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2017-11-07

DUNE NEAR DETECTOR WORKSHOP, CERN

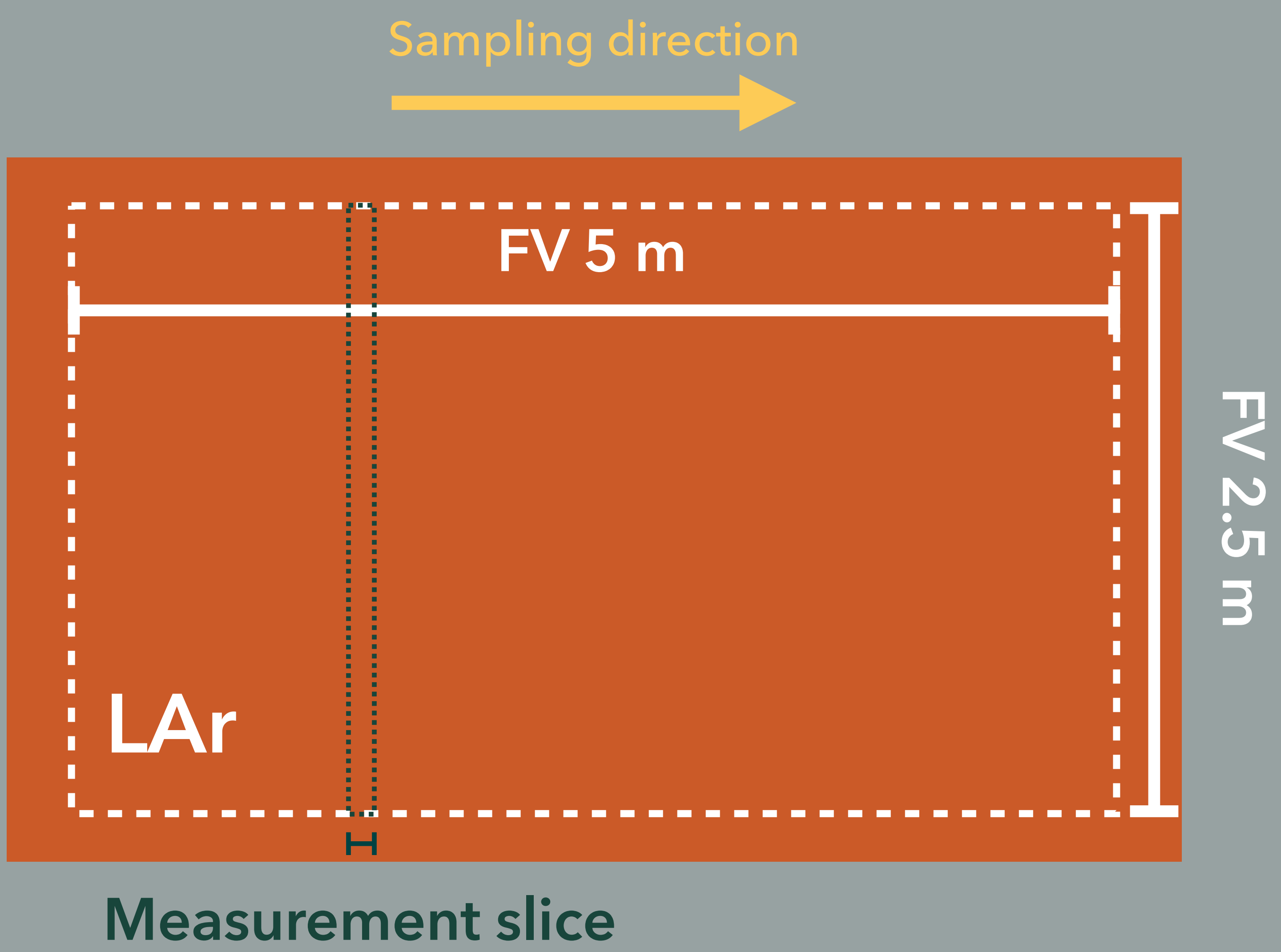
OFF-AXIS FLUX AND EVENT RATE PREDICTIONS

MICHIGAN STATE UNIVERSITY

- Event-rate predictions configuration
- Flux prediction
- Cross sections
- Possible run plans

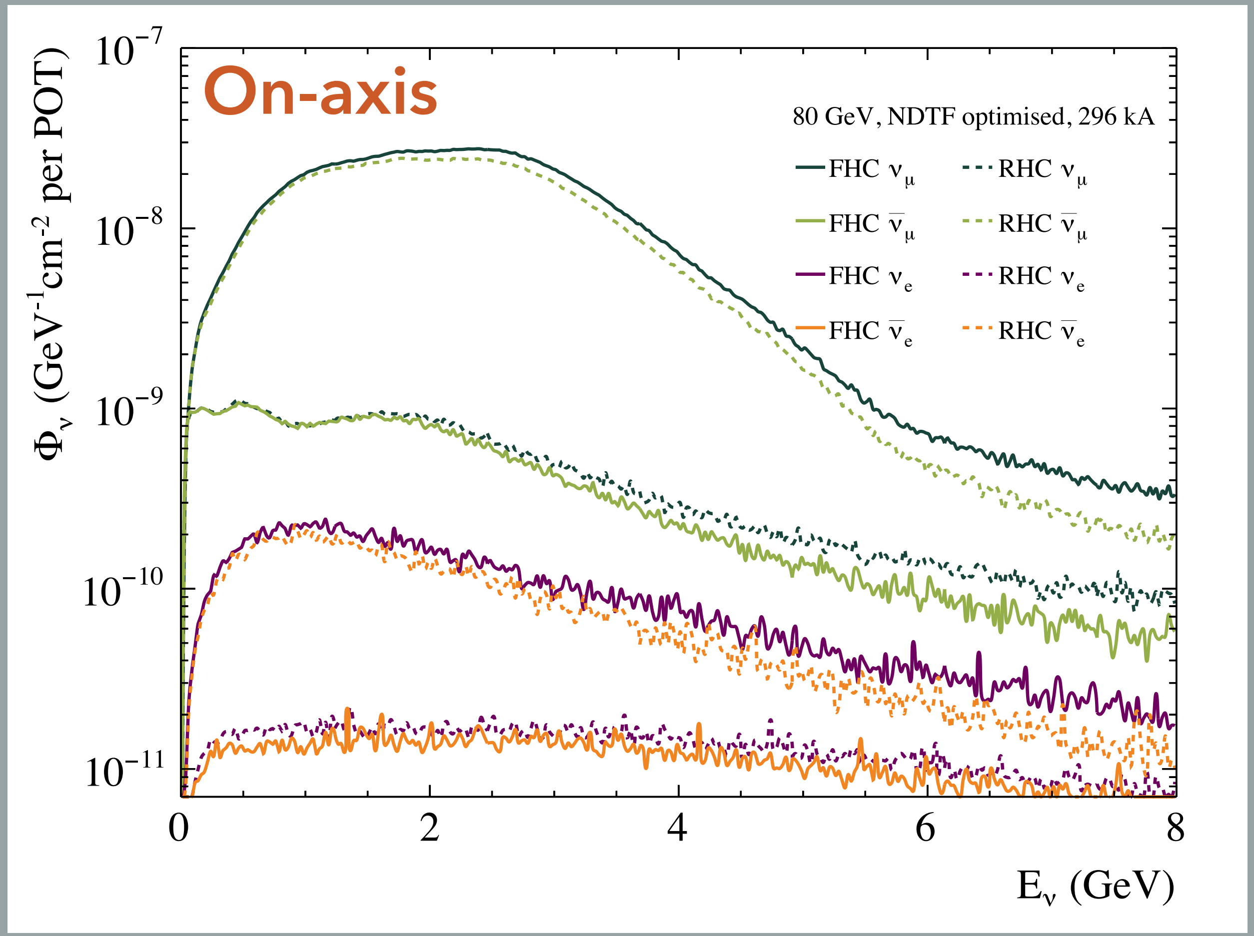
‘DETECTOR’ CONFIGURATION

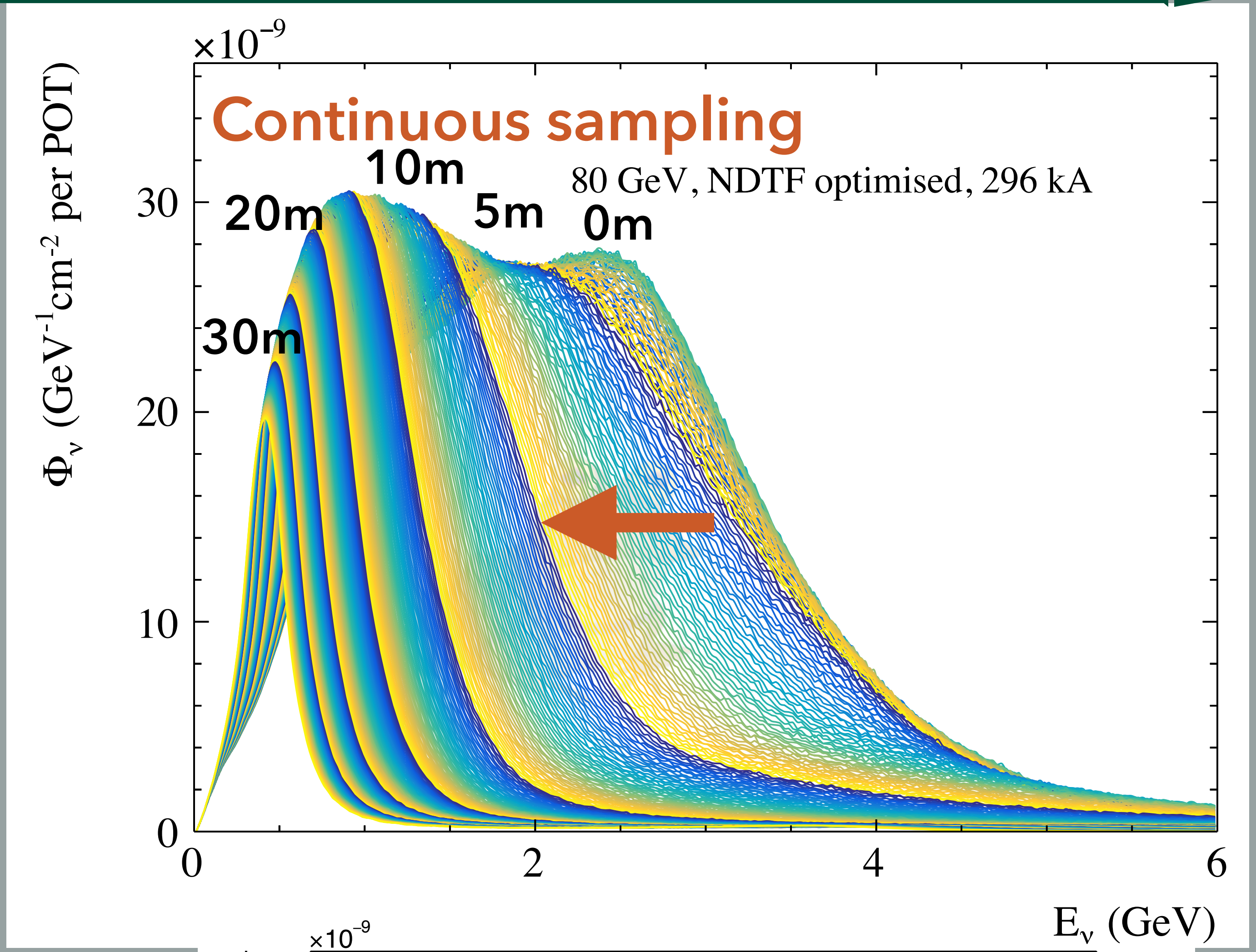
- Using ‘standard’ detector, but with twice the width in off-axis direction.
- LAr XYZ: 6mx3.5mx5m
  - FV: 5mx2.5mx4m
  - ➜ 70 T used to calculate event rates.
- Continuous sampling requires detector stops at 0m, 5m, 10m, 15m, 20m, 25m, 30m off axis

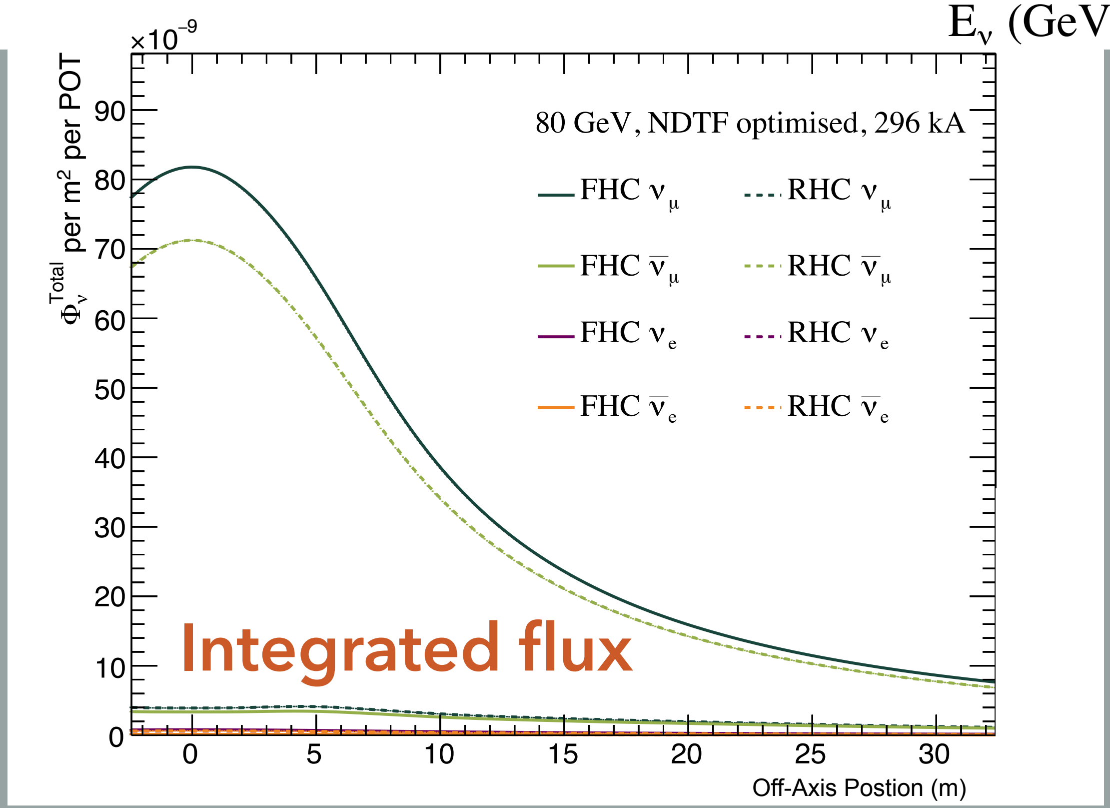


- Minor steps achieved by sub-dividing FV into slices:
  - Widths determined by vertex position resolution/statistics.

FLUX PREDICTIONS



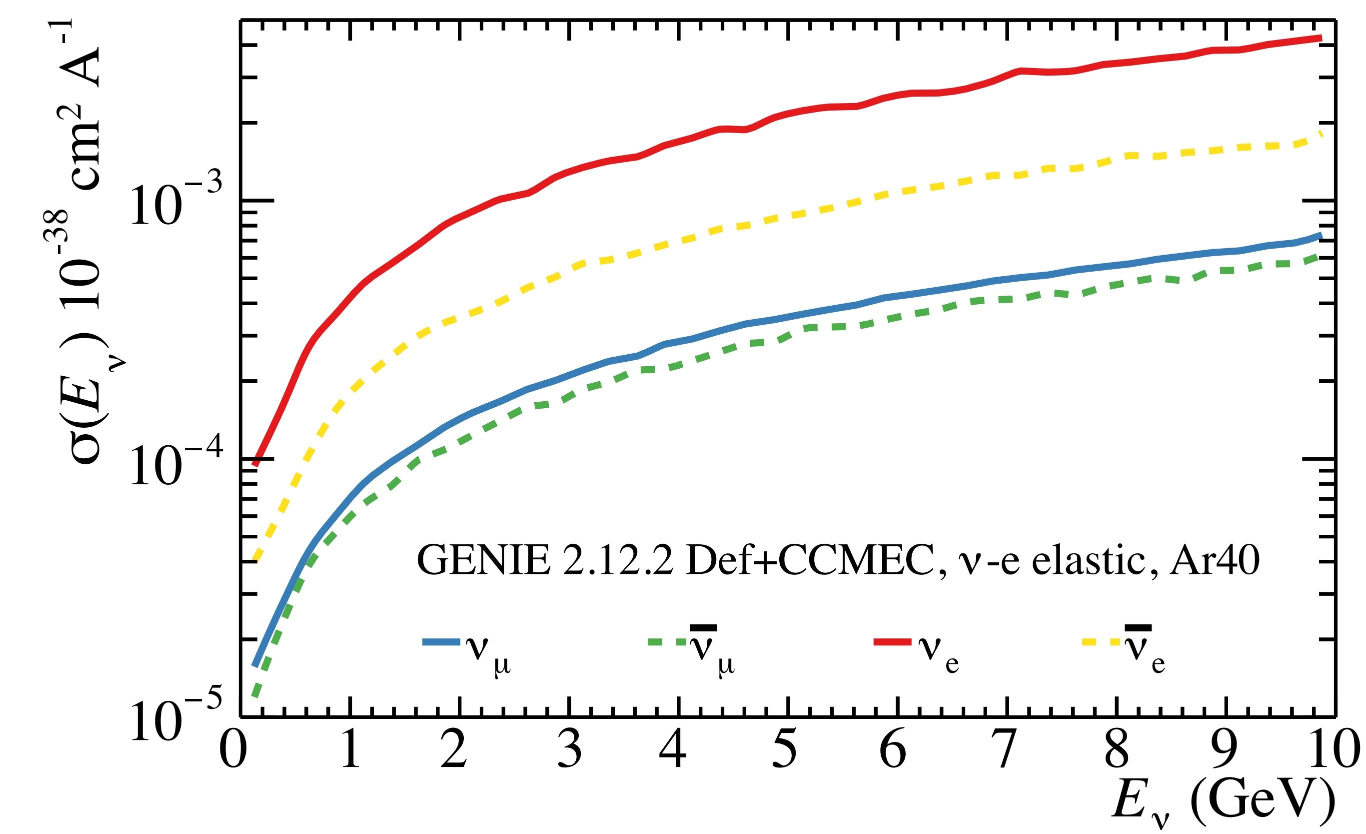


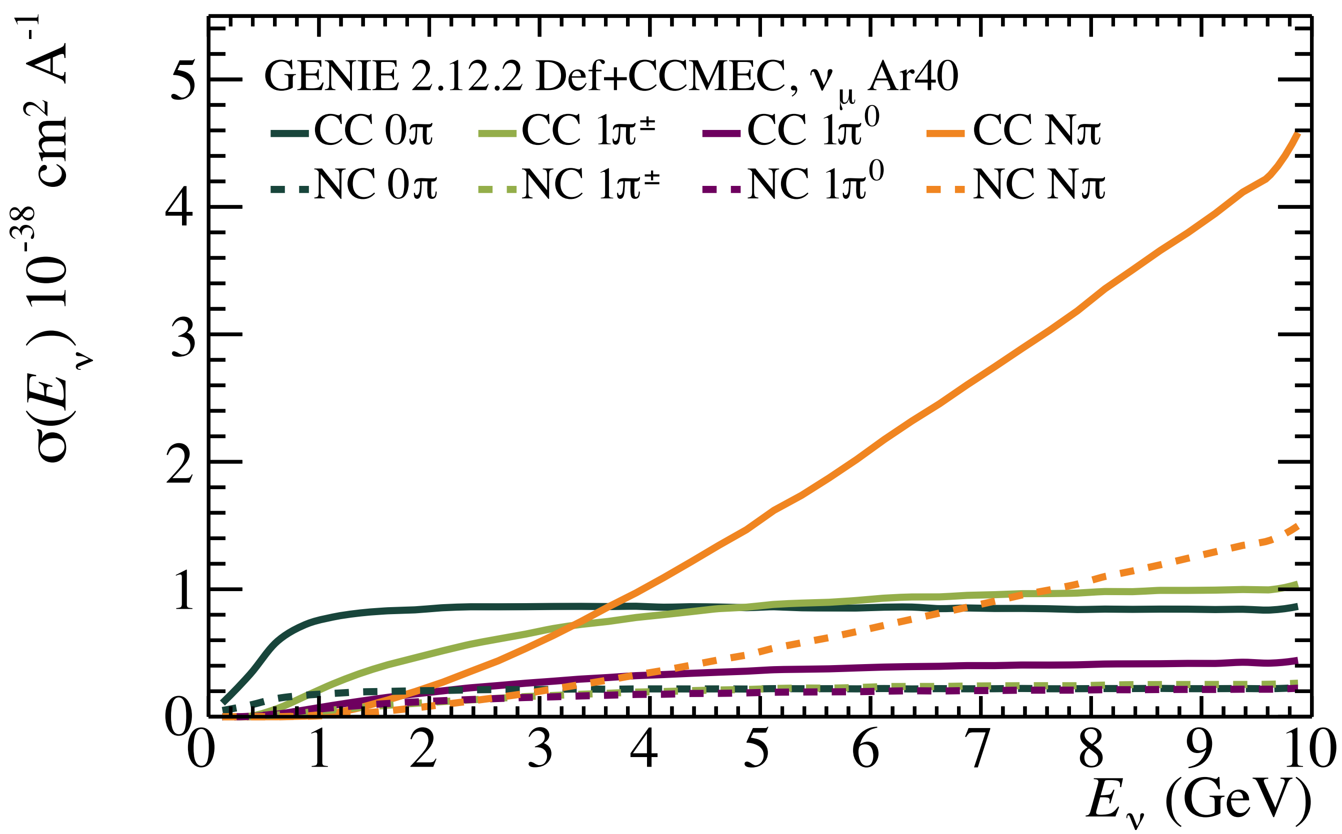


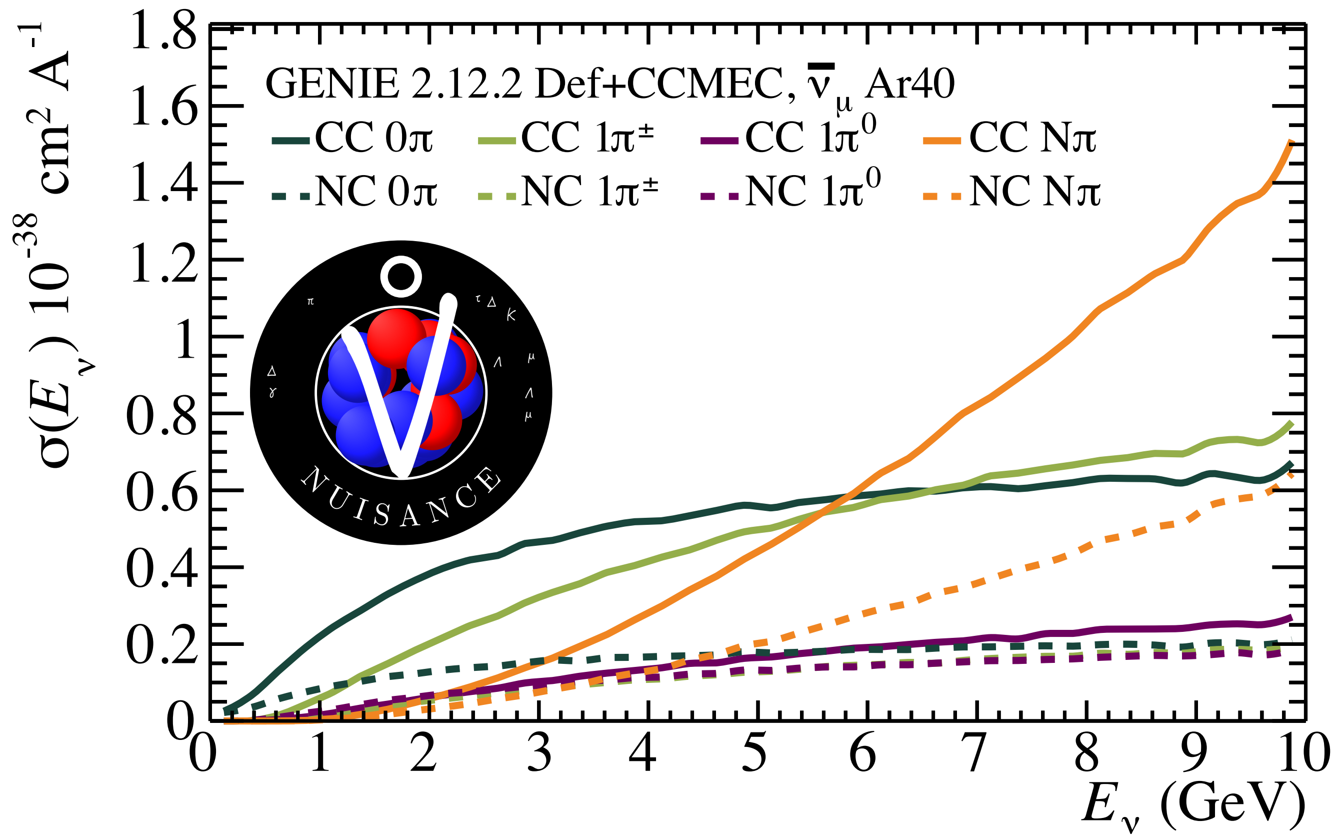
- Each minor detector stop blue → yellow within a major stop.
- Use code adapted from DUNE flux simulation to determine neutrino flux through a 2D plane.

CROSS SECTIONS

- Use GENIE & NUISANCE to calculate topology-based cross sections for use in event rate prediction.







RUN PLANS

- 80 GeV, NDTF optimised horn, 1.47E21 POT.
- Use 0.735x10^{21} POT to assume 50:50 FHC/RHC running.
- Could also imagine spending more time on- and far off-axis to compensate for flux drop off.

Equal POT per major stop

Half POT on axis

Offset	POT/1E21
0 m	0.105
5 m	0.105
10 m	0.105
15 m	0.105
20 m	0.105
25 m	0.105
30 m	0.105
All	0.735
0 m	0.367
5 m	0.0612
10 m	0.0612
15 m	0.0612
20 m	0.0612
25 m	0.0612
30 m	0.0612
All	0.735

EQUAL POT AT EACH STOP

FHC

Offset	10^{21}POT	ν_μCCInc	ν_μCC0*pi* / CCInc	ν_μCC1*pi* / CCInc	NCInc	CCInc $\bar{\nu}_\mu$	CCInc $\bar{\nu}_\mu/\nu_\mu$	CCInc ν_e	CCInc ν_e/ν_μ	ν_μ−e El.
0 m	0.105	7.1e+06	0.40	0.35	2.1e+06	1.3e+05	0.018	9e+04	0.013	612
5 m	0.105	5.4e+06	0.42	0.34	1.6e+06	1.4e+05	0.026	7.5e+04	0.014	463
10 m	0.105	2.6e+06	0.51	0.31	7.4e+05	9.2e+04	0.036	4.9e+04	0.019	205
15 m	0.105	1.2e+06	0.59	0.26	3.4e+05	6e+04	0.050	3e+04	0.025	92.3
20 m	0.105	6.6e+05	0.64	0.23	1.9e+05	4.3e+04	0.066	1.9e+04	0.029	50.4
25 m	0.105	4e+05	0.67	0.21	1.1e+05	2.9e+04	0.073	1.3e+04	0.032	30.8
30 m	0.105	2.6e+05	0.69	0.20	7.4e+04	1.9e+04	0.072	9.1e+03	0.035	20.3
All	0.735	1.8e+07	0.46	0.33	5.2e+06	5.2e+05	0.029	2.9e+05	0.016	1.48e+03

RHC

Offset	10^{21}POT	$\bar{\nu}_\mu$CCInc	$\bar{\nu}_\mu$CC0*pi* / CCInc	$\bar{\nu}_\mu$CC1*pi* / CCInc	NCInc	CCInc ν_μ	CCInc $\nu_\mu/\bar{\nu}_\mu$	CCInc $\bar{\nu}_e$	CCInc $\bar{\nu}_e/\bar{\nu}_\mu$	$\bar{\nu}_\mu$−e El.
0 m	0.105	2.4e+06	0.47	0.38	9.4e+05	4.2e+05	0.177	2.5e+04	0.011	419
5 m	0.105	1.8e+06	0.49	0.36	7e+05	4.6e+05	0.261	2.1e+04	0.012	312
10 m	0.105	7.4e+05	0.55	0.33	3e+05	3.1e+05	0.416	1.3e+04	0.017	137
15 m	0.105	3e+05	0.62	0.28	1.3e+05	2.1e+05	0.691	7.7e+03	0.025	60.9
20 m	0.105	1.5e+05	0.66	0.25	6.7e+04	1.5e+05	0.981	4.8e+03	0.031	33.1
25 m	0.105	8.9e+04	0.69	0.23	4e+04	1e+05	1.174	3.2e+03	0.036	20.2
30 m	0.105	5.6e+04	0.71	0.22	2.6e+04	7e+04	1.259	2.2e+03	0.039	13.2
All	0.735	5.5e+06	0.51	0.35	2.2e+06	1.7e+06	0.315	7.7e+04	0.014	996

- FHC+RHC here is one year running at 50:50.
- Peak energy down-shift as the detector moves off-axis: Get more **more-elastic** events.
- ν_e fraction **increases** off-axis: Higher signal/background for cross-section ratio measurements.

HALF ON-AXIS

Offset	10^{21}POT	ν_μCCInc	NCInc	CCInc $\bar{\nu}_\mu$	CCInc ν_e	ν_μ−e El.
0 m	0.367	2.5e+07	7.5e+06	4.6e+05	3.2e+05	2.14e+03
5 m	0.0612	3.2e+06	9.5e+05	8.3e+04	4.4e+04	270
10 m	0.0612	1.5e+06	4.3e+05	5.4e+04	2.9e+04	120
15 m	0.0612	7e+05	2e+05	3.5e+04	1.8e+04	53.9
20 m	0.0612	3.8e+05	1.1e+05	2.5e+04	1.1e+04	29.4
25 m	0.0612	2.3e+05	6.6e+04	1.7e+04	7.5e+03	18
30 m	0.0612	1.5e+05	4.3e+04	1.1e+04	5.3e+03	11.8
All	0.735	3.1e+07	9.3e+06	6.8e+05	4.3e+05	2.65e+03

Offset	10^{21}POT	$\bar{\nu}_\mu$CCInc	NCInc	CCInc ν_μ	CCInc $\bar{\nu}_e$	$\bar{\nu}_\mu$−e El.
0 m	0.367	8.4e+06	3.3e+06	1.5e+06	8.9e+04	1.47e+03
5 m	0.0612	1e+06	4.1e+05	2.7e+05	1.2e+04	182
10 m	0.0612	4.3e+05	1.8e+05	1.8e+05	7.5e+03	80
15 m	0.0612	1.8e+05	7.5e+04	1.2e+05	4.5e+03	35.5
20 m	0.0612	9e+04	3.9e+04	8.8e+04	2.8e+03	19.3
25 m	0.0612	5.2e+04	2.3e+04	6.1e+04	1.8e+03	11.8
30 m	0.0612	3.2e+04	1.5e+04	4.1e+04	1.3e+03	7.7
All	0.735	1e+07	4e+06	2.2e+06	1.2e+05	1.8e+03

- **Significant statistics off-axis**: More than at equivalent position for NuPRISM (J-PARC, Japan).
- Collect 4000 **nu-e elastic** events per FHC-year:
- Could feasibly spend more 1/2 the time on axis.
  - Propagated statistical error for linear combination of measurements is under study.

PER CYCLE

- Large near detector volume results in FV pile-up in the on-axis position:
  - But detector is transversely wide and ArgonCube drift direction is in Z.
- Wider detector collects more events per stop and has to make less stops for continuous sampling.
- Pile-up **decreases** off axis.

Per beam cycle

Offset	ν_μCCInc	NCInc	CCInc $\bar{\nu}_\mu$	CCInc ν_e	ν_μ−e El.
0 m	5.1	1.5	0.093	0.064	0.000438
5 m	3.9	1.2	0.1	0.054	0.000331
10 m	1.8	0.53	0.066	0.035	0.000147
15 m	0.85	0.24	0.043	0.022	6.59e-05
20 m	0.47	0.13	0.031	0.014	3.6e-05
25 m	0.28	0.081	0.021	0.0092	2.2e-05
30 m	0.18	0.053	0.013	0.0065	1.45e-05

Offset	$\bar{\nu}_\mu$CCInc	NCInc	CCInc ν_μ	CCInc $\bar{\nu}_e$	$\bar{\nu}_\mu$−e El.
0 m	1.7	0.67	0.3	0.018	0.0003
5 m	1.3	0.5	0.33	0.015	0.000223
10 m	0.53	0.22	0.22	0.0091	9.79e-05
15 m	0.22	0.092	0.15	0.0055	4.35e-05
20 m	0.11	0.048	0.11	0.0034	2.37e-05
25 m	0.063	0.029	0.075	0.0022	1.44e-05
30 m	0.04	0.018	0.05	0.0015	9.42e-06

WE APOLOGISE FOR ANY INCONVENIENCE

THANK YOU

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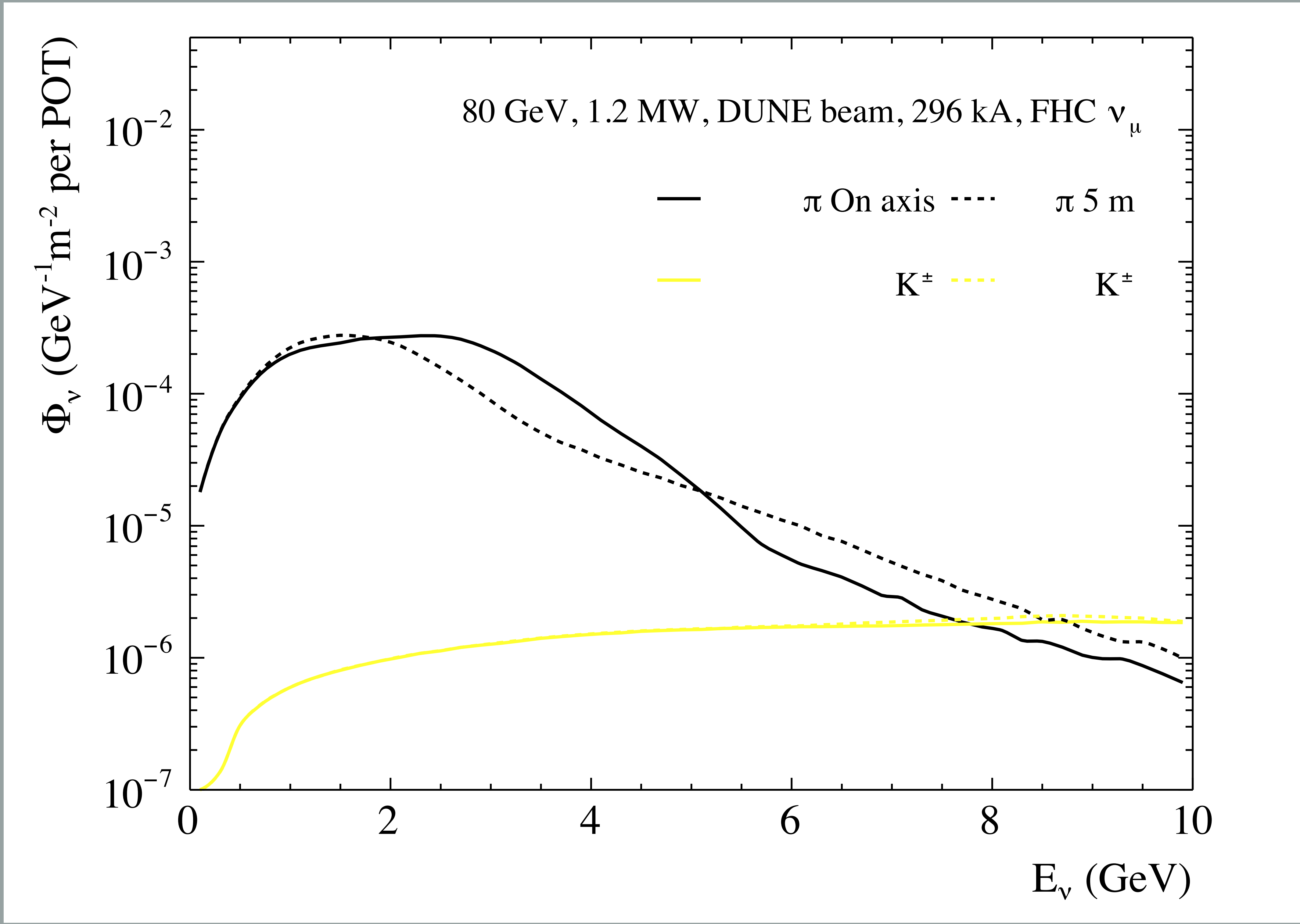
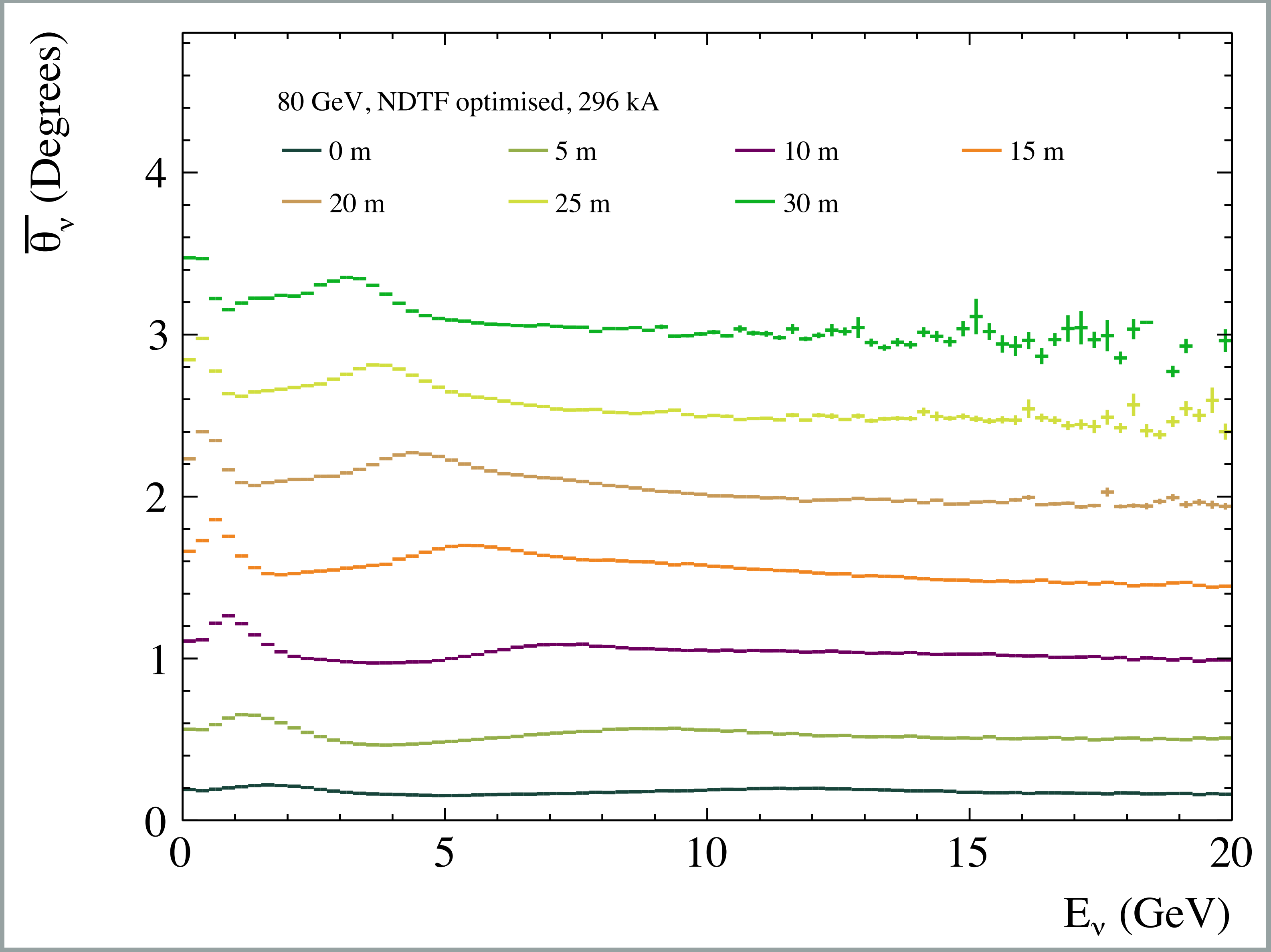
RHC/FHC SPECIES COMPONENTS

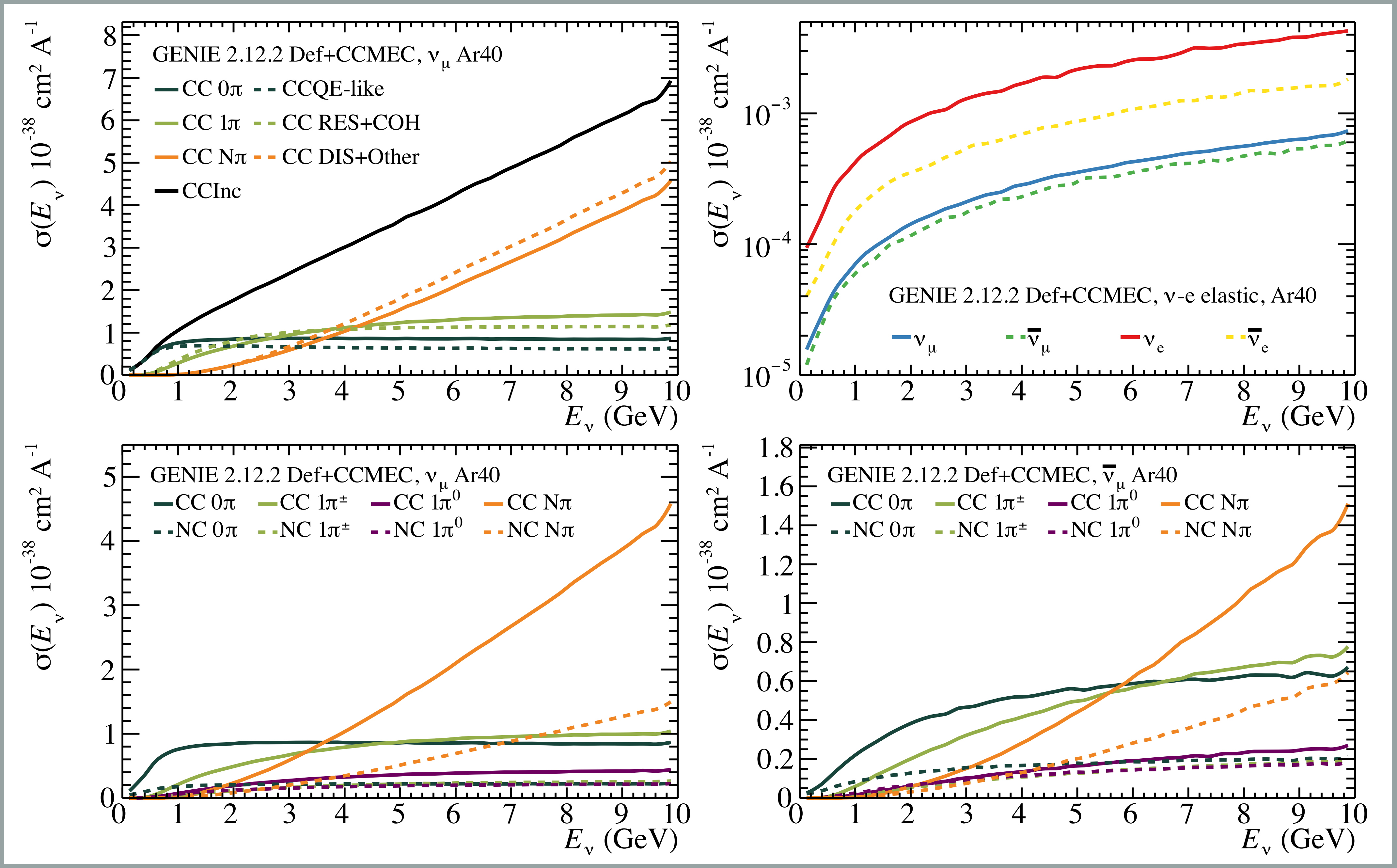


BEAM DIVERGENCE



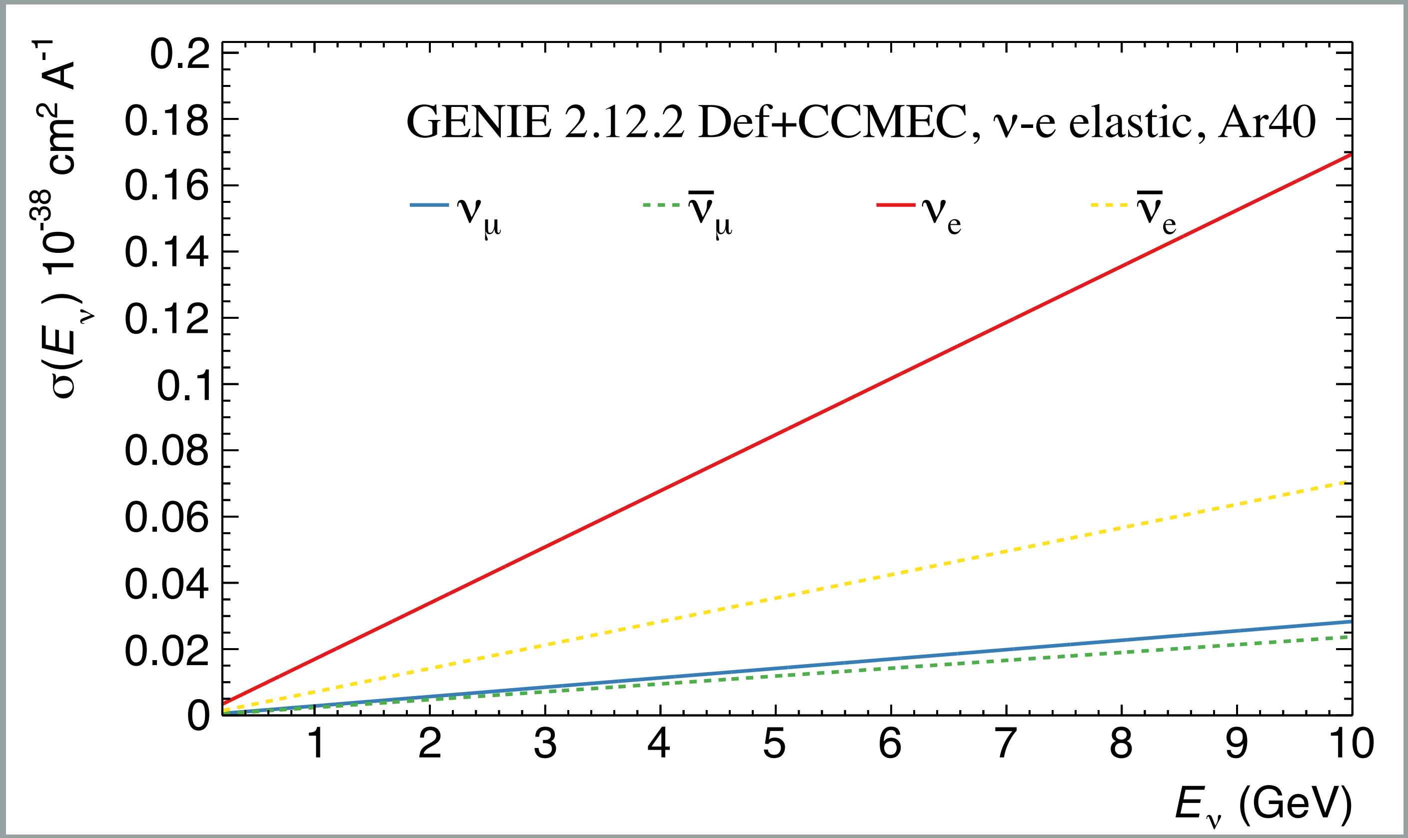
- Uncertainties on beam divergence limits resolution on θ_{ℓ}—problematic for ν-e elastic scattering.
- Correlations between divergence and energy further complicate measurements.

CROSS SECTIONS



- Use GENIE & NUISANCE to calculate topology-based cross sections for use in event rate prediction.

NU - E ELASTIC



$\nu_\mu e \to \nu_\mu e$	$1 - 4\sin^2\theta_W + \frac{16}{3}\sin^4\theta_W$	0.362
$\bar{\nu}_\mu e \to \bar{\nu}_\mu e$	$\frac{1}{3} - \frac{4}{3}\sin^2\theta_W + \frac{16}{3}\sin^4\theta_W$	0.309
$\nu_e e \to \nu_e e$	$1 + 4\sin^2\theta_W + \frac{16}{3}\sin^4\theta_W$	2.2
$\bar{\nu}_e e \to \bar{\nu}_e e$	$\frac{1}{3} + \frac{4}{3}\sin^2\theta_W + \frac{16}{3}\sin^4\theta_W$	0.922

- https://arxiv.org/pdf/hep-ph/0403168.pdf