MEG II実験における陽電子時間再構成法の研究

Study of Positron Timing Reconstruction in MEG II Experiment

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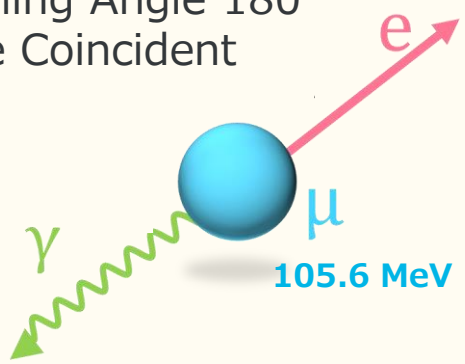
MEG II Requirement

In MEG II experiment we aim to search for charged lepton flavor violation, $\mu^+ \rightarrow e^+\gamma$ decay.

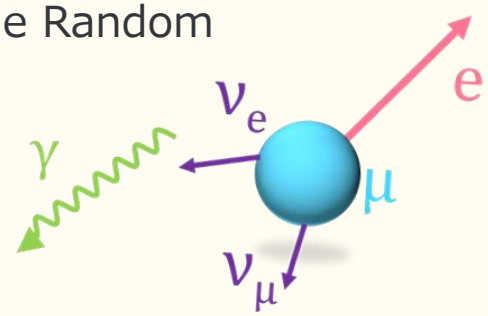
Signal: two-body decay

- 52.8 MeV
- Opening Angle 180°
- Time Coincident



Dominant BG: accidental

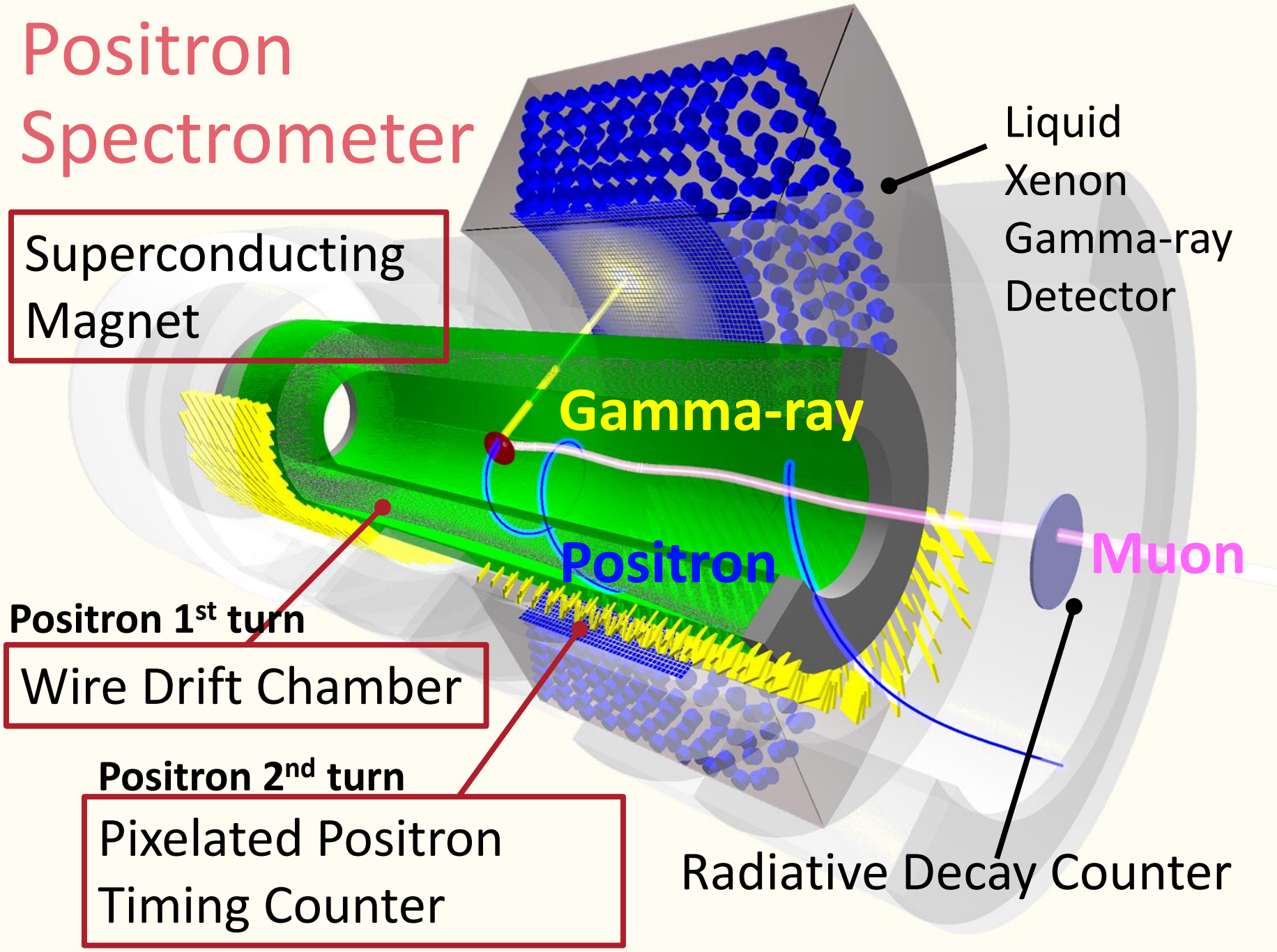
- <52.8 MeV
- Any angle
- Time Random



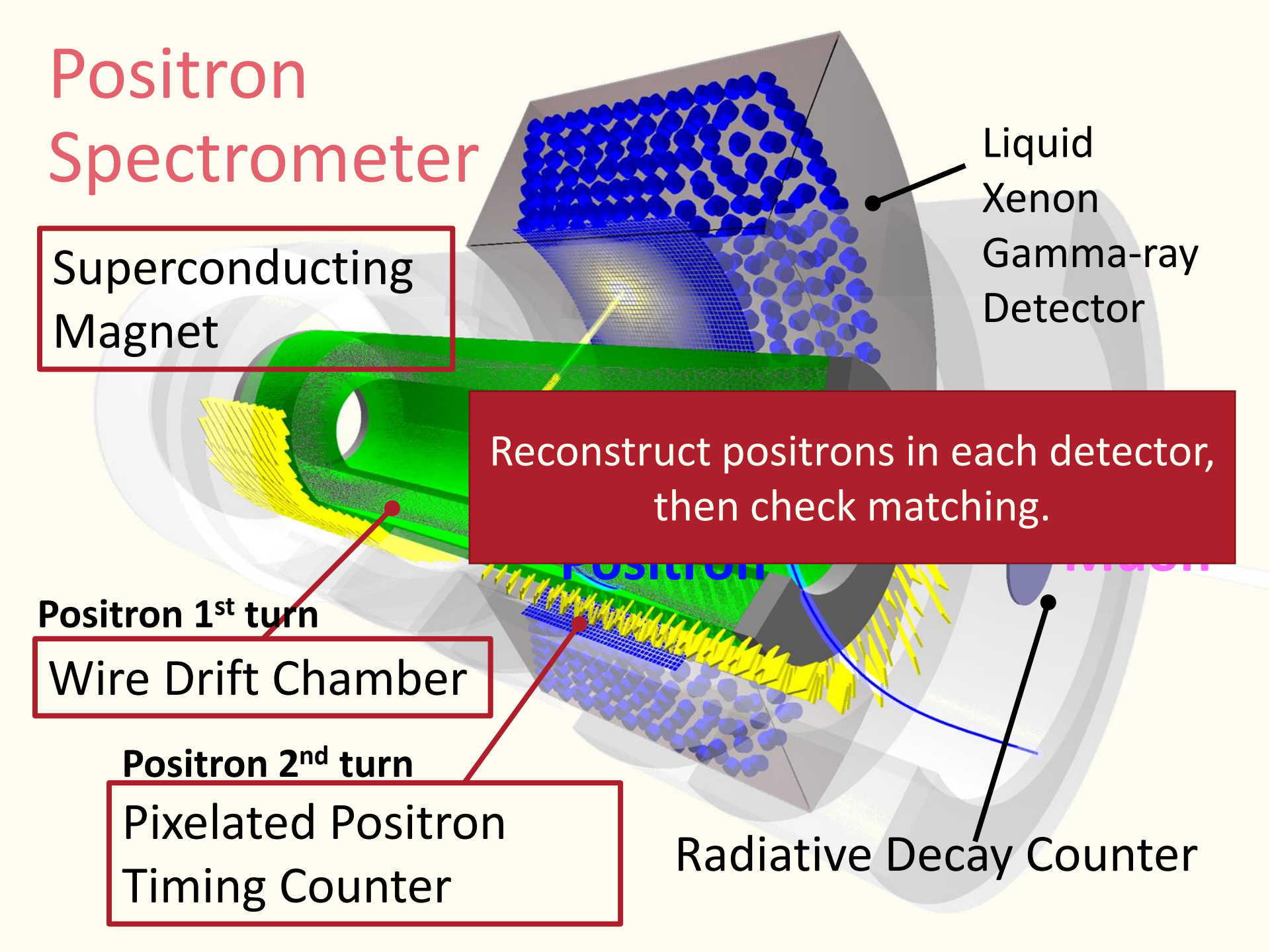
Precise measurement of emission angle, energy, and timing of both positron and γ is essential.

⇒ Today's topic is time measurement of positrons.

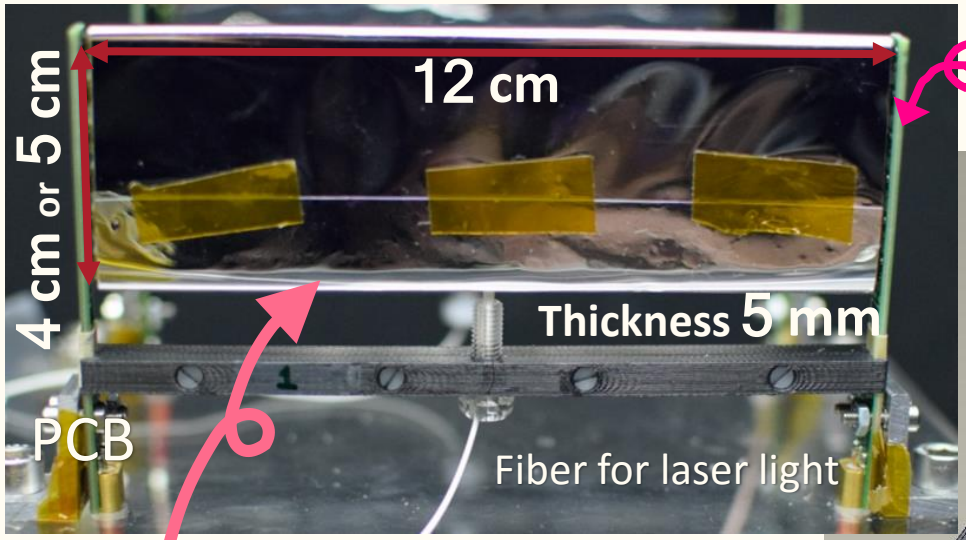
Positron Spectrometer



Positron Spectrometer

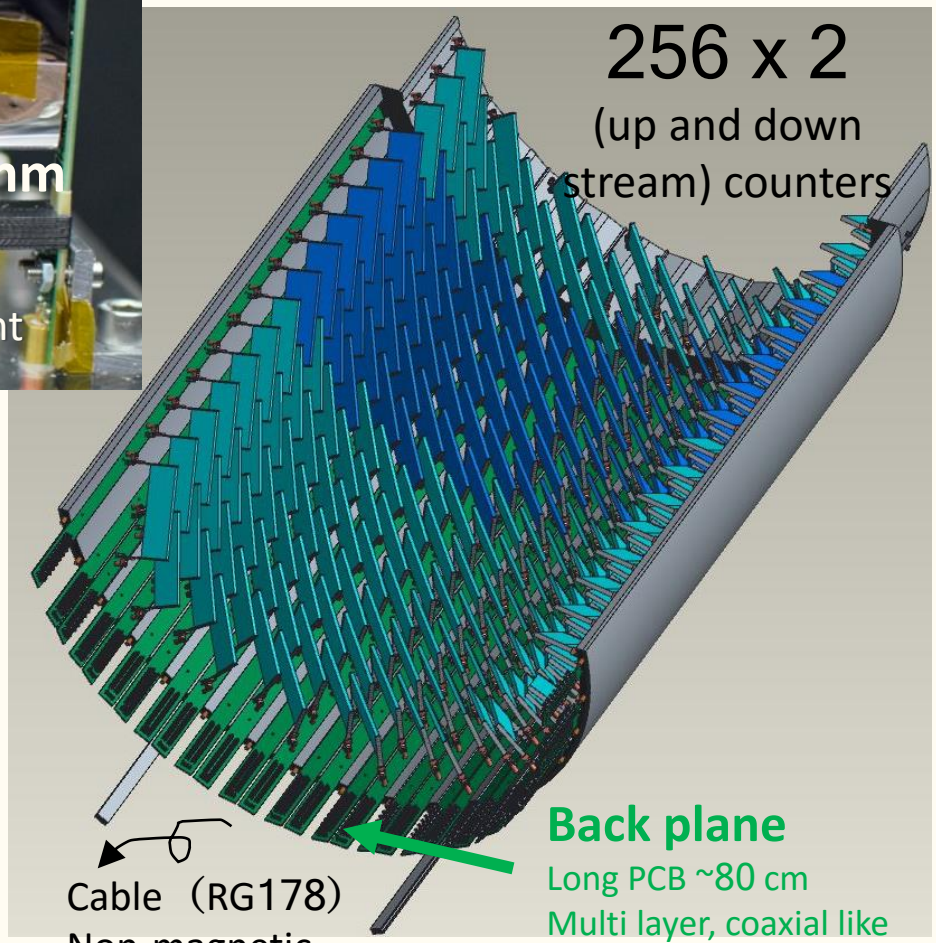


Timing Counter



6 SiPMs in series at the both ends
AdvanSiD (Italy) 3x3 mm², 50x50 um² pixels

Fast Plastic Scintillator BC422



One Counter

Time Resolution: 70-80 ps

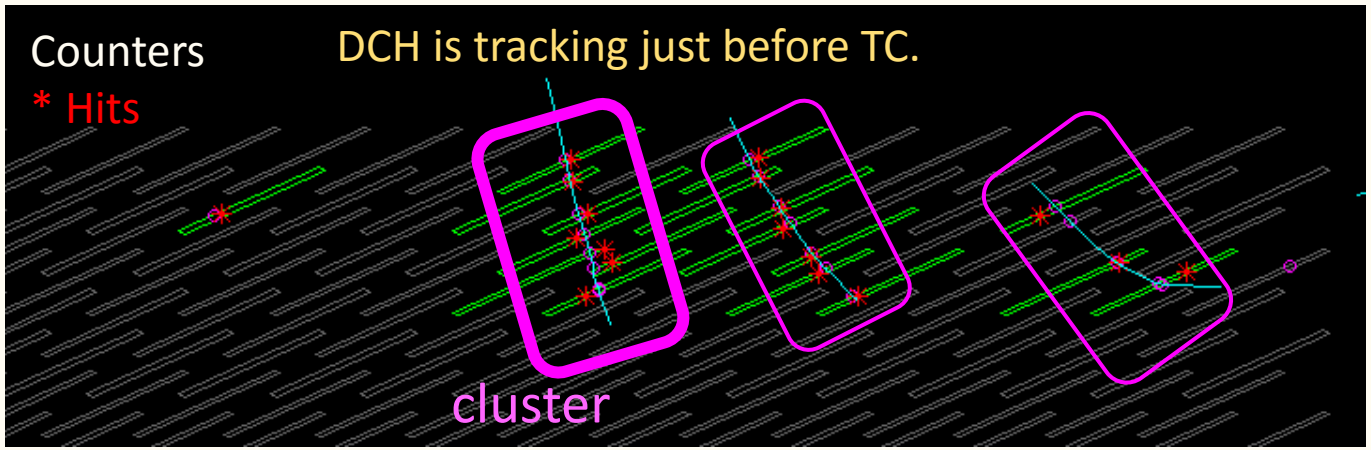
Position Resolution: ~ 1 cm

Since positron hits multi-counter, overall resolution is σ~30 ps
(demonstrated in beam test)

Clustering

- The TC is pixelated by 512 scintillator counters.
- Positron comes to the TC in high rate. (a few MHz in the TC region.)

→ Clustering of TC hits is necessary.



All hits from the same track and the same turn should be included in a cluster. Following parameters should be checked.

Cluster reconstruction efficiency
Miss hit in a cluster
Contamination hit of a cluster

Clustering Methods

- Local Geometrical Clustering
  - Make chain with geometrical order of positron hit one by one.

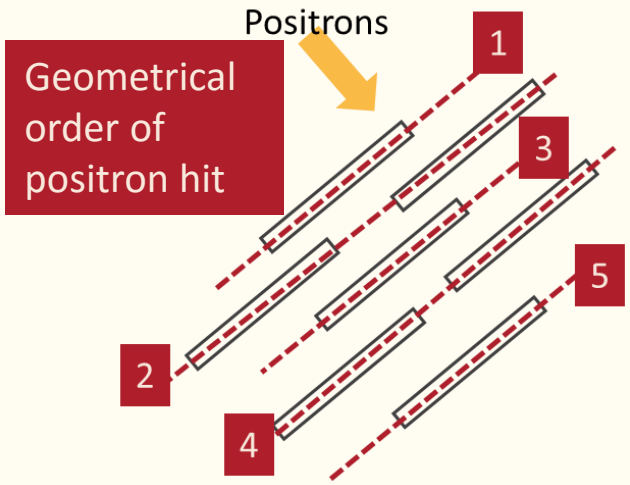
  Good: Don't need any calibration among the counters.

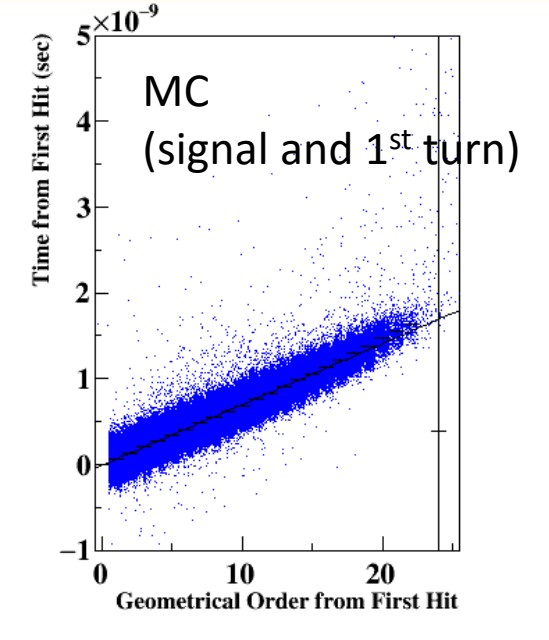
  Bad: The effect of contamination hit is large. Geometrically far hits are separated into the different clusters.

- **Global Clustering (NEW)**
  - Use relationship b/w hit time and counter position information.

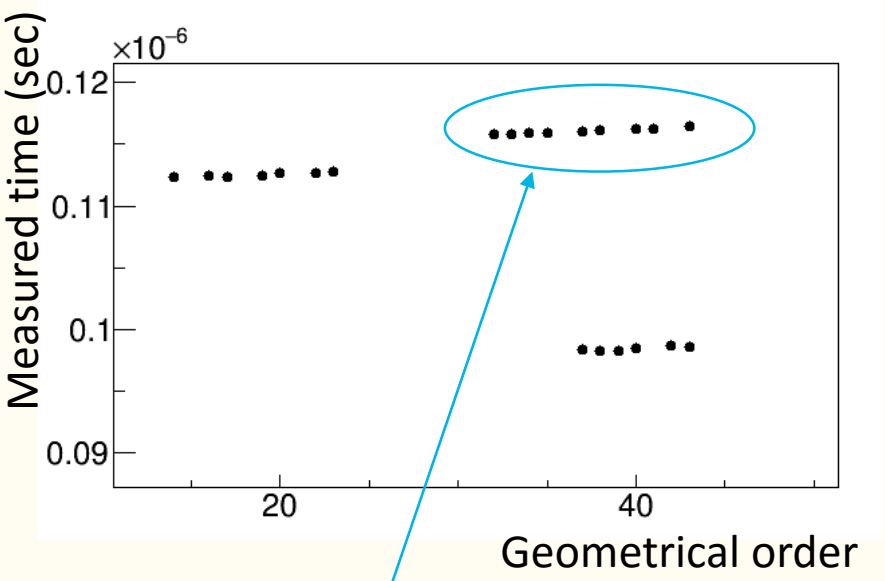
  Good: less affected by contamination hits. Combine geometrically far hits.

  Bad: Need good time calibration among the counters.

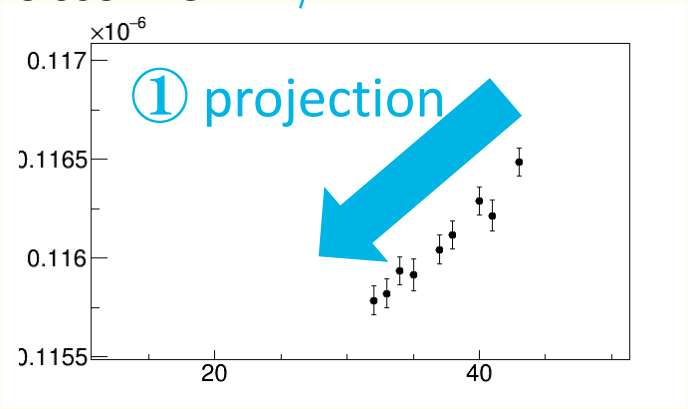


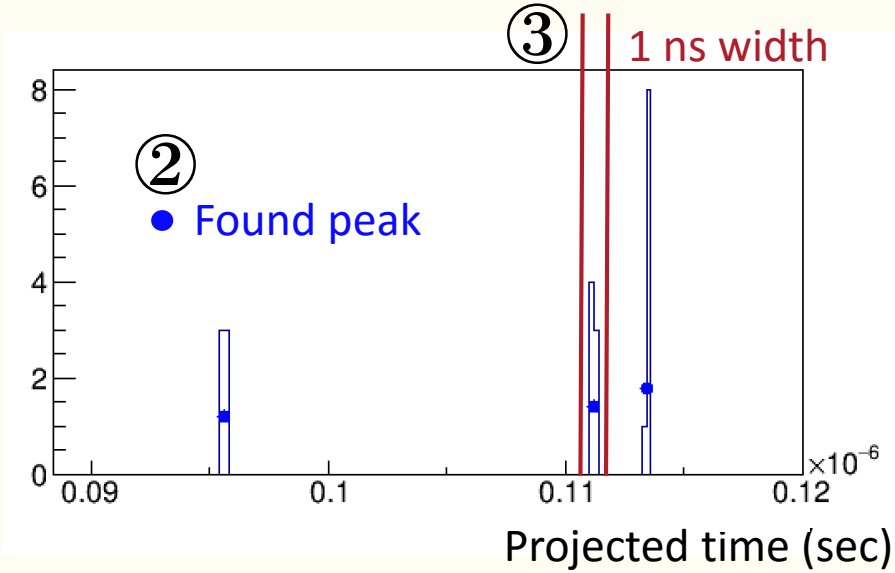


Global Clustering



Closer view





Algorithm

① Make projection for every hit time with geometrical order dependence.

② Peak Search

③ Make clusters in certain region (1 ns) from each peak.

Study of clustering performance with MC

Estimate the clustering performance with MC.

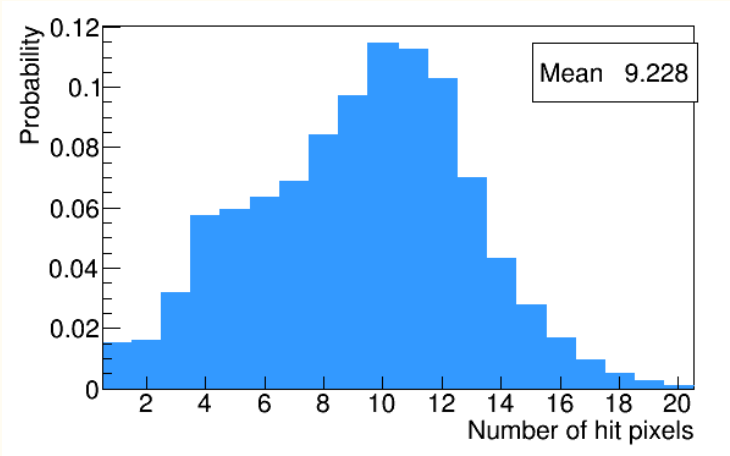
Performance is estimated for “target cluster”

- Cluster of 1st turn in TC
- Incident Momentum > 35 MeV
- Vertex of muon decay is on target
  - The positrons from muon decay out of target are identified by DCH.
- # of hit > 3

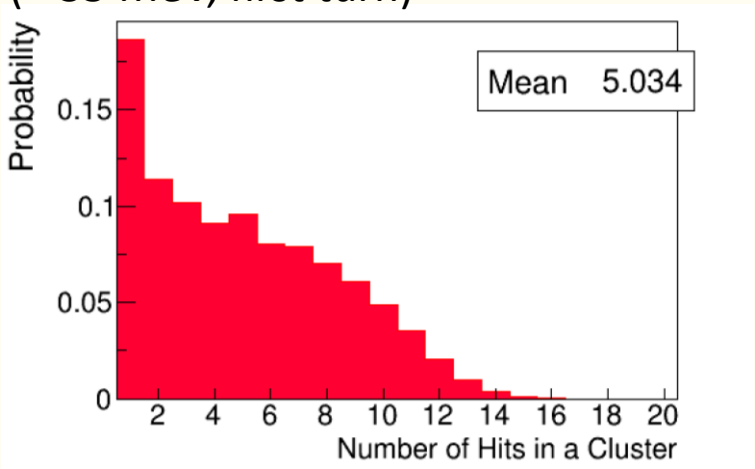
MC Set Up

- Geant4
- Generate muons, which are stopped on a target.
- Positron from normal muon decay hits the TC.
- Muon mixing rate is 7×10^7 μ/s (same as pilot run)
- Detector implementation follows a pilot run conducted on June to compare to data.
  - ¼ TC, No DCH

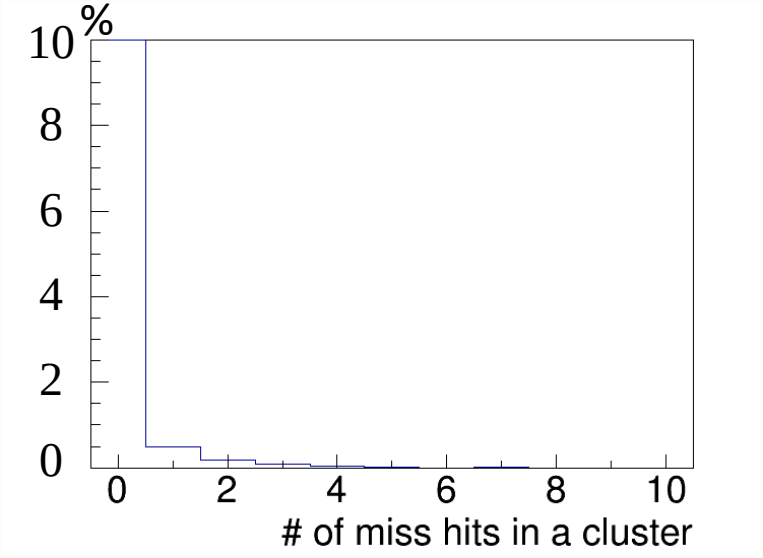
Signal positron

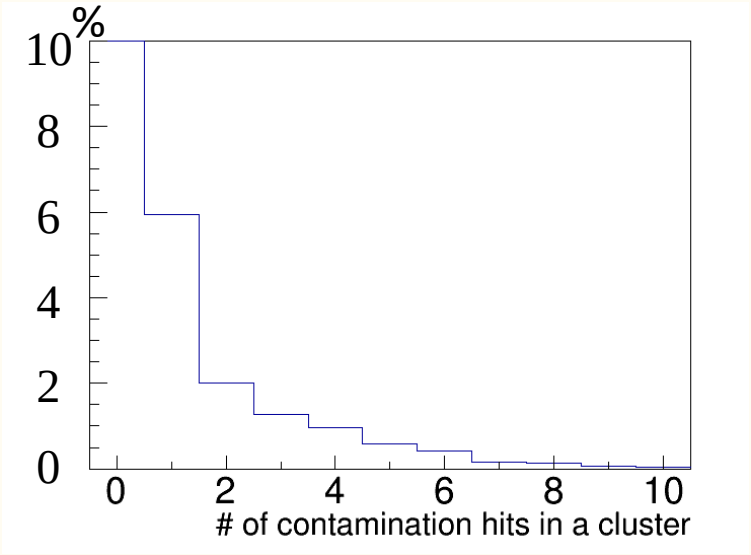


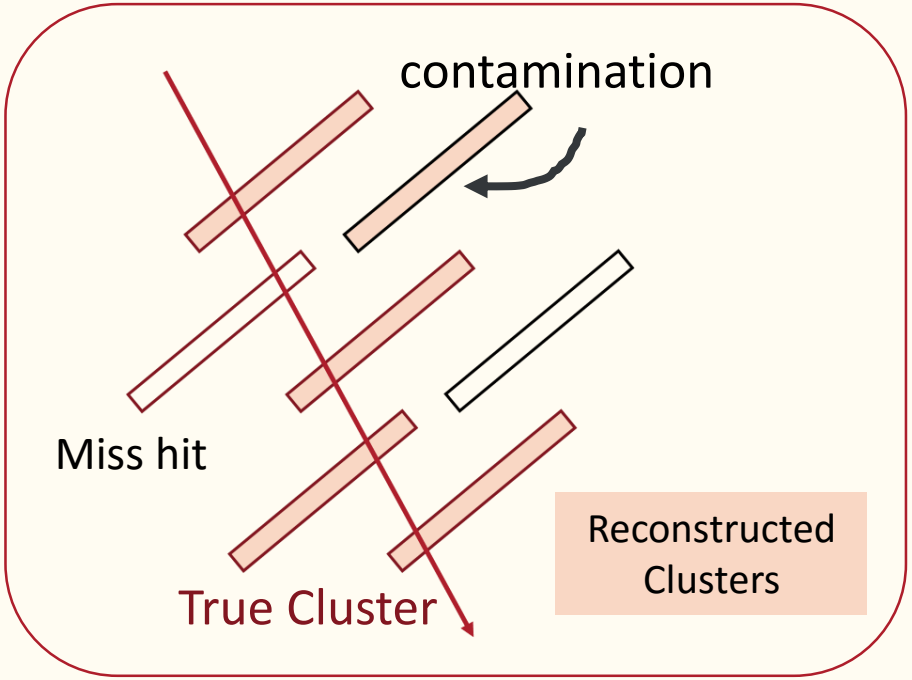
Michel positron
(> 35 MeV, first turn)



Cluster Quality







Clusters which have miss hit are not so many. (~ 1%)

However some clusters (~15 %) have contamination hit.

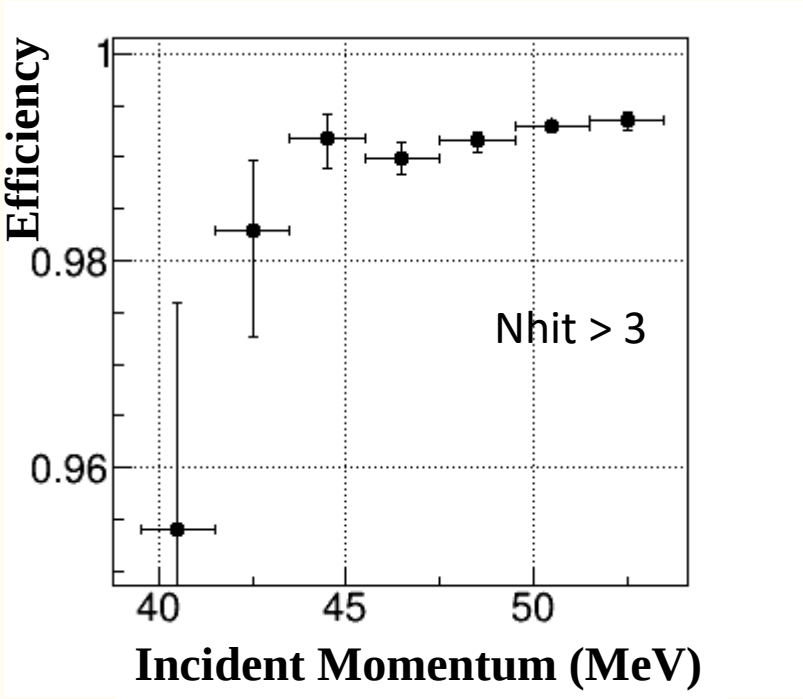
→ Cut with the fit result or reconstructed position will be studied.

Efficiency vs Incident Momentum

Cluster reconstruction efficiency :

$$\frac{\text{(reconstructed cluster)}}{\text{(\# of true cluster of 1}^{st}\text{ turn)}}$$

Matching b/w reconstructed cluster and true cluster is done with first hit in reconstructed cluster.

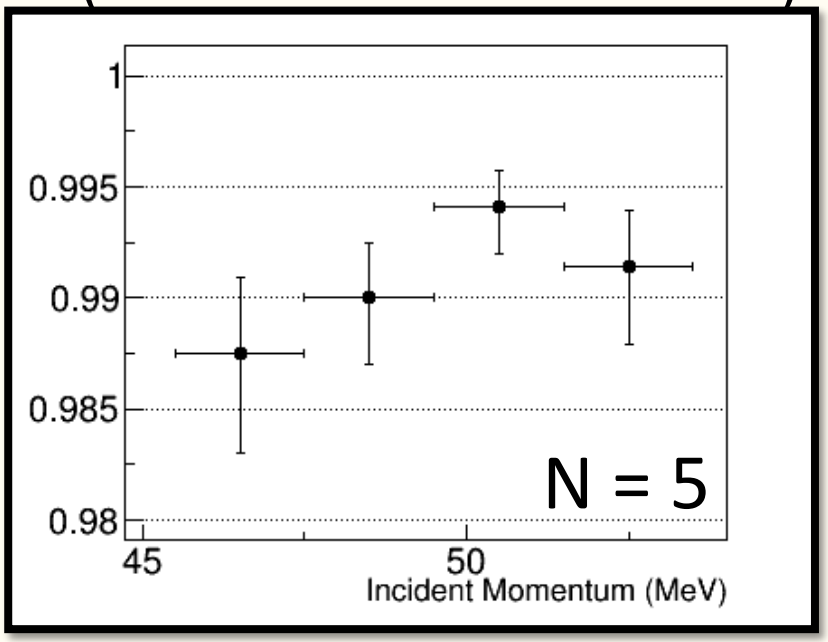


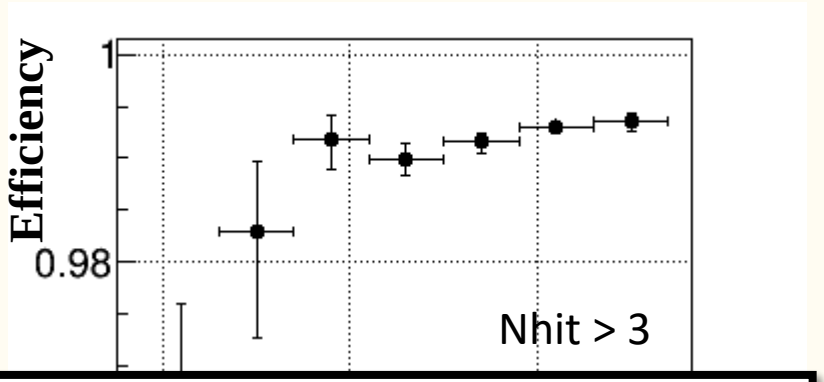
Around the signal region 99.3 % efficiency is achieved.

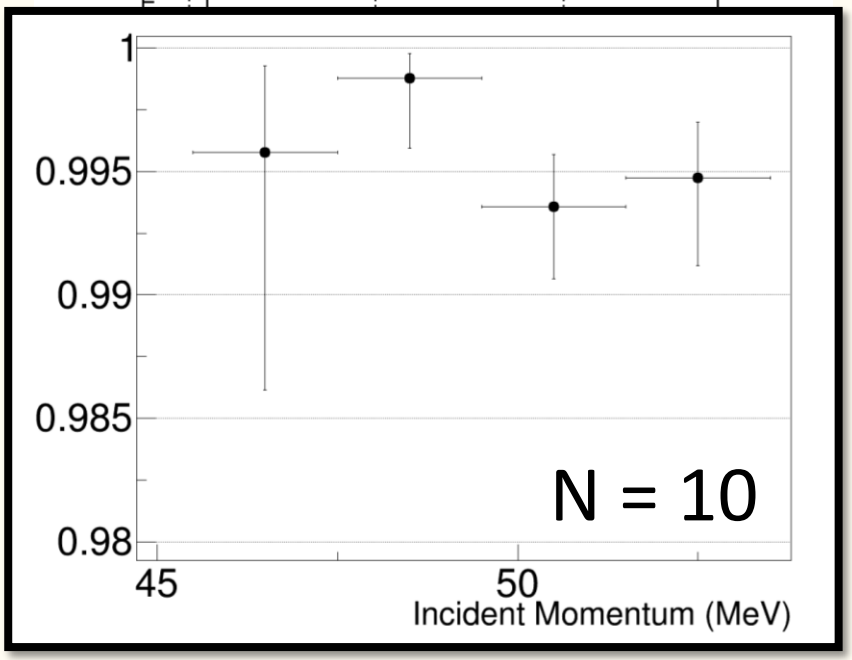
Efficiency vs Incident Momentum

Cluster reconstruction efficiency :

$$\frac{\text{(reconstructed cluster)}}{\text{(\# of true cluster of 1}^{st}\text{ turn)}}$$



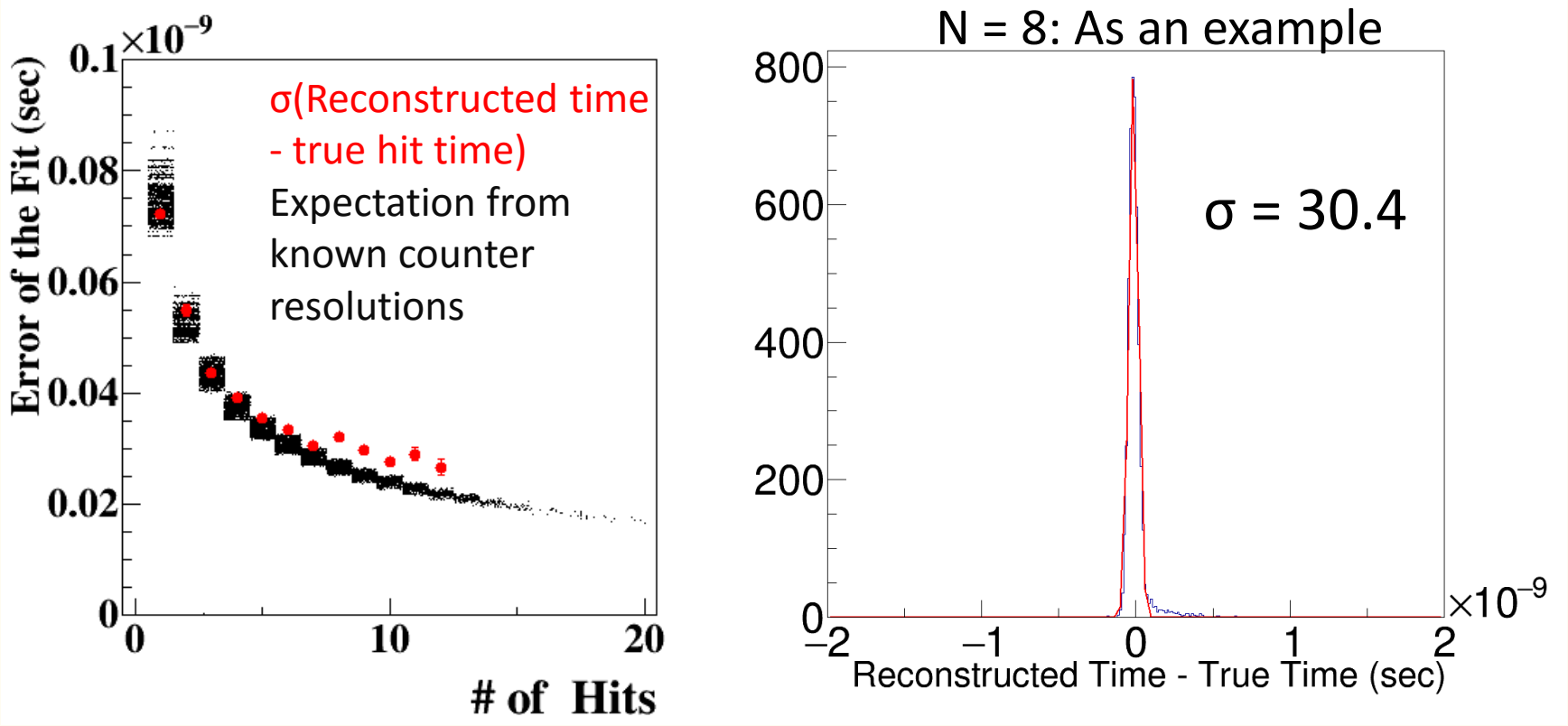




At larger # of hits, efficiency is better.

Performance of Time Reconstruction

Check the performance of time reconstruction with difference b/w reconstructed first hit time and true time of it.



σ is larger than expectation in N hit > 8

⇒Limit of the linear fit for hits.

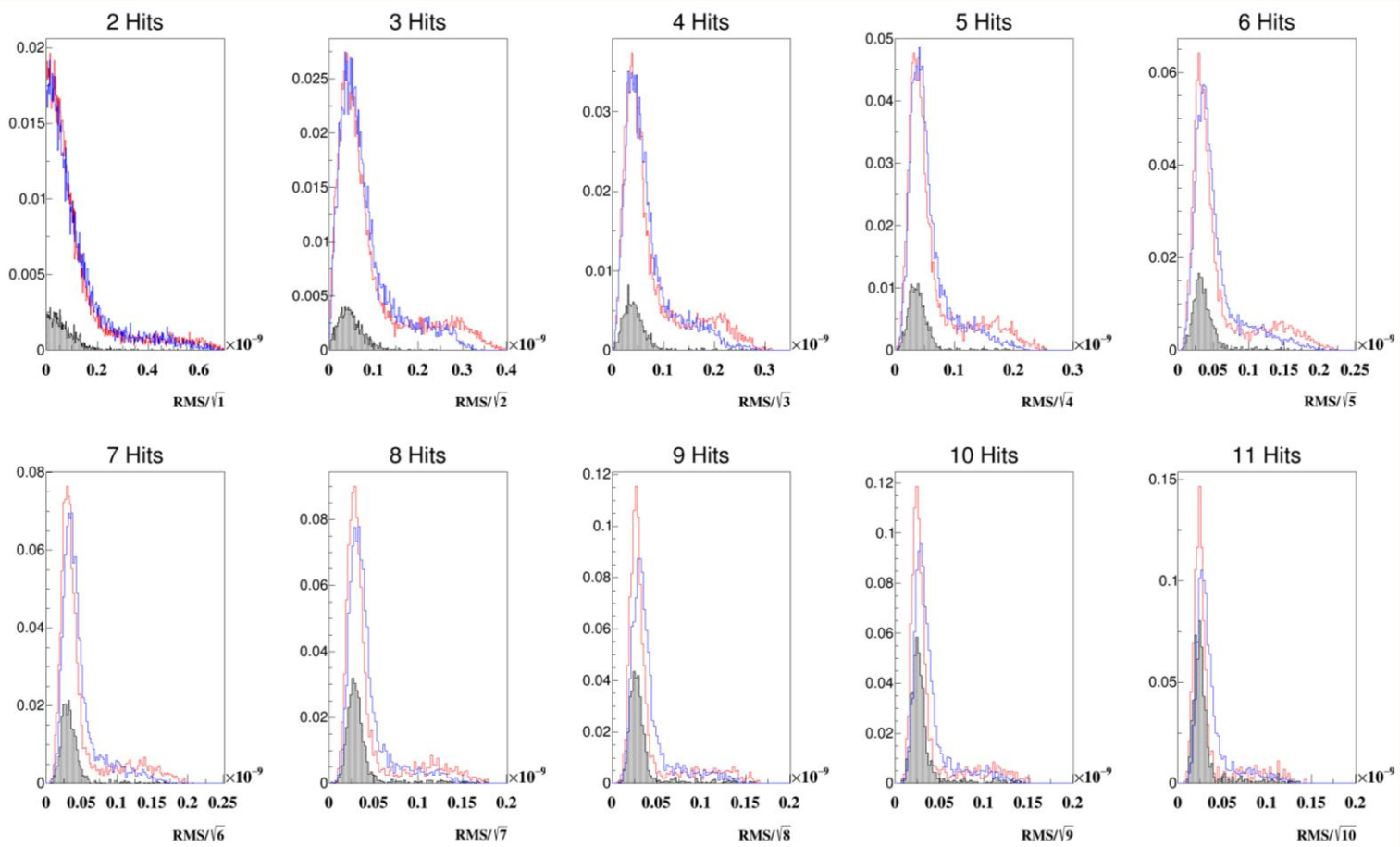
Comparison with Data

- Apply this clustering algorithm to data in pilot run.
  - ¼ TC in the MEG II site.
  - Muon beam (MEG II nominal rate. ~7x10^7 μ/s on target)
  - Trigger: > 1 hit in TC

- To check consistency
  - Standard deviation of projected times of clustered hits.
    - (RMS of projected time)/$\sqrt{N-1}$ → resolution @ large # of hits
- Comparison with the resolutions with the different analysis
  - Check the resolutions with certain counter combinations.

Standard deviation of projected times

Data, MC (all), MC (target cluster)



Resolutions of 28.5 ps (MC), 31.1 ps (Data) at *n hits* = 8.

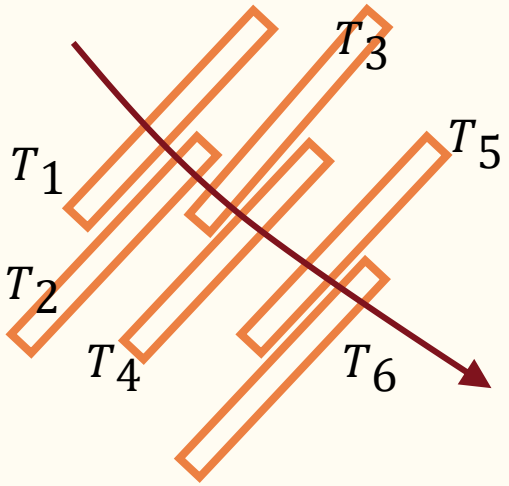
The distributions are consistent with MC, especially at smaller # of hits. At larger # of hits, the accuracy of the timing calibration affects them.

Resolution Estimation for Data

Even-Odd analysis

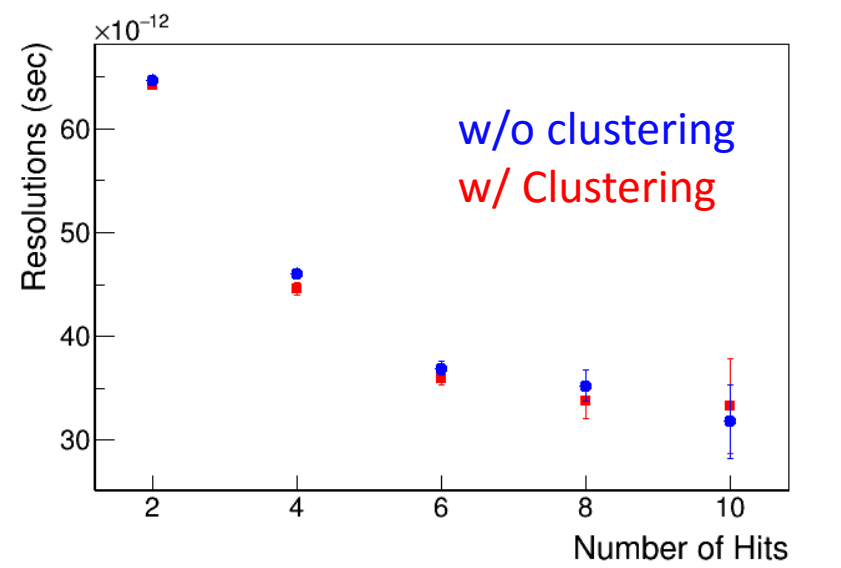
- To be estimate the TC multi-hits resolutions.
- Choose combination of the counters to be analyzed.
- $(\sum_i^{N/2} T_{2\times i})/N - (\sum_i^{N/2} T_{2\times i+1})/N$

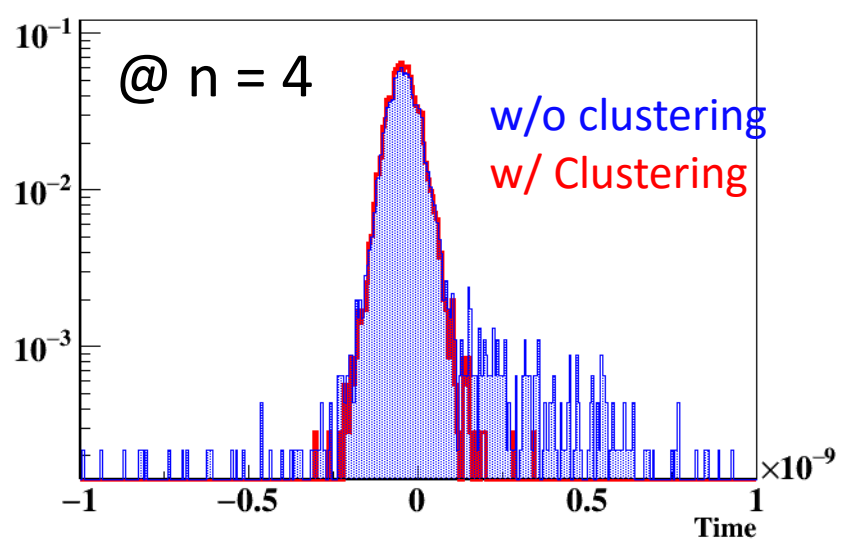
  N: number of hits
- Its resolution should be the same as $(\sum_i^N T_i)/N$ if each time measurement does not have any correlation with each other.



For example
at N=6: $((T_1+T_3+T_5)/3 - (T_2+T_4+T_6)/3)/2$

Even-Odd analysis w/ and w/o clustering





- Since the tail event are reduced due to the new clustering algorithm, the resolutions become better.
- Resolutions of 33.7 ps w/ clustering, 35.1 ps w/o clustering at N = 8

  (31.1 ps (Data) at *n hits* = 8 from standard deviation.)

Prospects

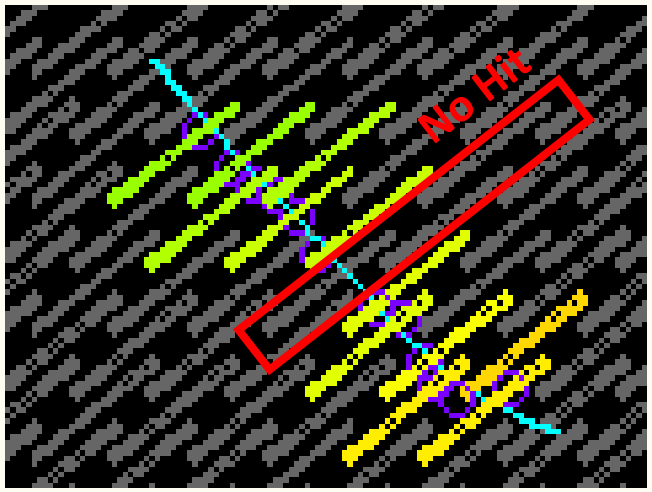
- Use reconstructed position of TC instead of geometry order
- Iteration
  - Cut contamination hits
  - Combine miss hits
- Combine with DCH reconstruction and the additional iteration.

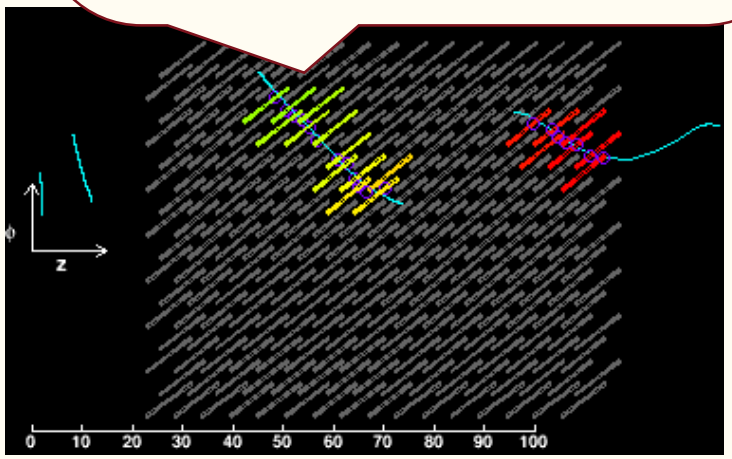
Summary

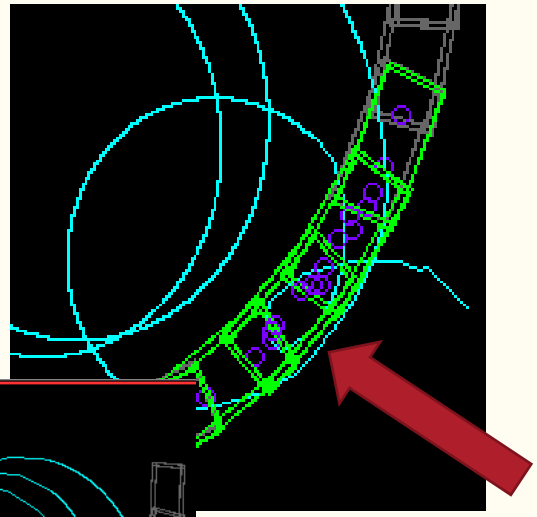
- $\mu^+ \rightarrow e^+\gamma$ search requires precise timing measurement of positron.
- New clustering algorithm for TC is developed.
- Its performance is checked.
  - Miss hit and contamination are checked. It have room for improvement with detailed cut.
  - Efficiency around signal region is 99.3 %.
- Clustering is applied to data.
  - The distribution of the RMS/$\sqrt{N-1}$ is checked as estimator for the analysis and ~30 ps resolution is obtained.
  - The new clustering analysis improves the resolution with even-odd analysis.

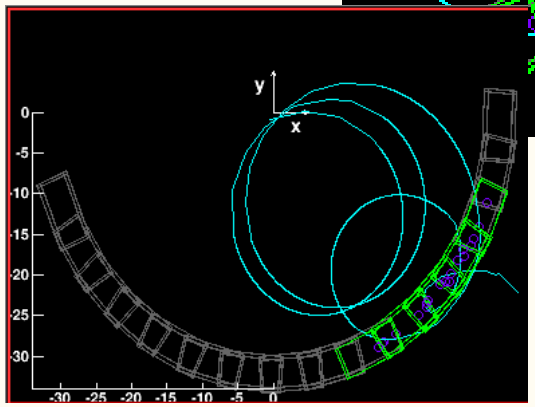
Back Up

In this case, two clusters are made.



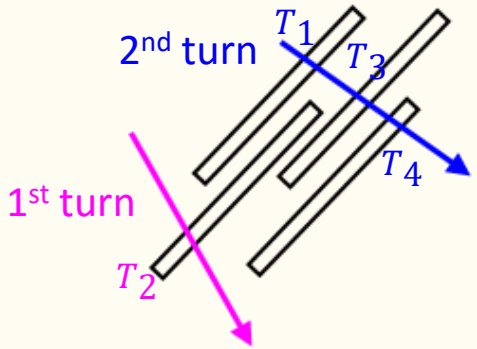




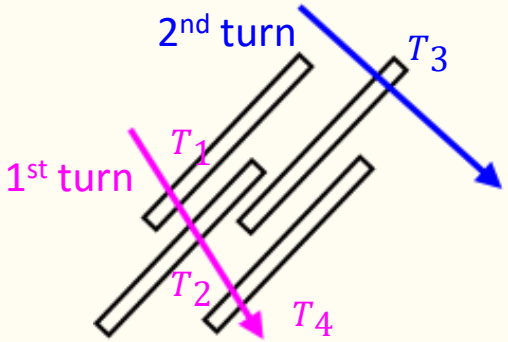


Tail events

- Tail in “clean” events come from hits from different turns of the same positron.
  - They affect final time measurement.
- These kind of hits should be separated by
  - Tracking
  - More precise timing cut in clustering

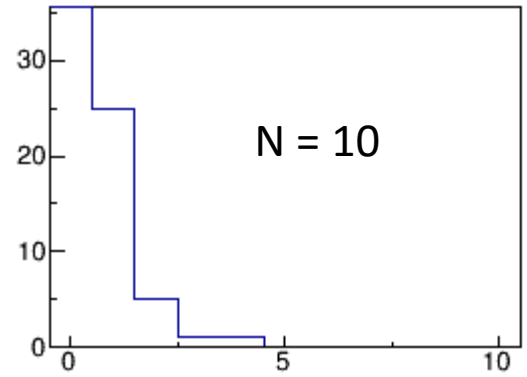


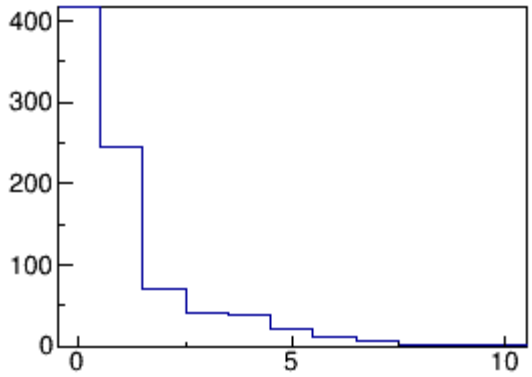
$((T_1+T_3)/2-(T_2+T_4)/2)/2$
⇒ make positive tail.

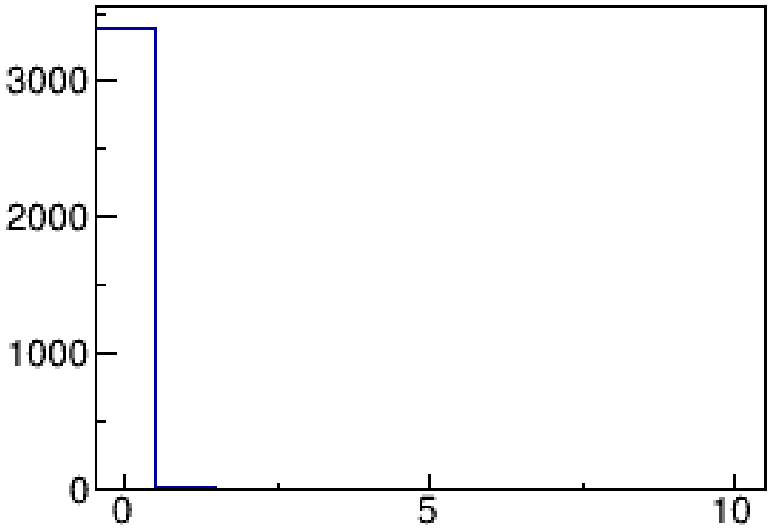


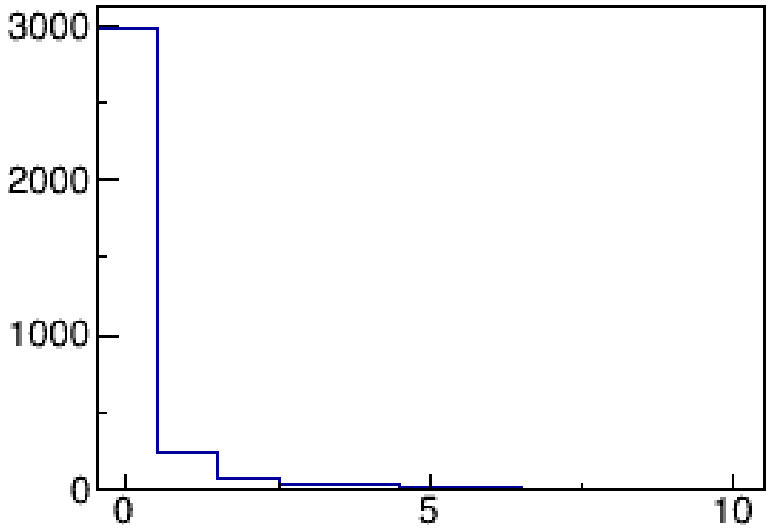
$((T_1+T_3)/2-(T_2+T_4)/2)/2$
⇒ make positive tail.

Cluster quality (n = 10)

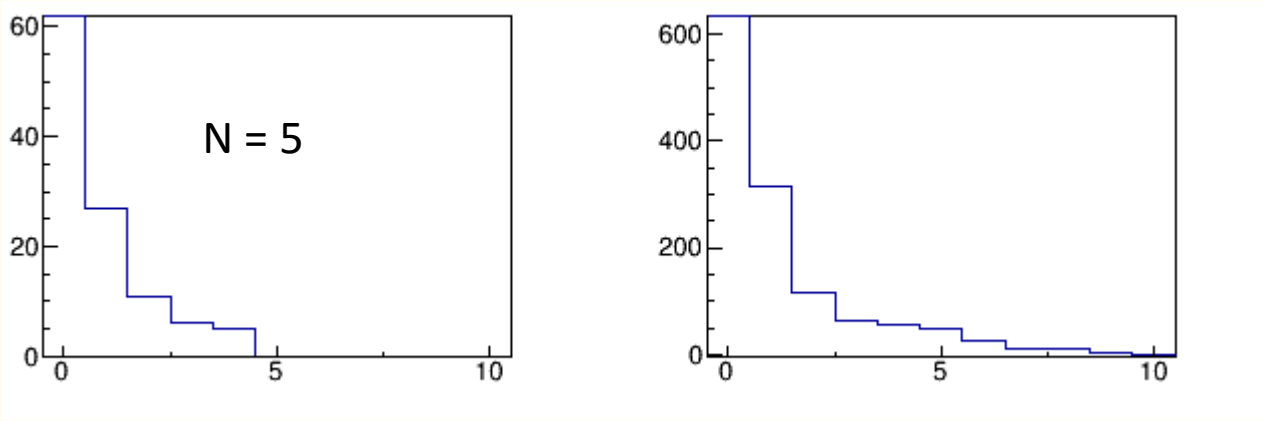


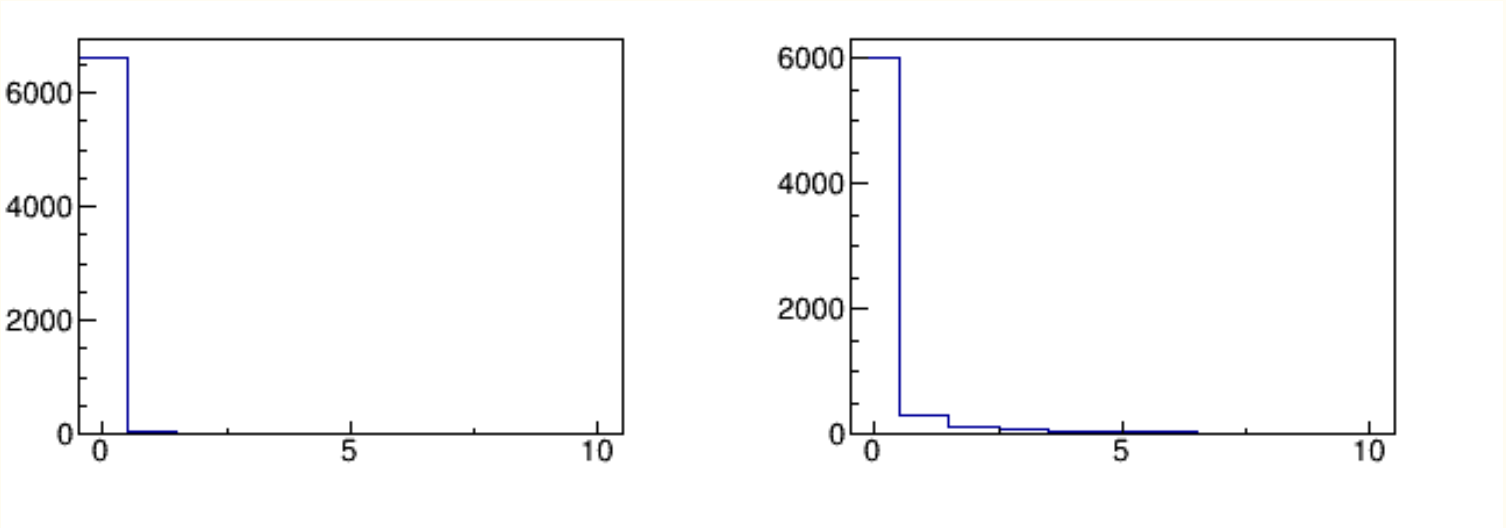




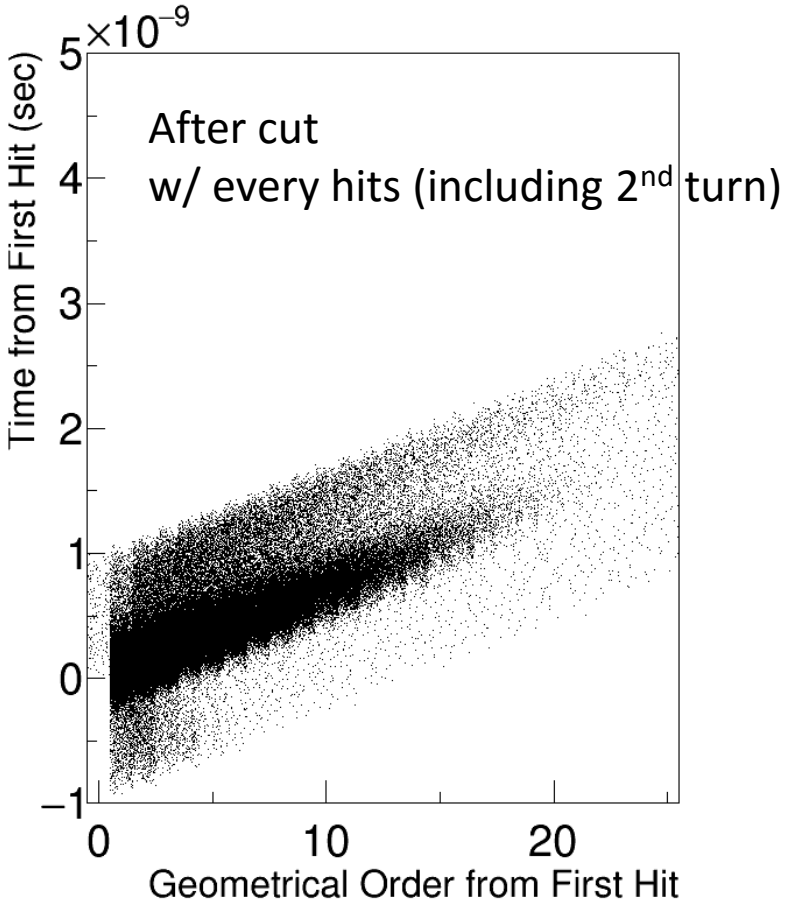


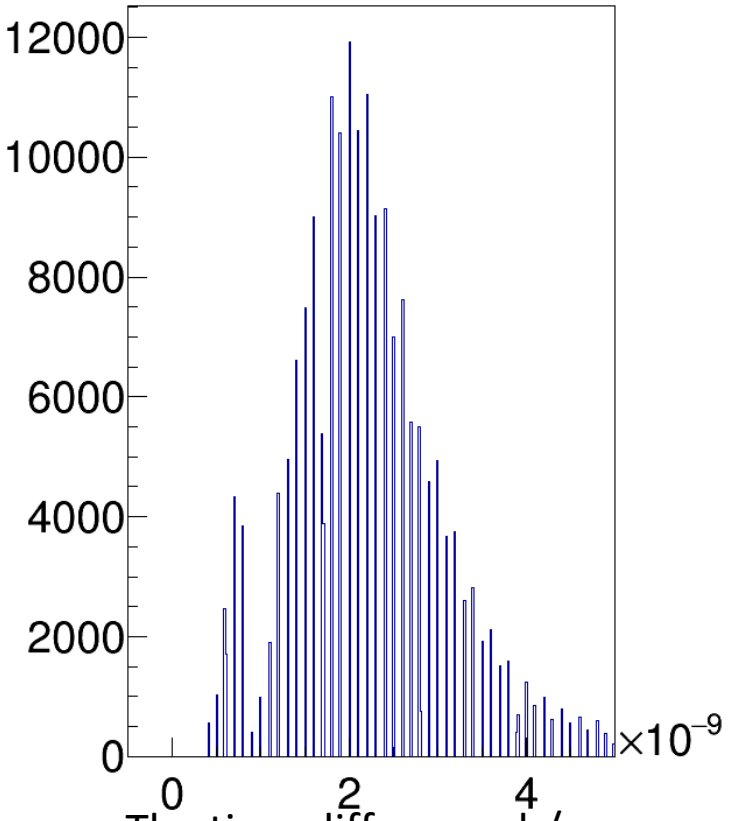
Cluster quality (n = 5)





The cut for the clustering





The time difference b/w a peak and its next peak.