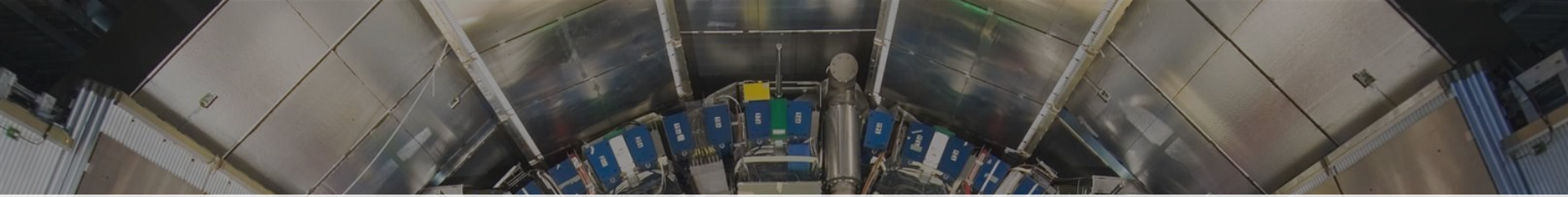


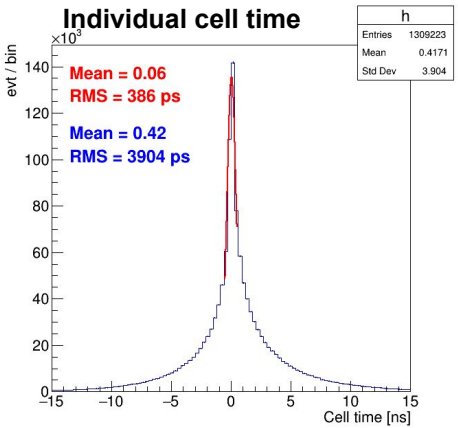
Study the potential of cell timing to improve cluster/jet calibration

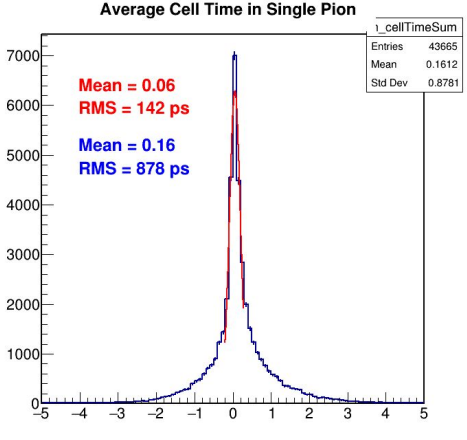
2023, September 15

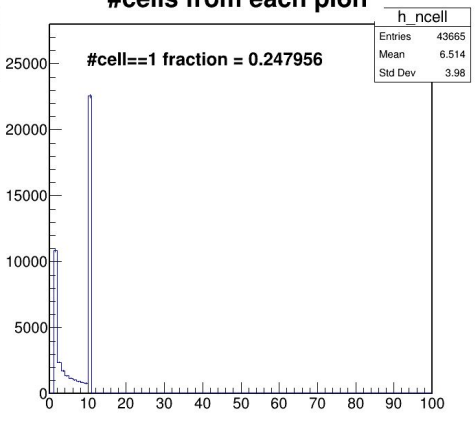
Kim Doyeong 김 도 영
Zahra Farazpay

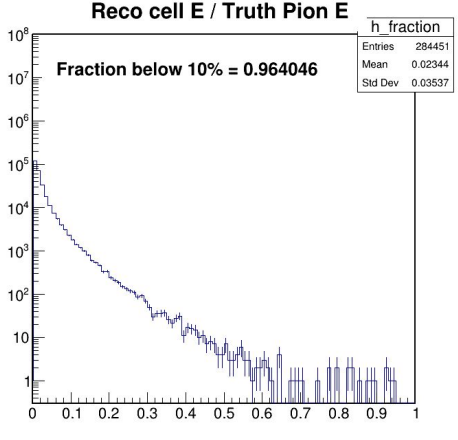
A bug in the avg. plot with fixed number of cells

Bug fix #1 - avg. fixed number of cells







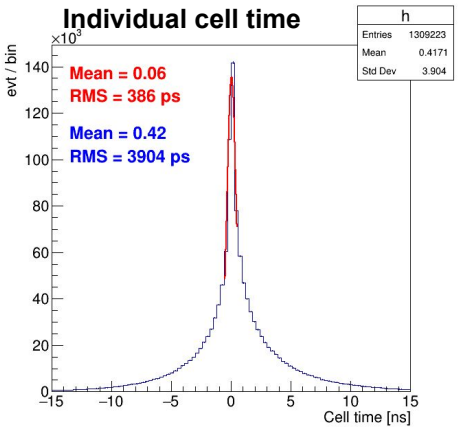


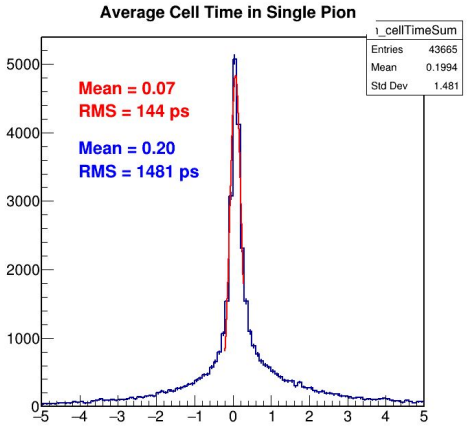
Before FIX

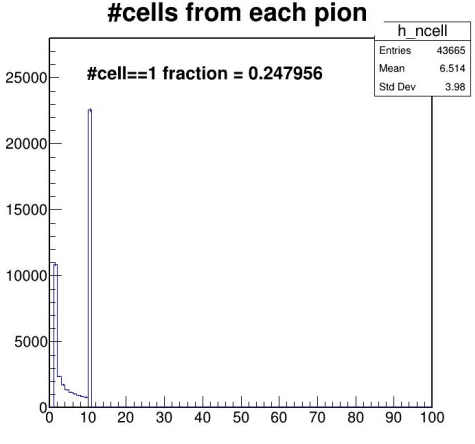
- Selection:
  - truth cell E > 0.001 GeV (cellEdep>0.001GeV motivation) !! temporary cut, will be removed !!
  - cellTime != 0
  - LAr Berrel (cell center R < 2.1 m && |cell eta| < 0.8)
  - reco cell E > 0.1 GeV

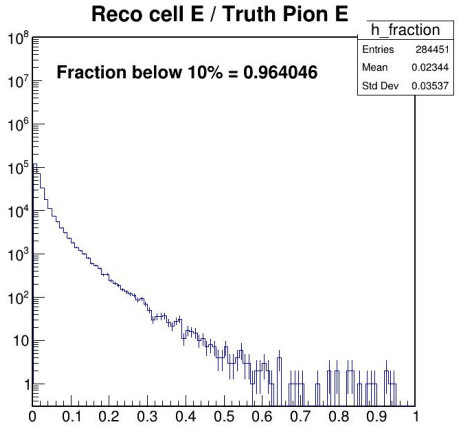
Only up to 10 energetic cells in each pion used for average (2nd plot), and one clean peak centered at near 0 remained

Bug fix #1 - avg. fixed number of cells







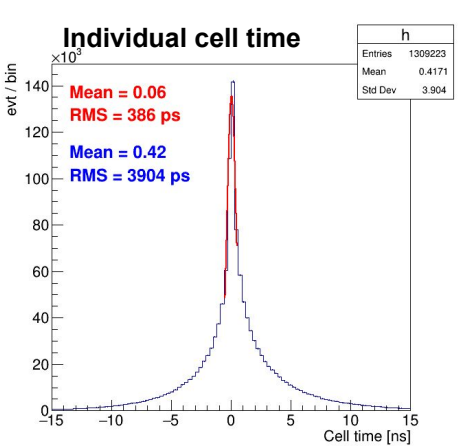


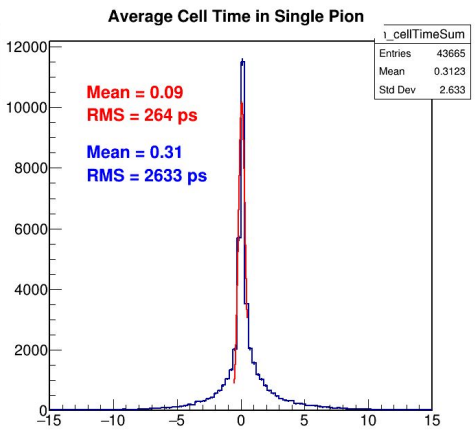
After FIX

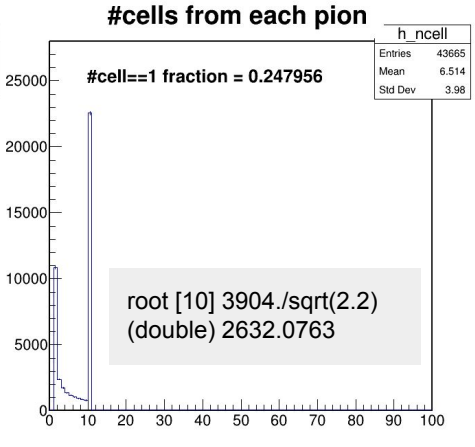
- Selection:
  - truth cell E > 0.001 GeV (cellEdep>0.001GeV motivation) !! temporary cut, will be removed !!
  - cellTime != 0
  - LAr Berrel (cell center R < 2.1 m && |cell eta| < 0.8)
  - reco cell E > 0.1 GeV

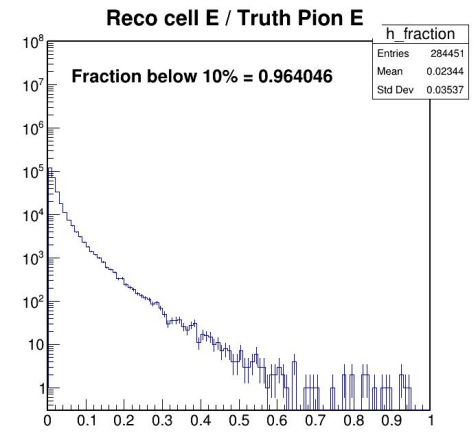
Only up to 10 energetic cells in each pion used for average (2nd plot), and one clean peak centered at near 0 remained

Bug fix #1 - avg. fixed number of cells









Same binning & range

- Selection:
  - truth cell E > 0.001 GeV (cellEdep>0.001GeV motivation) !! temporary cut, will be removed !!
  - cellTime != 0
  - LAr Berrel (cell center R < 2.1 m && |cell eta| < 0.8)
  - reco cell E > 0.1 GeV

Only up to 10 energetic cells in each pion used for average (2nd plot), and one clean peak centered at near 0 remained

Draw cell time with one cell

Does this really need to give us the same distribution as individual cell?

How we average with N cells?

After given selection,
we have (reco cell E, cell time) pair that is **sorted by reco cell E** for each pion

```
0       cellE = 1.0374          cellTime =      2.3166
1       cellE = 0.36766         cellTime =      1.9161
2       cellE = 0.3251          cellTime =      -0.24404
3       cellE = 0.25441         cellTime =      -0.64209
4       cellE = 0.22627         cellTime =      3.5027
5       cellE = 0.2012          cellTime =      -3.9121
6       cellE = 0.16394         cellTime =      12.035
7       cellE = 0.16394         cellTime =      12.035
8       cellE = 0.12405         cellTime =      9.5905
9       cellE = 0.10802         cellTime =      -1.4767
```

How we average with N cells?

If we average cell time from all cells that passed the selection criteria,

```
0       cellE = 1.0374          cellTime =      2.3166
1       cellE = 0.36766         cellTime =      1.9161
2       cellE = 0.3251          cellTime =      -0.24404
3       cellE = 0.25441         cellTime =      -0.64209
4       cellE = 0.22627         cellTime =      3.5027
5       cellE = 0.2012          cellTime =      -3.9121
6       cellE = 0.16394         cellTime =      12.035
7       cellE = 0.16394         cellTime =      12.035
8       cellE = 0.12405         cellTime =      9.5905
9       cellE = 0.10802         cellTime =      -1.4767

deno = 10
avg. = 3.5121
```

How we average with *N* cells?

If we average cell time from only leading cell,

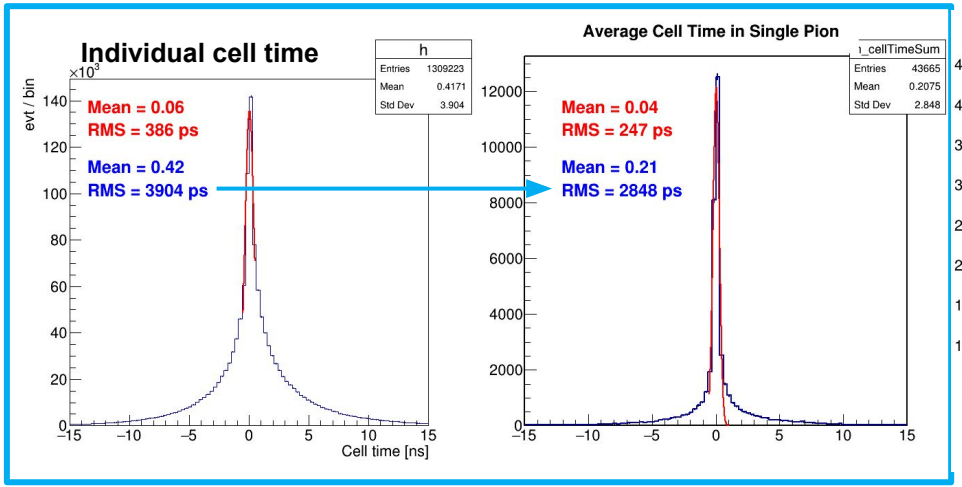
```
0       cellE = 1.0374          cellTime =      2.3166
1       cellE = 0.36766         cellTime =      1.9161
2       cellE = 0.3251          cellTime =      -0.24404
3       cellE = 0.25441         cellTime =      -0.64209
4       cellE = 0.22627         cellTime =      3.5027
5       cellE = 0.2012          cellTime =      -3.9121
6       cellE = 0.16394         cellTime =      12.035
7       cellE = 0.16394         cellTime =      12.035
8       cellE = 0.12405         cellTime =      9.5905
9       cellE = 0.10802         cellTime =      -1.4767

deno = 10
avg. = 3.5121
```

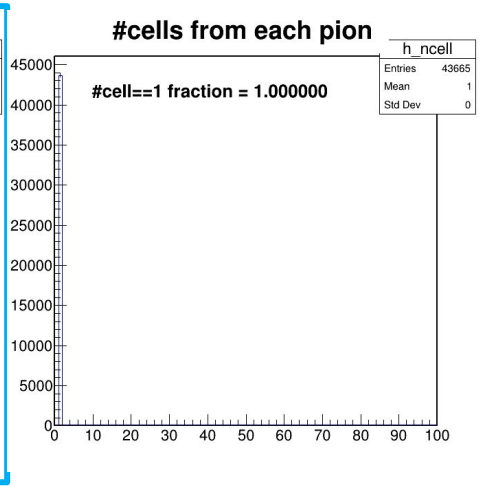
→ avg. cell time = 2.3166 ns

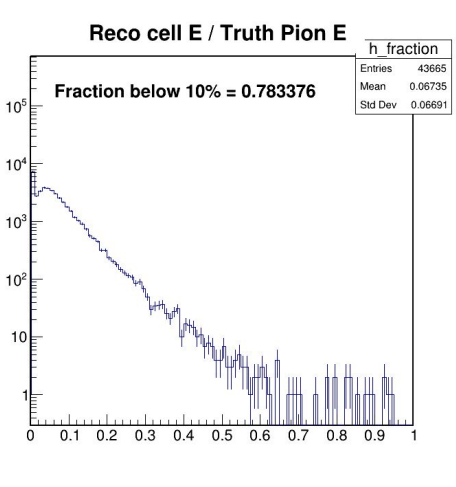
5D Calorimeter

Example

But, why RMS reduced by factor of 1/√(N>1)? FYI, 3904./sqrt(1.9) = 2832. → Do more energetic cells have smaller |cell time|?





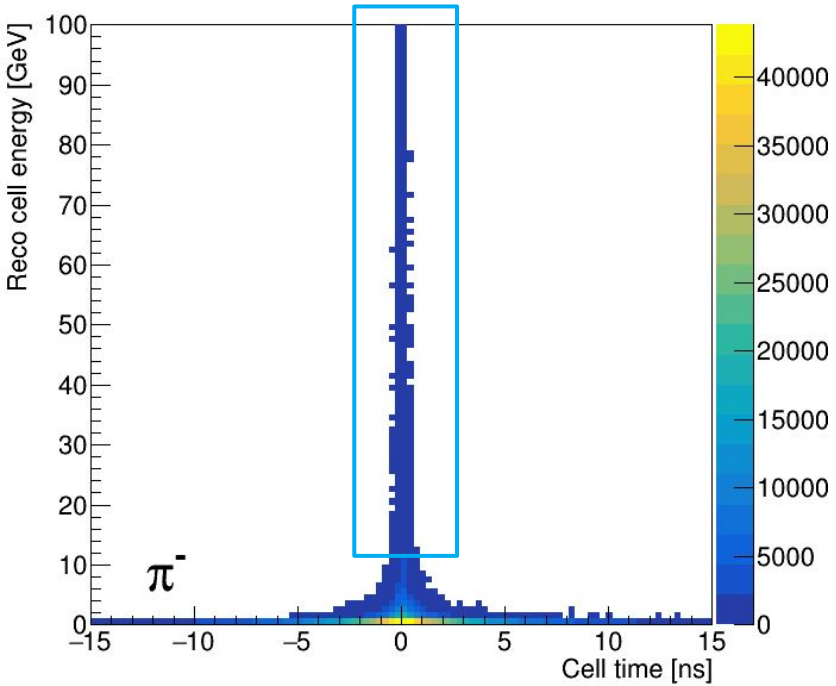


- Selection:
  - truth cell E > 0.001 GeV (cellEdep>0.001GeV motivation) !! temporary cut, will be removed !!
  - cellTime != 0
  - LAr Berrel (cell center R < 2.1 m && |cell eta| < 0.8)
  - reco cell E > 0.1 GeV
  - 0.2 GeV < truth pion p_T < 2000 GeV → no cut, how Ntuple was generated

Only up to 1 energetic cells in each pion used for average (2nd plot), and one clean peak centered at near 0 remained

There are two peaks

Why RMS drastically reduced?



Yes, that's clearly shown here!
* This 2D plot made with the same selection

If we choose the cell time of the leading cell only, cells in the blue box are more likely picked up

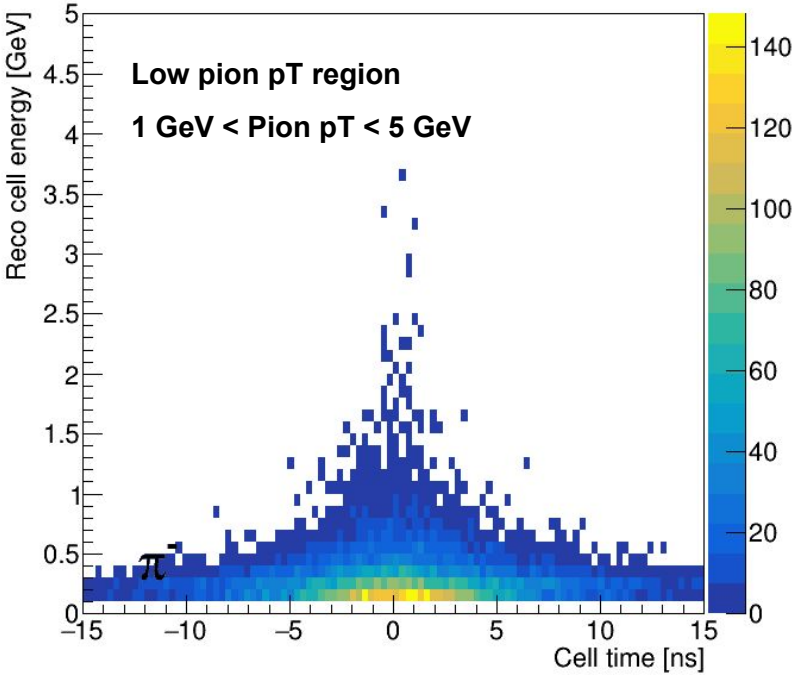
They have more than 10 GeV reco cell E (very high)

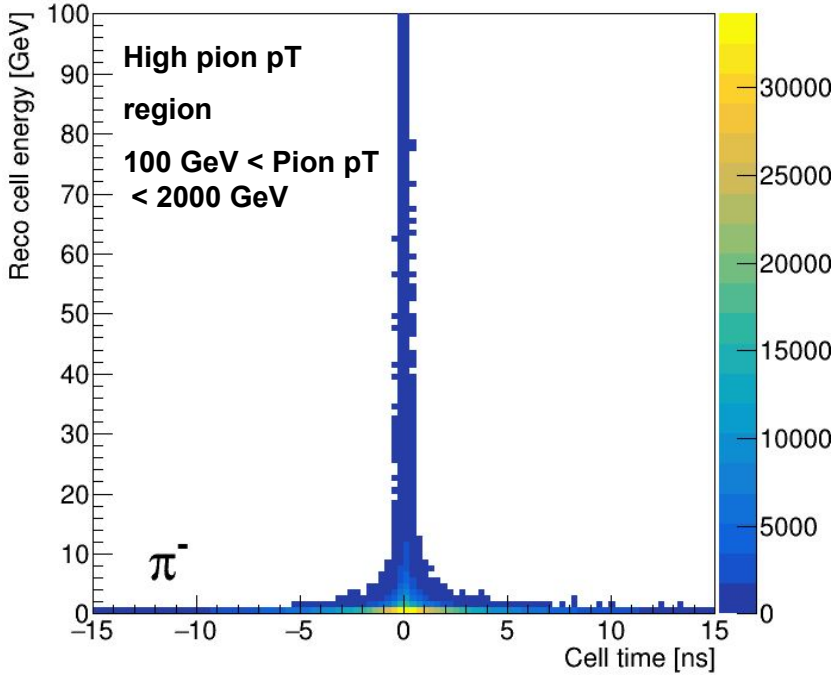
Any physics behind?

Hypothesis: test with two extreme cases

Hypothesis:

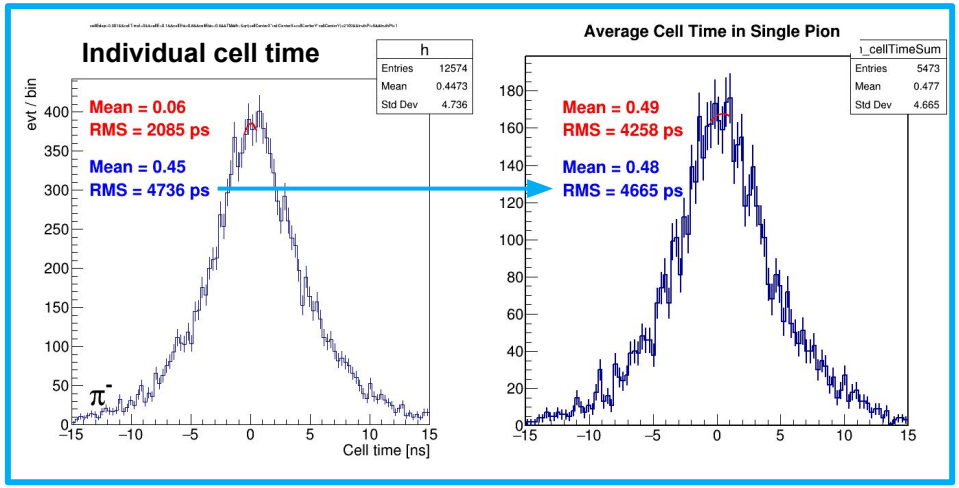
When there is less contributions from high energy cells (E>10 GeV), we should see less cell time resolution improvement in the avg. plot with leading cells

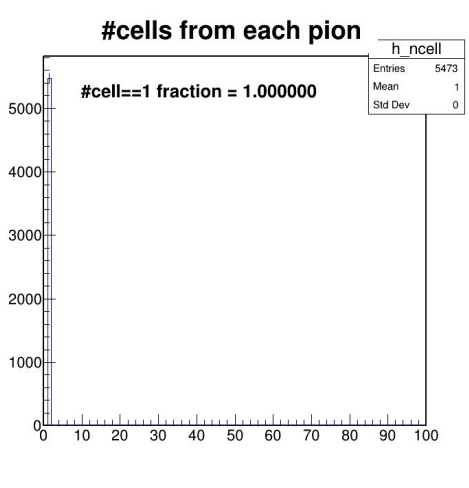


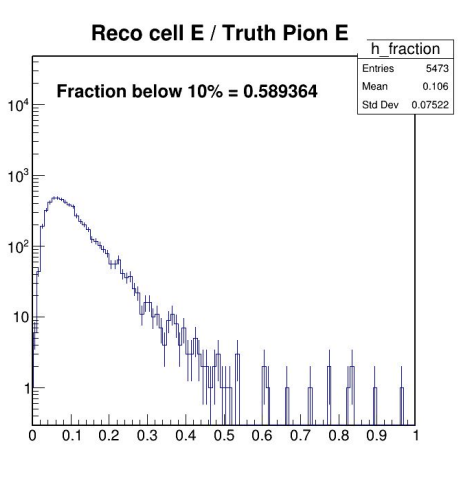


Case #1: low pion pT region

As expected, RMS reduced very slightly







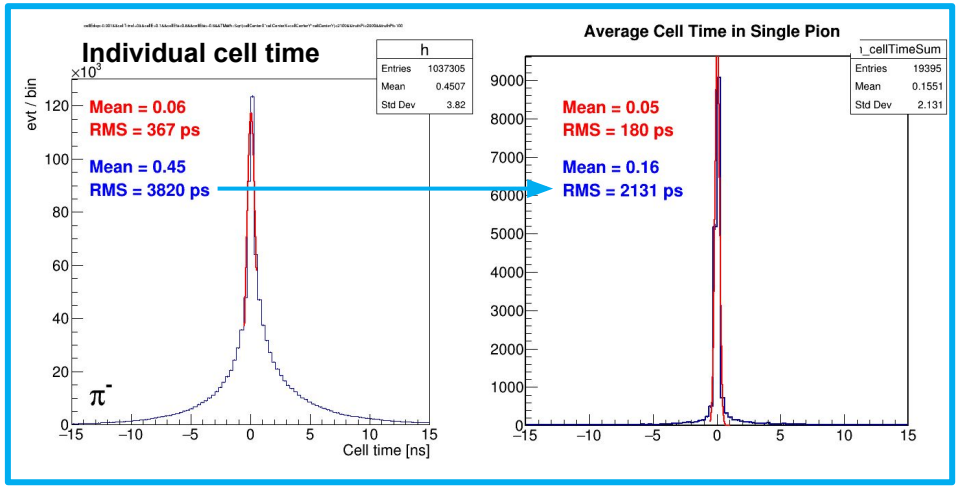
- Selection:
  - truth cell E > 0.001 GeV (cellEdep>0.001GeV motivation) !! temporary cut, will be removed !!
  - cellTime != 0
  - LAr Berrel (cell center R < 2.1 m && |cell eta| < 0.8)
  - reco cell E > 0.1 GeV
  - 1 GeV < truth pion p_T < 5 GeV

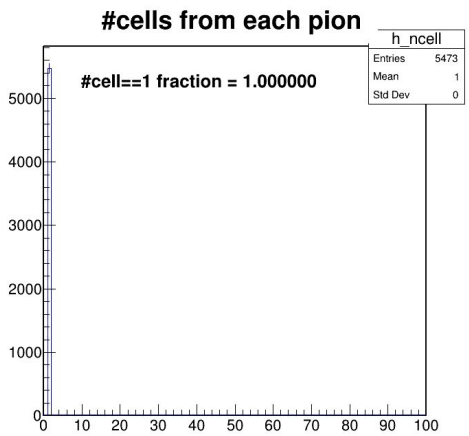
Only up to 1 energetic cells in each pion used for average (2nd plot), and one clean peak centered at near 0 remained

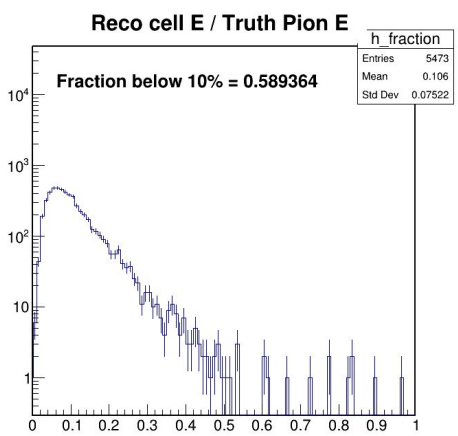
There are two peaks

Case #2: high pion pT region

As expected, RMS reduced very drastically





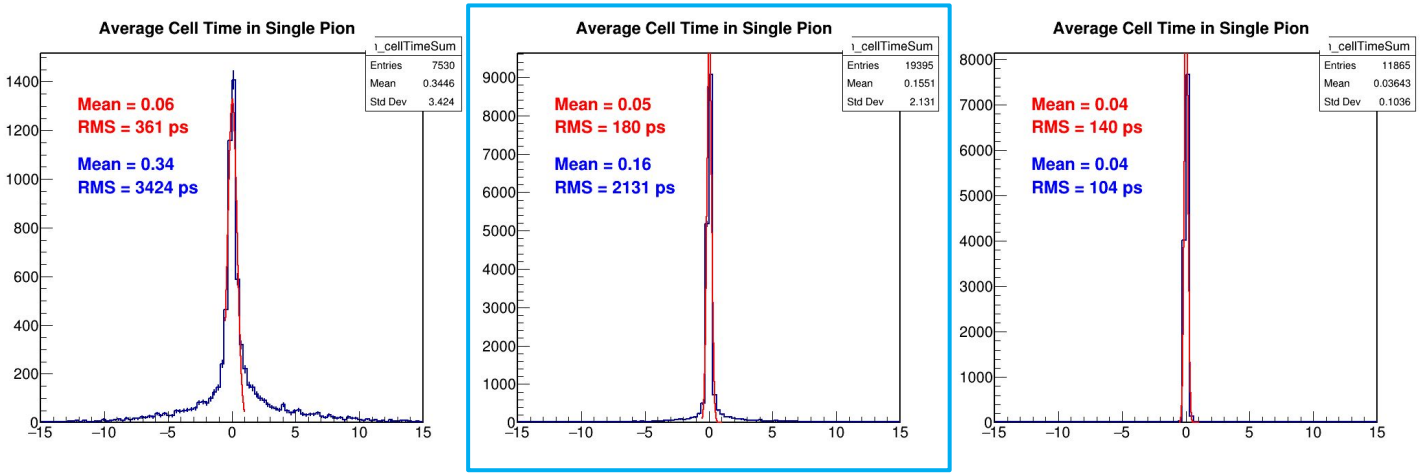


- Selection:
  - truth cell E > 0.001 GeV (cellEdep>0.001GeV motivation) !! temporary cut, will be removed !!
  - cellTime != 0
  - LAr Berrel (cell center R < 2.1 m && |cell eta| < 0.8)
  - reco cell E > 0.1 GeV
  - 100 GeV < truth pion p_T < 2000 GeV

Only up to 1 energetic cells in each pion used for average (2nd plot), and one clean peak centered at near 0 remained

There are two peaks

Case #2: high pion pT region

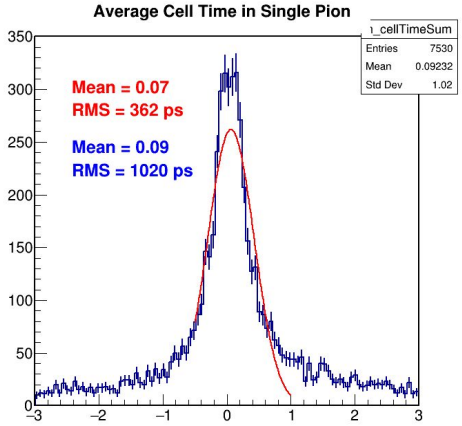


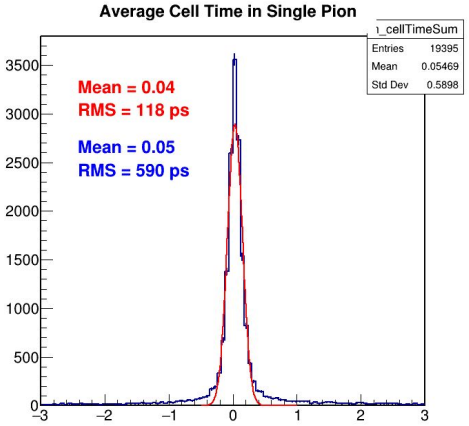
- cell time with pions which has leading cell E < 10 GeV (left, 7530 events)
- cell time with pions which has leading cell E >= 10 GeV (right, 11865 events)

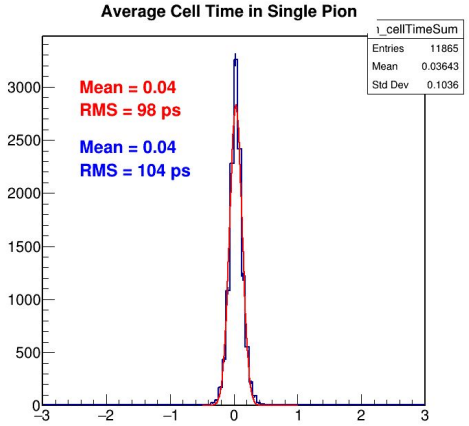
- Both together (center, 19395 = 11865+7530 events)

There are two peaks

Case #2: high pion pT region







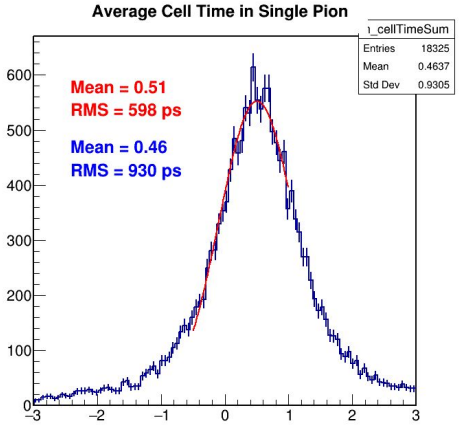
- cell time with pions which has leading cell E < 10 GeV (left, 7530 events)
- cell time with pions which has leading cell E >= 10 GeV (right, 11865 events)

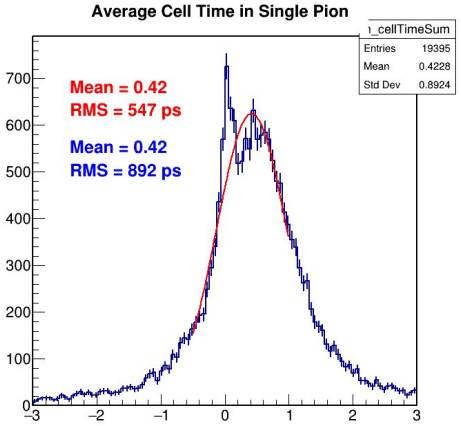
- Both together (center, 19395 = 11865+7530 events)

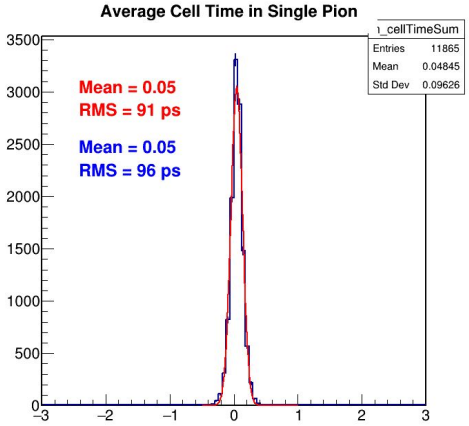
Zoomed in, no double peak (expected)

There are two peaks

Case #2: high pion pT region







- cell time with pions which has leading cell E < 10 GeV (left, 7530 events)
- cell time with pions which has leading cell E >= 10 GeV (right, 11865 events)

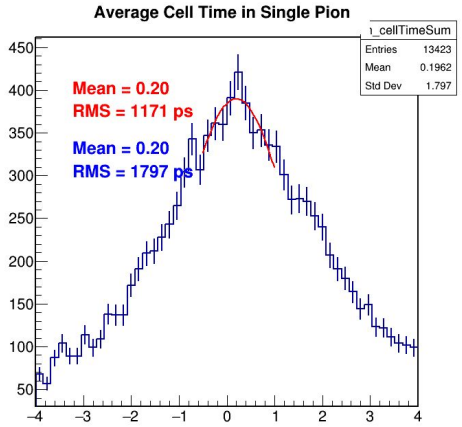
- Both together (center, 19395 = 11865+7530 events)

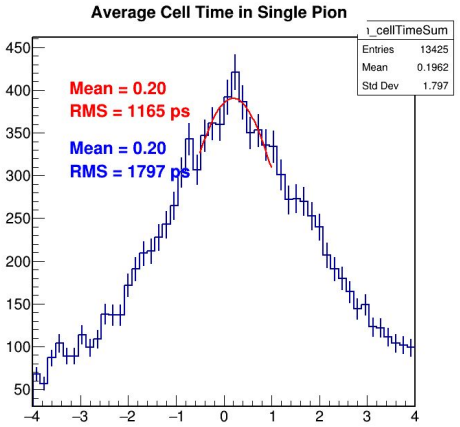
Zoomed in, average all cells that passed the selection, double peak (expected)

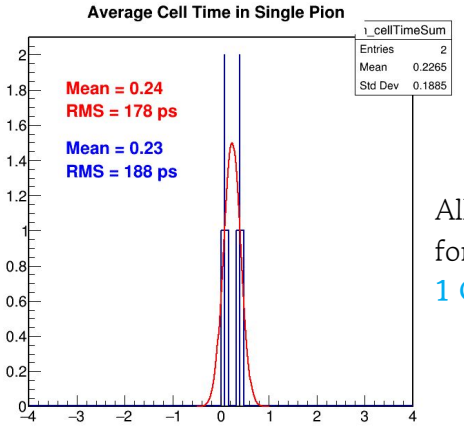
There are two peaks

5D Calorimeter

How about low energy region (our interest)







All the same as previous slides, but for truth pT range
1 GeV < pT < 20 GeV

- cell time with pions which has leading cell E < 10 GeV (left, 13423 events)
- cell time with pions which has leading cell E >= 10 GeV (right, 2 events)

- Both together (center, 13425 =13423+2 events)

Zoomed in, average all cells that passed the selection, double peak in *not noticeable* (expected)

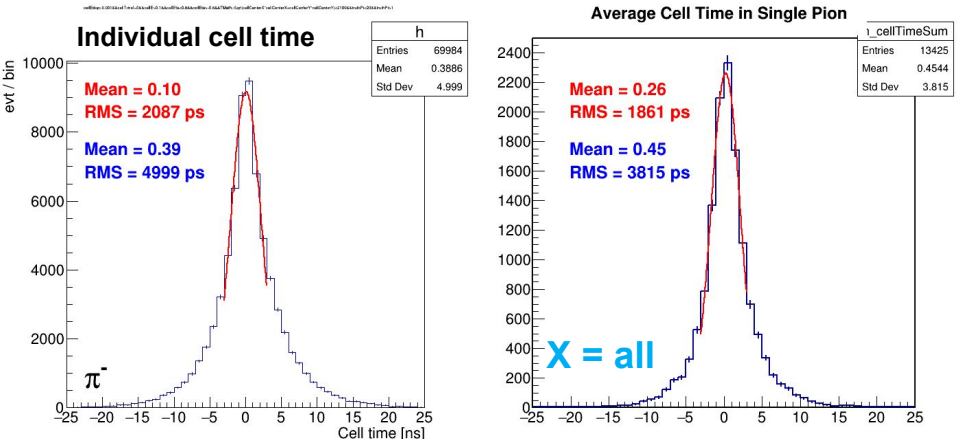
There are two peaks

Looking for the origin of non-Gaussian tail

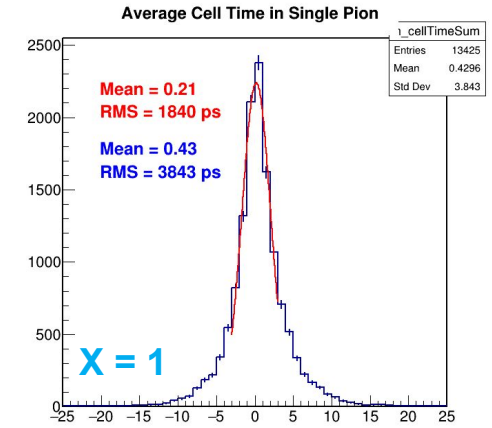
- **Default selection unless specified**
  - truth cell E > 0.001 GeV (cellEdep>0.001GeV motivation) !! temporary cut, will be removed !!
  - cellTime != 0
  - LAr Berrel (cell center R < 2.1 m && |cell eta| < 0.8)
  - reco cell E > 0.1 GeV
  - 1 GeV < truth pion p_T < 20 GeV

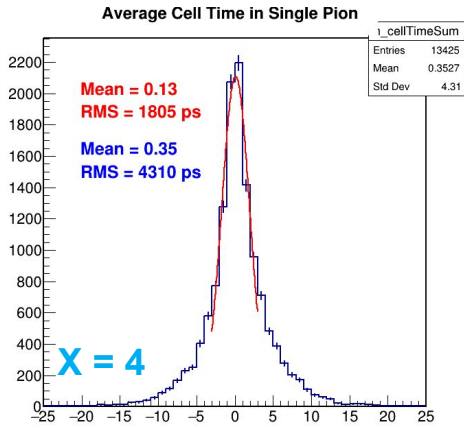
- **Reminder:**
  In this Ntuple, the cell time is a reconstructed feature with truth particles generated at t = 0

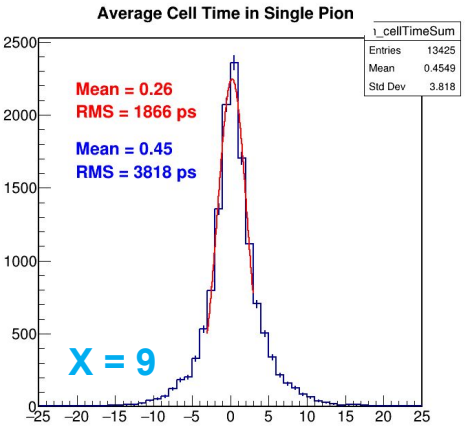
Avg. X cells after selection



In the phase region of interest (1 GeV < truth pion pT < 20 GeV), double peak effect is negligible, but still there is anomalous behavior in the averaged distributions

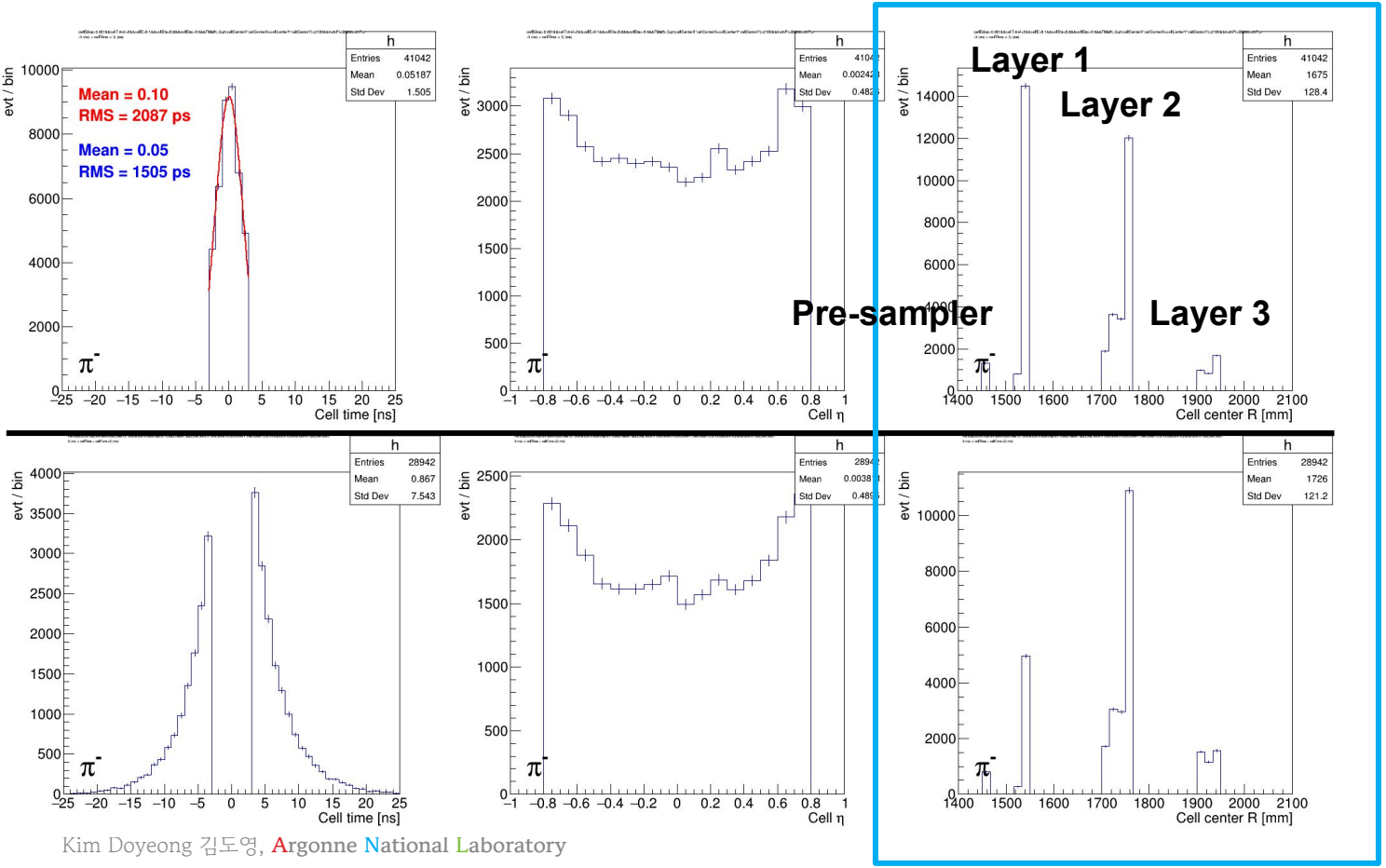






5D Calorimeter

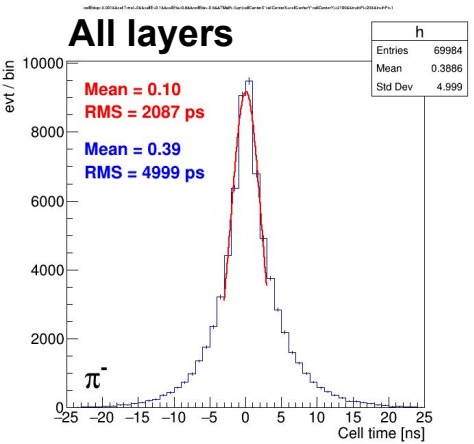
Eta and radius with |cell time| cut

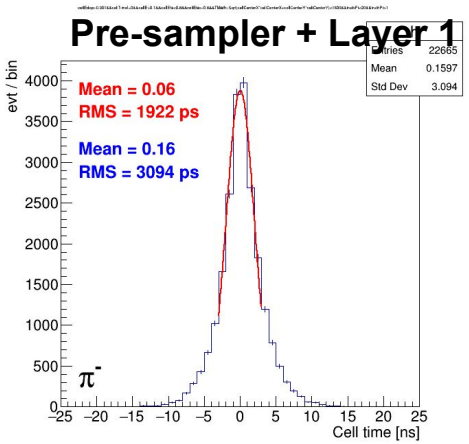


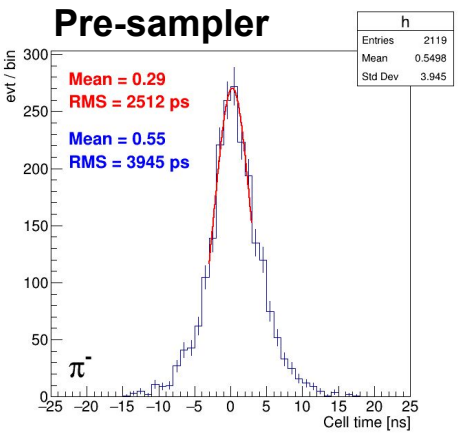
Top:
| cell time | < 3 ns
(Gaussian)

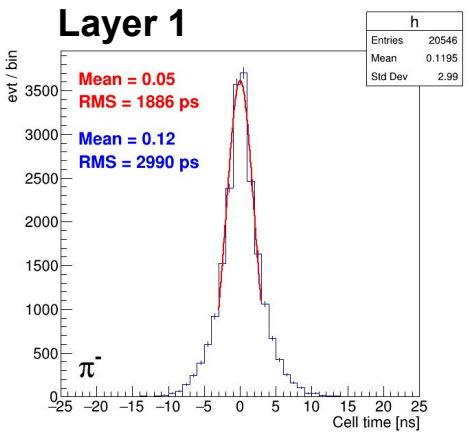
Bottom:
| cell time | > 3 ns
(non- Gaussian)

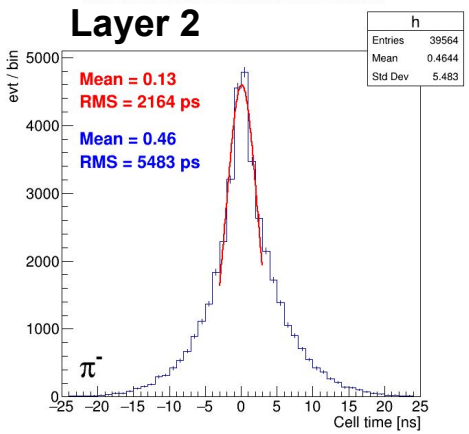
Cell time per LAr EM barrel layer

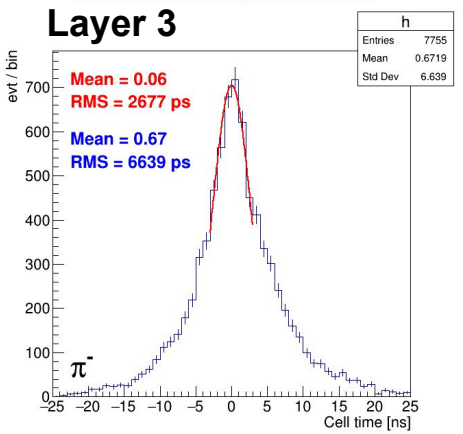








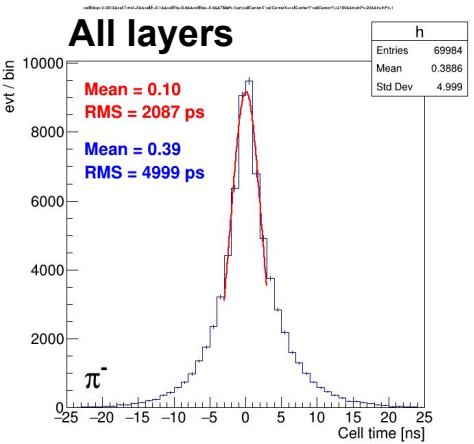


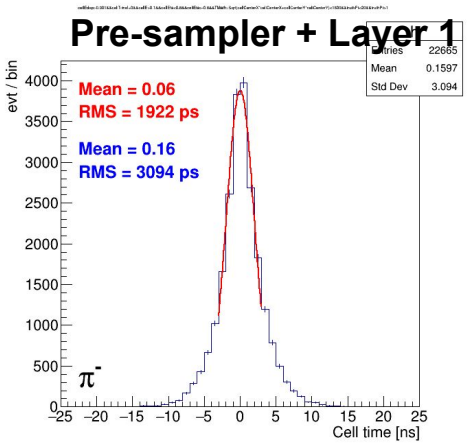


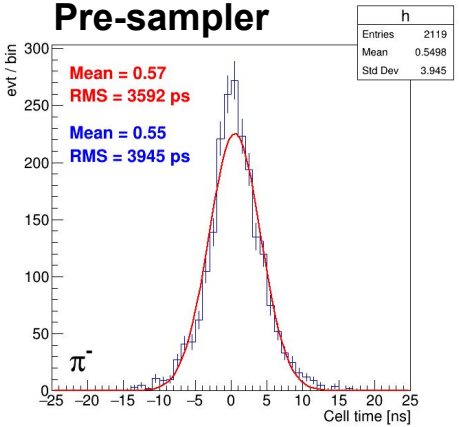
Btw there layers,
outer layer have larger |cell time|
which make sense as hit should arrive later

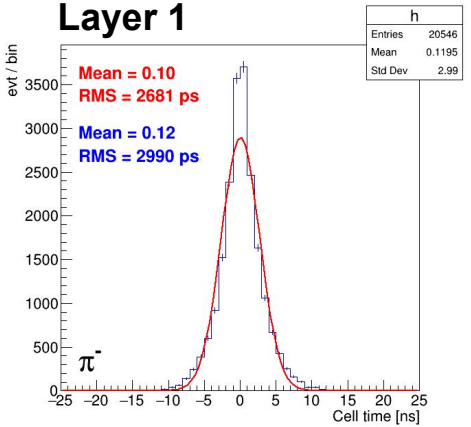
There are two peaks

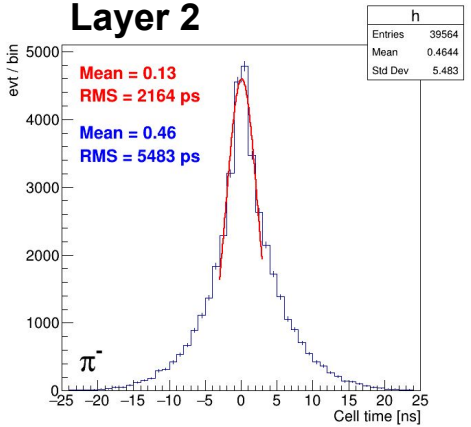
Cell time per LAr EM barrel layer (fitting range changed)

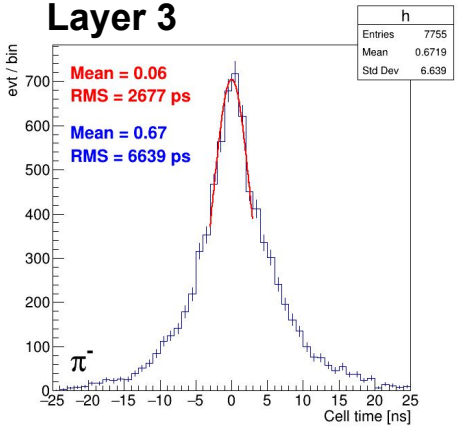










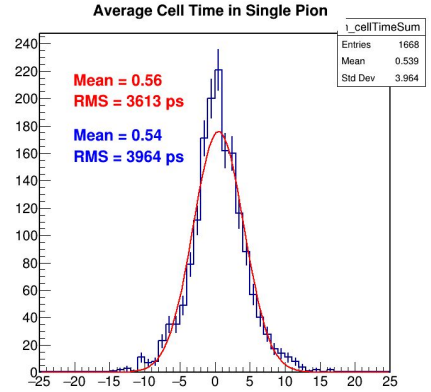


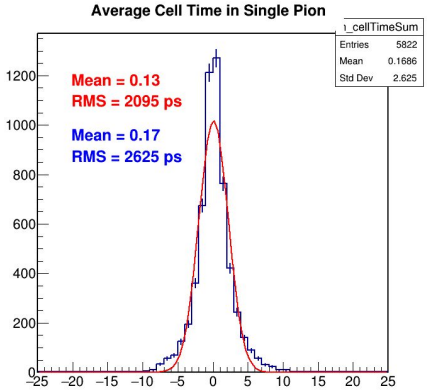
- Gaussian fitting range for bottom left two plots were expended
- Cell time shape becomes less Gaussian in the more outer layer
  (still don't know why)

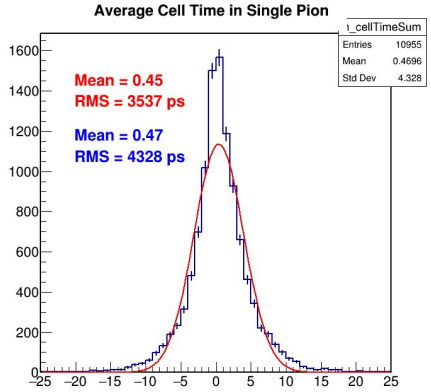
There are two peaks

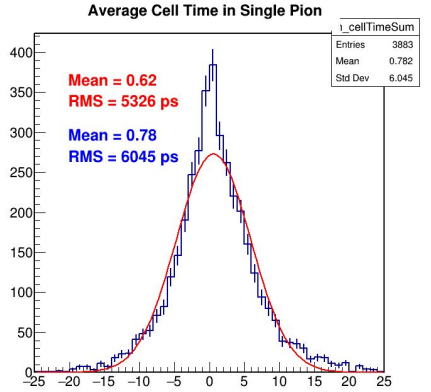
5D Calorimeter

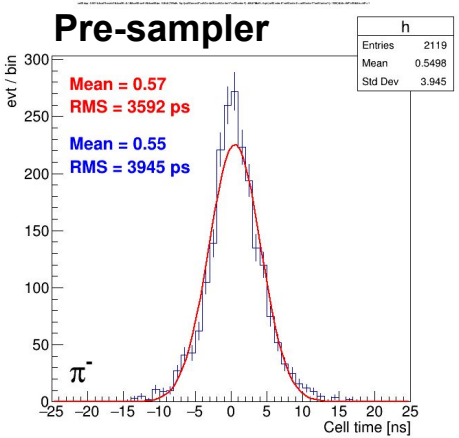
(Avg.) cell time per LAr EM barrel layer

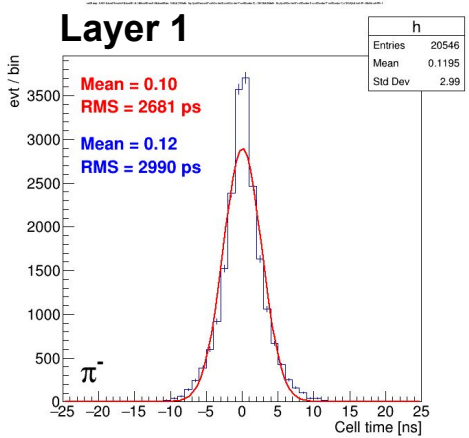


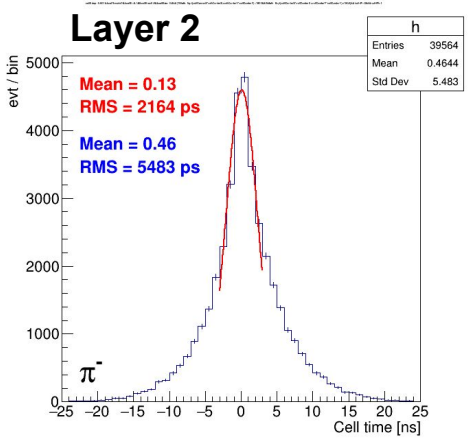


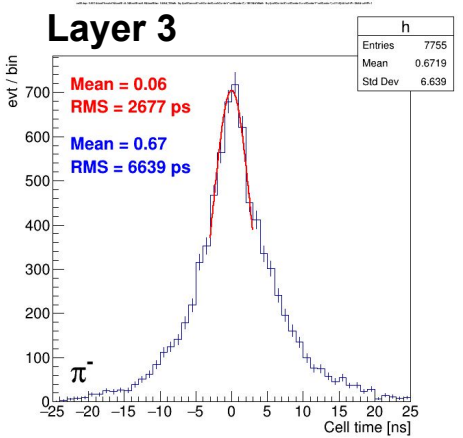












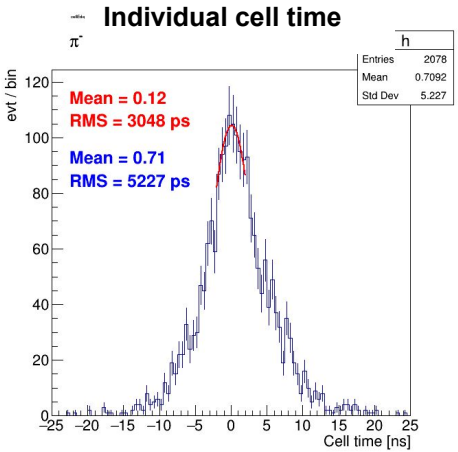
There are two peaks

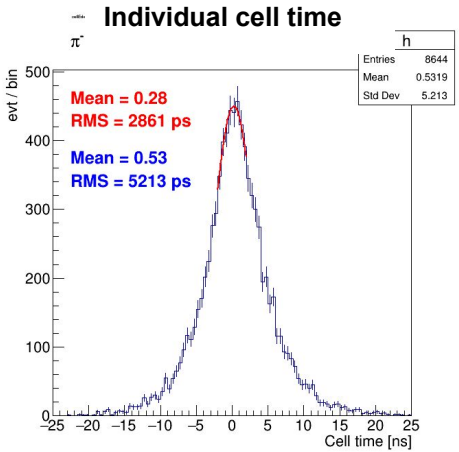
Cell time in bins of pion energy using π^- sample

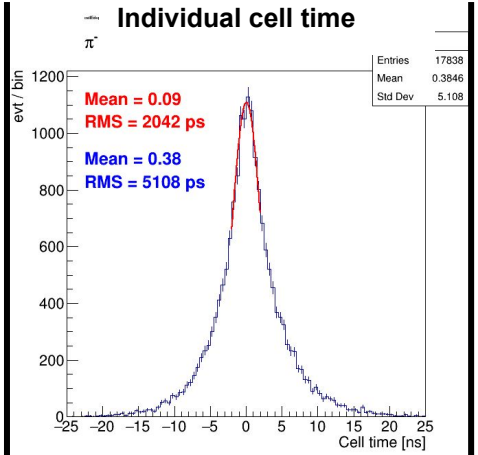
(we've been using since HFSF2023)

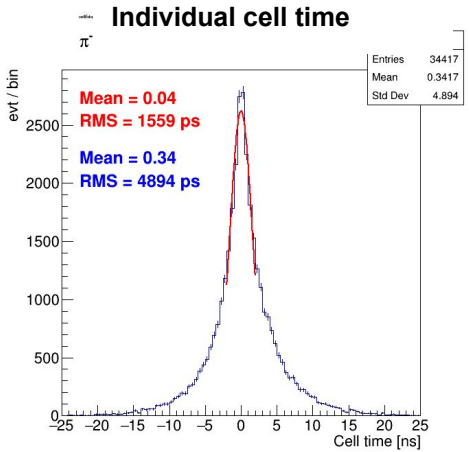
5D Calorimeter

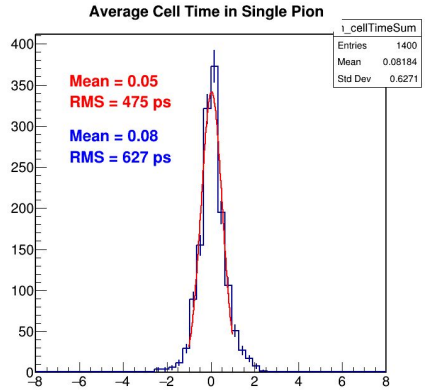
Cell time in bins of pion energy (Before Bug fix)

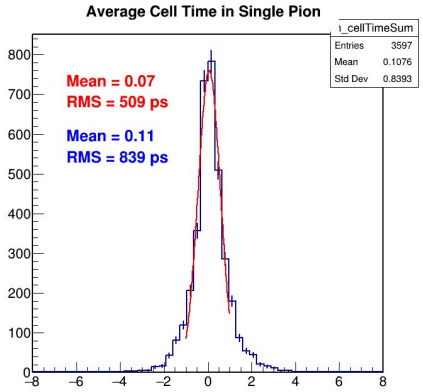


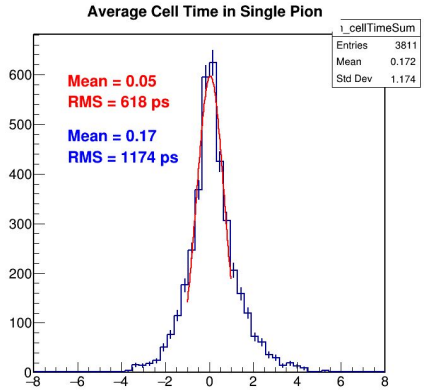


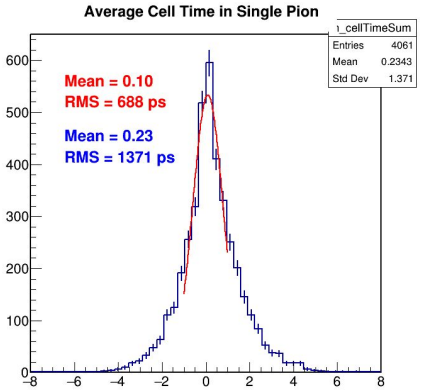












1 GeV < Truth pion E < 2 GeV

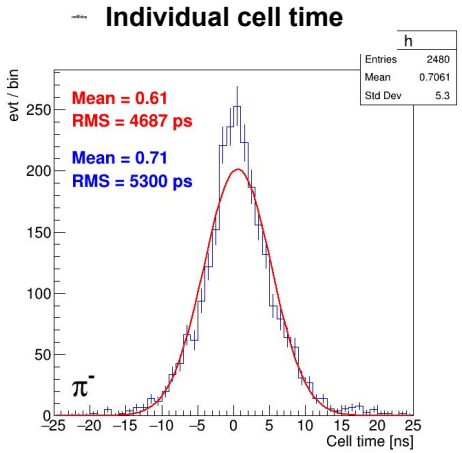
2 GeV < Truth pion E < 5 GeV

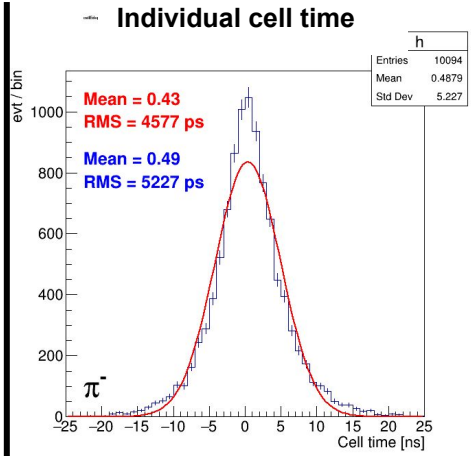
5 GeV < Truth pion E < 10 GeV

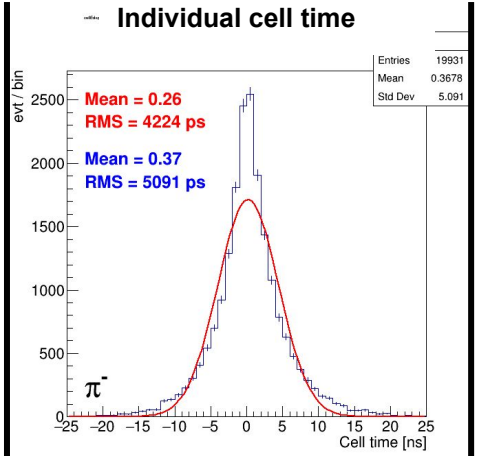
10 GeV < Truth pion E < 20 GeV

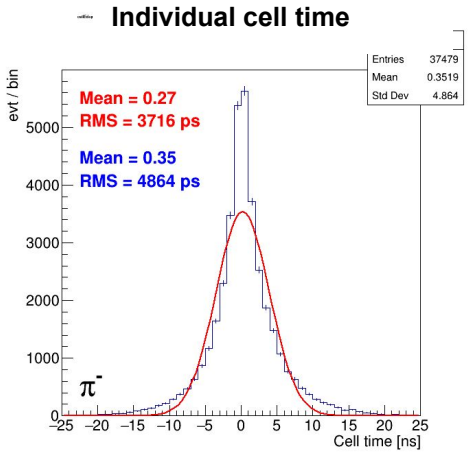
5D Calorimeter

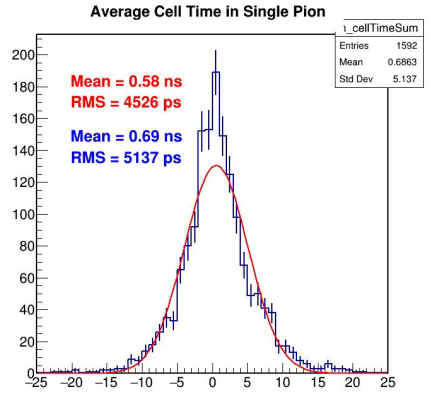
Cell time in bins of pion energy (Summary)

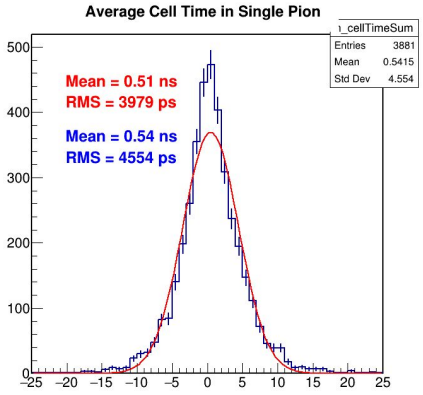


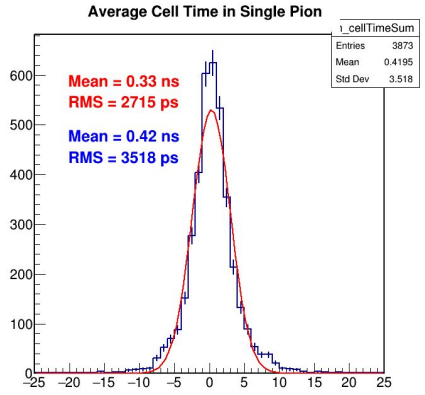


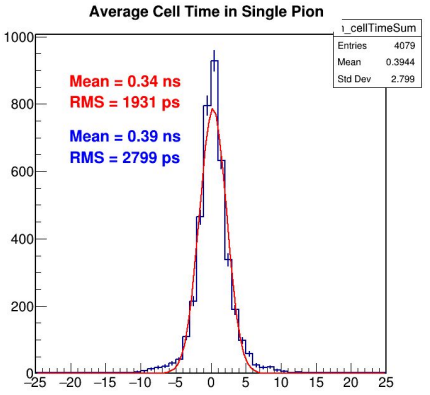












1 GeV < Truth pion pT < 2 GeV

2 GeV < Truth pion pT < 5 GeV

5 GeV < Truth pion pT < 10 GeV

10 GeV < Truth pion pT < 20 GeV

Checking E resolution

$(\sum_{\text{a pion}}\text{reco cell E} - \sum_{\text{a pion}}\text{truth cell E})/\#\text{cells}$

where, #cells are the number of cells that passed selection criteria

---

Working in progress...

Others

- Repeat cell time in bins of pion energy using → will do once we have more understanding about pi-
  - pi0
  - pi+/- with PU
  - pi0 with PU
- Energy resolution - for validation purpose
- Adding significance
  - I looked at it, and we should calculate it ourselves using depector noise map
    Athena topo-cluster implementation:
    https://gitlab.cern.ch/loch/athena/-/blob/SingleParticles/Calorimeter/CaloUtils/src/CaloTopoTowerBuilderTool.cxx#L221-225
  - Confirmed if this is right way with Peter, and he will provide me an example