

# Particle ID & Software

$e^-/\mu^-/\pi^-$  separation optimised for low energy TB May pion runs.

+ Software architecture studies

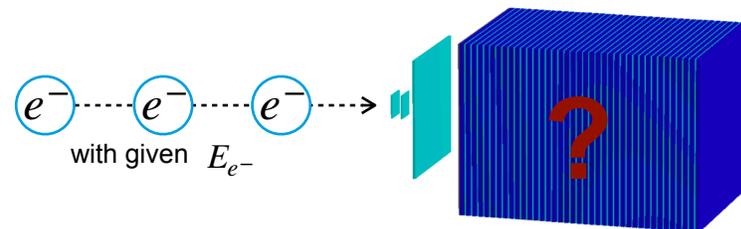
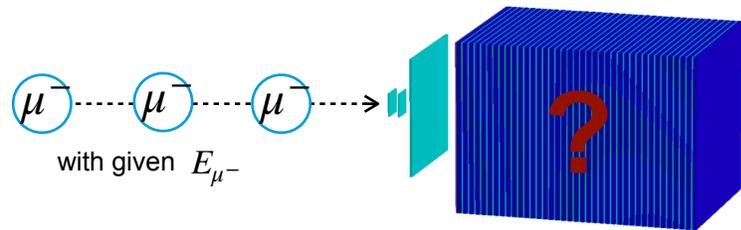
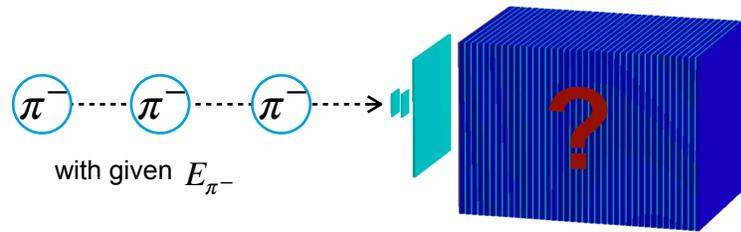
Vladimir Bocharnikov

Tokyo Test beam Analysis Workshop, 23 Aug 2018

# Particle ID

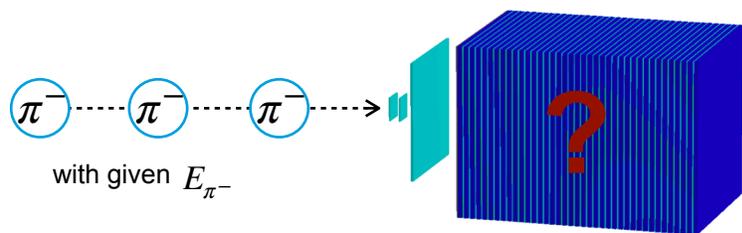
# Introduction

What do we want to investigate

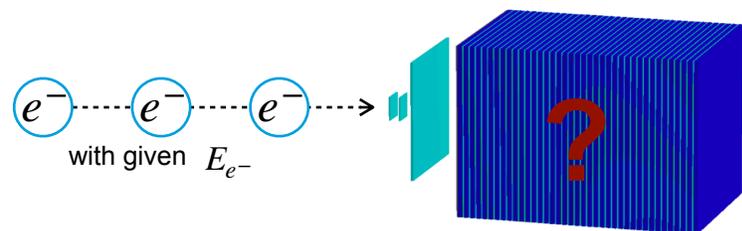
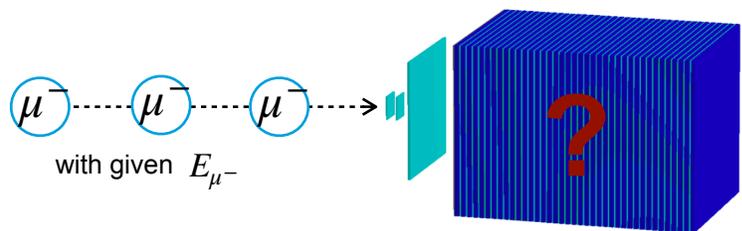


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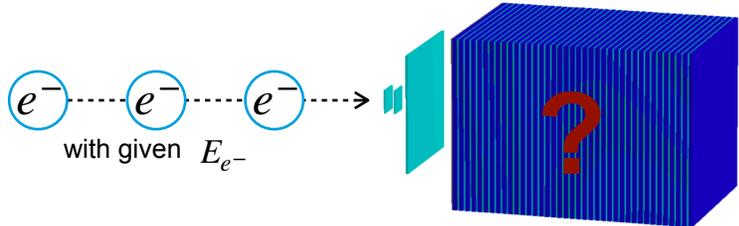
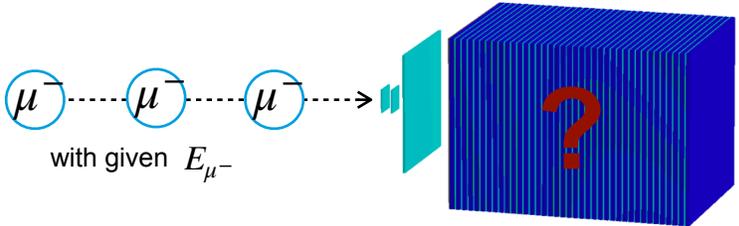
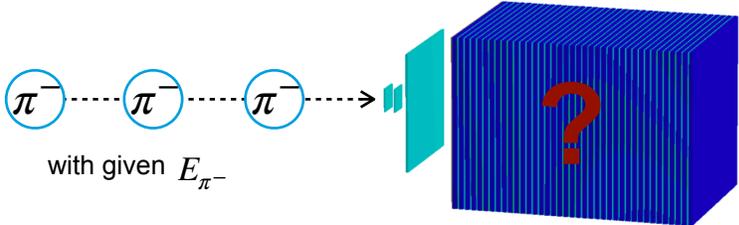


What if we want to check the energy resolution for 10GeV pion run?



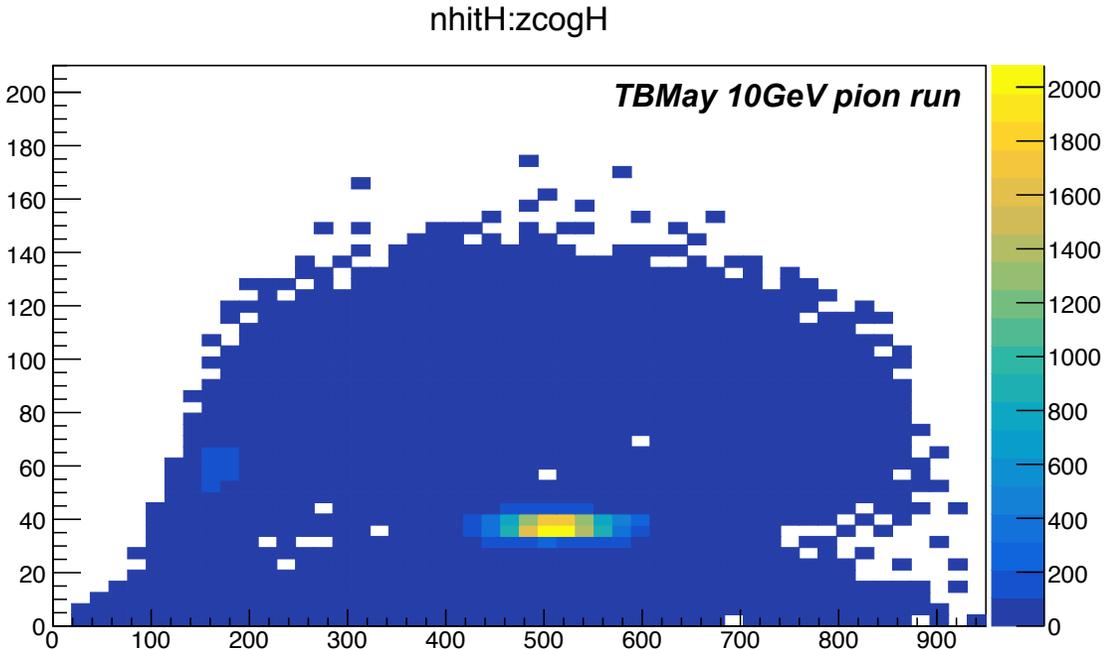
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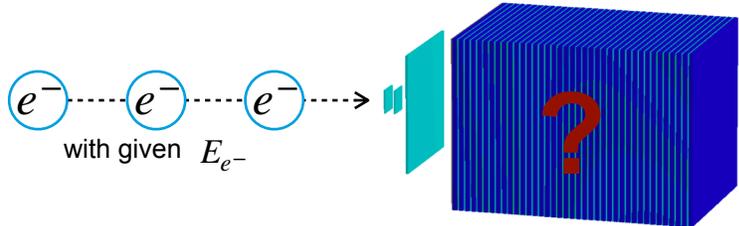
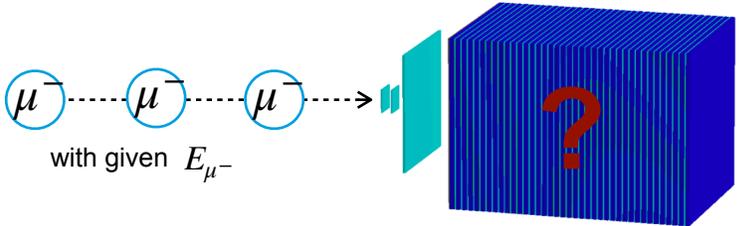
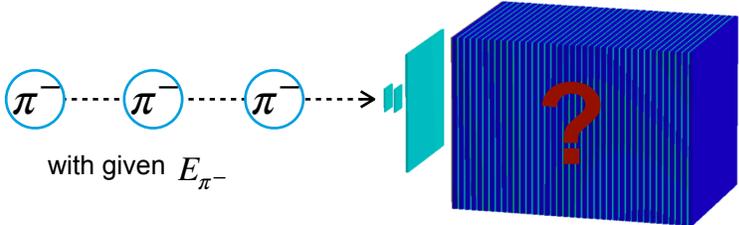
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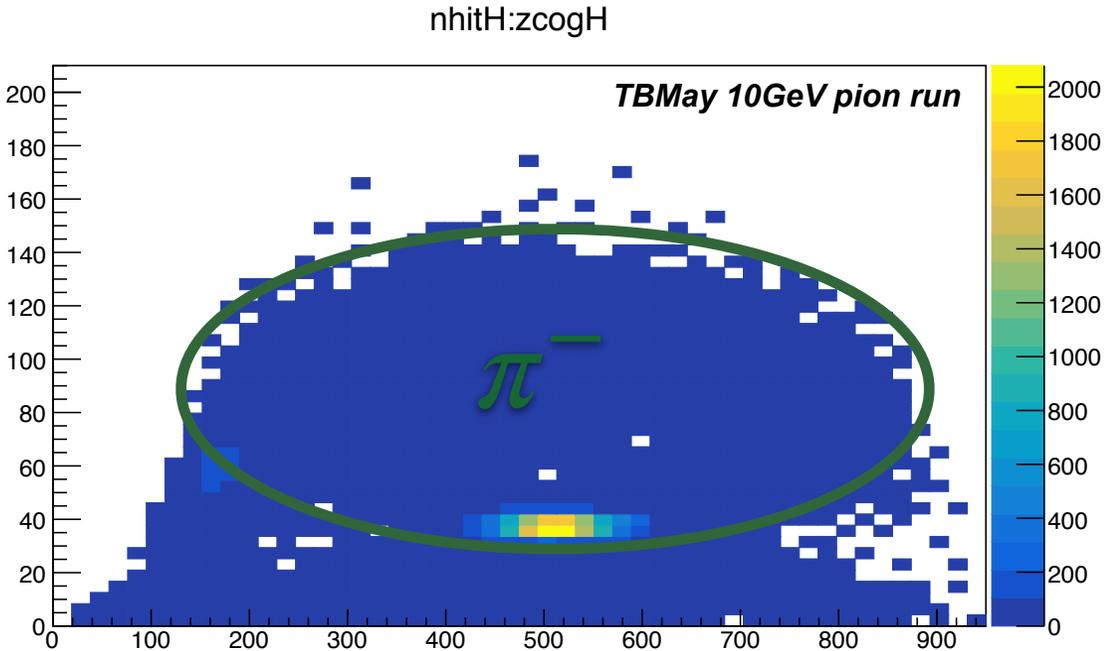
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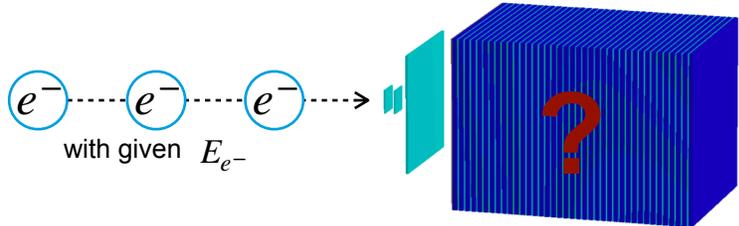
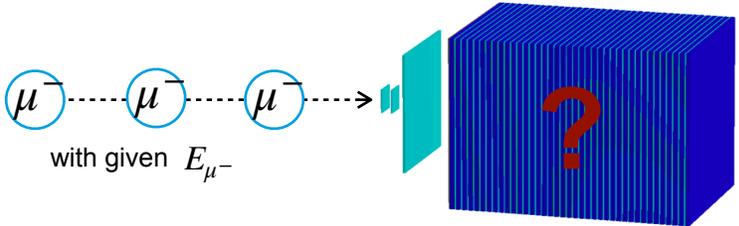
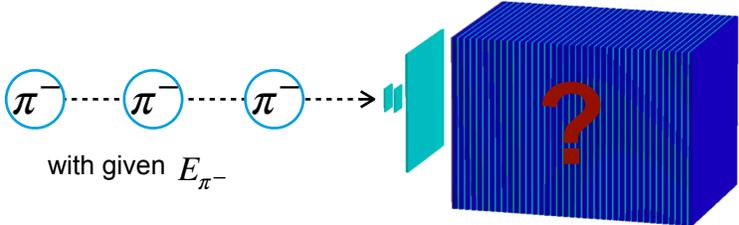
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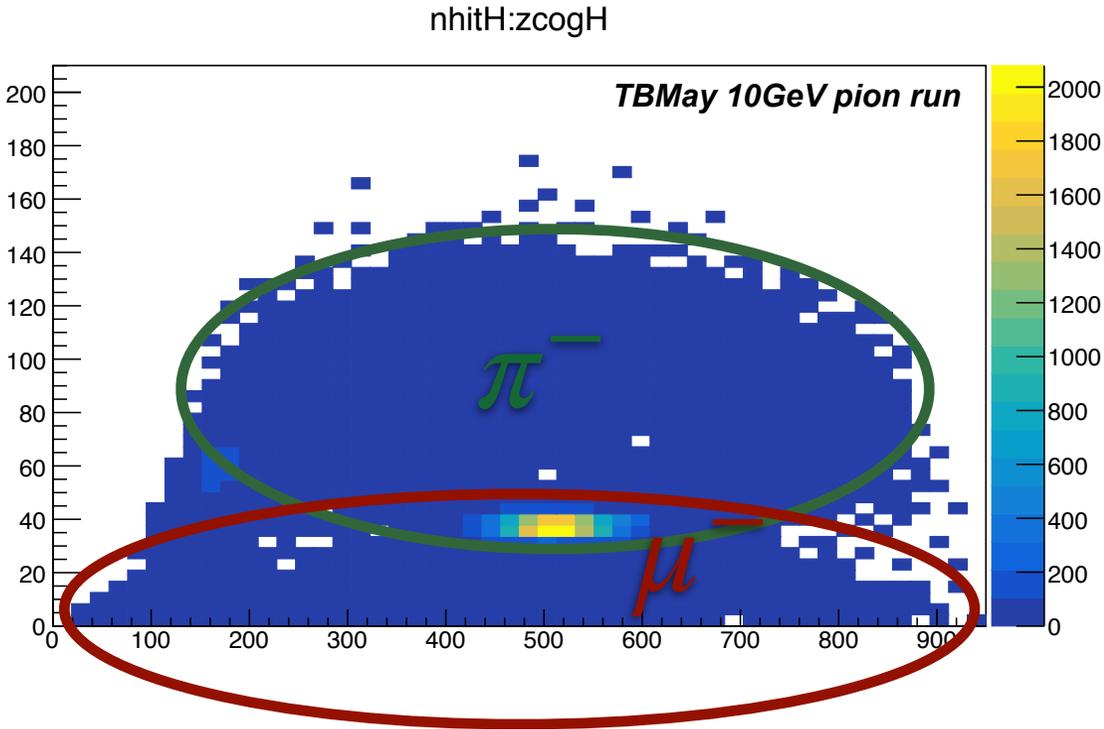
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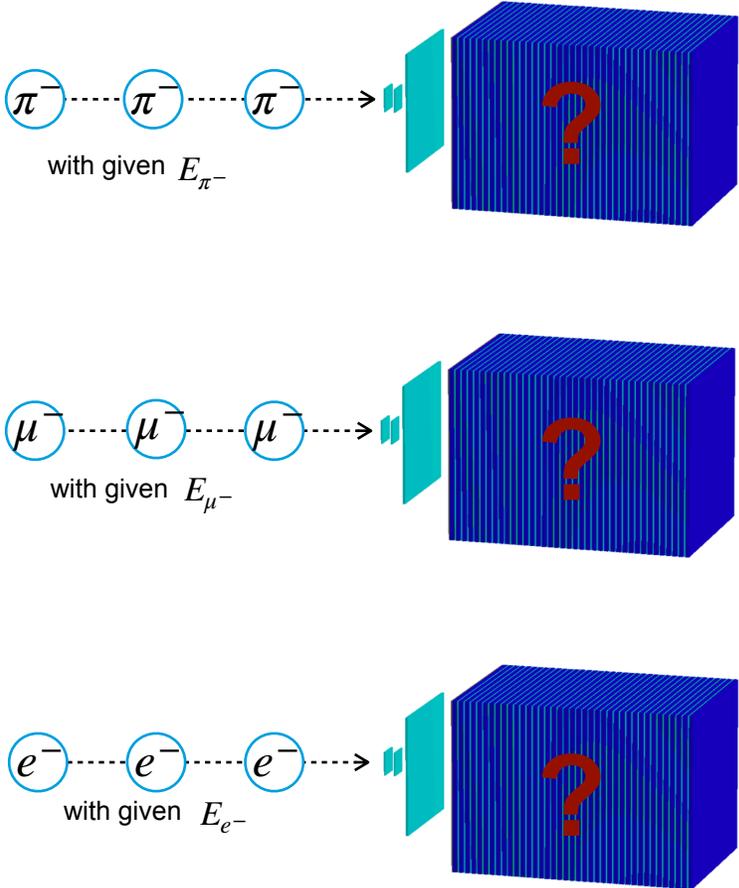
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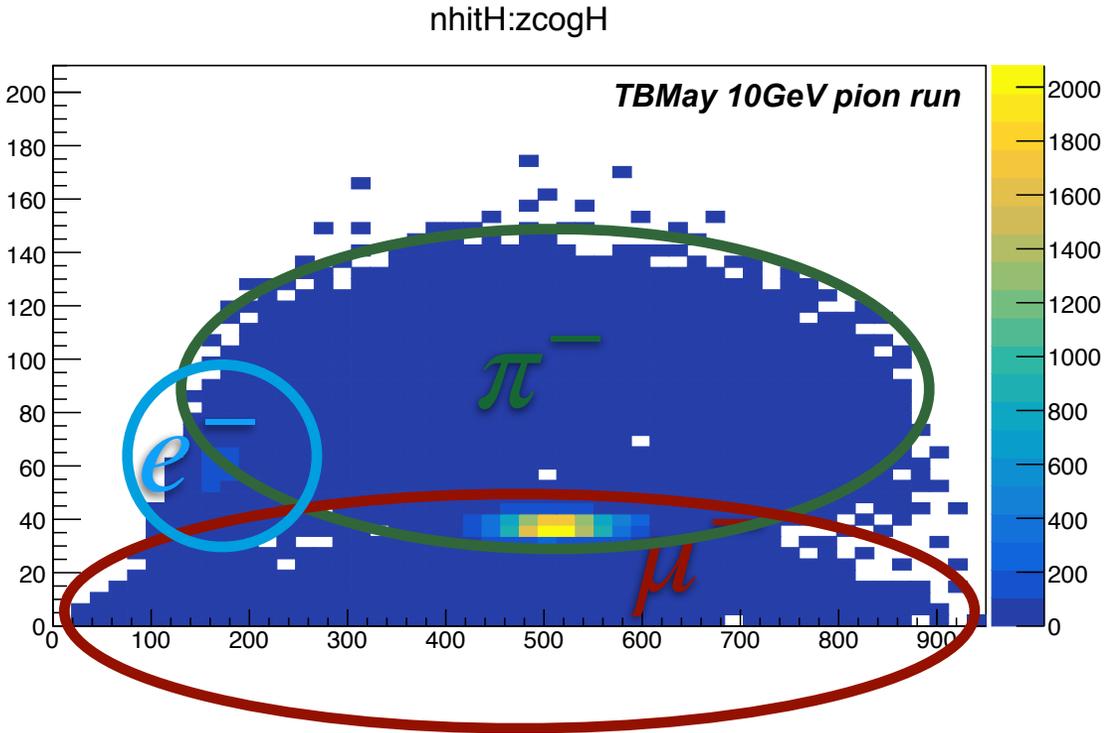
# Introduction

## What do we want to investigate



What if we want to check the energy resolution for 10GeV pion run?

## What do we have



# Introduction

## **How the particles can be separated**

- Distributions of observables
- Track studies
- Clustering studies

# Observables

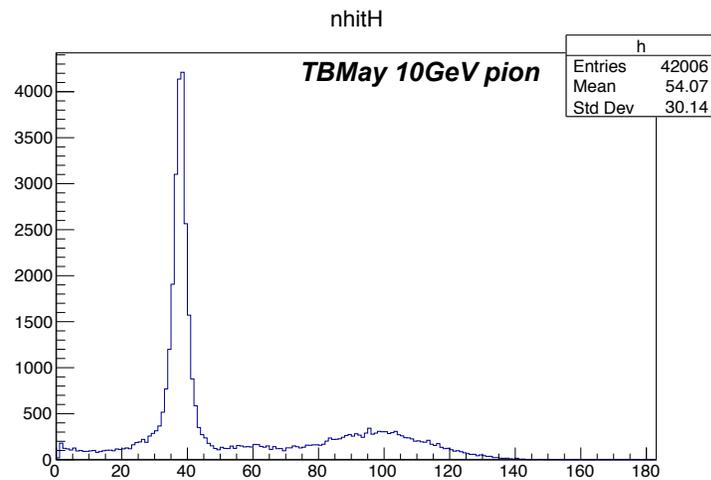
For particle ID

# Observables

## From the standard reco tree

Number of hits per event

- “clean”  $\mu^-$  :  $N_{hits} \approx N_{layers}$

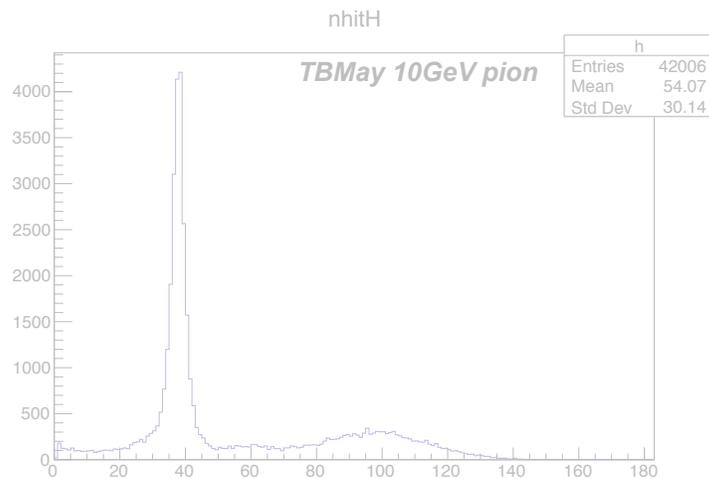


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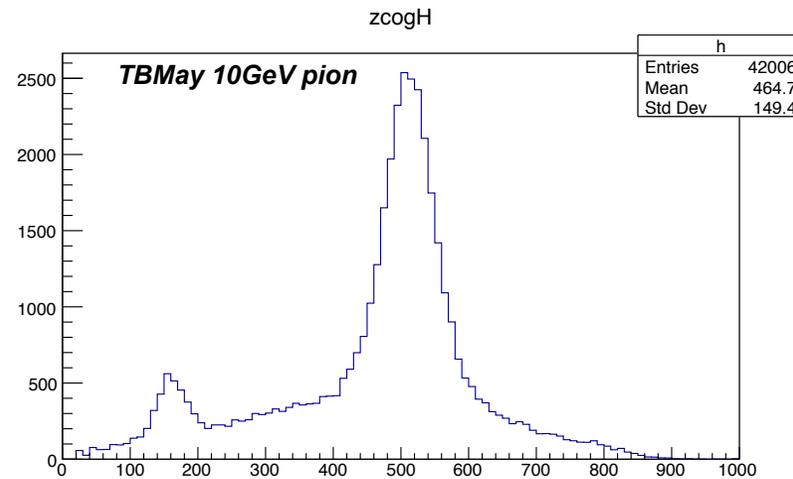
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Center of gravity in z

- $\mu^-$  :  $z_{cog}$  peaks in the middle of detector
- $e^-$  :  $z_{cog}$  peaks in the first half of detector
- $\pi^-$  :  $z_{cog}$  more-less spread

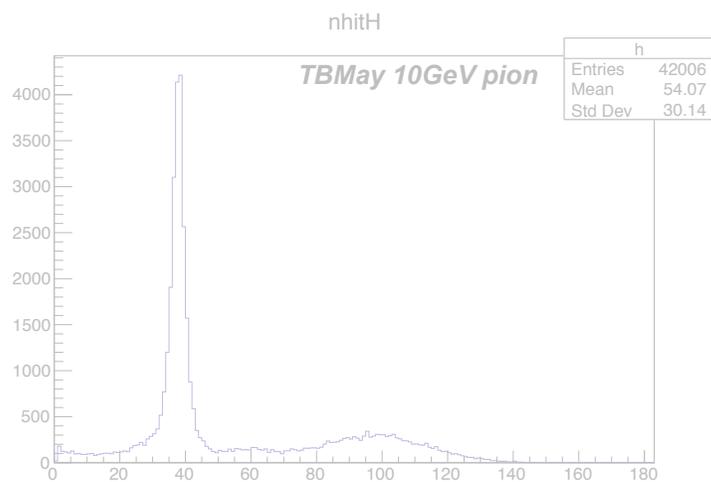


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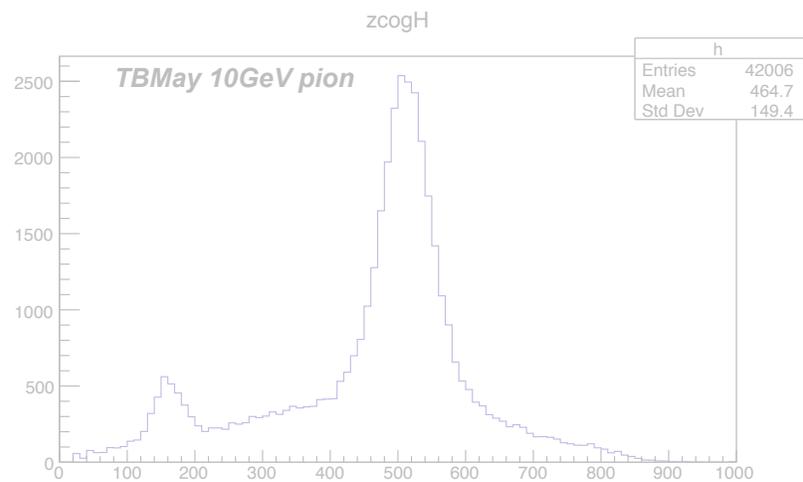
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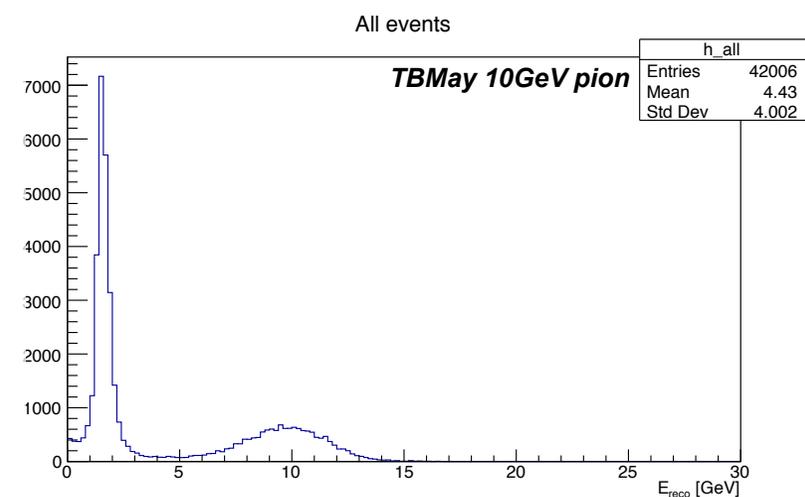
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Energy sum per event

- “clean”  $\mu^-$  :  $E_{sum} \approx N_{layers} * MIP$



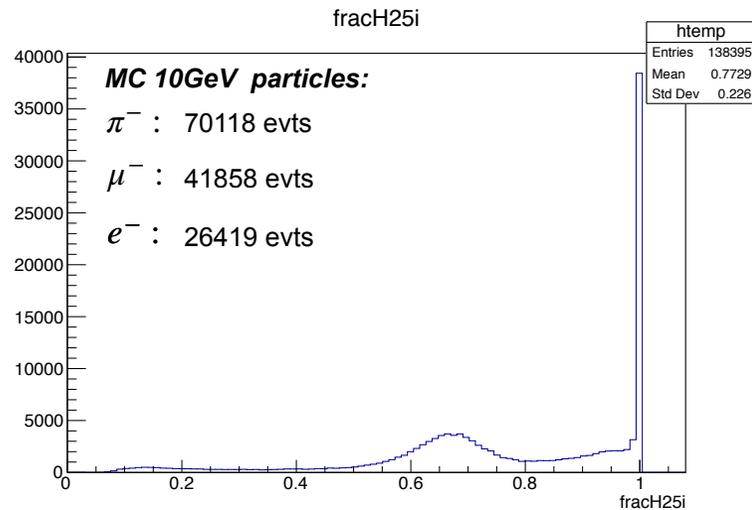
# Observables

Which require additional calculation

Fraction of energy in first 25 layers

$$(E_{25l}/E_{total})$$

- $\mu^-$  : fraction peaks at  $25/N_{layers}$
- $e^-$  : fraction  $\approx 1$
- $\pi^-$  : fraction more-less spread



# Observables

## Which require additional calculation

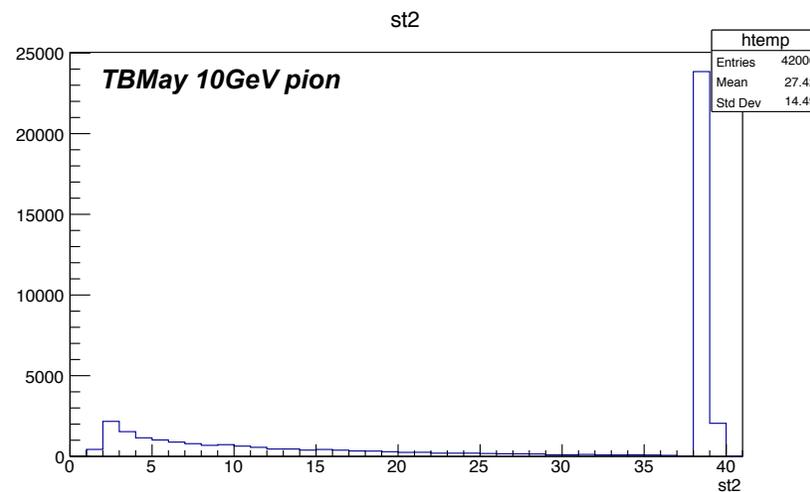
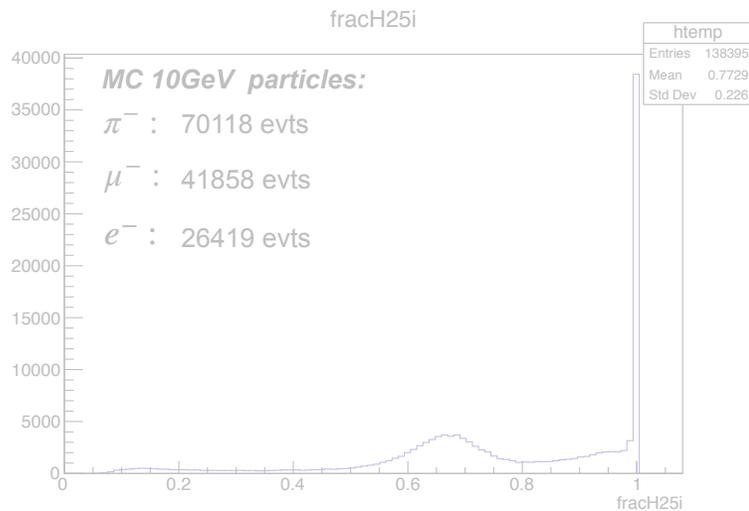
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Shower start layer number

- “clean”  $\mu^-$  : no shower
- $e^-$  : in the first half of detector
- $\pi^-$  : more-less spread



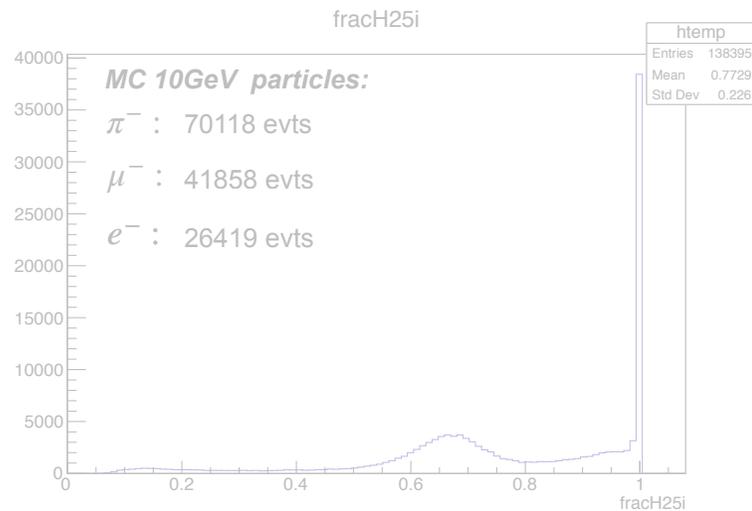
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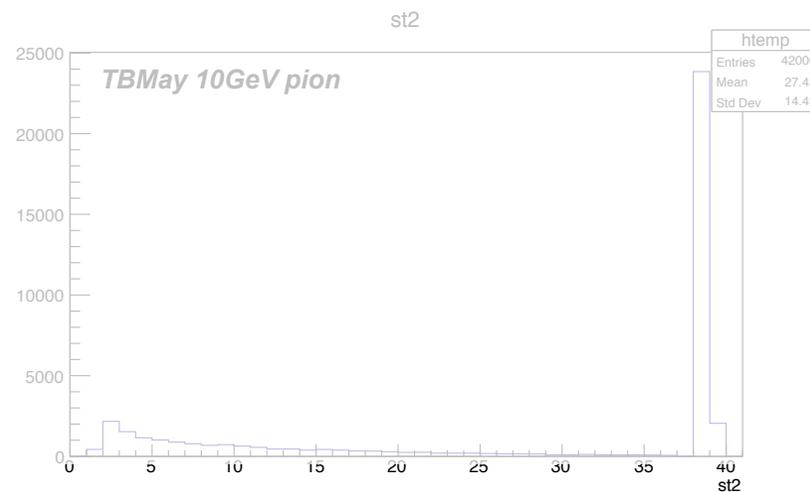
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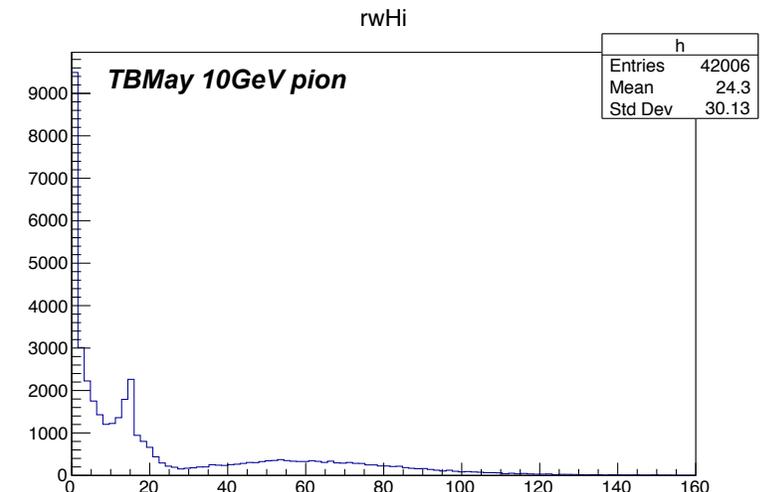
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Shower radius

- “clean”  $\mu^-$  : no cluster ( $r_{cl} = 0$ )
- $e^-$  :  $R$  has a peak
- $\pi^-$  : more-less spread



# Observables

## Which require additional calculation

Fraction of energy in first 25 layers

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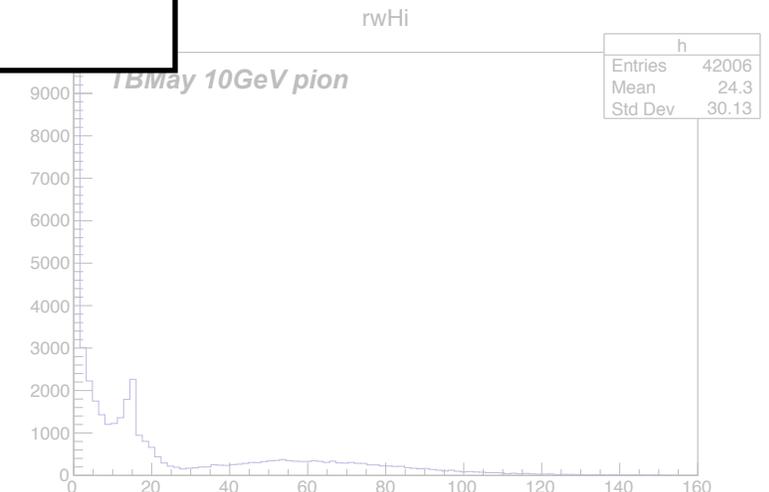
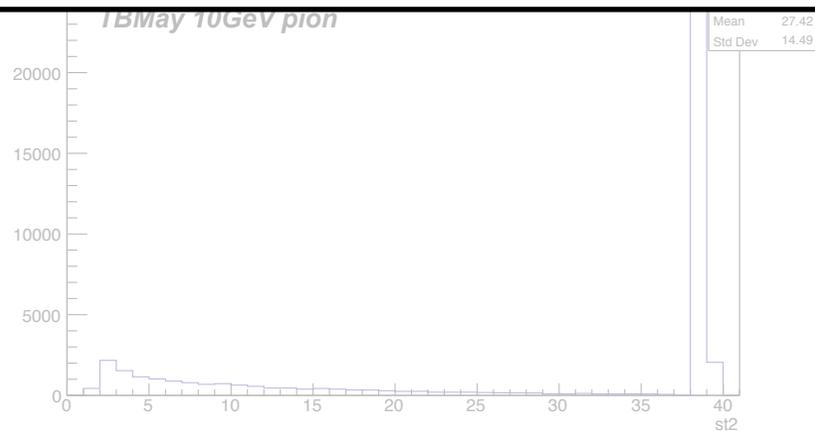
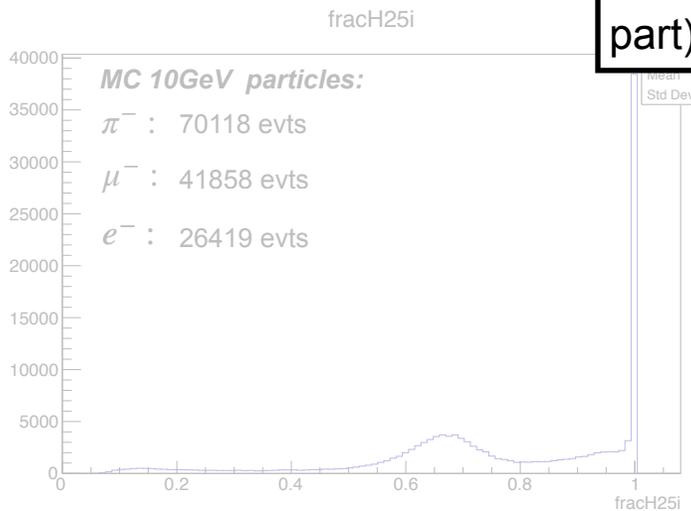
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Shower radius

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To make particle ID an integrated CaliceSoft tool we need to implement calculation of standard variables as a Marlin processor including existing in RootTreeWriter (in software part)

more-less spread



# Current cuts

## After some optimisation

### Muon (muon-like) cuts:

- **Hits:**  $20 < n_{hit} < 70$
- **(&)Energy:**  $0 < E < 5$  GeV (will be used after proper calibration)
- **(&)Shower radius:**  $0 < R < 30$  [mm]
- **(&)COGz:**  $260 < z_0 < 800$  [mm]
- **(&)Fraction in first 25 layers:**  $fr < 0.95$

### Electron cuts:

- **(&)Hits:**  $45 < n_{hit} < 95$
- **(&)Shower start layer:**  $st < 12$
- **(&)Shower radius:**  $0 < R < 35$  [mm]
- **(&)COGz:**  $COGz < 400$  [mm]
- **(&)Fraction in first 25 layers:**  $fr > 0.9$
- **(&)Additional shower radius cut:**  
 $R < -0,23*(COGz - 400)[mm]$

# Root script for cut adjustment

## MC 10GeV particles

### Before cuts:

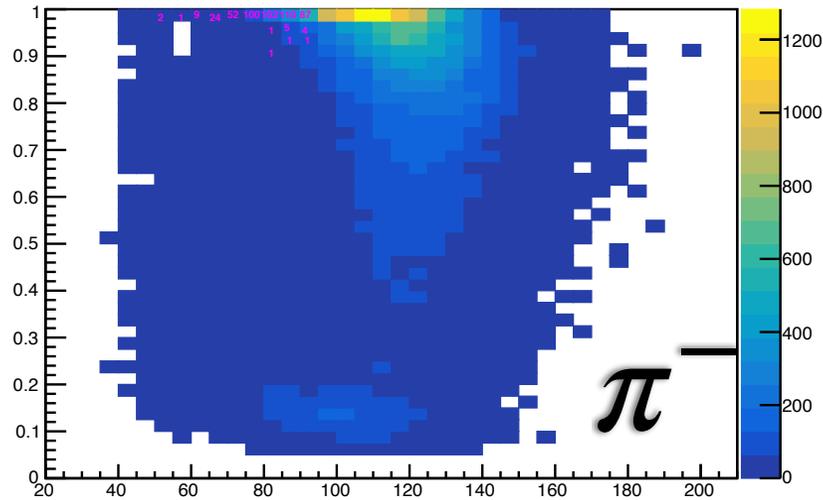
$\pi^-$  : 70118 events

$\mu^-$  : 41858 events

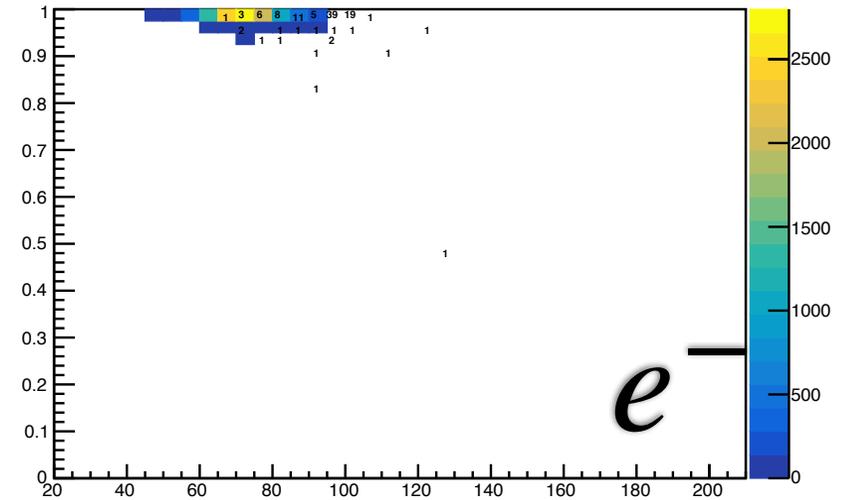
$e^-$  : 26419 events

*total* : 138395 events

Fraction in first 25 layers vs number of hits.



Fraction in first 25 layers vs number of hits.



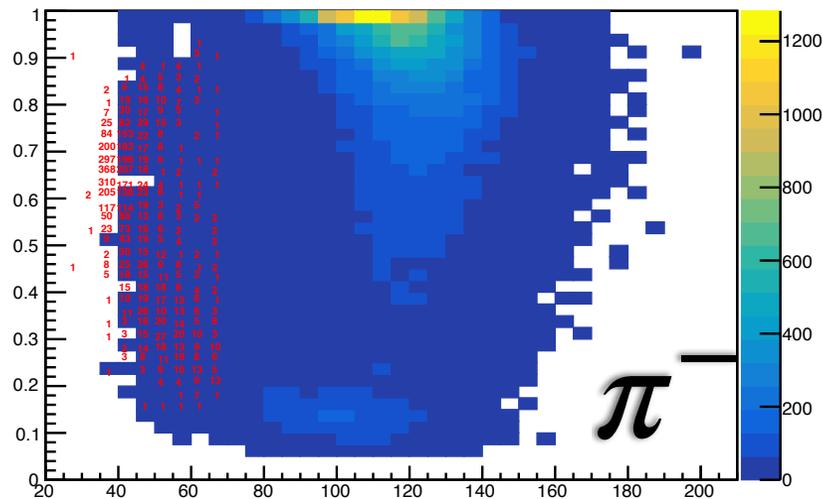
### After cuts:

$\pi^-$  : 64529 events (92%)

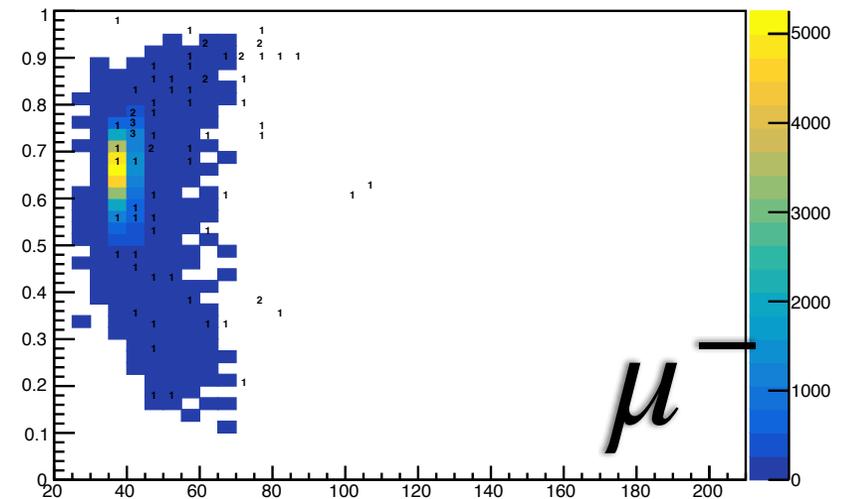
$\mu^-$  : 41783 events (99.7%)

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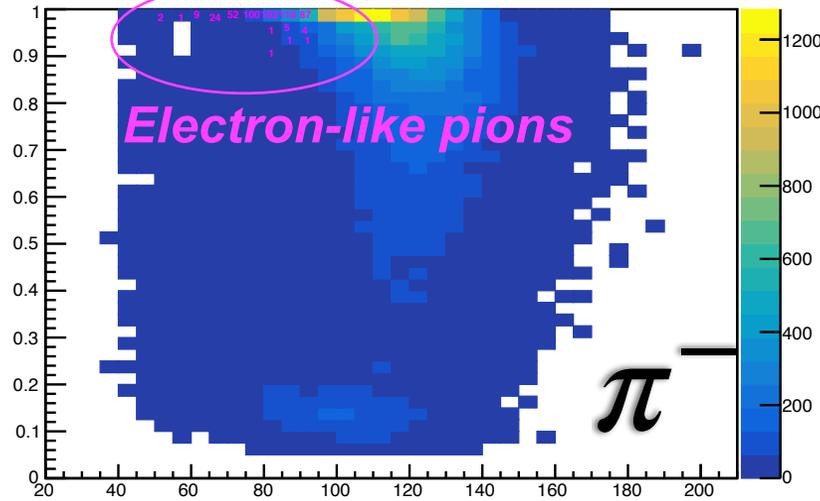
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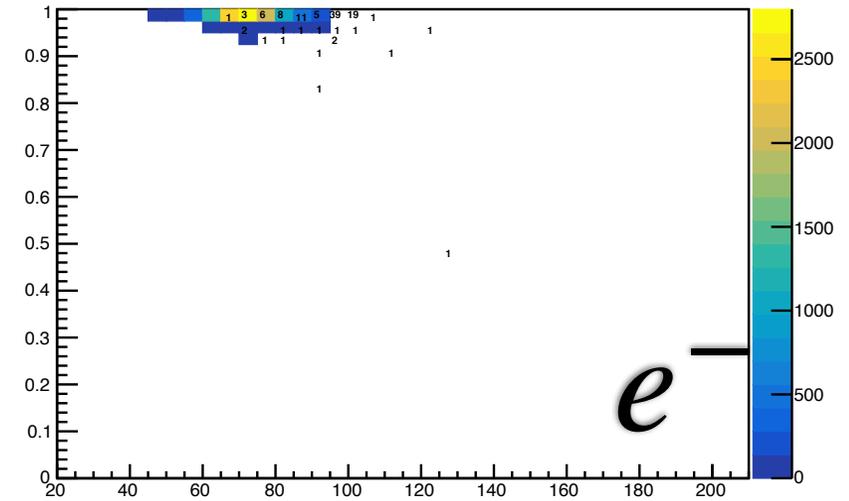
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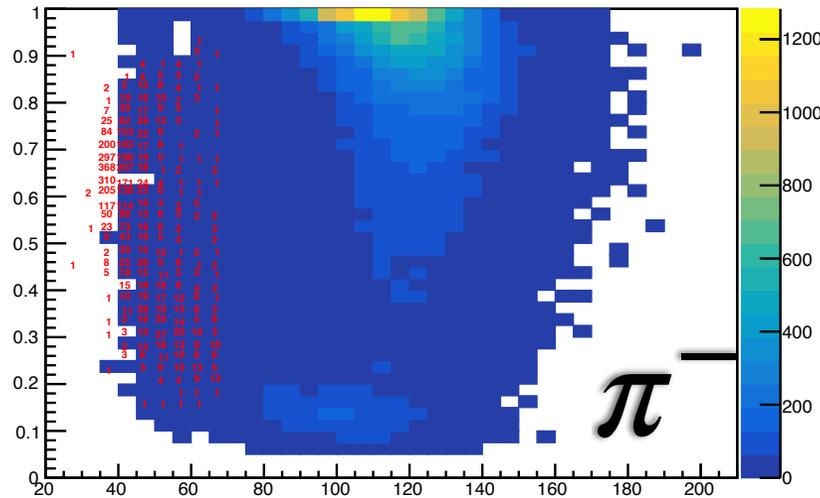
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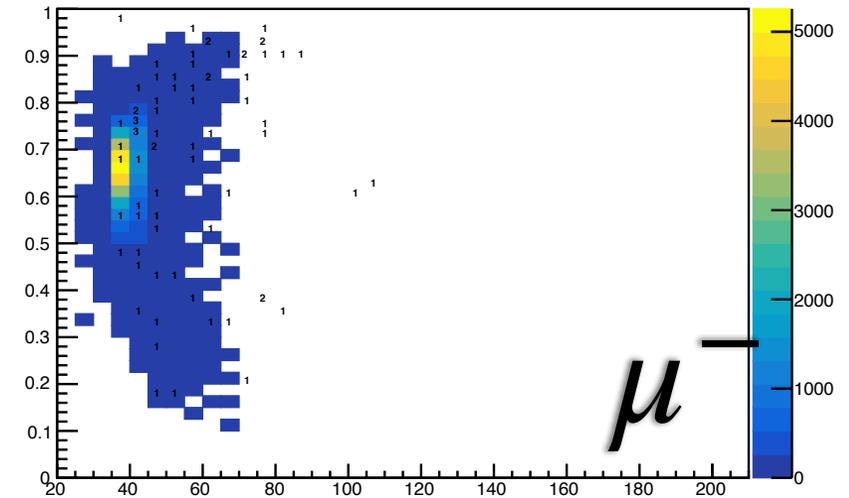
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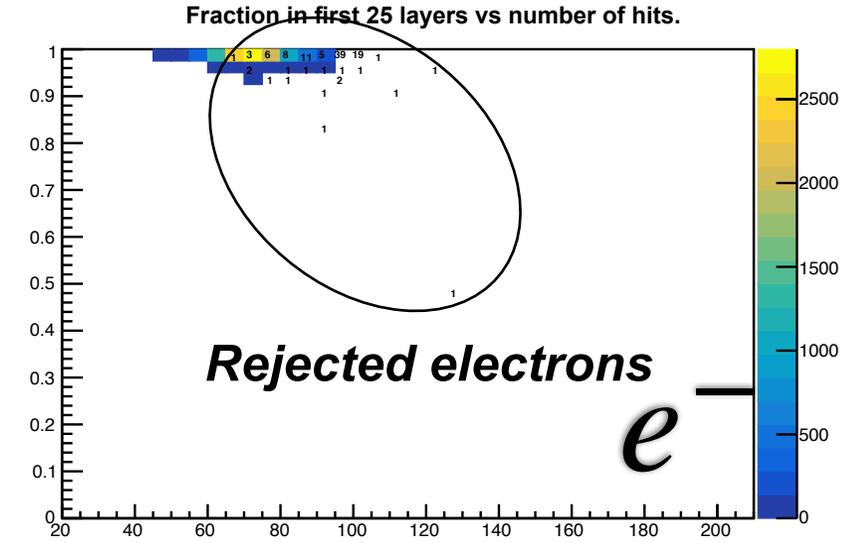
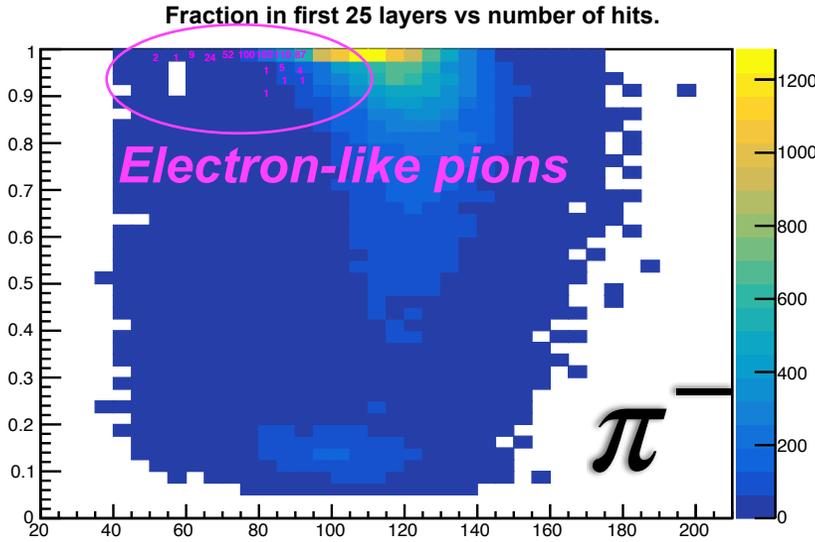


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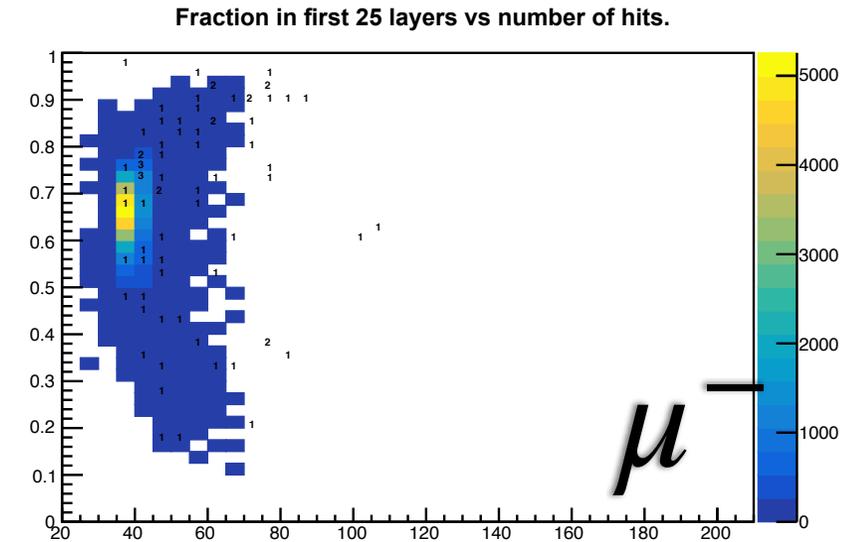
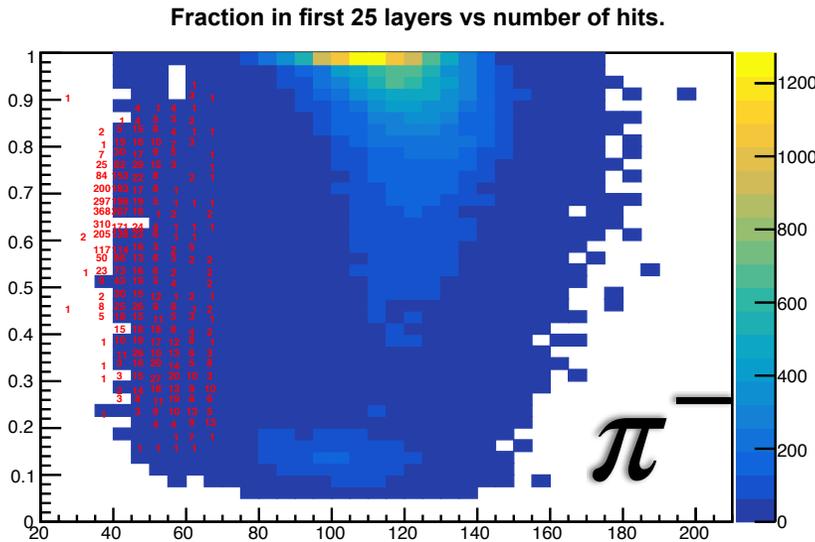
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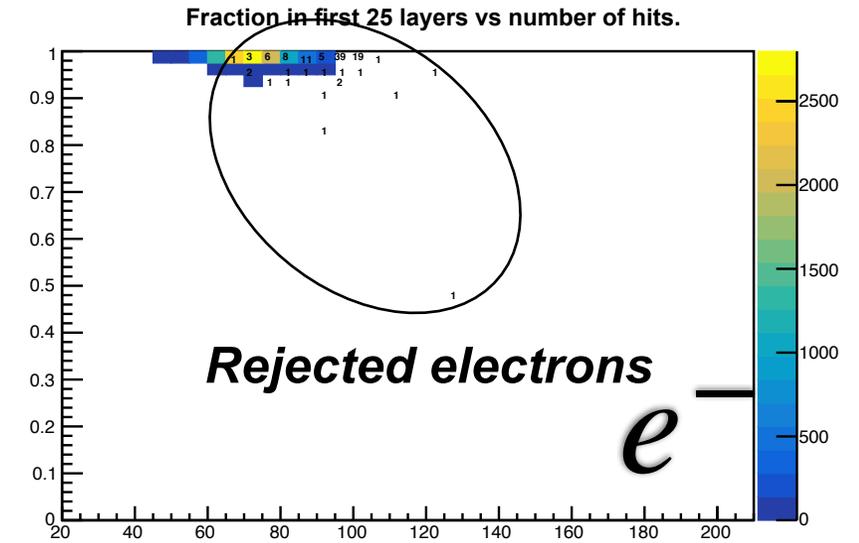
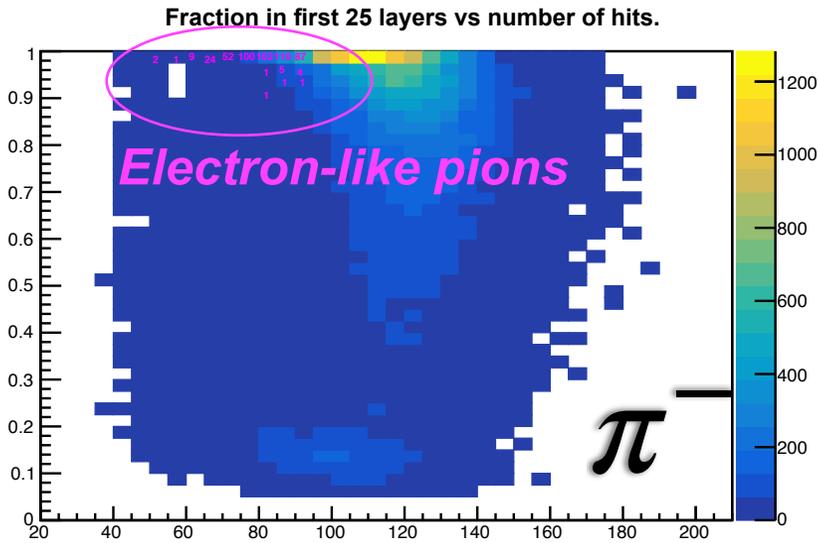


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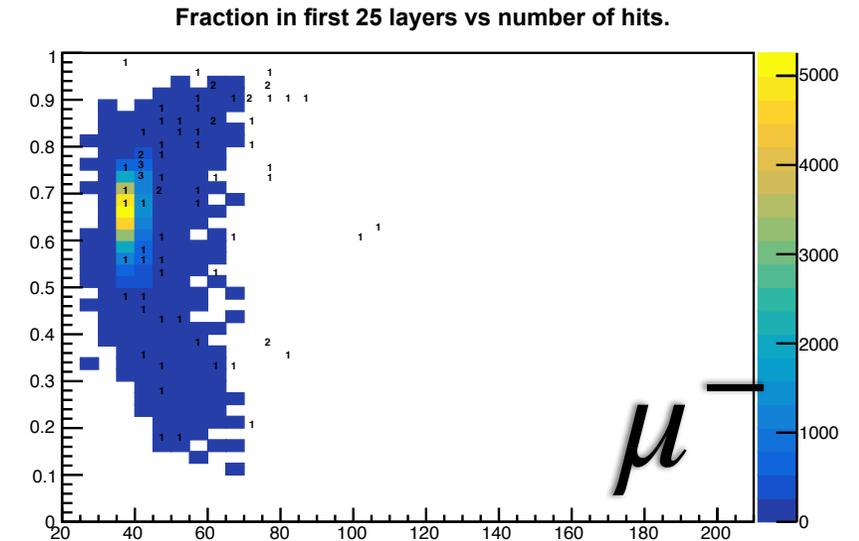
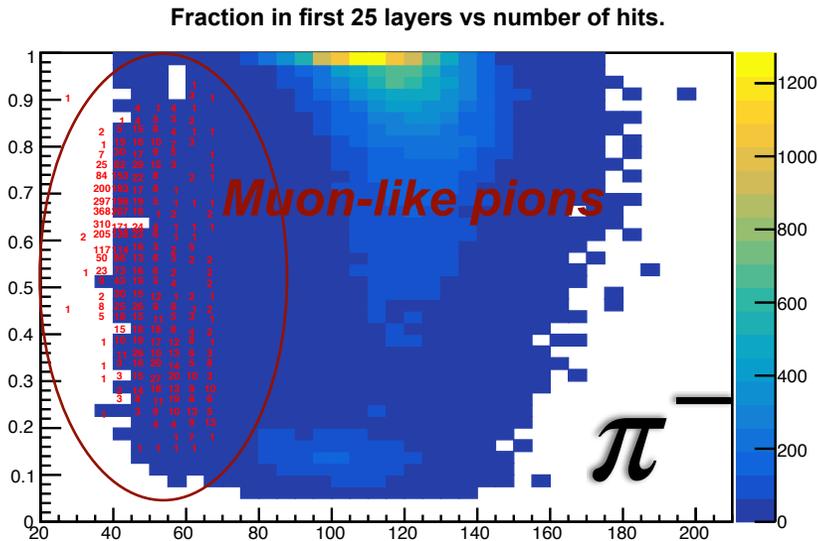
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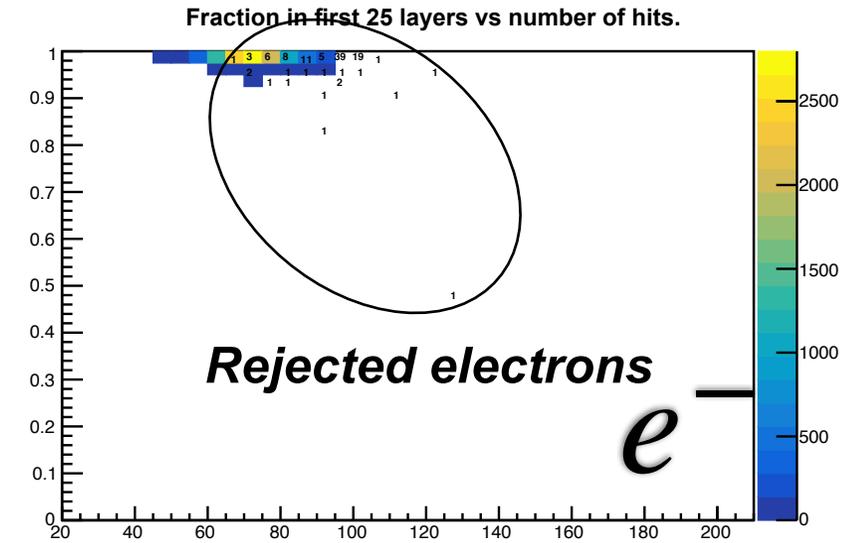
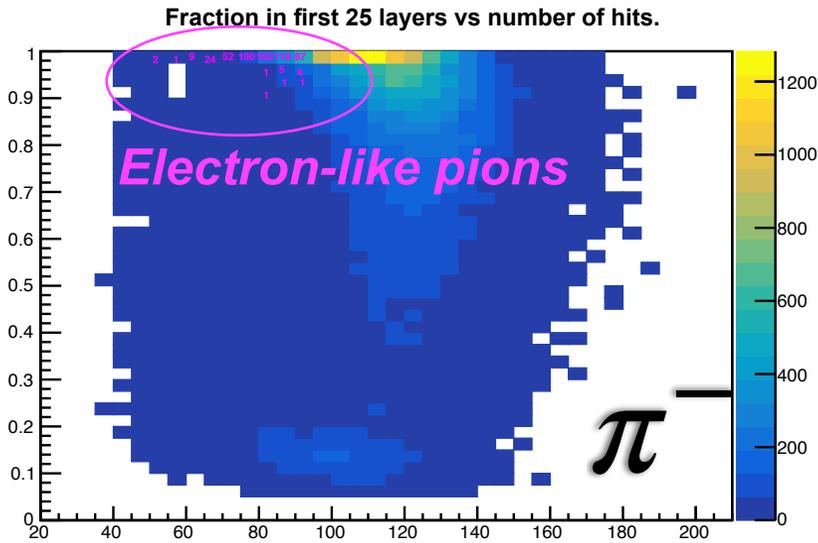


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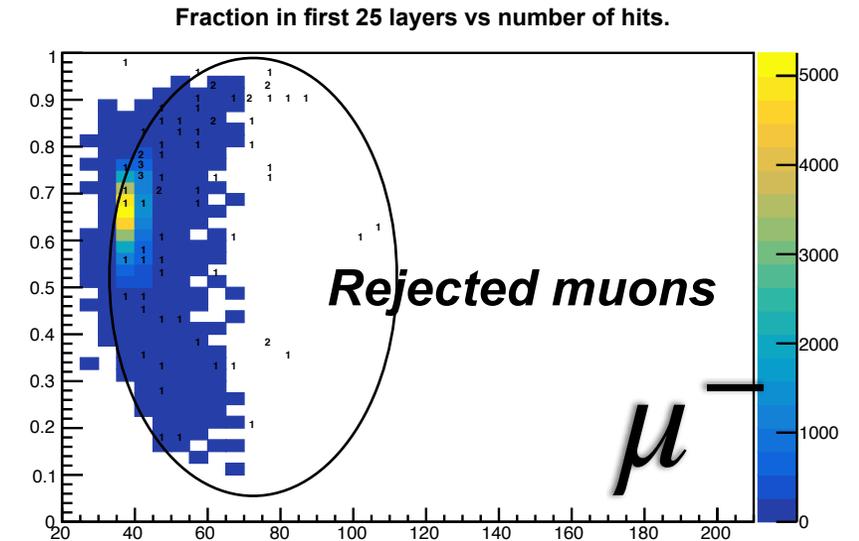
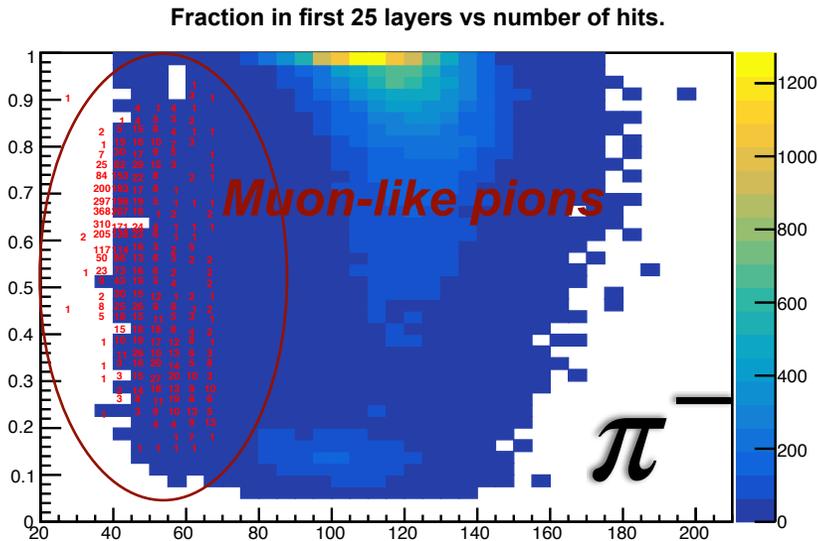
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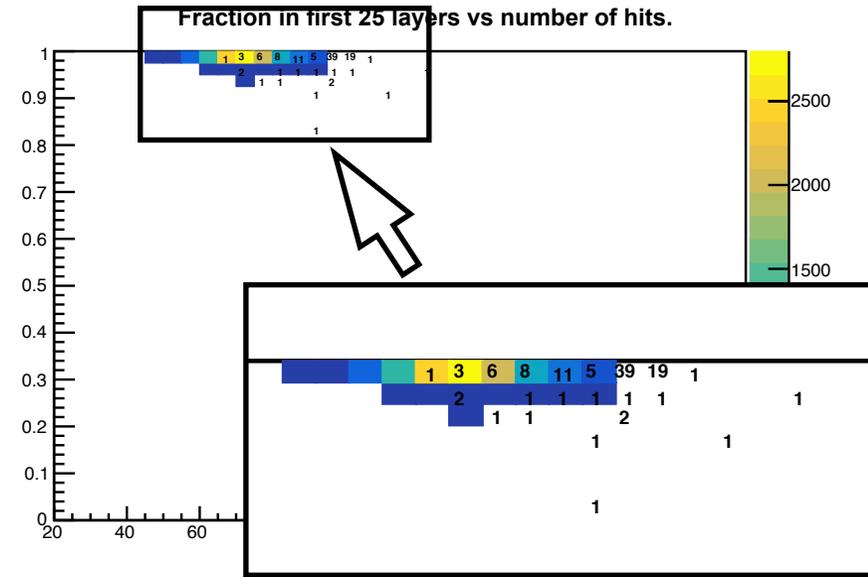
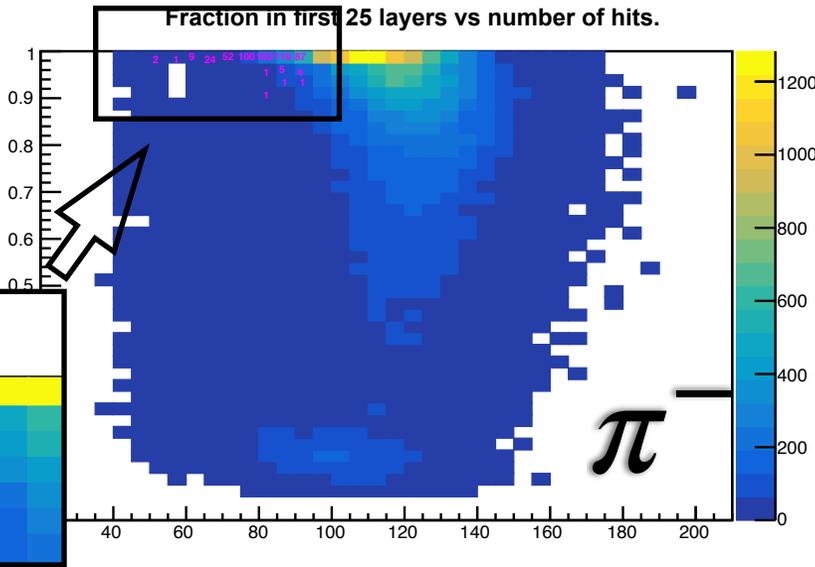
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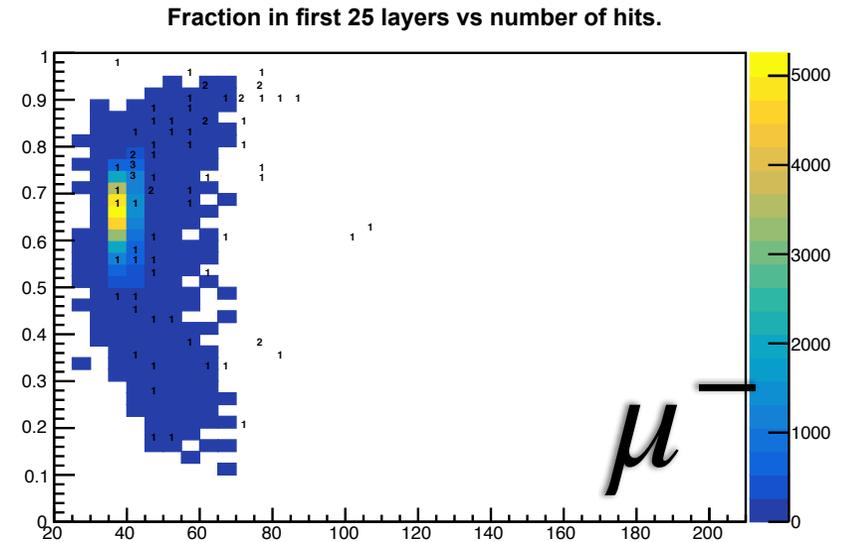
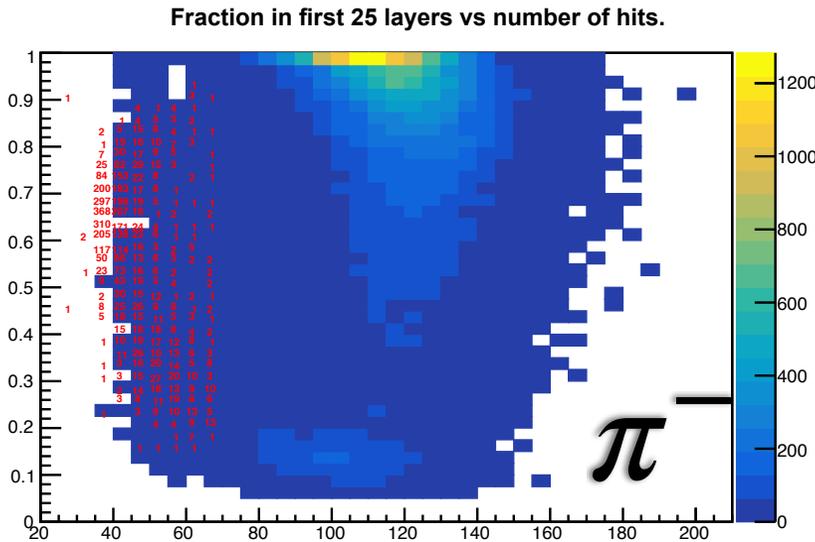


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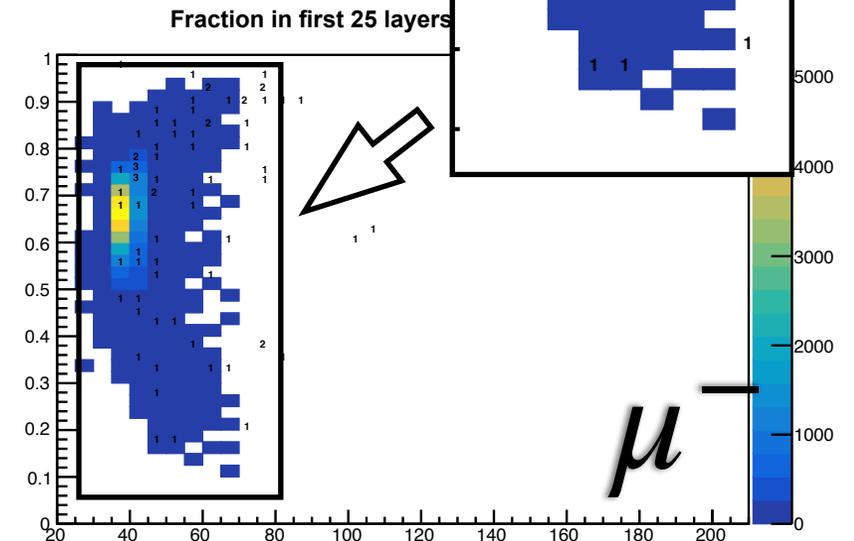
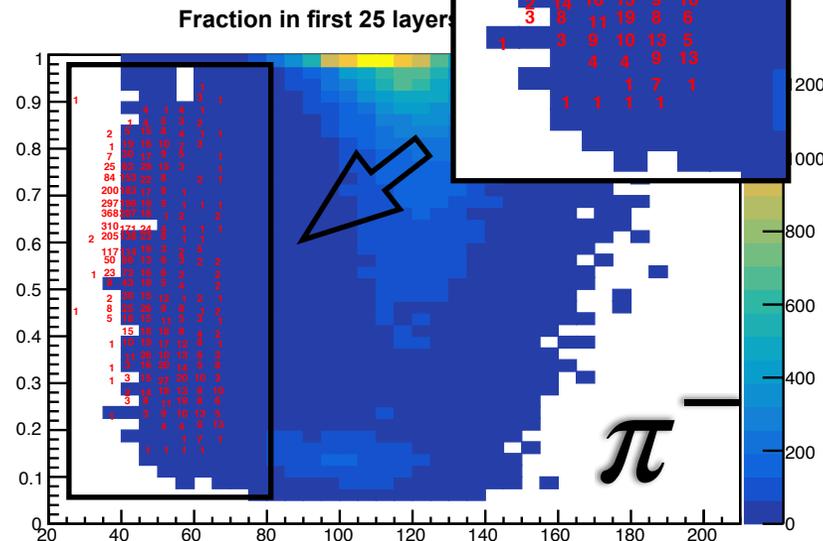
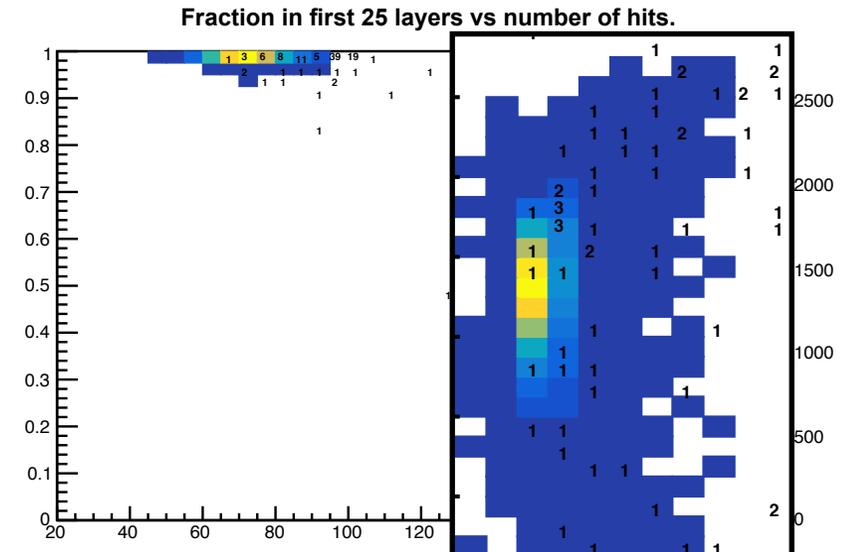
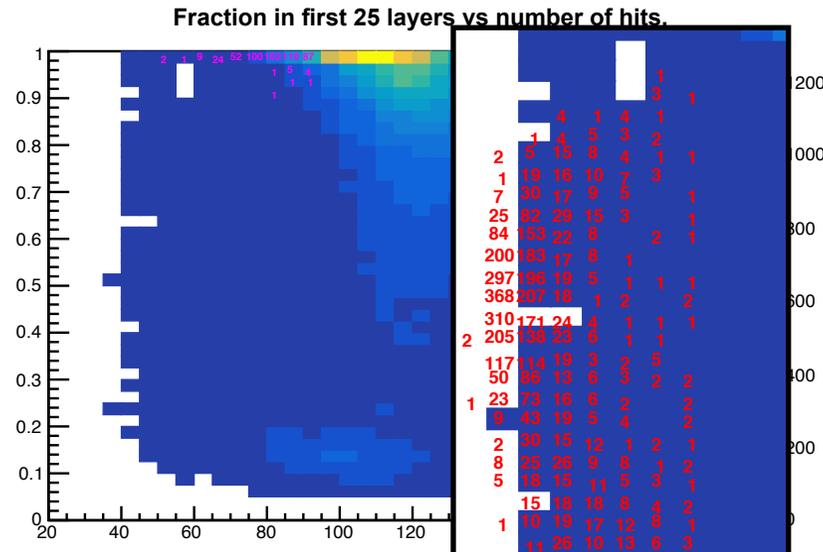
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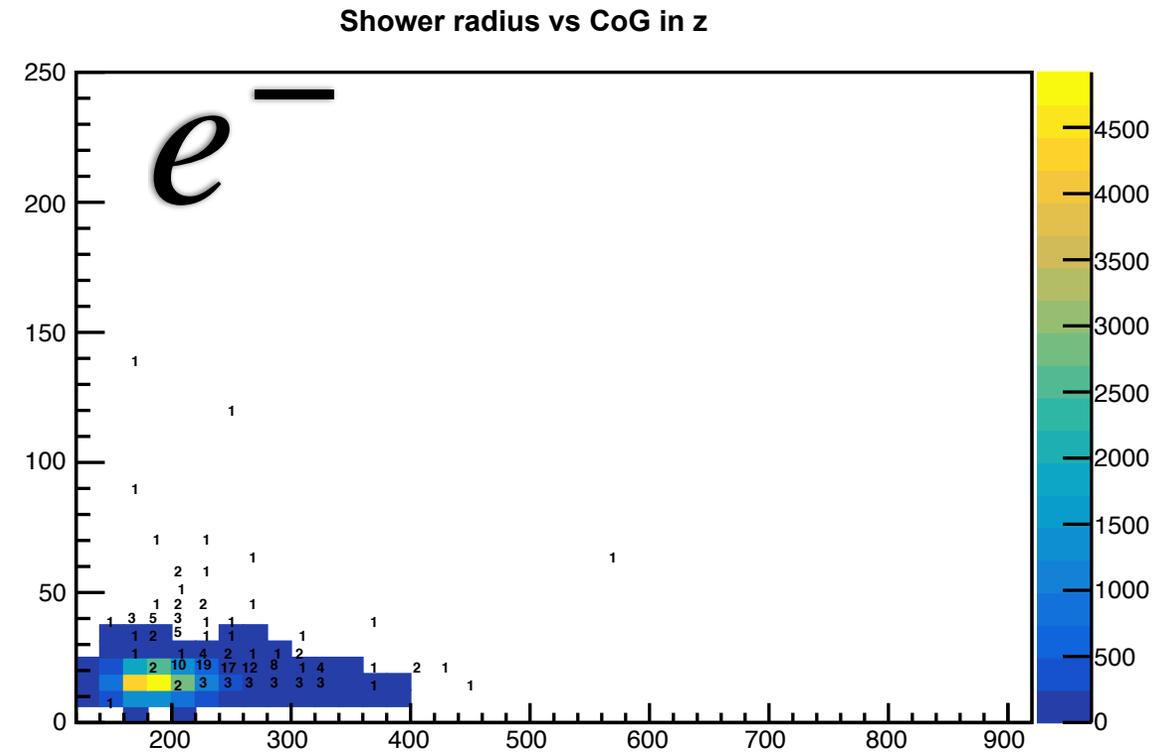
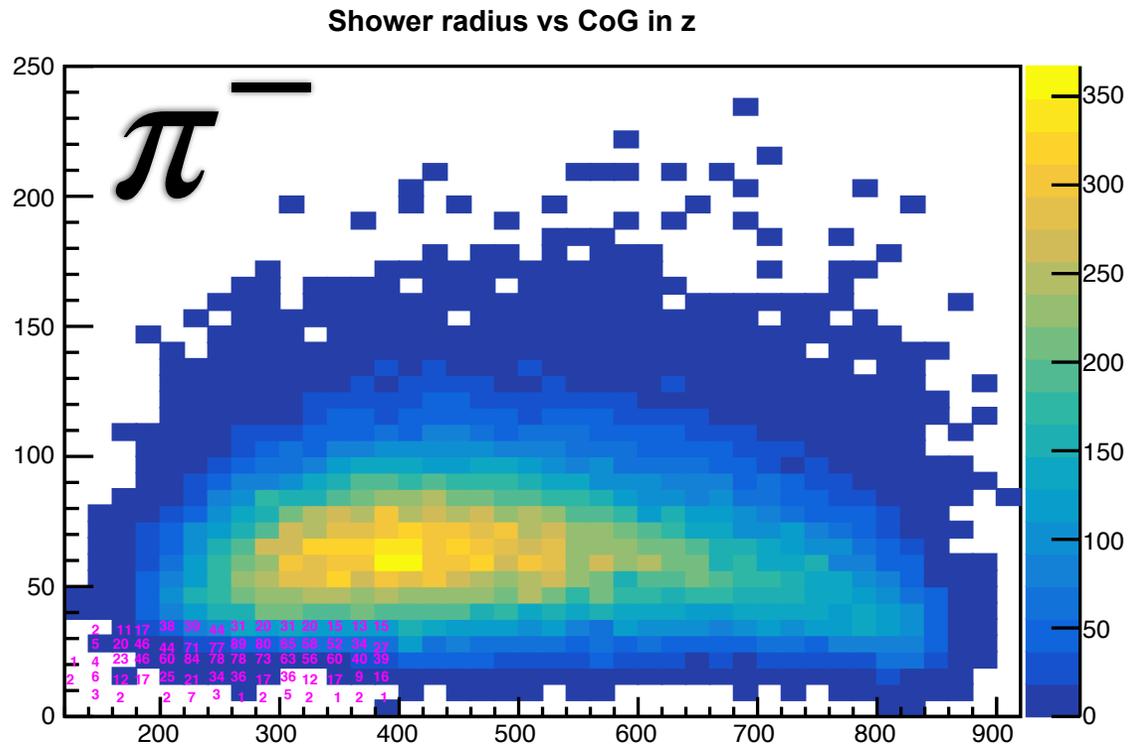
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# Additional cut for shower radius vs CoG in z.

MC 10GeV particles





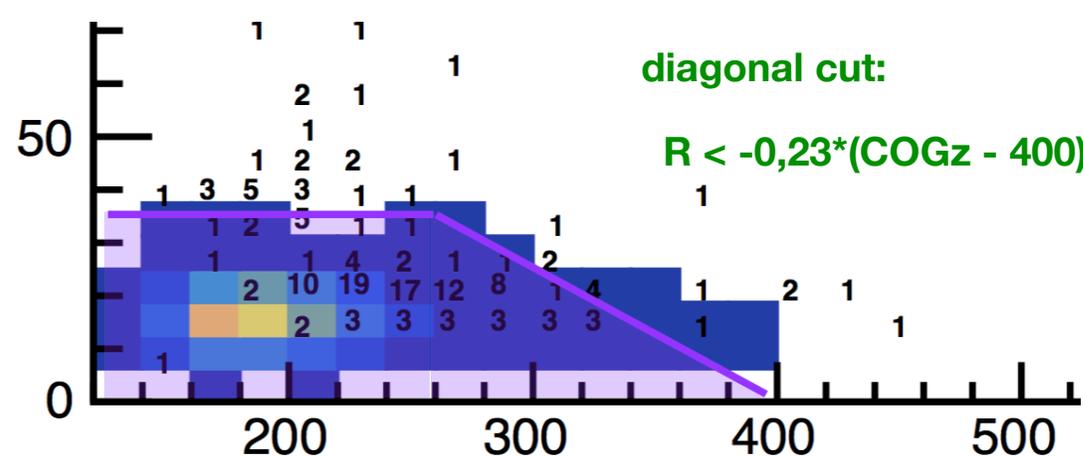
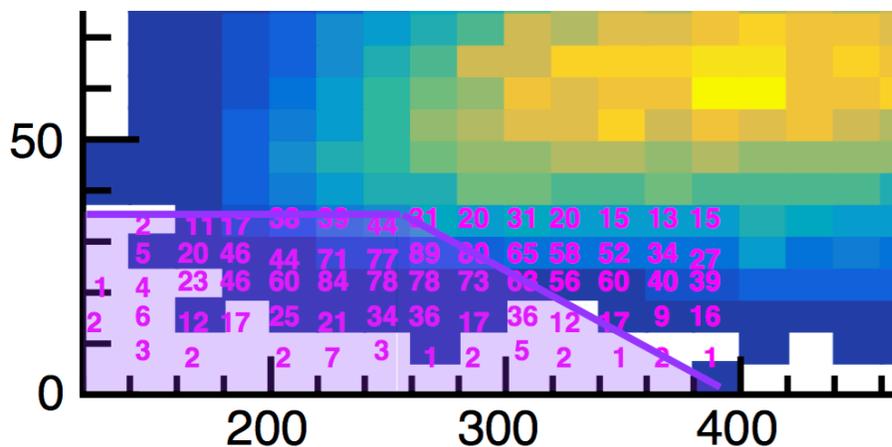
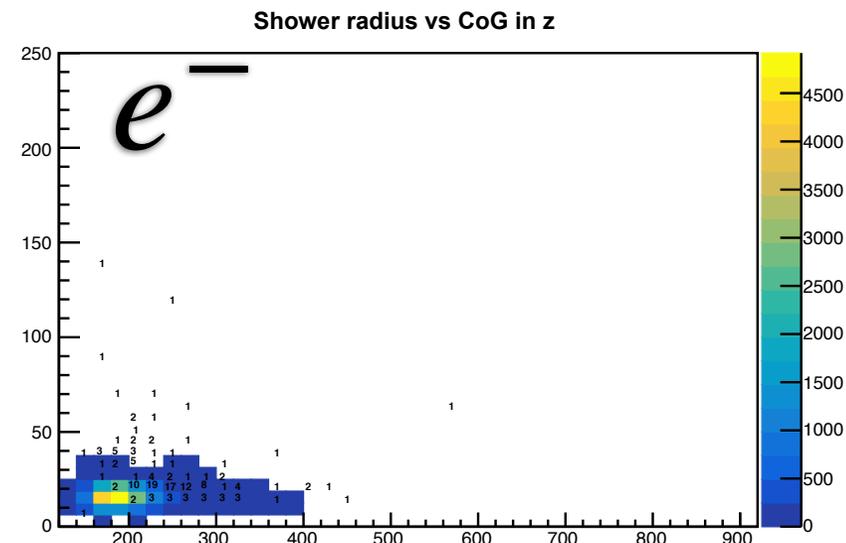
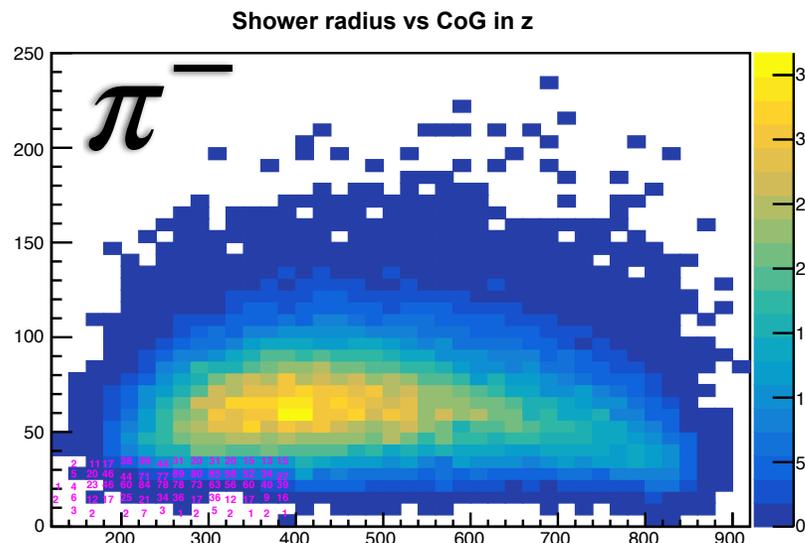
# Additional cut for shower radius vs CoG in z.

## MC 10GeV particles

Before additional cut:

$\pi^-$  : 63748 events (90,9%)

$e^-$  : 26264 events (99.4%)



• Additional shower radius

diagonal cut:

$$R < -0,23 \cdot (\text{COGz} - 400) [\text{mm}]$$

# Additional cut for shower radius vs CoG in z.

## MC 10GeV particles

Before additional cut:

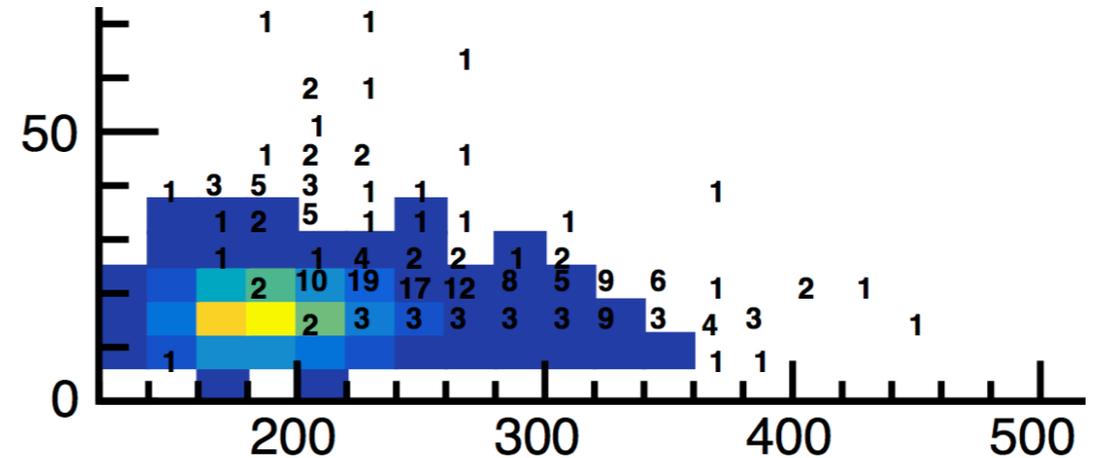
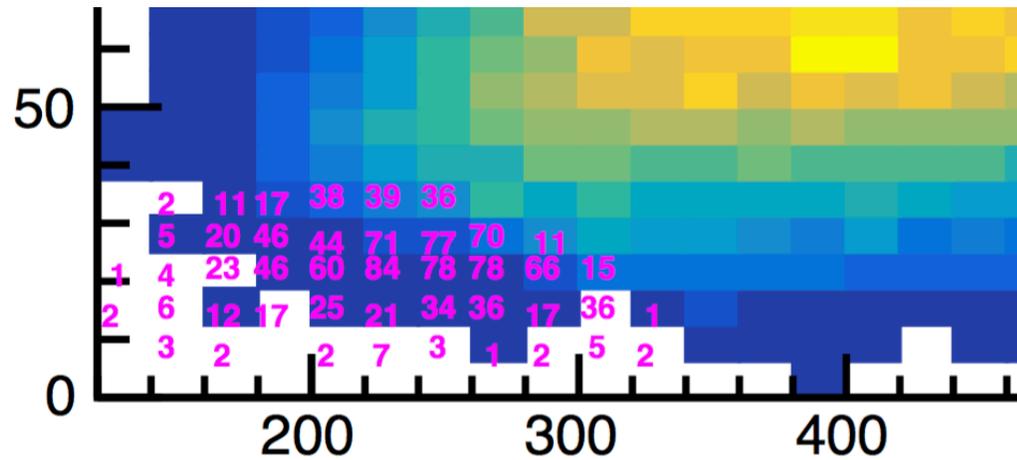
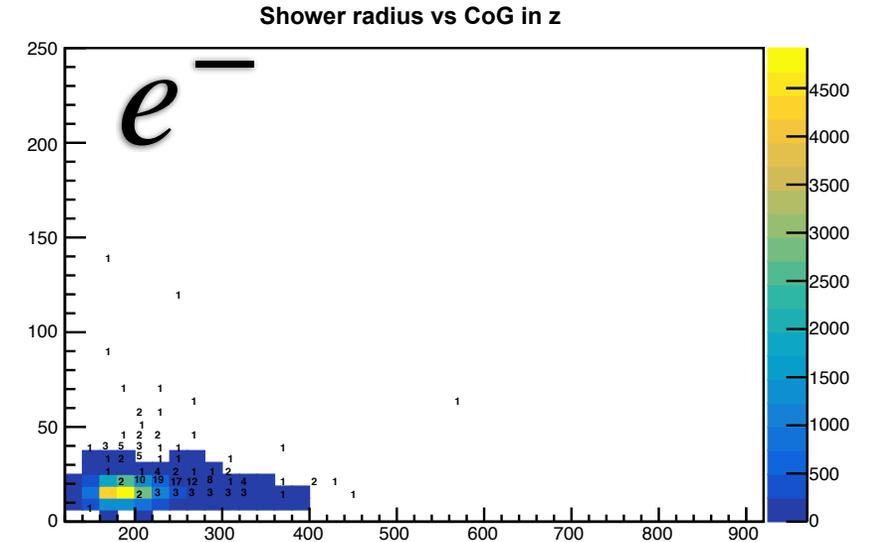
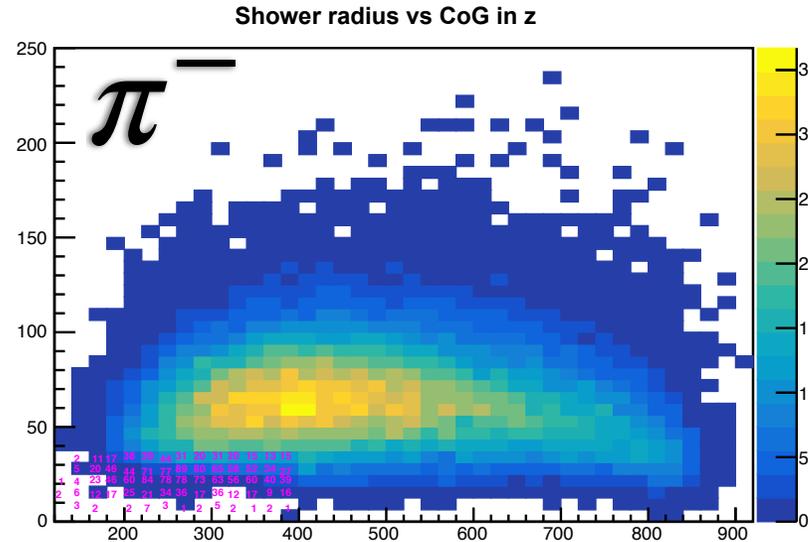
$\pi^-$  : 63748 events (90,9%)

$e^-$  : 26264 events (99.4%)

After additional diagonal cut:

$\pi^-$  : 64529 events (92%)

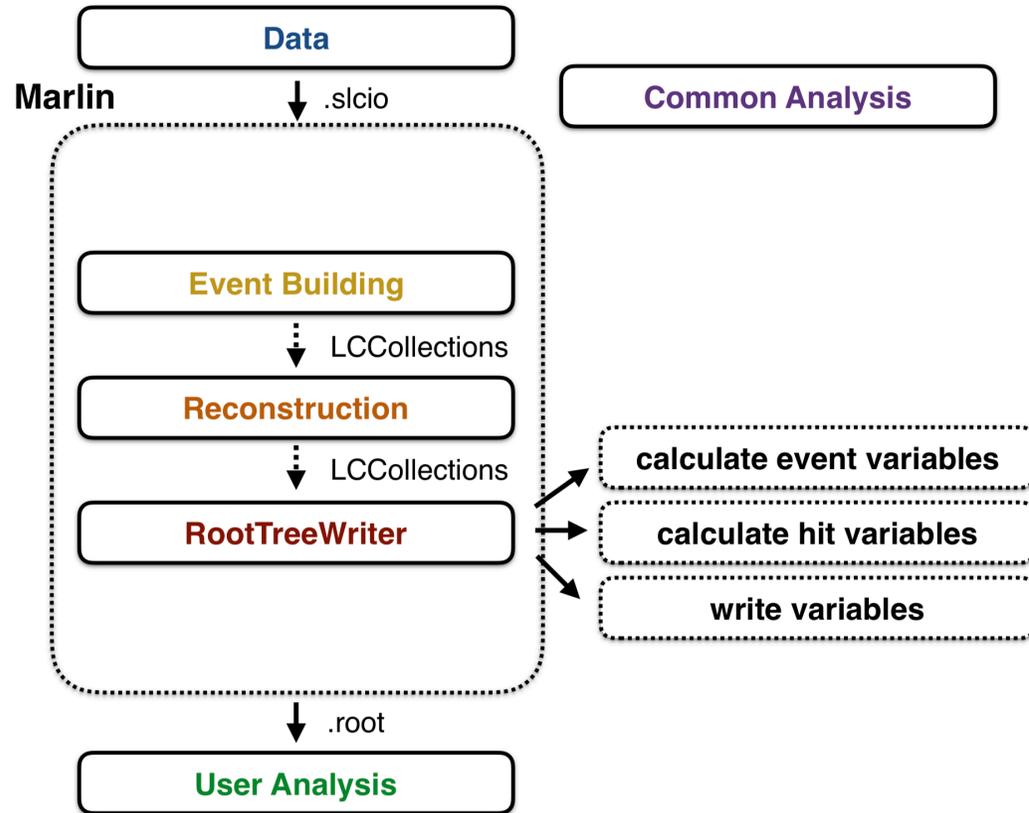
$e^-$  : 26230 events (99.2%)



# Software architecture studies

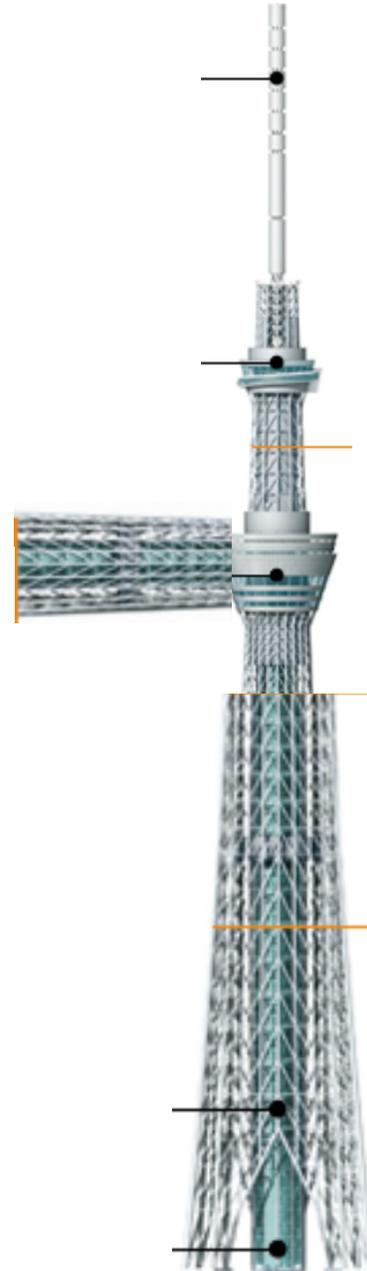
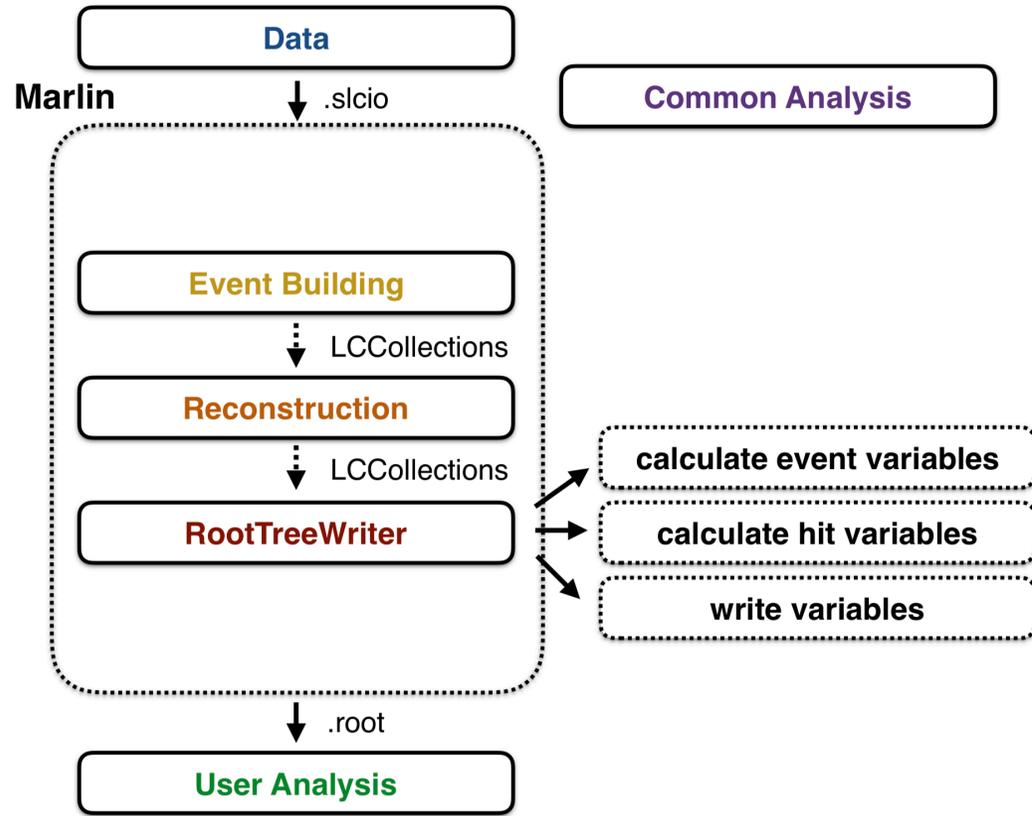
# Software architecture

## Current state



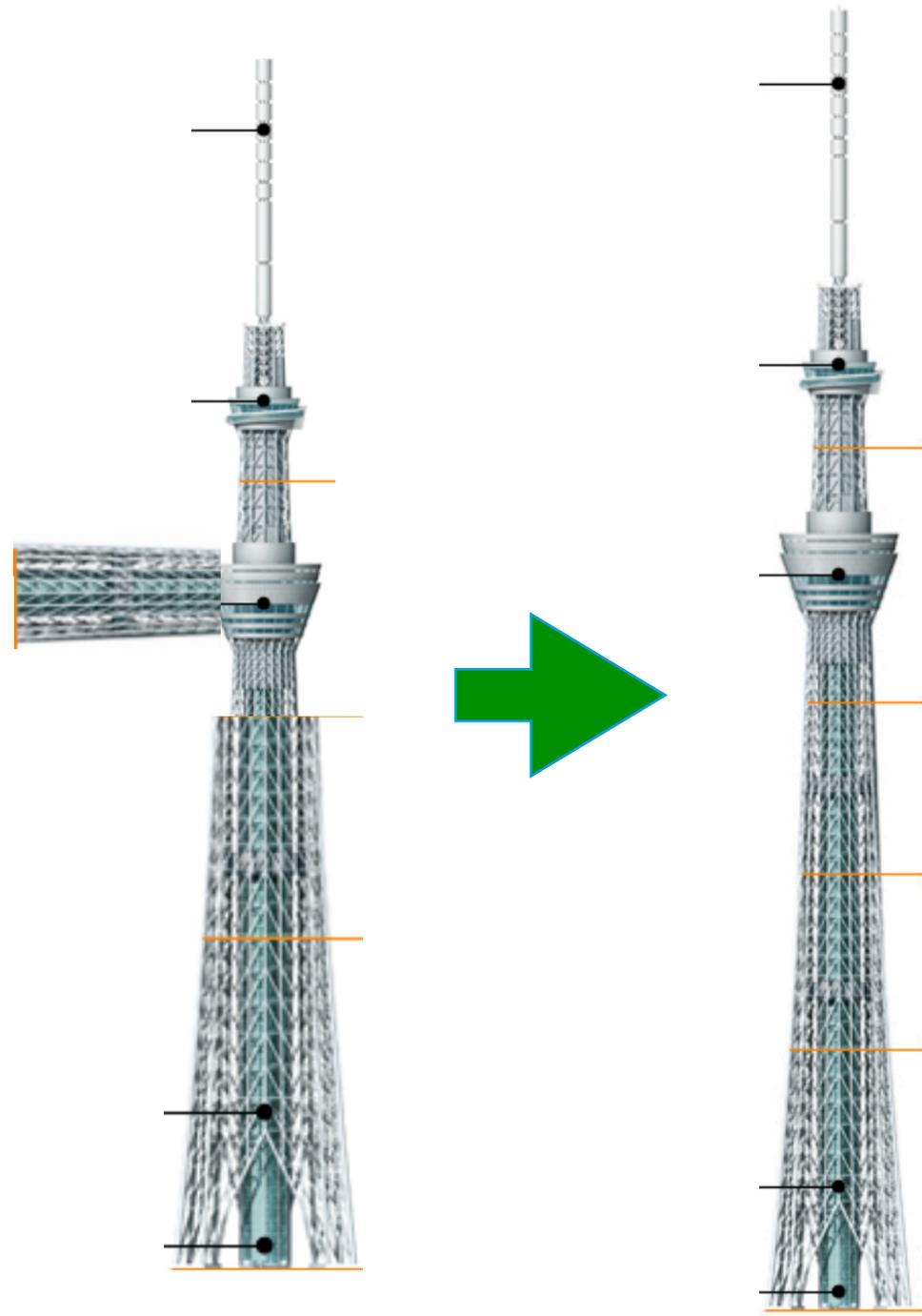
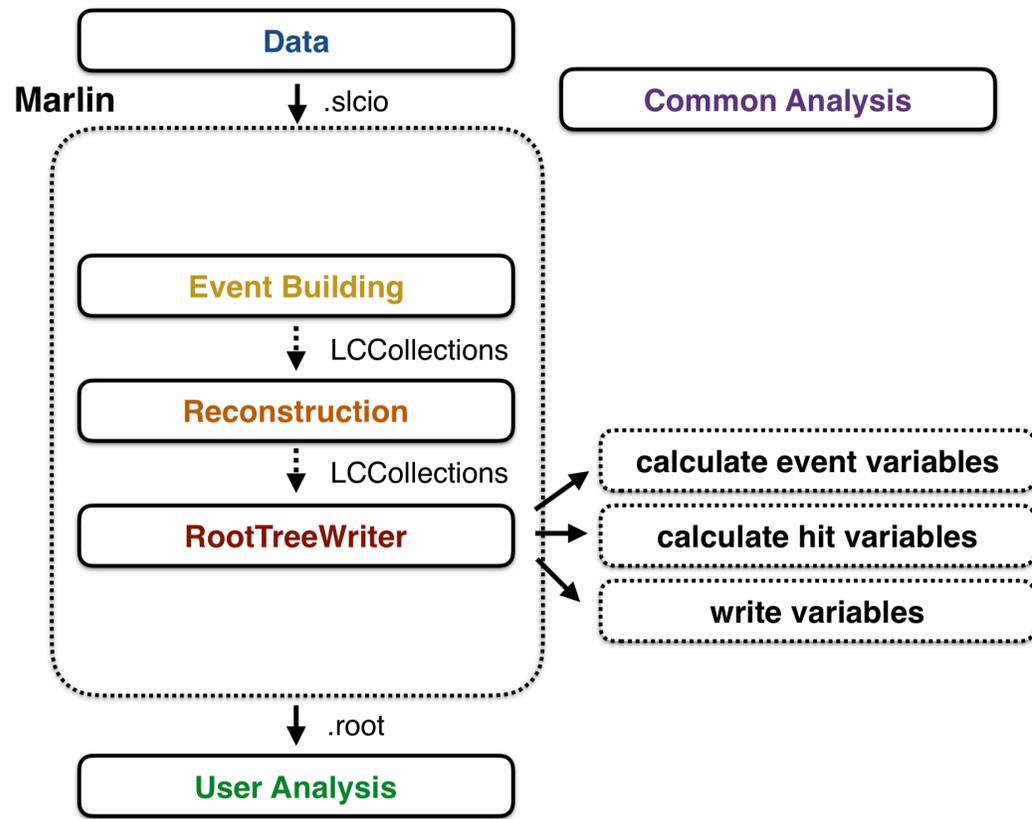
# Software architecture

## Current state



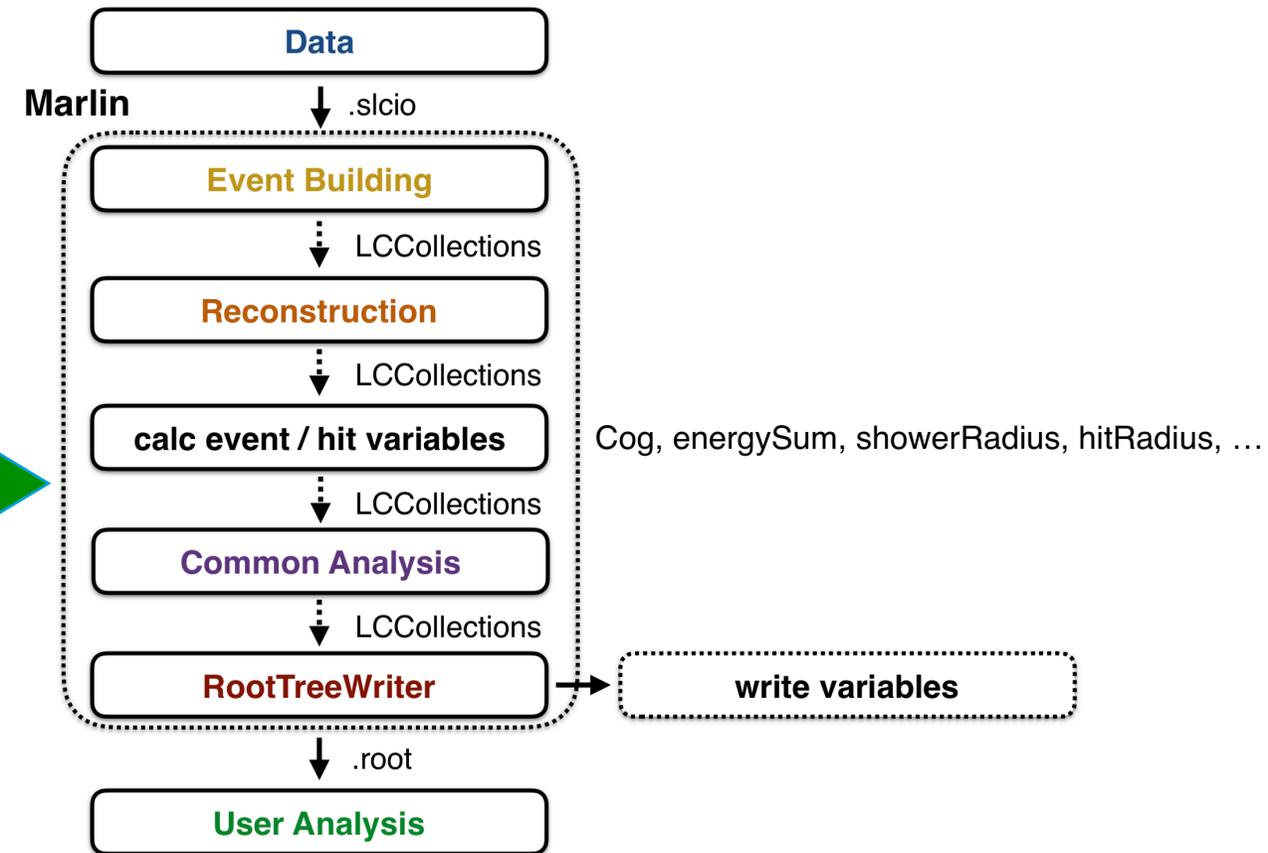
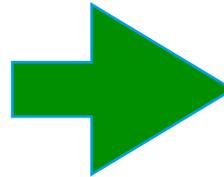
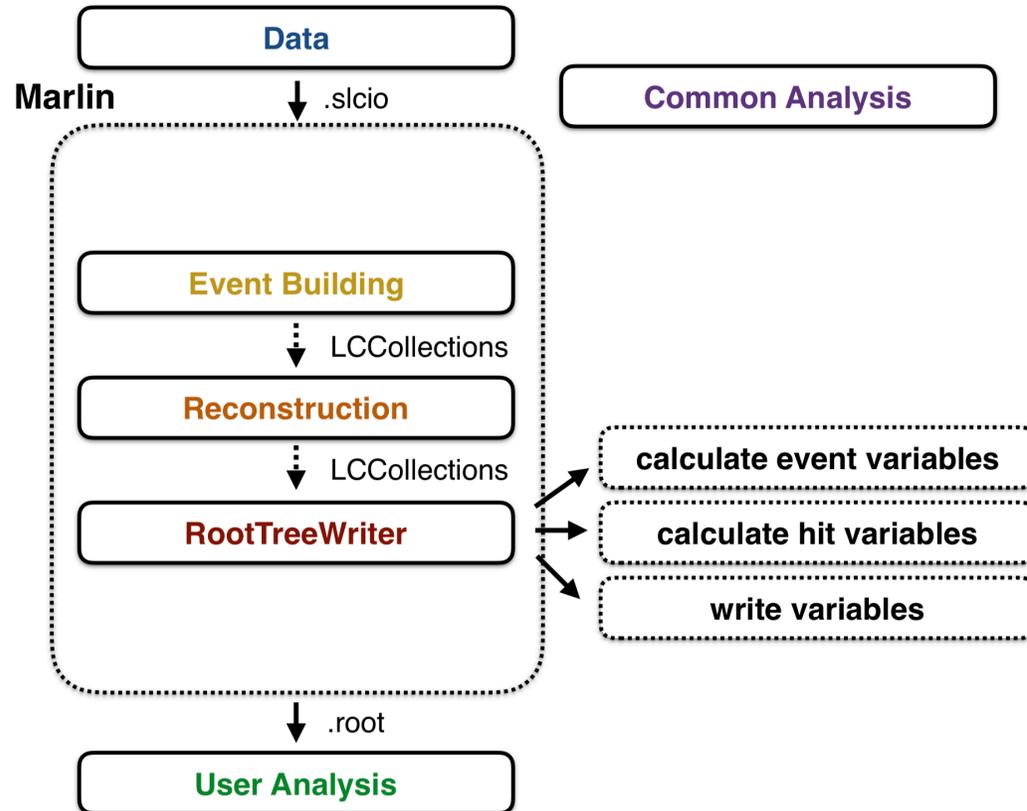
# Software architecture

## Current state



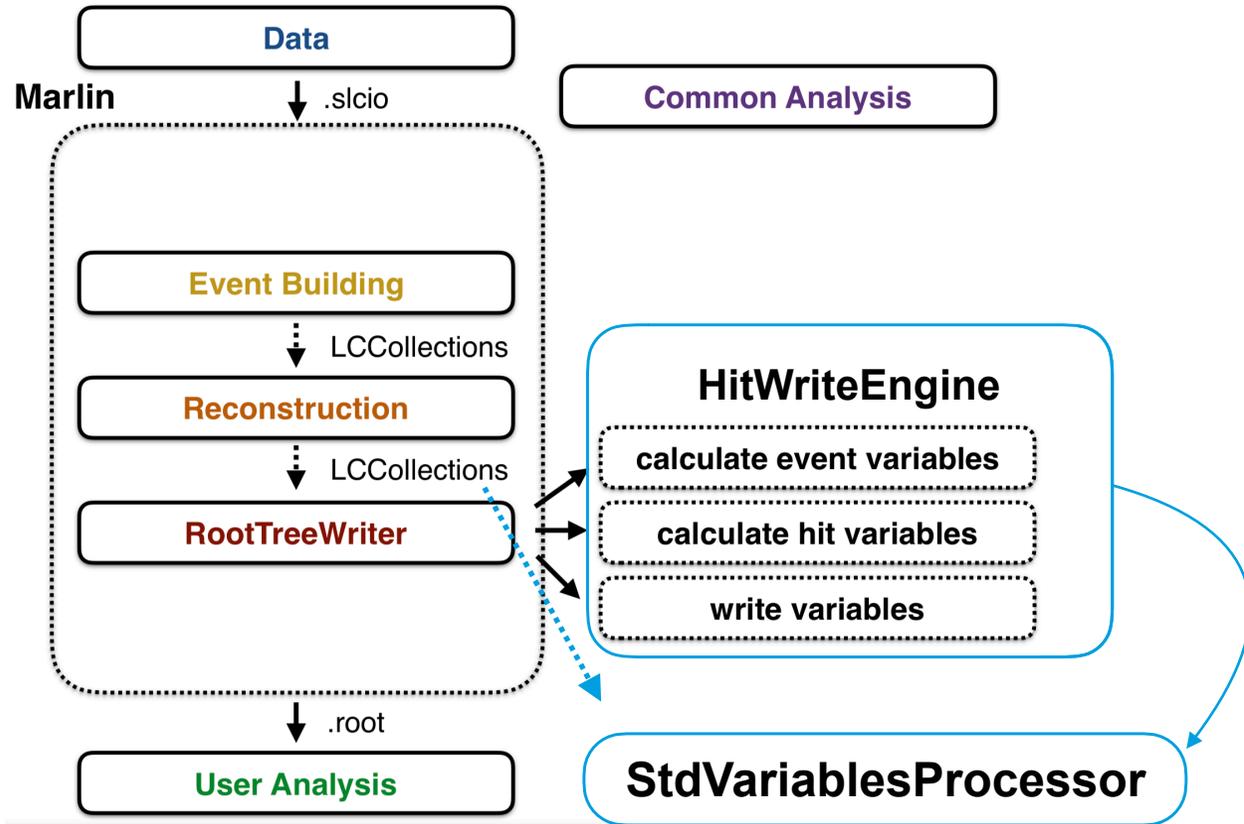
# Software architecture

## Current state & goal



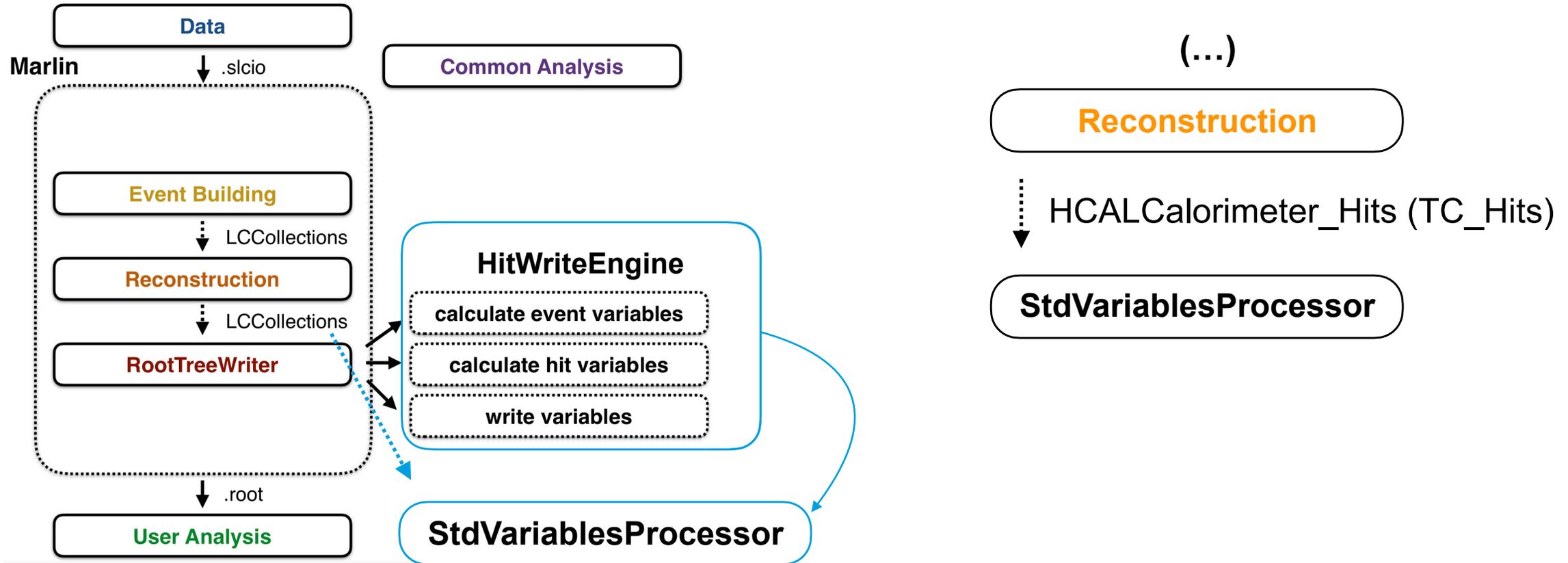
# Software architecture

## Variables calculation



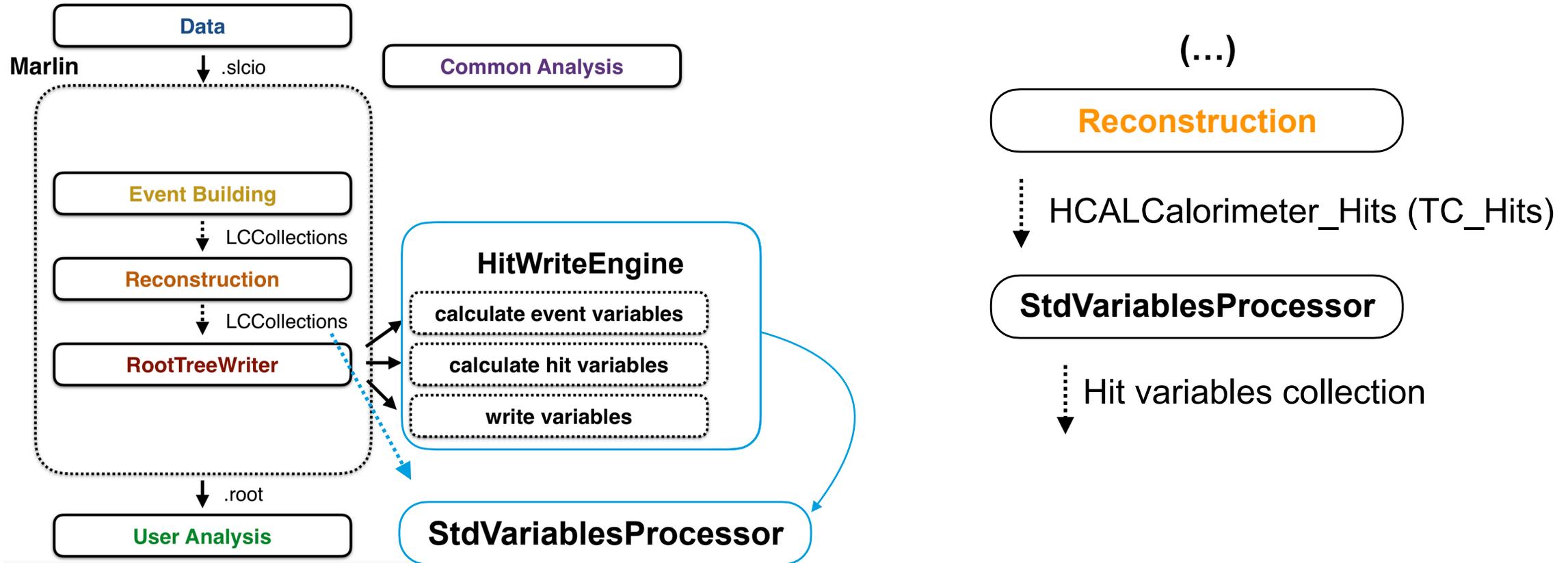
# Software architecture

## Variables calculation



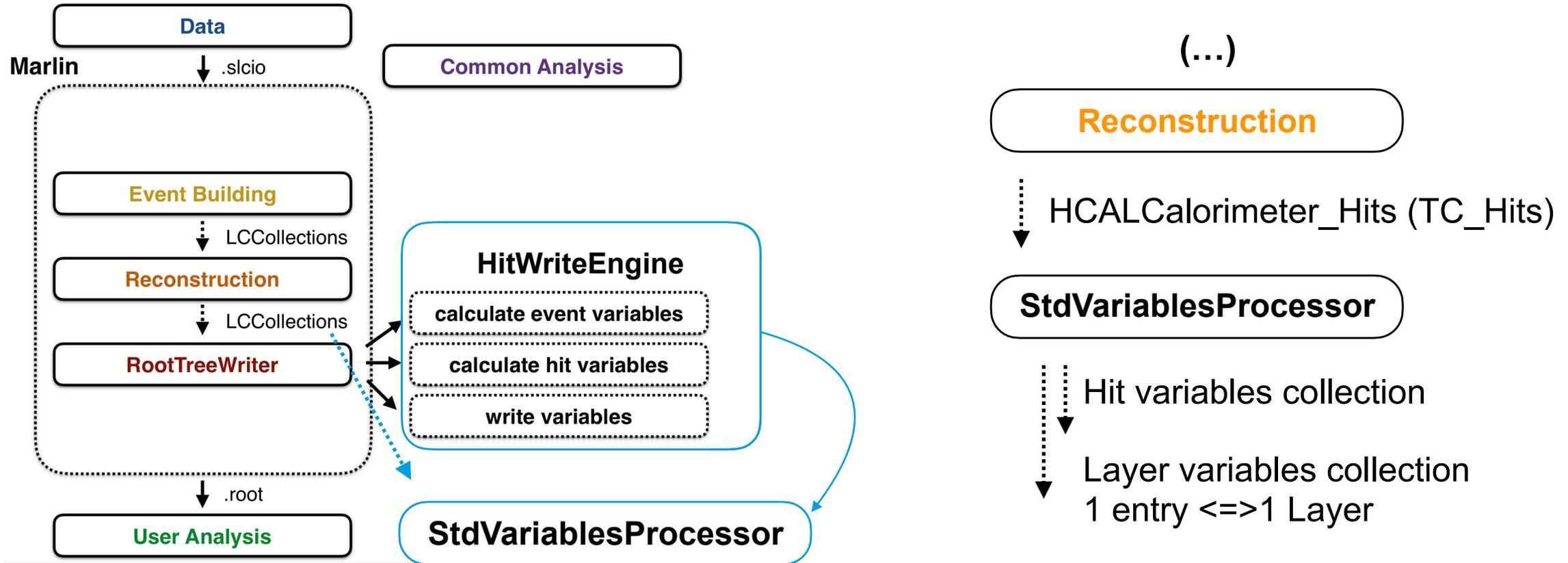
# Software architecture

## Variables calculation



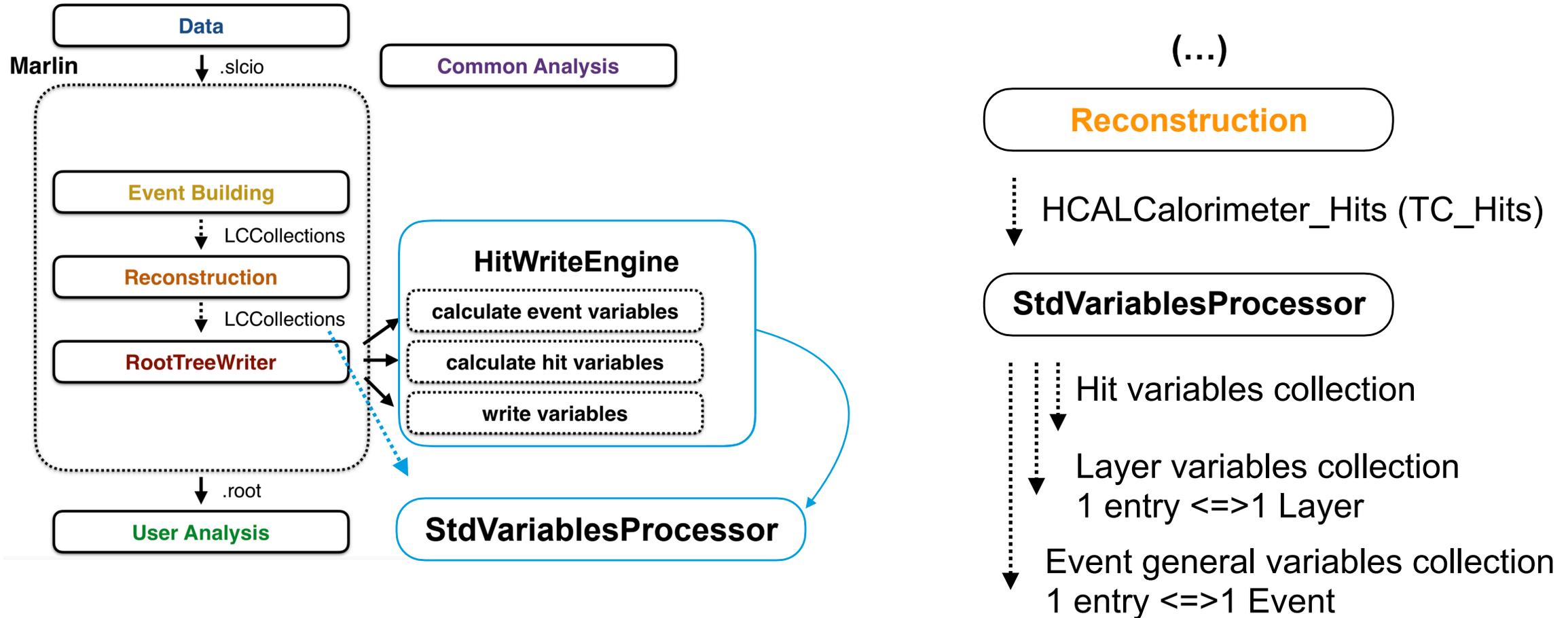
# Software architecture

## Variables calculation



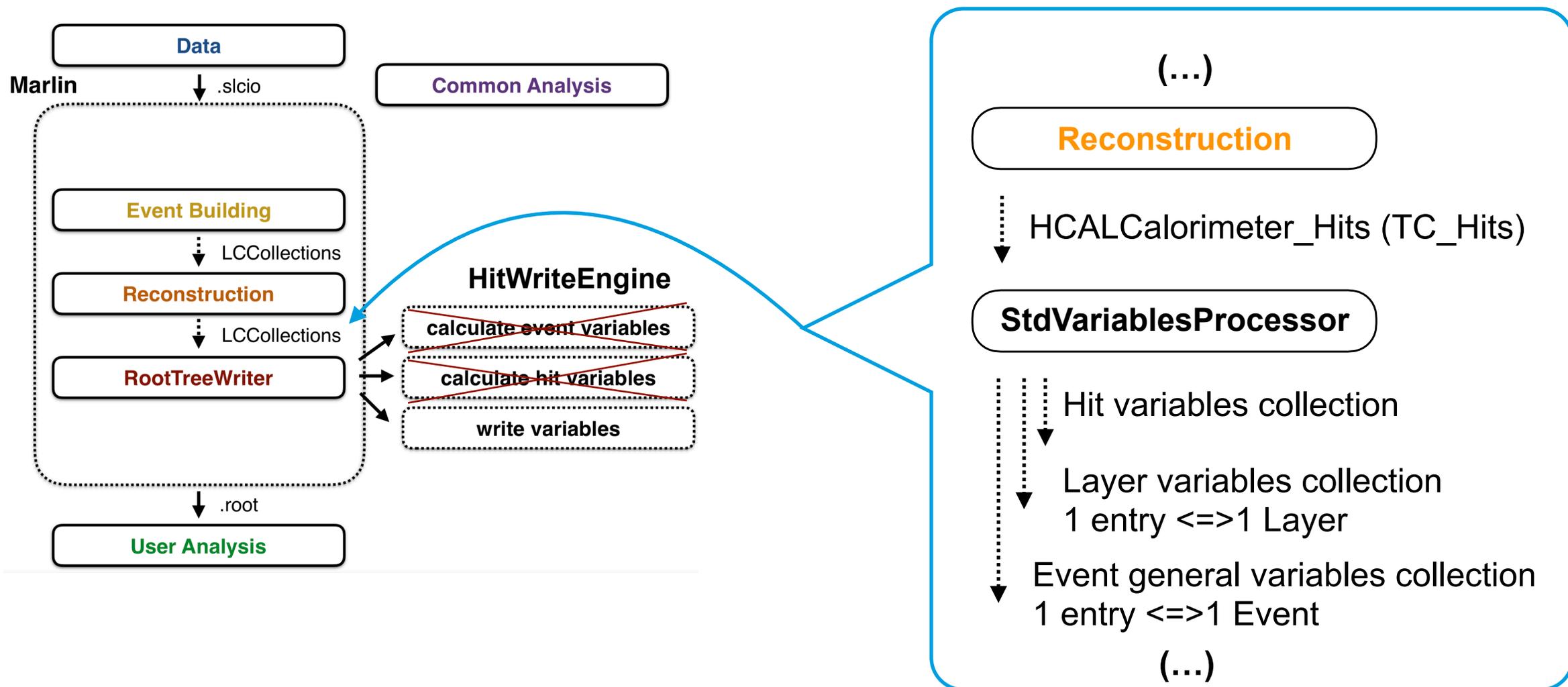
# Software architecture

## Variables calculation

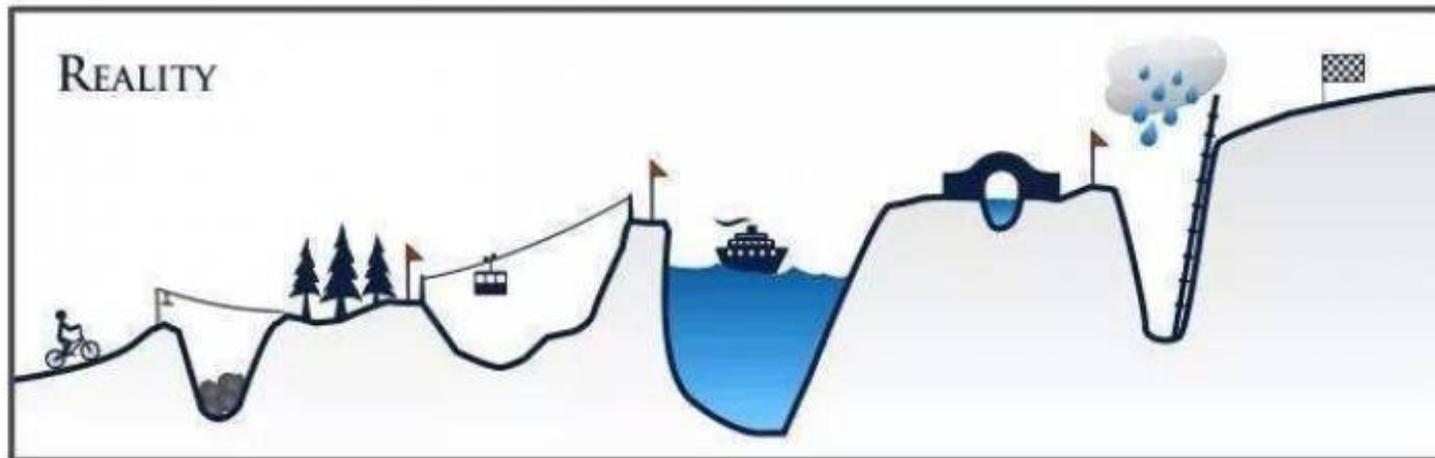


# Software architecture

## Variables calculation



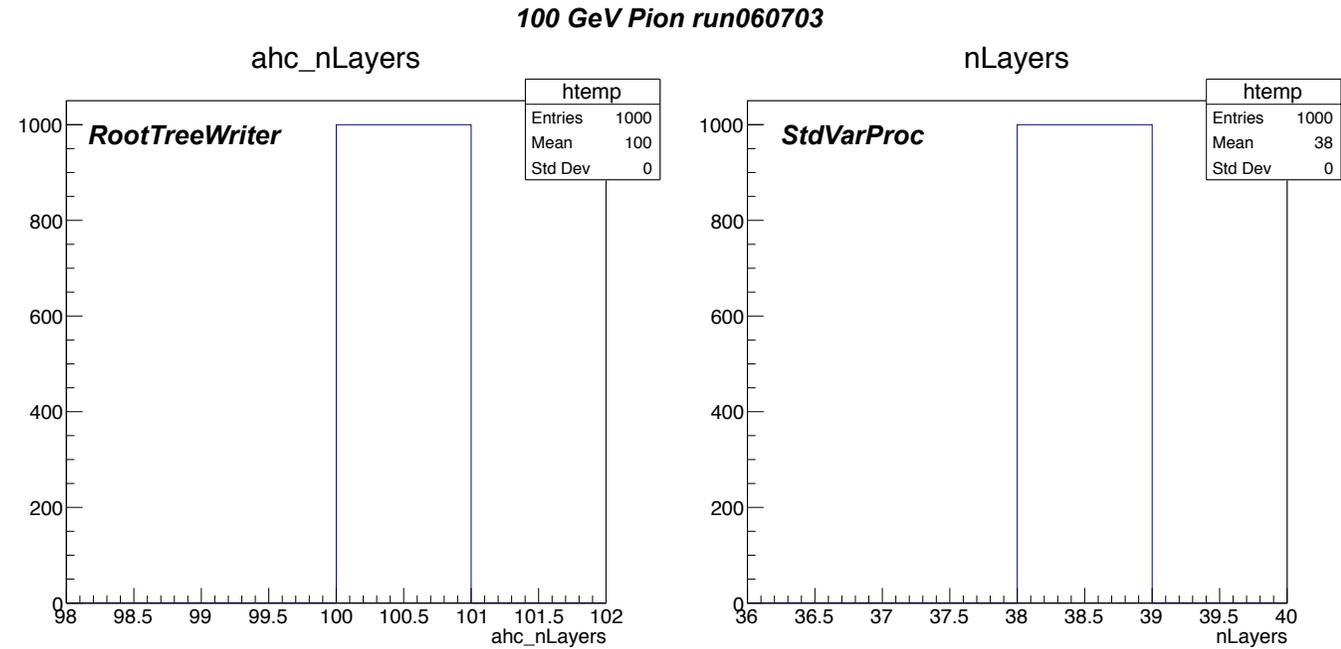
# StdVariablesProcessor



# StdVariablesProcessor

## Features

- **Number of layers** is extracted from DB module location collection



# StdVariablesProcessor

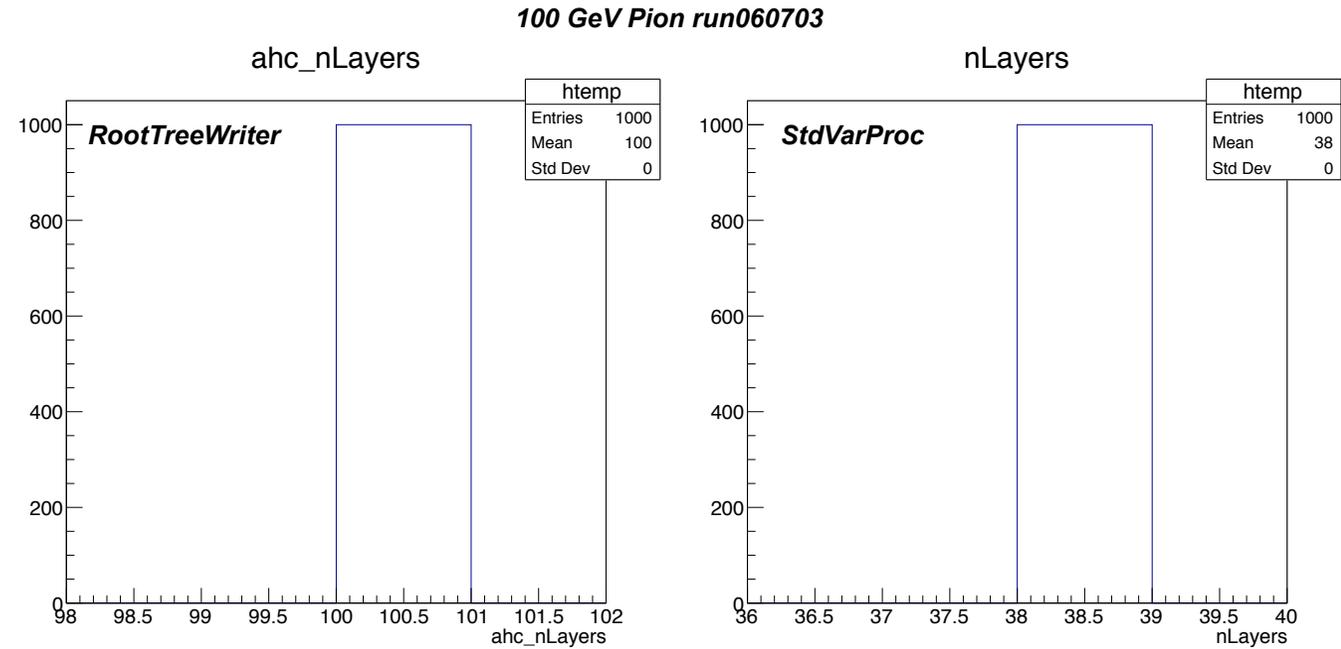
## Features

- **Number of layers** is extracted from DB module location collection

- **Inner processor data containers:**

Variable length arrays(VLA) (HitVar[nHits], LayVar[nLayers]) may generate bugs.

*- was used in some physics prototype processors*



# StdVariablesProcessor

## Features

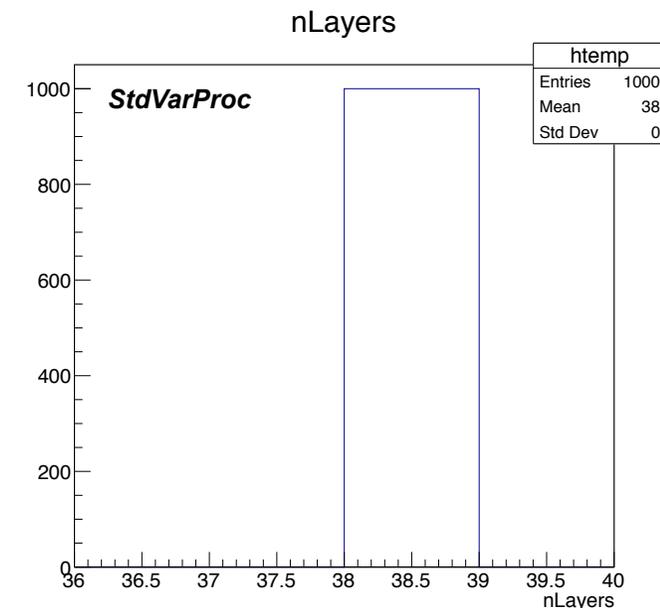
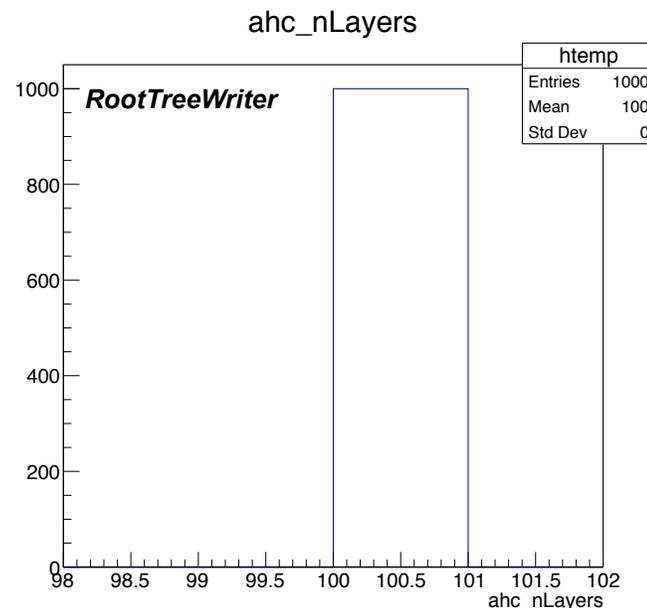
- **Number of layers** is extracted from DB module location collection

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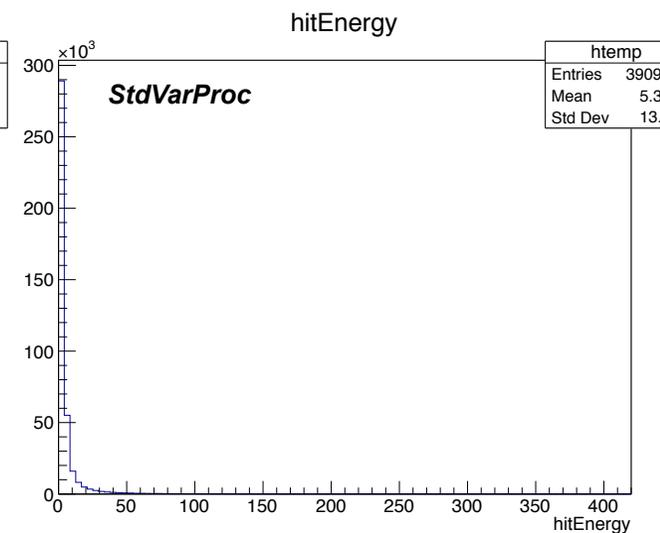
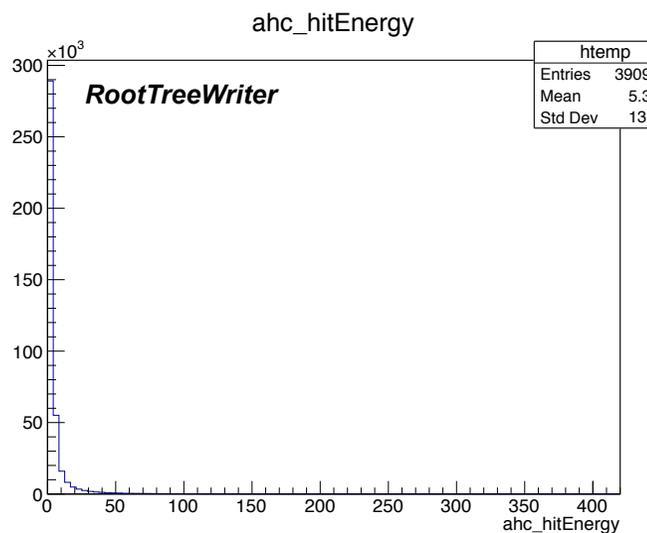
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100 GeV Pion run060703



100 GeV Pion run060703



# StdVariablesProcessor

## Features

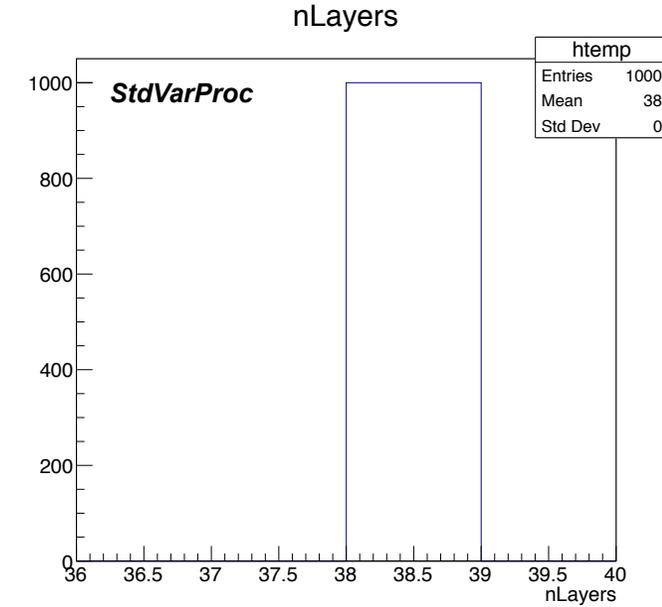
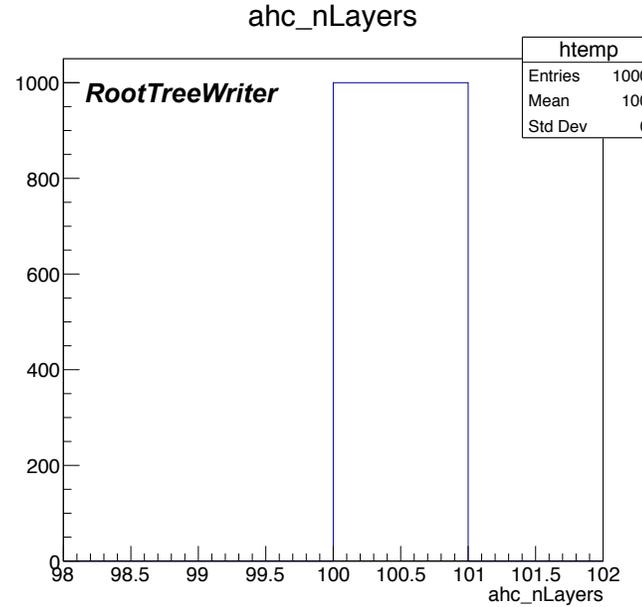
- **Number of layers** is extracted from DB module location collection

- **Inner processor data containers:**

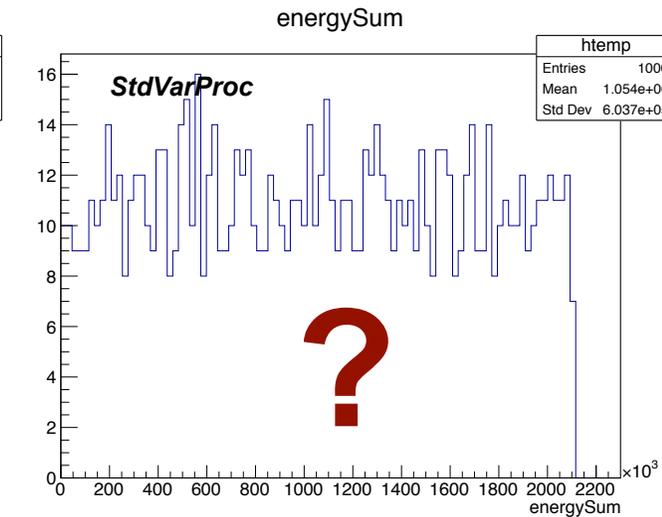
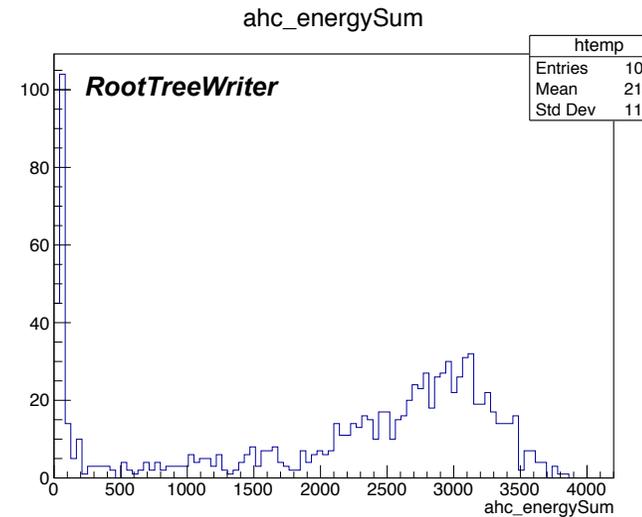
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100 GeV Pion run060703



100 GeV Pion run060703



# StdVariablesProcessor

## Features

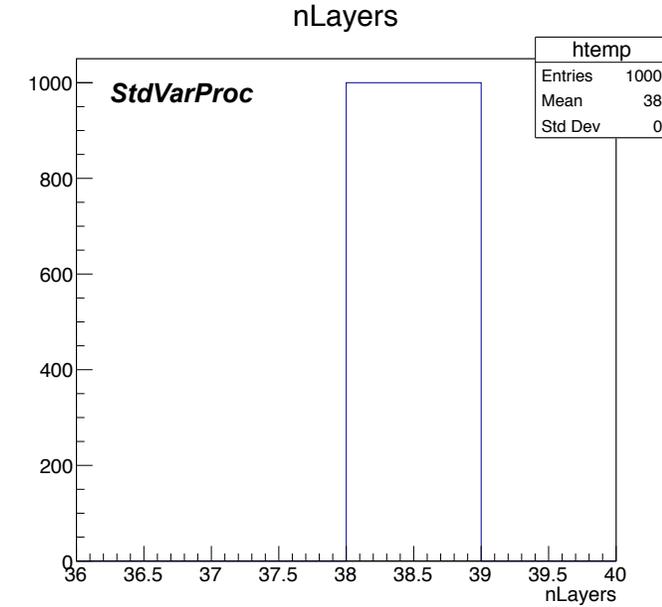
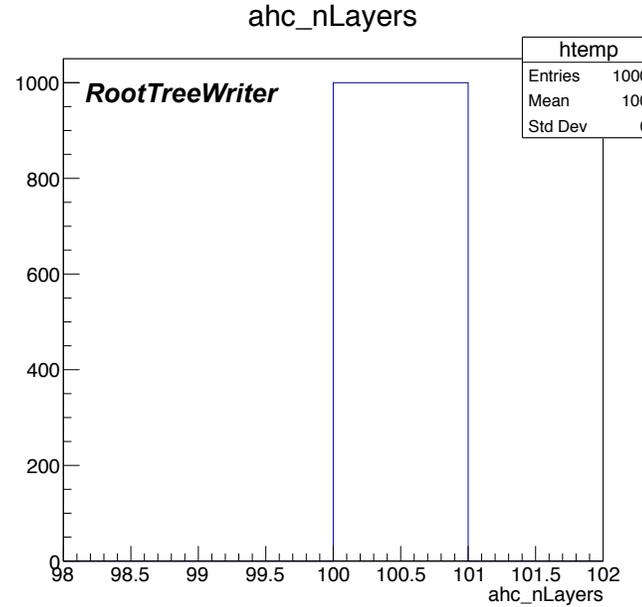
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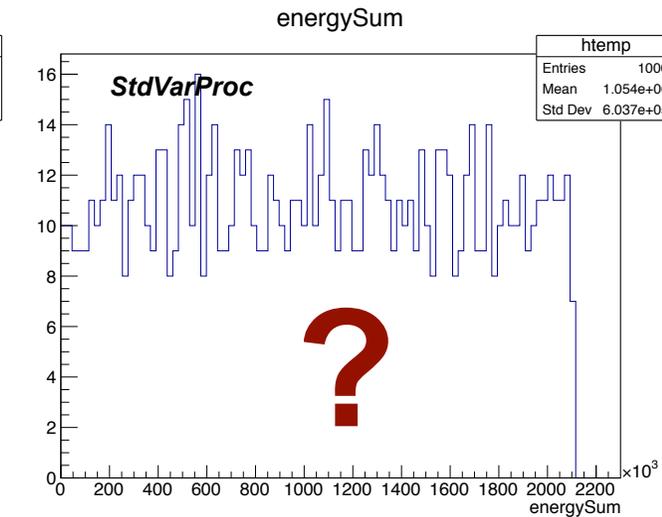
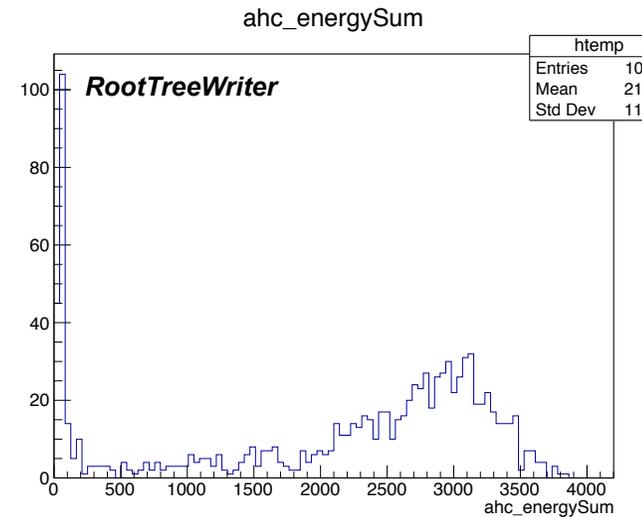
~~Variable length arrays (VLA) (HitVar[nHits], LayVar[nLayers]) may generate bugs.~~

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100 GeV Pion run060703



100 GeV Pion run060703



# StdVariablesProcessor

## Features

- **Number of layers** is extracted from DB module location collection

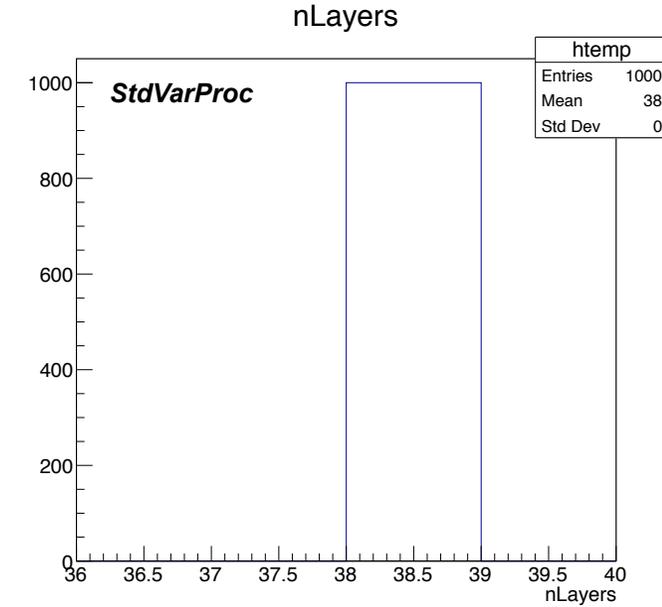
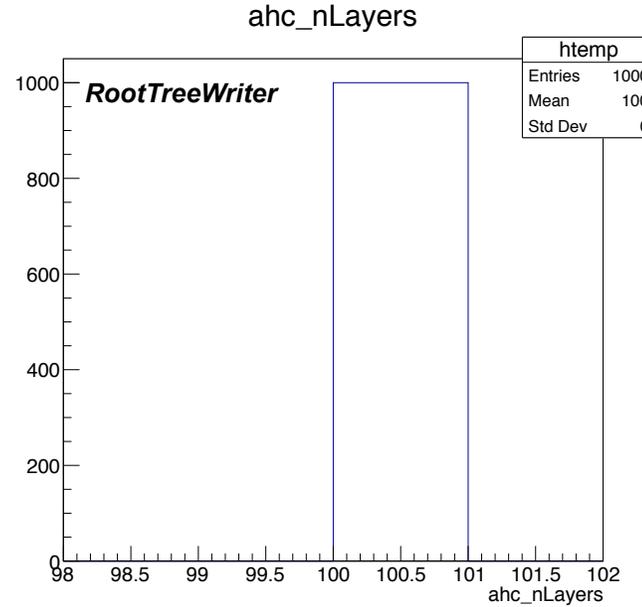
- **Inner processor data containers:**

~~Variable length arrays (VLA) (HitVar[nHits], LayVar[nLayers]) may generate bugs.~~

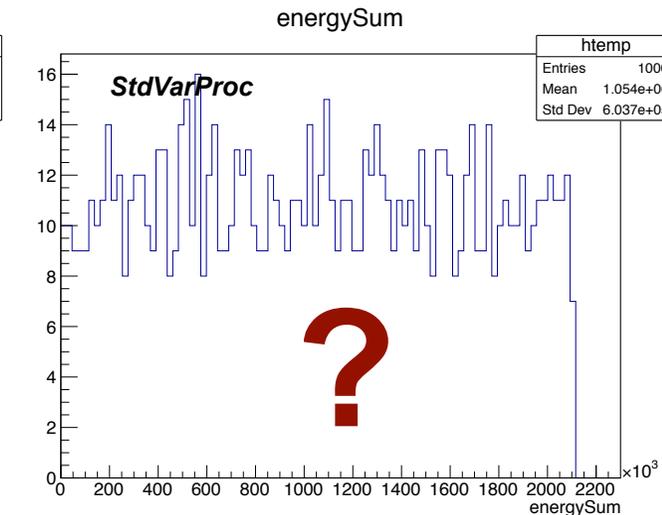
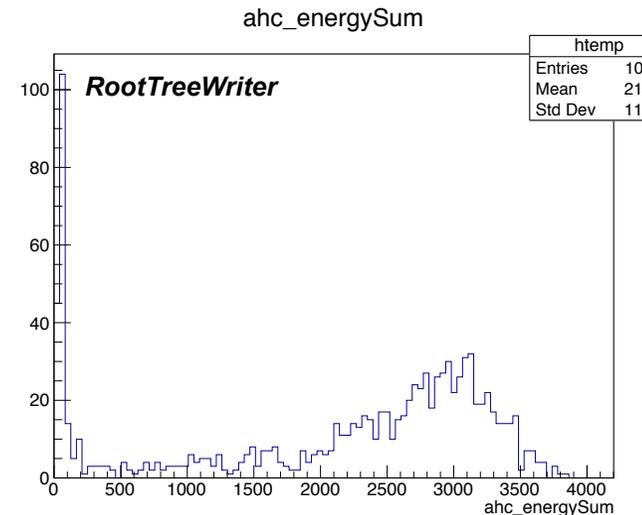
LCGenericObject seems to be good container (tricky but stable due to proper allocation)

- in “todo” list.

100 GeV Pion run060703

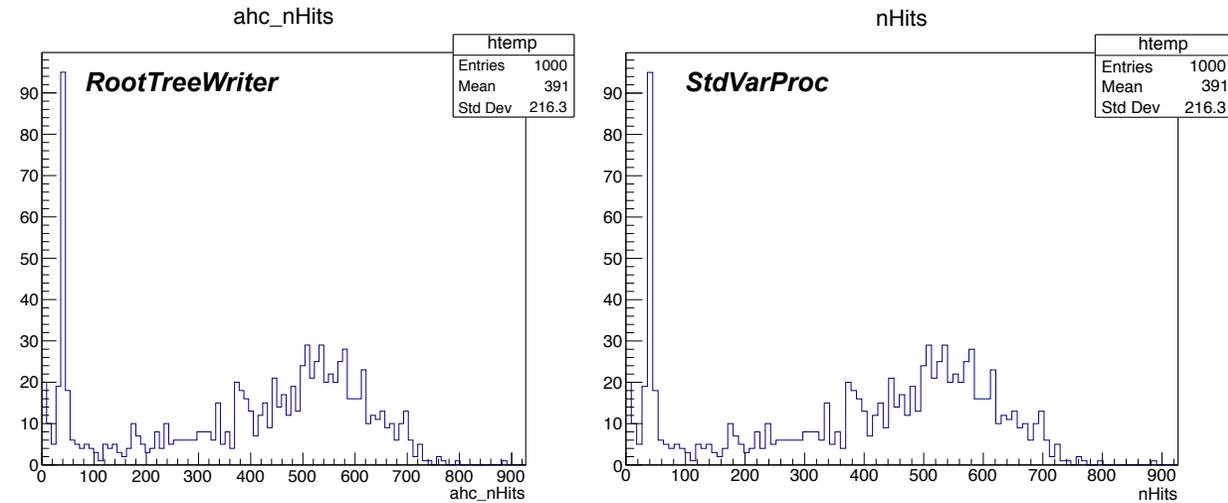


100 GeV Pion run060703



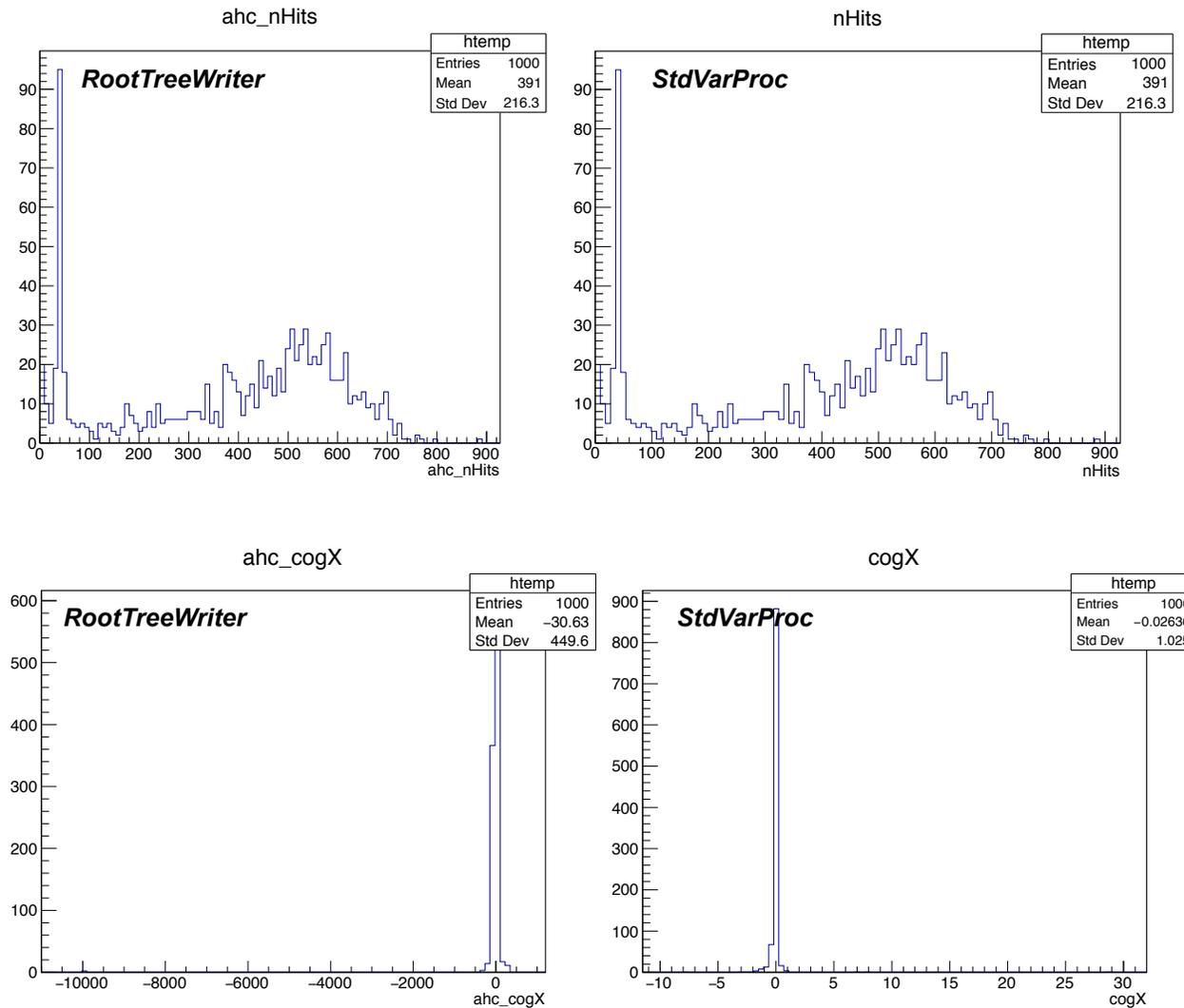
# Event general variables

Comparison of StdVarProc vs. RootTreeWriter. 100GeV pion run #60703



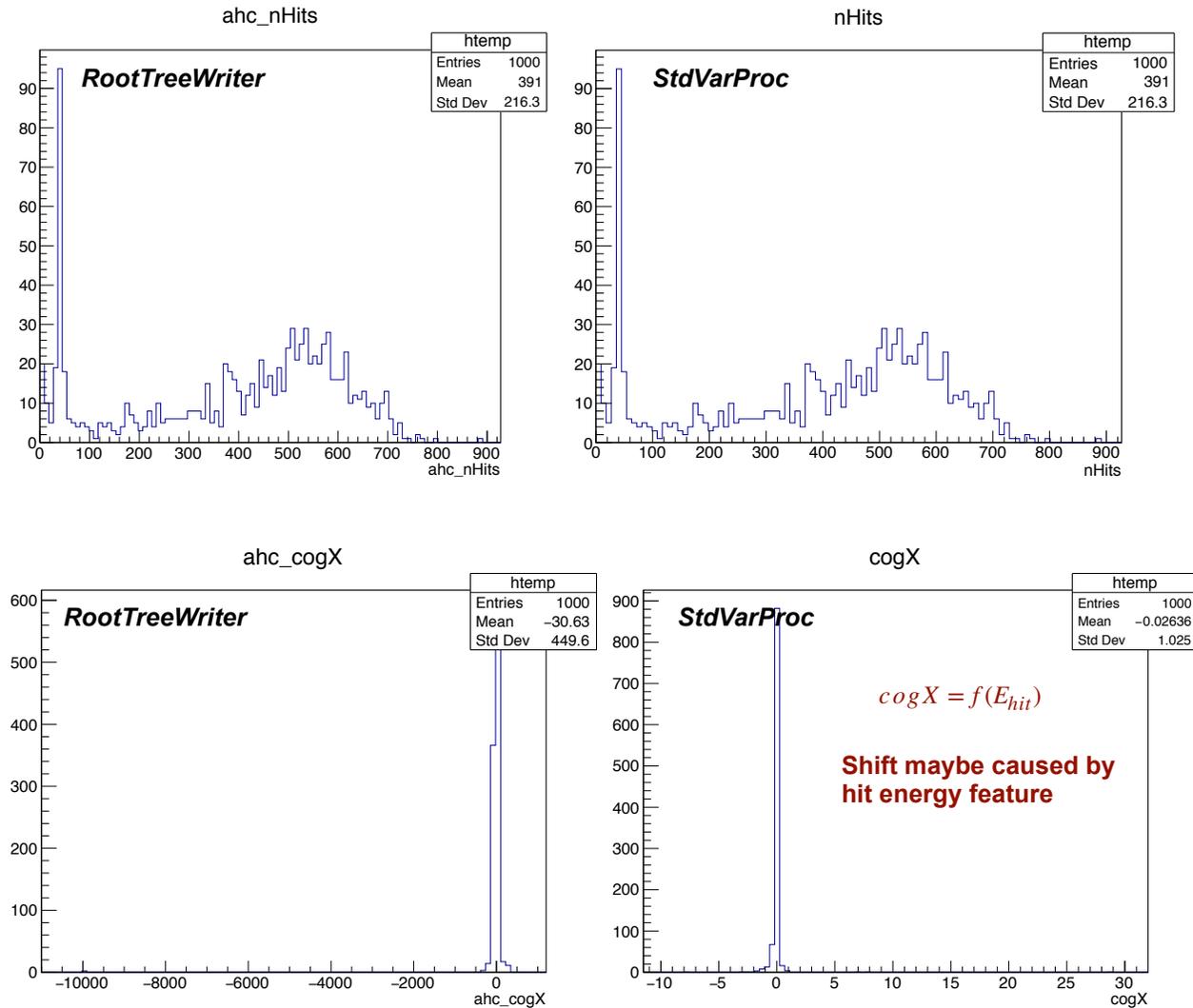
# Event general variables

Comparison of StdVarProc vs. RootTreeWriter. 100GeV pion run #60703



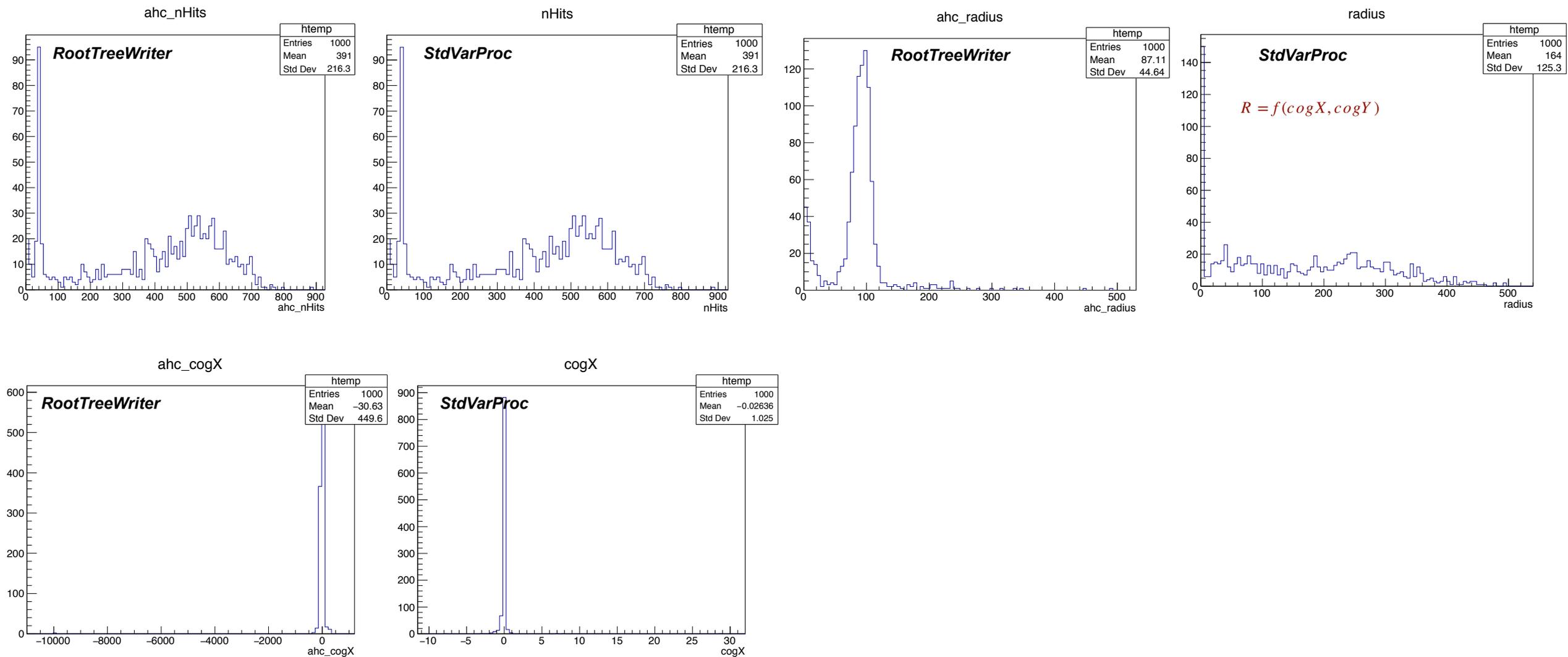
# Event general variables

## Comparison of StdVarProc vs. RootTreeWriter. 100GeV pion run #60703



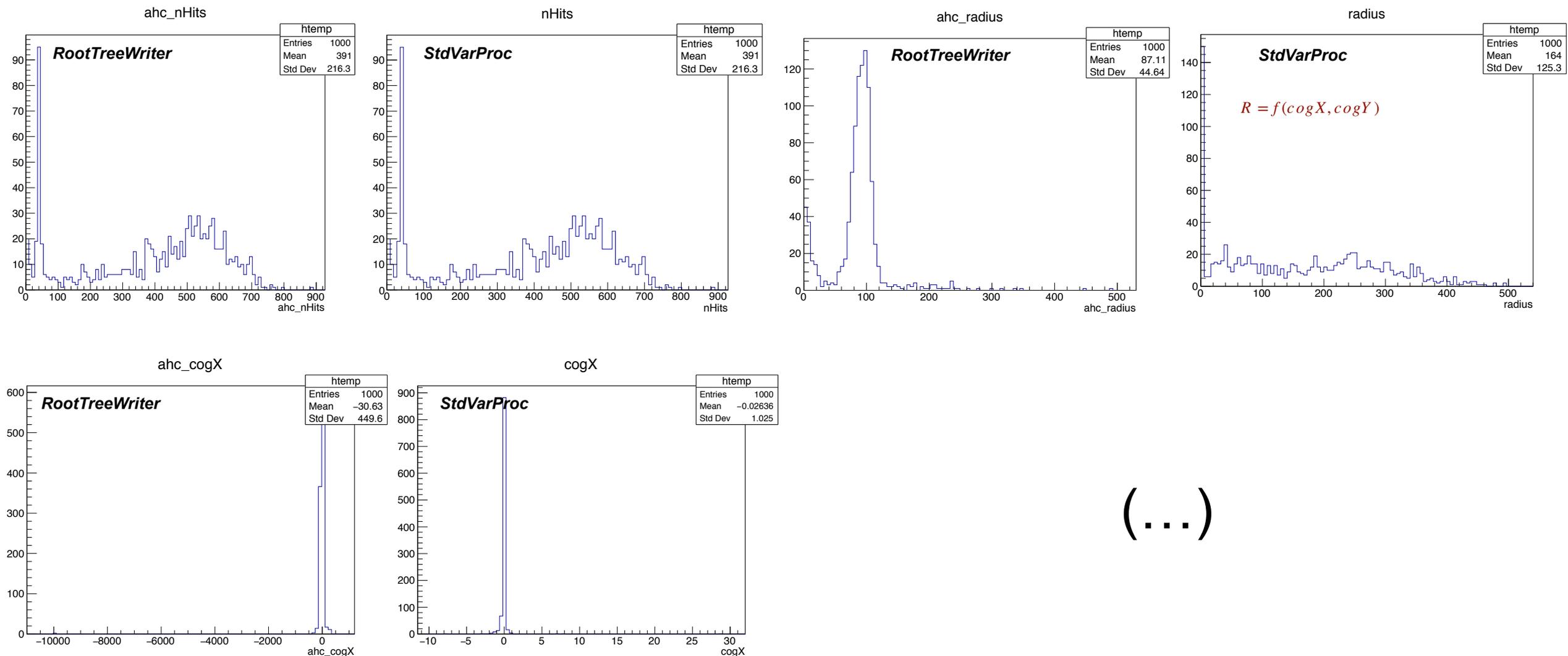
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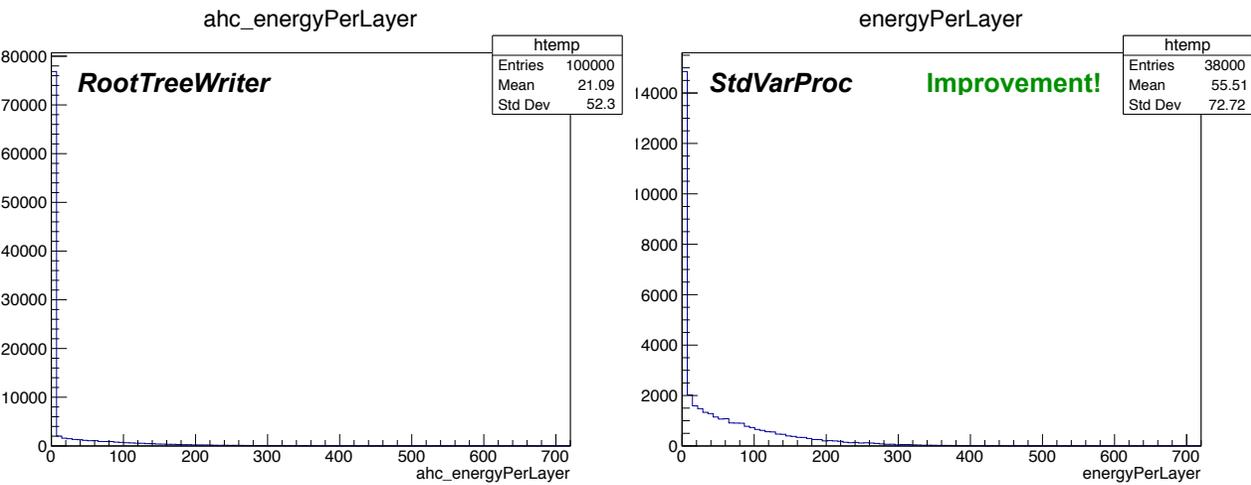
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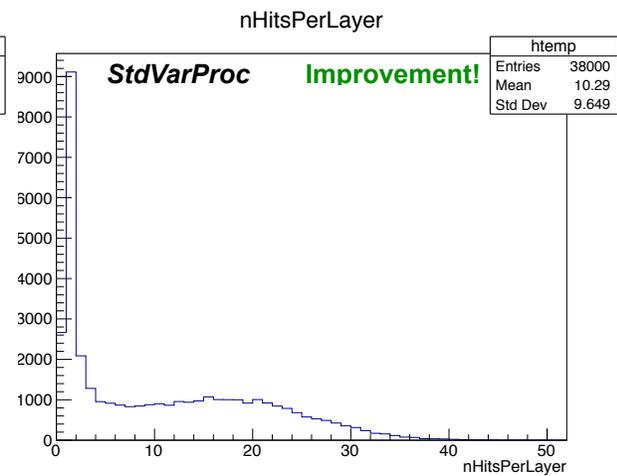
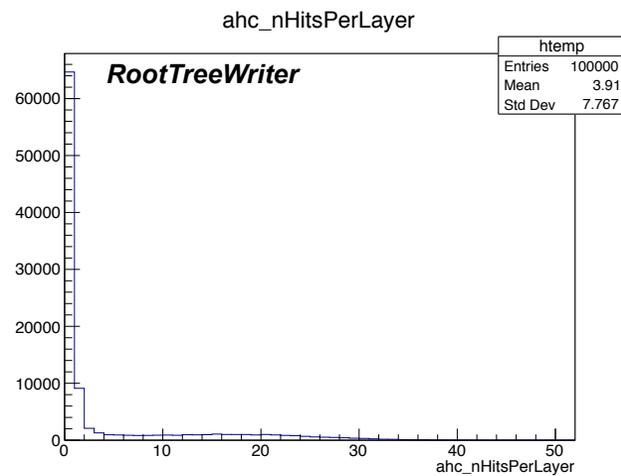
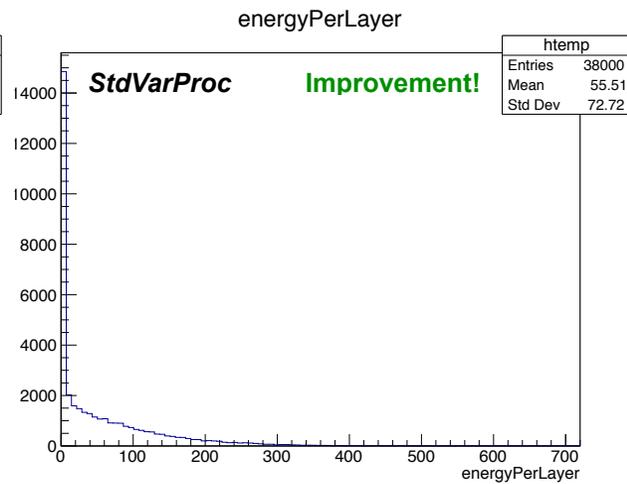
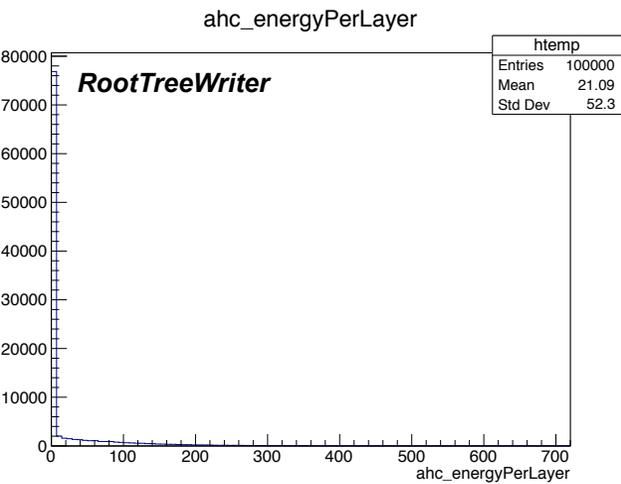
# Layer variables

Comparison of StdVarProc vs. RootTreeWriter. 100GeV pion run #60703



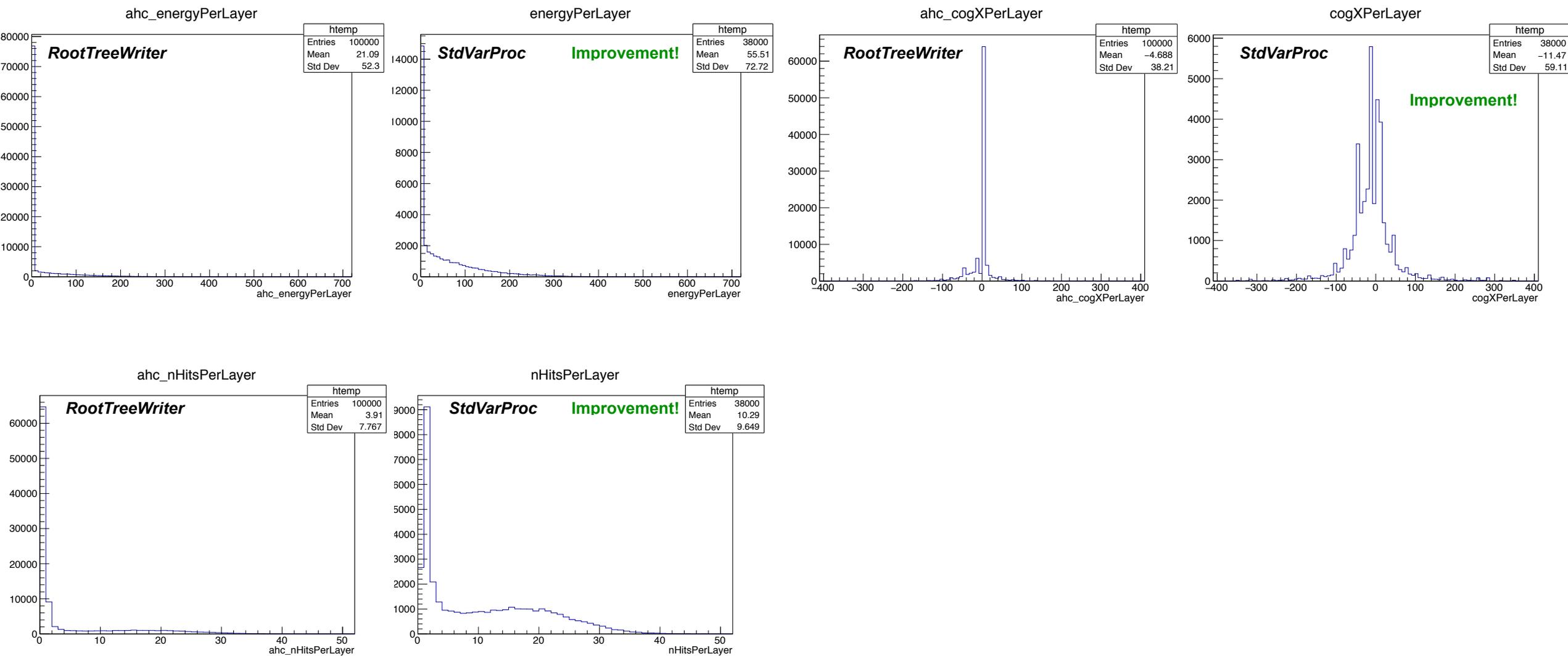
# Layer variables

Comparison of StdVarProc vs. RootTreeWriter. 100GeV pion run #60703



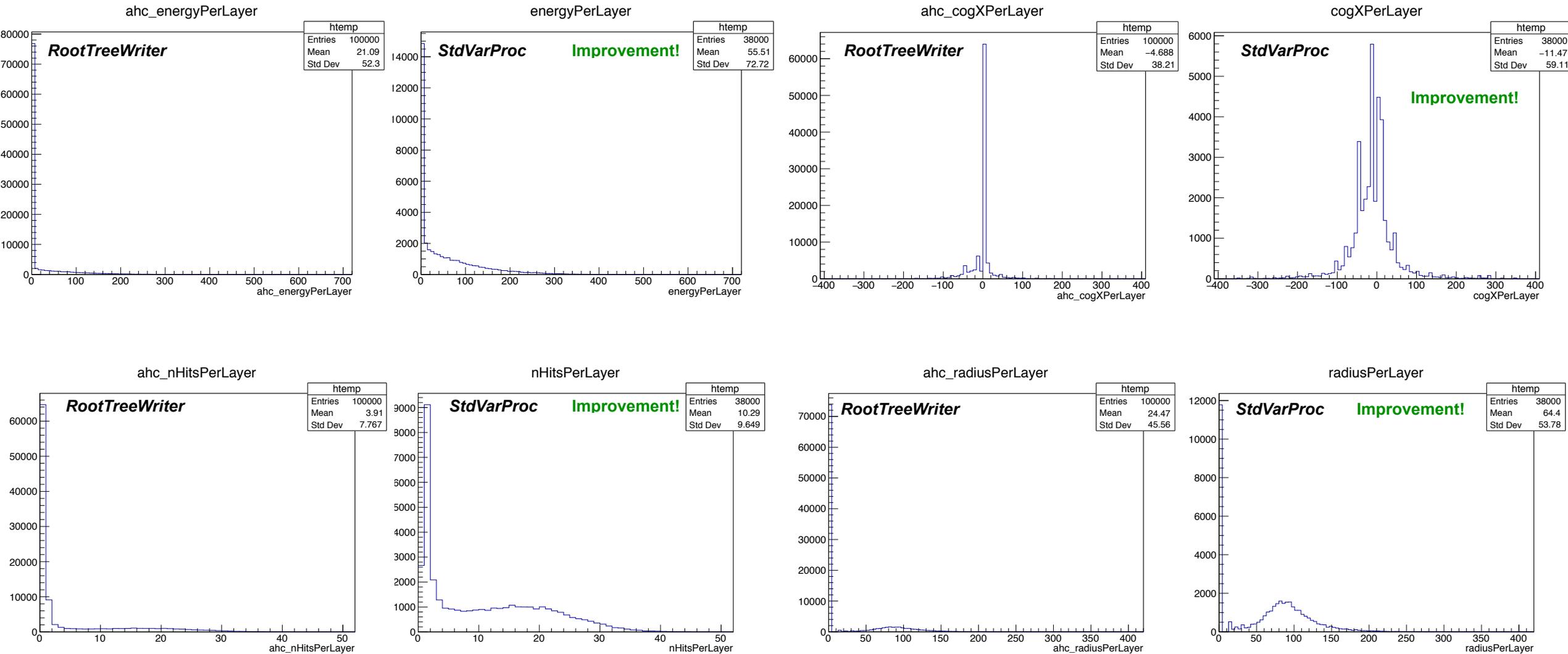
# Layer variables

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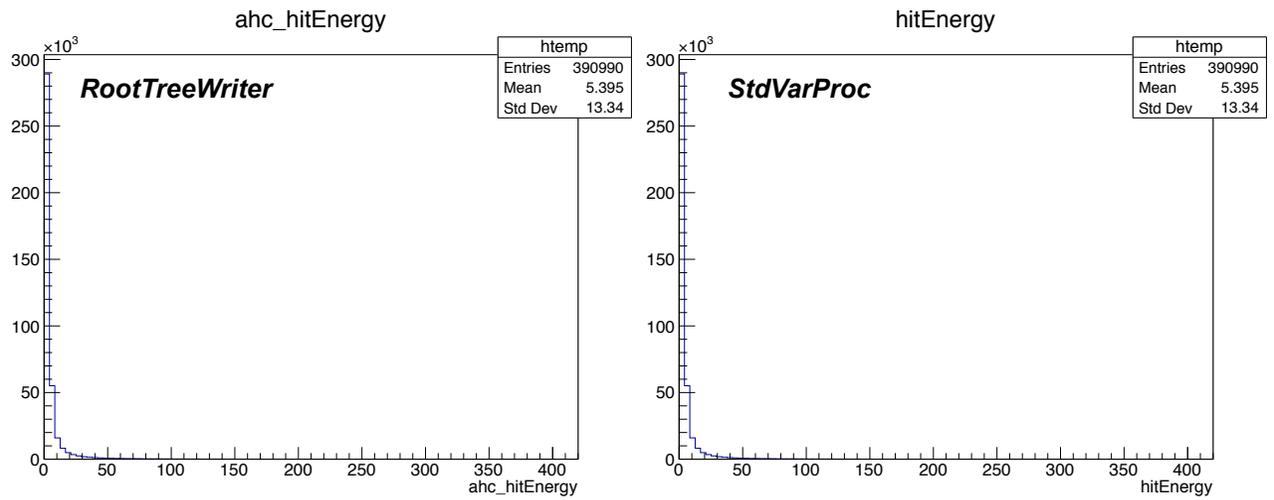
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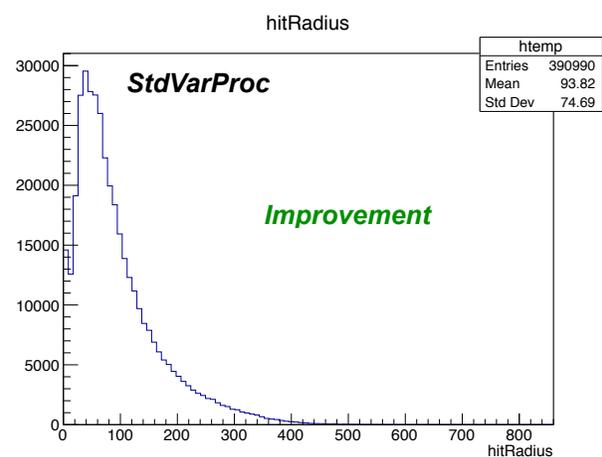
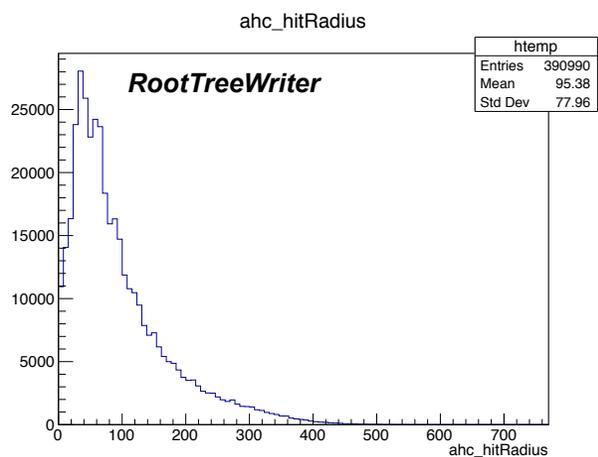
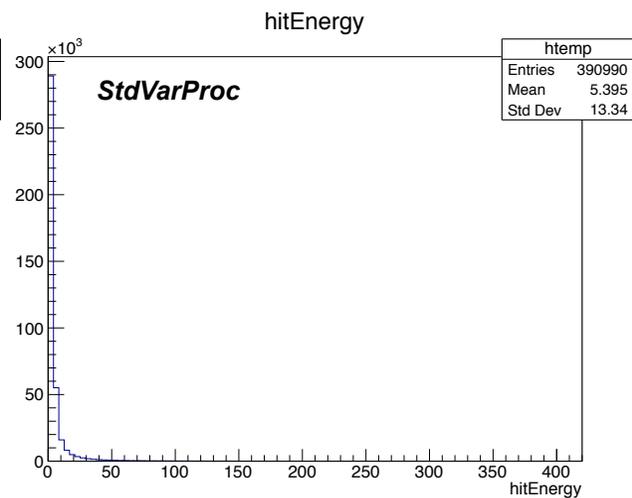
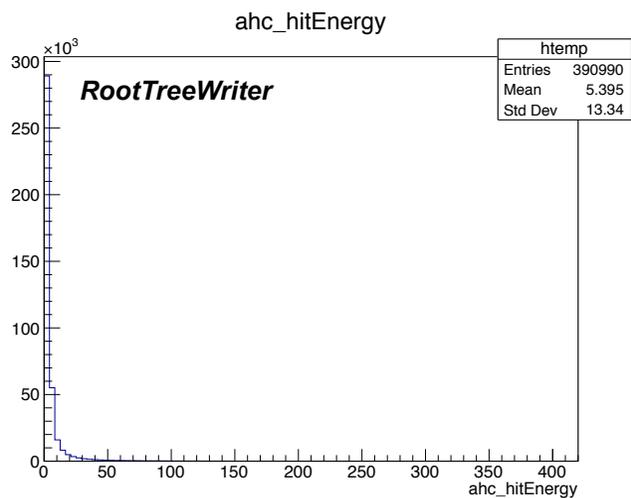
# Hit variables

Comparison of StdVarProc vs. RootTreeWriter. 100GeV pion run #60703



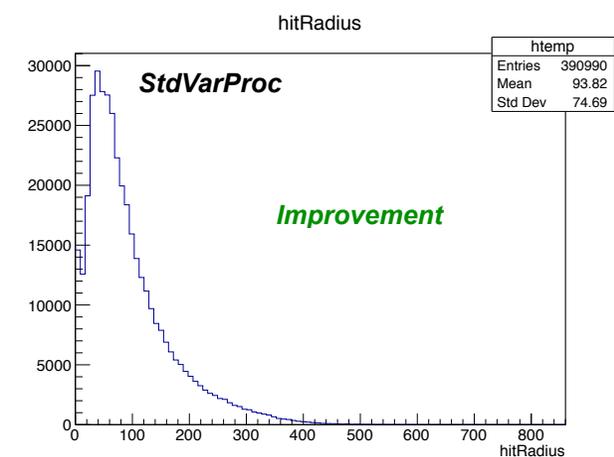
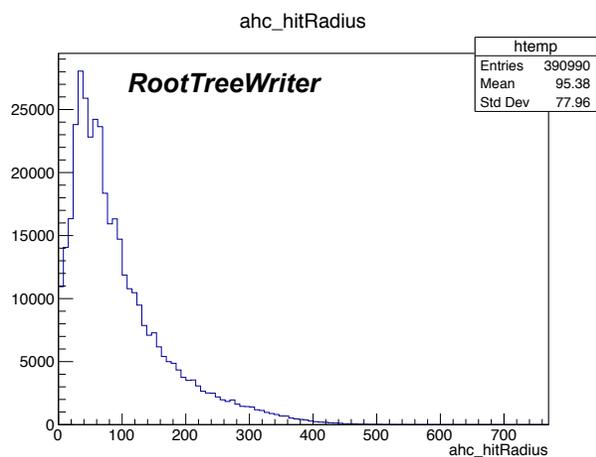
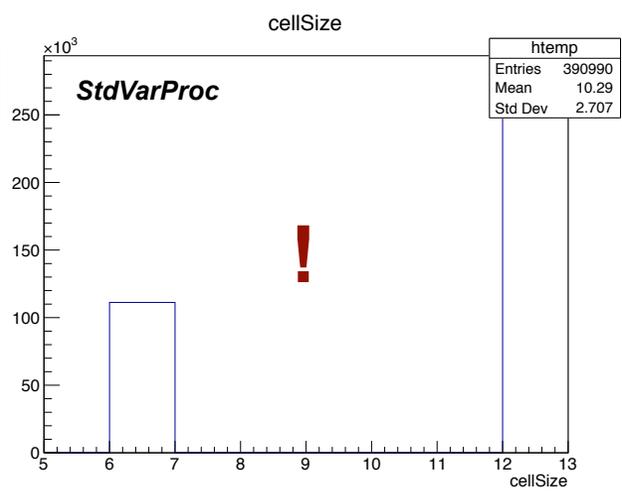
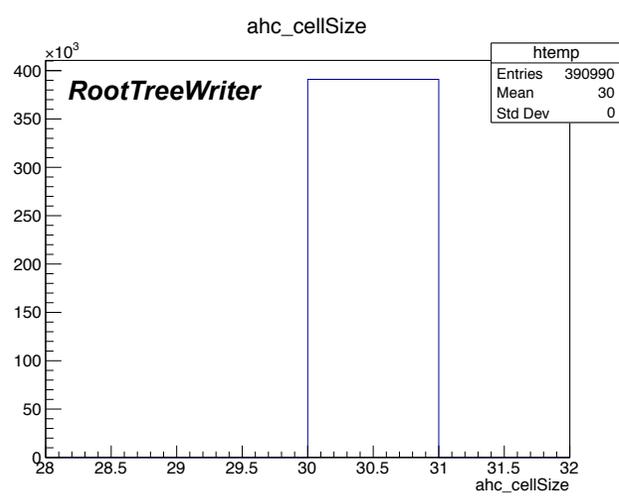
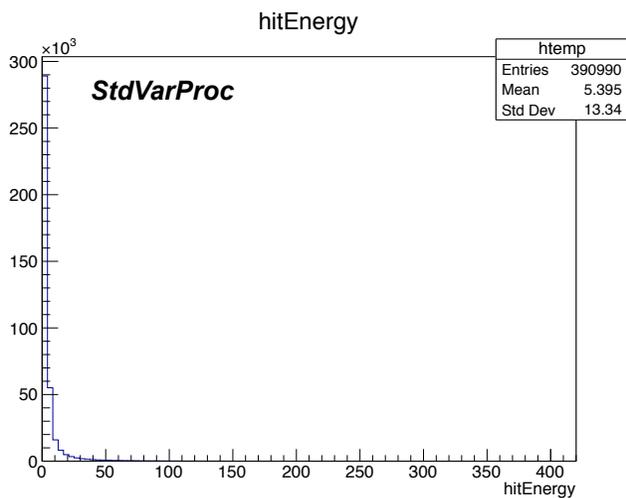
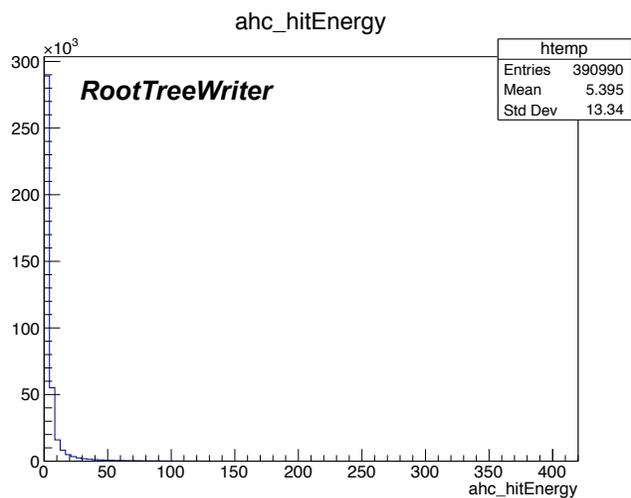
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Comparison of StdVarProc vs. RootTreeWriter. 100GeV pion run #60703



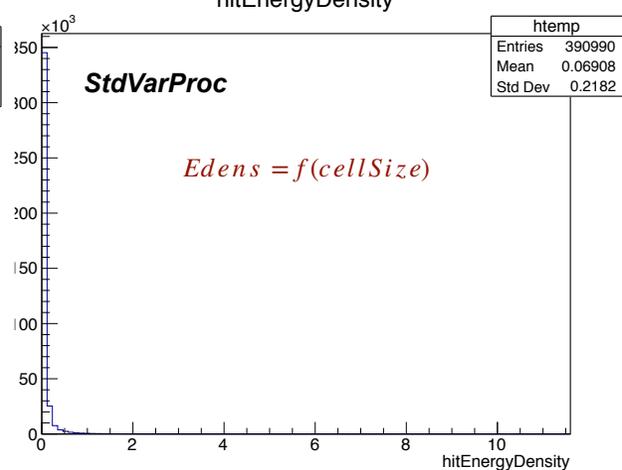
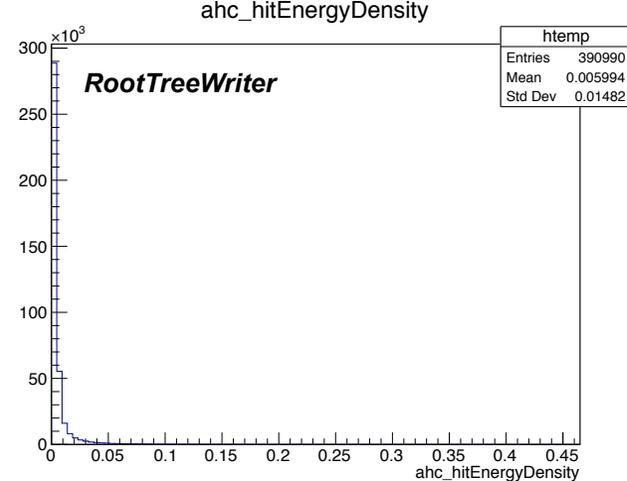
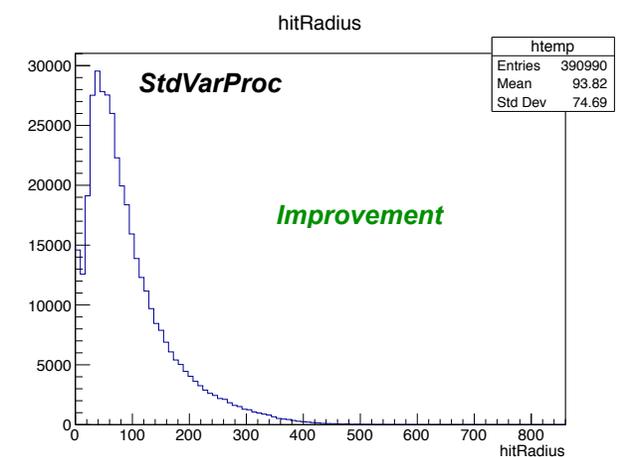
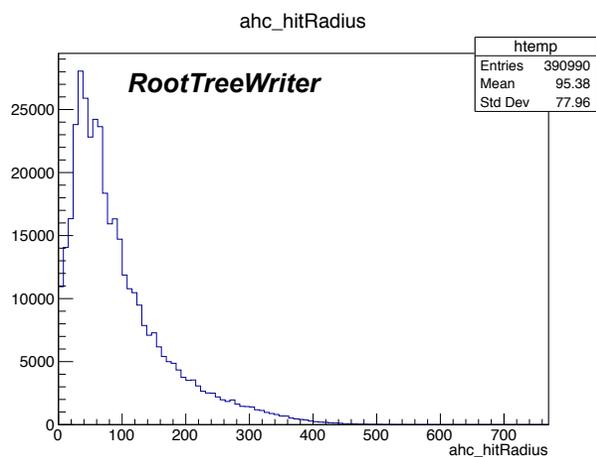
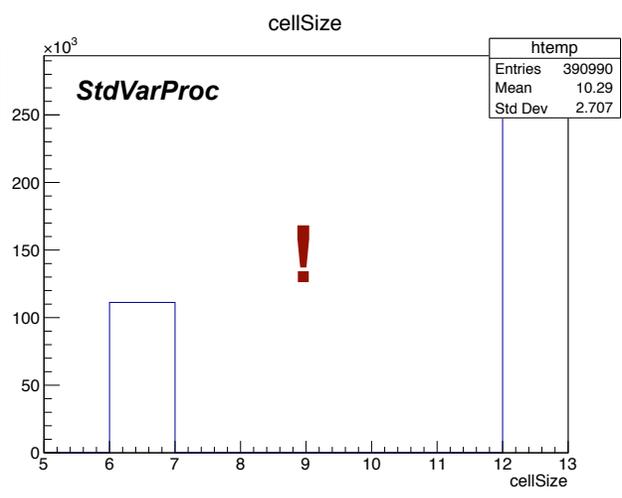
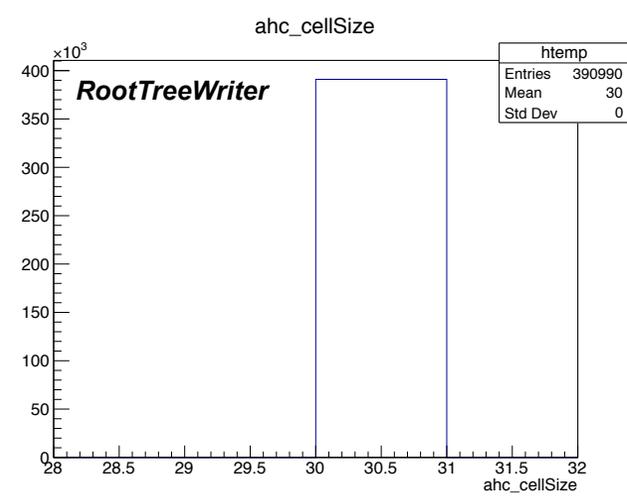
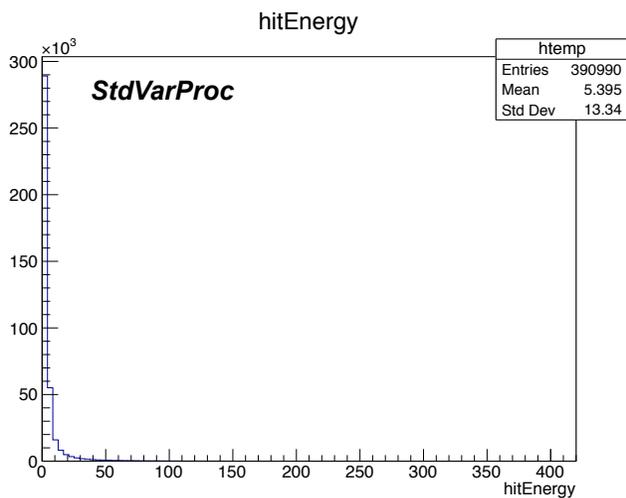
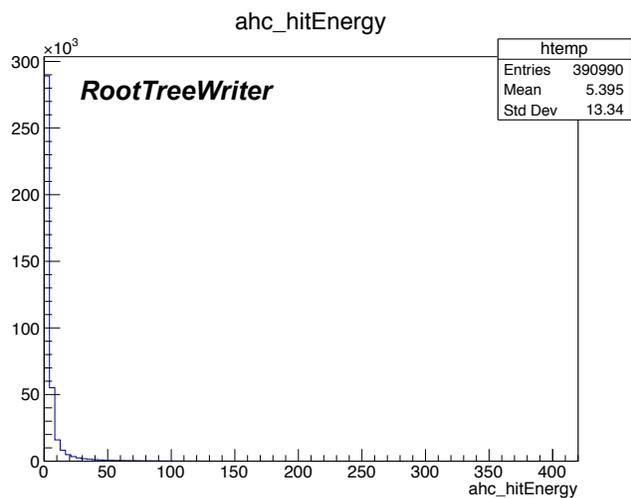
# Hit variables

Comparison of StdVarProc vs. RootTreeWriter. 100GeV pion run #60703



# Hit variables

Comparison of StdVarProc vs. RootTreeWriter. 100GeV pion run #60703



# Summary

- Observables for particle ID are well understood
  - Adjustment tool will help for optimising ID to the task you do
  - Can be implemented in the CaliceSoft
  - Which requires software architecture improvement
- Software architecture revolution has started
  - Preliminary results already indicate advantages of new approach
  - Work in progress...
- Good team work gives fast results

**Thank you**



# Backup

# Observables

## Which require additional calculation

Fraction of energy in first 25 layers

$$(E_{25l}/E_{total})$$

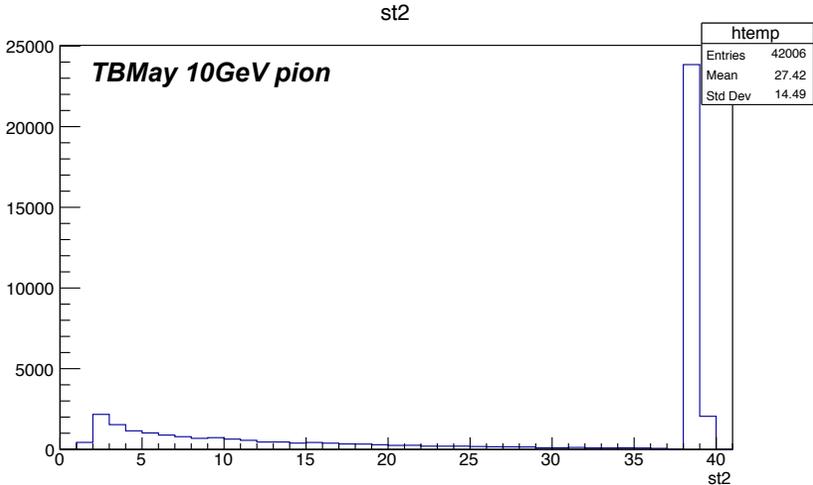
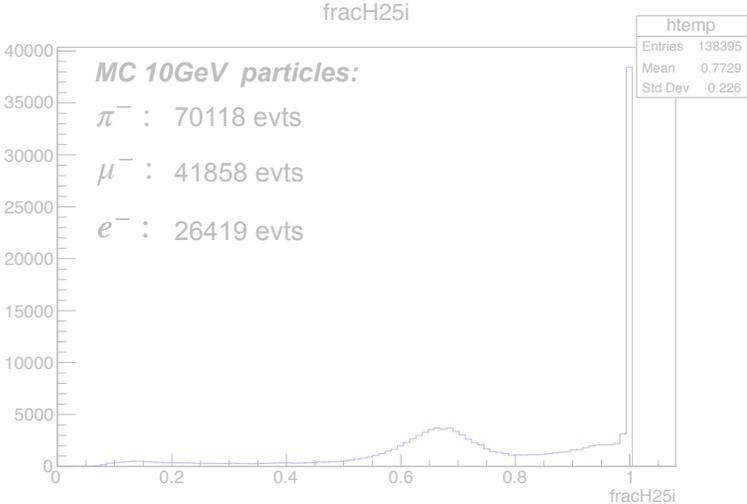
- $\mu^-$  : fraction peaks at  $25/N_{layers} \approx 1$
- $e^-$  : fraction
- $\pi^-$  : fraction more-less spread

Shower start layer number

- “clean”  $\mu^-$  : no shower
- $e^-$  : in the first half of detector
- $\pi^-$  : more-less spread

### 2 ways to calculate:

- by energy in layer and hit radius criterium - st0 (in addition isolated hits can be excluded - st1)
- by neighbouring hits criterium - st2



# Observables

## Which require additional calculation

Fraction of energy in first 25 layers

$$(E_{25l}/E_{total})$$

- $\mu^-$  : fraction peaks at  $25/N_{layers} \approx 1$
- $e^-$  : fraction
- $\pi^-$  : fraction more-less spread

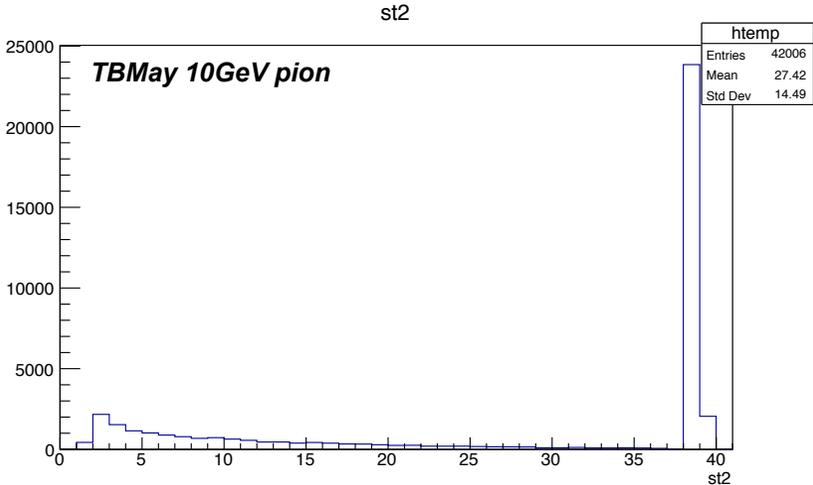
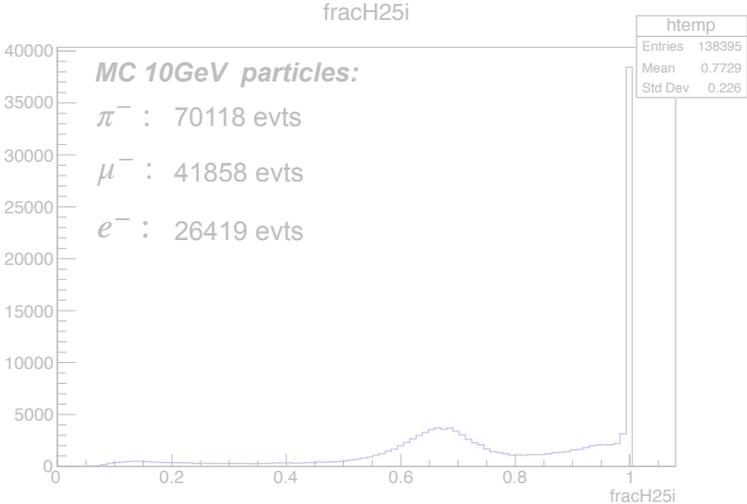
Shower start layer number

- “clean”  $\mu^-$  : no shower
- $e^-$  : in the first half of detector
- $\pi^-$  : more-less spread

### 2 ways to calculate:

- by energy in layer and hit radius criterium - st0 (in addition isolated hits can be excluded - st1)
- by neighbouring hits criterium - st2

**If there is no shower shower, start variable is equal to  $N_{layers}$**



# Observables

## Which require additional calculation

Fraction of energy in first 25 layers

$$(E_{25l}/E_{total})$$

- $\mu^-$  : fraction peaks at  $25/N_{layers} \approx 1$
- $e^-$  : fraction
- $\pi^-$  : fraction more-less spread

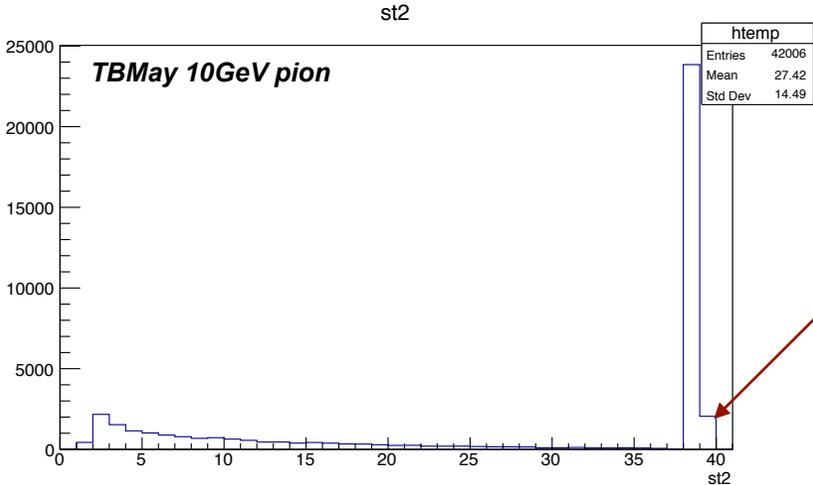
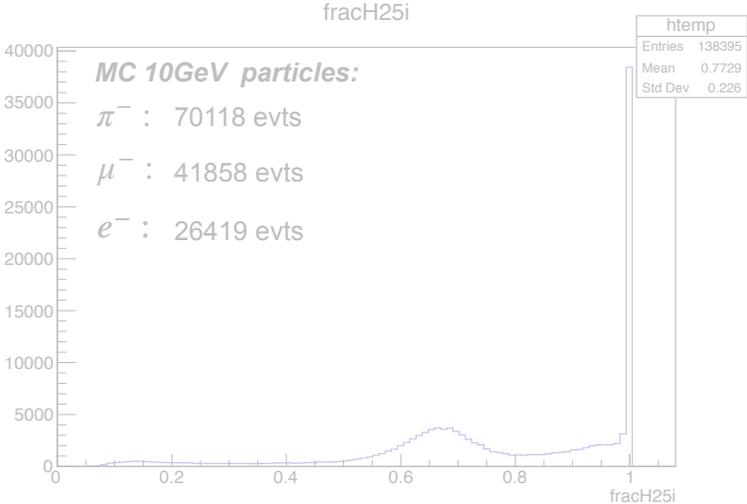
Shower start layer number

- “clean”  $\mu^-$  : no shower
- $e^-$  : in the first half of detector
- $\pi^-$  : more-less spread

### 2 ways to calculate:

- by energy in layer and hit radius criterium - st0 (in addition isolated hits can be excluded - st1)
- by neighbouring hits criterium - st2

If there is no shower shower, start variable is equal to  $N_{layers}$



Should not be  $> N_{layers}$   
(in “todo” list)

# Observables

## Which require additional calculation

Fraction of energy in first 25 layers

$$(E_{25l}/E_{total})$$

- $\mu^-$  : fraction peaks at  $25/N_{layers}$
- $e^-$  : fraction  $\approx 1$

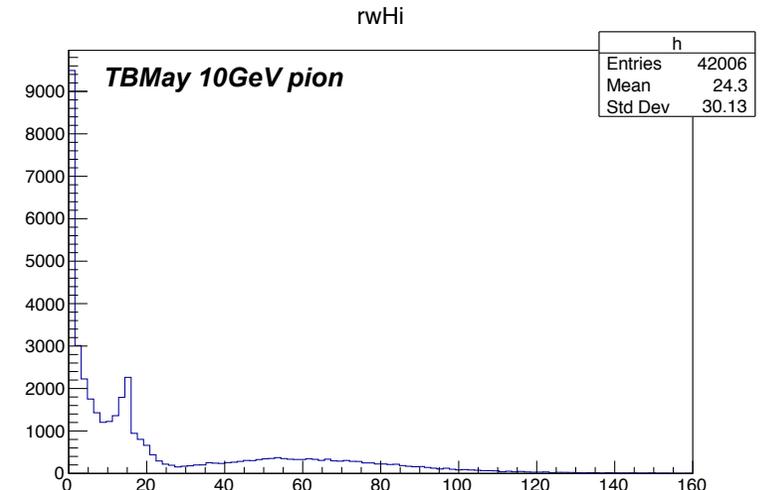
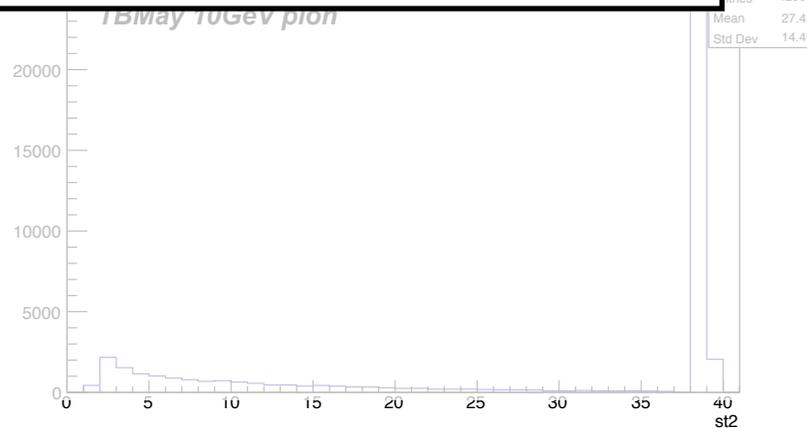
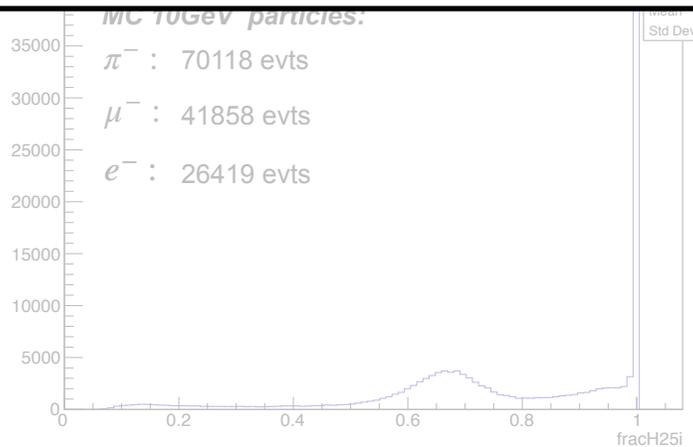
Shower start layer number

- “clean”  $\mu^-$  : no shower
- $e^-$  : in the first half of detector

Shower radius

- “clean”  $\mu^-$  : no cluster ( $r_{cl} = 0$ )
- $e^-$  :  $R$  has a peak
- $\pi^-$  : more-less spread

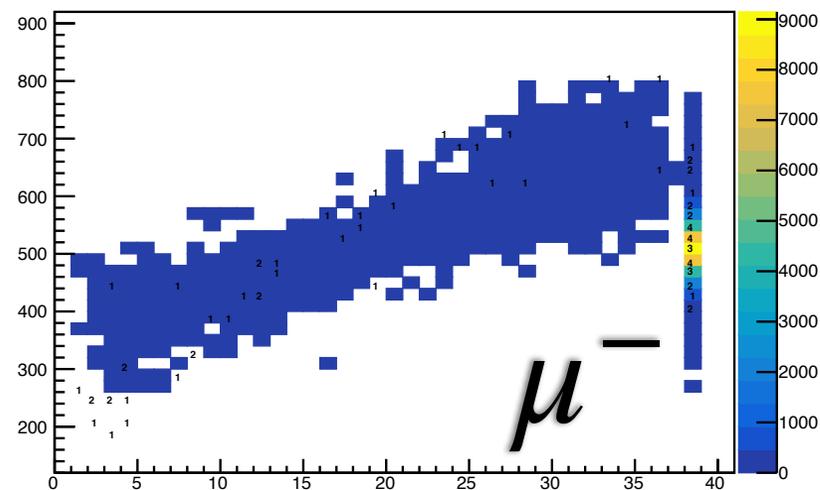
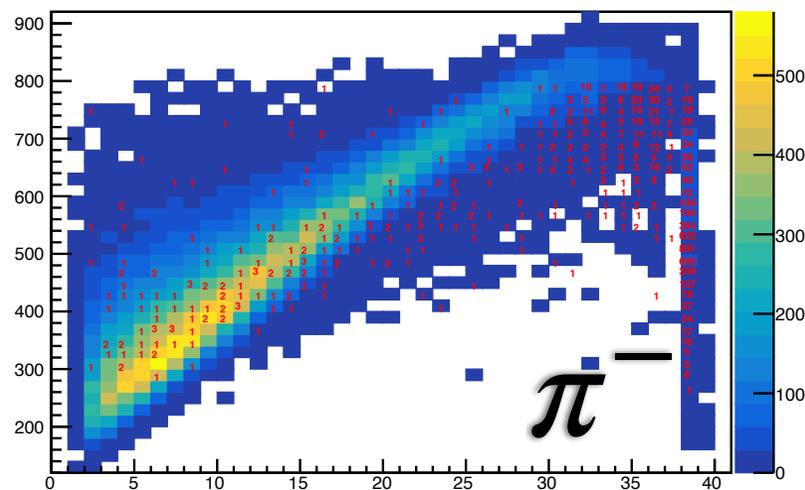
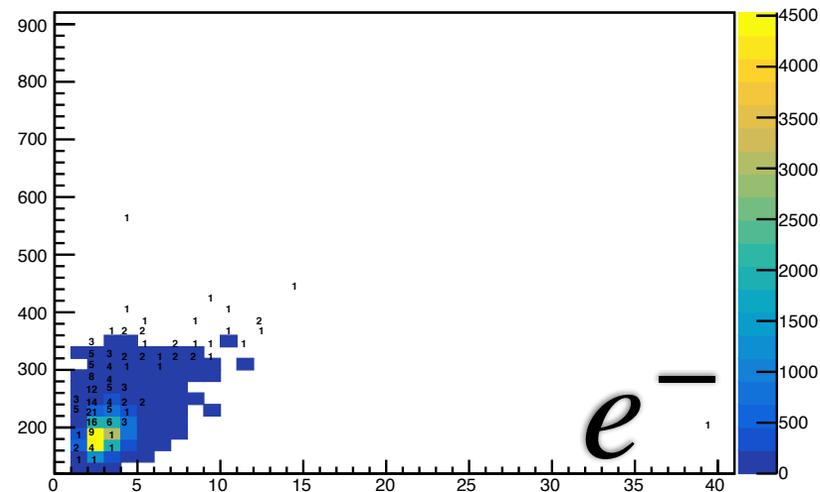
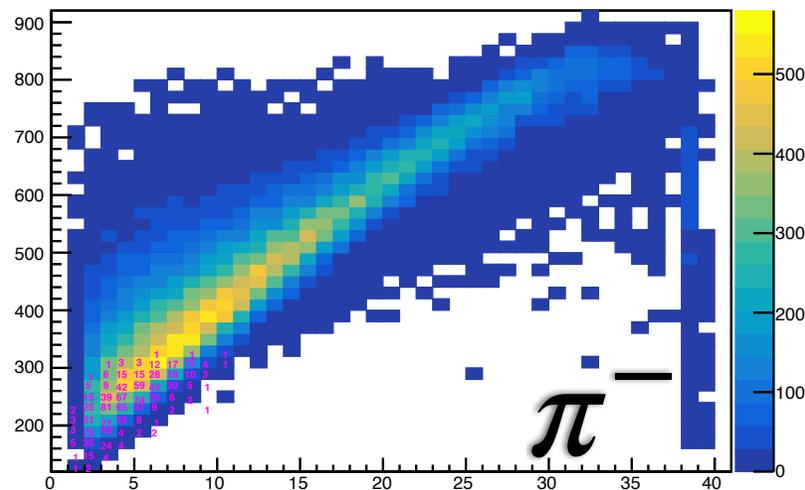
In each event:  $R = \frac{\sum_{i=1}^{N_{sh}} e_i \cdot r_i}{\sum_{i=1}^{N_{sh}} e_i}$   
 $N_{sh}$  is the number of shower hits  
 $e_i$  is the hit energy  
 $r_i = \sqrt{(x_i - x_0)^2 + (y_i - y_0)^2}$  is the hit radial distance from shower axis  $(x_0, y_0)$



# Other plots

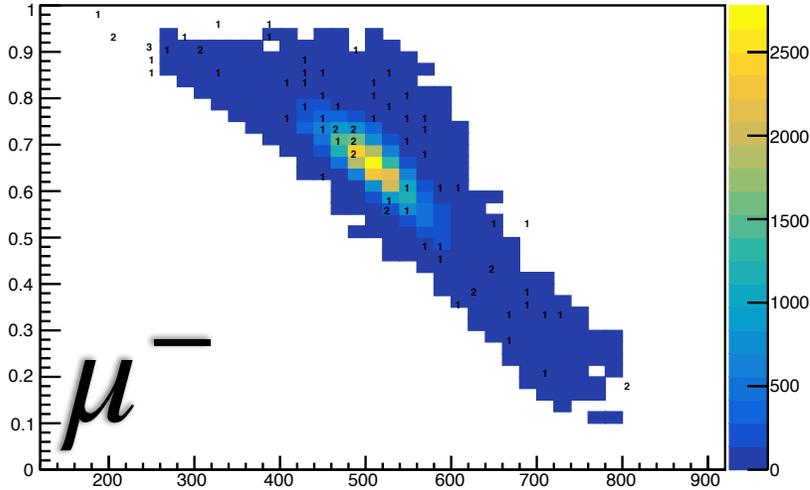
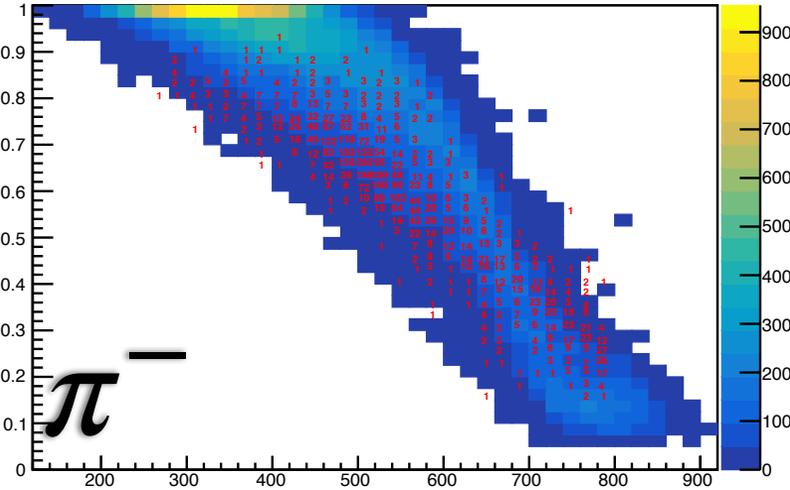
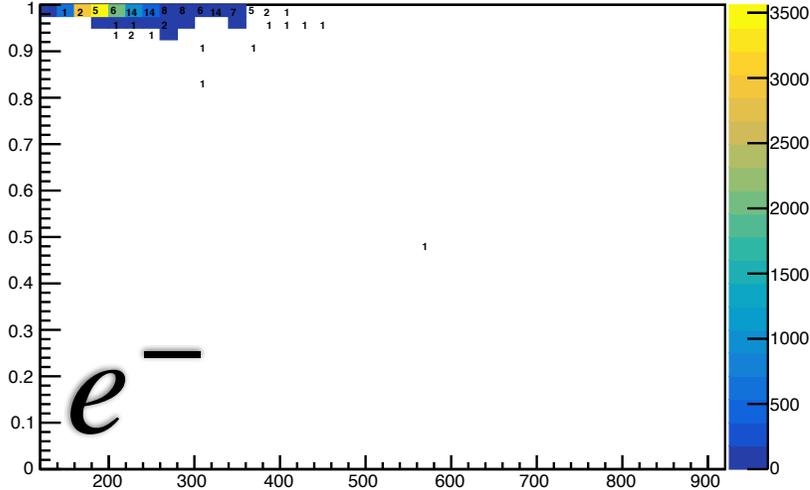
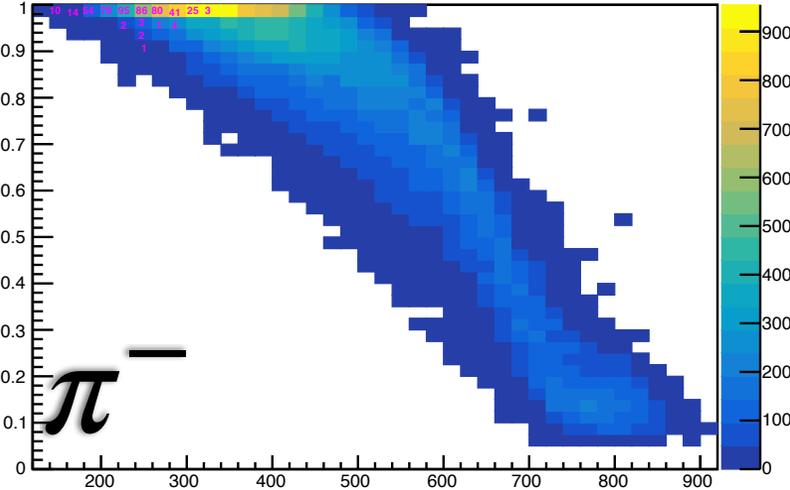
# Center of gravity in z vs shower start layer

MC 10GeV particles



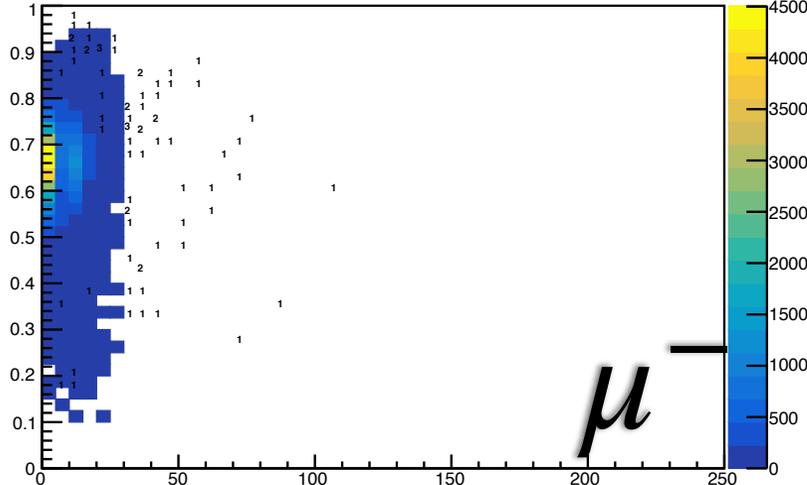
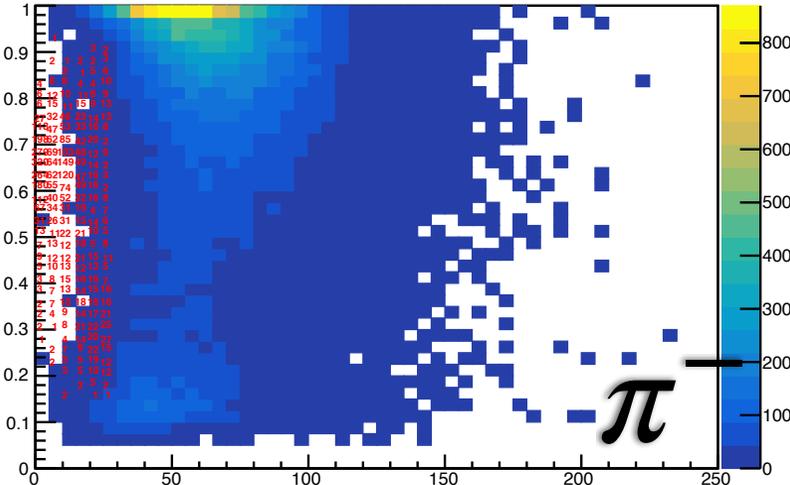
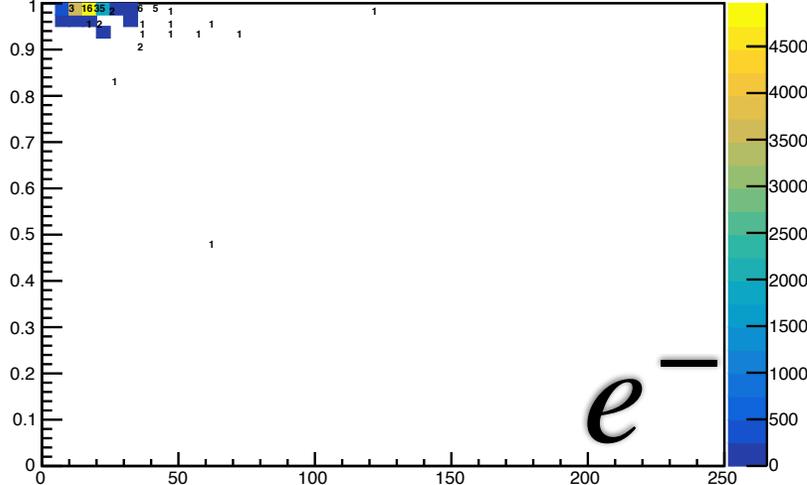
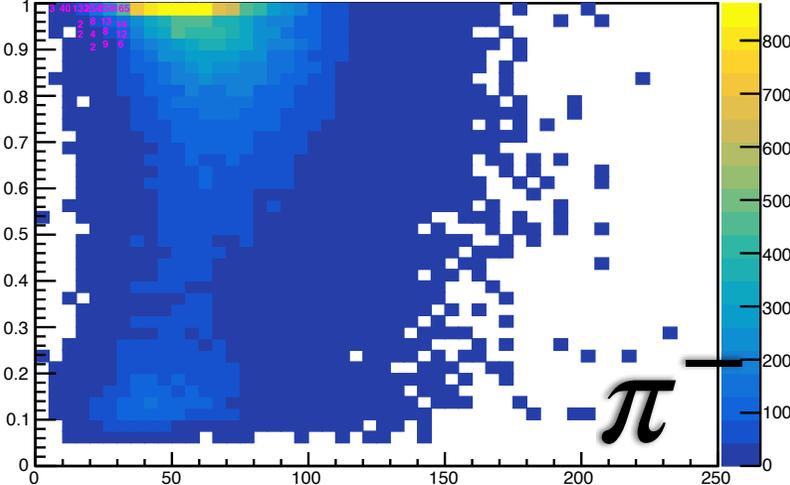
# Energy fraction in first 25 layers vs center of gravity in z

MC 10GeV particles



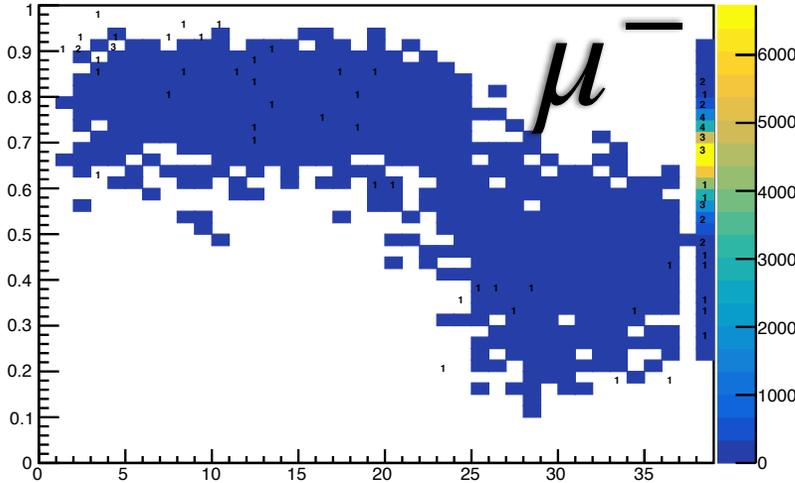
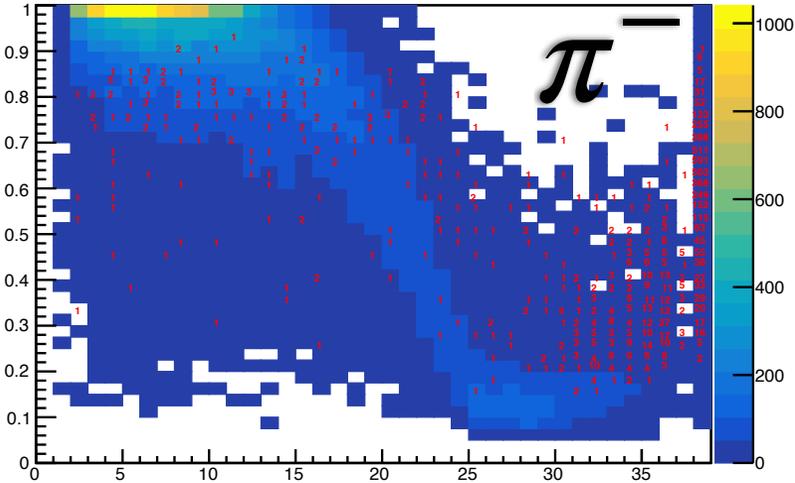
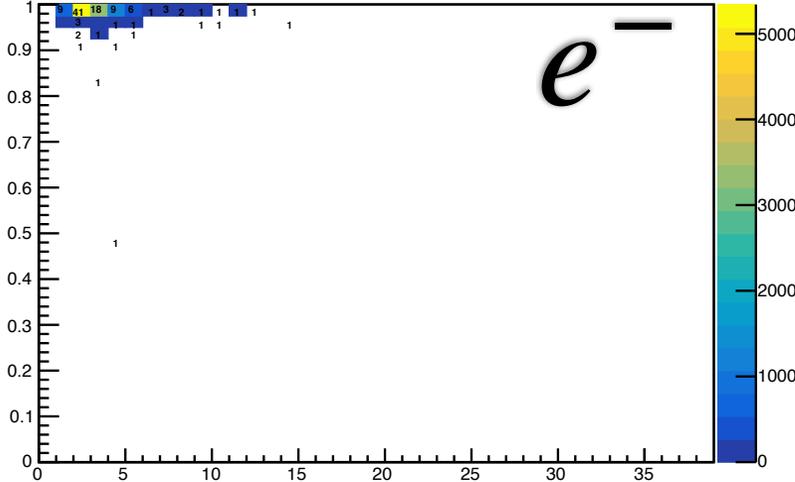
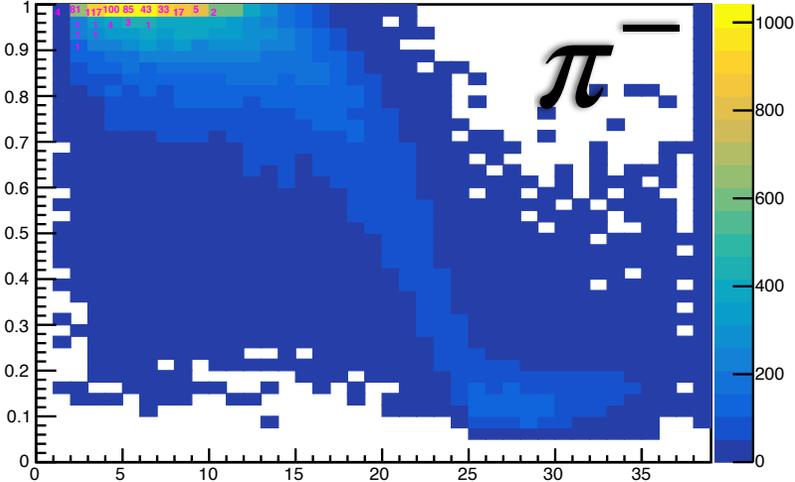
# Energy fraction in first 25 layers vs shower radius

MC 10GeV particles



# Energy fraction in first 25 layers vs shower start layer

MC 10GeV particles

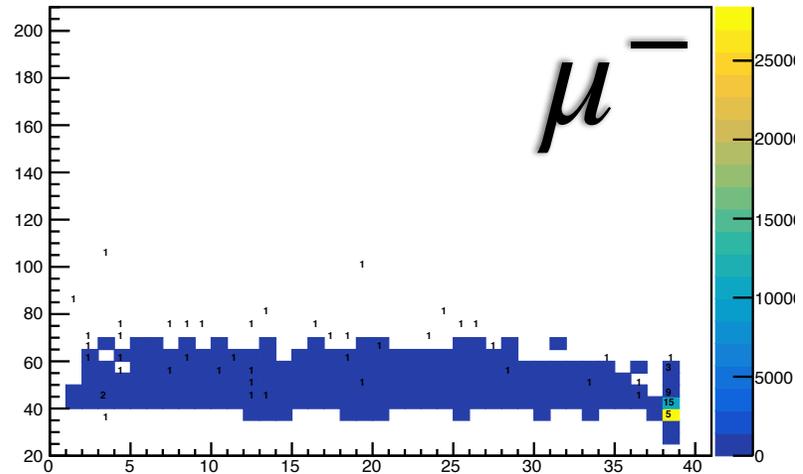
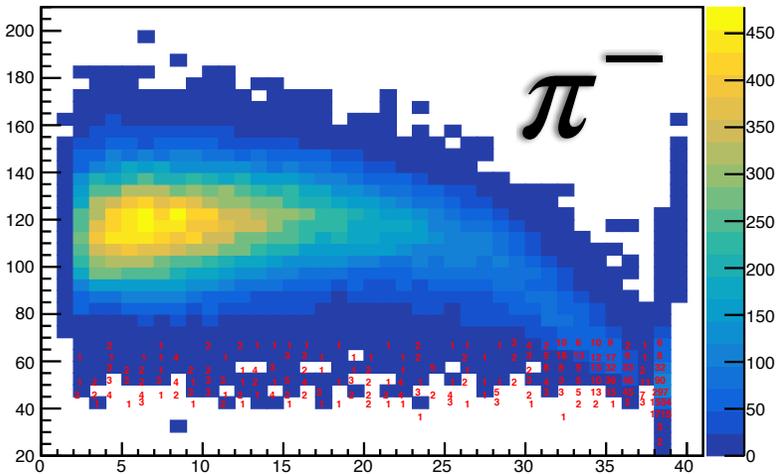
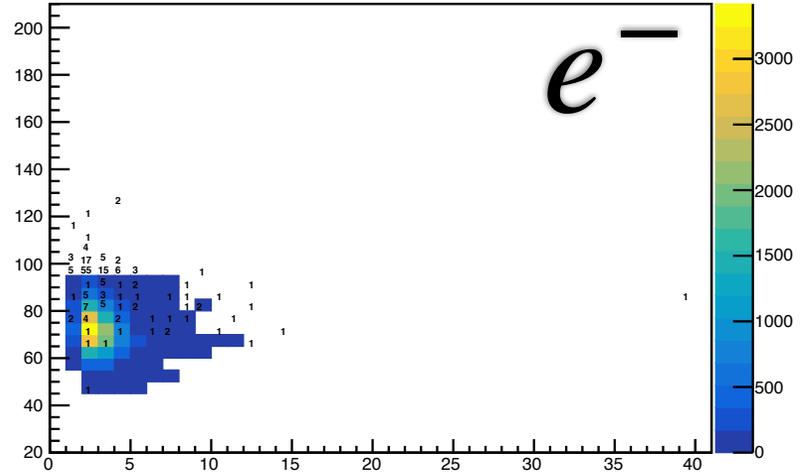
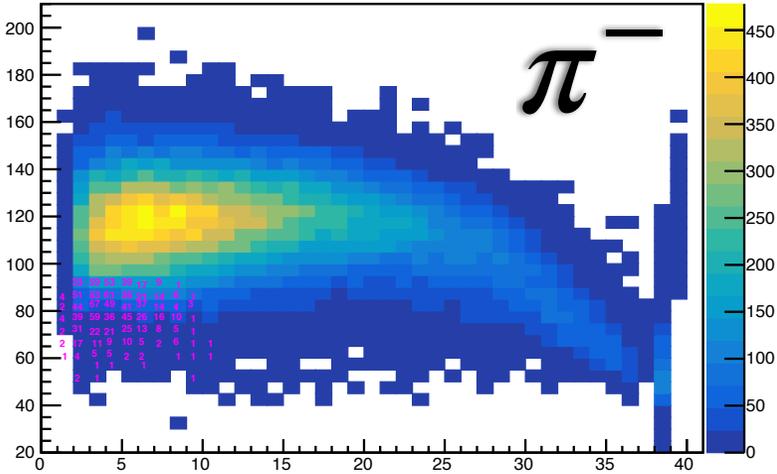






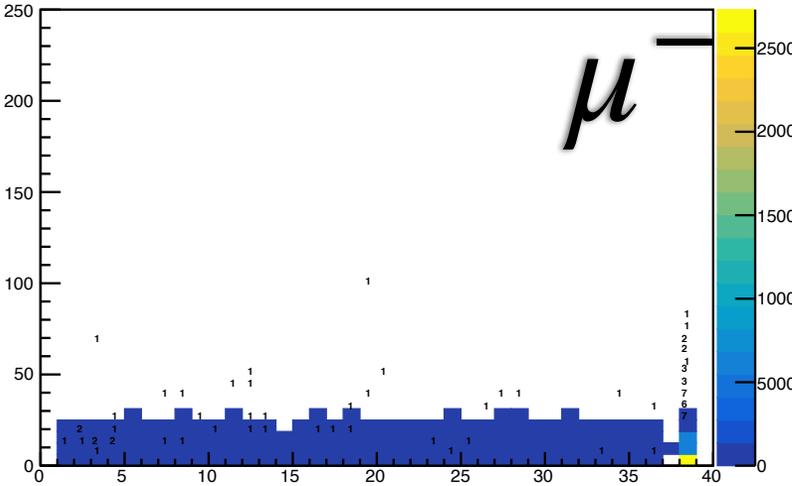
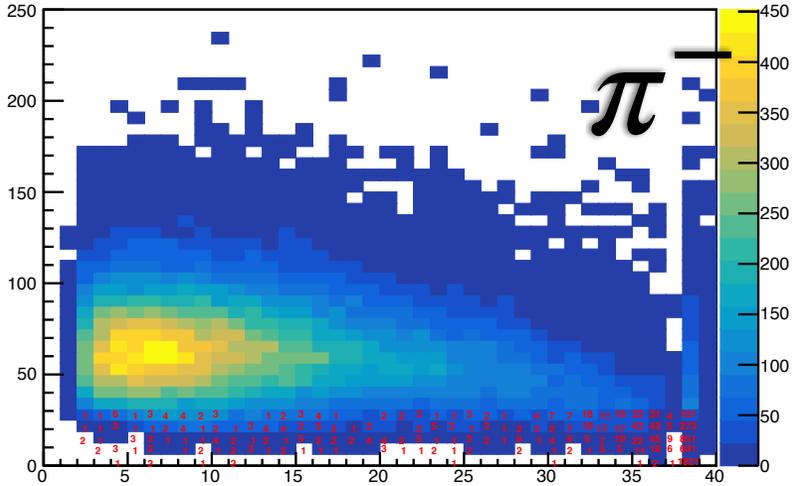
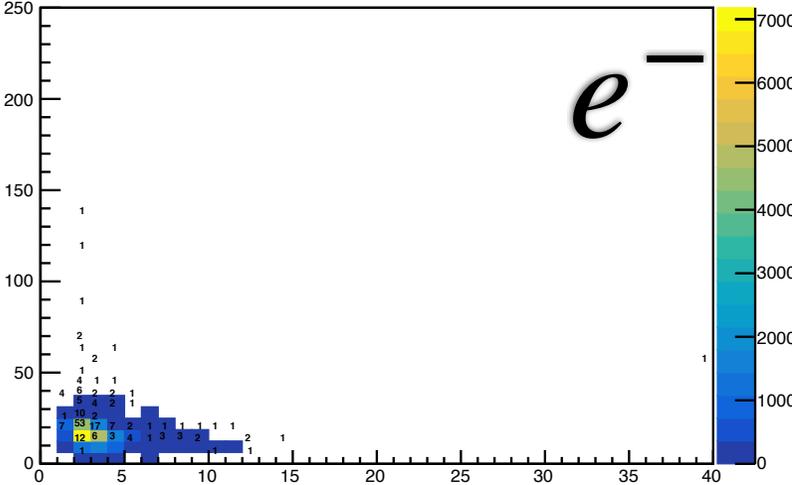
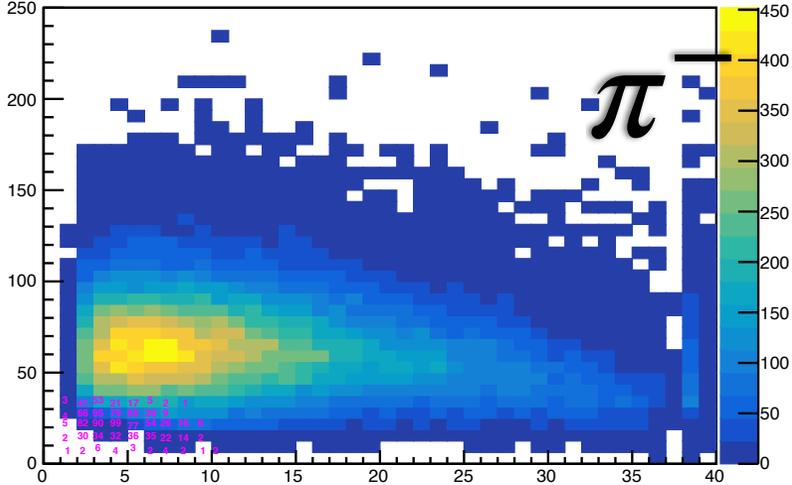
# Number of hits vs shower start

MC 10GeV particles



# Number of hits vs shower start

MC 10GeV particles

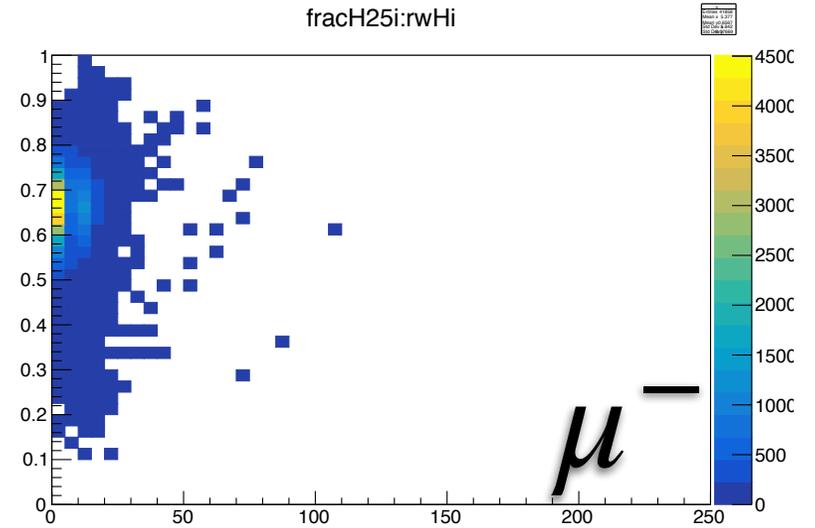
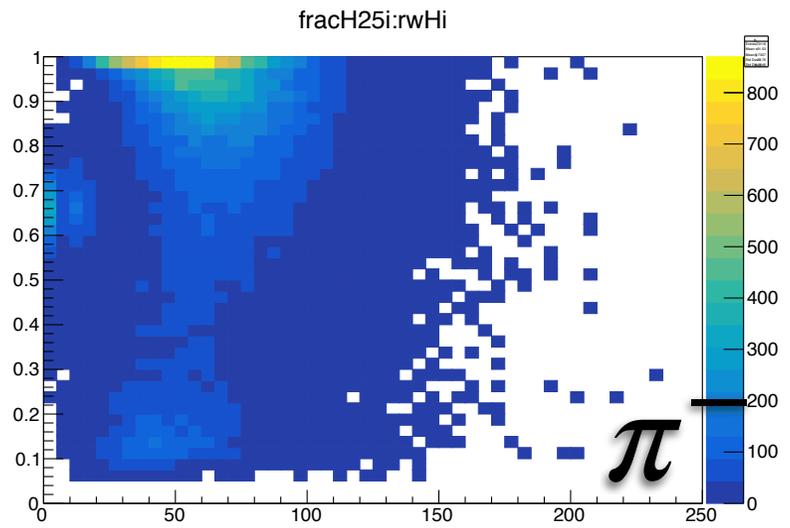
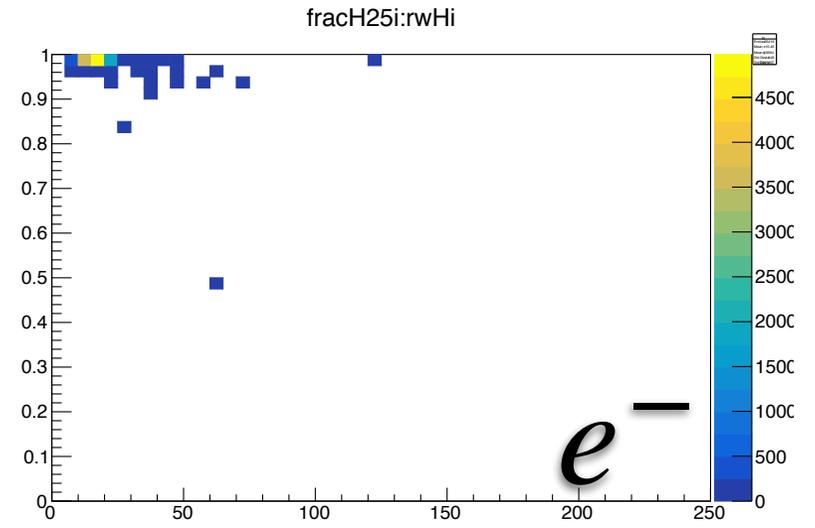
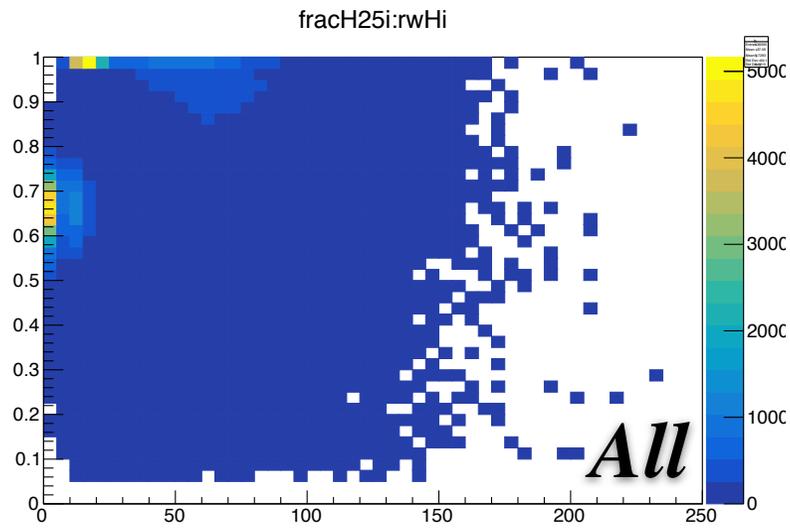


# 2D plots of observables

# Fraction in first 25 layers vs shower radius.

## MC 10GeV particles

- $\pi^-$  : 70118 events
- $\mu^-$  : 41858 events
- $e^-$  : 26419 events
- total* : 138395 events



# Fraction in first 25 layers vs shower start layer.

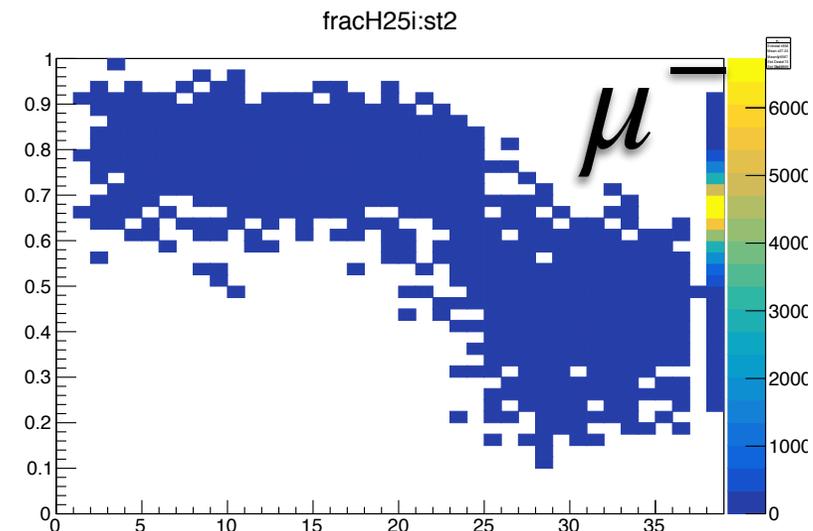
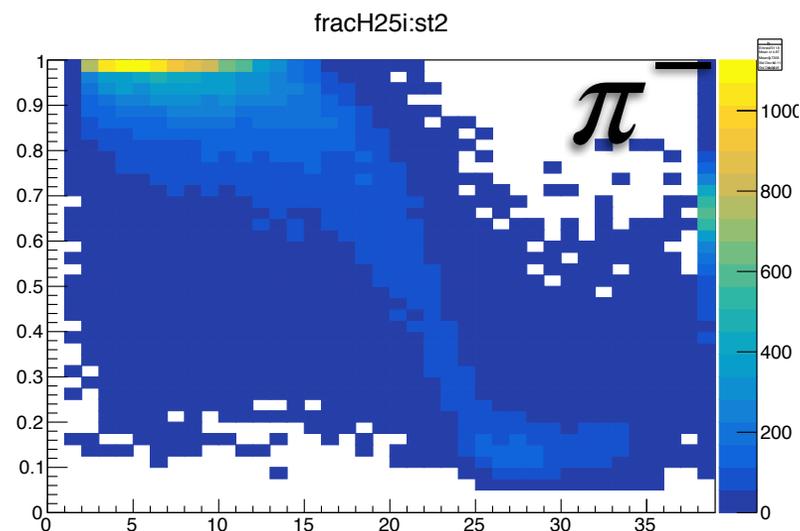
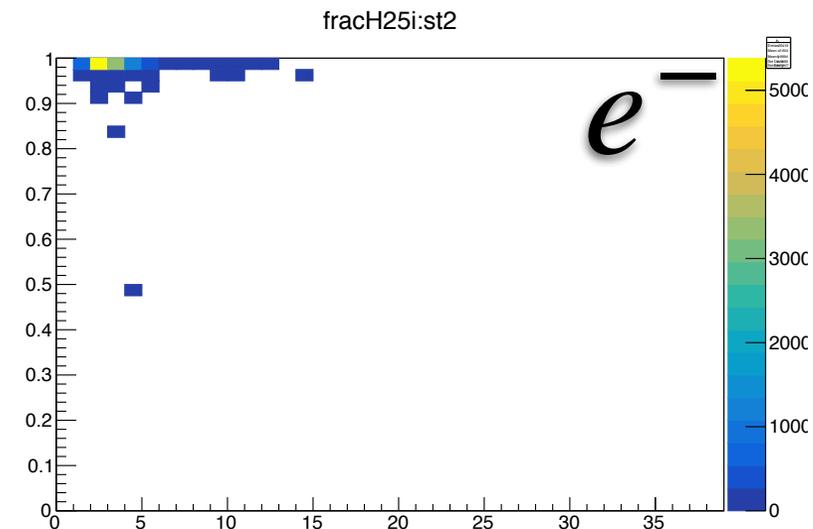
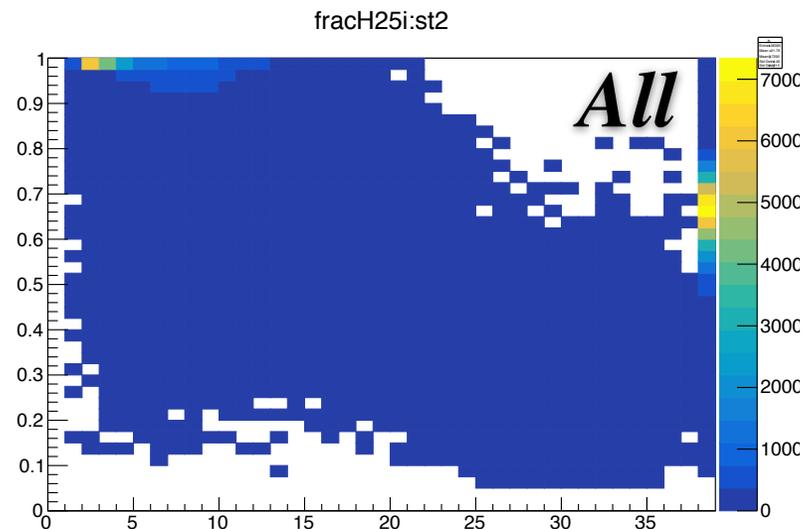
## MC 10GeV particles

$\pi^-$  : 70118 events

$\mu^-$  : 41858 events

$e^-$  : 26419 events

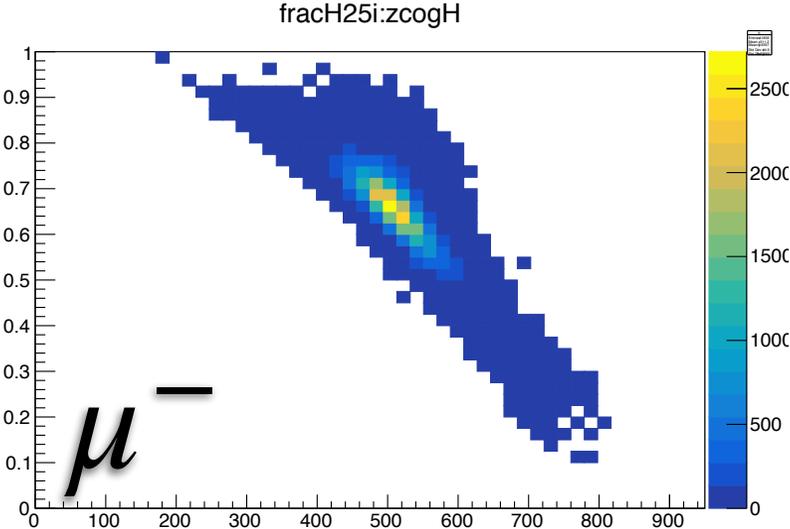
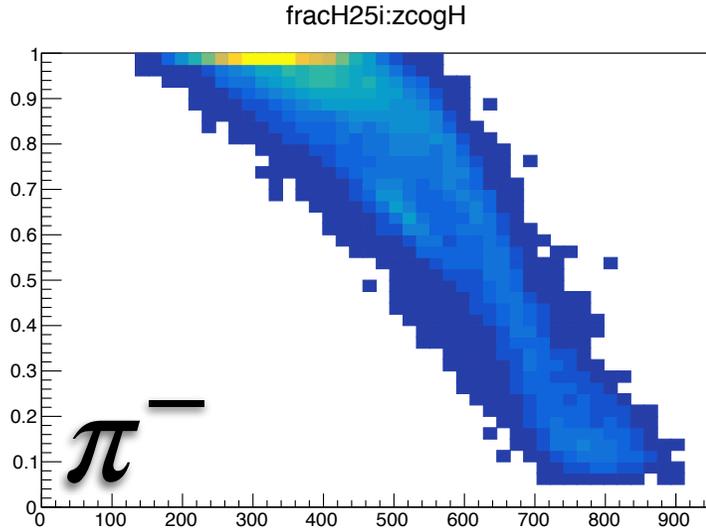
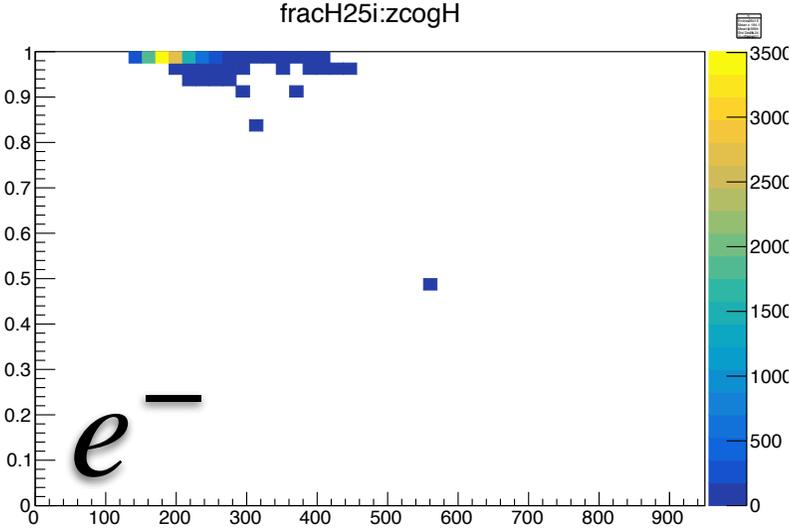
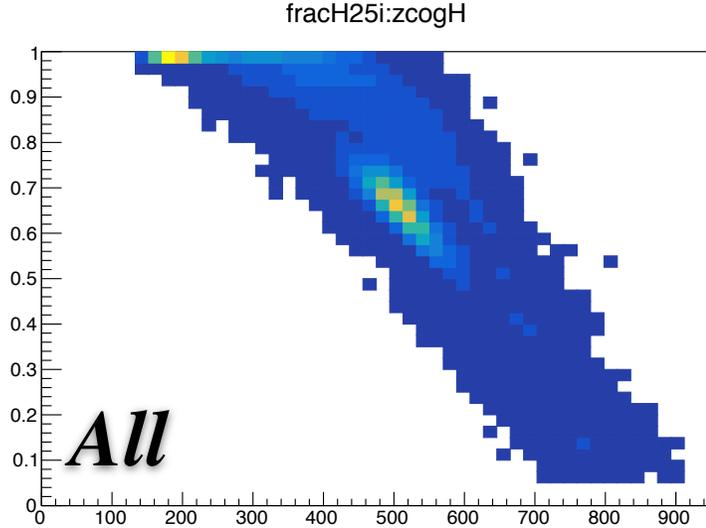
*total* : 138395 events



# Fraction in first 25 layers vs center of gravity in z.

## MC 10GeV particles

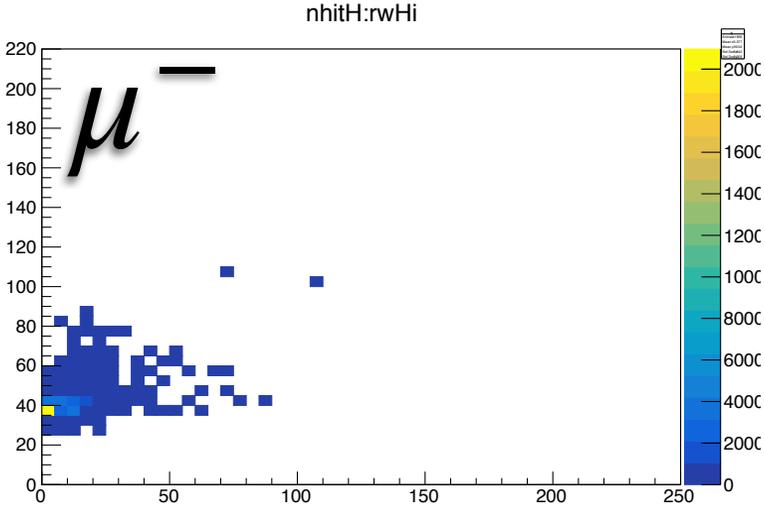
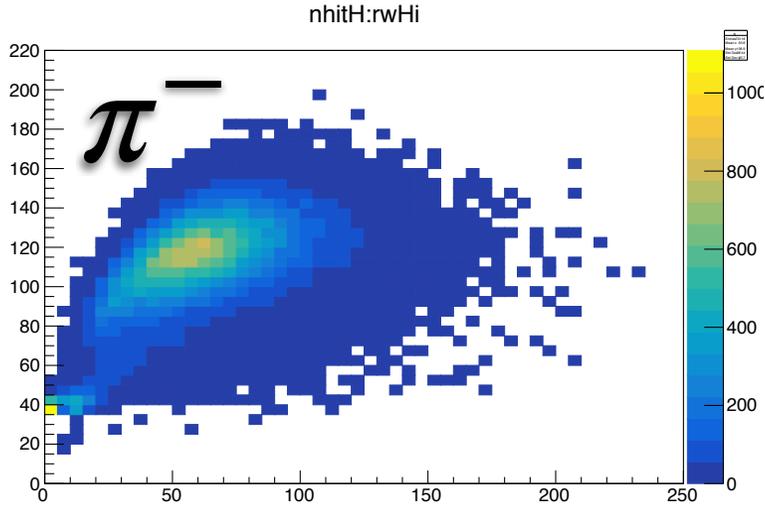
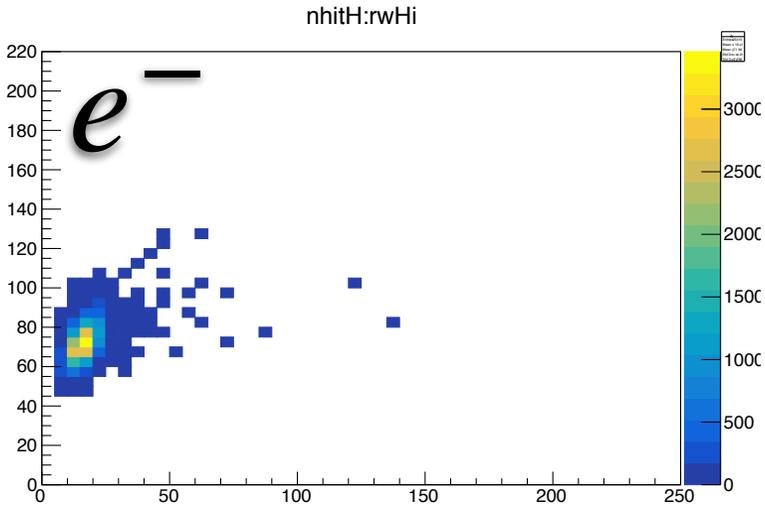
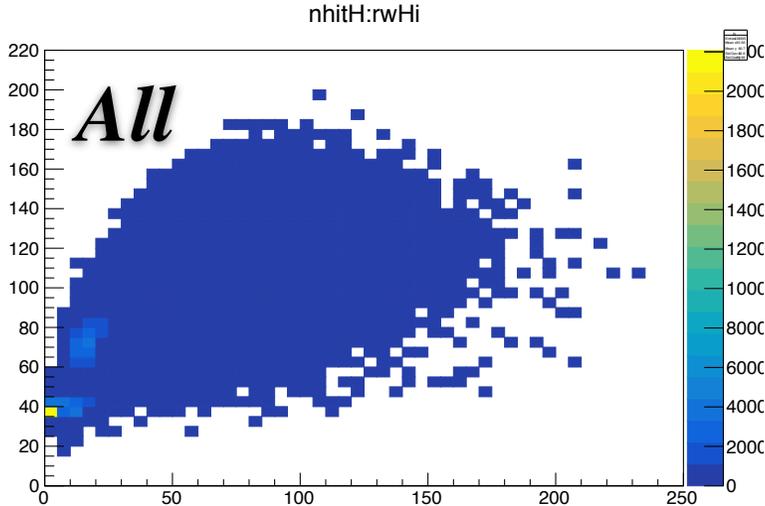
- $\pi^-$  : 70118 events
- $\mu^-$  : 41858 events
- $e^-$  : 26419 events
- total* : 138395 events



# Number of hits vs shower radius.

## MC 10GeV particles

- $\pi^-$  : 70118 events
- $\mu^-$  : 41858 events
- $e^-$  : 26419 events
- total* : 138395 events



# Number of hits vs center of gravity in z.

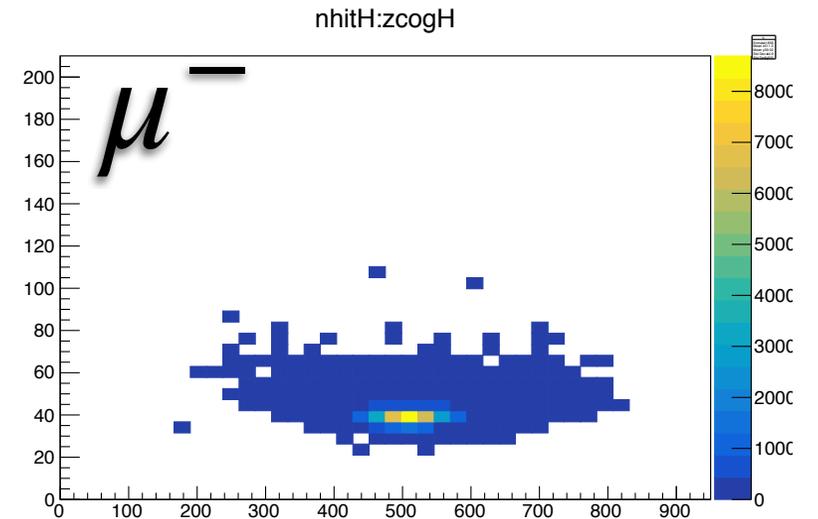
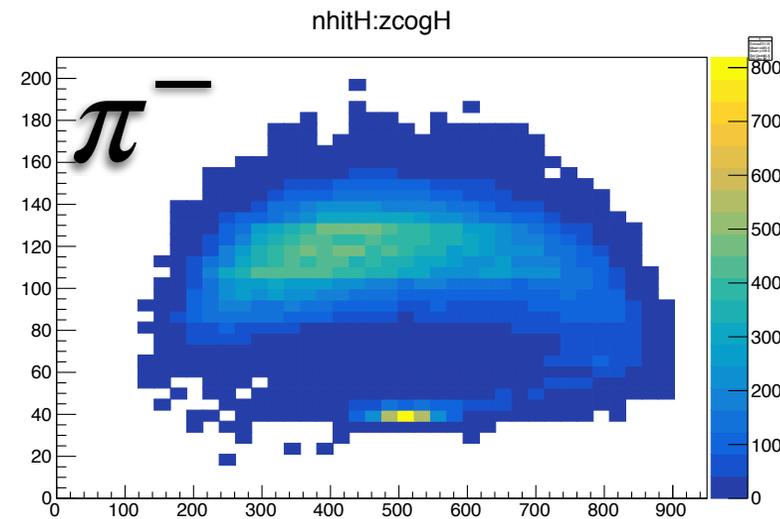
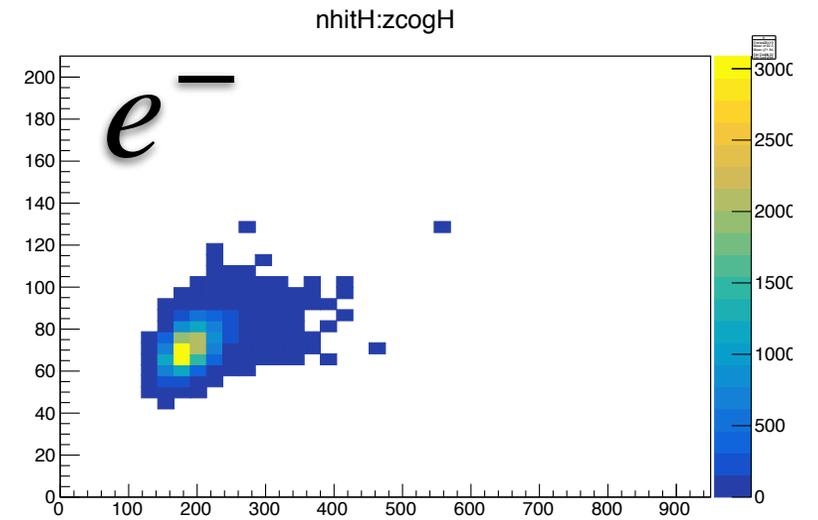
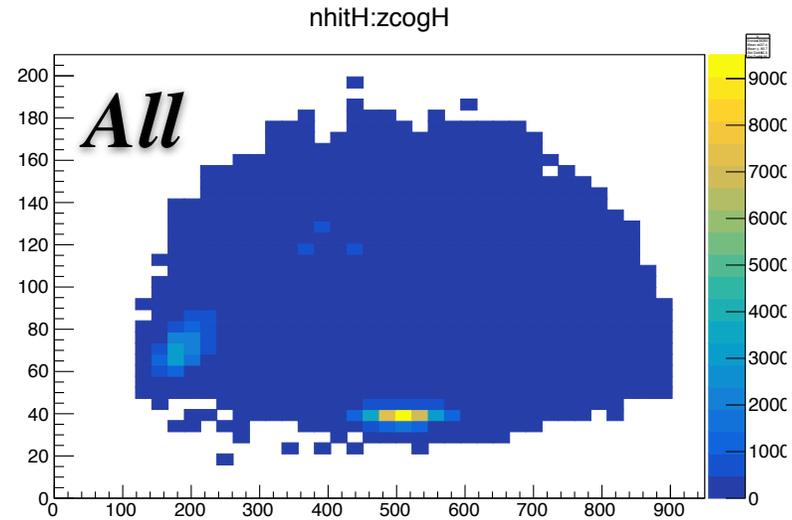
## MC 10GeV particles

$\pi^-$  : 70118 events

$\mu^-$  : 41858 events

$e^-$  : 26419 events

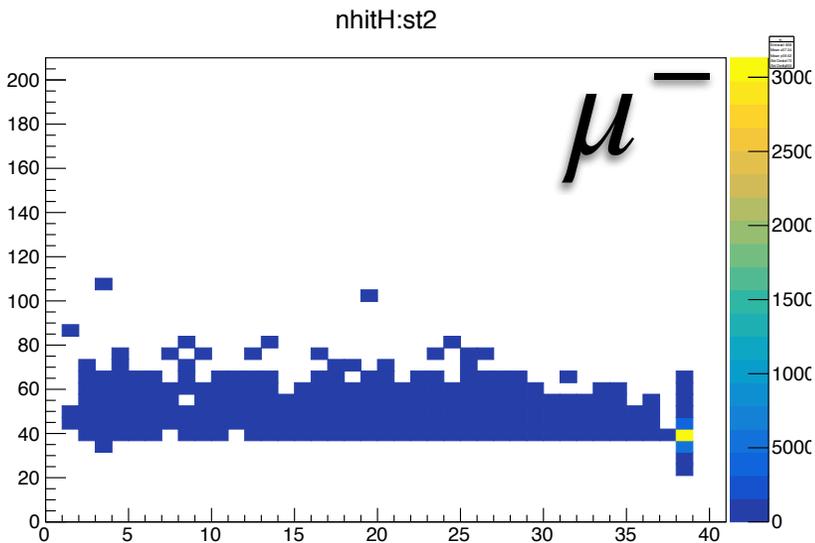
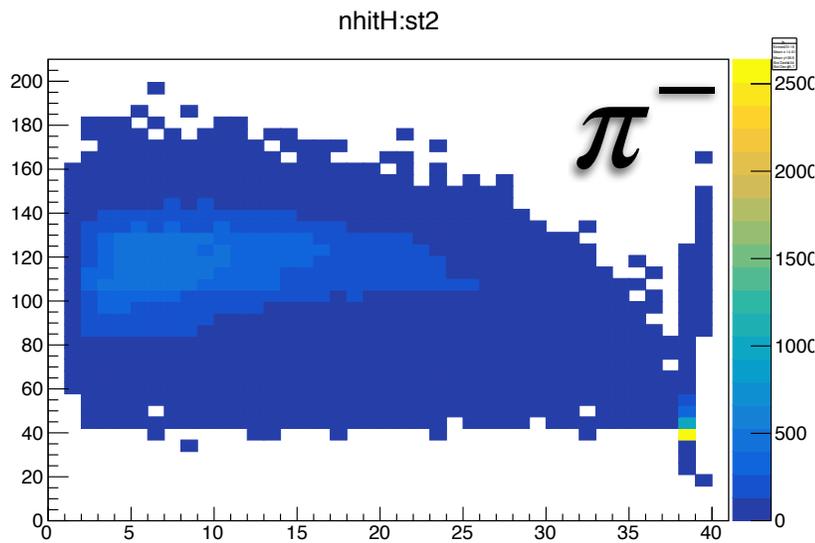
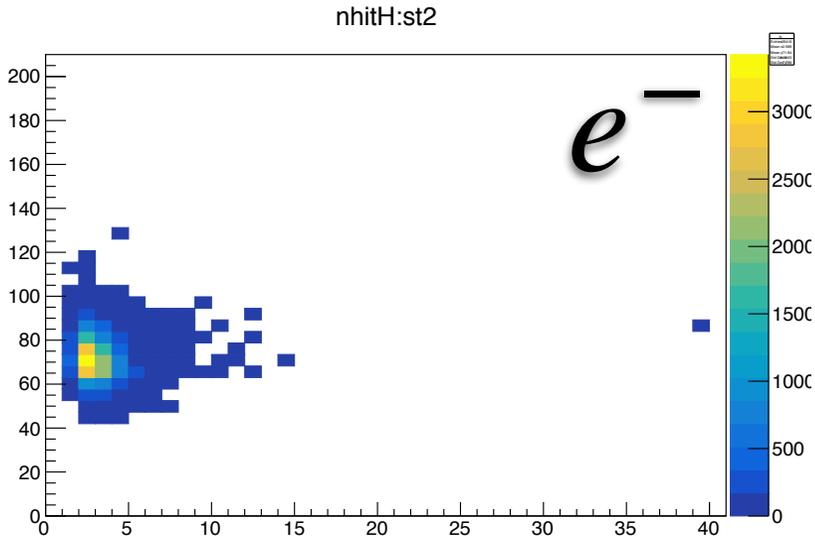
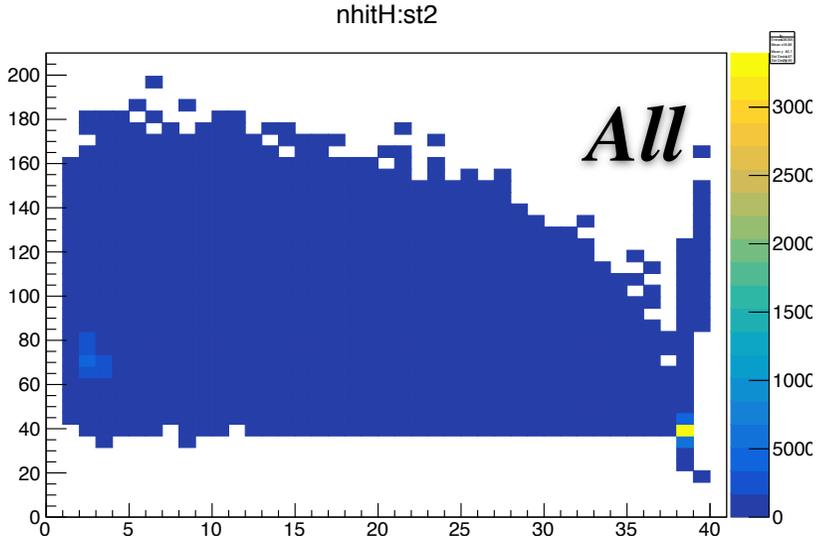
*total* : 138395 events



# Number of hits vs shower start layer.

## MC 10GeV particles

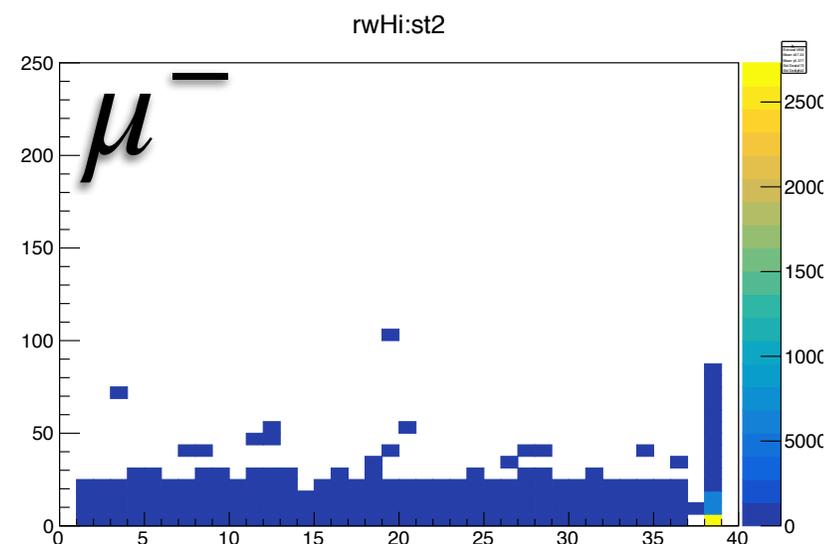
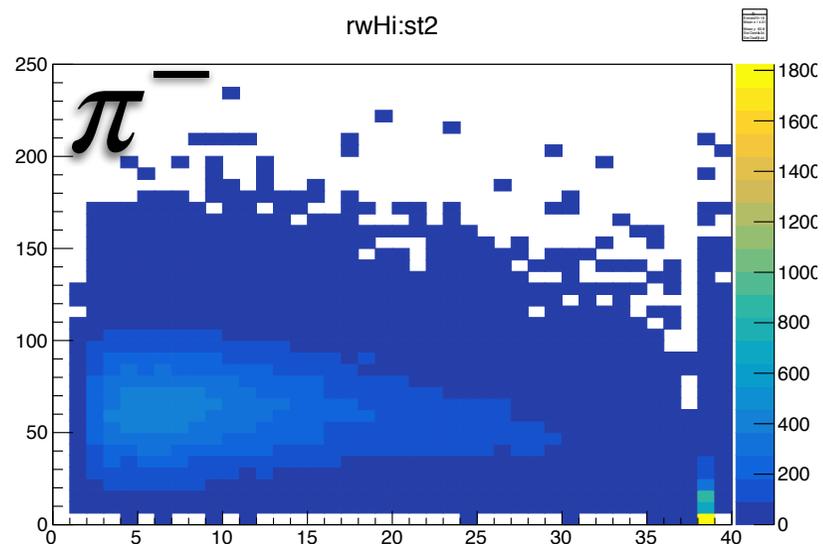
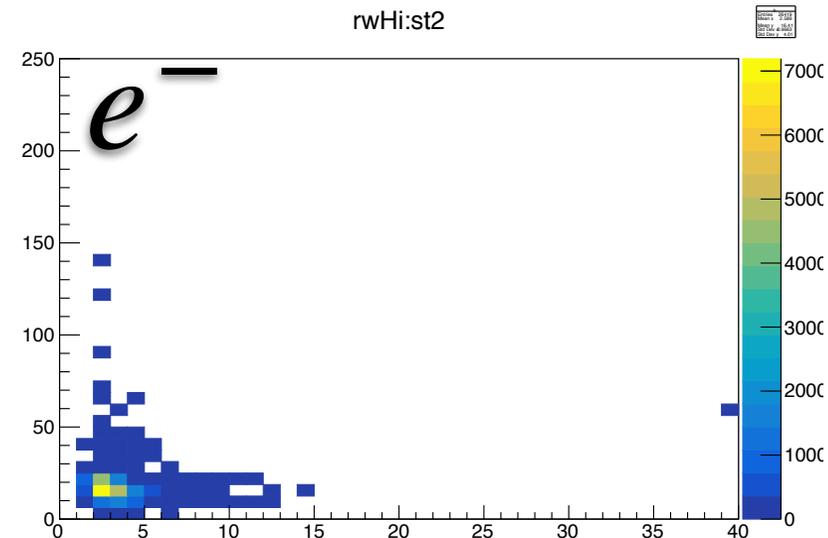
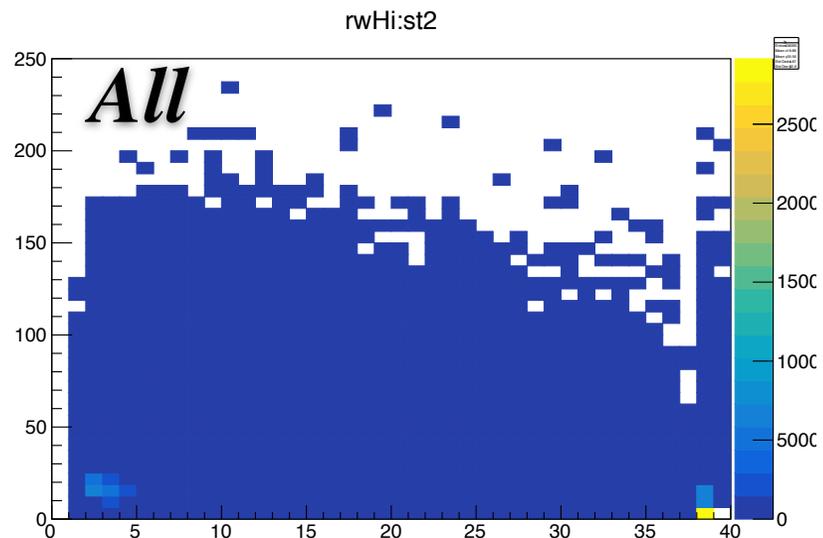
- $\pi^-$  : 70118 events
- $\mu^-$  : 41858 events
- $e^-$  : 26419 events
- total* : 138395 events



# Shower radius vs shower start layer.

## MC 10GeV particles

$\pi^-$  : 70118 events  
 $\mu^-$  : 41858 events  
 $e^-$  : 26419 events  
*total* : 138395 events



# Center of gravity in z vs shower start layer.

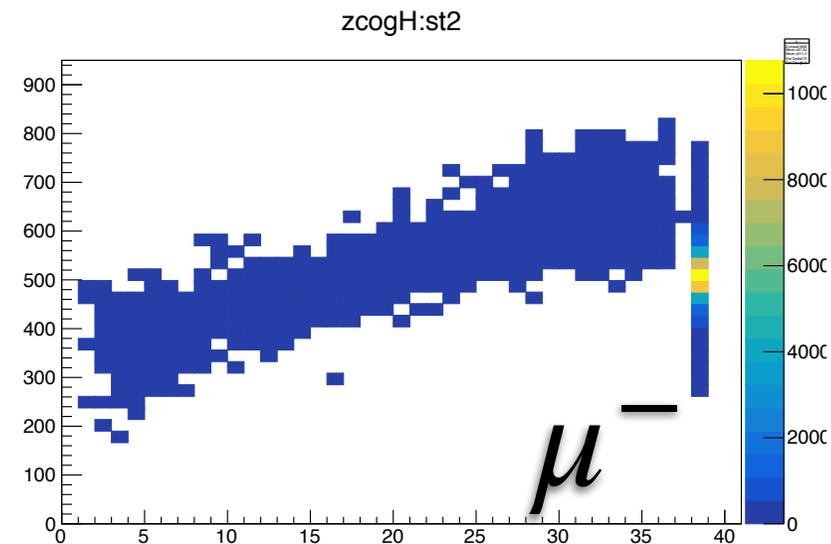
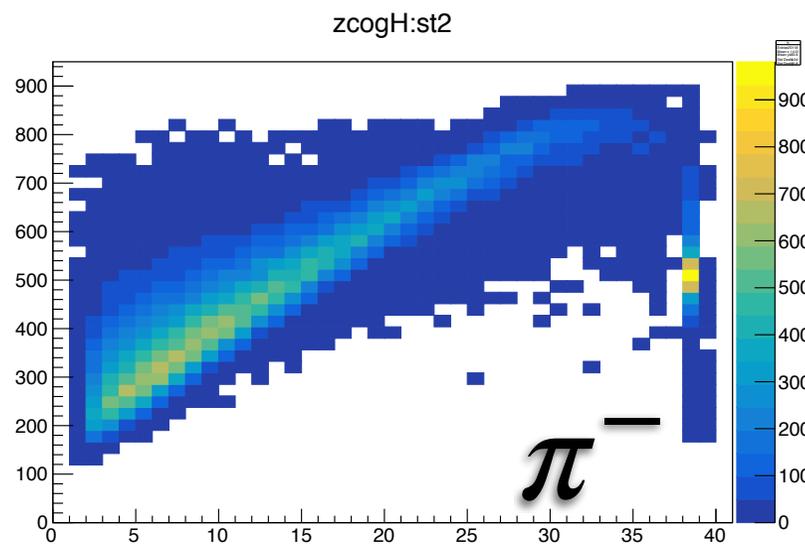
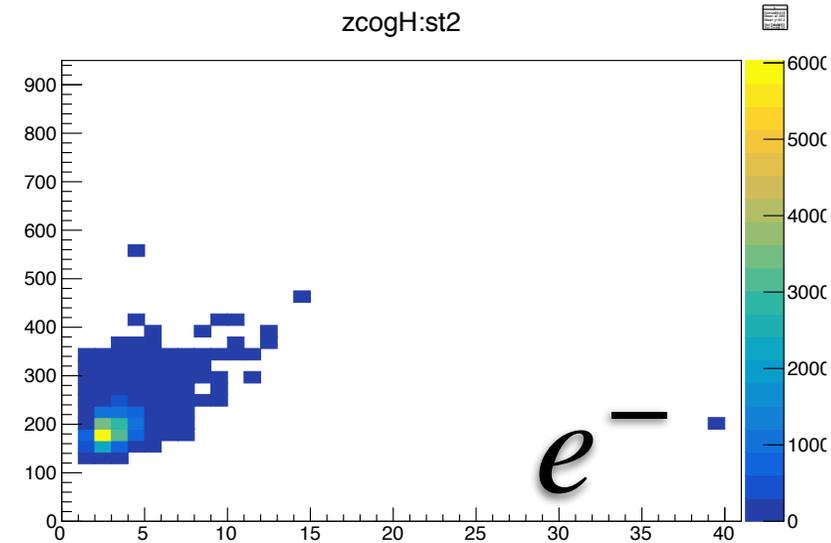
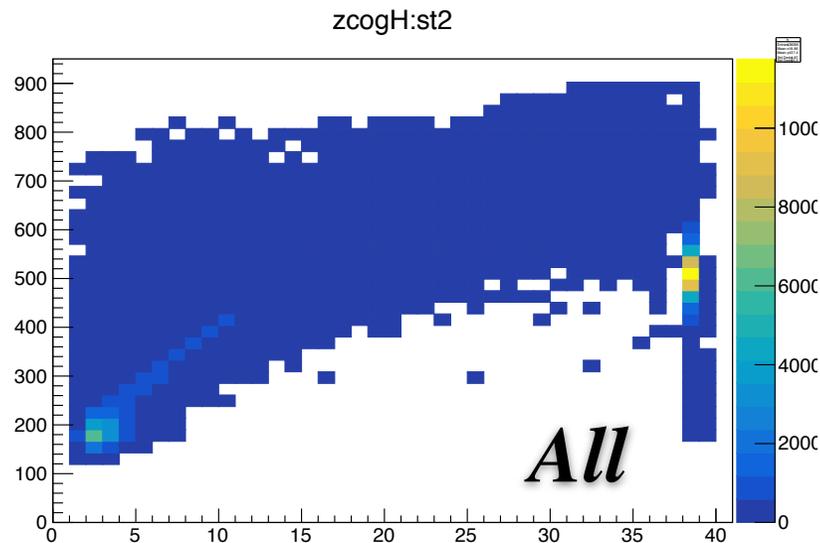
## MC 10GeV particles

$\pi^-$  : 70118 events

$\mu^-$  : 41858 events

$e^-$  : 26419 events

*total* : 138395 events



# Center of gravity in z vs shower start layer.

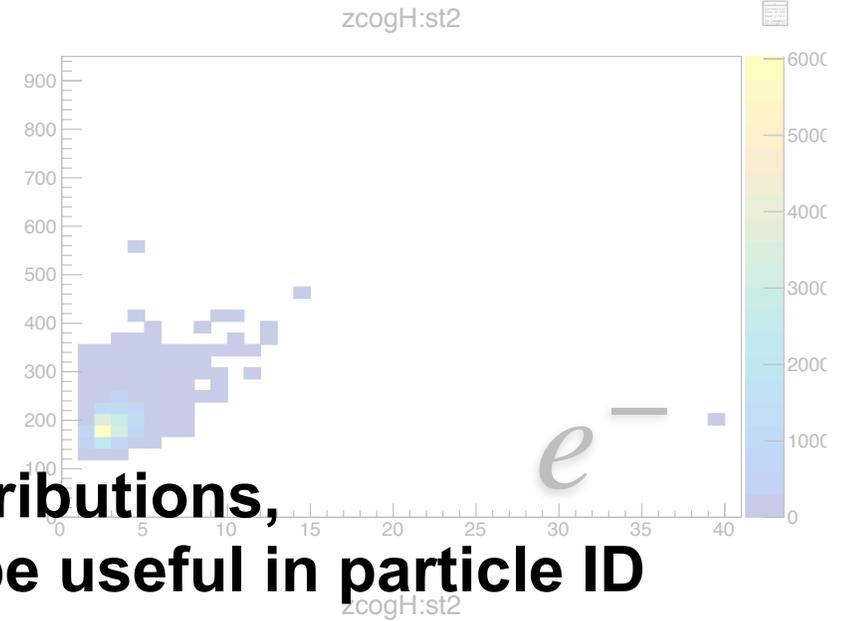
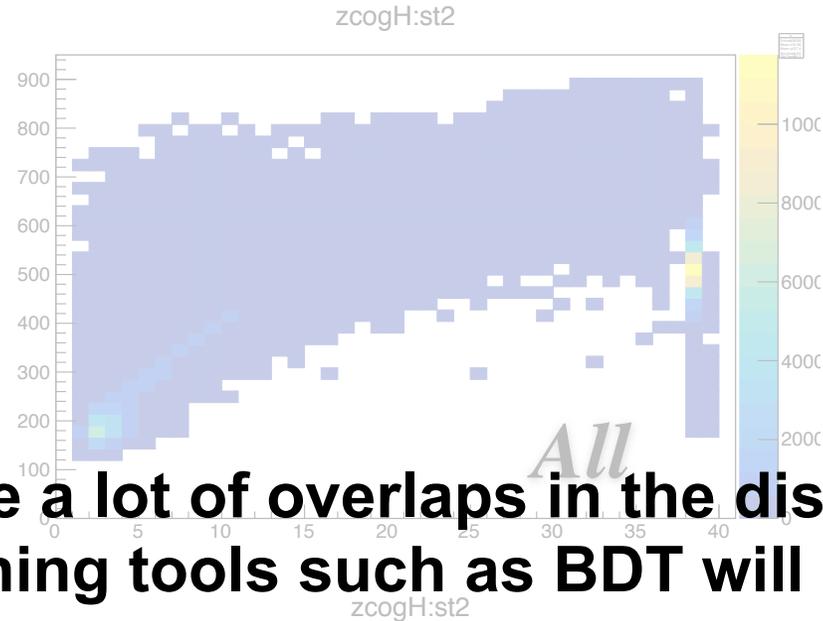
## MC 10GeV particles

$\pi^-$  : 70118 events

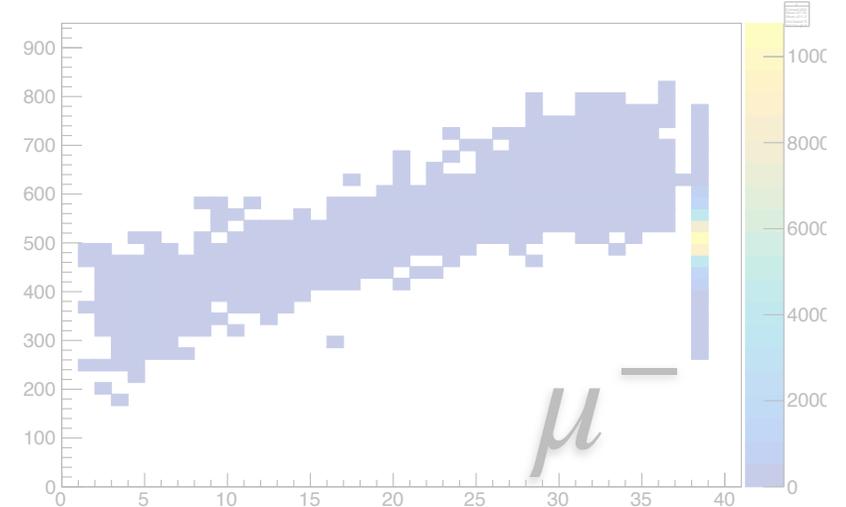
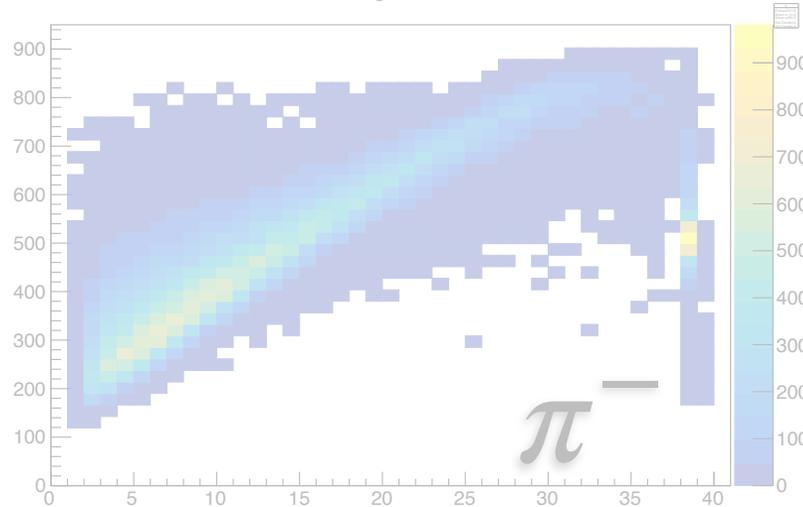
$\mu^-$  : 41858 events

$e^-$  : 26419 events

*total* : 138395 events



**Since we have a lot of overlaps in the distributions, machine learning tools such as BDT will be useful in particle ID**



# Event selection

By now optimised for low energy pion TB runs

# Event selection

By typology and cluster properties. Based on the physics prototype study\*.

Clustering, primary track and shower start finding precedes particle identification.  
The set of cuts need to be tuned more precisely.

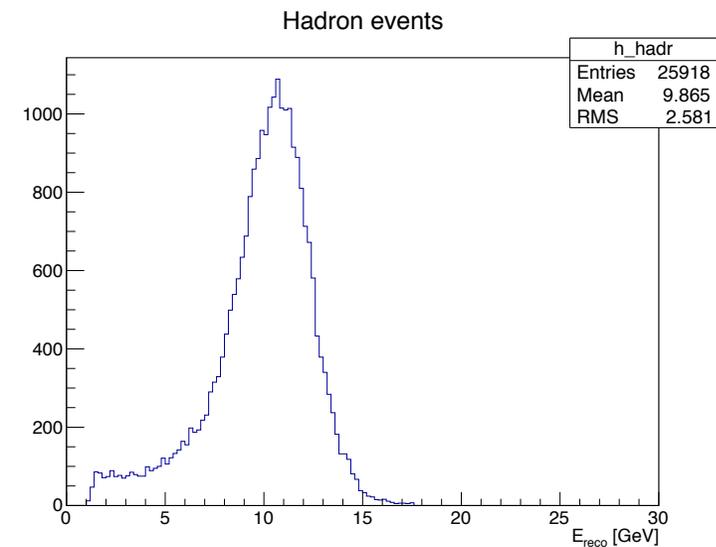
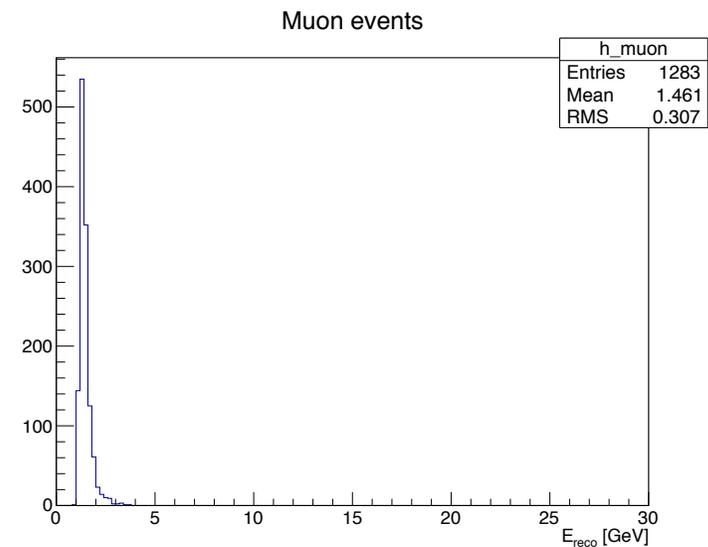
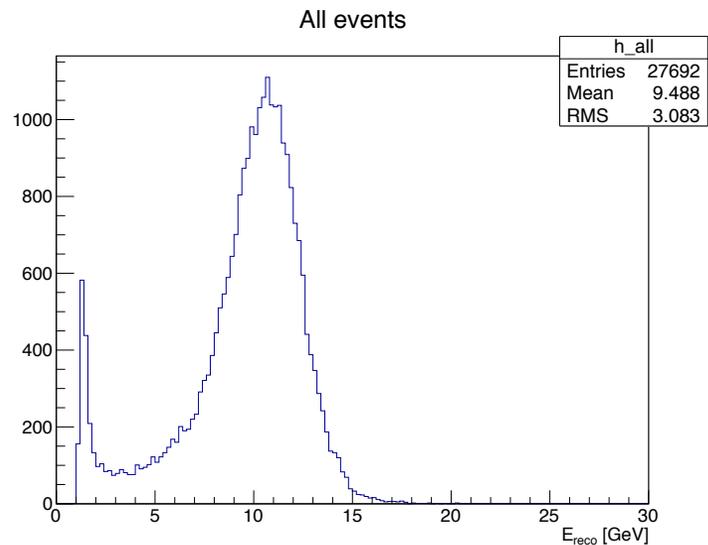
- **Multi-particle events**
  - Several clusters in first layers
  - Parallel tracks
  - Too high deposition
- **Muons or muon-like events**
  - Number of hits
  - Track finding
  - Shower start (optional w/o tail catcher)
- **Electrons**
  - Cluster radius
  - COG depth
  - 90% of measured energy deposited in first 25 layers
  - Shower start before 6th layer
- **Hadrons**
  - Remaining events
  - Events with shower start at first layer(electrons) and after 7th layer(muons, muon-like) can be rejected

\*[https://agenda.linearcollider.org/event/7454/contributions/38731/attachments/31380/47203/chadeeva\\_Fe-W\\_LL2017.pdf](https://agenda.linearcollider.org/event/7454/contributions/38731/attachments/31380/47203/chadeeva_Fe-W_LL2017.pdf)

# MC pions 10 GeV

## Energy distributions

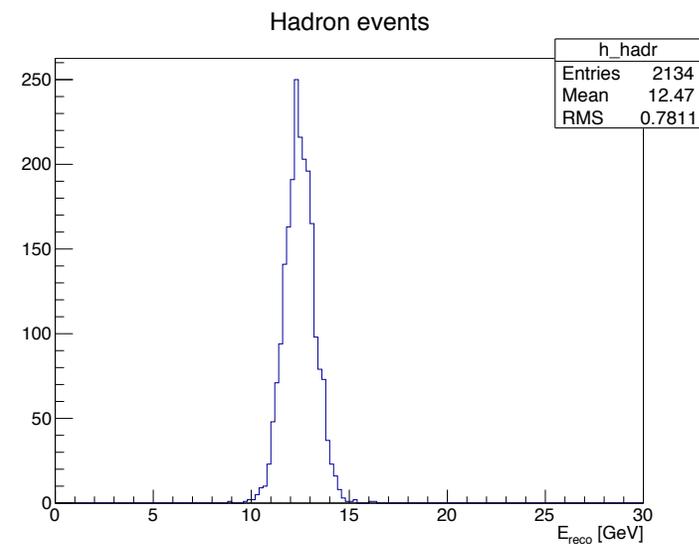
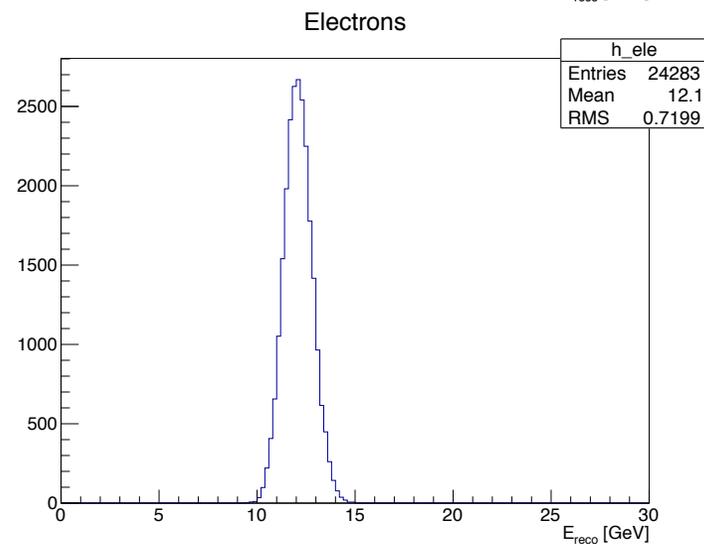
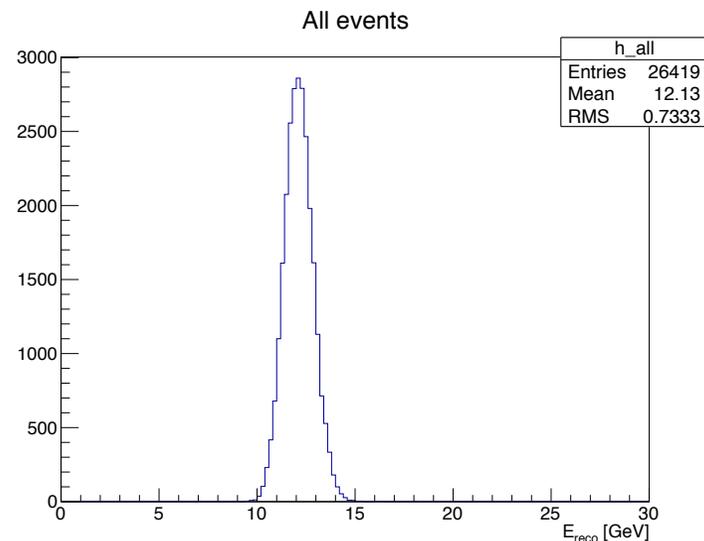
- **27692** events in total
- **1** - empty (low number of hits or deposited energy)
- **1283** muon-like events
- **415** multi-particle events
- **75** electron events
- **25918** hadron events (**~94%**)



# MC electrons 10 GeV

## Energy distributions

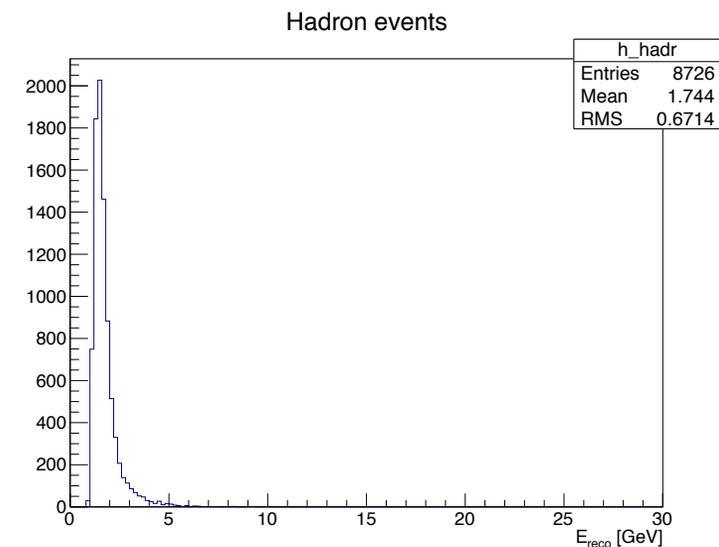
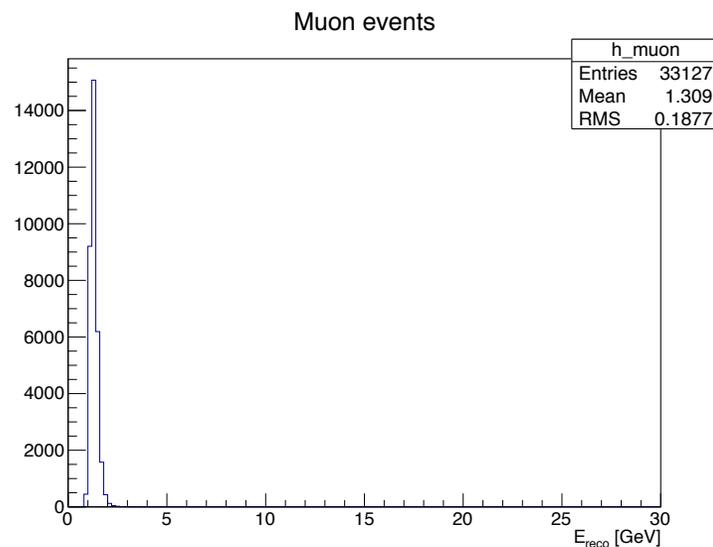
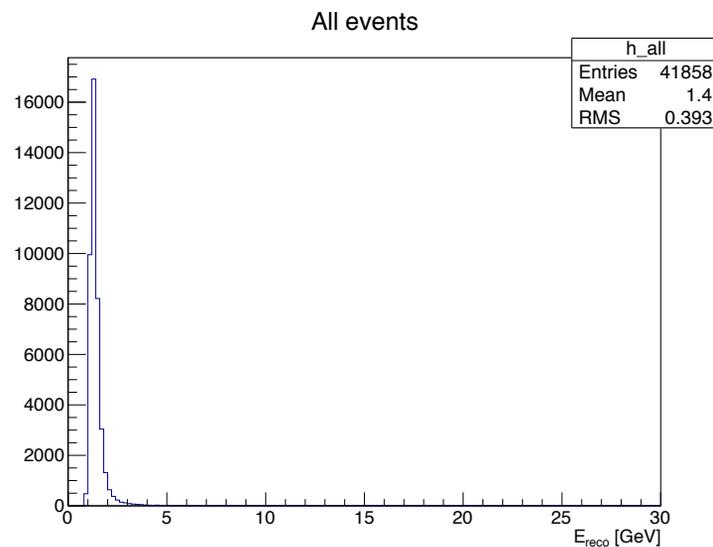
- **26419** events in total
- **0** empty events (low number of hits or deposited energy)
- **0** muon-like events
- **2** multi-particle events
- **24283** electron events (**~92%**)
- **2134** hadron events



# MC muons 10 GeV

## Energy distributions

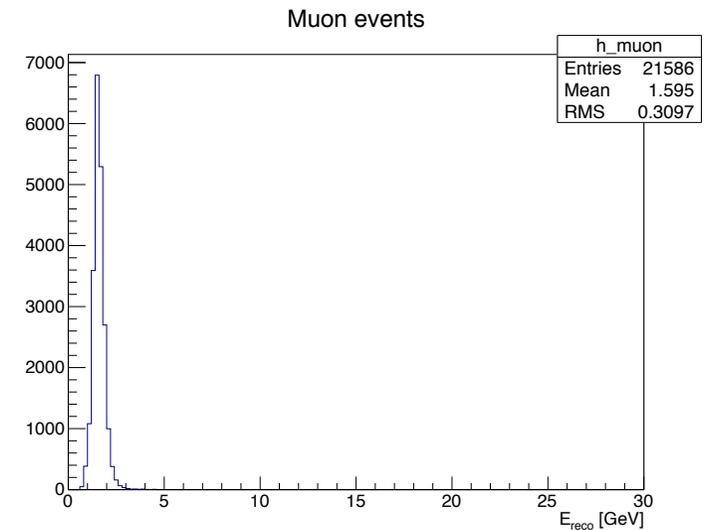
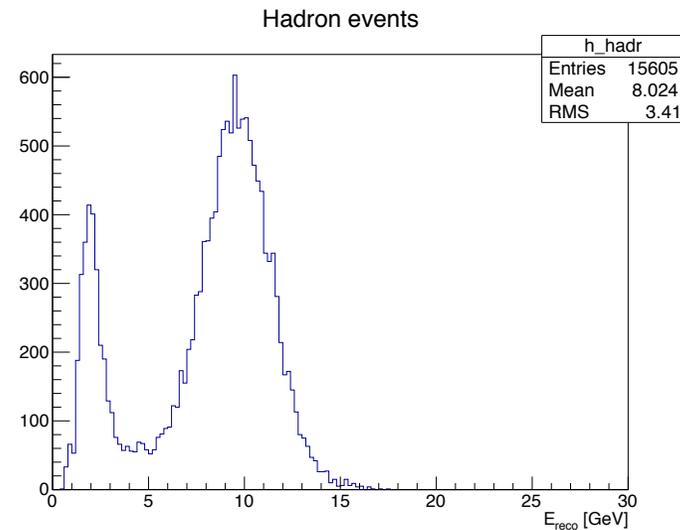
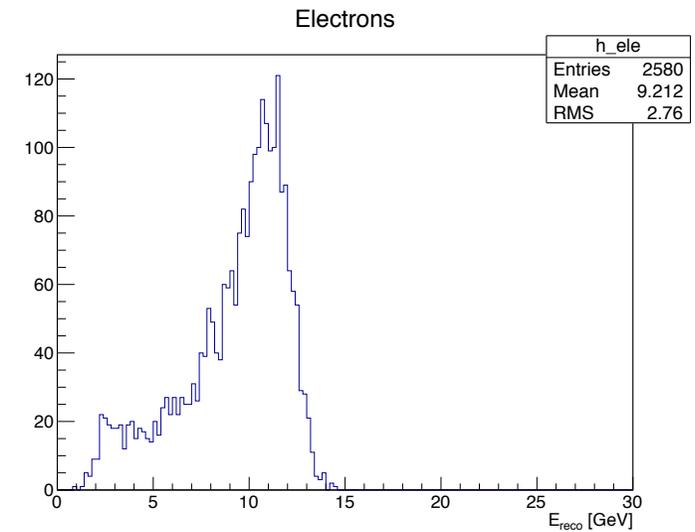
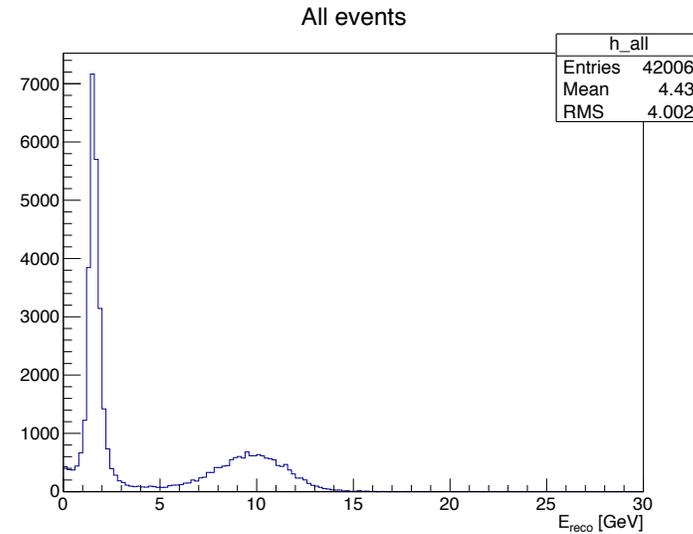
- **41858** events in total
- **0** empty events (low number of hits or deposited energy)
- **33127** muon-like events (~79%)
- **0** multi-particle events
- **5** electron events
- **8726** hadron events



# TBMay 10GeV pion run

## Energy distributions. Run 60629.

- **42006** events in total
- **2042** empty events (low number of hits or deposited energy)
- **21586** muon-like events
- **193** multi-particle events
- **2580** electron events
- **15605** hadron events



# TBMay 10GeV pion run

## Energy distributions. Run 60629.

- 42006 events in total
- 2042 empty events (low number of hits)

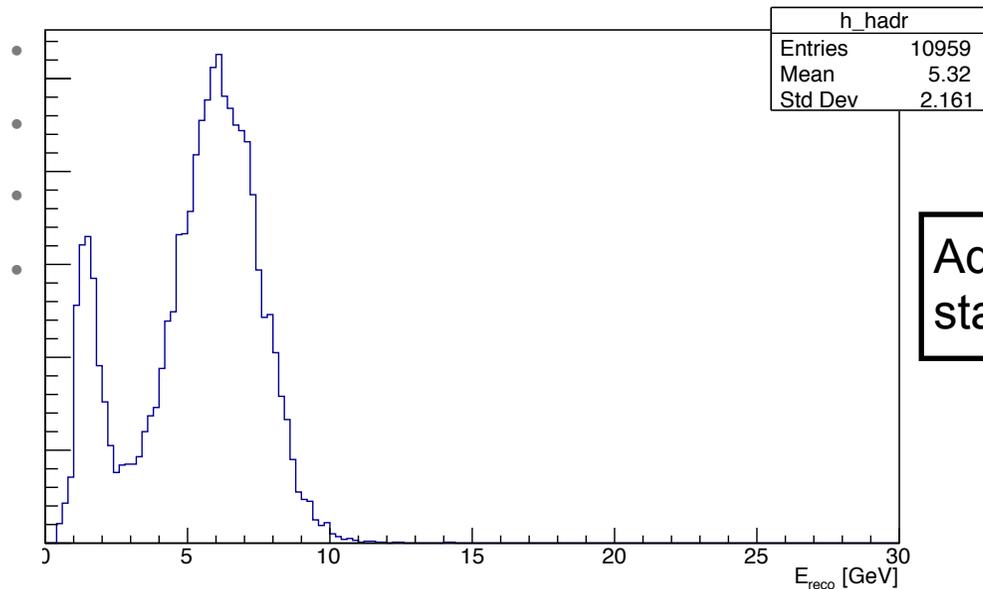
All events



Electrons

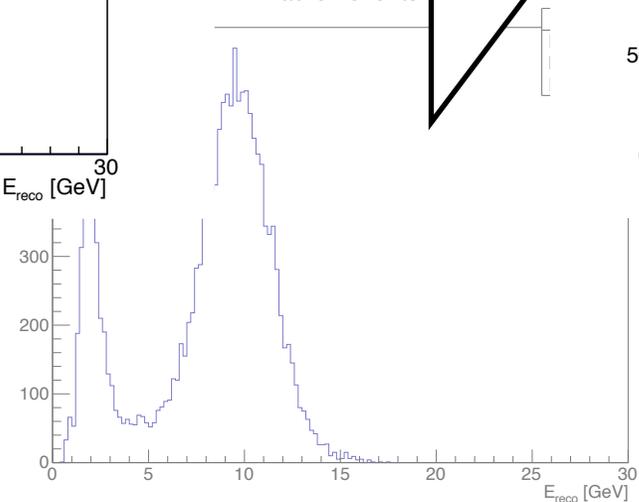


Hadron events



Additional shower start cut

Hadron events



Hadron events

