Updates on ν_τCC search based on kinematics for the $\tau \longrightarrow \rho \longrightarrow \pi^- \pi 0$ channel

ν_t meeting group

-

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DEEP UNDERGROUND NEUTRINO EXPERIMENT

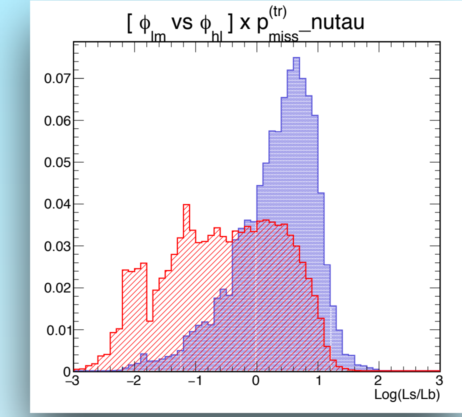
Abstract

• Can't rely on a **direct** τ identification for DUNE far detectors: look at the τ decay modes and develop for each channel a τ appearance analysis.

• Use the rich single event kinematic information available at DUNE FD. I'm working with the CAFANA NTuples used for the DUNE TDR, and developing a kinematic based search analysis for the τ flavor.

• Previously, I developped an analysis for leptonic decay mode, especially for τ —>e decay mode (18% BR). I had likelihood discrimination (cut at 0.7) + CVN pre-selection indicating 14% signal kept, while 7% nue contamination (not normalised). **Can be improved**.

See DUNE collaboration meeting January 2020.



• I extended the leptonic analysis to an **exclusif decay mode**: $\tau \longrightarrow \rho\nu_\tau \longrightarrow \pi^-\pi0\nu_\tau$: **large BR** (25%), recontruction of **resonance** with charged pion and π0, get inspiration from NOMAD experiment (which ran at higher energies than DUNE, though).

• The π0 case: I decay all π0 manually into two photons, isotropically in the π0 rest frame. No Dalitz decay. I use a conservative hypothesis: no *a priori* π0 reconstruction performance. Any pair of photons will be, to me, a π0 candidate.

The τ—>ρ—>π0π⁻ decay mode: cross check using the invariant mass

• In the CAFANA files, the ρ **isn't explicitely recorded**. Instead, one finds that $\tau^- \rightarrow \pi^- \pi_0 \nu_\tau$, I first checked that the ρ was well simulated underneath (one may find explicit ρ simulated within the hadronic system).

final state τ

τ decay daughters

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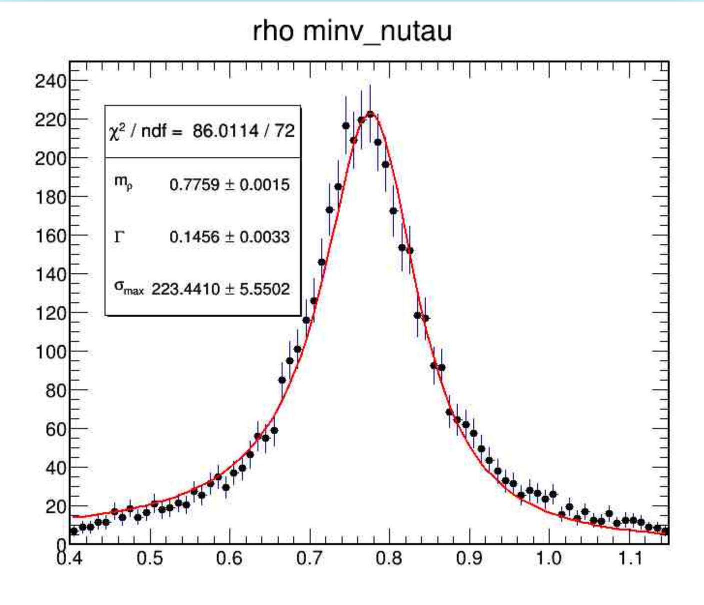
nu_tau	16	0	-1	-1	4	4	-0.000	1.526	15.060	15.137	0.000
Ar40	1000180400	0	-1	-1	2	3	0.000	0.000	0.000	37.216	37.216
neutron	2112	11	1	-1	5	5	0.041	-0.035	-0.004	0.930	0.940
Ar39	1000180390	2	1	-1	12	12	-0.041	0.035	0.004	36.286	36.286
tau-	15	3	0	-1	13	15	-1.286	0.429	9.426	9.688	1.777
HadrSyst	2000000001	12	2	-1	6	8	1.327	1.062	5.629	6.379	0.000
proton	2212	14	5	-1	9	9	0.771	0.014	1.437	1.882	0.938
pi+	211	14	5	-1	10	10	-0.240	0.400	0.684	0.840	0.140
pi-	-211	14	5	-1	11	11	0.796	0.647	3.507	3.657	0.140
proton	2212	1	6	-1	-1	-1	0.771	0.014	1.437	1.882	0.938
pi+	211	1	7	-1	-1	-1	-0.240	0.400	0.684	0.840	0.140
pi-	-211	1	8	-1	-1	-1	0.796	0.647	3.507	3.657	0.140
HadrBlob	2000000002	15	3	-1	-1	-1	-0.041	0.035	0.004	36.286	0.000
nu_tau	16	1	4	-1	-1	-1	0.313	0.191	2.999	3.021	0.000
pi-	-211	1	4	-1	-1	-1	0.005	0.037	0.447	0.469	0.140
pi0	111	1	4	-1	-1	-1	-1.605	0.202	5.981	6.197	0.135

A GENIE NTuple nutauCC event

• Invariant mass distribution of the true ρ (π_0 π^-) system (stat. errors), fitted by a relativistic Breit-Wigner gives correct ρ mass of 0.776 GeV and correct width decay (0.146 GeV).

The ρ is there, underneath.
ρ tagging equivalent to tagging a (π0 ; π⁻) system



• **Vocabulary :** in this talk, I will refer as :

- **The true** ρ**:** the (π0π⁻)system which are the true final decay products of the τ—>ρ resonance.
- **The fake** ρ: any (π0π±) system which doesn't fulfill the previous condition.

N.B: the π0 itself decays into two photons, thus I'm looking at triplets (γ1γ2π±) instead of doublets.

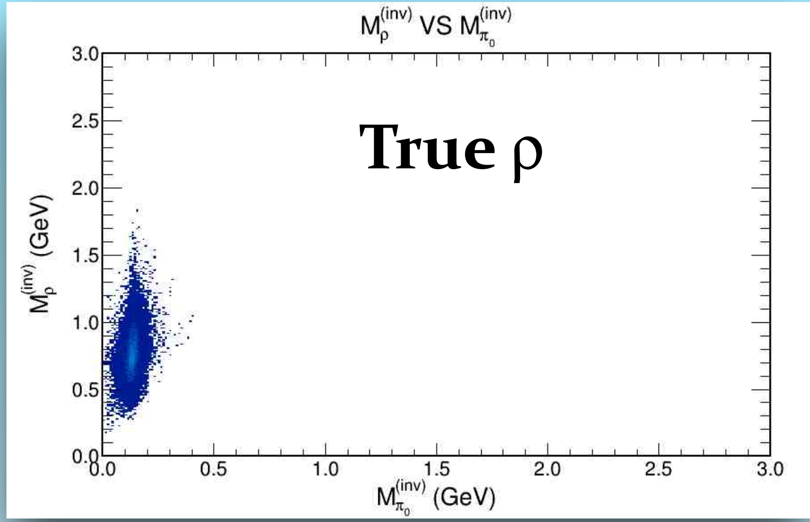
Developing a ρ tagging method with the invariant masses
(individual particle smearing activated)

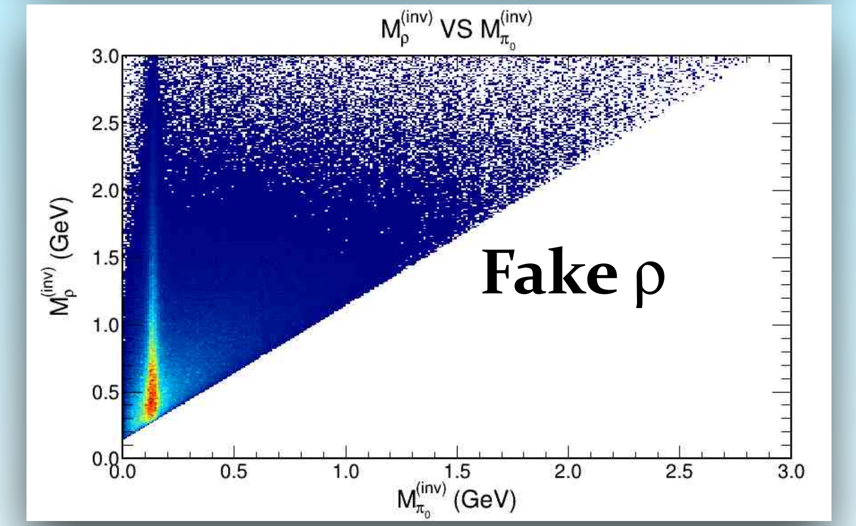
• Within a ν_τCC event, the hadronic system can be composed of pions too, thus **blurring** the true ρ decay system. To get some help, let's exploit the scatter plot of the **invariant masses** (π0;ρ) (the π0 momentum is thus present in both invariant masses).

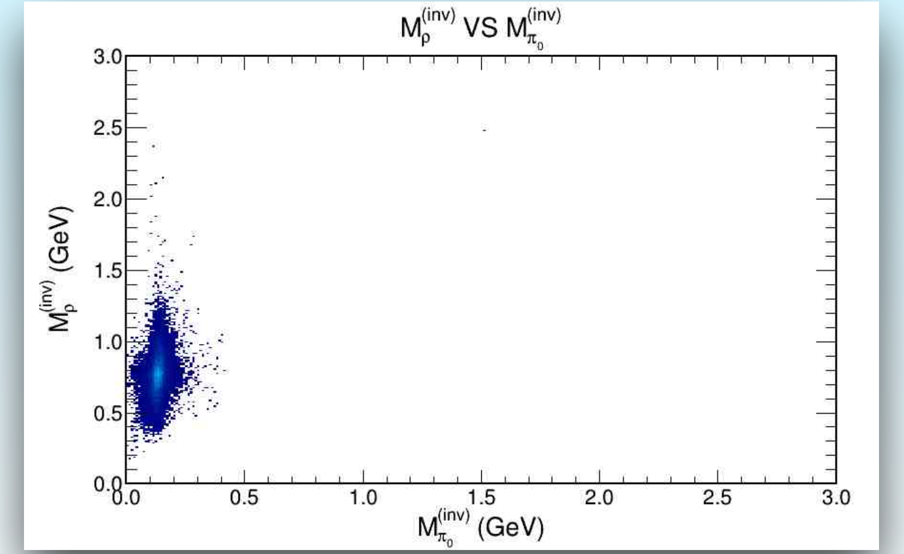
• We observe that the true ρ decay particles (top right) are distributed around (0.135 ; 0.776) GeV, the π0 and ρ true masses. All other ρ candidates are gathered in a single plot (bottom right), which we observe to be way more spread in the plane. Motivation for a **ranking method** based on the 2D cartesian distance:

$$d = \sqrt{\left(M_{\pi_0}^{(inv)} - m_{\pi_0}\right)^2 + \left(M_{\rho}^{(inv)} - m_{\rho}\right)^2}$$

Within an event, I refer as the **best** ρ, the ρ candidate which scored the smallest **d** . The best ρ can be either the true ρ, either a fake ρ.







The ranking selects events with an expected distributions. Contamination ?

The ρ degeneracy - numbers

Among a sample of ν_τCC(τ—>ρ), I found that :

- 54% had no ρ confusing candidate (no degeneracy)
- 27% had a ρ scoring the best score (I don't specify the number of fake ρ candidates defeated in the process).
- 9% finished 2nd
- 6% finished 3rd and more
- 3% were discarded (it happens, for instance, when one of the ρ daughters undergoes smearing and gets a null energy, thus considered unreconstructed).

→ **The correct ρ is selected 81% of the time, 19% contamination a this stage.**

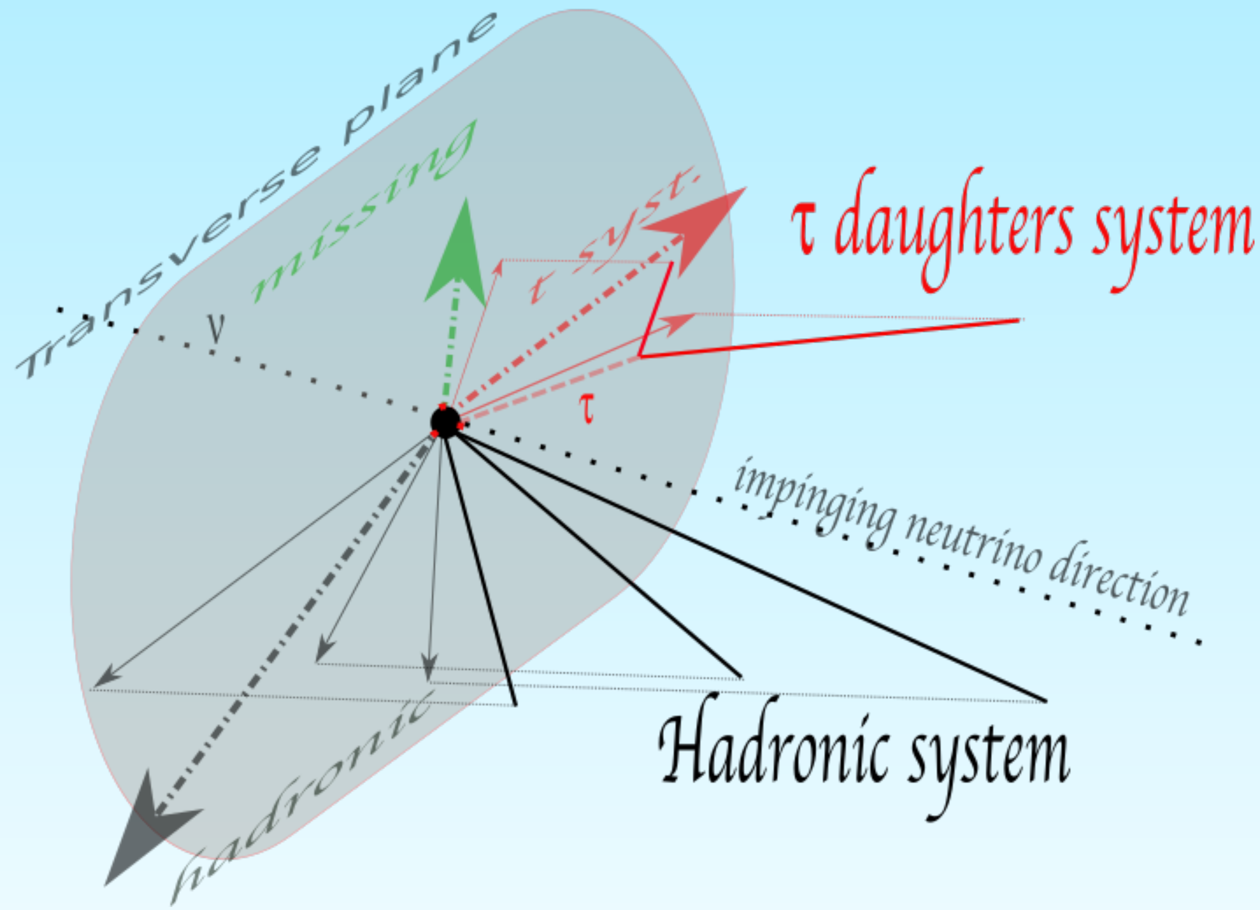
The analysis framework : assumptions, S and B definitions

For the following, I will assume that:

- I run in neutrino mode.
- I can reconstruct all charged particles energies (no smearing on them, but neutrons are discarded).
- I can identify them (as a consequence I can reconstruct their momentum), but I can't differentiate π+ from π-.

Signal = ντCC(τ—>ρ—>π⁻π0—>π⁻ γ1γ2)
Background = NC with an existing (π±π0) system. In case of ρ degeneracy, **pick the best** ρ.

- Because of the ρ degeneracy, in NC for each event I use the ρ candidate which scored the best invariant masses criteria, and use this candidate to construct the kinematic distributions.



Schematic view of a ν_τCC event

Thomas Kosc / IP2I (Lyon, France)

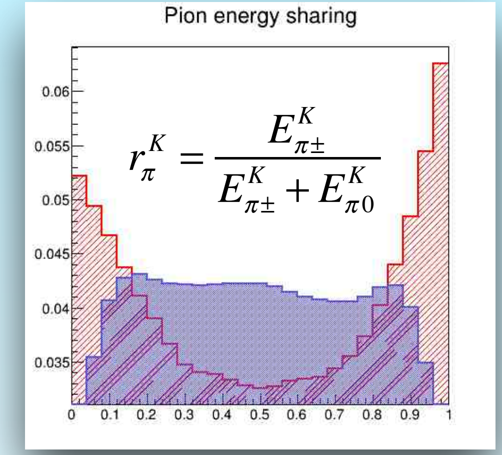
The set of kin. variables used ντCC true ρ VS NC best ρ

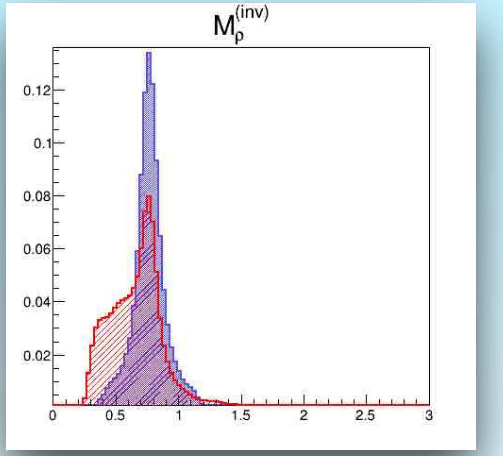
I use **16 kinematical variables**, including:

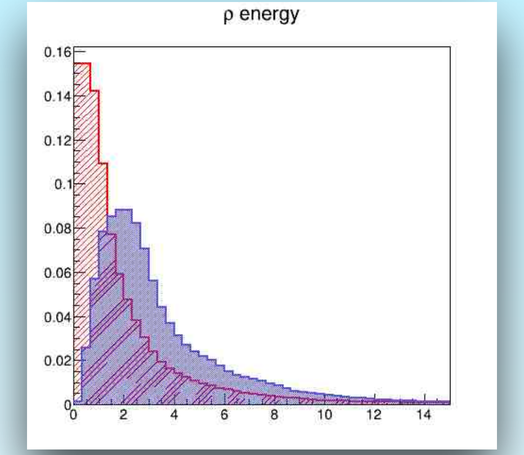
- Pions energie the sum of both (that I call the ρ energy, a terrible name), + pion energy sharing. $r_\pi^K = \frac{E^K_{\pi\pm}}{E^K_{\pi\pm}+E^K_{\pi 0}}$

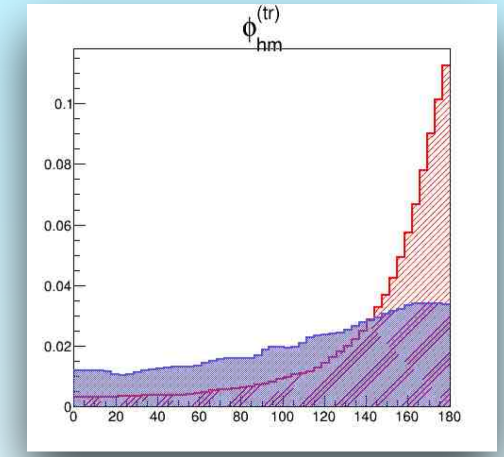
  $$E^K_{\pi_0}; E^K_{\pi^\pm}; \rho_K; r_\pi^K$$

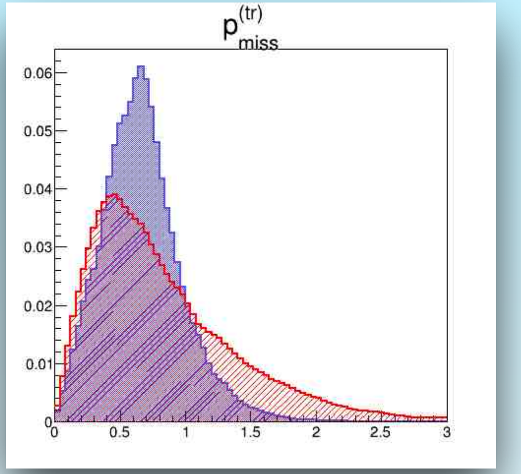
- Invariant masses for π0 and (π0π±) systems. $M^{(inv)}_{\pi 0}; M^{(inv)}_{\rho}$
- Various space angles (θ) between system momenta : ρ, h(hadronic), total, ν (beam direction). Some of these angles are representative of the isolation of the rho candidate with respect to the hadronic system. $\theta_{\rho h}; \theta_{\rho tot}; \theta_{h\nu}; \theta_{\rho\nu}$
- Transverse plane information of had. syst., ρ syst. and missing component (modulus of the momentum, plus relative direction with angle ϕ). $p^{(tr)}_\rho; p^{(tr)}_{had}; p^{(tr)}_{miss}; \phi^{(tr)}_{h\rho}; \phi^{(tr)}_{hm}; \phi^{(tr)}_{m\rho}$









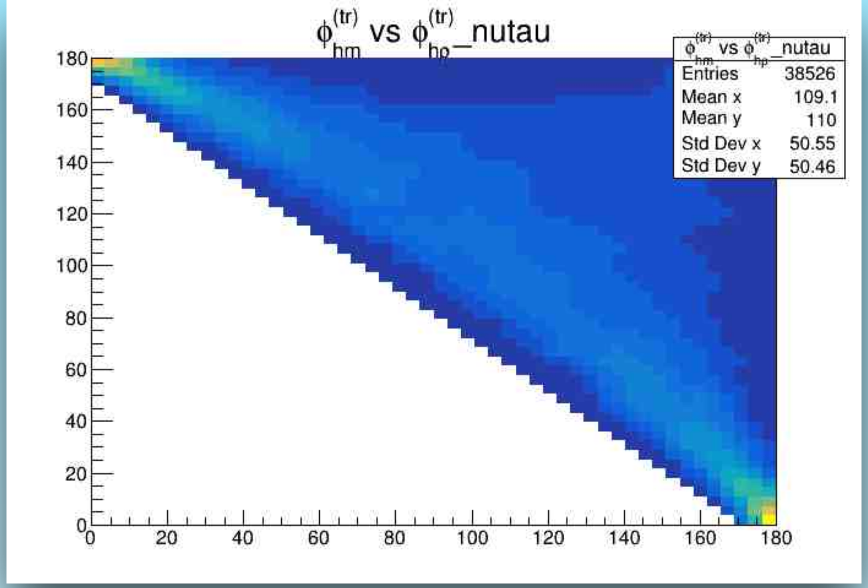


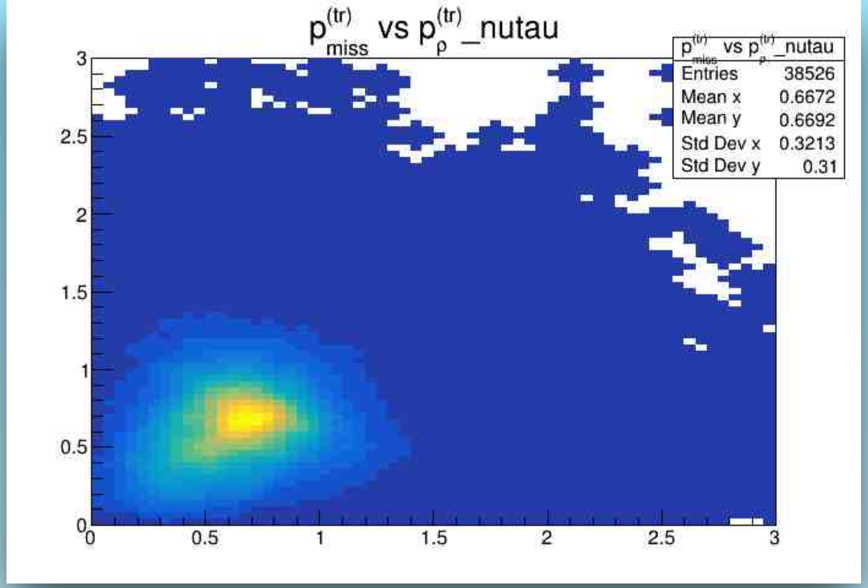
- Pion energy sharing: S has ~flat distribution, while B has asymmetry in the energy sharing.
- Red ρ invariant mass dist. has a strange shape because of the ρ selection criteria (cf. slide 4).
- Pions of S have higher energy than B.
- In the transverse plane, the missing momentum is ~180° with respect to the hadronic momentum for NC (which is what we expect, since their is no true ρ system)

The set of kinematic variable : 2D correlations

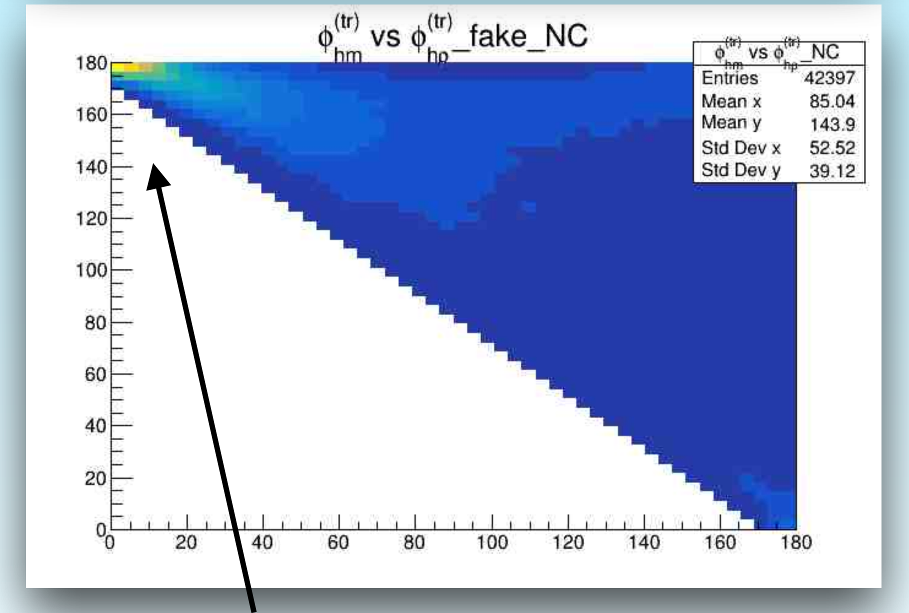
To improve the discrimination power, one can have a look at 2D correlations of variables. Some illustrations

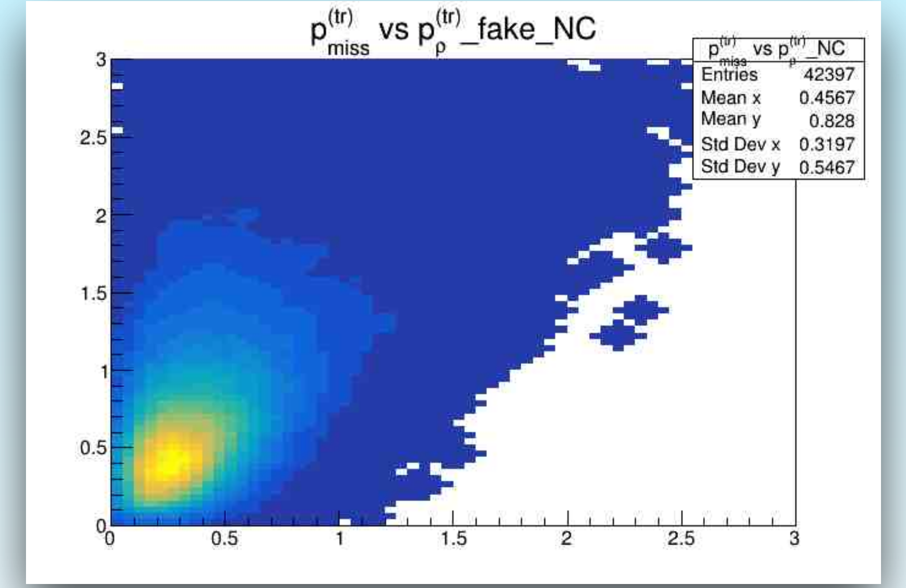
Signal





Background

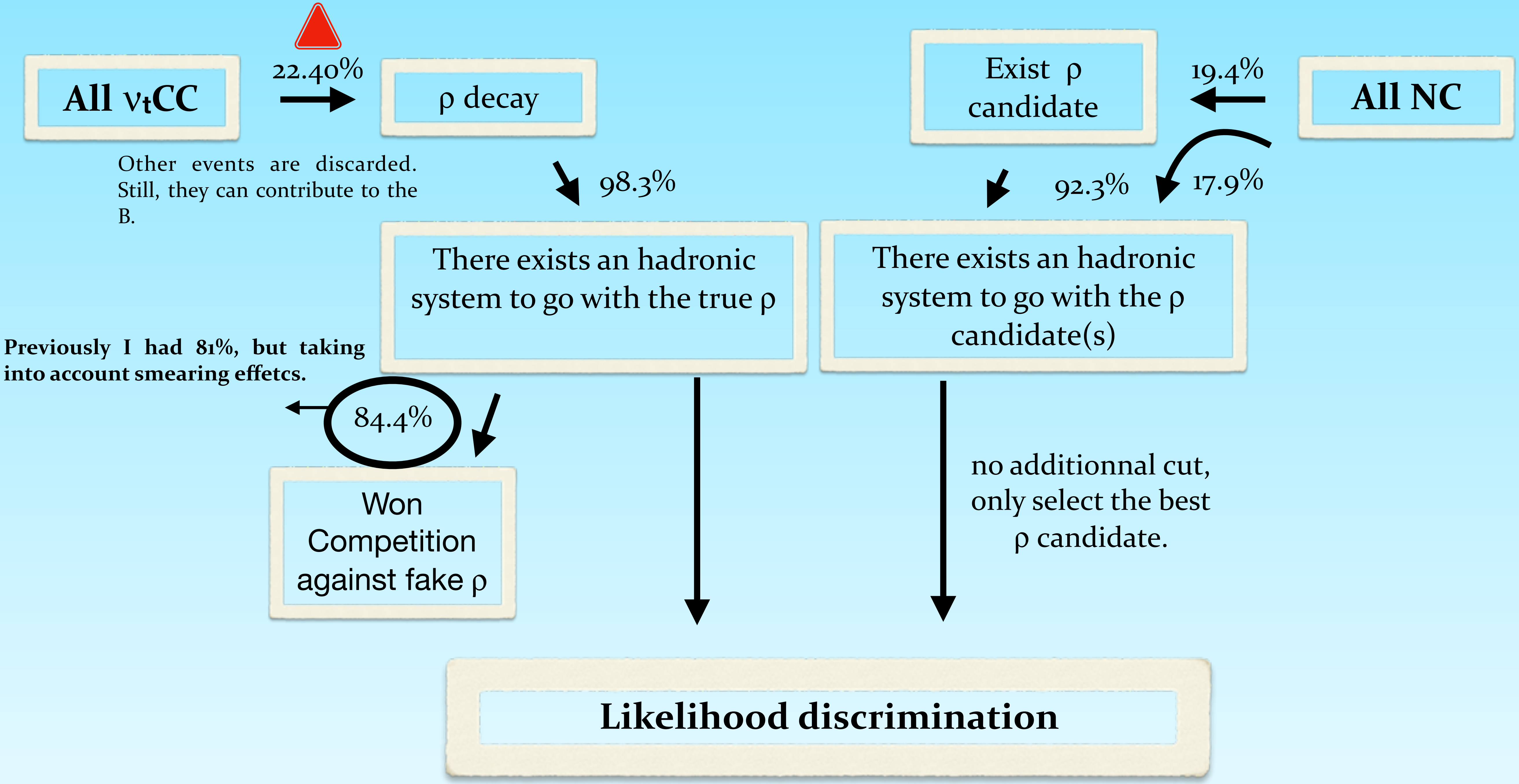




For NC: ~0° transverse rh angle and ~180°. Signal is more spread.

Different region of the plane prefered.

The process of the S/B analysis



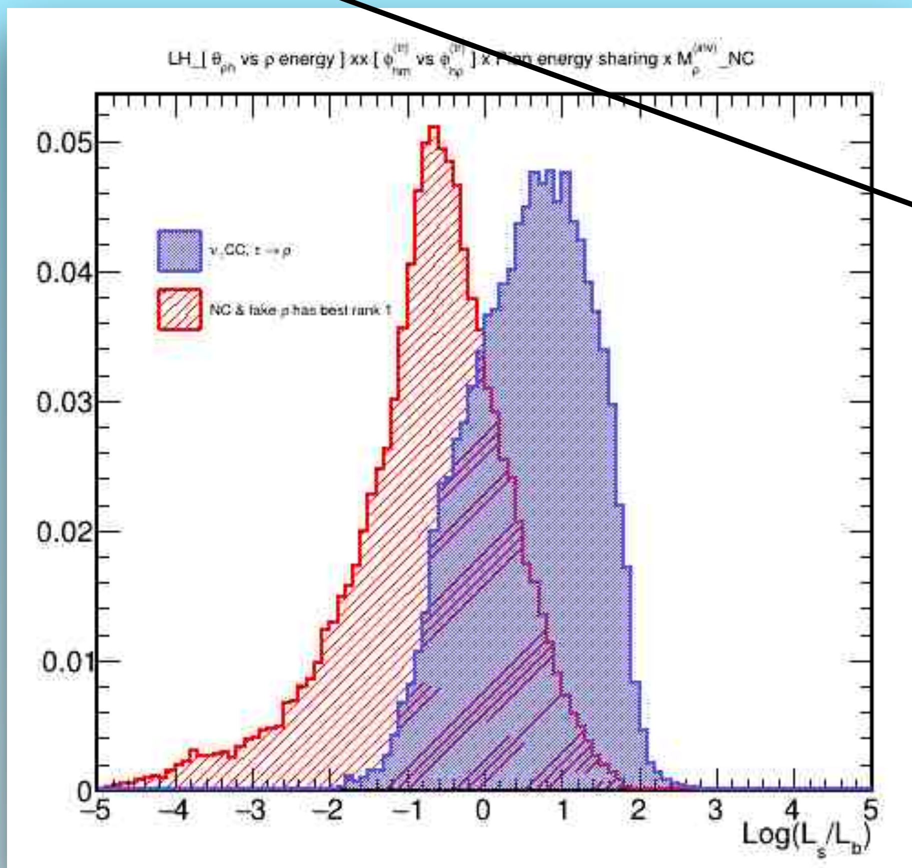
Many possibilities at this point. I isolated most powerful 2D correlation variables (one that had the greatest S/ B ratio), and tried diverse combinations of these most powerful candidates to optimise the likelihood search.

This BR decay isn't in agreement with the PDG, expected 25.49%, stat. fluctuation of my number is of the order 0.1%. I will reweight it, but a specific investigation is ongoing.

Optimised likelihood search

$$\left[\theta_{\rho h};\rho_K\right]\times\left[\phi_{hm}^{(tr)};\phi_{h\rho}^{(tr)}\right]\times M_{\rho}^{(inv)}\times r_{\pi}$$

$$\left[\theta_{\rho h};\rho_K\right]\times\left[p_{miss}^{(tr)};p_{\rho}^{(tr)}\right]\times M_{\rho}^{(inv)}\times r_{\pi}$$

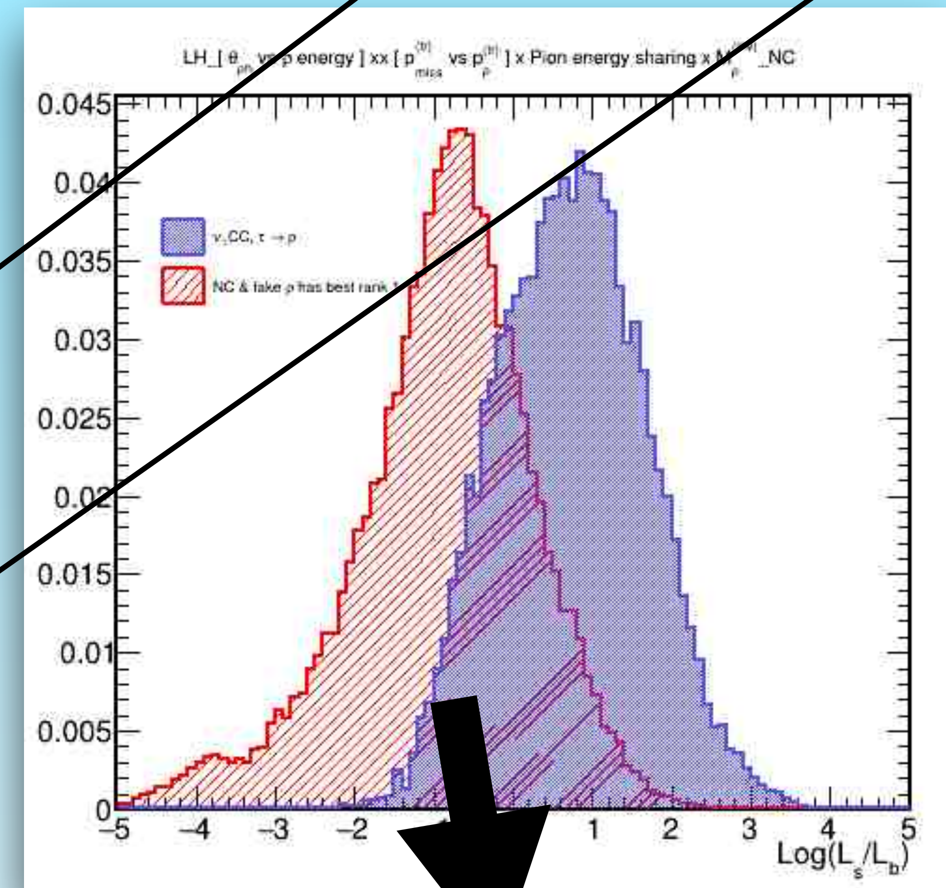


space angle between ρ daughters system and hadronic system

r energy

Transverse momenta

ratio of the pions energy sharing



LH Cut	0.2	0.4	0.6	0.8	1.0	1.2
S (%) fake ρ (%)	70.1 (6.3)	63.1 (5.1)	55.3 (4.0)	47.4 (3.0)	39.2 (2.3)	31.2 (1.6)
B (%)	15.1	11.0	7.8	5.3	3.2	2.1
S/sqrt(B)	1.80	1.90	1.98	2.06	2.16	2.15

Likelihood plots are normalised to 1. They inform on the discrimating power of the variables, but don't provide normalised S/B estimations.

Optimised likelihood search - normalisation

- 3.5 years staged
- 1.1e21 POT
- 1.2 MW beam
- DUNE CP violation optimised flux

$$\left[\theta_{\rho h};\rho_{energy}\right]\times\left[p^{(tr)}_{miss};p^{(tr)}_{\rho}\right]\times M^{inv}_{\rho}\times ratio$$

LH Cut	0.2	0.4	0.6	0.8	1.0	1.2
S_norm (fake r)	31.8 (2.9)	28.6 (2.3)	25.1 (1.8)	21.5 (1.4)	17.8 (1.0)	14.2 (0.7)
B_norm	187.9	136.9	97.1	66.0	41.1	26.1
S/ sqrt(B)_norm	2.32	2.44	2.55	2.65	2.78	2.78

DUNE 3.5 year staged expected number of events at FD.

181 ntCC → 25.49% → 46.1 τ—>ρ—>π⁻π0 → 98.3% → 45.4 There exists a counter had. syst.

6953 NC → 19.4% → 1348.9 Exist ρ candidate → 92.3% → 1245.0 There exists an hadronic system to go with each r candidate

Efficiency energy dependency for a LH cut at 1.0

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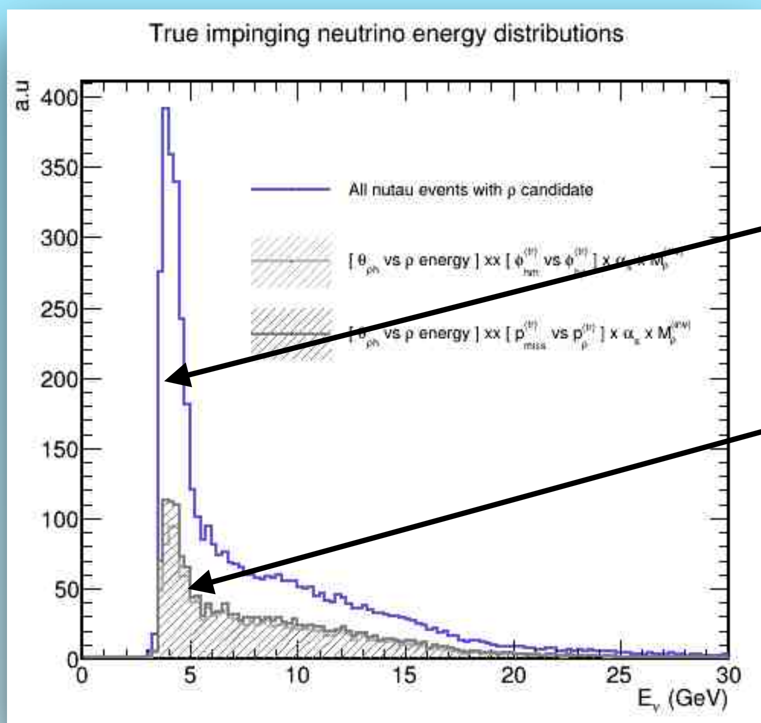
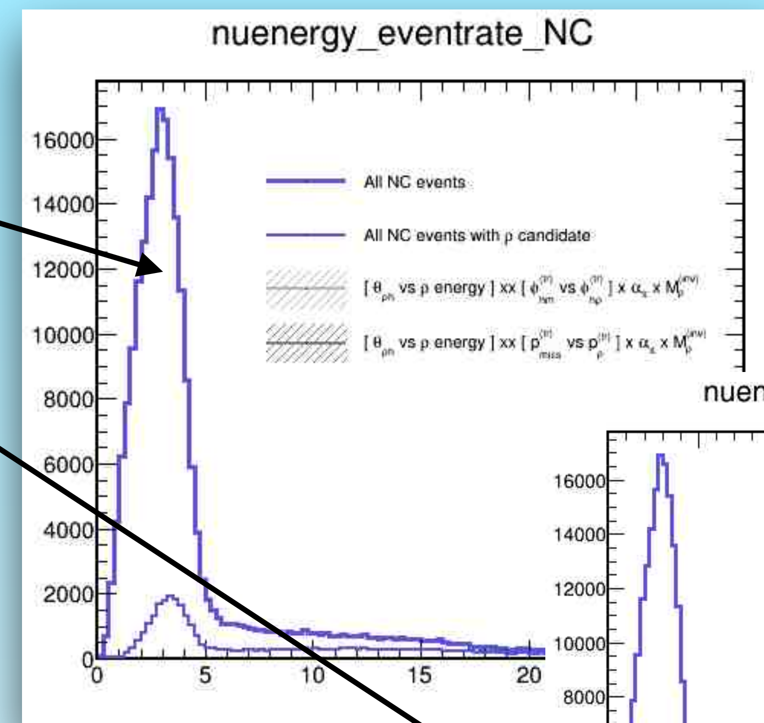
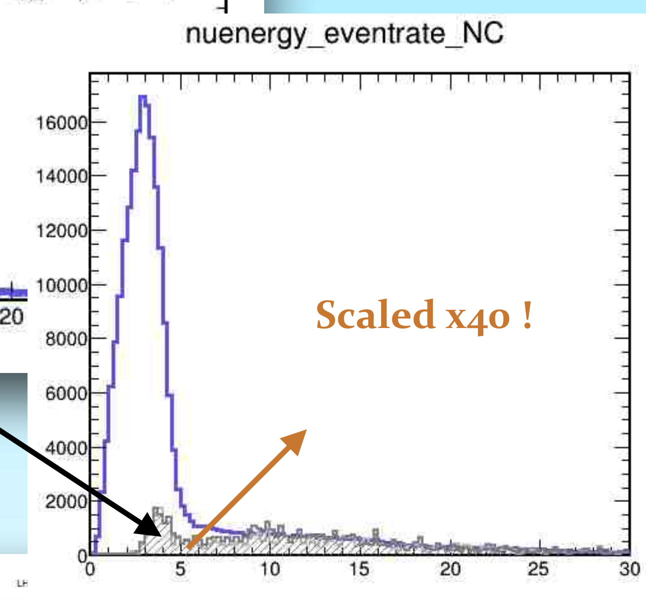
Not normalised to the DUNE flux

Signal



Background





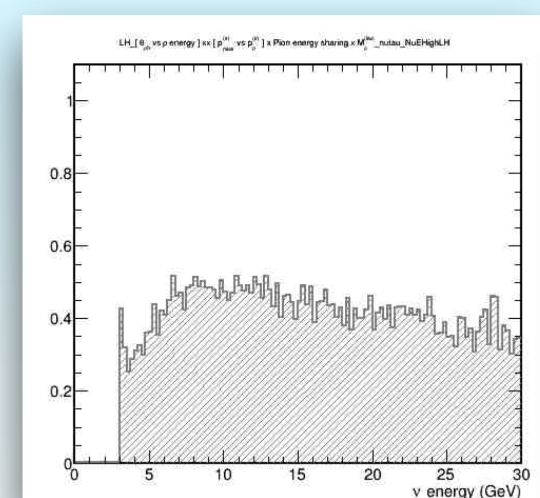
Scaled x40 !

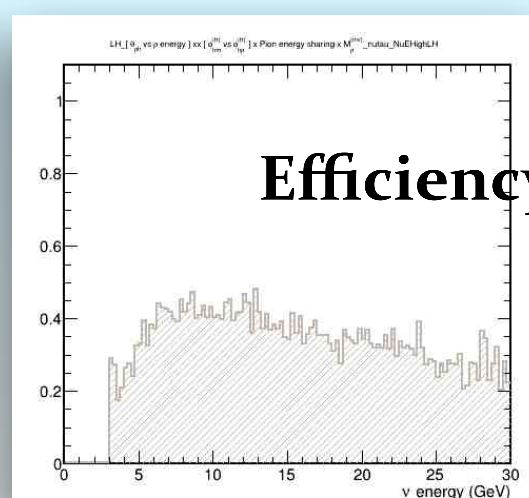
Total event rate (A.U)

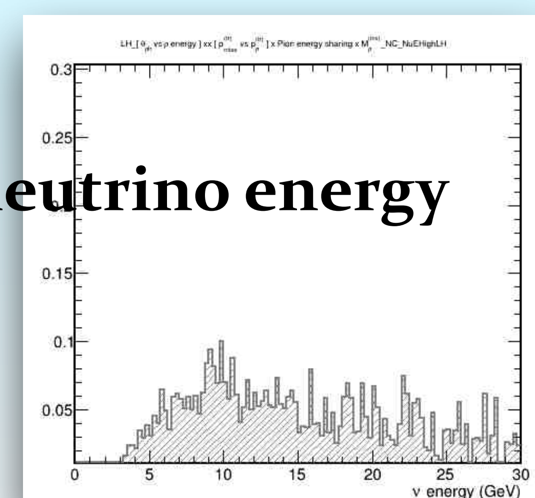
Analysis biased event rates

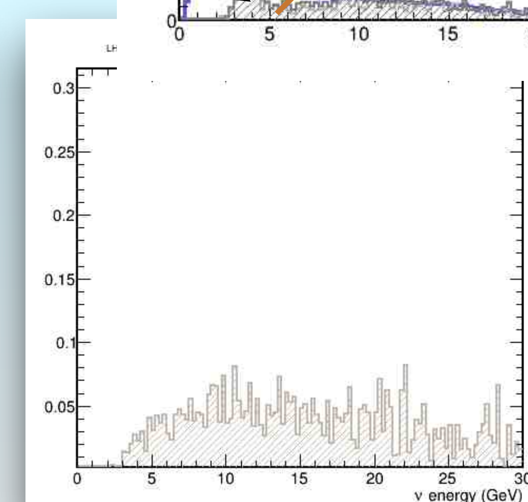
NC Event rate with ρ candidate(s)

Efficiency vs neutrino energy









Conclusion

• I presented an analysis for the ν_τ search based on kinematics for the ρ resonant decay mode, exploiting its large branching ratio (25%). It follows and extend an analysis I had made for the leptonic decay modes.

• The main background components of this process are the NC with final state pions that can mimic the true ρ signature. We exploited the rich kinematic information to discriminate between S and B. It appears there is the possibility to select a sample of ~18 ντCC events in a 3.5 years staged run, while having a NC contamination of ~41 (S/sqrt(B)=2.78).

• This analysis is slightly improvable injecting the π+/π− idendification, that helps reducing the background (less fake ρ candidates in a single event, thus less likely to mimic a true ρ). The previous S/B selection would move from 18/41 to ~20/32 (S/sqrt(B)=3.50)

• Additionnal stuff to be discussed: particle smearing effect…