Overview

Codes change

Geometry change

Simulation structure

Geant4 neutron tracking

Digitization

Trigger

Cosmic ray rejection

Analysis

Trilateration

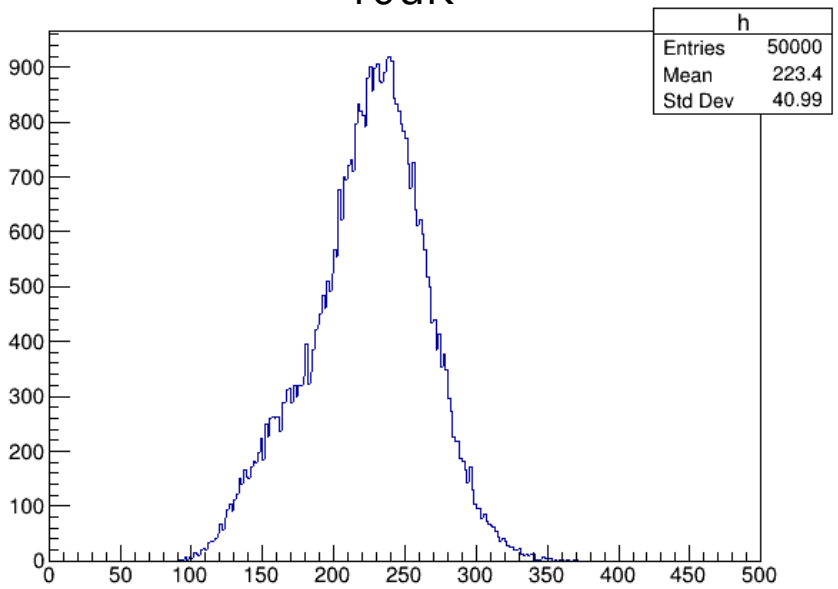
Gravity direction

Simulation structure

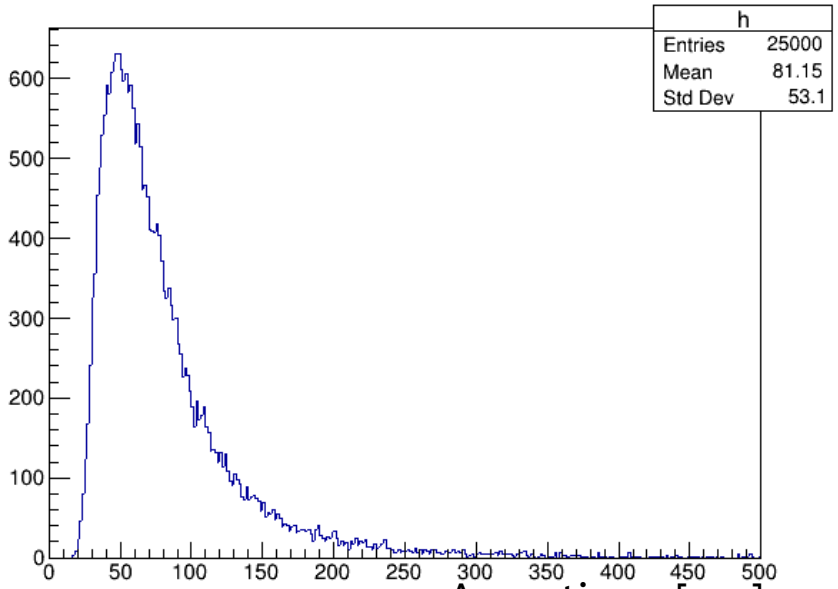
Codes change

- Add information about annihilation time after the free fall
- Upward gravity under some temperature
- Temperature change available

10uK

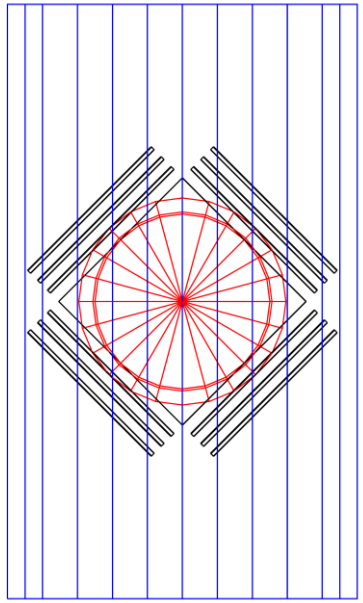


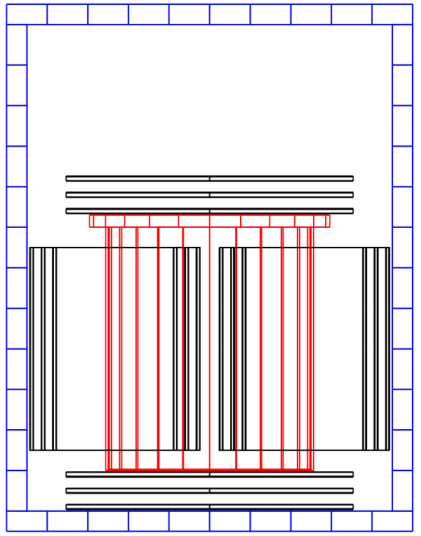
0.5mK

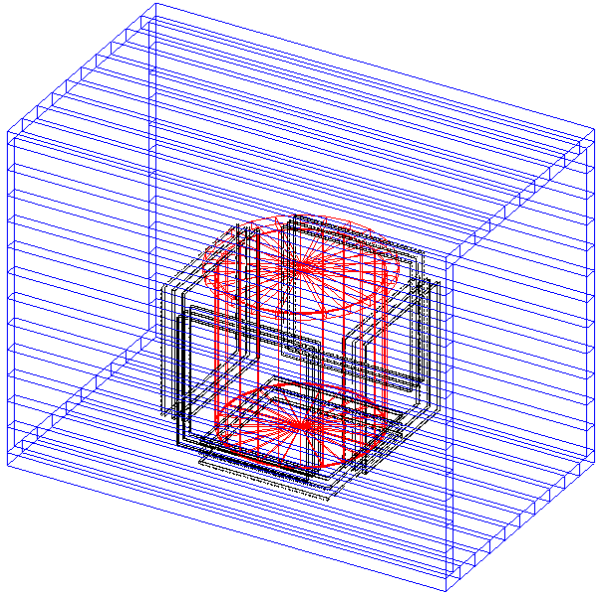


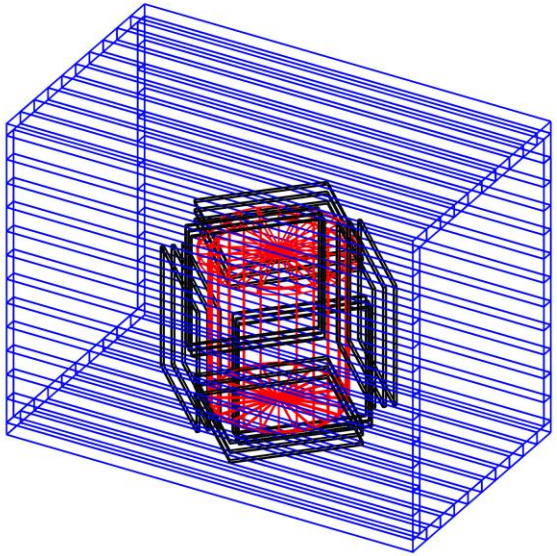
Geometry change

- Upper side MMs is added.
- MMs are rotated.









Geant4 neutron tracking problem

- Neutron tracking is stopped after 10us elapsed from a simulation start. (physicslist basic setting)

```
*********************************************************************************************
* G4Track Information:   Particle = neutron,   Track ID = 5891,   Parent ID = 5880
*********************************************************************************************

Step#    X(mm)    Y(mm)    Z(mm) KinE(MeV)  dE(MeV) StepLeng TrackLeng  NextVolume ProcName
    0     8.62   -0.392      309      4.89        0        0         0  ChamberTop initStep
    1     8.62   -0.392      309      4.89        0        0         0  ChamberTop nKiller

*********************************************************************************************
* G4Track Information:   Particle = neutron,   Track ID = 5890,   Parent ID = 5880
*********************************************************************************************

Step#    X(mm)    Y(mm)    Z(mm) KinE(MeV)  dE(MeV) StepLeng TrackLeng  NextVolume ProcName
    0     8.62   -0.392      309      8.16        0        0         0  ChamberTop initStep
    1     8.62   -0.392      309      8.16        0        0         0  ChamberTop nKiller
```

```
WARNING in G4StoppingPhysics::ConstructProcess:                    not able to deal with nucl
WARNING in G4StoppingPhysics::ConstructProcess:                    not able to deal with nucl
### G4HadronicAbsorptionBertini added for xi-
WARNING in G4StoppingPhysics::ConstructProcess:                    not able to deal with nucl
### Adding tracking cuts for neutron  TimeCut(ns)= 10000  KinEnergyCut(MeV)= 0
 Revised FTFTP_BERT_TRV - new threshold between BERT and FTFP  is over the interval 2 to 4 GeV
  -- quasiElastic was asked to be 0 and it is reset to 0
### kgbarPhysicsList::ConstructProcess is done
```

Geant4 neutron tracking problem

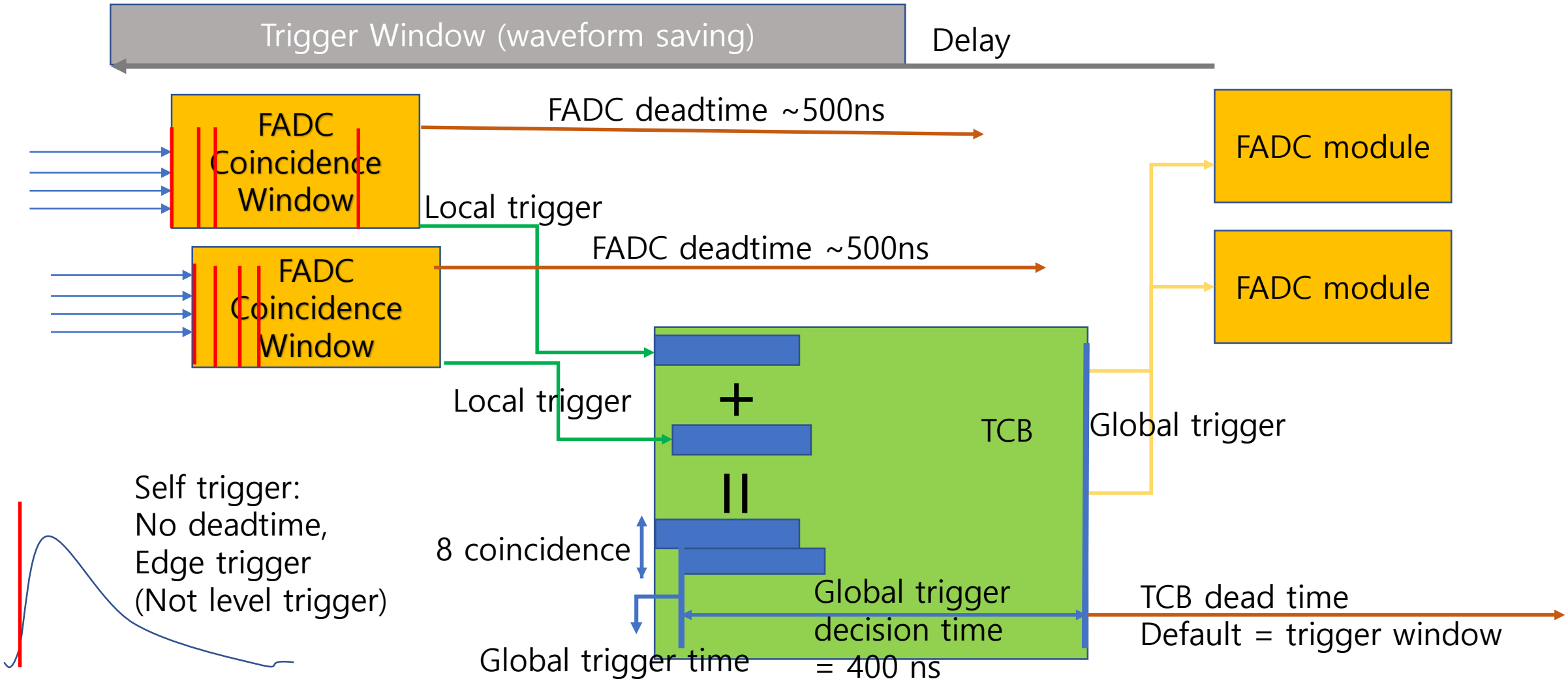
- Our simulation runs for at least 500ms.
- Therefore, make change of neutron tracking time

```
WARNING in G4StoppingPhysics::ConstructProcess:                    not able to
### G4HadronicAbsorptionBertini added for xi-
WARNING in G4StoppingPhysics::ConstructProcess:                    not able to
### Adding tracking cuts for neutron  TimeCut(ns)= 5.1e+08  KinEnergyCut(MeV)= 0
 Revised FTFTP_BERT_TRV - new threshold between BERT and FTFP  is over the interv
  -- quasiElastic was asked to be 0 and it is reset to 0
### kgbarPhysicsList::ConstructProcess is done
world cuts are set
```

Trigger

- Fake pulses for a bar (directly from hits) are considered.
- Simulate FADC and TCB.
- Same bar hits in a trigger are merged.

3 triggers : Self trigger(each channel), Local trigger(FADC to TCB) and global trigger(TCB to FADC)

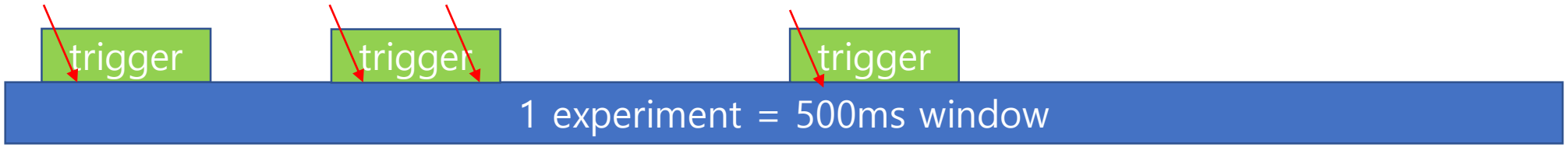


Analysis

Cosmic ray rejection

- 100k experiments(500ms window) are performed with changed geometry and all generated CRY not only muon.

- Trigger threshold ~ 3 MeV
- Single track trigger (224ns window)
- # of trigger per experiment ~ 300



Cosmic ray rejection

- To select annihilation induced trigger, 3 variables are considered. For now..
- dt cut, # of hits cut and offline threshold cut

- **Algorithm 1 :** use # of hits cut, threshold cut, and the dt between **the fastest hits** in T-B(L-R) bar sets.

- **Algorithm 2 :** use # of hits cut, threshold cut, and the dt between **the all hits** in T-B(L-R) bar sets.

Cosmic ray rejection

- Quantification
- **Selection efficiency :**

  # of experiments with only one trigger selected

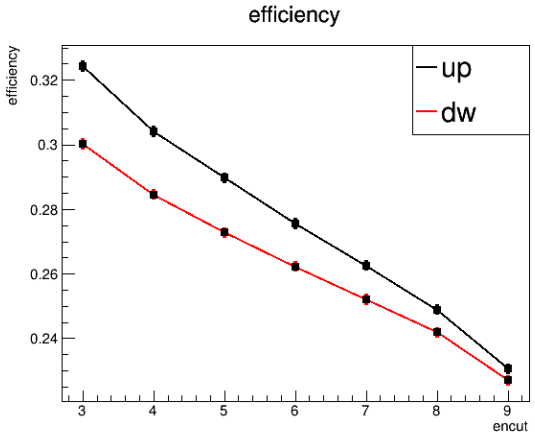
  /# of experiments
- **Selection accuracy :**

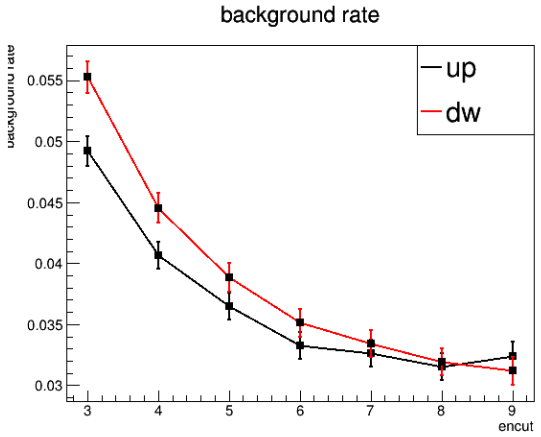
  # of experiments with the selected trigger is induced by pbar annihilation / # of experiments with only one trigger selected
- **Background rate** : 1 – (selection accuracy)
- **FOM(figure of merits)** : selection efficiency / background rate
- Errors are estimated with binomial distribution.

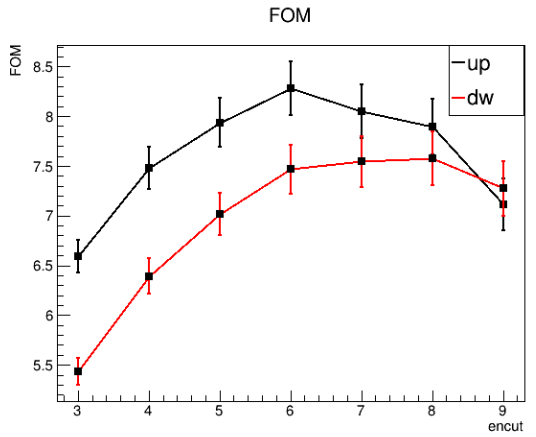
Cosmic ray rejection

- Algorithm1 is better at low threshold region.
- But its FOM is smaller than best FOM of algorithm 2.
- # of hits >2 and dt < 3ns cut

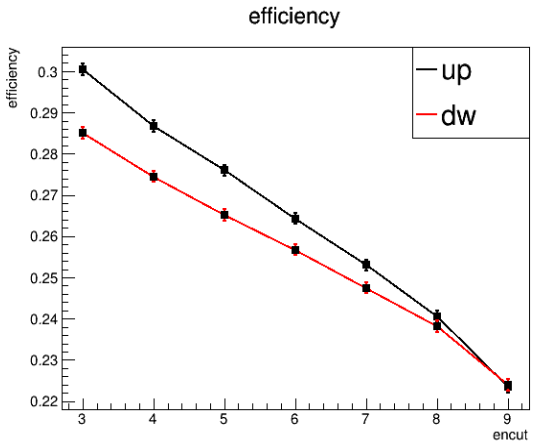
Algorithm1

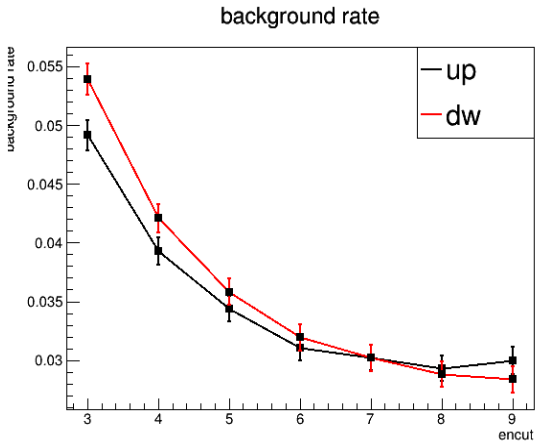


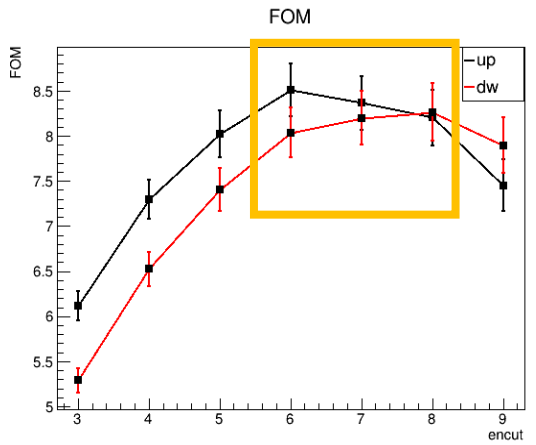




Algorithm2



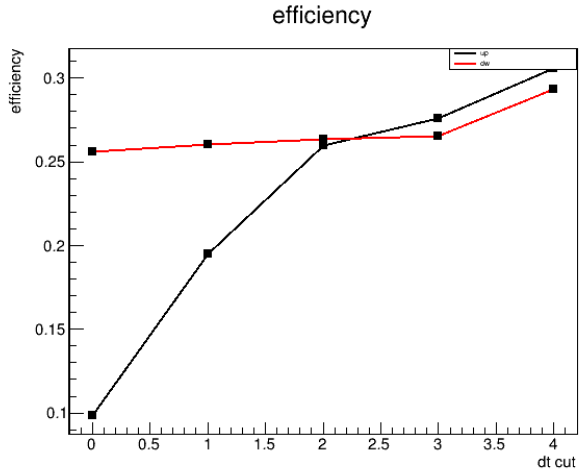


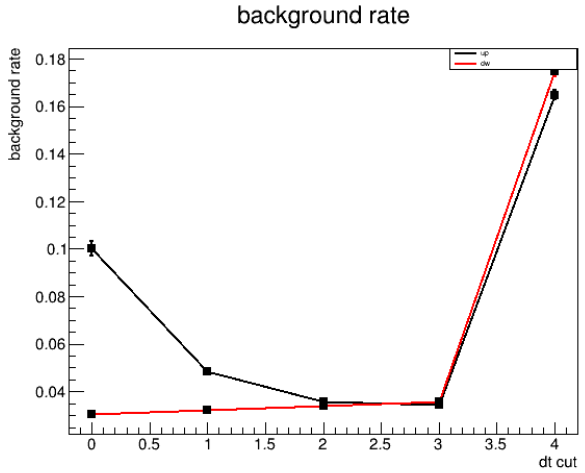


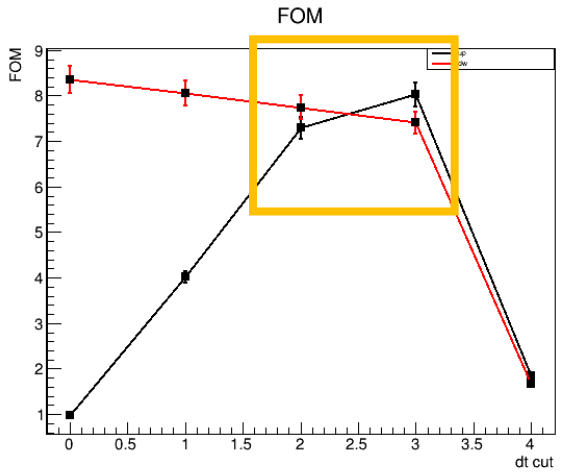
Cosmic ray rejection

- dt cut dependence (# of hits > 2)

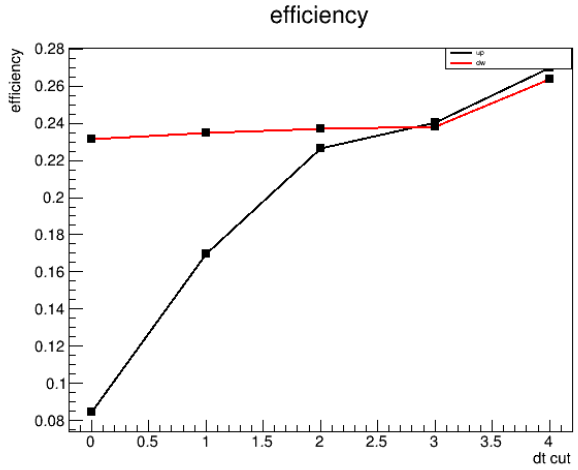
Threshold = 5MeV

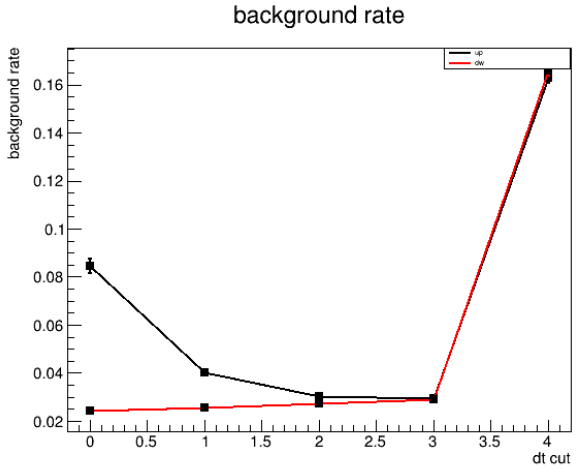


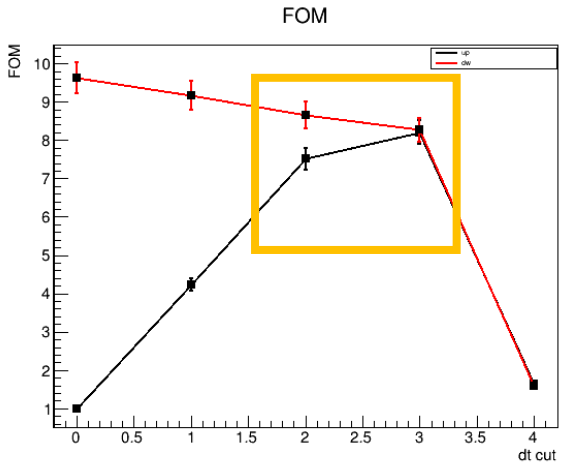




Threshold = 8MeV



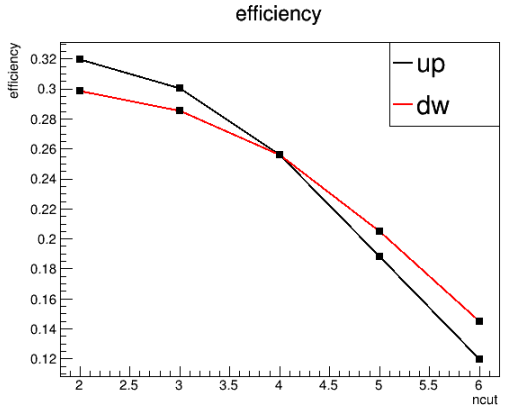


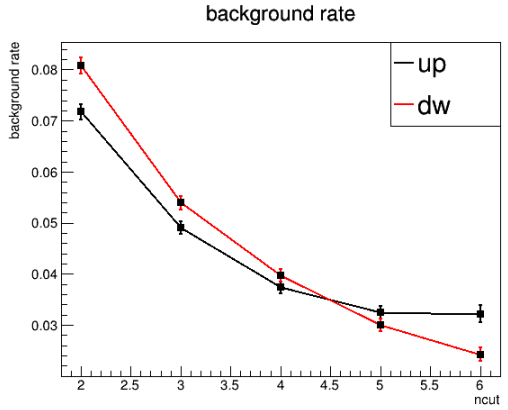


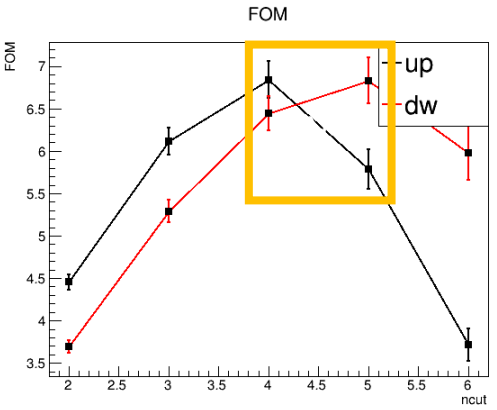
Cosmic ray rejection

• # of hits cut dependence (dt < 3 ns)

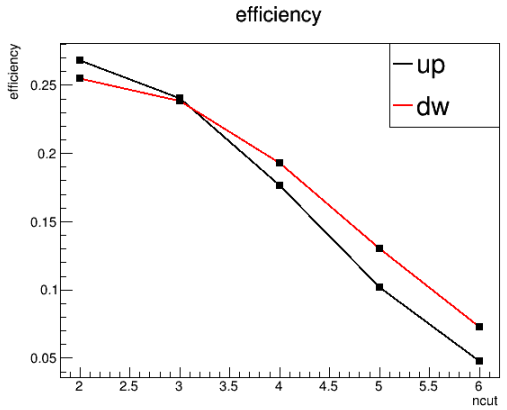
Threshold = 3 MeV

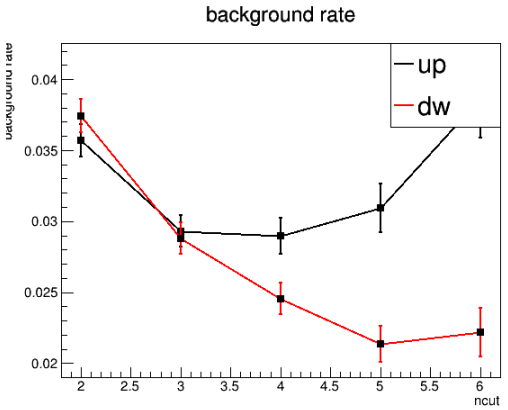


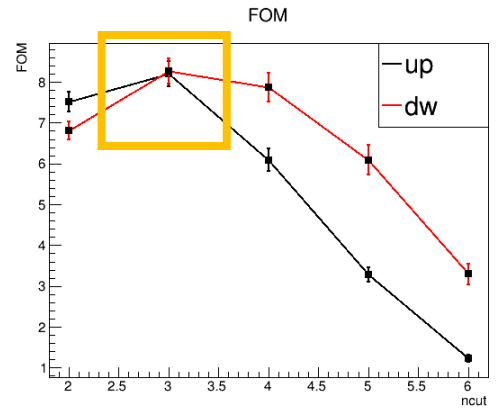




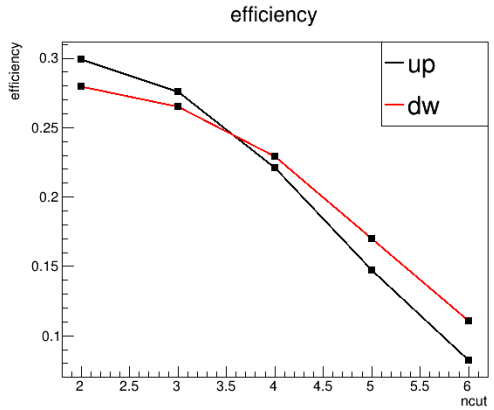
Threshold = 5 MeV

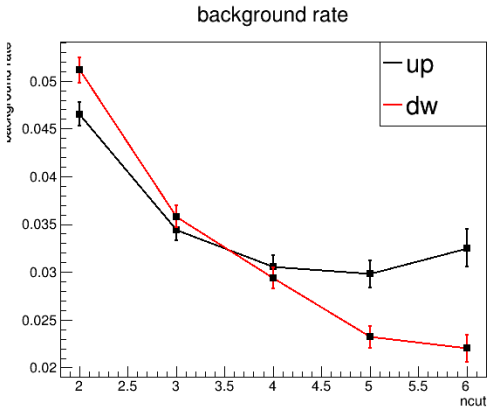


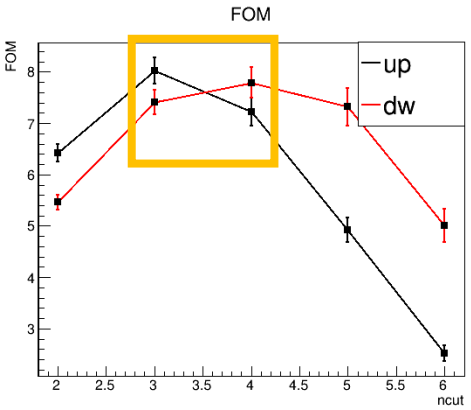




Threshold = 8 MeV







Cosmic ray rejection

- One best cut which can cover two extremal gravity :
  dt < 3 ns , # of hits > 2, threshold : 6~8 MeV

Threshold = 6 MeV

Gravity	Efficiency	Background rate	FOM
Upward	0.2643±0.0014	0.0311±0.0011	8.5098±0.2958
downward	0.2567±0.0014	0.0319±0.0011	8.0385±0.2796

Other rejection scheme

- **MVA**
- Machine running (NN, BDT, etc.)
- Cut for 3 variables -> Cut for 1 variable
- MVA with predetermined gravity will give bias to machine running.

Trilateration

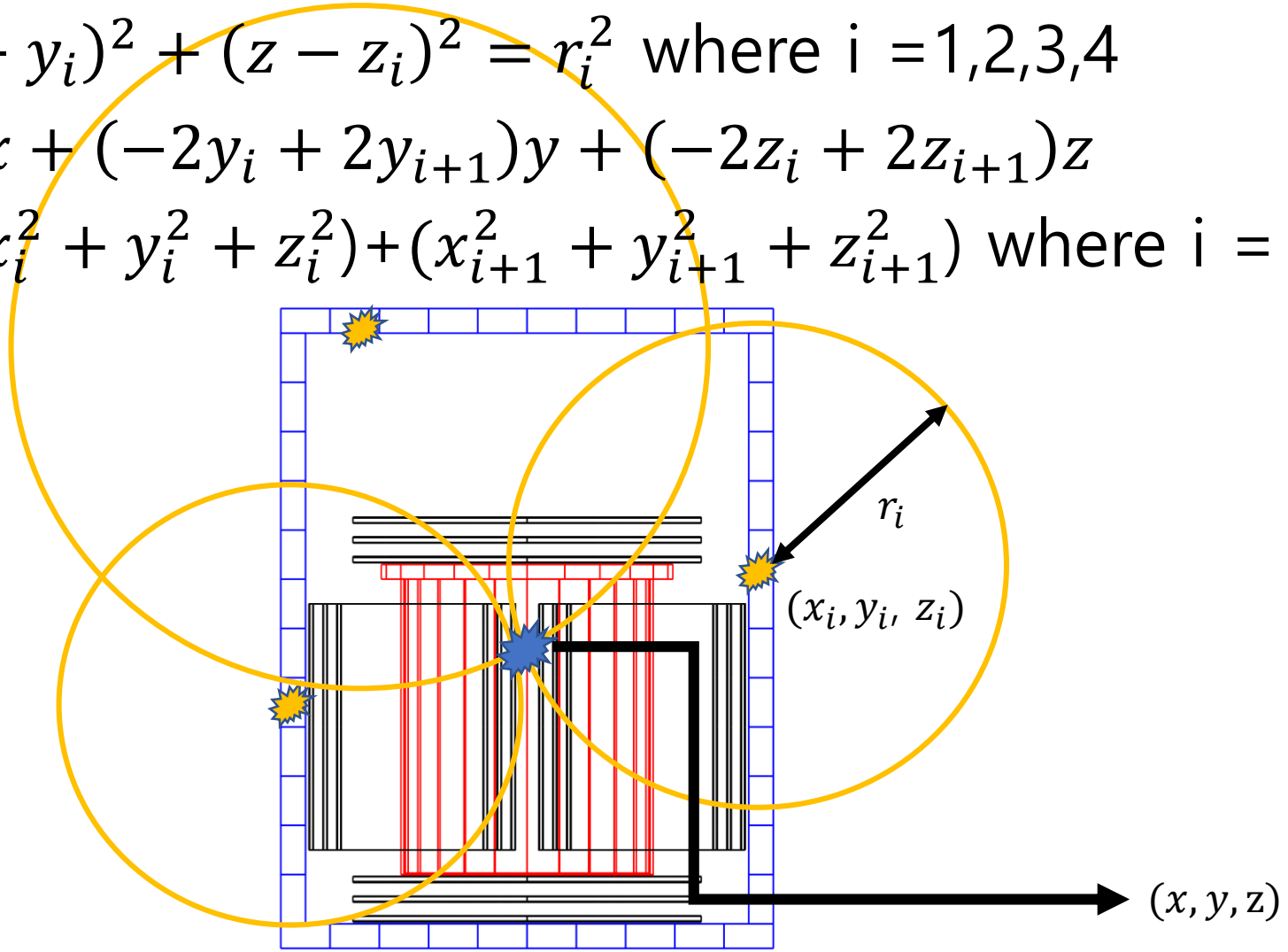
- Find out the position of annihilation by using hit positions and flight lengths.
- 4 hits are needed to find the annihilation position.
- <4 hits give multiple solutions.

->If we give constraint that annihilation occurs at chamber wall, it can be different.

- But the trilateration needs the flight lengths of particles.
- Can we estimate flight lengths only using TOF data?

Trilateration

- $(x - x_i)^2 + (y - y_i)^2 + (z - z_i)^2 = r_i^2$ where i =1,2,3,4
- $(-2x_i + 2x_{i+1})x + (-2y_i + 2y_{i+1})y + (-2z_i + 2z_{i+1})z$
  $= r_i^2 - r_{i+1}^2 - (x_i^2 + y_i^2 + z_i^2) + (x_{i+1}^2 + y_{i+1}^2 + z_{i+1}^2)$ where i = 1,2,3



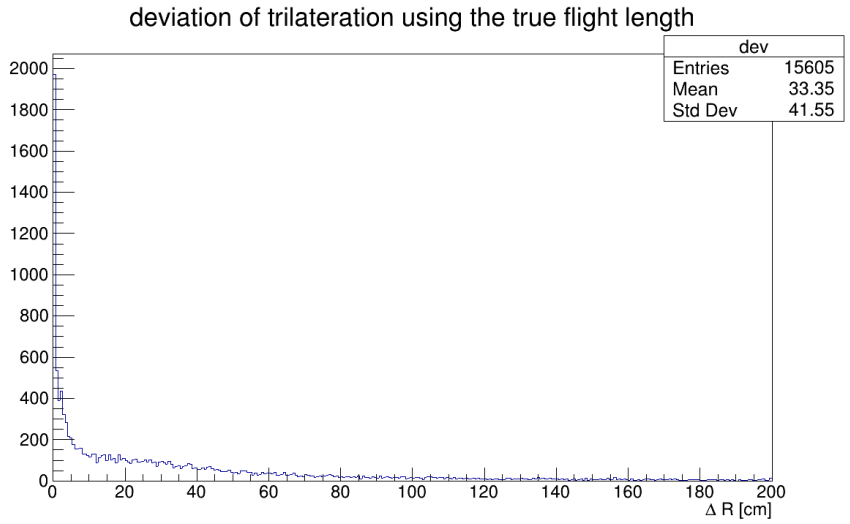
Trilateration

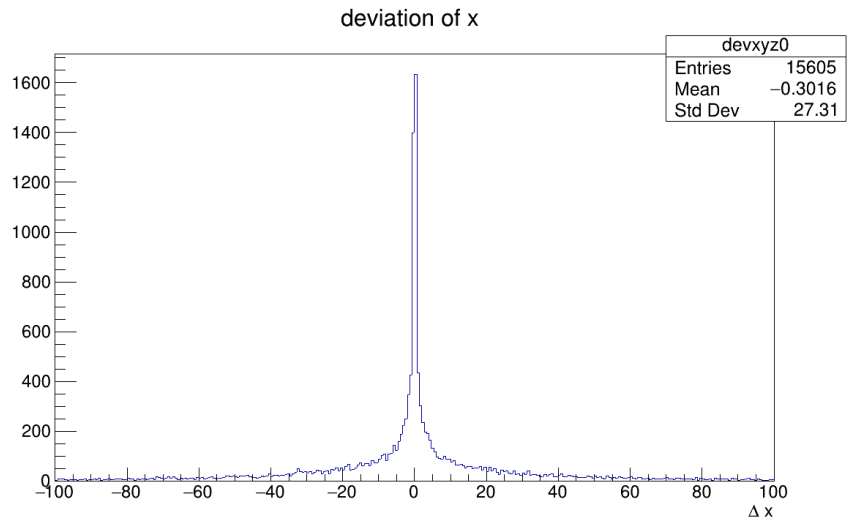
- T-B included 3< hits
- 3 MeV threshold
- Get (x, y, z) by using the positions of the fastest 4 hits
  -> (Not only prompted pion but all particles)

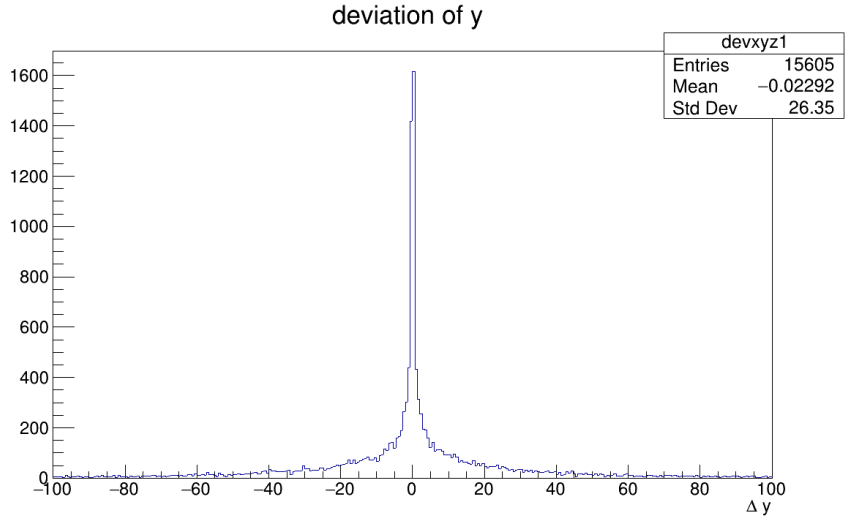
- Test 3 cases :

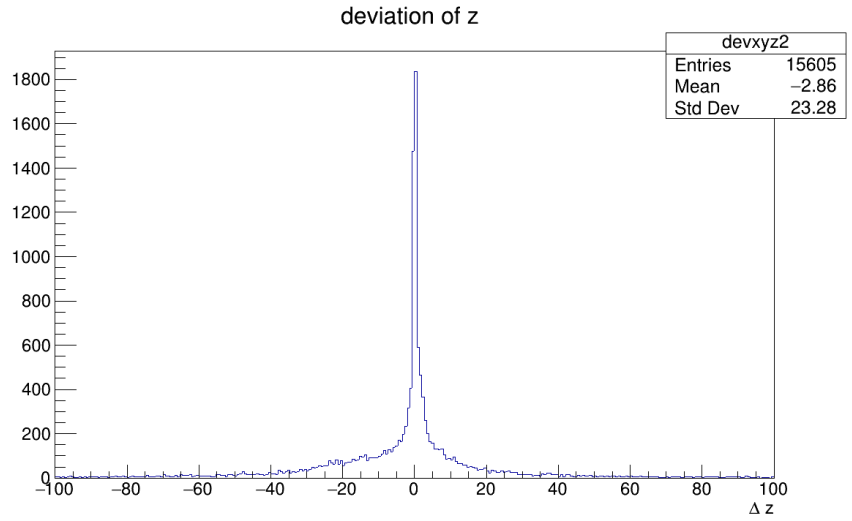
true flight lengths,
the same speed,
mean speed for each particle species

Trilateration : true flight length



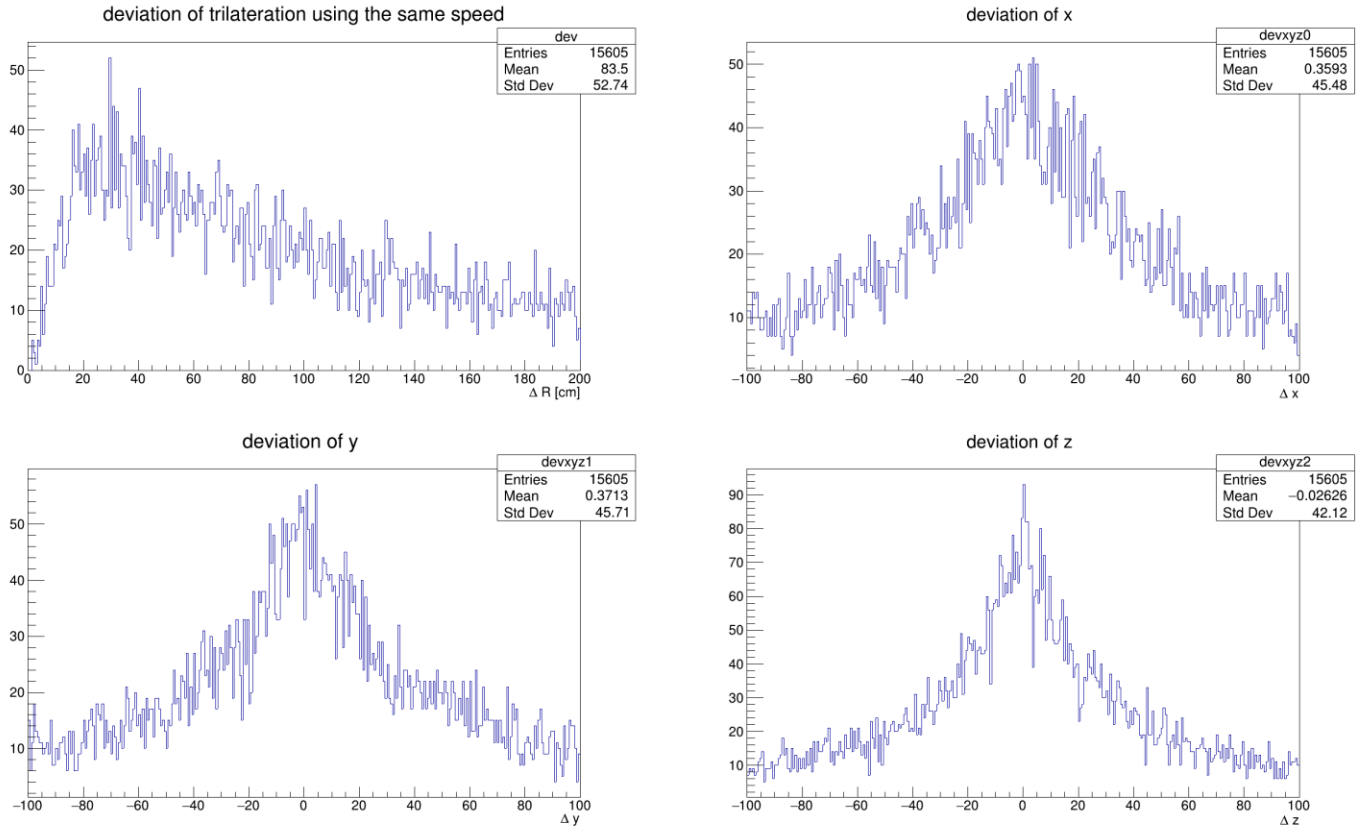






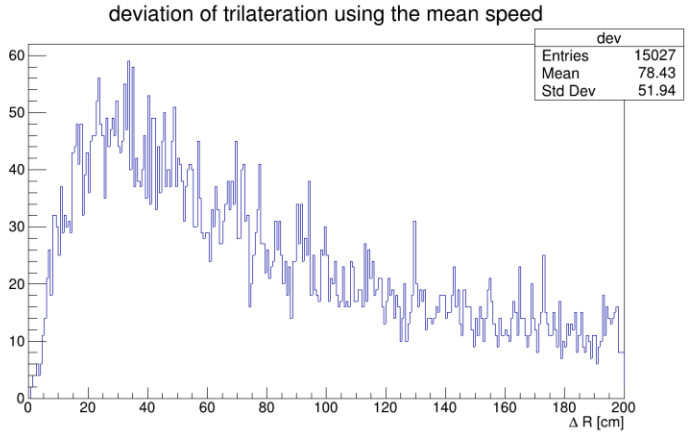
Trilateration : the same speed

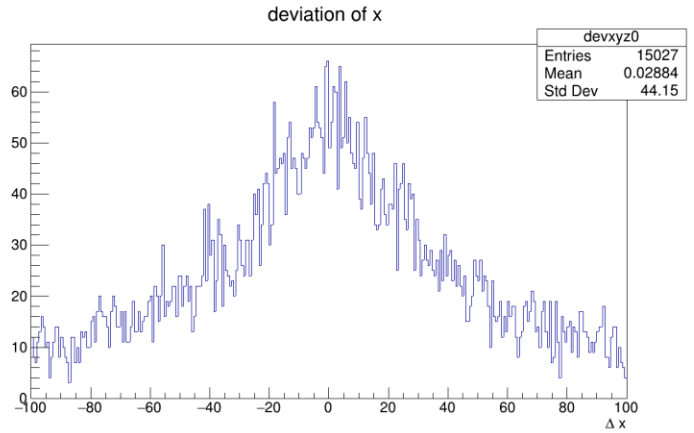
- Assume $r_i = c(t_{i,hit} - t_{ann})$, but we do not have information about t_{ann} in the real experiment.
- The result is also not good.

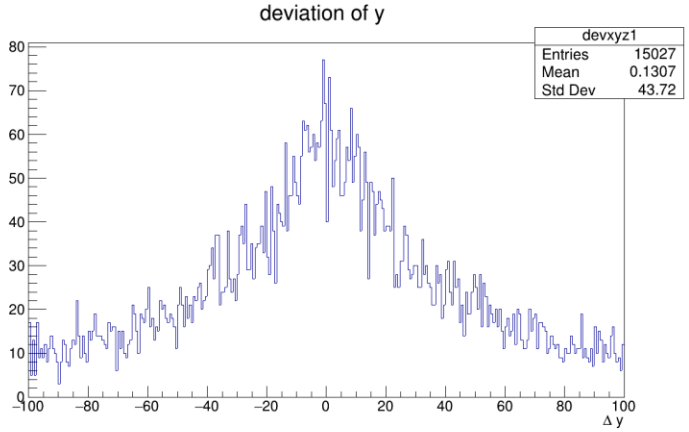


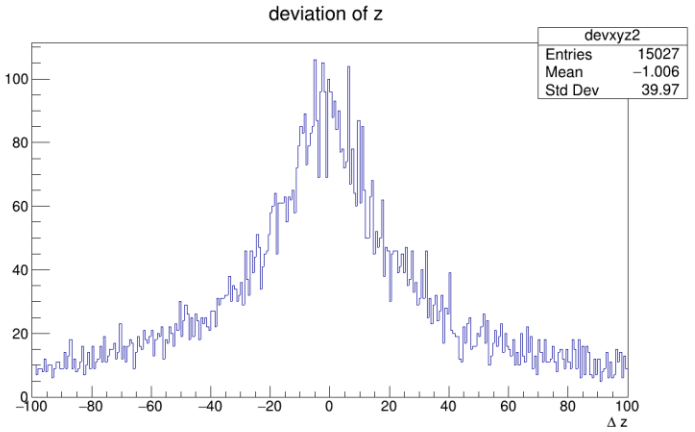
Trilateration : the mean speed

- Assume $r_i = v_{i,mean}(t_{i,hit} - t_{ann})$
- The results highly depend on accuracy of $r_i's$









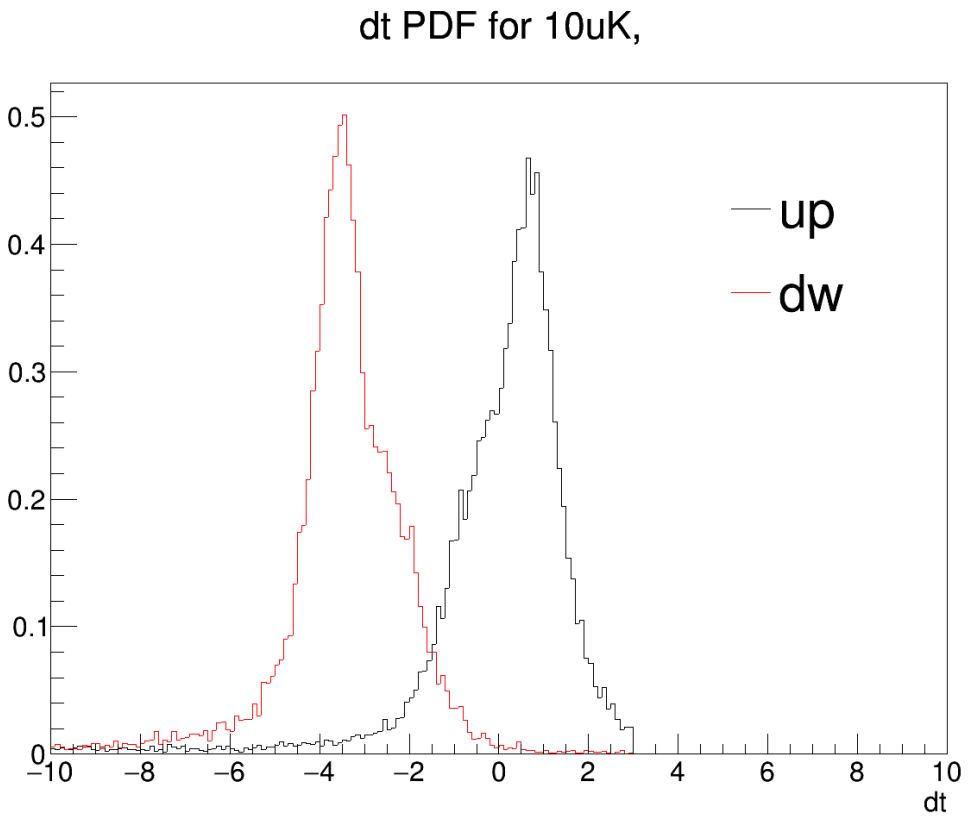
Likelihood ratio for u-d discrimination

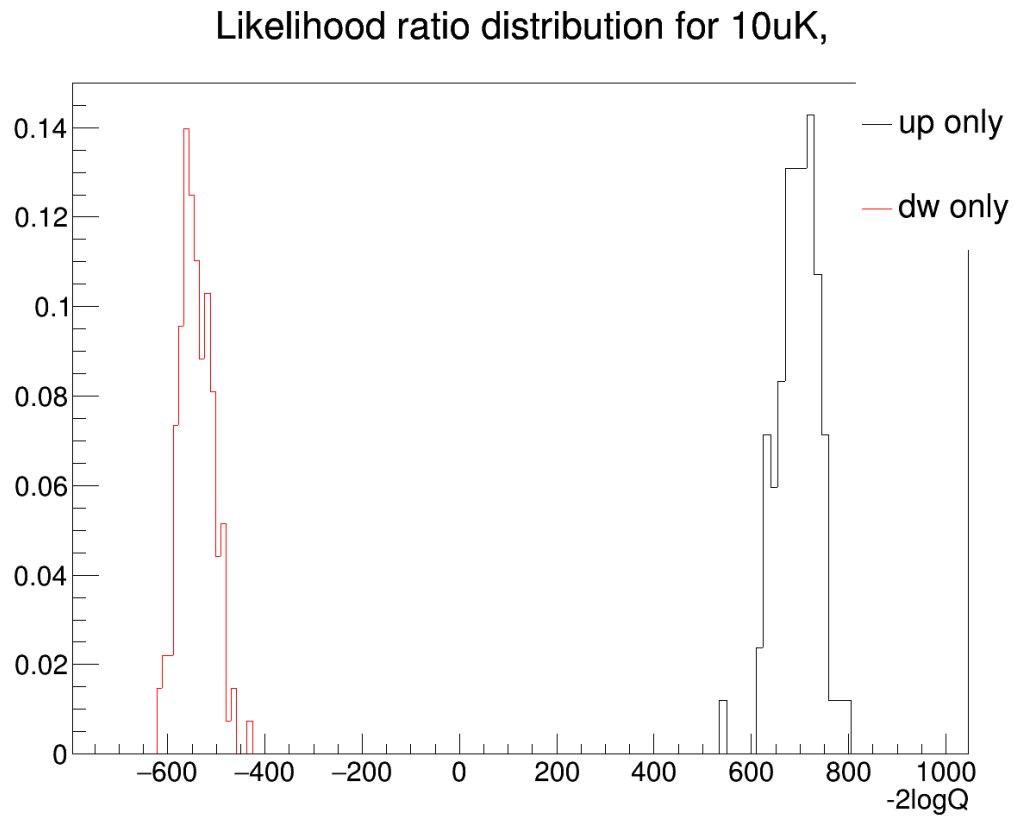
- Determine likelihood ratio distribution for 9 temperature
- 3 MeV threshold
- <3ns cut
- Make PDF with dt histograms (50k annihilation->about 15k recorded in the histogram)
- Assume the time for one free fall exp. -> 2 min.
- 100 selected event (about 12 hours data taking)

-> test statistics

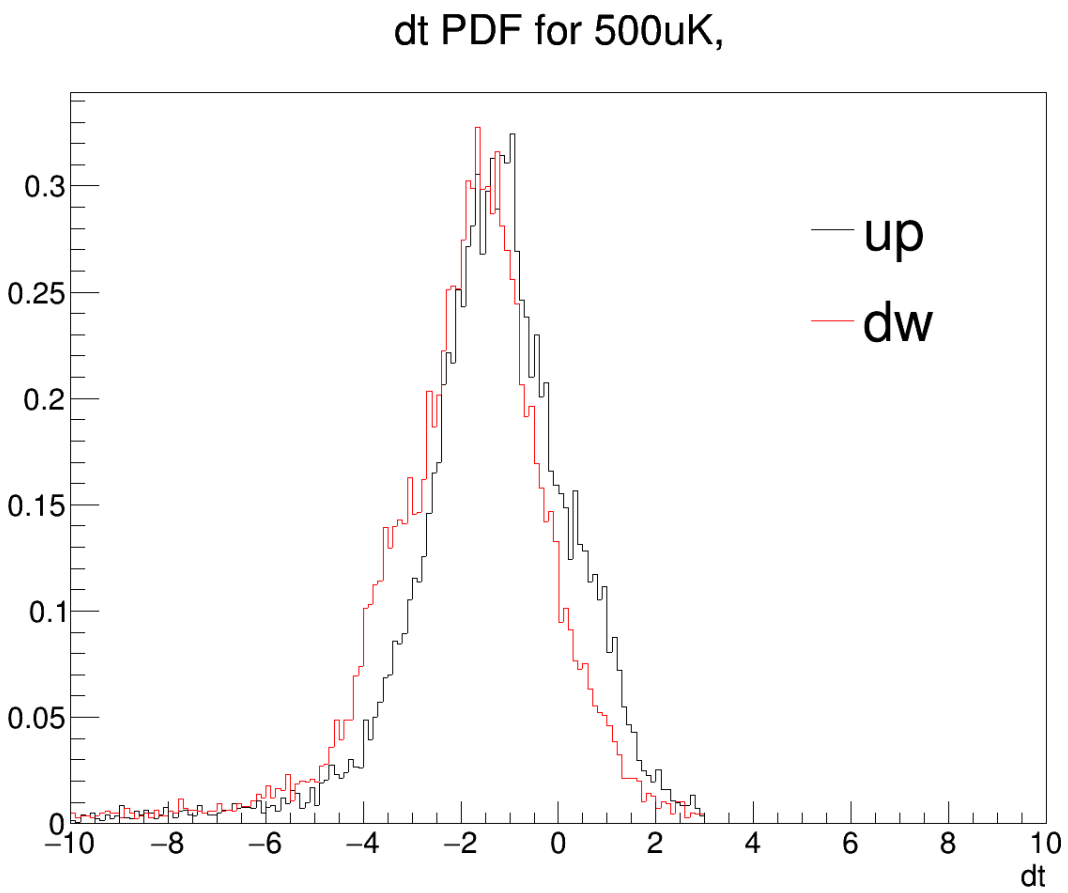
Likelihood ratio

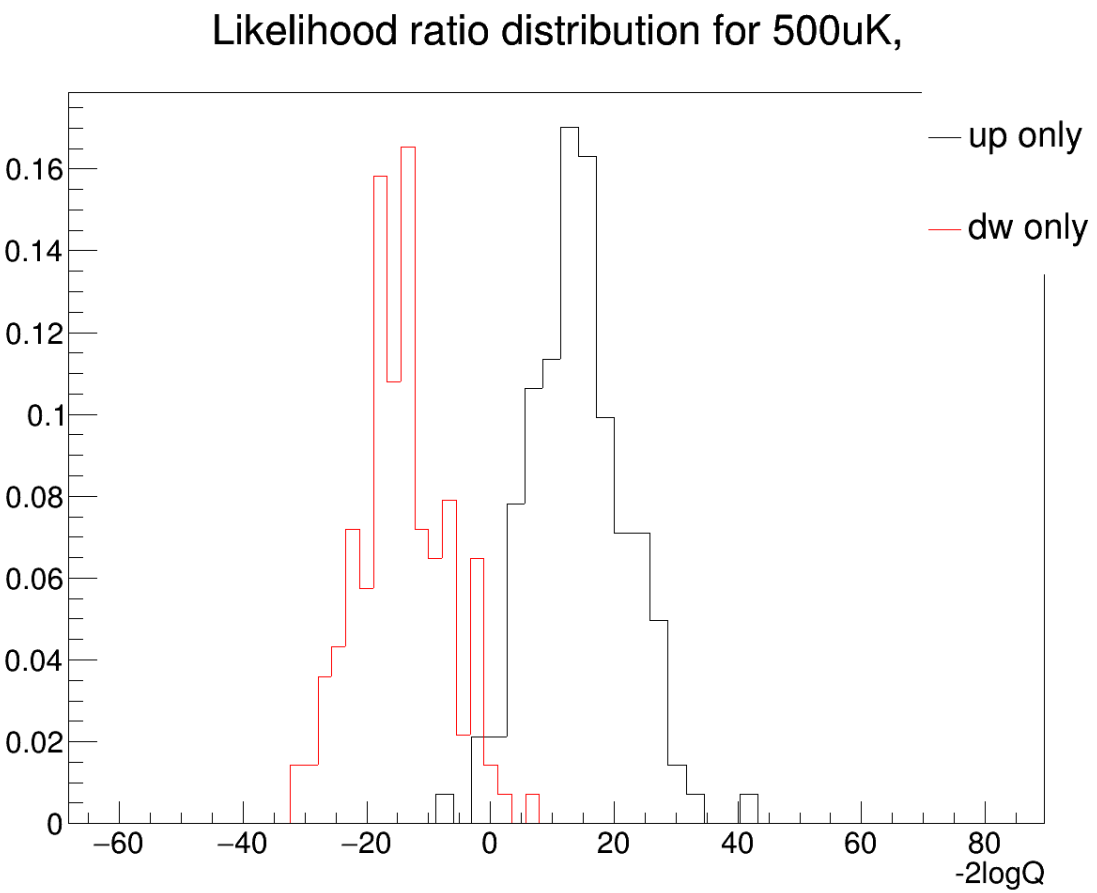
- $Q = \prod_{i=1}^{100} \frac{P(x_i|upward)}{P(x_i|downward)}$
- Up only -> x_i from upward ann.
- Dw only -> x_i from downward ann.





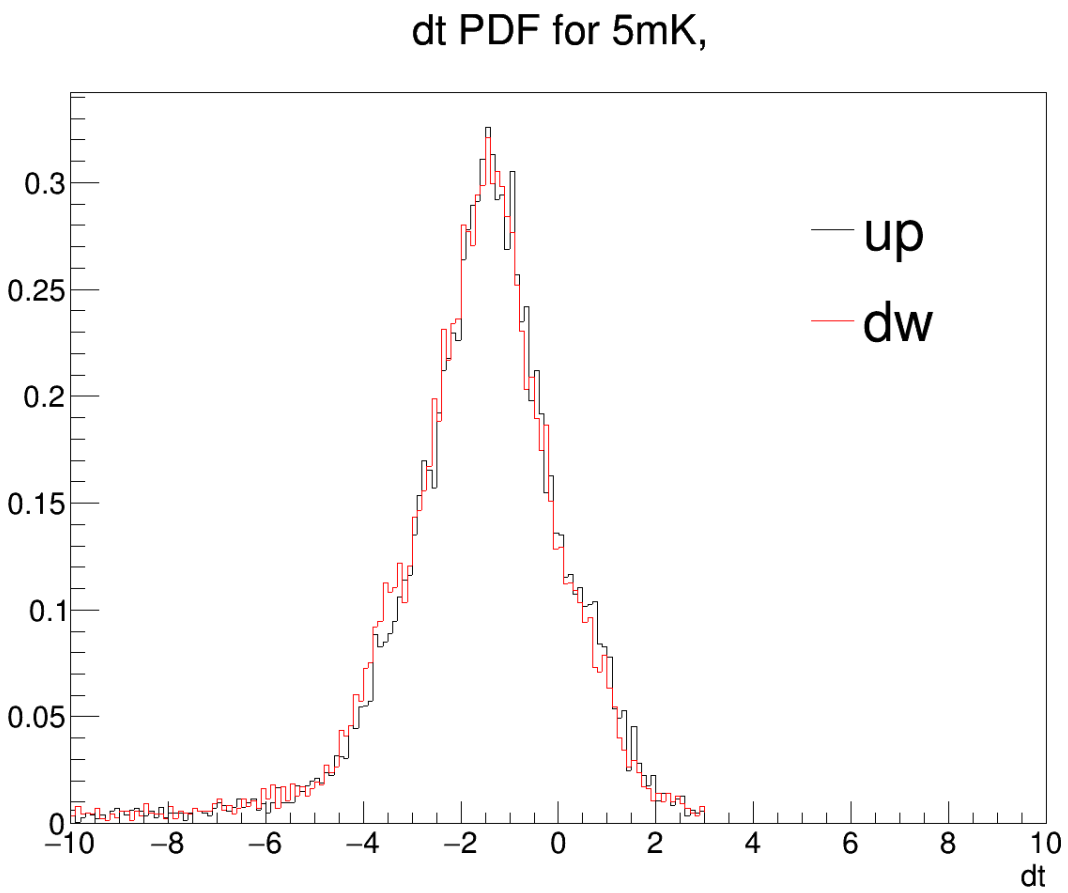
LR for 500uK

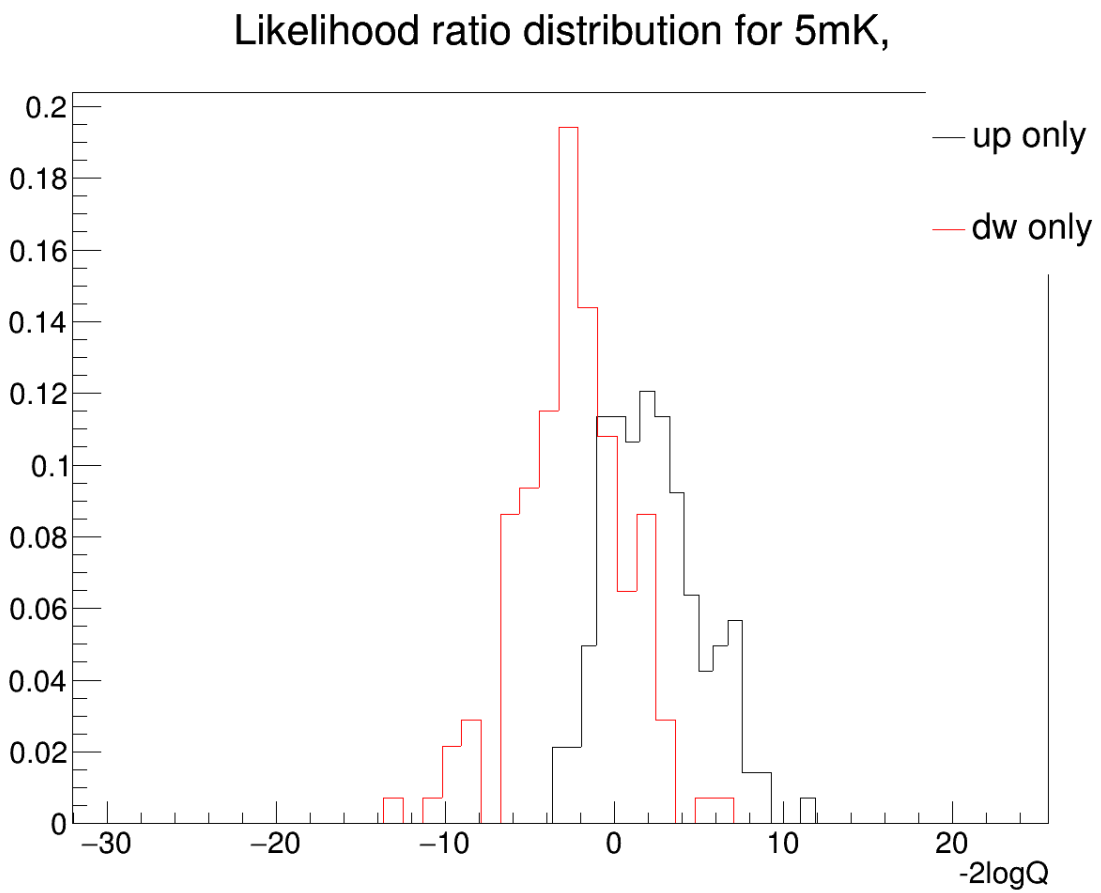

dt PDF for 500uK,
up
dw
0.3
0.25
0.2
0.15
0.1
0.05
0
−10
−8
−6
−4
−2
0
2
4
6
8
10
dt


Likelihood ratio distribution for 500uK,
up only
dw only
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
−60
−40
−20
0
20
40
60
80
-2logQ

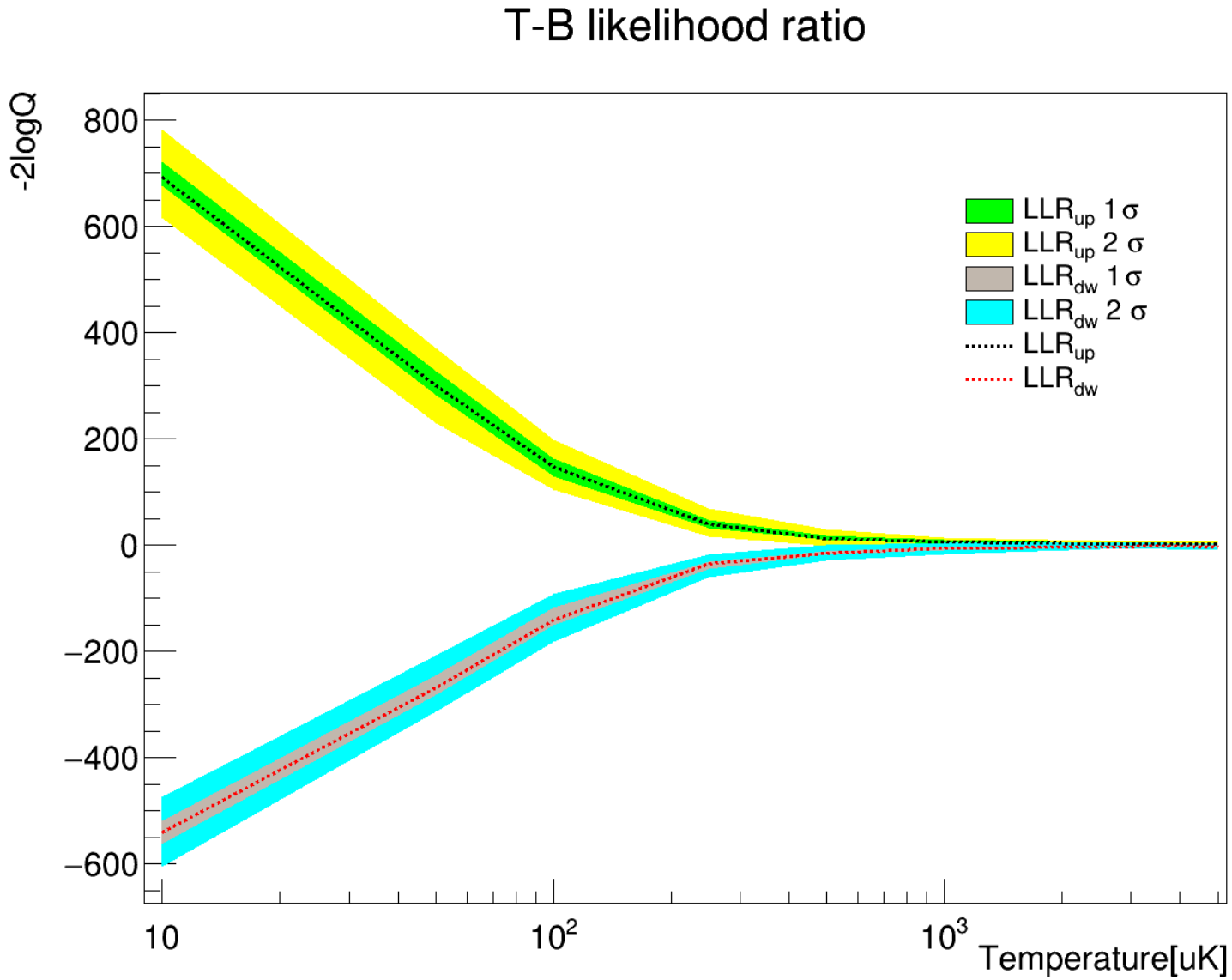
LR for 5mK

- Separable? or statistical error?





LR vs temperature



LR for 5mK with higher statistics

- Make PDF from 5 million ann.
- And test statistics = 2000 (10 days data taking)