Timing of hadronic showers in geant4

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AIDA Meeting
DESY, 28/03/2012

Overview

- Motivation: the Fall Test-beam
- The AHCAL technological prototype geometry
- Parent Particle Identification
- Time stamping: implementation of the ASIC logic in digitization
- Results of the simulations
- Outlook

The Fall 2012 Test Beam Experiment

Event:
• planned CALICE test beam in fall 2012 at CERN SPS
• (minimum) 1 layer of AHCAL technological prototype (4 HBUs) to be mounted downstream the DHCAL

Physics goal of the Test Beam Experiment:
•Electronic test of the multi-HBU readout in the beam
•Study of time development of hadronic showers (extended T3B study with one complete layer)

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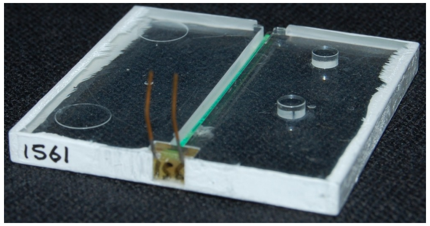
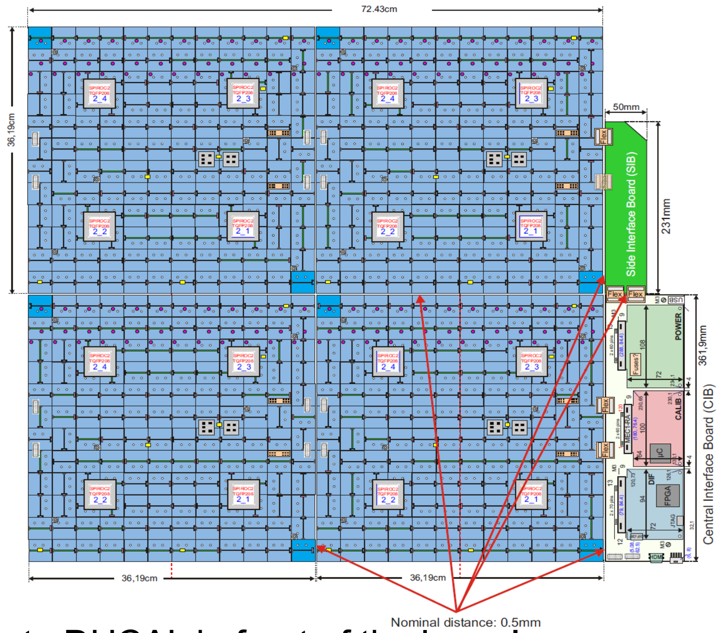
simulations have been performed to prepare the physics case:
Timing
Hadronic shower components

The Geometry Driver



The layer:

•4 HBUs each one equipped with 144 tiles with 3 cm side
•each tile is 3 mm thick



New Mokka geometry driver **TBhcal4d** had been written by Shaojun Lu
Meant to be flexible
Some AHCAL parameters can be set from steering file

parameter	value	steerable?
Cell border	30 mm	yes
N of cells x, y	30	yes
Integration time	500 ns	yes
Absorber	Tungsten	no
Cell thickness	3 mm	no
N of layers	38	yes

to simulate DHCAL in front of the layer !

10 GeV pions, 10^5 events with QGSP_BERT and QGSP_BERT_HP

Hadronic Shower : EM fraction

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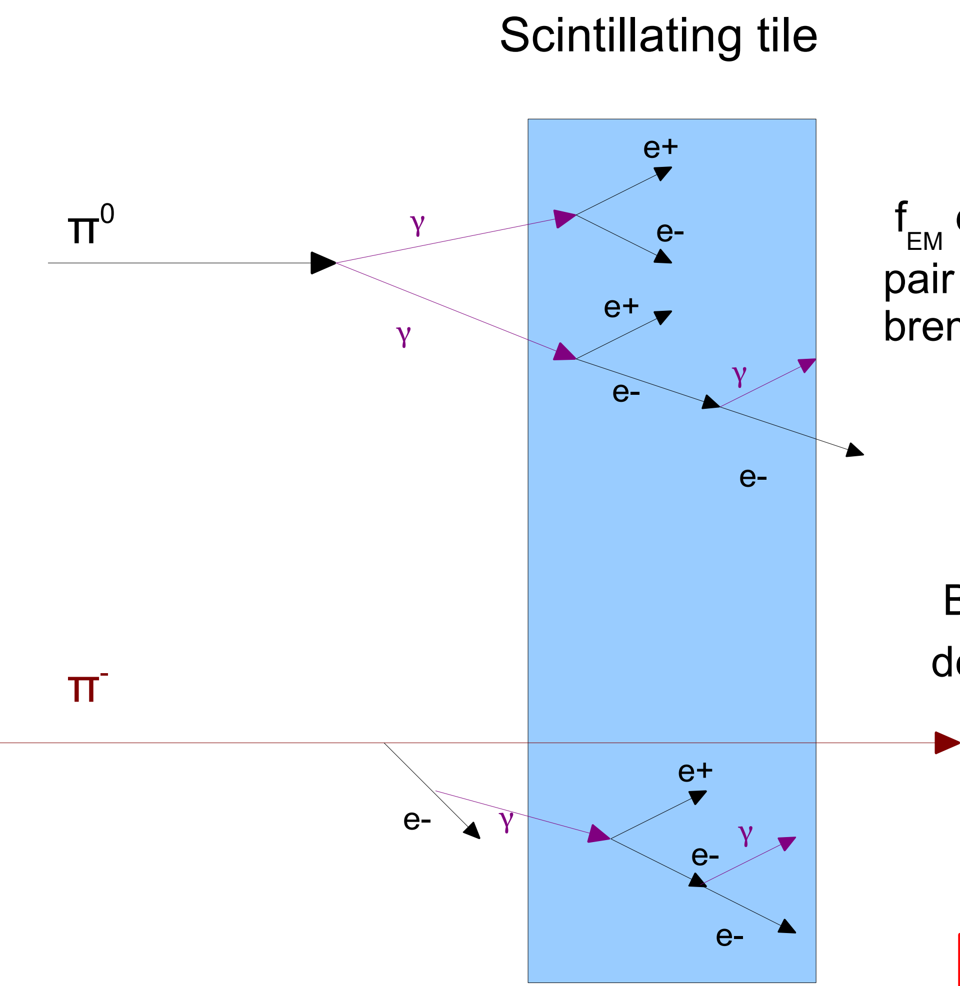
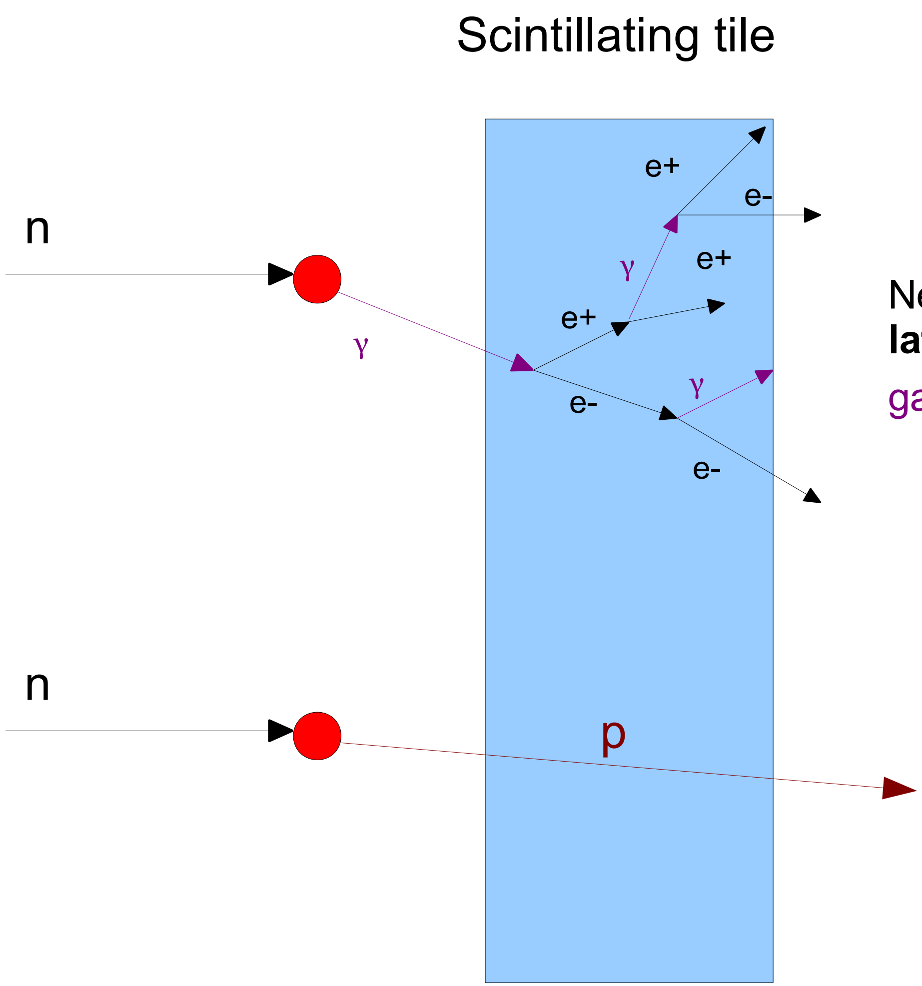


f_{EM} due to π^0 decay in two photons
pair production
bremsstrahlung

Background to f_{EM}:
delta electrons due to ionization by MIP hadrons

We want to be able to separate the true f_{EM} from the background

Hadronic Shower : neutrons



Neutron capture:
late nuclear de-excitation ($t_n >> t_{EM}$)
gamma emission and delta electrons (also background to f_{EM})

scattering with nucleus
proton (alpha ...) emission

We want to be able to trace back to neutrons

Particle Identification

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no information on parent particle in SimCalorimeterHit:
- PDG of particle depositing energy in the Sensitive Detector
- PDG of particle entering the calorimeter

Primary PDG

secondary PDG

```
[   id   ] |cellId0 |cellId1 |  energy  |        position (x,y,z)          | nMCParticles
        -> MC contribution: prim. PDG |  energy  |   time   | sec. PDG | stepPosition (x,y,z)
------------|--------|--------|----------|----------------------------------|-------------
[00000219] |00120d01|00000000|+2.232e-05|+7.500e+01, -7.500e+01, +1.547e+03|         +1
       id-fields: (K:1,J:13,I:18)
          ->                          -211|+2.232e-05|+2.412e+02|+2212| (+8.675e+01, -6.931e+01, +1.547e+03)
[0000021a] |00140d01|00000000|+2.211e-05|+1.350e+02, -7.500e+01, +1.547e+03|         +2
       id-fields: (K:1,J:13,I:20)
          ->                          -211|+1.881e-05|+2.140e+02|+2212| (+1.275e+02, -6.827e+01, +1.546e+03)
          ->                             0|+3.295e-06|+2.133e+02|+1000060120| (+1.313e+02, -6.296e+01, +1.546e+03)
[0000021b] |00100e01|00000000|+9.316e-06|+1.500e+01, -4.500e+01, +1.547e+03|         +1
       id-fields: (K:1,J:14,I:16)
          ->                          -211|+9.316e-06|+2.177e+02|+2212| (+2.463e+01, -3.946e+01, +1.548e+03)
[0000021c] |00100f01|00000000|+1.403e-04|+1.500e+01, -1.500e+01, +1.547e+03|         +2
       id-fields: (K:1,J:15,I:16)
          ->                          -211|+4.735e-05|+2.239e+02|+2212| (+1.420e+01, -4.478e+00, +1.548e+03)
          ->                             0|+9.294e-05|+2.204e+02|+2212| (+2.254e+01, -1.839e+00, +1.547e+03)
[0000021d] |00101001|00000000|+7.433e-04|+1.500e+01, +1.500e+01, +1.547e+03|         +9
       id-fields: (K:1,J:16,I:16)
          ->                             0|+4.691e-04|+2.053e+02|-211| (+1.524e+00, +1.722e+01, +1.547e+03)
          ->                          -211|+5.934e-05|+2.053e+02|-211| (+1.520e+00, +1.722e+01, +1.546e+03)
          ->                          -211|+1.908e-05|+2.053e+02|+11| (+1.488e+00, +1.723e+01, +1.546e+03)
          ->                          -211|+1.086e-05|+2.053e+02|+11| (+1.433e+00, +1.725e+01, +1.546e+03)
          ->                          -211|+2.113e-05|+2.053e+02|+11| (+1.376e+00, +1.725e+01, +1.546e+03)
          ->                          -211|+1.684e-05|+2.053e+02|+11| (+1.322e+00, +1.724e+01, +1.546e+03)
          ->                          -211|+3.809e-05|+2.053e+02|+11| (+1.286e+00, +1.721e+01, +1.546e+03)
          ->                          -211|+1.583e-05|+2.053e+02|+11| (+1.277e+00, +1.716e+01, +1.546e+03)
          ->                          -211|+9.299e-05|+2.053e+02|+11| (+1.281e+00, +1.715e+01, +1.546e+03)
[0000021e] |00111001|00000000|+2.273e-05|+4.500e+01, +1.500e+01, +1.547e+03|         +3
       id-fields: (K:1,J:16,I:17)
:
```

late protons ...

True f_{EM} component ?

Shower Components

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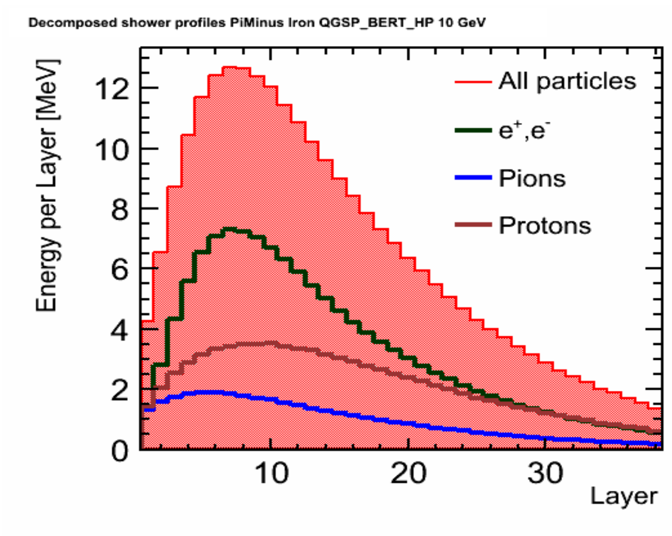
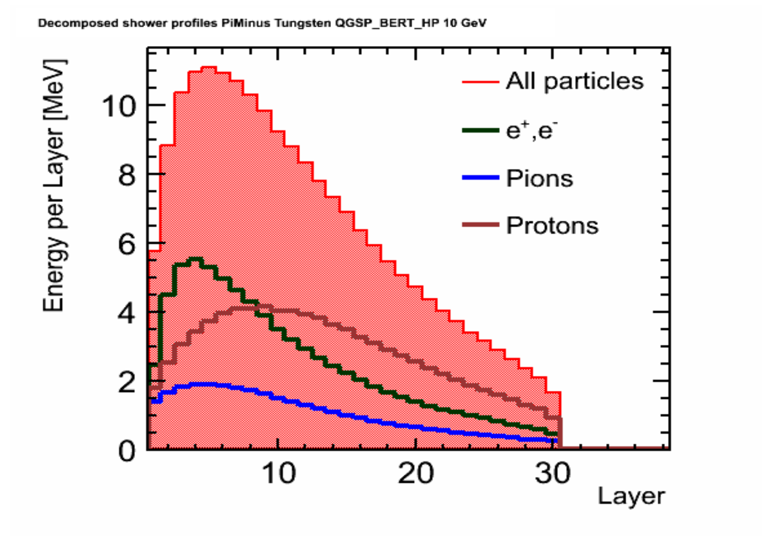
provided by Clemens Günter:





SimCalorimeterHit contains no information on the origin of electron and positrons

Writing a Mokka plugin:
Create a collection of LCIOGenericObject
Save there all the needed information:
- Hit time
- Hit position
- Hit energy
- Parent and grandparent particle ID
- ...

but: most information redundant
still a work in progress ...

Timing

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To access **time information** detailedShowerMode must be used

all the sub-hit structure of the SimCalorimeterHit is made explicit:
→each Hit is composed by many sub-hits
→position, time,deposited energy of each sub-hit is stored

```
[   id   ] |cellId0 |cellId1 |  energy  |        position (x,y,z)          | nMCParticles
          -> MC contribution: prim. PDG |  energy  |   time   | sec. PDG | stepPosition (x,y,z)
-----------|--------|--------|----------|----------------------------------|--------------
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          ->                        -211|+1.086e-05|+2.053e+02|+11| (+1.433e+00, +1.725e+01, +1.546e+03)
          ->                        -211|+2.113e-05|+2.053e+02|+11| (+1.376e+00, +1.725e+01, +1.546e+03)
          ->                        -211|+1.684e-05|+2.053e+02|+11| (+1.322e+00, +1.724e+01, +1.546e+03)
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       id-fields: (K:1,J:16,I:17)
:
```
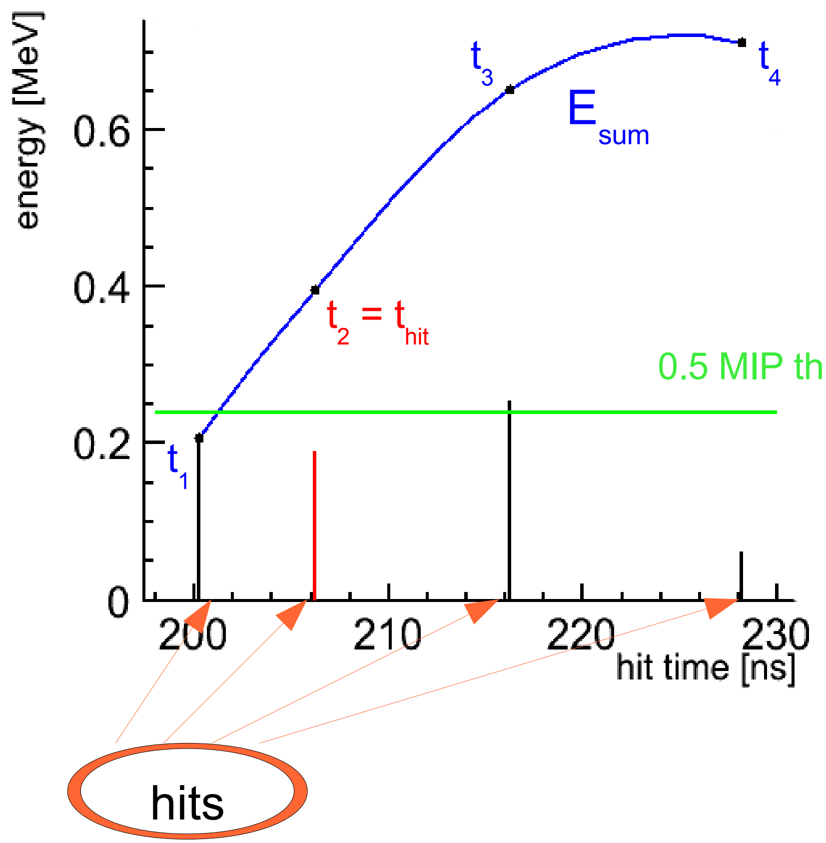

Sub-hits

Sub-hit energy   sub-hit time

Timestamping: digitization

For each cell several hits characterized by:
- A time value
- A deposited energy value



Writing a Marlin Processor
to simulate ASIC behavior, for each Cell:

1a) hits are temporally ordered
1b) hit energy is added until $t_i = t_1$ + fast shaper rise time
1c) $t_{hit} = t_i$ first hit passing threshold

2) E_{sum} = sum of E_i until $t < t_{hit} + t_{hold}$ $\quad t_{hold} \sim 50$ ns

No ASIC noise or time jitter had been considered yet ...

Pions: Hits time Distribution

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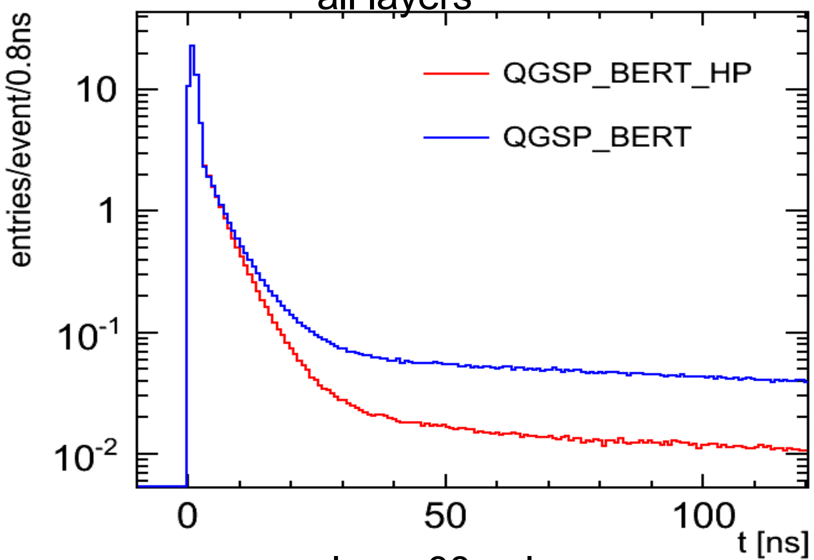
10 GeV pions hit time distribution:

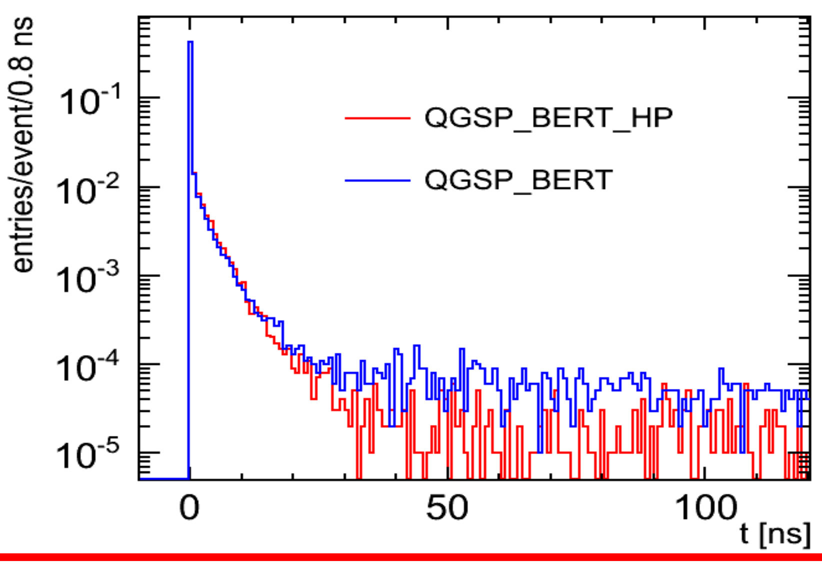
all layers



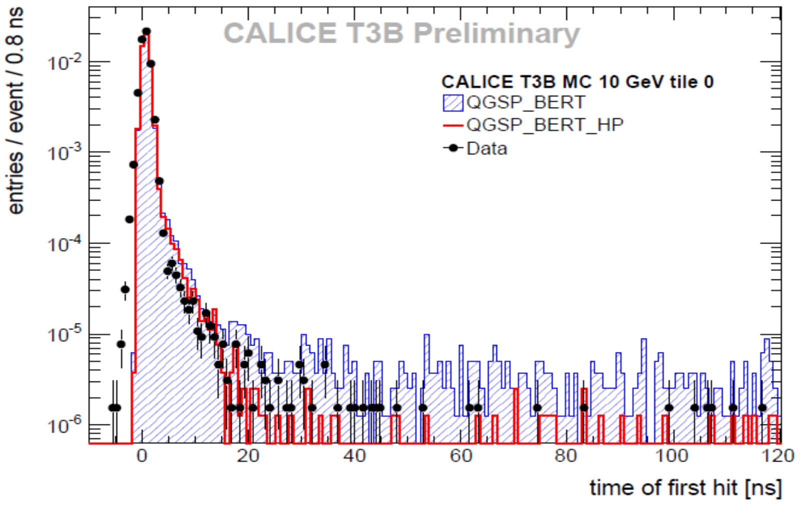
Physics lists predict different time behavior:
HP physics List has less late events over threshold

Less evident when restricting only to layer 38

layer 38 only



T3B simulations and data



Mean Layer Dependance

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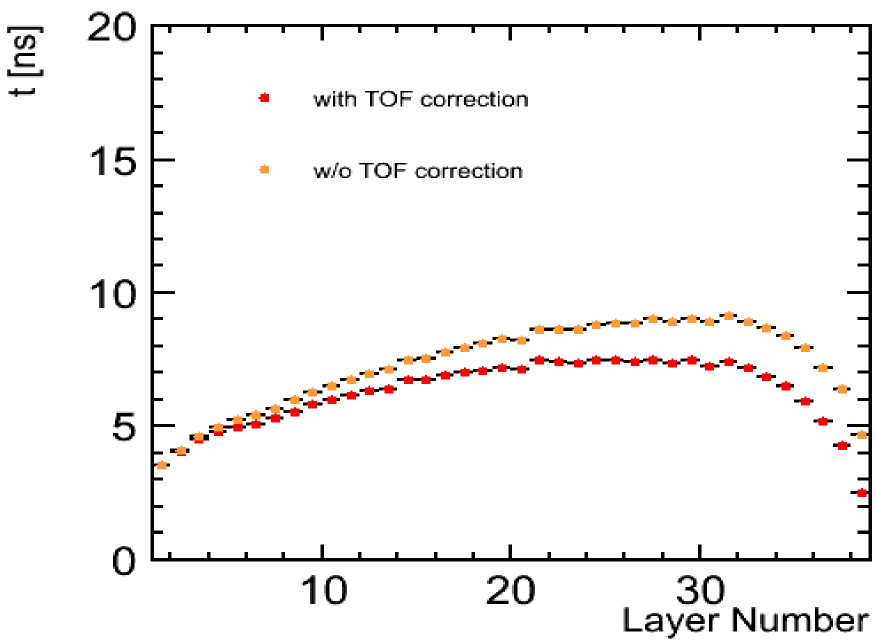
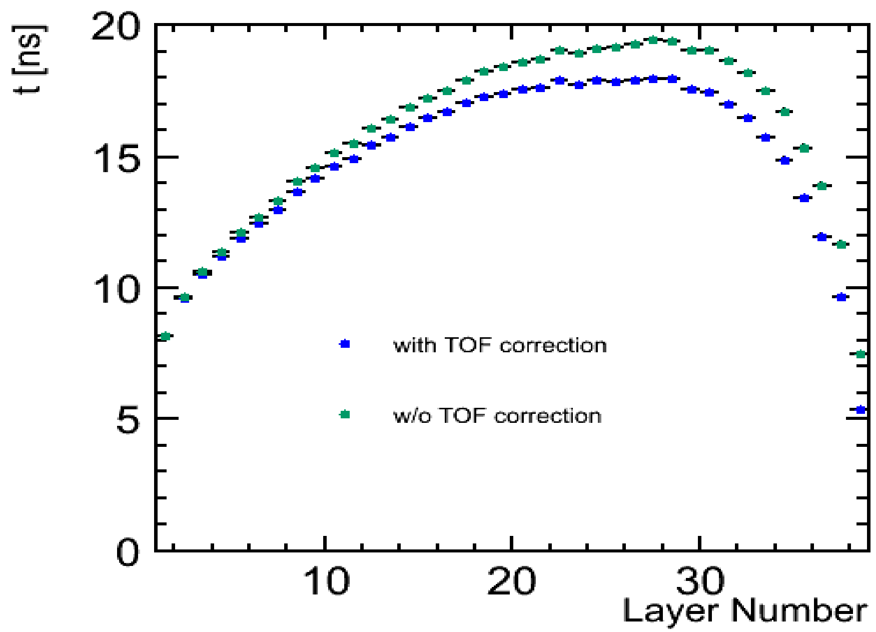
Mean hit time per layer:

10 GeV pions QGSP_BERT_HP



10 GeV pions QGSP_BERT



- Late shower component more present between layers 5 and 30;
- HP physics list predicts an overall faster shower development;

Single-Layer Time Distribution

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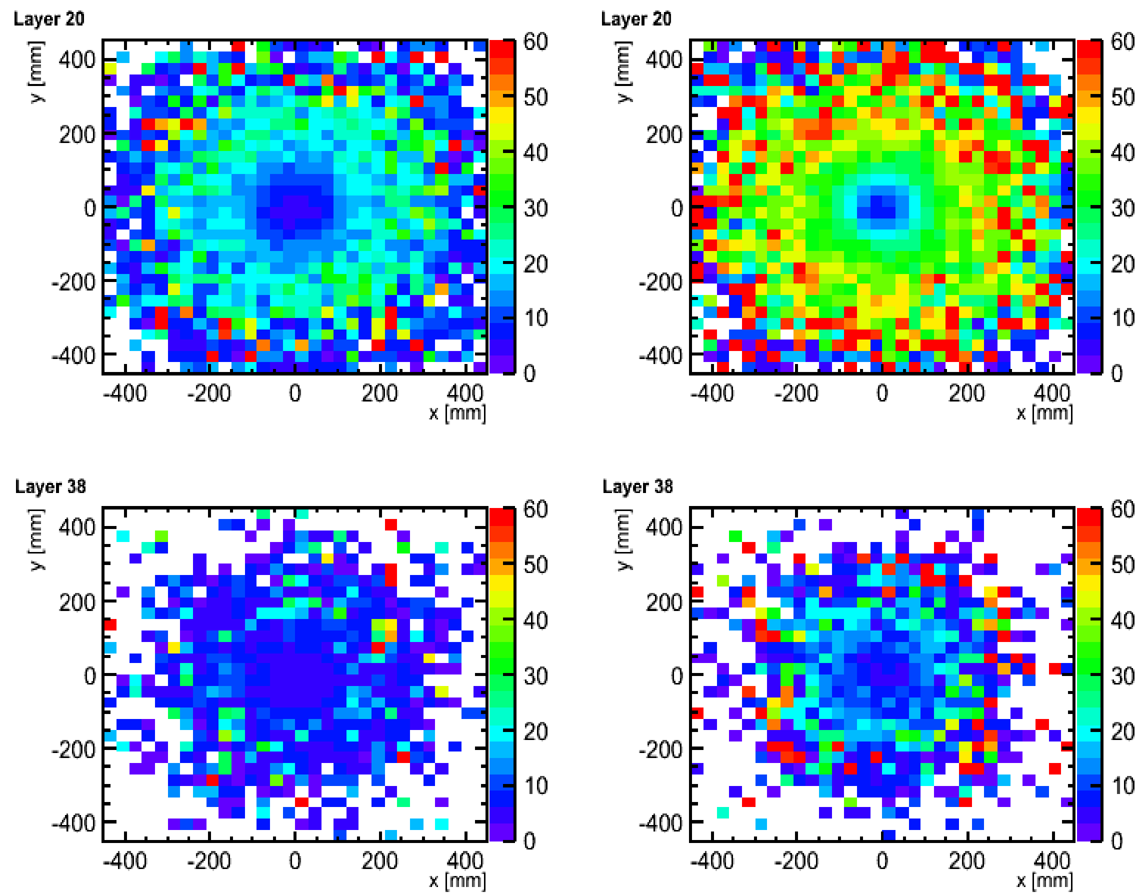
Average hit time distribution as function of the hit position:
(timescale in ns indicated by palette colors)

10 GeV pion QGSP_BERT_HP | 10 GeV pion QGSP_BERT



On average later hits are found:

- at larger radii
- in inner layers
- for non-HP physics list

Single-Layer Time Distribution

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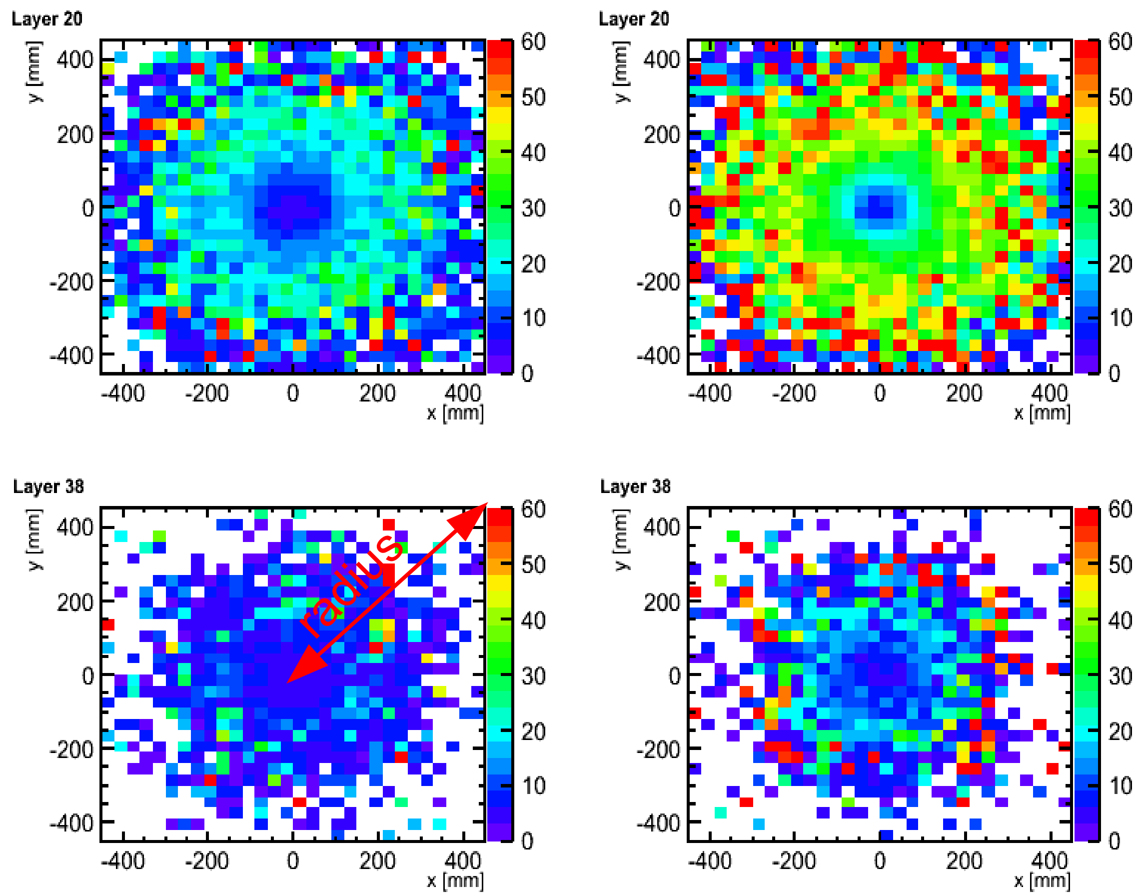
Average hit time distribution as function of the hit position:
(timescale in ns indicated by palette colors)

10 GeV pion QGSP_BERT_HP | 10 GeV pion QGSP_BERT



On average later hits are found:

- at larger radii
- in inner layers
- for non-HP physics list

need quantify radial dependence of hit time!

Mean values per layer

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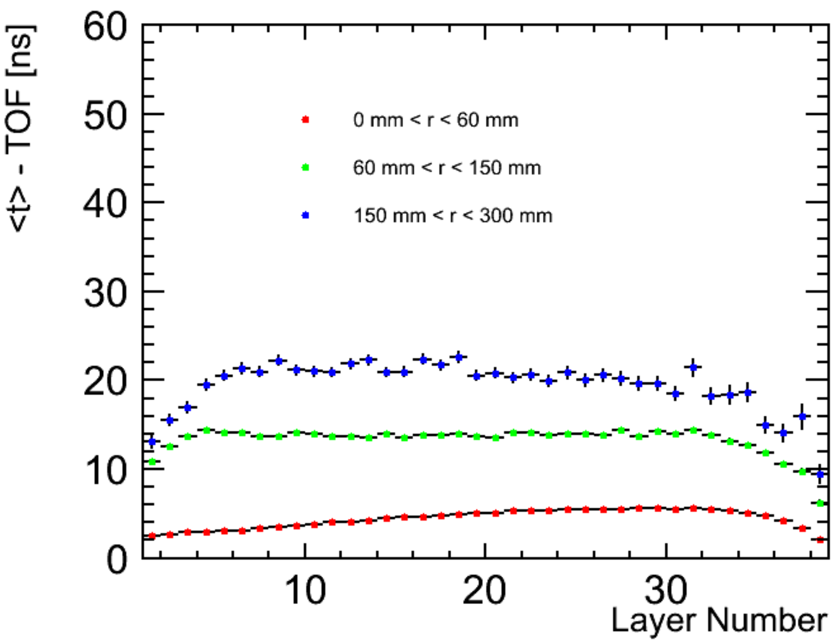
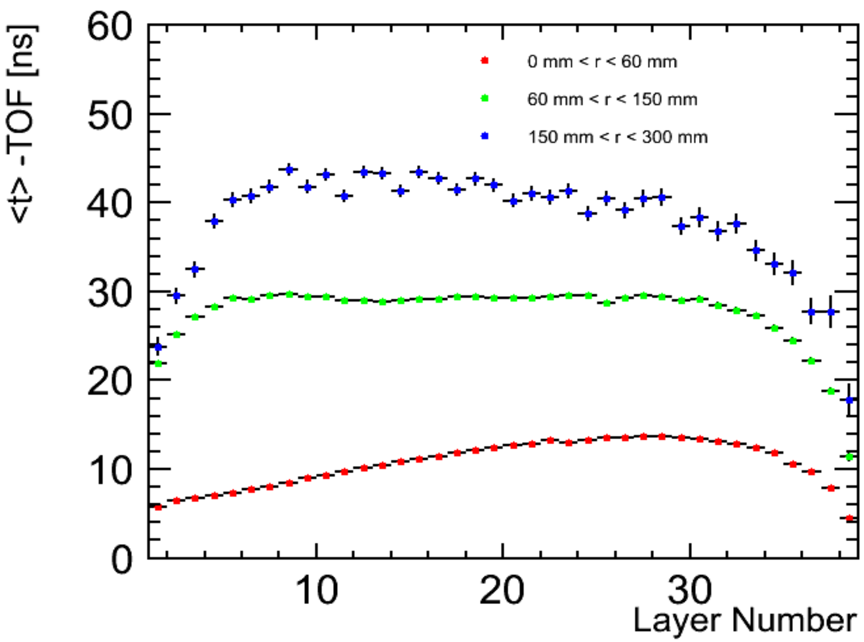
Each layer divided in 4 radial bins:

- 0 mm – 60 mm
- 60 mm – 150 mm
- 150 mm – 300 mm
- more than 300 mm → too few events ...

10 GeV pions QGSP_BERT_HP



10 GeV pions QGSP_BERT



Late hits are more found:

- at increasing radius
- between layer ~ 5 and layer ~ 30

Summary & Outlook

Thanks to:
•Shaojun Lu for the geometry driver implementation;

- First AHCAL Timestamping Mokka simulations;
- New Mokka Geometry TBhcal4d driver written
- Digitization algorithm simulating the ASIC behavior (in progress);

In future:

•Introduce noise an jitter effects;

•Identify parent and grandparent particle (work in progress...);

•Compare with data!

Backup Slides

Timestamping: the ASIC

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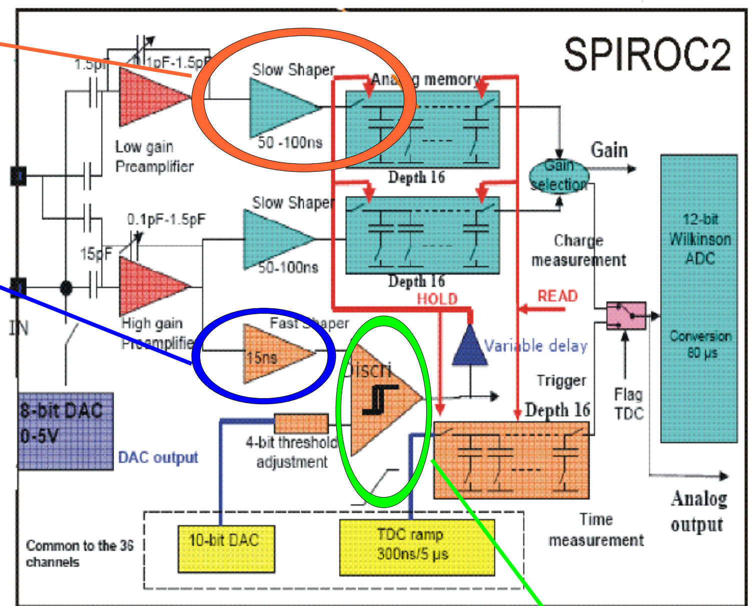
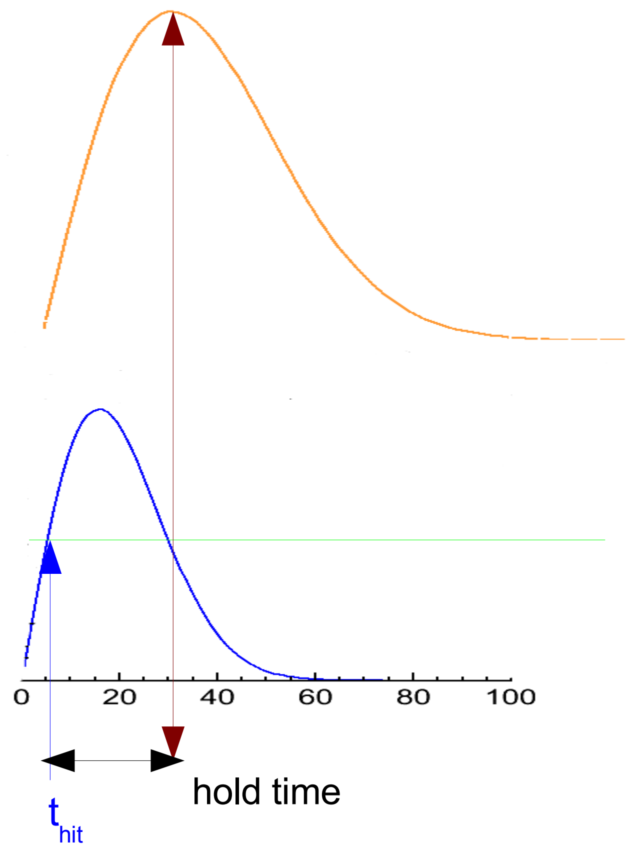
Slow shaper

Fast shaper



Threshold discriminator



Hit signal splitted:

- A fast shaper (~ 25 ns shaping time) feeds a threshold discriminator;
- A slow shaper (~ 50 ns) feeds the analog memory;

Whenever fast signal amplitude passes the threshold:

- Time information is stored (of threshold passing);
- Amplitude of slow signal at hold time is stored;

(Thanks to Mark for the useful discussions)

Muon Runs

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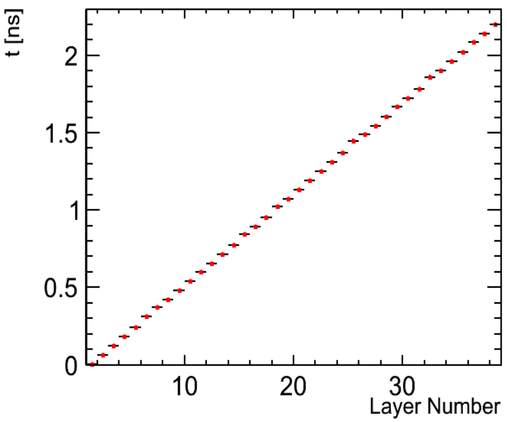
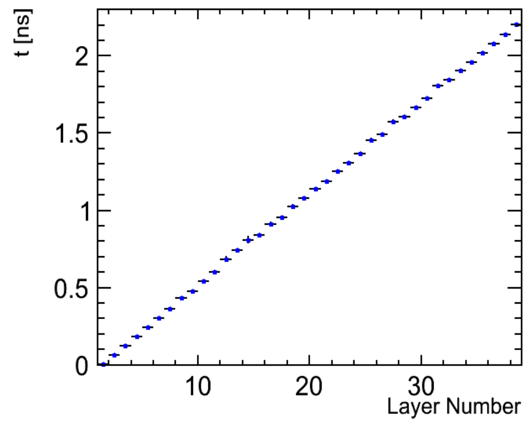
50 GeV muon QGSP_BERT_HP

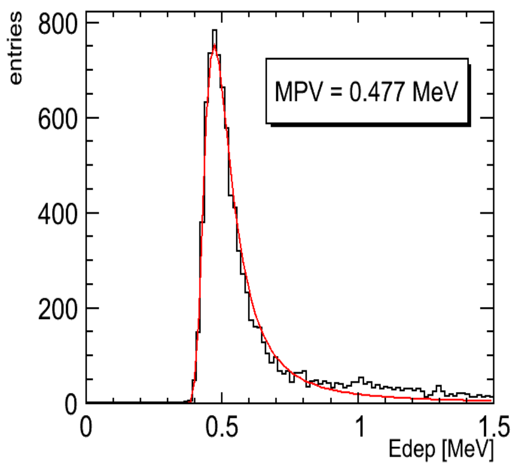


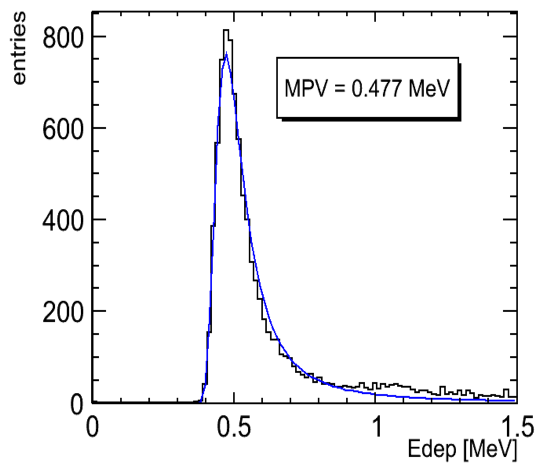
50 GeV muon QGSP_BERT



Time Of Flight correction:
0.06 ns/layer

Energy deposited in one cell:





MIP value cross-check:
MIP_{3mm} = 477 keV = 3/5 MIP_{5mm}

Radial Timing profiles ...

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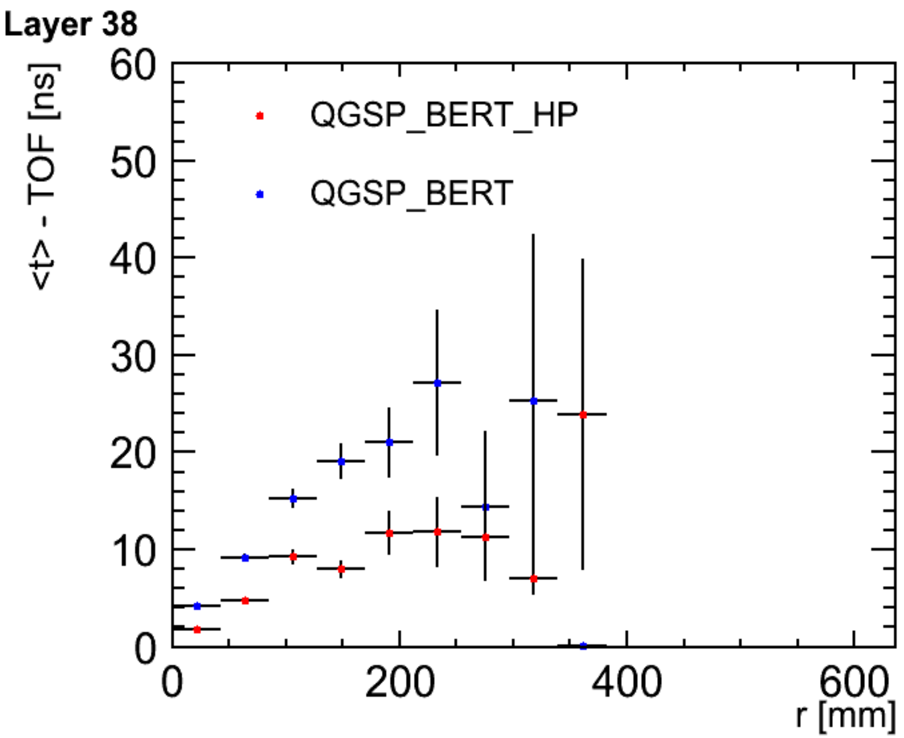
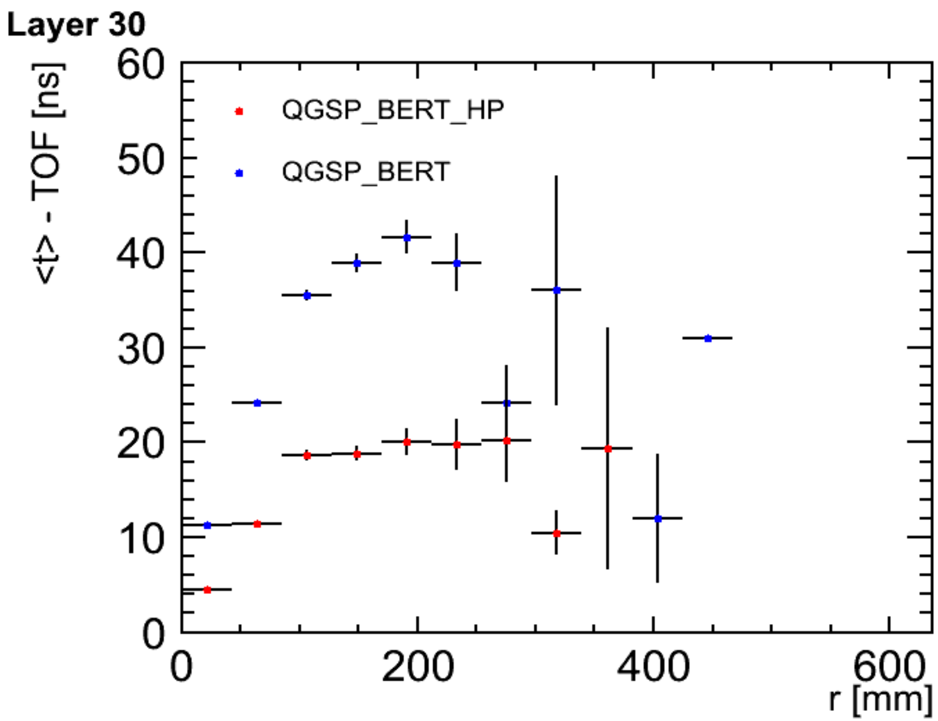
- Assigning hit position to the cell center
- Correcting for the Time Of Flight





r < 300 mm distinguishable behavior:
- separation greater than statistical error (with 100000 events)
- separation greater than expected time resolution (~ 1 ns)

More statistics and better separation

... at different layers

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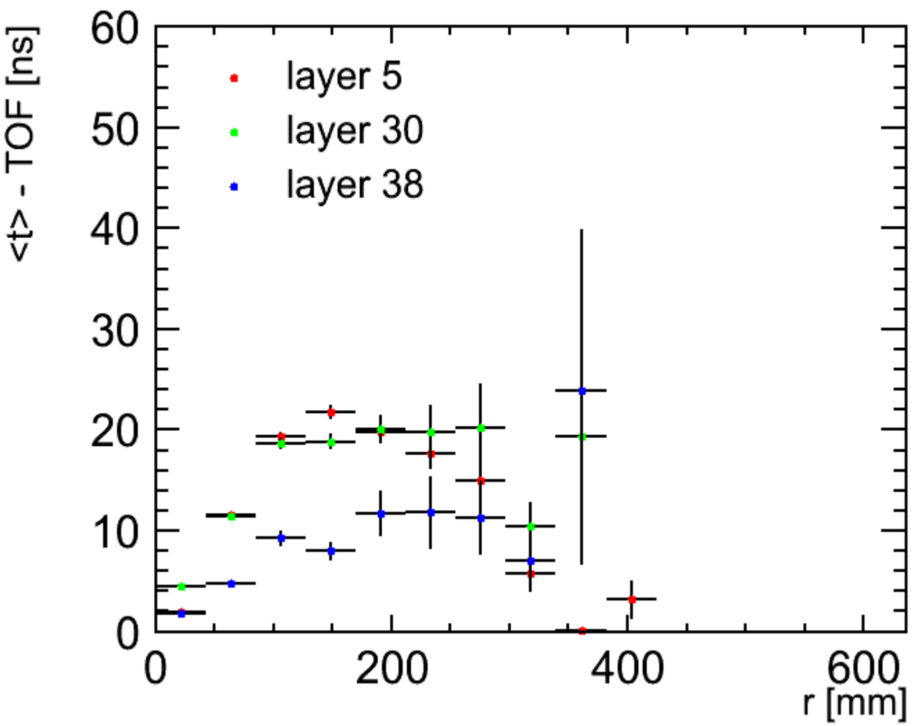
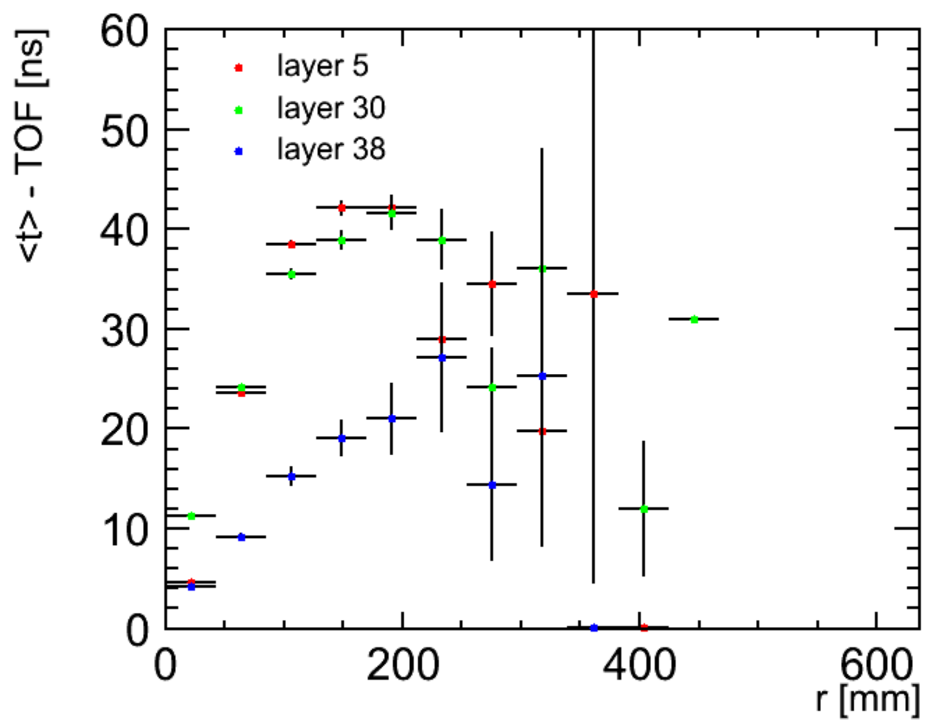
10 GeV pions QGSP_BERT_HP



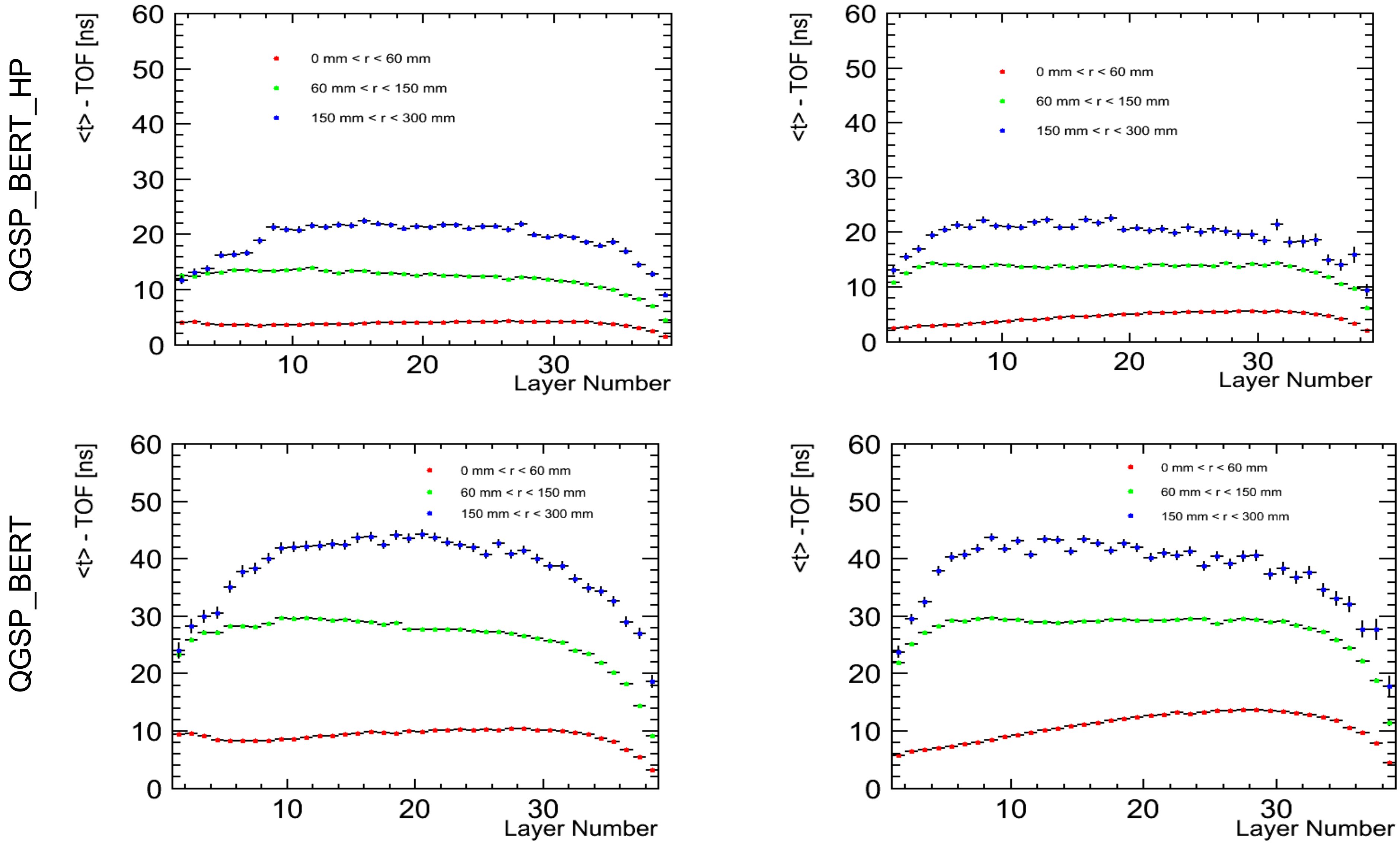
10 GeV pions QGSP_BERT



For inner layers:
statistical errors are lower (due to more hits)
better separation between physics lists

Comparison with 100 GeV

100 GeV pions | 10 GeV pions



Difference between physics lists: comparison

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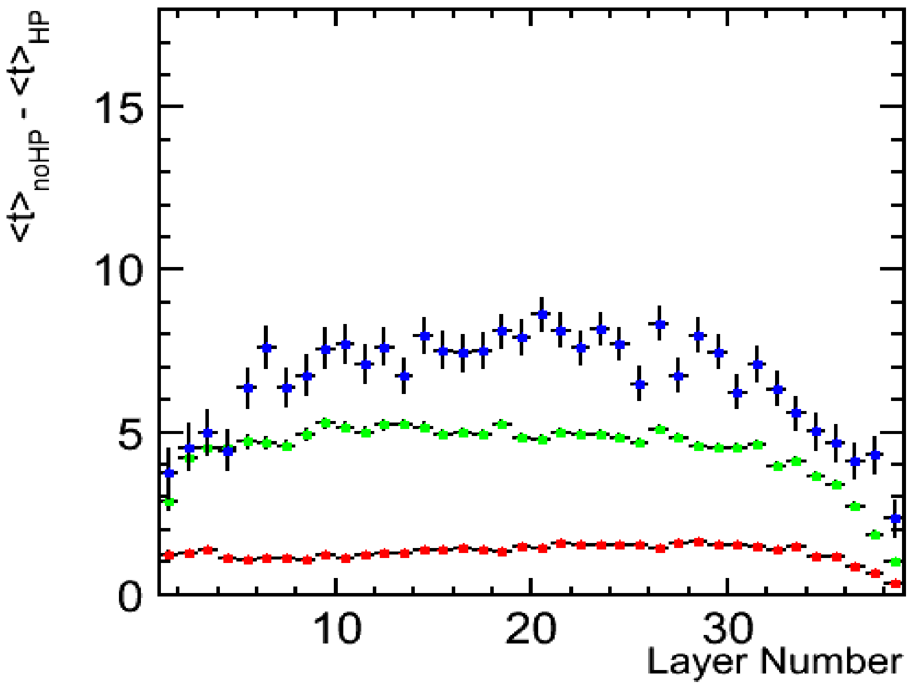
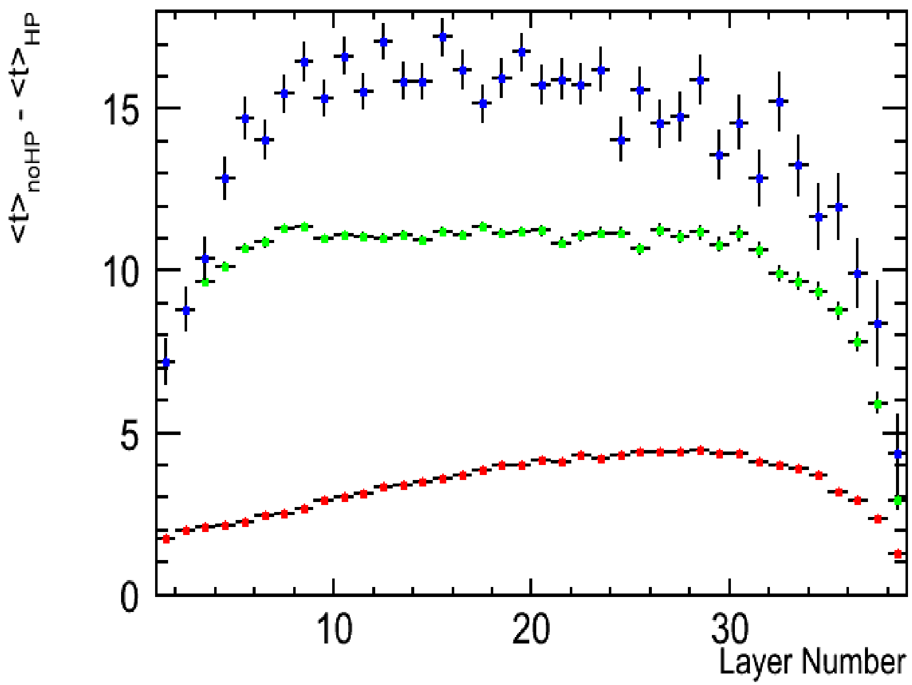
Comparison with a 100 GeV pion (10000 events):

100 GeV pion

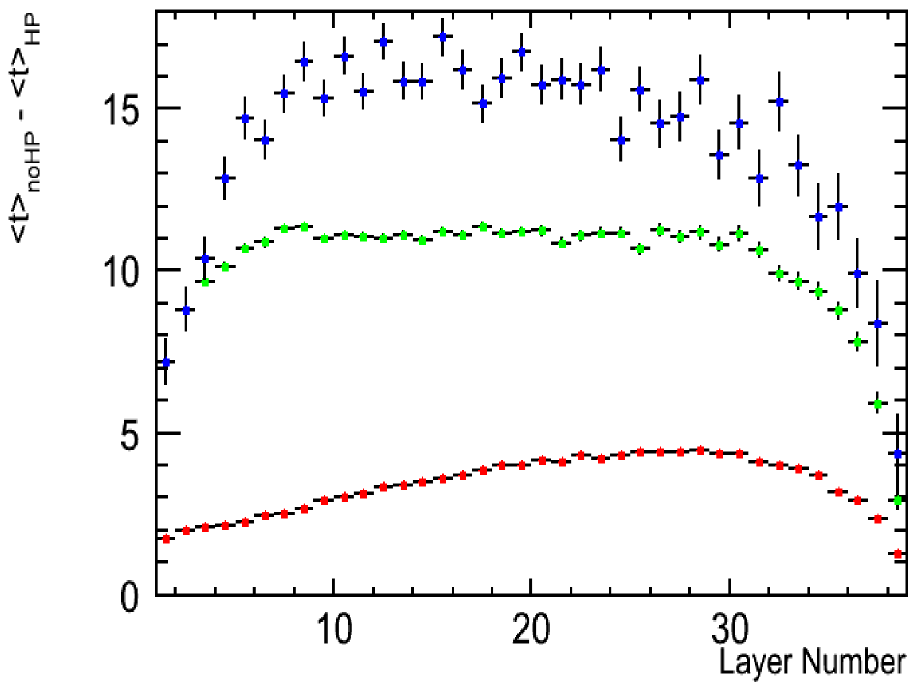


10 GeV pion



Difference between physics lists

For each radial bin difference between physics list predictions is computated



difference > 1 ns in every layer

(1 ns is the expected ASIC resolution)

@ 10 GeV
Best position for study around layer 30

Layer 38:
Suffers from low statistics (larger uncertainties)
Difference between PL is closer to ASIC resolution