Neutrino physics with muon-decay medium-baseline neutrino beam facility(MOMENT)

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Collaborators: Jing-Yu Tang's team at IHEP,

Sampsa Vihonen, Tse-Chun Wang and Yibing Zhang at SYSU…

Snowmass NF09 workshop

Dec. 3rd, 2020

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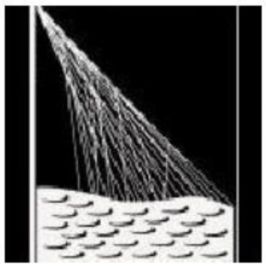
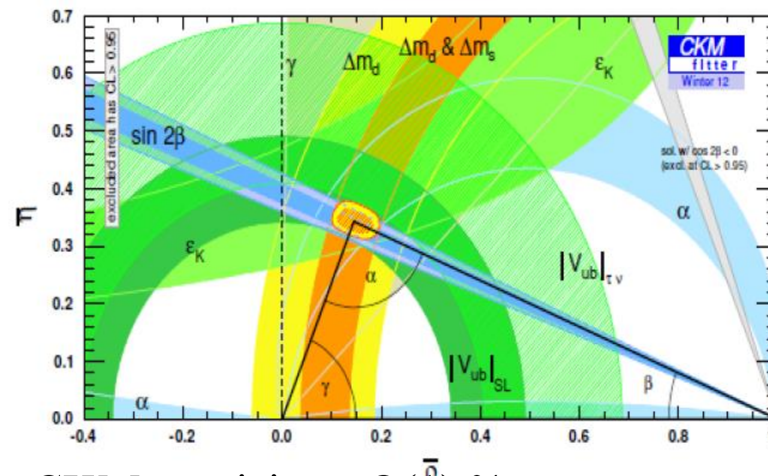
Motivations

$$U_{\mathrm{PMNS}} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{pmatrix} \begin{pmatrix} c_{13} & 0 & s_{13}\,e^{-i\delta} \\ 0 & 1 & 0 \\ -s_{13}\,e^{i\delta} & 0 & c_{13} \end{pmatrix} \begin{pmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix}.$$

= () x () x ()

Parameter	Value	Precision (%)
Δm^2_{21}	$7.37\ 10^{-5}$ eV^2	2.3
θ_{12}	34°	5.8
Δm^2_{32}	$2.52\ 10^{-3}$ eV^2	1.6
θ_{23}	42°	~9
θ_{13}	8.4°	4

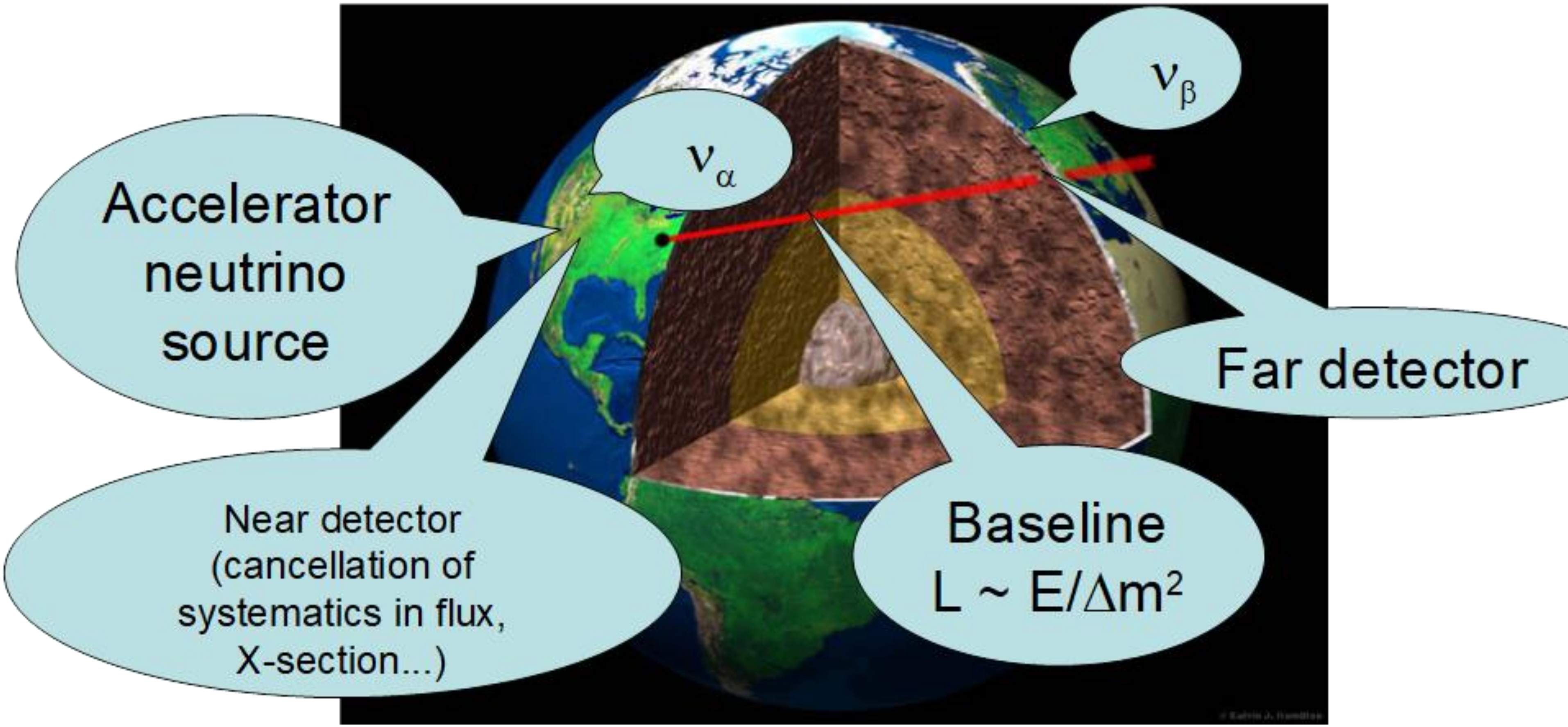
Capozzi et al.
PRD 95, 096014 (2017)



- PMNS precision ~ O(1) %
- New physics might be hidden there

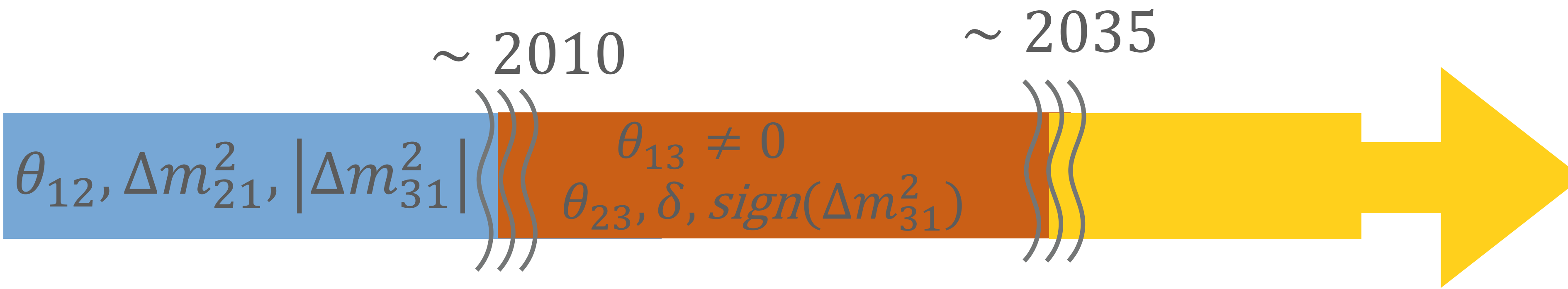
- CKM precision ~O(1) ‰
- Previous discovery used as a tool to probe new physics

Precision measurement and new physics searches by accelerator neutrino oscillations



- Get the neutrino source as clean as possible. Muon decay v.s pion decay beams.
- Deploy the best detector to reconstruct the oscillated neutrino spectra: Gd-WC, LAr TPC, scintillator detector with charge identifications…
- Data mining: precision measurement & discovery of new physics…

International efforts



solar e.g. SNO, etc…
atmosphere: SuperK, etc…
reactors: KamLAND, etc…

Reactor and superbeam experiments
DYB, Double Chooz, RENO…
MINOS, NOvA,T2K, T2HK, DUNE…

Neutrino factory
e.g. NuSTORM

It is important to upgrade the neutrino source:

1. decrease the statistical uncertainties, i.e. enhance the ν flux intensity;
2. decrease the systematic uncertainties from the source;
3. reduce backgrounds from the source…

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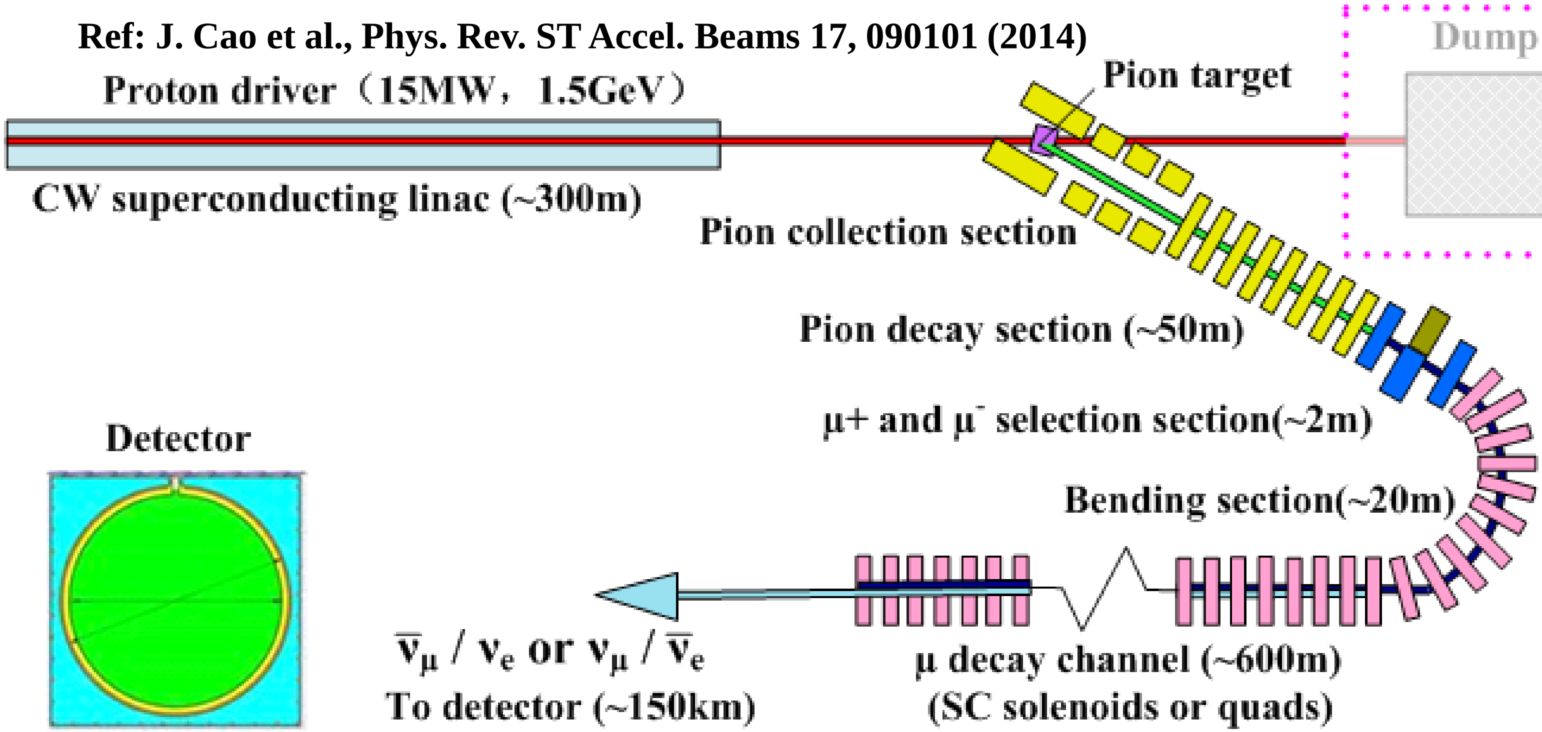
History of the MOMENT project

- As DYB-III, the original goal is to measure the leptonic CP phase.
- Features: ADS or ADS-like linac, High-field SC solenoids + fluidized target, DC muon beam for neutrinos, medium energy neutrinos.
- Three working areas: accelerator muon source, target station, detector and physics.

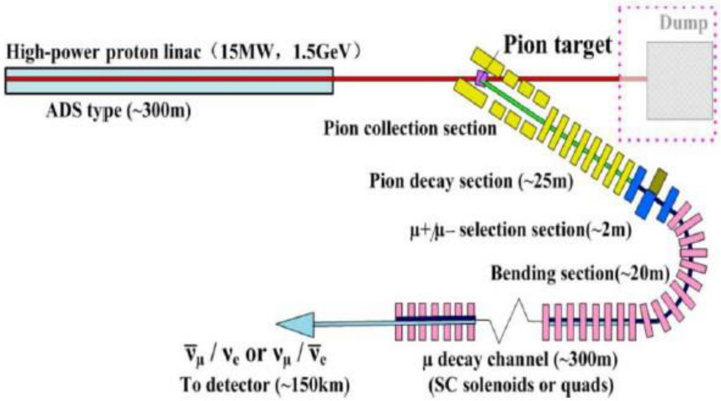
Ref: J. Cao et al., Phys. Rev. ST Accel. Beams 17, 090101 (2014)



Overview of MOMENT

(Muon-decay MEdium baseline NeuTrino beam facility)

•MOMENT: the proposal is still in an early stage ; the details have not been completely fixed.



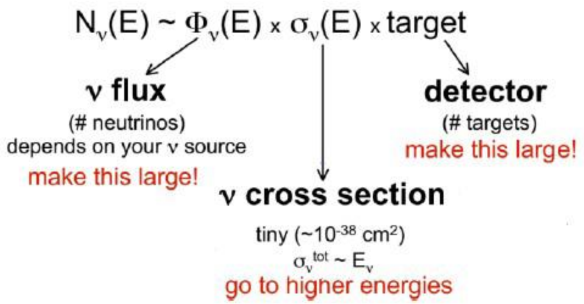
•Peak energy: 200 MeV

Neutrino energy range: 100MeV—800MeV

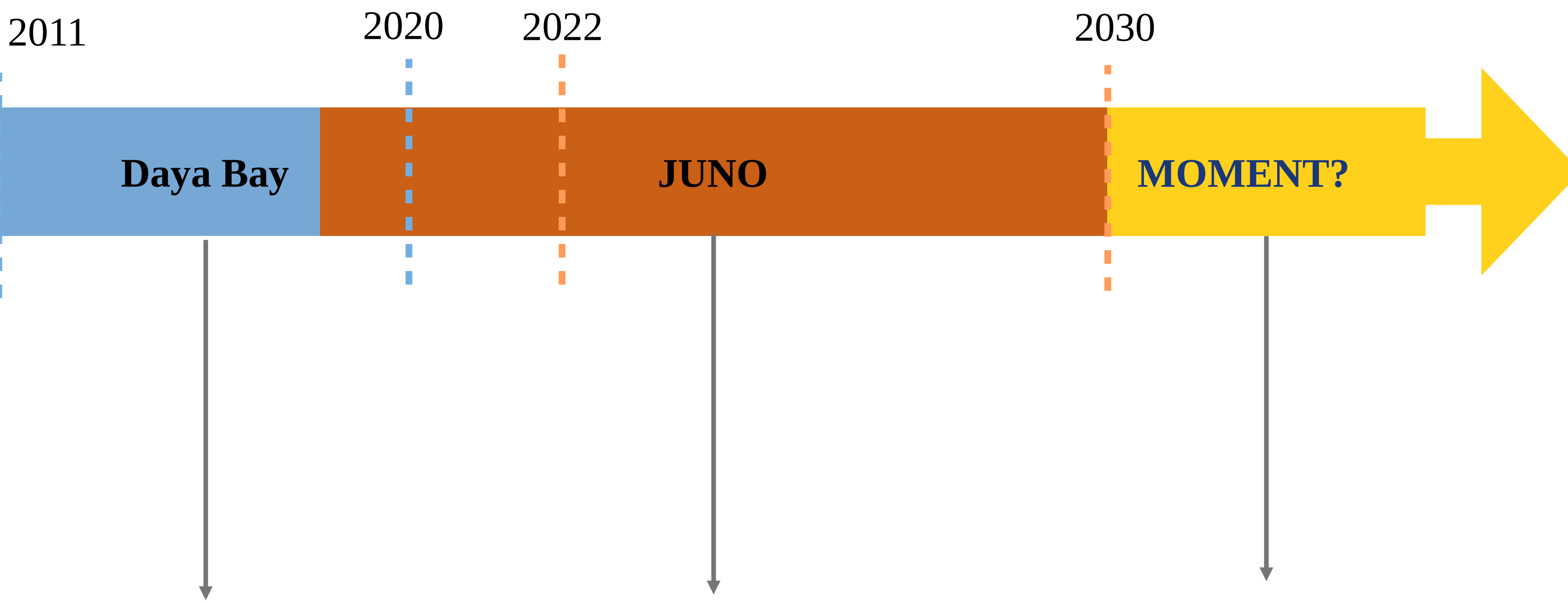
•The lower beam energy at ~ 300 MeV: free from pi0 background

•Baseline: L=150 km

In the MOMENT: the neutrino flux peak at low energies → require a very massive detector to compensate the low interaction cross section



Roadmap of Chinese efforts



- Discovery of non-zero

θ_{13}

- Determine mass ordering
- Precision measurements

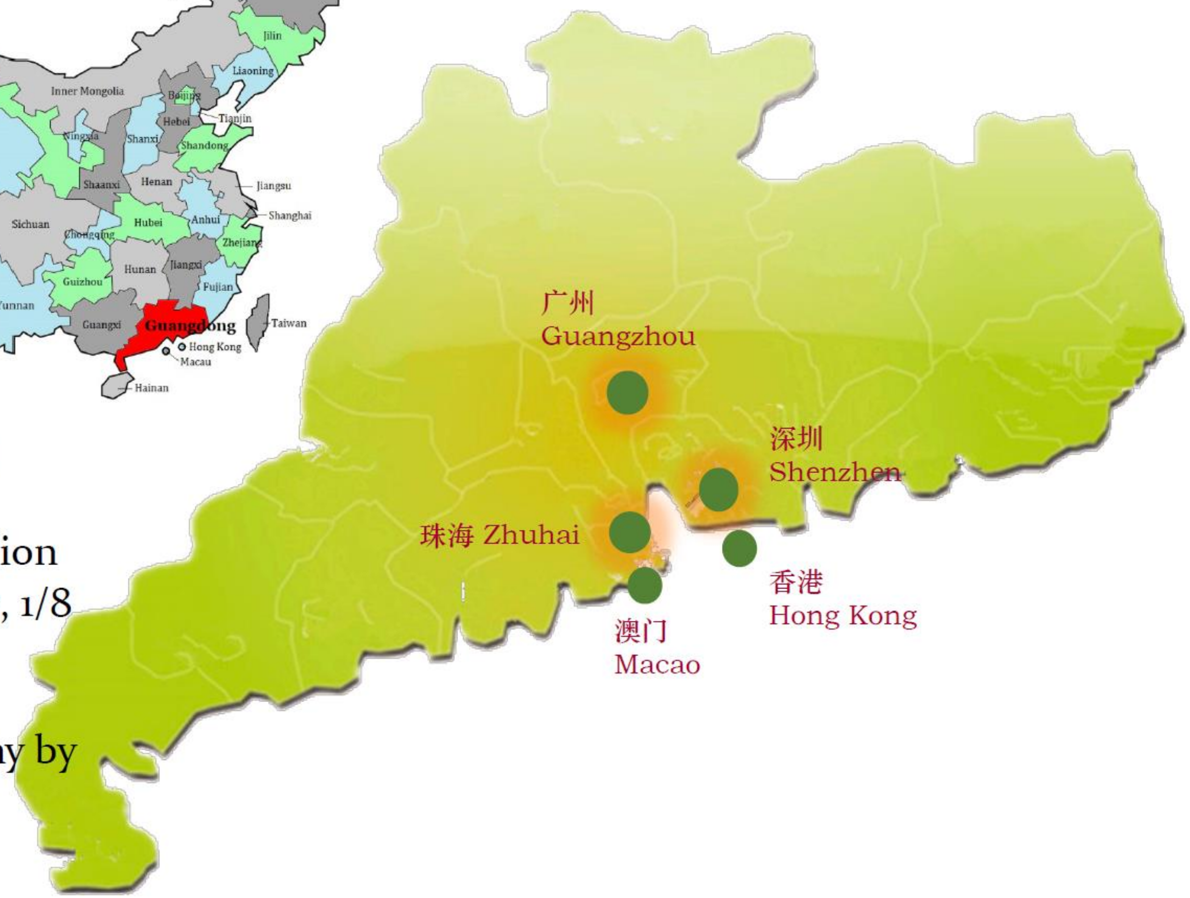
$\theta_{12}\& \Delta m^2_{21}\&\Delta m^2_{31}$

- New physics searches
- Precision measurement

$\theta_{23}\&\delta$

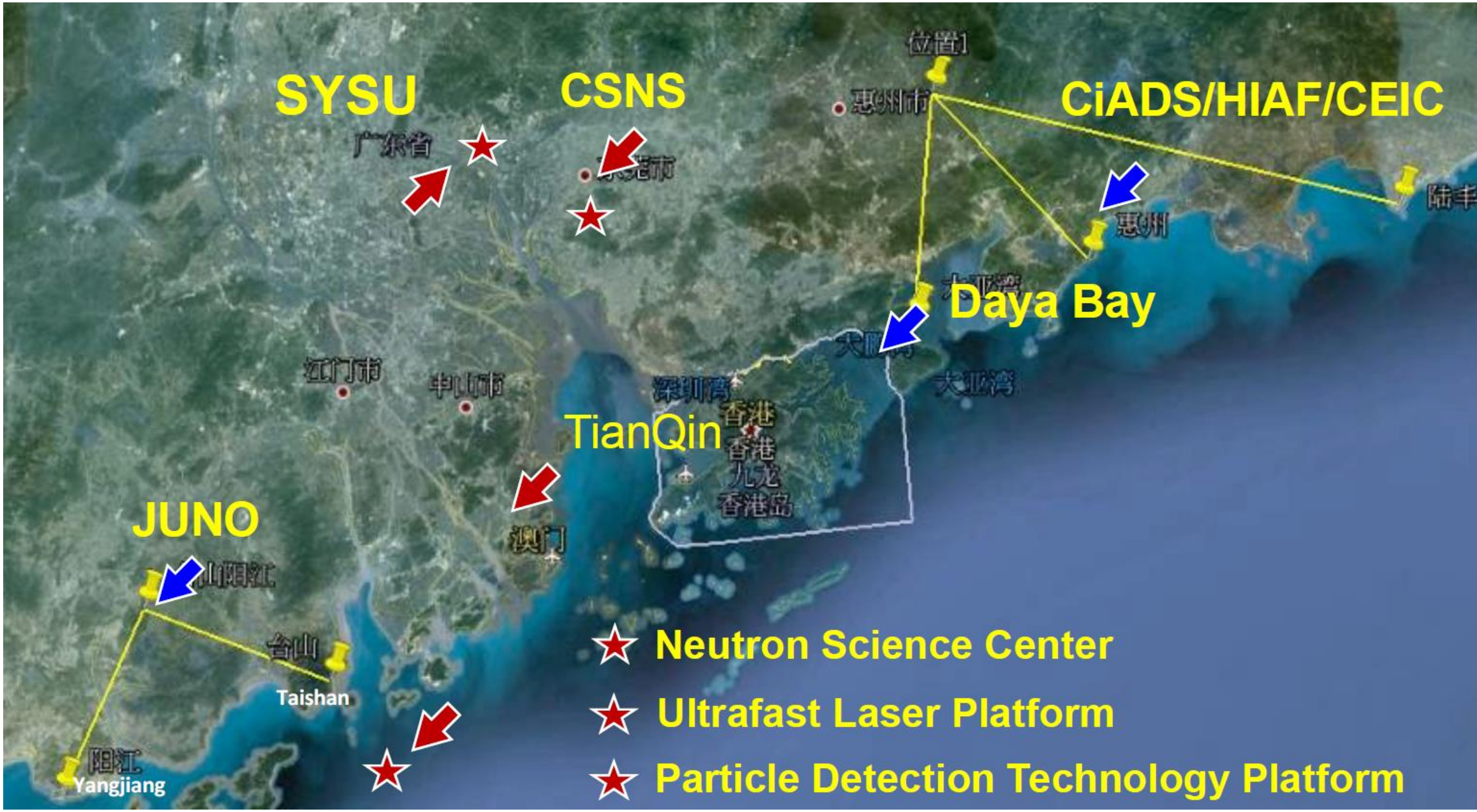
Guangdong-Hongkong-Macao Greater Bay Area

Guangdong-Hong Kong-Macao Greater Bay Area



- Population: ~100M
- GDP: RMB 11.7 trillion ($1.83 trillion) in 2017, 1/8 of national total
- Largest bay economy by 2020

High-intensity facility center in Greater Bay Area



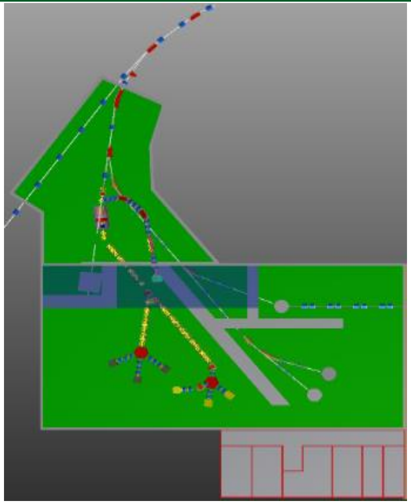
A nice place to conduct research in high-intensity frontier in this area.

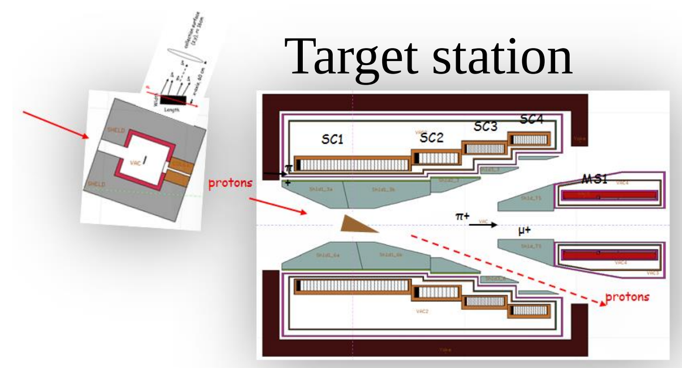
Recent activities of MOMENT

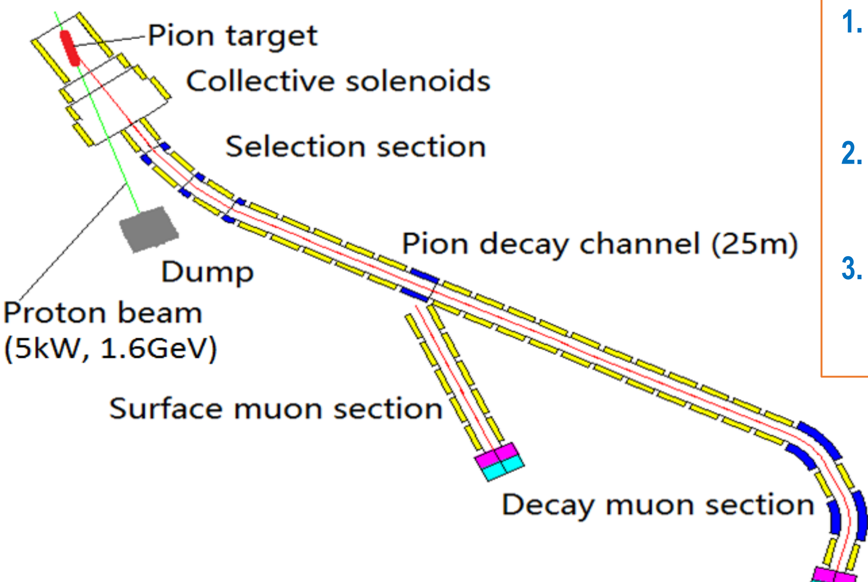
- Organize domestic workshop annually to coordinate the accelerator neutrino physics in China: develop local accelerator neutrino beam techniques, detector and physics performance studies, new physics ideas …
- Accelerator: CiADS project at Huizhou under civil constructions, 500 MeV, 2.5 MW DC proton beam. CSNS on service in 2 years: 1.6 GeV, 100 kW pulsed proton beam(design power reached) → 500 kW upgrade on the way.
- Muon beamline: Experimental Muon Source (EMuS) to be built in China Spallation Neutron Source (CSNS), pass the international review of CDR in November, 2018.
- EMuS is the first R&D effort towards MOMENT. Ref: talk at NuFact2019 by Nikolaos Vassilopoulos, poster at NuFact2019 by Nitin Yadav and Guang Zhao.
- Target station: further development on the waterfall target concept.
- Neutrino detector: not decided yet and welcome advanced technologies. Take a Gd-WC detector as the benchmark.
- Physics study: search for NSIs, neutrino scatterings, precision measurement of the CP phase, test flavor symmetry models, neutrino invisible decays …

China Spallation Neutron Source

Prototype muon source: Experimental Muon Source(EMuS)



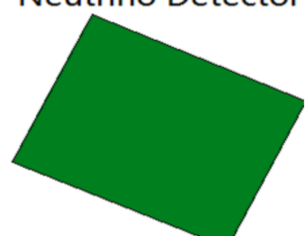




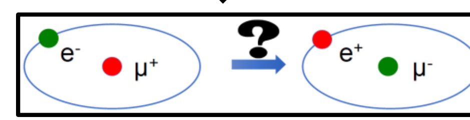
Working modes (indep.):

1. Surface μ mode
   a) Δp/p: <±5%
   b) Ref. Pμ=29 MeV/c
2. Decay μSR mode
   a) Δp/p: <± 10%
   b) Ref. Pμ =40-150 MeV/c
3. High-momentum μ mode
   a) μ imaging, neutrinos
   b) Ref. Pπ=200-450 MeV/c

Neutrino Detector



cLFV proposal:
MACE@EMuS
Muonium physics



Ref: LOI@RF05-126

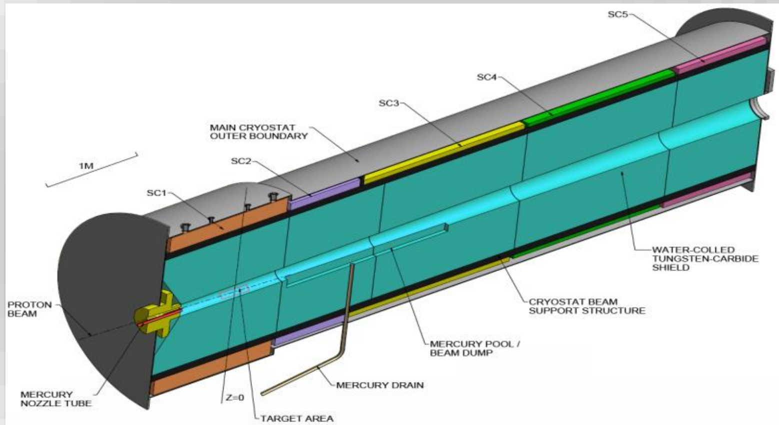
Planning for future: slow muons

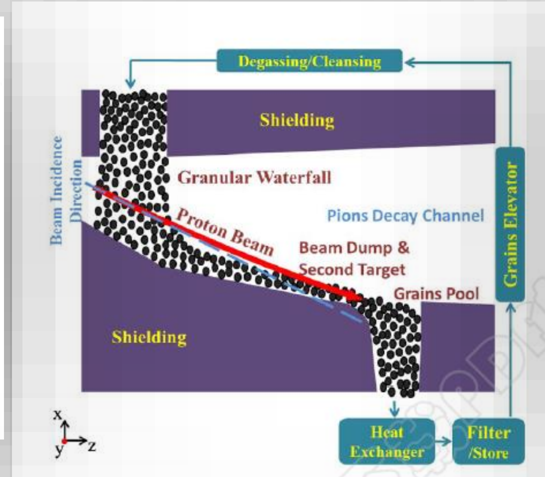
Credits: Jing-Yu Tang, Ye Yuan,Guang Zhao…

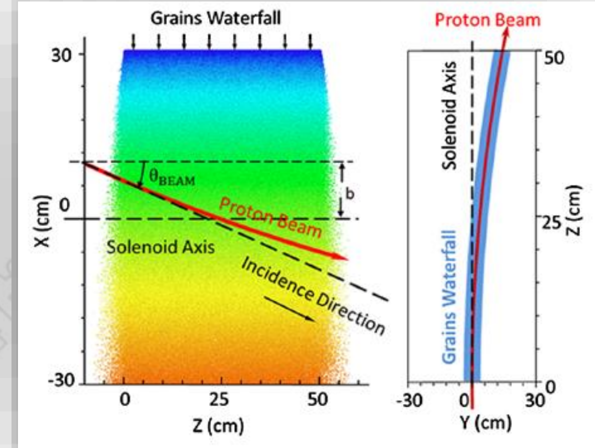
Granular waterfall target as an alternative to Hg-jet at MOMENT

MOMENT's capture solenoid (14 T -> 3 T)

Beam - Target geometry







target solution for multi-MW neutrino and muon beams:

- similar $\pi^{\pm}$ yields to Hg-jet as predicted by FLUKA and Geant4 + DEM, it does not act as an absorber for mesons in the adiabatic field
- higher mass flow rates and lower induced temperatures for heat exchange than Hg/W-jets (Geant4 + DEM simulation for 4 MW)
- initial tests for the waterfall target at 5 T
- complete tests in future to verify its stability, mass flow rates and effective densities

Presented at NuFact16/17, Phys.Rev.Accel.Beams 20 (2017) no.2, 023401, NBI2019

Credits: Hai-Jie Cai, Jing-Yu Tang, Nitin Yadav, Lei Yang, Ye Yuan, Nikos Vassilopoulos…

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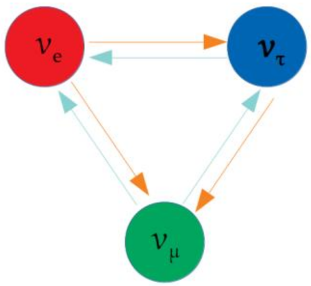
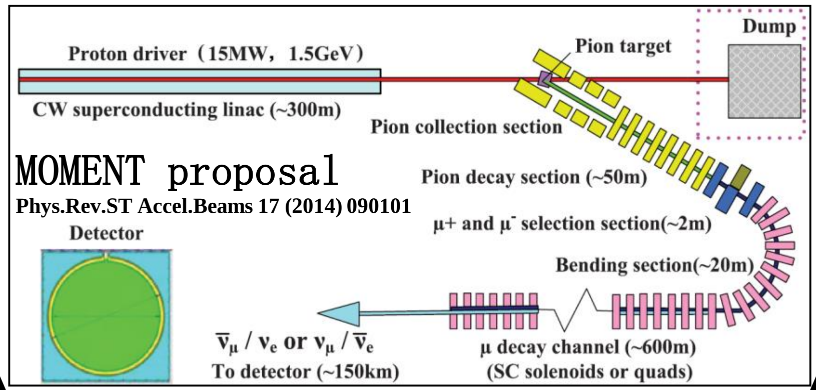
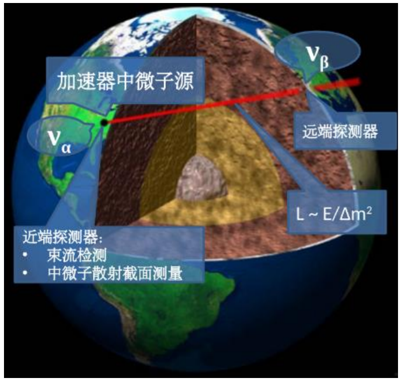
Precision measurements and new physics searches



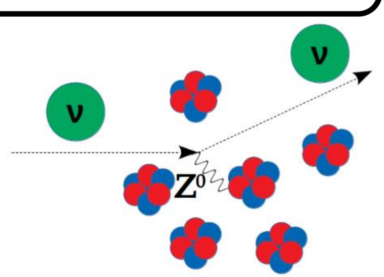
Precision measurement of δ_{CP}
JHEP 1912 (2019) 130.



+EMuS proposal



CEvNS at a near detector
Phys.Rev.D97(2018)11,113003.



Constraints on ν mass models
Nucl.Phys. B952 (2020) 114915.
Phys.Rev. D100 (2019) 5, 055022.

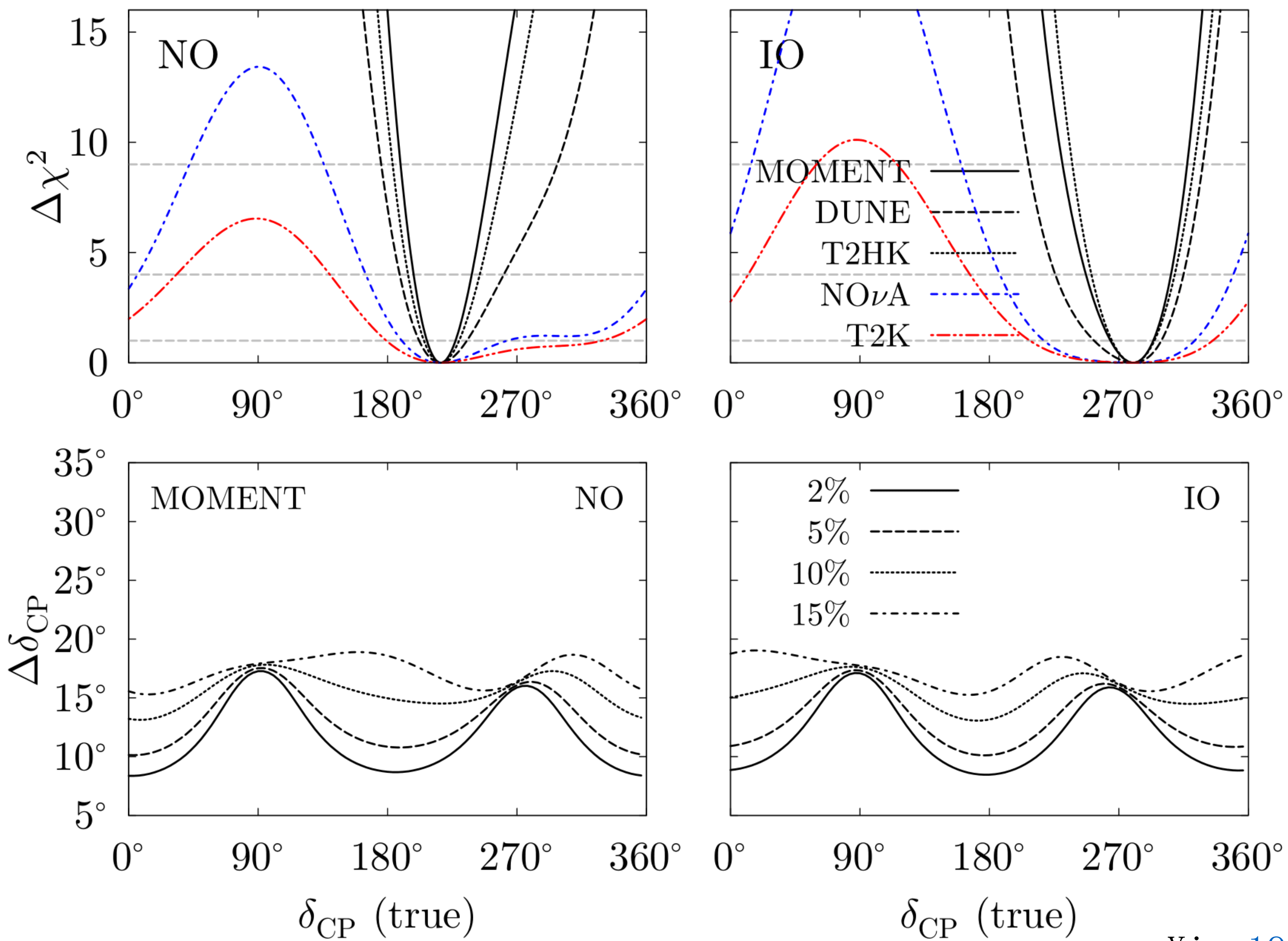
Opaque scintillator detector
Phys.Rev.D 102 (2020) 1, 013006.

Unitarity violations
Phys.Lett. B774 (2017) 217-224.

ν Invisible decays
JHEP 1904 (2019) 004.

Neutrino CC-NSI
Phys.Rev. D97 (2018) 3, 035018.

Precision measurement of δ_{CP}



arXiv:1909.01548

If a neutrino decays?

- Visible decays:

If the decay products are active, interact at the detector and give a visible signal.

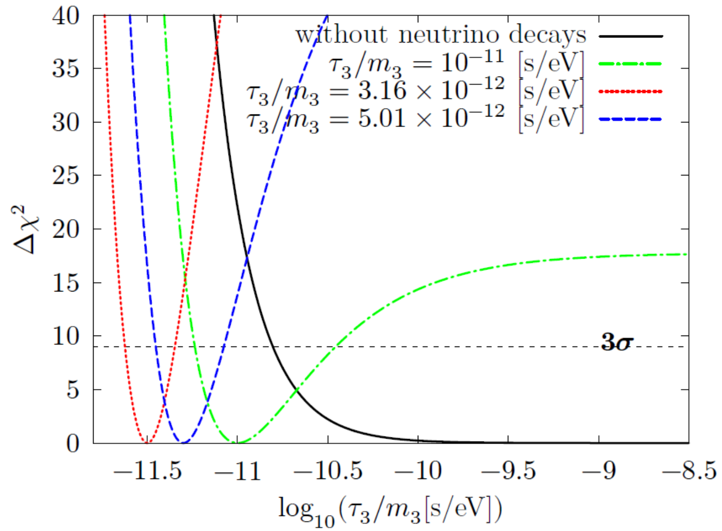
→ Increase/depletion of event rates.

- Invisible decays:

Sterile states, below the detector threshold, depletion of event rates...

- Consider the decay mode: $\nu_3 \to \nu_4 + J$

J is a majoron.

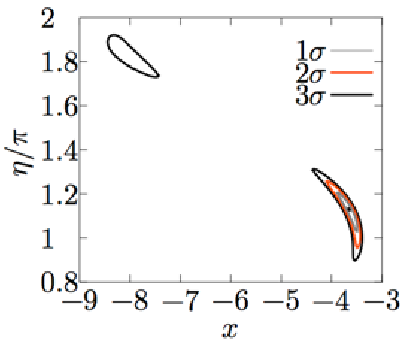


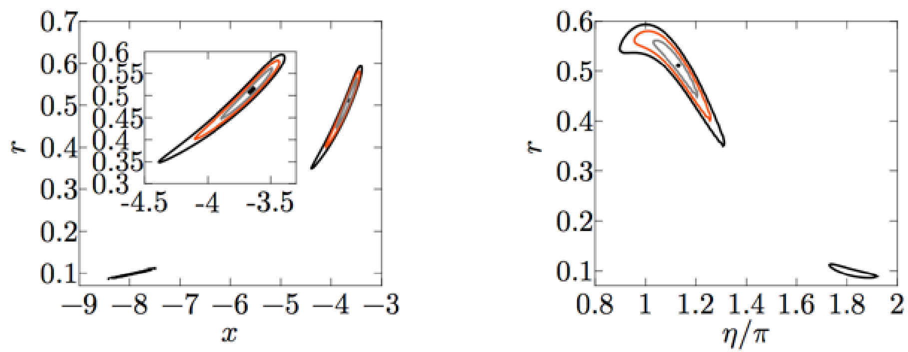
$$\begin{pmatrix} \nu_\alpha \\ \nu_s \end{pmatrix} = \begin{pmatrix} U & 0 \\ 0 & 1 \end{pmatrix} \begin{pmatrix} \nu_i \\ \nu_4 \end{pmatrix}$$

$$H = U\left[\frac{1}{2E}\begin{pmatrix} 0 & 0 & 0 \\ 0 & \Delta m_{21}^2 & 0 \\ 0 & 0 & \Delta m_{31}^2 \end{pmatrix} - i\frac{m_3}{2E\tau_3}\begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 1 \end{pmatrix}\right]U^+ + \begin{pmatrix} 2\sqrt{2}G_F N_e E & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix}$$

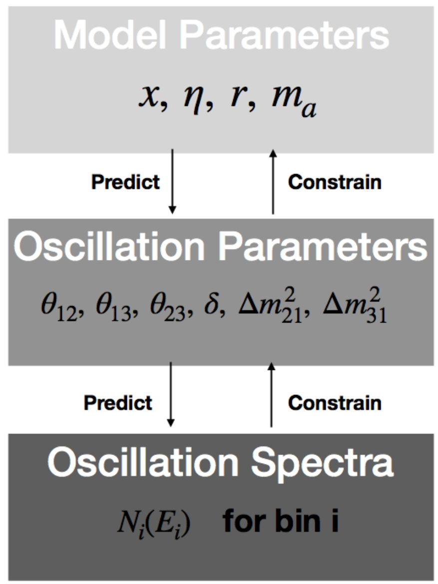
arXv:1811.05623

Constraints on flavor-symmetry neutrino models





Flavour Symmetry Embedded -- GLoBES (FaSE-GLoBES) arXiv: [2006.14886](https://arxiv.org/abs/2006.14886)

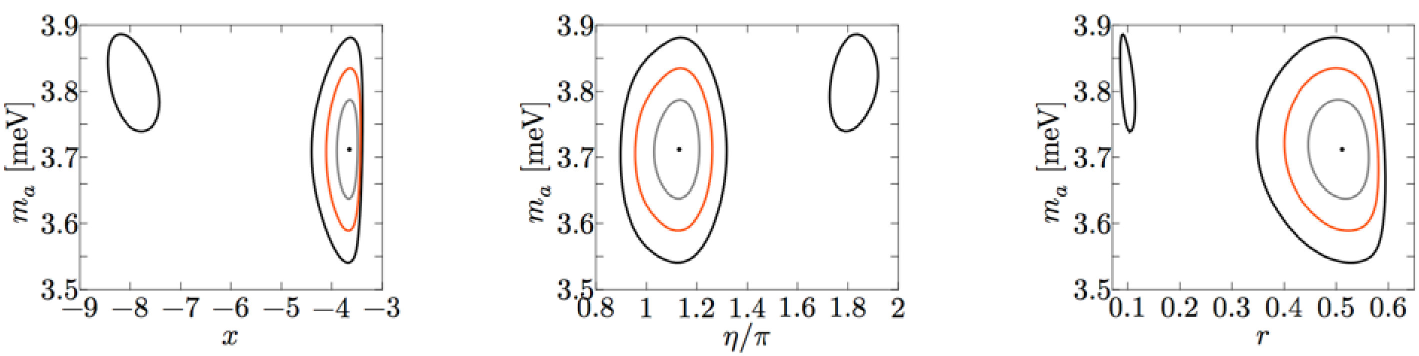


$$\vec{\mathcal{M}} = \{x\,, \eta\,, m_a\,, r\}$$

$$\chi^2(\vec{\mathcal{M}}) = \sum_{i=1}^{N} \frac{\left[\mu_i(\vec{\mathcal{O}}(\vec{\mathcal{M}})) - n_i\right]^2}{\sigma_i^2}$$

$$\vec{\mathcal{O}} = \{\theta_{12}\,, \theta_{13}\,, \theta_{23}\,, \delta_{\rm CP}\,, \Delta m^2_{21}\,, \Delta m^2_{31}\}$$

$$\chi^2(\vec{\mathcal{O}}) = \sum_{i=1}^{N} \frac{\left[\mu_i(\vec{\mathcal{O}}) - n_i\right]^2}{\sigma_i^2}$$



[arXv:1907.01371](https://arxiv.org/abs/1907.01371)

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Summary

- Push forward muon and neutrino physics based on accelerator muon beams in China.
- Detector of MOMENT not fixed yet. Benchmark: Gd-WC.
- Prototype of MOMENT: EMuS@CSNS in a good shape.
- Lots of physics to be done with accelerator muons/neutrinos: NSIs, neutrino decays, tests of flavor-symmetry models…
- Welcome new ideas in muon and neutrino physics…
- Welcome international cooperation…
- Still dream of neutrino factory…

◆ Job openings in our group for muon/neutrino physics: **~2K euros/month after tax + bonus + on-campus housing + funding** supported by local province**.**

◆ Please contact me by email for more info: tangjian5@mail.sysu.edu.cn

THANK YOU