Preliminary Results on ν_e/ν_τ selection at DUNE FD.

CP violation & ν_τ physics perspectives.

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Thesis : Development of the CP violation search analysis in DUNE and assessment of the related systematics.

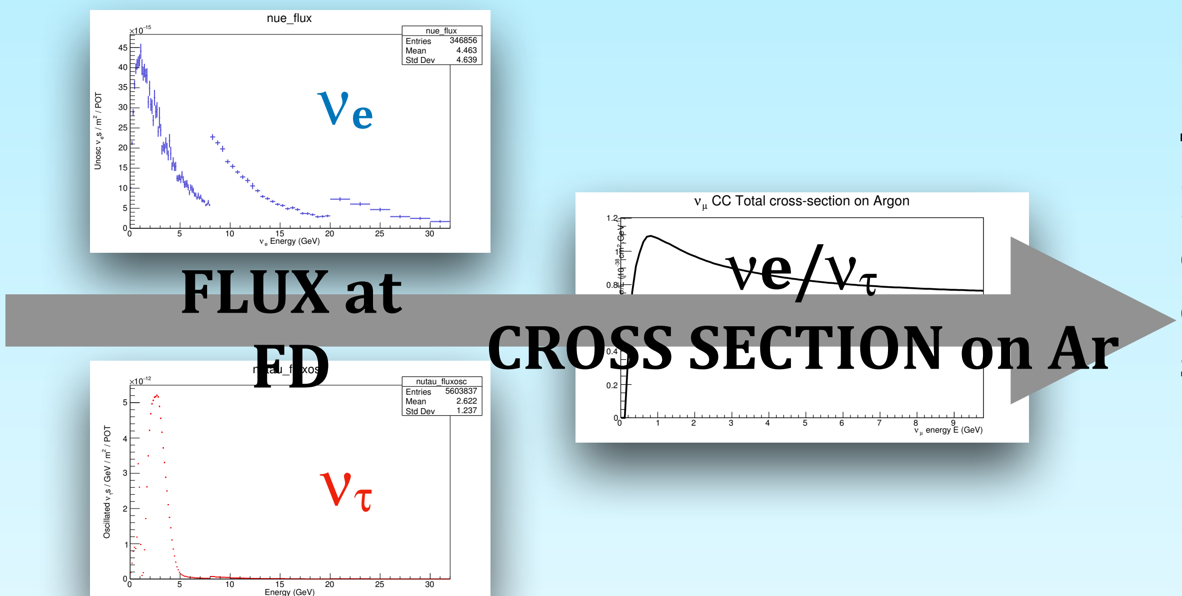
A priori discussion

- Some work on tau selection in previous meetings:
  - Herilala/Miriama thesis. ~80% of ν_e CC rejection and ~60% of ν_τ CC ($\tau \longrightarrow e^-$) kept, based on GENIE (version ?) and the ROOT Toolkit for Multivariate Analysis.
  - ν_τ appereance at NOMAD (R. Petti). Likelihood approach, up to ~1% background contamination ?
- Elaborate an analysis of ν_τ detection, based on simulations (GENIE v3.0.2). Outlook of CP violation analysis (ν_τ background rejection) and ν_τ physics (ν_τ selection).
- This talk focuses **only on CC** ν_τ **with** $\tau \longrightarrow e^- + 2\nu$ (easy channel and background of ν_e CC, but only ~17% of total branching ratio). Other channels require further analysis. The ν_τ come from the oscillation of ν_μ.
- ν_e are restricted to beam contamination at production point (without oscillation). ν_e from oscillation will depend on PMNS parameters, included later.
- Rely on GENIE only. τ decay ? ν_τ cross section ? Comparison with other generators ?

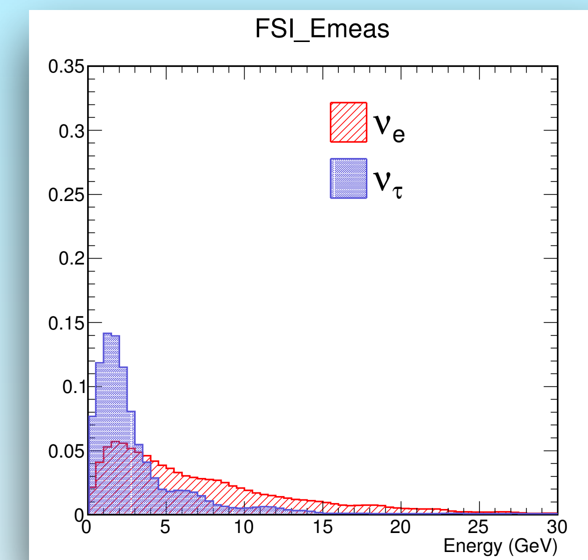
Tools & Method

- DUNE FD setup is implemented only via the flux. See the file I used: ***histos_g4lbne_v3r5p4_QGSP_BERT_OptimizedEngineeredNov2017_neutrino_LBNEFD_fastmc.root***. Results are flux dependent, any comparison should be careful with using the same flux.
- Neutrino cross sections, GENIE pre-computed file ***NULL_G1802a00000-k500-e1000*** (see "Associated data release" on **http://www.genie-mc.org/**).
- Two files generated and used for the time being: oscillated ν_μ —> ν_τ and unoscillated ν_e contamination. Both at FD.

Genie
UNIVERSAL NEUTRINO GENERATOR & GLOBAL FIT



Two files generated. Right : distributions of total kinetic energy in the final state interaction (neutrons removed).

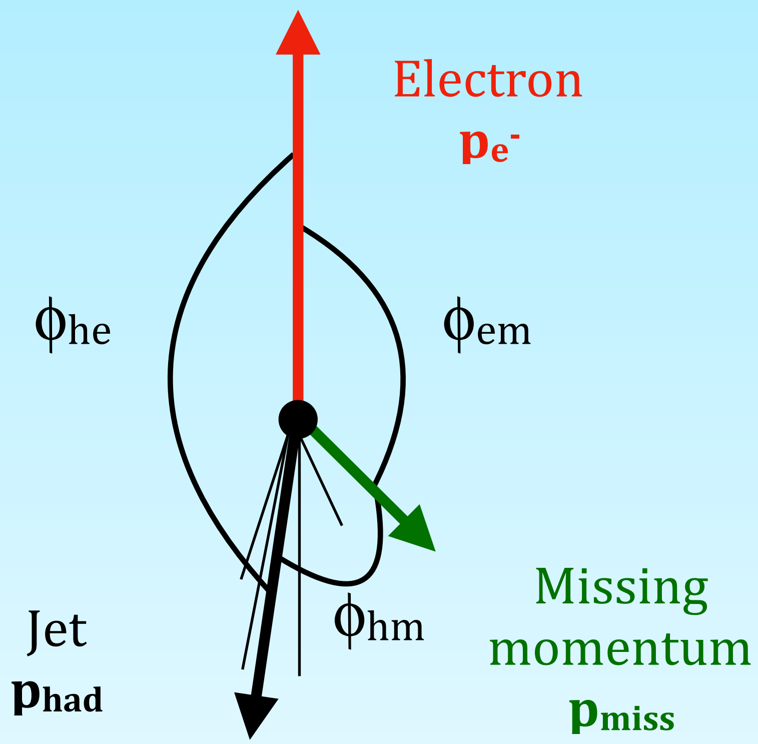


- No reconstruction effects (smearing) implemented yet. Should come in a near future.
- Easier to start with ν_e from beam contamination rather than oscillated ν_μ—>ν_e

Kinematics (neutrons removed !)

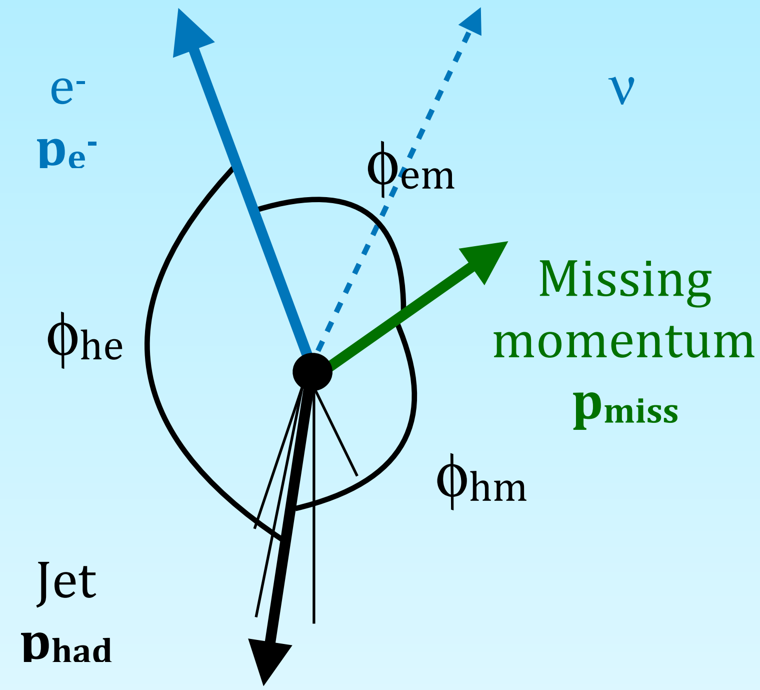
- Basic idea: distinguish CC ν_e from CC ν_τ with $\tau^- \longrightarrow e^- + \bar{\nu}_e + \nu_\tau$ using kinematical criteria (NOMAD).
- Transverse plane kinematics (TPK) (remove uncertainties due to incoming neutrino momentum).

ν_e CC in TPK



Small missing momentum, so ϕ_{he} close to 180°.

ν_τ CC in TPK with $\tau^- \longrightarrow e^-$

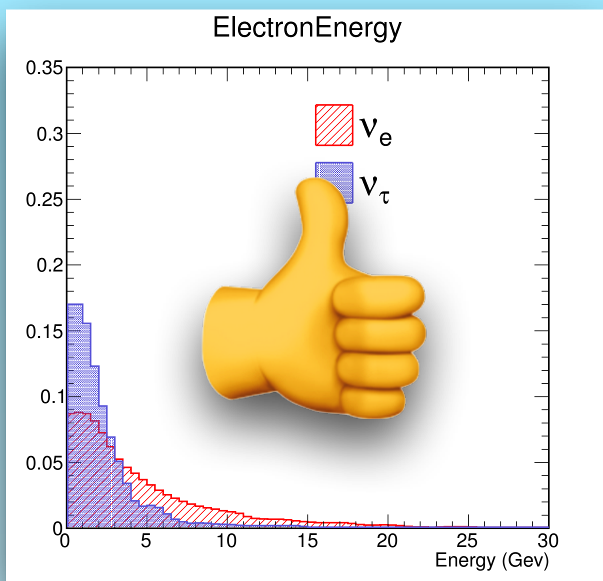


Unseen neutrinos increase the missing momentum and change the angles distributions.

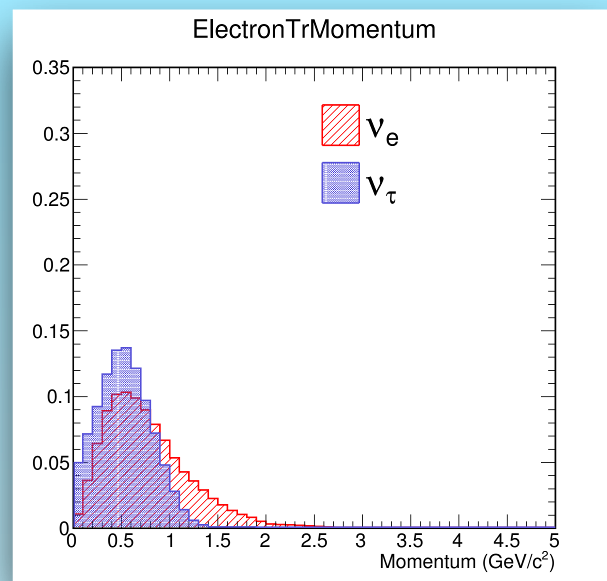
- **Kinetic variables at play:**
  - K_{e^-} = kinetic energy of the electron.
  - $p_{e^-}^{(tr)}$, $p_{had}^{(tr)}$, $p_{miss}^{(tr)}$ = tranverse momenta.
  - Angles between transverse momentum ϕ_{he}, ϕ_{hm}, ϕ_{em}.
  - $p_{asym} = \dfrac{p_{e^-}^{(tr)} - p_{had}^{(tr)}}{p_{e^-}^{(tr)} + p_{had}^{(tr)}}$

Distributions

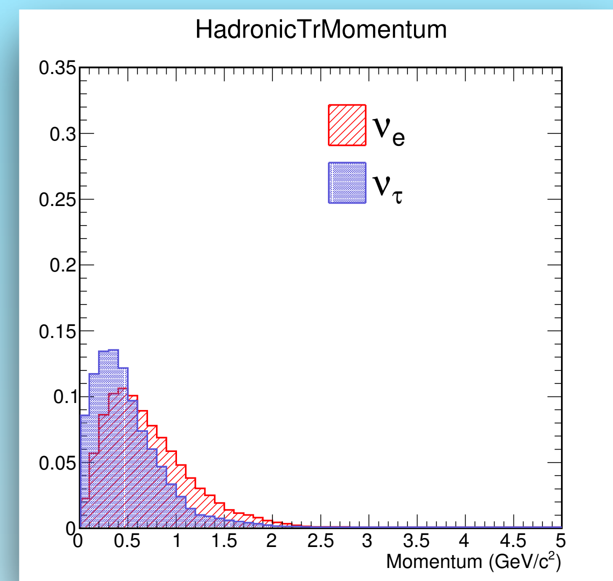
K$_{e-}$



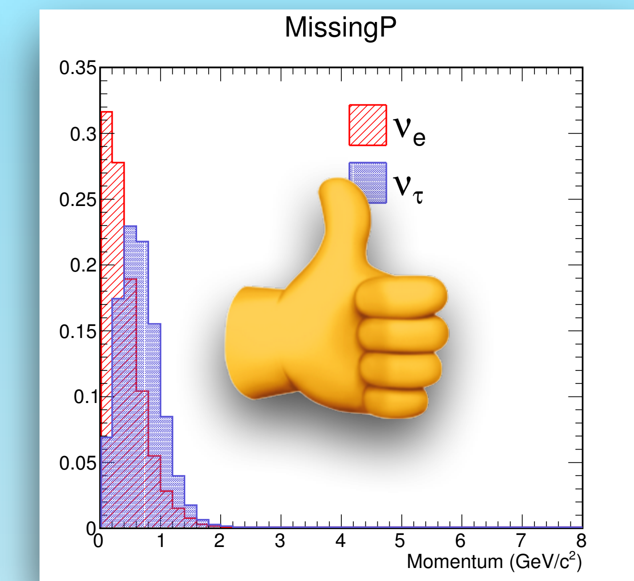
$p_{e^-}^{(tr)}$



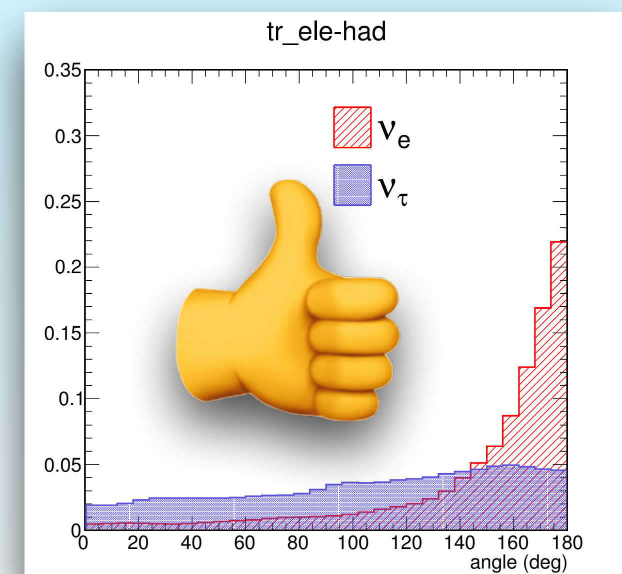
$p_{had}^{(tr)}$



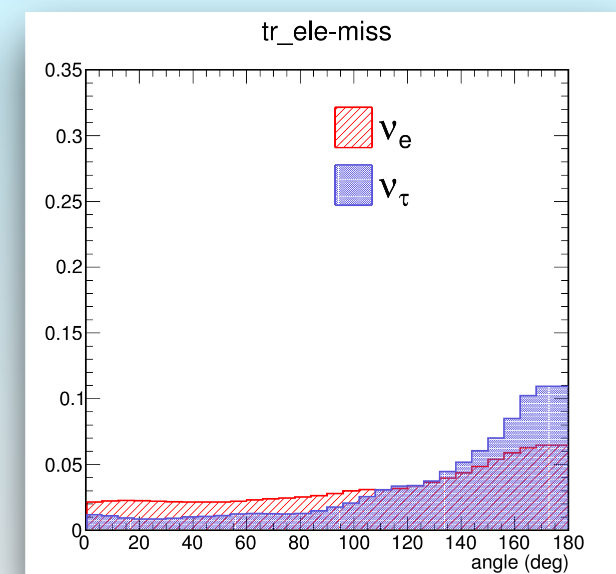
$p_{miss}^{(tr)}$



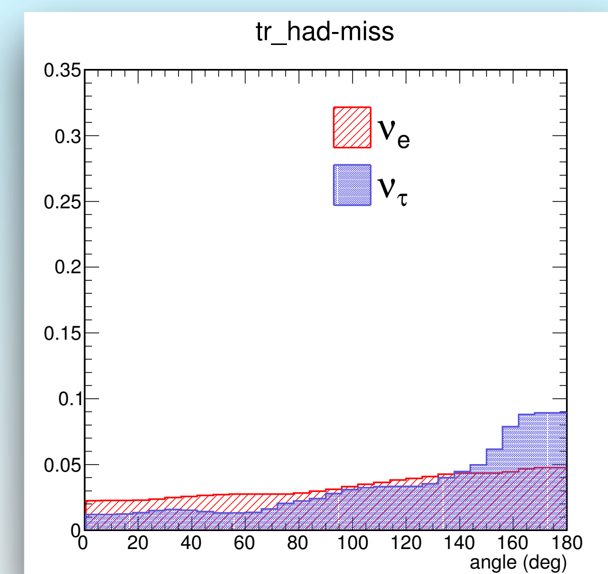
ϕhe



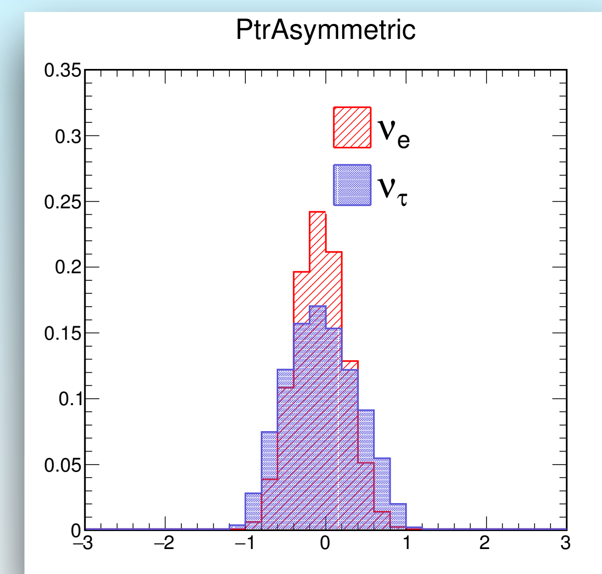
ϕem



ϕhm



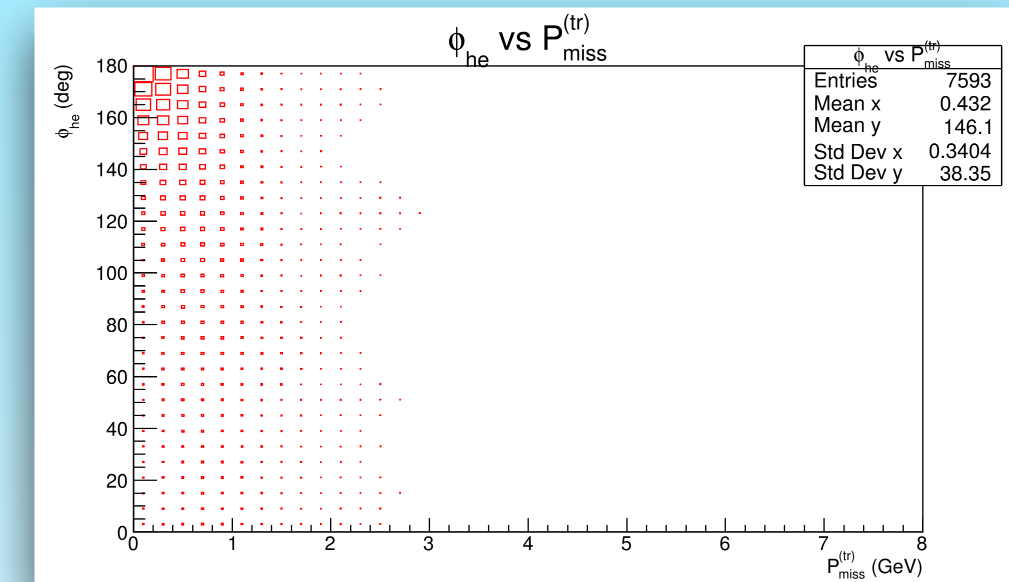
$$p_{asym} = \frac{p_{e^-}^{(tr)} - p_{had}^{(tr)}}{p_{e^-}^{(tr)} + p_{had}^{(tr)}}$$

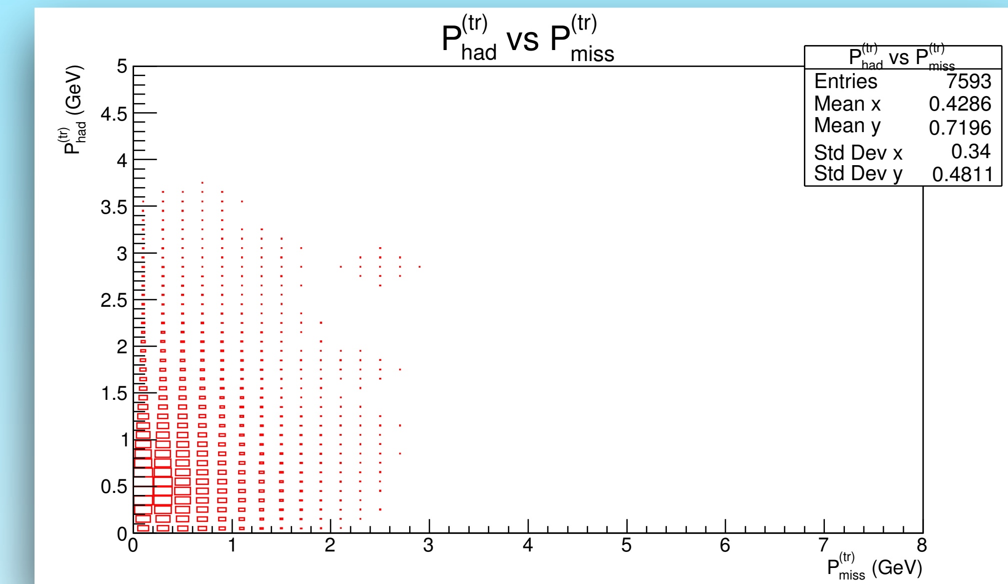


Correlations, two examples.

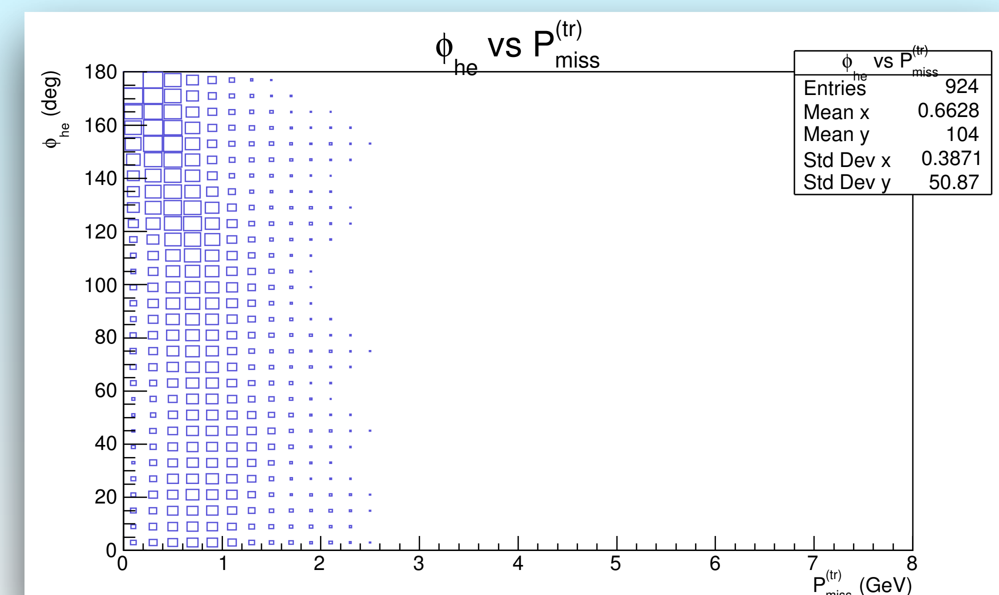
$$\left[\phi_{he}, p_{miss}^{(tr)}\right] \qquad \left[p_{had}^{(tr)}, p_{miss}^{(tr)}\right]$$

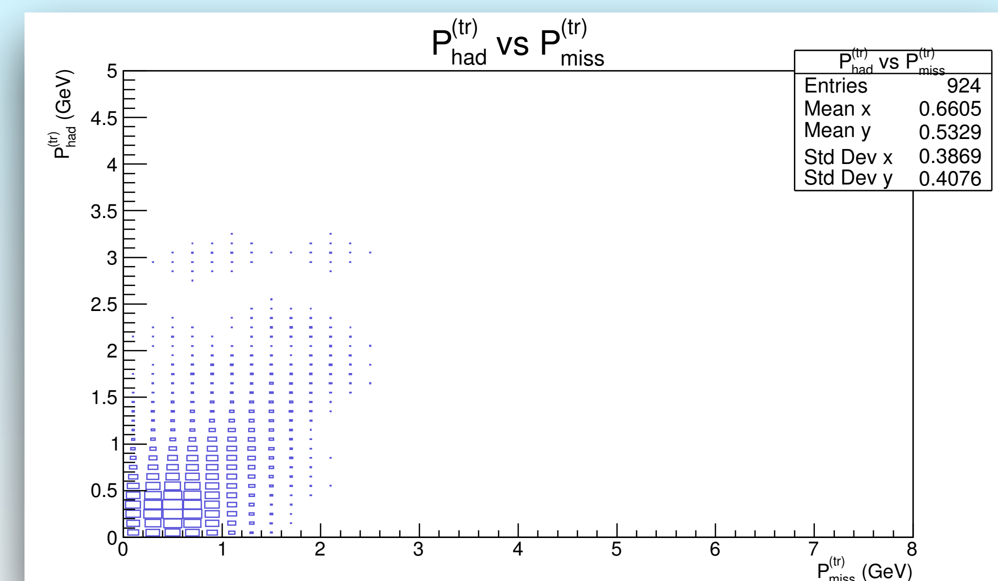
ν_e CC





ν_τ CC





Likelihood analysis

- Given an event (ν_e or ν_τ) with a set of kinematic variables, we compute the likelihood ratio L.

$$L = \log\left(\frac{L_S}{L_B}\right)$$

L_S (resp. L_B) is the probability that a given kinematic variable (or a correlation of several of them) occurs for the signal (resp. background).

Convention:
ν_τ CC = SIGNAL; ν_e CC (beam) = BACKGROUND.

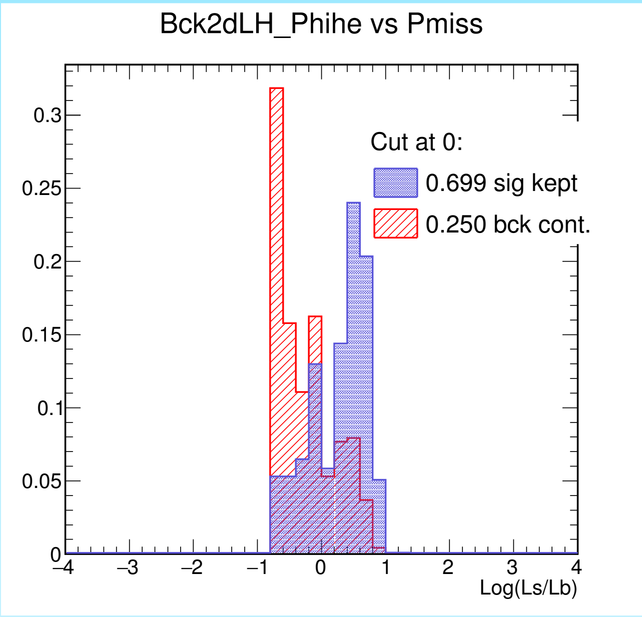
→ L_S for ν_τ

→ L_B for ν_e

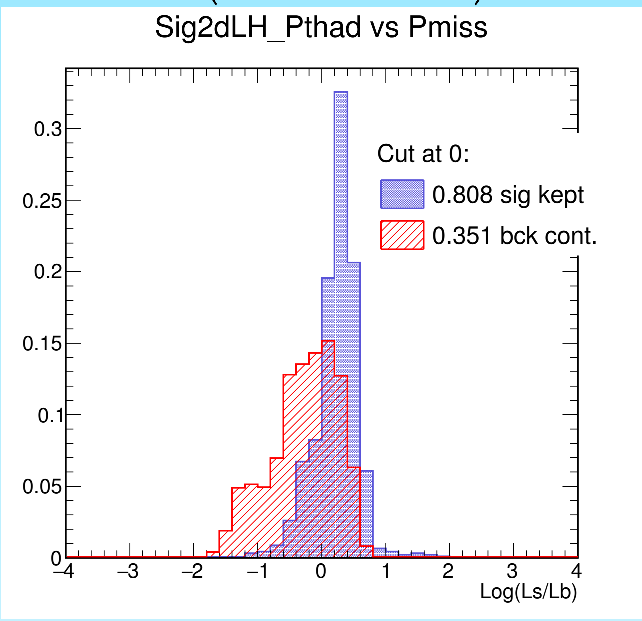
- Comparison of the signal/background likelihood distribution informs about the separability power of the kinematic variable (or of their correlation).

Some likelihood plots

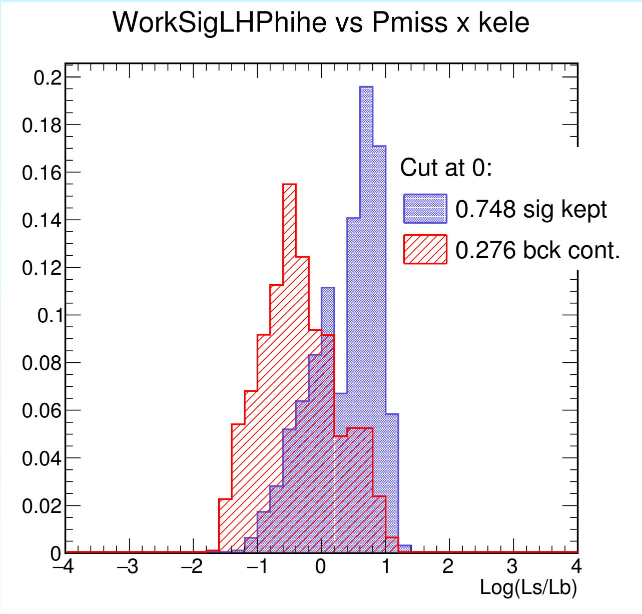
$$L\left(\left[\phi_{he}, p_{miss}^{(tr)}\right]\right)$$



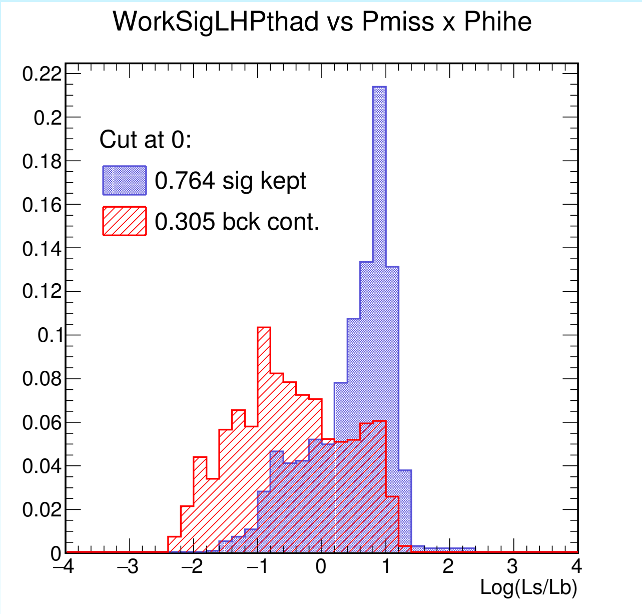
$$L\left(\left[p_{had}^{(tr)}, p_{miss}^{(tr)}\right]\right)$$



$$L\left(\left[\phi_{he}, p_{miss}^{(tr)}\right].K_{e^-}\right)$$



$$L\left(\left[p_{had}^{(tr)}, p_{miss}^{(tr)}\right].\phi_{he}\right)$$



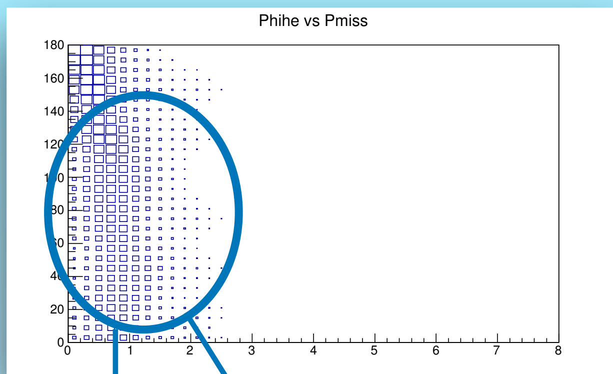
- The cut at 0 is shown as a matter of indication. We use **integral likelihood** distributions for more quantitative results.

- Using different combinations of the 8 variables, hard to get much improvement. Cuts at 0 reach ~[75;80]% of ν_τ selection and some [25;30]% of ν_e contamination.

A posteriori check : $\left[\phi_{he}, p_{miss}^{(tr)}\right]$

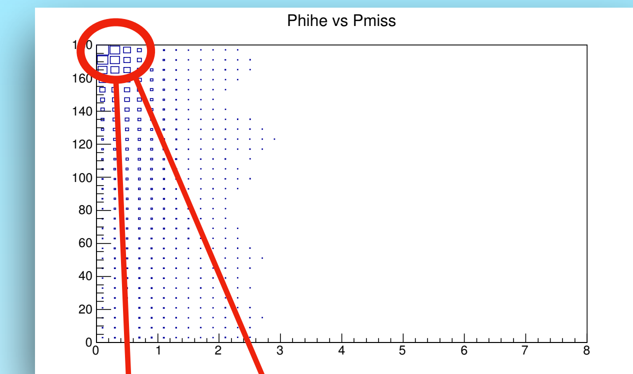
Full distributions

Signal (ν_τ)



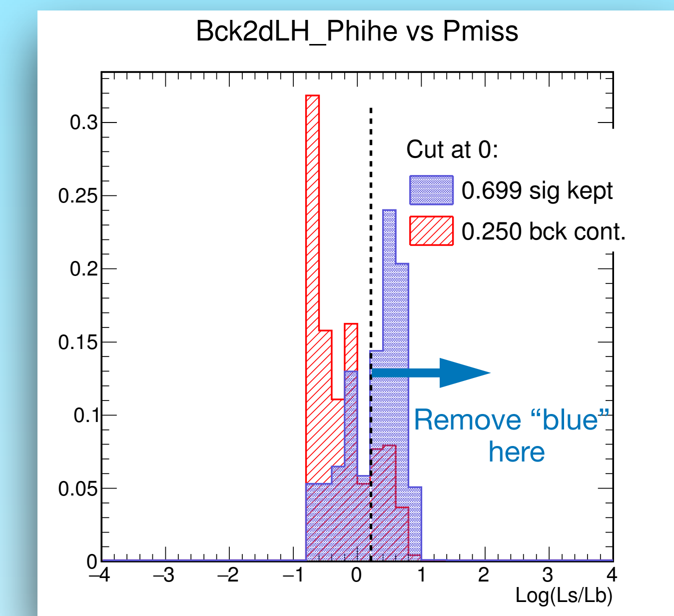
Discriminating signal region.

Background (ν_e)



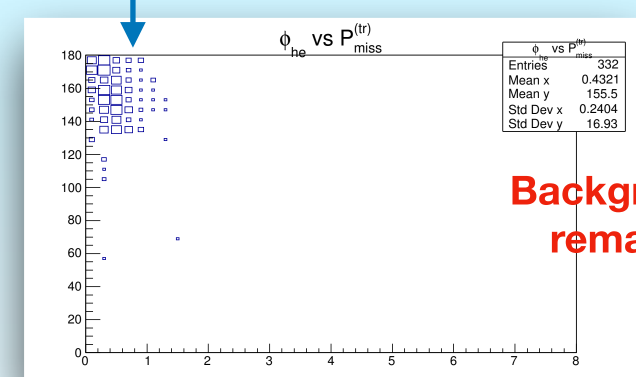
Discriminating background region.

Likelihood

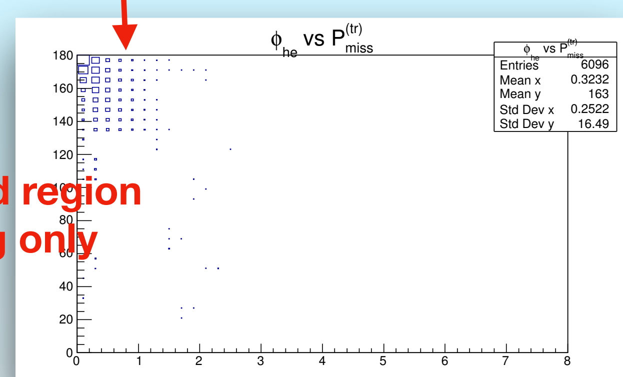


Apply cuts at **+0.2**, remove any contribution that's above.

If a signal or a background event gets a likelihood ratio above the arbitrary threshold 0.2, it is removed.



Background region remaining only



Truncated Distributions

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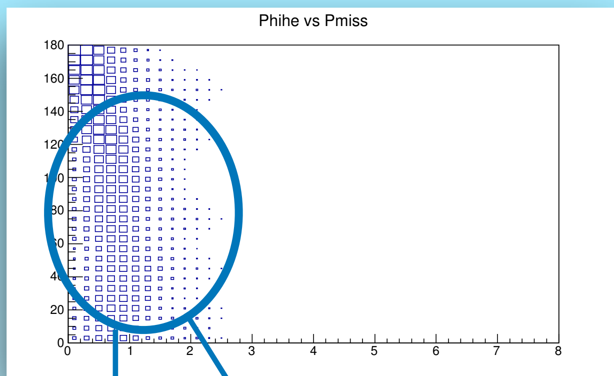
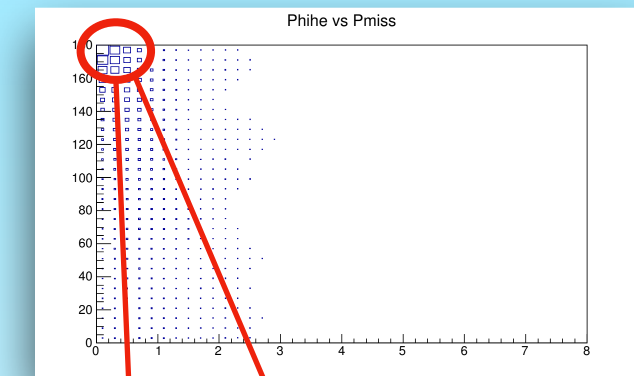
A posteriori check : $\left[\phi_{he}, p_{miss}^{(tr)} \right]$

Full distributions

Signal (ν_τ)



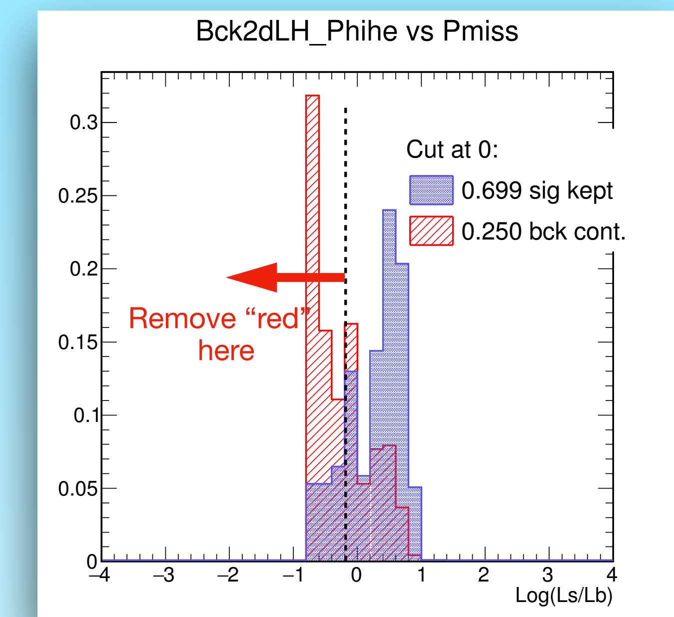
Background (ν_e)



Discriminating signal region.

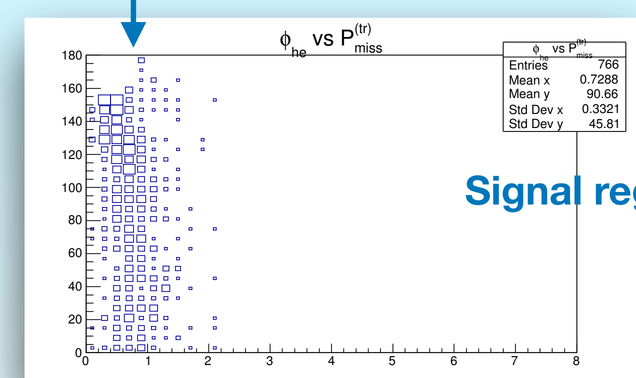
Discriminating background region.

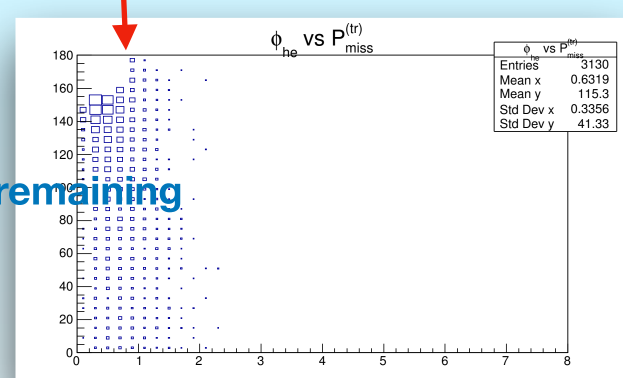
Likelihood



Apply cuts at -**0.2**, remove any contribution that's above.

If a signal or a background event gets a likelihood ratio under the arbitrary threshold -0.2, it is removed.





Signal region remaining only

Truncated Distributions

CONSISTENT

Outlook/Discussion

- Preliminary results plausible/encouraging. Though hard to get much improvement (looking for a good combination of variables isn't obvious). Simple cuts at 0 for likelihood ratio leads to ~75% of signal (oscillated ν_μ—>ν_τ) selection and ~30% of background (ν_e beam) contamination.

	Expected Events (3.5 years staged)
ν mode	
ν_e Signal NO (IO)	1346 (612)
$\bar{\nu}_e$ Signal NO (IO)	19 (34)
Total Signal NO (IO)	1365 (646)
Beam $\nu_e + \bar{\nu}_e$ CC background	234
NC background	83
$\nu_\tau + \bar{\nu}_\tau$ CC background	37
$\nu_\mu + \bar{\nu}_\mu$ CC background	17
Total background	371

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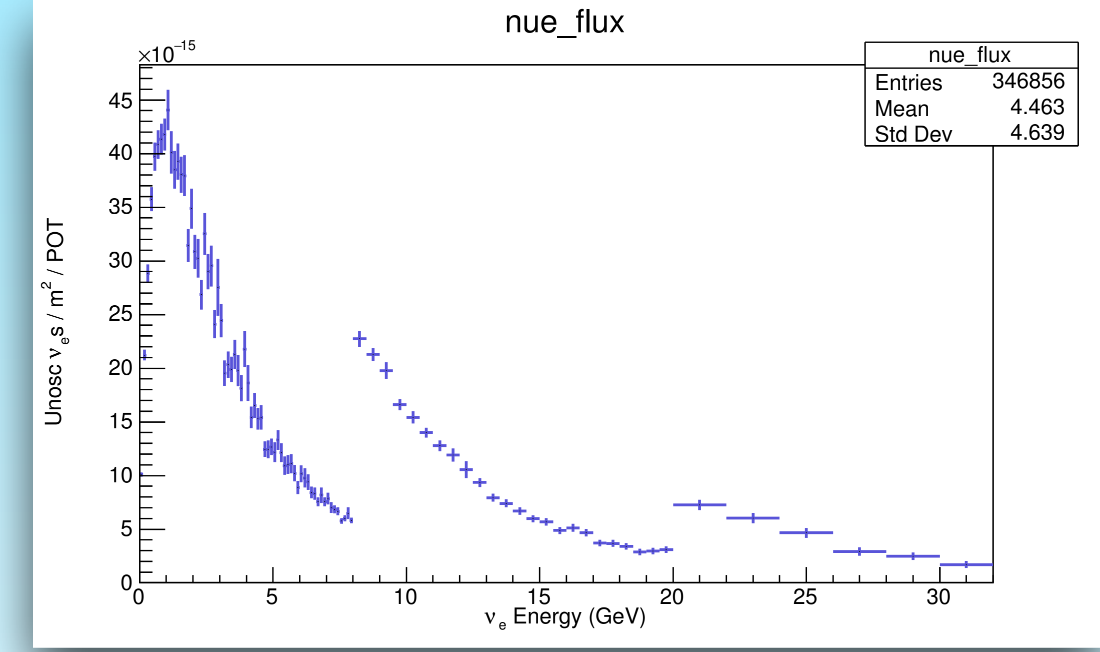
Apply the efficiencies obtained to ~234 n_e CC beam bck and ~37 n_t CC for 3.5 years staged.

- Add analysis with neutrons and see the difference as a crosscheck.
- Results not so good… Why ? Distinguish QEL/RES/DIS as a first clue.
- Include a reconstruction (smearing at fewer extent), detector response and geometry.
- Reproduce analysis with oscillated ν_e.
- Include a PMNS parametrisation of the analysis (i.e work on the flux part).

Back up: FD flux

ν_e from beam contamination.



ν_τ from ν_μ oscillation