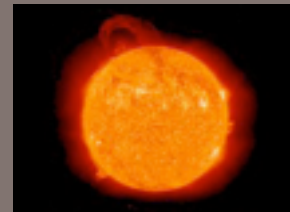
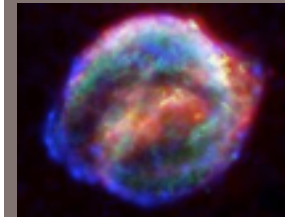
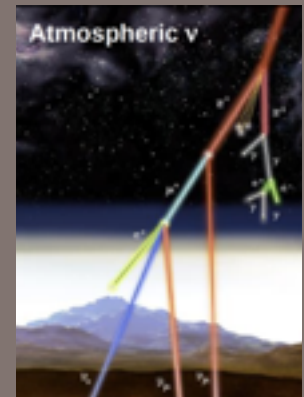
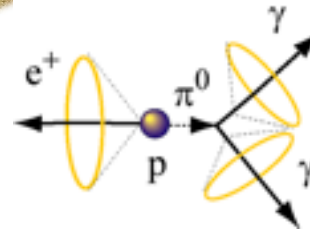
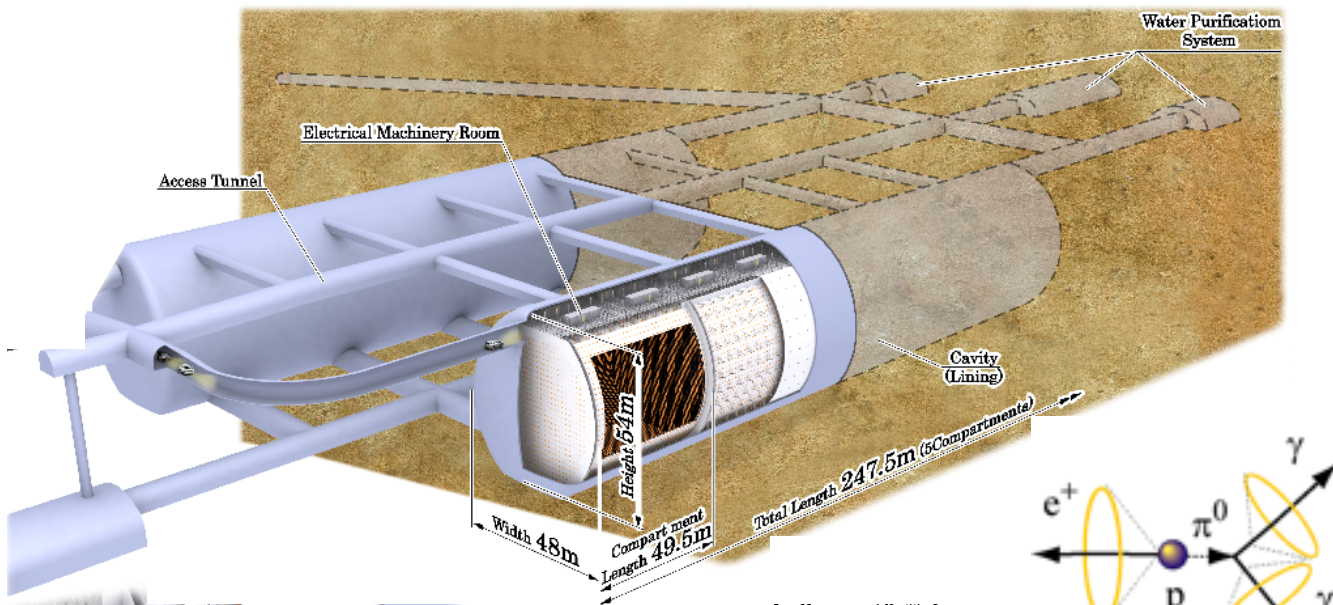


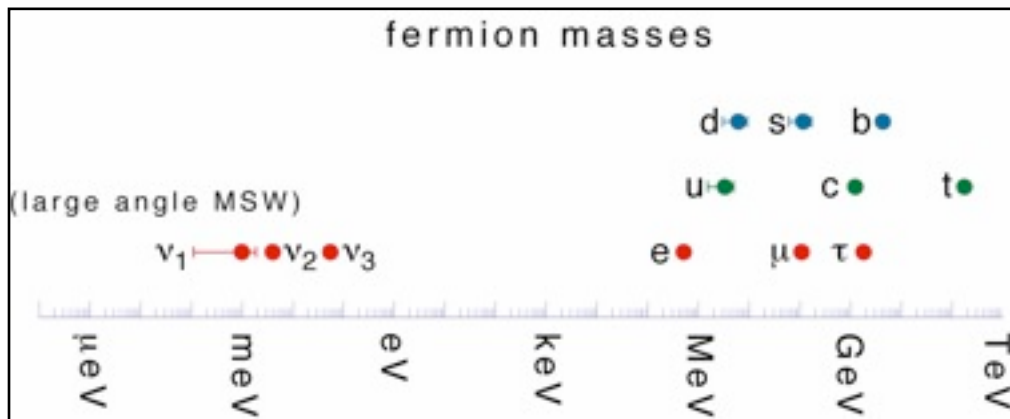
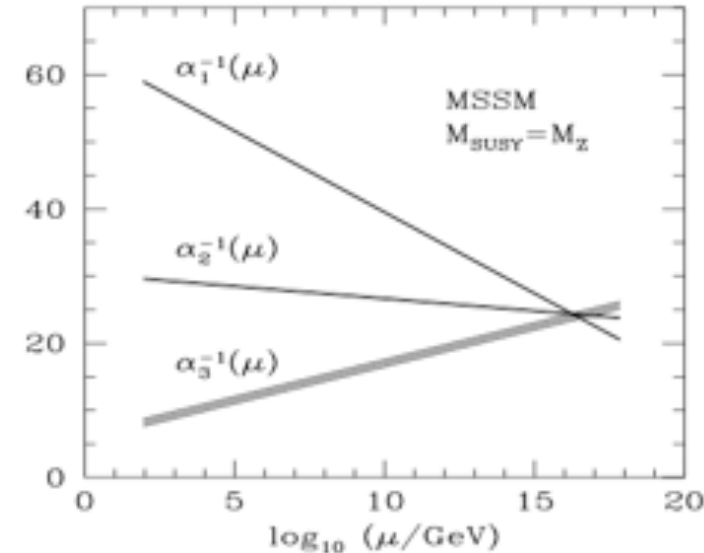
Hyper-Kamiokande

Akira Konaka, TRIUMF



Indication of very high energy scale

- Gauge couplings: $\Lambda_{\text{GUT}} \sim 10^{16} \text{ GeV}$
 - proton decay!
- Neutrino mass:
 - see-saw mechanism: $\Lambda \sim 10^{14} \text{ GeV}$
 - Baryon asymmetry: Leptogenesis
 - Different lepton mixing pattern
- Cosmic Inflation



$$V_{\text{CKM}} \sim \begin{pmatrix} 1 & 0.2 & 0.001 \\ 0.2 & 1 & 0.01 \\ 0.001 & 0.01 & 1 \end{pmatrix}$$

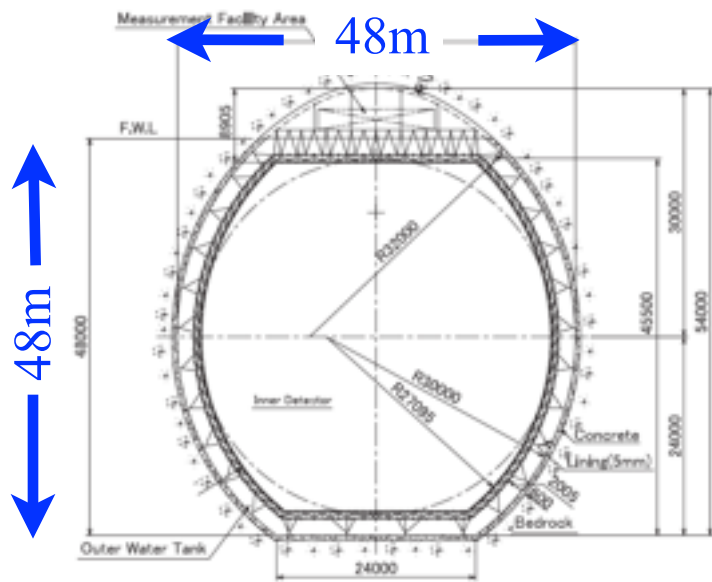
(Quarks)

$$V_{\text{PMNS}} \sim \begin{pmatrix} 0.8 & 0.5 & 0.2 \\ 0.4 & 0.6 & 0.7 \\ 0.4 & 0.6 & 0.7 \end{pmatrix}$$

(Leptons)

Hyper-Kamiokande

- 1Mton water Cherenkov in Kamioka, Japan
 - 25times more fiducial volume than Super-K
- General purpose observatory:
 - accelerator ν , atmospheric ν , solar ν , supernova ν
 - proton decays, exotic particles (WIMPs, monopole, Qball, ...)



	Hyper-K	Super-K
Total volume	990kton	50kton
inner volume	740kton	32kton
fiducial volume	560kton	22.5kton
PMT's (20-inch)	99,000	11,146
photocathode coverage	20%	40%
Overburden (water eq.)	1,750m	2,700m
Off-axis angle	2.5 degree	2.5 degree
Baseline	295km	295km

Why water Cherenkov?

- Large mass

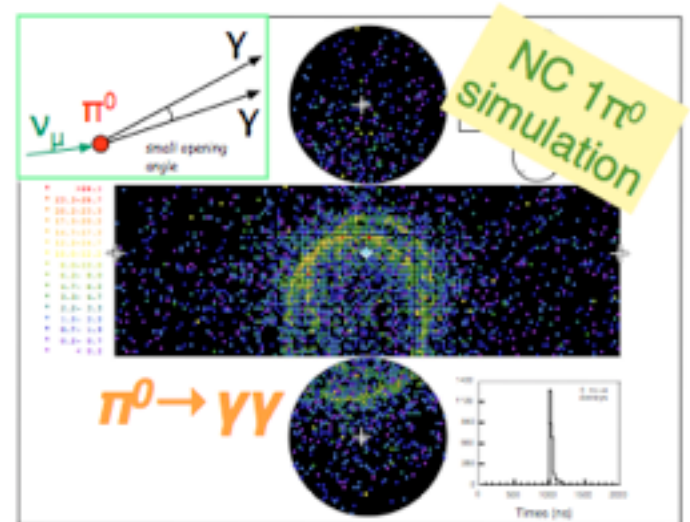
- x10 larger mass compared to Liq.Ar, Liq. scint. (for the same cost)
- Under sea/ice detectors: backgrounds? systematics?
 - HyperK already requires BG subtraction for p-decay

- Good event reconstruction

- Multi-track (ring counting)
- Energy resolution (1-2%/ \sqrt{E})
- Particle ID (e/ μ)

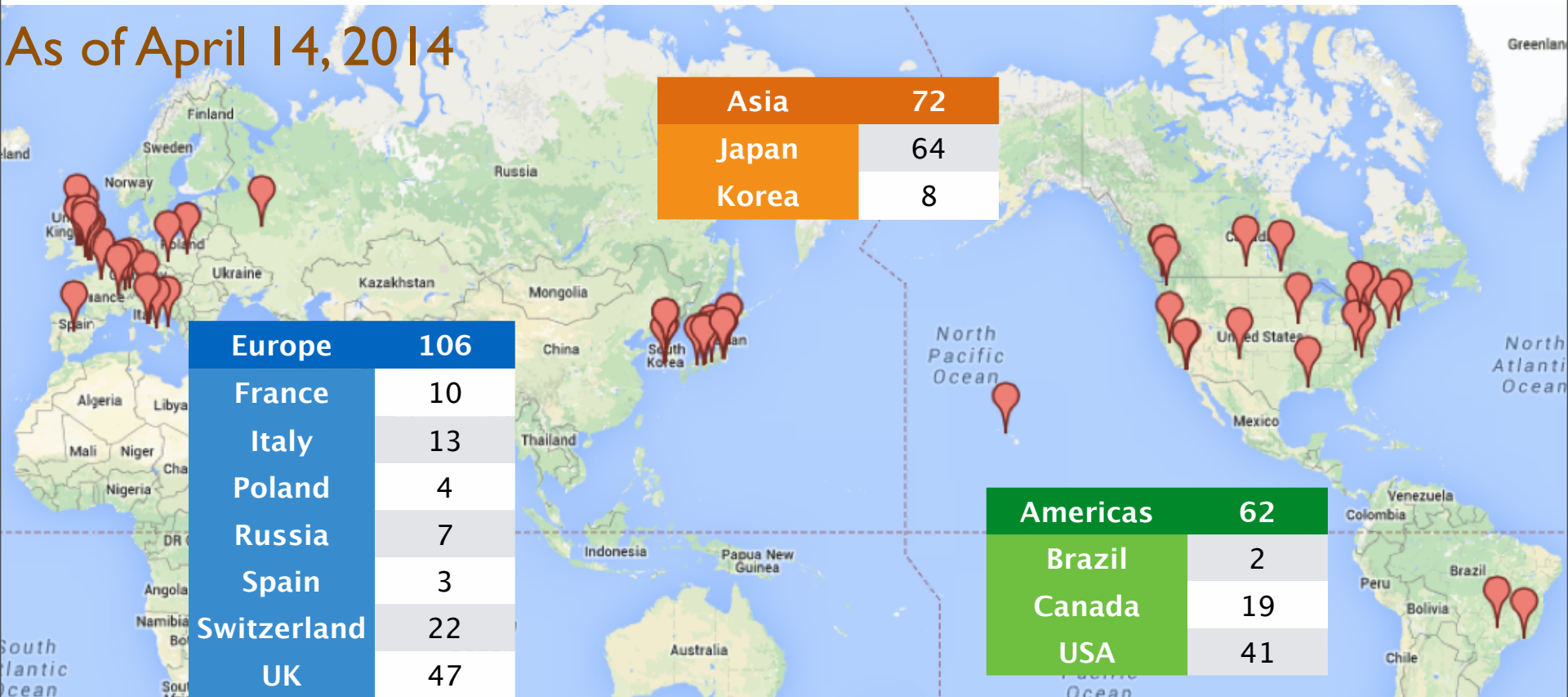
- Limitation & improvements

- Less precise vertex info.
- Detection only above Cherenkov threshold
- Potential Improvements: discussed later

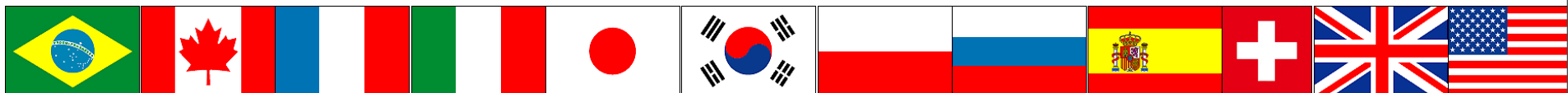


Hyper-Kamiokande International Working Group

As of April 14, 2014



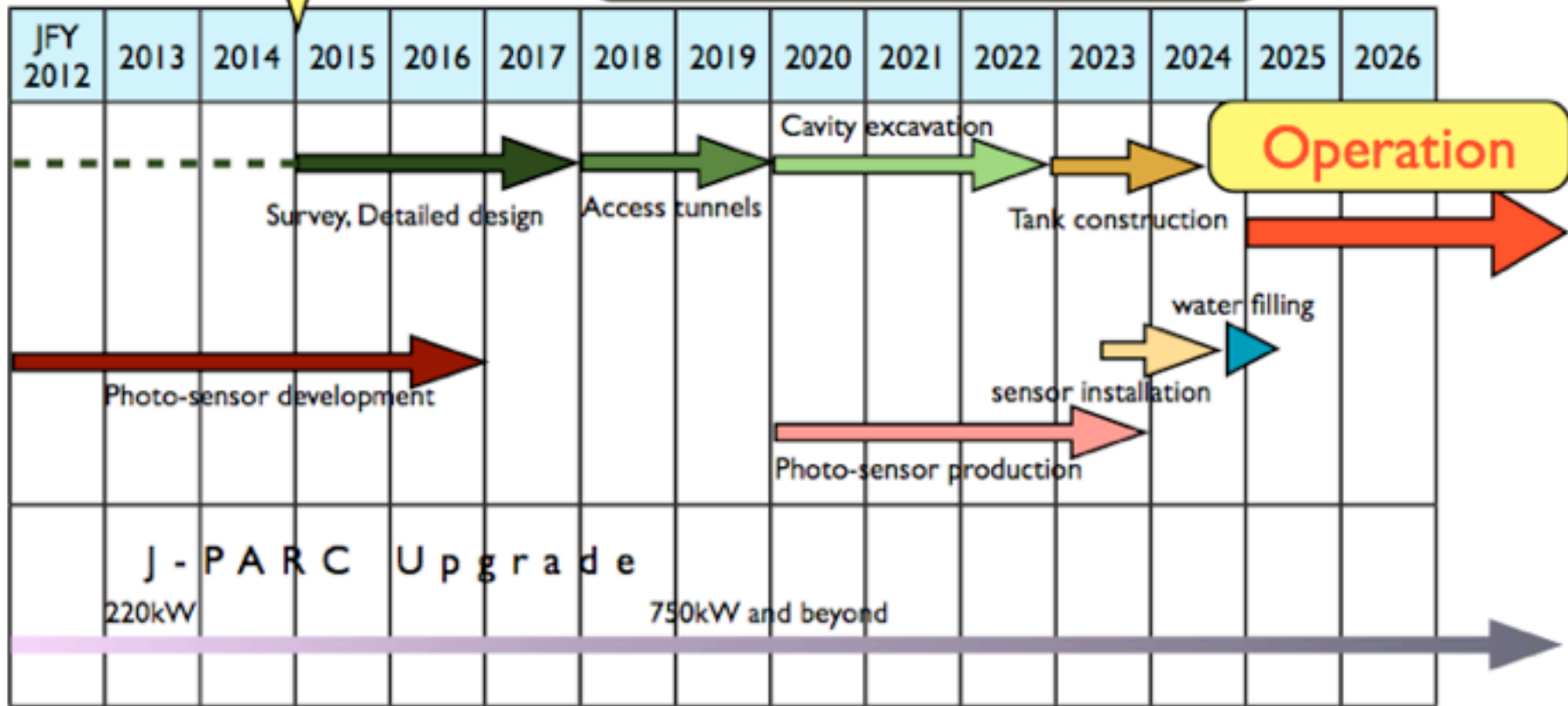
12 countries, 67 institutes, 240 people



Notional Timeline

Full survey, Detailed design

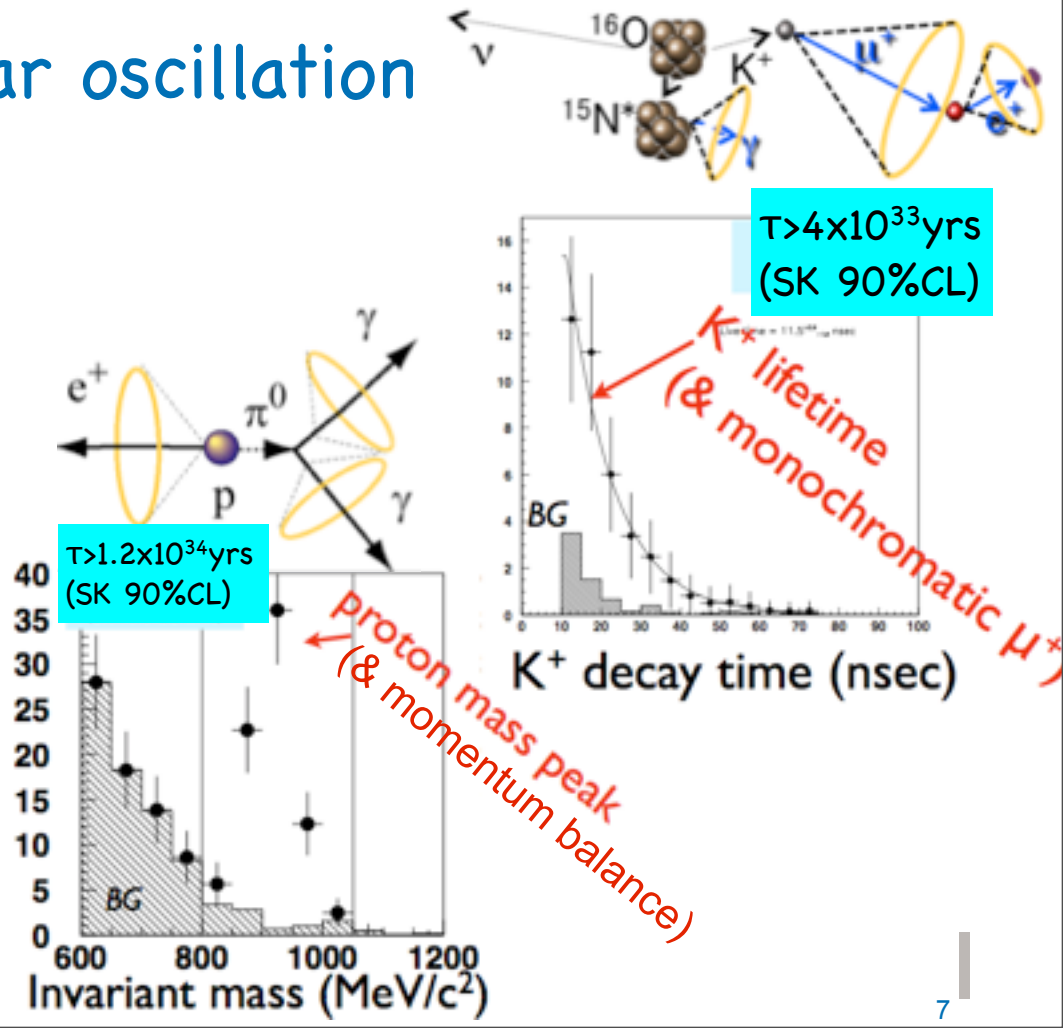
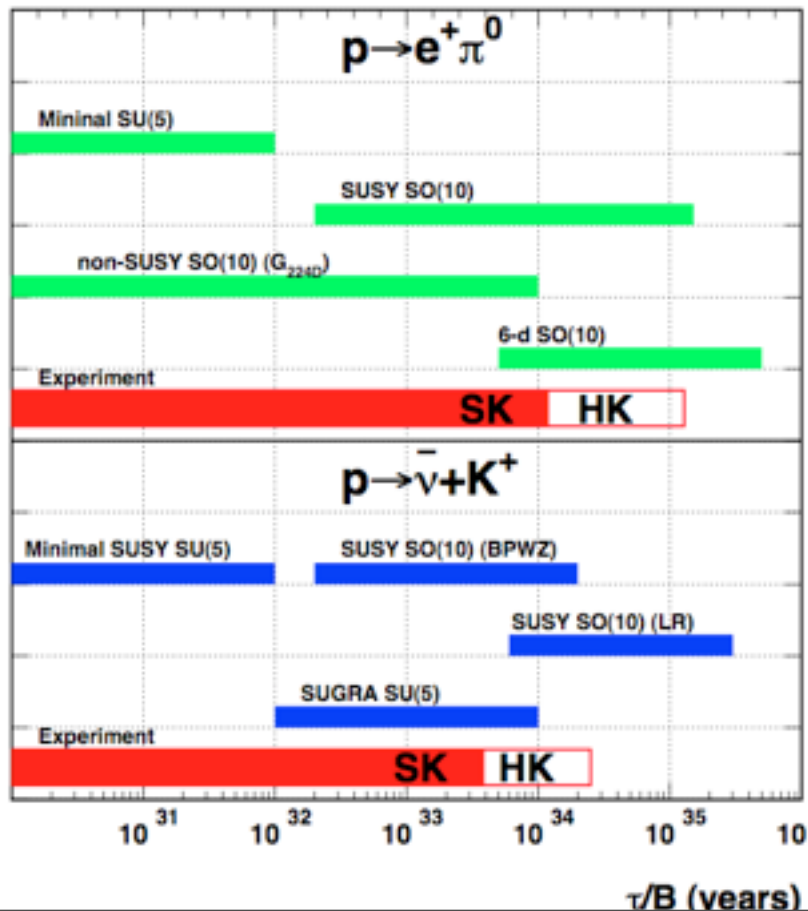
~7 yrs construction



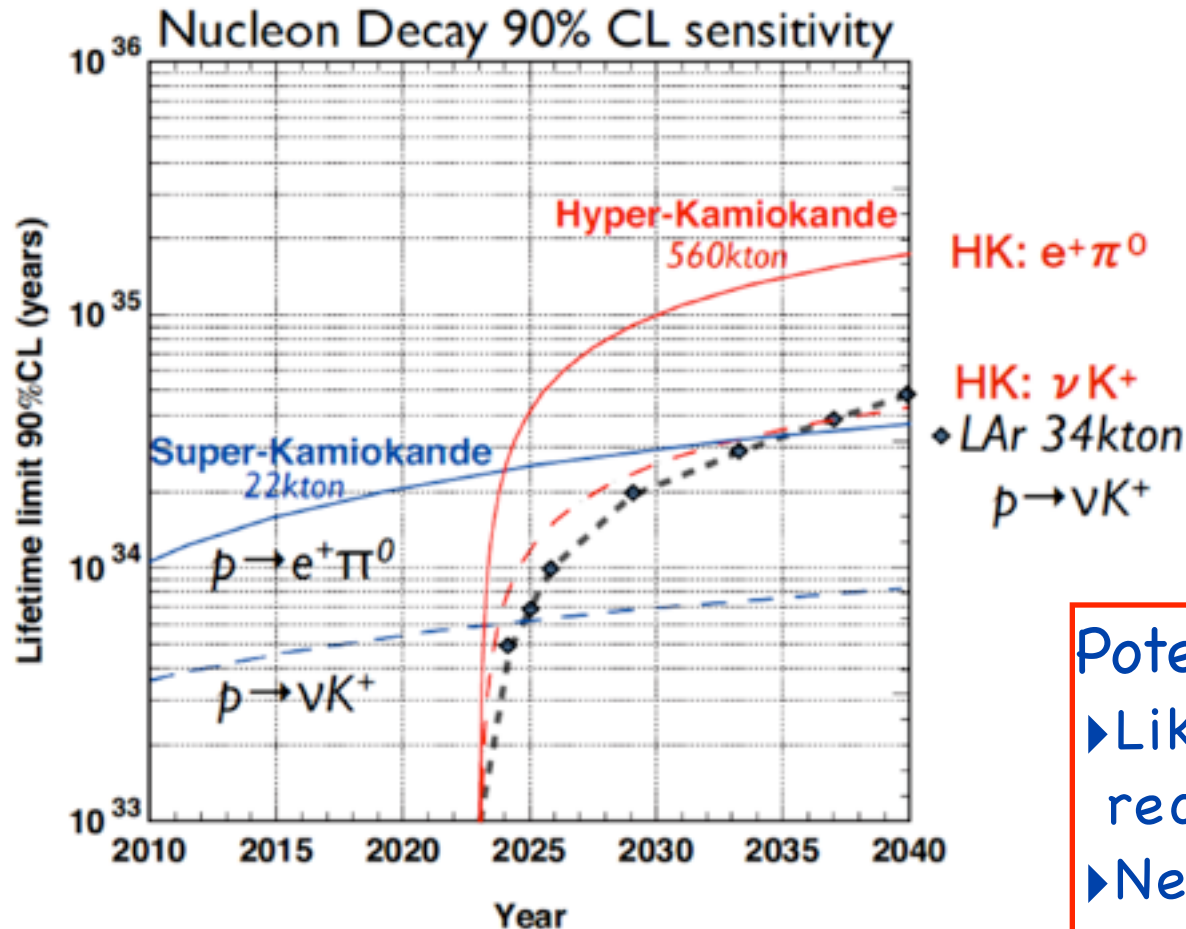
- 2015 Full survey, Detailed design (3 years)
- 2018 Excavation start (7 years)
- 2025 Start operation

Proton decay searches

- SK already in theoretically interesting region:
 - HK will be x10 better
- Also sensitive to n - \bar{n} oscillation



Proton decay sensitivities



- Hitting atm.v BG
- K from $p \rightarrow K \nu$ not visible in Water: tagging γ from residual nucleus (less efficient)

Potential Improvements:

- Likelihood fit in event reconstruction (fiTQun)
- Neutron tagging (Gd,p): suppresses atm.v BG
- Water based scint.:
K tag in $p \rightarrow K \nu$

Deeply into theoretically motivated region!

Long baseline ν beam

- Off-axis narrow band beam from J-PARC tuned at the oscillation maximum:

- $E_\nu = 600 \text{ MeV} @ L = 300 \text{ km}$
- suppresses high energy BG

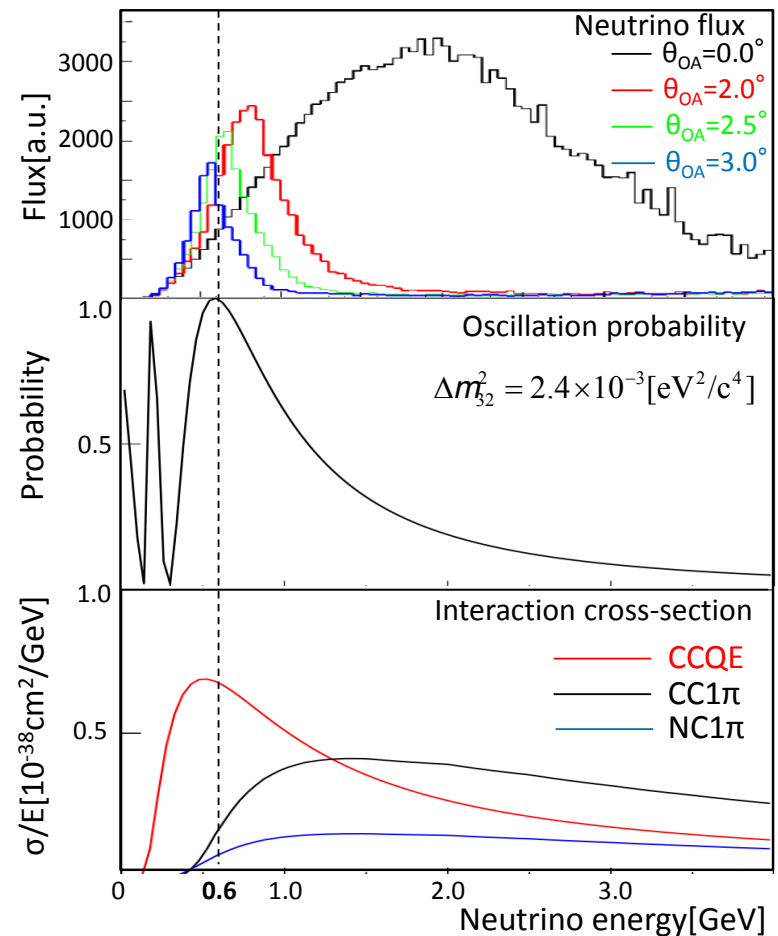
- Cross section dominated by CCQE at 600 MeV:

- clean detection by WC
- ν energy reconstruction:

$$E_\nu = \frac{2E_l m_N - m_l^2}{2(m_N - E_l + P_l \cos \theta_l)}$$

- Use the same T2K beam:

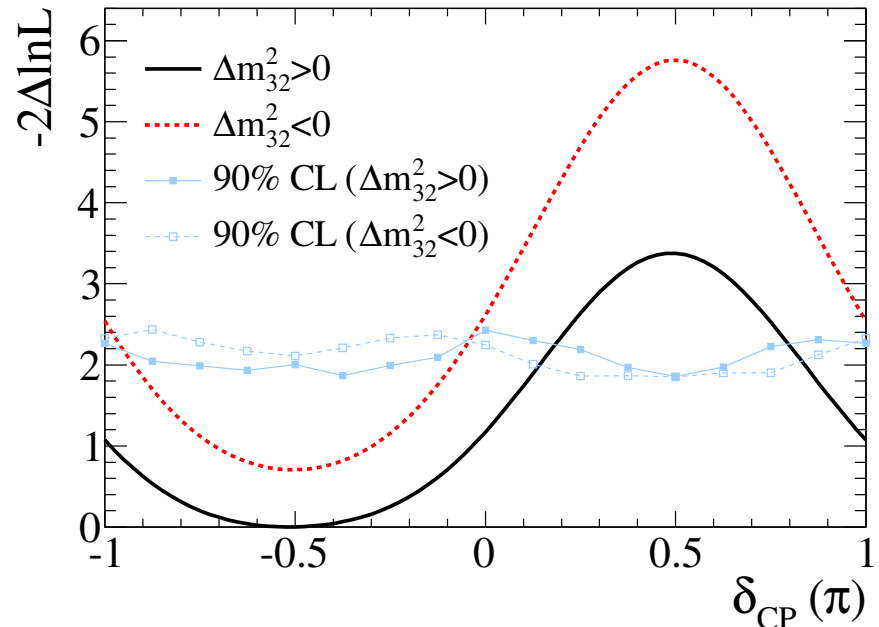
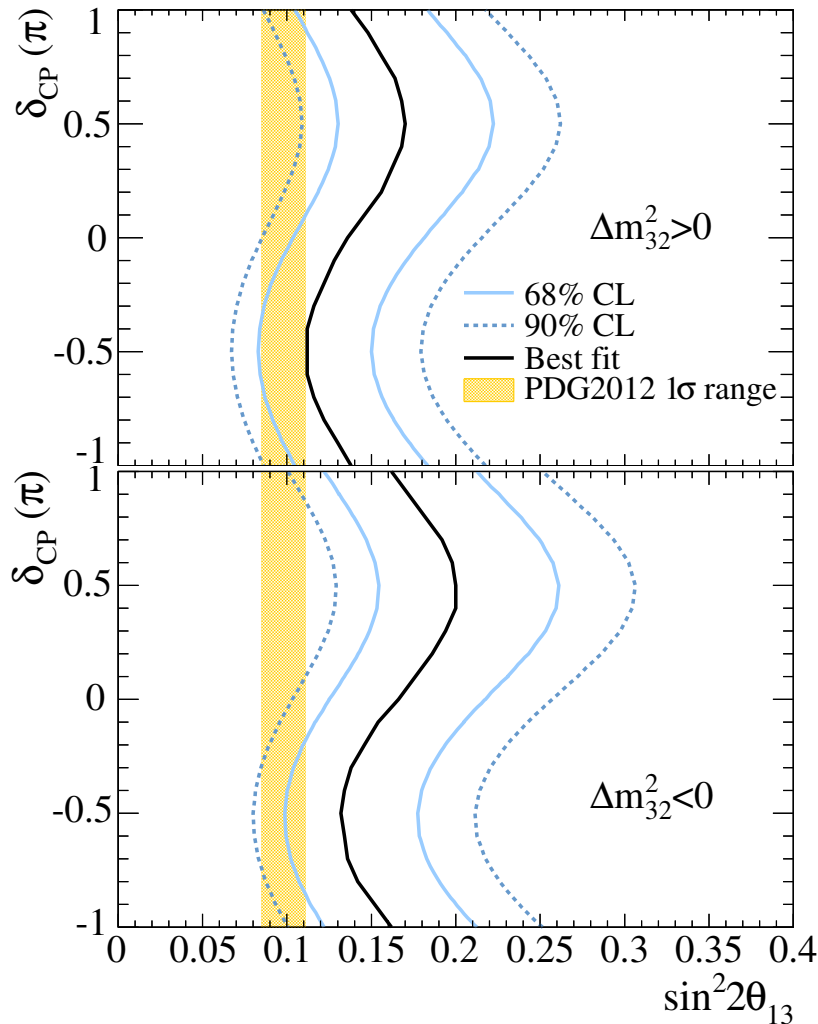
- Valuable T2K experience



T2K ν_e appearance

Normal hierarchy with
 $\delta_{CP} = -\pi/2$ is favoured

Phys. Rev. Lett. 112, 061802 (2014)

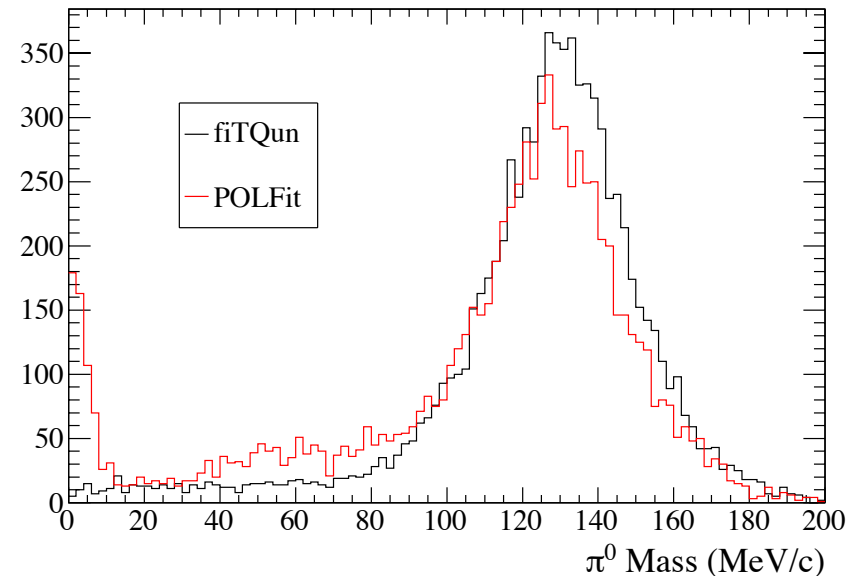
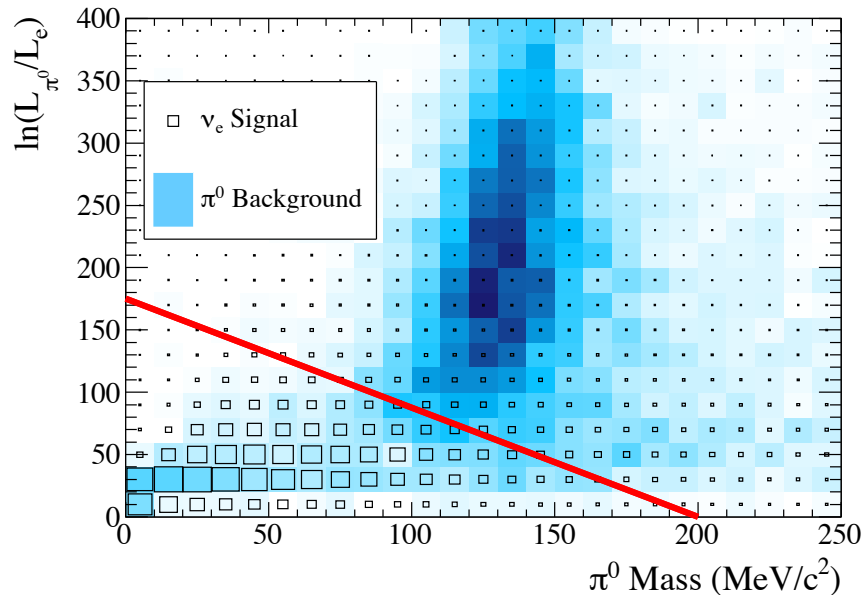


Preliminary Daya Bay result
further constrains CP phase

$$\sin^2 2\theta_{13} = 0.084^{+0.005}_{-0.005}$$

Likelihood fit reconstruction: fiTQun

- π^0 background is not so serious anymore
 - this was the main advantage of Liq.Ar



ν_e appearance @ HyperK

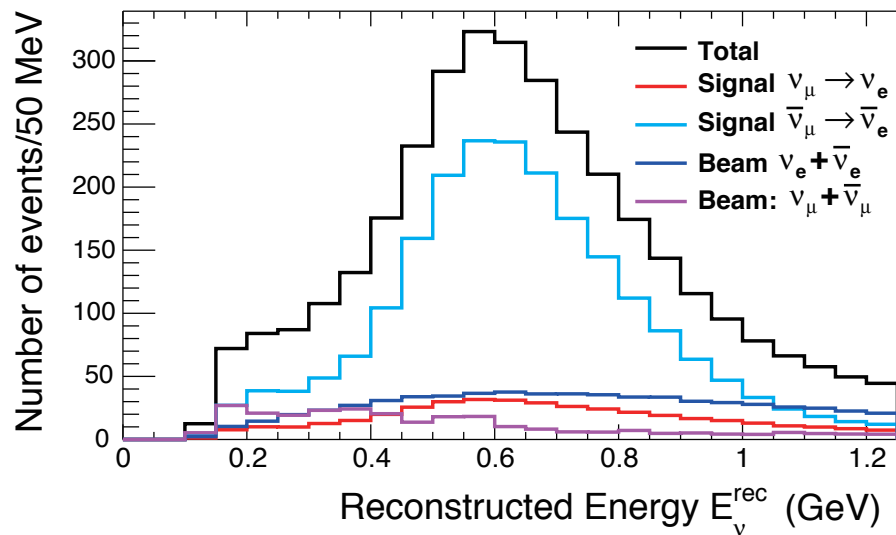
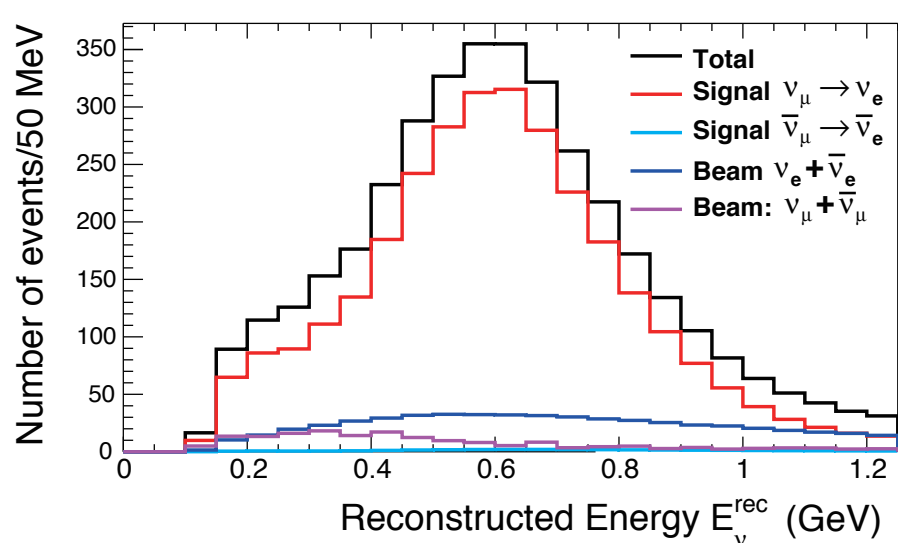
$7.5\text{MW} \times 10^7\text{s}$ (1.56×10^{22} POT)

$\sin^2 2\theta_{13} = 0.1, \delta = 0$, normal MH

Appearance ν mode

$\nu:\bar{\nu} = 1:3$

Appearance $\bar{\nu}$ mode



	Signal ($\nu\mu \rightarrow \nu_e$ CC)	Wrong sign appearance	$\nu\mu/\bar{\nu}\mu$ CC	beam $\nu_e/\bar{\nu}_e$ contamination	NC
ν	3,016	28	11	523	172
$\bar{\nu}$	2,110	396	9	618	265

New π^0 rejection (fiTQun) applied

HyperK(water) compared with LBNE(Liq. Ar)

HyperK 560kton: 2.5×10^7 sec ν 7.5×10^7 sec $\bar{\nu}$ (0.75MW beam)

	Signal ($\nu\mu \rightarrow \nu e$ CC)	Wrong sign appearance	$\nu\mu/\bar{\nu}\mu$ CC	beam $\nu e/\bar{\nu}e$ contamination	NC	BG
ν	3,016	28	11	523	172	734
$\bar{\nu}$	2,110	396	9	618	265	1287

LBNE 10kton LAr: 4.8×10^7 sec ν 4.8×10^7 sec $\bar{\nu}$ (1.2MW beam)

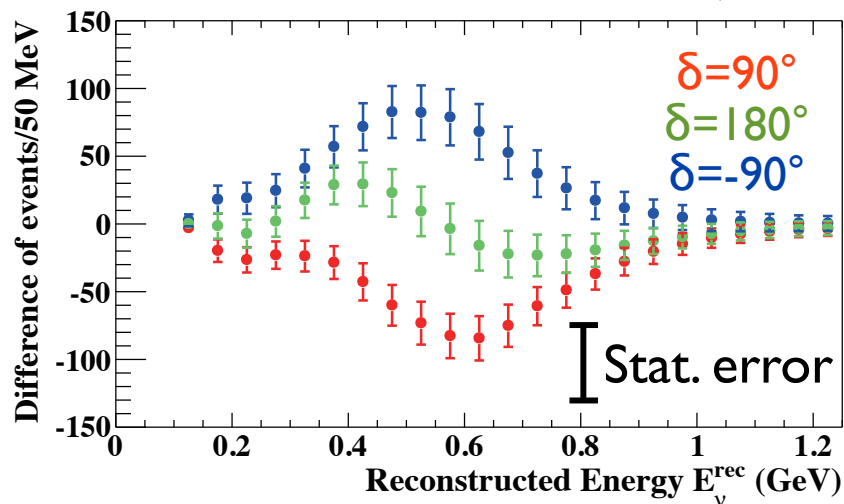
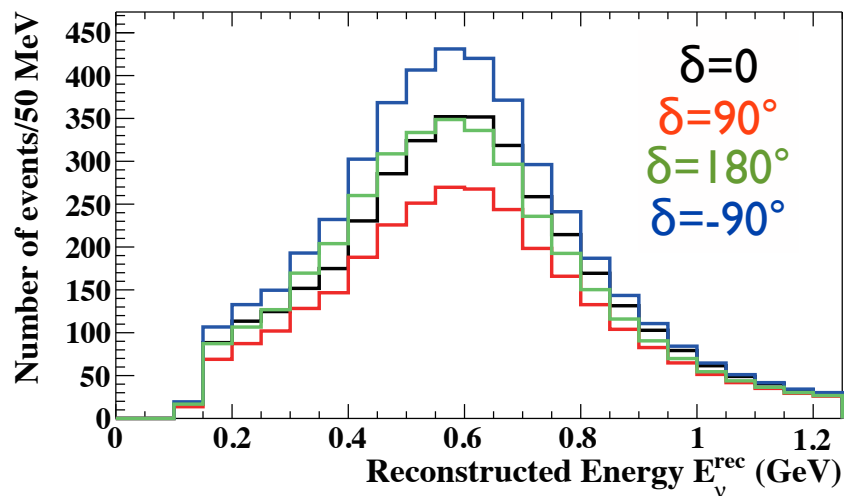
Beam	Hierarchy	Signal Events	Background Events				Total
		$\nu_x/\bar{\nu}_x$ CC	ν_μ NC	ν_μ CC	ν_e Beam	ν_τ CC	
		$\nu_\mu \rightarrow \nu_{x=e}$ (appearance)					
Neutrino	Normal	229/3	21	25	47	14	107
Neutrino	Inverted	101/5	21	25	49	17	112
Antineutrino	Normal	15/41	11	11	24	9	55
Antineutrino	Inverted	7/75	11	11	24	9	55

More signal and better S/N ratio for HyperK(water)

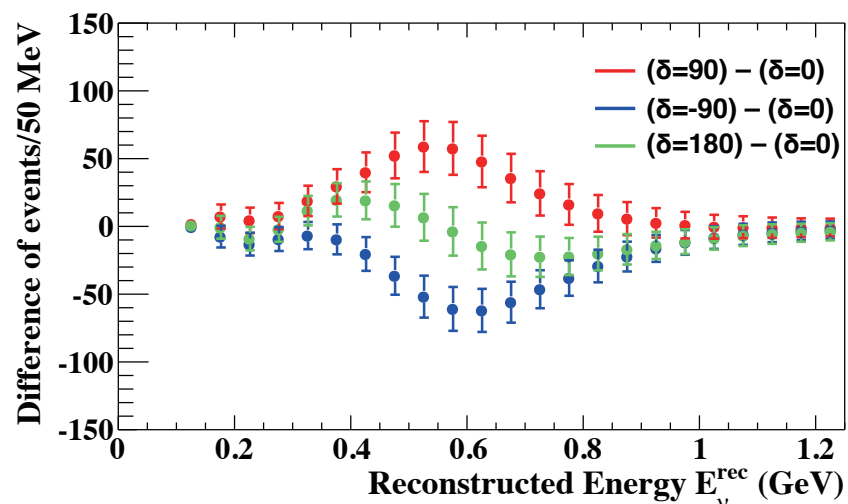
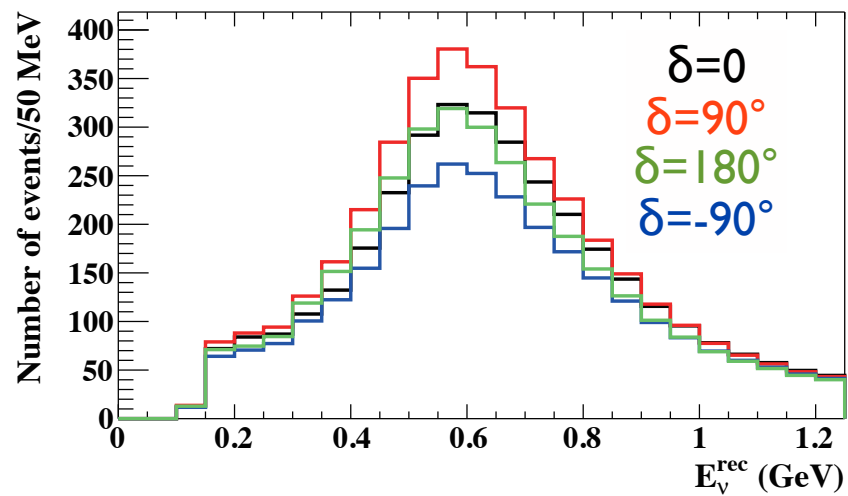
[Note: large θ_{13} , extra T2K π^0 rejection since decision to use LAr]

HyperK CP measurement

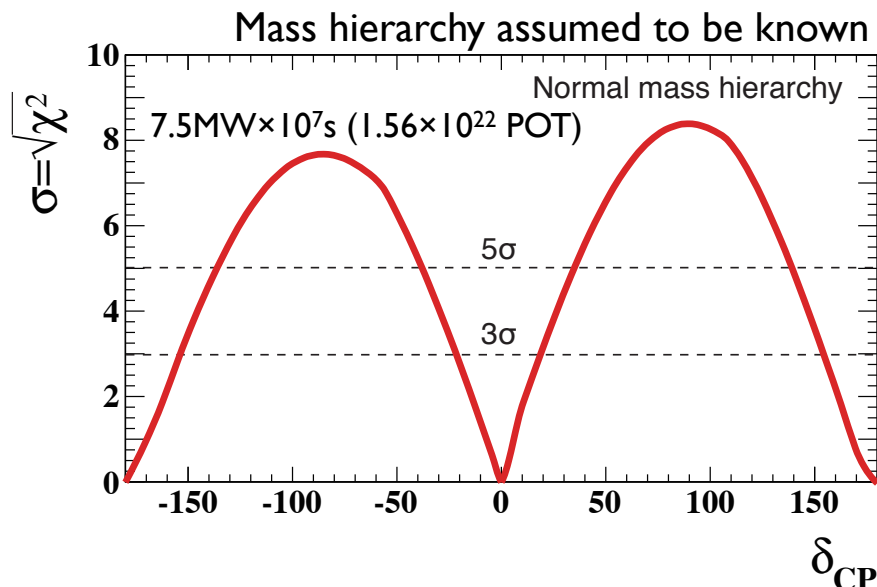
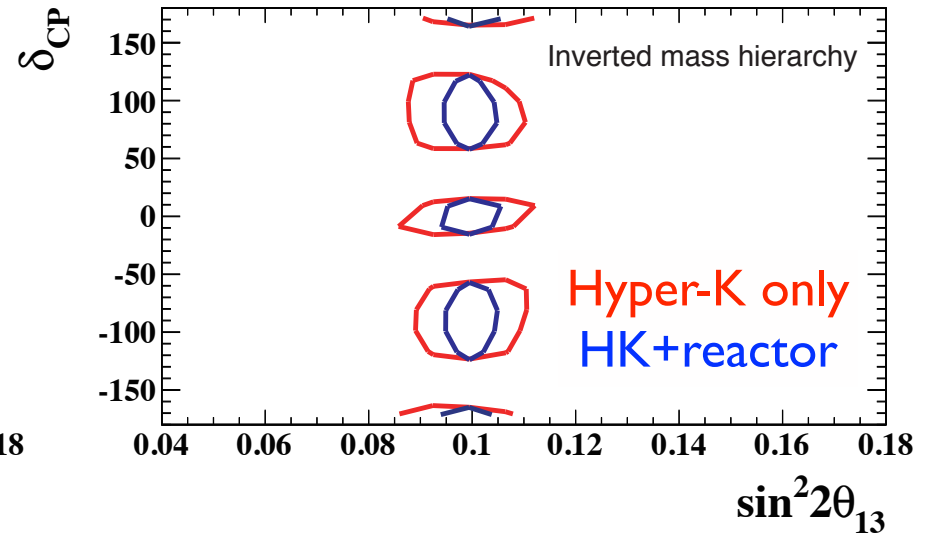
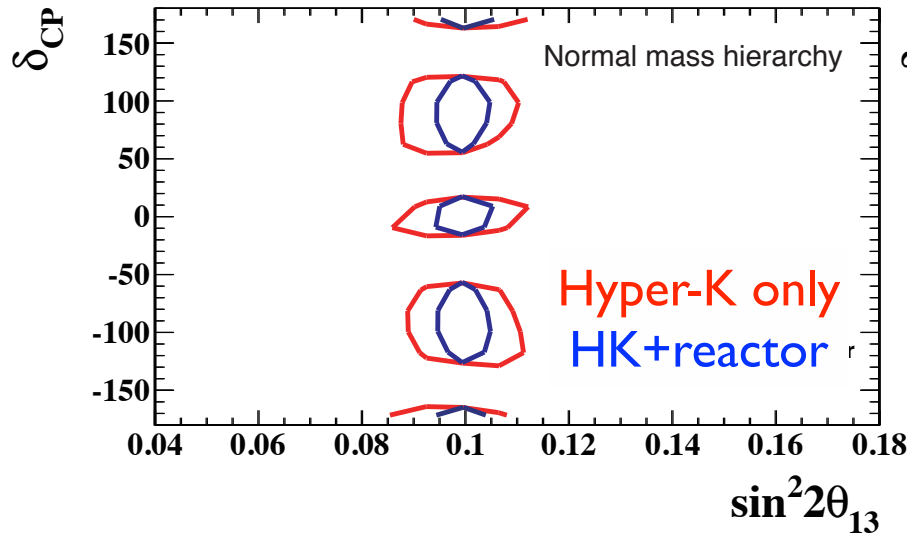
Neutrino mode: Appearance



7.5MW $\times 10^7$ s (1.56×10^{22} POT)
 Antineutrino mode: Appearance

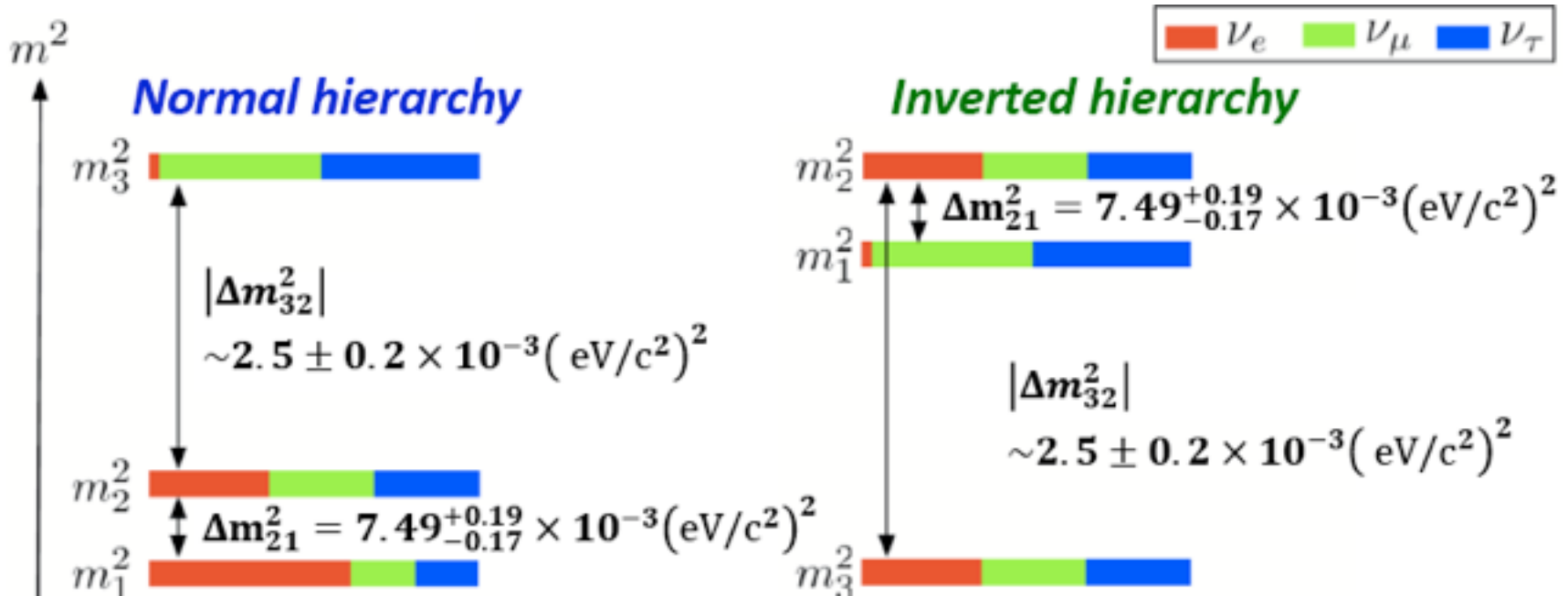


CP sensitivity



- HyperK has sensitivity to exclude $\delta_{CP}=0$ @ 3σ for 76% of δ_{CP}
- Comparison between ν & $\bar{\nu}$: CP violation without relying on 3 gen. PMNS theory

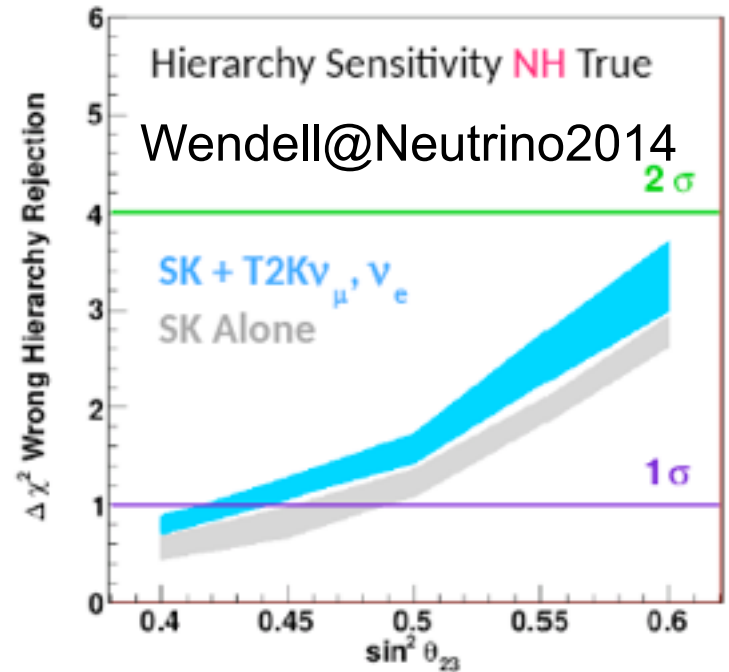
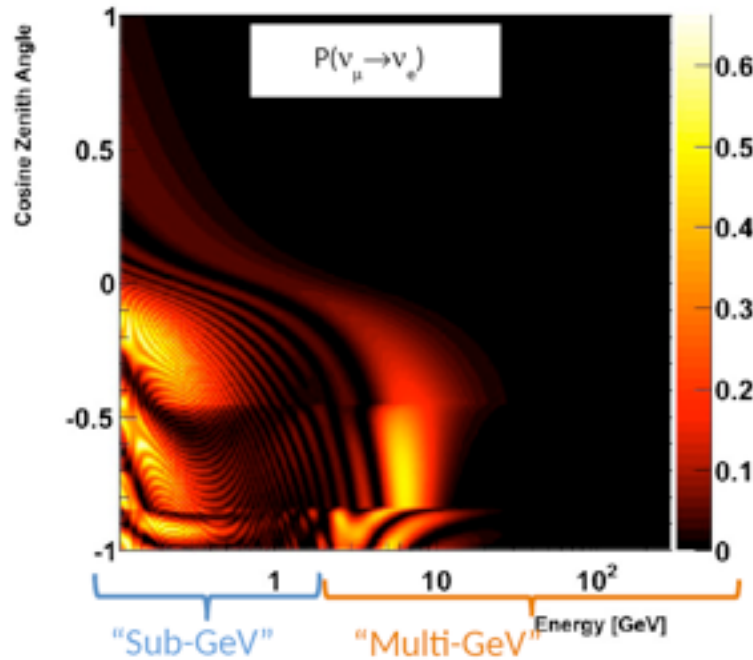
Neutrino mass hierarchy



- ν oscil. sensitive to Δm^2 : mass hierarchy uncertainty
- Matter effect shifts effective ν mass:
Additional phase shift resolves the mass hierarchy
(m_1/m_2 resolved by solar MSW)

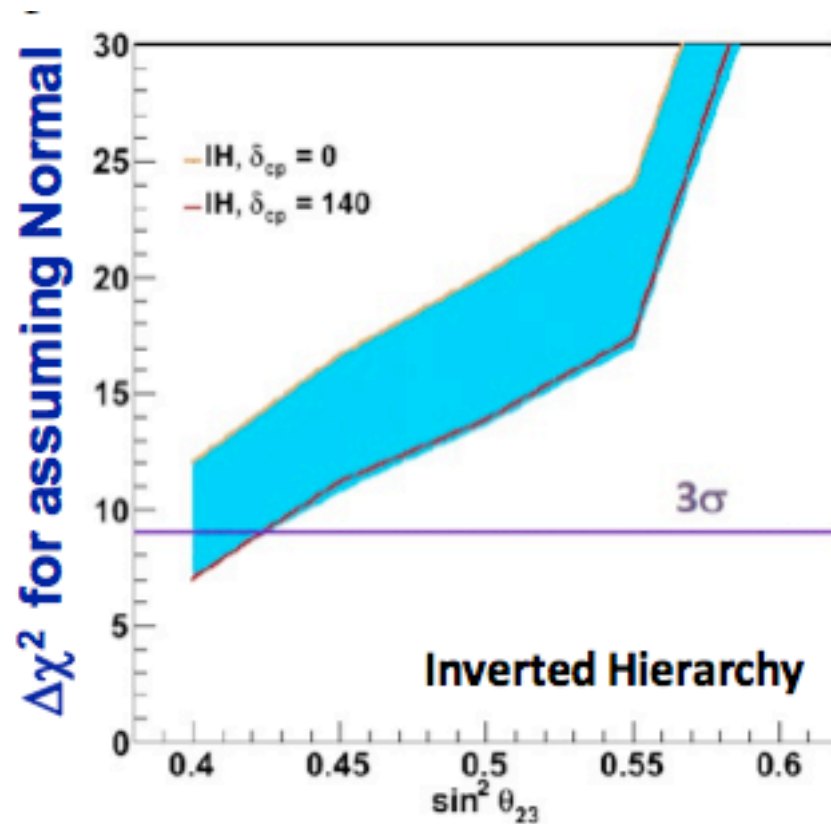
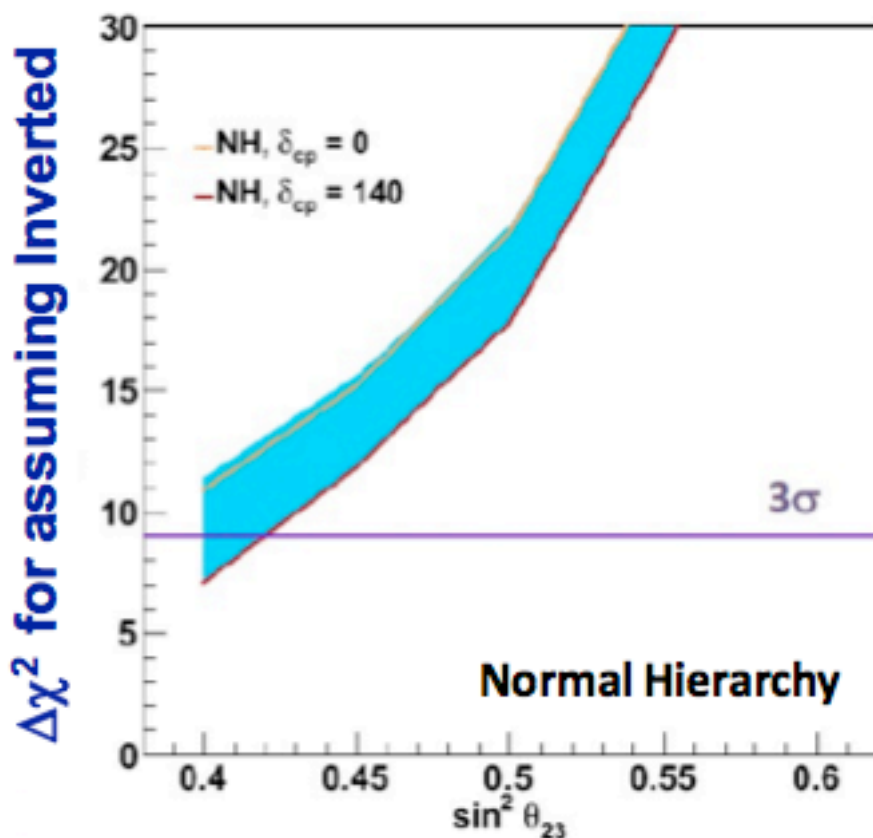
Earth matter effect (mass hierarchy)

- Earth resonant matter effect on atm. ν is large



- Preliminary SK result prefers normal hierarchy at 0.9σ (SK only) and 1.2σ (SK+T2K)
- Currently, very coarse binning is used: “Multi-GeV”
 - potential improvement with better kinematic reconstruction

Mass hierarchy sensitivity



> 3σ sensitivity expected for HyperK
(and possible further improvements with better
kinematic reconstruction, neutron tagging.)

HyperK Observatory

- Supernova ν : (Next Ikeda-san's talk)
 - Reaching Andromeda galaxy
 - Relic supernova neutrinos
- Solar ν
- ν from WIMP dark matter annihilation
 - from Sun, galactic centre
- Exotic particles
 - GUT monopole (Callen-Rubakov)
 - proton decay @sun: ν 's from μ/π decays
 - Qball
 - n - \bar{n} oscillations, di-nucleon decays

Status of HK working group

- In Japan
 - Selected as one of 27 important large-scale projects by the “Master plan 2014” of Science Council of Japan

No.	Scientific Field No.	Project Name	Project Summary	Scientific Significance	Social Value	Project Duration	Financial Requirement (1billion yen)
85	23-2	Nucleon decay and neutrino oscillation experiment with a large advanced detector	The project is to construct an 1 million ton scale water Cherenkov detector Hyper-Kamiokande as a successor of Super-Kamiokande and to perform world leading studies of nucleon decays and neutrinos with the J-PARC accelerator facility.	The project will explore CP violation (matter-antimatter asymmetry) of neutrinos to help understand the evolution of the universe. Along with world best nucleon decay searches, it aims to establish unification of elementary particles and their forces.	I will challenge to solve profound problems on particle unification and universe which should appeal to intellectual curiosities of human being. It will also represent dreams of basic science by advancing the world leading project in Japan.	2015 to 2038	Total:1,880 Construction of Hyper-Kamiokande800, Operating cost of Hyper-Kamiokande450, Operating cost of J-PARC600, Neutrino monitor30

- discussions w/ MEXT (funding agency) toward budget request
- 5 yrs Grant-in-Aid for Hyper-K R&D and design from 2013
 - Prototype detector project was launched
- Budget request for Hyper-K R&D projects being submitted in Canada and UK
- In Switzerland, included in the SERI inventory of planned research infrastructures
- Travel grant request submitted in EU (UK,France,Italy,Poland, Spain)

5th Open Meeting for the Hyper-Kamiokande Project

19-22 July 2014

Canada/Pacific timezone

Overview

Meeting photo [last HK meeting]

Important Dates

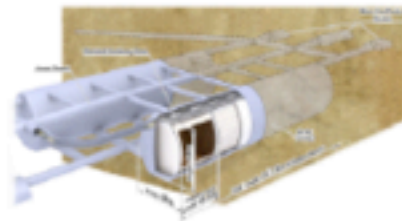
Registration Form

Call for Abstracts

View my abstracts

Submit a new abstract

Contact Information



Overview

The Hyper-Kamiokande project is being designed to be the next decade's flagship experiment for the study of neutrino oscillations, nucleon decays, and astrophysical neutrinos.

Following the successful format of the previous meetings, we will hold the 5th International Open Working Group Meeting for Hyper-Kamiokande. The meeting will be open to all interested scientists and community members.

The outline of the meeting is:

- **19 July (Sat.):** Premeetings and IBR (International Board of Representatives) Meeting
- **20 July (Sun.):** Plenary Sessions, Workshop Dinner
- **21 July (Mon.):** Plenary Sessions
- **22 July (Tue.):** Plenary Session till noon, followed by tour of TRIUMF.

Meeting in Vancouver (UBC, TRIUMF) on July 19-22, 2014

<http://indico.ipmu.jp/indico/conferenceDisplay.py?confId=34>

- It is an open meeting: we welcome those who are interested
- Discussion session for “message to Fermilab v summit”.

Summary

- Hyper-K explores potential very high energy scale through
 - Nucleon decays predicted by GUT
 - Precision measurement of neutrino oscillations
- Water Cherenkov is very effective:
 - Large mass for given budget
 - Good event reconstruction, Particle ID
- Hyper-K is also a unique observatory
 - solar ν , atmospheric ν , supernova ν
 - exotic particles: WIMPs, monopole, Qball, etc.
- Hyper-K collaboration is being formed:
 - Open meeting on July 19–22 in Vancouver, Canada

Thank you!

Merci

TRIUMF: Alberta | British Columbia | Calgary
| Carleton | Guelph | Manitoba |
McGill | McMaster | Montréal | Northern
British Columbia | Queen's | Regina |
Saint Mary's | Simon Fraser | Toronto |
Victoria | Winnipeg | York



Latest and on-going WC improvements

- Likelihood fit of all PMT charge/timings: fitQun
 - π^0 background rejection for ν_e appearance (done!)
 - Particle ID for pions, kaons, and protons
 - better kinematic reconstruction of multi-rings:
 - proton decays, e.g. γ tagging in $p \rightarrow K\nu$ mode
 - mass hierarchy study with atmospheric ν
- Neutron tagging: Gd (GAZOOKS), $np \rightarrow d\gamma$
 - atmospheric ν BG rejection in p -decay, relic supernova ν
 - anti-neutrino tagging: $\bar{\nu}p \rightarrow \mu^+n$ [CP, mass hierarchy]
- Water based scintillator (BNL)
 - neutrino/anti-neutrino separation: $\nu n \rightarrow \mu^-p$
 - K tagging in $p \rightarrow K\nu$ mode
- **vPRISM: precise ν cross section study in water**

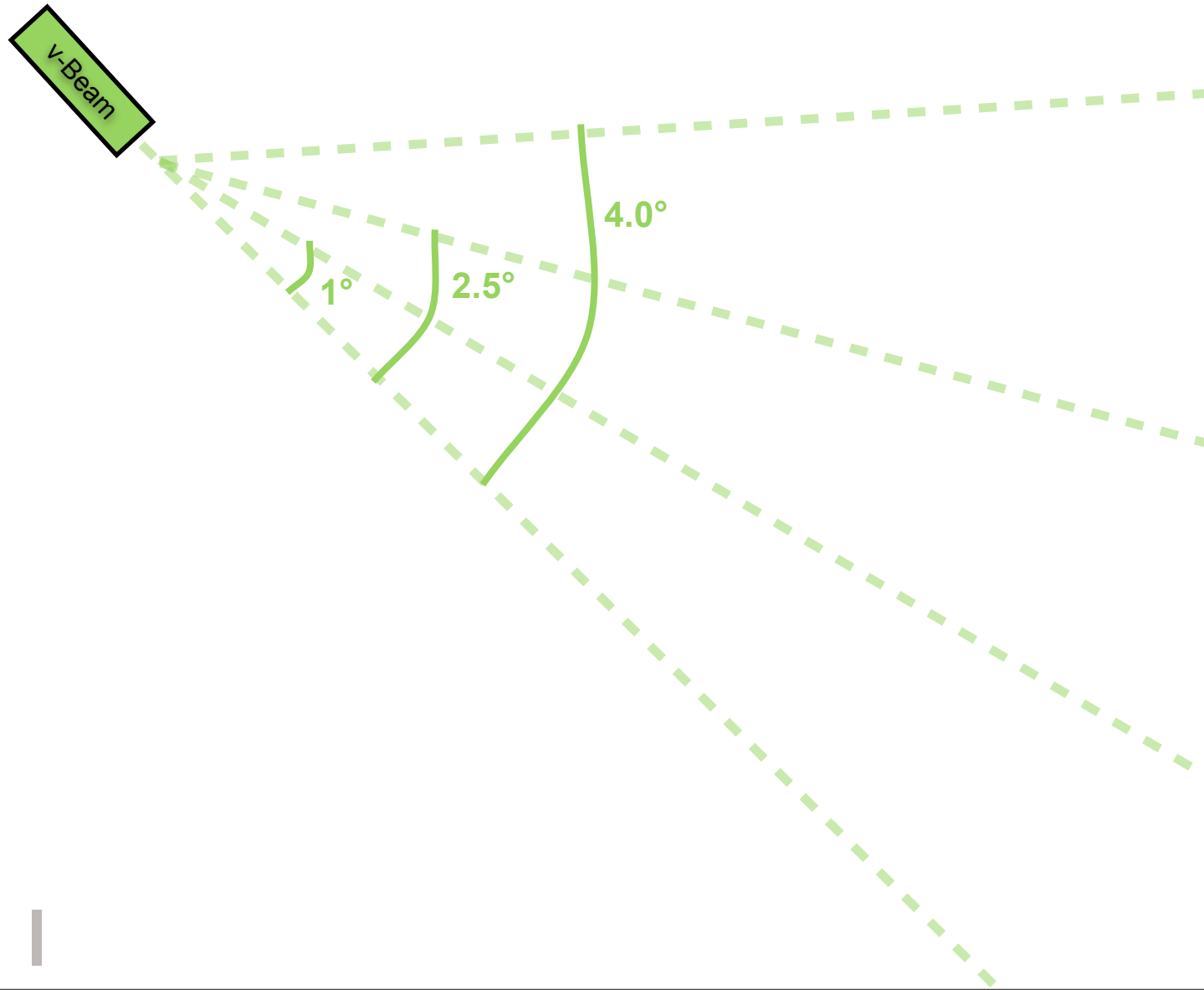
vPRISM Concept

v-Beam

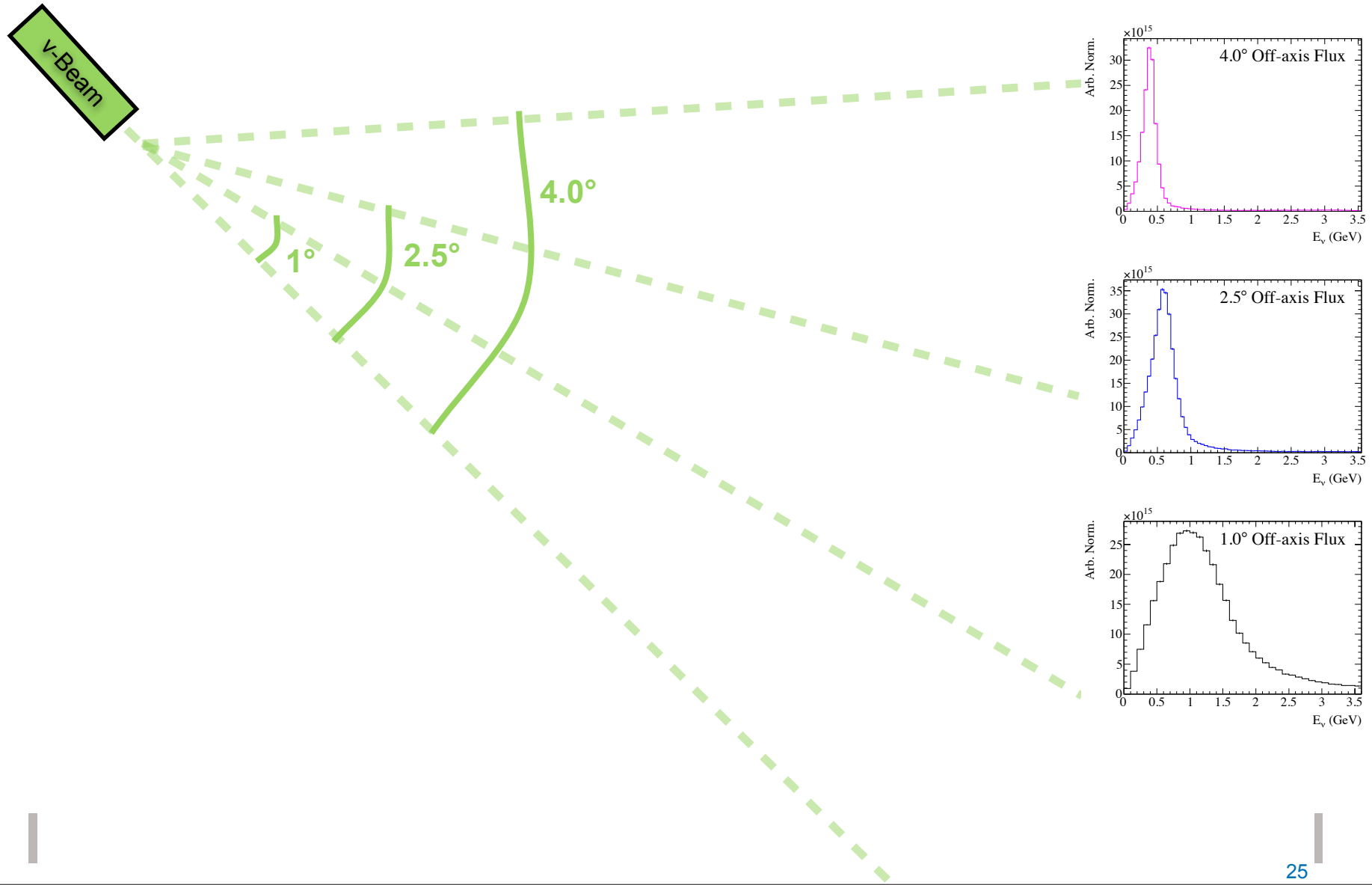


A diagram illustrating the vPRISM concept. A green rectangular box with a black border, labeled "v-Beam", is positioned in the upper left. A dashed green line extends diagonally from the bottom right corner of this box across the slide, representing the beam's path.

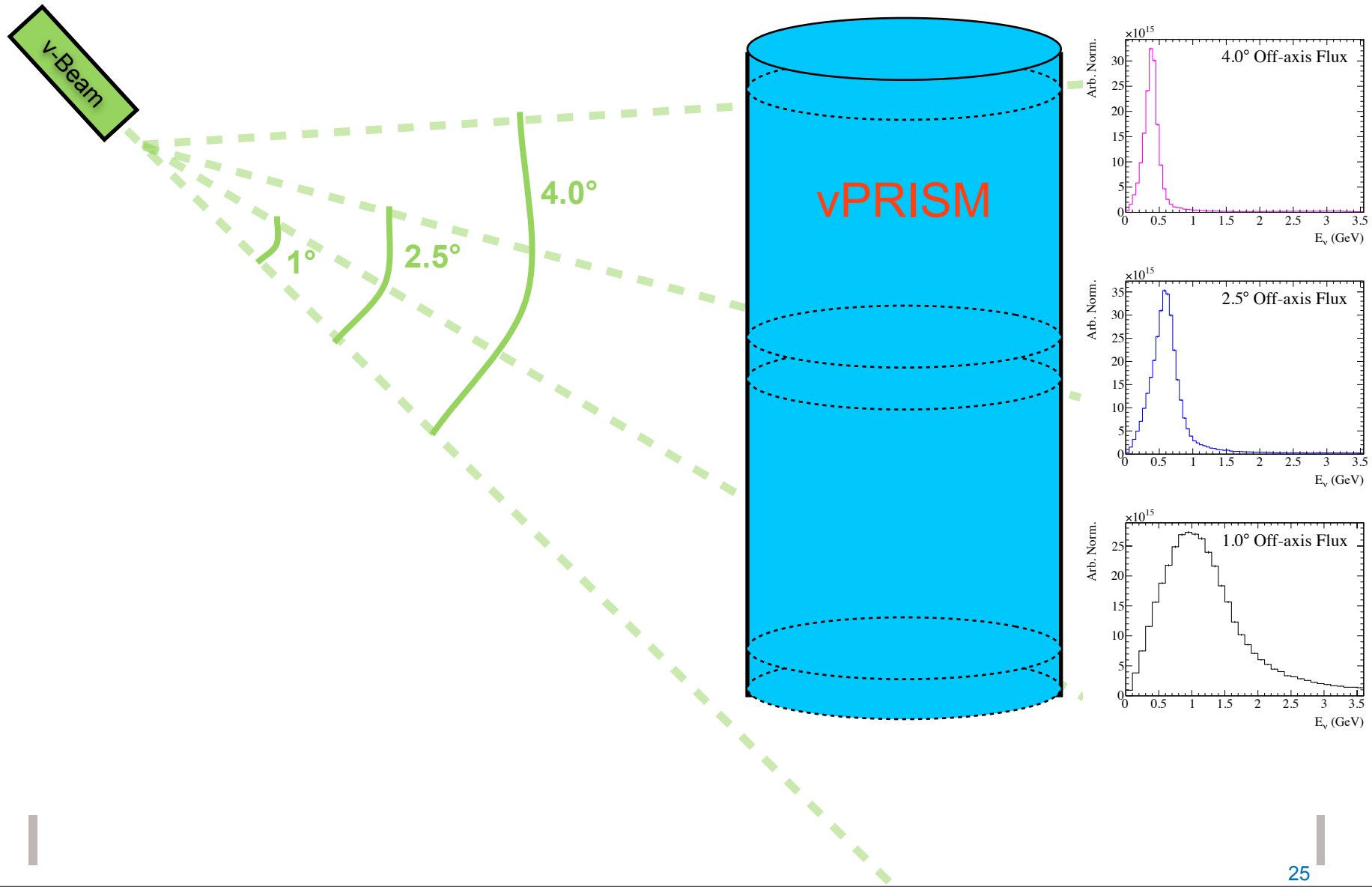
vPRISM Concept



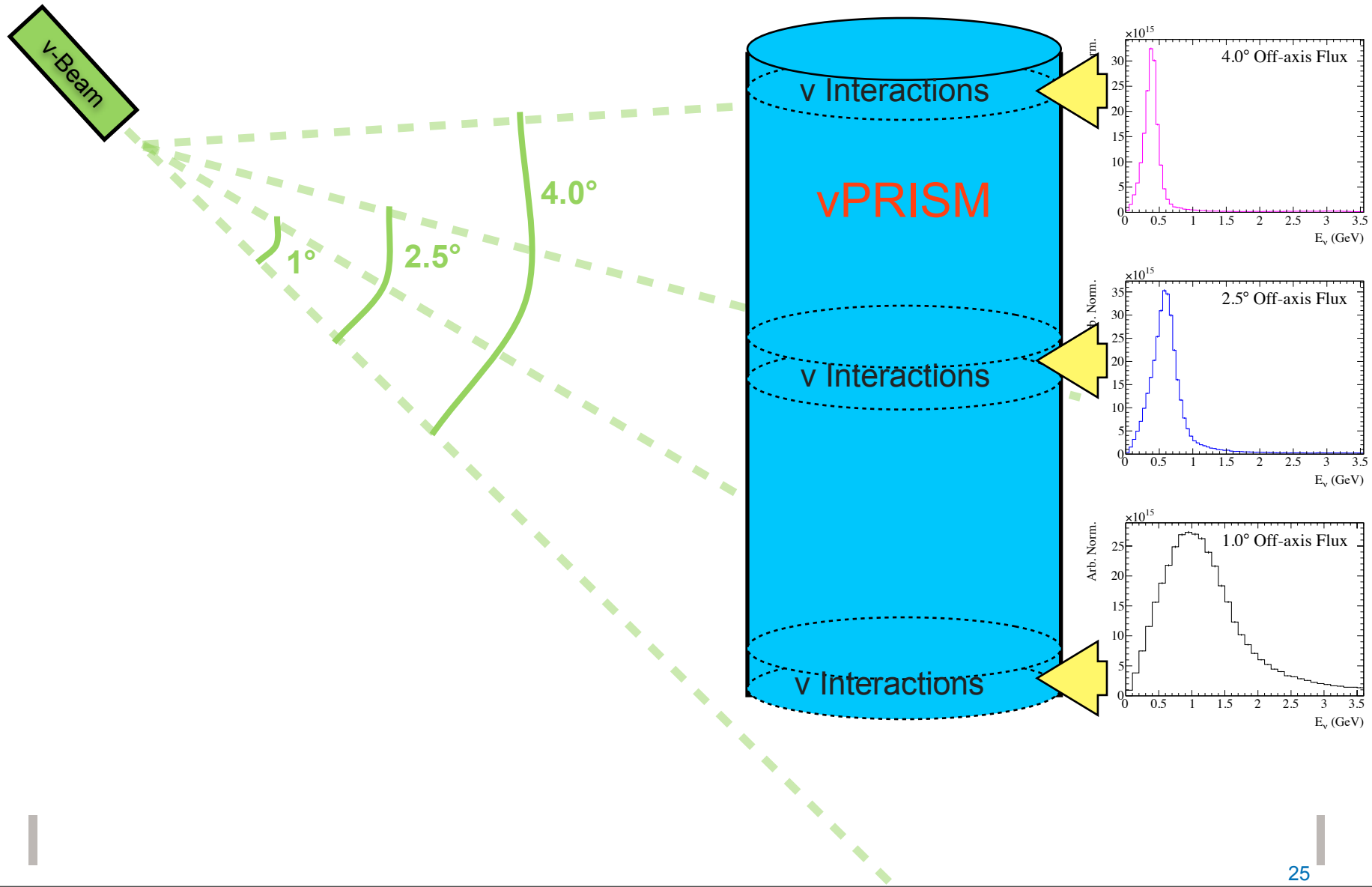
vPRISM Concept



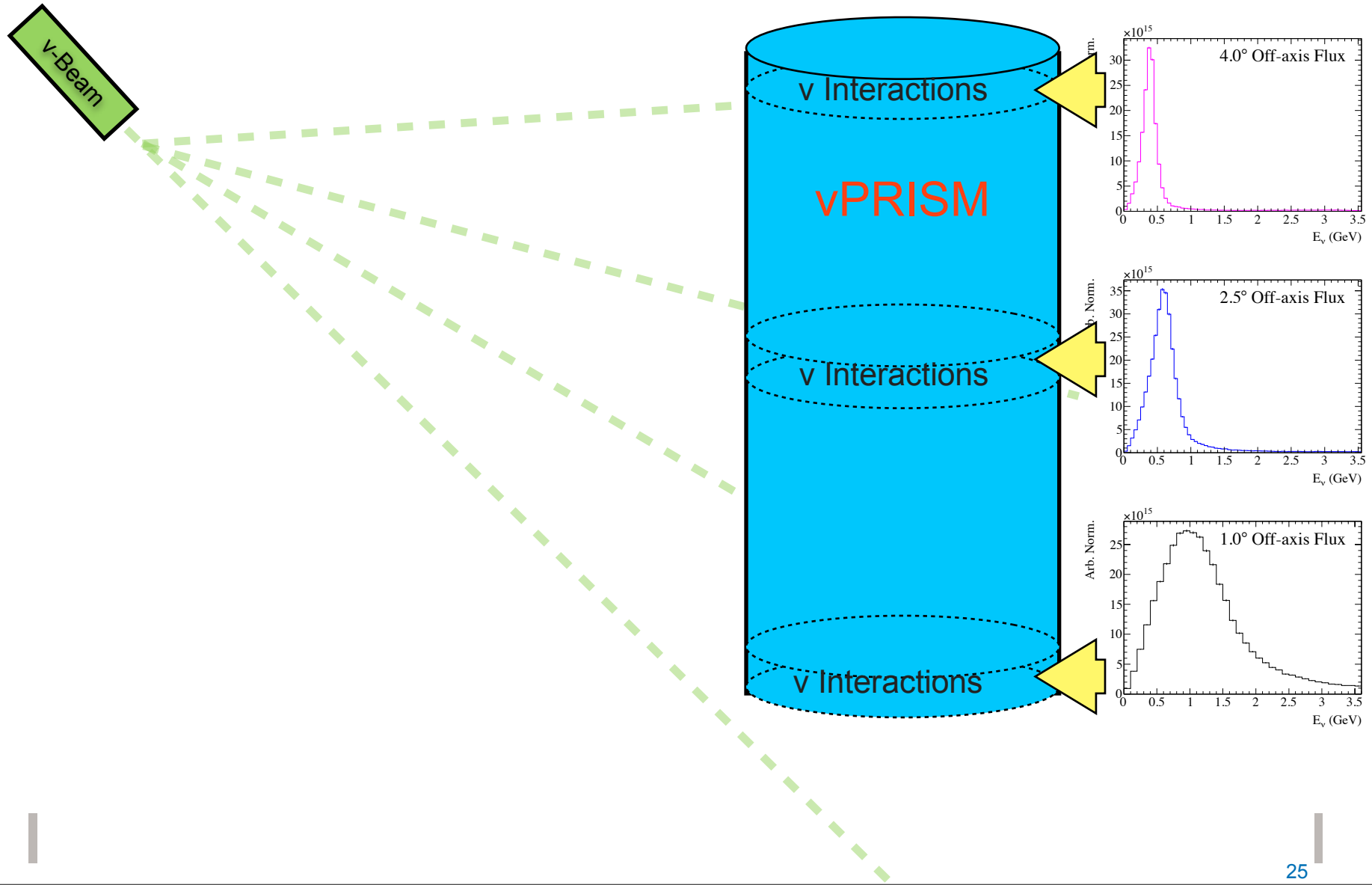
vPRISM Concept



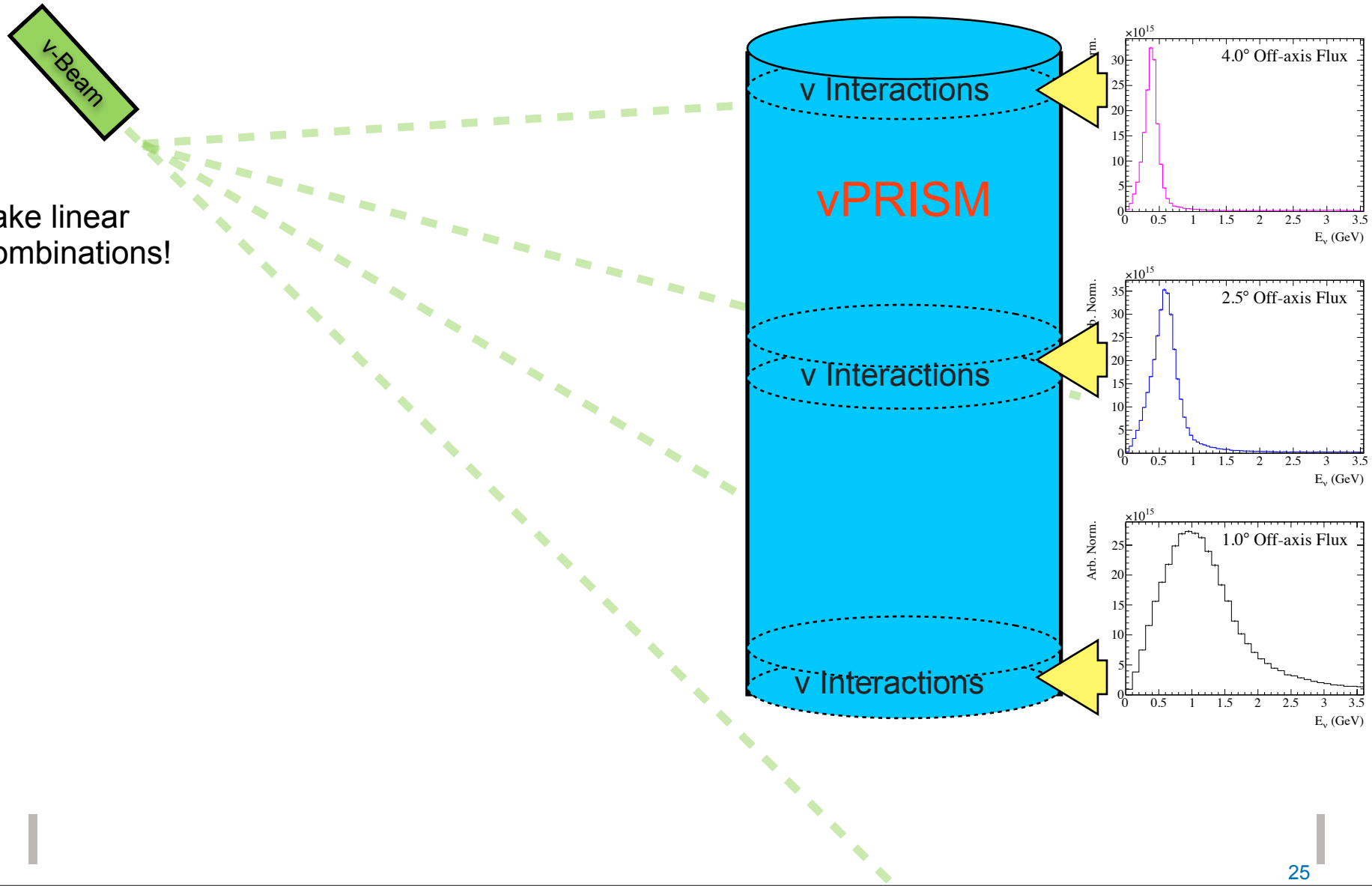
ν PRISM Concept



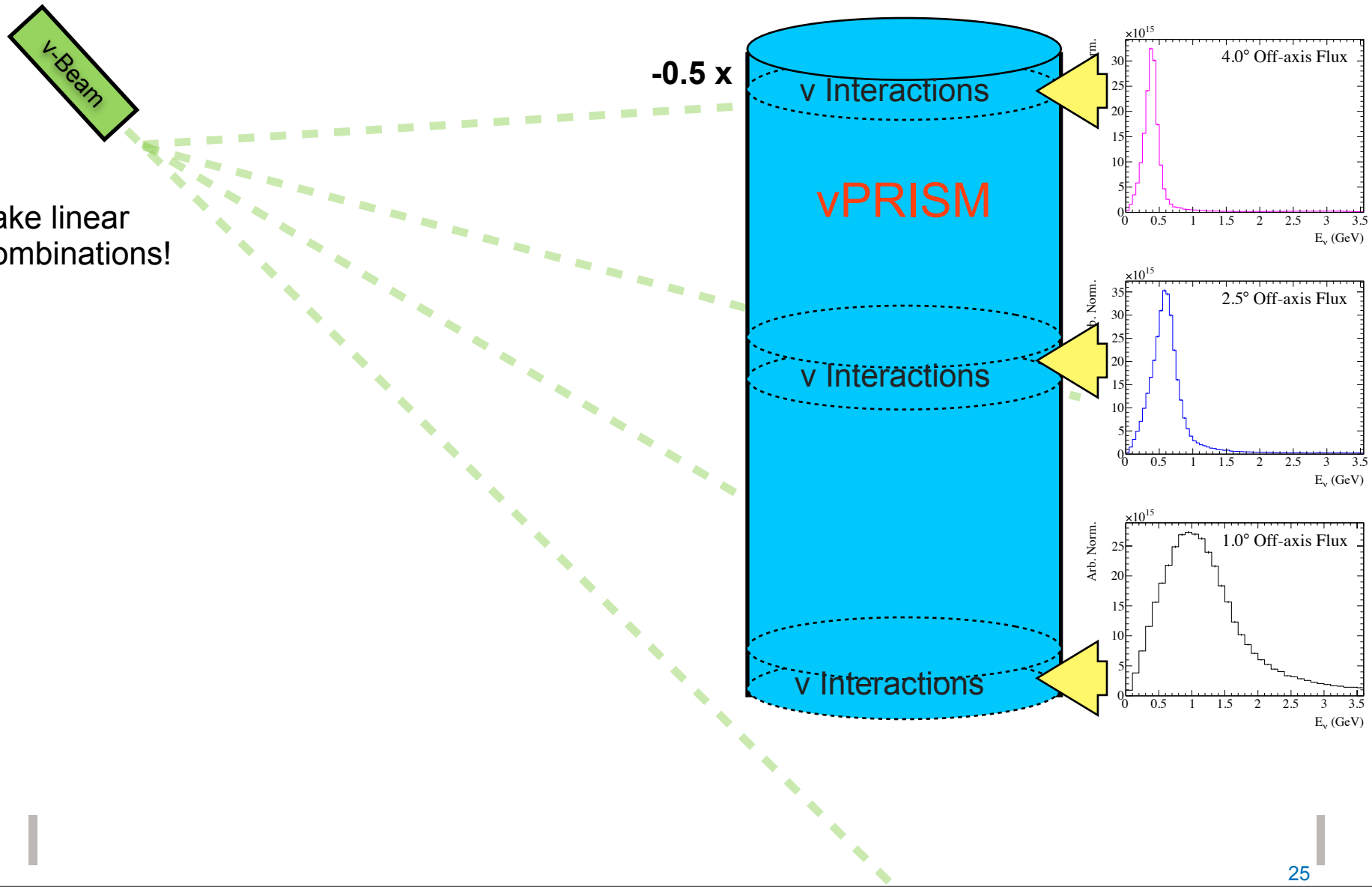
ν PRISM Concept



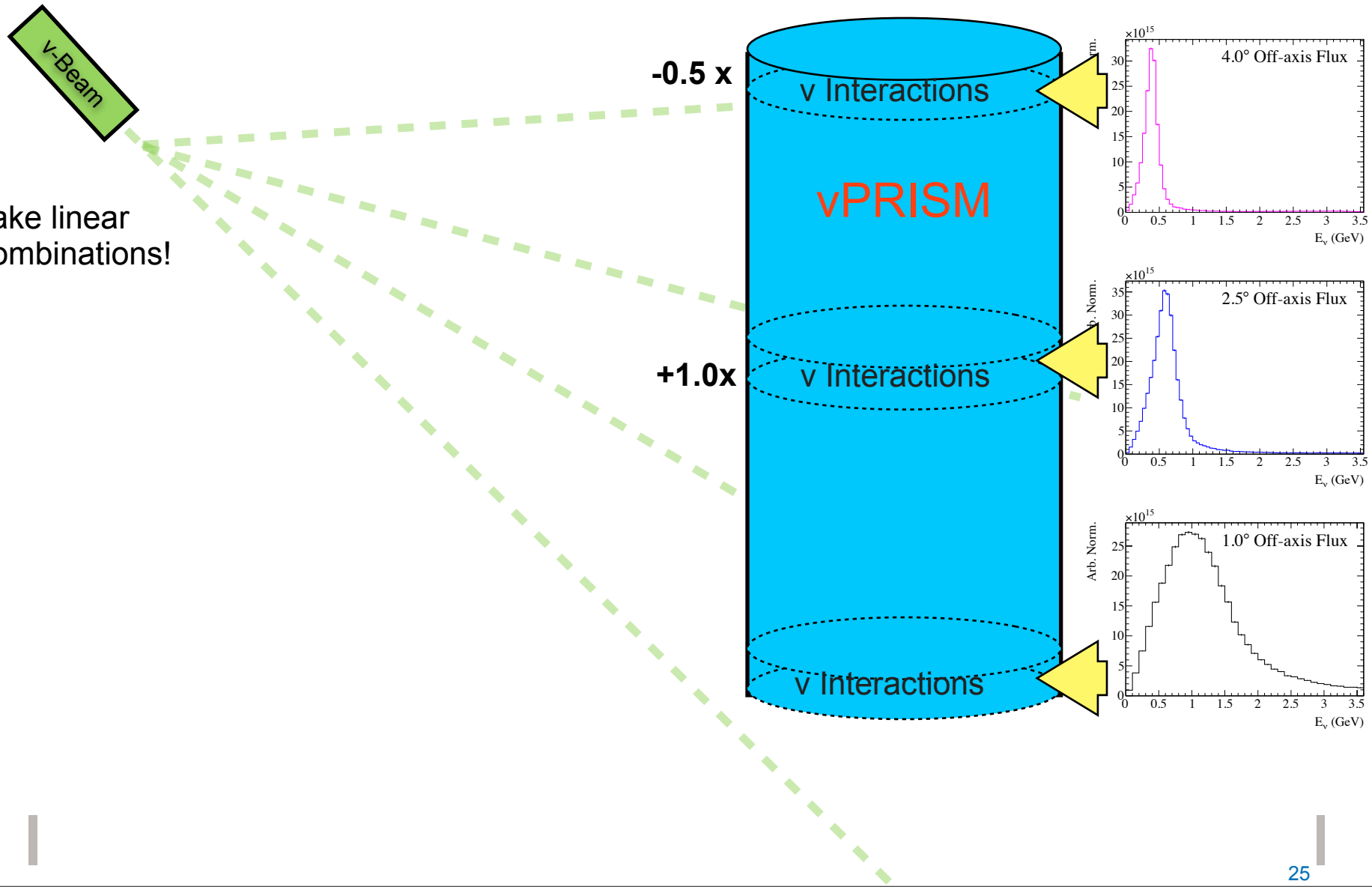
ν PRISM Concept



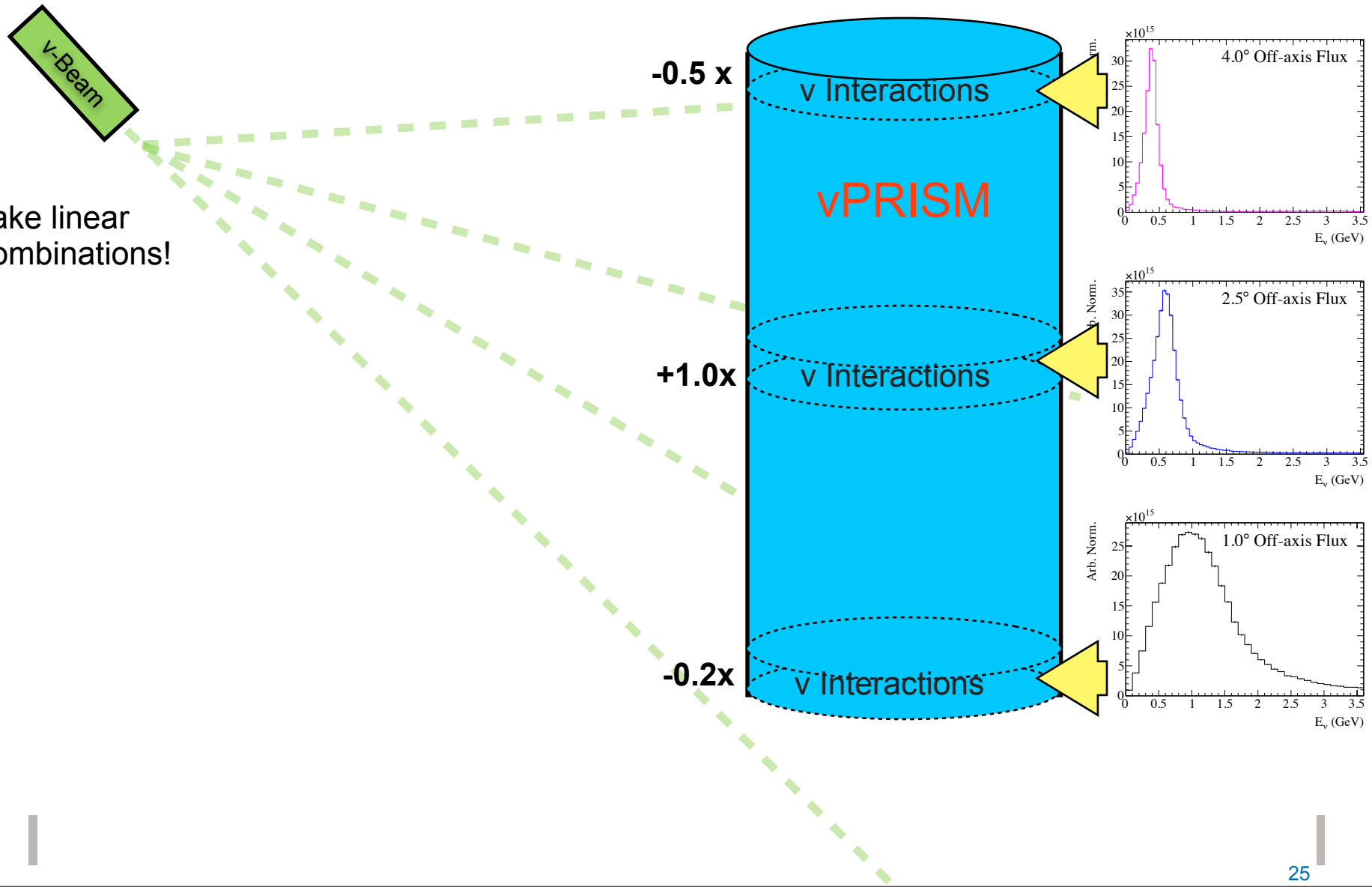
ν PRISM Concept



ν PRISM Concept



ν PRISM Concept

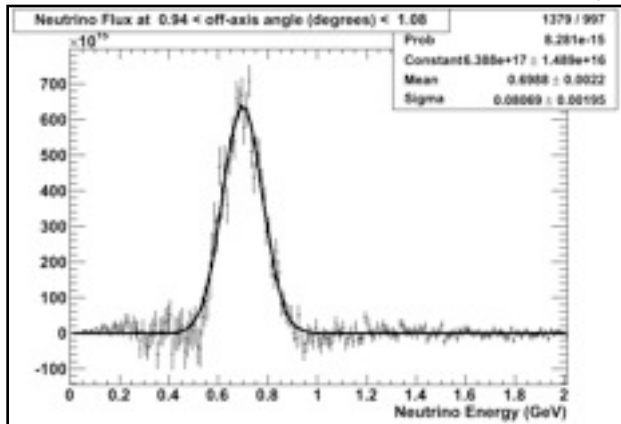


vPRISM Concept

ν -Beam

Take linear combinations!

700 MeV Monoenergetic Beam
using 30 slices
in off-axis angle



$-0.5 \times$

ν Interactions

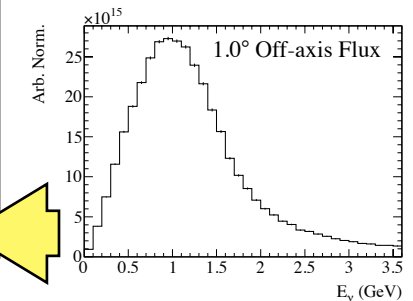
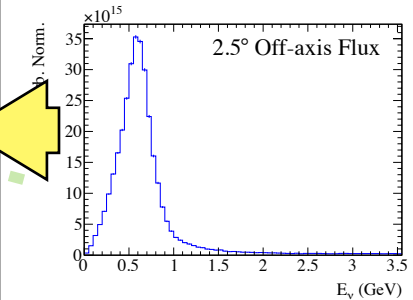
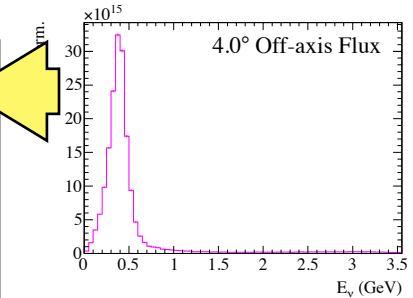
vPRISM

$+1.0 \times$

ν Interactions

$-0.2 \times$

ν Interactions



T2K ν_μ disappearance

