PROSPECTS OF PROBING PHYSICS BEYOND THE STANDARD MODEL IN MOMENT

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- *CP*-violation and precision on Dirac *CP* phase
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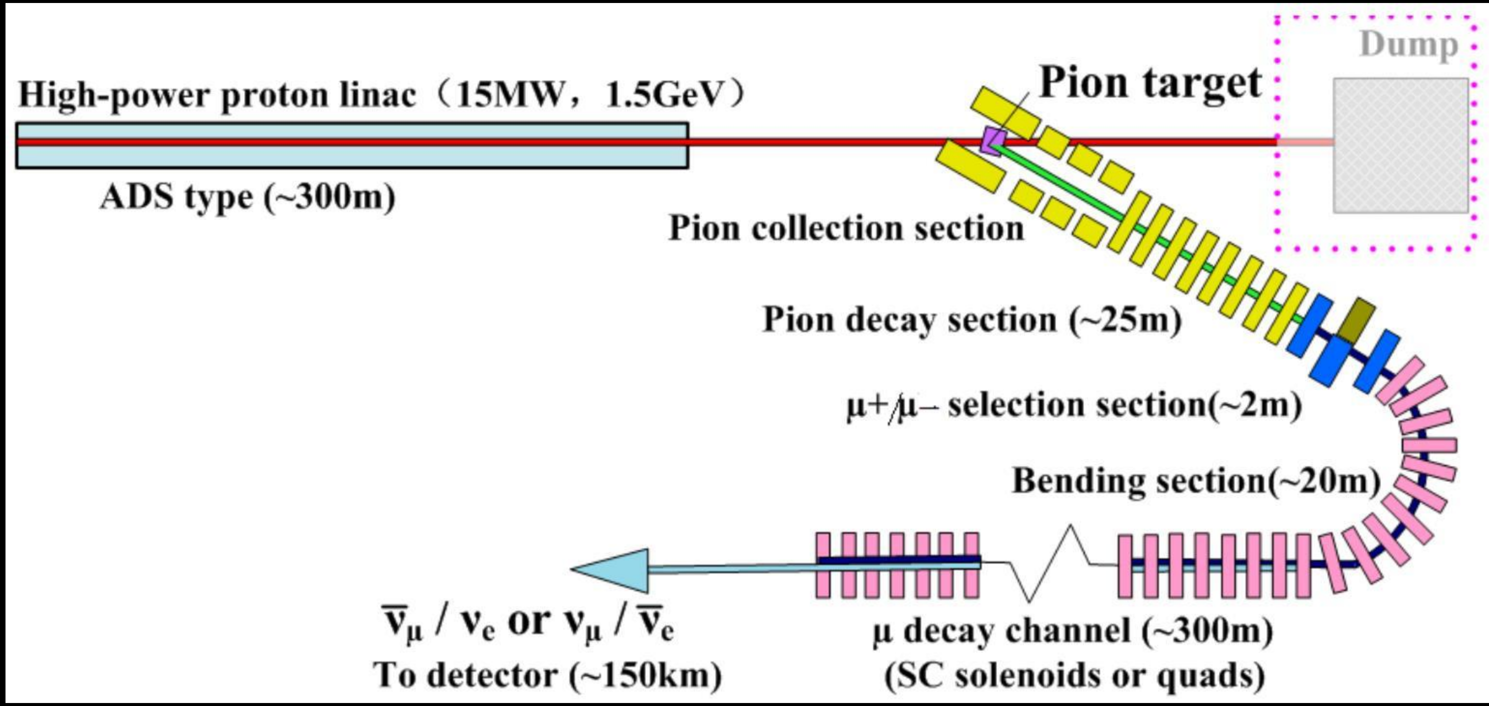
OVERVIEW OF MOMENT AND ITS OBJECTIVES

MOMENT has numerous advantages over superbeam experiments:



- Access to eight oscillation channels
- Negligible beam background
- Very good control of the systematic uncertainties
- Extremely powerful neutrino beam

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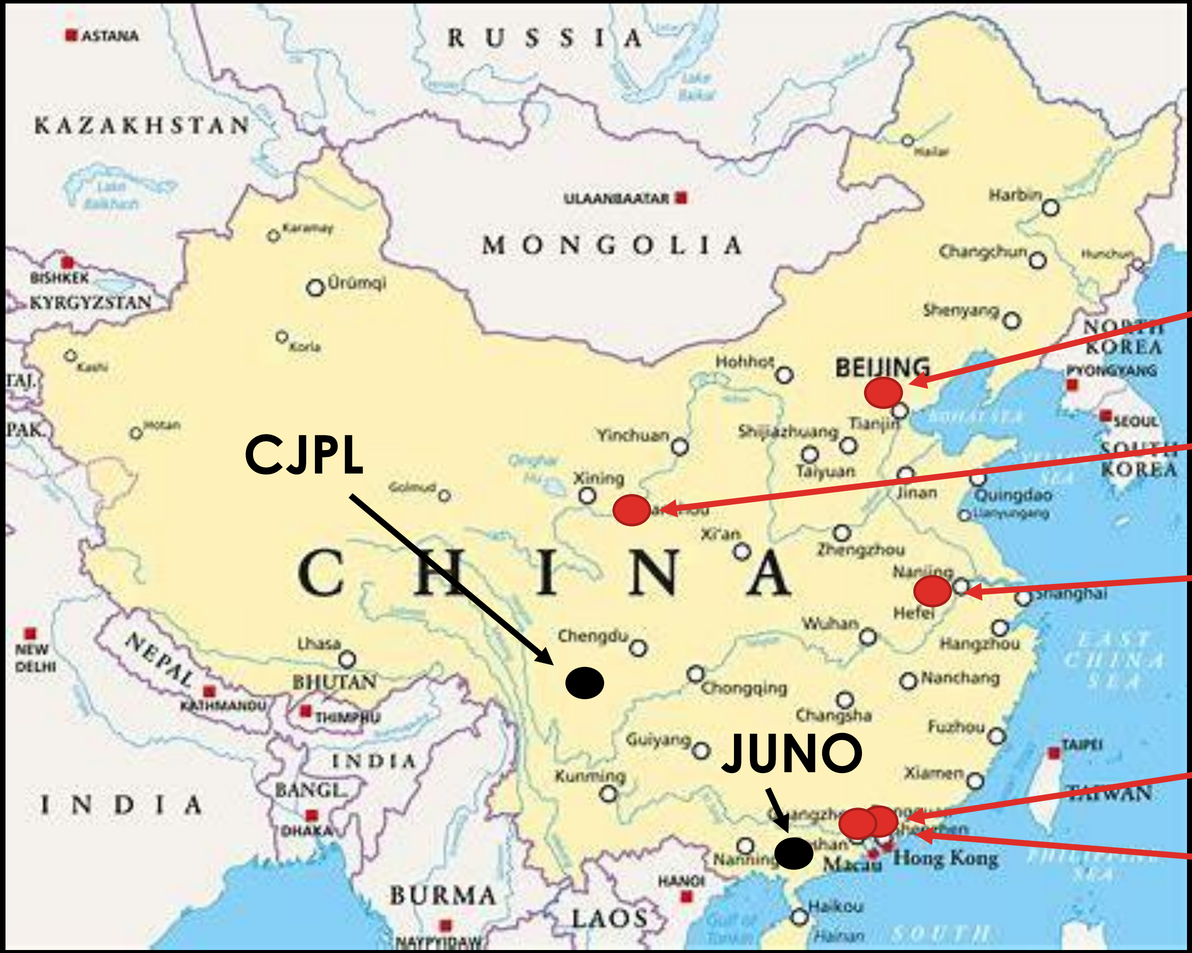
OVERVIEW OF MOMENT AND ITS OBJECTIVES



MOMENT:

- Beam power: 15 MW
- Beam width: 100…300 MeV
- Baseline length: 150 km

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OVERVIEW OF MOMENT AND ITS OBJECTIVES

MOMENT in comparison with the other laboratories:

MOMENT

Accelerator facility	Baseline	1st max	2nd max	Baseline	1st max	2nd max
CAS-IMP	894 km	2.7 GeV	600 MeV	1742 km	3.5 GeV	1.2 GeV
CSNS	1329 km	2.8 GeV	900 MeV	84 km	170 MeV	60 MeV
CiADS	1389 km	1.8 GeV	940 MeV	146 km	300 MeV	100 MeV
Nanjing University	1363 km	3.4 GeV	1.1 GeV	1189 km	2.4 GeV	800 MeV
SPPC	1736 km	3.5 GeV	1.2 GeV	1814 km	3.7 GeV	1.2 GeV

MOMENT beam width (100 MeV… 300 MeV) is enough to cover the first oscillation maximum and part of the second maximum.

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OVERVIEW OF MOMENT AND ITS OBJECTIVES

Introduction to neutrino mixing:

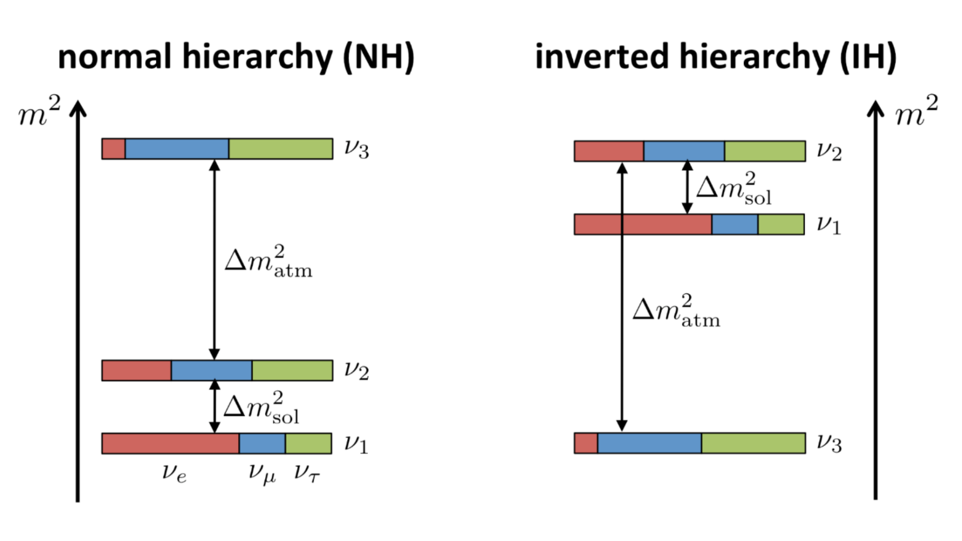
$$\begin{pmatrix}\nu_e\\ \nu_\mu\\ \nu_\tau\end{pmatrix} = \begin{pmatrix}1 & 0 & 0\\ 0 & c_{23} & s_{23}\\ 0 & -s_{23} & c_{23}\end{pmatrix}\begin{pmatrix}c_{13} & 0 & s_{13}e^{-i\delta_{CP}}\\ 0 & 1 & 0\\ -s_{13}e^{i\delta_{CP}} & 0 & c_{13}\end{pmatrix}\begin{pmatrix}c_{12} & s_{12} & 0\\ -s_{12} & c_{12} & 0\\ 0 & 0 & 1\end{pmatrix}\begin{pmatrix}\nu_1\\ \nu_2\\ \nu_3\end{pmatrix}$$

Global fit to the world data (normal ordering, after July 2020):

Parameter	Central value	Error (1σ CL)
θ_{12}	33.44°	0.77°
θ_{13}	8.57°	0.12°
θ_{23}	49.2°	1.2°
δ_{CP}	197°	27°
Δm^2_{21}	7.42×10^{-5} eV^2	0.21×10^{-5} eV^2
Δm^2_{31}	2.517×10^{-3} eV^2	0.027×10^{-3} eV^2

Unsolved problems:

- What is the value of δ_{CP}?
- Is $\theta_{23} > 0$ or $\theta_{23} < 0$?
- What is the sign of $\Delta m^2_{\mathrm{atm}}$



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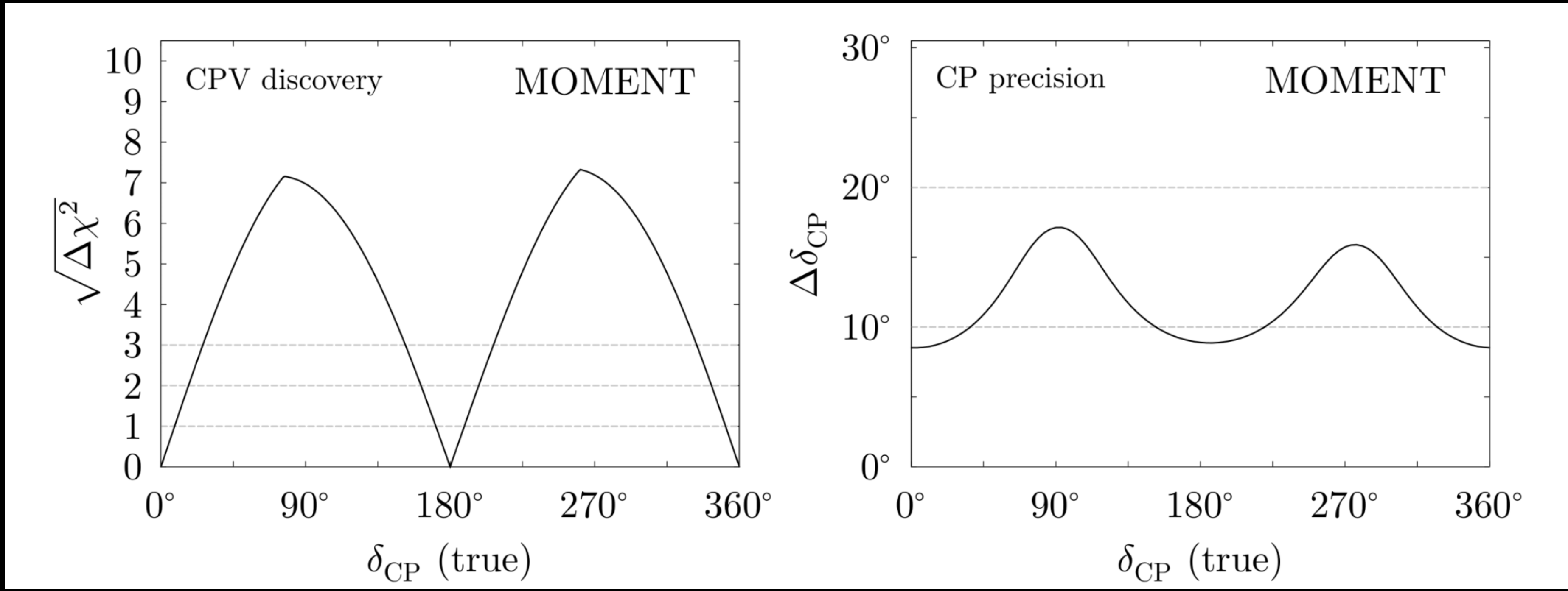
CP-VIOLATION AND PRECISION ON DIRAC *CP* PHASE

The *CP* violation discovery potential and precision on the Dirac *CP* phase:



update from S. Vihonen (2020)

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CP-VIOLATION AND PRECISION ON DIRAC *CP* PHASE

Publication timeline:

- The search for *CP* violation was proposed as original goal (arXiv:1401.8125)
- MOMENT can compete with T2HK and DUNE, but it can not outperform them (arXiv:1511.02859)
- LBL experiments suffer from degeneracy with NC-NSI. MOMENT can rid them from this problem. (arXiv:1602.07099)
- Precision measurement of δ_{CP} was later considered (arXiv:1909.01548)

The conclusion so far:

Altogether, MOMENT can not outperform other experiments but it can act as a decider in reaching important milestones.

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SHAPING THE PHYSICS PROGRAM OF MOMENT

What else can MOMENT do besides *CP* measurements?

- Non-standard interactions (arXiv:1705.09500)
- Invisible neutrino decay (arXiv:1811.05623)
- Flavour symmetries (e.g. tri-direct littlest seesaw arXiv:1907.01371)
- Sterile neutrinos (arXiv:2003.02792)

The answer: precision measurements and

searches for physics beyond the Standard Model

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NON-STANDARD NEUTRINO INTERACTIONS

Charged-current NSI can affect neutrino production and detection:

$$|\nu_\alpha^s\rangle = \frac{(1+\epsilon^s)_{\alpha\gamma}}{N_\alpha^s}|\nu_\gamma\rangle \qquad \langle\nu_\beta^d| = \langle\nu_\gamma|\frac{(1+\epsilon^d)_{\gamma\beta}}{N_\beta^d}$$

Neutral-current NSI alters the propagation in matter:

$$H = \frac{1}{2E}\begin{pmatrix} 0 & 0 & 0 \\ 0 & \Delta m^2_{21} & 0 \\ 0 & 0 & \Delta m^2_{31} \end{pmatrix} + V_{\mathrm{CC}}\, U^\dagger \begin{pmatrix} 1+\epsilon_{ee} & \epsilon_{e\mu} & \epsilon_{e\tau} \\ \epsilon^*_{e\mu} & \epsilon_{\mu\mu} & \epsilon_{\mu\tau} \\ \epsilon^*_{e\tau} & \epsilon^*_{\mu\tau} & \epsilon_{\tau\tau} \end{pmatrix} U$$

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NON-STANDARD NEUTRINO INTERACTIONS

The present bounds on NSI parameters:

$$|\epsilon^{\mu e}| < \begin{pmatrix} 0.025 & 0.03 & 0.03 \\ 0.025 & 0.03 & 0.03 \\ 0.025 & 0.03 & 0.03 \end{pmatrix}$$

at 90 % CL

MOMENT sensitivities:

$$|\epsilon^{\mu e}| < \begin{pmatrix} 0.020 & 0.017 & 0.069 \\ 0.018 & 0.020 & 0.054 \\ - & - & - \end{pmatrix}$$

at 90 % CL

MOMENT can improve the bounds on muon-based source NSI.

from arXiv:1705.09500

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STERILE NEUTRINOS

- MOMENT can probe the mixing with a sterile neutrino and limit its interference on the *CP* violation search with a suitable near detector.
- In arXiv:2003.02792, we investigated a novel opaque detector technology in this purpose:

MOMENT performs better than J-PARC

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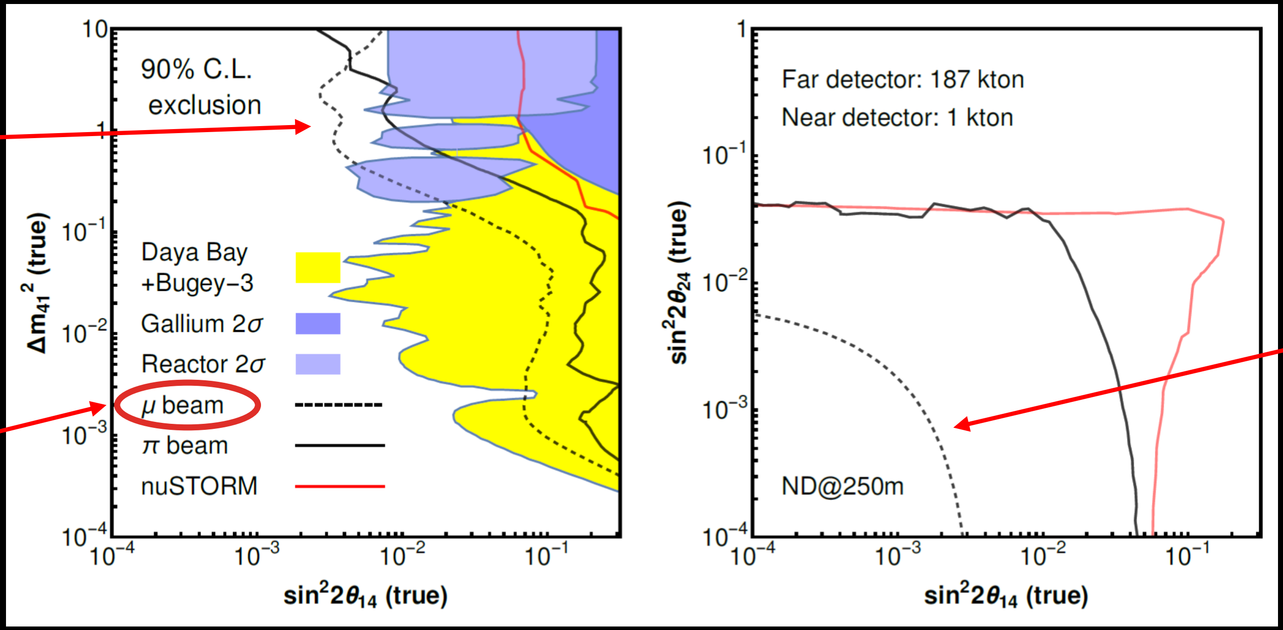


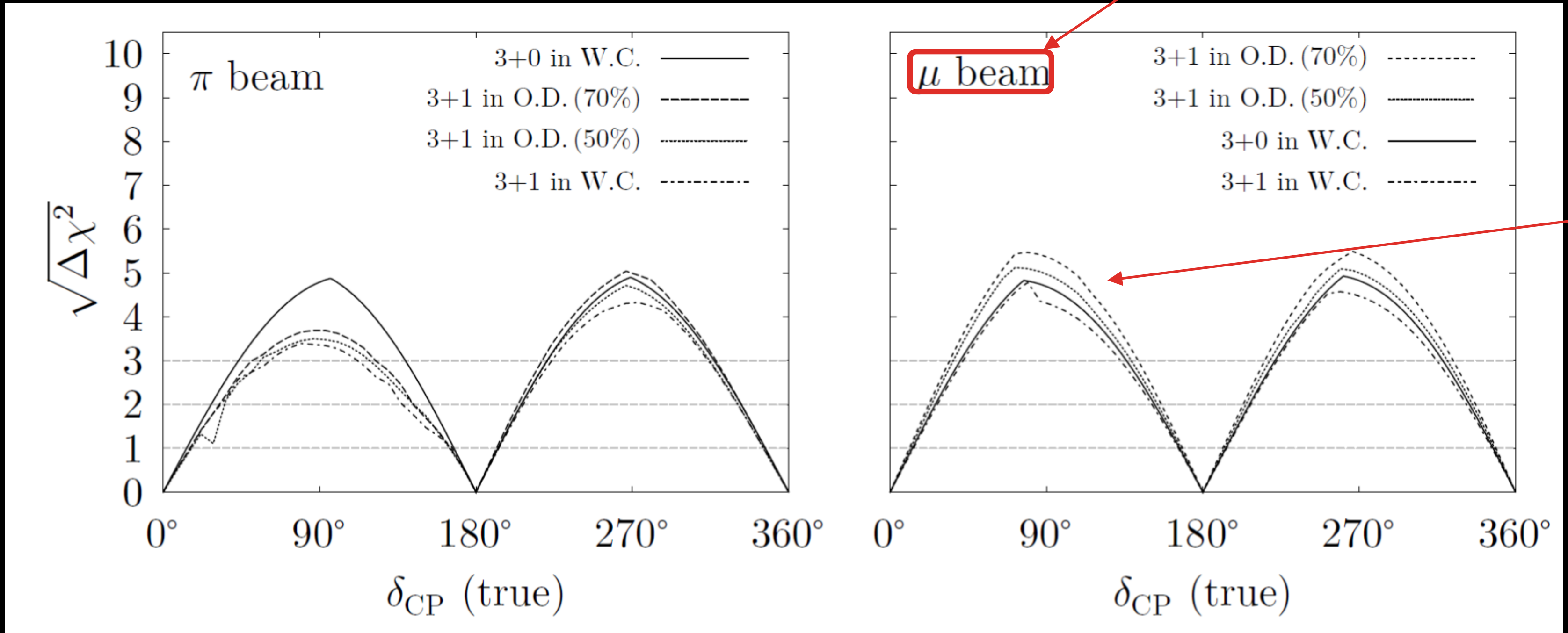
A near detector of 1 kt is sufficient to surpass nuSTORM

STERILE NEUTRINOS

Limiting the interference on the *CP* measurements:

MOMENT with 187 kton detector

Comparison with a beam from J-PARC



MOMENT does not suffer from the dip in 0…180° region.

Jian Tang, SV and TseChun Wang, arXiv:2003.02792

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WHAT IS NEXT FOR MOMENT?

- Choosing the right physics program for MOMENT
  - Good results in *CP* violation, but it cannot outperform T2HK and DUNE
  - Precision measurements on δ_{CP} and other oscillation parameters
  - Search for new physics and measure NSI in source and detector
- Now is the time to prepare a white paper
  - Update on the neutrino fluxes
  - Need to think about the near detector
  - A more careful evaluation of the atmospheric neutrino background

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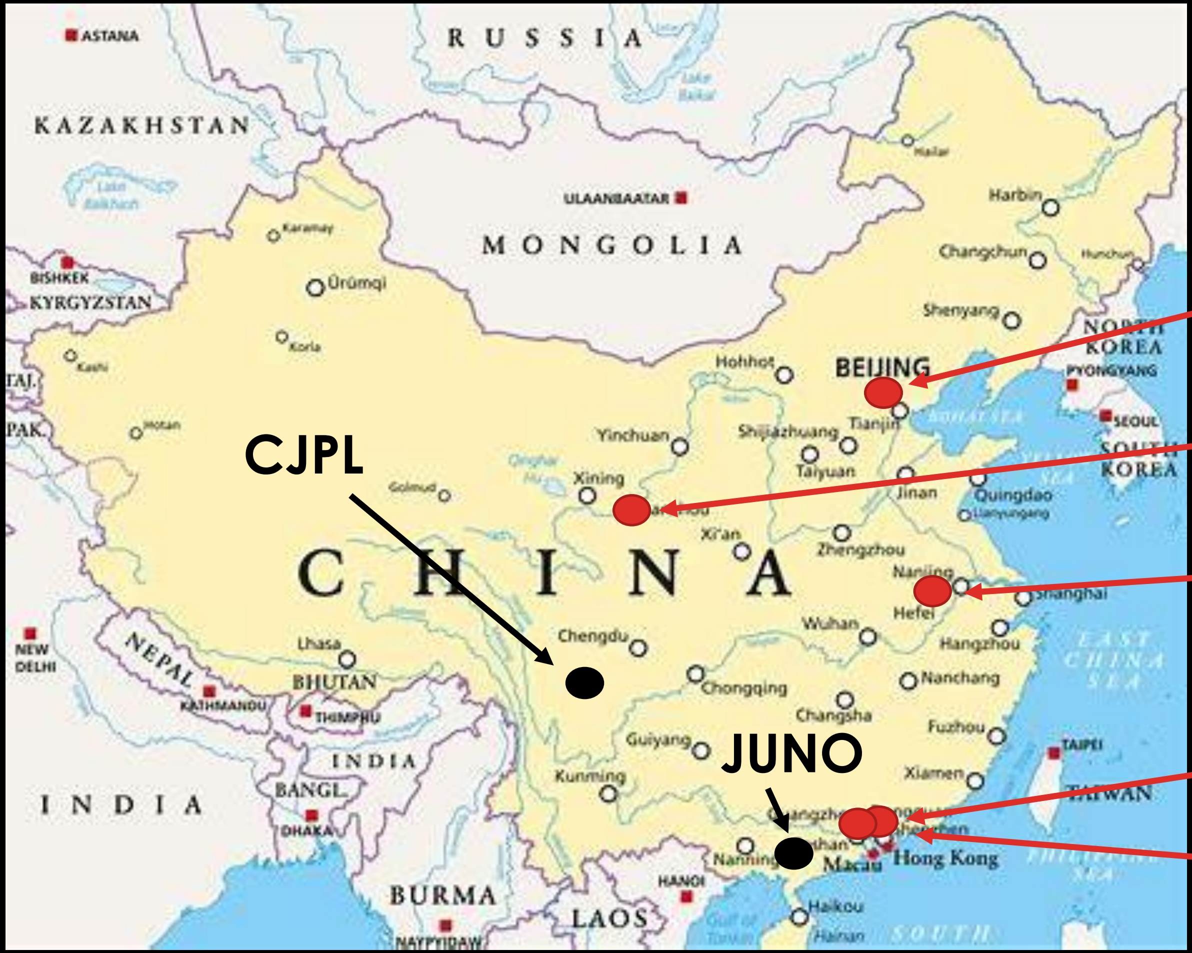
IS THERE HOPE FOR A CHINESE ACCELERATOR NEUTRINO EXPERIMENT?



There are many accelerator laboratories and two under-ground laboratories in China.

We are currently investigating the synergies of these sites in an accelerator experiment.

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IS THERE HOPE FOR A CHINESE ACCELERATOR NEUTRINO EXPERIMENT?

Available baseline lengths and required energies:

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CAS-IMP	894 km	2.7 GeV	600 MeV	1742 km	3.5 GeV	1.2 GeV
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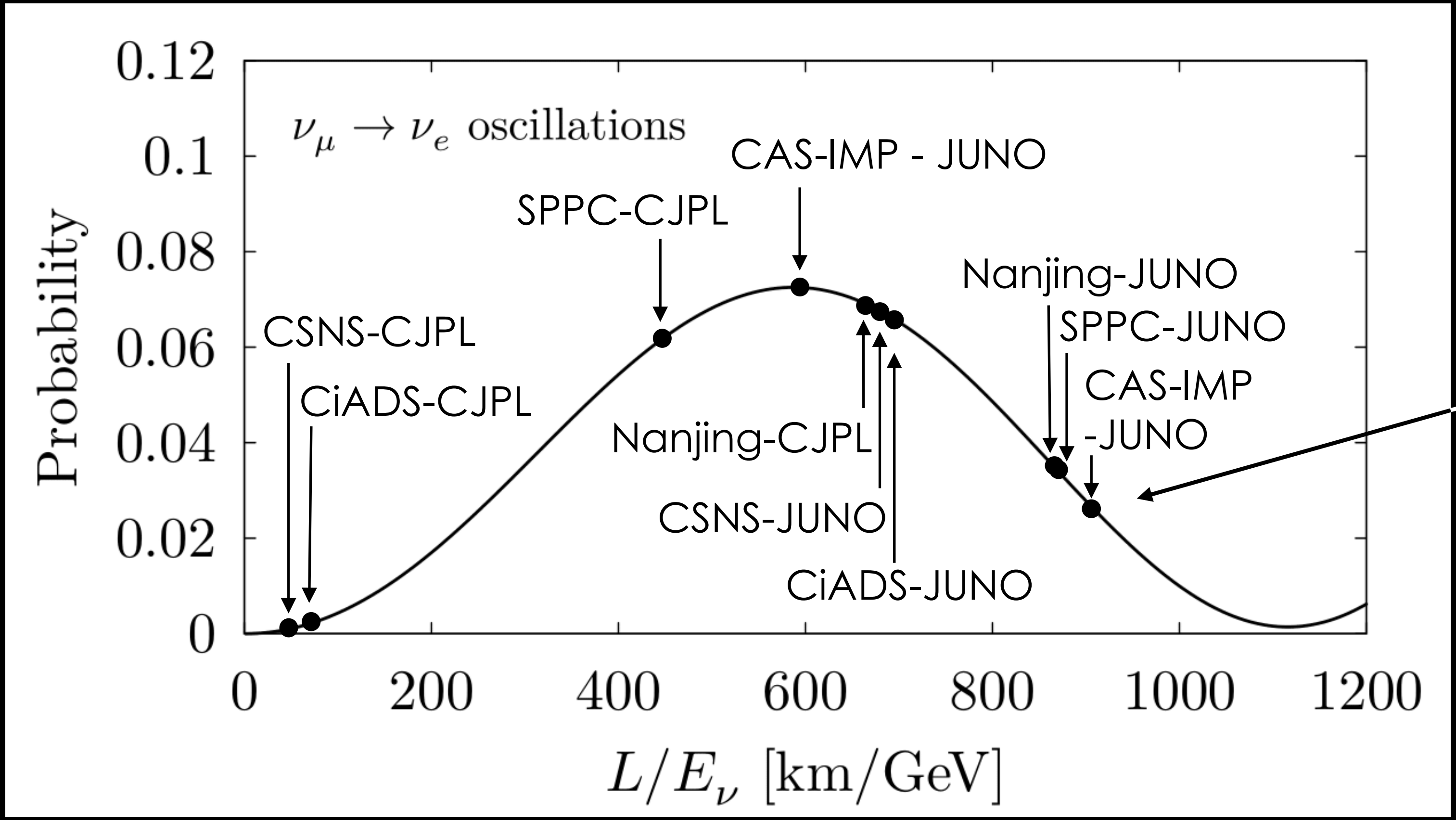
IS THERE HOPE FOR A CHINESE ACCELERATOR NEUTRINO EXPERIMENT?

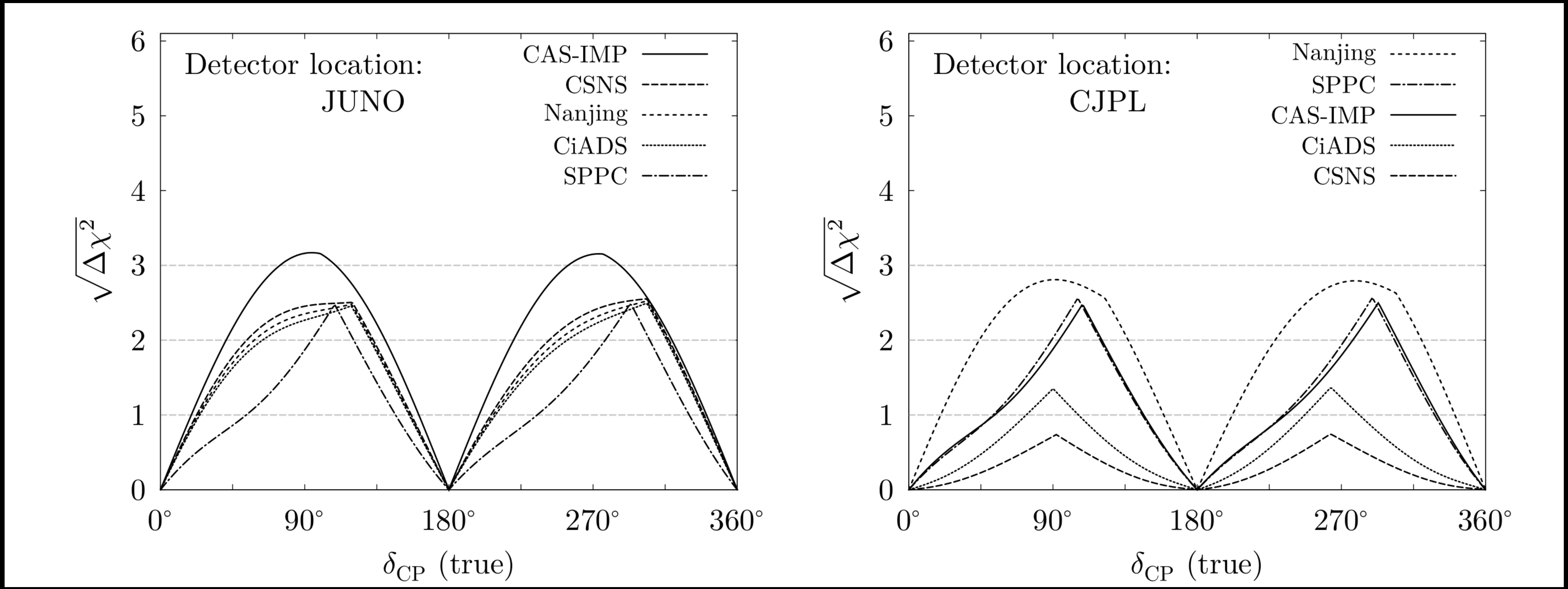
Oscillation probability vs L/E_ν :



Markers show the projection for E_ν~ 2 GeV beam energy

IS THERE HOPE FOR A CHINESE ACCELERATOR NEUTRINO EXPERIMENT?

CP violation discovery potential:



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SUMMARY

- MOMENT will do well in the CP violation search and precision measurements
- It also has a well-established case for searching for new physics
- The near detector will be an important part in new physics studies
  (see about light sterile neutrino in arXiv:2003.02792)
- Now is a good time to start preparing a white paper about MOMENT
- We are currently investigating the synergies of the different accelerator and underground laboratories in mainland China → stay tuned…