Atm Neutrino OEC (Online Event Classification) update report

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EU JUNO Collaboration meeting
2023-05-11

Background

Keypoint of OEC

- Saving T/Q pairs for all triggered events by default
- Waveforms according storage strategy may be removed/compressed

For high energy events:

- Atmospheric neutrinos can improve JUNO's sensitivity to the mass ordering, it’s useful to keep atmo neutrinos waveform.
- Muon’s rate is about 4Hz, If save all muon waveforms , the data transmission is 217 MB/s, while the aim is to 60MB/s.

Goal : to correctly classify atmospheric neutrinos with OEC

Here we study :

- **Part 1: How to reduce the muon as much as possible (to ~ the same level as signal), keeping high signal (from atm ν events) selection efficiency**

- **Part 2 : In case of atm ν signal, how to select only the first readout and remove the secondary readout**

Muon detsim: root://junoeos01.ihep.ac.cn//eos/juno/dirac/juno/production/muon/muon_202201/prd***

Atmospheric neutrinos generator:
/storage/gpfs_data/juno/junofs/users/sgiulio/Atmo/GENIE/V3_00_06/gstroot/root/atmo_numu_nue_LS_0-30GeV_20-12_10M.gst.root

Software version : studies based on J22.2-rc2

Part 1 : Reduce the muon contamination

- **How to identify a muon?**

  Muons : will first trigger the water pool (WP) or top tracker (TT)

  Partly contained (PC) atm neutrinos (that can be used for physics) will trigger CD first

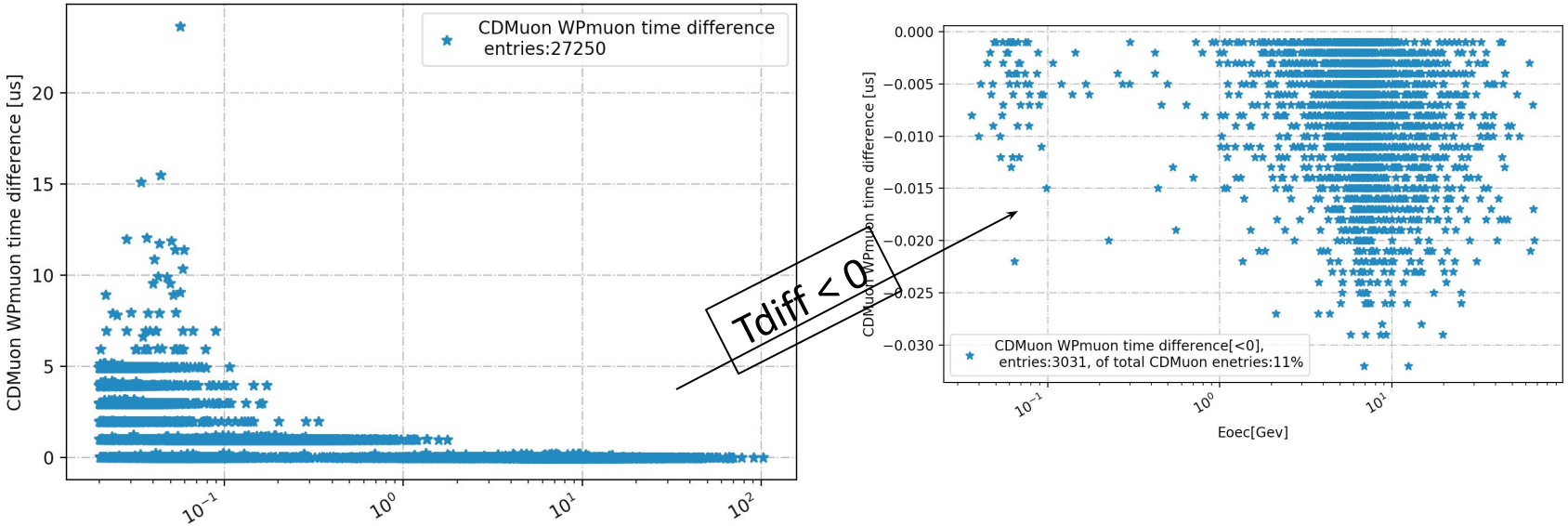
Muon events - CDTrigger/WPTrigger time diff VS Eoec(CD)

OEC's default selection >20 MeV: 27250 CD trigger

Muno's WP trigger time and CD trigger time:

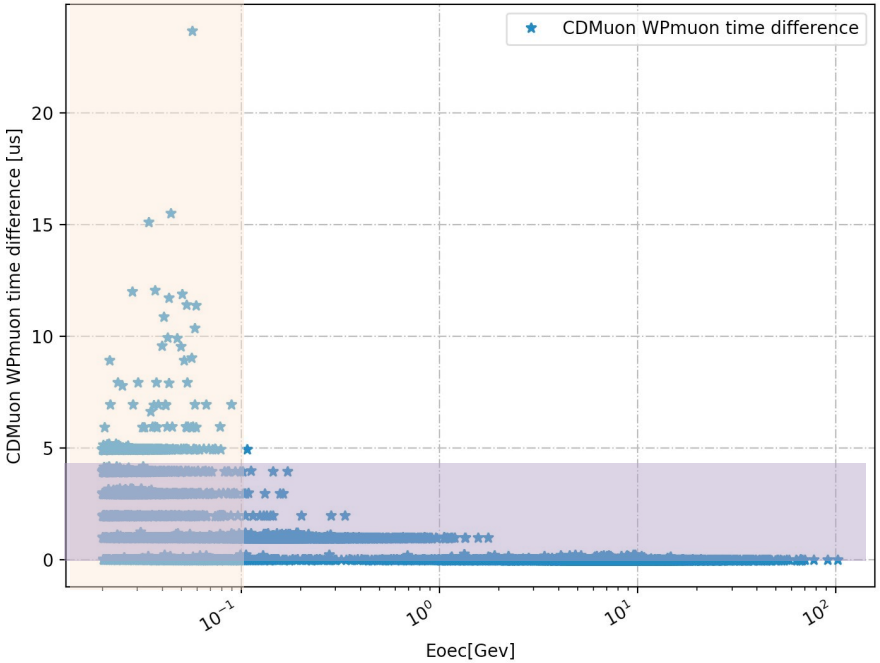
- 89% WP trigger time early than secondary CD trigger time, 11% reverse, the minimum time difference is 32ns.

-> veto time: [-32 ns, X us] after WP Muon is used to remove muon events.



Muon events:

- Muon is vetoed by WP or TT, remove secondary events by time window around it
- Energy cut removes lots of secondary entries which is far to primary WP Muon
- Time veto removes the high energy secondary readout tagged as CD Muon



- 80567 CD trigger

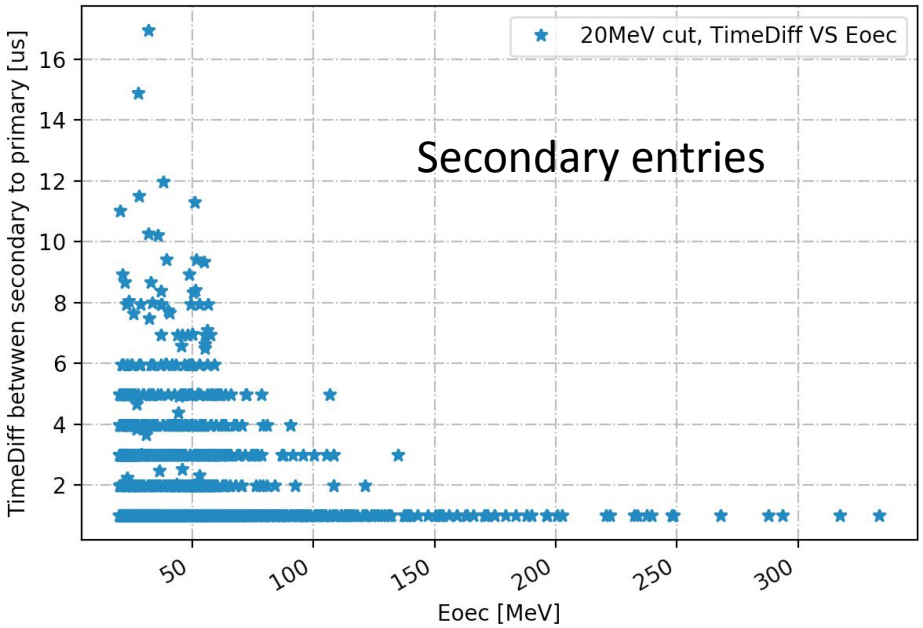
time / energy	20 MeV		100 MeV	
	entries	rate	entries	rate
none	27250	33.8%	13935	17.3%
veto 1us	12041	14.9%	1249	1.55%
veto 2us	9075	11.3%	11	1.37E-04
veto 3us	3994	4.7%	5	6.21E-05
veto 4us	1998	2.5%	1	1.24E-05
veto 5us	70	0.09%	0	0.00E+00

Part 2 : Keep atom’s first readout - remove secondaries

- Keep only the first readout (primary lepton):
    - Secondary triggers dominated by AP have less energy -> energy cut
    - Secondary triggers: time window veto around the primary

Atmo events: selection of first readout efficiency and loss after cuts

- 2k Atmo true events, 1495 primary +1886 secondary Atmo entries.
- Secondary entries focus on the combined area of E < 100 MeV and Tdiff < 1 us



- 20642 CD trigger, Secondary entries and ratio

selection	20MeV		100MeV	
	entries	ratio	entries	ratio
none	1495	7.24%	116	0.56%
veto 1us	632	3.06%	7	0.03%

Atmo events: primary CC/NC ratio

- 2k atmo events, 69.5% CC event, 30.5% NC event. 11% PC event, 89% FC events.
- For FC events, they sometimes also produce WP triggers, using the same strategy of muon, the atmo efficiency is calculated (NB: limited statistics sample)

Cut E	Tagged						Lost				
	total-eff		CC-eff		NC-eff		loss	CC-lost		NC-lost	
20MeV	1886	94.3%	1391	100%	495	81.3%	5.7%	0	0%	114	18.7%
100MeV	1717	85.9%	1366	98.2%	351	57.6%	14.1%	25	1.8%	258	42.4%
100MeV +WP	1571	78.5%	1230	88.4%	341	56.0%	21.5%	161	11.6%	268	44.0%

From OEC's default selection: 20 MeV to 100 MeV + WP trigger:

- tagged events ratio goes from 94.3% (20MeV default) to 78.5% (after our cuts)
- High efficiency for charge current (CC) events: 88.4% are tagged.

$$total\ efficiency = \frac{first\ readout\ tagged\ as\ CDMuon}{ture\ totall\ number\ of\ atmo}$$

$$CC\ efficiency = \frac{first\ readout\ tagged\ as\ CDMuon: CC}{ture\ totall\ number\ of\ atmo: CC}$$

Summary

Applying Energy cut and time veto

- To remove muon and its secondary events, 100 MeV cut and [-32 ns, 4 us] time veto after WP trigger are used.

  The remaining contamination going down to: 1.24E-05.
- When applying same cuts to atmospheric neutrinos, and 1us time after primary atmo:

  The remaining rate of secondary triggers is: 0.03%

  High efficiency for charge current (CC) events: 88.4% are tagged.

backup

By checking the pz of 2k neutrinos:

- 1044 upgoing atmo 52.2%
- 956 downgoing atmo 47.8%

1886 Atmo events from OEC selection(>20MeV)

- 972 upgoing atmo, efficiency: 93.1%
- 914 downgoing atmo, efficiency:95.6%

1717 Atmo events from custom selection(>100MeV)

- 874 upgoing atmo, efficiency: 83.7%
- 843 downgoing atmo, efficiency:88.17%

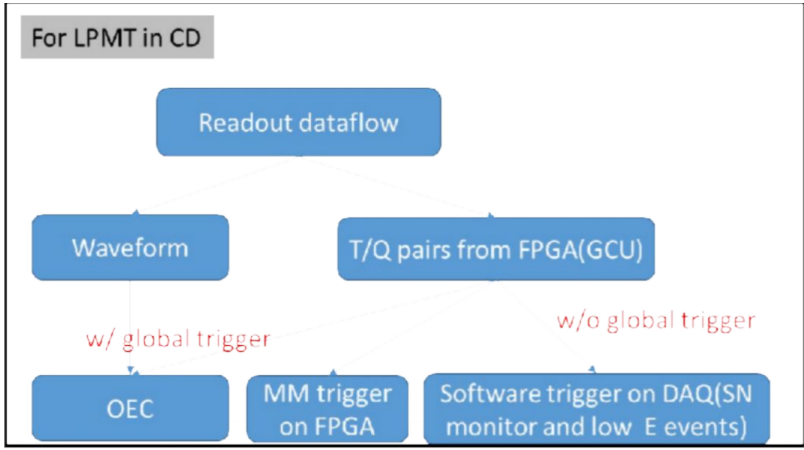
1571 Atmo events from custom selection(>100MeV+strategy)

- 808 upgoing atmo, efficiency: 77.4%
- 763 downgoing atmo, efficiency:79.8%

Overview：from Maxim，JUNOdocdb：9884

- Function of OEC

✓ OEC will be implemented on DAQ
✓ Converts the 40.7 GB/s data stream with full waveform (@1kHz) to the about 60 MB/s
✓ Classify event based on physical characteristics and determine waveform storage strategy



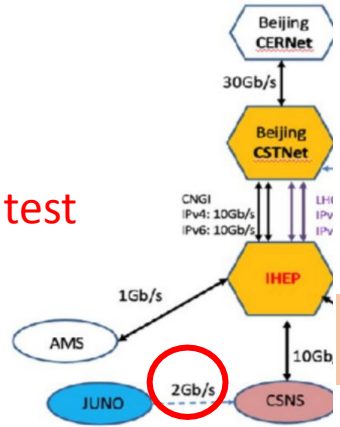
- Key point

Doc-6670, Doc-6672, Doc-6689, Doc-7338, Doc-7342, Doc-4892

✓ Saving T/Q pairs for all triggered events by default
✓ Waveforms according storage strategy may be removed/compressed

- The OEC software is ready to deal with the real data, and the test shows well stability and reliability.

✓ OEC software implement during commissioning period is ongoing

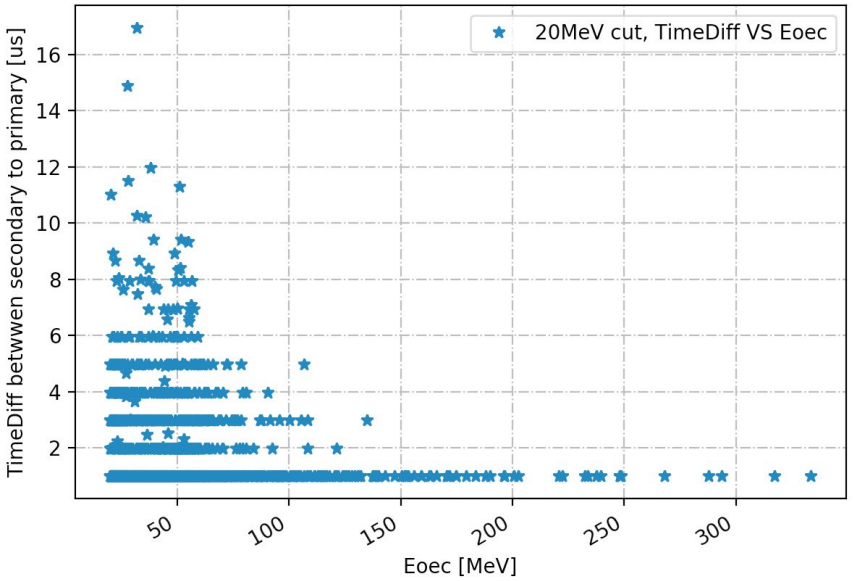


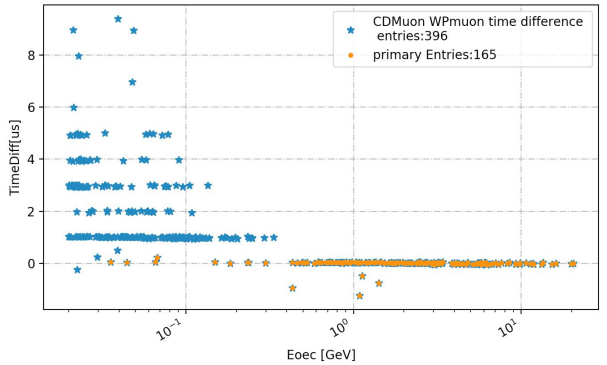
doc-8687

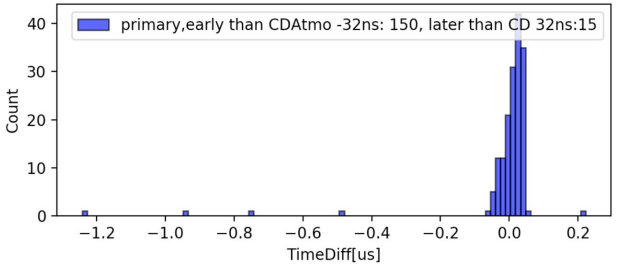
Upgraded bandwidth: from 1Gb/s to 2Gb/s

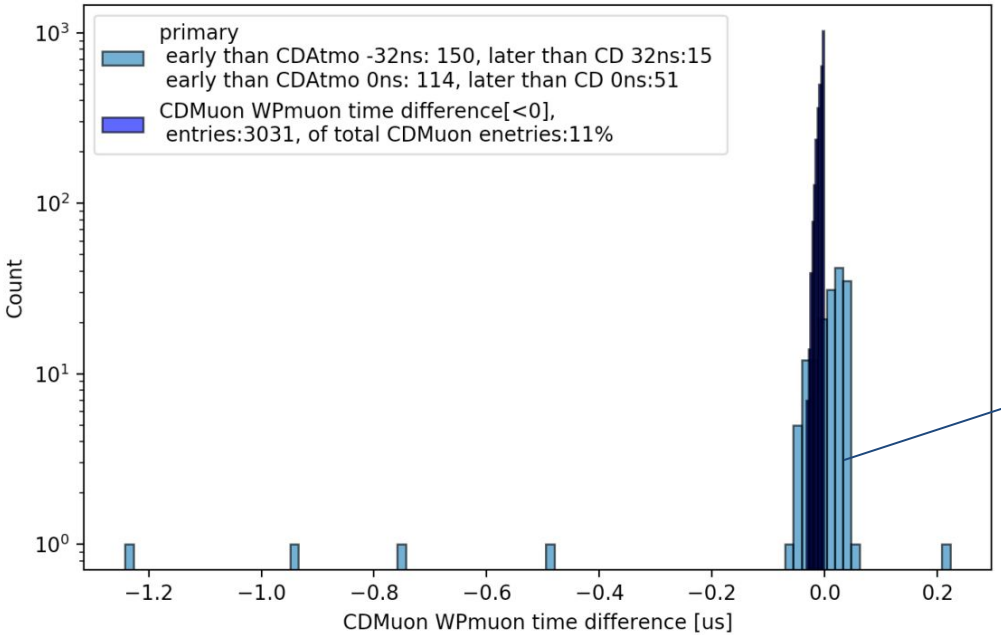
Atmo events - Secondary Atmo/ Primary time diff VS Eoec(CD)

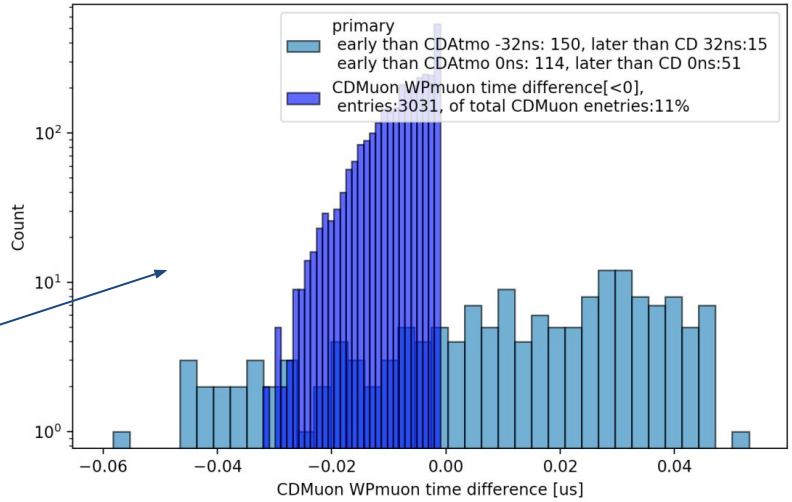
- 2k Atmo true events, based on 20 MeV cut, 1495 primary +1886 secondary Atmo entries.
- primary: 165 PC(11%), 1330 FC(89%)
    - PC: WP trigger early than CD atmo -32ns: 150,90.9% (not able to distinguish from muon), later than 32ns: 15, 9.1% (able to distinguish from muon)
- Secondary entries focus on the combined area of E<100MeV








primary
early than CDAtmo -32ns: 150, later than CD 32ns:15
early than CDAtmo 0ns: 114, later than CD 0ns:51
CDMuon WPmuon time difference[<0],
entries:3031, of total CDMuon enetries:11%
Count
CDMuon WPmuon time difference [us]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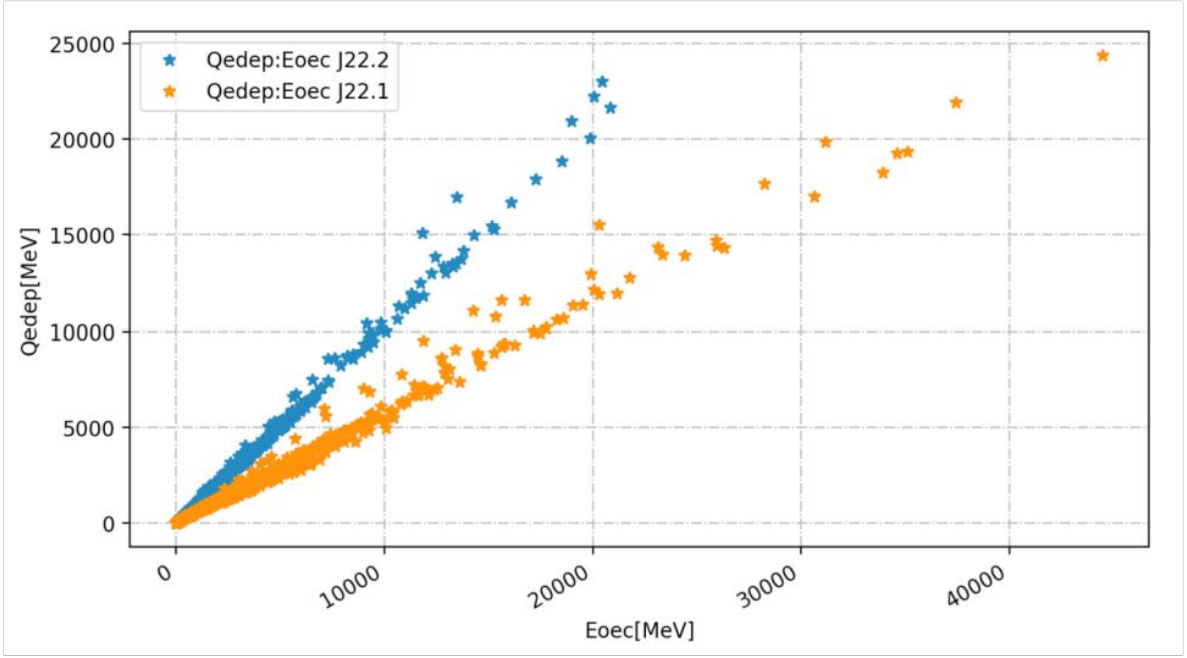
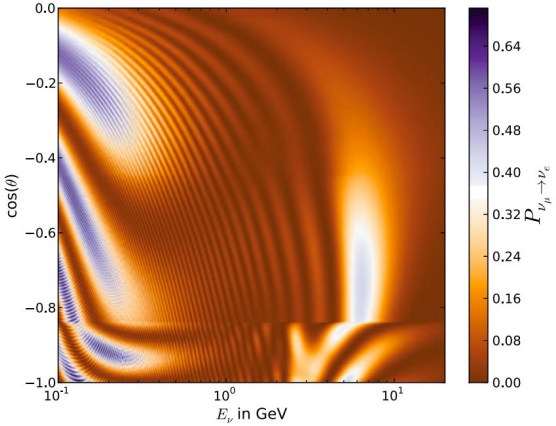
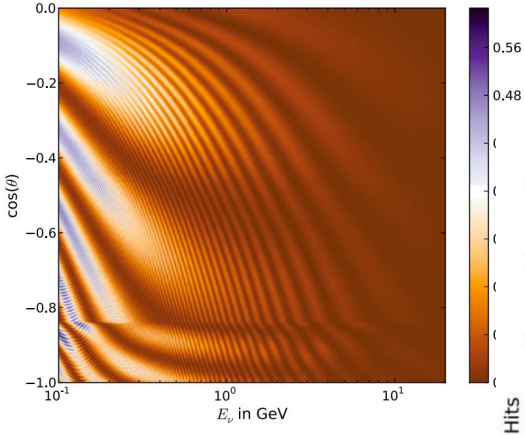
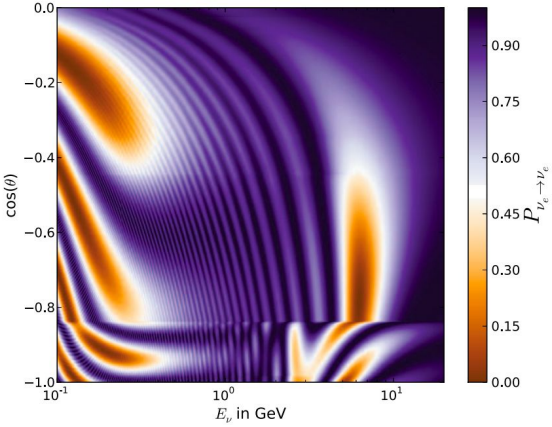
compare J22.2.rc2 and J22.1.rc4: Oec output

Eoec and Qedep




cos(θ)
E_ν in GeV
$P_{\nu_\mu \to \nu_e}$


cos(θ)
E_ν in GeV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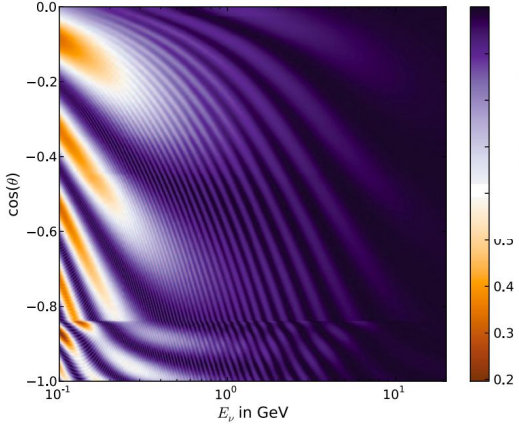
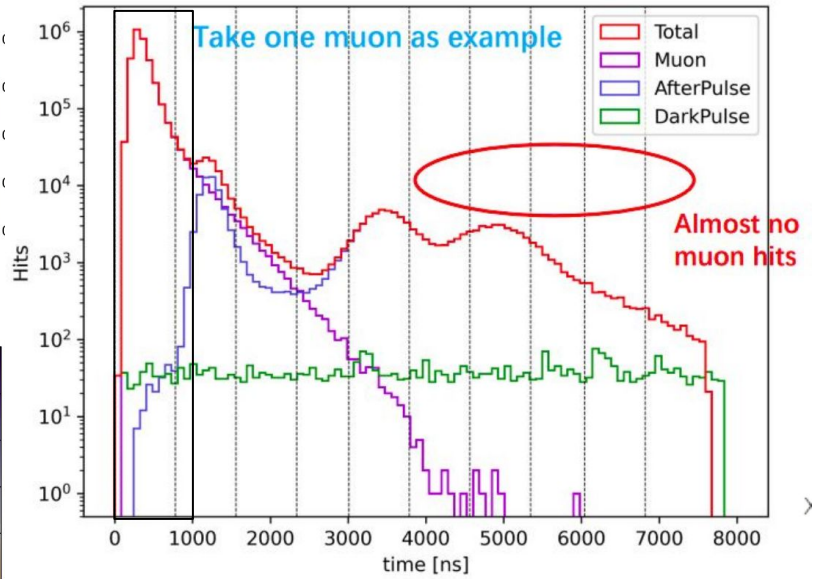

cos(θ)
E_ν in GeV


Take one muon as example
Total
Muon
AfterPulse
DarkPulse
Almost no muon hits
Hits
time [ns]