T3B Status

The Time Structure of Hadronic Showers

CALICE Collaboration Meeting
Argonne Nat'l Lab, March 2014

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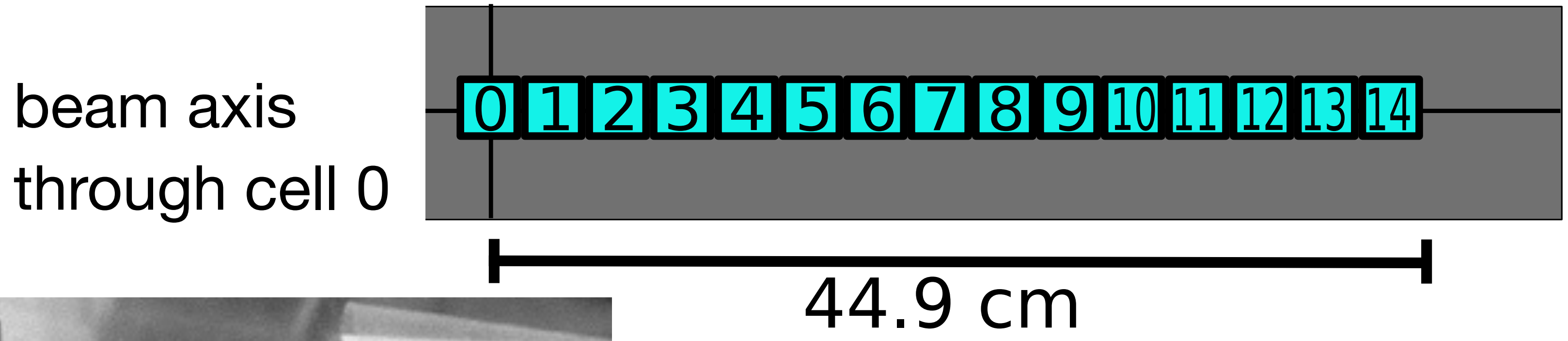
Outline

- Intro: The T3B Setup
- The Physics of the Shower Time Structure
- T3B Results
  - Comparing Hadrons in Steel and Tungsten, and Muons
  - Comparison to Simulations
- Longitudinally resolved analysis
- Conclusions

Reminder - The T3B Setup

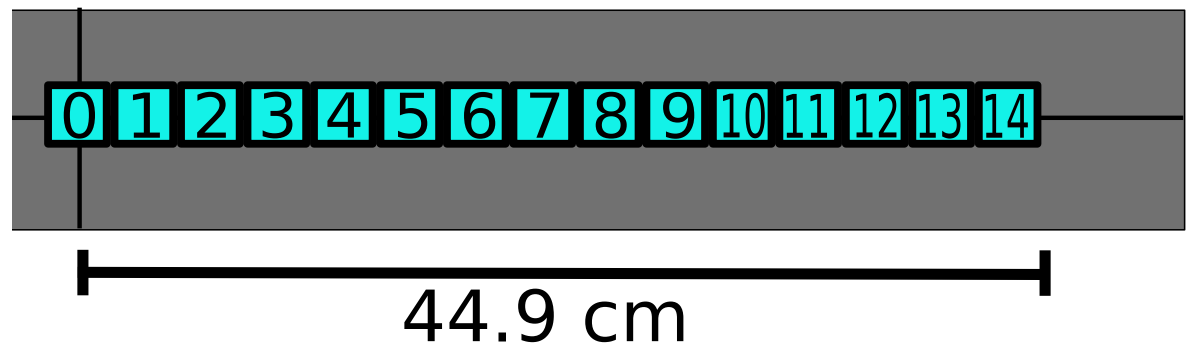
- 15 3 x 3 cm^2 scintillator cells, sampling the radial extent of the shower



Reminder - The T3B Setup

- 15 3 x 3 cm^2 scintillator cells, sampling the radial extent of the shower

beam axis
through cell 0



Stand-alone system:

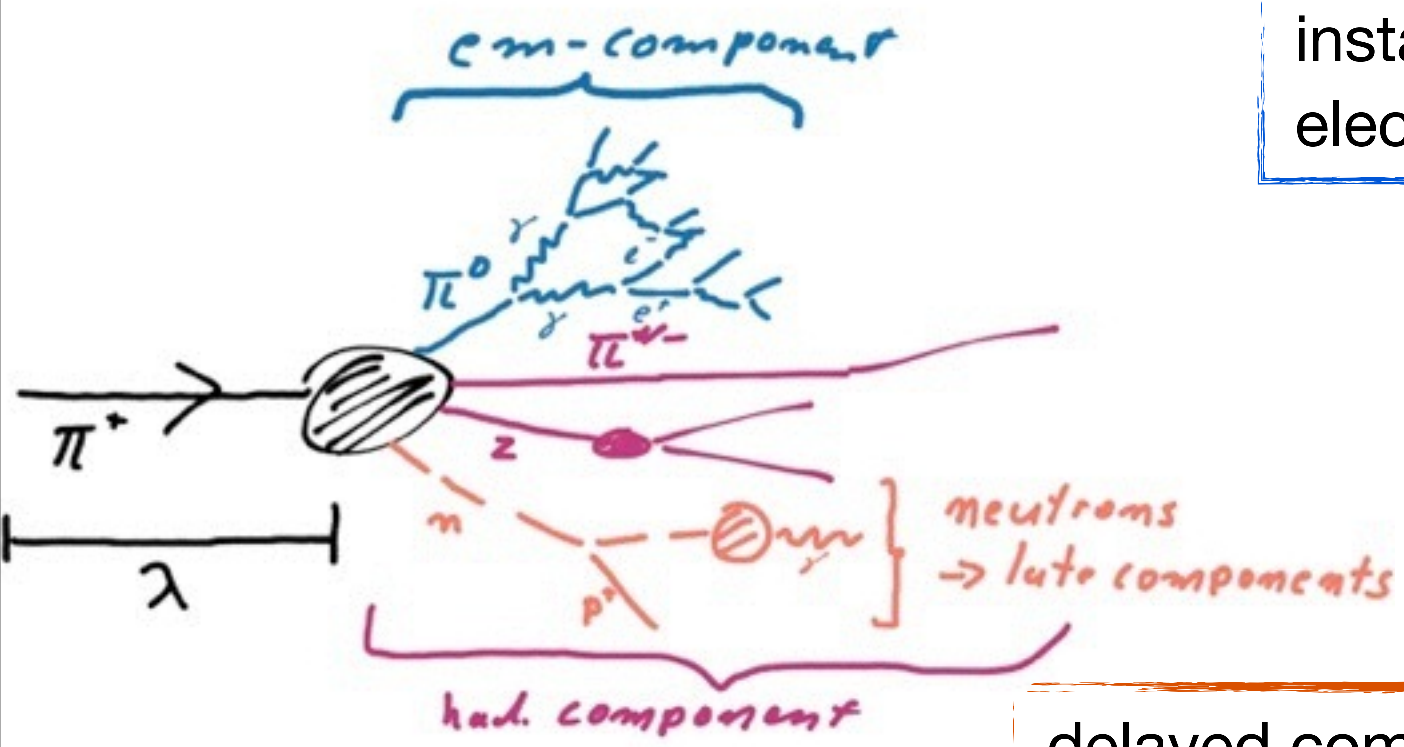
- Installed downstream of CALICE WHCAL or SDHCAL, depth ~ 5.1 λ / 6.5 λ
- Each cell read out with 1.25 GS oscilloscope, 2.4 μs sampling time per event
- Calibration triggers on dark noise between spills

Synchronization with CALICE

- Triggered by CALICE trigger - common analysis possible

The Time Structure of Hadronic Showers - Origin

- 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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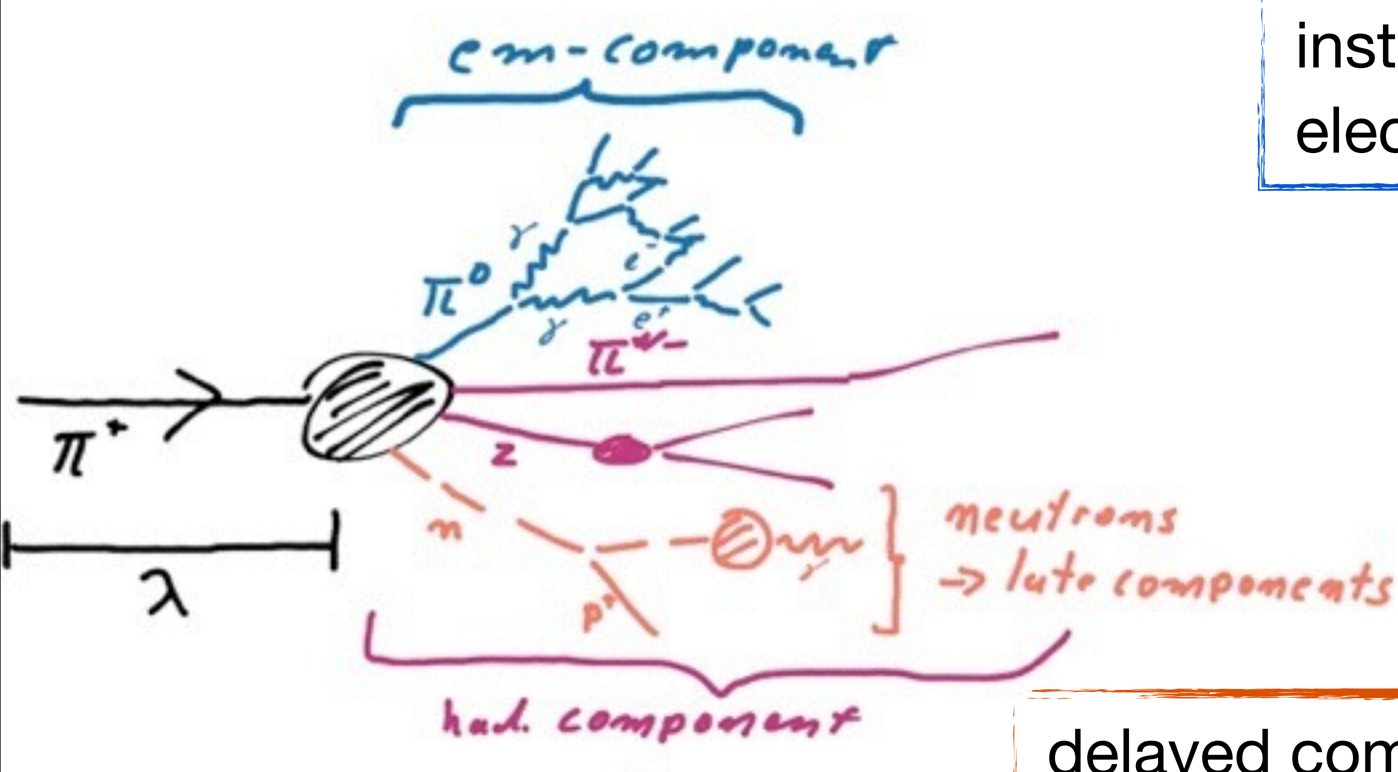

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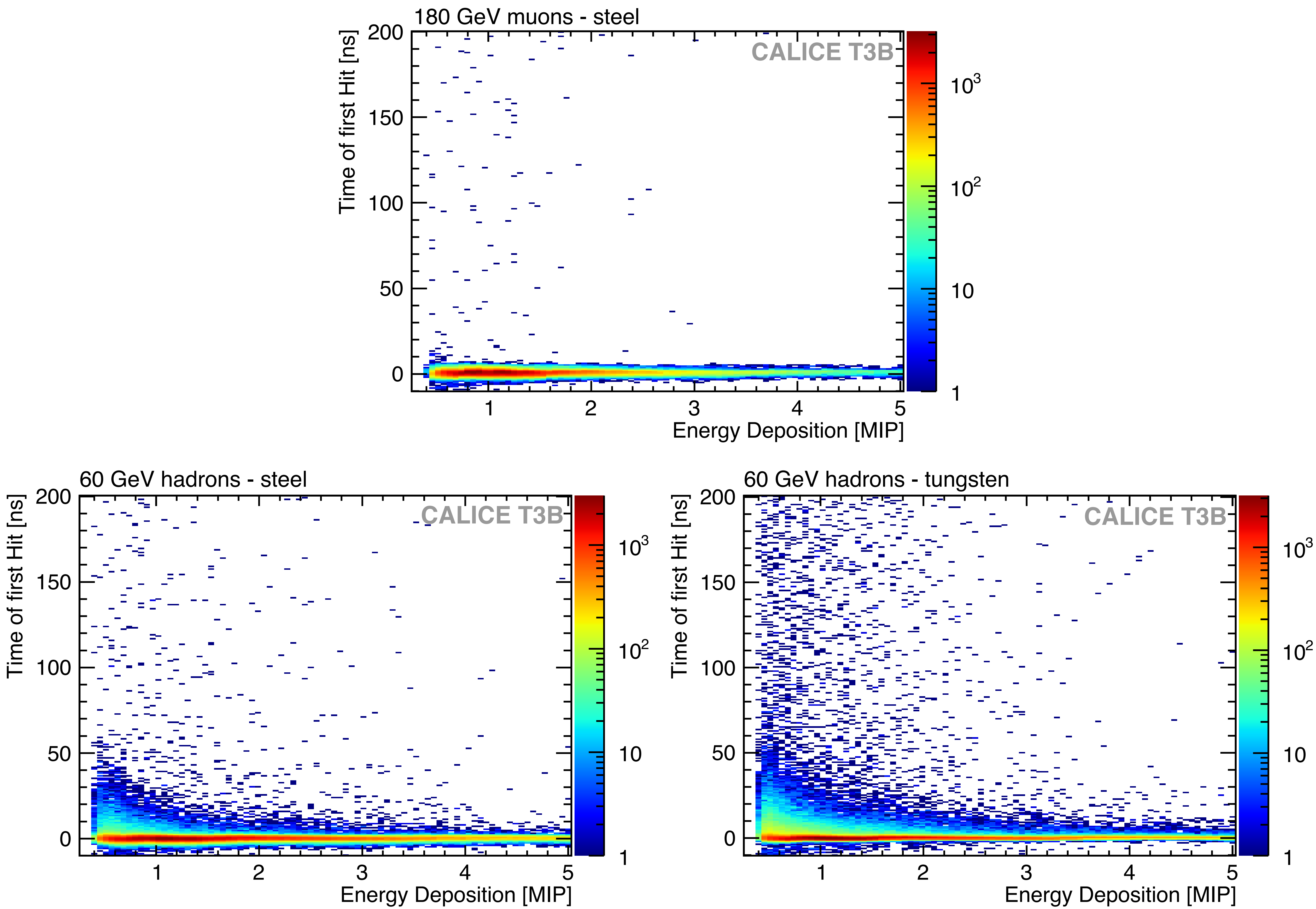
➡ Importance of delayed component strongly depends on target nucleus

➡ Sensitivity to time structure depends on the choice of active medium

T3B Results - Measurements in Fe, W and with μ



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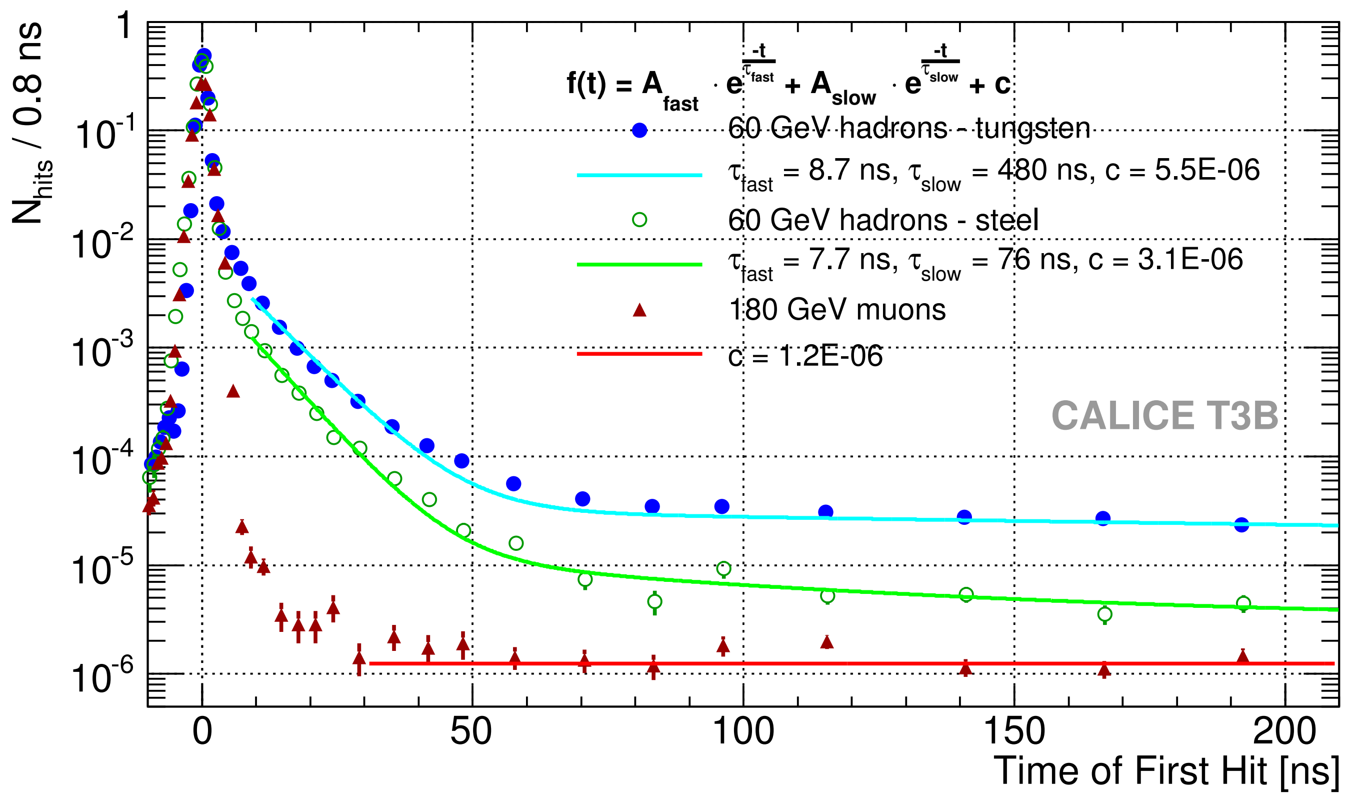
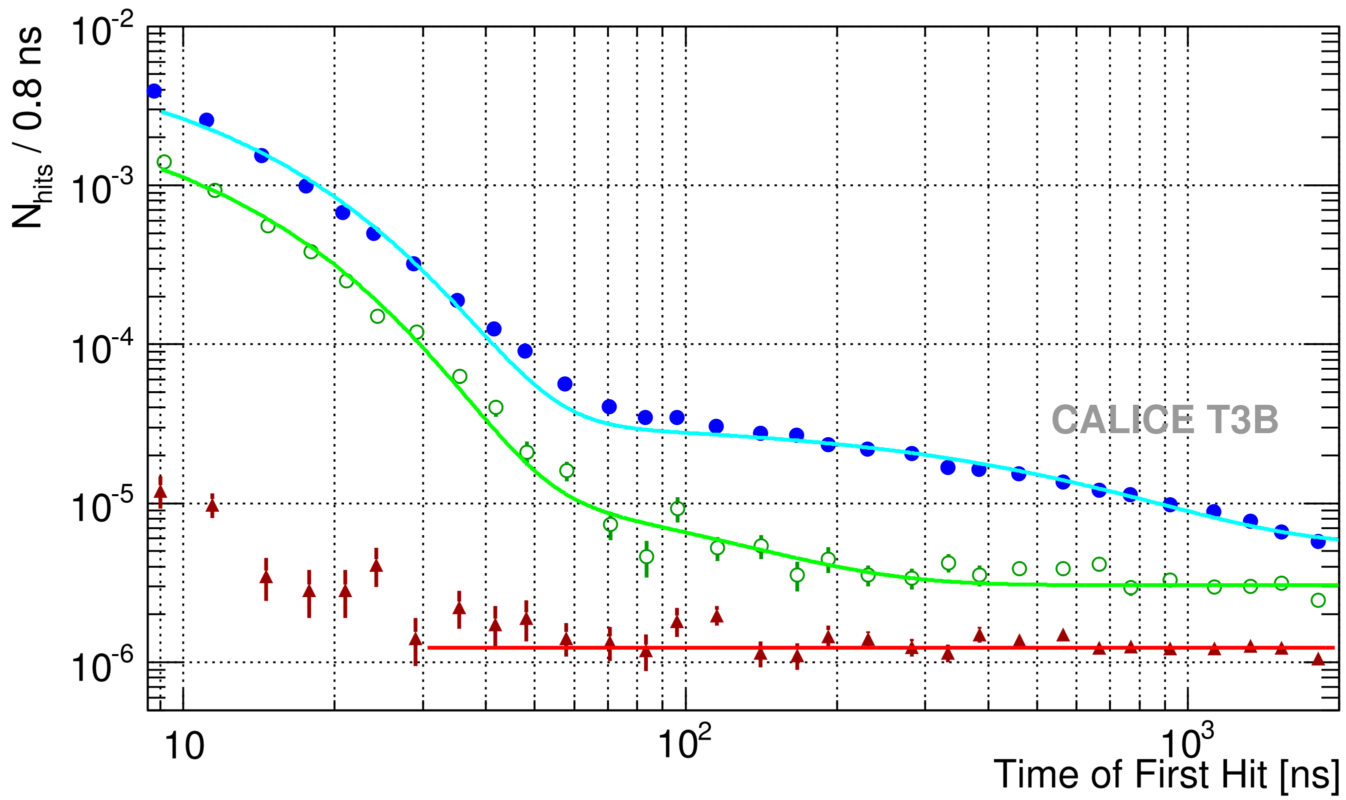




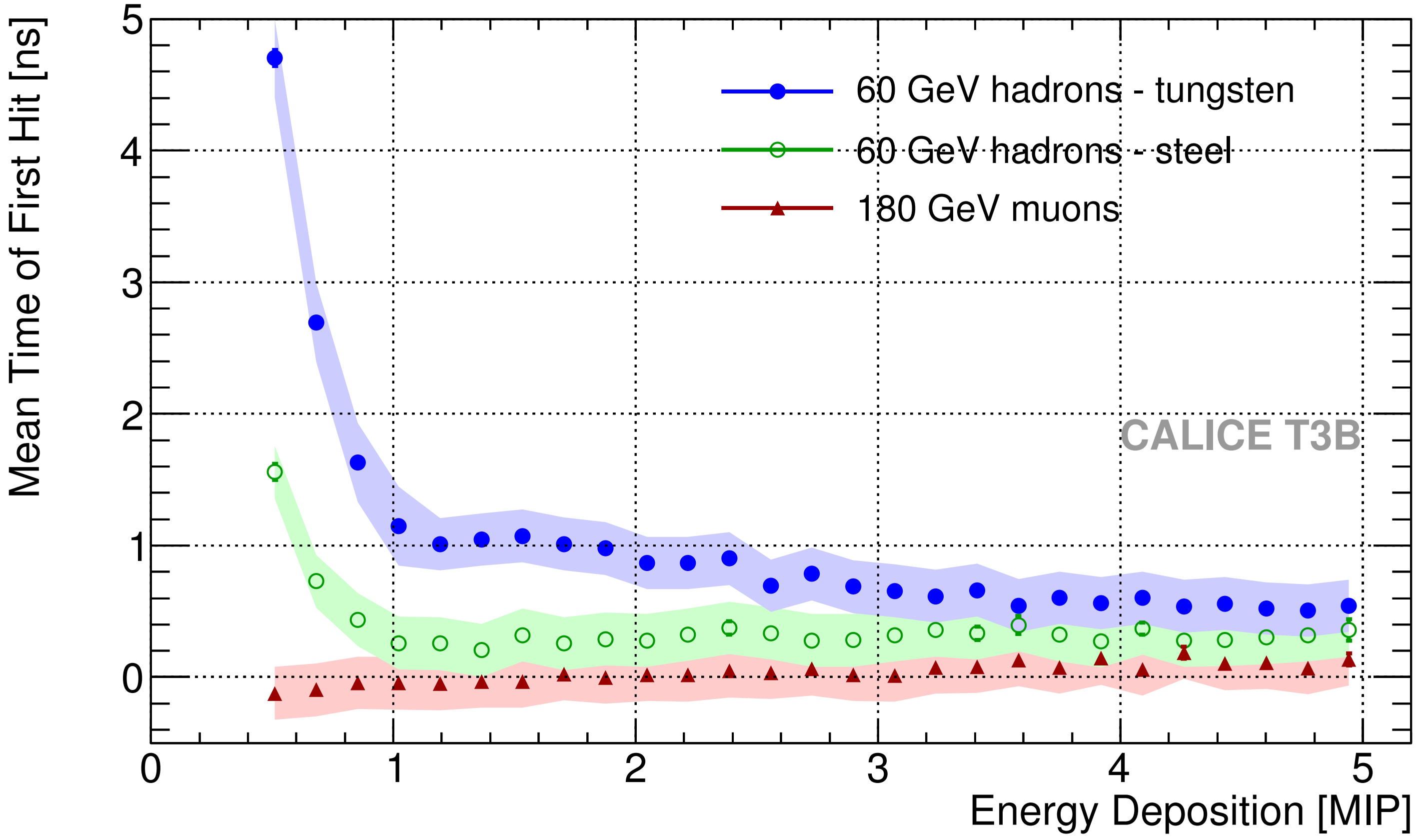
- Fit with two-component exponential, to model the two different visually apparent time components:

$$\frac{dN}{dt}\frac{1}{N_{tot}} = A_{fast} \cdot e^{\left(-\frac{t}{\tau_{fast}}\right)} + A_{slow} \cdot e^{\left(-\frac{t}{\tau_{slow}}\right)} + c$$

fit parameter	steel	tungsten
τ_{fast}	7.7 ± 0.1 ns	8.7 ± 0.1 ns
τ_{slow}	76 ± 1 ns	480 ± 20 ns
	steel	tungsten
constant	$(3.06 \pm 0.08) \times 10^{-6}$	$(5.48 \pm 0.19) \times 10^{-6}$

fit parameter	ratio of integrals R_i
τ_{fast}	2.3 ± 0.5
τ_{slow}	13.4 ± 2.7
	muons
constant	$(1.24 \pm 0.03) \times 10^{-6}$

T3B Results - Measurements in Fe, W and with μ



- Late energy deposits concentrated at low hit energies
- In W also some late activity at higher hit amplitudes seen

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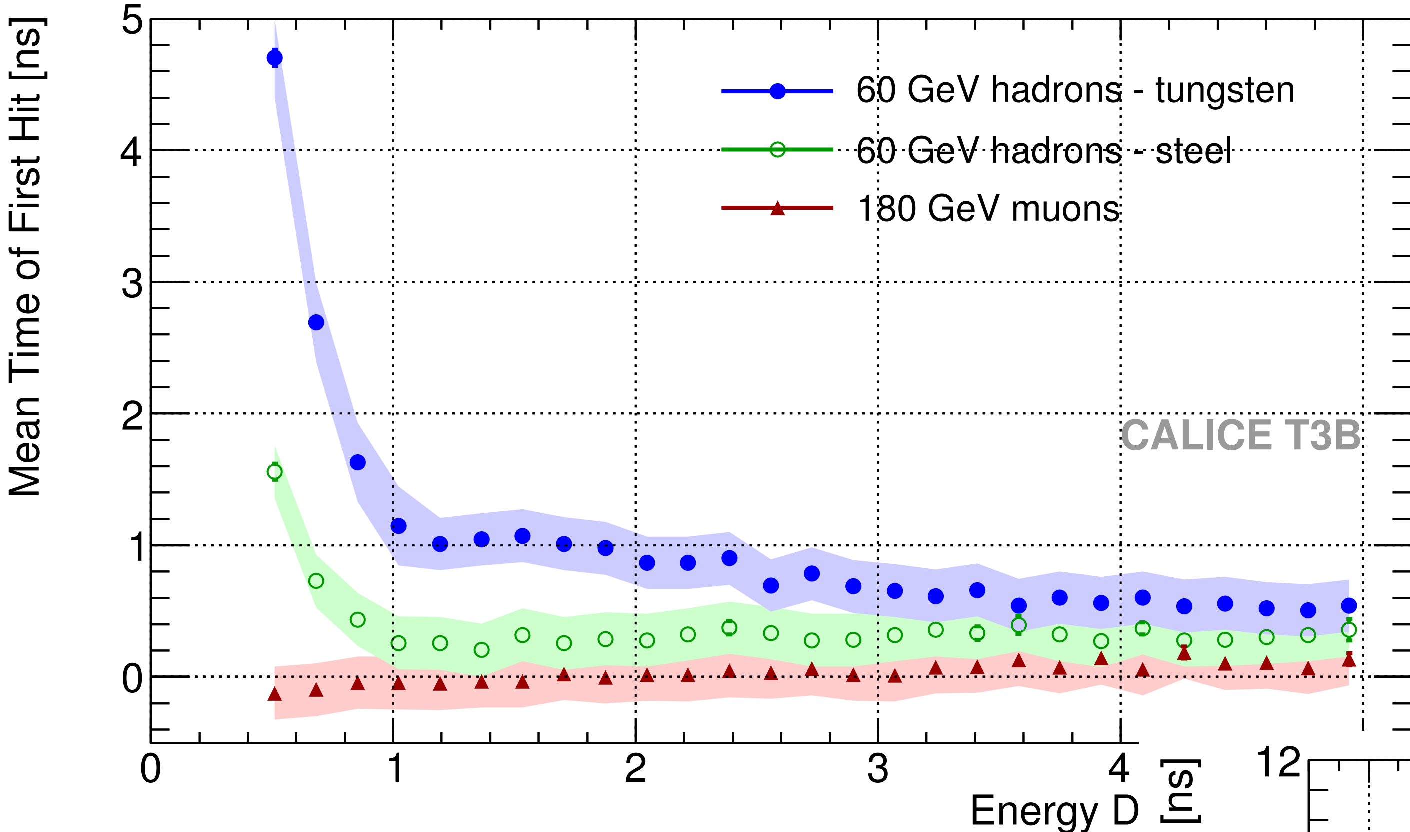

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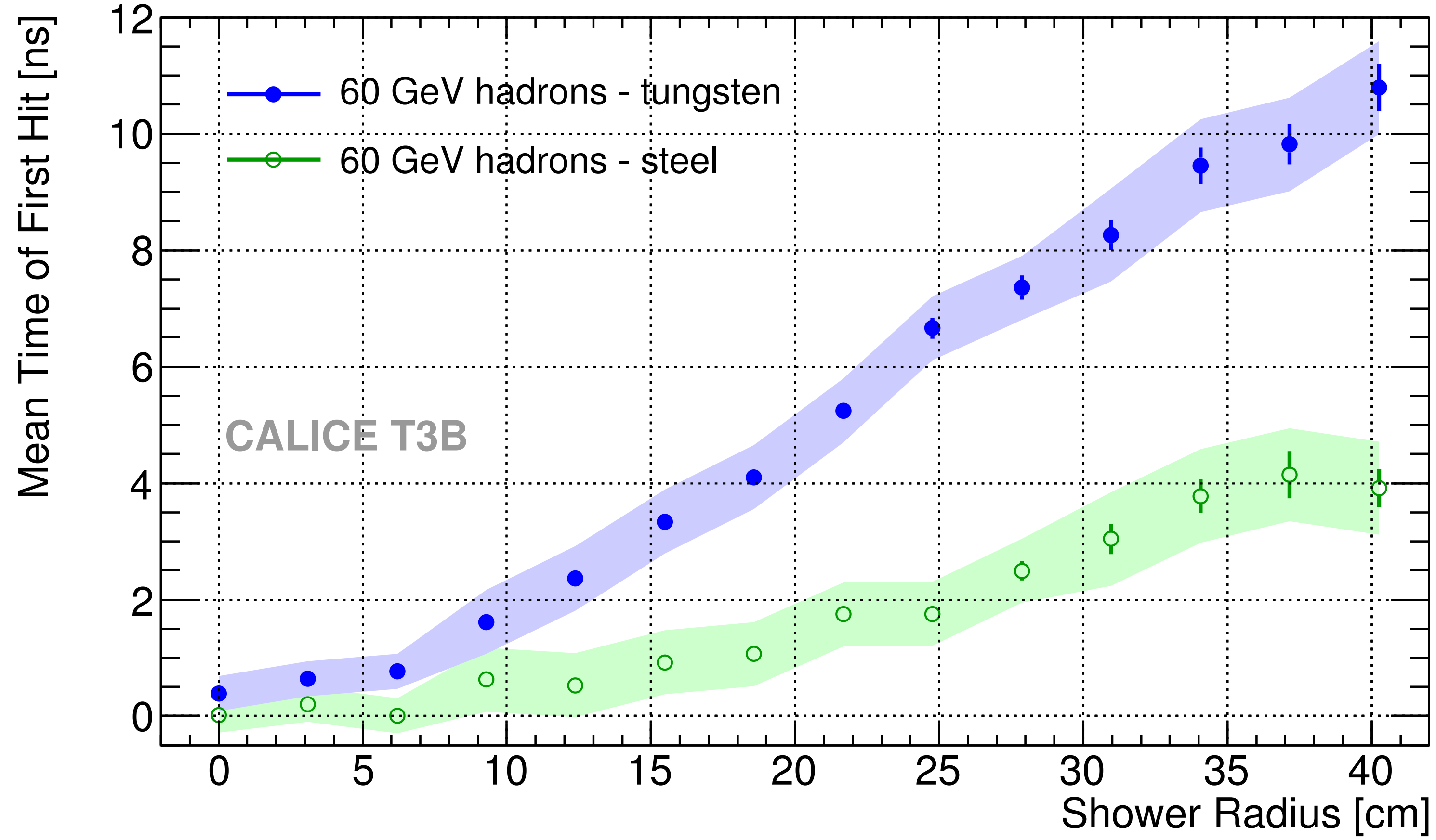


- Late energy deposits get more important at larger distances from the shower axis: Neutrons tend to spread out more
  - x 2.5 enhanced in W compared to Steel

T3B Simulations

- Full GEANT4 modle of T3B, and the WAHCAL / SDHCAL

T3B Layer

Component	d [mm]
Al Cassette	1.0
Air	2.3
Scintillator	5.0
Air	1.0
PCB	1.7
Al Cassette	2.0
Total	13

W-AHCAL Layer

Component	d [mm]
Steel Support	0.5
Tungsten	10
Air	1.25
Steel Cassette	2.0
Cable Mix	1.5
PCB	1.0
Scintillator	5.0
Steel Cassette	2.0
Air	1.25
Total	24.5

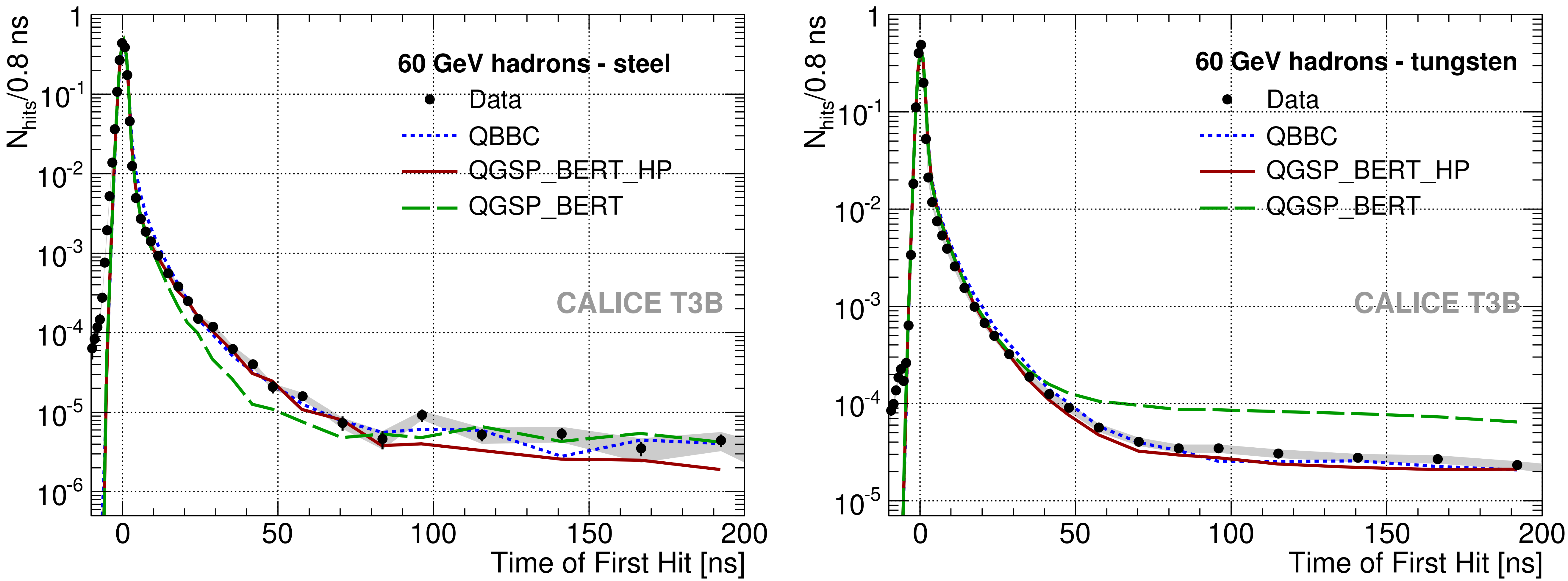
Fe-SDHCAL Layer

Component	d [mm]
Steel	20
Epoxy	1.6
PCB	1.2
Mylar	0.23
Graphite	0.1
Glass	1.8
RPC Gas	1.2
Total	26.13

- Data-driven digitization: Measured response to muons taken to model time evolution of T3B response to instantaneous signals
    - GEANT4 energy deposits binned in time (0.8 ns time bins), each bin is passed through digitizer

Using GEANT4.9.4p03 (4.9.5 had a problem with timing, 4.9.6 came to late for us…)

Comparing Data and Simulations



- QGSP_BERT performs worse than others:
  - In Steel slight underestimation of intermediate time component - Neutron elastic scattering?
  - In W substantial overestimation of late component - Neutron capture?

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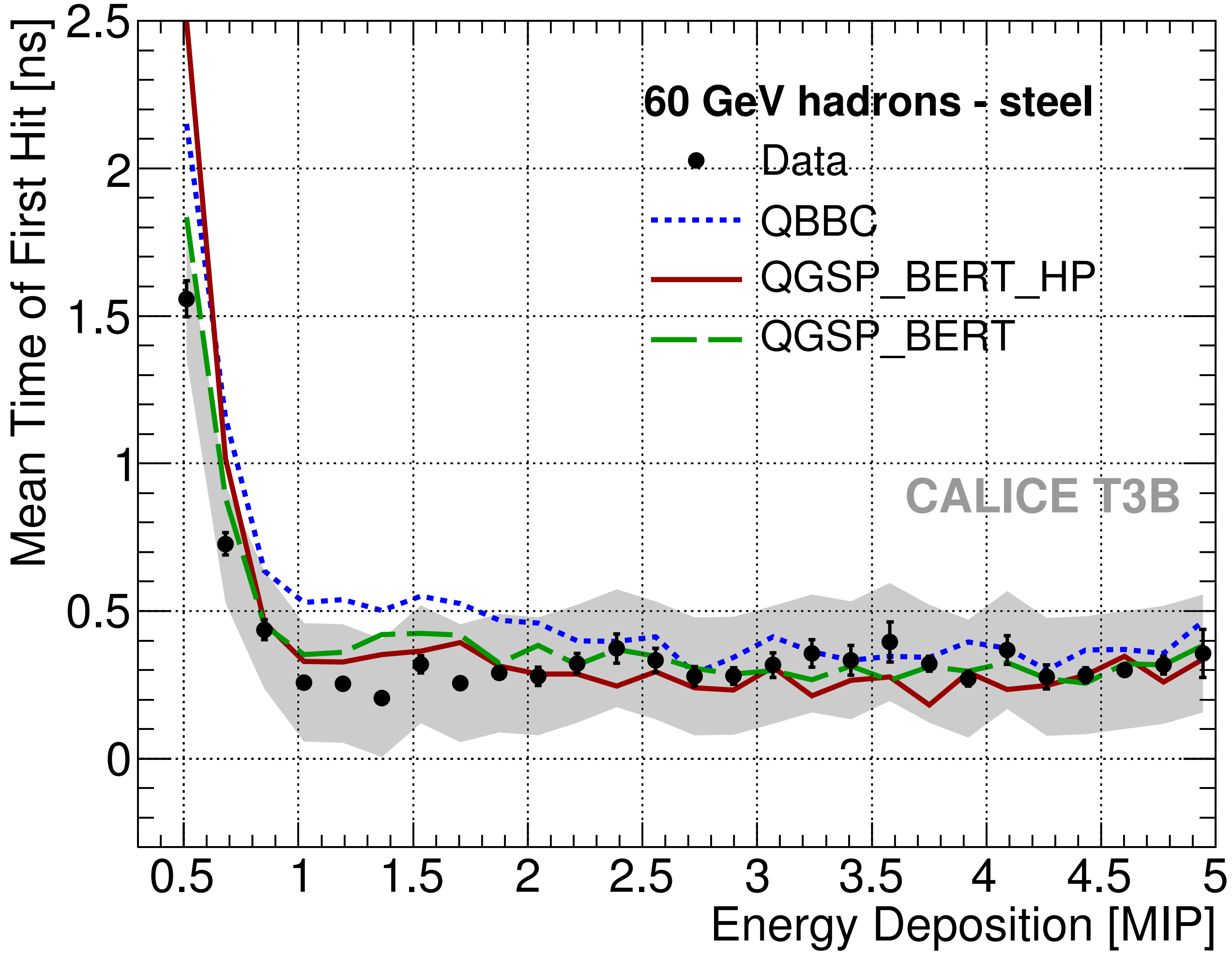
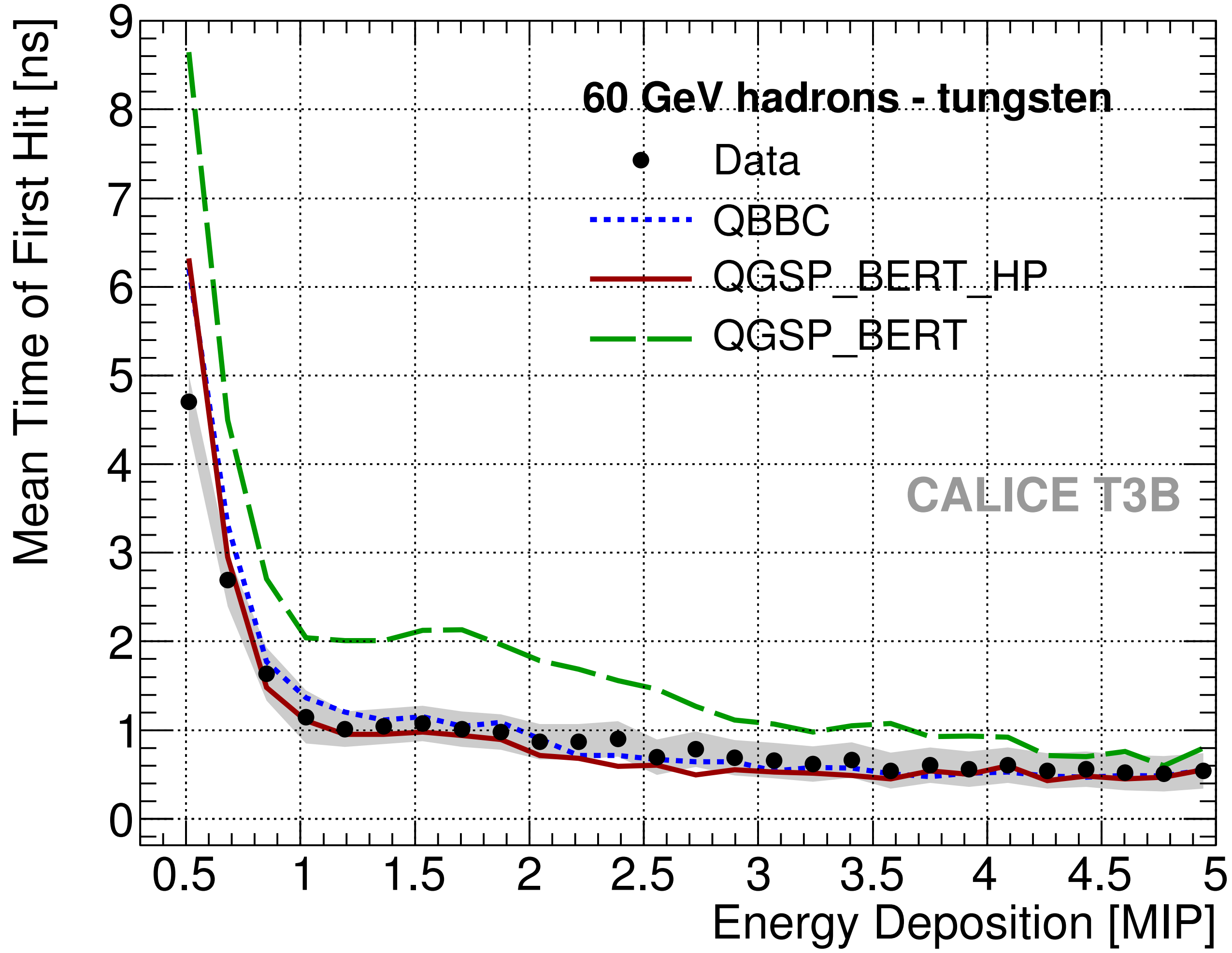
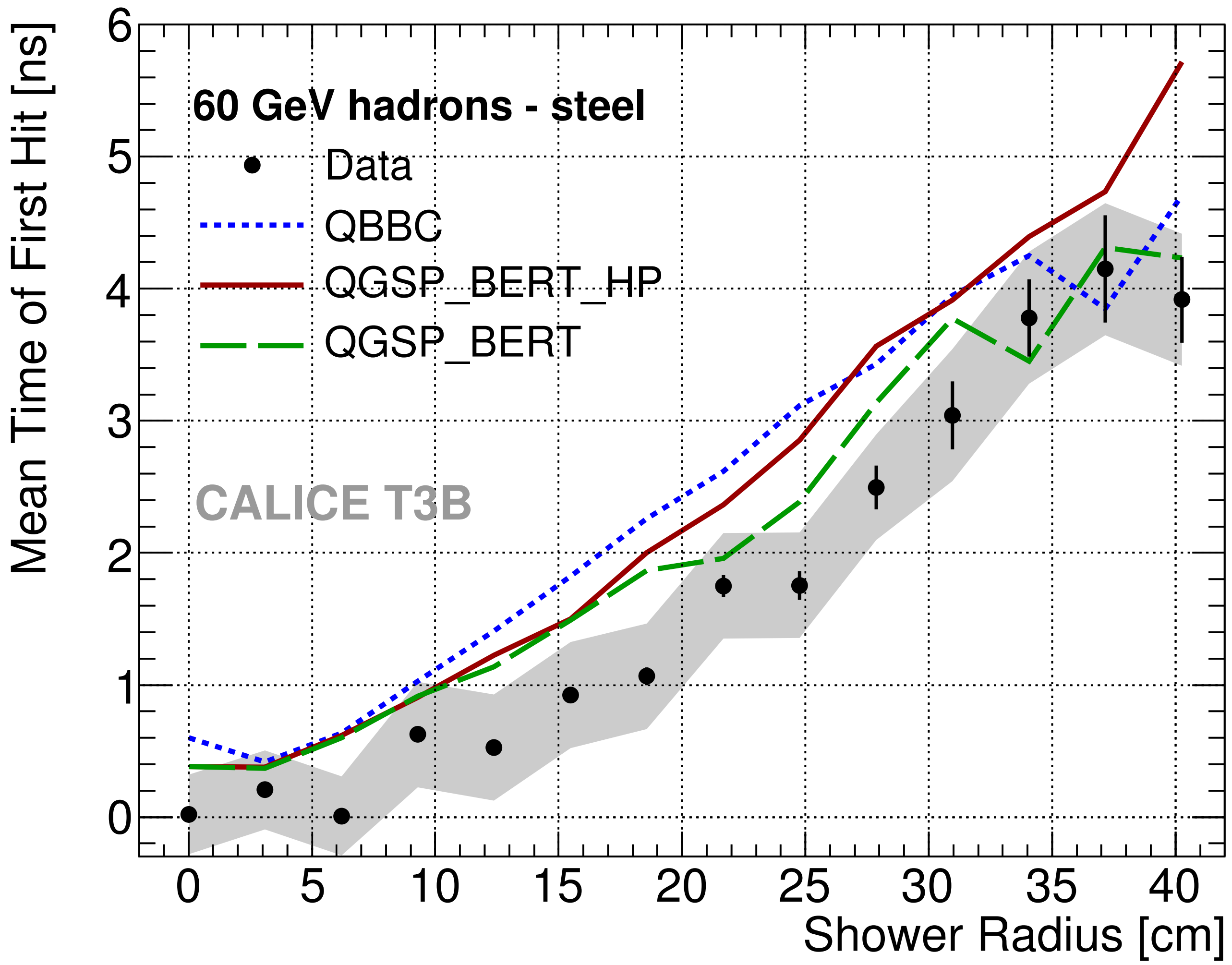
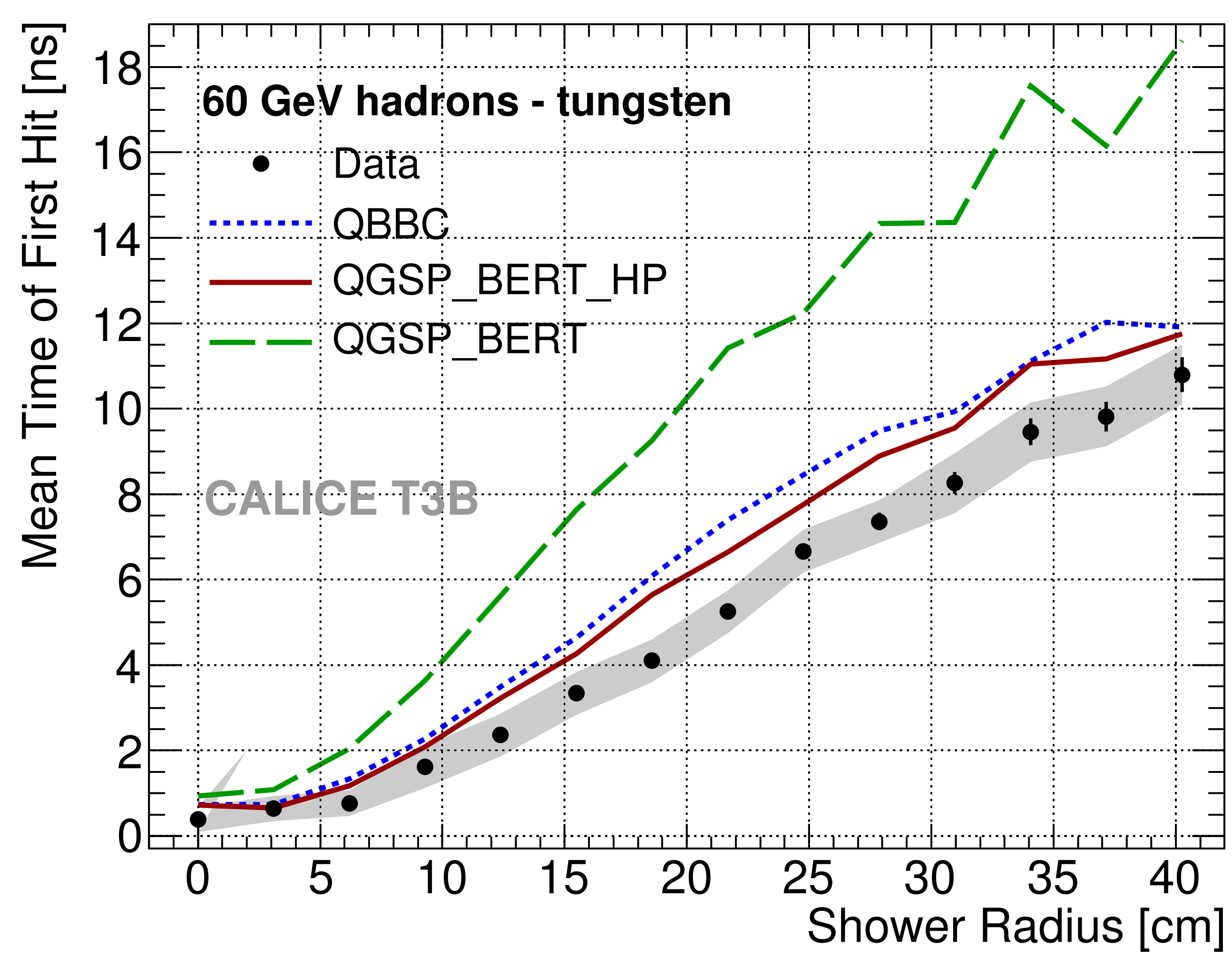




- Means well reproduced in steel by all lists
- In tungsten too much late energy seen for all amplitudes, largest effect at low energies

Comparing Data and Simulations

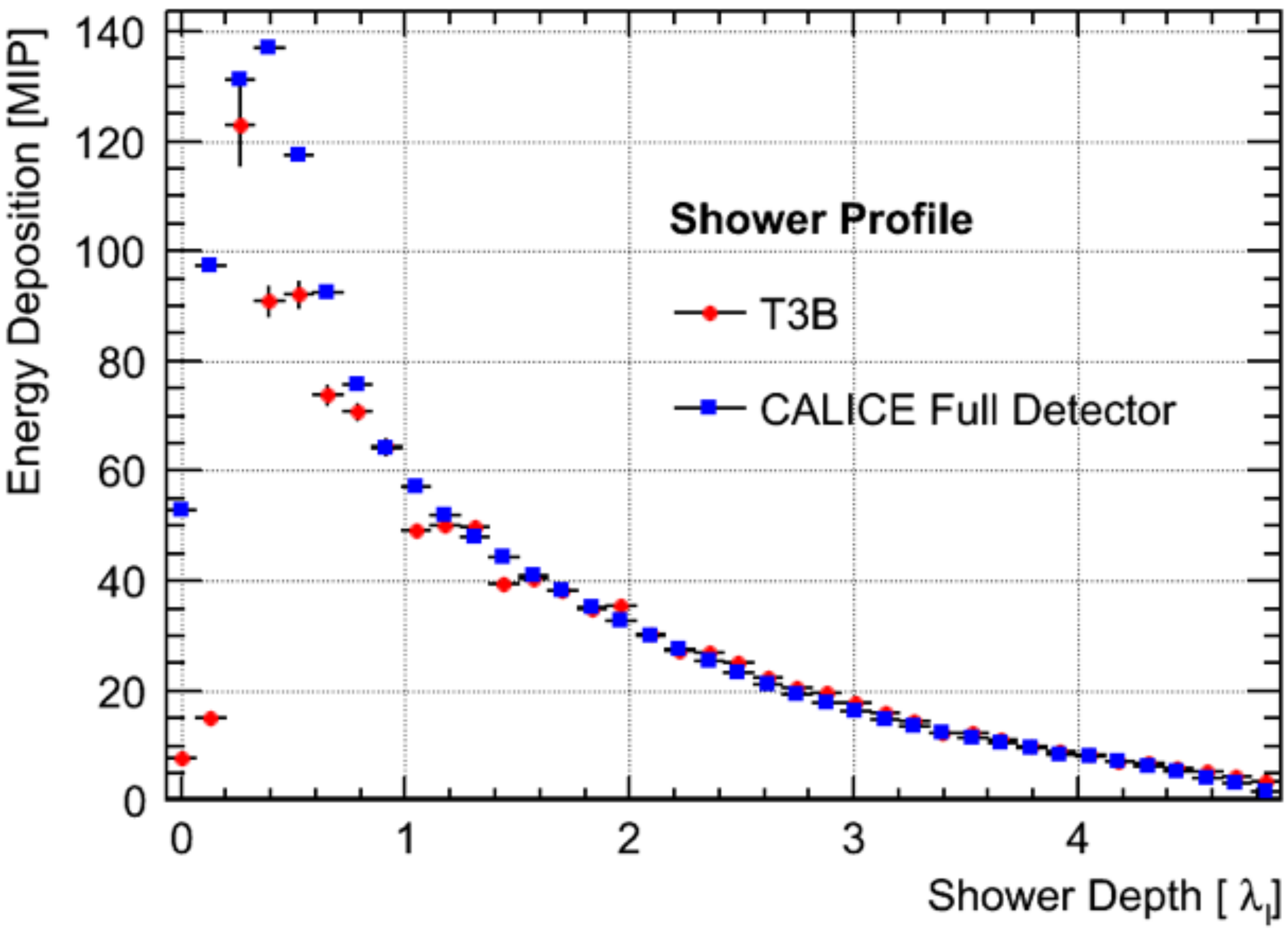




- Means well reproduced in steel by all lists
- In tungsten too much late energy seen for all radii, largest effect at high radius

Longitudinal Analysis

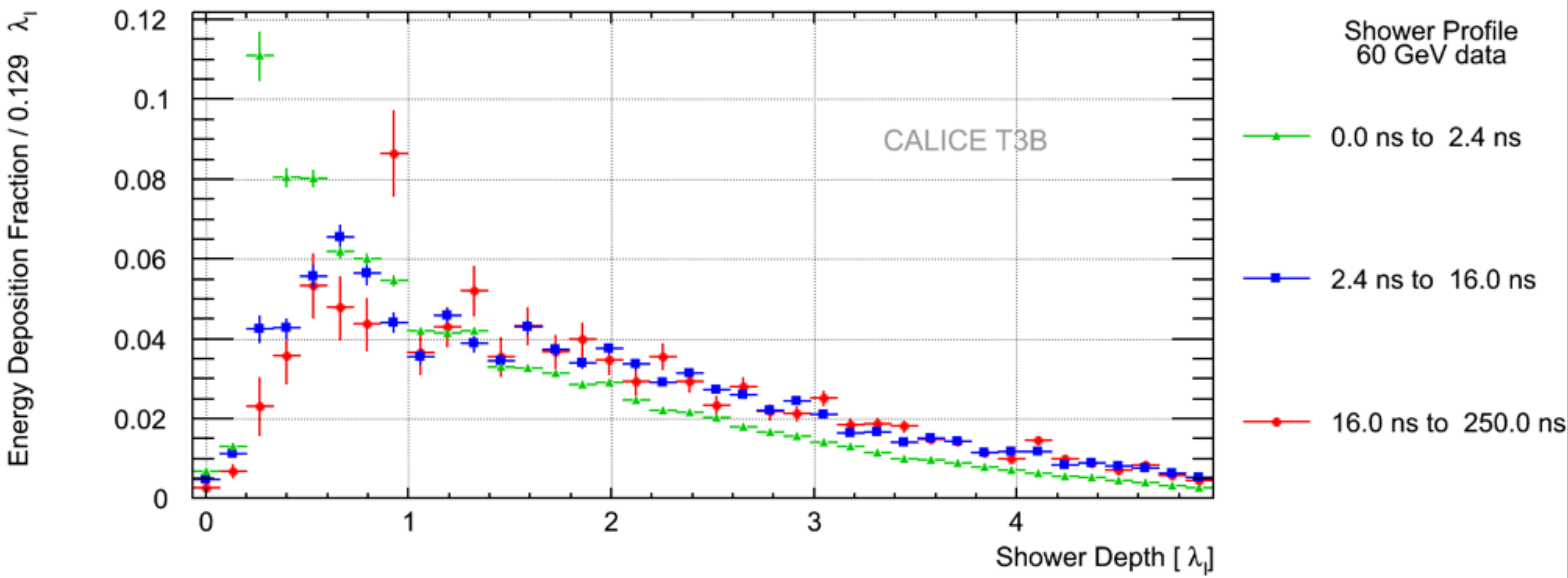
- A few updates compared to Annecy - fine-tuning of area-based scaling of data



- Event-by-event shower start used to reconstruct full calorimeter profile - includes weighting based on shower start position
- Limitations in the first few layers: Shower-start finding very close to T3B limited (works somewhat better in MC: Use shower start from MC record, with smearing)

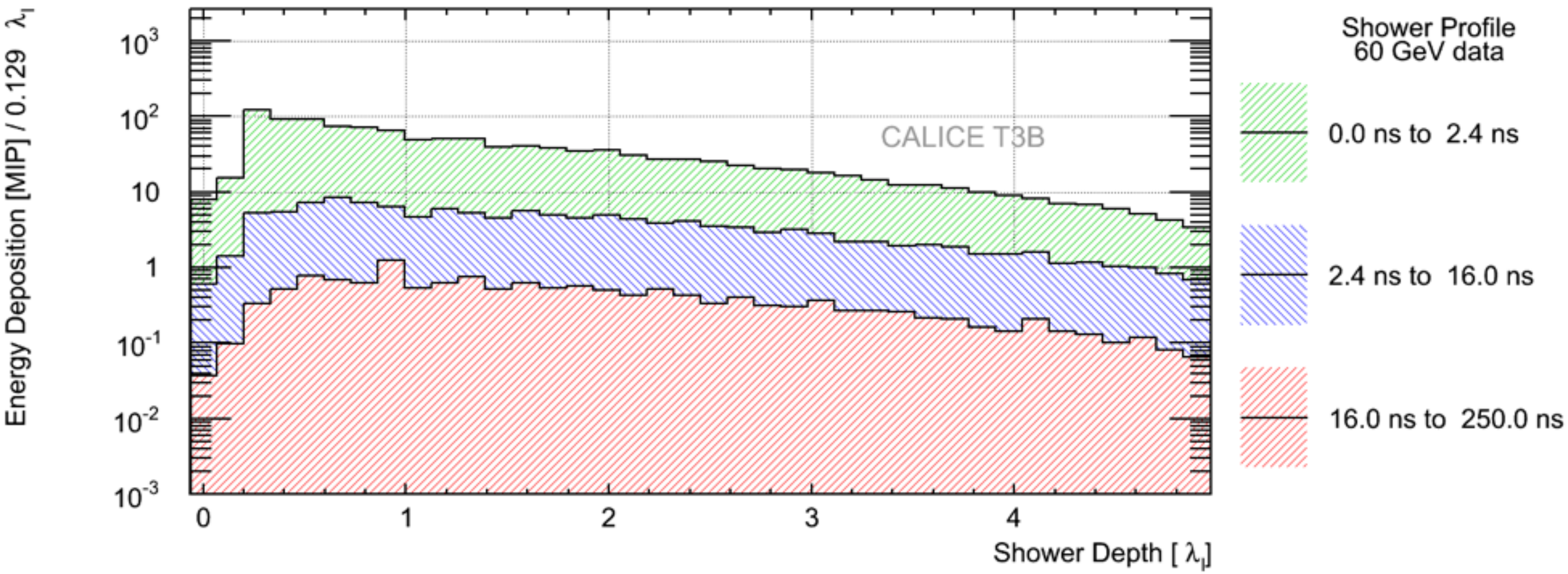
▸ Have to see how to handle this for comparisons - corrections or large systematic?

Longitudinal Profile - Time Dependence



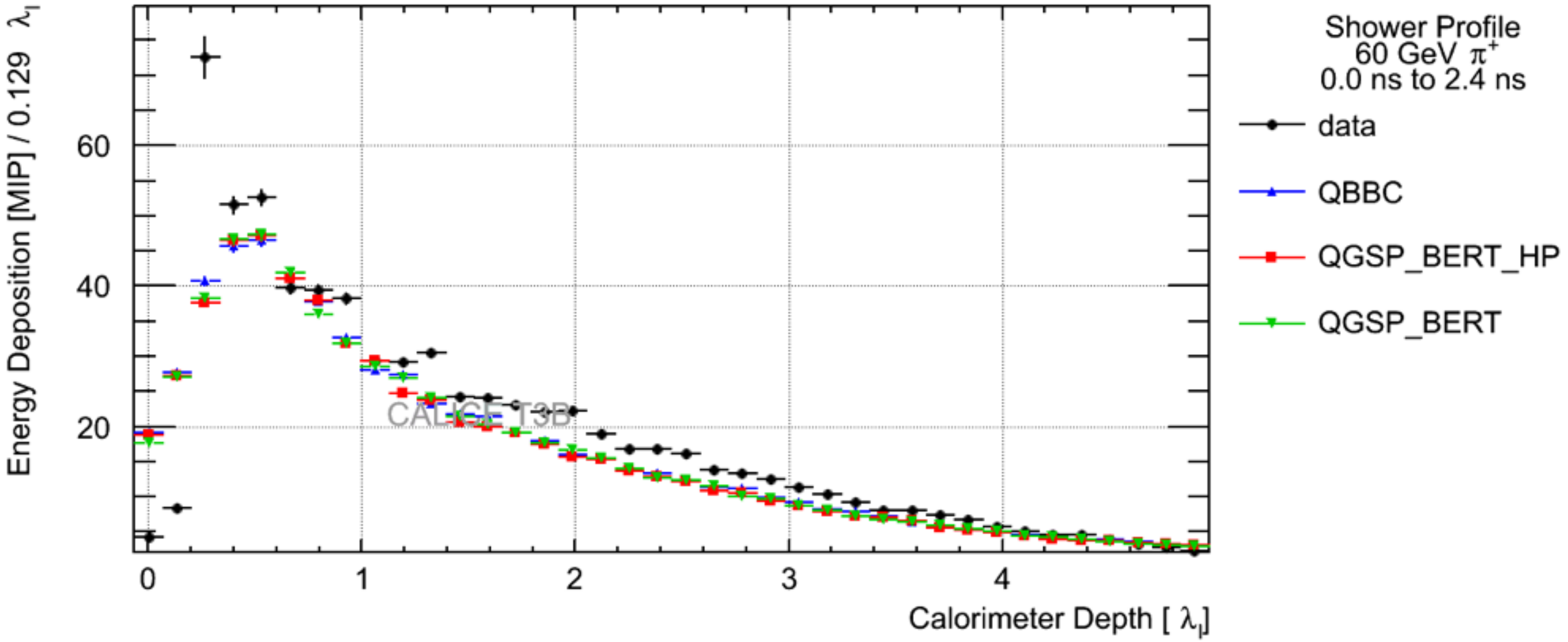
- Fast component peaks early ~ 0.4 λ_I
- Slow components peak later: ~ 0.6 - 1 λ_I

Longitudinal Profile - Time Dependence



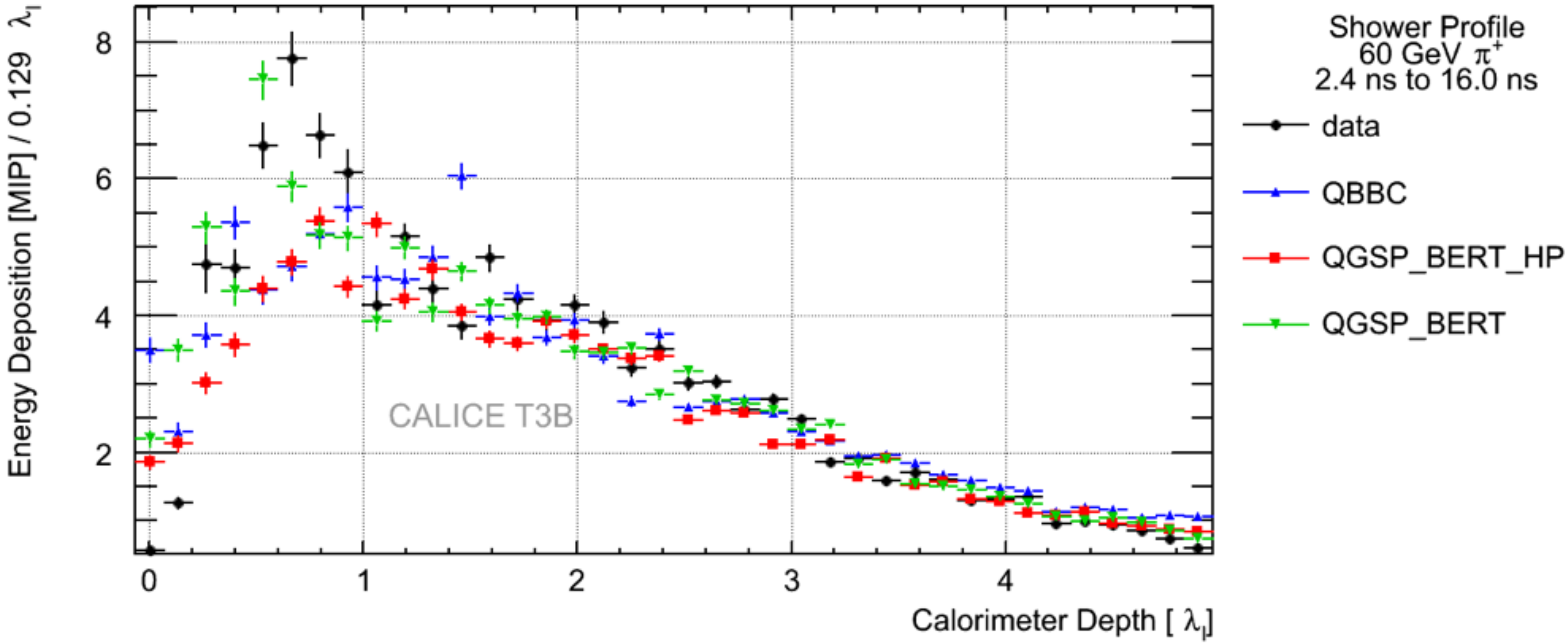
- Stacked distribution of three time windows

Longitudinal Distributions - Compared to MC



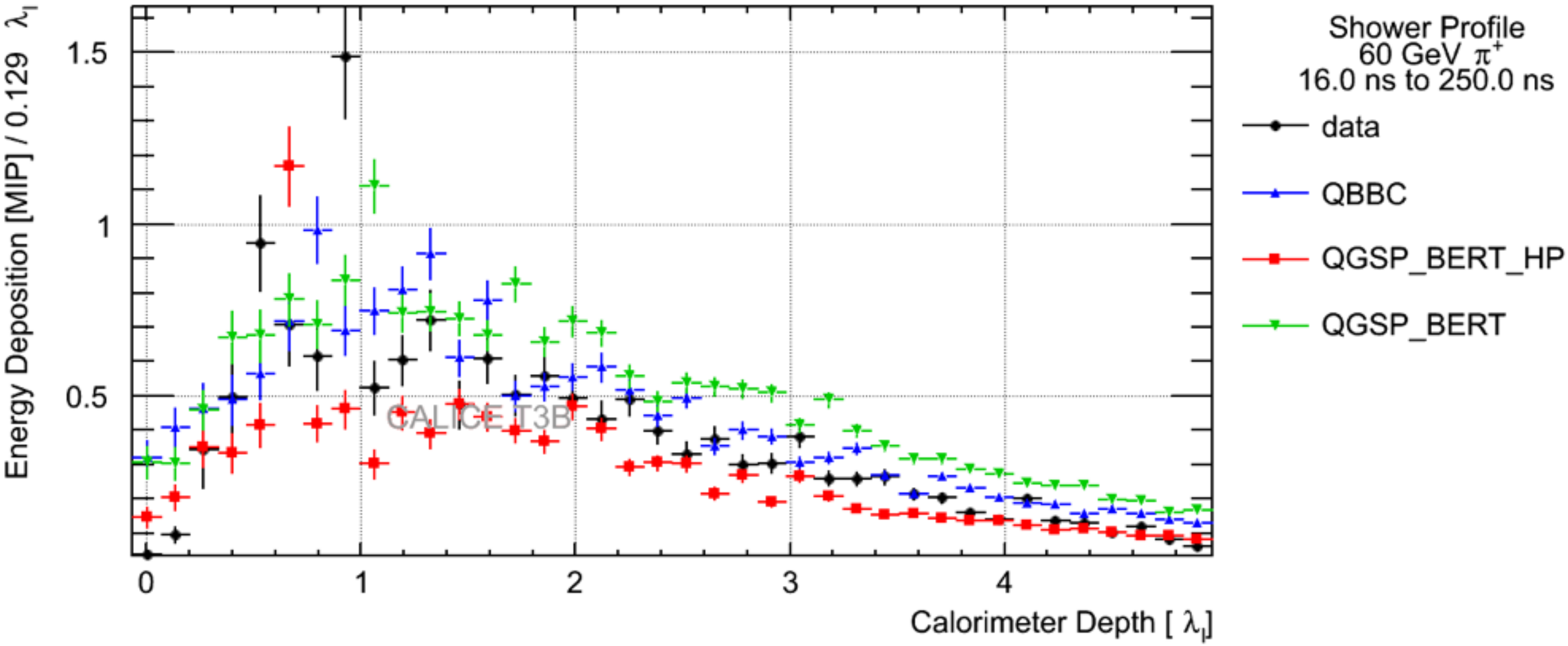
- Early shower components

Longitudinal Distributions - Compared to MC



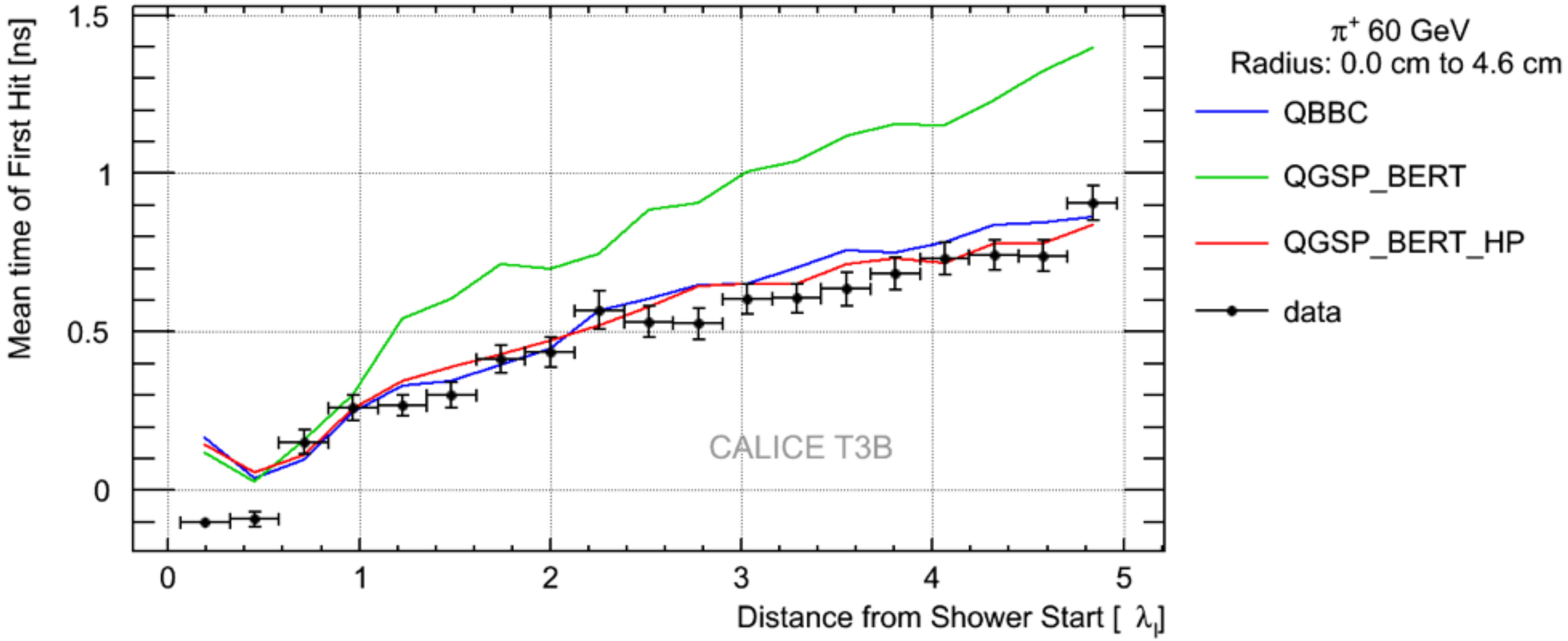
- Late components I

Longitudinal Distributions - Compared to MC



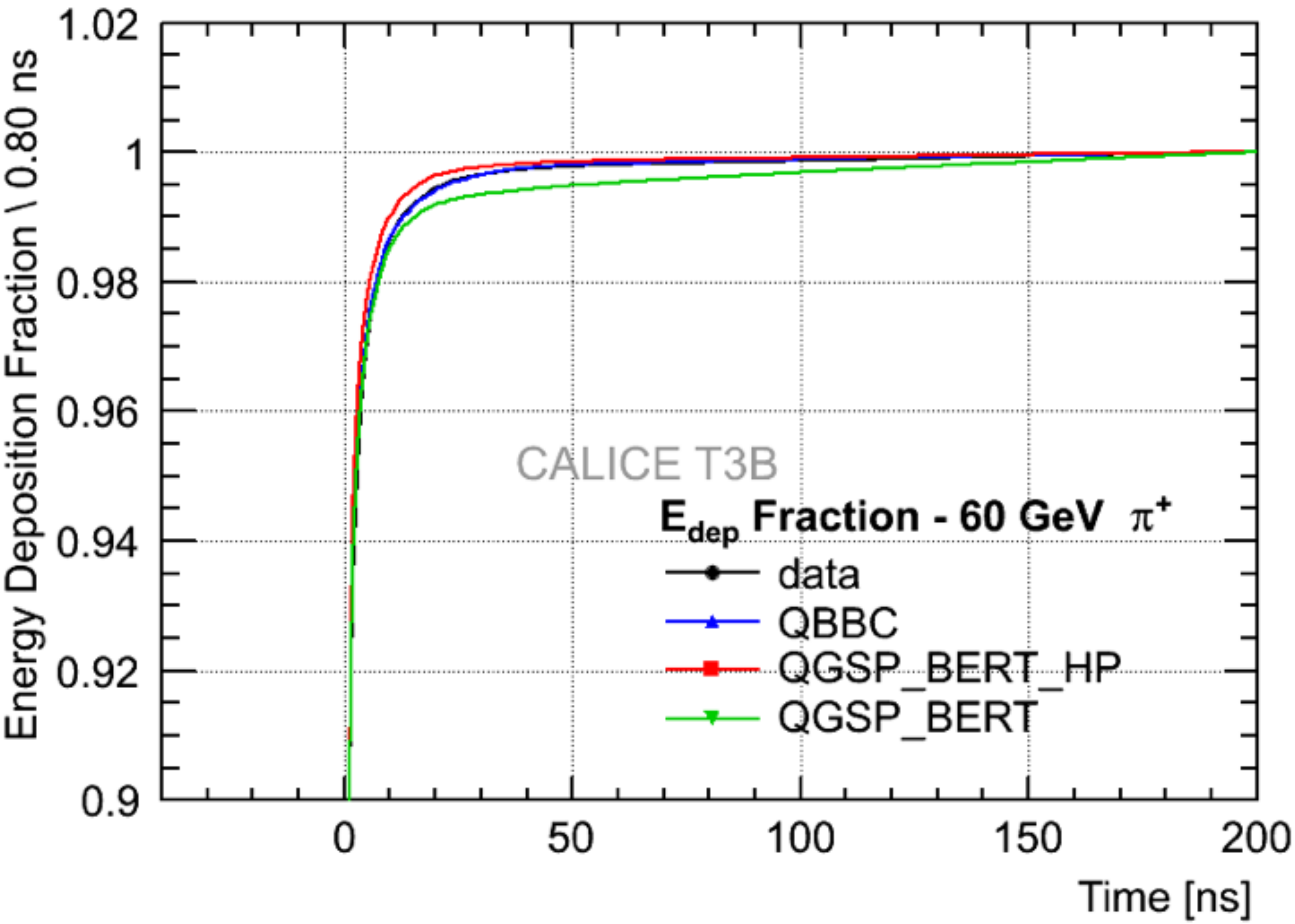
- Late components II
- General observations: Simulations consistent with observed distributions with all physics lists
  - NB: The real differences (for the longitudinally non-separated distributions) appear at times > 50 ns - An order of magnitude lower statistics

Comparisons to MC: Integrated Values



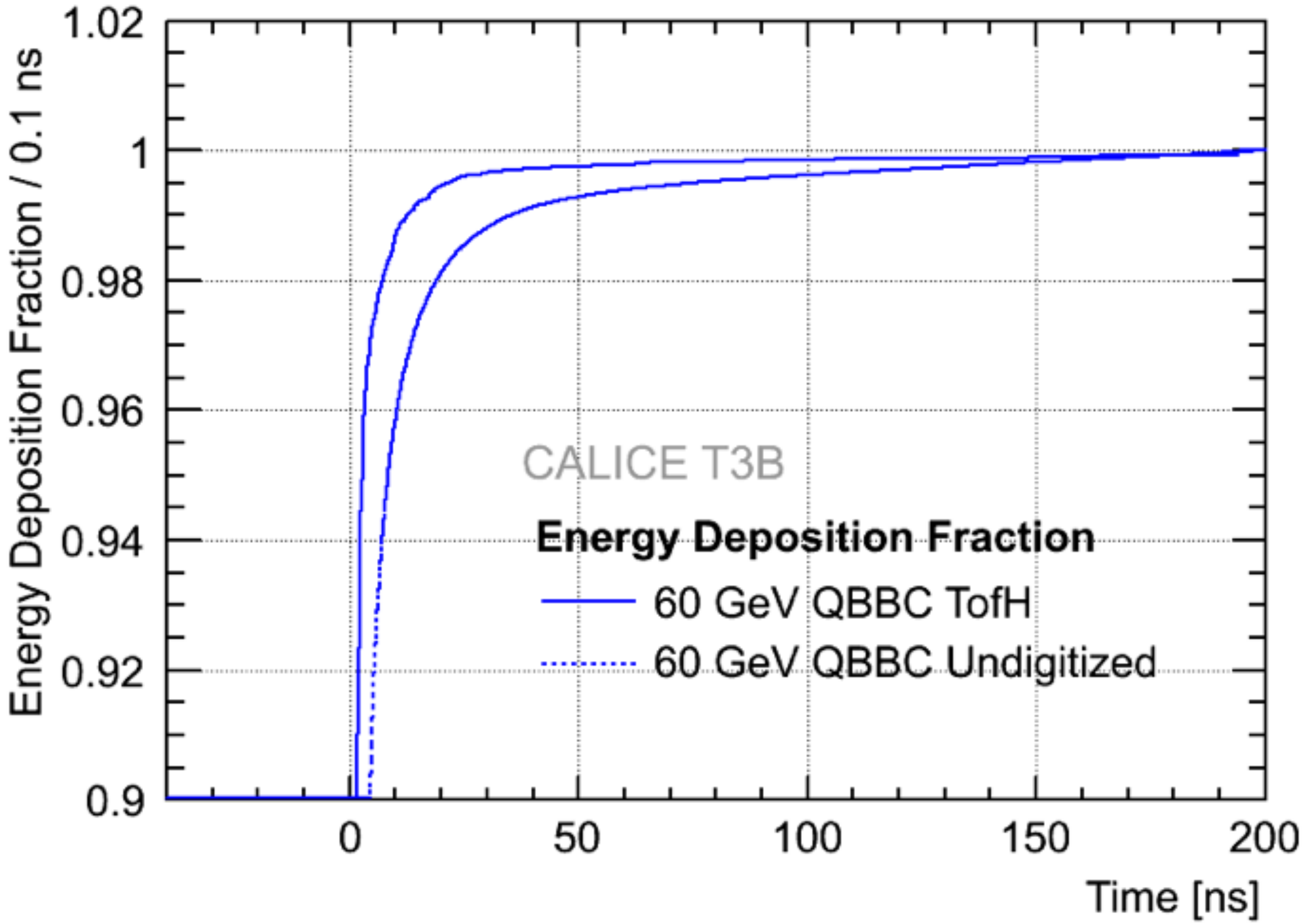
- Mean time of first hit vs distance from shower start: Late components gain in importance in shower rear
    - Restricted to center of shower - very low statistics further out

Consequences for Integration Times



- Based on time of first hit: 98% reached after 10 ns - QGSP_BERT predicts a too slow integration for the last 1 %

Impact of Using Time of First Hit



- Substantially faster integration with first hit only- but actually quite realistic in terms of a real detector (time stamp provided by start of signal in a cell, not by extension…)

Conclusions

- T3B analysis for now complete
  - Experts are now in industry…

- First analysis paper nearing submission:
  - Late shower part substantially more pronounced in W than in Fe
  - Physics lists with high precision neutron treatment reproduce observed distributions quite well, QGSP_BERT fails for tungsten at $t > 50$ ns, some smaller discrepancies at $20 \text{ ns} < t < 60$ ns in Fe

- Potential for a second paper using longitudinally resolved analysis based on reconstructed shower start (W only)
  - Fast component peaks shorter after shower start
  - Mean time of first hit gets later towards rear of the shower - needs HP to reproduce with simulations