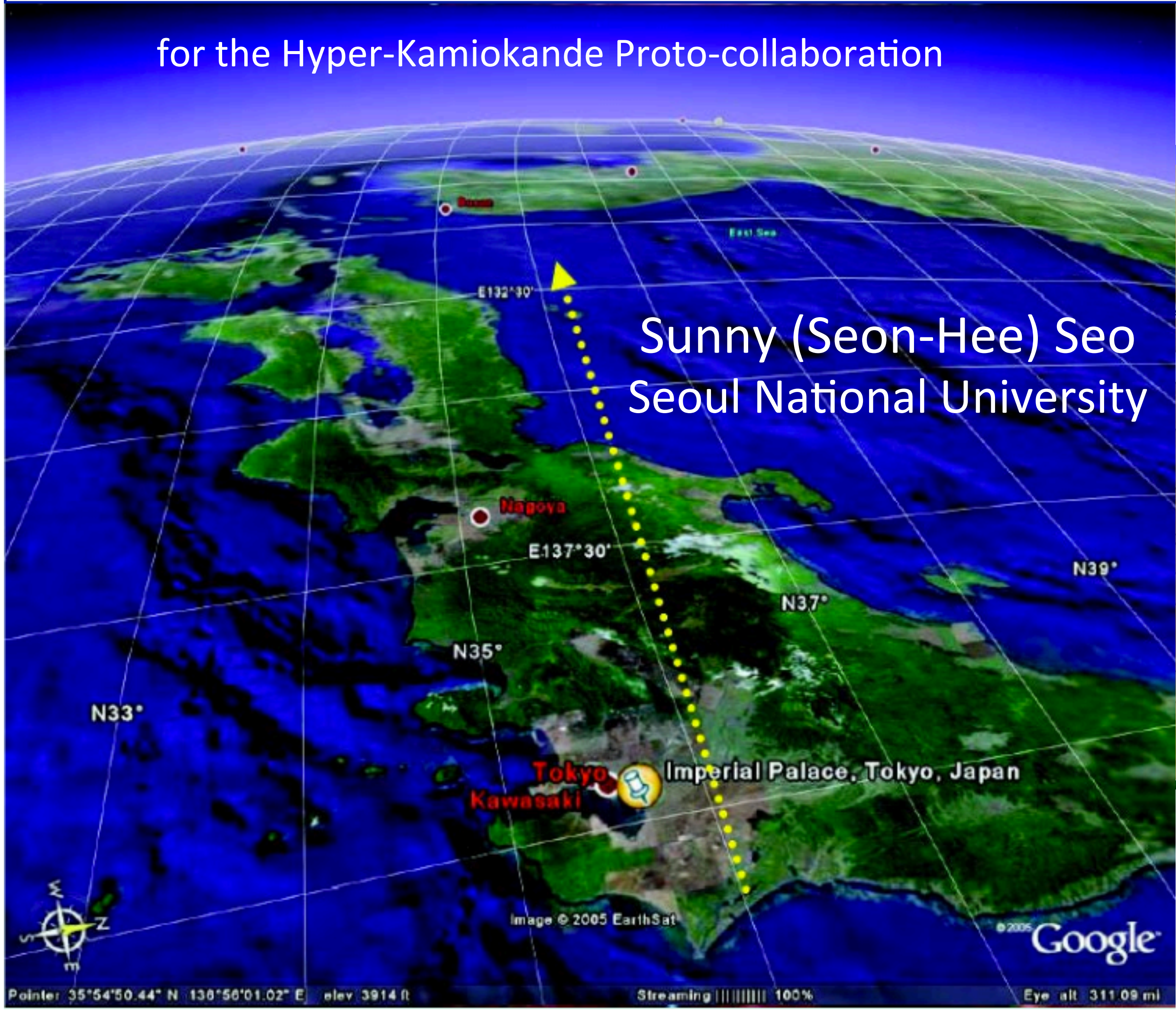
The 2nd Hyper-K detector in Korea

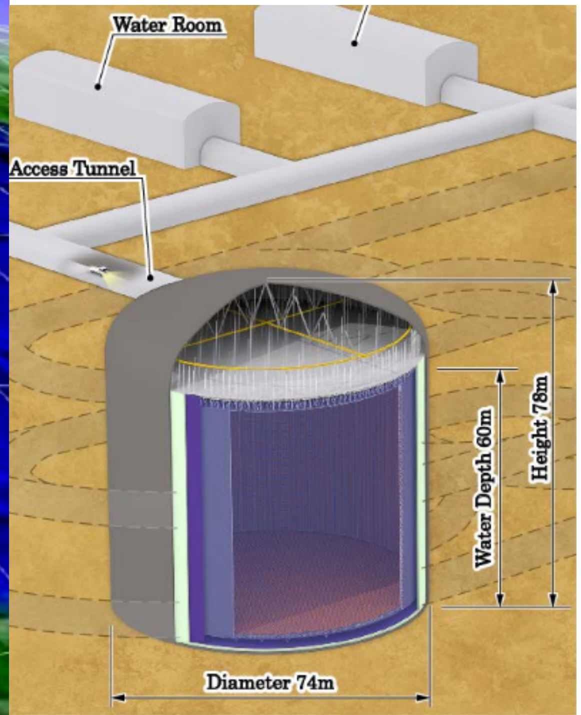
TAUP 2017, Sudbury, ON, Canada

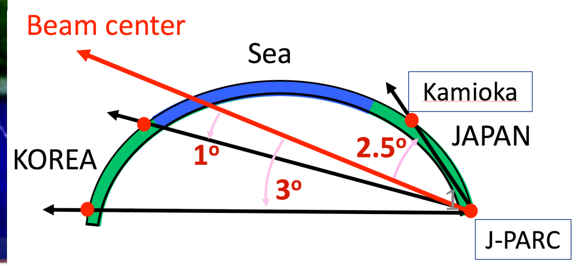
for the Hyper-Kamiokande Proto-collaboration

Sunny (Seon-Hee) Seo
Seoul National University



Hyper-Kamiokande



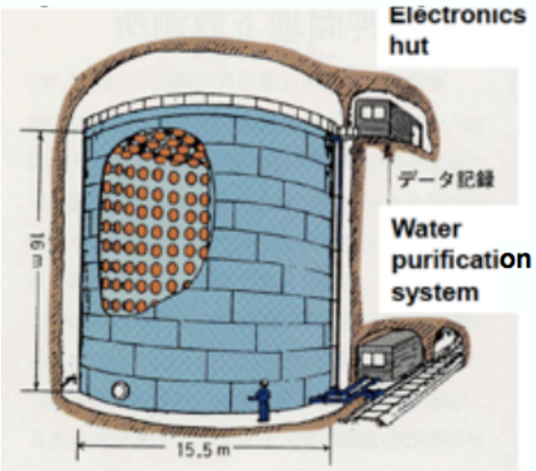


3 Generations of Kamiokande

3,000 ton

Kamiokande

1983–1996



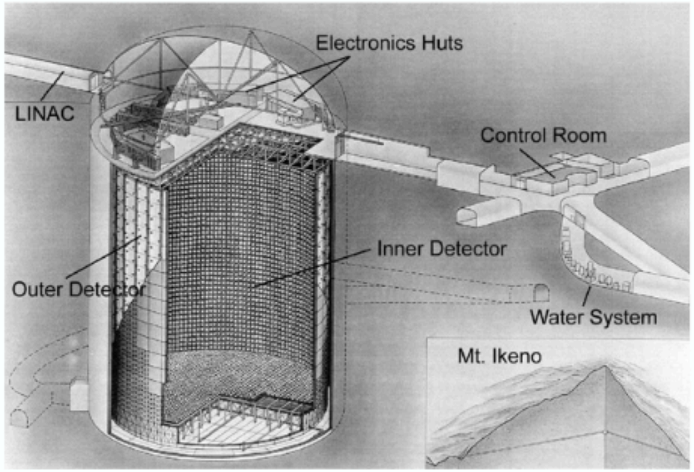

Koshiba, 2002

SN1987a

50,000 ton

Super-Kamiokande

1996–today (and beyond)



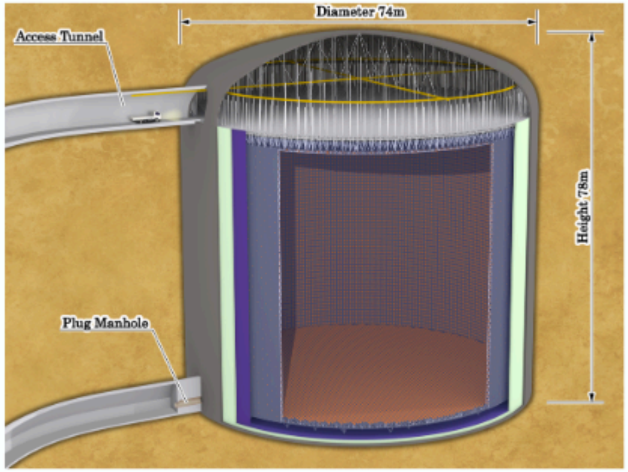

Kajita, 2015

ν oscillation

2 x 260,000 ton

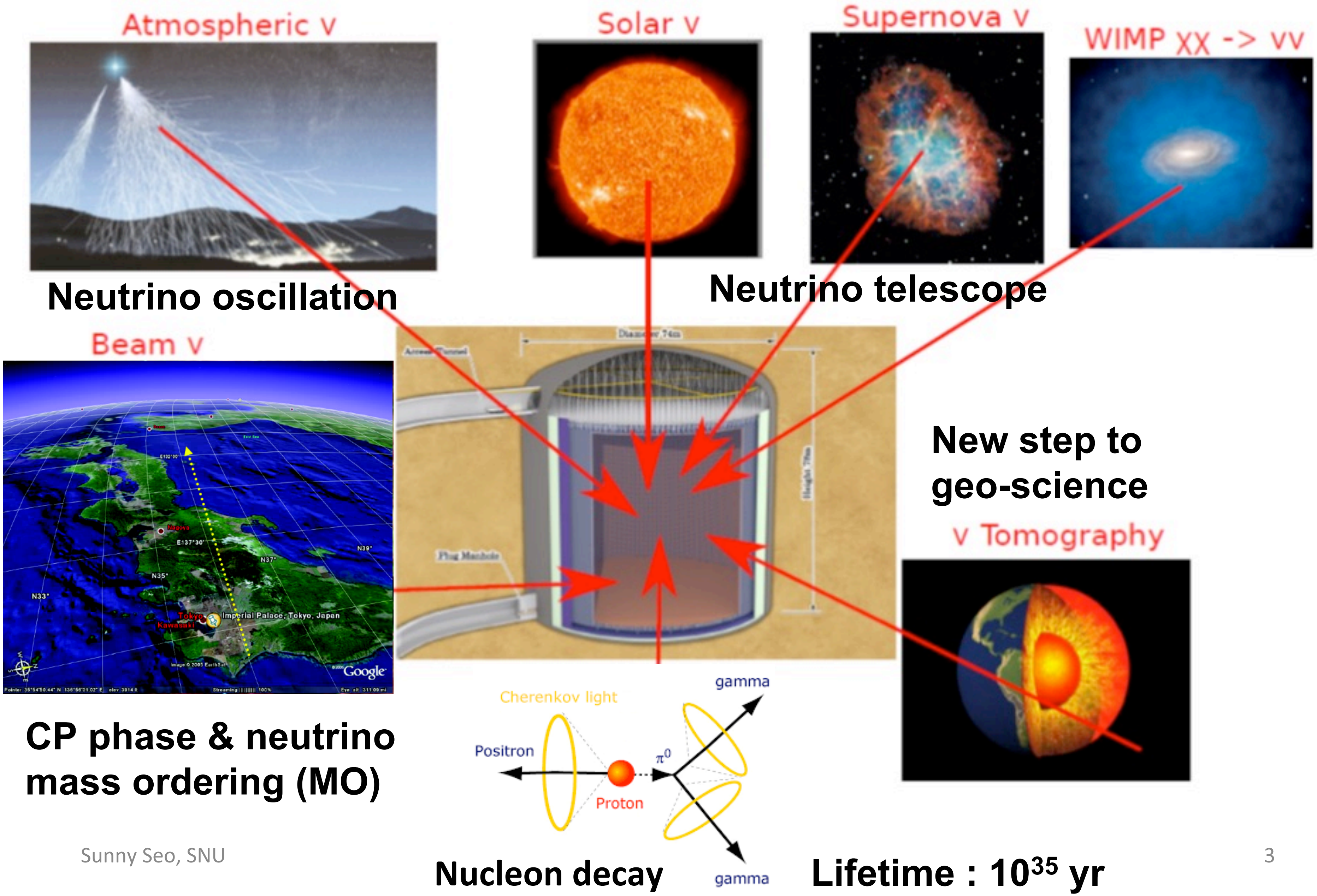
Hyper-Kamiokande

~2026–???

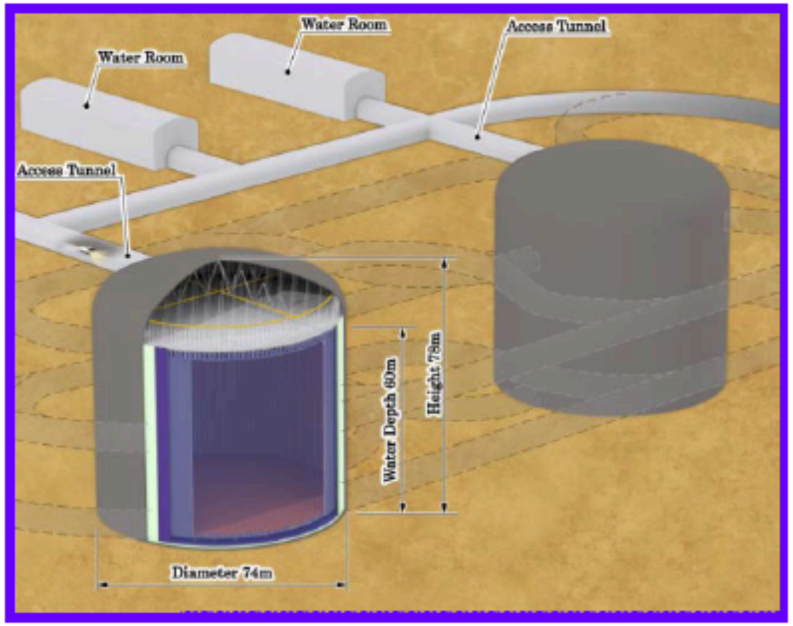



???, 20??

Hyper-K Physics Program

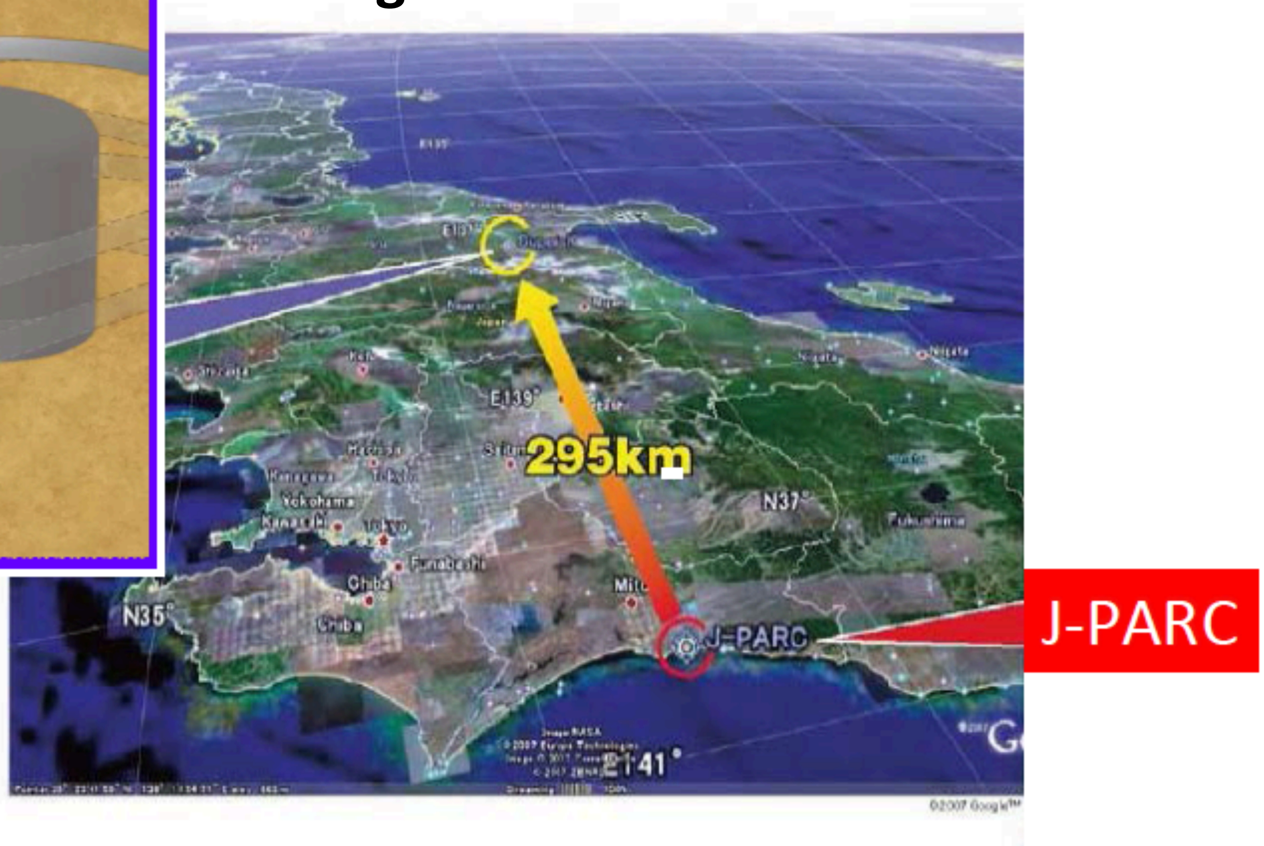


Hyper-Kamiokande (Hyper-K)

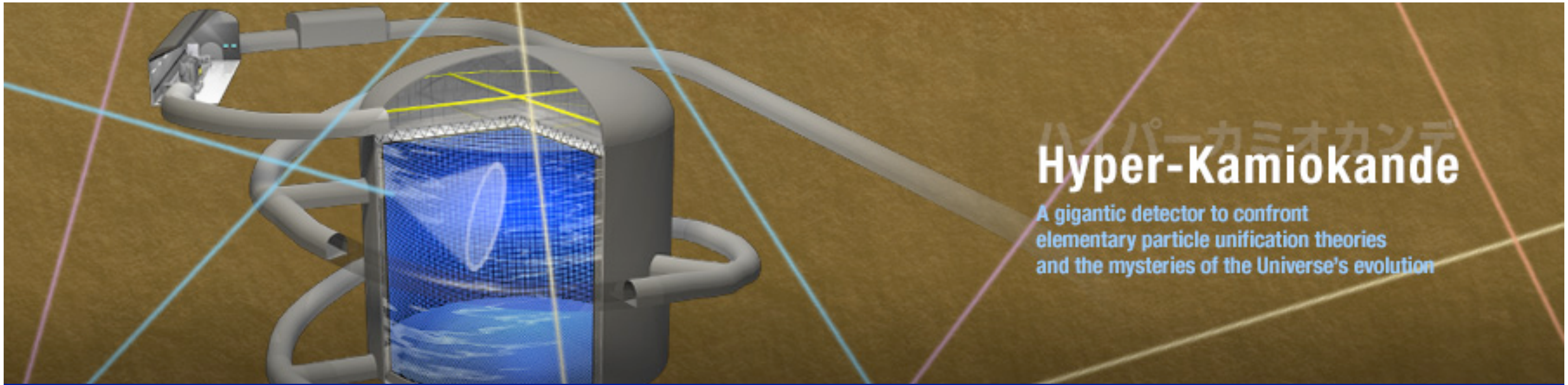


Hyper-K

Inauguration: Jan. 2015



Hyper-K proto-collaboration: 15 countries, ~300 members and growing



Hyper-K Strategy

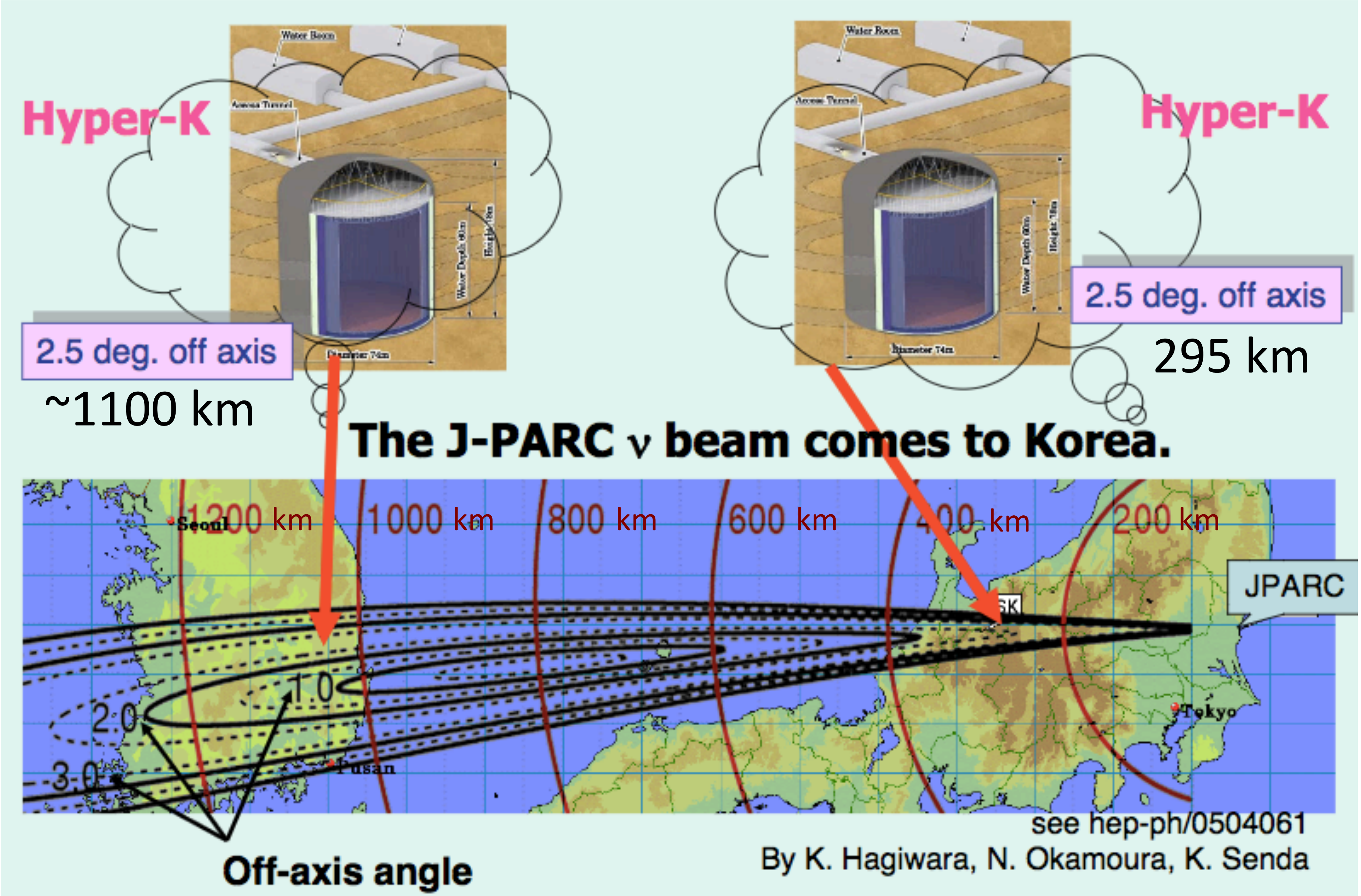
❑ Realize 1st tank quickly

- Status: -- Selected in the future roadmap of Japan by MEXT.
  -- Funding application is on-going.
- Data taking: 2026 (if funding approval by the end of 2017)

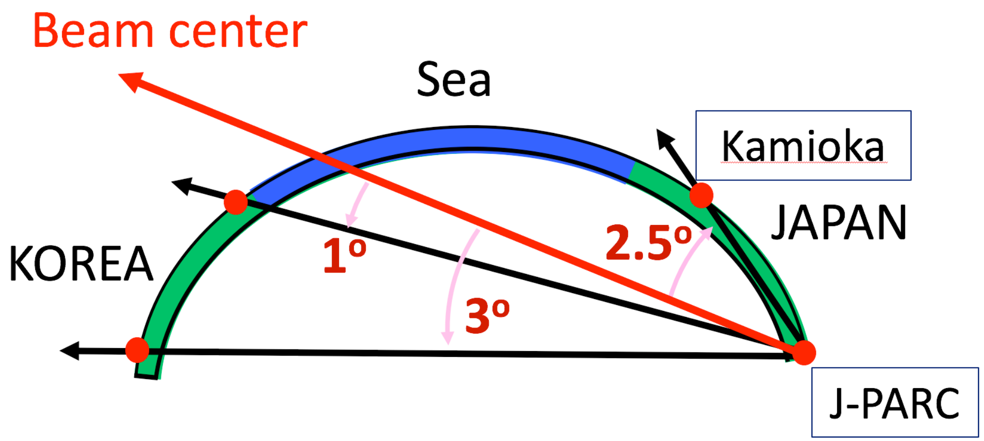
❑ The 2nd tank options

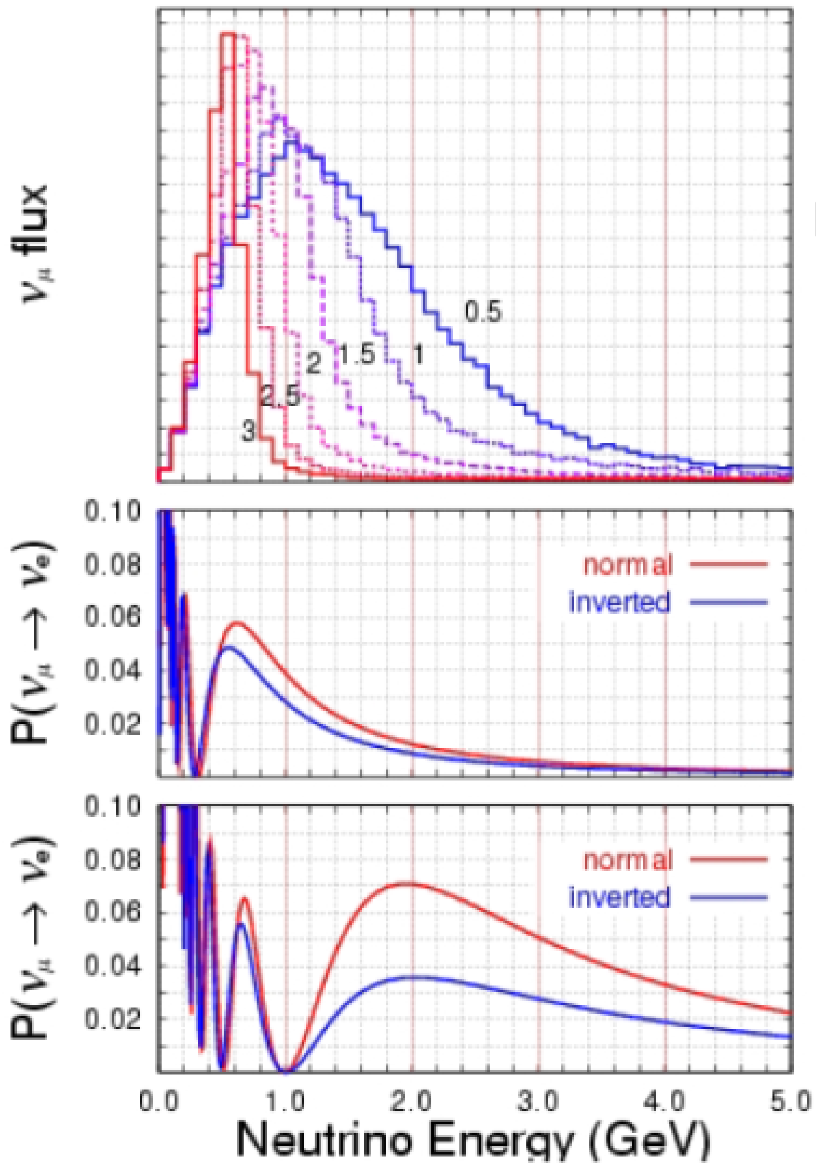
- Default: 2nd tank in Kamioka (295 km) with 6 years of delay
- **Alternative: 2nd tank in Korea (~1100 km) ASAP**

The 2nd Hyper-K Detector in Korea



Neutrino Oscillations in Kamioka & Korea





← Profile of off-axis beams

← $P(\nu_\mu \to \nu_e)$ at SK/HK (Japan)
(L = 295 km)

← $P(\nu_\mu \to \nu_e)$ at Korea
(L=1000km)

Unique benefits of a Korean Detector

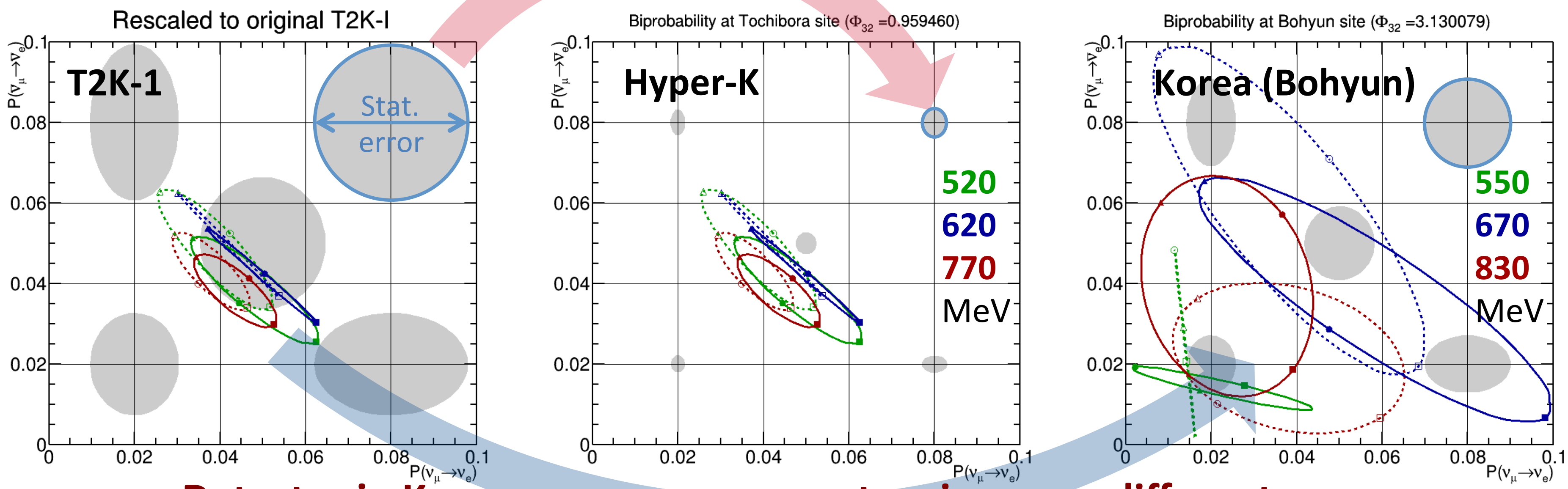
Biprobablitiy plots often used to compare experiments. (e.g. T2K vs NOνA). Extend these to multiple energies, to gain understanding of 2nd maxima measurement.

Larger ellipses mean less sensitivity to systematic errors.
Shape differences unpick degeneracies with other parameters. (e.g. θ_{23})

Blue: Energy of peak QE rate
Red: median of high-energy tail
Green: " " low-energy "

Solid lines: Normal Hierarchy
Dotted lines: Inverted Hierarchy

New detector at Kamioka improves statistics



Detector in Korea measures parameters in a very different way

Benefits of T2HKK

T2HKK = **T**okai to(**2**) **HK** to **K**orea

The following physics sensitivities are improved by locating the 2nd detector to Korea

- Neutrino mass ordering determination
- Leptonic CP violation phase measurement

← **1st&2nd oscillation maxima**

- Non-standard neutrino interaction

← **Higher ν energy**
Longer baseline
Higher matter density

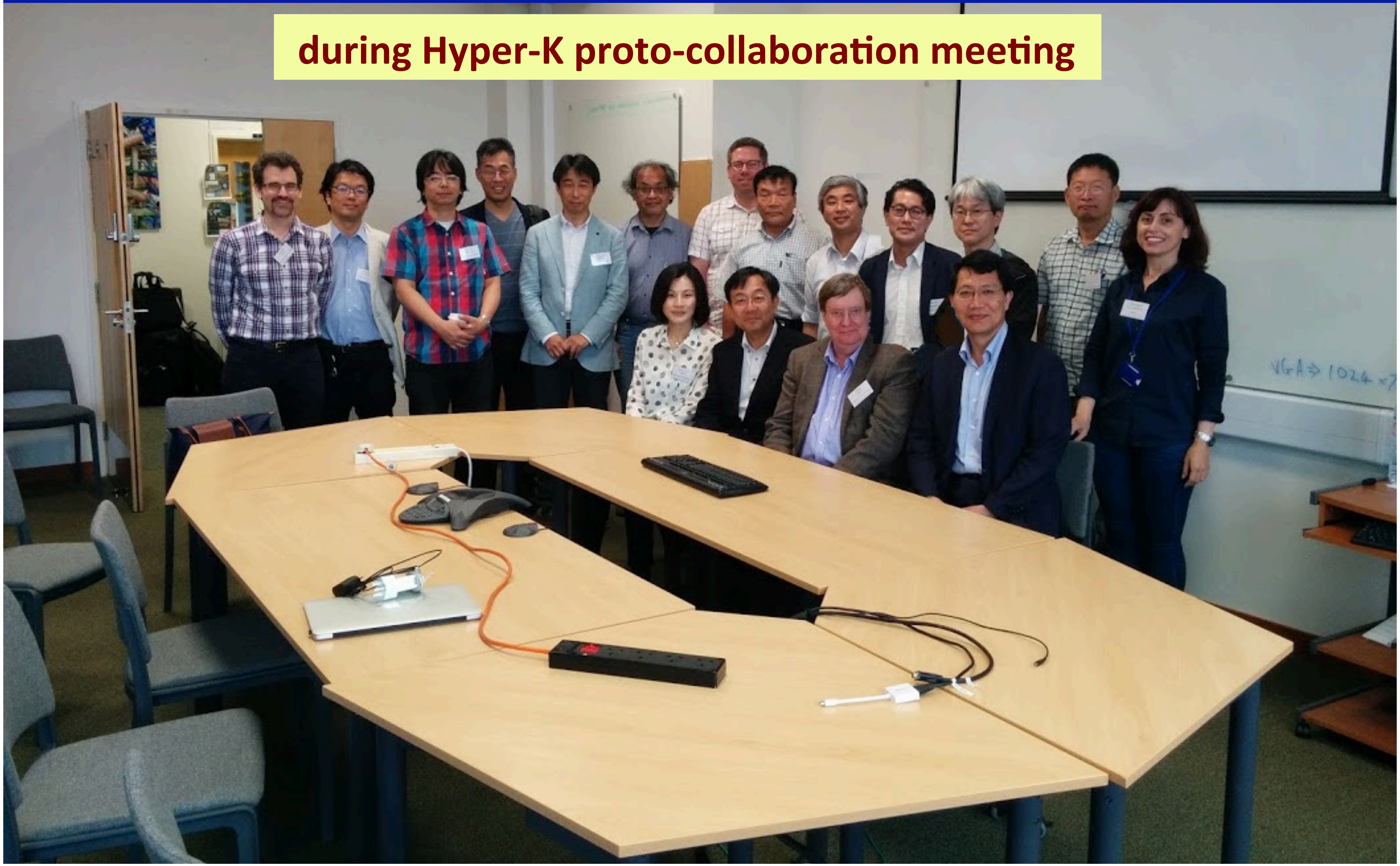
- Solar/SN/SRN/ν geo physics sensitivities

← **Deeper site: 650 vs. 1000 m**

T2HKK Inauguration

July 10th 2016, London

during Hyper-K proto-collaboration meeting



T2HKK White Paper

November 21st 2016

~ 4 months later
from the inauguration

arXiv:1611.06118

(60 pages)

Physics Potentials with the Second Hyper-Kamiokande Detector in Korea

(Hyper-Kamiokande Proto-Collaboration)

K. Abe,[57,59] Ke. Abe,[24] H. Aihara,[59,60] A. Aimi,[18] R. Akutsu,[58] C. Andreopoulos,[28,43] I. Anghel,[21] L.H.V. Anthony,[28] M. Antonova,[20] Y. Ashida,[25] M. Barbi,[44] G.J. Barker,[66] G. Barr,[40] P. Beltrame,[11] V. Berardi,[16] M. Bergevin,[3] S. Berkman,[2] T. Berry,[45] S. Bhadra,[73] F.d.M. Blaszczyk,[1] A. Blondel,[12] S. Bolognesi,[6] S.B. Boyd,[66] A. Bravar,[12]

1st T2HKK Workshop @SNU

- 1st T2HKK workshop (Nov. 21-22) at SNU was successfully finished.

δ_{CP} & MO Sensitivity Studies

Simulation parameters

- 2.7×10^{22} POT with $\nu : \bar{\nu} = 1 : 3$ operation ratio

  → 10 years of operation with 1.3 MW beam

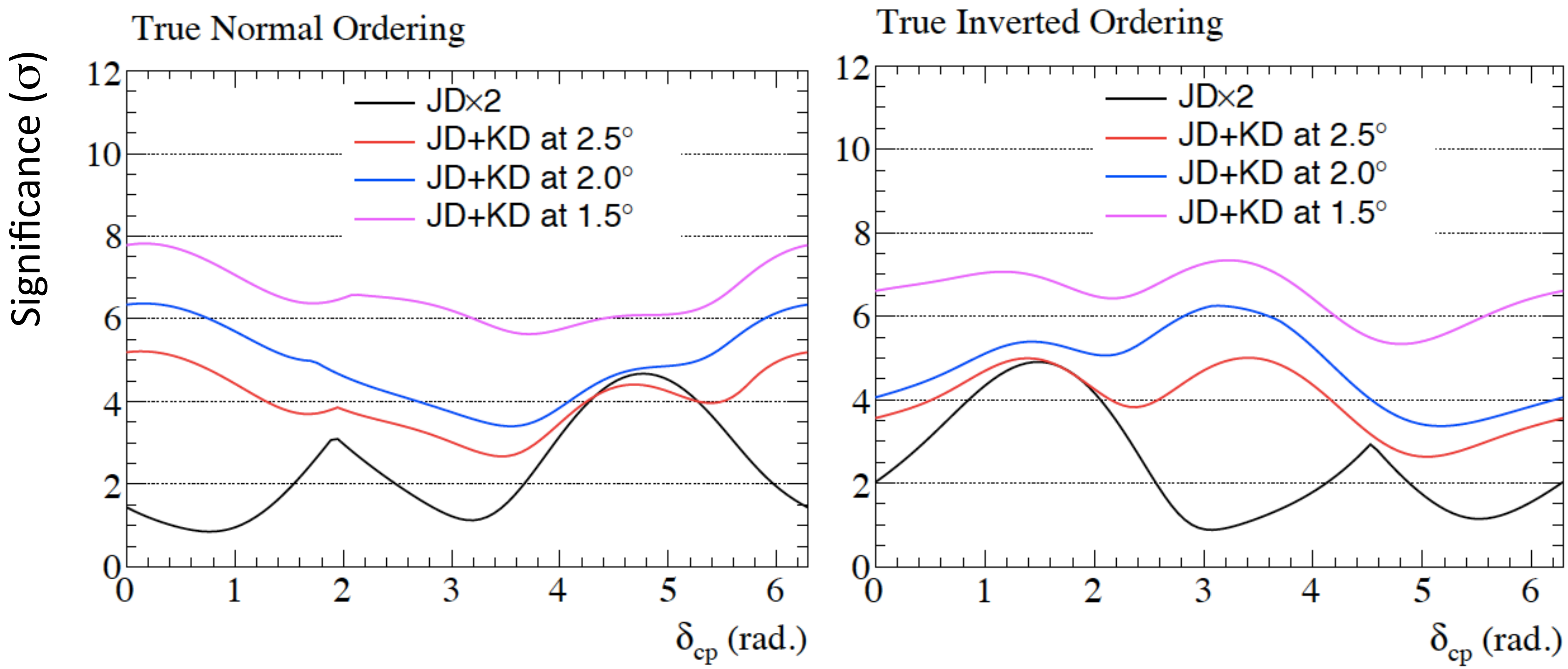
- 187 kton fiducial volume (compared to 22.5 kton for SK)
- Baseline to Korea is 1100 km
- Off-axis beam: 1.5°, 2.0°, 2.5°
- Oscillation parameters: →

$$|\Delta m^2_{32}| = 2.5 \times 10^{-3}\ \text{eV}$$
$$\sin^2\theta_{23} = 0.5$$
$$\sin^2 2\theta_{13} = 0.085$$
$$\Delta m^2_{21} = 7.53 \times 10^{-5}\ \text{eV}$$
$$\sin^2\theta_{12} = 0.304$$
$$\delta_{cp} = 0, \pi/2, \pi, 3\pi/2$$

◆ Note: Relatively simple systematic uncertainty model is used.
More realistic systematic uncertainty implementation is needed.

Mass Ordering Sensitivities

Normal arXiv:1611.06118 Inverted



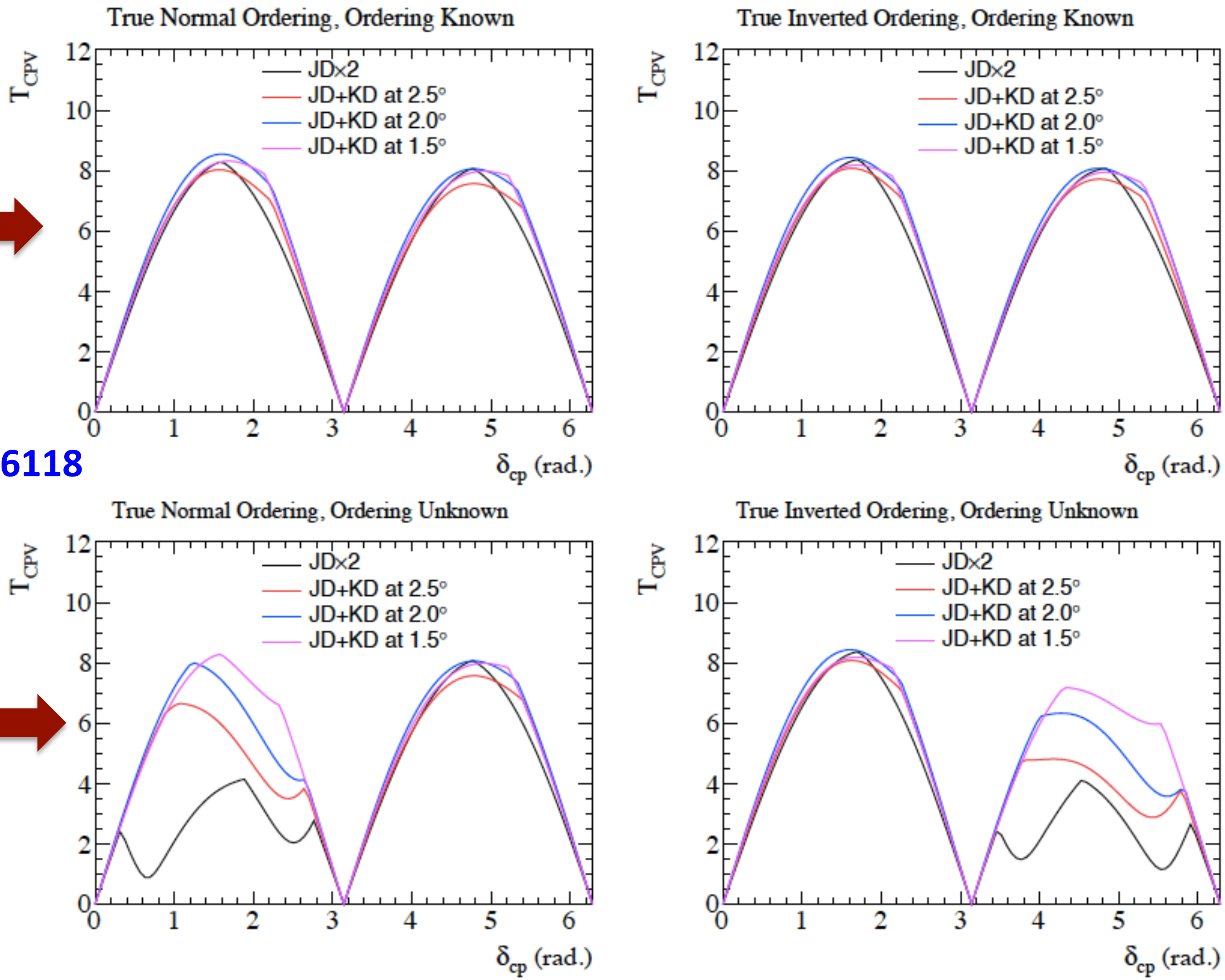
JD+KD 1.5°: 6 ~ 8 σ for all δ_{CP}
JD x2 : 1 ~ 4.5 σ for all δ_{CP}
(< 3 σ for most cases)

JD+KD 1.5°: 5.5 ~ 7 σ for all δ_{CP}
JD x2 : 1 ~ 5 σ for all δ_{CP}
(< 3 σ for most cases)

CP Sensitivities

Known MO

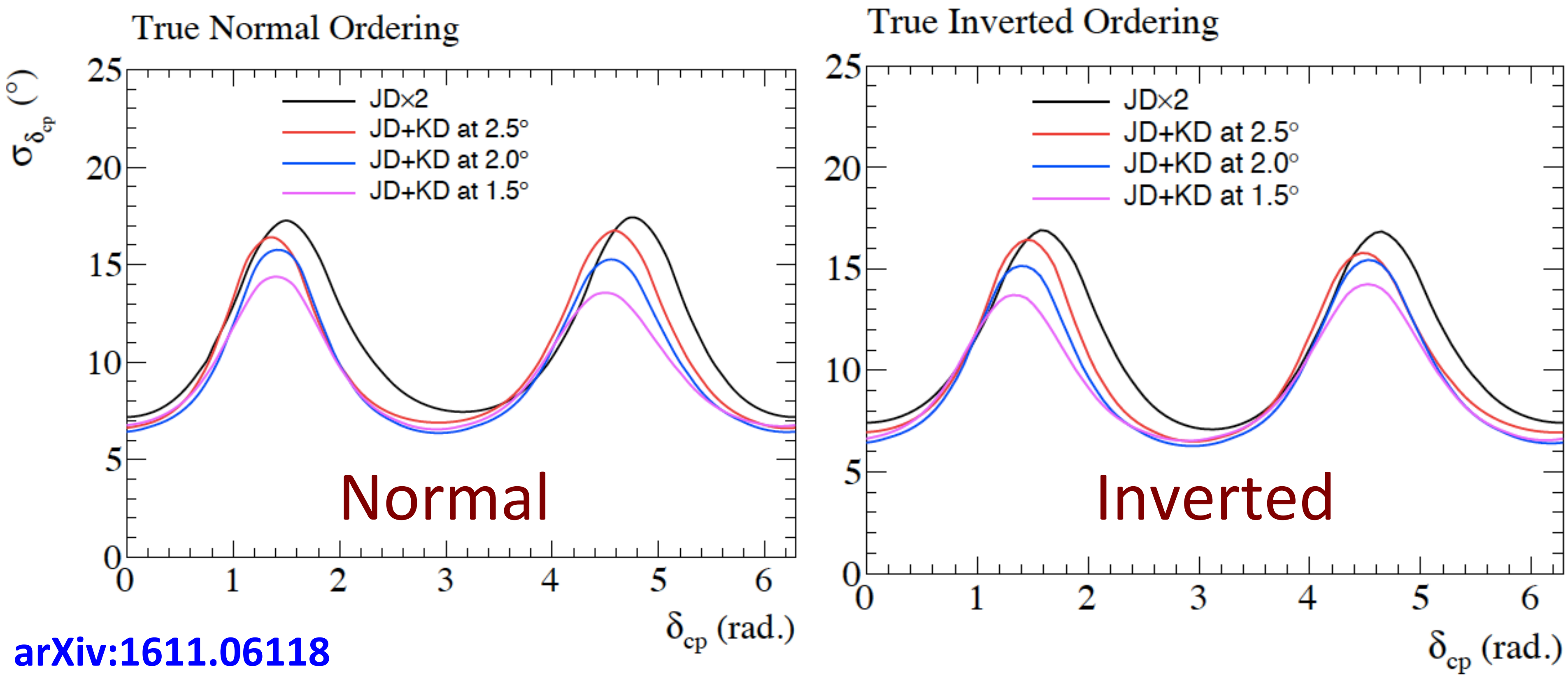
Unknown MO



arXiv:1611.06118

δ_{CP} Precision Sensitivities

→ Important for flavor symmetry model of neutrino mixing

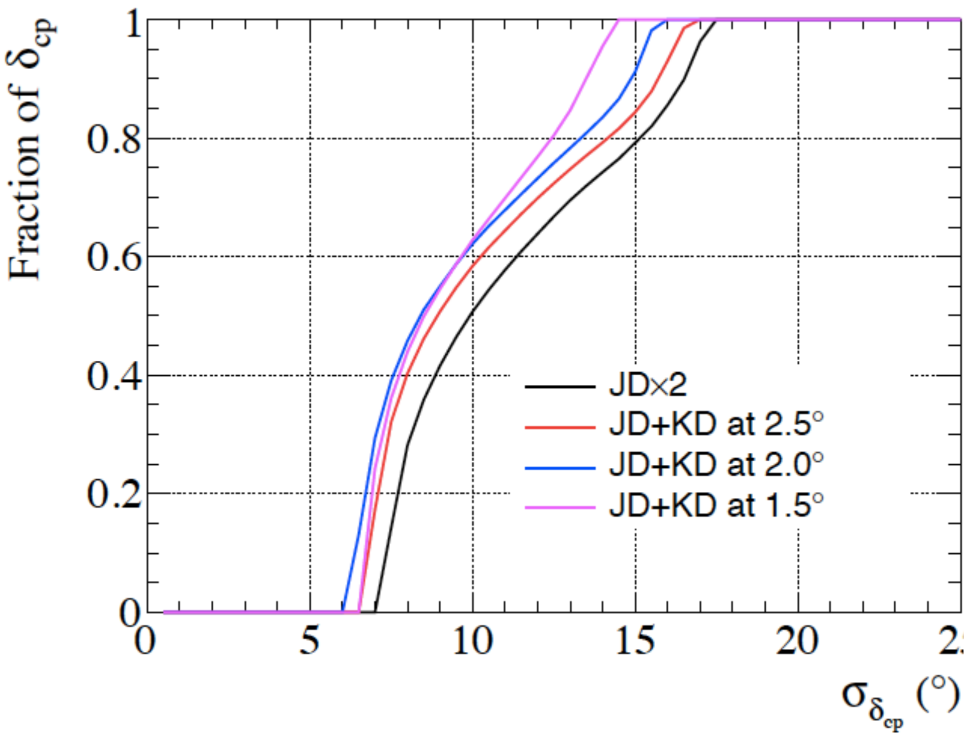


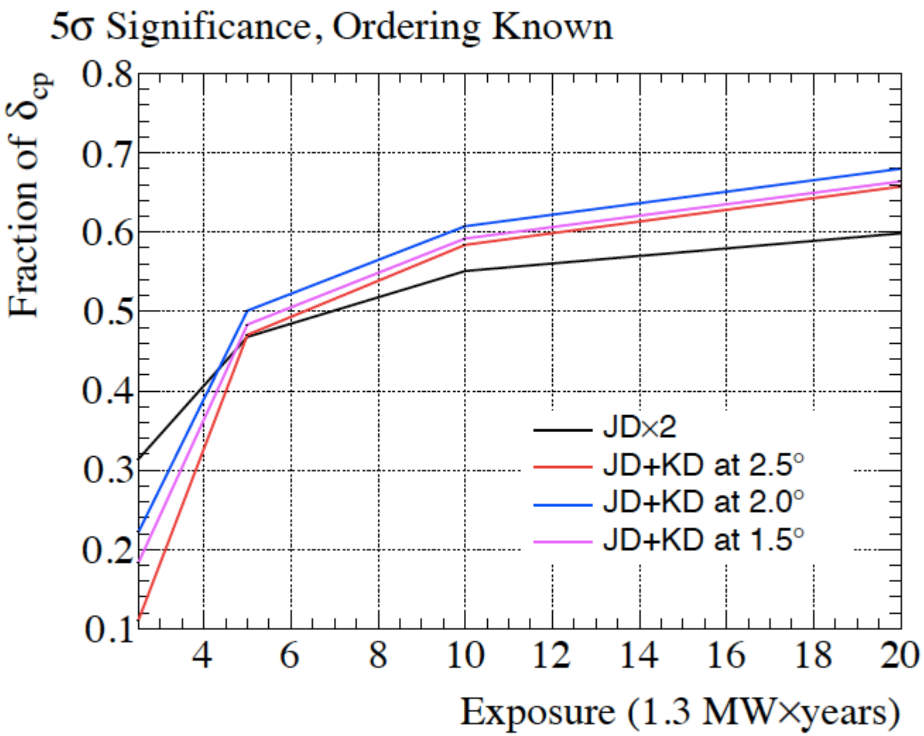
arXiv:1611.06118

At maximum CP violation: JD+KD 1.5°: $\sigma(\delta_{CP})$ = 13~14 degree
JD x2 : $\sigma(\delta_{CP})$ ~ 17 degree

Fraction of δ_{CP}

How much fraction of δ_{CP} can we cover ?

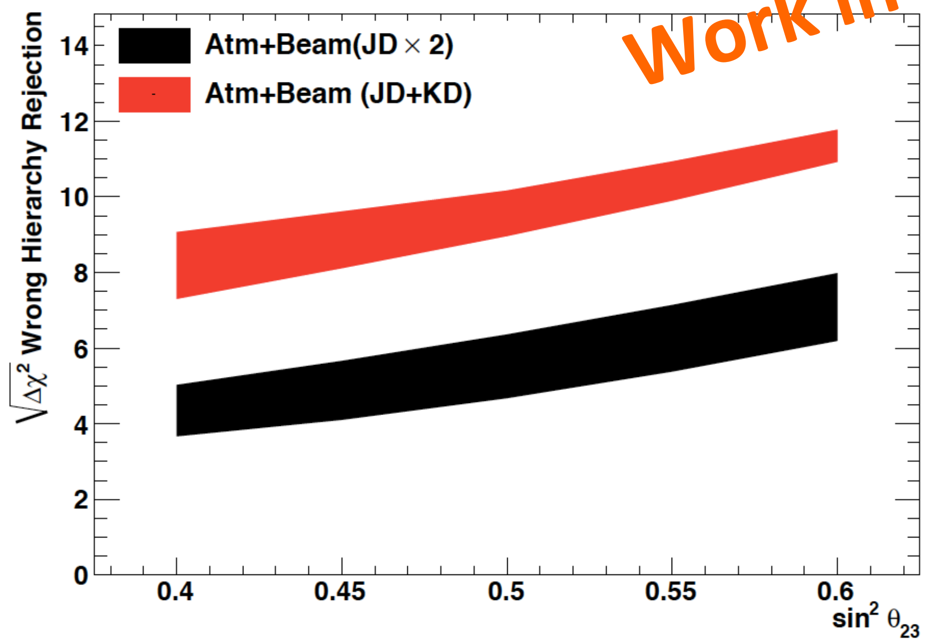


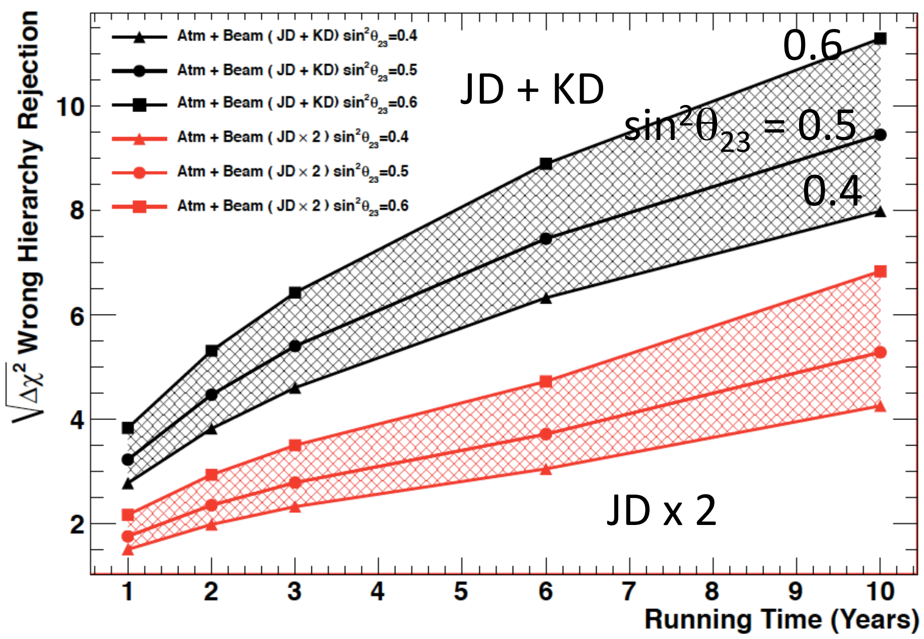


Beam + Atm. Data

Mass ordering sensitivity

Work in progress

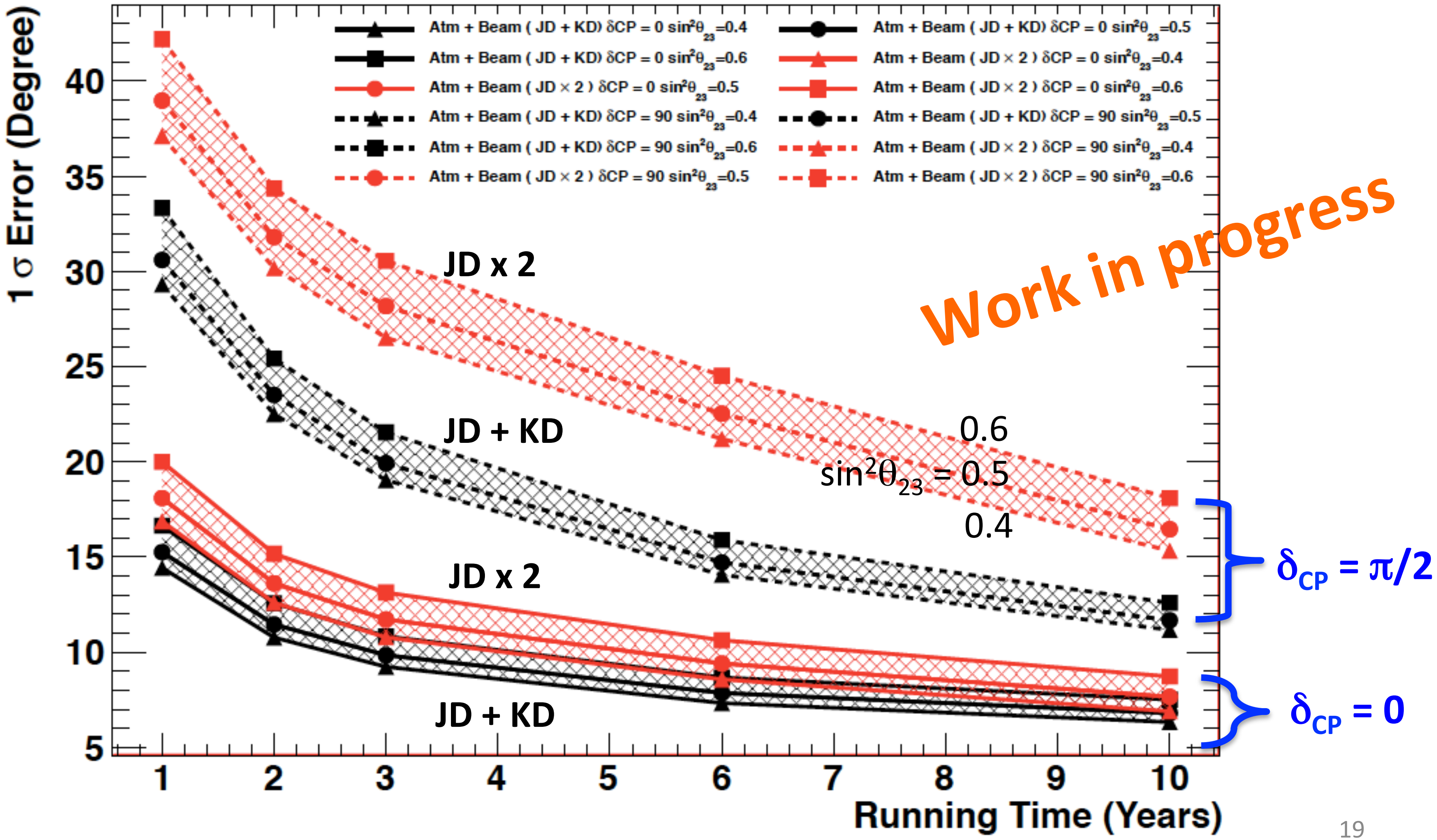




- Beam+atm. Results will be included in the upcoming white paper update.

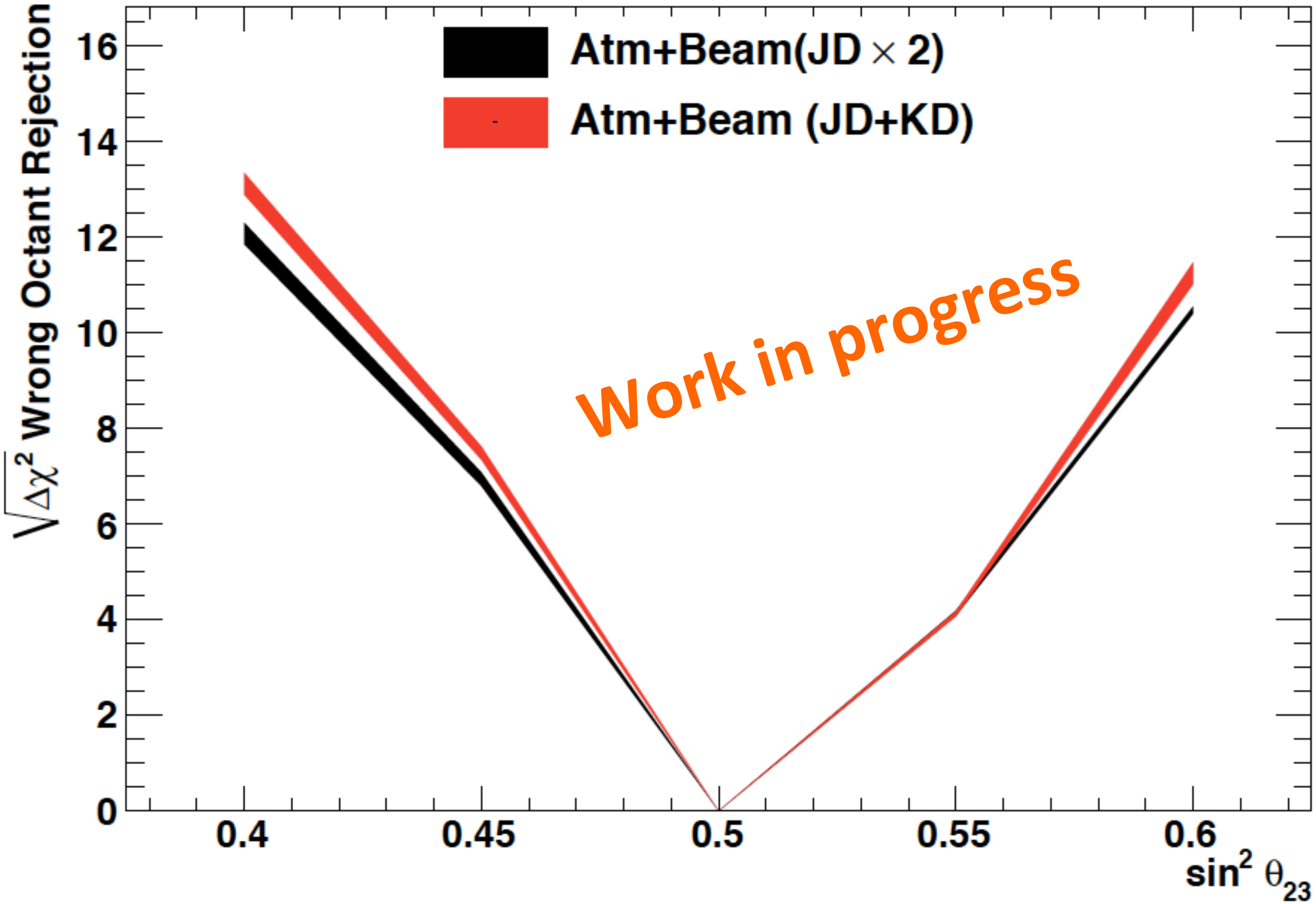
Beam + Atm. Data

δ_{CP} precision sensitivity



Beam + Atm. Data

θ_{23} octant sensitivity

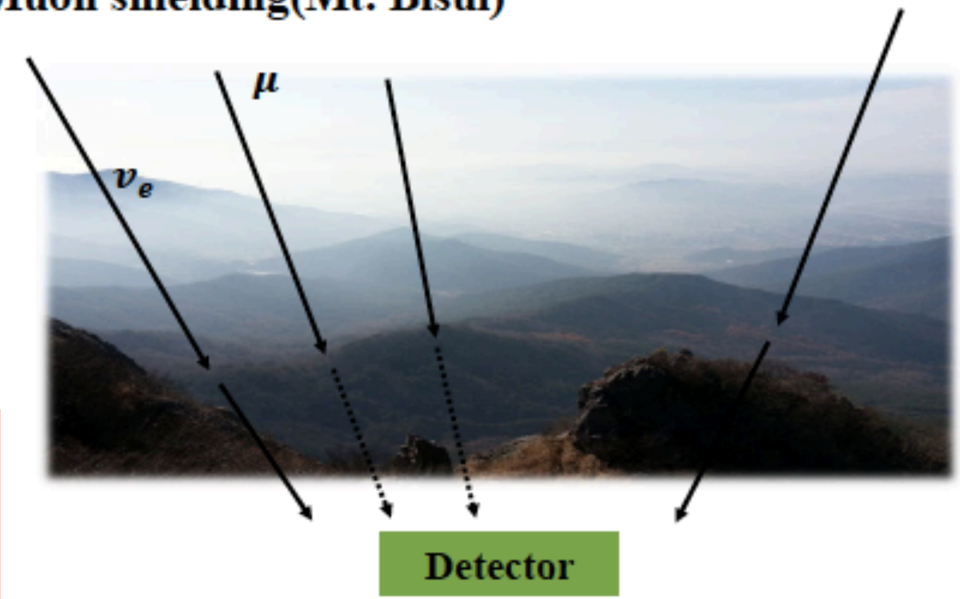


Low E benefits

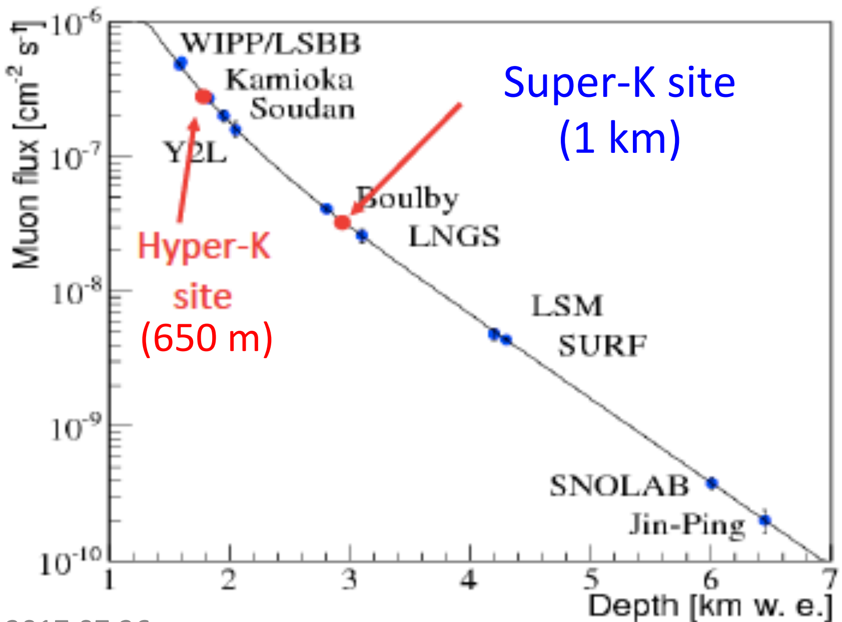
1. Deeper site:
lower muon flux,
lower spallation BKG

2. Geographical separation:
signal coincidence,
degeneracy break-up

Muon shielding(Mt. Bisul)



Due to the detector being located deep underground,
The background level is decreased



Muon flux to each laboratory

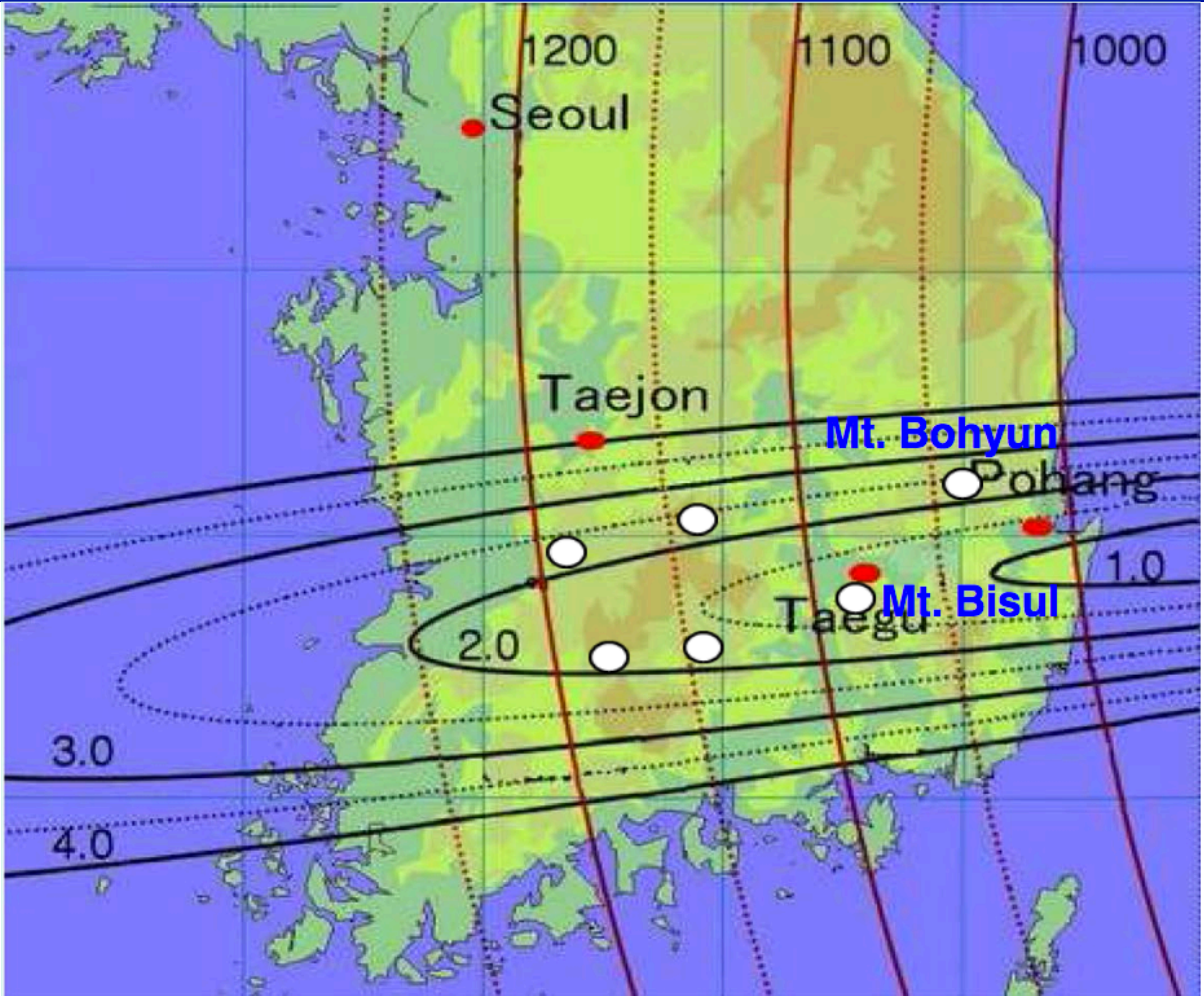
Some candidate sites in Korea

Site candidates for a 2nd osc. maximum detector in Korea

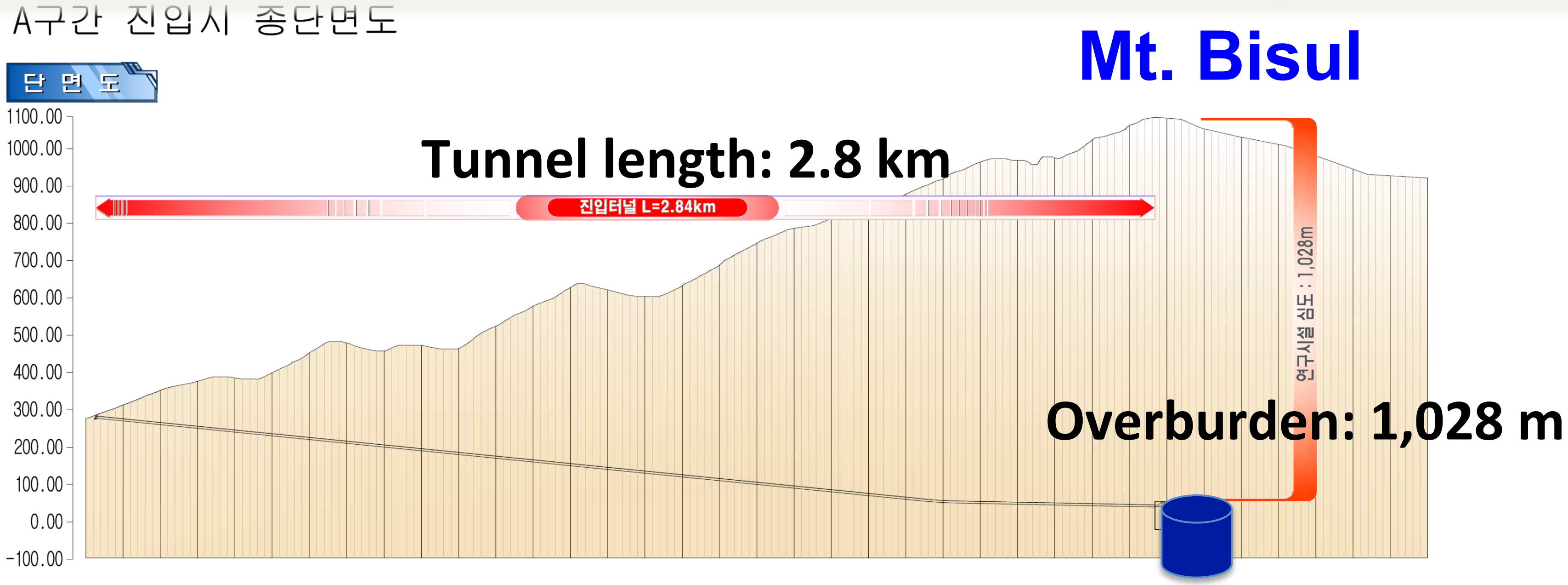
- Baselines with 1,000~1,200 km
- 2.0~2.5° or 1.5~2.0° off axis beam directions
- >1,000 m high mountains with hard granite rocks

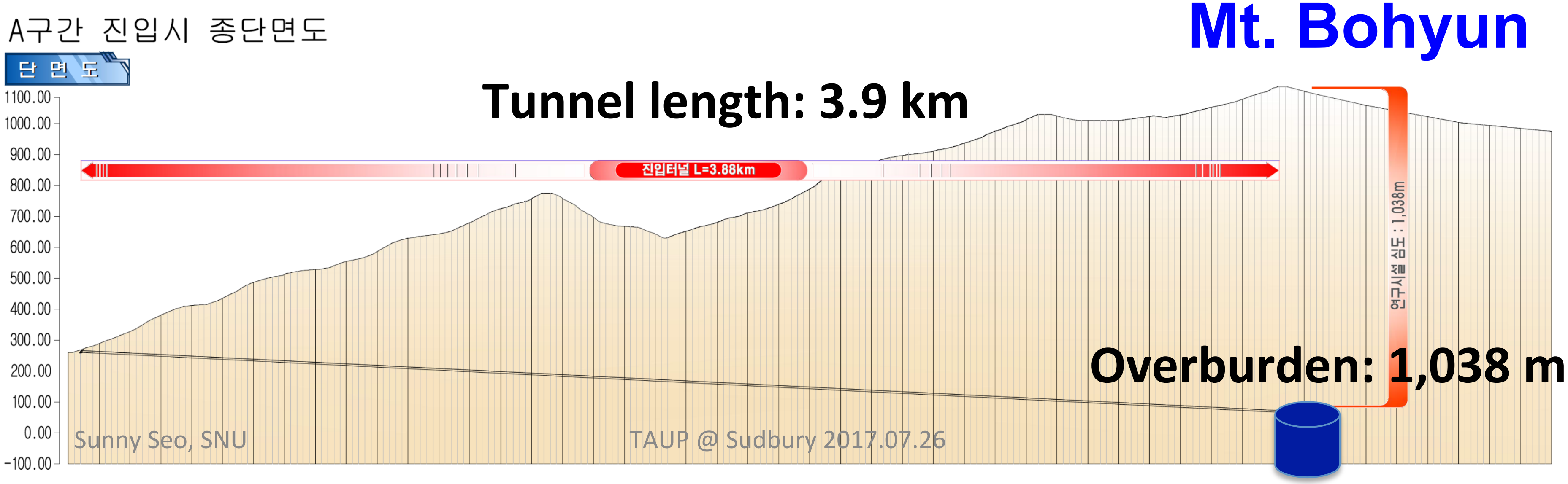
Site	OAB	Baseline [km]	Height [m]
Mt. Bisul	**~1.3°**	**1088 km**	**1084 m**
Mt. Hwangmae	~1.8°	1140 km	1113 m
Mt. Sambong	~1.9°	1180 km	1186 m
Mt. Bohyun	**~2.2°**	**1040 km**	**1126 m**
Mt. Minjuii	~2.2°	1140 km	1242 m
Mt. Unjang	~2.2°	1190 km	1125 m

Some Candidate Sites

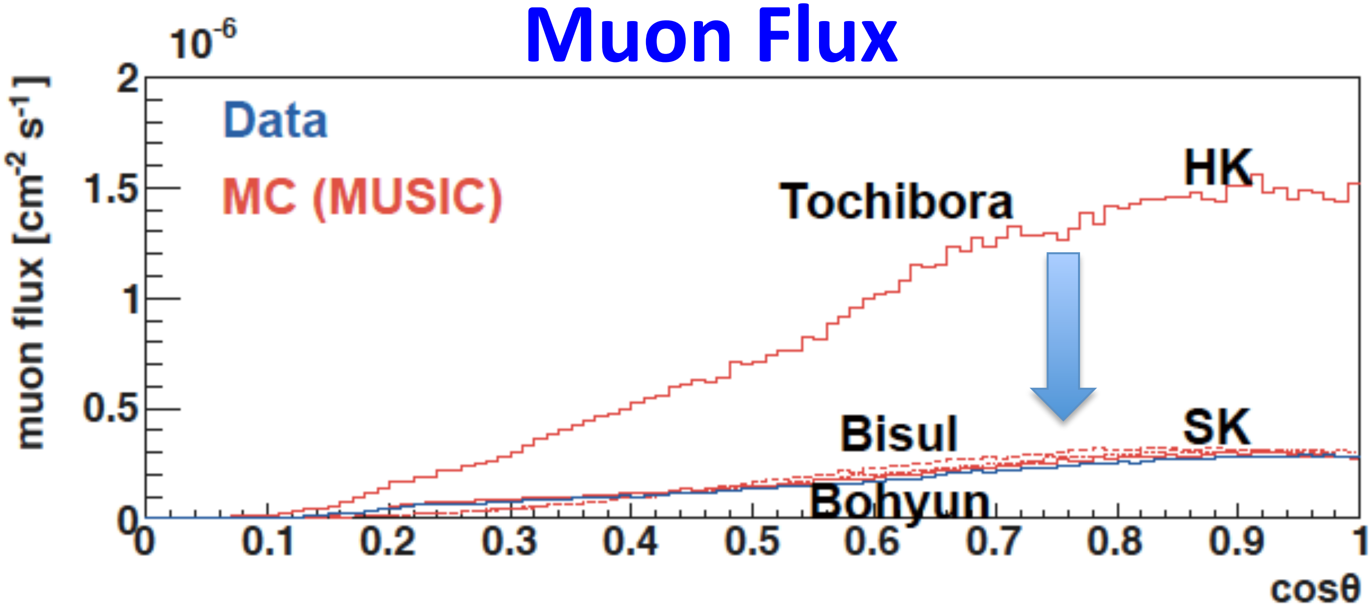


Tunnels at Mt. Bisul & Bohyun

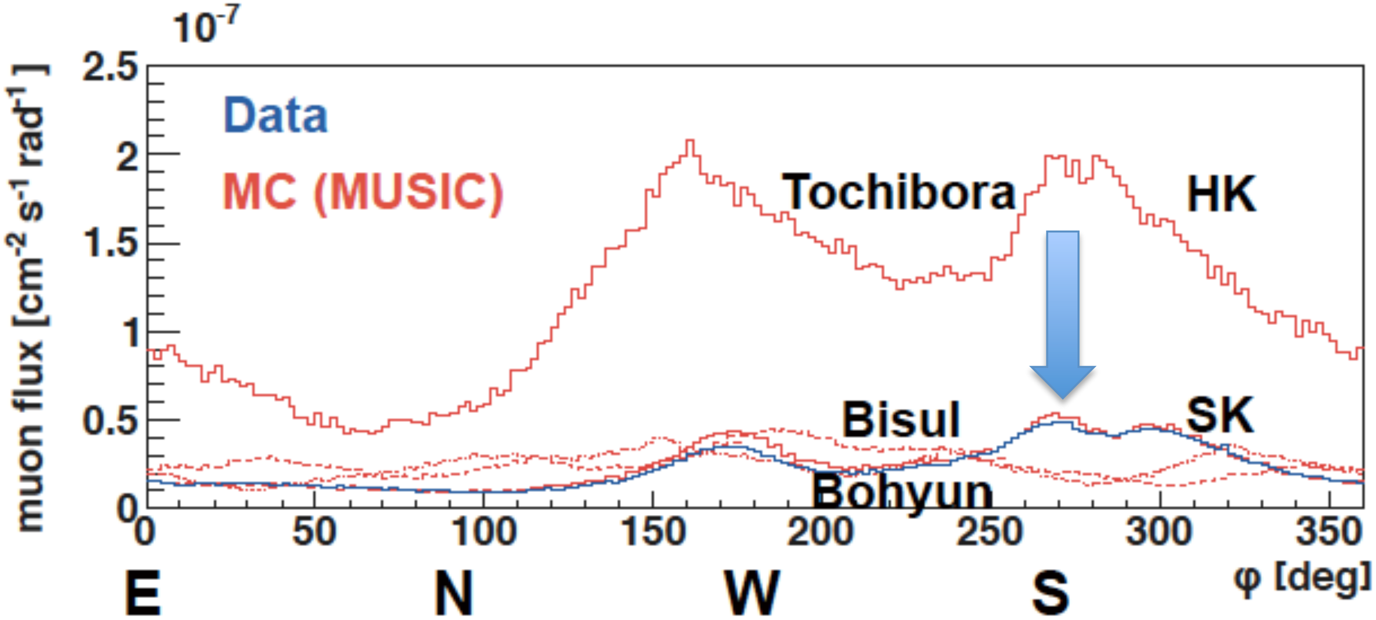




Muon Flux



10^-6
muon flux [cm^-2 s^-1]
Data
MC (MUSIC)
HK
Tochibora
Bisul
SK
Bohyun
0
0.5
1
1.5
2
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
cosθ



10^-7
muon flux [cm^-2 s^-1 rad^-1]
Data
MC (MUSIC)
Tochibora
HK
Bisul
SK
Bohyun
0
0.5
1
1.5
2
2.5
0
50
100
150
200
250
300
350
φ [deg]
E
N
W
S

Summary

❑ Korea is the best location for the 2nd detector of the Hyper-K.

- Longer baseline: 300 km vs. 1100 km
- 1st and 2nd oscillation maxima
- Larger overburden: 650 m vs ~ 1km

❑ Physics sensitivities are improved with 2nd detector in Korea.

- Neutrino mass ordering determination
- CPV, CP precision, CP coverage
- Non-standard ν interaction
- Solar/SN/SRN etc…

❑ Site survey in Korea is on-going.

- We hope to take data in 2026 (→ depends on funding approval).

You are very welcome to join us !

Thank you very much for your attention !