Physics Studies for ND280 Upgrade

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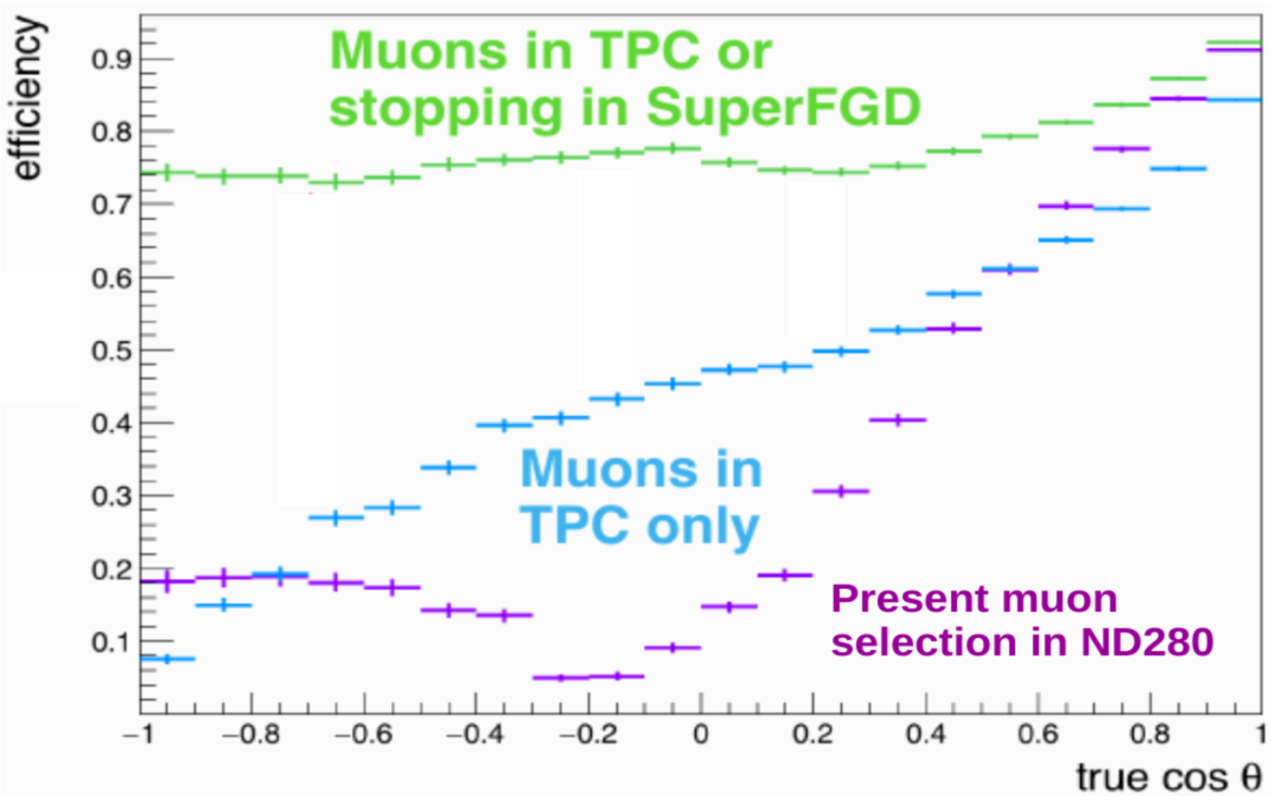
Introduction

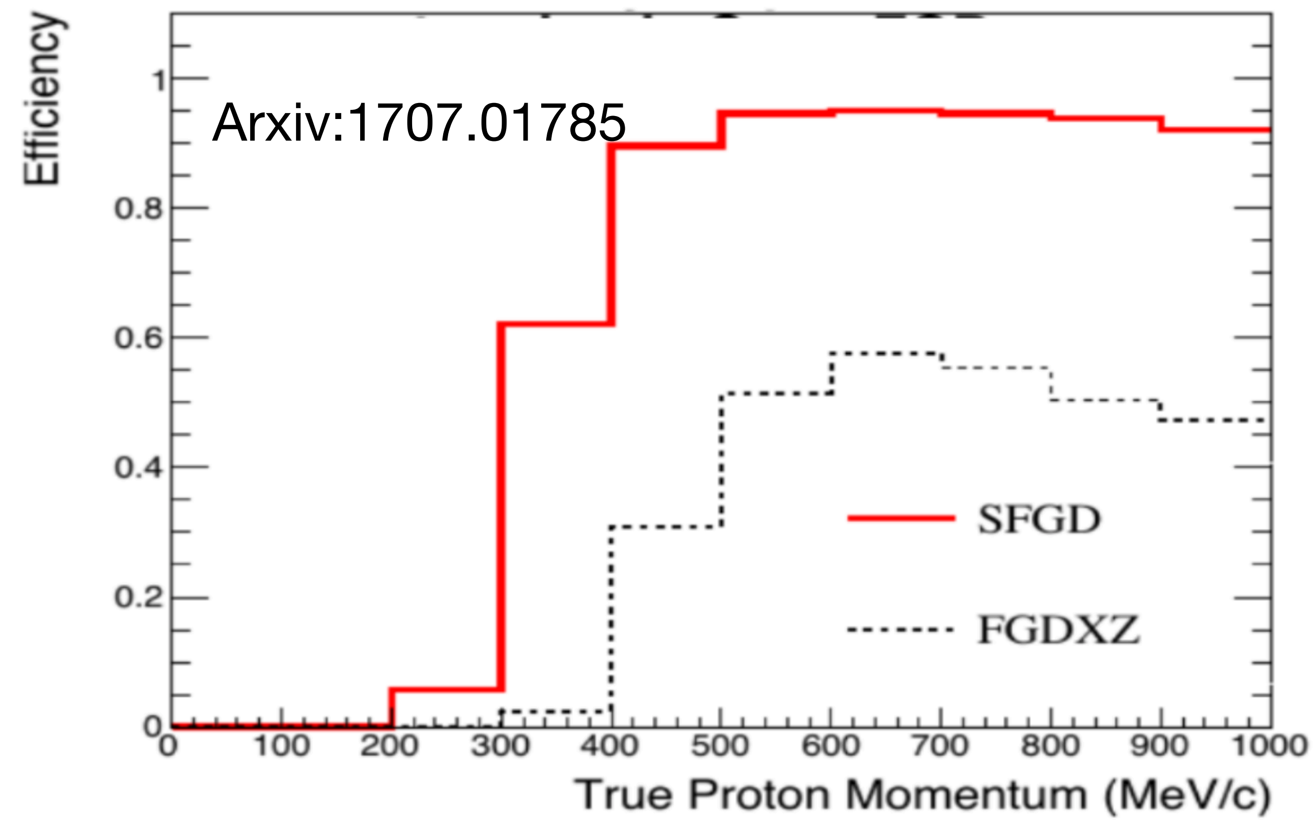
- We do a likelihood fit to evaluate sensitivity of the upgrade to flux and cross-section model by exploiting Single Traverse Variables (STVs)

- The fitter aims to find the quantitative sensitivities to key systematic uncertainties such as CCQE, 2p2h, Proton Final State Interaction (FSI), Hydrogen normalisation.

- We are using the fake data, the Monte Carlo is generated by NEUT generator for 3 models: Relativistic Fermi Gas (RFG), Local Fermi Gas (LFG) and Spectral Function (SF). In this talk I will mention studies with SF only.

Better efficiency



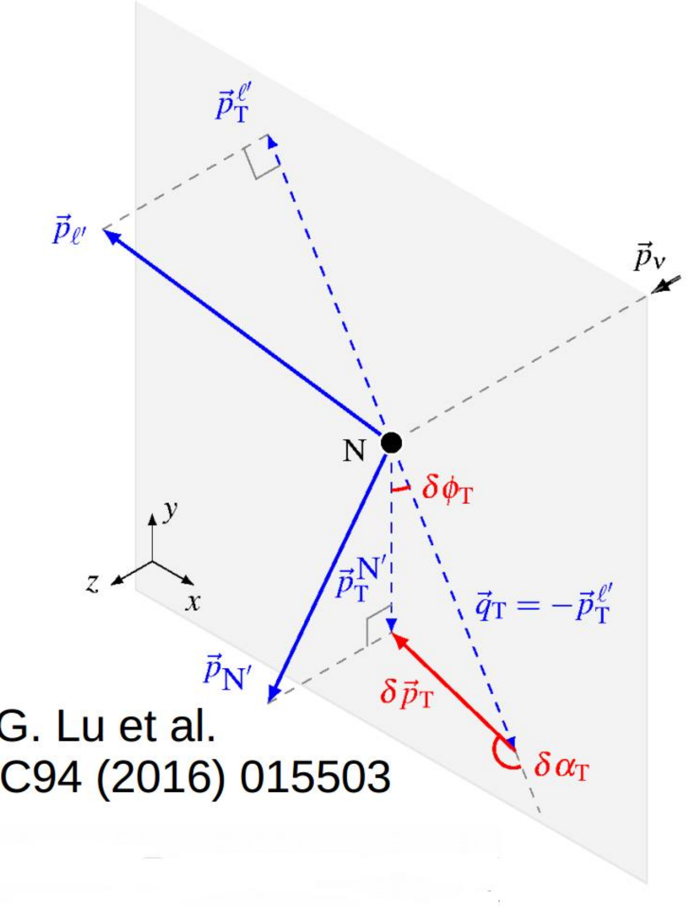


- Upgraded ND280 helps to better measure high angle tracks, lower momentum particles, and better reconstruction of the hadronic part.
  => It is then much more sensitive to the traverse variables.

- Events selection:
  Neutrino interaction: 1 muon and one proton in the final state
  Anti neutrino interaction: 1 muon and one neutron in the final state.
  For 1×10^{21} POT => 51k events in nu mode, 11k events in anti-nu mode pass the selection

Input

- 2D histograms of Single Transverse Variables $\delta\alpha_T$, δp_T, nucleon fermi momentum (pn), visible energy (Evis).
- These are reconstructed including detector effects (smearing and efficiency). The detector effects are simulated on the basis of TDR simulation
- Focus on CC0π events
  CC0π = CCQE+2p2h+1π(not detected)



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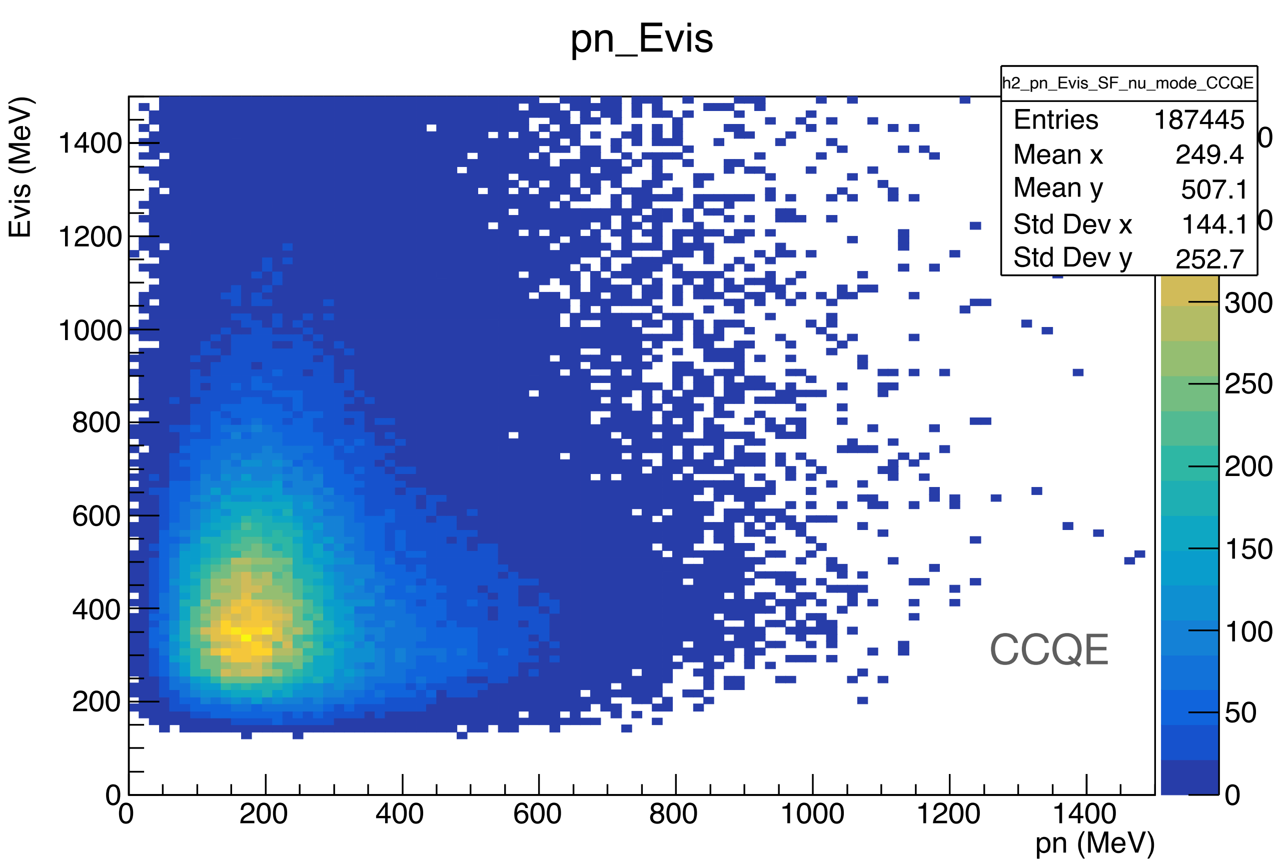
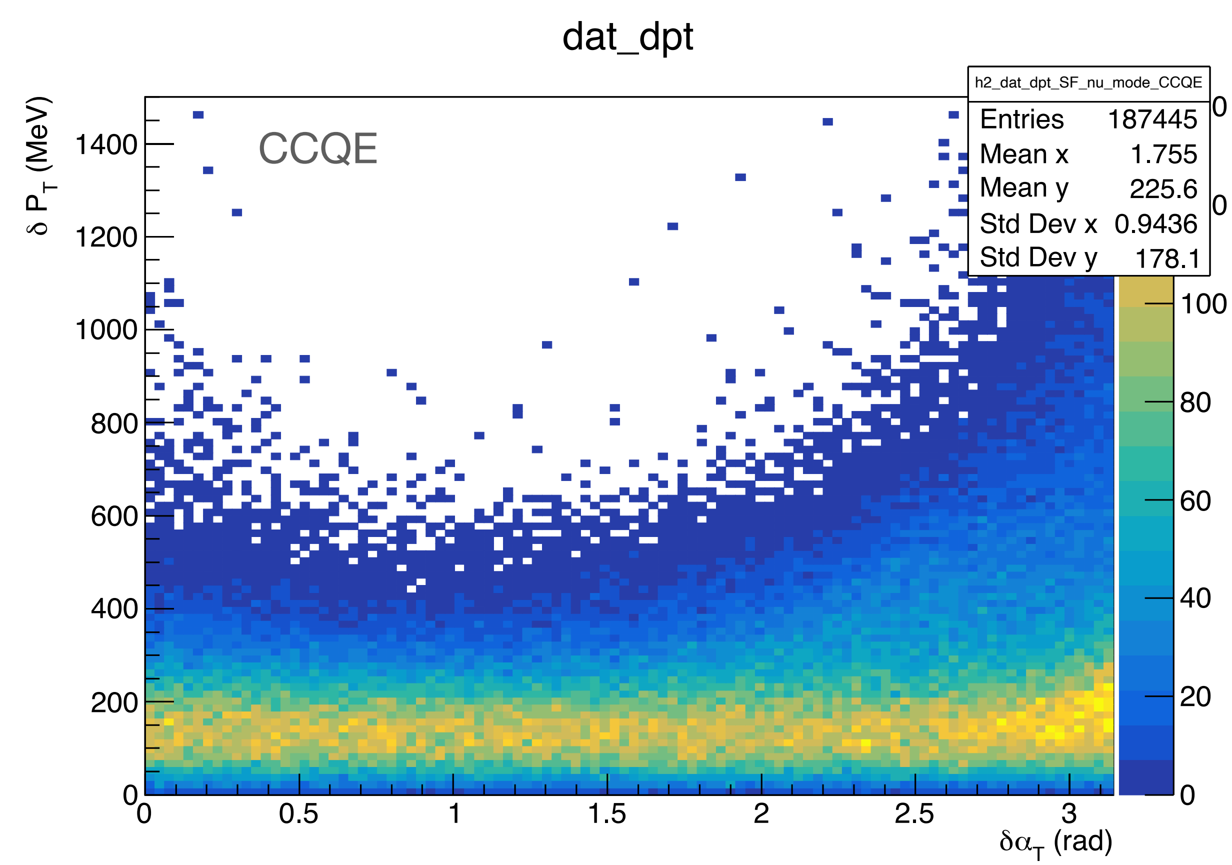
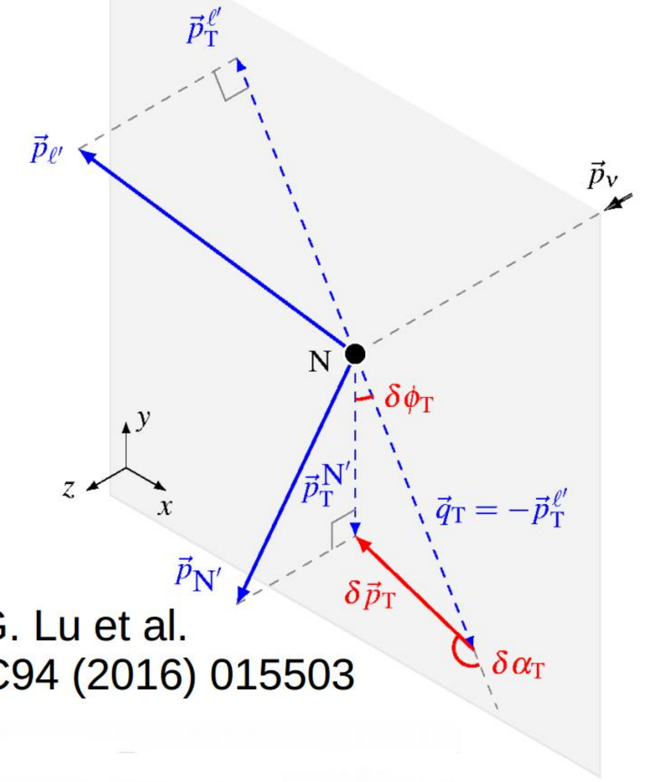




Input for fitter ($\delta\alpha_T$)

- $$\delta\alpha_T = \arccos\left(-\frac{\mathbf{p}_T^{\mu}\cdot\delta\mathbf{p}_T}{p_T^{\mu}\delta p_T}\right),$$



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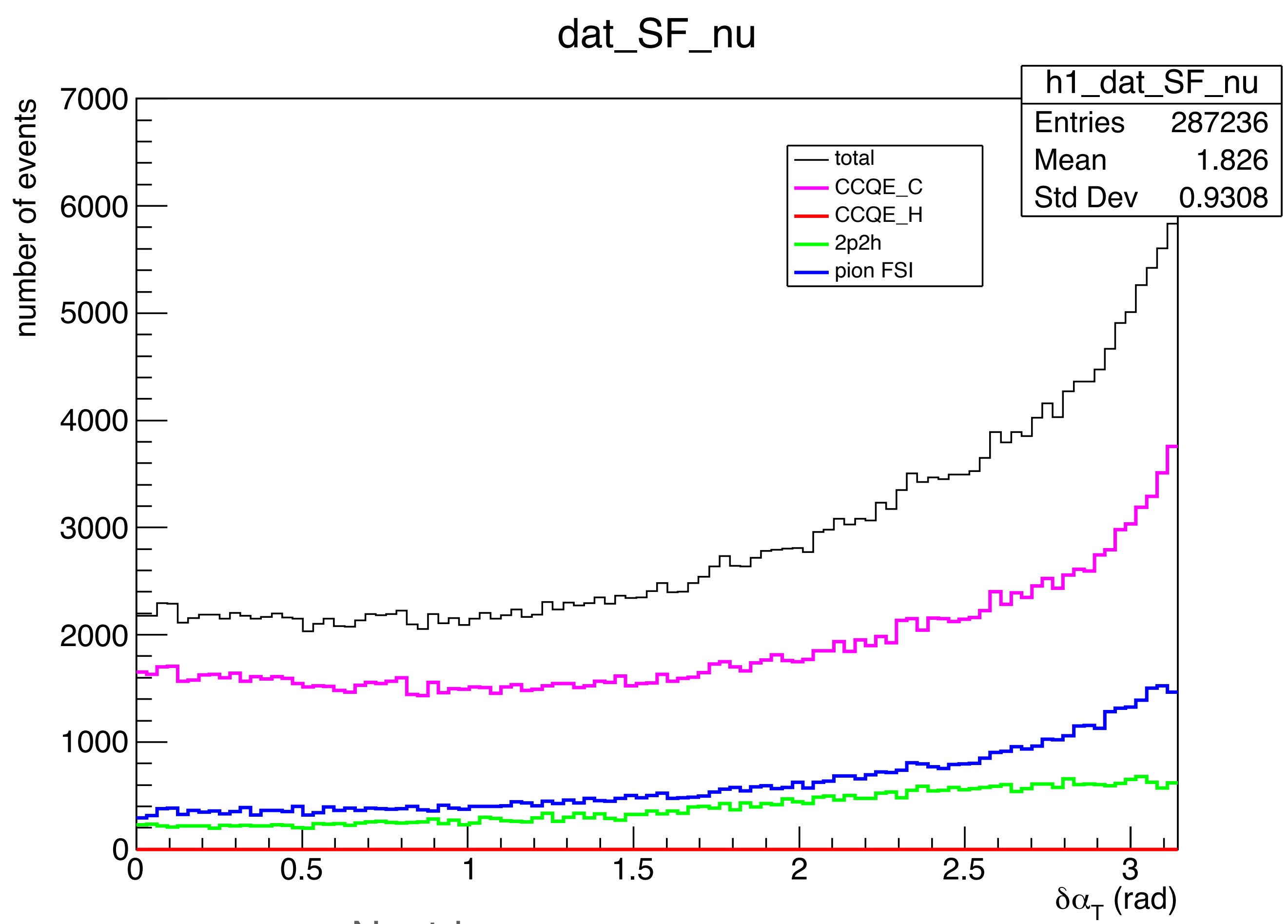
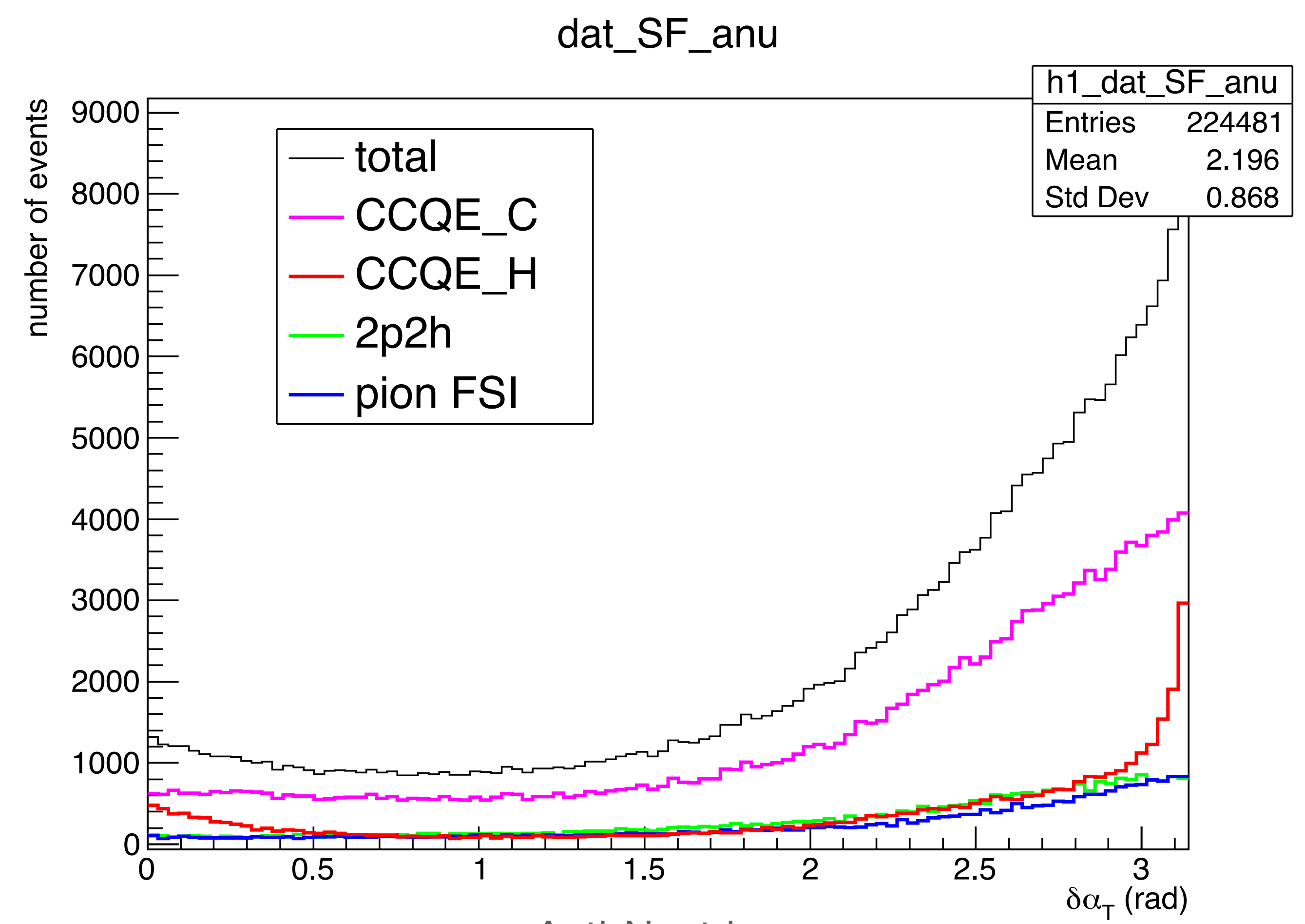


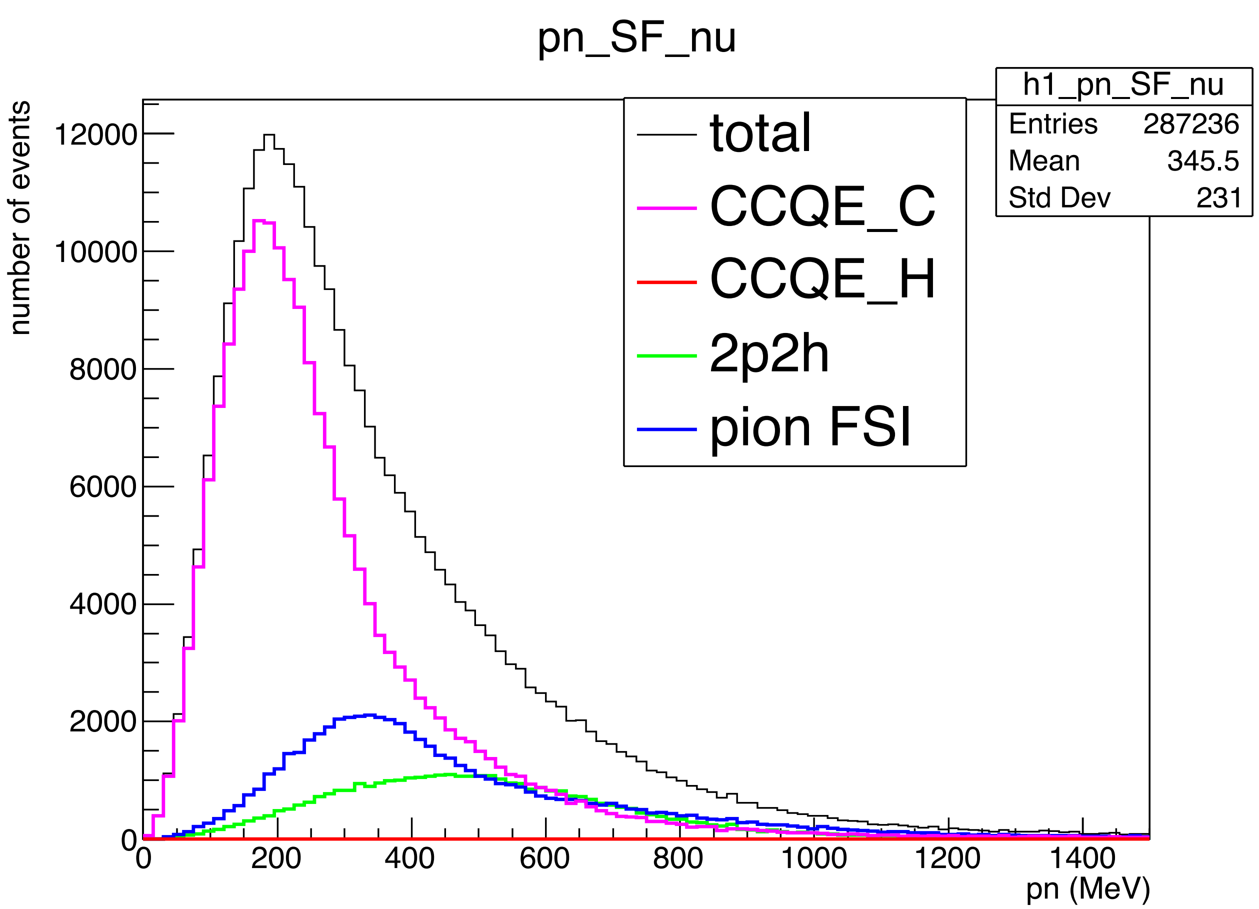
Neutrino



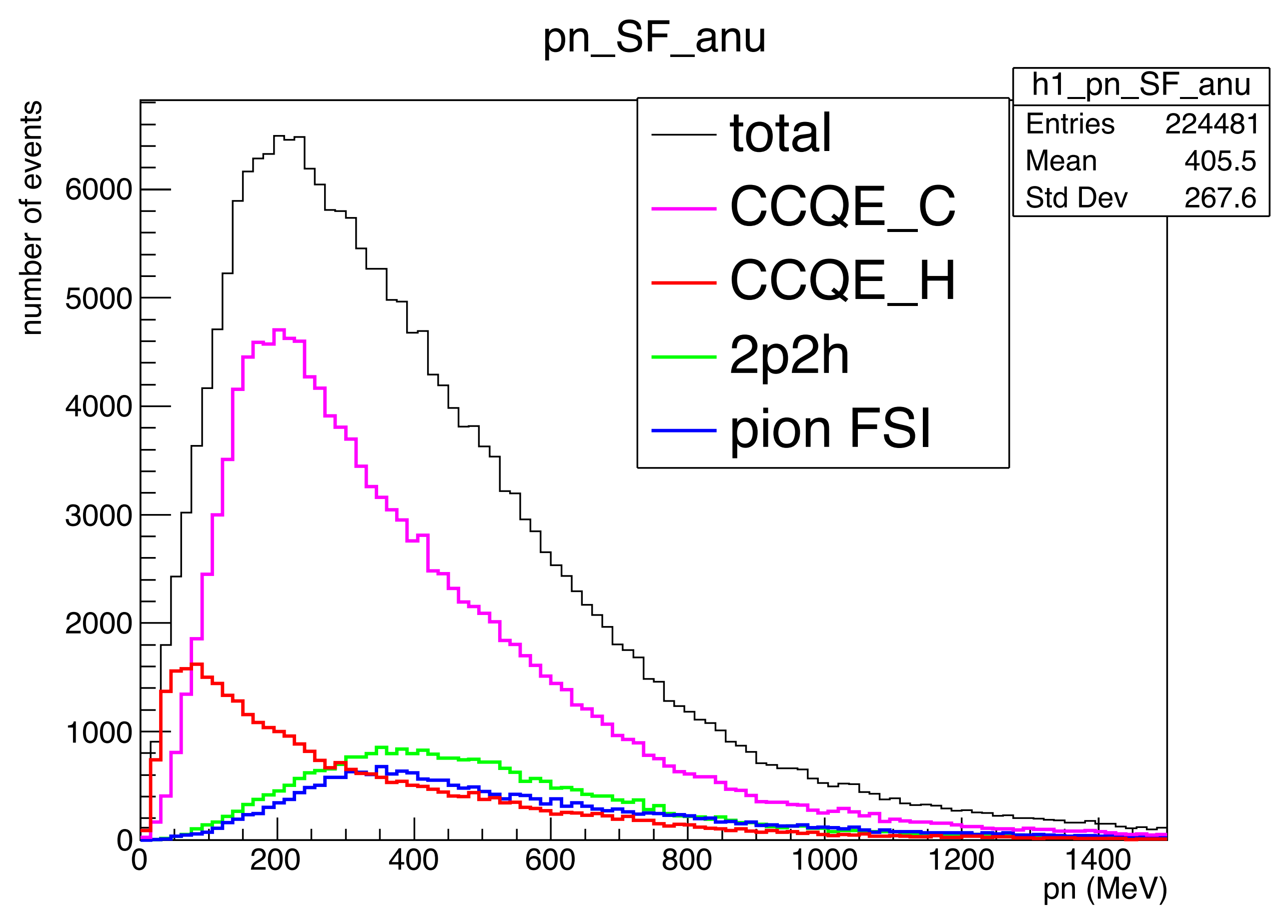
Anti-Neutrino

Input for fitter (Fermi momentum)

- Calculation in back up
- The peaks are at around 200MeV which is the expectation
- In anti-neutrino we have a broader Pn distribution due to the better reconstruction of protons compared to that of neutrons in the final state.



Neutrino

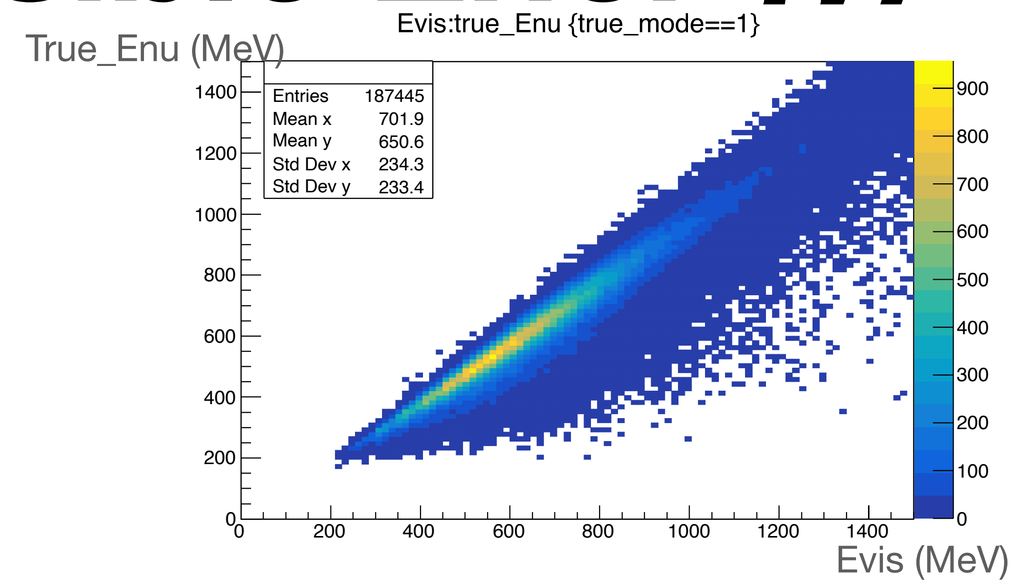


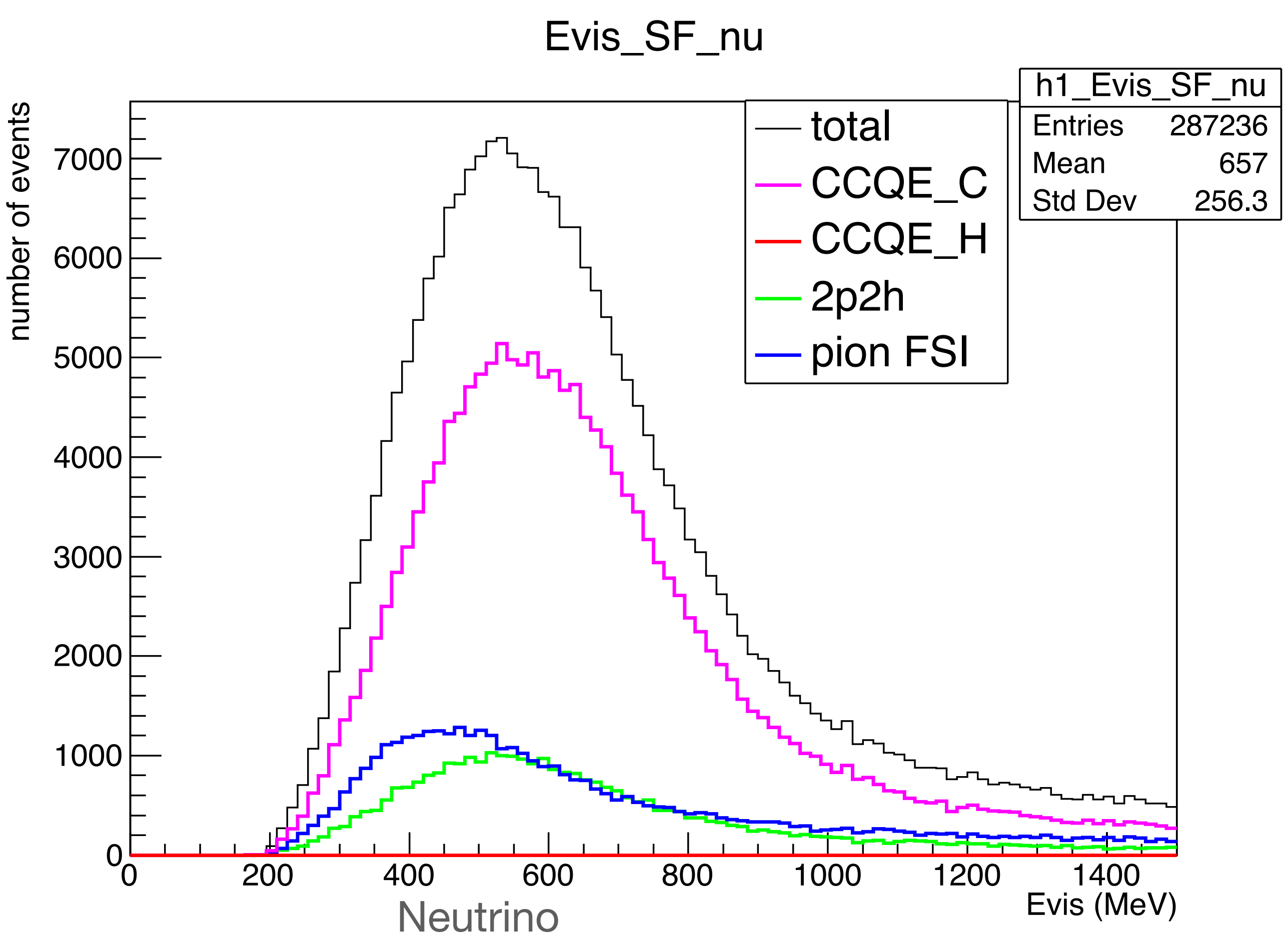
Anti-Neutrino

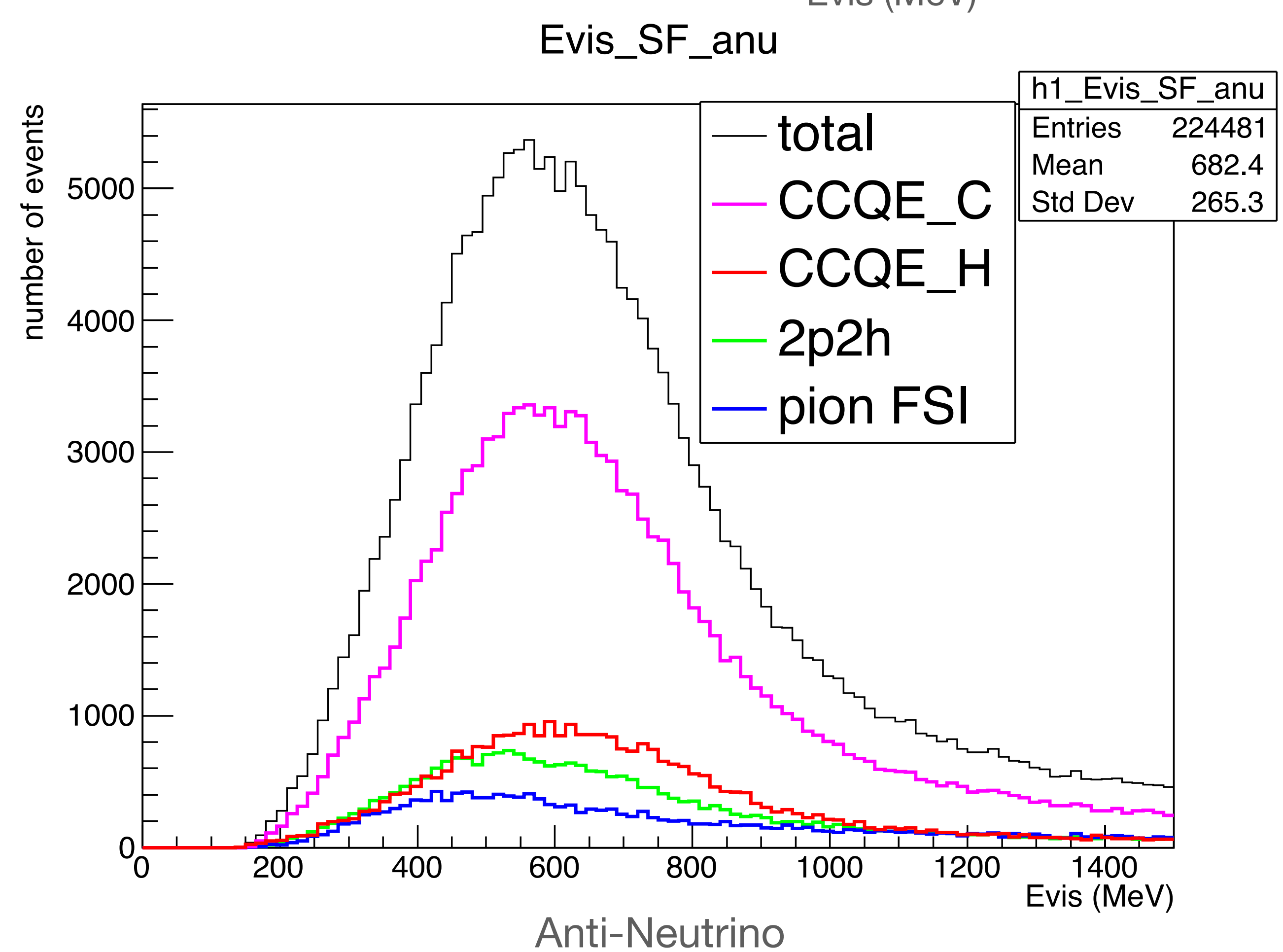
Input for fitter (Visible Energy)

- Evis = $E_\mu + T_p$ (nu interaction)
  Evis = $E_\mu + T_n$ (anti-nu interaction)
  => good estimator for neutrino energy

- Peak around 600 MeV, shape similar to the one of the T2K flux







We do a binned likelihood fit with two variables pn and Evis

Systematic included in fitter

- 2p2h
  +2p2h_c1 < 600MeV
  +2p2h_c2 > 600MeV

- CCQE (modelled in Spectral Function)
  +Mean Field (MF)
  +Short Range Correlation (SRC)
  +P Shell
  +S Shell

- Pion Absorption

- Pion Background

- Global normalisation systematic
  (An overall normalization uncertainty of 3.7% is applied)
  + Flux 3%
  + Detector modelling 2%
  + Background subtraction 1%

- proton Final State Interaction (FSI)

- Eb: binding energy

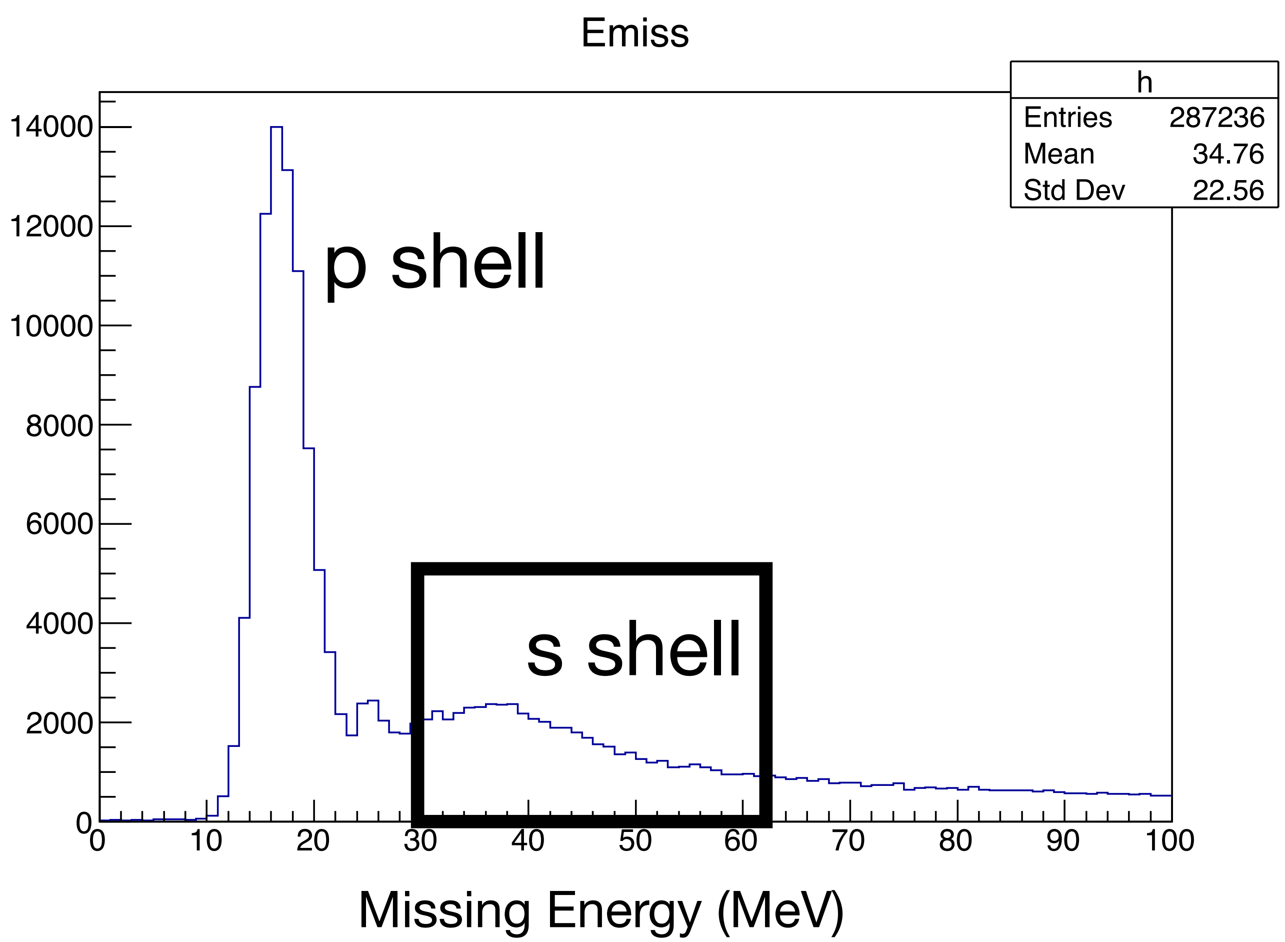
- Hydrogen interaction normalisation

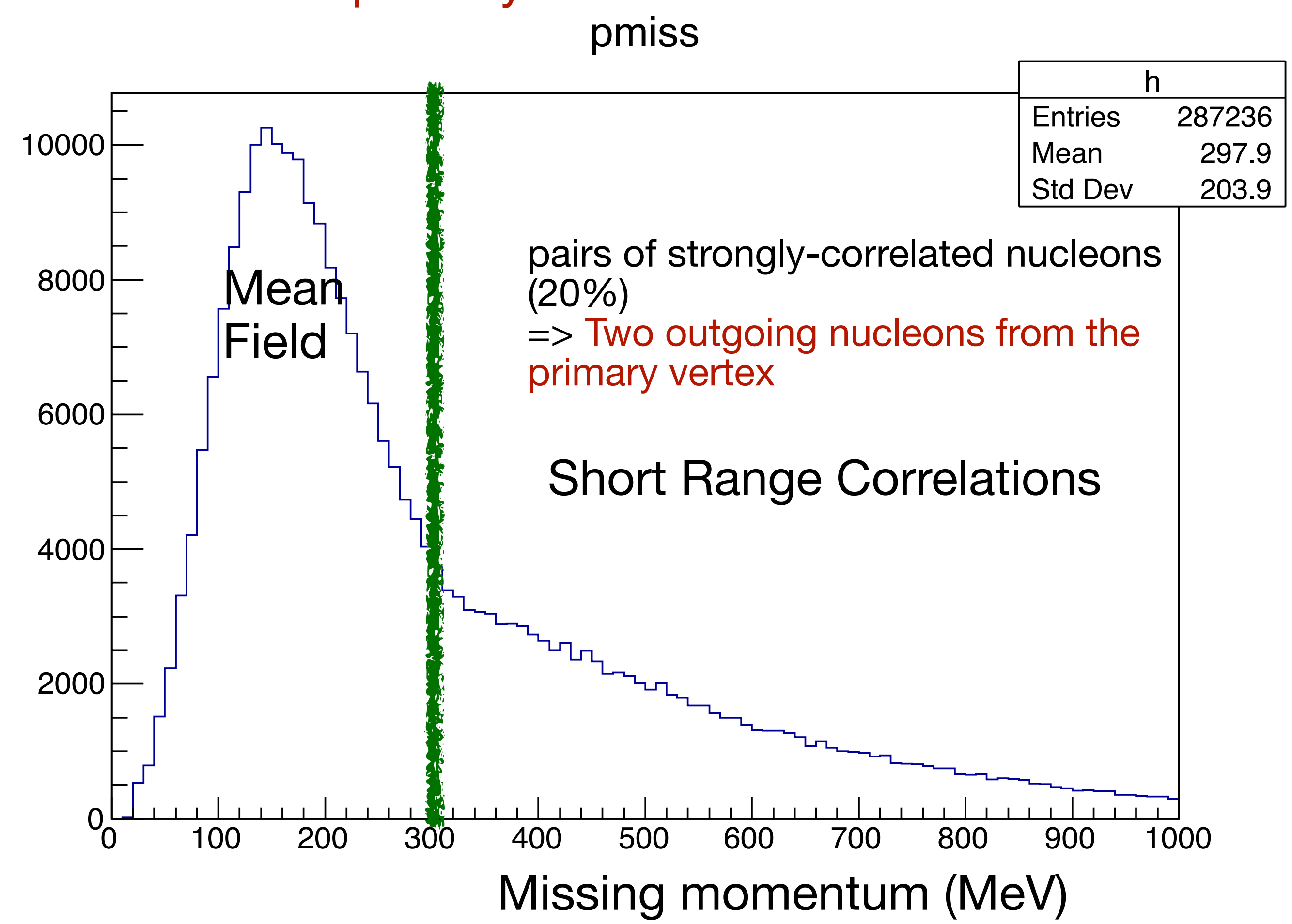
- Flux covariance uncertainty

CCQE model systematic

Spectral Function

Mean Field: Independent nucleons, moving in a mean-field potential within the shell-model picture => One outgoing nucleons from the primary vertex





SRC: Emiss > 100 MeV & pmiss > 300 MeV
MF: Emiss < 100 MeV & pmiss < 300 MeV

Each region (MF, SRC, Pshell, Sshell) is treated as a normalization systematics

Pn(CCQE, P-shell High) = Pn(CCQE, s-shell only) + Pn(CCQE, p-shell only)*1.3 + Pn(CCQE, tail only)

Pn(CCQE, P-shell Low) = Pn(CCQE, s-shell only) + Pn(CCQE, p-shell only)*0.7 + Pn(CCQE, tail only)

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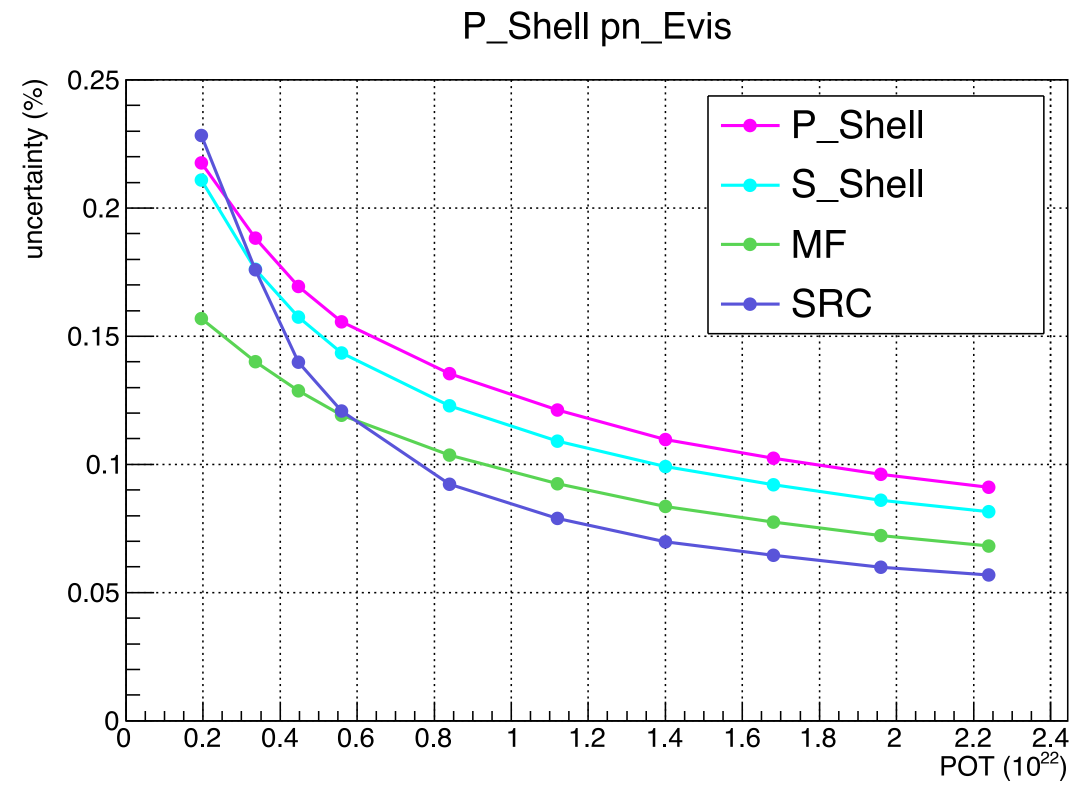
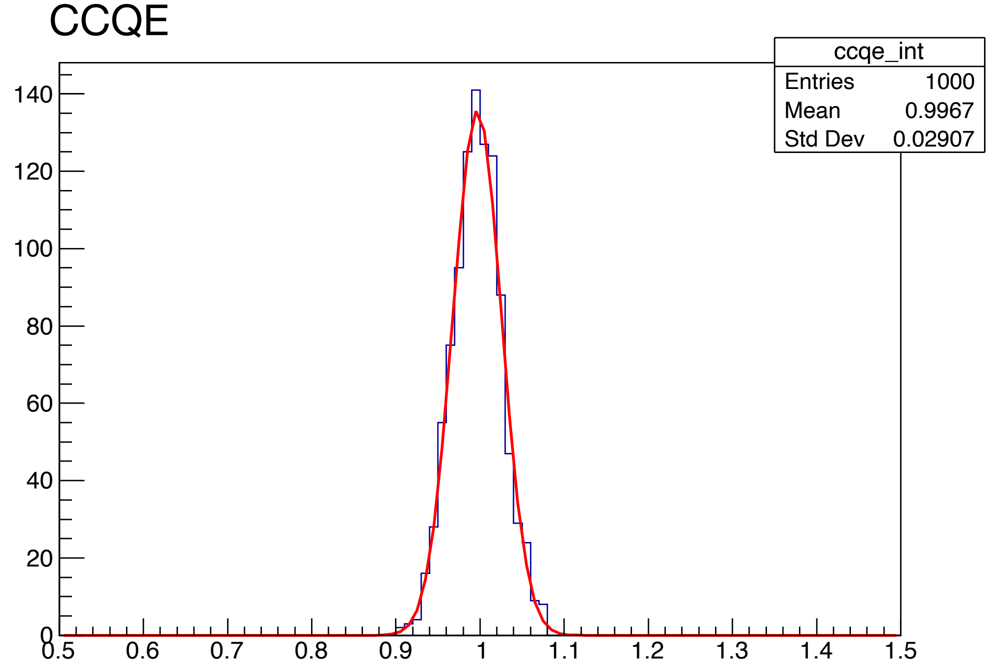
CCQE uncertainty propagation

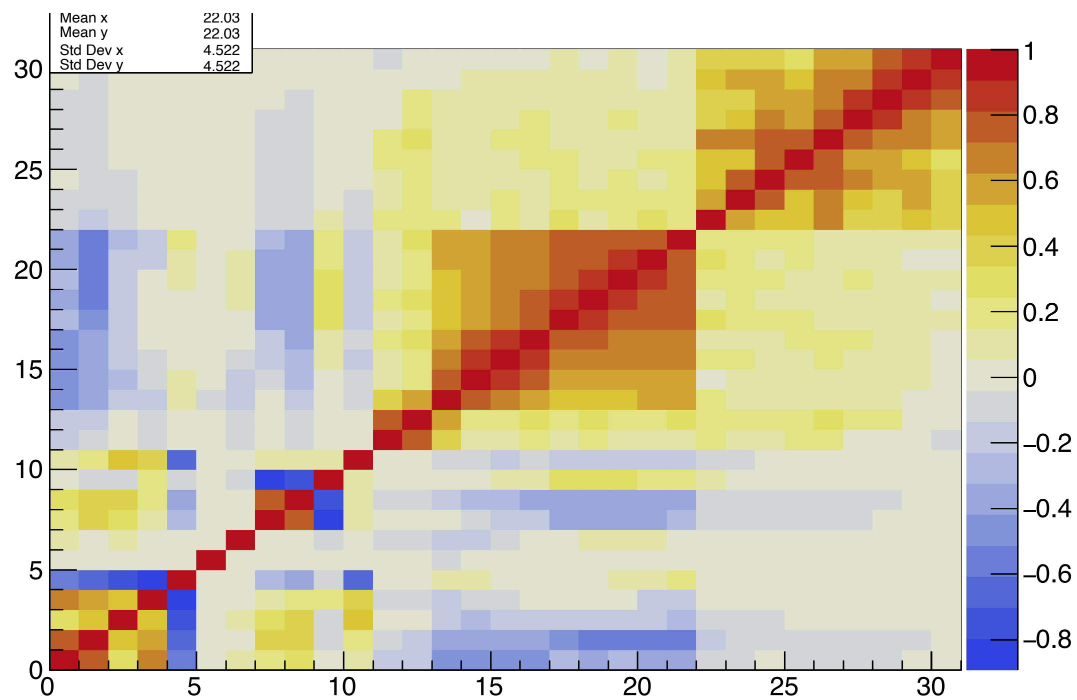
To evaluate the uncertainty on CCQE normalization due to SF model. We throw toys from postfit errors and covariance matrix and compute number of CCQE from each toy



Rhe uncertainty = std dev/ mean ~=0.03 for CCQE

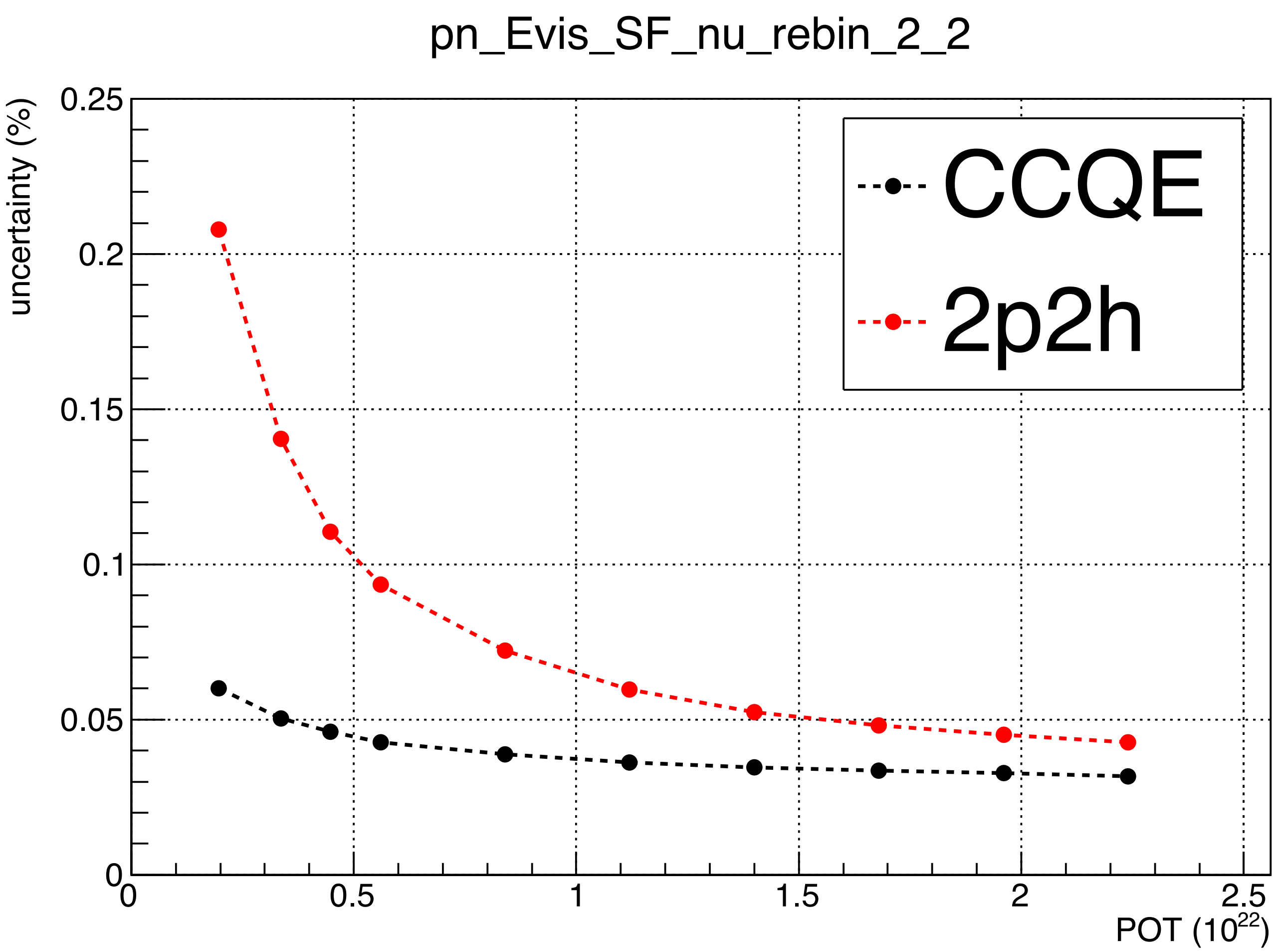


0->1: 2p2h
2->3: pion FSI
4: norm cyst
5: proton FSI
6: Eb
7: P Shell
8: S Shell
9: MF
10: SRC
>11: flux

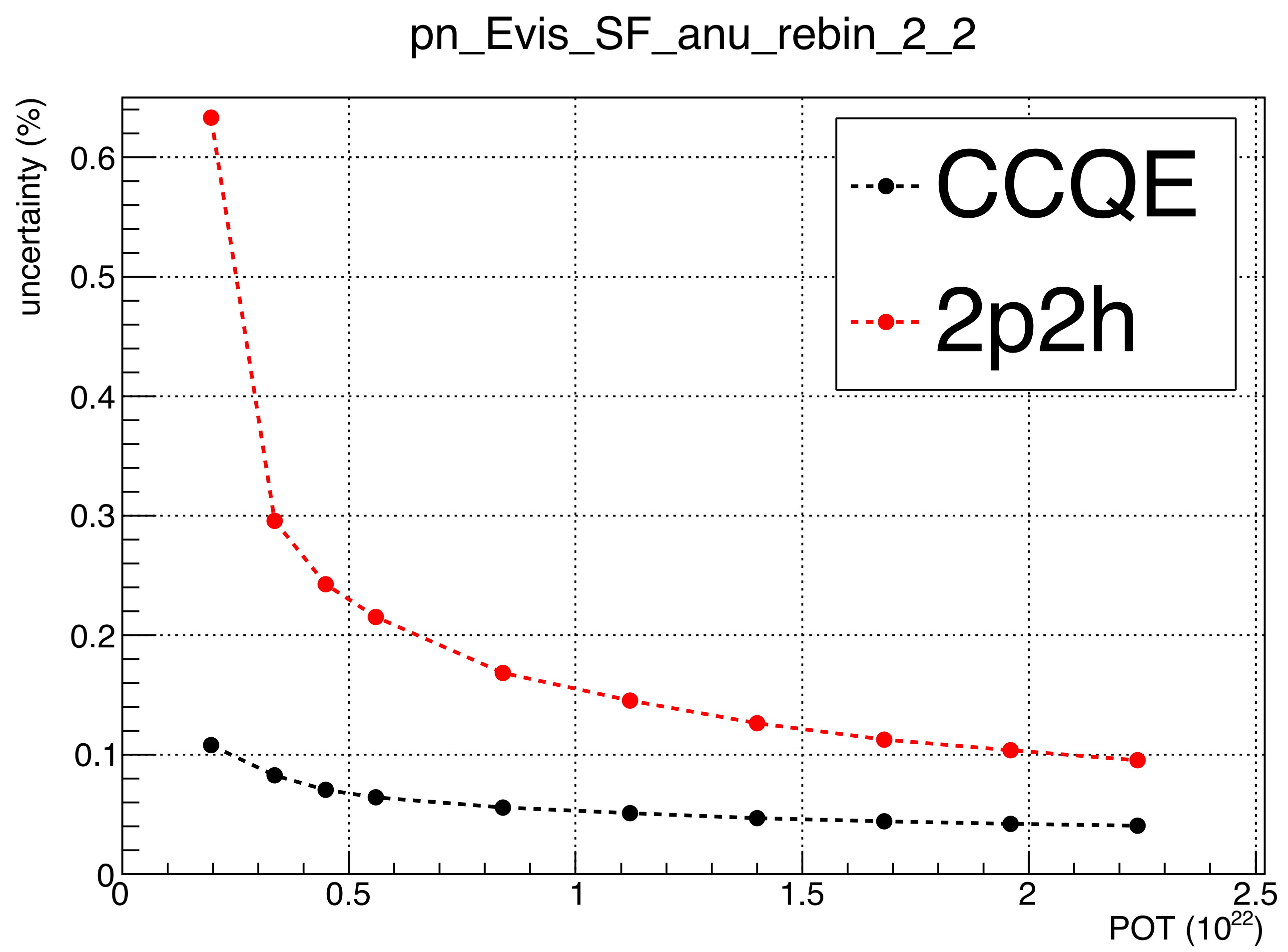


Pn_Evis nu fit

CCQE and 2p2h uncertainty



Neutrino



Anti-Neutrino

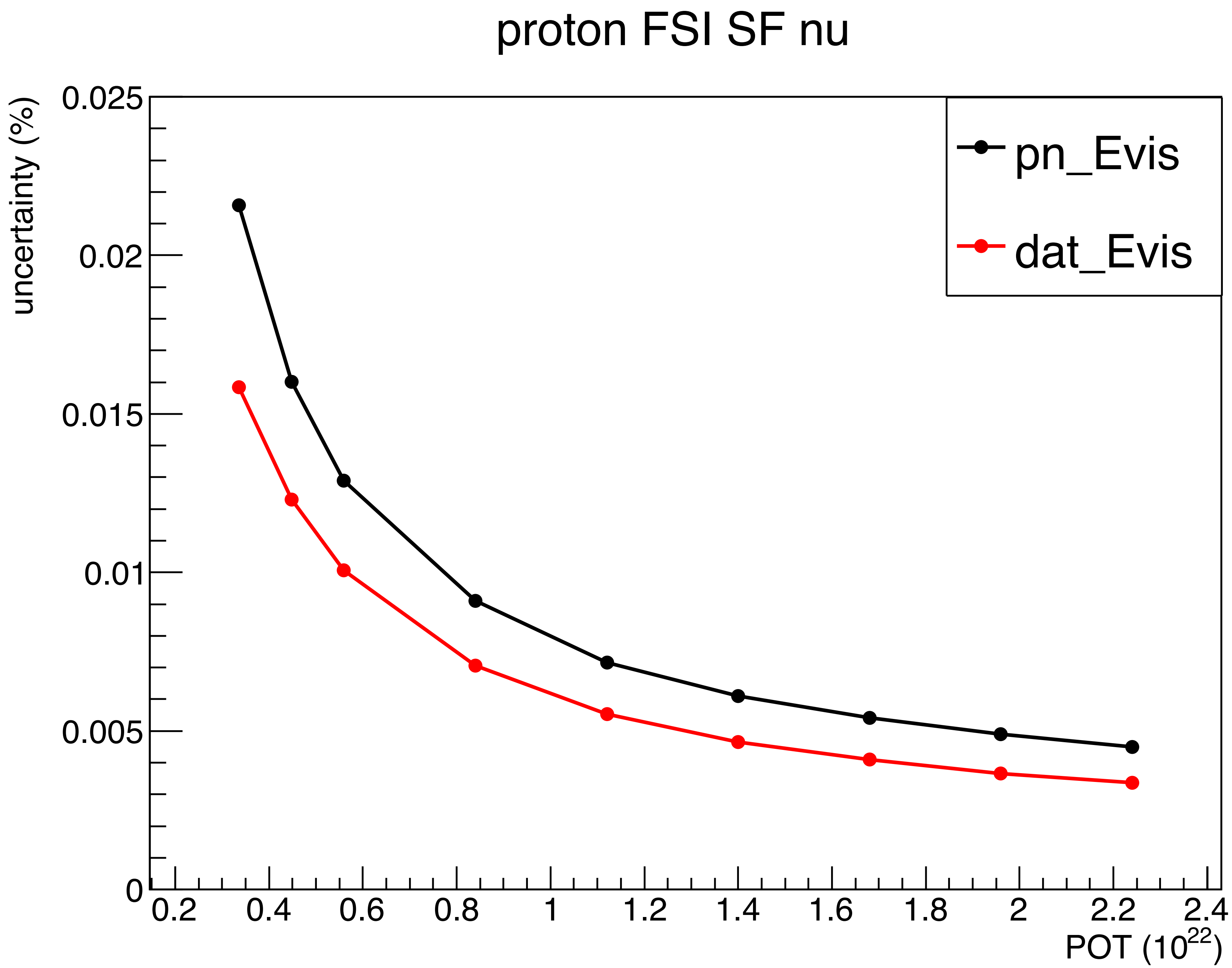
At 2×10^{22} POT : 2p2h uncertainty 4.5%
CCQE uncertainty 3.3%

At 2×10^{22} POT : 2p2h uncertainty 10%
CCQE uncertainty 4.2%

Proton Final State Interaction

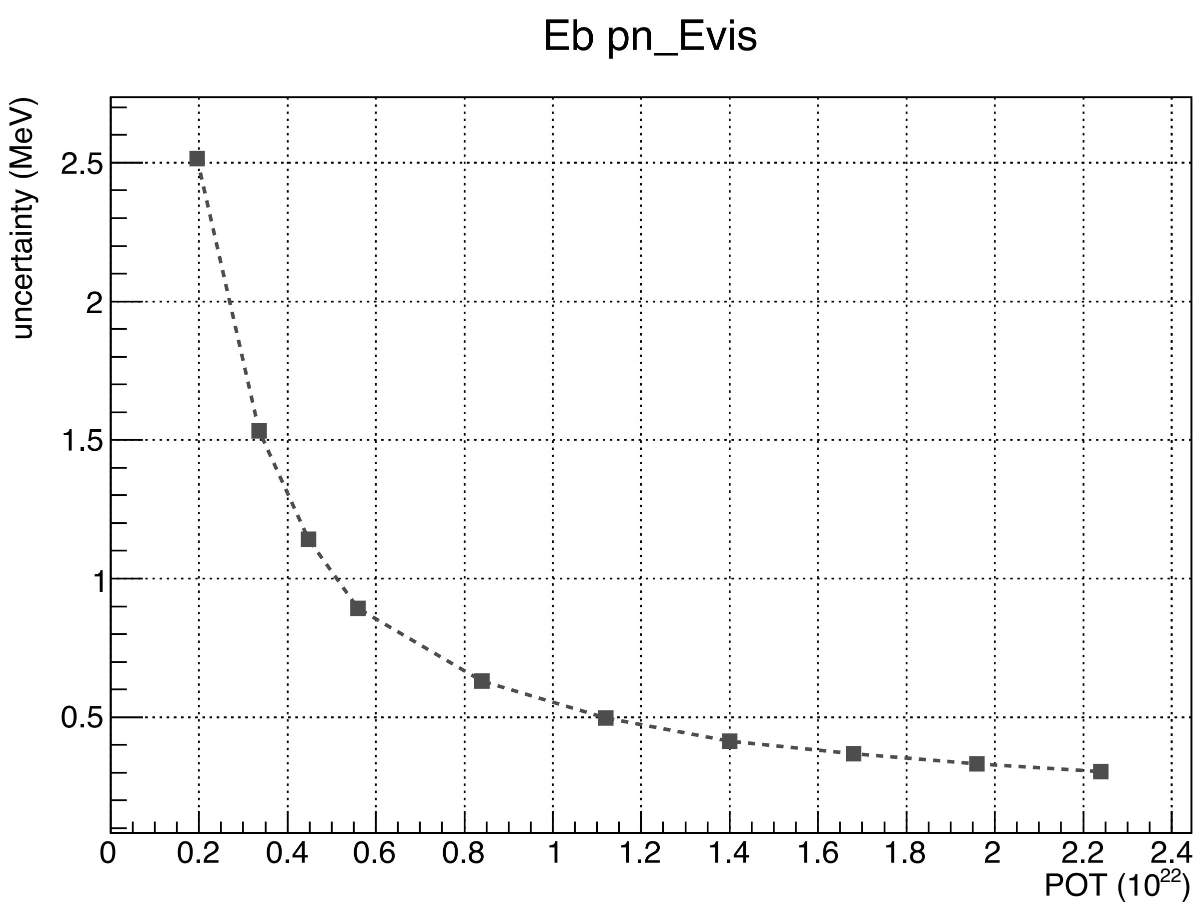
$\delta\alpha_T$ is more sensitive to proton FSI

In both cases proton FSI < 1%

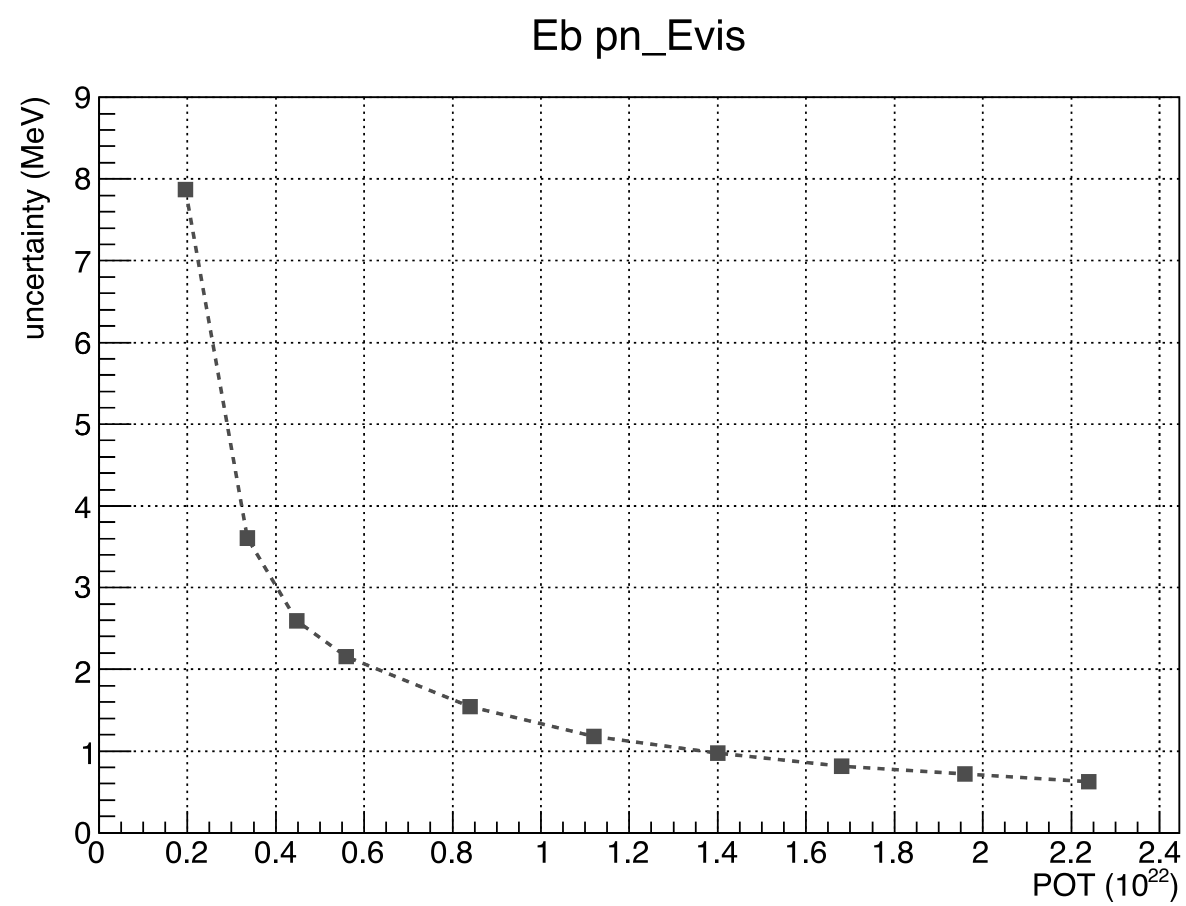


Constraint for binding energy

- At 2×10^{22} POT, uncertainty of Eb is
  <0.5 MeV for neutrino
  <1.0 MeV for anti-neutrino



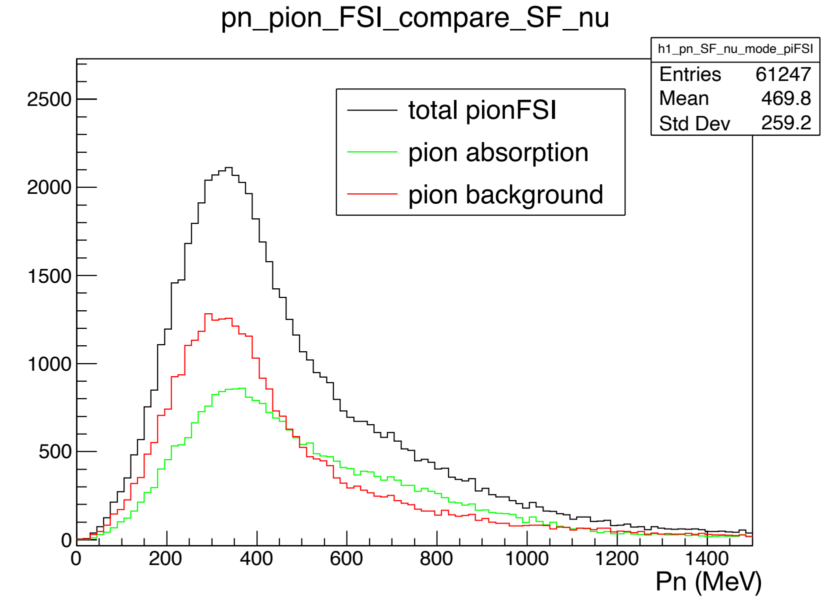
Neutrino

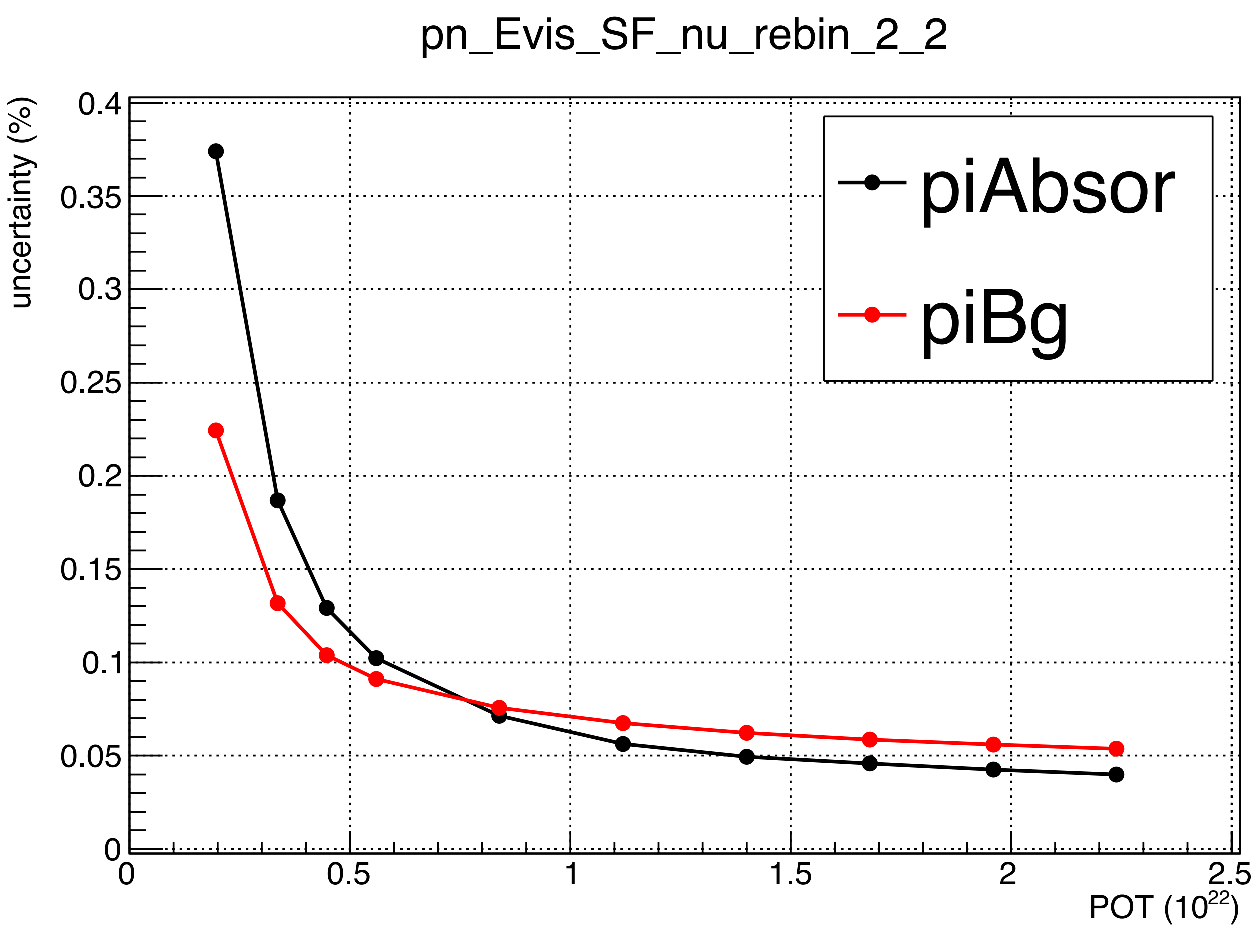


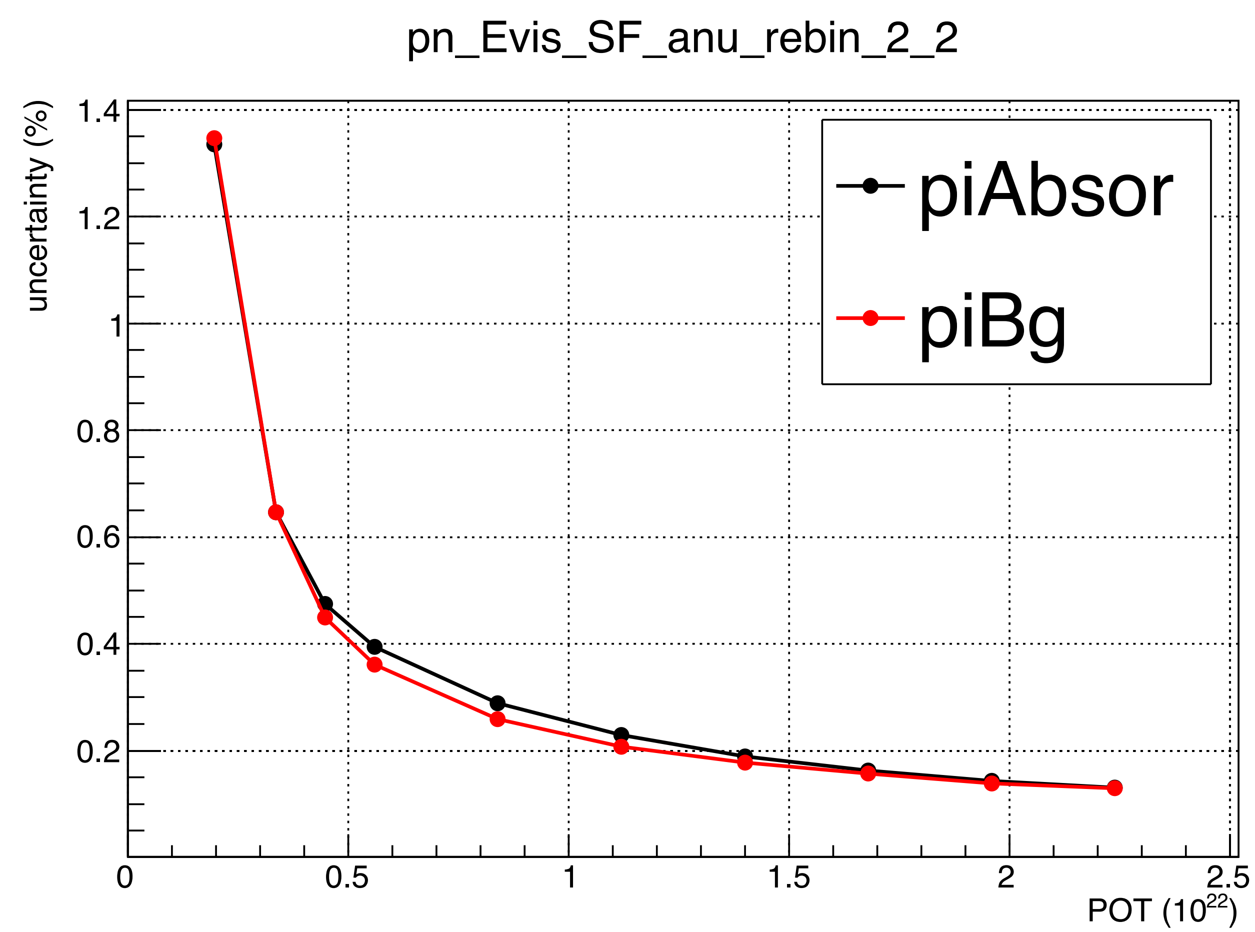
Anti-Neutrino

Pion Final State Interaction

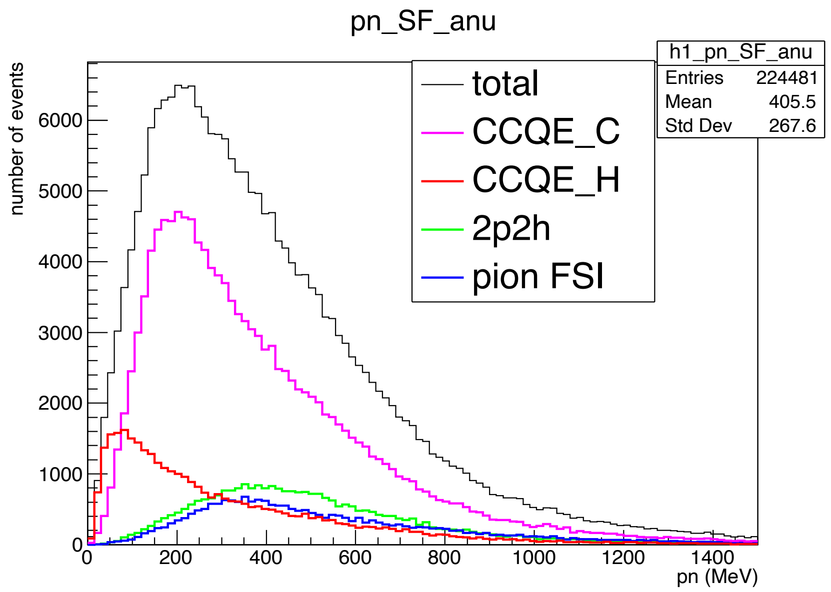
- After: Pion FSI is divided into 2 new parameters:
  - Pion Absorption: (pion absorbed inside nucleus)
  - Pion Background:(pion was below detection threshold)
  Notice that all of them are CC0pi by reconstruction.

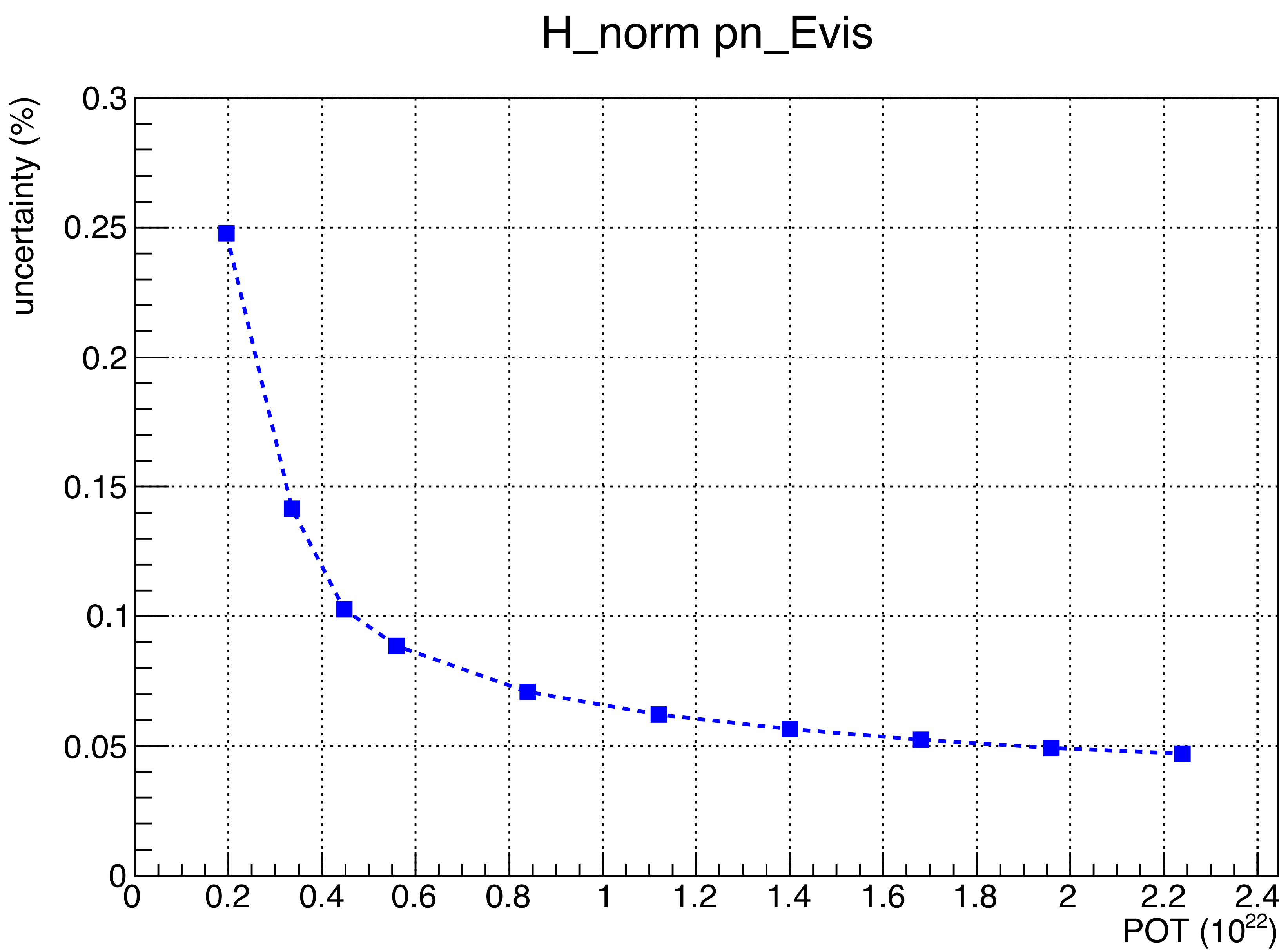






Hydrogen normalisation





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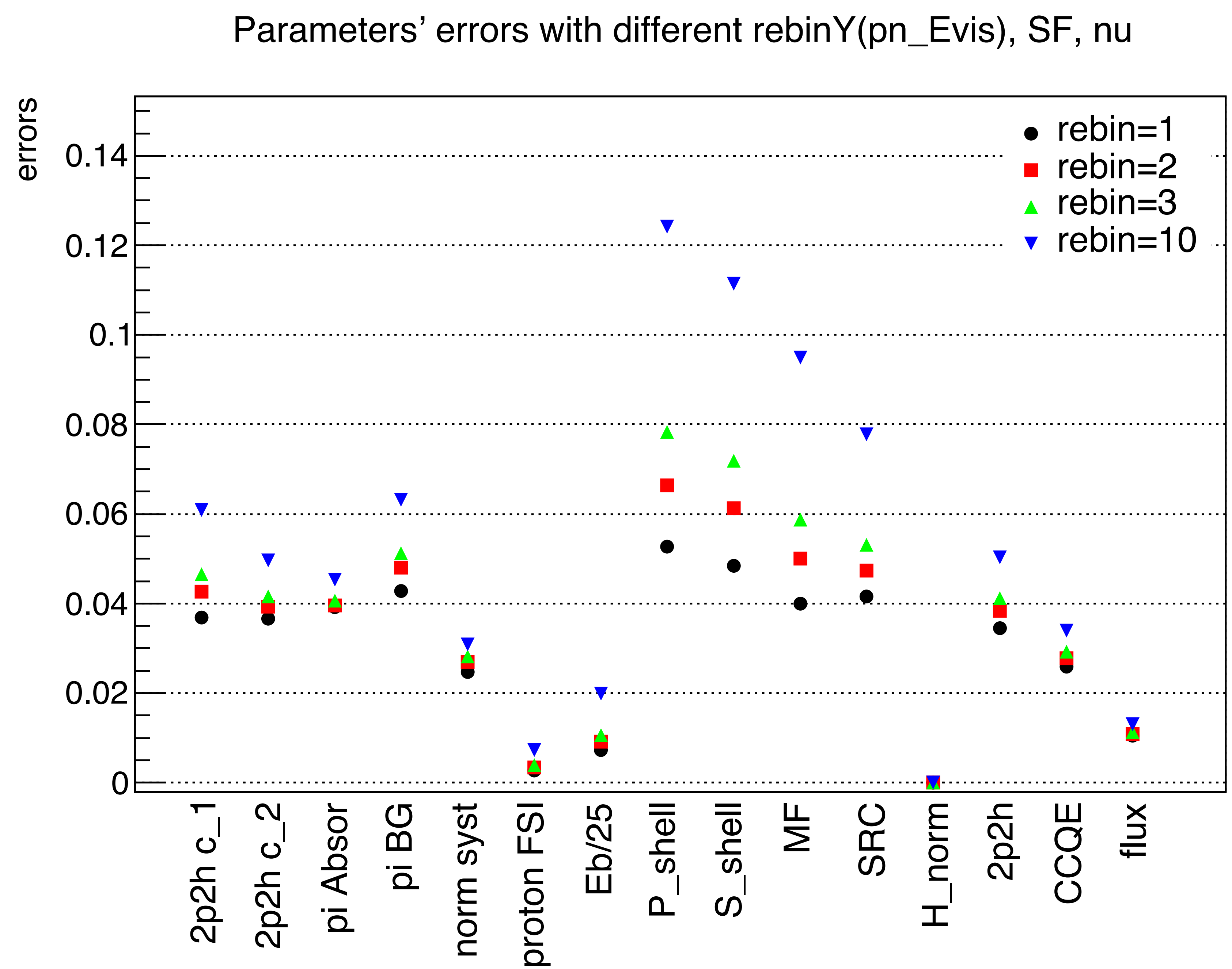
Rebin study

The fit was done with pn_Evis 2×10^{22}POT.

The rebin was change in Evis histogram. The rebin used for pn is 2.

We have 150 bins, each one has the bin width of 10MeV

The more bin we have, the better uncertainties we can obtain.

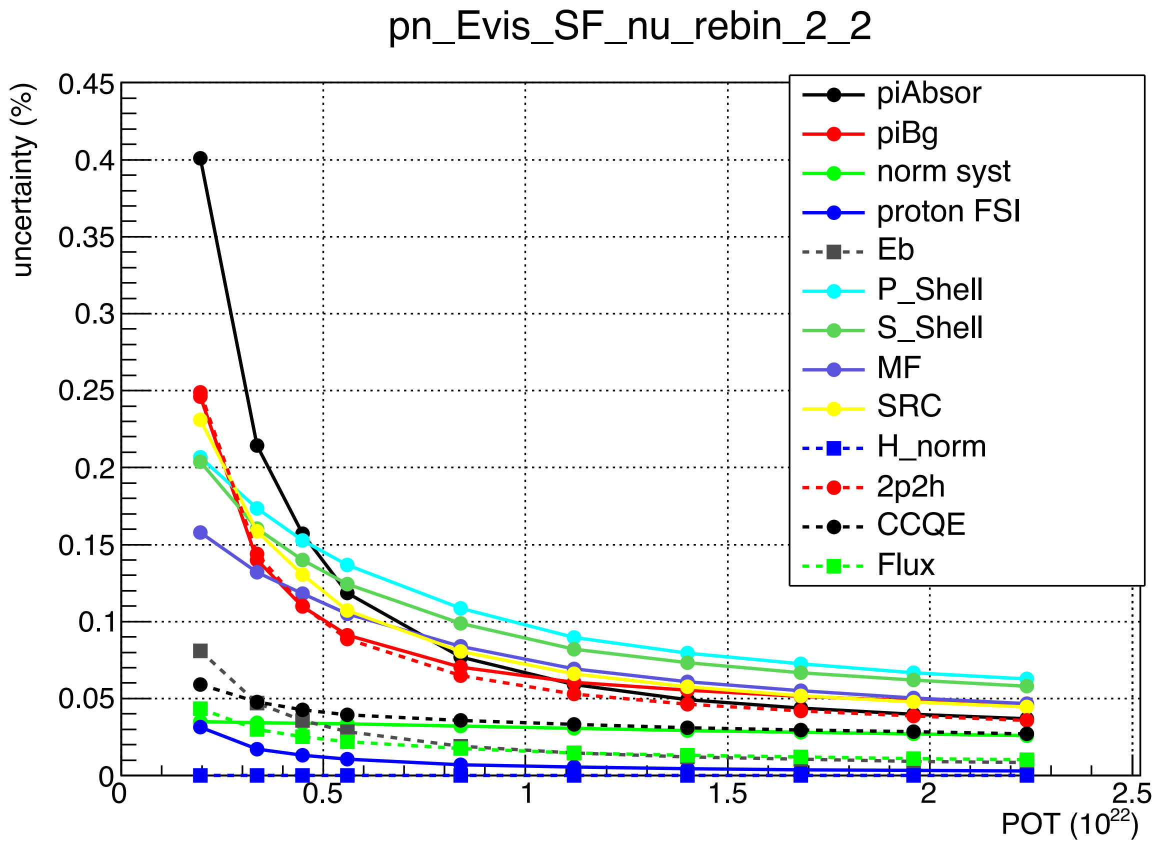


Sensitivity to cross-section parameters

POT 2×10^{22}, observables: pn_Evis

	Nu	Anti-nu
2p2h normalisation	4.5%	10.2%
CCQE normalisation	3.2%	4.0%
Eb	0.33 MeV	0.70 MeV
Pion absorption	4.2%	14.2%
Pion Background	5.6%	13.8%
Hydrogen normalisation		4.9%

Summary



- This fitter is the first step to obtain the quick physics studies for ND280 Upgrade, before having a real complete fitter.

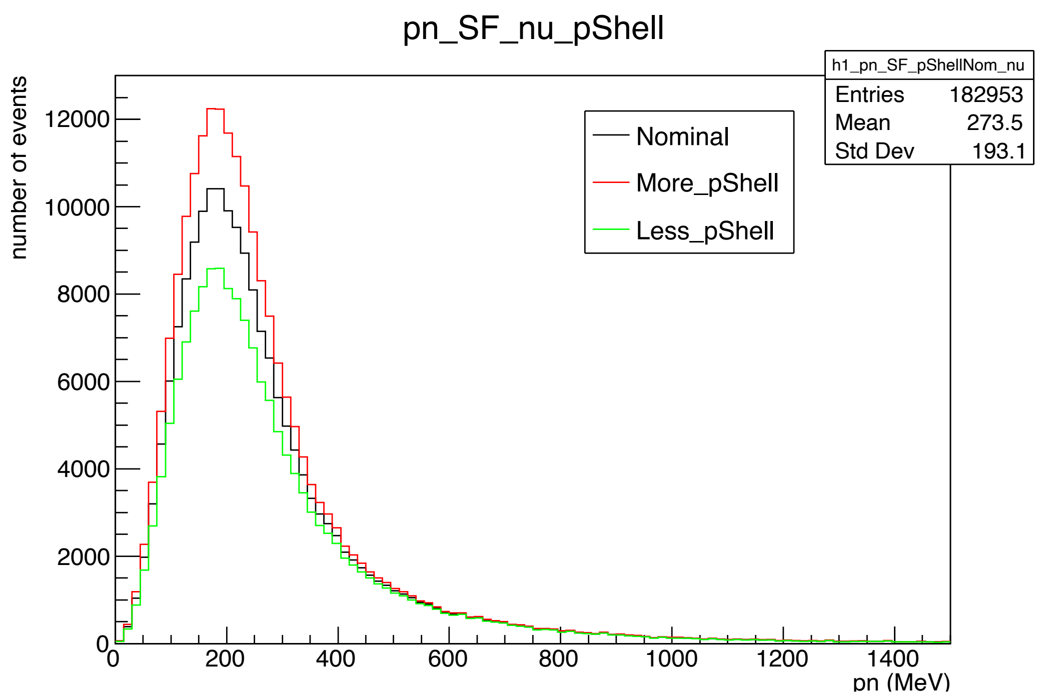
- The fitter aims to find the quantitative sensitivities to key systematic uncertainties.

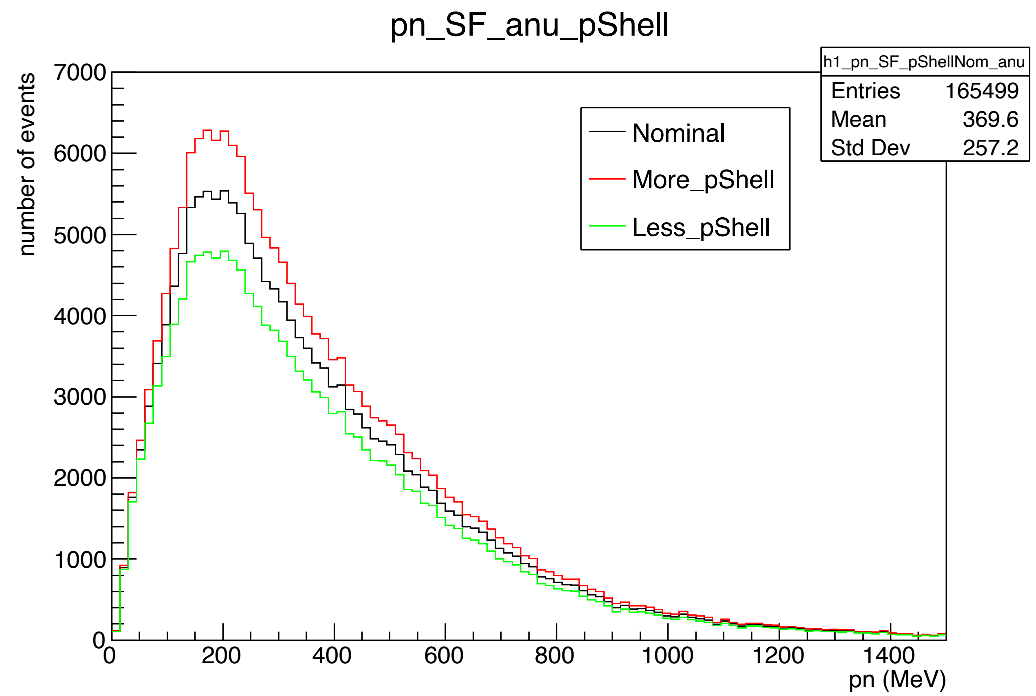
- This binned fitter was dedicated for the use of STVs, the studies was done with new observable which is Evis. We do not used the muon kinematics (momentum, angle) so these results are certainly conservative

- The results show promising constraints on key parameters such as 2p2h component (5% for neutrino and 10% for anti neutrino with 2×10^{22}), Hydrogen interaction (5%). And all parameters uncertainties are below 10% for 1×10^{22} POT (in nu fit).

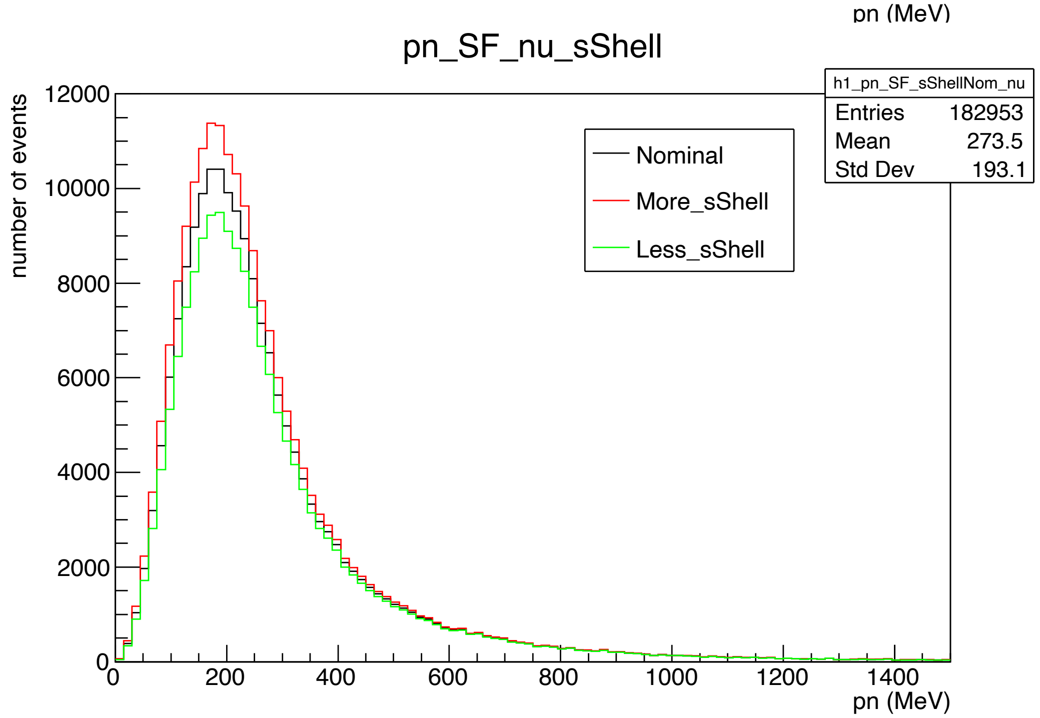
Back up

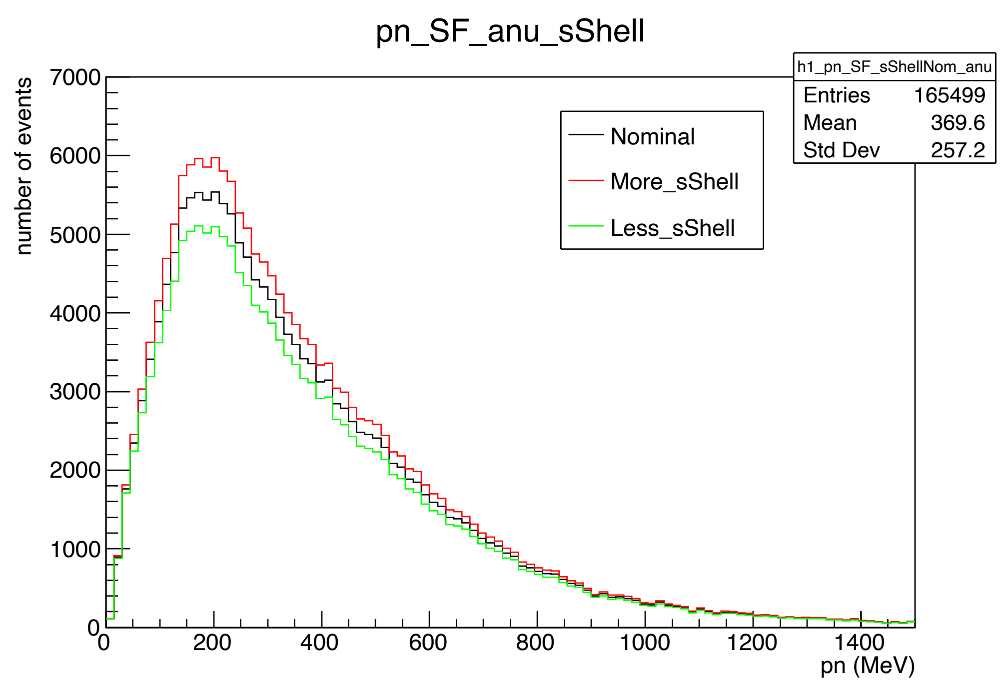
Pn histograms for P/S Shell





P Shell
if(Emiss>10
&& Emiss<25)





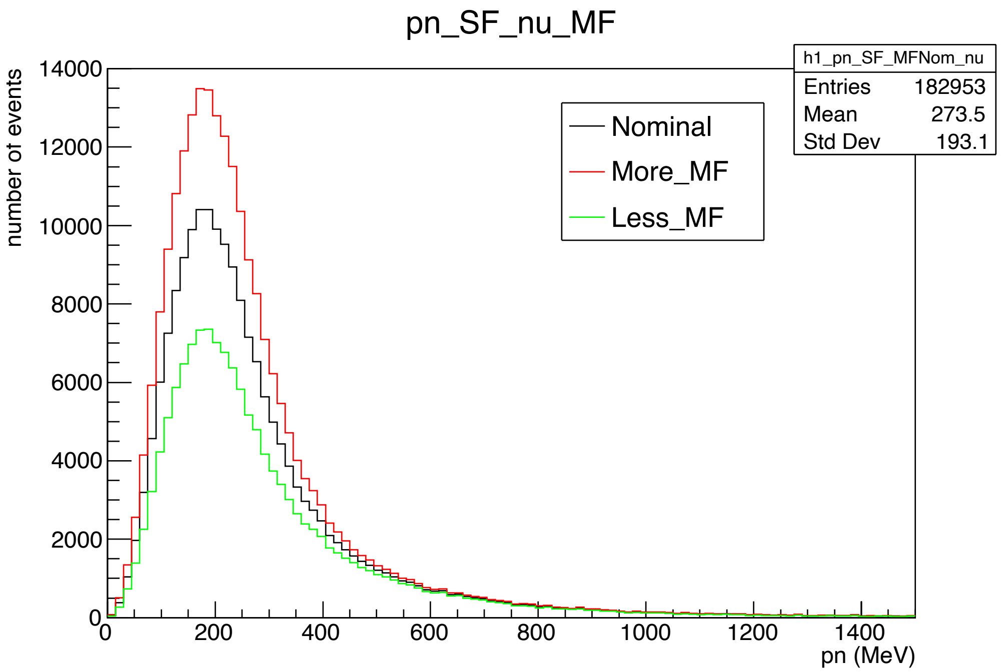
S Shell
if(Emiss>25
&& Emiss<60)

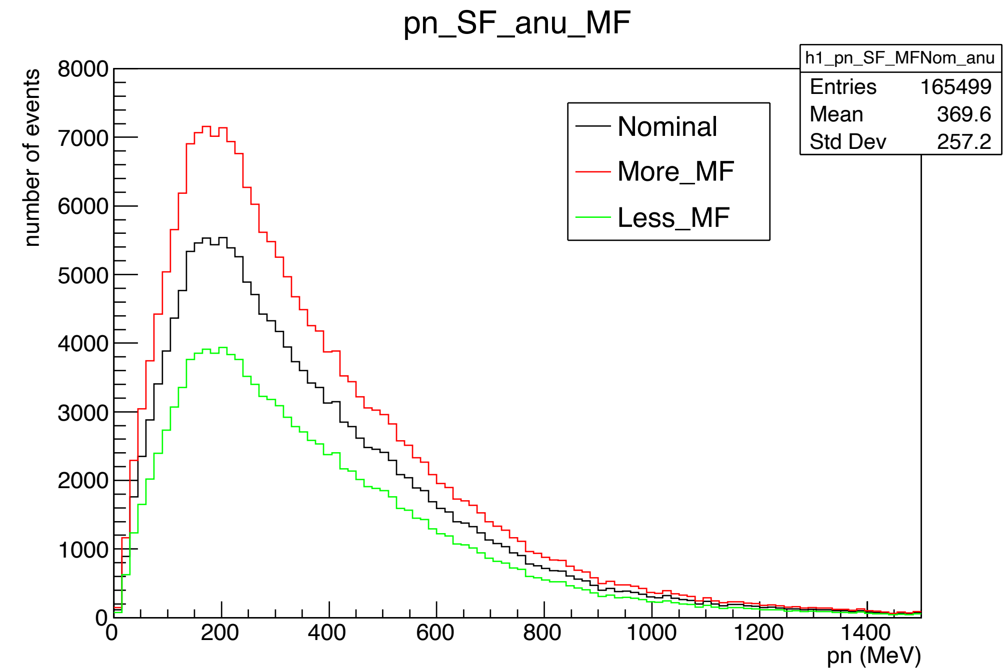
More = reweight(Nom,1.3)
Less = reweight(Nom,0.7)

Neutrino

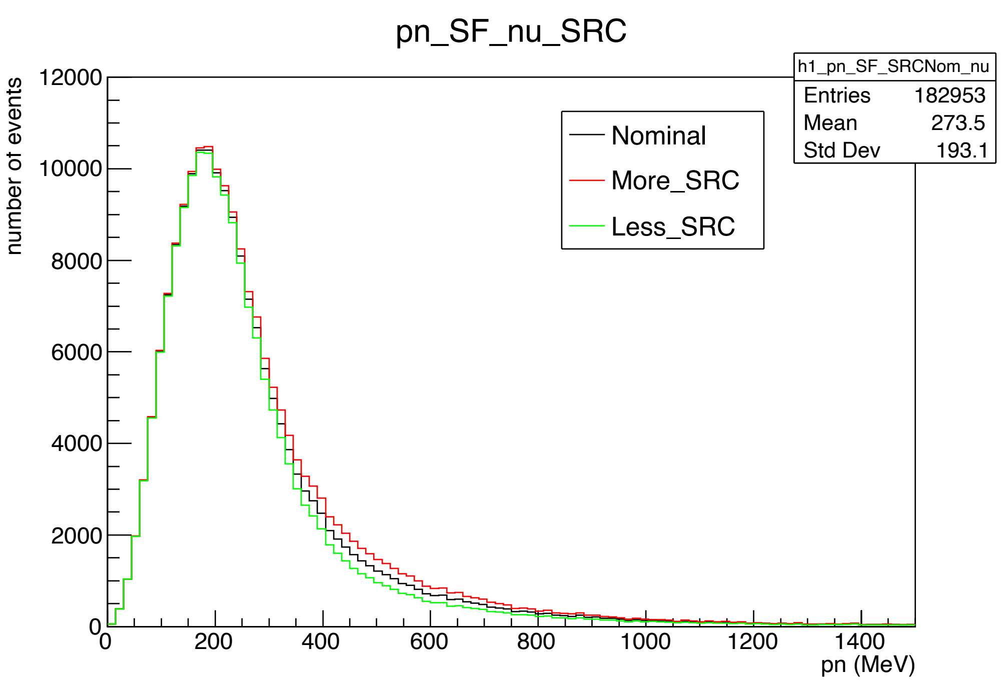
Anti-Neutrino

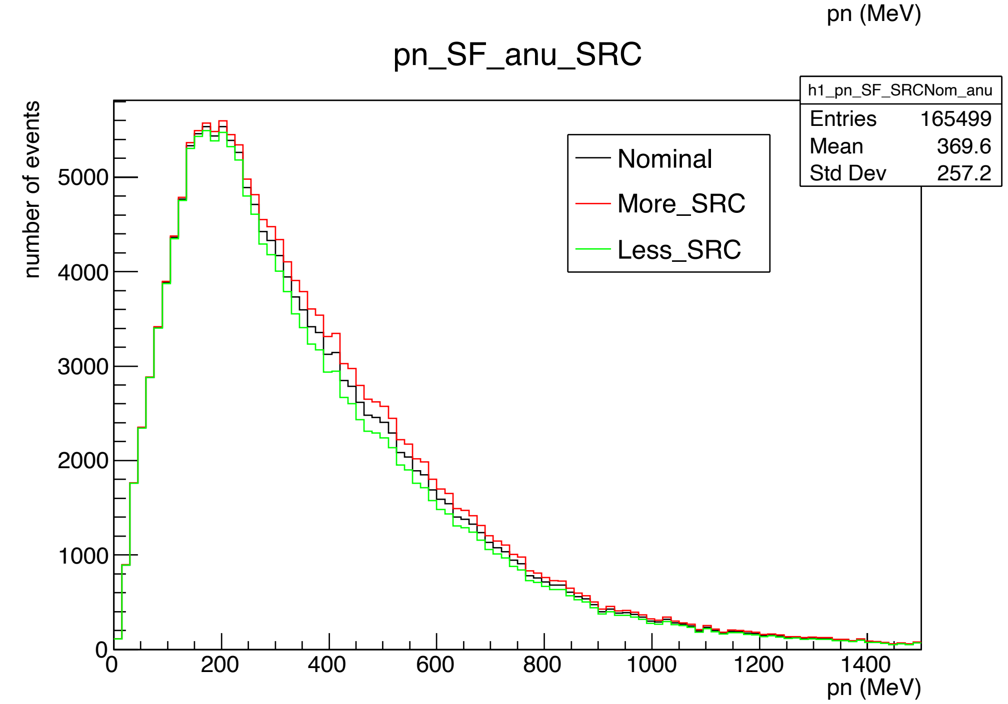
Pn histograms for MF, SRC





Mean Field





Short Range Correlations

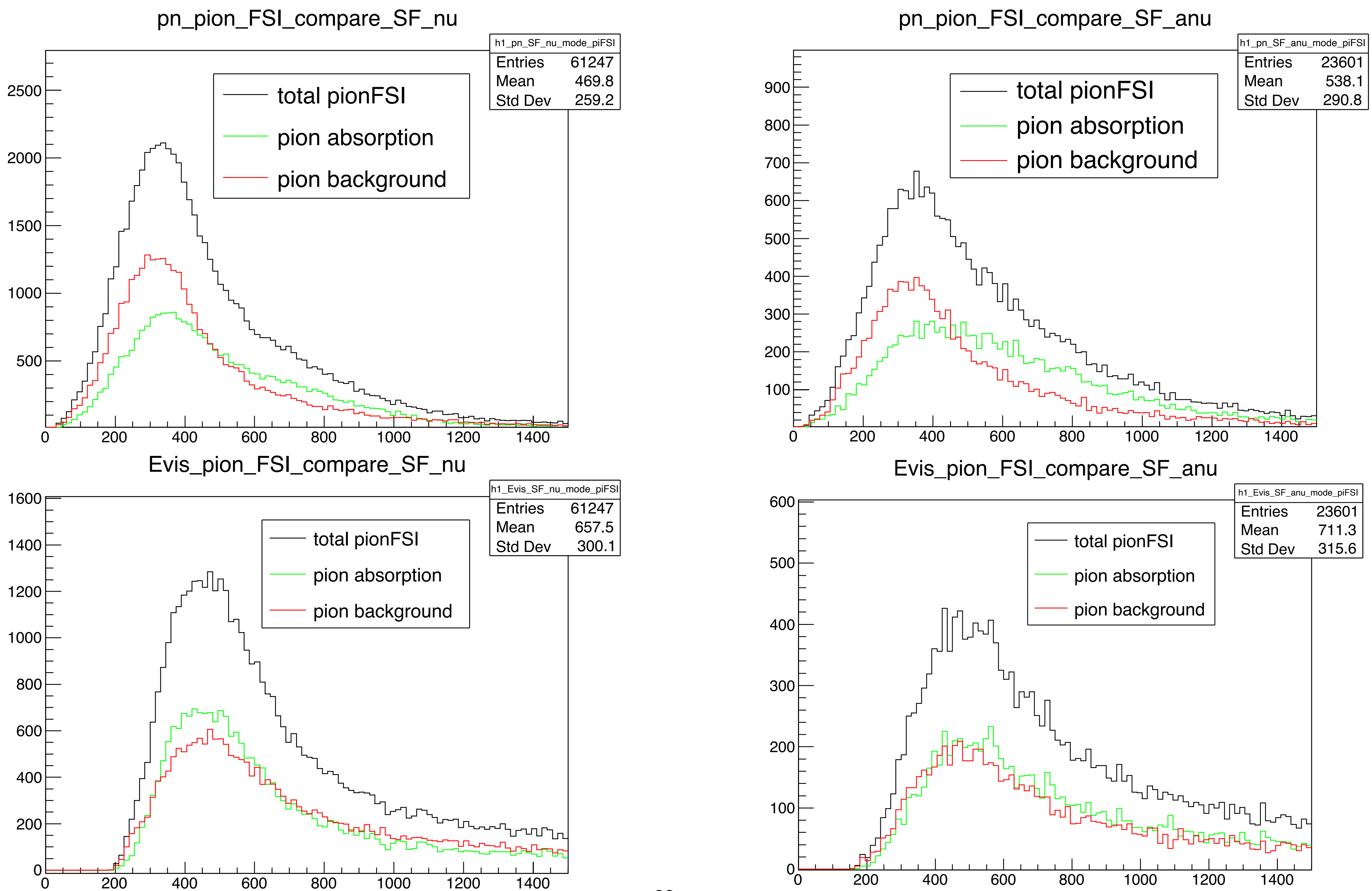
More = reweight(Nom,1.3)

Less = reweight(Nom,0.7)

Neutrino

Anti-Neutrino

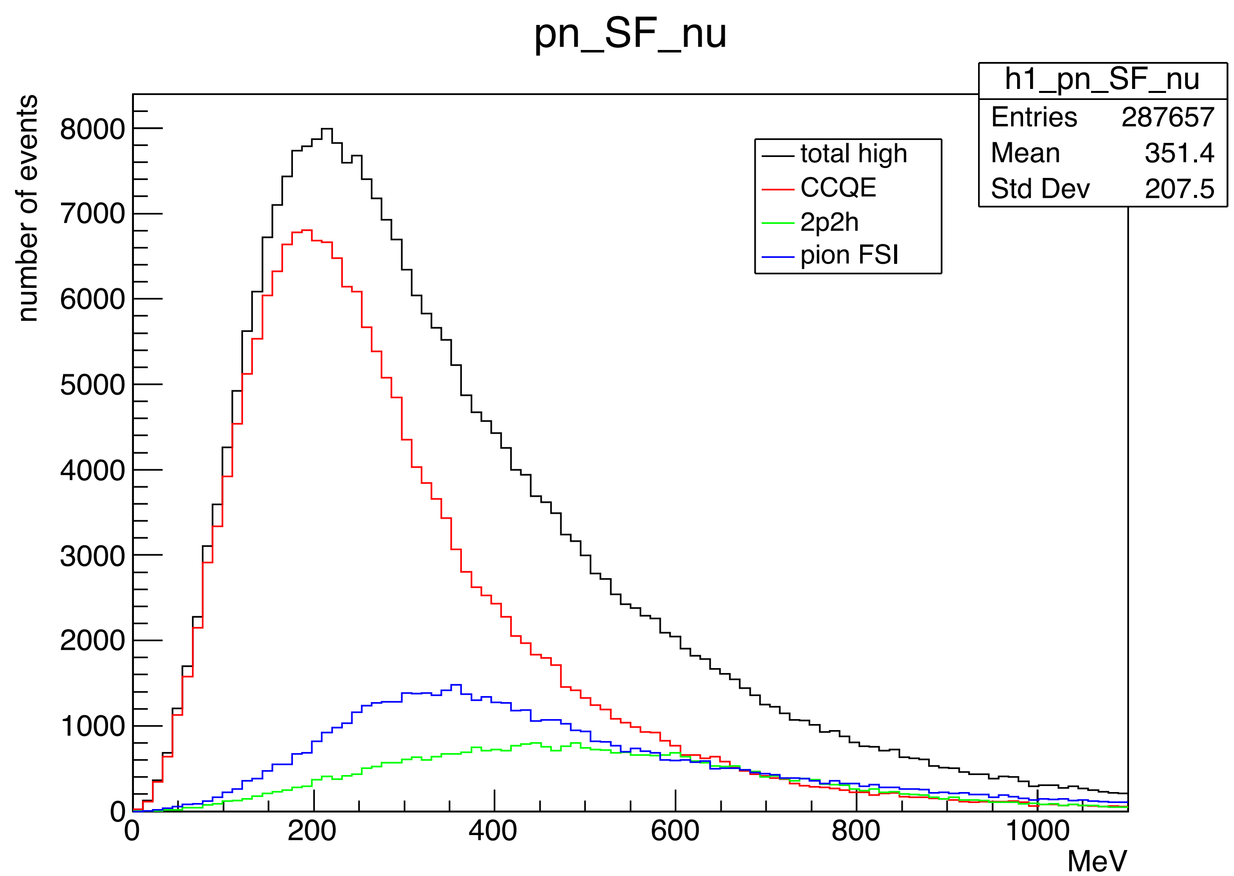
Pion FSI plot for pn and Evis



Pn calculation

pn is the Fermi momentum of initial nucleon

$$p_n = \sqrt{\delta p_L^2 + \delta p_T^2}$$



Longitudinal component of the Fermi momentum

$$\delta p_L = \frac{1}{2}R - \frac{M_{A-1}^2 + \delta p_T^2}{2R}, \text{ where}$$

$$R = M_A + p_L^\mu + p_L^n - E^\mu - E^n$$

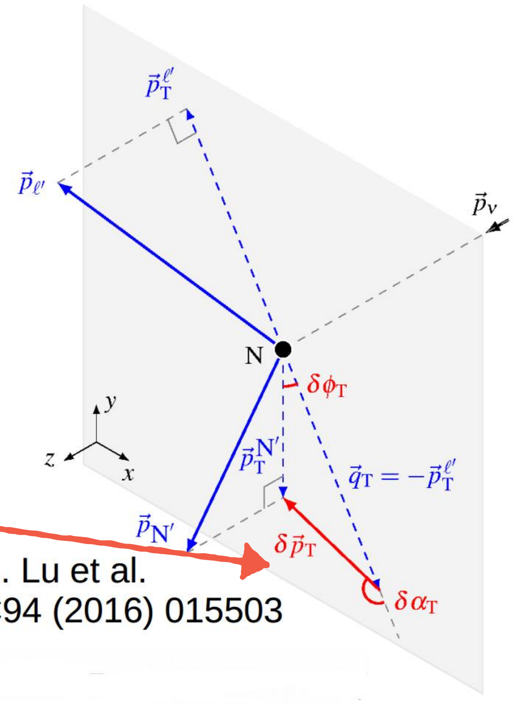
$$M_{A-1} = M_A - M_n + E_b$$

n is the nucleon that (anti-)neutrino interact with.
n is neutron (nu case) or proton (anu case)
M_A is mass of target nucleus.

Transverse component of the Fermi momentum:

momentum difference between muon and proton in the transverse plane

$$\delta p_T = \left| \mathbf{p}_T^\mu + \mathbf{p}_T^p \right|$$



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