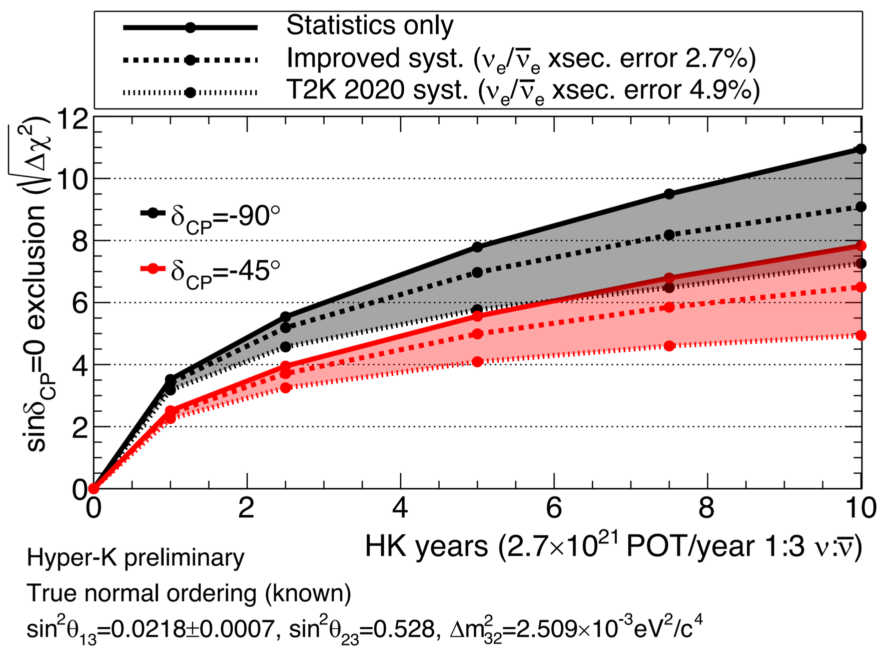
The Intermediate Water Cherenkov Detector for the Hyper-Kamiokande Experiment

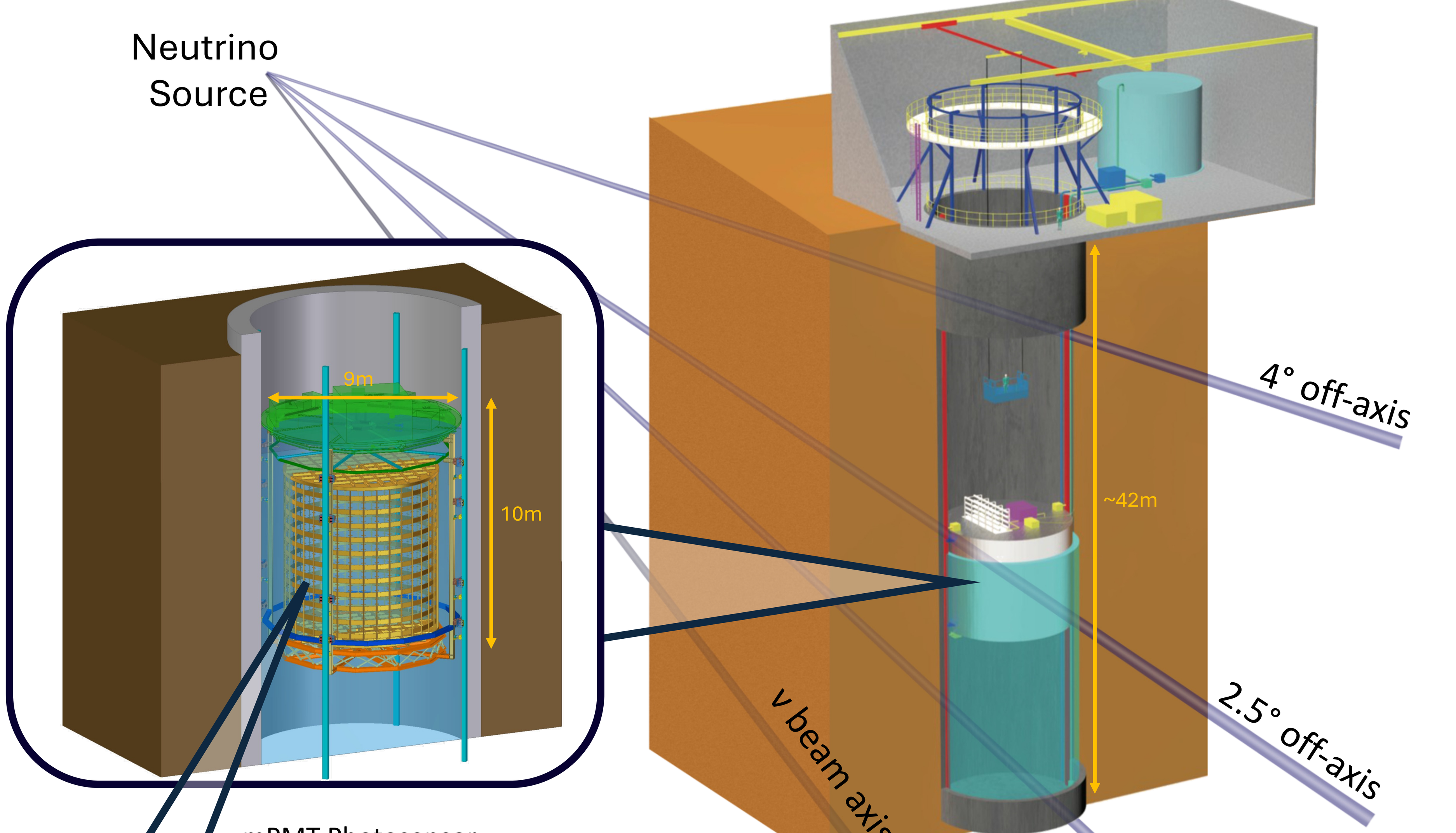
Laurence Cook, lcook@triumf.ca, TRIUMF
On behalf of the IWCD group and Hyper-Kamiokande Collaboration

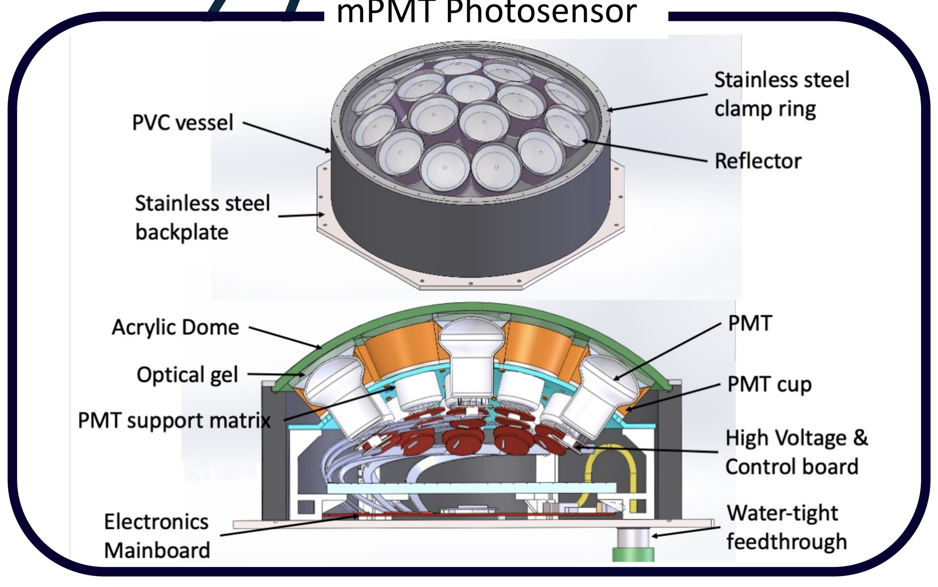
Hyper-Kamiokande

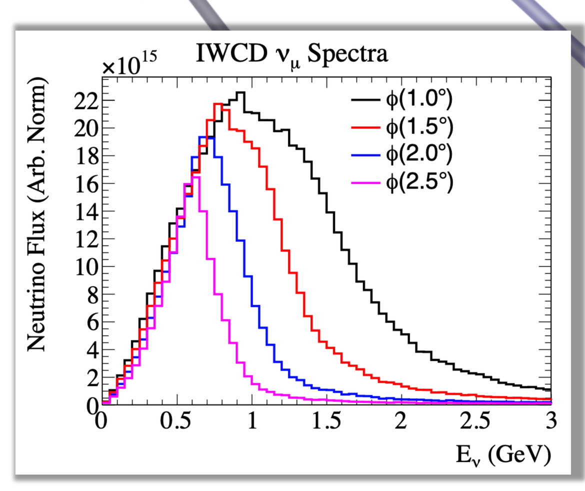
- Wide ranging physics program including: **atmospheric neutrinos, proton decay** searches, **long baseline accelerator neutrino oscillation, solar neutrinos, astrophysical neutrinos**
- Precision measurement of oscillation parameters
- **1.6x more powerful beam** and **8.4x larger fiducial volume** far detector than T2K



- CP violation measurement limited by systematic uncertainty within a few years of operation
- Need to understand and reduce systematic uncertainties to achieve measurement



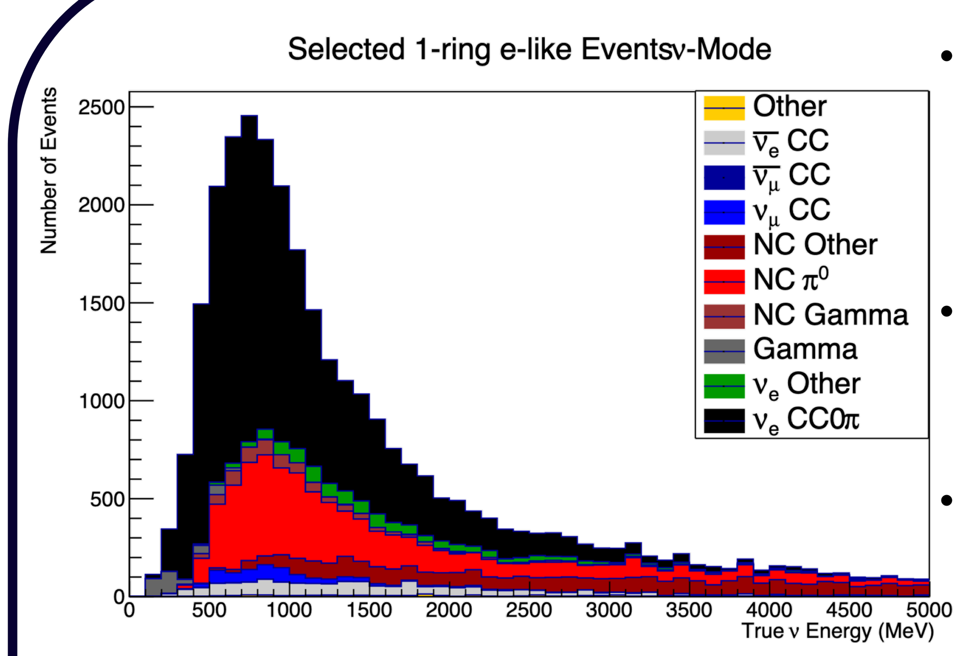




IWCD: A Movable Intermediate Detector

- **Intermediate Water Cherenkov Detector** ~850m from the neutrino source
- Make measurements with the neutrino flux before oscillations
  - In addition to the upgraded **ND280** and **INGRID** near detectors
- Water Cherenkov detector, same as the far detector
  - Can study neutrino interactions on the **same material (water) as far detector**
- Due to kinematics of pion and muon decay, the detector can sample different neutrino energy distributions by varying its vertical position
- **Outer detector** to reduce background from entering particles and tag events which aren't fully contained

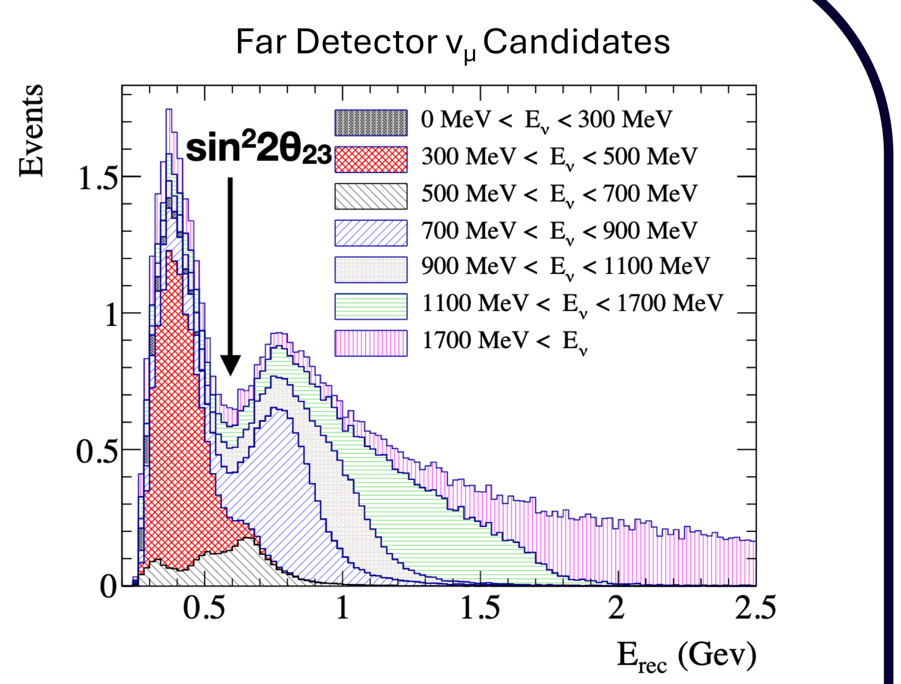
Electron Neutrino Cross Section Measurement

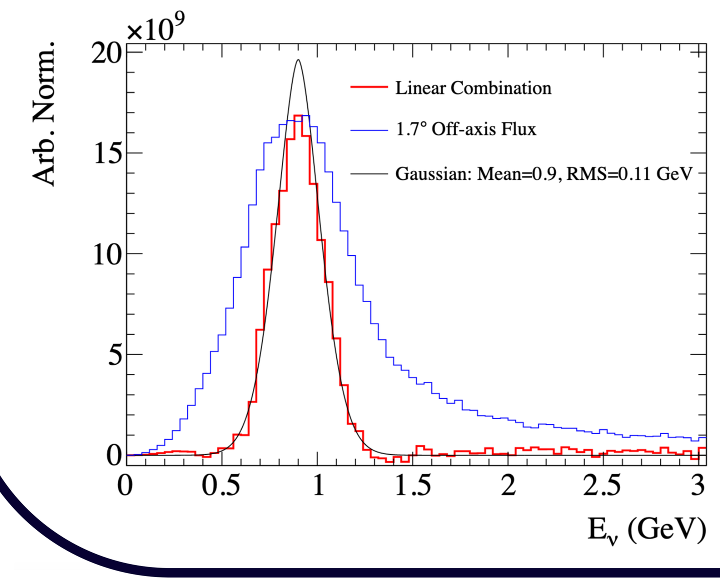


- CP violation measurement by comparing $\nu_\mu \to \nu_e$ oscillations with $\bar{\nu}_\mu \to \bar{\nu}_e$ oscillations at the far detector
- Uncertainty on ratio of $\sigma(\nu_e)/\sigma(\nu_\mu)$ to $\sigma(\bar{\nu}_e)/\sigma(\bar{\nu}_\mu)$ is the most significant uncertainty for CP violation
- IWCD can measure these ratios by measuring the **intrinsic, unoscillated 1% of ν_e** in the neutrino beam
- **Gammas** have similar signature to **electron** event since both **electromagnetically shower** in the detector
  - IWCD **outer detector (OD)** can veto events originating outside the detector
- Additionally introducing **cuts on fiducial volume** limits background from **gammas entering the inner detector (ID)**

Using data at different off-axis angles

- Neutrino energy reconstruction challenging as not all final state particles seen by the detector
  - Important as **oscillation is a function of energy**
- Reconstruction assumes quasi-elastic scattering
  - Non-quasi-elastic events reconstructed as lower energy, **feed-down effect**
- Use the different fluxes at **different off-axis** angles to study **relationship between reconstructed and true energy**

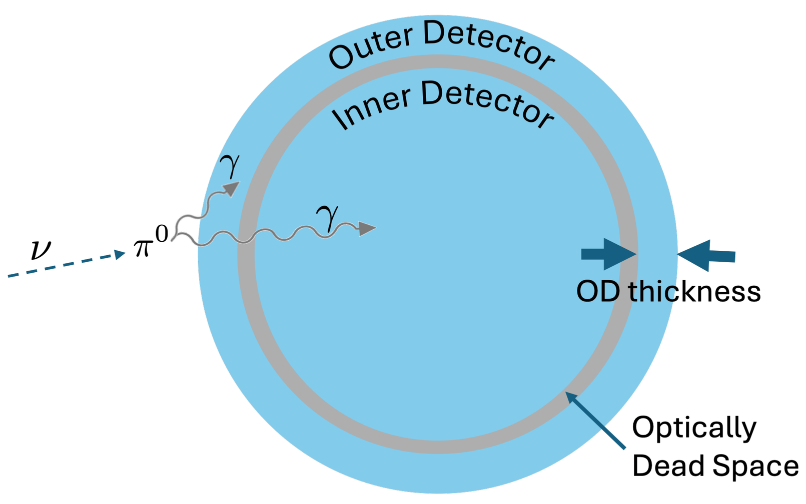




- **Linear combinations** of different off-axis fluxes can remove tail and produce **narrow peaked flux distribution** to study energy response
- Alternatively produce a linear combination of fluxes to **match the far detector oscillated flux** and study neutrino oscillations with **reduced dependence on neutrino interaction models**

IWCD Outer Detector and External Backgrounds

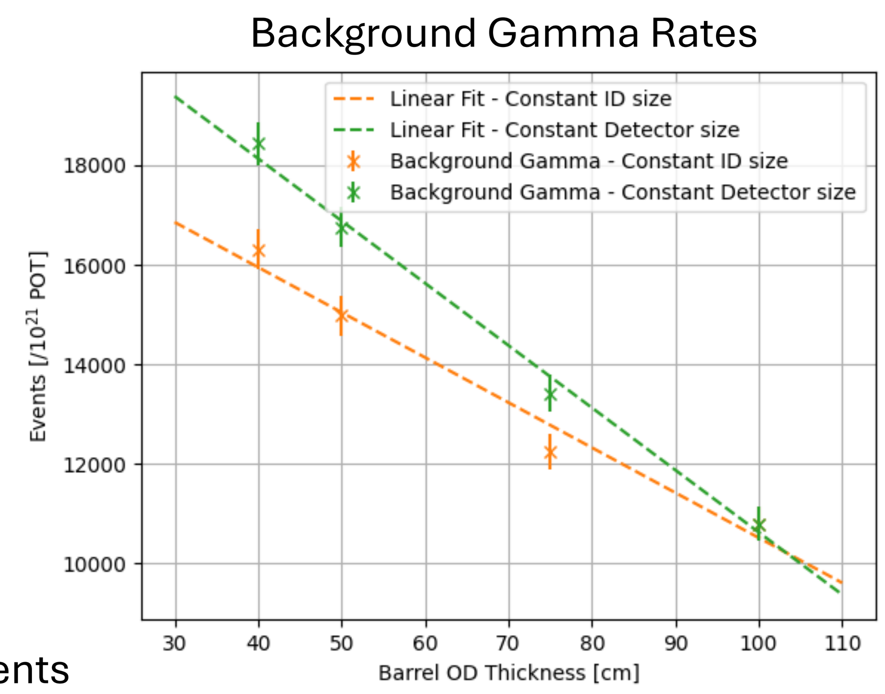
- Beam neutrinos interact in material surrounding the detector
- Daughter particles from these interactions enter the detector
- **Outer detector** used to **veto** these events
  - With a fixed pit diameter **balance** of the **OD size** (veto power) and **ID size** (fiducial volume for neutrino interaction)
- This study focuses on **gammas entering the ID** without the OD veto triggering
  - Not the dominant background the ν_e measurement which is due to NC π^0 interactions
  - Still need to understand how this rate varies with OD thickness as this will influence the design of the OD
- To study this, we simulate interactions of beam neutrinos within IWCD and the material surrounding the detector
  - **NEUT interaction generator** to simulate interactions in the sand outside the detector volume, concrete in the pit and steel and water in the detector volumes
  - GEANT4 simulation to track daughters and **estimate visible energy deposit** in the detector volumes

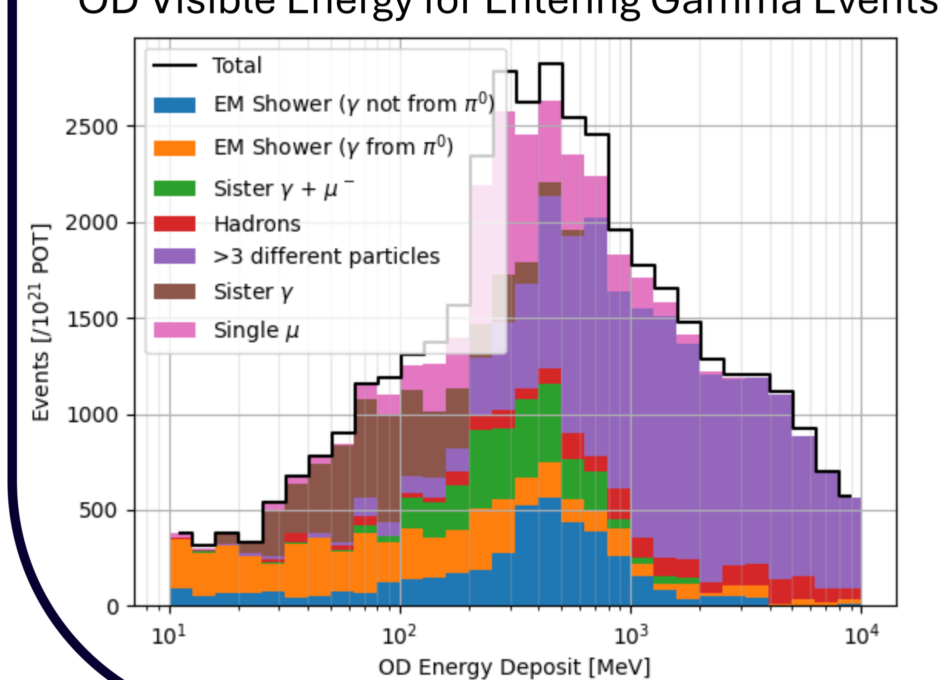


Cross section of IWCD with neutrino event outside the detector and daughter gamma entering the detector

OD Veto of Entering Gammas

- Background gamma event is an event with a **>100 MeV gamma entering ID** with **< 50 MeV visible energy in the OD**
- IWCD at 1.5^0 off axis position
- Rates are shown per 10^{21} incident protons on neutrino production target (POT)
- **Decreasing the OD size** from **1m to 40cm increases the gamma rate** by a factor of **1.7**





- **90% of background gamma** originate in from **π^0 decay**
- Calculate the OD visible energy and breakdown by which particles trigger the OD veto for events where a single gamma enters the ID
- At the 50 MeV OD visible energy threshold the OD visible energy is primarily coming from the sister gamma from π^0 decay (either directly or detecting EM shower)

TRIUMF