Update on Simulation of Time Structure
- Progress for T3B and FastRPC -

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CALICE Collaboration Meeting
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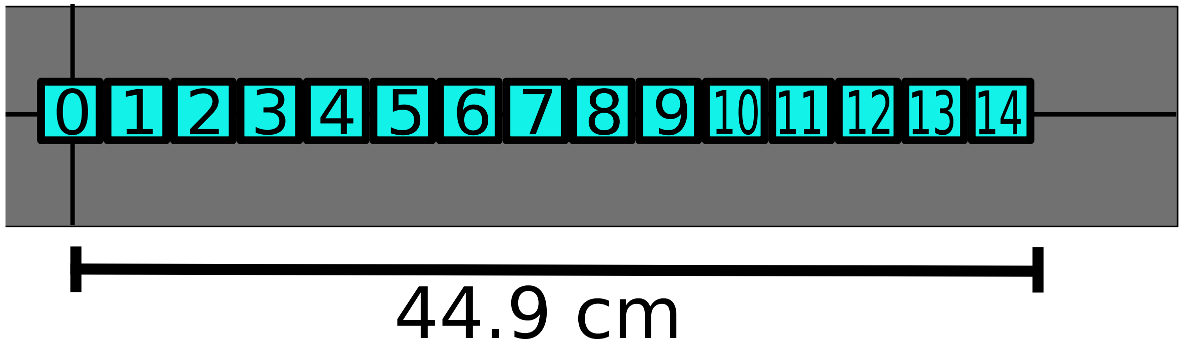
(Werner-Heisenberg-Institut)

Reminder: T3B & FastRPC

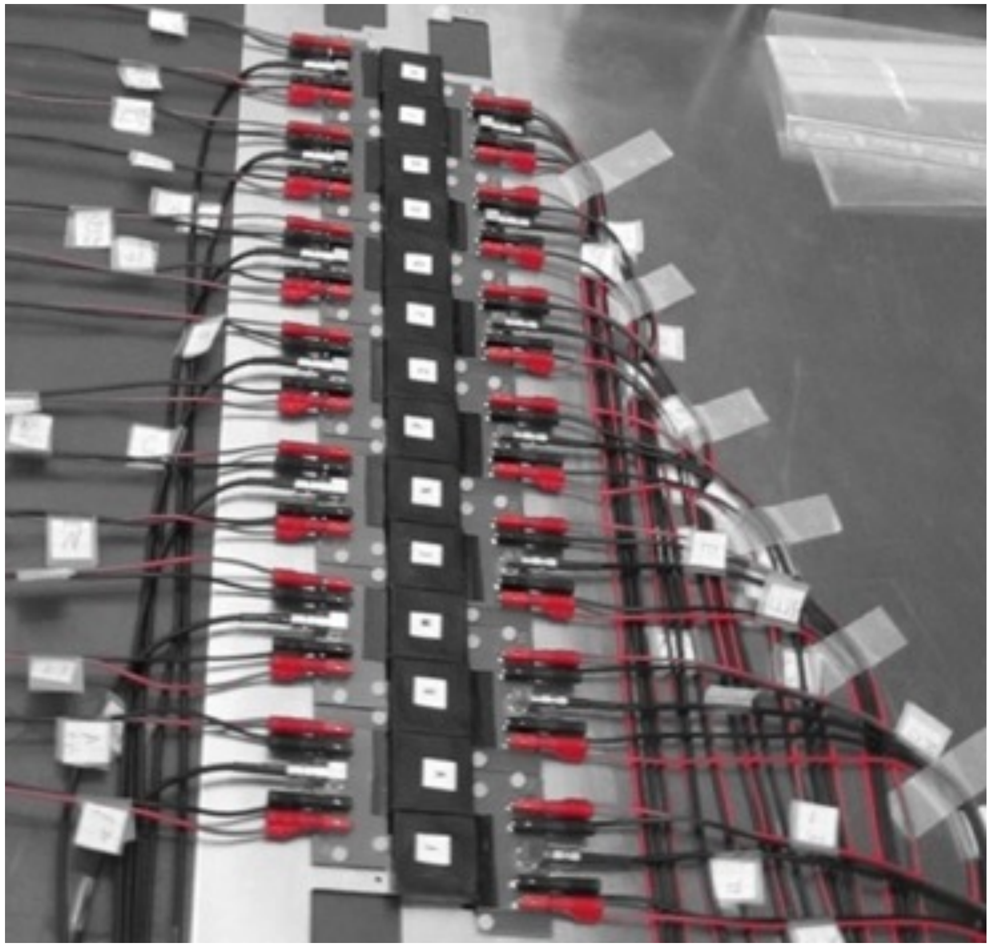
- Dedicated detectors for time structure measurements operated behind CALICE prototypes at CERN SPS (T3B 2011 WAHCAL & SDHCAL, FastRPC 2012 WDHCAL)

15 cells, read out with fast digitizers over long (~ 2 μs) times

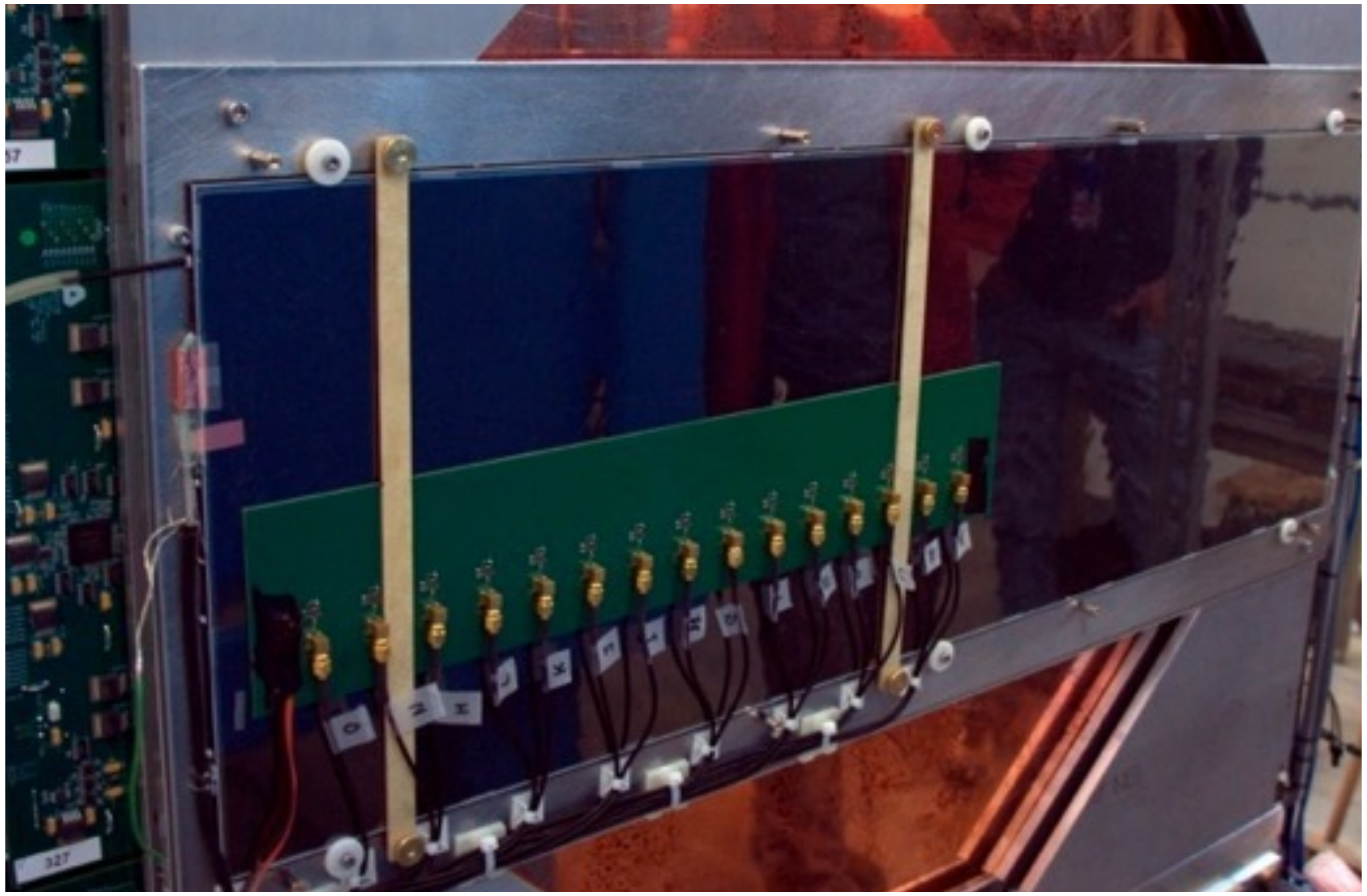
beam axis through cell 0



T3B: Plastic Scintillator

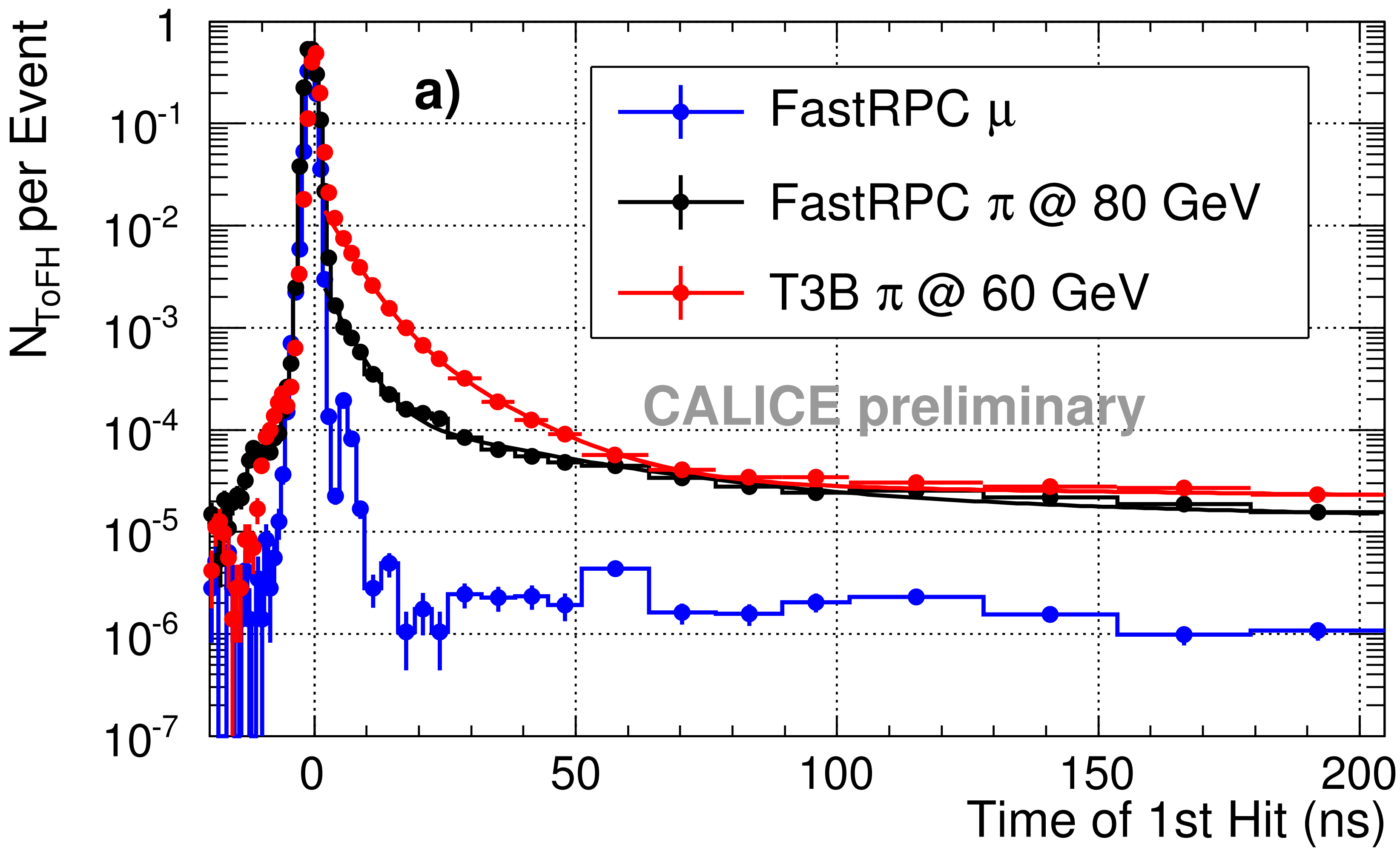


FastRPC: ANL Glass RPC



What the Data tells us

- From the T3B and FastRPC measurements:



The interpretation:

Prompt component - relativistic hadrons, em subshowers

Intermediate component - substantial contributions by MeV - scale neutrons

Late component - dominated by neutron capture

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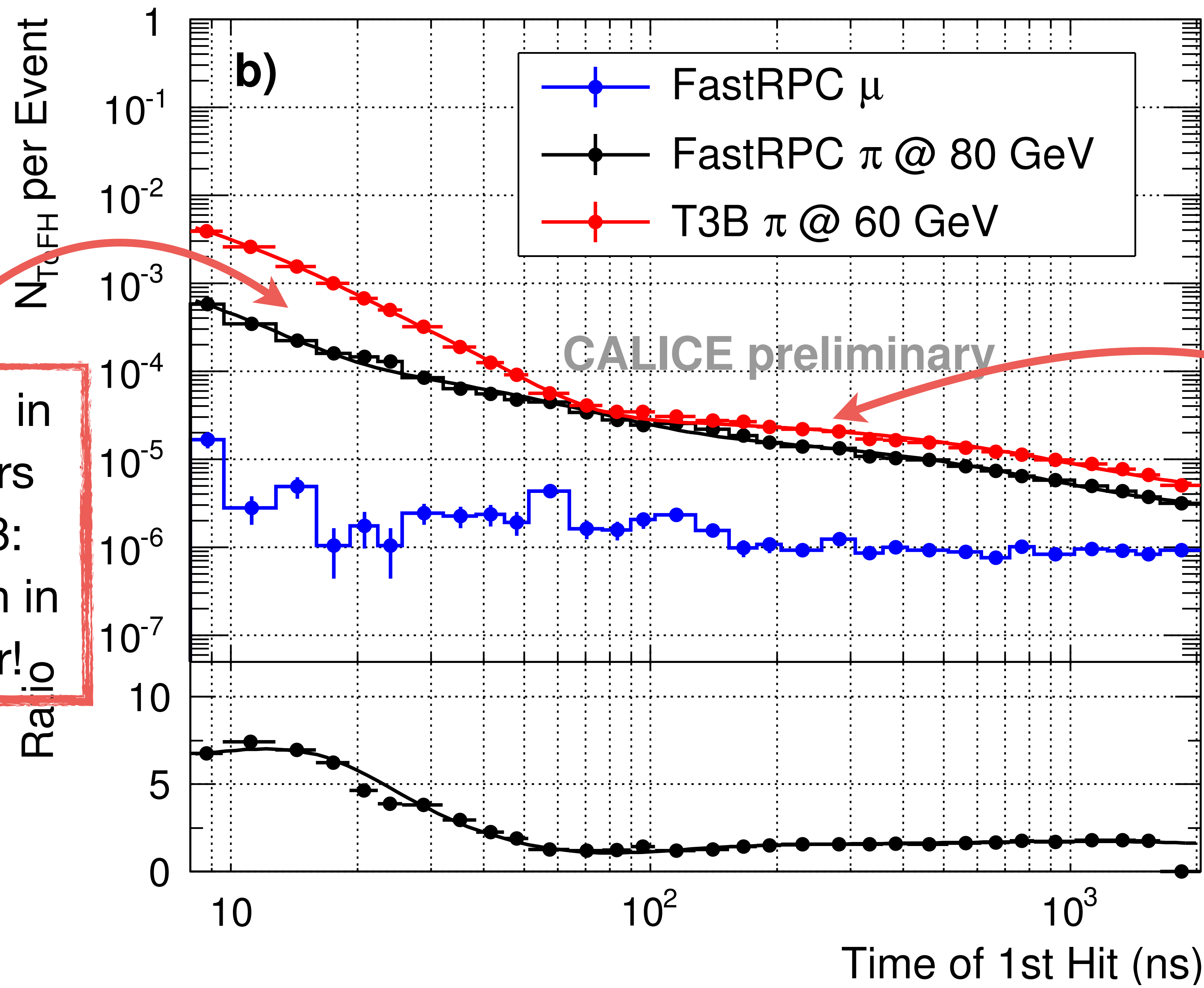

suppression in gas detectors by a factor 8: no hydrogen in gas detector!

light suppression in gas detectors by a factor 1.5 - 2: neutron capture in absorber, sensitivity to de-excitation in both technologies

The Simulation Study

- Study performed by Philipp Goecke
  Main goal: Identify sub-processes responsible for late components, and for the difference seen between scintillator and gas - done by adding sophisticated process-tracking to T3B G4 simulations (see backup)

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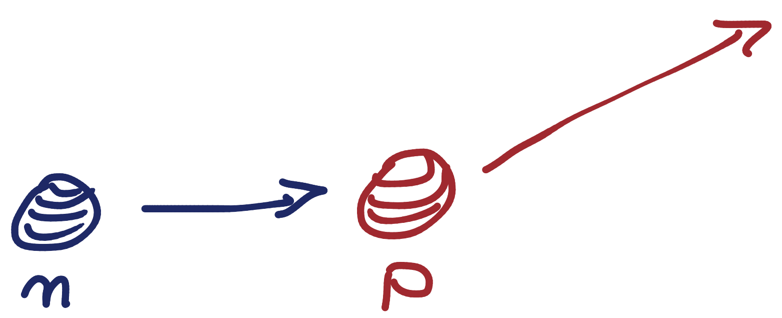
Processes of particular interest:



Neutron elastic scattering

most efficient when scattering on protons - particularly relevant for hydrogenous materials: plastic scintillator
Assumed to be behind the difference in the few 10 ns region - scattering of MeV - scale neutrons results in *O* 1 MIP signals

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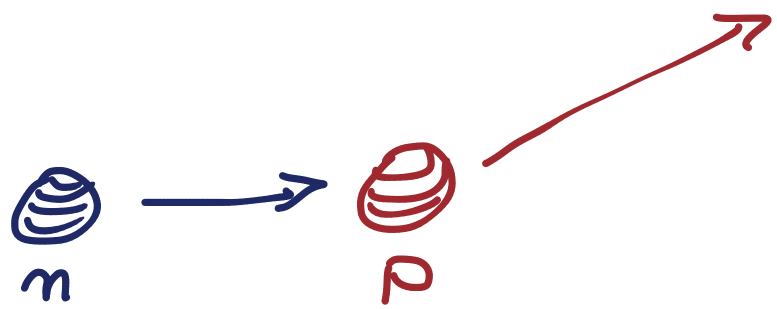

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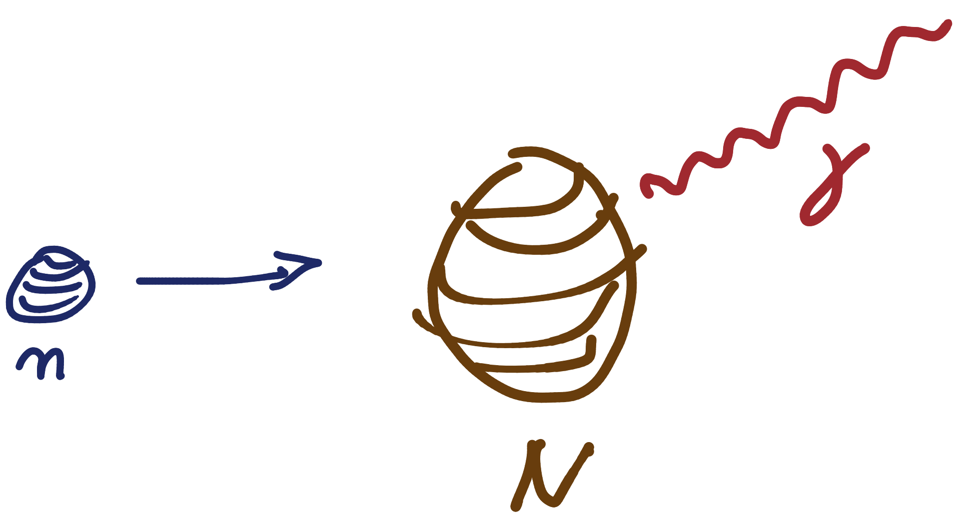


Neutron capture

capture of eV - scale neutrons on heavy nuclei, results in emission of few MeV photons
Capture takes place in absorber, photons convert to e^+e^- pairs (or e^- via Compton scattering), resulting in signal in sensitive volume - only “second-order” dependence on exact active material

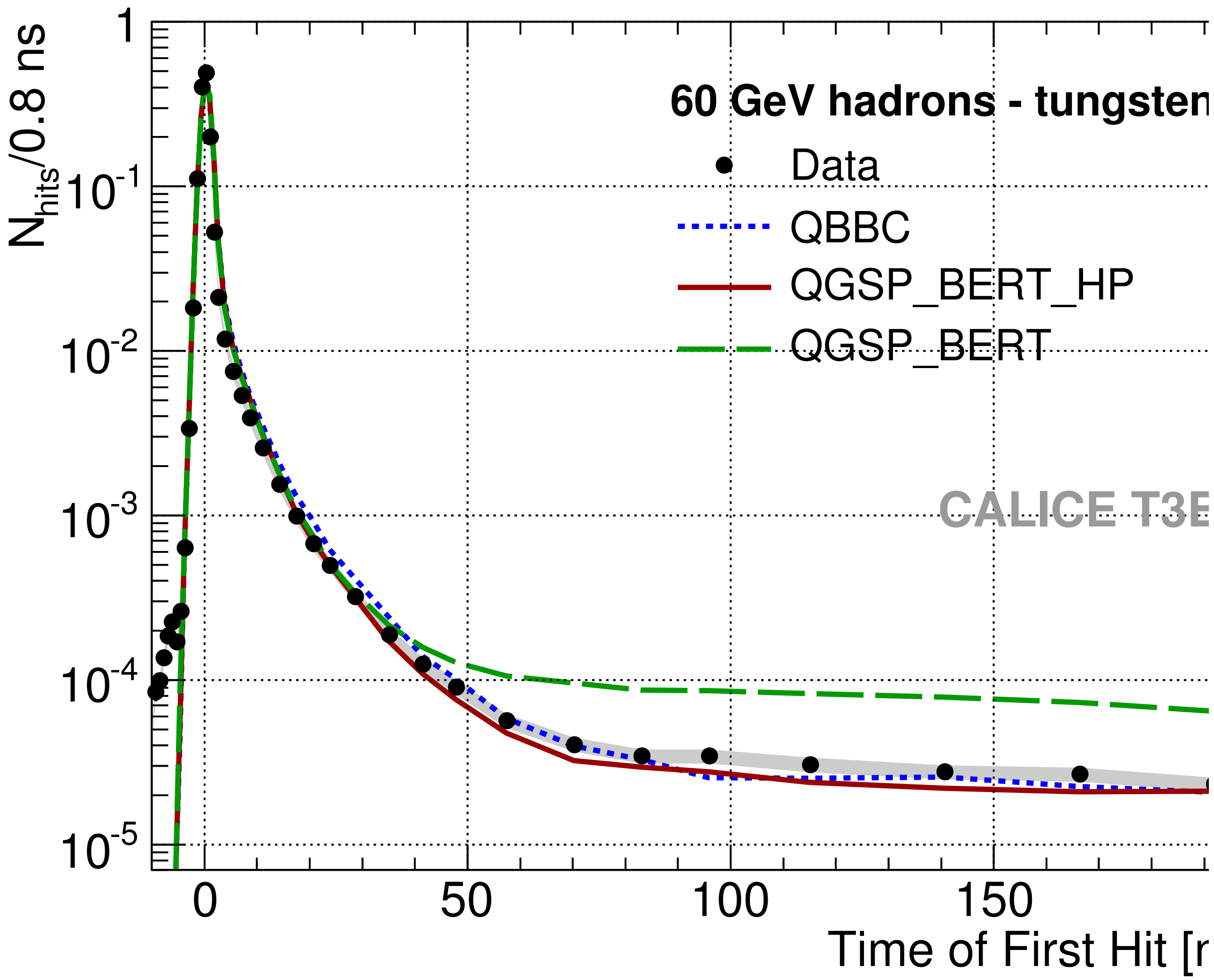
The Simulation Study - News Since Kyushu

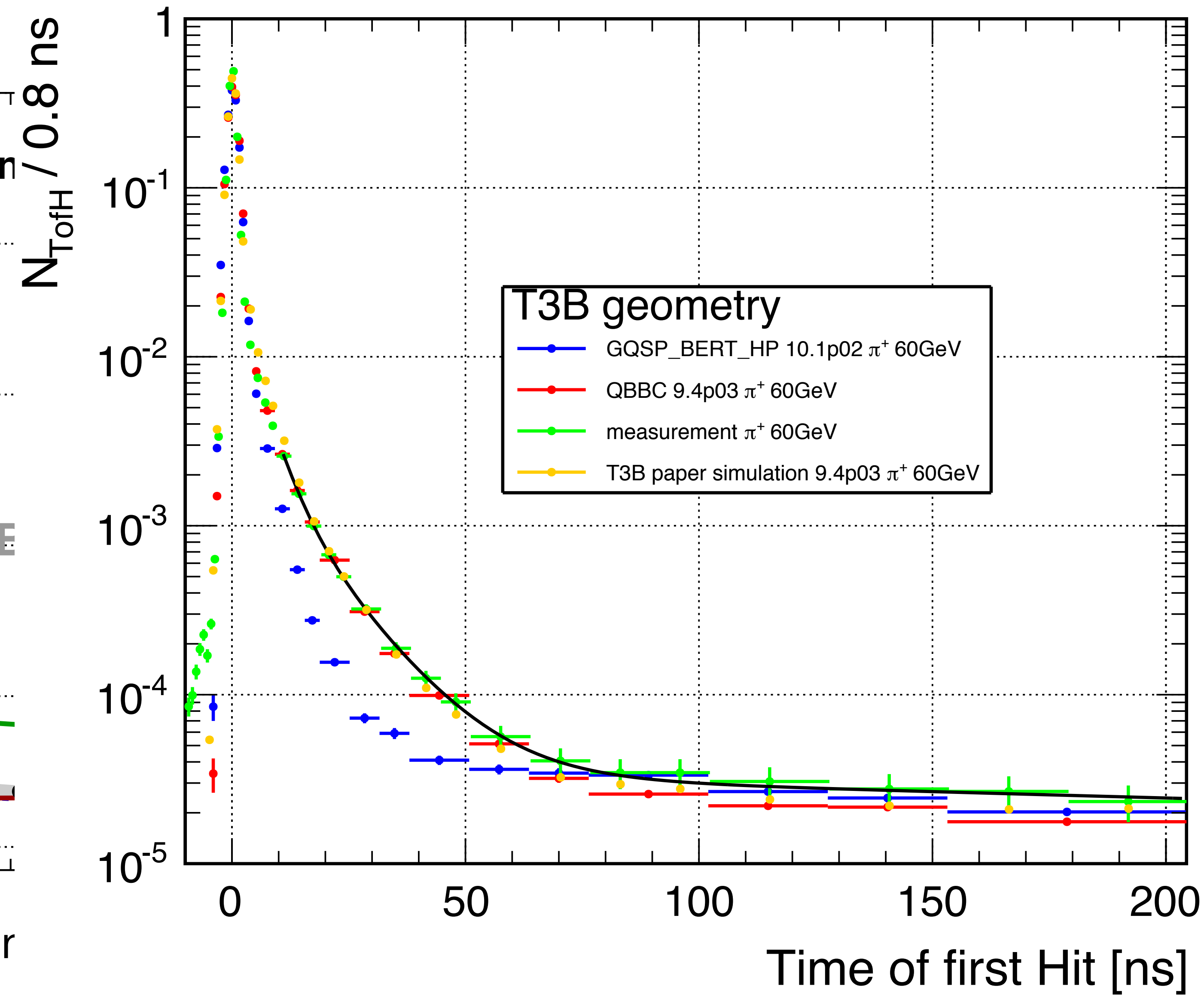
- Based on GEANT4 10.01.p02
- Two different geometries
  - W-DHCAL geometry for the simulation of FastRPC (fixed W composition) - also used for scintillator by replacing the gas + glass volumes are replaced by plastic scintillator - about 3 mm of scintillator per layer
    - *used for FastRPC MC, comparison of physics lists for both gas and scintillator*
  - Full implementation of T3B geometry (as in T3B analysis paper)
    - *used for T3B MC with G4 10.01, QGSP_BERT_HP only*

- For scintillator data full T3B digitization is now again available
  - Accounting for photon statistics, SiPM afterpulsing etc, time distribution of muon response used to build reference digitisation
  - No sophisticated digitisation in RPC case - time smearing taken from muon reference to account for time resolution of system and trigger jitter

Comparison of GEANT4 Versions

- In the T3B paper, we saw good agreement of the data with QBBC-based simulations (GEANT 9.4p03)

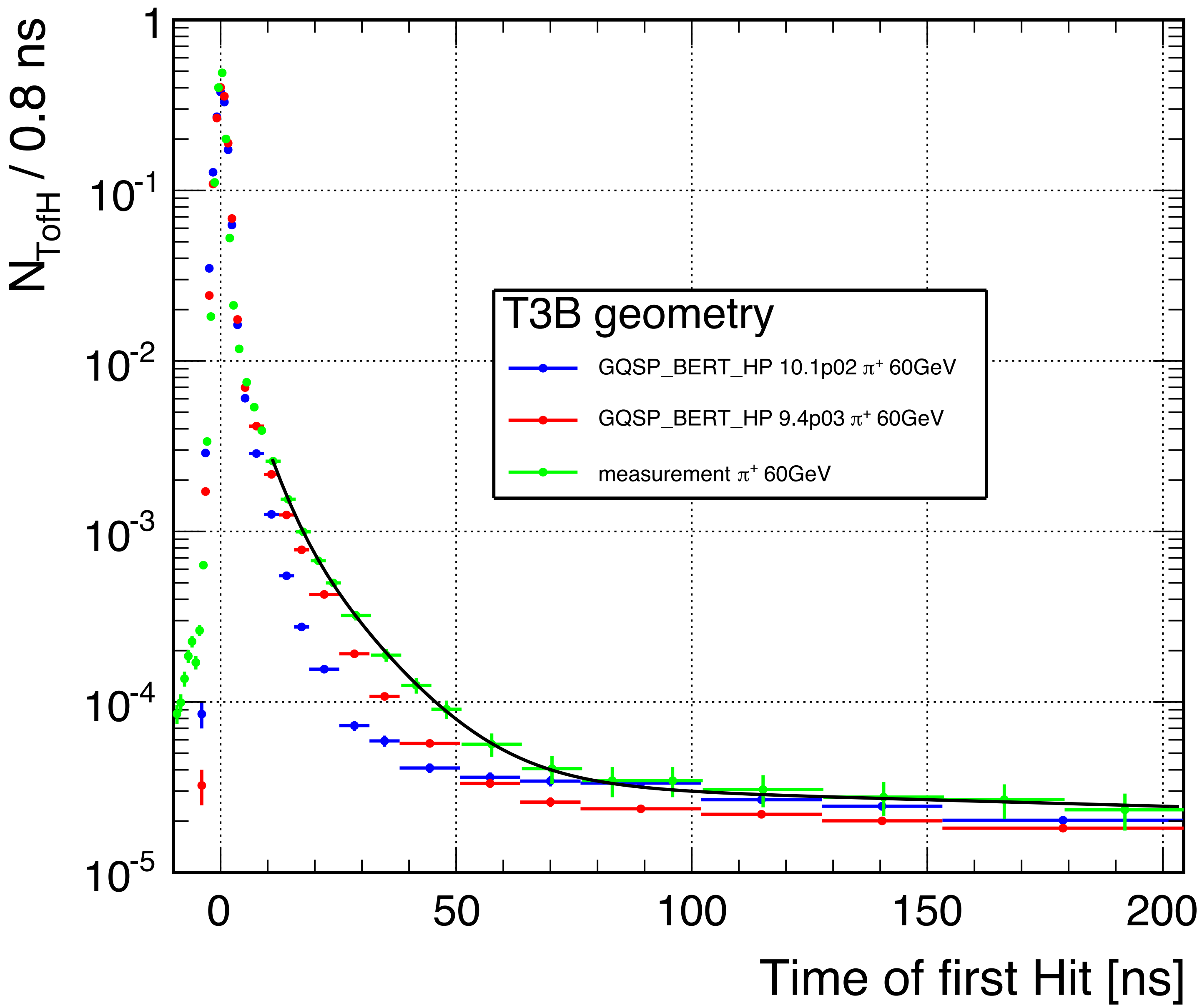




- We can now reproduce the old simulation results with re-implemented digitization
- GEANT 10.01p02 shows substantially lower activity in medium time frame: less MeV - scale neutrons?

Comparison of GEANT4 Versions

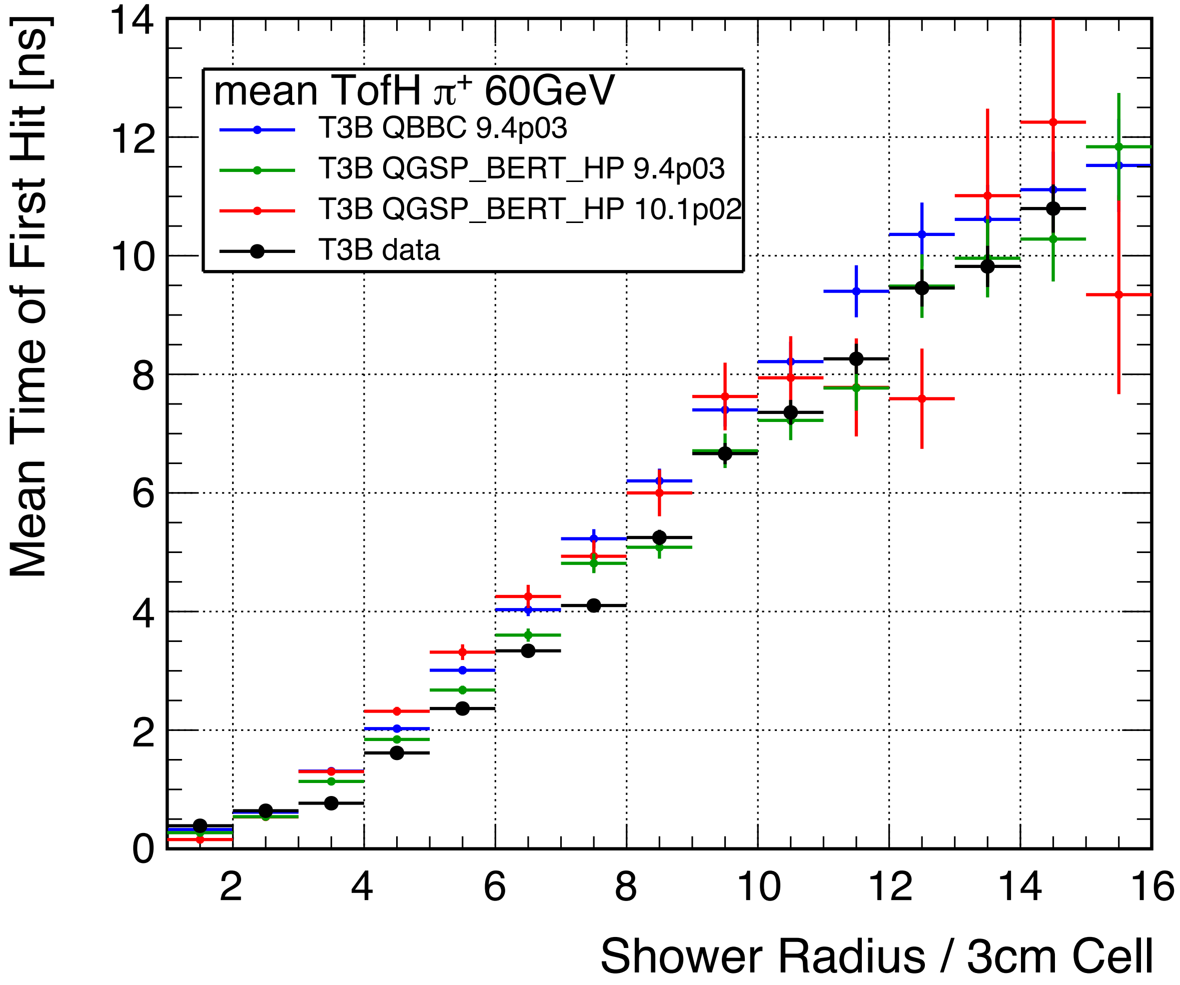
- QGSP_BERT_HP in 9.4p03 and 10.01.p02



- Differences seen in the same region - G4 10 has less activity from 20 to 40 ns

What is different in GEANT4.10?

- Still at the beginning - ongoing investigation
- The observation: mean time of first hit as a function of radius consistent



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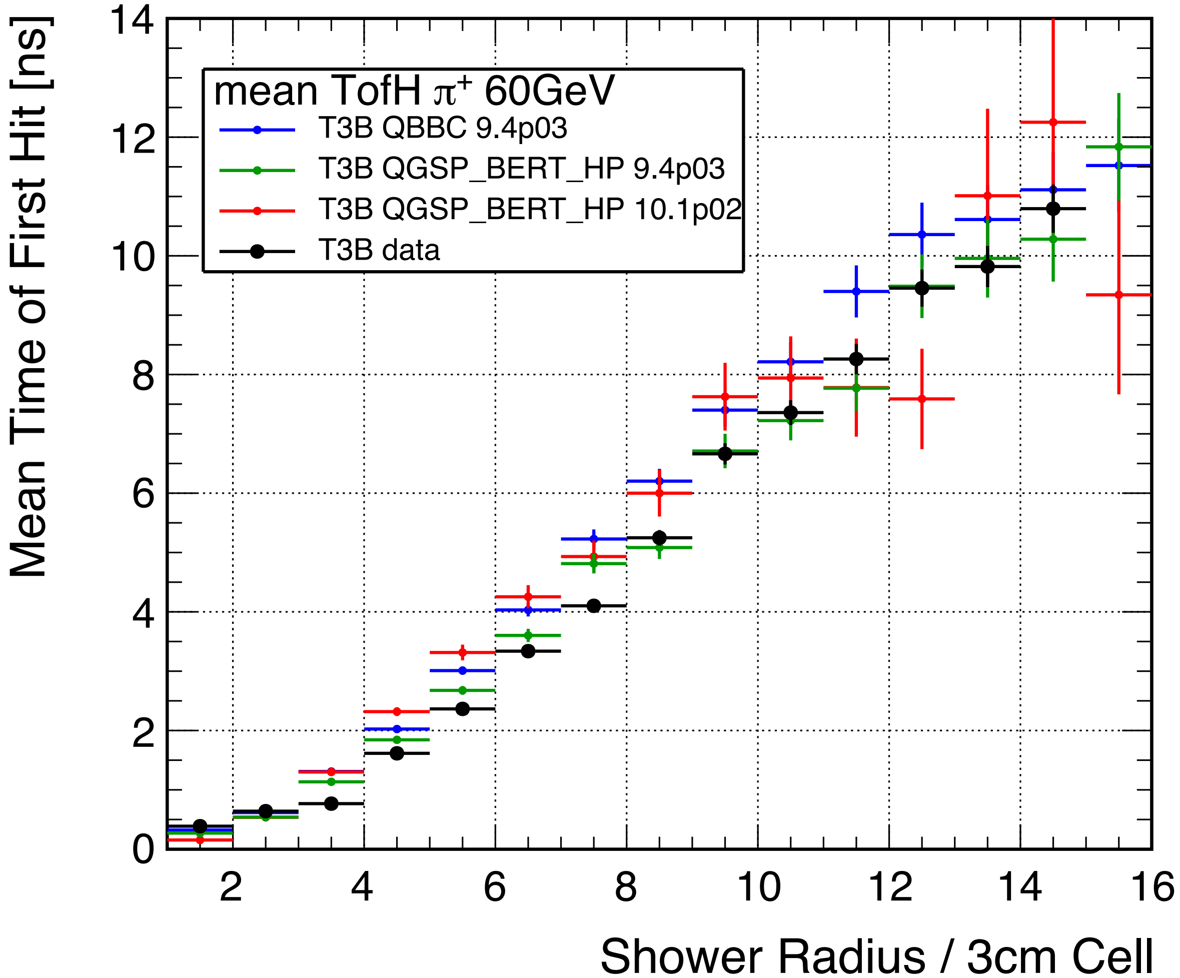
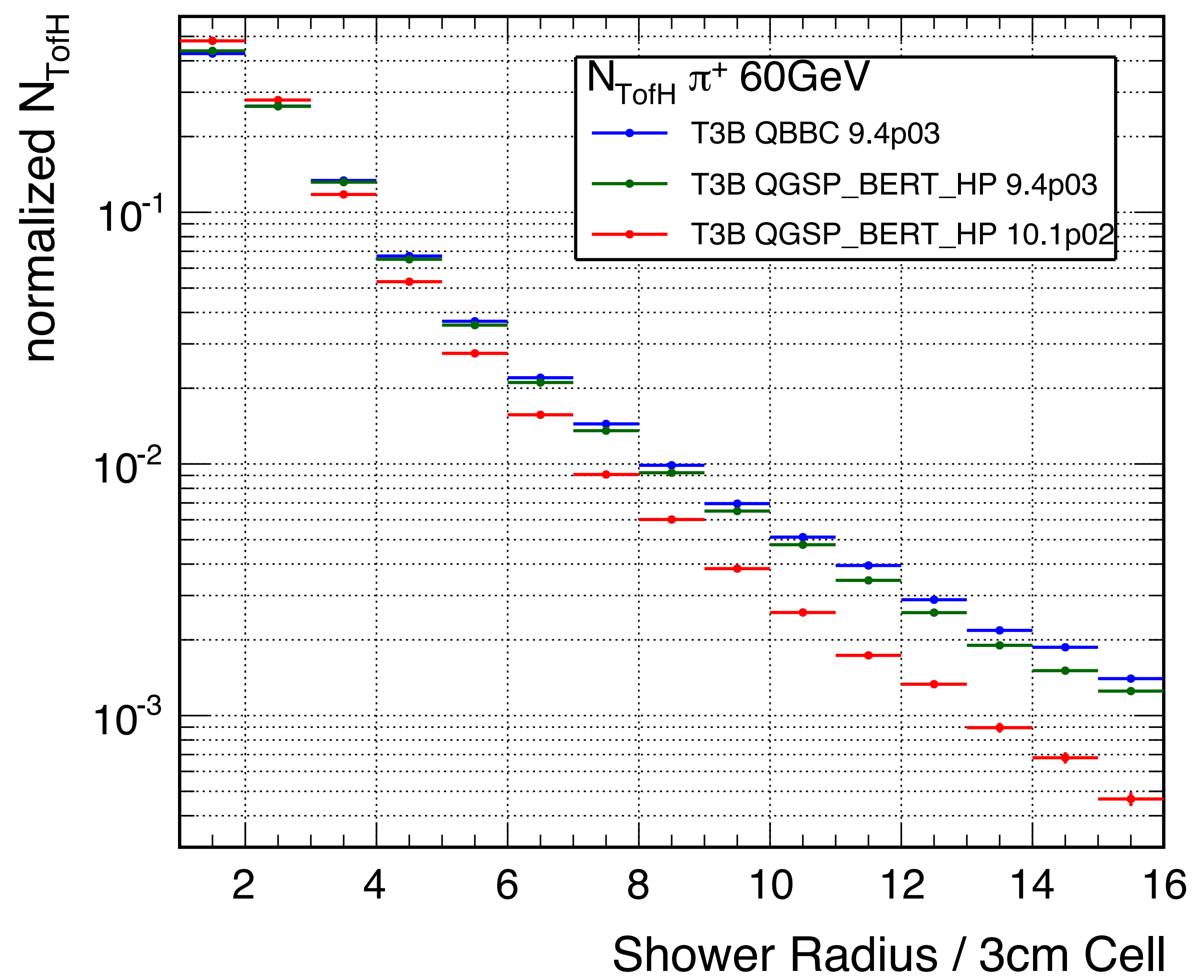
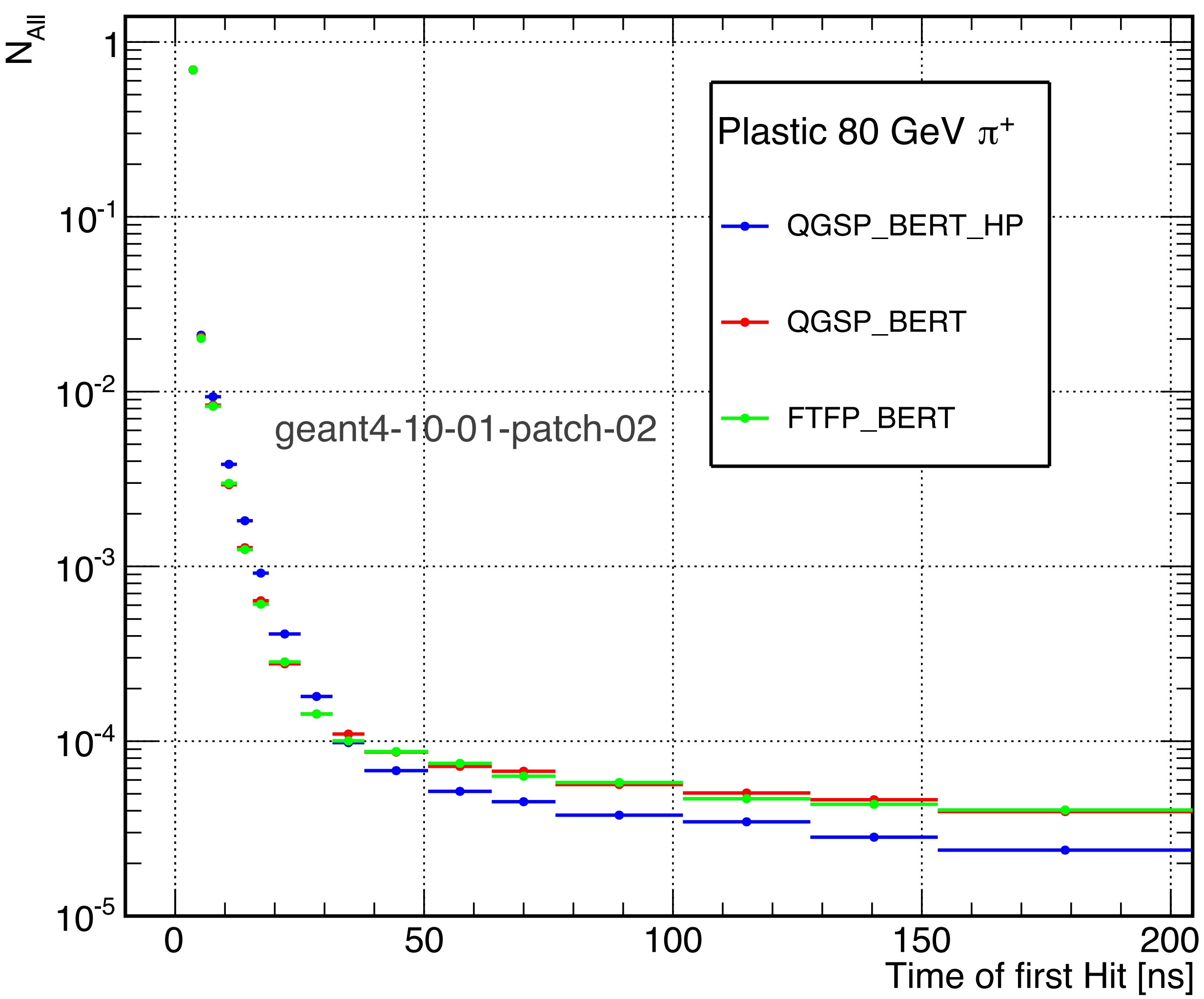


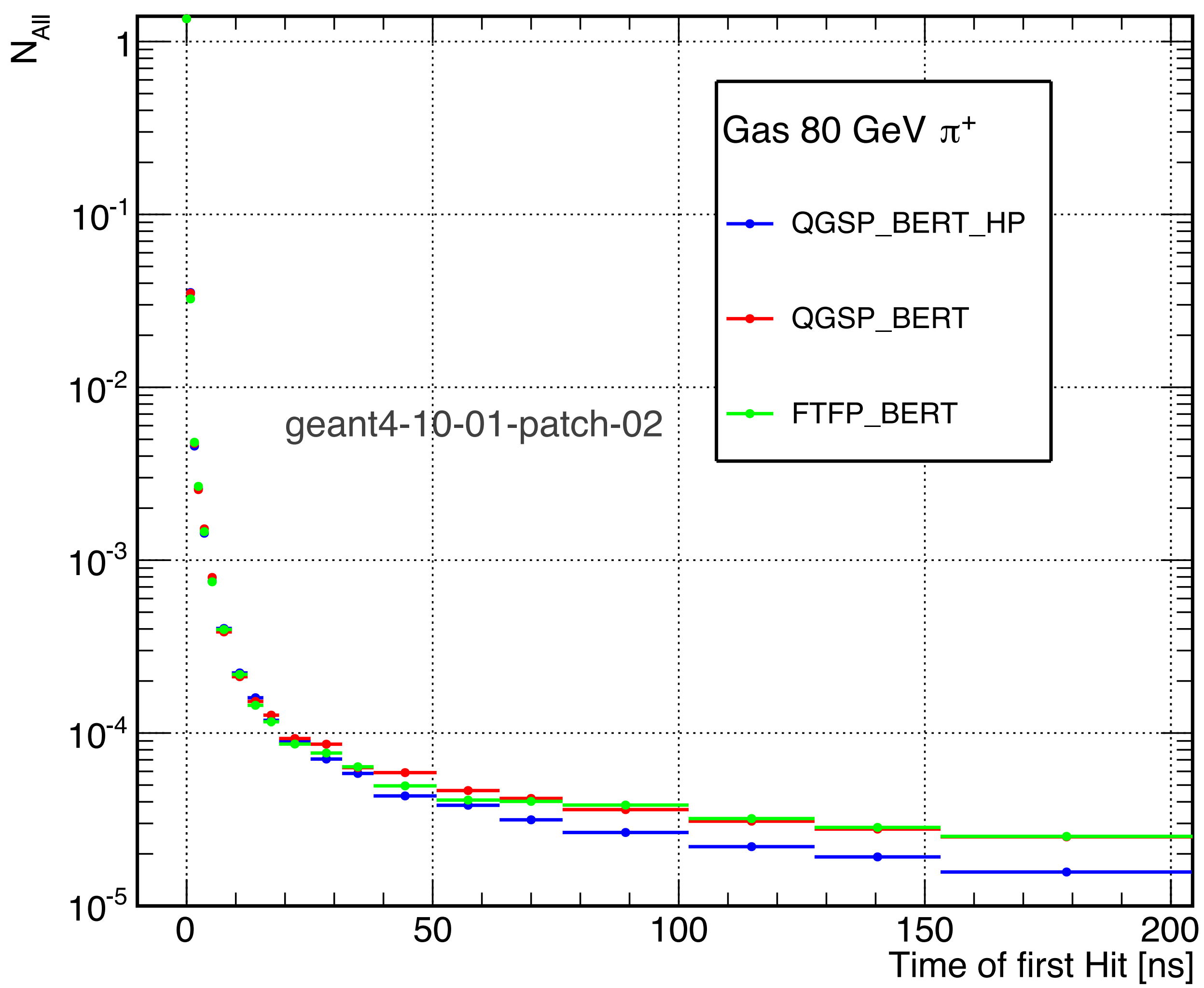


- But: less “first hits” at larger radius - results in less late hits in total
  - ▸ Consistent with MeV - scale neutron interpretation - less pronounced “neutron cloud” in 4.10 -> would result in fewer hits at high r, since neutrons spread out most

Different Physics Lists

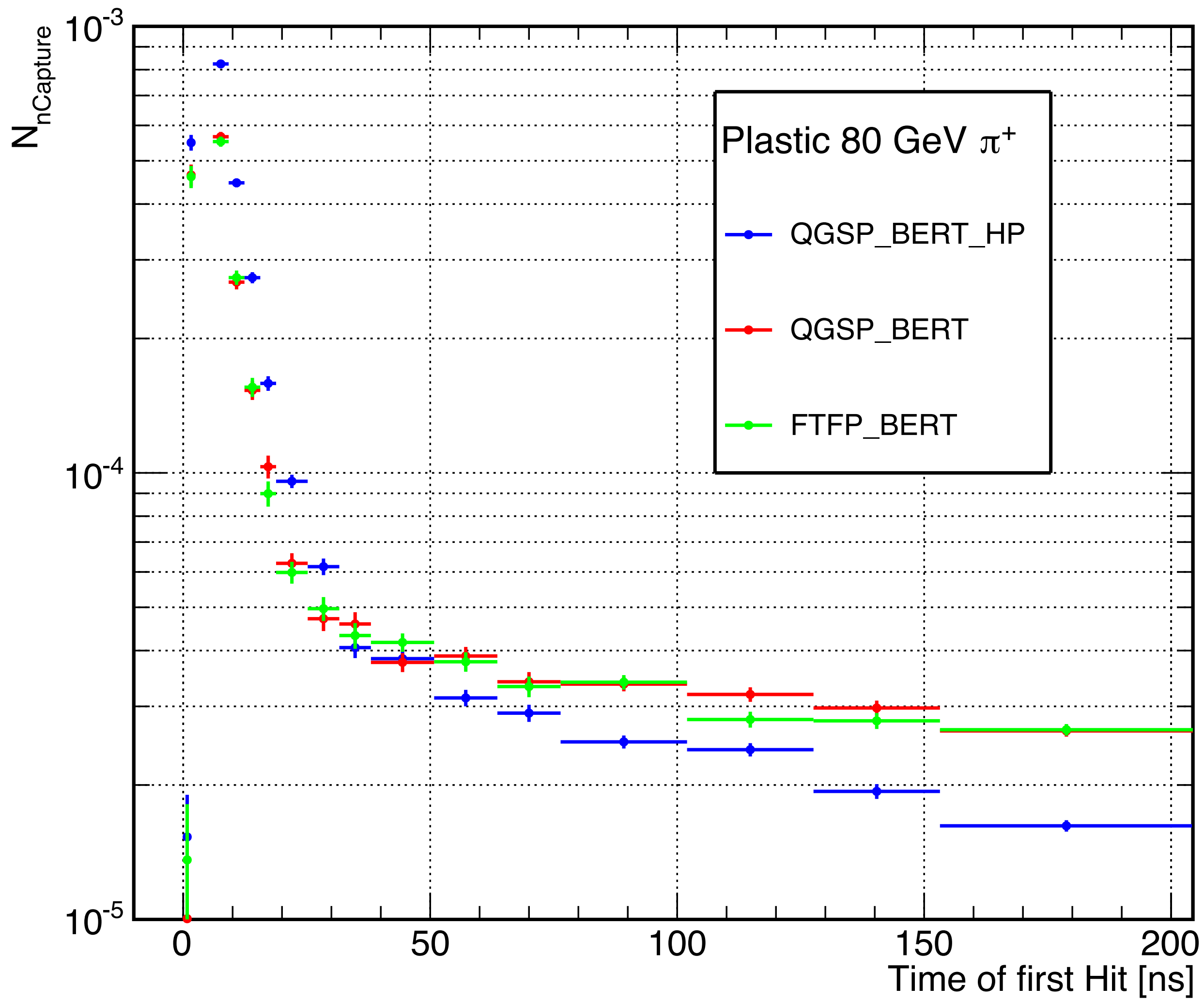
- Simulations in W-DHCAL configuration - for scintillator gas + gas replaced by plastic
  - no digitization, no smearing

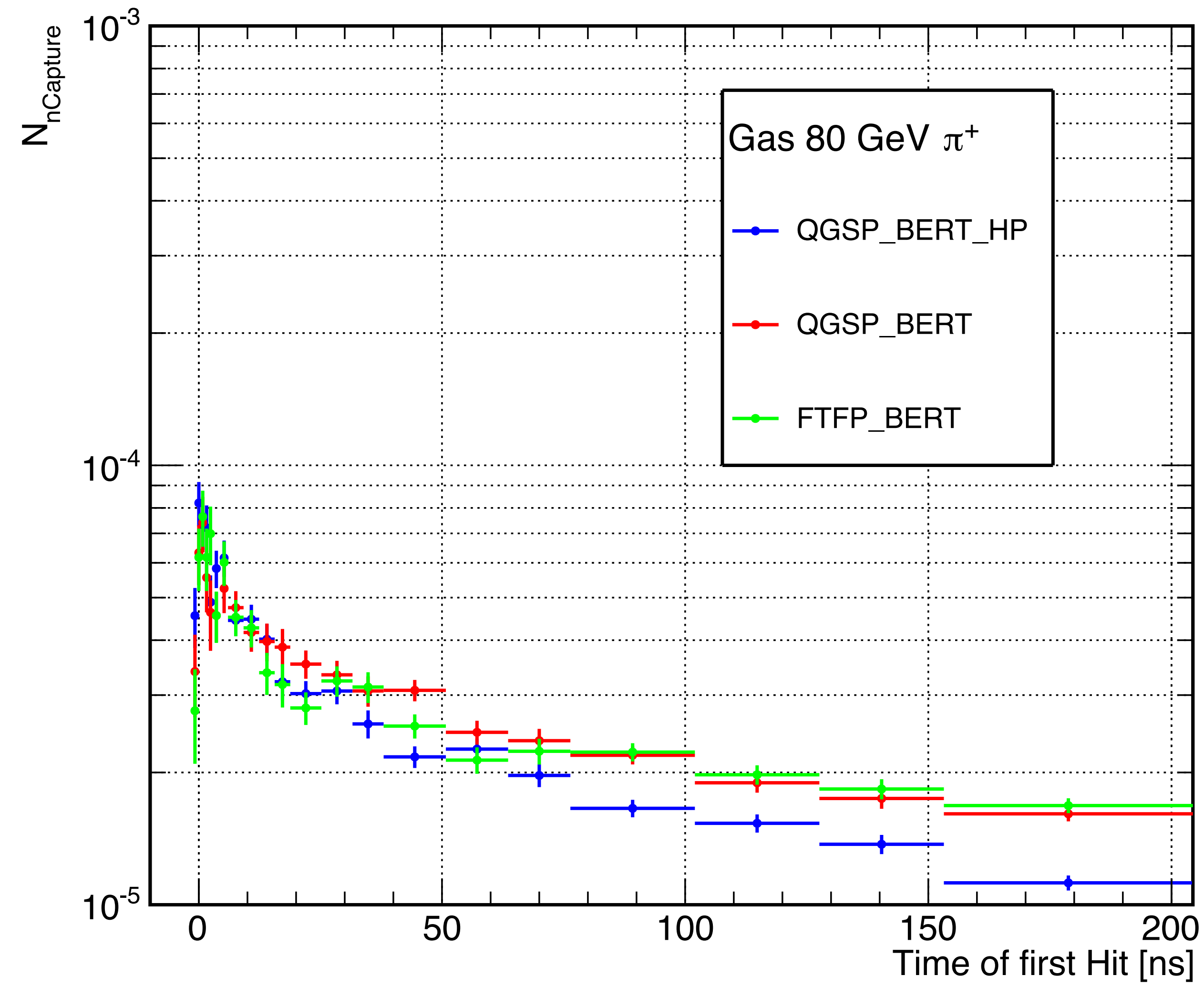


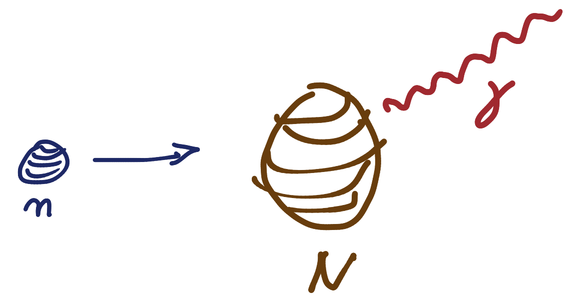


- QGSP_BERT and FTFP_BERT identical - only HP shows differences
- Similar trends in gas and plastic: HP low at late times
  - in plastic also smaller differences observed in the 10 - 30 ns time frame (HP higher)

Where the differences are

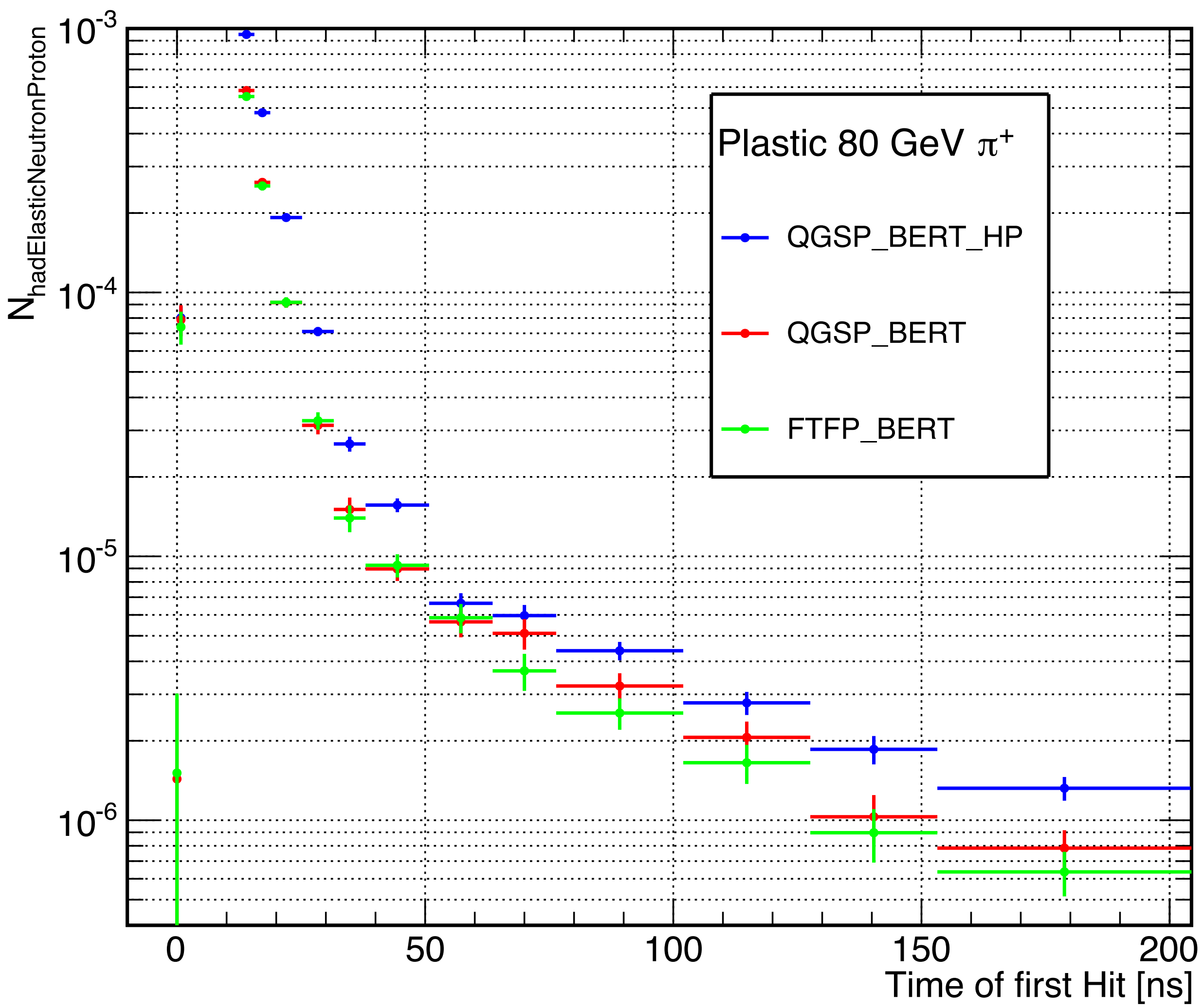


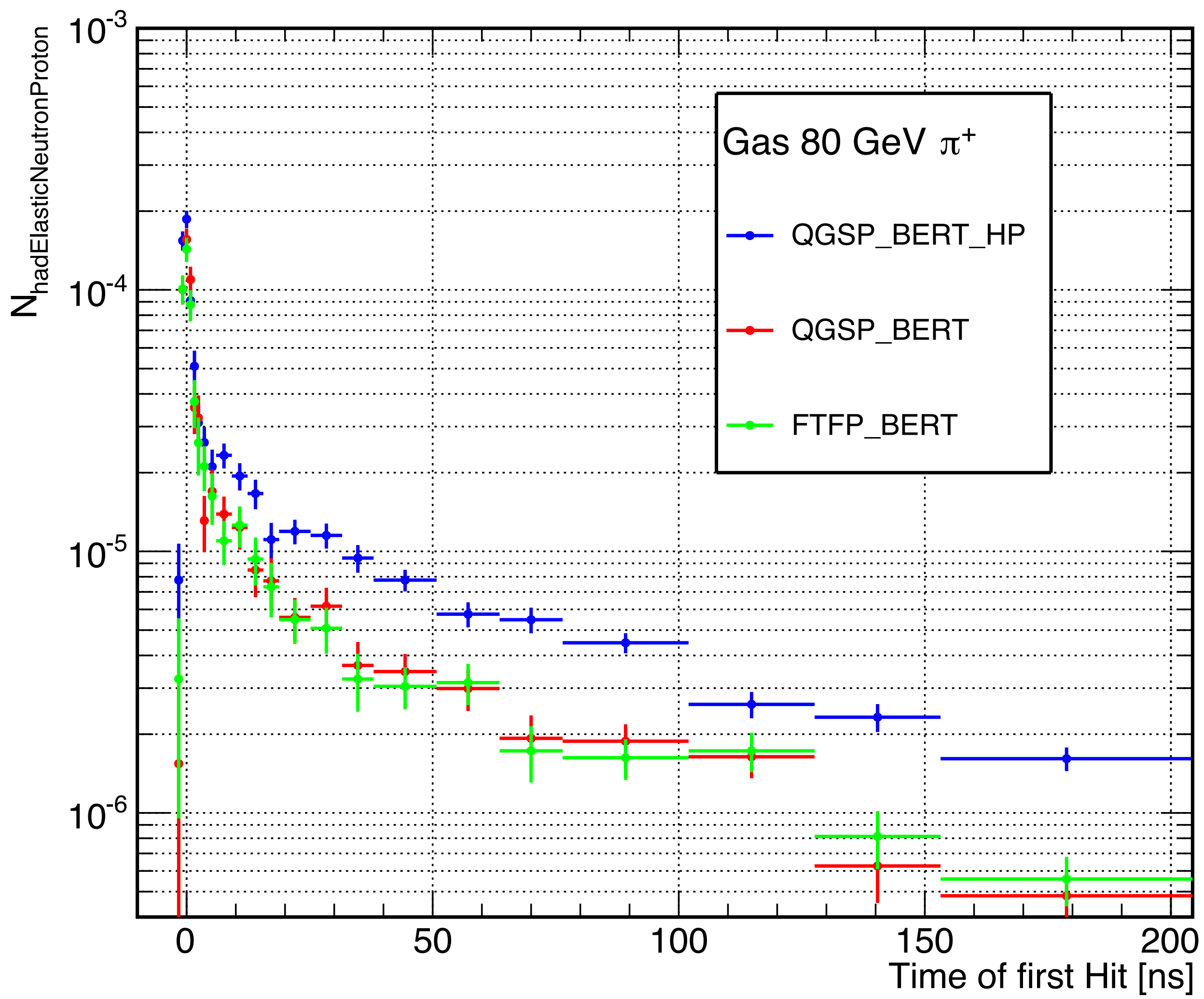


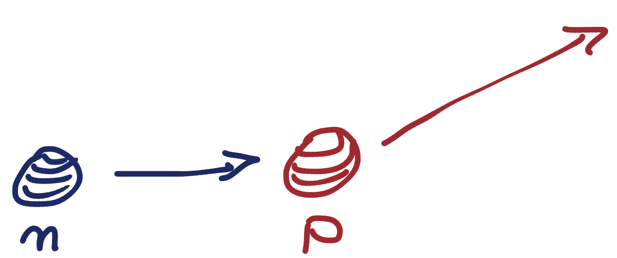


- The dominant source of the differences: Neutron capture - points at less slow neutrons in the HP physics lists

Where the differences are







- In the 10 - 30 ns time frame n-p elastic scattering important source of differences in scintillator - dominates over n capture
- At late times slightly higher rate in HP (but overall small contribution)

Conclusions

- Extended GEANT4 10.01 based simulations to different physics lists: See some differences between HP and non-HP lists in both scintillator and gas

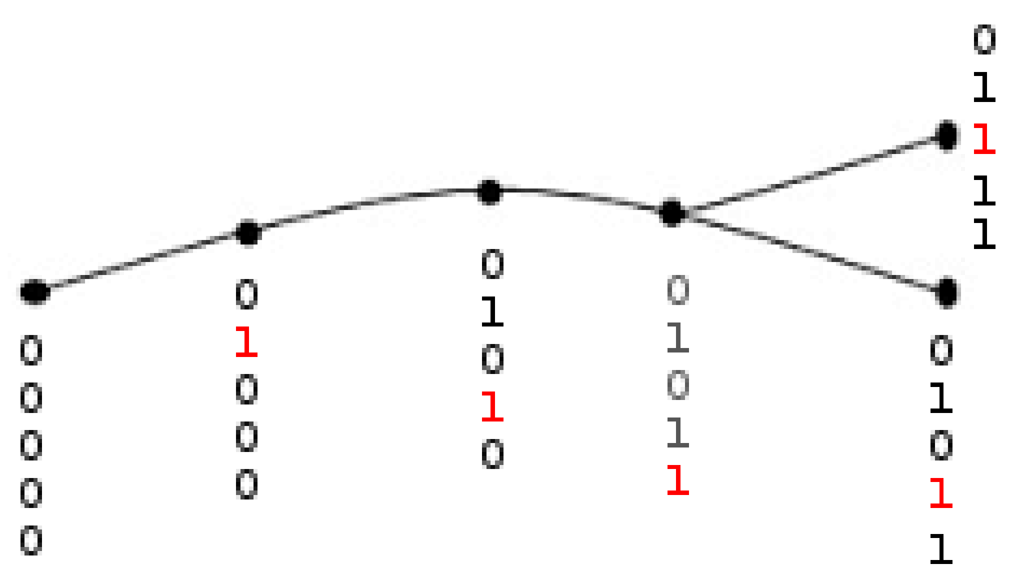
- Have successfully re-established full T3B simulation & digitization, now also on GEANT4 10
  - We observe differences in the time structure of G4 9.4 and G4 10.1: Apparently less MeV - scale neutrons in newer G4 versions, below the T3B data

- Started looking at different physics lists - see consistent differences in plastic and gas
  - HP has less late hits: less neutron capture for times > 50 ns

Backup

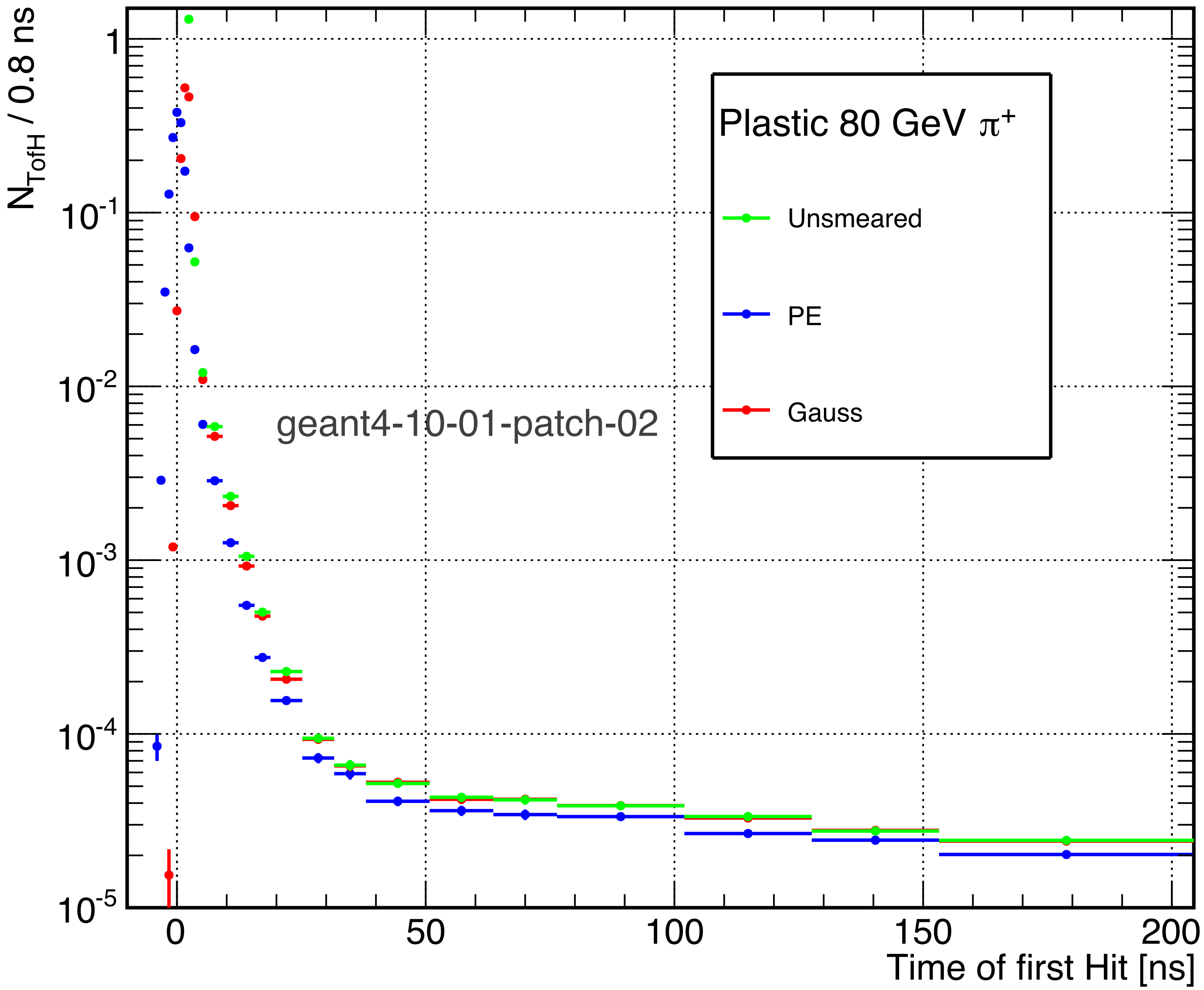
The Simulation Study - Process Accounting

- It is not sufficient to look at the particle that deposits the energy in the active medium: typically these are electrons, pions, protons - (almost) never neutrons
  - also the direct parent is not enough: for neutron capture the energy is often deposited by electrons, which have a photon as parent
- Our solution: Each particle in our G4 simulation gets a process variable that stores information about all processes that have happened to that particle. When new particles are produced, they inherit the state of their parents.
  - Technically: A 64 bit integer - allows to encode 64 different processes

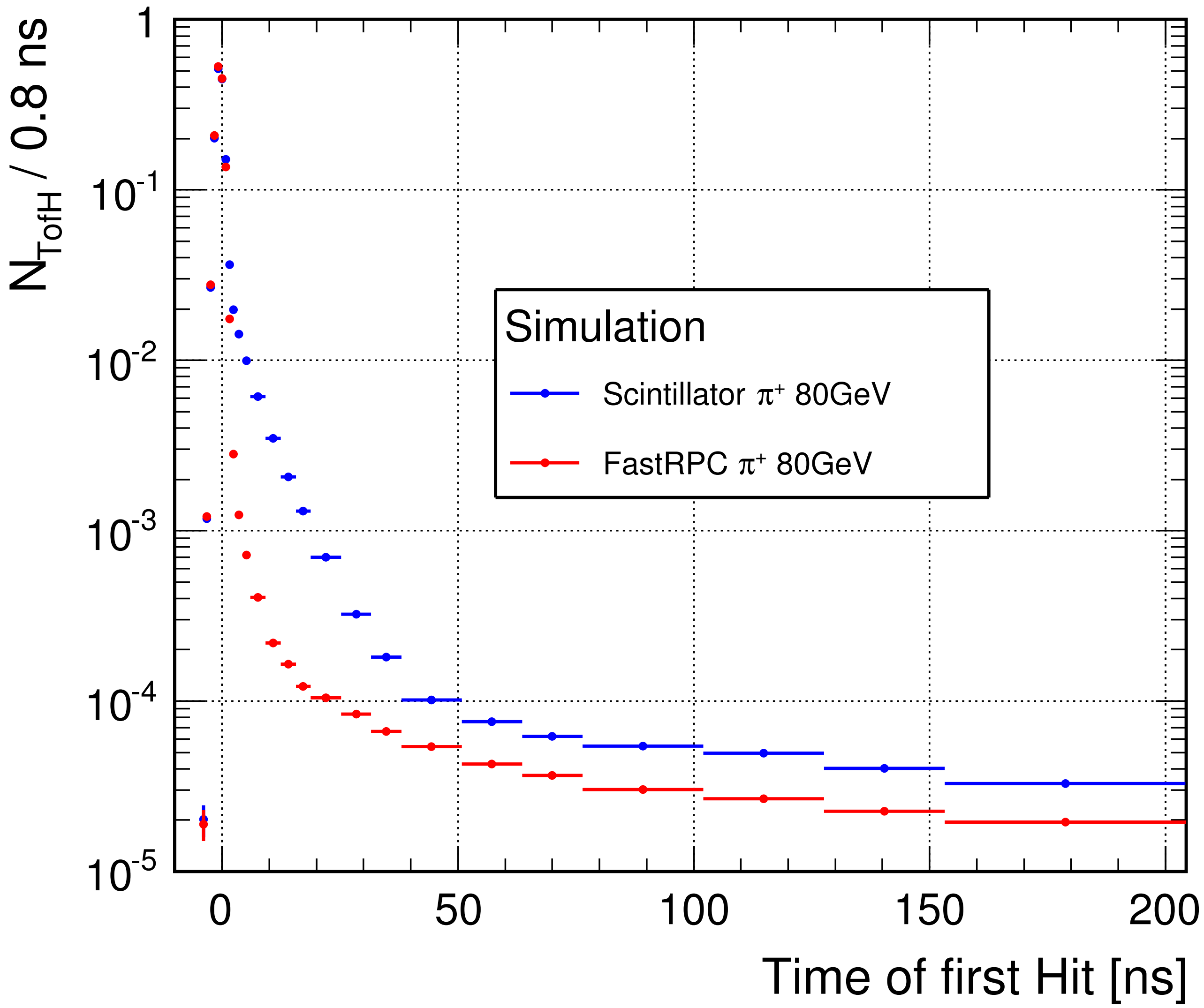


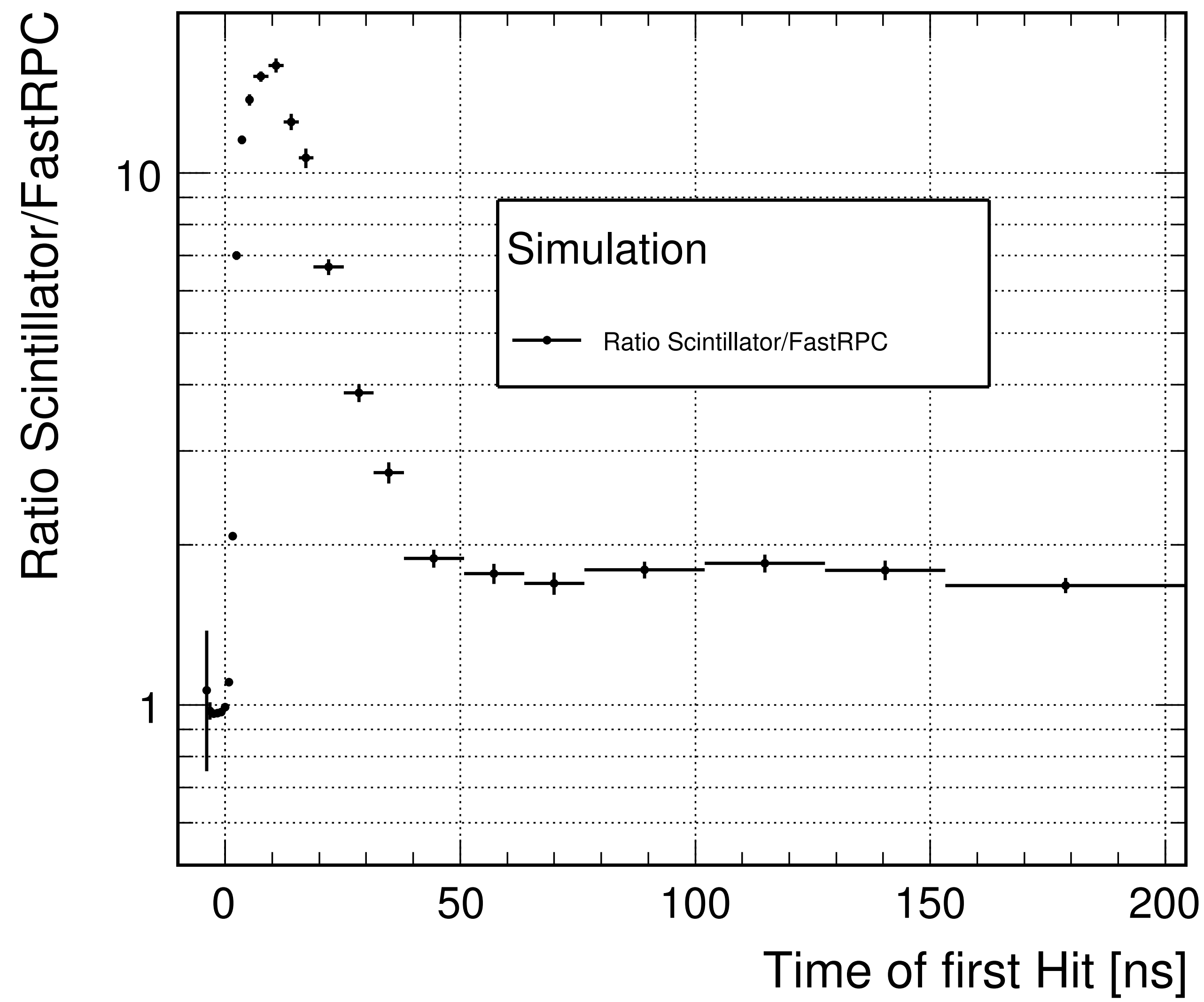
one bit for each process implemented in the physics list
In addition: Identification of neutron-proton elastic scattering (in G4 a sub-set of hadron elastic) specifically in active medium

T3B MC: Impact of Digitization

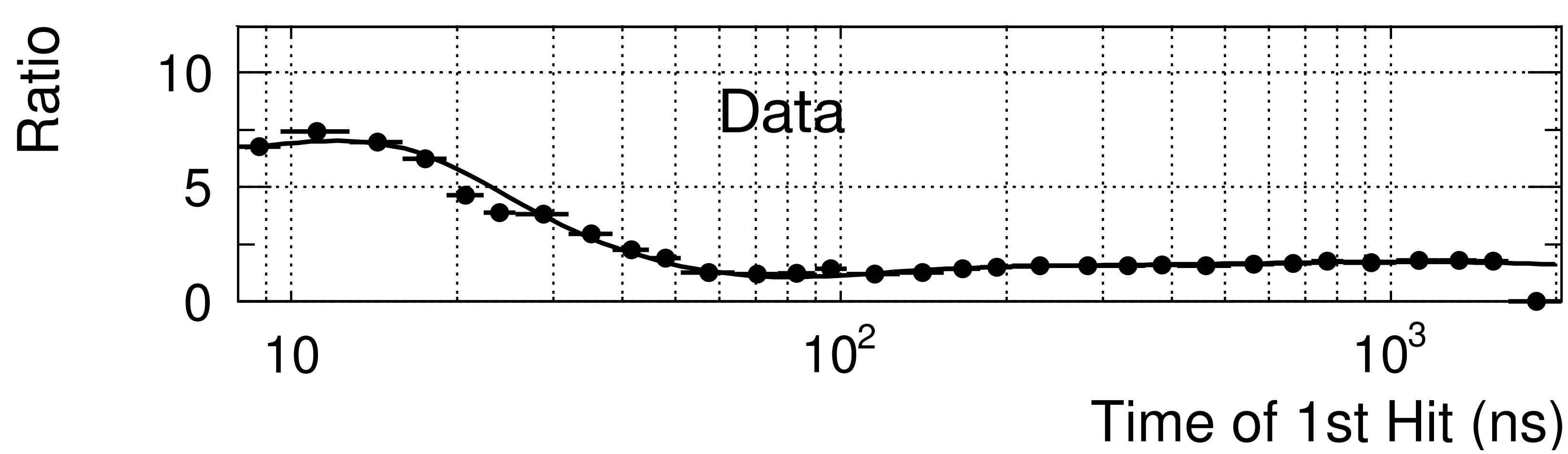


Old Results - Comparing Gas and Scintillator

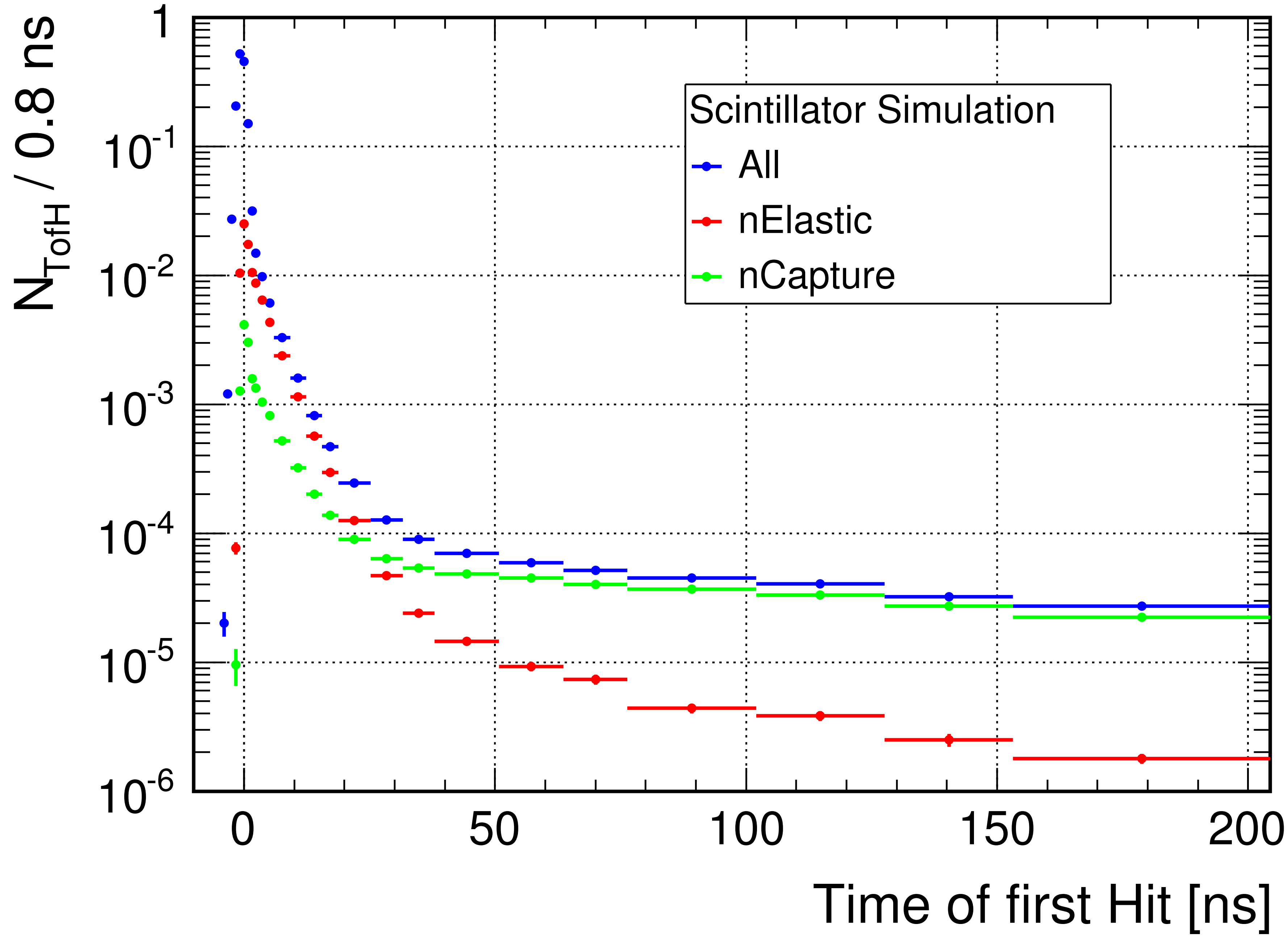




- Excess of Scintillator signal in the few 10 ns range well reproduced

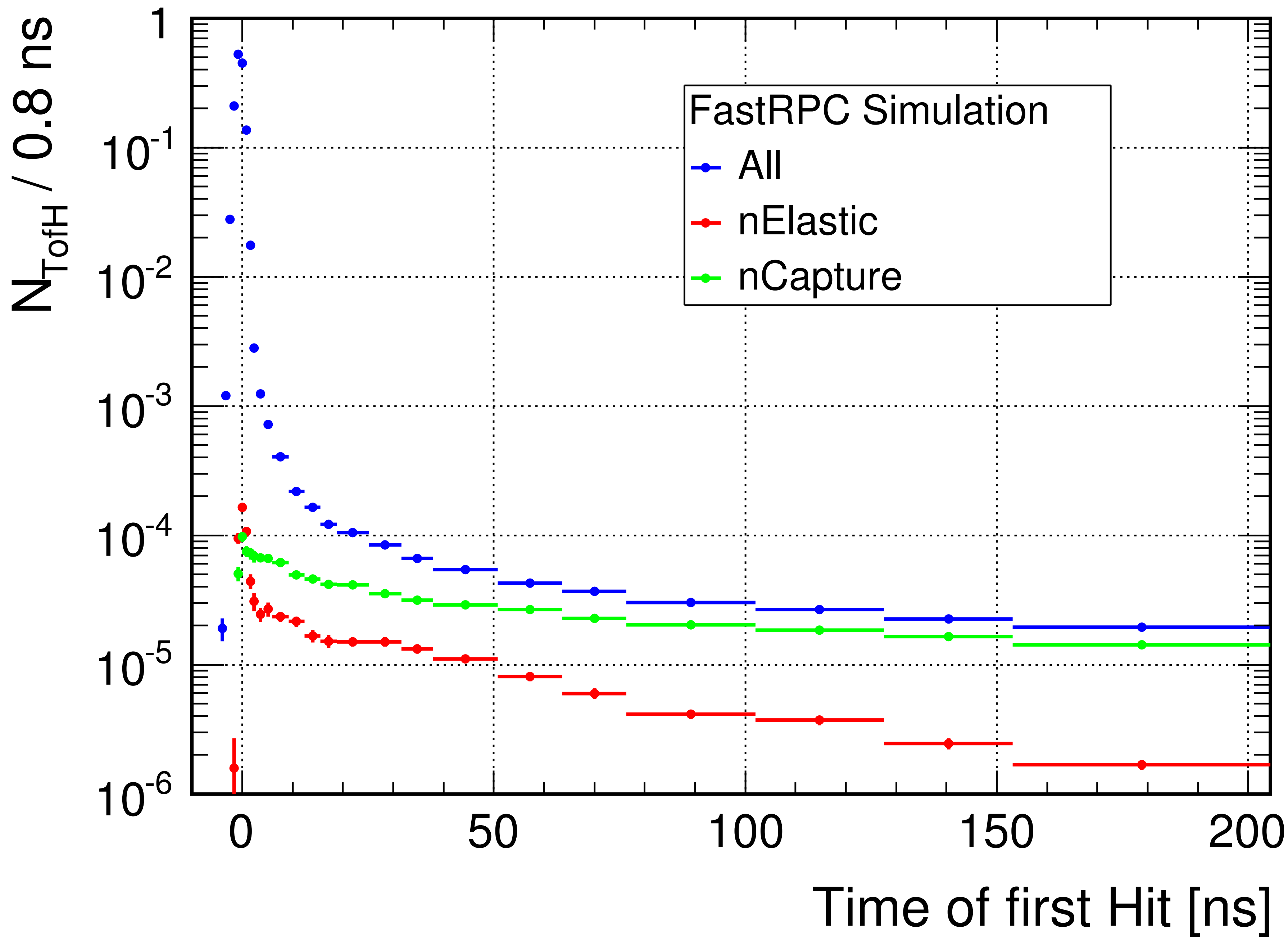


Old Results: Neutron Contributions - Scintillator



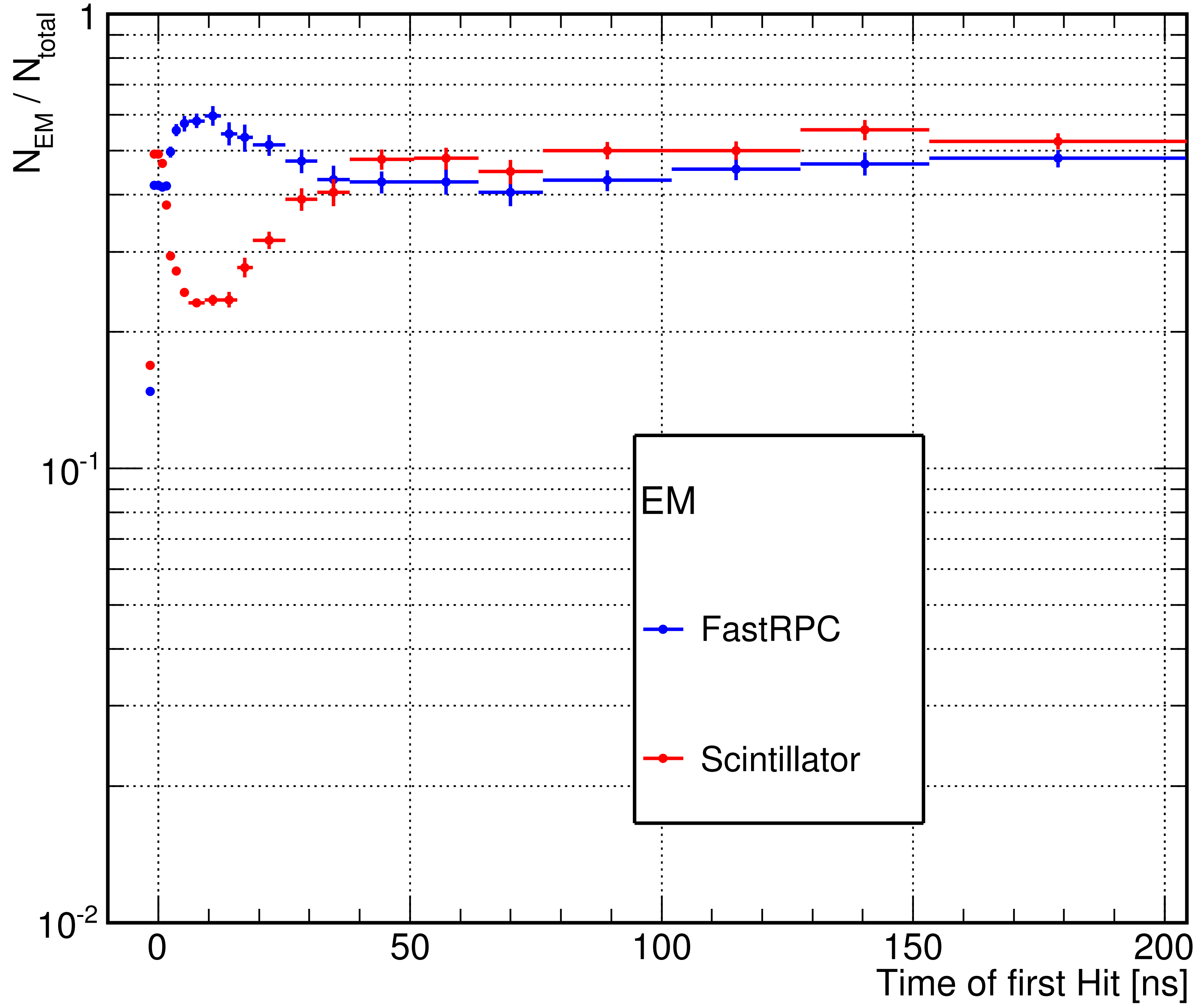
- Dominant contribution of neutron elastic scattering between ~ 5 ns and 30 ns
- Neutron Capture Taking over at ~ 50 ns

Old Results: Neutron Contributions - Gas



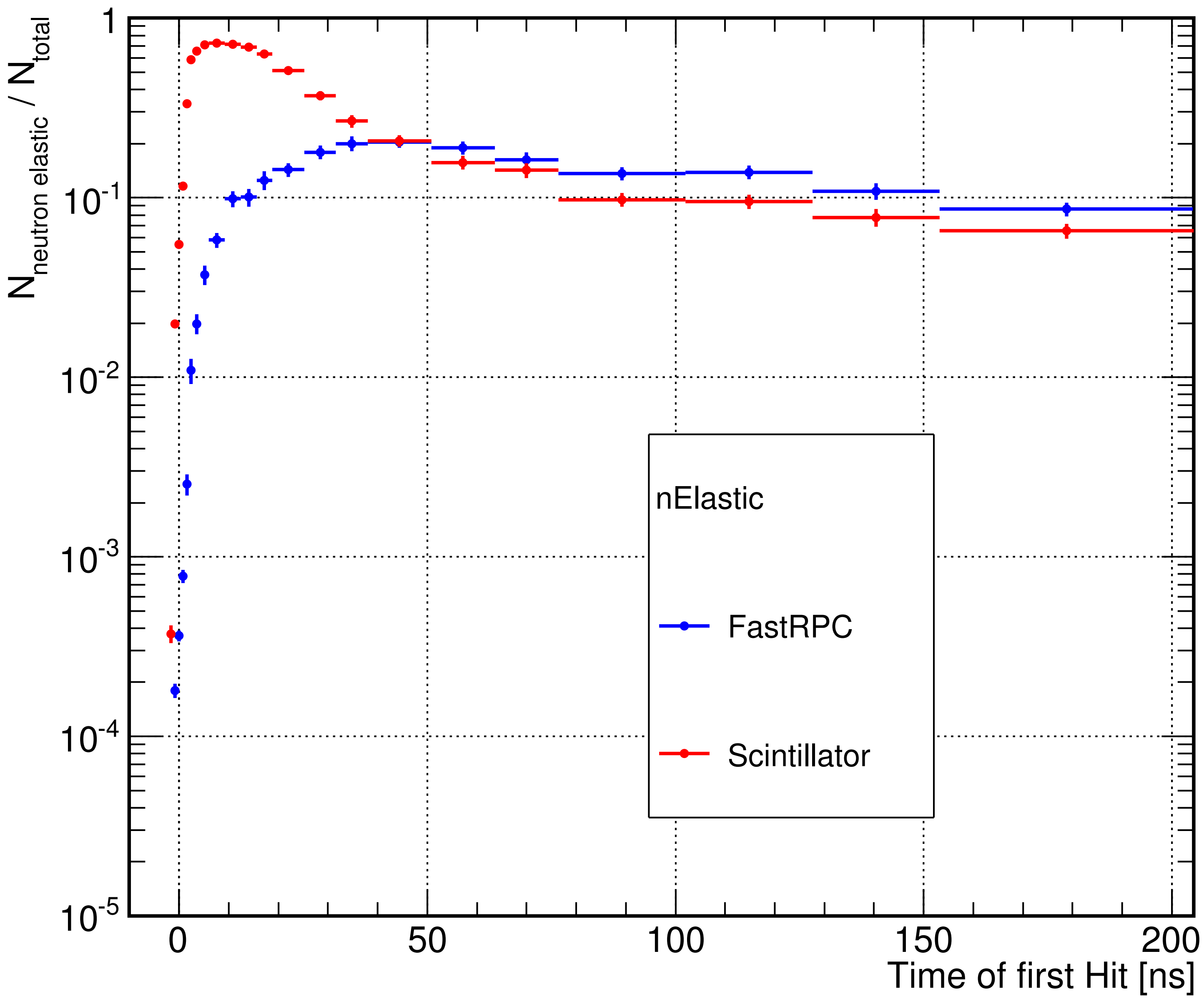
- Neutron elastic scattering not relevant
- Neutron Capture Taking over at ~75 ns - somewhat later than in scintillator

Old Results: Relative Contributions - EM



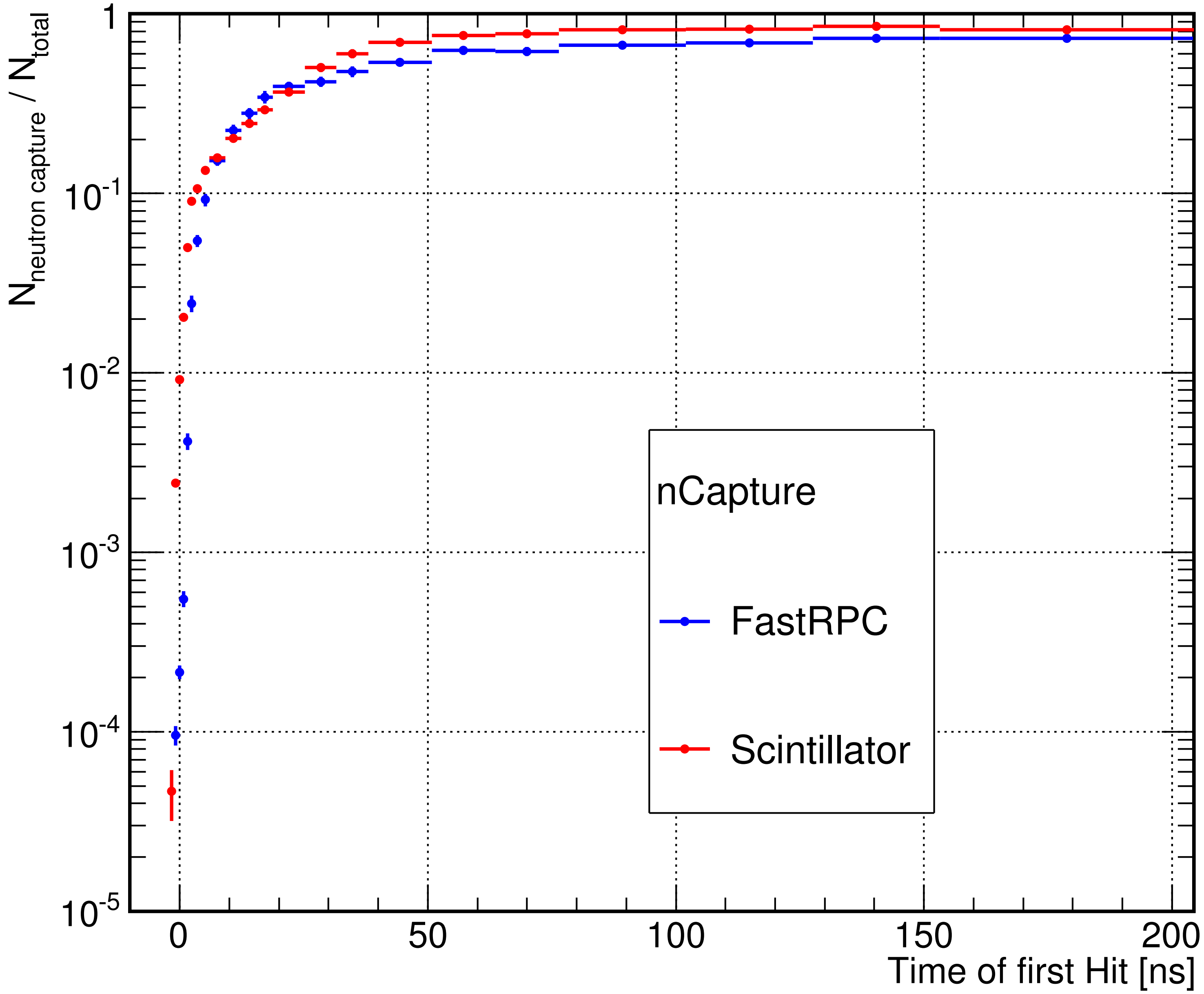
- Electromagnetic contributions important throughout the shower development

Old Results - Relative Contributions: Neutron Elastic



- In scintillator: Almost all energy deposits from 5 ns - 30 ns are connected to neutron elastic scattering in the scintillator

Old Results - Relative Contributions: Neutron Capture



- In the late shower phase (> 50 ns) almost all activity has a neutron capture in its history