T3B: A brief Story of Time

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Munich, Germany

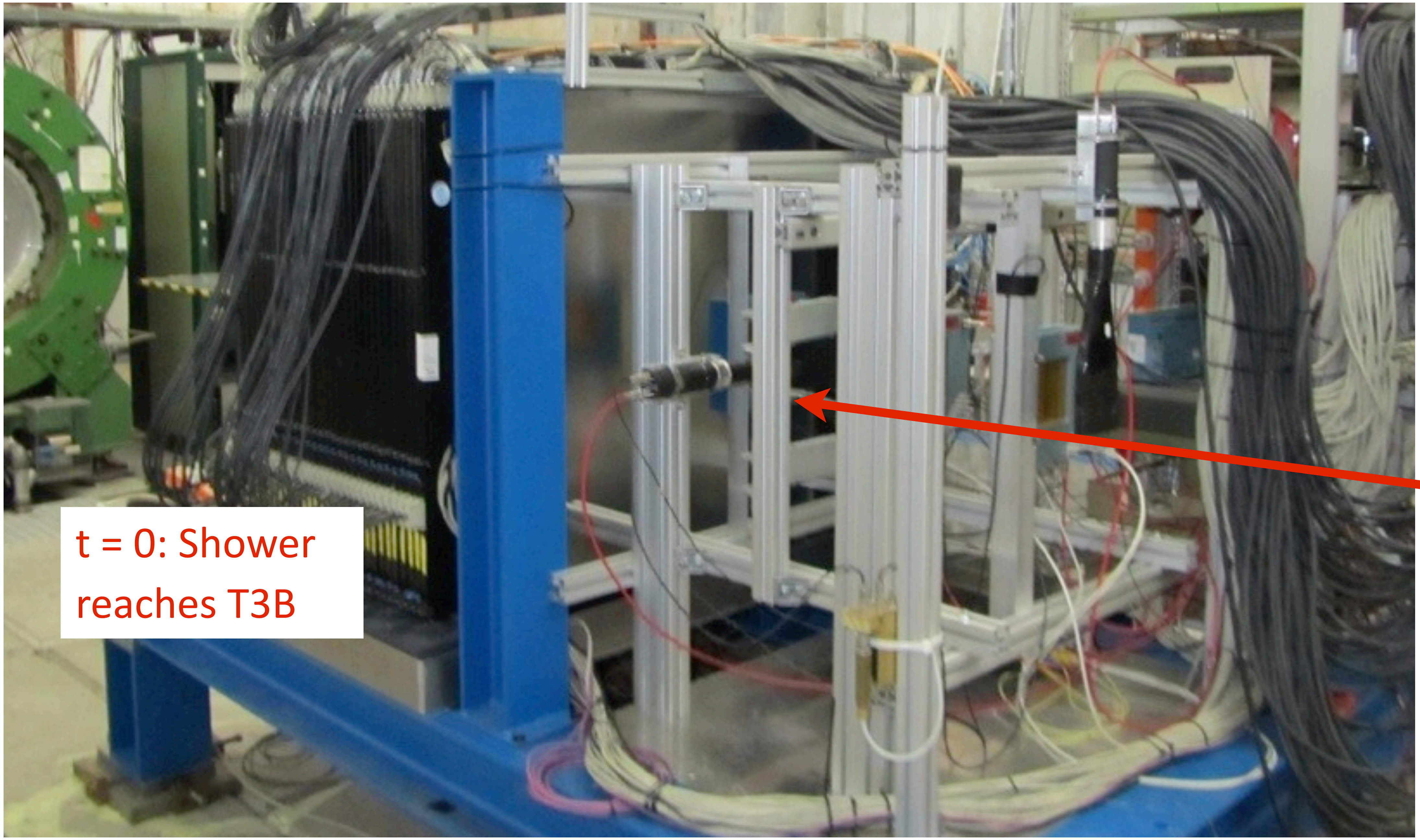
CALICE Collaboration Meeting, Cambridge, UK, September 2012

Max-Planck-Institut für Physik
(Werner-Heisenberg-Institut)

Calorimeter for ILC

TUM
LMU
Excellence Cluster
Universe

The Life of a Pion in the WHCAL



60 GeV pion

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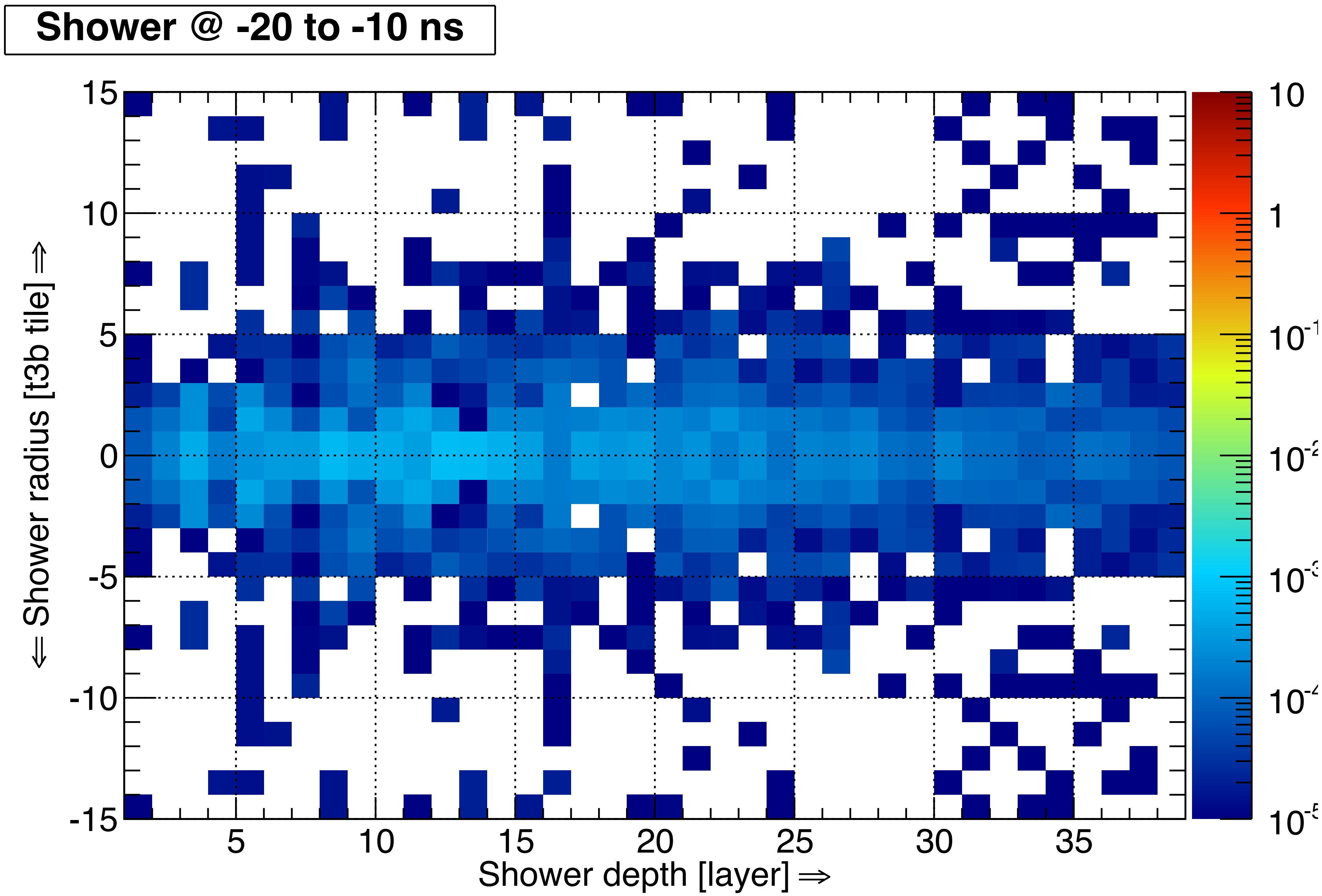

60 GeV
in WHCAL

- t = 0: Aktivity peak in T3B (layer 39), Depth in calorimeter by identification of shower start layer

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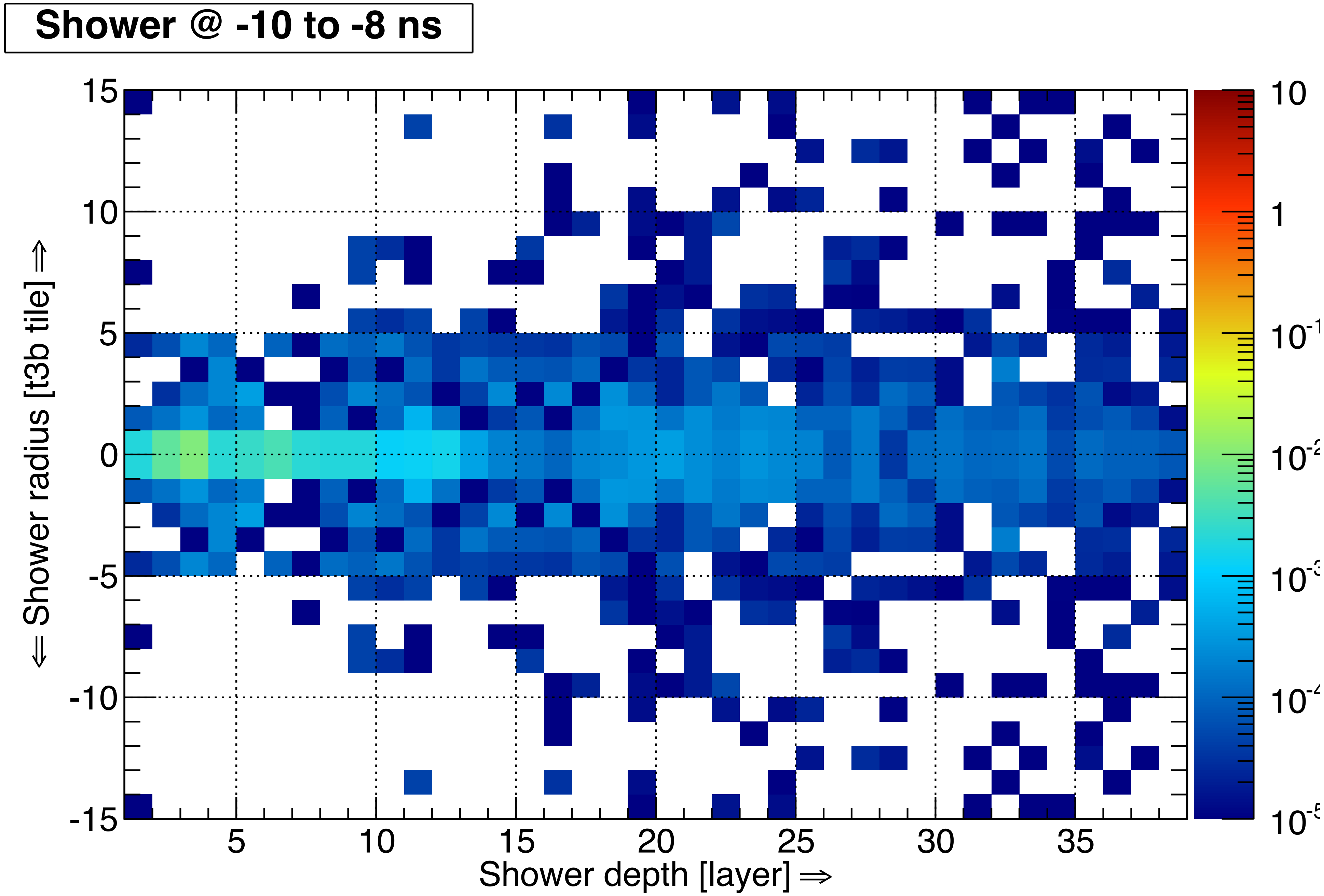

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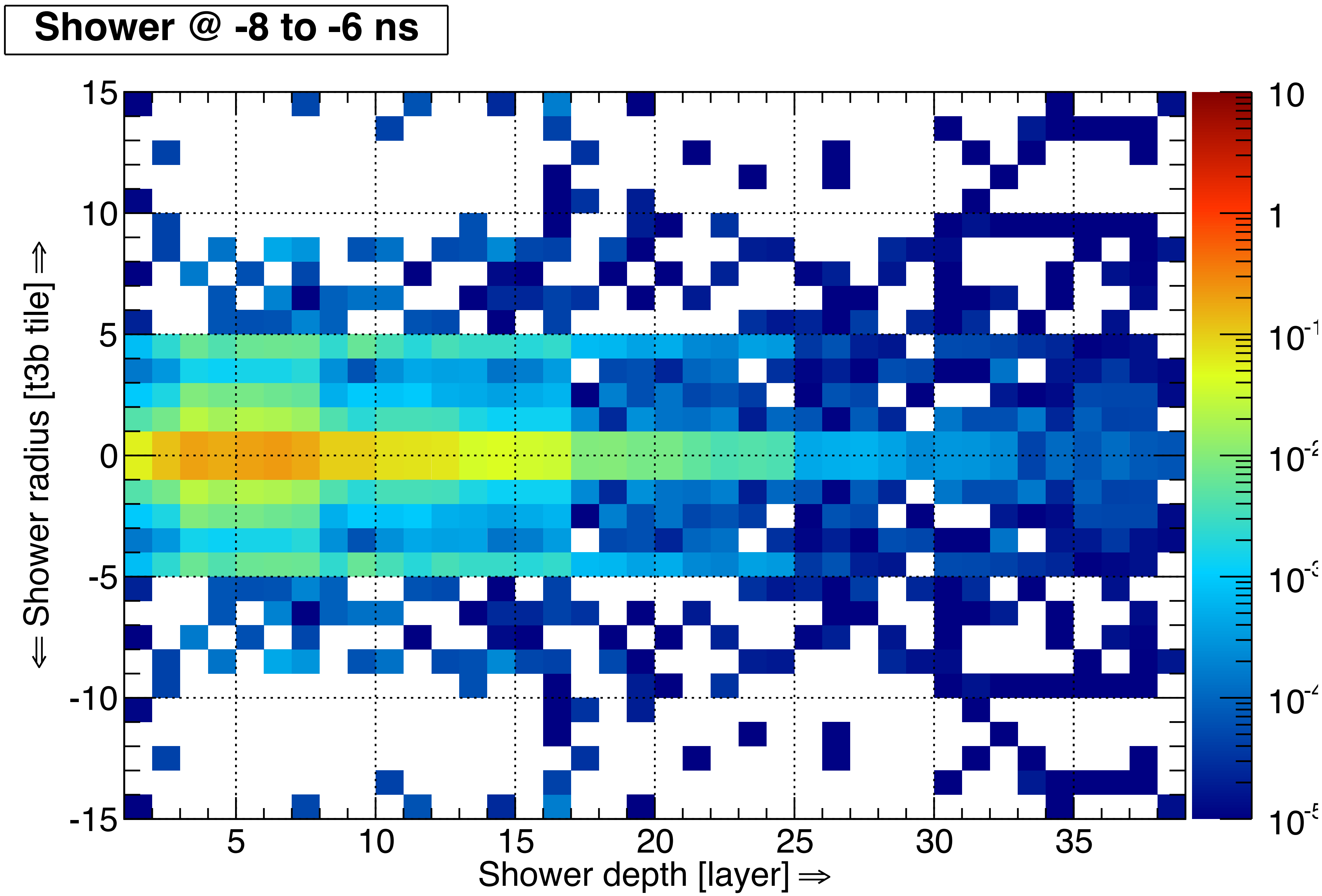

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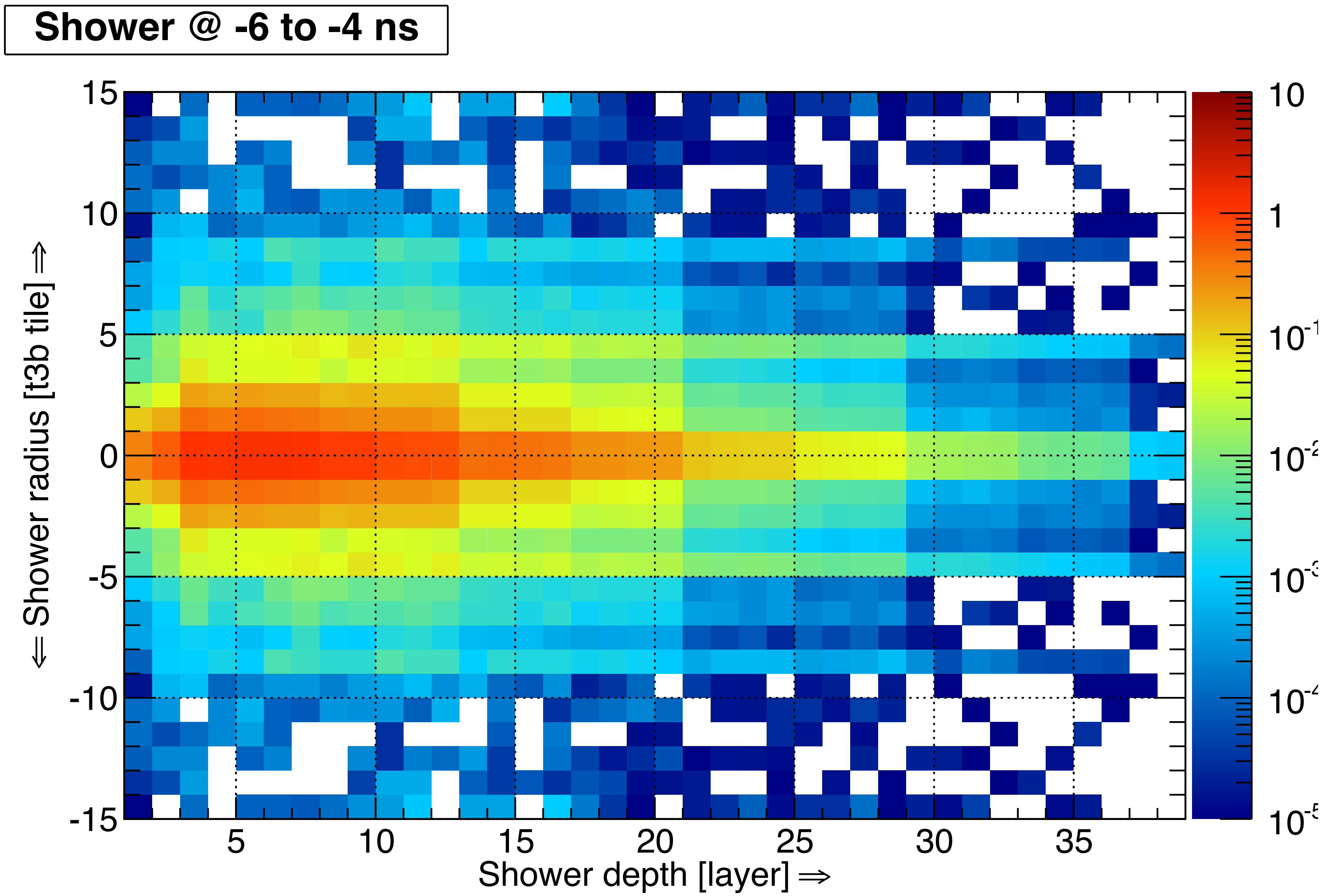

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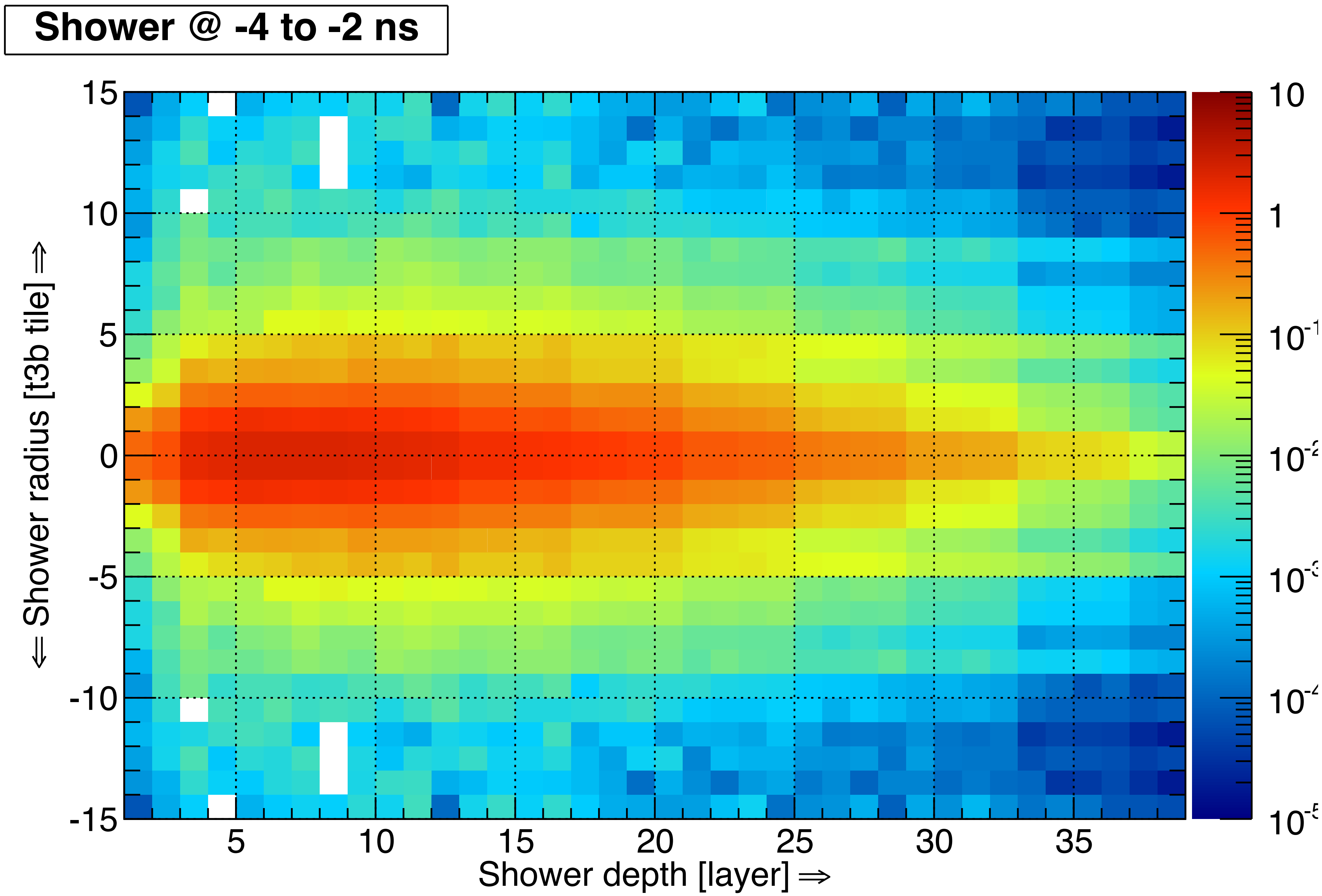

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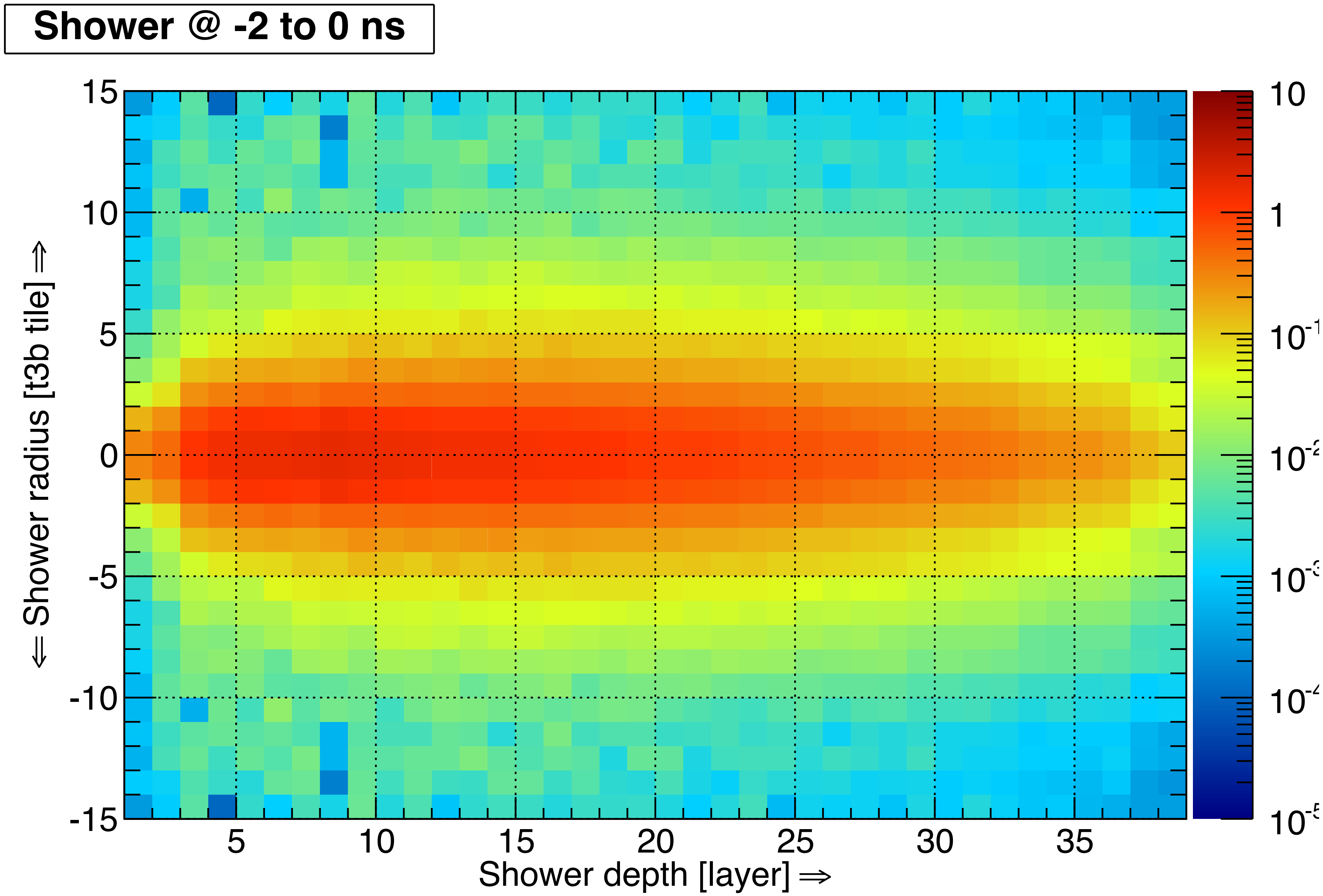

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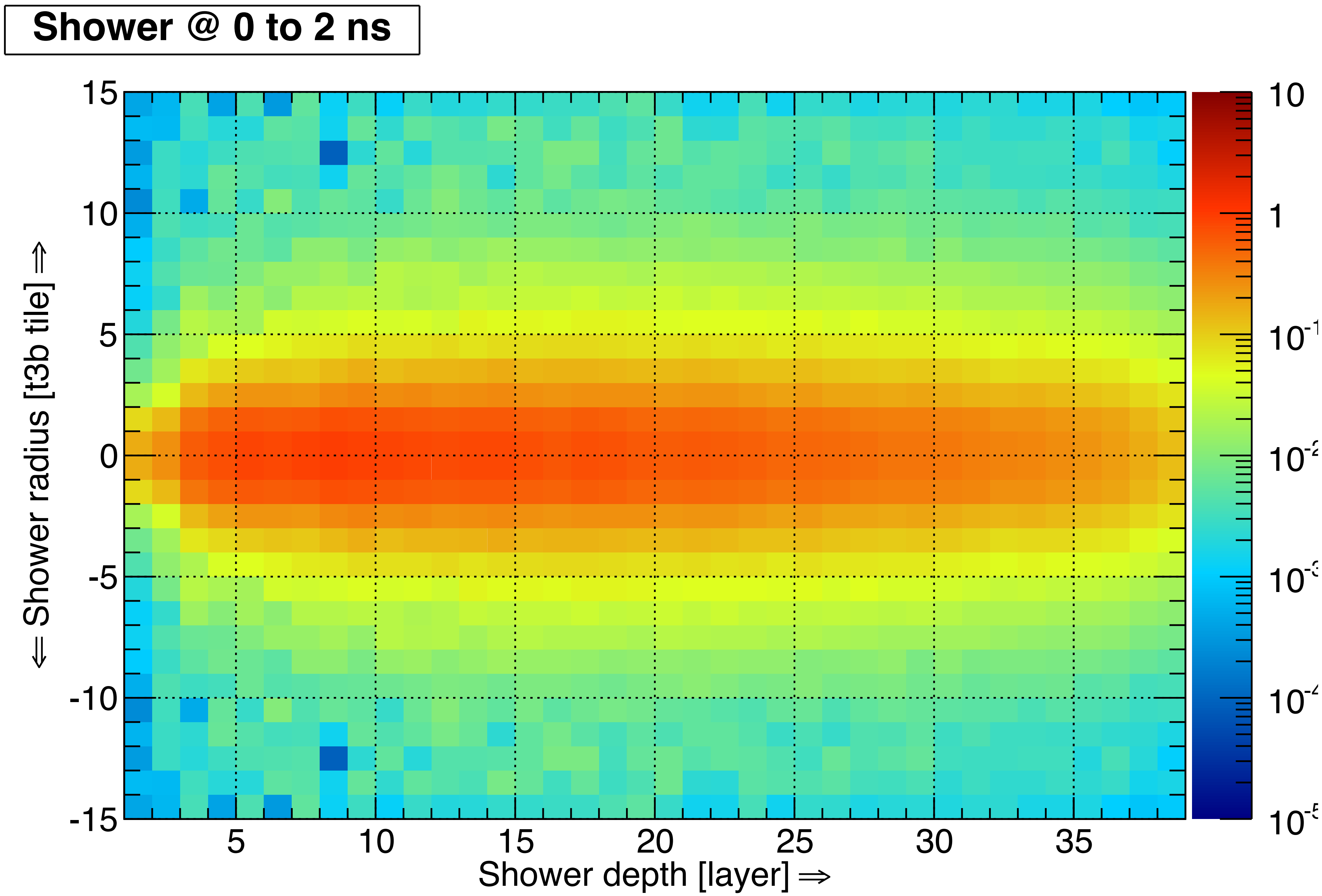

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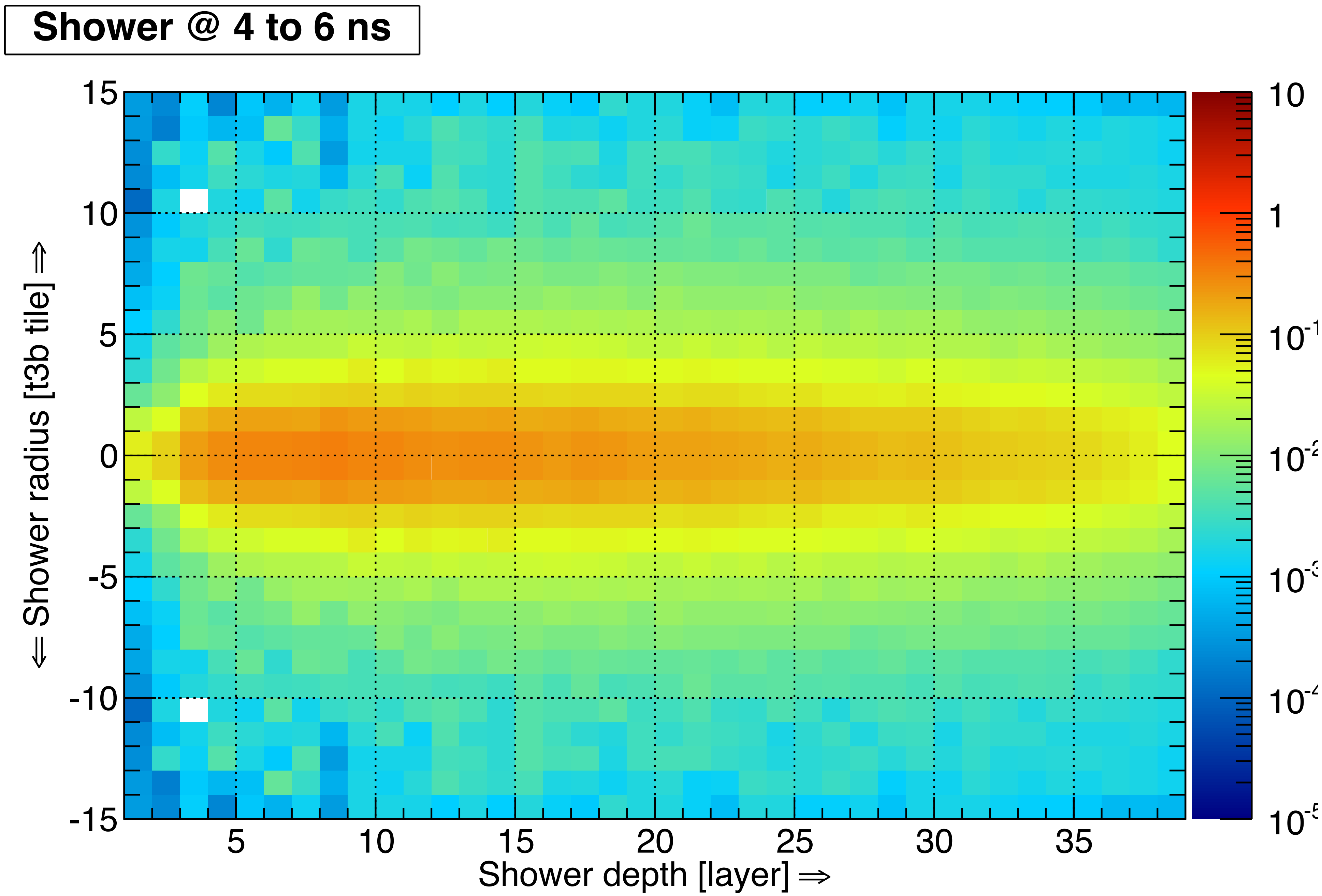

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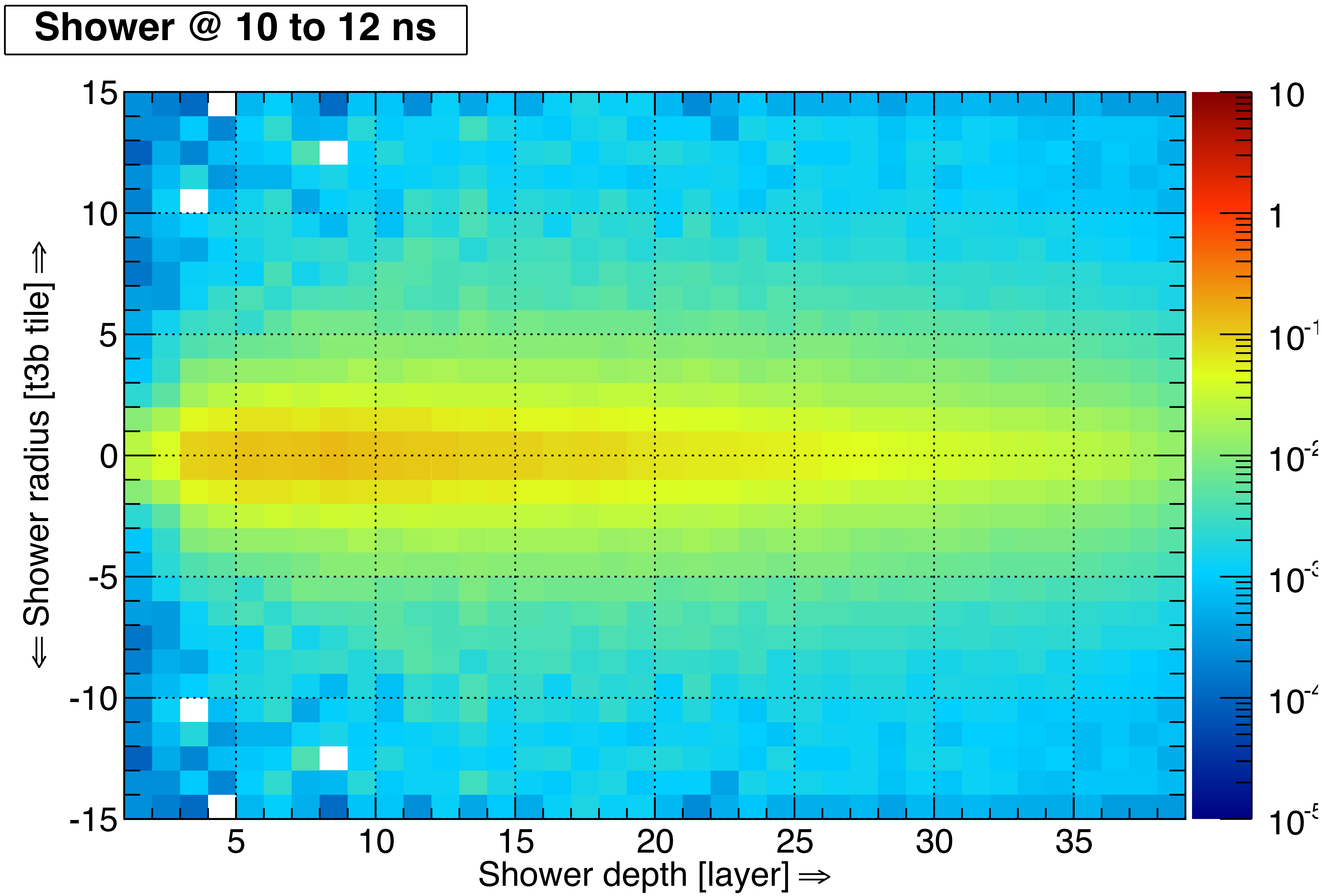

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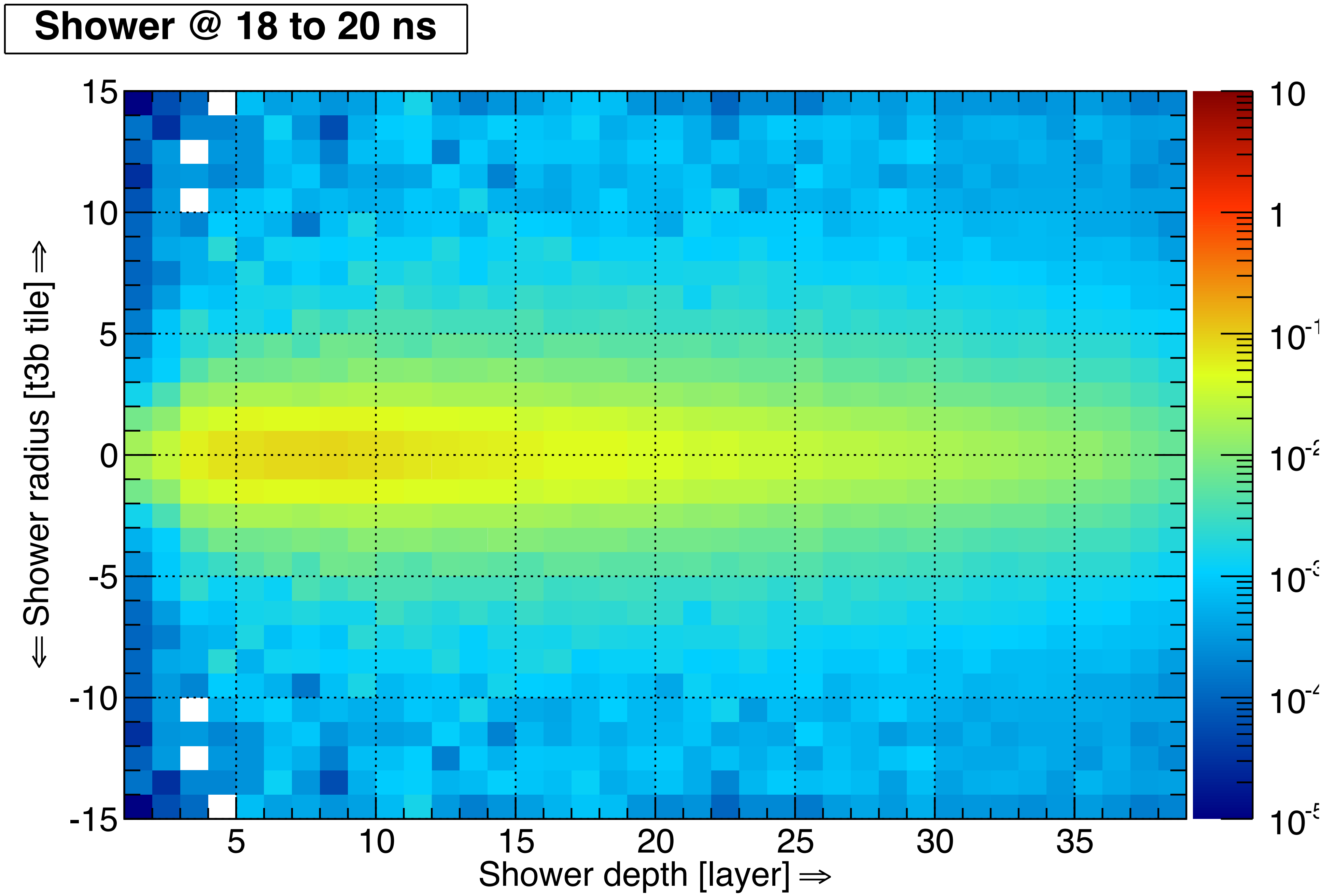

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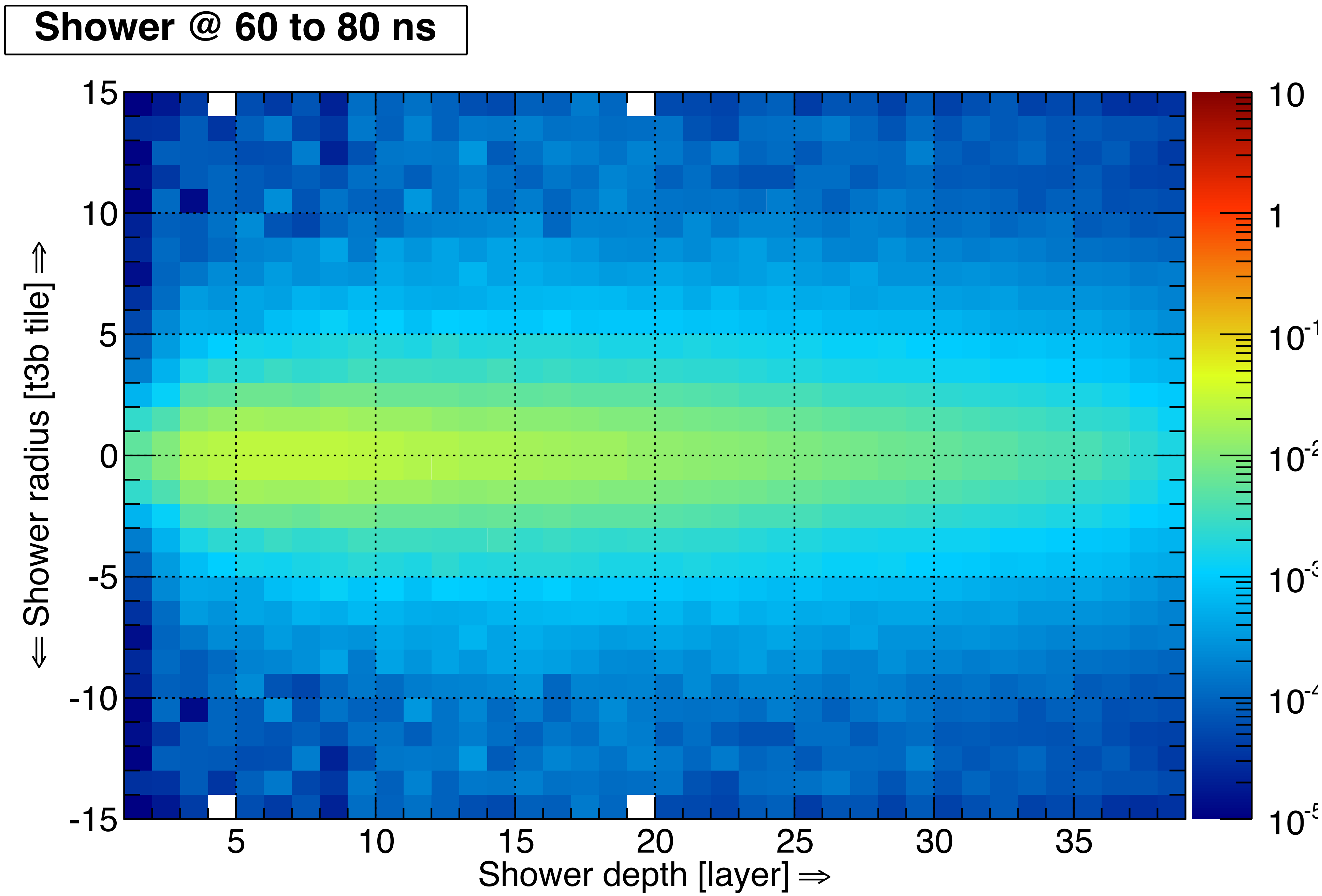

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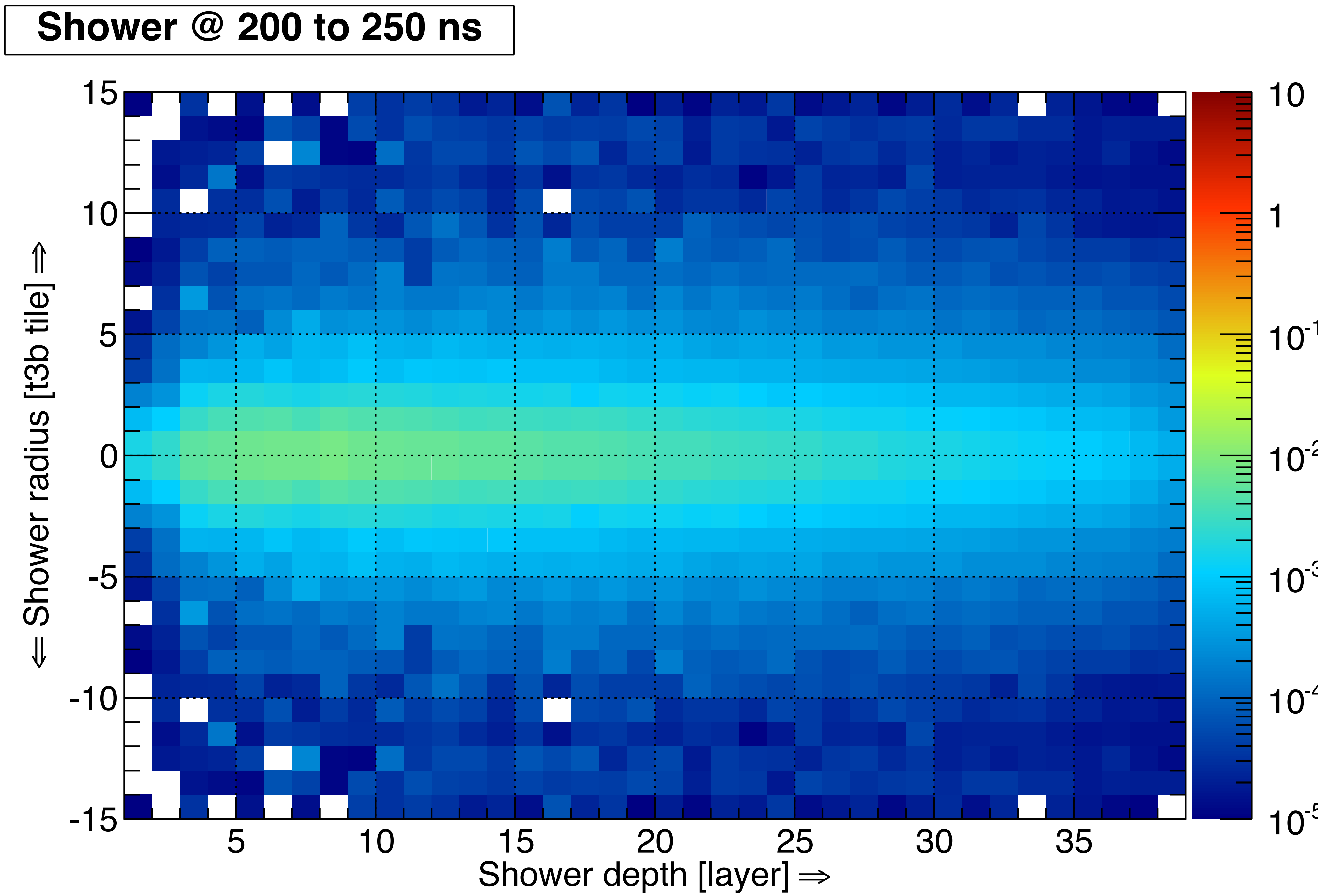

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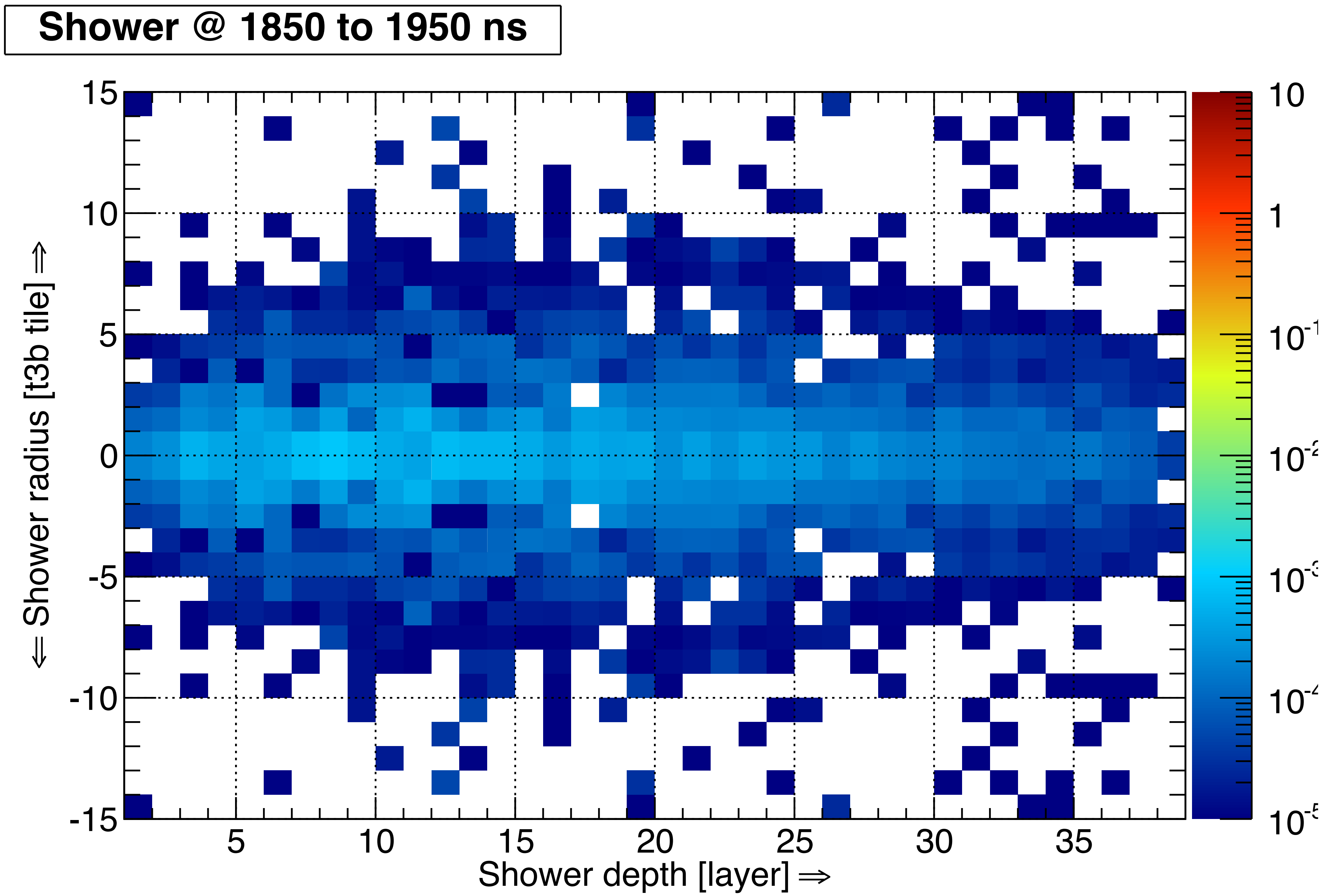
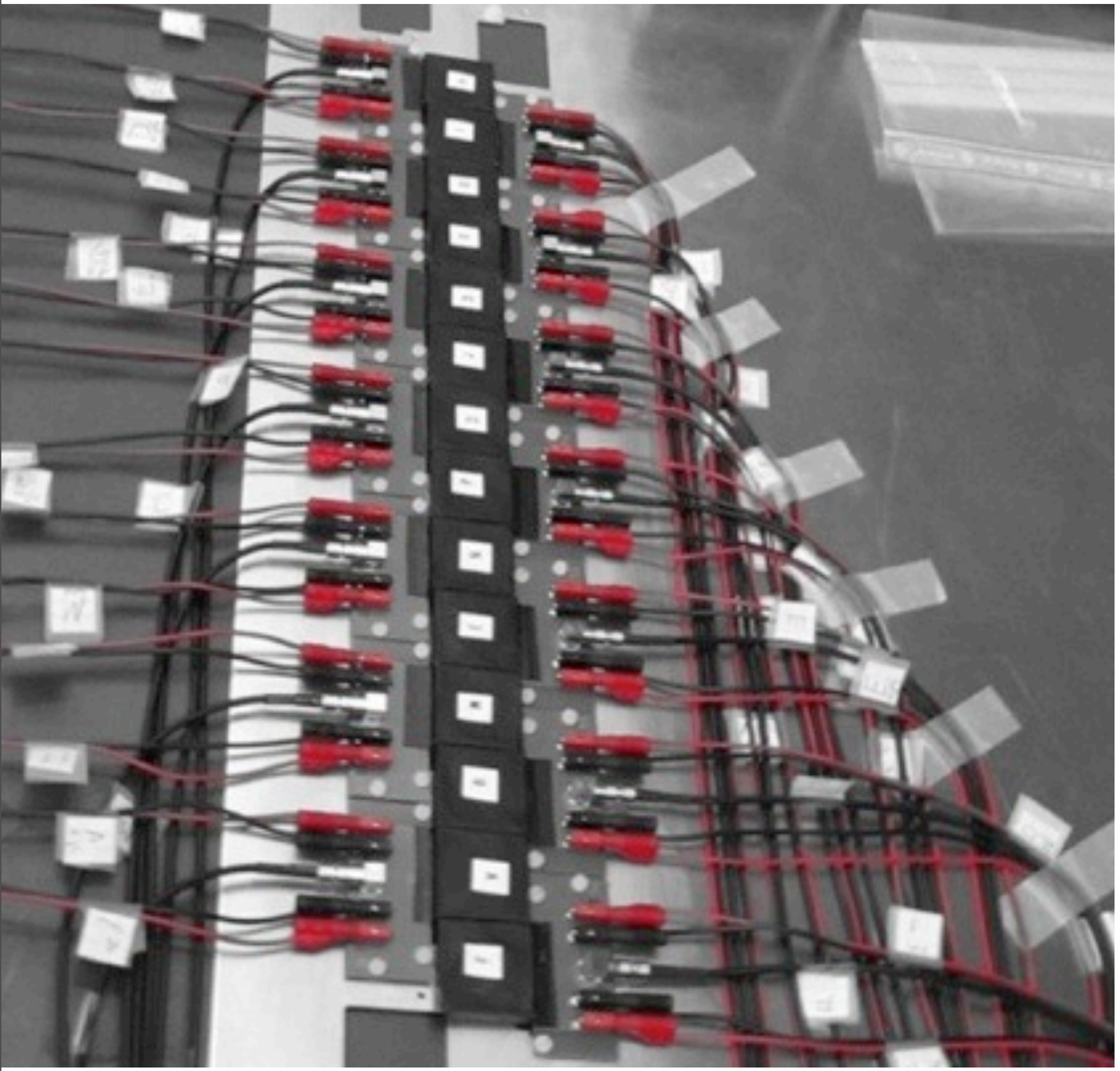
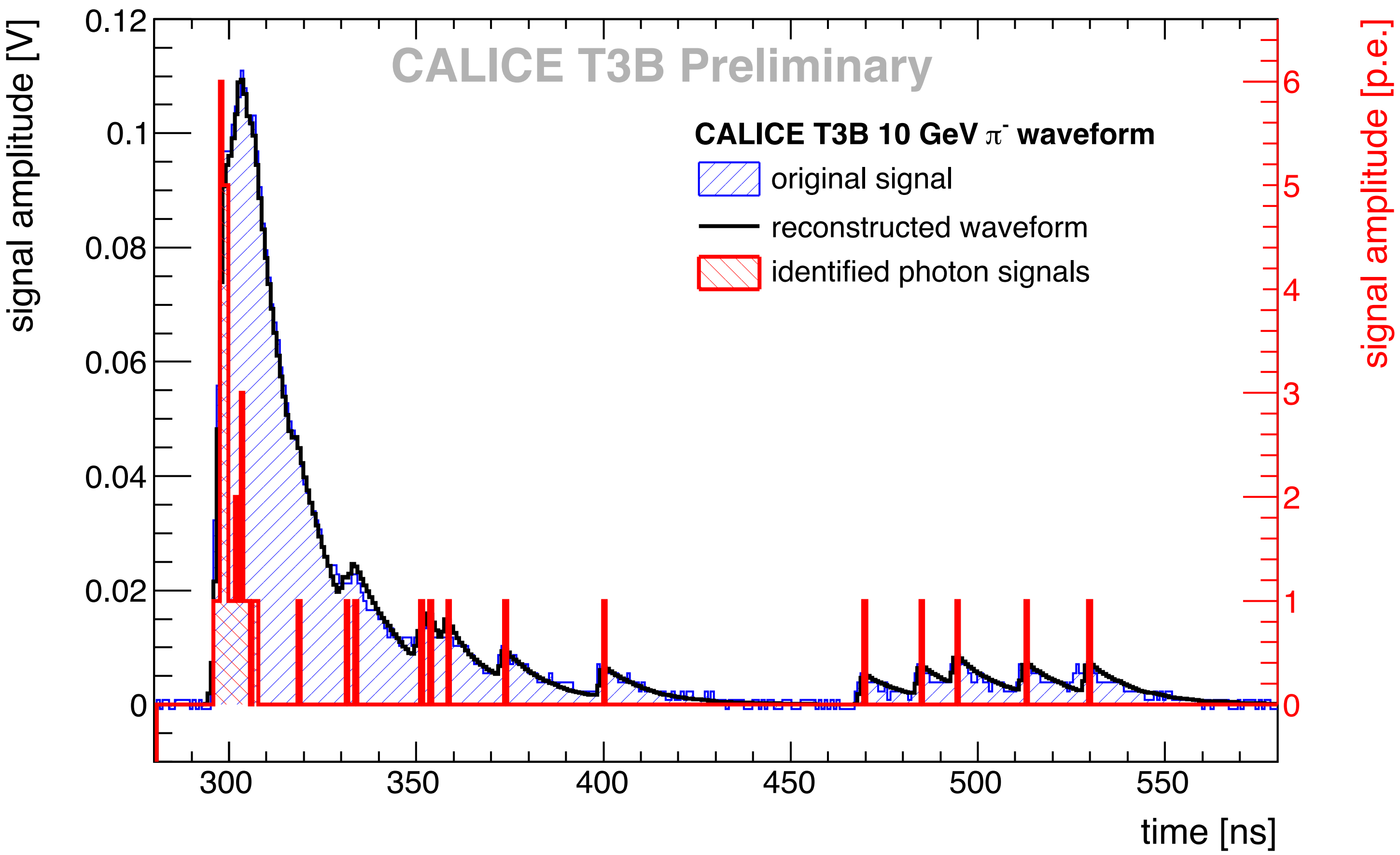


T3B - The Technique in short

- Has run together with W-AHCAL (layer 39) and SDHCAL (behind layer 50)
  - 15 scintillator cells (direct coupling), read out with fast digitizers over 2.4 µs with 800 ps sampling
  - Identify the time of arrival of each photon on the SiPM - Measure time structure of response by averaging over many events





Signal on one tile, decomposed into individual single photon signals

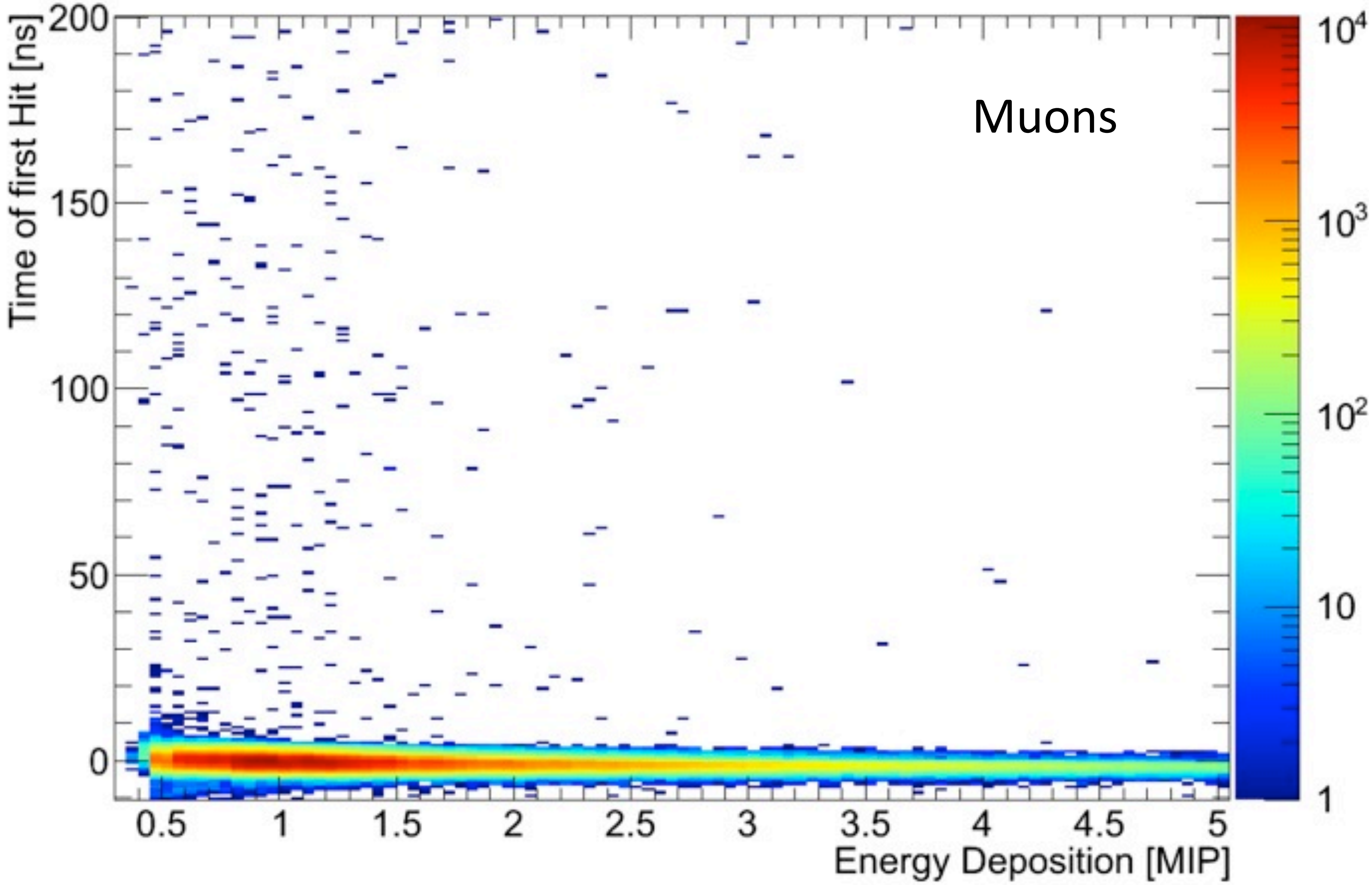
Analysis & Simulations

- Analysis:
  - With the WAHCAL, event-by-event correlation is possible: Identification of shower start, measurements as a function of shower depth, main focus still on integral measurements
  - SDHCAL: No correlation, only integral measurements
  - In general: Time of first hit, corrections for afterpulses to measure time of hit still under test
- Simulations:
  - Comparison to Geant4 crucial - Using 4.9.4p2, due to timing problem discovered in 4.9.5
  - Now: Improved digitization, based on muon reference data to take time structure of instantaneous signal into account (including afterpulses etc.)

Basic Results - Time of First Hit

Data Analysis: The Starting Point

- Identified first hits as a function of hit amplitude (calibrated with muons to the MIP scale)



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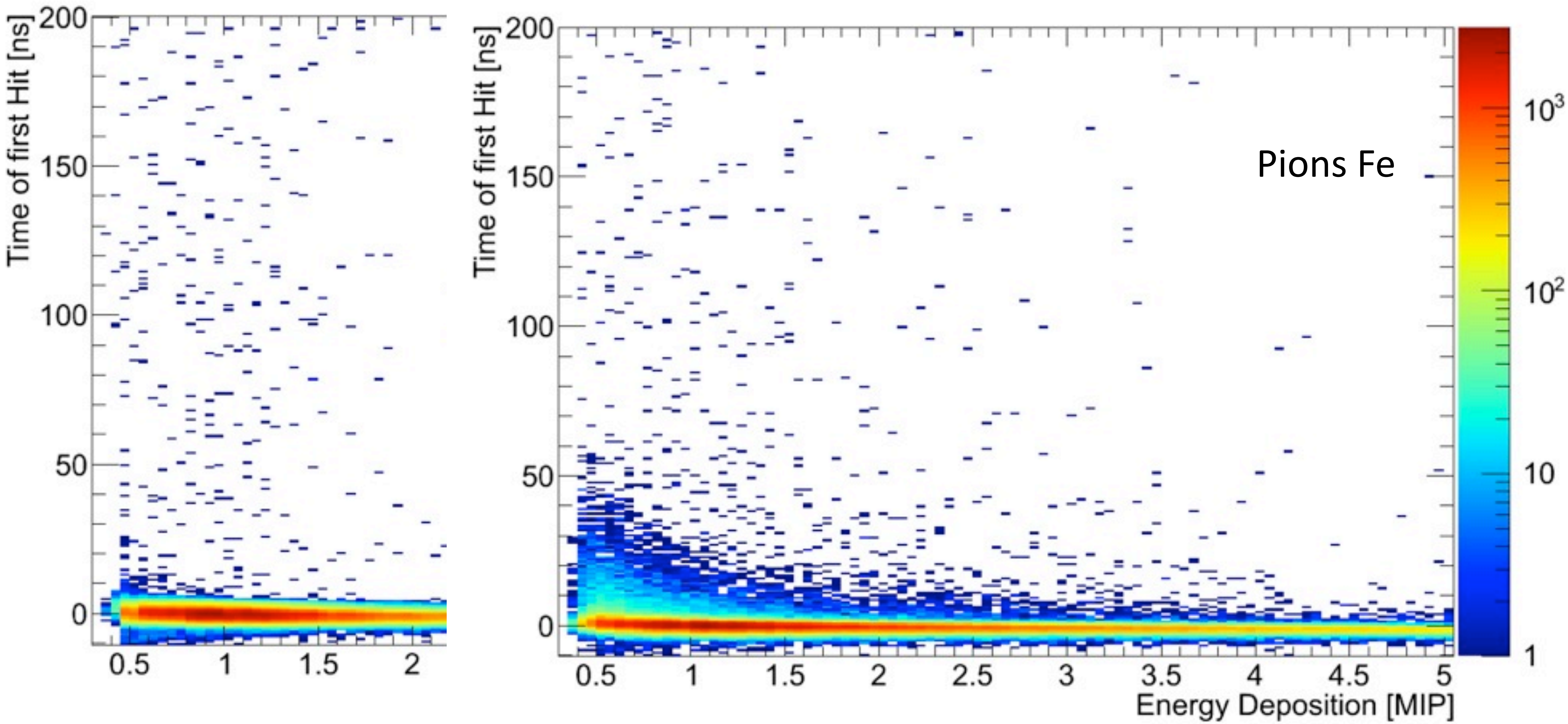

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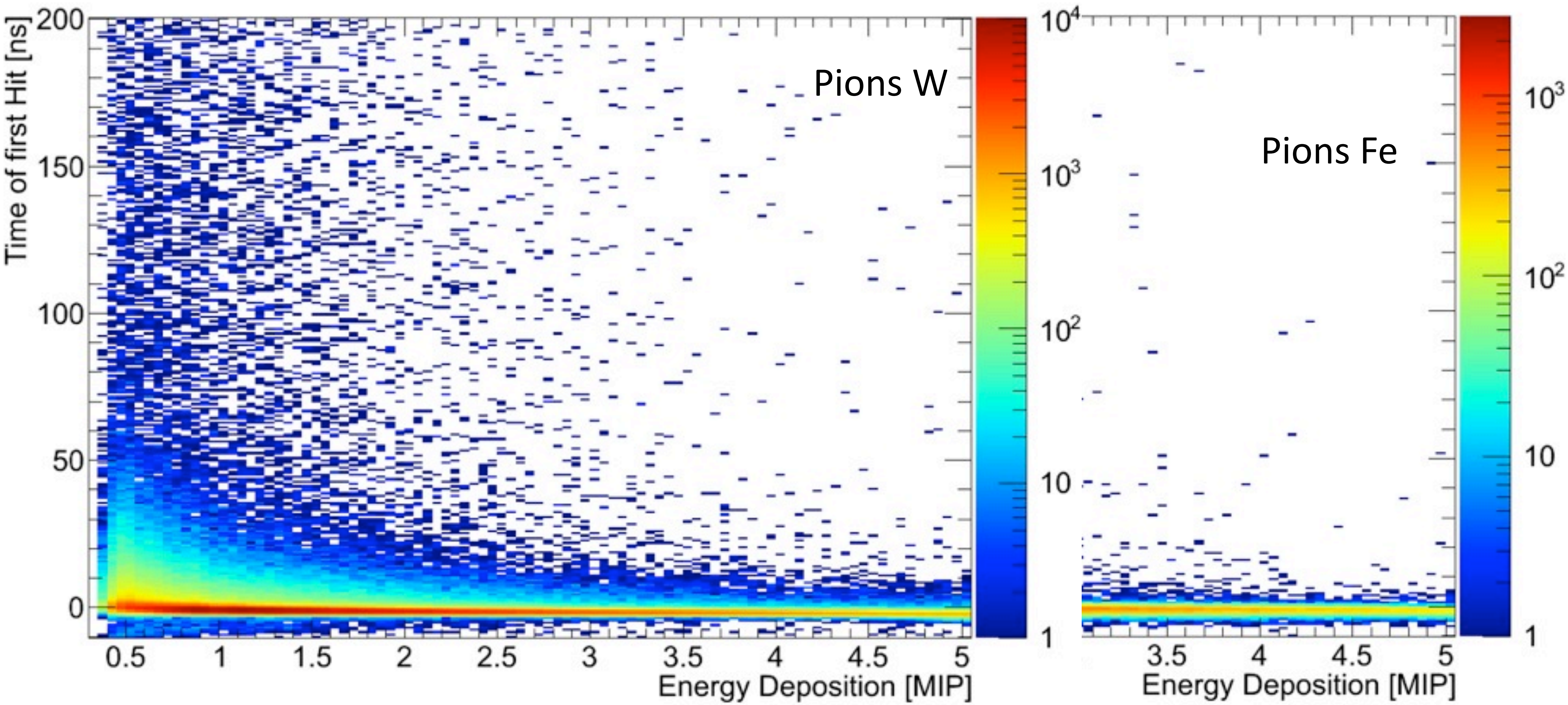
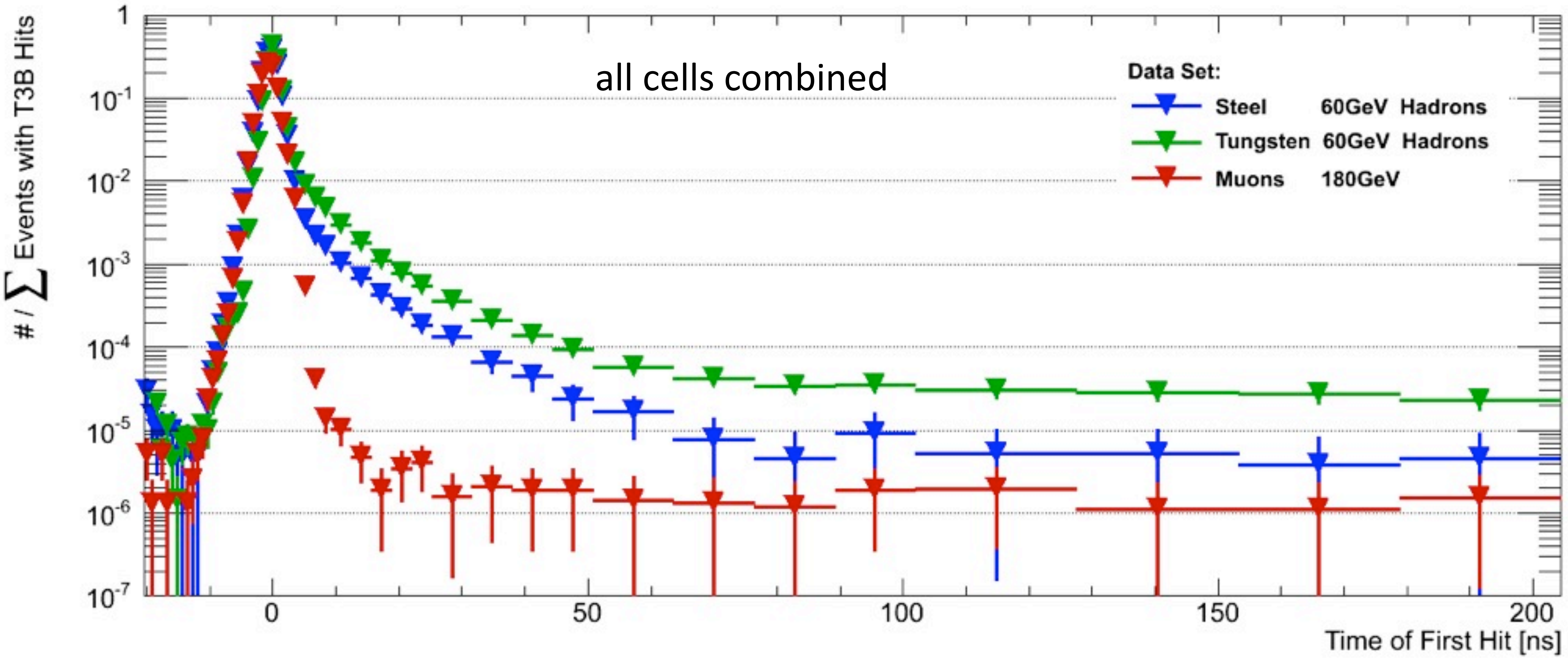
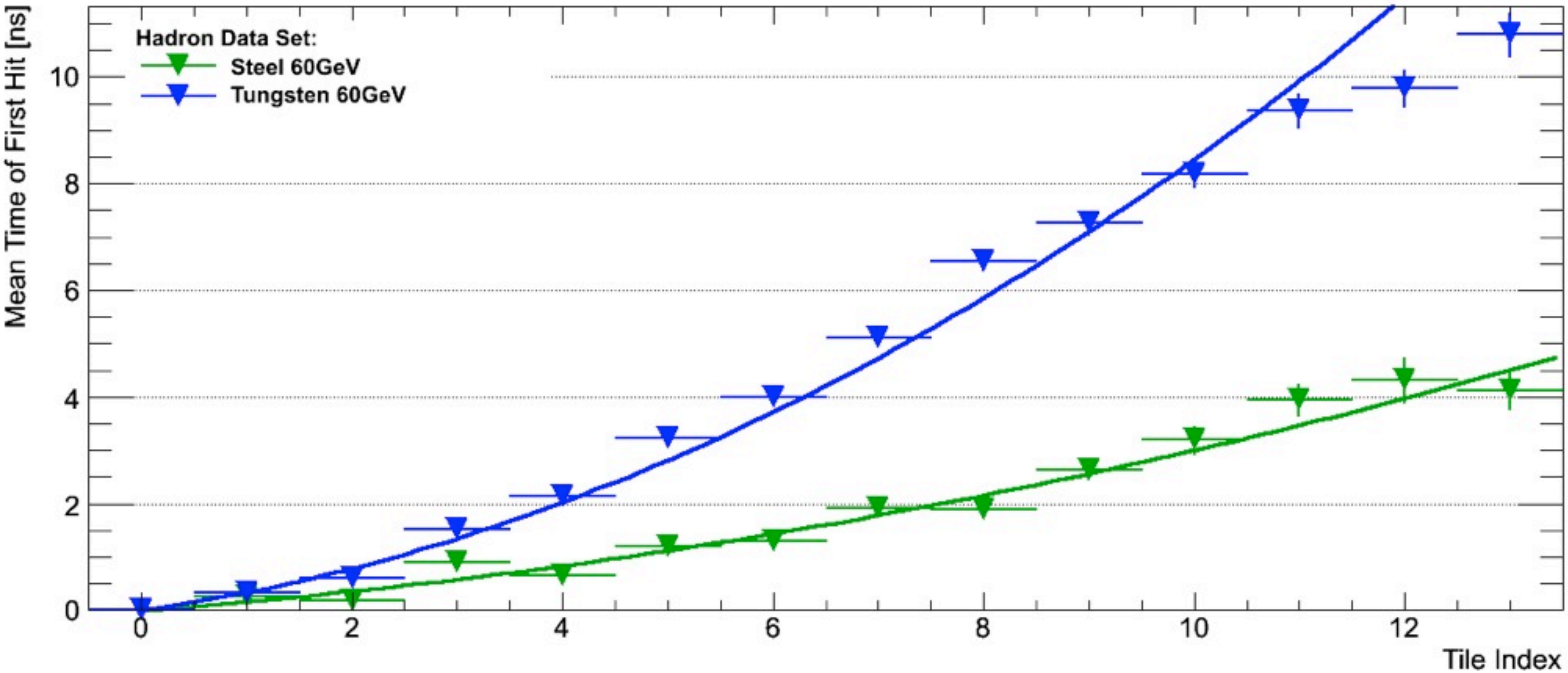


Late Activity in different Absorbers



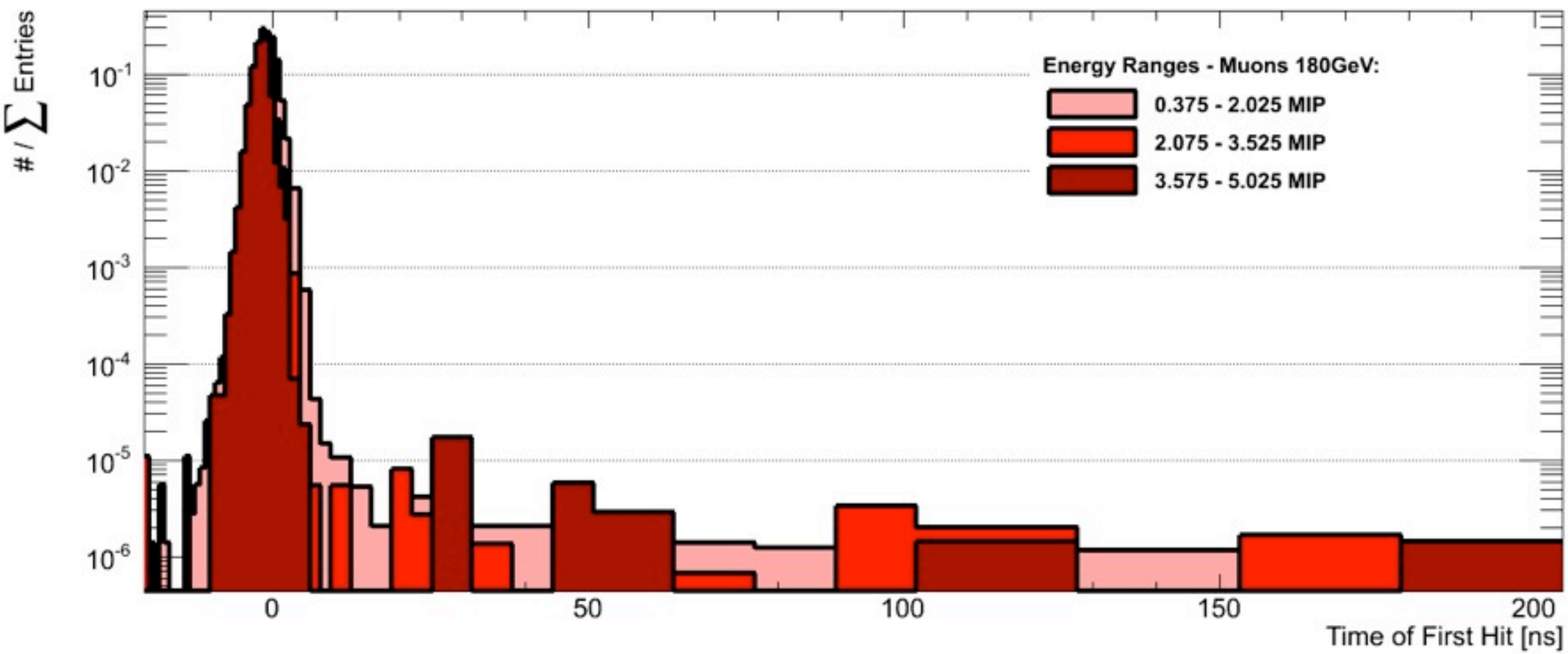
- Hadronic showers show considerable late shower activity
  - Significantly more pronounced in Tungsten than in Steel

Late Activity in different Absorbers



- In general, hits in the outer shower region tend to be later than hits close to the core (fully expected!)
- In Tungsten this behavior is more pronounced than in Steel

Energy & Hit Timing



- Late shower activity depends on energy of deposit: predominantly at low energies (for muons no dependence visible)

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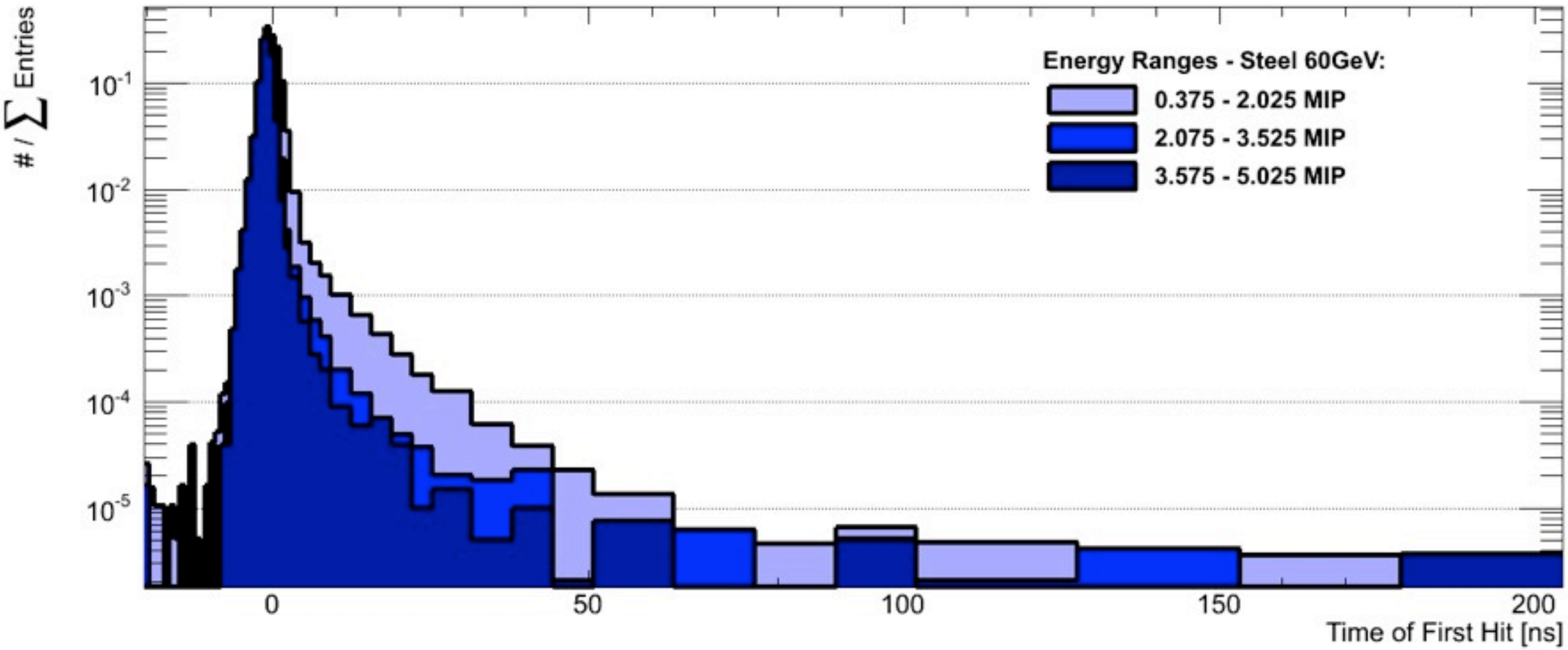

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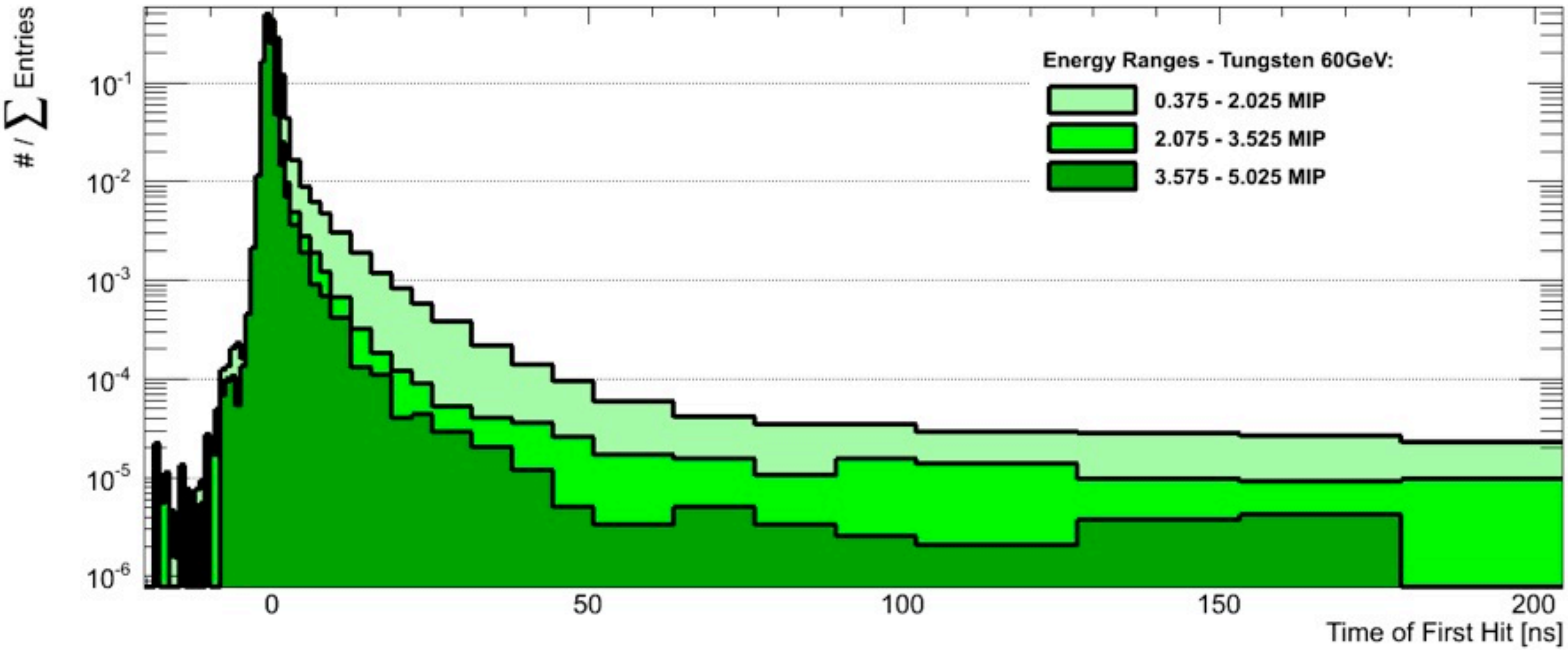

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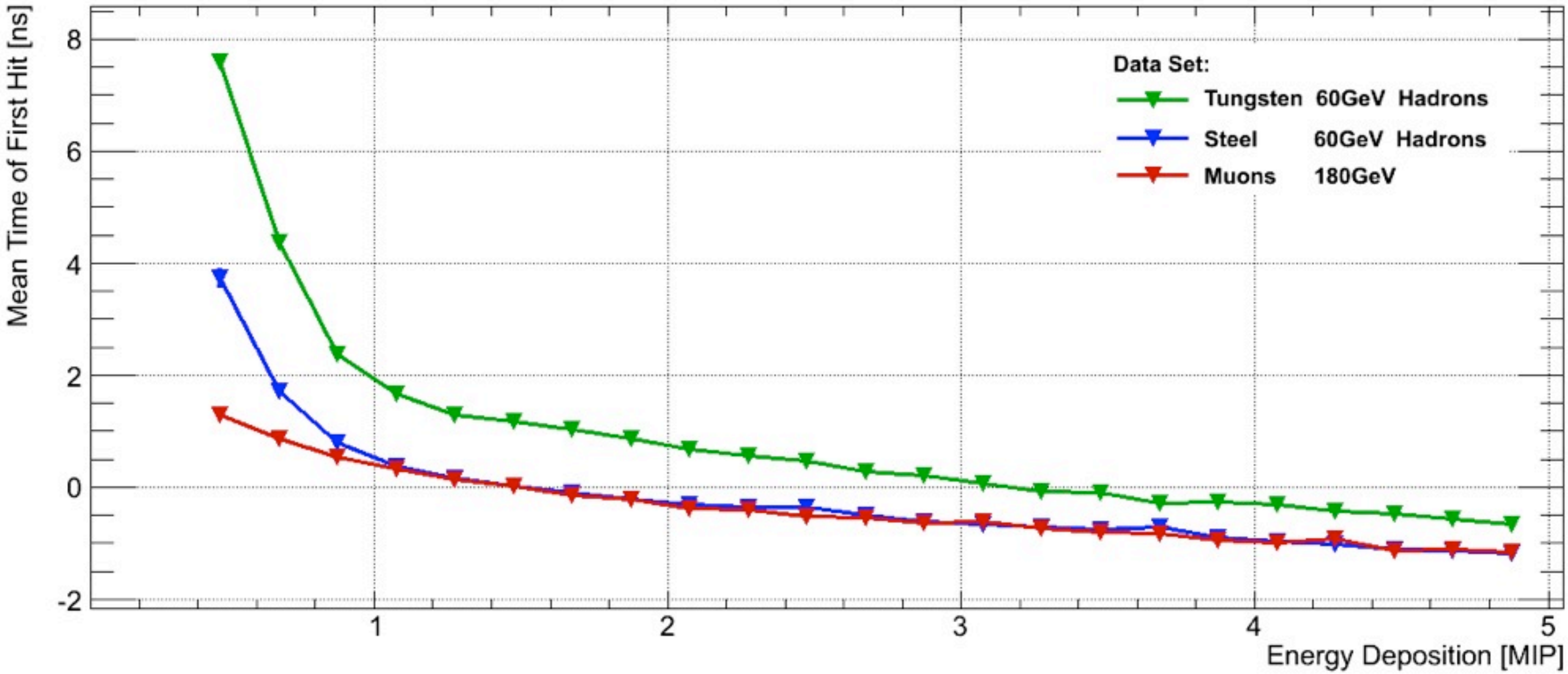
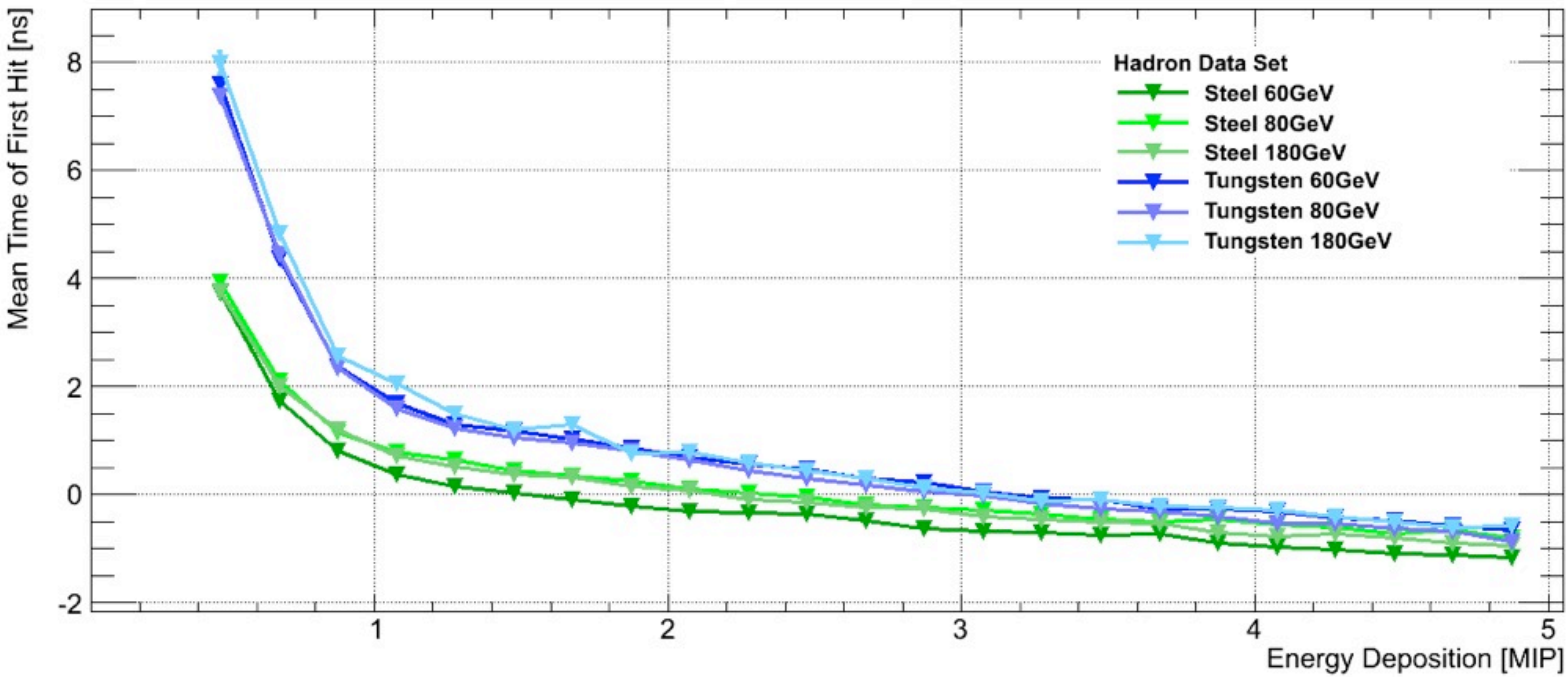


- Late energy depositions tend to be low in amplitude
  - For Steel: No significant late shower activity beyond 1 MIP
  - For Tungsten: Late activity also to higher amplitudes

Does Beam Energy Matter?



- Not much: Very little dependence on beam energy

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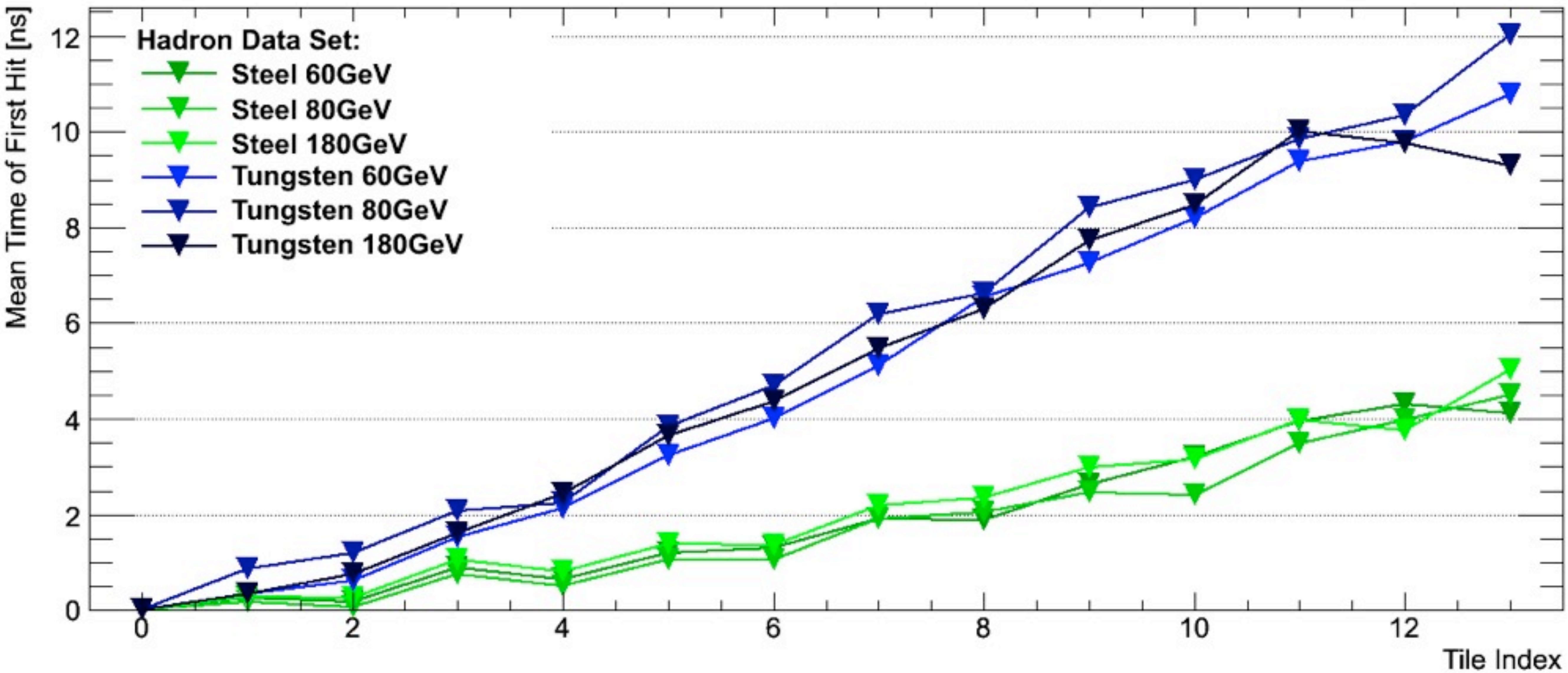

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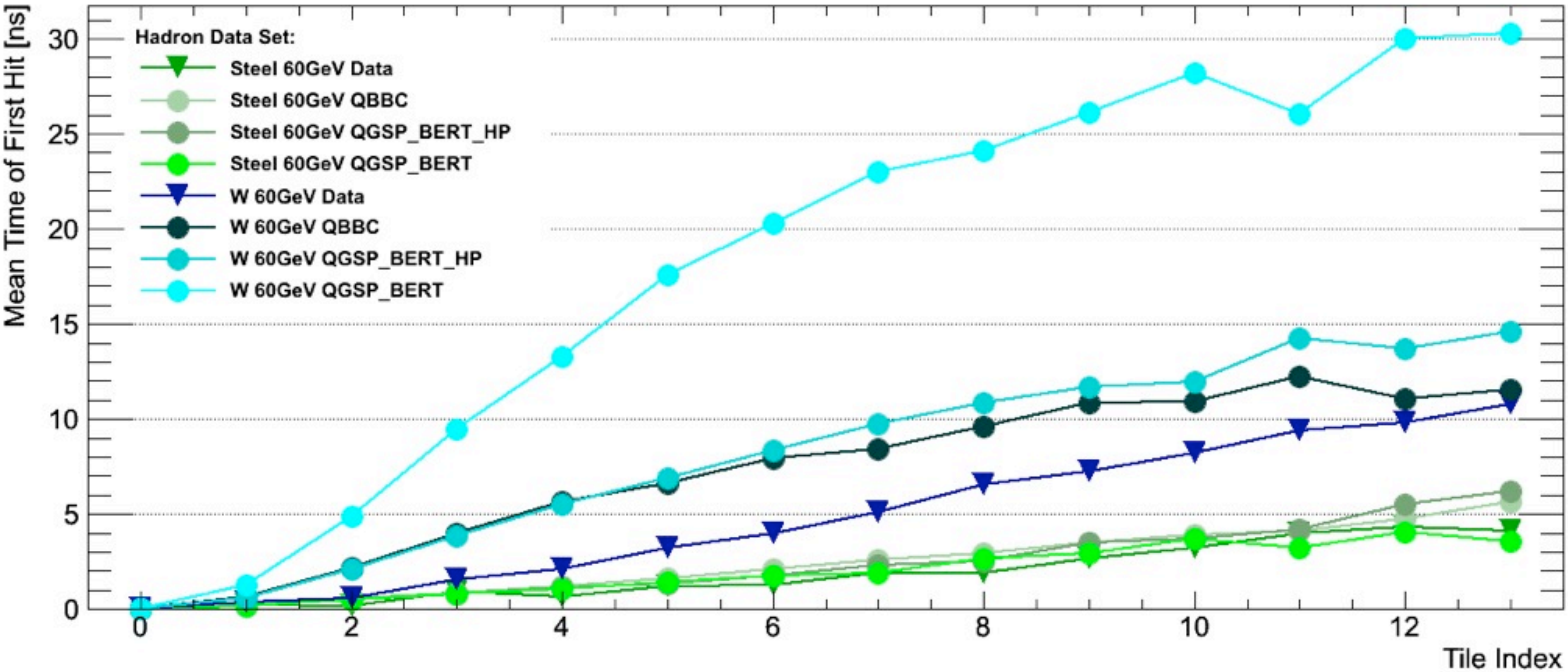
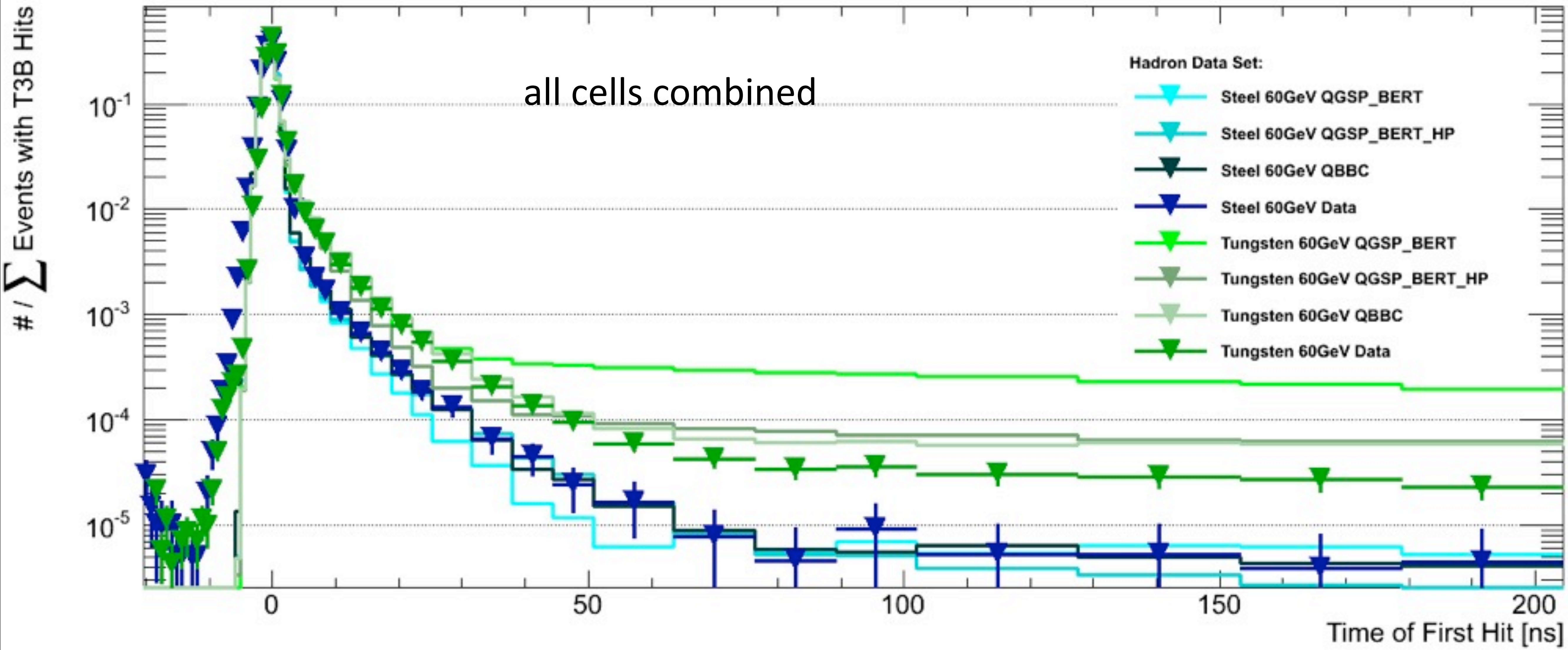
Can we reproduce it? - Comparison to Simulations

The T3B Classic: Time vs Radius



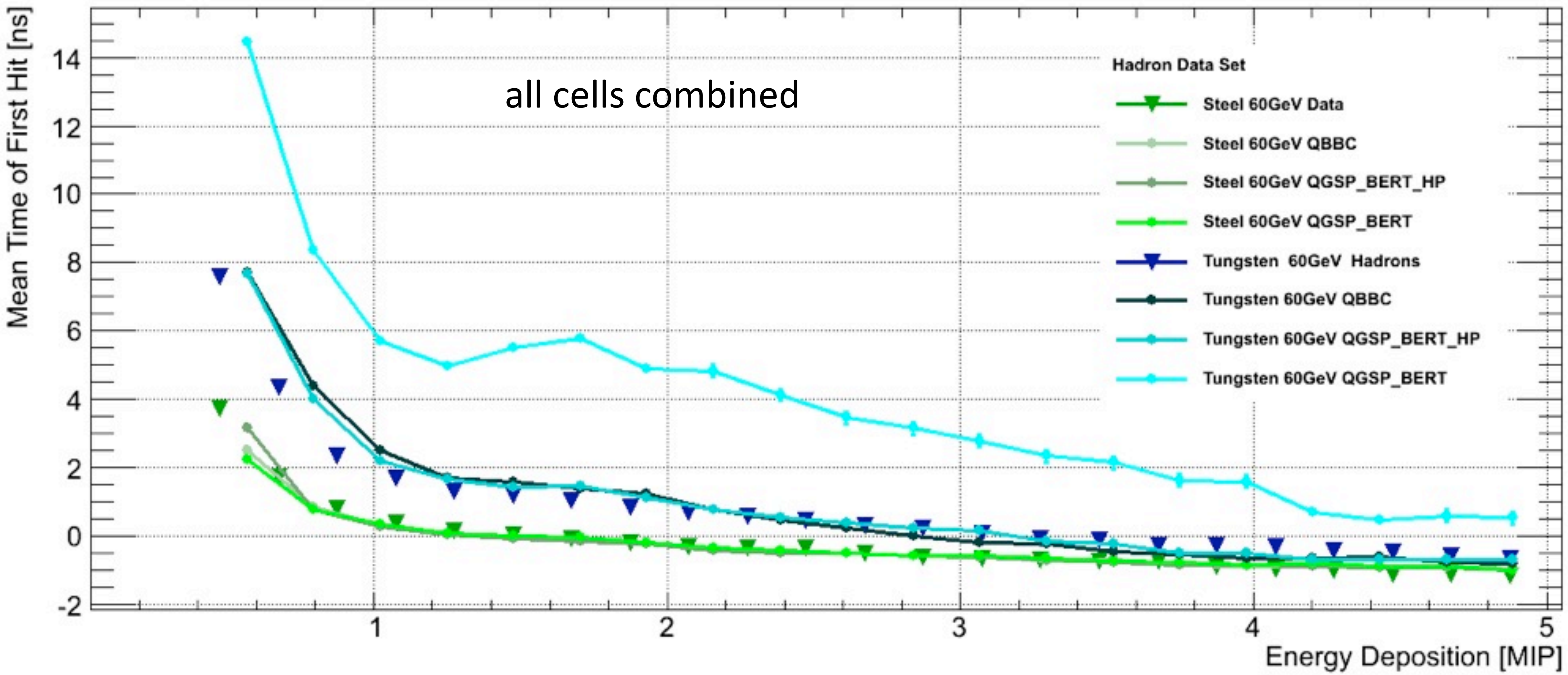
- Excellent agreement for Steel with all physics lists
- For Tungsten QGSP_BERT is far off, QGSP_BERT_HP and QBBC perform satisfactory (somewhat worse agreement than seen previously: Further developed simulation / digitization)

Distribution in Time



- For Steel: QGSP_BERT has too few hits at intermediate times , and slightly too much at high times: Fixes the mean
- For Tungsten: QGSP_BERT significantly overestimates late contributions, QGSP_BERT_HP and QBBC are slightly too high, QGSP_BERT_HP shows slight underestimation at intermediate times

Time vs Hit Energy

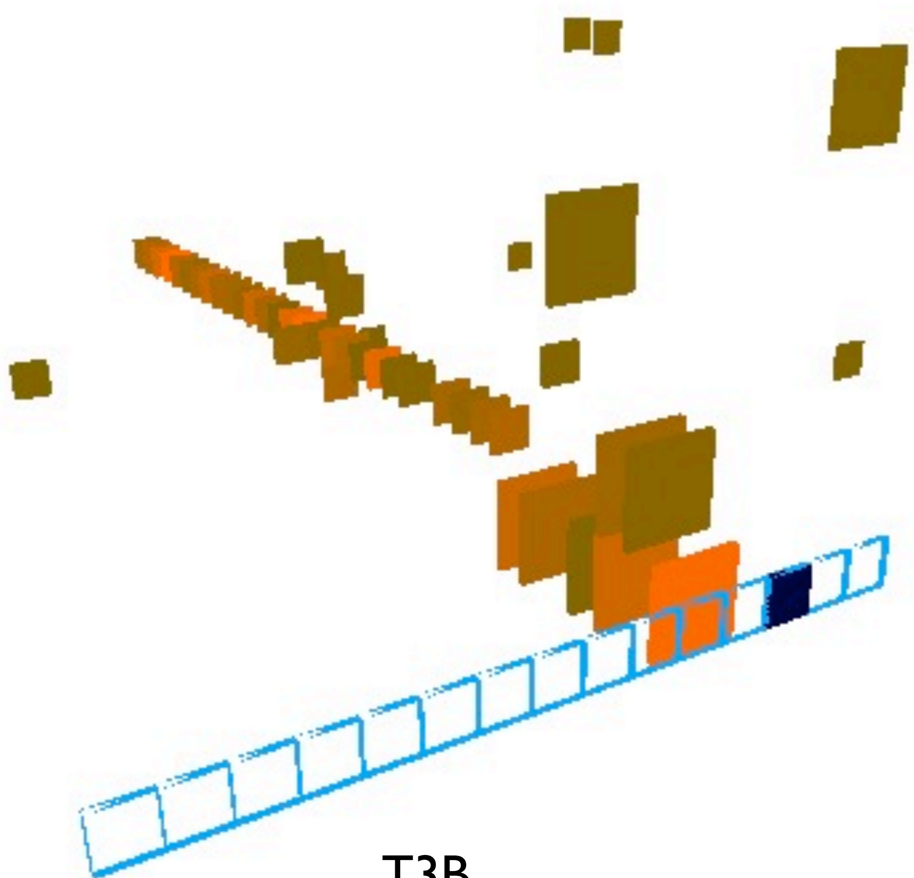


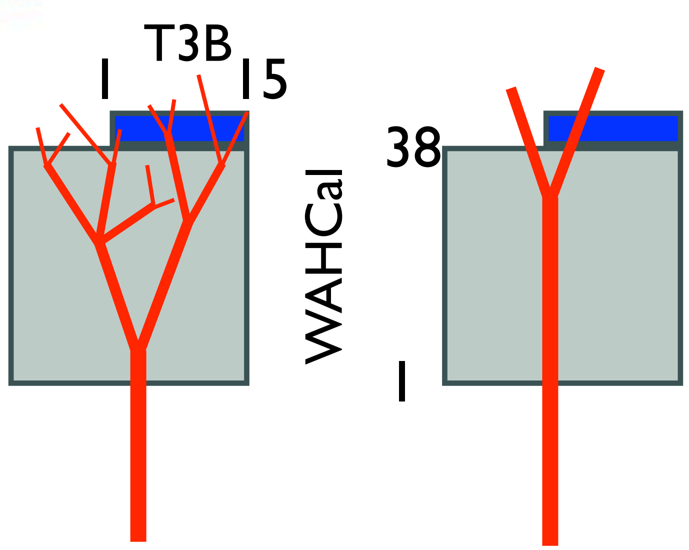
- Steel: All models reproduce data well
- Tungsten: Trend is reproduced by all models, QGSP_BERT has significantly too many late hits at all energies

Adding Depth

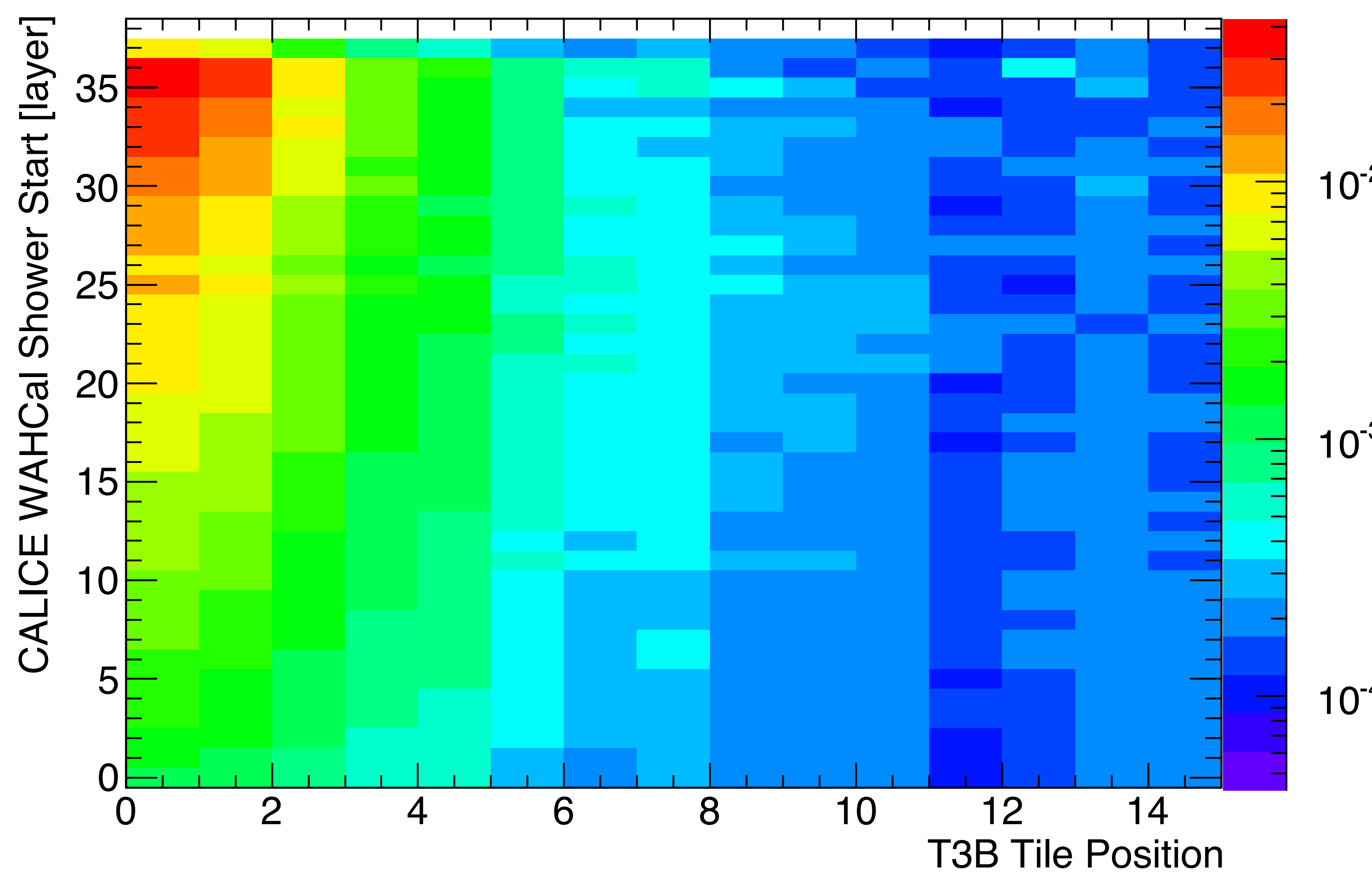
Measurement of Shower Depth

- Correlation of T3B events with W-AHCAL (not possible with SDHCAL)
  - Spill-by-spill matching of event numbers, then sequential matching

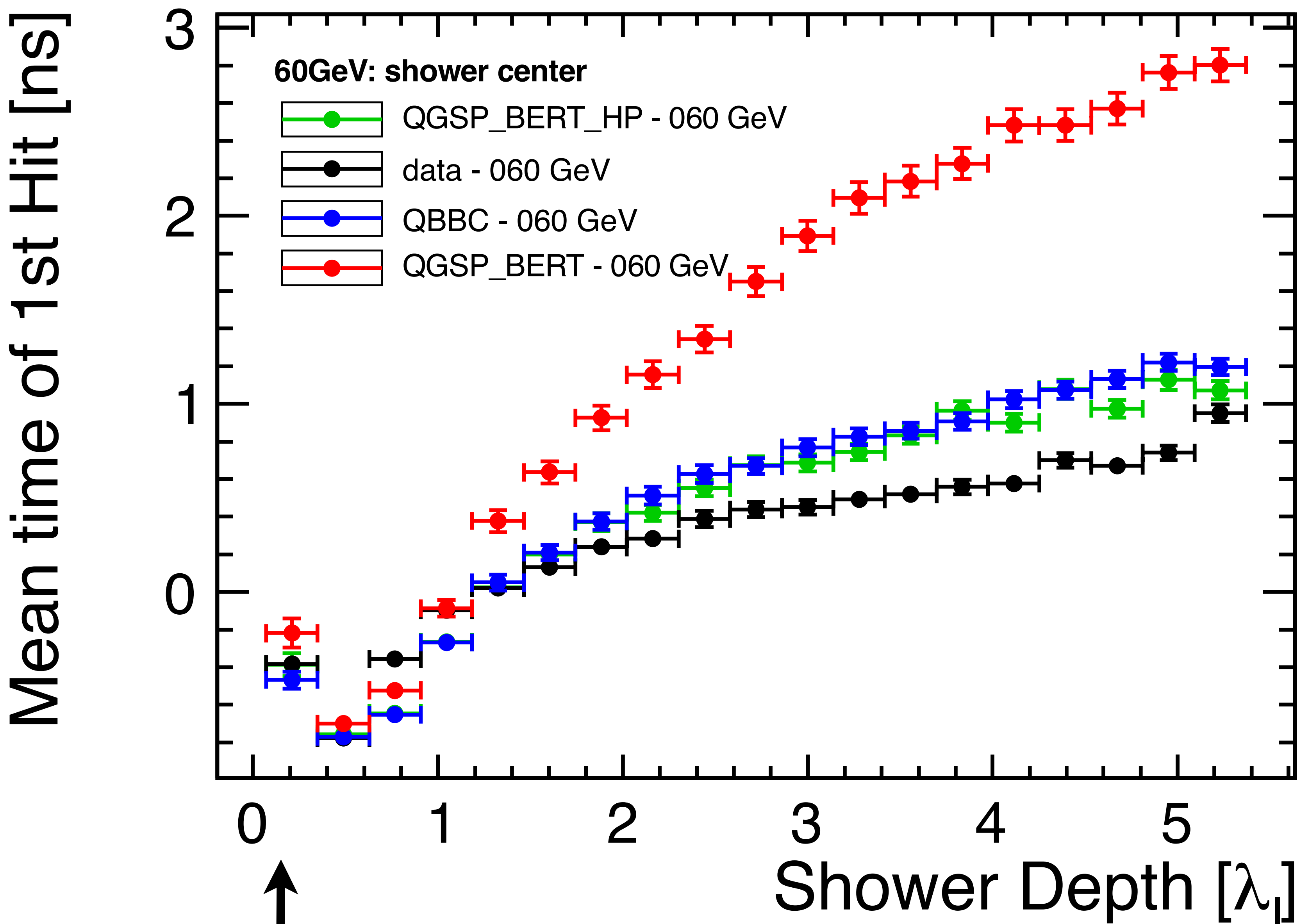




- Identification of shower start based on Marina’s shower start finder - uses increase in hit multiplicity and energy, ~ 1 layer resolution



Mean Time of 1st Hit vs Shower Depth



shower start directly in front of T3B

shower start early in W-AHCAL

- Shower start in simulations: endpoint of primary particle due to inelastic interaction
- QGSP_BERT shows large discrepancy deep in the shower, ok in first λ (dominated by prompt em-component)

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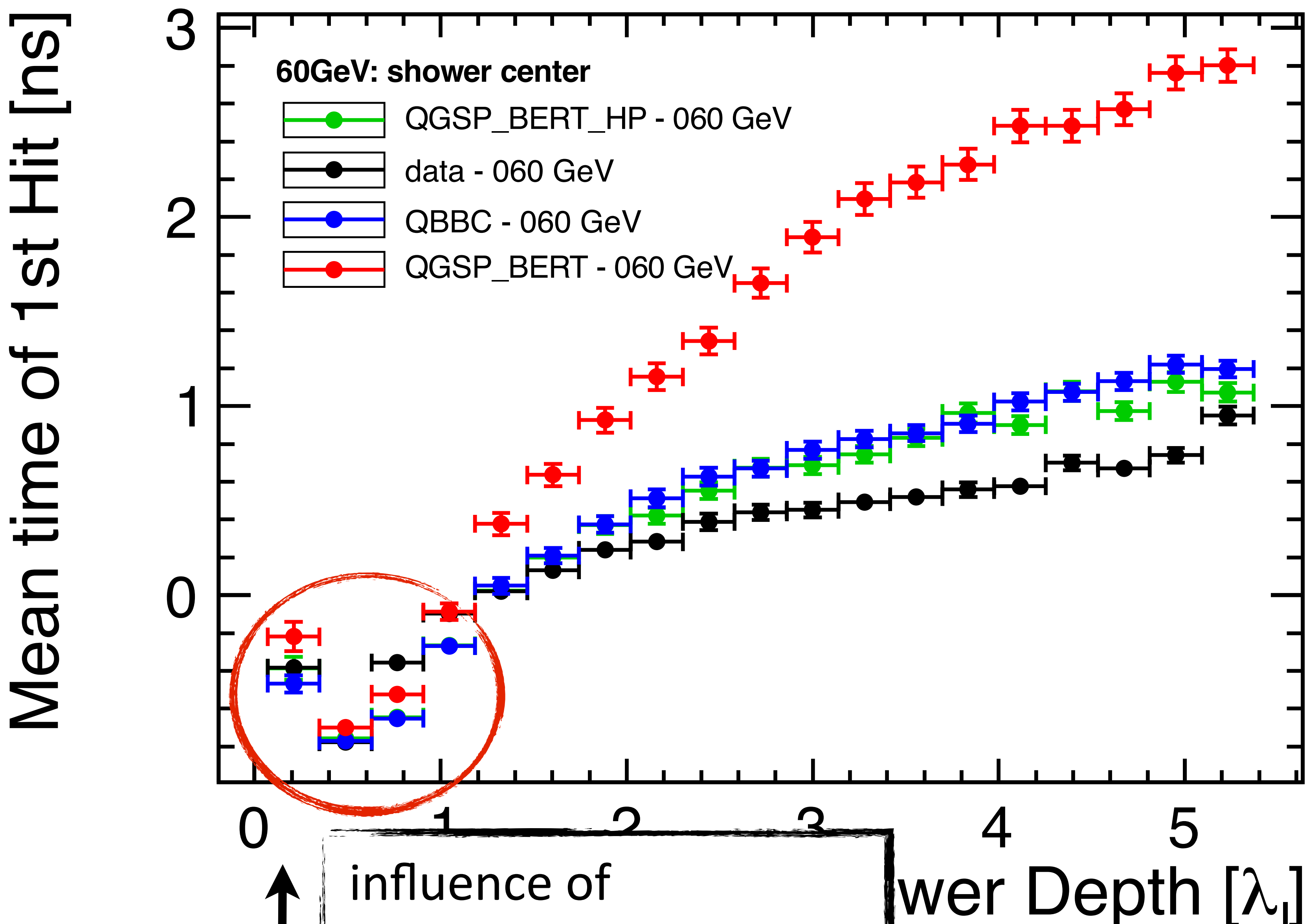

influence of high-amplitude hits in em-subshowers

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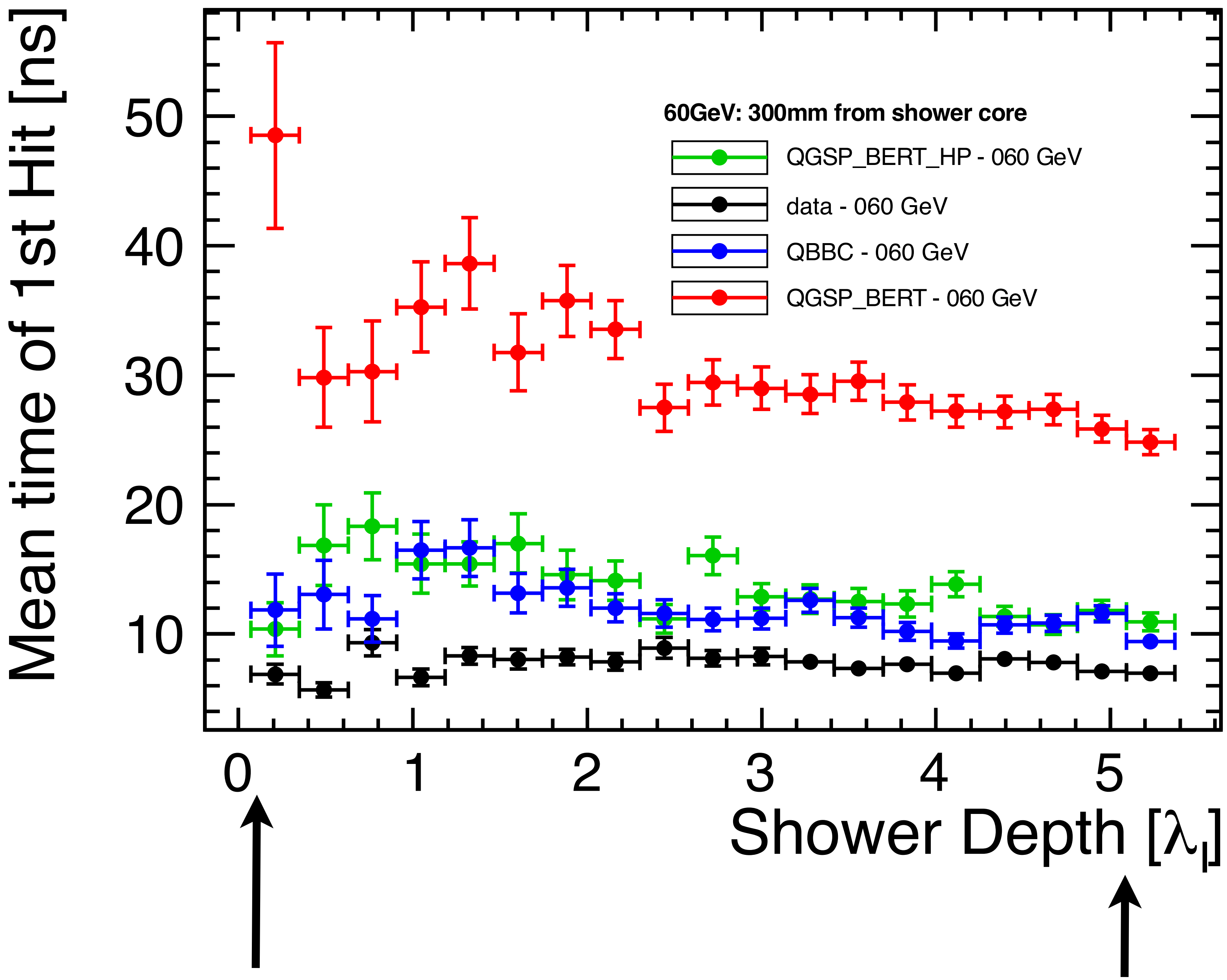
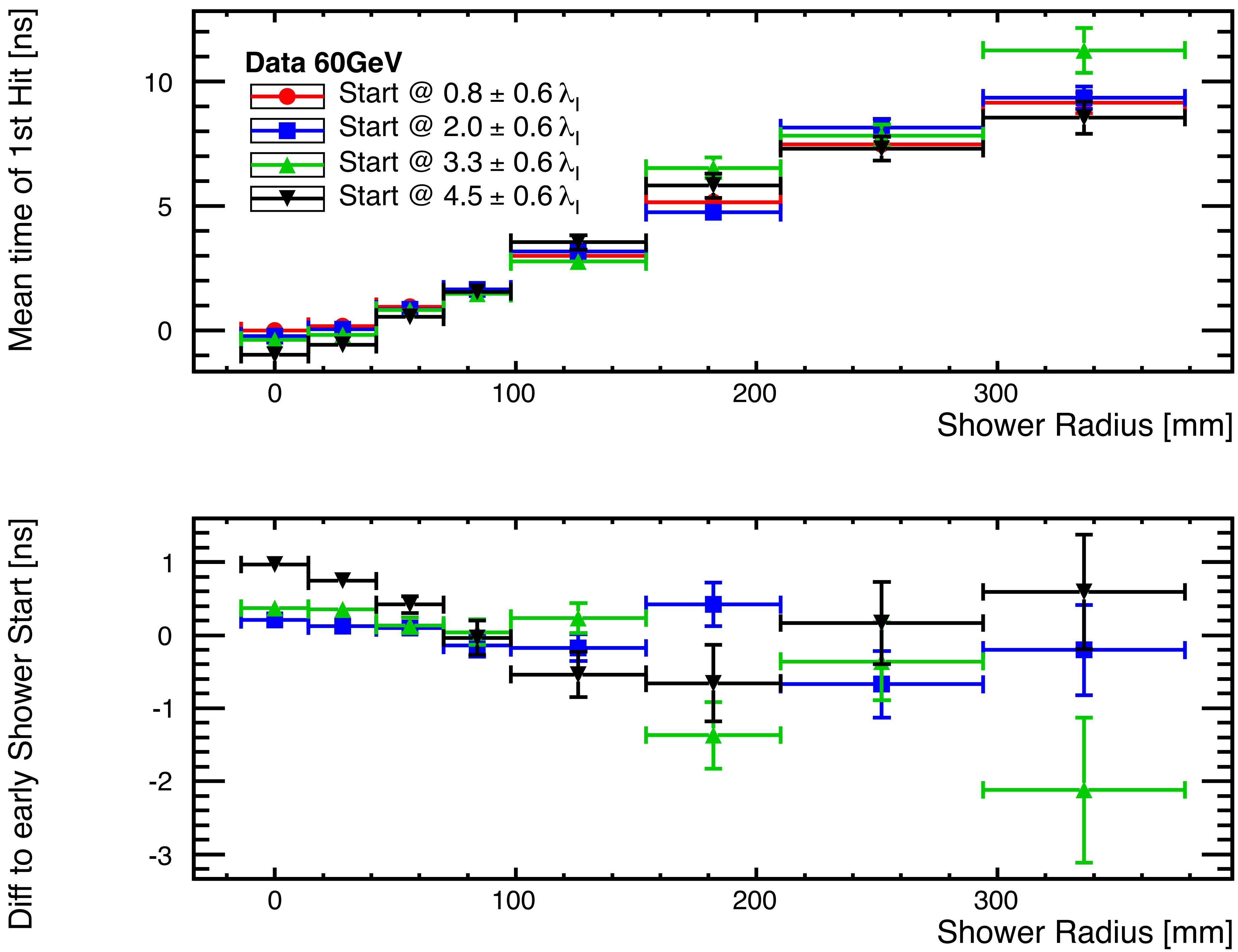


shower start directly in front of T3B

shower start early in W-AHCAL

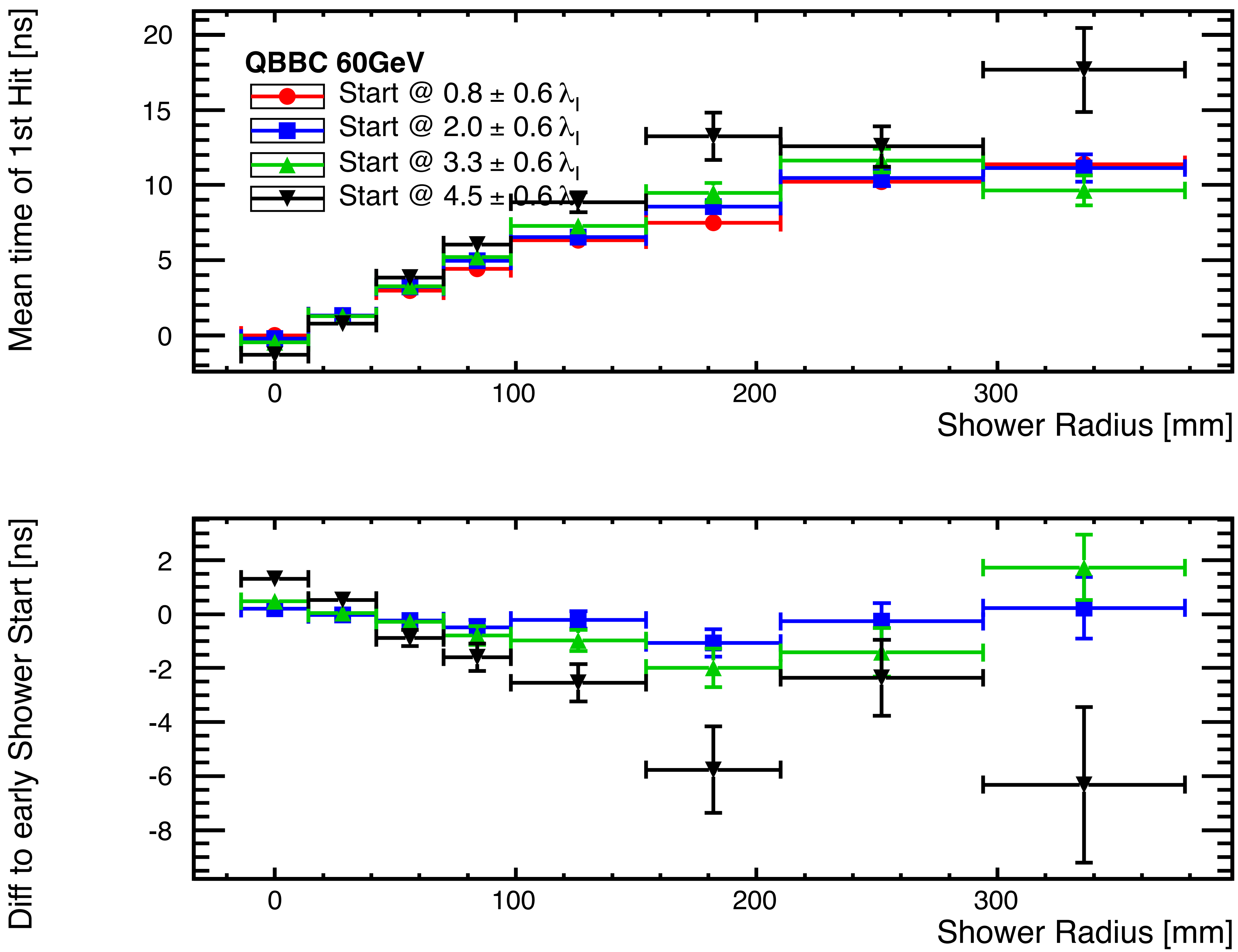
- Outside of shower core no significant dependence of mean time on depth (note the scale and the size of uncertainties!)
- QGSP_BERT far off, others do better (but not perfect, as seen previously)

Depth and Radius



- Small (but significant) differences at low radius: late shower start (early part of shower) at earlier times
- Trends also at larger radius, but statistical limits

Depth and Radius - MC



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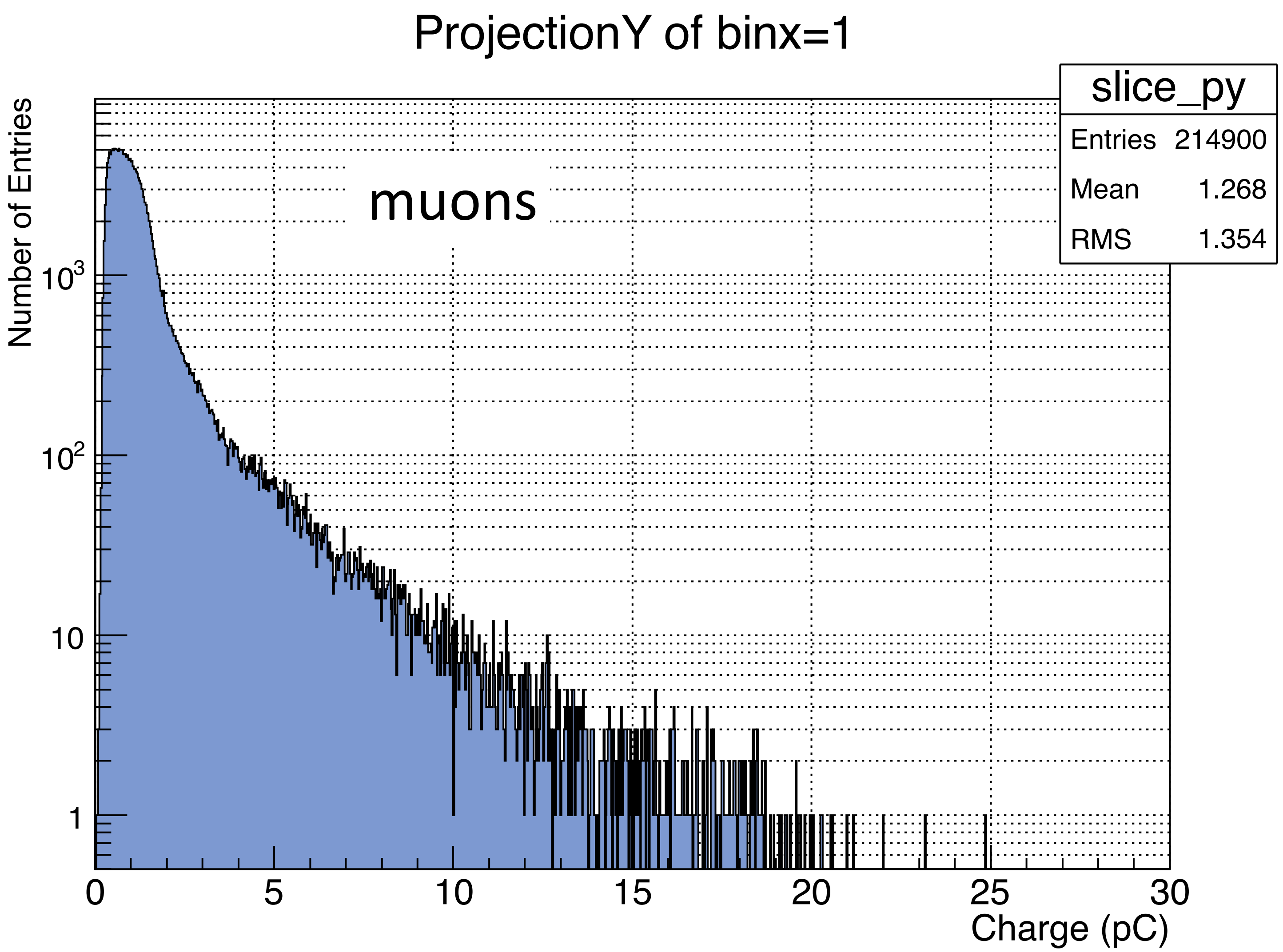
T3B FastRPC - Timing in a Gaseous Calorimeter

T3B FastRPC - The Setup

- One Argonne RPC with a readout board with 15 3x3 cm^2 cells
- Same readout as T3B: Preamp + Picoscopes, 800 ps sampling, 2.4 μs recording per event

In beam in 2012
(1 PS period, 1 SPS period together with W-DHCAL)

T3B FastRPC: First Results - Amplitude



- Total charge of identified pulse (given by integral with appropriate scaling factors)

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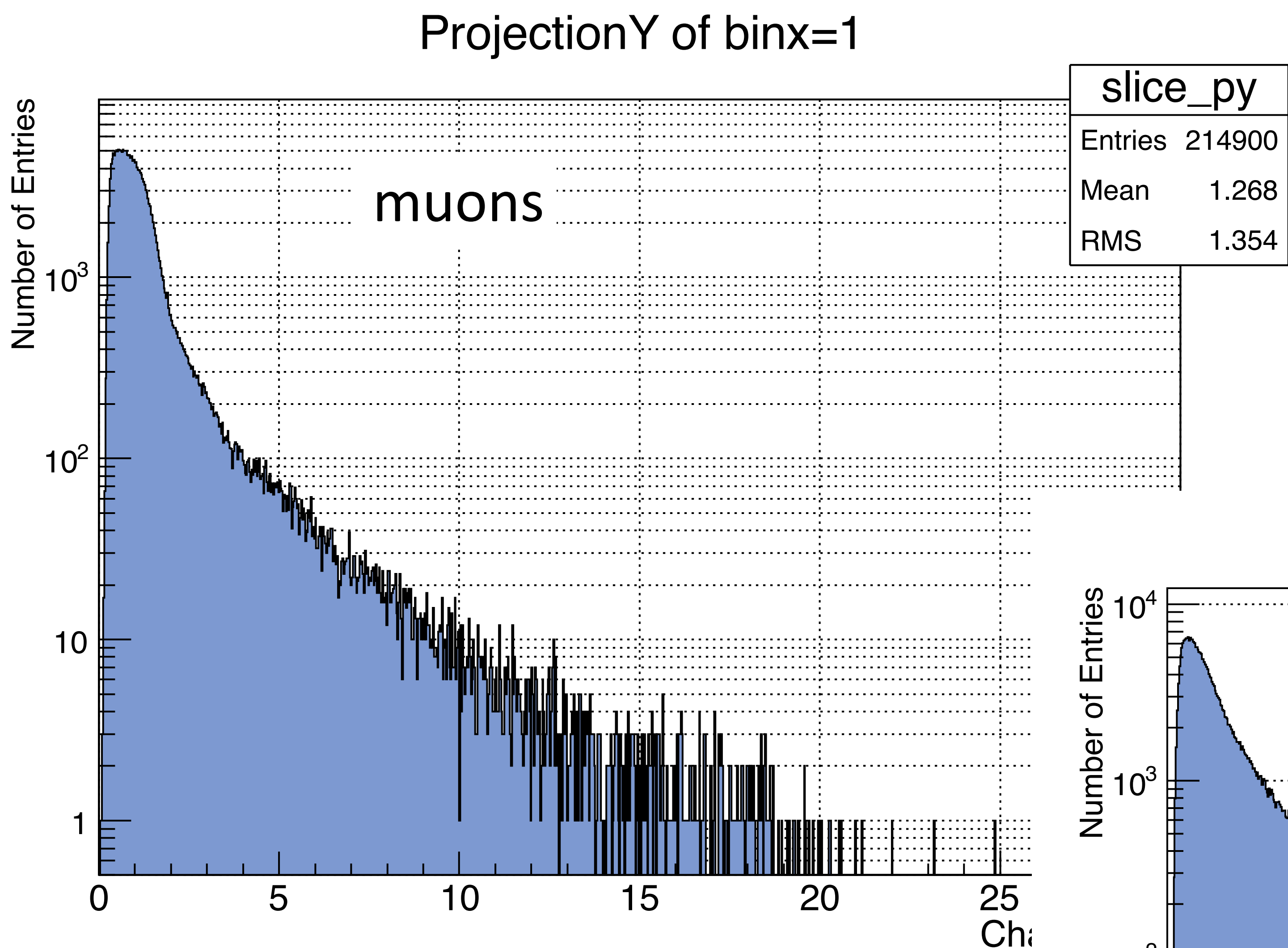

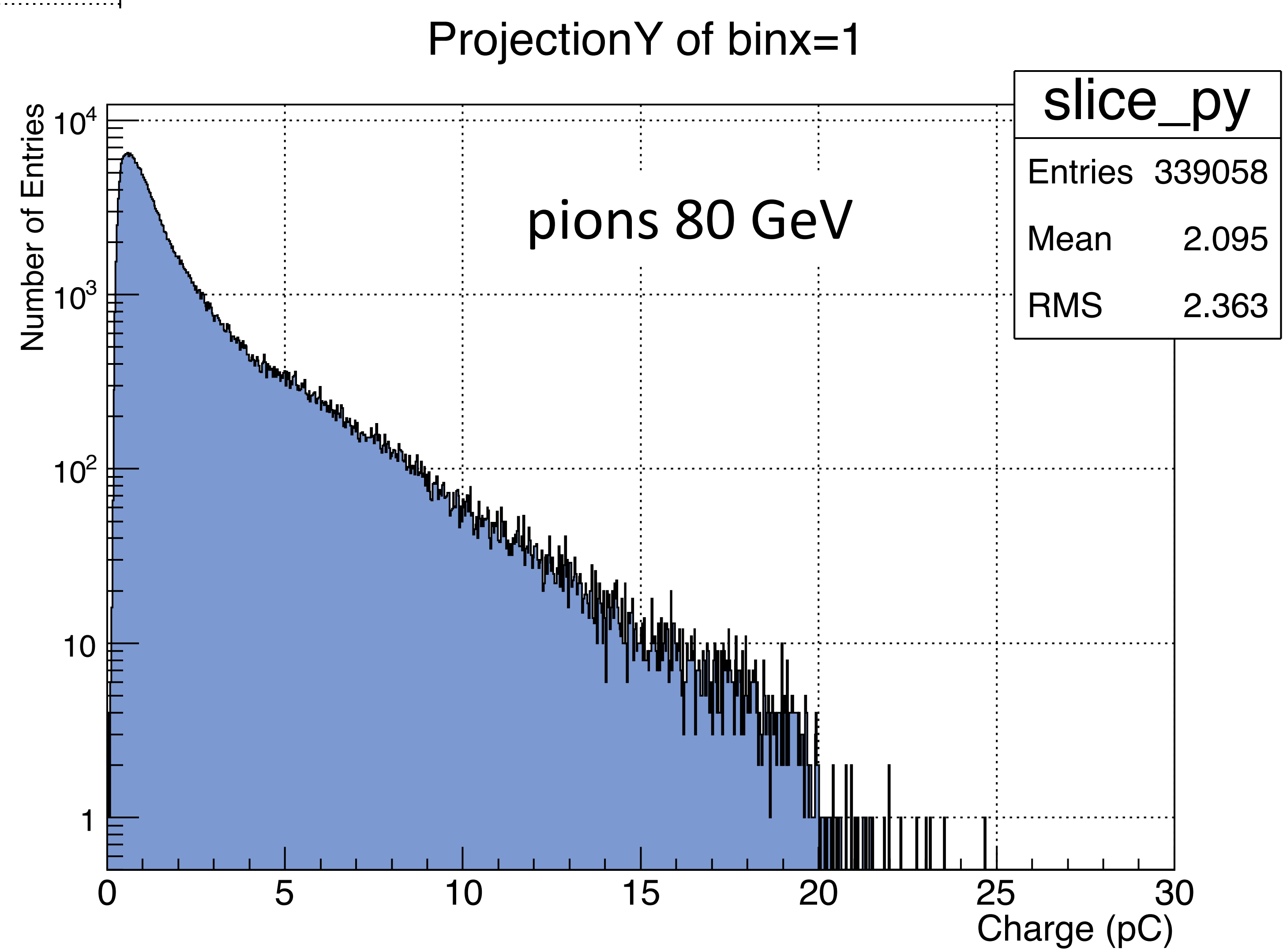

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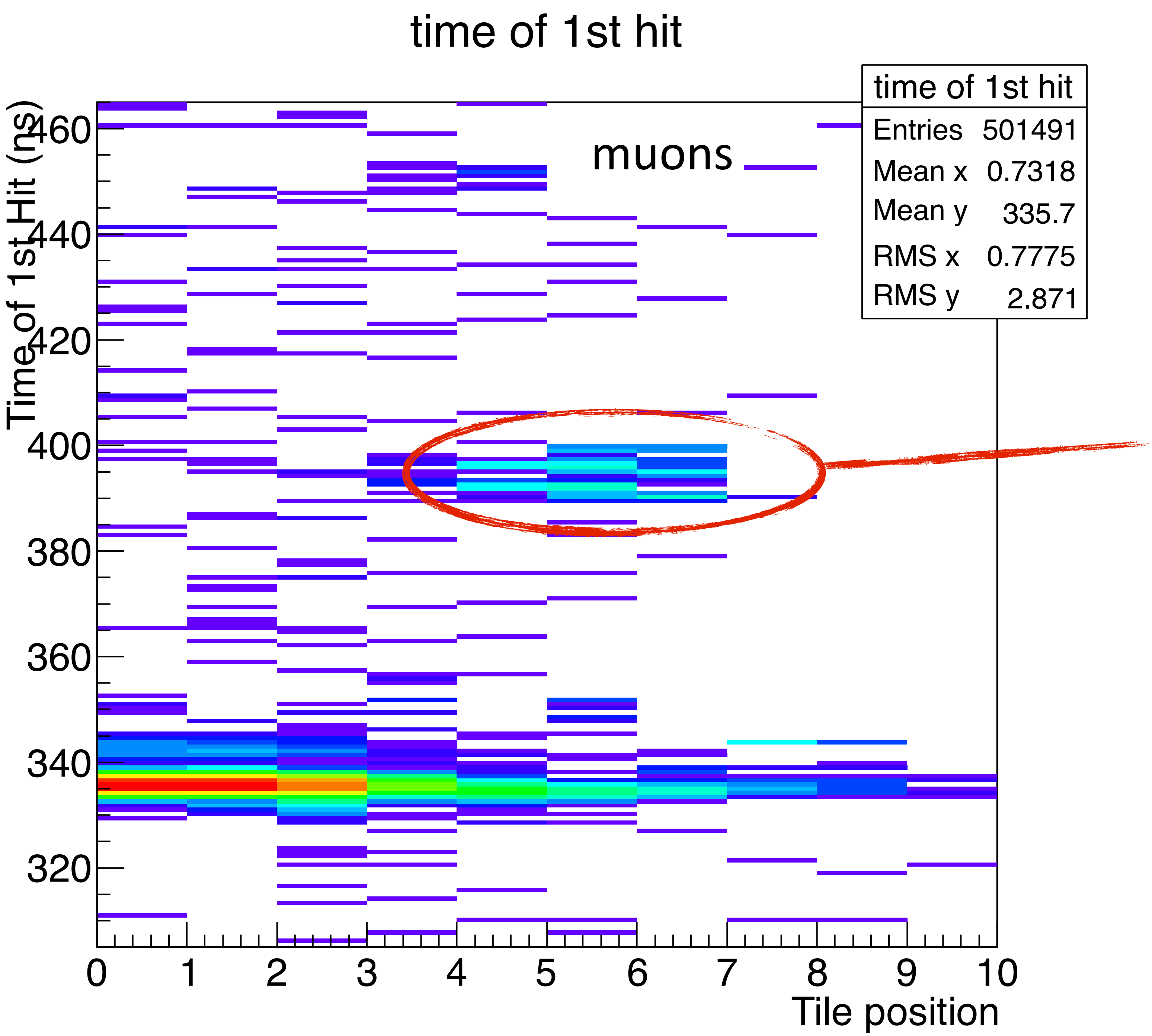
T3B FastRPC: First Results - Time of First Hit



cross-talk / electronic reflection - under investigation

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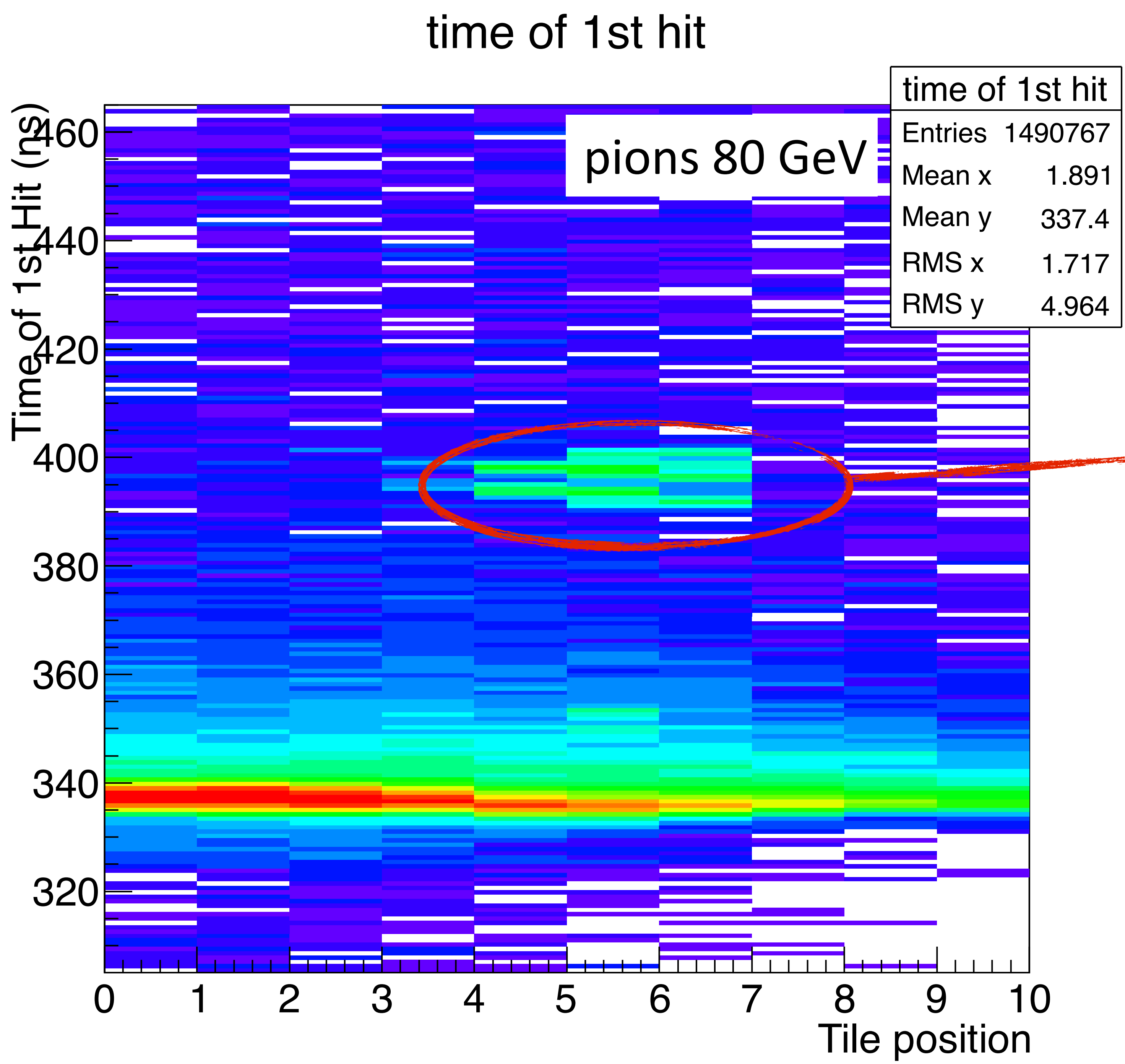

cross-talk / electronic reflection - under investigation

- Broadened main peak, increased late component: Evidence for visible time structure also in RPC calorimeter

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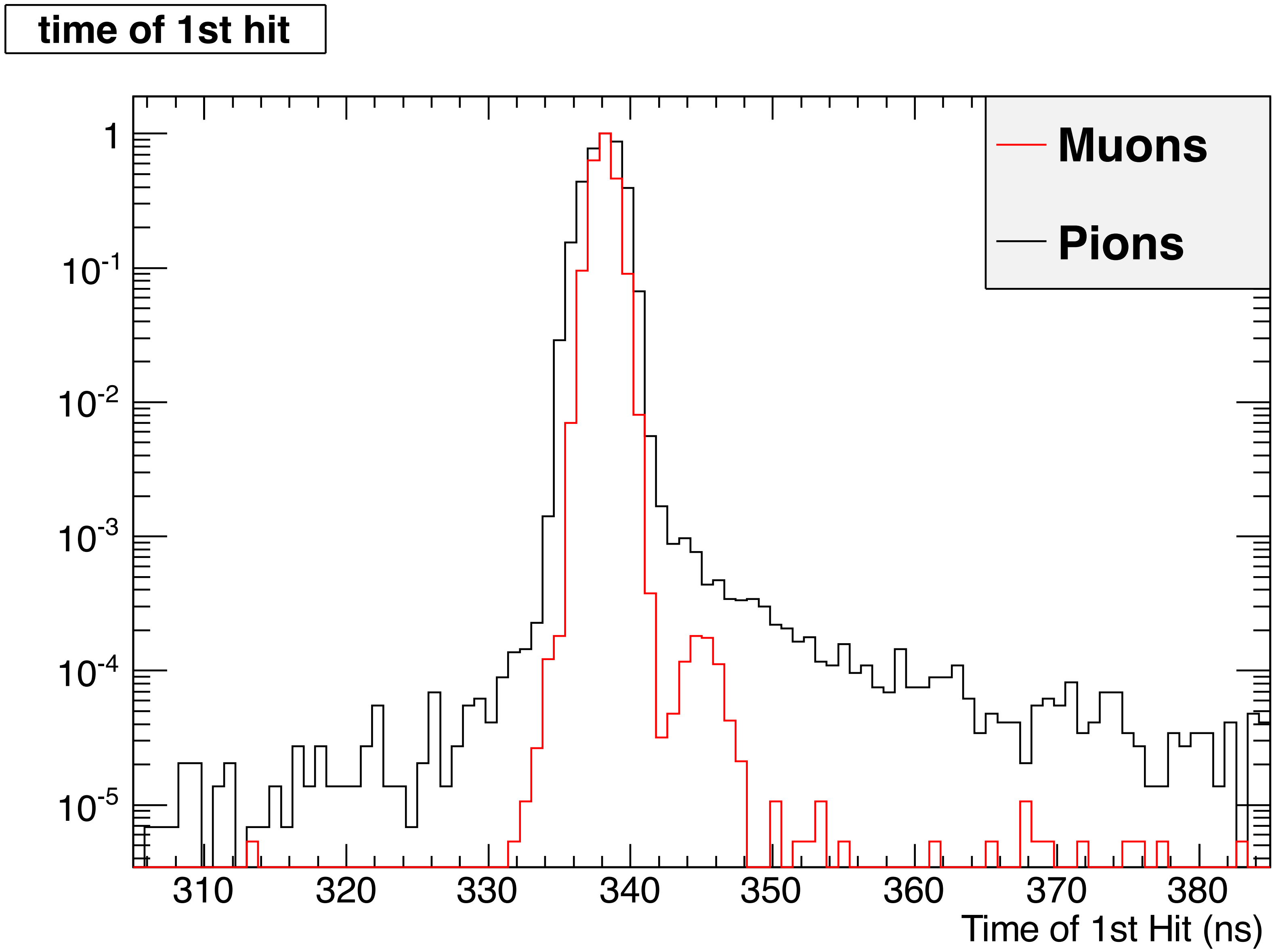
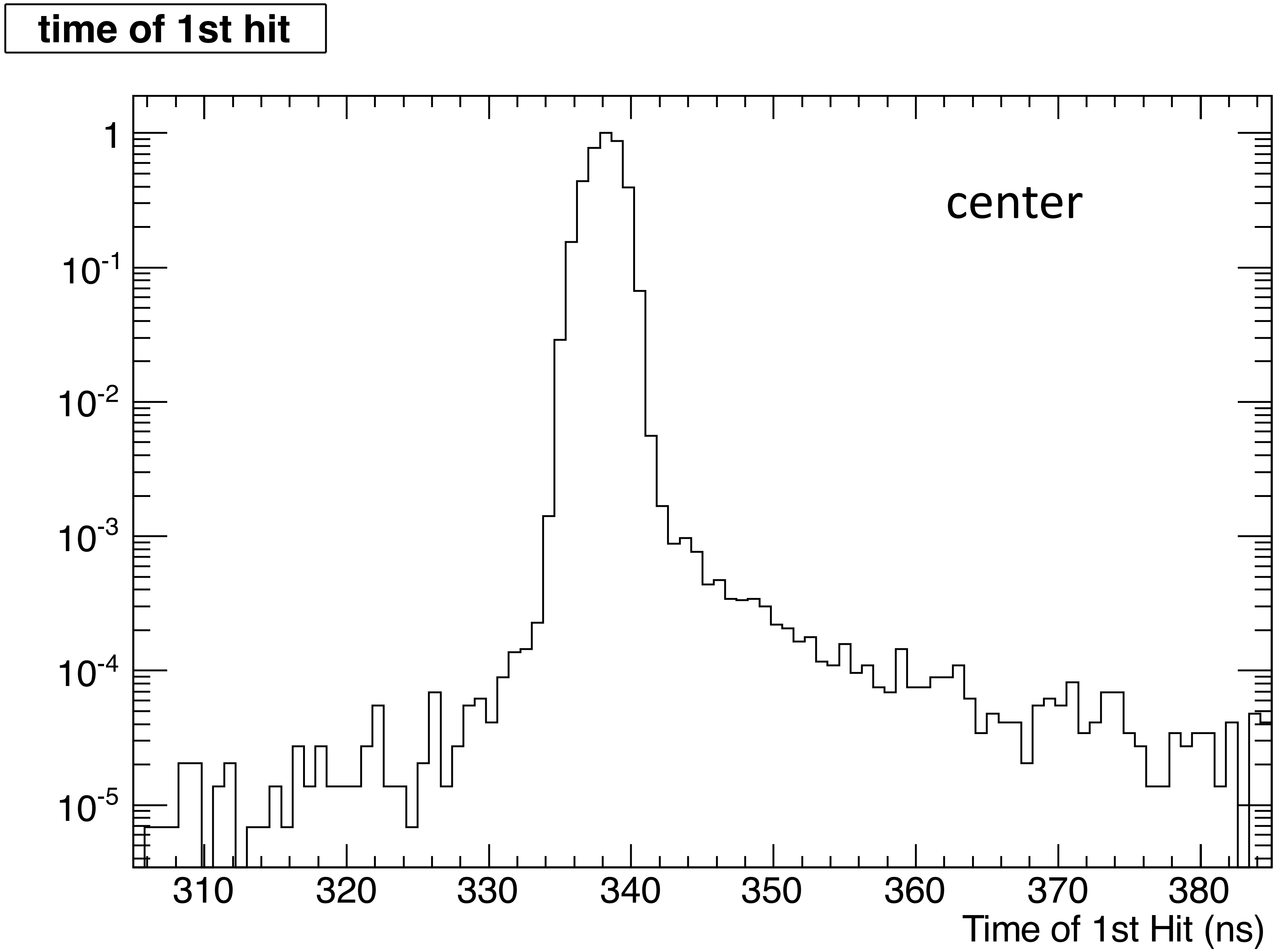


- Pions vs Muons along beam axis
  - Evidence for late component in pion showers

T3B FastRPC: First Results - Time of First Hit



- Pions @ 80 GeV
- Increasing distance to beam center: increasing late component, broadened main peak

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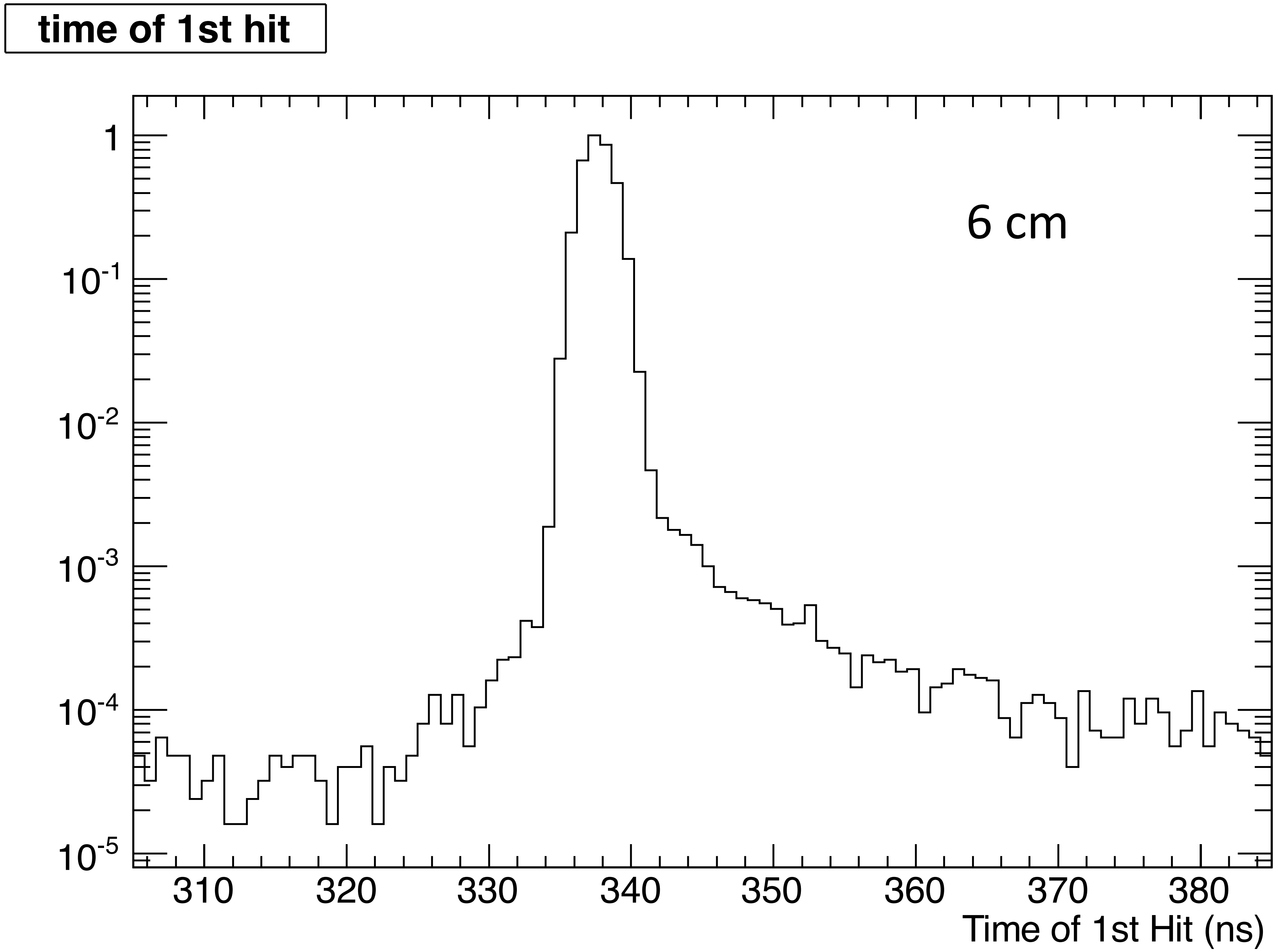

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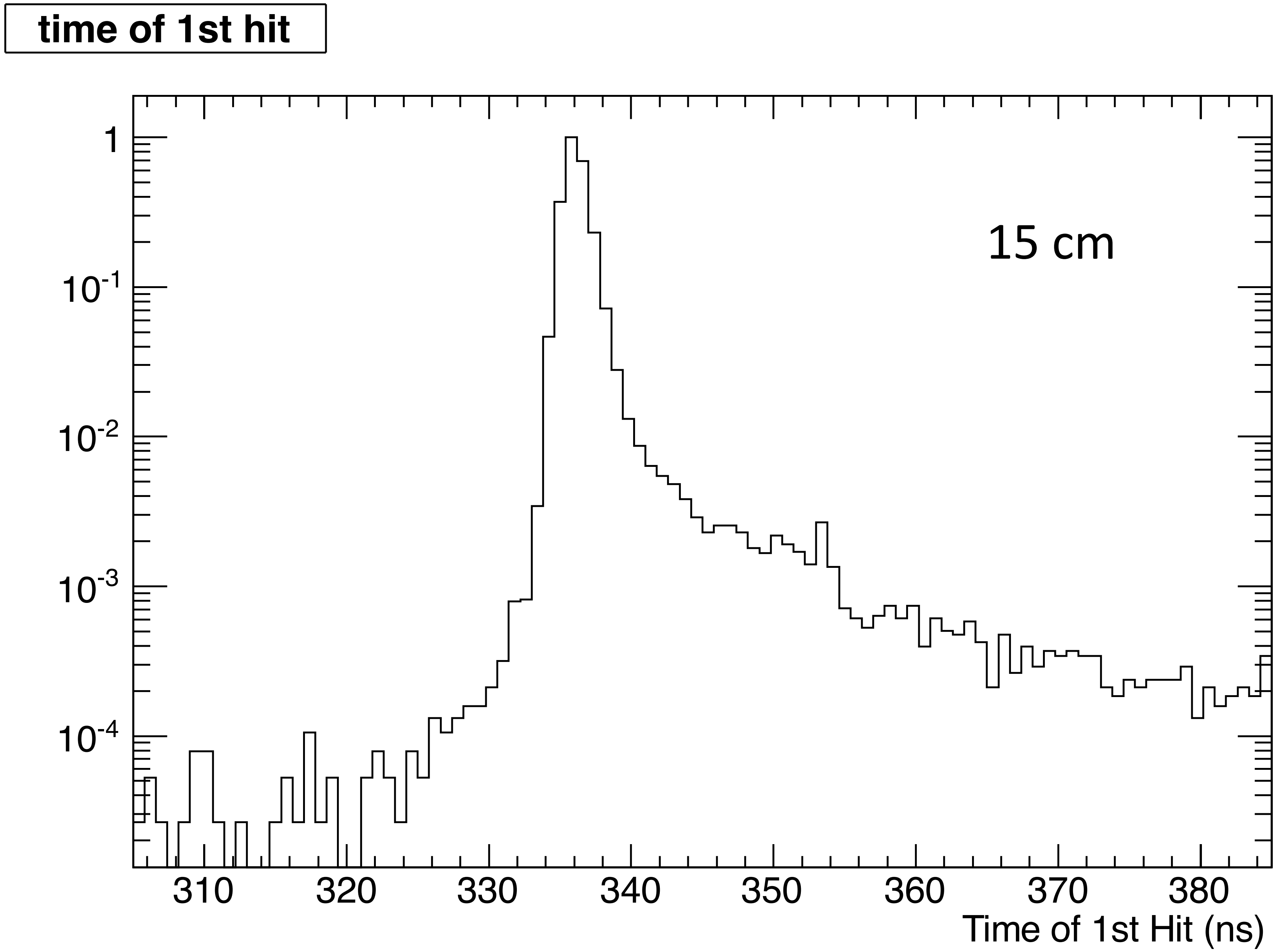

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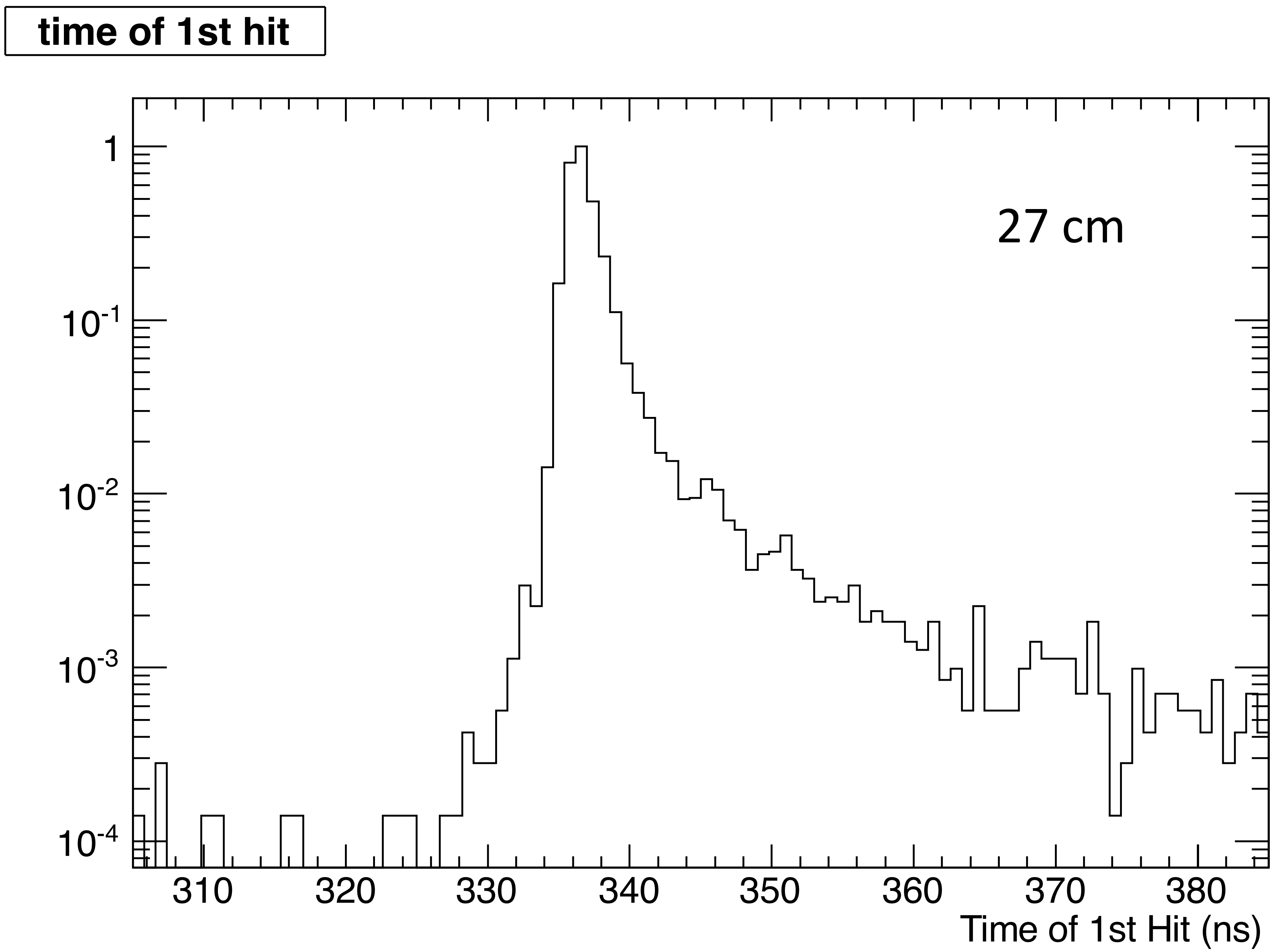

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Summary

- T3B can provide a full averaged profile of the time evolution of a hadronic shower in the W-AHCAL - at present including detector effects such as afterpulsing
- Detailed study of the time of first hit without longitudinal shower information for Tungsten & Steel absorbers and Muons as reference
  - Corrections for full time evolution under study
- Full longitudinal information available for Tungsten - First results
- Extensive comparison to simulations
  - Steel data in general very well reproduced
  - Tungsten needs QGSP_BERT_HP or QBBC for satisfactory description

- First analysis results from T3B-FastRPC:
  - Proof of principle - Time structure visible in RPC calorimeter

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Next Step: A new analysis note for LCWS & IEEE

Time is short - Please comment already now!

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  - Proof of principle - Time structure visible in RPC calorimeter