T3B Results & Plans

CLICdp Meeting

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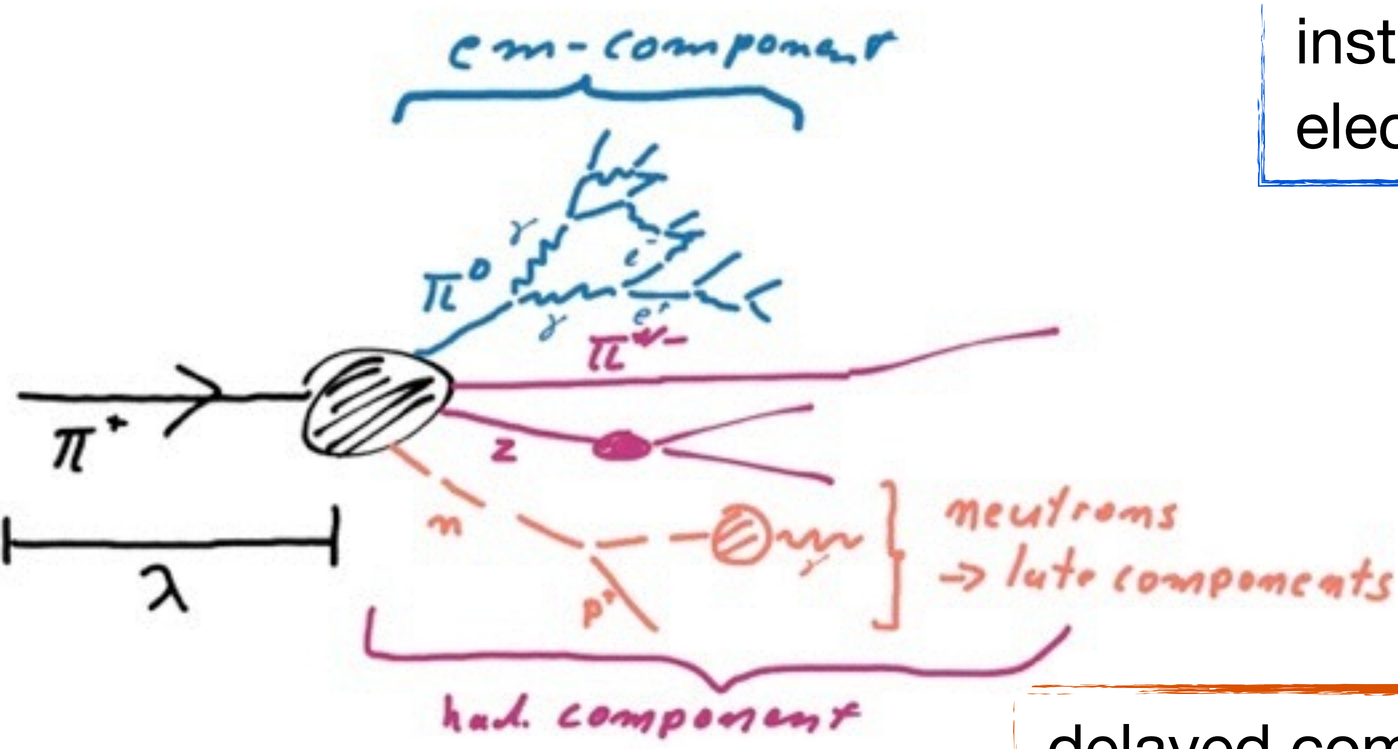
Outline

- Time structure in hadronic showers
- CALICE T3B and FastRPC - Experiments for timing measurements
- The time structure of hadronic showers
  - In Tungsten and Steel
  - With plastic scintillator and RPC active elements
- Confronting simulations with data
- Summary

Exploring Hadronic Showers in Time

- Hadronic showers have a complex structure - also in time!



instantaneous, detected via energy loss of electrons and positrons in active medium

instantaneous component: charged hadrons detected via energy loss of charged hadrons in active medium

delayed component:

- neutrons from evaporation and spallation
- photons, neutrons, protons from nuclear de-excitation following neutron capture
- momentum transfer to protons in hydrogenous active medium from slow neutrons

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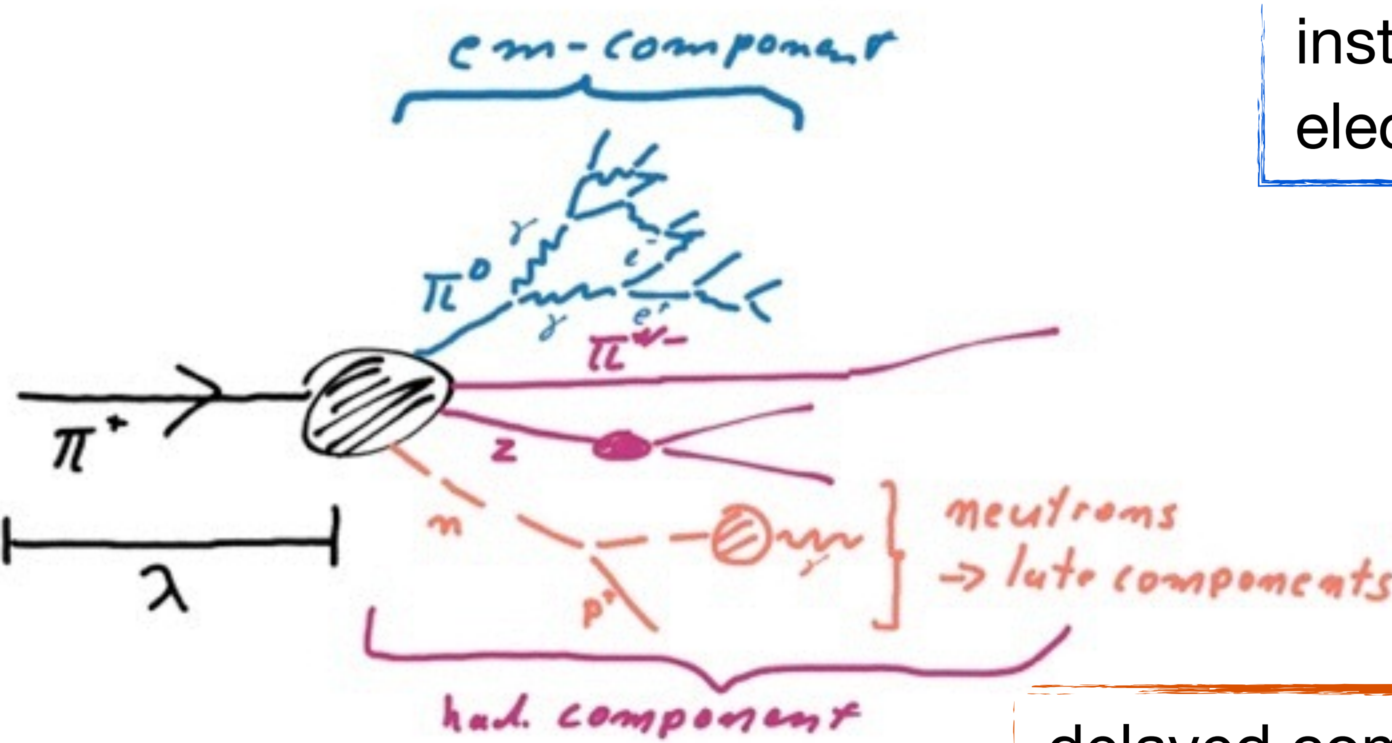

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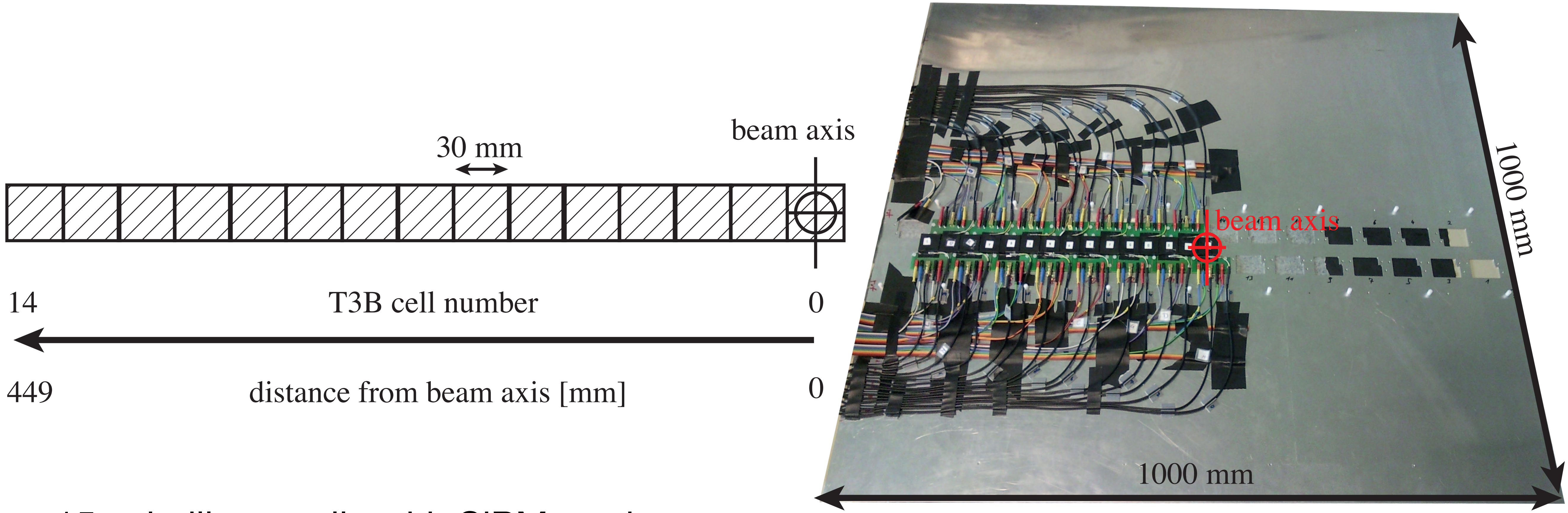
➩ Importance of delayed component strongly depends on target nucleus
➩ Sensitivity to time structure depends on the choice of active medium

The T3B Detector



- 15 scintillator cells with SiPM readout
- DAQ based on 4 - channel USB Oscilloscopes (PicoScope), 800 ps sampling, 2.4 μs acquisition per event
- Installed downstream of CALICE calorimeters: W-AHCAL (5 λ), SDHCAL (6 λ)
- With W-AHCAL: Synchronisation of data streams possible (and demonstrated): Allows for event-by-event identification of shower start

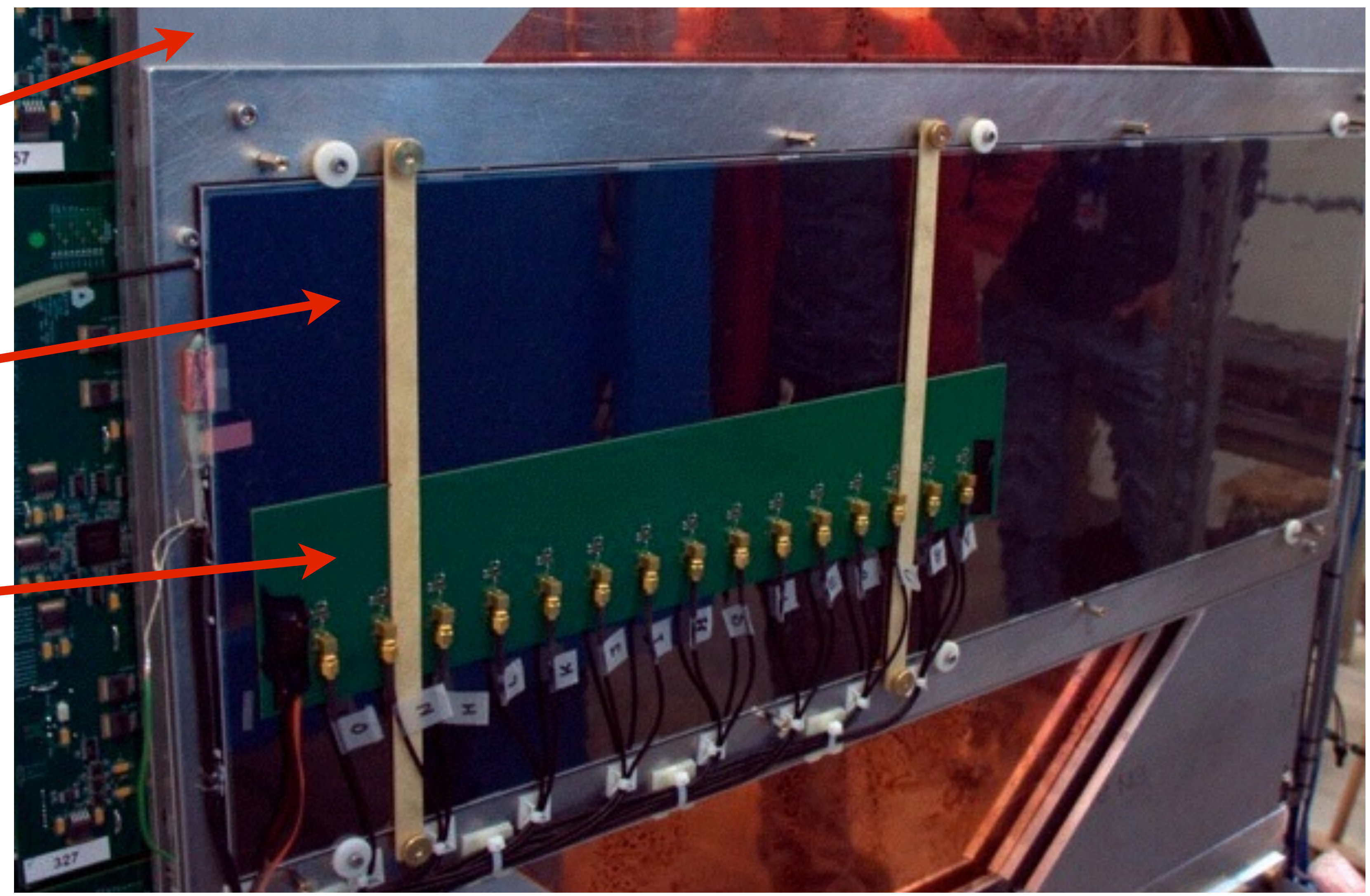
Alternative Readout: Glass RPCs - Tungsten Only

- Provide a direct comparison of scintillator and gaseous readout: FastRPC - A 1 to 1 copy of T3B, but with a glass RPC instead of scintillators
  - identical granularity: 3 x 3 cm^2, one strip behind the CALICE WDHCAL
  - identical data acquisition: 2.4 μs acquisition window with 800 ps readout

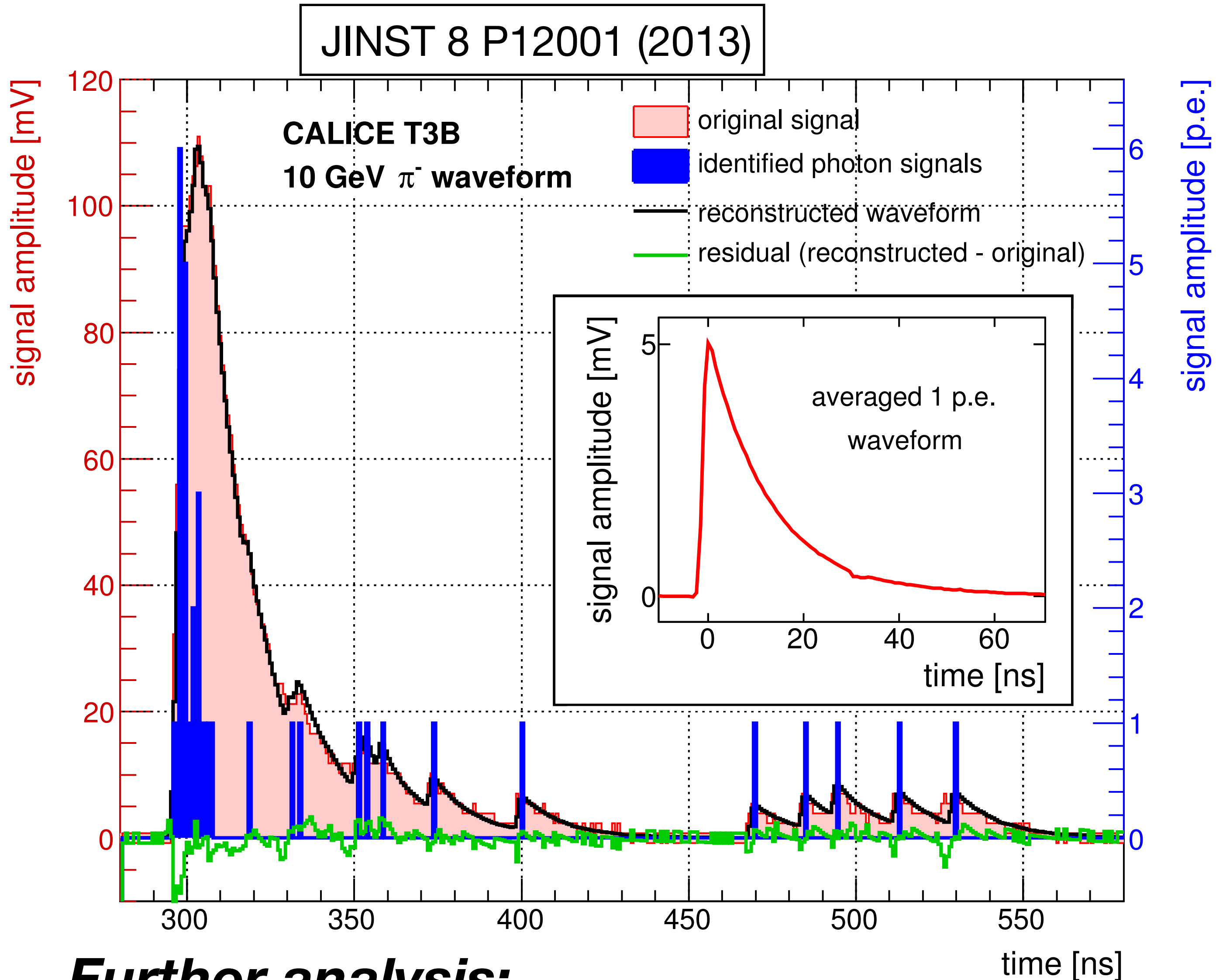
CALICE WDHCAL, ~ 5λ tungsten & RPC active layers

RPC (produced at ANL)

FastRPC readout board, connected to oscilloscopes



Data Analysis



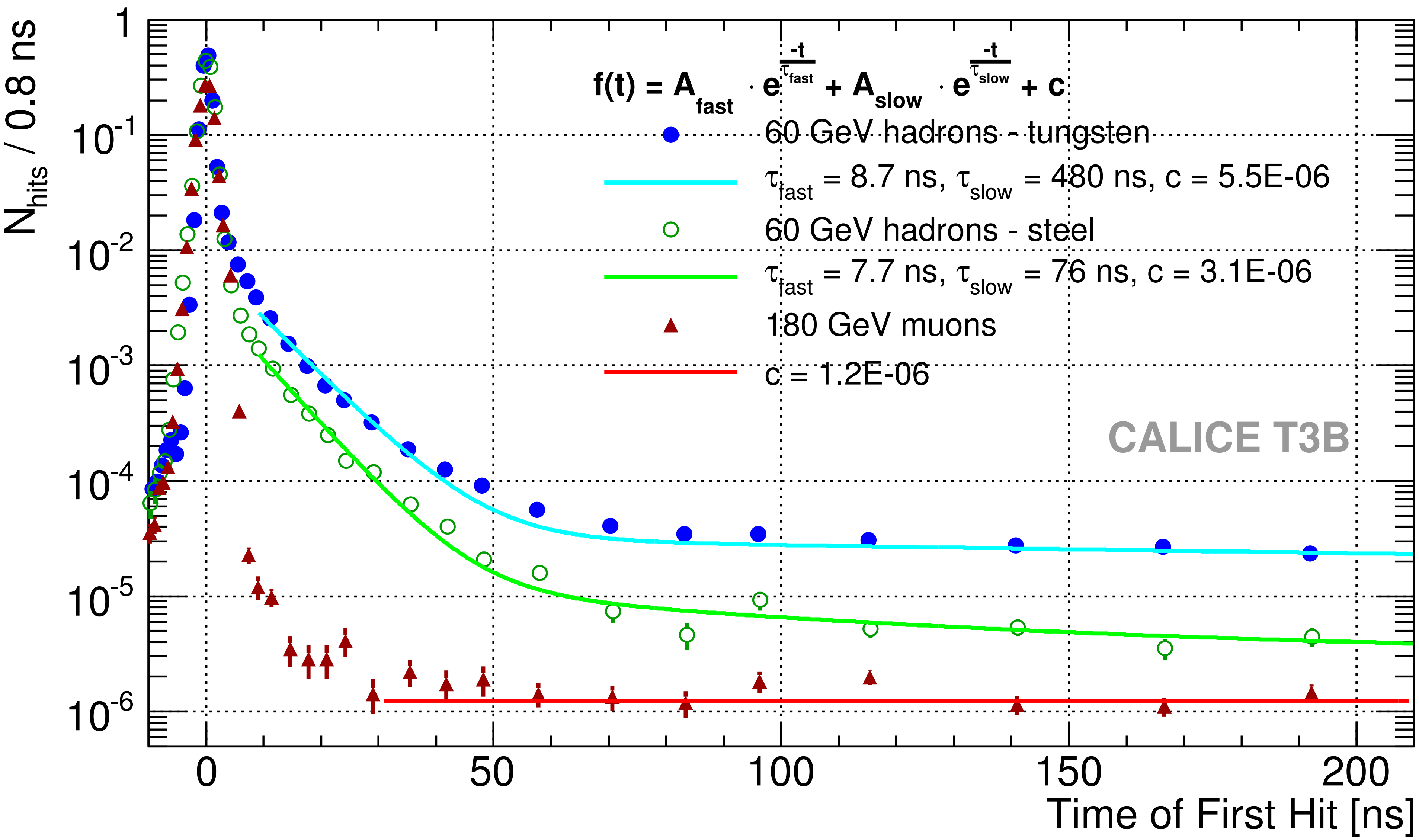
Cell-wise reconstruction

- With scintillator / SiPM readout:
  - Reconstruction of time of each photon
  - Reconstruct hits by clustering in time - require at least ~ 0.3 MIP equivalents within 9.6 ns
- With RPC readout:
  - Analogous to SiPM readout, but based on waveform integral

Further analysis:

- For robustness: Use only the first hit in each cell in an event - avoids uncertainties from hit separation, afterpulsing, … High granularity ensures multiple real hits are rare (at the %-level)
- Main observable: "Time of first hit" - Timing given by the second reconstructed photon (SiPM) / start of signal waveform (RPC)

The Time Structure: Tungsten vs Steel



- Hadronic showers characterized by a main prompt signal and a long tail

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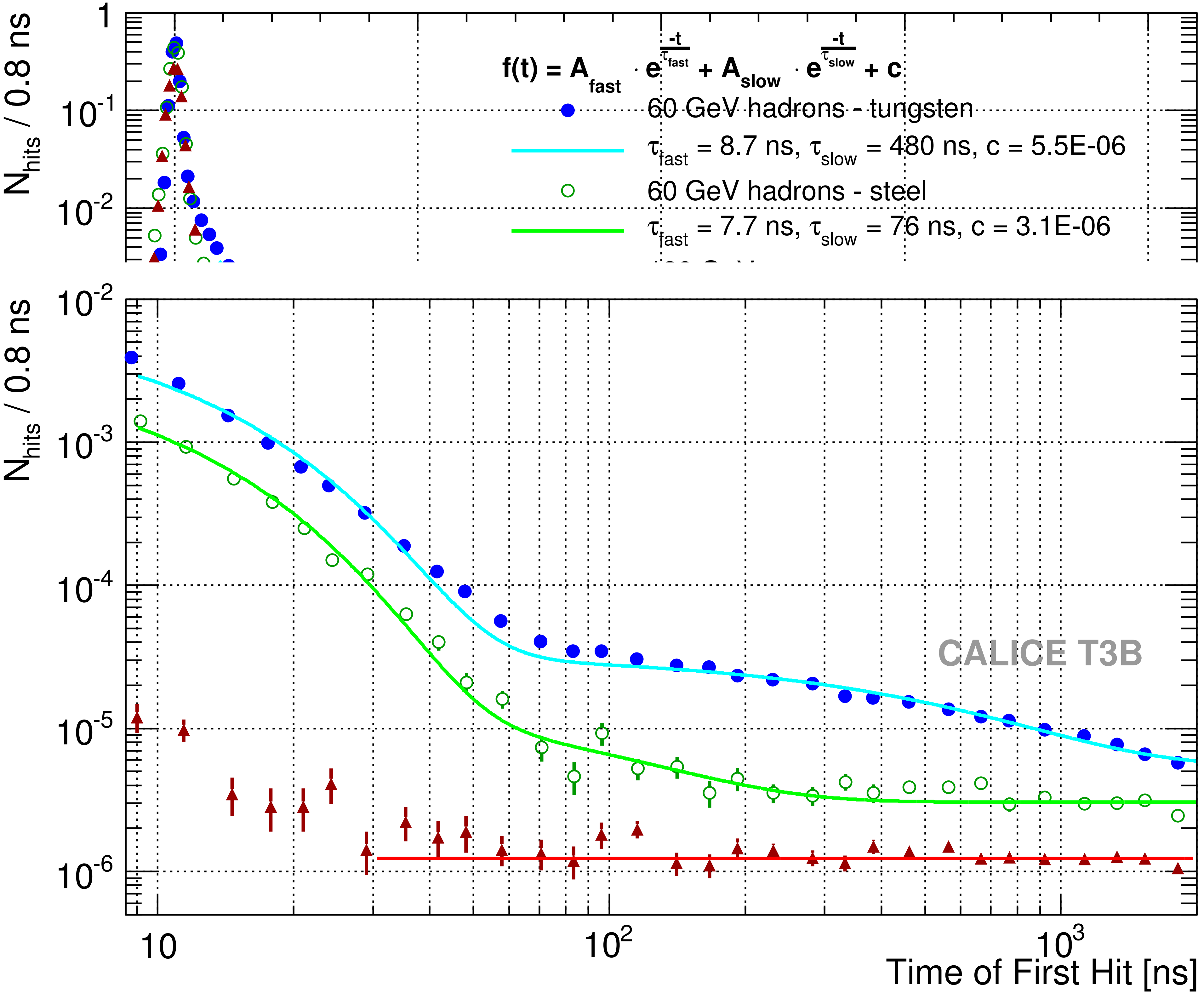
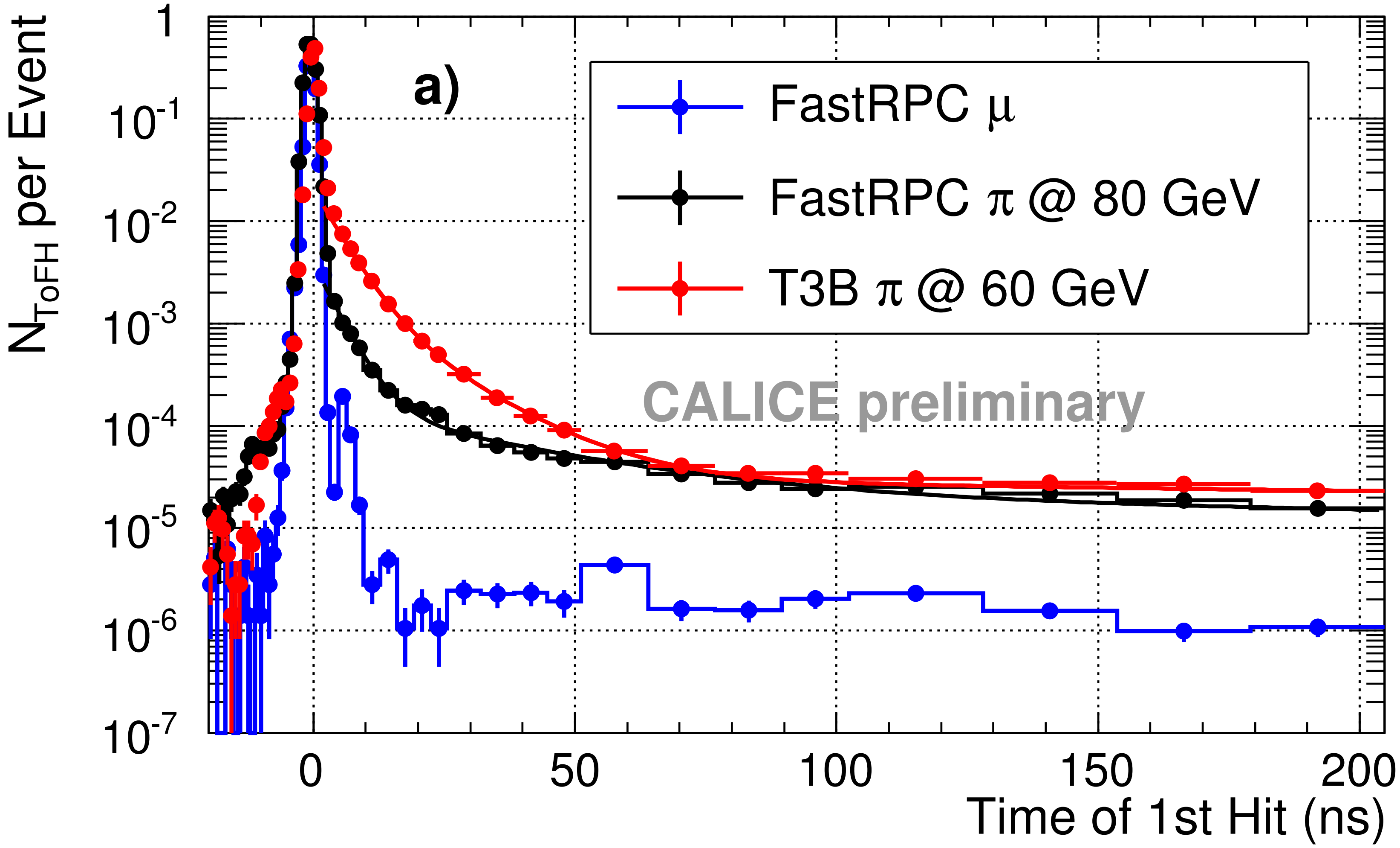


- Hadronic showers characterized by a main prompt signal and a long tail
- Late components in tungsten substantially more pronounced than in steel
  - “fast” late component (~ 8 ns - ~ 50 ns) enhanced by a factor of ~ 2.3 in W
  - “slow” late component (> ~ 50 ns) enhanced by a factor of ~ 13 in W)

The Impact of the Active Medium: Scintillator vs Gas



- Comparable behavior for prompt component
- Striking difference in intermediate range: ~ 8 ns to 50 ns

Absorber material: Tungsten

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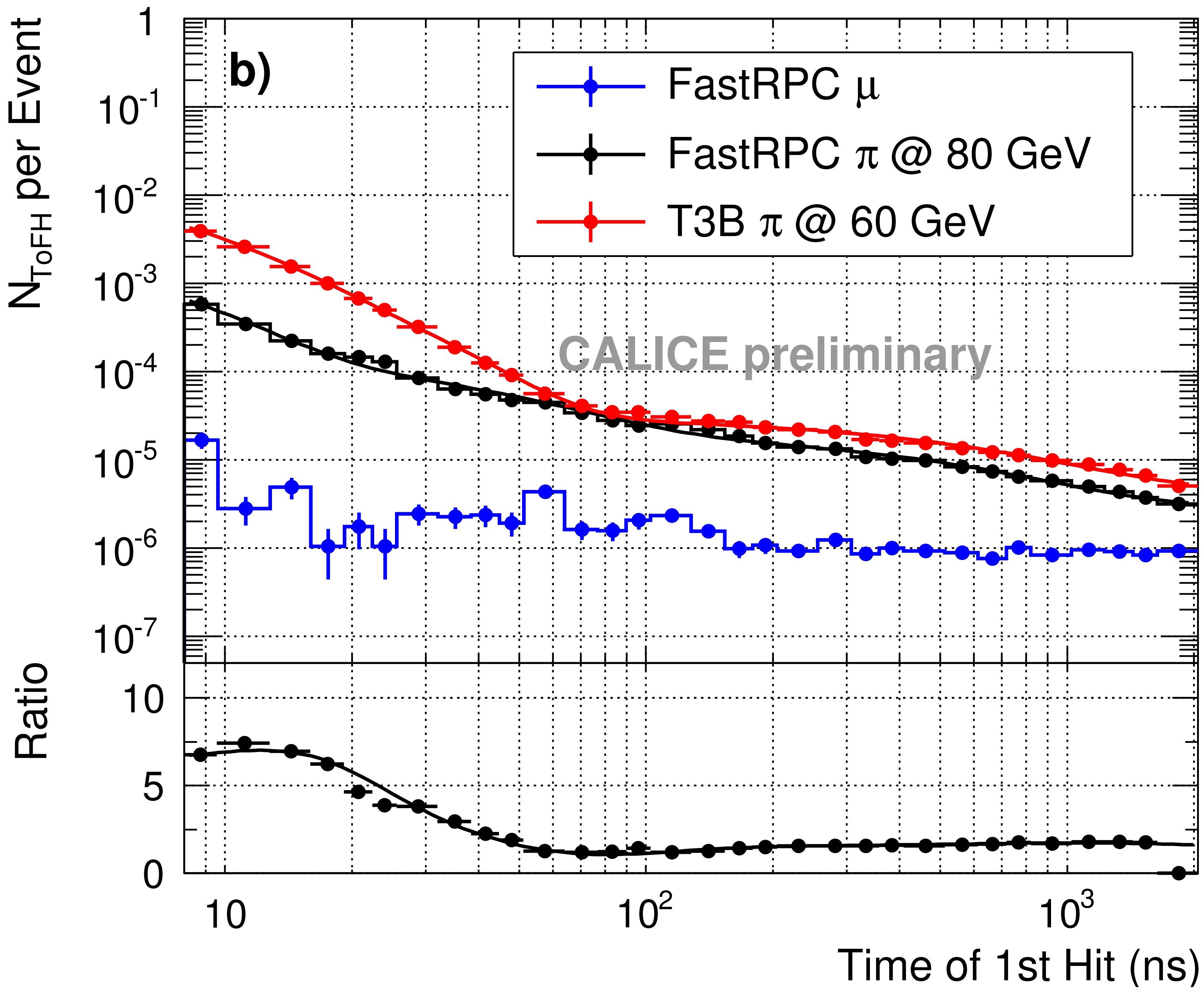


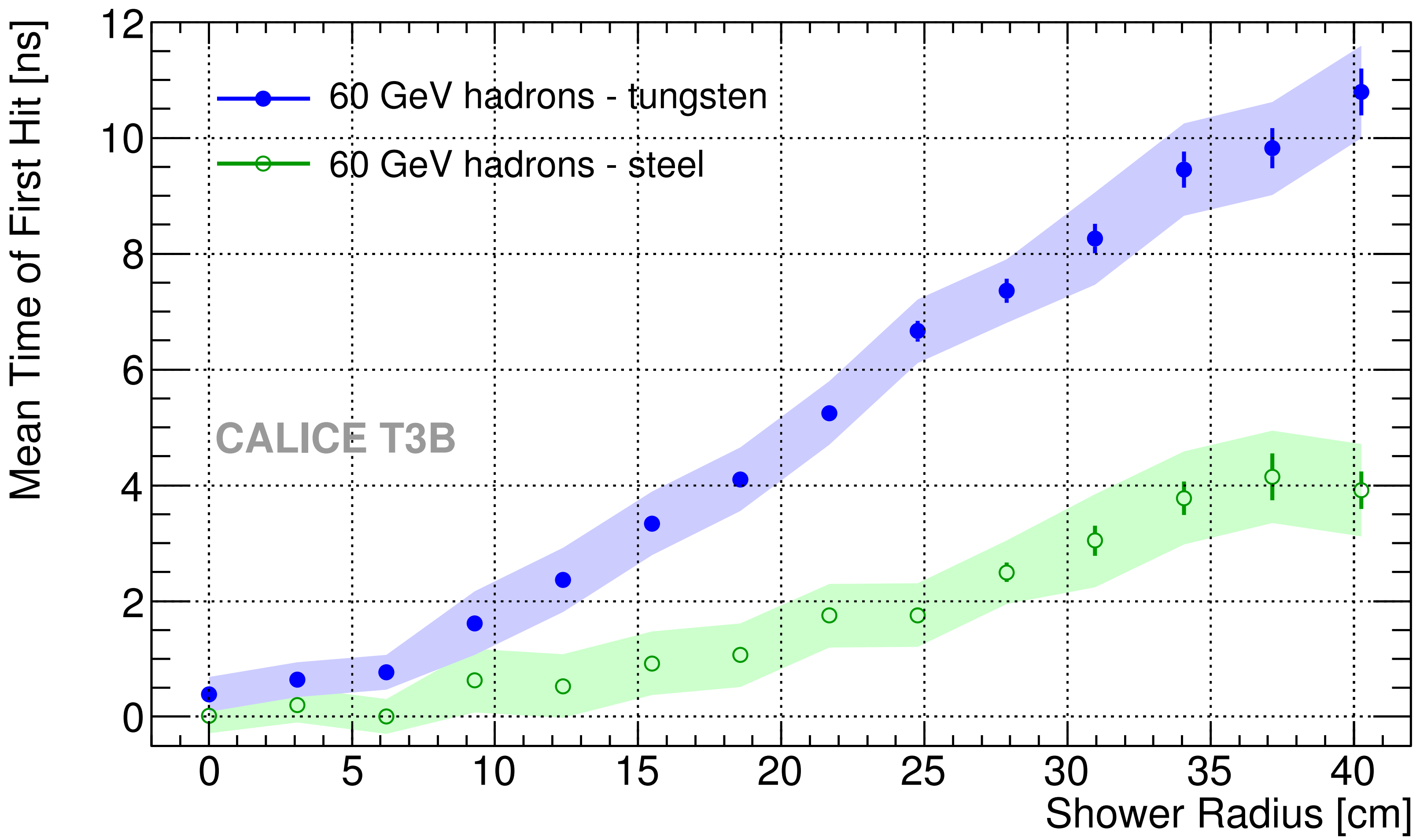
Absorber material: Tungsten

Comparable behavior for prompt component

Striking difference in intermediate range: ~ 8 ns to 50 ns

- Further quantified: Factor 5 - 8 suppression of intermediate component in gaseous detectors: MeV - scale neutrons: High sensitivity of scintillators through elastic scattering on H

Impact of Time Structure on Shower Shape



- In the outer shower regions late hits are more important: Neutrons spread far, prompt component concentrated along shower axis

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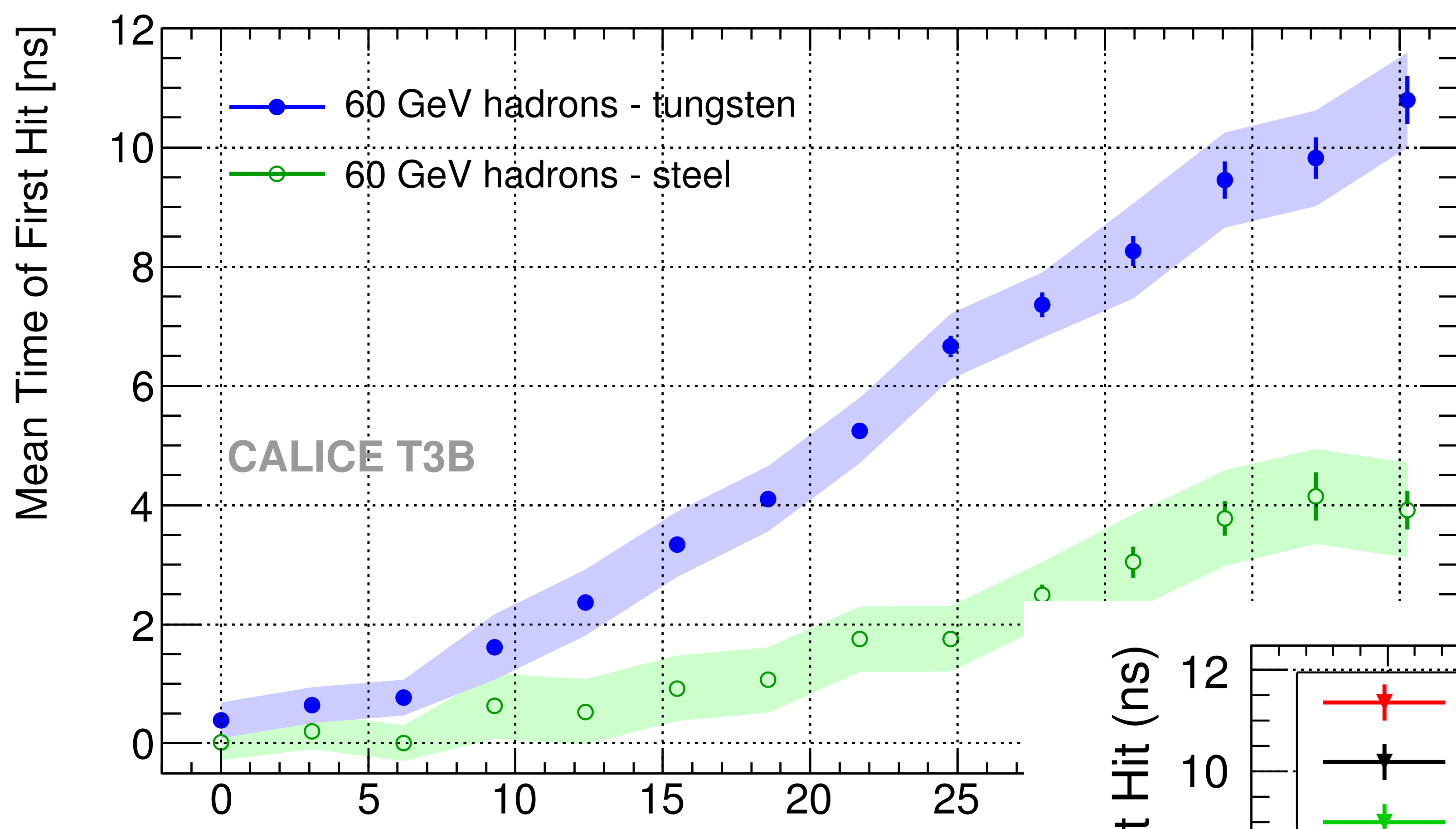

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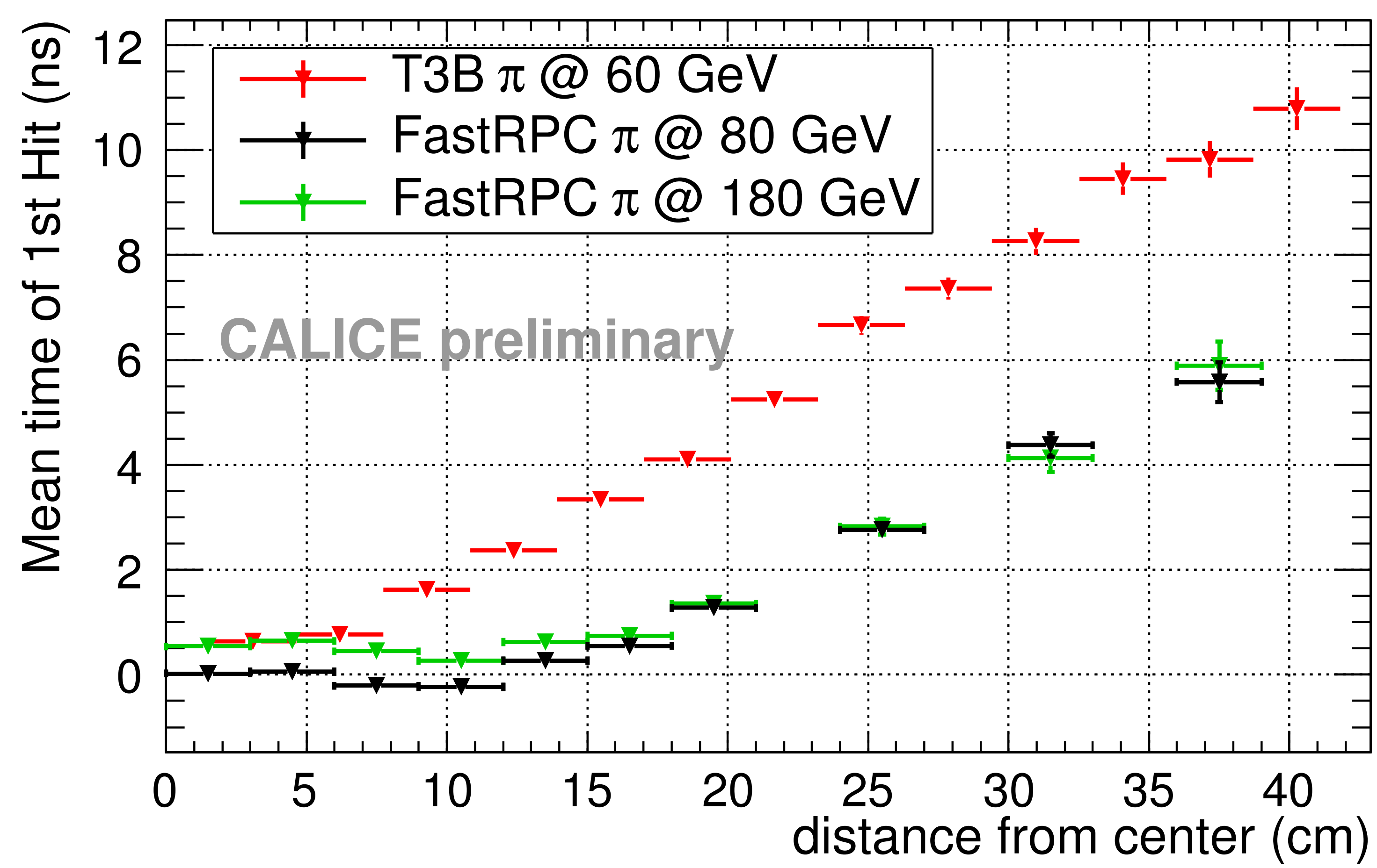
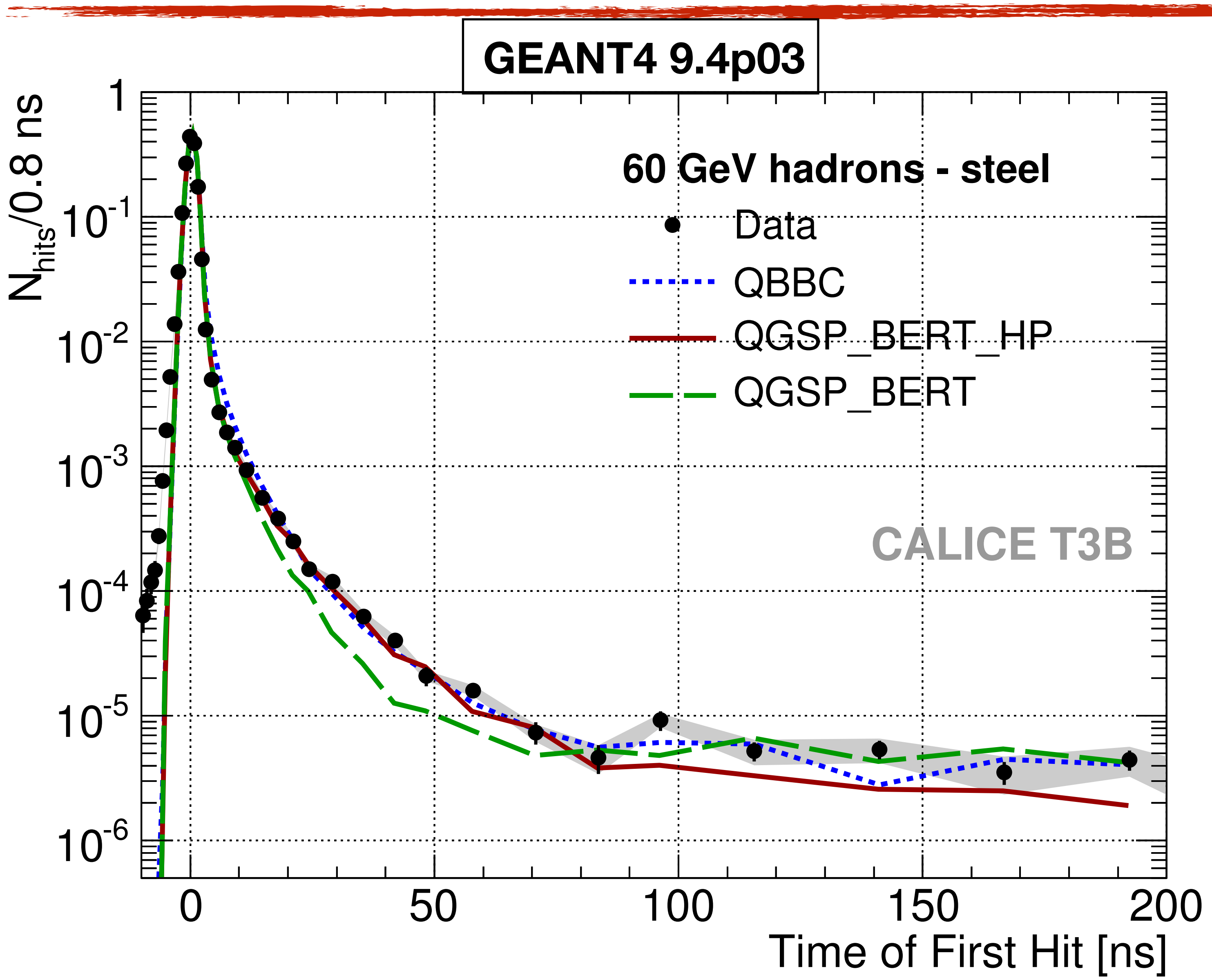
- Effect less pronounced with RPC readout: Reduced sensitivity to MeV-scale neutrons



Comparison to Simulations



- In general good agreement of simulations with data for steel - slight underestimation of intermediate late component without HP neutron treatment

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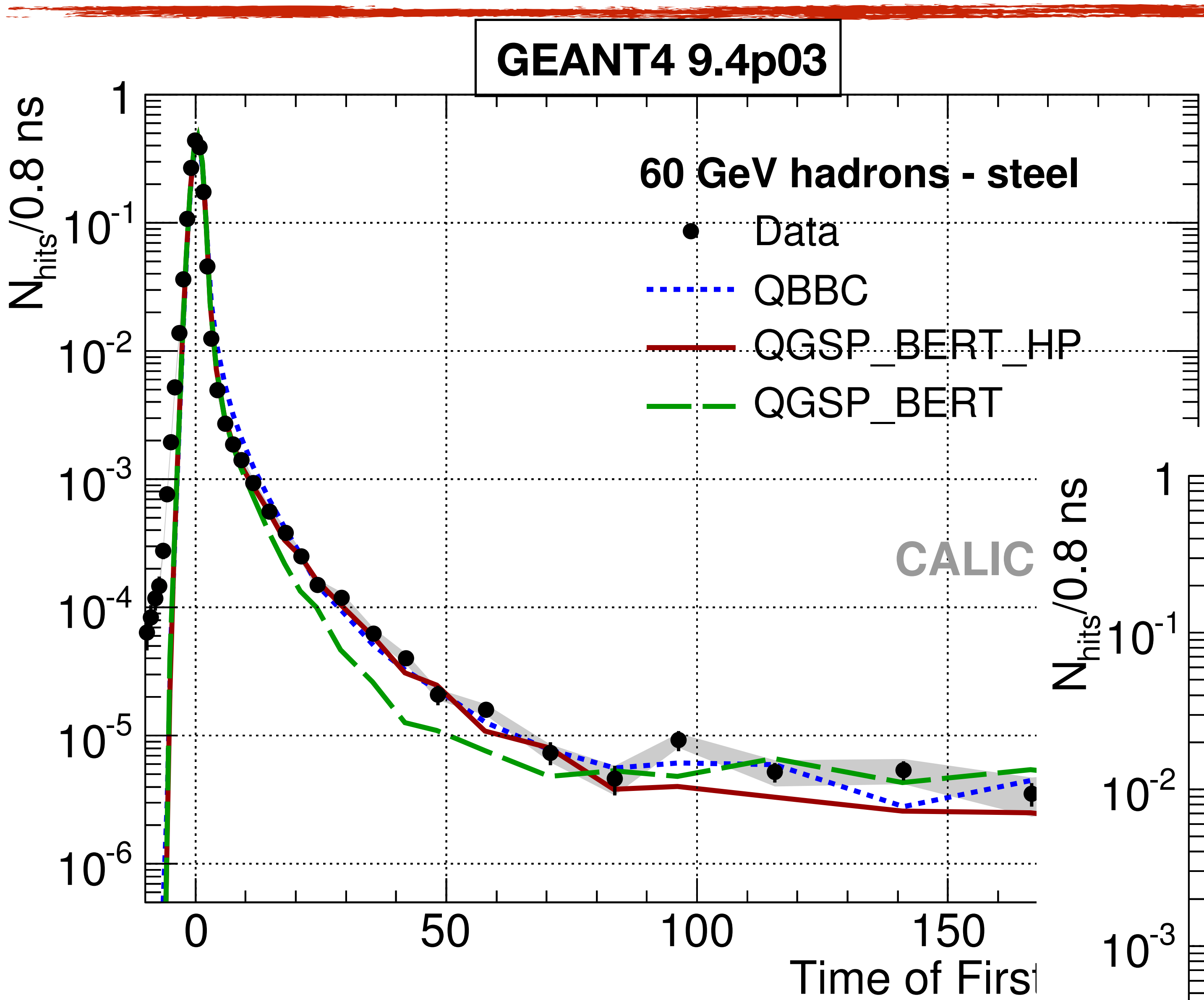

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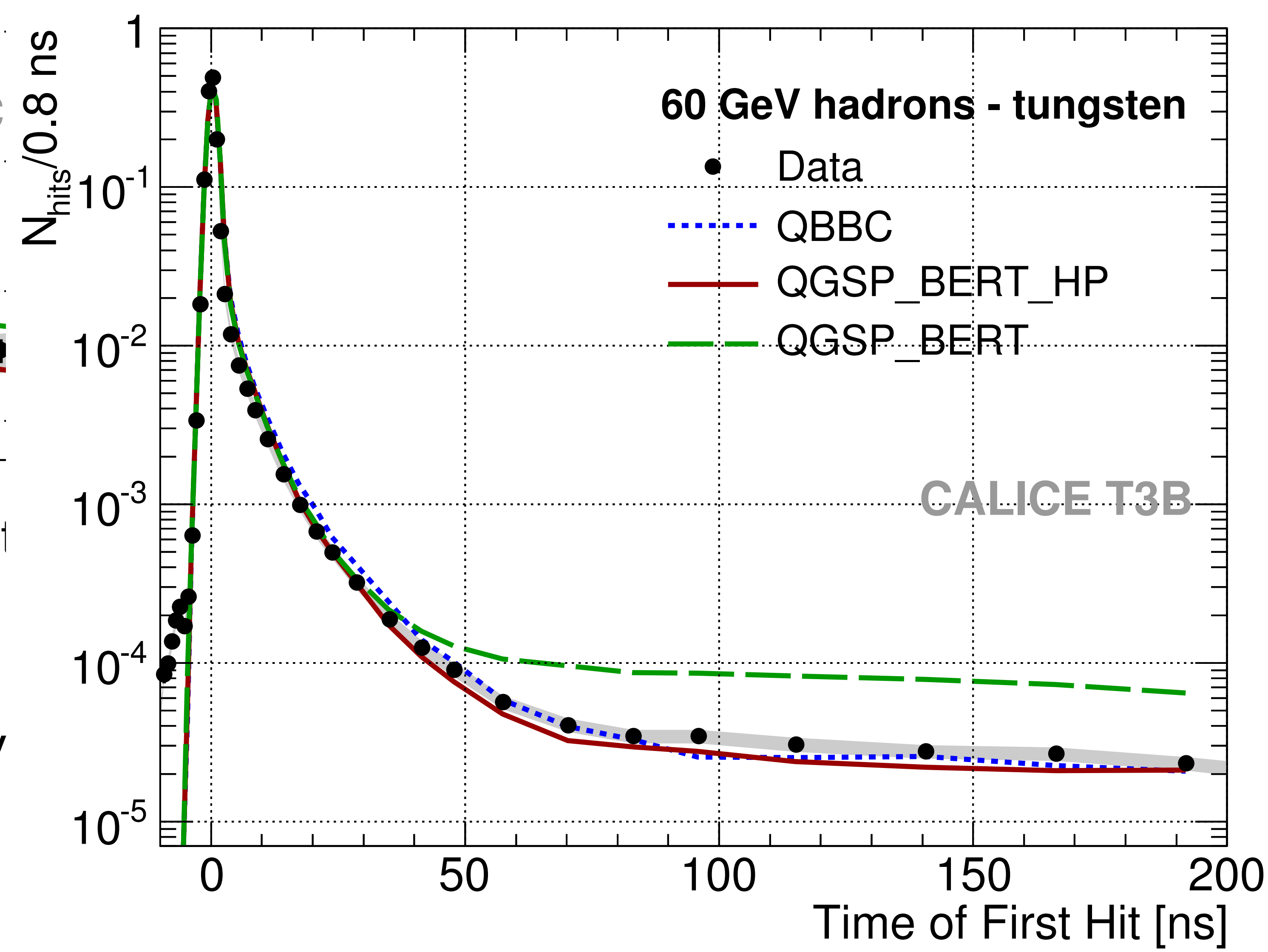
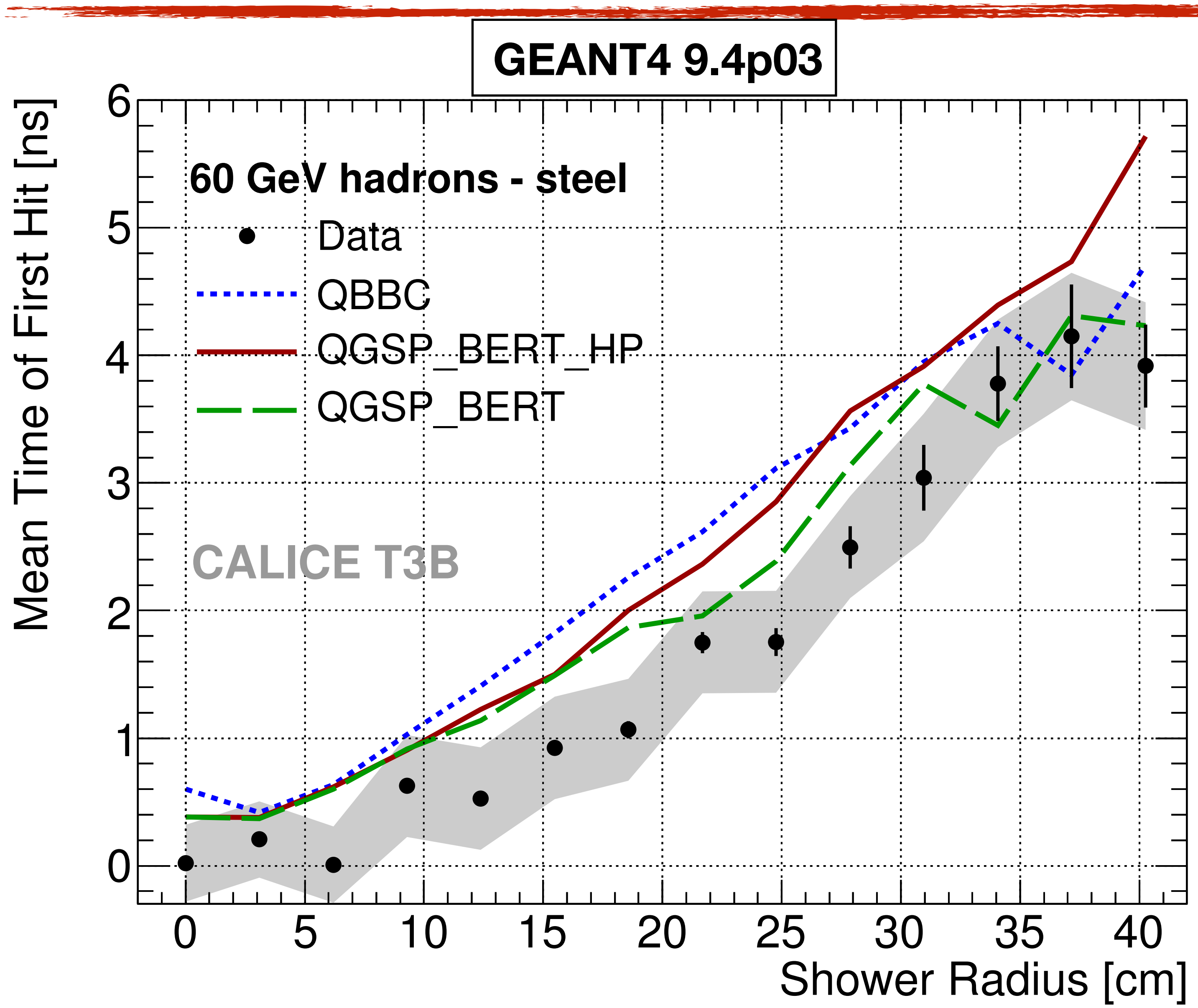


- HP neutron treatment crucial for tungsten: severe overestimation of very late component by QGSB_BERT

Comparison to Simulations



- Radial dependence well modelled for steel - within a few 100 ps

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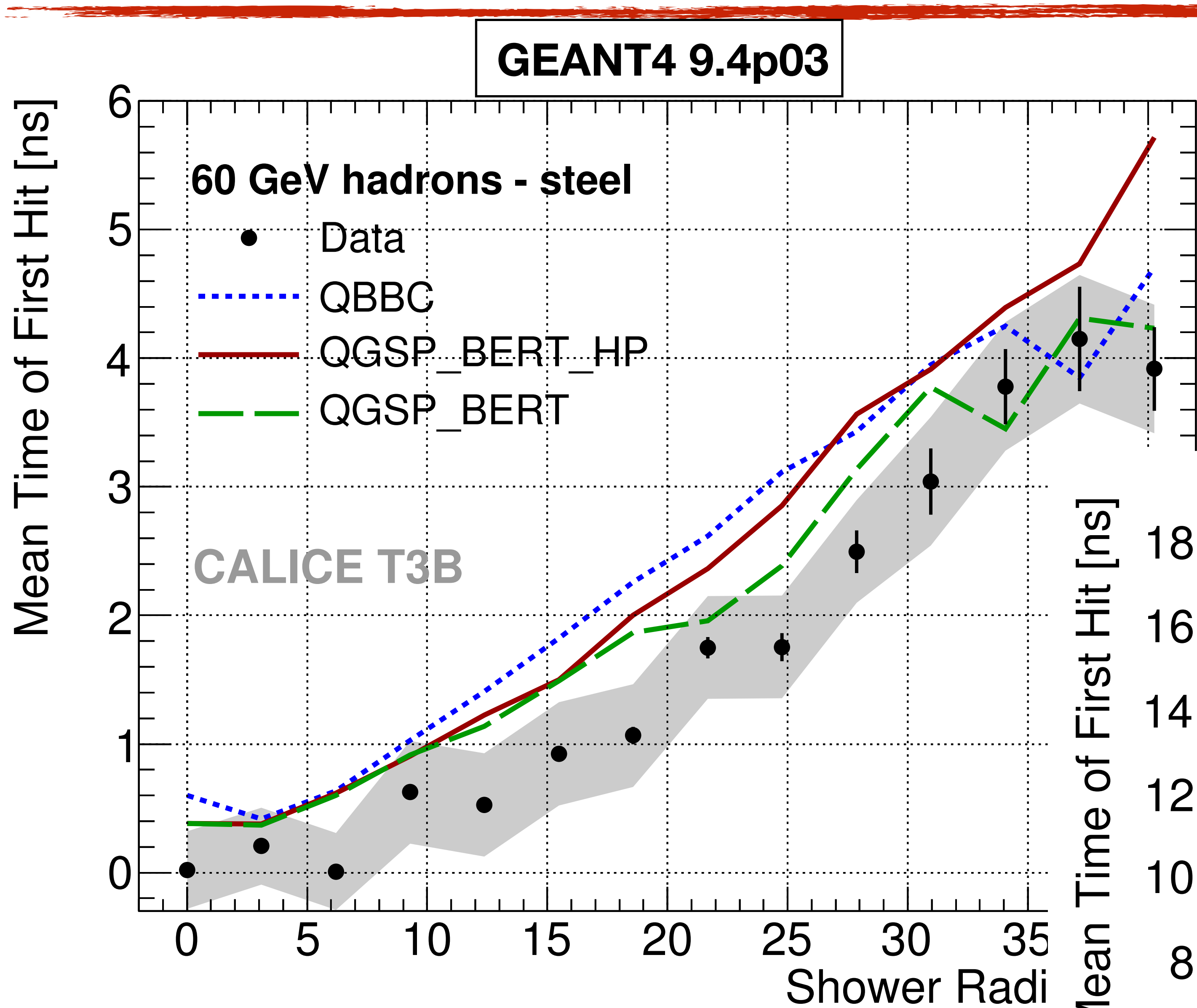
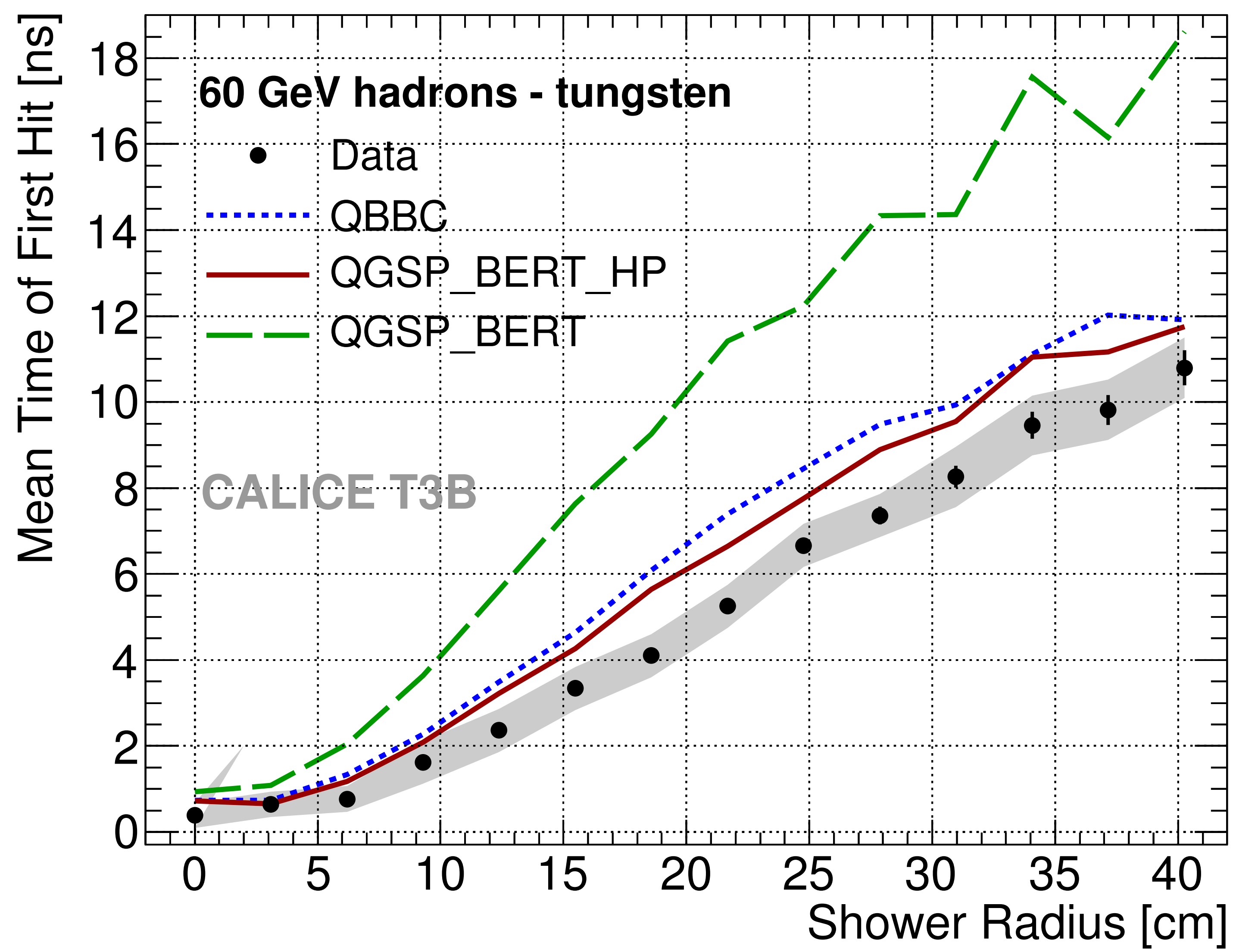


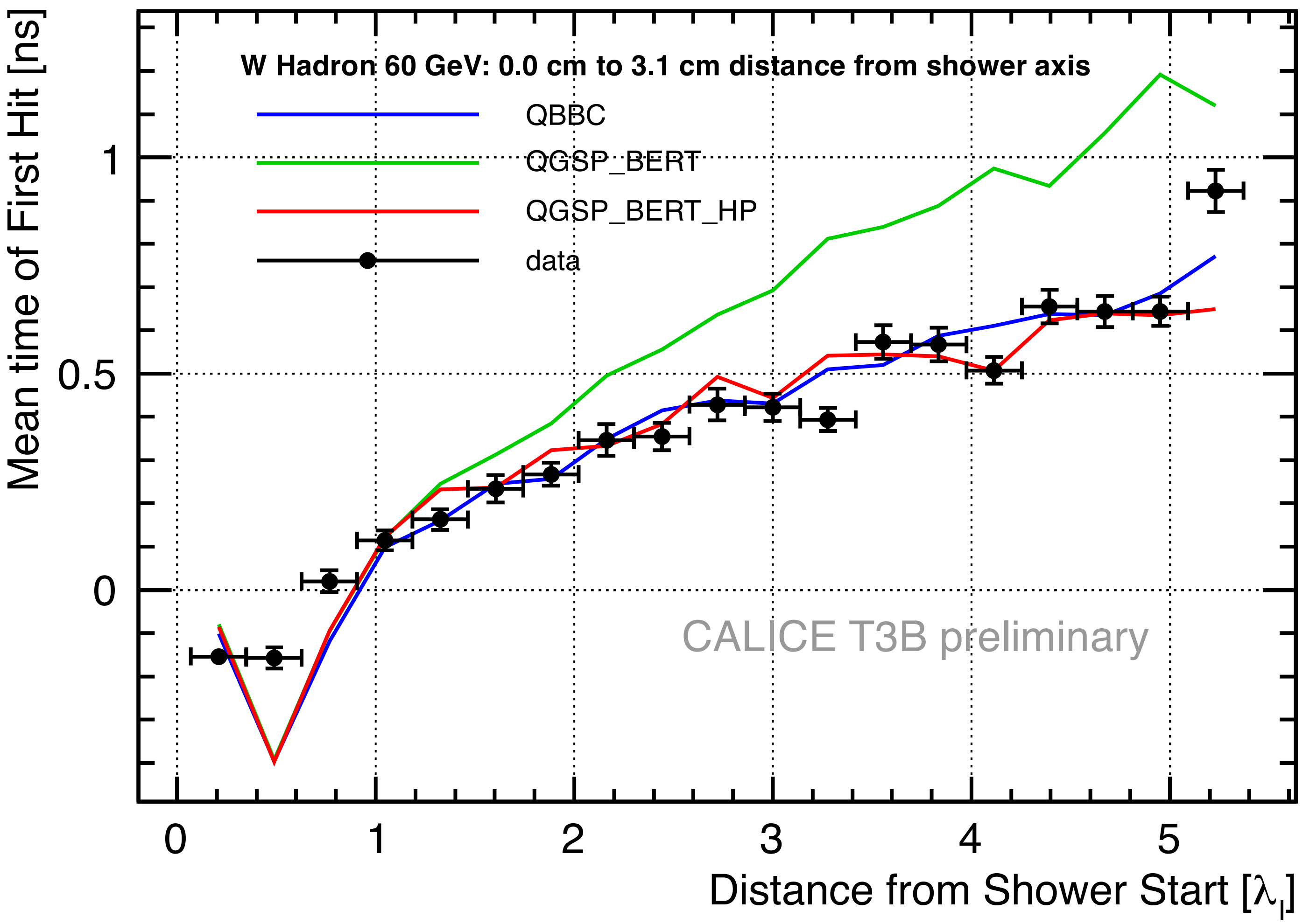
- Radial dependence well modelled for steel - within a few 100 ps

- Radial dependence for tungsten needs HP neutron treatment



T3B: Longitudinally Resolved Analysis

- Shower start identified in W-AHCAL - used to measure depth of first interaction



Late components more important at rear of shower

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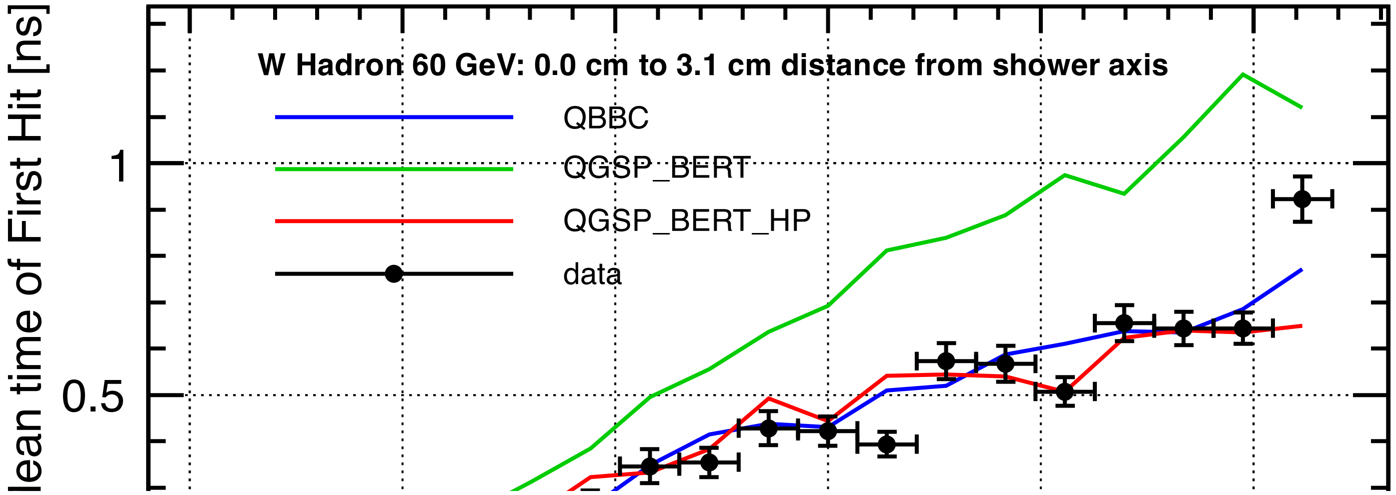
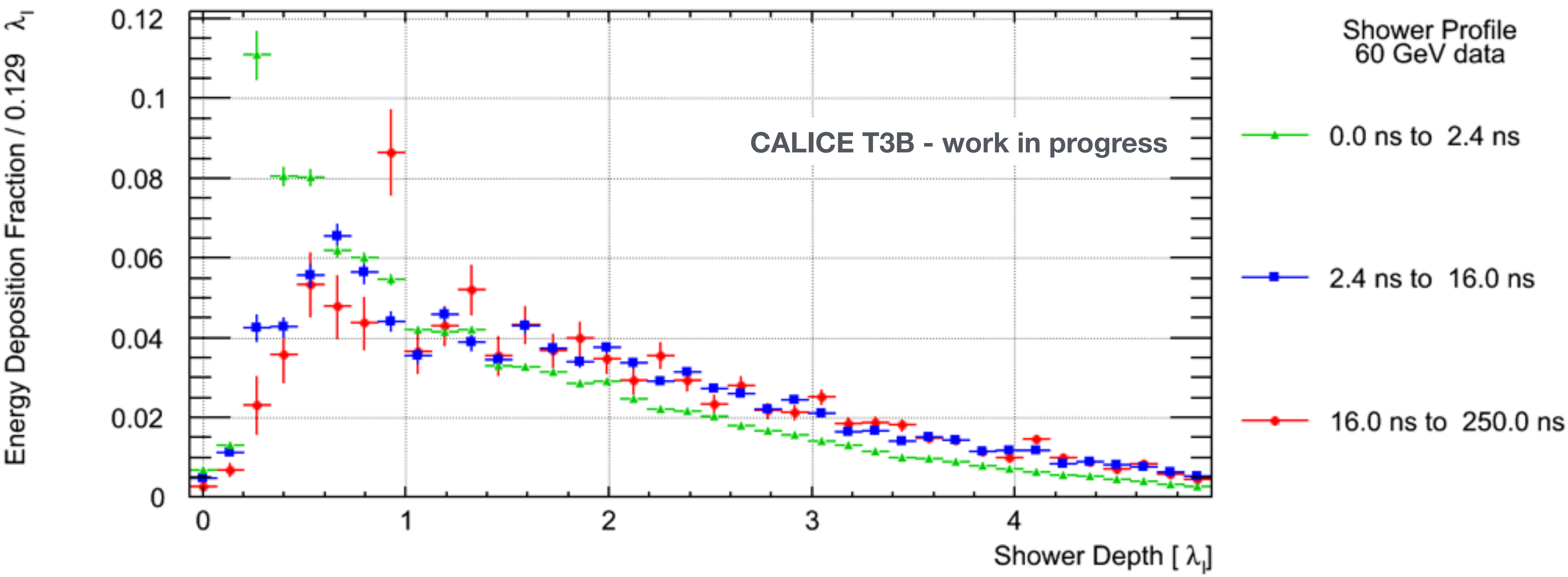


Late components more important at rear of shower

Late shower components peak deeper in detector (~ 0.6 - 1 λ vs ~ 0.4 λ), less pronounced maximum



Next Steps

- One main missing thing: Simulations for FastRPC - Will be started once Higgs analysis project at MPP is complete
- To be decided: Publication of Longitudinally resolved data - Needs understanding of systematics
  - Problem: Used GEANT4 version is getting old…

- Global challenge: T3B “data preservation” - Experts have been gone for ~ 9 Months, need to make sure data is useable
  - Can start once current analysis projects have been completed

Summary

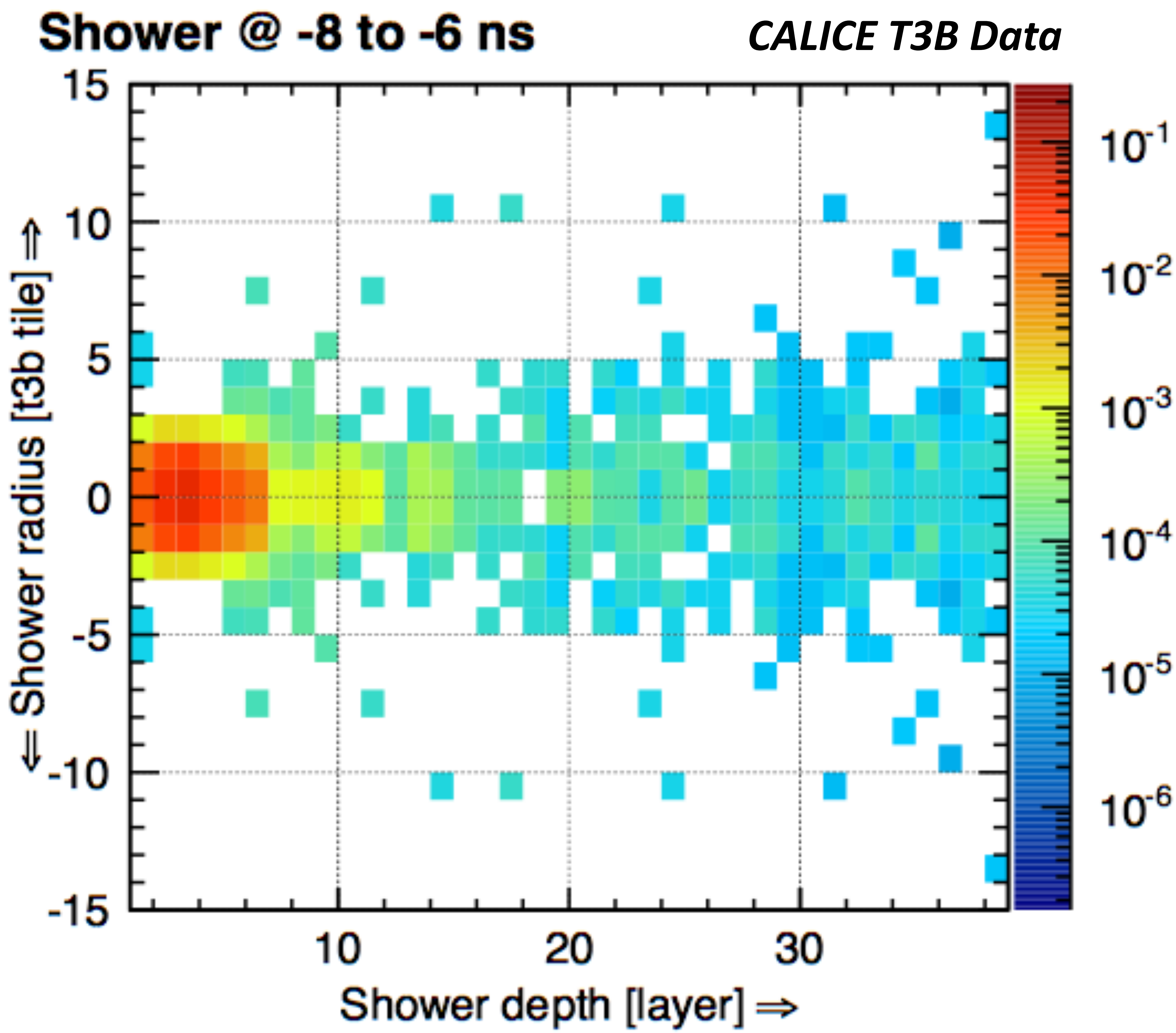
- Time structure of hadronic showers highly relevant for calorimetry at future colliders
  - Within CALICE dedicated experiments have been carried out to study it in tungsten and steel with scintillators (T3B) and gaseous detectors (FastRPC)

- In gaseous detectors, the sensitivity to the intermediate time component is reduced in particular the region from a few to a few 10 ns
  - Reduced sensitivity to MeV-scale spallation neutrons due to low hydrogen content of active medium

- The comparison of GEANT4 simulations to the data shows:
  - The time structure in steel is in general quite well described, but profits from high precision neutron models
  - For the simulation of showers in tungsten high precision neutron models are mandatory to reproduce the late components of the shower
  - Simulations to compare to the RPC data in preparation

Backup

The Life of a Pion in the WAHCAL



T = 0: Activity maximum in layer 39 (rear of calorimeter)

Shown: First hits in each cell only

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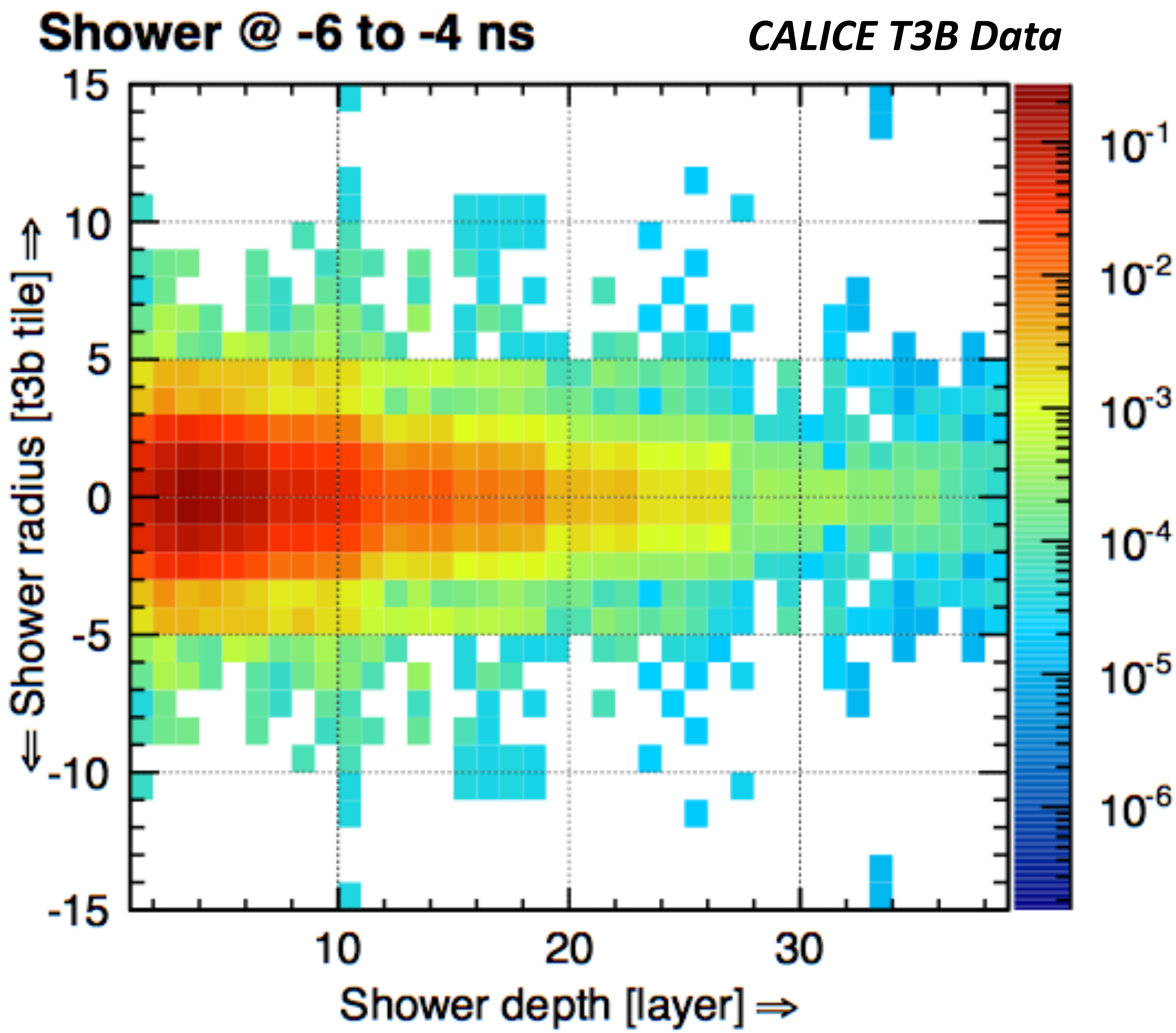

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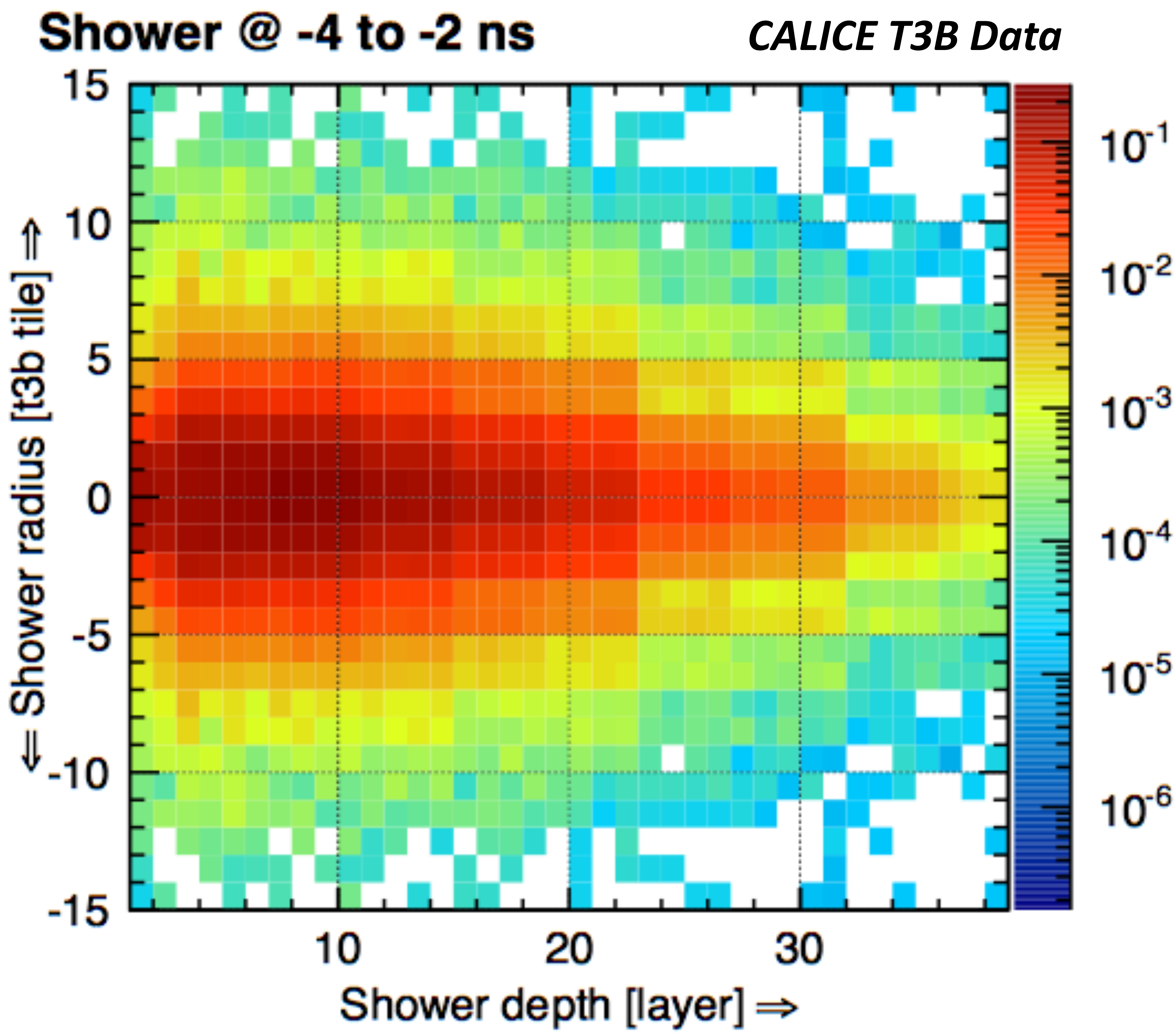

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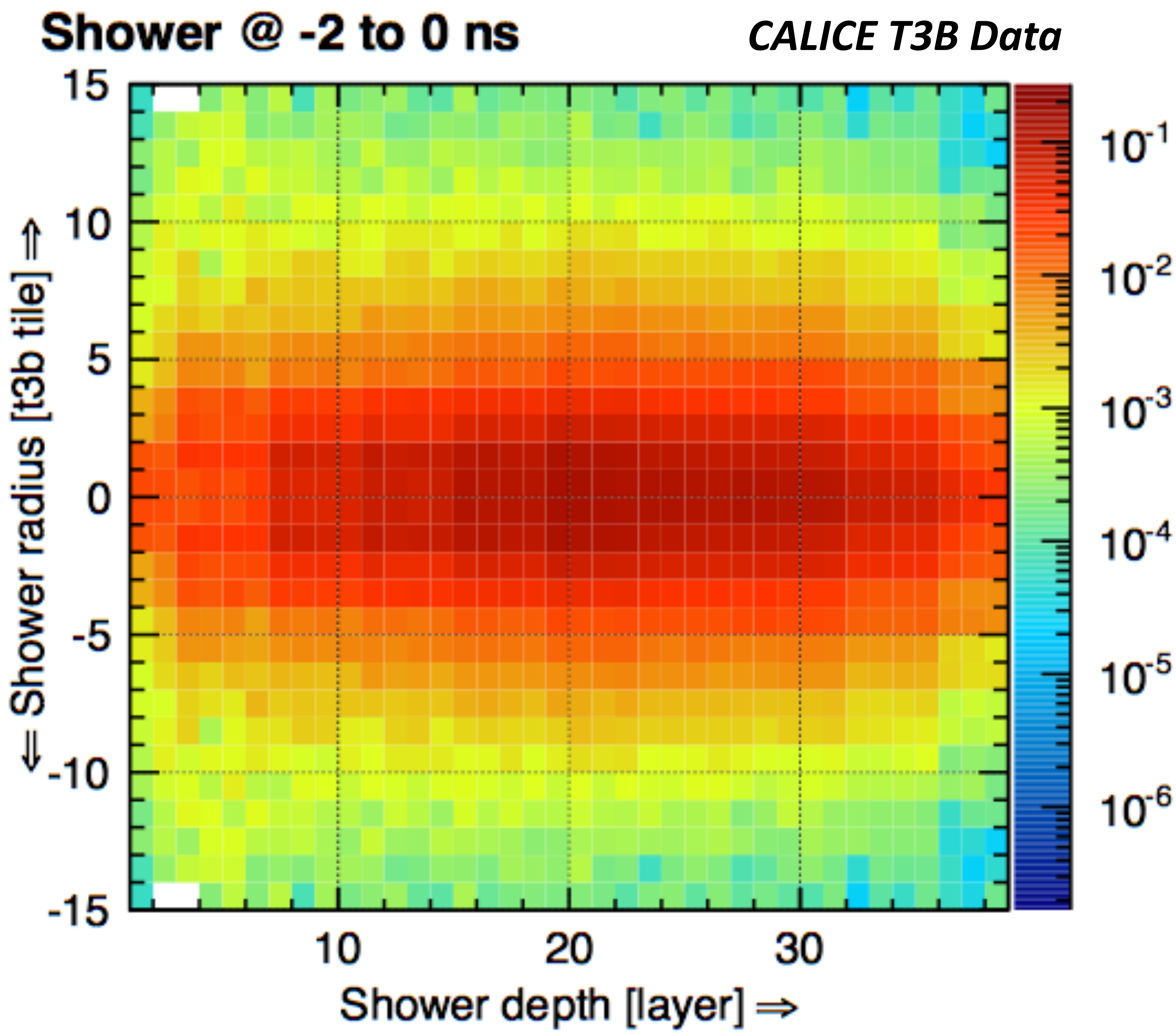

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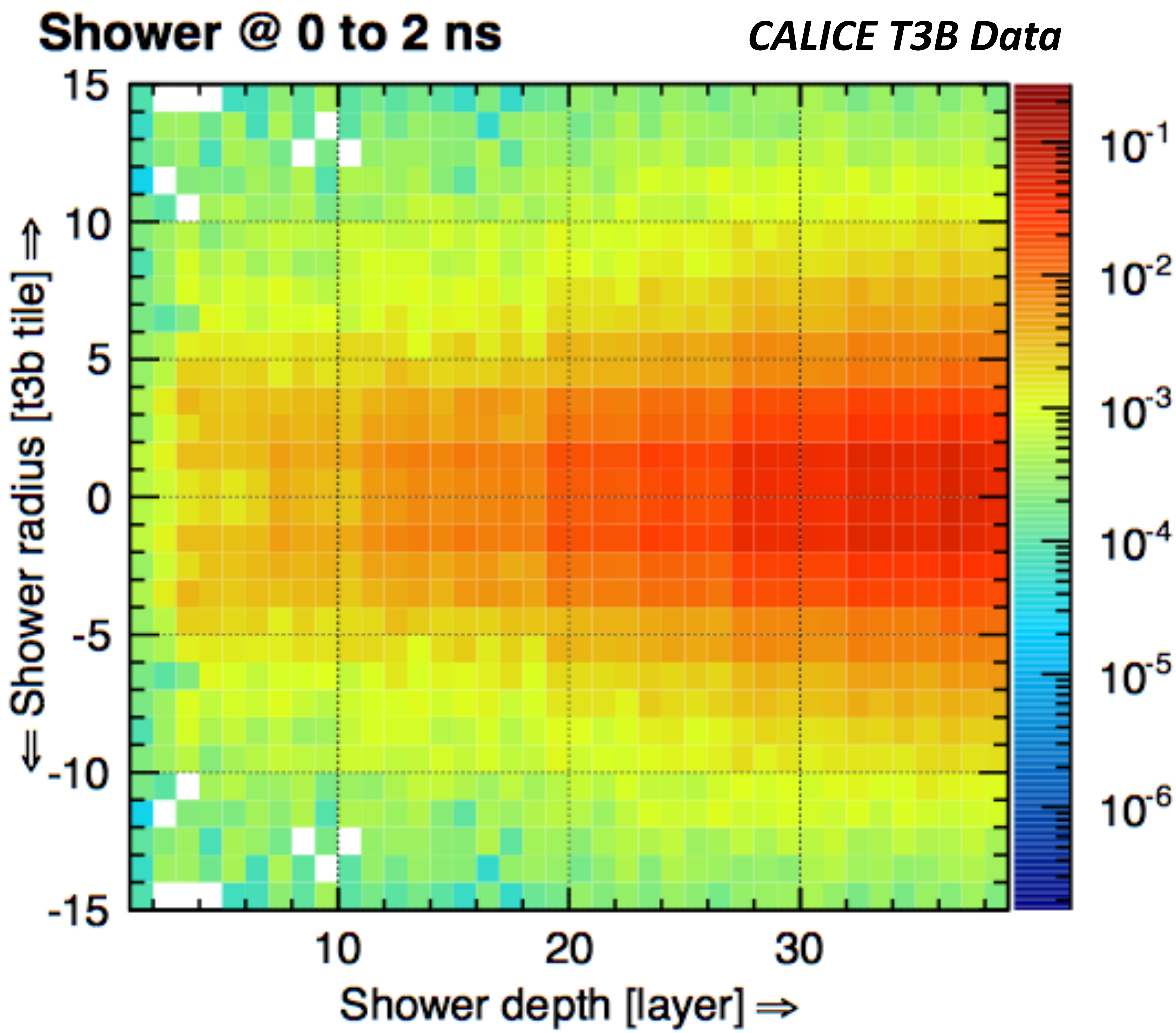

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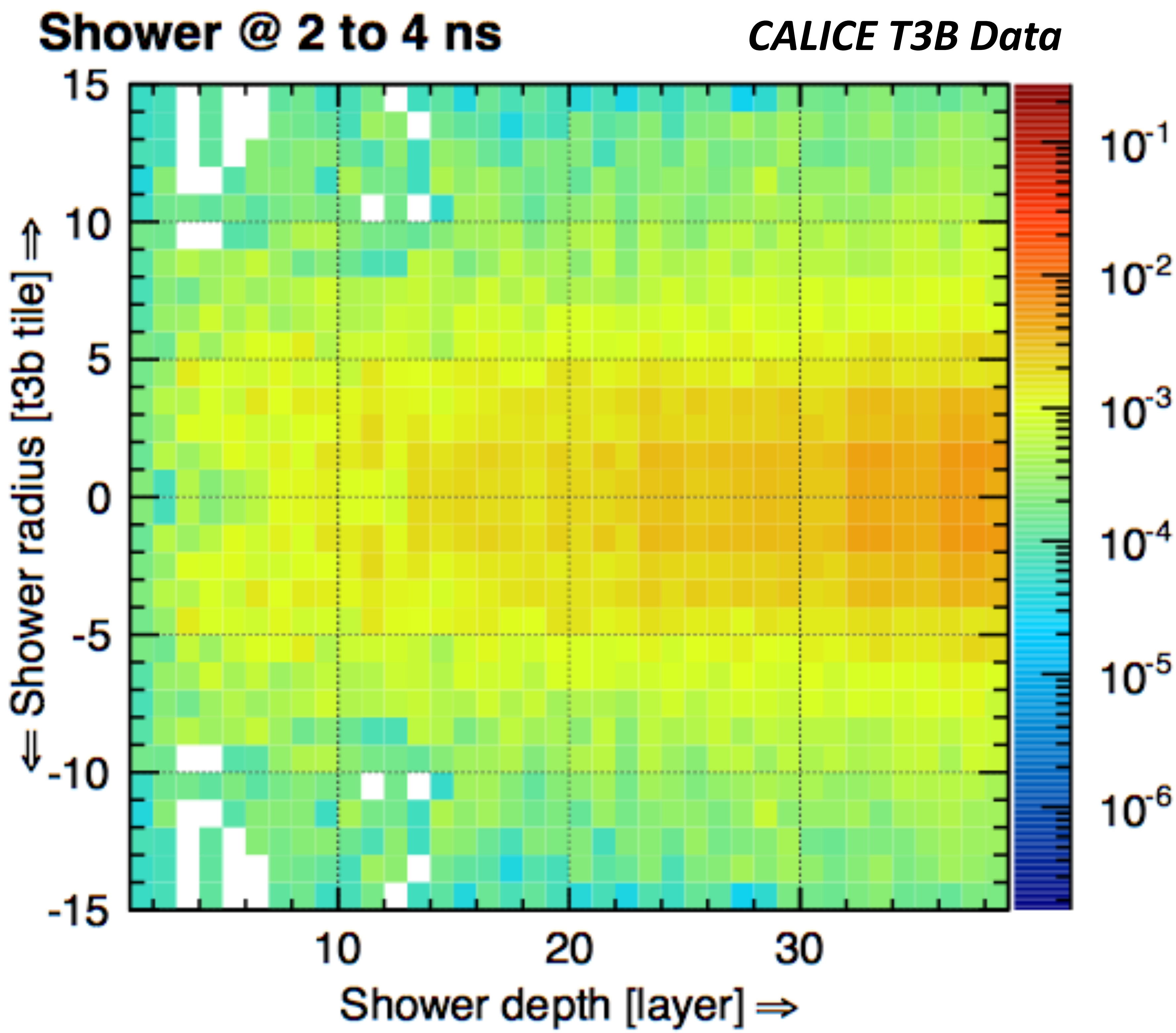

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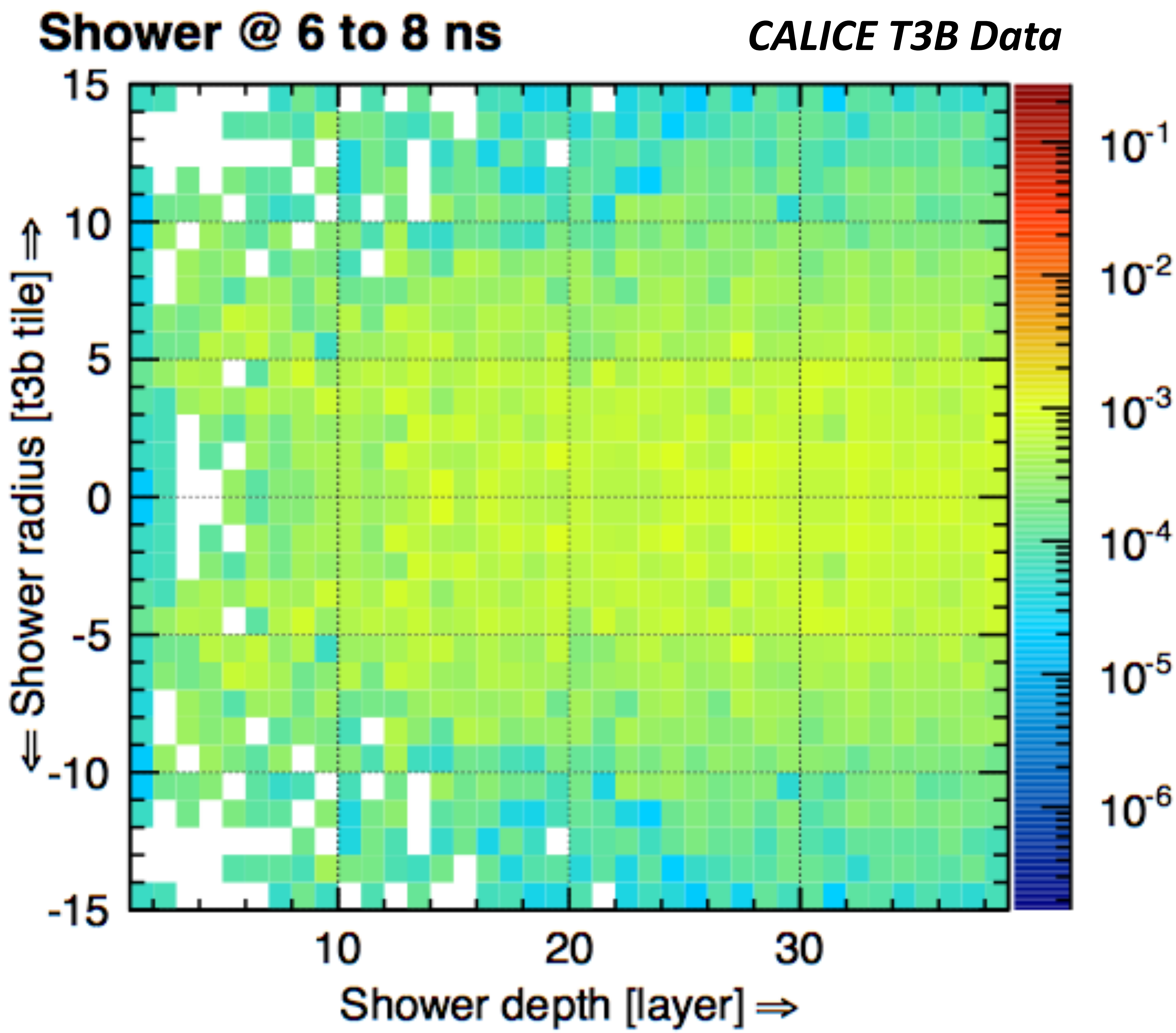

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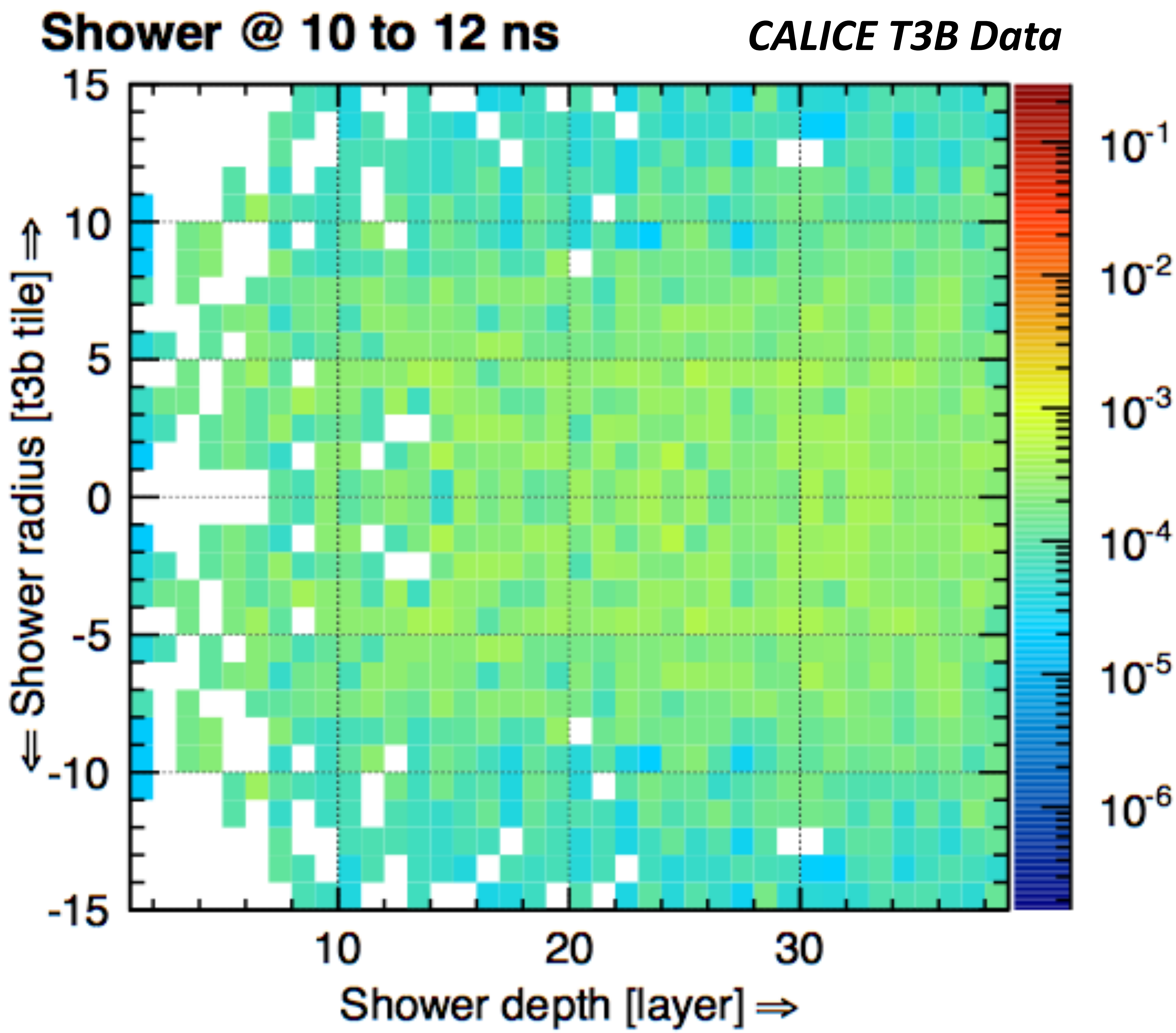

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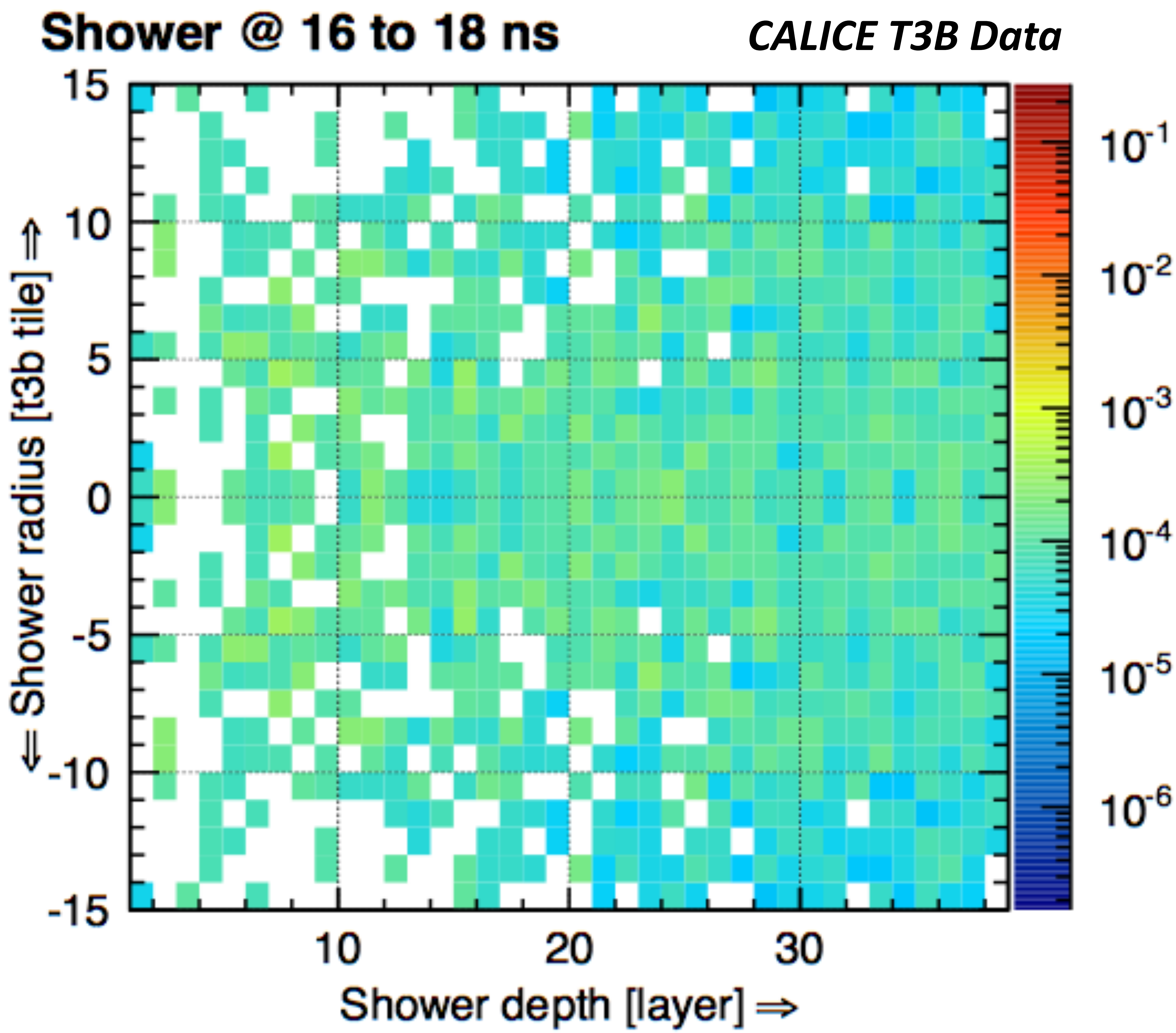

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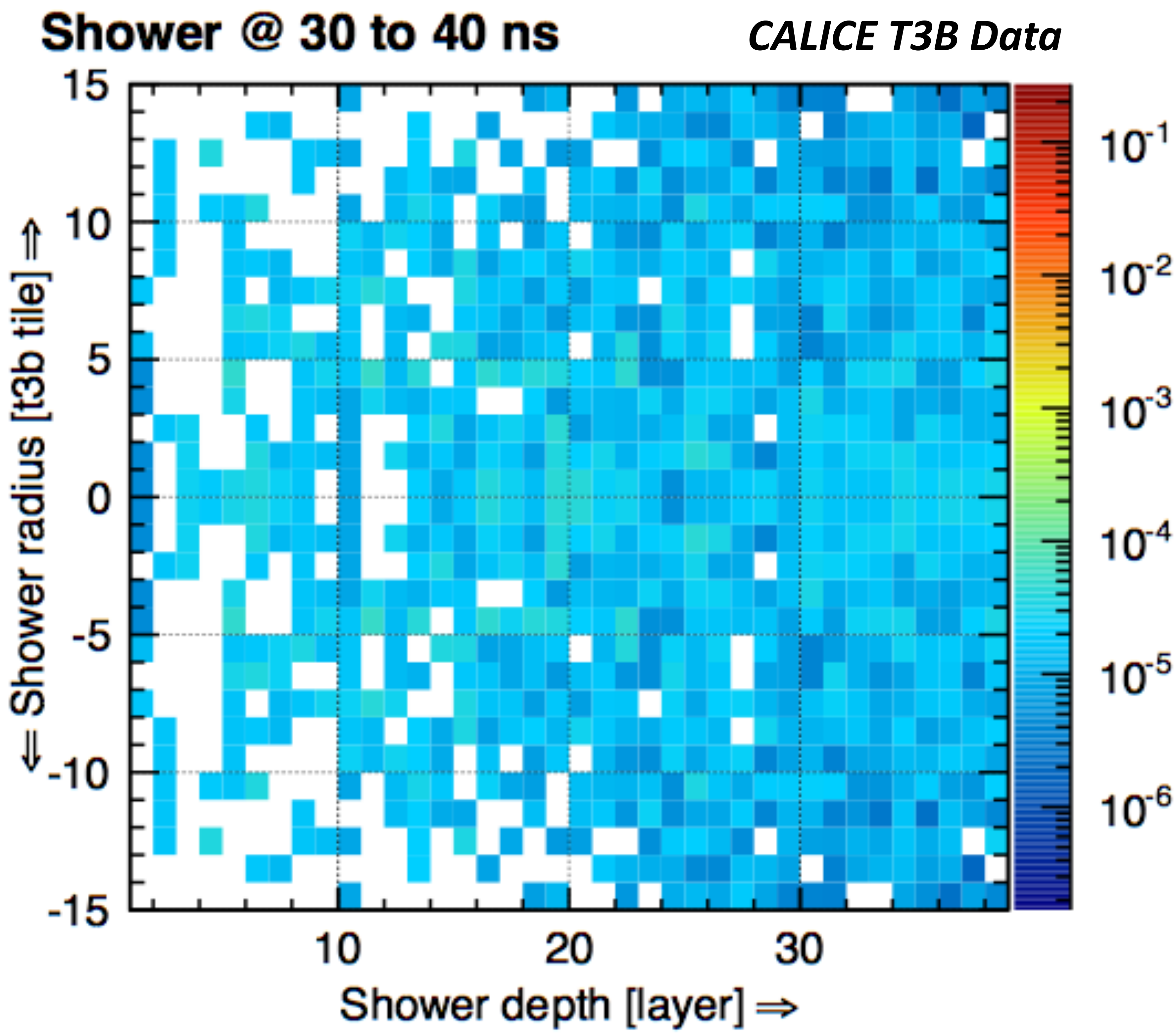

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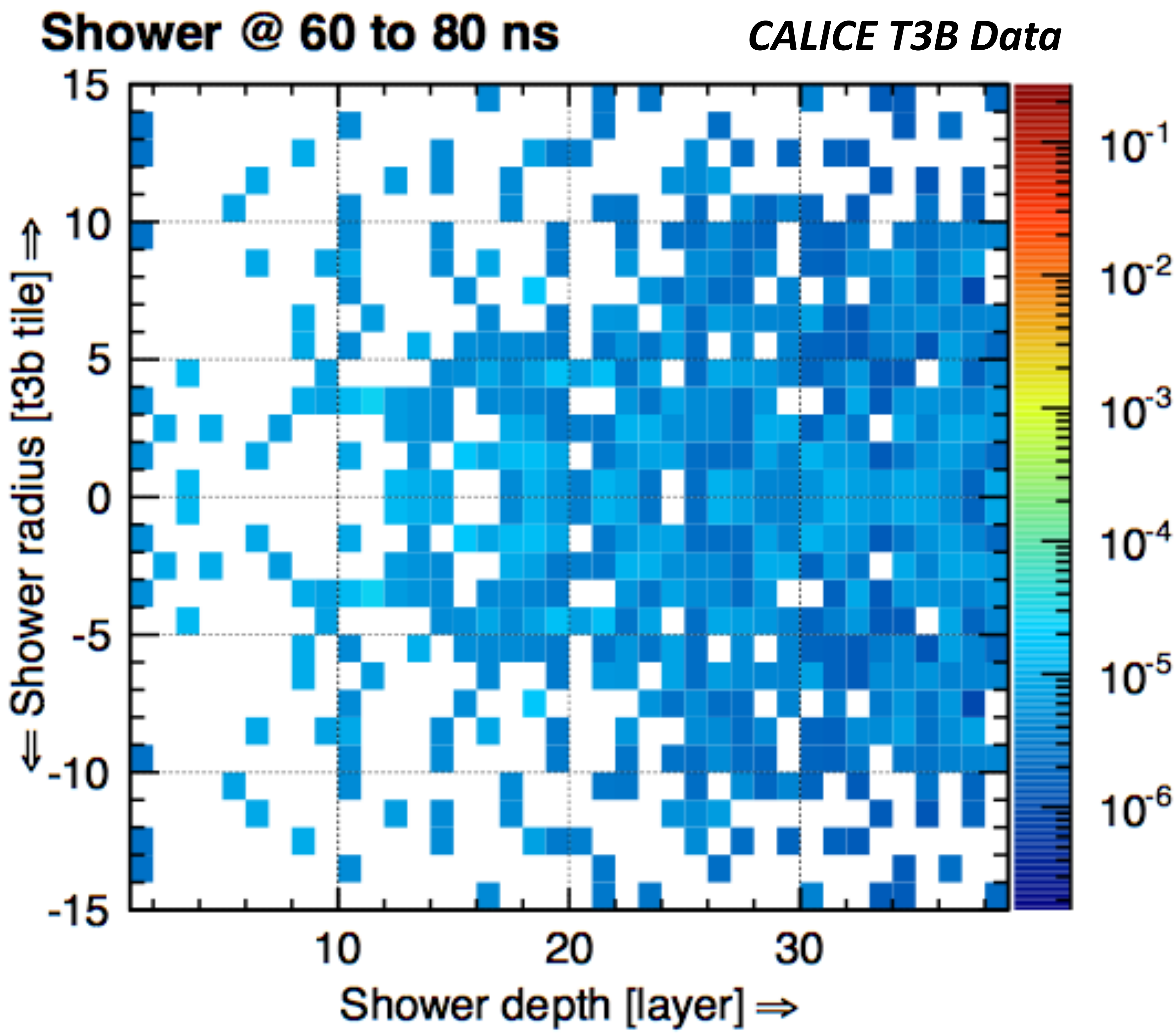

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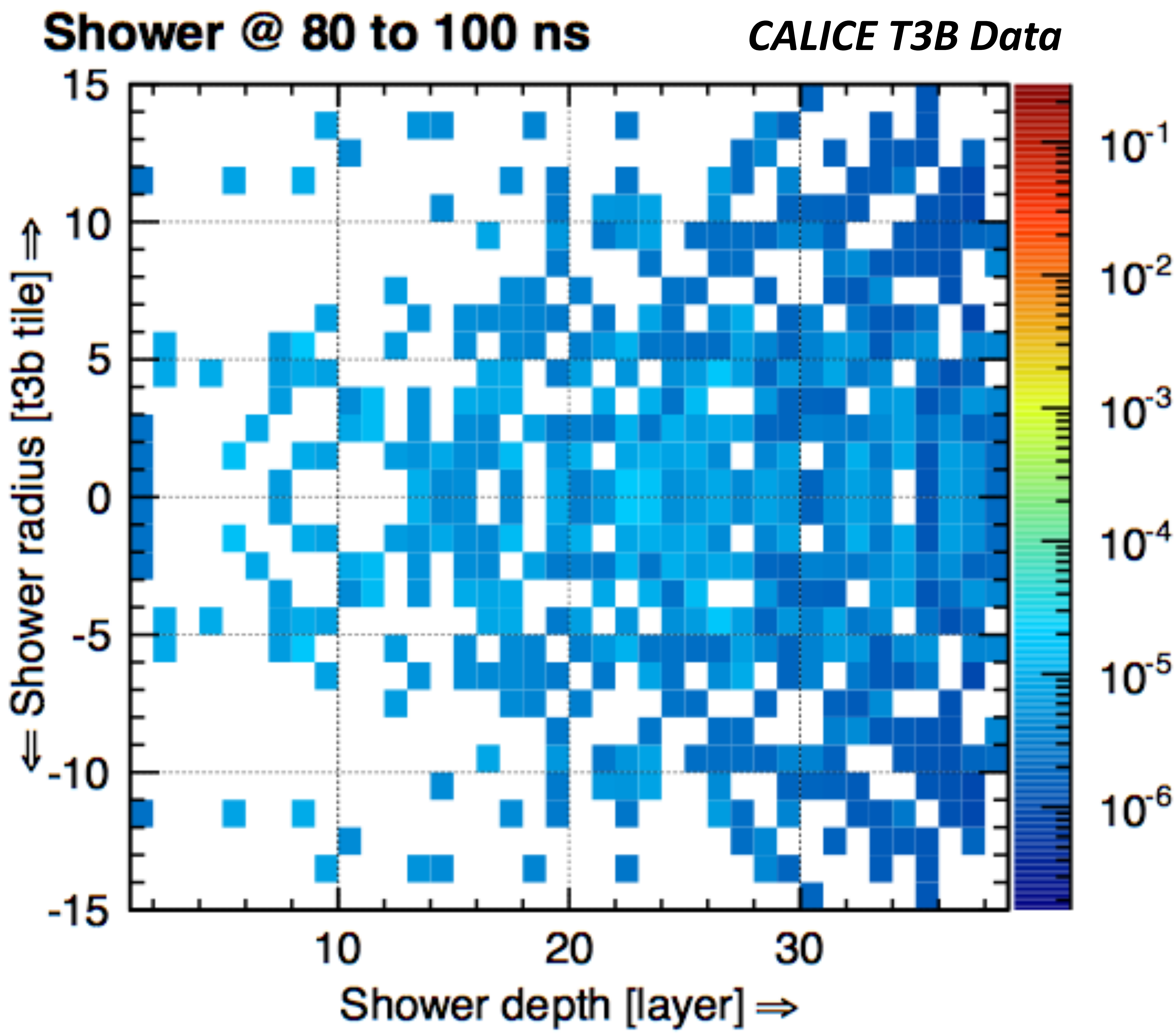

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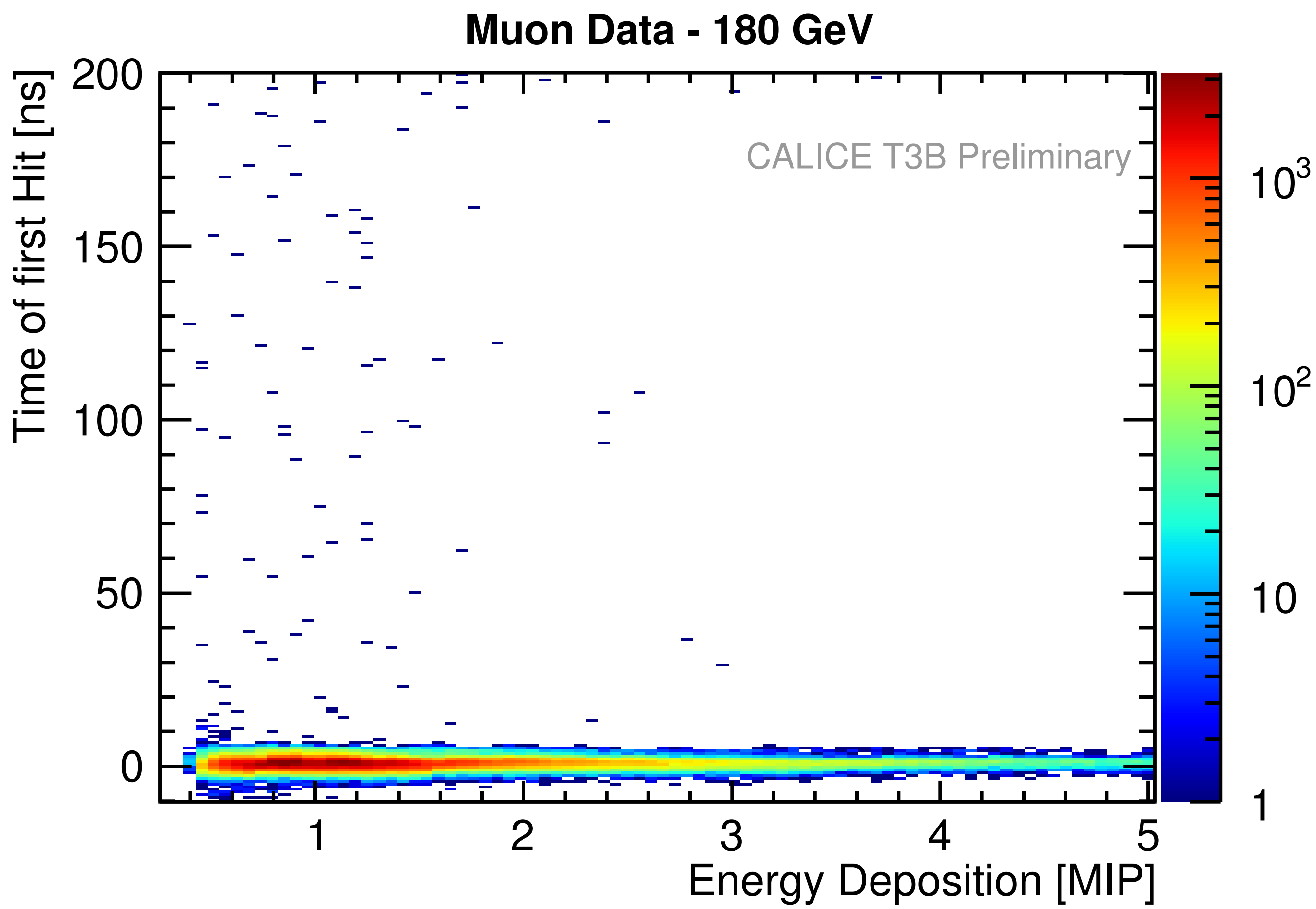
Time vs Energy of First Hits in T3B



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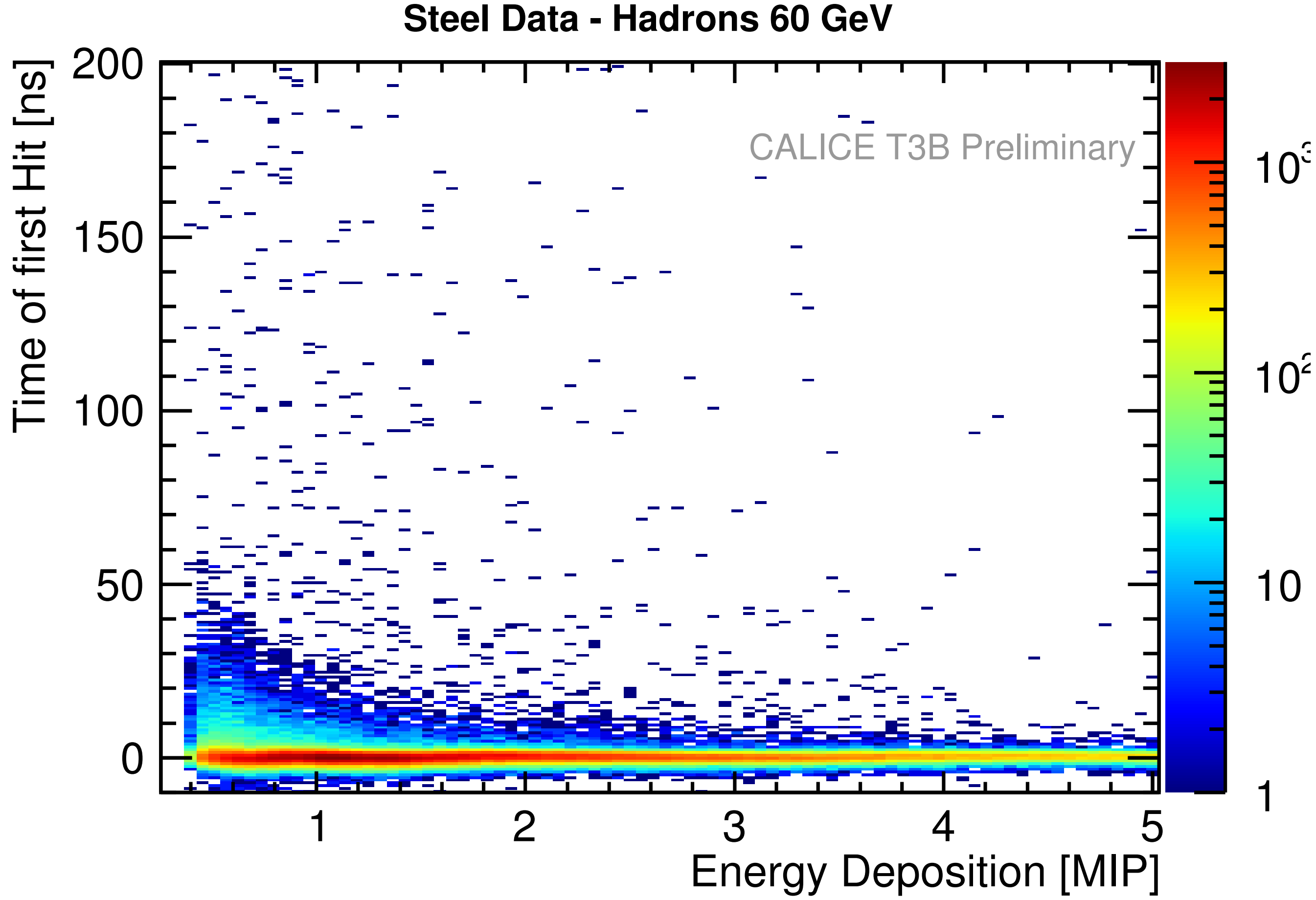

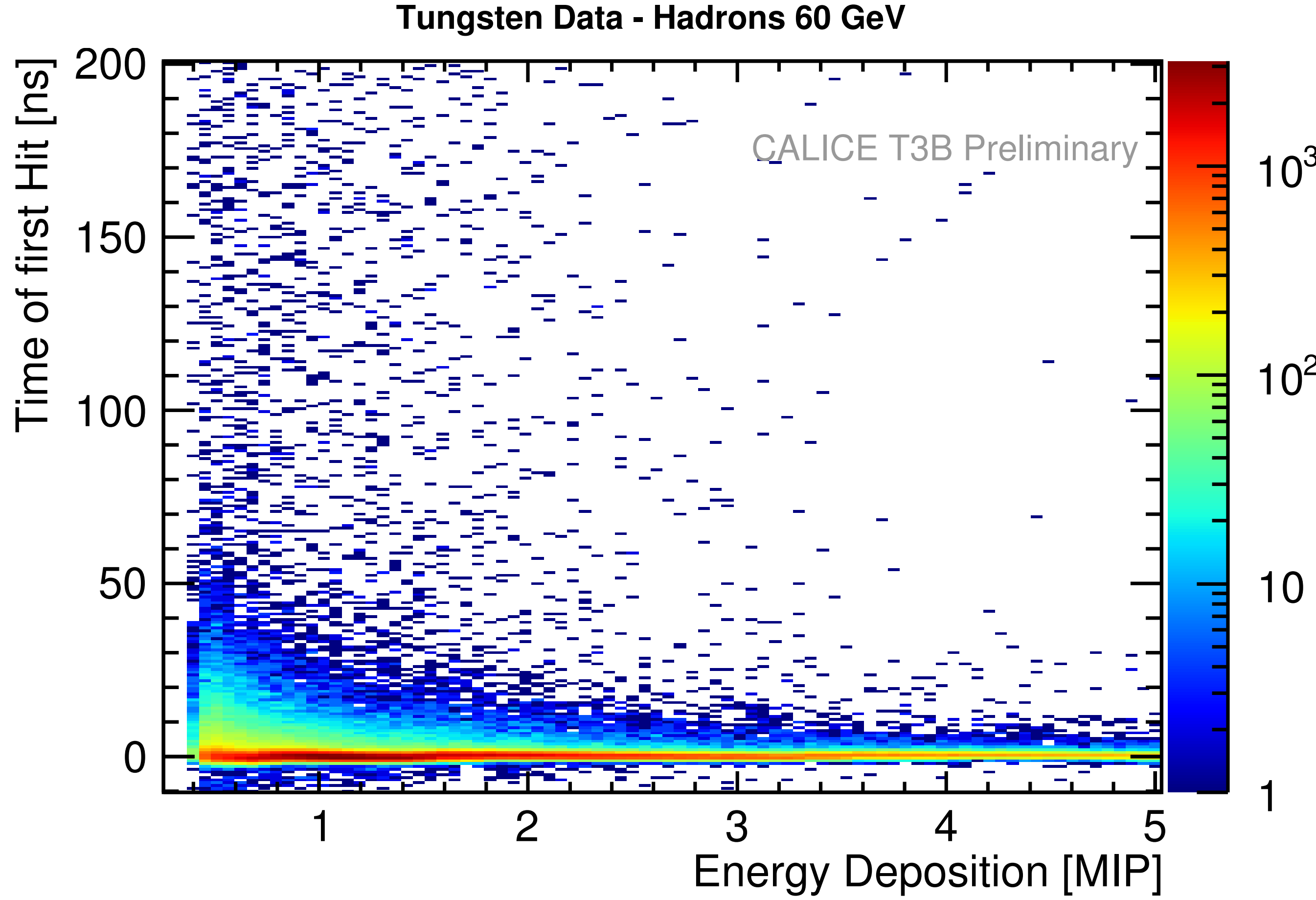

- The “universal” T3B observable: Time of First Hit
  - Multiple hits per tile in one event are rare: < 3% at 30% amplitude of primary hit
- Substantial difference between showers in steel and tungsten: More pronounced late activity in W