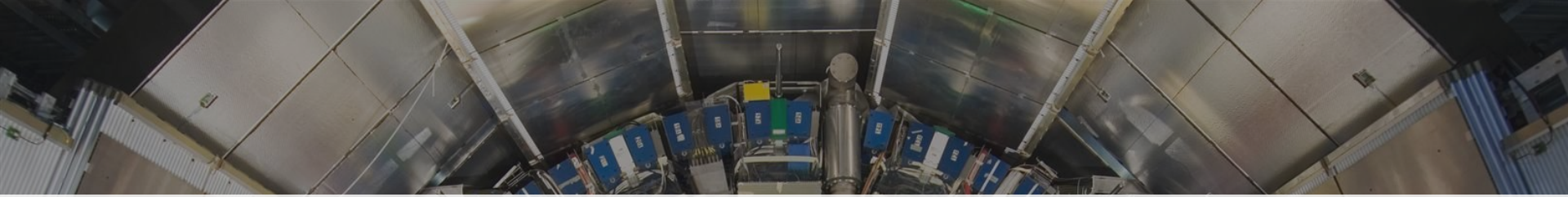


Timing calibration using single neutral pion events

2023, October 18

https://indico.slac.stanford.edu/event/8494/

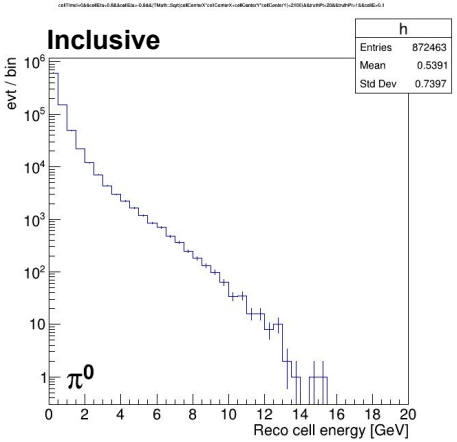
Kim Doyeong 김 도 영

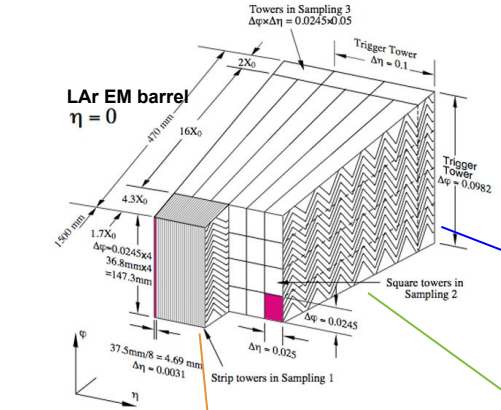
Zahra Farazpay

Timing calibration using single neutral pion events

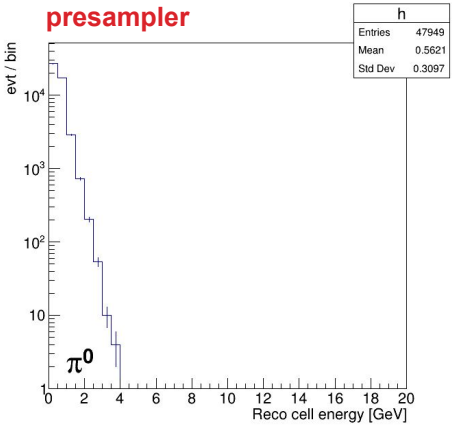
5D Calorimeter

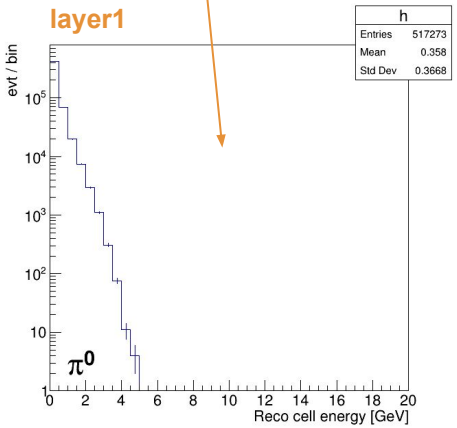
Reco cell E per layer (1 GeV < truth pion p_T < 20 GeV)

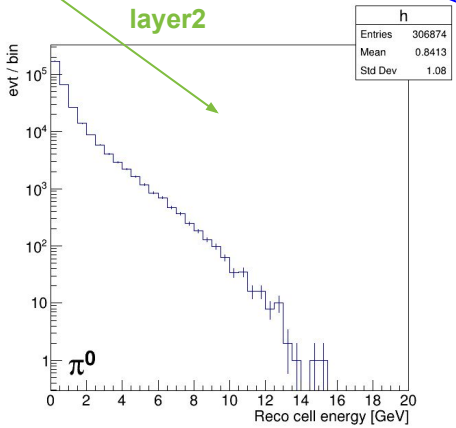


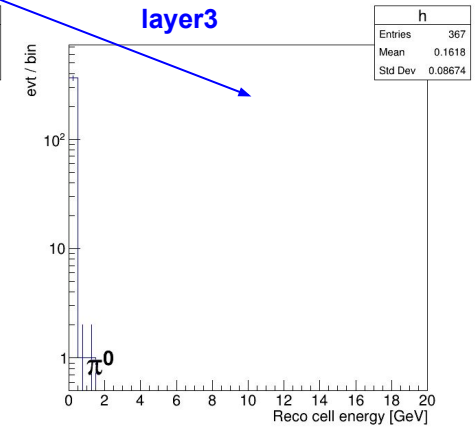


- Check reco cell E range within the region of our interest
- There is no cell which has more than 16 GeV



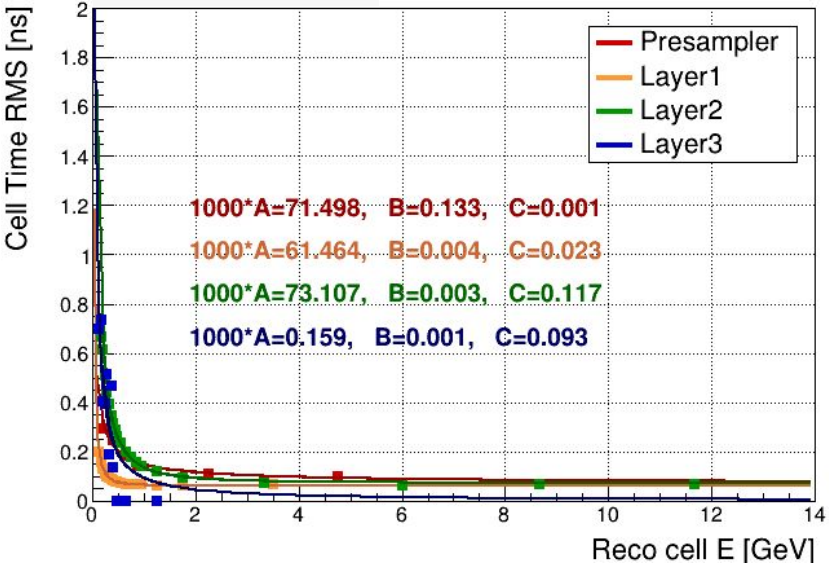




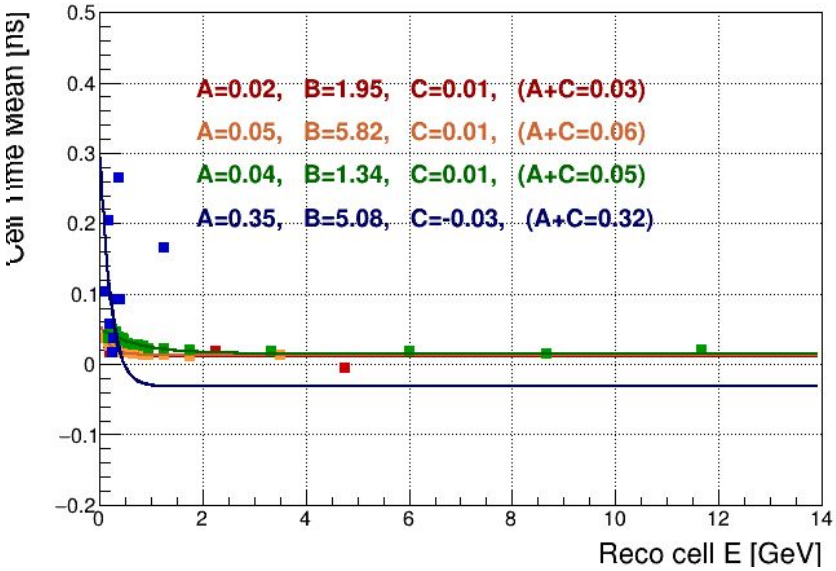


RMS vs Reco cell E per EM LAr Barrle layer

$$\sqrt{A^2 + \frac{B^2}{E} + \frac{C^2}{E^2}}$$



$$A \cdot e^{-B \cdot E} + C$$



- Timing resolution and mean are parametrized by cell E (E)
- The constant term (i.e. **A**) depends on **layer** (range from 61.5 ~ 73.1 ps)

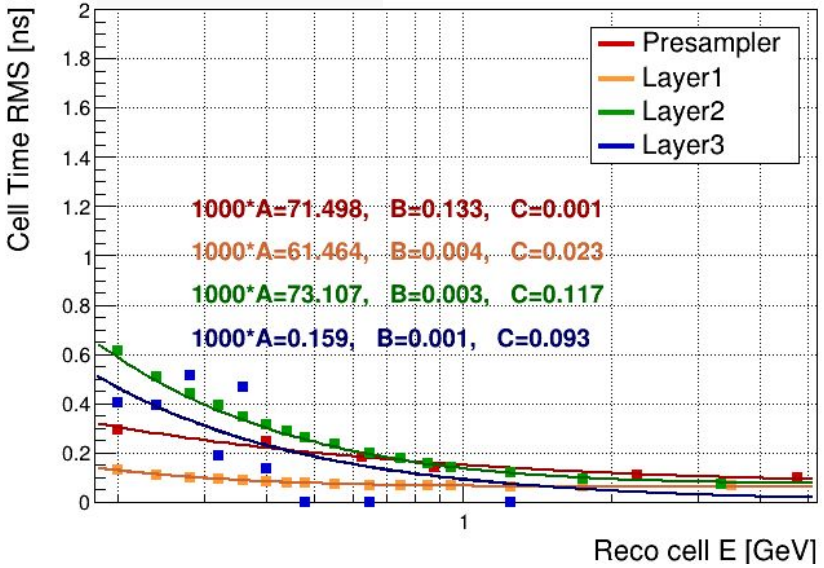
Only layer 1 and layer 2 will be considered in this study

5D Calorimeter

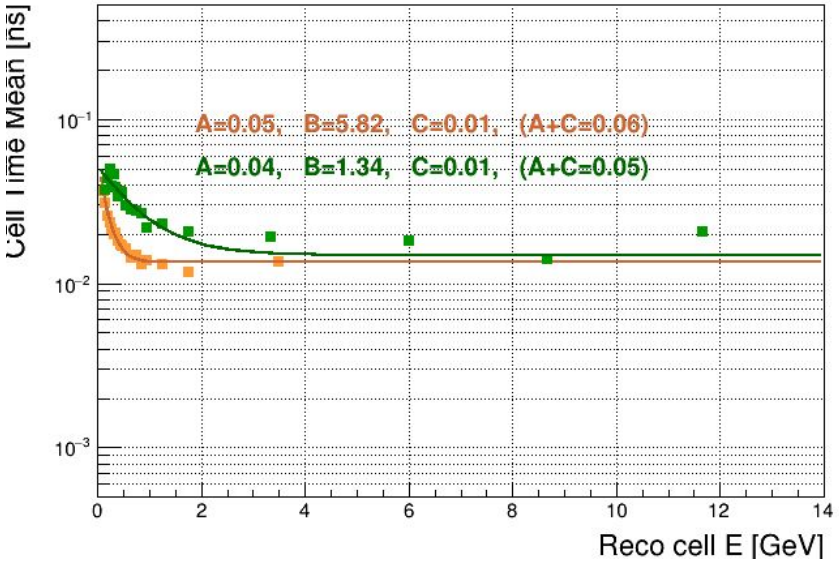
RMS vs Reco cell E per EM LAr Barrle layer

$$\sqrt{A^2 + \frac{B^2}{E} + \frac{C^2}{E^2}}$$

Log scale X-axis



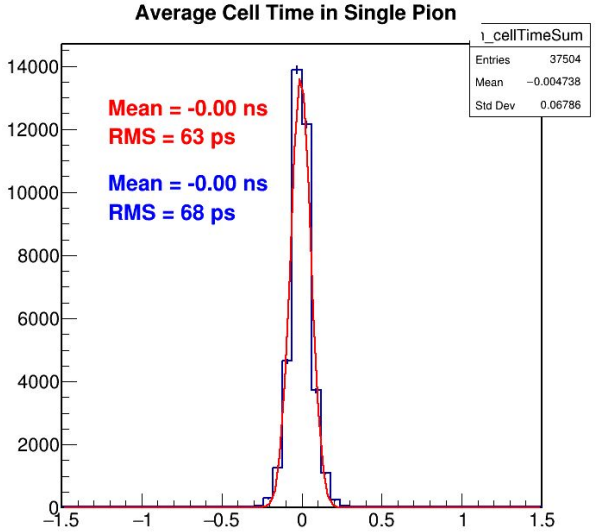
$$A \cdot e^{-B \cdot E} + C$$



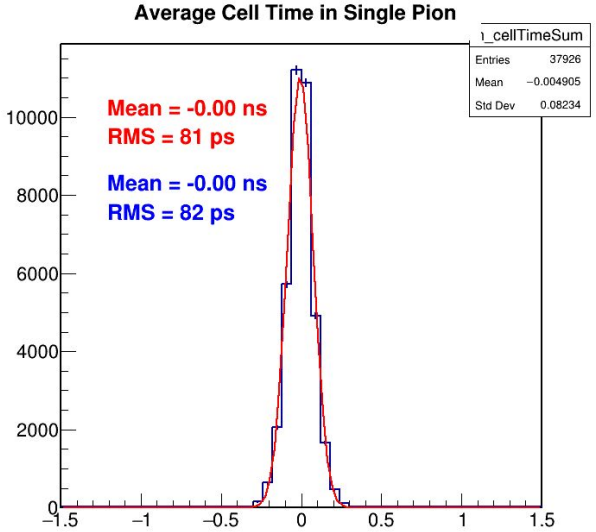
- Timing resolution and mean are parametrized by cell E (E)
- The constant term (i.e. **A**) depends on **layer** (range from 61.5 ~ 73.1 ps)

Only layer 1 and layer 2 will be considered in this study

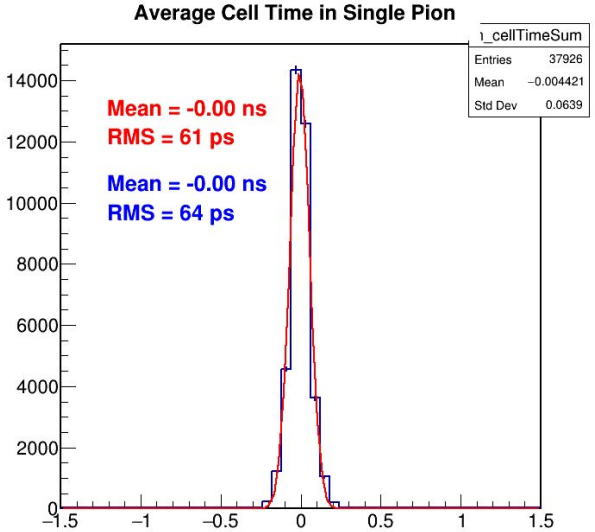
Validation of RMS weights & calibration



Layer 1 only



Layer 2 only



Layer 1+2

- **All plots are weighted average with calibration,** where $w_i = (1/RMS^2)$
- **Calibration** is well done and distributions are centered at 0 in each layer and inclusively Calibration is done using fits functions for mean values t_0(cell E, layer) then offset is subtracted cell by cell $(t_i - t_0)$ before averaging cell time of single pion

$$\frac{\sum_i (w_i \cdot (t_i - t_0))}{\sum_i w_i}$$

Draw cell time with one cell

Why it does not follow $1/\sqrt{N}$ rule?

This section will be in the backup for presentation

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,

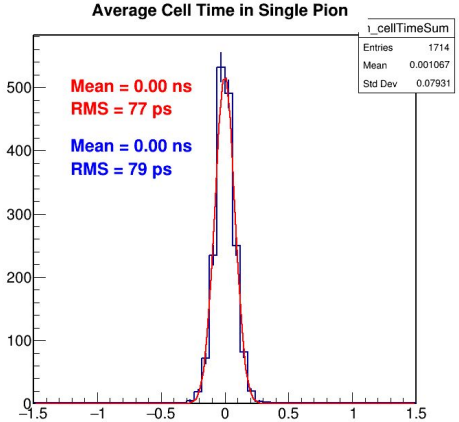
```
0       cellE = 1.0374          cellTime =      2.3166
1       cellE = 0.36766         cellTime =      1.9161
2       cellE = 0.3251          cellTime =      -0.24404
3       cellE = 0.25441         cellTime =      -0.64209
4       cellE = 0.22627         cellTime =      3.5027
5       cellE = 0.2012          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
```

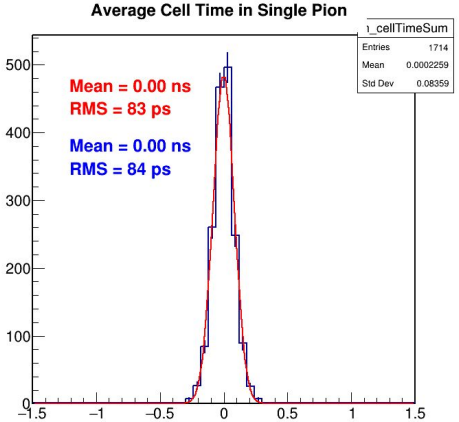
avg. cell time = 2.3166 ns (example of arithmetic mean)

5D Calorimeter

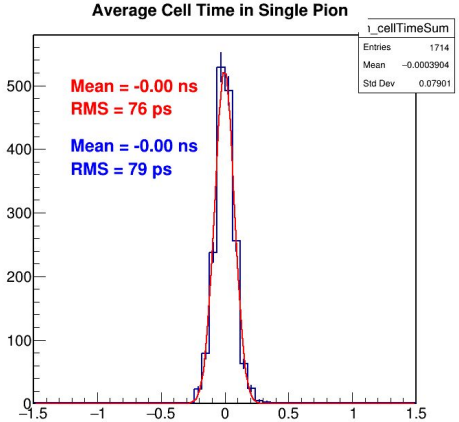
Checking stat error change with different sample size



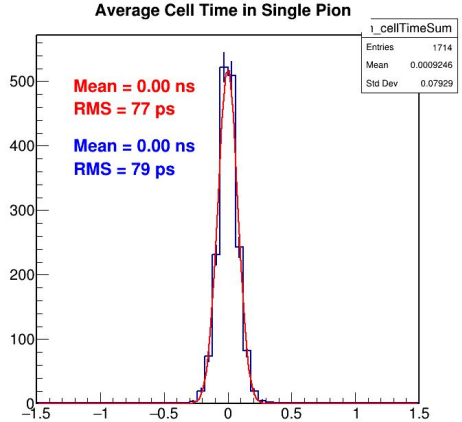
Averaged all cells after the selection



Averaged 1 cell after the selection



Averaged 4 cell after the selection



Averaged 9 cell after the selection

To have a same set of pions for comparison, the following selections are applied

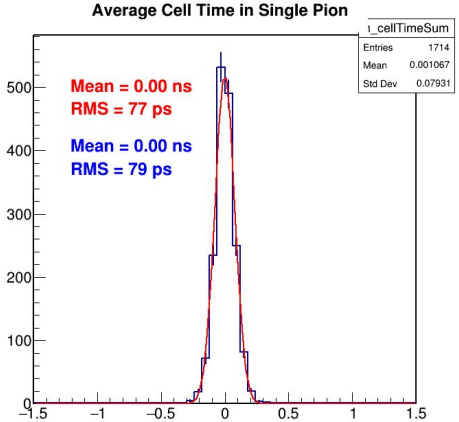
- 1 GeV < Truth pion pT < 20 GeV
- Only non-zero cell time cells
- LAr EM Barrel (|eta| < 0.8)
- Only **layer2(where most of the energy is deposited)** is considered
- After the above selection #cell in a pion >= 9
- At least one cell in a pion has reco cell E > 1 GeV

All distributions are **sorted by cellE** after selection, then $1/RMS^2$ weighted average without calibration

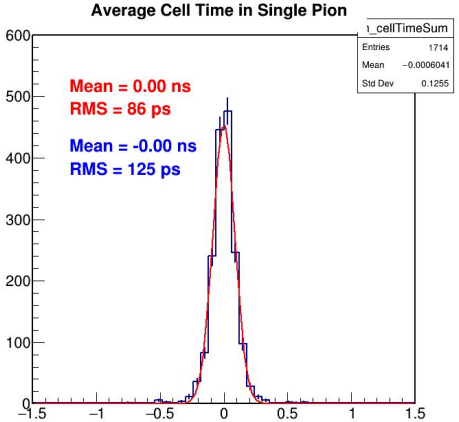
1/sqrt(N) is generally applicable when we are dealing with simple arithmetic averages of independent and identically distributed random variables, so we don't see that effect here

5D Calorimeter

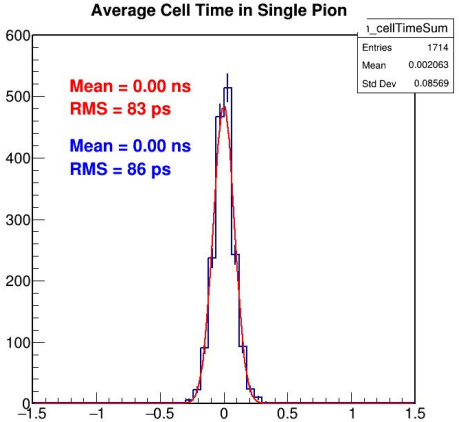
Checking stat error change with different sample size



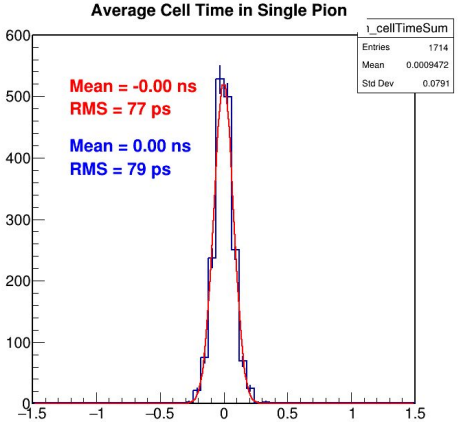
Averaged all cells after the selection



Averaged 1 cell after the selection



Averaged 4 cell after the selection



Averaged 9 cell after the selection

To have a same set of pions for comparison, the following selections are applied

- 1 GeV < Truth pion pT < 20 GeV
- Only non-zero cell time cells
- LAr EM Barrel (|eta| < 0.8)
- Only **layer2(where most of the energy is deposited)** is considered
- After the above selection #cell in a pion >= 9
- At least one cell in a pion has reco cell E > 1 GeV

All distributions are $1/RMS^2$ weighted average without calibration (**cells are ordered at Ntuple level**)

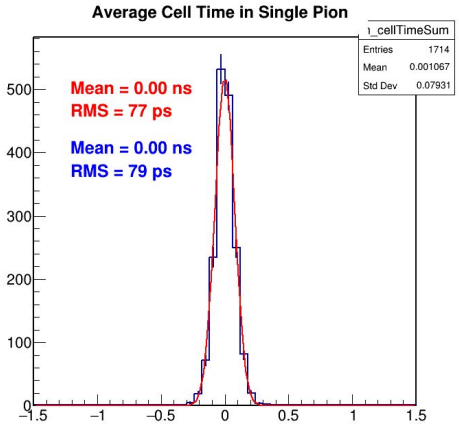
Checking stat error change with different sample size

```
root [4] CellTree->Scan("cellE:eventNumber")
************************************
*    Row   *     cellE * eventNumb *
************************************
*        0 * 0.8483136 *       837 *
*        1 * 0.0939839 *       837 *
*        2 * 0.5843032 *       837 *
*        3 * 0.1696579 *       837 *
*        4 * 0.0289775 *       837 *
*        5 * 0.0239537 *       837 *
*        6 * 0.0160578 *       837 *
*        7 * 0.1386839 *       837 *
*        8 * 0.0460442 *       837 *
*        9 * 0.0588638 *       837 *
*       10 * 0.2087058 *       837 *
*       11 * 0.5918792 *       837 *
*       12 * 0.3367217 *       837 *
*       13 * 0.1200660 *       837 *
*       14 * 0.0588638 *       837 *
*       15 * 0.0470919 *       837 *
*       16 * 0.0588638 *       837 *
*       17 * 0.0099955 *       837 *
*       18 * 0.9332099 *       837 *
*       19 * 0.0460442 *       837 *
*       20 * 0.0219919 *       837 *
*       21 * 0.0090269 *       837 *
*       22 * 0.0099955 *       837 *
*       23 * 0.0289775 *       837 *
*       24 * 0.0010085 *       837 *
Type <CR> to continue or q to quit ==>
```

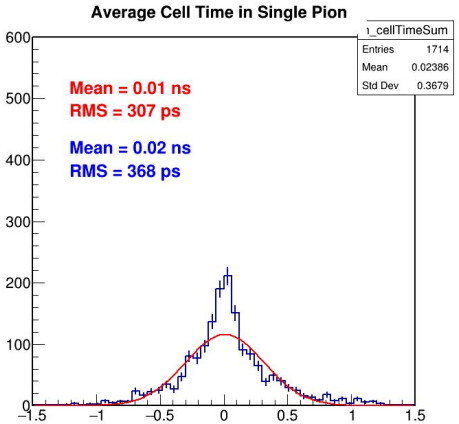
Ntuple is not ordered in cell significance (need to check)
Working on it, but has technical error. This was asked to Peter this morning.

5D Calorimeter

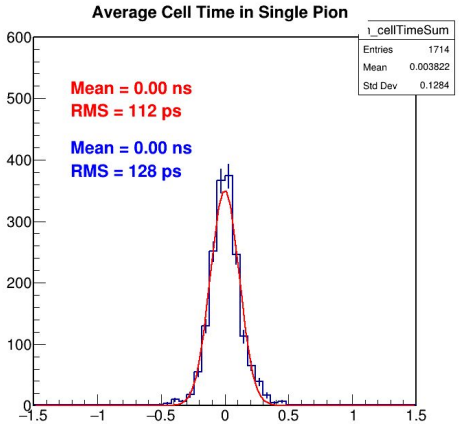
Checking stat error change with different sample size



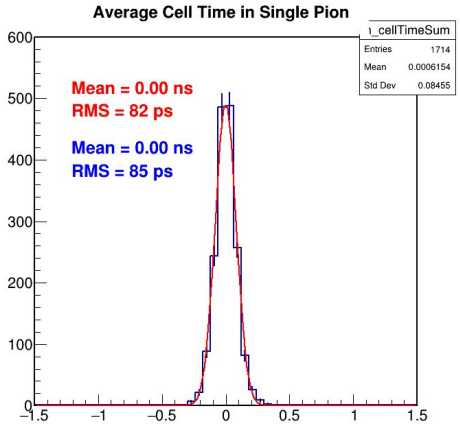
Averaged all cells after the selection



Averaged 1 cell after the selection



Averaged 4 cell after the selection



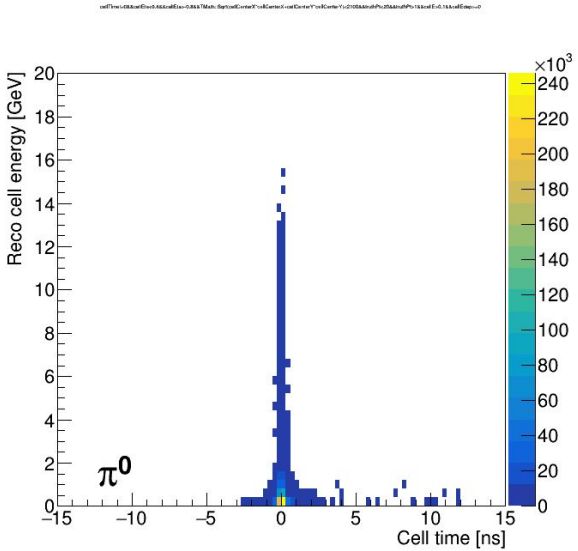
Averaged 9 cell after the selection

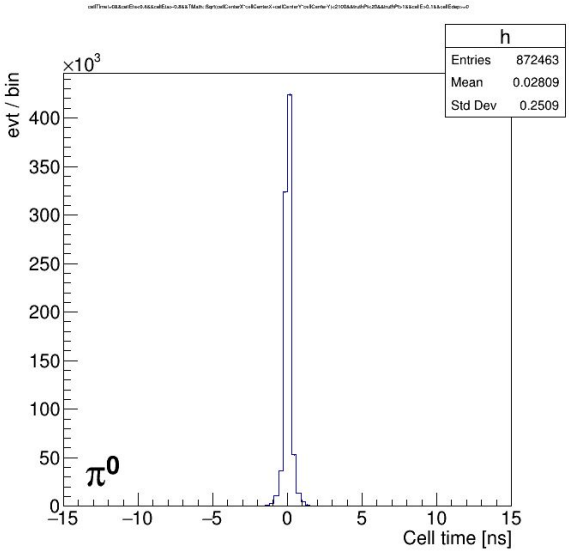
To have a same set of pions for comparison, the following selections are applied

- 1 GeV < Truth pion pT < 20 GeV
- Only non-zero cell time cells
- LAr EM Barrel (|eta| < 0.8)
- Only **layer2(where most of the energy is deposited)** is considered
- After the above selection #cell in a pion >= 9
- At least one cell in a pion has reco cell E > 1 GeV

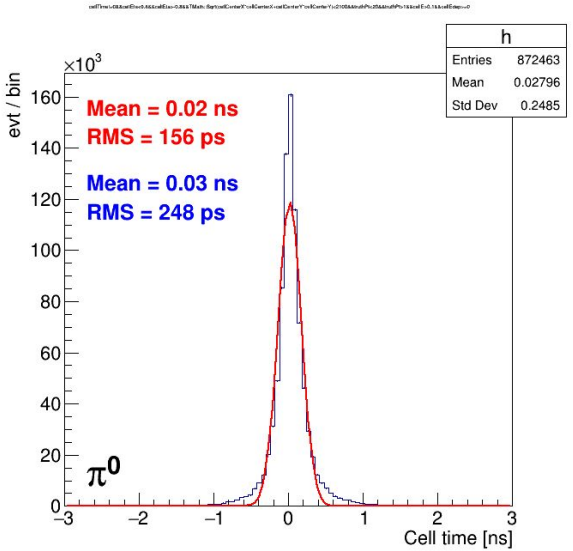
All distributions are **randomly mixed** after selection, then $1/RMS^2$ weighted average without calibration

Cell time vs reco cell E





Projection to clle time,
with the same binning&range



Projection to clle time,
with different binning&range
+ Gaussian fit

Timing resolution of neutral pion with various average methods

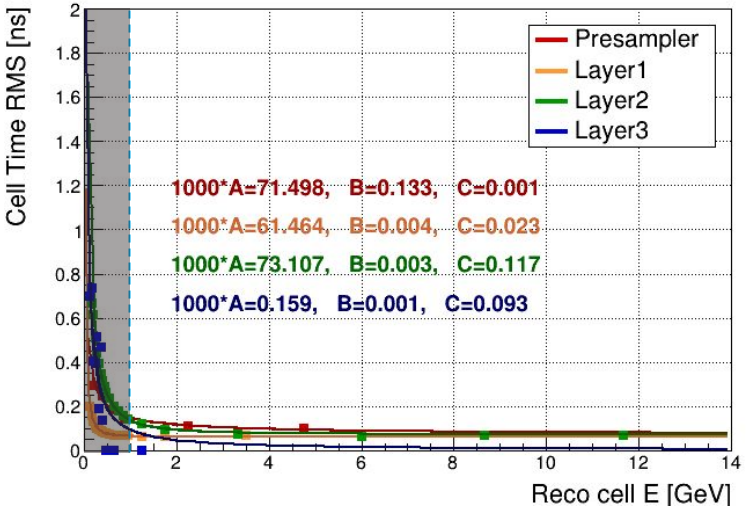
Event selections

To have a same set of pions for comparison, the following selections are applied

- 1 GeV < Truth pion pT < 20 GeV
- Only non-zero cell time cells
- LAr EM Barrel (|eta| < 0.8)
- Layer 1 and 2 only

Baseline selection

Up to this selection, 88504 pions (= Total #pion)



- **At least one cell in a pion has reco cell E > 1 GeV**

To pick up same set of events after additional cut on reco cell E

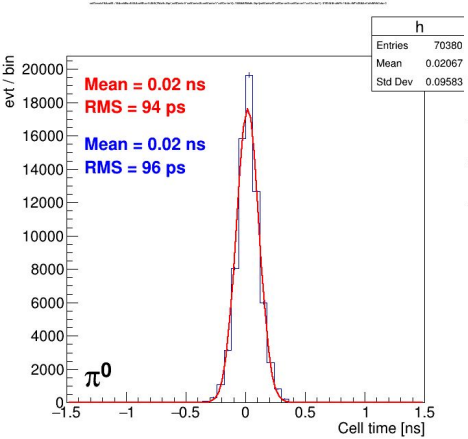
→ **37926 pions** (37926/88504 = 42.9%)

(= #pion with 1GeV cell)

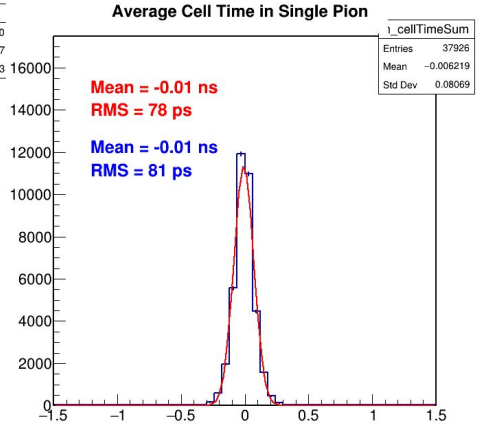
FYI, this fraction was **8.65%** in case of charged pion due to higher cell E cut (2GeV) so neutral pion seems much more promising

5D Calorimeter

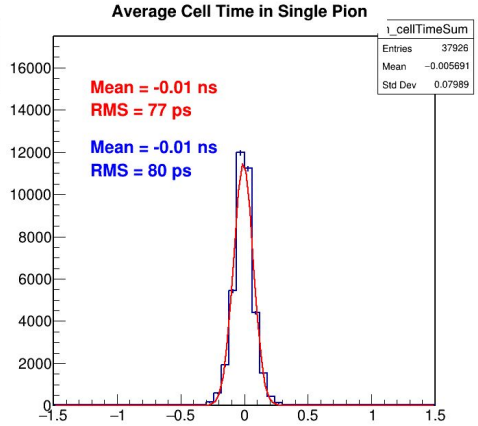
Pions with 1GeV cell (37926 pions) + all reco cell E > 1 GeV



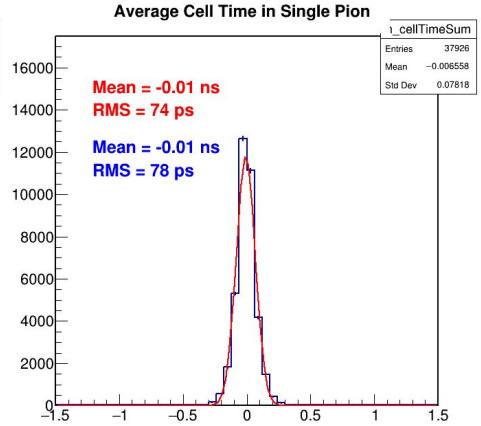
cell time per cell
(Not averaged)



Averaged cell time per pion
Arithmetic mean

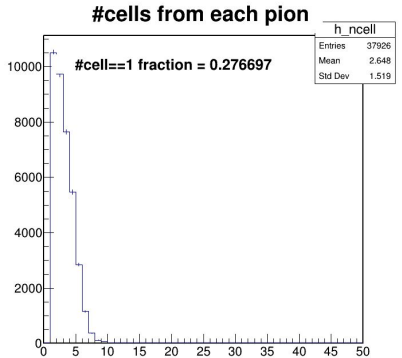


Averaged cell time per pion
Cell E weighted



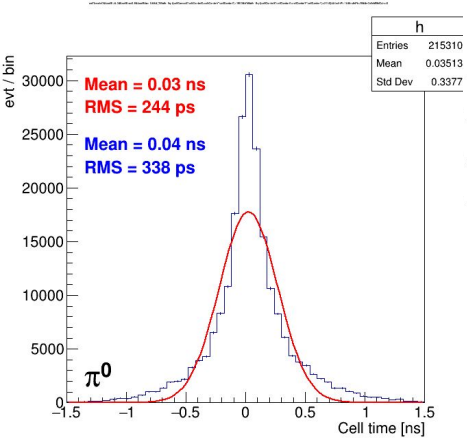
Averaged cell time per pion
$1/RMS^2$ weighted

- All cells in the leftmost plots contributed to the rest of three plots
- **Additional selection: reco cell E > 1 GeV**
- Single cell faction in averaged distributions = 27.7 %
- All averaged distributions are calibrated

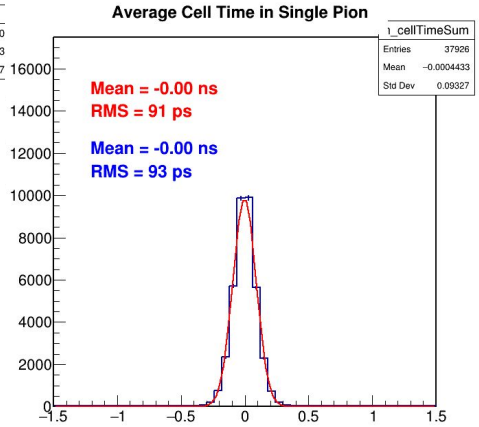


5D Calorimeter

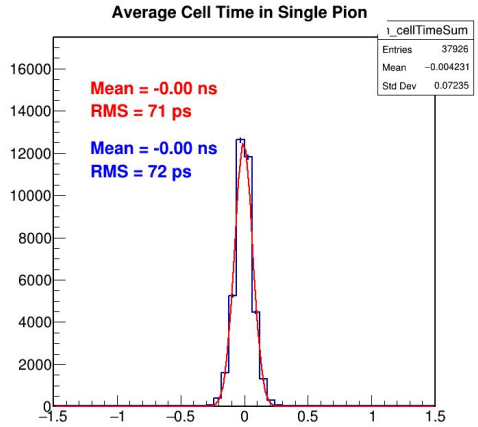
Pions with 1GeV cell (37926 pions) + all reco cell E > 0.1 GeV



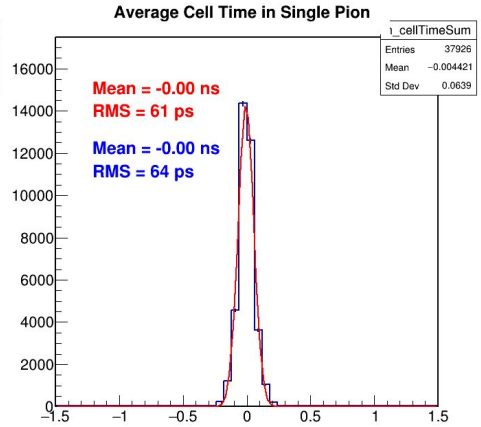
cell time per cell (Not averaged)



Averaged cell time per pion Arithmetic mean

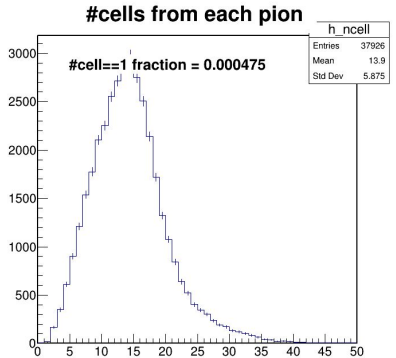


Averaged cell time per pion Cell E weighted



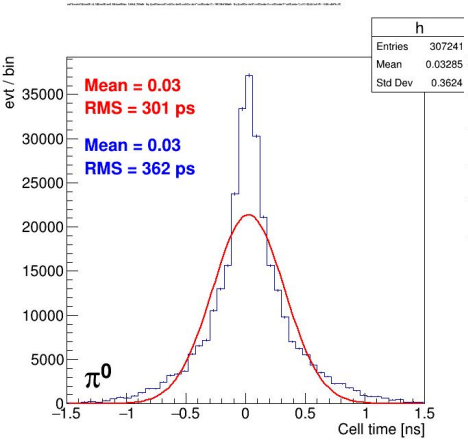
Averaged cell time per pion 1/RMS^2 weighted

- All cells in the leftmost plots contributed to the rest of three plots
- **Additional selection: reco cell E > 0.1 GeV**
- Single cell faction in averaged distributions = 0.05 %
- All averaged distributions are calibrated

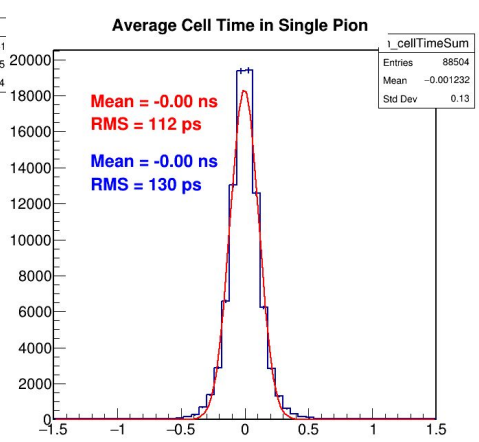


5D Calorimeter

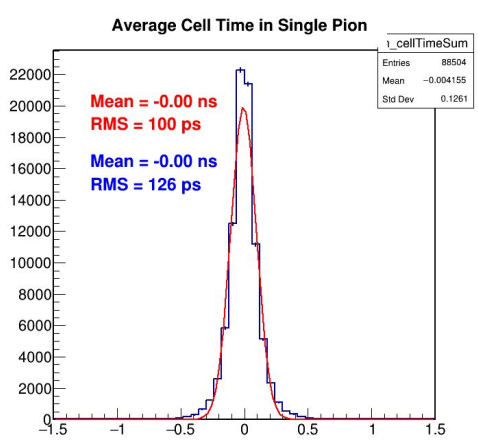
Total pions (88508 pions) + all reco cell E > 0.1 GeV



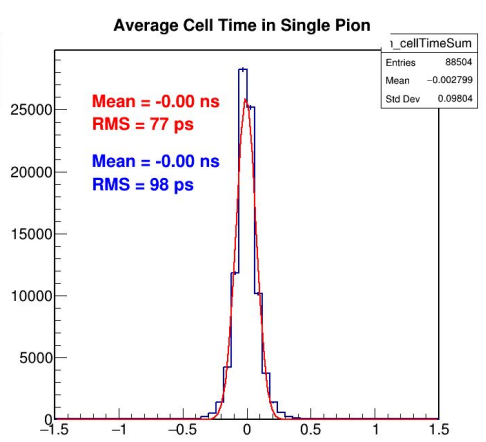
cell time per cell
(Not averaged)



Averaged cell time per pion
Arithmetic mean

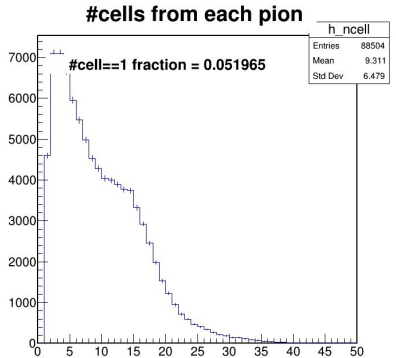


Averaged cell time per pion
Cell E weighted



Averaged cell time per pion
1/RMS^2 weighted

- All cells in the leftmost plots contributed to the rest of three plots
- **Additional selection: reco cell E > 0.1 GeV**
- Single cell faction in averaged distributions = 5.20 %
- All averaged distributions are calibrated



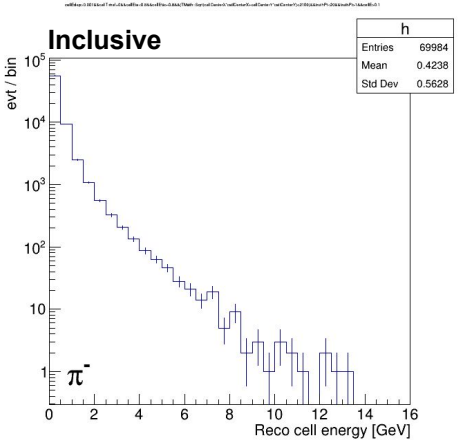
Summary with neutral pion study

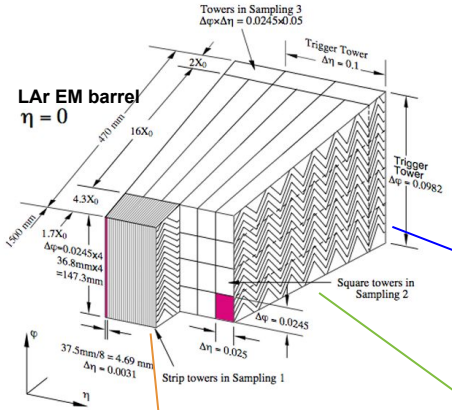
- **Using pions with at least one energetic cell (>1GeV),**
  we can achieve a very decent timing resolution with neutral pions
- 1GeV cut on reco cell E still kept 42.9% of pions among all pion that passed baseline selection
- Cell significance may give us better cut than 1GeV cut on cell E and allow us to keep more than 42.9% of pions
  - Working on implementation

Timing resolution of neutral pion with various average methods

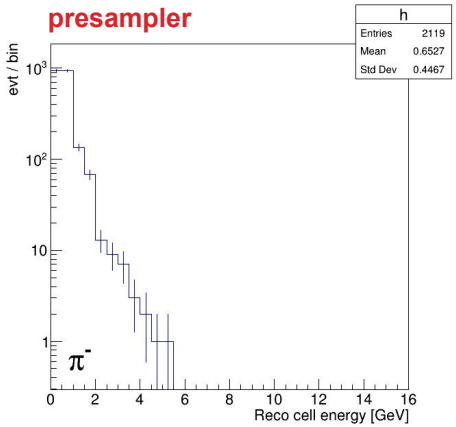
5D Calorimeter

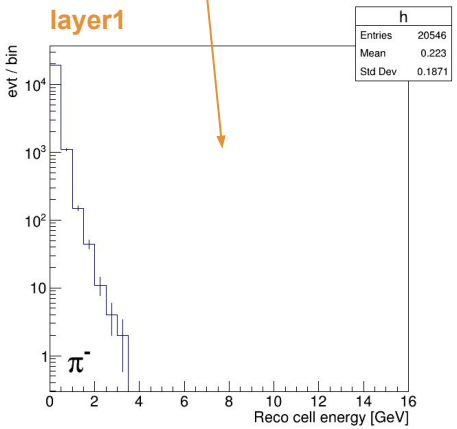
Reco cell E per layer (1 GeV < truth pion p_T < 20 GeV)

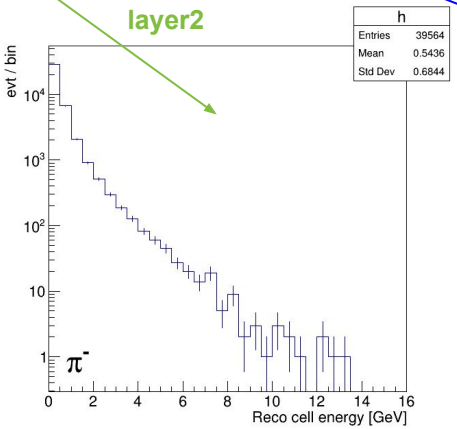


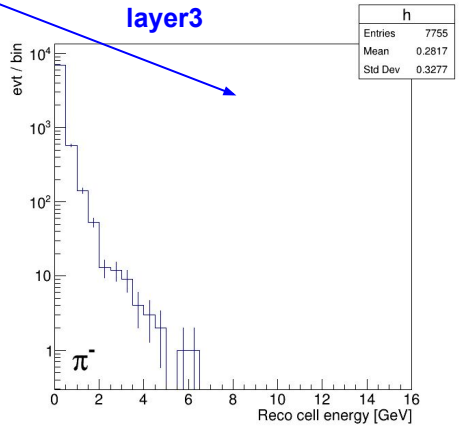


- Check reco cell E range within the region of our interest
- There is no cell which has more than 14 GeV





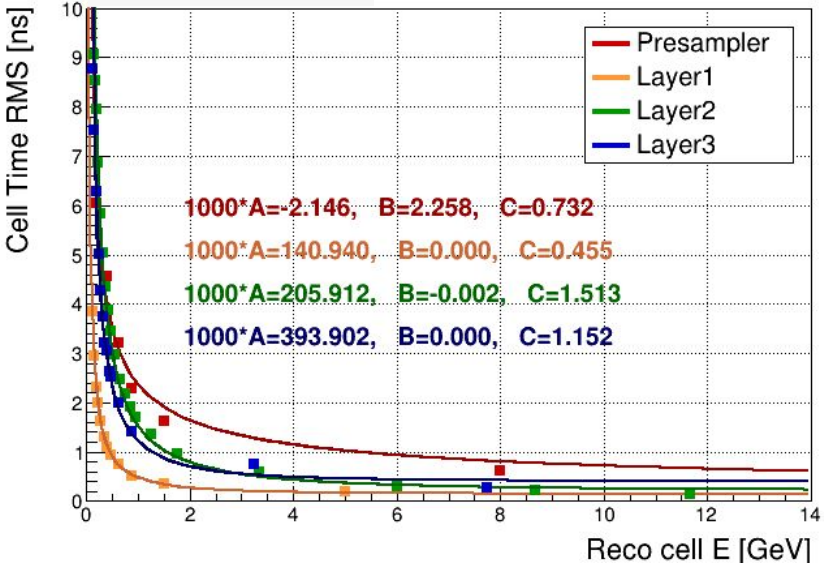




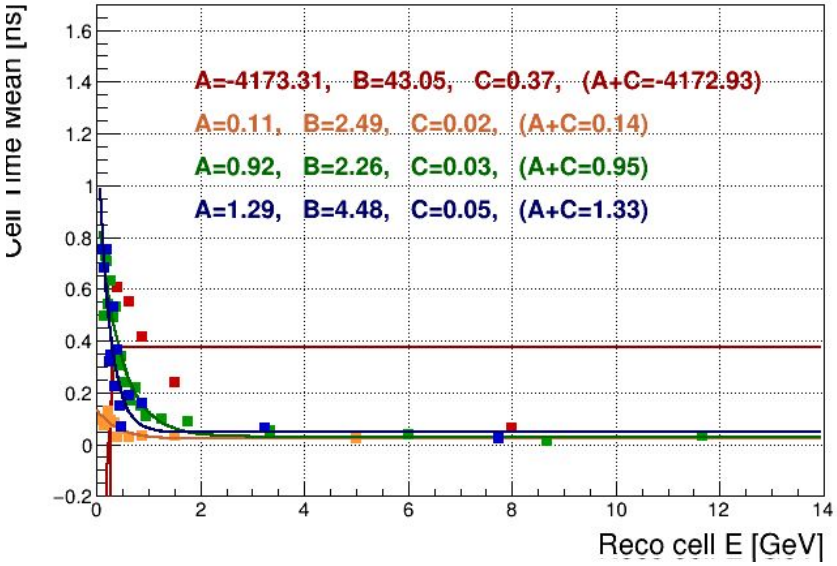
5D Calorimeter

RMS vs Reco cell E per EM LAr Barrle layer

$$\sqrt{A^2 + \frac{B^2}{E} + \frac{C^2}{E^2}}$$



$$A \cdot e^{-B \cdot E} + C$$



- Timing resolution and mean are parametrized by cell E (E)
- The constant term (i.e. A) depends on **layer**
- RMS differences between layers are ~50ps at cell E of 5 GeV

Can remove presampeler…

Event selections

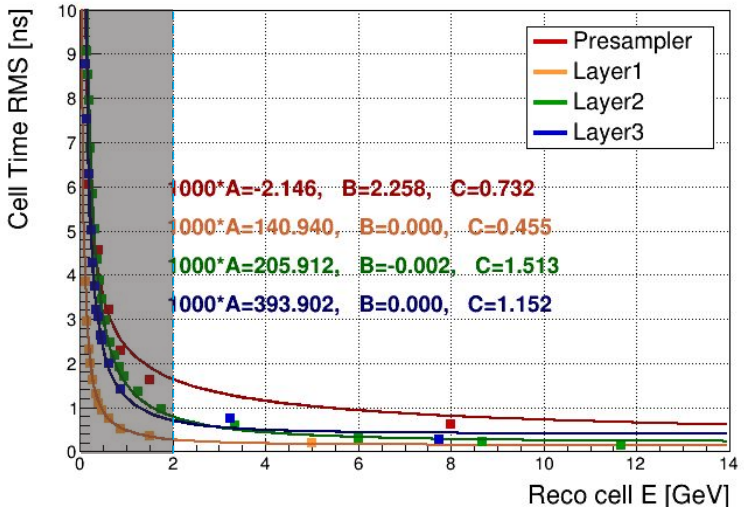
To have a same set of pions for comparison, the following selections are applied

- 1 GeV < Truth pion pT < 20 GeV
- Only non-zero cell time cells
- LAr EM Barrel (|eta| < 0.8)
- Pre-sampler is excluded
- Truth cell E < 0.001 GeV
  (temporary cut till we have significance)

Up to this selection, 13111 pions

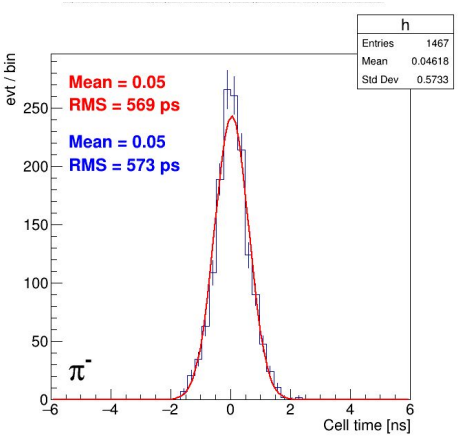
- **At least one cell in a pion has reco cell E > 2 GeV**

→ 1134 pions (1134/13111 = 8.65%)

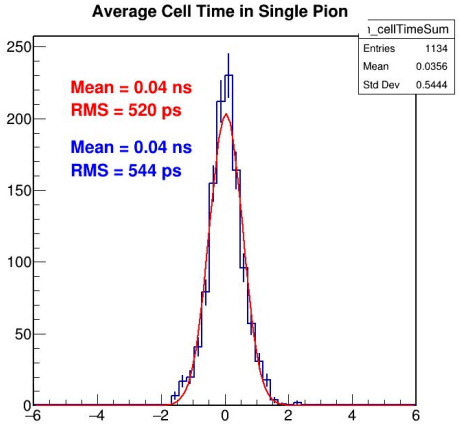


5D Calorimeter

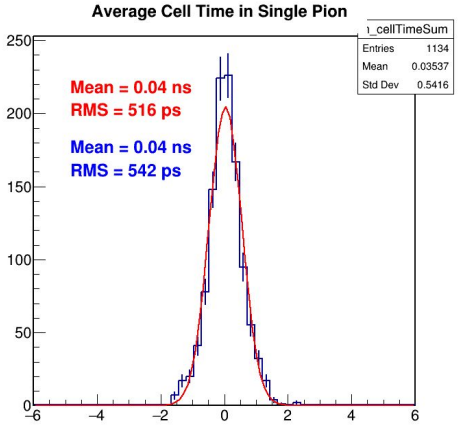
Various way to average (average only reco cell E > 2 GeV)



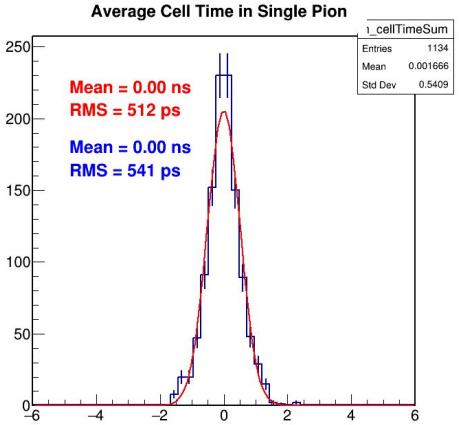
Individual cell time



Arithmetic mean

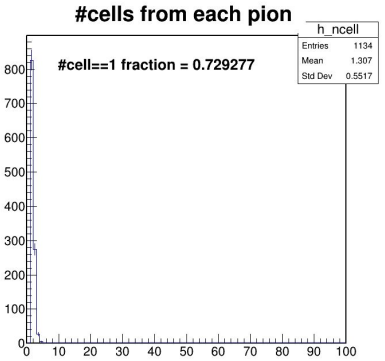


Cell E weighted



1/RMS^2 weighted

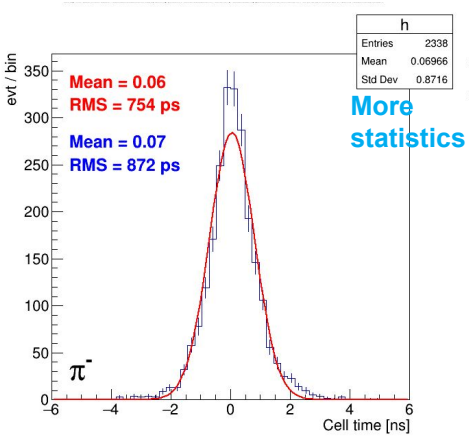
- Average only cells with **reco cell E > 2 GeV**
- Single cell faction in averaged distributions = 72.9 %



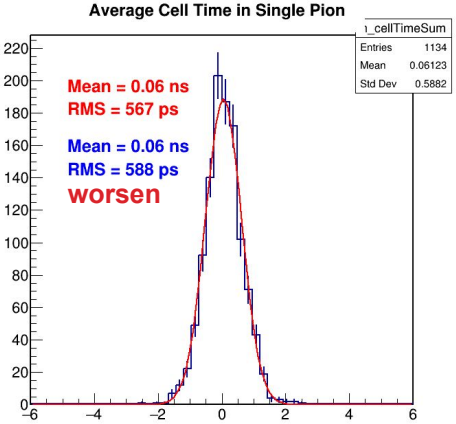
Can fix Y-asxis maximum for easier comparison

5D Calorimeter

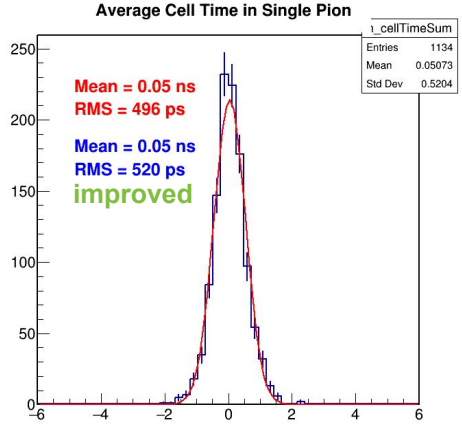
Various way to average (average only reco cell E > 1 GeV)



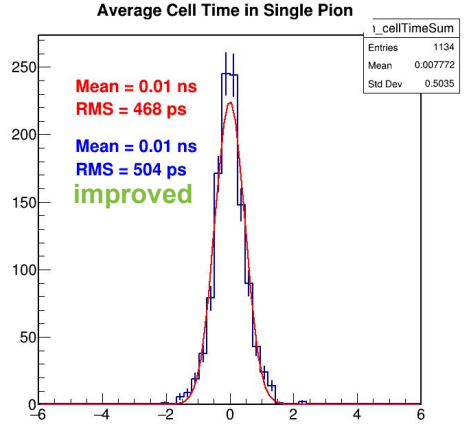
Individual cell time



Arithmetic mean

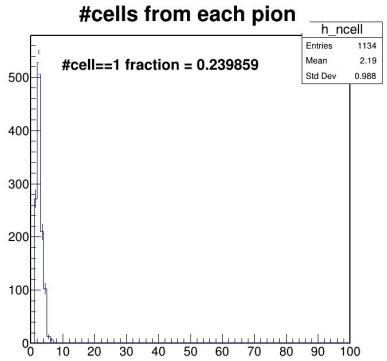


Cell E weighted



1/RMS^2 weighted

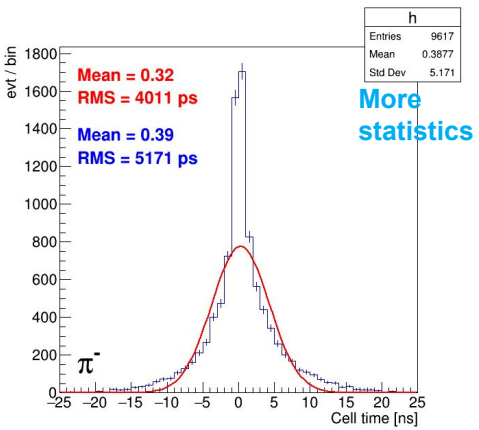
- Average only cells with **reco cell E > 1 GeV**
- Single cell faction in averaged distributions = 24.0 %



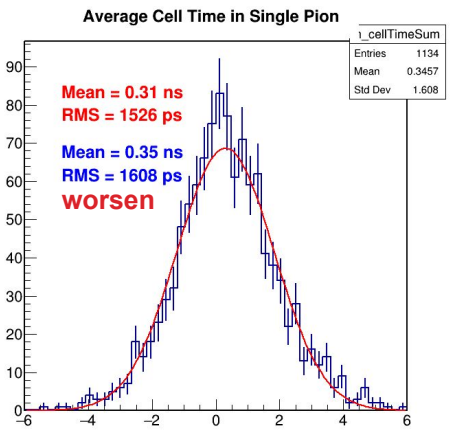
Can fix Y-asxis maximum for easier comparison

5D Calorimeter

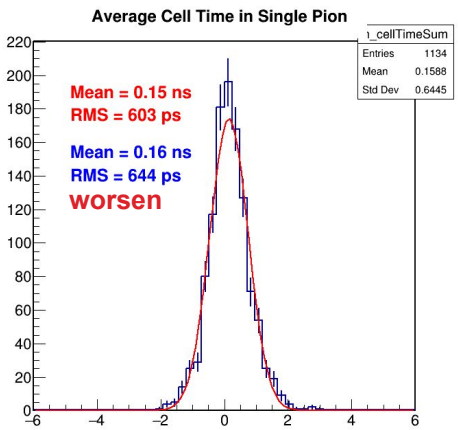
Various way to average (average only reco cell E > 0.1 GeV)



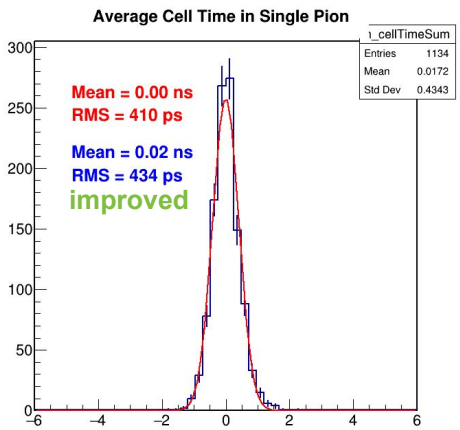
Individual cell time



Arithmetic mean

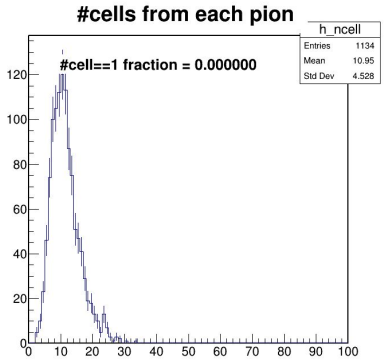


Cell E weighted



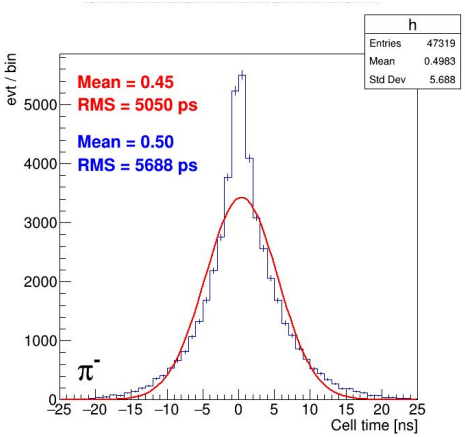
1/RMS^2 weighted

- Average only cells with **reco cell E > 0.1 GeV**
- Single cell faction in averaged distributions = 0.00 %

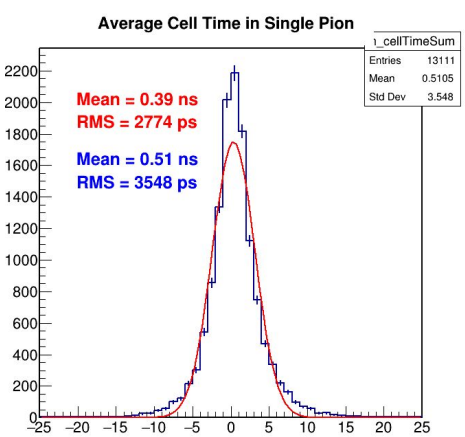


Can fix Y-asxis maximum for easier comparison

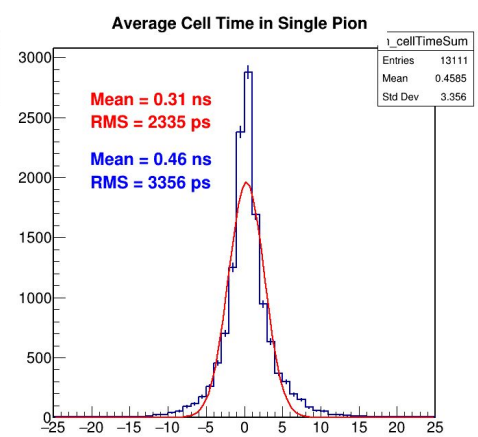
Various way to average (average only reco cell E > 0.1 GeV)



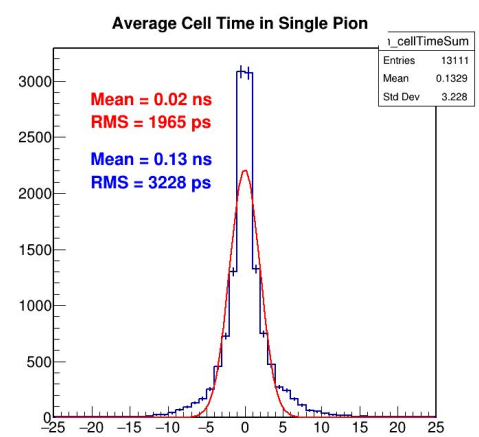
Individual cell time



Arithmetic mean

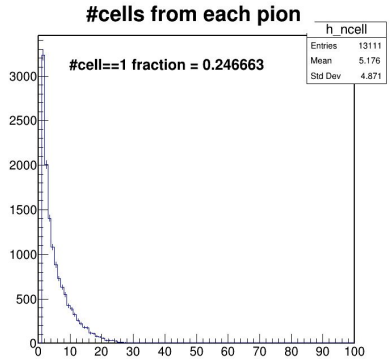


Cell E weighted



1/RMS^2 weighted

- Average only cells with **reco cell E > 0.1 GeV**
- Single cell faction in averaged distributions = 24.0 %
- **At least one cell in a pion has reco cell E > 2 GeV (removed)**

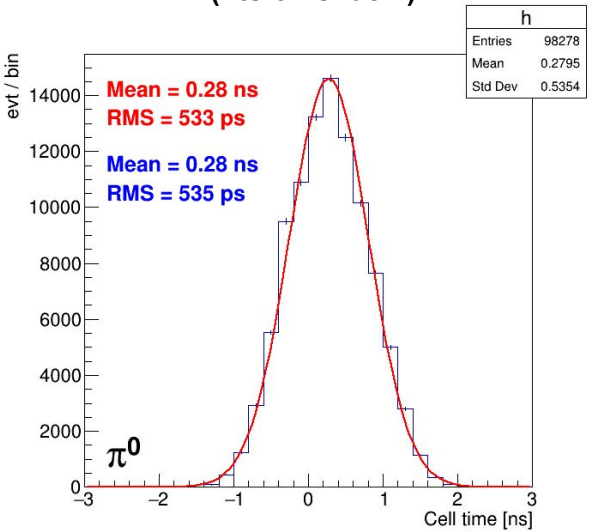


Backup

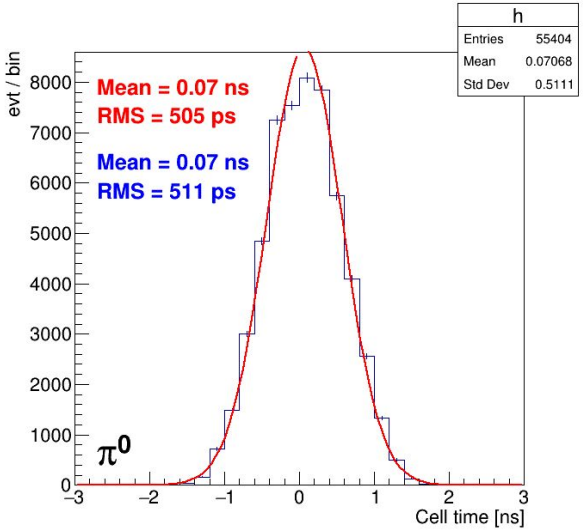
Discrepancy btw old and new fits

Old fits are made of Ntuple with bug (mistakenly used a wrong file, sorry about the confusion)
Three plots below are made with the same selection using 0.22 GeV < reco cell E < 0.26 GeV but for

1 < GeV Truth pion pT < 50 GeV
With buggy Ntuple
(fits on slide 4)



1 < GeV Truth pion pT < 50 GeV
Without buggy Ntuple



1 < GeV Truth pion pT < 20 GeV
Without buggy Ntuple
(fits on slide 5)