Hyper-Kamiokande Sensitivity and Systematic Uncertainties Studies

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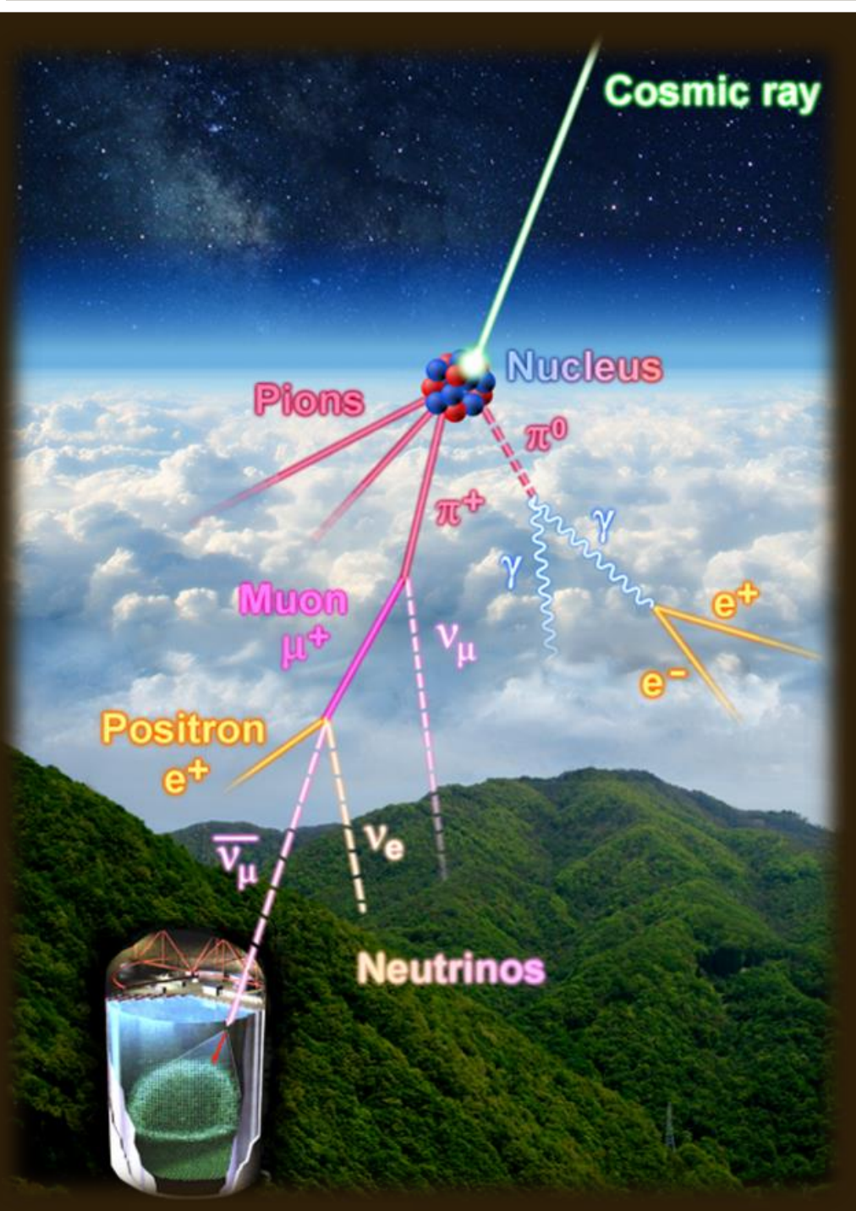
One of goals: CP violation measurement

Oscillation analysis Framework: Osc3++

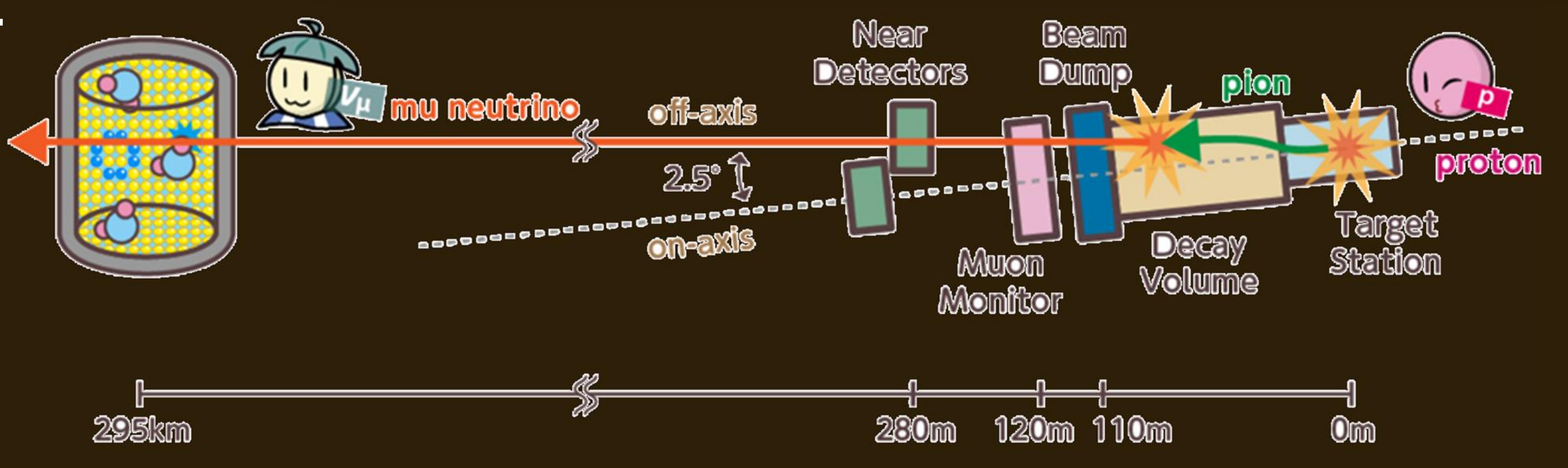
Hyper-Kamiokande (HK)

- 8 times fiducial volume of Super-K (SK) water Cherenkov detector[2];
- J-PARC neutrino beam is expected to reach 1.3 MW by 2027;
- Long baseline 295 km located in Japan.

Oscillation & Event Build

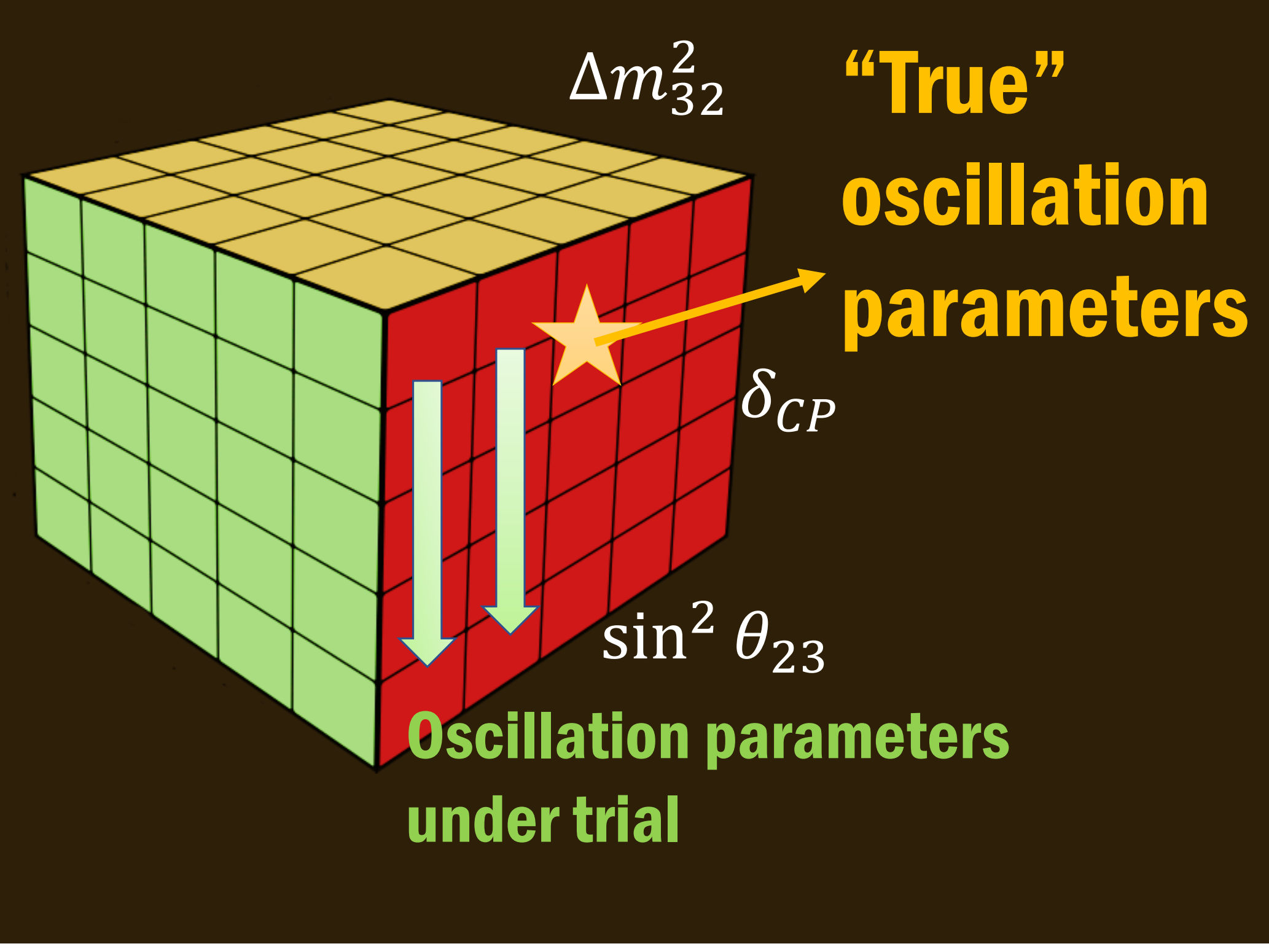


ATMOSPHERICS[3] + BEAM[4]



Oscillate **event by event** ⟶ reconstructed energy spectra

Fits



$$\chi^2_{tot} = \sum_n \left[E'_n - \underset{\uparrow}{O}_n - 0_n log \frac{E'_n}{O_n} \right] + \boxed{\sum_{kj} \varepsilon_k \rho^{-1}_{kj} \varepsilon_j} \longleftarrow$$

Observed events

Systematic parameter correlations

$$\text{Where} \quad E'_n = \sum_m \frac{E_m \prod_k (1 + \boxed{\varepsilon_k f^k_m})}{4(1+\hat{\varepsilon}\sigma)\Delta \mathrm{b_m}} \zeta_{n,m}(1+\hat{\varepsilon}\sigma)$$

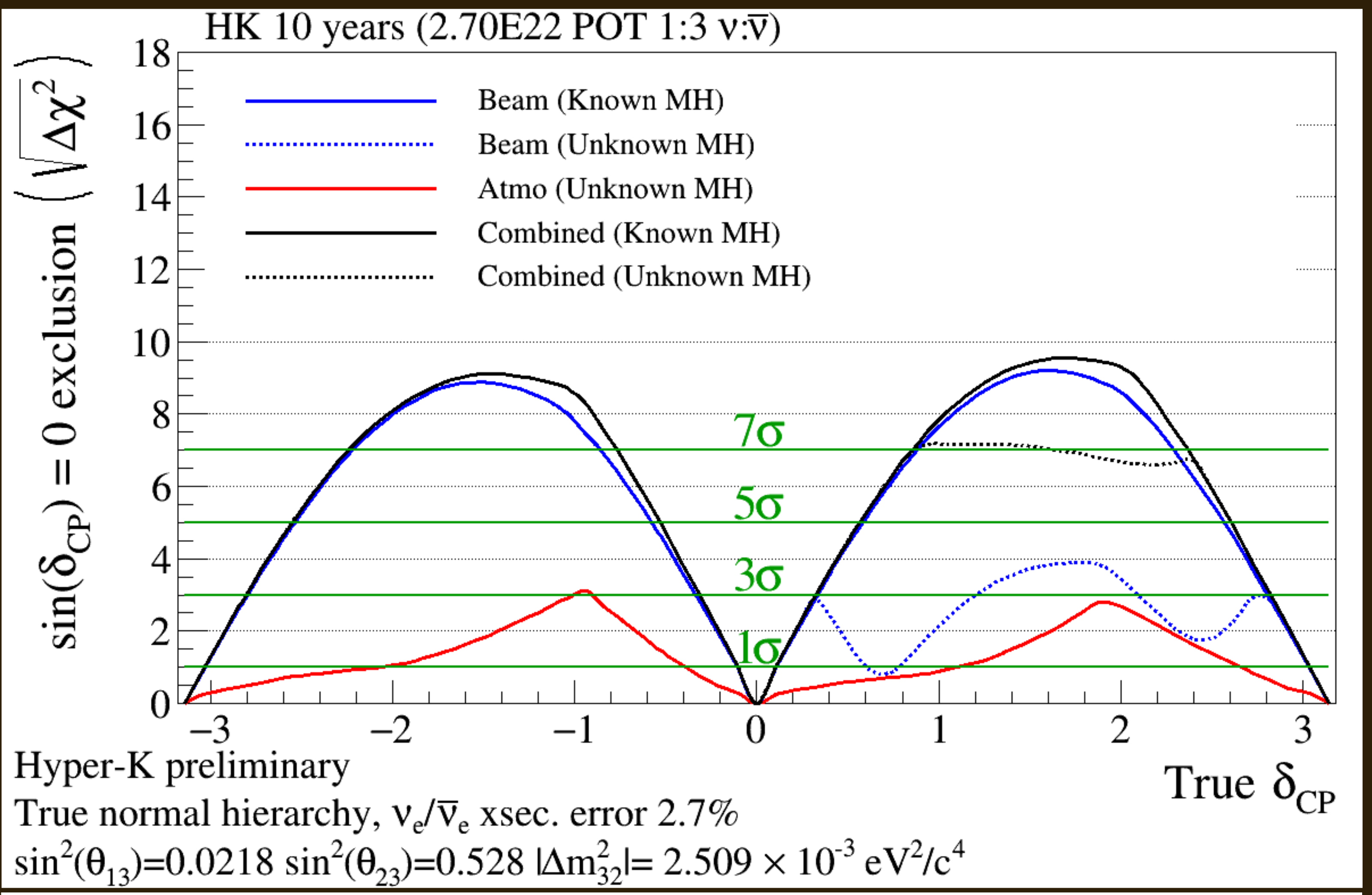
Expected events

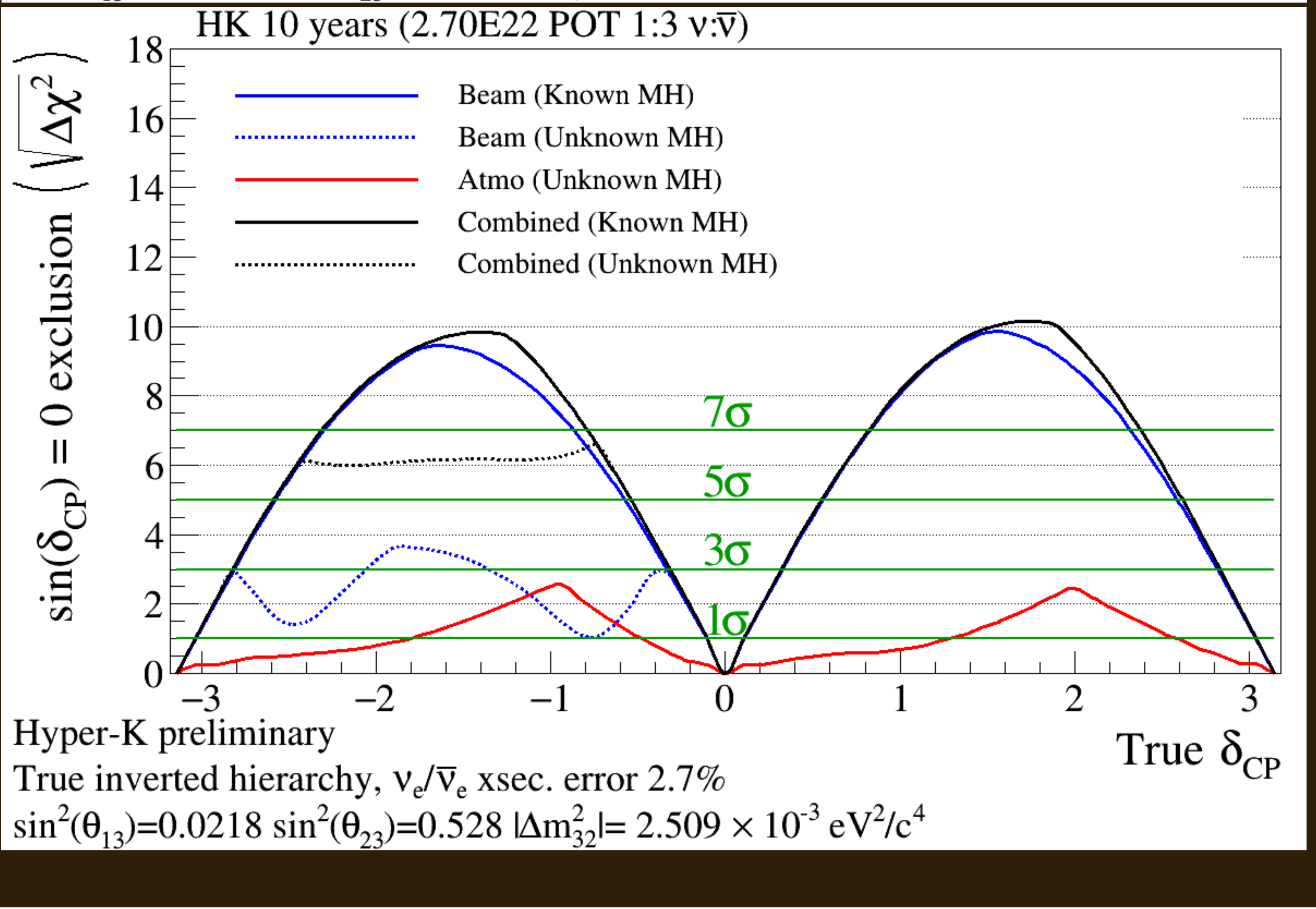
Fractional change caused by systematic parameter variations

Minimize χ^2 w.r.t systematic parameters [5,6]

HK improved systematic model:
Scaled down T2K-2018 errors

Sensitivity to CP-violation

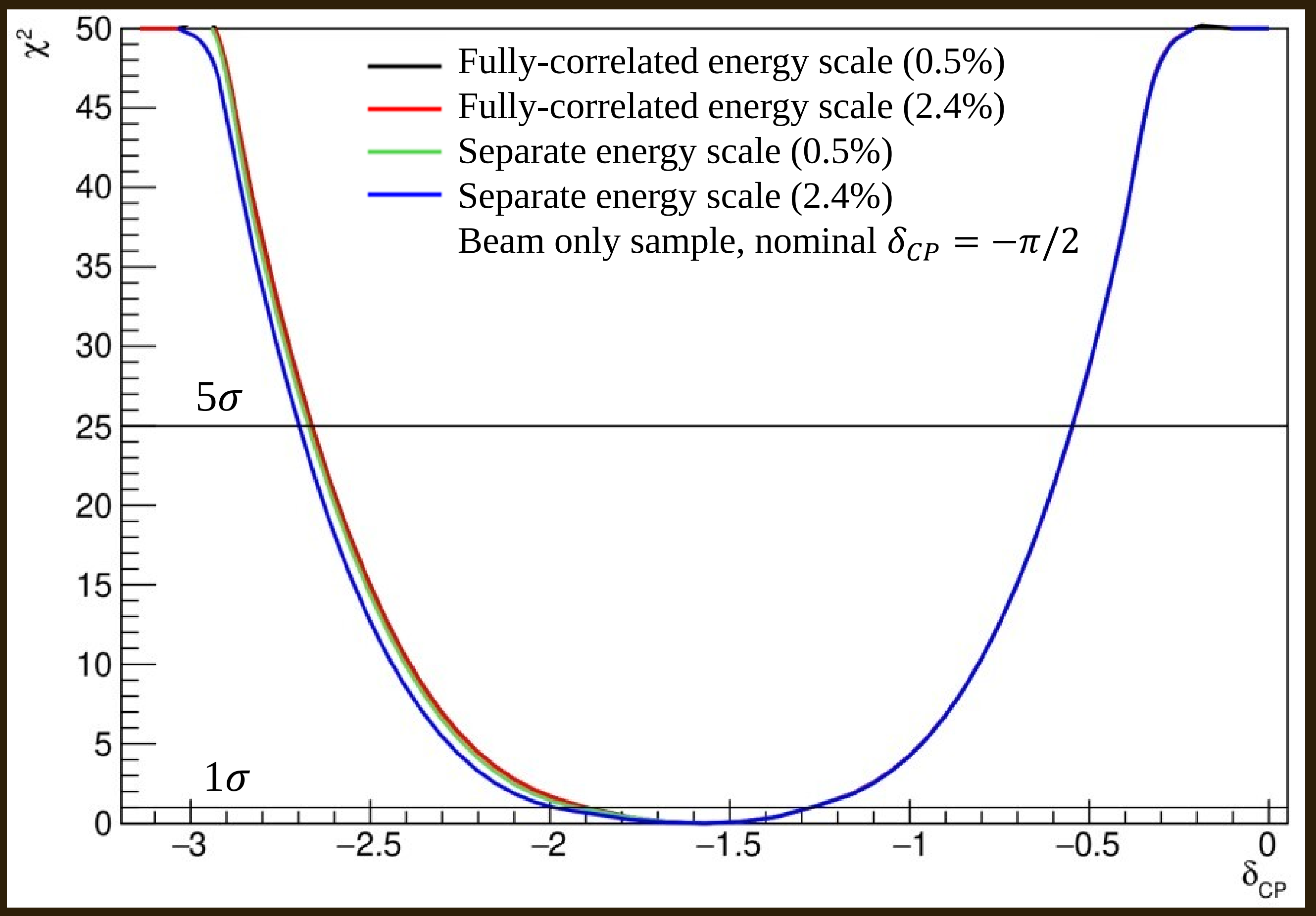




What's the energy scale (ES) uncertainty?

The systematic uncertainty of the preliminary reconstructed momentum

SK ES
2.4%
⇩
HK target ES
0.5%
⇩
Different methods to estimate ES of $\nu_e(\bar{\nu}_e)$ and $\nu_\mu(\bar{\nu}_\mu)$ Separately!



Fully correlated ES: The same 1σ error on ES for μ-like samples and e-like samples

Separate ES: Two ES parameters for μ-like samples and for e-like samples are uncorrelated

Conclusion

Sensitivity to CP-violation

Combining beam and atmospheric neutrinos can recover lost CPV Sensitivity ⟶ 5-σ

Systematic uncertainties

Increasing the energy scale error or separate energy scale of $\nu_e(\bar{\nu}_e)$ and $\nu_\mu(\bar{\nu}_\mu)$ lead to the loss of sensitivity.

What's next?

Other systematic uncertainties studies, sensitivity studies of HK configuration...

[1] higgstan.com
[2] K. Abe et al. "Hyper-Kamiokande Design Report". In: (2018). arXiv: 1805.04163 [physics.ins-det].
[3] M. Jiang et al., "Atmospheric Neutrino Oscillation Analysis with Improved Event Reconstruction in Super-Kamiokande IV," PTEP, vol. 2019, no. 5, p. 053F01, 2019.
[4] K. Abe et al., "Improved constraints on neutrino mixing from the T2K experiment with 3.13 × 1021 protons on target," 1 2021.
[5] K. Levenberg, "A method for the solution of certain non-linear problems in least squares," *Quarterly of Applied Mathematics*, vol. 2, p. 164–168, Jul 1944.
[6]D. W. Marquardt, "An algorithm for least-squares estimation of nonlinear parameters," *Journal of the Society for Industrial and Applied Mathematics*, vol. 11, no. 2, pp. 431–441, 1963.

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