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

ν_τ meeting group

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DEEP UNDERGROUND NEUTRINO EXPERIMENT

Abstract

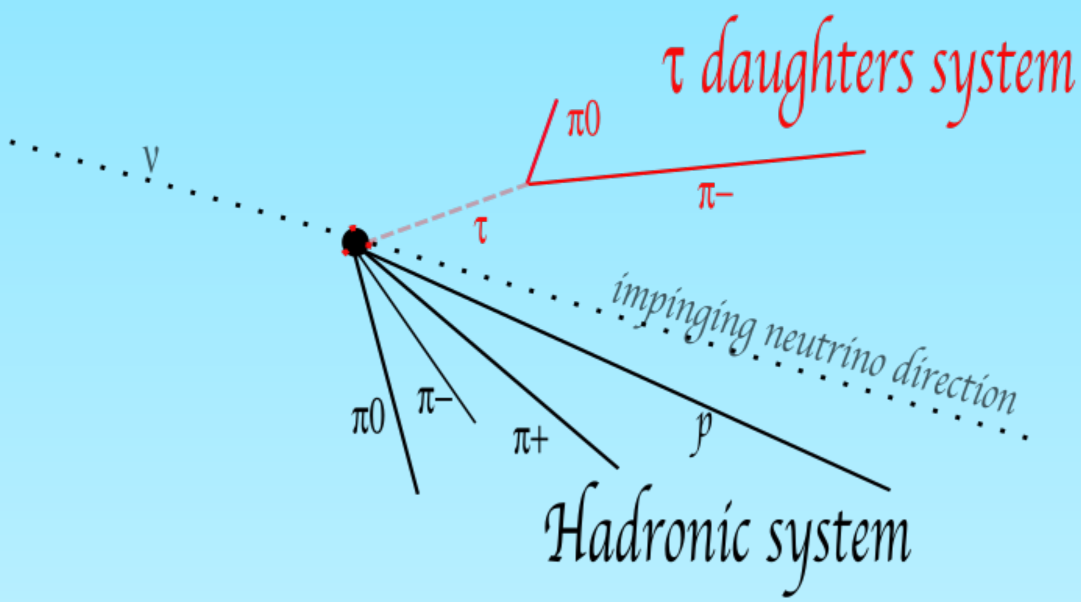
- I developed a likelihood method to identify ν_τCC interactions at DUNE FD (*https://indico.fnal.gov/event/46717/*). Recently I focused on the τ—>ρ decay channel. Large BR (~25%), resonance (kinematic signature with invariant masses). ''à la NOMAD''.
I worked on the DUNE TDR simulation files.

- In addition to the likelihood method, I worked on comparing this analysis with one based on artificial neural networks, using the **tensorflow** plateform (python). The neural networks are built using the keras library.

- Until now, I had used the reference neutrino beam design (CP-optimized flux) https://home.fnal.gov/~ljf26/DUNEFluxes/. Discussions exist to run with a τ optmised neutrino beam. It stands at higher energy to get rid of the 3.4 GeV threshold limitations.

In this presentation I will also assess the high energy beam effect on the previously made τ—>ρ decay mode analysis.

Previous likelihood based work



Proceed in two steps:

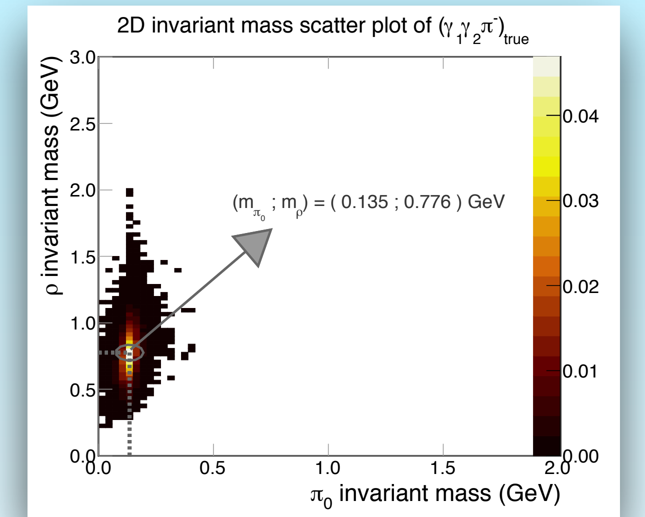
1°/ Identify the correct ρ (=**true** ρ) daughter system = $\pi_0\pi^-$ = 2γ π^- within ν_τCC(τ—>ρ) events. Had. syst. provides pions as well =>**fake** ρ.
2°/ Discriminate between a ν_τ CC and other(s) class(es) of events which mimic this signature, like NC.

Note that all NC events don't contribute to background, they must be ''ρ-like''. Fraction observed = 18%.

1°/ Identify the correct ρ in ν_τ CC events

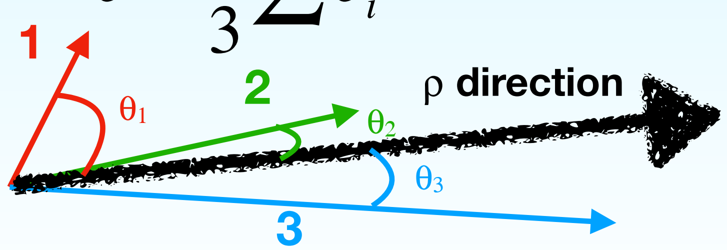
A ρ candidate is a triplet (2γ π±).

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



- One can use the invariant masses (π0 ; ρ) and compute a score to reward ρ close to the expected masses.
- The sum of pions kinetic energies is expected to be at higher energy for the leptonic system of the event. Reward higher energy candidates.
- Penalize scattered ρ candidates (higher values of mean θ).

$$\bar{\theta} = \frac{1}{3}\sum \theta_i$$



Results

Rank	-1	0	1	2	3	>3
%	2.9	52.6	29.2	6.7	1.9	6.7

Rank 0 = no fake r candidate
Rank -1 = true ρ is undetected (smearing).

81.8% correct ρ

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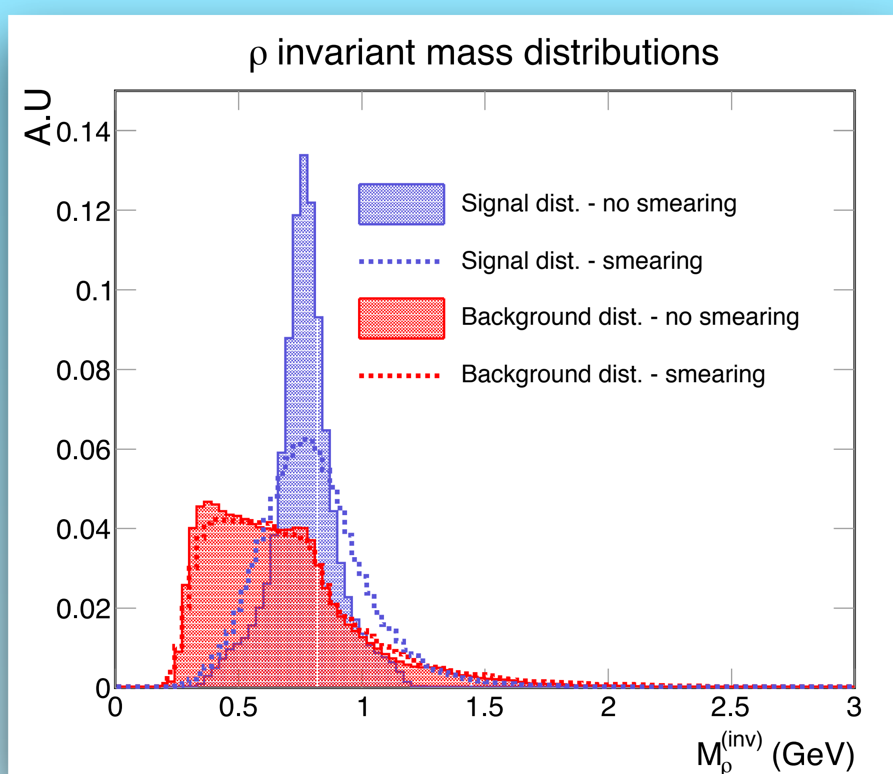
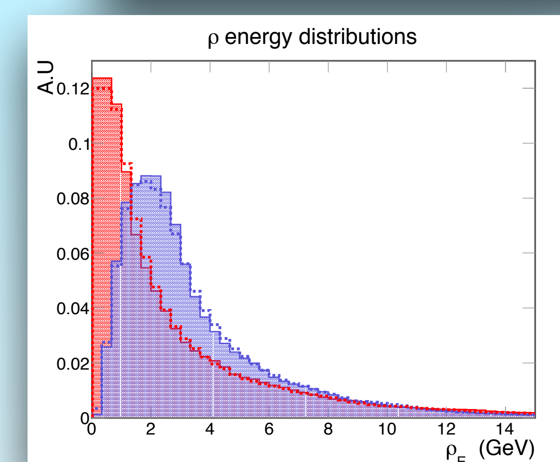
Previous likelihood based work



2°/ Discriminate between true ν_τ CC (τ—>ρ) and NC "ρ-like".

In both event classes, a best ρ is selected based on the previous method (blindly w.r.t MC truth). Events are classified based on a log-likelihood ratio.

In total I used 17 variables, their 2d-correlation, and combined the most promising ones.



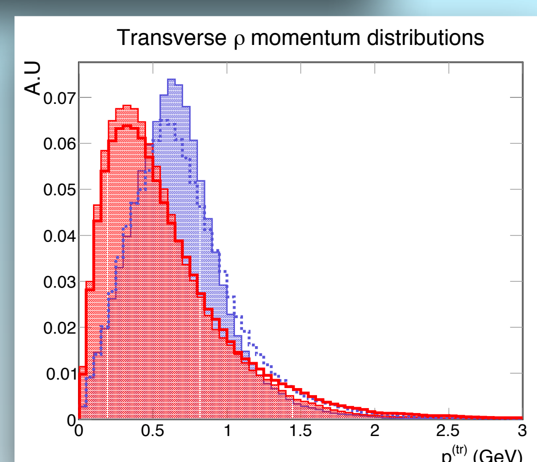
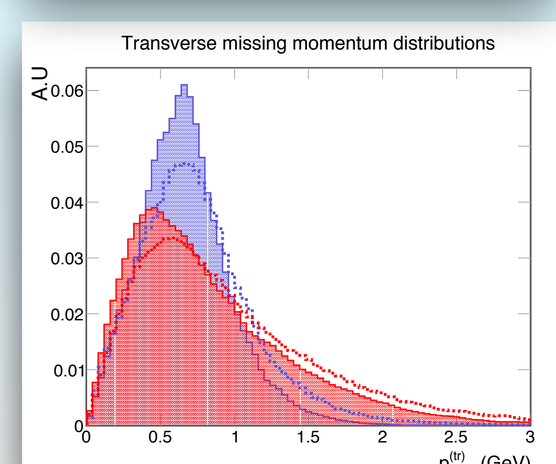
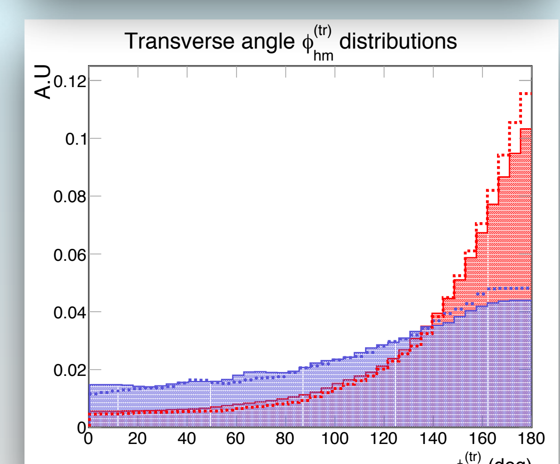
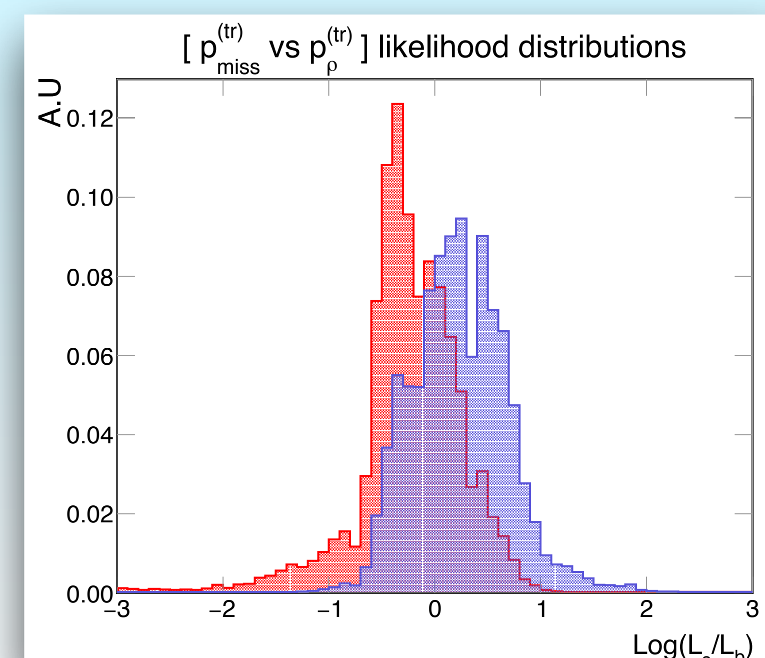


Illustration (without smearing effects) of correlation of transverse ρ momentum and missing momentum.







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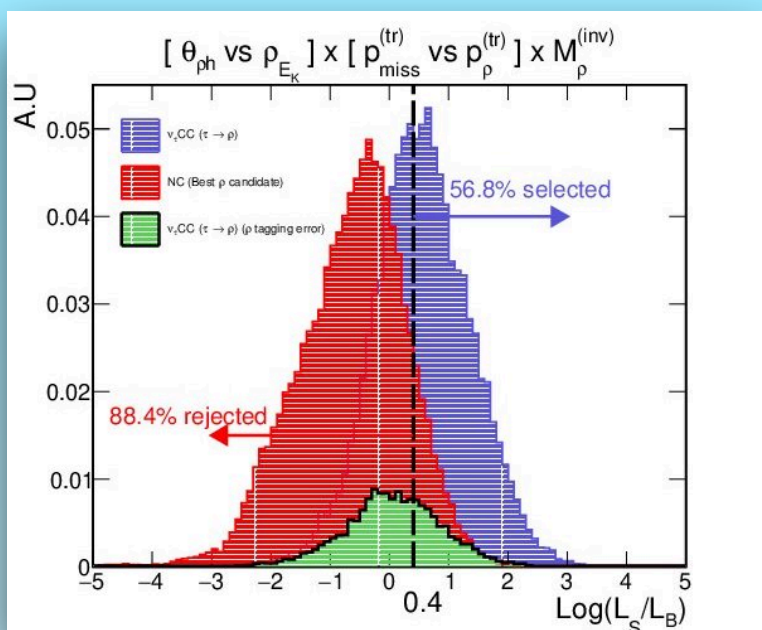
Previous likelihood work - Results

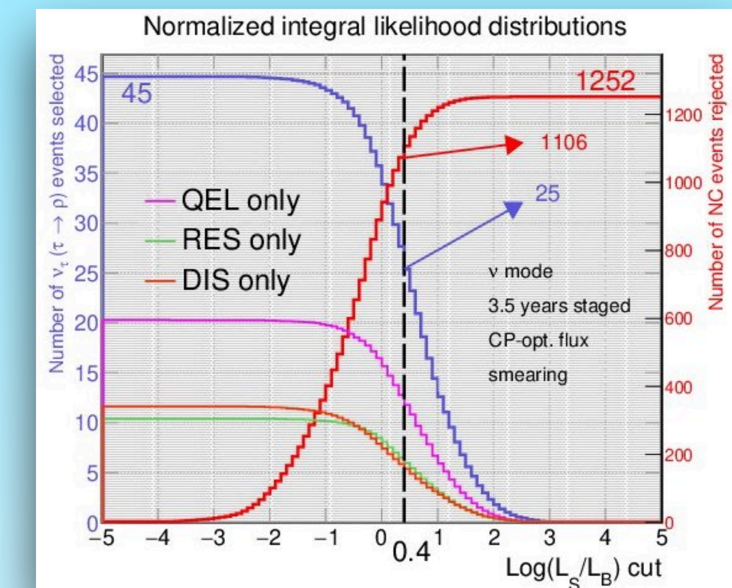
ν_τCC (τ—>ρ) and NC normalized to 1



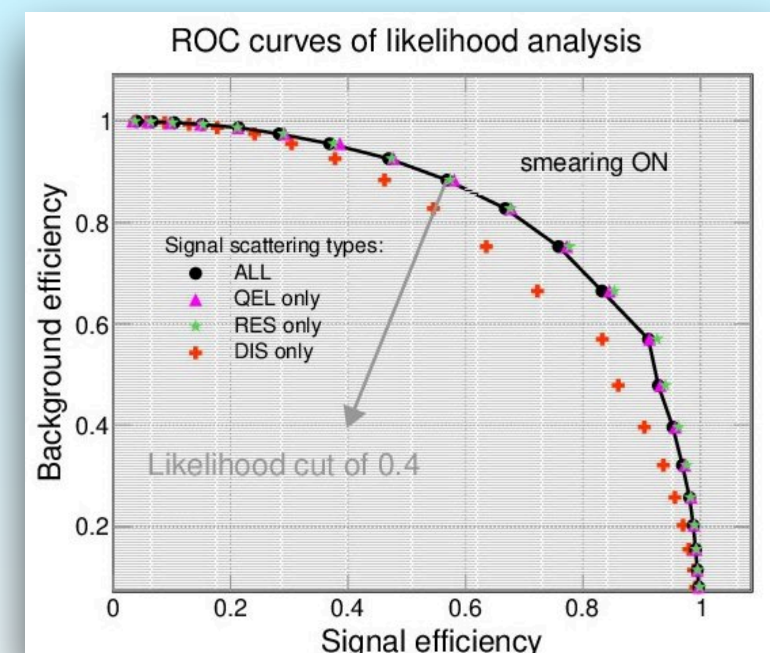
Here a cut at 0.4 would allow ~57% signal selection and ~88% background rejection

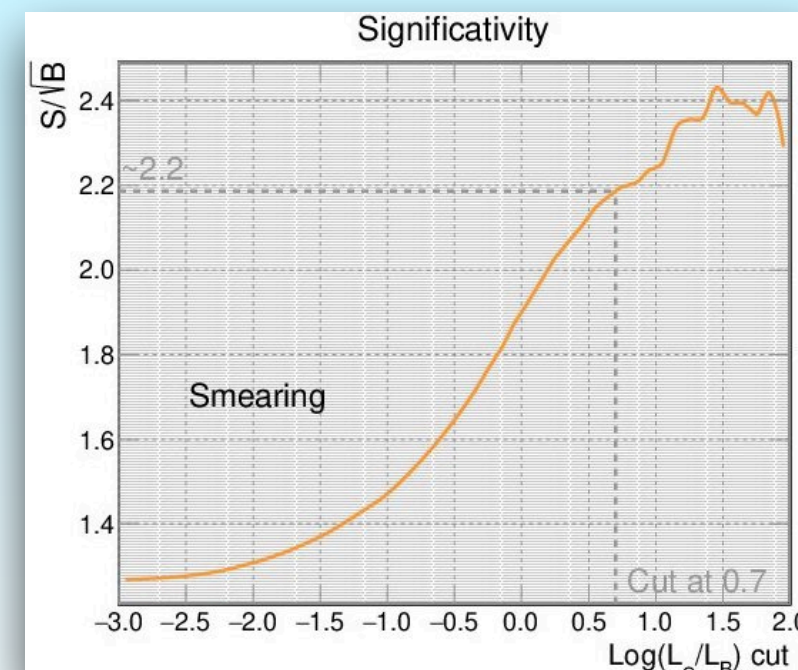
3.5 years staged normalized. I used 181 ν_τCC events and 18% x 6953 (ρ-like events).

25 ν_τ CC events, 1252-1106=146 NC events



Analysis less good on DIS than RES and QEL





Performance of an artificial Neural Network - I

I used the **tensorflow** machine learning plateform to train neural networks on the classification previously done by the likelihood. **I used 3 layers, hidden layers activation function = relu, output layer function = sigmoid.**

```
model_RhoTag = tf.keras.models.Sequential([
  tf.keras.layers.Flatten(input_shape=(X_train_RhoTag.shape[1],)), # input layer
  tf.keras.layers.Dense(32, activation='relu'), # 1st hiddden layer
  tf.keras.layers.Dense(32, activation='relu'), # 2nd hidden layer
  tf.keras.layers.Dense(64, activation='relu'), # 3rd hidden layer
  tf.keras.layers.Dense(1,activation="sigmoid") # output layer
])
model_RhoTag.compile(loss="binary_crossentropy", optimizer="adam")
```

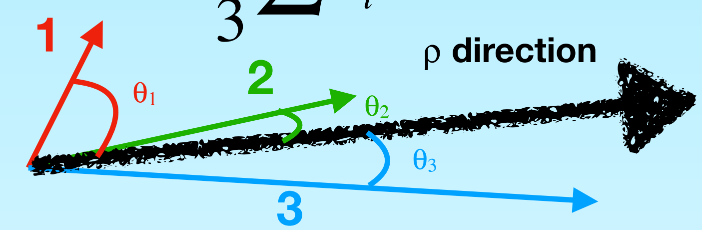
1°/ Identify the correct ρ in ν_τ CC events

- Isolate the ~40000 ν_τCC (τ—>ρ) events of DUNE TDR files. Split into ~30000 training events and ~10000 test events.

- Randomly pick ~40000 fake ρ candidates, split the same way.

- I trained using the same 3 features [NN3] (invariant masses distance to true masses, ρ energy and angle dispersion). Two other attempts [NN5 & NN7] adding the **invariant masses** as well (5 features), and adding two **transverse angles** (7 features).

$$\bar{\theta} = \frac{1}{3}\sum \theta_i$$



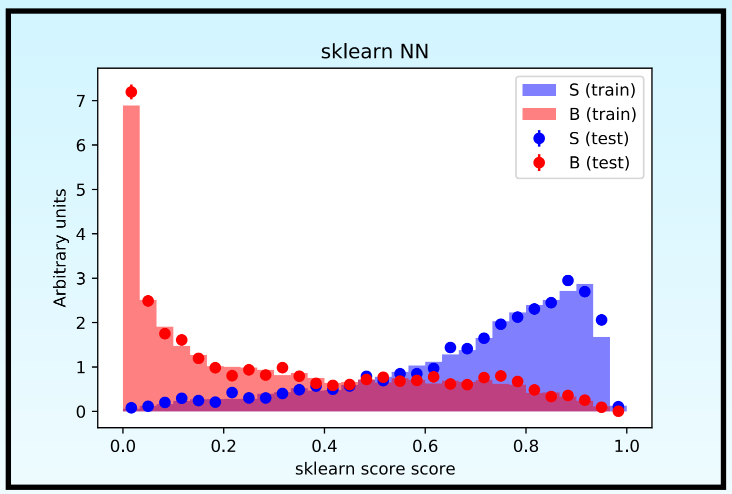
Results

NN slightly worse than standard selection based on medal game

True ρ Rank	-1	0	1	2	3	>3
Standard Selection	2.9	52.6	29.2	6.7	1.9	6.7
NN 3	2.9	52.6	**26.7**	8.7	2.7	6.5
NN 5	2.9	52.6	**27.3**	8.5	2.7	6.2
NN 7	2.9	52.6	**28.2**	8.6	2.6	5.3

No significative change w.r.t new features

I'm not a pro ! Training size ? NN structure ?



NN output for 5 features training and testing samples. Blue = true ρ. Red = fake ρ.

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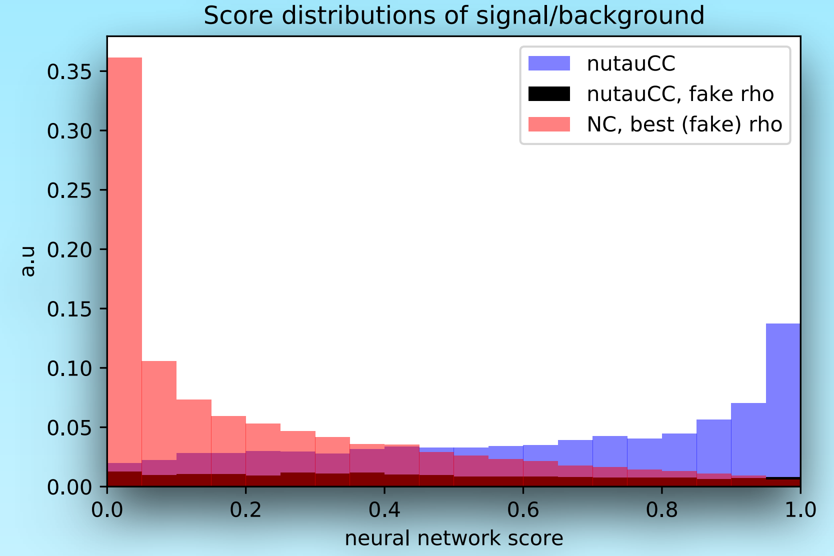
Performance of an artificial Neural Network - II

2°/ Discriminate between true ν_τ CC ($\tau \rightarrow \rho$) and NC "ρ-like".

Small hist. at the bottom concerns cases of ν_τ CC with a fake ρ propagated

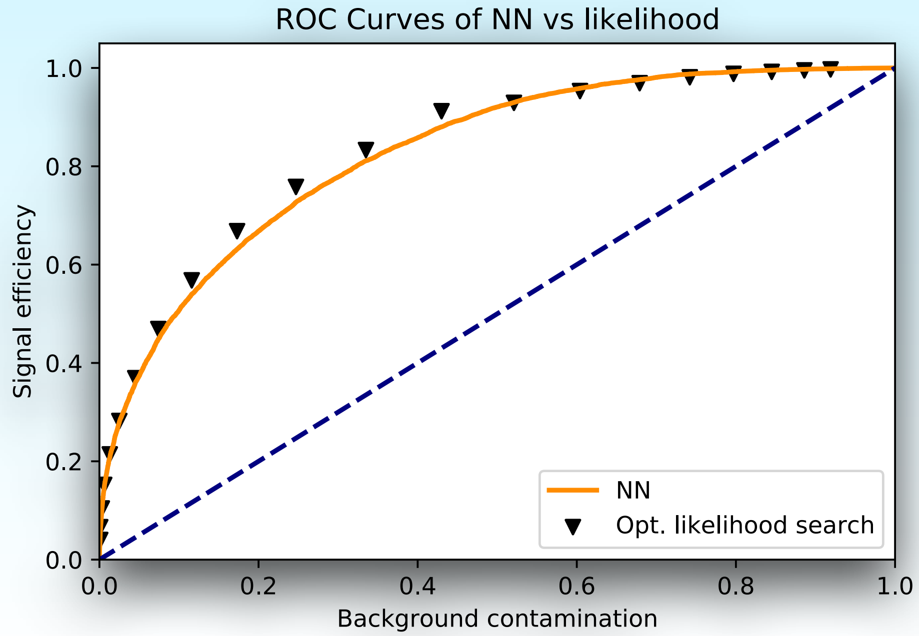


Training NN

- Isolate the ~40.000 ν_τCC ($\tau \rightarrow \rho$) events of DUNE TDR files. Split into ~30000 training events and ~10000 test events.
- Define a similar pool for NC "ρ-like" events, randomly select 40.000 of them.
- Train an other NN with the 17 variables used in the likelihood analysis.

Applying NN

- Apply this trained NN to the best ρ as selected by the previous NN (5 features), for ν_τ CC ($\tau \rightarrow \rho$) and NC ρ-like.
- Build the ROC curve as the figure of merit, and compare to the likelihood based method.



Similar performance of NN and the previously done likelihood based analysis.

Performance of an artificial Neural Network - III

The artificial neural networks, at first, didn't outperform the previous likelihood based method, both for ρ identification and S/B analysis. Similar results observed.

Further optimizing of the neural networks performance ? Ideas are welcome !

Anyway, it's reassuring to recover similar results. It indicates that the likelihood analysis had already reached a good level of optimization.

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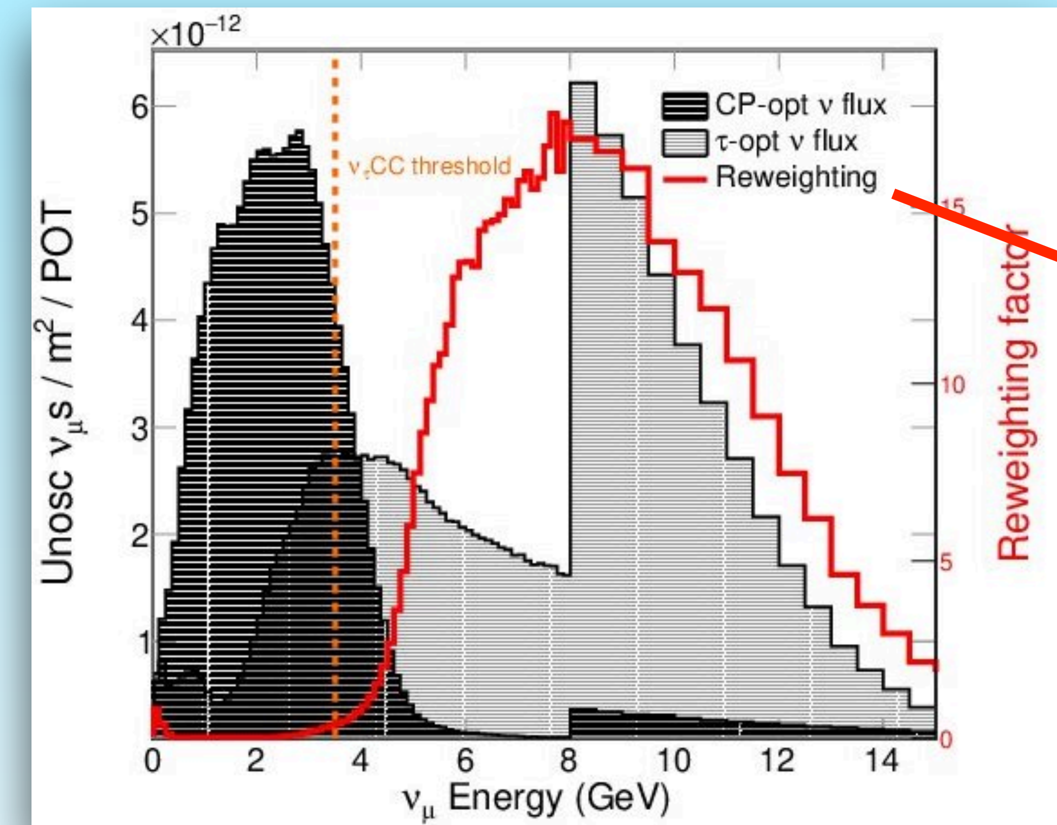
CP optimized & τ optimized flux - I

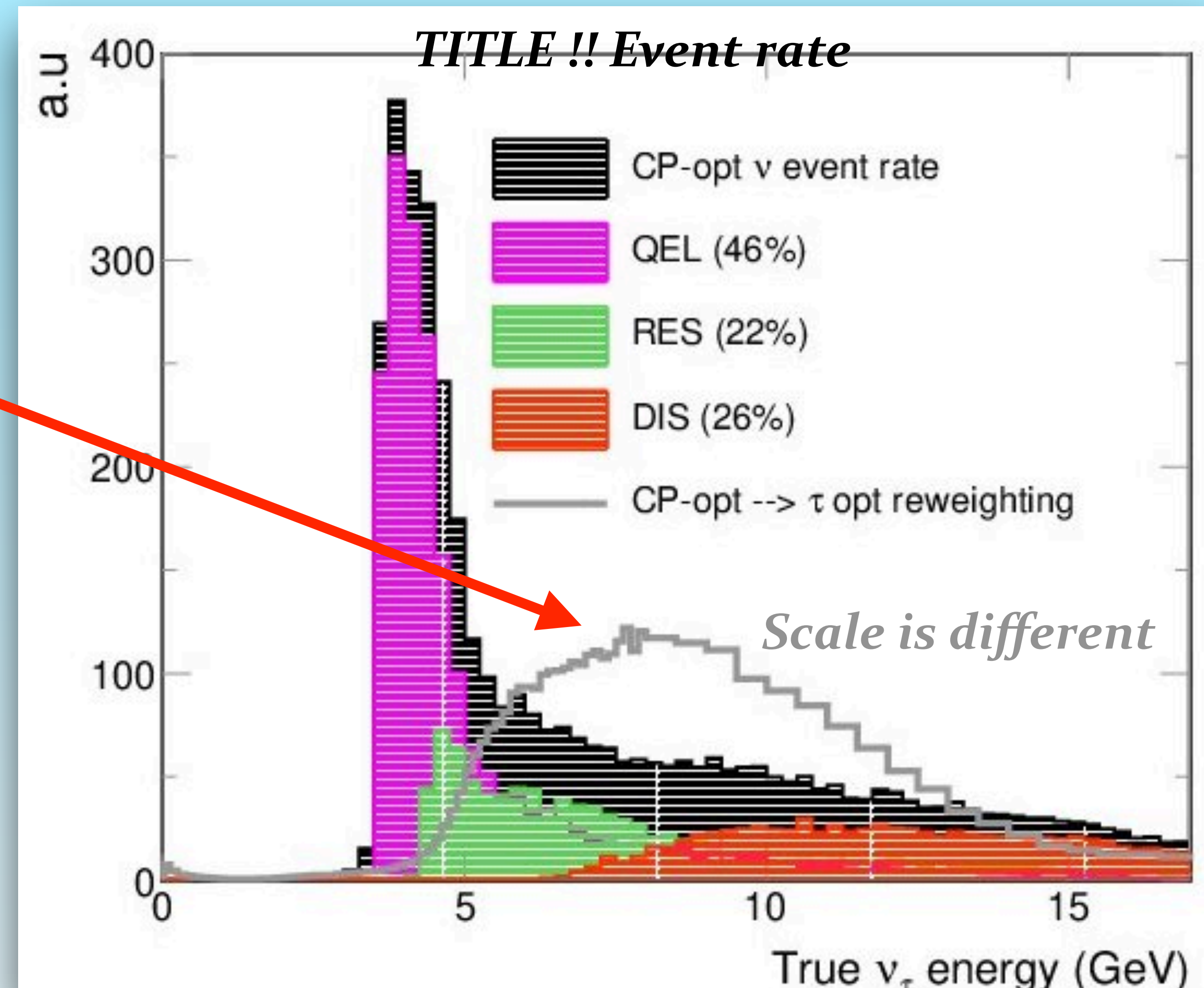
- DUNE is planned to run with the reference neutrino beam, which was designed in order to reach a maximum CP violation sensitivity https://home.fnal.gov/~ljf26/DUNEFluxes/.

Discussion ongoing on the neutrino beam to use ''after'' CP-violation measurement (if any). To support the discussion, I'll provide a direct comparison between the two fluxes on the τ—>ρ analysis.

Flux comparison



The reweighting mostly occurs at neutrino energies > 4GeV, and peaks at ~8GeV (red histogram).



On the right, one can see that the reweighting will favor RES/DIS events and disfavor QEL events.

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Discussion ongoing on the neutrino beam to use ''after'' CP-violation measurement (if any). To support the discussion, I'll provide a direct comparison between the two fluxes on the τ—>ρ analysis.

Number of events (3.5 years staged)

	CP optimized flux	τ optimized flux
ν mode		
ν_e from osc.	1187	1011
$\bar{\nu}_e$ from osc.	16	9
ν_e from beam cont.	197	146
$\bar{\nu}_e$ from beam cont.	20	15
ν_μ	5922	14258
$\bar{\nu}_\mu$	278	178
ν_τ from oscillation (QEL/RES/DIS)	181 (83/42/47)	901 (292/328/231)
$\bar{\nu}_\tau$ from oscillation	13	9
NC	6953	9188

- ν_τ CC events get a factor 5 in statistics !
- QEL / RES / DIS from 46%/22%/26% to 32%/36%/27%.
- More NC background (gain factor ~1.3). Also more NC are ''ρ-like'' (higher energy beam). The fraction of ''ρ-like'' NC increases from 18% to 33% of the total NC.

Real Background increase factor = (0.33*9188) / (0.18*6953) ~ 2.4

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CP optimized & τ optimized flux - II

1°/ Identify the correct ρ in ν_τ CC events

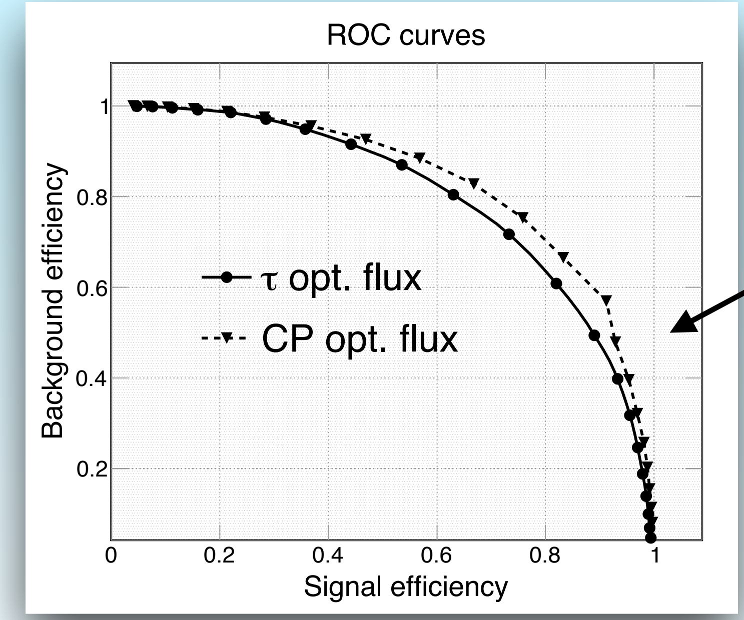
True ρ Rank	-1	0	1	2	3	>3
CP flux (%)	2.9	52.6	29.2	6.7	1.9	6.7
τ flux (%)	2.6	42.9	37.4	8.5	2.3	6.5

52.6+29.2 = 81.8% VS 42.9+37.4 = 80.3%.

No overall significative change in ρ tagging efficiency !

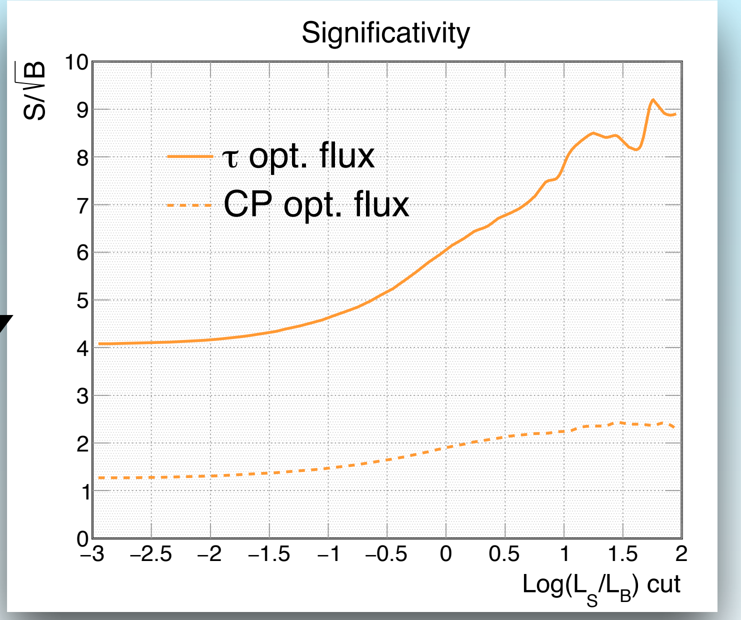
2°/ Discriminate between true ν_τ CC (τ—>ρ) and NC "ρ-like".

Run over the 17 kinematic variables previously used again, to see if other sets and combinations work better with the new flux. I didn't find such improvement. Comparison between the figure of merits of the likelihood analysis with both neutrino flux :



Slight decrease in the overall S/B discriminating power

Significative increase in the significativity (factor ~3.5)



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Conclusion

- I had presented in a previous tau meeting an analysis for the ν_τ search based on kinematics for the ρ resonant decay mode, exploiting its large branching ratio (25%).

- I compared the likelihood analysis to a simple artificial neural network (tensorflow) performance. The NN gets a similar performance.

- I compared the impact of the use of the τ optimized neutrino beam https://home.fnal.gov/~ljf26/DUNEFluxes/. This flux would multiply the ν_τ statistics by ~5 and reduce the QEL fraction of about 2/3. In parallel, the NC background (for the τ—>ρ analysis) statistics would be multiplied by ~2.4. The S/B discrimination would be slightly decreased, but largely compensated by the statistics boost of the $\nu\tau$ CC.

- **Not discussed here**: I looked at the effect of the charged pion identification (see protoDUNE-SP paper) on the same figure of merits. I observed a S/sqrt(B) increase by a factor of ~1.4.

- I started some work on the τ—>π decay mode (small BR but less fake candidate contamination). I can show results on a next meeting.