Missing p_T for CC/NC separation

Chris Marshall
Lawrence Berkeley National Laboratory
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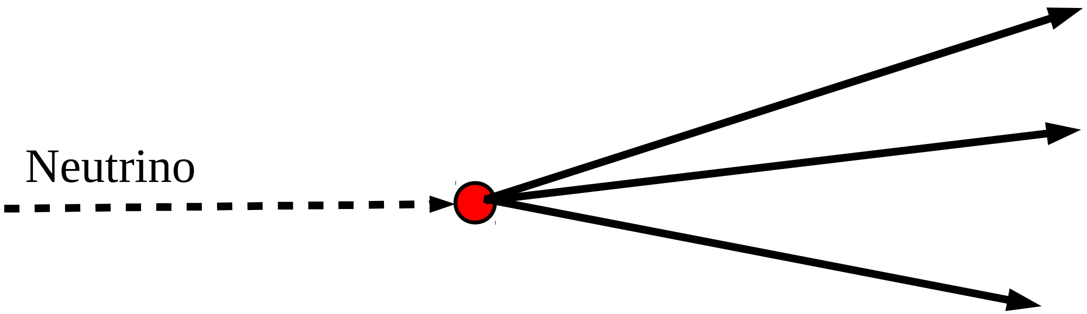
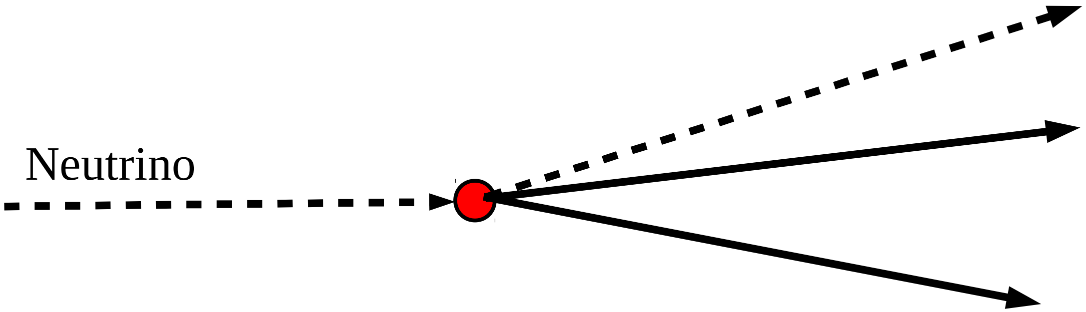
Missing p_T

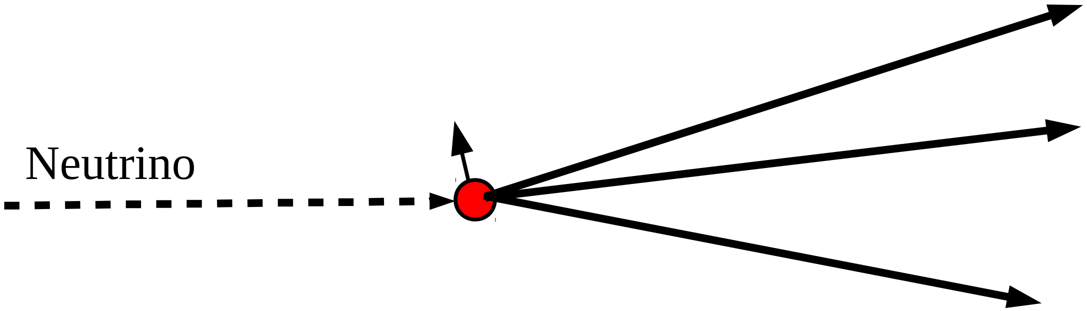


CC event:
$\Sigma \vec{\mathbf{p}}_{\mathbf{T}} = 0$

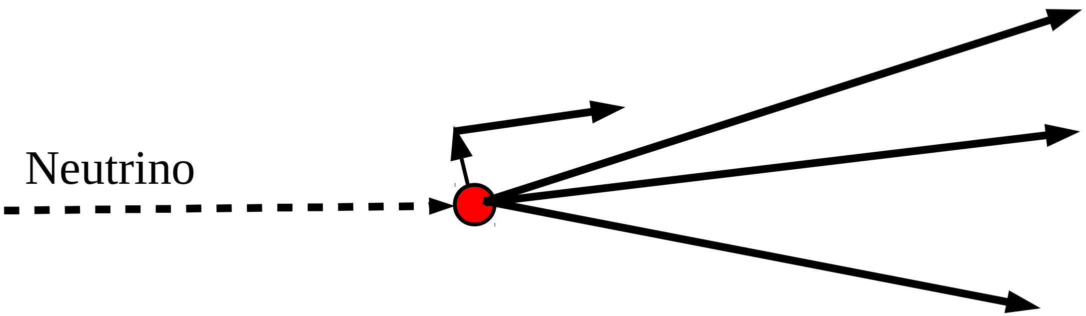


NC event:
$\Sigma \vec{\mathbf{p}}_{\mathbf{T}} \neq 0$

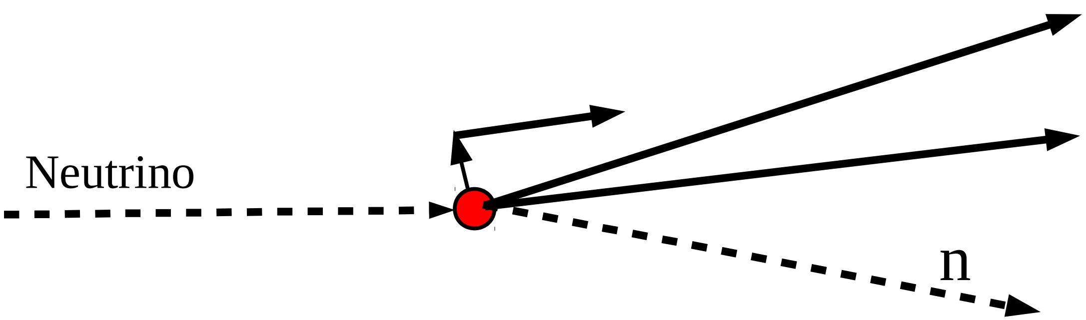
Missing p_T



CC event, with
Fermi motion:
$\Sigma\, \vec{\mathbf{p}}_T \approx 0$



CC event, with
Fermi motion, FSI:
$\Sigma\, \vec{\mathbf{p}}_T \stackrel{?}{\approx} 0$



CC event, with Fermi
motion, FSI, neutrons:
$\Sigma\, \vec{\mathbf{p}}_T \stackrel{?}{\approx} 0$

Outline

- NOMAD was able to use missing p_T to discriminate between CC and NC scattering events
- Compared to NOMAD, DUNE has
  - heavier nucleus, higher Fermi cutoff, more initial nucleon momentum
  - More FSI, likely more final-state neutrons
  - lower energy neutrinos, so nucleon initial momentum is larger compared to neutrino momentum
- We therefore expect less separation between CC and NC in DUNE

Study

- Generated events on Argon, GENIE 2.10.0 with MEC
- Used 80 GeV optimized flux for FHC and RHC
- Corrected for mean beam angle, which results in ~2mrad smearing at 574m location

Fast MC reconstruction

- Three different assumptions for particle thresholds:
  - All particles reconstructed
  - All particles except neutrons reconstructed
  - "realistic": >25 MeV KE for $\mu/\pi^{\pm}$, no threshold for π^0, 50 MeV for protons, 50 MeV for anything else
- Three different assumptions for momentum and angular resolution:
  - Perfect
  - FGT-ish: 3% momentum, 2 mrad angular
  - LAr-ish: 6% momentum, 5 mrad angular

Separated by “reco” E_ν

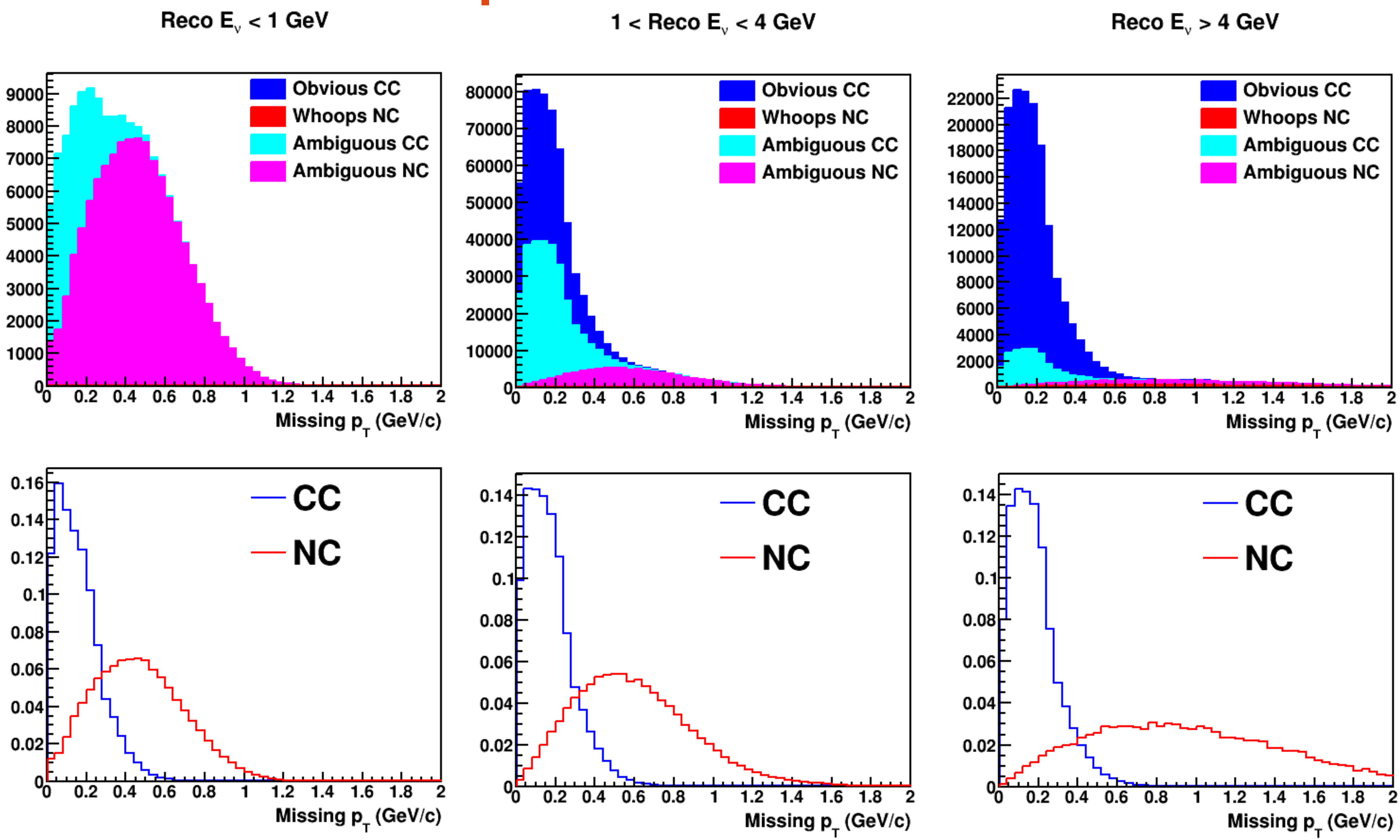
- Missing p_T distributions are shown in three bins of “reconstructed” neutrino energy:
  - $E_\nu < 1$ GeV – second oscillation maximum at 0.85
  - $1 < E_\nu < 4$ GeV – PMNS region, most important for first oscillation maximum at 2.54 GeV
  - $E_\nu > 4$ GeV – flux tail
- “Reco” E_ν is the sum of the total energy of all “detected” mesons and kinetic energy of all “detected” nucleons, with kinetic energy smeared using same resolution as for the momentum, and PID assumed perfect
- “Detected” means above threshold for given detector

“Obvious” CC events

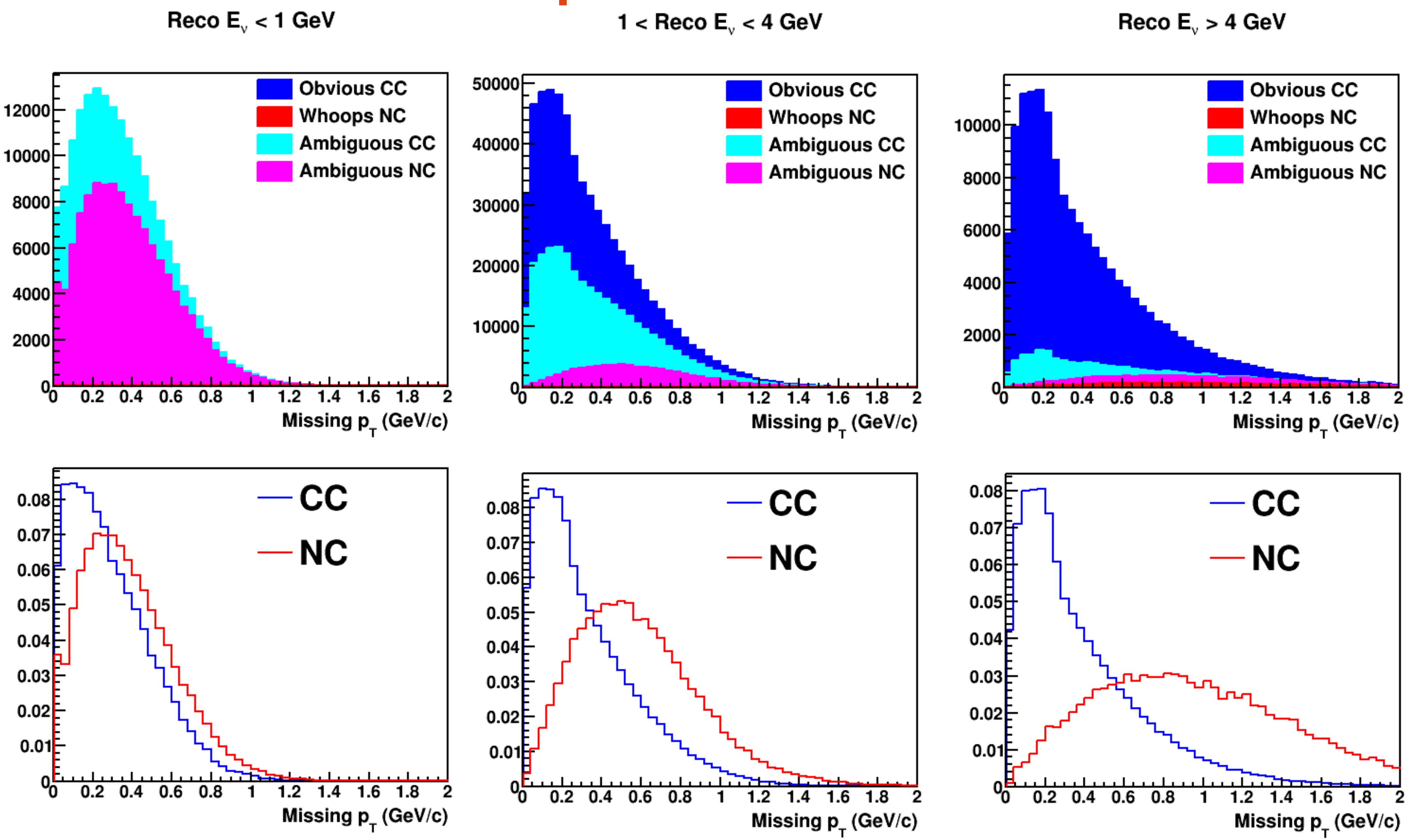
- Missing p_T is not necessary for events with long, right-sign muon tracks
- Events with right-sign muons (FHC μ^- or RHC μ^+) above 1.25 GeV are classified as “obvious CC”
- True NC events with pions (FHC π^- or RHC π^+) above 1.5 GeV are classified as “whoops NC”, i.e. they would be removed by the obvious CC cut
- Remaining events are “ambiguous”
- Wrong-sign NC is included, but wrong-sign CC is assumed to be rejected with 100% efficiency (for example, low-energy μ^- do not show up as NC in the RHC sample; this is a very optimistic assumption)

FHC ν_μ

FHC ν_μ perfect detector



FHC ν_μ no neutrons



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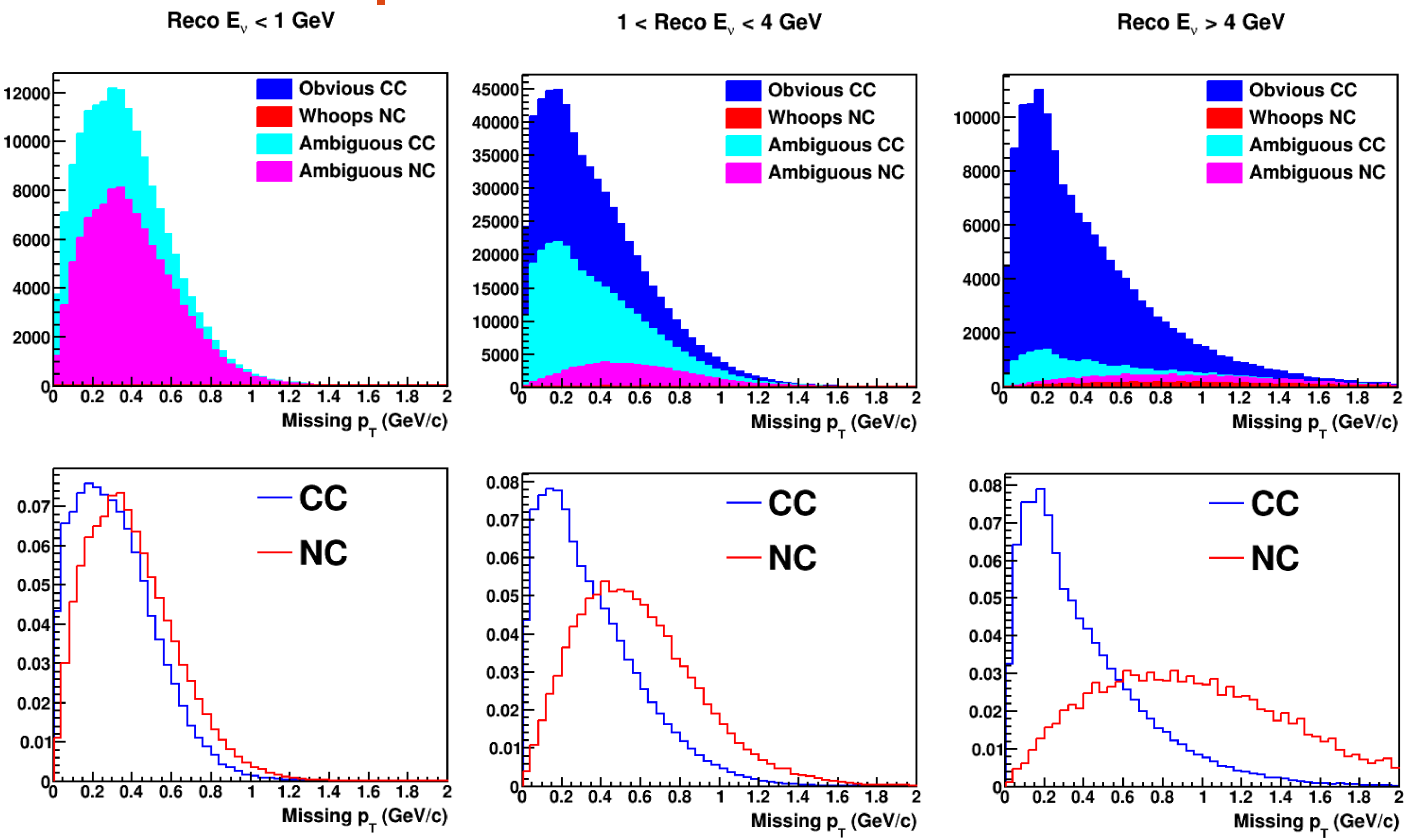
FHC ν_μ thresholds & FGT-like



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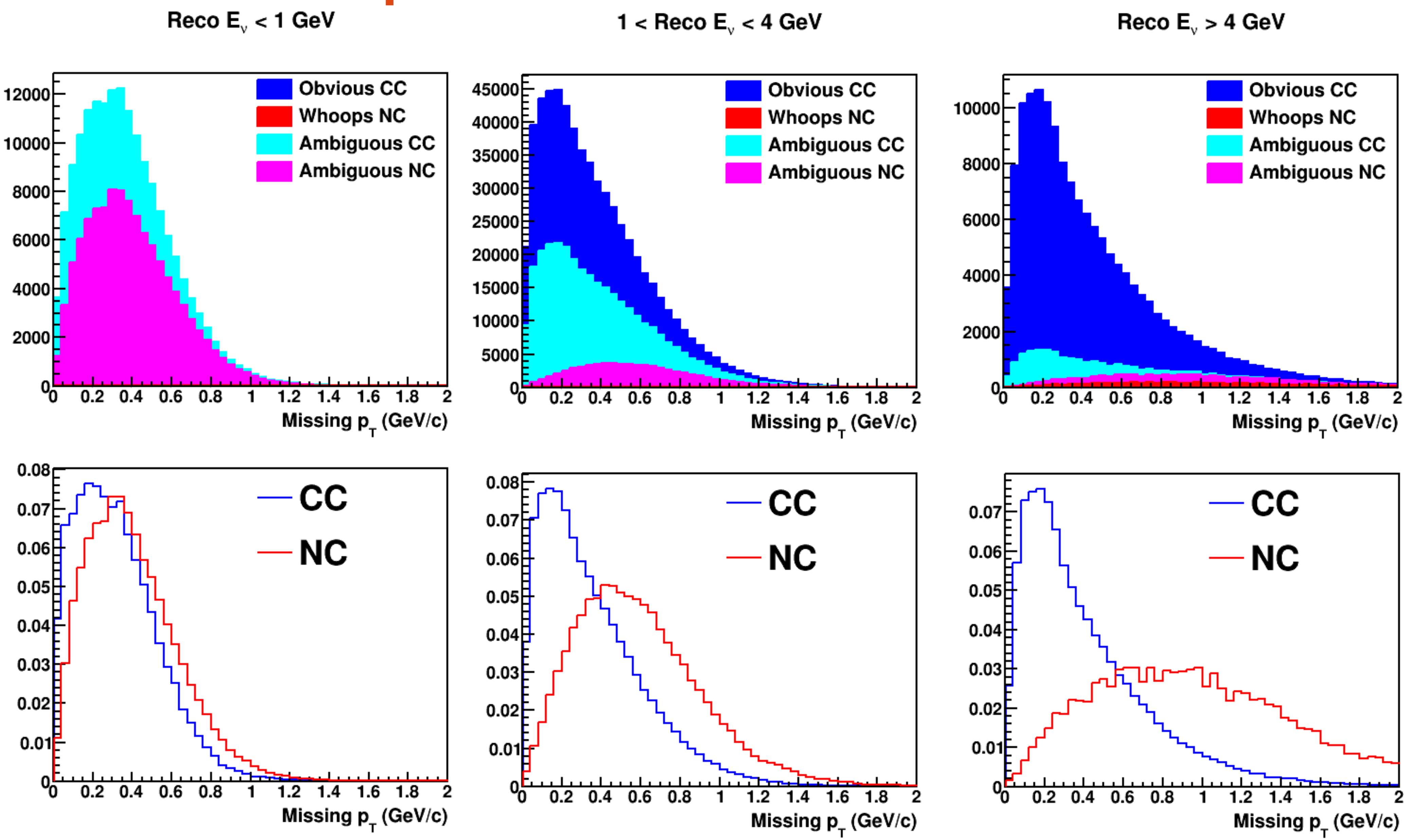
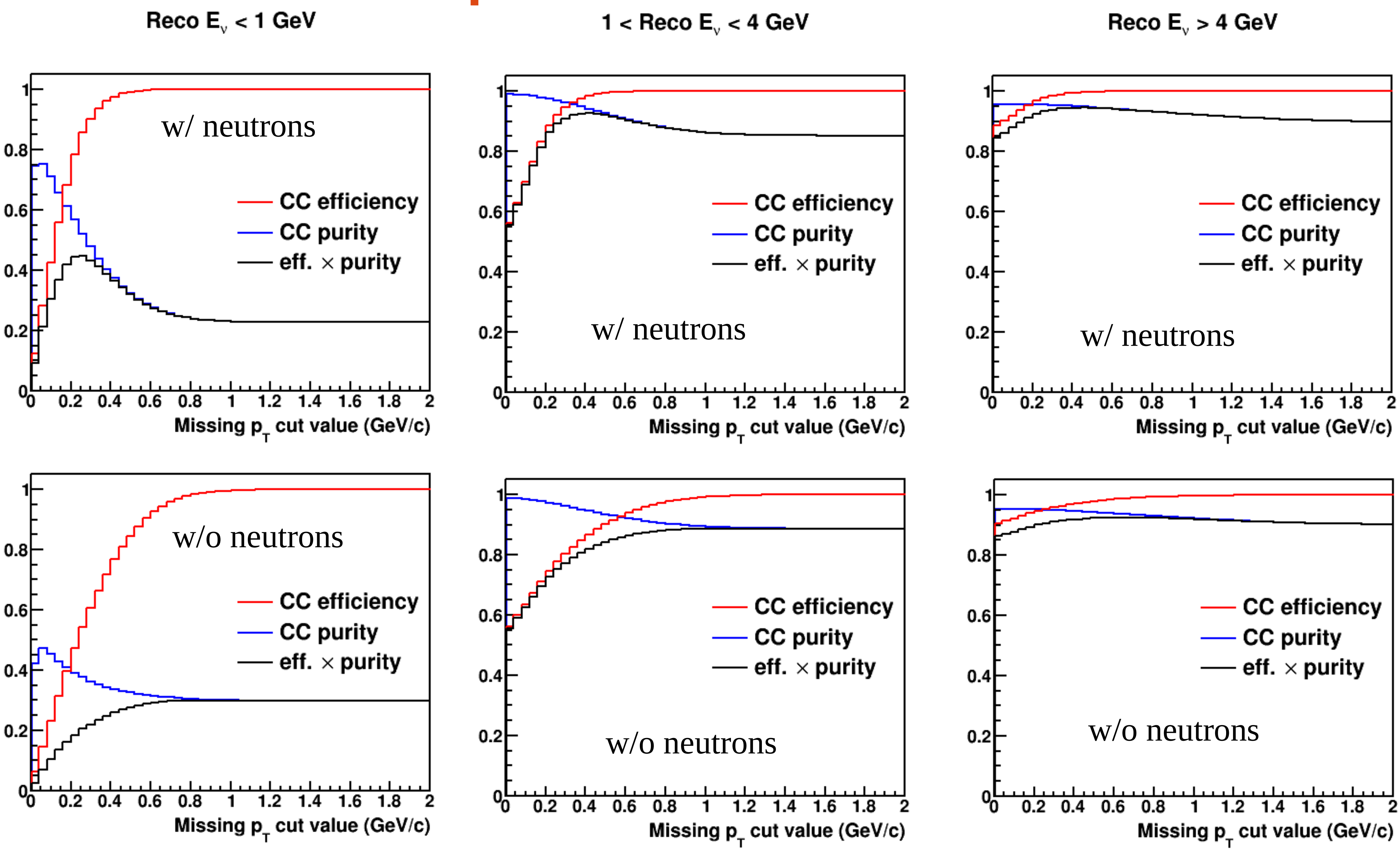
FHC ν_μ thresholds & LAr-like



FHC ν_μ perfect detector



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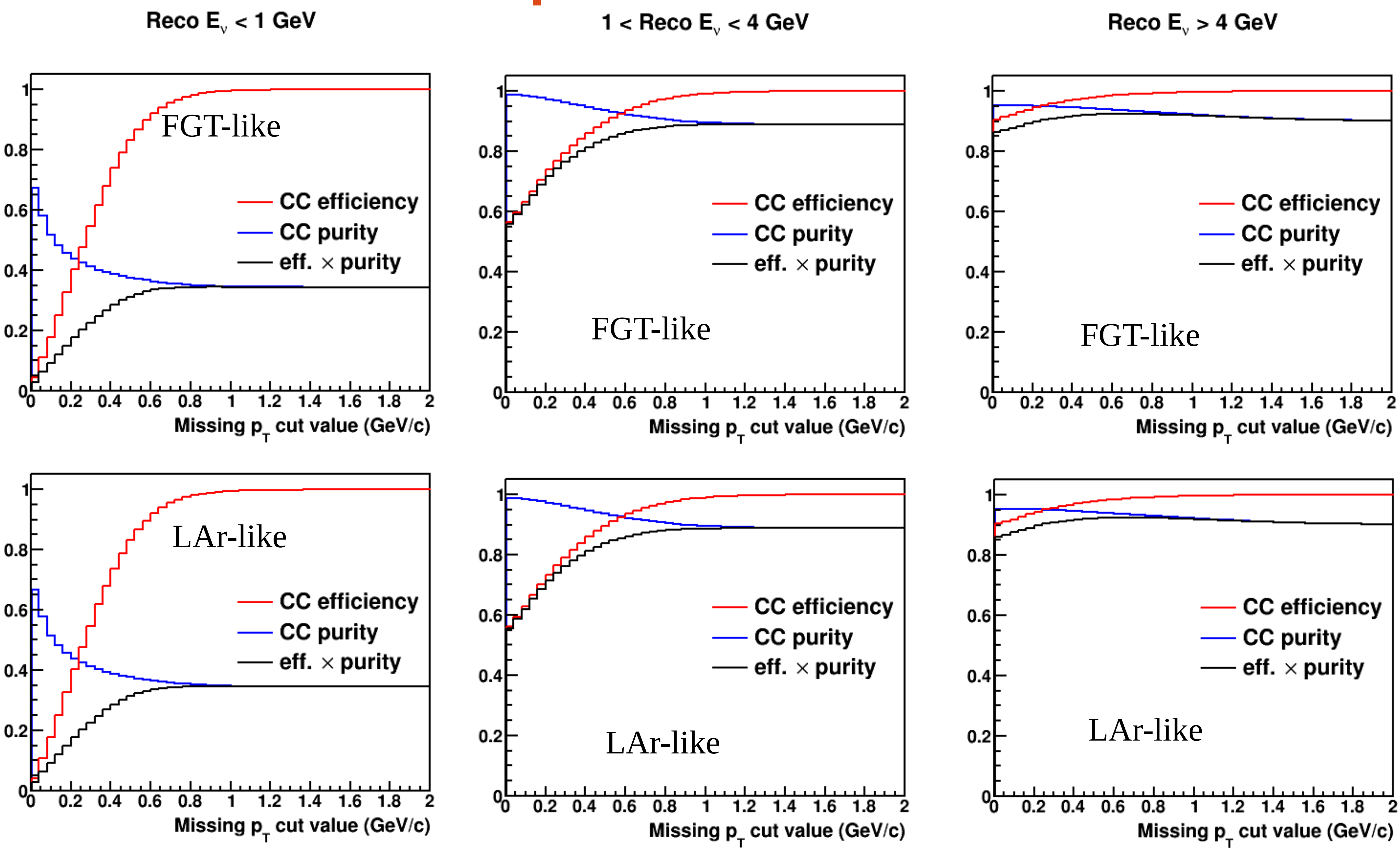
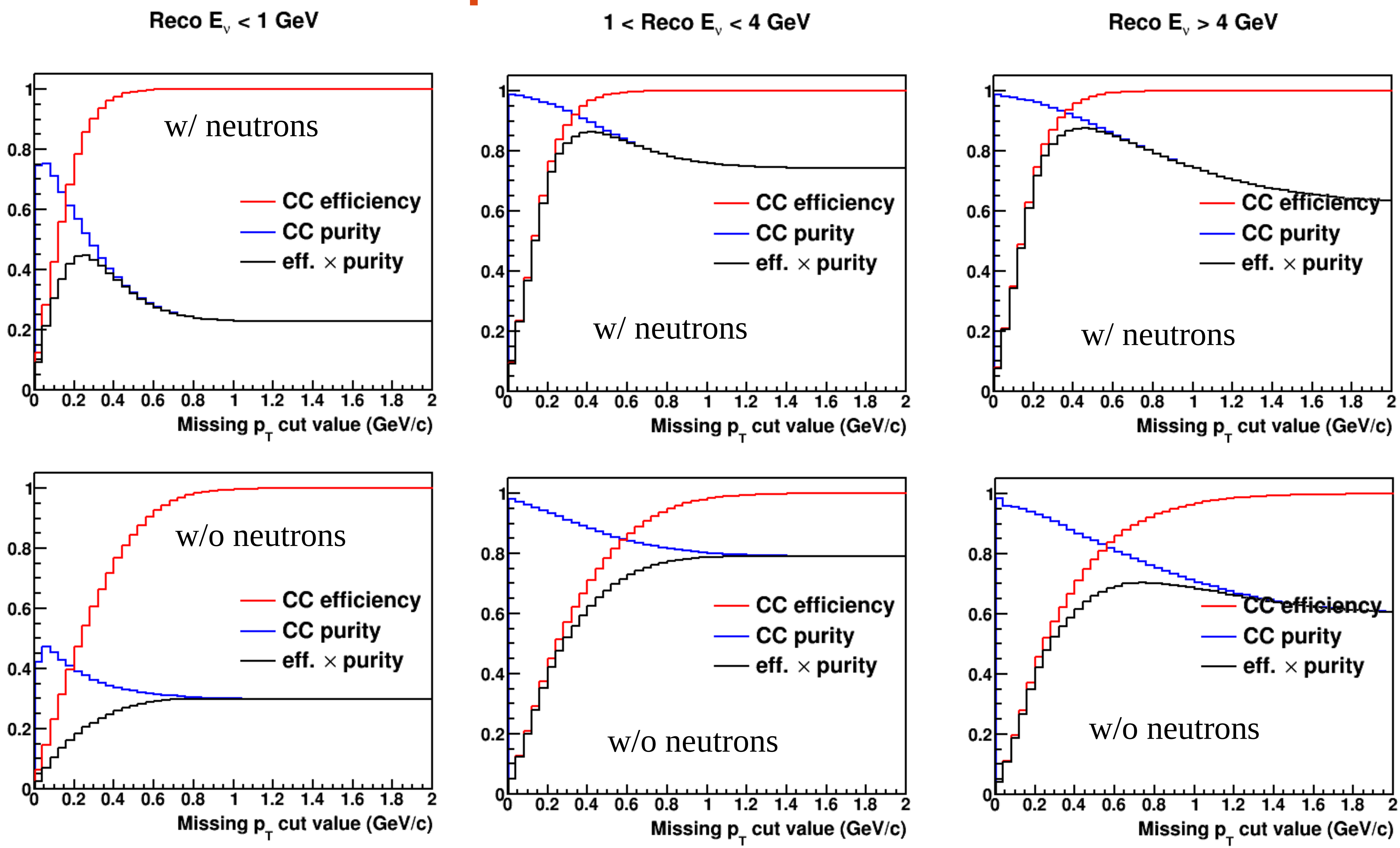
FHC ν_μ real detector



FHC $E_{\mu-} < 1.25$ GeV only



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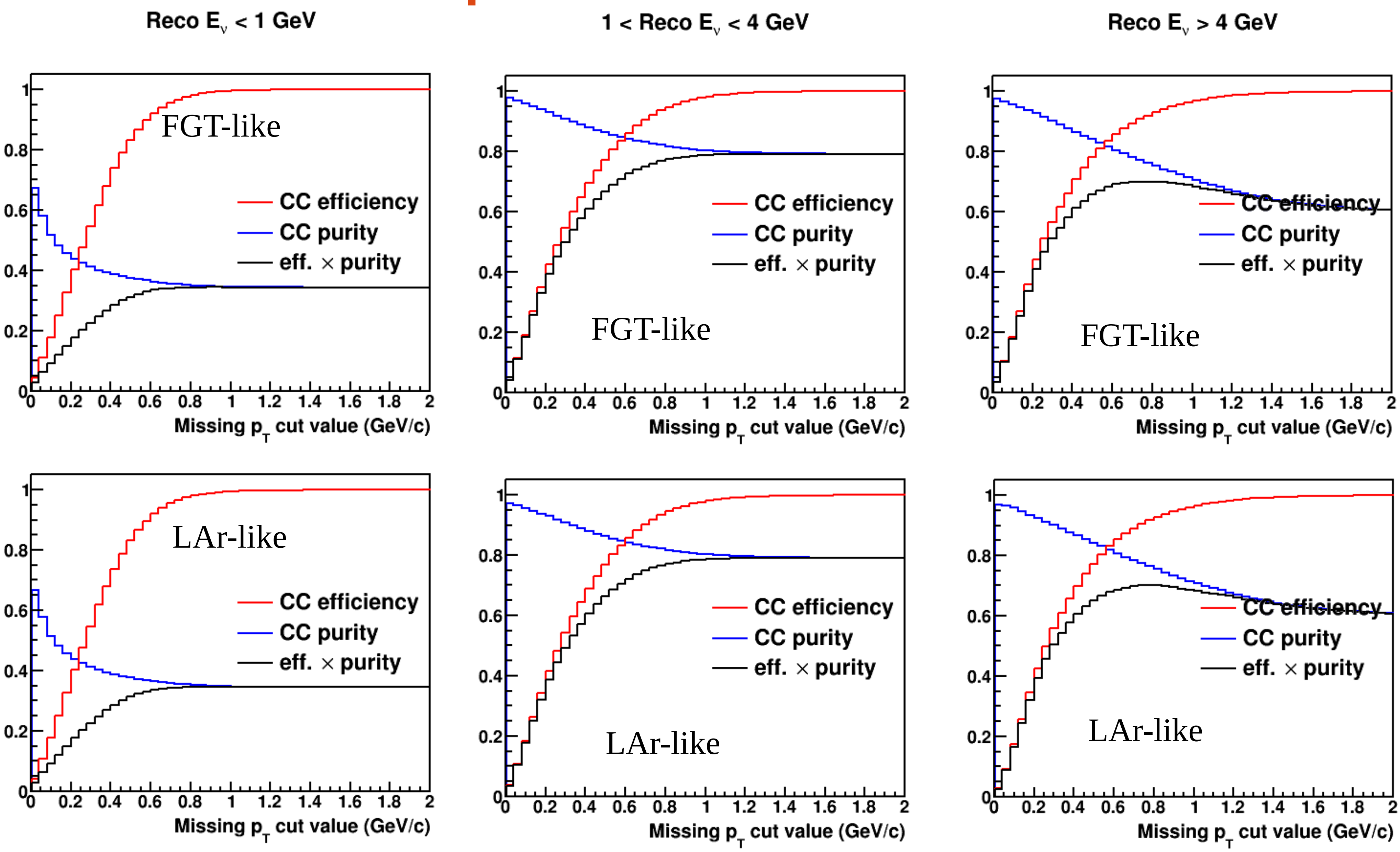
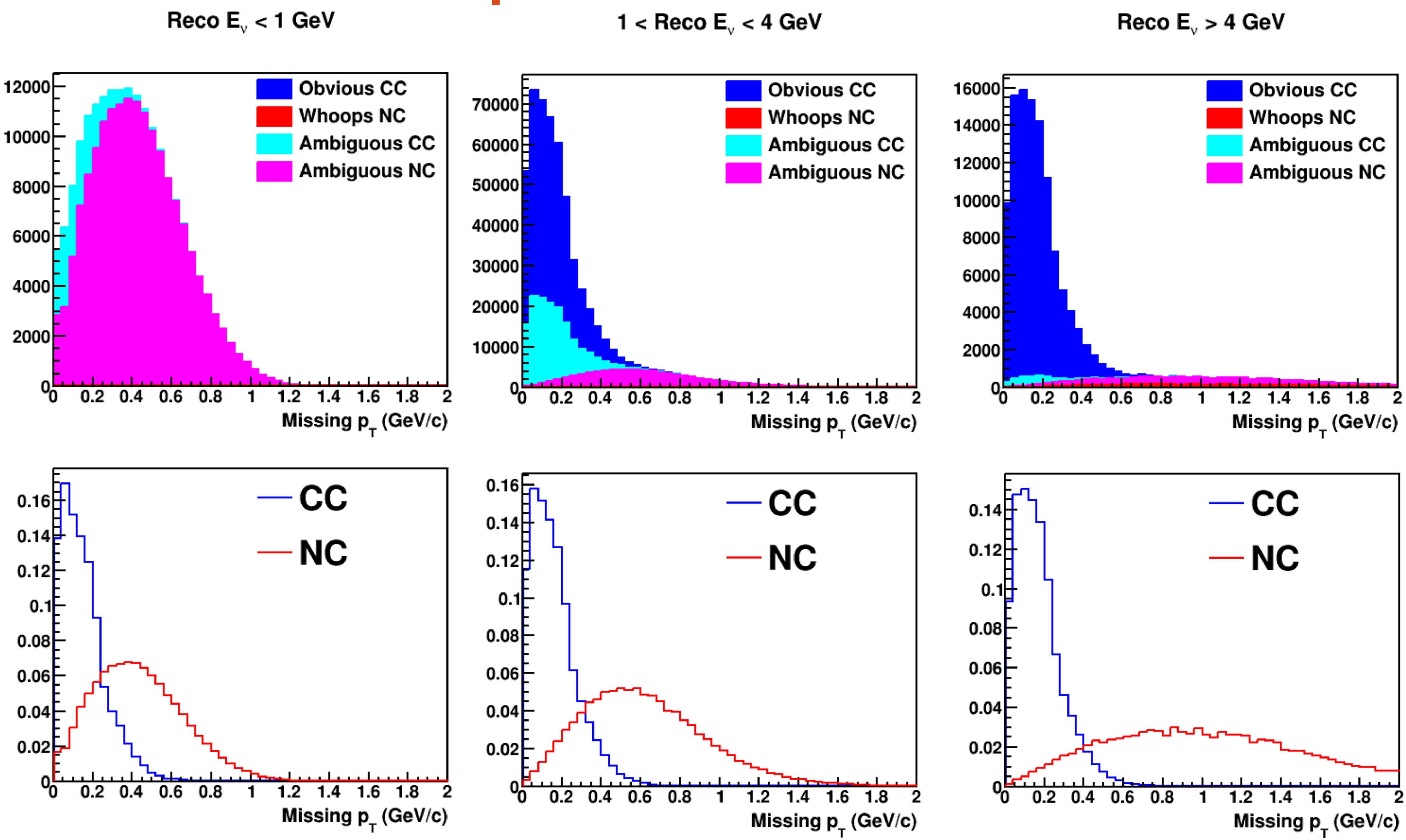
FHC E_{μ^-} < 1.25 GeV only

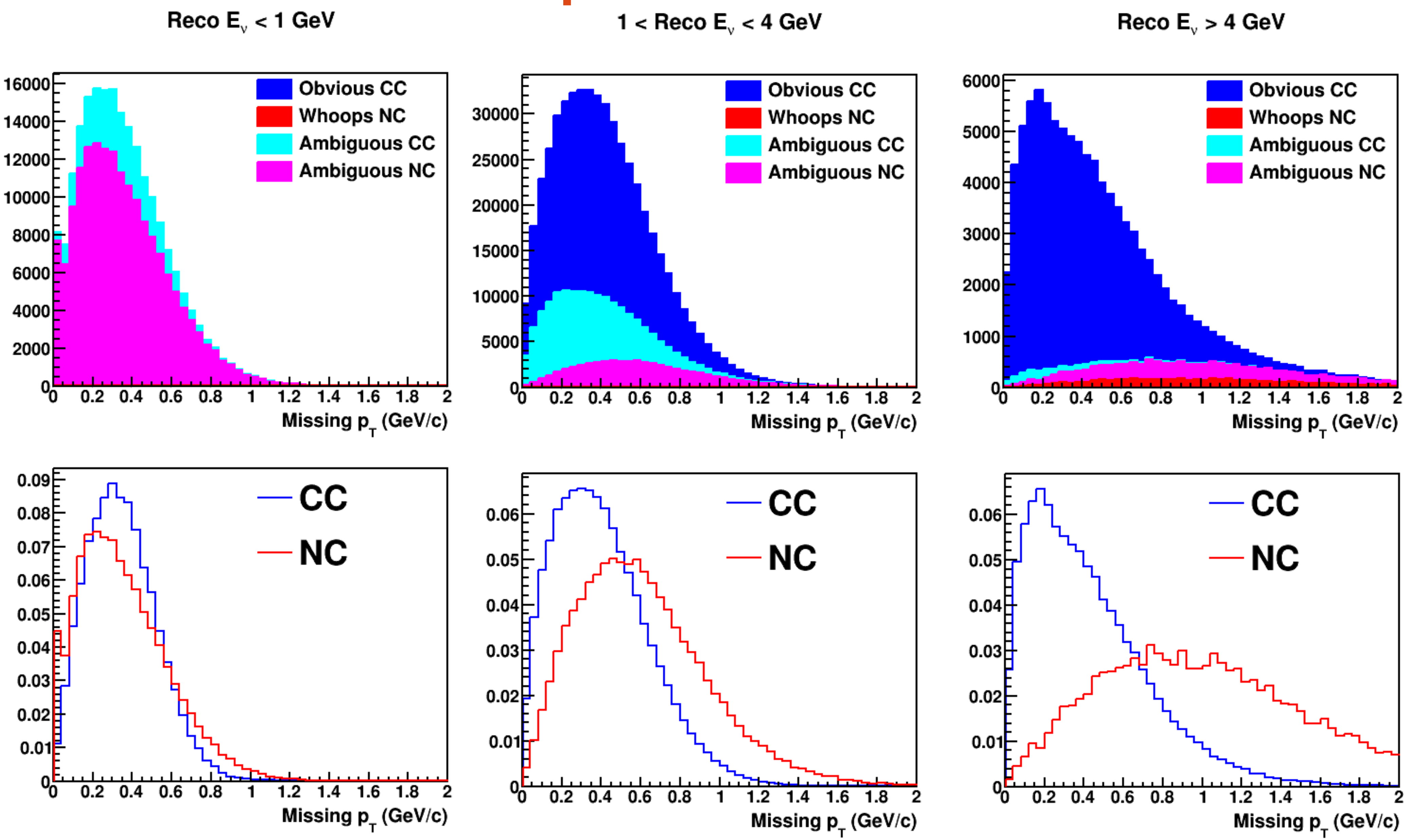


RHC $\bar{\nu}_\mu$

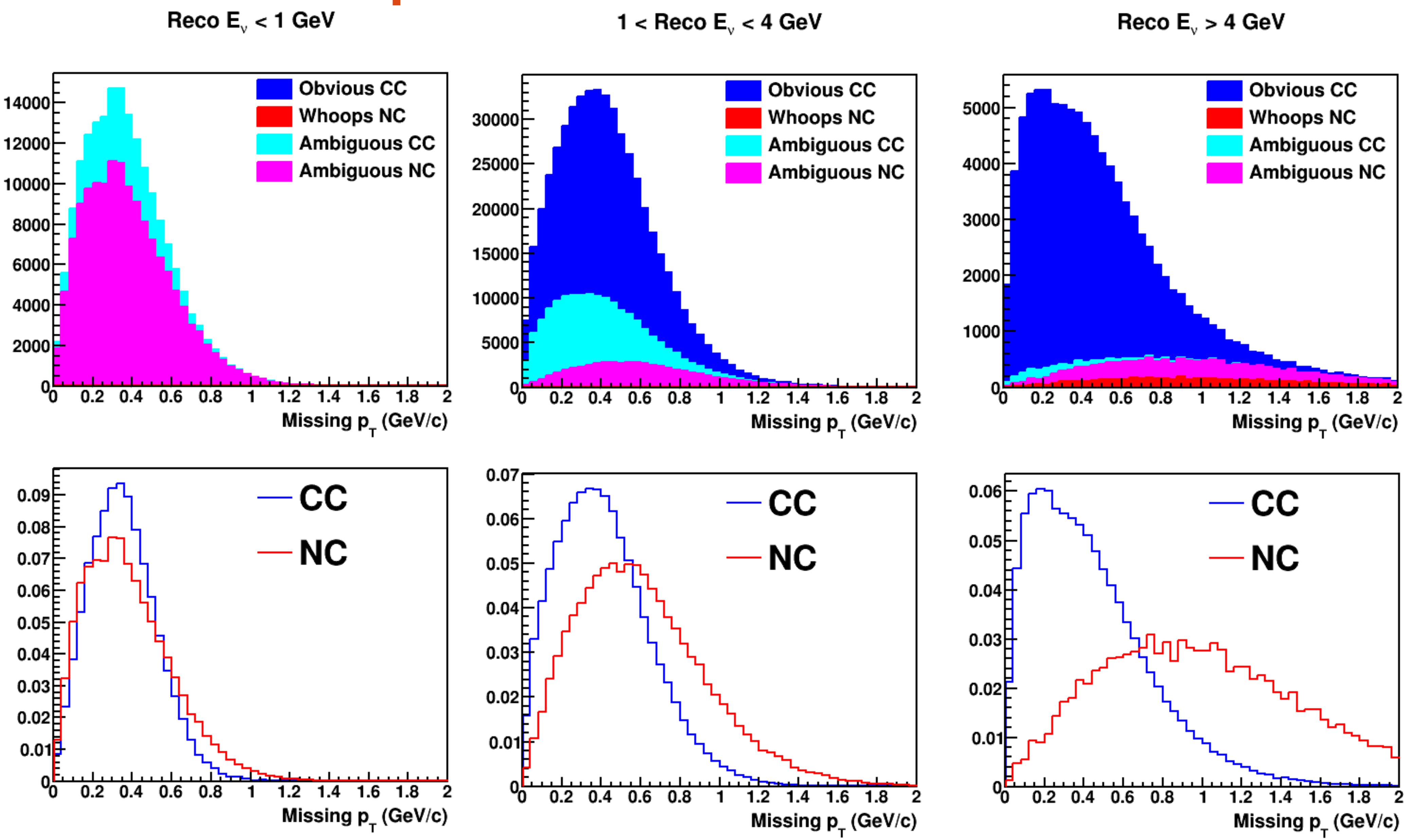
RHC $\bar{\nu}_\mu$ perfect detector



RHC $\bar{\nu}_\mu$ no neutrons



RHC $\bar{\nu}_\mu$ thresholds & FGT-like



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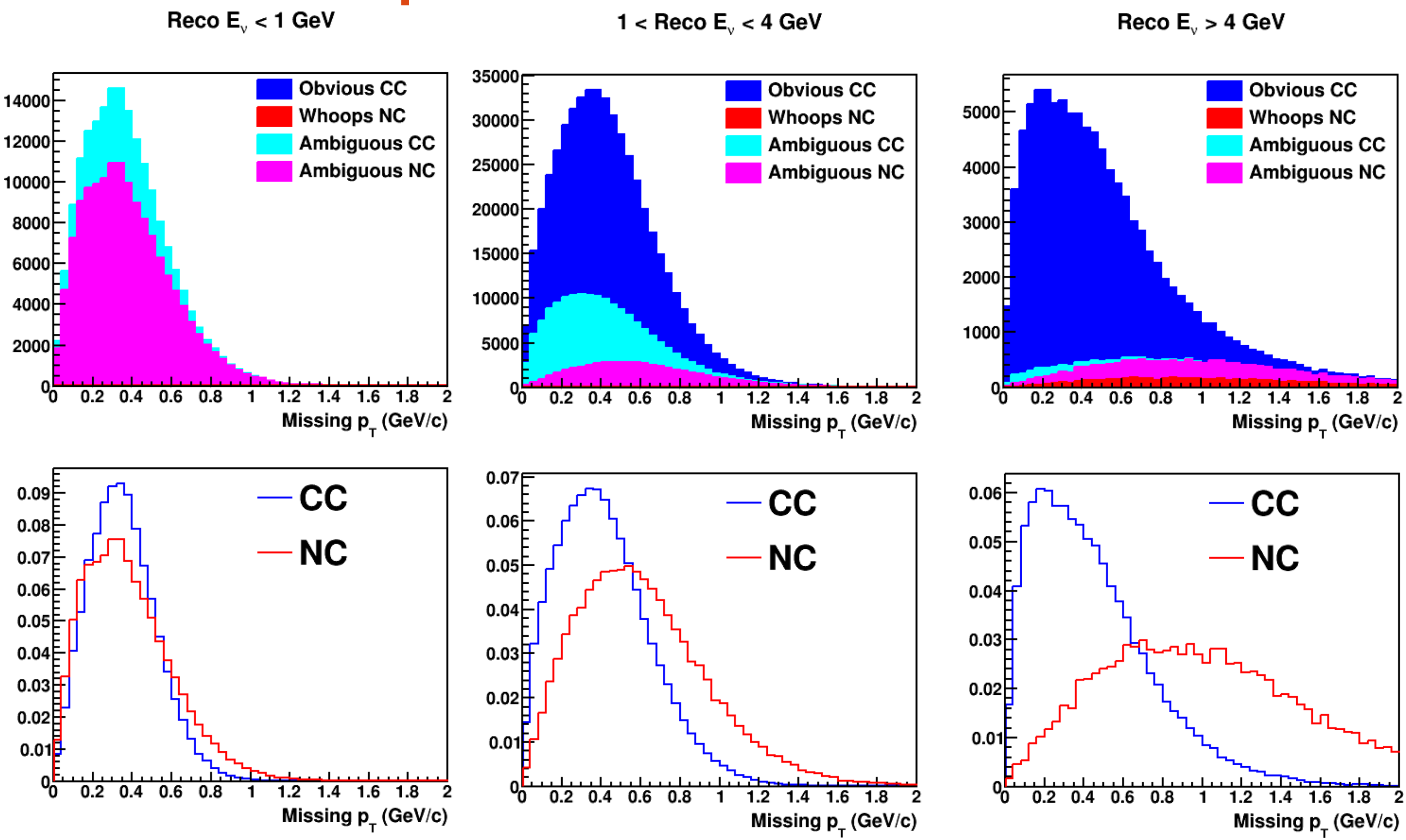
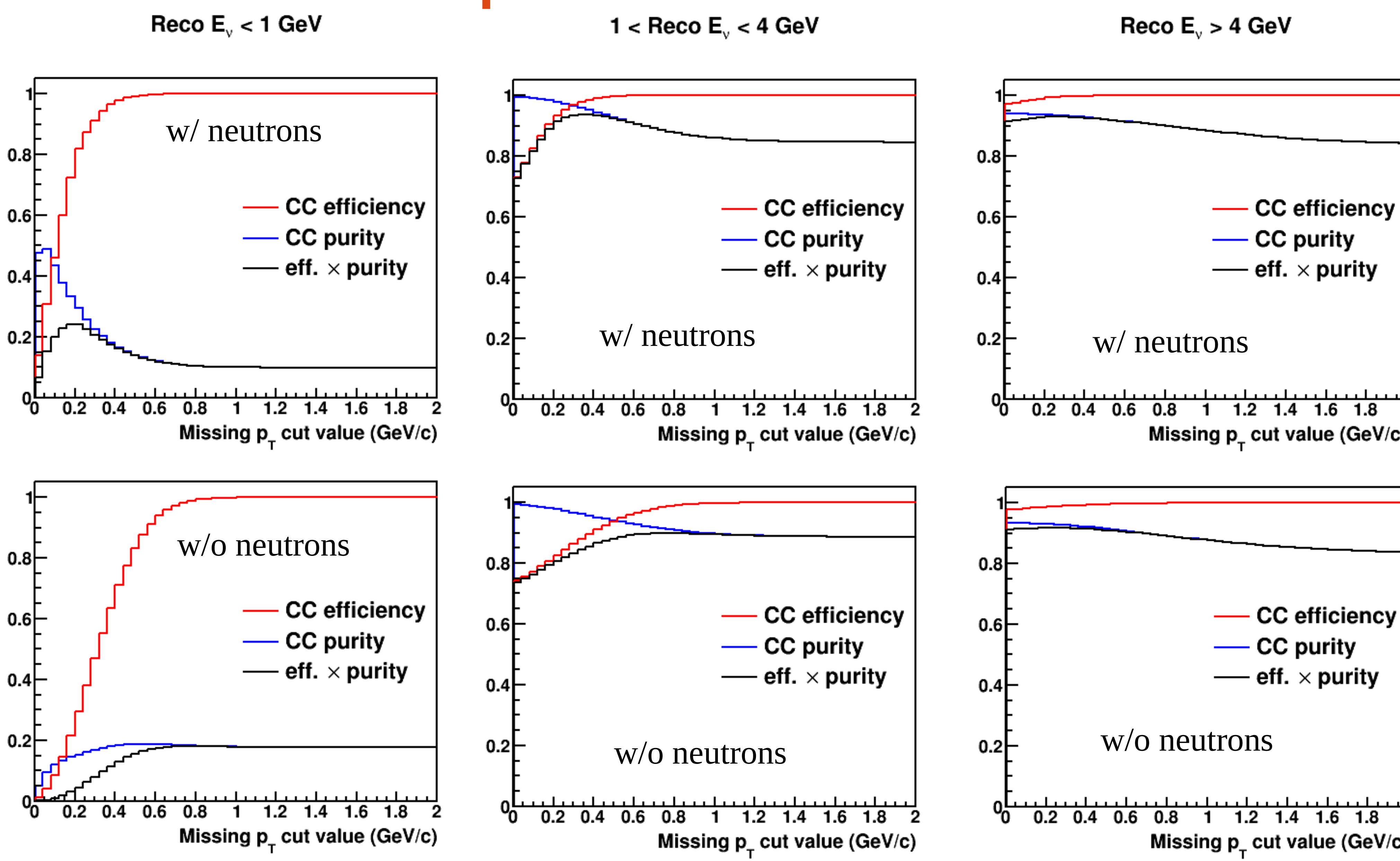
RHC $\bar{\nu}_\mu$ thresholds & LAr-like



RHC $\bar{\nu}_\mu$ perfect detector



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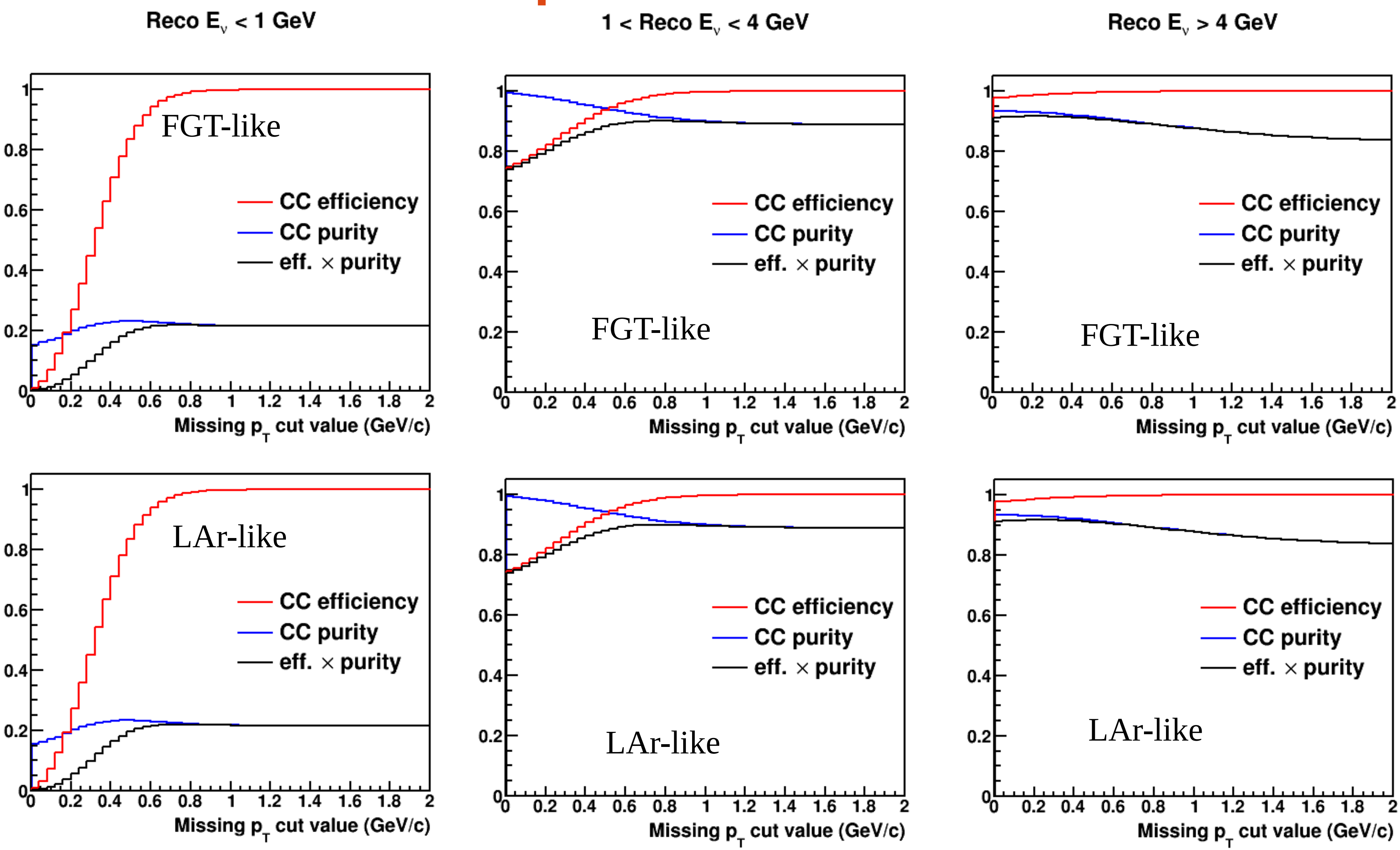
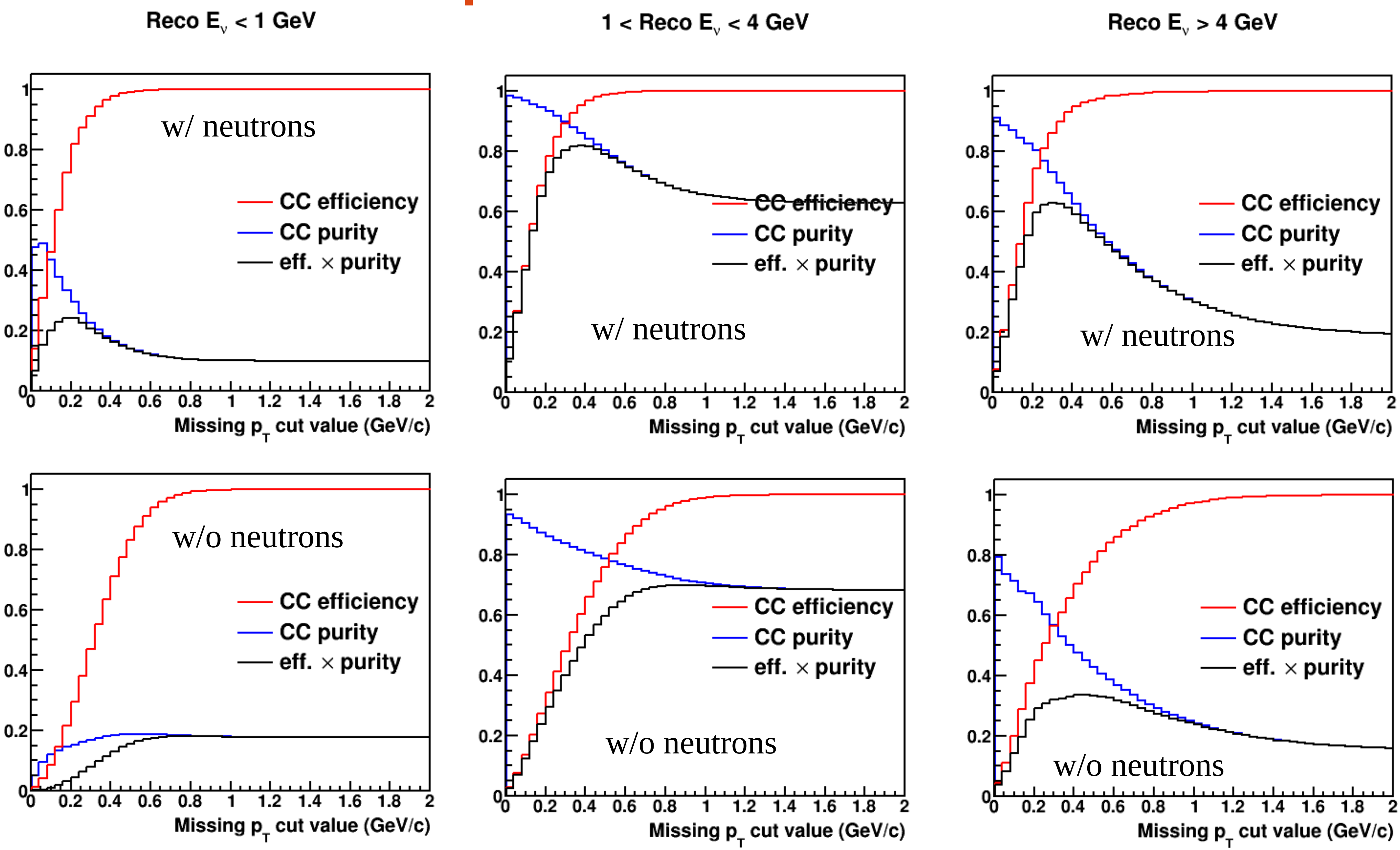
RHC $\bar{\nu}_\mu$ real detector



RHC $E_{\mu+}$ < 1.25 GeV only



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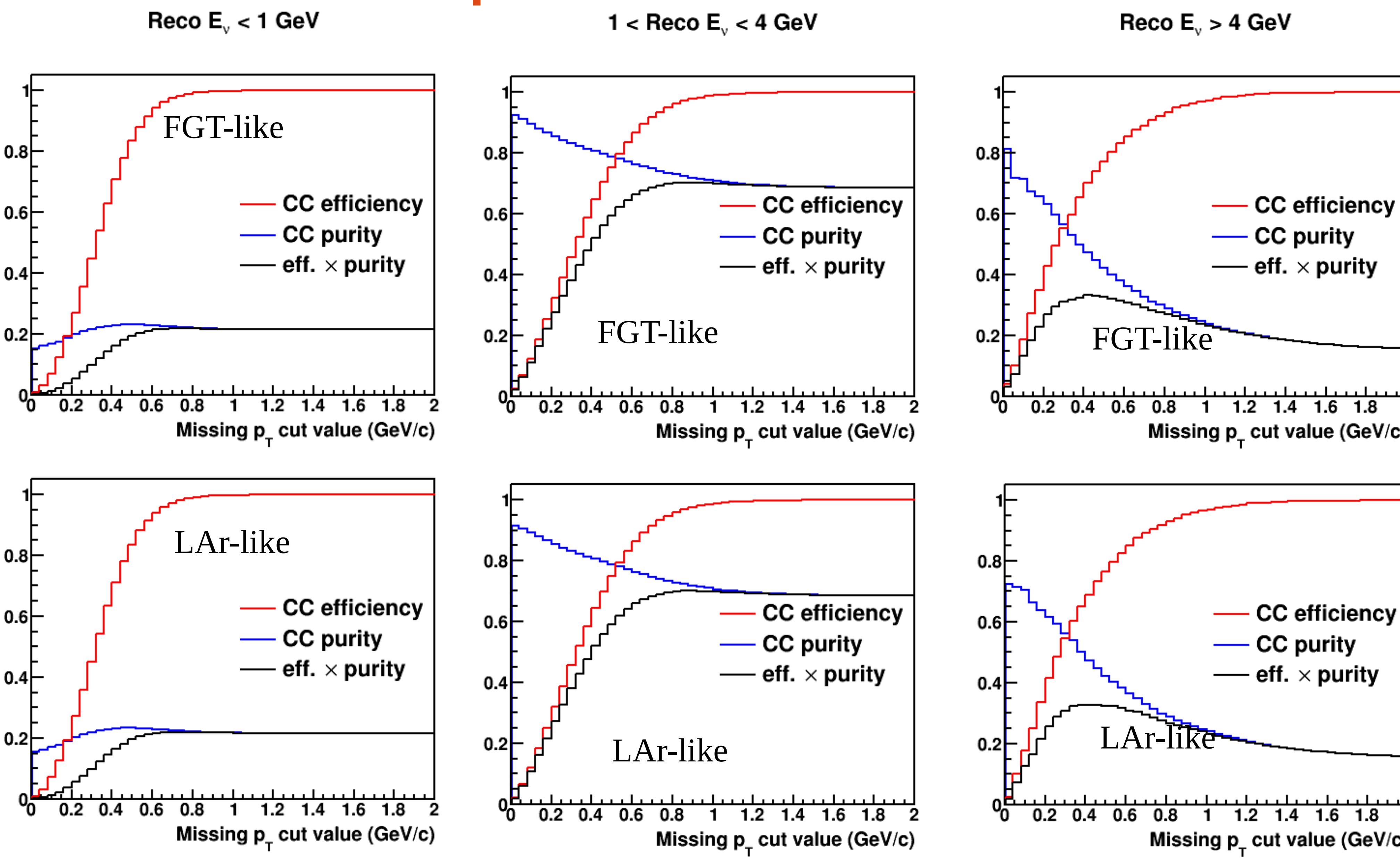
FHC $E_{\mu-}$ < 1.25 GeV only



Conclusions

- Simply requiring that the detector $E_{visible}$ > 1 GeV gives high CC purity in PMNS region, albeit highly dependent on flux model
- Missing p_T is not useful for improving CC purity in 1-4 GeV energy region, even once you have already removed very long muon tracks
- Missing p_T could be an interesting variable for studies of nuclear effects even if it is not used to select CC events