



Hyper-Kamiokande

Comité de suivi de thèse 2ème année

Préparation de l'expérience Hyper-Kamiokande



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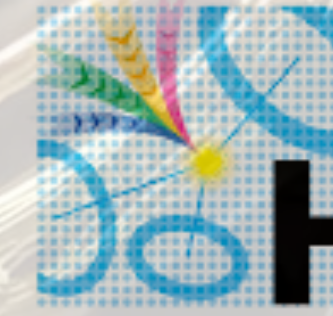


Hyper-Kamiokande

- Études de sensibilité pour HK
- Synchronisation de HK avec J-PARC et l'UTC
- Calibration et analyse des données de NA61/SHINE sur la cible réplique de T2K
- Présentations et conférences
- Articles
- Points de thèse



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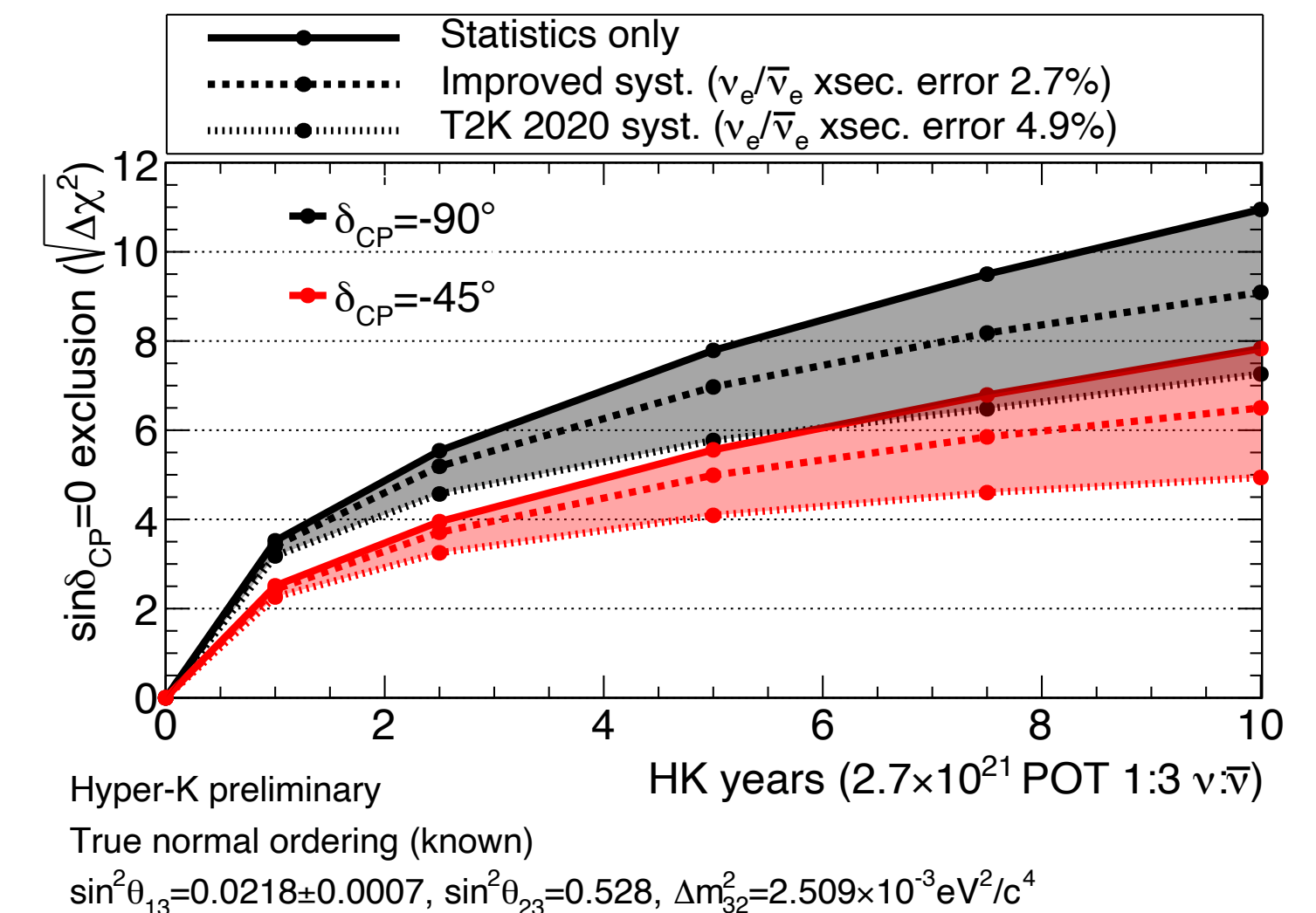


Hyper-Kamiokande

Études de sensibilité pour HK

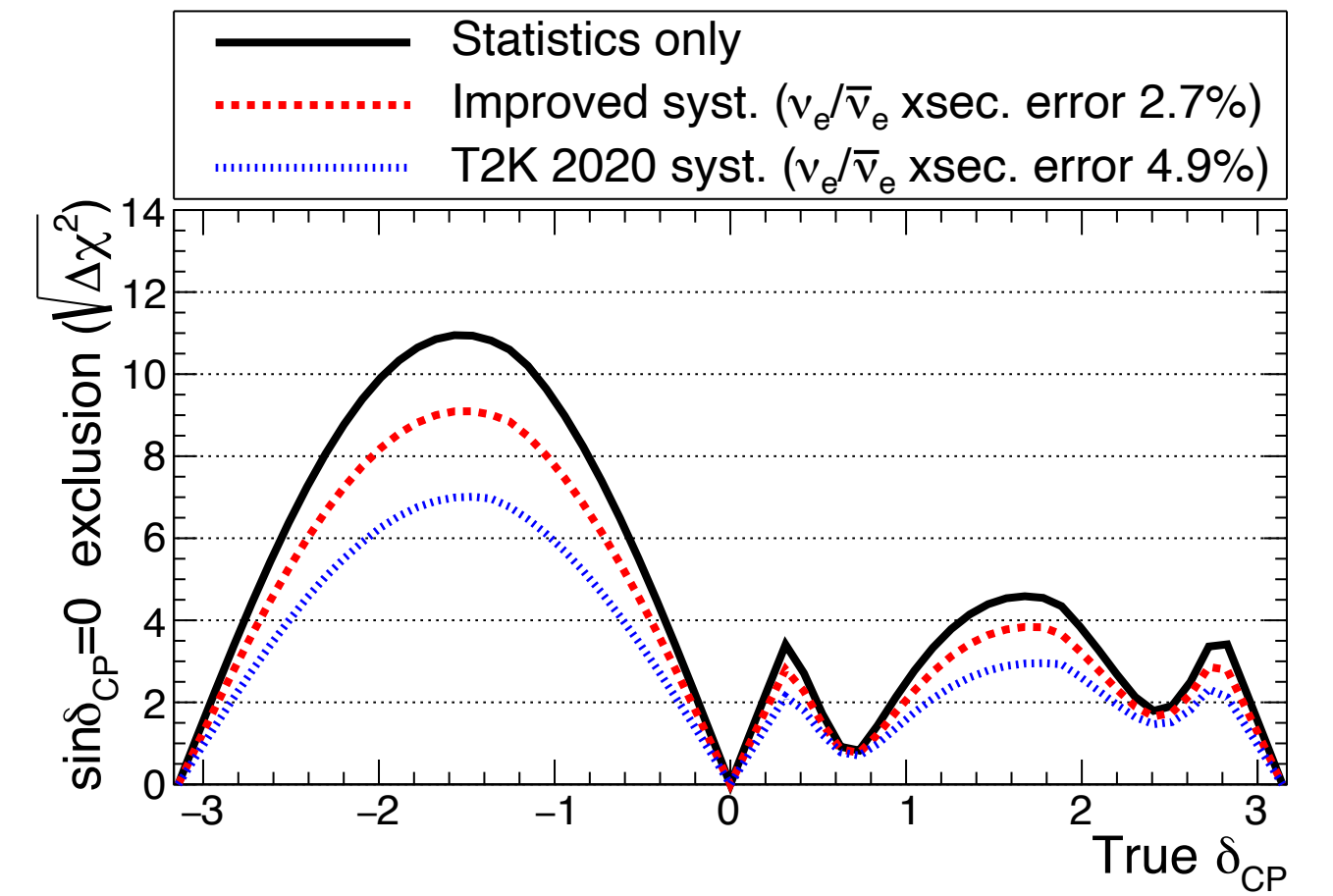
Études de sensibilité pour HK

- Juin 2023: présentation au meeting de collaboration HK et annonce de la TN à venir.
- Juillet 2023: circulation de la TN au groupe de travail.
- Janvier 2024: revue de la collaboration avec comité dédié, officialisation des plots.
- Avril 2024: circulation de la dernière version.
- Les conveners ont commencé l'écriture d'un papier. Un premier draft est en circulation.



Études de sensibilité pour HK Future

- William travaille à ajouter les neutrinos atmosphériques: un fit joint faisceau+atmosphériques permettrait une meilleure sensibilité à la hiérarchie de masse et à la violation de CP
- Chapitre du manuscrit de thèse en cours d'écriture sur ce travail



Hyper-K preliminary
 True normal ordering (Unknown), 10 years (2.7×10^{22} POT 1:3 $\nu:\bar{\nu}$)
 $\sin^2\theta_{13}=0.0218\pm 0.0007$, $\sin^2\theta_{23}=0.528$, $\Delta m_{32}^2=2.509\times 10^{-3}\text{eV}^2/c^4$

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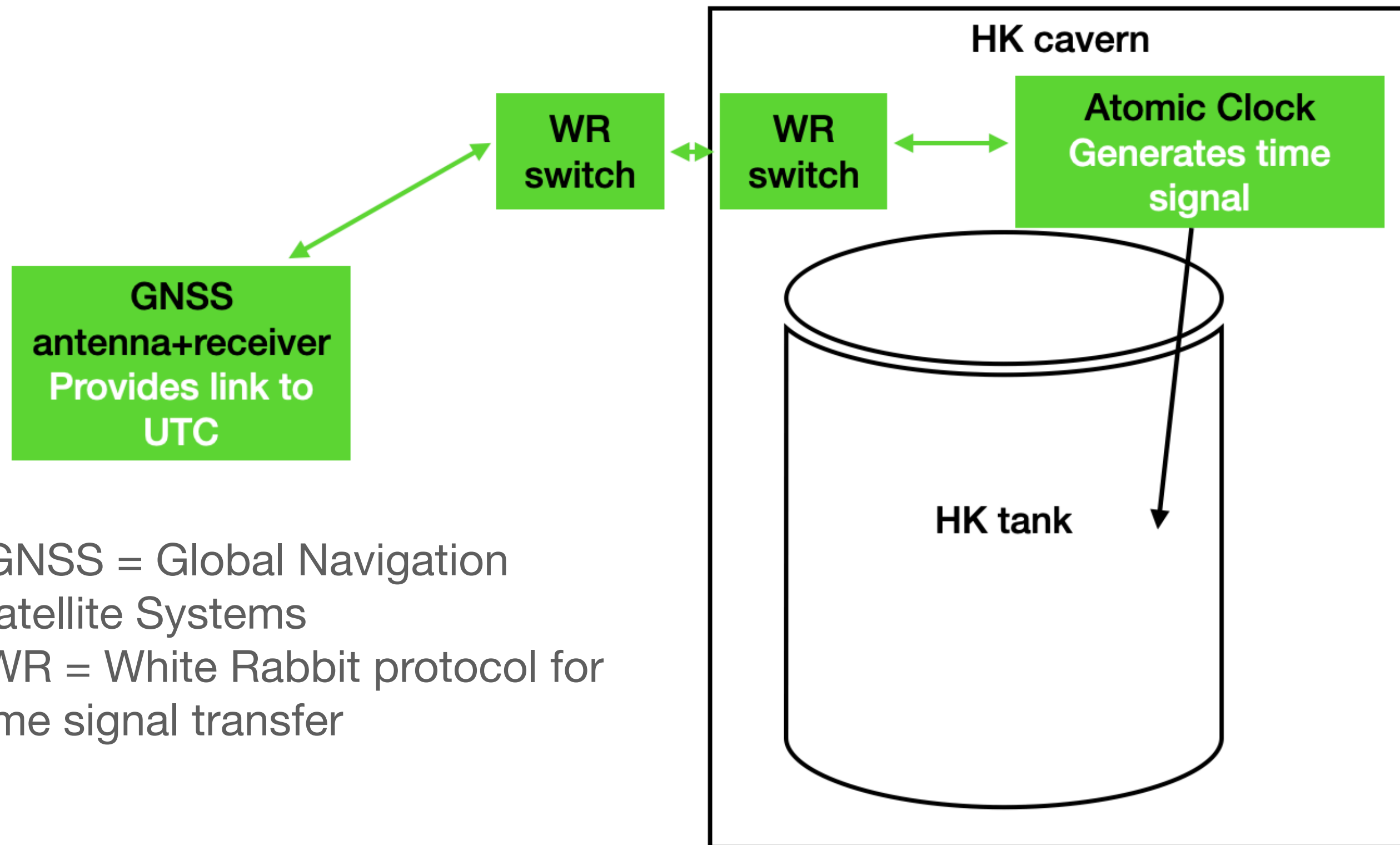
Hyper-Kamiokande

Synchronisation de HK avec J- PARC et l'UTC

*UTC: Universal Time Coordinated



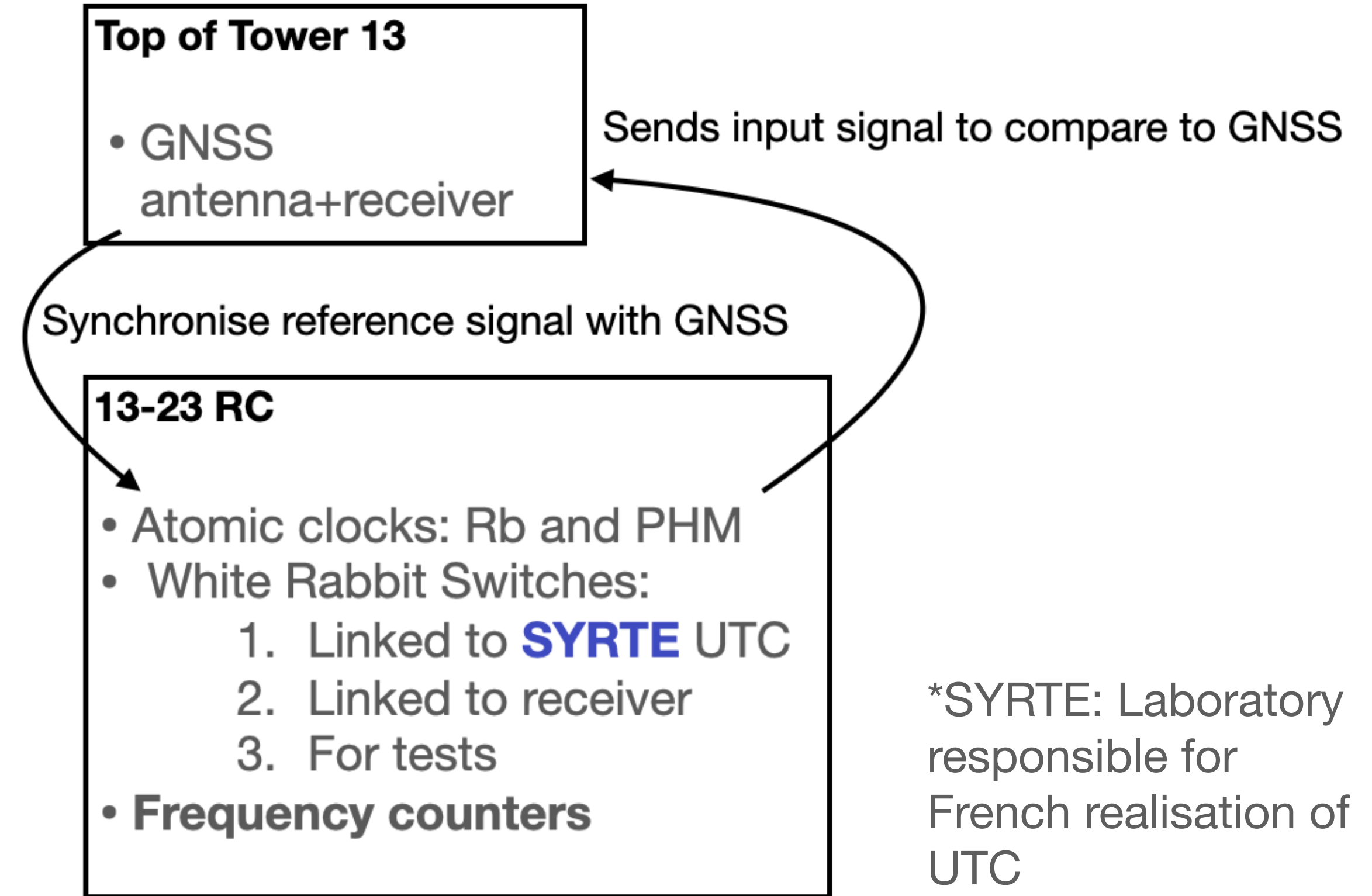
Timing distribution Setups for the time generation



Foreseen setup for HK

*GNSS = Global Navigation Satellite Systems

*WR = White Rabbit protocol for time signal transfer



Setup at LPNHE

*SYRTE: Laboratory responsible for French realisation of UTC

Timing distribution

Tests in Japan

In summer 2023, we brought an antenna in Japan to check the reception of GNSS signals on site.

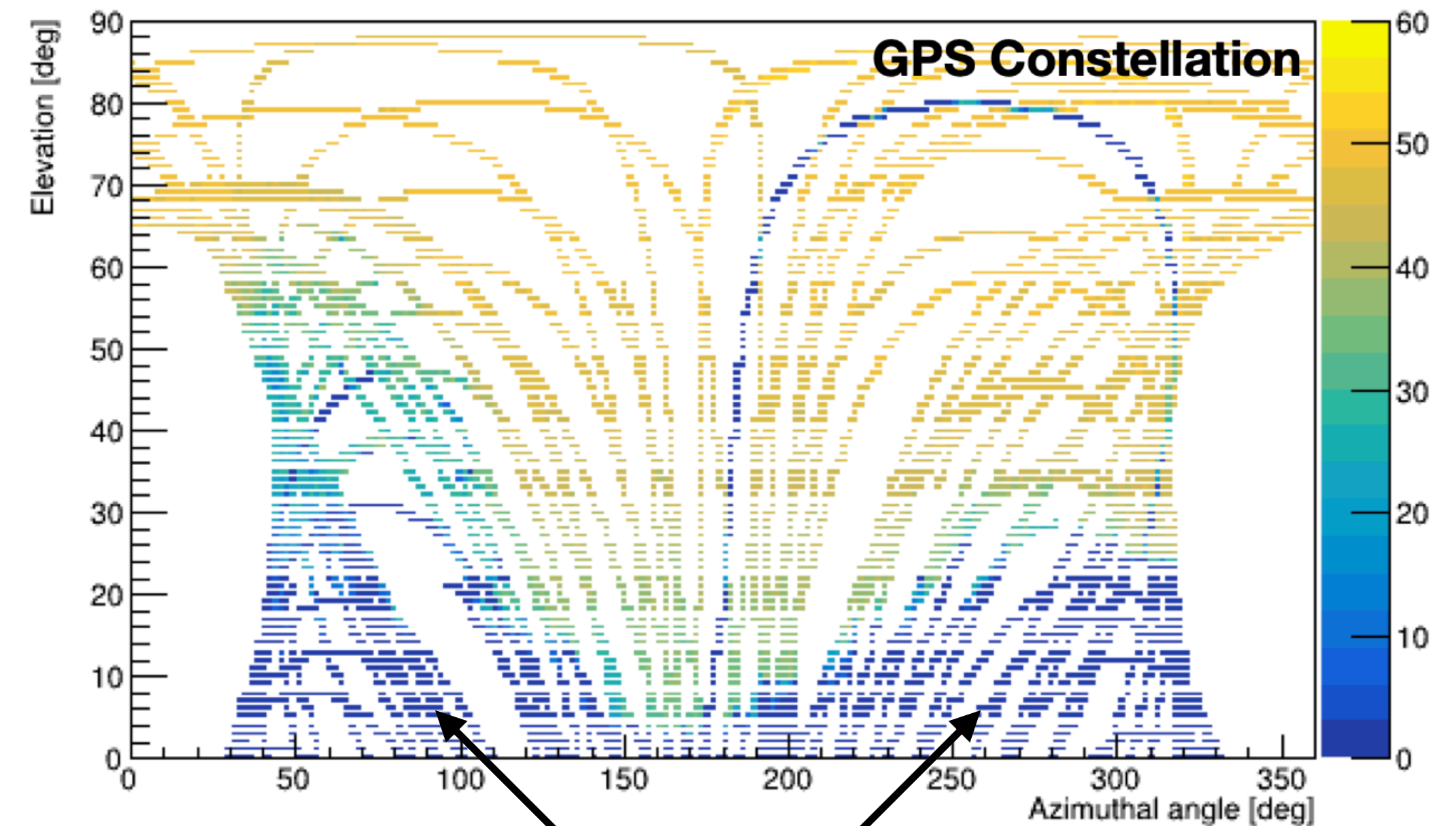
Credit: Mathieu Guigue



Tunnel to HK cavern



Our antenna



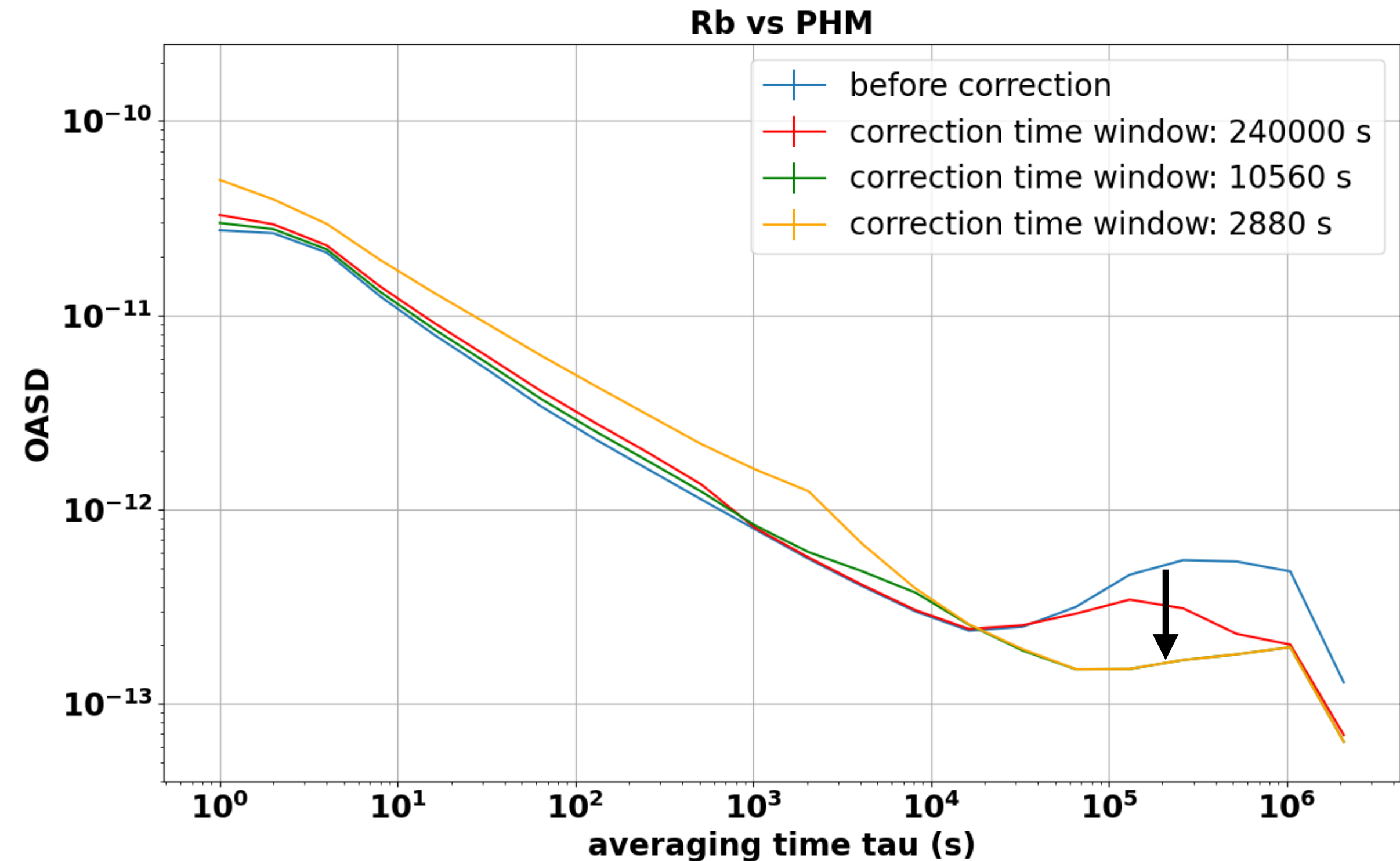
Low signal because of mountains!

Génération du temps dans HK

Test de la correction pour la synchronisation avec le GPS

2 mesures simultanées de 50 jours en février-mars 2024:

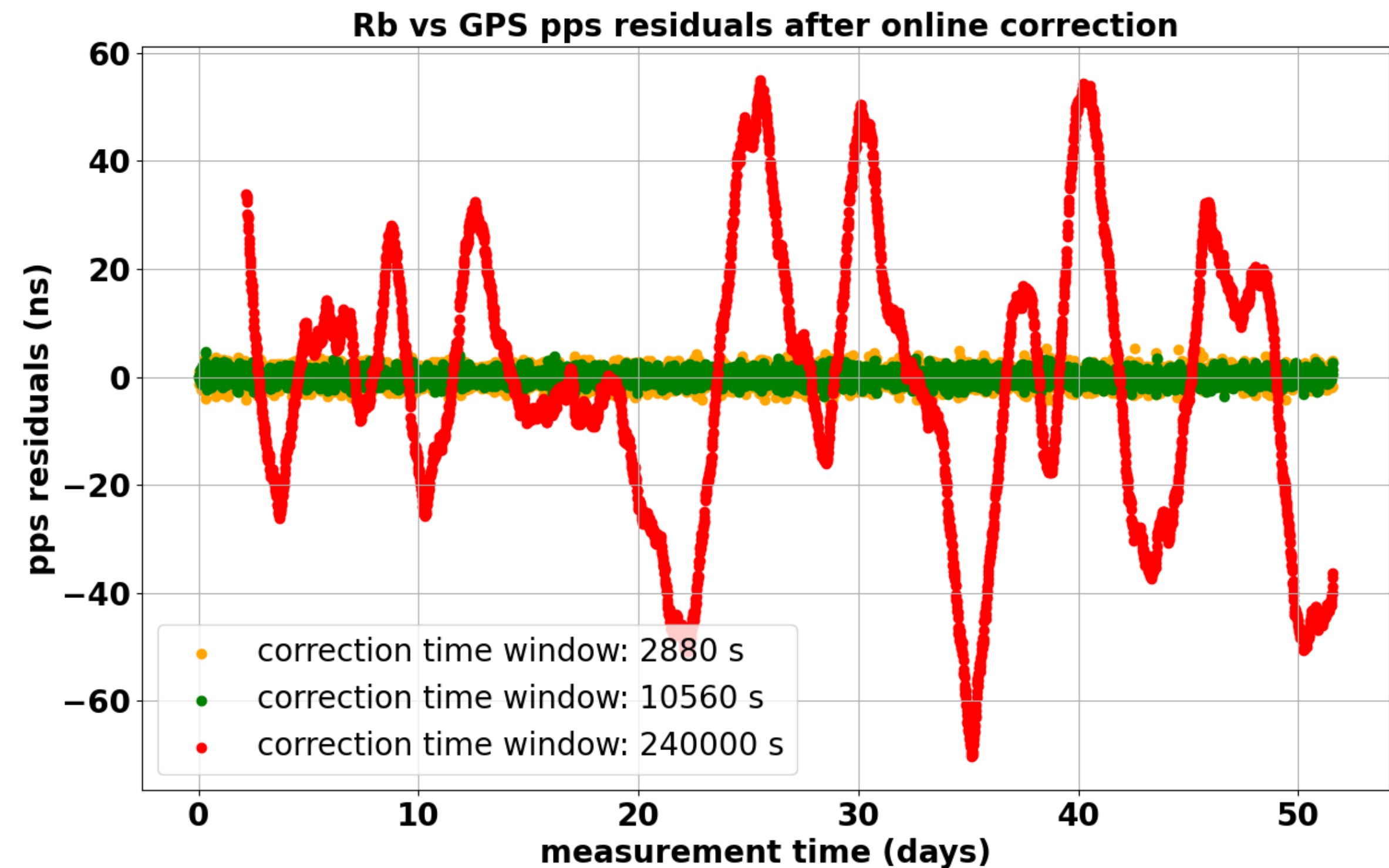
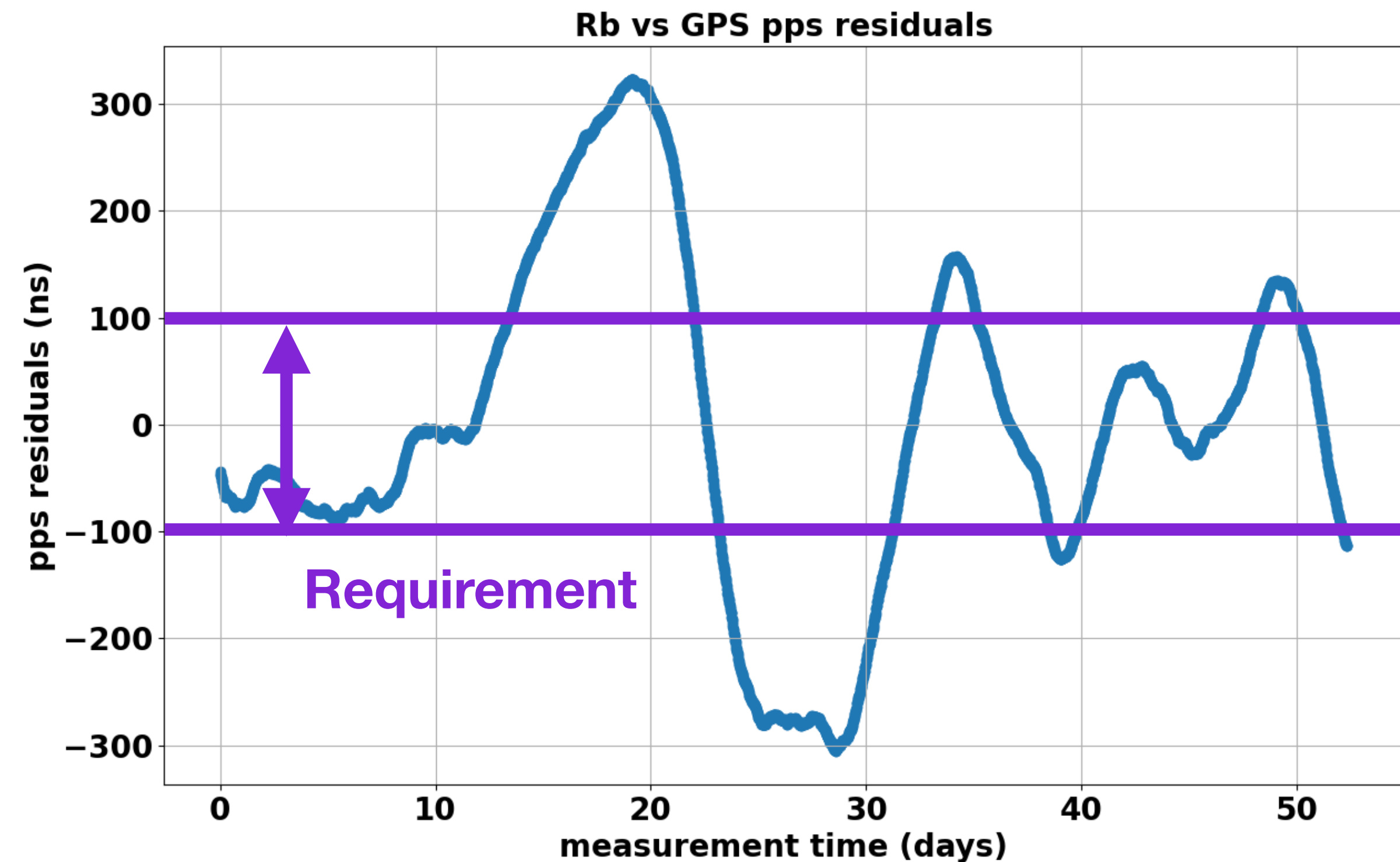
- Rubidium vs GPS: pour extraire la correction
- Rubidium vs PHM: pour vérifier la stabilité du signal rubidium après correction



Génération du temps dans HK

Test de la correction pou la synchronisation avec le GPS

Papier en cours d'écriture: on montre une synchronisation à l'UTC de l'ordre de ± 5 ns!



Génération du temps dans HK

Future

- Finaliser et soumettre le papier
- Nouvelle mesure utilisant le signal de temps qui vient du SYRTE (réalisation française officielle de l'UTC) au lieu de la PHM
- Implémentation de la correction “online”



Article

TBD: Correction of a free running Rubidium clock time signal for synchronisation with the UTC using GPS
Suggestion from BP: Development of a time correction algorithm for a precise synchronization of a free-running Rubidium clock with the UTC

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† Current address: Affiliation 3.

‡ These authors contributed equally to this work.

Abstract: We present results of our study devoted to development of a time correction algorithm needed to precisely synchronize a free-running Rubidium clock with the Universal Time Coordinated (UTC). This R&D is performed in view of the Hyper-Kamiokande (HK) experiment currently under construction in Japan.

Keywords: precise timing; atomic clock; Rb; PHM; GNSS; GPS; UTC



Hyper-Kamiokande

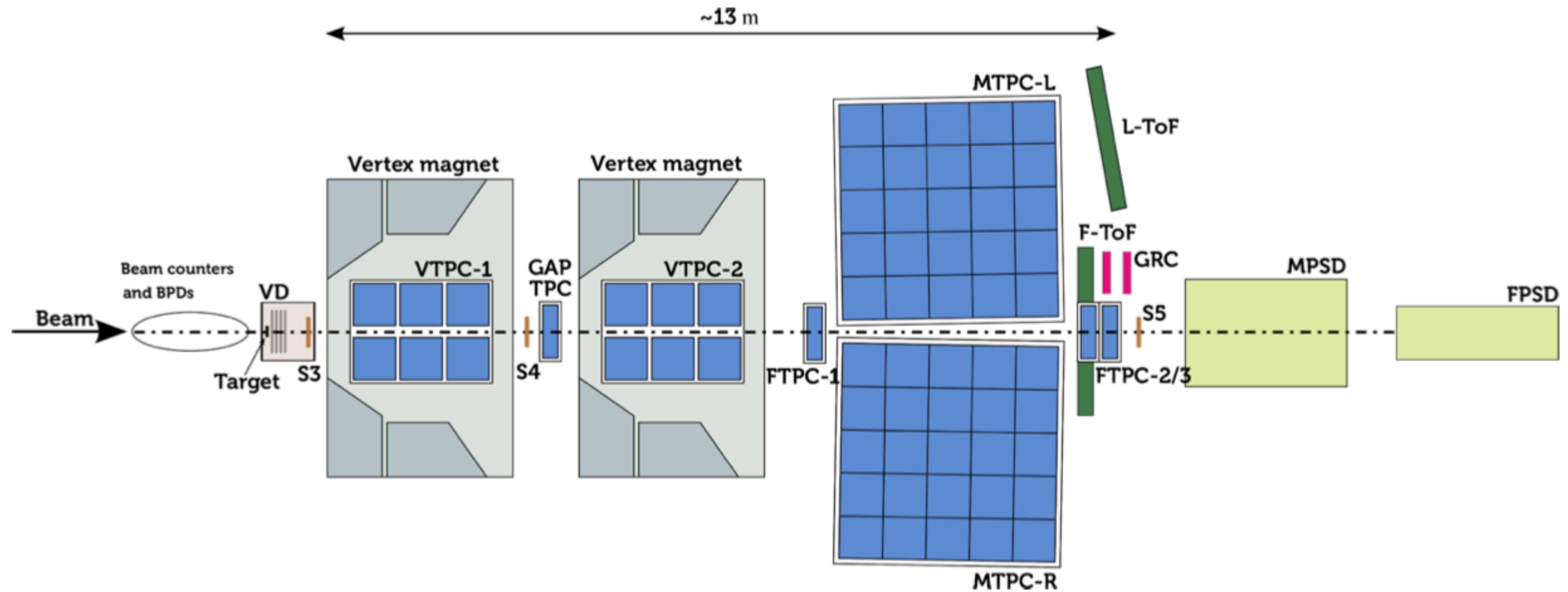
Calibration et analyse des données NA61/SHINE sur la cible réplique de T2K

NA61/SHINE

The detector



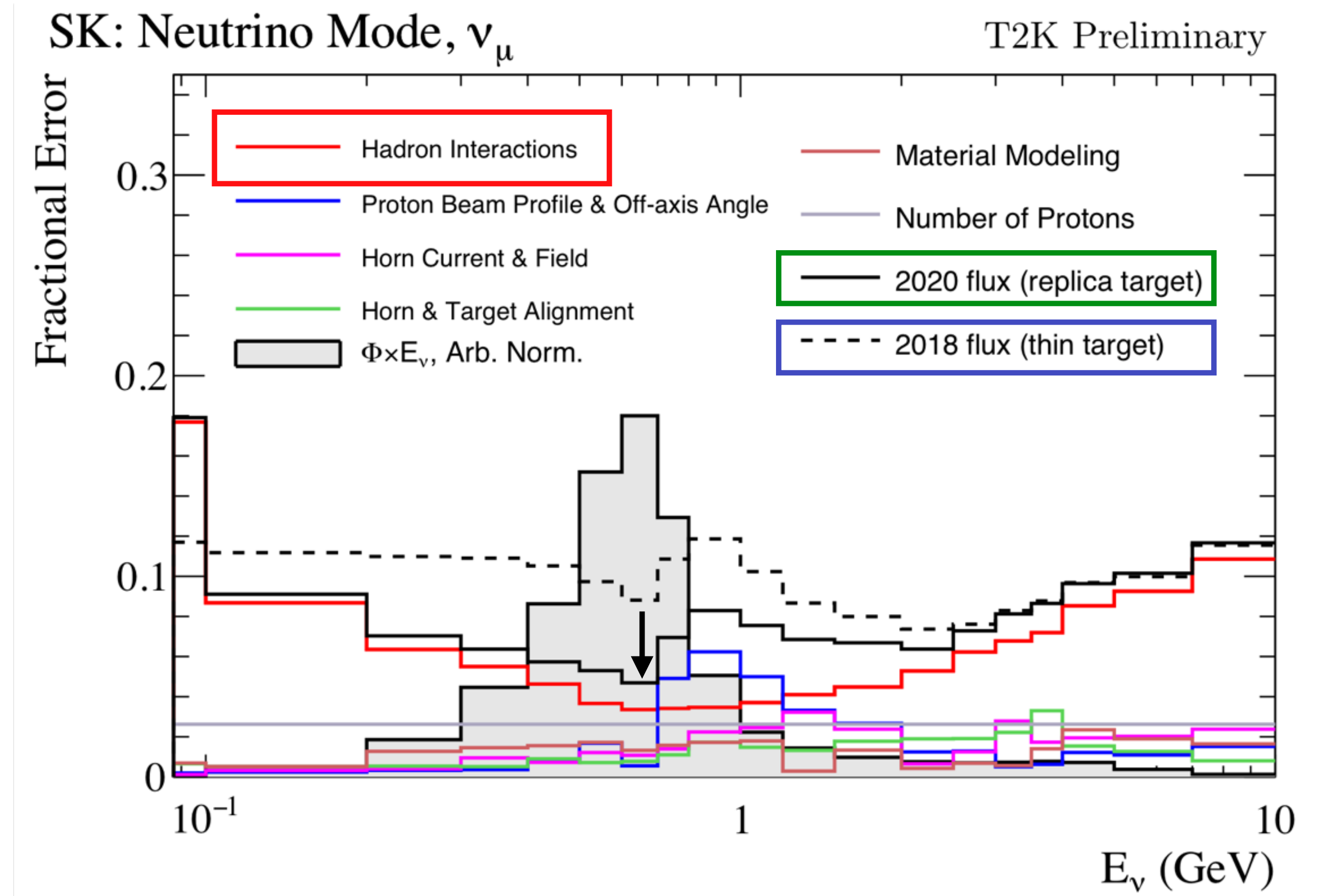
Hyper-Kamiokande



NA61/SHINE

Reducing the flux uncertainties

- Main uncertainty on flux: **hadron interaction uncertainties**.
- The last **replica target** measurements allowed to reduce the uncertainty to **5% at the flux peak!**
- **New NA61/SHINE data with replica target in 2022:** measure charged hadron + K_S^0 production in T2K target
- **My task:** calibration (in progress) and analysis of the new dataset



Calibration des données NA61/SHINE

Calibration des TPCs en cours:

- Habituellement la position des chassis des TPCs est mesurées par des géomètres mais pour les données post LS2, il semble y avoir des gros biais sur la vraie position des parties sensibles. Cela biaise la calibration de la vitesse de dérive.
- Nous avons mis en place une méthode d'alignement des TPCs utilisant des données sans champs magnétique
- La position des MTPCs et VTTPCs ont été déterminées avec cette méthode. Je suis en train de l'appliquer aux FTTPCs et Gap-TPC.

Calibration des données NA61/SHINE

Les prochaines étapes sont:

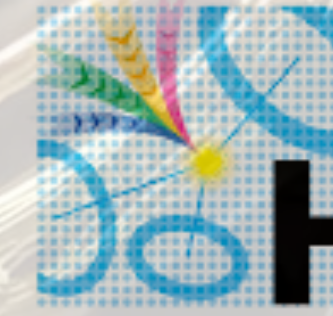
- Calibration par TPC de la vitesse de dérive et du délai du trigger
- Calibration par TPC du gain (dEdx)
- Alignement des TPCs avec les autres détecteurs

Analyse des données NA61/SHINE

- L'analyse des données nécessite la calibration...
- Cependant, une analyse des particules neutres qui se désintègrent en hadrons chargés (V0) peut se faire sans la calibration du gain.
- Une analyse avec MC est en cours par une autre étudiante (Sakiko)
- En 2022, les données ont été prises pour deux champs magnétiques différents (158 GeV/c, 80 GeV/c). Une répartition possible des tâches:
 - Sakiko: analyse V0 à 158 GeV/c
 - Claire: analyse V0 à 80 GeV/c



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Hyper-Kamiokande

Présentations et conférences

Présentations et conférences

Octobre 2022 - Septembre 2023

- Poster at the International Workshop on the Origin of Matter/Antimatter asymmetry: *Towards a better measurement of the CP violation phase with Hyper-Kamiokande*
- Présentations des études de sensibilité pour HK au meeting de l'IRN neutrinos à Nantes (juin 2023)
- Présentations de ces résultats au meeting de collaboration HK en juin 2023 pour débiter l'officialisation

Towards a better measurement of the CP violation phase with Hyper-Kamiokande
Claire Dalmazzo
LPNHE

Figure 1. The HK long baseline program will use the same neutrino beam as T2K but a bigger far detector. The beam will still be off axis by 2.5°.

The neutrino flux and interaction cross-sections are characterized at the near detectors including the upgraded ND280 and the future Intermediate Water Cherenkov Detector (IWCD). The appearance (and disappearance) of electron (and muon) neutrinos or antineutrinos will be measured at the far detector (HK). The comparison of the measured spectra with MC predictions allows to measure some parameters of the neutrino mixing matrix (PMNS). The bigger volume of the far detector and the more intense (500kV ~ 1.3MW) and frequent (1.36e ~ 1.16e per spill) proton beam will allow HK to accumulate statistics much faster than T2K.

Figure 2. Parametrization of the PMNS matrix

$$U_{PMNS} = \begin{pmatrix} c_{12}c_{13} & s_{12}c_{13} & s_{13}e^{-i\delta} \\ -s_{12}c_{13} & c_{12}c_{13} & s_{13} \\ s_{12}s_{13}e^{i\delta} & -s_{13}c_{12} & c_{13} \end{pmatrix}$$

Figure 3. Flux parameters errors before and after the ND fit (Fig 34 in [2]).

Figure 4. Prediction of HK sensitivity to the neutrino CP violation phase [4].

Figure 5. NA61/SHINE experimental setup

Figure 6. Sources of uncertainty on the neutrino flux prediction in T2K and impact of the last replica target tuning. The tuning was done with NA61/SHINE measurements presented in [2].

References

- [1] N. Abgral et al. NA61/SHINE facility at the CERN SPS, beams and detector system, JHEP, 9, 2014.
- [2] N. Abgral et al. Measurements of π^+ differential yields from the surface of the T2K replica target for neutrino flux prediction with the NA61/SHINE spectrometer at the CERN SPS, Eur. Phys. J. C, 76(11):1817, 2016.
- [3] K. Abe et al. Improved constraints on neutrino mixing from the T2K experiment with 1.1×10^{11} protons on target, Physical Review D, 103(11), Jan 2021.
- [4] Laura Aulenta Mouton, Long baseline neutrino oscillation sensitivities with Hyper-Kamiokande, in 22nd International Workshop on Neutrino Mass Accelerators, volume NuTeV2022, page 556, Capri, Italy, September 2021.

Présentations et conférences

Octobre 2023 - Maintenant

- Talk at NNN23 , octobre 2023, Procida, Italie (Next Generation Neutrino and Nucleon decay detectors): *Addressing the challenge of neutrino interaction uncertainties in Hyper-Kamiokande*
- 2 posters HCERES: *Préparation à l'expérience Hyper-Kamiokande: Transfert de temps au LPNHE* (Vincent Voisin) + *Towards Hyper-Kamiokande analyses* (with Gonzalo Diaz Lopez)
- Réunion du vendredi: 19 janvier 2024
- Présentation des résultats de calibration au meeting collaboration NA61, avril 2024, Sofia, Bulgarie
- Poster biennale similaire à l'HCERES



**Addressing the challenge of
neutrino interaction uncertainties
in Hyper-Kamiokande**

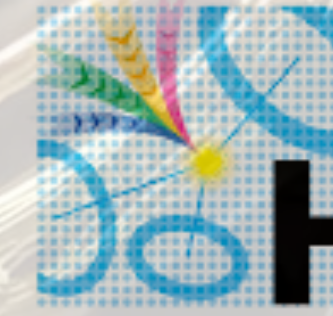


Claire Dalmazzone, 13th October 2023
On behalf of Hyper-Kamiokande Collaboration





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Hyper-Kamiokande

Articles publiés

Articles publiés

Co-autrice de 2 collaborations

- T2K grâce aux shifts remote de 2023 et shifts sur site en juin 2024. Un nouvel article depuis Mai 2023:
 - ▶ [arXiv:2308.16606v2](https://arxiv.org/abs/2308.16606v2)
- NA61/SHINE grâce à ma contribution sur la calibration et aux shifts de aout 2023 et juillet 2024.

Articles publiés

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 - ▶ [arXiv:2402.17025](https://arxiv.org/abs/2402.17025), [arXiv:2401.03445](https://arxiv.org/abs/2401.03445), [arXiv:2312.13706](https://arxiv.org/abs/2312.13706),
[arXiv:2312.06572](https://arxiv.org/abs/2312.06572), [arXiv:2308.16683](https://arxiv.org/abs/2308.16683), [arXiv:2306.02961](https://arxiv.org/abs/2306.02961),
[arXiv:2305.07557](https://arxiv.org/abs/2305.07557)



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Hyper-Kamiokande

Points de thèse

Points de thèse

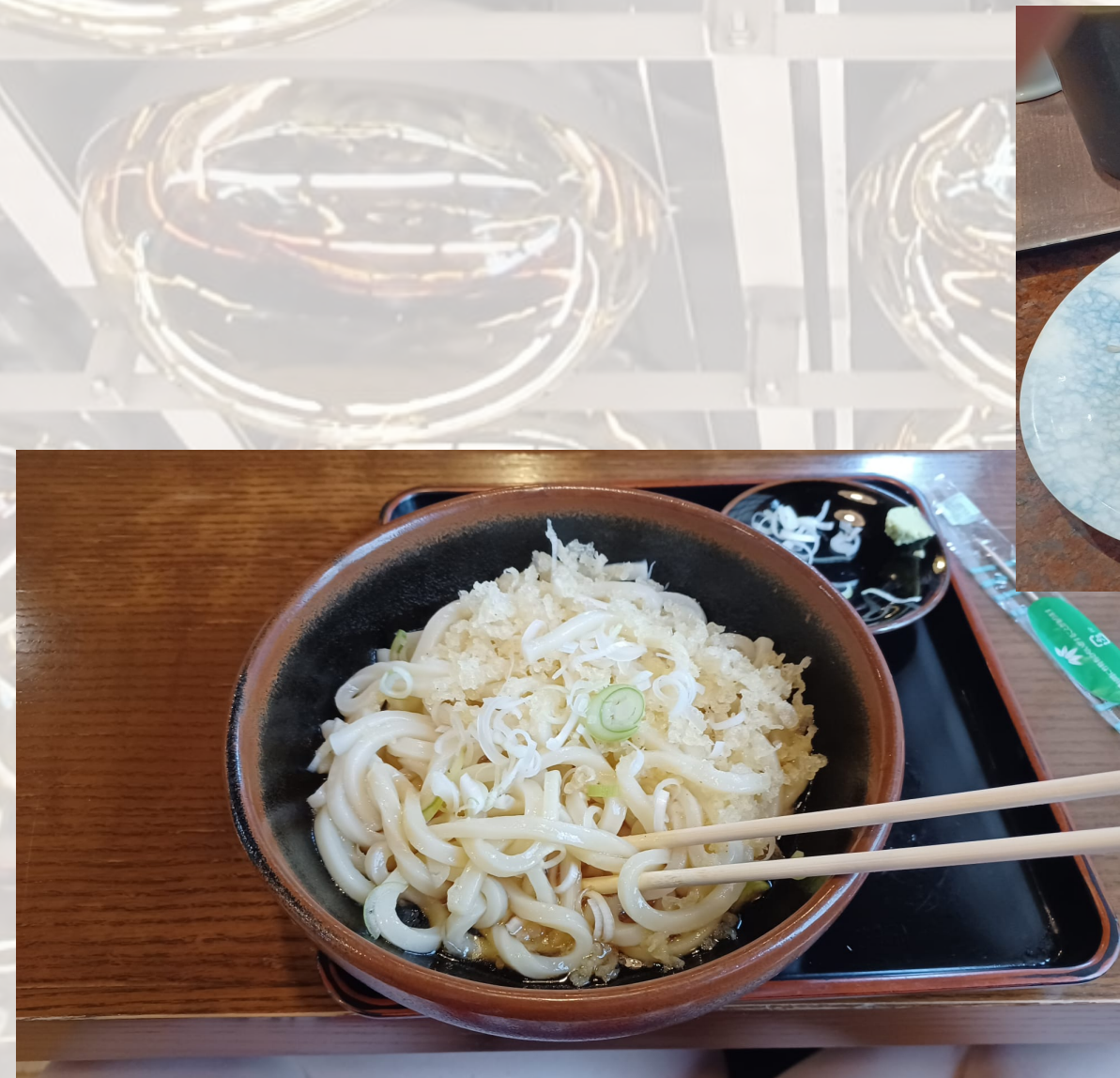
14 points:

- Cours intégrité scientifique (10 novembre 2022): 1pt
- 2 ans d'enseignement (déjà fait ~107h/128h): 2pts
- Formation à l'enseignement (octobre 2022 + janvier 2023): 2pts
- Applied Data Analytics (novembre 2022) + Advanced Applied Data Analytics (janvier 2024): 5pts
- Elements of Statistics (juin 2023): 4pts



Hyper-Kamiokande

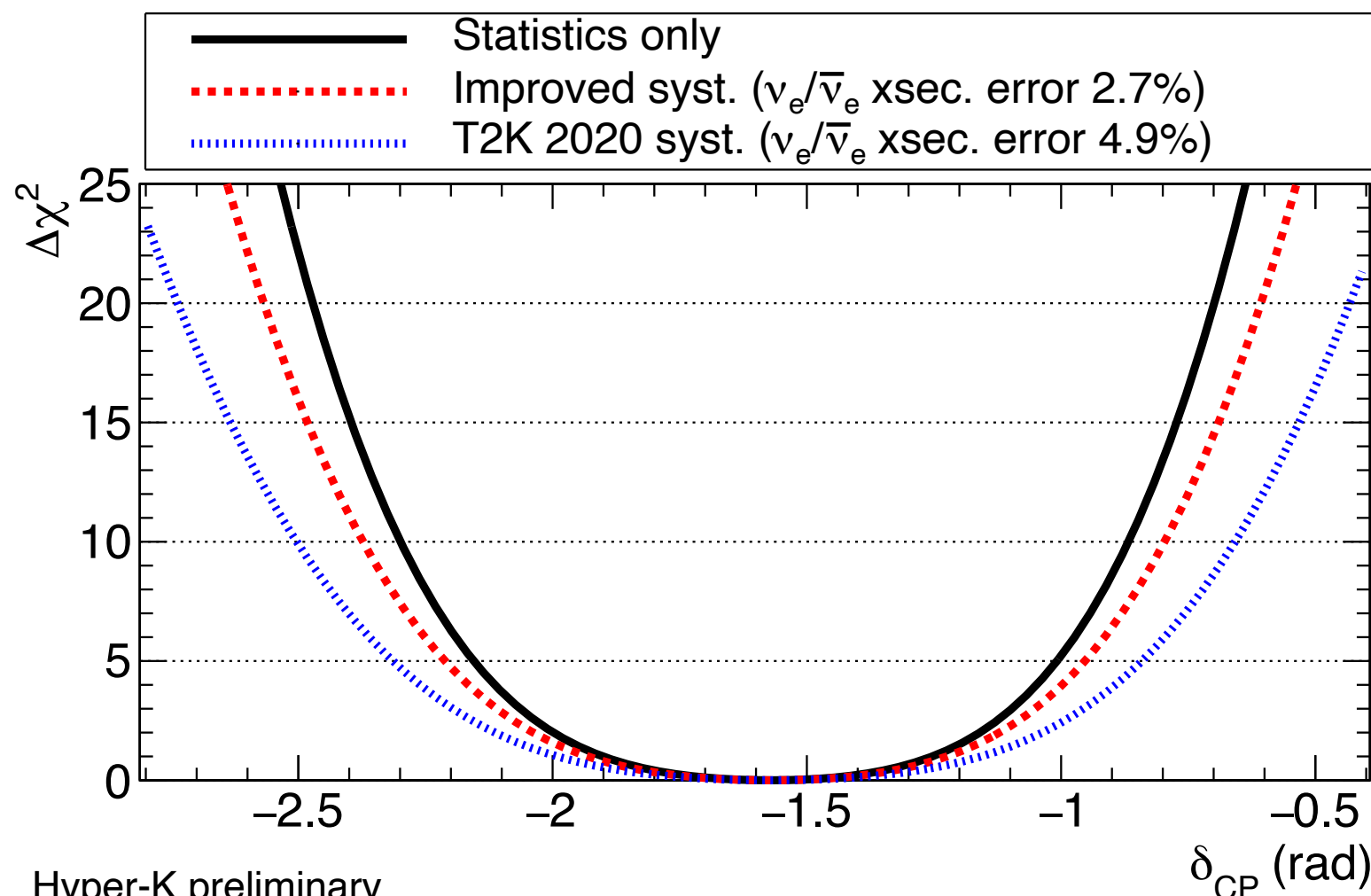
Thank you!



HK sensitivity studies

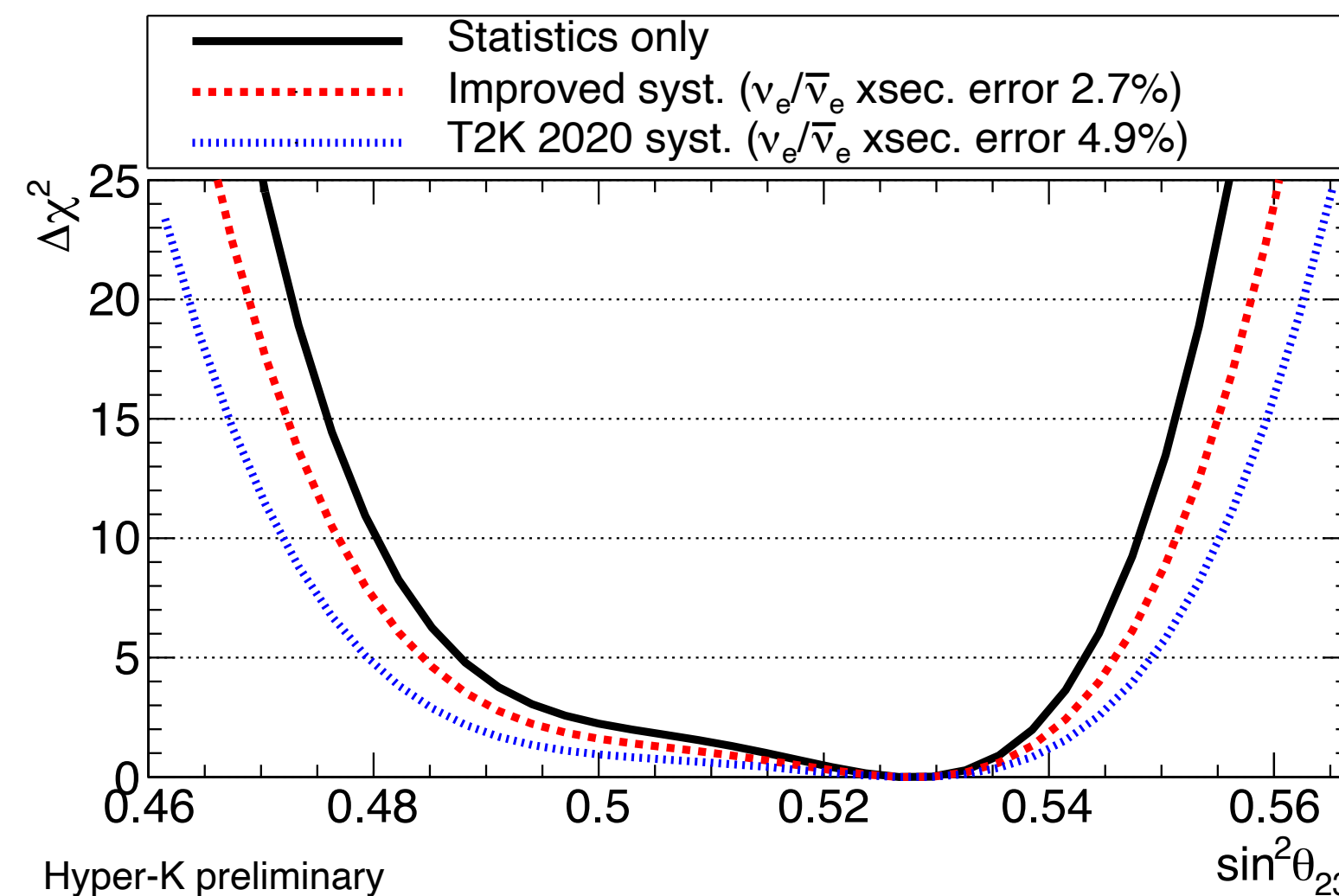
Results

Sensitivity after 10 years of data-taking: $\Delta\chi^2$ curves



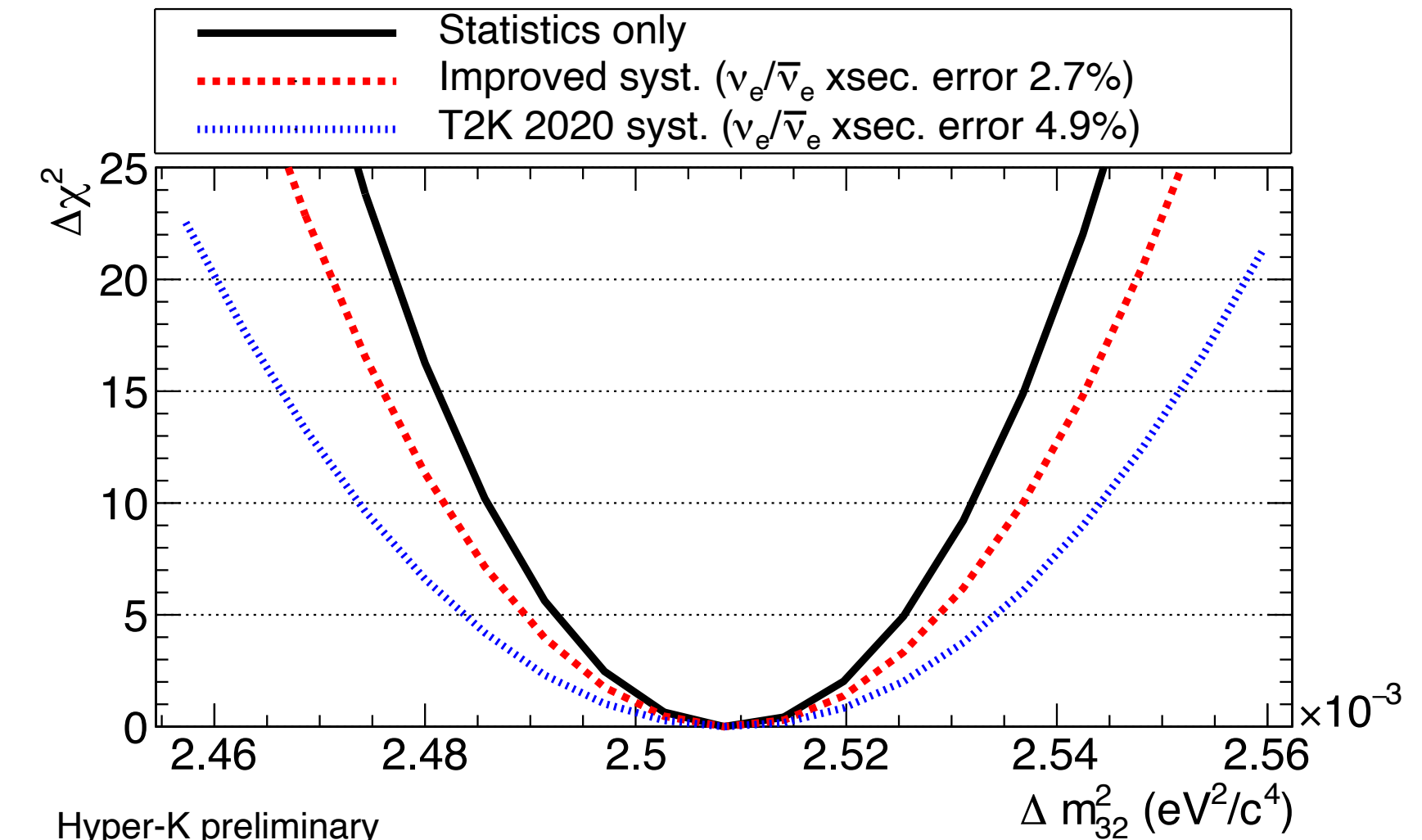
Hyper-K preliminary
 True normal ordering (known), 10 years (2.7×10^{22} POT 1:3 $\nu:\bar{\nu}$)
 $\sin^2\theta_{13}=0.0218 \pm 0.0007$, $\sin^2\theta_{23}=0.528$, $\Delta m_{32}^2=2.509 \times 10^{-3} \text{ eV}^2/c^4$, $\delta_{CP}=-\pi/2$

δ_{CP}



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$\sin^2 \theta_{23}$



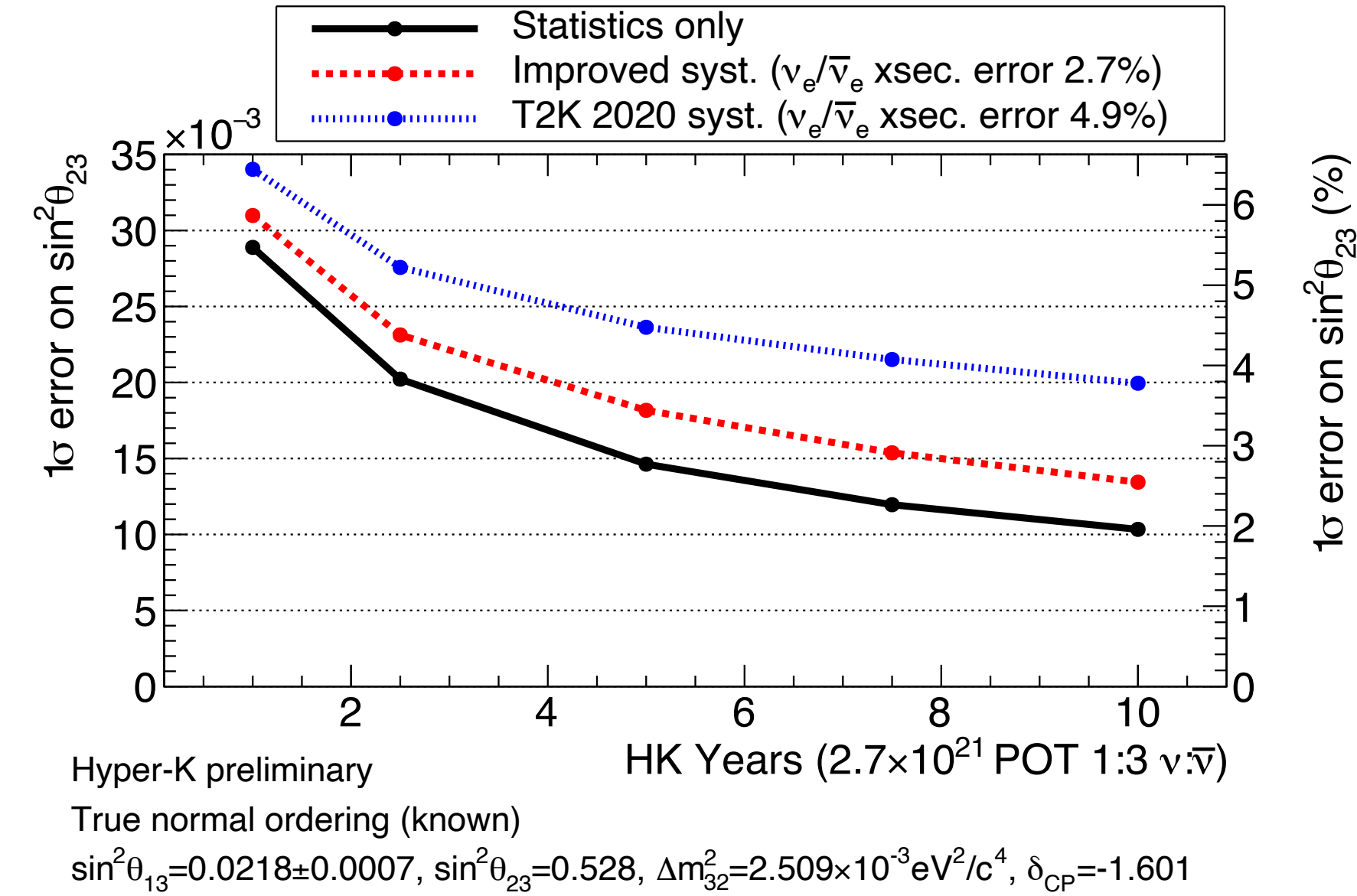
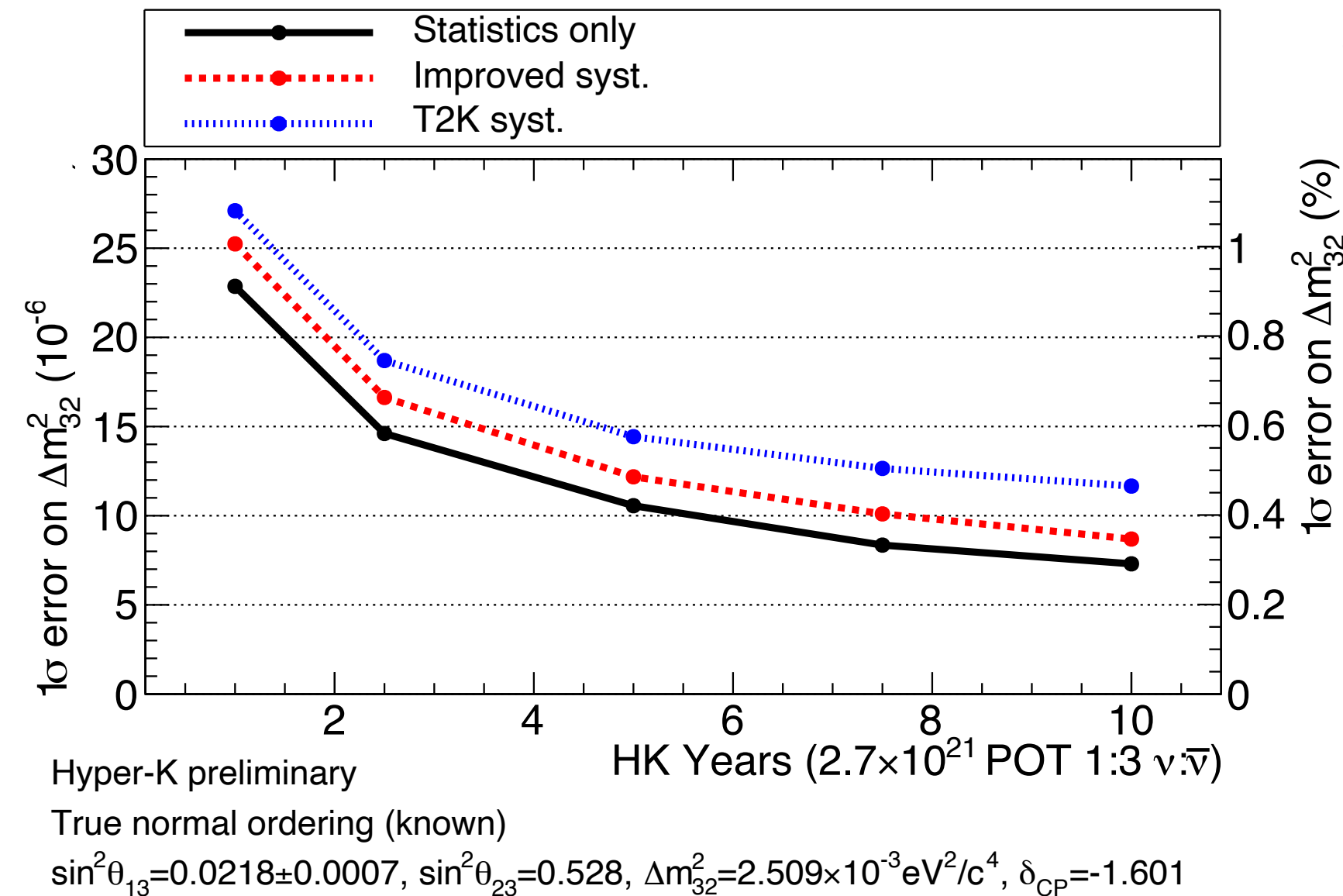
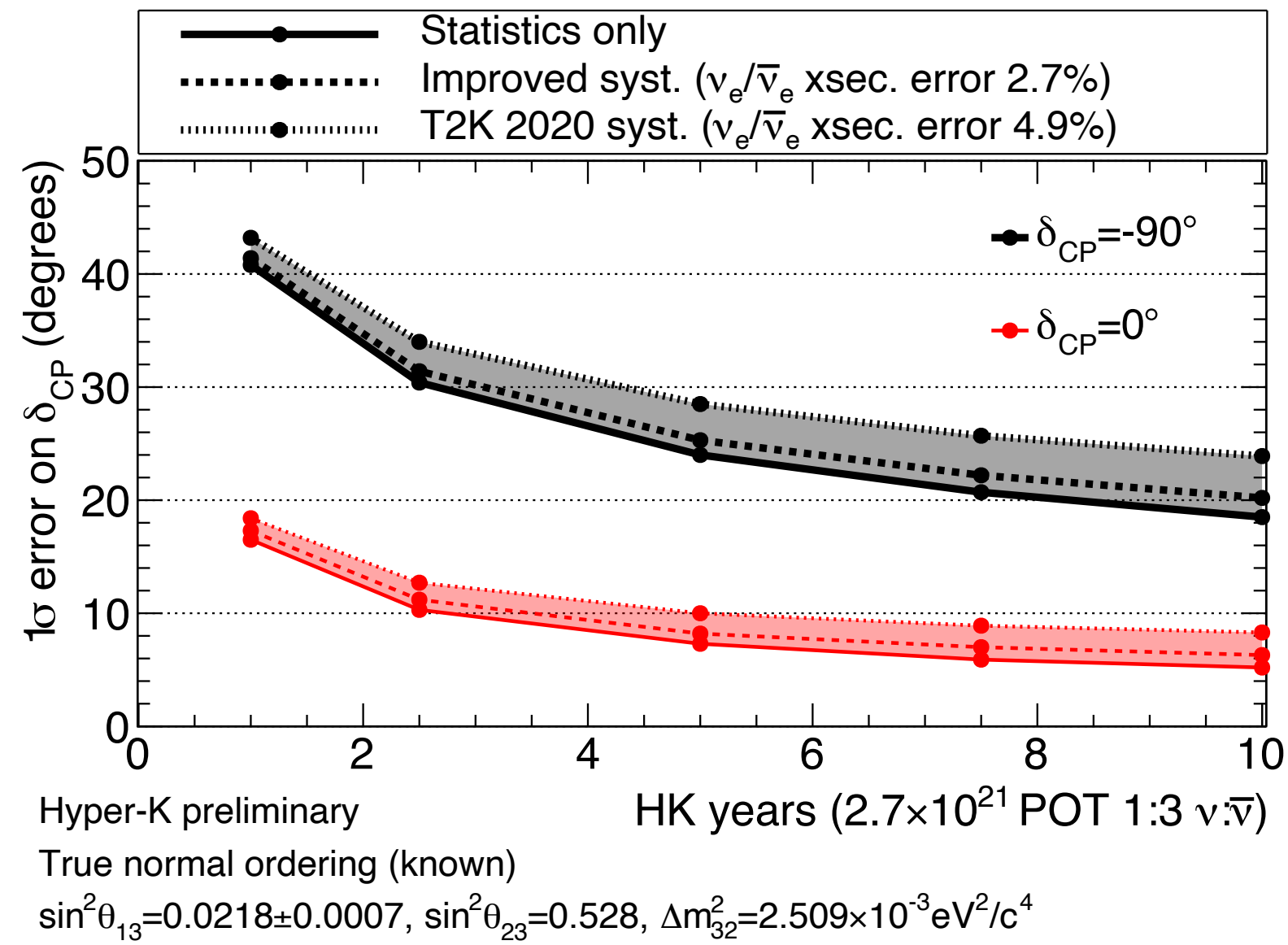
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Δm_{32}^2

We estimate the resolution by taking the width of the curves at $\Delta\chi^2 = 1$

HK sensitivity studies

Results

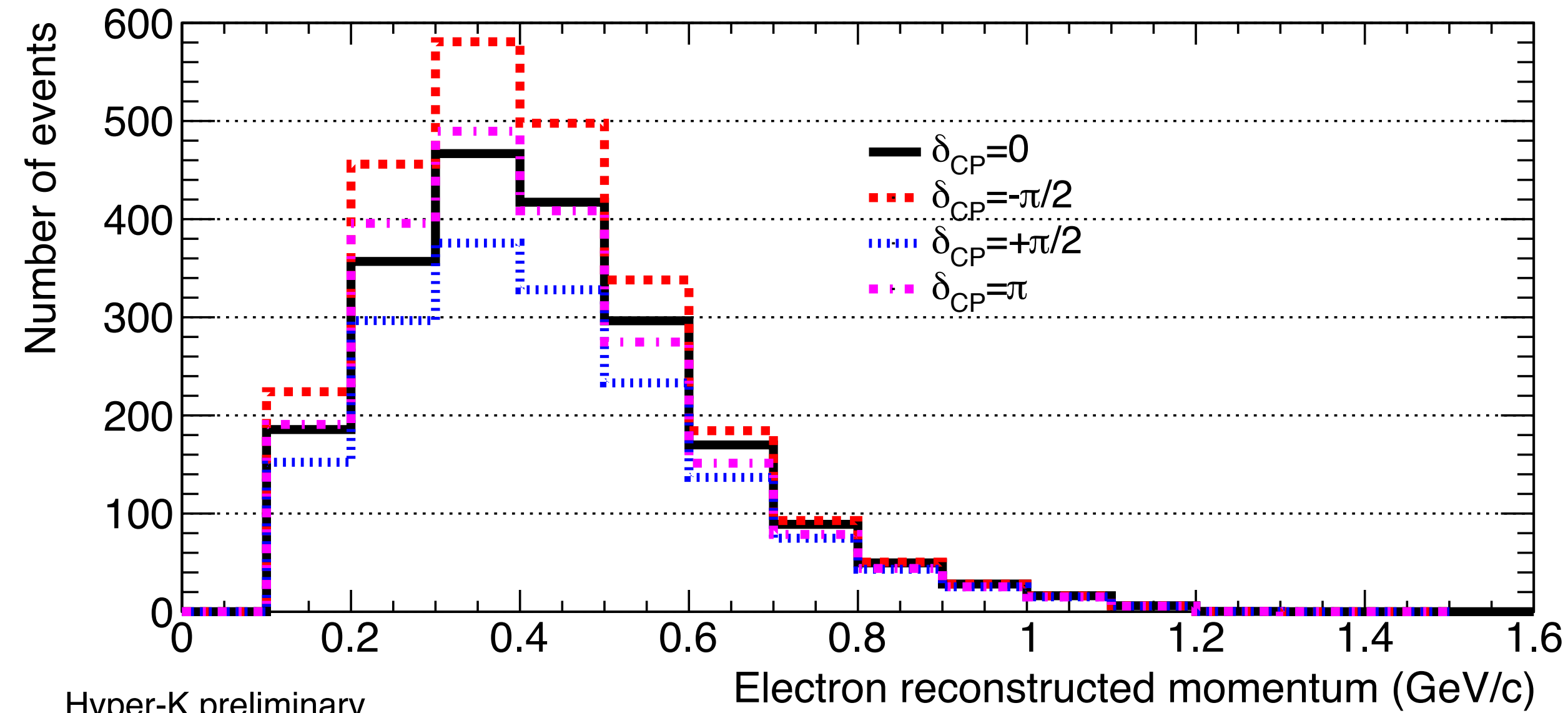




Plan to reduce systematics

Example: $\nu_e/\bar{\nu}_e$ cross-section ratio uncertainty

Far Detector, ν mode, 1-ring e-like + 0 decay e

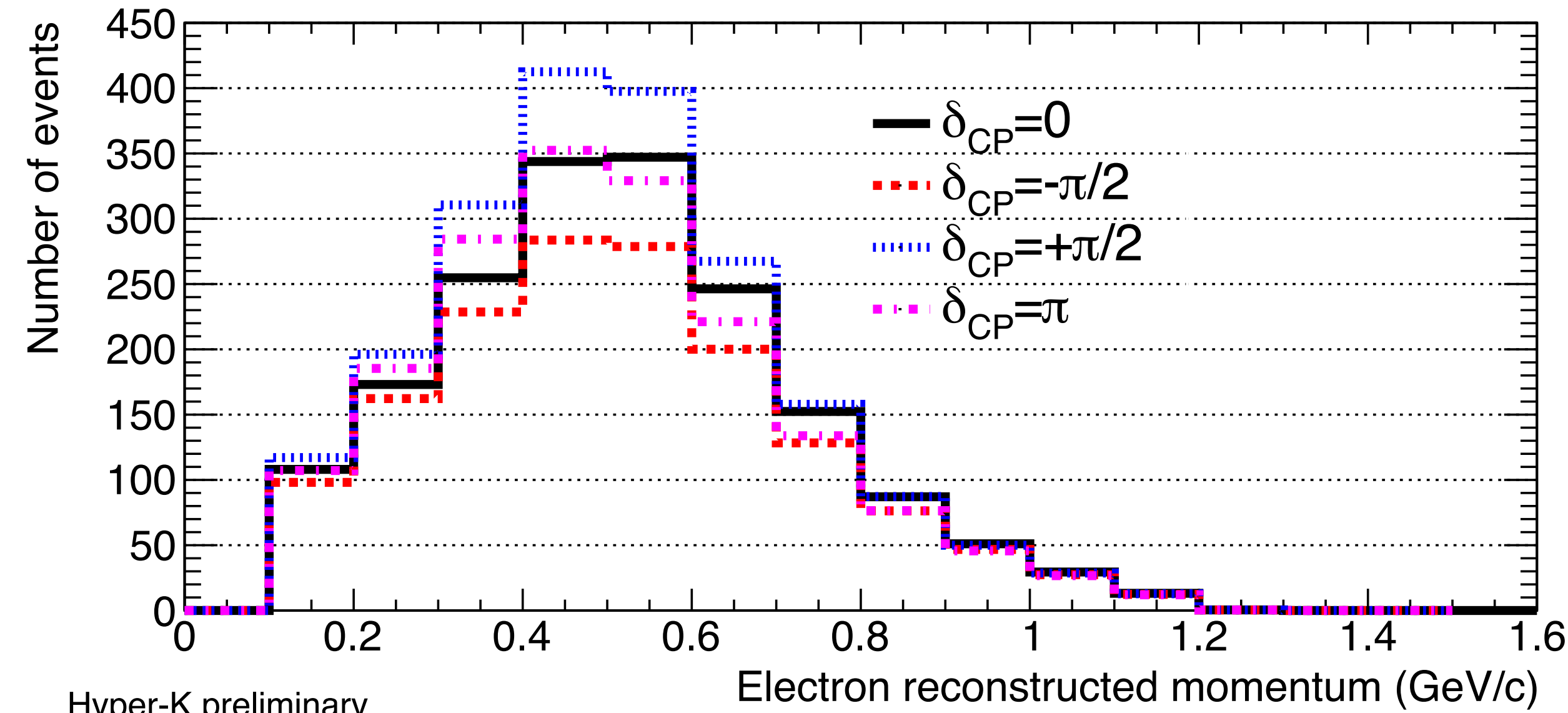


Hyper-K preliminary

10 years (2.7×10^{22} POT 1:3 $\nu:\bar{\nu}$)

True Normal Ordering, $\sin^2\theta_{13}=0.0218$, $\sin^2\theta_{23}=0.528$, $\Delta m_{32}^2=2.509 \times 10^{-3} \text{eV}^2/c^4$

Far Detector, $\bar{\nu}$ mode, 1-ring e-like + 0 decay e



Hyper-K preliminary

10 years (2.7×10^{22} POT 1:3 $\nu:\bar{\nu}$)

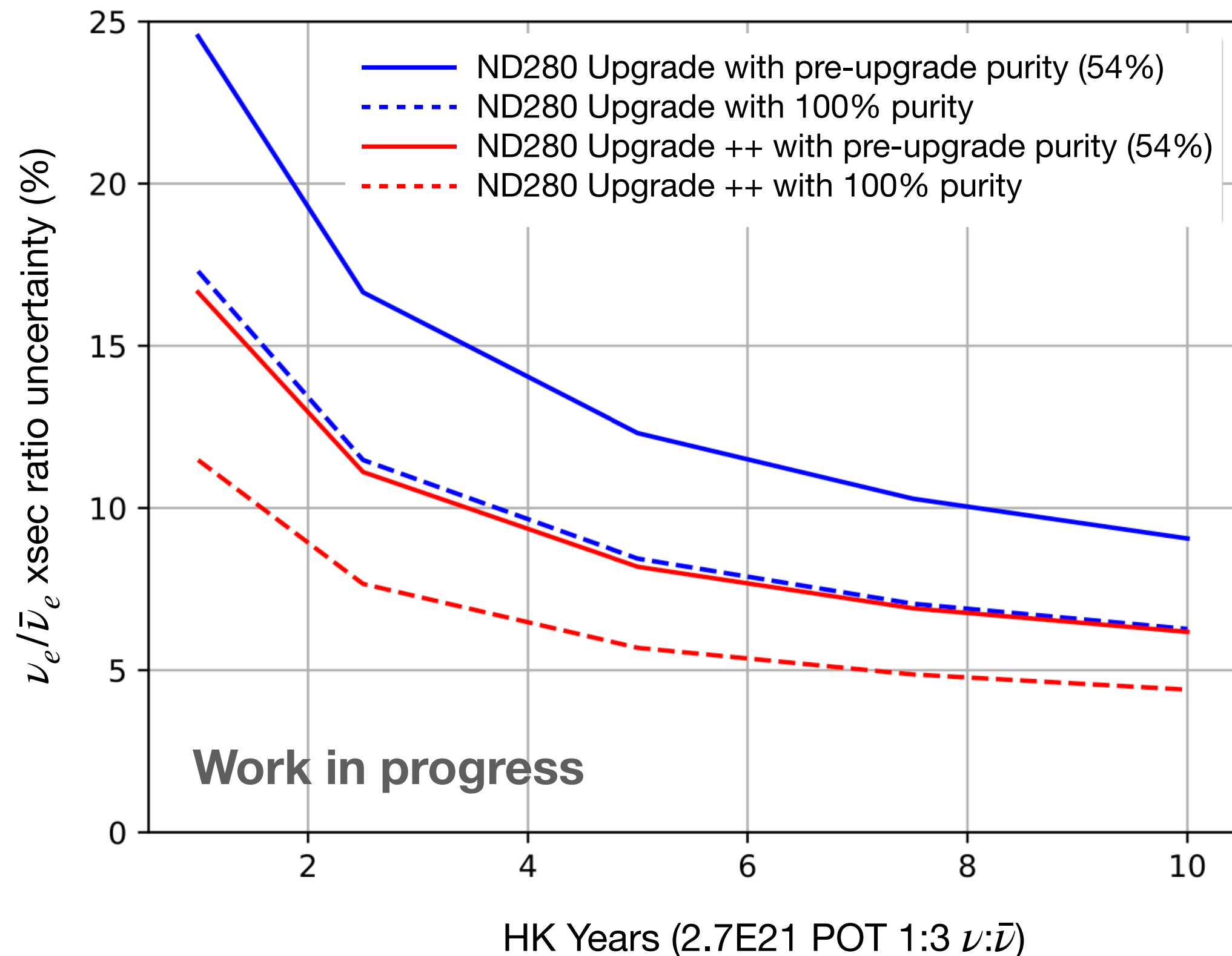
True Normal Ordering, $\sin^2\theta_{13}=0.0218$, $\sin^2\theta_{23}=0.528$, $\Delta m_{32}^2=2.509 \times 10^{-3} \text{eV}^2/c^4$



Plan to reduce systematics

Example: $\nu_e/\bar{\nu}_e$ cross-section ratio uncertainty

This measurement is challenging as the $\nu_e/\bar{\nu}_e$ contamination of the beam is very low (few percents)



With **only ND280 upgrade**, could reach a **$\sim 7.5\%$** uncertainty or below with the upgrade ++

Estimation of ND280 constraint on $\sigma(\nu_e)/\sigma(\bar{\nu}_e)$ with upgrade or upgrade ++ mass, pre-upgrade efficiency and pre-upgrade or 100% purity.

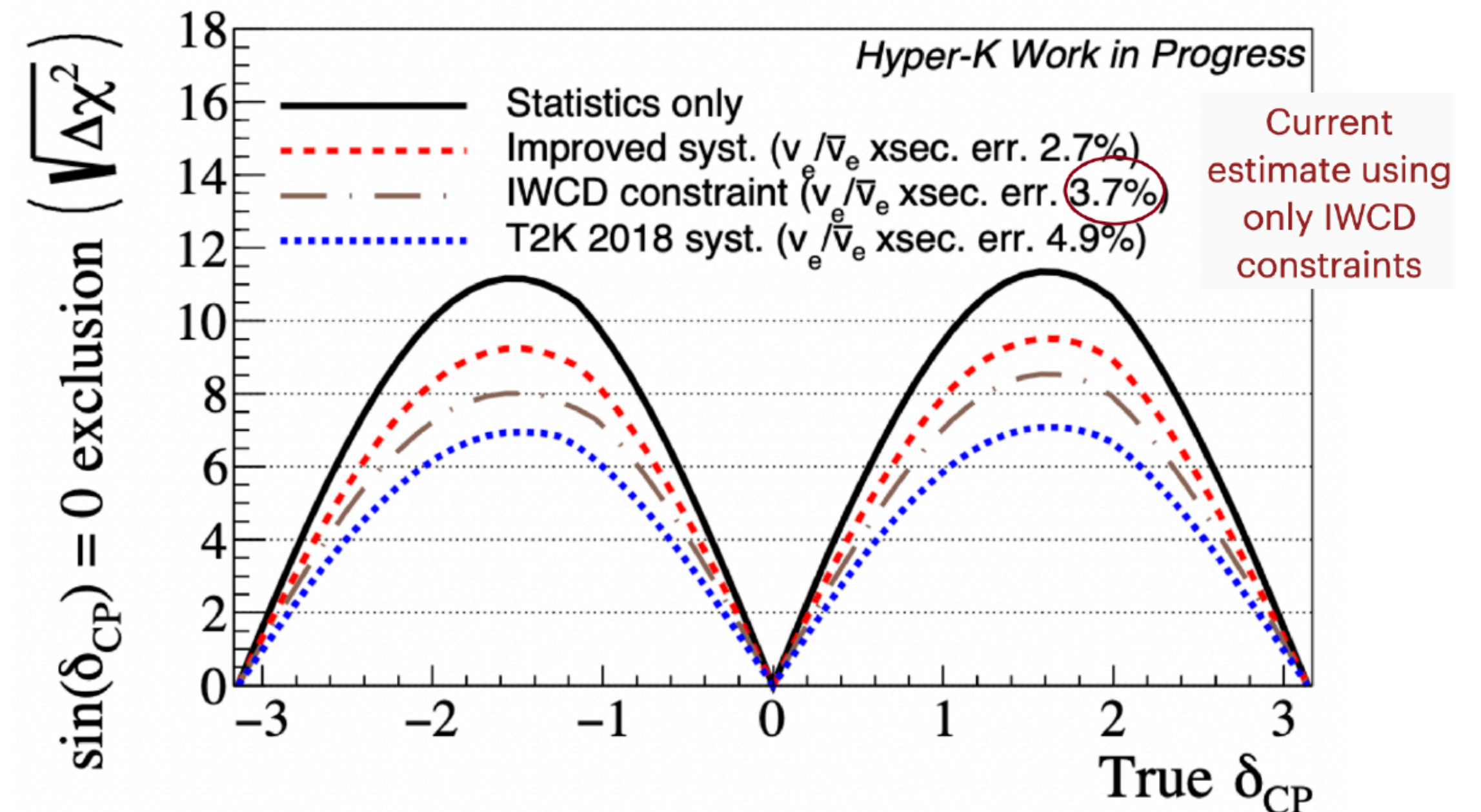


Plan to reduce systematics

Example: $\nu_e/\bar{\nu}_e$ cross-section ratio uncertainty

With **only IWCD**, could reach a **$\sim 3.7\%$** uncertainty

With **ND280 upgrade (++) and IWCD**, the goal is to go **below 3%** uncertainty after 10 years of HK-LBL

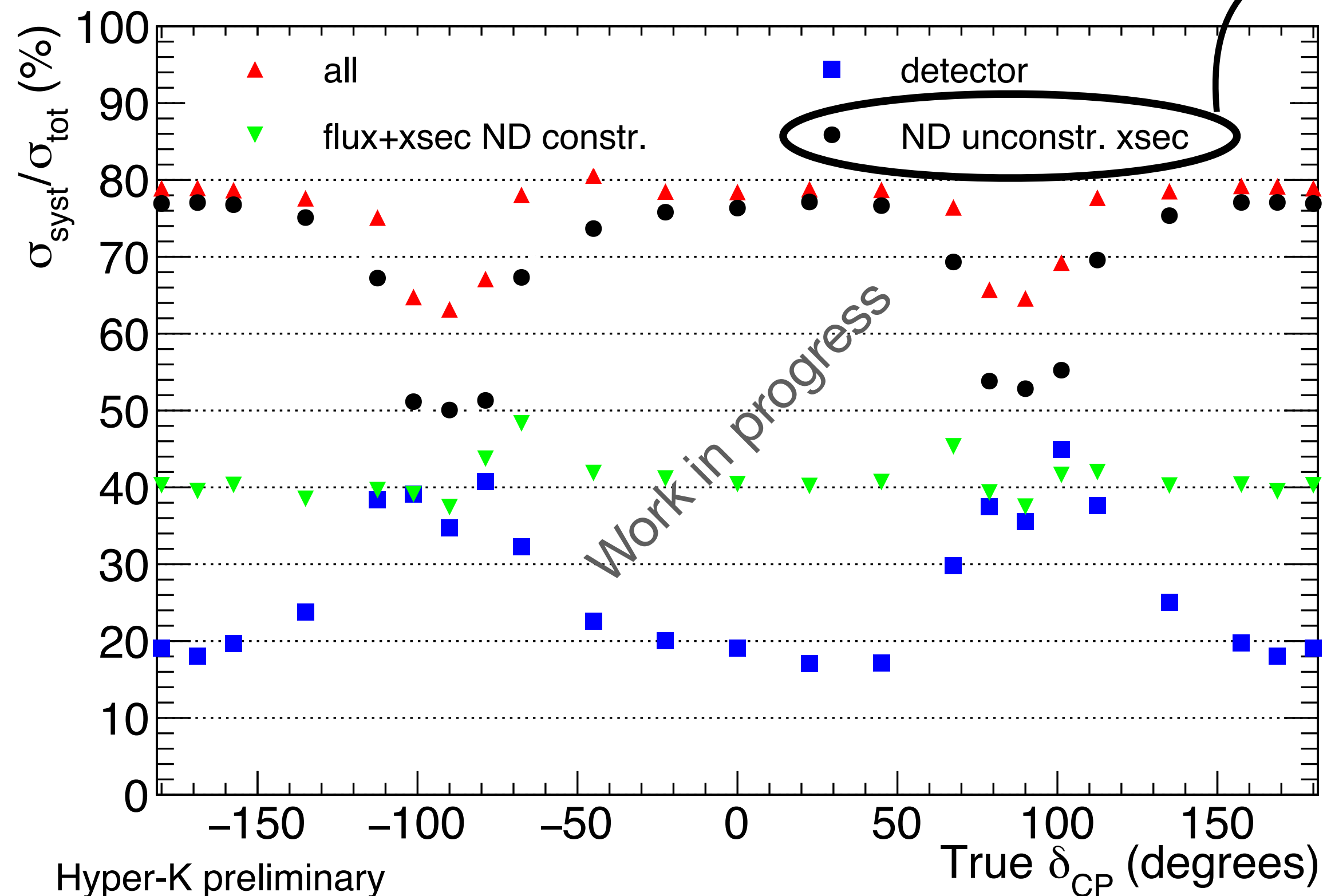


Significance level to exclude the CP-conserving values (0 and $\pm\pi$) of δ_{CP} after 10 years with HK.

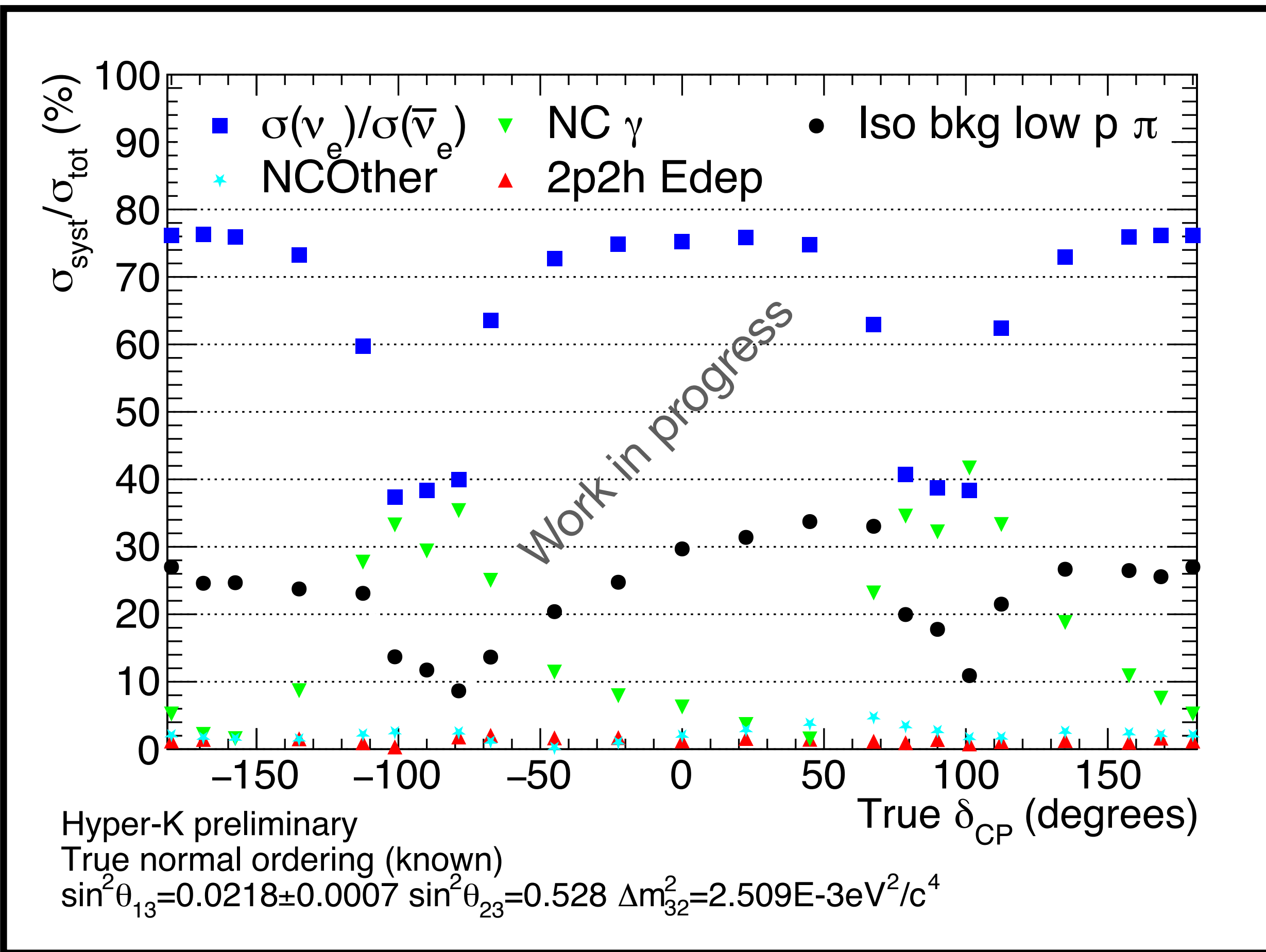
Plan to reduce systematics



Systematics not currently measured by ND280



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 True normal ordering (known)
 $\sin^2\theta_{13}=0.0218\pm 0.0007$ $\sin^2\theta_{23}=0.528$ $\Delta m_{32}^2=2.509E-3eV^2/c^4$

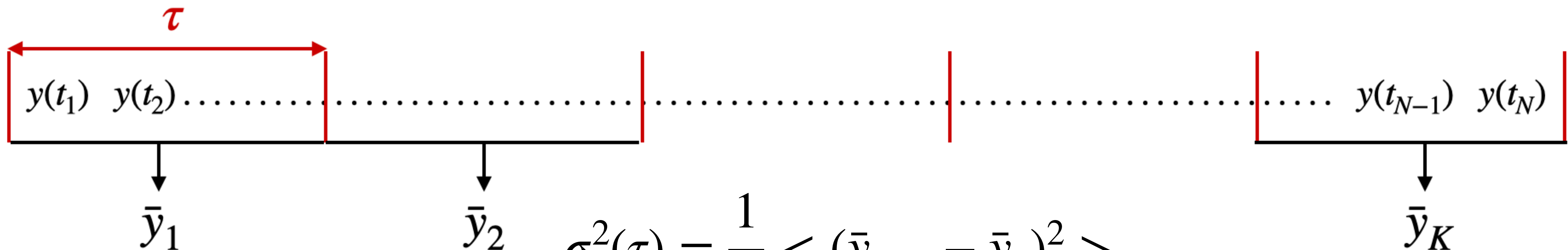


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Timing distribution

Equipment characterisation

The Allan Standard Deviation is used to characterise the stability of a signal compared to another using **frequency ratio** y . For N measurements, we split the measurement time into K time intervals of a given length τ .



Difference of the mean of y for two consecutive intervals of length τ

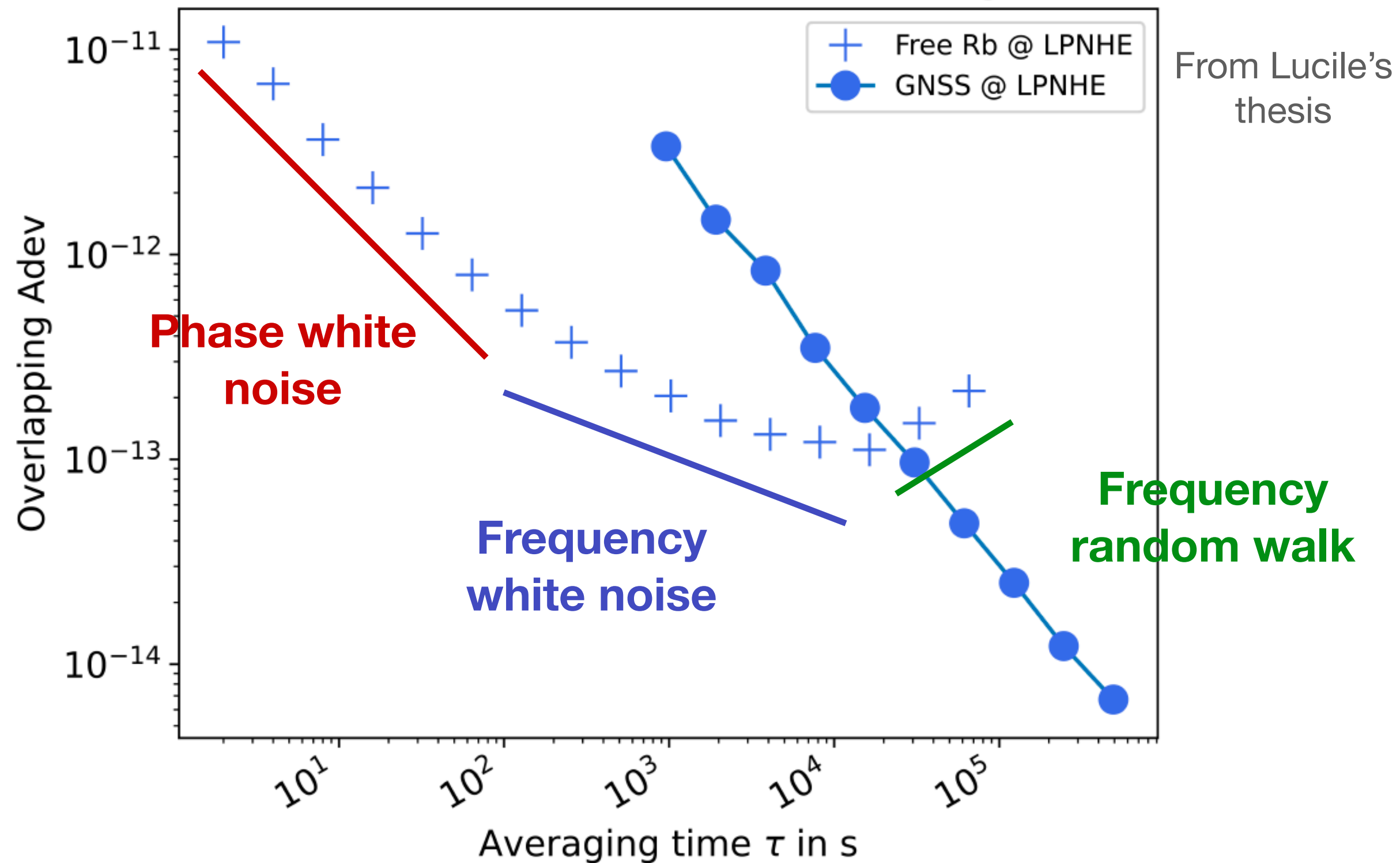
A similar formula can be derived for overlapping intervals and for time differences instead of frequency ratios

Timing distribution

Equipment characterisation

The ASD $\sigma(\tau)$ can then be plotted as function of τ . The dependency in τ depends on the type of noise in the signal.

Allan standard deviations of free Rb clock and GPS signals @ LPNHE



The Rubidium signal is more stable than the GNSS at short term but gets worse at long term because of the frequency random walk.

Need to correct the long term instability due to the frequency random walk

From Lucile's thesis



Timing distribution

Rubidium clock signal correction

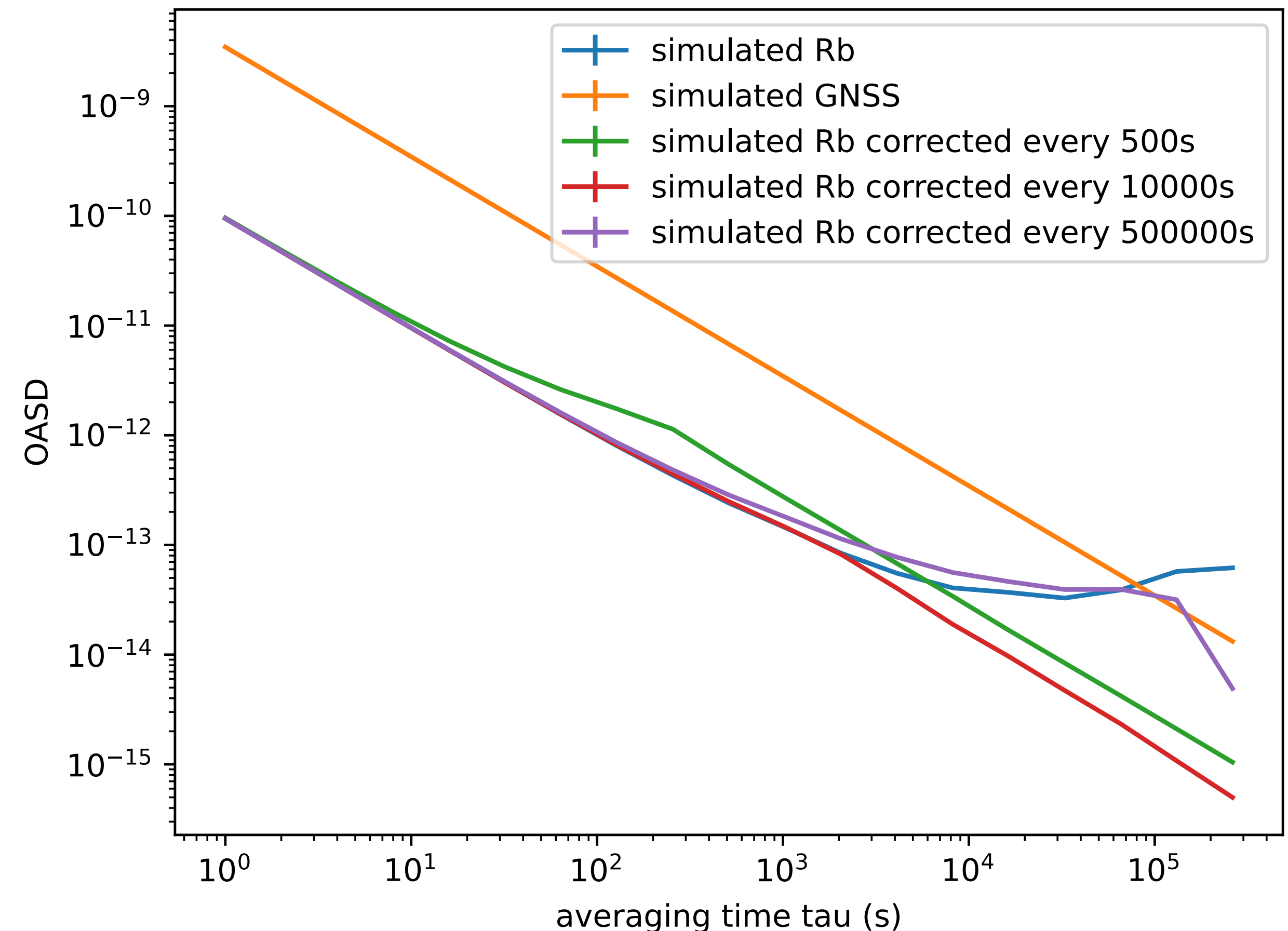
The frequency random walk leads to a polynomial time dependency of the time differences between the Rb and the GNSS PPS:

$$t_{Rb}^i - t_{GNSS}^i = a \times t_i^2 + b \times t_i + c \text{ for } i^{th} \text{ measurement}$$

So one can **regularly** fit $\Delta t_{Rb,GNSS}(t)$ and correct:

$$t_{Rb,corr}^i = t_{Rb}^i - (a \times t_i^2 + b \times t_i + c)$$

Measurement in progress to try the correction with experimental data.

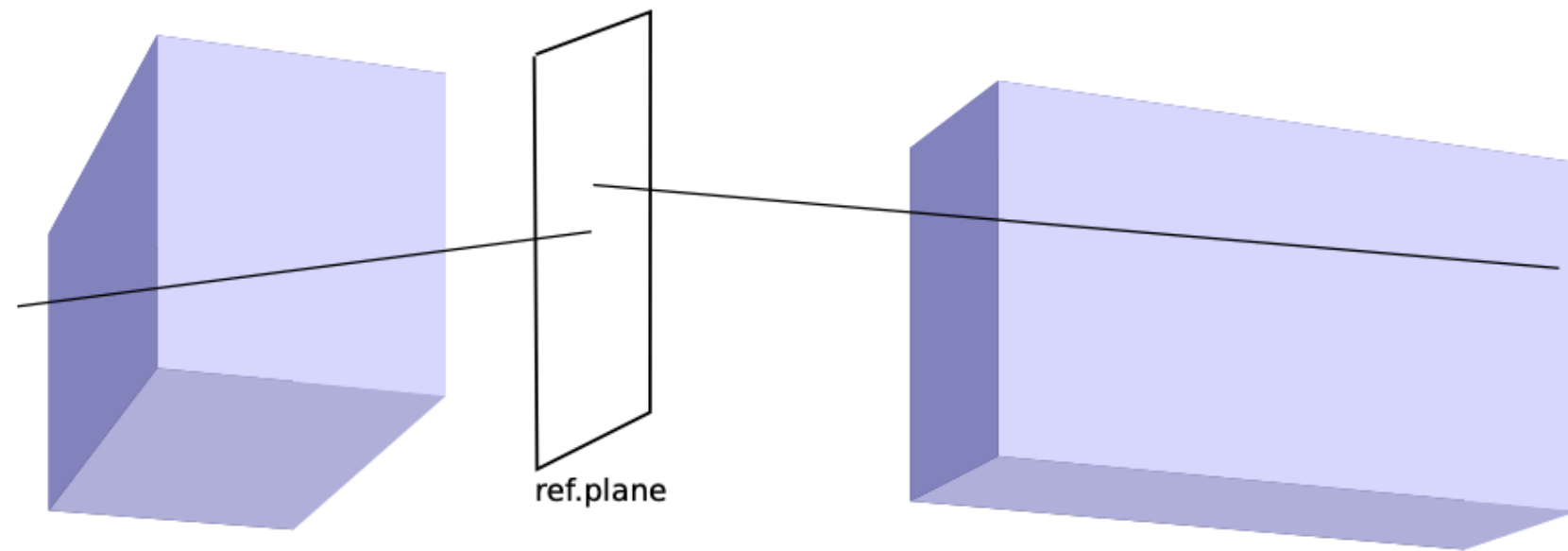


Field off alignment procedure

Description



Take main-vertex tracks, dissect to local tracks, refit them locally, check mismatch.



Local tracks parametrisation

$$x = M_x + (z - z_{ref}) \cdot N_x$$

$$y = M_y + (z - z_{ref}) \cdot N_y$$

Each chamber has 8 unknowns: $\theta_x, \theta_y, \theta_z, x_0, z_0, v_{drift}, t_0, y_0$.

Assume that e.g. downstream chamber is calibrated (except for t_0, y_0): our reference.

Field off alignment procedure

Description

For field off data and approximately horizontal tracks ($N_y \approx 0$):

$$\Delta N_x = (N_x^2 + 1) \cdot \theta_y$$

$$\Delta N_y = -N_x \cdot \theta_z + \theta_x$$

$$\Delta M_x = (\theta_x \cdot M_y + \theta_y \cdot M_x + z_0) \cdot N_x + \theta_y \cdot z + \theta_x \cdot M_y - x_0$$

First calibrate rotations using ΔN_x vs N_x and ΔN_y vs N_y . Then correct and calibrate x_0 and z_0 using ΔM_x vs N_x .



Field off alignment procedure

Workflow

- A working example with documentation of the chain is at [Shine/Applications/Examples2022Plus/Calibration/AlignmentFieldOff](#)
- Calibration done in three steps:
 1. MTPCL vs GRC
 2. VTPC2, FTPC1, FTPC2 vs MTPCL
 3. FTPC3 vs FTPC2 and others vs VTPC2



Field off alignment procedure

Workflow

- A working example with documentation of the chain is at [Shine/Applications/Examples2022Plus/Calibration/AlignmentFieldOff](#)
- Calibration done in three steps
- At each step, iterate the mismatch analysis to calibrate:
 - A. Rotation angles (field off data only, not necessary for MTPCL)
 - B. x_0 and z_0 (field off data only, not necessary for MTPCL)
 - C. Drift velocity
 - D. t_0
 - E. y_0