Imperial College London

Recent results from High Pressure TPC (HPTPC) R&D efforts

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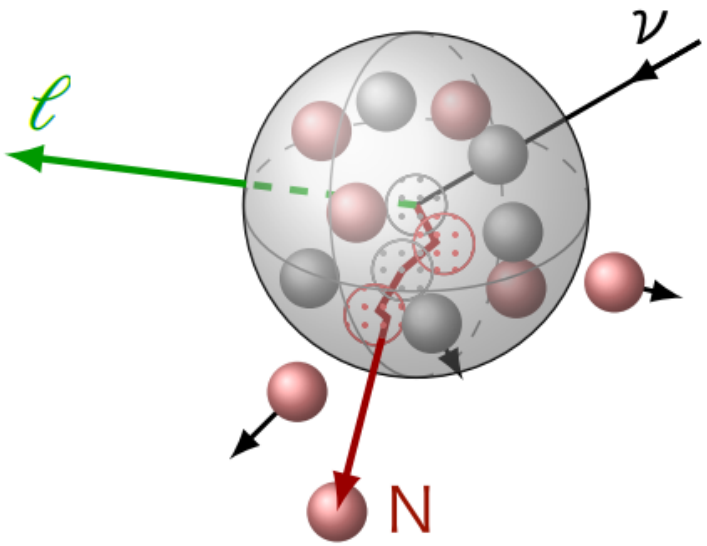
Overview

- Why would an HPTPC be helpful for T2K?
- Transverse variables
- What R&D is being done into HPTPCs?
- Some early sensitivity studies
- Things to work on and what's next

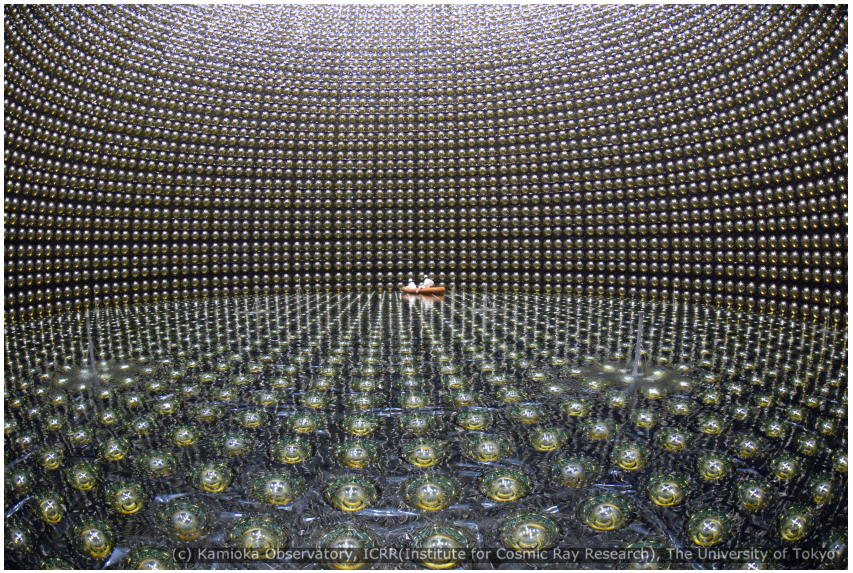
T2K neutrino interaction model

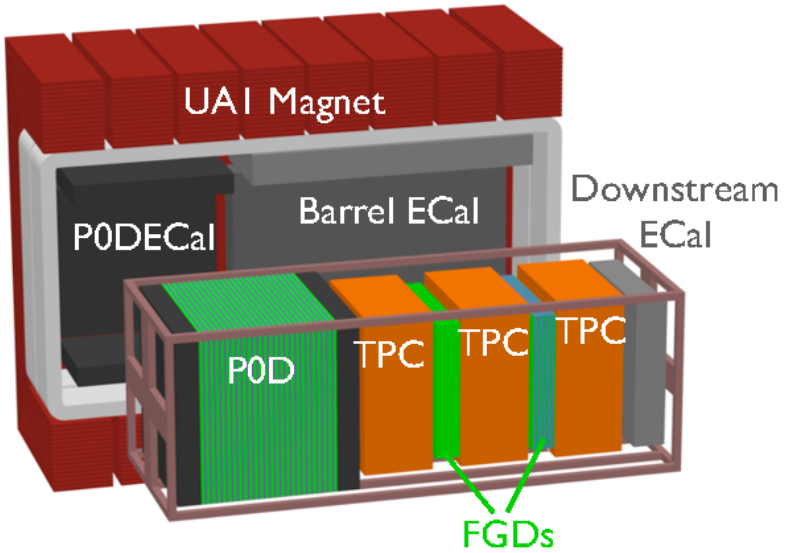
- Several elements convoluted:
  - Neutrino nucleon interaction
  - Nucleon kinematics
  - Secondary interactions etc.
- Even if your model correctly describes lepton kinematics in one target can't tell if it's right



What problems could we have?

- Different nuclei at near and far detector

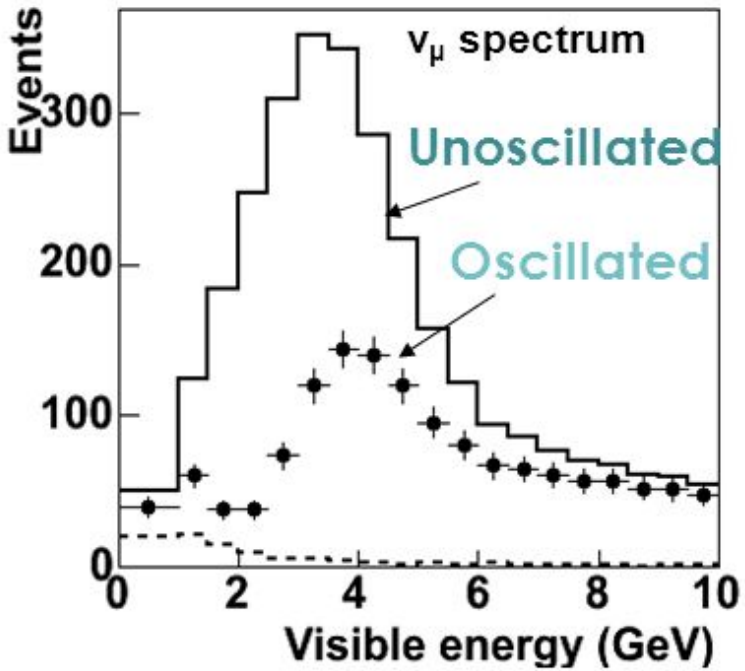




- Could use a water near detector like Nu-Prism/Titus

What problems could we have?

- Different energy spectrum at near and far detector



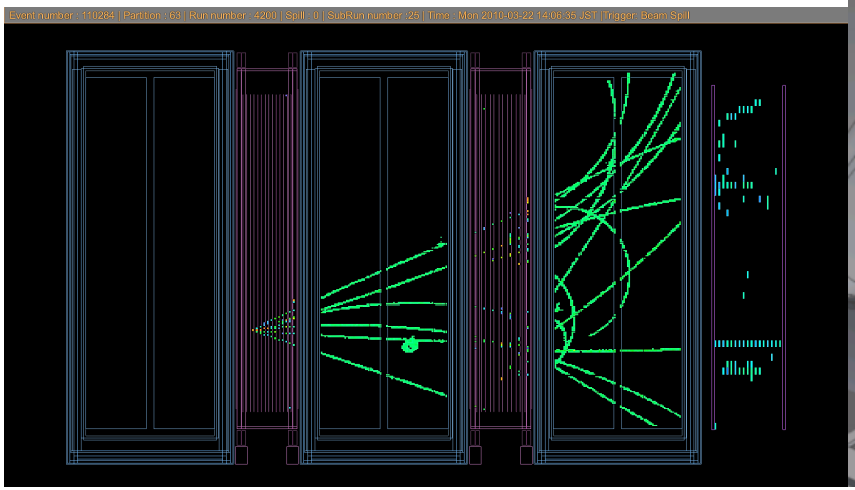
- Even if same nucleus this can be problematic
- Other problems too, efficiency and misreconstruction (see Kevin's talk)

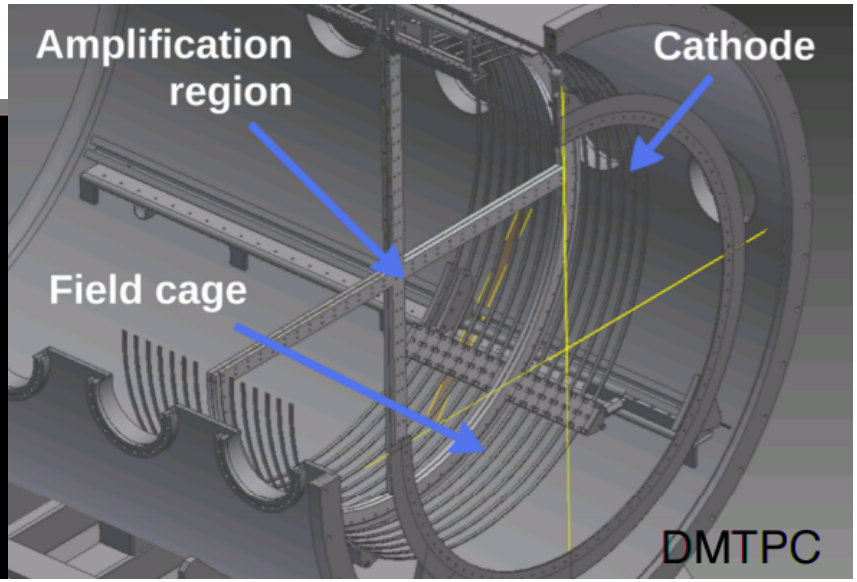
What can we do about it?

- Great work already being done by xsec/external fitting etc. groups (see other talks)
- Need to do more to test if $\nu/\bar{\nu}$ difference is from CP violation
  - Must look at more variables including hadronic ones
  - Must look at as many nuclei as possible
- Can use an HPTPC to do this

What is an HPTPC?

- Has the fine resolution and low thresholds of a TPC
- High pressure gives enough density to use as a target
- Can look at different nuclei by altering gas mix





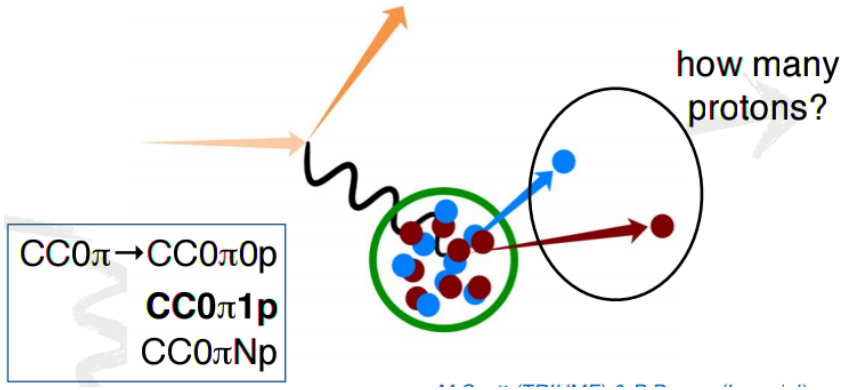
Sensitivity studies with HPTPC

- Plan to include a $40m^3$ HPTPC as an HK near detector
  - $\sim$600kg of Argon gas
  - $\sim$42,000 events per 10^{21} POT
- Envisage the following thresholds and efficiencies:

Particle	ND280 Threshold/MeV	HPTPC Threshold/MeV
μ	100	15
π	120	16
p	450	60
e	100	1

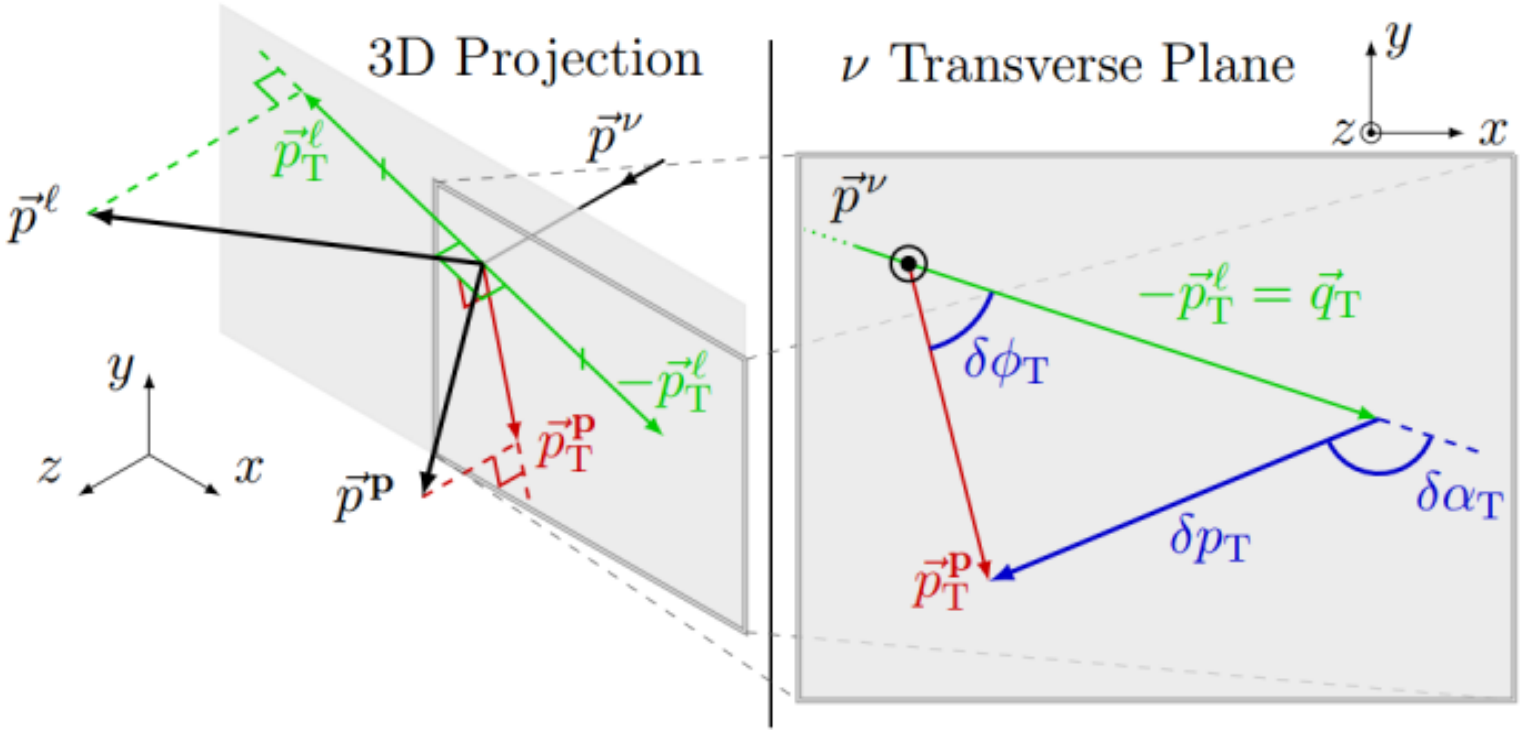
Sensitivity studies with HPTPC

- Have taken ND280 truth MC and applied HPTPC like efficiencies and thresholds
  - Assumes same target nuclei as ND280
- Separate CC0π and CC1π events by number of protons
- Calculate event variables and compare detectors
- Low hadronic thresholds allow for use of hadron kinematics



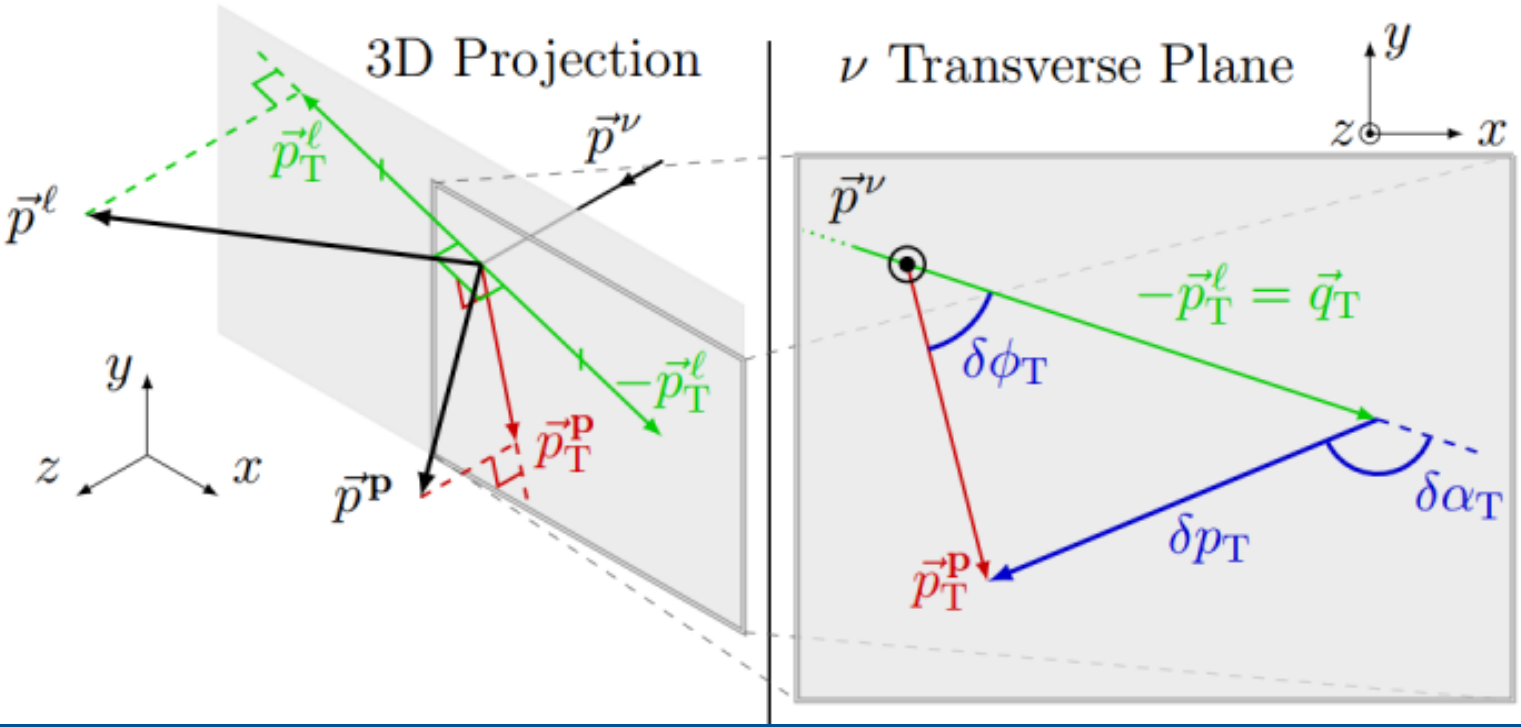
Single Transverse Variables

- Use hadronic information to estimate nuclear effects
- Any imbalance perpendicular to neutrino direction should come from nuclei/unseen particles
  - Details in Xianguo's talk
- Variables widely used in other areas of particle physics



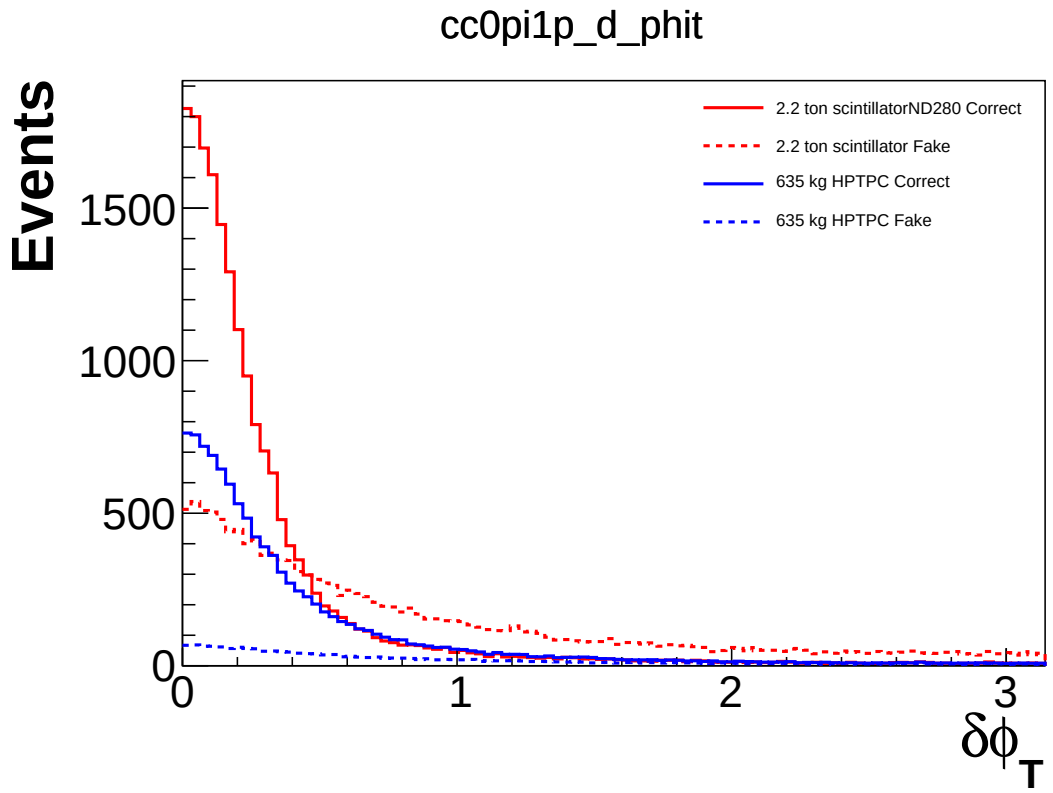
Aside on naming for STV

- Naming that is emerging in neutrino physics is different from other areas: e.g. hadron colliders
  - $\delta p_T = p_T^{miss}$, $\delta\phi_T = \pi - \Delta\phi_T(lep, had)$, $\delta\alpha_T = \pi - \Delta\phi_T(lep, p_T^{miss})$
- Personally find hadron collider naming more intuitive
- Worth considering whether we want to standardise



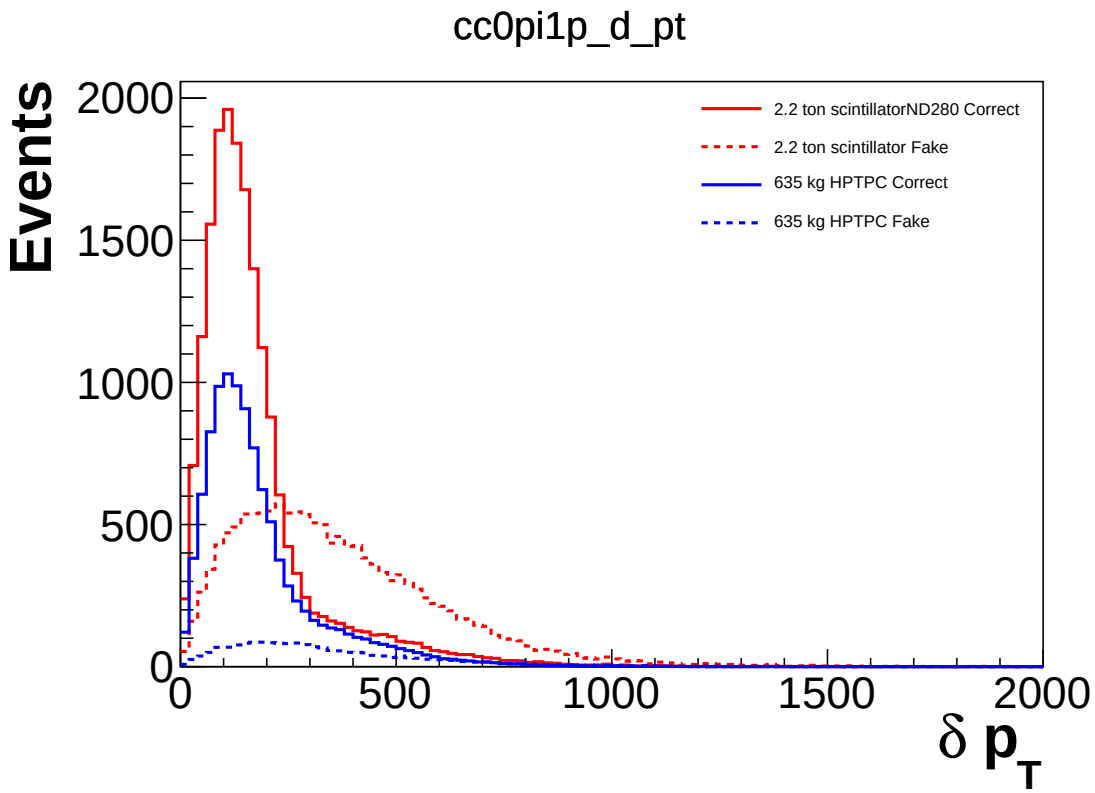
1D distributions for CC0π1p

- Use truth information to separate correctly identified real CC0π1p events from fakes
- HPTPC event rates are lower but purity is much better



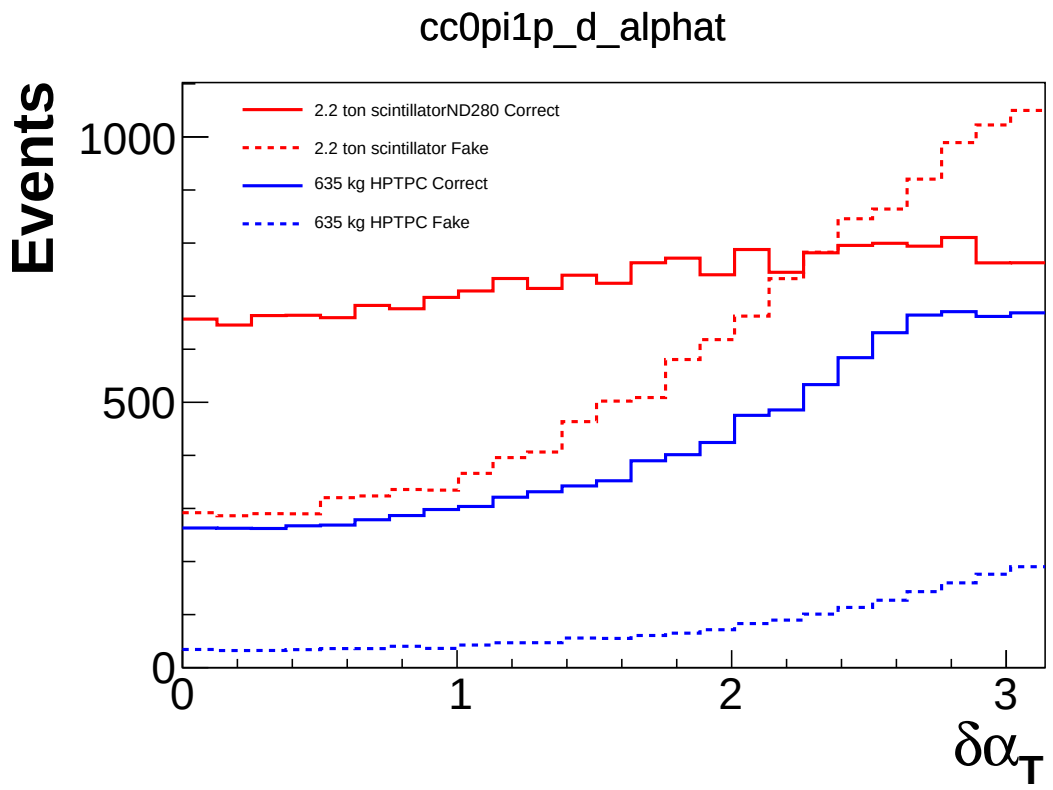
1D distributions for CC0π1P

- Shape differences with nominal model aren't that great
- But aim is not just to add samples to BANFF fit



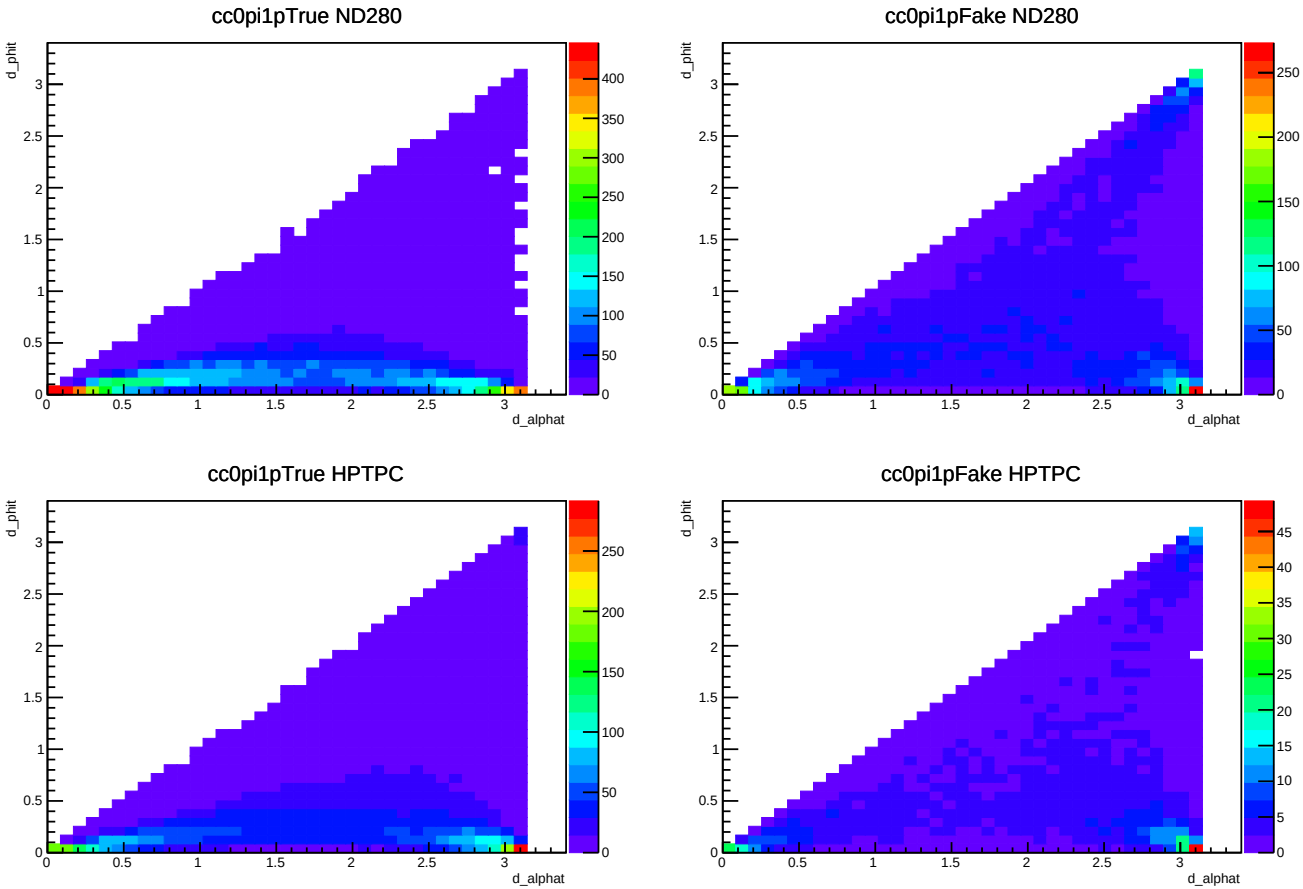
1D distributions for CC0π1P

- Hope to use HPTPC for model selection
- High purity sample can be reliably compared to MC



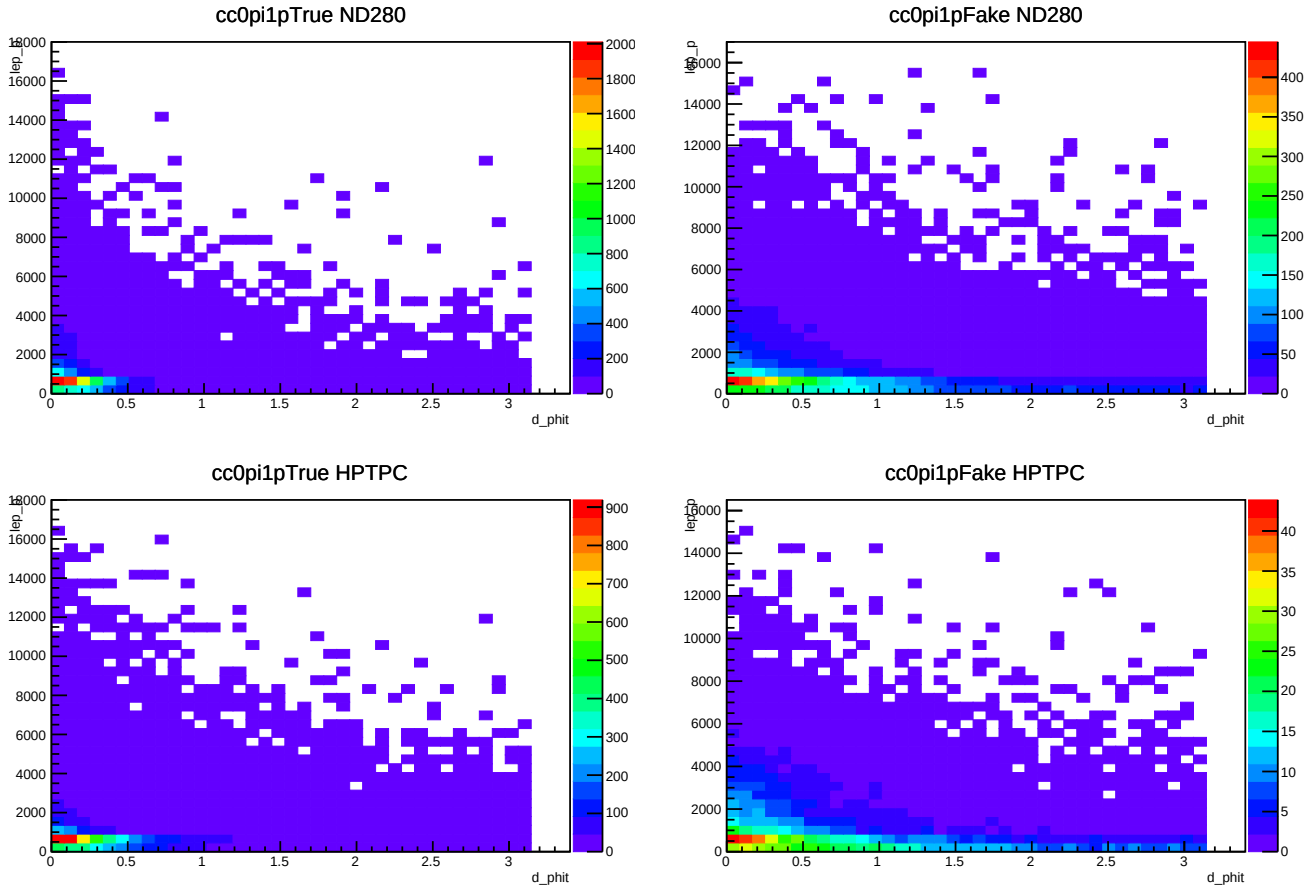
2D distributions for CC0π1P

- Also look at 2D distributions



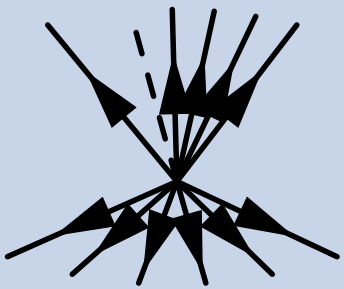
2D distributions for CC0π1P

- And compare lepton and hadron variables

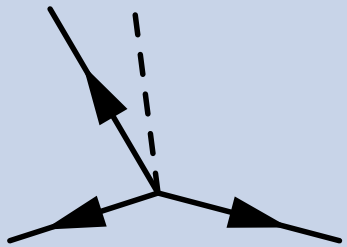


Other Transverse Variables - Reminder

- Particularly for p_T^{miss} context is important



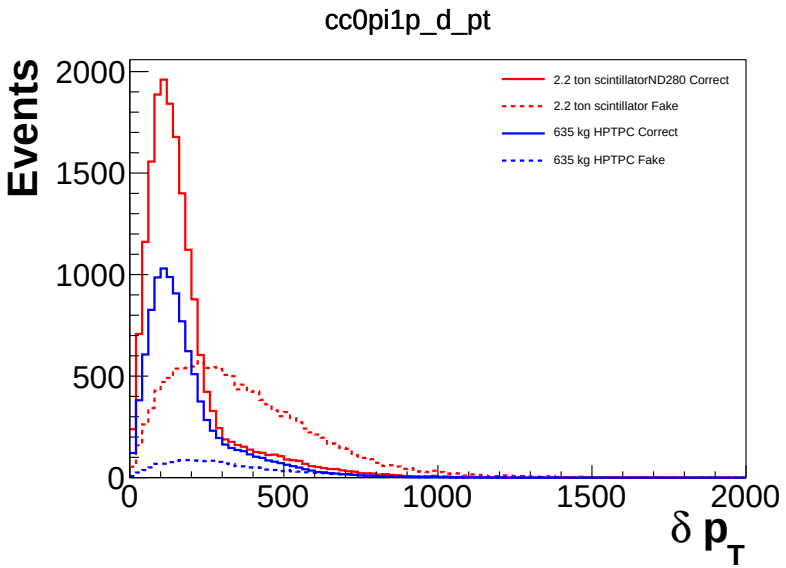
VS

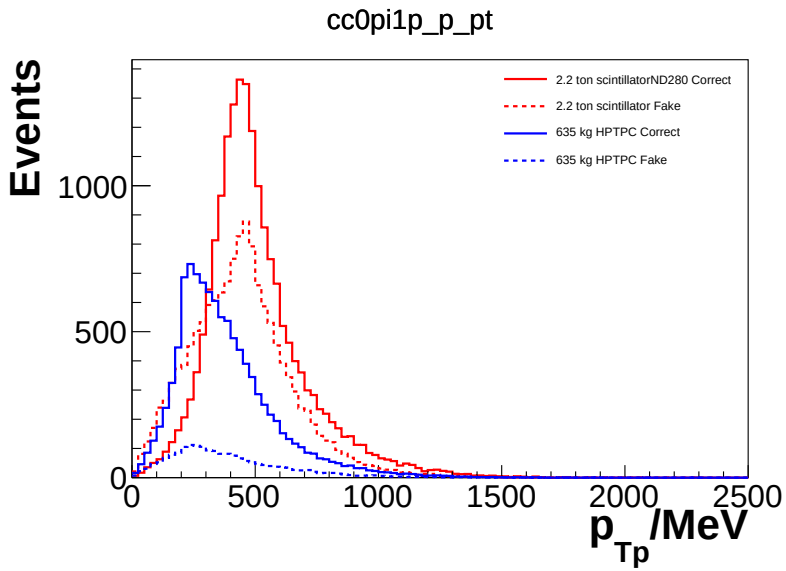


- Both events have the same $p_T^{miss}/\delta p_T$ but on the right this is clearly more significant compared to uncertainties on visible object momenta

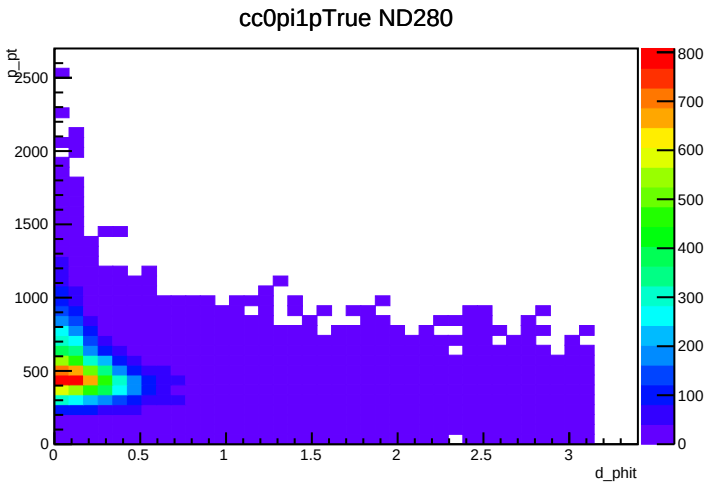
Additional information

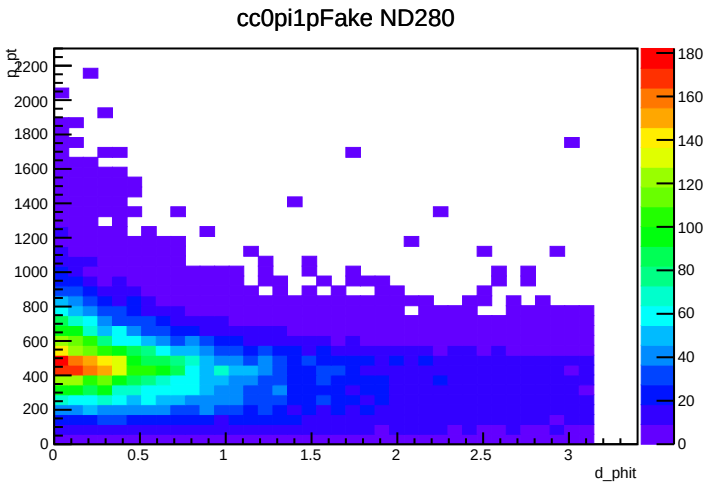
- Look at component of proton momentum in transverse plane

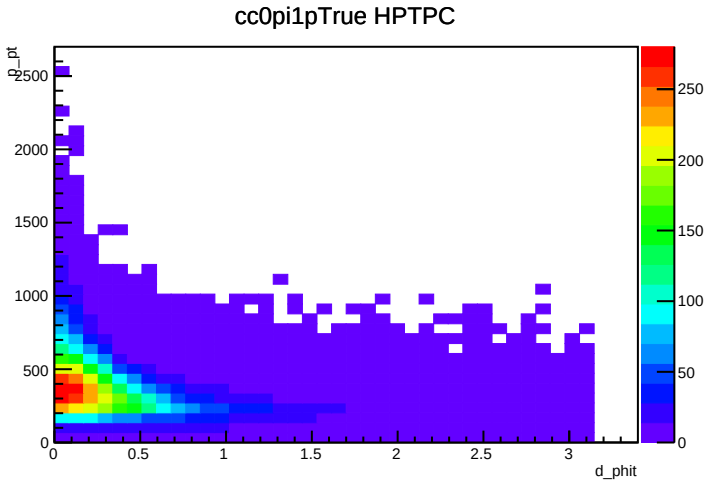


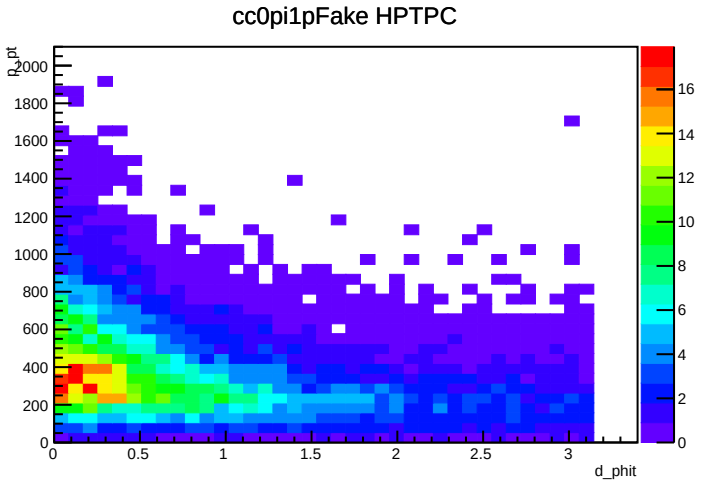


2D distribution highlights for CC0π1P

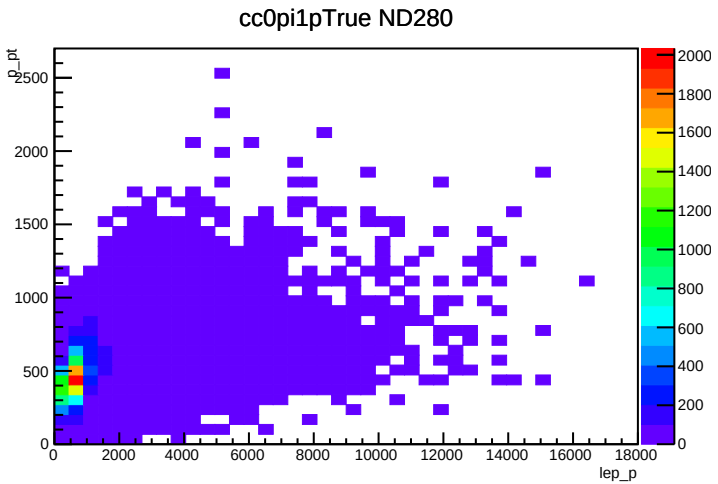


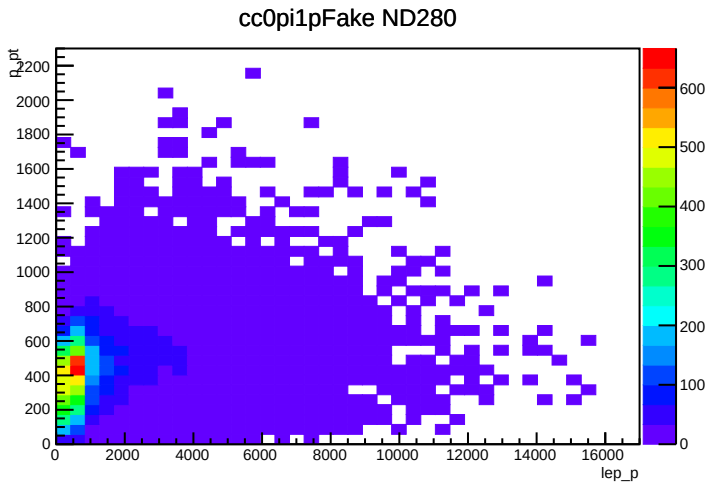


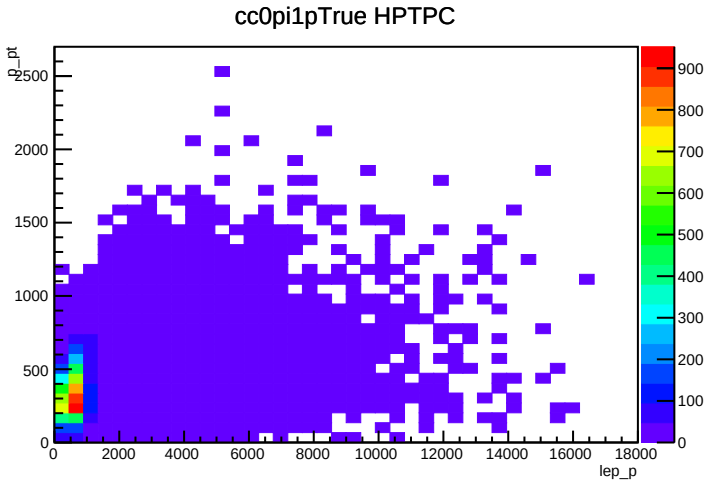


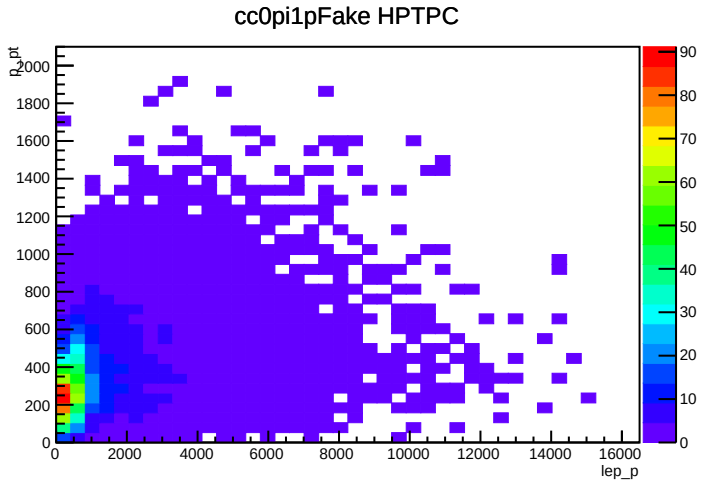


2D distribution highlights for CC0π1P







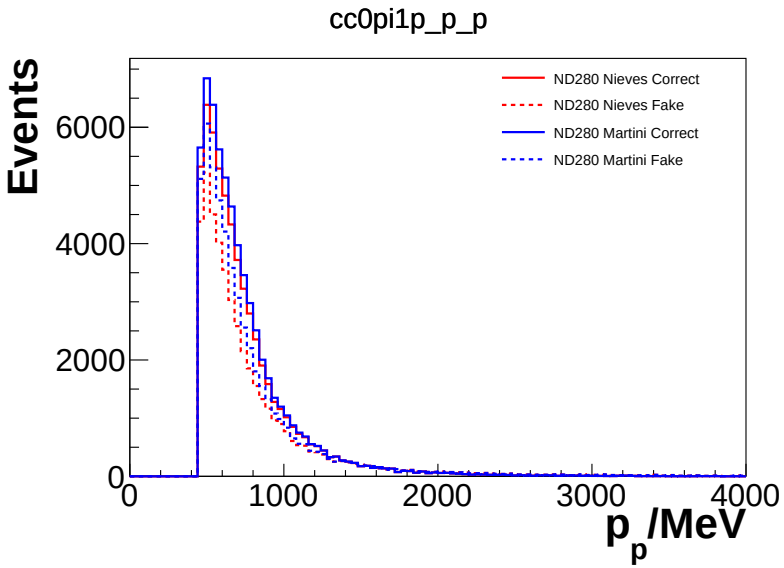


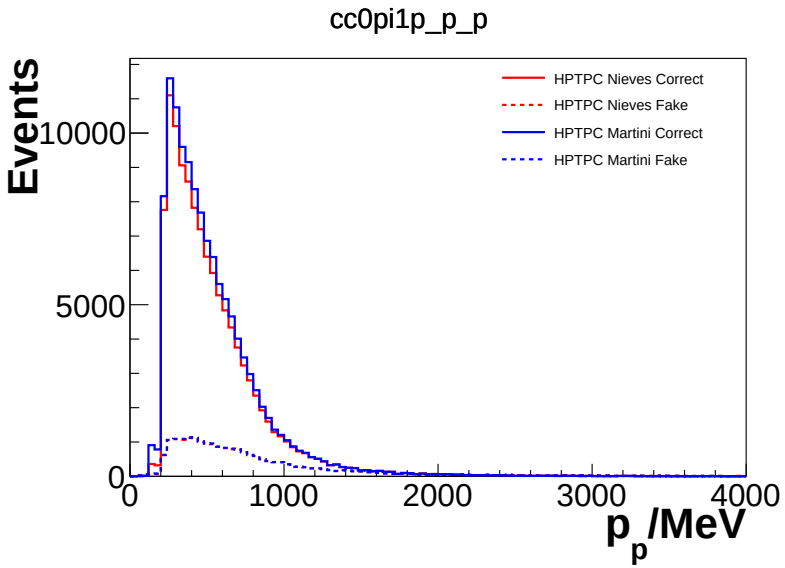
Model selection

- Have studied HPTPC ability to discriminate between 2p2h models
- 2p2h Describes interactions between neutrino and 2 nucleons
- MC is generated with Nieves model
- Existing fake data studies use reweighting to study Martini model

CC0π1p - Martini/Nieves

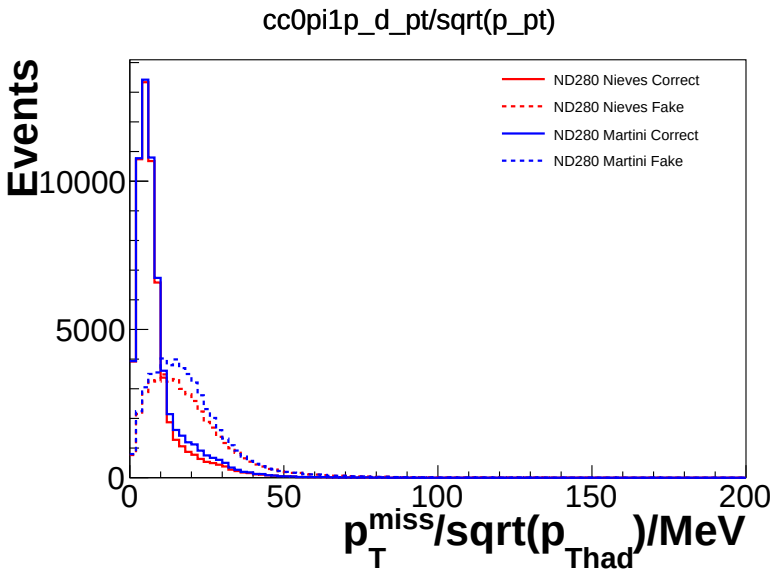
- Don't see that much sensitivity when looking at proton momentum

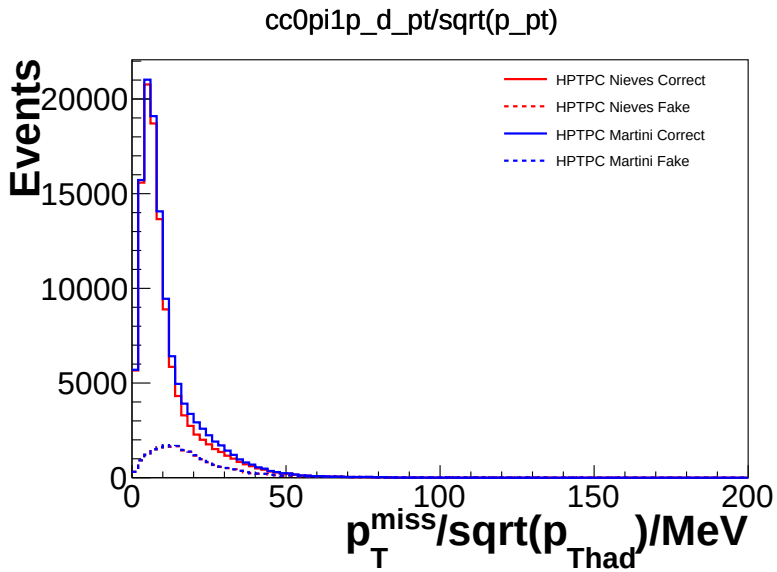




CC0π1p - Martini/Nieves

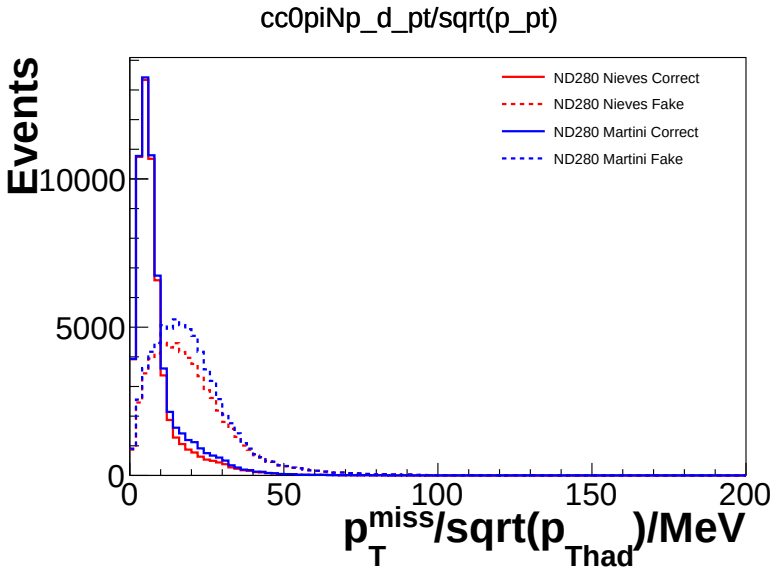
- Try 'p_T^{miss} significance' variable
- Divide p_T^{miss} by $\sqrt{p_{Tp}}$
- Provides good fake/correct discrimination
- Still not much model sensitivity

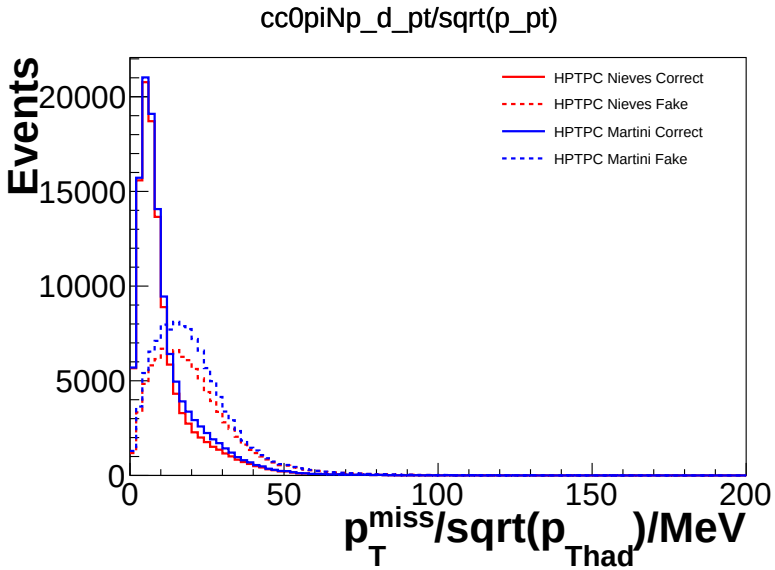




CC0πNp

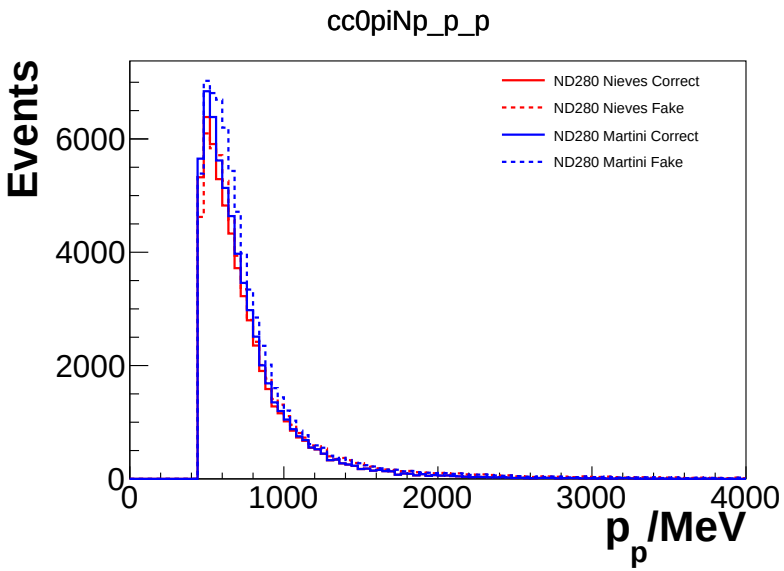
- Look at sample with >=1 proton and no pions
- Expect there may be more power in CC0πNp because Martini and Nieves predict different proton multiplicities

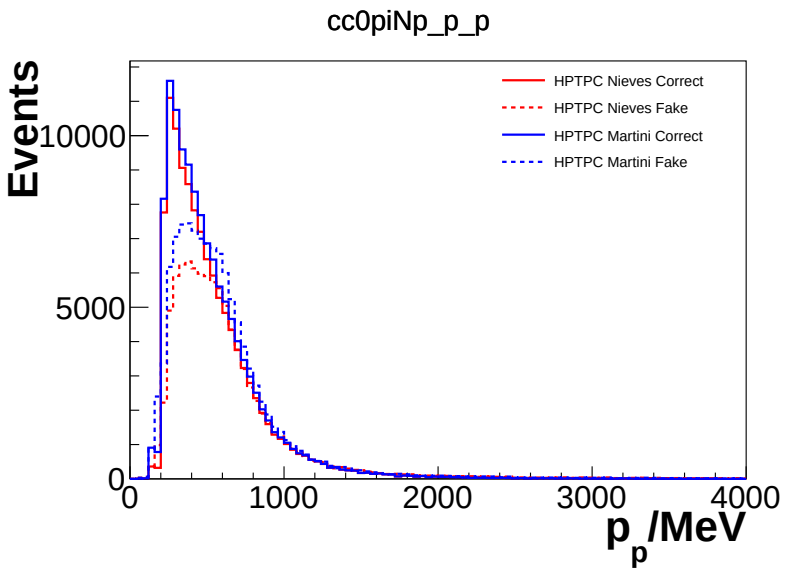




CC0πNp

- Slightly better than CC0π0p but still not great



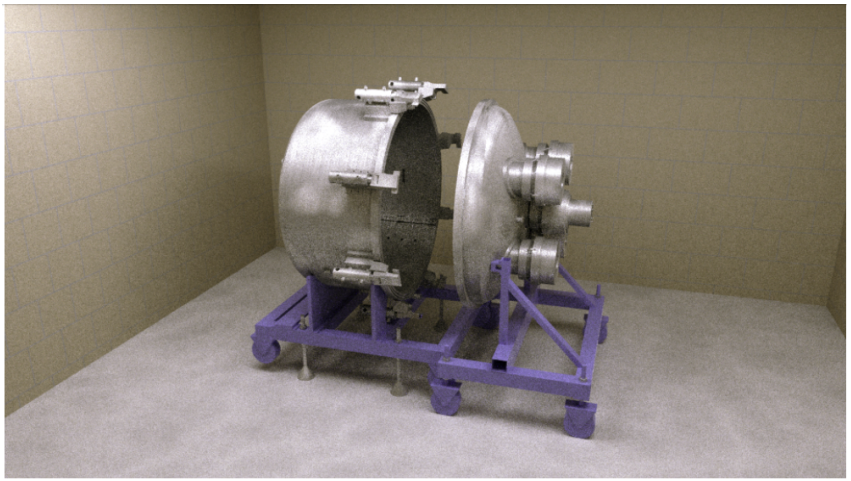


Why don't we see much model difference?

- Martini reweighting is done in 1D as a function of E_ν
- Would not expect this to give a good description of hadronic variables
- Solutions:
  1) Generate Martini events
     - Computationally prohibitive
  2) Come up with a better reweighting scheme
     - Open to suggestions/help from experts

HPTPC Hardware R&D

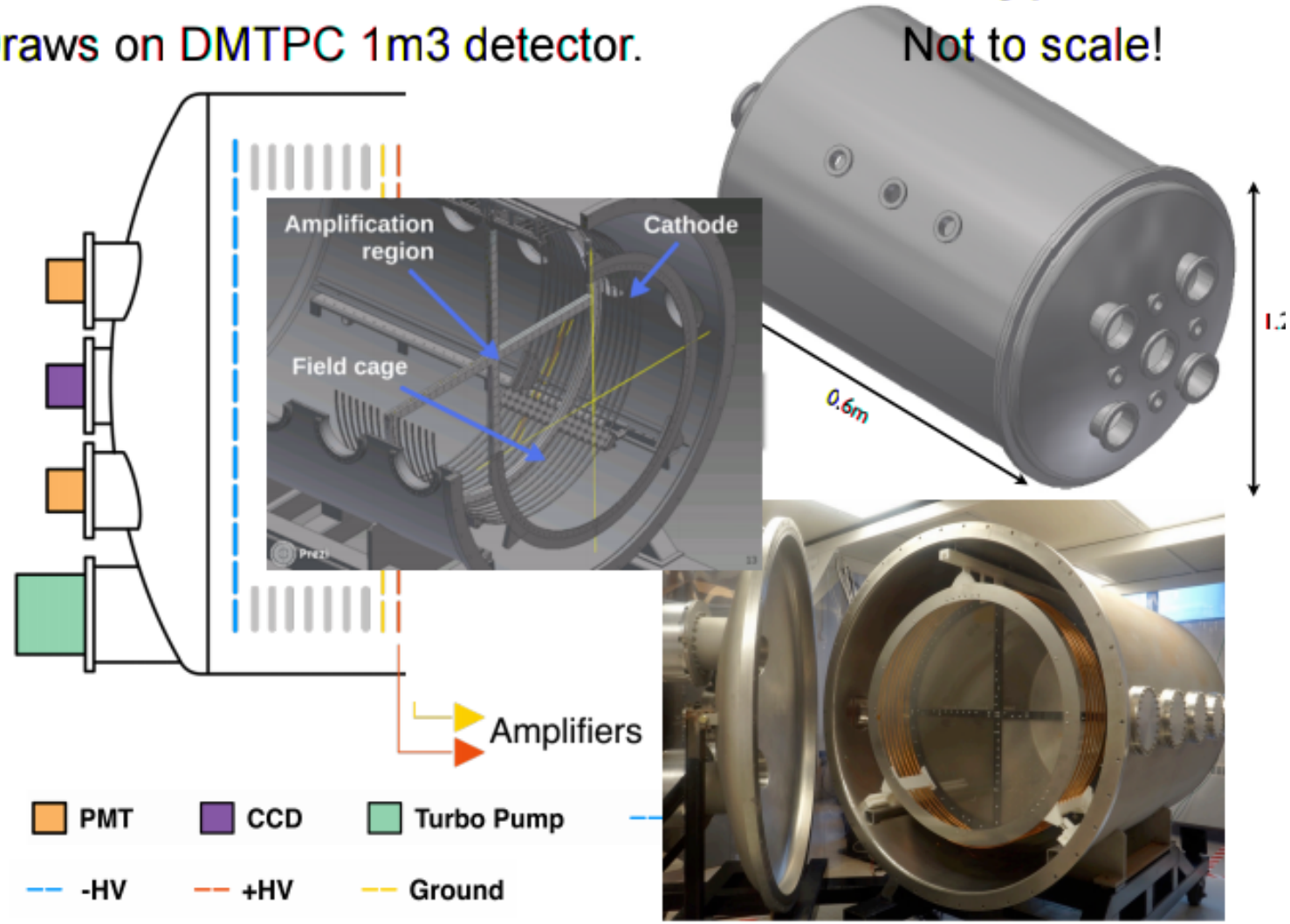
- Building 5 Bar, $1m^3$ prototype HPTPC in UK
- Will be being tested in the next year in CERN beam line
- Several T2K collaborators involved
- Developing full simulation
- Looking at reconstruction using T-Rex



UK STFC PRD: HPTPC Prototype

Draws on DMTPC 1m3 detector.

Not to scale!



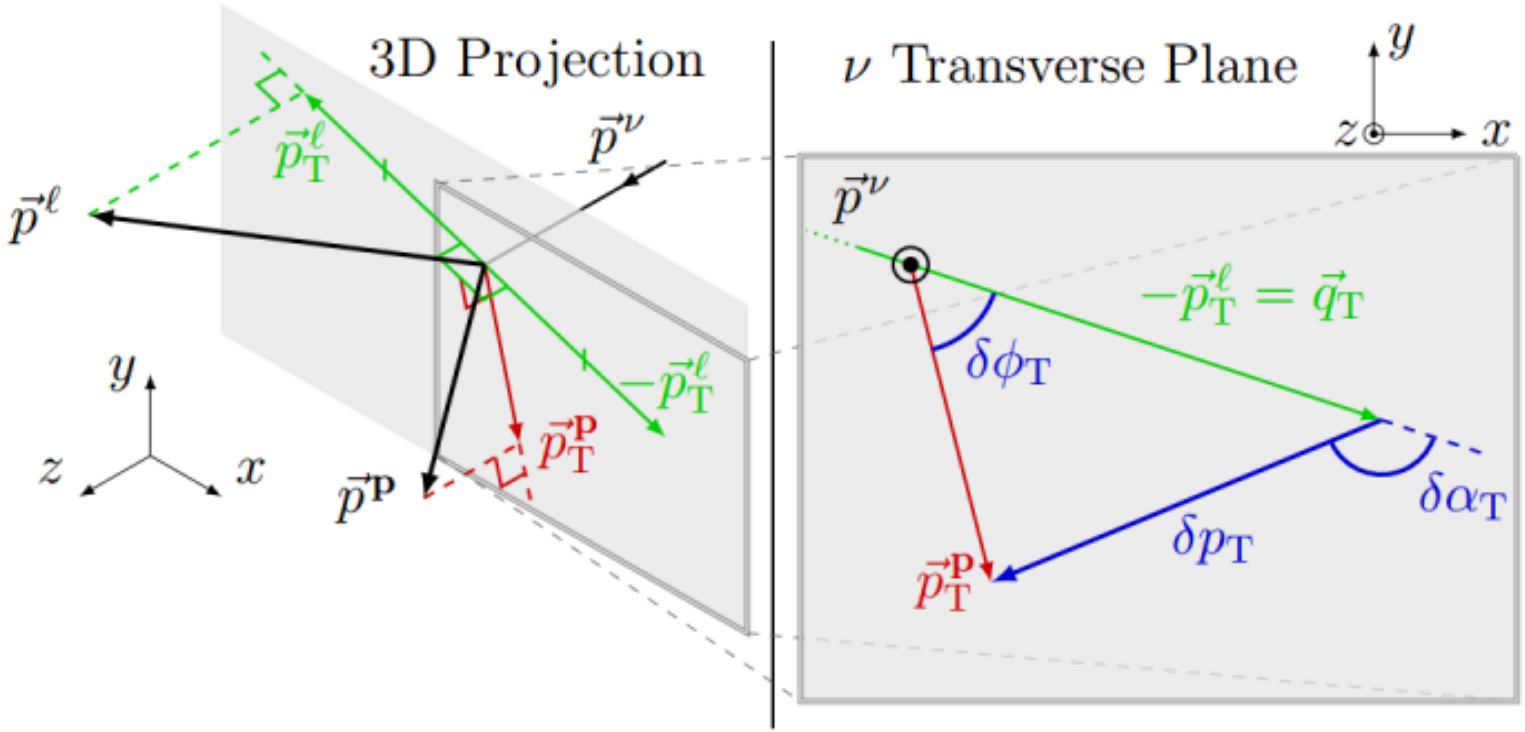
Conclusions

- HPTPC will have very good hadronic and leptonic momentum thresholds and efficiencies
- Will give high purity samples of events to test models with
  - Full exploitation of this data will need development of model comparison tools
- Hardware development well underway with beam tests in the near future
- In conjunction with other HK near and intermediate detectors will give much more confidence in our interaction model

Backup

Single Transverse Variables

- Use hadronic information to estimate nuclear effects
- For simple CCQE without nuclear effects $\delta p_T = 0$, $\delta \alpha_T = \pi$, $\delta \phi_T = 0$



HPTPC Study

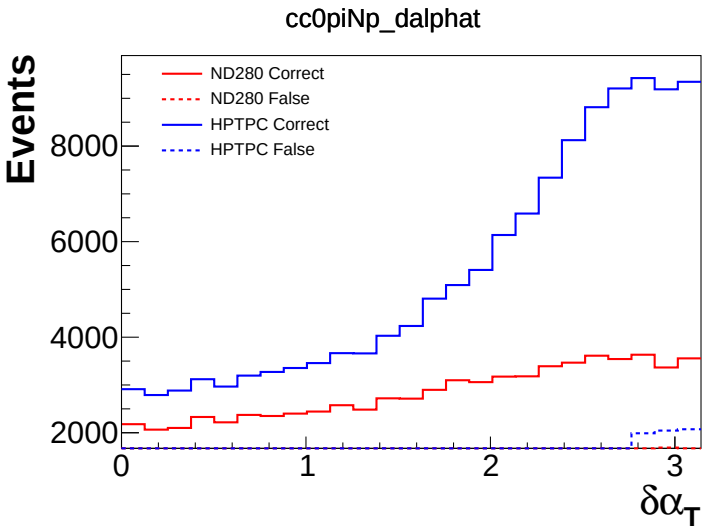
- HPTPC-like and ND280-like momentum thresholds (below) and efficiencies (see Mark's talk) were applied to ND280 MC truth
  - Same as shown by Mark Scott previously
- Then calculated transverse variables
  - Only make sense in samples with a proton or a pion
  - CC0πNp, CC1π0p, CC1πNp

Particle	ND280 Threshold/MeV	HPTPC Threshold/MeV
μ	100	15
π	120	16
p	450	60
e	100	1

HPTPC Study

- Will show the $\delta\alpha_T$, $\delta\phi_T$ and δp_T for all four samples
  - apologies for large number of plots
- Will show both ND280 and HPTPC thresholds and efficiencies
- Truth information is used to determine which events truly belong in the sample ("correct"), and which are fakes ("false")
  - Distributions of transverse variables are shown for both

CC0πNP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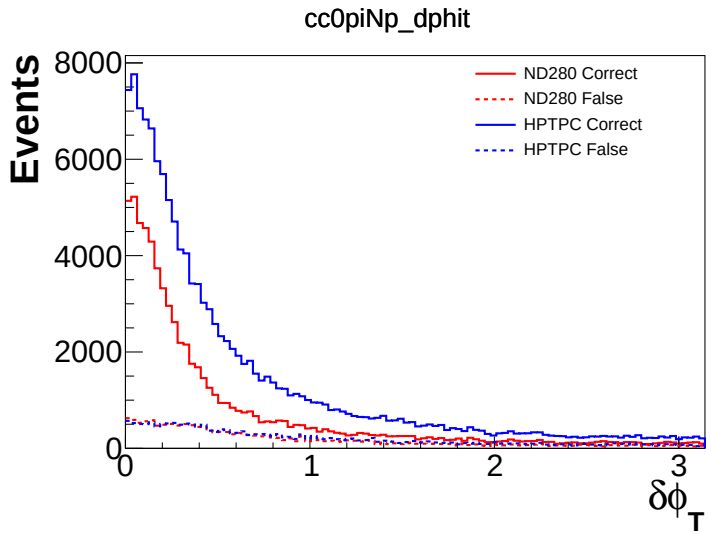
Events
ND280 Correct
ND280 False
HPTPC Correct
HPTPC False
8000
6000
4000
2000
0
1
2
3
$\delta\alpha_T$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HPTPC Correct
HPTPC False
8000
6000
4000
2000
0
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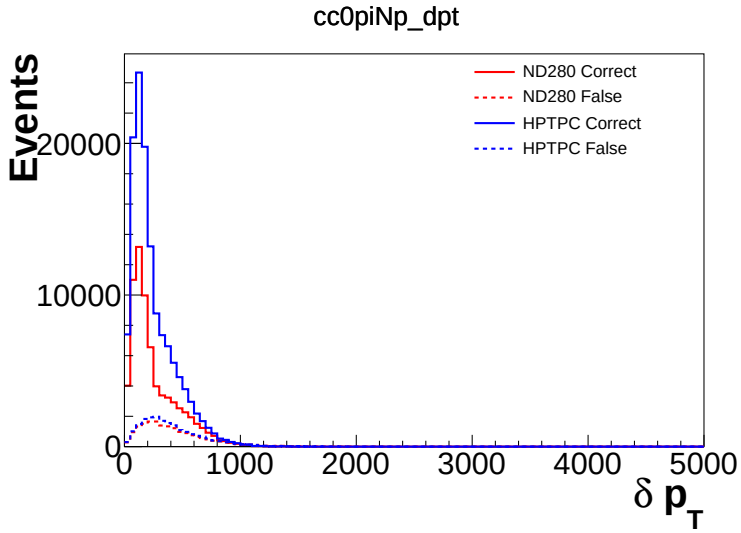
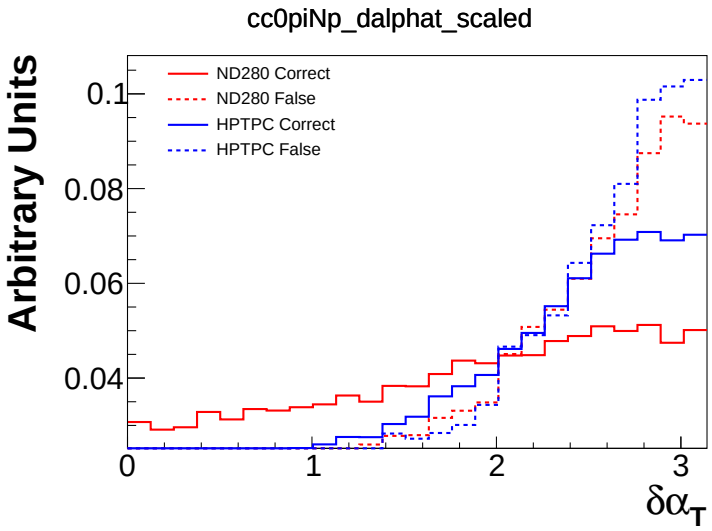
2
3
$\delta\phi_T$


cc0piNp_dpt
Events
ND280 Correct
ND280 False
HPTPC Correct
HPTPC False
20000
10000
0
1000
2000
3000
4000
5000
$\delta\ p_T$

CC0πNP


cc0piNp_dalphat_scaled
Arbitrary Units
ND280 Correct
ND280 False
HPTPC Correct
HPTPC False
0.1
0.08
0.06
0.04
0
1
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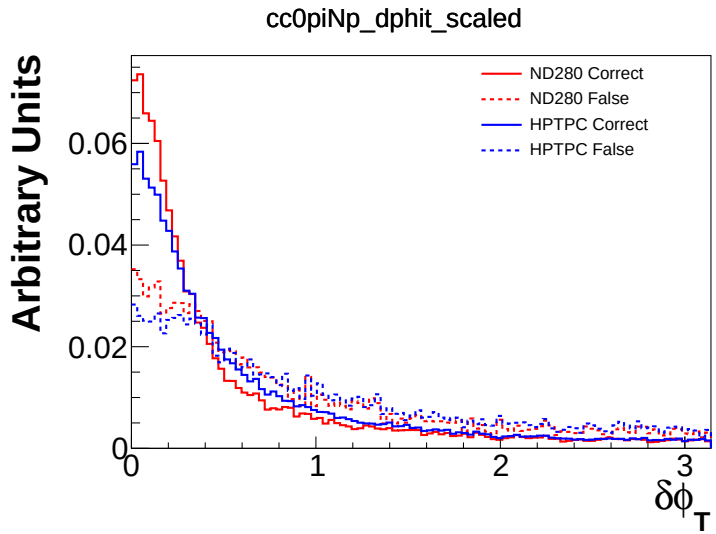
$\delta\alpha_T$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Arbitrary Units
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ND280 False
HPTPC Correct
HPTPC False
0.06
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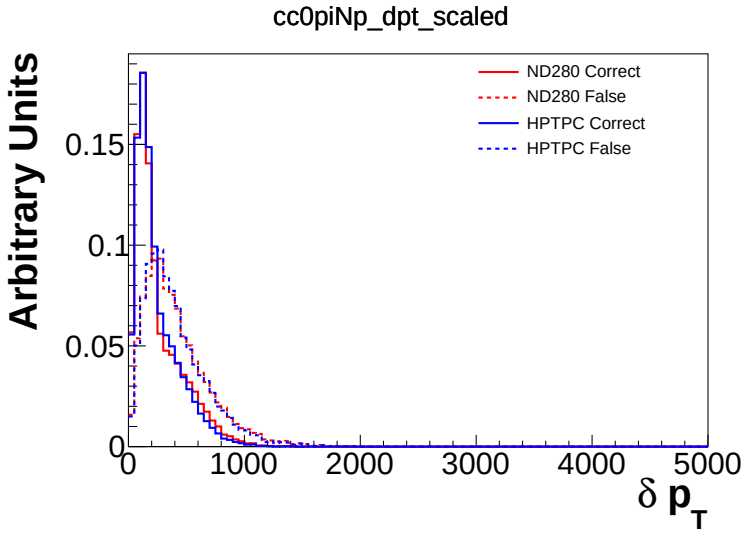
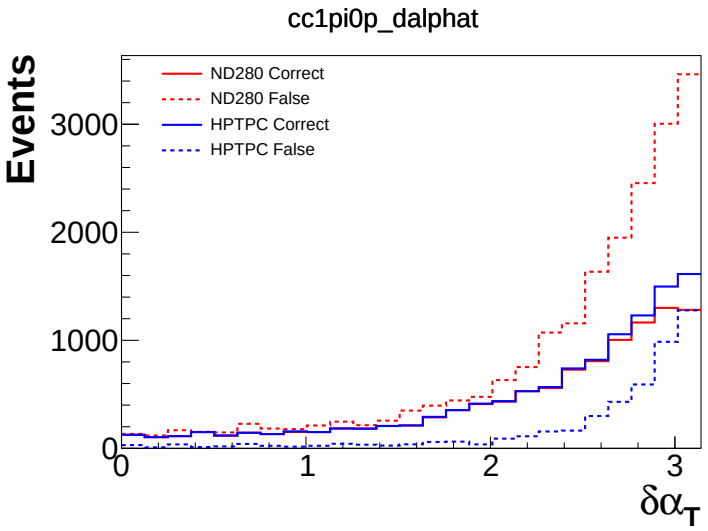
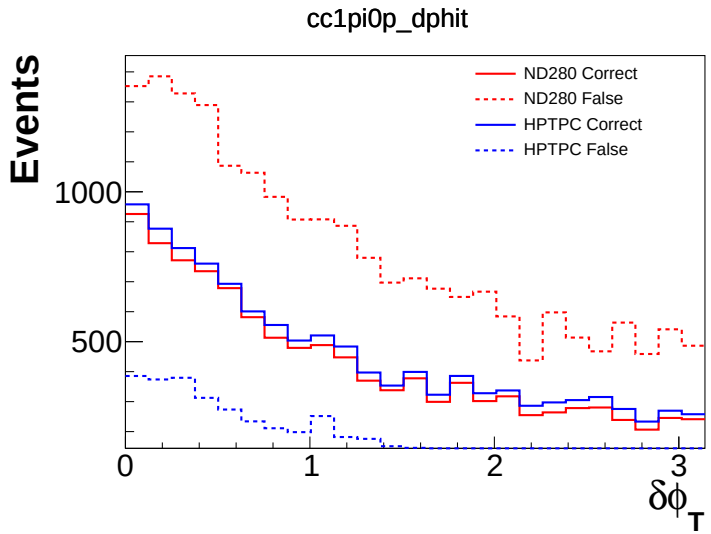
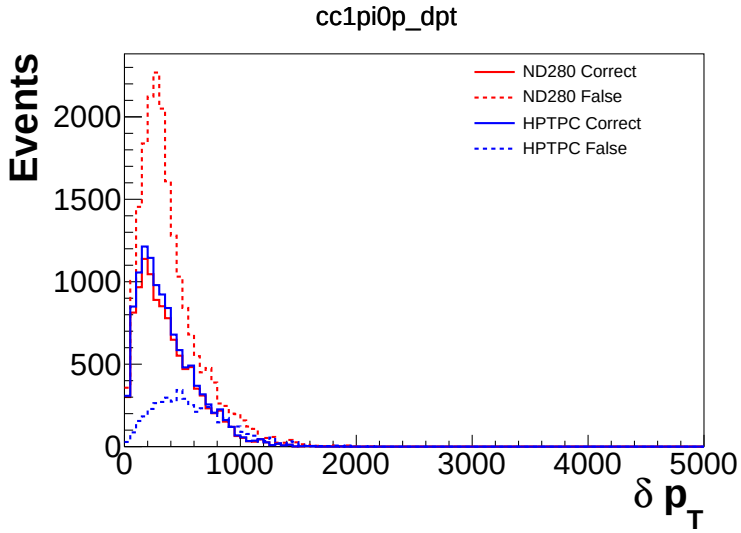
1
2
3
$\delta\phi_T$


cc0piNp_dpt_scaled
Arbitrary Units
ND280 Correct
ND280 False
HPTPC Correct
HPTPC False
0.15
0.1
0.05
0
0
1000
2000
3000
4000
5000
$\delta\ p_T$

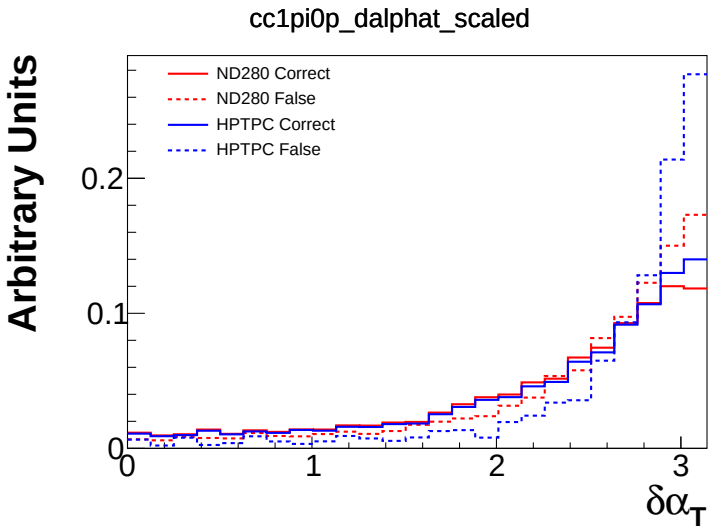
CC1π0P

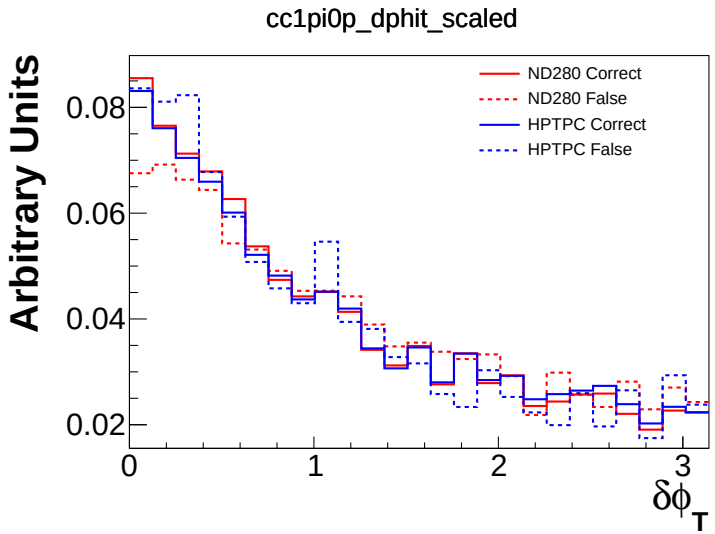

cc1pi0p_dalphat
Events
ND280 Correct
ND280 False
HPTPC Correct
HPTPC False
3000
2000
1000
0
0
1
2
3
$\delta\alpha_T$

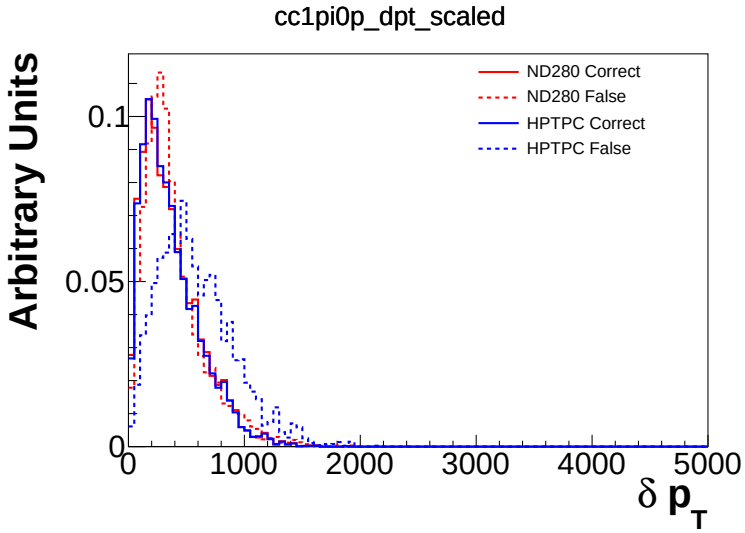

cc1pi0p_dphit
Events
ND280 Correct
ND280 False
HPTPC Correct
HPTPC False
1000
500
0
1
2
3
$\delta\phi_T$


cc1pi0p_dpt
Events
ND280 Correct
ND280 False
HPTPC Correct
HPTPC False
2000
1500
1000
500
0
0
1000
2000
3000
4000
5000
$\delta\ p_T$

CC1π0P

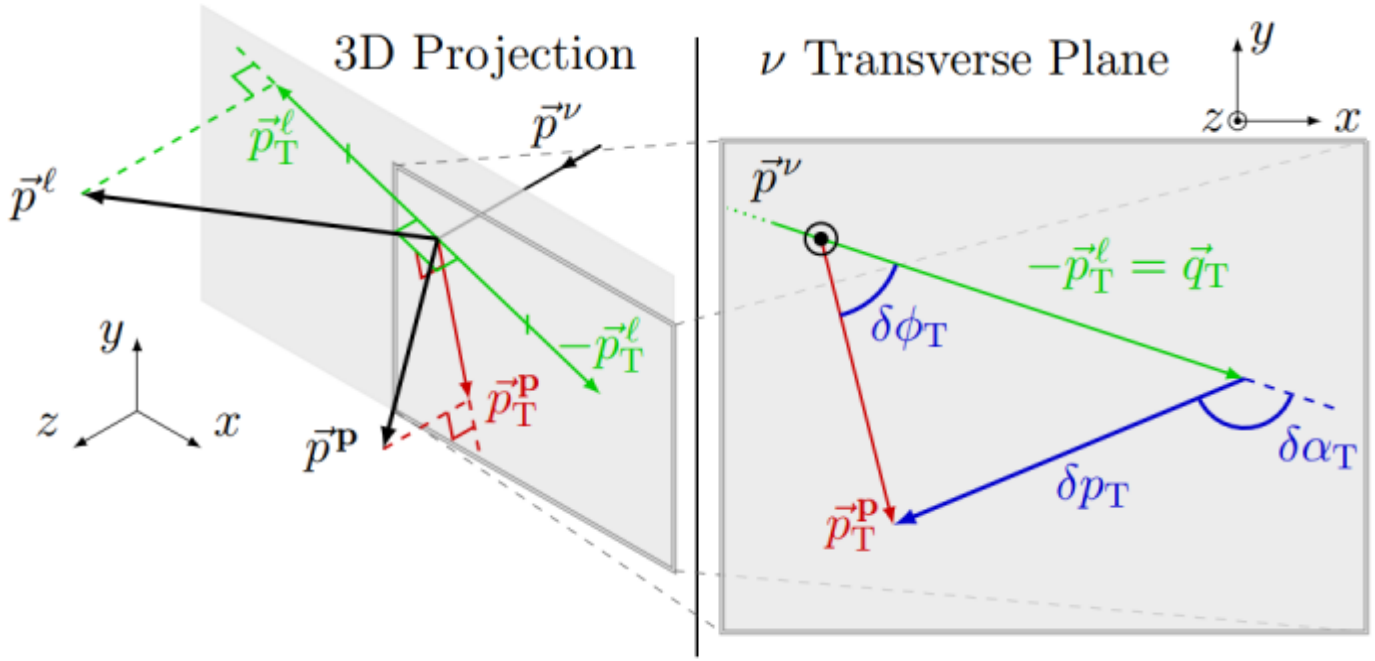

cc1pi0p_dalphat_scaled
Arbitrary Units
ND280 Correct
ND280 False
HPTPC Correct
HPTPC False
0.2
0.1
0
0
1
2
3
$\delta\alpha_T$


cc1pi0p_dphit_scaled
Arbitrary Units
ND280 Correct
ND280 False
HPTPC Correct
HPTPC False
0.08
0.06
0.04
0.02
0
1
2
3
$\delta\phi_T$

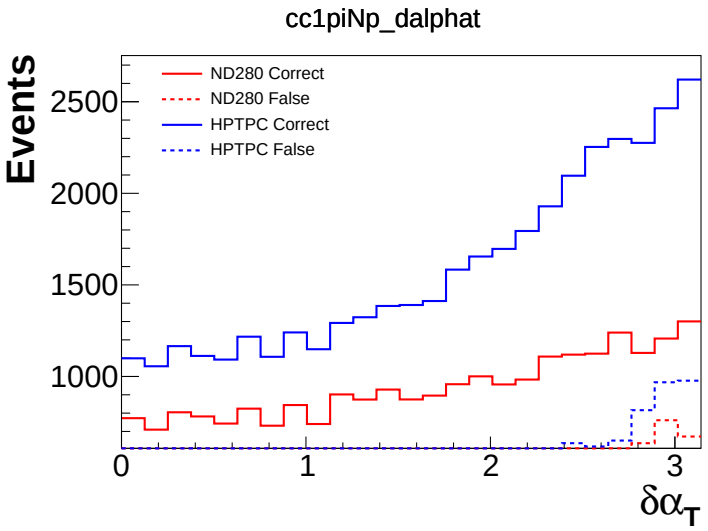

cc1pi0p_dpt_scaled
Arbitrary Units
ND280 Correct
ND280 False
HPTPC Correct
HPTPC False
0.1
0.05
0
0
1000
2000
3000
4000
5000
$\delta\ p_T$

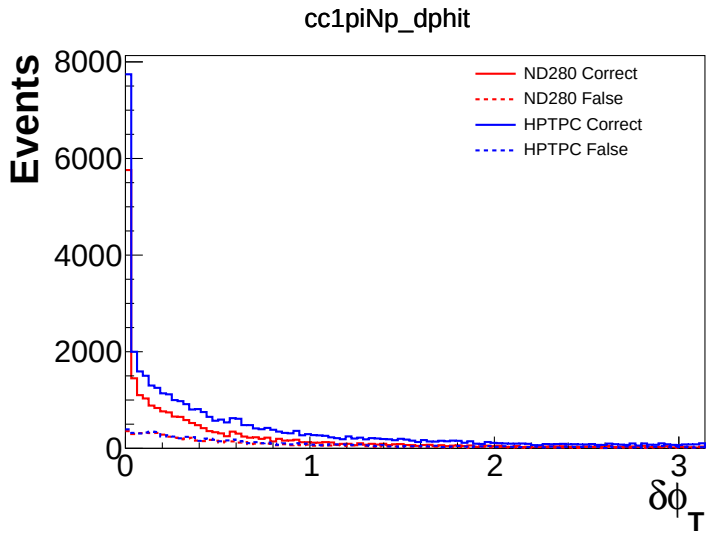
CC1π0P - difference hypothesis

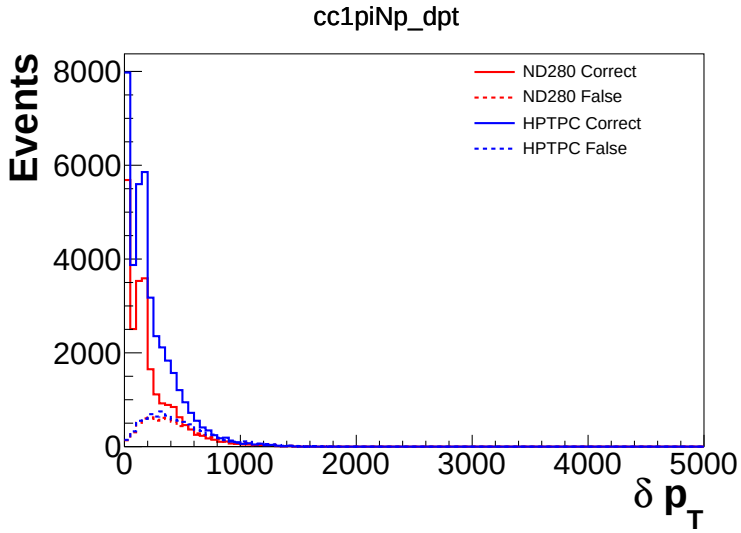
- Pion threshold is much lower in HPTPC (120 vs 16 MeV)
- Therefore HPTPC sample contains more $p+\pi$ events where the proton is missed and the pion is of low energy
- Increases the number of false events with high δp_T and $\delta \alpha_T$
- Will investigate 2D distributions of events



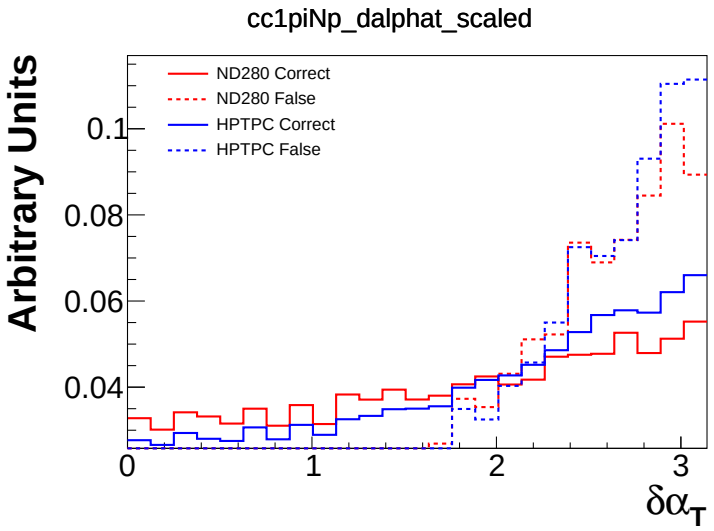
CC1πNP

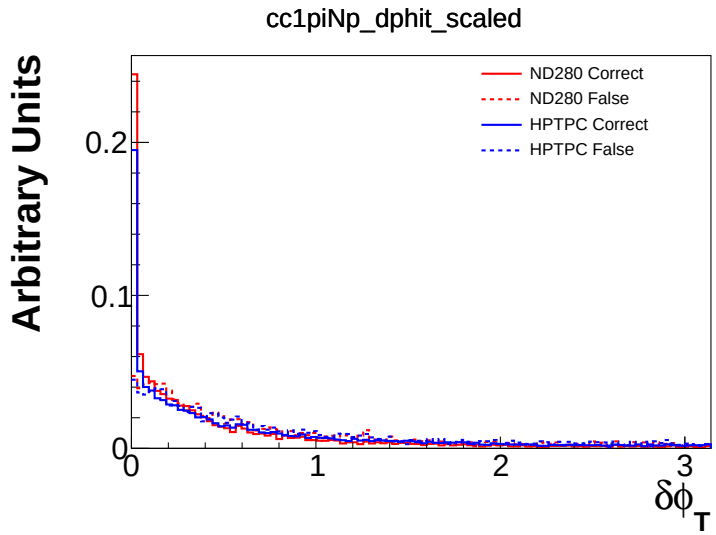

cc1piNp_dalphat
Events
ND280 Correct
ND280 False
HPTPC Correct
HPTPC False
2500
2000
1500
1000
0
1
2
3
$\delta\alpha_T$

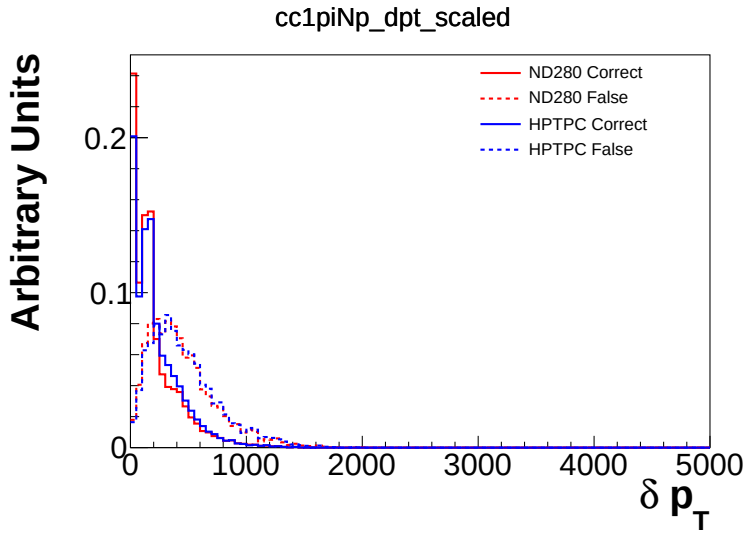

cc1piNp_dphit
Events
ND280 Correct
ND280 False
HPTPC Correct
HPTPC False
8000
6000
4000
2000
0
0
1
2
3
$\delta\phi_T$


cc1piNp_dpt
Events
ND280 Correct
ND280 False
HPTPC Correct
HPTPC False
8000
6000
4000
2000
0
0
1000
2000
3000
4000
5000
$\delta\ p_T$

CC1πNP


cc1piNp_dalphat_scaled
Arbitrary Units
ND280 Correct
ND280 False
HPTPC Correct
HPTPC False
0.1
0.08
0.06
0.04
0
1
2
3
$\delta\alpha_T$


cc1piNp_dphit_scaled
Arbitrary Units
ND280 Correct
ND280 False
HPTPC Correct
HPTPC False
0.2
0.1
0
0
1
2
3
$\delta\phi_T$


cc1piNp_dpt_scaled
Arbitrary Units
ND280 Correct
ND280 False
HPTPC Correct
HPTPC False
0.2
0.1
0
0
1000
2000
3000
4000
5000
$\delta\ p_T$