Simulation of ν_τ

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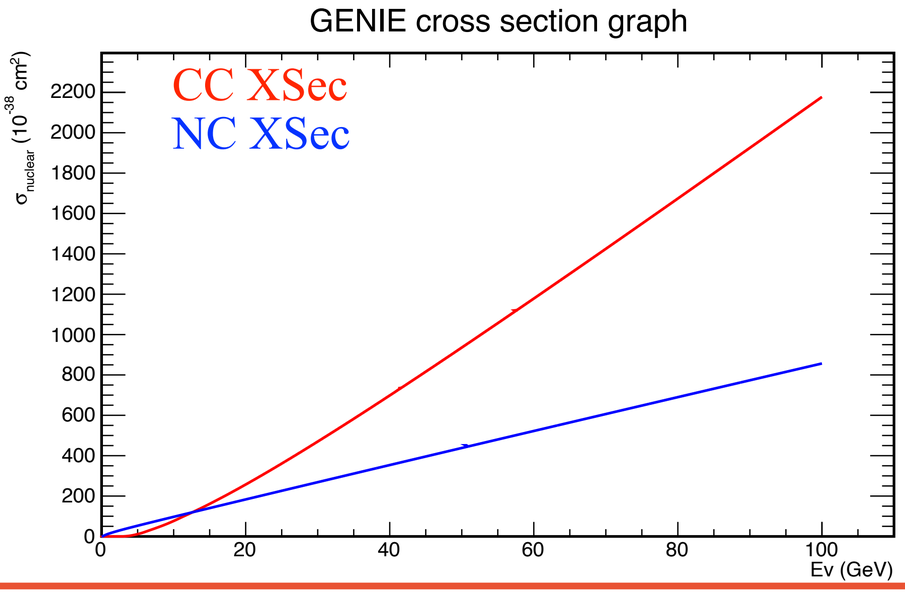
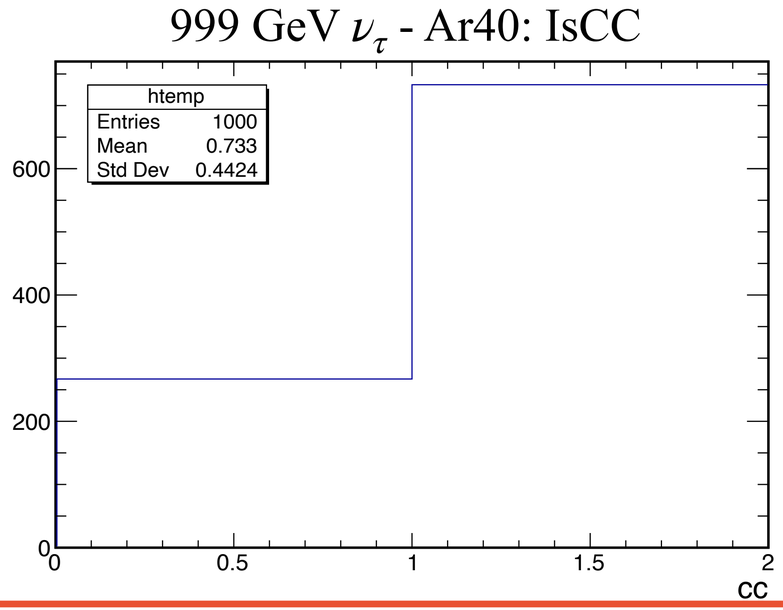
Current Status

- We did energy containment studies for both LAr and LKr
  - Lepton simulation (e-, mu-, tau-) using Geant4
  - Containment for tau- looks quite good considering missing energy of neutrino
- The hadronic shower from ν_τ interactions is also helpful for ν_τ recognition. In order to look into the signatures of ν_τ events in the detector, we started to work on the simulation of ν_τ
  - Neutrino simulation is not well supported by Geant4 due to the complexity of neutrino interactions
  - The default GENIE doesn't have the cross-section splines above 100 GeV. The cross-section splines need to be calculated in advance. We'll need to consider ν_τ with energy up to several TeV
  - Need to read kinematics of final state particles from GENIE and input those to Geant4, in order to study the event topology of ν_τ interactions

ν_τ-Ar interactions in GENIE

- Found a pre-calculated spline for ν_τ-Ar interactions, with energy up to 999 GeV
  - Will use this spline for now, as the placeholder to develop the interface in Geant4 application to read GENIE results
- As pointed out by Felix, there is a new dedicated interaction model for high energy neutrino interactions in GENIE called HEDIS (high energy DIS): https://arxiv.org/abs/2106.09381
  - It's available in the GENIE repository (master branch), but not a released version of GENIE
  - Consider to move to the newer version of GENIE in the future, need more understanding on the simulation results





Importing GENIE events to Geant4

- Gean4 doesn't know anything about GENIE formats (.ghep.root). What we're doing now is
  - to link to GENIE libraries, so we can have a dictionary for the ROOT file format
  - read in the event record and then loop over the particles in the event record
- This work is in progress, hope to have some results soon.

GENIE GHEP Event Record [print level: 3]

Idx	Name	Ist	PDG	Mother	Daughter	Px	Py	Pz	E	m	
0	nu_tau	0	16	-1	-1	4	4	0.000	0.000	999.000	999.000	0.000	
1	Ar40	0	1000180400	-1	-1	2	3	0.000	0.000	0.000	37.216	37.216	
2	neutron	11	2112	1	-1	5	5	0.143	0.034	-0.048	0.929	**0.940	M = 0.916
3	Ar39	2	1000180390	1	-1	23	23	-0.143	-0.034	0.048	36.286	36.286	
4	tau-	3	15	0	-1	24	26	4.942	-0.842	614.564	614.587	1.777	P = (-0.008,0.001,-1.000)
5	HadrSyst	12	2000000001	2	-1	6	7	-4.800	0.876	384.388	385.342	**0.000	M = 26.660
6	u	12	2	5	-1	8	8	-4.801	0.876	384.527	384.558	0.330	
7	ud_1	12	2103	5	-1	8	8	0.002	-0.000	-0.139	0.784	0.771	
8	string	12	92	6	-1	9	13	-4.800	0.876	384.388	385.342	**0.000	M = 26.660
9	pi0	14	111	8	-1	16	16	-2.716	0.496	257.866	257.880	0.135	FSI = 1
10	pi+	14	211	8	-1	17	17	-0.980	0.207	38.737	38.751	0.140	FSI = 1
11	pi-	14	-211	8	-1	18	18	-1.522	0.658	85.730	85.747	0.140	FSI = 1
12	neutron	14	2112	8	-1	19	19	0.654	-0.624	1.056	1.678	0.940	FSI = 1
13	rho+	12	213	8	-1	14	15	-0.235	0.140	0.998	1.286	**0.767	M = 0.764
14	pi+	14	211	13	-1	20	21	0.210	-0.069	0.162	0.307	0.140	FSI = 2
15	pi0	14	111	13	-1	22	22	-0.445	0.209	0.836	0.979	0.135	FSI = 1
16	pi0	1	111	9	-1	-1	-1	-2.716	0.496	257.866	257.880	0.135	
17	pi+	1	211	10	-1	-1	-1	-0.980	0.207	38.737	38.751	0.140	
18	pi-	1	-211	11	-1	-1	-1	-1.522	0.658	85.730	85.747	0.140	
19	neutron	1	2112	12	-1	-1	-1	0.654	-0.624	1.056	1.678	0.940	
20	pi0	1	111	14	-1	-1	-1	-0.007	0.124	0.014	0.184	0.135	
21	proton	1	2212	14	-1	-1	-1	0.334	-0.354	0.088	1.061	0.938	
22	pi0	1	111	15	-1	-1	-1	-0.445	0.209	0.836	0.979	0.135	
23	HadrBlob	15	2000000002	3	-1	-1	-1	-0.261	0.127	0.108	35.349	**0.000	M = 35.347
24	nu_mu_bar	1	-14	4	-1	-1	-1	3.601	-0.718	355.999	356.018	**0.000	M = 0.106
25	mu-	1	13	4	-1	-1	-1	0.586	0.193	125.415	125.417	**0.106	M = 0.101
26	nu_tau	1	16	4	-1	-1	-1	0.756	-0.317	133.150	133.152	**0.000	M = -0.038
	Fin-Init:							0.000	-0.000	-0.000	-0.000		

Vertex: nu_tau @ (x = 0.00000 m, y = 0.00000 m, z = 0.00000 m, t = 0.000000e+00 s)

Err flag [bits:15->0] : 0000000000000000 | 1st set: none
Err mask [bits:15->0] : 1111111111111111 | Is unphysical: NO | Accepted: YES

sig(Ev) = 1.19811e-34 cm^2 | d2sig(x,y;E)/dxdy = 2.76522e-34 cm^2 | Weight = 1.00000

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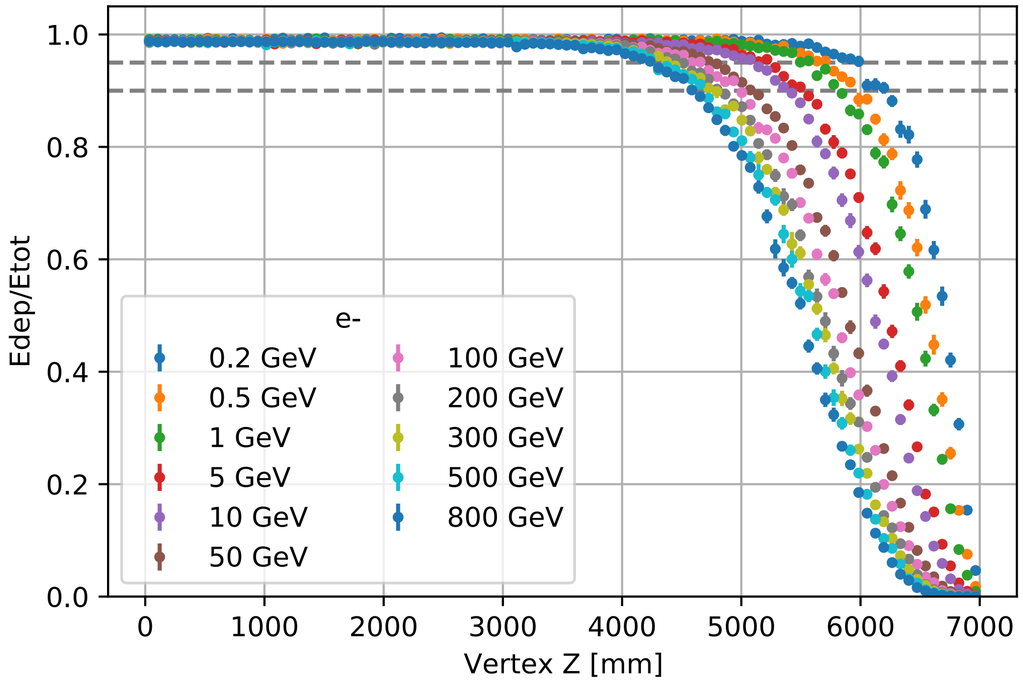
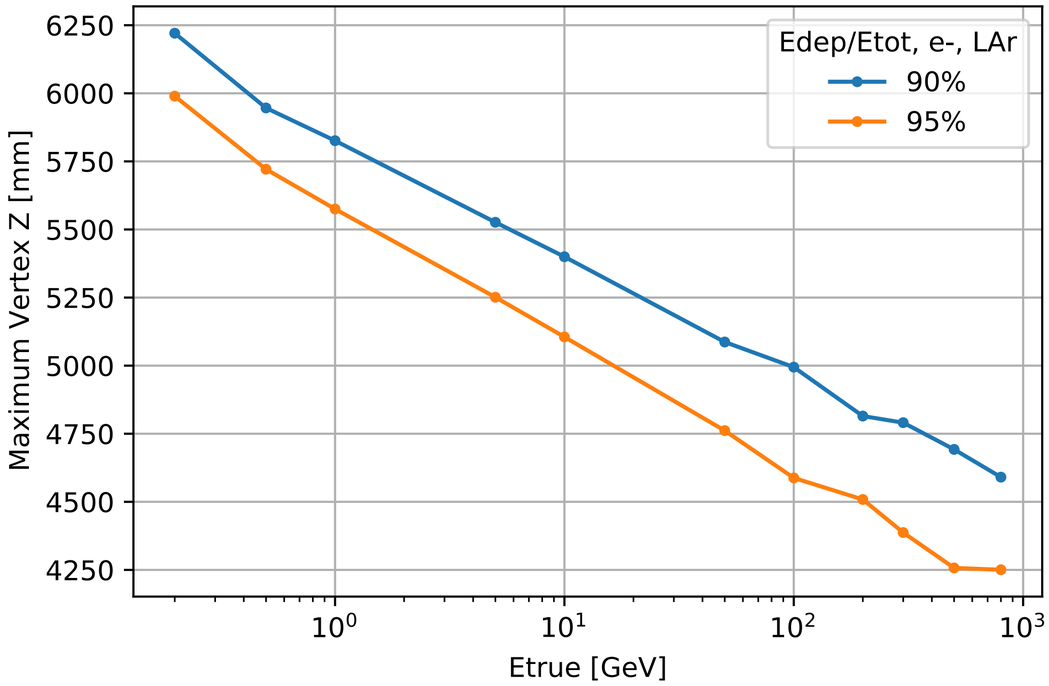
Backup

Energy Containment

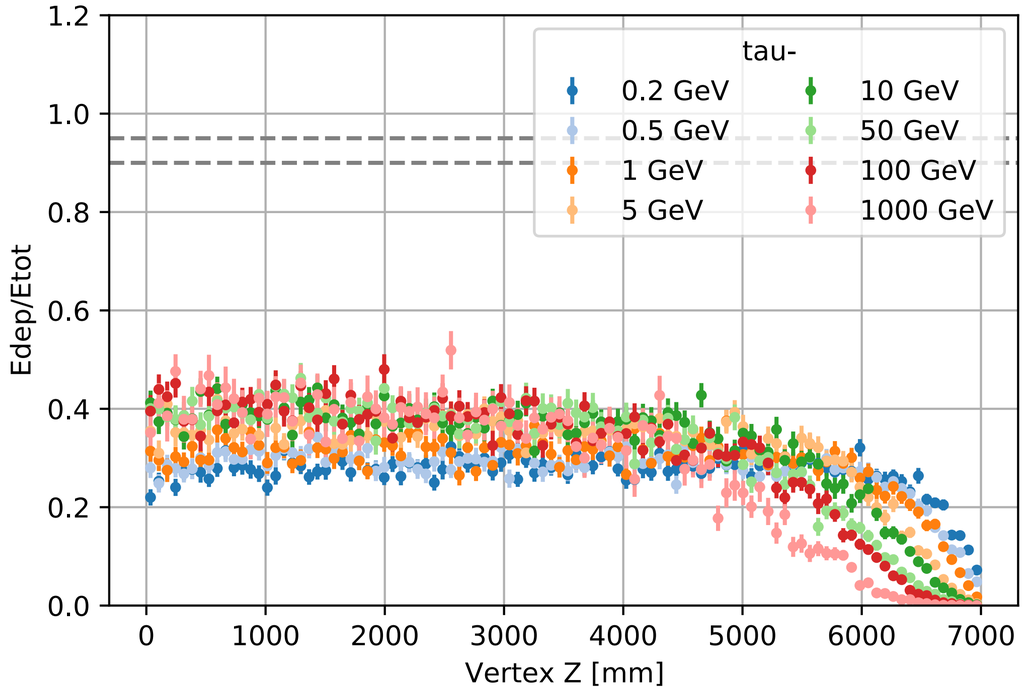
- Electron shower in LAr





Energy Containment

- τ^- in LAr: missing energy from τ^- decay

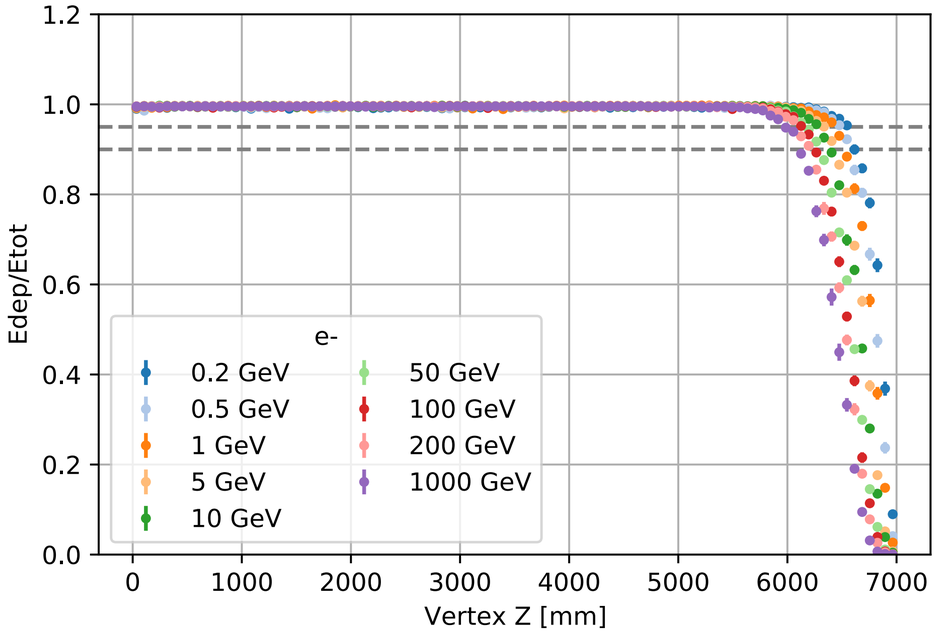


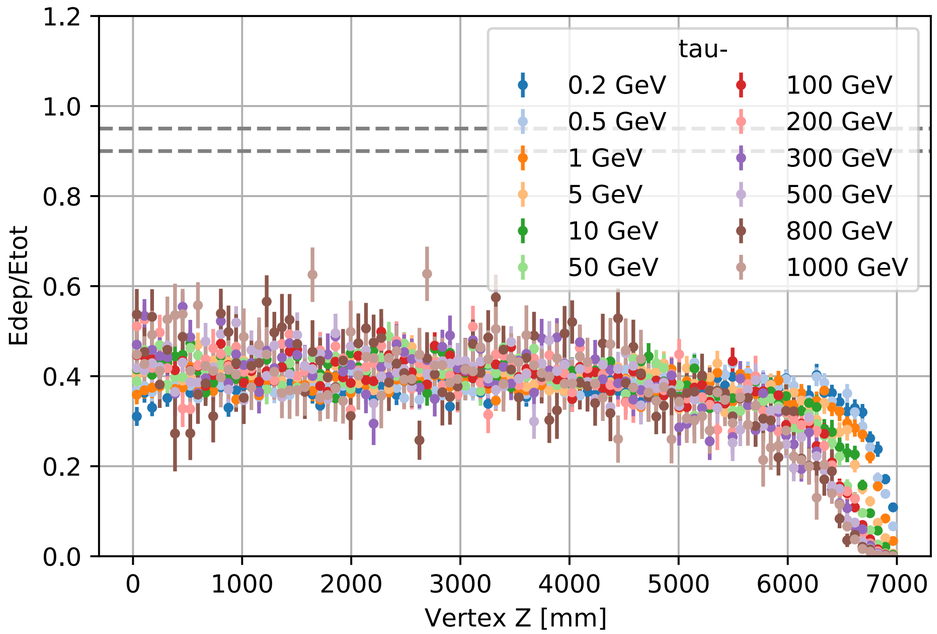
Decay mode	Branching ratio
Leptonic	35.2%
$e^-\bar{\nu}_e\nu_\tau$	17.8%
$\mu^-\bar{\nu}_\mu\nu_\tau$	17.4%
Hadronic	64.8%
$\pi^-\pi^0\nu_\tau$	25.5%
$\pi^-\nu_\tau$	10.8%
$\pi^-\pi^0\pi^0\nu_\tau$	9.3%
$\pi^-\pi^-\pi^+\nu_\tau$	9.0%
$\pi^-\pi^-\pi^+\pi^0\nu_\tau$	4.5%
other	5.7%

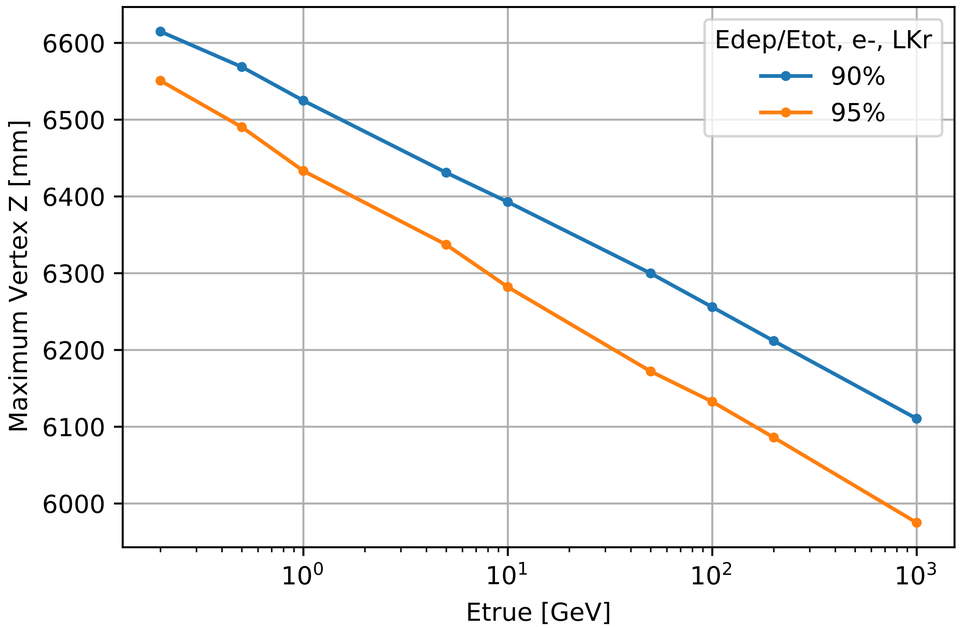
https://arxiv.org/pdf/2007.00015.pdf

Energy Containment

- Krypton has better energy containment ability as expected

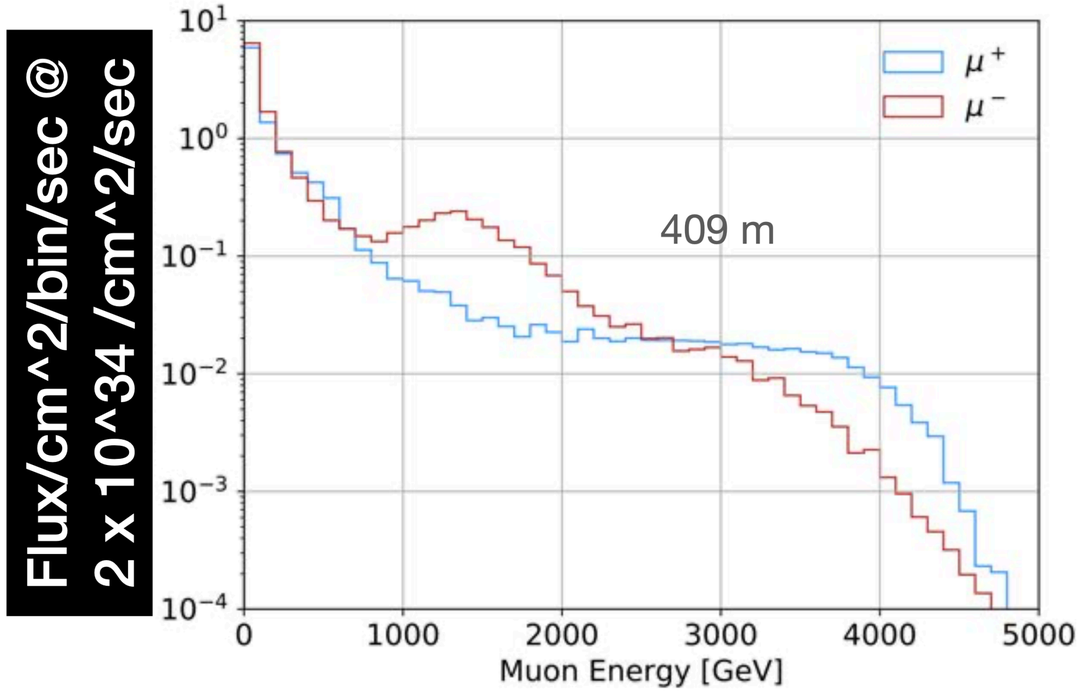






ν_τ recognition

- For ν_τ recognition, we need to consider the backgrounds
  - Muon flux from the interaction point
  - ν_μ/ν_e



calculation	From JB for Flare-10
generator	approx
Normalization mass*fb	1ton*fb
angular range	1 m / 620m
numu/anti-numu	43
nue/anue	10
nutau/ anutau	0.13

Numbers from Milind's slides