Simulation of the Time Structure of Hadronic Showers in Highly Granular Calorimeters with RPC and Scintillator Readout

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Outline

- Motivation
- Time Structure of hadronic showers
- CALICE Measurements of

  the Time Structure of Hadronic Shower
- Simulation and interpretation of observed time structure
- Conclusions & Outlook

Motivation

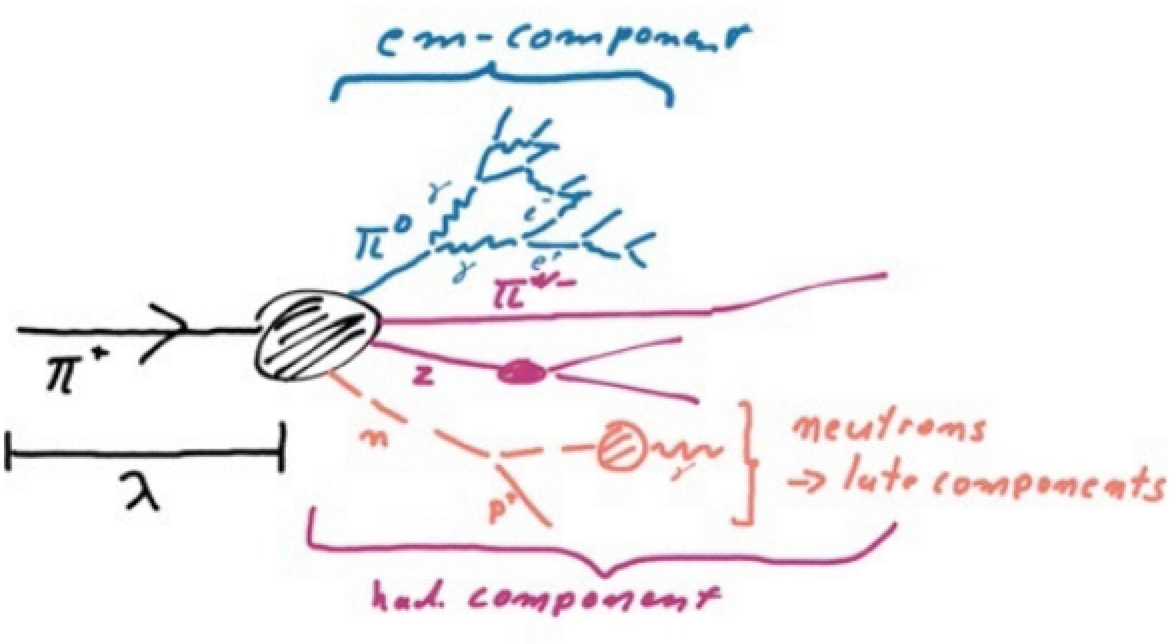
- Highly Granular Calorimeter are important in modern HEP experiments
  - Interest in rare events with high precision
  - to cope with pile-up
  - to be able to use Particle Flow Algorithm
    - to cope with background
    - to improve jet reconstruction
- Today it is possible to highly integrate digital electronics
- Originally invented in Linear Collider context
  - Developed at the CALICE Collaboration
  - today in use at every modern HEP experiments
    - LHC HL upgrade
      - CMS phase II Endcap Calorimeter upgrade

Time Structure of hadronic showers

- Understanding of the time structure of hadronic showers may play a key role in exploiting the full potential of highly granular calorimeter

  add a further dimension (space, energy and time)

- Relativistic component → instantaneous



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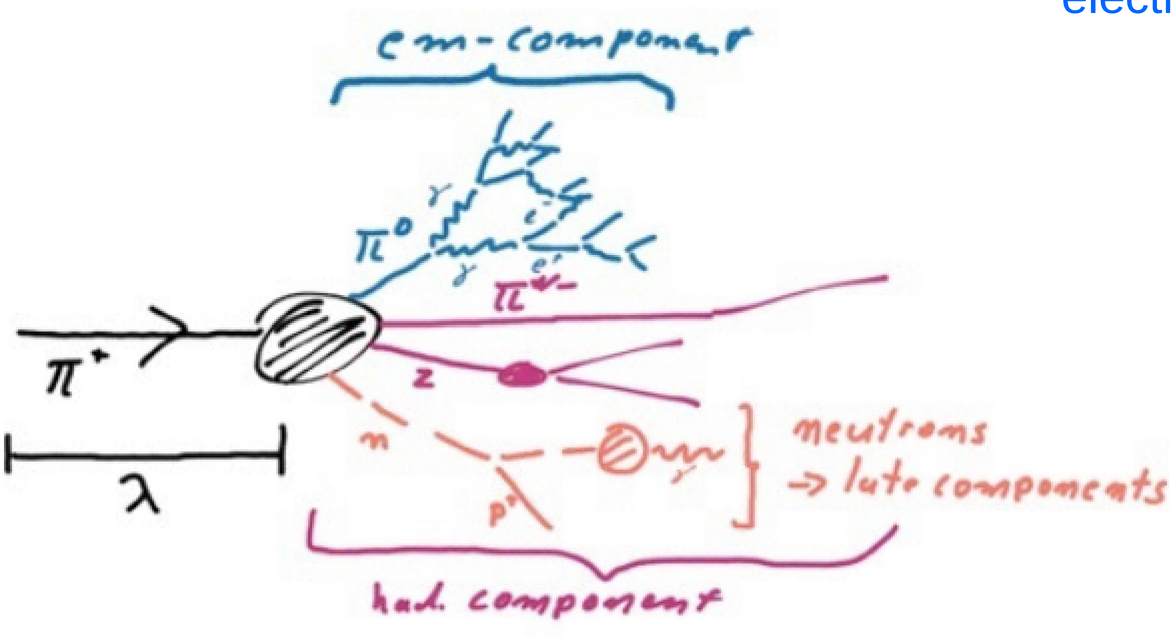
instantaneous component: charged hadrons detected via ionisation in active medium



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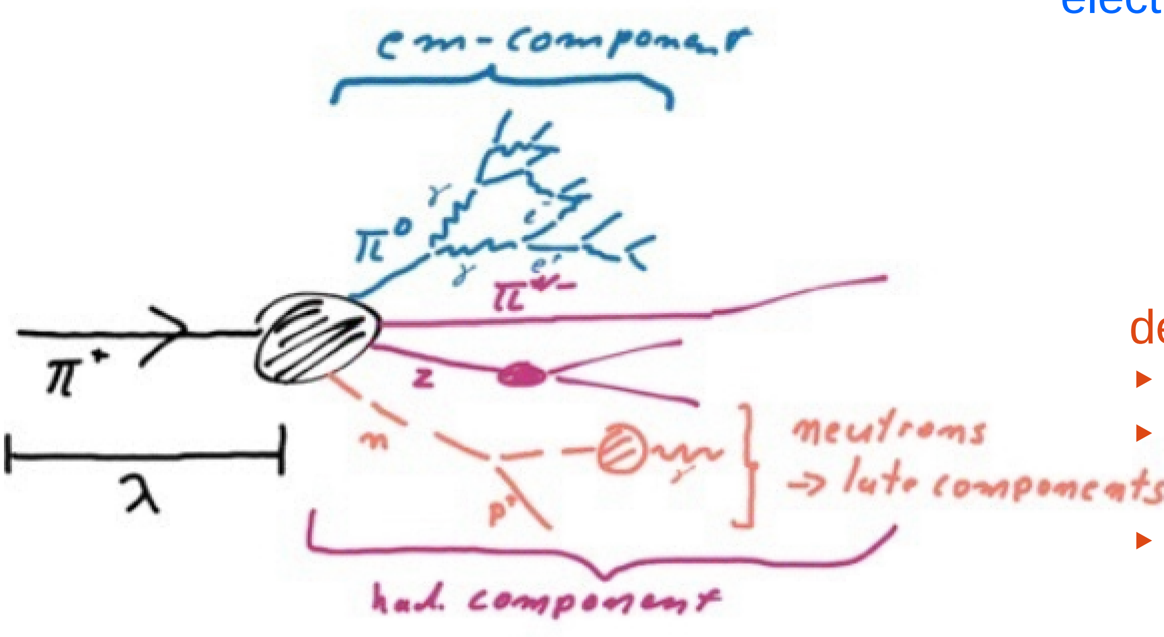

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- neutrons from evaporation and spallation
- photons, neutrons, protons from nuclear de-excitation following neutron capture
- momentum transfer to protons in hydrogenous active medium from slow neutrons

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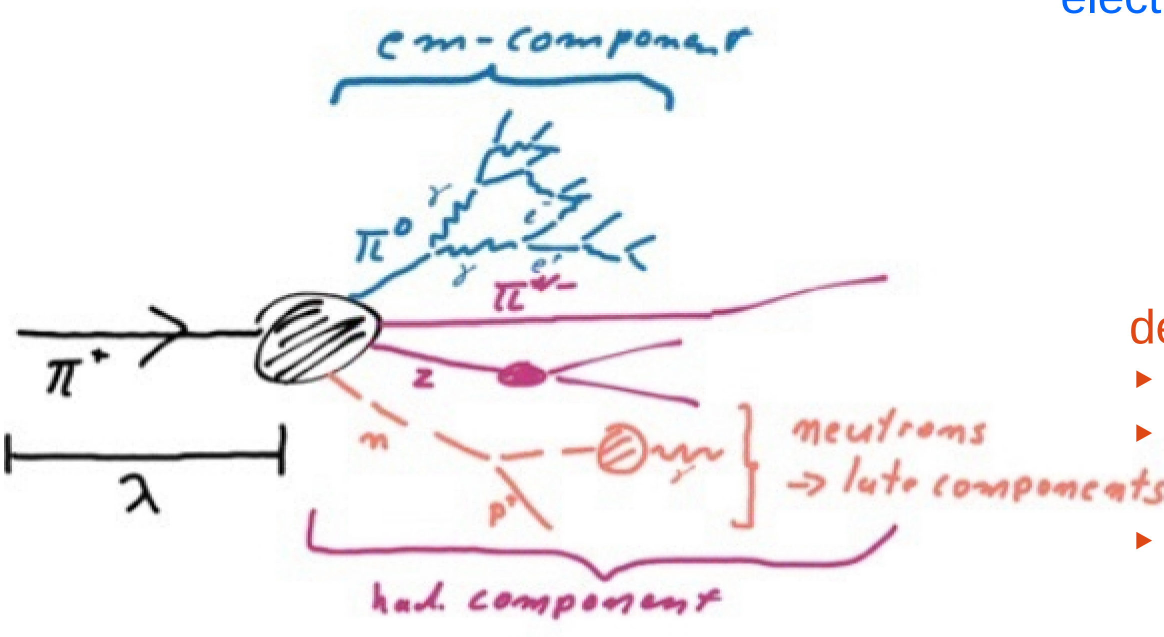

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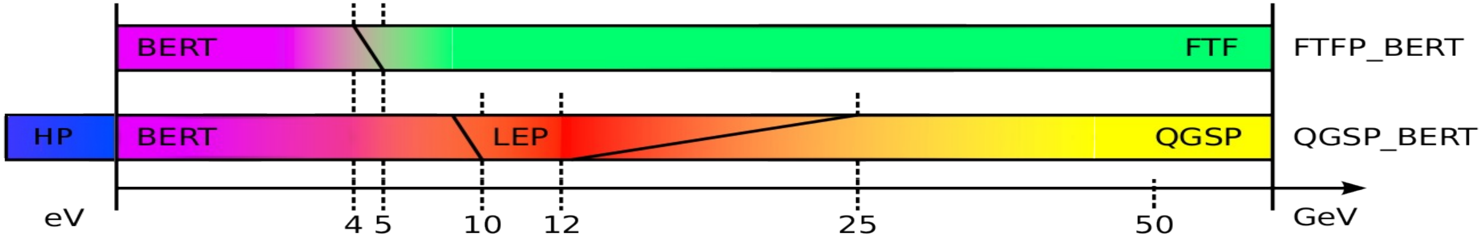
- Separation of components originating from different processes may enable improved energy resolution – time is the perfect handle to access this

Simulation

- To be able to develop new Calorimeter it is very important to be able to simulate it - HEP: GEANT4

- Make sure that CALICE data, that didn't exist beforehand, is matched by GEANT4 LHC Physics List QGSP_BERT



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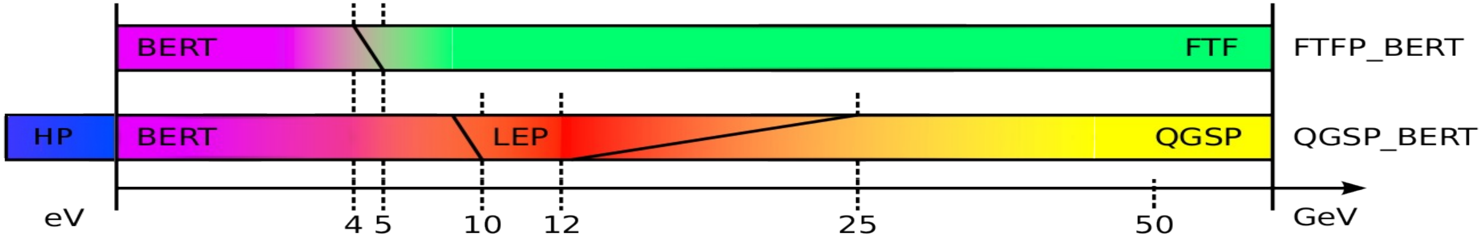

- Quark-Gluon String Model for high energy interactions with Bertini cascade for below ~10 GeV interactions
- In CALICE Testbeams looked at timing
  - Neutrons important → QGSP_BERT_HP

    HP neutron package → thermal neutrons

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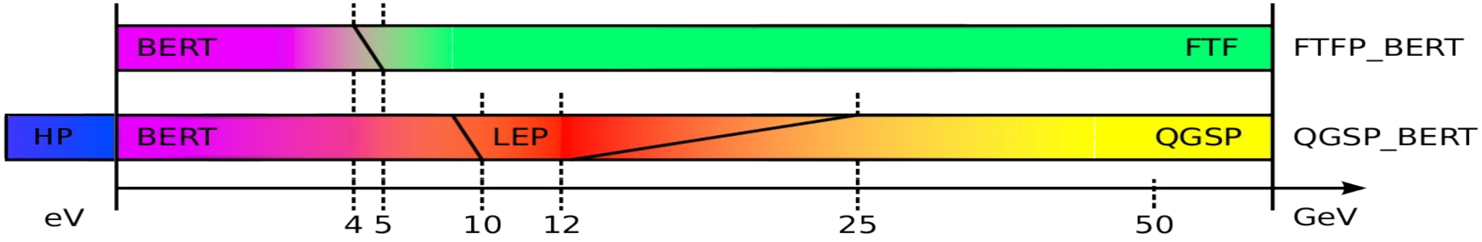

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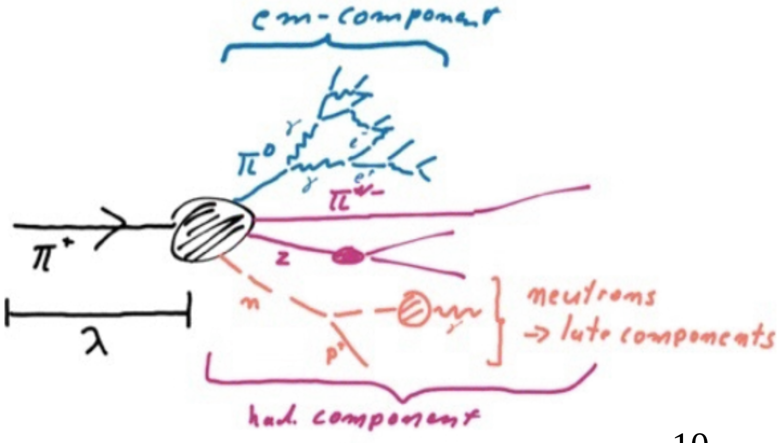
    HP neutron package → thermal neutrons
  - Only looking at particles that deposit Energy is not sufficient

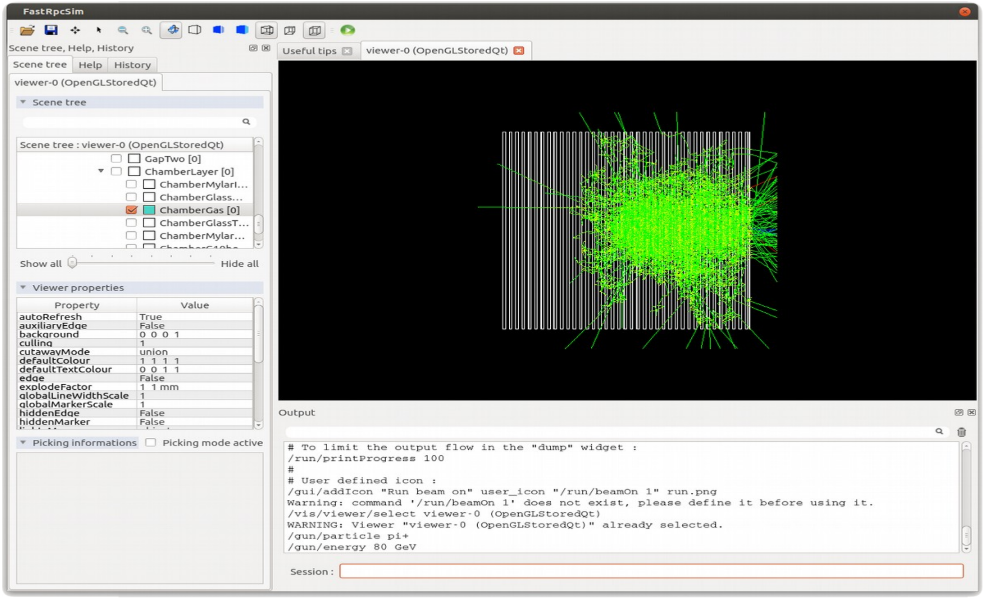


GEANT4 Simulation

- One has to rebuild the geometry

  of the detector in software

  - Here the full HCal is required

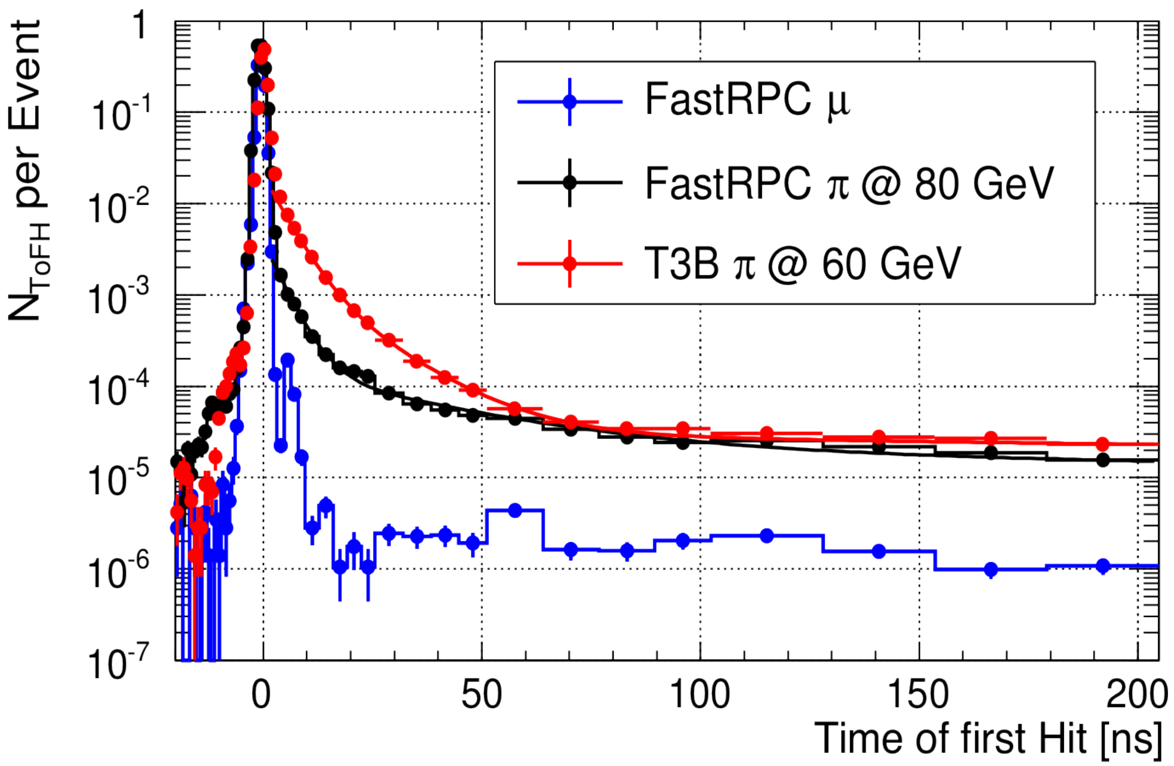


- Implement detector specific circumstances
  - For the T3B setup digitisation and photon statistics is important
  - The RPC setup is fast and digital – so this is more simple to emulate it

- To be able to know which signal had what kind of history of processes before it ended up in the detector
  - Implement a Memory-Efficient way to track each particle

Experiments

- In CALICE there are two experiments to measure the time structure of hadronic showers
  - The T3B with hydrocarbon scintillator as active material
  - The FastRPC with gas as active material
- Public results of CALICE Collaboration → I provide the final interpretation



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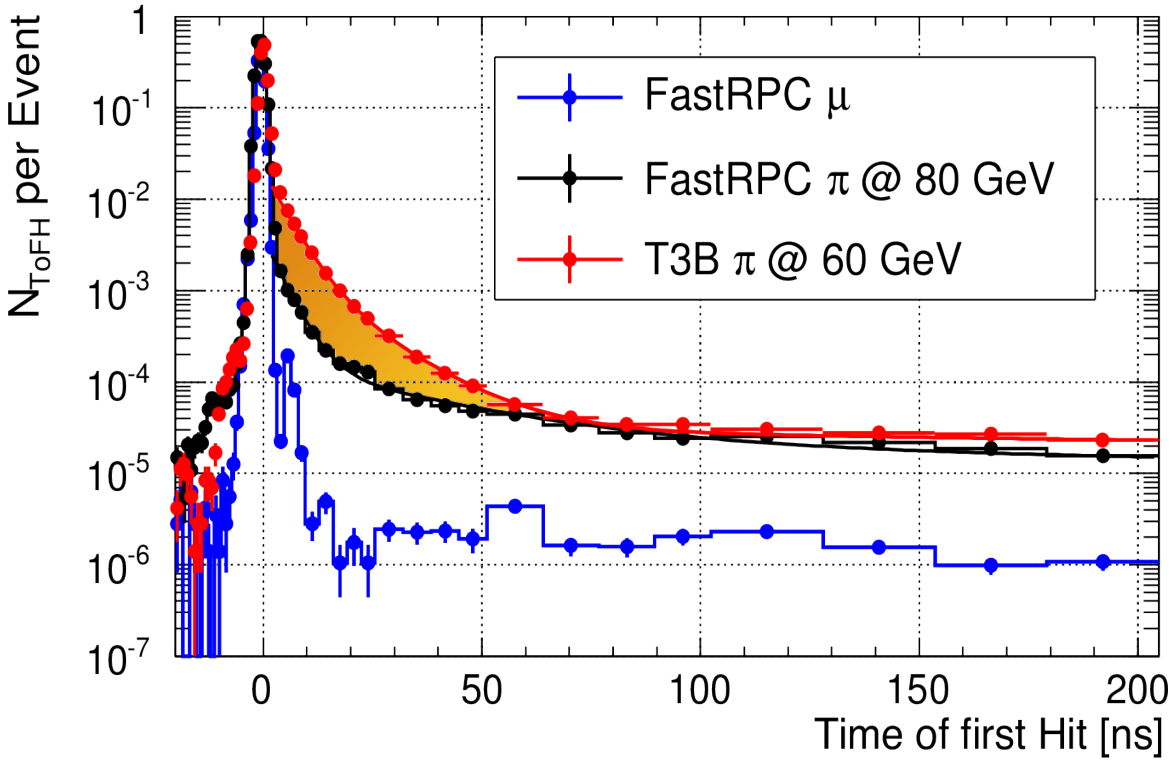

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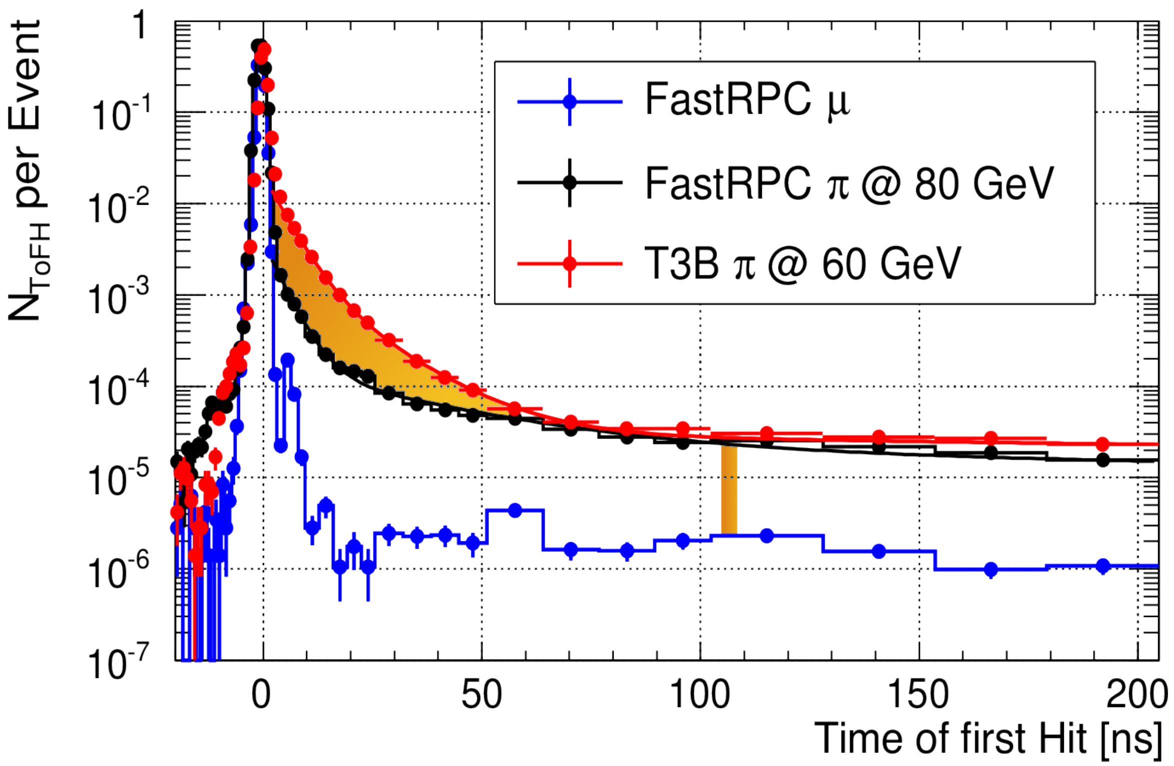

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- Not a detector effect (compare Muon and Pion)
- But there is an almost equal signal in the gas detector in tail

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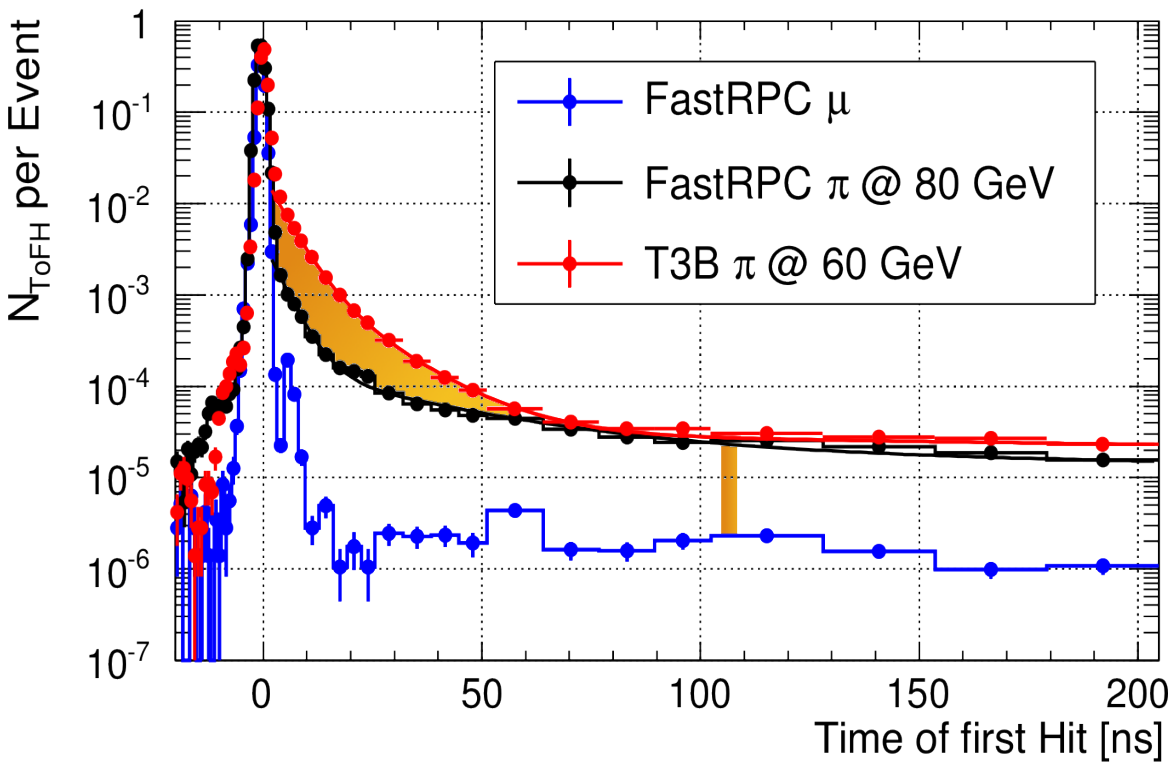

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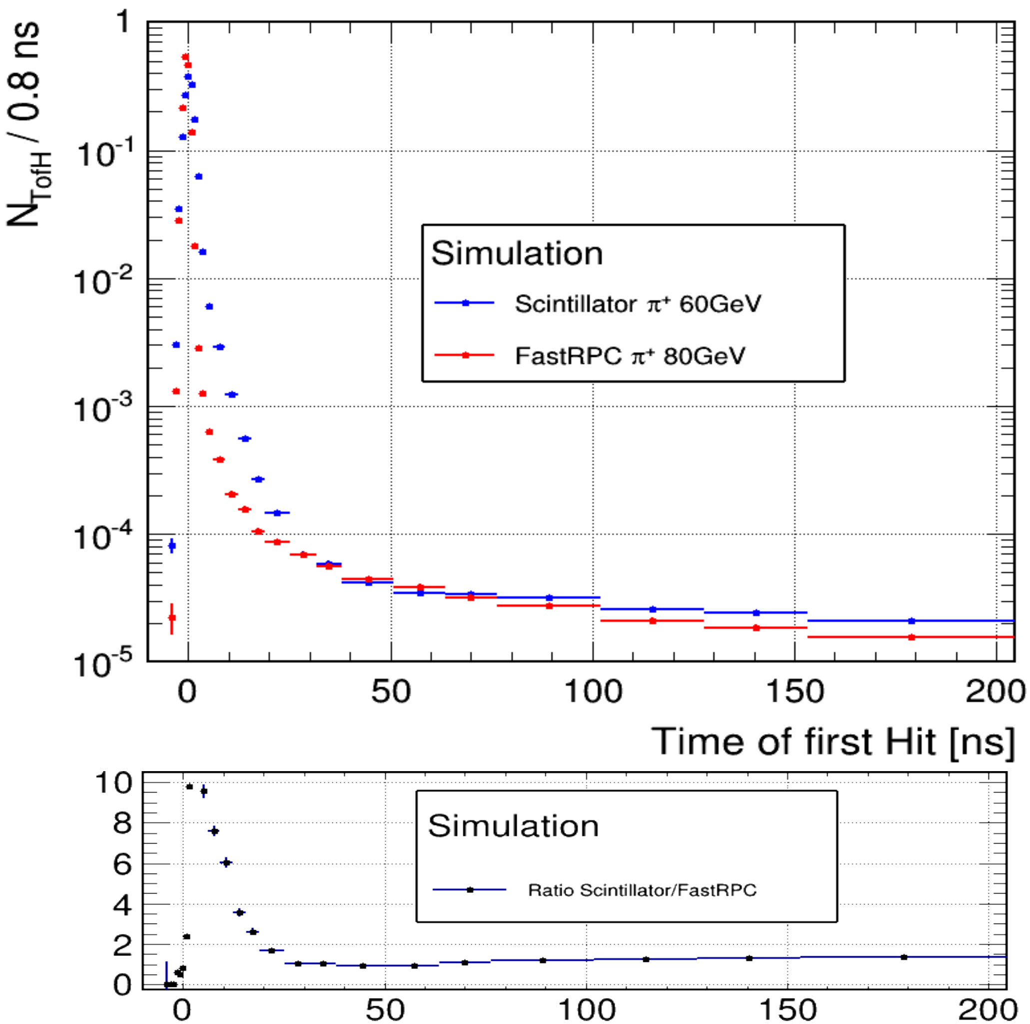
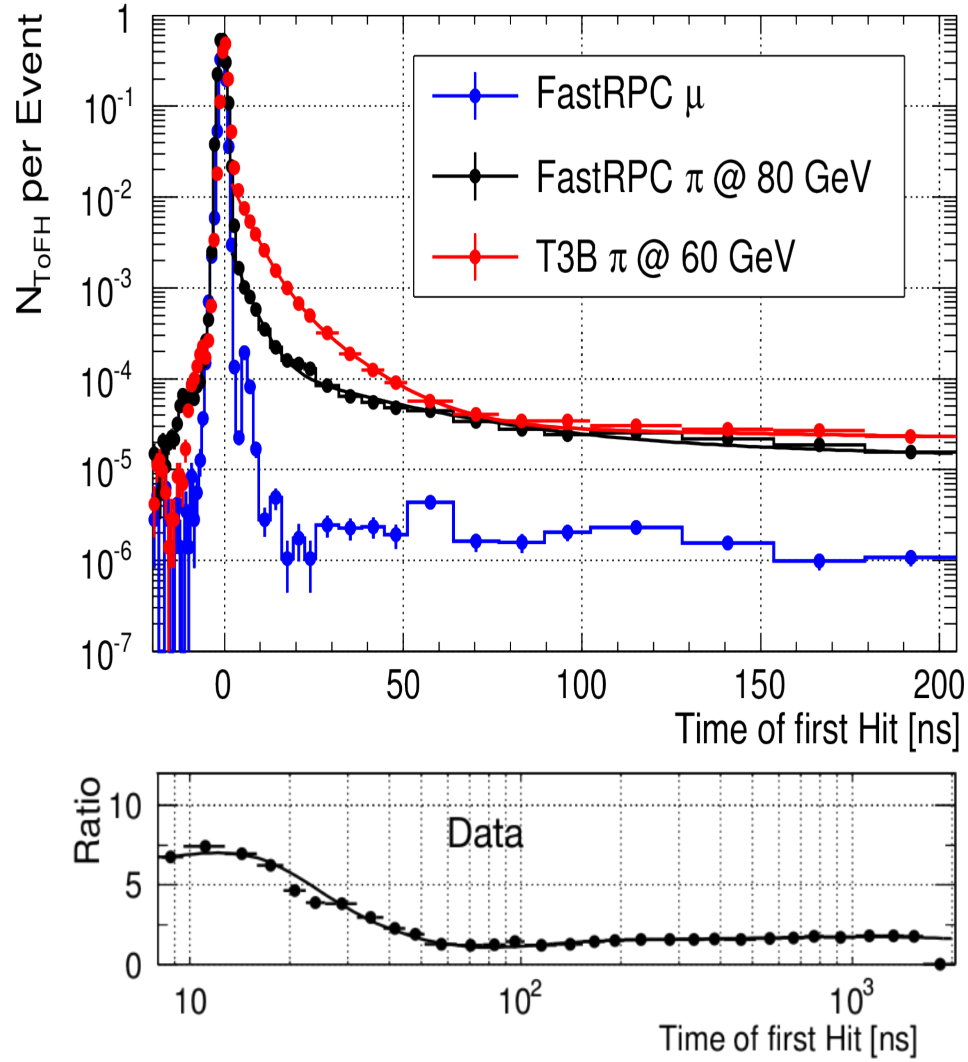
Can we understand this in simulations?

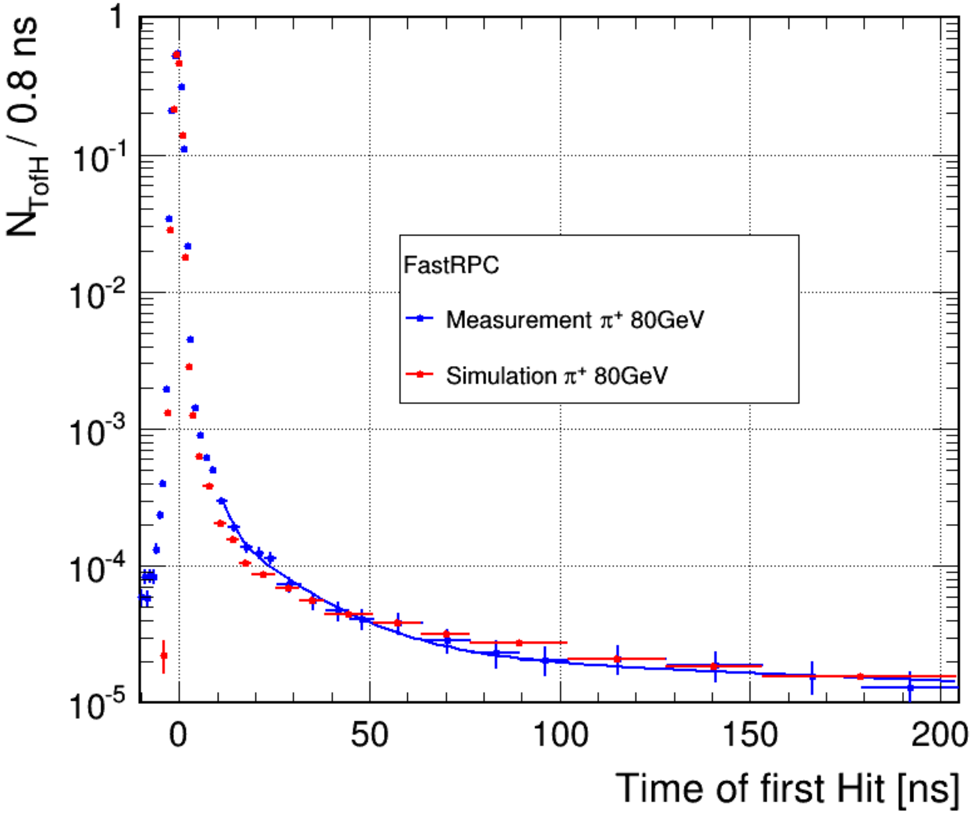
The Simulation

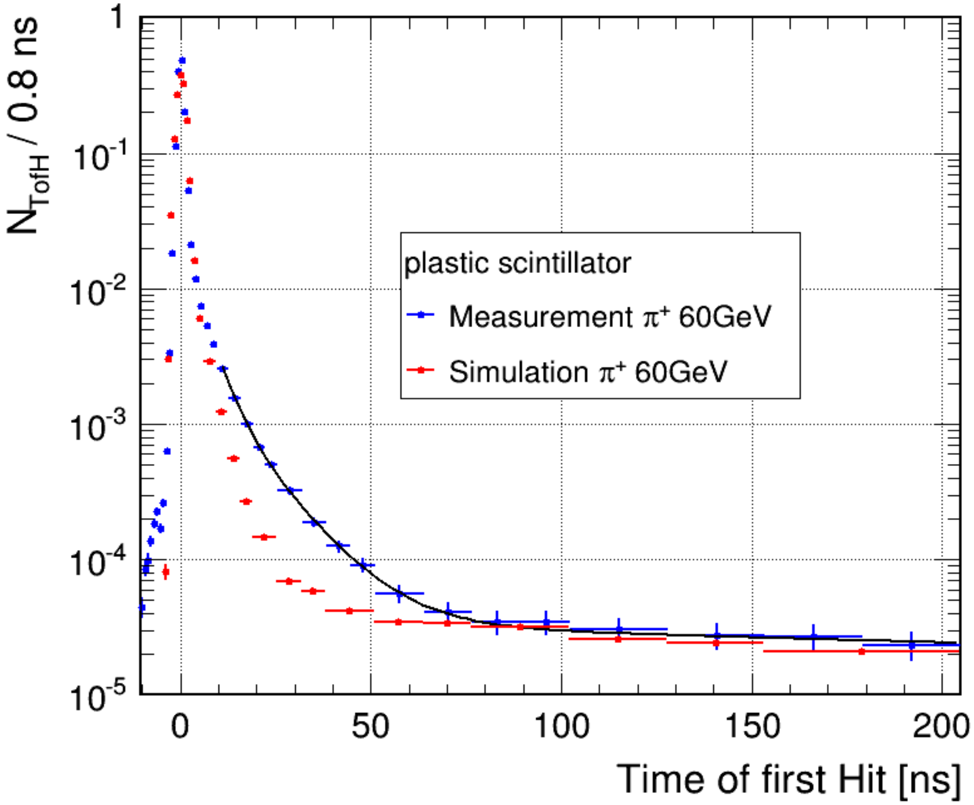




- I am able to reproduce the general features
- The difference of both signals is also in the simulation

Data vs Simulation

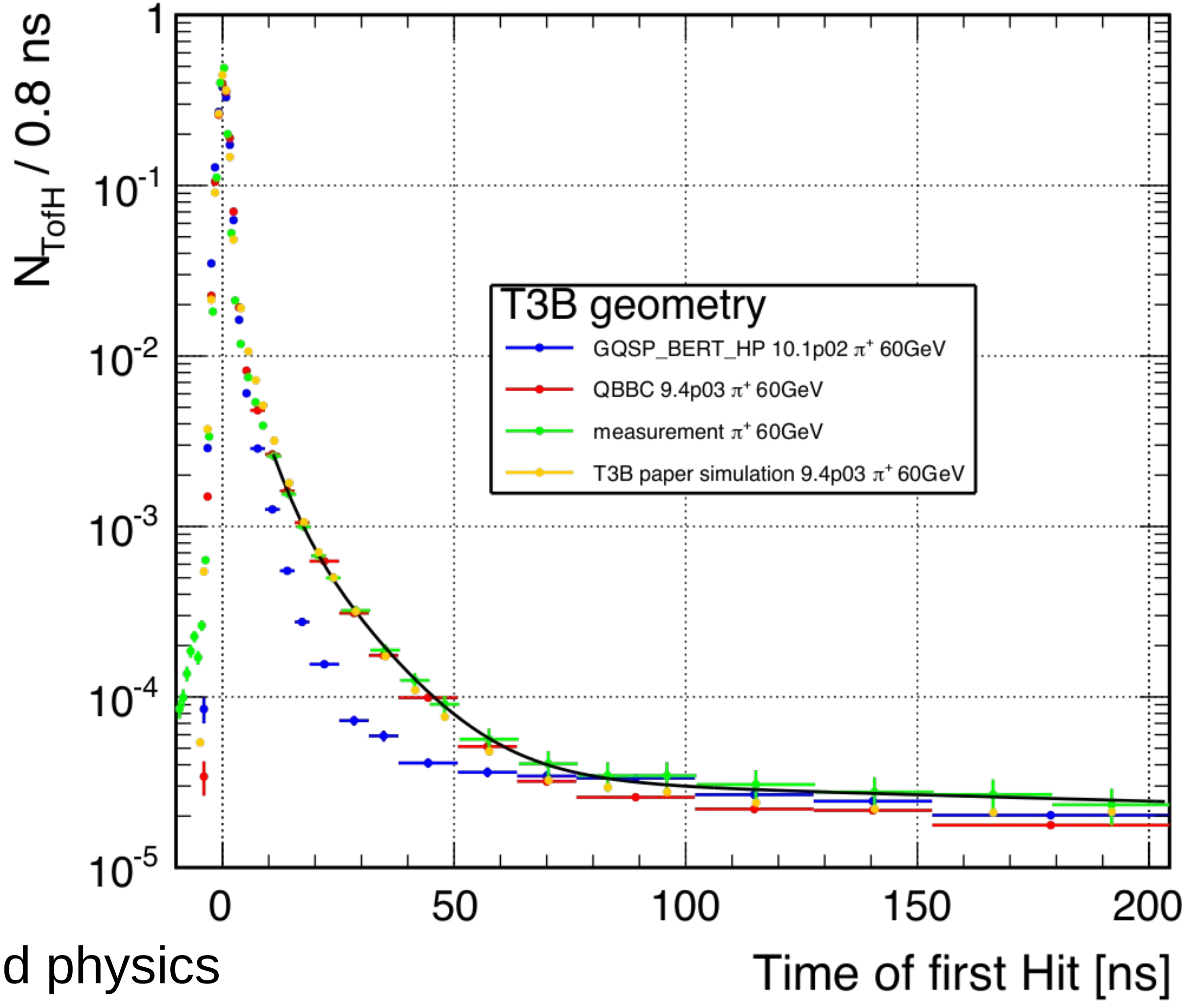




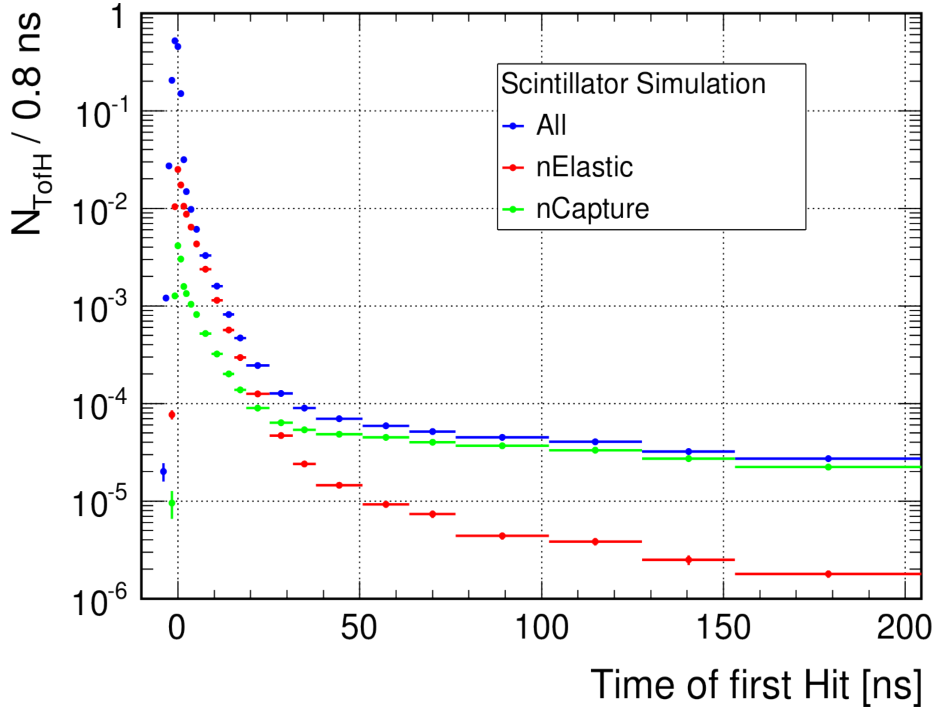
- Good agreement of data with MC in the FastRPC Simulation
- Scintillator: Too few TofH in the time range from ~ 20 to 50 ns

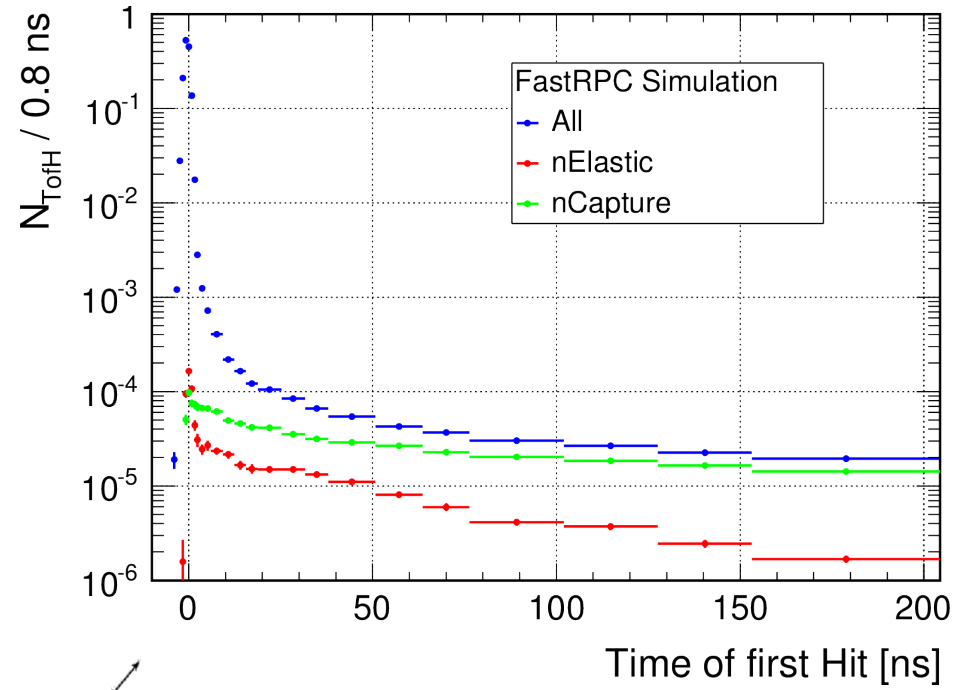
Validation of simulation analysis with old simulations

- Old simulated data is reanalyzed with re-implemented digitization
- Too few MeV – scale neutrons In Geant4 Version 10.1
- Simulation of detector effects is working correctly
  - I can look into the simulated physics

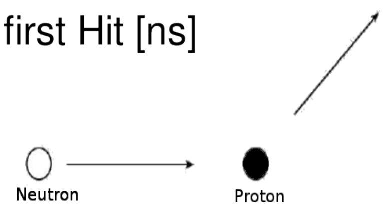


Where does the difference come from?



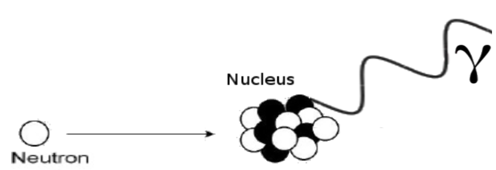


- neutron elastic scattering:
  dominant between ~5 and ~30 ns



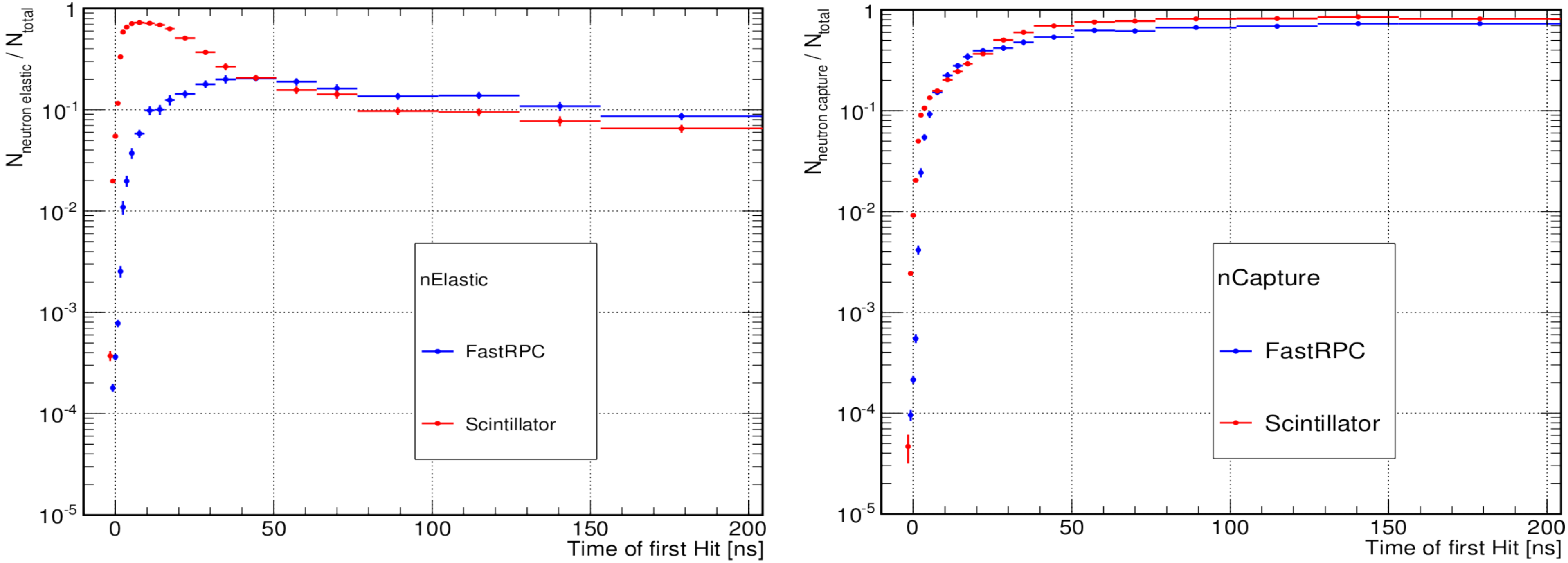
not relevant

- neutron capture:
  kicks in immediately
  taking over at ~50 ns



taking over at ~75 ns

Results - Relative Contributions



- Scintillator: almost all energy deposits within ~5 and ~30 ns are connected to neutron elastic scattering
- Almost all late activity has neutron capture in its history
- Scintillator moderates the neutrons down to ~ eV “thermal neutrons”
  Gas lacking the n-moderation → has less neutron Capture

Conclusions

- Attribution of processes to hadronic shower time structure possible
- Clears up the difference of both setups in intermediate phase:

  Strong sensitivity to MeV-scale neutrons in scintillator results in substantial visible activity a few 10 ns into the shower development

- Clears up the observation of almost equal response of scintillators and RPCs in late contribution:

  Neutron capture in the absorber, followed by detection of secondaries (large photon contribution) in the active medium

Outlook

- CALICE will study to improve the Energy resolution with the help of hadron shower timing information

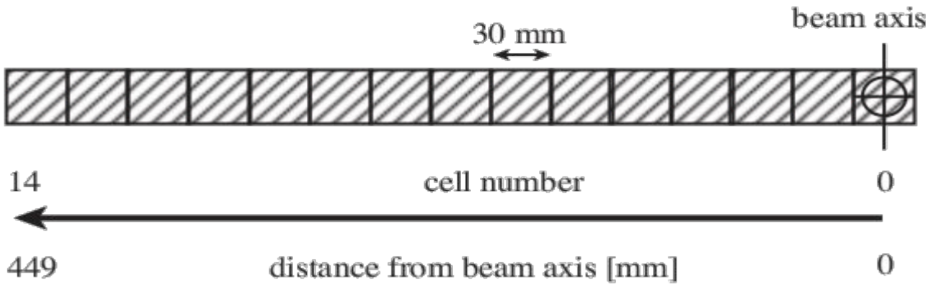
- LHC HL upgrade will use the time of occurrence of events within the same bunch ("in-time pileup") to resolve events of interest
  - Pile-up suppression for neutral particles
  - Higher time resolution → better vertex association

The End

Thank you!

Backup

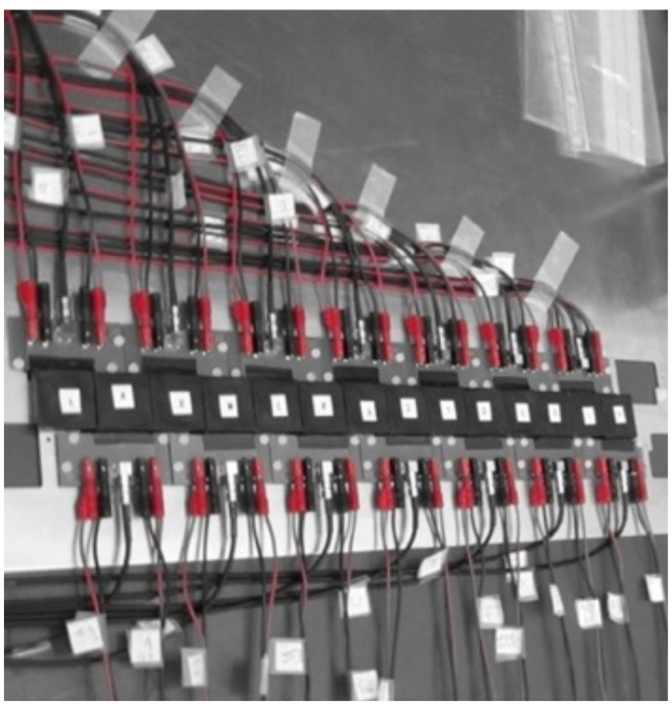
T3B & FastRPC Setups behind 38 Layers of sampling HCal



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

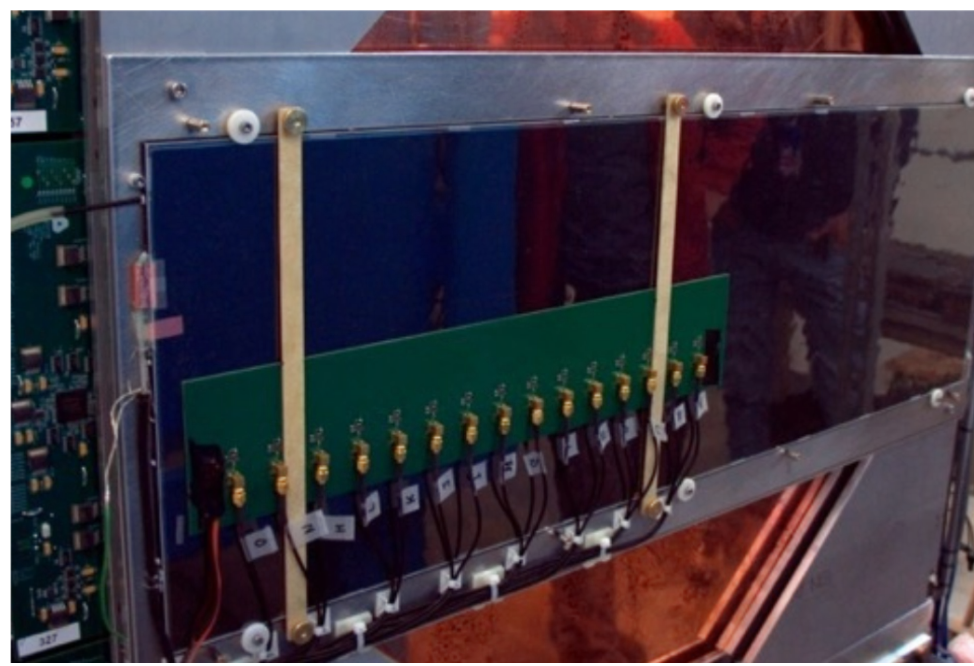
- T3B (Tungsten Timing Test Beam):

  Plastic Scintillator



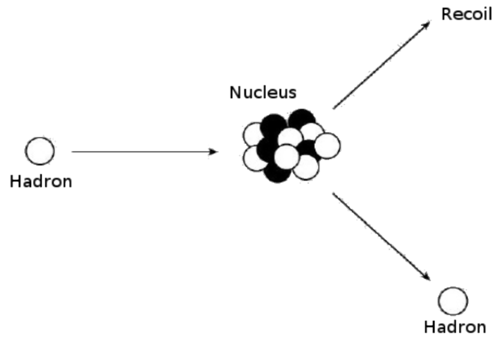
- FastRPC (Resistive Plate Chambers)

  Gaseous Detector



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



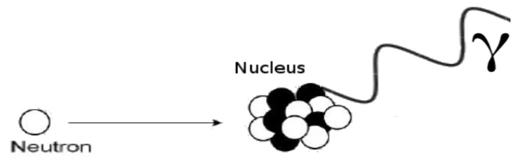
- Neutron capture
  - capture of eV - scale neutrons on heavy nuclei,

    results in emission of few MeV photons
  - Capture takes place in absorber,

    photons convert to e+ e- pairs

    (or e- via Compton scattering),

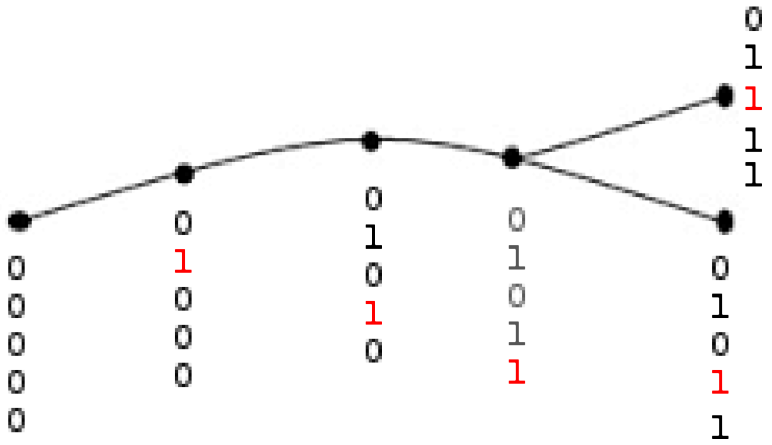
    resulting in signal in sensitive volume



Simulation Process Accounting

- Geant4 has ~ 60 Processes of interest

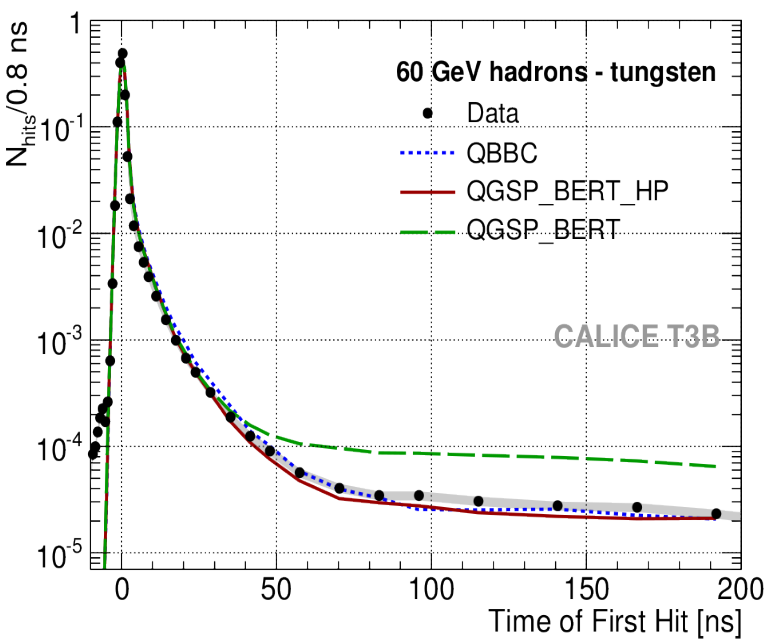
- Each particle in the Geant4 simulation gets a process variable that stores information about all processes that have happened to that particle. When new particles are produced, they inherit the state of their parents.
  - Technically: A 64 bit integer - allows to encode 64 different processes



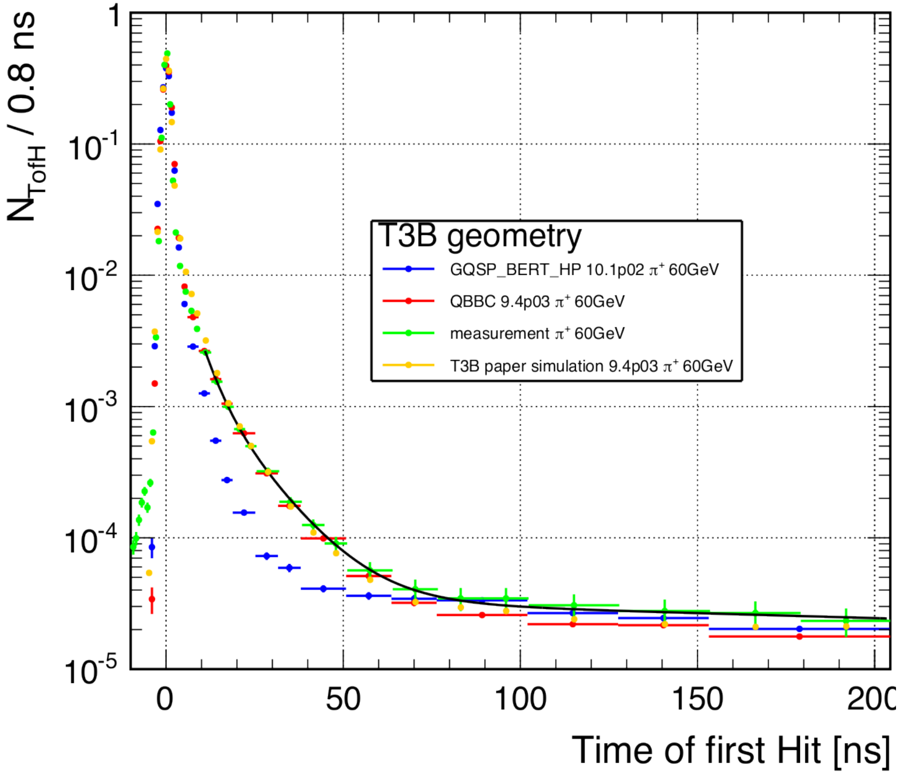
  - one bit for each process implemented in the physics list
  - Tagging of processes of interest
    - Identification of neutron-proton elastic scattering

Geant4 physics list

- The physics list defines particles and their interactions
- under heavy development



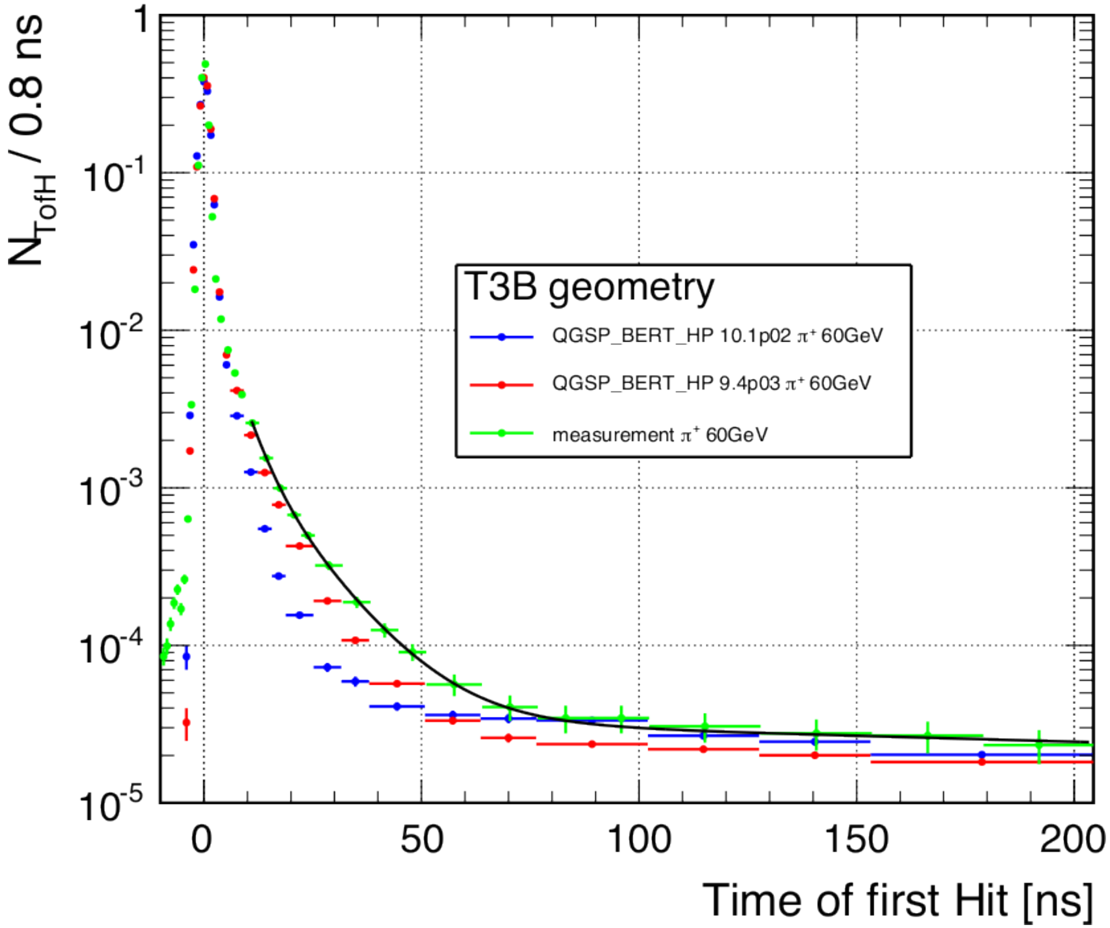
Old T3B Simulation:
good agreement of the data with QBBC-based simulations (GEANT4 9.4p03)



New T3B Simulation:
shows substantially lower activity in Intermediate time frame:
less MeV - scale neutrons?
(GEANT4 10.01p02)

Comparison of GEANT4 Versions

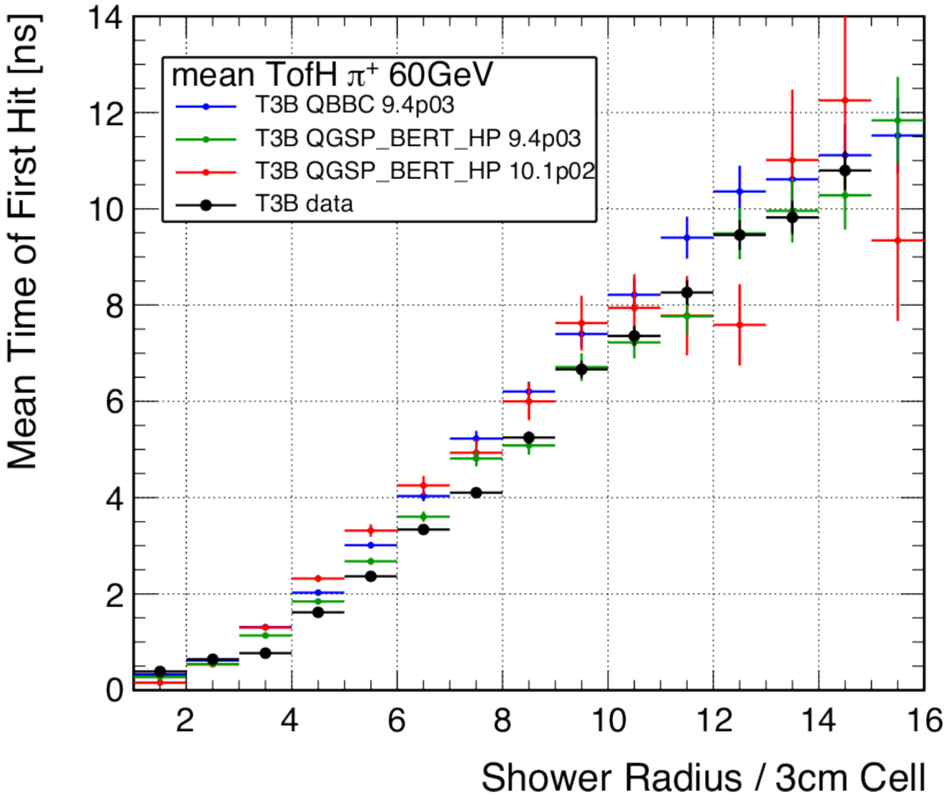
QGSP_BERT_HP in 9.4p03 vs 10.01.p02

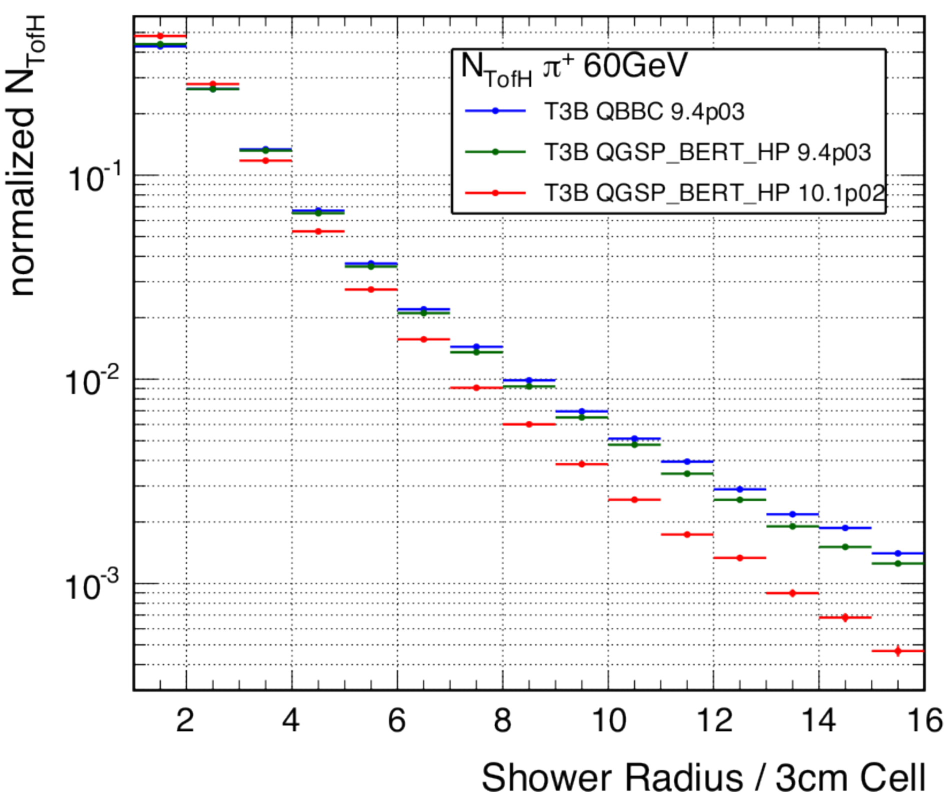


Differences seen in the same region

Geant4 10.1 has less activity from 20 to 40 ns

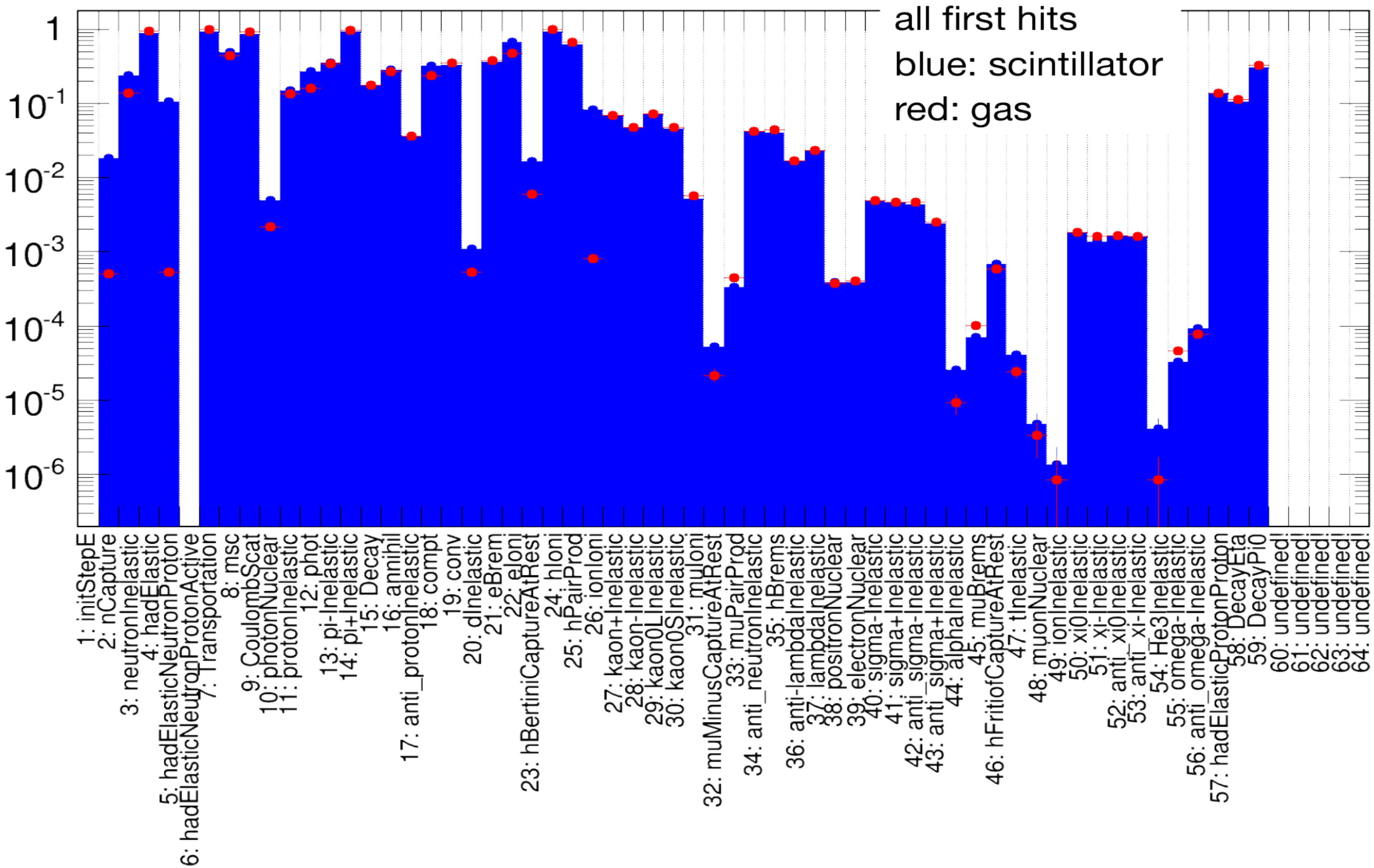
Comparison of GEANT4 Versions



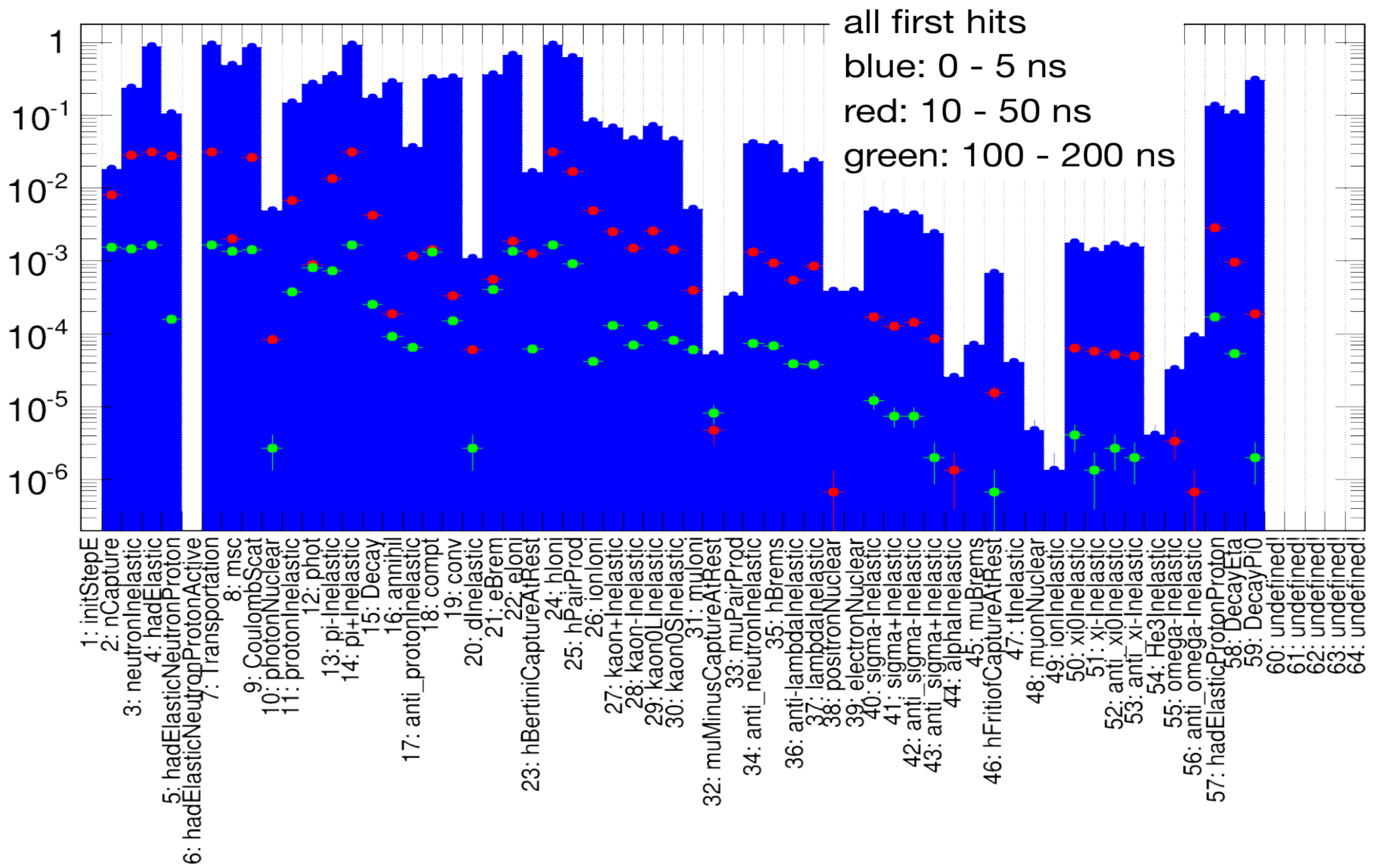


- mean time of first hit as a function of radius consistent
- But: less “first hits” at larger radius - results in less late hits in total
- Consistent with MeV - scale neutron interpretation - less pronounced “neutron cloud” in 4.10 -> would result in fewer hits at high r, since neutrons spread out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

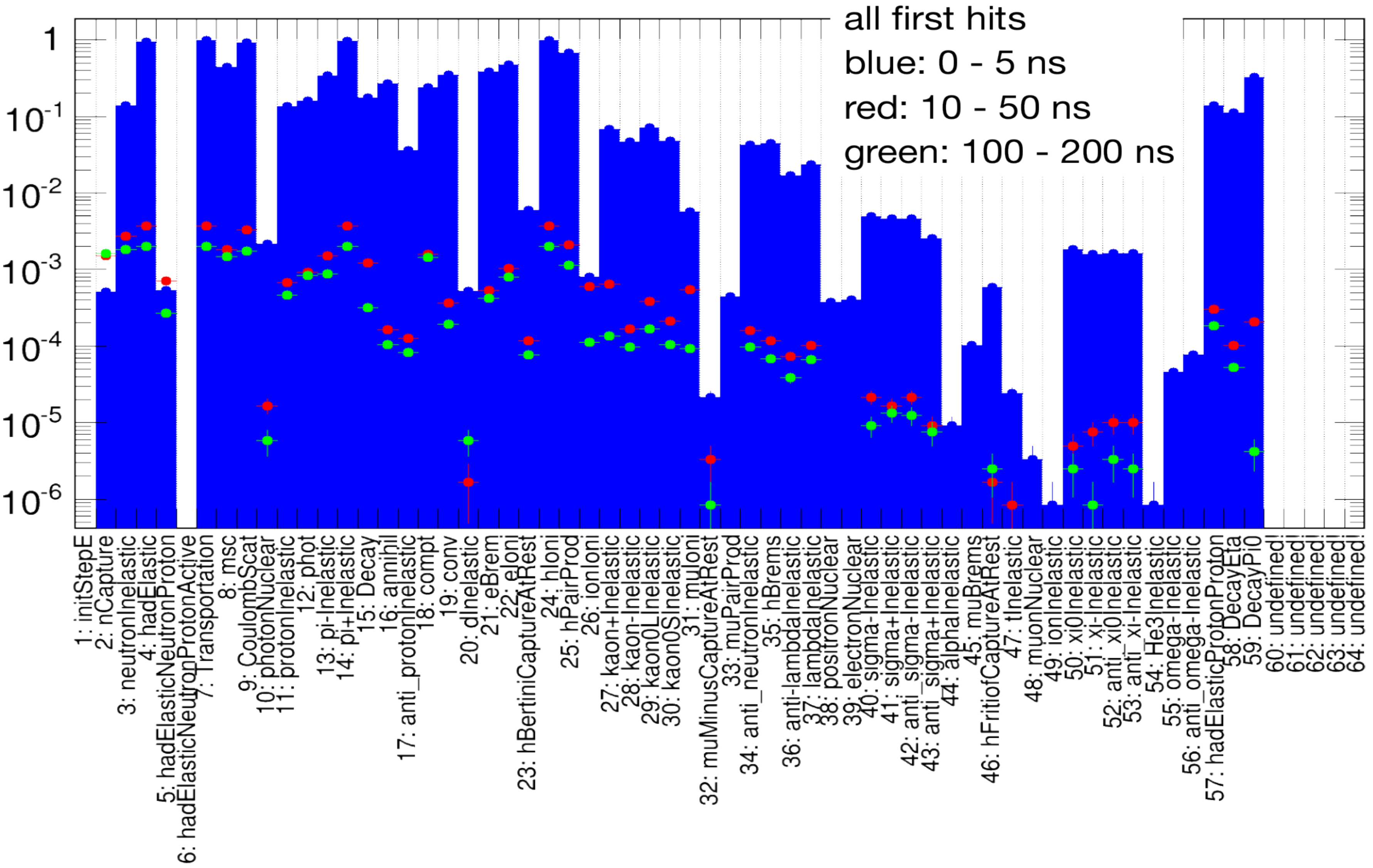
All Processes



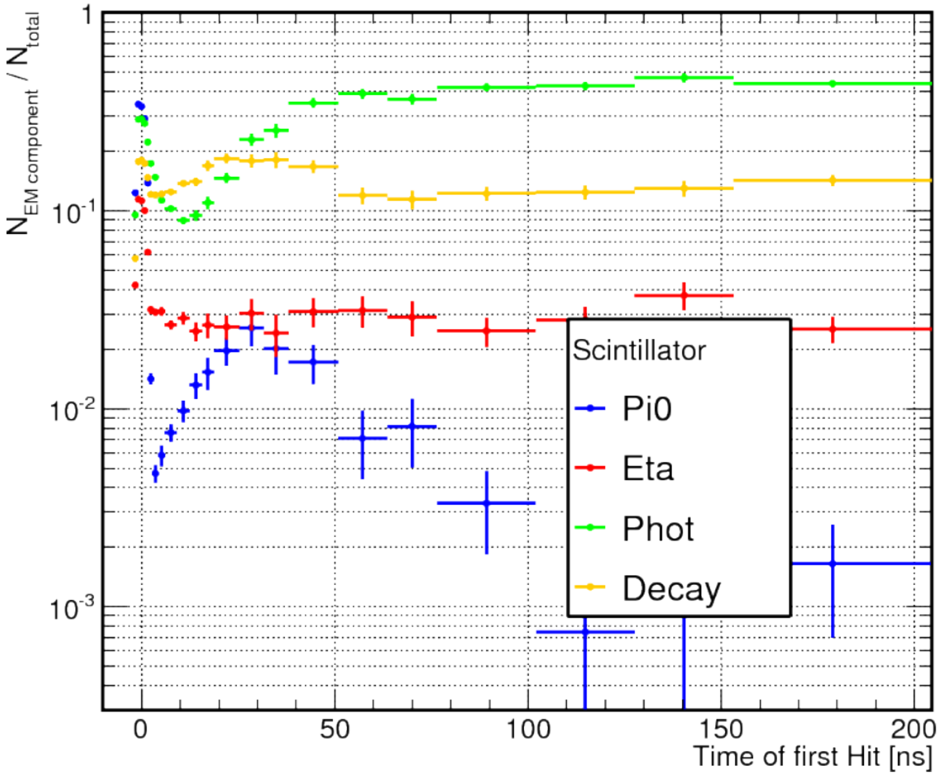
All Processes Scintillator

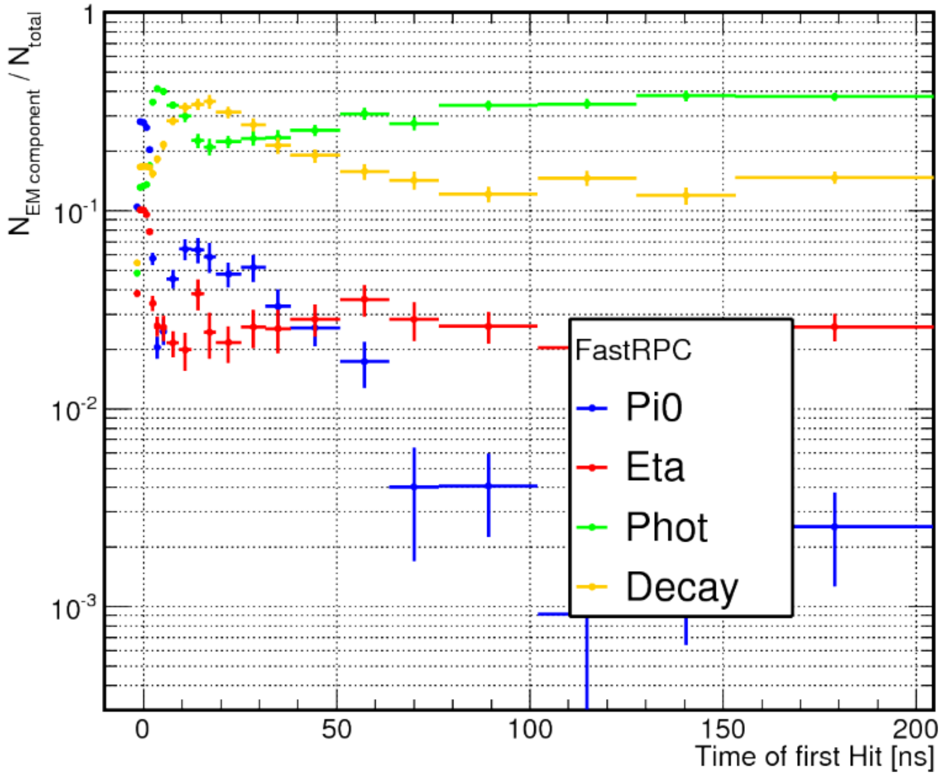


All Processes Gas



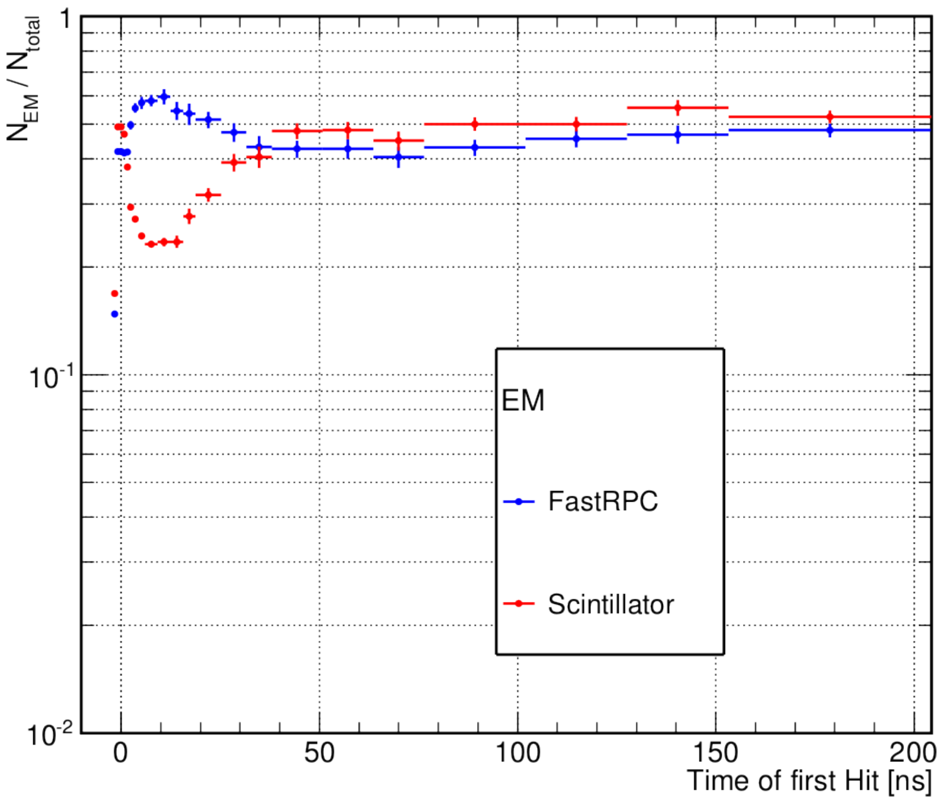
Electromagnetic Contributions





- Promt processes driven by π^0 and Photons
- Also at late times the shower is quite electromagnetic – photons from neutron capture

Simulation Results
Relative Contributions



- Electromagnetic contributions important throughout the shower development
- In the Scintillator less EM contribution in the intermediate phase → neutron Elastic Scattering taking over