Physics impact of LBNF target outer container & support fins

John Back
University of Warwick

23 June 2022

DUNE-doc-25880

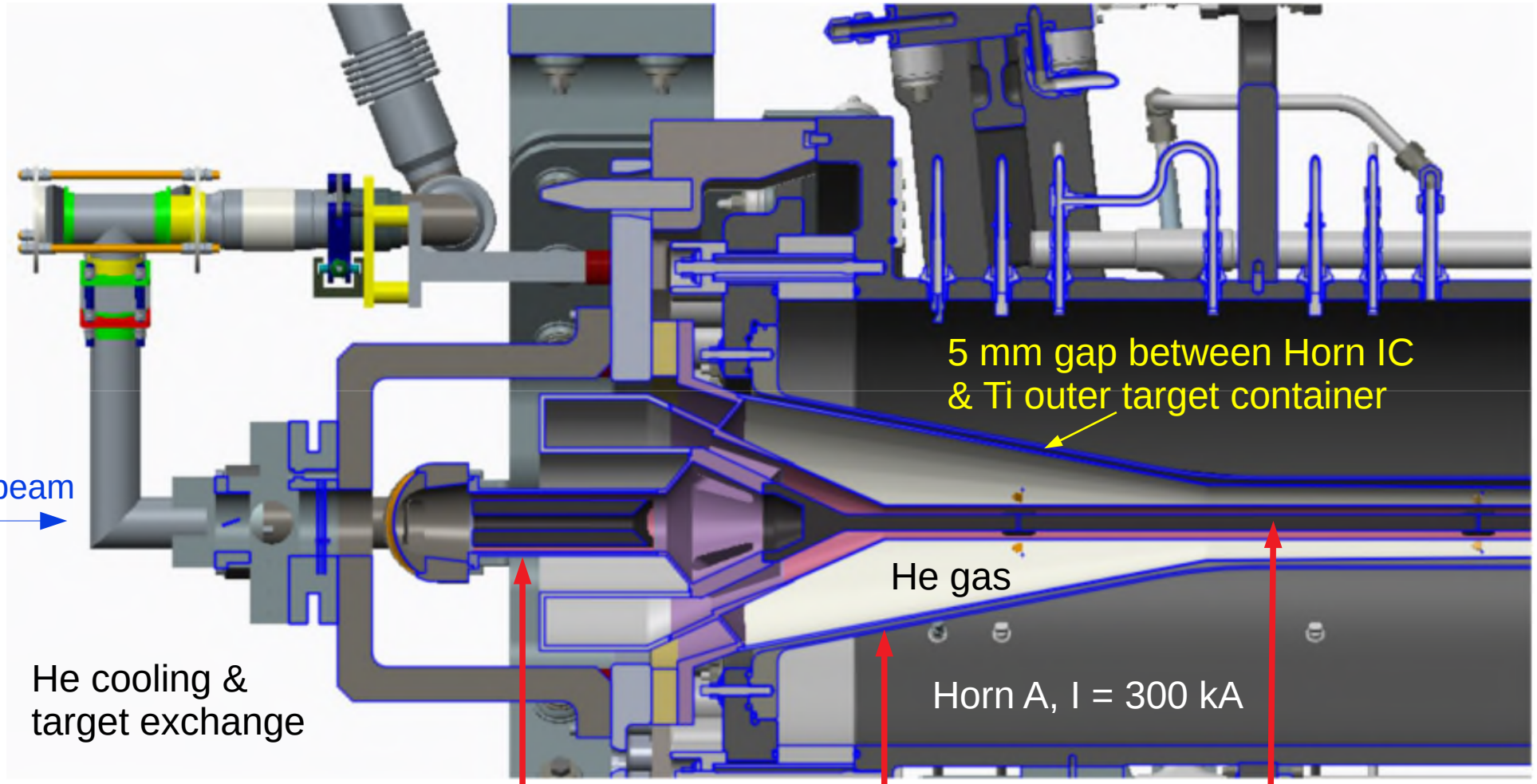
Introduction

- Geant4 simulations of LBNF beamline: **graphite target & 3 focusing horns**
  - **Cantilevered target**, double-cone Ti support structure with He cooling
  - Proton beam: **120 GeV, 1.2 MW**; QGSP_BERT hadronic model
  - Target core: **r = 8 mm**, **L = 1.5 m** (prototype) & **1.8 m** (aspiration)

- Overview of **physics impact** when we vary:
  - **Outer titanium container thickness** (0 to 2.5 mm in 0.5 mm steps)
  - **Amount of material** in the **titanium target support fins** (±45 & ±135 deg)

- Plots of **unoscillated ν signal & bkgnd fluxes** extrapolated to far detector
- Plots of **CP sensitivity & exposure** (run time x far detector 40 kt mass)
  - GLoBES, NuFit 4.0 parameters, normal neutrino mass ordering

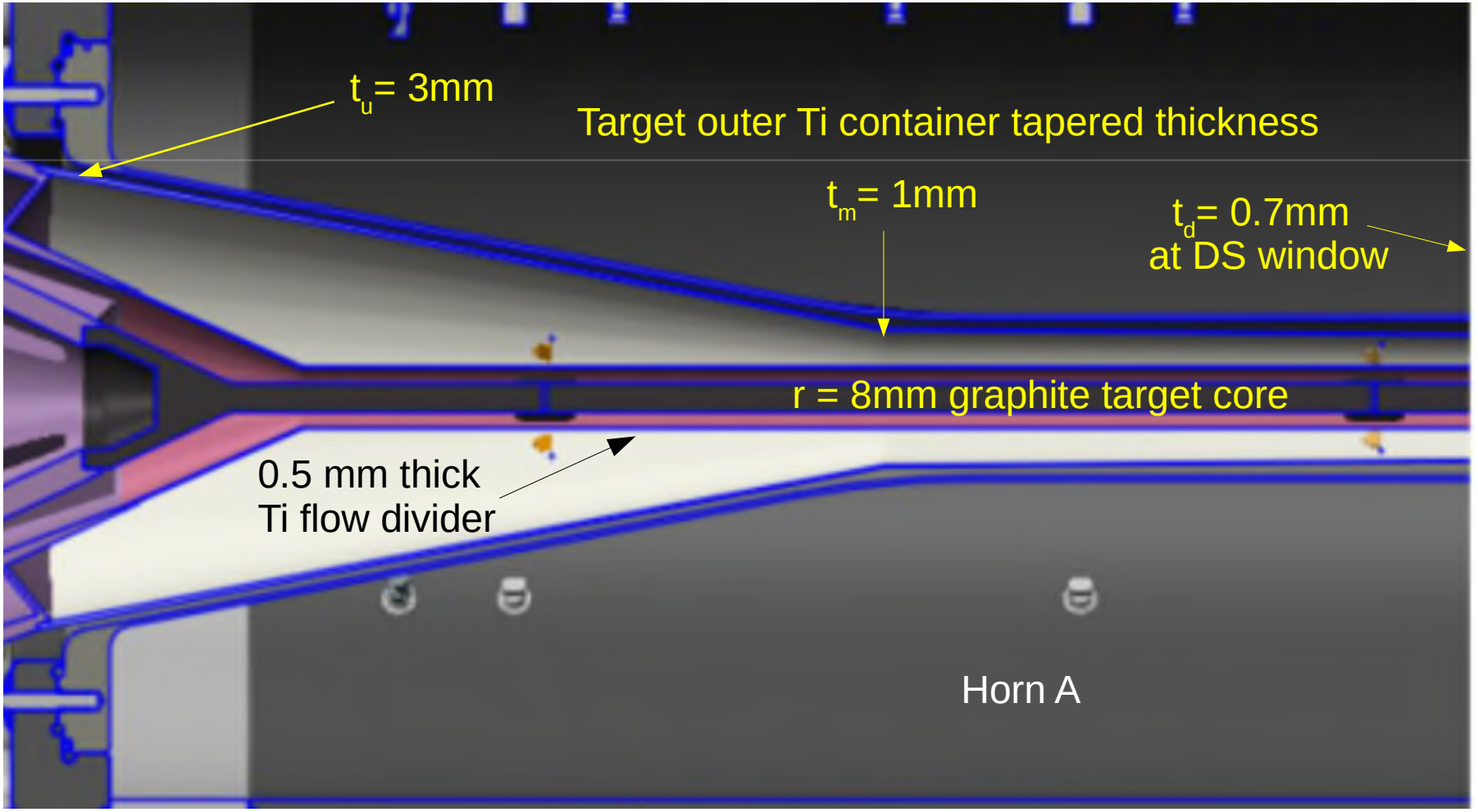
Target and Horn A integration



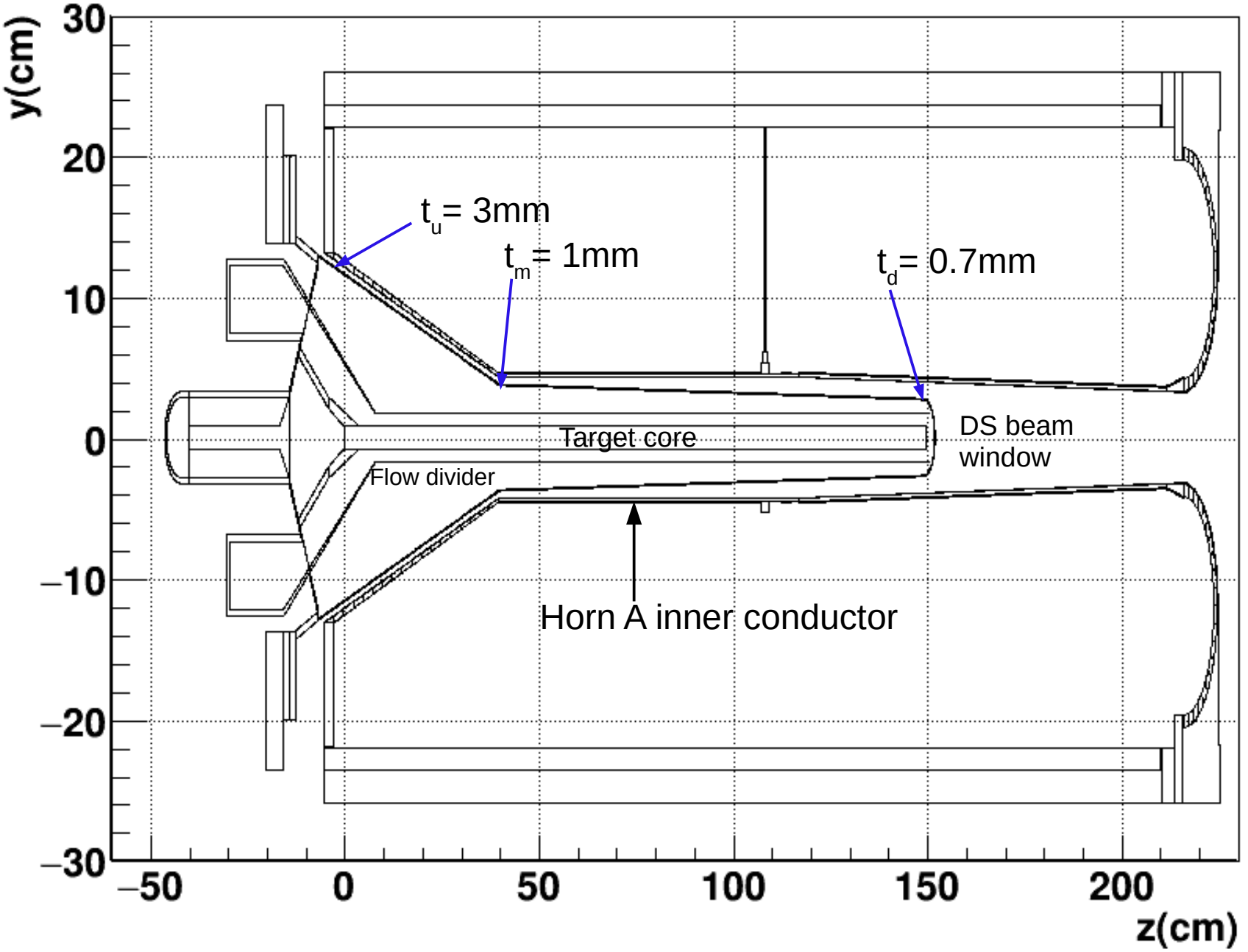
Horn A inner conductor cone (r_{base} = 14cm, L_z = 40cm)
to allow space for upstream target support structure

Courtesy RAL
High Power Targets Group

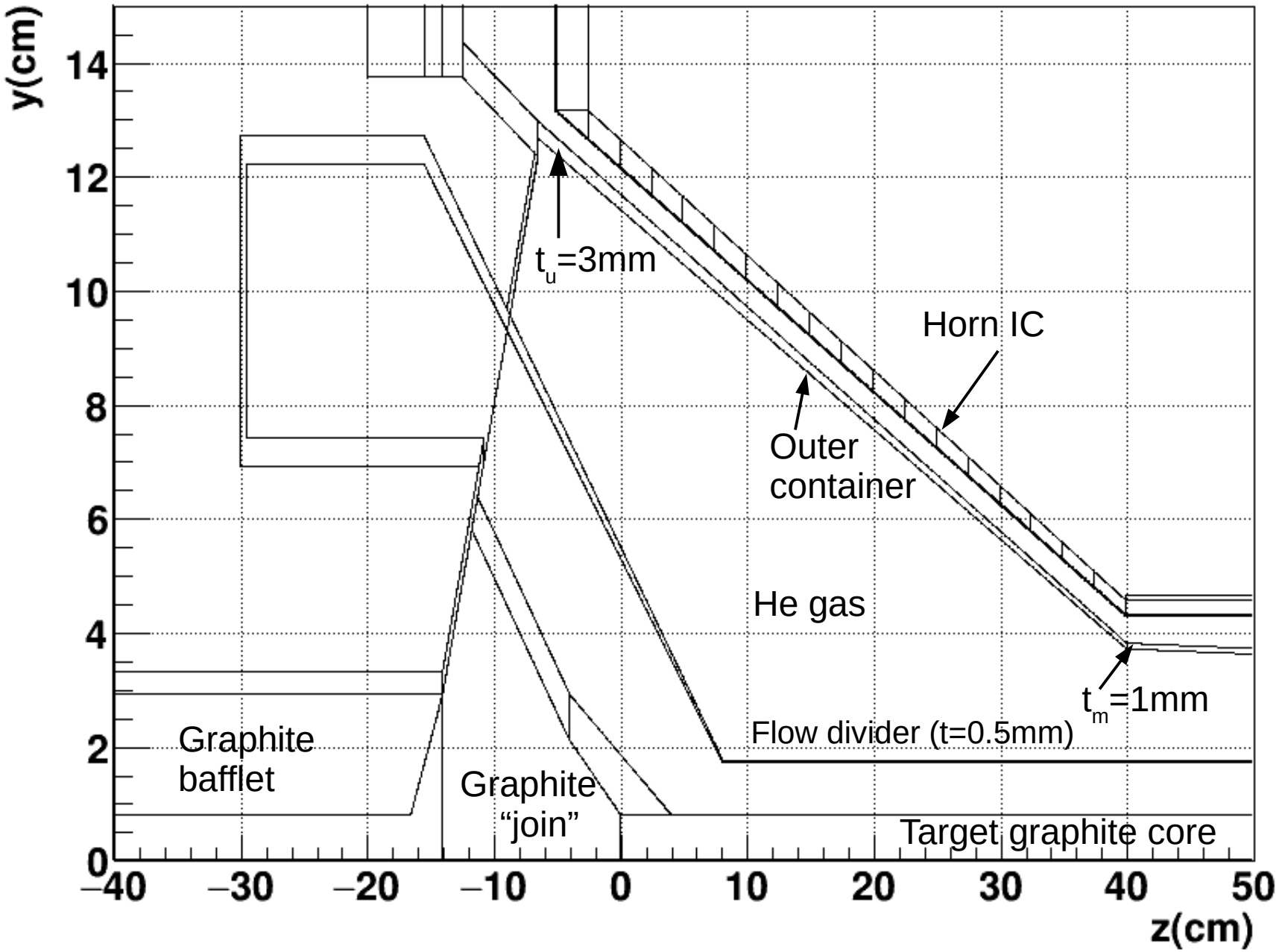
Target detail: tapered outer container (titanium)



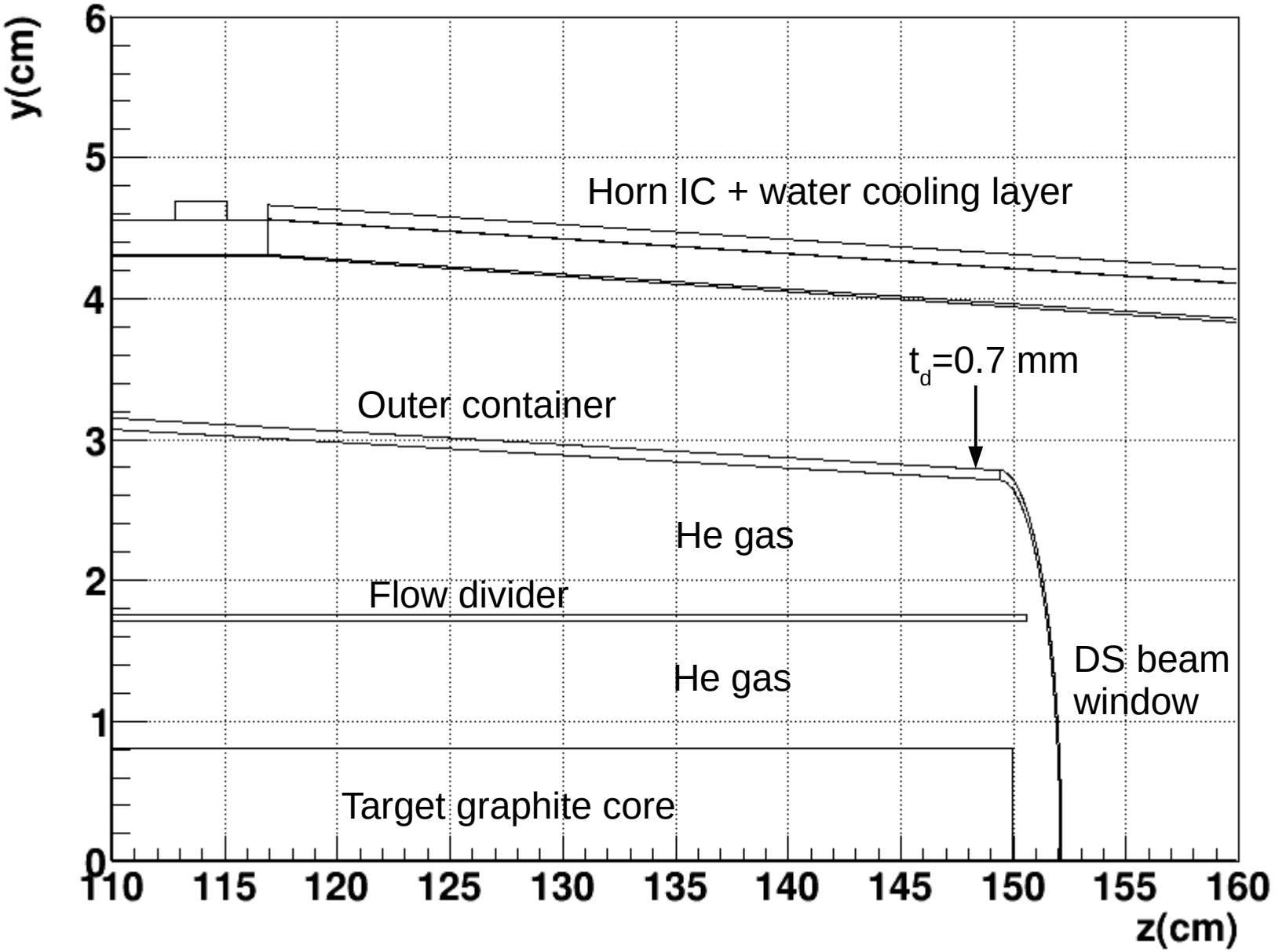
Geant4 geometry



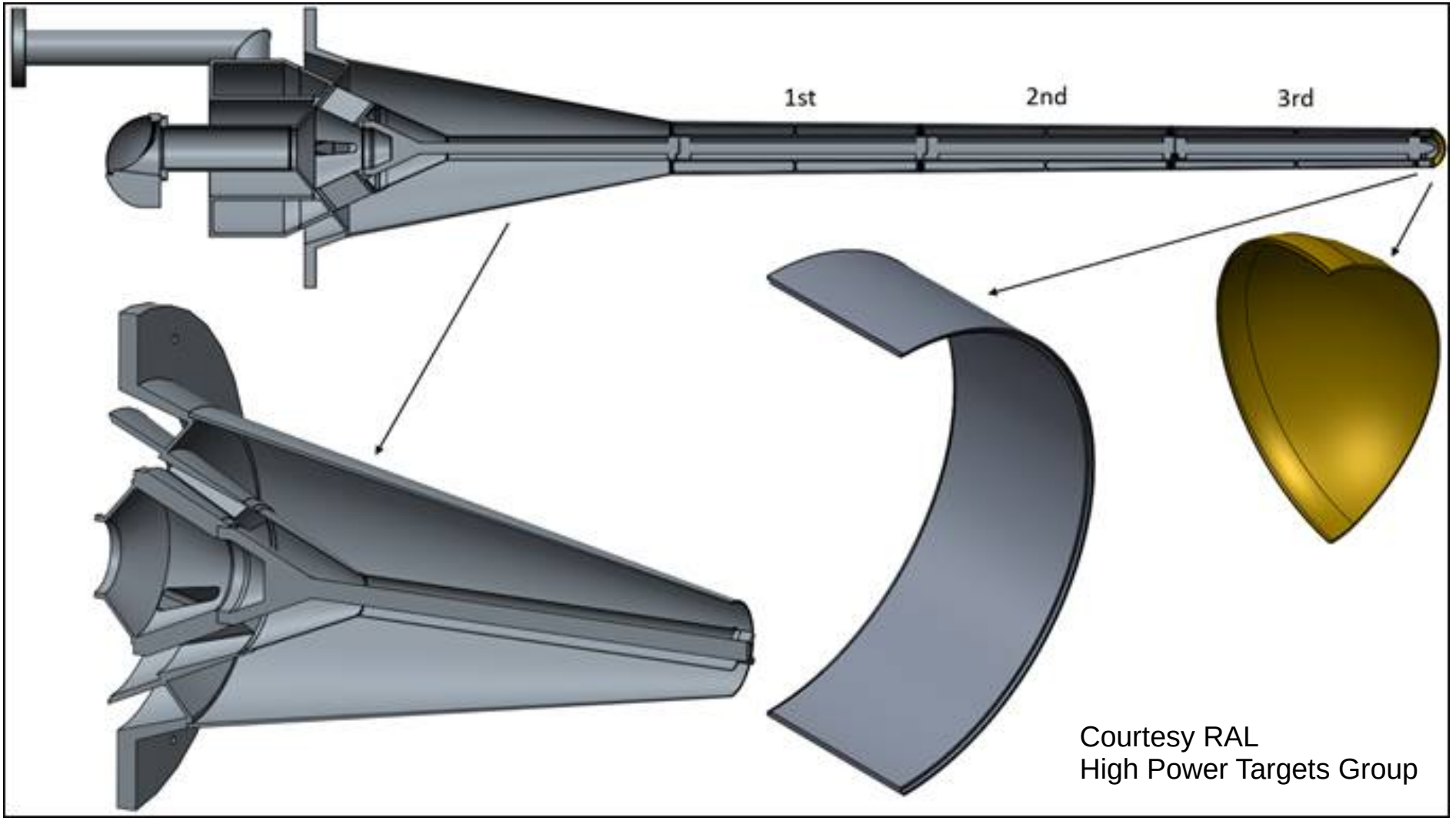
Outer container upstream detail



Outer container downstream detail

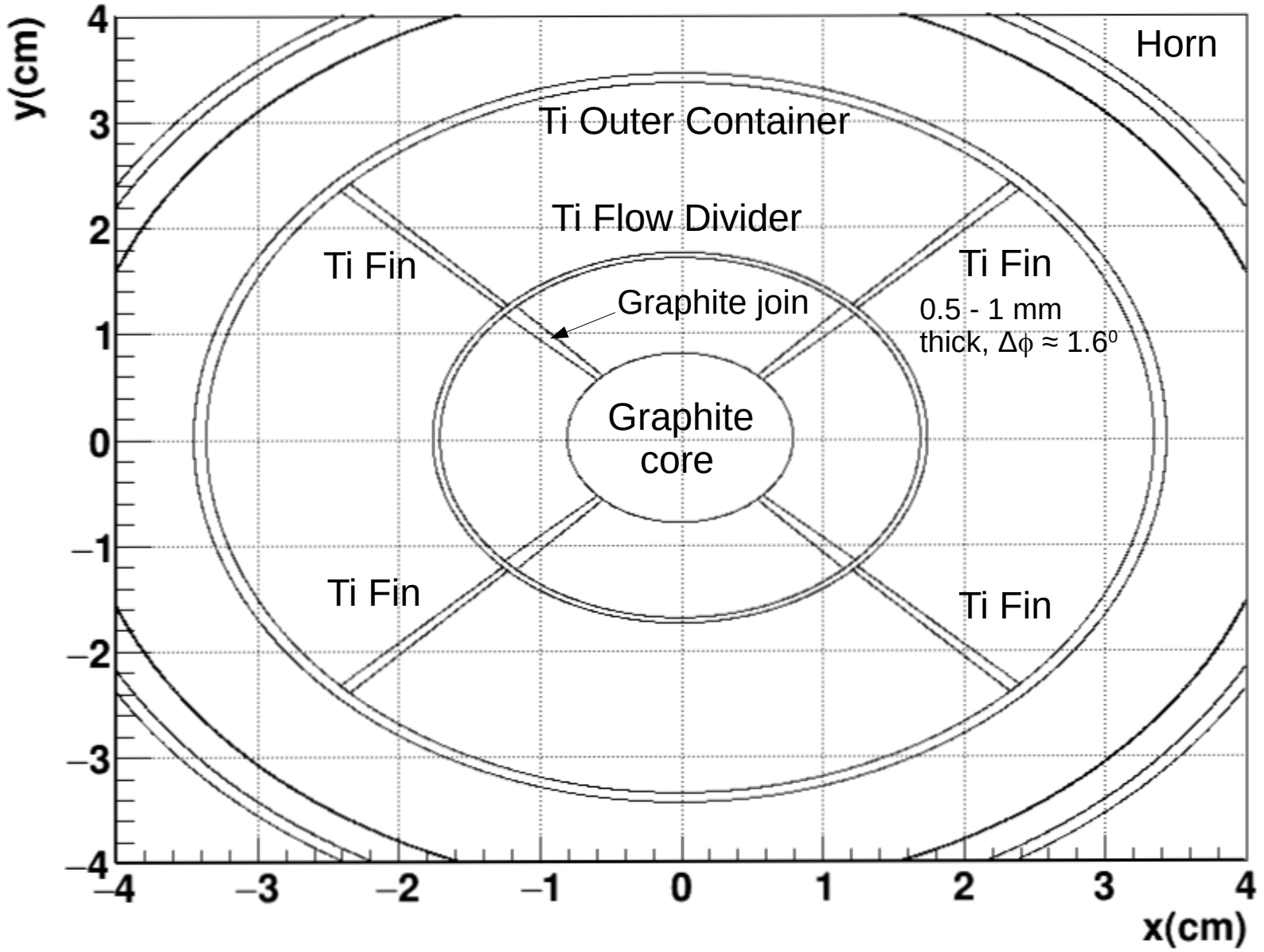


Target titanium support fins

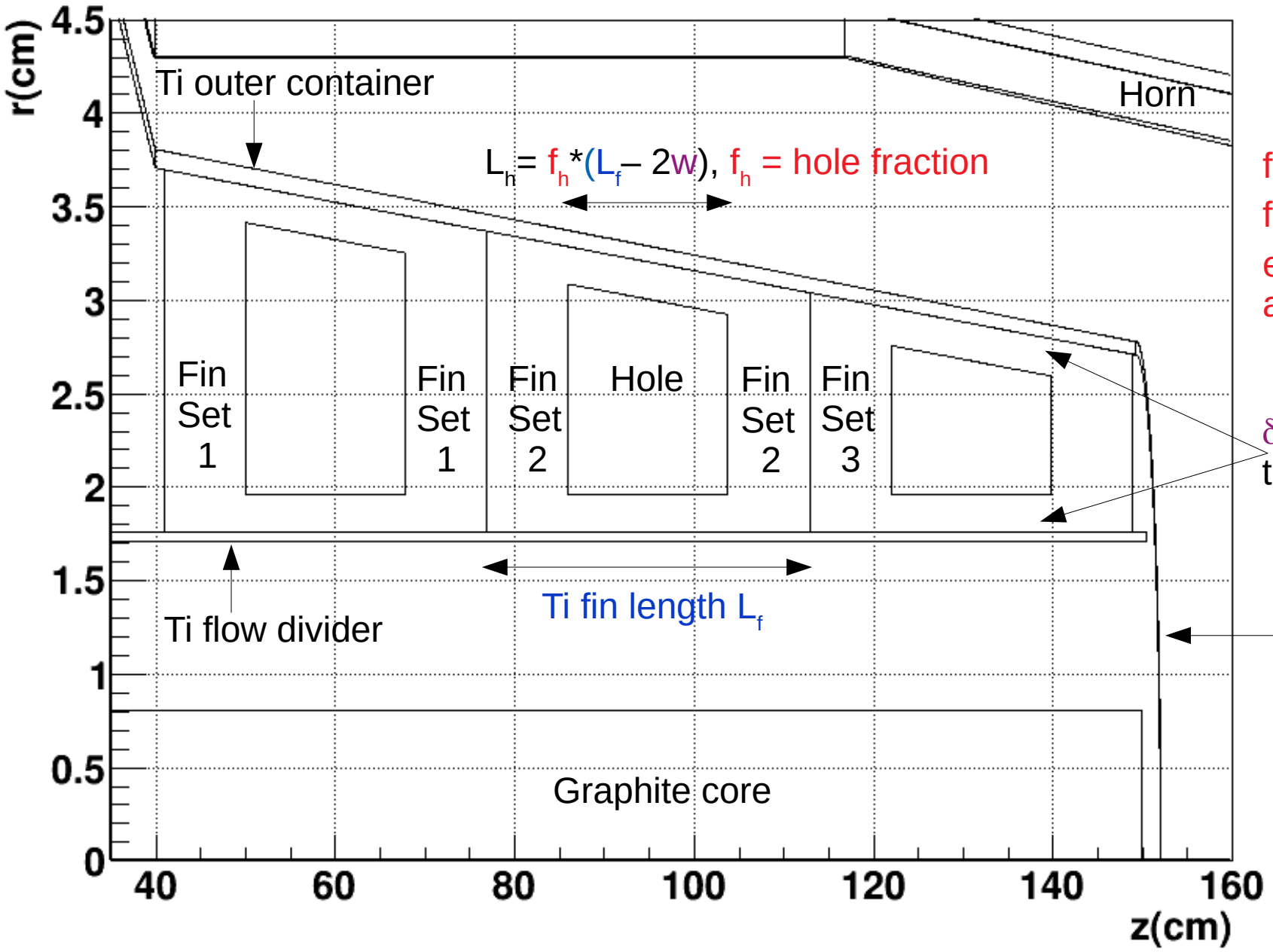


Titanium fins placed at ±45 and ±135 deg in x-y plane
0.5 to 1 mm thick, fully extending along beam z axis
3 equal sections starting from end of upstream cone region

Geant4 geometry: target support fins in x-y plane



Creating holes in fin supports: r-z plane view



$f_h = 0 \Rightarrow$ solid

$f_h = 1 \Rightarrow$ empty, except for 2mm around r-z edge

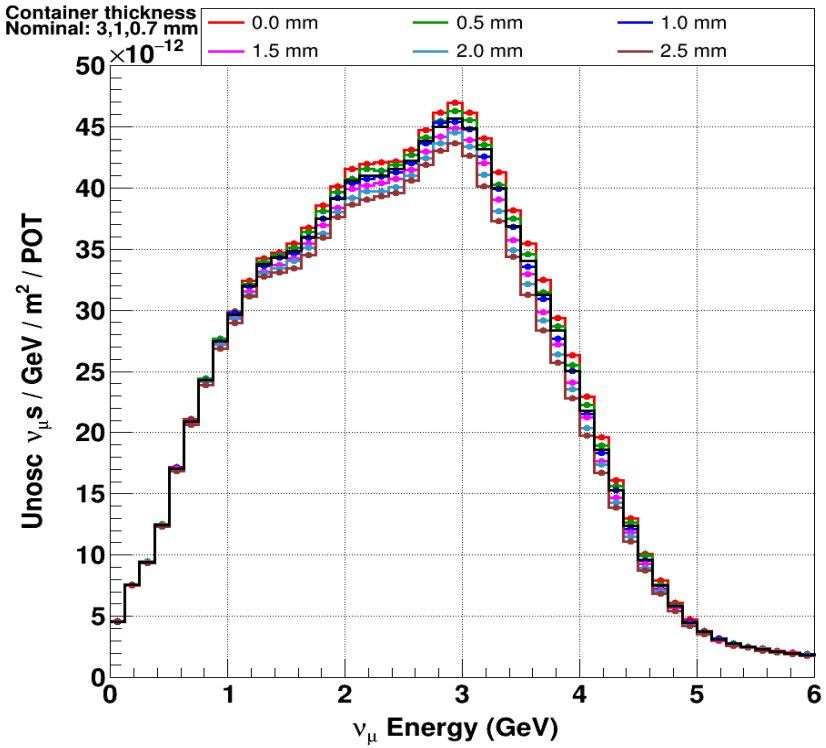
$\delta r = w = 2$mm, thick=1mm

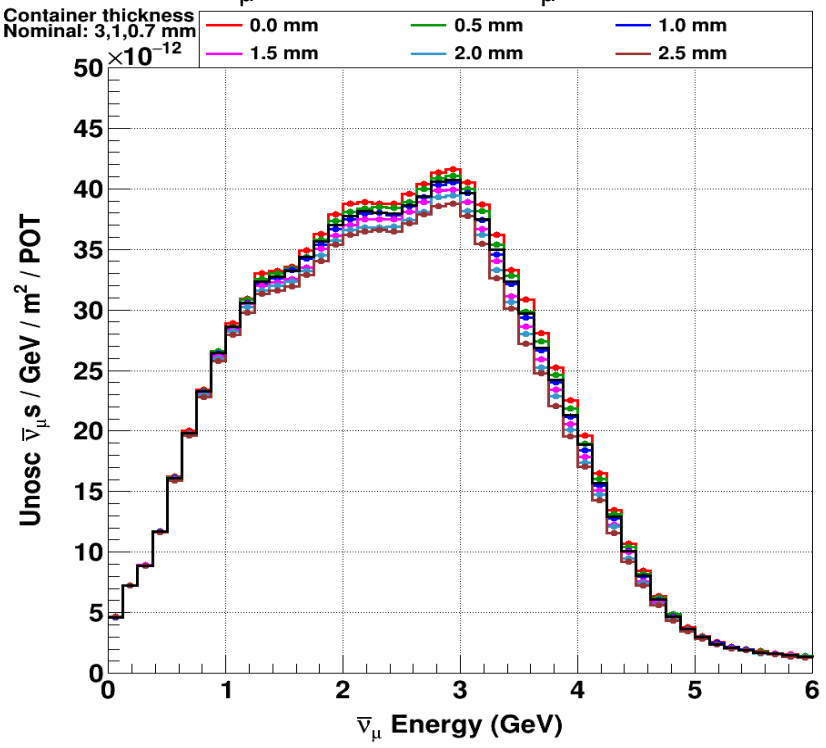
Beam window

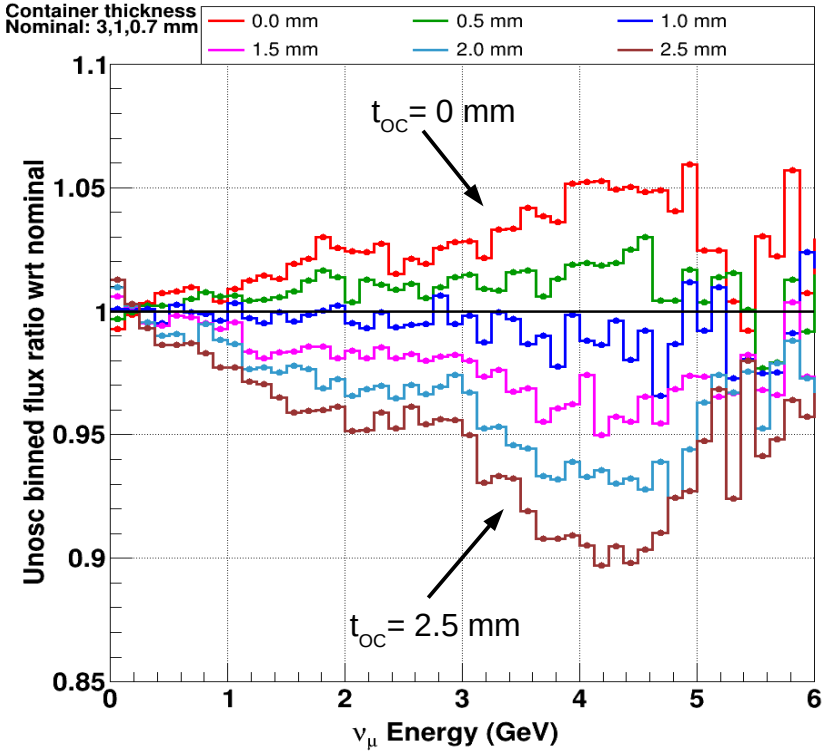
Neutrino Flux Spectra at Far Detector

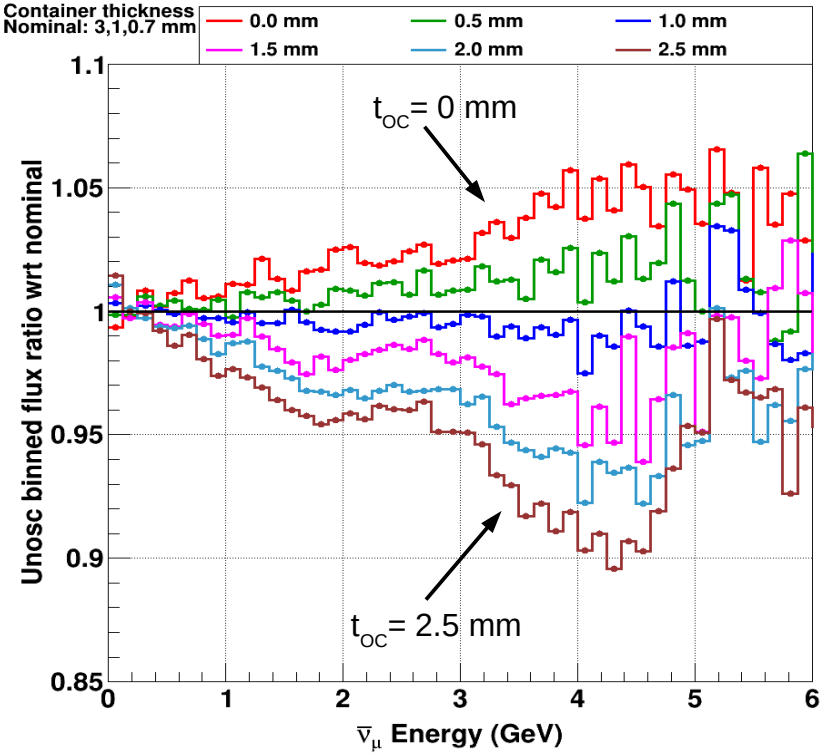
- Nominal histos: **t_u = 3 mm, t_m = 1 mm, t_d = 0.7 mm** container taper
- All other histos: **$t_u = t_m = t_d = t_{OC}$ = 0 to 2.5 mm,** in 0.5 mm steps
- For **L = 1.5 m** and **1.8 m** core target lengths
- Target support **fin hole fractions**:
  - **0.0** (solid)
  - **0.5** (half solid)
  - **1.0** (2 mm edges only)
- Neutrino & anti-neutrino running
- Unoscillated fluxes extrapolated to far detector

L = 1.5 m, f_h = 0 (solid fins) signal mode: ν_μ (left) & anti-ν_μ (right)

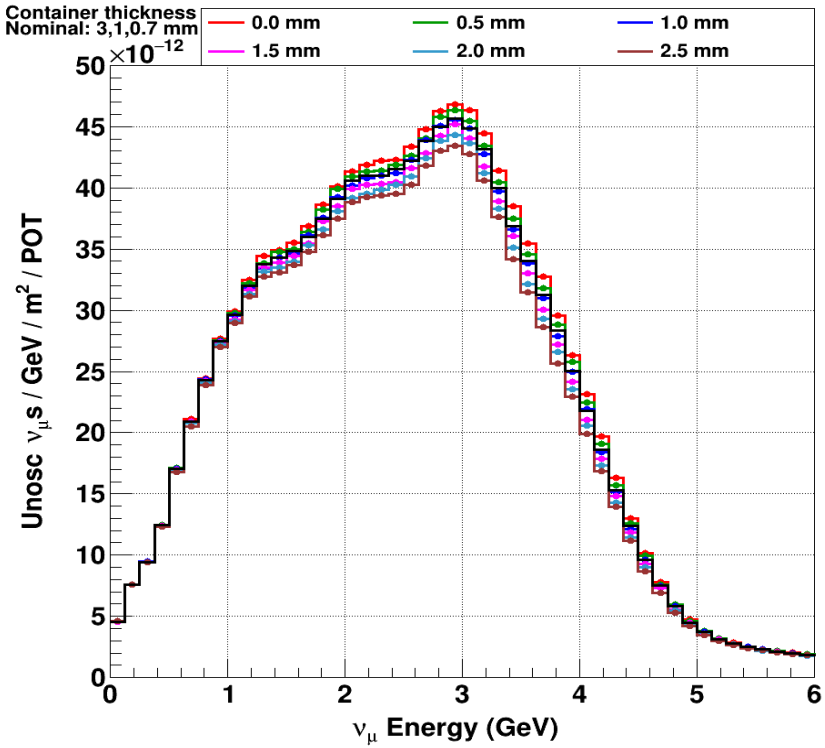


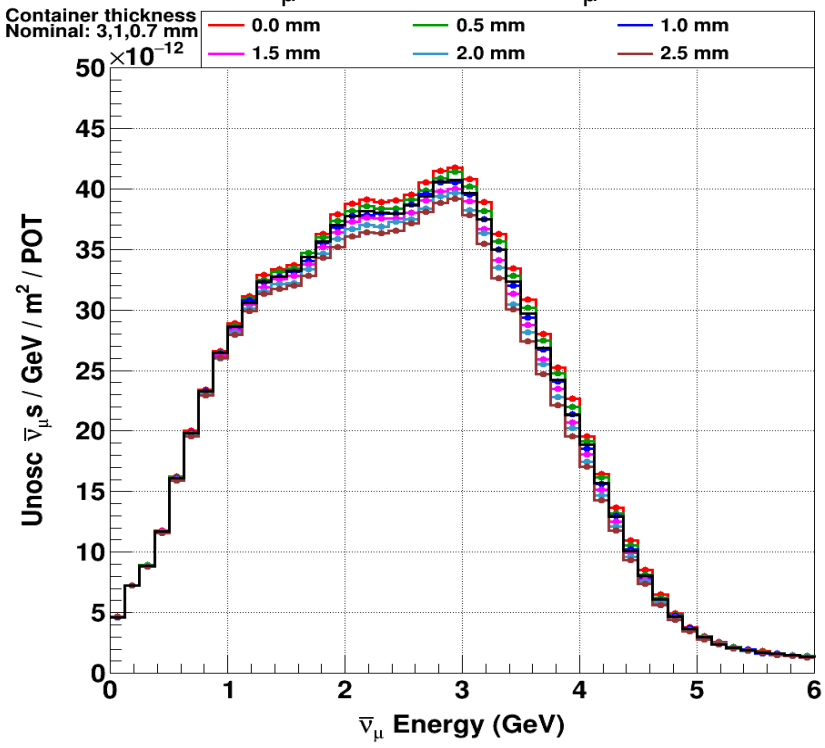


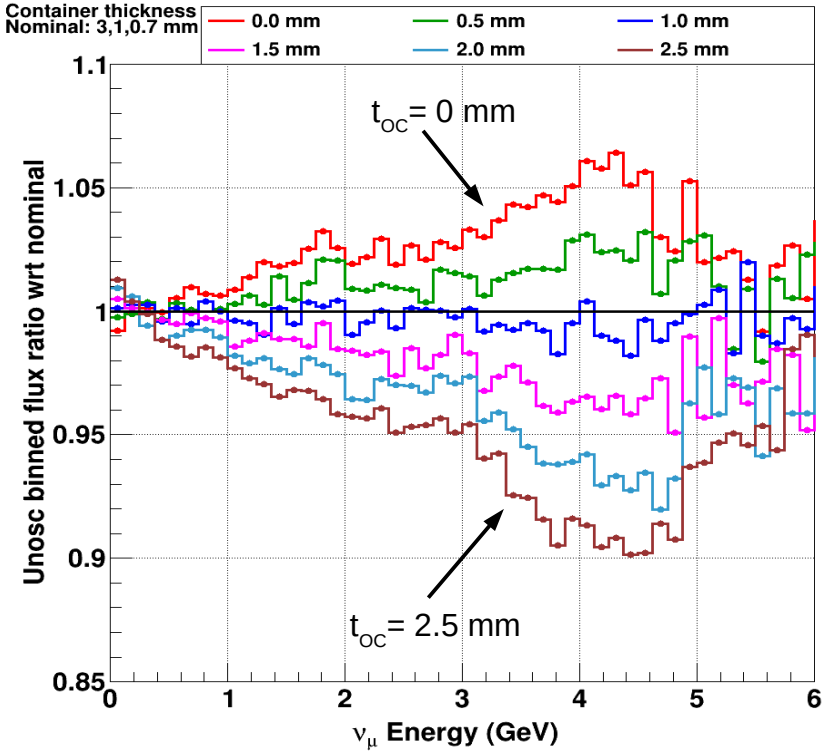


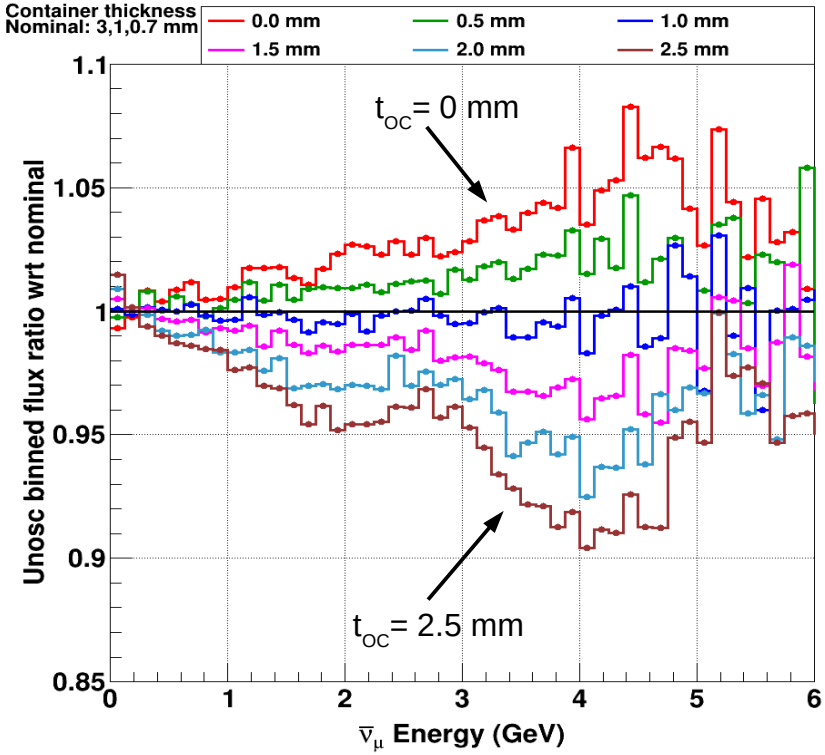


L = 1.5 m, f_h = 0.5 (half solid) signal mode: ν_μ (left) & anti-ν_μ (right)

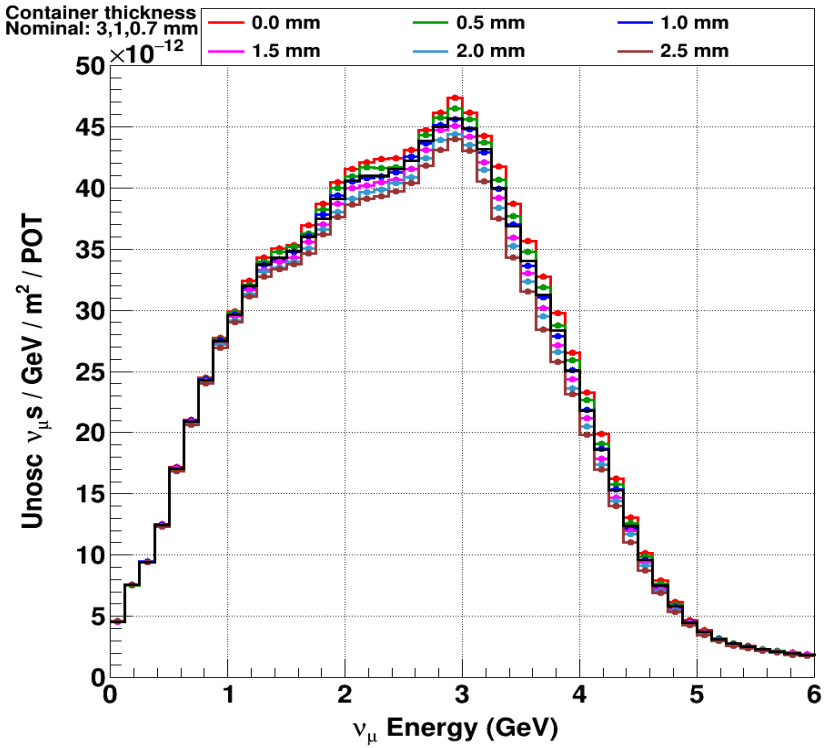


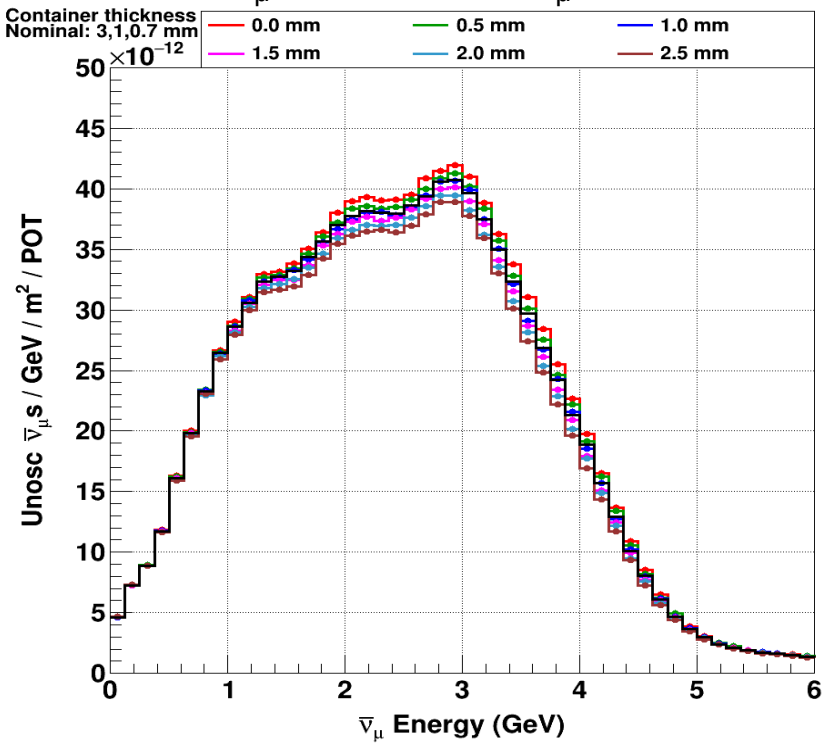


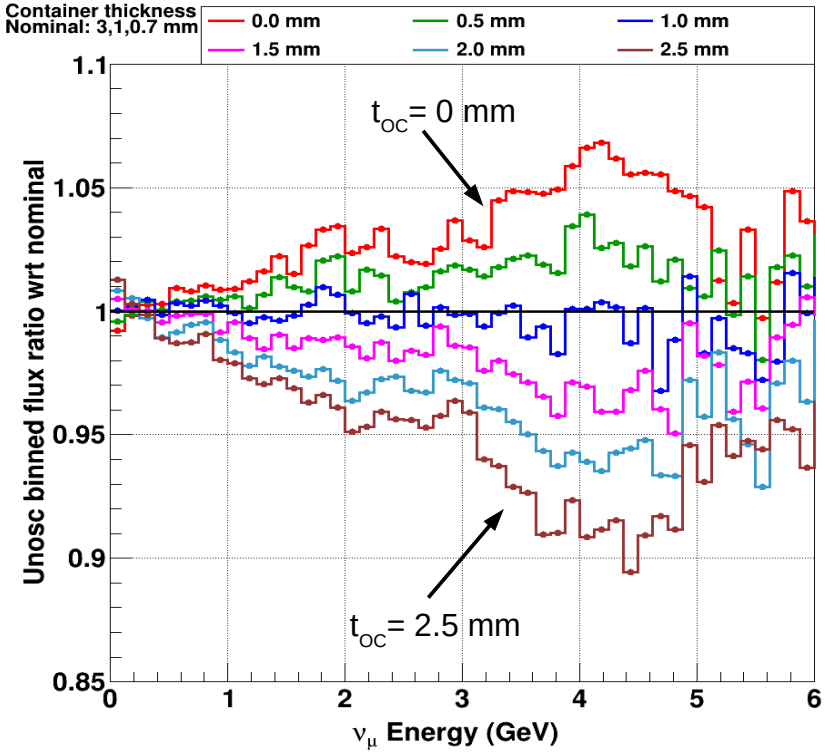


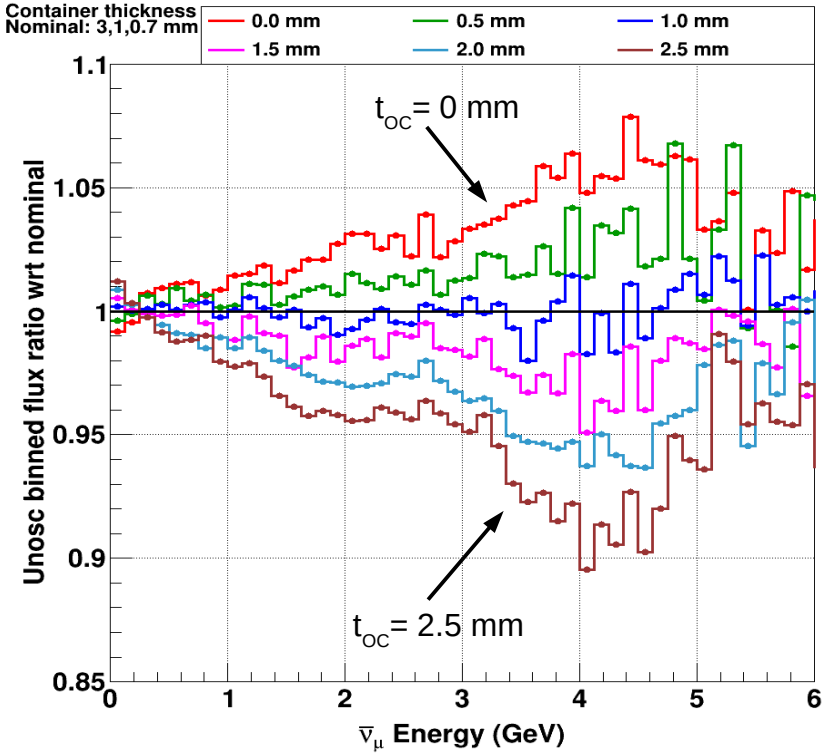


L = 1.5 m, f_h = 1.0 (fin edge) signal mode: ν_μ (left) & anti-ν_μ (right)

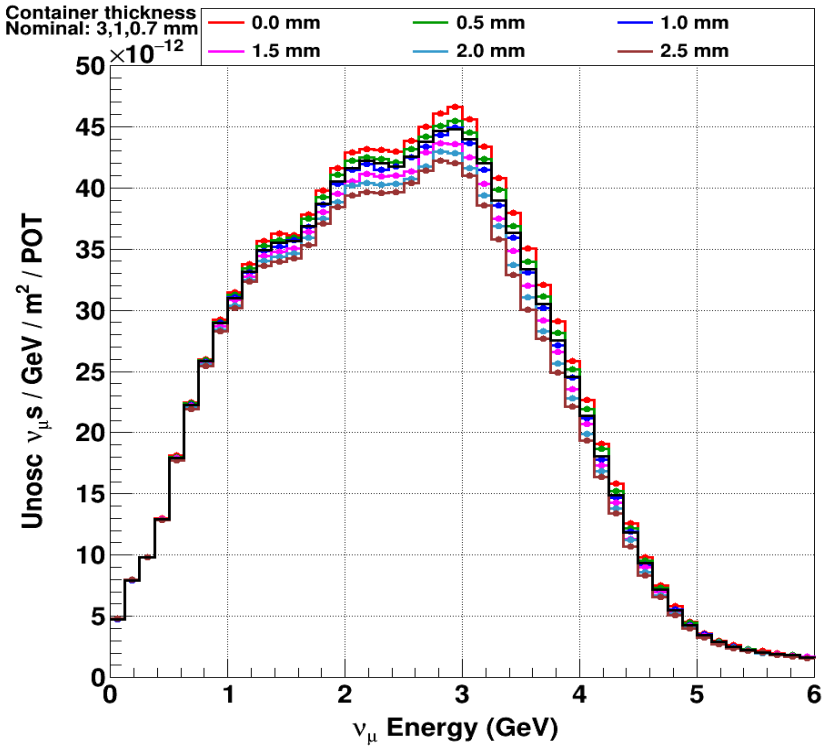


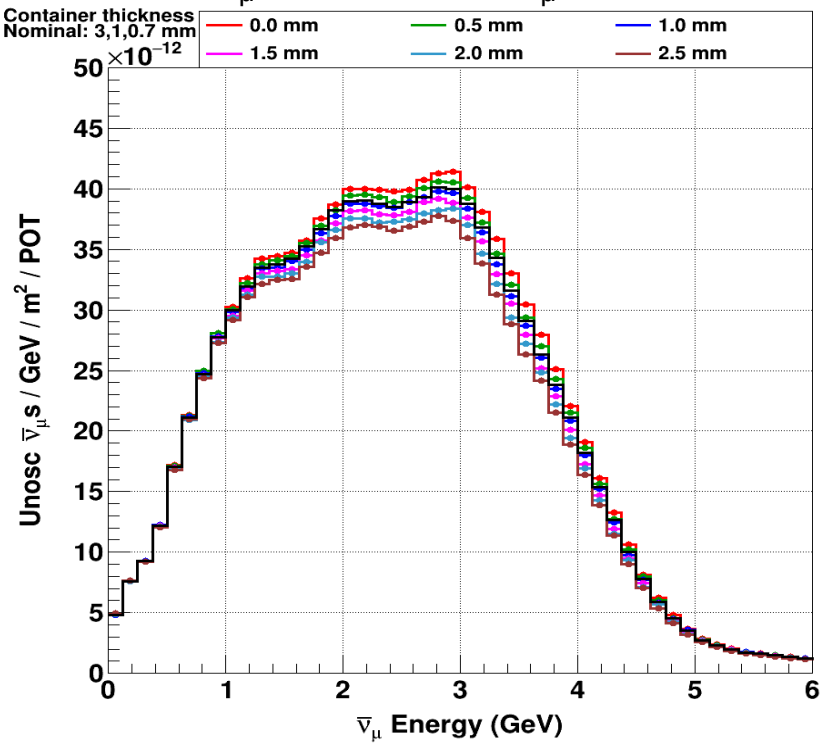


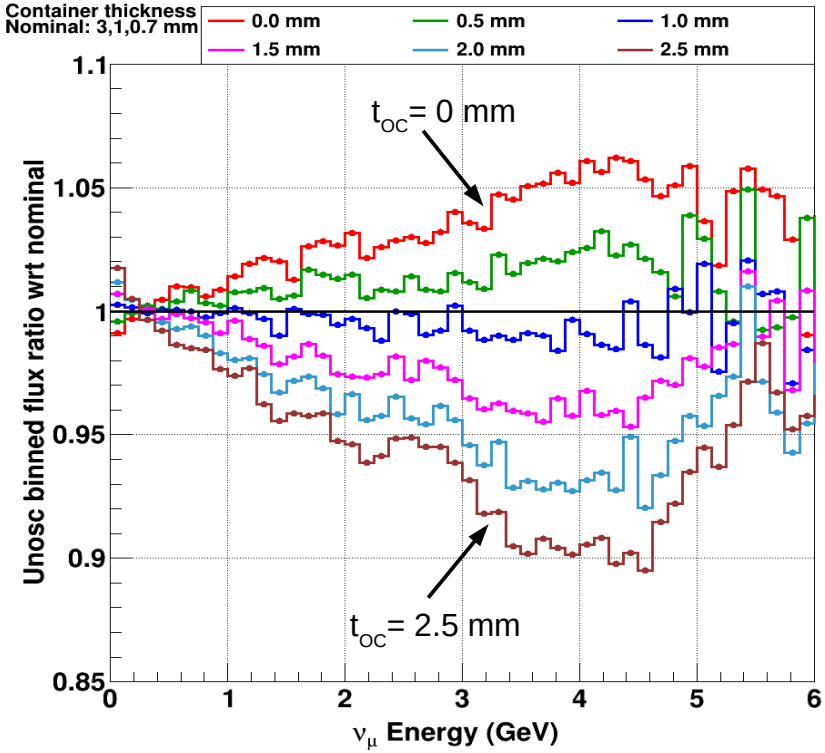


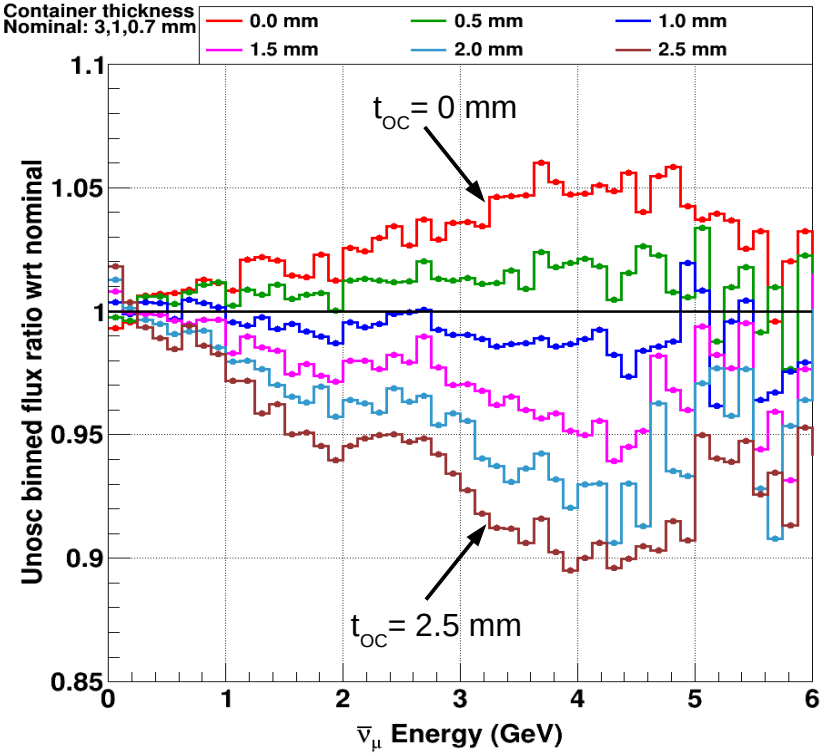


L = 1.8 m, f_h = 0 (solid fins) signal mode: ν_μ (left) & anti-ν_μ (right)

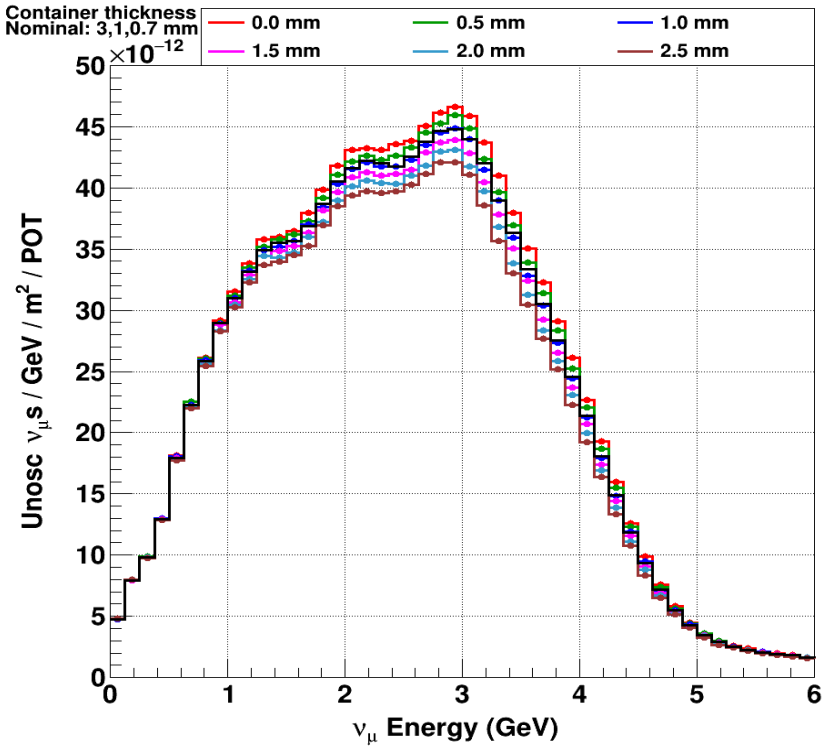


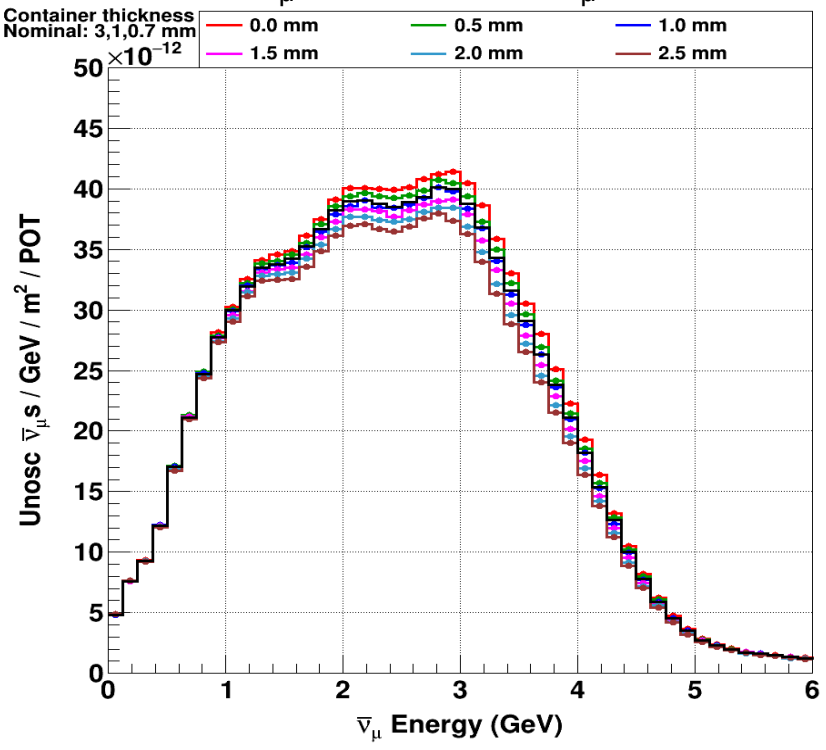


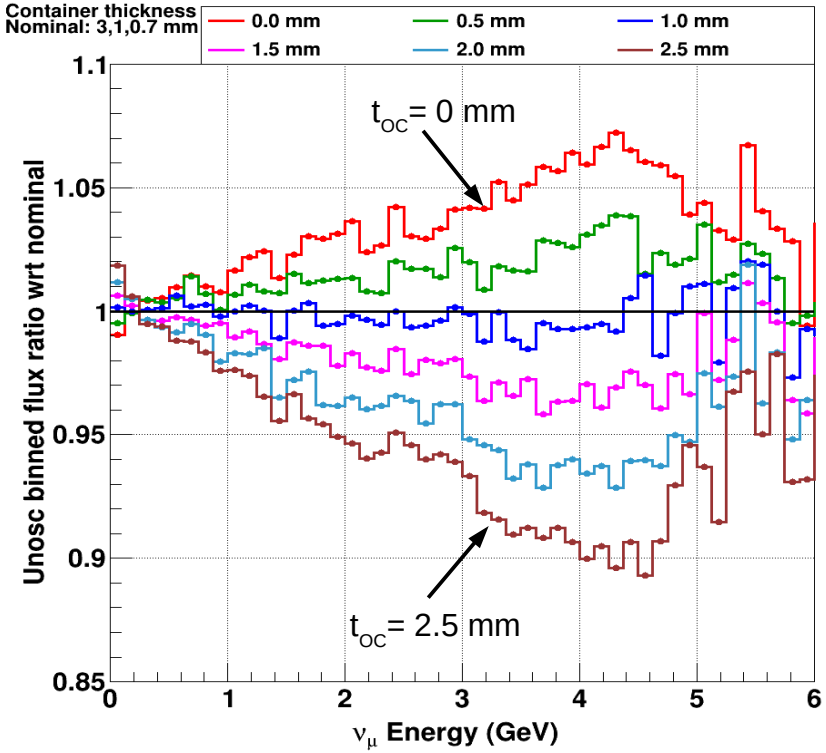


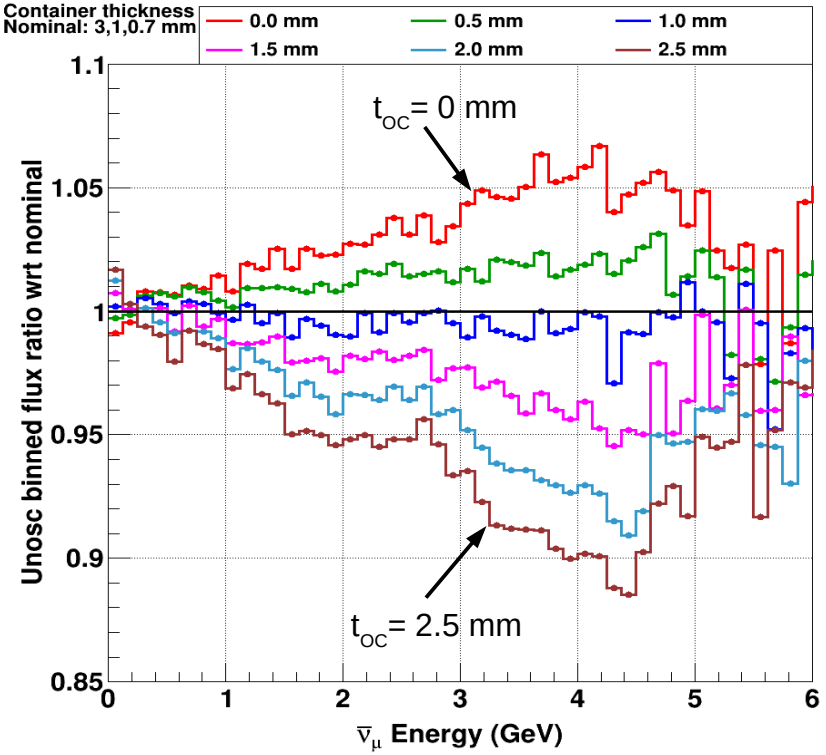


L = 1.8 m, f_h = 0.5 (half solid) signal mode: ν_μ (left) & anti-ν_μ (right)









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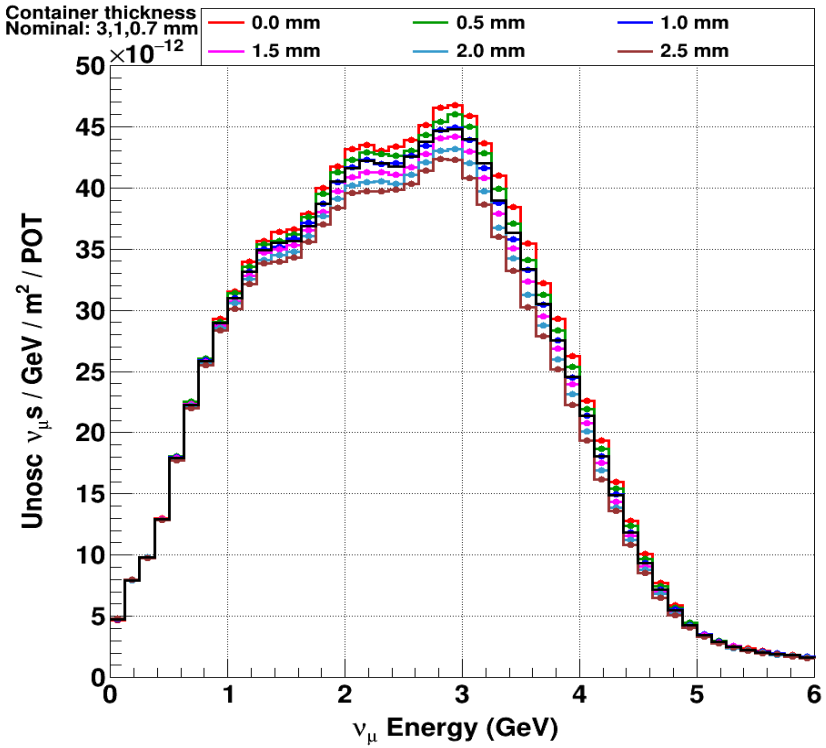
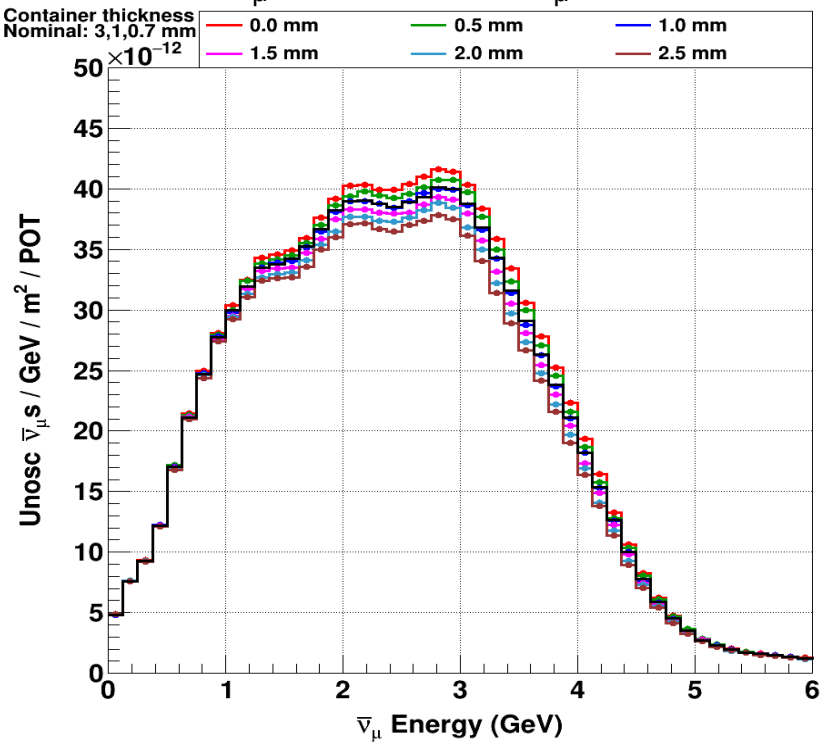
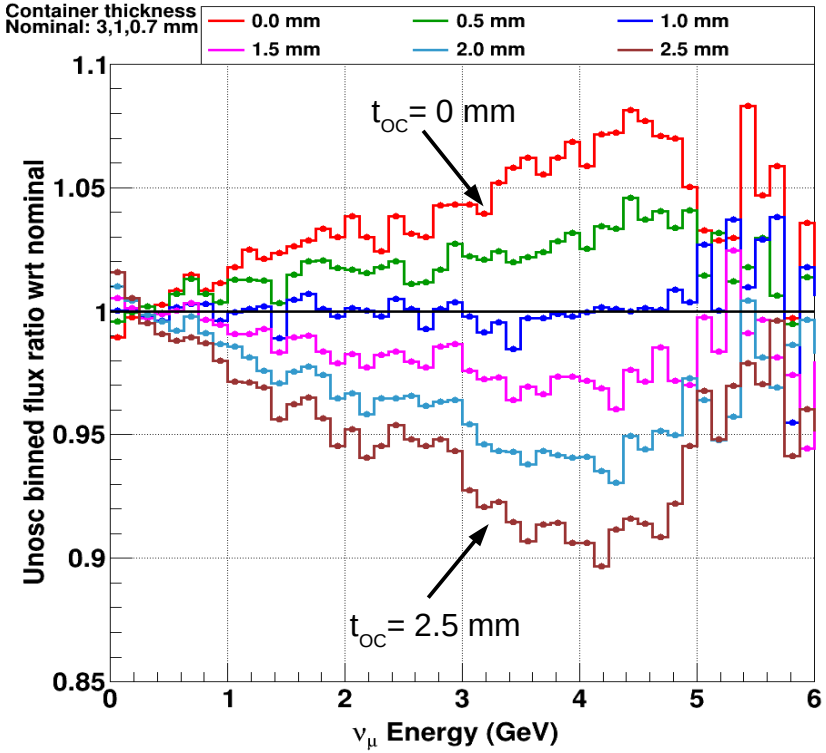
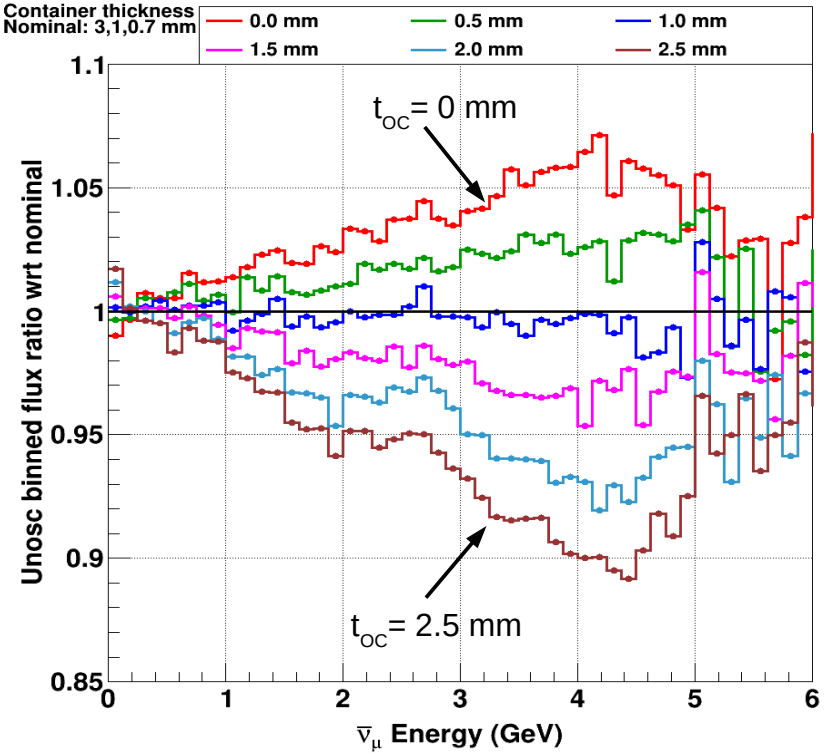
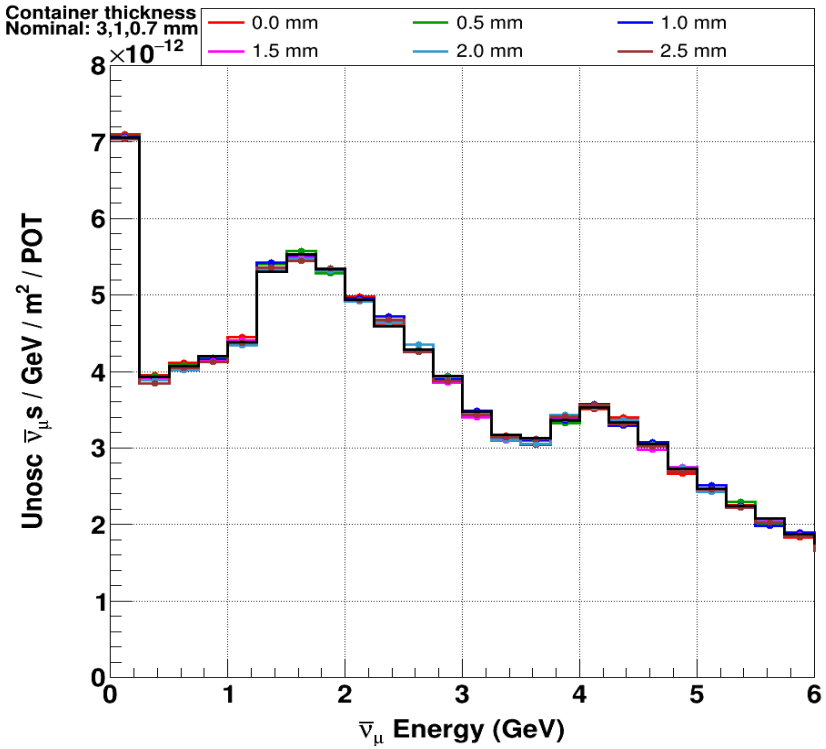


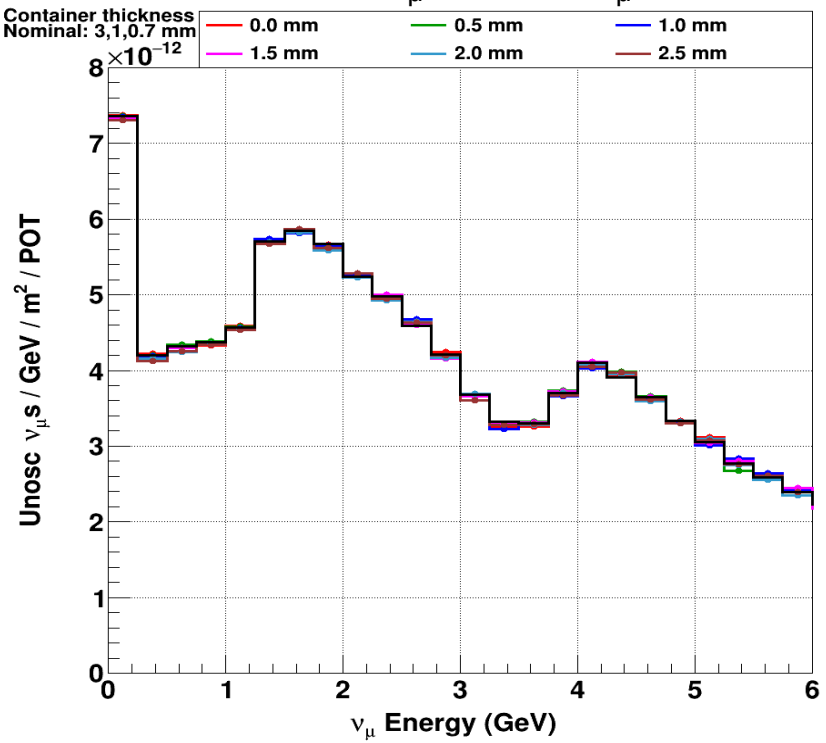


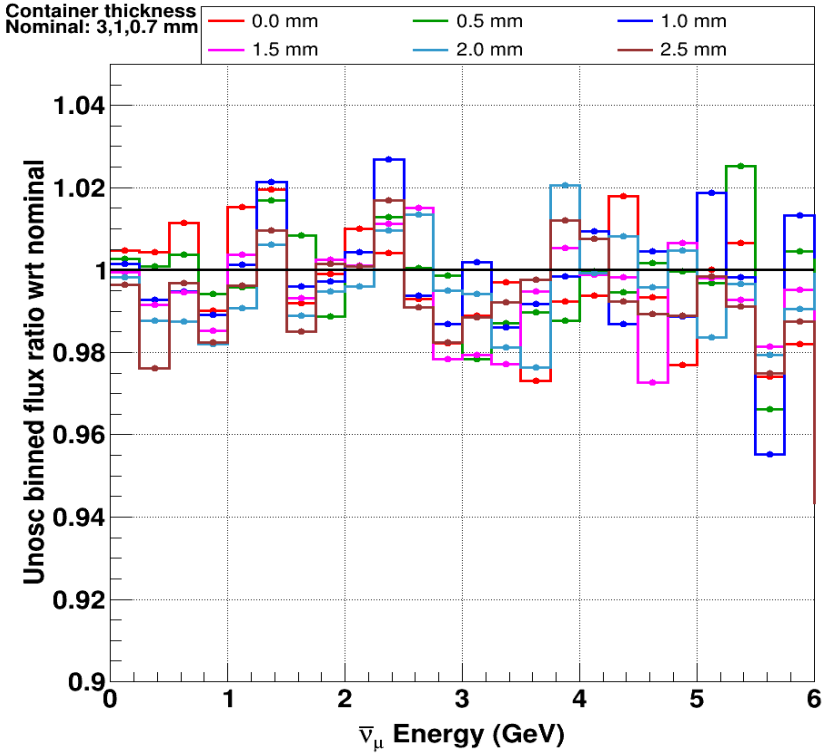


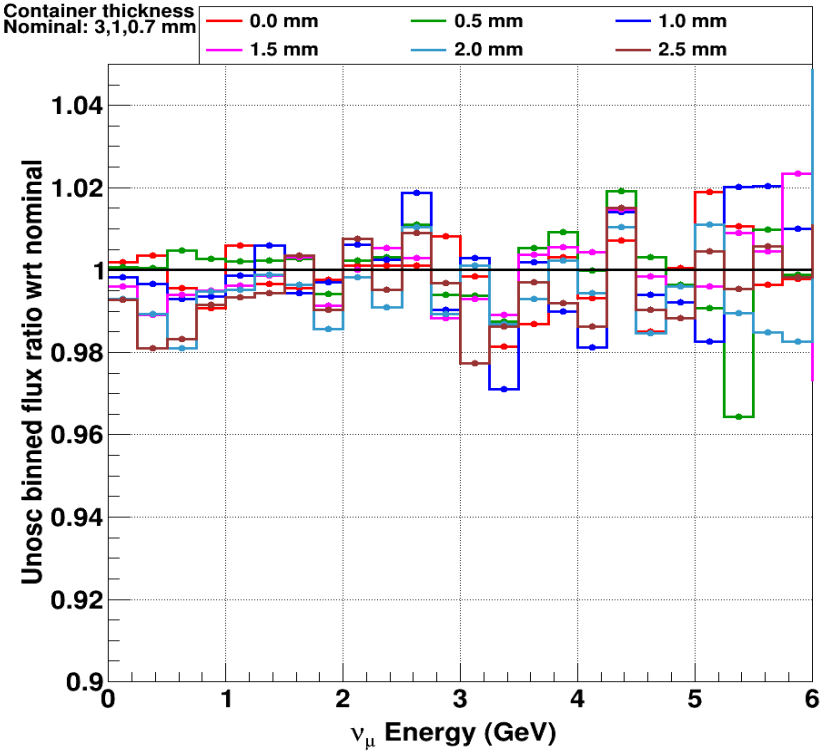


L = 1.5 m, f_h = 0 (solid fins) wrong sign bkg: anti-ν_μ (left) & ν_μ (right)









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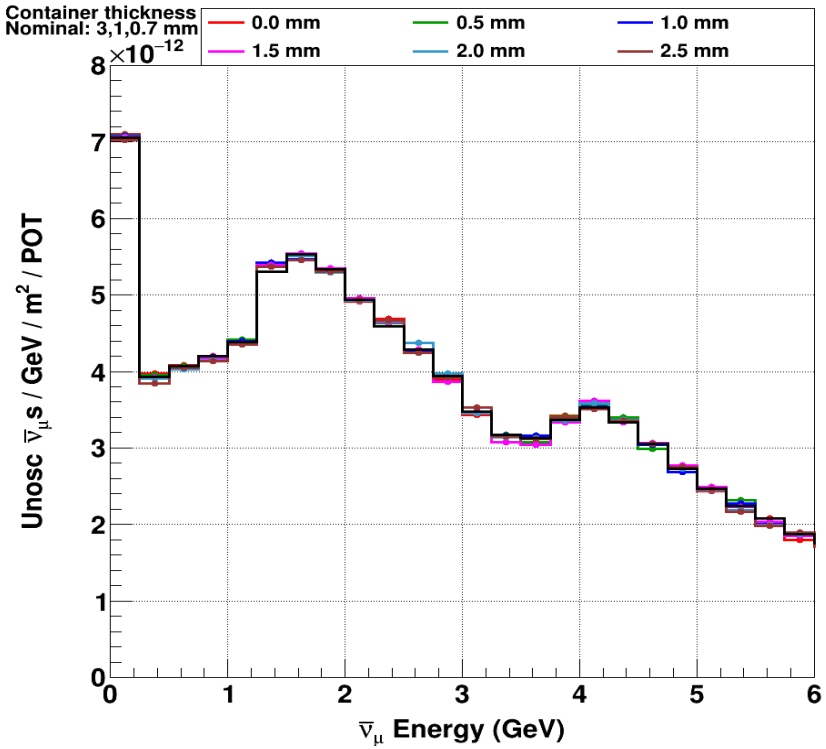

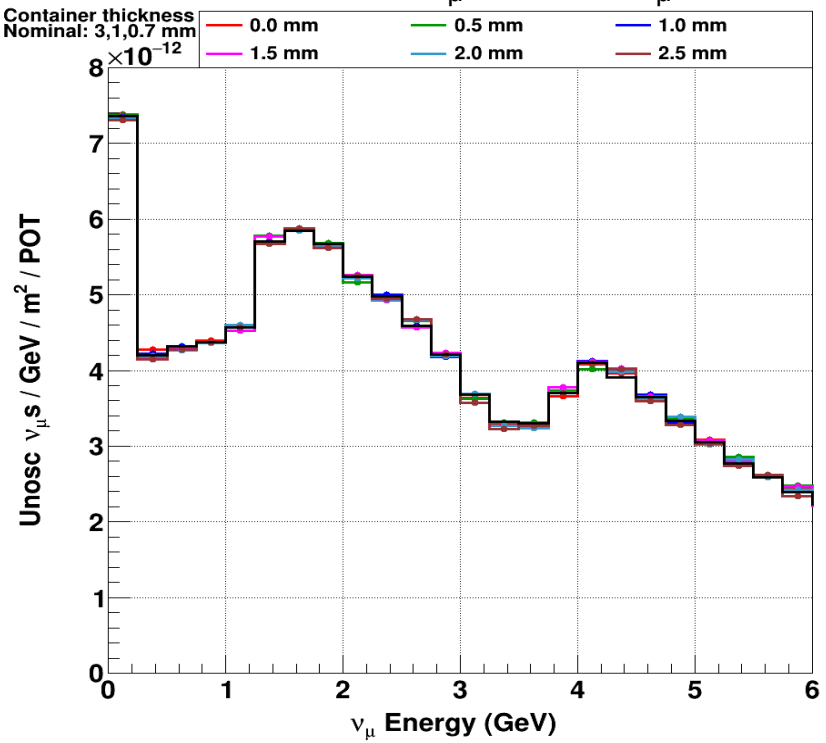

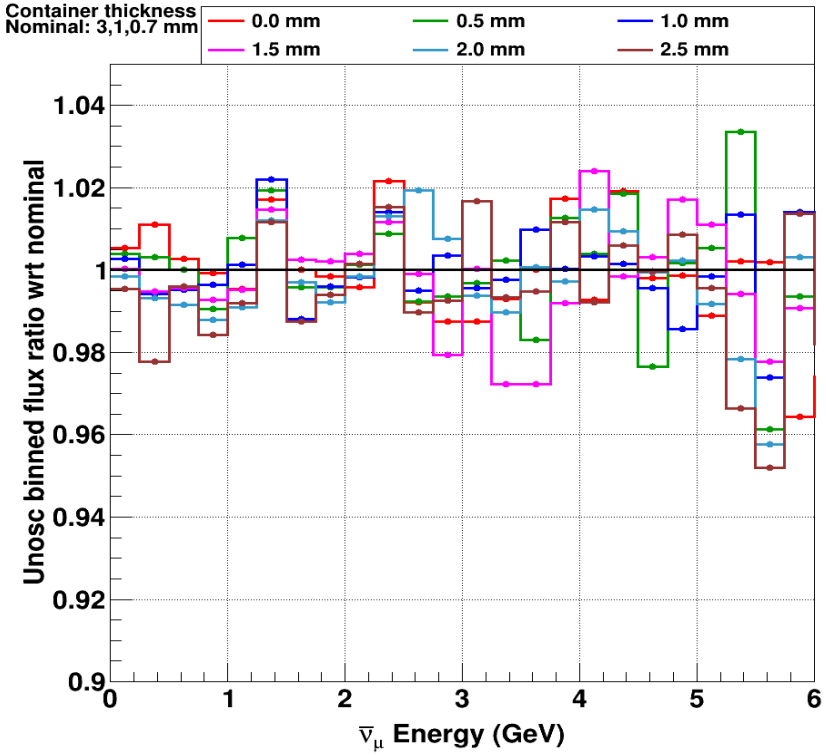

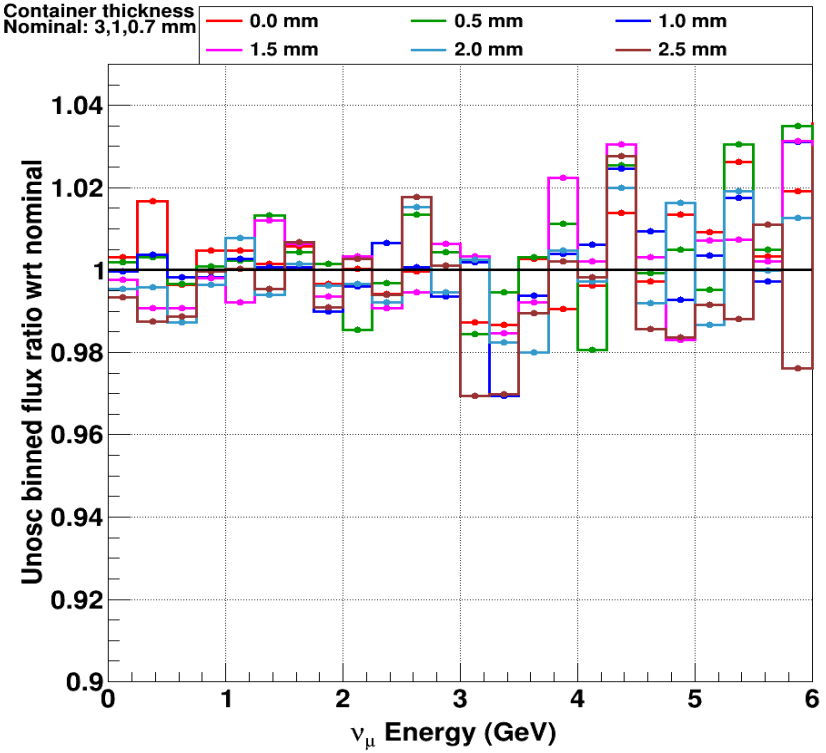

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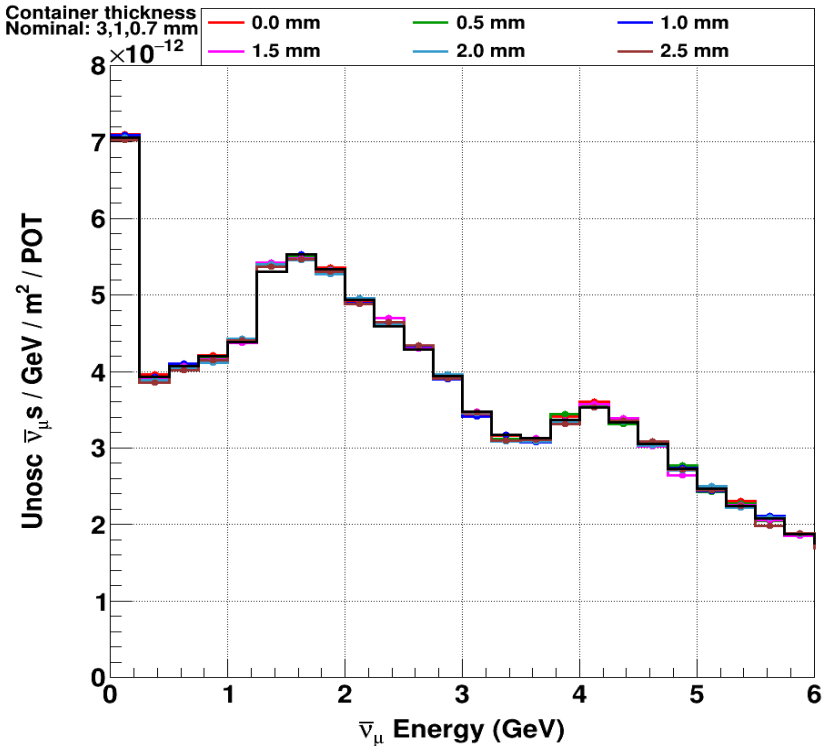
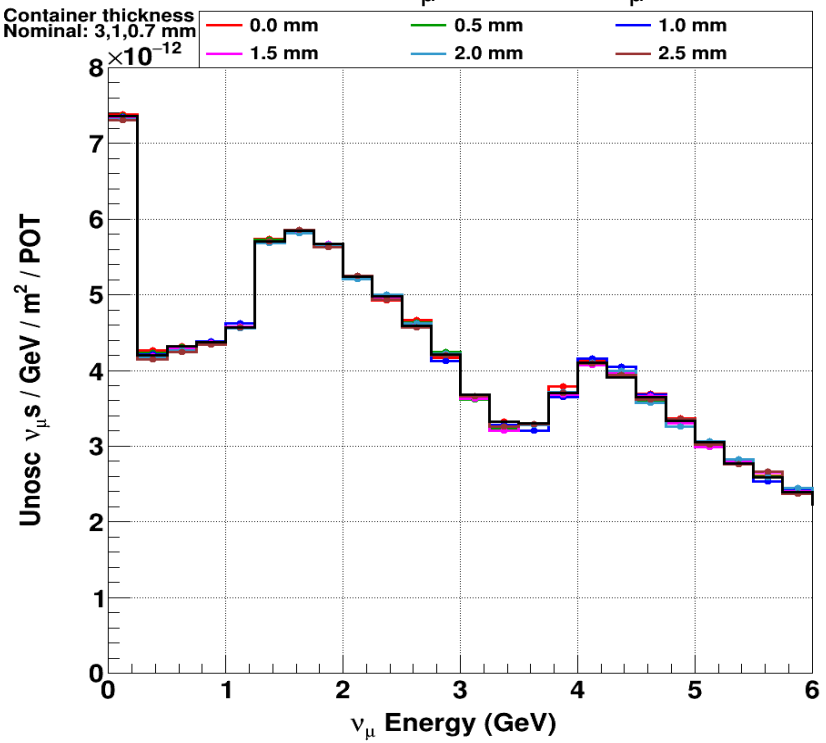
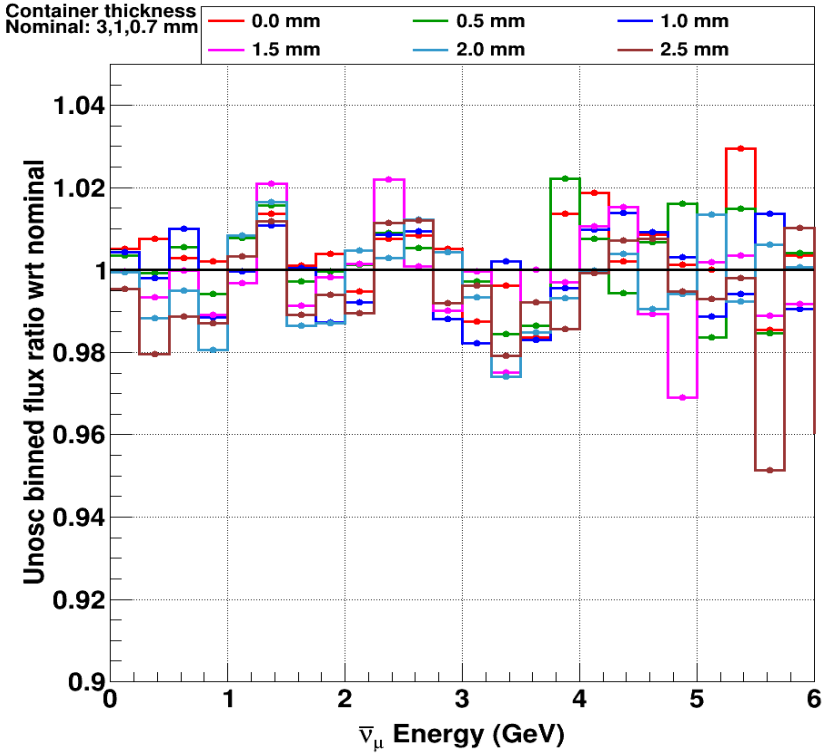
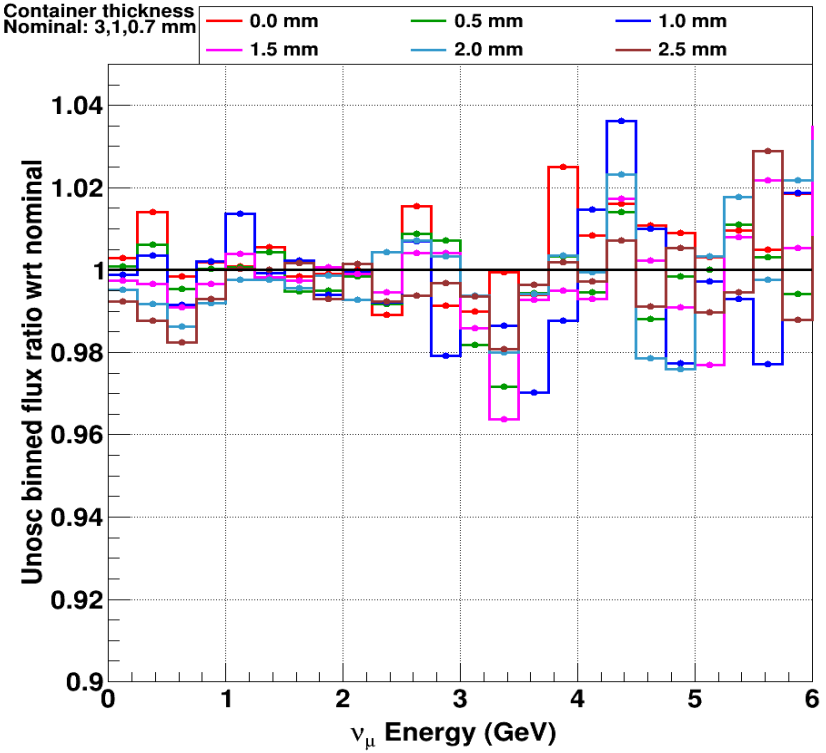
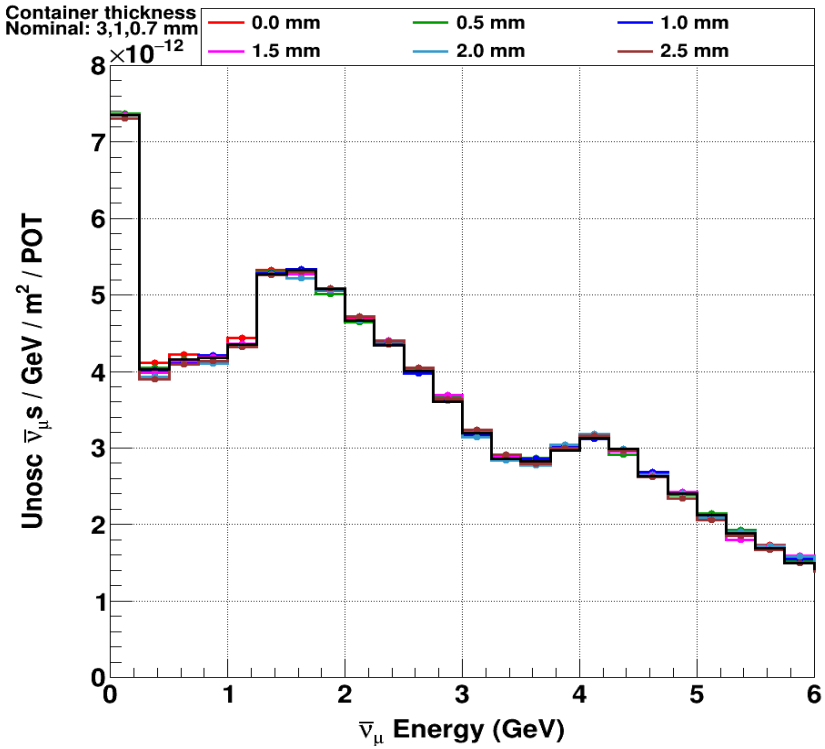


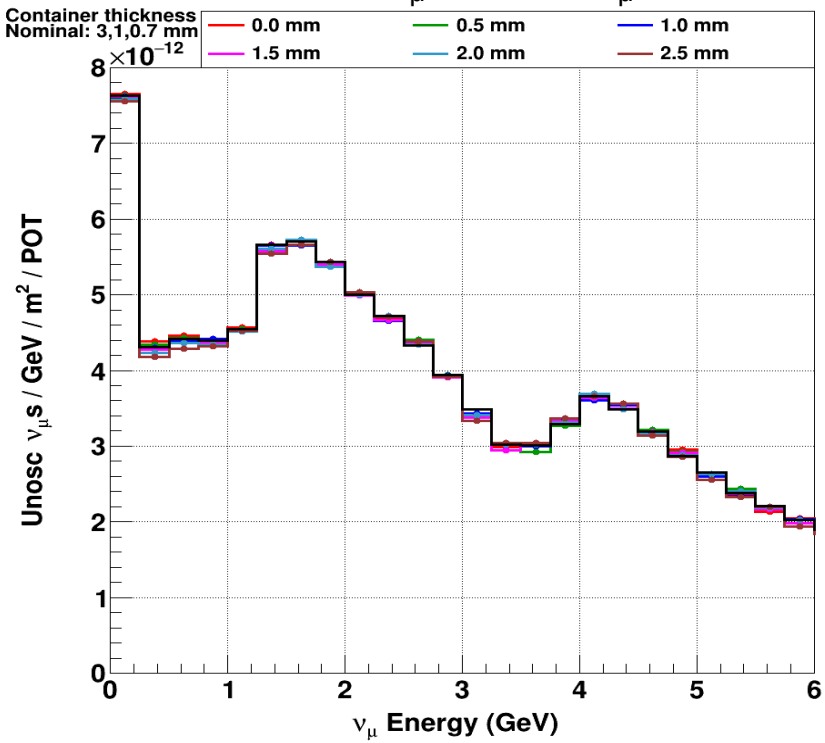


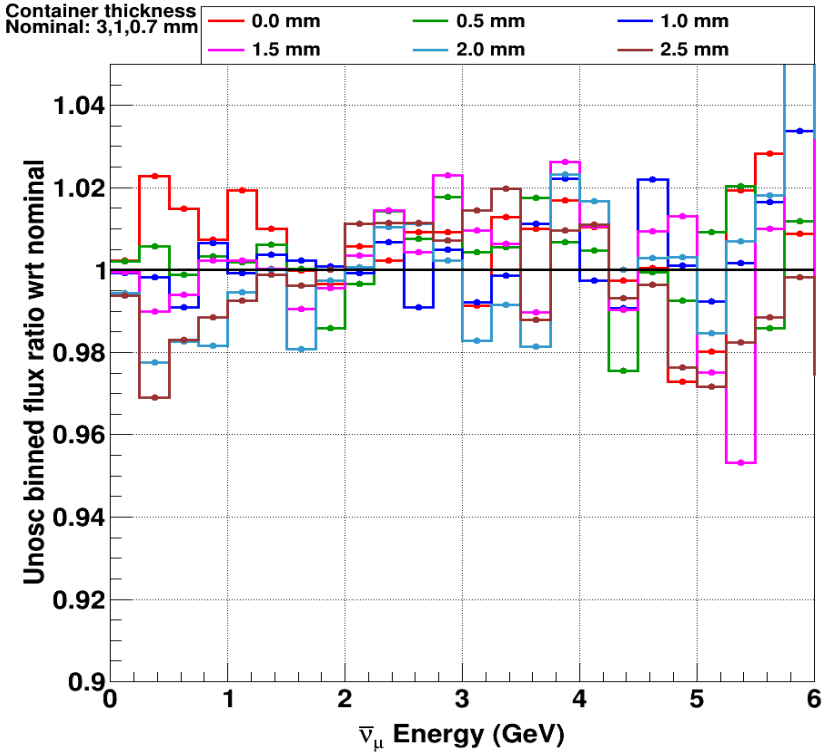


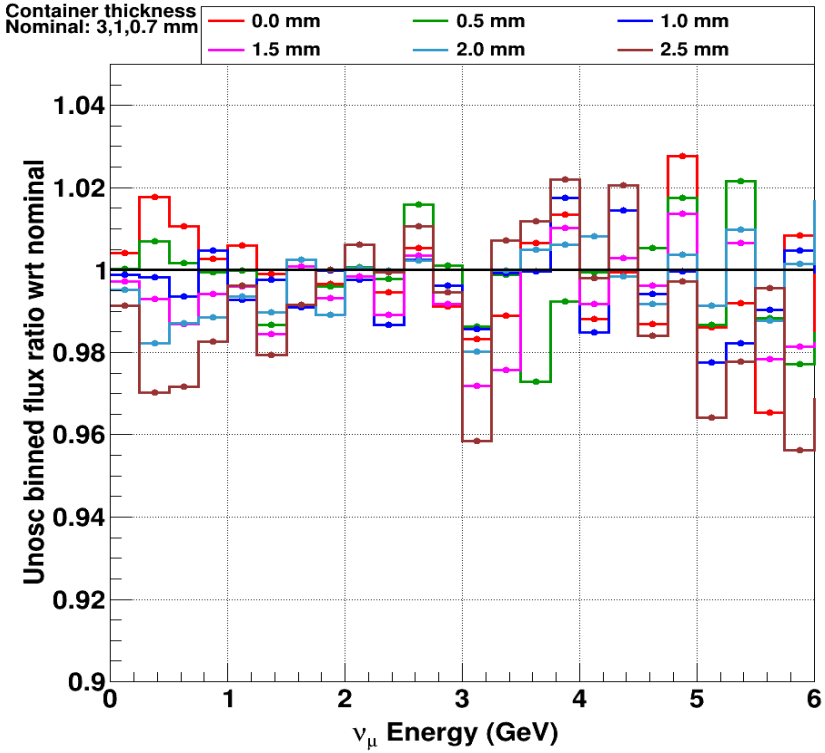


L = 1.8 m, f_h = 0 (solid fins) wrong sign bkg: anti-ν_μ (left) & ν_μ (right)

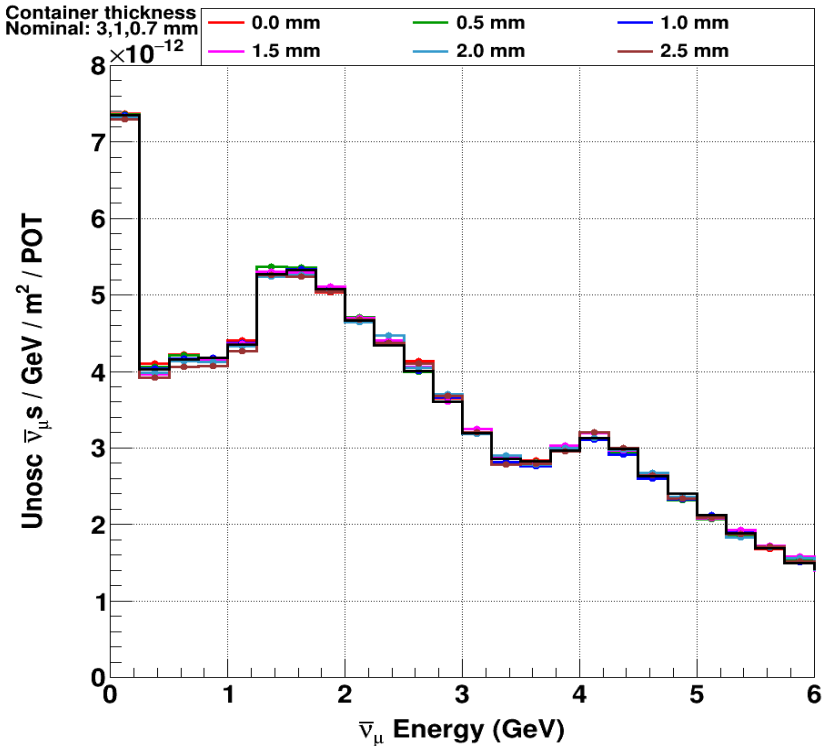


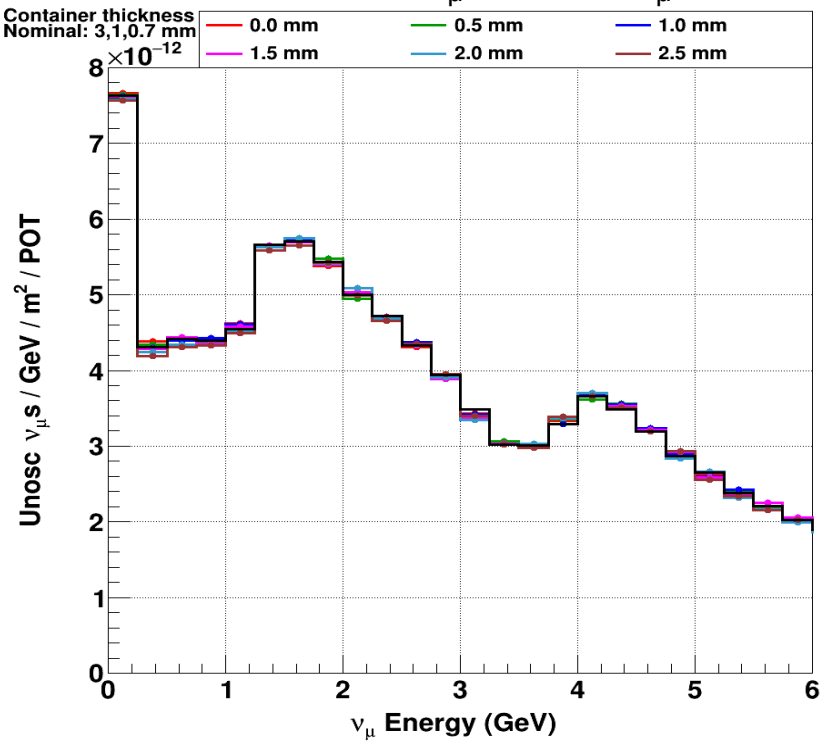


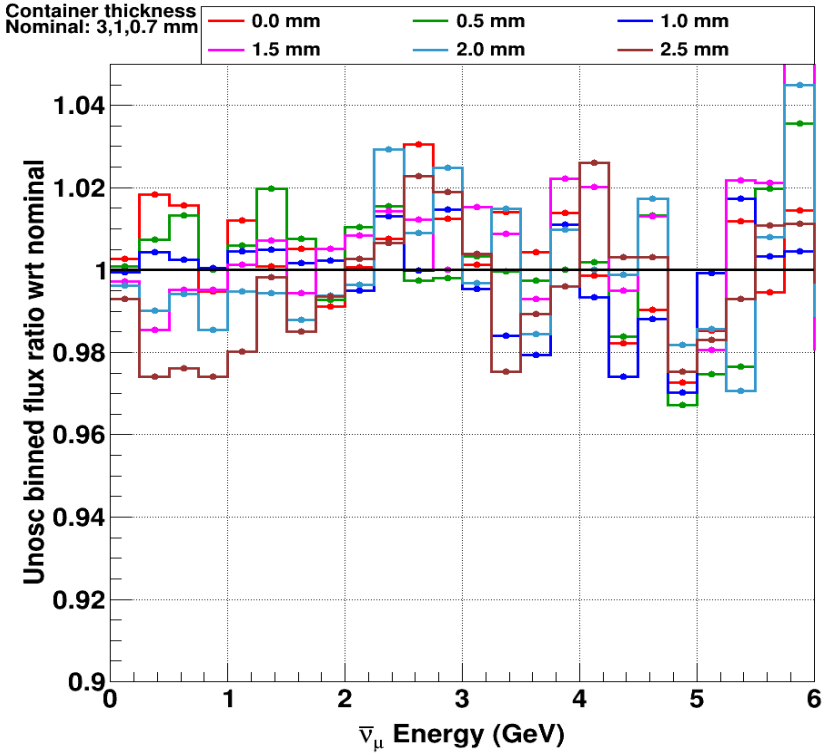


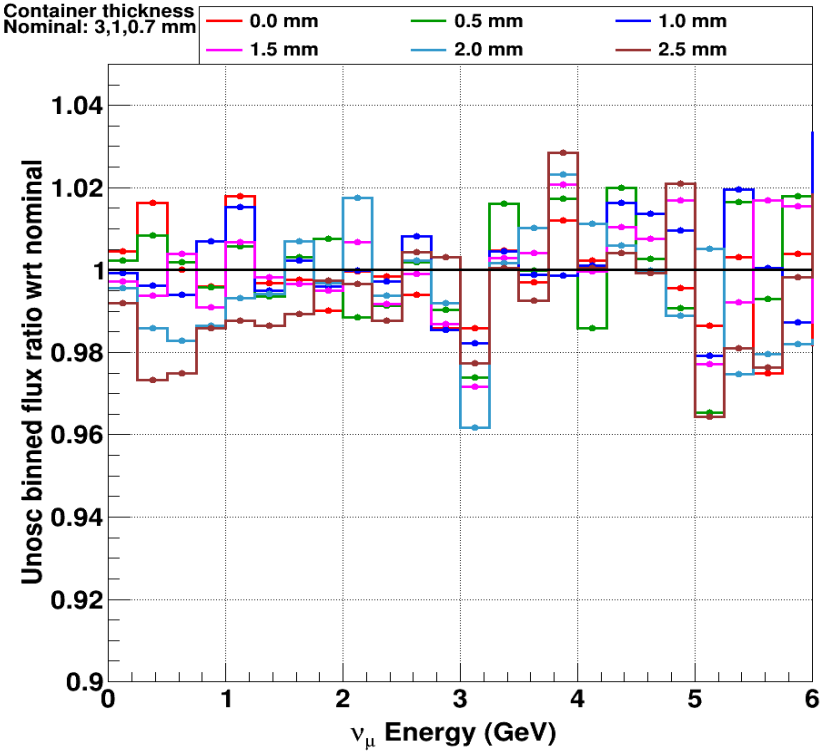


L = 1.8 m, f_h = 0.5 (half solid) wrong sign bkg: anti-ν_μ (left) & ν_μ (right)









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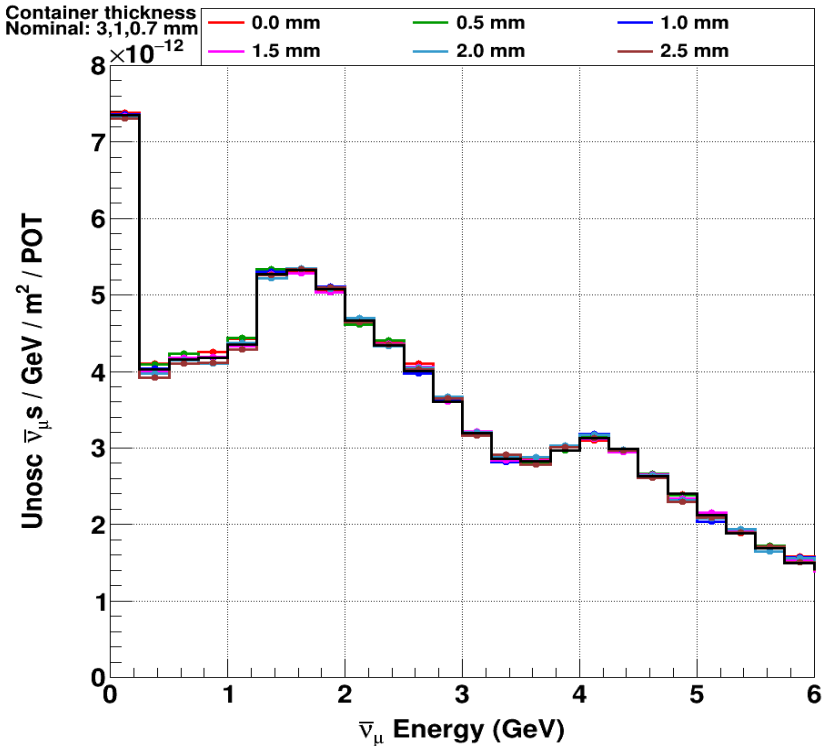
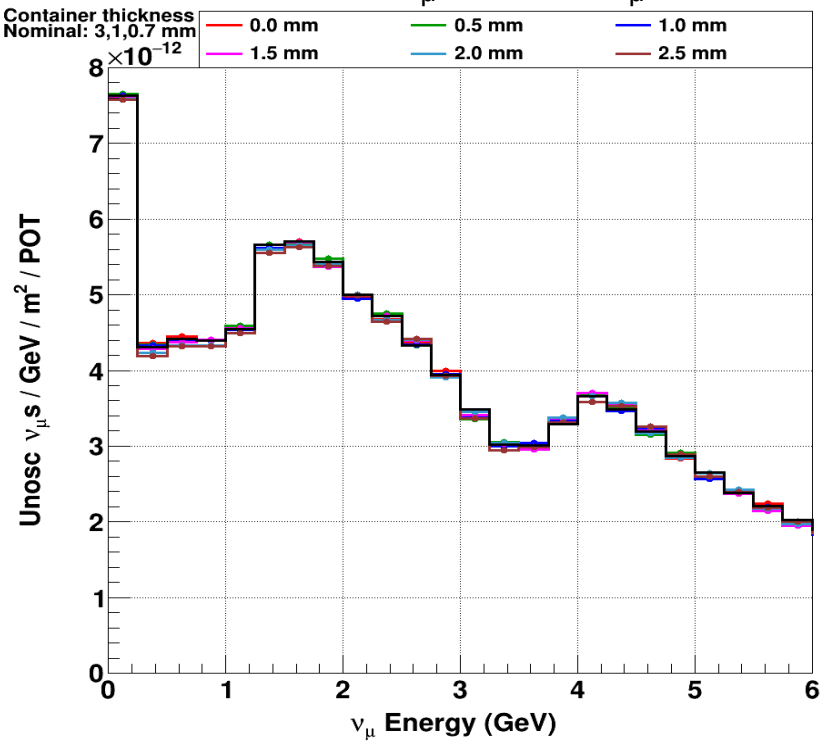
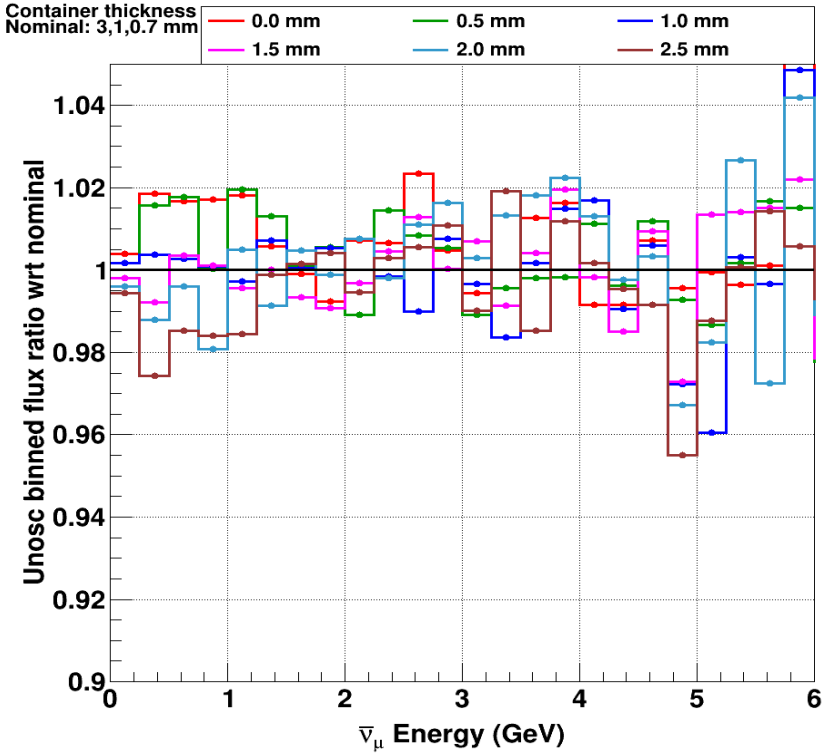
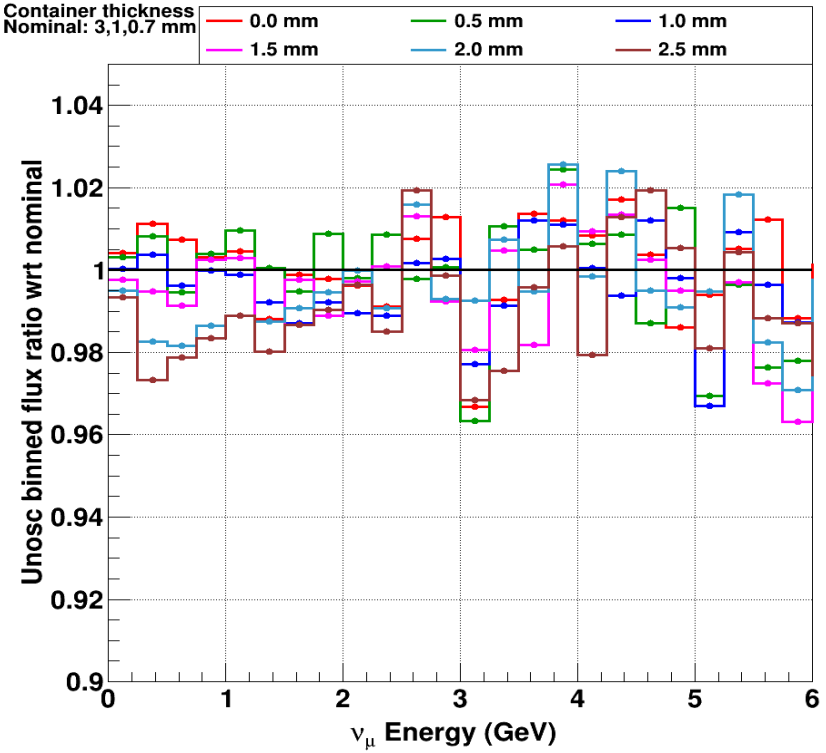
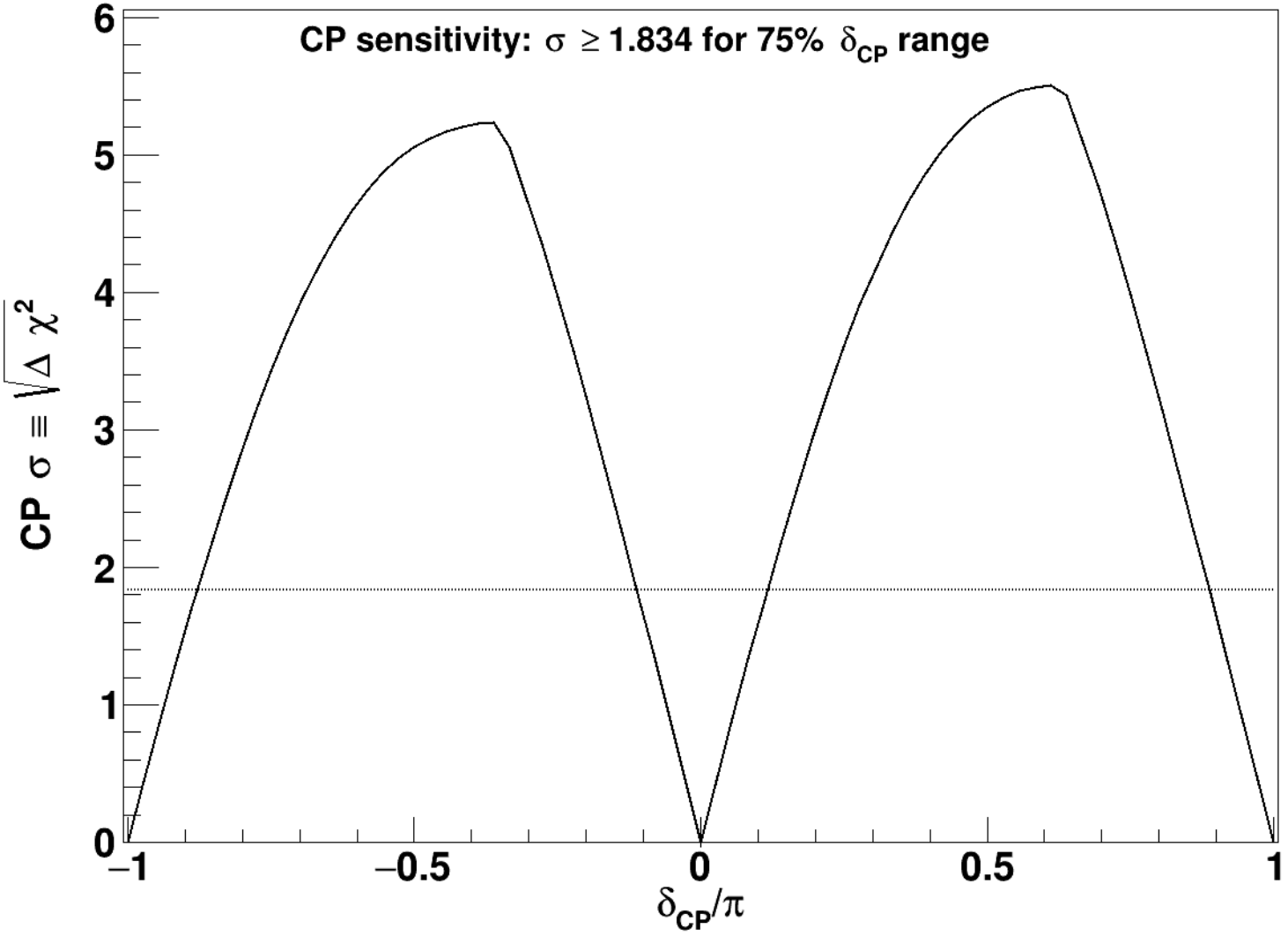




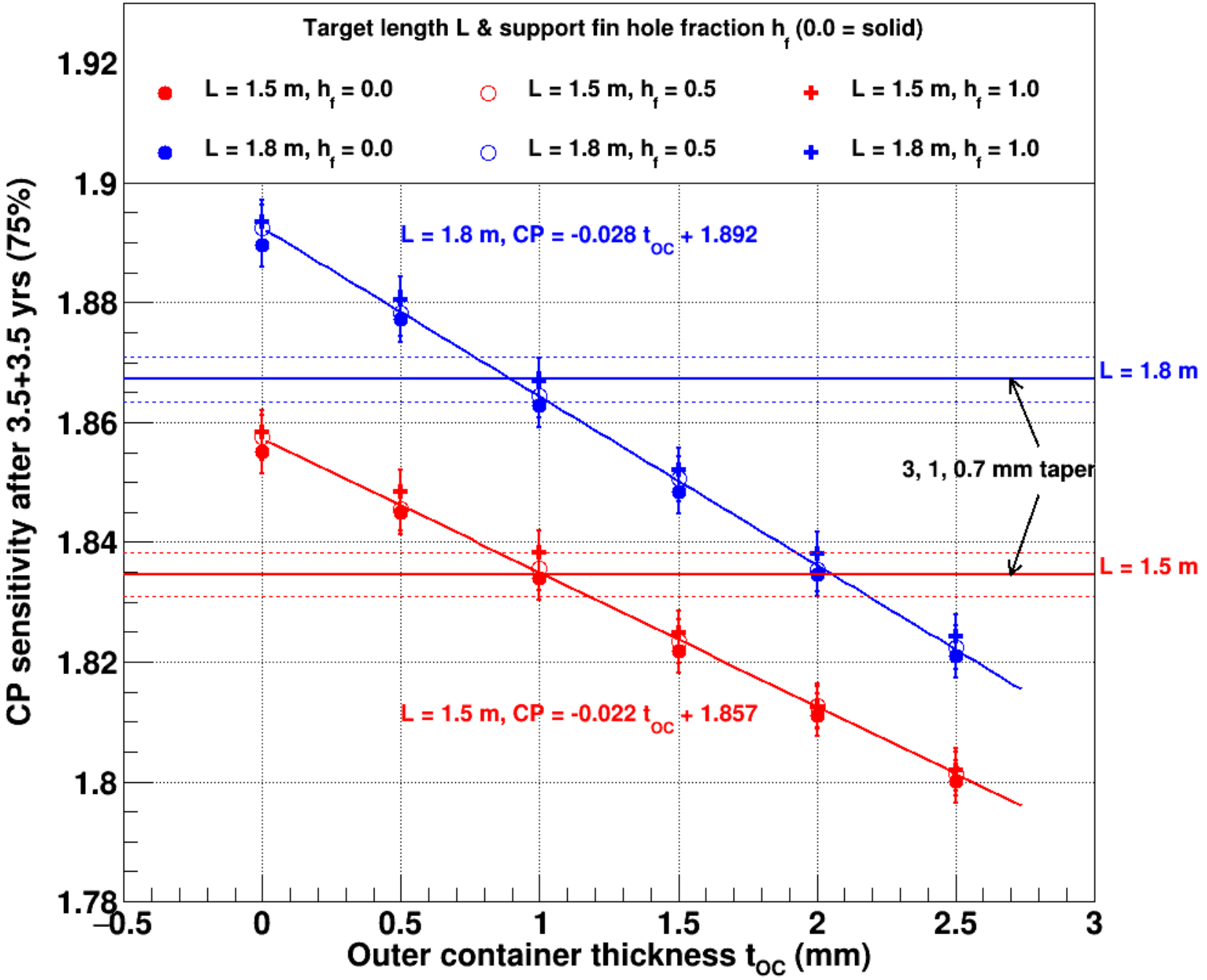




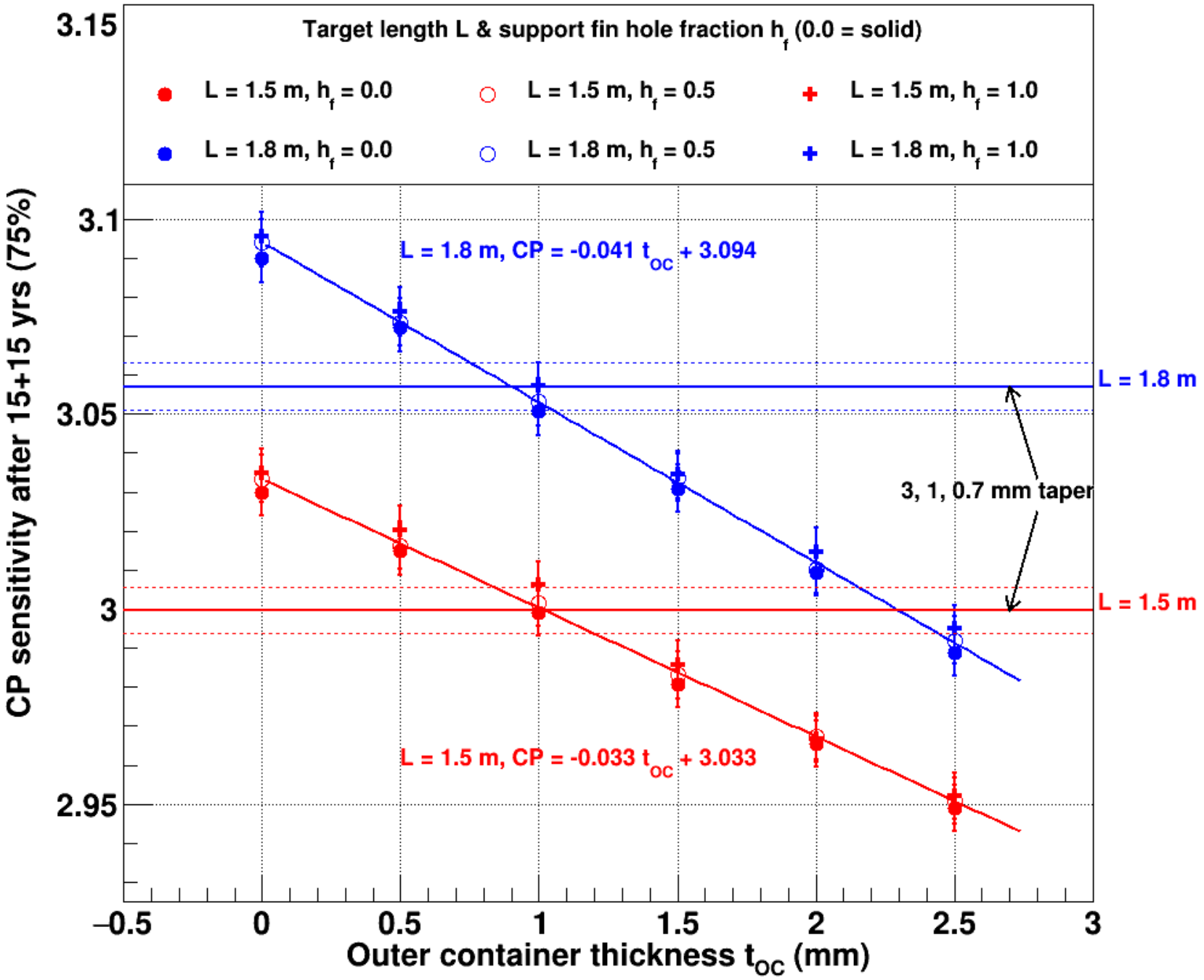
CP sensitivity for L = 1.5 m, t_{OC}= 1 mm (solid fins)
3.5 ν + 3.5 anti-ν run years, 1.2 MW, 1.1x10^{21} POT/year



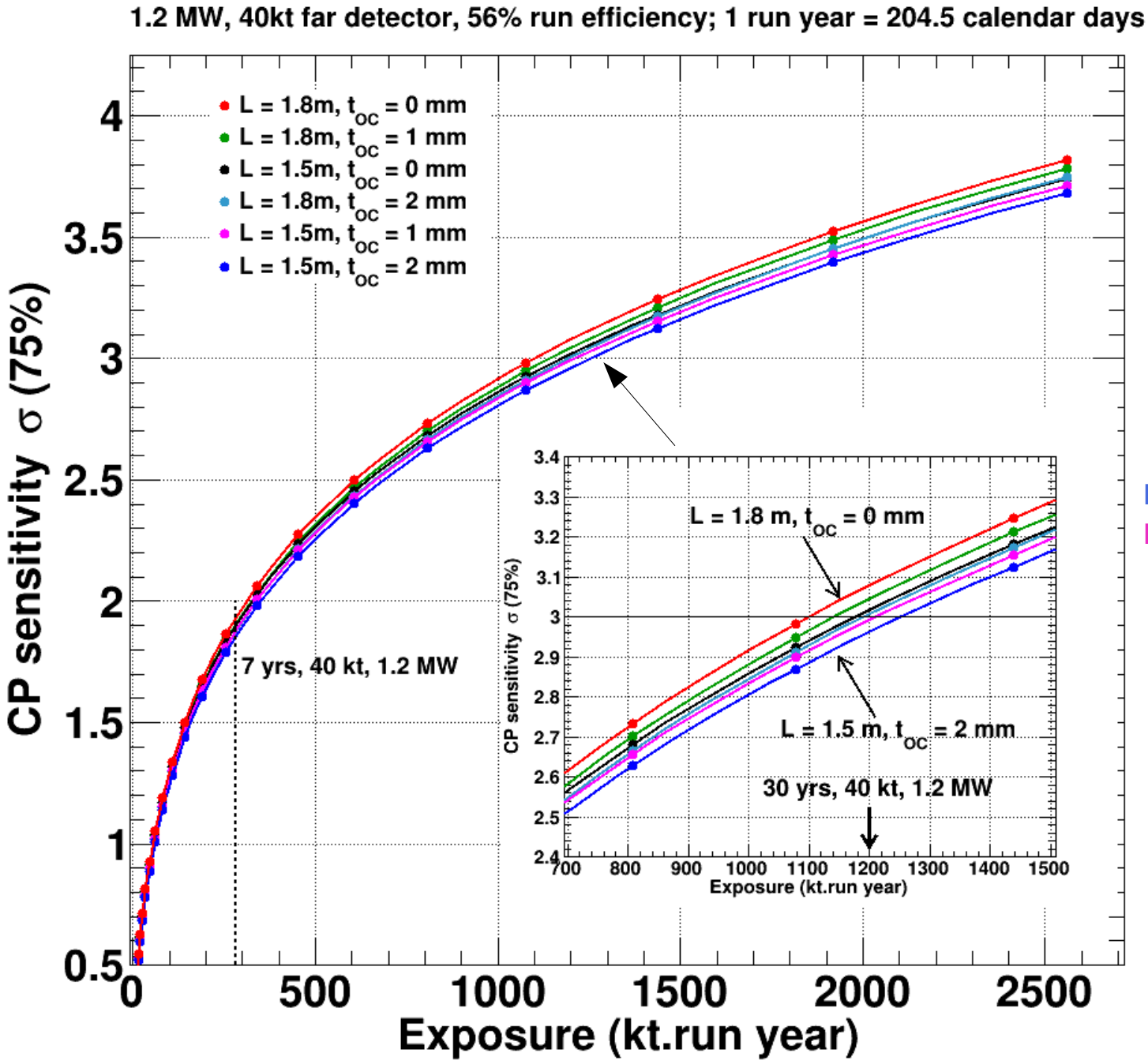
CP sensitivities (75% δ_{CP} range, **3.5+3.5 run yrs**, 1.2 MW)



CP sensitivities (75% δ_{CP} range, **15+15 run yrs**, 1.2 MW)



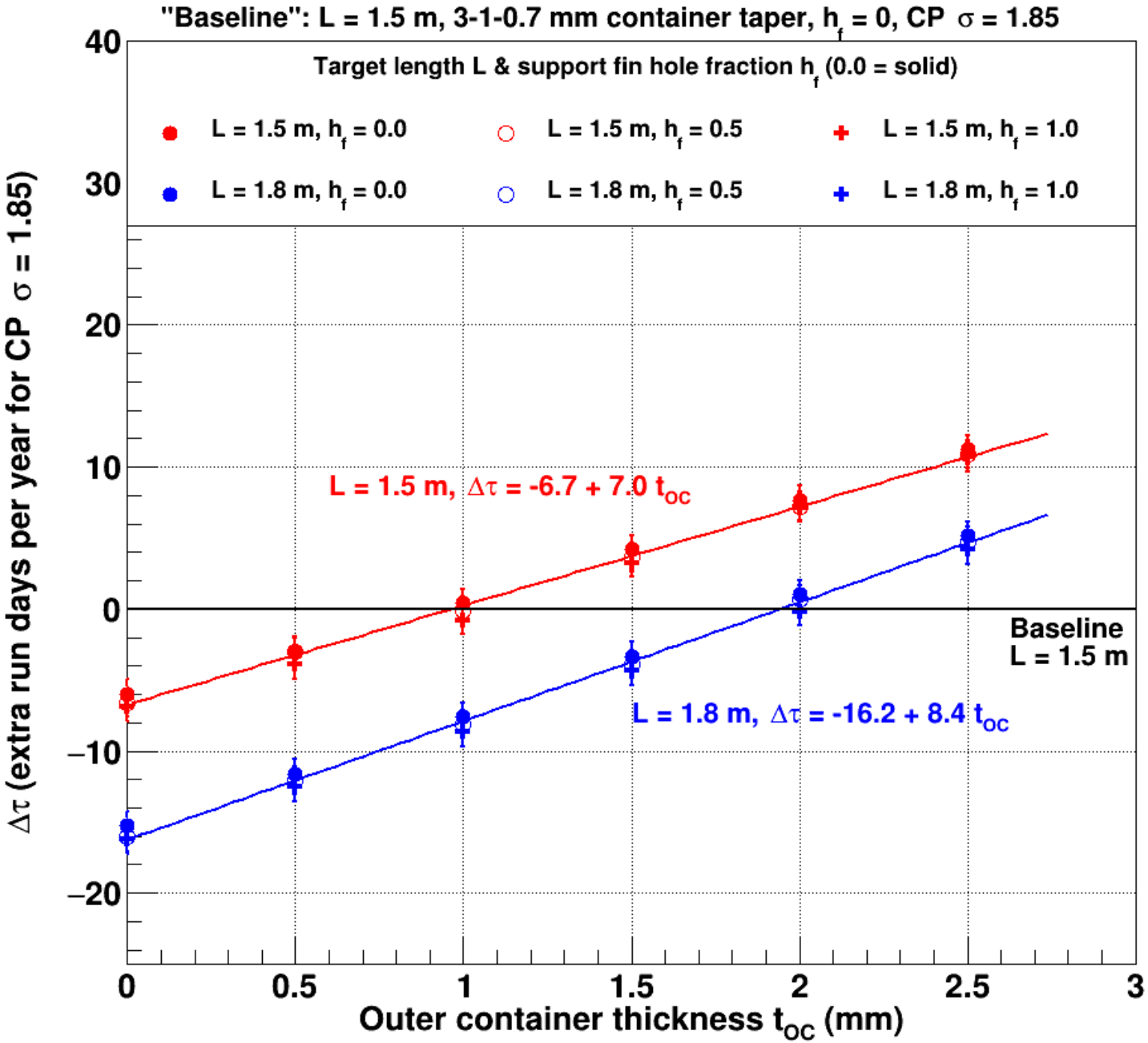
CP sensitivity vs exposure (solid support fins)



L=1.8m, t_{oc}=2mm
L=1.5m, t_{oc}=1mm

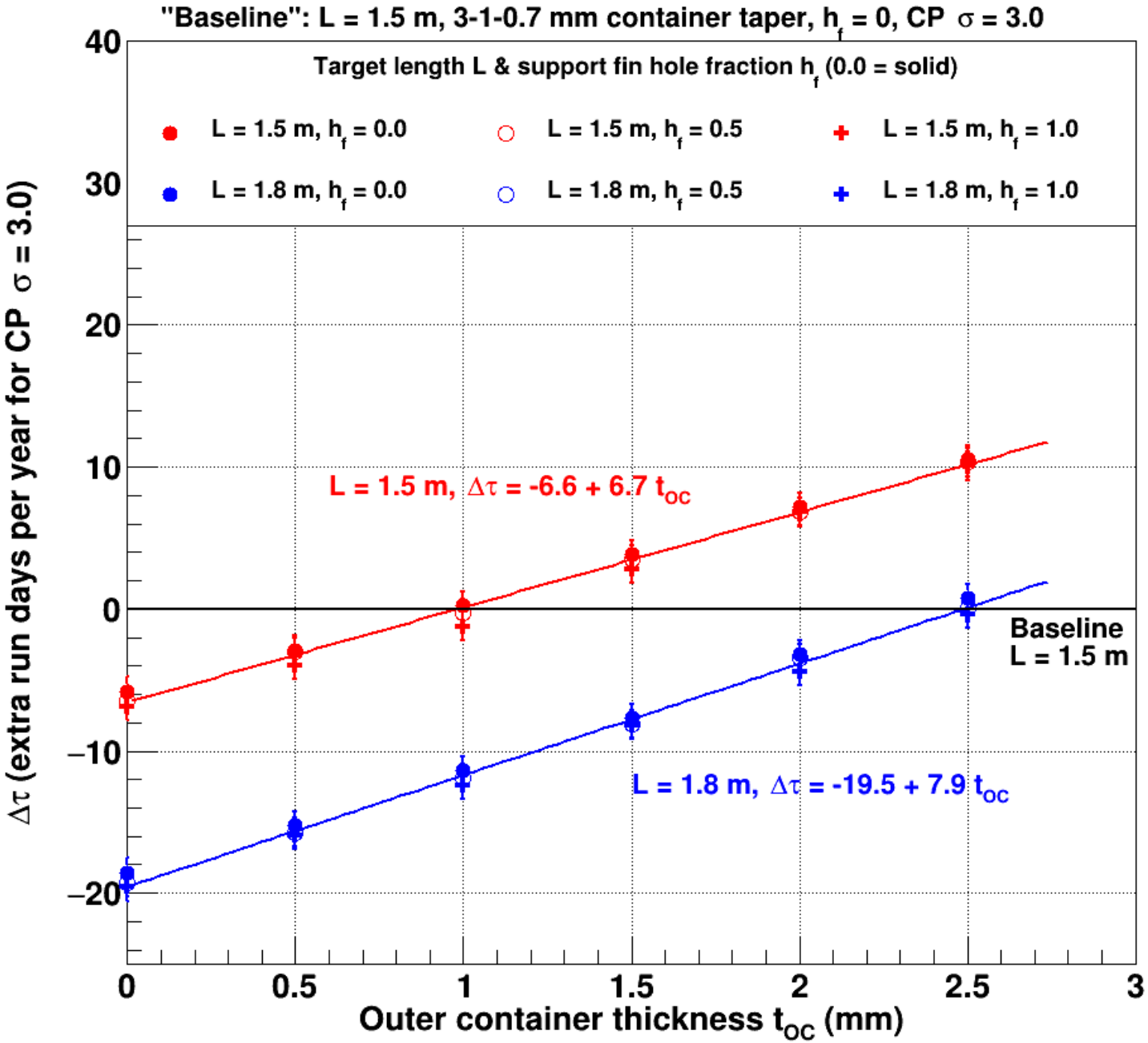
detector mass (40 kt) x run time

Extra run days per year to match **L = 1.5 m**, CP **σ = 1.85**



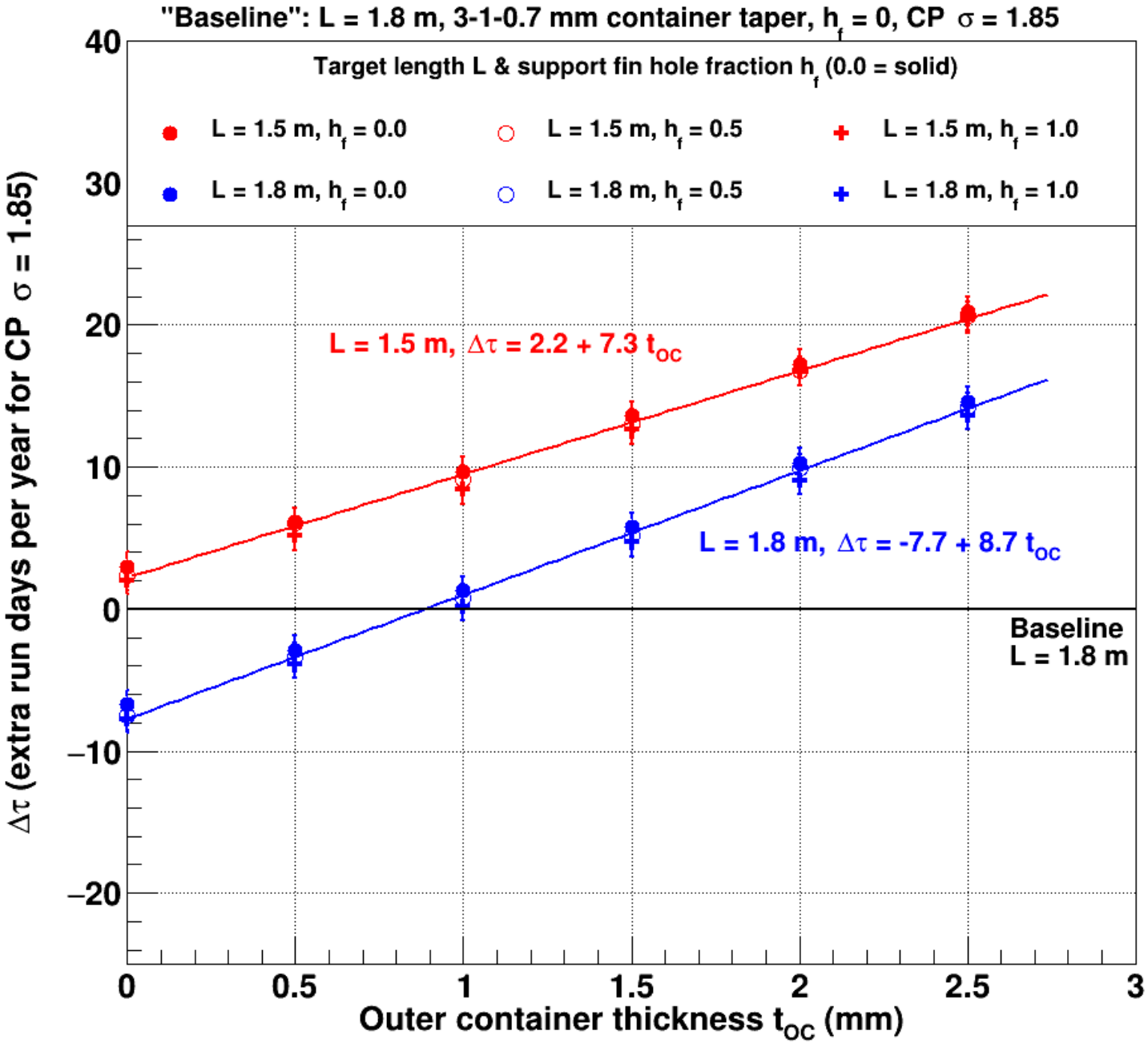
Δτ extra days/yr = fractional exposure change x 204.5 days; same 40 kt far detector mass

Extra run days per year to match **L = 1.5 m**, CP **σ = 3.0**



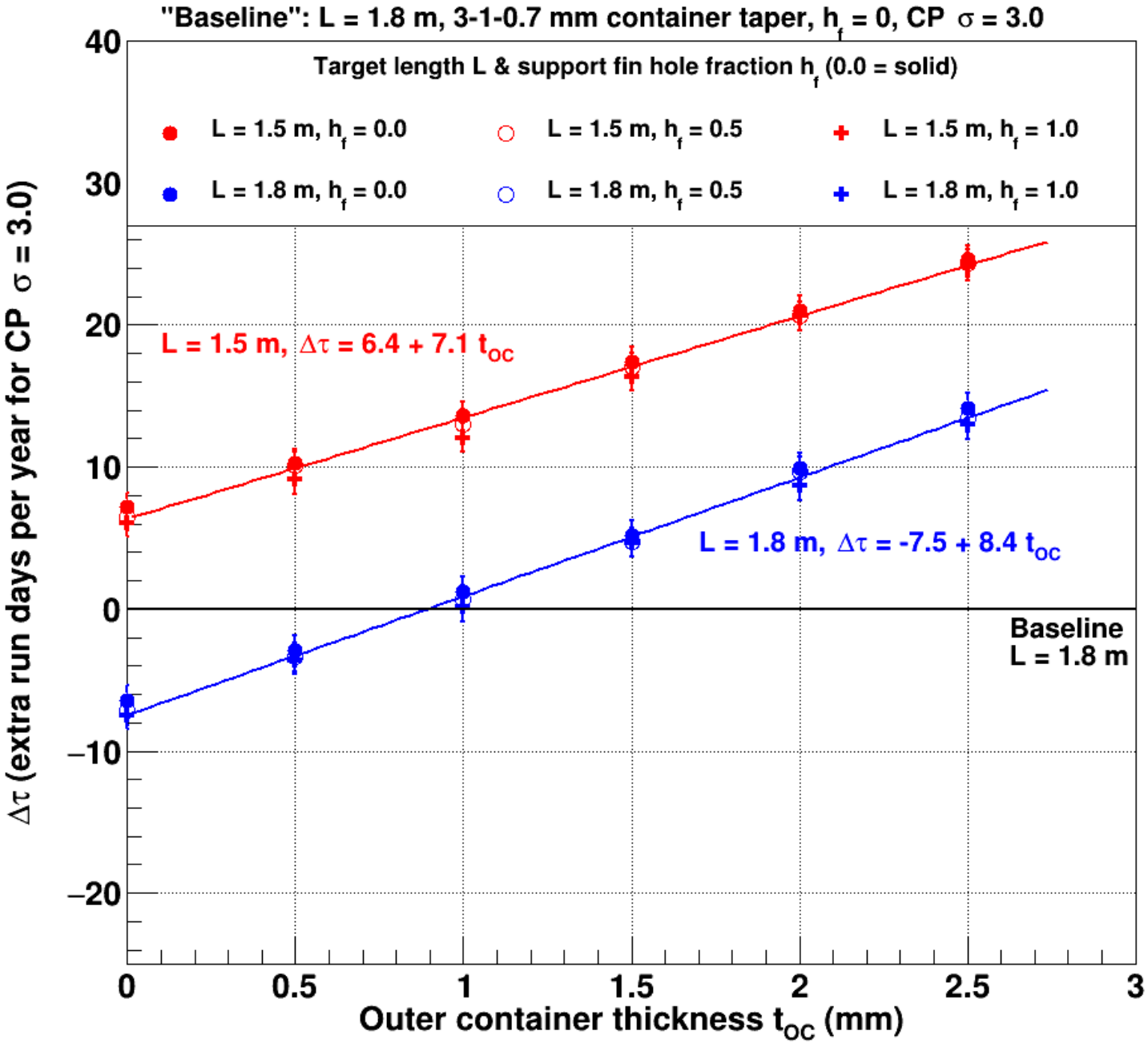
Δτ extra days/yr = fractional exposure change x 204.5 days; same 40 kt far detector mass

Extra run days per year to match **L = 1.8 m**, CP **σ = 1.85**



Δτ extra days/yr = fractional exposure change x 204.5 days; same 40 kt far detector mass

Extra run days per year to match **L = 1.8 m**, CP **σ = 3.0**



Δτ extra days/yr = fractional exposure change x 204.5 days; same 40 kt far detector mass

Summary

- Investigated physics performance, varying:
  - **outer container thickness** (0 to 2.5 mm in 0.5 mm steps): **dominant effect**
  - **target support fin material** (solid, half-solid or 2 mm edge): **small changes**

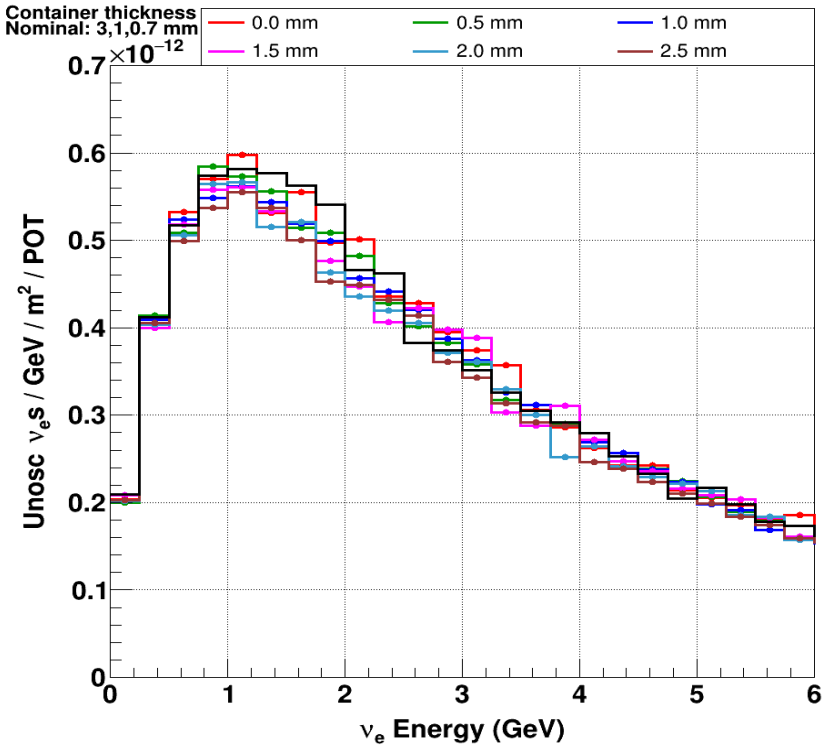
- **Performance** gets **worse** as **outer container thickness increases**
  - More transverse material to scatter π away from horn focusing trajectories
  - All π have to pass through the container (or the DS beam window)
  - **Need outer container thickness as thin as practicable (within engineering constraints)**
    - **3 to 1 to 0.7 mm taper is probably a good compromise (approx equivalent to t_{oc} = 1 mm)**

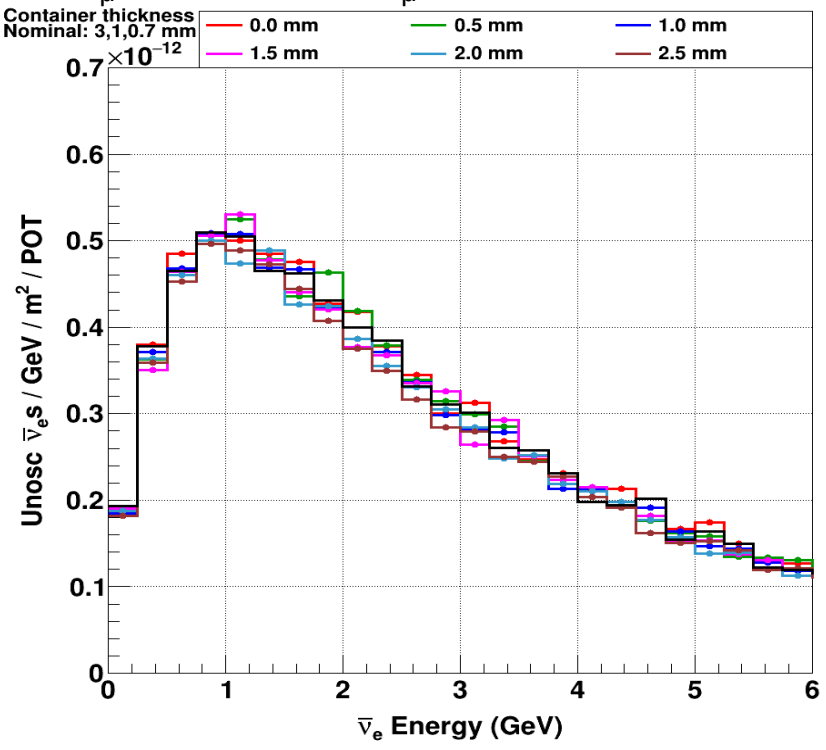
- **Small performance changes** with **material fraction** for ~1 mm thick **target support fins** (±45, ±135 deg)
  - Only π trajectories near these angles are affected (within approx ±1 deg arc span)
  - Slightly better performance with less material: introduce holes along the fins (also good for cooling)

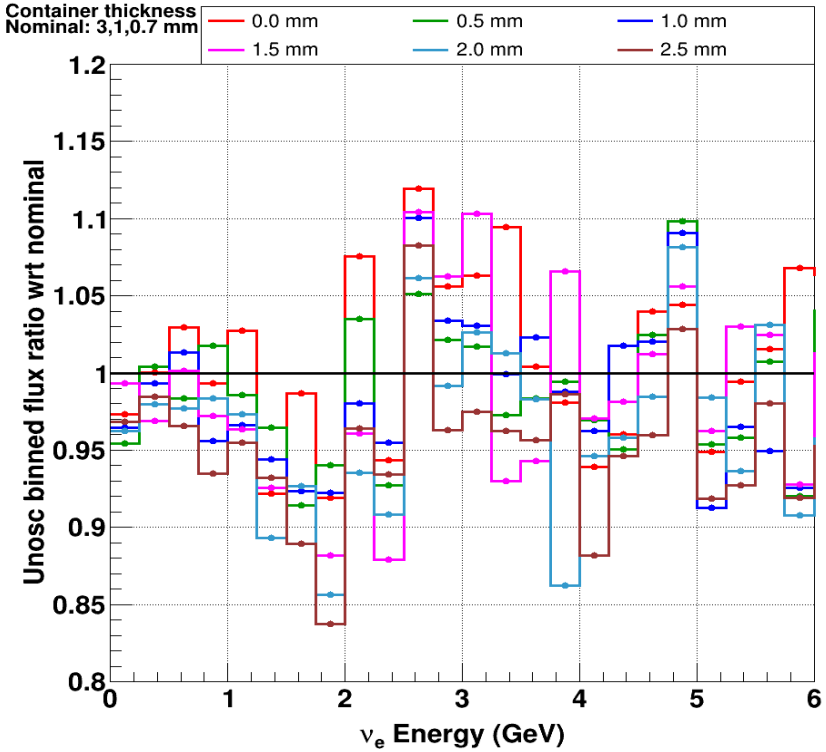
- **Increasing container thickness** t_{oc} from **1 to 2.5 mm**:
  - Binned **signal neutrino flux spectrum decreases** by **5% to 10%** (E_ν = 2 to 4 GeV)
  - Wrong sign backgrounds change by ~±2%, sometimes more

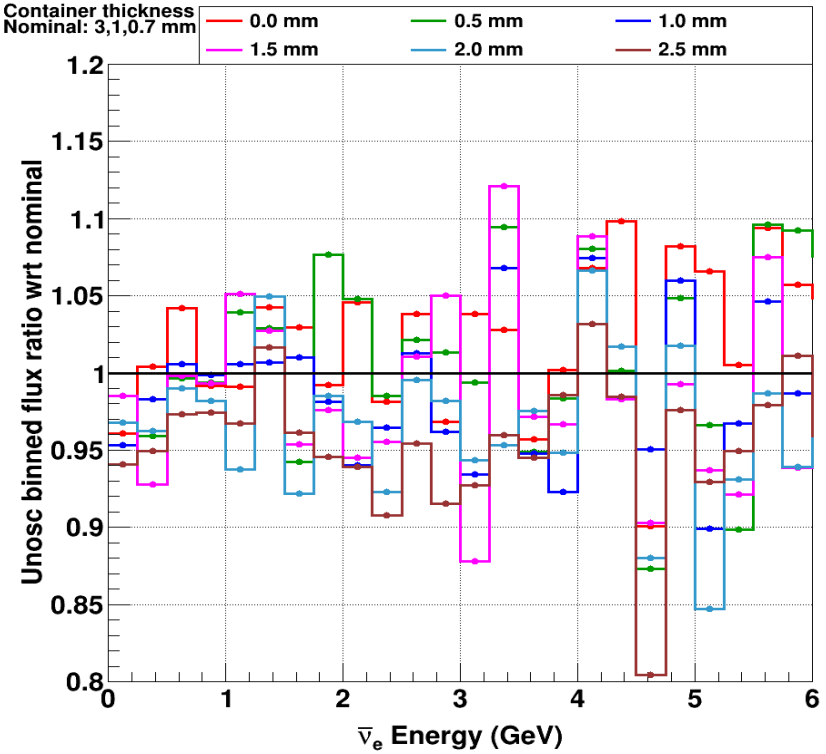
- **CP sensitivity** (1.2 MW, 40 kt far detector) vs **outer container thickness t_{oc}**: **linear dependence**
  - **L = 1.8 m with t_{oc} = 2 - 2.5 mm** equivalent to **L = 1.5 m with t_{oc} = 1 mm** (CP σ = 1.85 - 3.00)

L = 1.5 m, f_h = 0 (solid fins) ν_e bkg: ν_μ (left) & anti-ν_μ (right) running

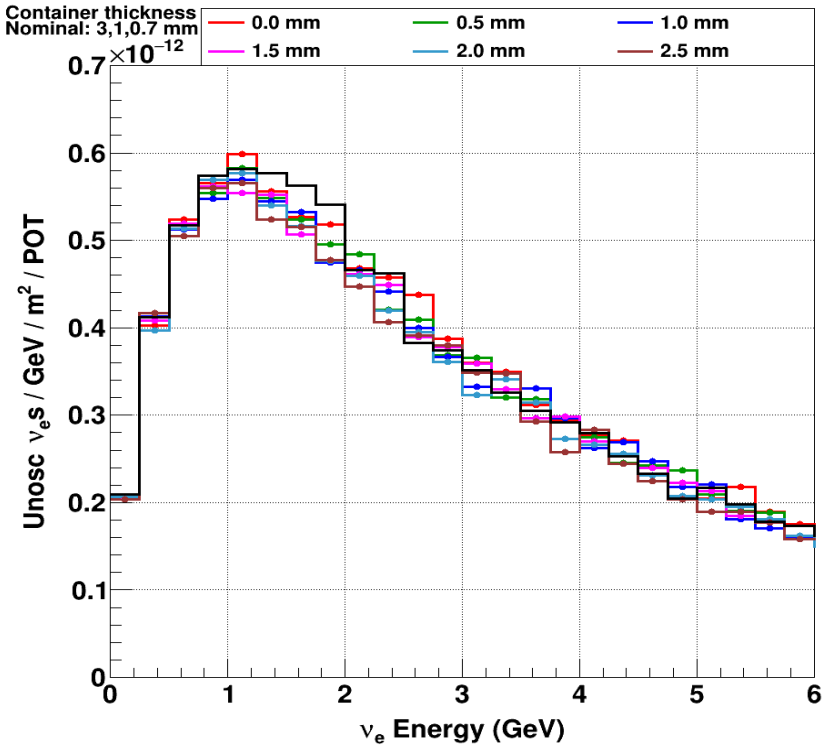


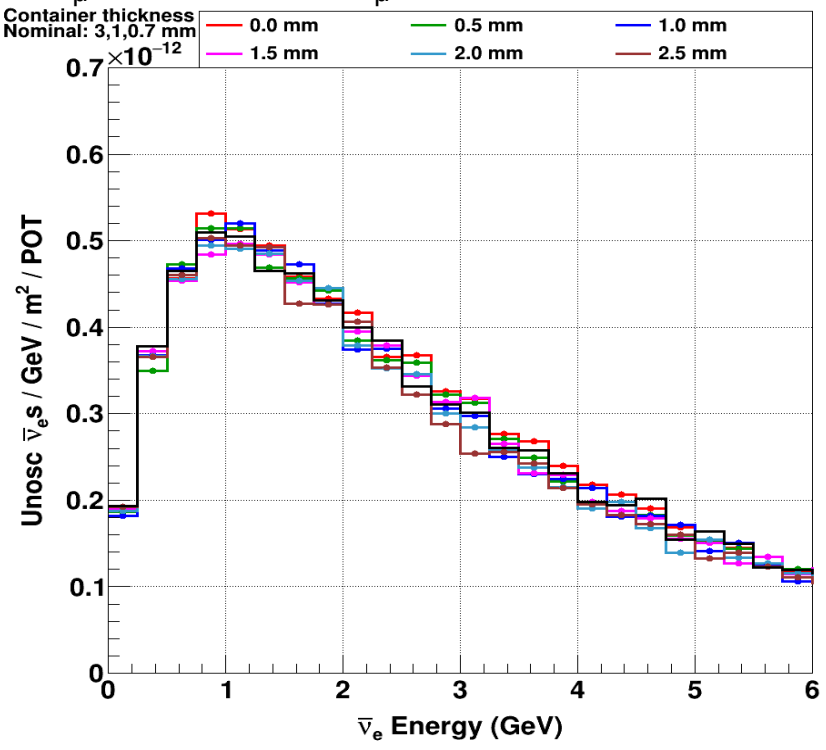


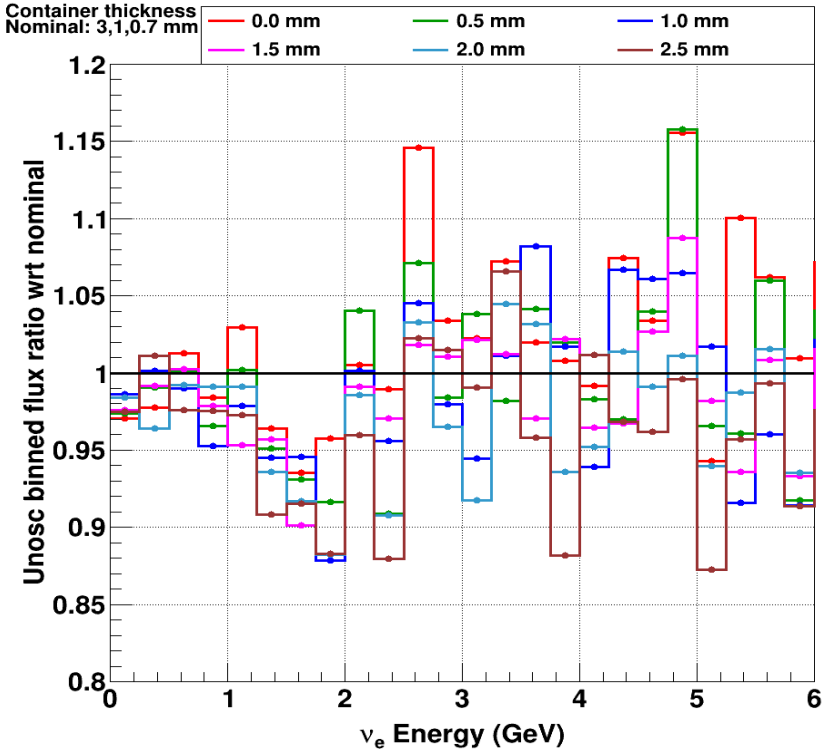


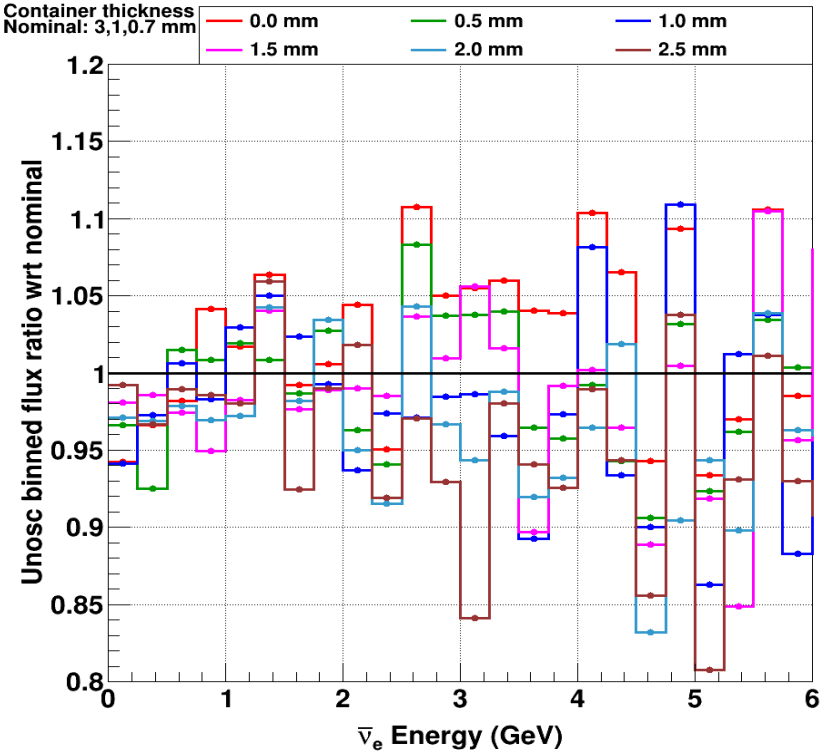


L = 1.5 m, f_h = 1 (fin edge) ν_e bkg: ν_μ (left) & anti-ν_μ (right) running

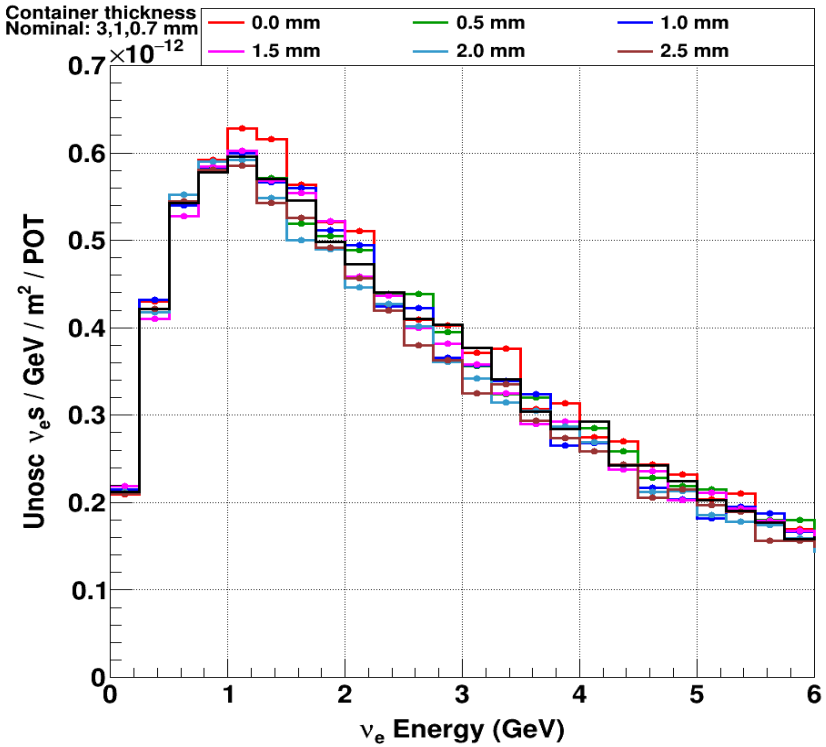


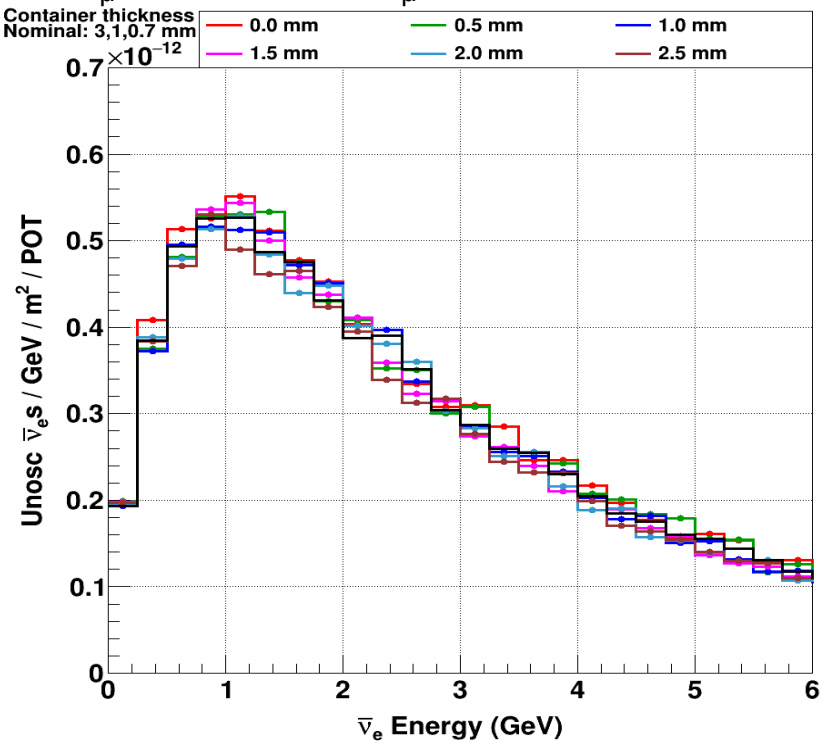


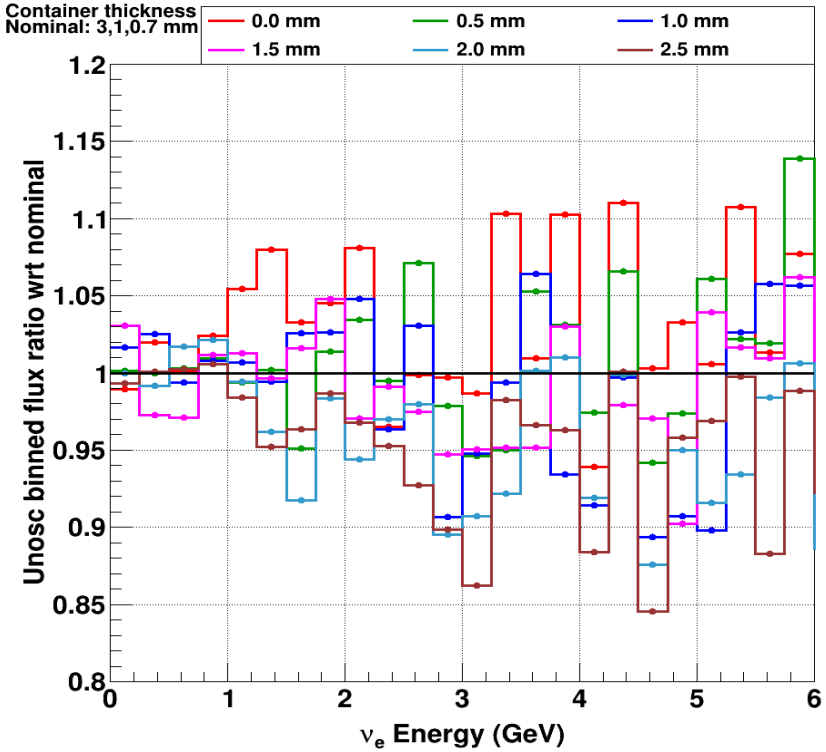


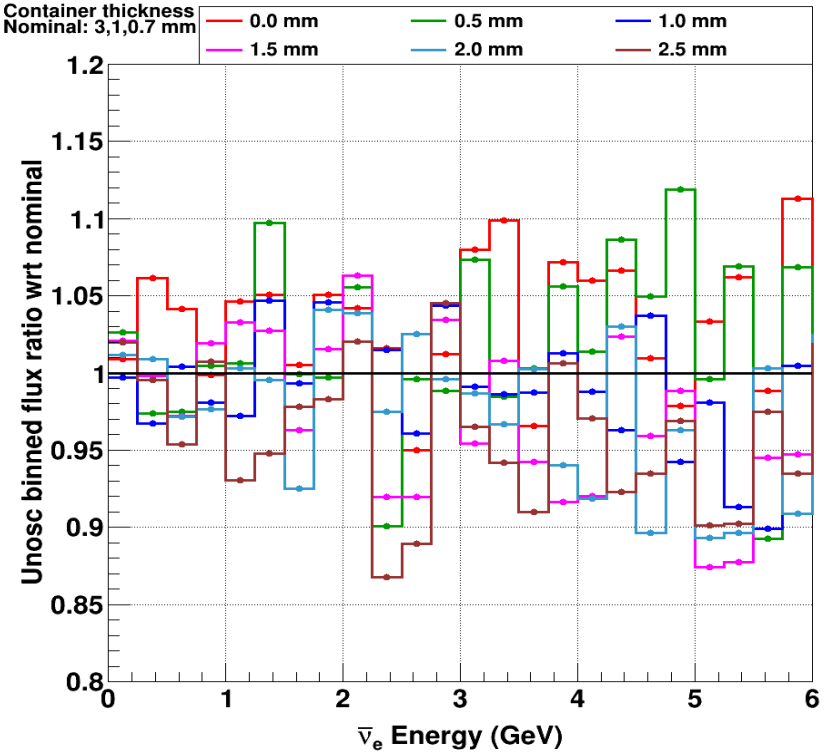


L = 1.8 m, f_h = 0 (solid fins) ν_e bkg: ν_μ (left) & anti-ν_μ (right) running

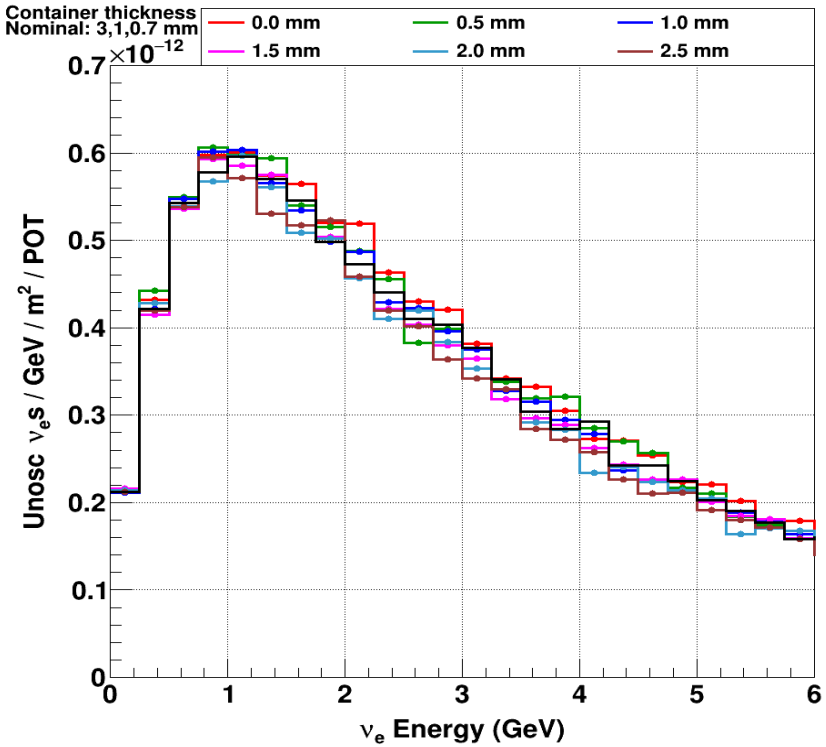


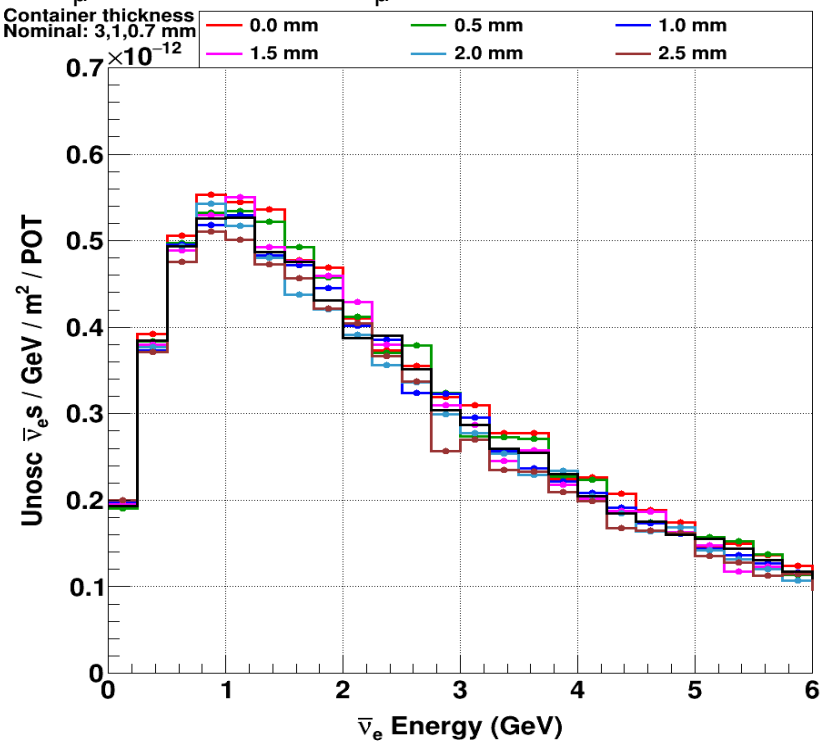


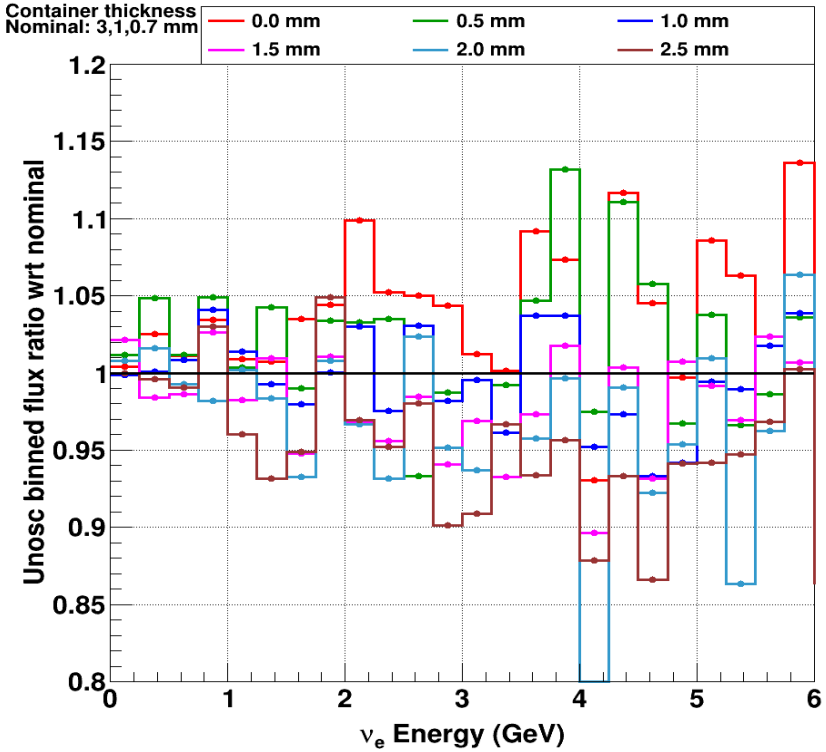


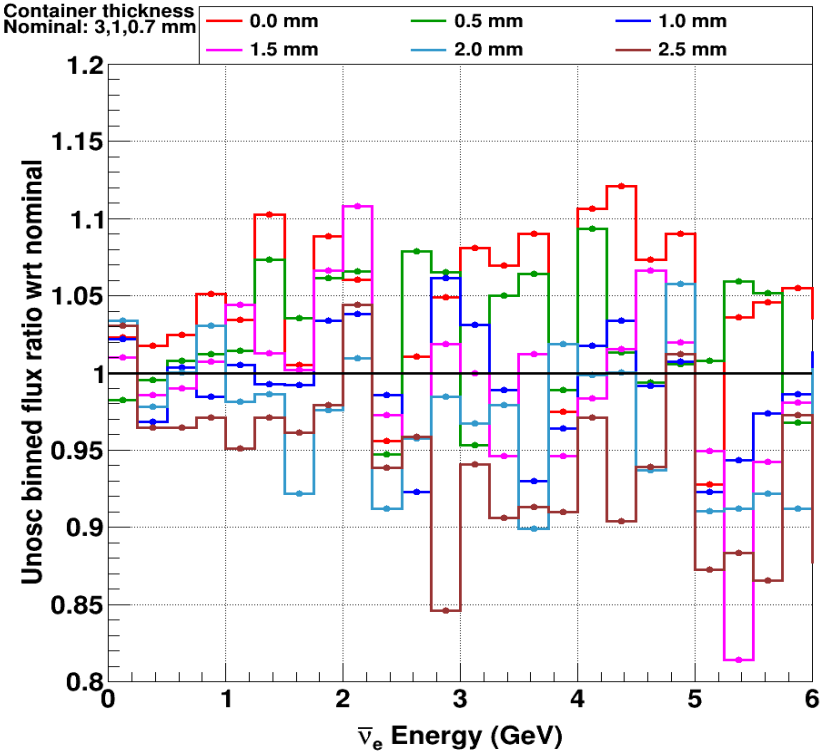


L = 1.8 m, f_h = 1 (fin edge) ν_e bkg: ν_μ (left) & anti-ν_μ (right) running

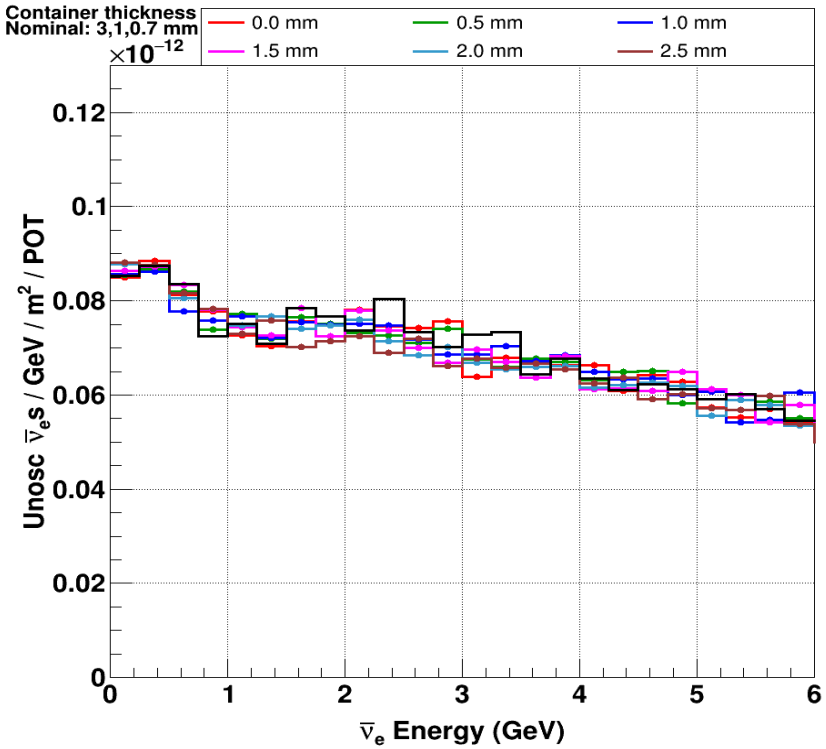


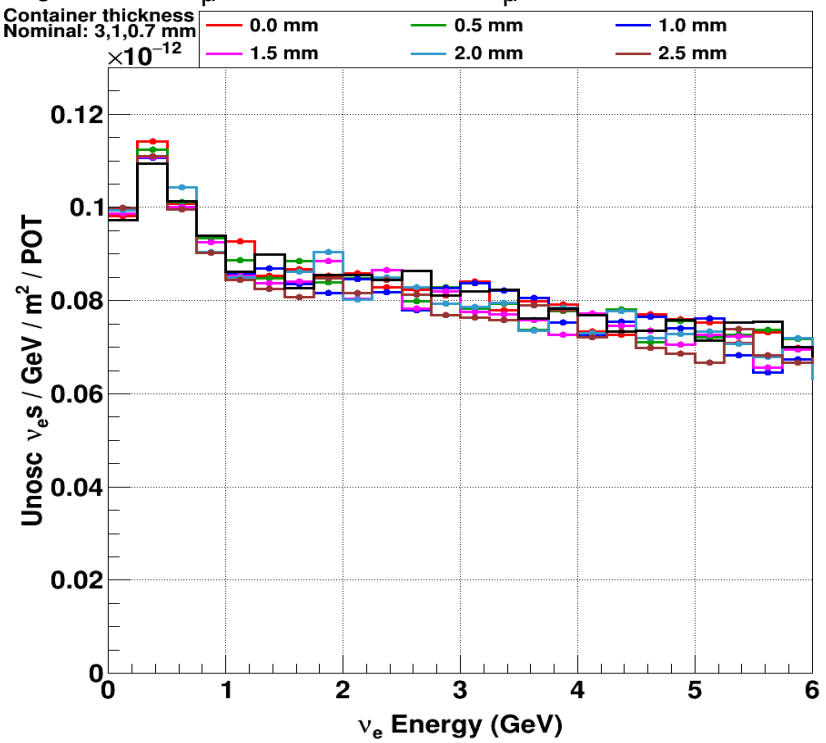


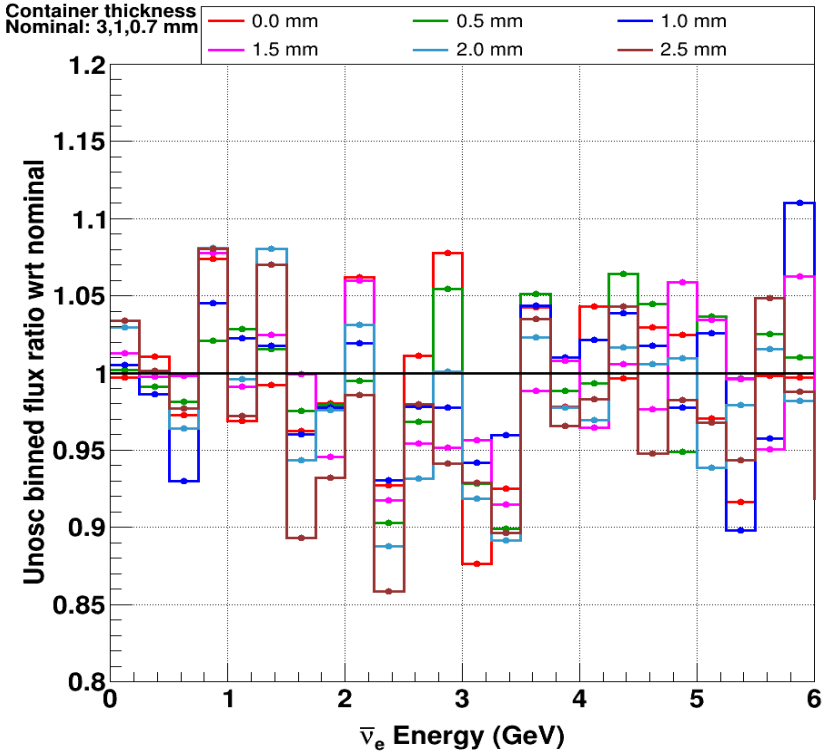


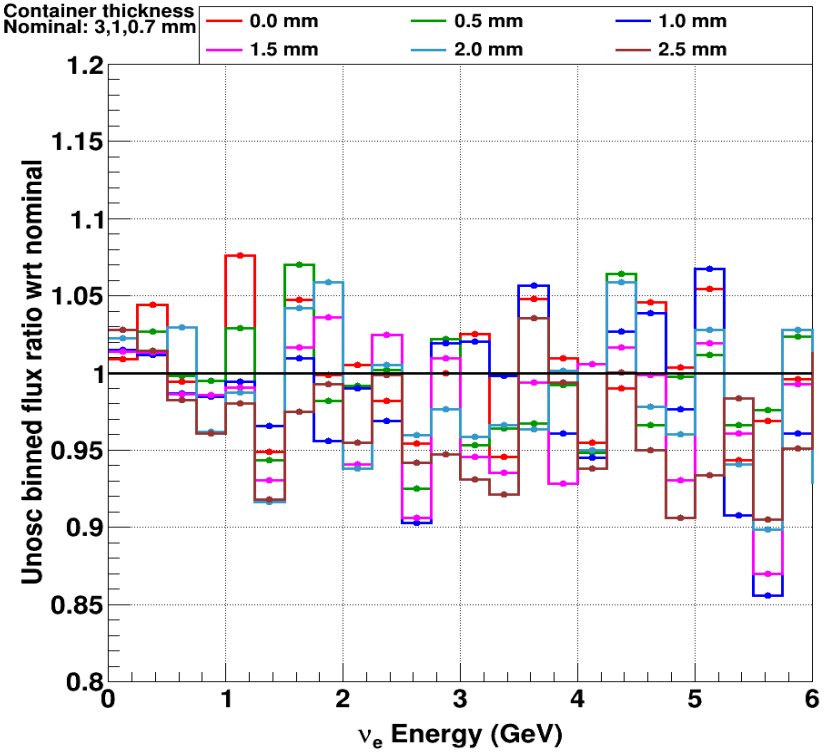


L = 1.5 m, f_h = 0 (solid fins) anti-ν_e bkg: ν_μ (left) & anti-ν_μ (right) running

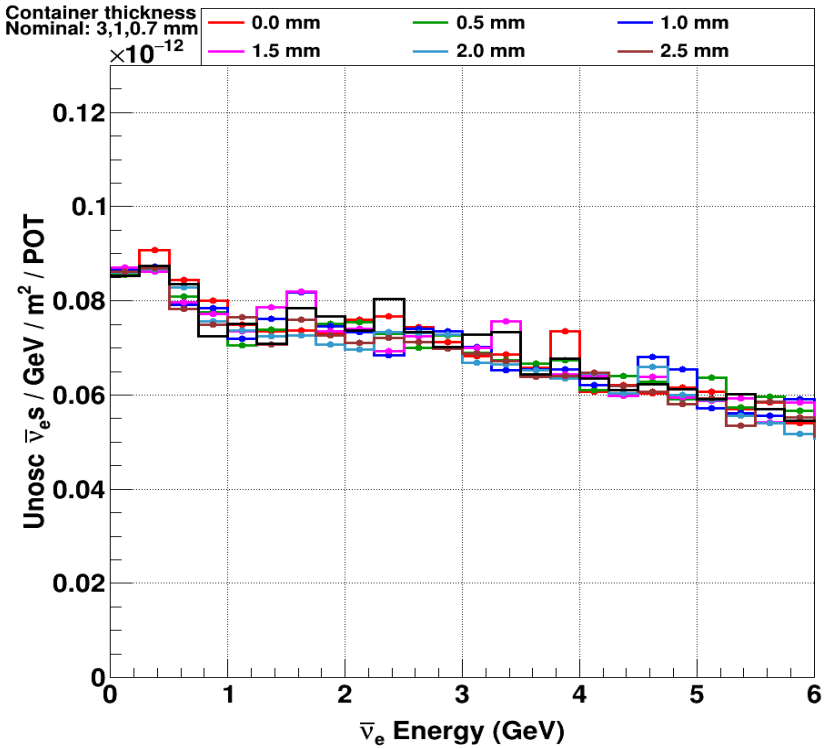


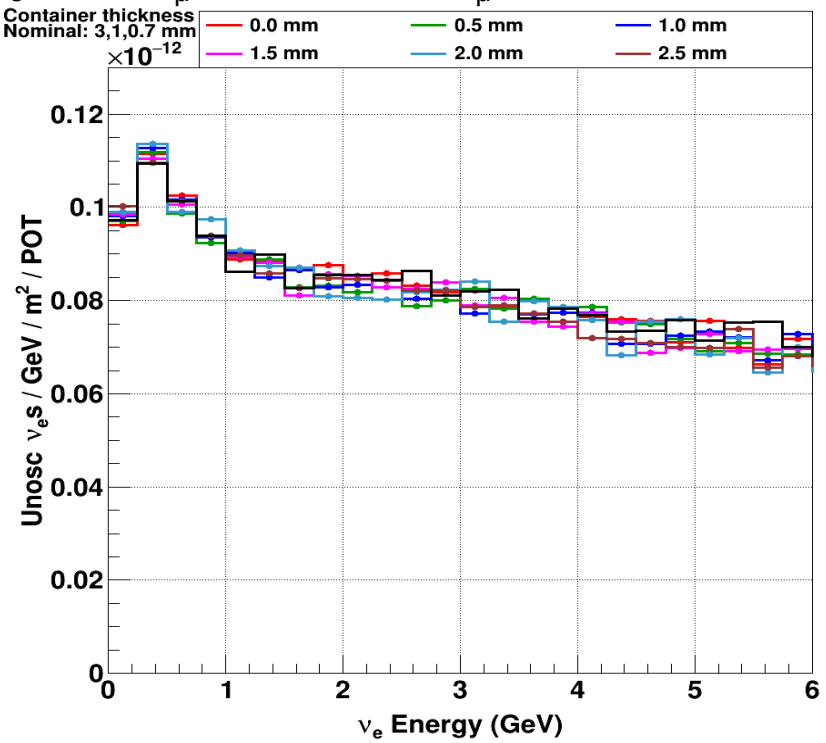


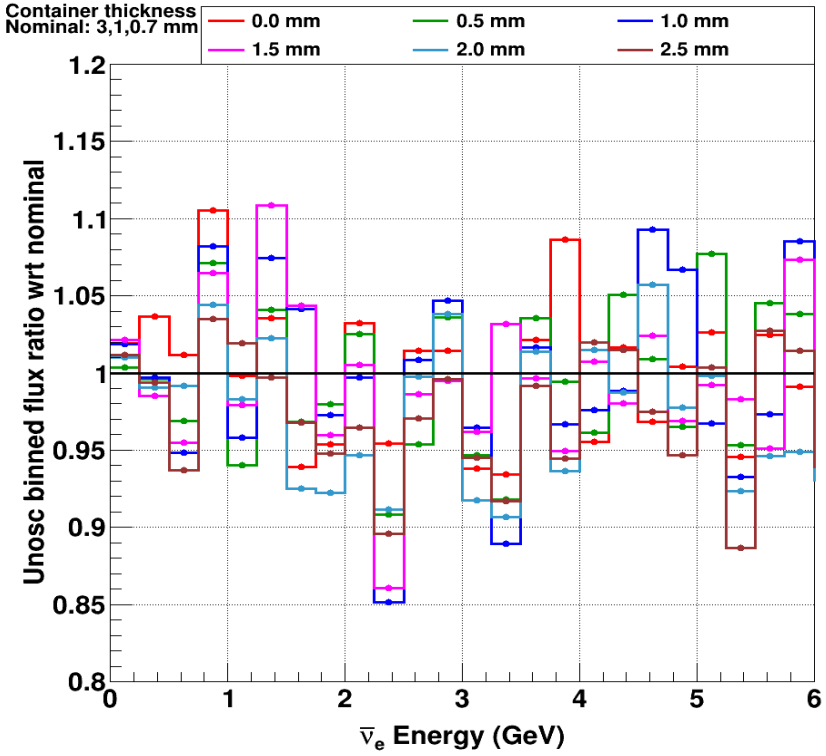


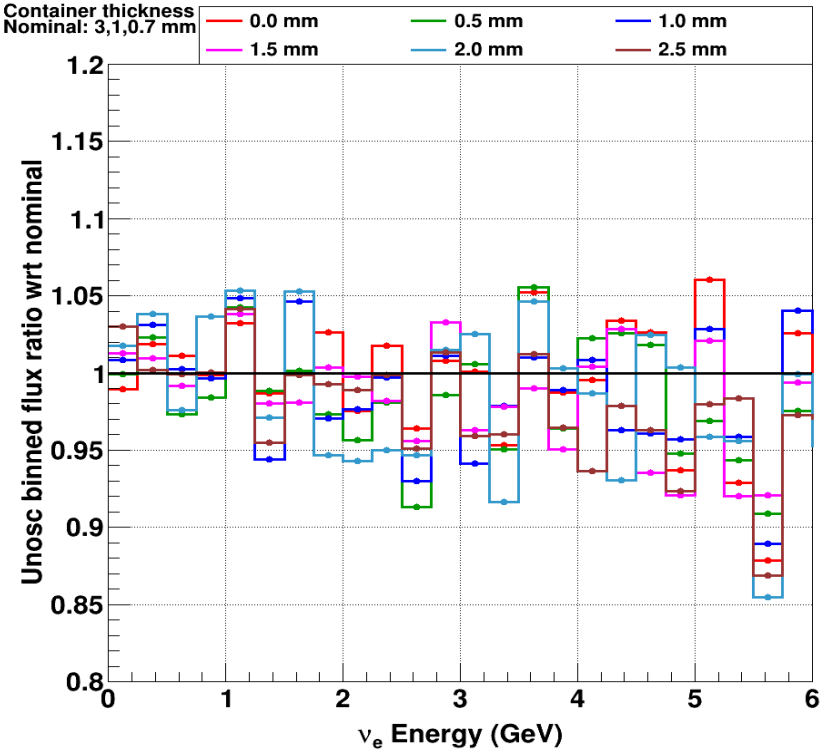


L = 1.5 m, f_h = 1 (fin edge) anti-ν_e bkg: ν_μ (left) & anti-ν_μ (right) running

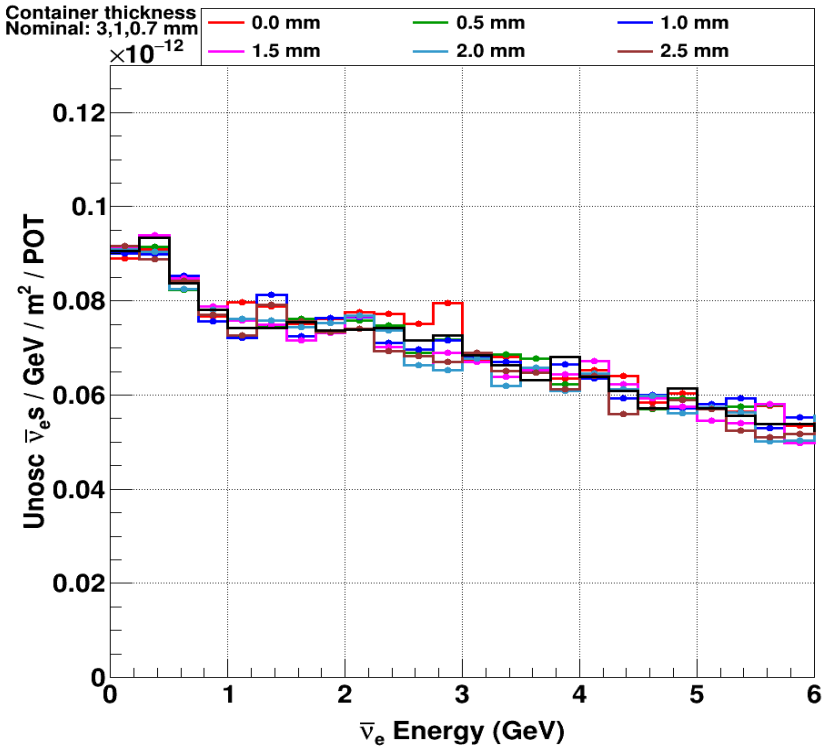


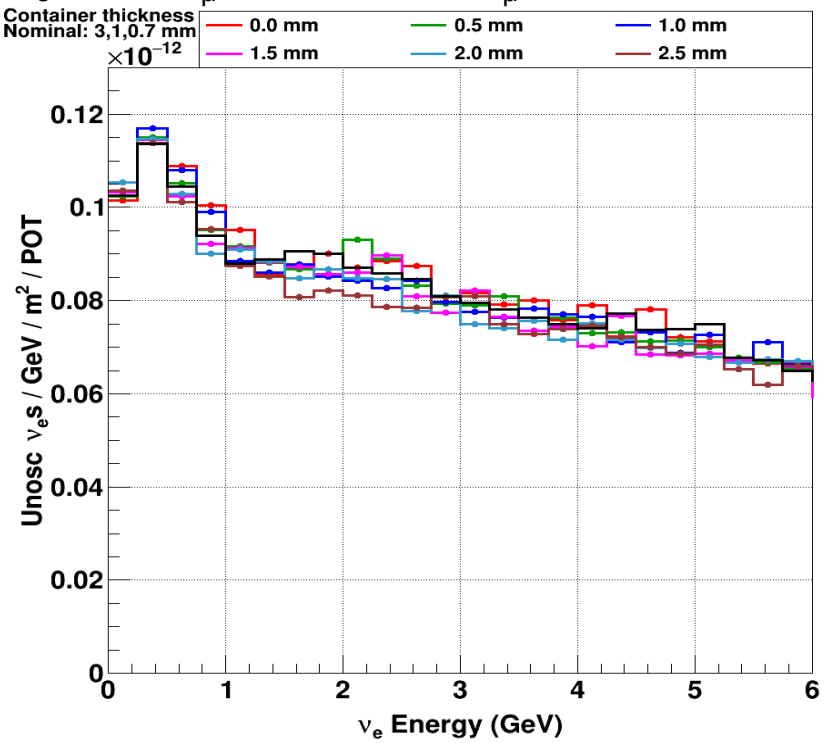


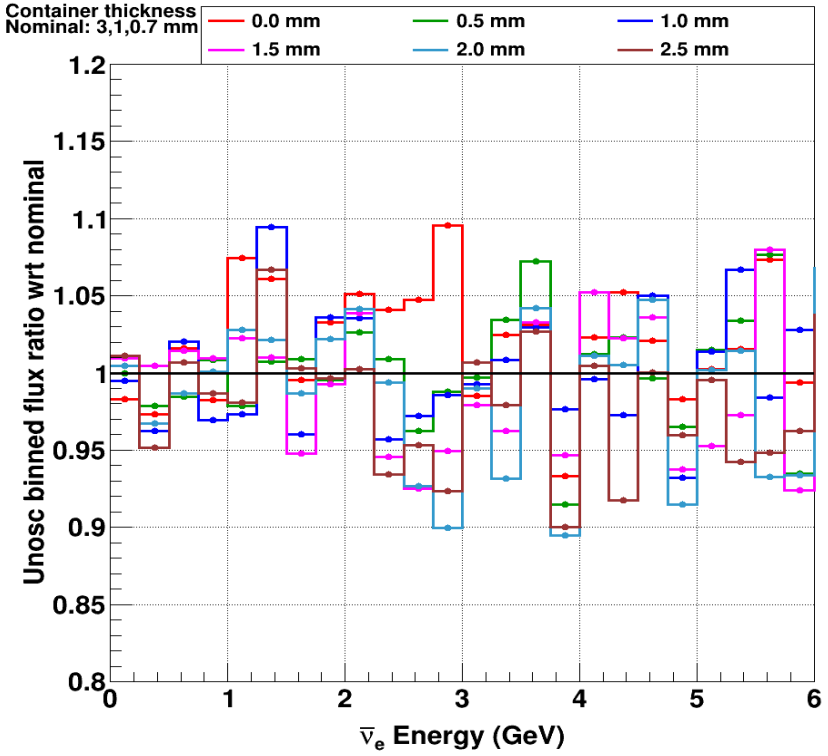


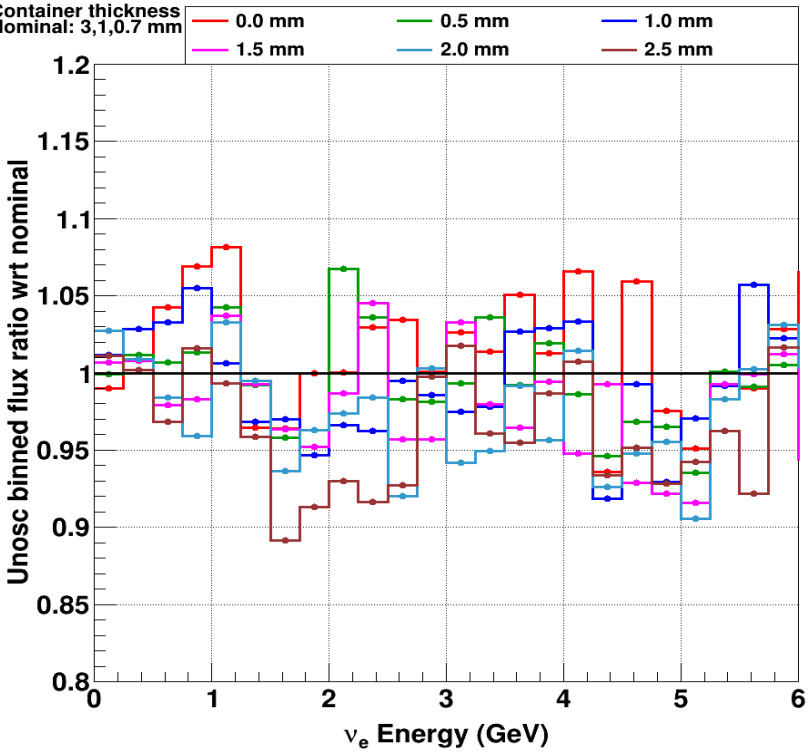


L = 1.8 m, f_h = 0 (solid fins) anti-ν_e bkg: ν_μ (left) & anti-ν_μ (right) running









L = 1.8 m, f_h = 1 (fin edge) anti-ν_e bkg: ν_μ (left) & anti-ν_μ (right) running