

Neutrino fluxes and CC interaction rates with LEMNB

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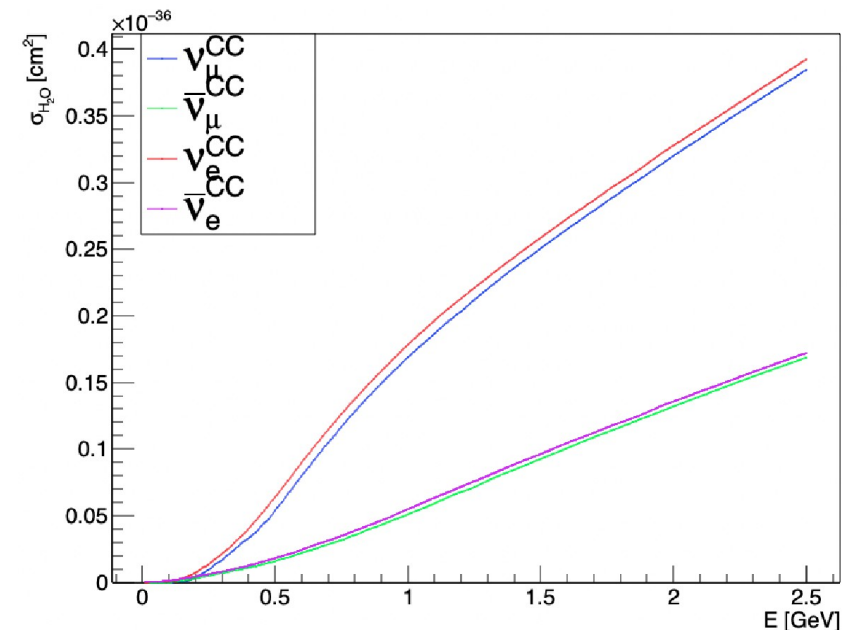
ESSnuSB+ 4th Annual meeting
Wik's Castle - 6/10/2026

- G4beamline simulation of the final version of LEMNB (see Daniele's talk) used to estimate fluxes and interactions expected at LEMMOND – 10 Gpot simulated
- Neutrinos scored on a circular surface with 3 m radius placed at 25 m from the end of the decay tunnel
 - ✓ Add flexibility to the study
 - ✓ Project neutrino tracks to the proposed LEMMOND location and cut on the expected transverse size
- Interaction rates roughly estimated neglecting effect related the beam divergence and to the real path of neutrinos in the detector

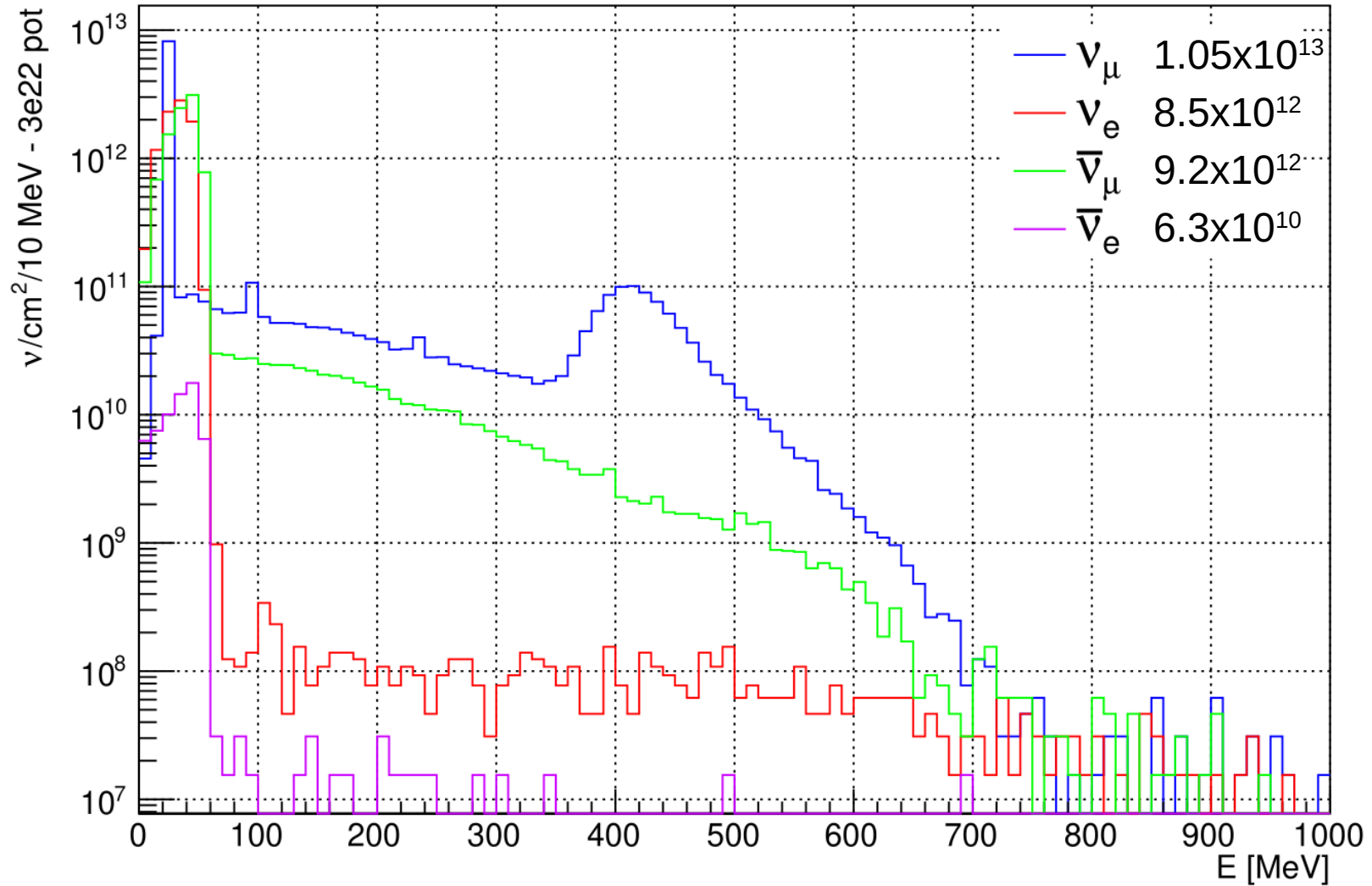
$$\phi = n\nu/S \quad N = \phi * \sigma * n_{\text{nucl}}$$

S: detector surface: 2.5 m radius ; $n\nu$: neutrinos impinging on it

- Assumed 200 ton mass for LEMMOND
2.5 m radius, 10.4 m length
- Simplified Charged Current (CC) cross section model on H_2O as linear combination of the Oxygen and Hydrogen ones taken from GENIE (thanks to L. Halic)
- Fluxes and interaction rates normalized to 3×10^{22} POT
expected yearly protons delivered to LEMNB

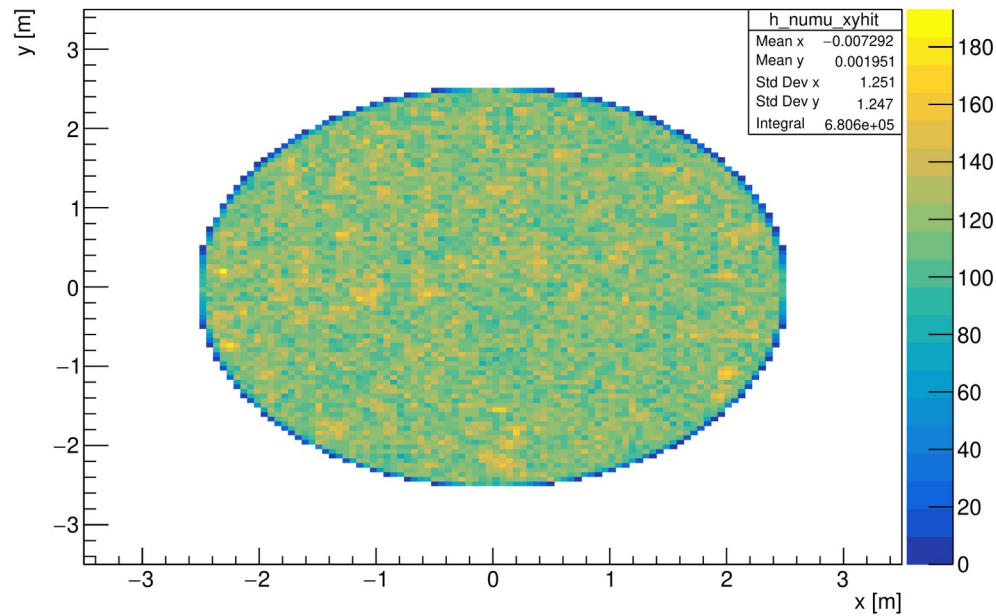


Neutrino fluxes at LEMMOND

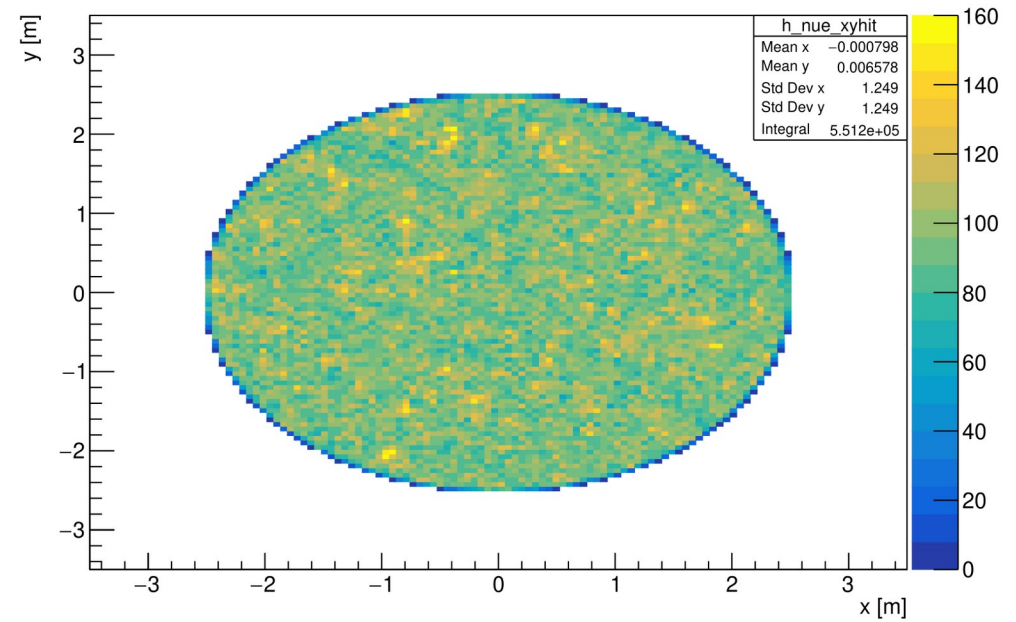


- Peak around 400 MeV in the ν_μ flux originated from decays of momentum selected π^+
- Sharp peak at low energy due to the monochromatic line at $\sim 29.8 \text{ MeV}$ from the DAR of π^+ (and at $\sim 236 \text{ MeV}$ from DAR of K^+)
- Large contribution at low energy to anti- ν_μ and ν_e fluxes from DAR of μ^+ with $E_{\text{max}} \sim 52.8 \text{ MeV}$
- At higher energies ν_e exhibit the shape expected from 3-body decays of μ^+ (shadowed in the case of anti- ν_μ by the large contribution from DIF of π^-)

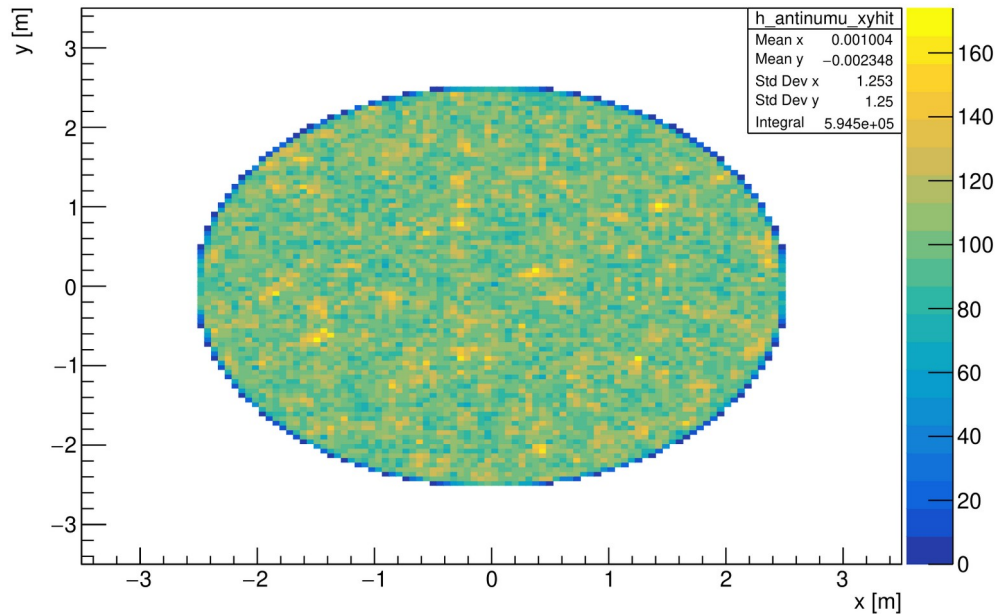
ν_μ detector hit



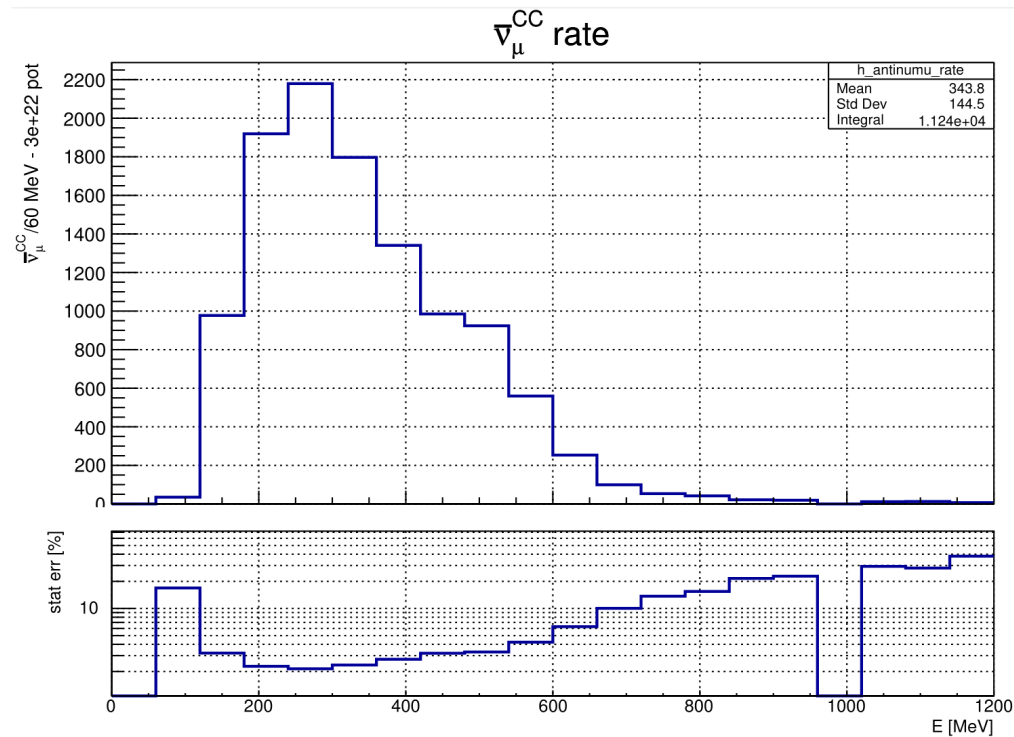
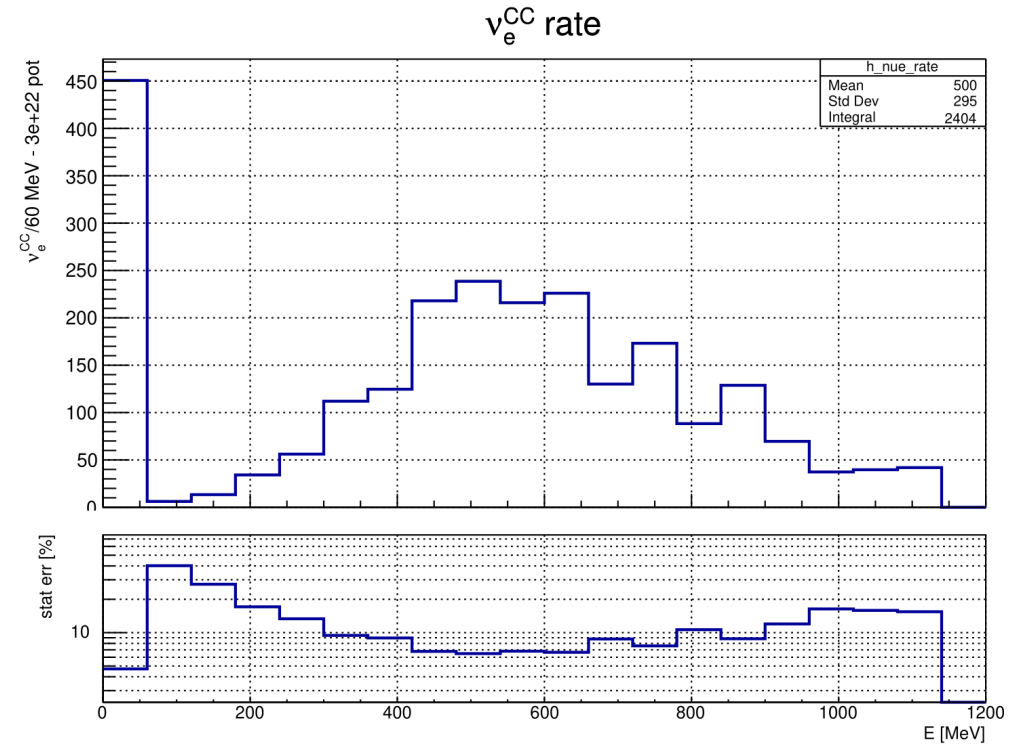
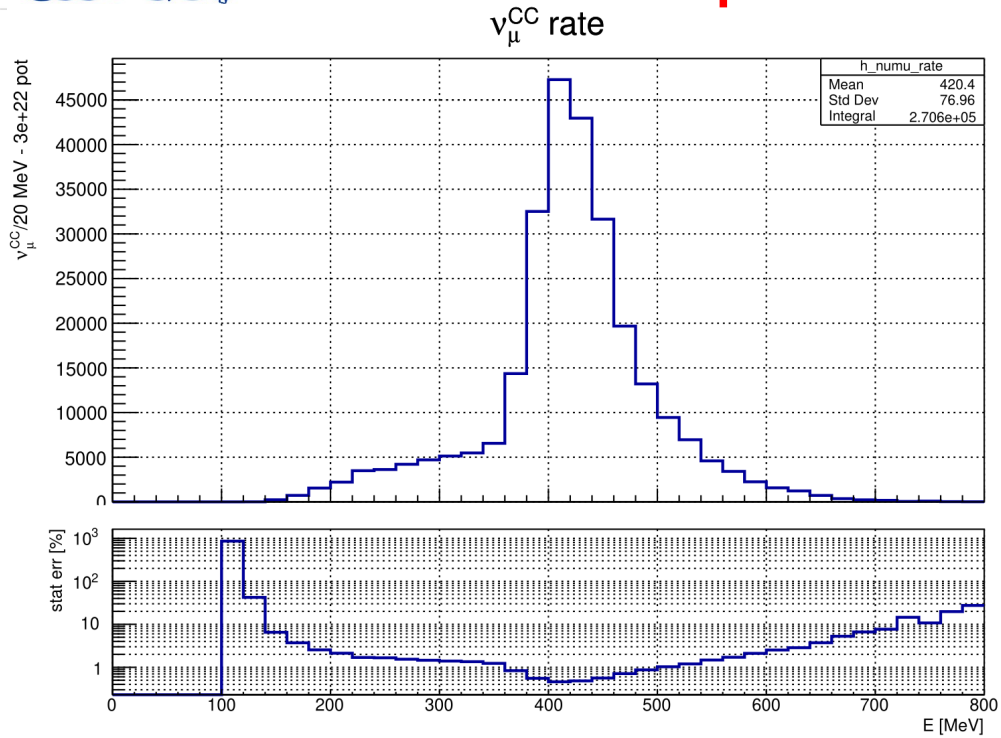
ν_e detector hit



$\bar{\nu}_\mu$ detector hit



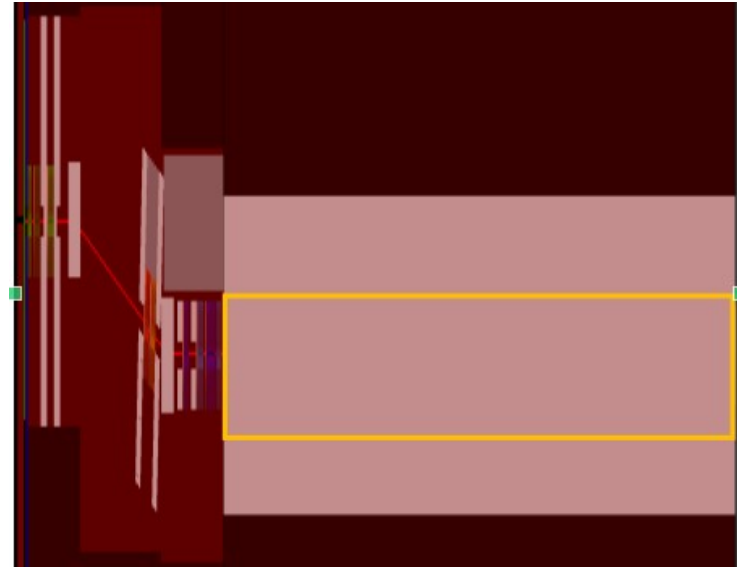
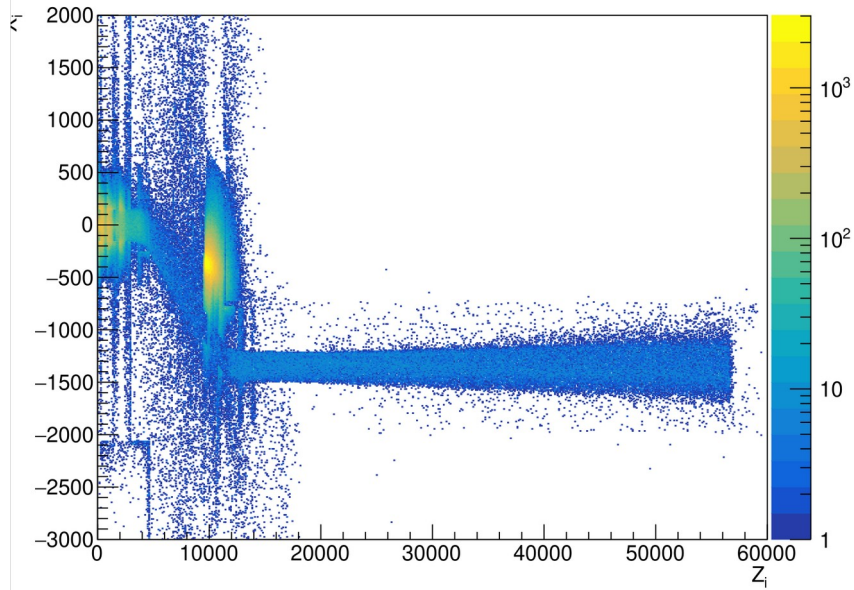
- Low energy pion beam $\rightarrow$ large neutrino beam divergence
- Quite uniform distribution of neutrino's impact points at LEMMOND



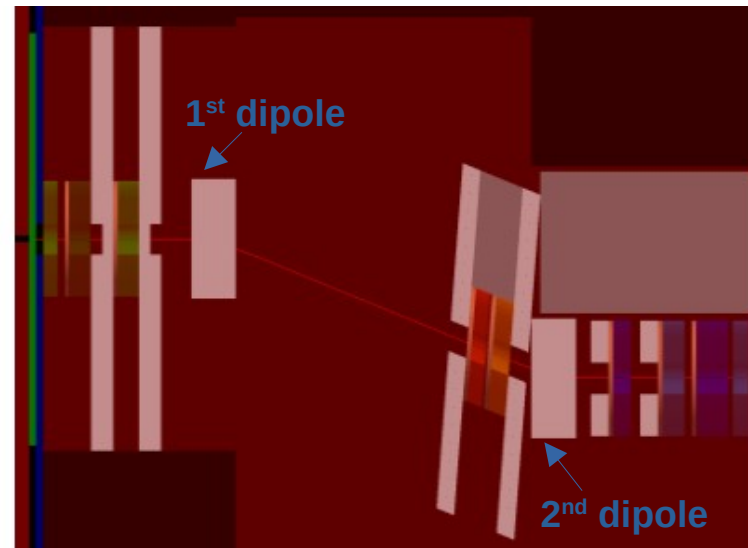
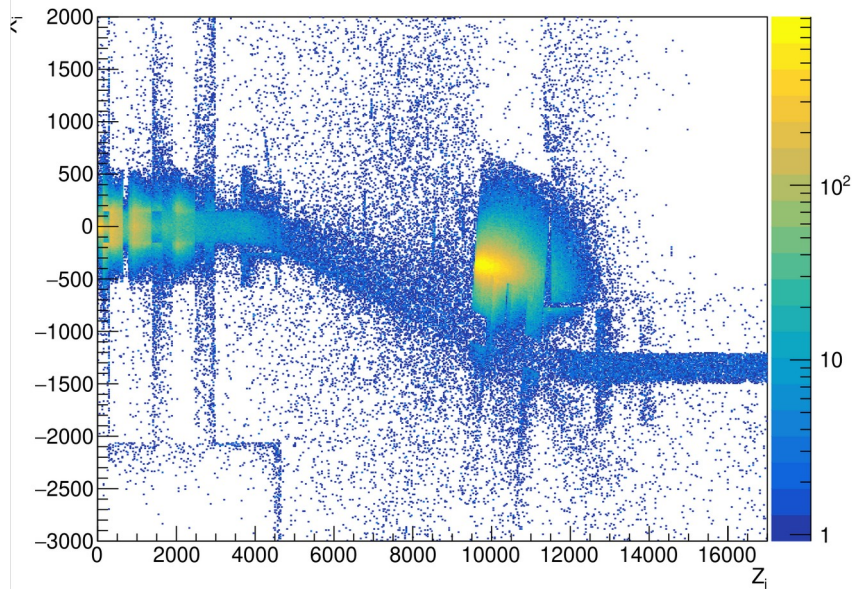
Flavor	Total CC interactions
ν_{μ}	27.0×10^4
anti- ν_{μ}	1.1×10^4
ν_e	0.24×10^4
anti- ν_e	0.01×10^4

Neutrinos production point

14: X_1 vs Z_1 - Full Z Range [0, 75 m] (Unweighted)

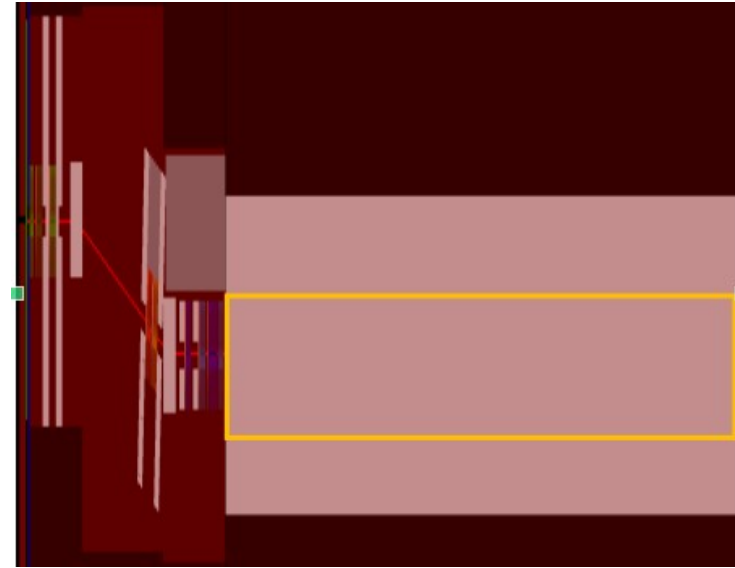
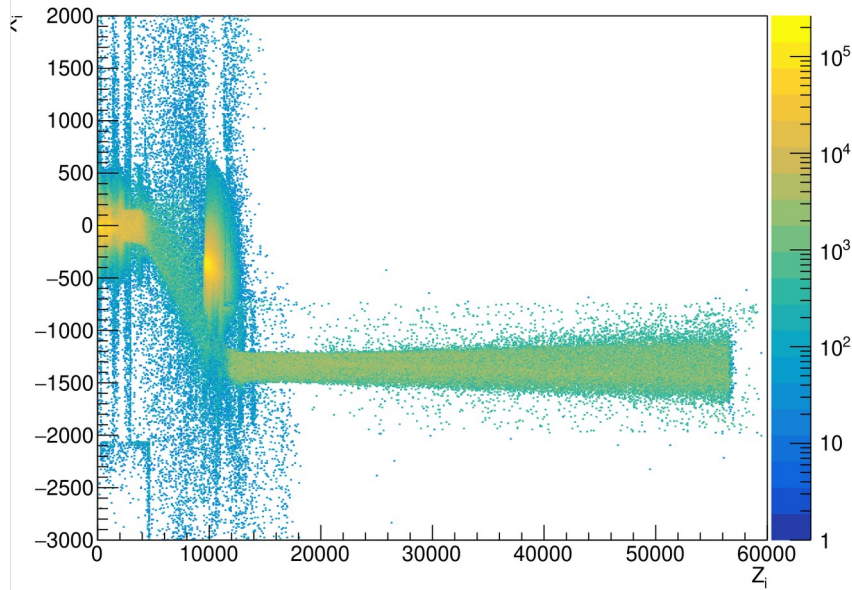


14: X_1 vs Z_1 - Zoomed Z Range [0, 17 m] (Unweighted)

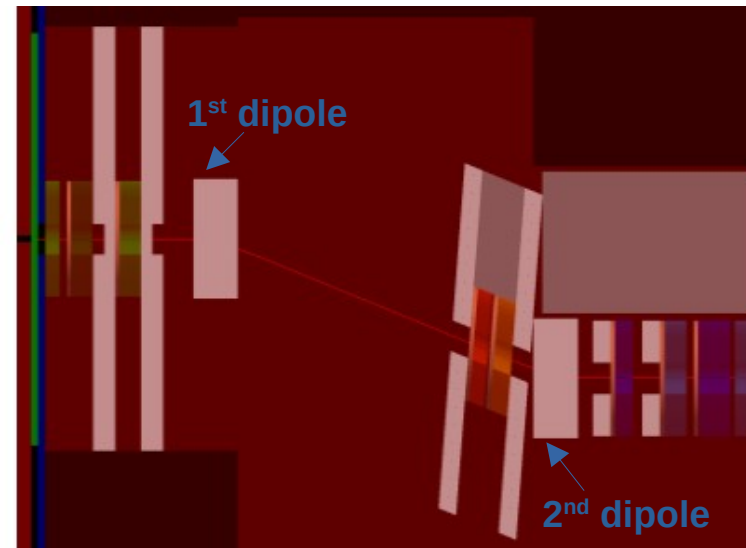
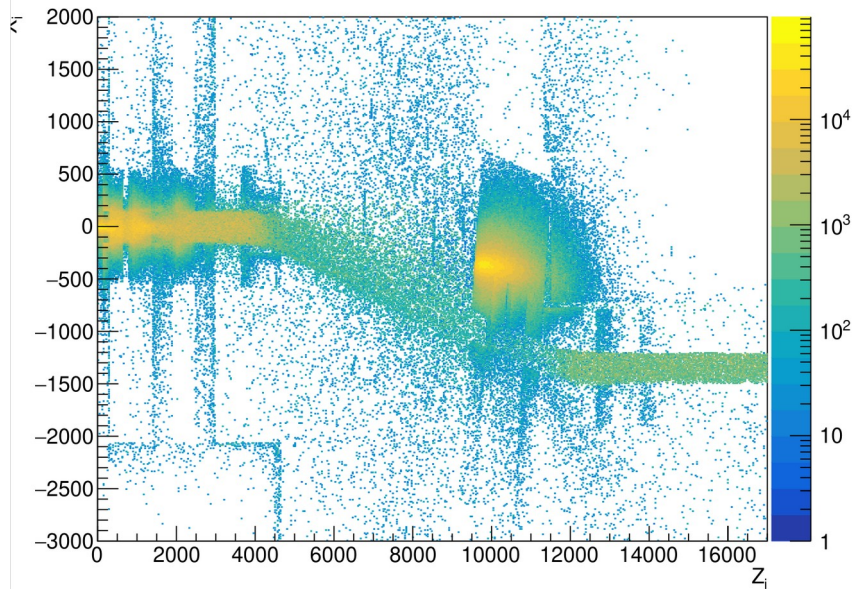


Muon neutrinos (E-weighted)

14: X_1 vs Z_1 - Full Z Range [0, 75 m] (Momentum Weighted)

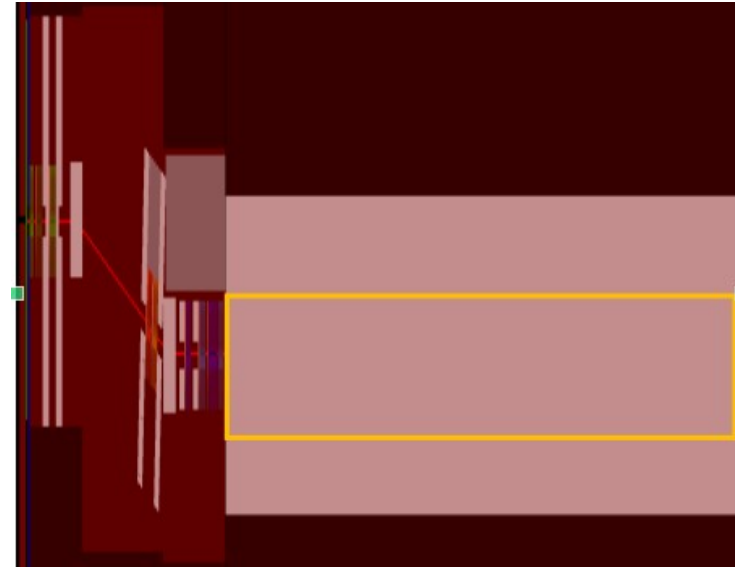
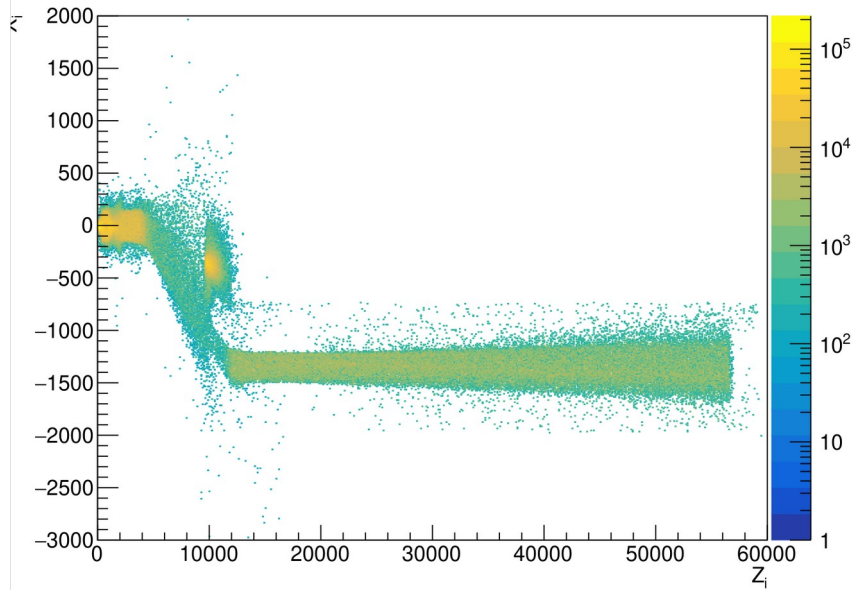


14: X_1 vs Z_1 - Zoomed Z Range [0, 17 m] (Momentum Weighted)

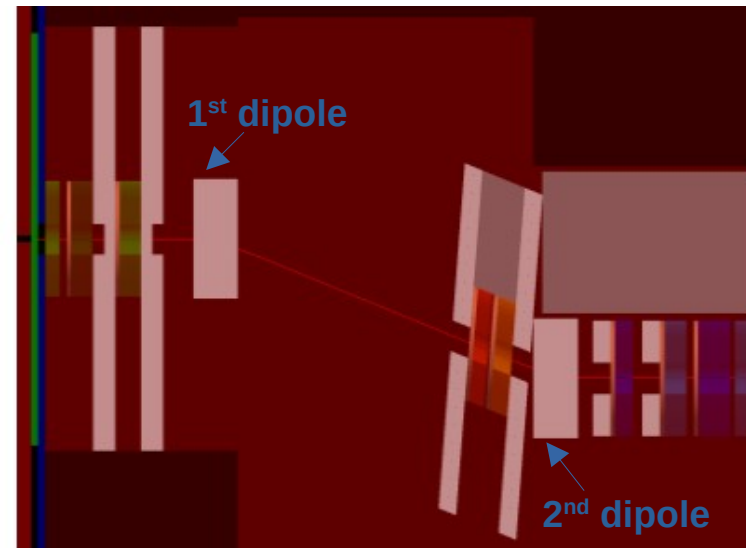
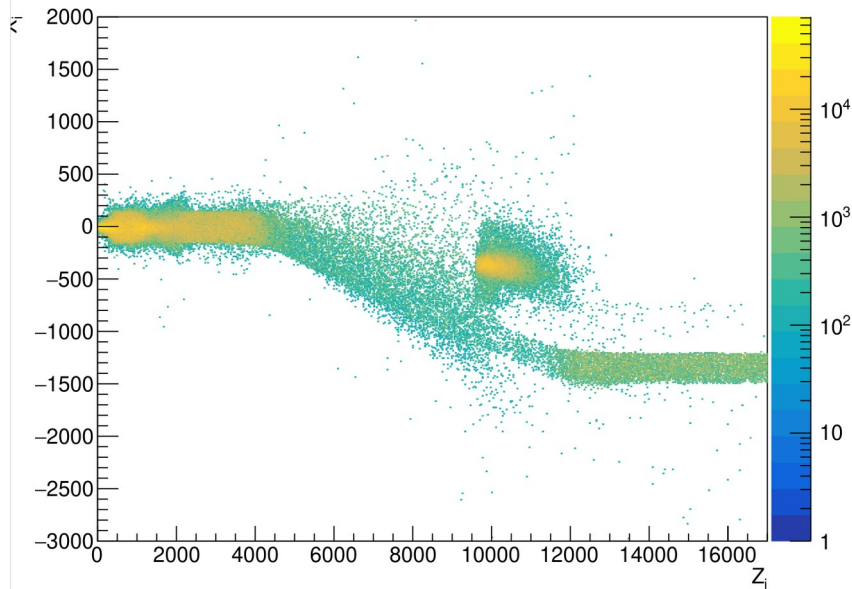


Weighting by neutrino energy as a proxy of the interaction probability

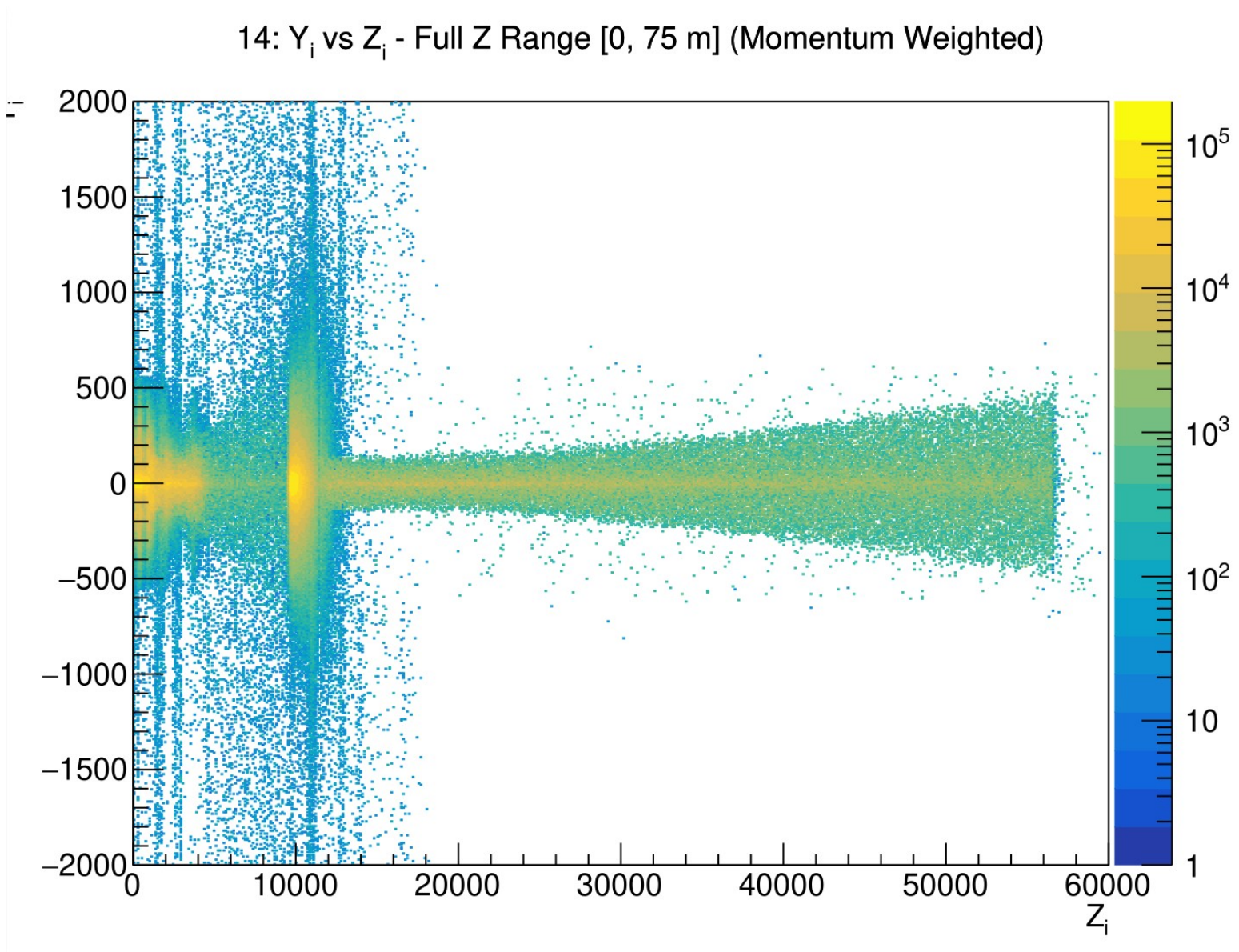
14: X_i vs Z_i - Full Z Range [0, 75 m] (Momentum Weighted)



14: X_i vs Z_i - Zoomed Z Range [0, 17 m] (Momentum Weighted)

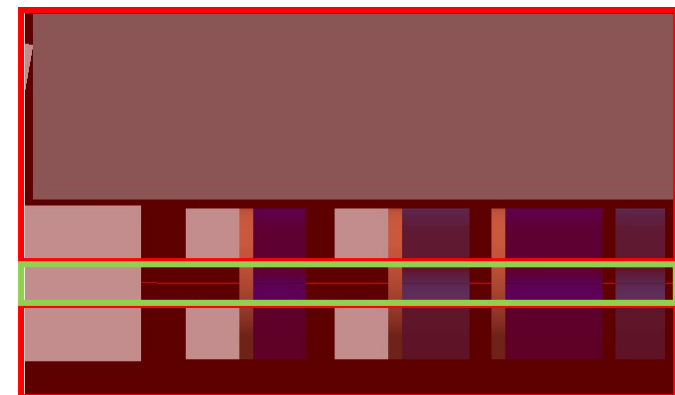
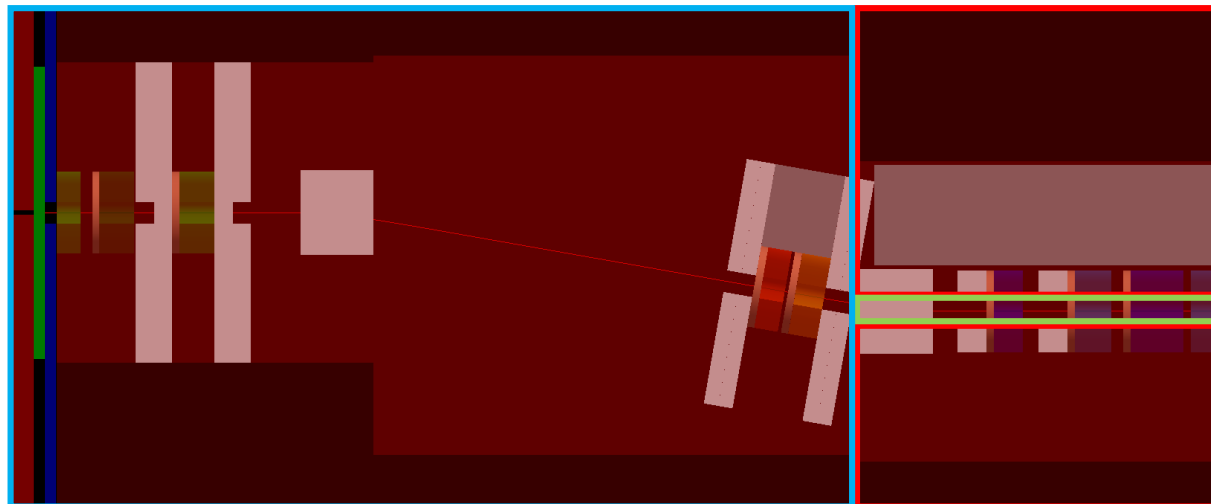
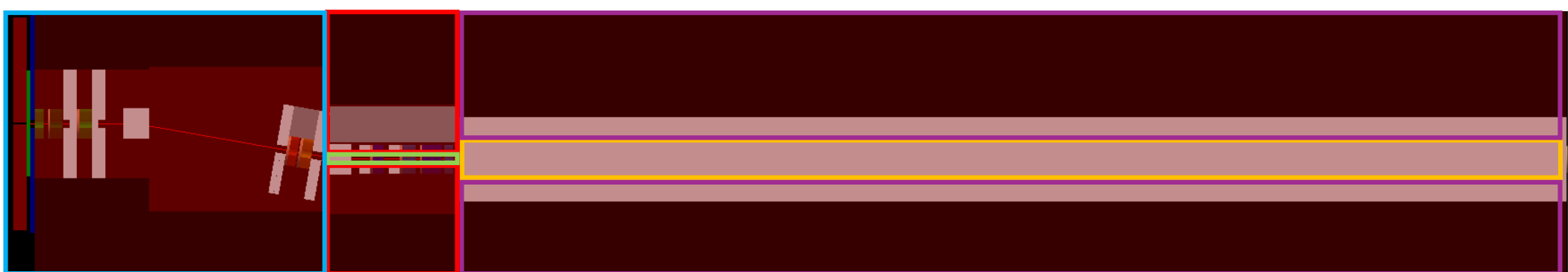


Cut applied on the muon production energy



Top-down symmetry as expected

Breaking down in regions



Cyan: before 2nd bending

Red: shielding after 2nd bending

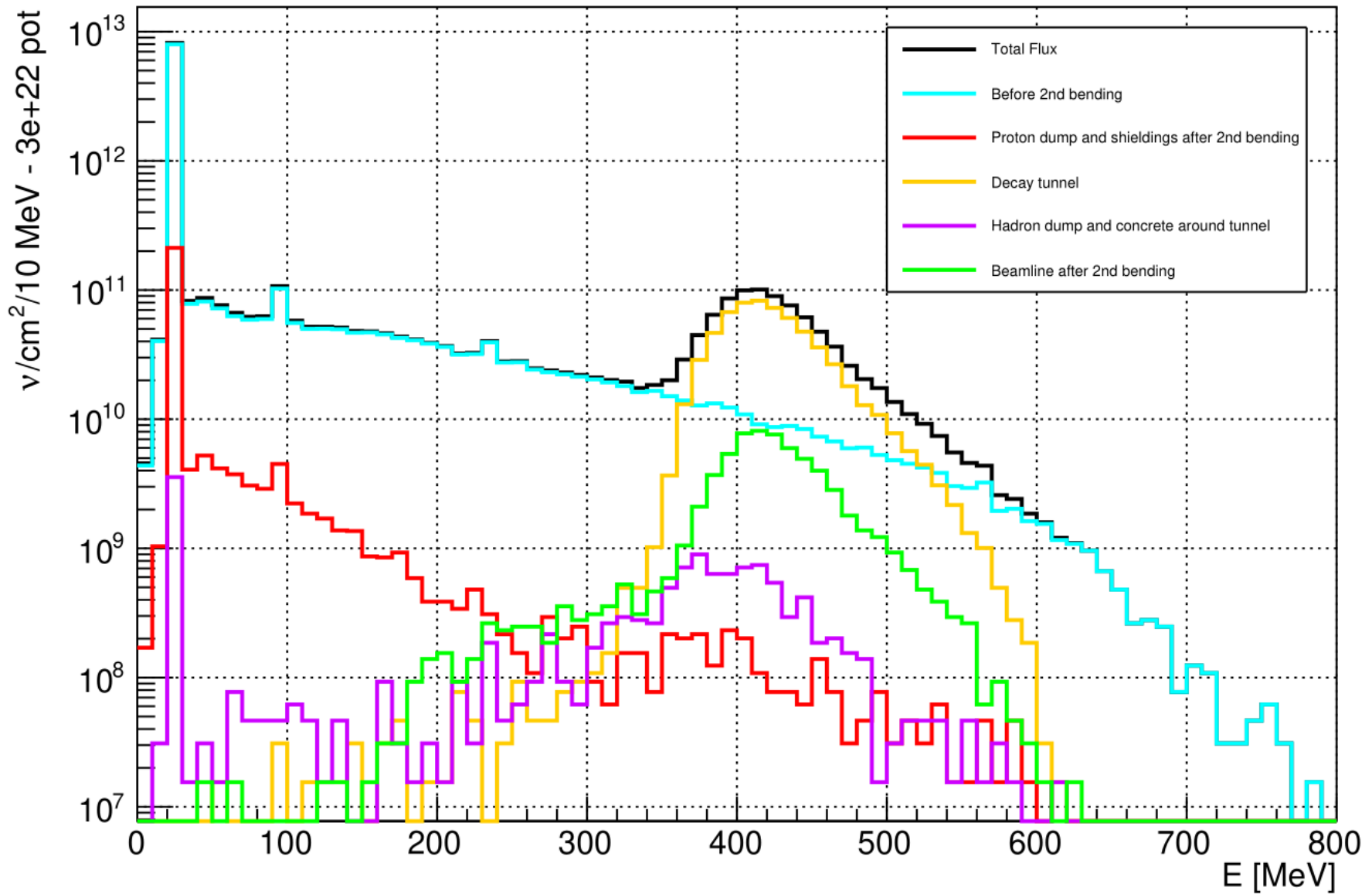
Green: beamline after 2nd bending

Yellow: Decay tunnel

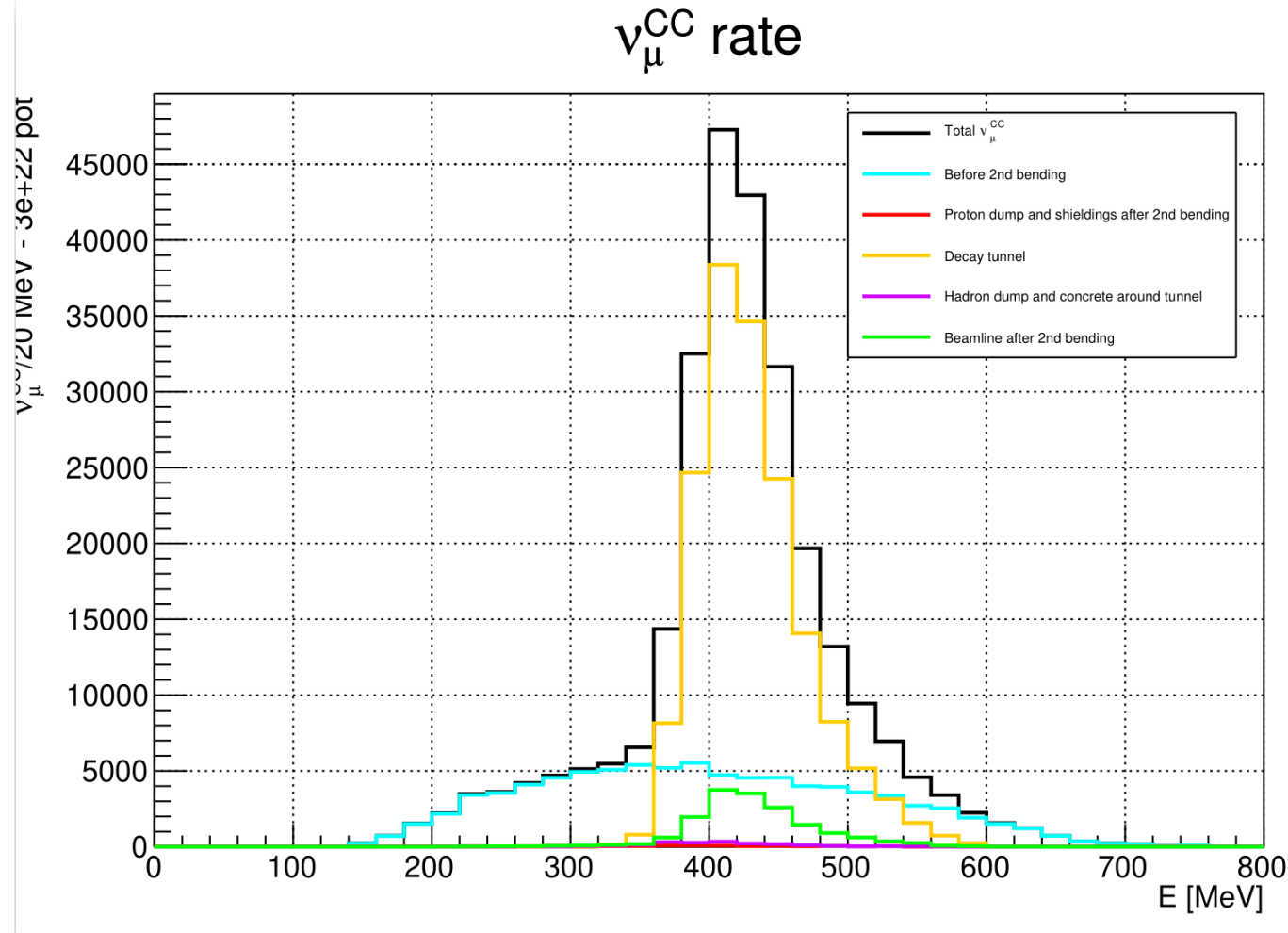
Violet: Hadron dump and concrete around tunnel

ν_μ flux breakdown

ν_μ flux



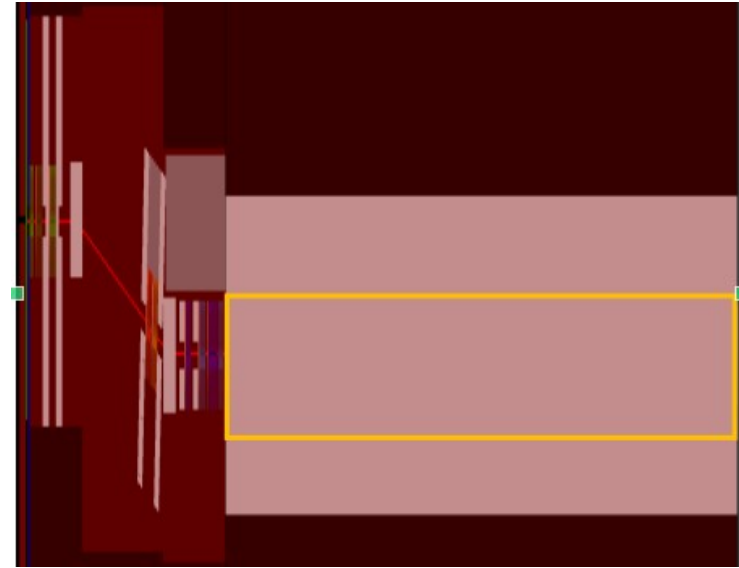
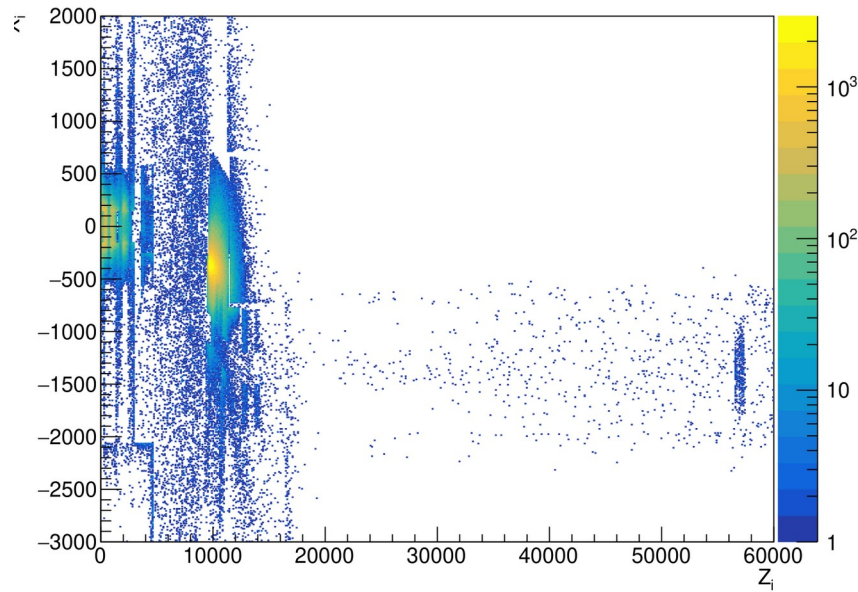
ν_μ CC interactions breakdown



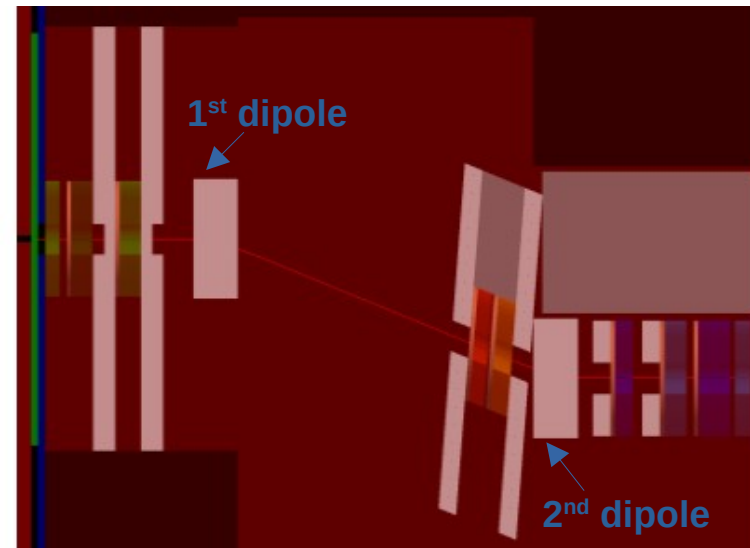
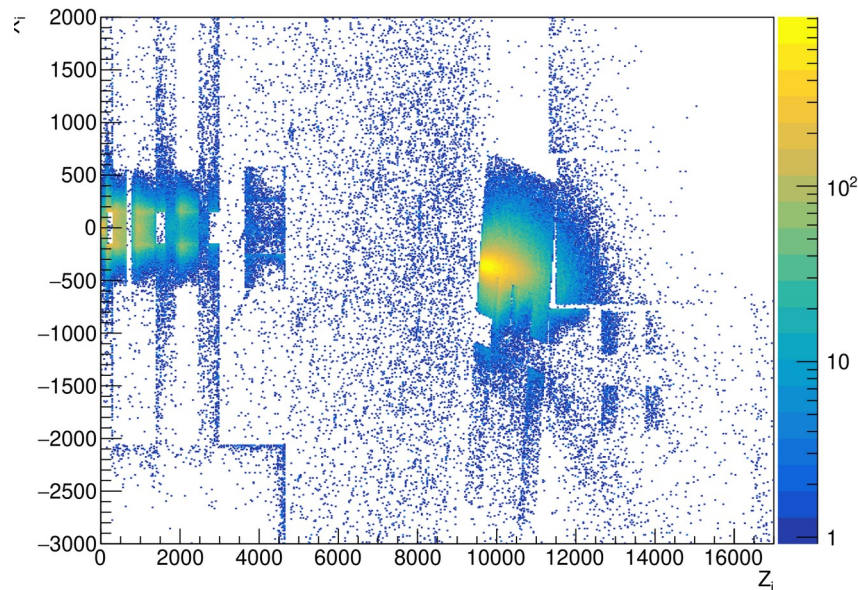
61% of total CC interactions come from neutrinos produced in the decay tunnel (67% when considering also those produced in the collinear region after the 2nd bending)

When restricting to the range 350÷550 MeV this fraction reaches 71% (78% when considering the region after the 2nd bending)

12: X_i vs Z_i - Full Z Range [0, 75 m] (Unweighted)



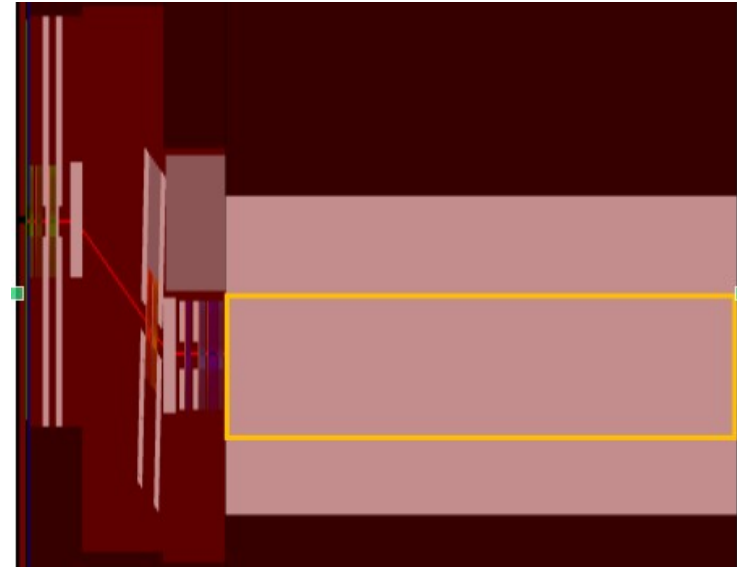
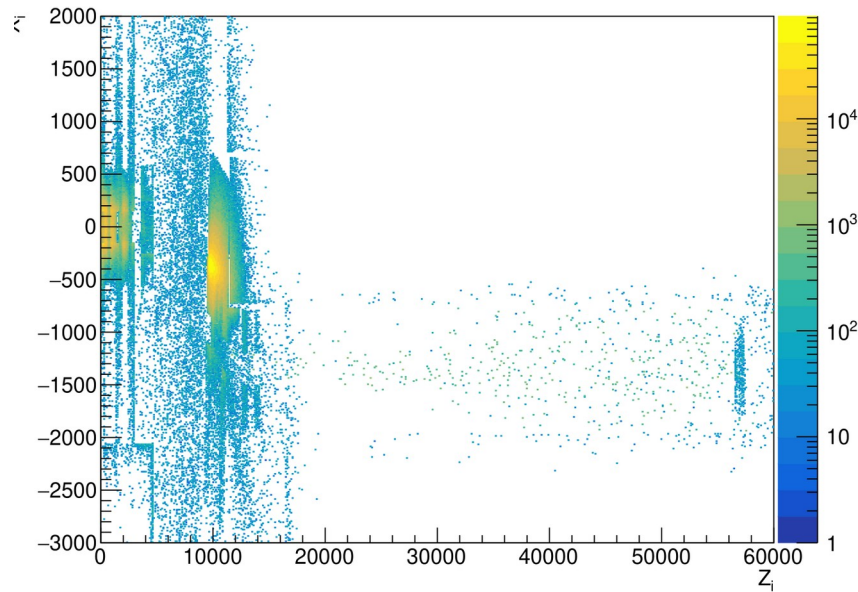
12: X_i vs Z_i - Zoomed Z Range [0, 17 m] (Unweighted)



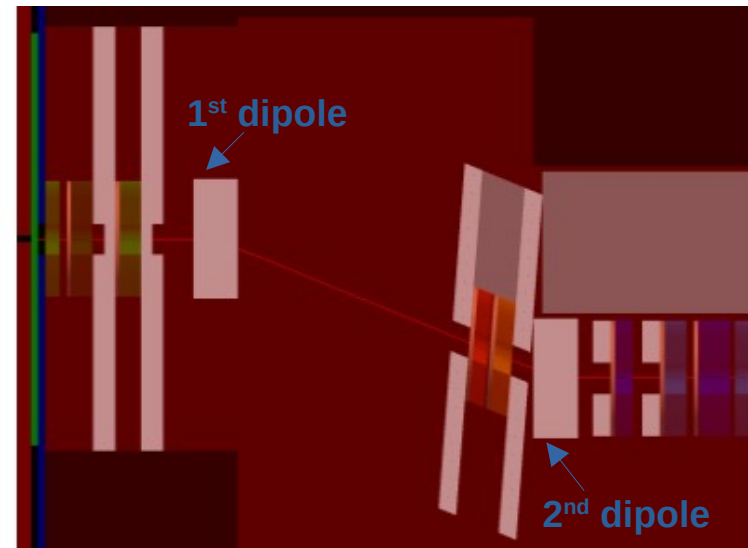
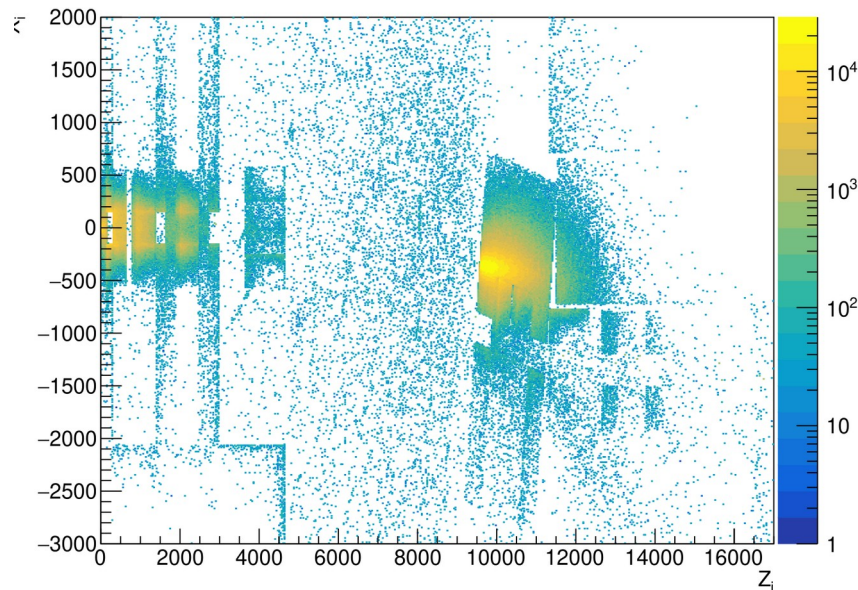
Limited simulated statistics → not easy to highlight the contribution of ν_e from tunnel

Electron neutrinos (E-weighted)

12: X_i vs Z_i - Full Z Range [0, 75 m] (Momentum Weighted)

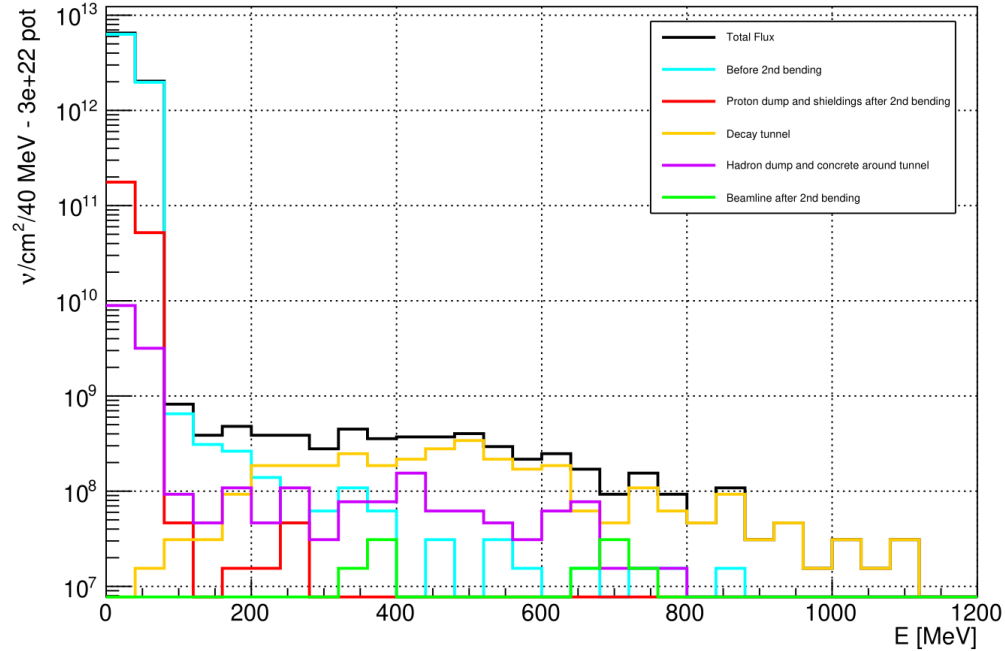


12: X_i vs Z_i - Zoomed Z Range [0, 17 m] (Momentum Weighted)



Limited simulated statistics → not easy to highlight the contribution of ν_e from tunnel

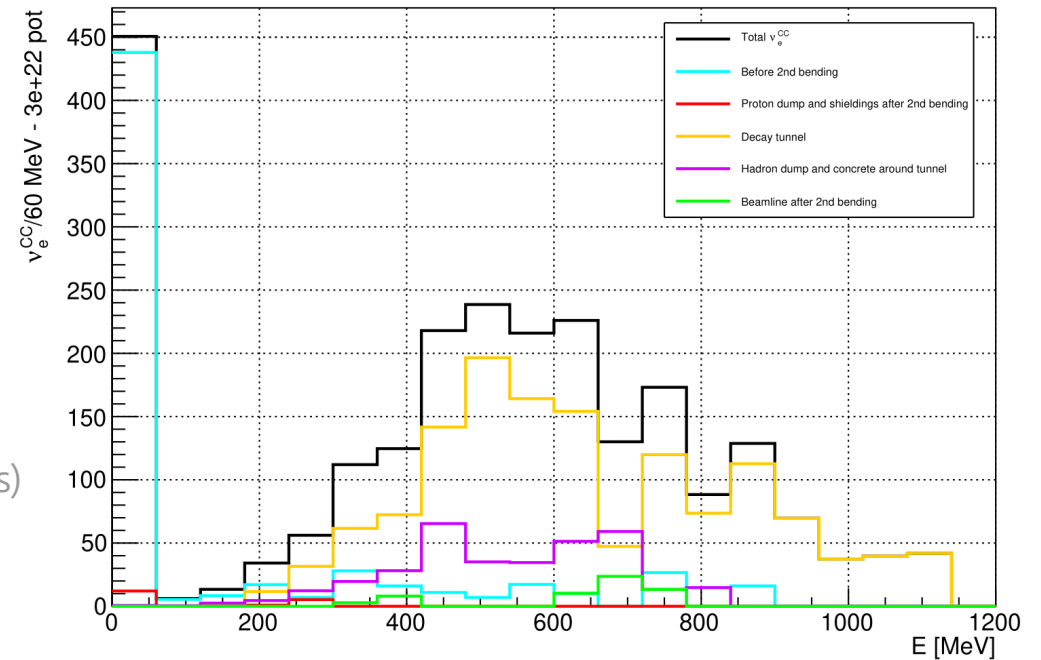
ν_e flux



57% of total CC interactions come from neutrinos produced in the tunnel

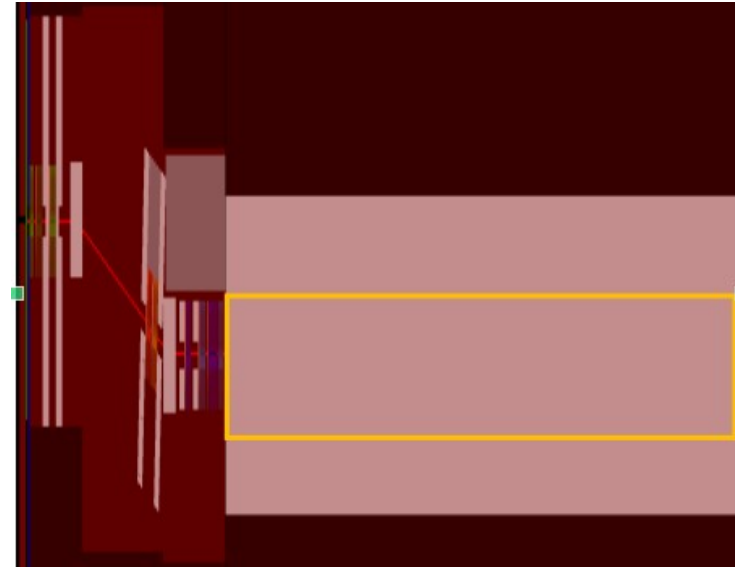
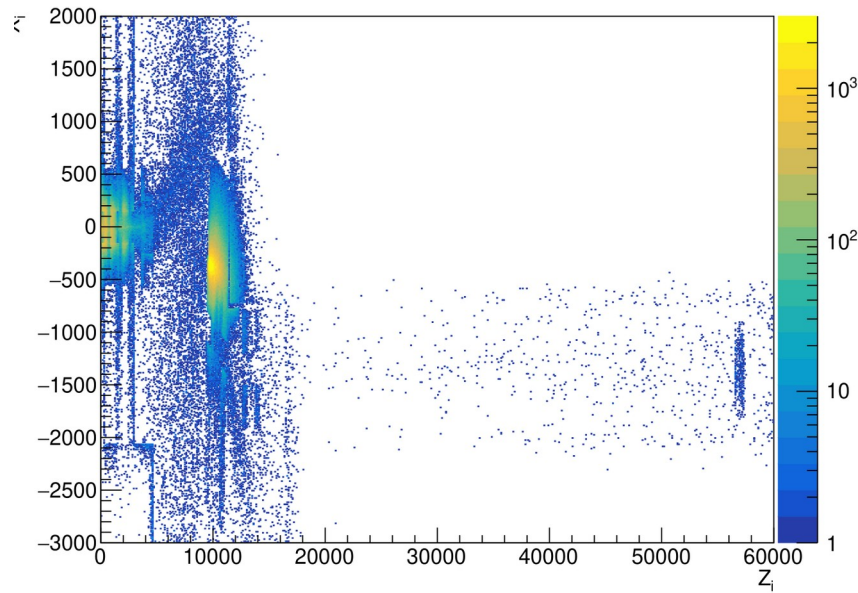
(77% of the total cutting away the ones from DAR of muons)

ν_e^{CC} rate

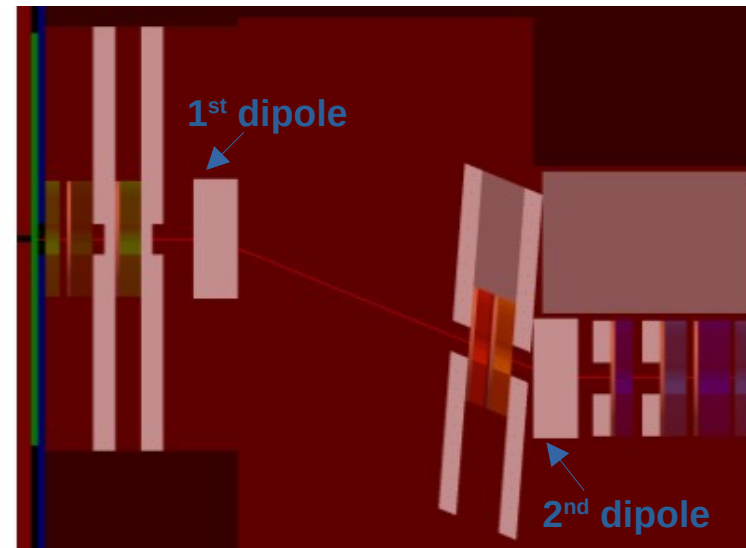
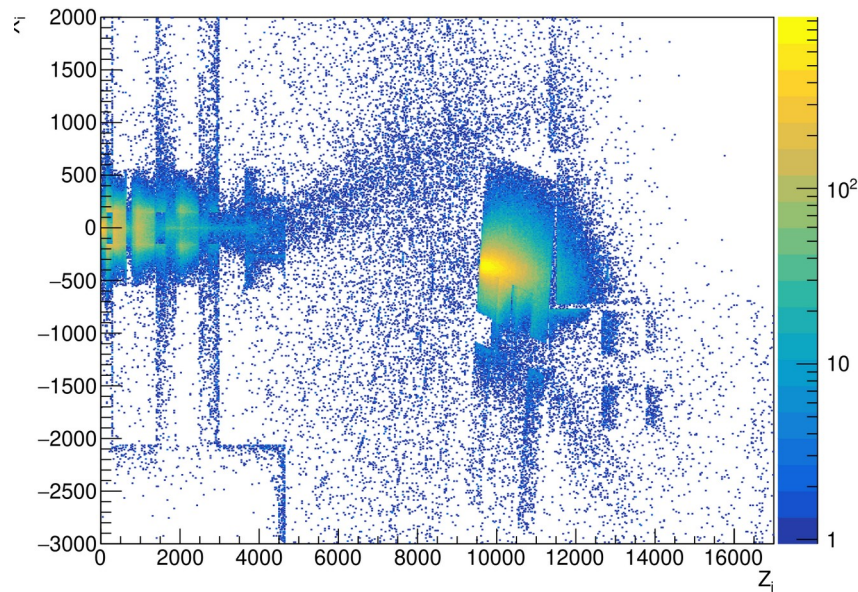


Muon anti-neutrinos

-14: X_i vs Z_i - Full Z Range [0, 75 m] (Unweighted)

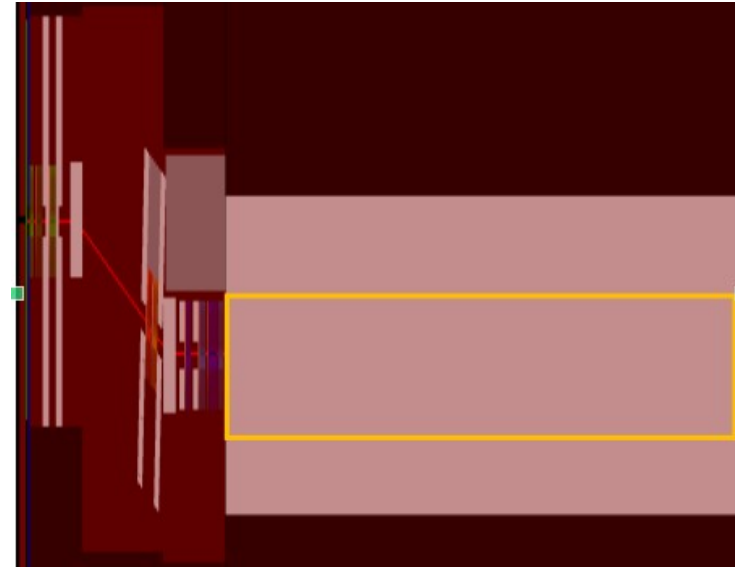
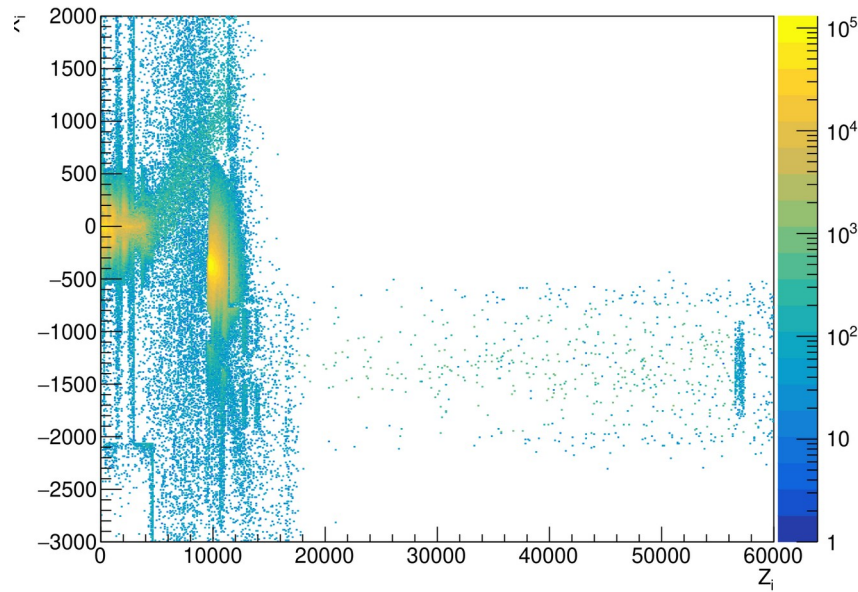


-14: X_i vs Z_i - Zoomed Z Range [0, 17 m] (Unweighted)

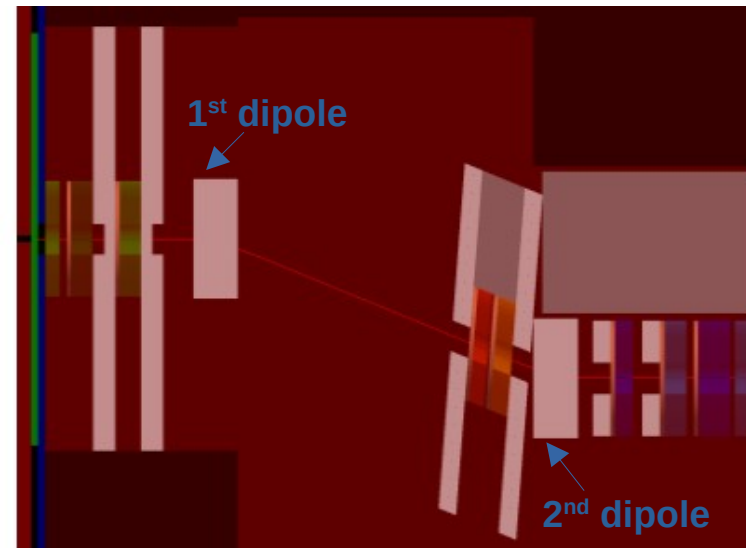
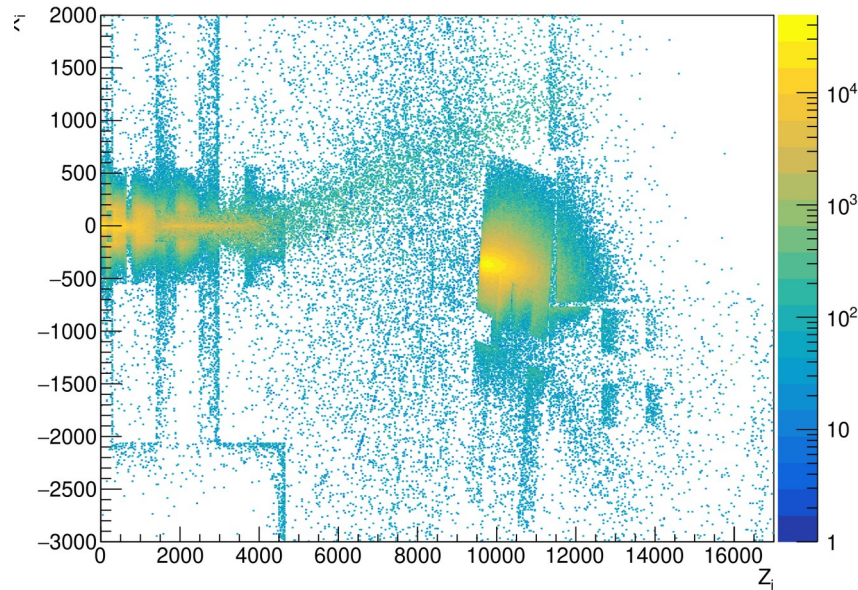


Muon anti-neutrinos (E-weighted)

-14: X_1 vs Z_1 - Full Z Range [0, 75 m] (Momentum Weighted)

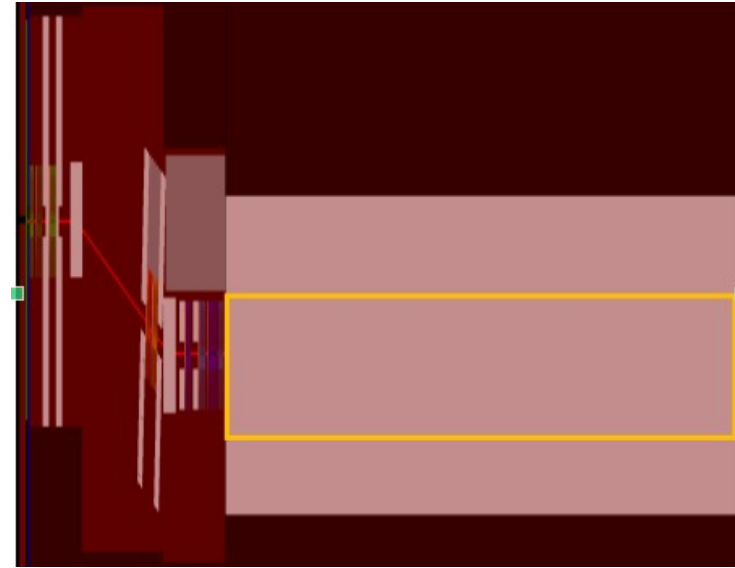
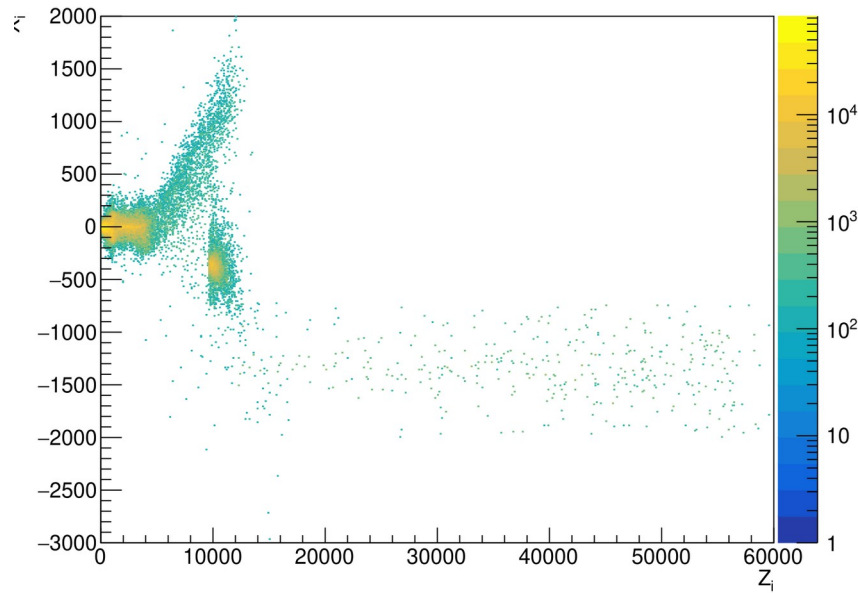


-14: X_1 vs Z_1 - Zoomed Z Range [0, 17 m] (Momentum Weighted)

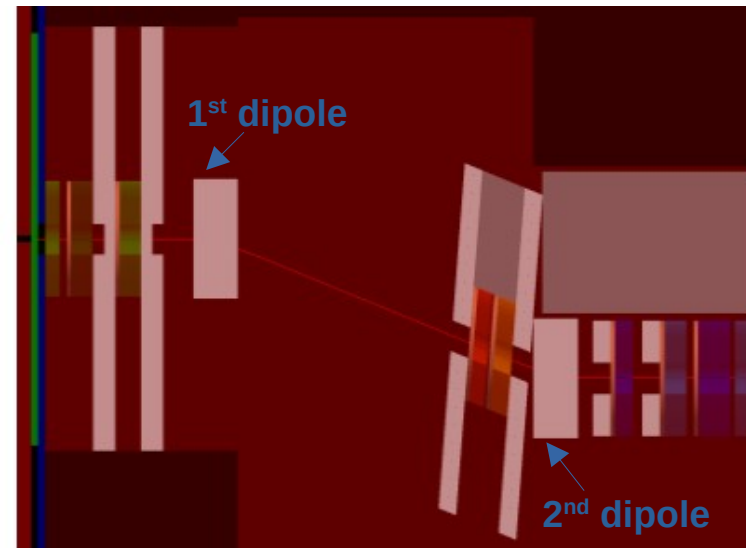
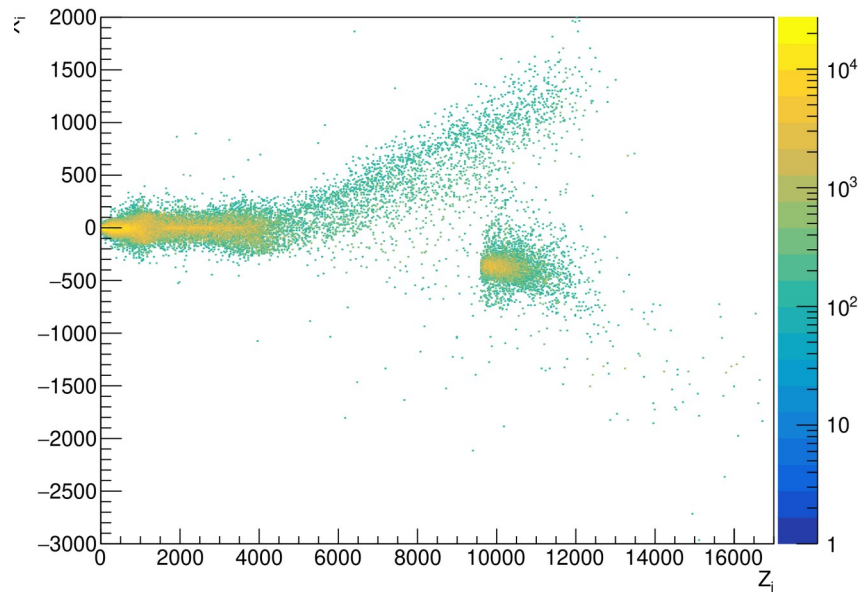


Muon neutrinos (E-weighted, anti-mu threshold)

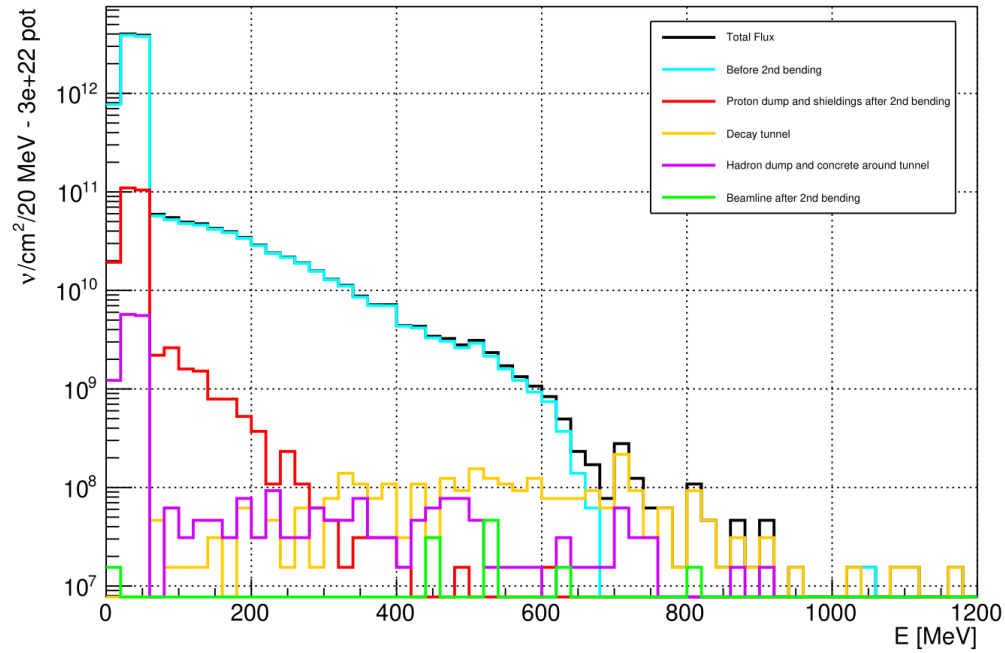
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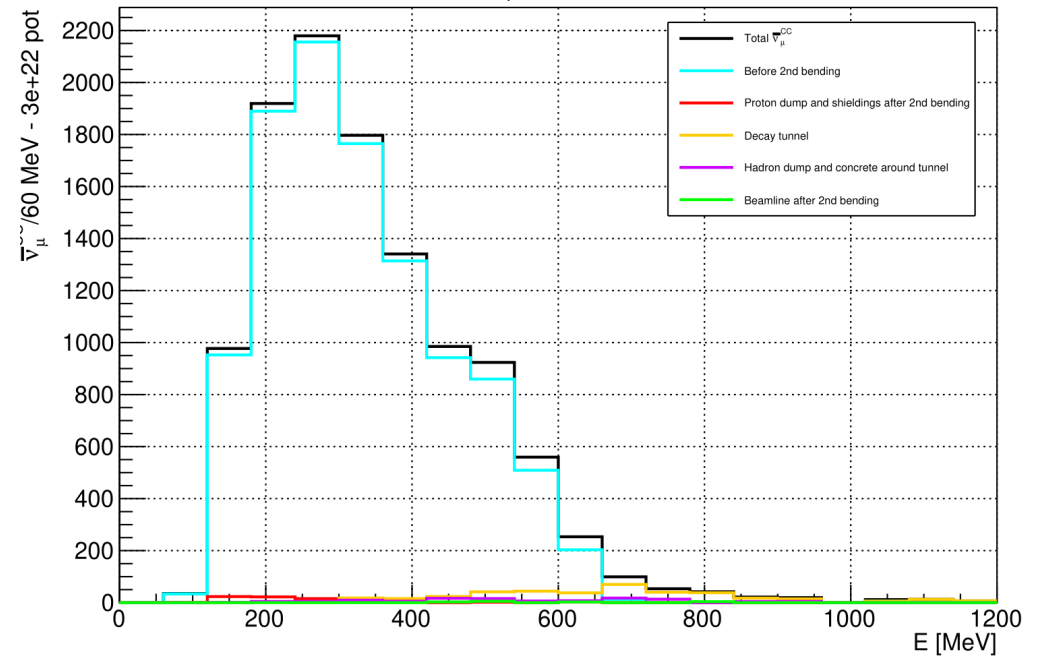
-14: X_1 vs Z_1 - Zoomed Z Range [0, 17 m] (Momentum Weighted)



$\bar{\nu}_\mu$ flux

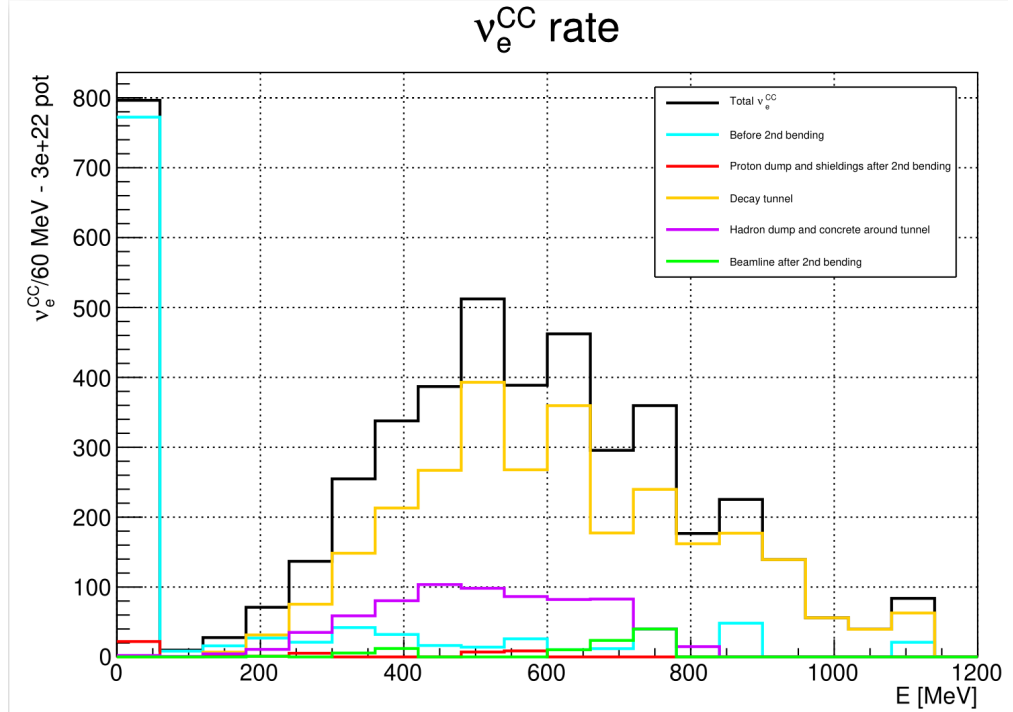
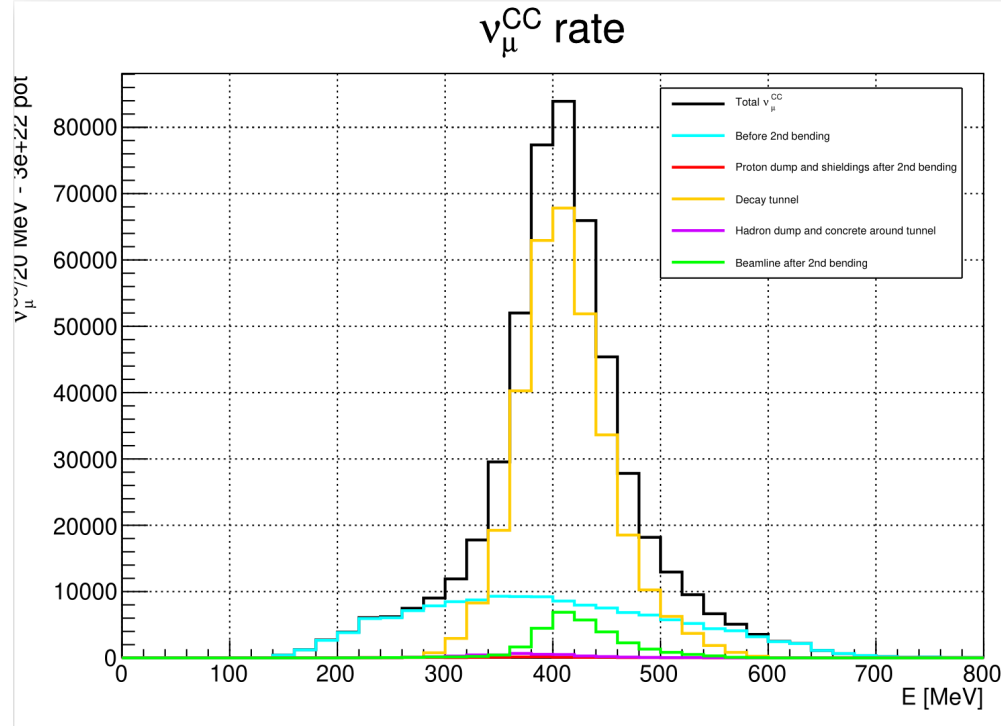


$\bar{\nu}_\mu^{\text{CC}}$ rate



Given the quite large beam divergence, reducing the distance of the neutrino detector has a relevant impact on the collected statistics

Considering a distance of 25 m:



Flavor	Total CC interactions
ν_{μ}	51.2×10^4
$\text{anti-}\nu_{\mu}$	1.9×10^4
ν_e	0.47×10^4
$\text{anti-}\nu_e$	0.02×10^4



Almost x2 increase in statistics

Fraction of ν_{μ} CC interactions in the monitored region: 70% [80% in the 350÷550 MeV range]

- Realistic neutrino fluxes from LEMNB available
- LEMNB is able to deliver about $2.7 \times 10^4 \nu_{\mu}^{\text{CC}}$ and $0.24 \times 10^4 \nu_e^{\text{CC}}$ interactions per year to LEMMOND
- A large fraction of those are generated by neutrinos produced in the directly monitored part, for which a systematic budget of 1% is achievable
- Halving the distance of the facility from LEMMOND (from 50 to 25 m) almost doubles the expected statistics with even slightly better relative fractions of monitored neutrinos