UNIVERSITÉ DE GENÈVE

FACULTÉ DES SCIENCES

Quantitative assessment of upgraded performance

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TPC Workshop at CERN
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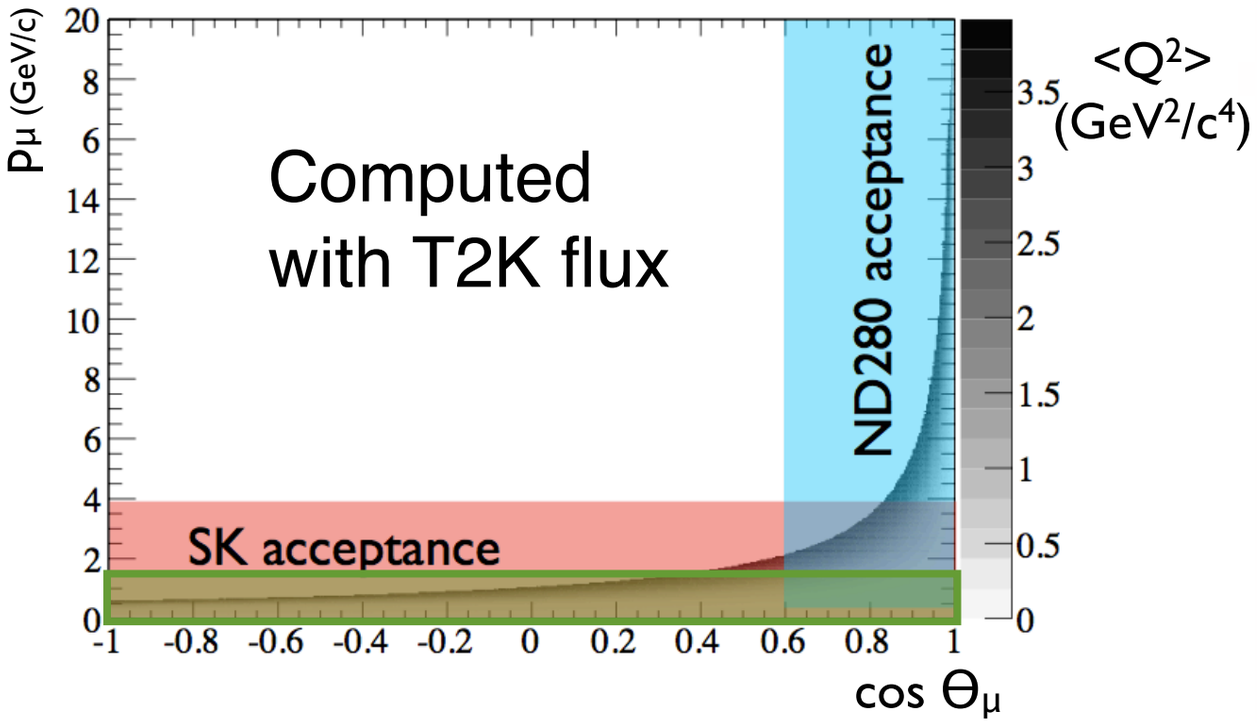
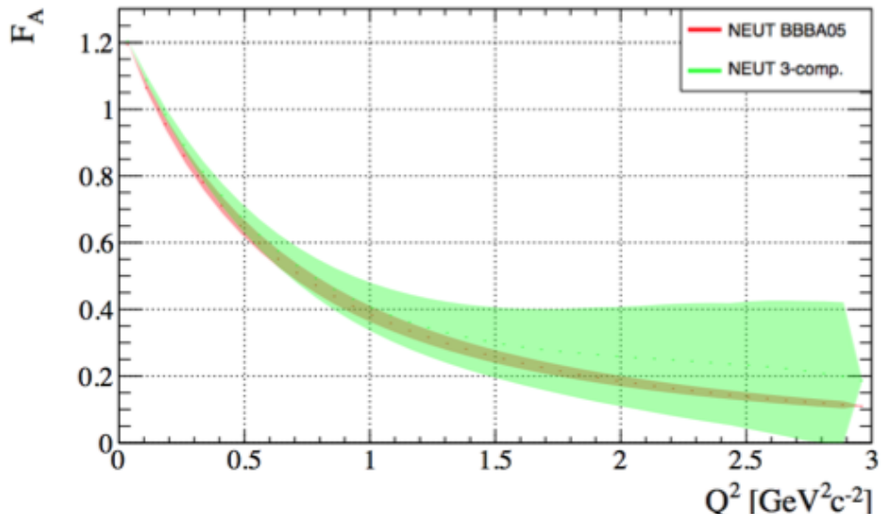
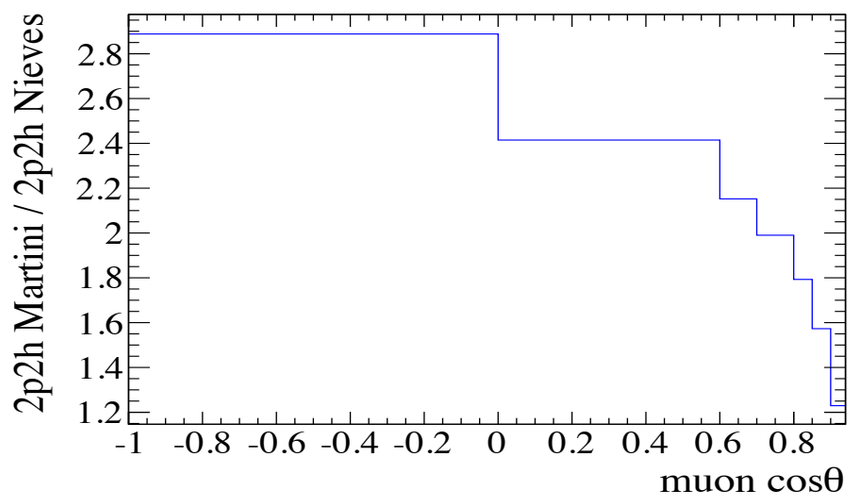
Goals of ND280 upgrade

- Proposal to extend the T2K data taking until ~2026 (2×10^{22}POT)
- However we need to reduce the systematic uncertainties
- Improve the ND280 acceptance and cover the full cosΘ range at far detector







- Currently ND280 covers approximately only the 20-30% of the cosΘ region
- The goal is to cover also the high angle region
- Need a full simulation to optimize the new ND280 configuration

Simulation framework

• Goal: estimate selection efficiency for primary muons produced in the targets by neutrino interactions and detected in the TPCs

• Optimization of the ND280 upgrade geometry will depend on the acceptance performance of different ND280 upgrade configurations

• GEANT 4.10.1.03 with same physics lists as in official ND280 simulation:
  - QGSP_BERT for the hadronic physics
  - emstandard_opt3 for the electromagnetic physics
  - G4DecayPhysics for the particle decays

• Uniform magnetic field (0.2 T) along drift direction (X)

• Neutrino events are generated with GENIE neutrino event generator (R. 2.10.6): 6×10^{20} POT ~ same T2K statistic collected with neutrino mode beam

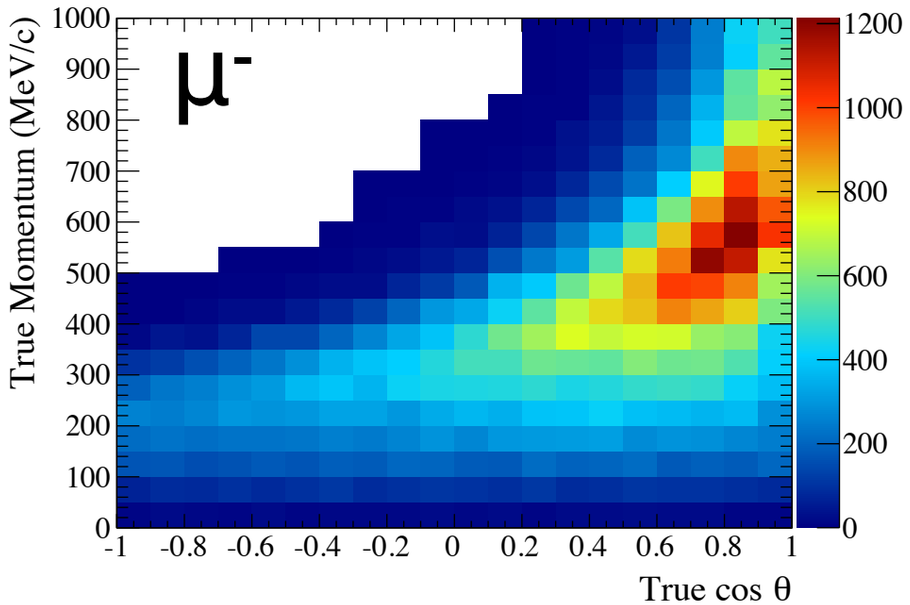
• The neutrino flux is exactly the same as used in official ND280 simulations (JNuBeam flux simulations)

• Analysis done with truth informations

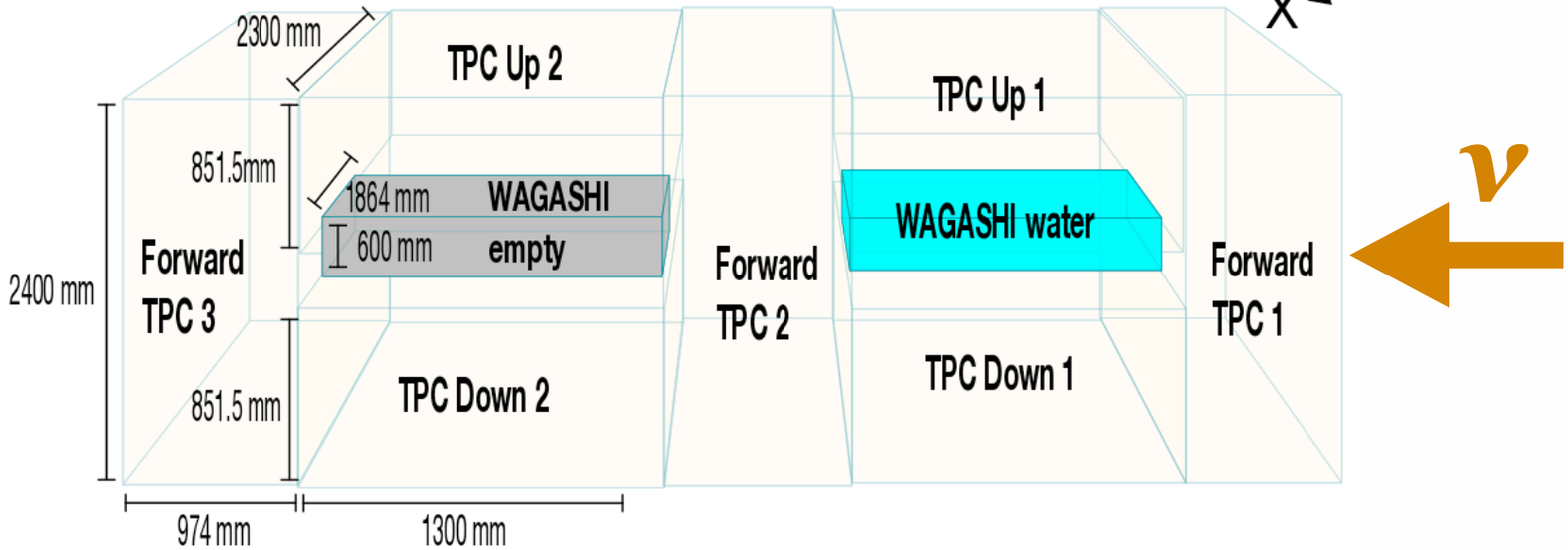
• Framework is different from what is used for the WAGASCI simulation: merging will be done in the upcoming weeks

Simulation of ND280 upgrade configuration

- Two horizontal targets (WAGASCI water-in and -out)
- 4 “Side” TPCs (above and below each target) to cover the high angle tracks exiting the target
  - boxes filled with same gas as ND280 current (Ar:CF4:C4H10 95:3:2)
- 3 “Forward” TPCs: simulation is exactly the same as in official ND280 MC



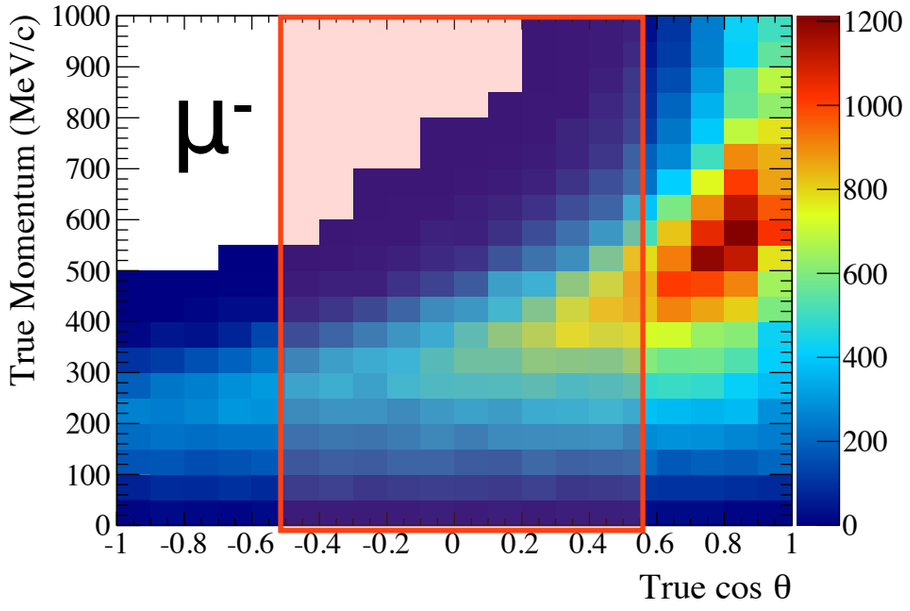
Simulated ND280-upgrade detector size



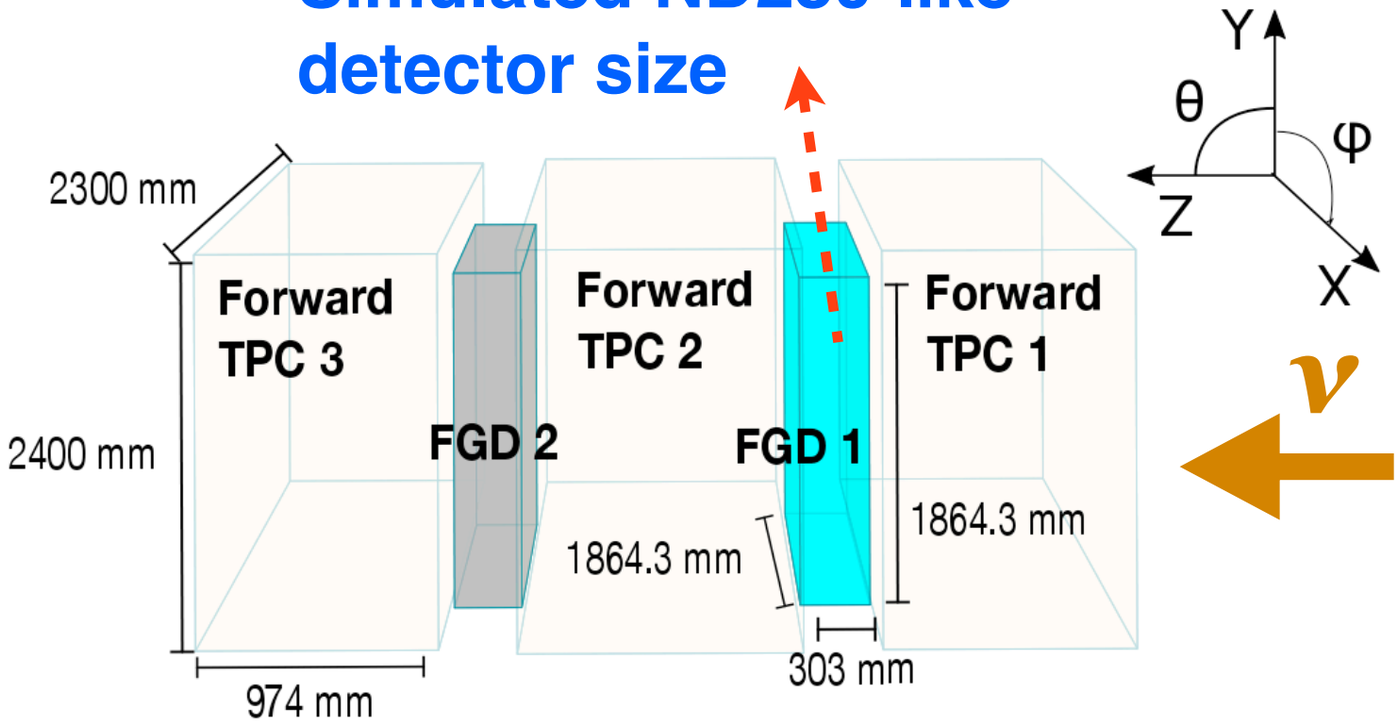
- Sizes of the TPCs could differ a bit depending on the optimization studies, but we don’t expect drastic changes
- The height of the TPC sensitive volume should be at least ~80cm

Simulation of ND280-like configuration

- Simulation of ND280-like detector in order to provide a direct comparison of the geometric acceptance to ND280 upgrade one
- 3 “Forward” TPCs (identical to ND280 upgrade case)
- Two FGDs: vertical targets with uniform material:
  - FGD1: C12
  - FGD2: C12:H20 50:50



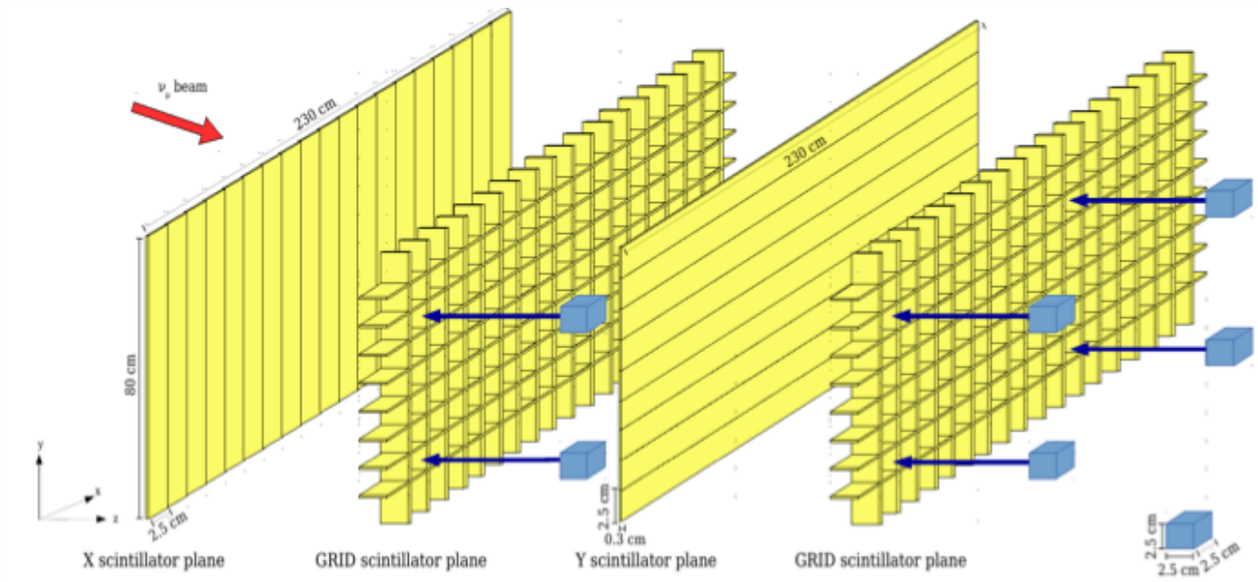
Simulated ND280-like detector size



- Ideal efficiency for a detector with the same geometry as ND280 for muons detected in the TPC assuming perfect TOF coverage
- In reality many backward tracks in ND280 are lost because of missing T_0 from other detectors
- T2K is working on recovering muons at high angle (momentum by range)

The target in the ND280 upgrade simulation

- The goal is to have a reliable estimation of the acceptance for muons reaching the TPCs and not stopping in the target
- TPC measurements provide a good determination of momentum and dE/dx

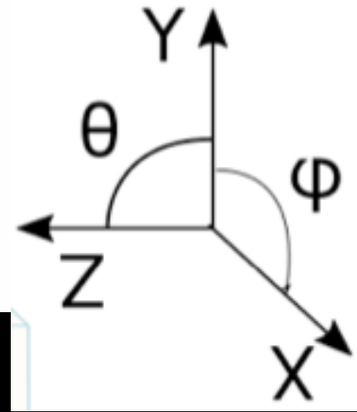


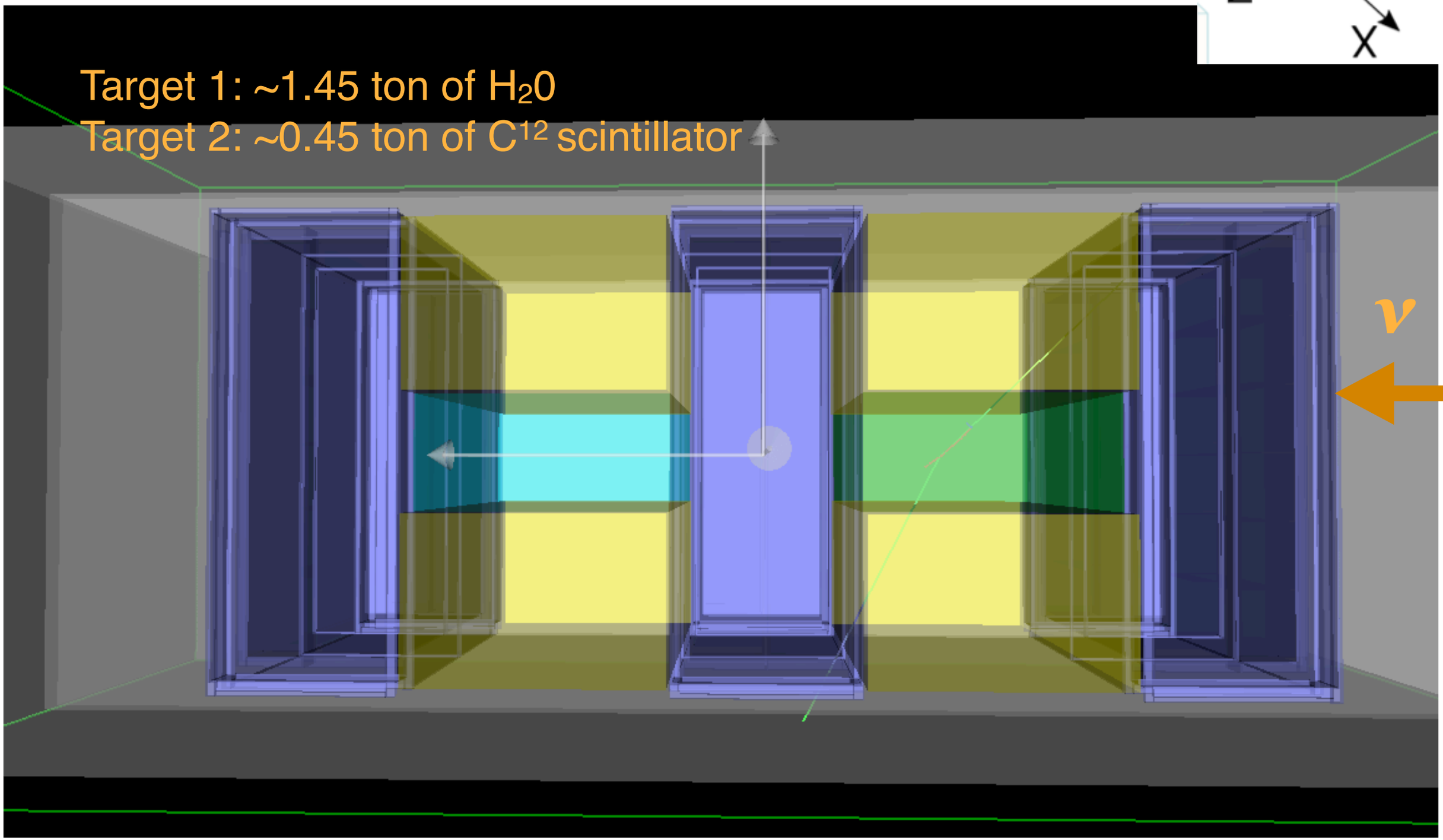
Simulate WAGASCI as a target of uniform material

- Target 1 (WAGASCI water-in):
  - 1864 (width) x 600 (height) x 1300 (length) mm^3 of water
  - Mass = 1.45 ton
- Target 2 (WAGASCI empty):
  - 1864 (width) x 600 (height) x 1300 (length) mm^3 of carbon
  - 30% of density, consistent with $(2.5\ cm)^3$ cells --> Mass = 0.45 ton

Event display: ND280 upgrade

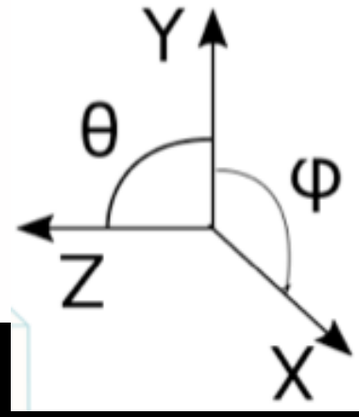
- B // E (along X)
- TPCs read-out on YZ plane
- Charged track is reconstructed in a TPC if YZ length> 200mm (consistent > than 18 hits on read-out plane)



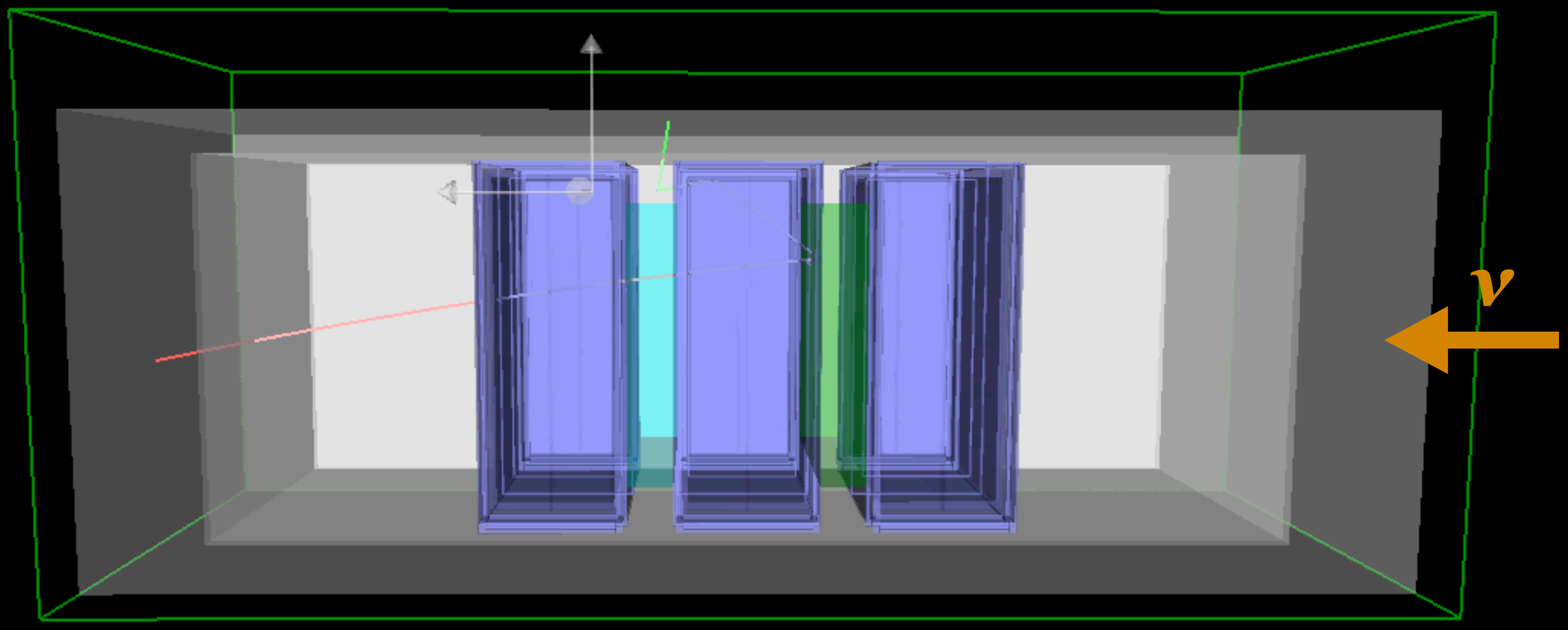


Event display: ND280-like

- B // E (along X)
- TPCs read-out on YZ plane
- Charged track is reconstructed in a TPC if YZ length> 200mm (consistent > than 18 hits on read-out plane)



FGD1: ~1 ton of C^{12} scintillator
FGD2: ~1 ton of C:H_20 50:50

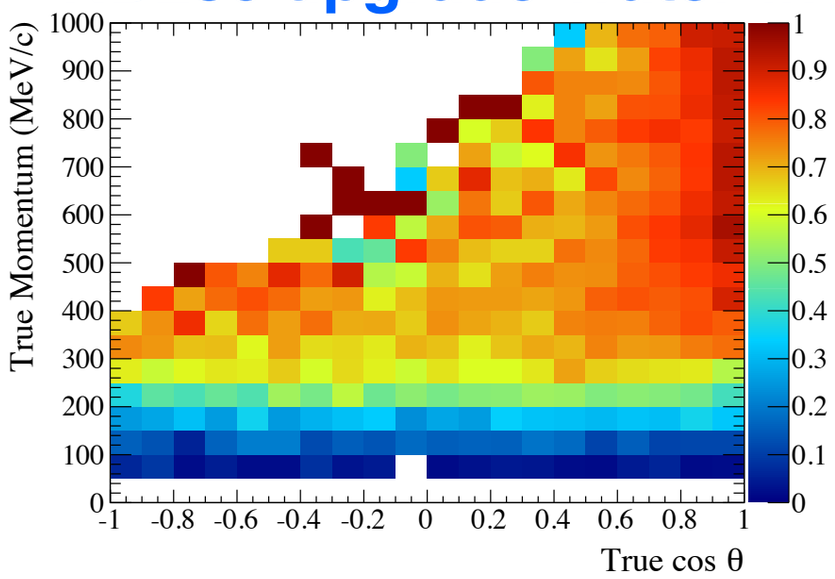


Acceptance studies for primary tracks

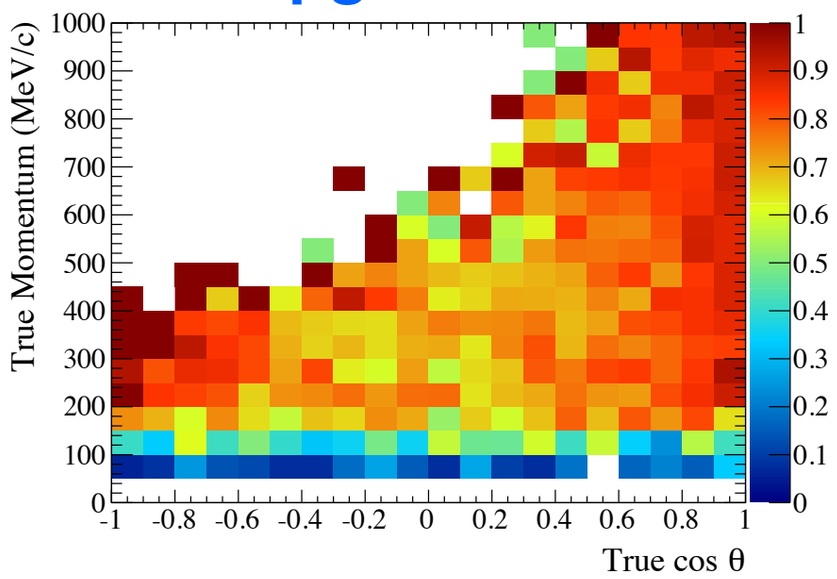
- NuMu beam with 6x10^{20} Protons On Target (POT) with GENIE neutrino event generator
- Neutrino vertex in one of the targets
- Track is primary particle, i.e. from the neutrino vertex

$$\text{Eff} = \frac{\text{\# of primary tracks reco in TPC}}{\text{\# of primary tracks from FV vertex}}$$

ND280 upgrade Water-in

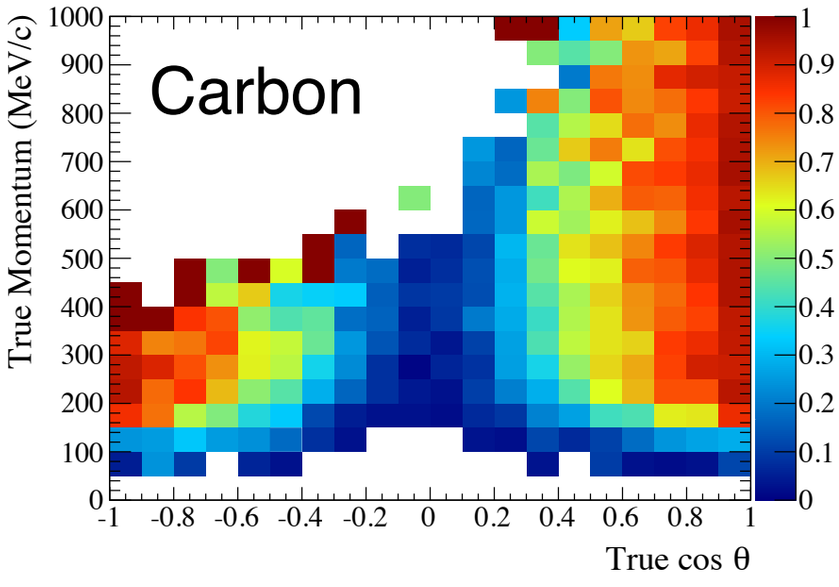


ND280 upgrade Water-out

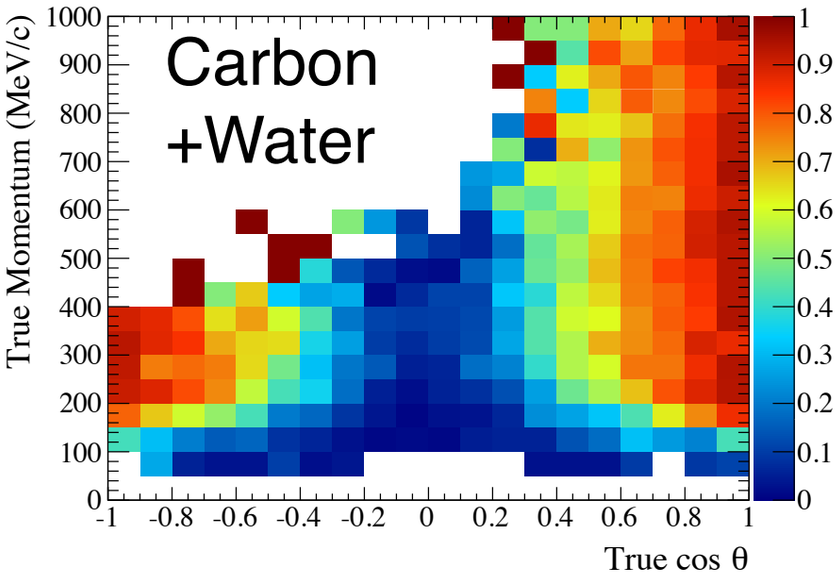


Primary Muons

ND280-like current FGD1



ND280-like current FGD2



Primary Muons

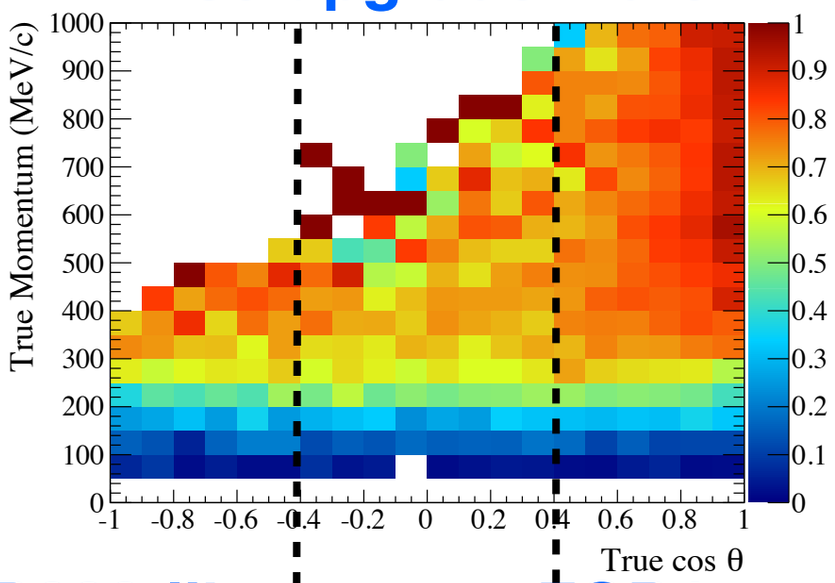
- Water-out WAGASCI allows to see muons in TPCs down to ~100 MeV/c

Acceptance studies for primary tracks

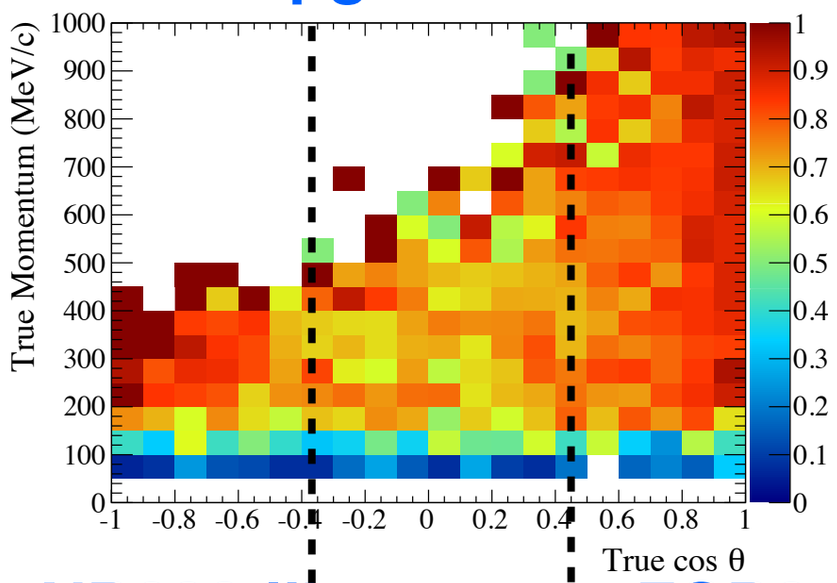
- NuMu beam with 6x10^{20} Protons On Target (POT) with GENIE neutrino event generator
- Neutrino vertex in one of the targets
- Track is primary particle, i.e. from the neutrino vertex

$$\text{Eff} = \frac{\text{\# of primary tracks reco in TPC}}{\text{\# of primary tracks from FV vertex}}$$

ND280 upgrade Water-in

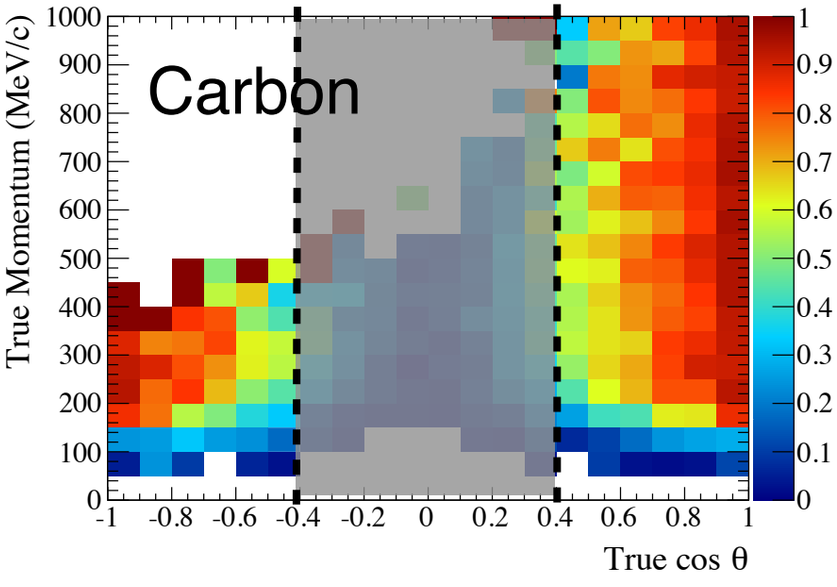


ND280 upgrade Water-out

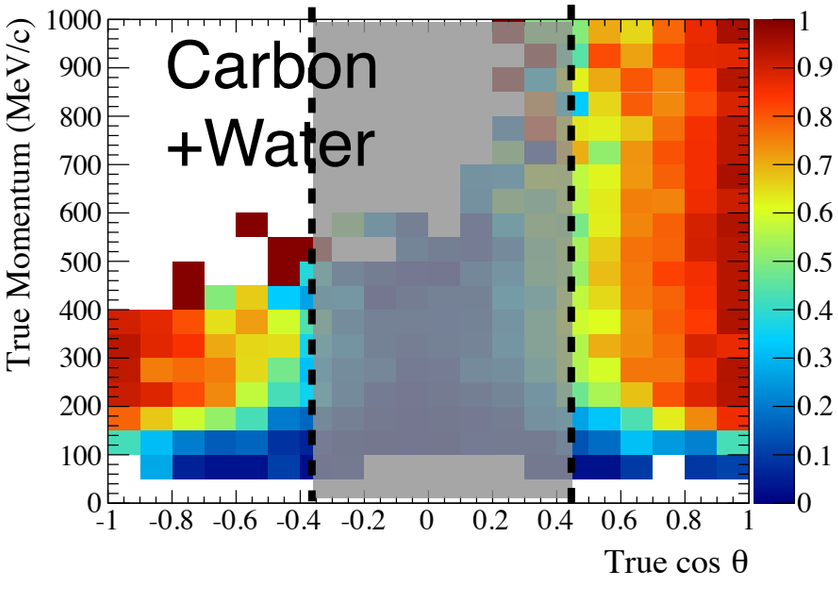


Primary Muons

ND280-like current FGD1



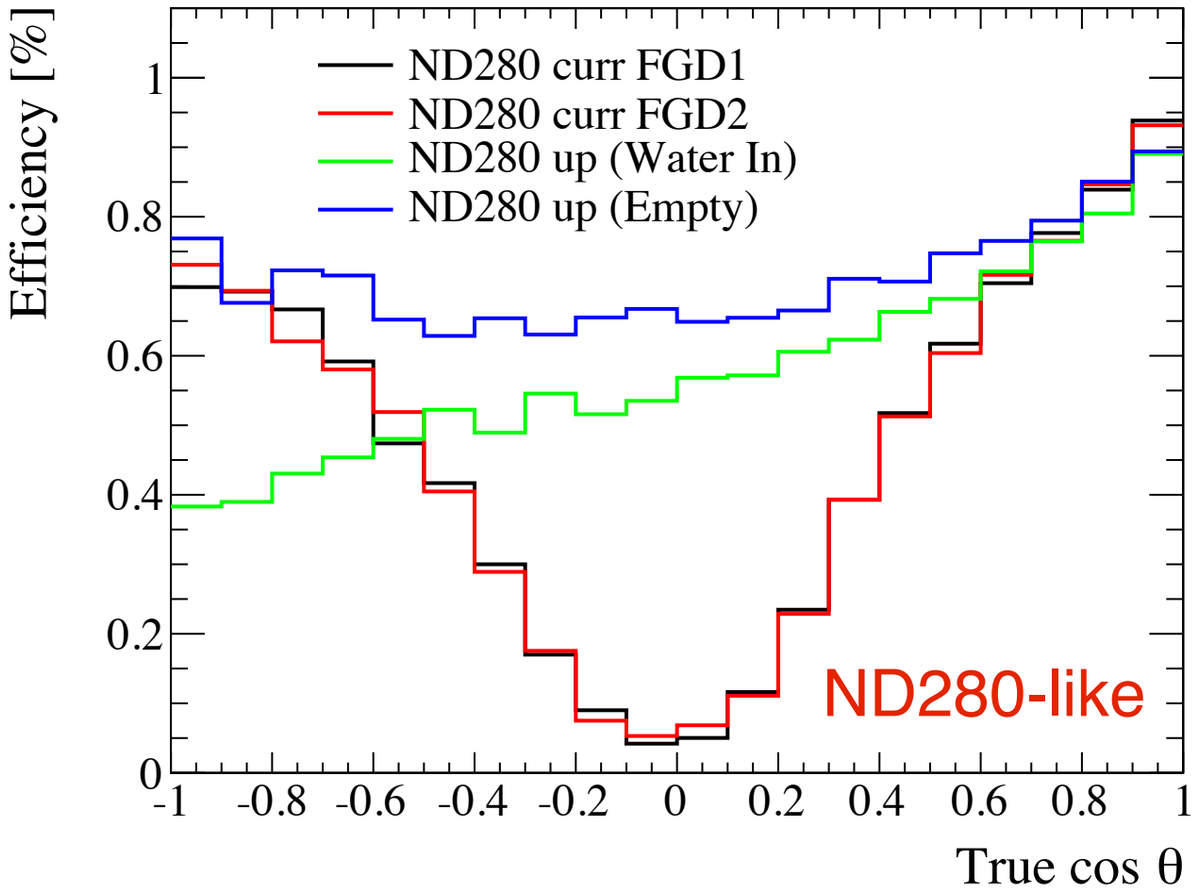
ND280-like current FGD2

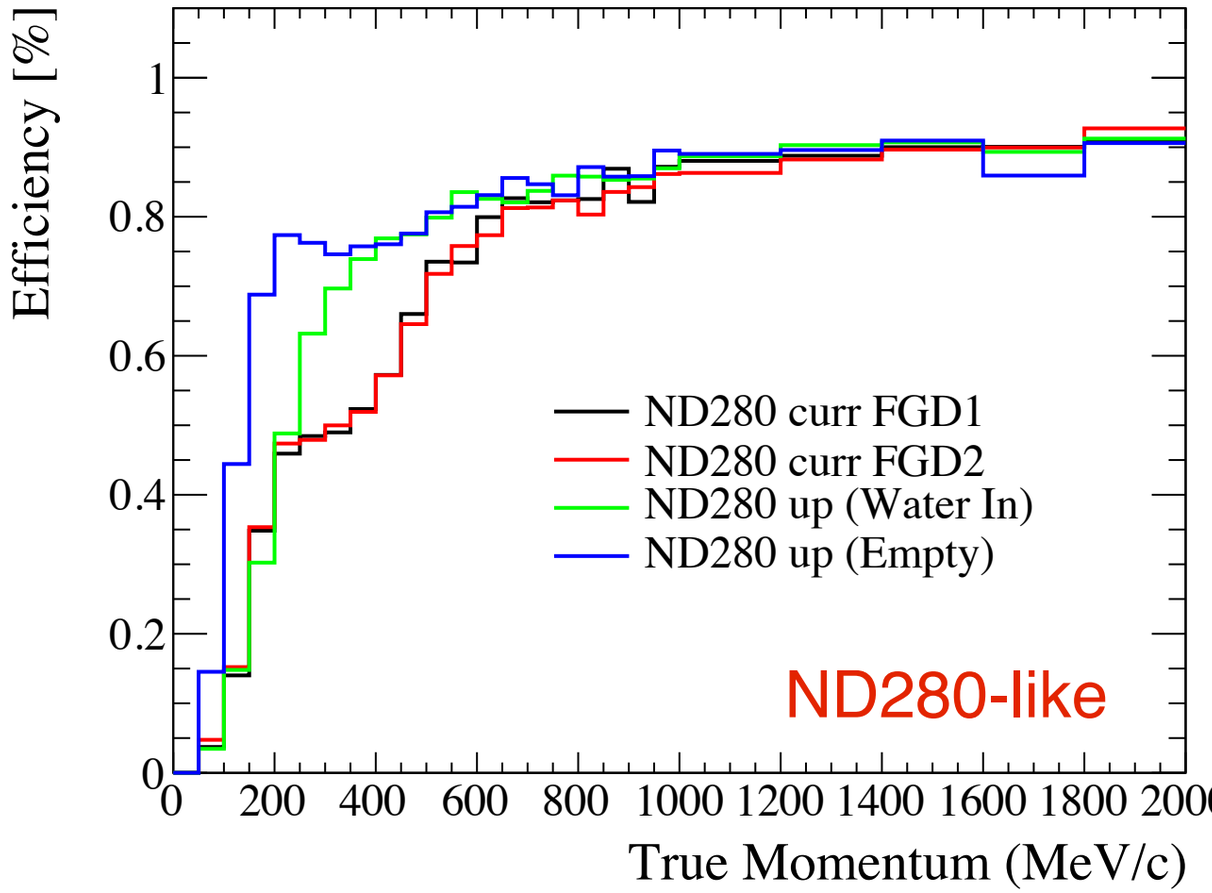


Primary Muons

- The new configuration can cover the high angle tracks very well

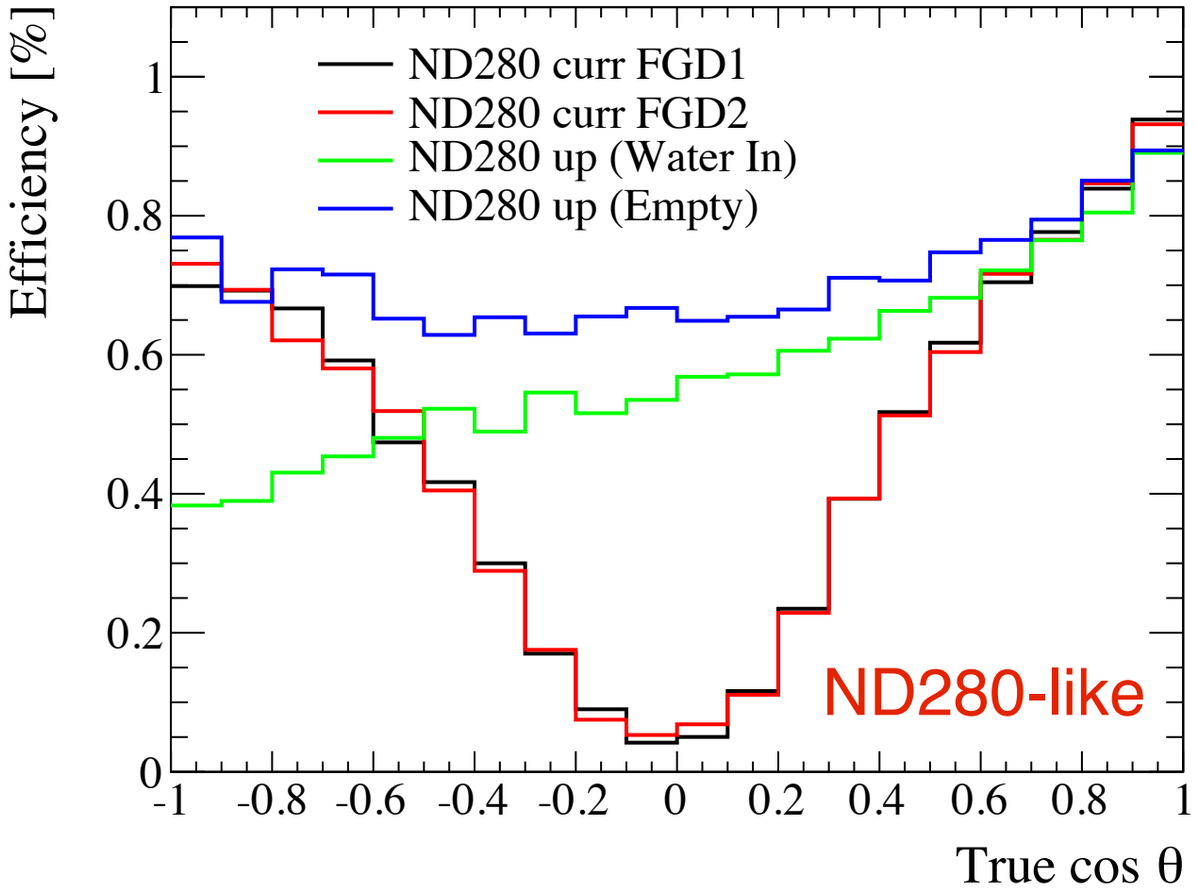
ND280 upgrade performance

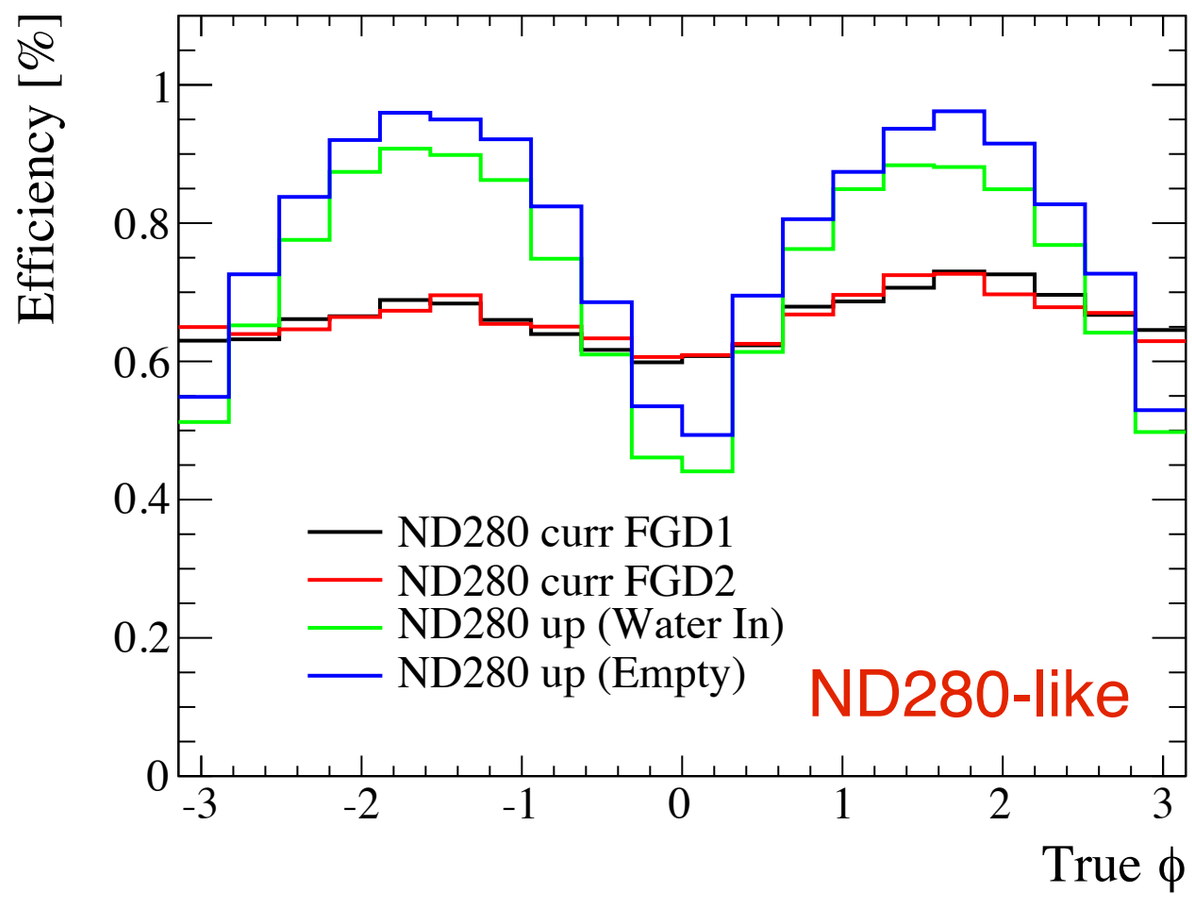




- Horizontal targets and new TPCs can measure very well the high angle region both for Water-in and Water-out WAGASCI targets
- At cosΘ~0 the efficiency is improved to >50% for water-in, ~70% for water-out
- Also momentum threshold is lower with the new configuration

ND280 upgrade performance

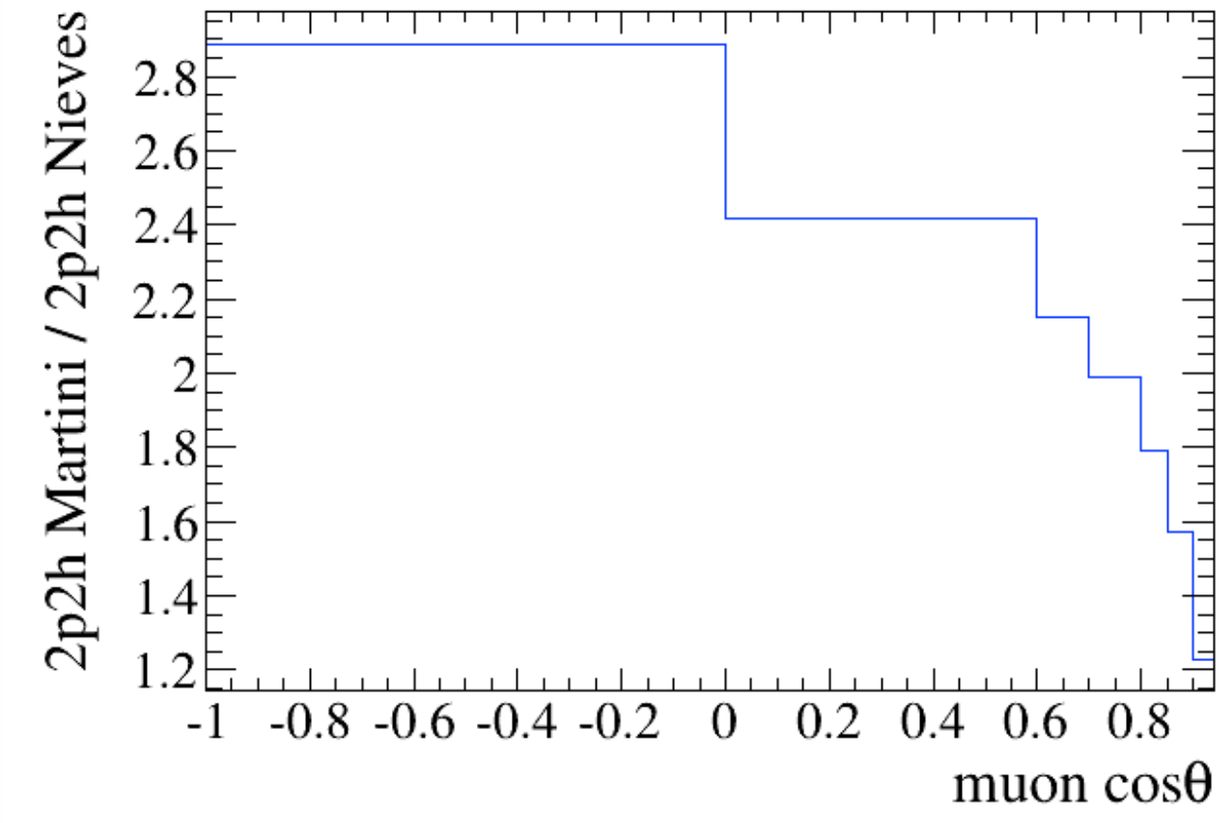




- Horizontal targets and new TPCs can measure very well the high angle region both for Water-in and Water-out WAGASCI targets
- At cosΘ~0 the efficiency is improved to >50% for water-in, ~70% for water-out
- Also momentum threshold is lower with the new configuration
- With 60 cm thickness target we do not loose much in efficiency

Test of model separation

- Example of neutrino cross section component that affects the neutrino energy reconstruction
- 2p2h: nuclear correlations between protons and neutrons involved in the neutrino interaction (see Sobczyk' and Bolognesi's talks)
- In literature there are two main models (Martini et al. and Nieves et al.)

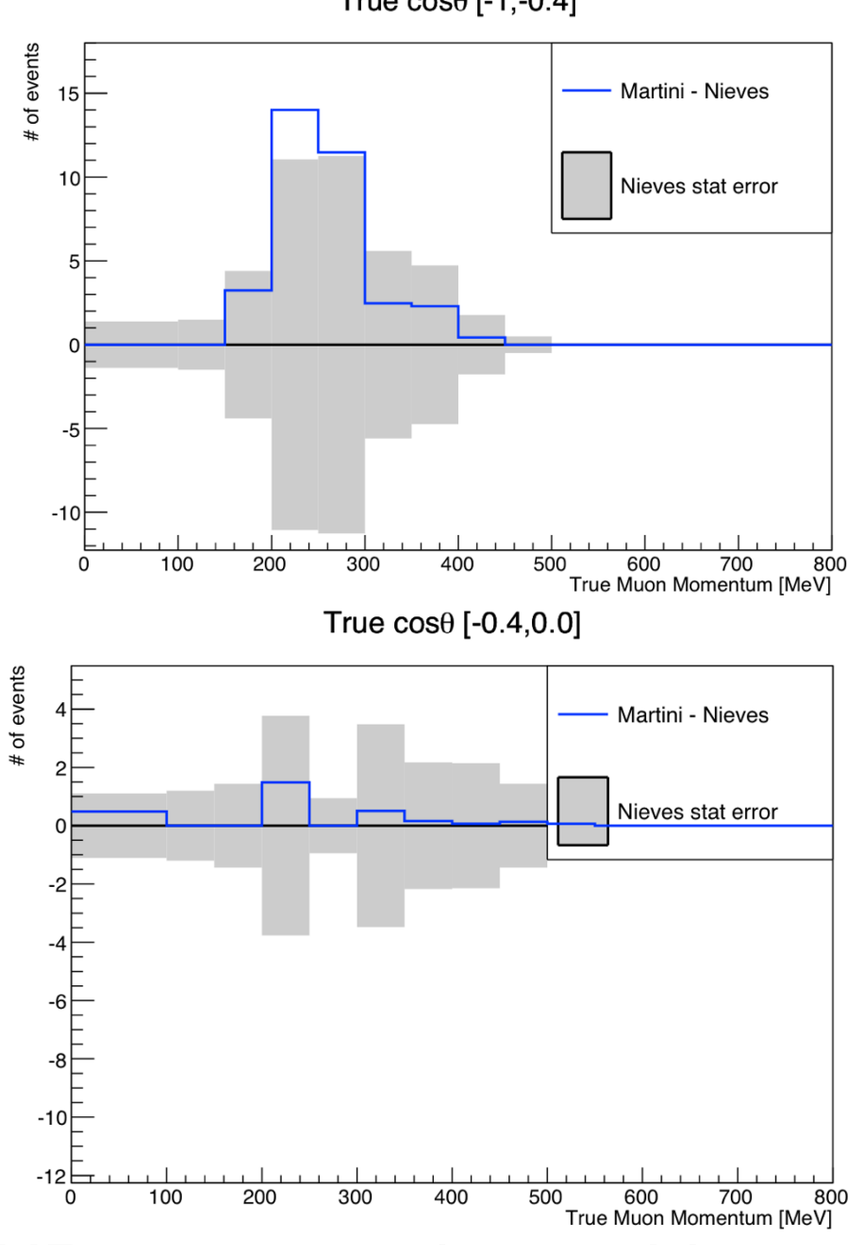


- Major difference is for high angle / backward muons
- Better sensitivity to neutrino cross section by measuring the whole phase space

Fake data study

- Check cross section model separation in muon CC0π sample
- ND280 current and upgrade normalized to same mass (~1 ton)
- Smearing to true dEdx / PID and momentum is applied to ND280 upgrade one

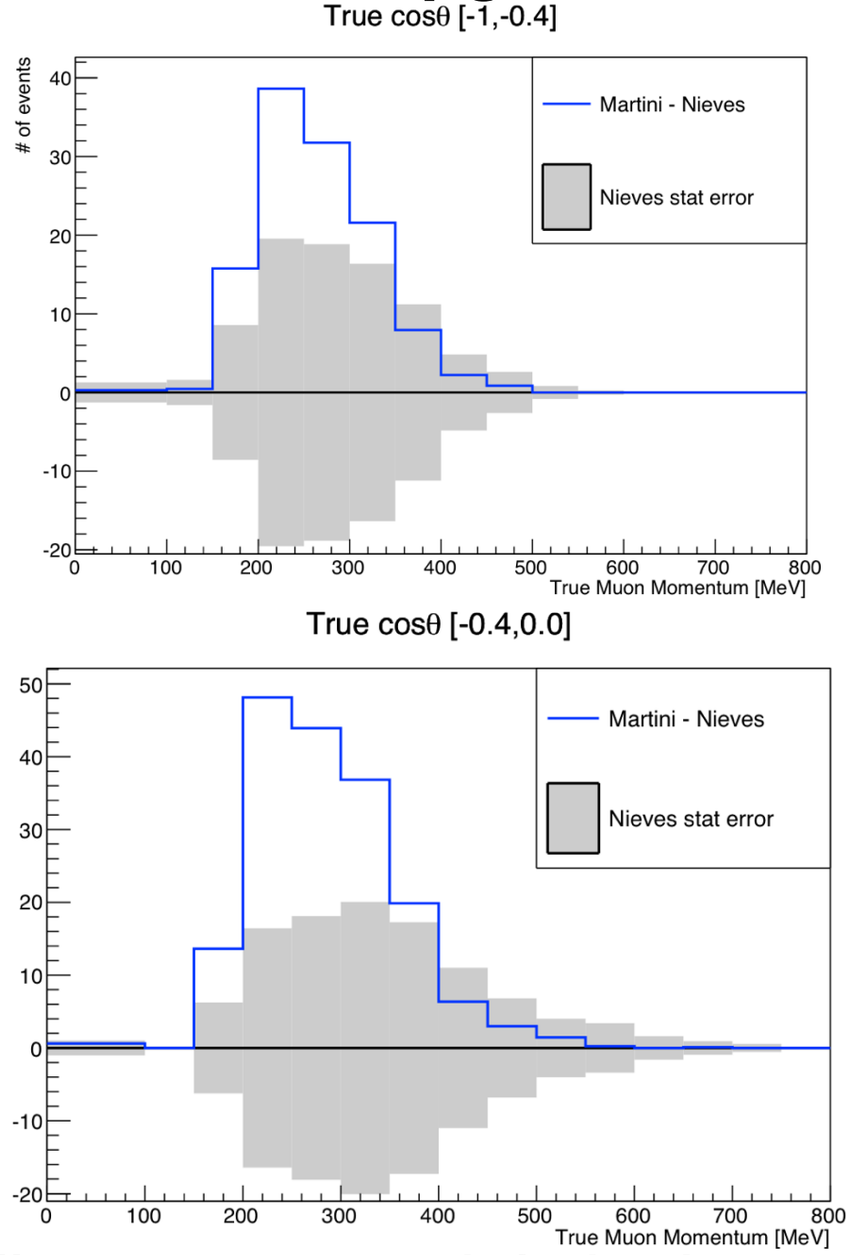
ND280 (official)



True cosΘ
[-1;-0.4]

True cosΘ
[-0.4;0]

ND280 upgrade



- ND280 upgrade provide enough statistic to well separate models in the backward and high angle region

Fake data study

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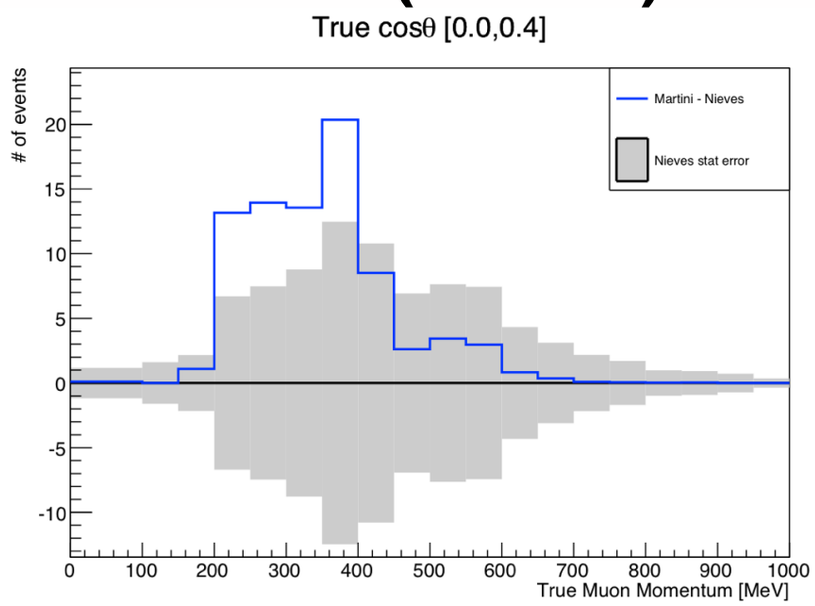
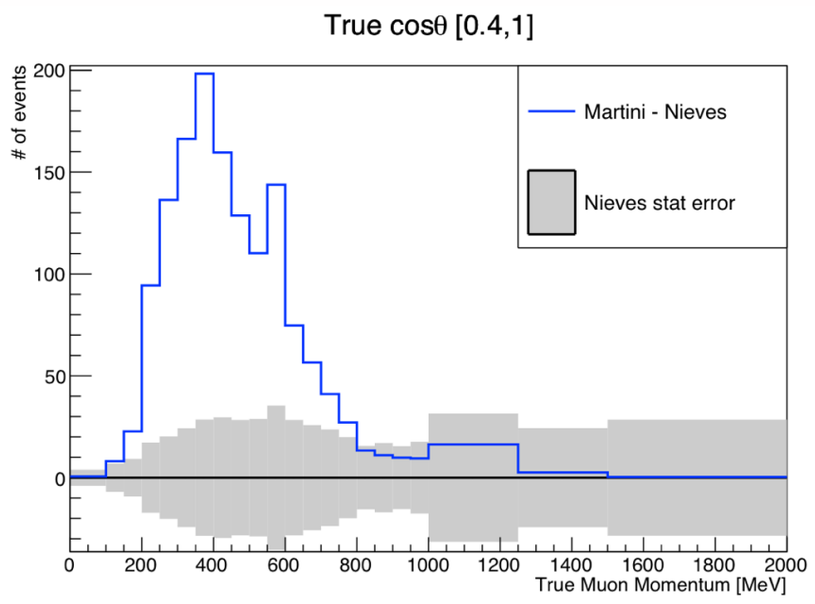
ND280 (official)

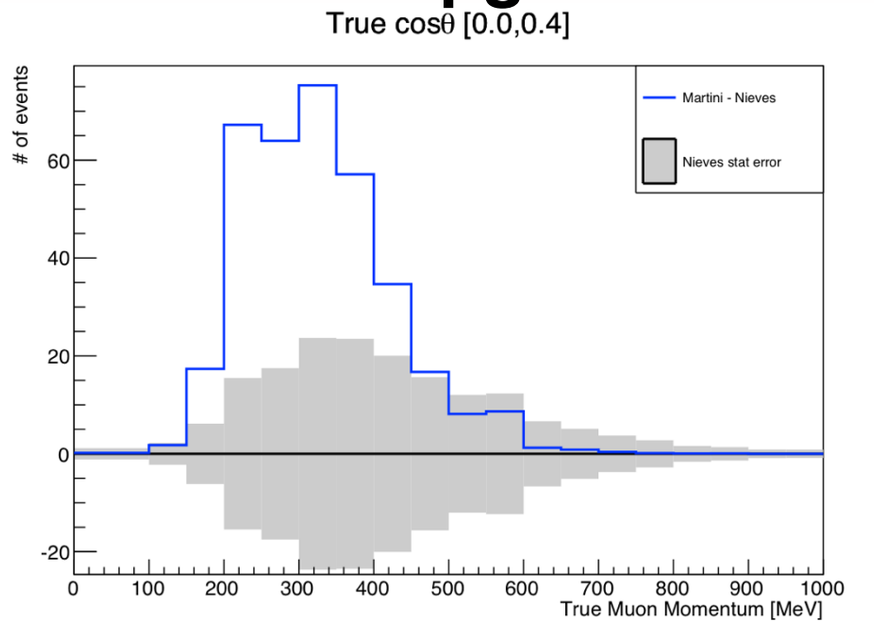


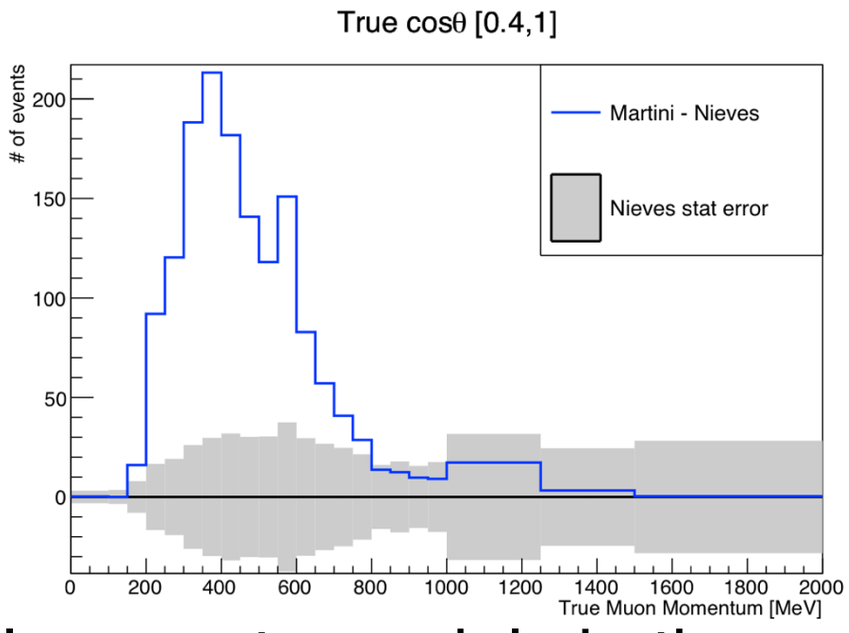
True cosΘ [0;0.4]



True cosΘ [0.4;1]

ND280 upgrade





- ND280 upgrade provide enough statistic to well separate models in the backward and high angle region

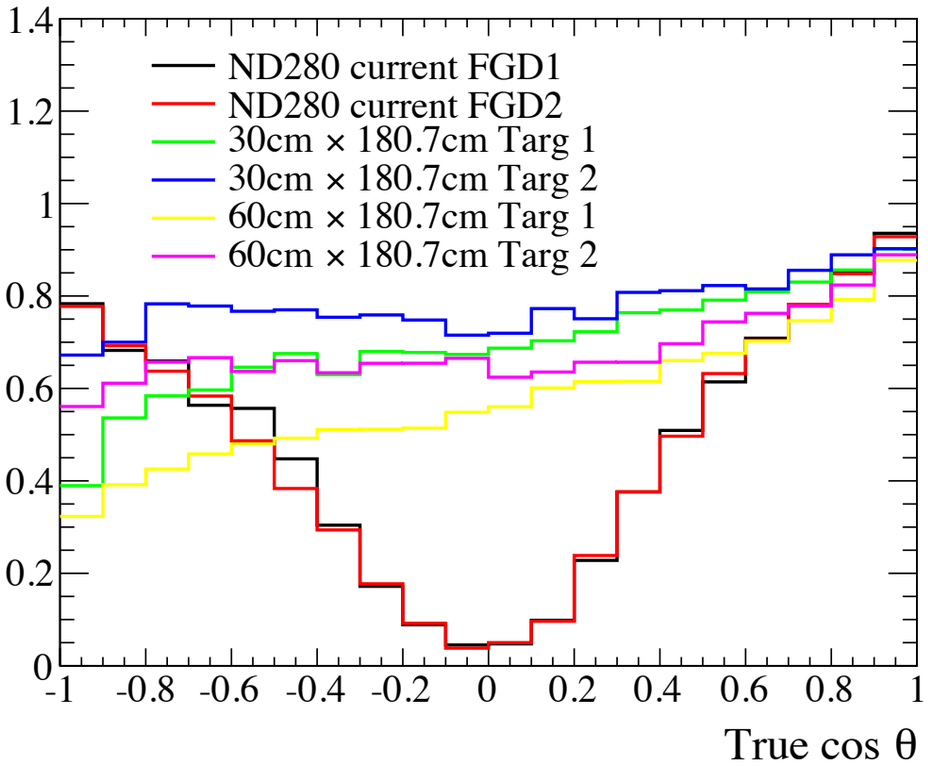
Conclusions

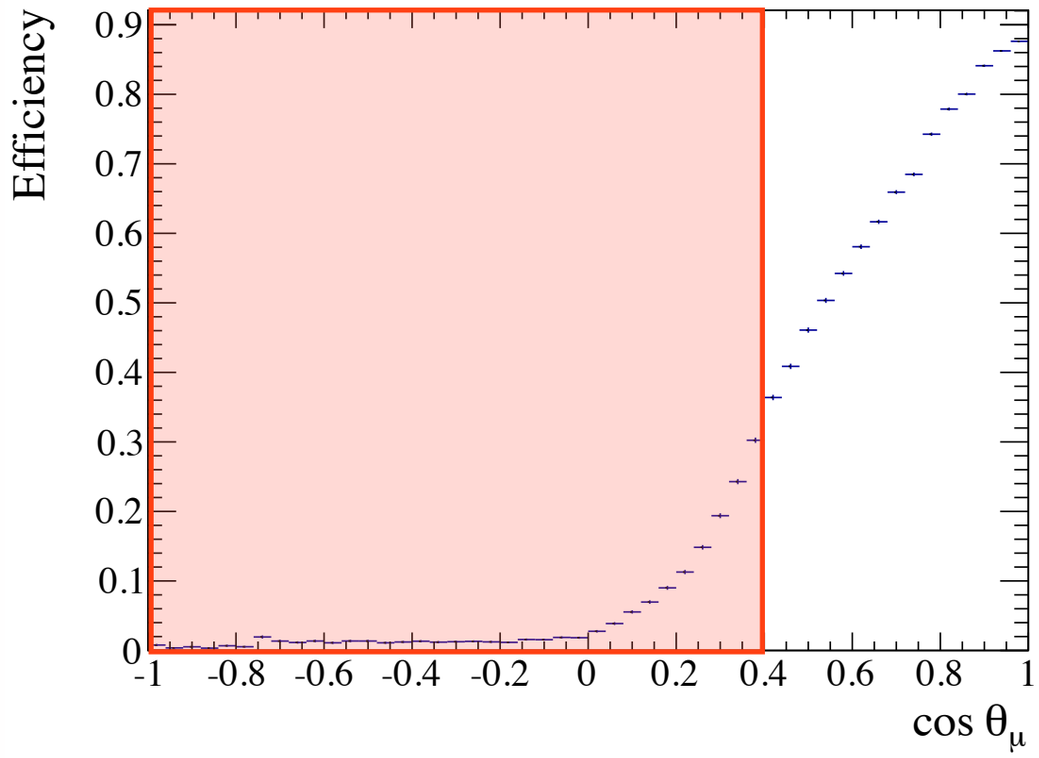
- Performed a GEANT4 simulation of the ND280 upgrade configuration
- Direct comparison with a ND280-like detector
- ND280 upgrade provides a better acceptance for high angle tracks
- Simulation framework will be merged with WAGASCI one after the workshop (also optimization of WAGASCI size, resolution using TPC)
- A more realistic event selection will be done with the same tools as used for the official ND280 analysis
- Sensitivity studies will be performed for both Near and Far detector to optimize the ND280 upgrade configuration based on

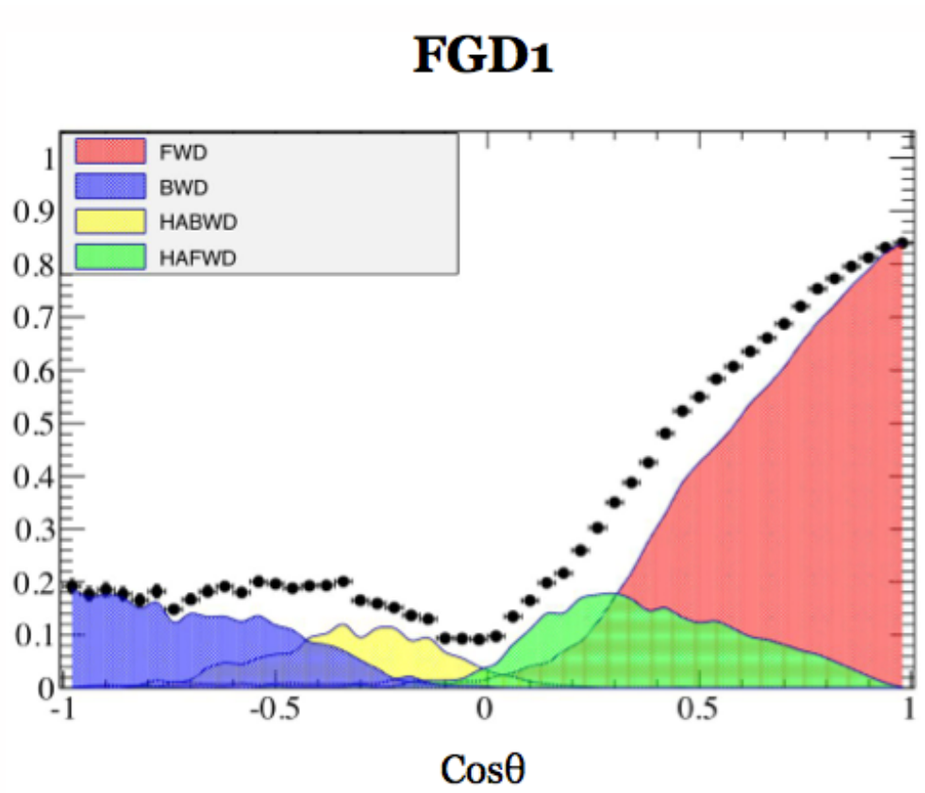
  - constraint of flux and cross section
  - sensitivity to different cross section models
  - sensitivity to oscillation parameters

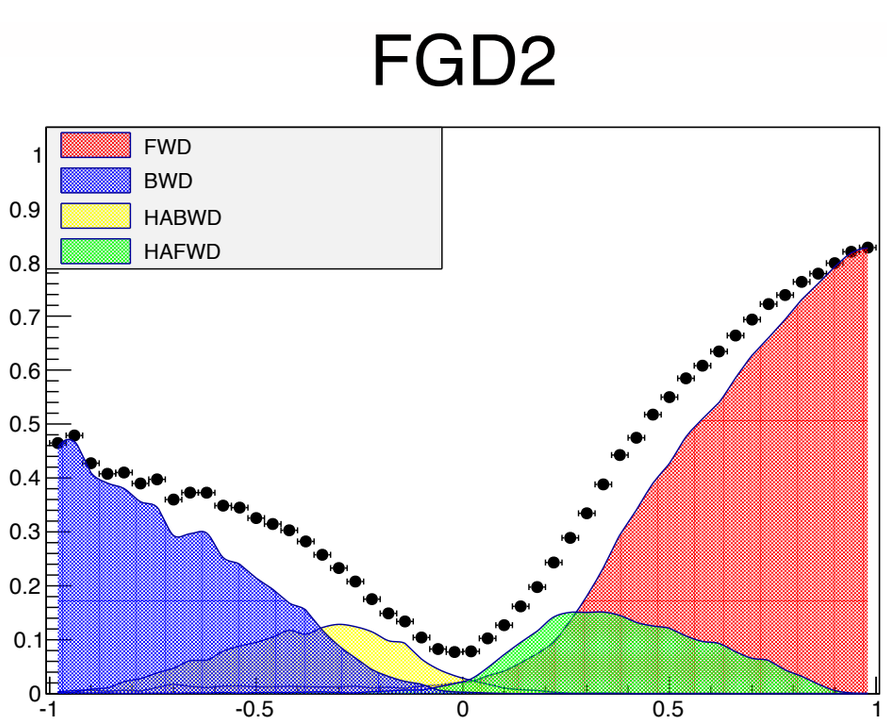
BACKUP

Comparison with ND280 current: Muons



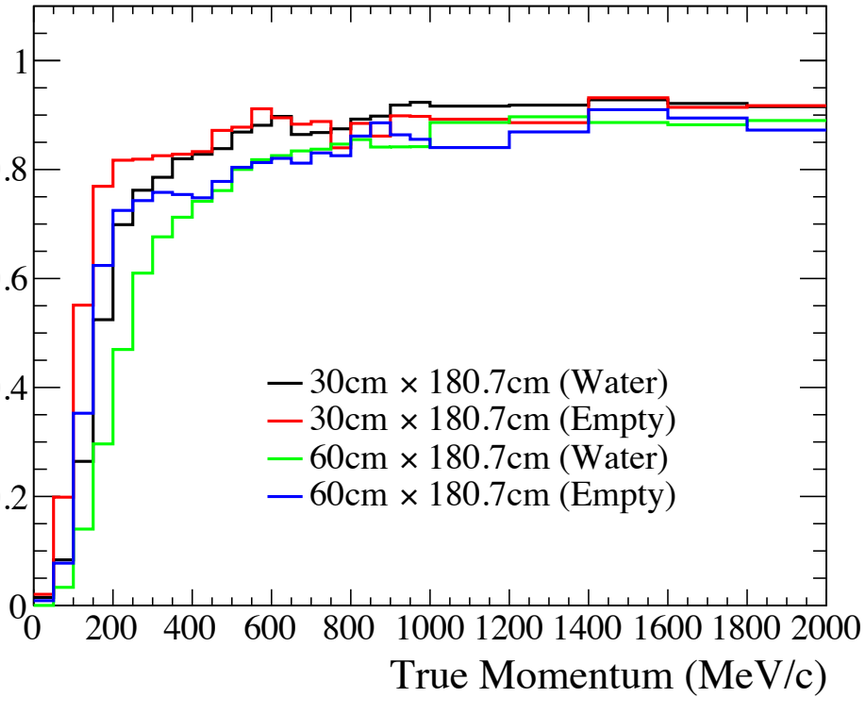


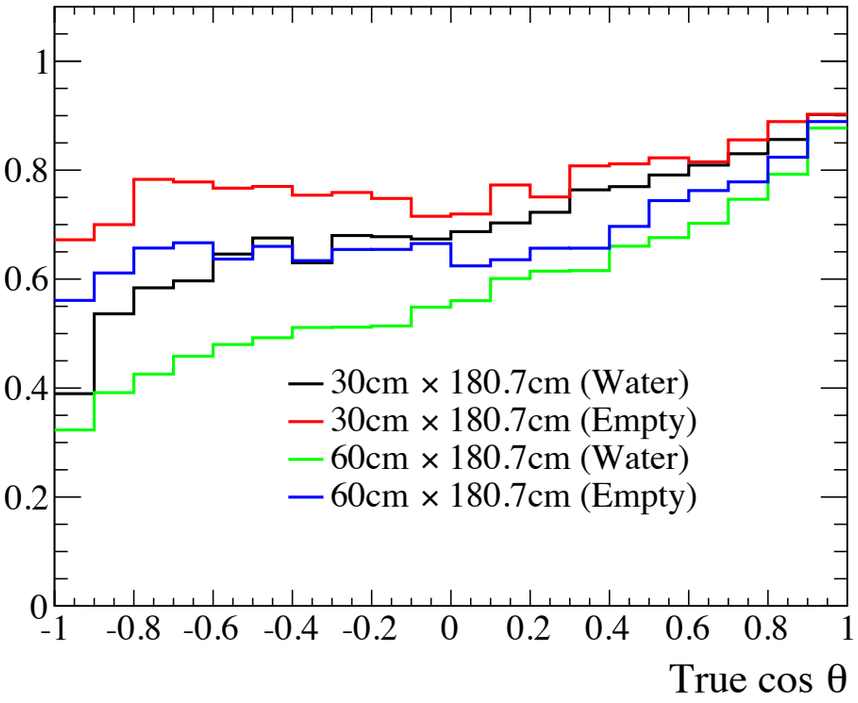


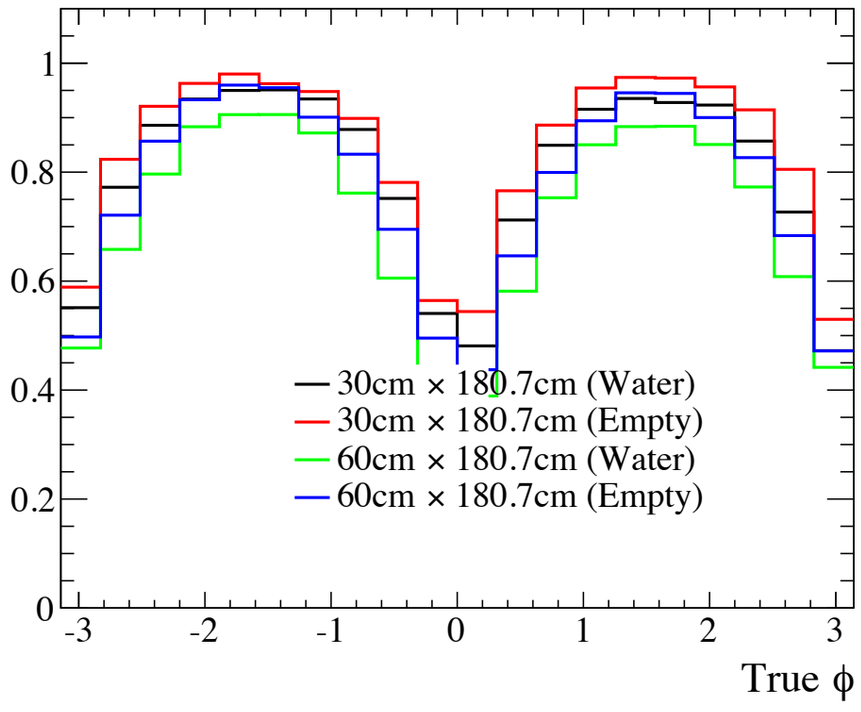


Efficiency Vs target thickness

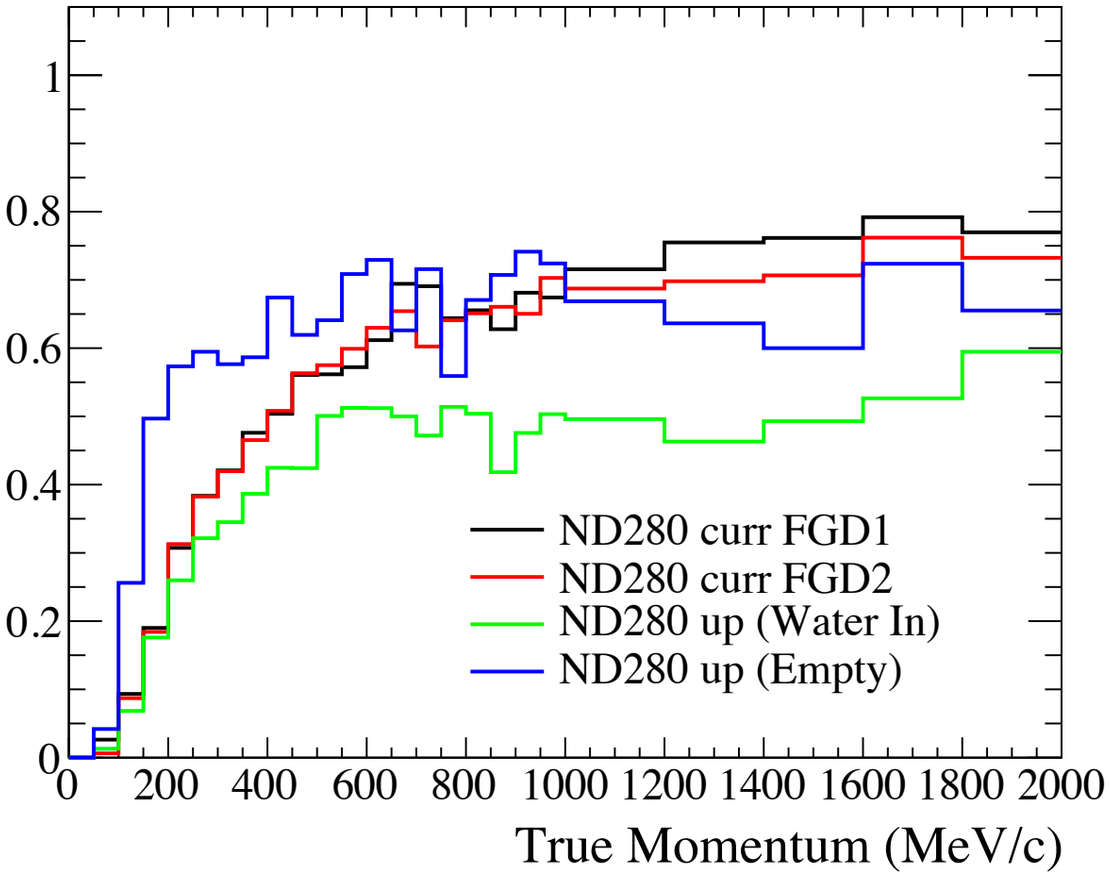
Select true muons μ^-

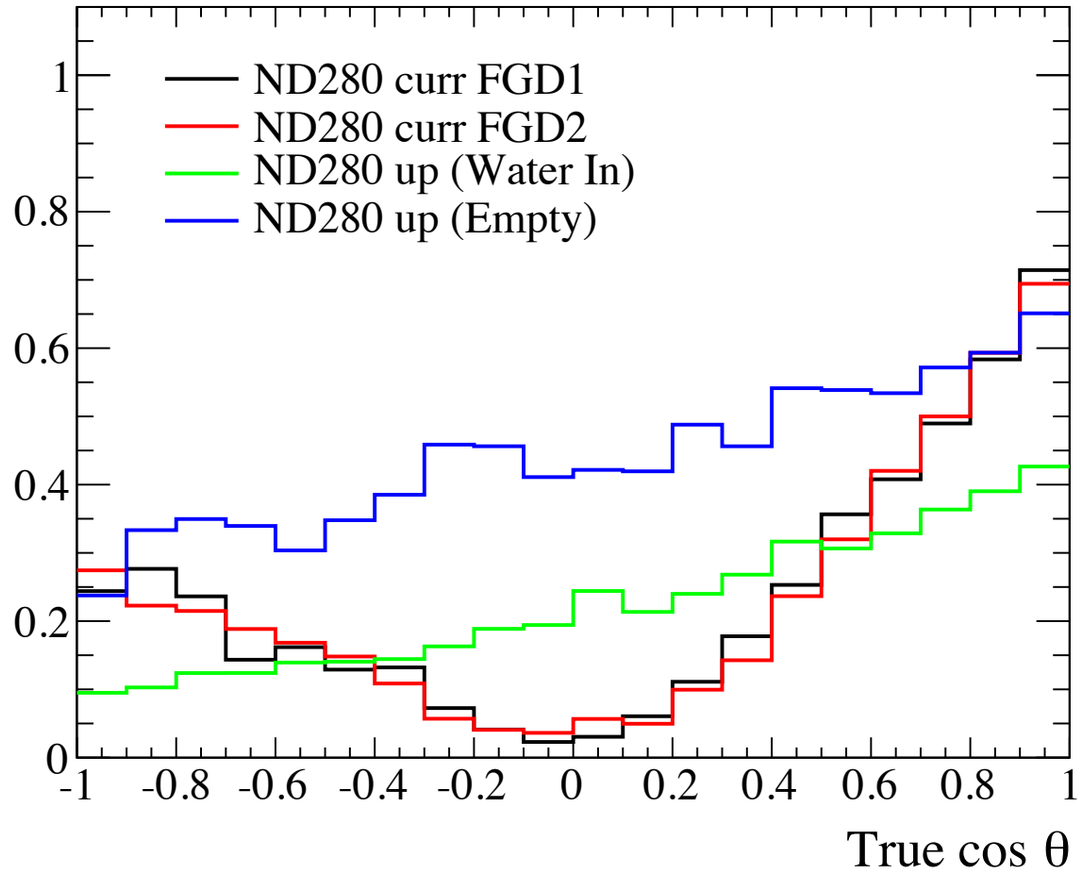






Comparison with ND280 current: charge pions



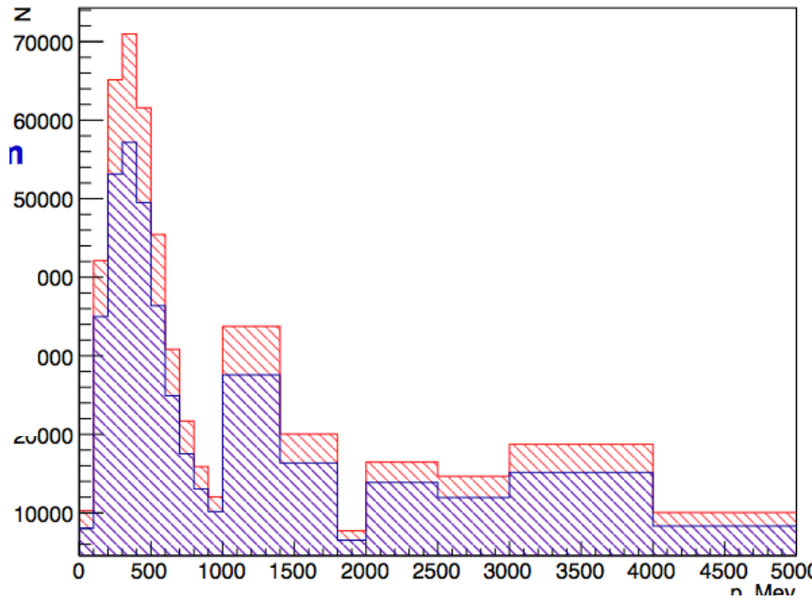


- Still better acceptance for charged pions
- Best performance given by water-out target

PID and momentum smearing

- PSyCHE/HighLAND is used for selection and smearing
- Take the output from GEANT4 simulation and provide smeared variables based on the true informations
- Smeared momentum
  - needs true momentum, track length in TPC,

$$\text{Gaus}(p_{true}, \sigma(p_{true})), \text{ where } \sigma(p_{true}) = p_{true} \sqrt{\left(\sqrt{\frac{720}{N+4}} \frac{\sigma_x p_{true} \sin\vartheta}{0.3\, B\, L^2}\right)^2 + \left(\frac{0.2}{\beta B \sqrt{X_0 \sin\theta}}\right)^2}$$



- Smeared dE/dx

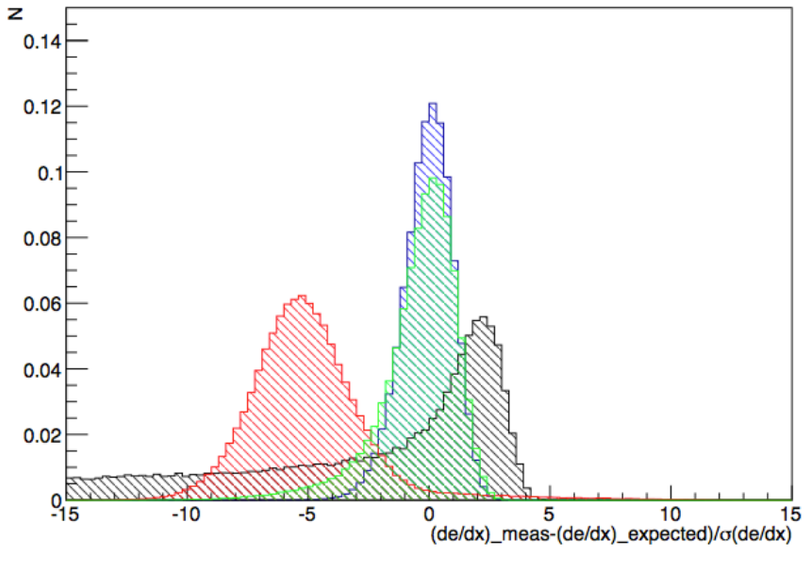
➢ Compute expected $\frac{dE}{dx}(p_{true}) = \frac{e_0}{\beta^{e_3}}\left(e_1 - log\left(e_2 + \frac{1}{(\beta\gamma)^{e_4}}\right)\right)$, TN-001

➢ Get the measured $\frac{dE}{dx}$ by smearing expected one with Gaus($\frac{dE}{dx}$,σ) , where $\sigma =$

$$\sqrt{(0.08\sqrt{\frac{72cm}{Lsin\theta}}\frac{dE}{dx})^2 + (\frac{dE'}{dx}(p)\sigma_p)^2}$$

$$\delta = \frac{\frac{dE}{dx}(p_{true})exp - \frac{dE}{dx}(p_{true})meas}{\sigma}$$

muon

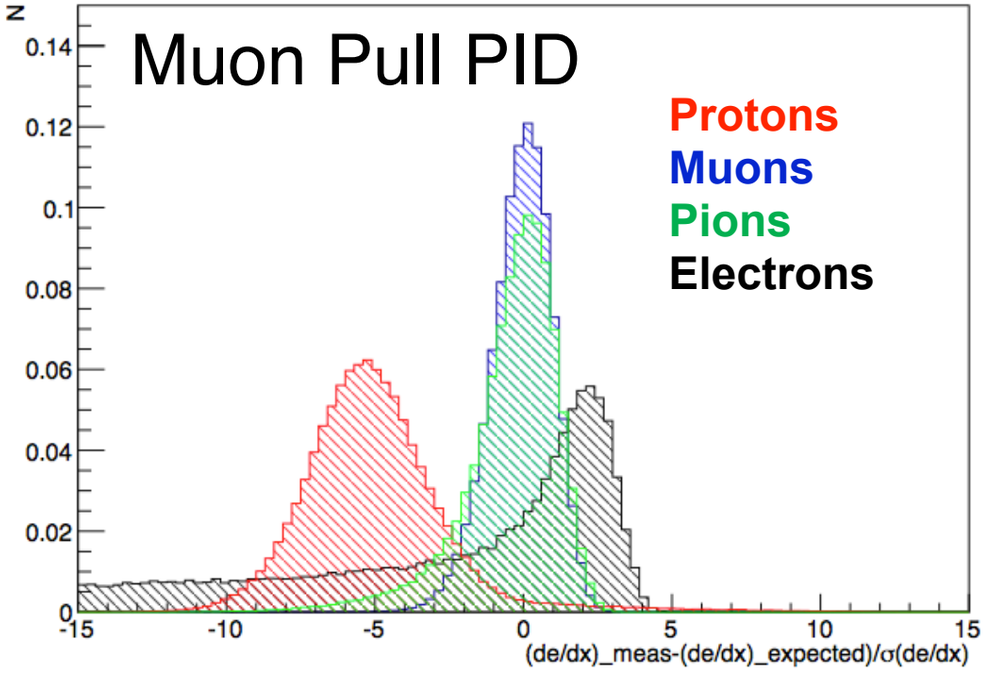


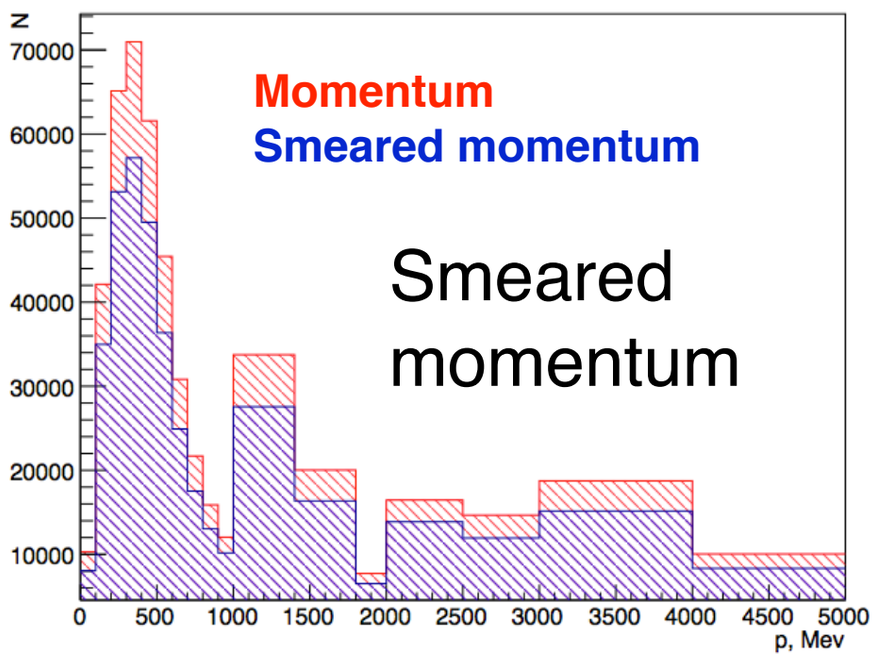
- These informations will be included in the efficiency study next week

PID and momentum smearing

- PSyCHE/HighLAND will be used for selection and smearing soon
- Take the output from GEANT4 simulation and provide smeared variables based on the true informations
- Pull PID distributions produced with theoretical formulas (see backup)
- Smearing of dE/dx and momentum based on standard parametrizations (see backup)
- Selection will be based on the PID using smeared dE/dx

muon

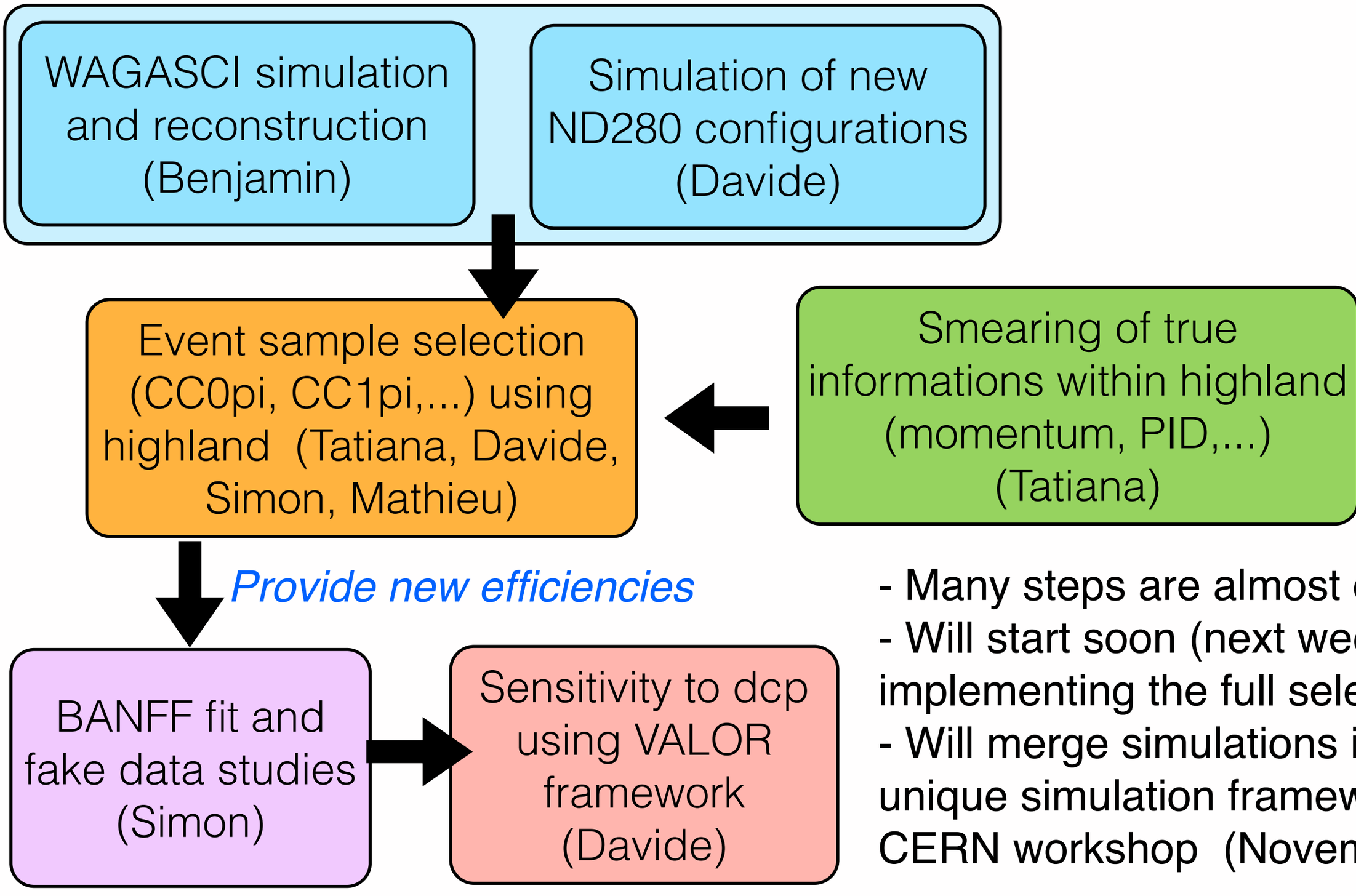




- These informations are ready to be used and will be included in the efficiency study next week

ND280 task force

- The task force has been set (Benjamin, Davide, Minamino-san, Sasha, Simon, Tatiana) and is still growing.
- Several people showed interest. Anybody is interested is welcome to join us



- Many steps are almost completed
- Will start soon (next week) implementing the full selection
- Will merge simulations in a unique simulation framework after CERN workshop (November)

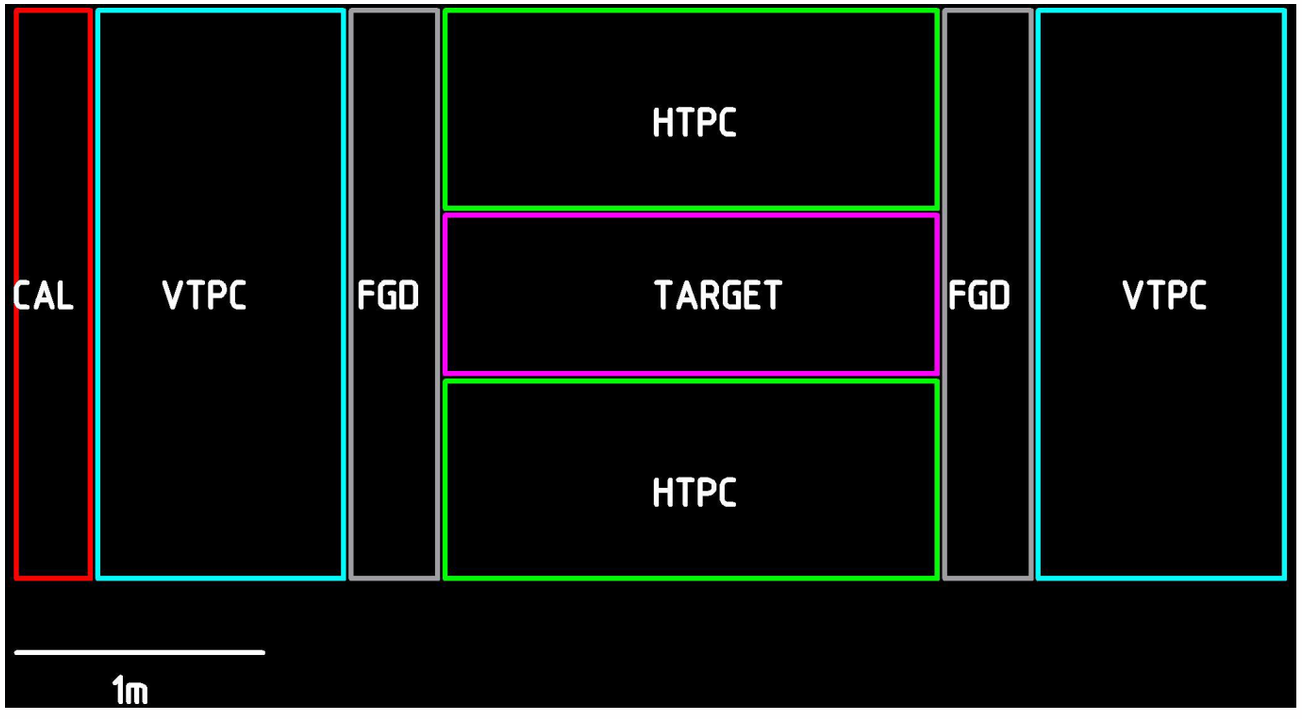
Other possible configurations

• Horizontal targets provide a very good measurements of high angle and backward muons in the TPCs

• We are studying other possible configurations:

- add more target mass

- collect samples for both high angle, backward and forward tracks



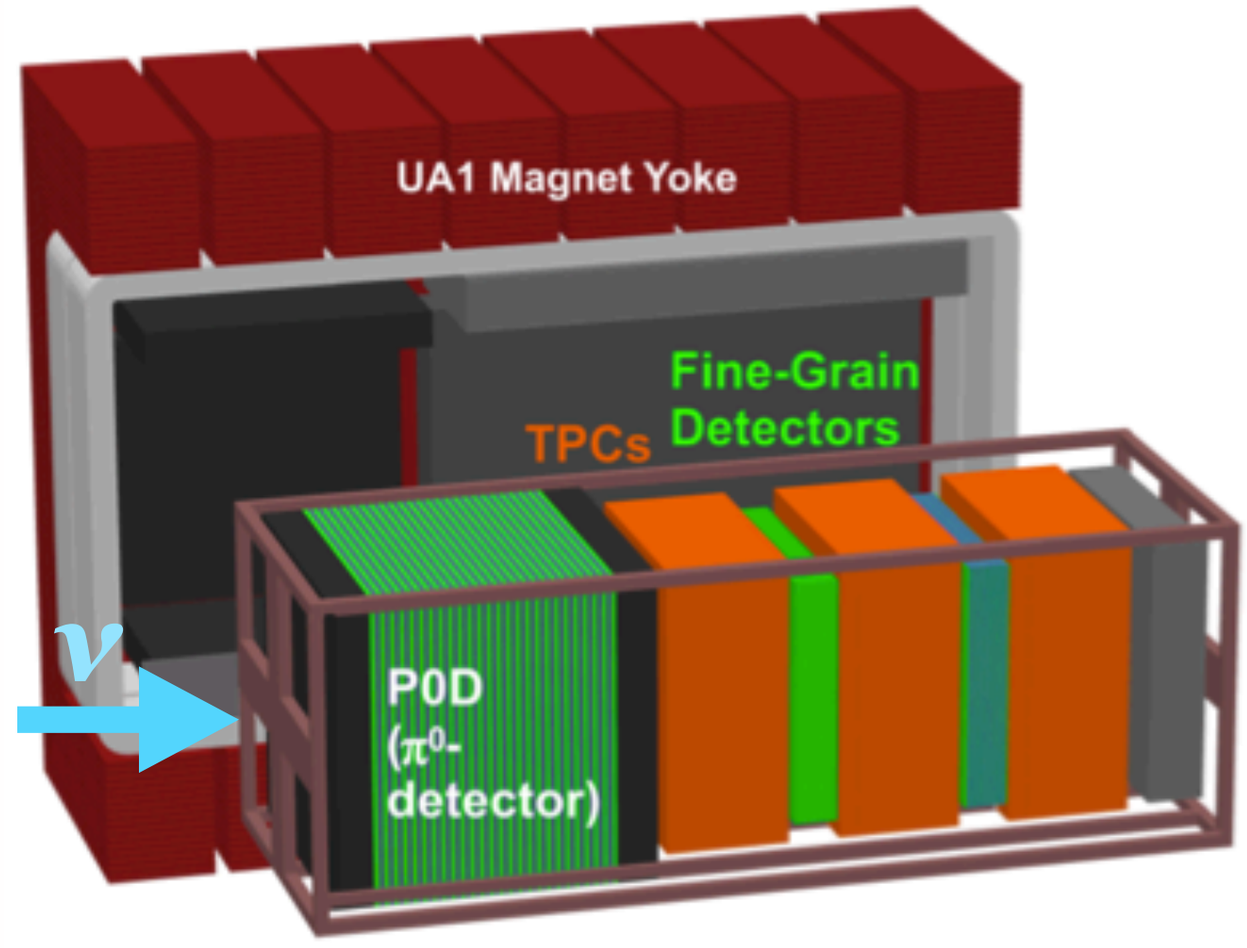
plus a few other ideas...
Work is in progress

• TPCs size will depend on the optimal configuration

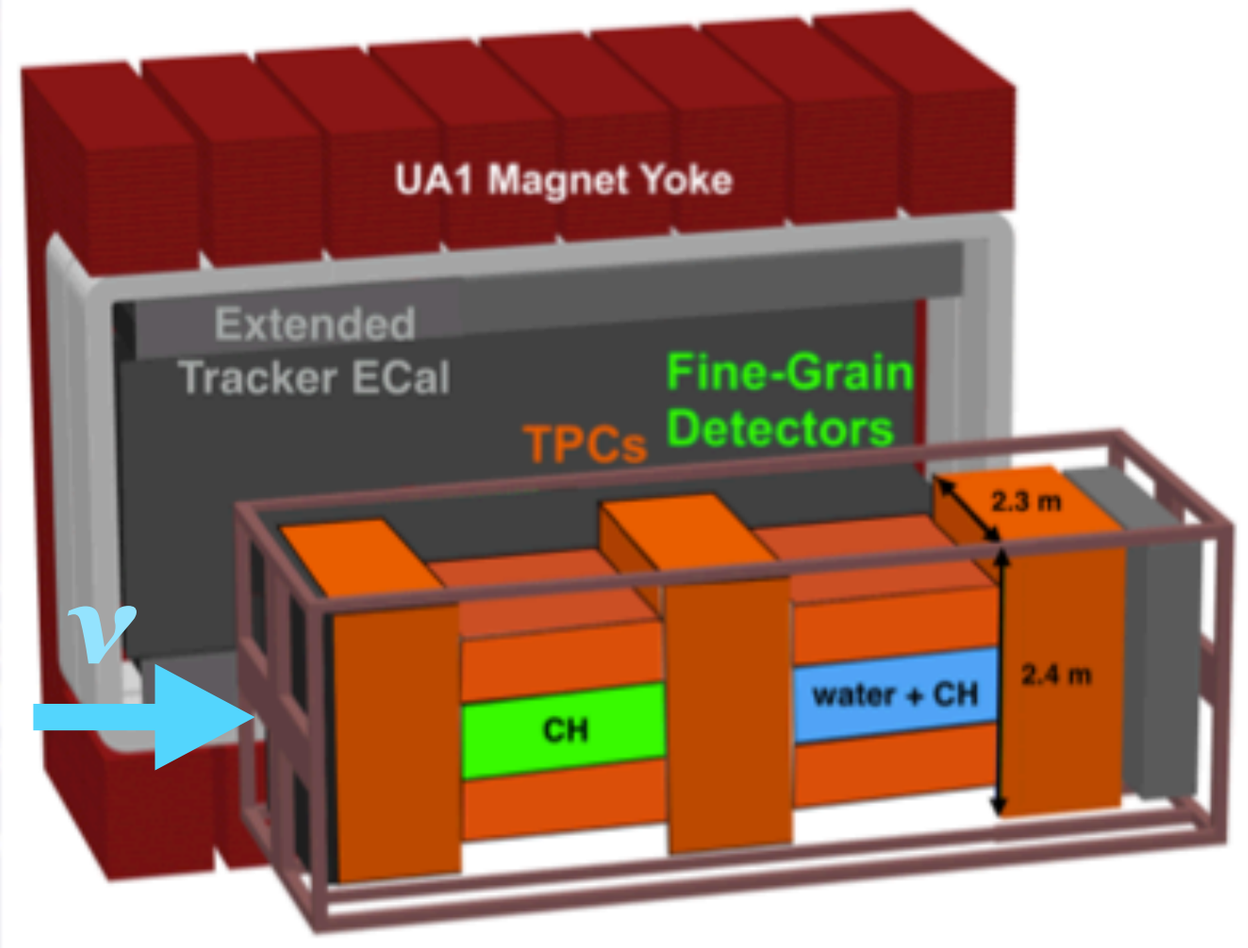
Current ND280 detector

- Current ND280 tracker has low acceptance for high angle tracks

Current ND280



Possible upgraded ND280



- Horizontal targets and “side TPCs”: acceptance for high angle tracks can be largely improved
- Need to keep the calorimeter in the downstream part to “screen” from photons produced in the magnet
- Optimize acceptance for particles produced in target and detected from TPCs

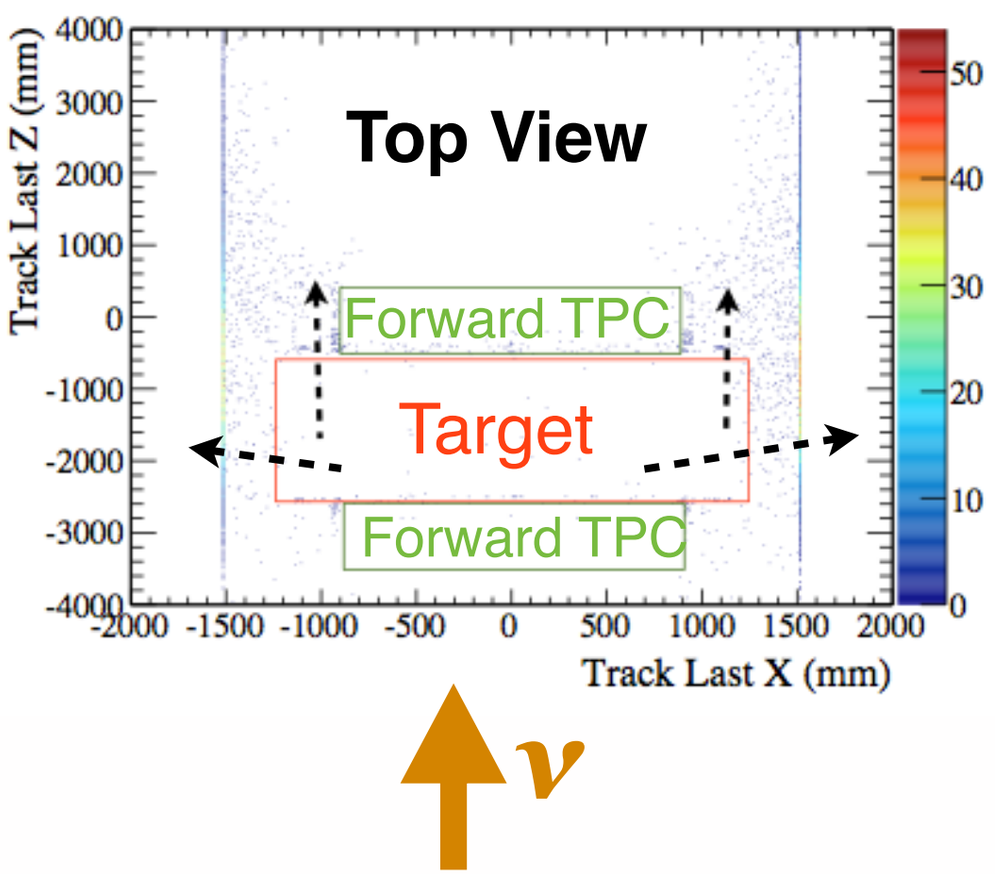
of events in the FV

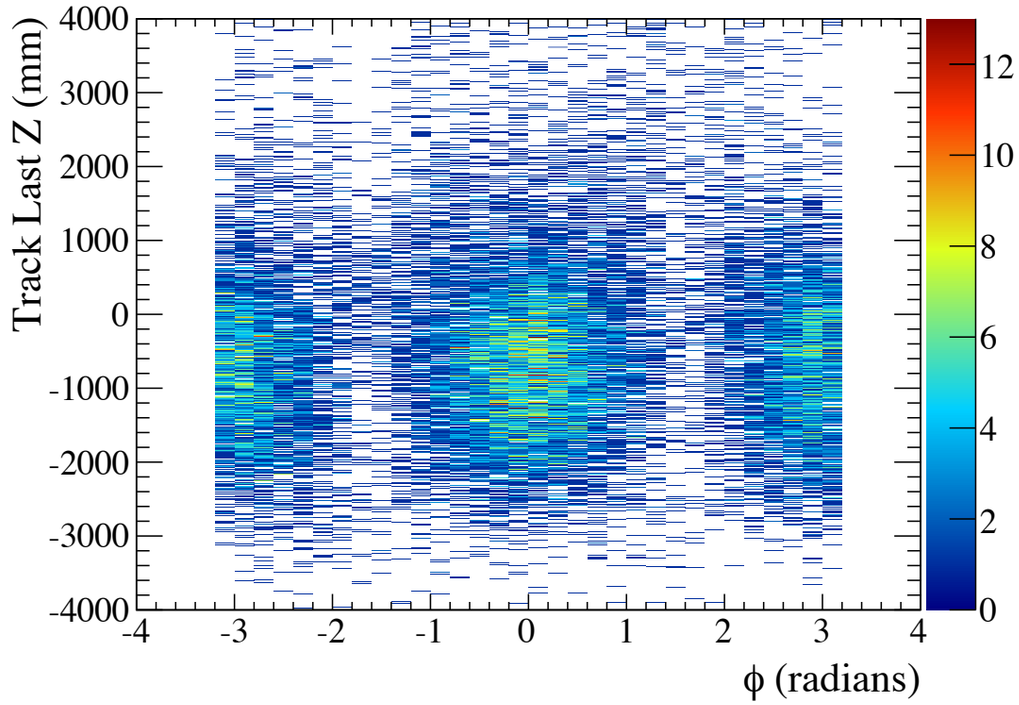
- Numu beam 6x10^{20} POT
- The fiducial volume is the target box

ND280 current		
Reaction Mode (FV)	FGD 1	FGD 2
CCQE	22011	21074
CC1pi	14124	13796
CCcoh	322	268
CCDis	5320	5328
NC	15744	15438
Total	57521	55904

1864x600x1300 mm^3		
Reaction Mode (FV)	Target 1	Target 2
CCQE	31299	9826
CC1pi	20173	6371
CCcoh	342	148
CCDis	6843	2099
NC	22700	6979
Total	81357	25423

ND280 upgrade performance





- ϕ=0,π region is not covered by any TPC. Minimize thickness
- Forward TPC acceptance: target width is 2.3 m while Forward TPC drift region width is ~1.8 m
- But thinner target means less events...

1864 (width) x 600 (height) x 1300 (length) mm^3