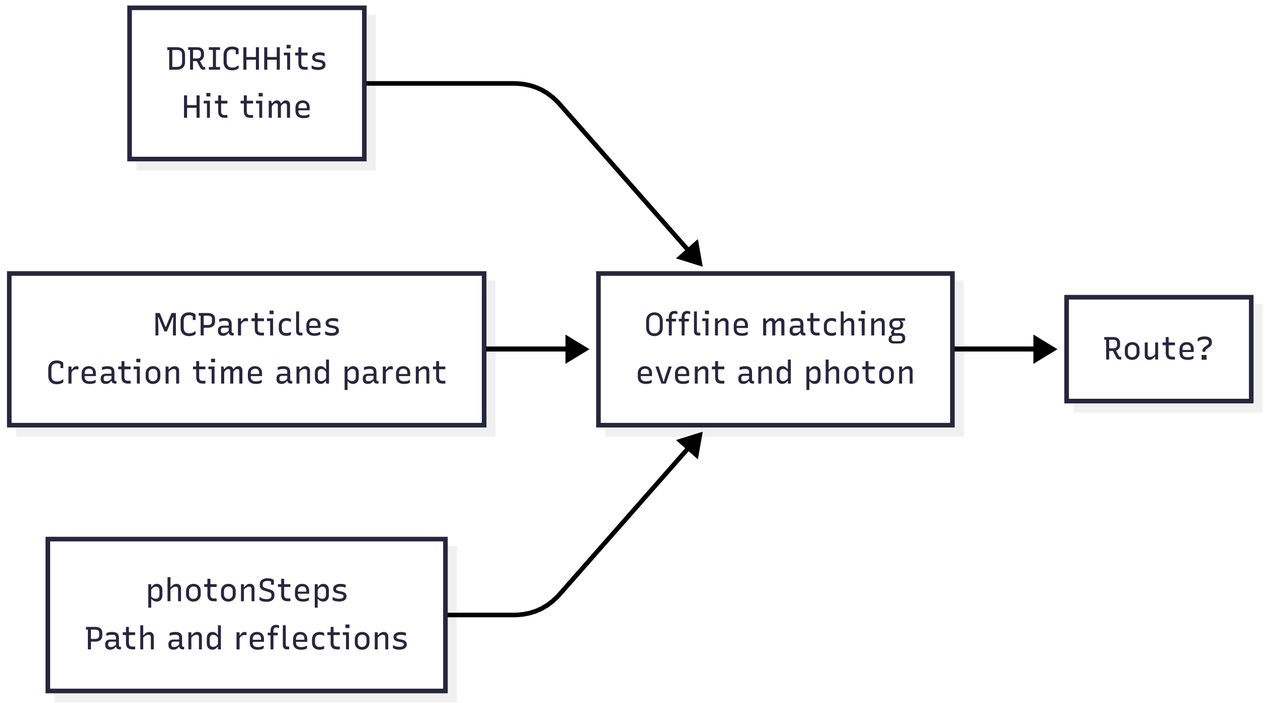
- eventID, trackID, parentTrackID, stepNumber;
- pre-step and post-step position;
- pre-step and post-step global time;
- step length and cumulative track length;
- photon kinetic energy;
- pre-step and post-step volume names;
- process defining the step;
- GEANT4 optical-boundary status;
- sensitive-volume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

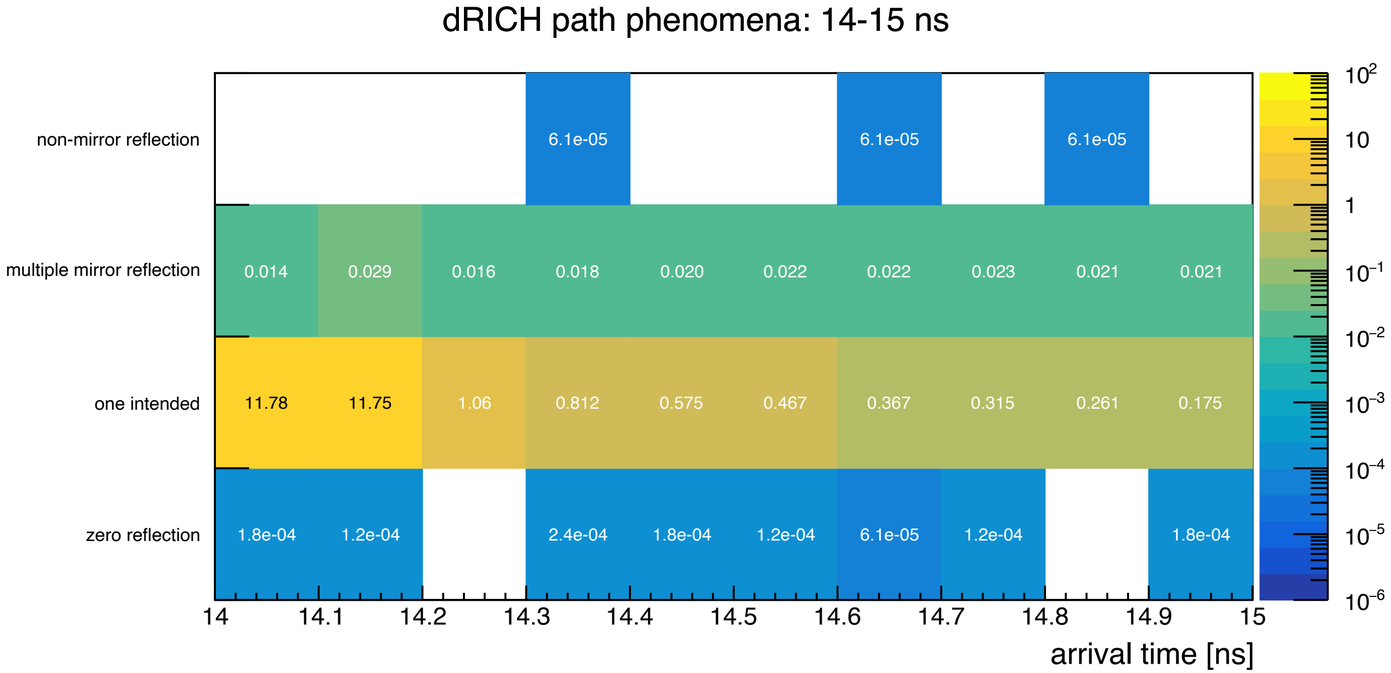


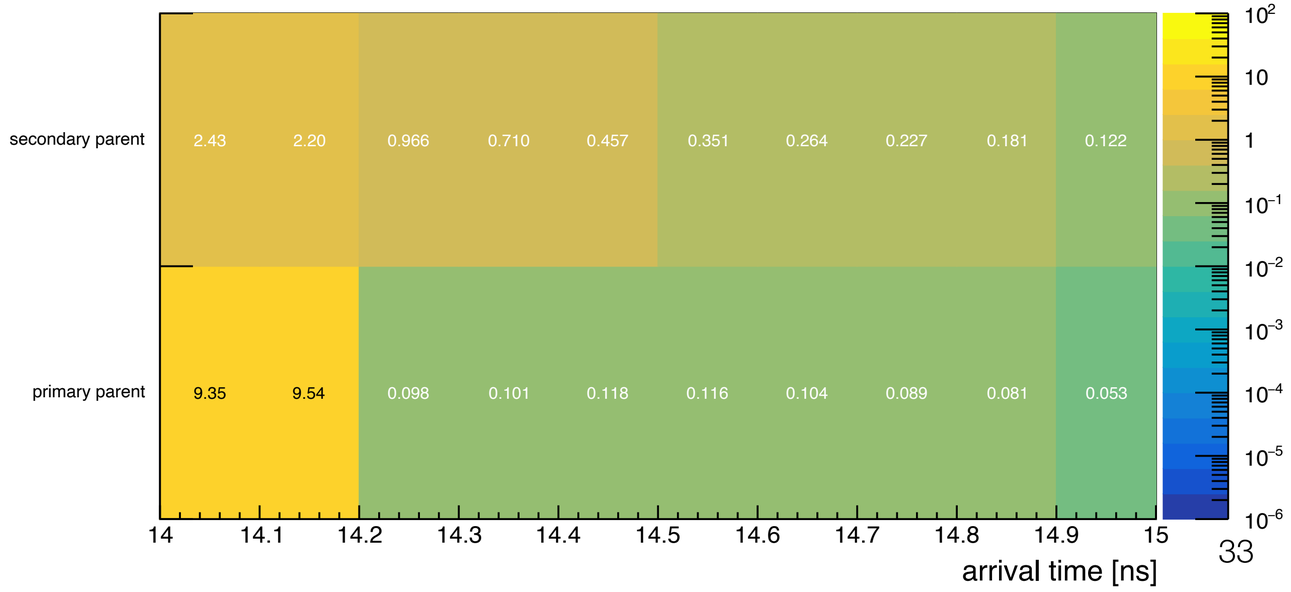
Optical History Check : From recorded information to timing diagnosis



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

How the Photon-Origin Composition Changes Across the Prompt Peak





In the 14–15 ns window, one-intended-mirror photons remain the leading optical-path population, while the charged-particle origin changes rapidly with arrival time.