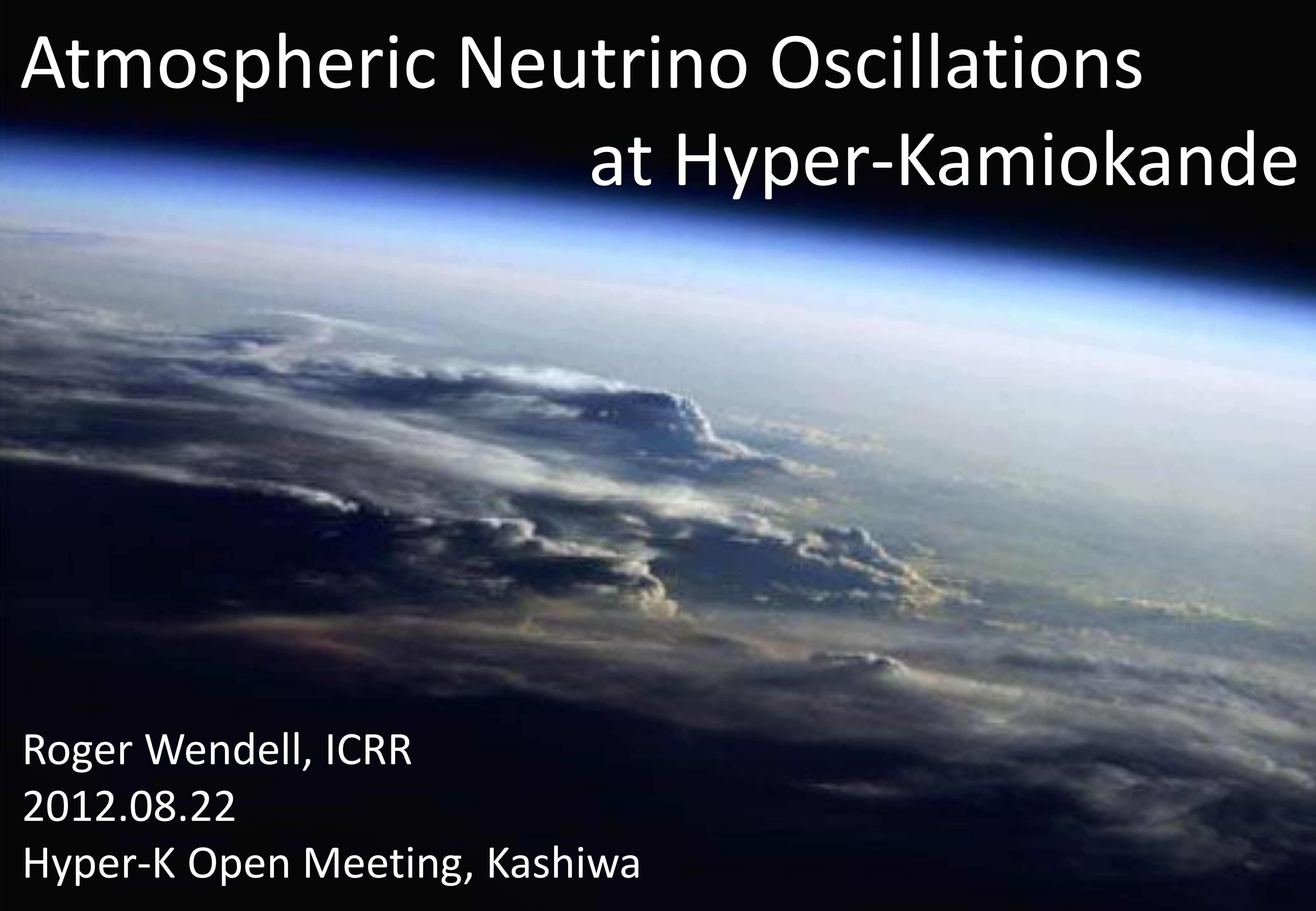


Atmospheric Neutrino Oscillations at Hyper-Kamiokande

Roger Wendell, ICRR

2012.08.22

Hyper-K Open Meeting, Kashiwa

Introduction

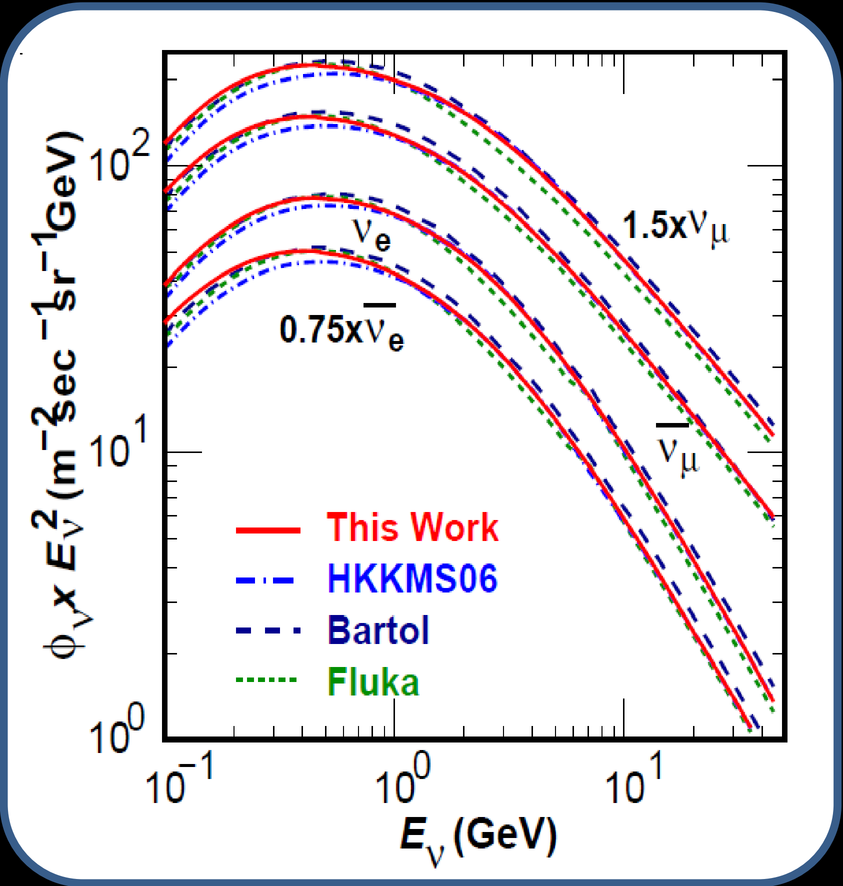
- Atmospheric neutrinos are a good tool for studying L/E-style oscillations in a broad sense
  - With larger statistics though, they can also provide information on sub-leading effects

- Now that θ_{13} is known to be quite large the goals of atmospheric neutrino measurements become more focused:
  - Can we determine **Mass Hierarchy**
  - Can we determine the $\boldsymbol{\theta_{23}}$ **octant**
  - Can we constrain the allowed values of $\boldsymbol{\delta_{cp}}$
  - N.B. $\sin^2 2\theta_{13} = 0.10$ is assumed below unless otherwise stated

- Can they provide extra information to the beam data?

- Not covered today
  - Tau physics – appearance, cross-section measurements
  - Atmospheric neutrinos as a probe of the Earth's interior
  - Etc.

Atmospheric Neutrino Generation



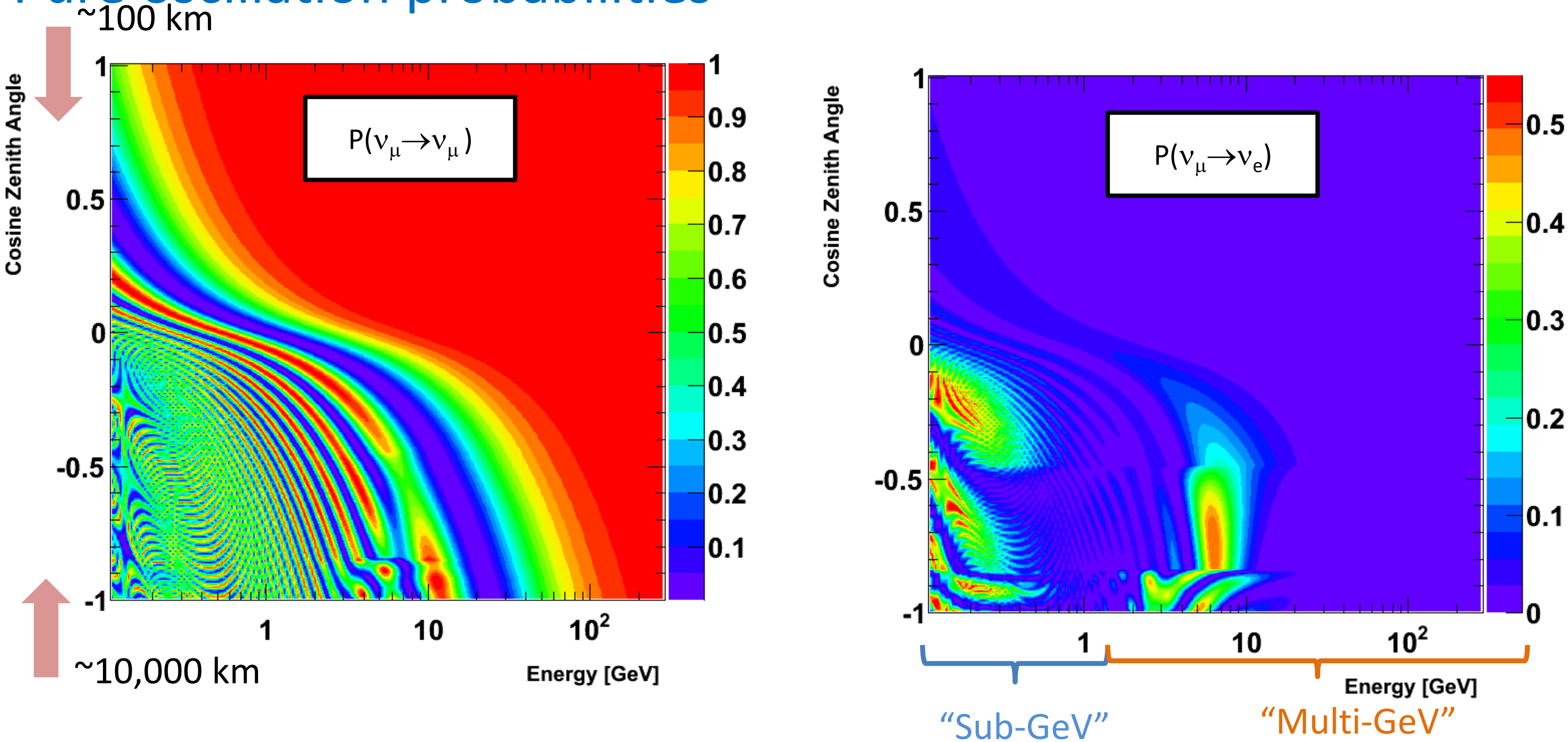
- Cosmic rays strike air nuclei and the decay of the out-going hadrons gives neutrinos

$$P + A \rightarrow N + \pi^+ + x$$

$$\hookrightarrow \mu^+ + \boxed{\nu_\mu} \rightarrow e^+ + \boxed{\nu_e} + \boxed{\bar{\nu}_\mu}$$

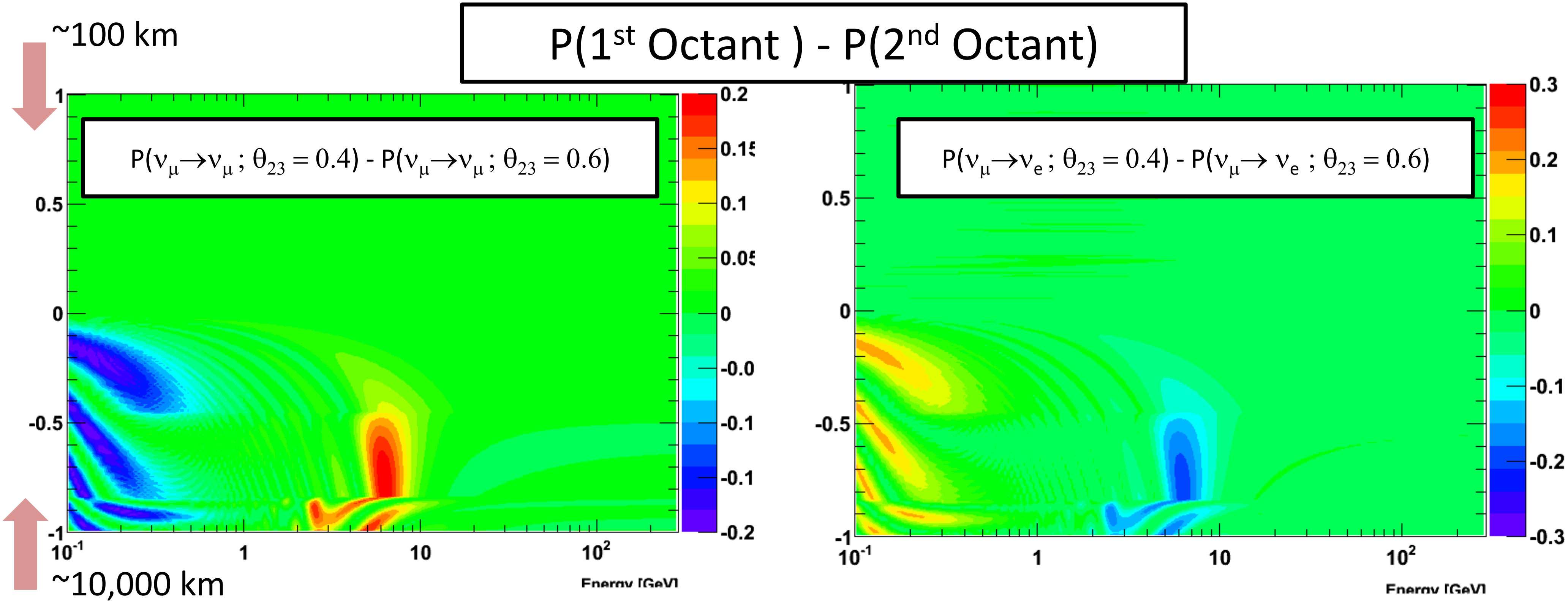
- Isotropic about the Earth
  - Path length to the detector spans 10 – 10,000 km
- Both neutrinos and antineutrinos
  - about 30% of the final samples are antineutrinos
- Spans many decades in energy ~100 MeV – 100TeV$^+$
- Excellent tool for broad studies of neutrino oscillations
  - Access to sub-leading effects with high statistics

Pure oscillation probabilities



- In the presences of the now large θ_{13} resonant enhancement of the $P(\nu_\mu \to \nu_e)$ oscillation probability occurs via matter interactions
- Resonance occurs only for (anti-)neutrinos under the Normal (Inverted) Hierarchy
  - Effects are roughly halved going to the IH

Oscillation probability difference between the θ_{23} octants



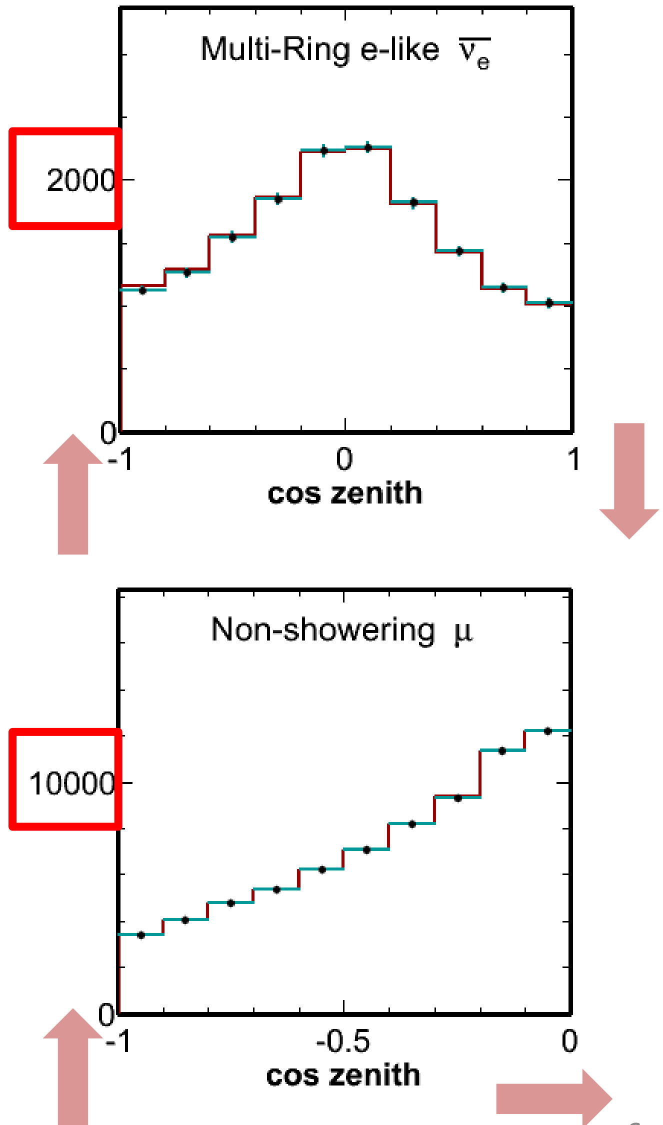
- Matter effect gives improved sensitivity
  - Mass hierarchy $\rightarrow$ Asymmetry between neutrinos and antineutrinos
  - size of θ_{13} and δ_{cp} $\rightarrow$ Magnitude of resonance effect
  - Octant of θ_{23} $\rightarrow$ Appearance and disappearance interplay

(Trends are Independent of Hierarchy)

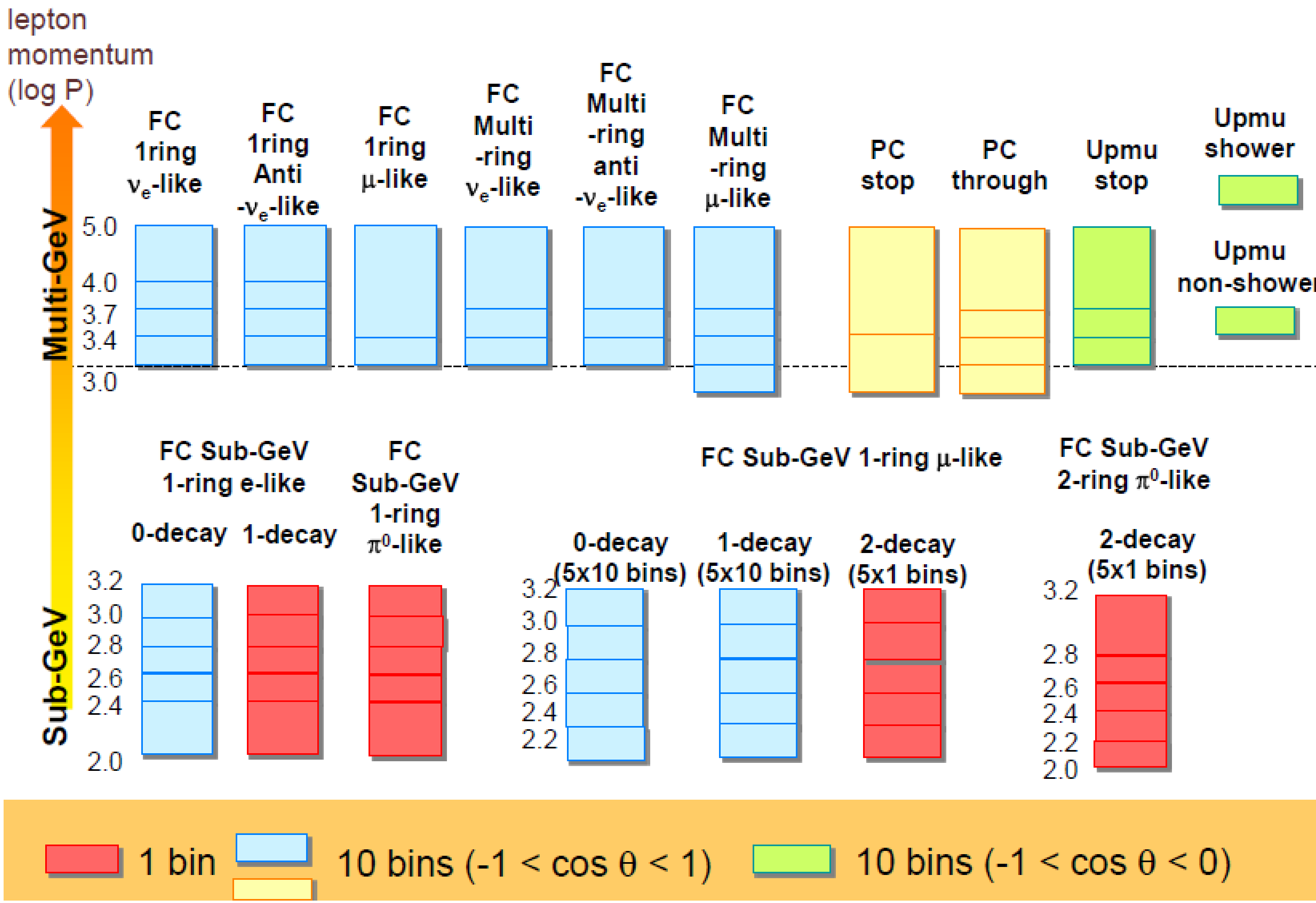
About the Atmospheric Neutrino Fit

- This study is an extrapolation of the standard three-flavor oscillation fit done at Super-K
  - Approximately ~8 Fully Contained events per day
  - Assumes no future enhancements, just project the SK exposure onto Hyper-K scales
- Atmospheric neutrino sample
  - 18 Event categories, binned by momenta and zenith angle, classified by
    - Number of rings
    - Sub-Gev / Multi-GeV
    - Whether or not all particles are contained in the inner volume
- No event-by-event discrimination between neutrinos and anti-neutrinos…do this statistically
- Primary three-flavor signal occurs in Multi-GeV electron-like samples

MC Event Rates for 10years of HK



Zenith Angle Analysis – 480 Bins



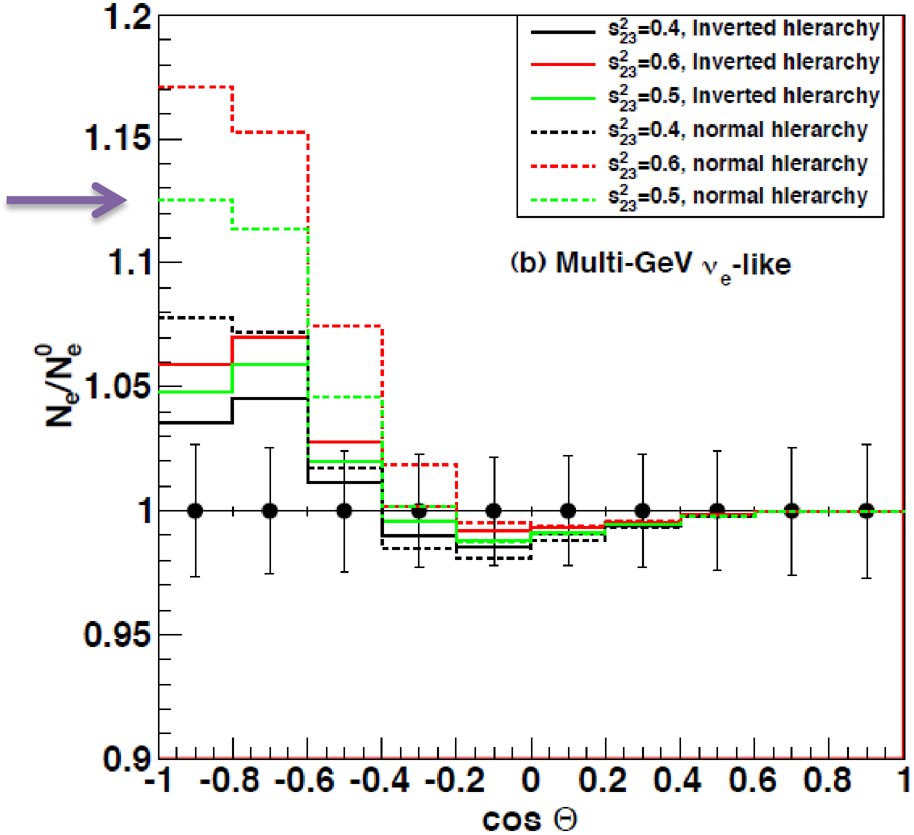
Sample Composition

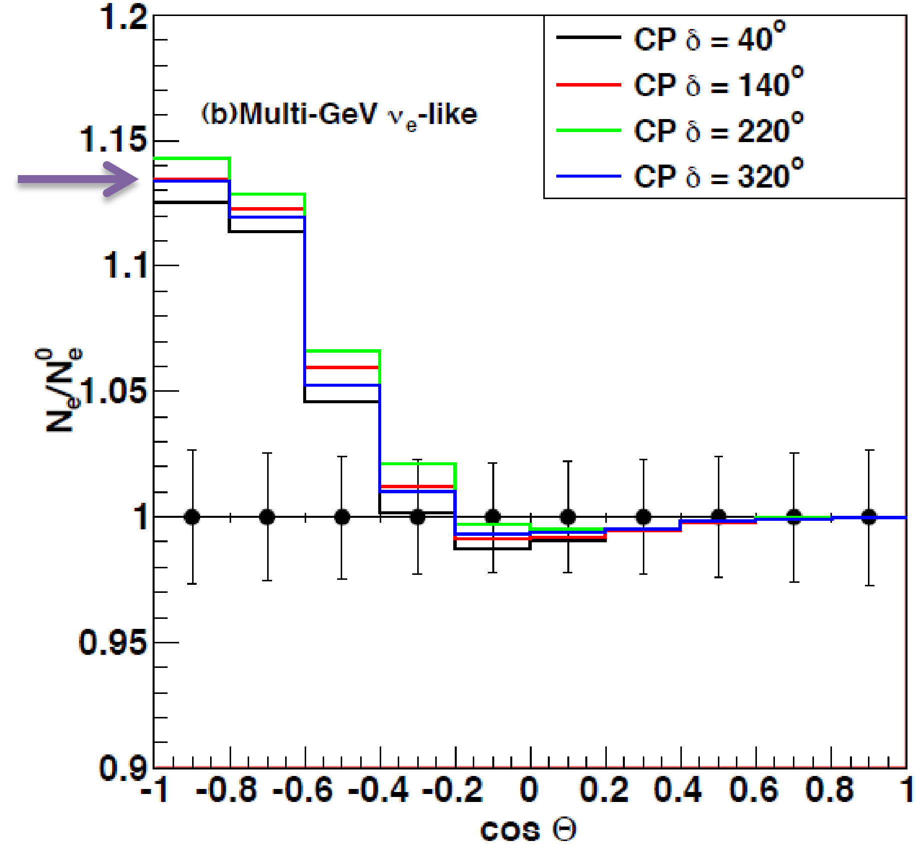
Composition (%)		CC ν_e	CC anti-ν_e	CC ν_μ+anti-ν_μ	NC
ν_e like	1R	60.2	10.6	13.5	14.8
	MR	57.5	17.4	10.7	13.7
Anti-ν_e like	1R	55.7	36.6	1.1	6.4
	MR	51.9	20.7	8.2	19.7

Composition (%)		CC ν_e	CC anti-ν_e	CC ν_μ+anti-ν_μ	NC
ν_μ like	1R	0.2	0.08	98.8	0.2
	MR	2.5	0.3	91.7	4.4

- Generally the background component of the e-like signal samples is **~20-30%**
- Muon-like samples on the other hand tend have high-purity and reasonable sensitivity to small effects

Expected Effects : electron-like samples

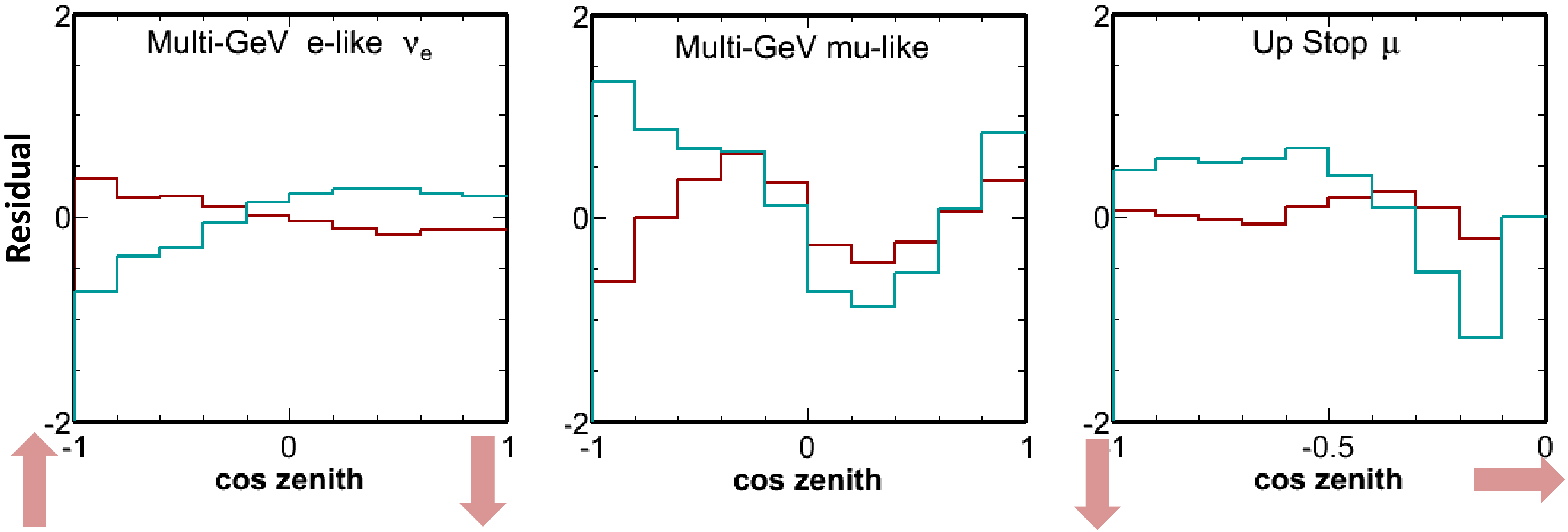




- Effect of the θ_{23} octant can be larger than that from δ_{cp} on electron appearance
- Effect of the latter is smaller than the expected statistical uncertainty in each bin

→ Equivalent MC

Octant: Residual at Maximal Mixing ($x - MC^{\theta = 0.5}$)/ sqrt($MC^{\theta = 0.5}$)



θ_{23} = **0.4** vs. θ_{23} = 0.5

θ_{23} = **0.6** vs. θ_{23} = 0.5

- Clear differences between the two octants in both the electron and muon samples
- Overall slightly better sensitivity to the first octant

About Systematics

- Super-K analysis considers 151 sources of systematic uncertainty from the usual cadre of errors
  - Flux, cross-section, detector performance

- This is a partial listing of things relevant to three-flavor issues

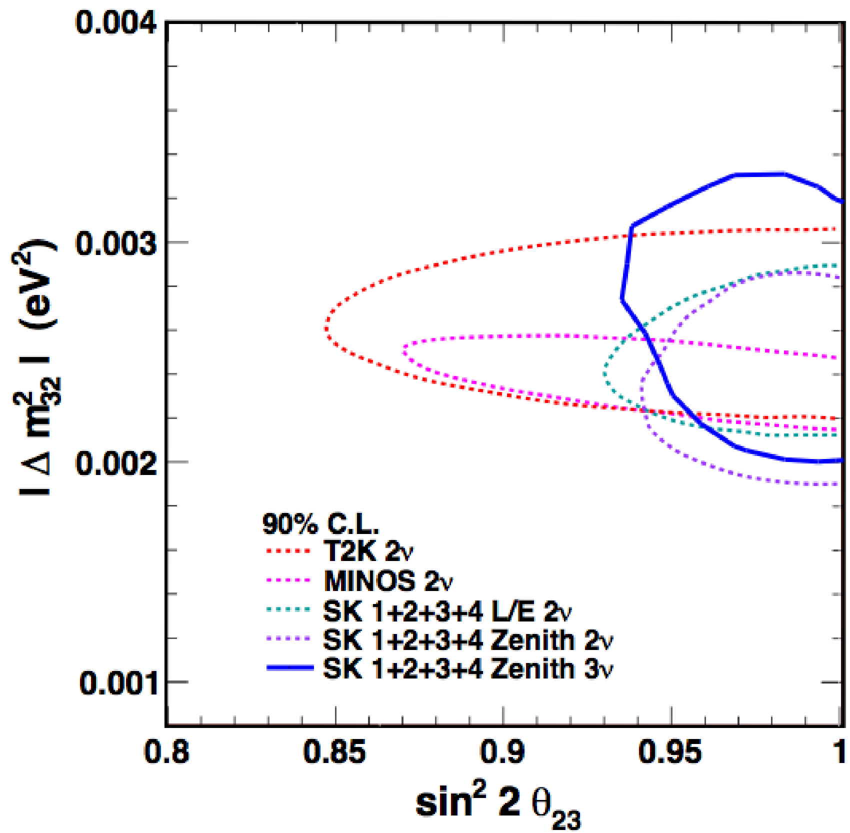
Error Source	Uncertainty
ν_e vs. anti-ν_e sample selection	7%
Charged-Neutral Pion Production	40%
Tau Production Cross section	25%
DIS Cross Section	5-10%
NC / CC Ratio	20%
Single-Pion Production	20%
Flux Normalization above 1 GeV	7%
Flux Ratio ν to ν bar above 1 GeV	5-8%

Notes about Parameter Values

- In the studies below, unless specified otherwise the following inputs have been used to compute sensitivities

Parameter	Value	$\sin^2(2x)$	Comment
Δm^2_{32}	2.4×10^{-3} eV^2		Global Fit
$\sin^2\theta_{23}$	0.4-0.6	0.96 - 1.0	**
$\sin^2\theta_{13}$	0.025	0.10	Reactor Data
δ_{cp}	40 degrees		Min.P($\nu_\mu \rightarrow \nu_e$)
$\sin^2\theta_{21}$	0.31	0.85	Global Solar
Δm^2_{21}	7.6×10^{-5} eV^2		Global Solar
Hierarchy	Normal		Assumption

Neutrino 2012

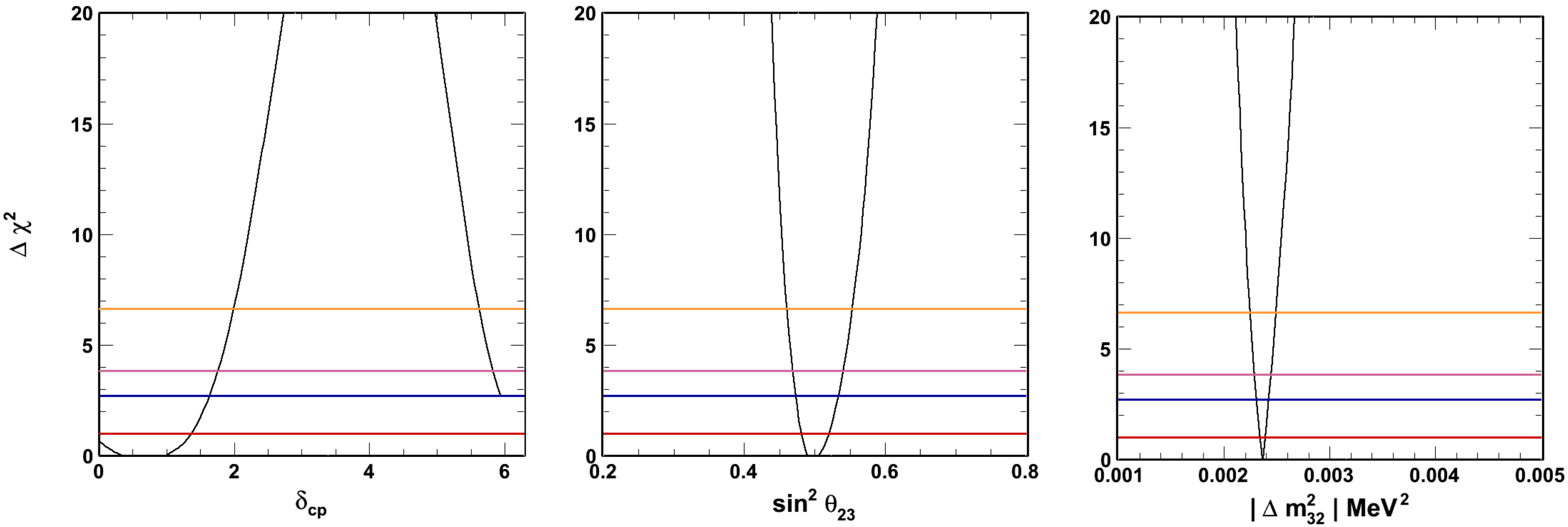


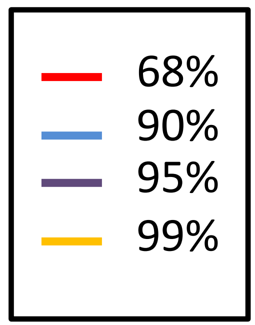
** MINOS central value from Neutrino 2012: $\sin^2(2\theta_{23}) = 0.96$

Atmospheric Neutrino Sensitivity

+ Simultaneous fitting performed on Δm^2_{32}, θ_{23}, δ_{cp}
+ Both hierarchies considered

Example Fit : Normal Hierarchy Sensitivity - 10 Years

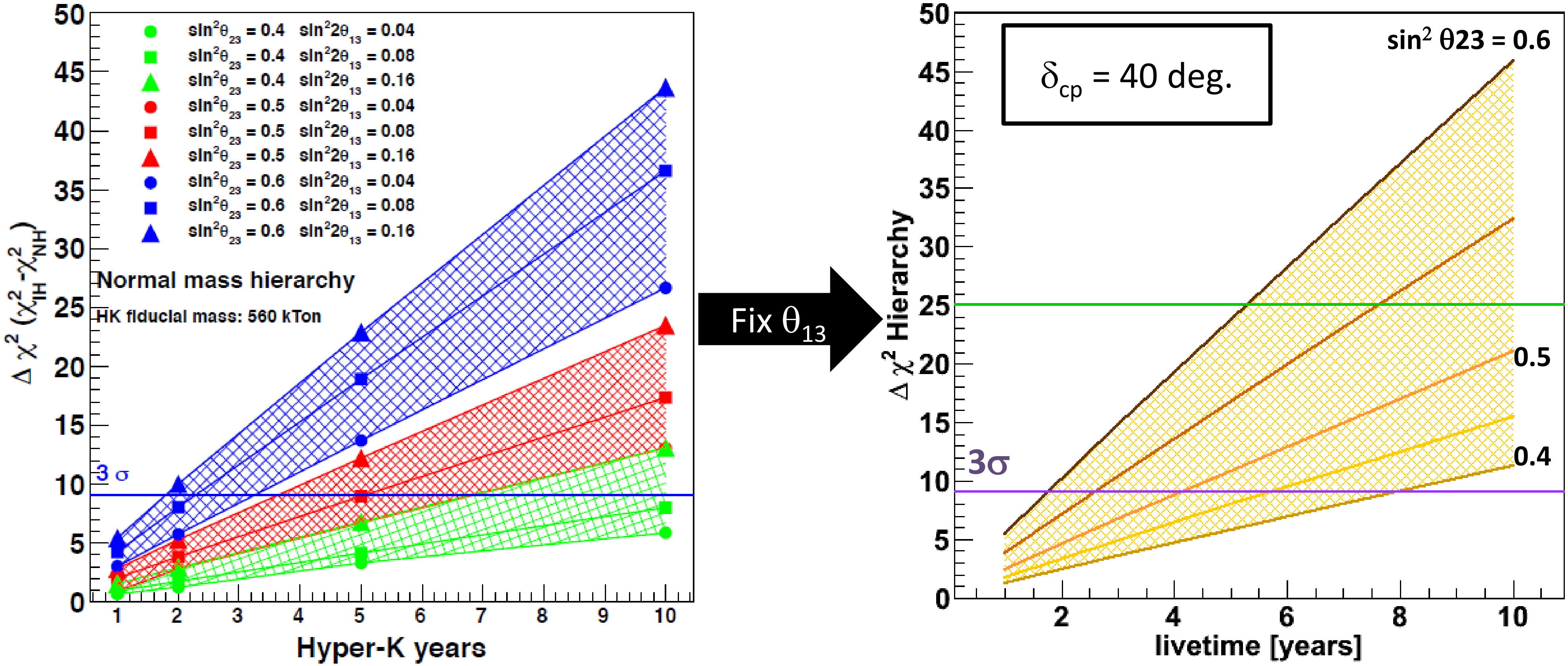




- For these parameters at the 99% C.L.
  - Constrain about 40% of δ_{cp} space
  - ~8% measurement of Δm^2_{32}
  - 10% measurement on θ_{23}
- Not competitive with near and future beam measurements

Δm^2_{21}	7.6×10^{-5} eV^2
Δm^2_{32}	2.4×10^{-3} eV^2
$\sin^2\theta_{12}$	0.31
$\sin^2\theta_{13}$	0.025
$\sin^2\theta_{23}$	0.5
δ	40°

Hierarchy Sensitivity : Normal Hierarchy



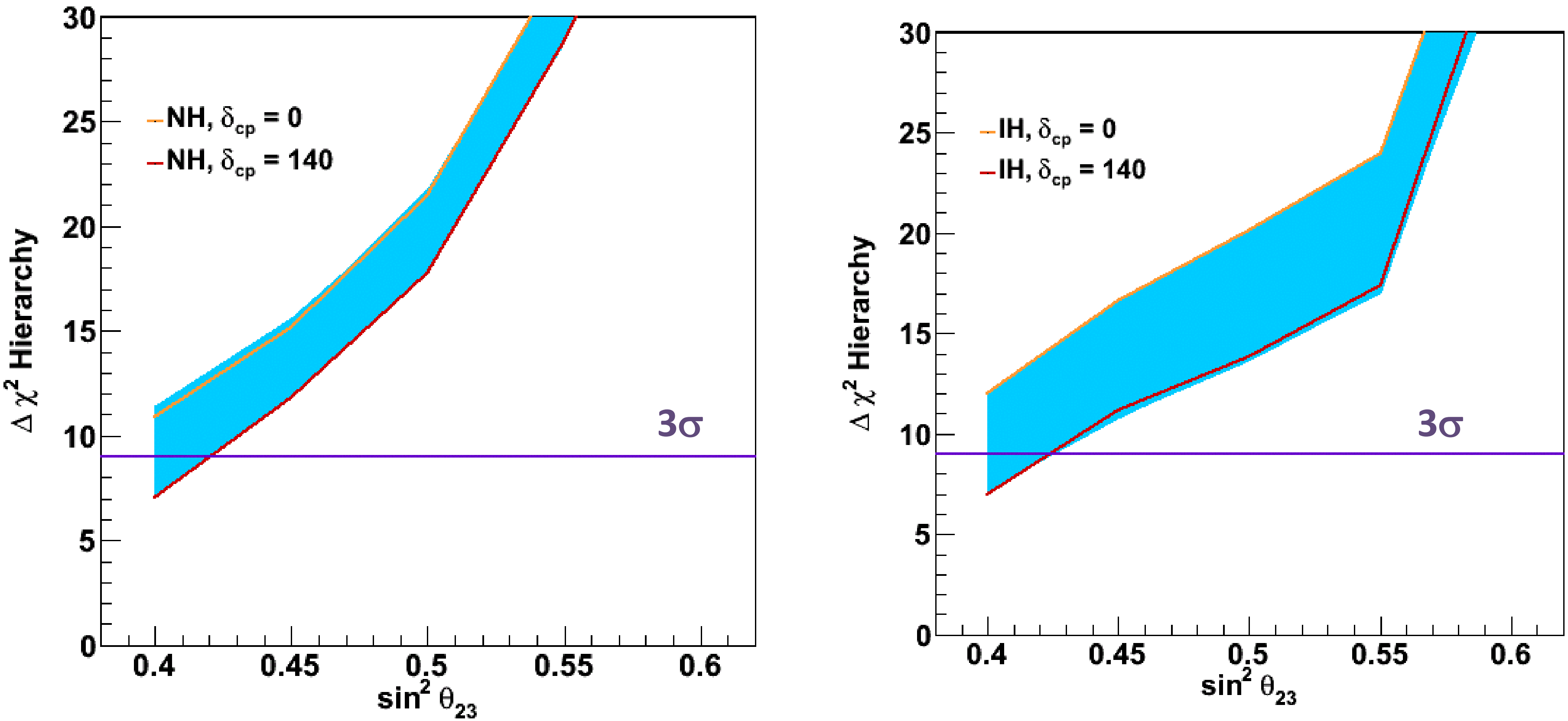
- Intensity of the matter effect and hence electron appearance scales with the size of θ_{13}
- By the time Hyper-K is running, the value of θ_{13} should be very well known
- However this sensitivity is a function of both the θ_{23} octant and true value of δ_{cp}

Hierarchy sensitivity, 10 years of Atmospheric neutrino data

NH, unknown

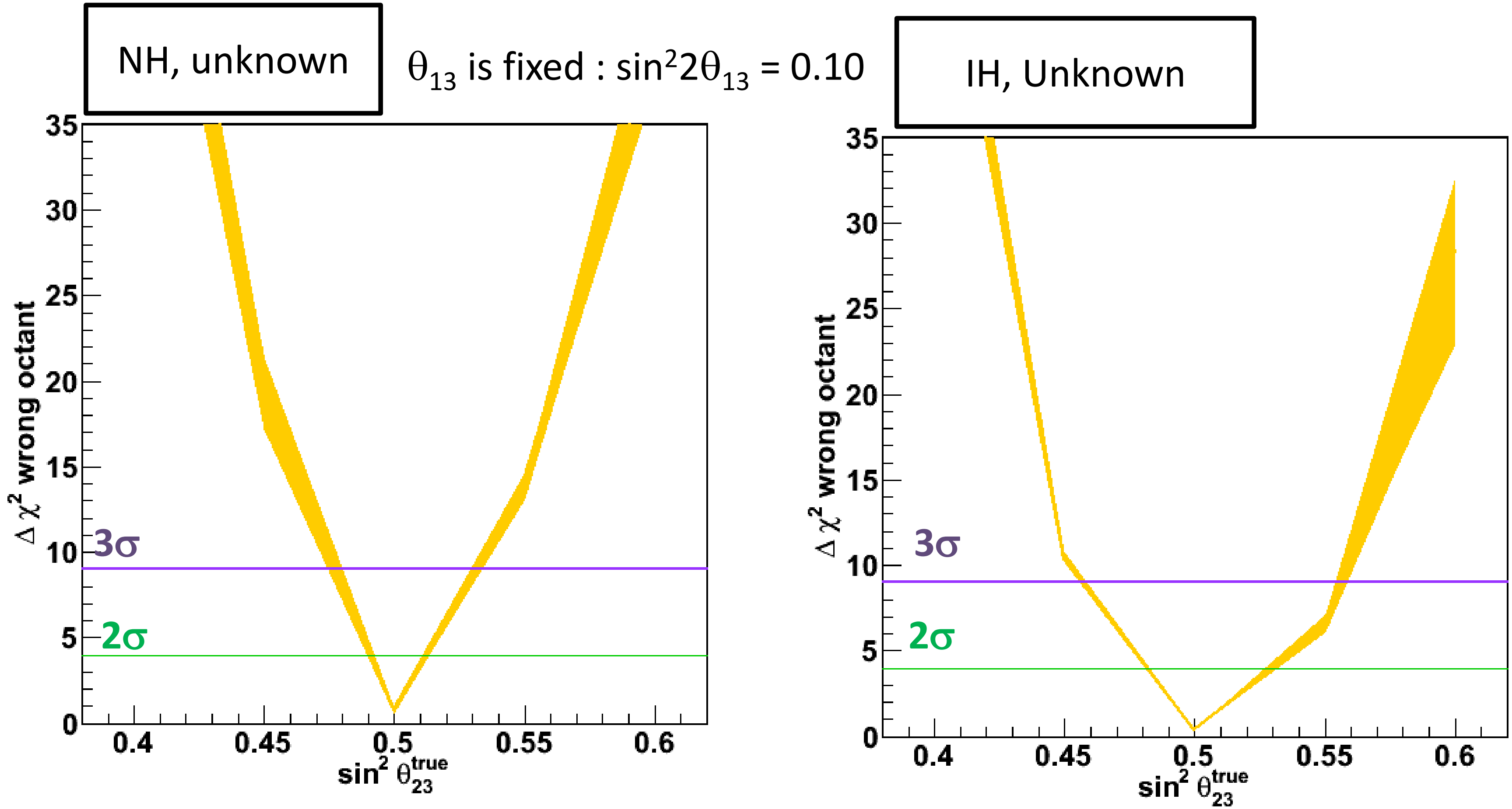
θ_{13} is fixed : $\sin^2 2\theta_{13} = 0.10$

IH, Unknown



- Thickness of the band corresponds to range of δ_{cp}
- Weakest sensitivity overall in the tail of the first octant

θ_{23} Octant sensitivity , 10 year Exposure



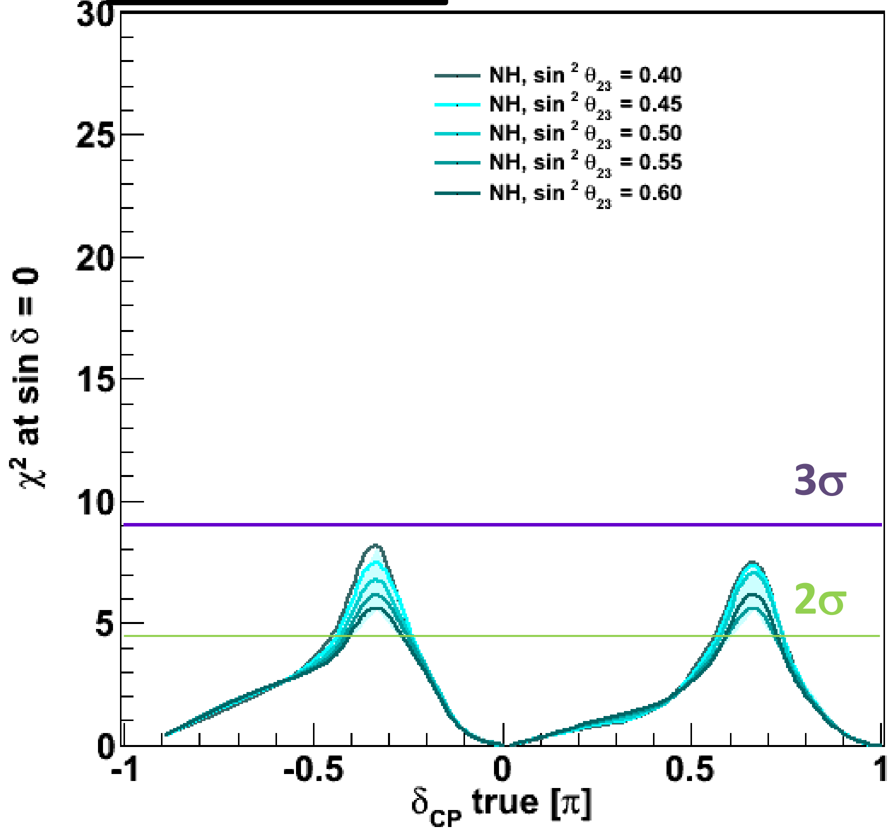
- Thickness of the band corresponds to the uncertainty from δ_{cp}
- Best value of δ_{cp} = 40 degrees
- Worst value of δ_{cp} = 140 (260) degrees, for 1st (2nd) octant

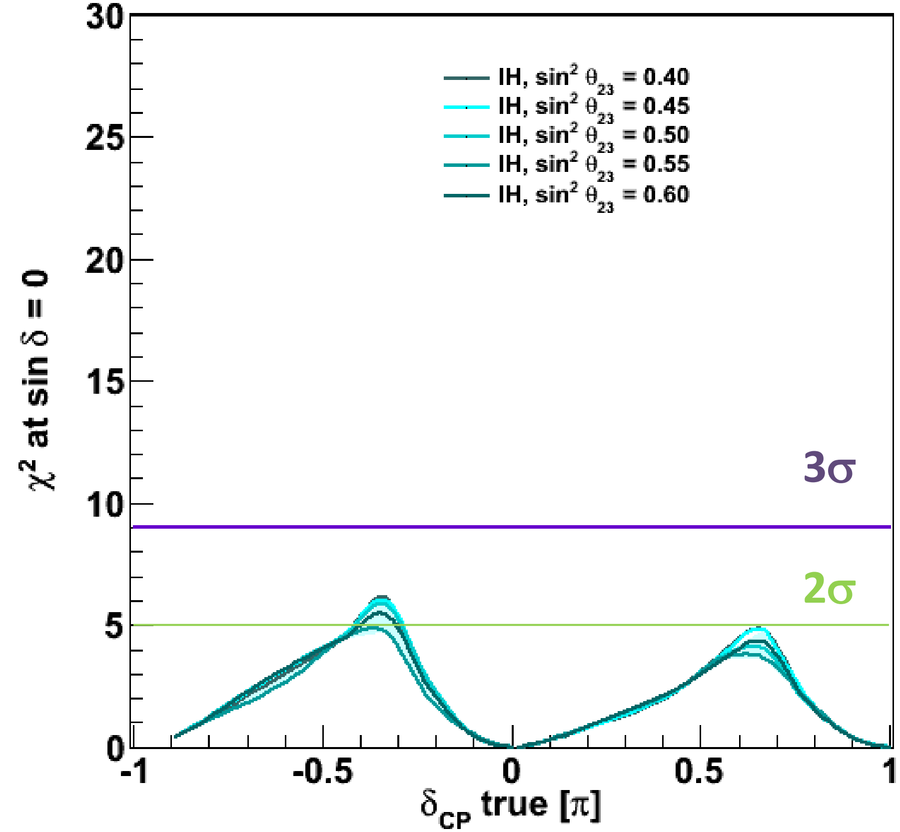
CP-Violation Sensitivity - Exclusion of $\sin\delta_{cp} = 0$

NH, unknown

θ_{13} is fixed : $\sin^2 2\theta_{13} = 0.10$

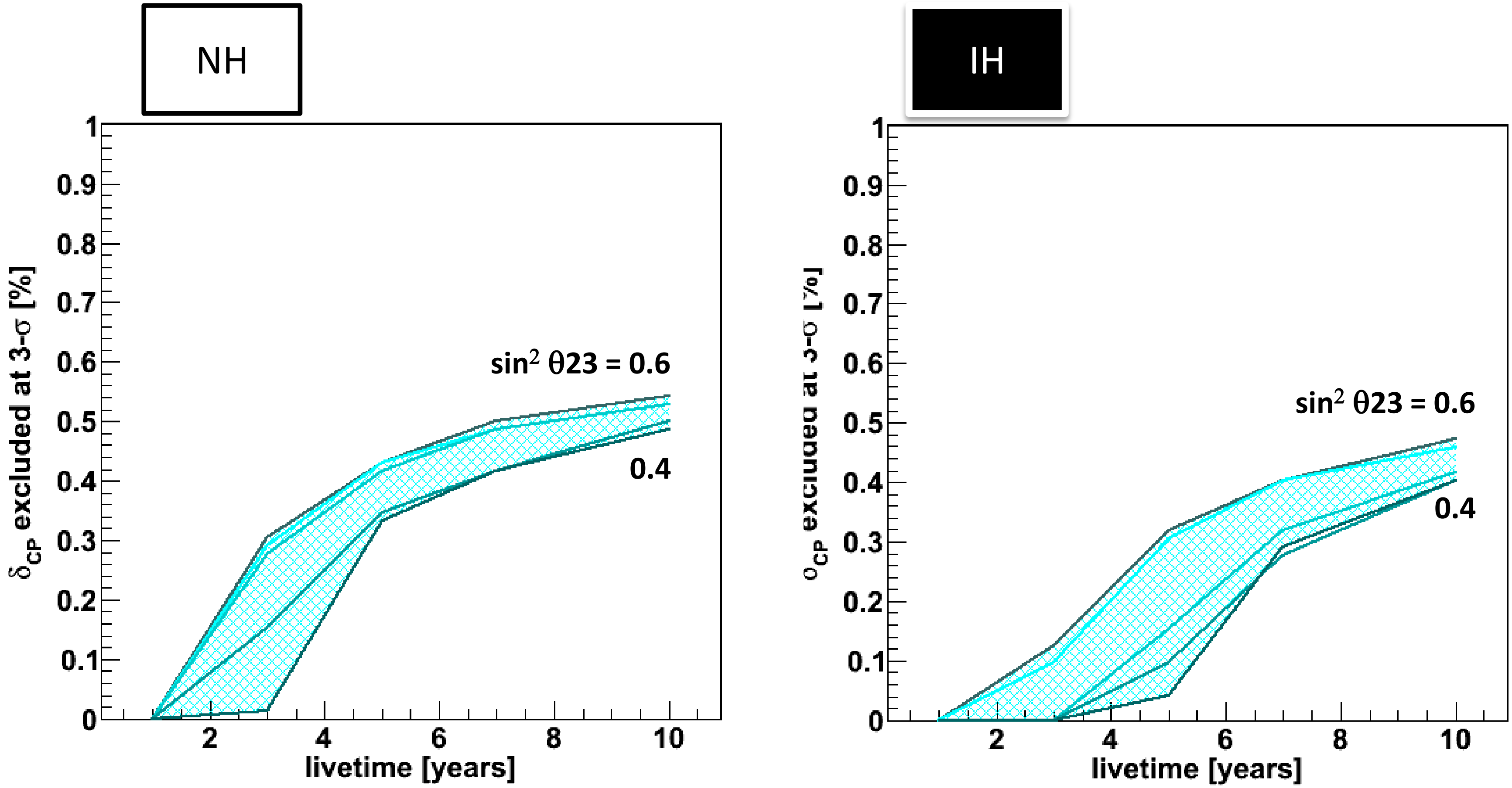
IH, Unknown





- Sensitivity to CP-violation is limited under both hierarchy assumptions
- The addition of this information to the beam data does not make much of an impact

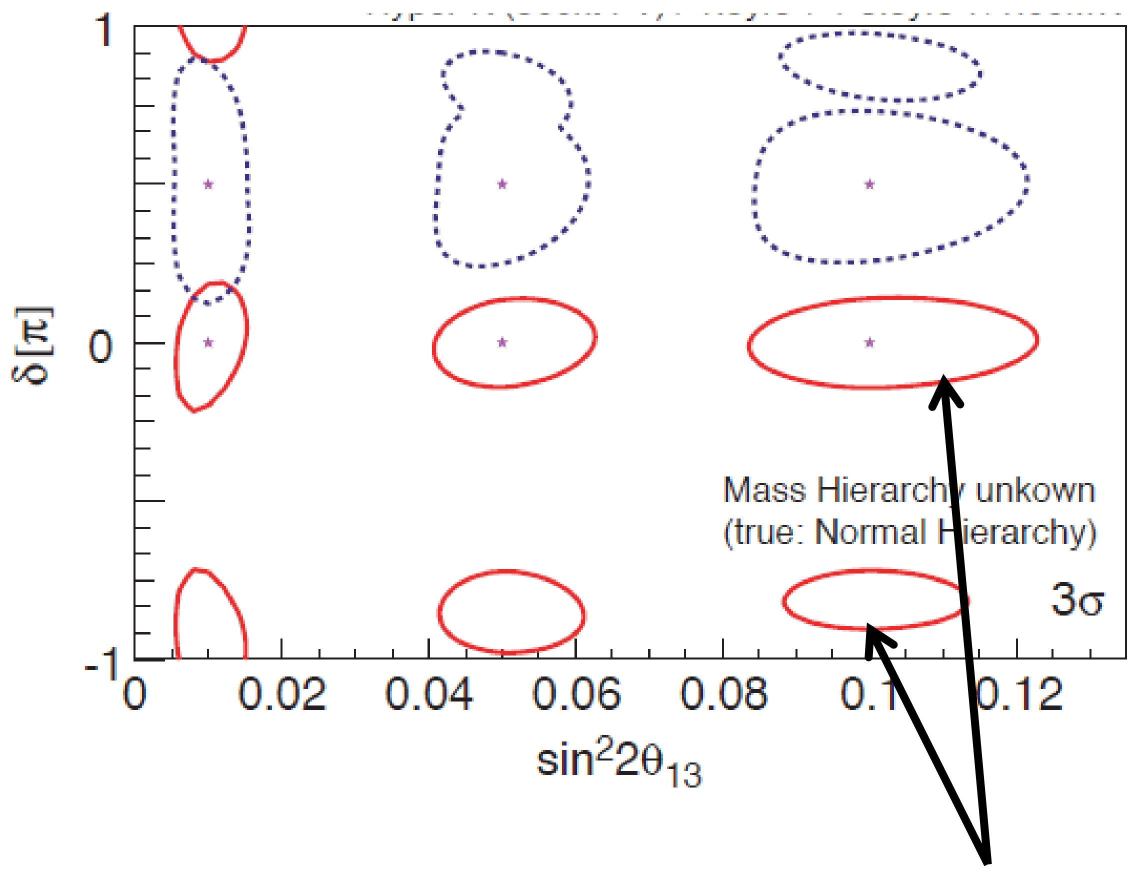
Fraction of δ_{cp} excluded at 3σ for a fixed value of δ_{cp}



- For this particular input, the constraint atmospheric neutrinos can place on dcp is about 50% of

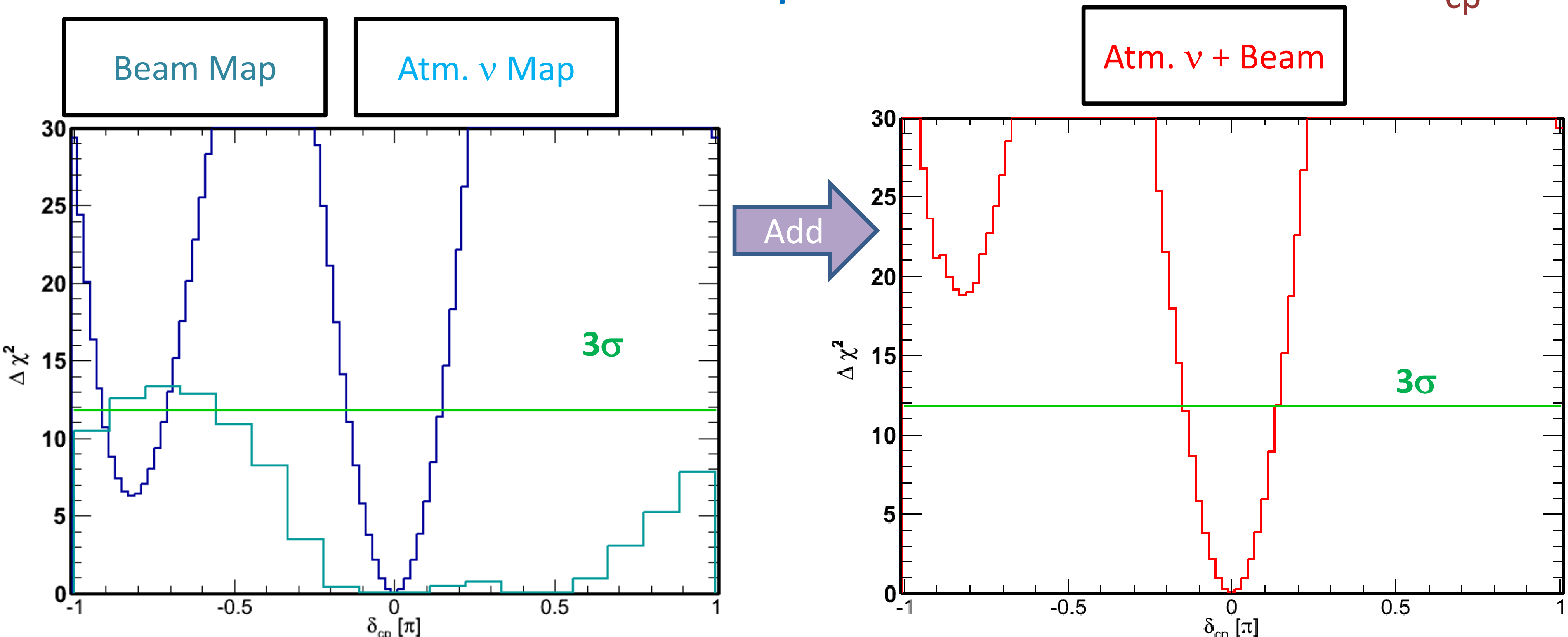
Complementarity of Beam and Atmospheric Samples

Allowed Regions of δ_{cp}



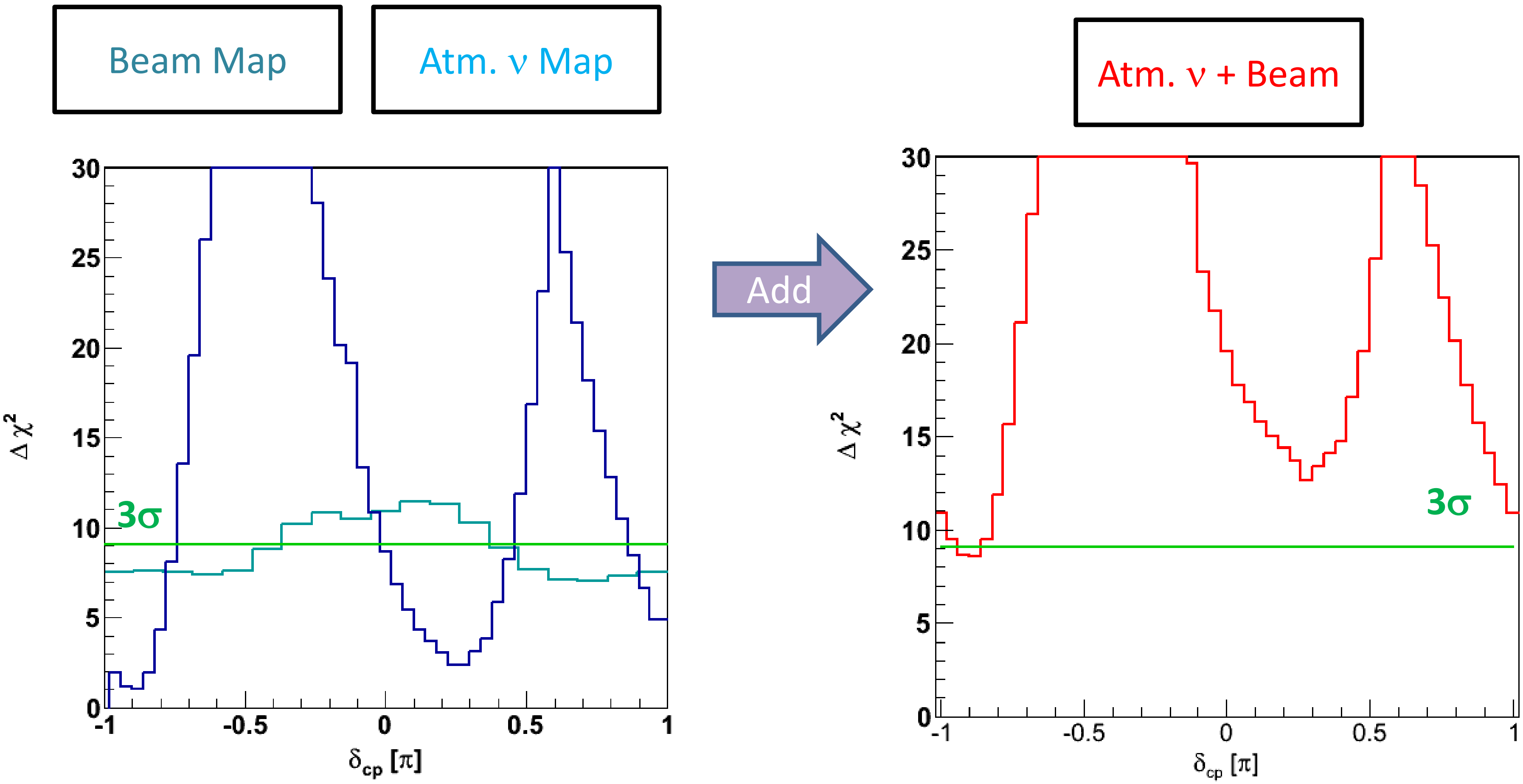
- With beam only data degenerate solutions exist when the mass hierarchy is unknown
- Study the case with fixed θ_{13}

Combination of Beam and Atmospheric Neutrinos : Allowed δ_{cp}



- Hierarchy is unknown, but NH is true
- True δ_{cp} = 0.0
- True $\sin^2 2\theta_{13}$ = 0.10
- Maximal mixing , $\sin^2 2\theta_{23}$ = 1.0
- Degenerate solution exists at 3σ in the beam only case - just add the χ^2 maps
- In the real world, something more sophisticated is in order

Hierarchy sensitivity : Combination of Beam and Atm. Neutrinos



- Hierarchy is unknown, but the NH is true
- True $\sin^2 2\theta_{13} = 0.10$
- Using $\sin^2\theta_{23} = 0.4$
- Even under a conservative assumption its possible to achiev ~3σ discrimination or all values of δ_{cp} if the true hierarchy is normal

Summary

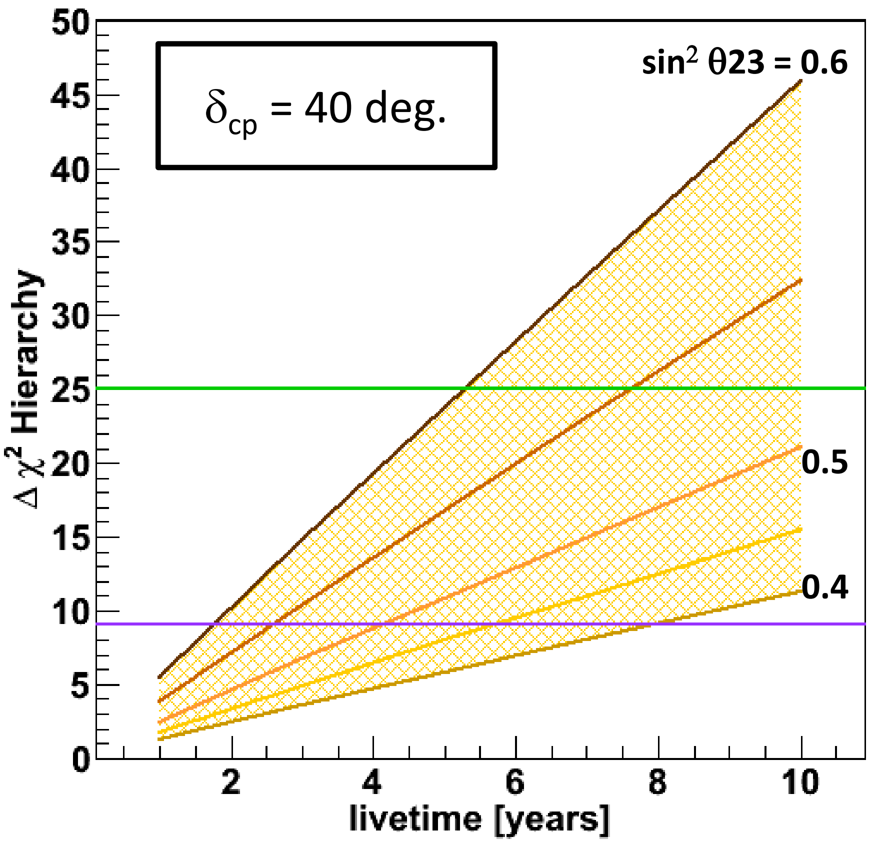
- Atmospheric Neutrinos have a lot to offer
  - Sensitivity to Mass Hierarchy
  - Sensitivity to θ_{23} octant
  - Limited sensitivity to δ_{cp} by themselves but coupled with long-baseline measurements can help resolve parameter degeneracies

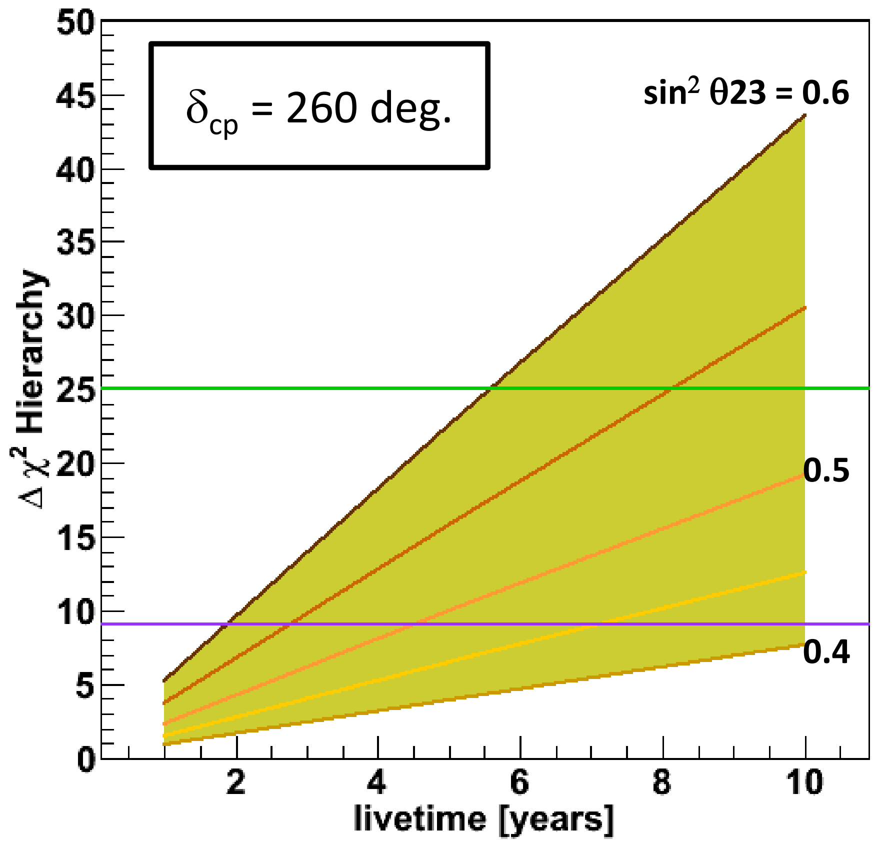
Objective		Normal	Inverted	Comment
Hierarchy	2σ	$\sin^2 2\theta_{23} > 0.96$	$\sin^2 2\theta_{23} > 0.96$	5 years
	3σ	$\sin^2\theta_{23} > 0.4$	$\sin^2 \theta_{23} > 0.4$	10 years
Octant	2σ	$\sin^2 2\theta_{23} > 0.997$	$\sin^2 2\theta_{23} > 0.99$	5 years
	3σ	$\sin^2 2\theta_{23} > 0.99$	$\sin^2 2\theta_{23} > 0.97$	5 years

- Please look forward to further contributions from atmospheric neutrinos

Supplements

Hierarchy Sensitivity - NH True

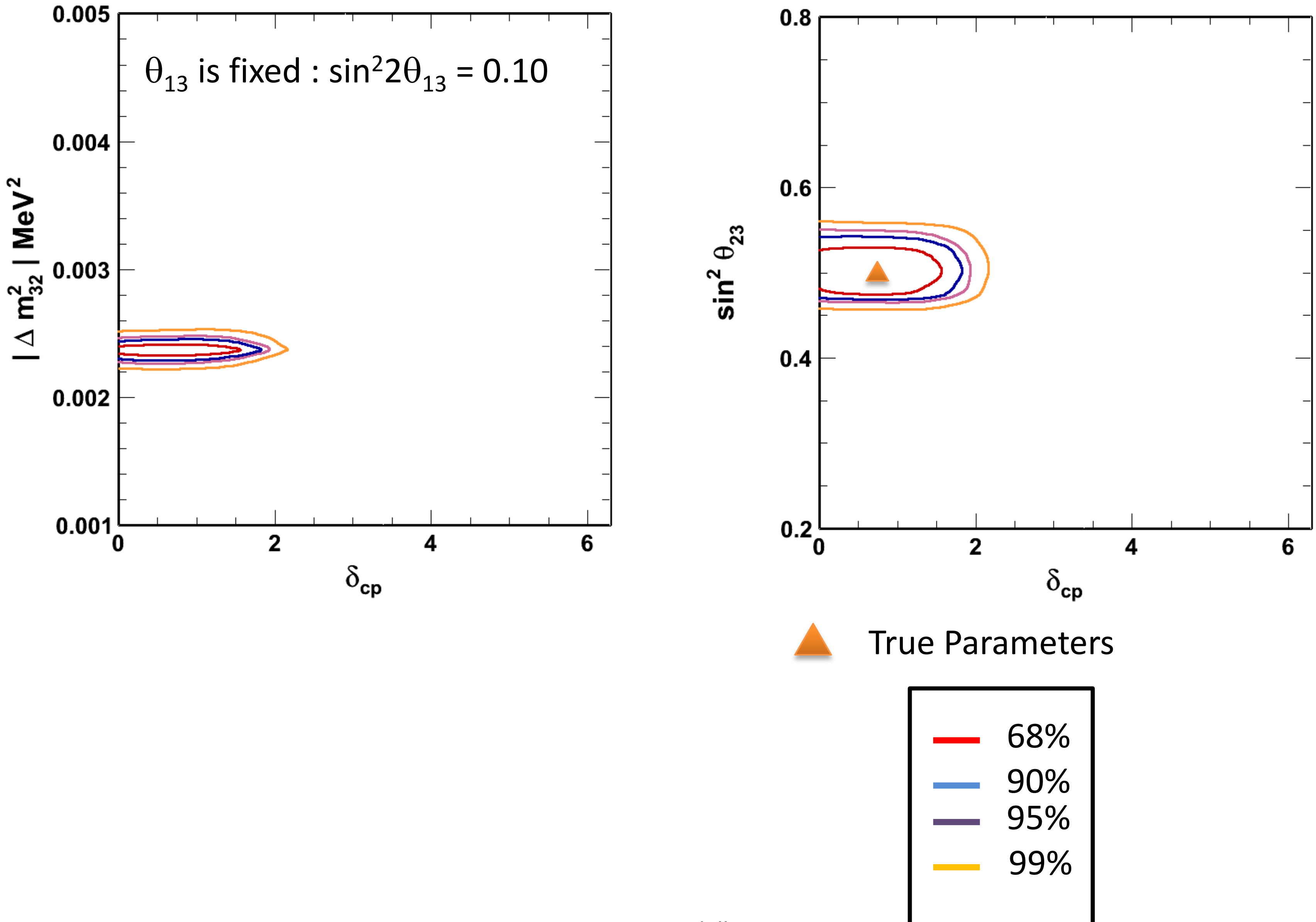




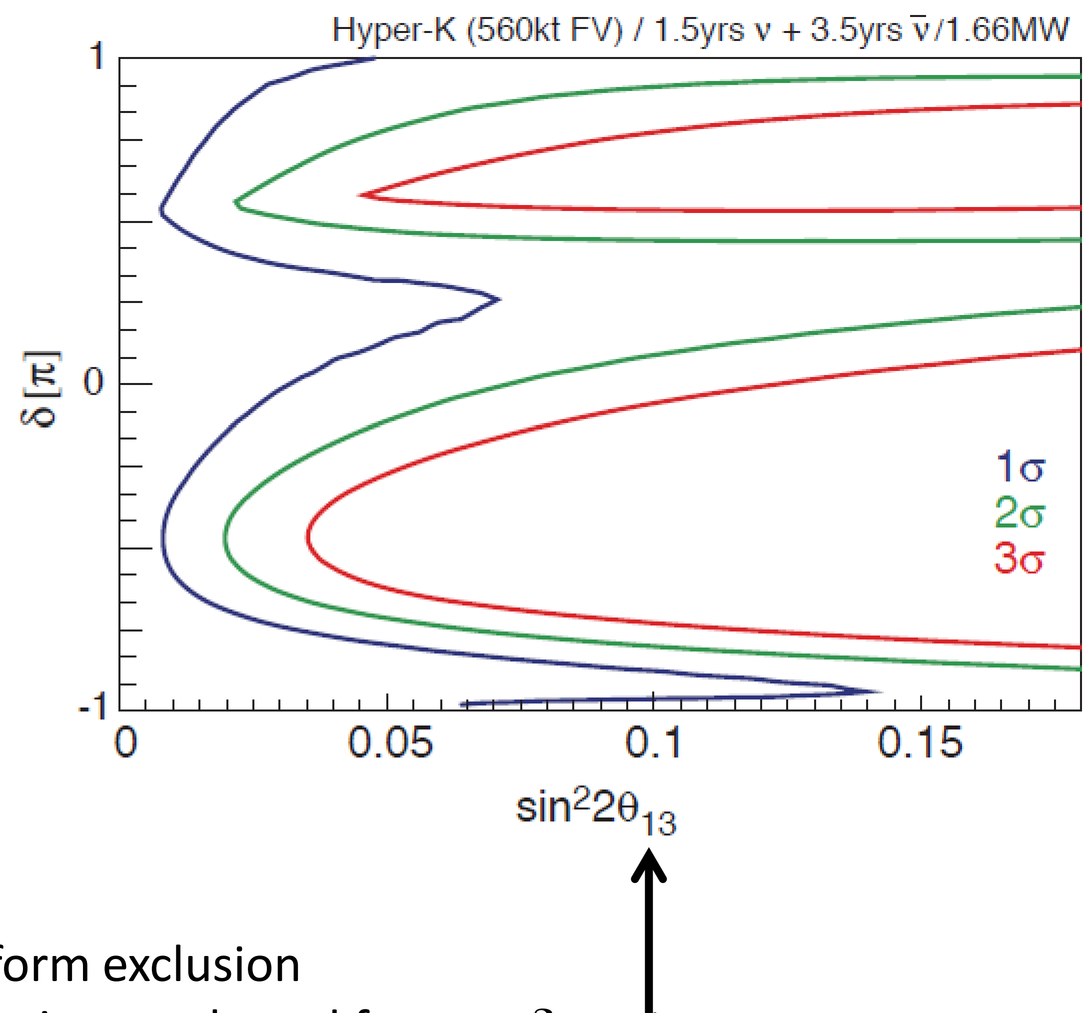
θ_{13} is fixed : $\sin^2 2\theta_{13} = 0.10$

- Whether or not the sign of the mass hierarchy can be determined with atmospheric neutrinos is a function of the true value of δ_{cp} and the θ_{23} octant
- Focus on the far side of these plots…

Normal Hierarchy Sensitivity - 10 Years Example Fit

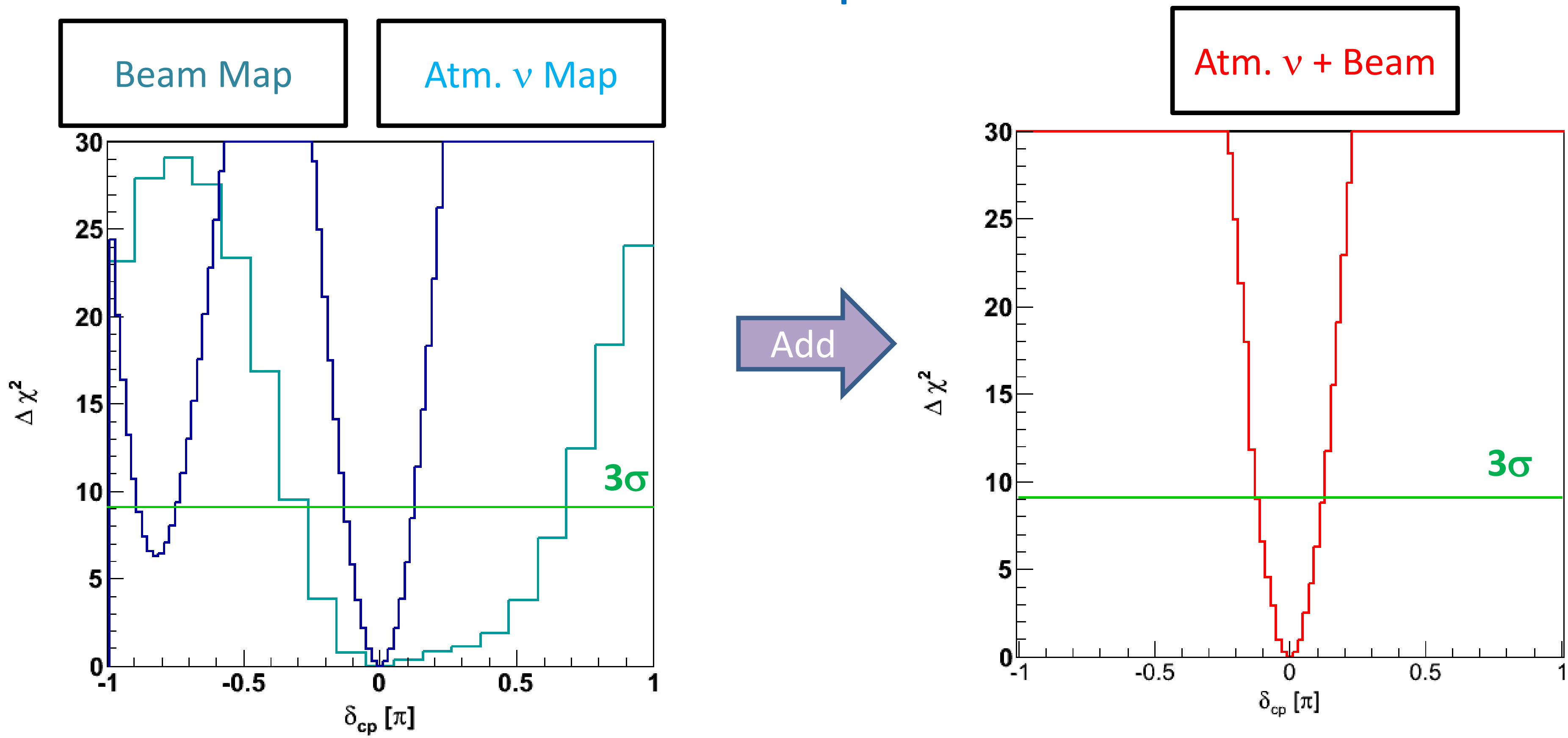


Hierarchy sensitivity, Beam only



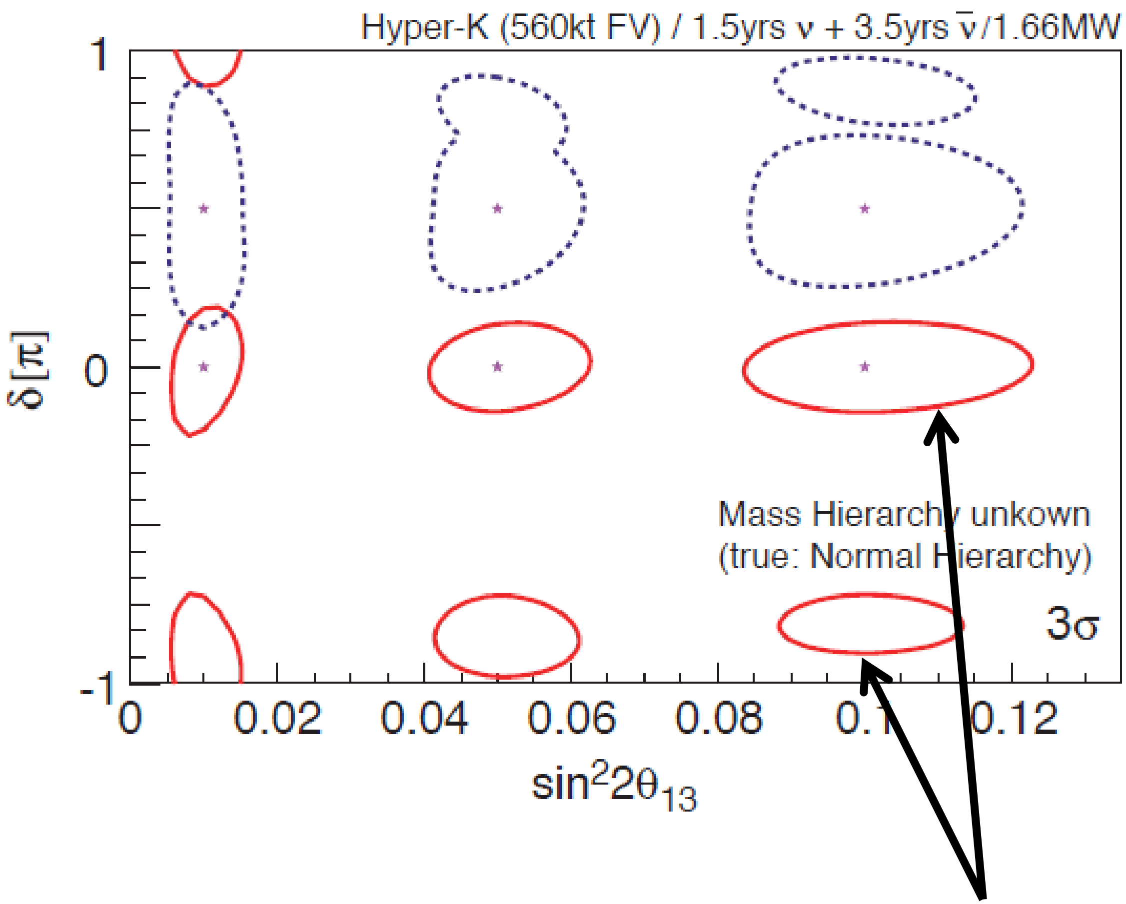
- Non-uniform exclusion
  - Exclusion weakened for true $\delta_{cp} = \pm\,\pi$
- Study the case with fixed θ_{13}

Combination of Beam and Atmospheric Neutrinos : Allowed δ_{cp}



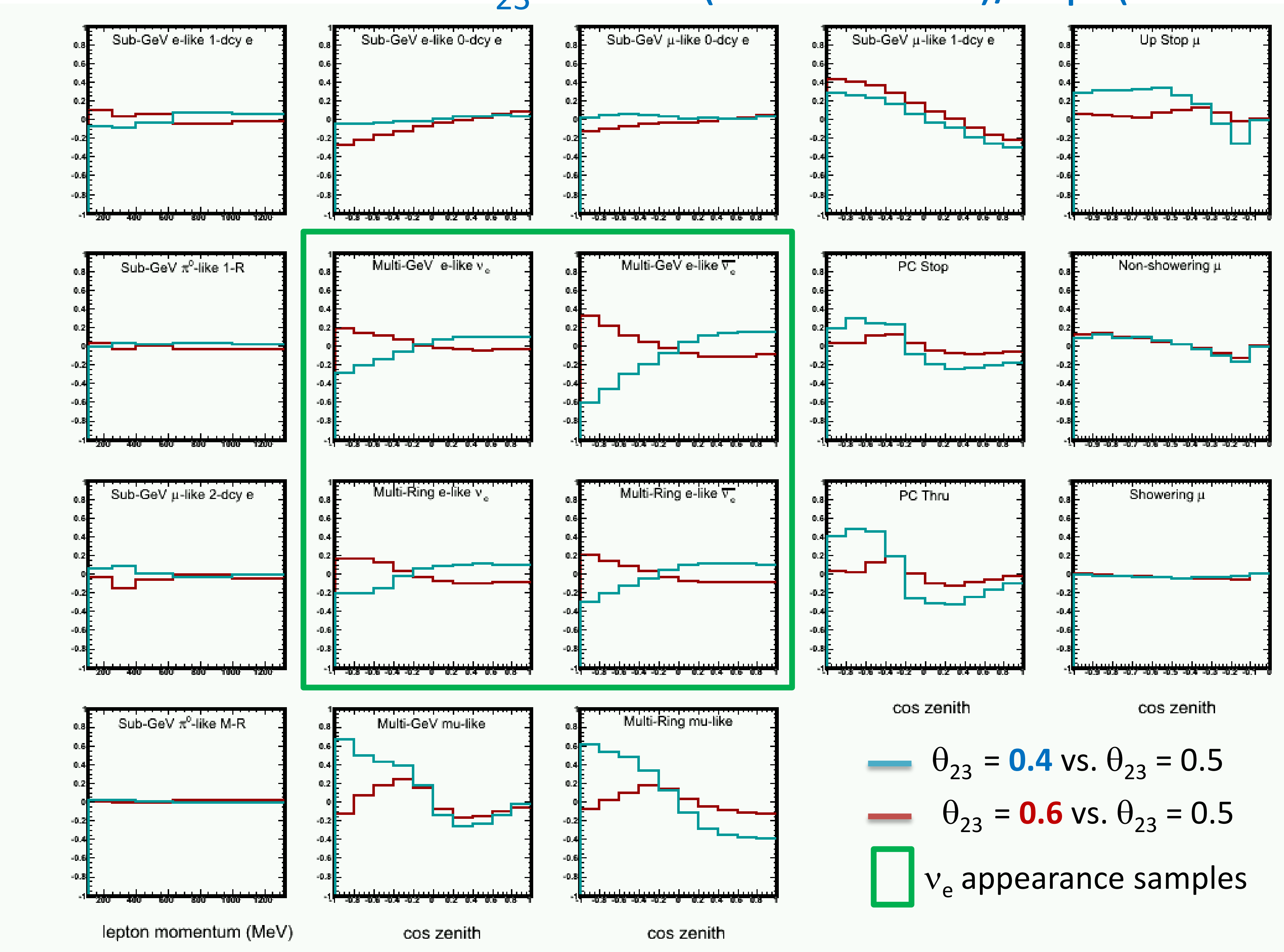
- Hierarchy is unknown, but NH is true
- True $\delta_{cp} = 0.0$
- True $\sin^2 2\theta_{13} = 0.10$
- Maximal mixing , $\sin^2 2\theta_{23} = 1.0$
- Degenerate solution exists at 3σ in the beam only case - just add the χ^2 maps
- In the real world, something more sophisticated is in order

Allowed Regions of δ_{cp}

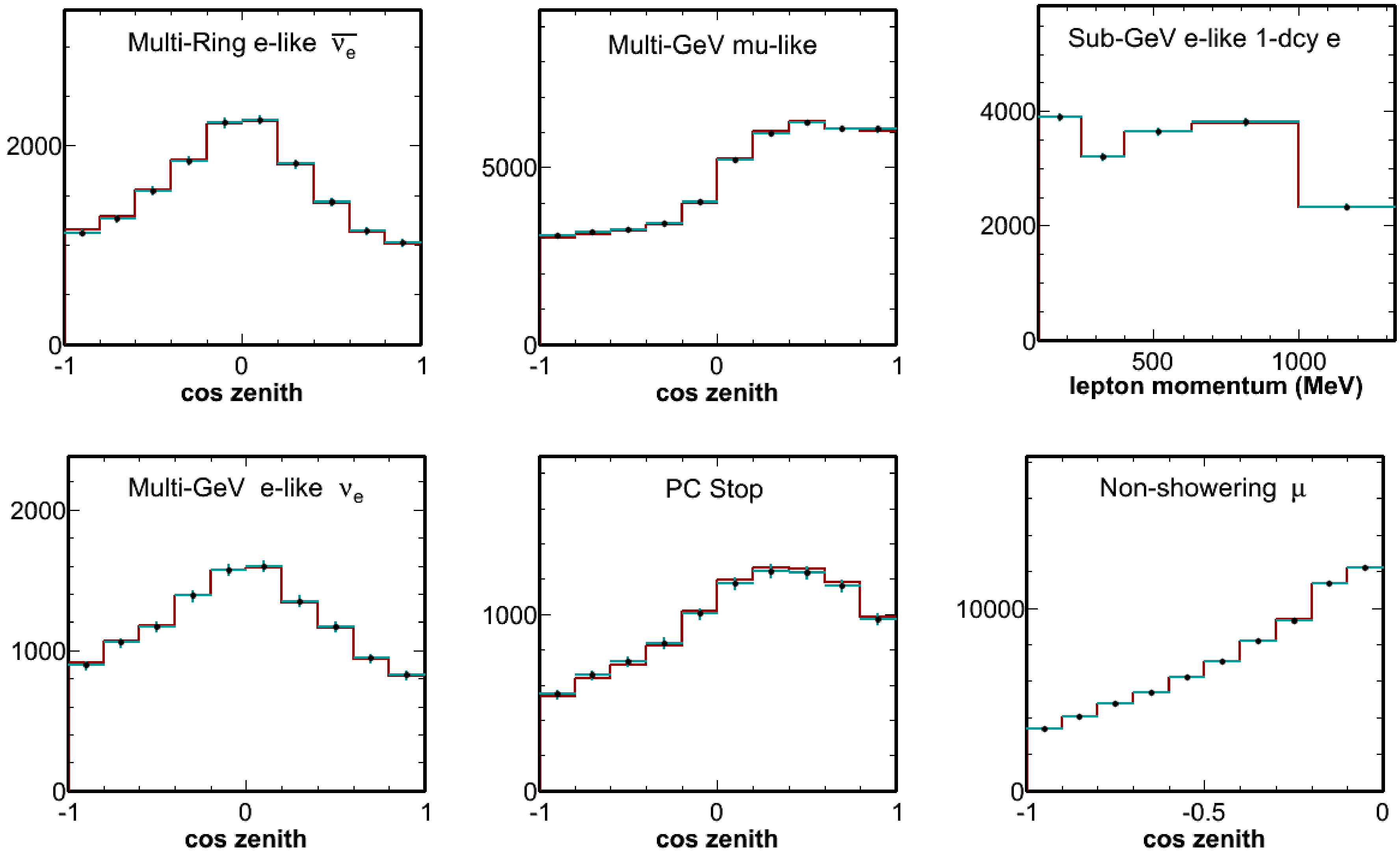


- With beam only data degenerate solutions exist when the mass hierarchy is unknown
- Study the case with fixed θ_{13}

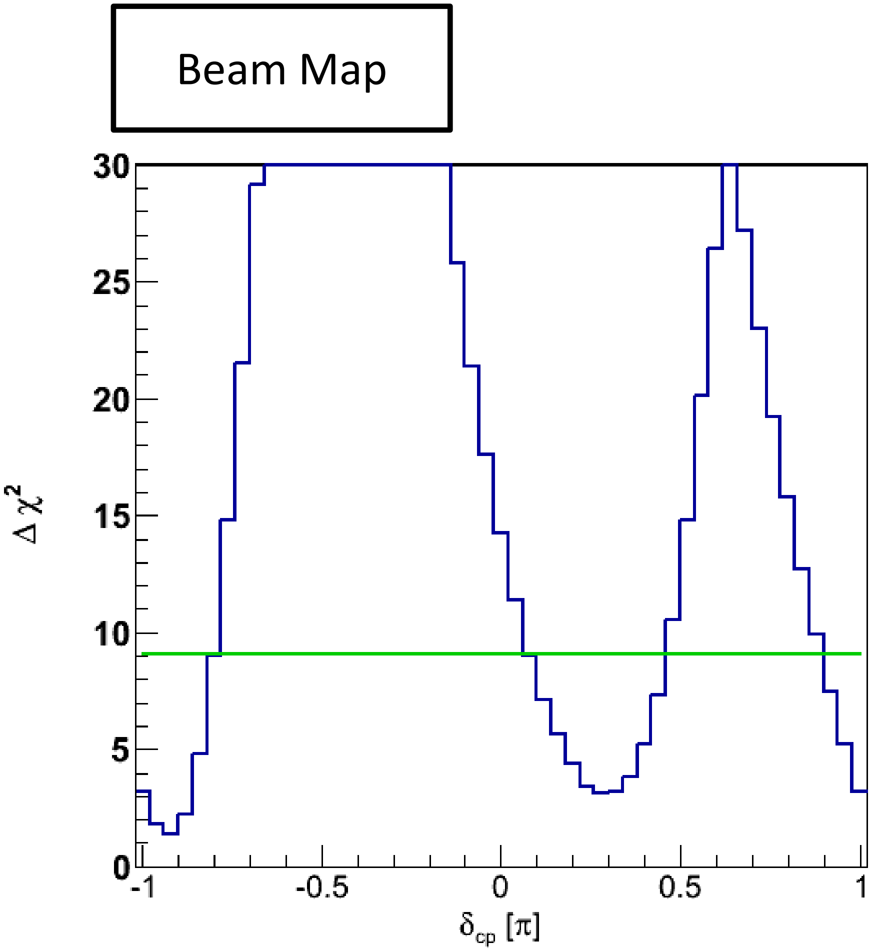
Residual to MC at $\sin^2\theta_{23} = 0.5$ $(x - MC^{\theta = 0.5})/ \mathrm{sqrt}(MC^{\theta = 0.5})$

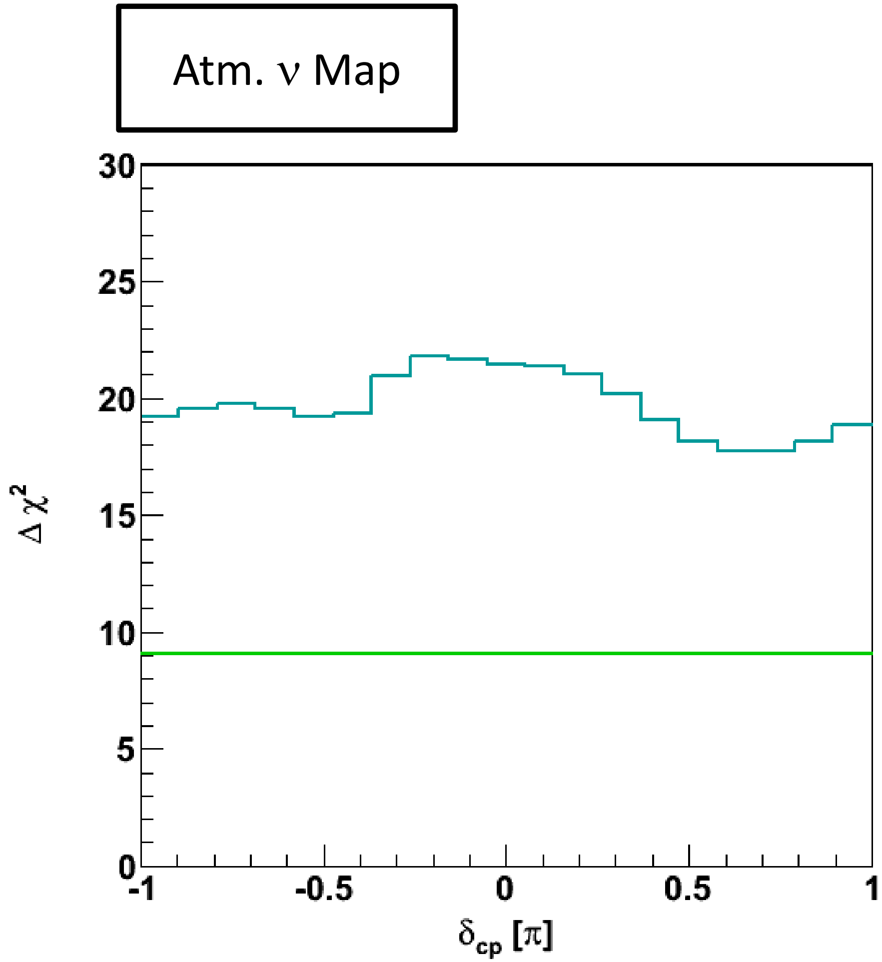


Zenith Angle Analysis Binning



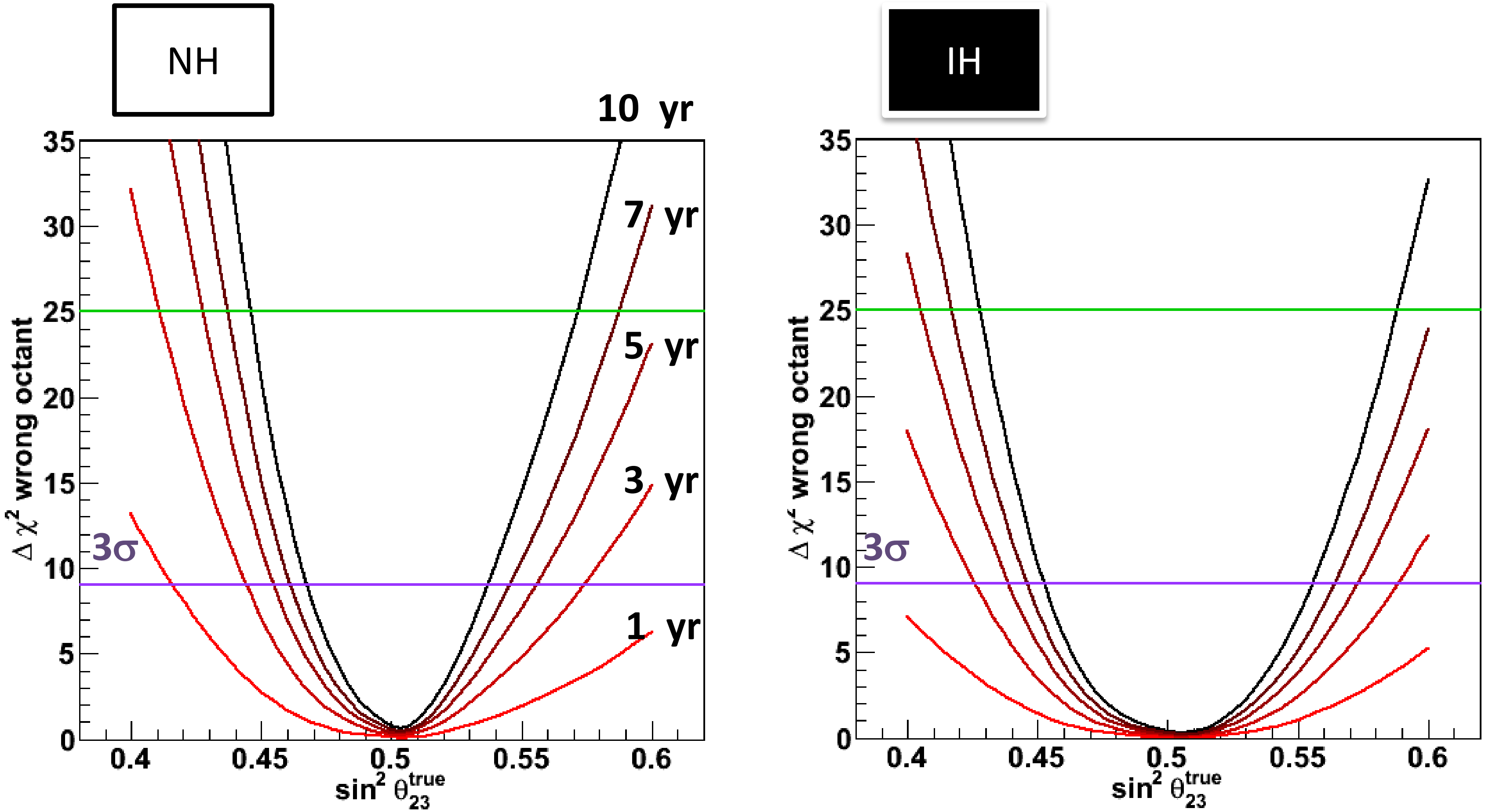
For maximal mixing…





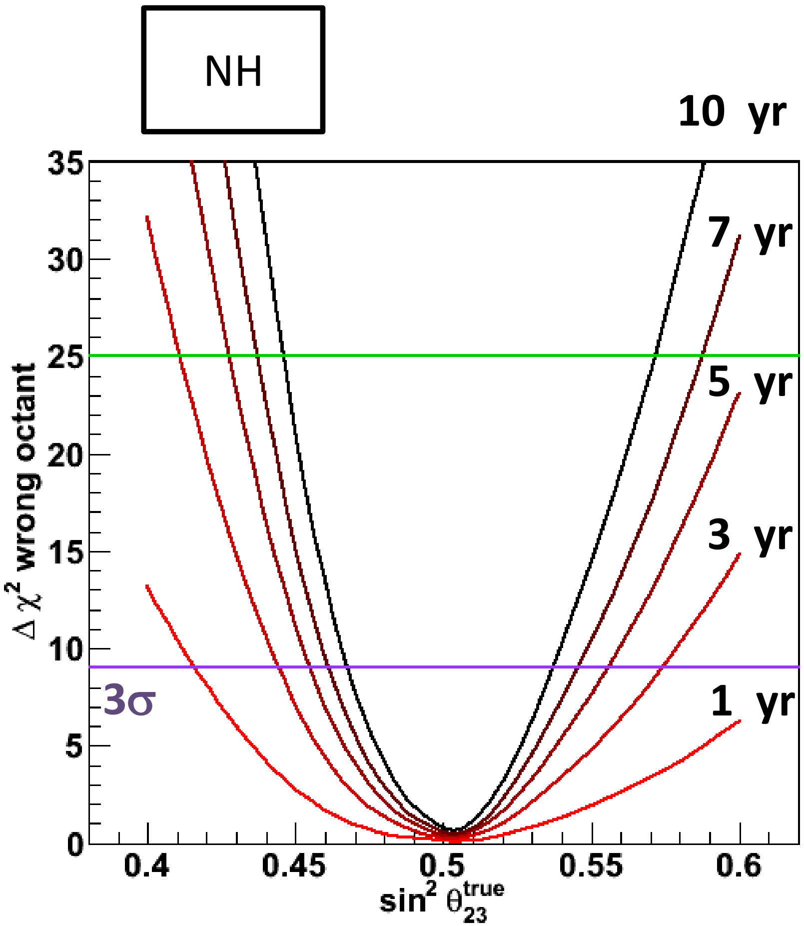
- At maximal mixing, atmospheric neutrinos can do the work by themselves

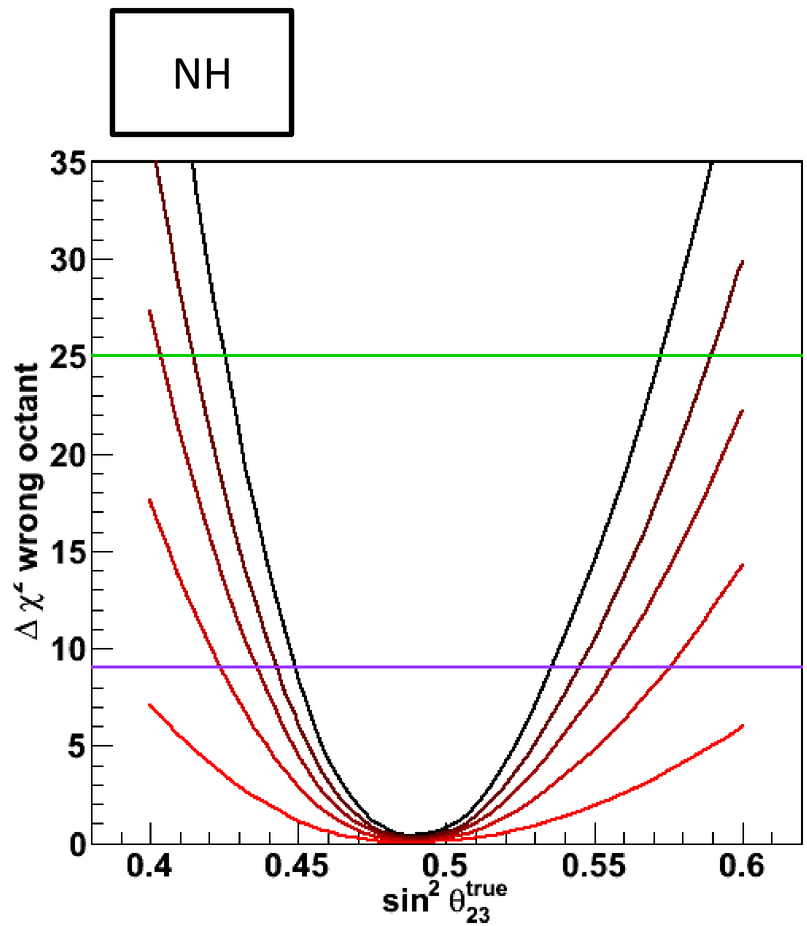
Octant Discrimination as a function of HK running years



- Defined as the difference in χ^2 between the lowest χ^2 values from each octant

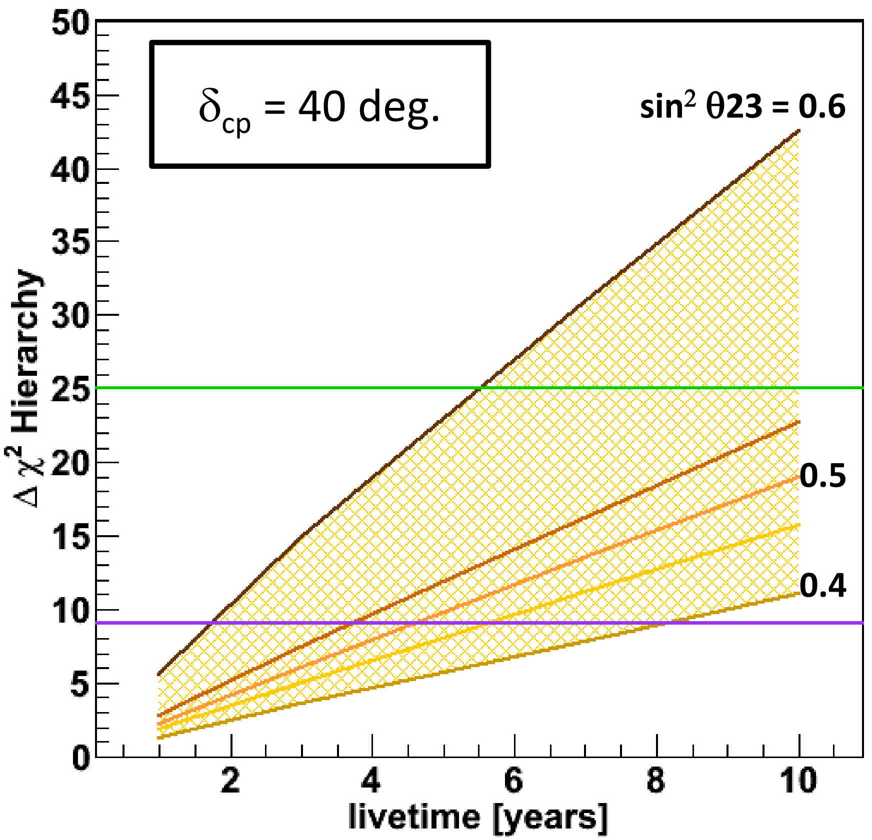
Octant Discrimination as a function of HK running years

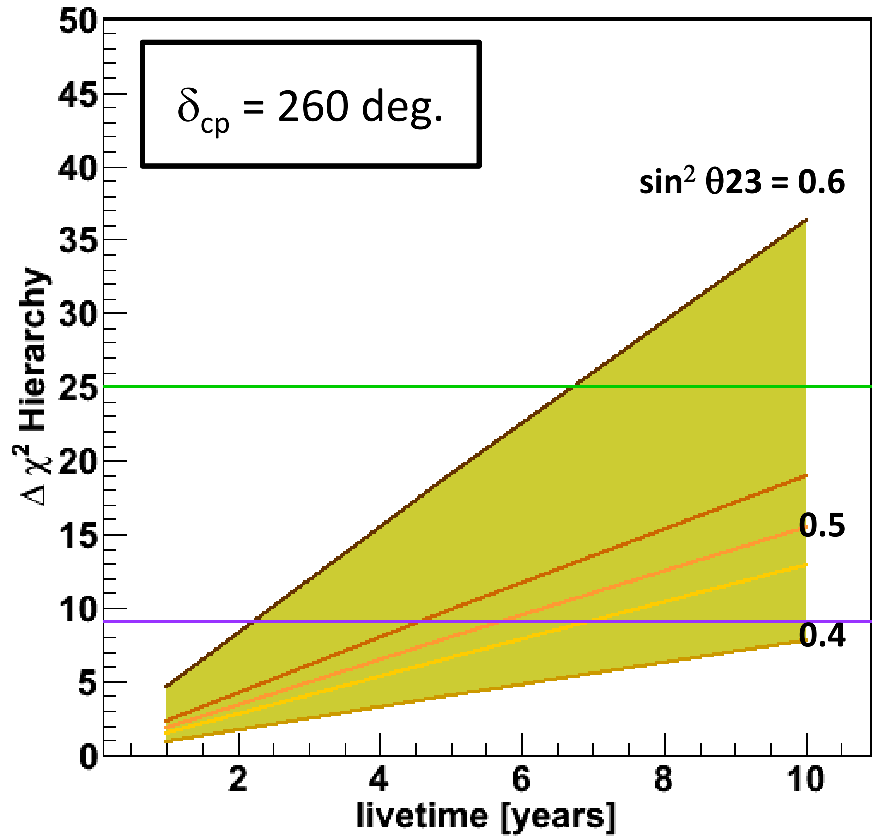




- NH assumed true and known
- NH true but **unknown**
- Defined as the difference in χ^2 between the lowest χ^2 values from each octant

Hierarchy Sensitivity – IH True





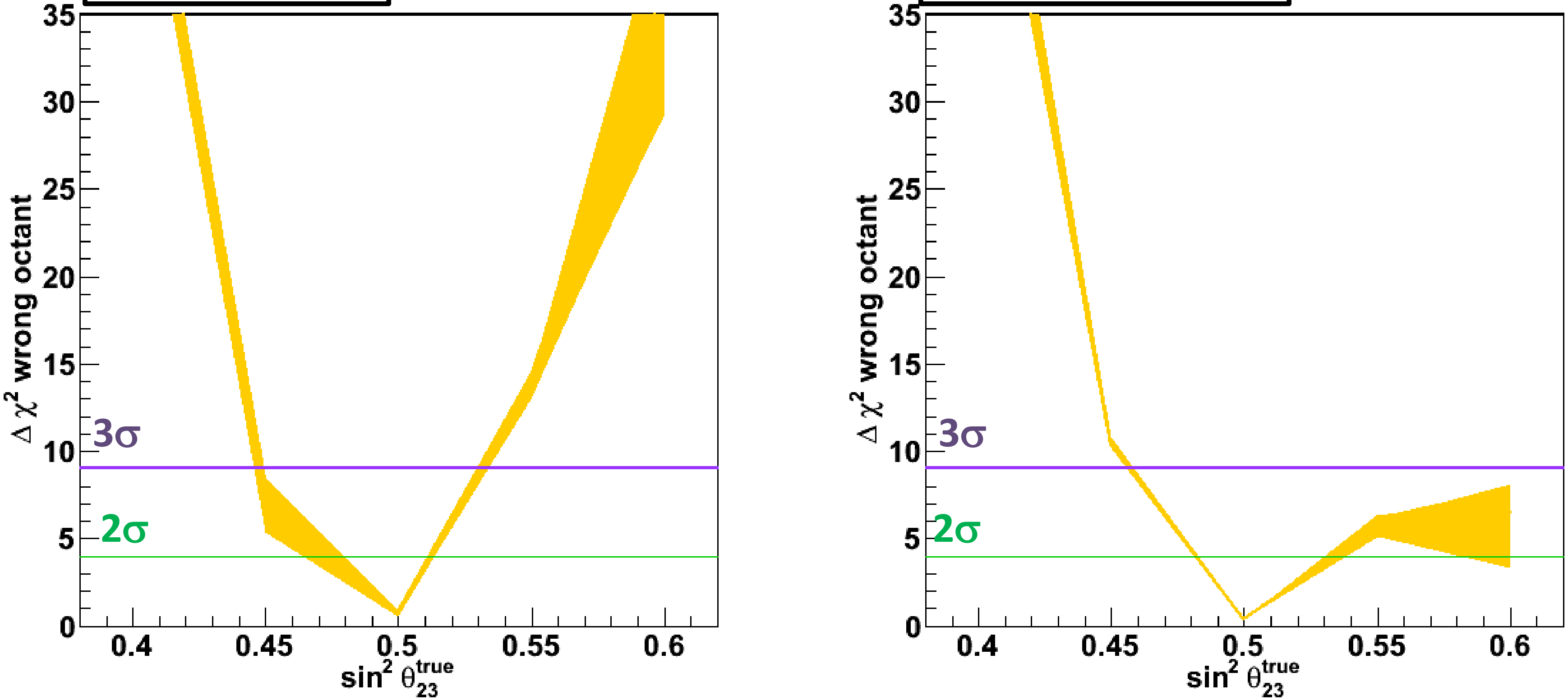
θ_{13} is fixed : $\sin^2 2\theta_{13} = 0.10$

θ_{23} Octant sensitivity , 10 year Exposure – Total Ignorance

NH, unknown

θ_{13} is fixed : $\sin^2 2\theta_{13} = 0.10$

IH, Unknown



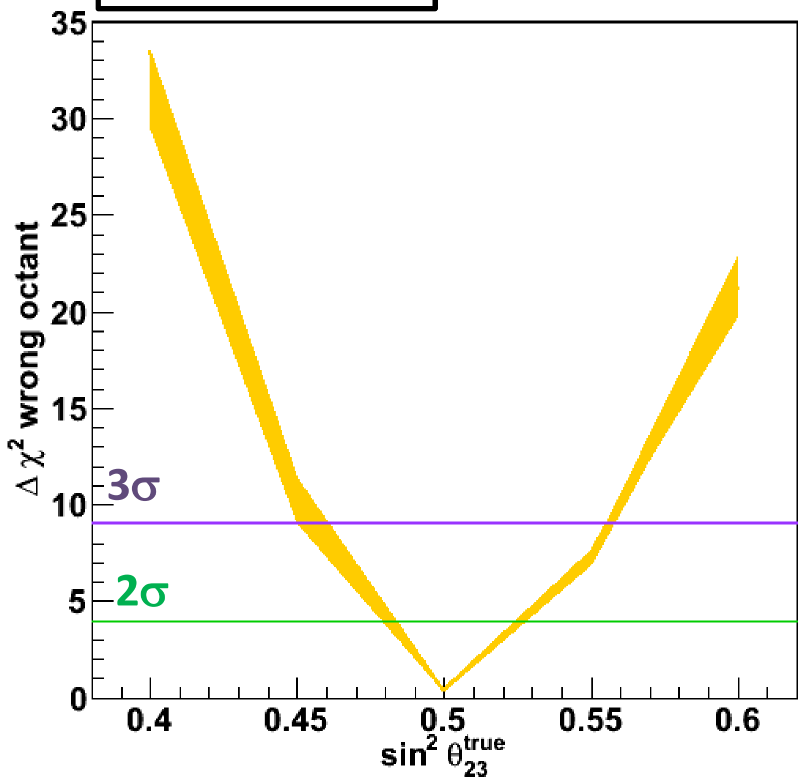
- Thickness of the band corresponds to range of δ_{cp}
- Best value of δ_{cp} = 40 degrees
- Worst value of δ_{cp} = 140 (260) degrees, for 1st (2nd) octant

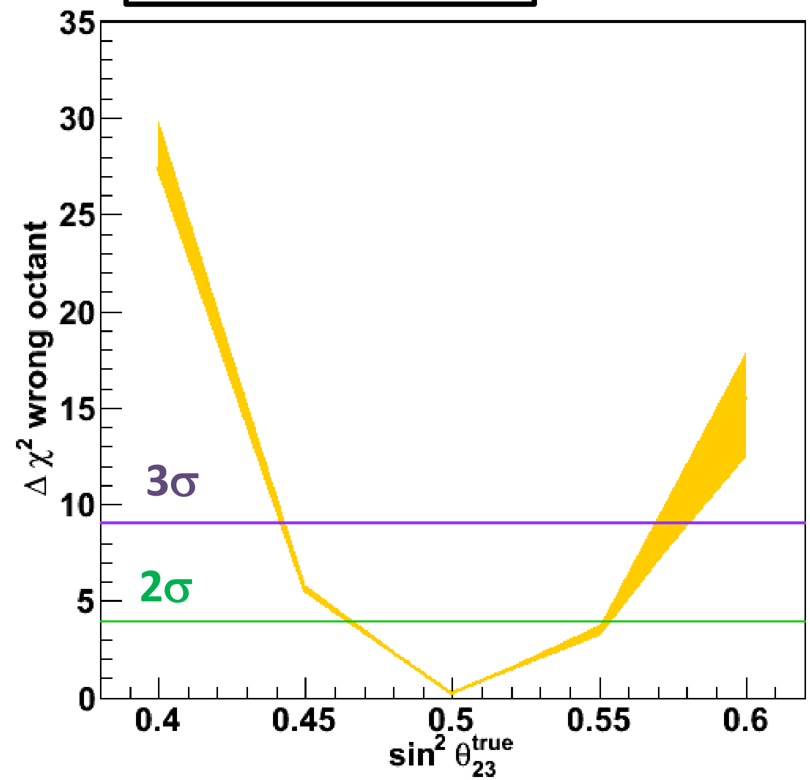
θ_{23} Octant sensitivity , 5 year Exposure

NH, unknown

θ_{13} is fixed : $\sin^2 2\theta_{13} = 0.10$

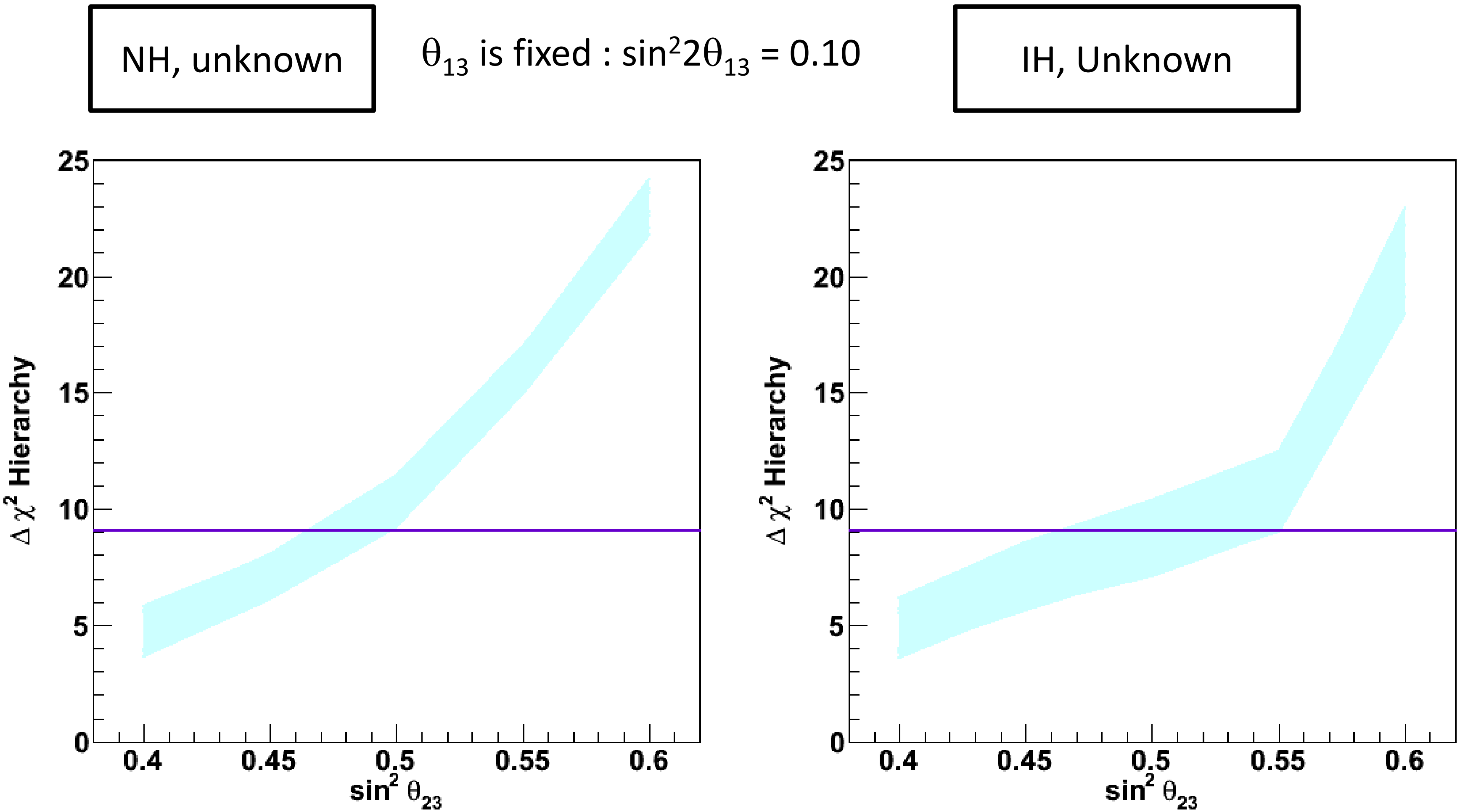
IH, Unknown





- Thickness of the band corresponds to range of δ_{cp}
- Best value of δ_{cp} = 40 degrees
- Worst value of δ_{cp} = 140 (260) degrees, for 1st (2nd) octant

Hierarchy sensitivity, 5 yrs Atm.



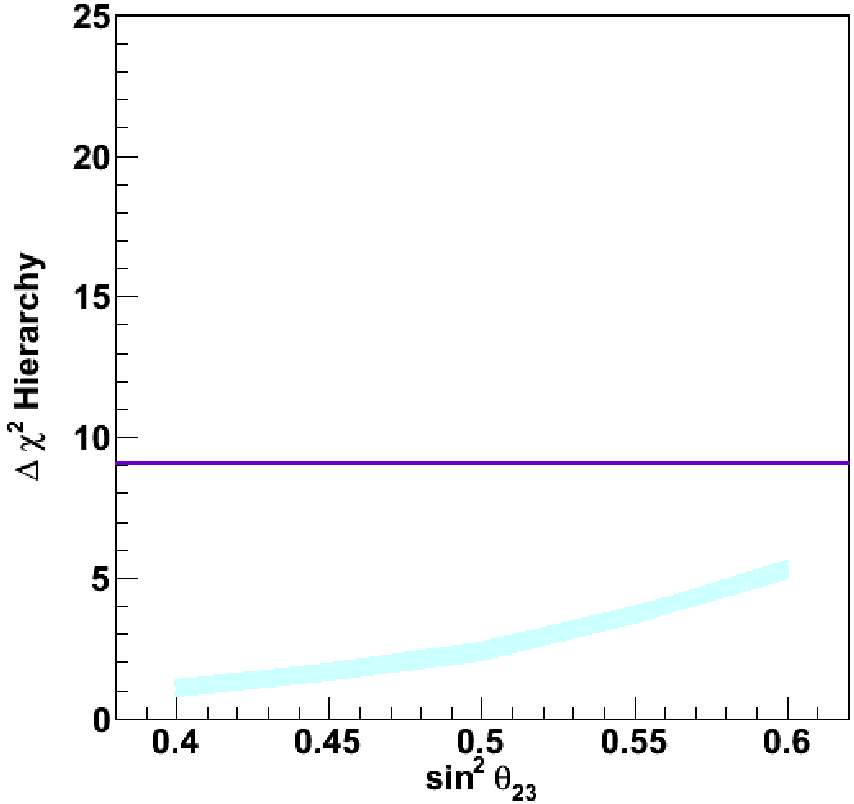
- Thickness of the band corresponds to range of δ_{cp}
- Weakest sensitivity overall in the tail of the first octant

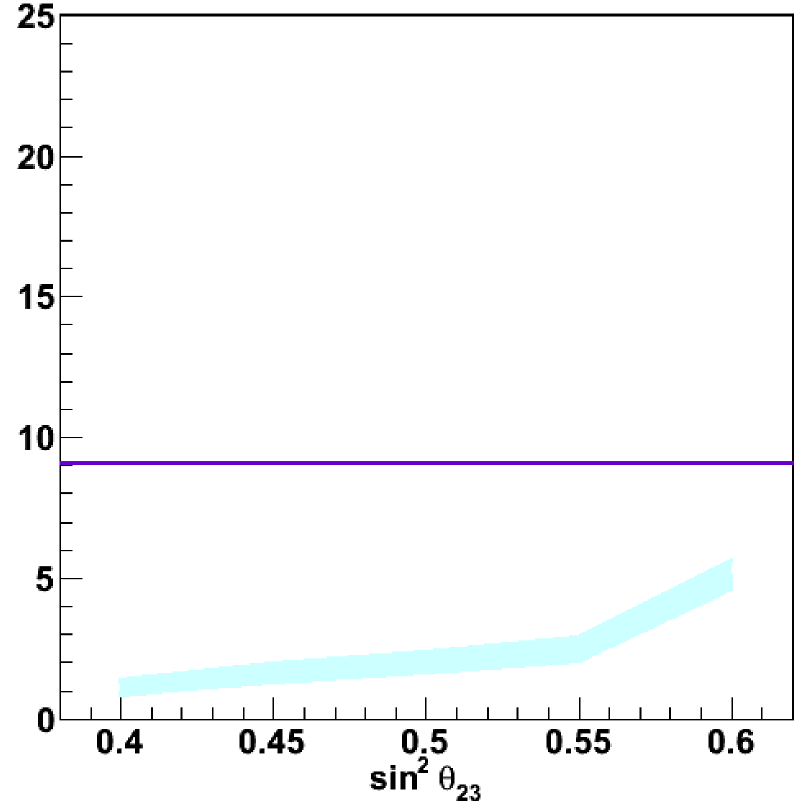
Hierarchy sensitivity, 5 yrs Atm.

NH, unknown

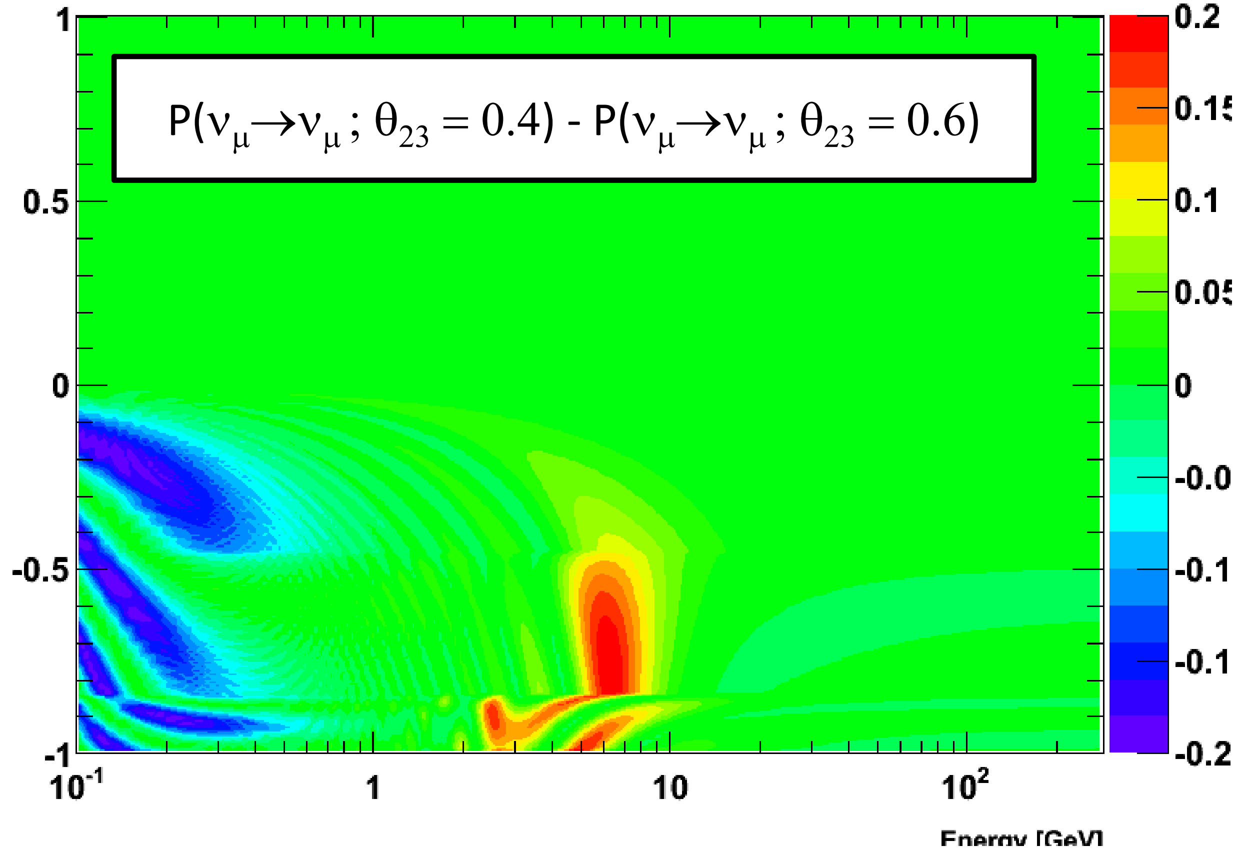
θ_{13} is fixed : $\sin^2 2\theta_{13} = 0.10$

IH, Unknown



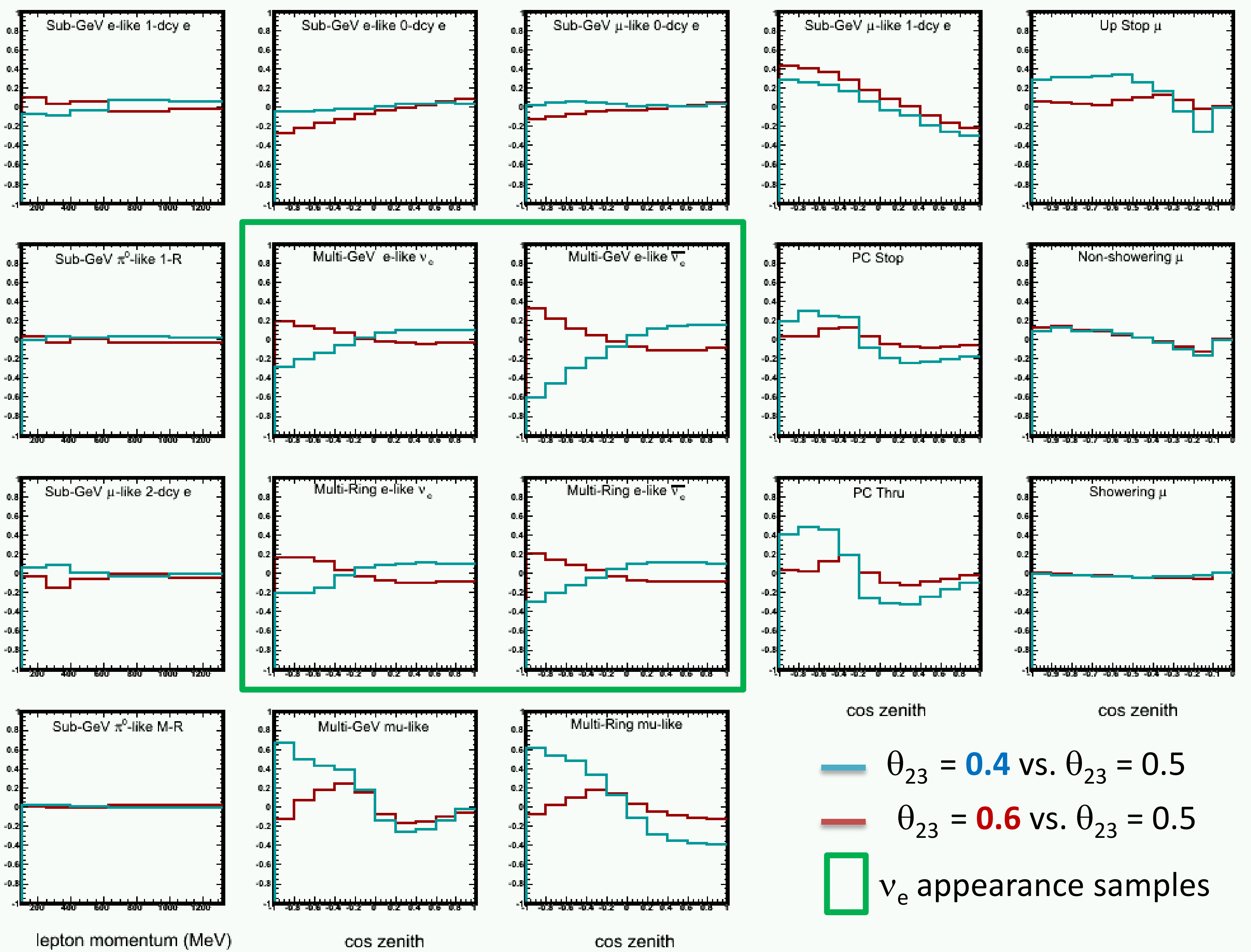


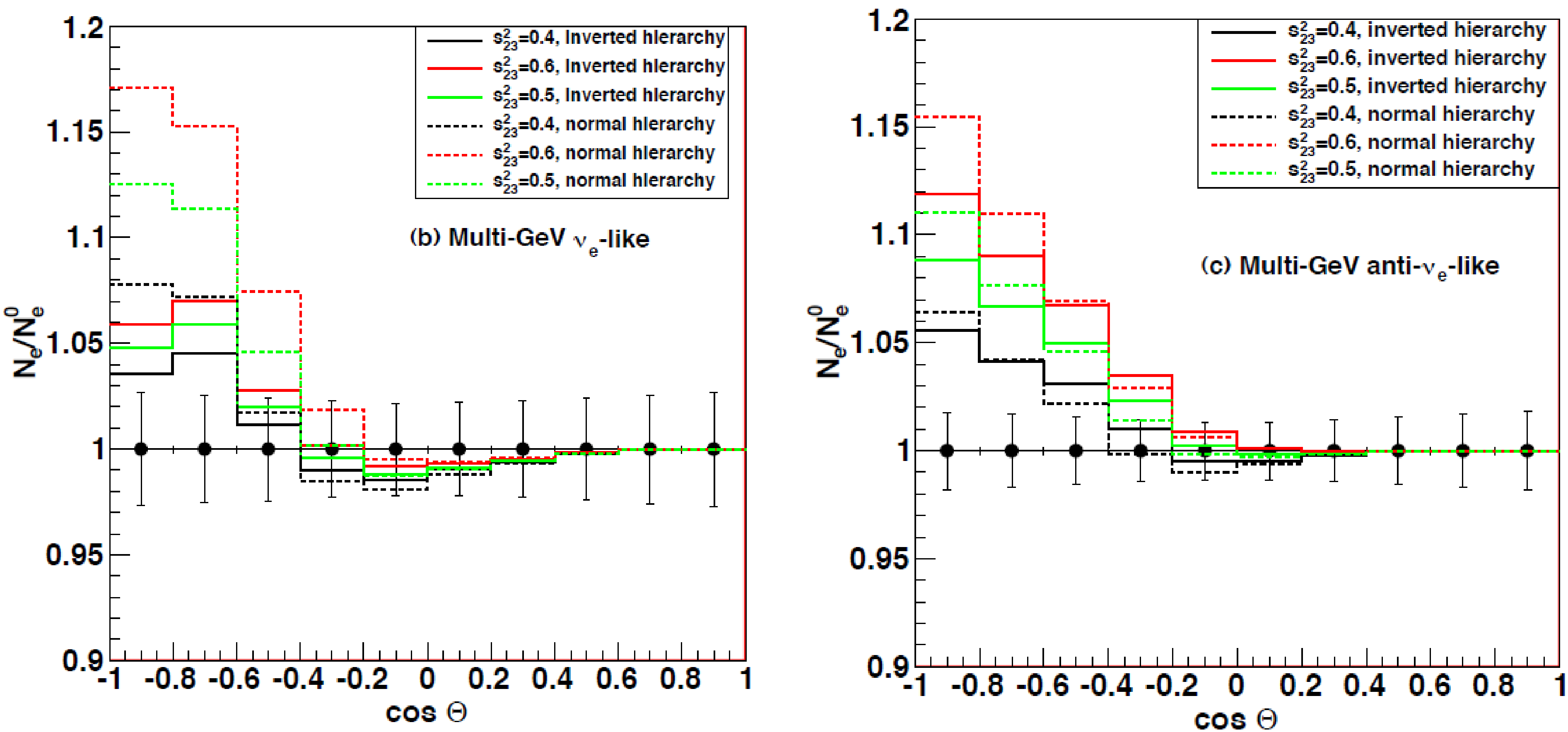
Residual to MC at $\sin^2 \theta_{23} = 0.5$ $(x – MC^{\theta = 0.5})/ \text{sqrt}(MC^{\theta = 0.5})$



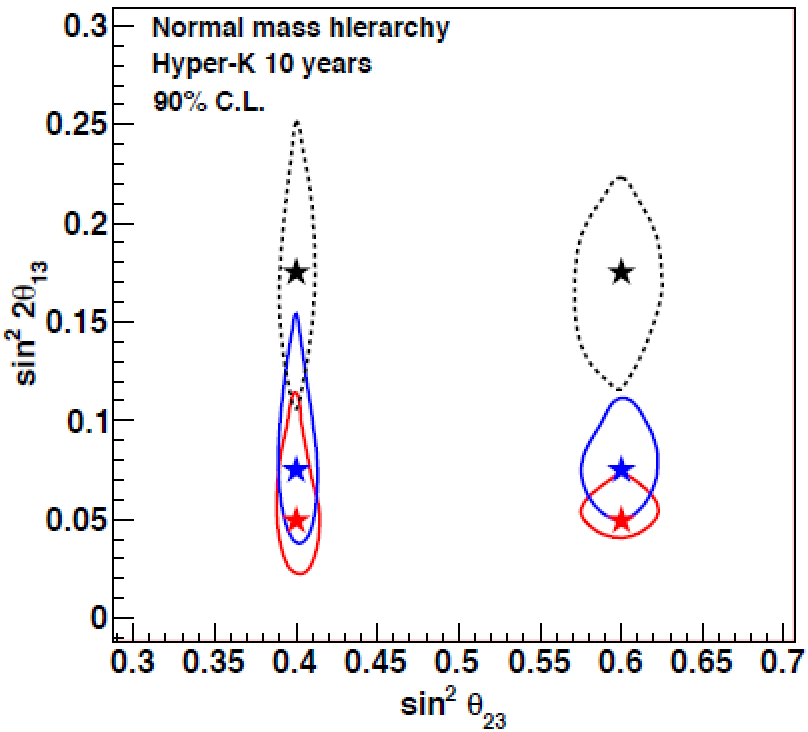
- This plot shows the difference in the muon **survival** probability between the first and second octant
- The survival probability is larger at E > 1 GeV for the first octant, meaning there is less muon disappearance

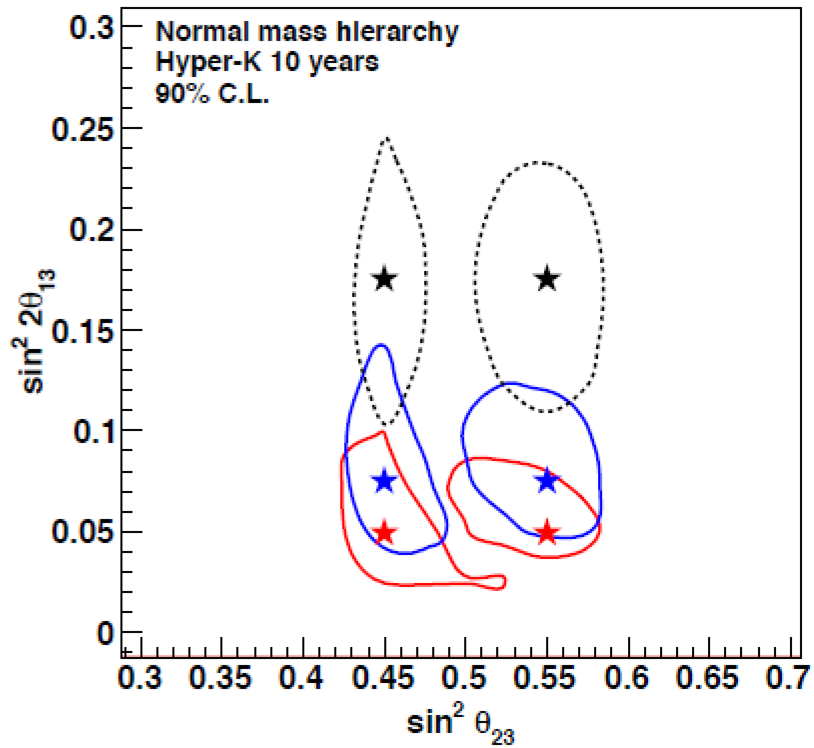
Residual to MC at $\sin^2\theta_{23} = 0.5$ $(x - MC^{\theta=0.5}) / \mathrm{sqrt}(MC^{\theta=0.5})$

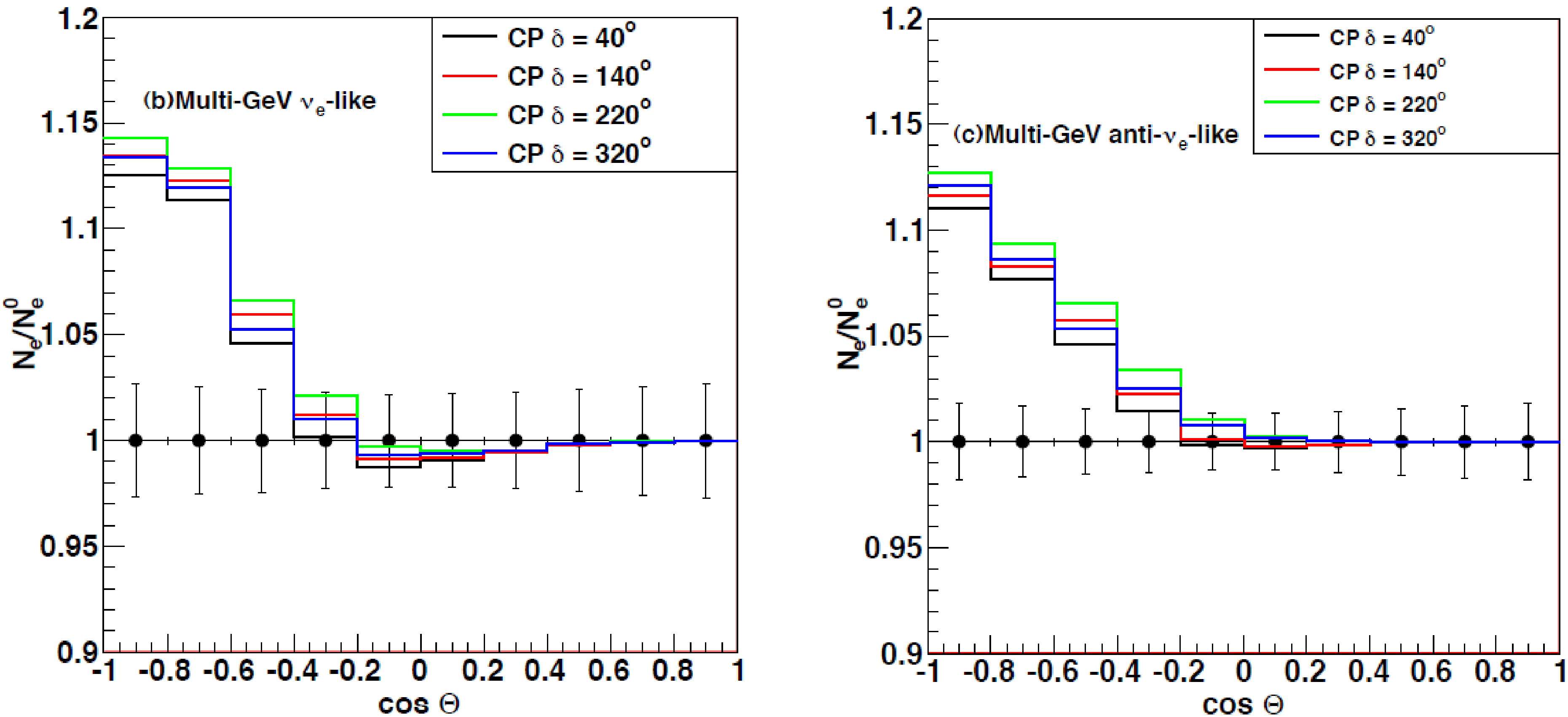




s^2_{23}=0.4, inverted hierarchy
s^2_{23}=0.6, inverted hierarchy
s^2_{23}=0.5, inverted hierarchy
s^2_{23}=0.4, normal hierarchy
s^2_{23}=0.6, normal hierarchy
s^2_{23}=0.5, normal hierarchy
(b) Multi-GeV ν_e-like
N_e/N_e^0
cos Θ
s^2_{23}=0.4, inverted hierarchy
s^2_{23}=0.6, inverted hierarchy
s^2_{23}=0.5, inverted hierarchy
s^2_{23}=0.4, normal hierarchy
s^2_{23}=0.6, normal hierarchy
s^2_{23}=0.5, normal hierarchy
(c) Multi-GeV anti-ν_e-like
N_e/N_e^0
cos Θ


Normal mass hierarchy
Hyper-K 10 years
90% C.L.
$\sin^2 2\theta_{13}$
$\sin^2 \theta_{23}$
0.3
0.25
0.2
0.15
0.1
0.05
0
0.3 0.35 0.4 0.45 0.5 0.55 0.6 0.65 0.7


Normal mass hierarchy
Hyper-K 10 years
90% C.L.
$\sin^2 2\theta_{13}$
$\sin^2 \theta_{23}$
0.3
0.25
0.2
0.15
0.1
0.05
0
0.3 0.35 0.4 0.45 0.5 0.55 0.6 0.65 0.7



(b)Multi-GeV ν_e-like
CP δ = 40°
CP δ = 140°
CP δ = 220°
CP δ = 320°
N_e/N_e^0
cos Θ
(c)Multi-GeV anti-ν_e-like
CP δ = 40°
CP δ = 140°
CP δ = 220°
CP δ = 320°
N_e/N_e^0
cos Θ

Systematic Error			fit value	σ
Flux normalization	$E_\nu < 1$ GeV		34.7	25^a
	$E_\nu > 1$ GeV		8.8	7^b
ν_μ/ν_e				
	$E_\nu < 1$ GeV		-1.9	2
	$1 < E_\nu < 10$ GeV		-2.5	3
	$E_\nu > 10$ GeV		-3.7	5^c
$\bar{\nu}_e/\nu_e$				
	$E_\nu < 1$ GeV		5.54	5
	$1 < E_\nu < 10$ GeV		1.13	5
	$E_\nu > 10$ GeV		-0.10	8^d
$\bar{\nu}_\mu/\nu_\mu$				
	$E_\nu < 1$ GeV		-0.48	2
	$1 < E_\nu < 10$ GeV		-1.35	6
	$E_\nu > 10$ GeV		-1.75	6^e
Up/down ratio	<400 MeV	e-like	-0.07	0.1
		μ-like	-0.23	0.3
		0-decay μ-like	-0.84	1.1
	>400 MeV	e-like	-0.61	0.8
		μ-like	-0.38	0.5
		0-decay μ-like	-1.29	1.7
	Multi-GeV	e-like	-0.53	0.7
		μ-like	-0.15	0.2
	Multi-ring Sub-GeV	μ-like	-0.15	0.2
	Multi-ring Multi-GeV	e-like	-0.23	0.3
		μ-like	-0.15	0.2
	PC		-0.15	0.2

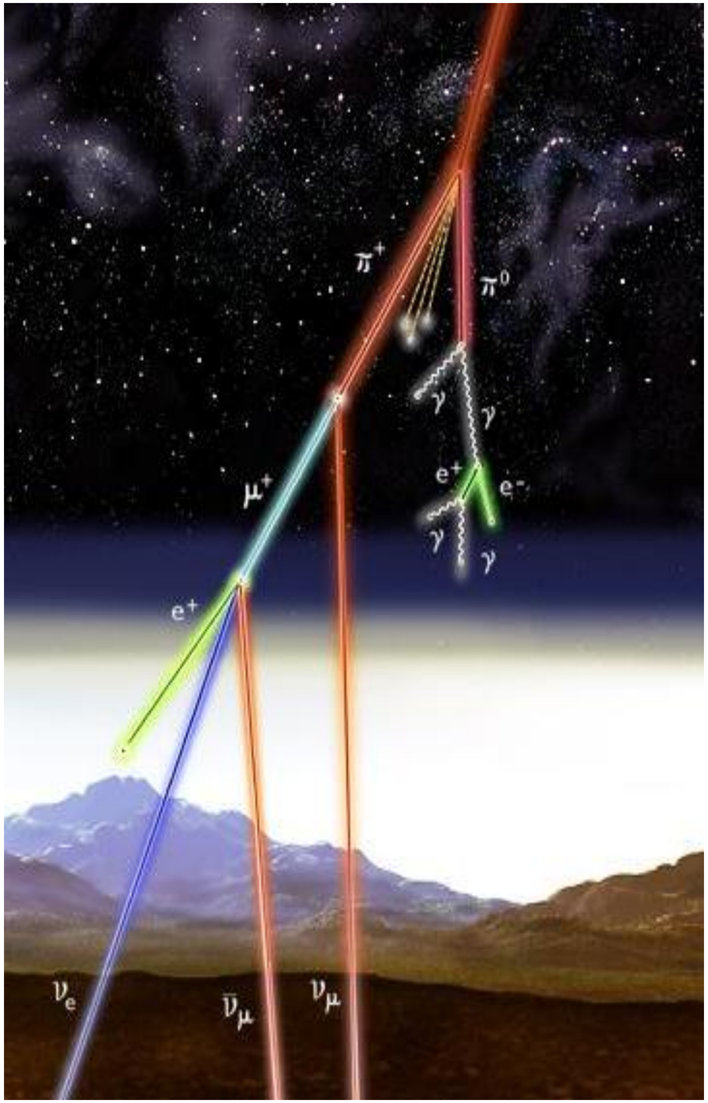
Horizontal/Vertical ratio	$<$ 400 MeV	e-like	-0.01	0.1
		μ-like	-0.01	0.1
		0-decay μ-like	-0.03	0.3
	$>$ 400 MeV	e-like	-0.14	1.4
		μ-like	-0.19	1.9
		0-decay μ-like	-0.14	1.4
	Multi-GeV	e-like	-0.33	3.2
		μ-like	-0.23	2.3
	Multi-ring Sub-GeV	μ-like	-0.13	1.3
	Multi-ring Multi-GeV	e-like	-0.29	2.8
		μ-like	-0.15	1.5
	PC		-0.17	1.7
K/π ratio in flux calculation			-12.9	10^f
Neutrino path length			-8.8	10
Sample-by-sample	FC Multi-GeV		-4.5	5
	PC + Up-stop μ		-7.1	5

Systematic Error		fit value	σ
MA in QE and single π		-2.4	10
CCQE cross section		0.66	1.0^a
Single meson production cross section		7.8	20
DIS cross section ($E_{nu} < 10$ GeV)		-0.16	1.0^b
DIS cross section		2.27	5
Coherent π production		1.53	100
NC/(CC)		1.51	20
Nuclear effect in ^{16}O nucleus		-13.8	30
Nuclear effect in pion spectrum		0.8	1.0^c
ν_τ contamination		1.0	30
NC in FC μ-like (hadron simulation)		-4.6	10
CCQE $\bar{\nu}_i/\nu_i$ (i=e,μ) ratio		0.84	1.0^a
CCQE μ/e ratio		1.12	1.0^a
Single π production, $\pi^0/\pi^\pm$ ratio		-29.0	40
Single π production, $\bar{\nu}_i/\nu_i$ (i=e,μ) ratio		-0.04	1.0^d
π^+ decay uncertainty Sub-GeV 1-ring	e-like 0-decay	-0.48	0.5
	μ-like 1-decay	0.77	-0.8
	e-like 1-decay	3.9	-4.1
	μ-like 0-decay	-0.77	0.8
	μ-like 2-decay	5.46	-5.7

Systematic Error			SK-I fit	SK-I σ	SK-II fit	SK-II σ	SK-III fit	SK-III σ
FC reduction			0.005	0.2	0.008	0.2	0.061	0.8
PC reduction			-0.99	2.4	-2.12	4.8	0.034	0.5
FC/PC separation			-0.058	0.6	0.068	0.5	-0.28	0.9
PC-stop/PC-through separation (top)			7.84	14	-17.47	21	-20.03	31
PC-stop/PC-through separation (barrel)			-2.27	7.5	-31.51	17	3.44	23
PC-stop/PC-through separation (bottom)			-2.32	11.	-7.32	12	1.59	11
Non-ν BG (e-like)	Sub-GeV		0.077	0.5	0.004	0.2	0.003	0.1
	Multi-GeV		0.047	0.3	0.005	0.3	0.011	0.4
Non-ν BG (μ-like)	Sub-GeV		-0.01	0.1	0.02	0.1	0.052	0.1
	Multi-GeV		-0.01	0.1	0.02	0.1	0.11	0.2
	Sub-GeV 1-ring	μ-like 0-decay	-0.04	0.4	0.02	0.1	0.052	0.1
	PC		-0.02	0.2	0.14	0.7	0.95	1.8
Fiducial volume			-0.23	2	0.43	2	0.93	2
Ring separation	$<$ 400 MeV	e-like	1.23	2.3	-1.67	1.3	0.12	2.3
		μ-like	0.37	0.7	-2.96	2.3	0.037	0.7
	$>$ 400 MeV	e-like	0.21	0.4	-2.19	1.7	0.021	0.4
		μ-like	0.37	0.7	-0.90	0.7	0.036	0.7
	Multi-GeV	e-like	1.97	3.7	-3.35	2.6	0.19	3.7
		μ-like	0.91	1.7	-2.19	1.7	0.089	1.7
	Multi-ring sub-GeV	μ-like	-2.40	-4.5	10.56	-8.2	-0.24	-4.5
	Multi-ring multi-GeV	e-like	0.05	0.1	-2.45	1.9	0.16	3.1
		μ-like	-2.19	-4.1	1.03	-0.8	-0.21	-4.1

Particle identification	Sub-GeV	e-like	-0.007	0.1	0.13	0.5	0.004	0.1
		μ-like	0.007	-0.1	-0.13	-0.5	-0.004	-0.1
	Multi-GeV	e-like	-0.014	0.2	0.023	0.1	0.008	0.2
		μ-like	0.014	-0.2	-0.023	-0.1	-0.008	-0.2
Particle identification (multi-ring)	Sub-GeV	μ-like	-0.18	-3.9	-0.55	-2.2	-0.15	-3.9
	Multi-GeV	e-like	0.078	1.7	0.45	1.8	0.063	1.7
		μ-like	-0.13	-2.9	-0.86	-3.4	-0.11	-2.9
Energy calibration			-0.002	1.1	-0.56	1.7	-0.35	2.7
Up/Down asymmetry energy calibration			-0.4	0.6	-0.15	0.6	-0.03	1.3
Upward-going muon reduction	Stopping		-0.057	0.7	-0.14	0.7	0.14	0.7
	Through-going		-0.041	0.5	-0.10	0.5	0.10	0.5
Upward stopping/through-going μ separation			-0.04	0.4	0.006	0.4	0.04	0.6
Energy cut for upward stopping μ			-0.13	0.8	-0.26	1.4	0.78	2.1
Path length cut for upward through-going μ			0.39	1.8	-1.0	2.1	0.4	1.6
Upward through-going μ showering separation			9.42	9.0	2.28	13.0	6.1	6.0
BG subtraction of upward μ [a]	Stopping		4.16	16	-7.47	21	0.004	20
	Non-showering		-1.24	11	8.08	15	6.34	19
	Showering		2.27	18	-18.16	14	24.7	24
Multi-GeV Single-Ring Electron BG			5.95	16.3	-4.67	23.4	1.06	41.4
Multi-GeV Multi-Ring Electron BG			-4.38	35.6	-1.4	22.3	-16.8	38.0
Multi-GeV Multi-Ring e-like likelihood			-1.12	6.4	0.5	11.1	-0.3	5.3
Sub-GeV 1-ring π^0 selection	$100 < P_e < 250$	MeV/c	-3.94	11.2	-4.08	7.5	-5.34	7.7
	$250 < P_e < 400$		-4.05	11.5	-4.85	8.9	-18.37	26.4
	$400 < P_e < 630$		-8.23	23.4	-9.52	17.5	-8.70	12.5
	$630 < P_e < 1000$		-6.72	19.1	-5.81	10.7	-18.58	26.7
	$1000 < P_e < 1330$		-4.57	13.0	-6.03	11.1	-18.58	26.7
Sub-GeV 2-ring π^0			-0.31	2	0.024	2	0.009	1
Decay-e tagging			0.16	1.5	0.41	1.5	1.06	1.5
Solar Activity			0.6	20	27.9	50	3.78	20

Systematic errors for MME likelihood and ν_e and anti-ν_e separation likelihood



Multi-GeV multi-ring ν_e and anti-ν_e separation

SK1	7.16 %
SK2	7.91 %
SK3	7.68 %
SK4	6.82 %

*% of CC(ν_e+anti-ν_e) in MME sample