



Muon Bundle Reconstruction

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JUNO Physics and software workshop @ Wuhan



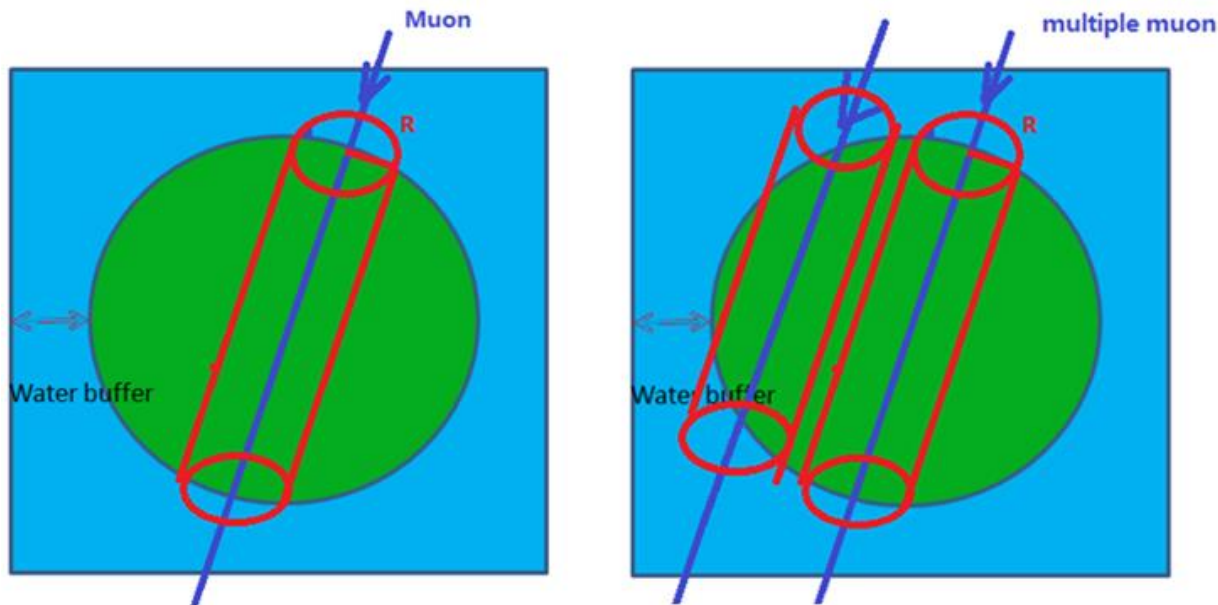
Outline

- Motivation and simulation
- Reconstruction method
- CD SPMT Reconstruction
- Spmt number and UWB impact on recon.
- Summary



Motivation

- Muon induced $9\text{Li}/8\text{He}$ background is the main background.
- Multiple muon $\sim 10\%$. So not only single muon, but also multiple muon should be reconstructed.





Simulation



- Software version J16v2r1-pre5 and J17v1r1.
- Muon generator from muon samples(all angles and energies).
- Full muon optical process simulation.
- Package available:
[\\$JUNOTOP/offline/Reconstruction/SpmtMuonRecTool](#) and [PoolMuonRecTool](#)

Muon simulation and rec. commands e.g.:

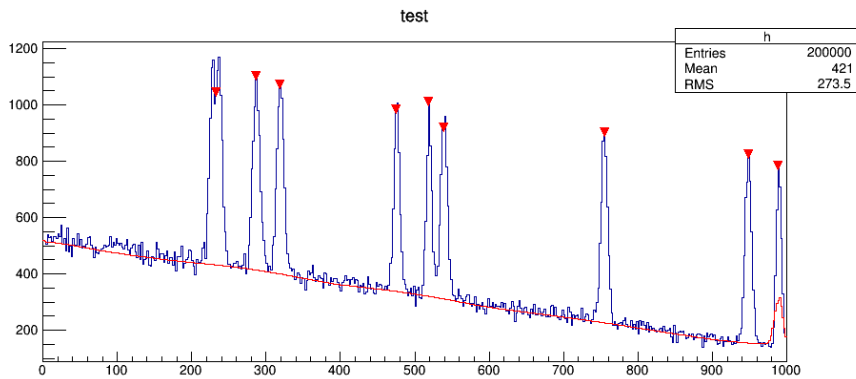
1. `python tut_detsim.py --no-gdml --no-anamgr-deposit --no-anamgr-interesting-process --anamgr-config-file load_mu_config.py --evtmax 2 --seed 85840 --output general_85840.root --user-output muon_85840.root --detoption Acrylic hepevt --exe Muon`
2. `python tut_det2calib.py --input inmu.root --output calibmu.root`
3. `python tut_calib2rec.py --input calibmu.root --output recmu.root --method spmt-track`



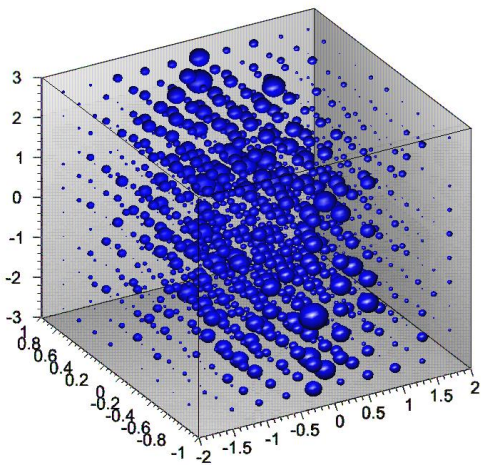
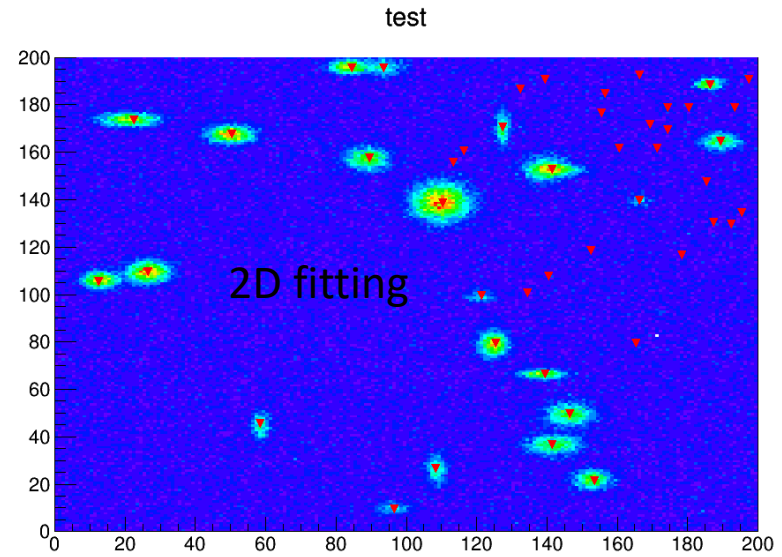
TSpectrum fitting



- ROOT tool: TSpectrum, TSpectrum2, TSpectrum3 can be used in 1D, 2D, 3D fitting.
- E.g. from ROOT tutorial:



1D fitting



- JUNO pmt are all assembled on the surface of sphere or cylinder, so TSpectrum2 should be used to do fitting.

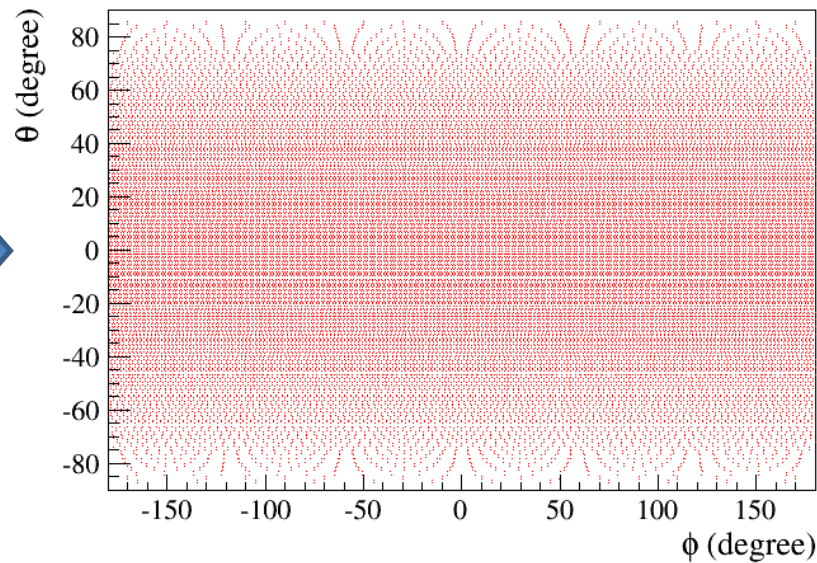
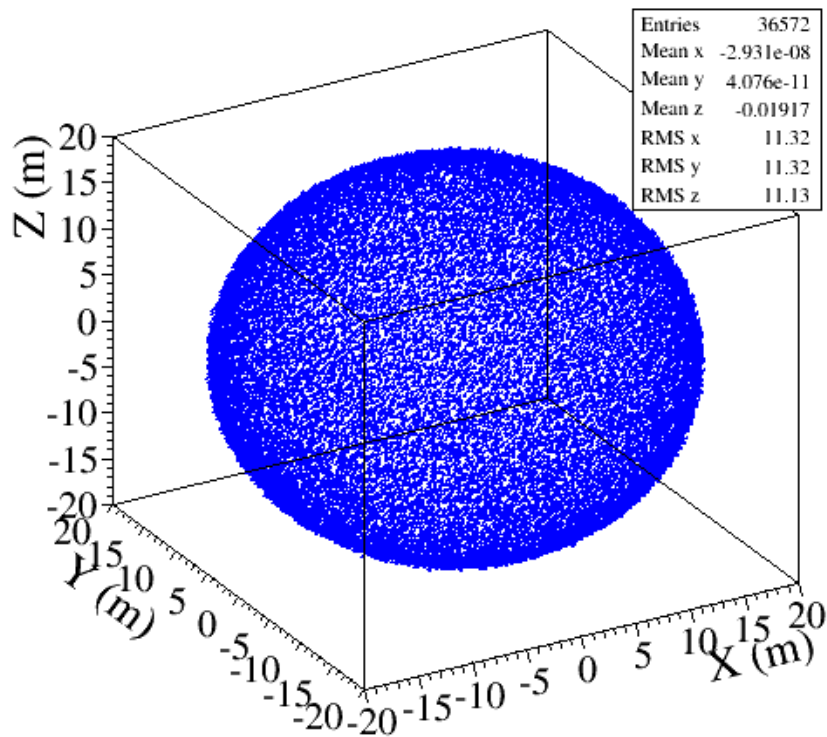


Reconstruction method

- Charge weighted
- Steps:
 - 1. Project ball pmts onto 2D plane.
 - 2. Find clusters by TSpectrum Tool fitting.
 - Sometimes it finds too much clusters to match muon tracks.
 - Set maxFit 7 points currently.
 - 3. Check fit points.
 - E.g. Merge two point into one if too near...
 - 4. Re-reconstruct points manually.
 - Charge weighted around each fit point in a certain distance.
 - 5. Select the most possible track or parallel tracks
 - 1 track ~ 2, 3 points; 2 tracks ~4, 5 points; 3 tracks ~6, 7 points.
 - 6. Compare reconstruction and muon truth.



CD SPMT or LPMT project onto 2D panel



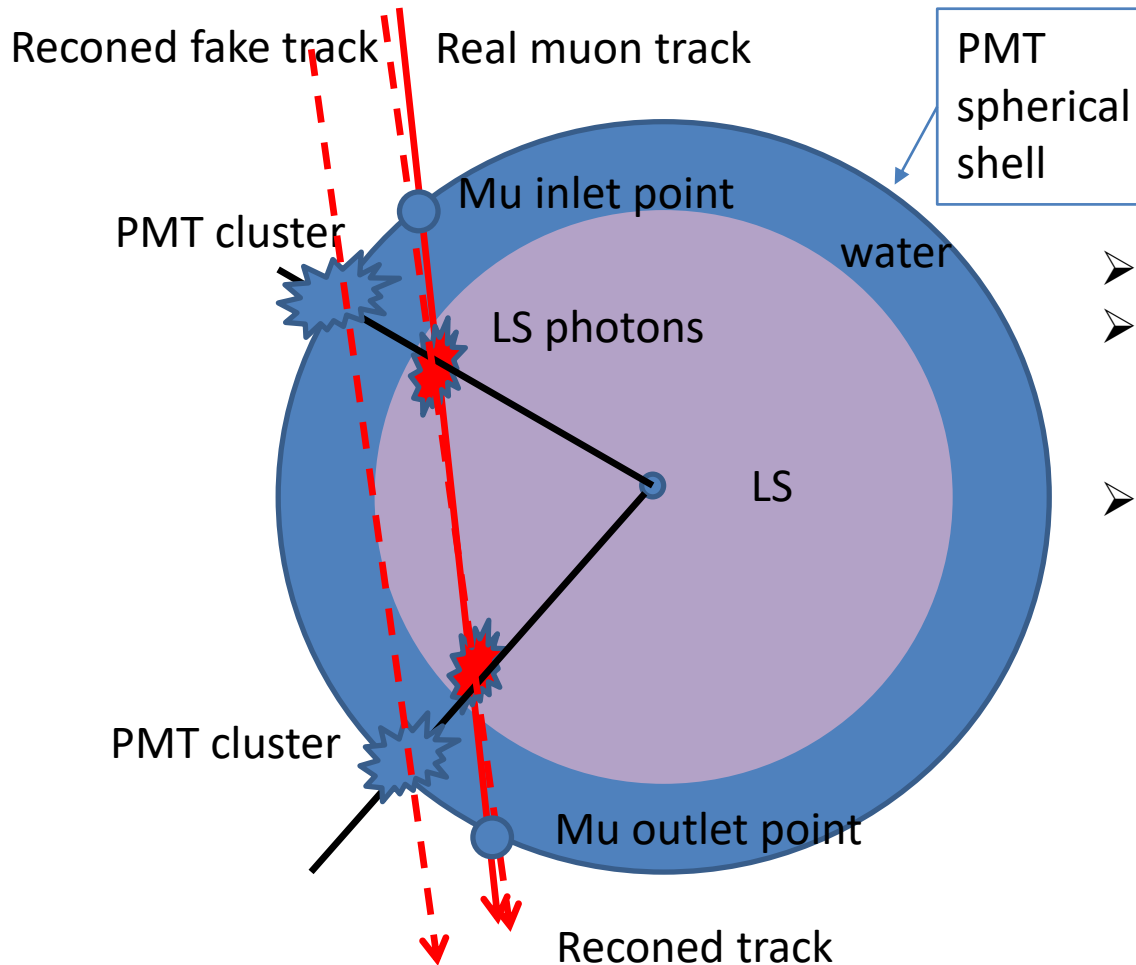
- 3D spmts project onto 2D (ϕ , θ).



Recon. correction for CD pmts



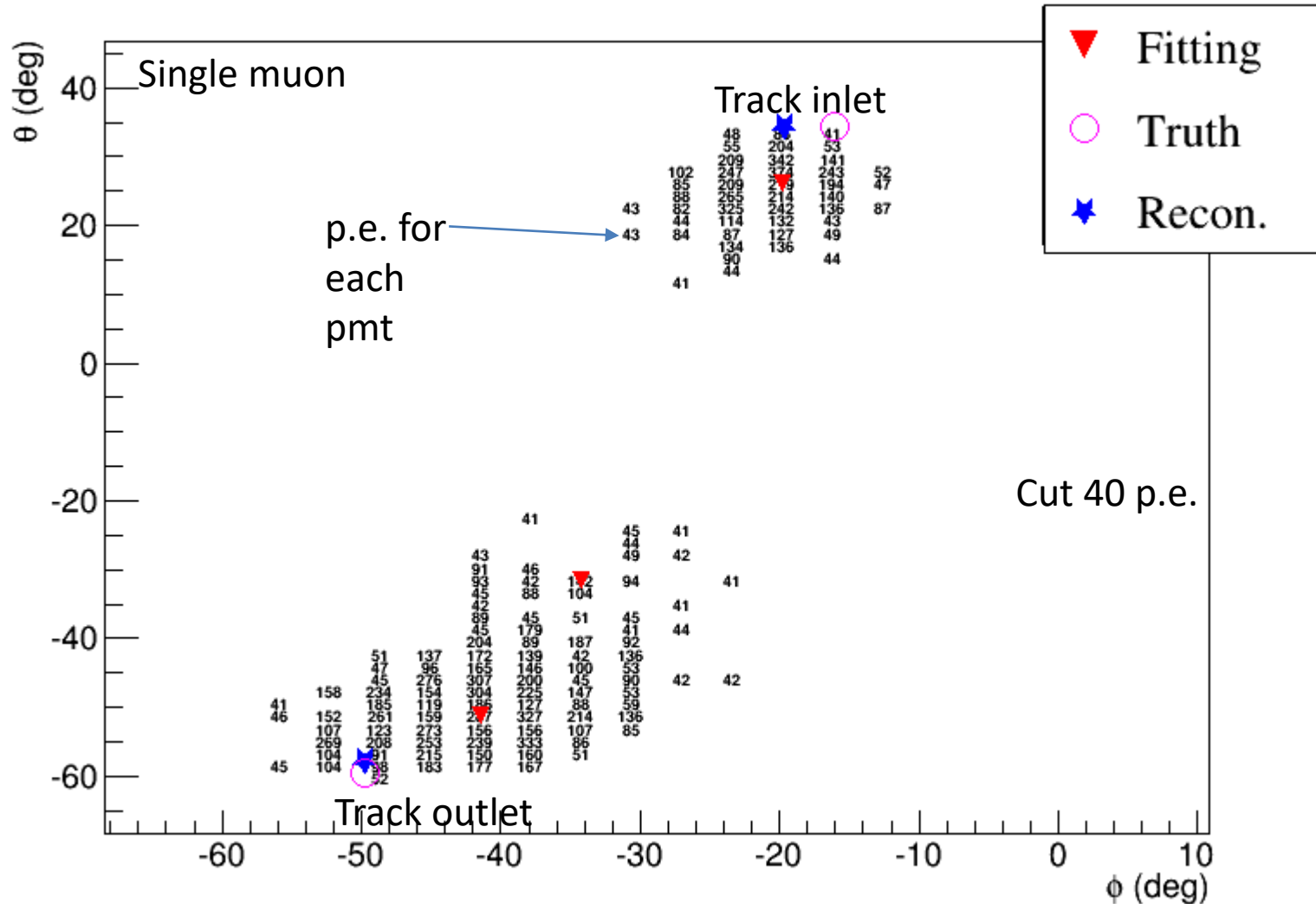
This is the main improvement from Doc1978



- Define PMT Spherical shell
- All reconstructed inlet and outlet positions (XYZ) are on this shell.
- Compare inlet and outlet points of reconstruction and truth. E.g. $\Delta X = X_{rec} - X_{truth}$.

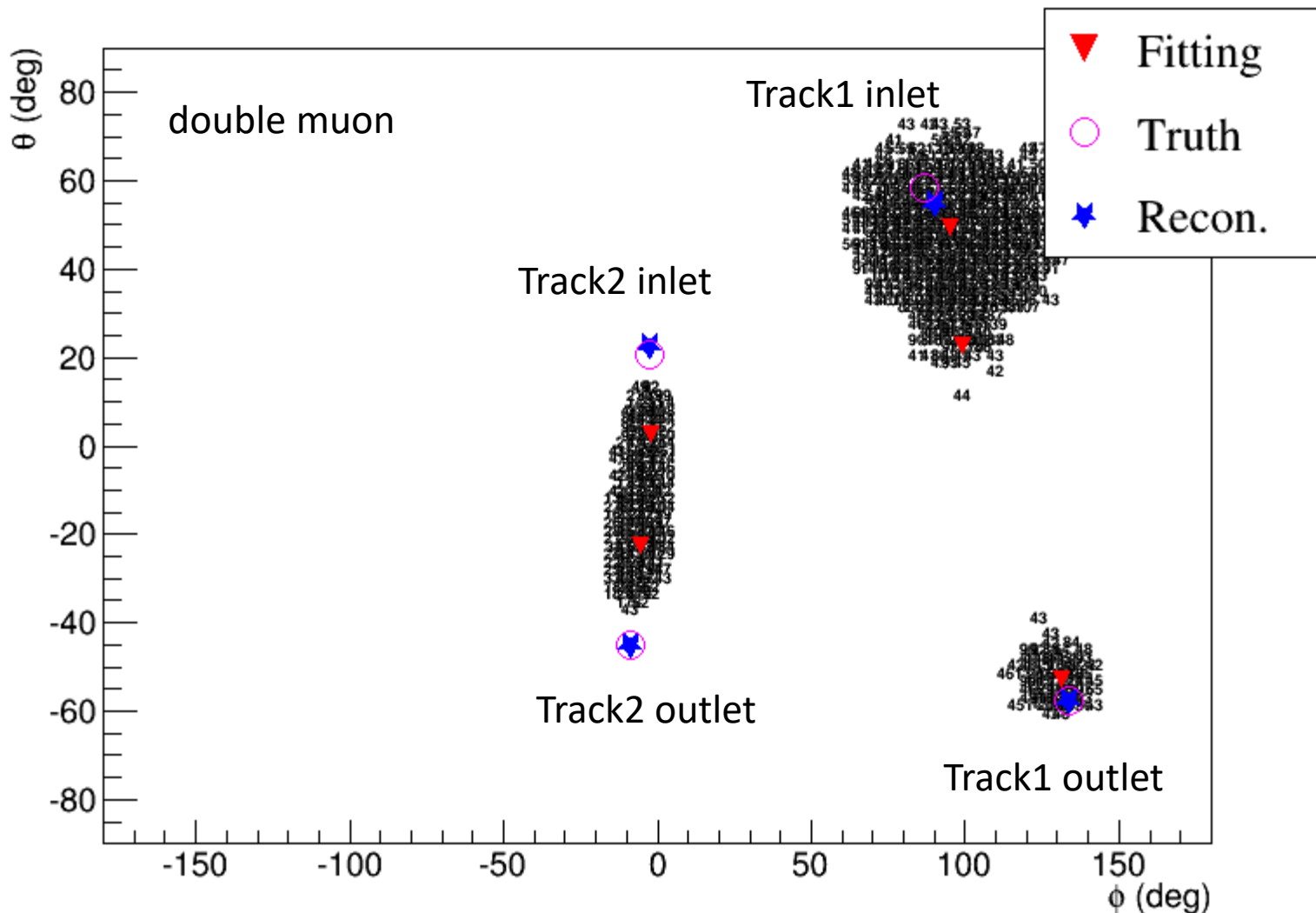


E.g. CD single mu clusters on (θ, ϕ)



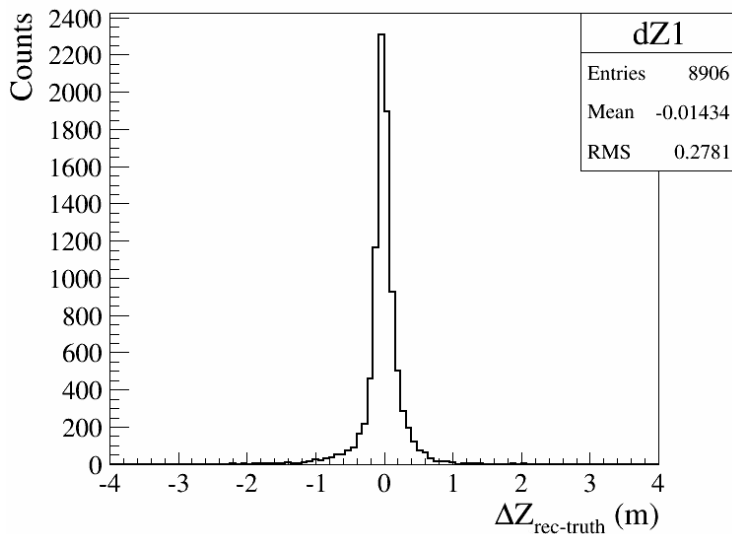
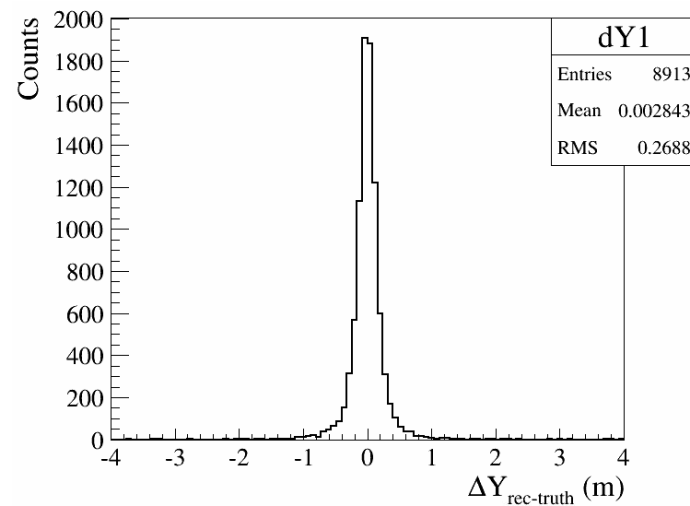
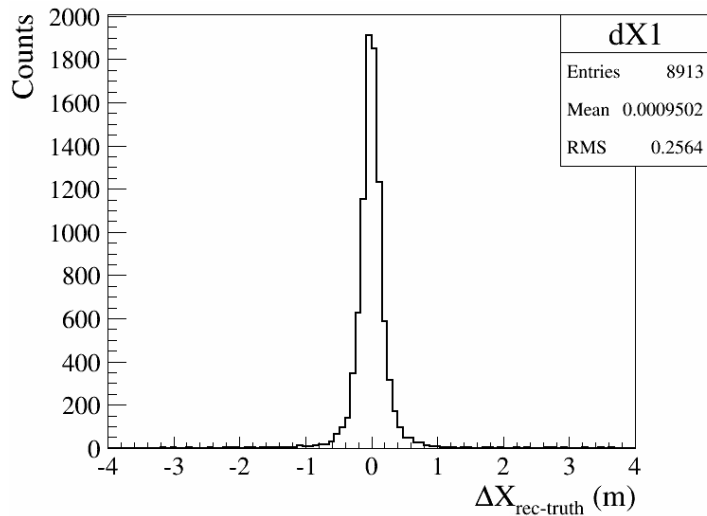


E.g. CD double mu clusters on (θ, ϕ)





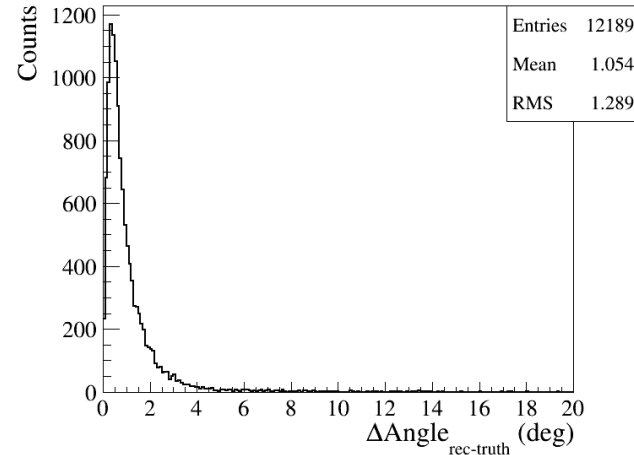
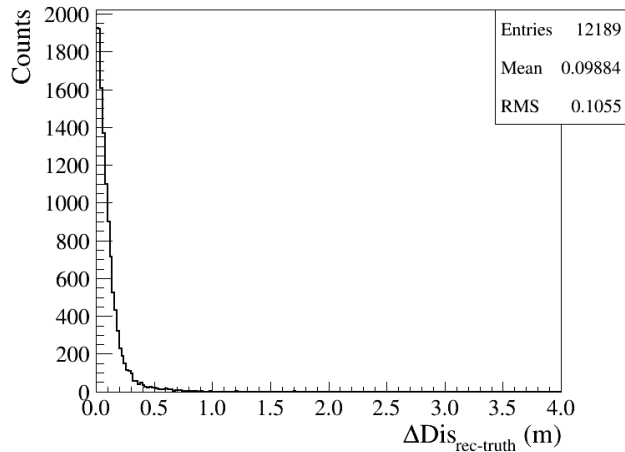
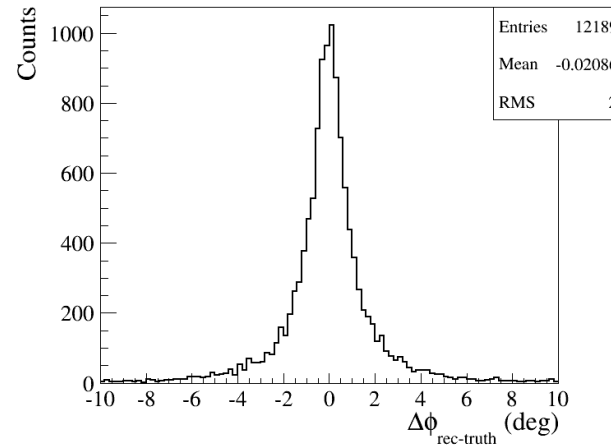
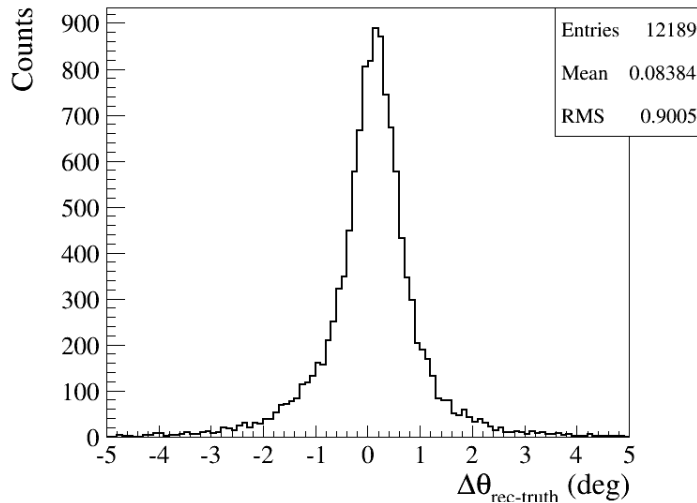
inject points



- Recon. Eff. = (reconed mu position in [-4,4]m)/(all mu tracks>0 in CD)
- **RMS ~0.26m** with reconstruction efficiency **95%** by Charge only of spmt.



Angle resolution

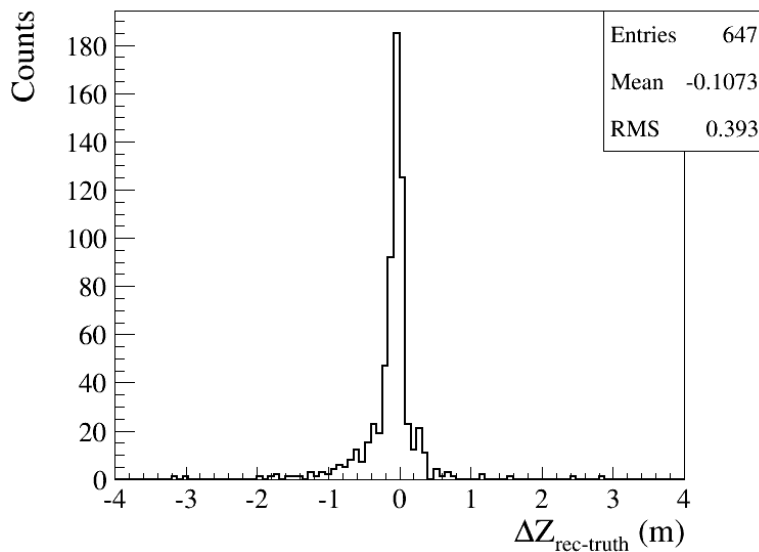
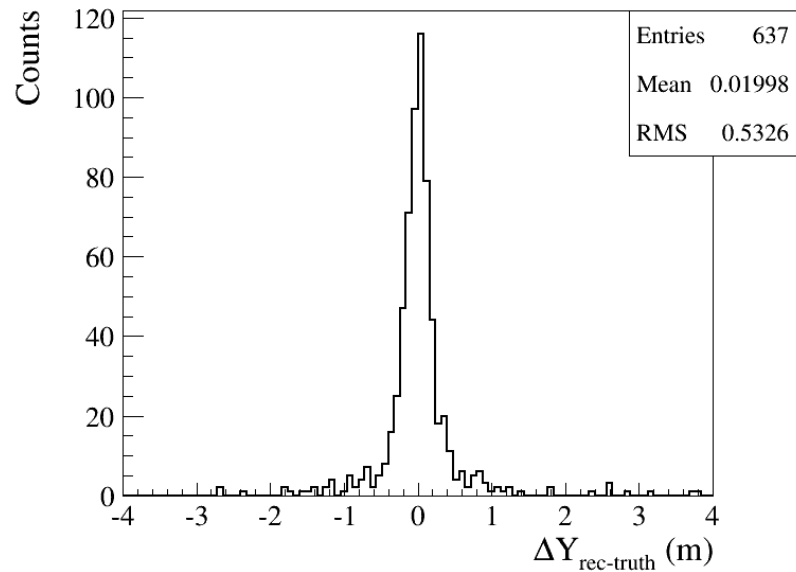
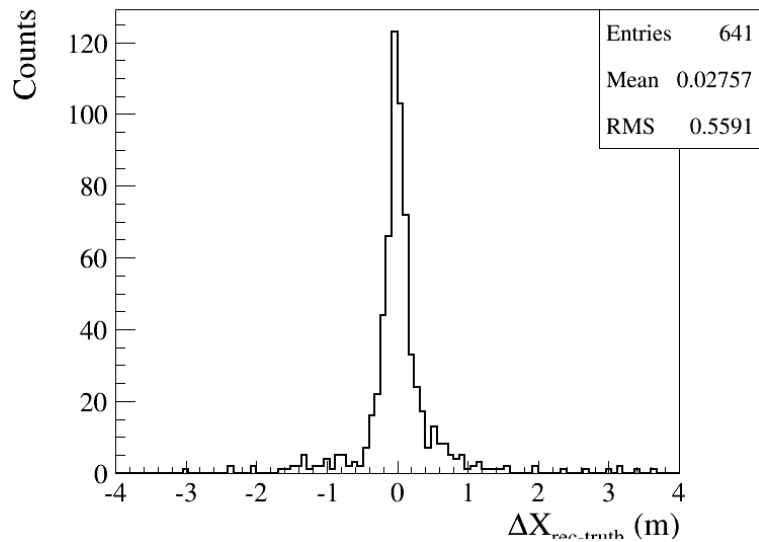


- Theta RMS ~ 1 deg, phi RMS ~ 2 degs
- Mean distance ~ 10 cm, mean angle ~ 1 deg.



Rec. of double muon

Inject points of track1



- RMS $\sim 0.55\text{m}$ with recon. eff. 72%.



Recon. Unefficiency seeking

Shower Cut: PE/cm<100

Distance Cut: dis2Center<16m

Single mu No stop	Event num	Rec stop	Rec N=1	Rec N=2	Rec N=3
HitLS	14020	9.5%	86.9%	3.1%	0.6%
Shower cut	11858	9.5%	89%	1.5%	0
Distance cut	11343	3.4%	92.2%	3.7%	0.7%
Both cuts	9395	3.3%	95%	1.7%	0

Bundle mu No stop	Event num	Rec Stop	Rec N=1	Rec N=2	Rec N=3
HitLS	989	1.2%	21.1%	67.8%	9.8%
Shower cut	795	0.9%	21.6%	72.3%	5.2%

- Single mu rec eff ~95%. Bundle mu ~72%.
- Reconstruction algorithm needs to be polished continually.



Stop muon recon.

- JUNO stop mu ratio in LS: $N_{\text{stopInLS}}/N_{\text{throughLS}} \sim 3.6\%$

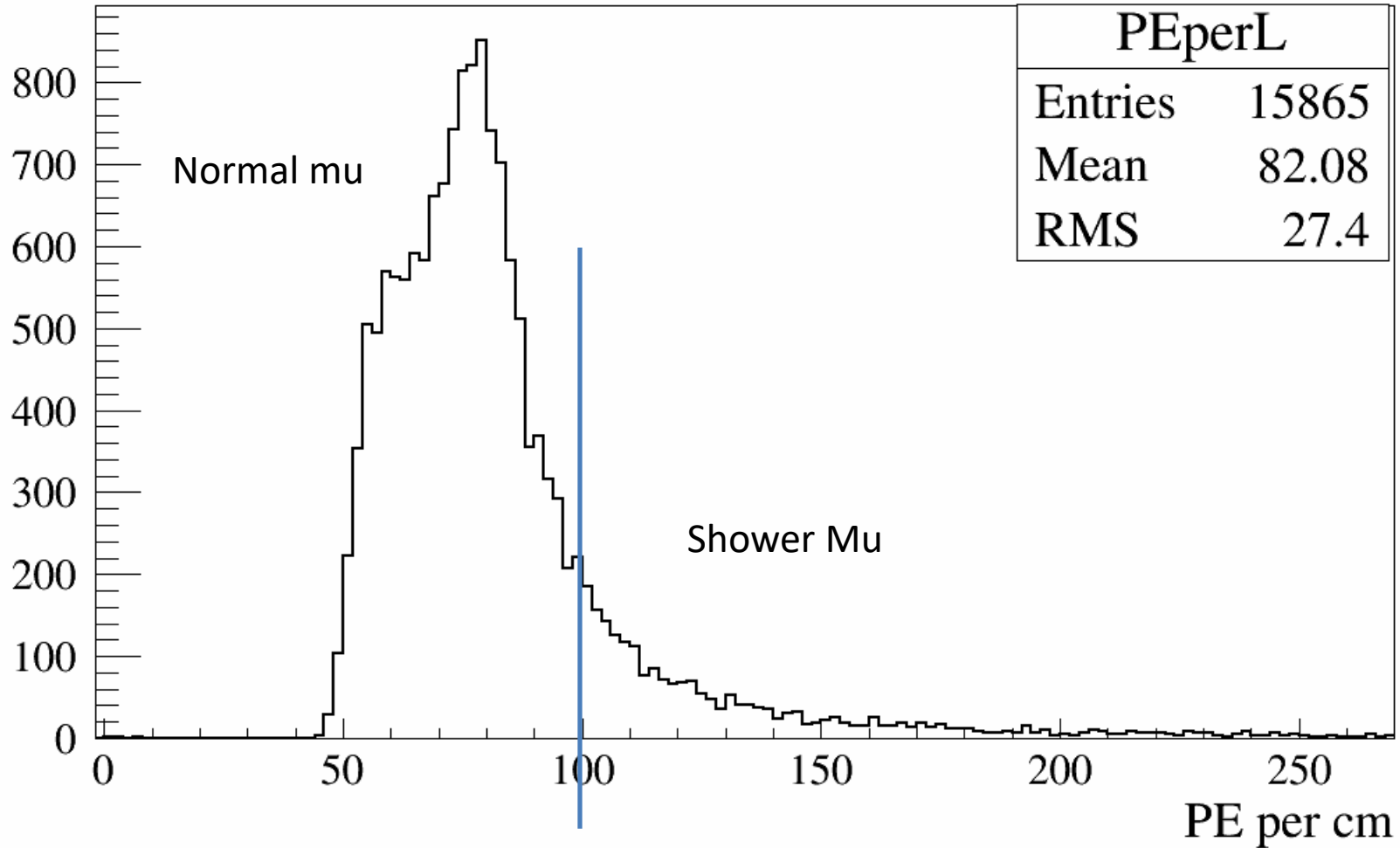
Stop	Edvent number	Rec stop	Rec 1 track	Rec 2 tracks	Rec 3 tracks
Stop in LS	465	91.2%	8.8%	0	0
dis2Center<16	433	93.1%	6.9%	0	0

Stop mu reconstructed efficiency can reach 93%.

Even some events were reconstructed into single mu but they are edge mu, which also can effectively discard He9/Li8.



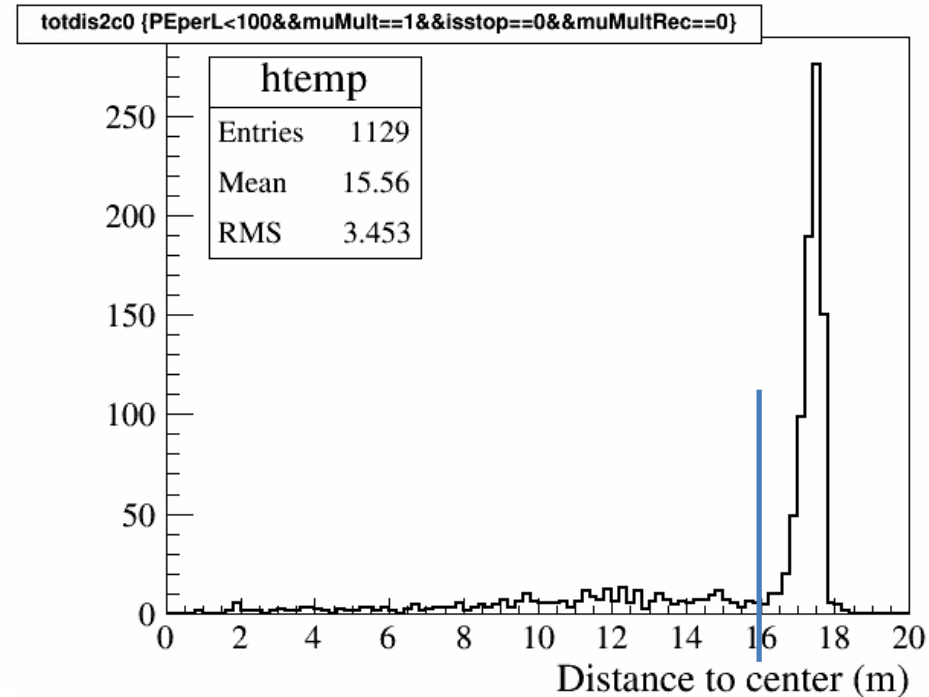
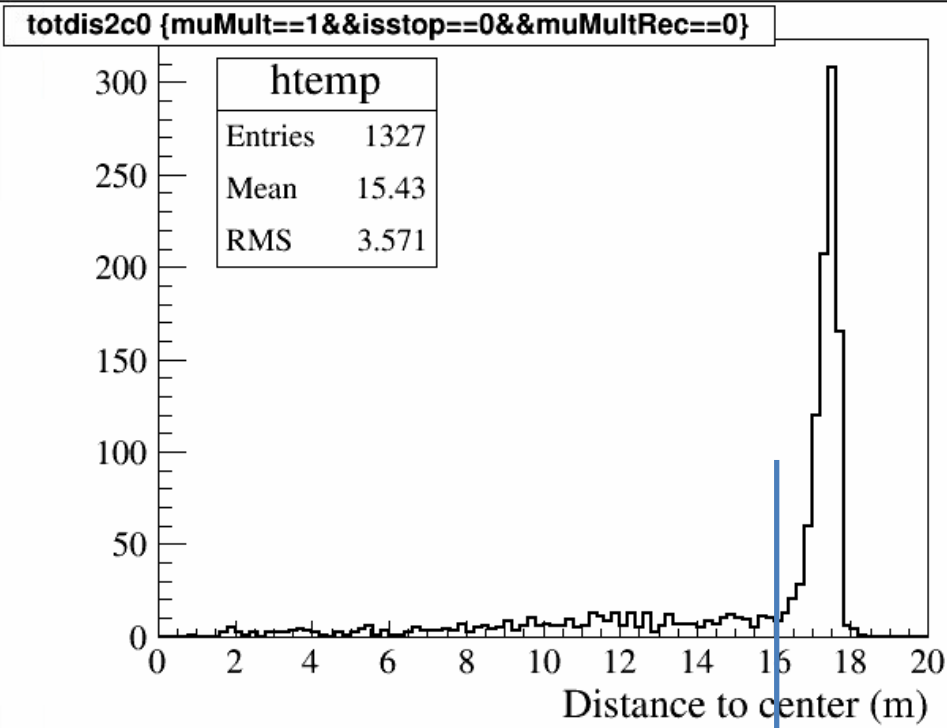
Spmt PE per cm





Truth single track -> rec. stop muon

- Most of them are edge muons.

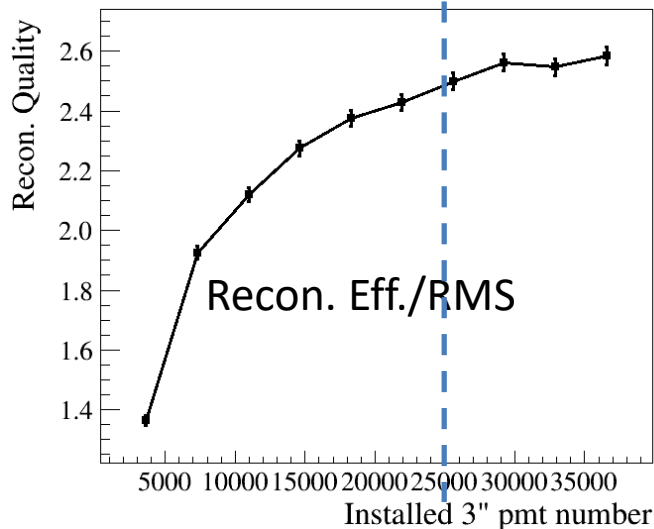
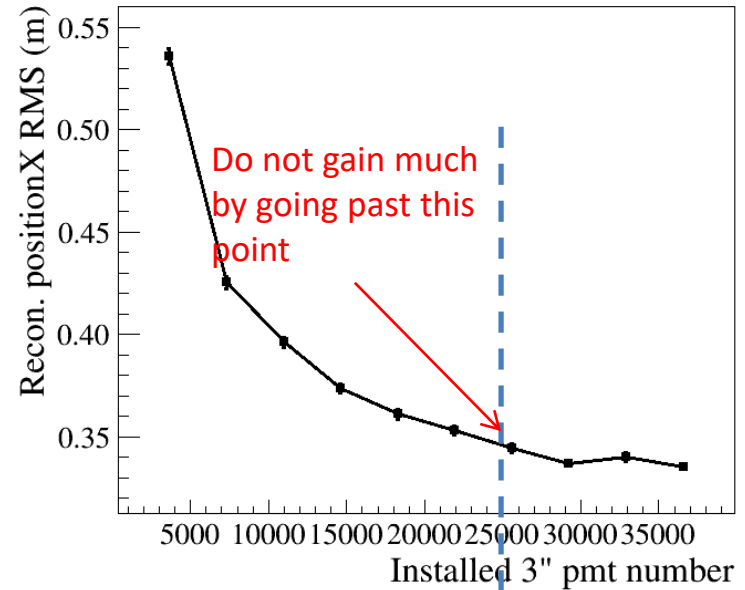
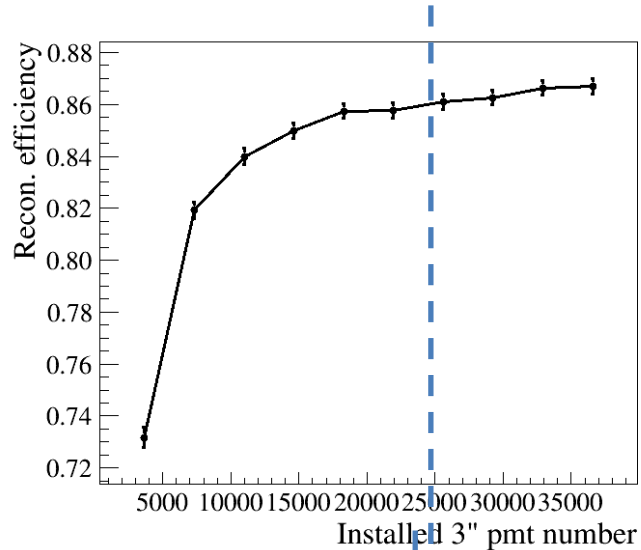




Spmt number impact on mu recon.



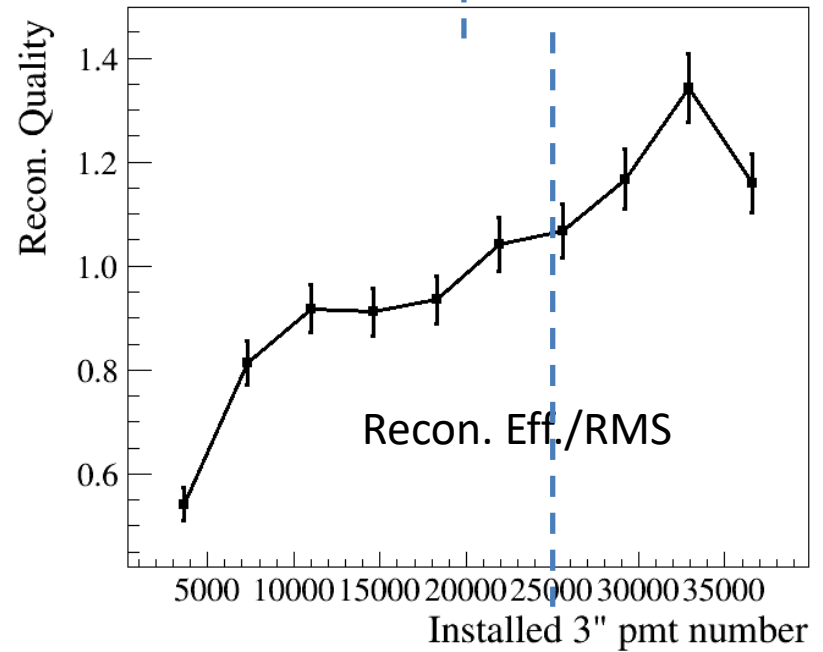
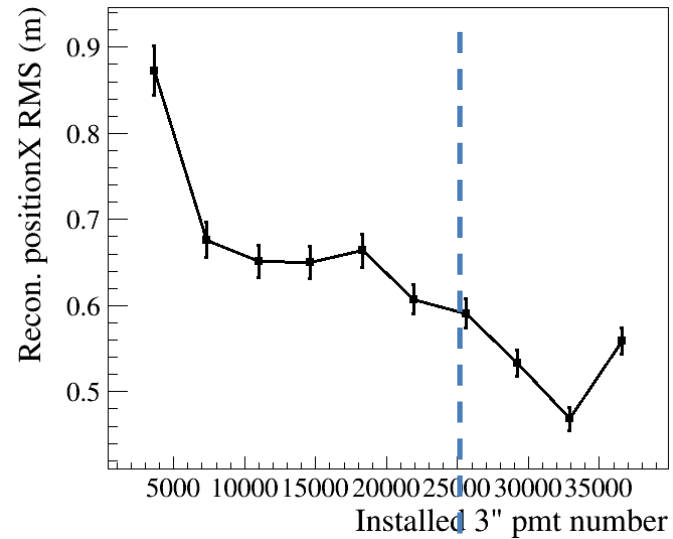
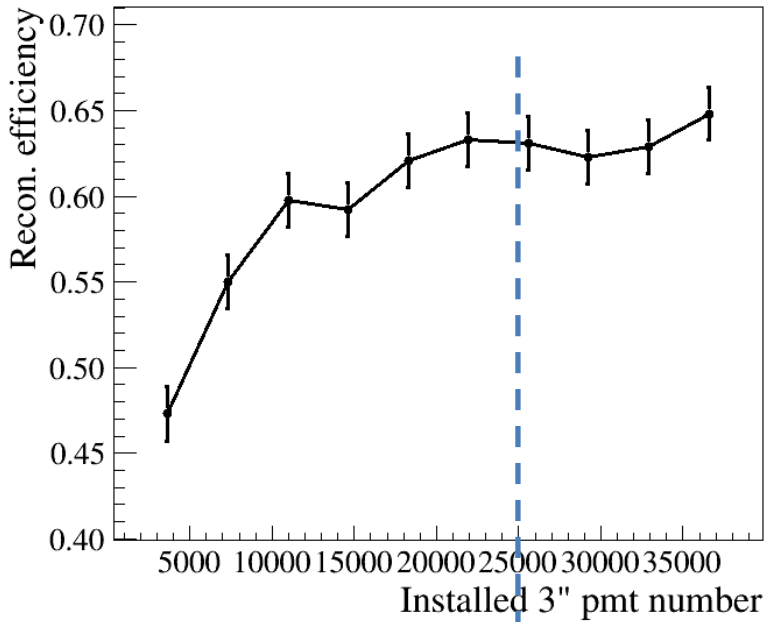
- Randomly mute spmt number in analysis.



- Efficiency is largely insensitive to N_{SPMTS} after crossing a certain threshold (20k).
- RMS also not decrease much after 20k pmts.
- Recon Quality increase slowly after 20k pmts.



Spmt number influence on double-mu recon.



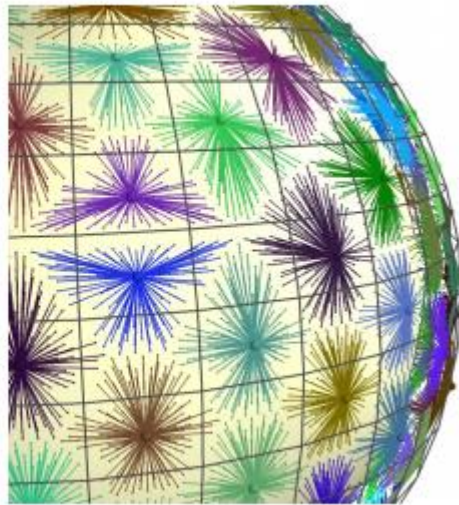
- Efficiency stable after a certain threshold.
- If no enough spmts, maybe **install >20k spmts** is OK for muon bundle reconstruction.



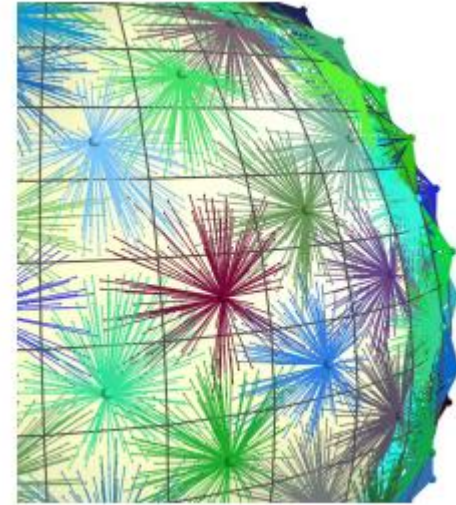
UWB broken impact on reconstruction

- UWB-map get from Yury
- Total 212 UWBs
- “Nearest” option: 24952 pmts
- “Overlap” option: 24684 pmts

nearest



Overlap

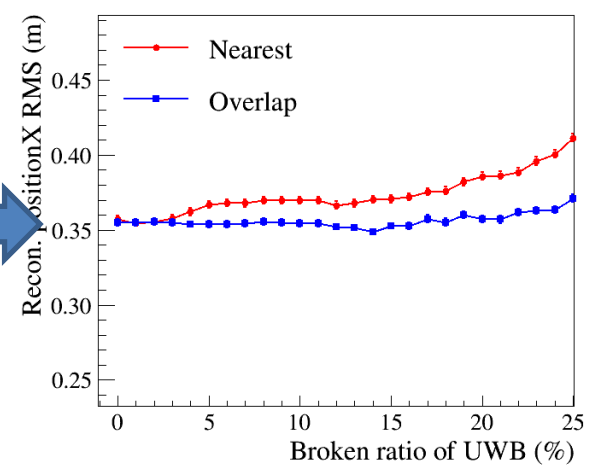
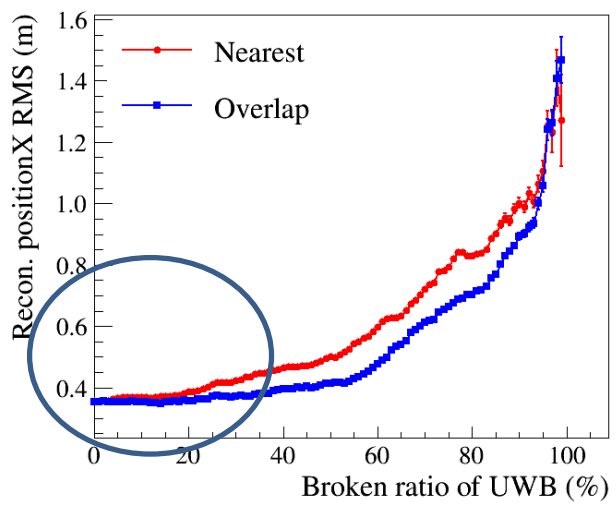
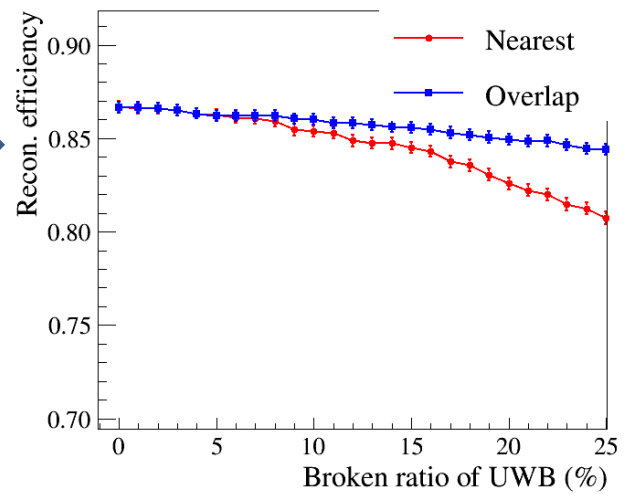
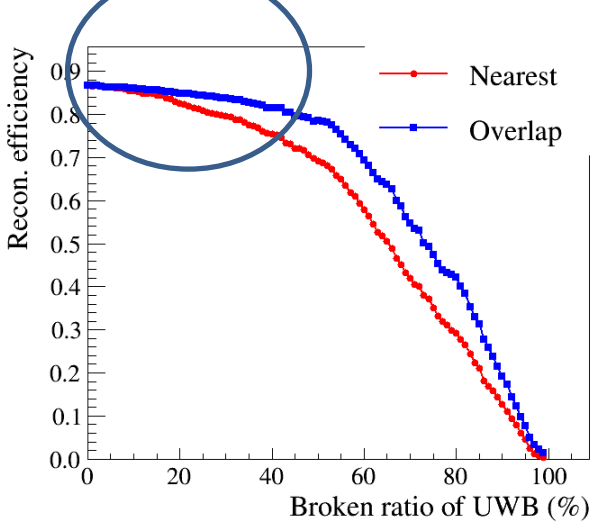


- Randomly broken UWBs in simulation, 1%, 2%, ...



UWB broken impact on recon. (1)

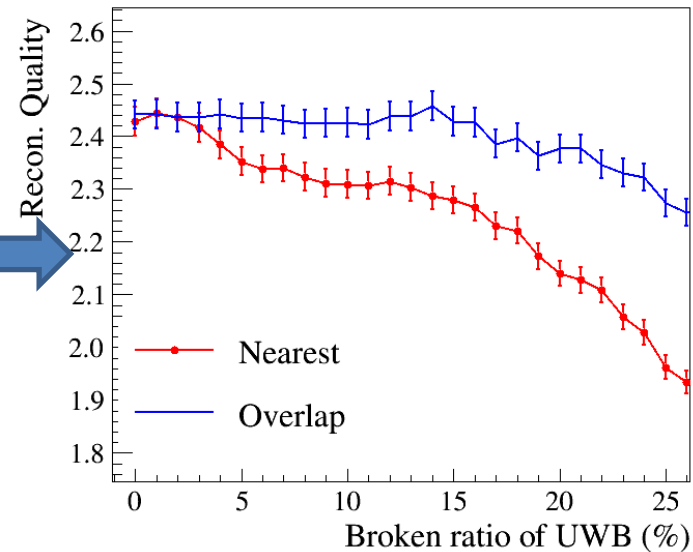
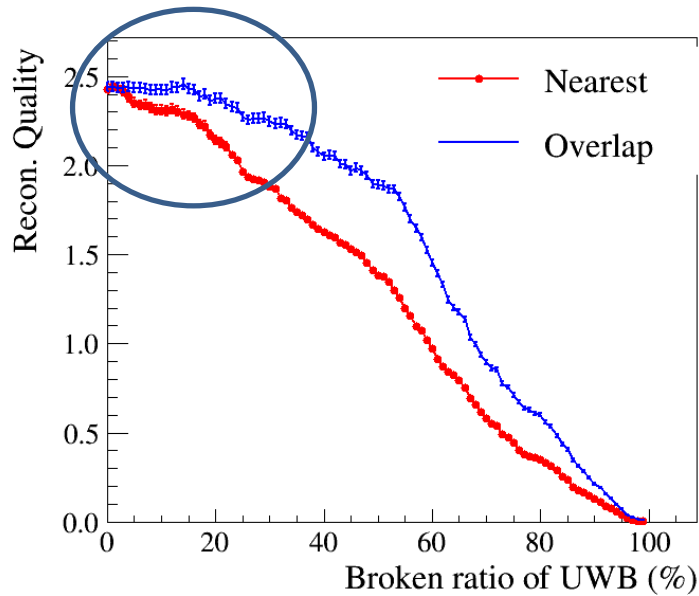
- Single mu





Reconstruction Quality factor

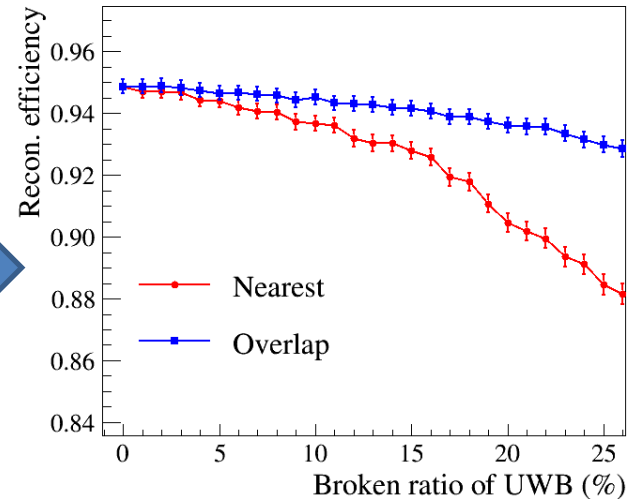
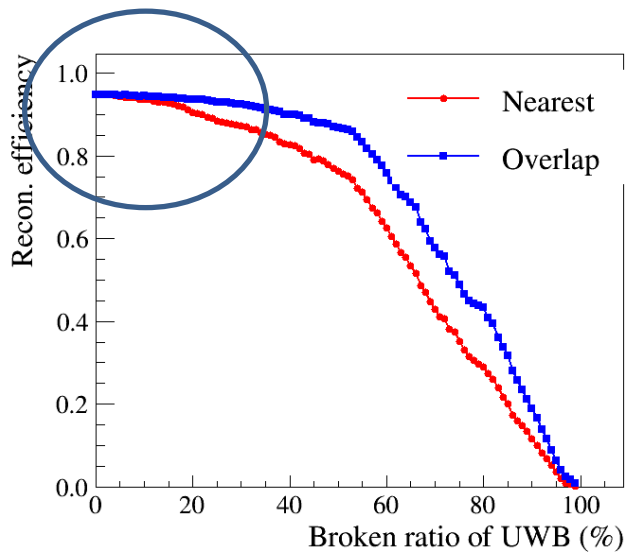
- $Q_f = \text{Eff}_{\text{rec}} / \text{RMS}_{\text{rec}}$

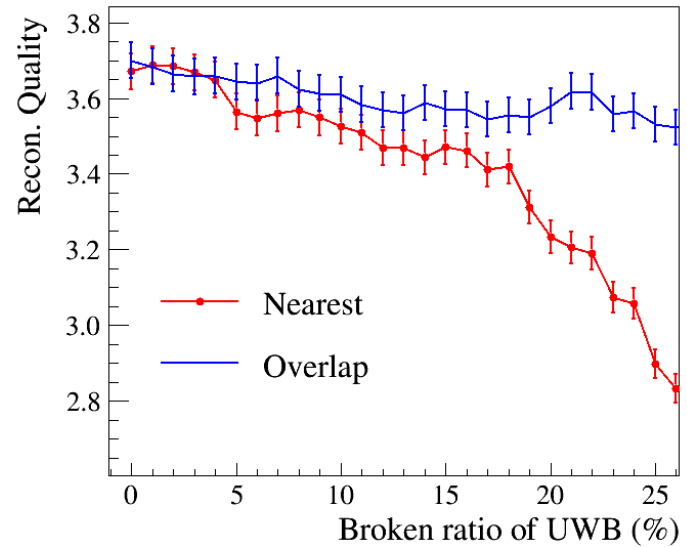
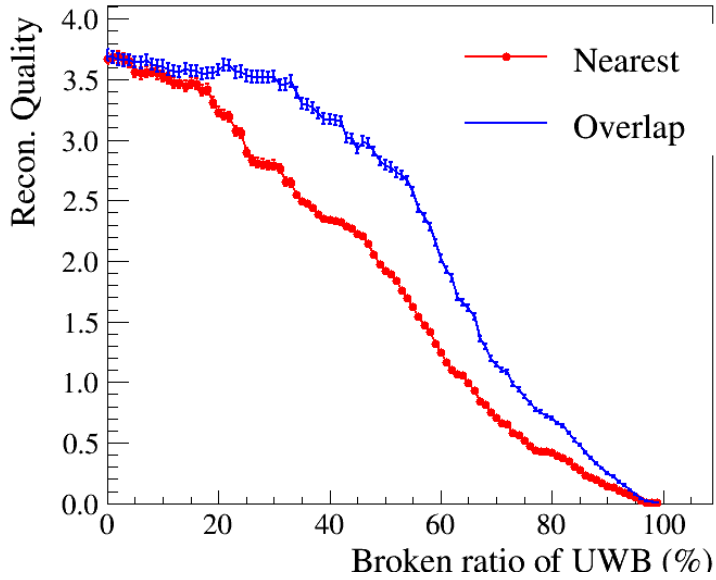
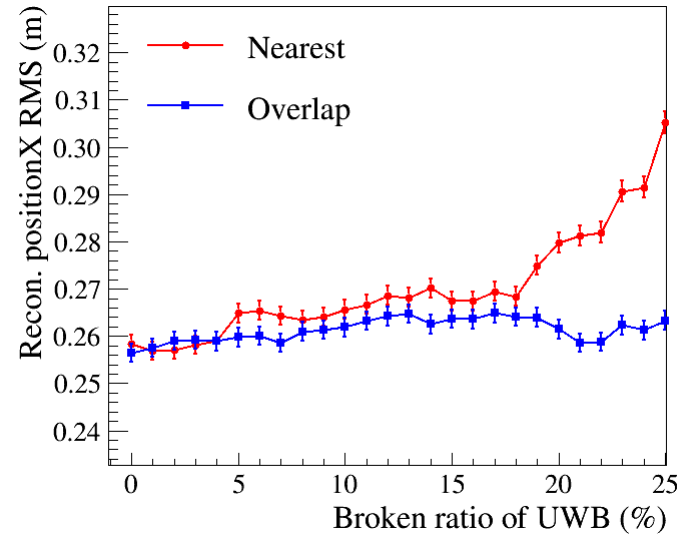
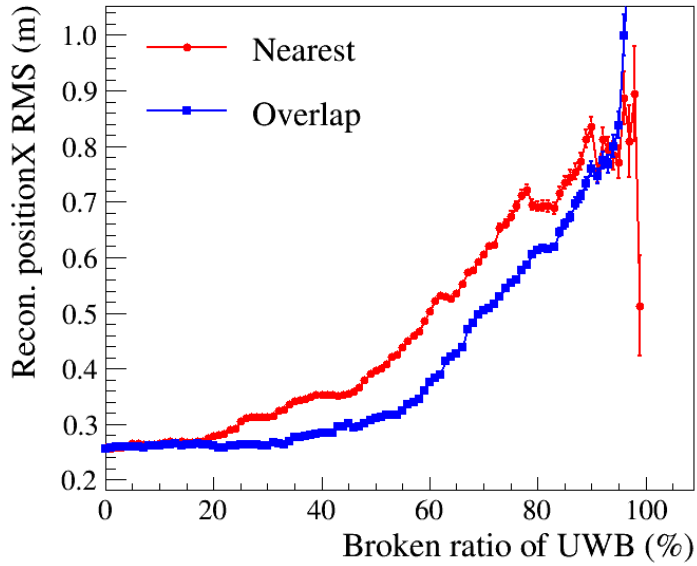
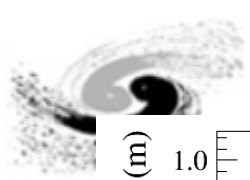




UWB broken impact on recon. (2)

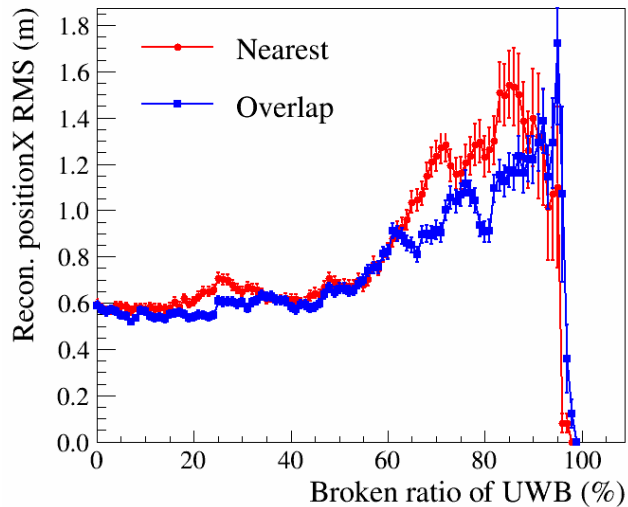
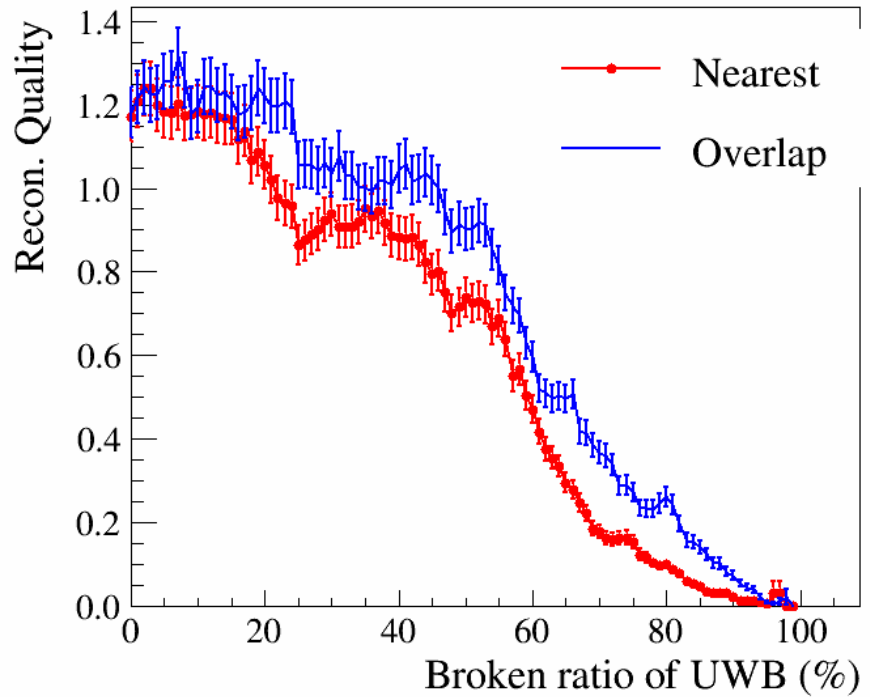
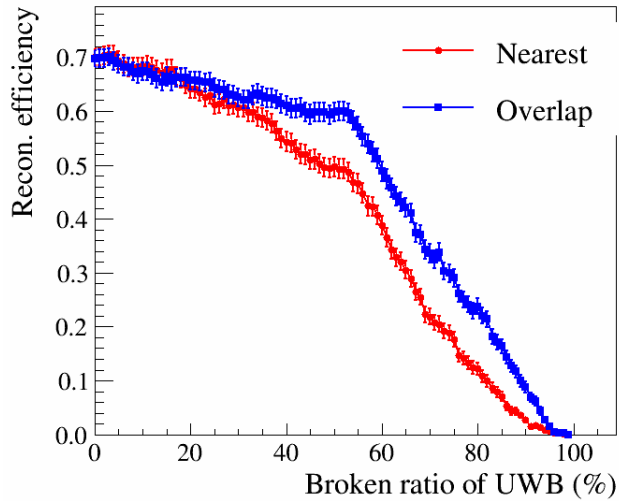
- Single mu, discard distance to center >16m and shower mu ($\text{pe/cm} > 100$ for spmt)





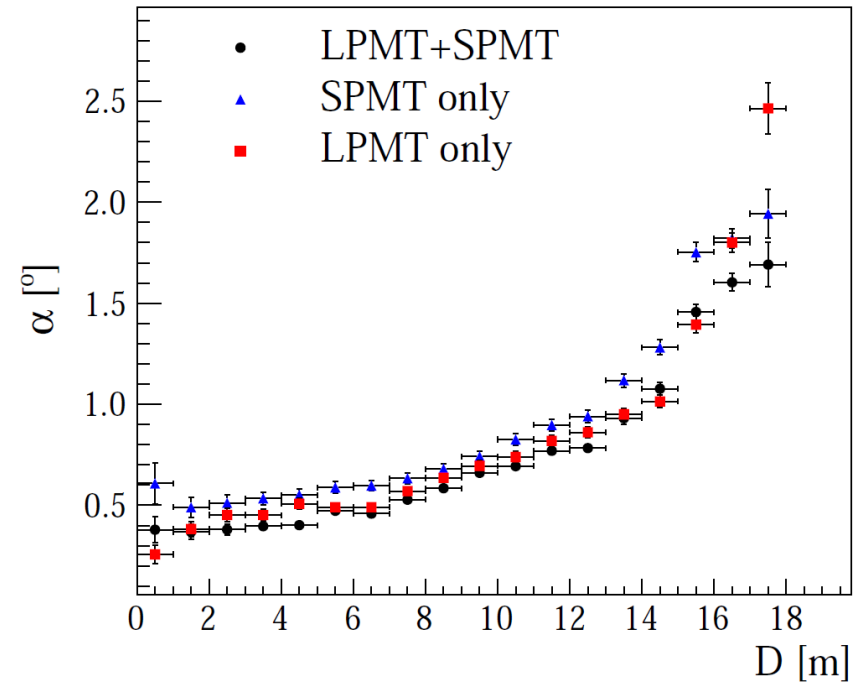
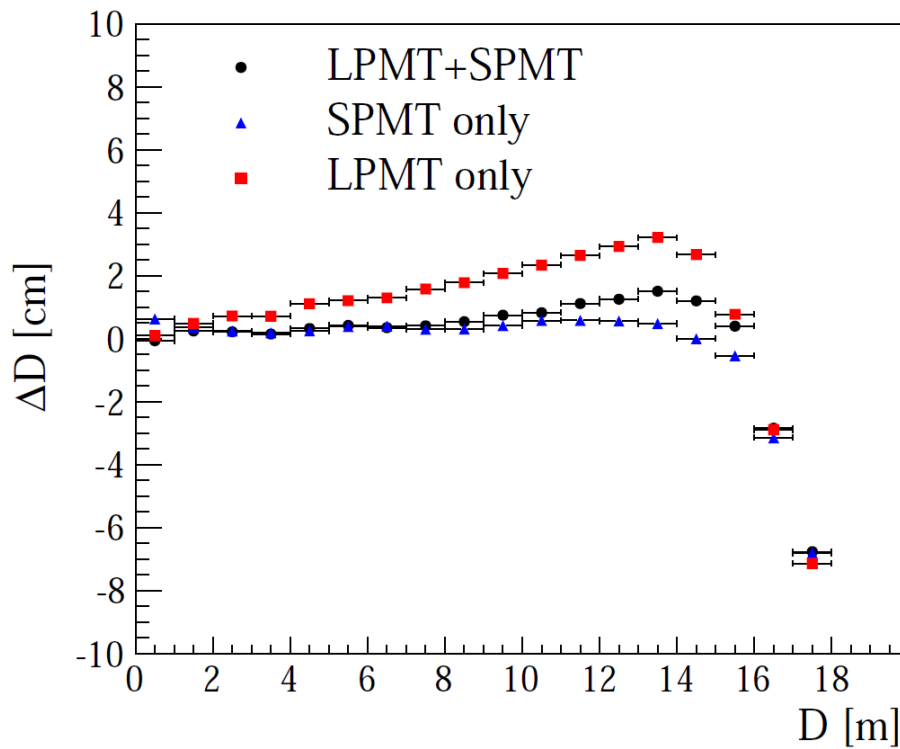


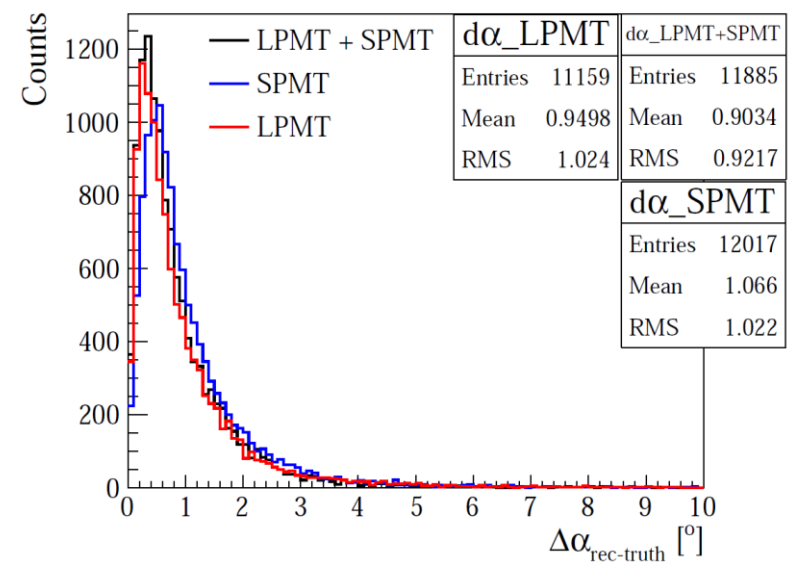
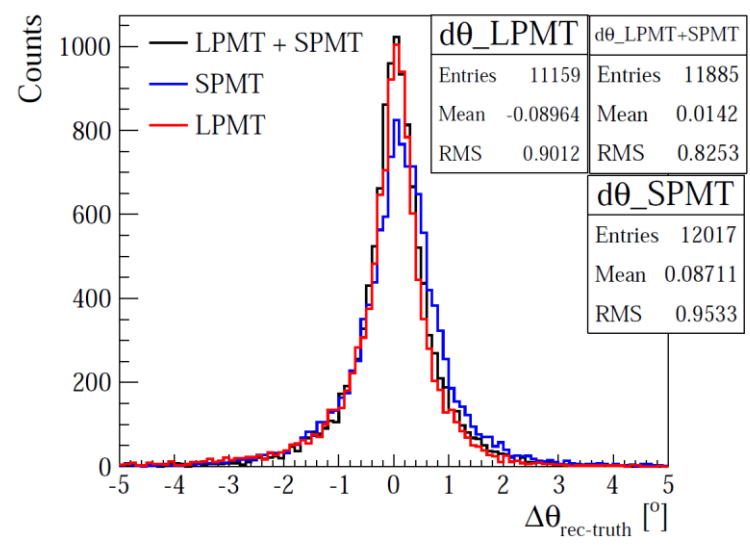
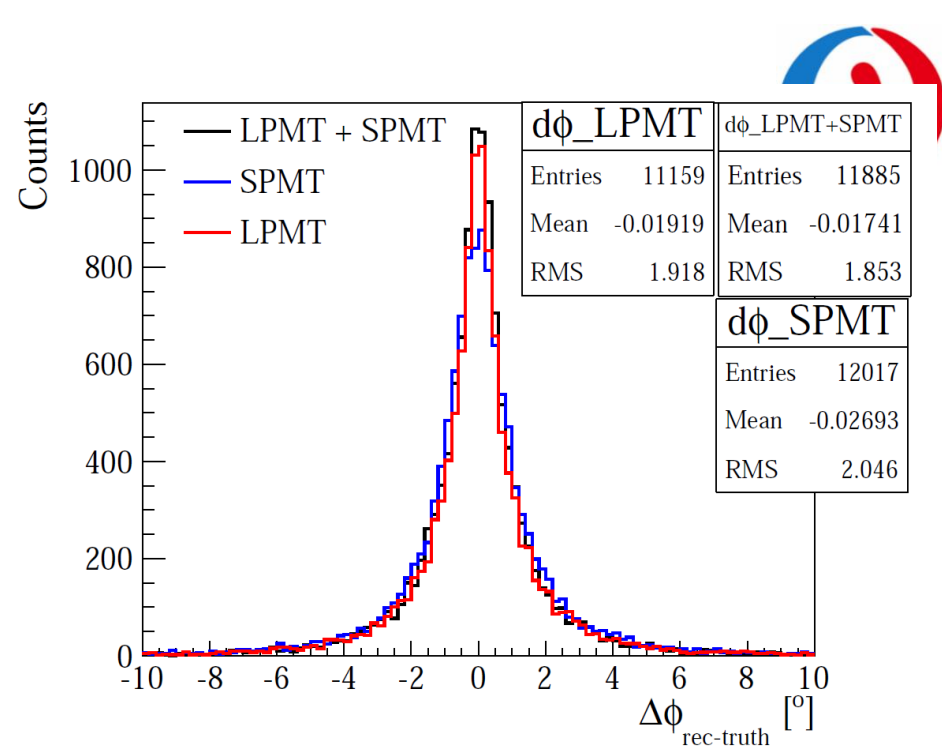
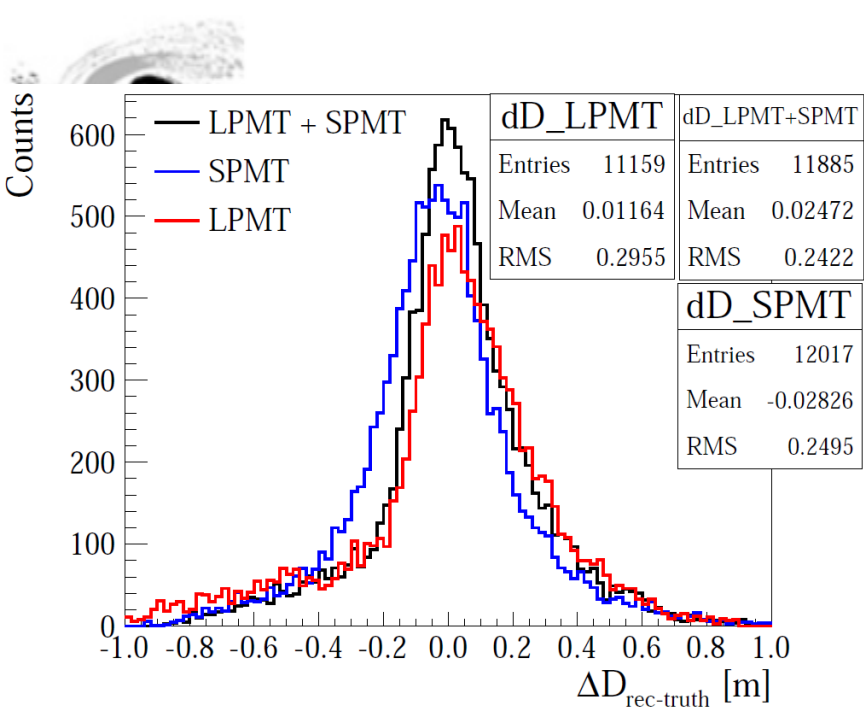
Double mu





Comparison







Tuning dependent for real data analysis

- In reconstruction, the parameters of N_{pmt} and N_{pe} cutting will be used.
- For real data in the future, calibration data or other detector data are needed to tune, like using TT data to do calibration and tune the parameters to make the reconstruction algorithm working at the best point.



Summary

- ROOT “Tspectrum” can be used for both single and bundle muon track reconstruction. Method based on charge is available on JUNO software.
- The current reconstruction position resolution is 0.26m with eff. 95% for all single muons by spmt, 0.5m for double muon with eff 72%. Eff. 93% for stop mu.
- UWB broken in 5% (10), two option will not influence recon result. >5% broken will obviously difference, overlap will give better performance.
- The algorithm needs to be polished to improve the resolution and reconstruct efficiency.



THANKS!



All muons plots with spmt

