Decay Pipe Size on Fluxes and Precision Requirements

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BIWG Meeting

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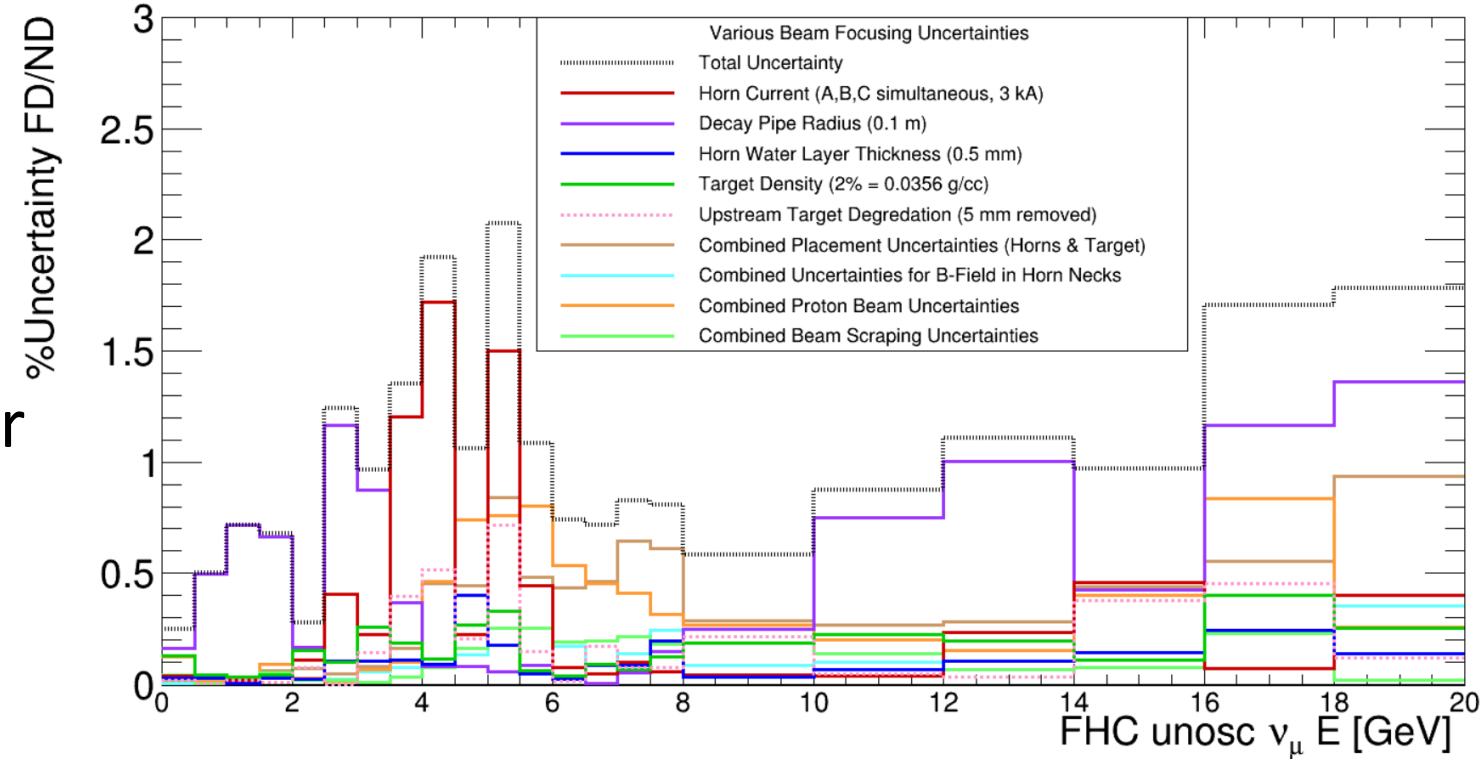
Motivation/Goal

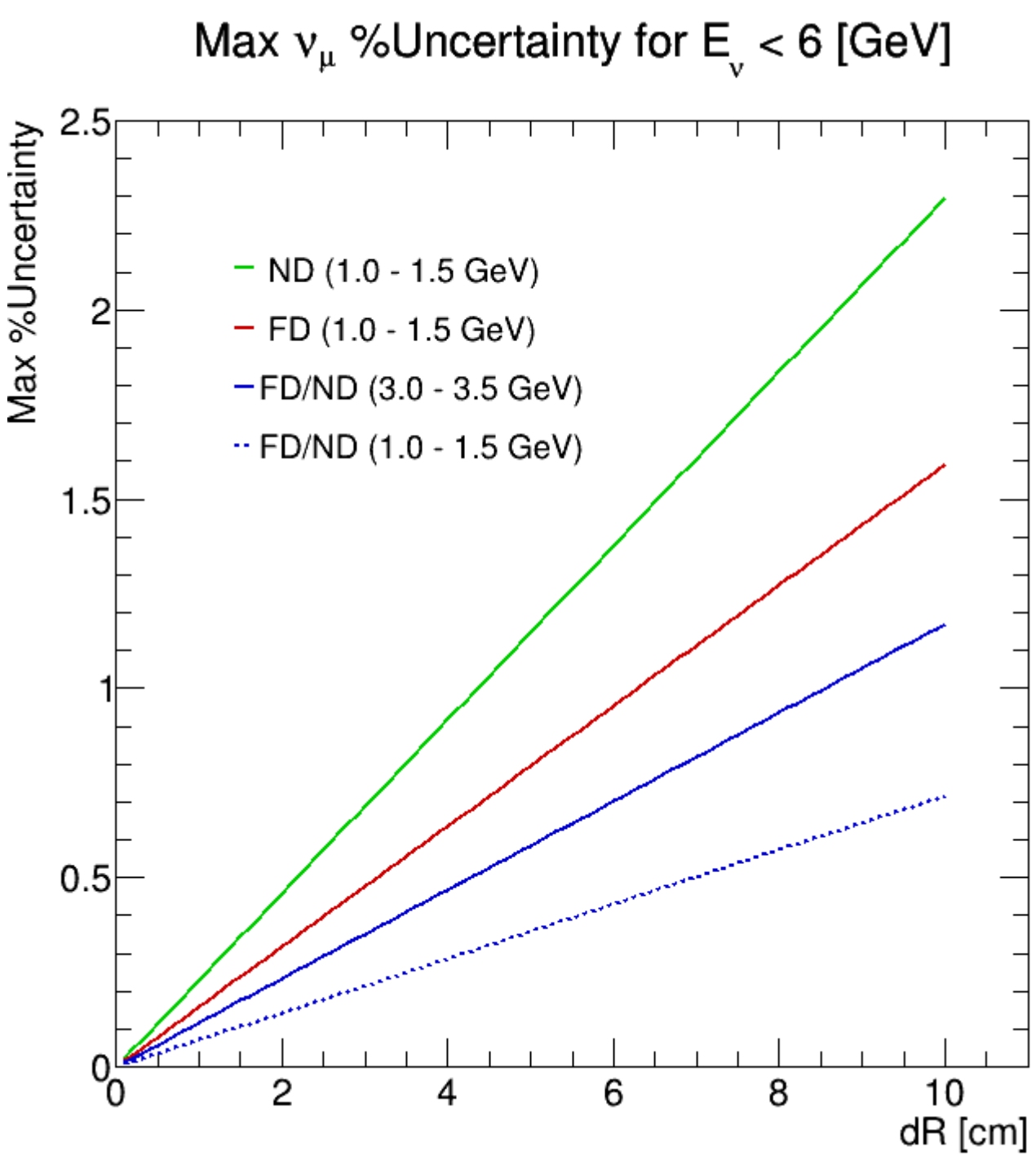
- Decay Pipe Size is a significant systematic uncertainty source in beam focusing uncertainties for primary physics region.
- Uncertainties are for Unoscillated ν_μ flux



- Asked to see how uniform we need the decay pipe to be to reduce uncertainty.
  - In terms of deviation in “decay pipe radius” dR
    - “Radius” is a stand in for multiple deformation effects of the pipe
  - Find an acceptable level of deviation in muon neutrino flux, corresponding dR value, that fits within engineering budget/constraints

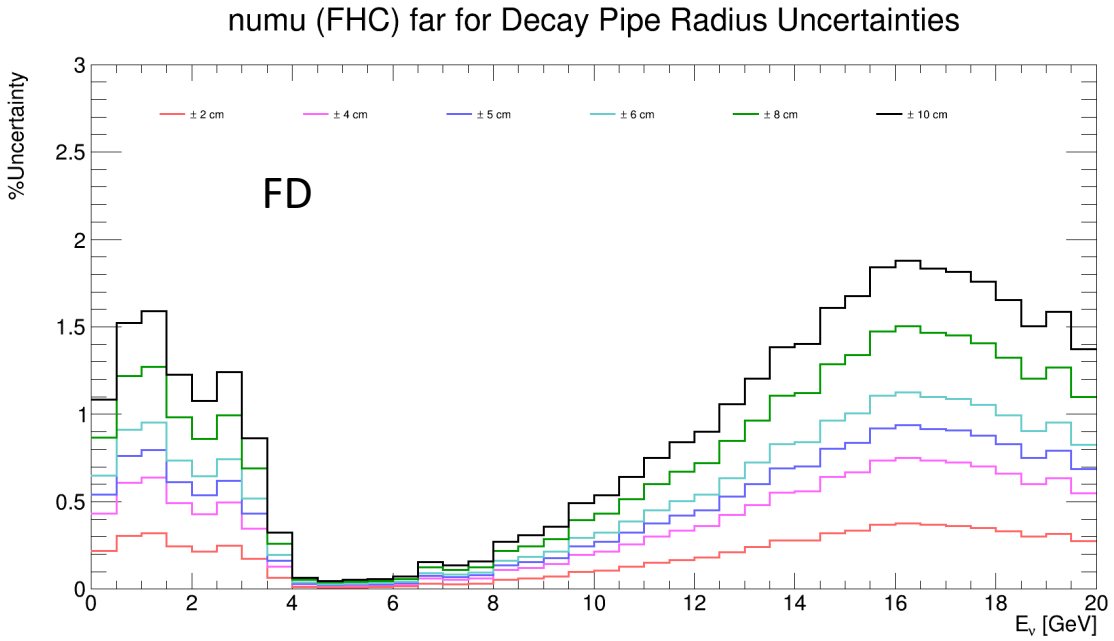
Max %Uncertainty(dR) in Flux ROI

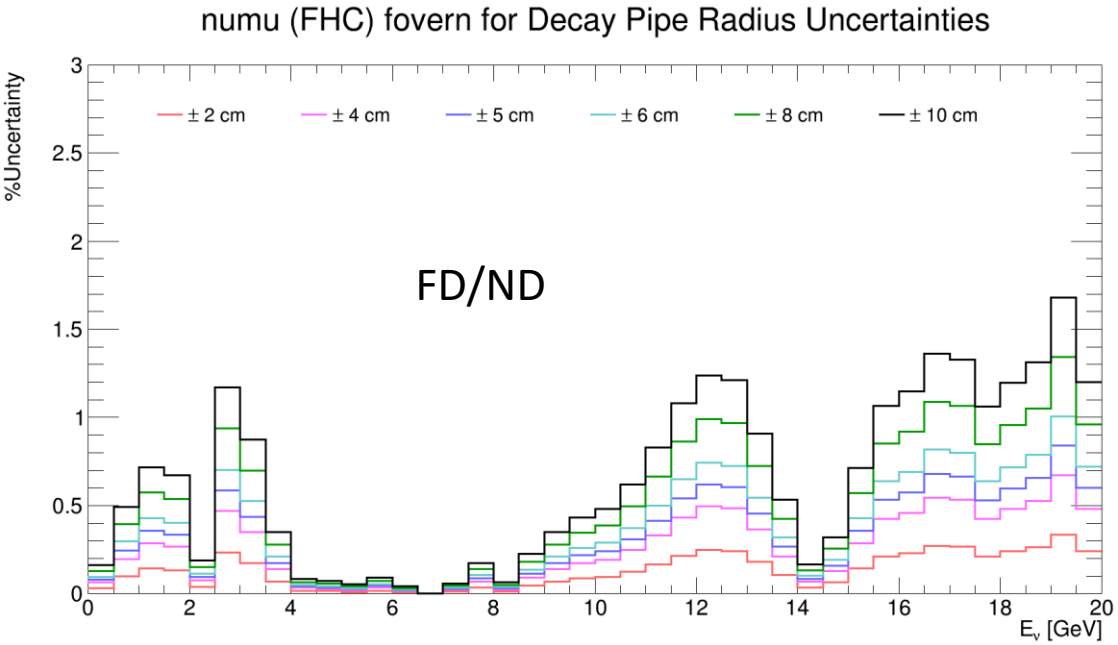
- R_0= 2.0 m, 1σ = 10 cm
- -5σ – +5σ & Sub-1σ samples:
  - $\pm$0.2, $\pm$0.4, $\pm$0.5, $\pm$0.6, $\pm$0.8 σ (2-8 cm)
- Fit in σ for each energy bin with all simulations
  - Include Sub-1σ simulation samples
    - 1σ sample has very high stats (>1e9), so no significant change to best fit after including
- Result (right)
  - extract values from fit (1 mm steps)
  - All 4 are very shallow P_2's

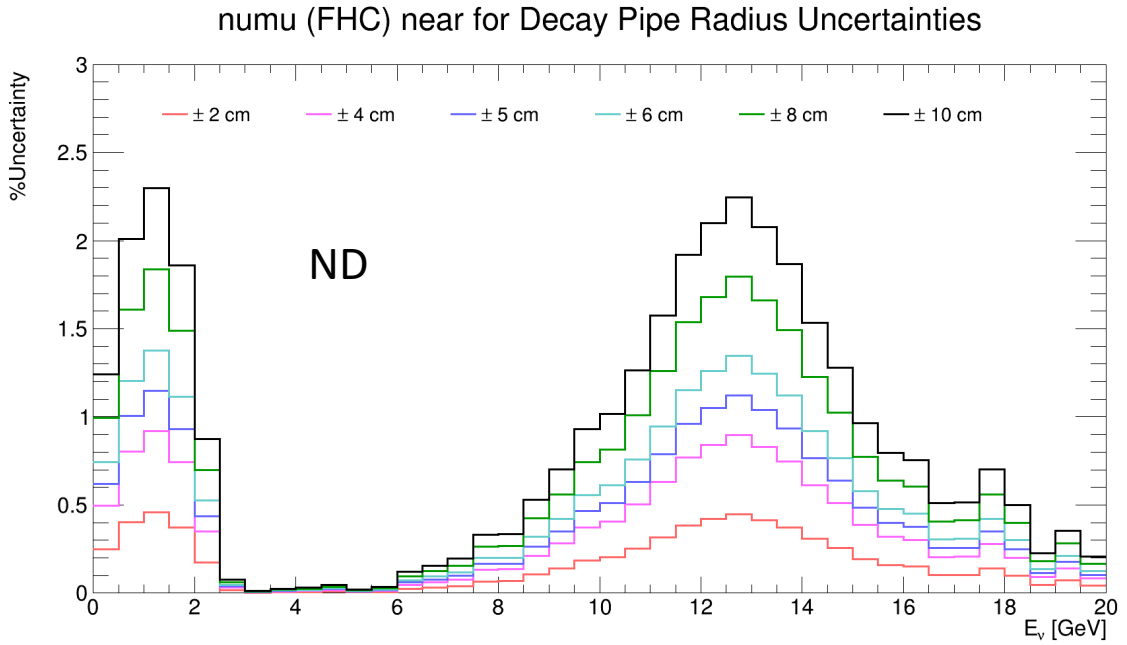


Details

- This page: %Uncertainties for FD, ND, FD/ND
- Large plots on following pages
- $\pm 1\sigma$ has > 1e9 PoT
- -5σ to 5σ samples ~ 0.5e9 PoT,
- Sub-1σ samples
  - $\pm 0.2, \pm 0.4, \pm 0.6, \pm 0.8\ \sigma$ samples generated with 0.25e9 PoT each
  - $\pm 0.5\sigma$ have 0.5e9 PoT

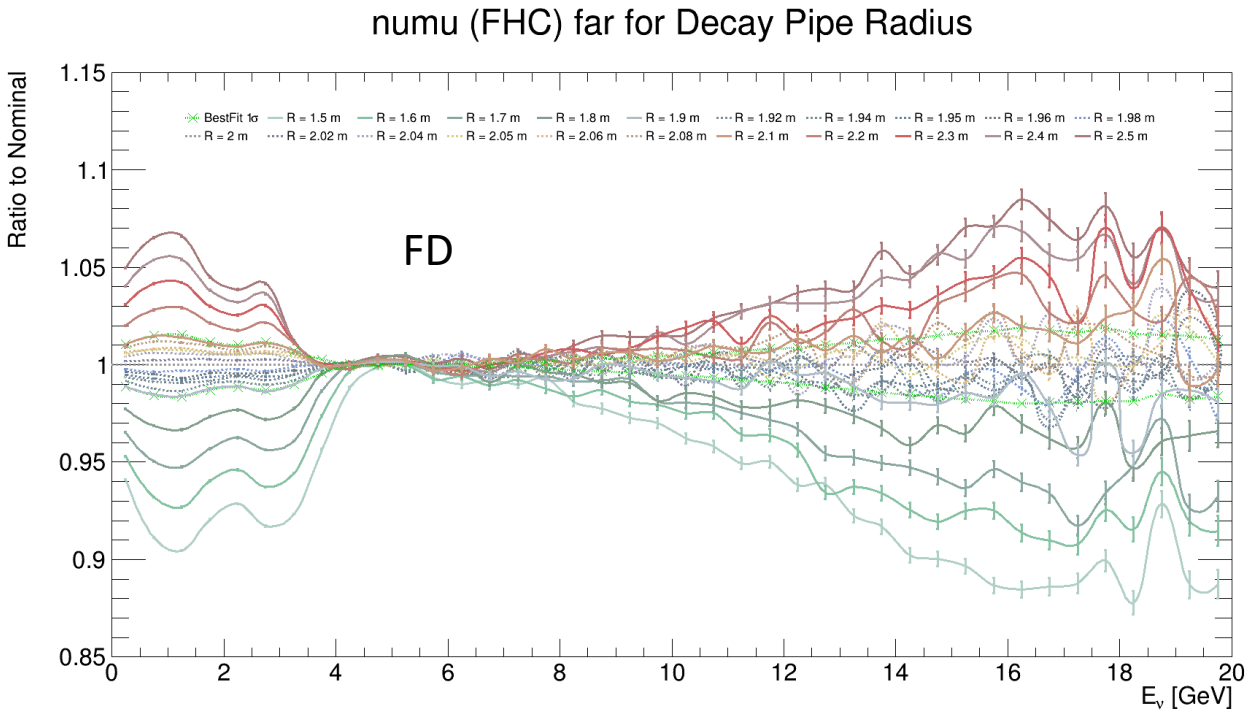


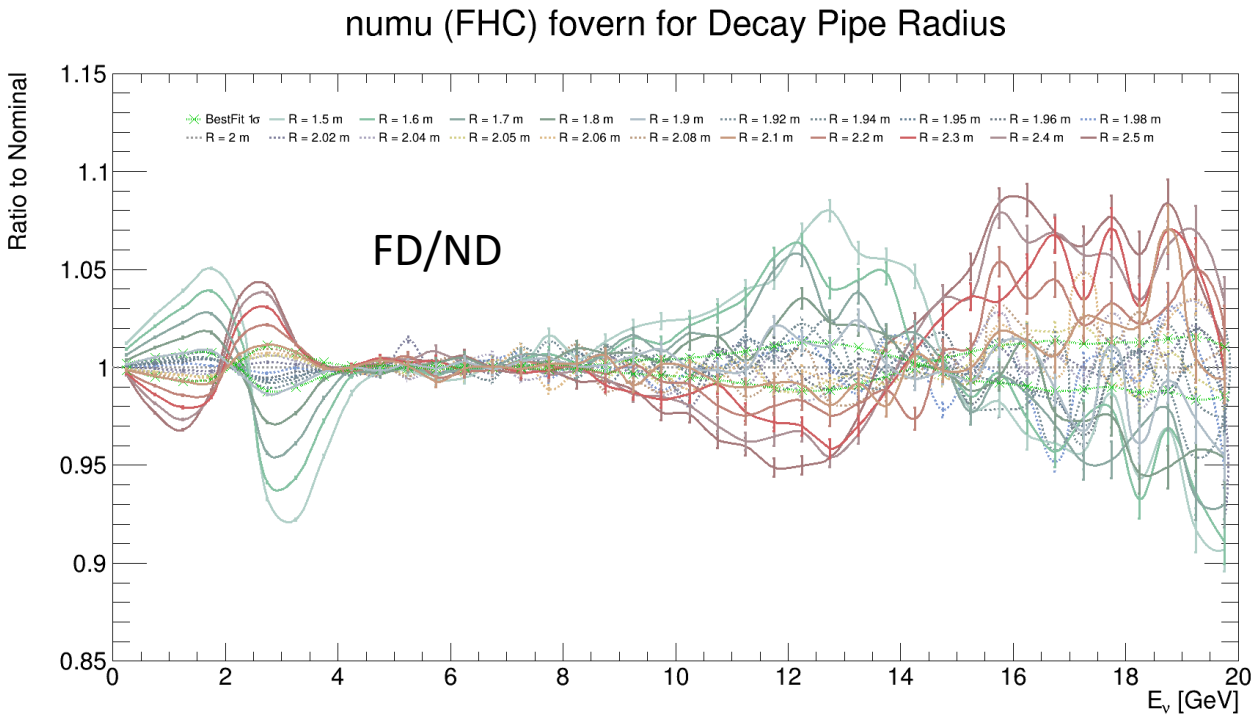


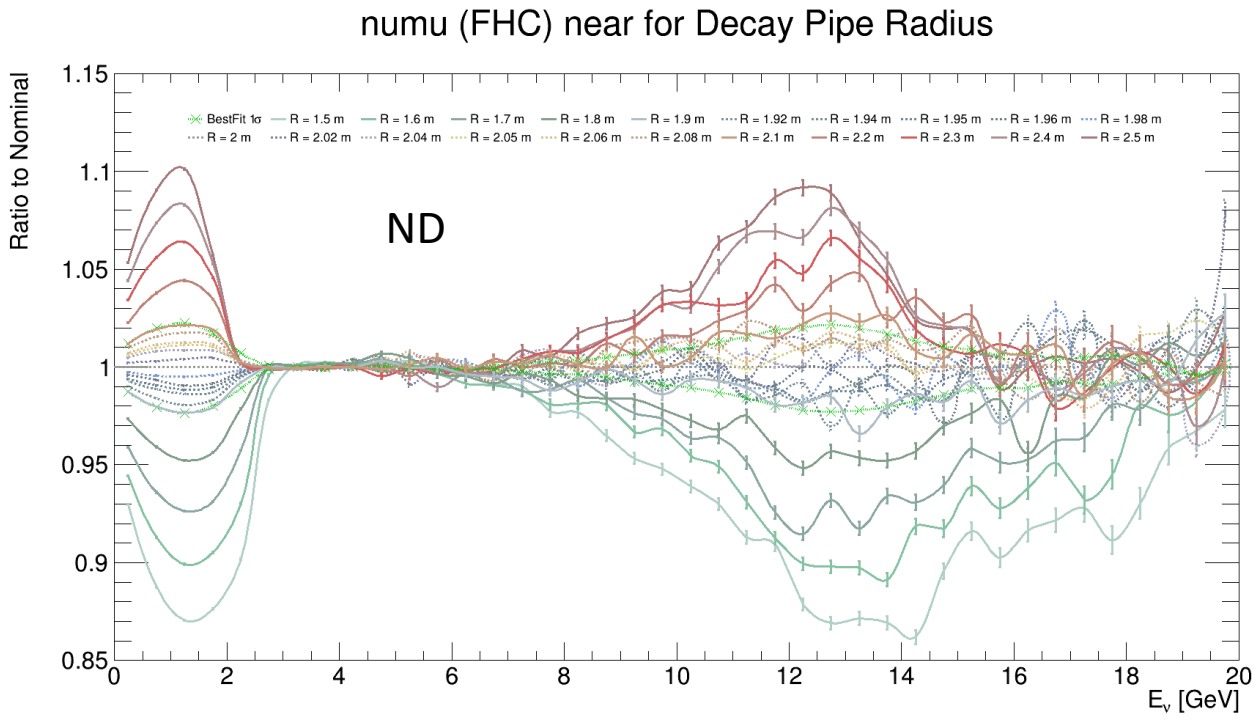


Flux Ratios to Nominal Simulation: -5σ to 5σ, $d\sigma$ = 1σ & $\pm$0.2, $\pm$0.4, $\pm$0.5, $\pm$0.6, $\pm$0.8σ

- Fits are performed in each energy bin on the data from these plots (including errors)







Flux Ratios to Nominal Simulation: -5σ to 5σ, $d\sigma$ = 1σ & $\pm$0.2, $\pm$0.4, $\pm$0.5, $\pm$0.6, $\pm$0.8σ

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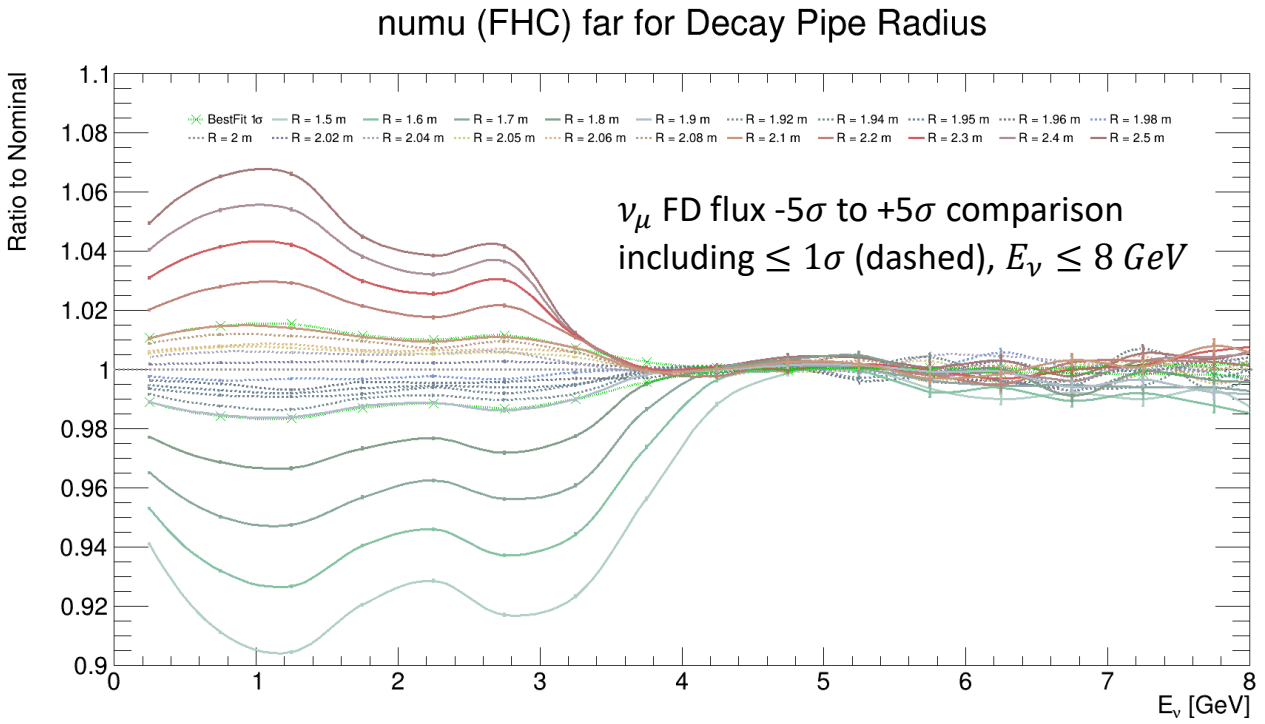
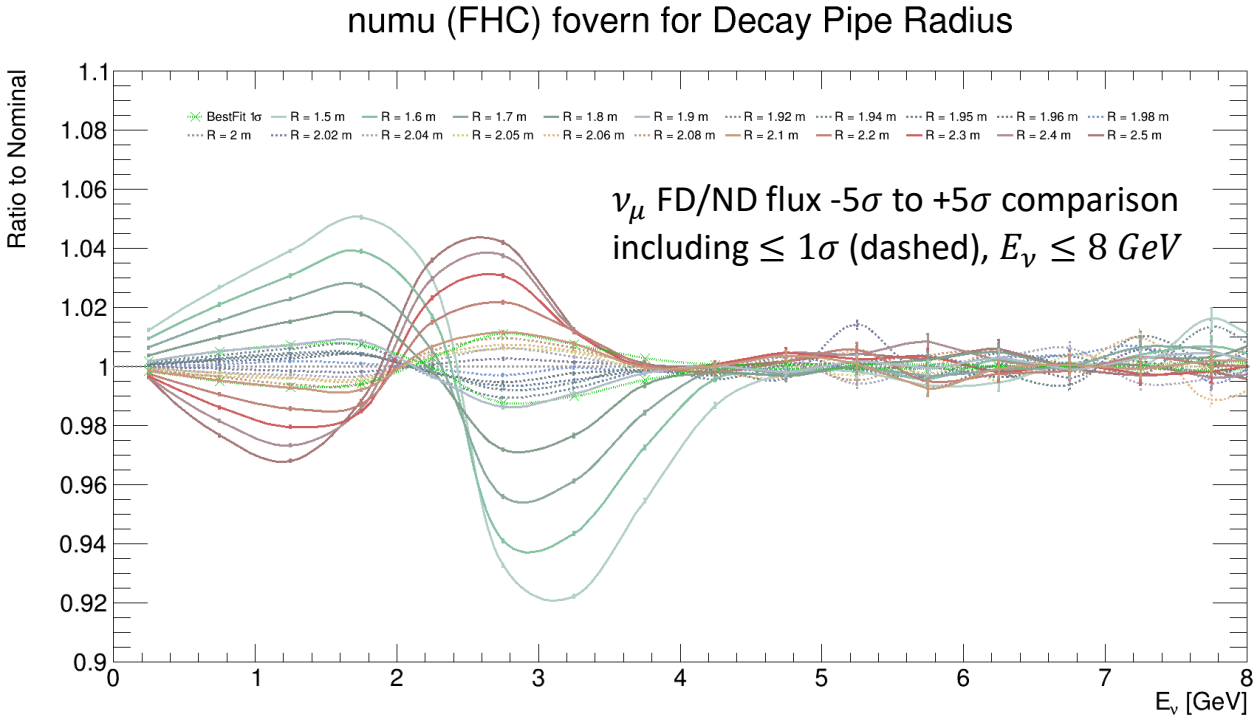
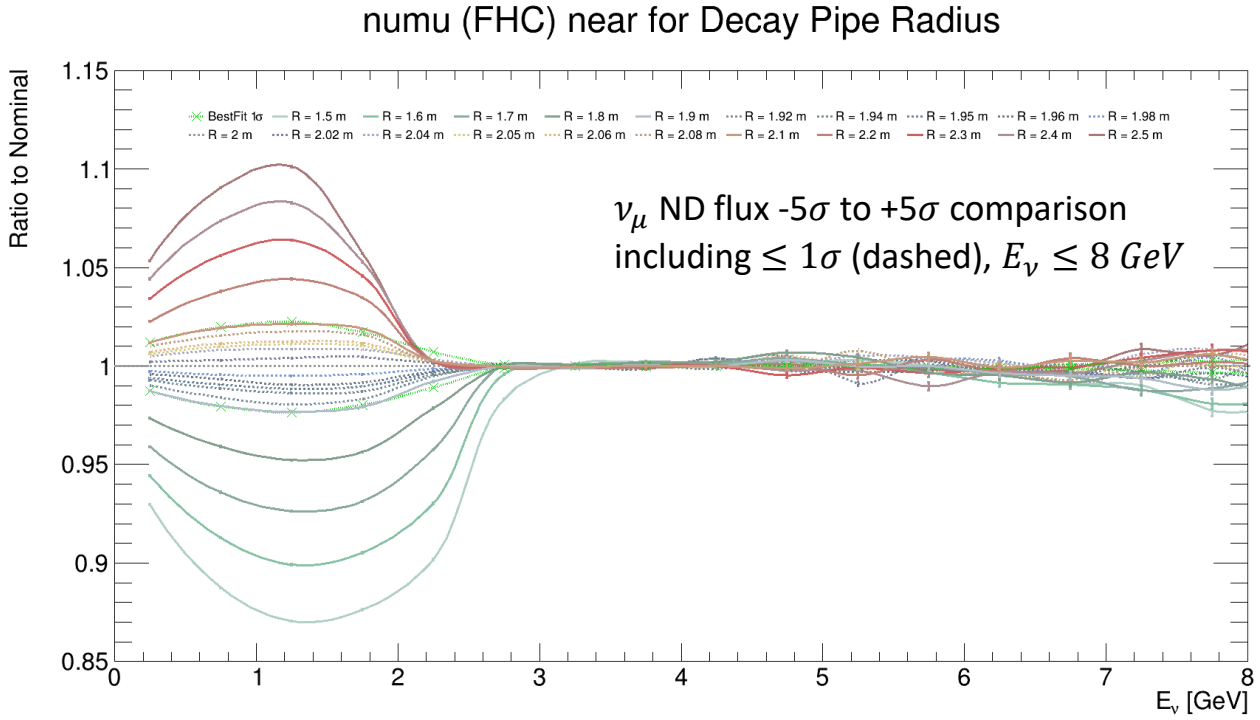
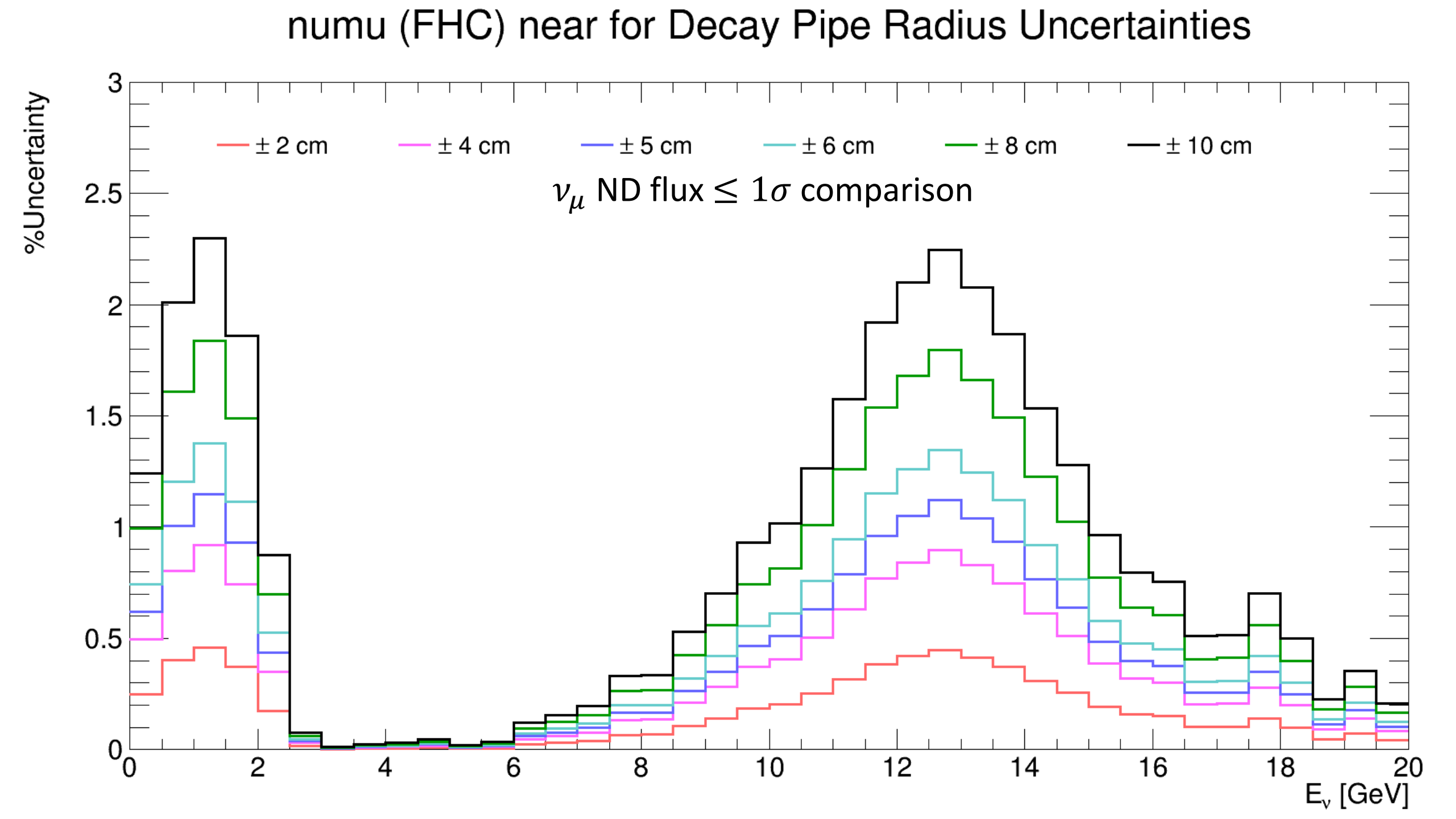
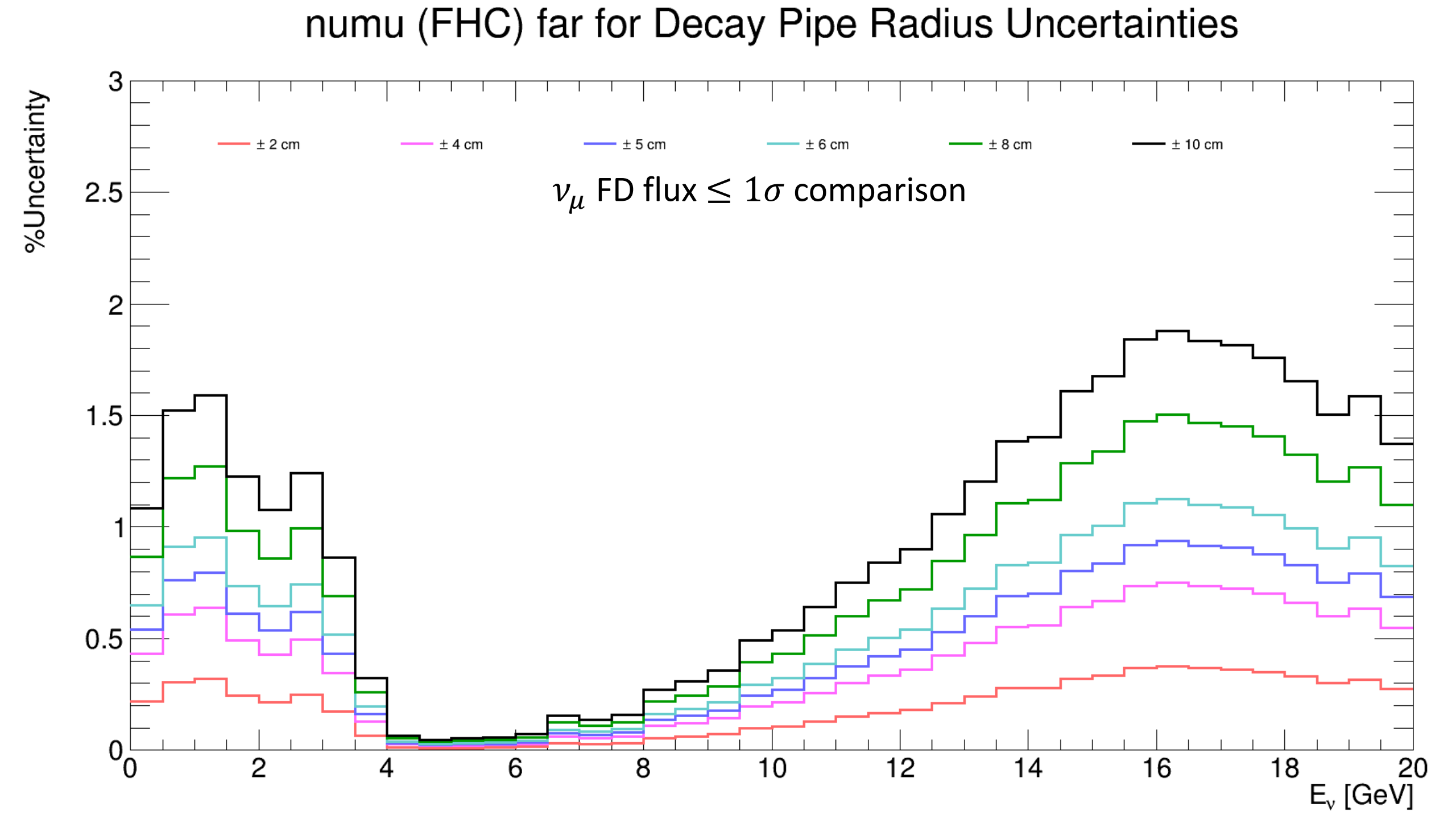







numu (FHC) near for Decay Pipe Radius Uncertainties
± 2 cm
± 4 cm
± 5 cm
± 6 cm
± 8 cm
± 10 cm
ν_μ ND flux $\leq 1\sigma$ comparison
%Uncertainty
E_ν [GeV]
0
0.5
1
1.5
2
2.5
3
0
2
4
6
8
10
12
14
16
18
20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6
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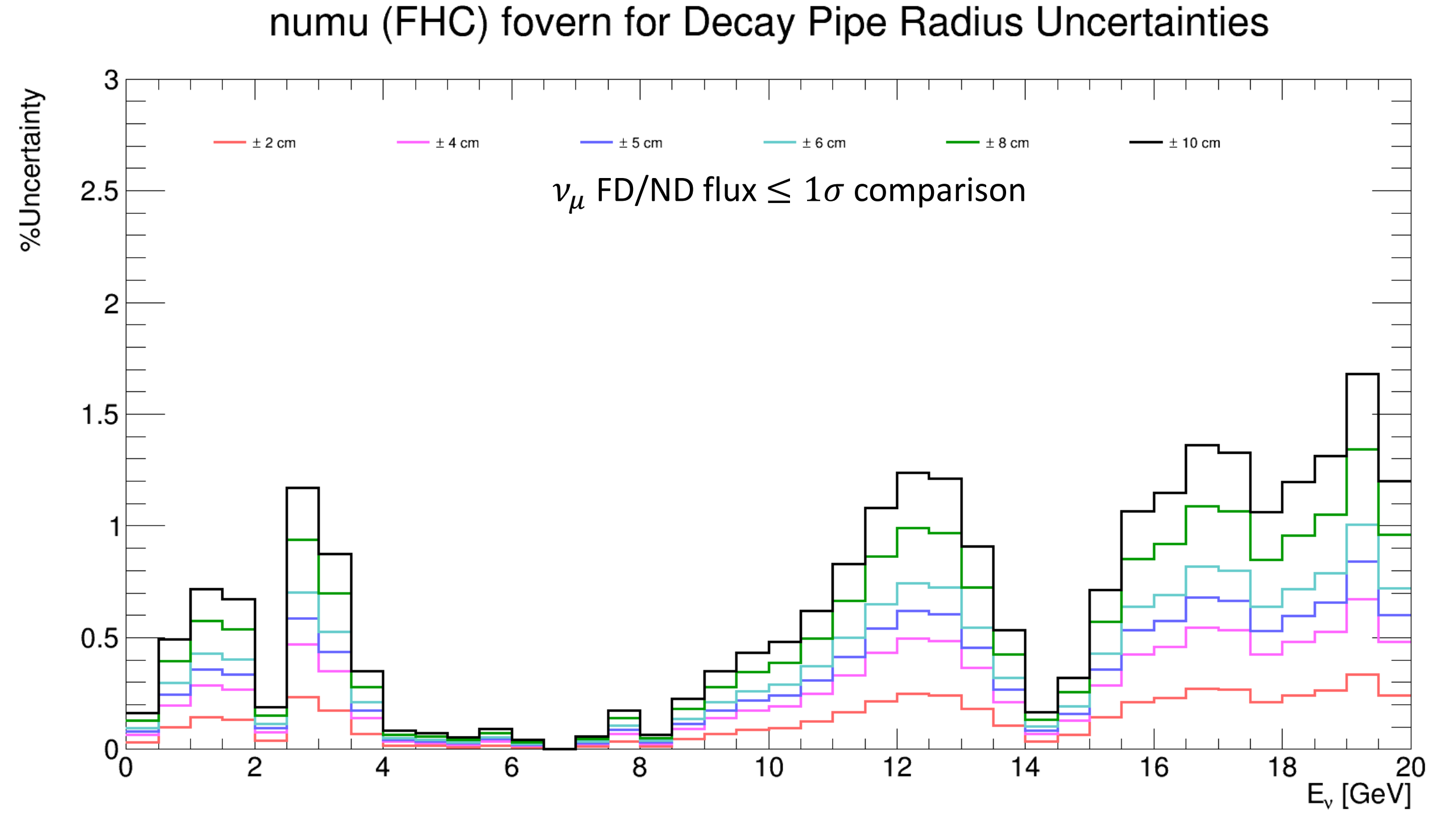
20
E_ν [GeV]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%Uncertainty
± 2 cm
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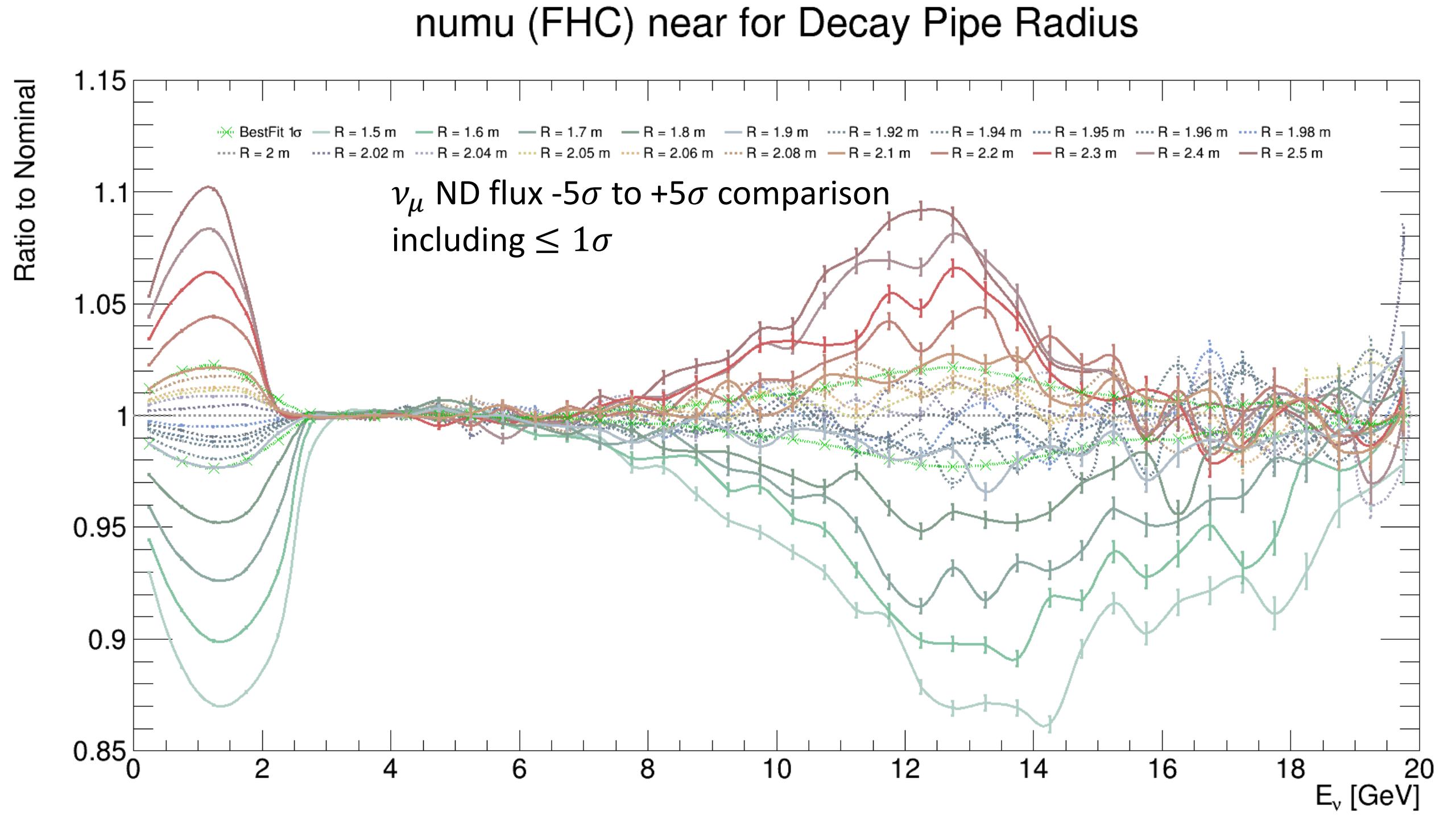
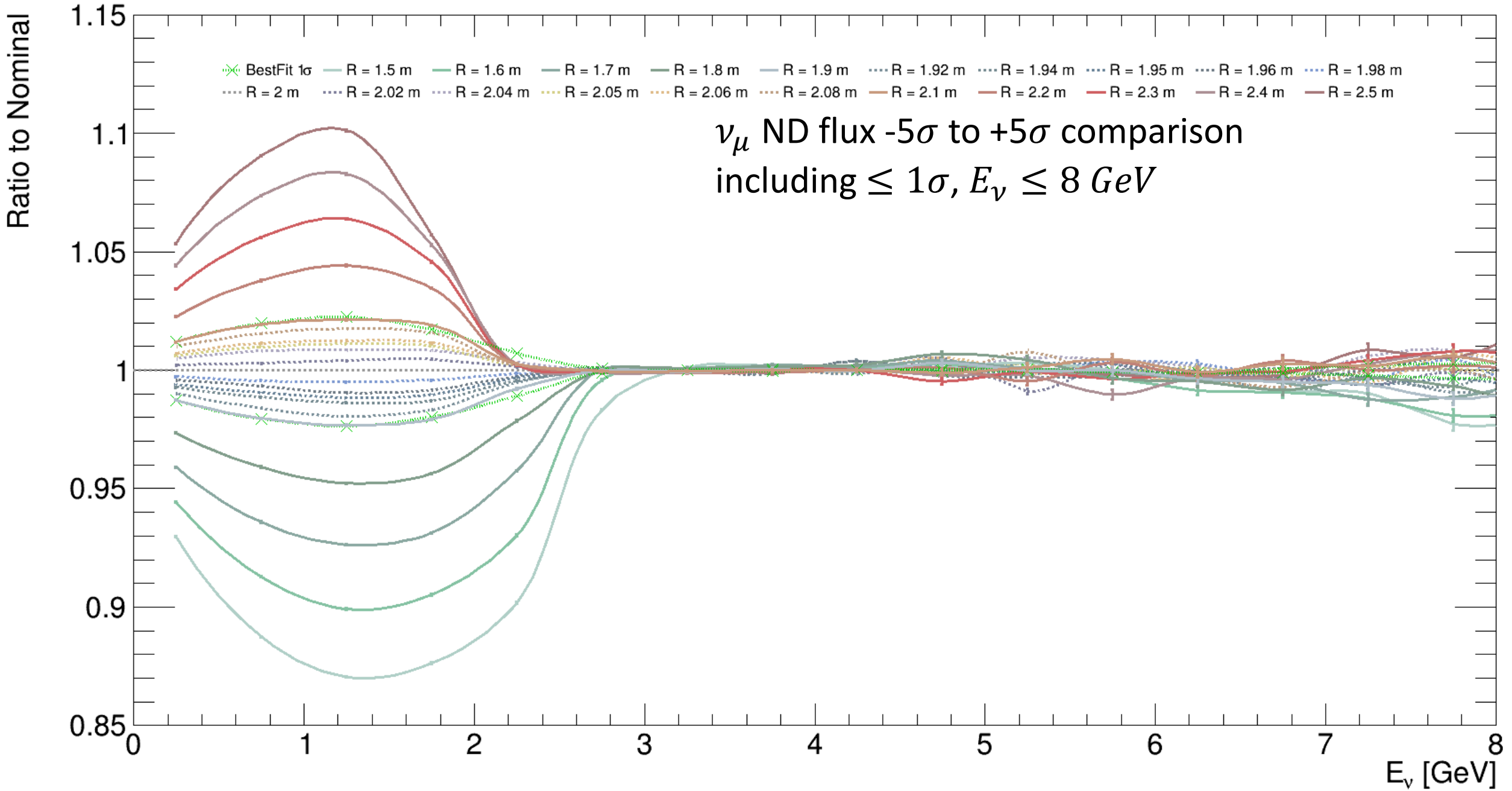
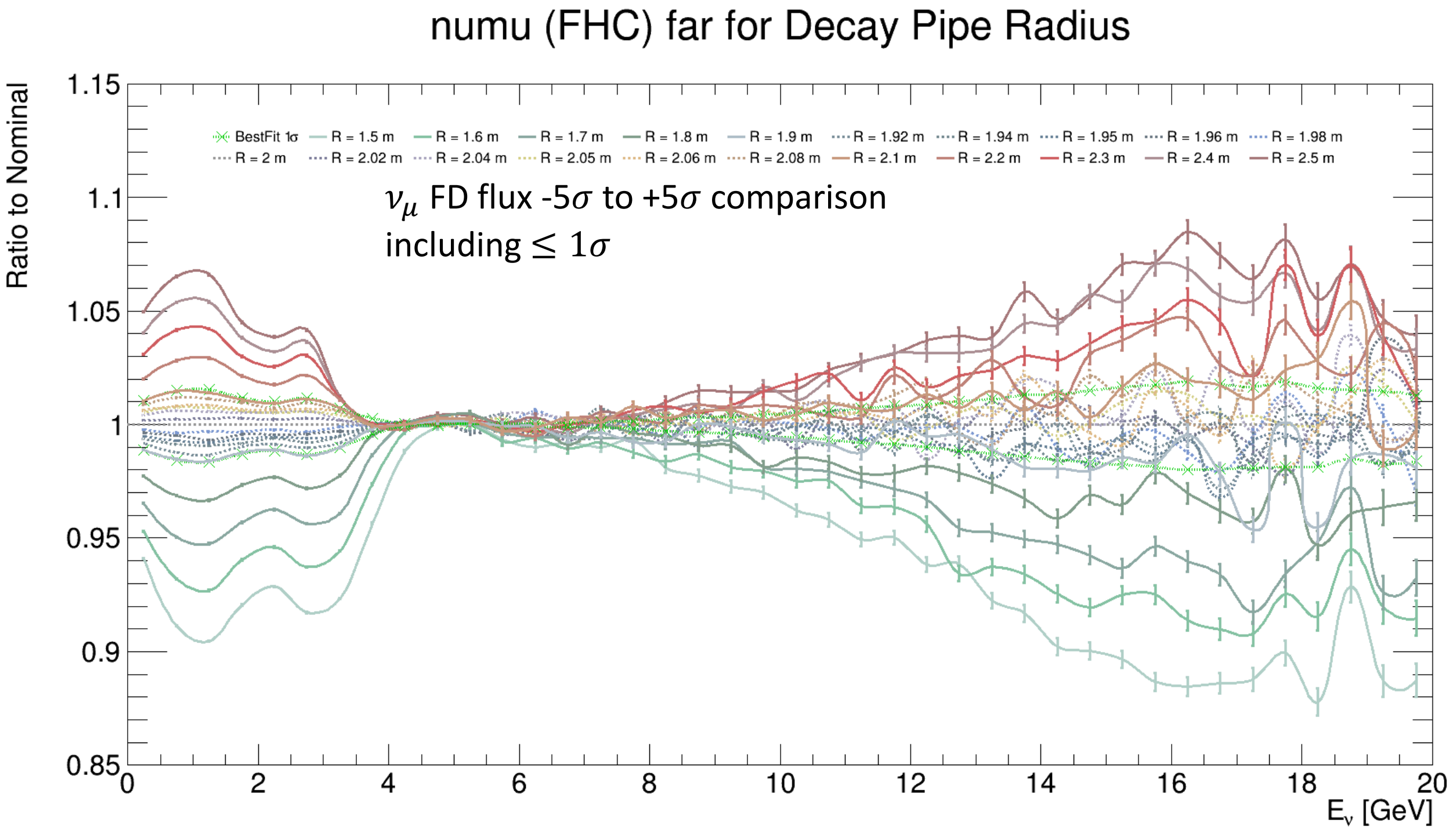
± 8 cm
± 10 cm
ν_μ FD/ND flux $\leq 1\sigma$ comparison
3
2.5
2
1.5
1
0.5
0
0
2
4
6
8
10
12
14
16
18
20
E_ν [GeV]


numu (FHC) near for Decay Pipe Radius
Ratio to Nominal
1.15
1.1
1.05
1
0.95
0.9
0.85
0
2
4
6
8
10
12
14
16
18
20
E_ν [GeV]
BestFit 1σ
R = 1.5 m
R = 1.6 m
R = 1.7 m
R = 1.8 m
R = 1.9 m
R = 1.92 m
R = 1.94 m
R = 1.95 m
R = 1.96 m
R = 1.98 m
R = 2 m
R = 2.02 m
R = 2.04 m
R = 2.05 m
R = 2.06 m
R = 2.08 m
R = 2.1 m
R = 2.2 m
R = 2.3 m
R = 2.4 m
R = 2.5 m
ν_μ ND flux -5σ to +5σ comparison
including $\leq 1\sigma$

numu (FHC) near for Decay Pipe Radius

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Ratio to Nominal
1.15
1.1
1.05
1
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2
4
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E$_\nu$ [GeV]
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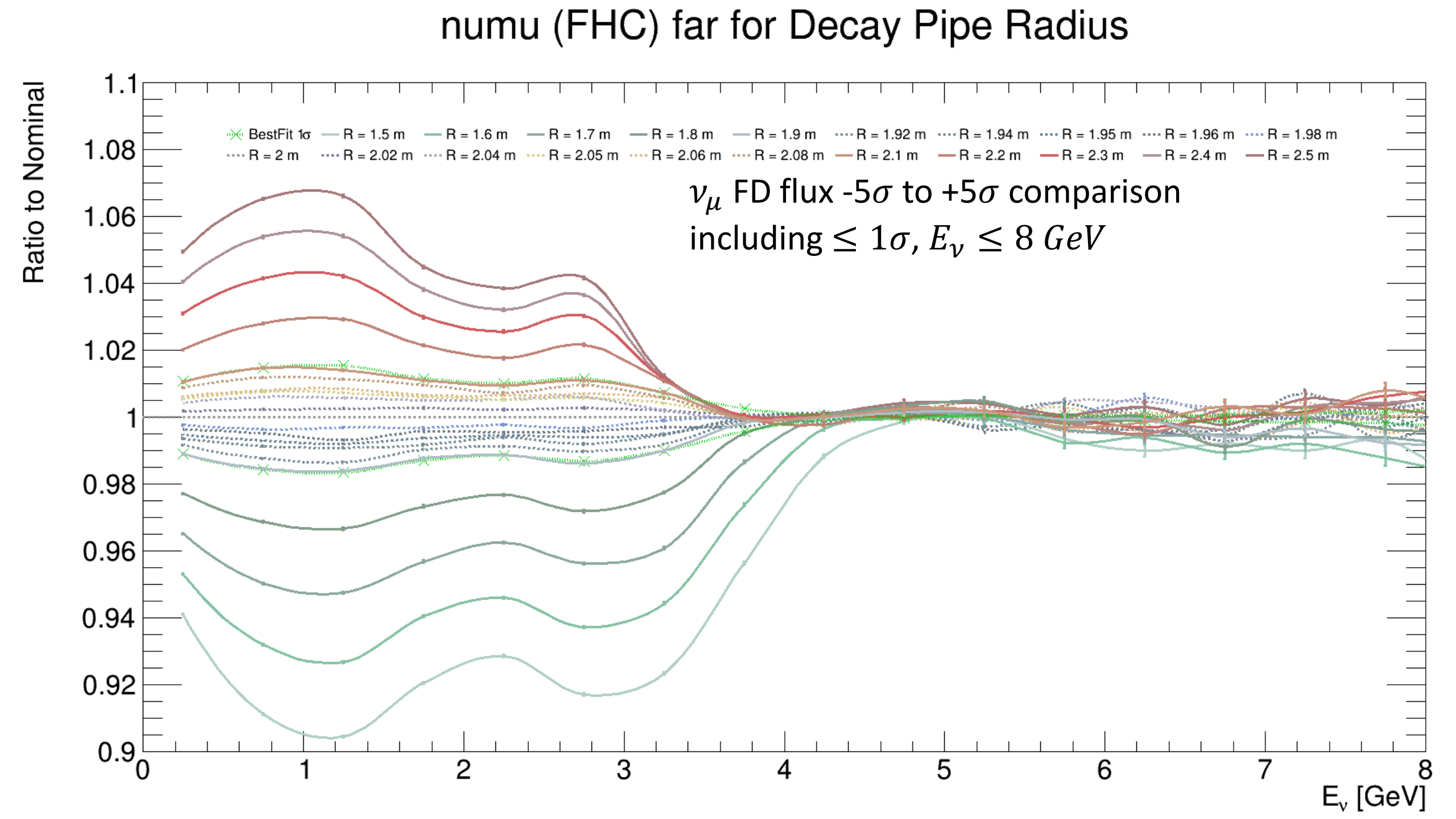
R = 2.5 m
ν_μ FD flux -5σ to +5σ comparison
including $\leq 1\sigma$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Ratio to Nominal
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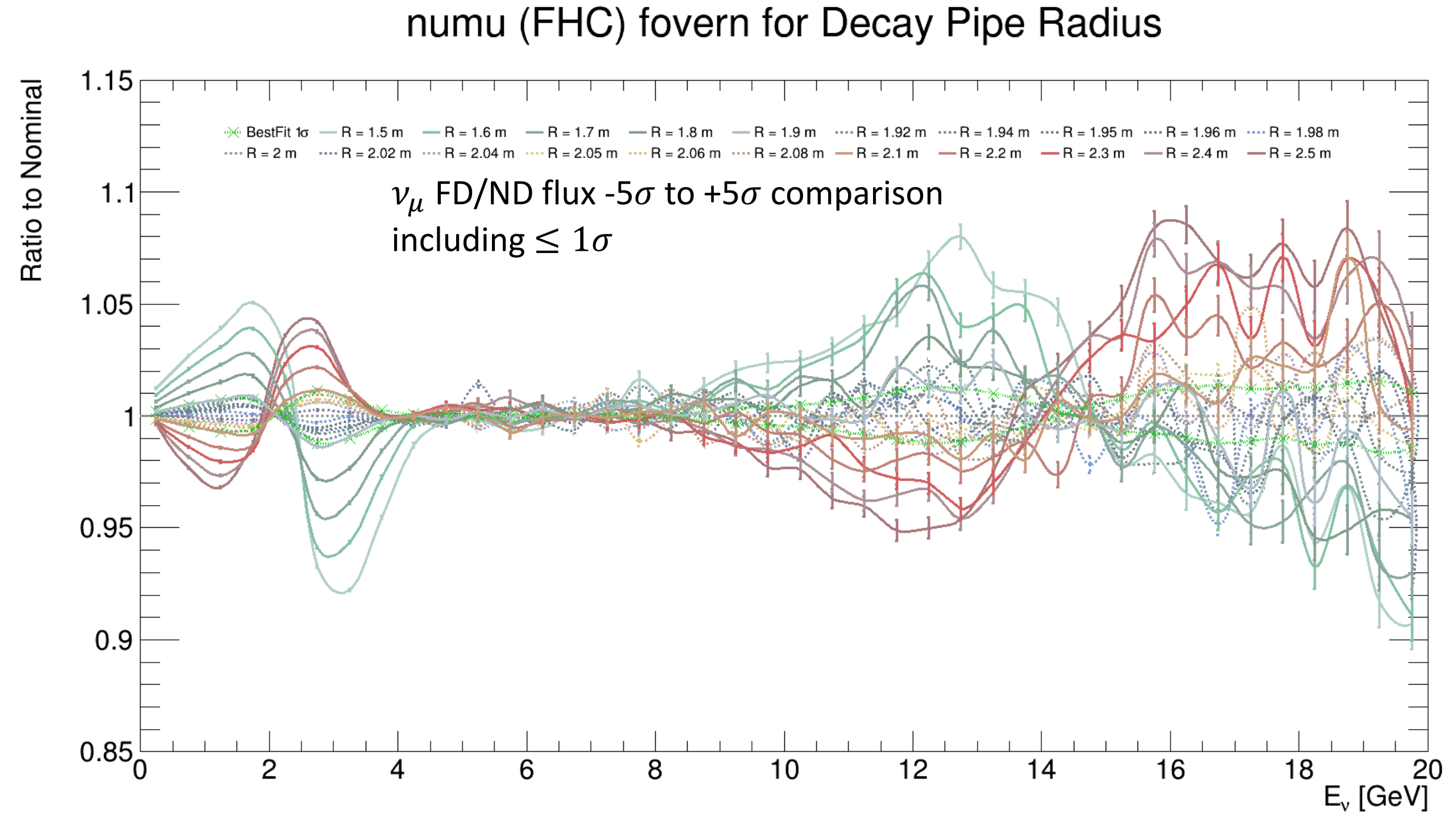
R = 2.1 m
R = 2.2 m
R = 2.3 m
R = 2.4 m
R = 2.5 m
ν_μ FD flux -5σ to +5σ comparison
including $\leq 1\sigma$, $E_\nu \leq 8\ GeV$
1.1
1.08
1.06
1.04
1.02
1
0.98
0.96
0.94
0.92
0.9
0
1
2
3
4
5
6
7
8
E_ν [GeV]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R = 2.5 m
ν_μ FD/ND flux -5σ to +5σ comparison
including $\leq 1\sigma$
1.15
1.1
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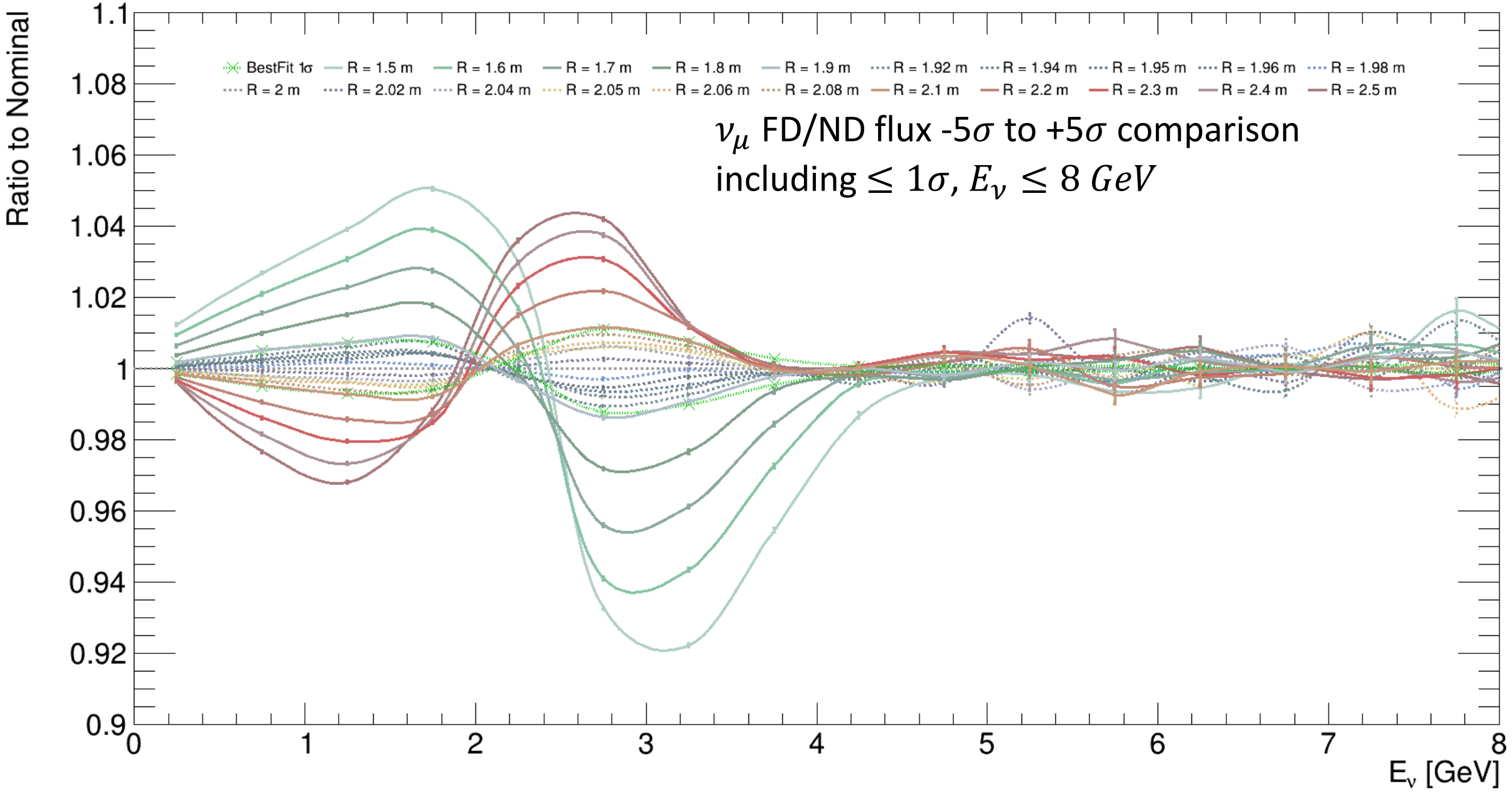
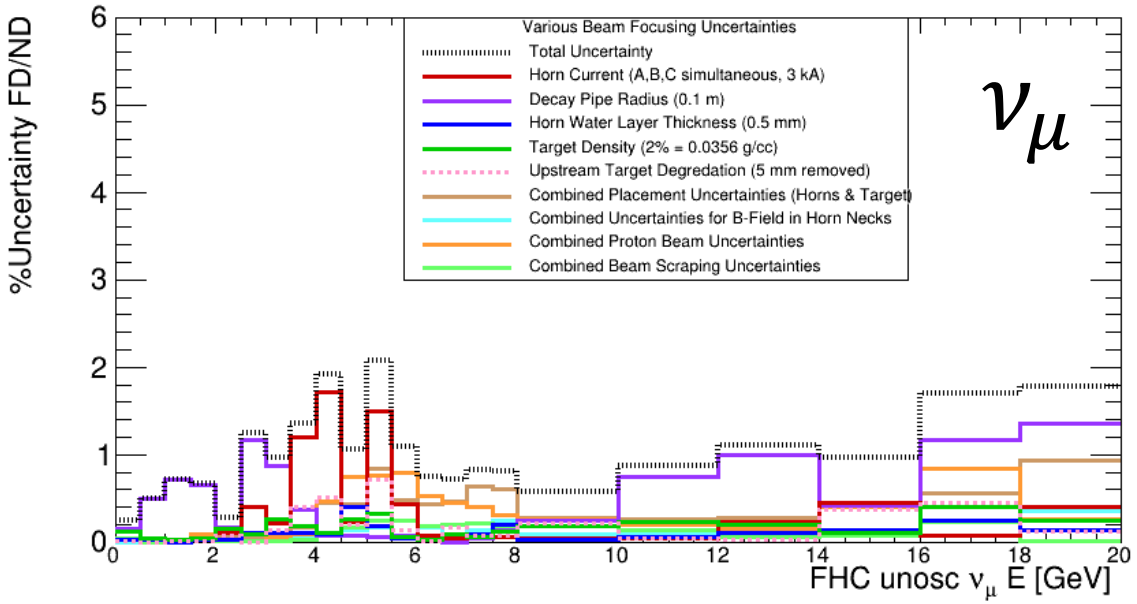
20
E_ν [GeV]

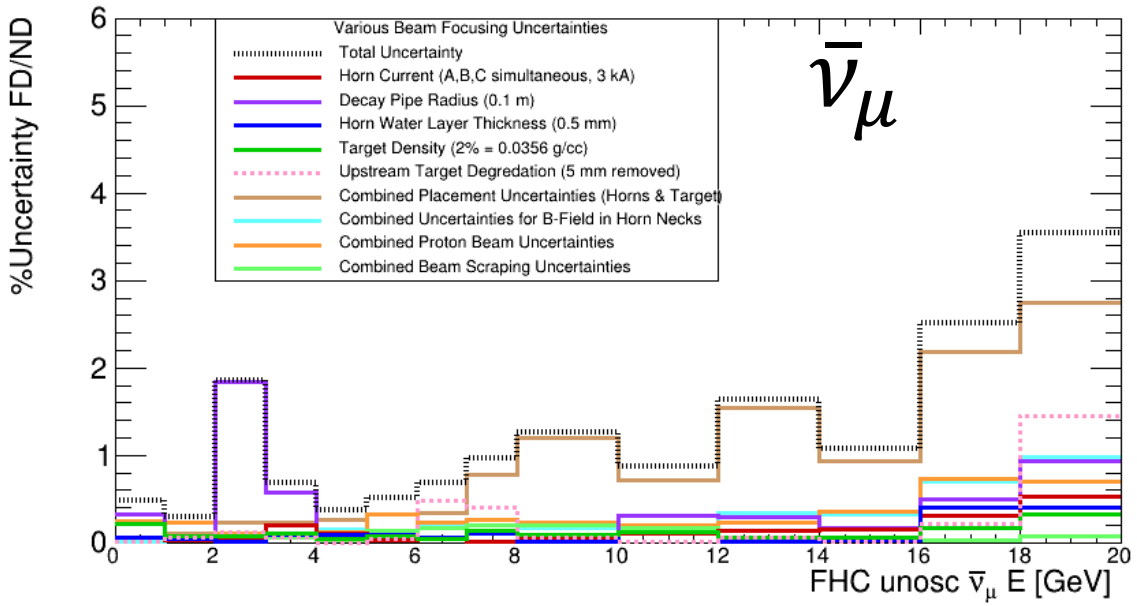
numu (FHC) fovern for Decay Pipe Radius

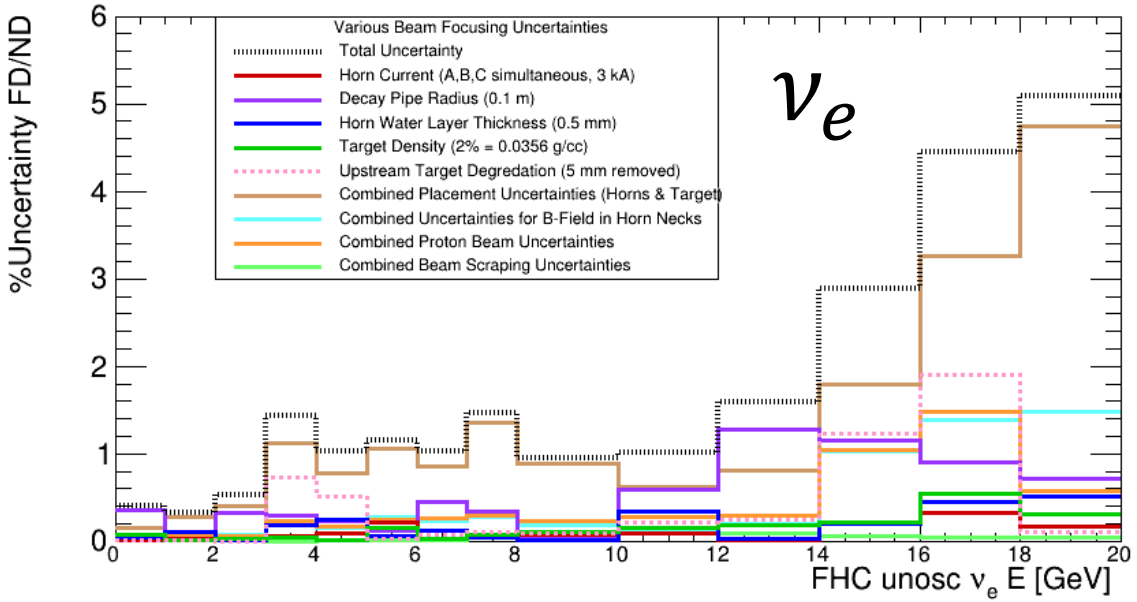


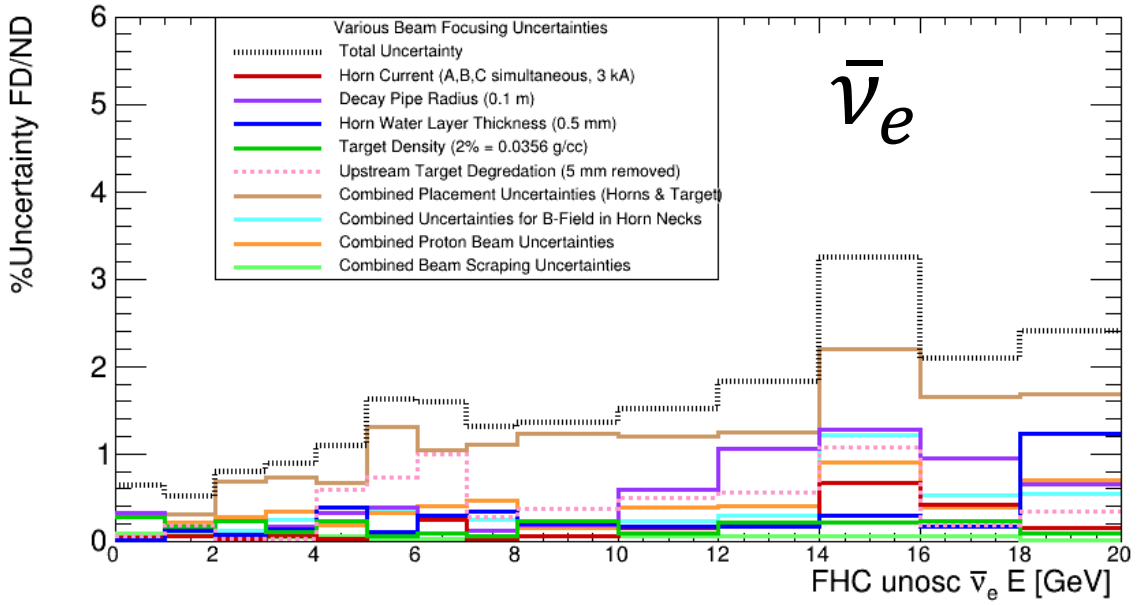
Backup

Uncertainties for FHC FD/ND, all flavors



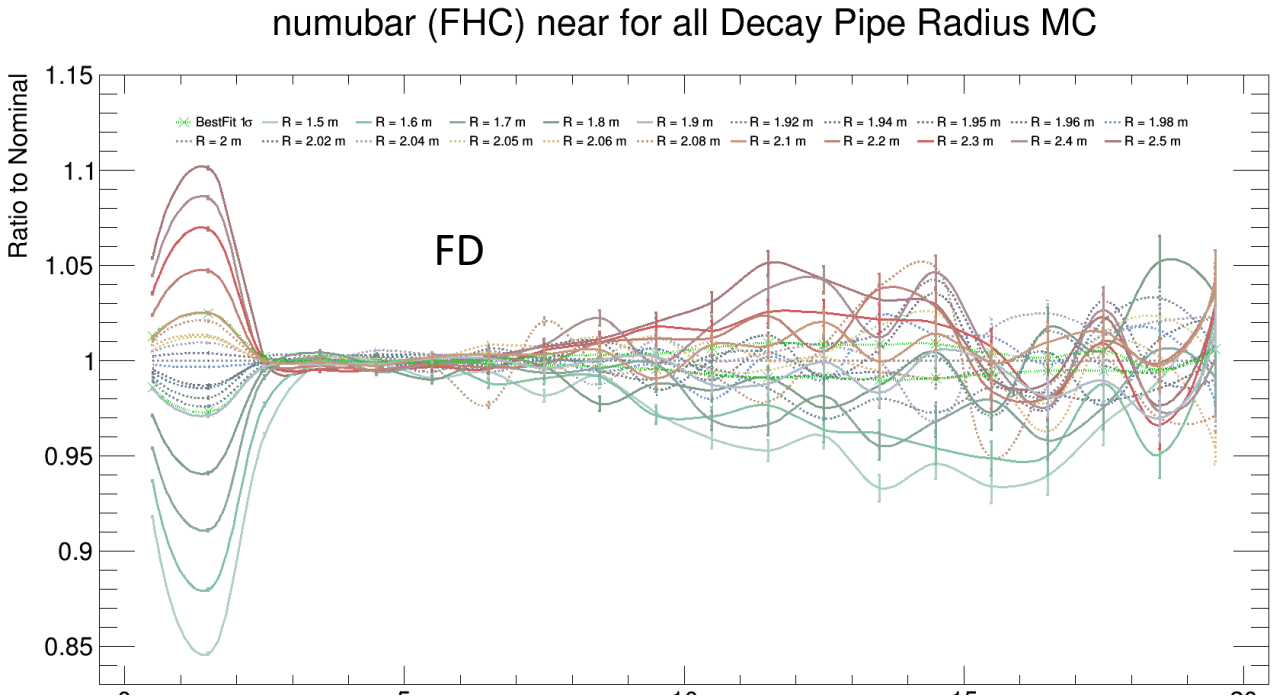


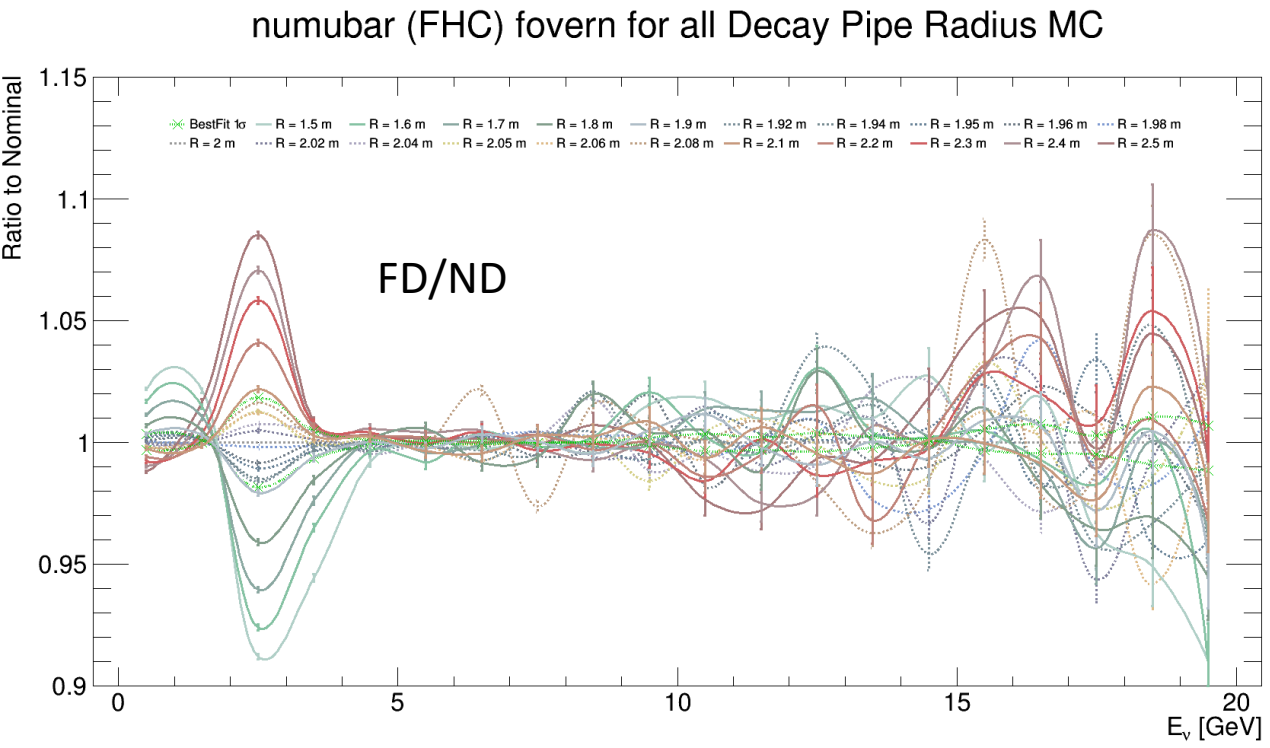


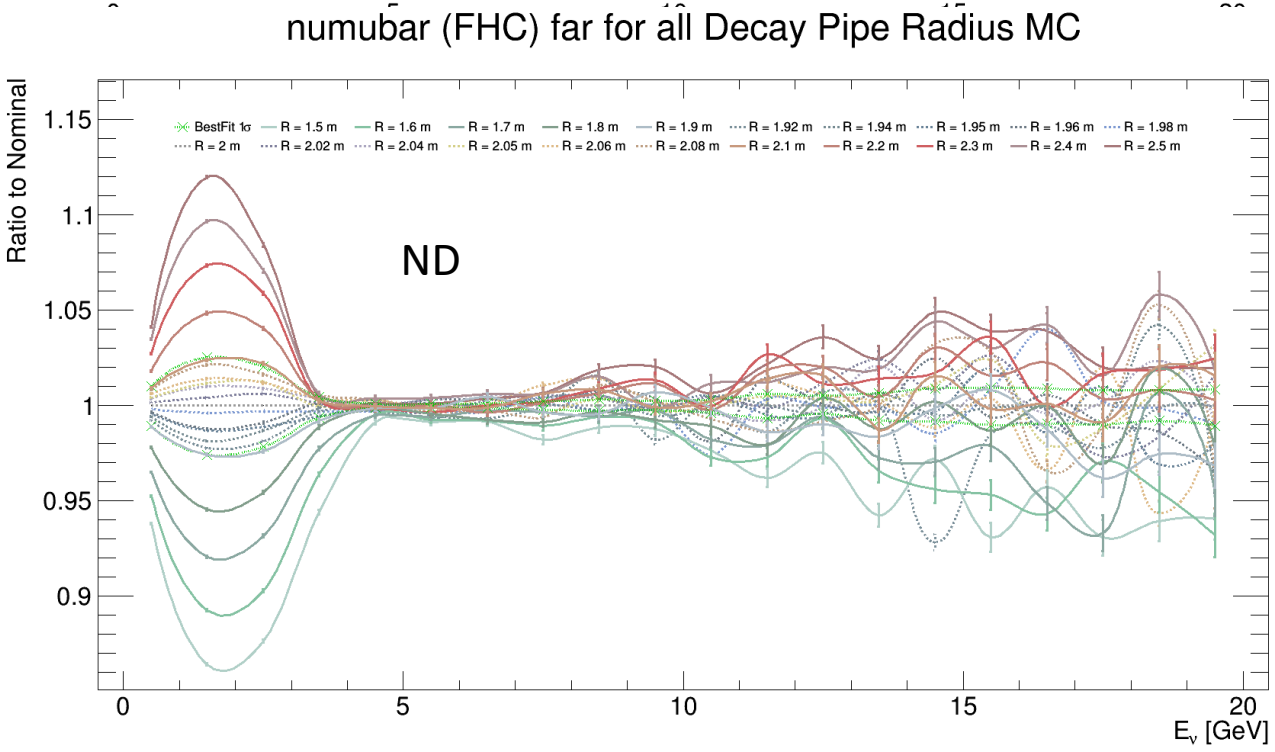


$\bar{\nu}_\mu$ Flux Ratios to Nominal Simulation: -5σ to 5σ, $d\sigma$ = 1σ & $\pm$0.2, $\pm$0.4, $\pm$0.5, $\pm$0.6, $\pm$0.8σ

- Fits are performed in each energy bin on the data from these plots (including errors)







ν_e Flux Ratios to Nominal Simulation: -5σ to 5σ, $d\sigma$ = 1σ & $\pm$0.2, $\pm$0.4, $\pm$0.5, $\pm$0.6, $\pm$0.8σ

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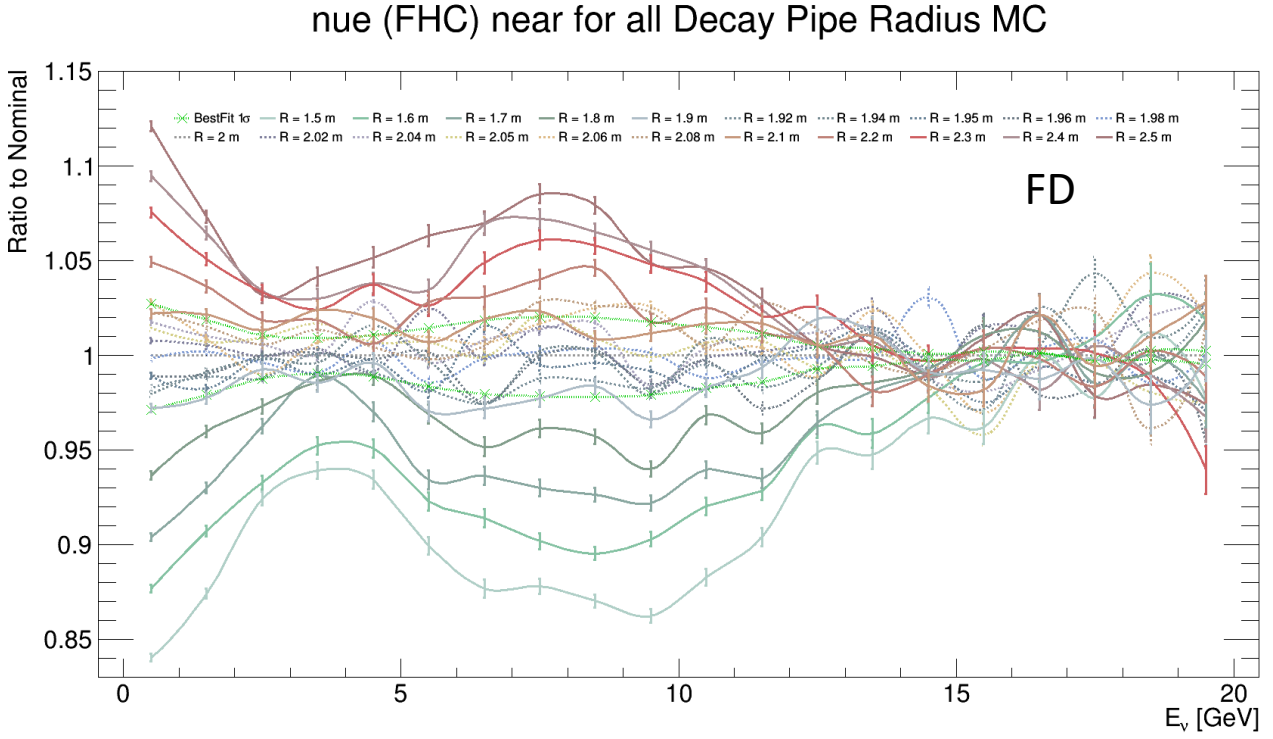

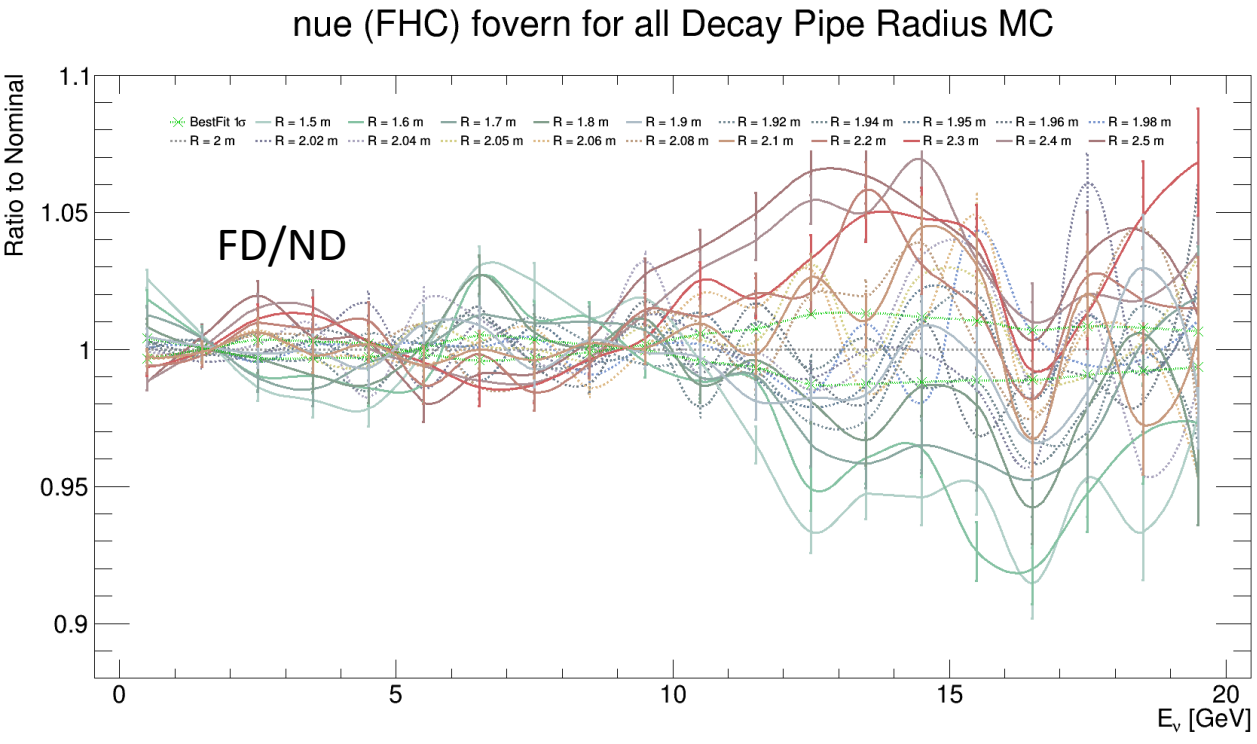

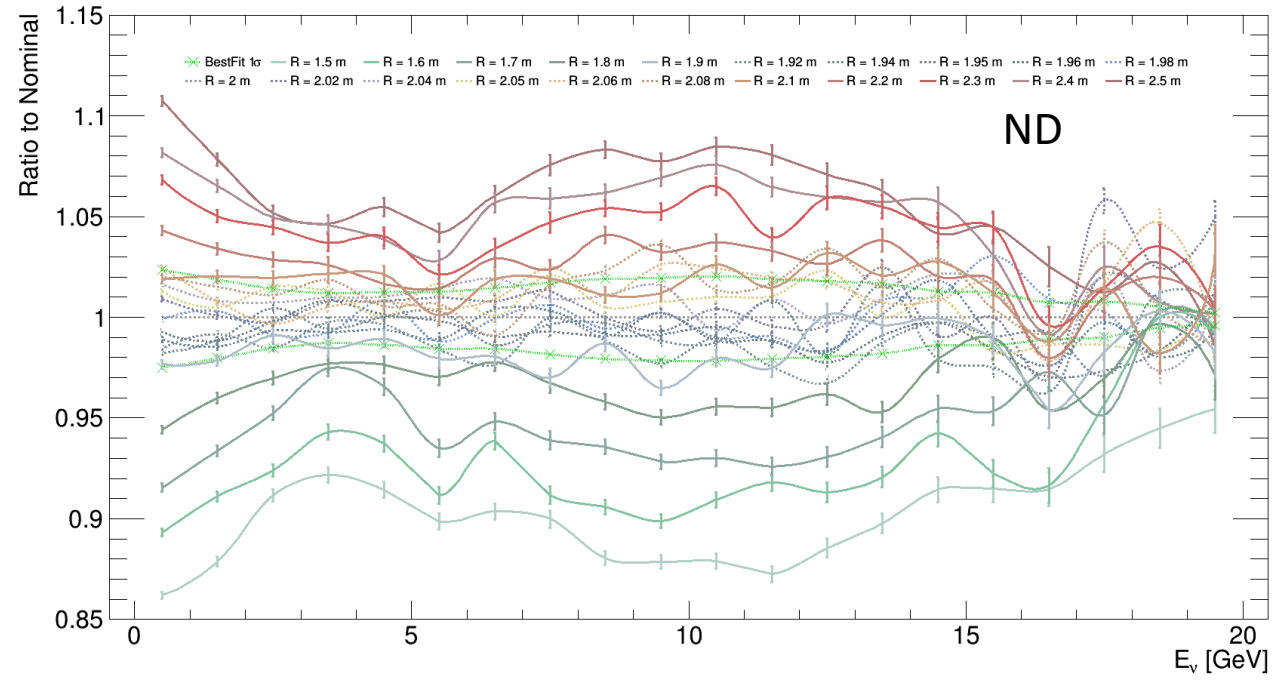

$\bar{\nu}_e$ Flux Ratios to Nominal Simulation: -5σ to 5σ, $d\sigma$ = 1σ & $\pm$0.2, $\pm$0.4, $\pm$0.5, $\pm$0.6, $\pm$0.8σ

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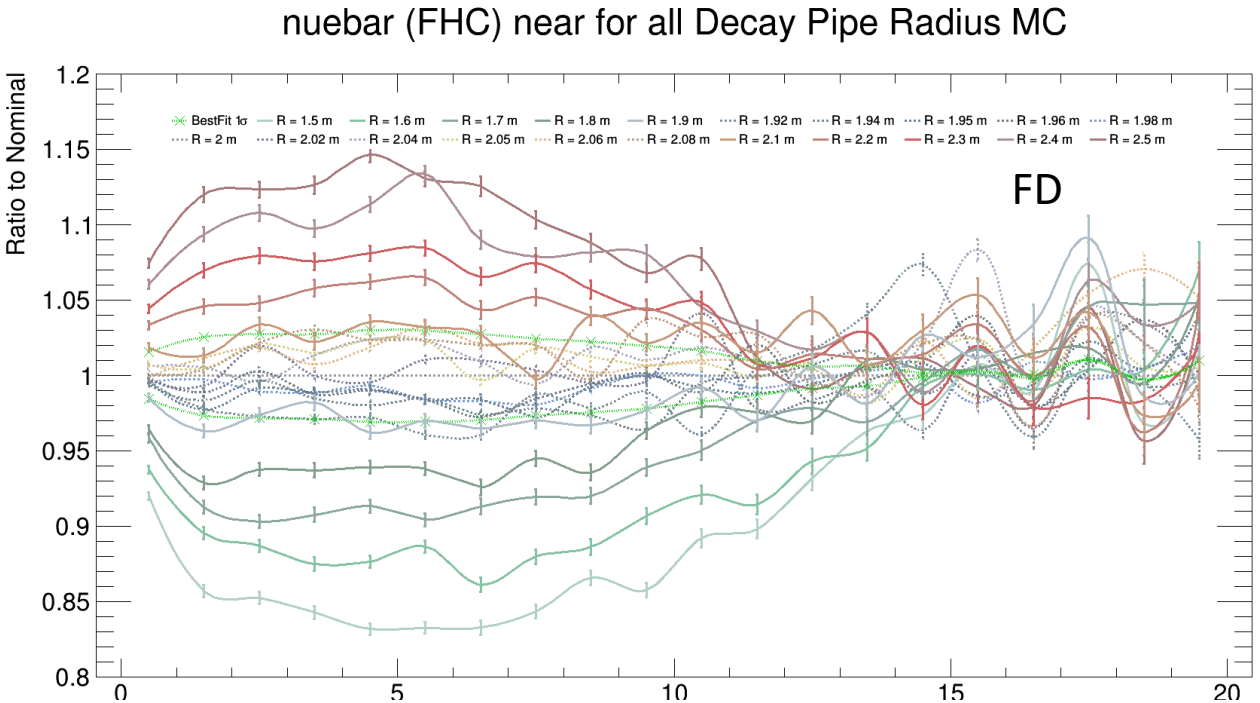
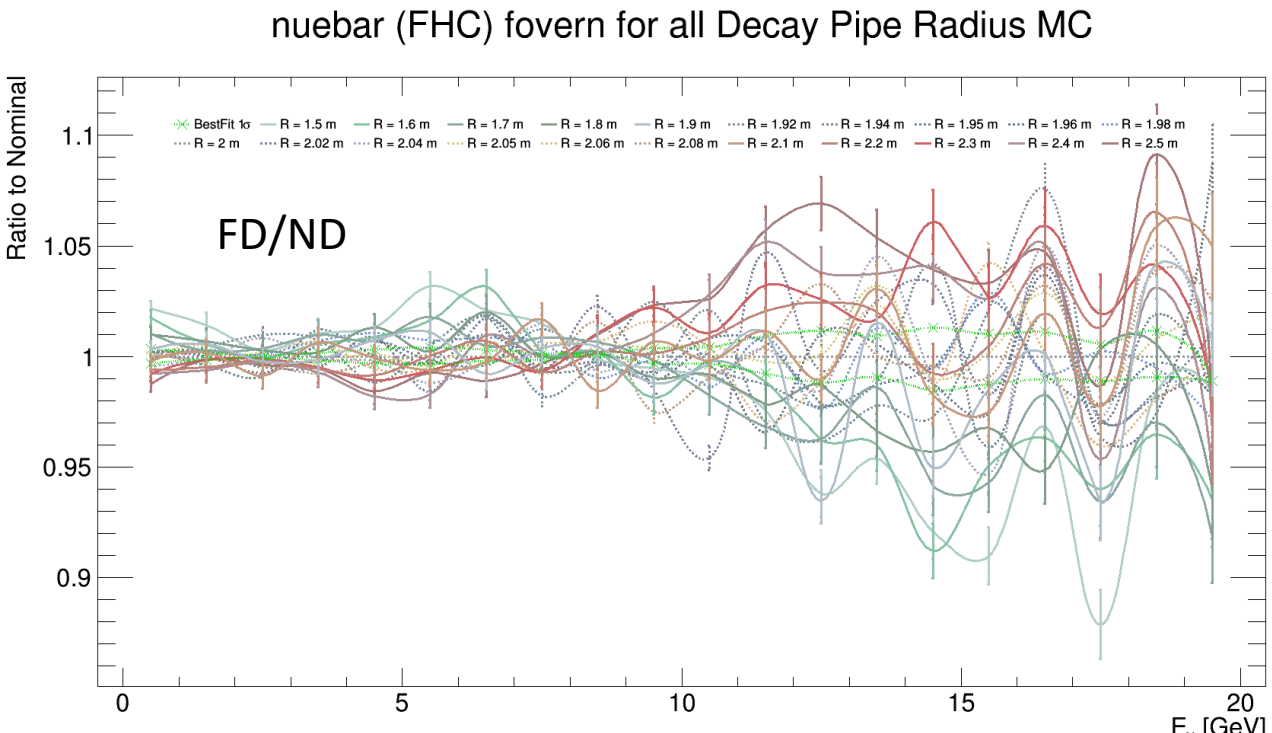
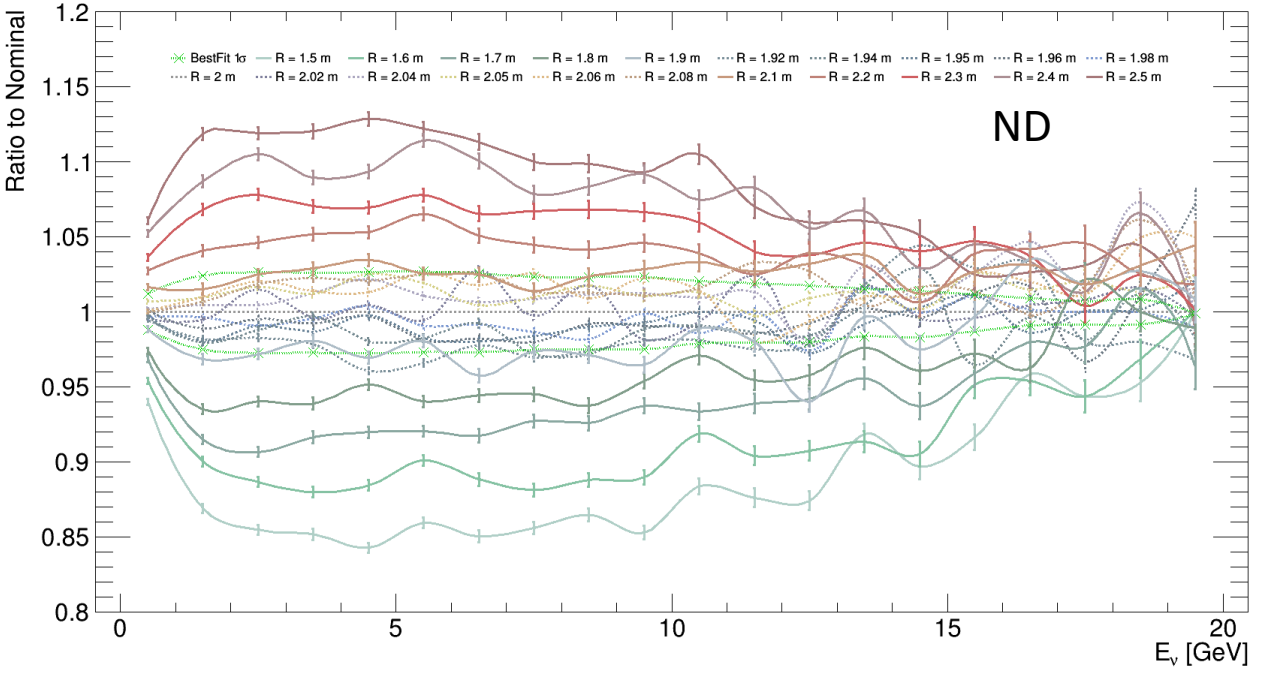
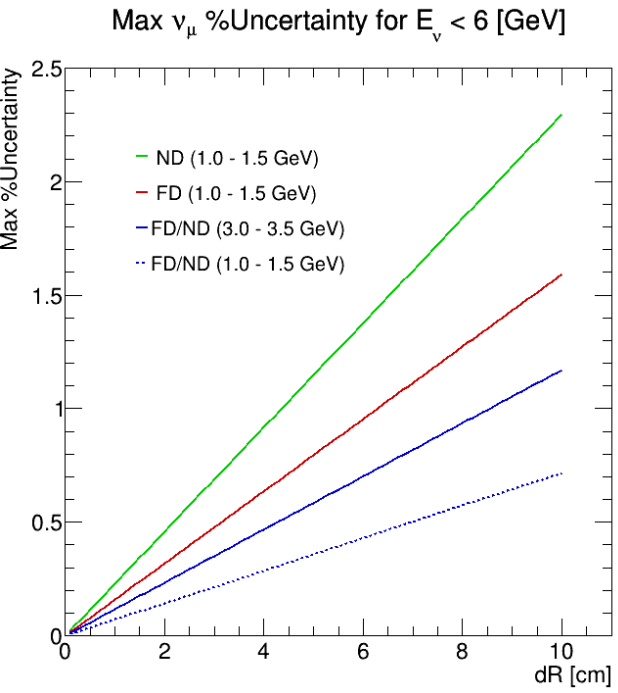
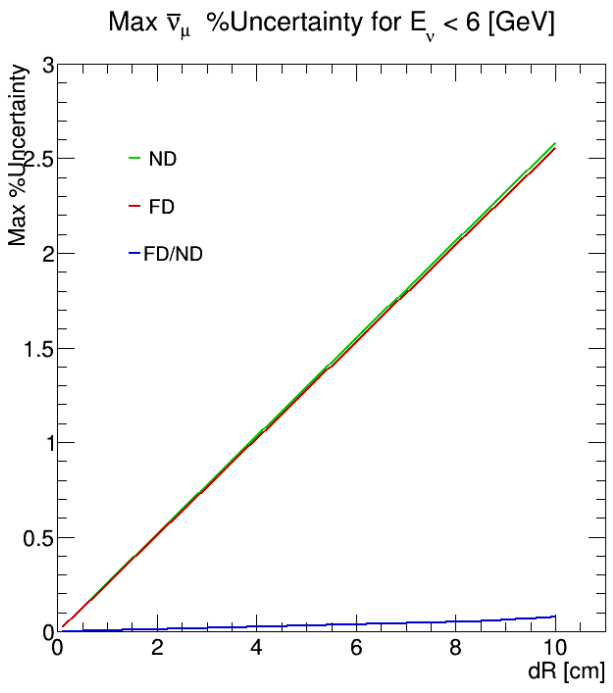
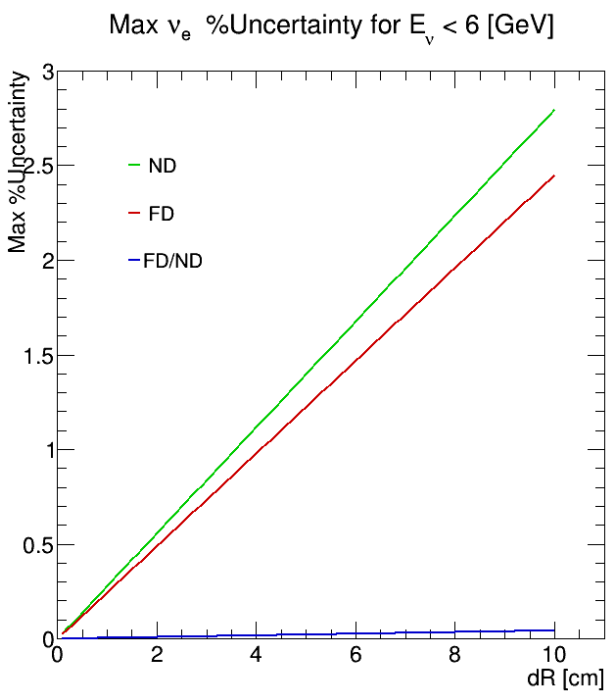


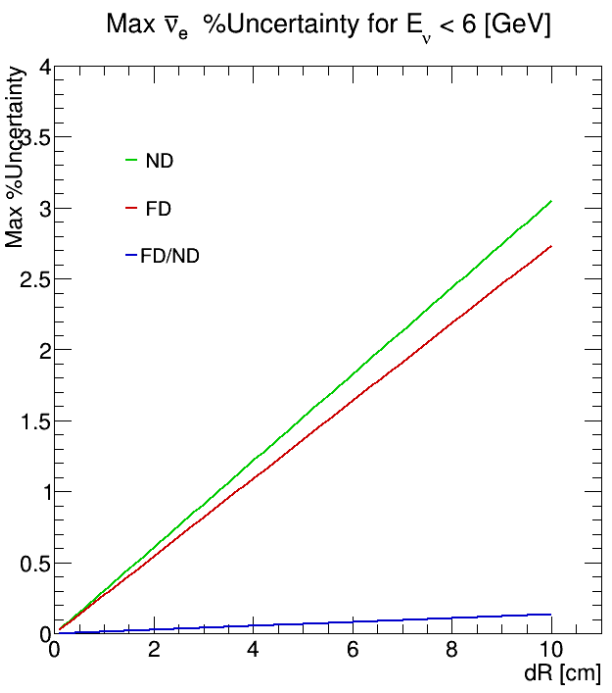


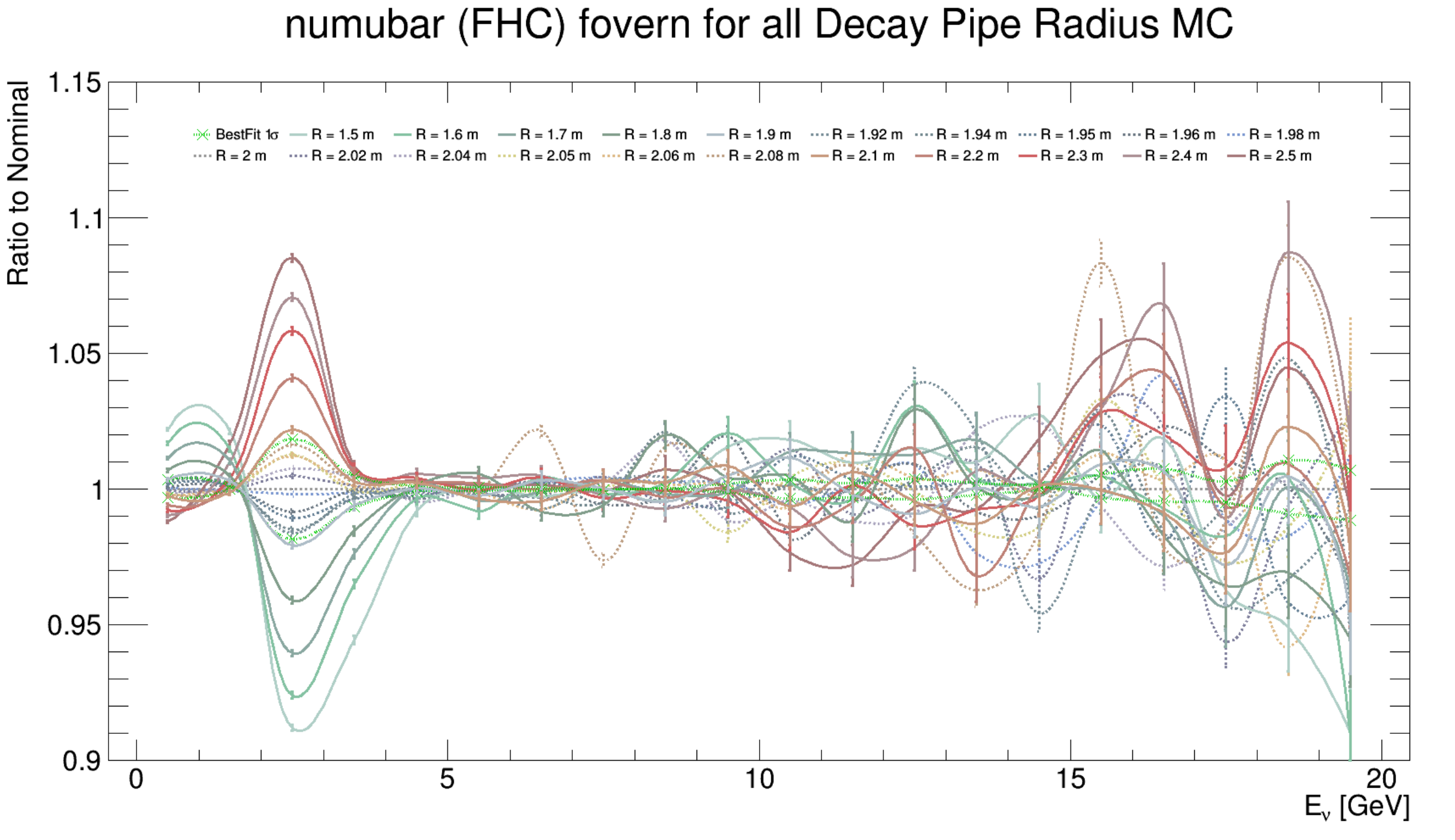



Max ν_μ %Uncertainty for E_ν < 6 [GeV]
Max %Uncertainty
dR [cm]
ND (1.0 - 1.5 GeV)
FD (1.0 - 1.5 GeV)
FD/ND (3.0 - 3.5 GeV)
FD/ND (1.0 - 1.5 GeV)


Max $\bar{\nu}_\mu$ %Uncertainty for E_ν < 6 [GeV]
Max %Uncertainty
dR [cm]
ND
FD
FD/ND


Max ν_e %Uncertainty for E_ν < 6 [GeV]
Max %Uncertainty
dR [cm]
ND
FD
FD/ND


Max $\bar{\nu}_e$ %Uncertainty for E_ν < 6 [GeV]
Max %Uncertainty
dR [cm]
ND
FD
FD/ND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E_ν [GeV]
BestFit 1σ
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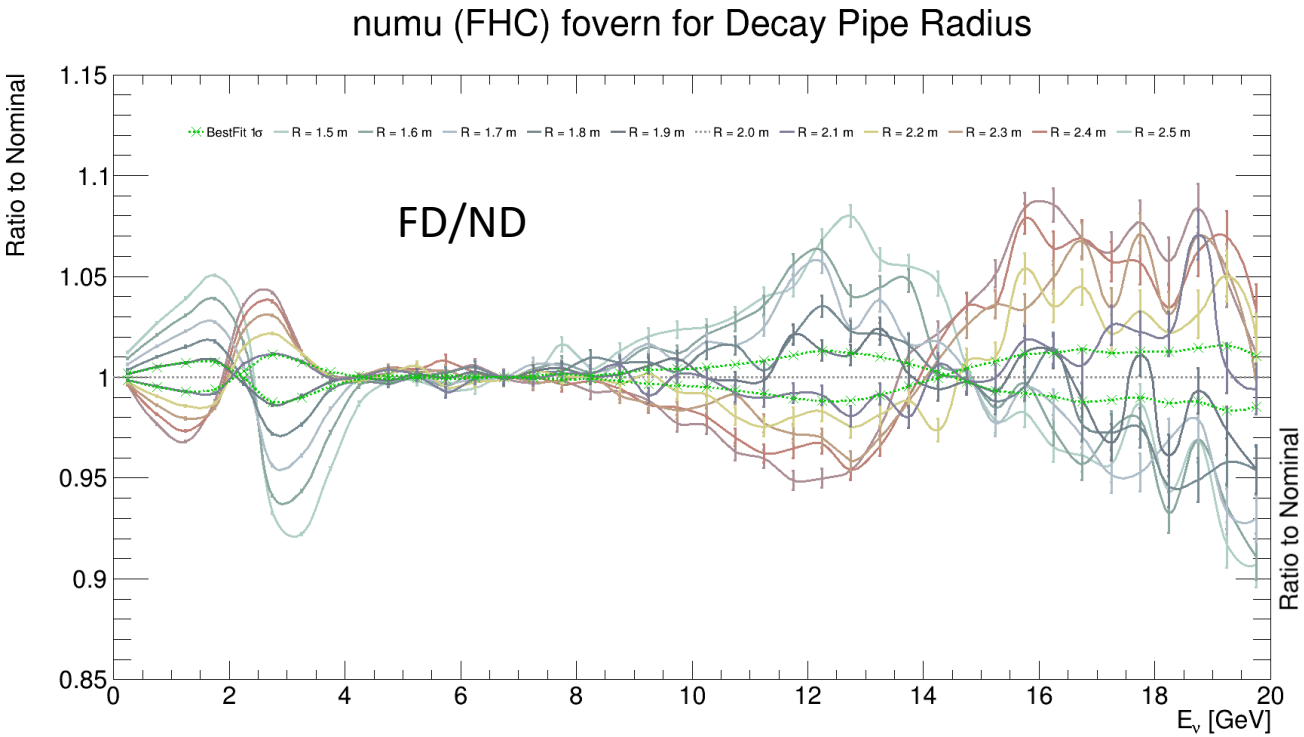
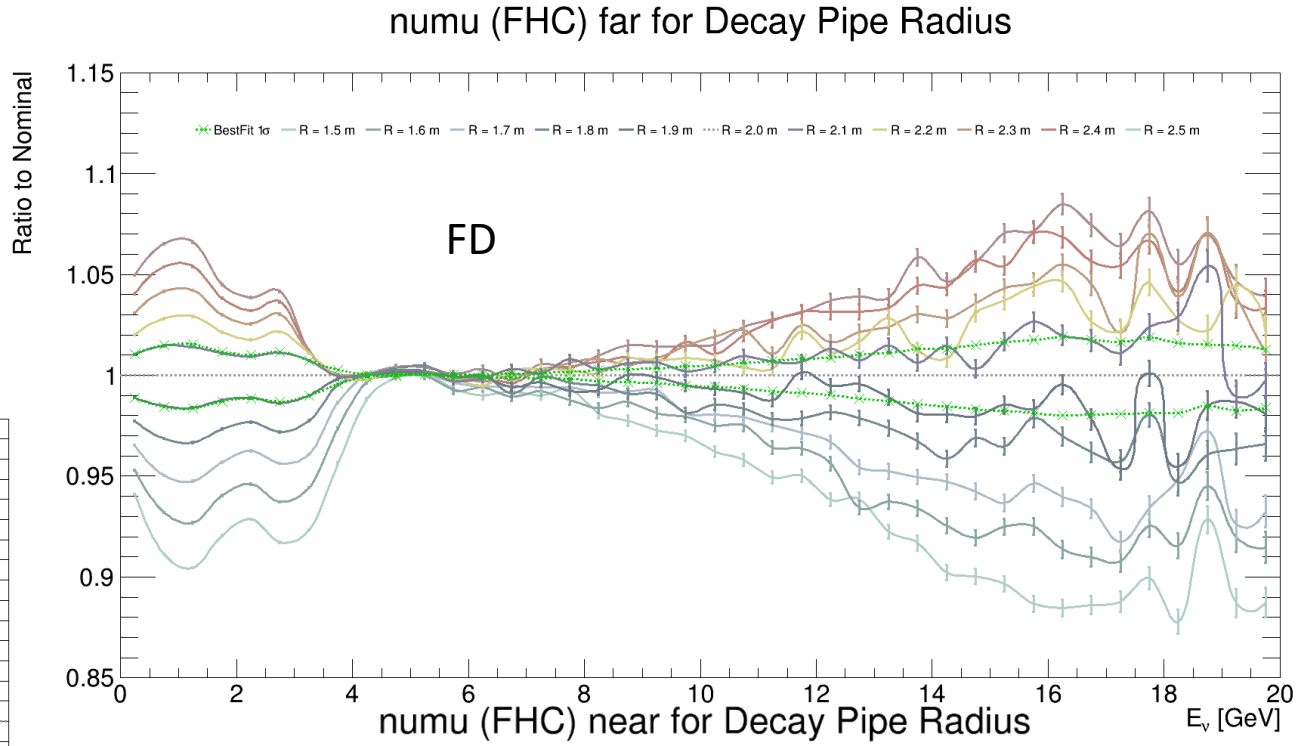
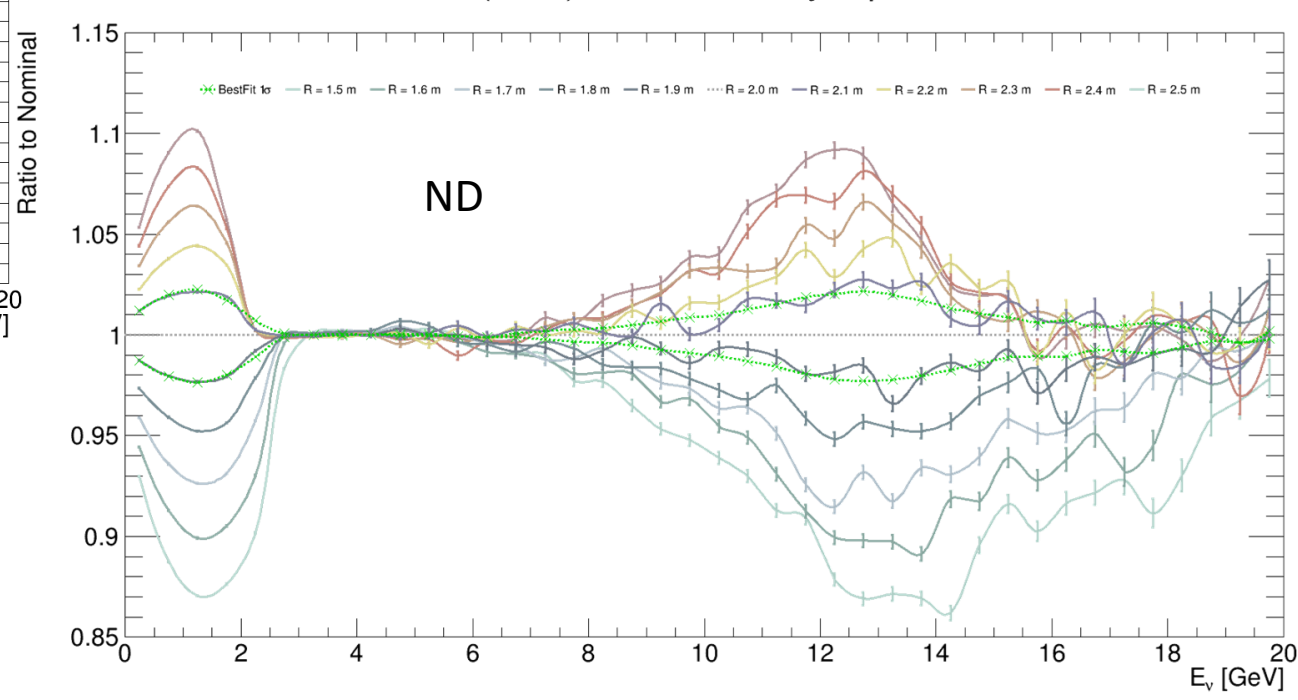
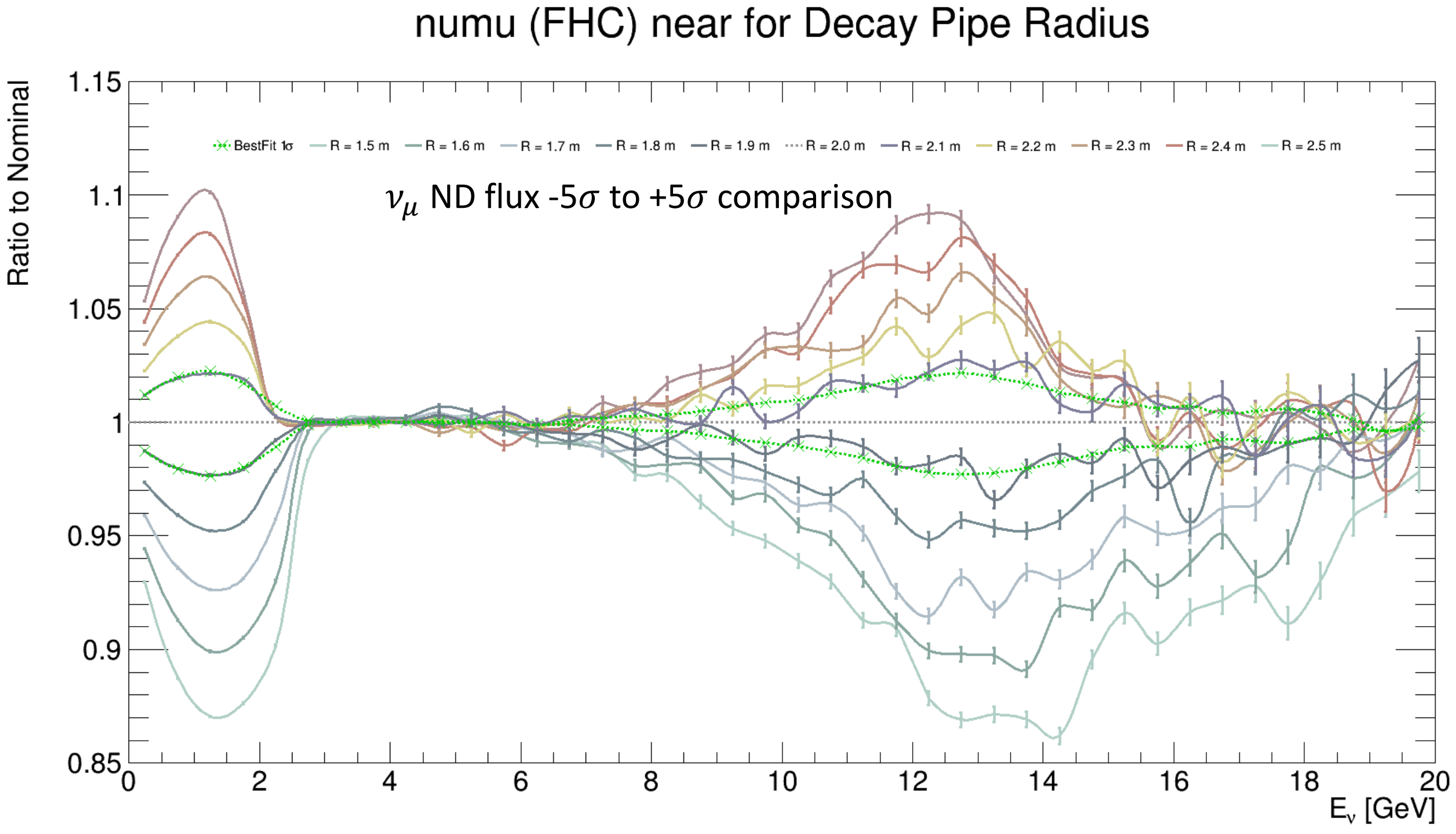
R = 2.3 m
R = 2.4 m
R = 2.5 m

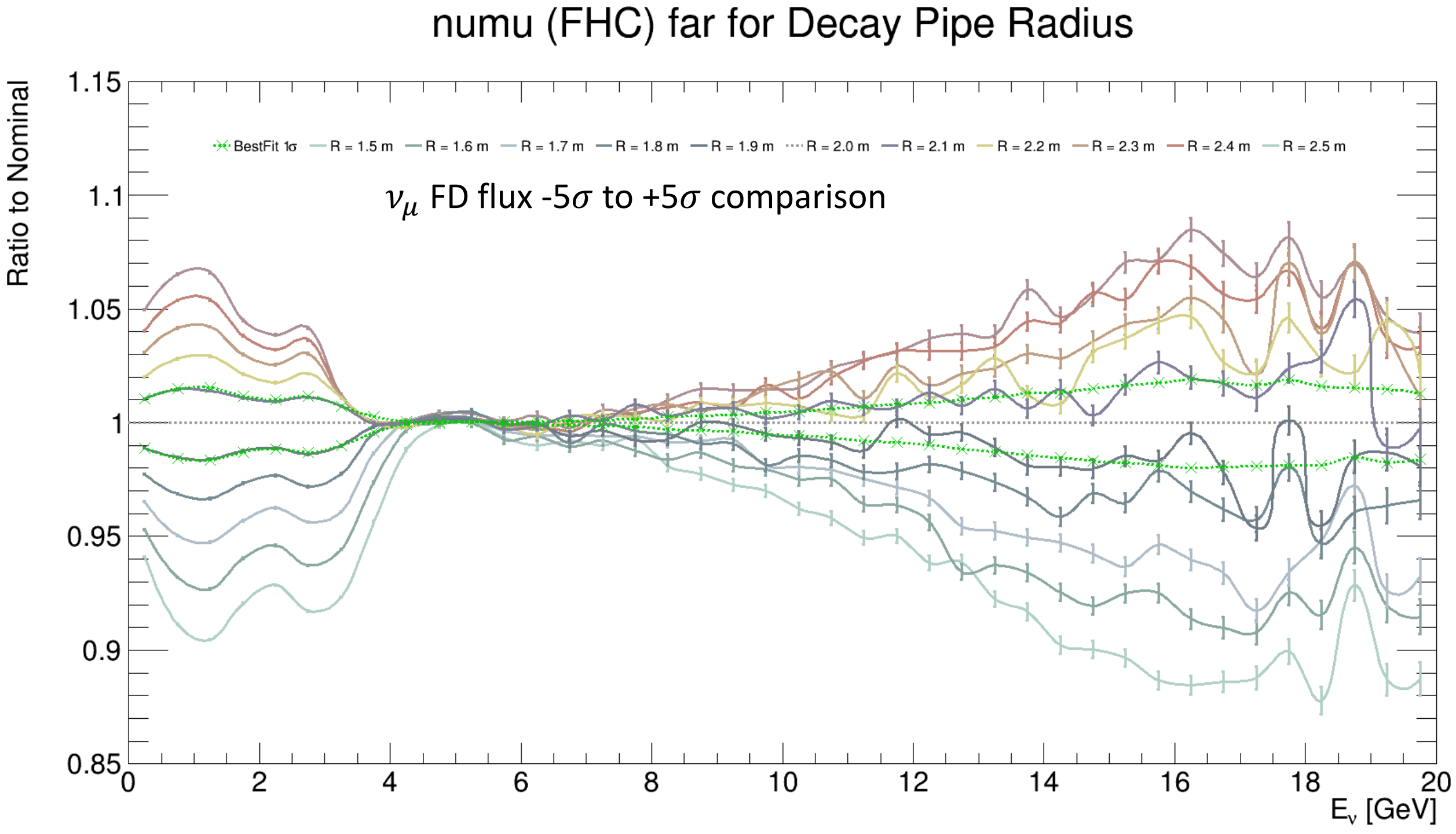
-5σ to 5σ, $d\sigma$ = 1σ

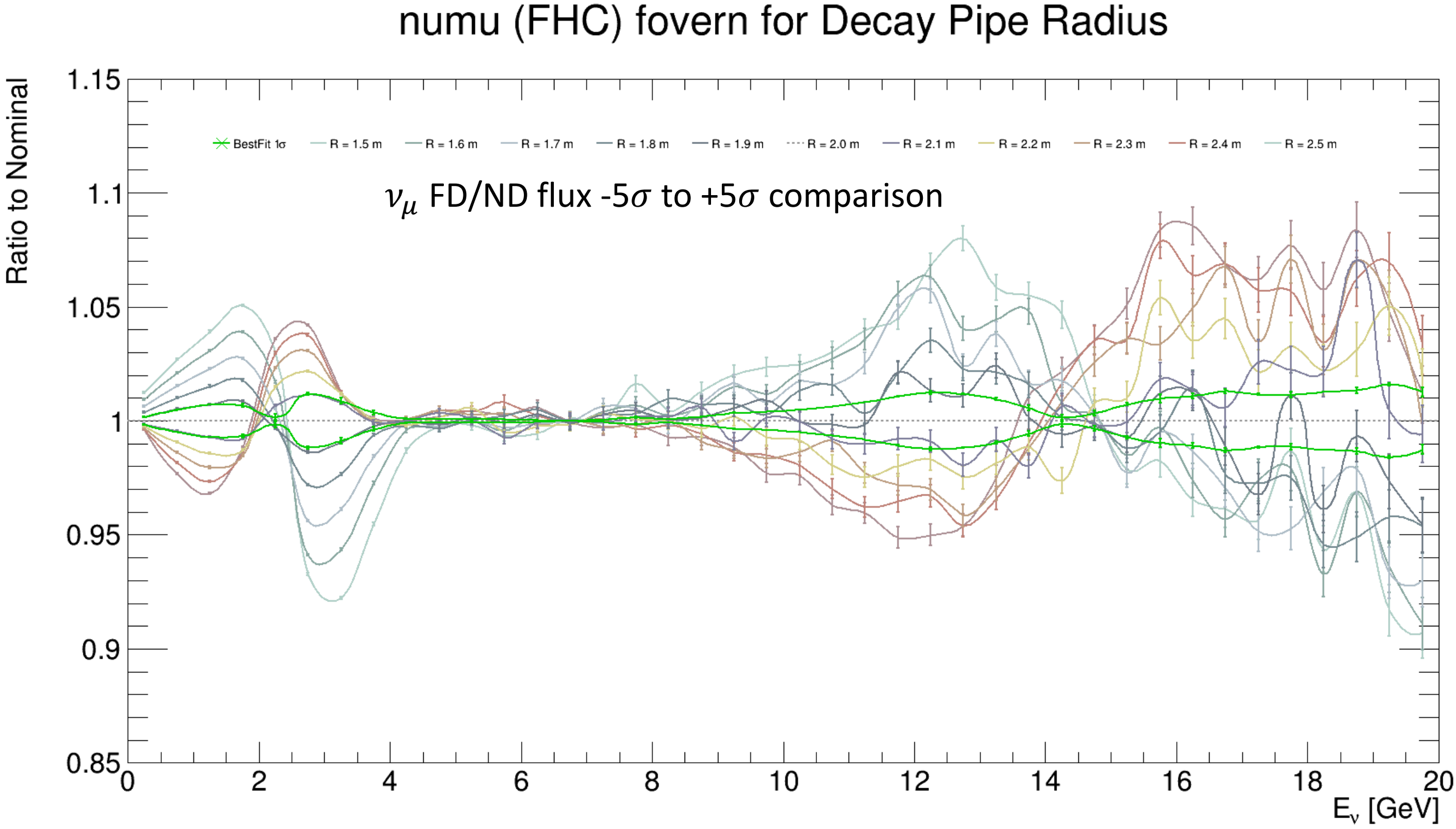




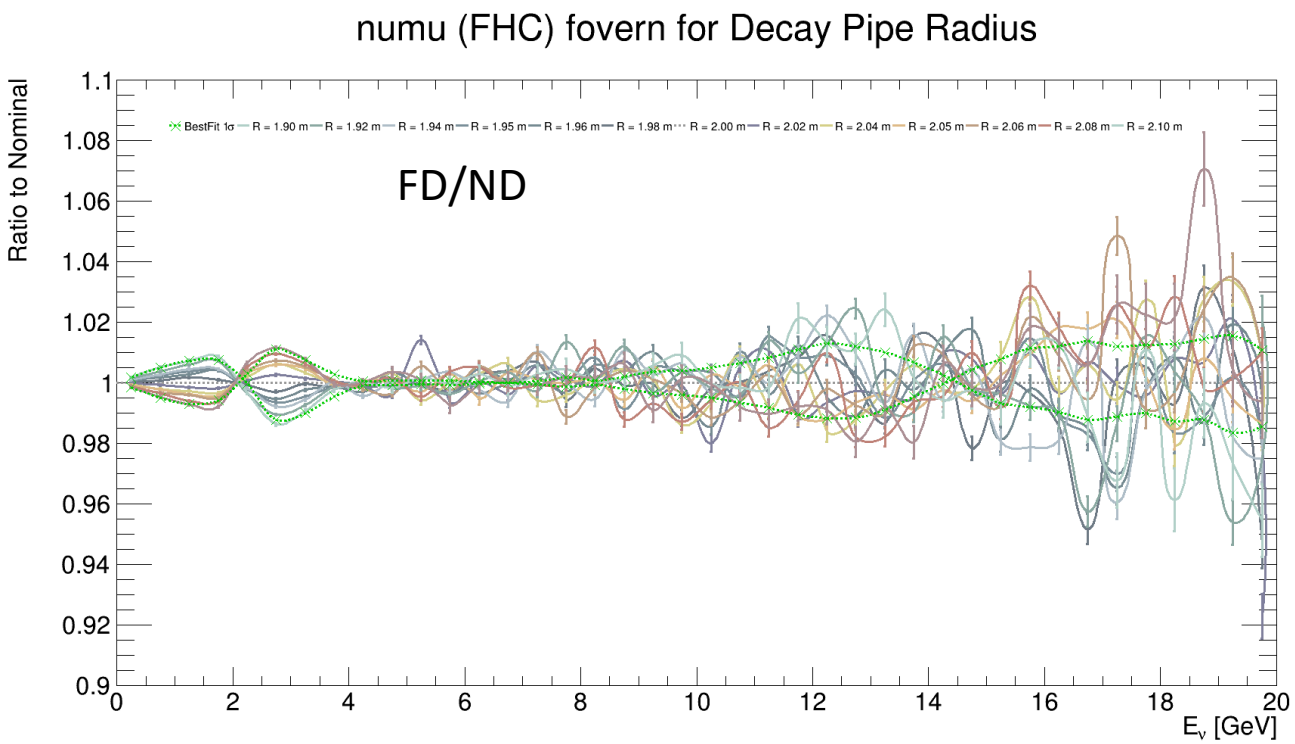


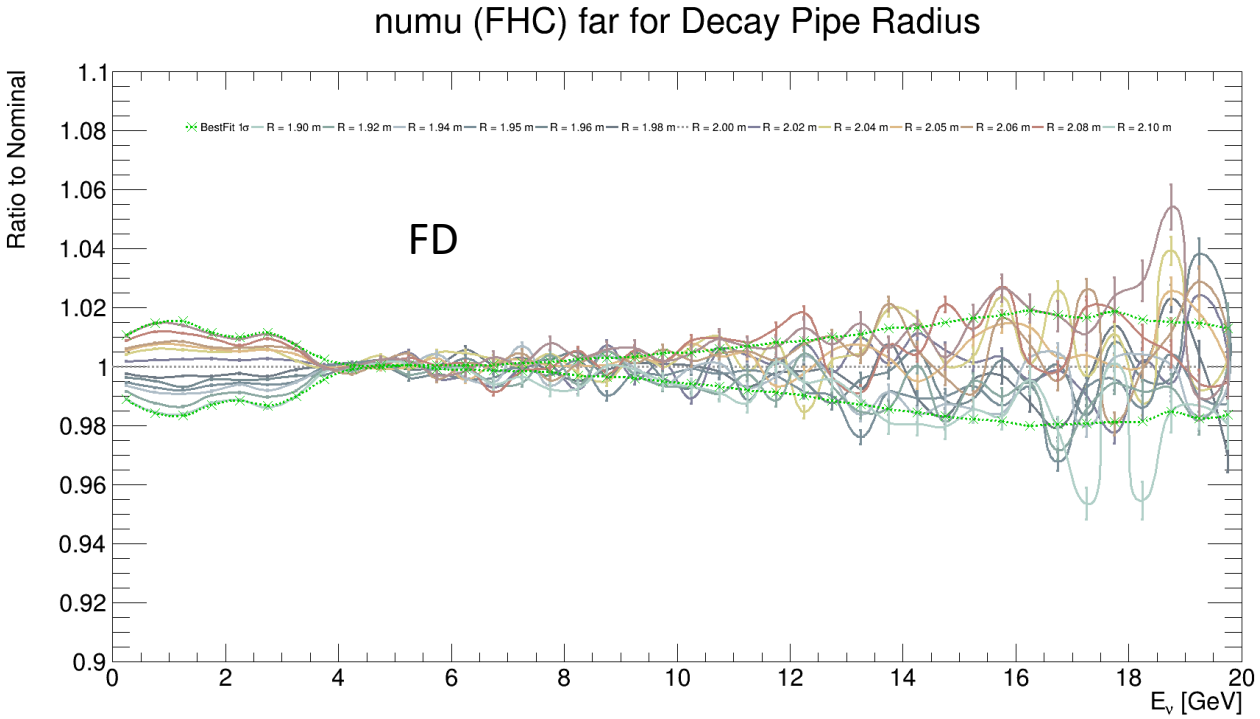

numu (FHC) near for Decay Pipe Radius
Ratio to Nominal
BestFit 1σ
R = 1.5 m
R = 1.6 m
R = 1.7 m
R = 1.8 m
R = 1.9 m
R = 2.0 m
R = 2.1 m
R = 2.2 m
R = 2.3 m
R = 2.4 m
R = 2.5 m
ν_μ ND flux -5σ to +5σ comparison
1.15
1.1
1.05
1
0.95
0.9
0.85
0
2
4
6
8
10
12
14
16
18
20
E_ν [GeV]

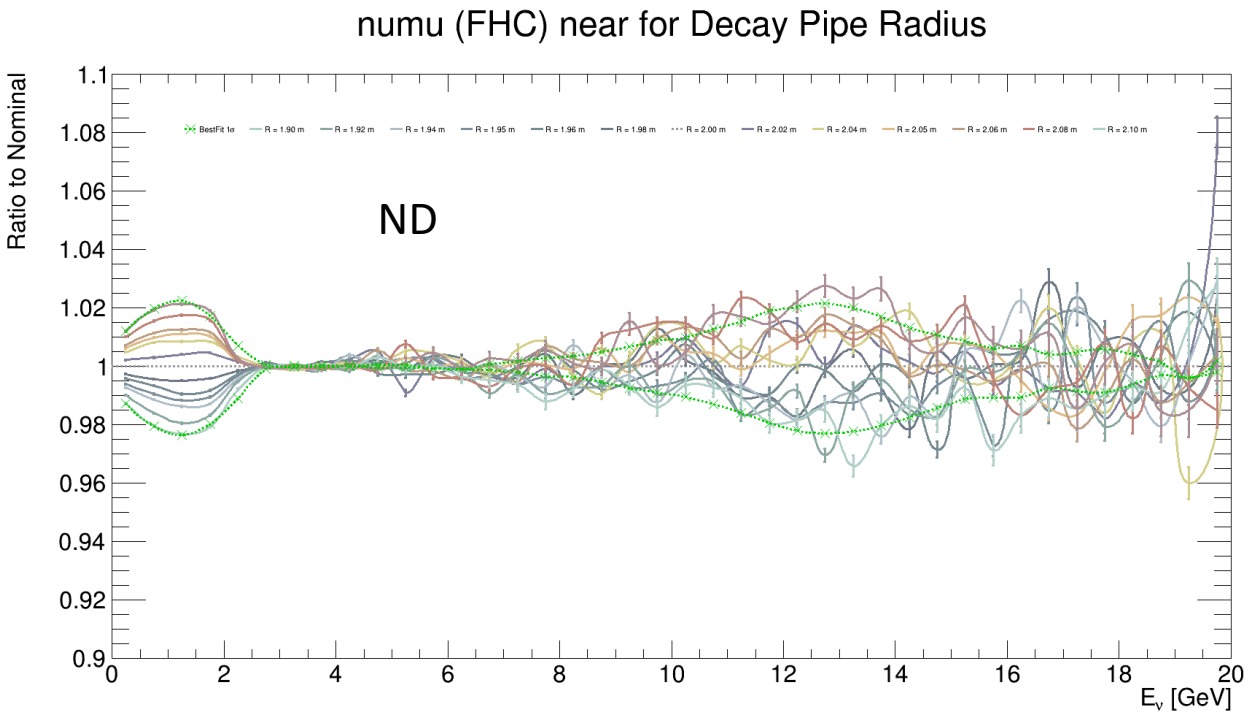

numu (FHC) far for Decay Pipe Radius
ν_μ FD flux -5σ to +5σ comparison
BestFit 1σ
R = 1.5 m
R = 1.6 m
R = 1.7 m
R = 1.8 m
R = 1.9 m
R = 2.0 m
R = 2.1 m
R = 2.2 m
R = 2.3 m
R = 2.4 m
R = 2.5 m
Ratio to Nominal
1.15
1.1
1.05
1
0.95
0.9
0.85
0
2
4
6
8
10
12
14
16
18
20
E_ν [GeV]


numu (FHC) fovern for Decay Pipe Radius
ν_μ FD/ND flux -5σ to +5σ comparison
BestFit 1σ
R = 1.5 m
R = 1.6 m
R = 1.7 m
R = 1.8 m
R = 1.9 m
R = 2.0 m
R = 2.1 m
R = 2.2 m
R = 2.3 m
R = 2.4 m
R = 2.5 m
Ratio to Nominal
1.15
1.1
1.05
1
0.95
0.9
0.85
0
2
4
6
8
10
12
14
16
18
20
E_ν [GeV]

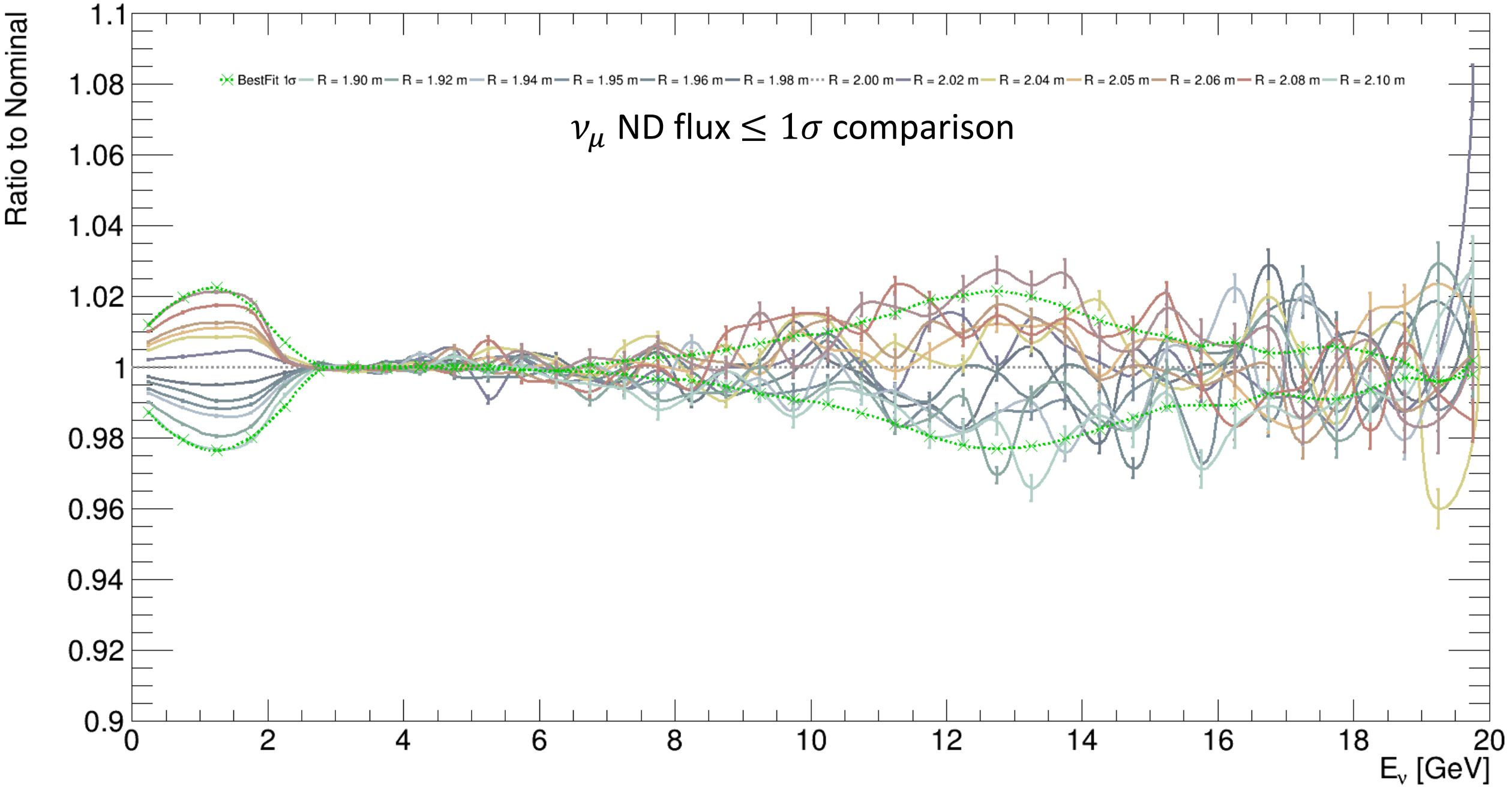
$\leq 1\sigma$ simulations
$\pm 0.2, \pm 0.4, \pm 0.5, \pm 0.6, \pm 0.8\sigma$

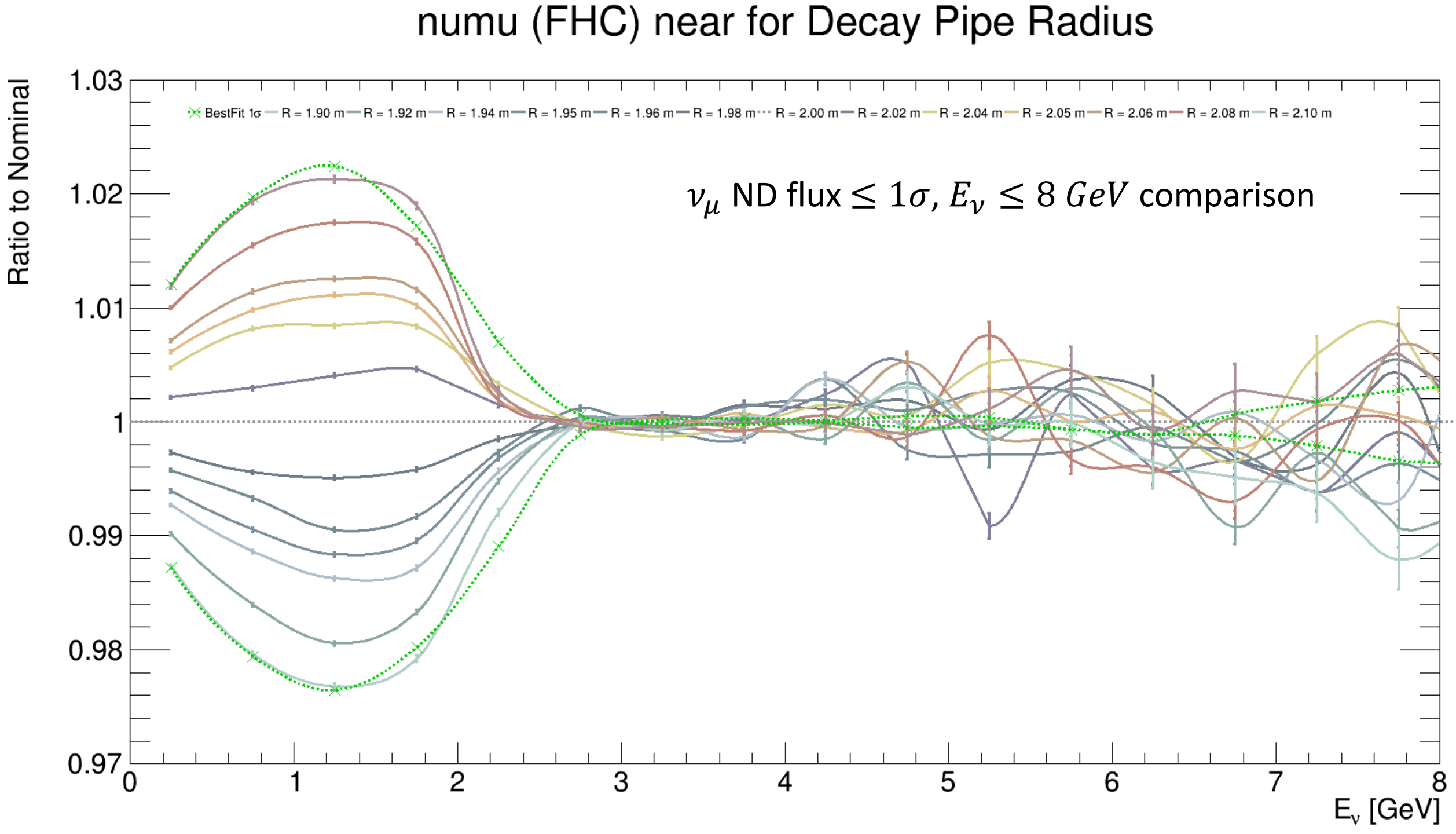


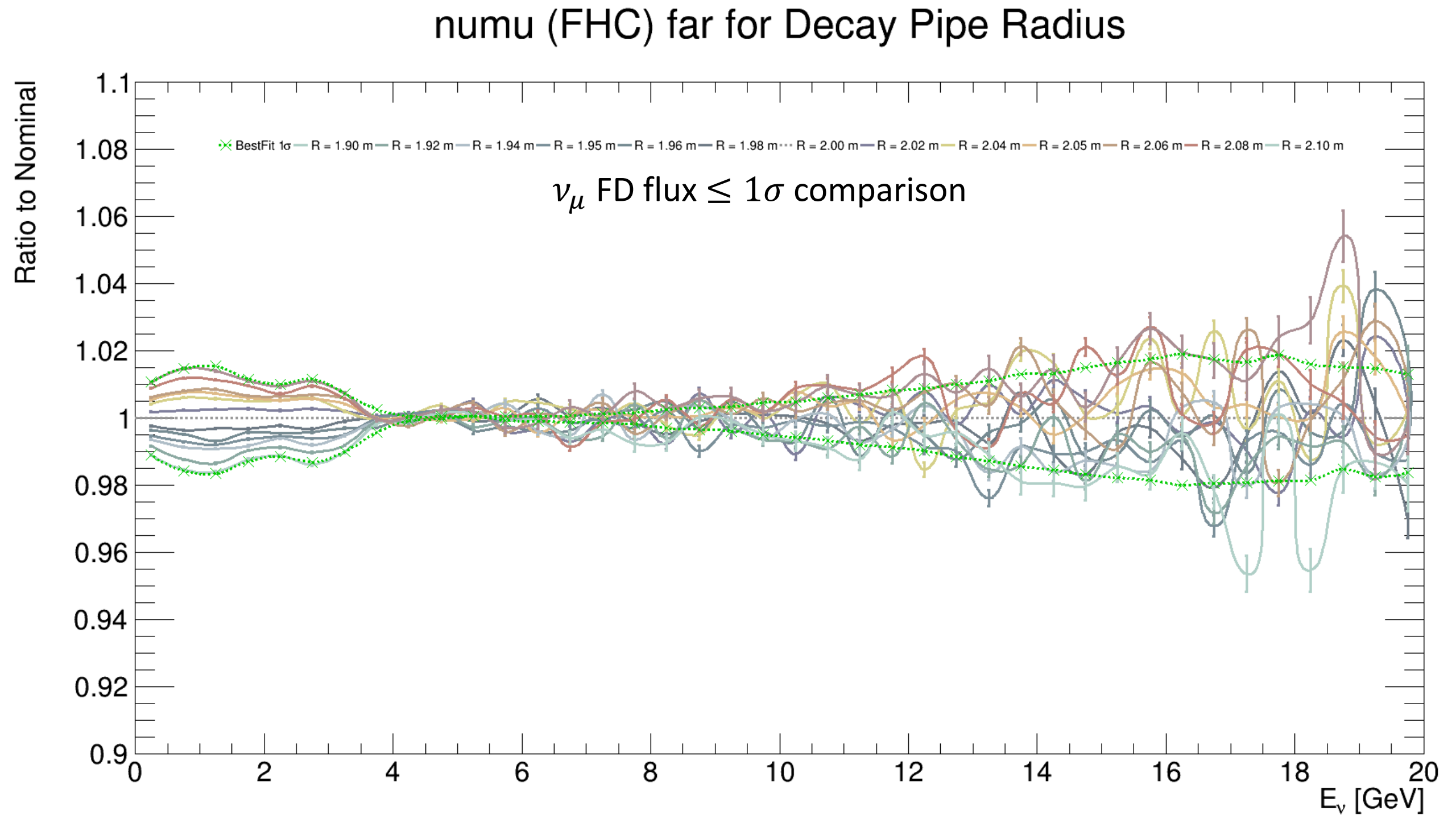




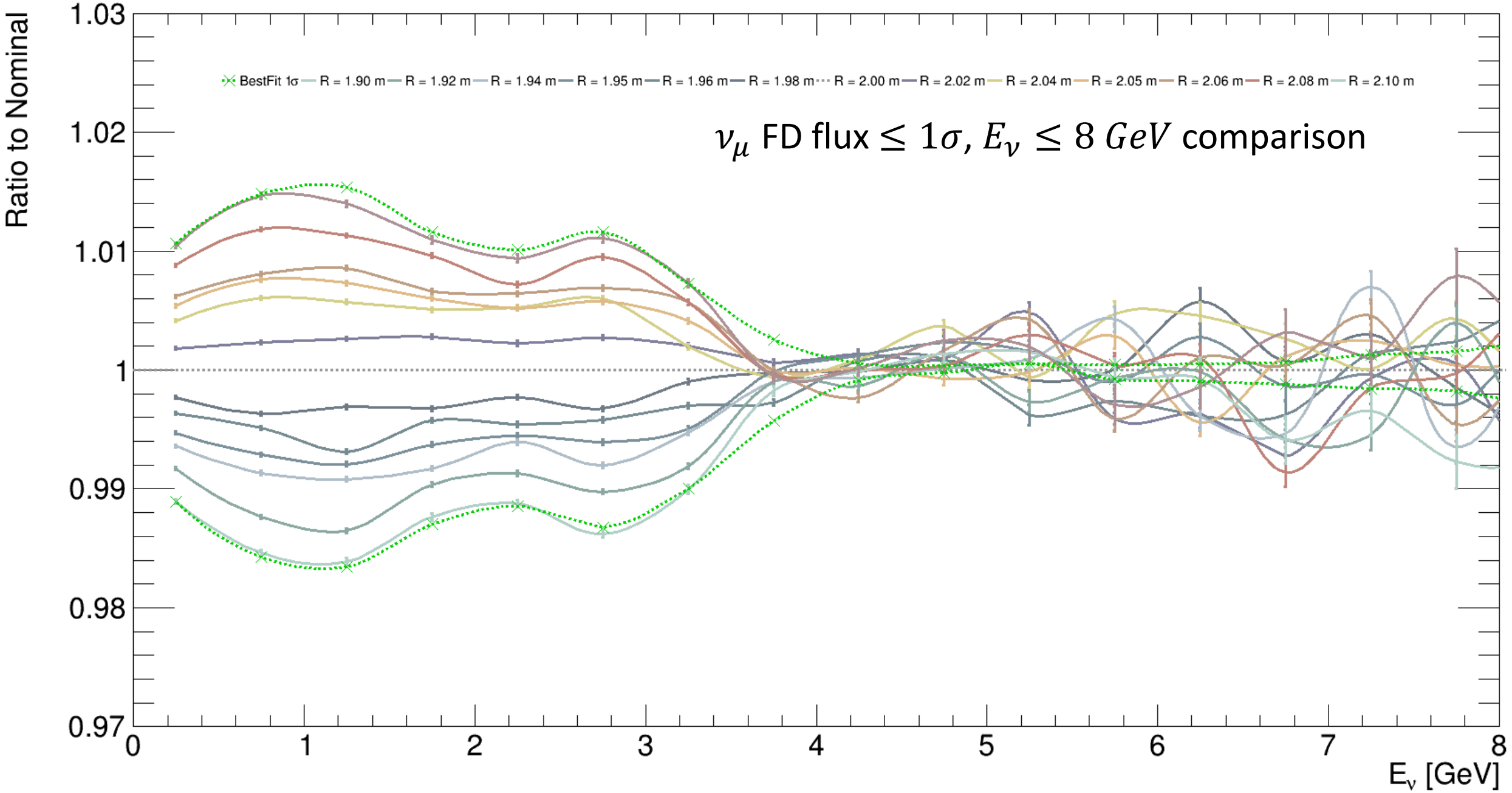
numu (FHC) near for Decay Pipe Radius

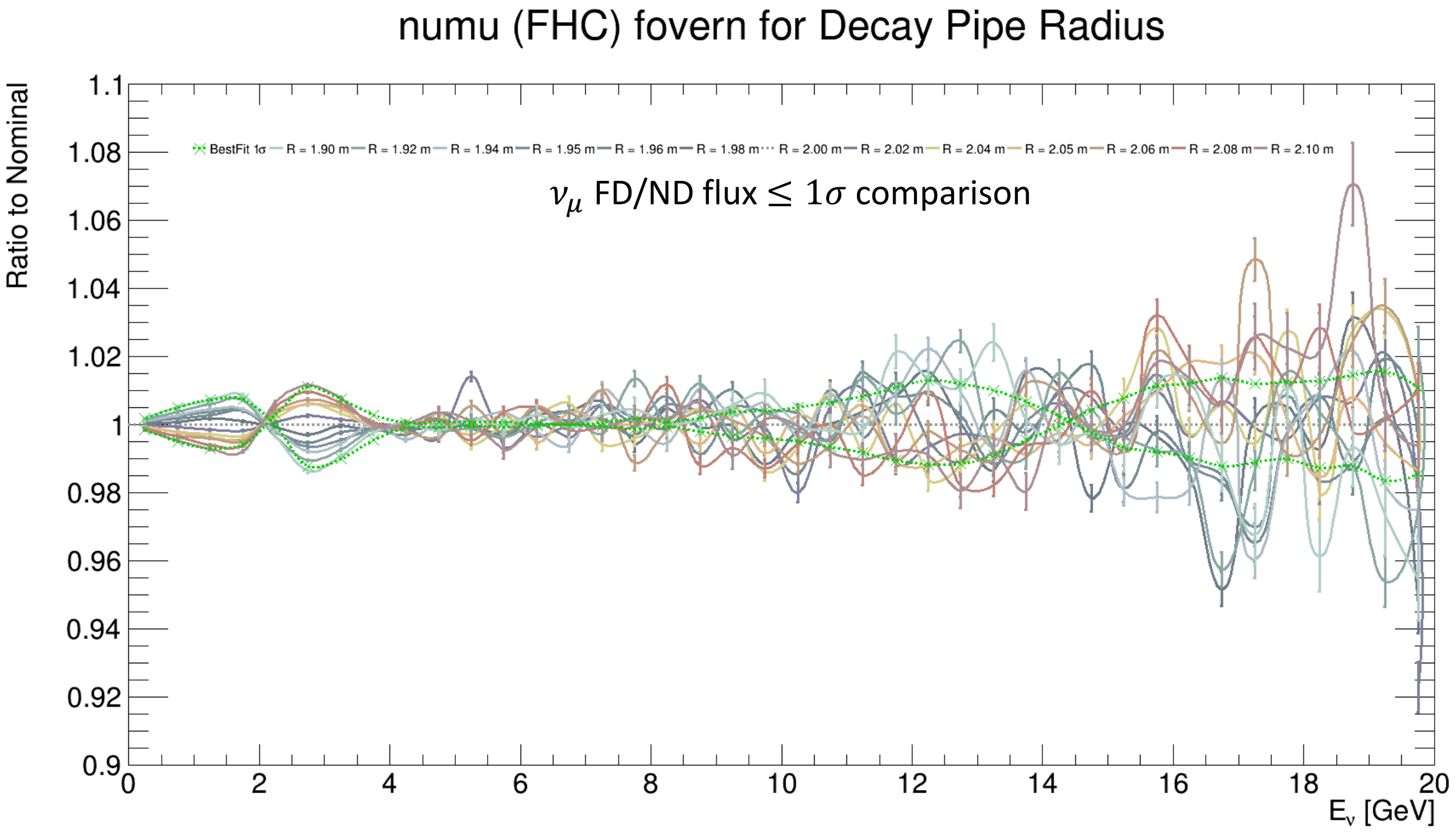


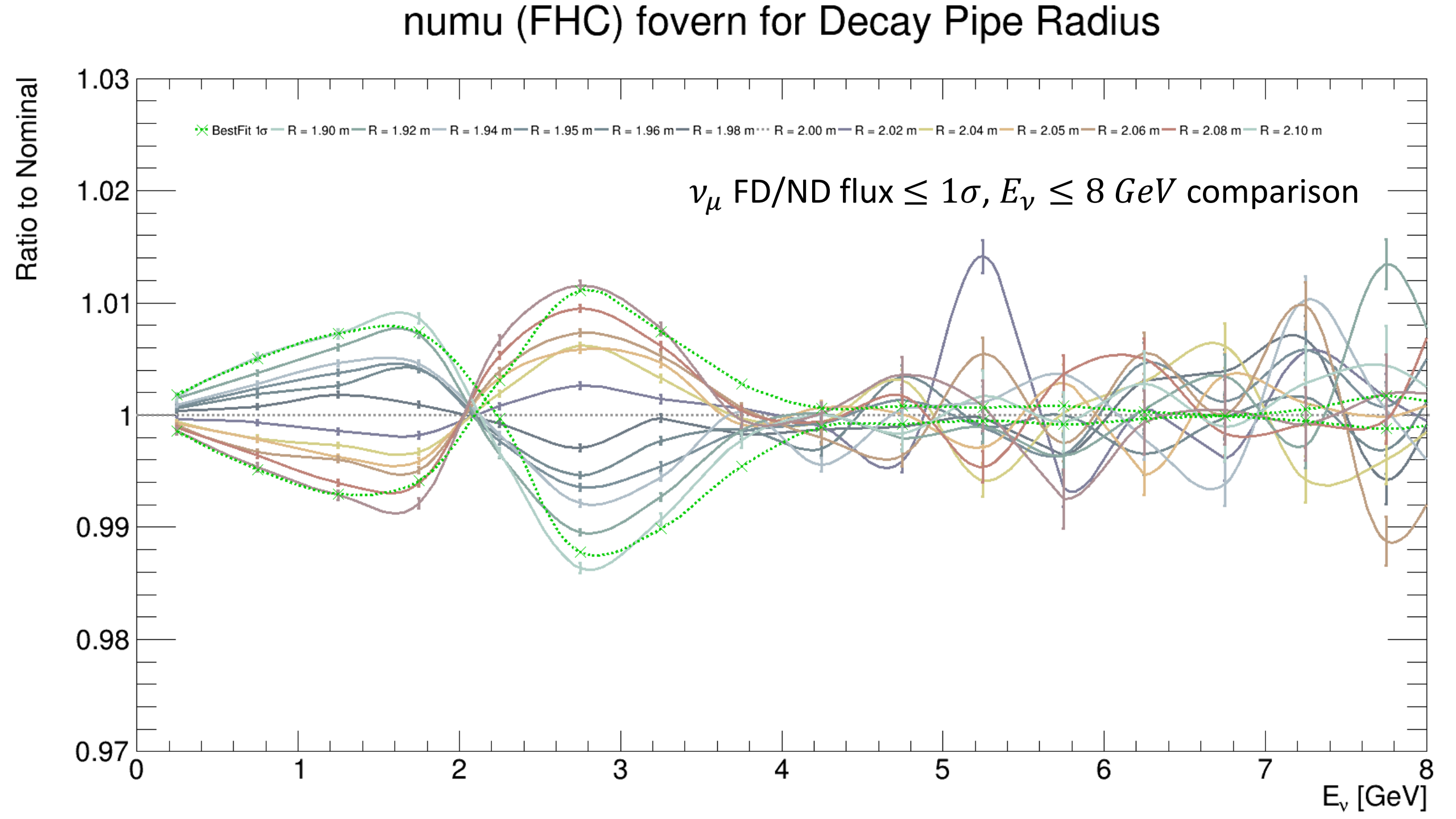

numu (FHC) near for Decay Pipe Radius
Ratio to Nominal
BestFit 1σ
R = 1.90 m
R = 1.92 m
R = 1.94 m
R = 1.95 m
R = 1.96 m
R = 1.98 m
R = 2.00 m
R = 2.02 m
R = 2.04 m
R = 2.05 m
R = 2.06 m
R = 2.08 m
R = 2.10 m
ν_μ ND flux $\leq 1\sigma$, $E_\nu \leq 8\ GeV$ comparison
1.03
1.02
1.01
1
0.99
0.98
0.97
0
1
2
3
4
5
6
7
8
E_ν [GeV]

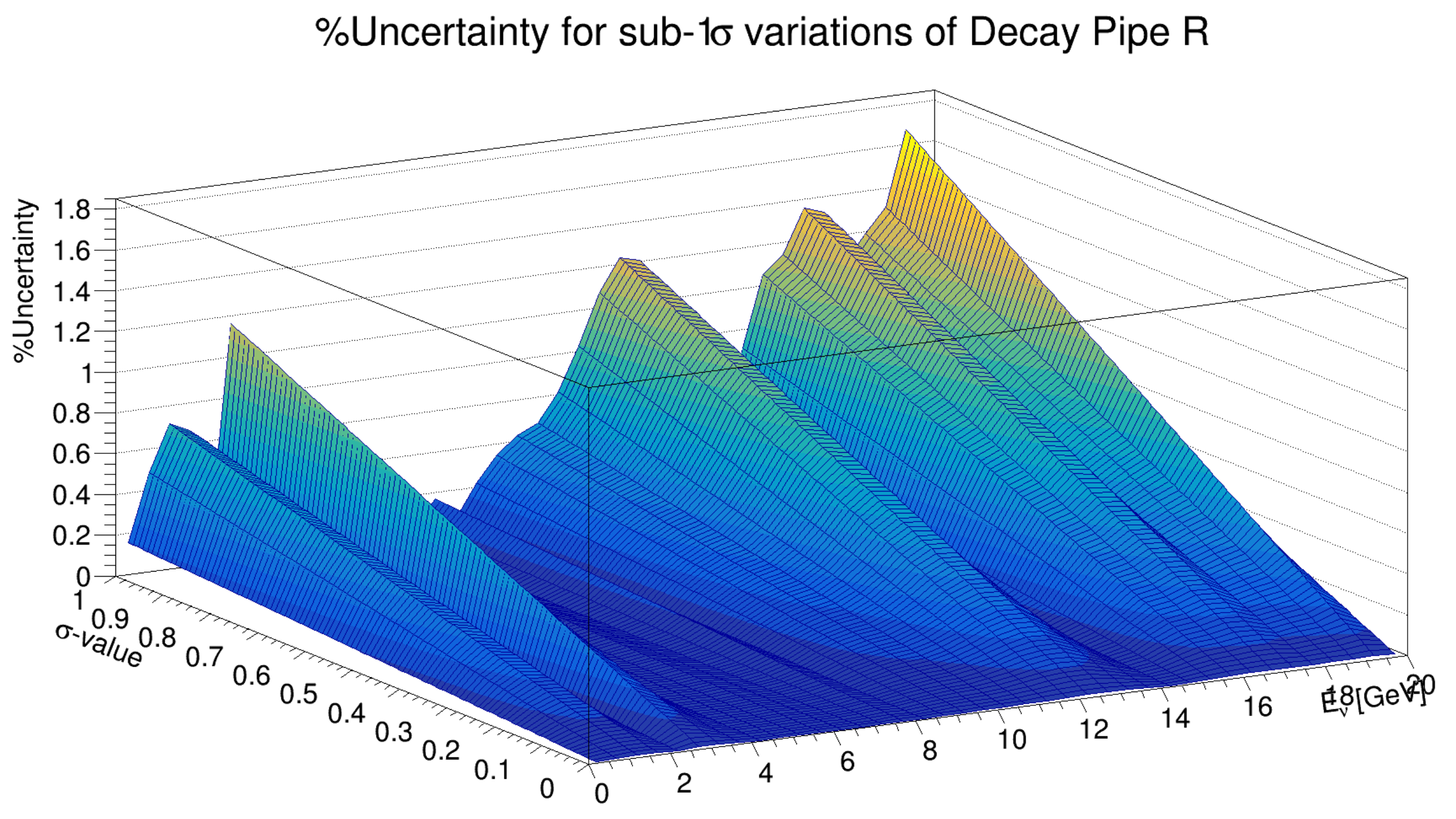

numu (FHC) far for Decay Pipe Radius
ν_μ FD flux $\leq 1\sigma$ comparison
Ratio to Nominal
BestFit 1σ
R = 1.90 m
R = 1.92 m
R = 1.94 m
R = 1.95 m
R = 1.96 m
R = 1.98 m
R = 2.00 m
R = 2.02 m
R = 2.04 m
R = 2.05 m
R = 2.06 m
R = 2.08 m
R = 2.10 m
1.1
1.08
1.06
1.04
1.02
1
0.98
0.96
0.94
0.92
0.9
0
2
4
6
8
10
12
14
16
18
20
E_ν [GeV]

numu (FHC) far for Decay Pipe Radius




numu (FHC) fovern for Decay Pipe Radius
Ratio to Nominal
BestFit 1σ
R = 1.90 m
R = 1.92 m
R = 1.94 m
R = 1.95 m
R = 1.96 m
R = 1.98 m
R = 2.00 m
R = 2.02 m
R = 2.04 m
R = 2.05 m
R = 2.06 m
R = 2.08 m
R = 2.10 m
ν_μ FD/ND flux $\leq 1\sigma$ comparison
1.1
1.08
1.06
1.04
1.02
1
0.98
0.96
0.94
0.92
0.9
0
2
4
6
8
10
12
14
16
18
20
E_ν [GeV]


numu (FHC) fovern for Decay Pipe Radius
Ratio to Nominal
BestFit 1σ
R = 1.90 m
R = 1.92 m
R = 1.94 m
R = 1.95 m
R = 1.96 m
R = 1.98 m
R = 2.00 m
R = 2.02 m
R = 2.04 m
R = 2.05 m
R = 2.06 m
R = 2.08 m
R = 2.10 m
ν_μ FD/ND flux $\leq 1\sigma$, $E_\nu \leq 8\ GeV$ comparison
1.03
1.02
1.01
1
0.99
0.98
0.97
0
1
2
3
4
5
6
7
8
E_ν [GeV]


%Uncertainty for sub-1σ variations of Decay Pipe R
%Uncertainty
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
σ-value
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
2
4
6
8
10
12
14
16
18
20
E_{ν} [GeV]