Background in the Neutron Detection with 3DST

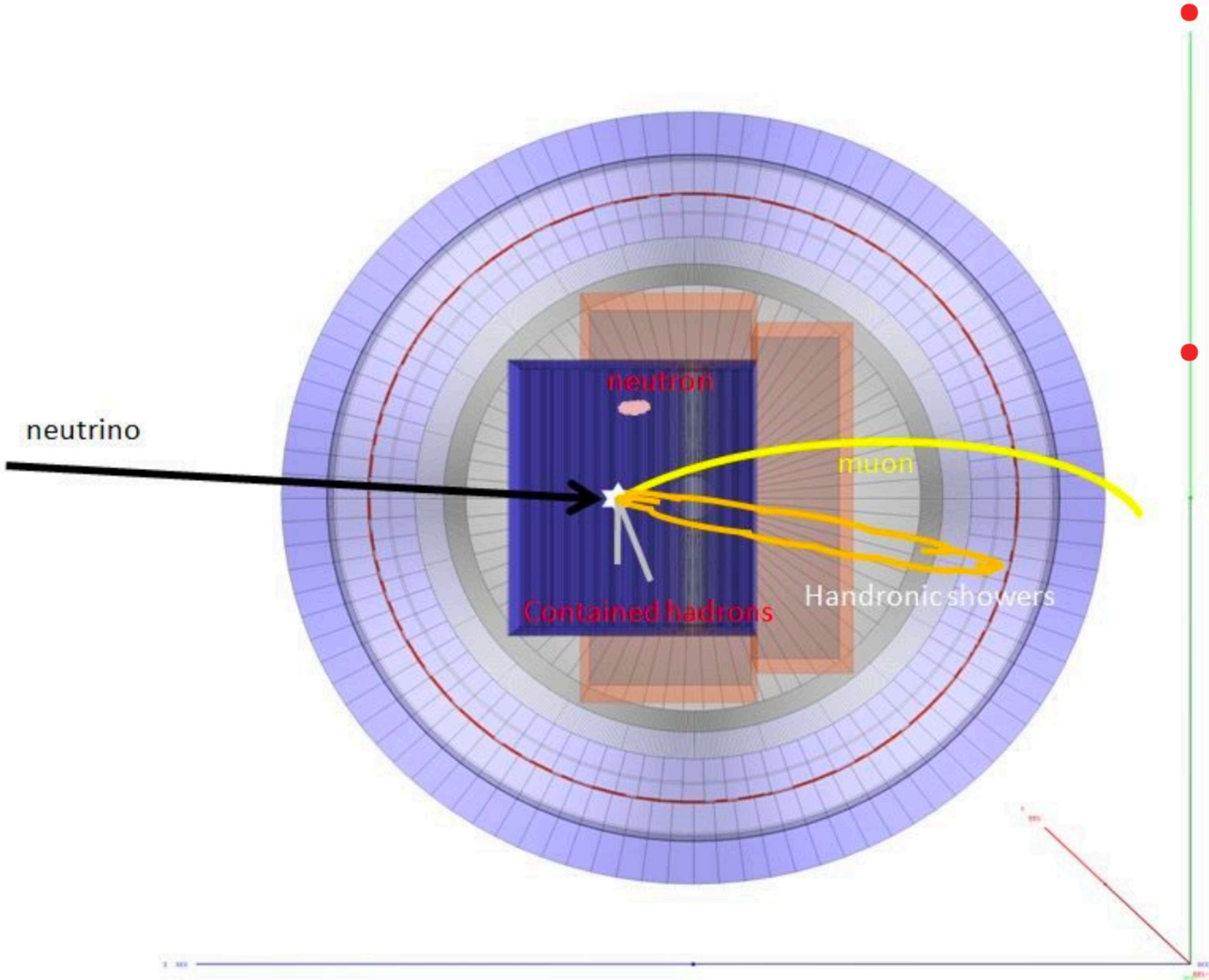
Sunwoo Gwon, Wonseok Bae, Kim Siyeon

Chung-Ang University, Seoul, Korea

Guang Yang

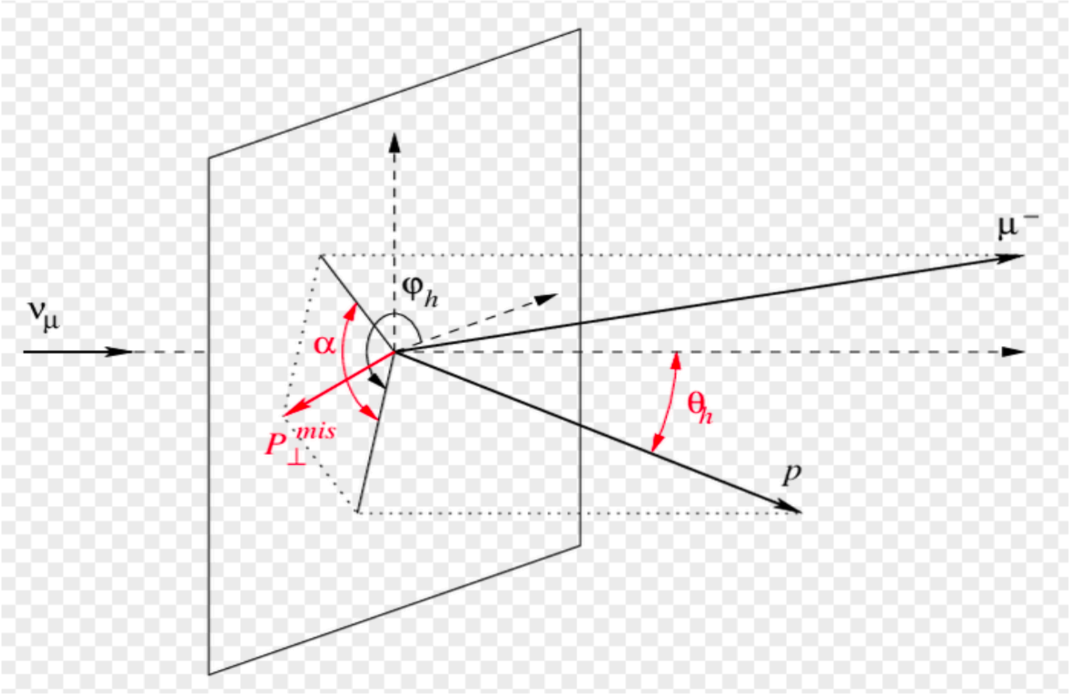
Stony Brook University, NY, USA

Introduction
Neutrino interaction



- **Final state particles are key to extract the incident neutrino flux information**
- **Goal in short: get all final state particle information in good precision for each desired exclusive channel in order to constrain the neutrino flux and cross section model**

Introduction
why we need neutron?



- **Getting all final state particle information is necessary to constrain the neutrino flux and cross section model**

- **Neutron information helps to finish the full picture of reconstruction of neutrino interaction**

- **Neutron provides a complete piece of information on the transverse plane balance**

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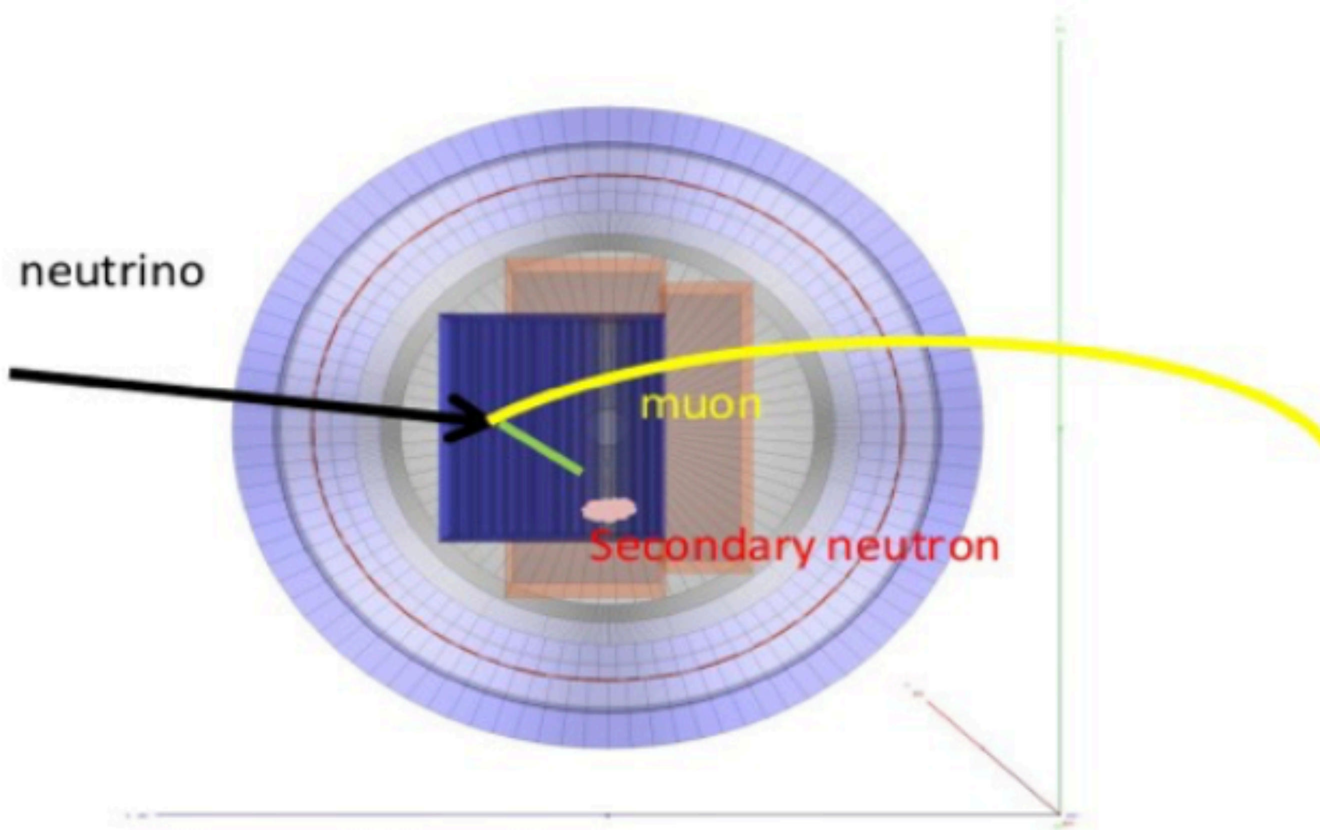
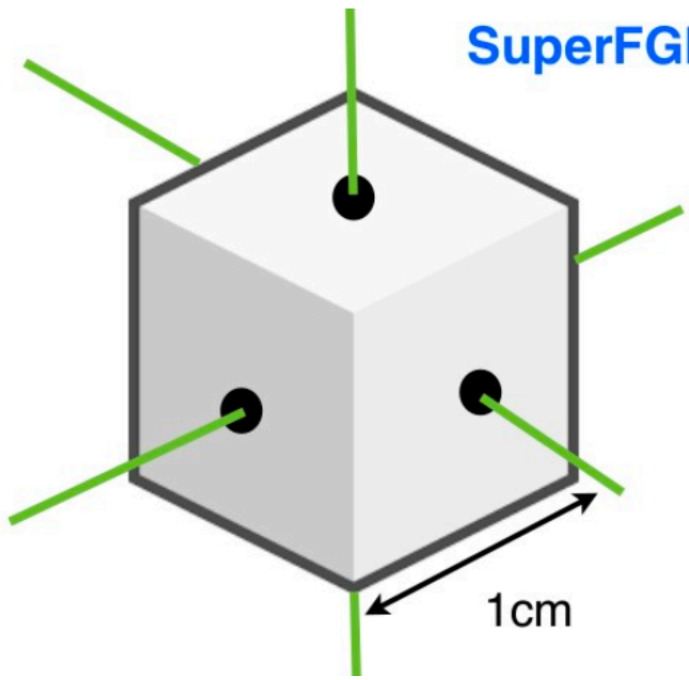
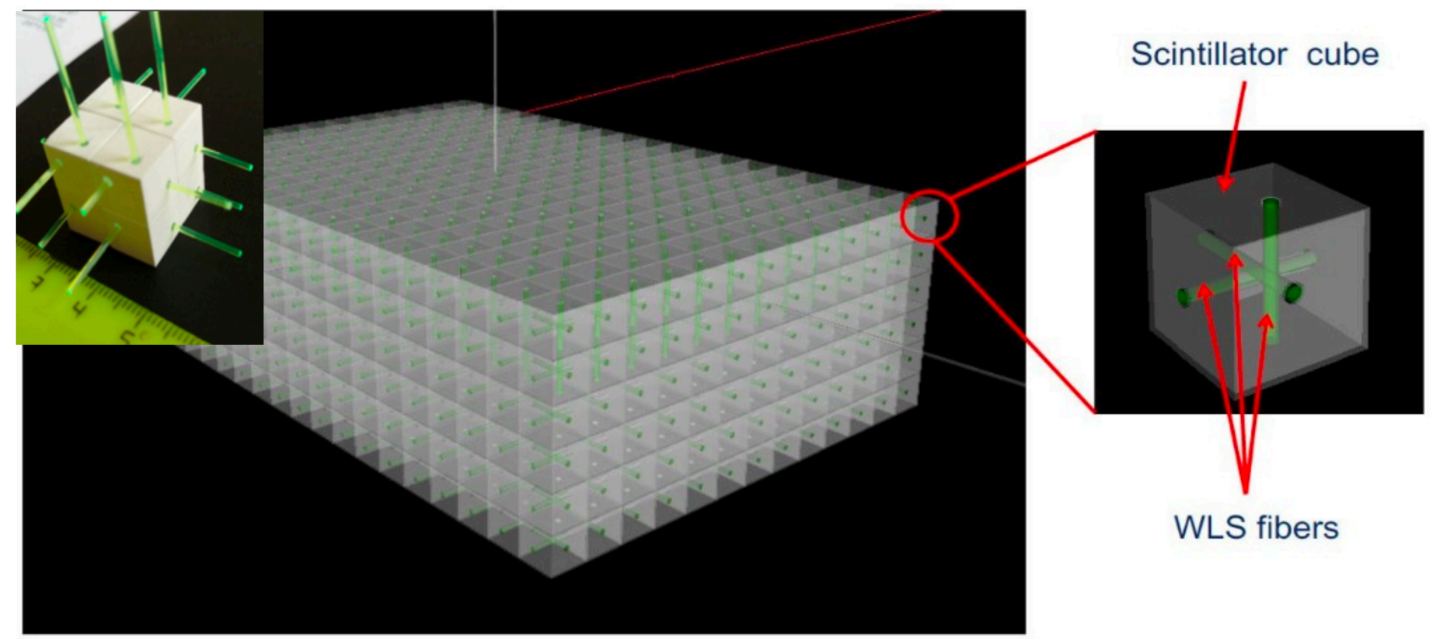
Introduction
why we care about background?



- **In order to reconstruct the neutrino interaction properly, we need pure signal sample**
- **Out of fiducial volume background is around 1%, so we care about secondary neutron and gamma**

Introduction
3D projection Scintillator Tracker (3DST)



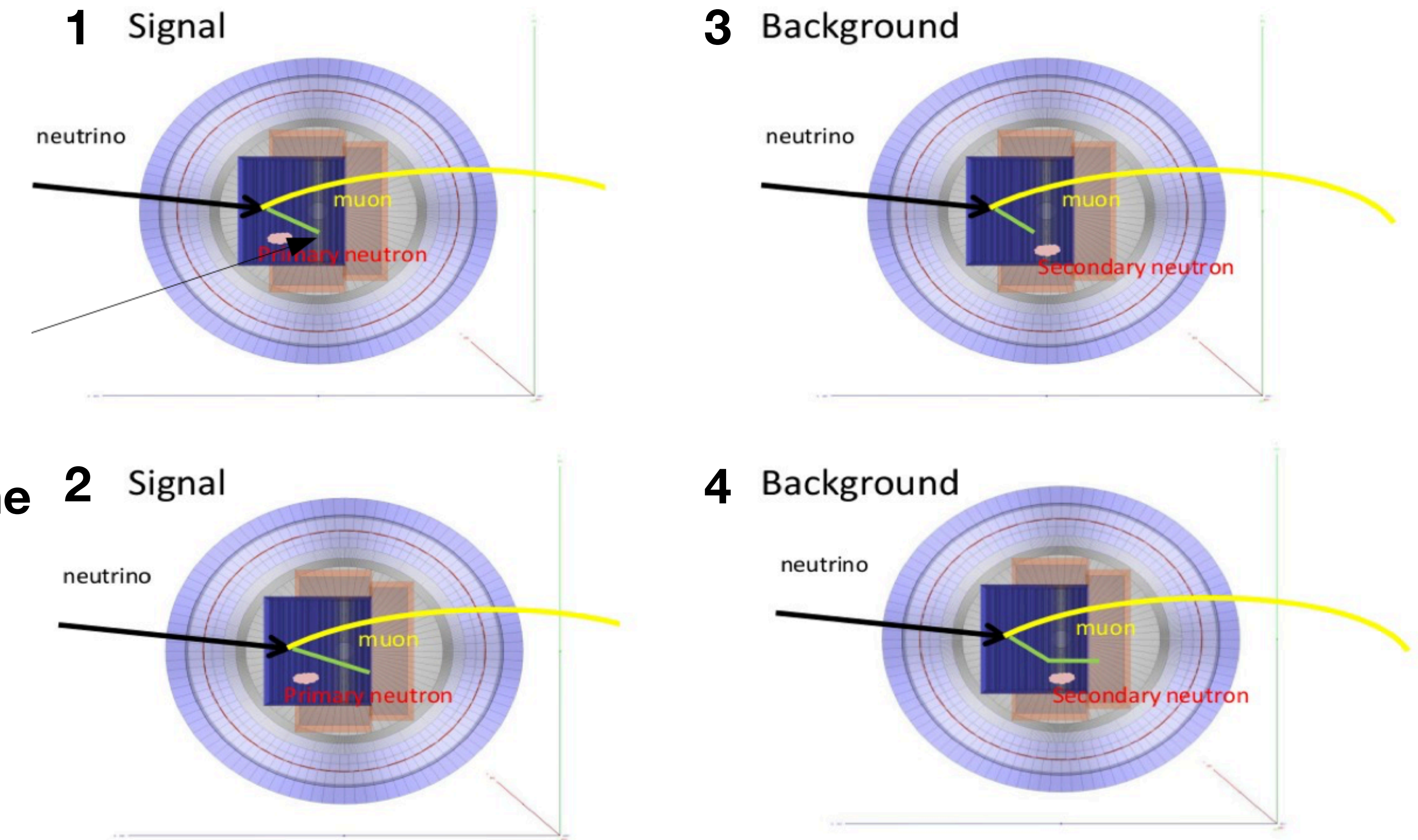


- **3DST has these features;**
  Fully active detector : no dead material as a massive target
  Uniform : neutrino interaction is not depending on the interaction location
  Full solid angle acceptance
  Pseudo-3D reconstruction with fine granularity
  Super fast time resolution : NEUTRON!

Definition

Critical point(C point):

- Primary final state particle's end point in 3DST.
- For exiting primary particles, the C point is the last point inside 3DST.

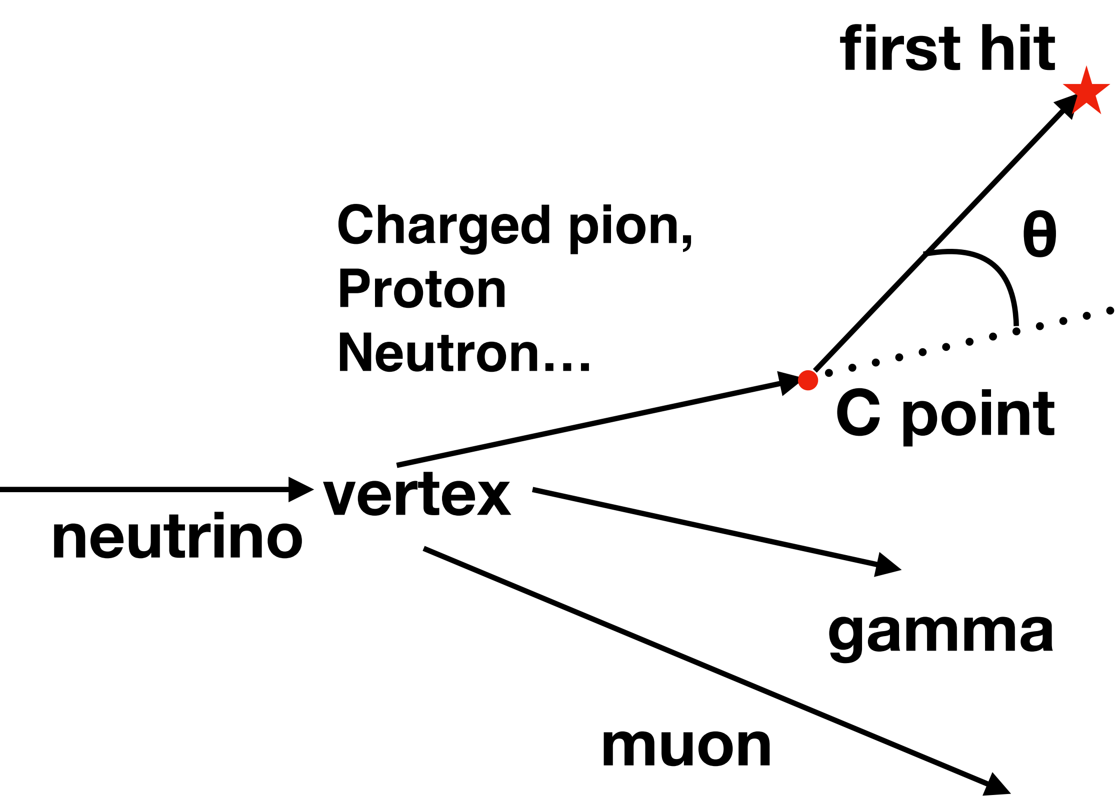


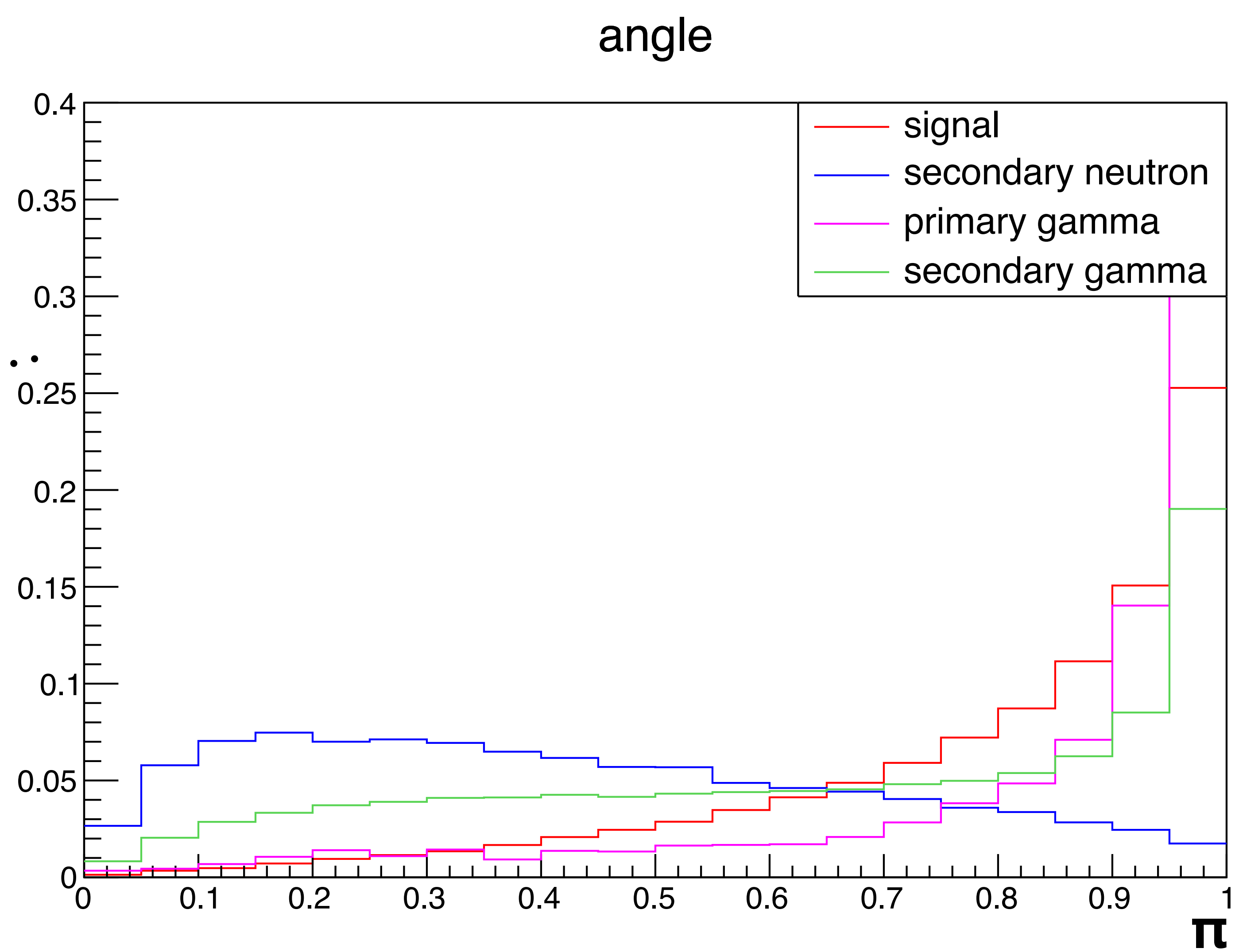
1: Earliest neutron hit is the primary neutron. - signal
2: The C point is at boundary of 3DST. - signal
3: Earliest neutron hit is a secondary neutron which comes from C point.
- secondary background
4: Earliest neutron hit is a secondary neutron which comes from kink point.
- secondary background

Variable definition
- angle

- **angle(θ in the figure): angle between two direction: from vertex to C point, from C point to the first hit**

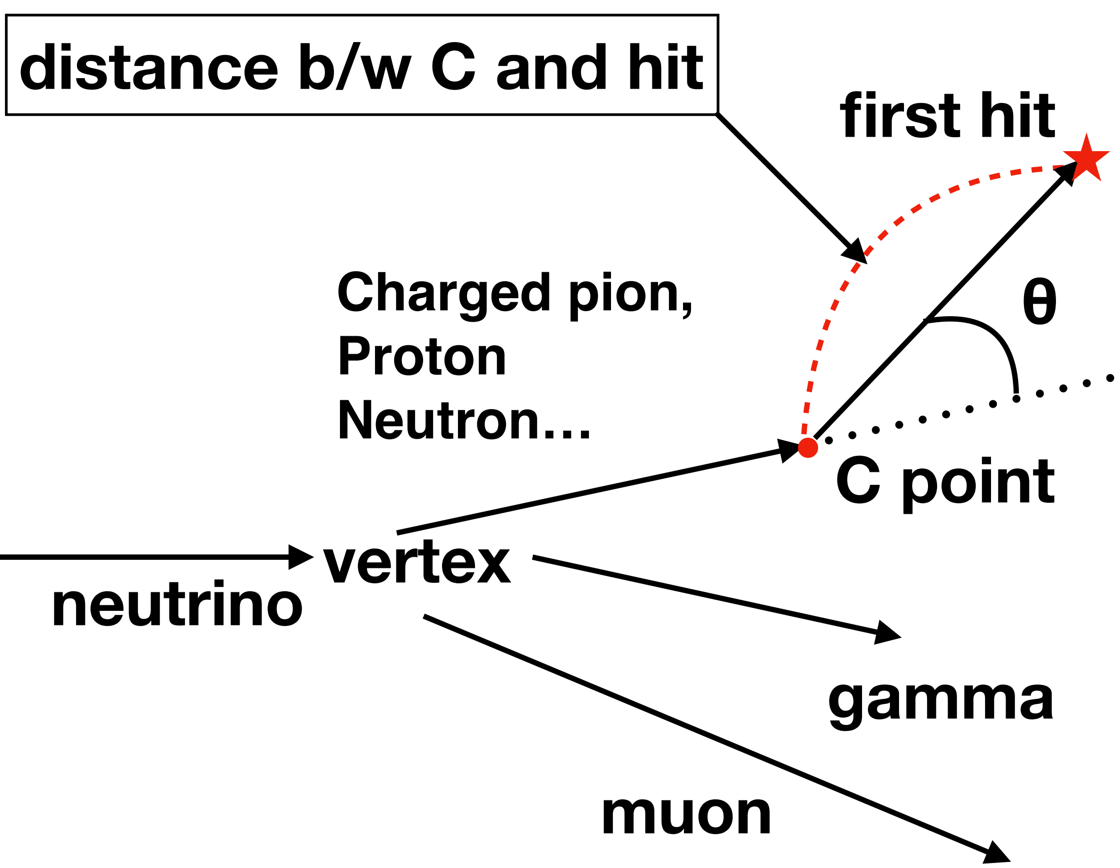
- **We expected that signal has large angle while secondary neutron has small angle**

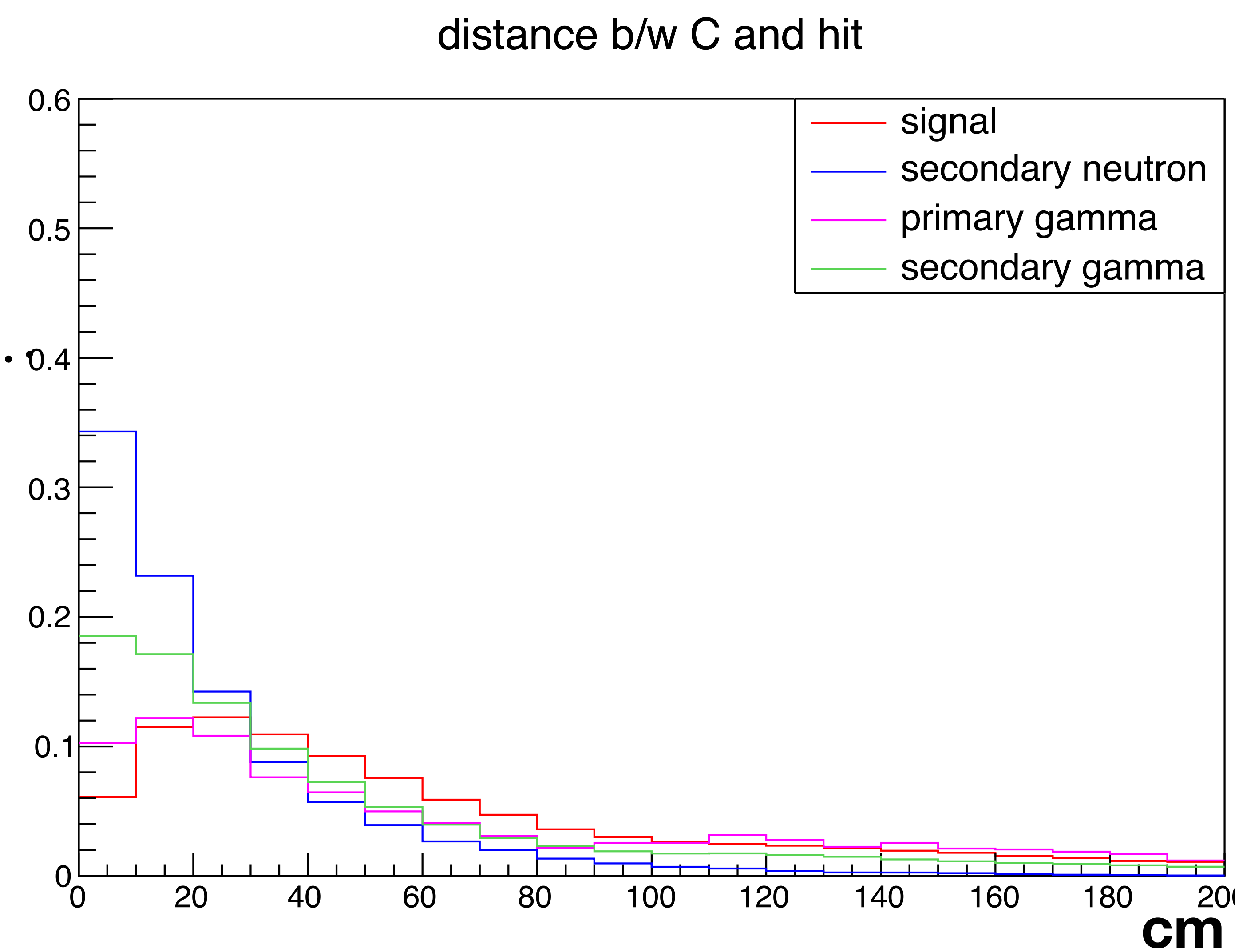




Variable definition
- distance between C and hit

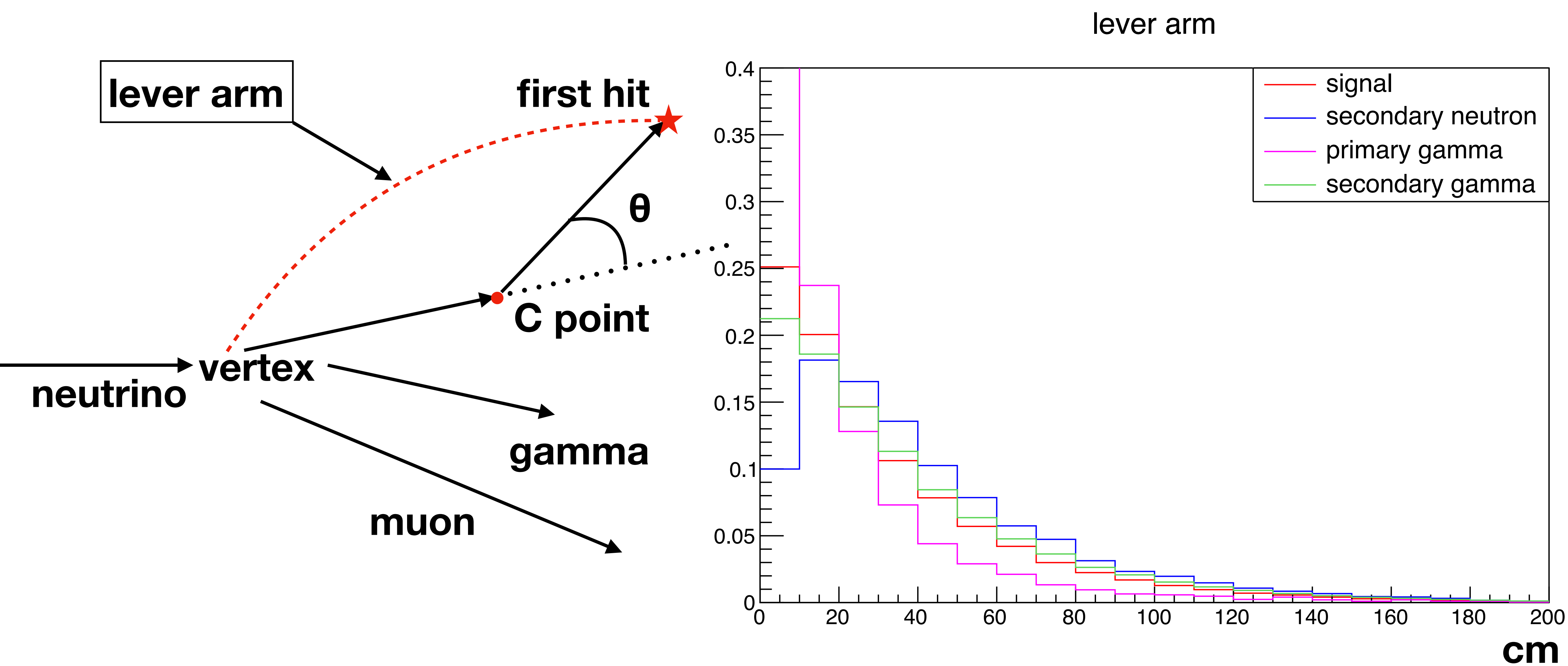
- **Distance between C and hit is the distance between C point and the hit.**
- **We expected that secondary neutron and secondary gamma has smaller distance than signal and primary gamma.**



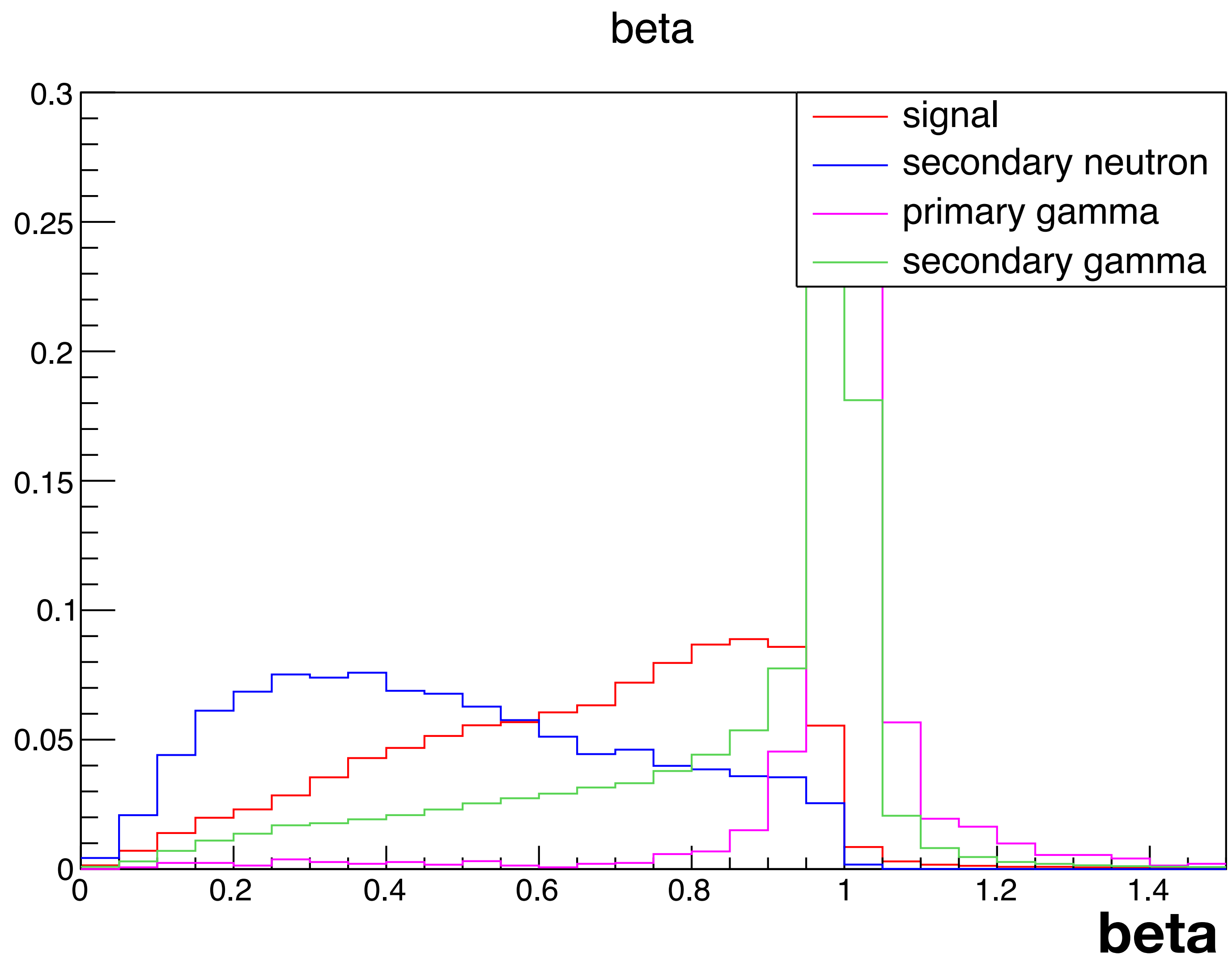


Variable definition
- lever arm

- **lever arm: distance between vertex and the first hit.**
- **We expected that signal has smaller lever arm than backgrounds.**

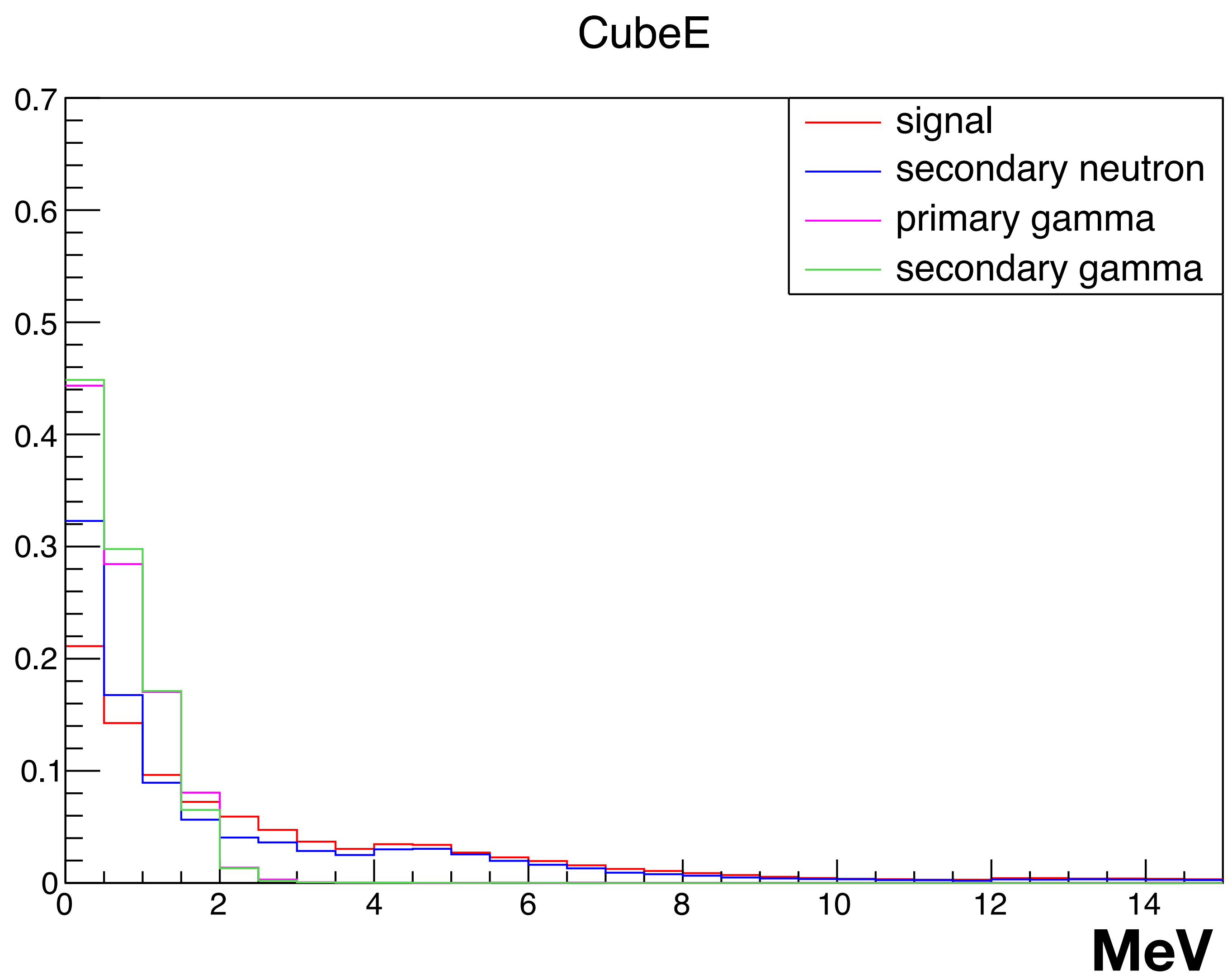


Variable definition - beta



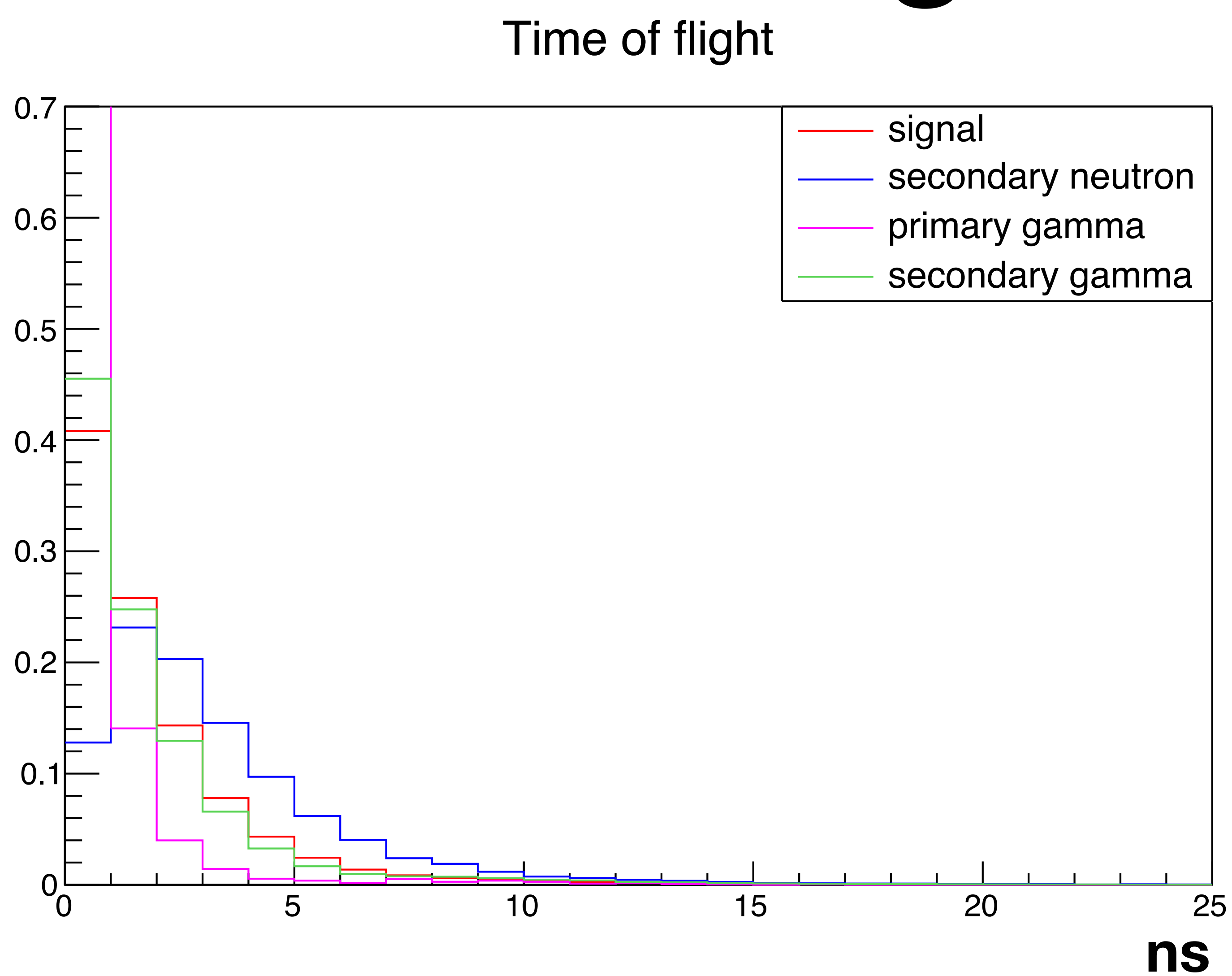
- **beta: v/speed of light, v is calculated from two points.**
- **We expected gamma has beta around 1, and this can help reduce gamma background.**

Variable definition -CubeE



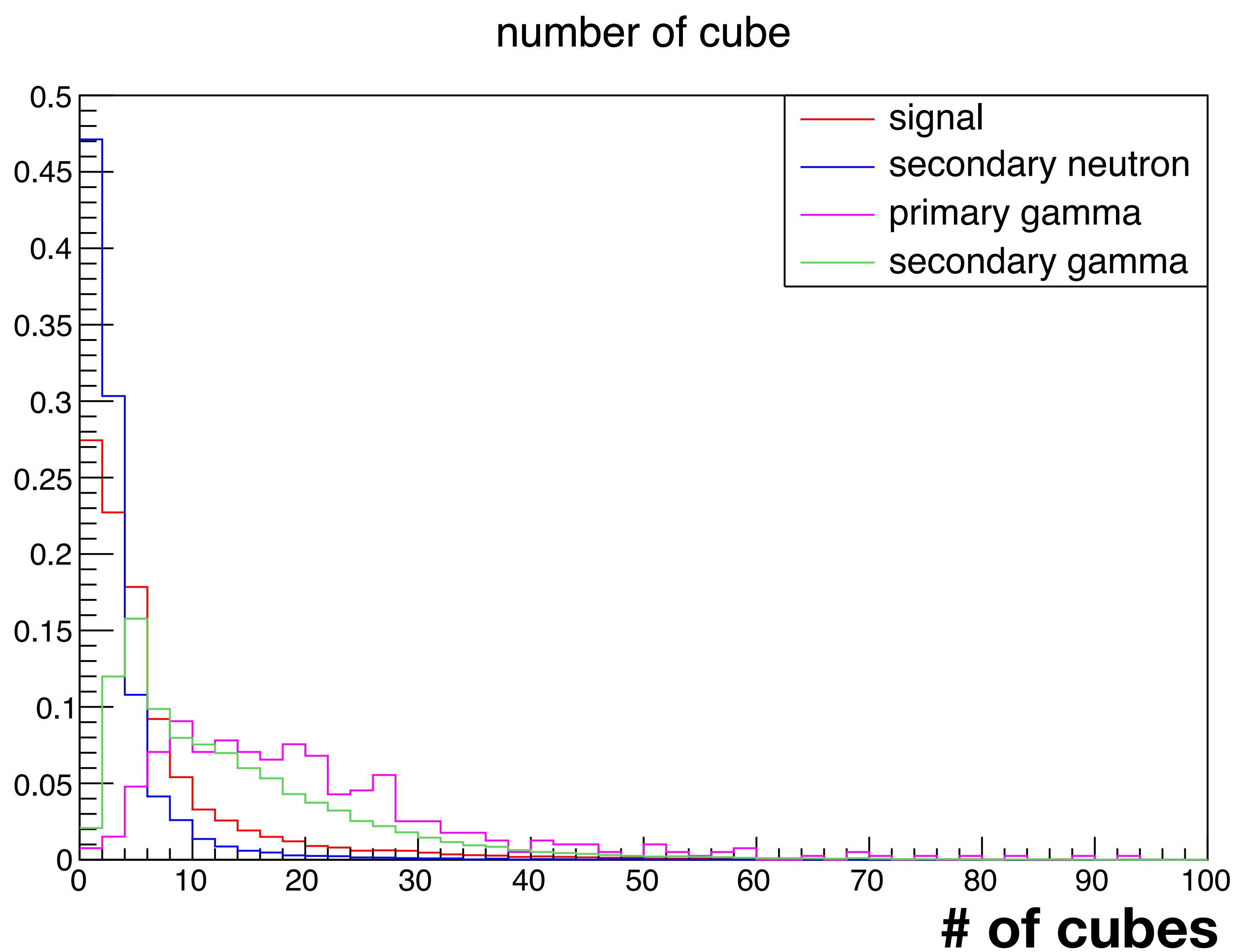
- **cubeE: energy accumulated by Geant4 hits inside the cube.**
- **We expected that gamma has smaller CubeE than neutron, and it can help reduce gamma.**

Variable definition
- time of flight



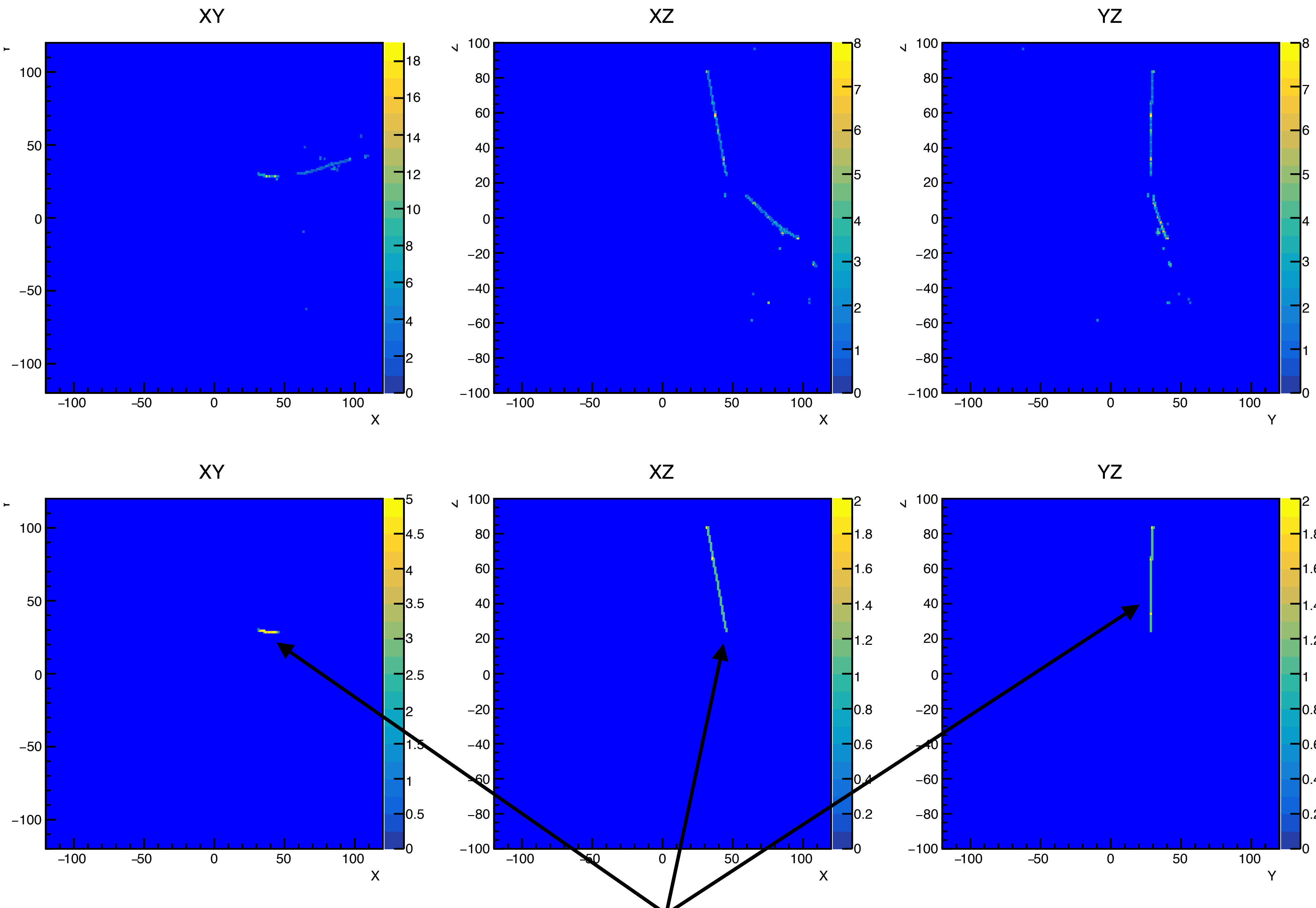
- **time of flight: time difference between vertex and the first hit.**
- **We expected that signal has smaller time of flight than secondary neutron.**

Variable definition
- number of cubes



- **We made a cluster of fired cubes including the first hit and number of cubes is the number of cubes of the cluster.**
- **We expected that gamma has more cubes than neutron and it can help reduce gamma**

Number of cubes event display



contains all neutron, gamma induced hits

only the cluster

cube cluster

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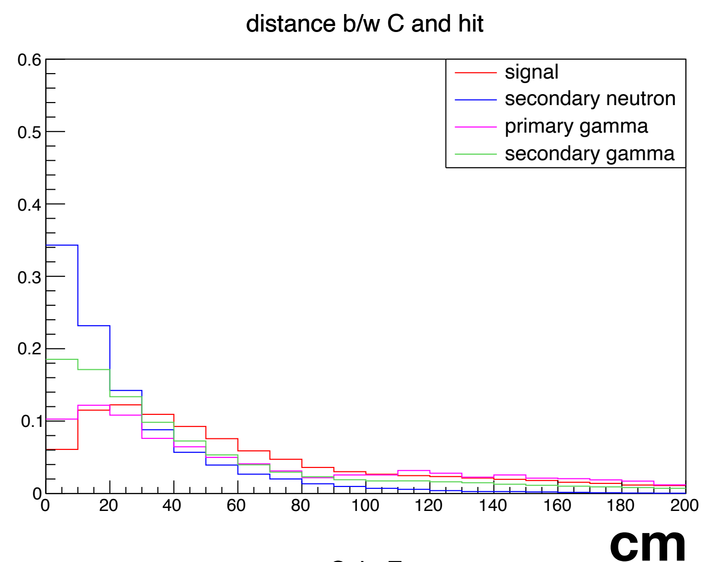
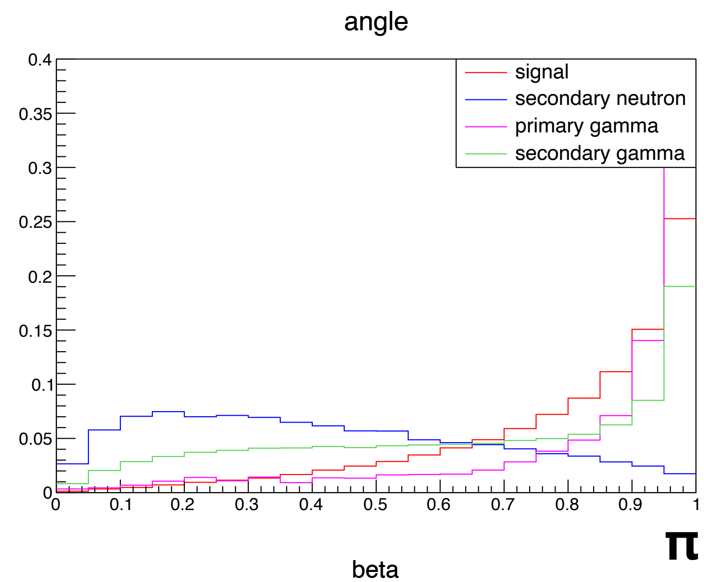
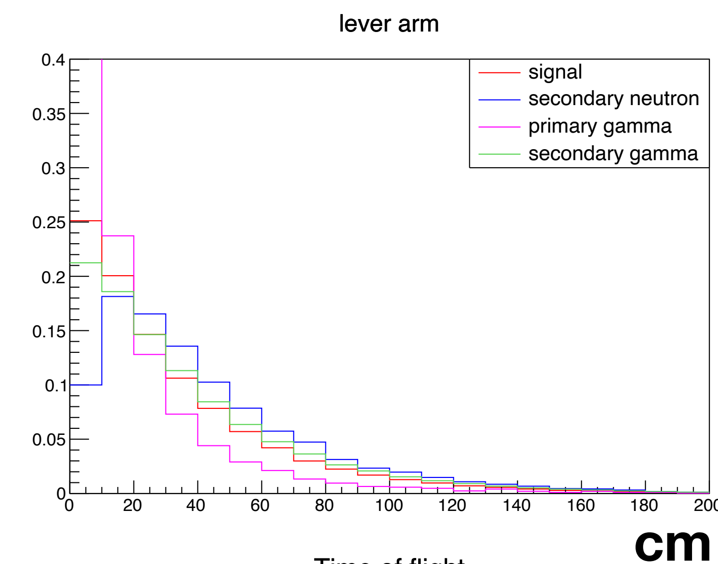
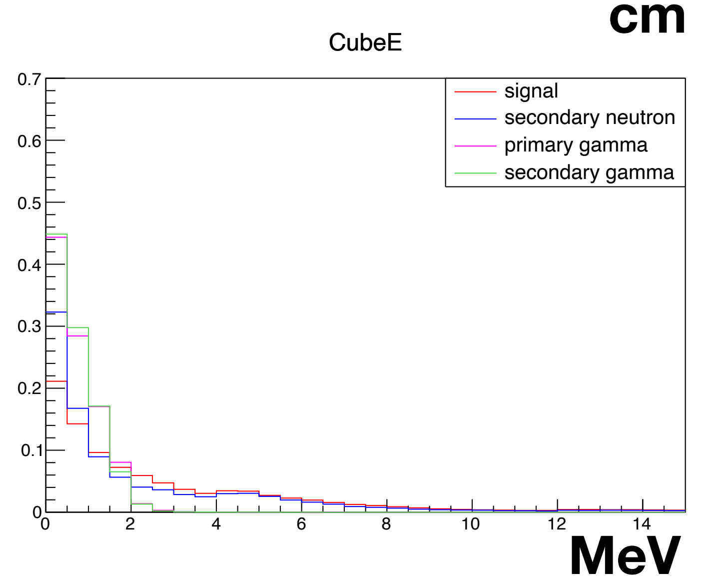
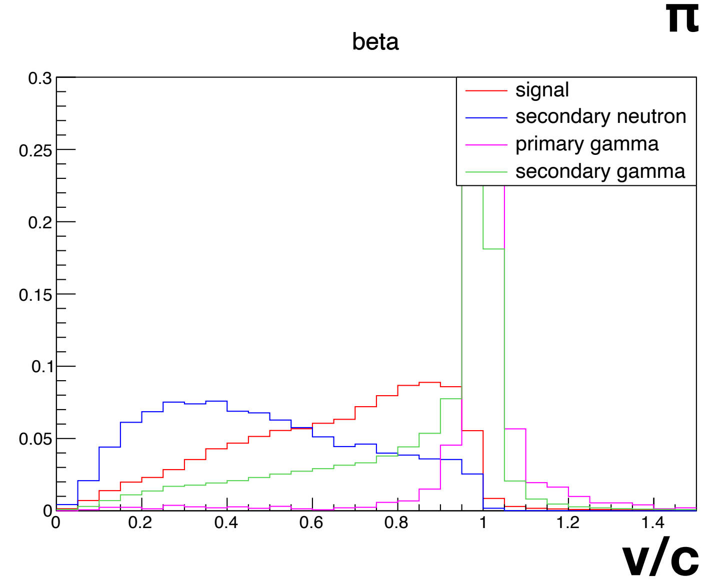
BDT input variables

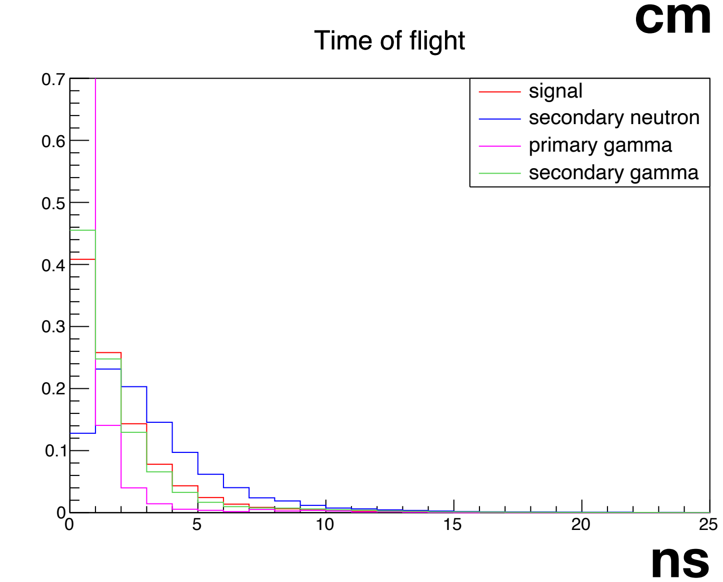


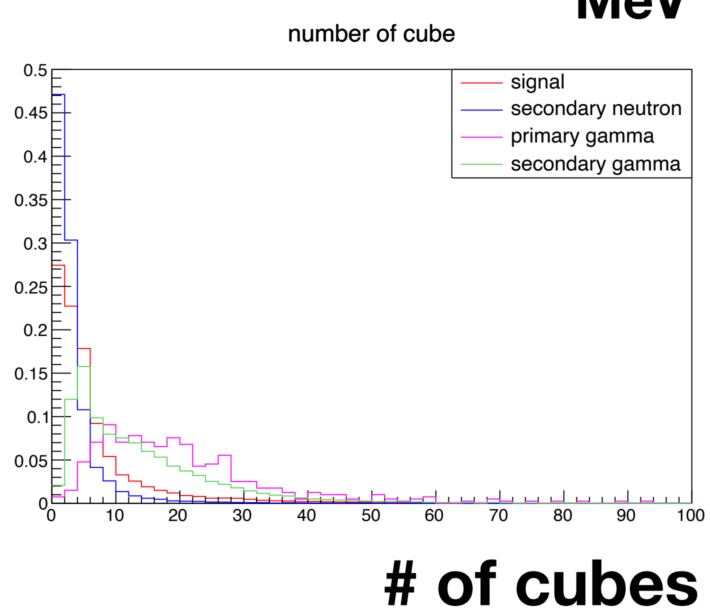






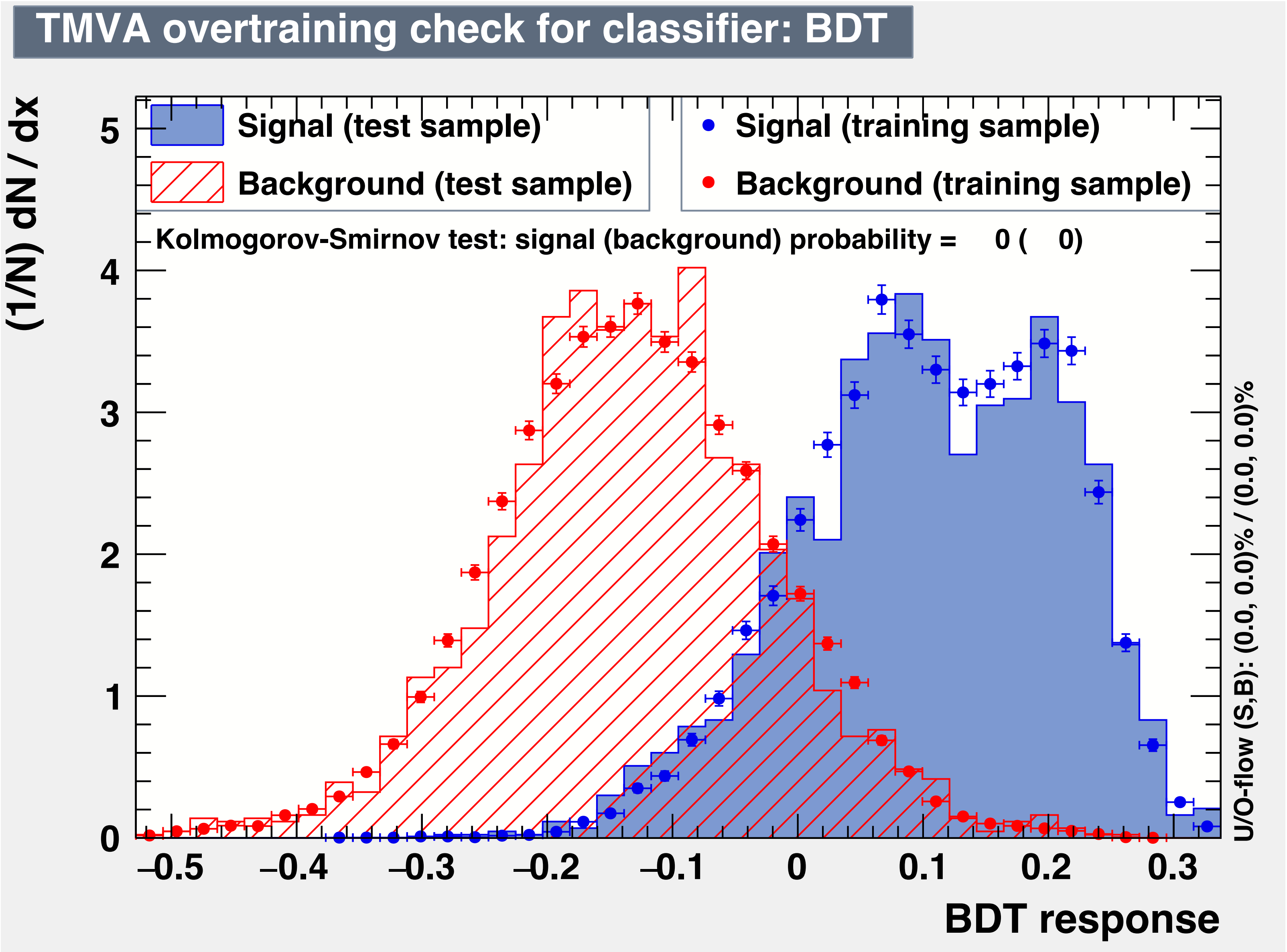






- **We used 7 variables as an input of BDT.**
- **Signal and backgrounds(secondary neutron + primary, secondary gamma)**

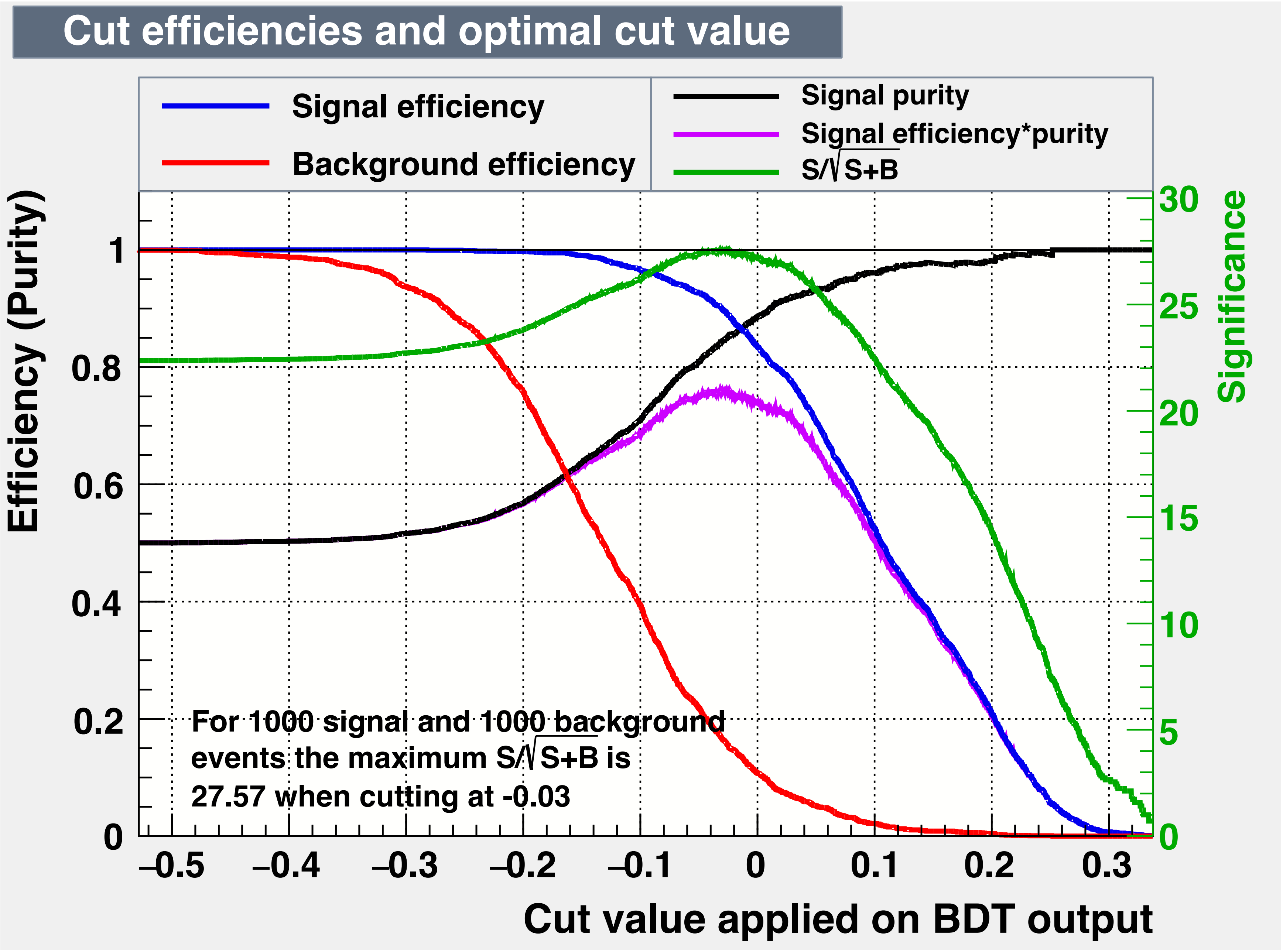
BDT result (1pi 0P)



- Training sample; signal: 17338, background: 31490
- Test sample; signal: 2000, background: 2000

- In BDT response > 0.1 region, there is almost no background.

BDT result (1pi 0P)



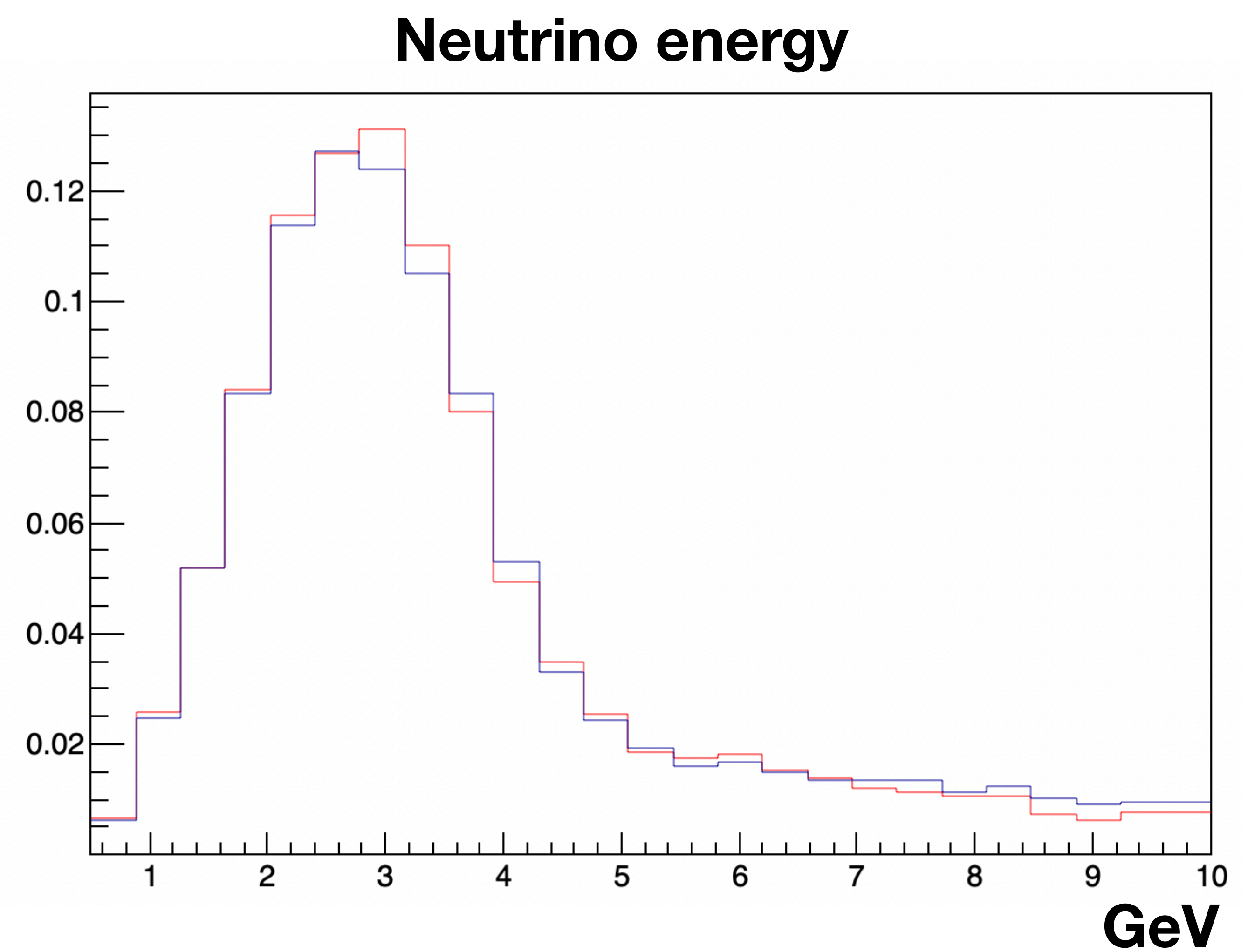
- **If we have BDT cut at 0.1, background is almost removed and signal efficiency is around 0.5.**

Validation
-applying 3 1D cuts

- **We applied a simple set of the 1D cuts(CubeE, beta, angle) to check the BDT result is valid**

- **We can get 90% purity with 42% efficiency after applying the set of cuts.
→BDT result is valid**

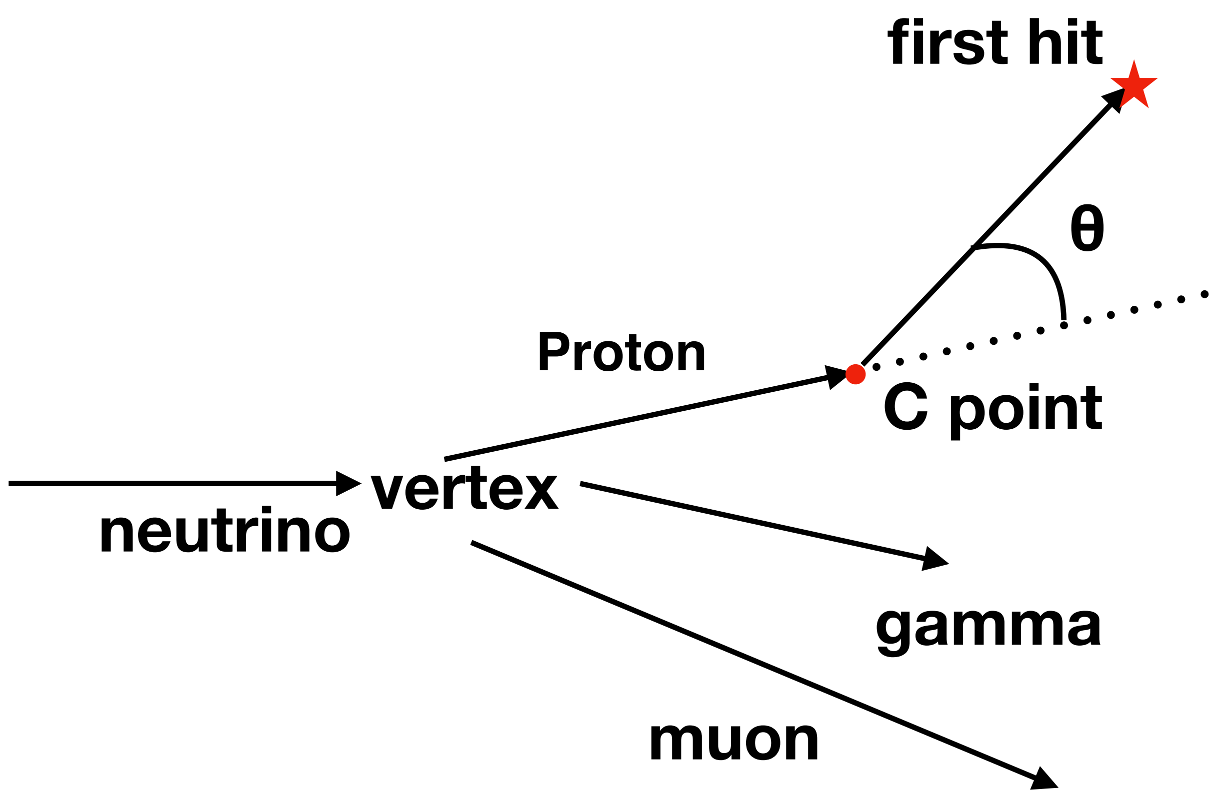
Neutrino energy spectrum after BDT cut



- blue: before BDT cut
  red: after BDT > 0.1 cut
- two spectra are area normalized
- after the cut, the efficiency ~ 0.5

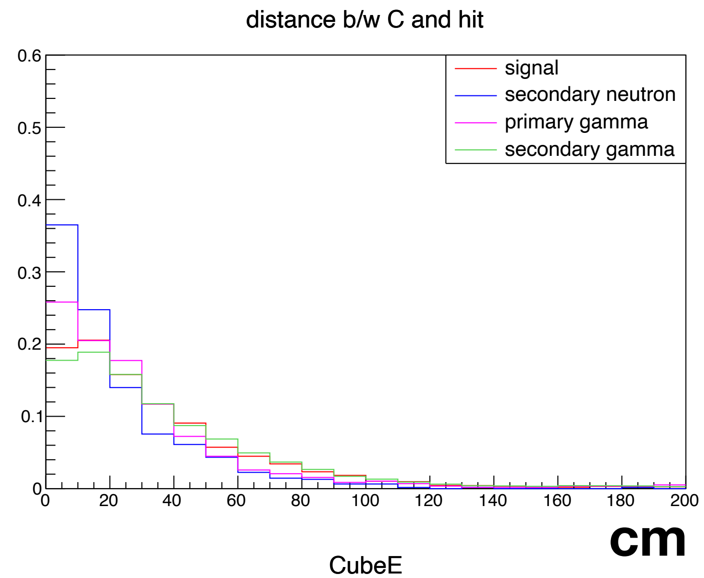
- We checked two neutrino energy spectra, before any cut and after BDT > 0.1 cut.
- Two spectra are almost the same.
  →There is no particular energy cut-off

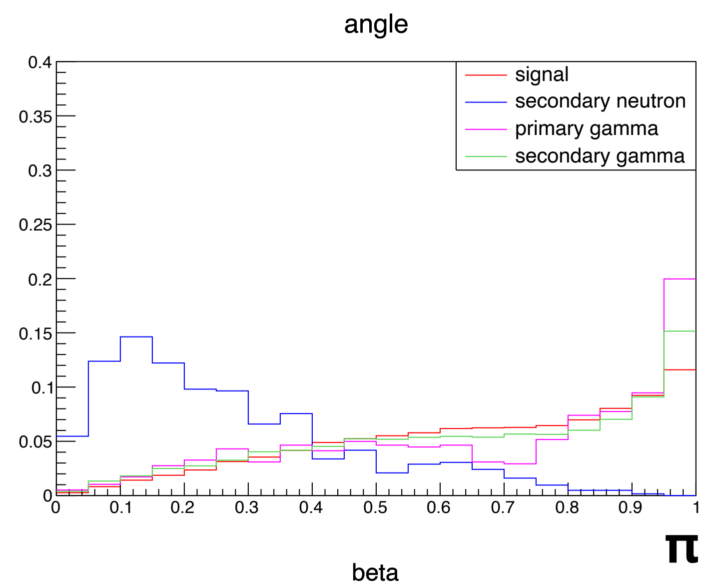
0 charged pion 1 Proton channel

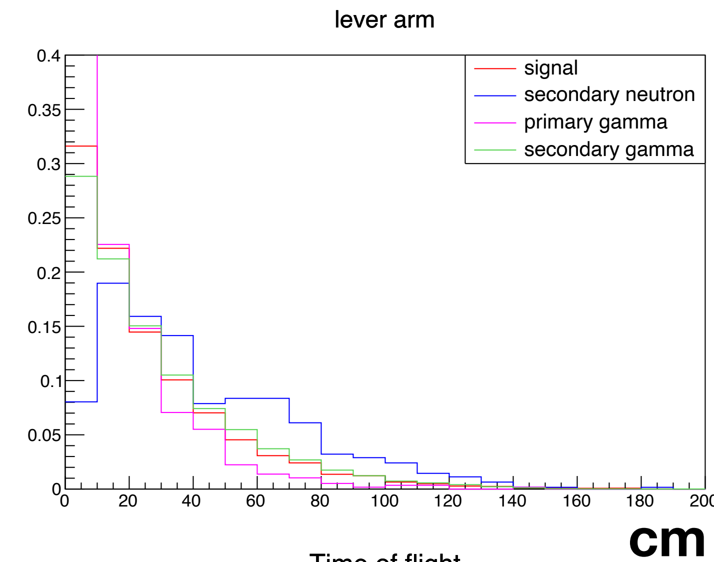


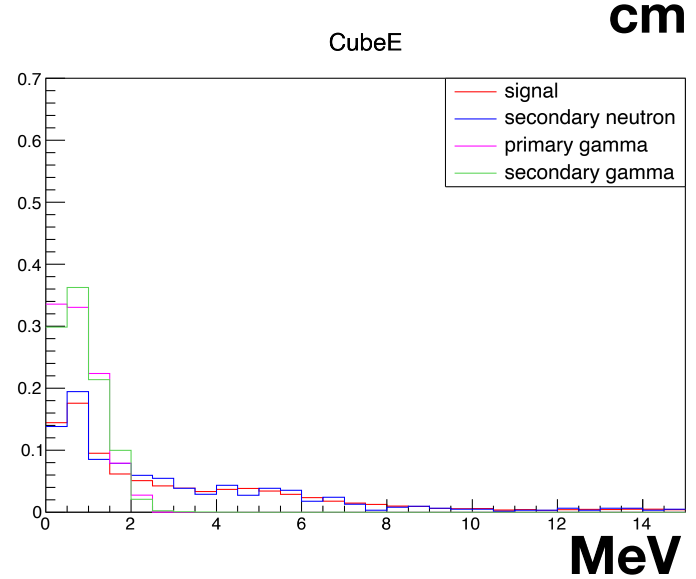
- In the final state particles, there is no charged pion but proton: 0pi 1P channel
- We use the same definitions of variable (angle, beta, lever arm etc)

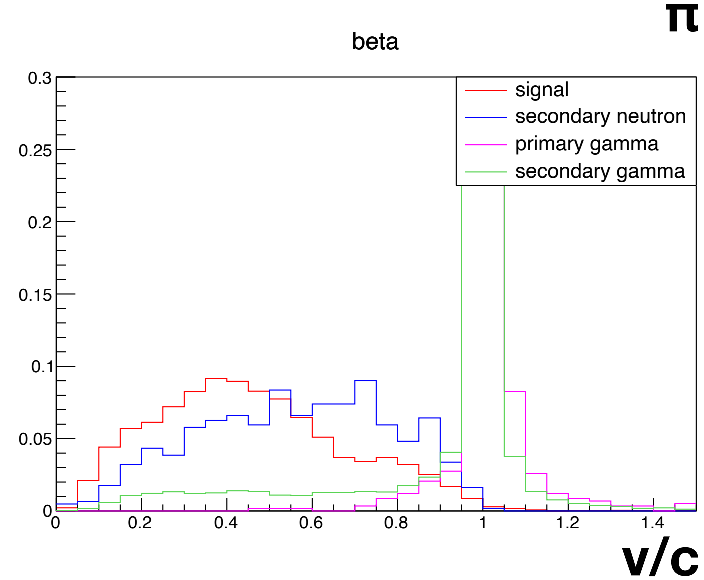
BDT result (0pi 1P)

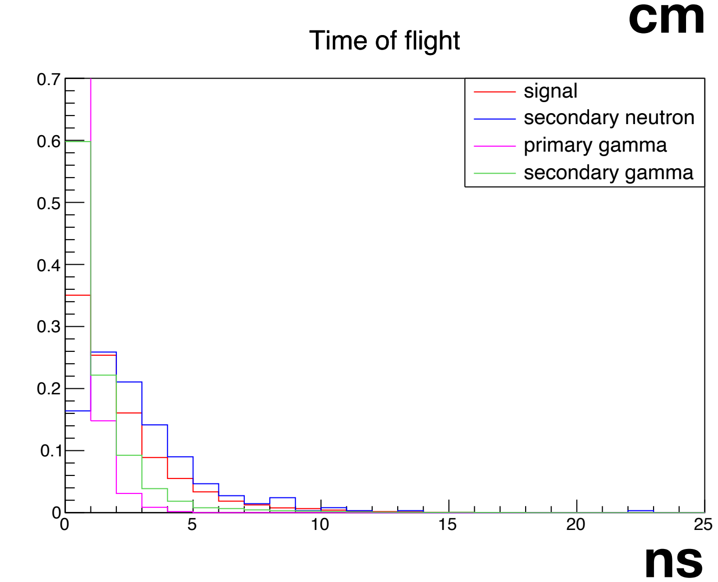


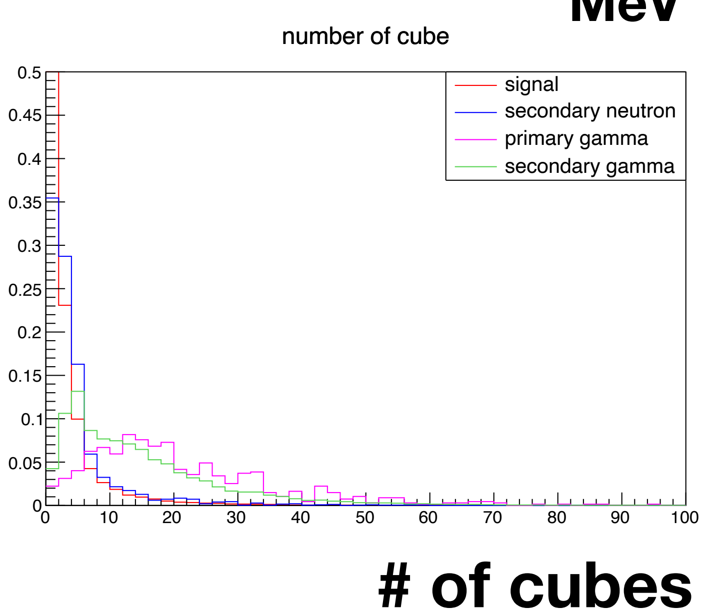












- **We used 7 variables as an input of BDT.**
- **Signal and backgrounds(secondary neutron + primary, secondary gamma)**

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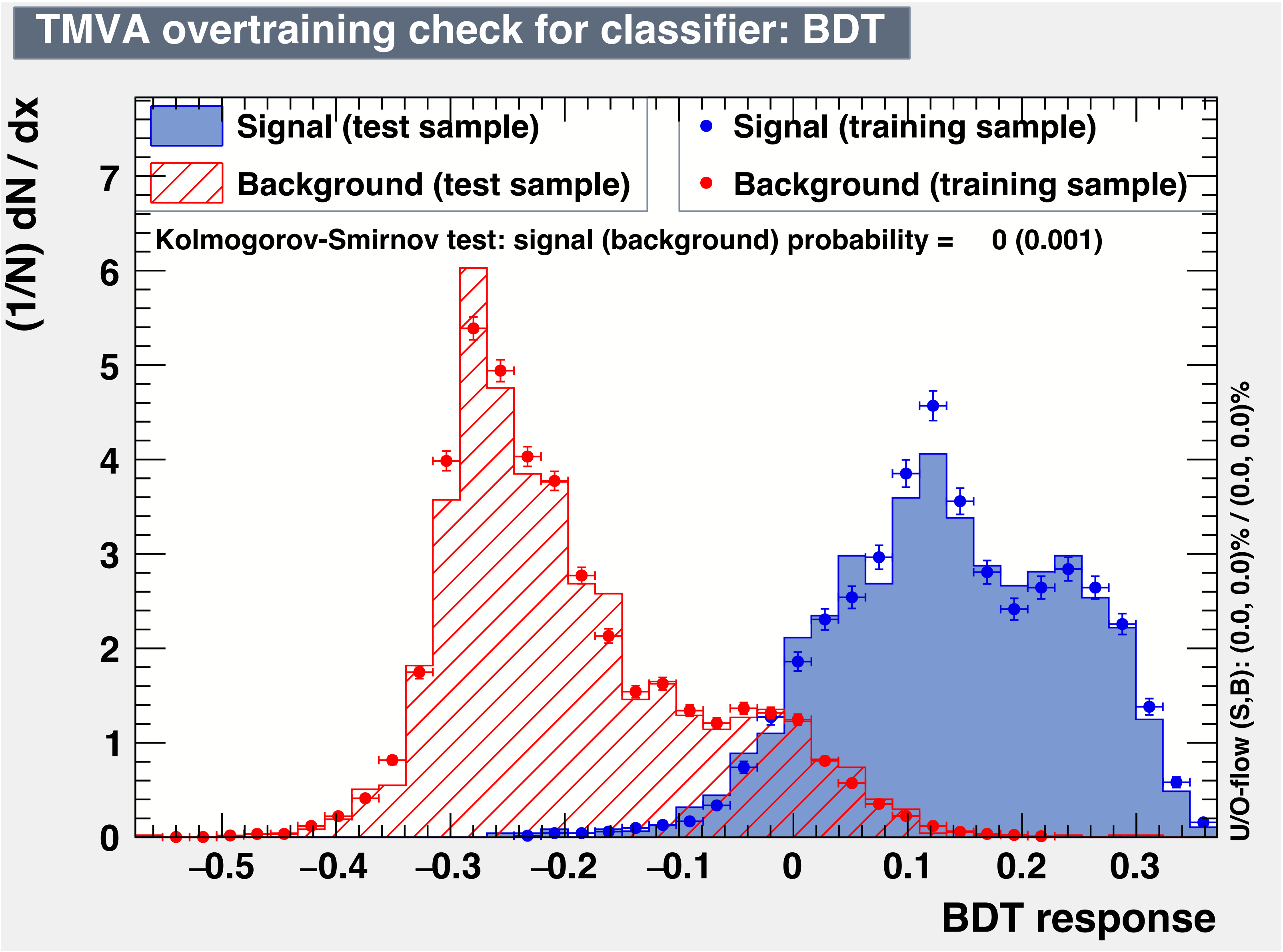
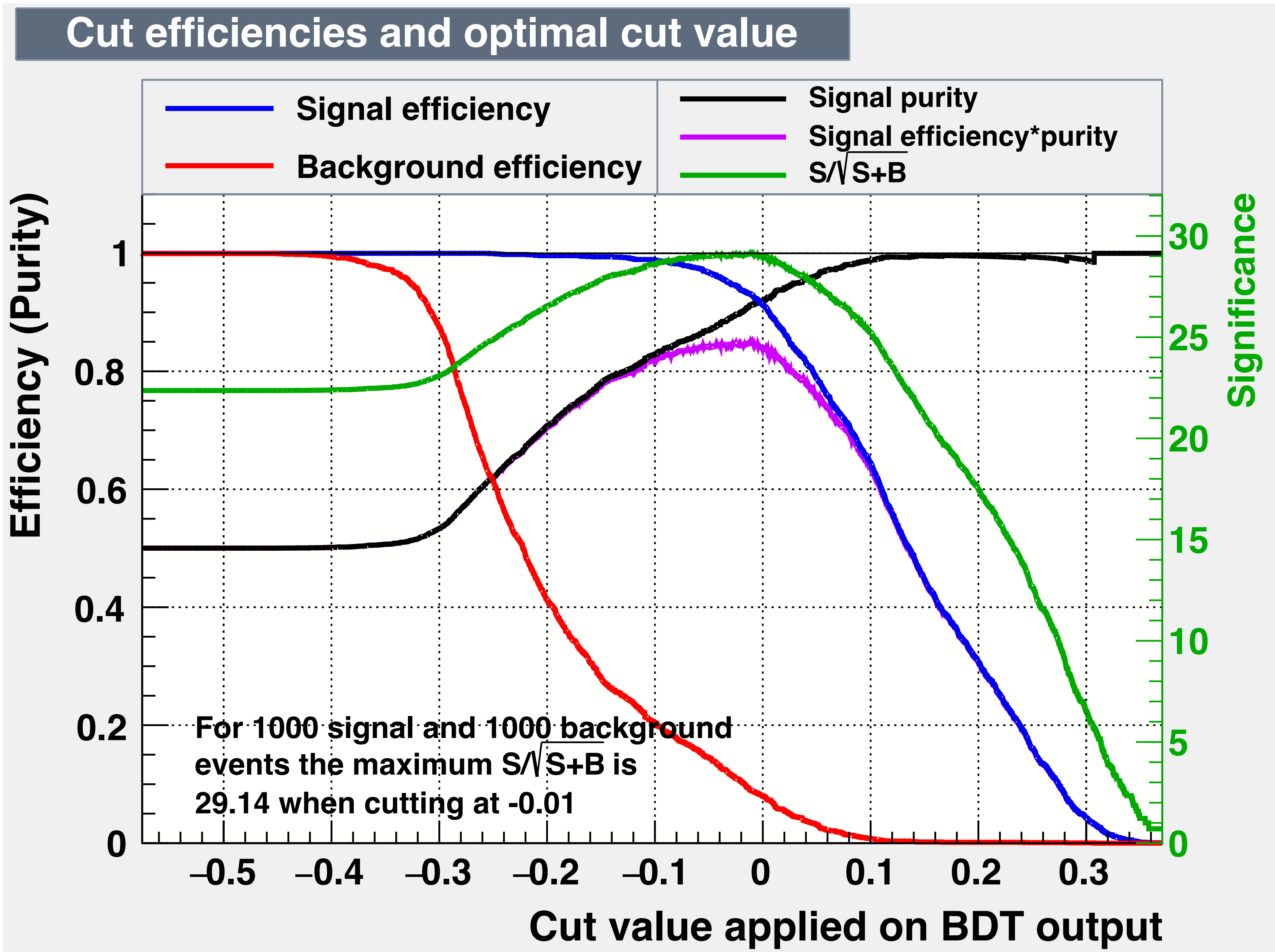
BDT result (0pi 1P)

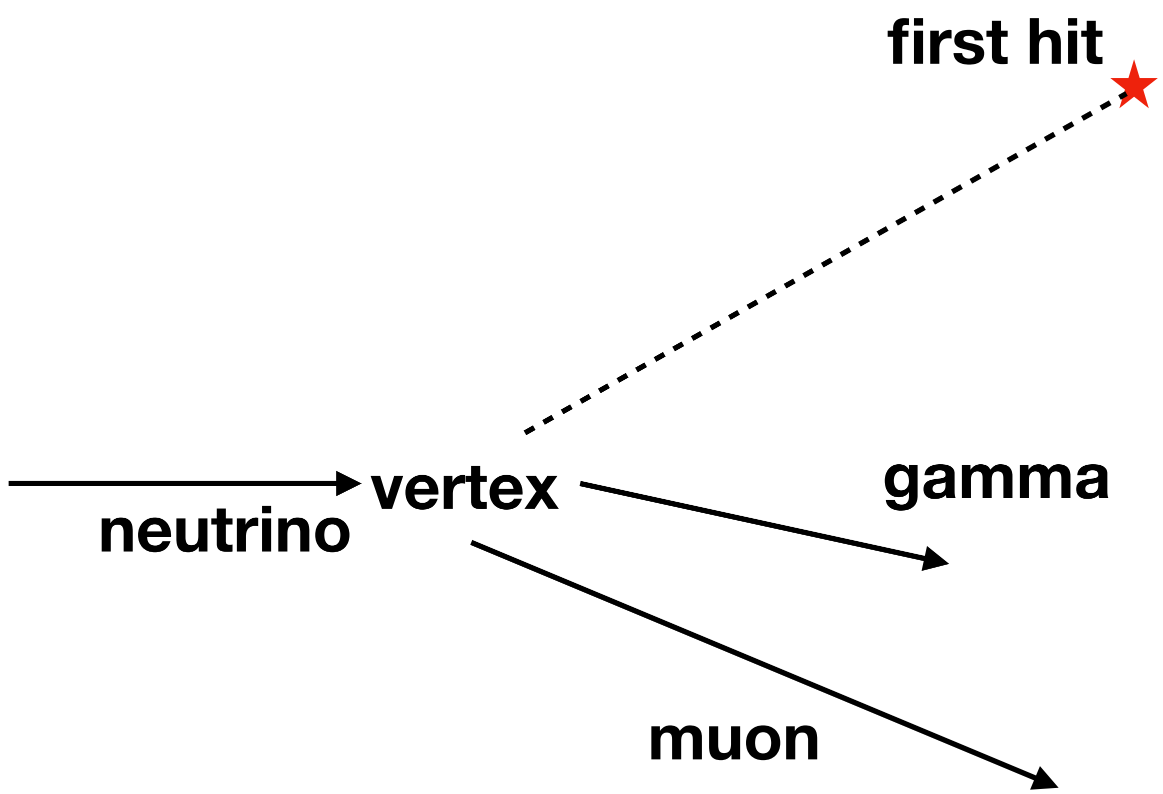


- **Training sample; signal: 7778, background: 15579**
- **Test sample; signal: 2000, background: 2000**

BDT result (0pi 1P)

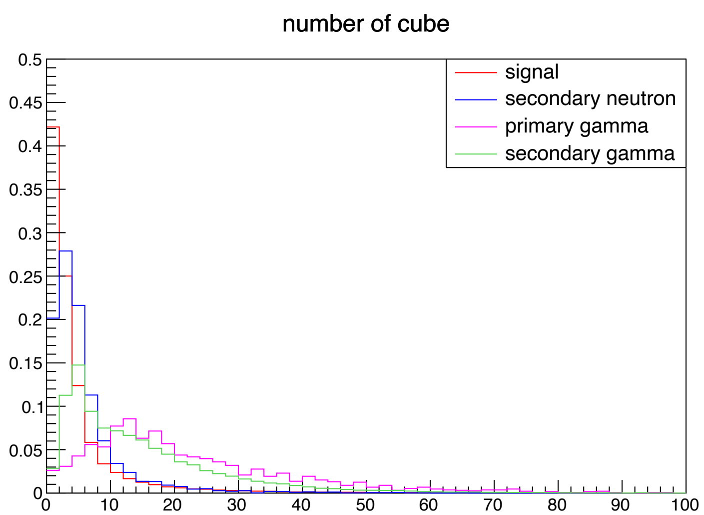


0 charged pion 0 Proton channel

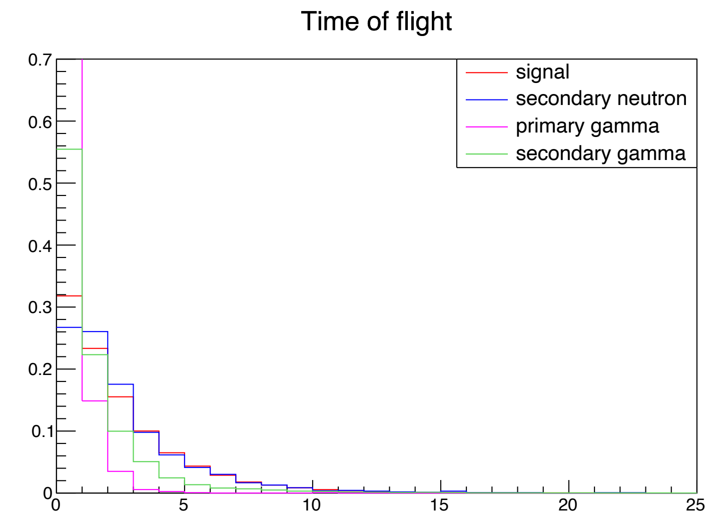


- In the final state particles, there is no charged pion no proton: 0pi 0P channel
- We use the same definitions of variable.
- There is no C point → angle, distance b/w C and hit are not available

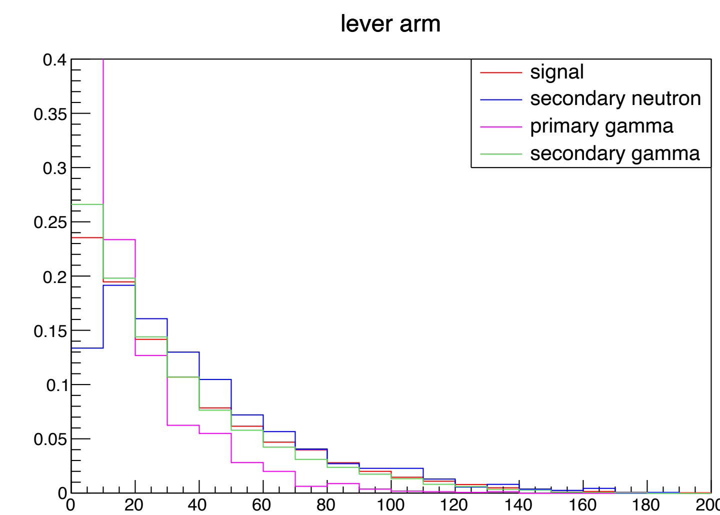
BDT result (0pi 0P)



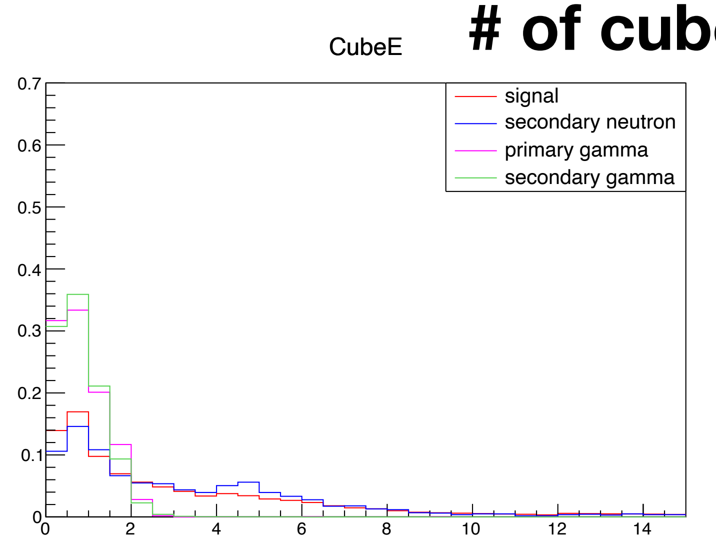
# of cubes



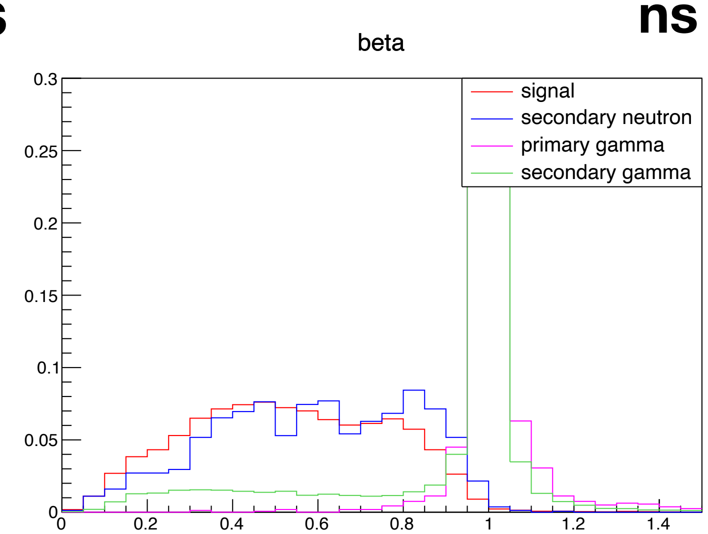
ns



cm



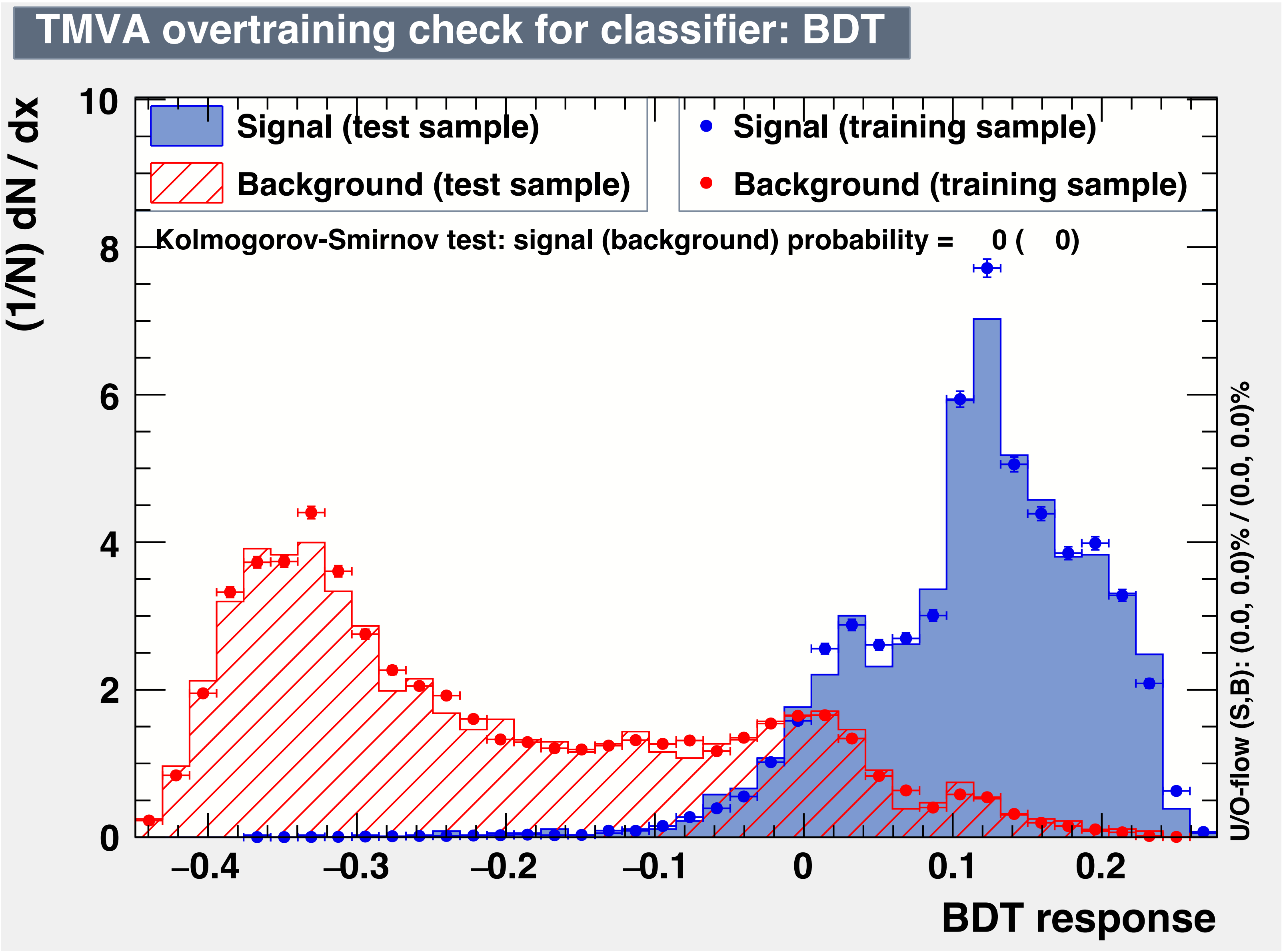
MeV



v/c

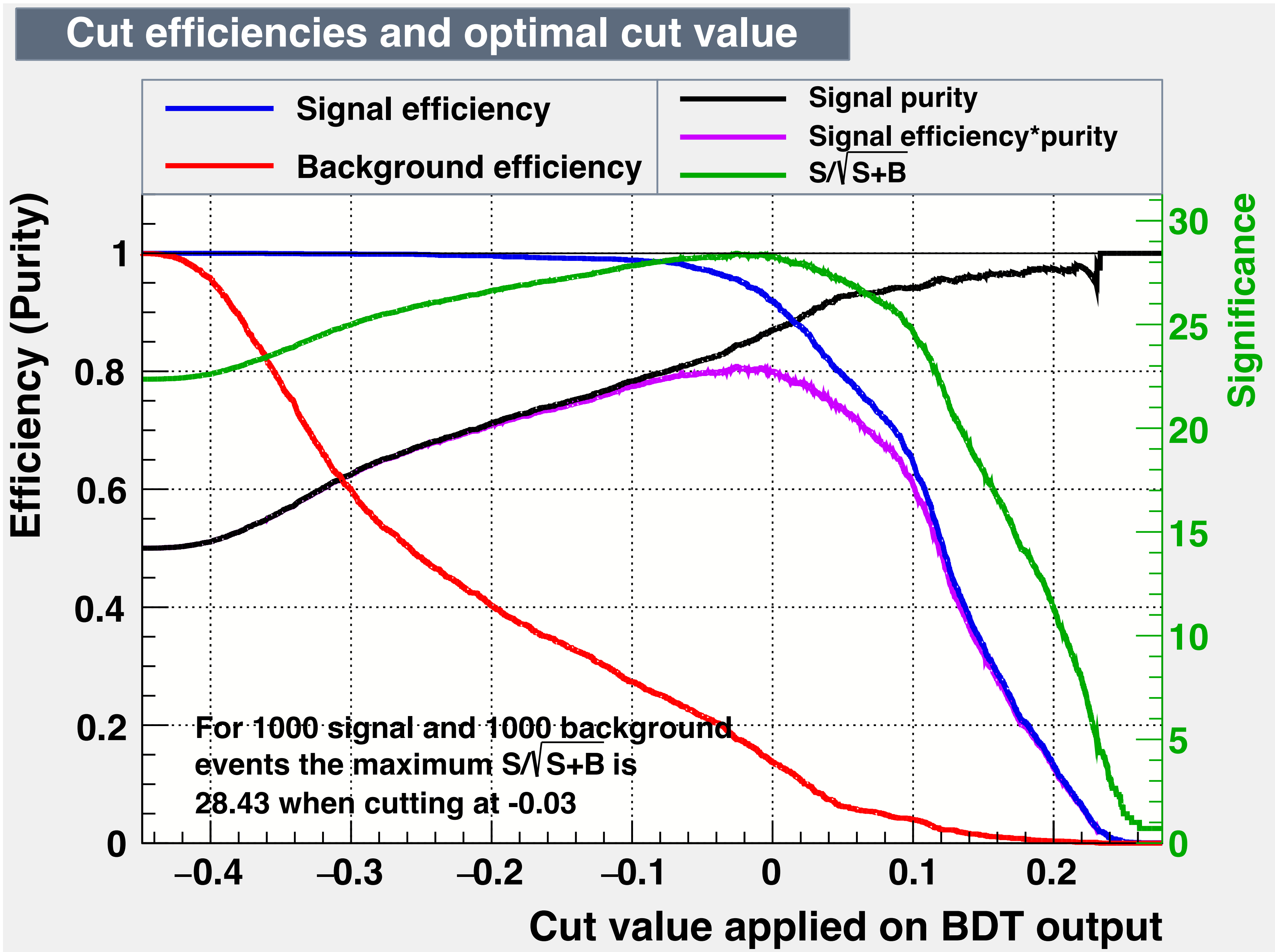
- **We used 5 variables as an input of BDT; we can't use angle, distance b/w C and hit because there is no C point**
- **Signal and backgrounds(secondary neutron + primary, secondary gamma)**

BDT result (0pi 0P)



- **Training sample; signal: 27837, background: 34764**
- **Test sample; signal: 2000, background: 2000**

BDT result (0pi 0P)



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Summary

- 3DST can constrain all the out-of-FV , secondary and gamma background for CC0pi0p, CC0pi1p and CC1pi0p to a level of >90% purity with 80% efficiency.

- We expect some physics performance studies such as antineutrino flux constraint based on a pure signal sample