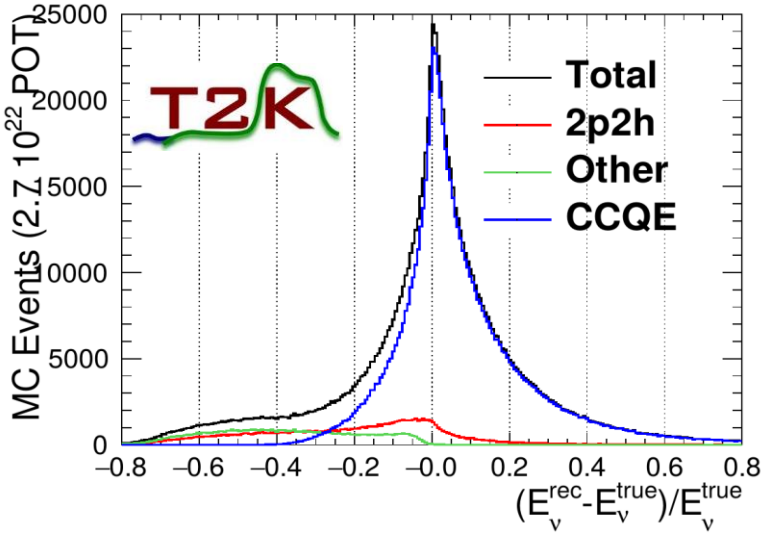
What do we need to know?



Kinematic energy reconstruction

$$E_\nu^{QE} = \frac{m_p^2 - (m_n - E_b)^2 - m_\mu^2 + 2(m_n - E_b)E_\mu}{2(m_n - E_b - E_\mu + p_\mu cos\,\theta_\mu)}$$

Fermi motion causes a **smearing** on E_ν^{QE}

Nuclear binding energy effects introduce a **bias**

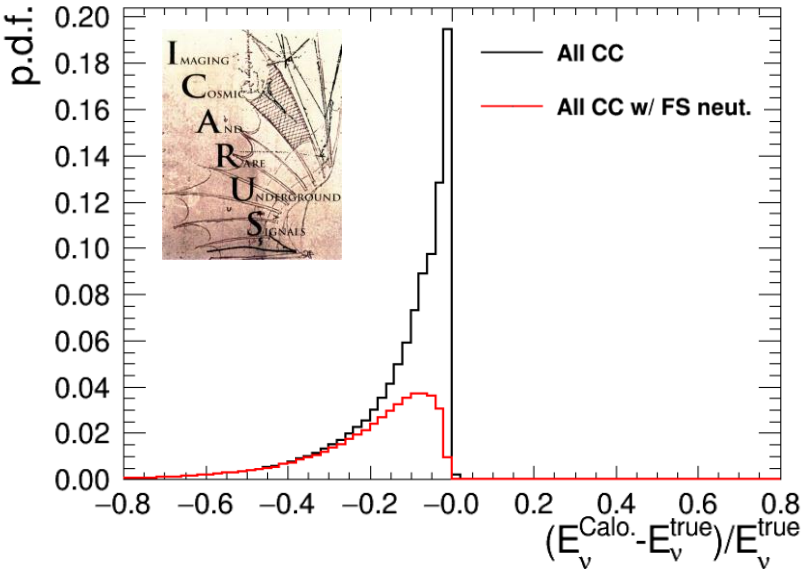
2p2h and pion abs. *FSI* cause further **bias**

Calorimetric energy reconstruction

$$E_\nu^{calo} = E_\ell + E_{had.} = E_\ell + \Sigma T_p + \Sigma T_{\pi^\pm} + \Sigma E_\gamma$$

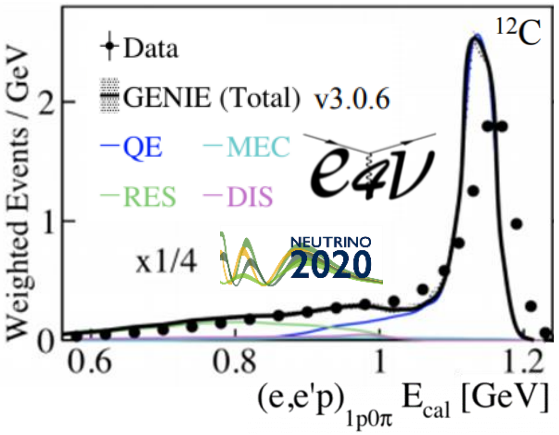
Mis-modelling of *charged pion multiplicity* can cause some **bias**

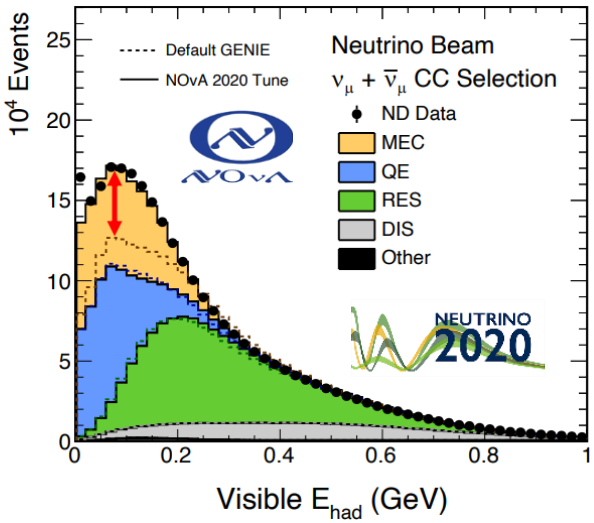
Fraction of E_ν in neutrons is a critical source of mis-reconstruction

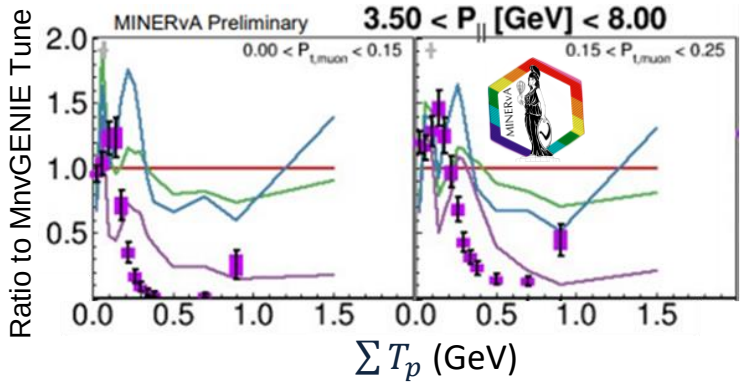


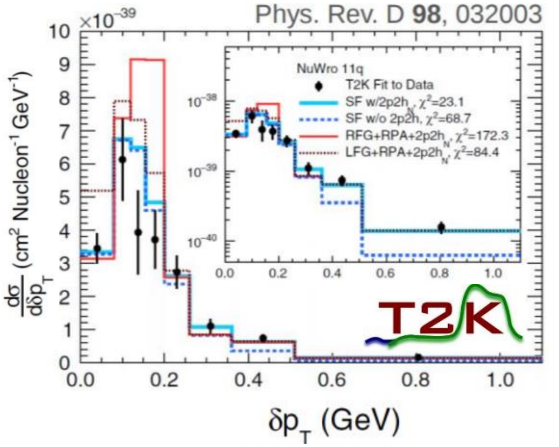
How well do we know it now?

- ✓ As a community we have made a wide range of innovative measurements aimed to precisely target the physics most pertinent to future oscillation analyses
- X None of our current simulations are able much describe more than the lepton kinematics …

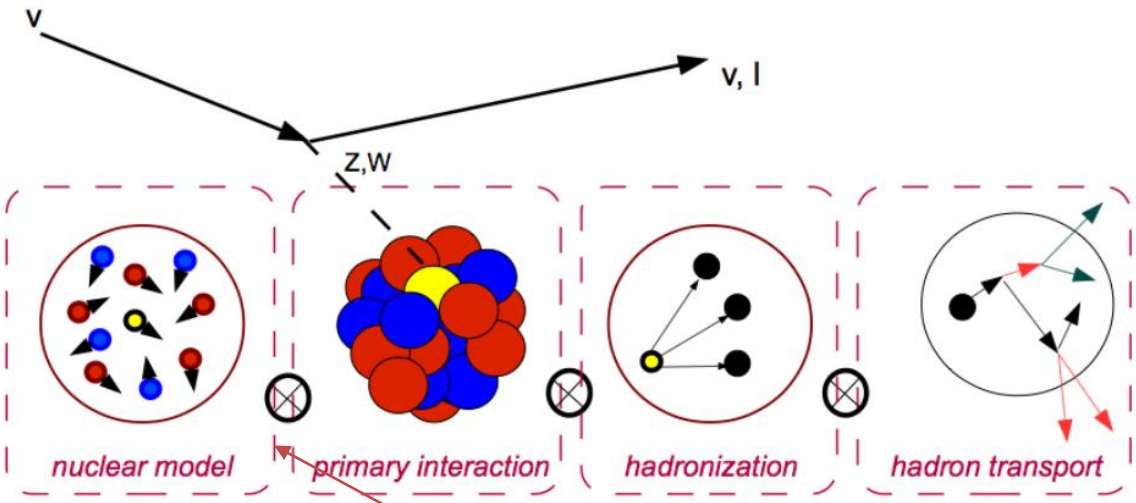








Why do we do so bad?



The majority of our theory inputs give us only *inclusive* models for this bit

Inclusive = only predicts lepton kinematics

We then take all the other pieces from other places and stick it all together (because what else can we do?)

Hadron kinematics are from "frankenmodels"

We do not have a complete set of uncertainties on these franken-components, most systematics we do have for this are pretty basic …

Where do we go from here?

- From me, finding ways to add conservative uncertainties to cover limitations of our input models should be a high priority for our community. Some nice examples already exist. E.g.:
  - Reweighting of interaction probabilities within FSI cascades in NEUT/GENIE
  - Alterations of the way momentum transfer is shared between nucleons in 2p2h interactions from NuWro
  - Ongoing work in T2K adds a momentum transfer dependent alteration of removal energy in 1p1h interactions
- But ultimately the best solution is to implement more predictive *exclusive* models in our generators. Unfortunately this isn't easy, but we've already seen some very promising work:
  - Improved theory-generator interfaces
  - New methods to allow MC sampling of high dimensional spaces
  - Closer collaboration with theorists to implement new models