UNIVERSITÉ DE GENÈVE
FACULTÉ DES SCIENCES

T2K

Simulation of the upgraded ND280 detector

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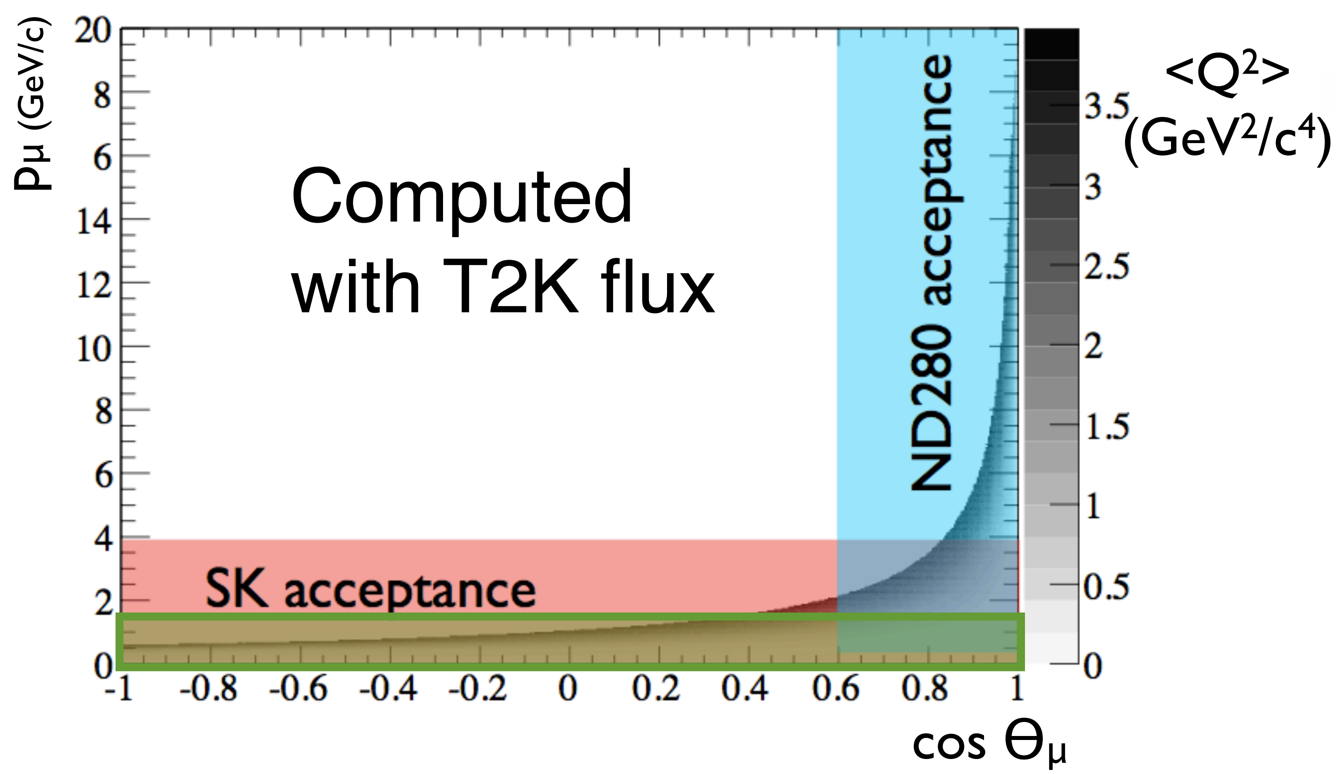
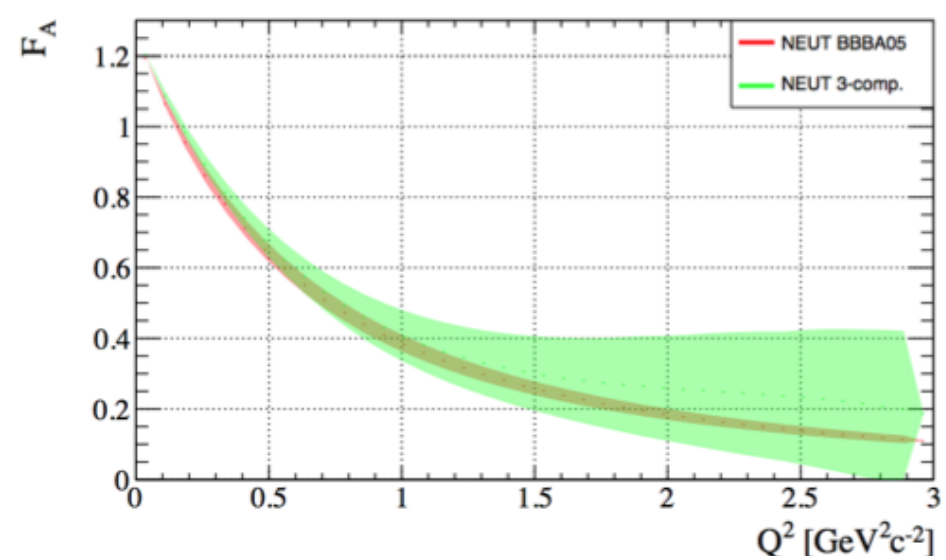
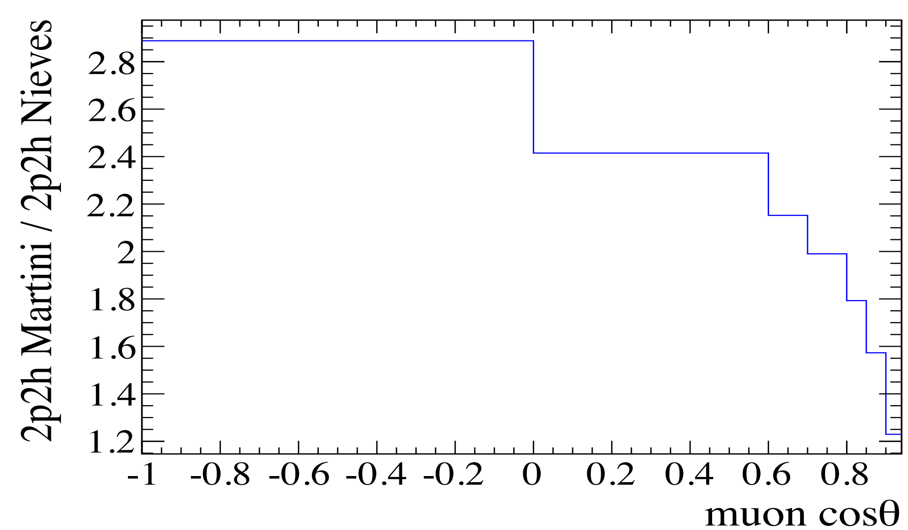
“Neutrino Near Detectors based of gas TPCs” workshop, CERN
March 21 2017

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



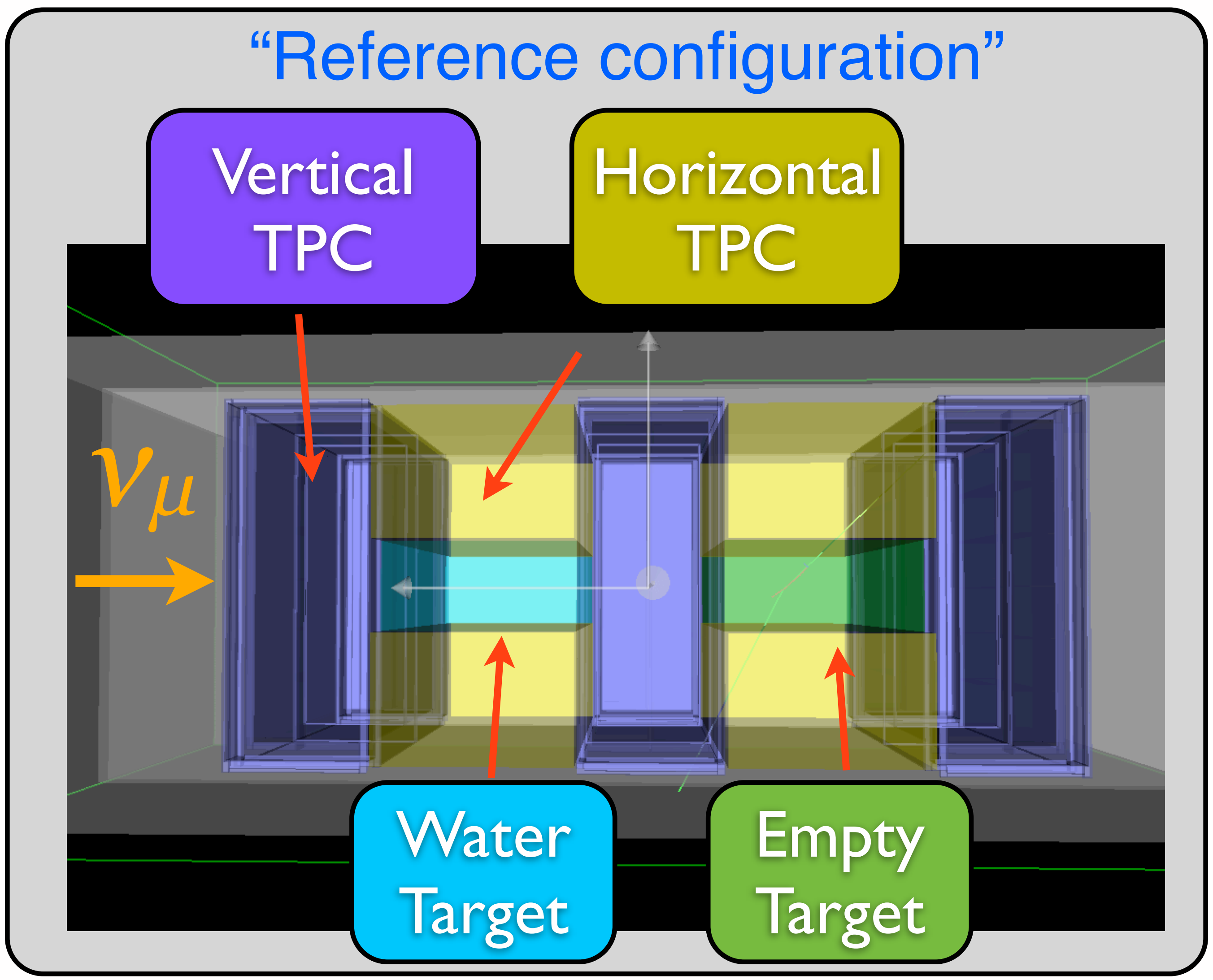


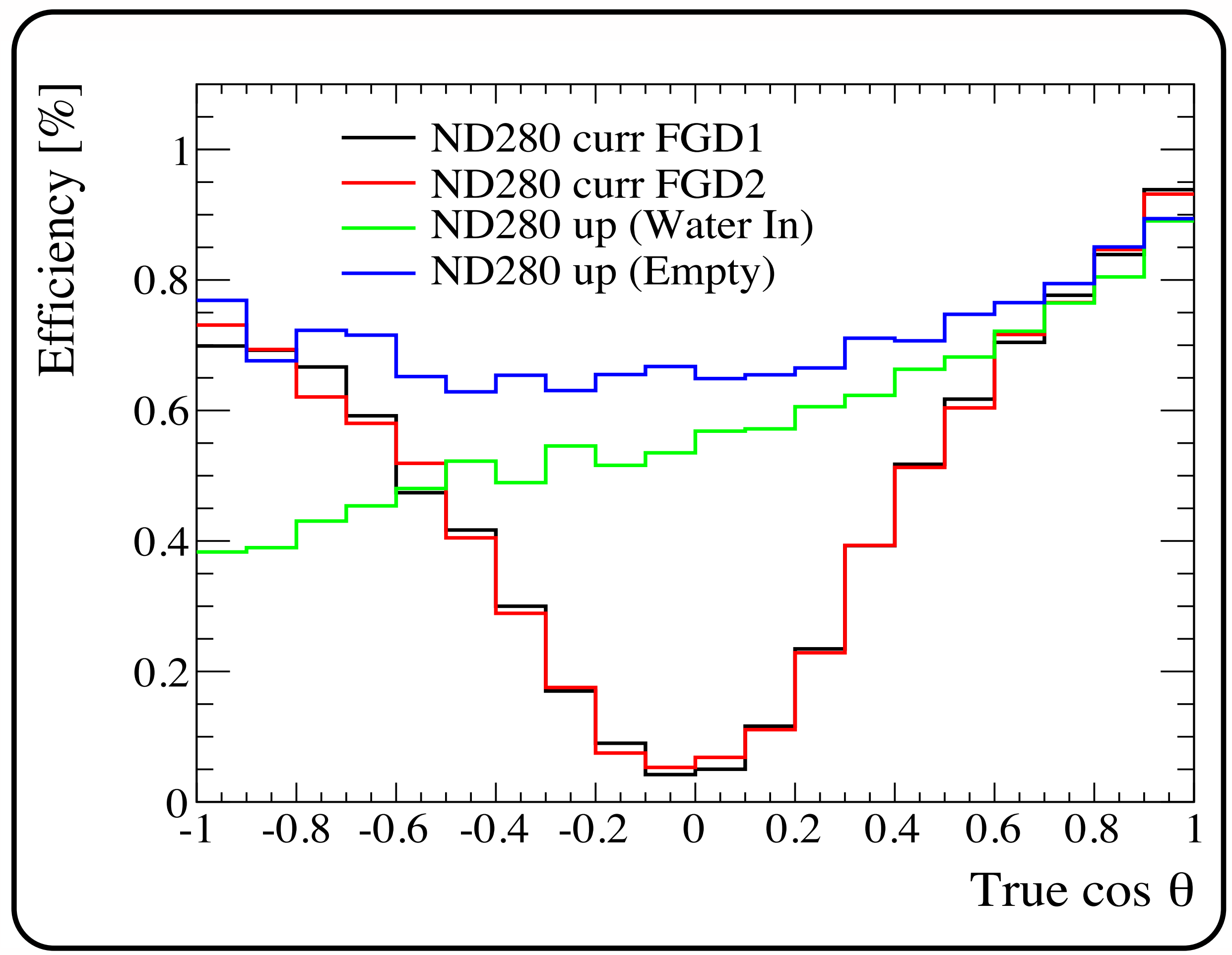


- The goal is to better cover also the high angle region
- Need the full analysis chain to quantify the improvement and optimize ND280

What was presented at the past workshop

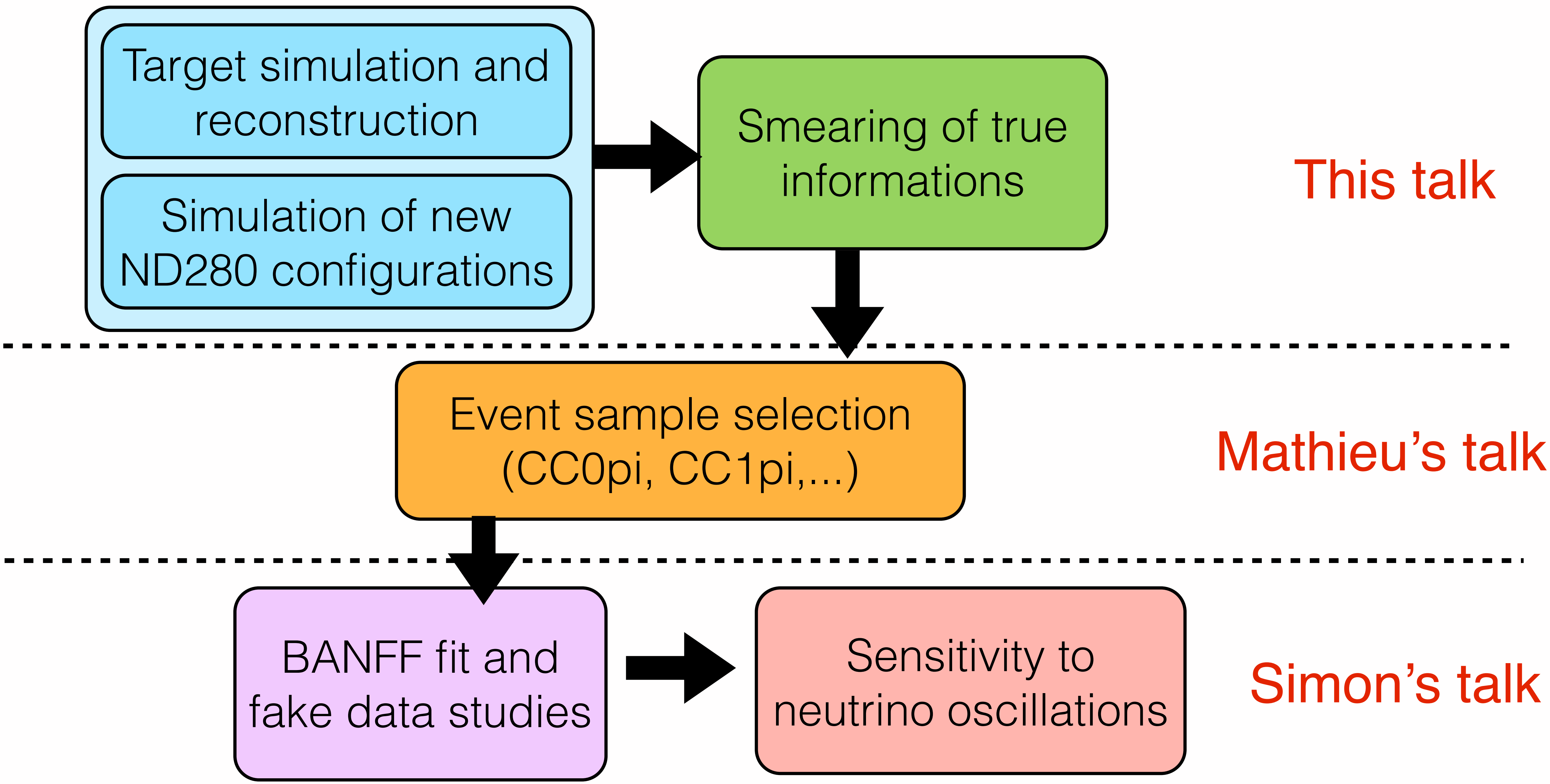
- Simulation:
  - 3 vertical TPCs (same as current ND280)
  - 4 horizontal TPCs + 2 horizontal targets
  - target size: 1864 (width) x 600 (height) x 1300 (length) mm^3
  - target mass: 1.45 ton (water), 0.45 ton (carbon)
- Event selection:
  - true tracks w/o smearing (geometrical acceptance for muons)
- Studies were done for only 1 ND280 upgraded configuration





Analysis chain

- Follow the full analysis chain as in the T2K official analysis
- Many tools recycled from ND280 official tools and adapted
  - Highland software for event selection
  - BANFF for ND280 fit
  - VALOR for sensitivity studies on neutrino oscillations



Updates since the CERN workshop

- Studies on the stand-alone simulation and reconstruction of the WAGASCI detector (see next slides)

- Added all the current ND280 detectors that will be kept in the upgraded configuration

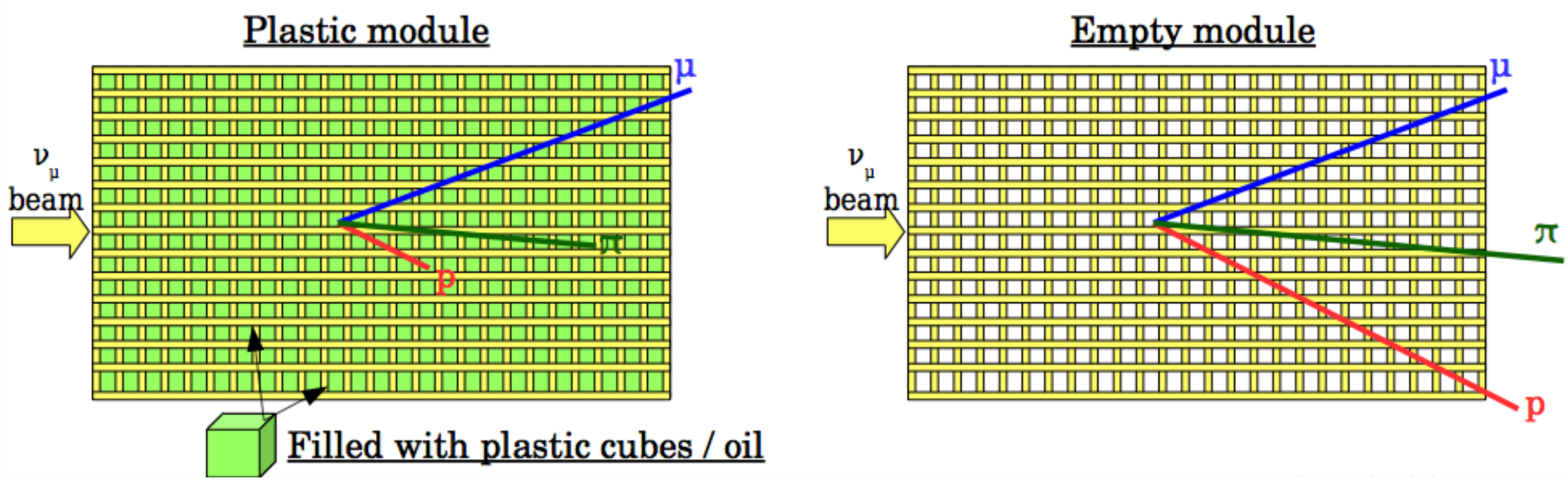
- Preliminary studies of Time of Flight detectors (Tatiana’s talk)

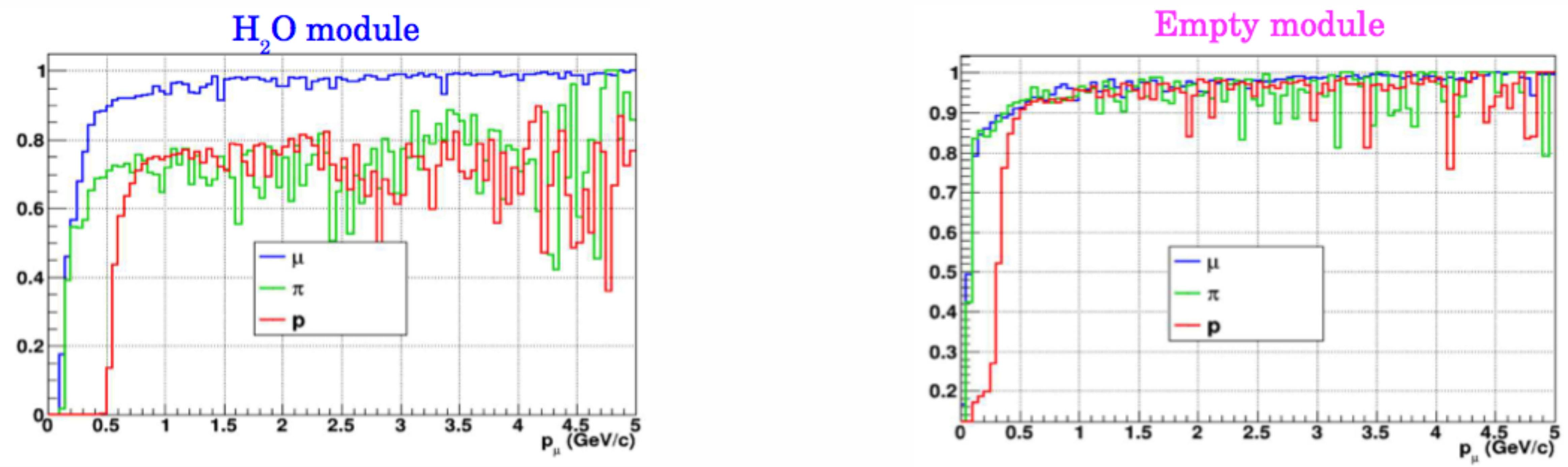
- Developed a full selection using the same tools as in the ND280 official analyses (see Mathieu’s talk)

- Preliminary sensitivity studies

The neutrino target detector

- Plastic scintillator structure: 4π acceptance

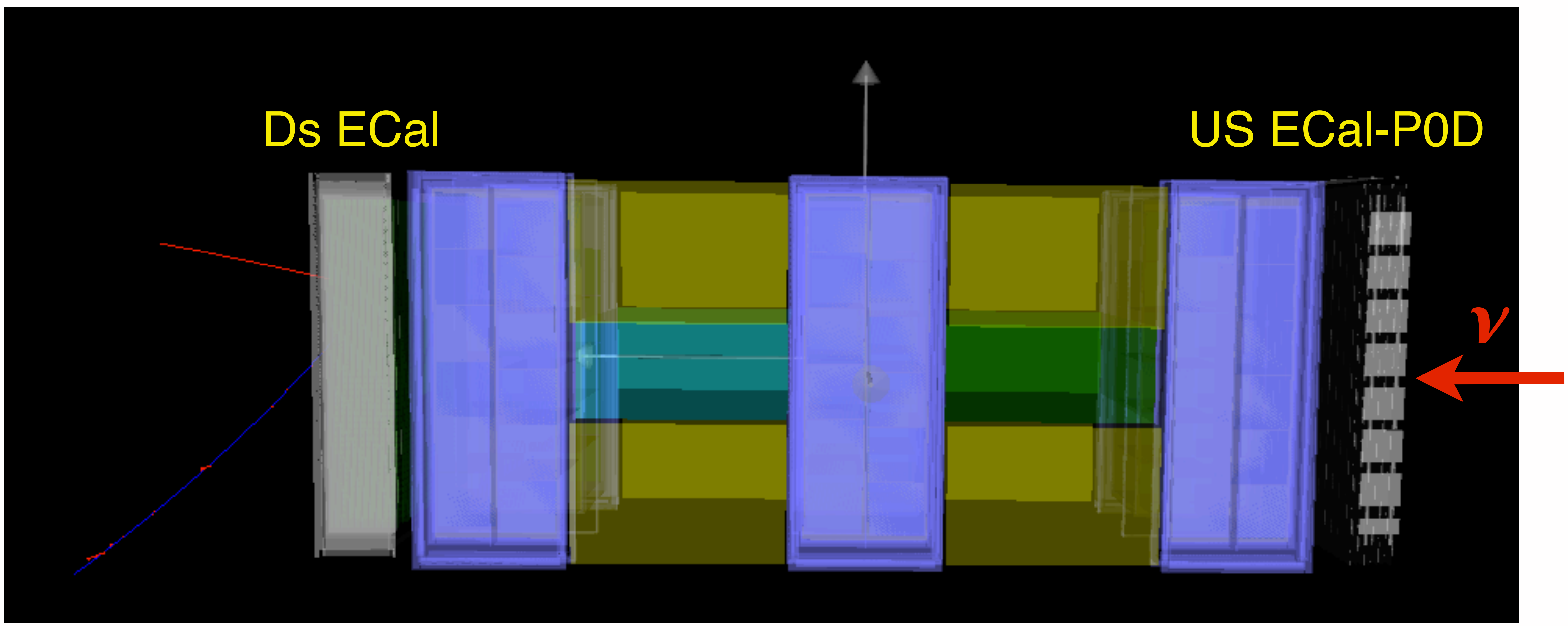




- Empty module drastically reduces the momentum threshold but ~30% mass
- Protons threshold down to ~300 MeV/c (close to Fermi momentum)
- Efficiency >90% over the full solid angle

The electromagnetic calorimeter

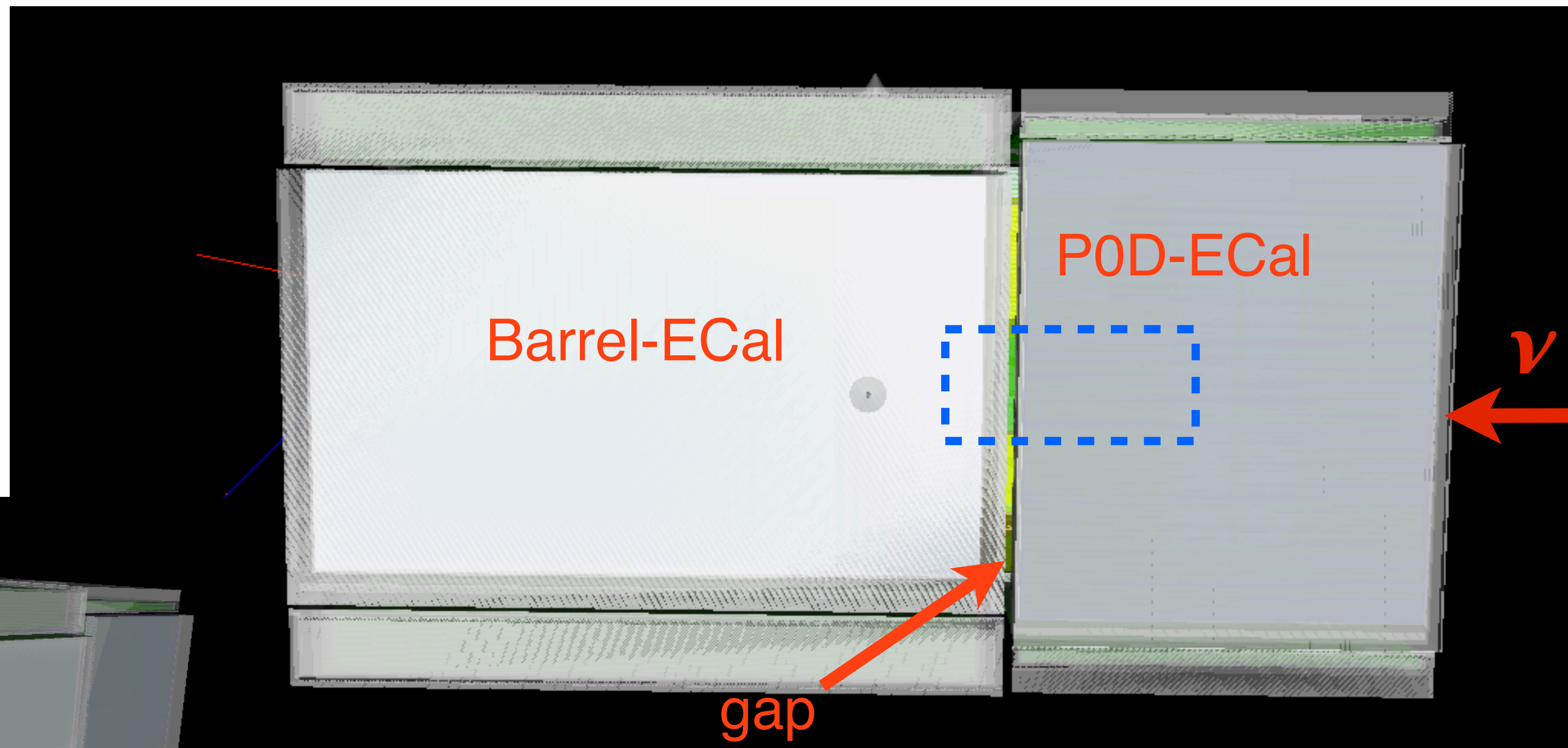
- Implemented the Downstream ECal (31 layers, XY plastic scintillator):
  - 31 layers of XY plastic scintillator and lead
- Implemented Upstream ECal-P0D
  - took the upstream calorimeter of the P0D
  - 7 layers of XY plastic scintillator and lead
  - needed to screen from gamma bkg from the magnet
- Same implementation as in the ND280 official MC

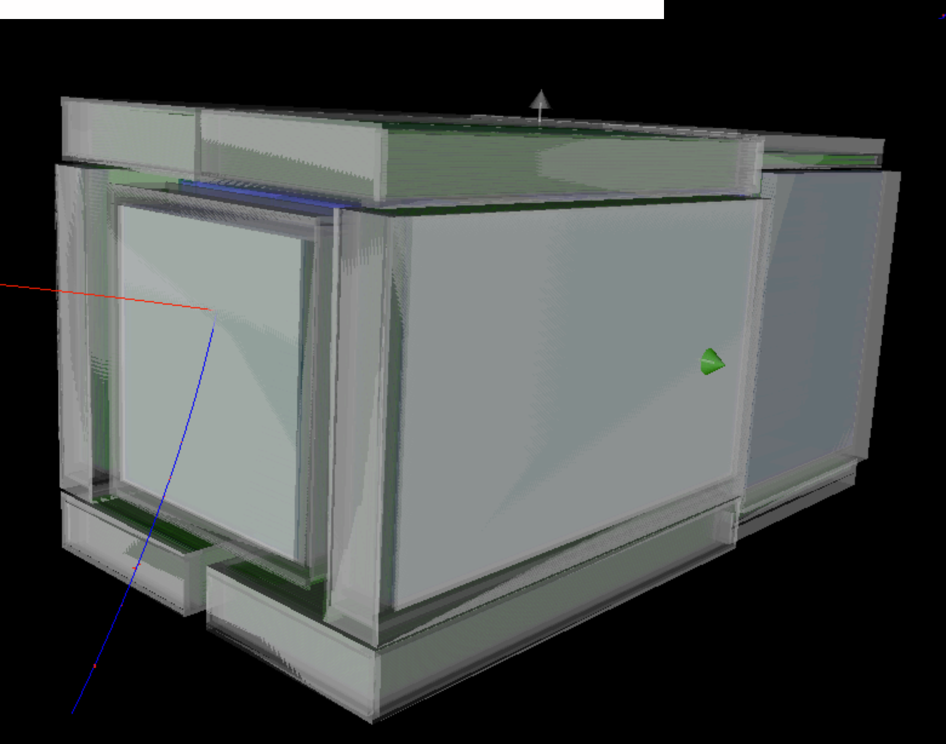


The electromagnetic calorimeter

- Implemented the ECal that covers the tracker at 4π
- Barrel-ECal covers the ND280 current tracker (3 vertical TPCs + 2 FGDs)
- P0D-ECal covers the space occupied by the P0D

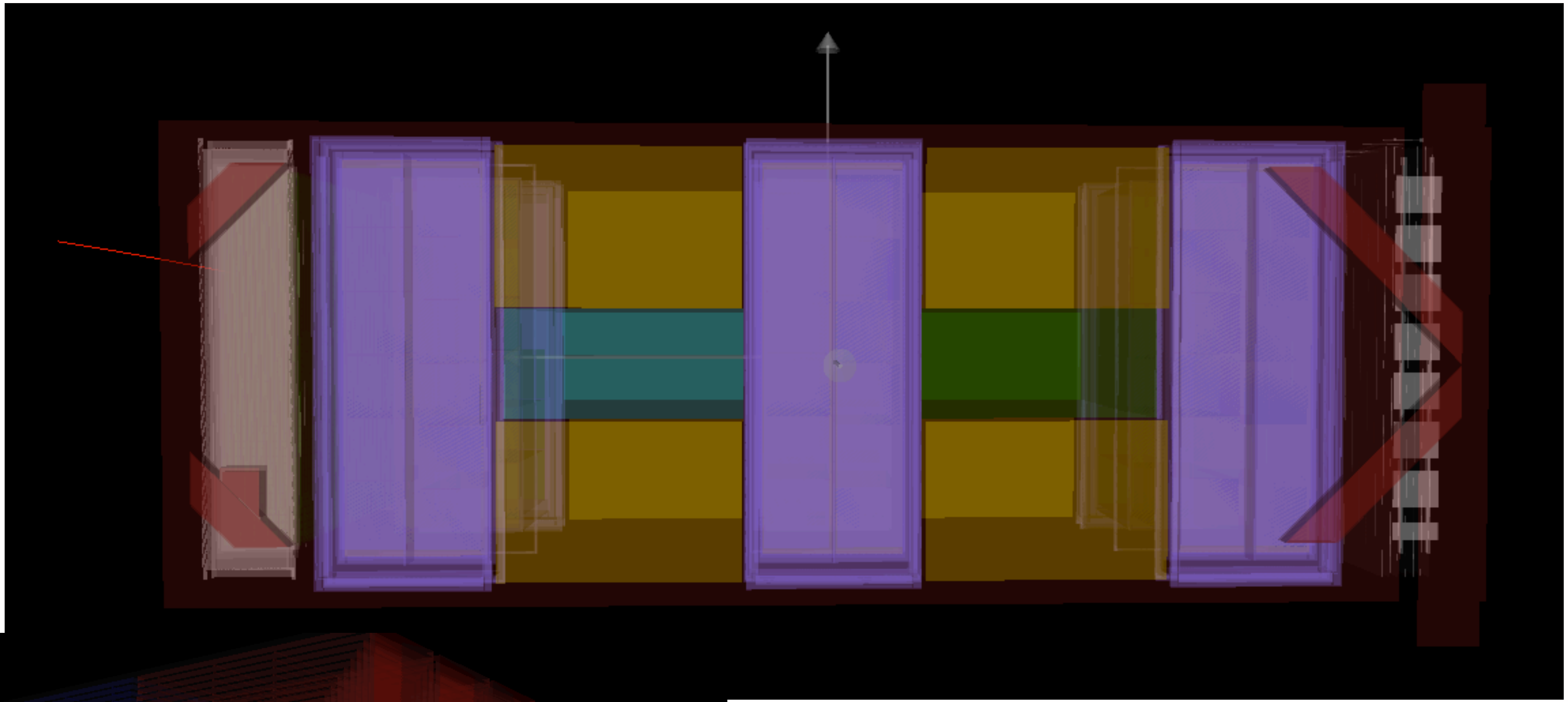
- Barrel-ECal:
  - 31 layers
- P0D-ECal:
  - 7 layers

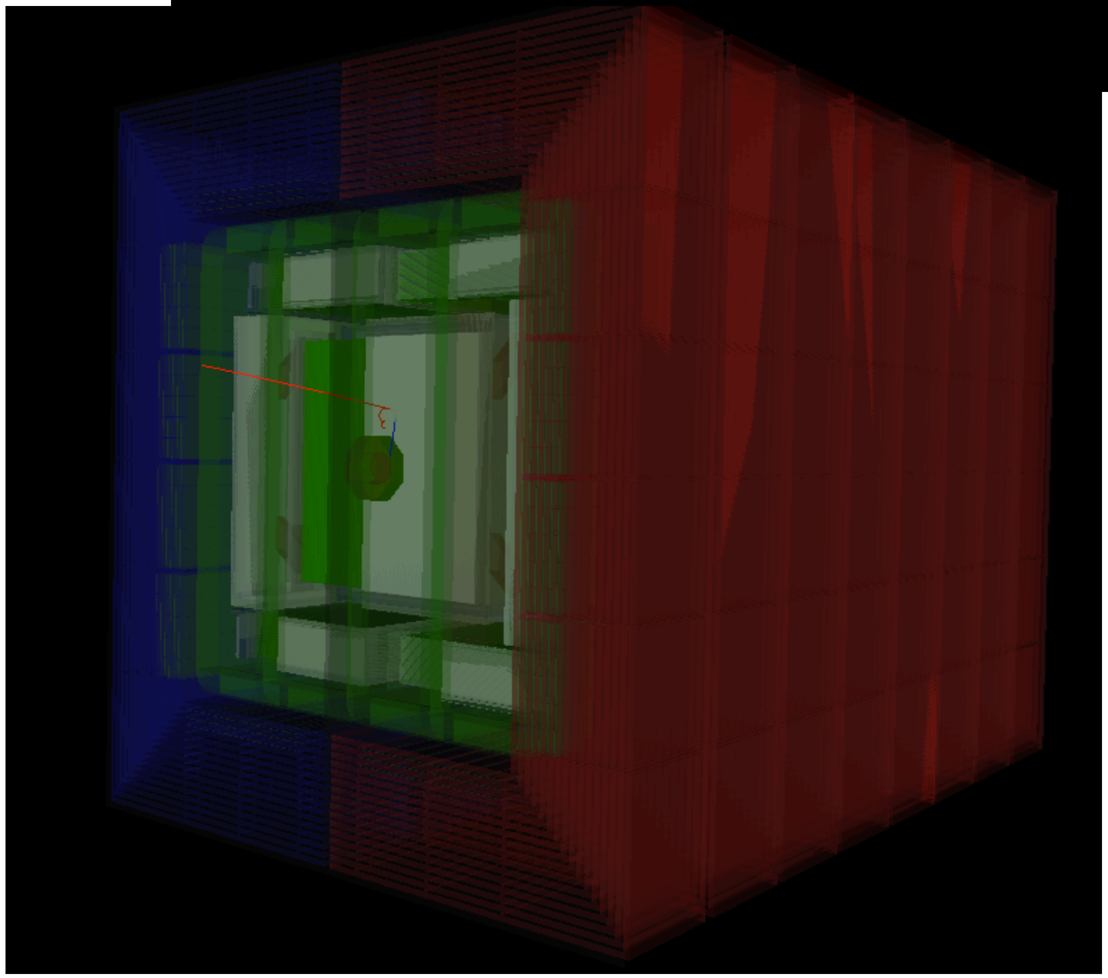




- P0D-ECal has only Y bars: no tracking
- Gap between Barrel-ECal and P0D-ECal
- Need to understand whether we need XY bars in P0D-ECal through MC studies

The Basket and the magnet





- SMRD embedded in the magnet
- They will be used for Out-Of-FV background
- Not used in the current muon event selection
- Will be important for nue event selection (gamma background)

Alternative ND280 upgrade configurations

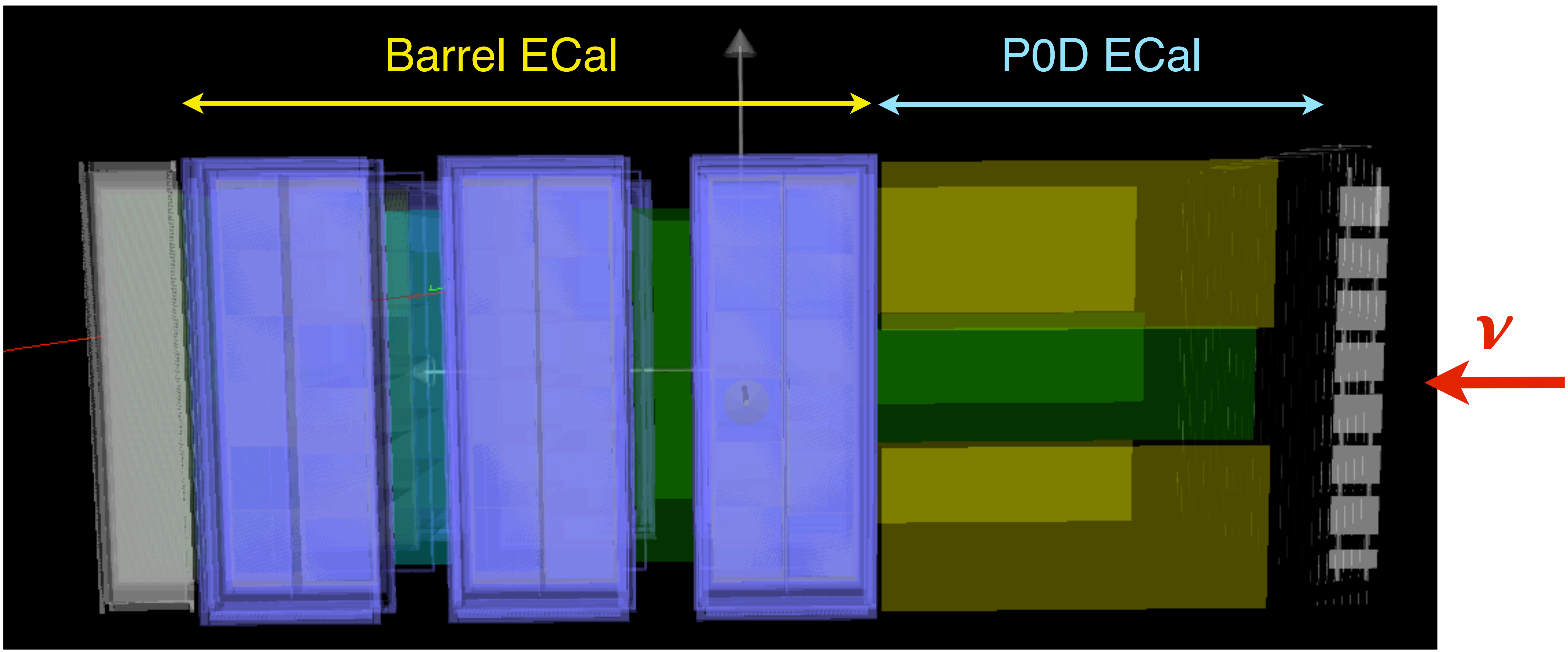
- Studying alternative ND280 upgrade configurations:
  - keep the current tracker and add 1 horizontal target (longer) and 2 TPCs
- Advantages:
  - more mass for neutrino interactions
  - continue to perform very good measurements of the neutrino interactions with particles produced in the forward region
  - perform at the same time precise measurements of high angle tracks
  - no need to move the current detectors (or partially)

	FGD1	Target (reference)	Target (alternative)
Width (mm)	1864.3	1864	1864
Height (mm)	1864.3	600	600
Length (mm)	303	1300	1994
Mass (tons)	1.09	1.45 (0.45)	2.23 (0.67)

	Total Mass (tons)
Current	2.18
Reference	1.90
Alternative	4.41 (2.85)

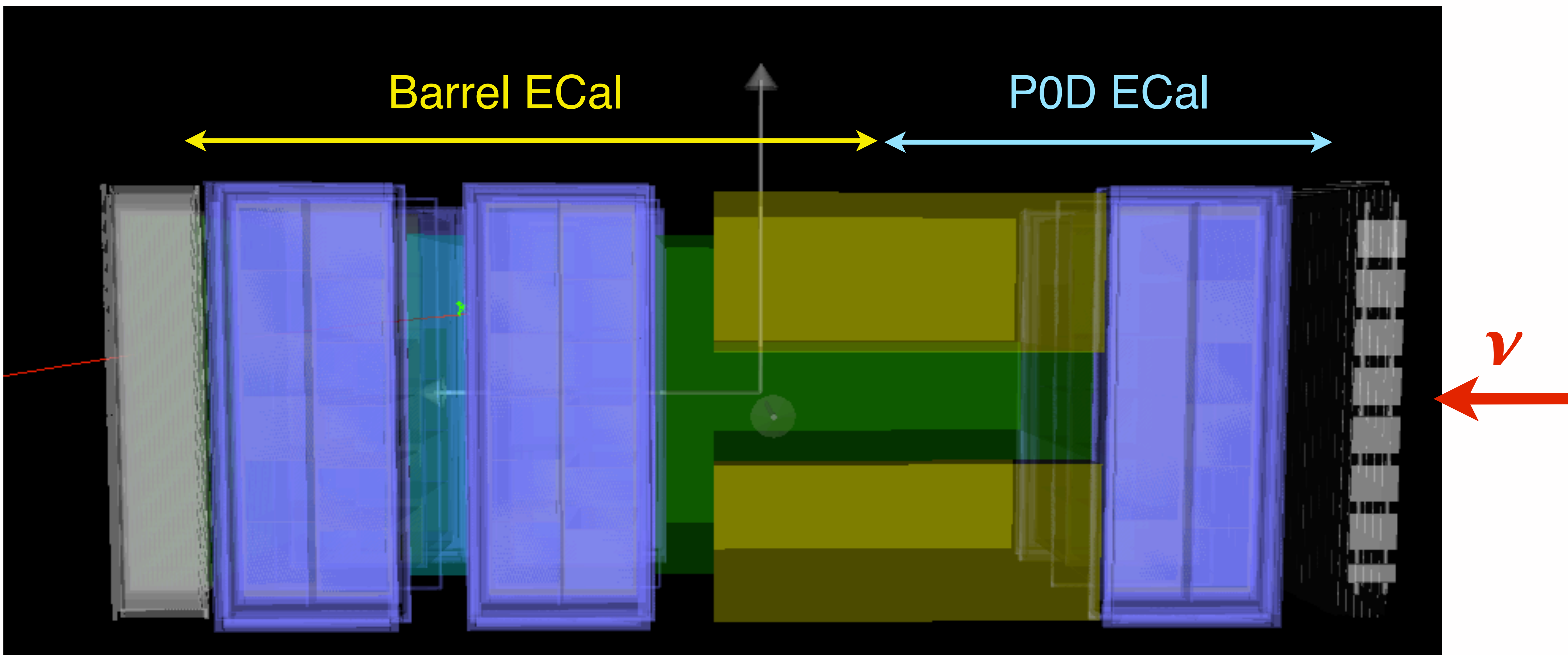
Alternative configurations (Target->TPC)

- Advantages:
  - no need to move the current tracker
  - replace the P0D (expect USECal-P0D) with the horizontal tracker
  - no gap in the middle of the horizontal target
- Disadvantages:
  - worse backward efficiency in horizontal target but backward sample with FGDs



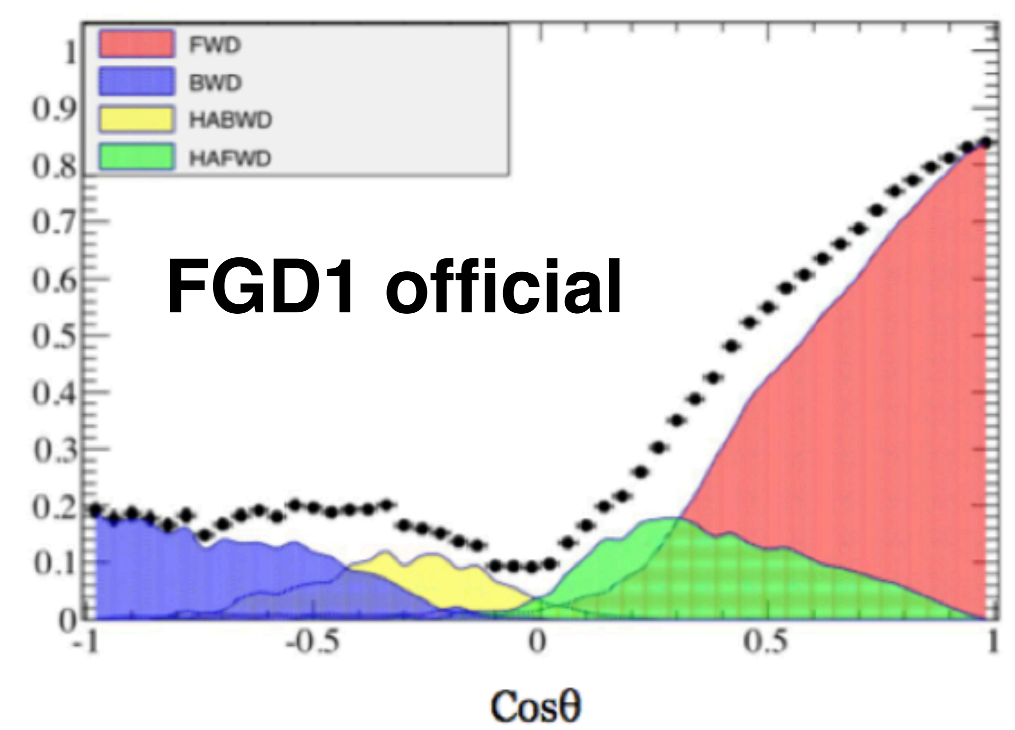
Alternative configurations (TPC->Target)

- Advantages:
  - better backward efficiency in horizontal target but still not good as FGD since it's ~2m long
- Disadvantages of alternatives:
  - need to move 1 vertical TPC
  - gap in the middle of the horizontal target
  - slightly worse forward efficiency: FGD1 before the TPC
  - worse backward efficiency in FGD1



Time of Flight

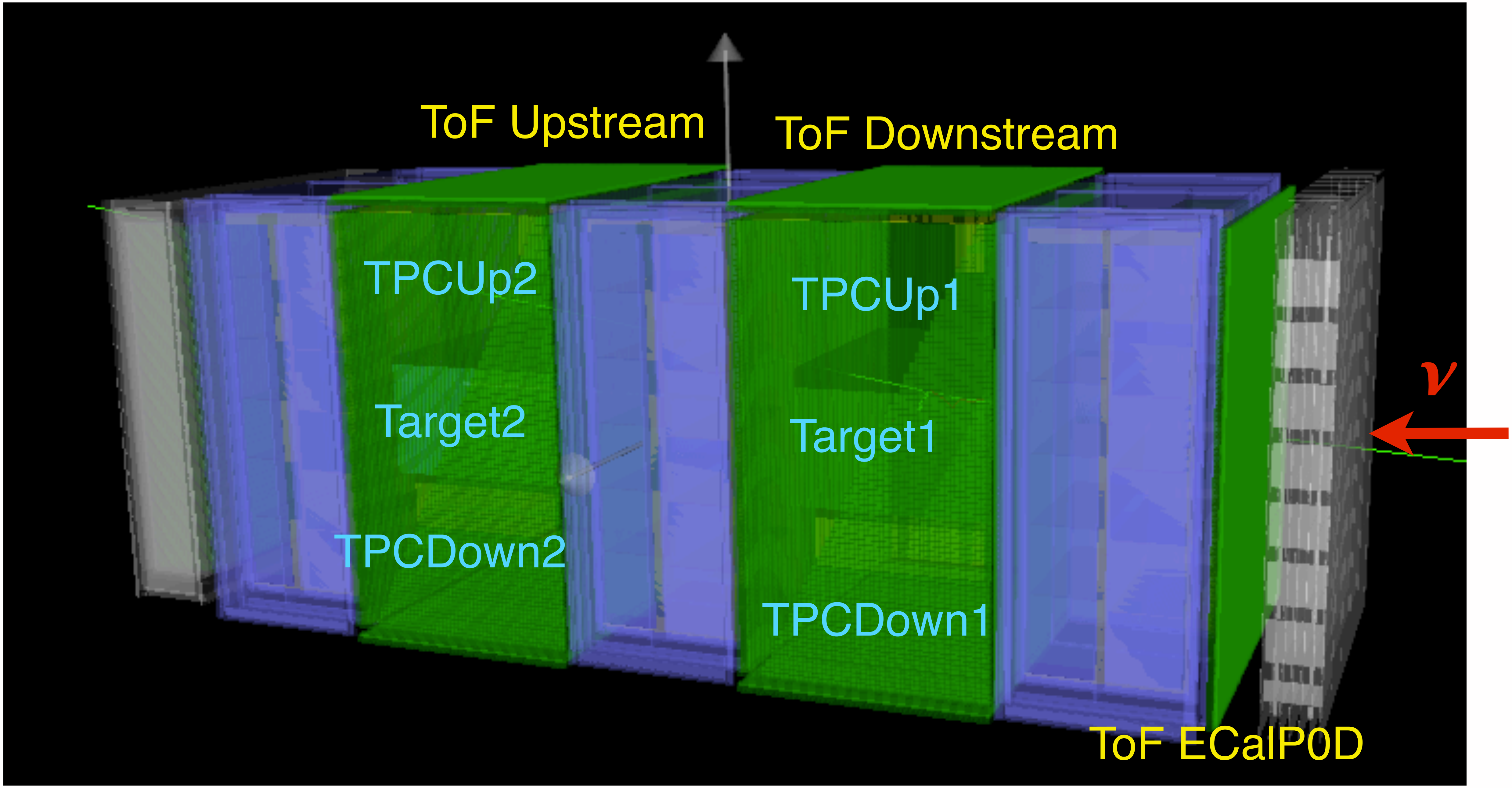
- Bad backward reconstruction at ND280



- ToF detectors will provide timing for most of the tracks and PID for protons (see Tatiana's talk)
- Flexibility in the framework to enable/disable the several ToF detectors, define the size, the # of plastic scintillator bars, the cross section of each bar, rotation, etc...
- Use the following scintillator bar dimensions:
  - 2 layers to measure XY
  - cross section: 25 (width) x 25 (height) mm^2
- Scintillator bars simulated as rectangular bar with WLS fiber (same as ECal)

ToF in reference configuration

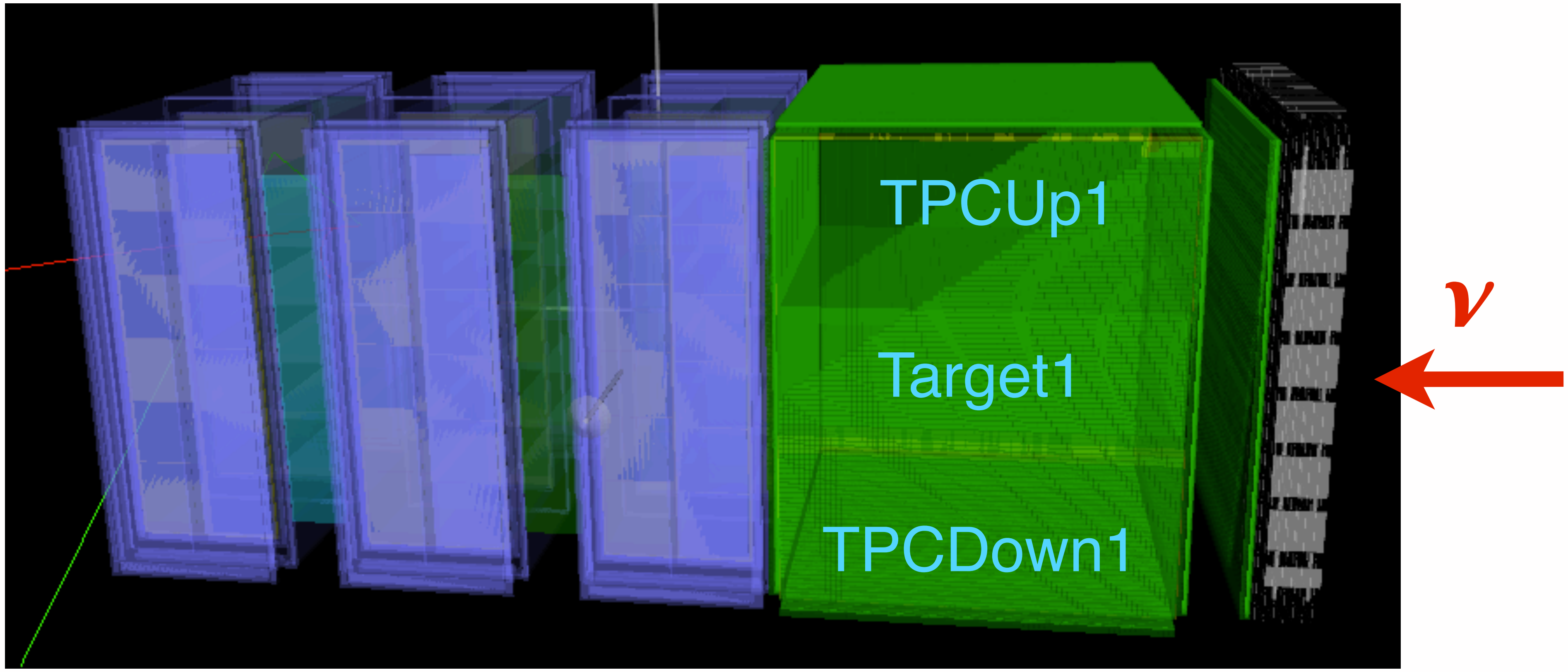
- ND280 upgrade reference configuration

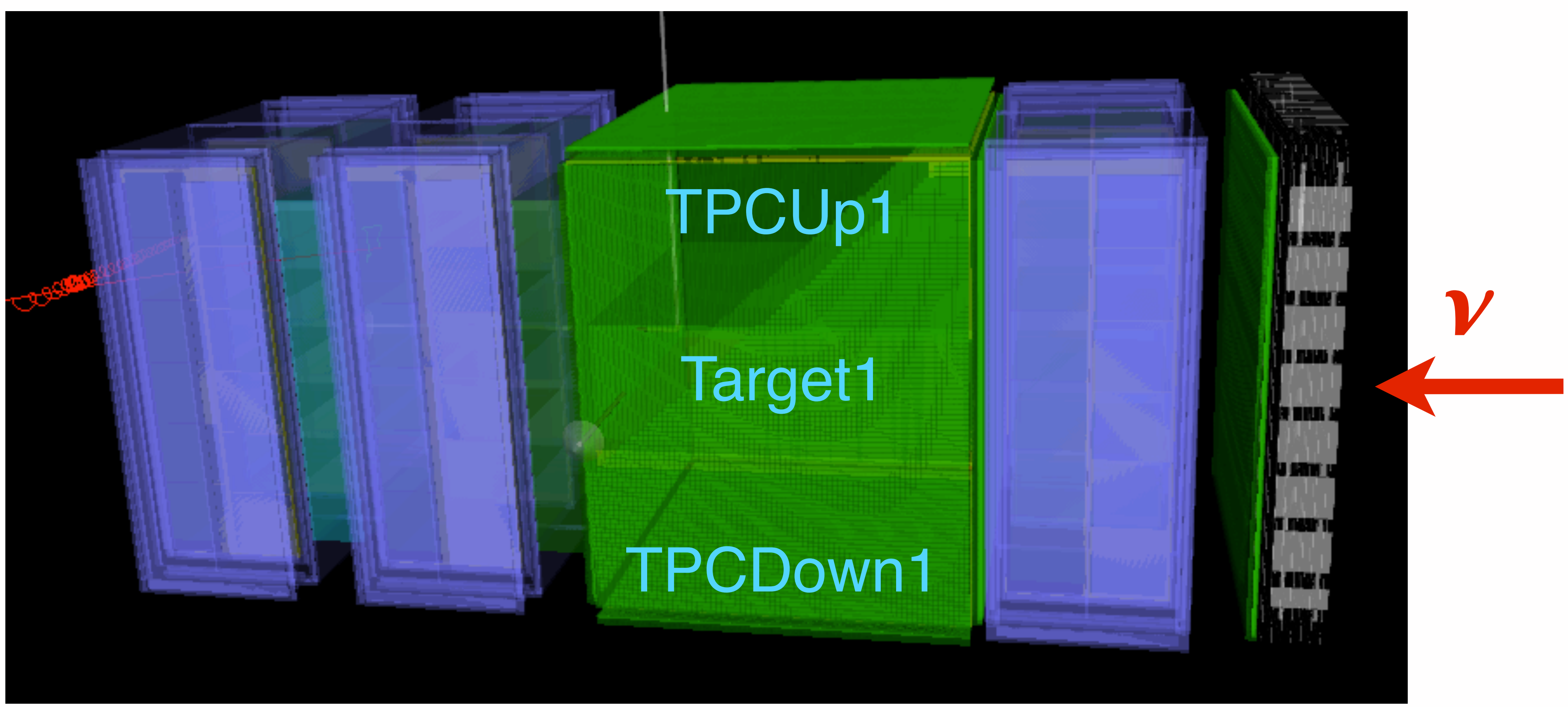


- 6 ToFs around the tracker (Top, Bottom, Right, Left, Back, Front)

- 1ToF next to ECal-P0D

ToF in Alternative configurations



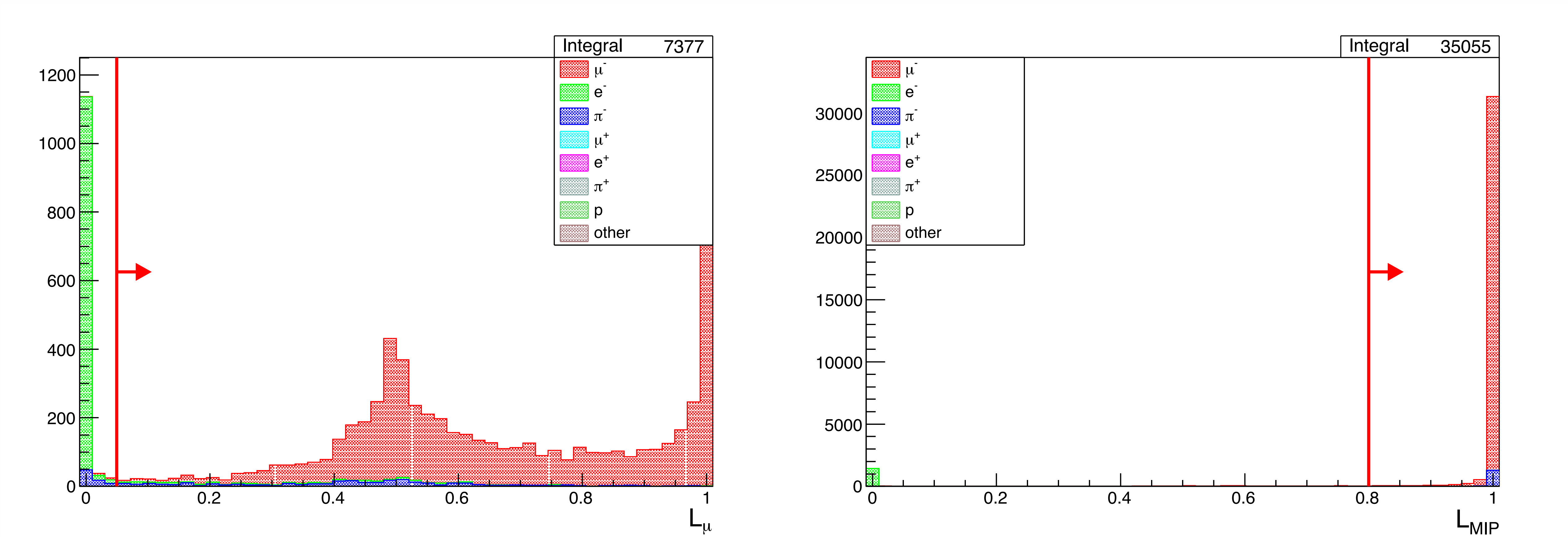


Reconstruction of TPC informations

- Take the true dE/dx from the simulation and smear with standard formulas
  - need true track length, deposited energy and momentum in TPC

Bethe-Block parametrized with fit of ND280 data (TN-01)

$$\delta = \frac{\frac{dE}{dx}(p)_{exp} - \frac{dE}{dx}(p)_{meas}}{\sigma_{\frac{dE}{dx}}}, \quad i = e, \mu, p, \pi \qquad \mathcal{L}_i = \frac{e^{-\delta_i^2}}{\sum_i e^{-\delta_i^2}}$$



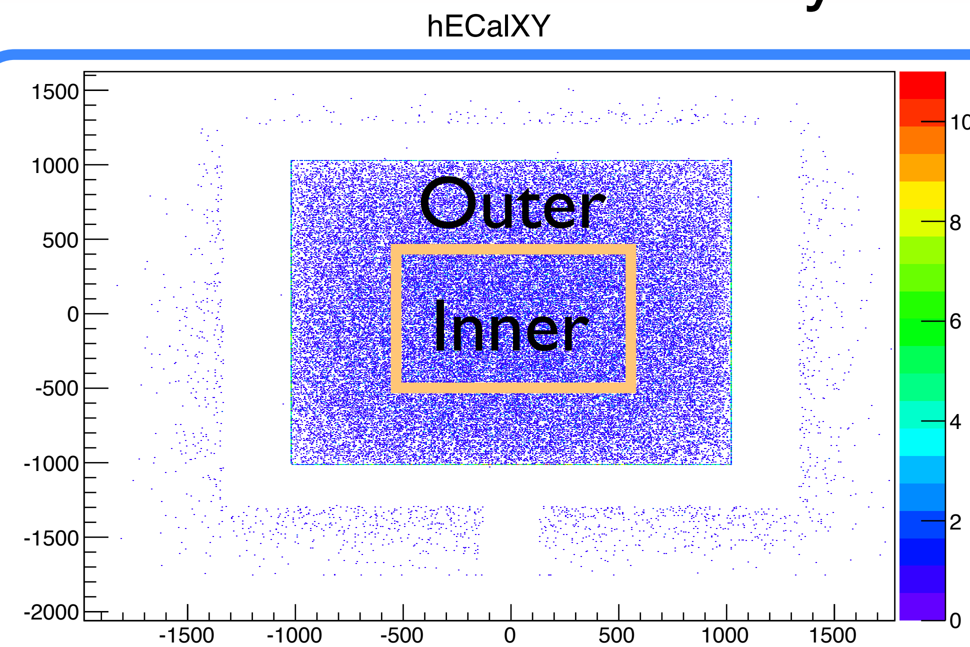
- Assume a track reconstructed in the TPC is projection on YZ plane (read-out) is higher than 20cm (consistent with 18 clusters in TPC)

Pseudo-reconstruction of ECal informations

- Use same variables as in the official ND280 analyses

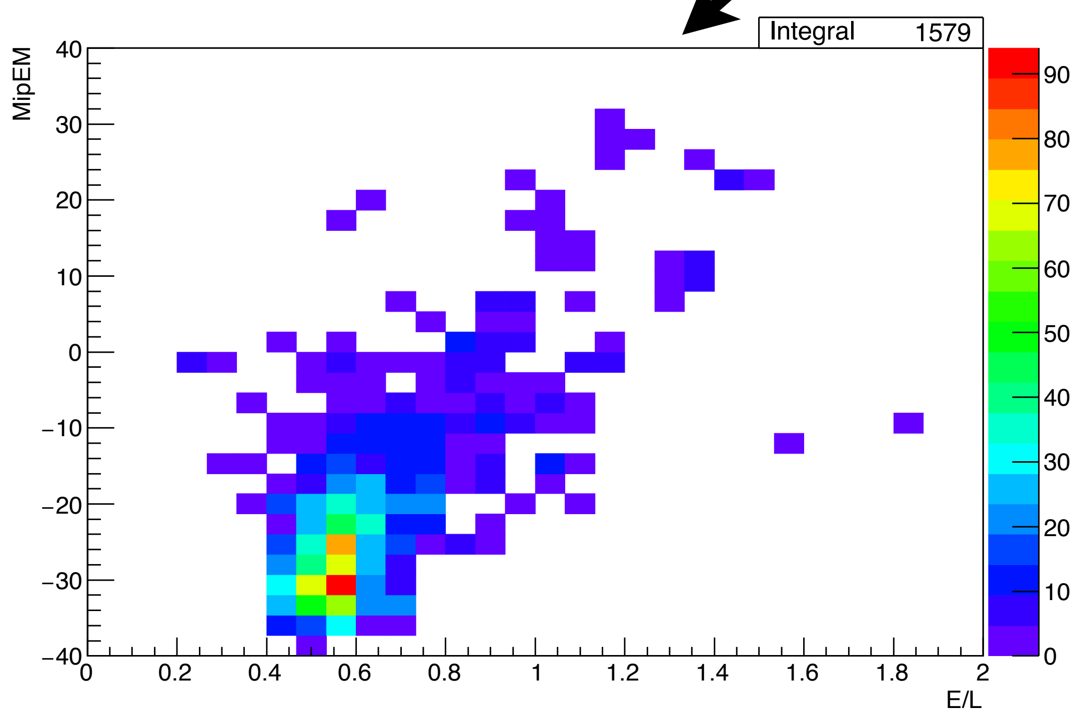
Select muon entering ECal in ND280up GEANT4

Take true ECal entrance {p,cosθ}



p (GeV):0,0.4,0.6,0.8, 1,1.2,1.5,2,30

cosθ: -1,-0.5,0,+0.5,+1



Random sampling:
- {EMenergy/length}$_{reco}$
- {MIPem}$_{reco}$

Apply cuts defined in TN-245 (or optimized for ND280upgrade)

- Random sampling based on ~50% reconstruction and ~50% FGD-ECal matching efficiency is applied (same values as evaluated with ND280 data)
- Using DsECal parametrization. ECal group will provide particle guns soon

Conclusions

- Simulation of the full ND280 current detectors is available

- Finalizing integration of WAGASCI detector in the framework, then study alternative neutrino target detectors. Find optimal requirements

- Preliminary ToF studies: need to understand the time resolution we need for track reconstruction, PID and rejection of Out-of-FV

BACKUP

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)

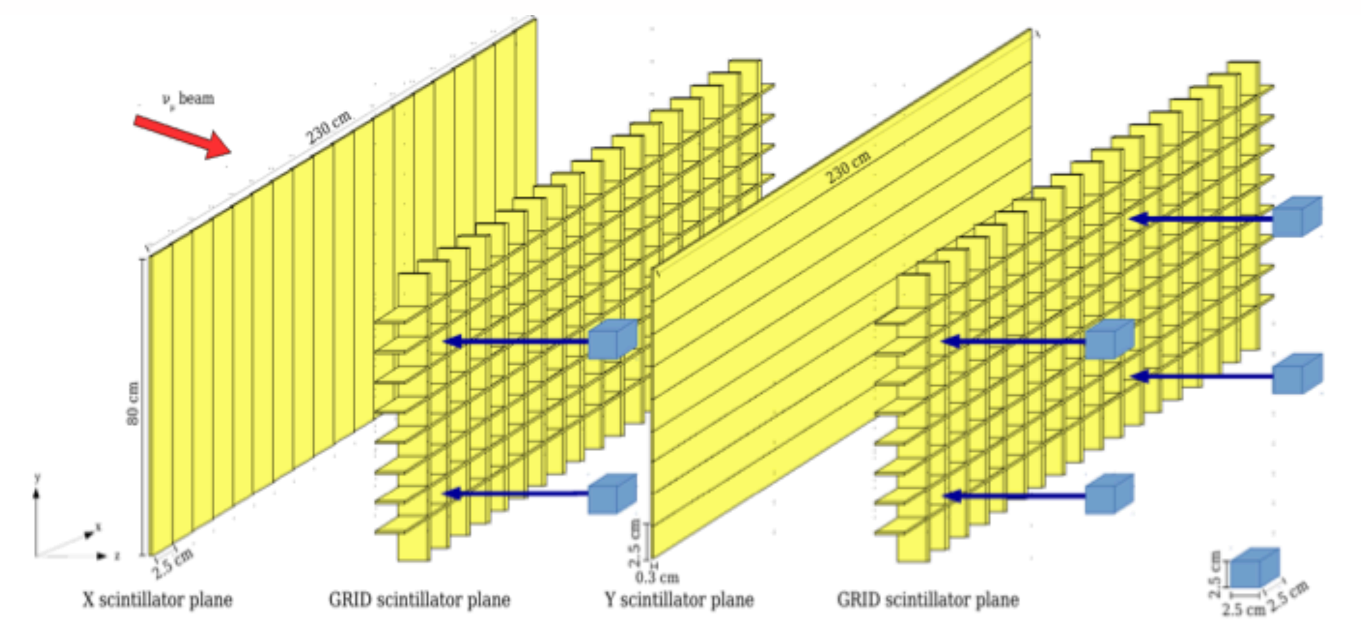
• Analysis done with truth informations

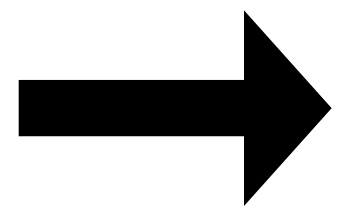
• Framework is different from what is used for the WAGASCI simulation: merging will be done in the upcoming weeks

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



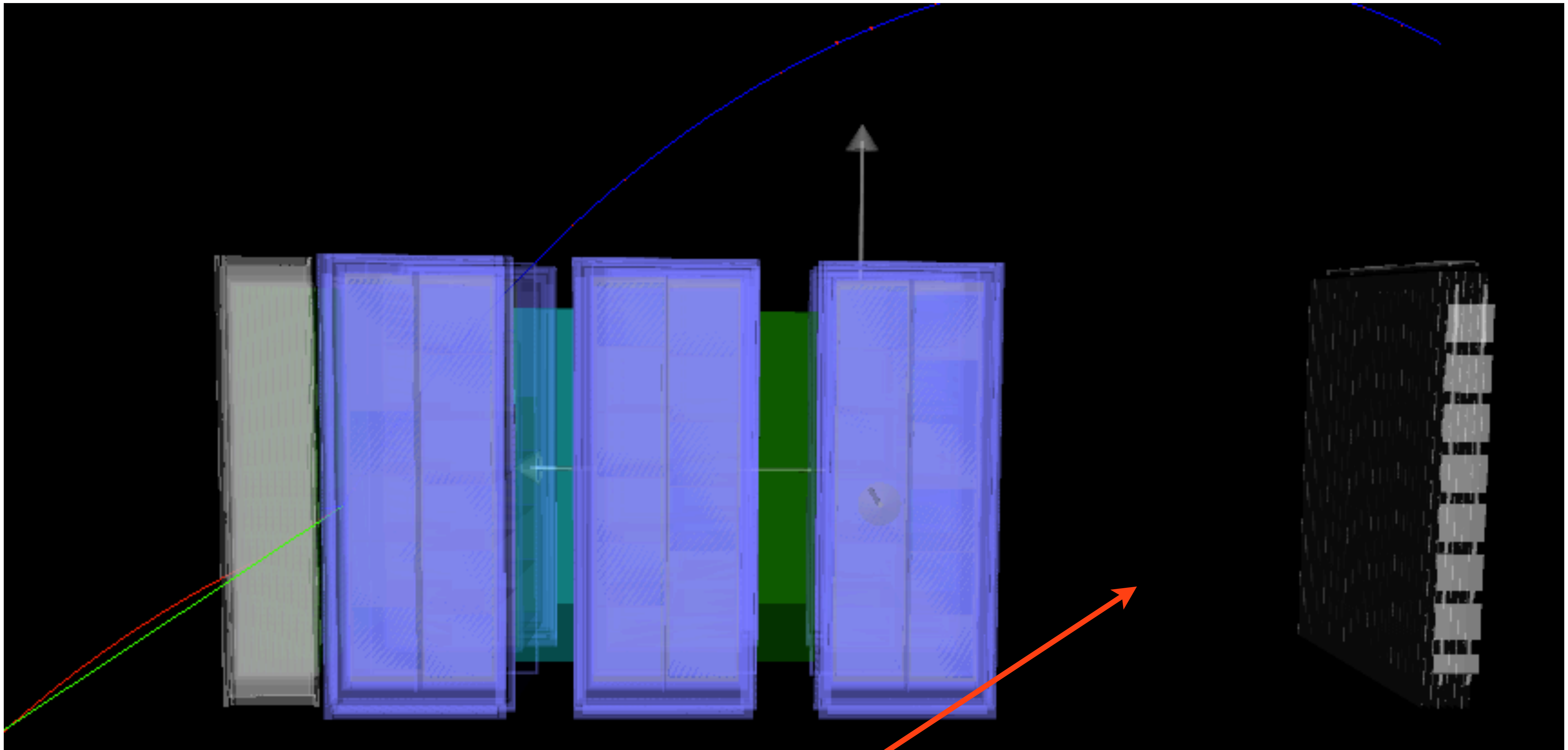


Simulate WAGASCI as a target of uniform material

• 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 current-like



- This space is for the P0D
- Full P0D can be included easily, but maybe not needed

Reconstruction of TPC informations

- Take the true dE/dx from the simulation and smear with standard formulas

$$\frac{dE}{dx}(p_{true}) = \frac{e_0}{\beta^{e_3}}\left(e_1 - \ln\left(e_2 + \frac{1}{(\beta\gamma)^{e_4}}\right)\right)$$

e_0	785 ADC
e_1	6.047
e_2	0.00064
e_3	2.308
e_4	1.359

$$\sigma(p) = p\sqrt{\left(\sqrt{\frac{720}{N+4}}\frac{\sigma_x p \sin\theta}{0.3BL^2}\right)^2 + \left(\frac{0.2}{\beta B\sqrt{X_0 \sin\theta}}\right)^2}$$

$$\sigma_{\frac{dE}{dx}} = \sqrt{\left(0.08\sqrt{\frac{72}{L\sin\theta}}\frac{dE}{dx}\right)^2 + \left(\frac{dE'}{dx}(p)\sigma_p\right)^2}$$

Bethe-Block parametrized with fit of ND280 data (TN-01)

$$\delta = \frac{\frac{dE}{dx}(p)_{exp} - \frac{dE}{dx}(p)_{meas}}{\sigma_{\frac{dE}{dx}}}, \quad i = e, \mu, p, \pi$$

$$\mathcal{L}_i = \frac{e^{-\delta_i^2}}{\sum_i e^{-\delta_i^2}}$$

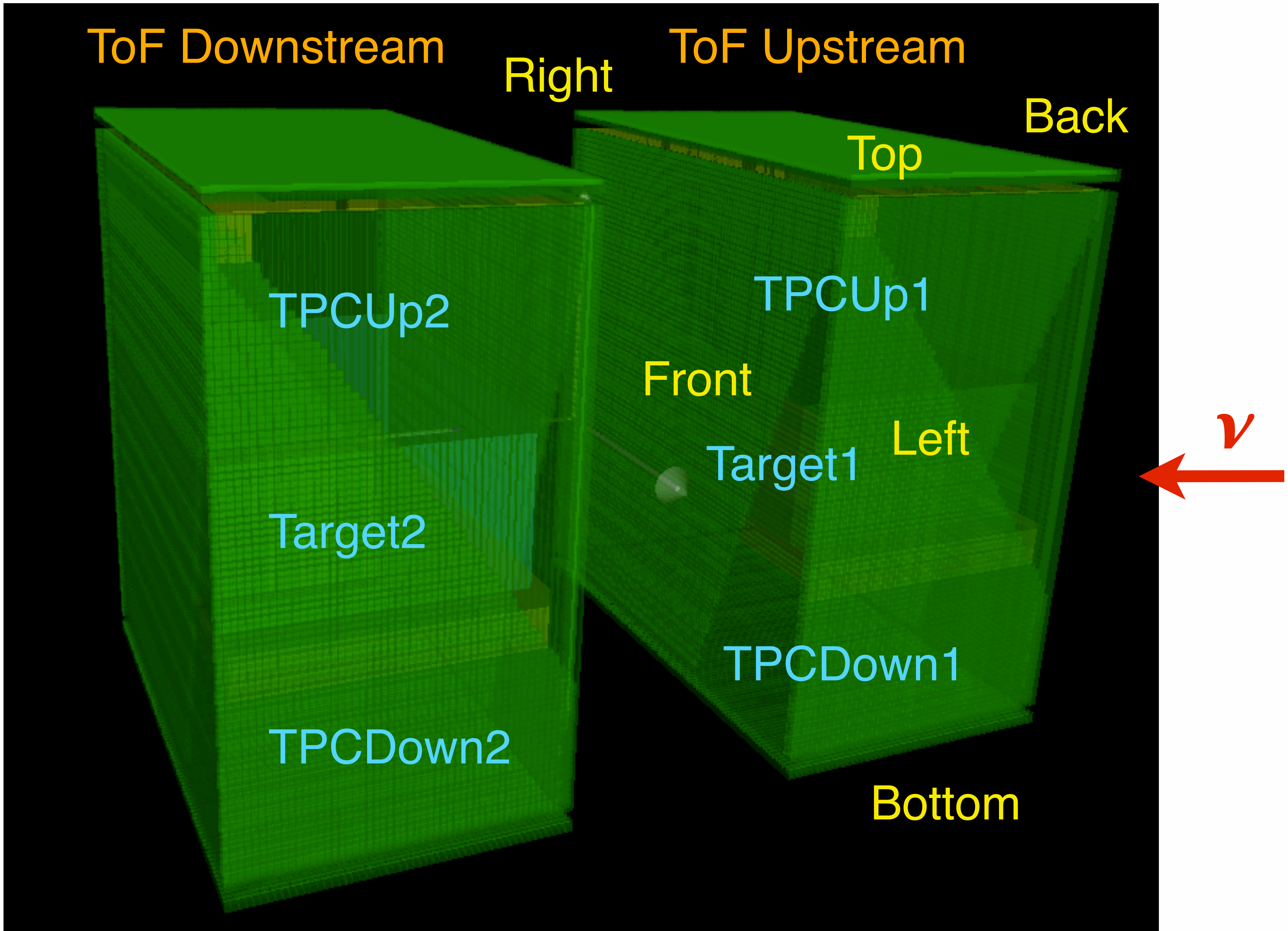
ECal efficiencies

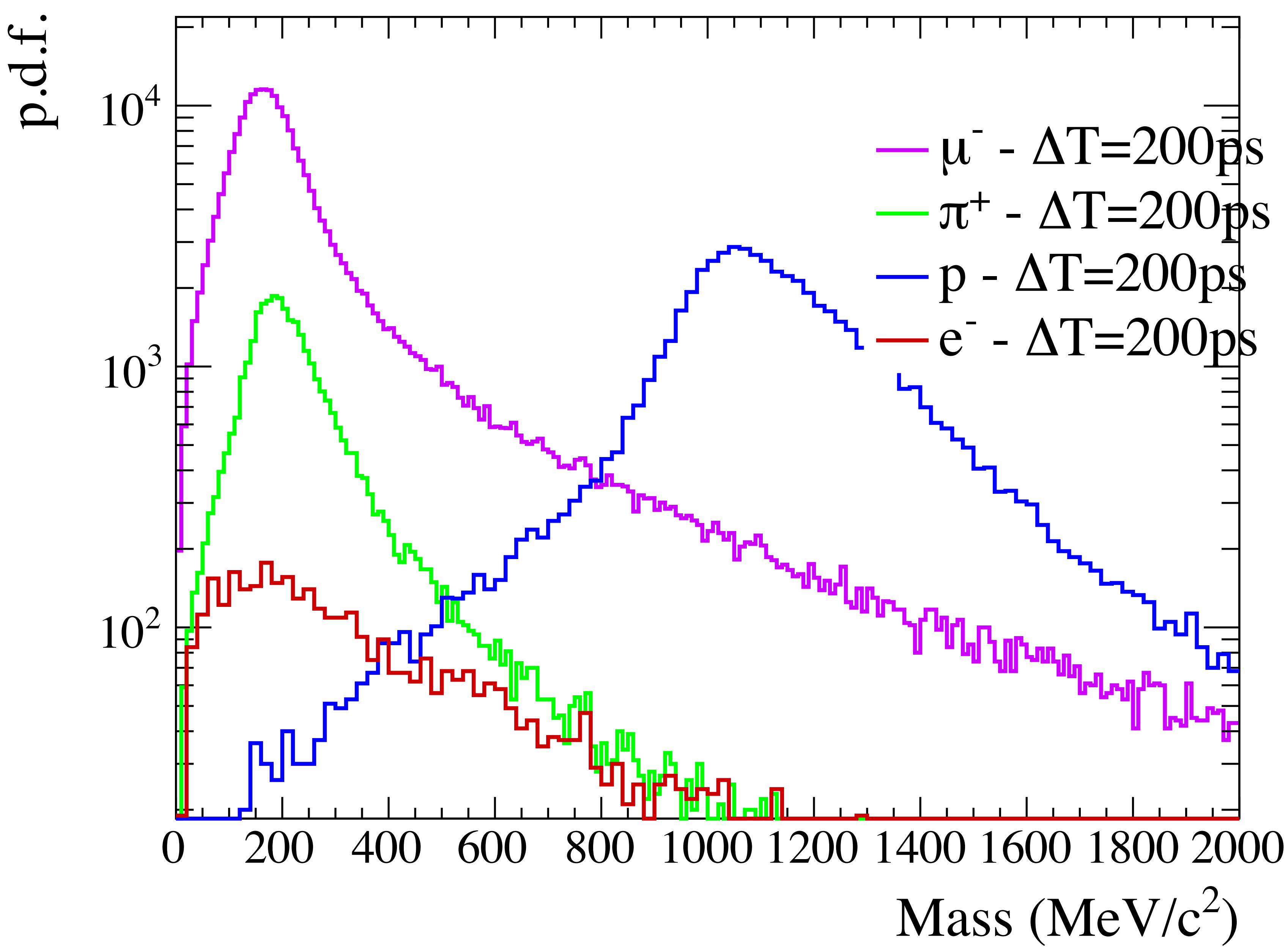
The upgrade framework does not have full ECal reconstruction (building a track from the hits).

- We take all the true tracks reaching ECal
- We apply ECal efficiencies on it:
  - $\varepsilon_{reco} \sim 30\%$ for $0 < p_\mu < 300$ MeV/c
  - $\varepsilon_{reco} \sim 50\%$ for $300 < p_\mu < 900$ MeV/c
  - $\varepsilon_{reco} \sim 40\%$ for $p_\mu > 900$ MeV/c
- Same thing is done for FGD-ECal matching efficiencies (we assume same for Target-ECal matching)
- Muon is asked to stop in ECal to reconstruct momentum-by-range

ND280 upgrade reference

- For each target we have 6 ToFs, that cover the tracker like a box




p.d.f.
10^4
10^3
10^2
0
200
400
600
800
1000
1200
1400
1600
1800
2000
Mass (MeV/c^2)
μ^- - ΔT=200ps
π^+ - ΔT=200ps
p - ΔT=200ps
e^- - ΔT=200ps