Future Long Baseline Neutrino Experiment in Japan

Akira Konaka
(TRIUMF)

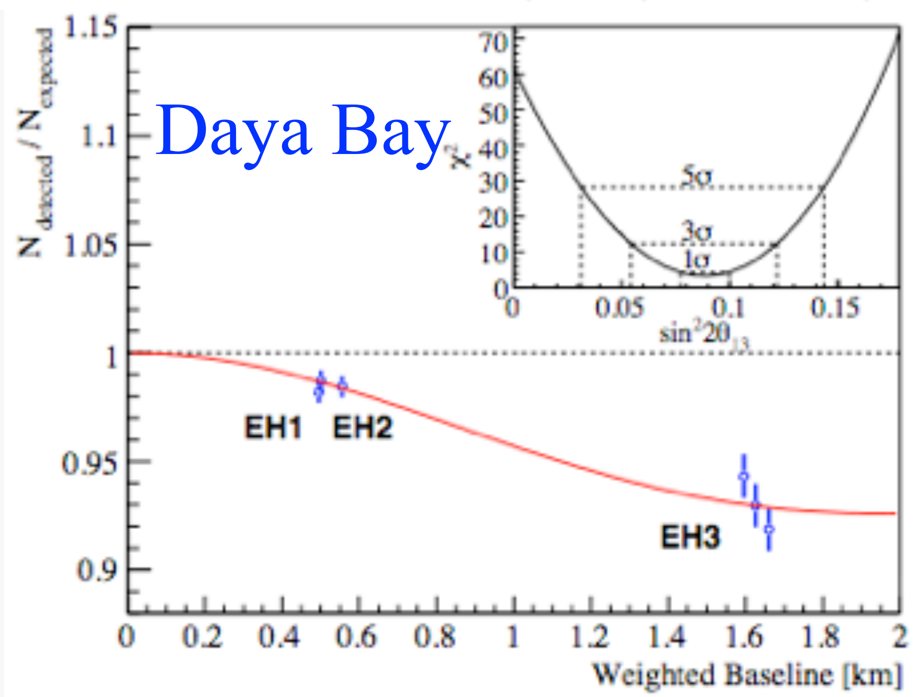
Contents

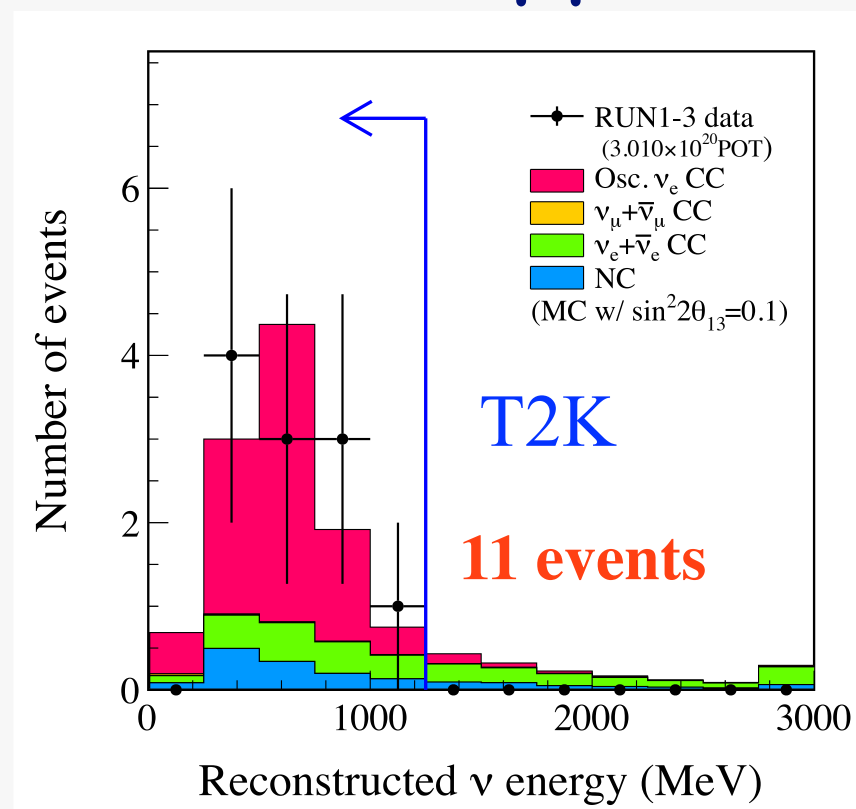
- Introduction of T2K and HyperK experiments
- Motivation of future long baseline neutrino exp'ts
  - What sensitivities do we aim at?
- T2K/HyperK: Physics reaches
  - Accelerator based long baseline experiment
  - Atmospheric neutrinos (very long baseline)
  - Proton decay search
- Disclaimer
  - Official future T2K sensitivity is still in preparation
  - "Potential improvements" are my own thougths

θ_{13} is non-zero!

- 2012: non-zero θ_{13} established
  - Reactor $\bar{\nu}_e$ disappearance exp'ts: 8σ discovery
  - T2K: 11 evts→3.2σ evidence in ν_e appearance mode

$$\sin^2 2\theta_{13} = 0.089 \pm 0.010(\mathrm{stat.}) \pm 0.005(\mathrm{syst.})$$



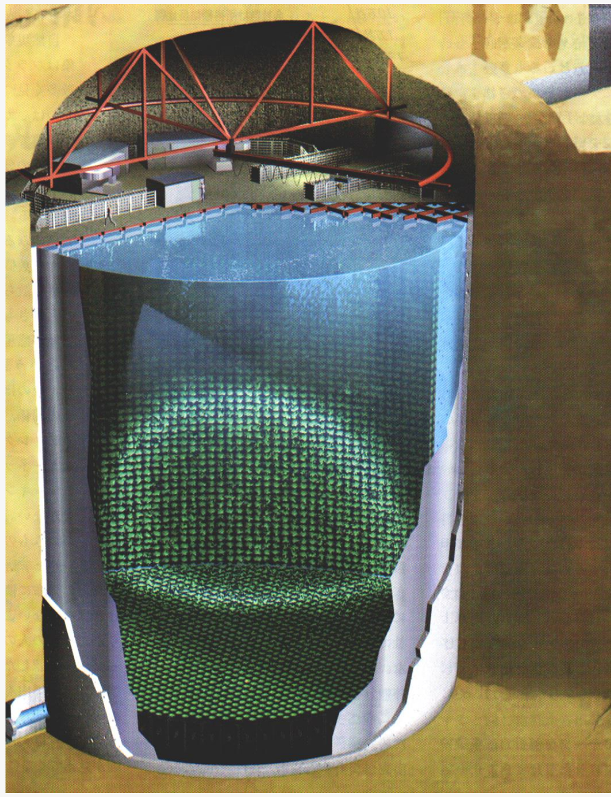


- CP measurement is feasible @ long baseline ν

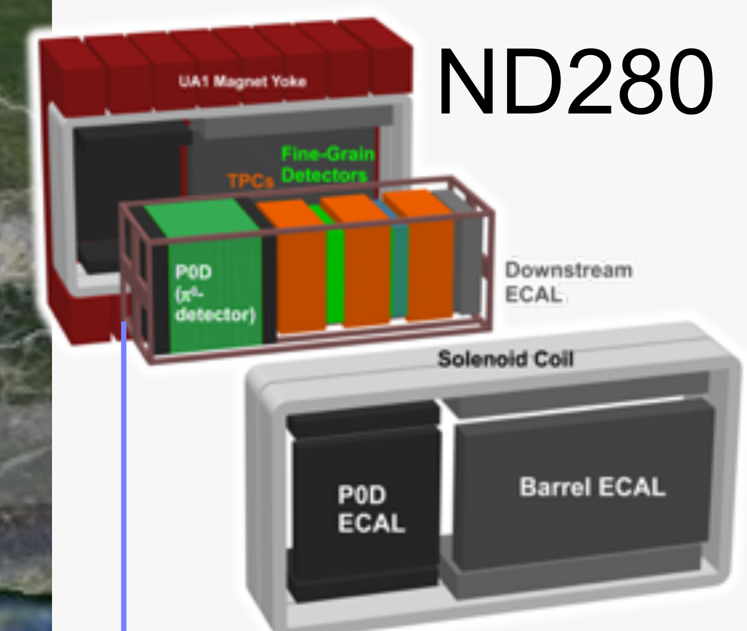
$$A_{CP} = \frac{P(\nu_\mu \to \nu_e) - P(\bar{\nu}_\mu \to \bar{\nu}_e)}{P(\nu_\mu \to \nu_e) + P(\bar{\nu}_\mu \to \bar{\nu}_e)}$$

(reactor ν is not sensitive to δ_{CP})

Future of T2K and SK



Super-Kamiokande



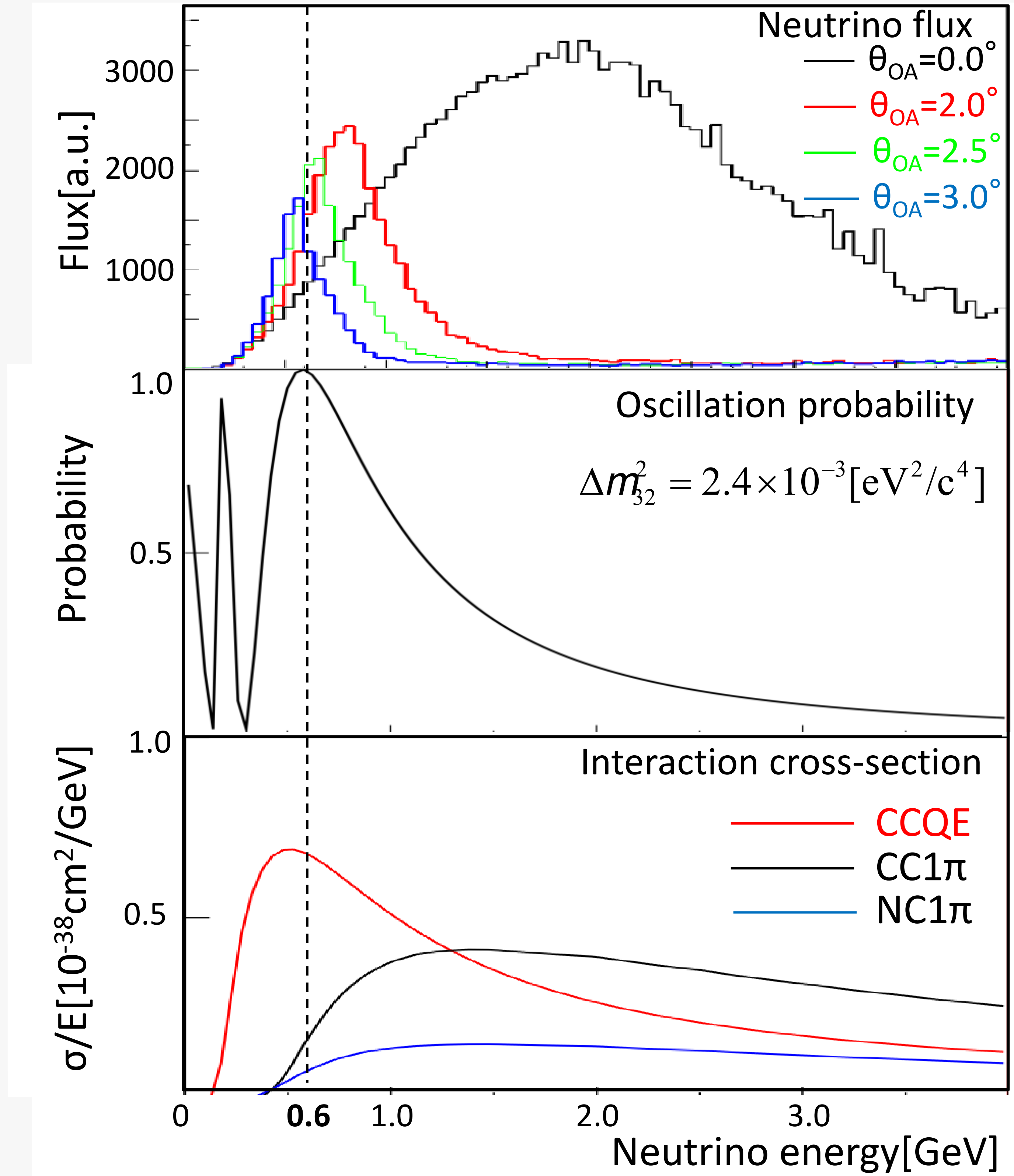
- Long baseline neutrino oscillation experiment from Tokai to Kamioka.
- $\nu_\mu \rightarrow \nu_e$ appearance to measure θ_{13}, which leads to CP violation studies.

Approach of the T2K experiment

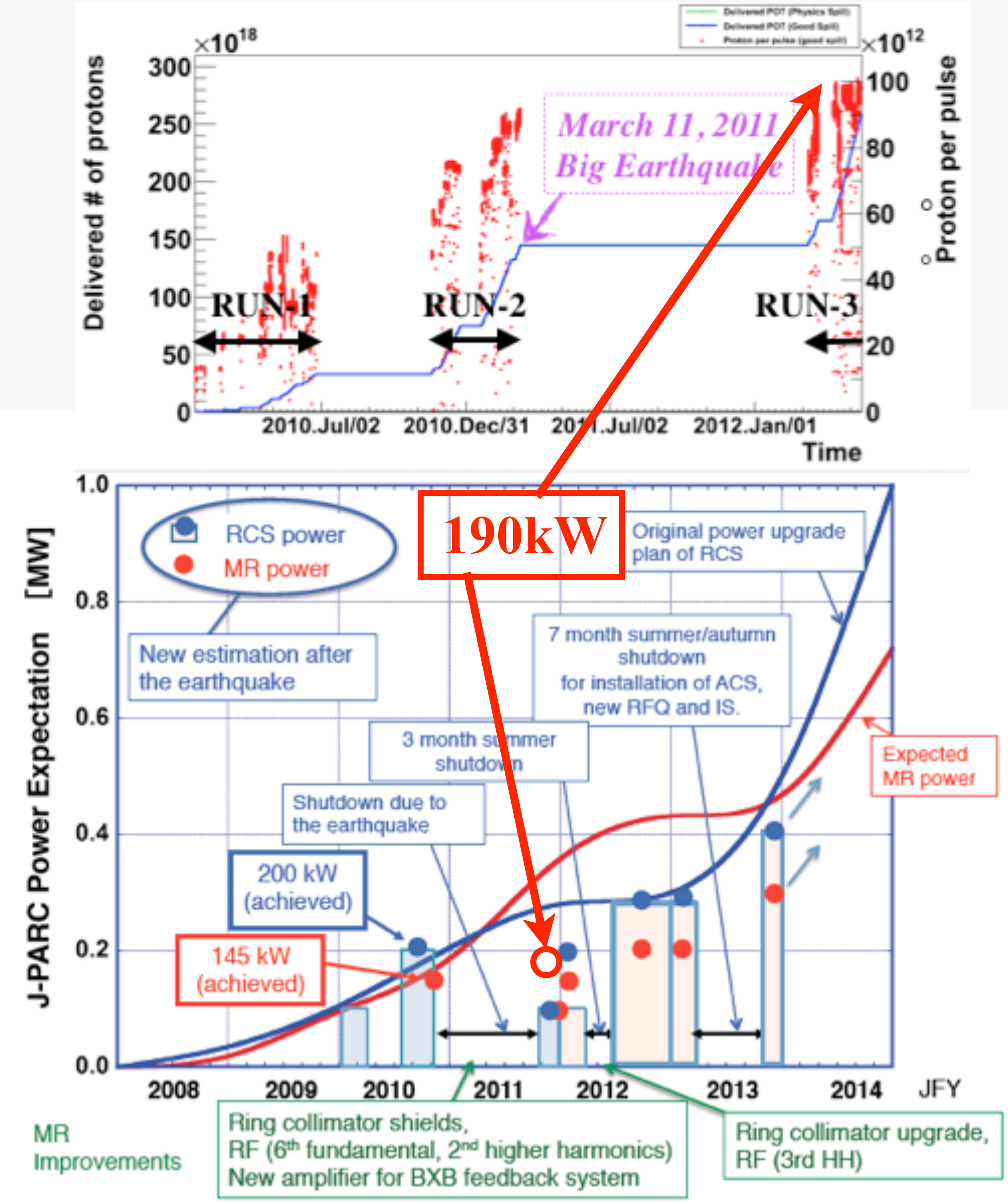
- Narrow band beam tuned at the oscillation maximum
  - Off-axis ν beam (2.5 deg.)
  - Maximize ν oscillation
- Sub-GeV ν beam (0.5-1GeV)
  - CCQE($\nu_\mu n \rightarrow \mu p$) dominates E_ν reconst. by μ momentum

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

  - Works well for water Cerenkov (Super-K)



J-PARC beam status



- Earthquake Recovery
  - In less than a year
  - 190kW operation in 2012
    - 145kW before earthquake
    - exceed post-earthquake plan
- Plan towards full 750kW
  - Collimator upgrade
  - Linac upgrade
  - Main ring RF upgrade

The medium-term plan of the MR-FX until 2017

We adopt the high repetition rate scheme to achieve the design beam intensity, 750 kW.
Rep. rate will be increased from ~ 0.4 Hz to ~1 Hz by replacing magnet PS's and RF cavities.

JFY	2011	2012	2013	2014	2015	2016	2017
			Li. upgrade				
FX power [kW]	**150**	**200**	**300**	**400**			**750**
Cycle time of main magnet PS **New magnet PS for high rep.**	3.04 s	2.56 s R&D	2.4 s		Manufacture installation/test		1.3 s
Present RF system **New high gradient rf system**	Install. #7,8	Install. #9 R&D			Manufacture installation/test		
Ring collimators	Additional shields	Add.collimators and shields (2kW)	Add.collimators (3.5kW)				
Injection system **FX system**	New injection kicker	Kicker PS improvement、Septum 2 manufacture /test LF septum, PS for HF septa manufacture /test					

T.Koseki@HyperK meeting

Potential MW upgrade of J-PARC

For the MR, scenarios for Multi-MW output beam power for neutrino experiment are being discussed .

T.Koseki@HyperK meeting

1. Large aperture MR
   Enlarging the physical aperture from 81 to > 120 πmm.mrad
   A new synchrotron in the MR tunnel

2. Second booster ring for MR (emittance damping ring)
   A ring with extraction energy ~ 8 GeV, between the RCS and the MR

3. New rapid cycling synchrotron using 3 GeV RCS beam
   - as a proton driver for neutrino beam production
   - as an injector of MR, which is exclusively operated for the SX users

4. New rapid cycling synchrotron using the upgraded ~1 GeV linac beam
   - as a proton driver for neutrino beam production
   - as an injector of MR, which is exclusively operated for the SX users

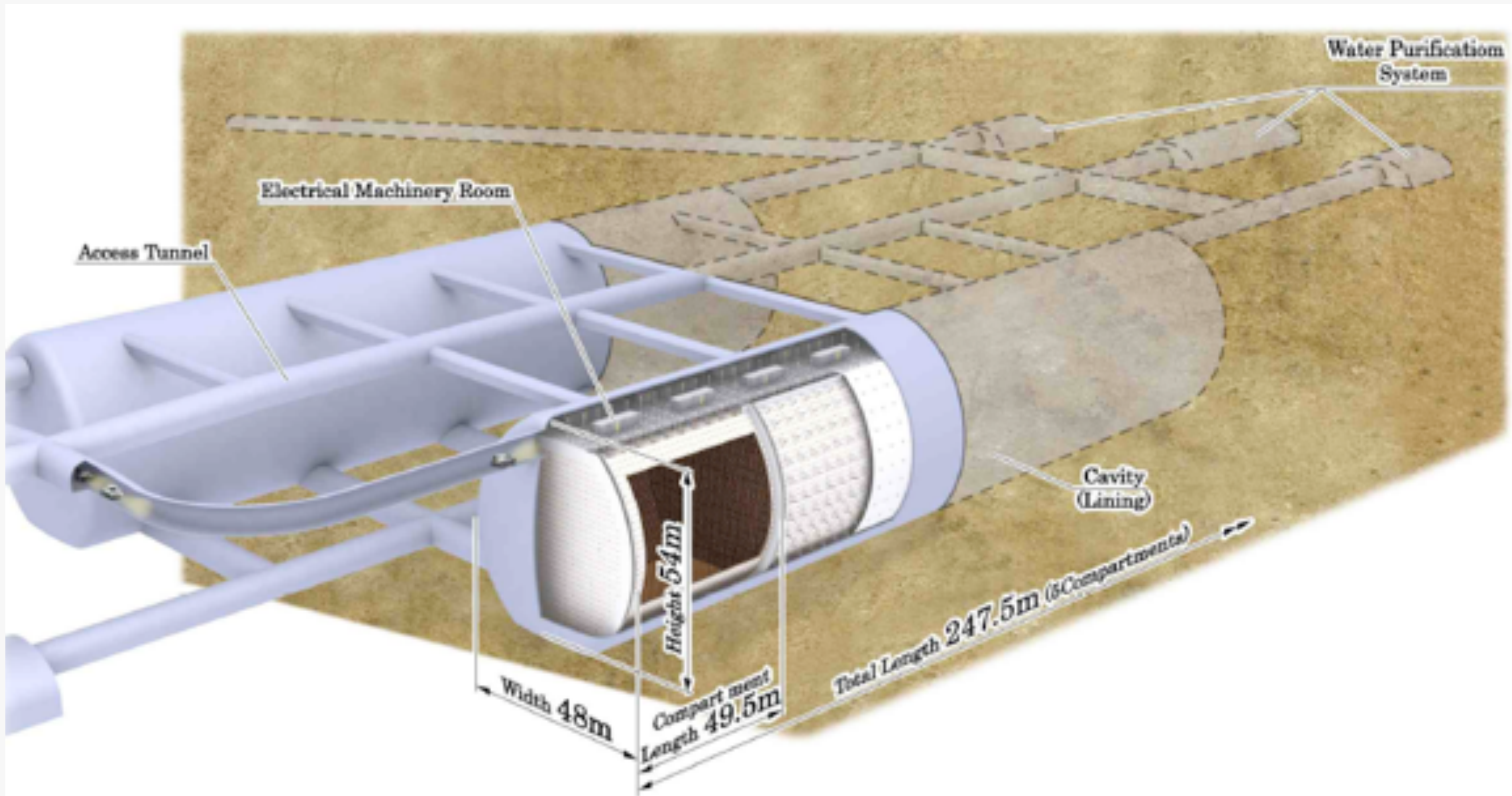
....

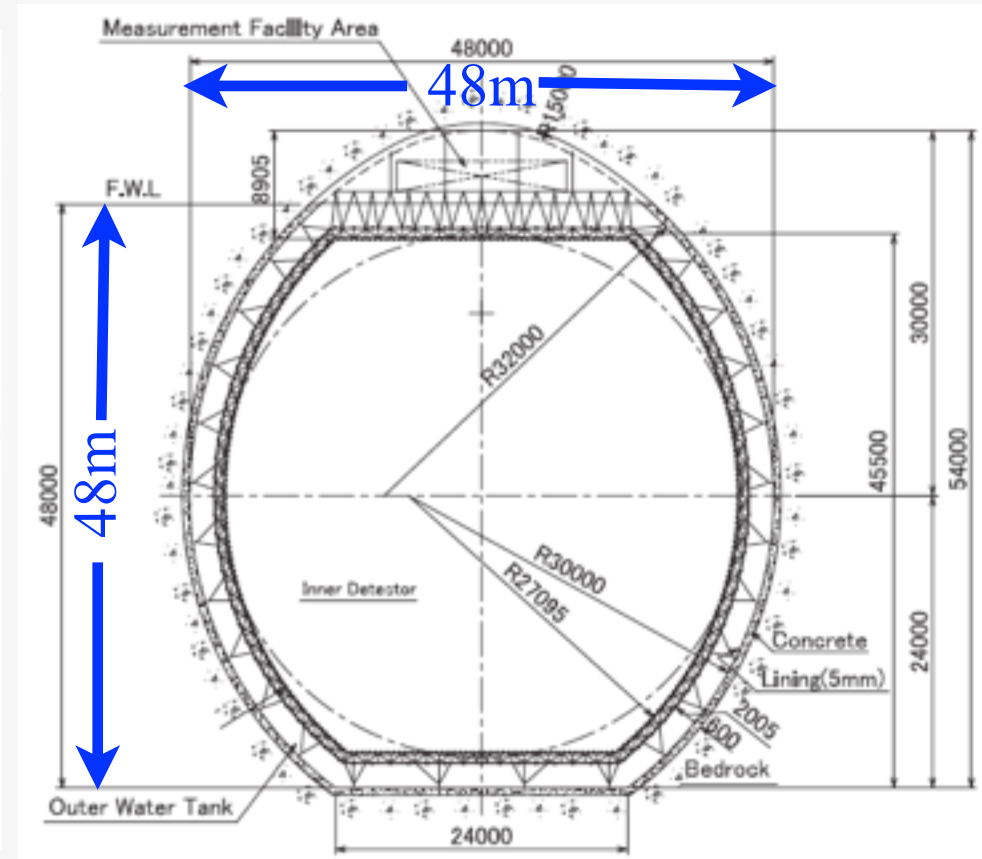
The detailed scheme of the future MW proton driver is discussed in the next five years and prepare to submit budget proposal to the government in 2018 or later.

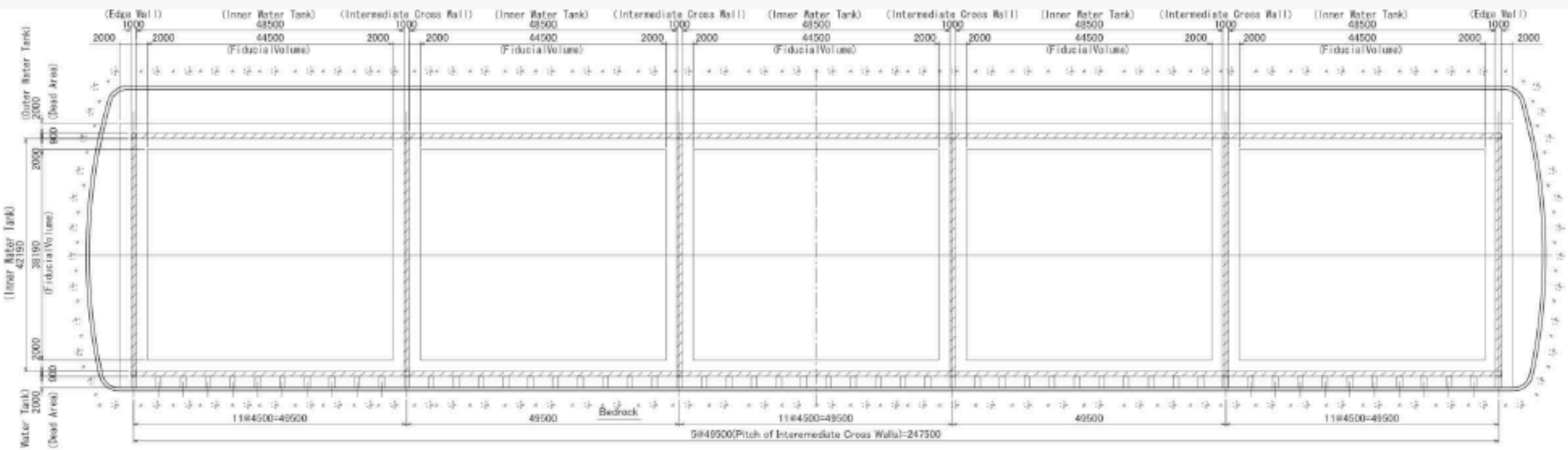
J-PARC upgrade status

- Effort to achieve 750kW is on going
  - R&D to double the repetition rate has started:
    - high gradient RF
    - magnet power supply for high repetition rate
  - R&D to double the #protons/bunch to be done
- Scenario to go beyond 750kW beam power is being discussed, but no concrete scenario or timeline yet.

Hyper-Kamiokande project







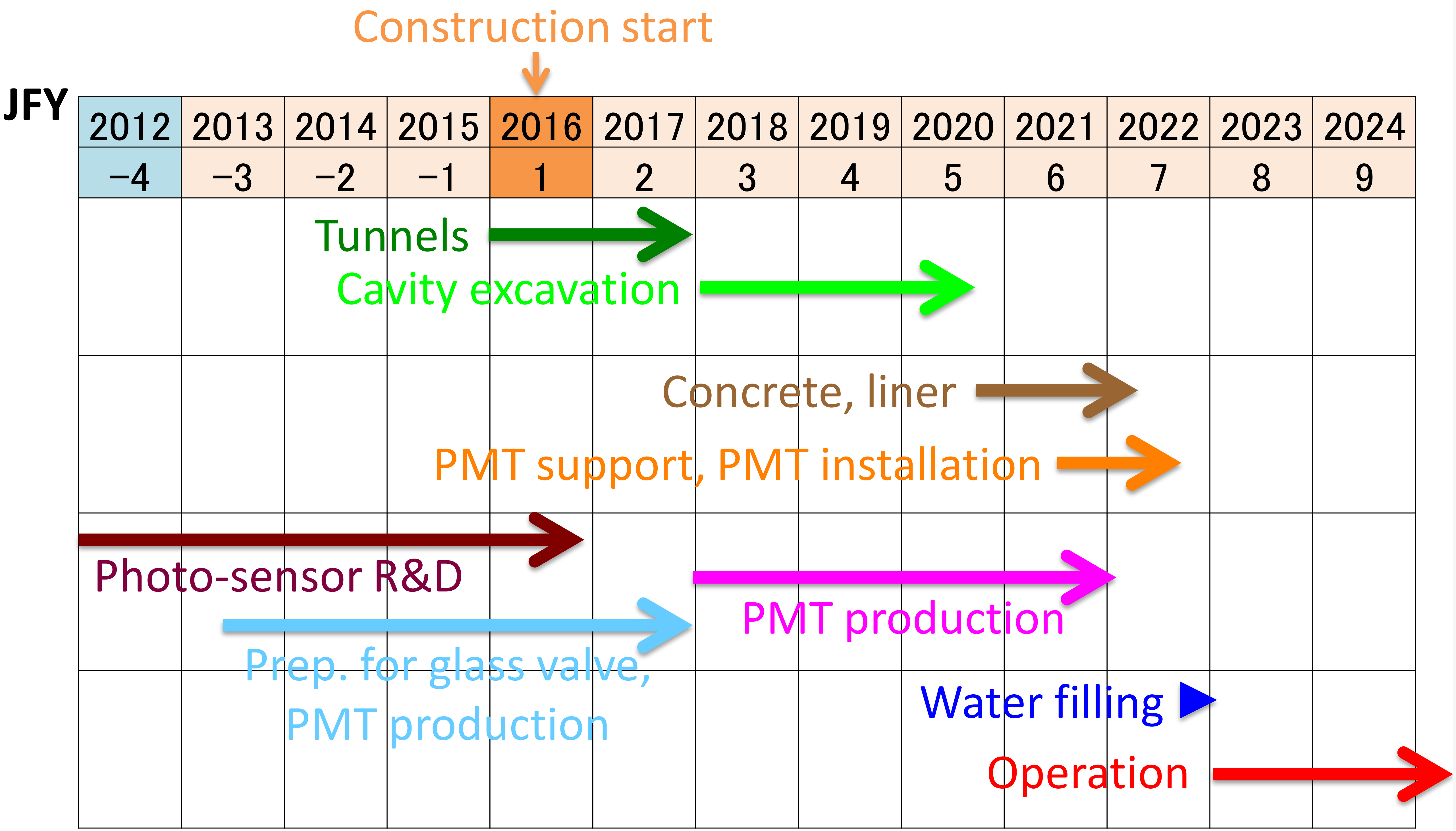
Comparison with SuperK

	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

- 25 times larger fiducial volume than SuperK

Schedule

assuming budget being approved from JPY2016



PMNS texture

- Large mixing angles:
  - Indicating different origin for leptons from quarks
  - Lead us to understand the origin of family? GUT?
- Textures
  - Anarchy: random
  - Bi-maximal: $\theta_{12}=\theta_{13}=45^o$
  - Tri-bimaximal: fits the data reasonably well

$$\sin^2\theta_{12} = \frac{1}{3}$$
$$\sin^2\theta_{23} = \frac{1}{2}$$
$$\sin^2\theta_{13} = 0$$

$$|\nu_3> = \frac{1}{\sqrt{2}}(-|\nu_\mu> + |\nu_\tau>)$$
$$|\nu_2> = \frac{1}{\sqrt{3}}(|\nu_e> + |\nu_\mu> + |\nu_\tau>)$$
$$|\nu_1> = \frac{1}{\sqrt{6}}(2|\nu_e> - |\nu_\mu> - |\nu_\tau>)$$

Follow the History of CKM?

- Cabbibo quark mixing: $\lambda=\cos\theta_C=0.224$
- GIM mechanism: unitarity → no FCNC, predict charm
- Kobayashi-Maskawa: δcp, predict 3 families (t, b)
- Precision studies (Wolfenstein parametrization)

$$V = \begin{pmatrix} 1-\frac{1}{2}\lambda^2 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\frac{1}{2}\lambda^2 & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix}$$

CKM expanded by λ

$\lambda=0.2243\pm0.0016$
$A=0.82$
$\rho=0.20$, $\eta=0.33$

- Tri-bimaximal in lepton mixing? Expand in $\sin\theta_{13}$?
- Precision down to $\sin^2\theta_{13}=0.024$ (~2%) level.
- Discovery of the underlying principle? GUT?

Global fit (2012)

- Global fit results are getting very interesting:
  - consistent with tri-bimaximal but some hints
  - $\sin^2\theta_{13}>0$, $\sin^2\theta_{23}<½$?, $\sin^2\theta_{12}<⅓$?, δ_{cp}?

parameter	best fit	1σ range	2σ range	3σ range	tri-bimaximal
$\sin^2\theta_{12}$ (NH/IH)	0.307	0.291-0.325	0.275-0.342	0.259-0.359	0.333
$\sin^2\theta_{13}$ (NH)	0.0241	0.0216-0.0266	0.0193-0.0290	0.0169-0.0313	0.0
$\sin^2\theta_{13}$ (IH)	0.0244	0.0219-0.0267	0.0194-0.0291	0.0171-0.0315	0.0
$\sin^2\theta_{23}$ (NH)	0.386	0.365-0.410	0.348-0.448	0.331-0.637	0.5
$\sin^2\theta_{23}$ (IH)	0.392	0.370-0.431	0.353-0.641	0.335-0.663	0.5
δ(NH)	1.08π	(0.77-1.36)π	-	-	-
δ(IH)	1.09π	(0.83-1.47)π	-	-	-

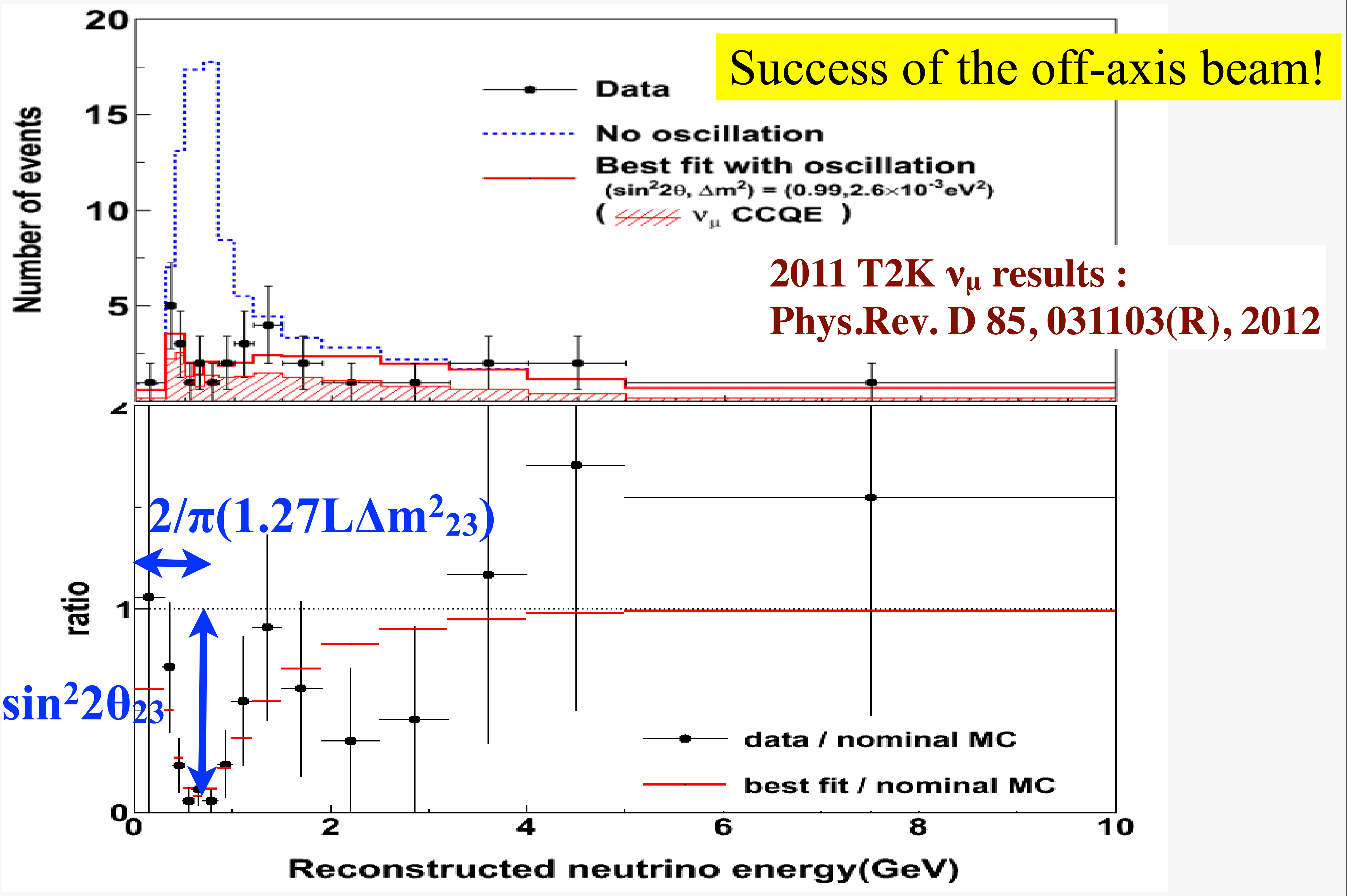
Fogli et. al. ArXiv:1205.5254v3

Future precision measurements

- θ_{12}: solar neutrinos
  - θ_{12}:SNO (CC and NC solar), Δm^2_{12}: Kamland (reactor)
  - Future: Daya Bay2 (60km detector), pp/pep solar ν's
- θ_{13}: Reactor neutrinos
  - Improvements expected by Daya Bay and others.
- θ_{23}: **Long baseline neutrinos**
- δ_{cp}: **Long baseline neutrinos**
- Degeneracy: mass hierarchy, θ_{23} octant
  - Very long baseline (accelerator, **atm. neutrinos**)

θ_{23}

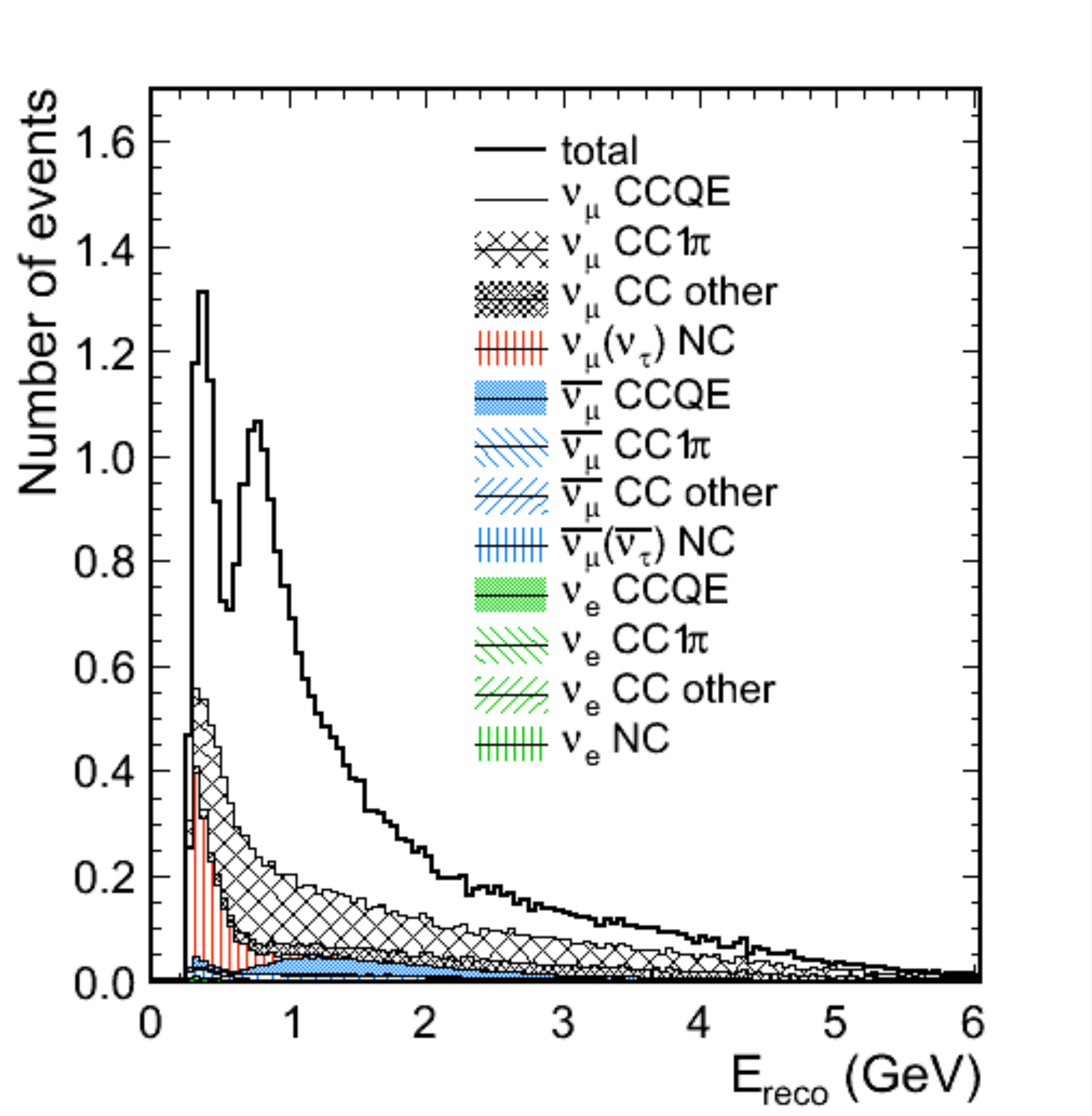
T2K ν_μ disappearance



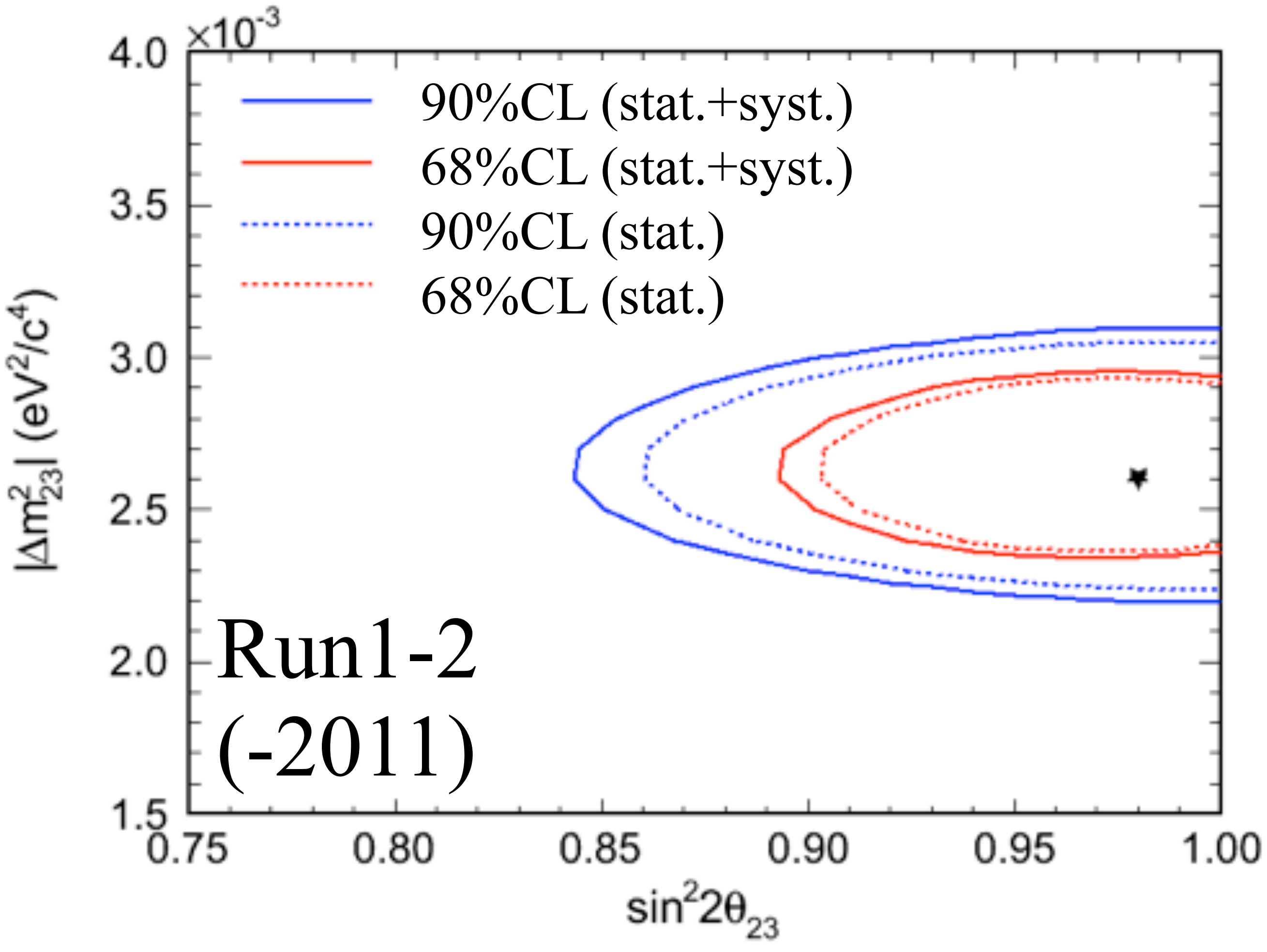
2011 T2K ν_μ results :
Phys.Rev. D 85, 031103(R), 2012

Backgrounds

- Main backgrounds at the dip:
  - CC1π
  - NC1π
  - CCQE resolution tail



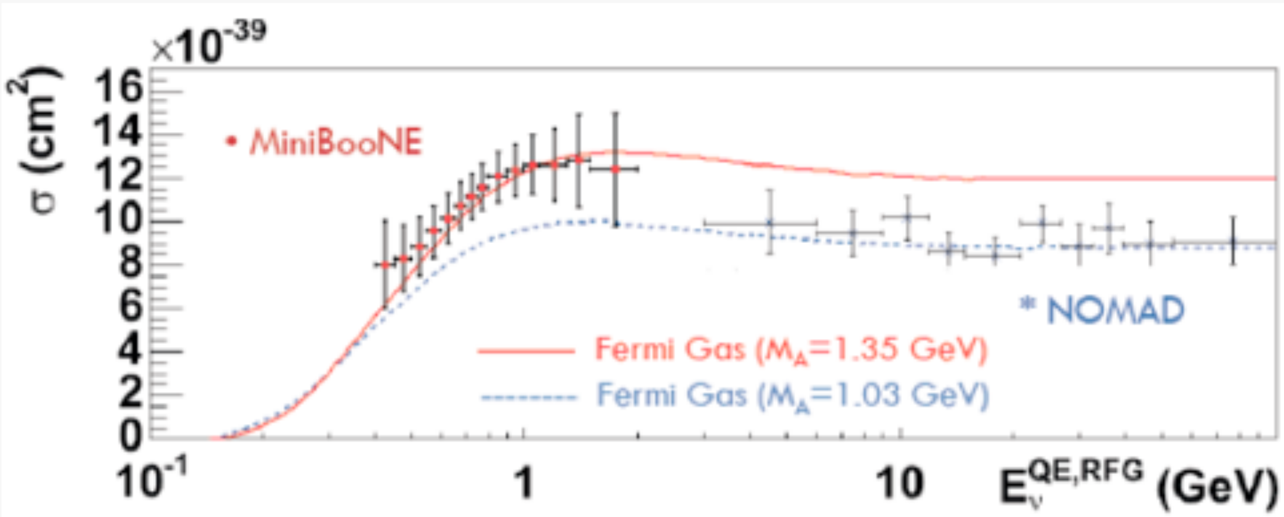
Systematics in ν_μ disap.

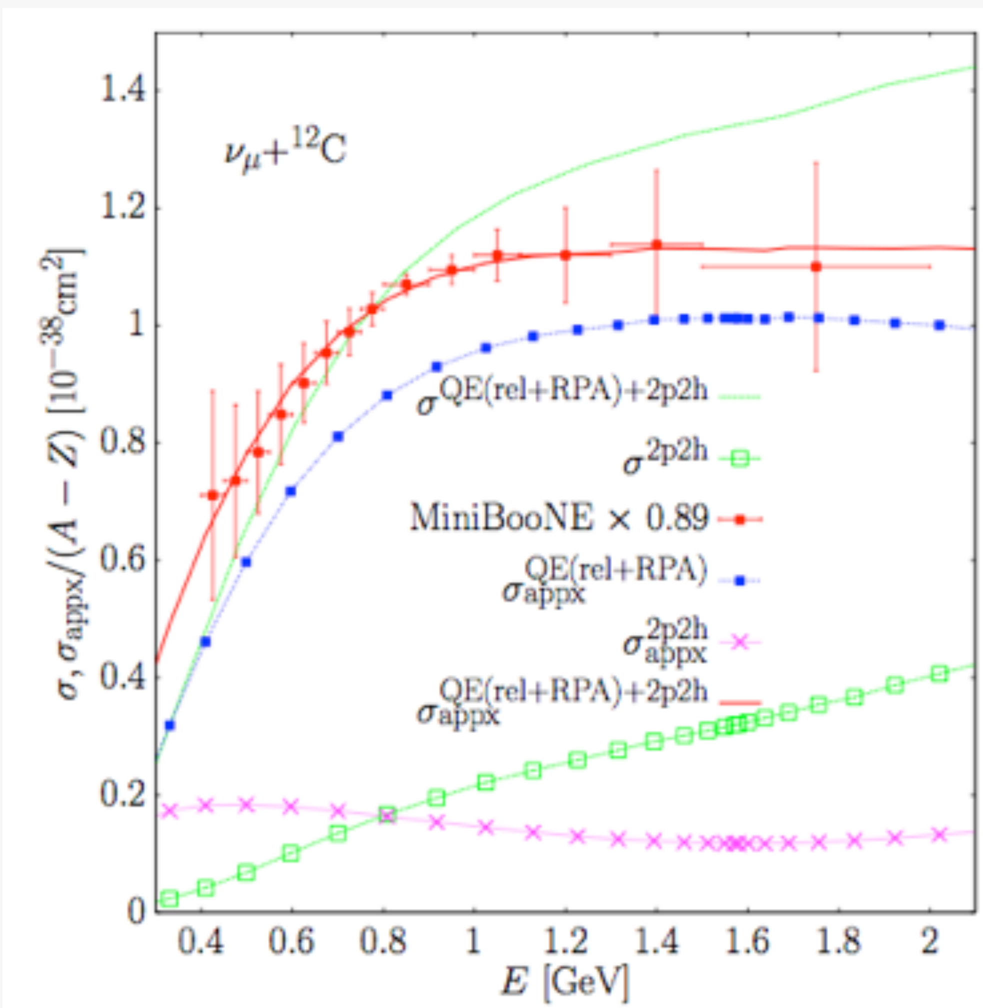


Error source	$\delta N_{SK}^{exp}/N_{SK}^{exp}$
SuperK CCQE efficiency (ring-counting)	±3.23%
SuperK CCQE efficiency (other)	±1.04%
SuperK CCnonQE efficiency	±6.51%
SuperK NC efficiency	±6.96%
SuperK ν_e CC efficiency	±0.05%
ND280 efficiency	+5.59% -5.30%
ND280 normalization	±2.62%
Flux normalization	±4.73%
CCQE cross section	±2.36%
CC1pi/CCQE cross section ratio	+0.52% -0.59%
CCother/CCQE cross section ratio	+4.10% -3.67%
NC/CCQE cross section ratio	+0.82% -0.84%
FSI	±5.80%
Total	+14.79% -14.61%

- Run1-3 (-2012): x2 stat.
- Run1-4 (-2014): x4 stat. expected
- Systematcs started to impact
  - NCπ, CC1π(CCnonQE), FSI
    ➩π detection is the key

Neutrino cross section

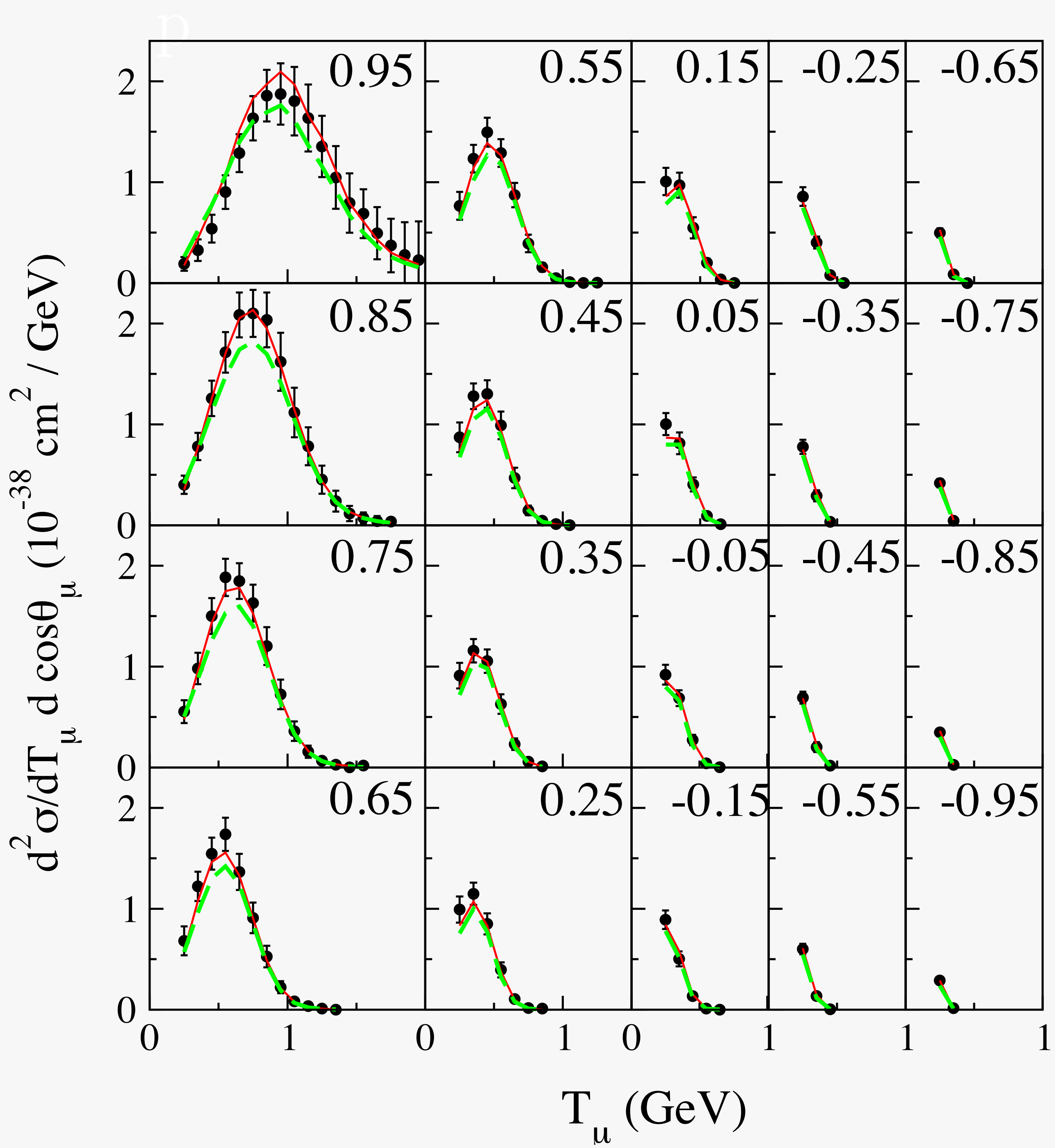


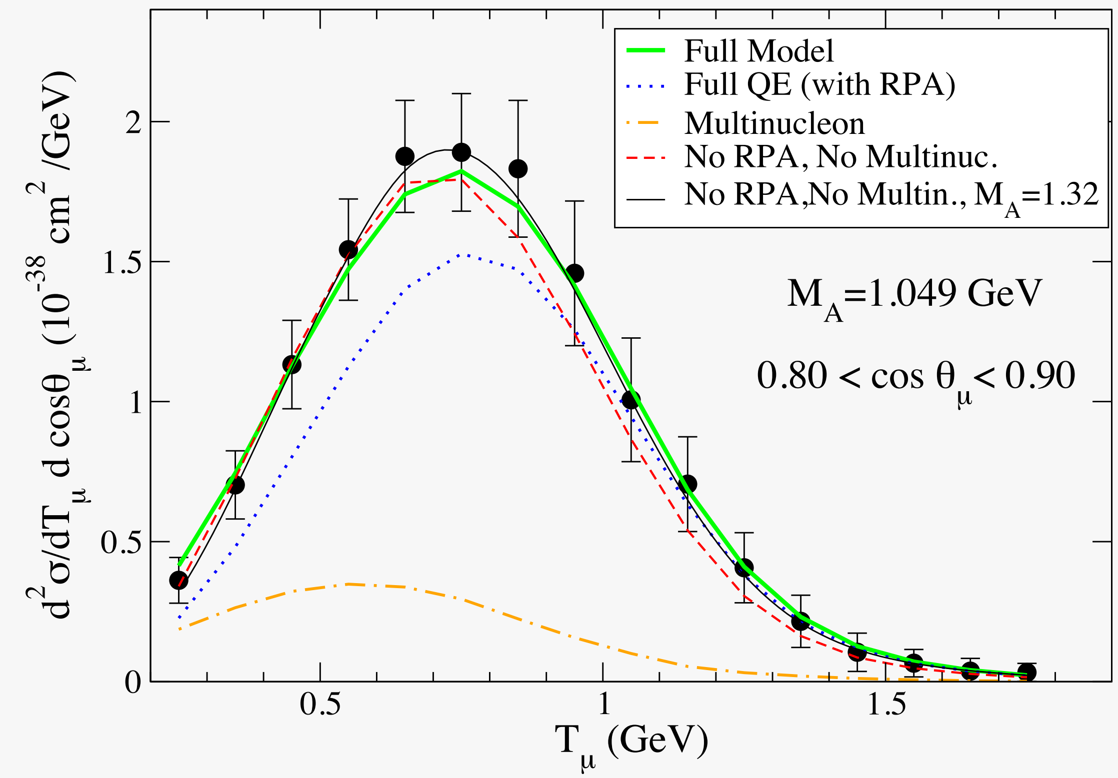


- CCQE cross section shows enhancement at ~GeV
  - Multi-nucleon process: 20-30% contributions?
  - Reconstructed neutrino energy is not correct:
    - It assumes 2 body react. with proton recoil
  - Neutrino reaction model need to be developed!

CCQE model

Nieves NuInt2012





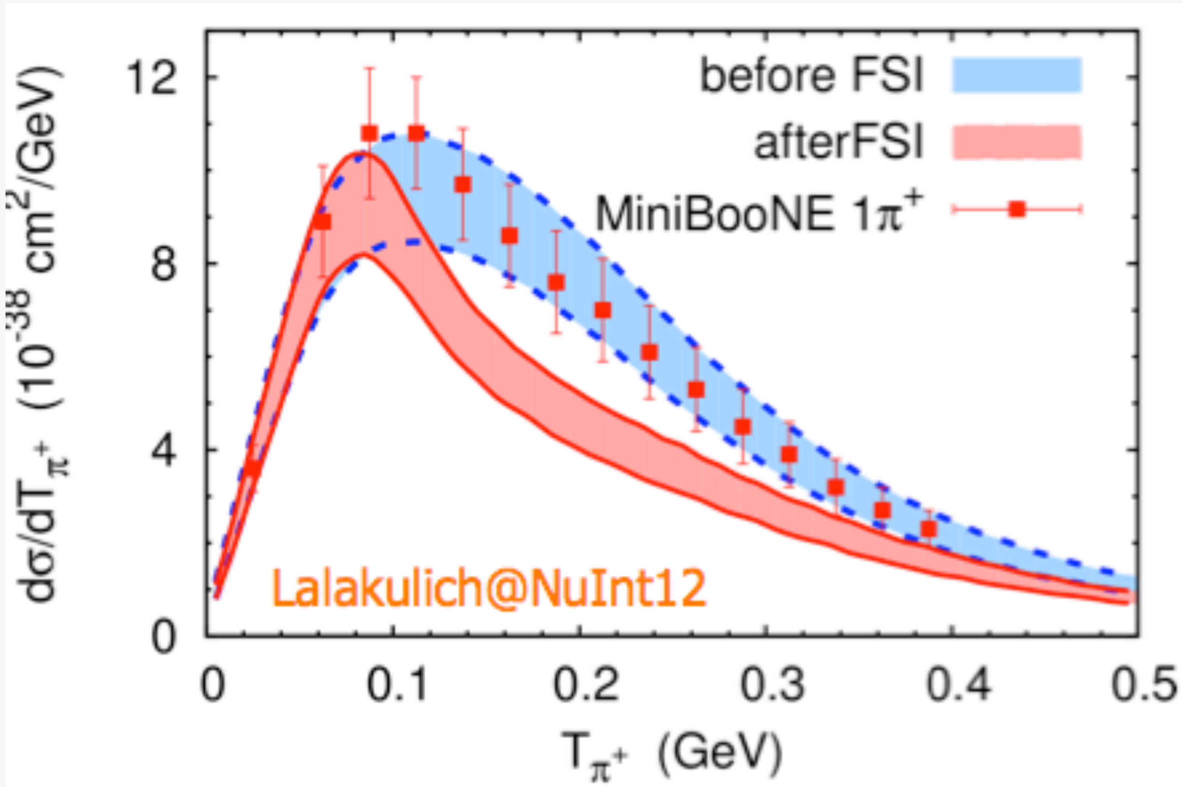
Model	Scale	M_A (GeV)	$\frac{\chi^2}{\#\text{bins}}$
LFG	0.96±0.03	1.32±0.03	35/137
Full	**0.92±0.03**	**1.08±0.03**	**50/137**
Full $\lvert q \rvert > 0.4^\dagger$ GeV	0.83±0.04	1.01±0.03	30/123

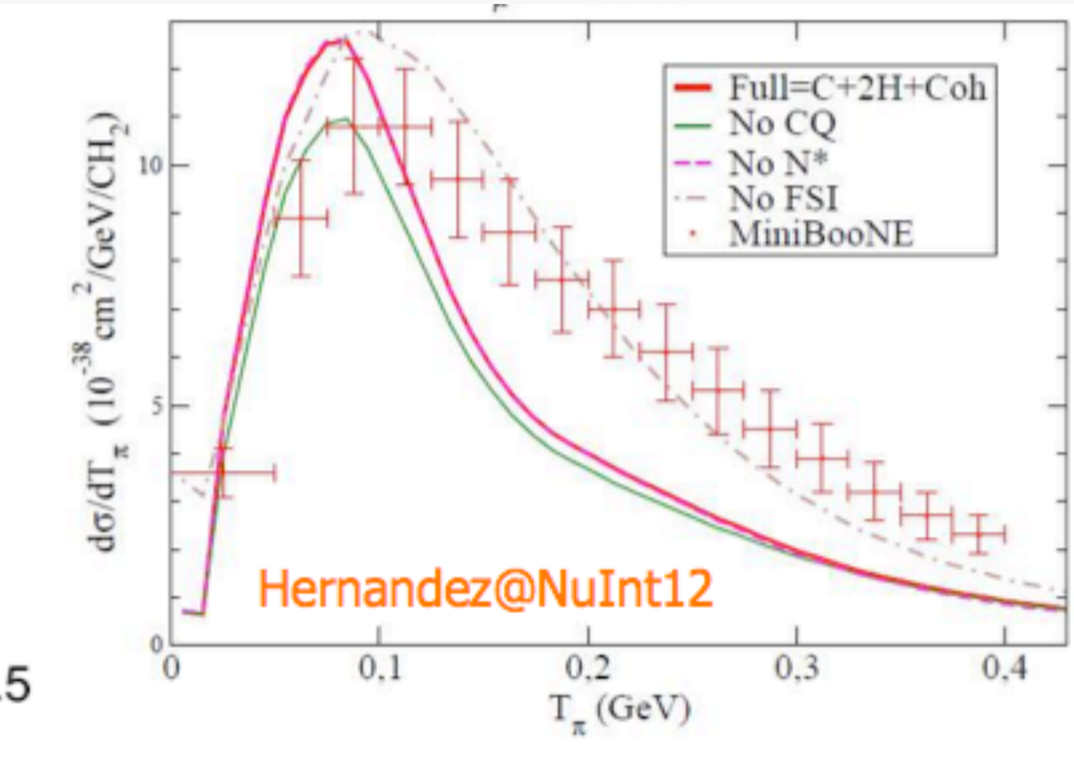
† : As suggested by Sobczyk et al. PRC 82, 045502

Model with 2p2h and RPA fits MiniBooNE CCQE data well when data is scaled by 0.89 (within MiniBooNE error)

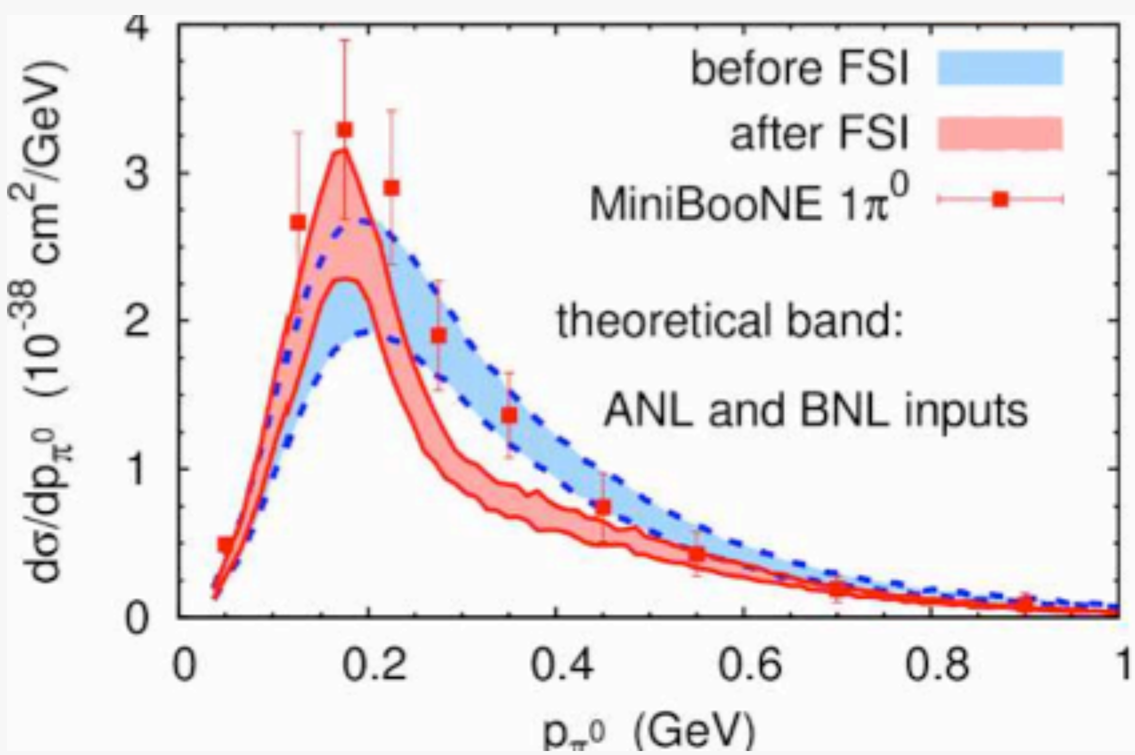
CC1π consistent with no FSI?

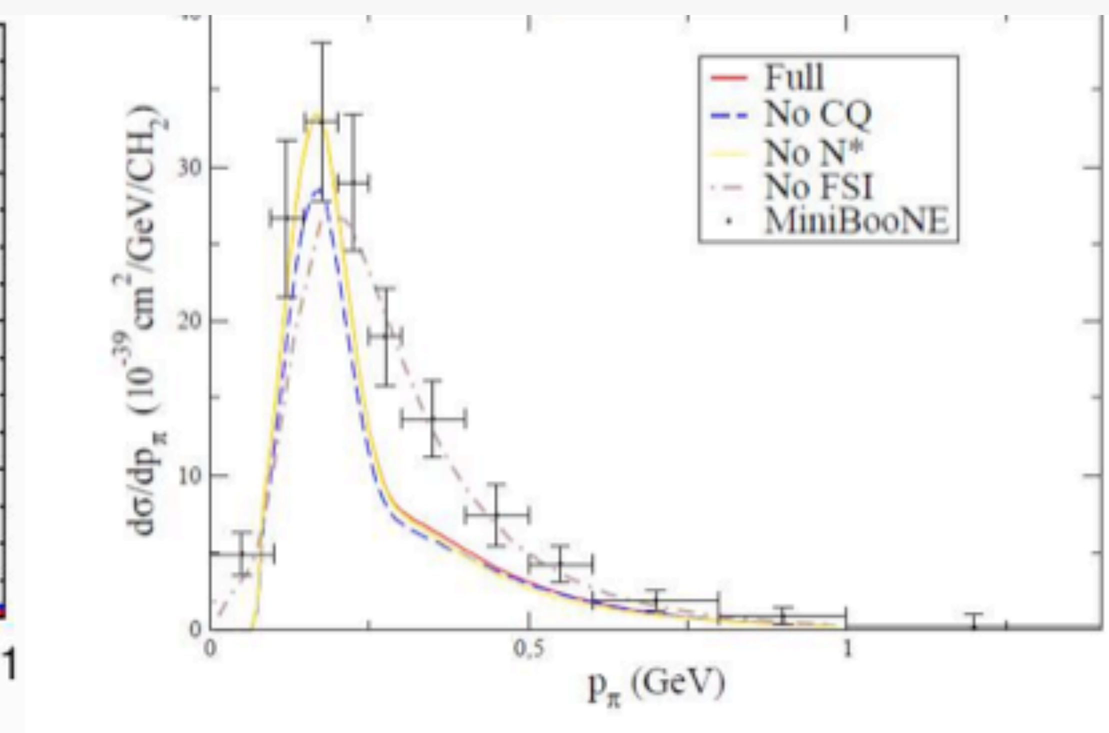
CC1π^+





CC1π^0



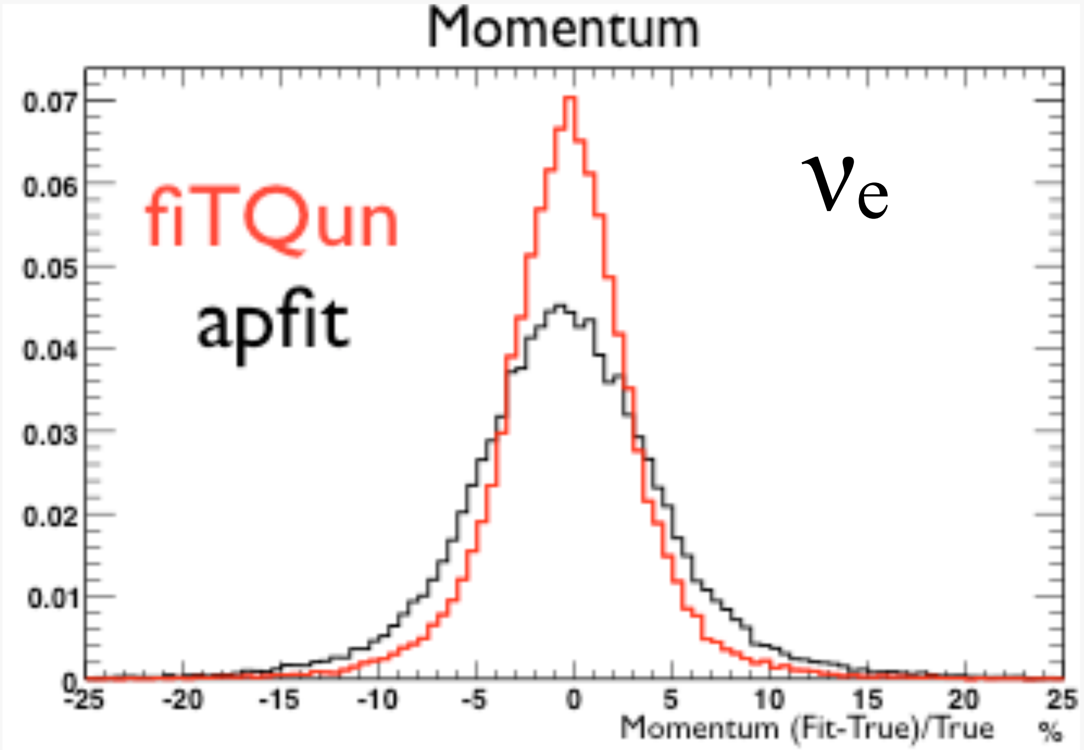


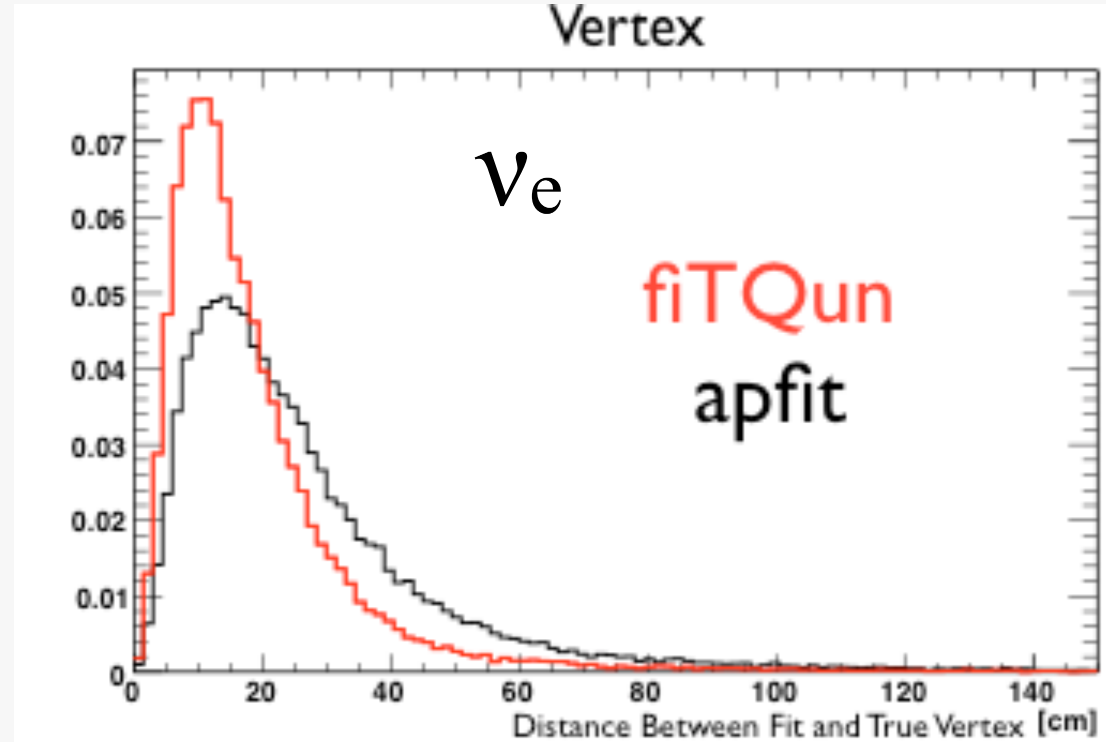
New SK Reconstion code

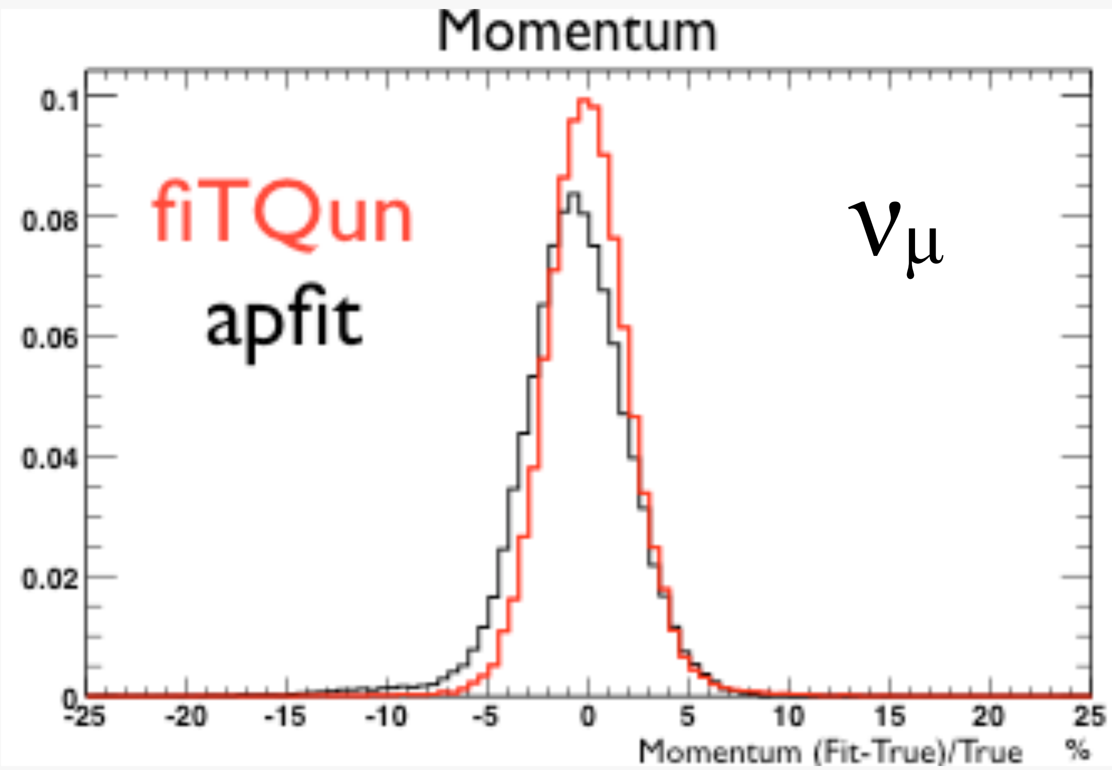
- Current SK reconstruction code (APFIT)
  - –Originally written for Kamiokande experiment.
  - –Works well with detailed check with data.
  - –Limitation in the design for limited CPU power.
- New SK reconstruction code (fitQun) M.Wilking et. al.
  - –Likelihood fit of all the PMT charge and timing
    - taking advantage of all available information
    - simultaneous fit of vertex and particle kinematics
    - based on the method that worked well for MiniBooNE
  - –To be used for Hyper-K event reconstruction, too.

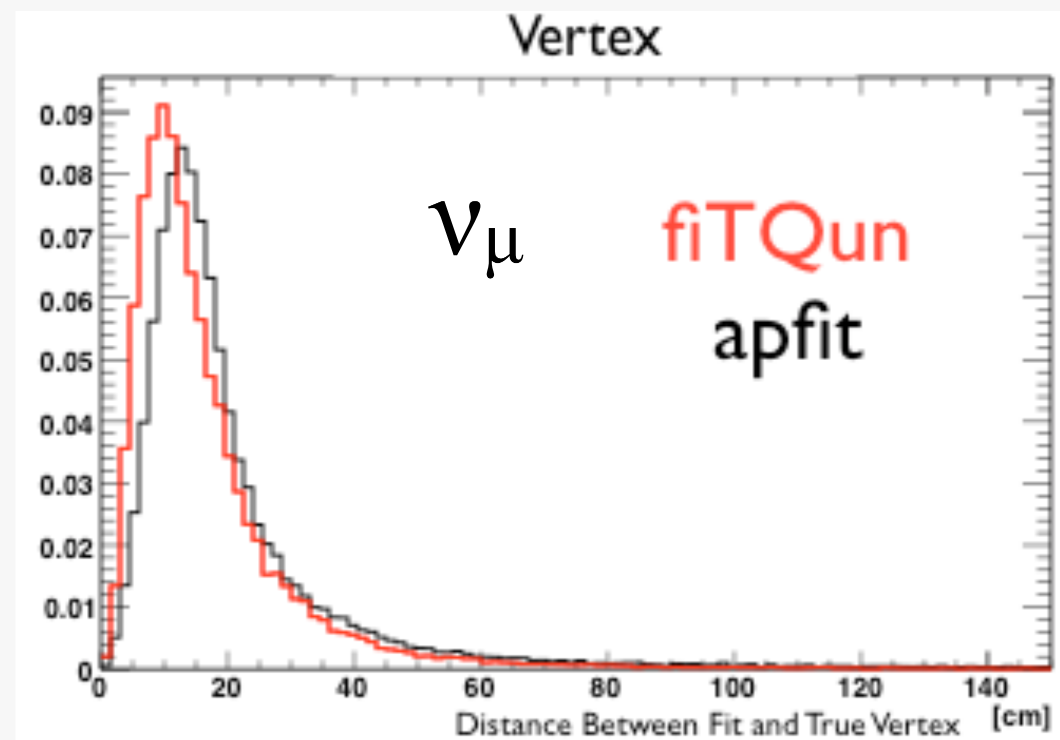
Single ring with FitQun

M.Wiliking@HyperK meeting

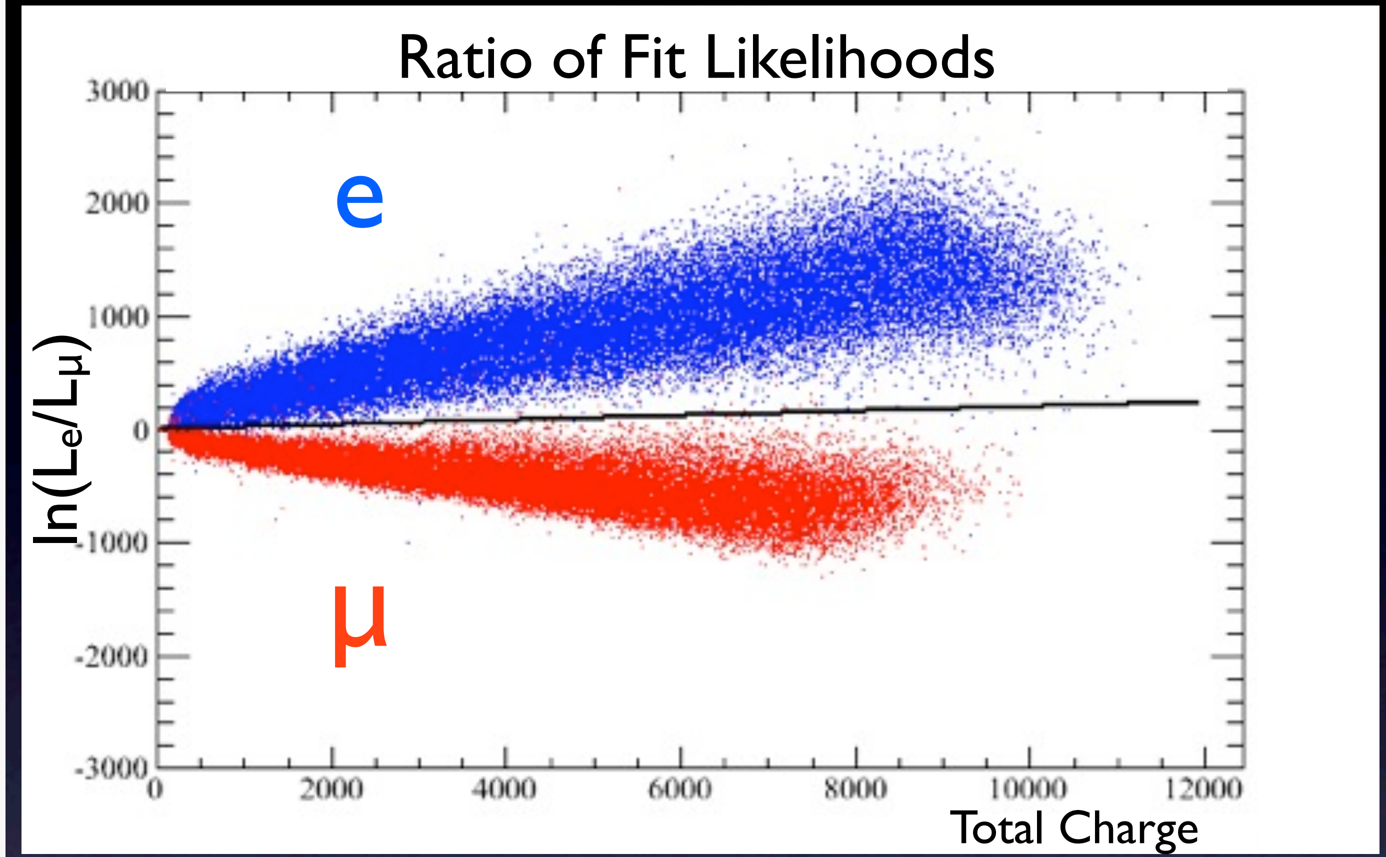




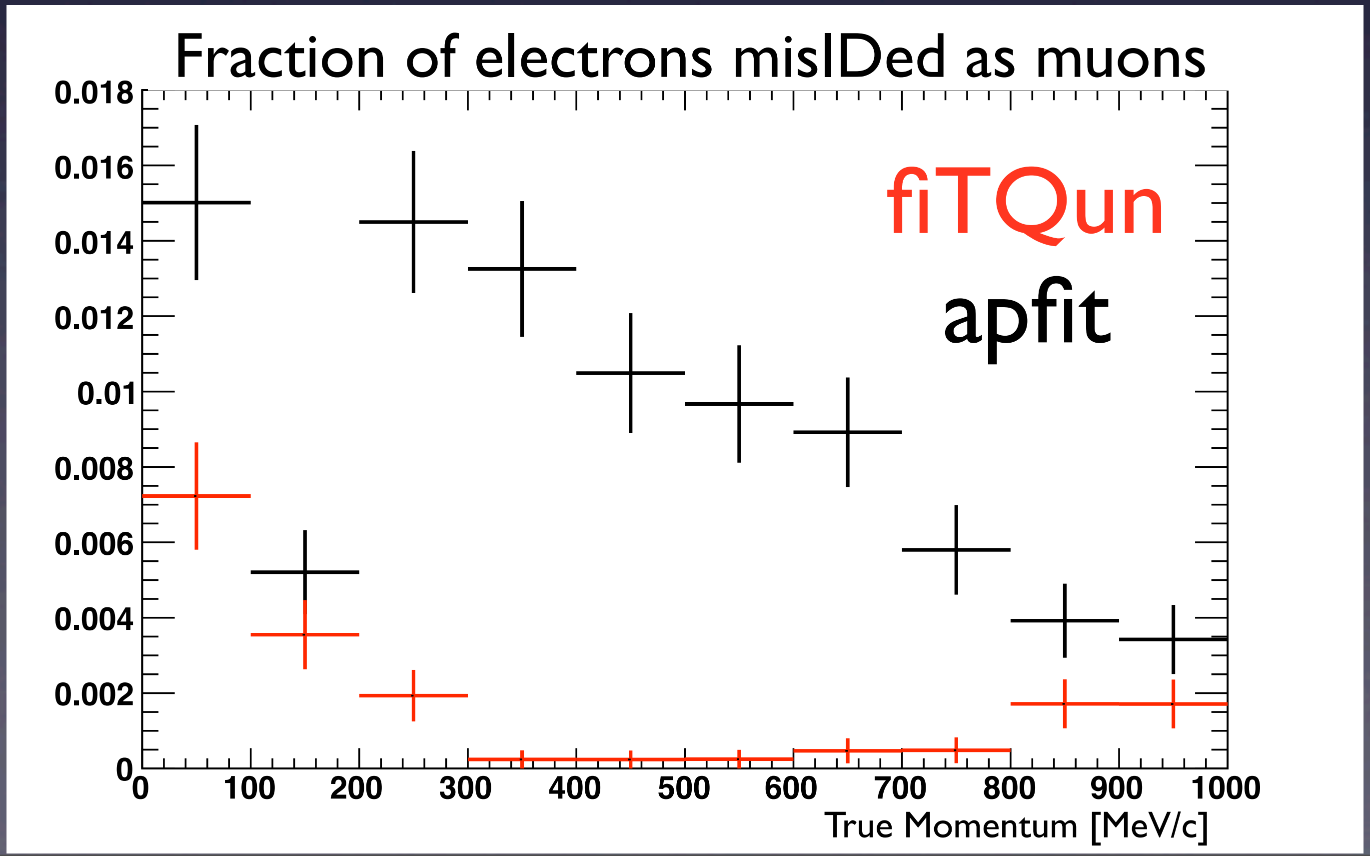


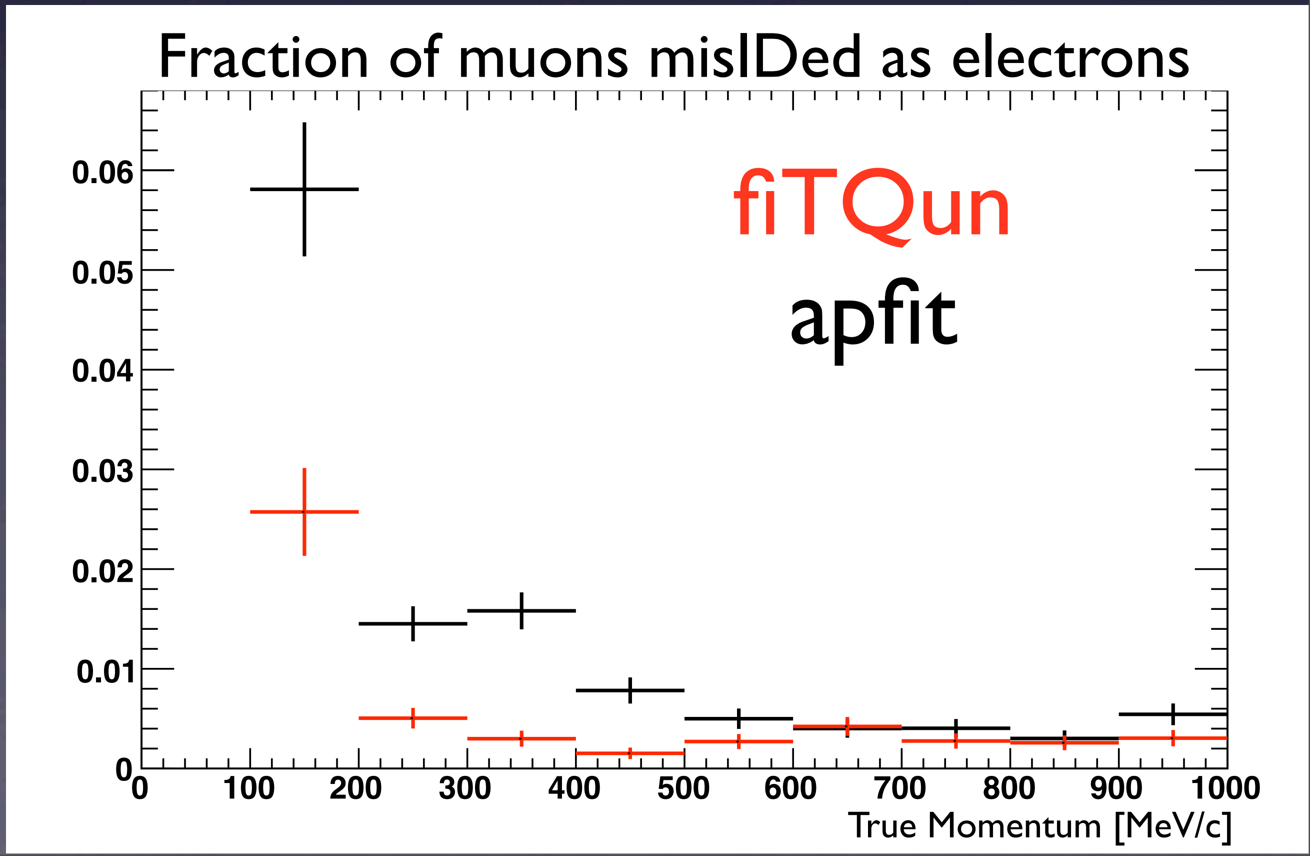


Single Track Particle ID



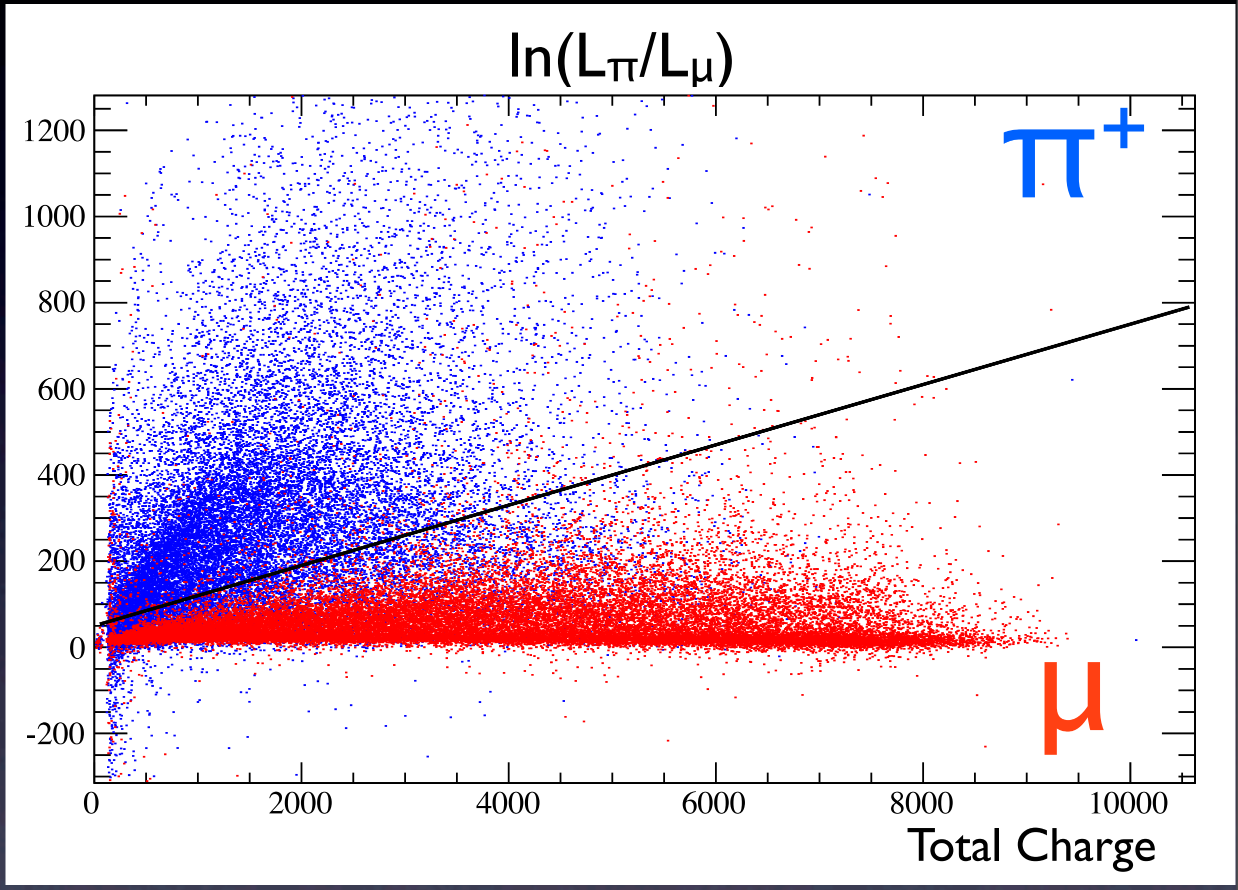
- Simple line cut can be used to separate muons and electrons
- Significantly improved particle ID

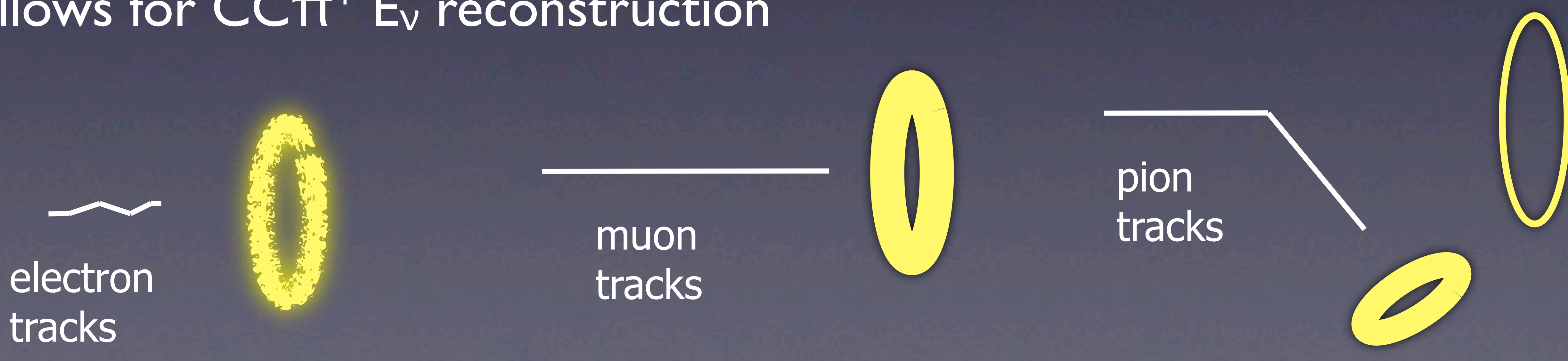




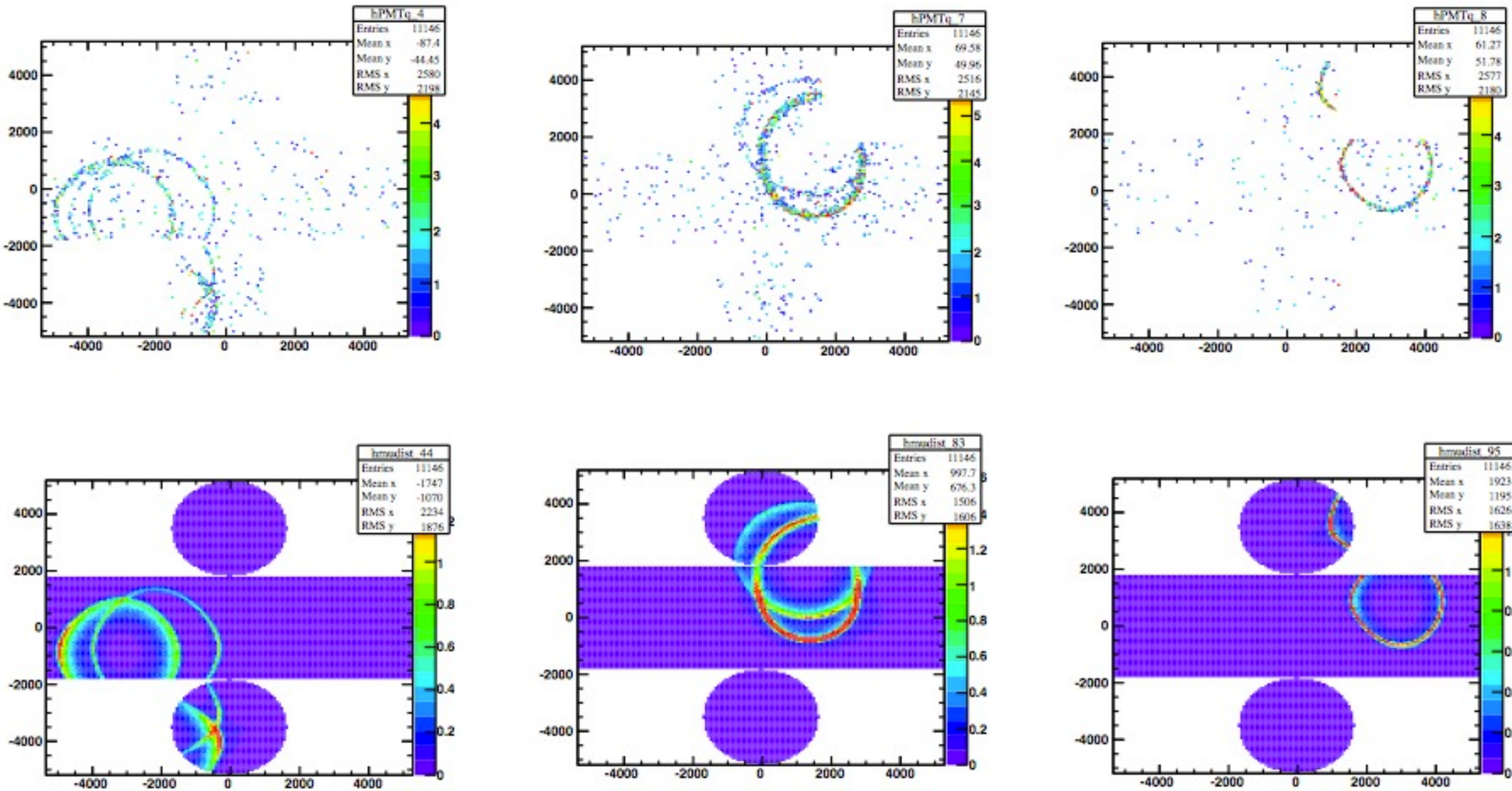
π^+ Fitter

- Pions and muons propagate and produce Cherenkov light in a very similar manner (similar masses)
- The main difference is due to hadronic interactions
- Ring pattern observed is a “kinked” pion trajectory
- This is the first demonstration of pion/muon separation at SK (in MC)
- Allows for $CC\pi^+$ E_ν reconstruction





Kinked-track π^+ Fitter



Potential improvements

- Background suppression & measurement (fitQun)
  - ν_μ disappearance (θ_{23}): $NC\pi^+$,$CC\pi^+$
- Reduction of systematic uncertainties
  - Background suppression & measurement
  - Cross section modeling and measurements
- Statistics to improve:
  - T2K: runs with continuously increasing intensity
  - Hyper-K: 25 time more fiducial volume

θ_{13} and CP

ν_e Appearance probability

$$
\begin{aligned}
P(\nu_\mu \to \nu_e) = {} & 4C_{13}^2 S_{13}^2 S_{23}^2 \cdot \sin^2\Delta_{31} \\
& +8C_{13}^2 S_{12} S_{13} S_{23}(C_{12}C_{23}\cos\delta - S_{12}S_{13}S_{23}) \cdot \cos\Delta_{32}\cdot\sin\Delta_{31}\cdot\sin\Delta_{21} \\
& -8C_{13}^2 C_{12} C_{23} S_{12} S_{13} S_{23} \sin\delta\cdot\sin\Delta_{32}\cdot\sin\Delta_{31}\cdot\sin\Delta_{21} \\
& +4S_{12}^2 C_{13}^2 (C_{12}^2 C_{23}^2 + S_{12}^2 S_{23}^2 S_{13}^2 - 2C_{12}C_{23}S_{12}S_{23}S_{13}\cos\delta) \cdot \sin^2\Delta_{21} \\
& -8C_{13}^2 S_{13}^2 S_{23}^2 \cdot \frac{aL}{4E_\nu}(1-2S_{13}^2)\cos\Delta_{32}\cdot\sin\Delta_{31} \\
& +8C_{13}^2 S_{13}^2 S_{23}^2 \frac{a}{\Delta m_{31}^2}(1-2S_{13}^2)\sin^2\Delta_{31}
\end{aligned}
$$

Leading term

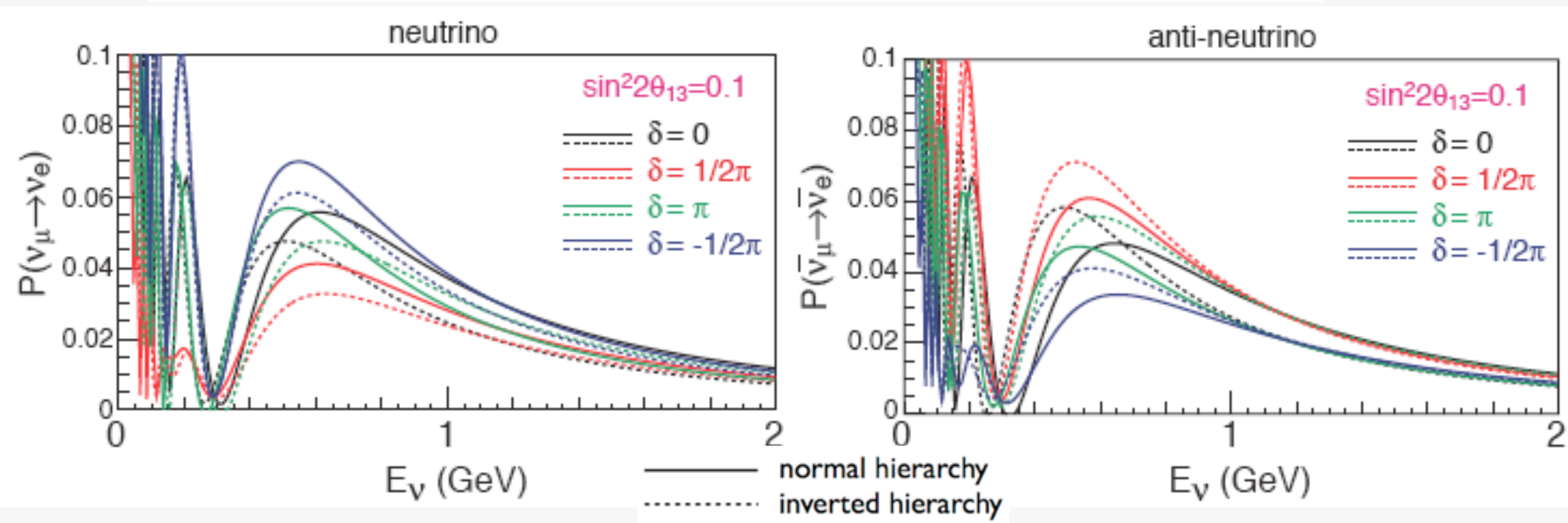
CP conserv.

CP violating

Solar

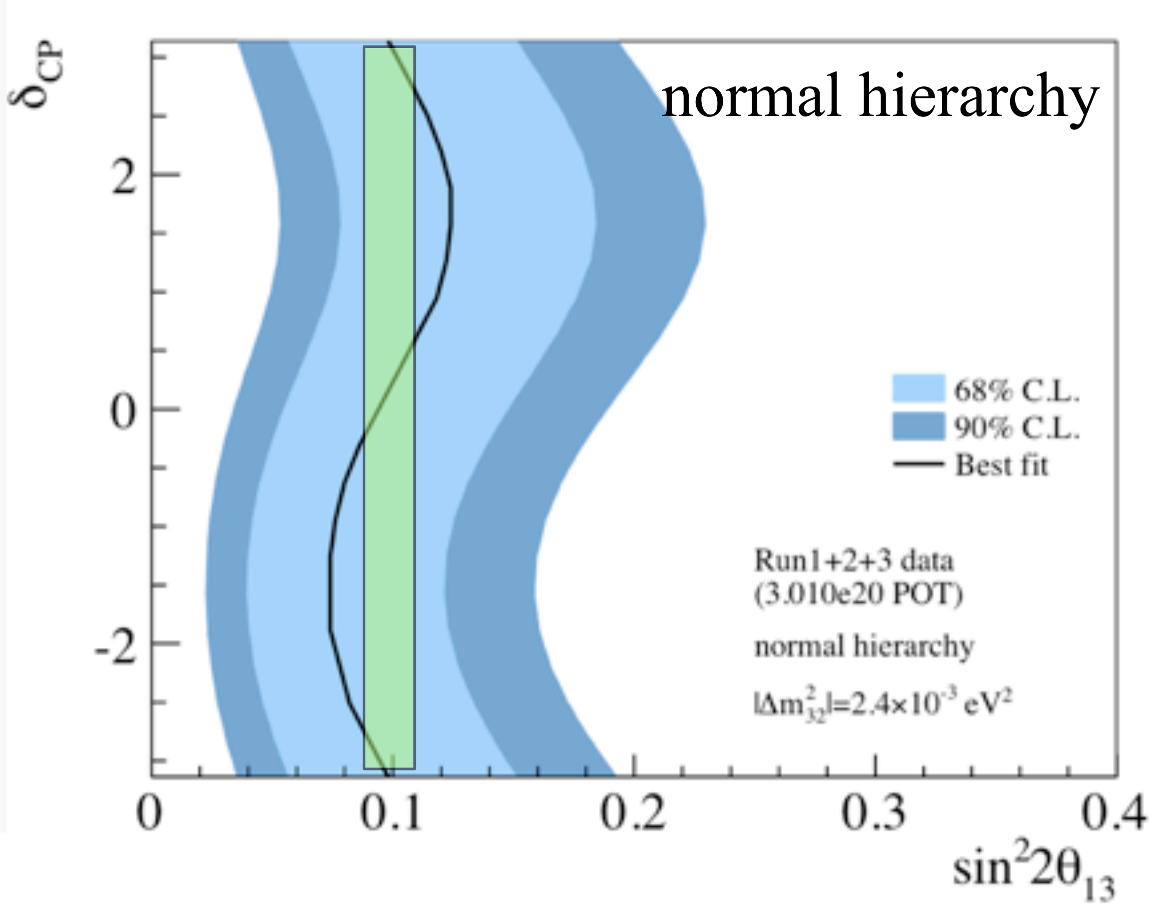
Matter effect

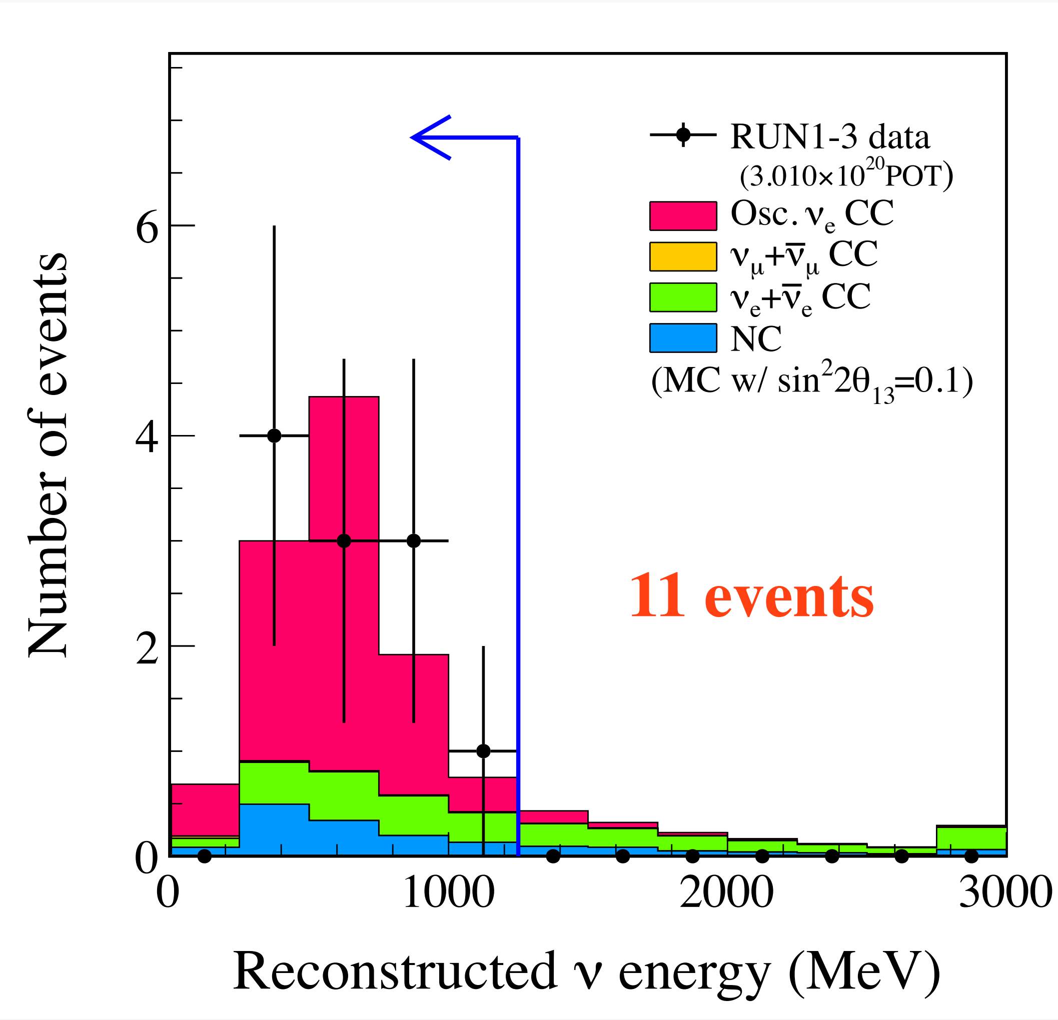
Changes sign between ν&$\bar{\nu}$

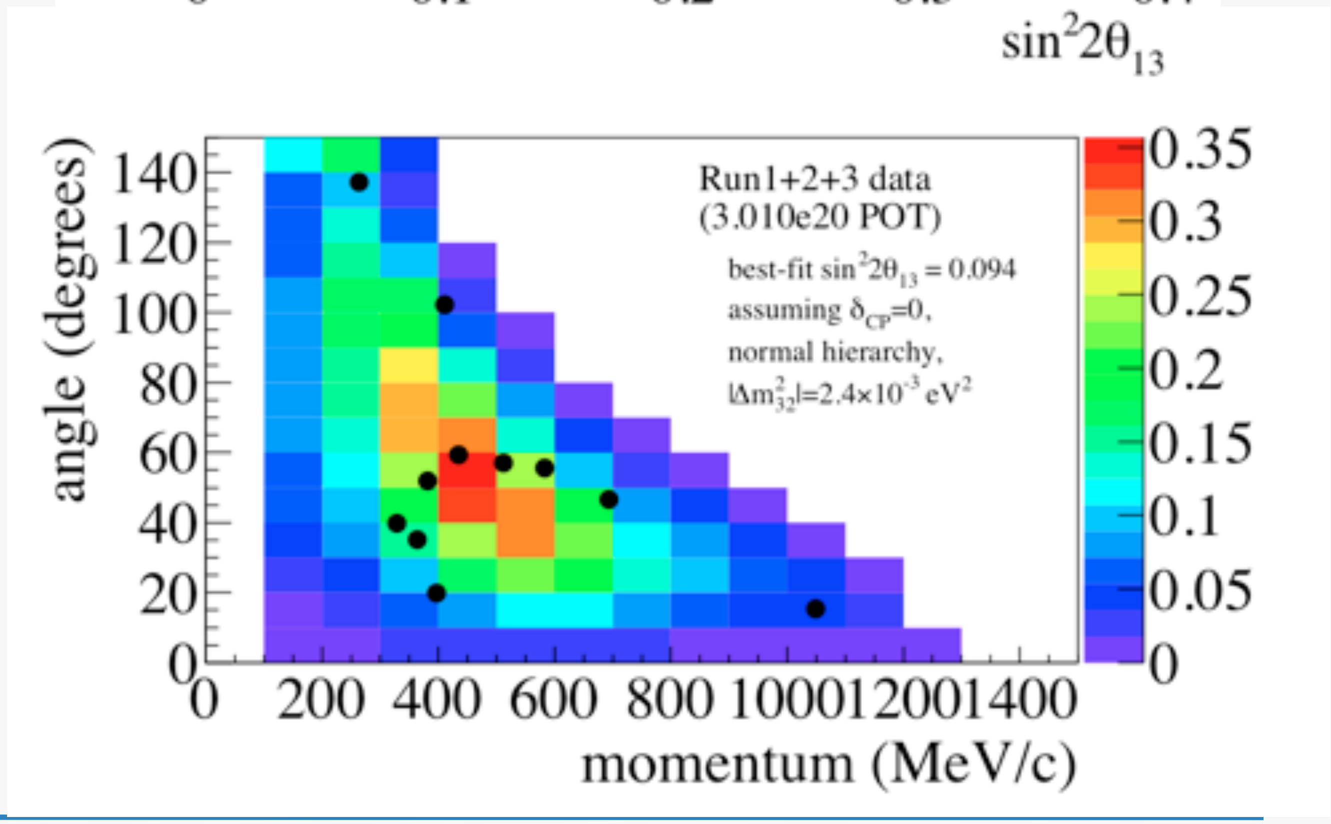


T2K ν_e appearance

- Run1-3 (-2012) data
  - 3.2σ evidence in ν_e appearance



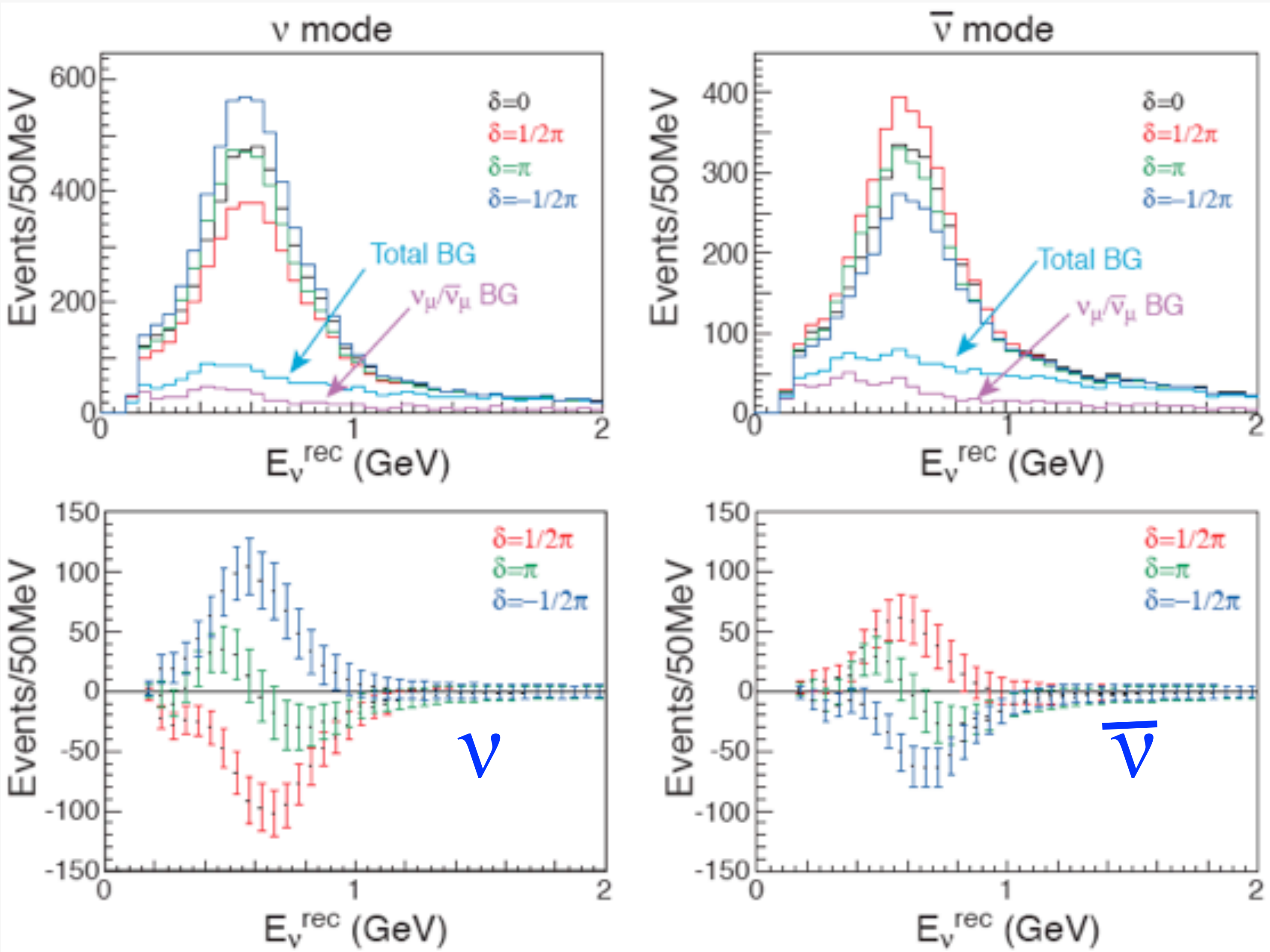




CP violation @ HyperK

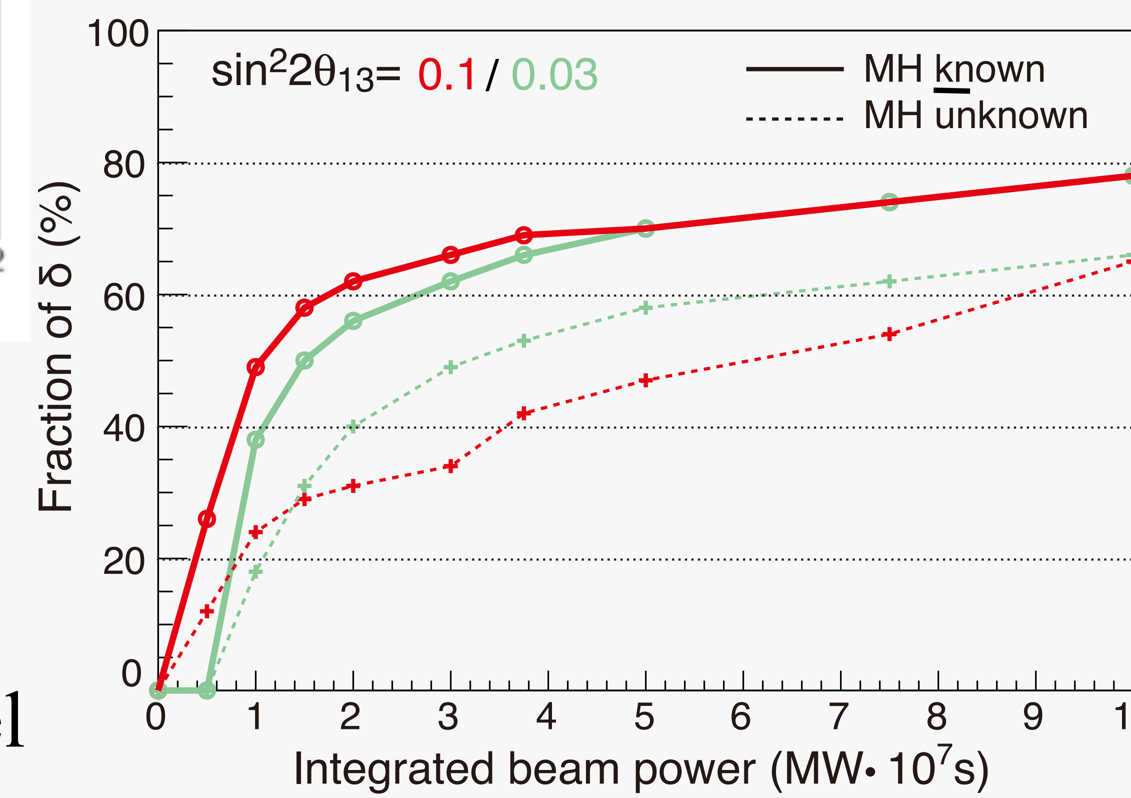
Event rate at HyperK

Event rate relative to δ=0



ν and ν̄ rate changes with CP phase

δ=0 and π are different in spectrum (cosδ term)



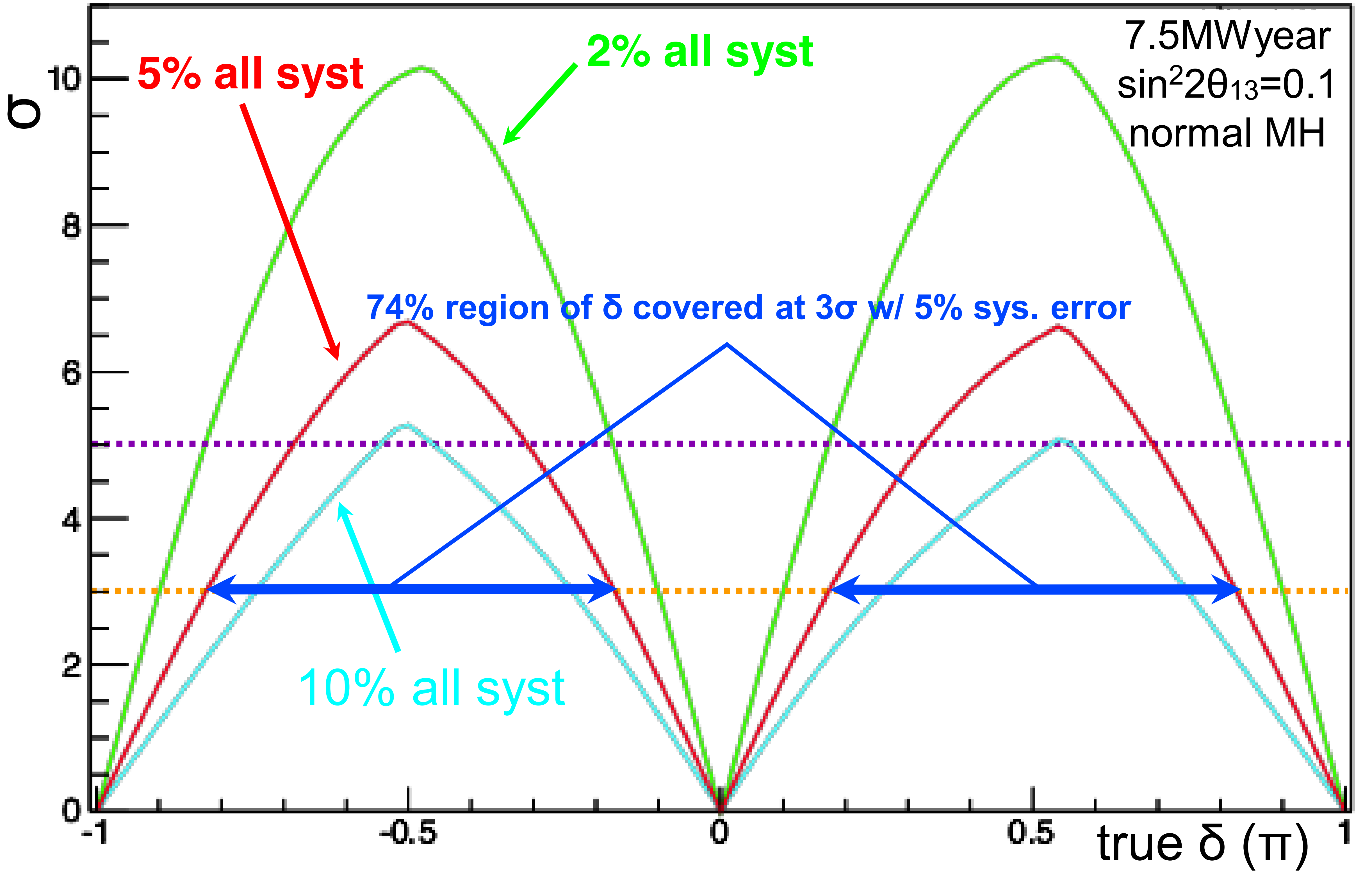
Assumes overall 5% systematics

realistic?

Fraction of δ phase space that can be observed at 3σ level

CPV Discovery Sensitivity

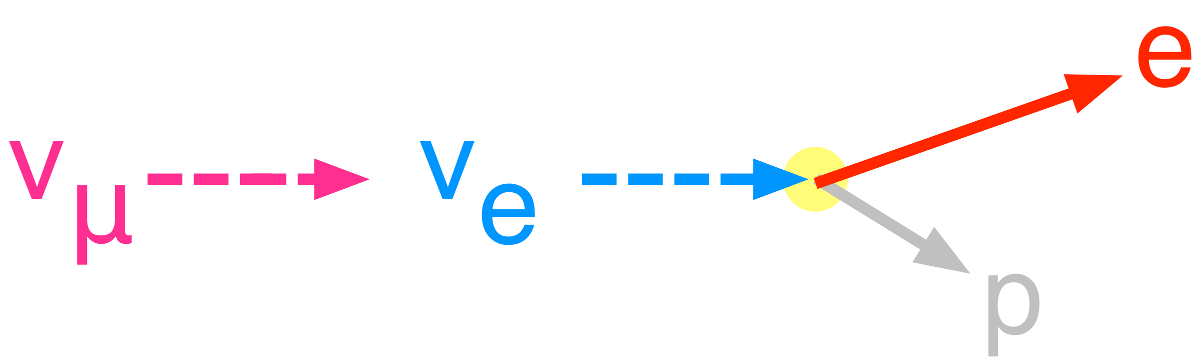
(w/ Mass Hierarchy known)



High Sensitivity to CPV w/ <~5% sys. error

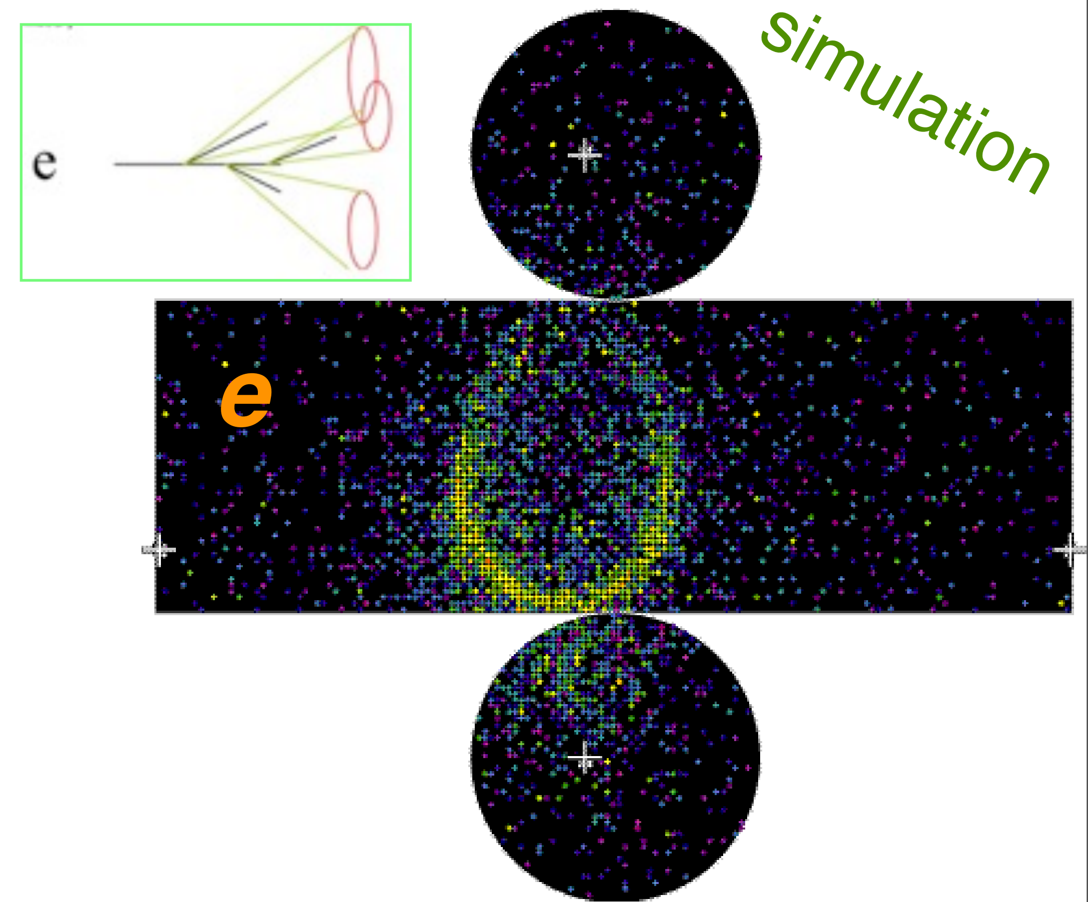
T2K Signal & Background for ν_e appearance

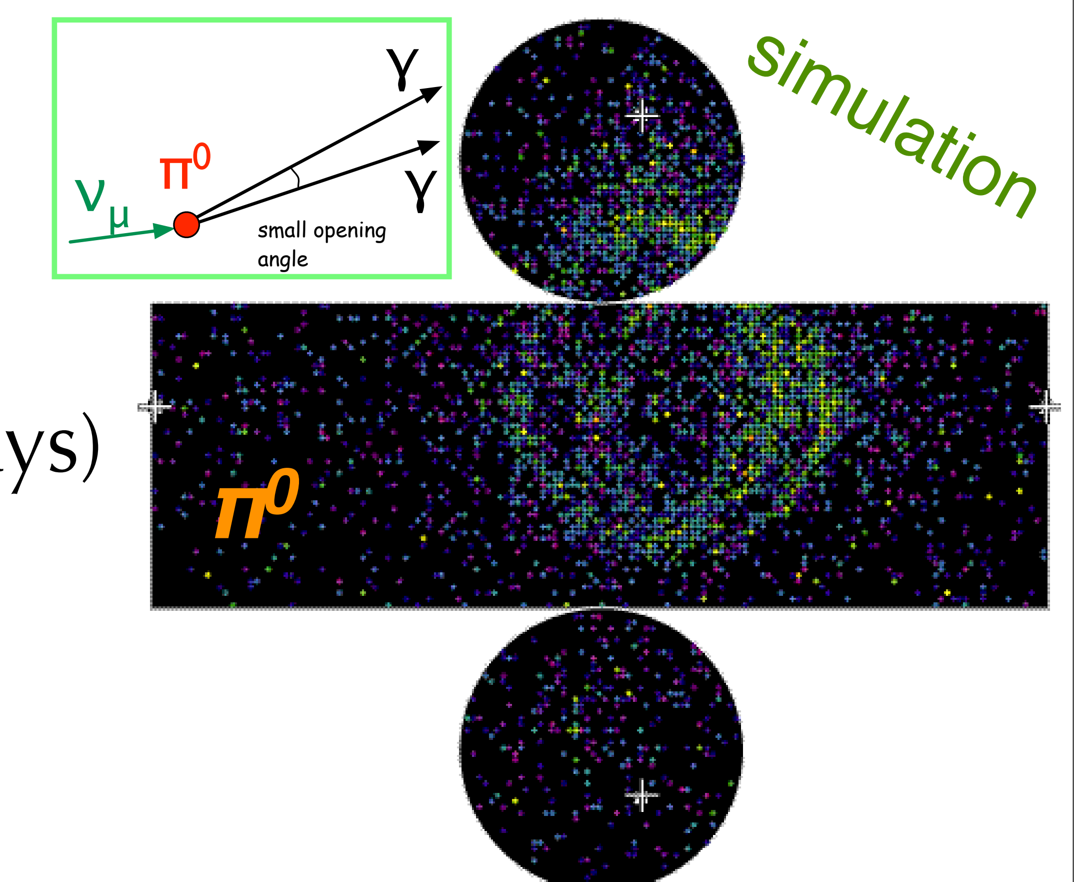
- Signal = **single electron event**
  - oscillated ν_e interaction :



CCQE : $\nu_e + n \rightarrow$ **e** $+ p$

(dominant process at T2K beam energy)





- Background
  - intrinsic ν_e in the beam (from μ, K decays)
  - π^0 from NC interaction

K.Sakashita@ICEHP

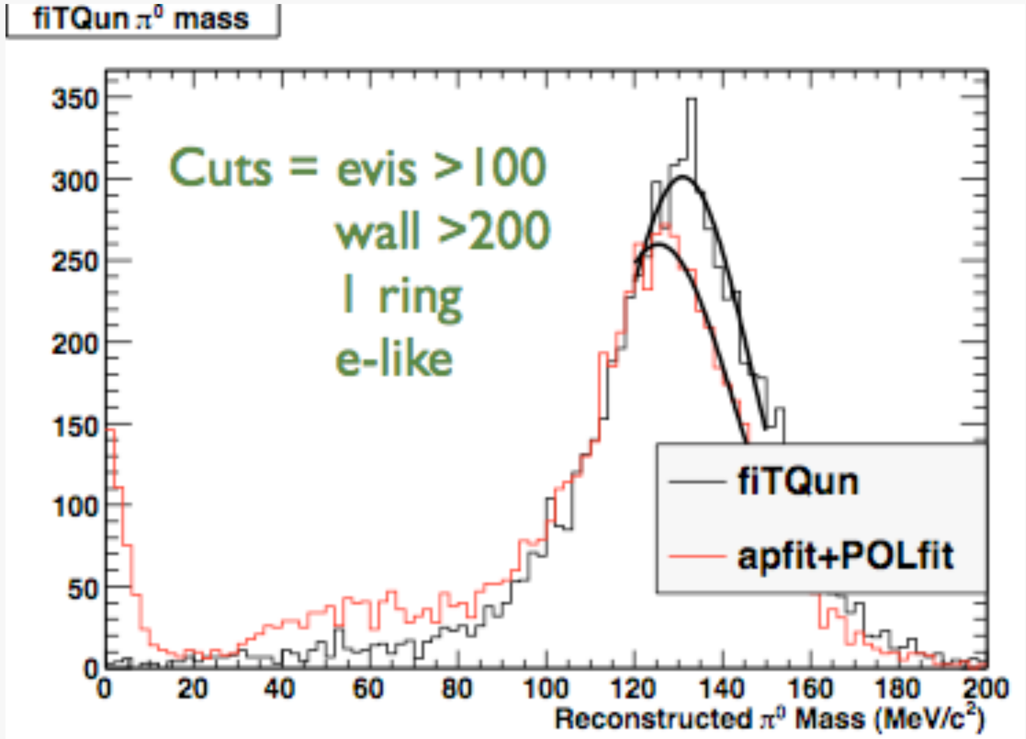
Background suppression

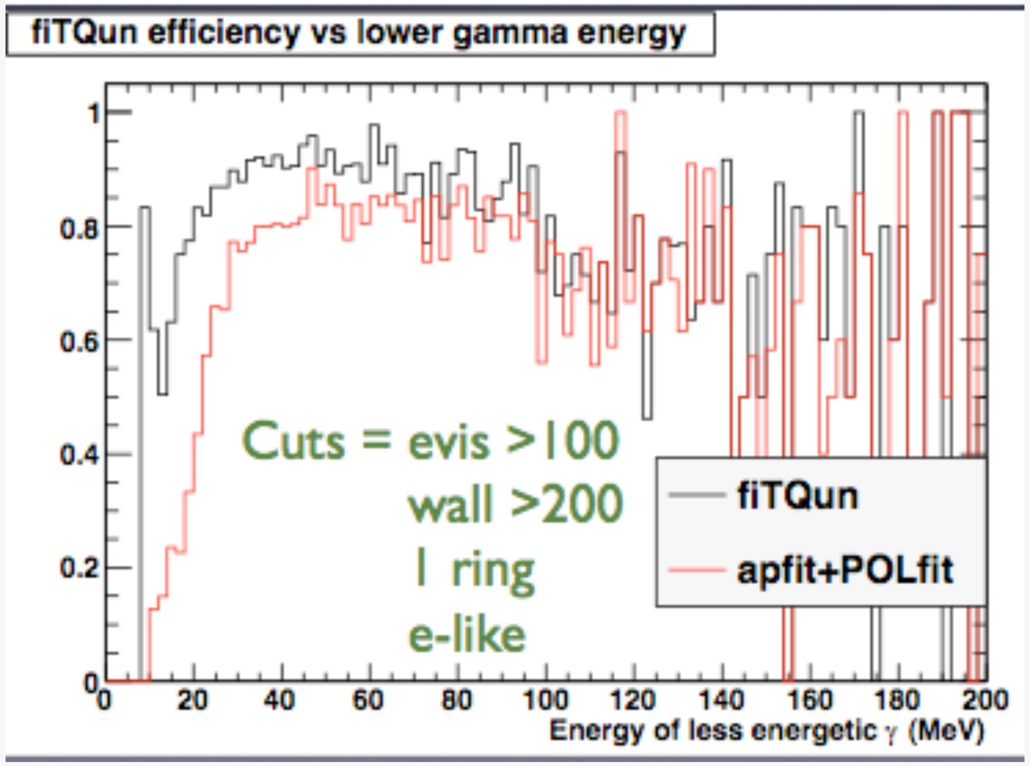
- New reconstruction code suppress NCπ^0 background in ν_e appearance to ~1/3

  M.Wilking @HyperK meeting

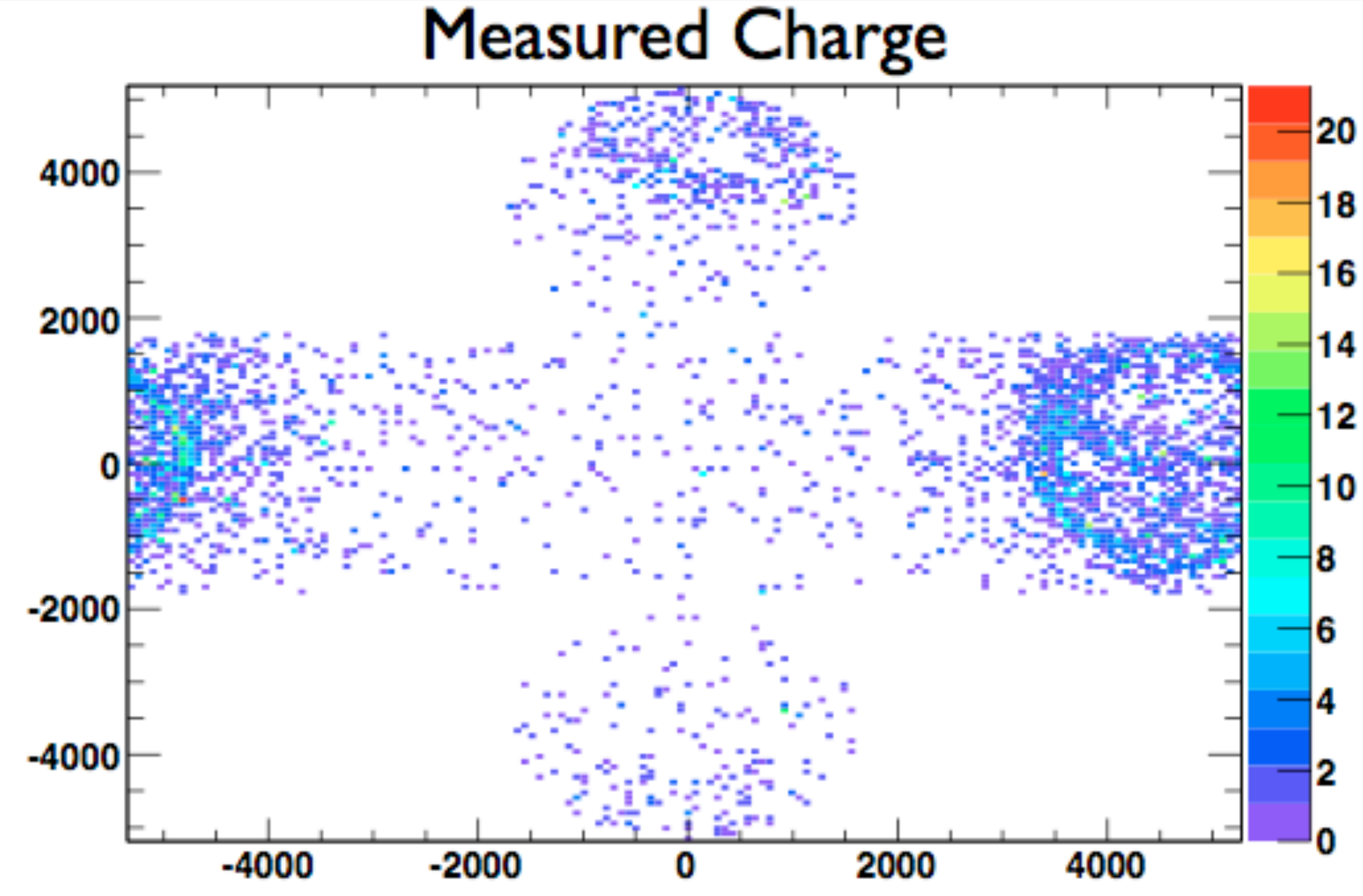
- Also effective to suppress CCπ^+ in ν_μ disappearance

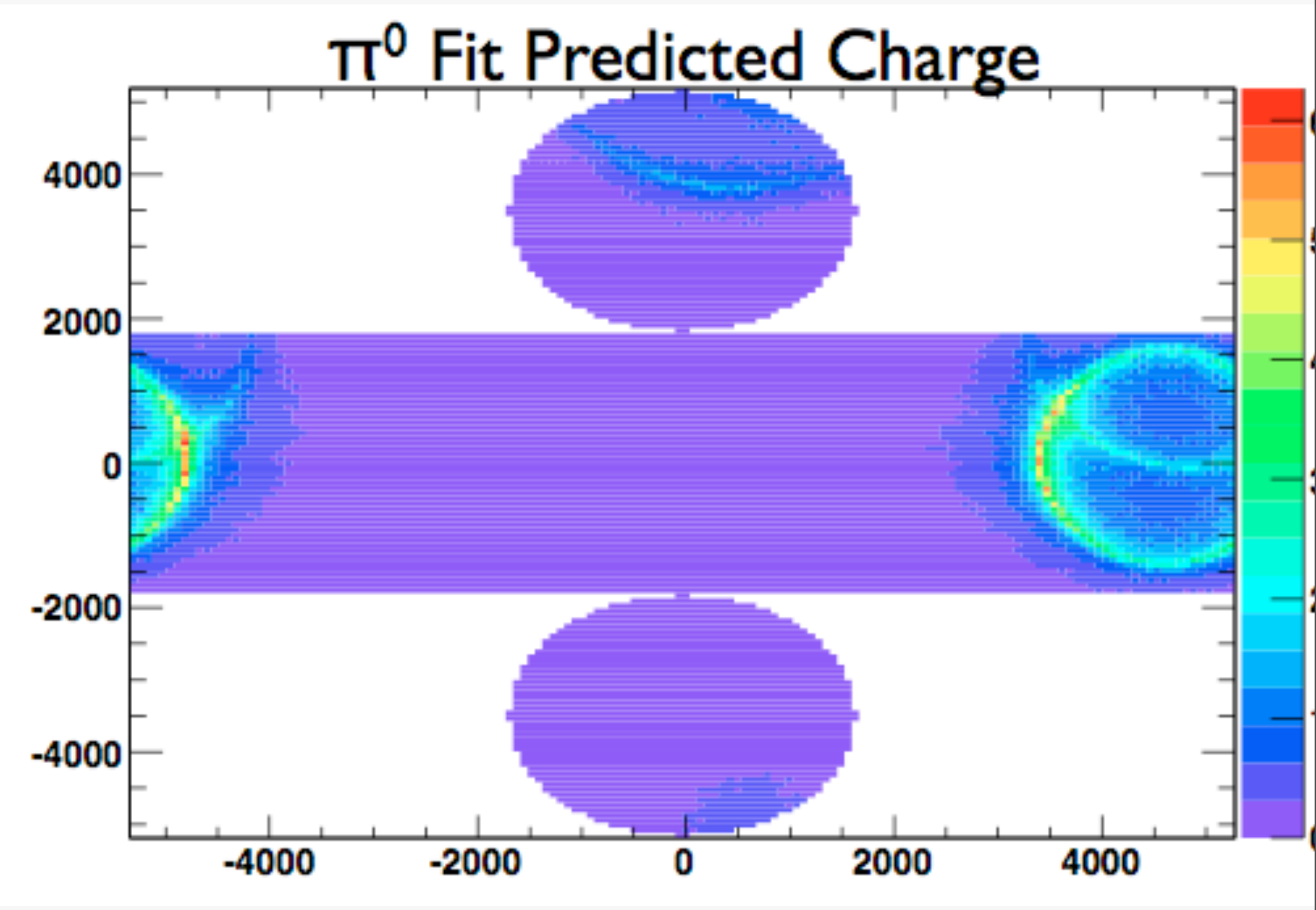
Event category	$\sin^2 2\theta_{13} = 0.0$	$\sin^2 2\theta_{13} = 0.1$
Total	3.22±0.43	10.71±1.10
ν_e signal	0.18	7.79
ν_e background	1.67	1.56
ν_μ background (mainly NCπ^0)	1.21	1.21
$\bar{\nu}_\mu + \bar{\nu}_e$ background	0.16	0.16





fitQun π^0 fitter





Potential improvements

- Background suppression & measurement (fitQun)
  - νe appearance (θ_{13}, δcp): $NC\pi^0$ [down to <30%]
- Reduction of systematic uncertainties
  - Background suppression & measurement
  - Cross section modeling and measurements
- Statistics to improve:
  - T2K: runs with continuously increasing intensity
  - Hyper-K: 25 time more fiducial volume

Atmospheric neutrino

mass hierarchy

$\theta_{23}<45°$ or $\theta_{23}>45°$

Atmospheric neutrino

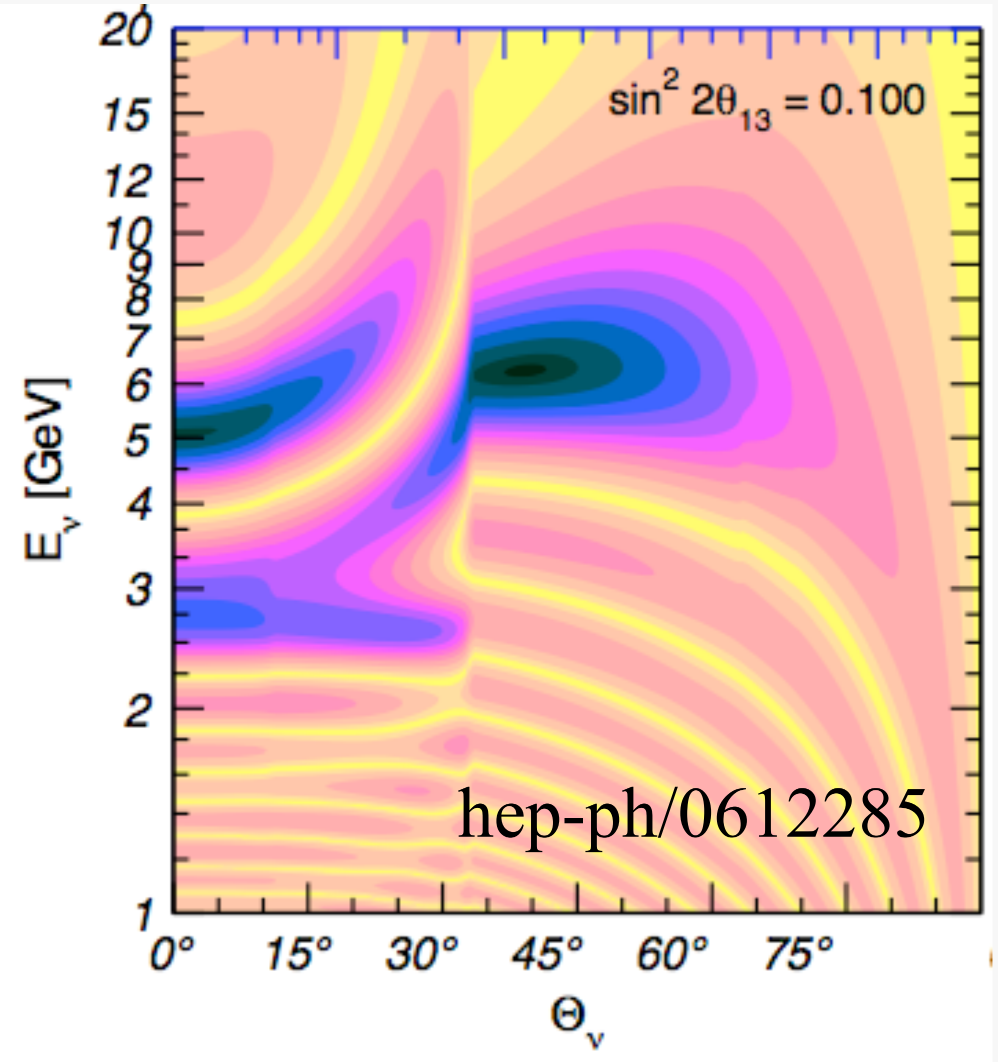
$$\frac{\Phi(\nu_e)}{\Phi_0(\nu_e)} - 1 \approx P_2 \cdot (r \cdot \cos^2\theta_{23} - 1) \quad \theta_{12}$$

interference (δcp)

$$-r \cdot \sin\tilde{\theta}_{13} \cdot \cos^2\tilde{\theta}_{13} \cdot \sin 2\theta_{23} \cdot (\cos\delta \cdot R_2 - \sin\delta \cdot I_2)$$

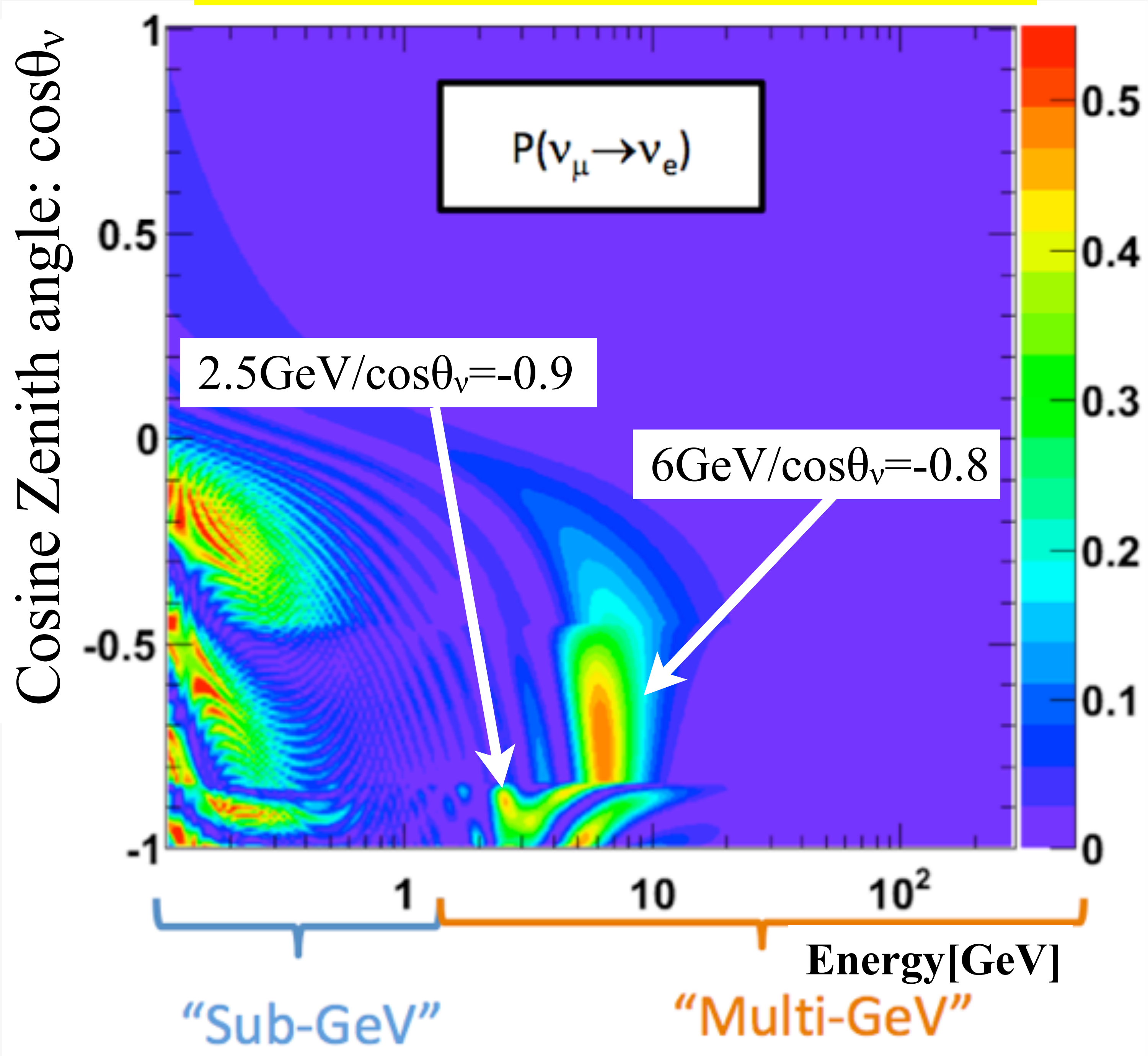
$$+2\sin^2\tilde{\theta}_{13} \cdot (r \cdot \sin^2\theta_{23} - 1) \quad \theta_{13} \text{ resonance}$$

- Resonant oscillation (oscillogram)
  - Zenith angle dependence
    - 0–33°: core+mantle
    - 33°–75°: mantle
  - $r = \Phi_\mu / \Phi_e$
    - r=2.1@1GeV, 2.4@3GeV, 2.6@6GeV
    - cancellation for $\sin^2\theta_{23} < 0.5$



Resonant $\nu_\mu \to \nu_e$ oscillation

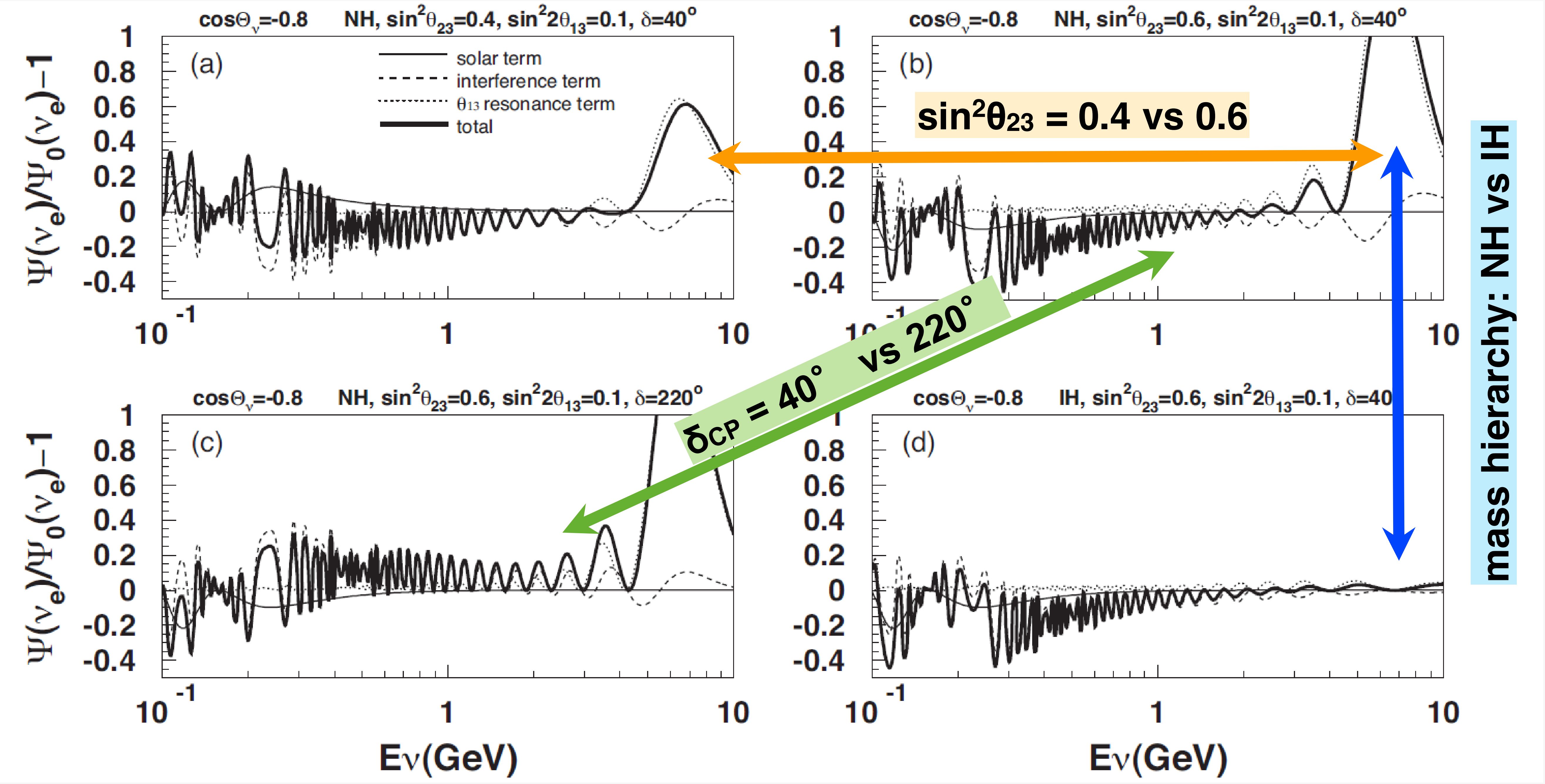
R.Wendel@HyperK meeting



- $\nu_\mu \to \nu_e$ resonance
  - 2.5GeV/$\cos\theta_\nu$=-0.9
  - 6GeV/$\cos\theta_\nu$=-0.8
- Resonance depends on
  - $\cos\theta_\nu$ and E_ν
    - multi-GeV, upward
  - $\nu/\bar{\nu}$, mass hierarchy
    - ν for normal hierarchy
    - $\bar{\nu}$ for inverted hierarchy

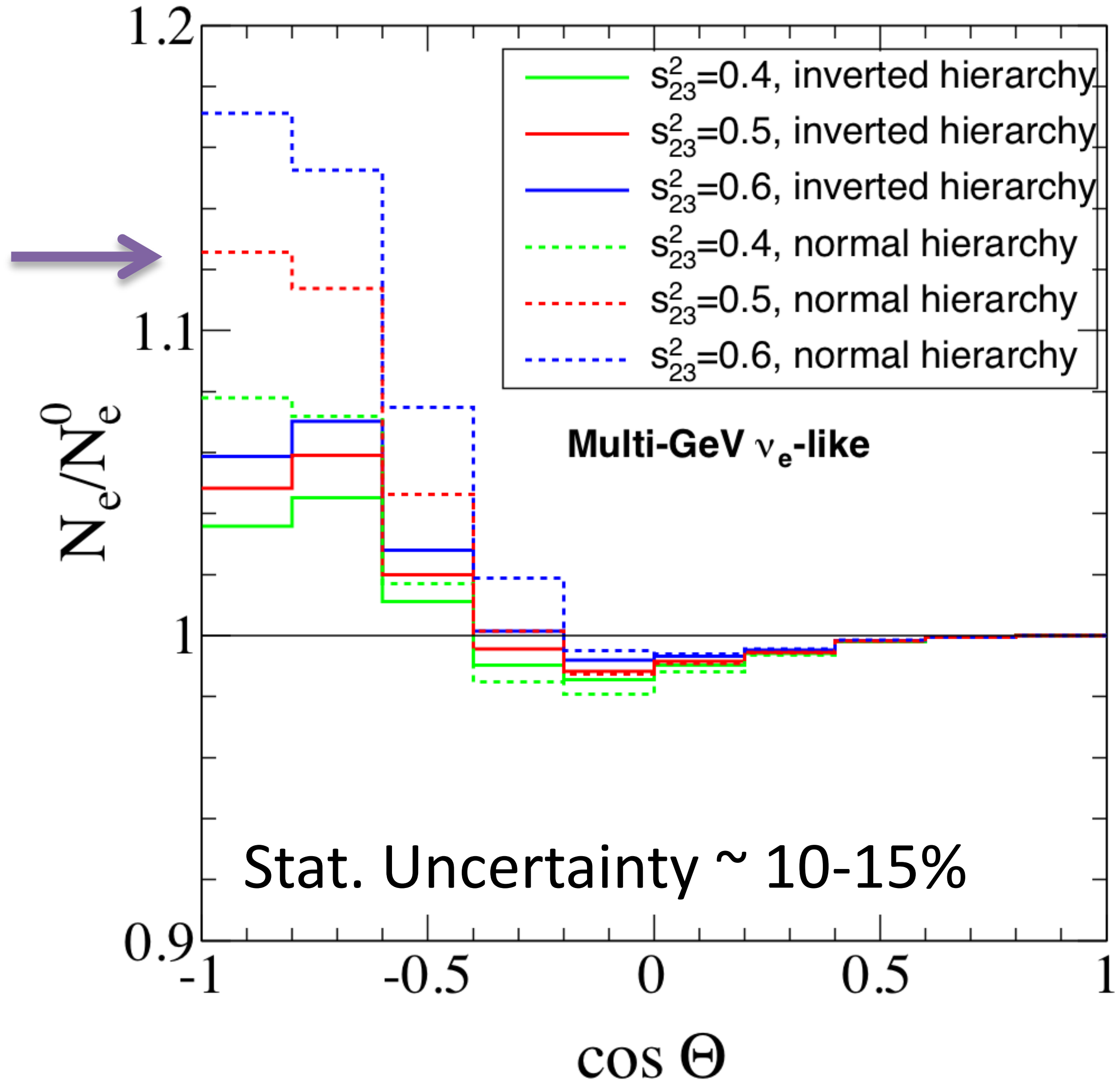
atmospheric ν_e appearance

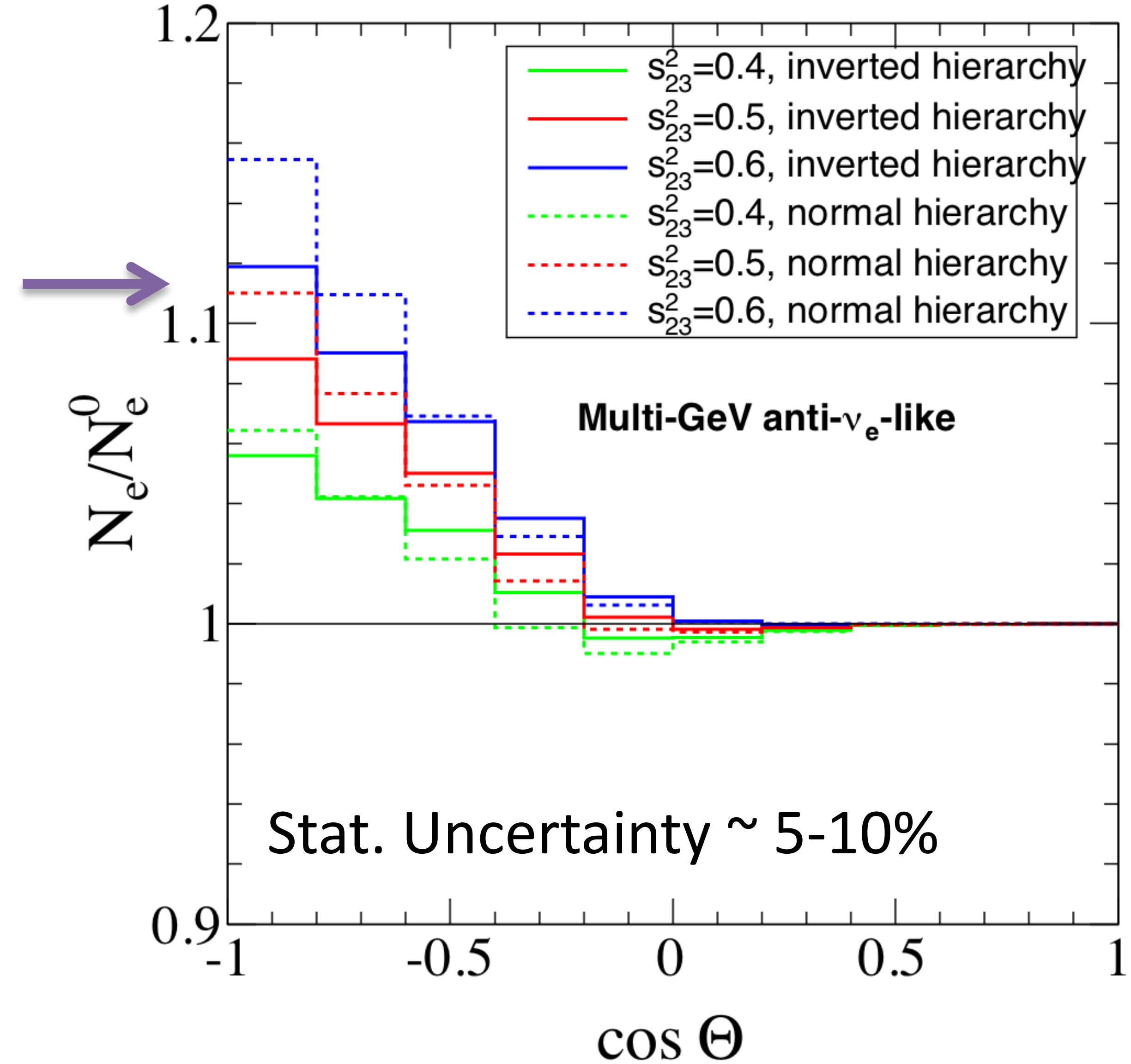
$\cos\theta_\nu$=-0.8



Sensitive to mass hierarchy, θ_{23} octant, δ_{CP}

Expected Effects : Single-Ring e-like and anti-e-like samples





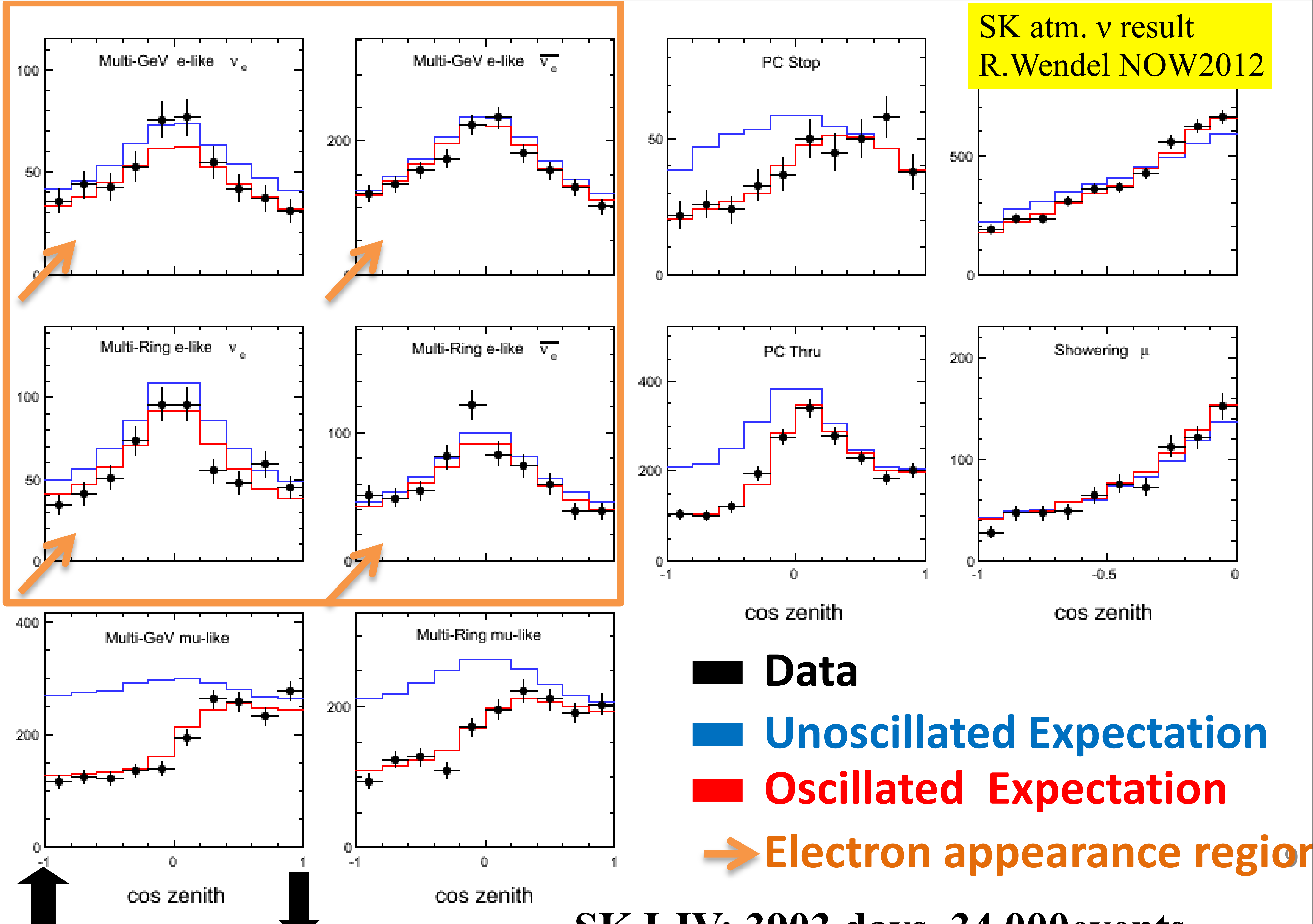
→ Equivalent MC

ν_e-like: $CC1\pi^+$ ⇨ with decay electron

$\bar{\nu}_e$-like $CC1\pi^-$ ⇨ without decay electron

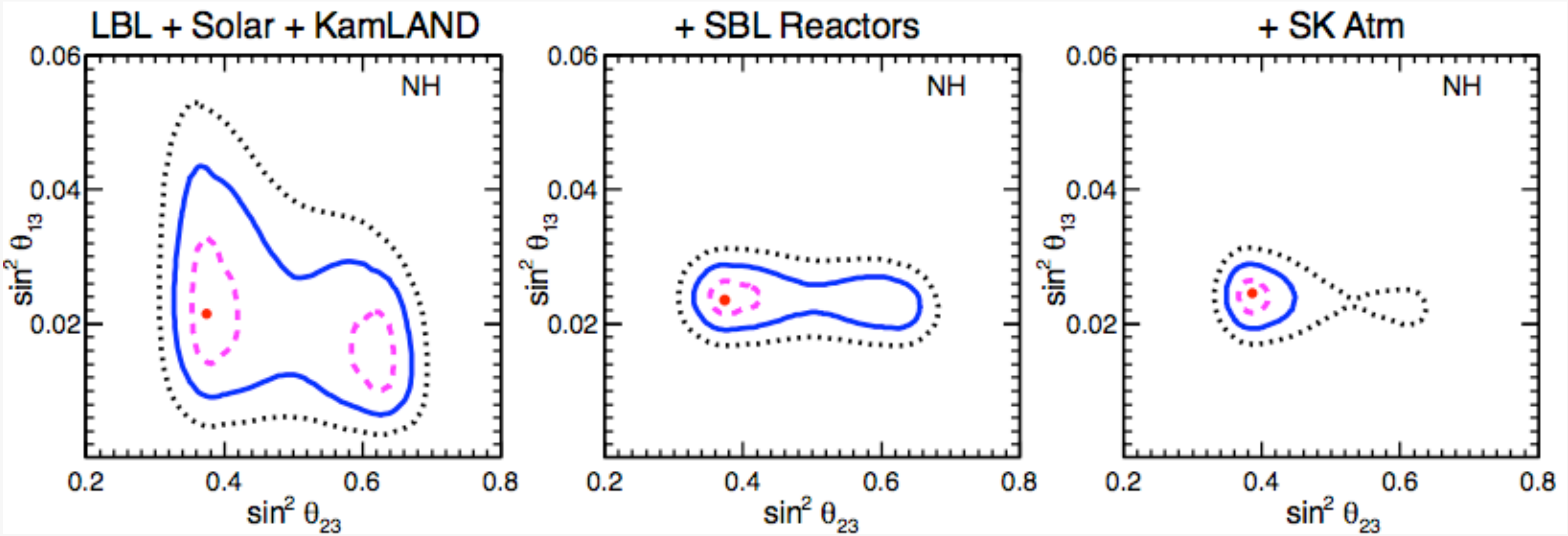
R.Wendel NOW2012

SK atm. ν result
R.Wendel NOW2012



SK I-IV: 3903 days, 34,000events

Systematics in Atm. ν



In practice, it is difficult to infer —from atmospheric data— clean 3ν information beyond the dominant parameters (Δm^2, θ_{23}). Subdominant oscillation effects are often smeared out over wide energy-angle spectra of events, and can be partly mimicked by systematic effects. For this reason, "hints" coming from current atmospheric data should be taken with a grain of salt, and should be possibly supported by independent datasets. **Fogli et. al. ArXiv:1205.5254v3**

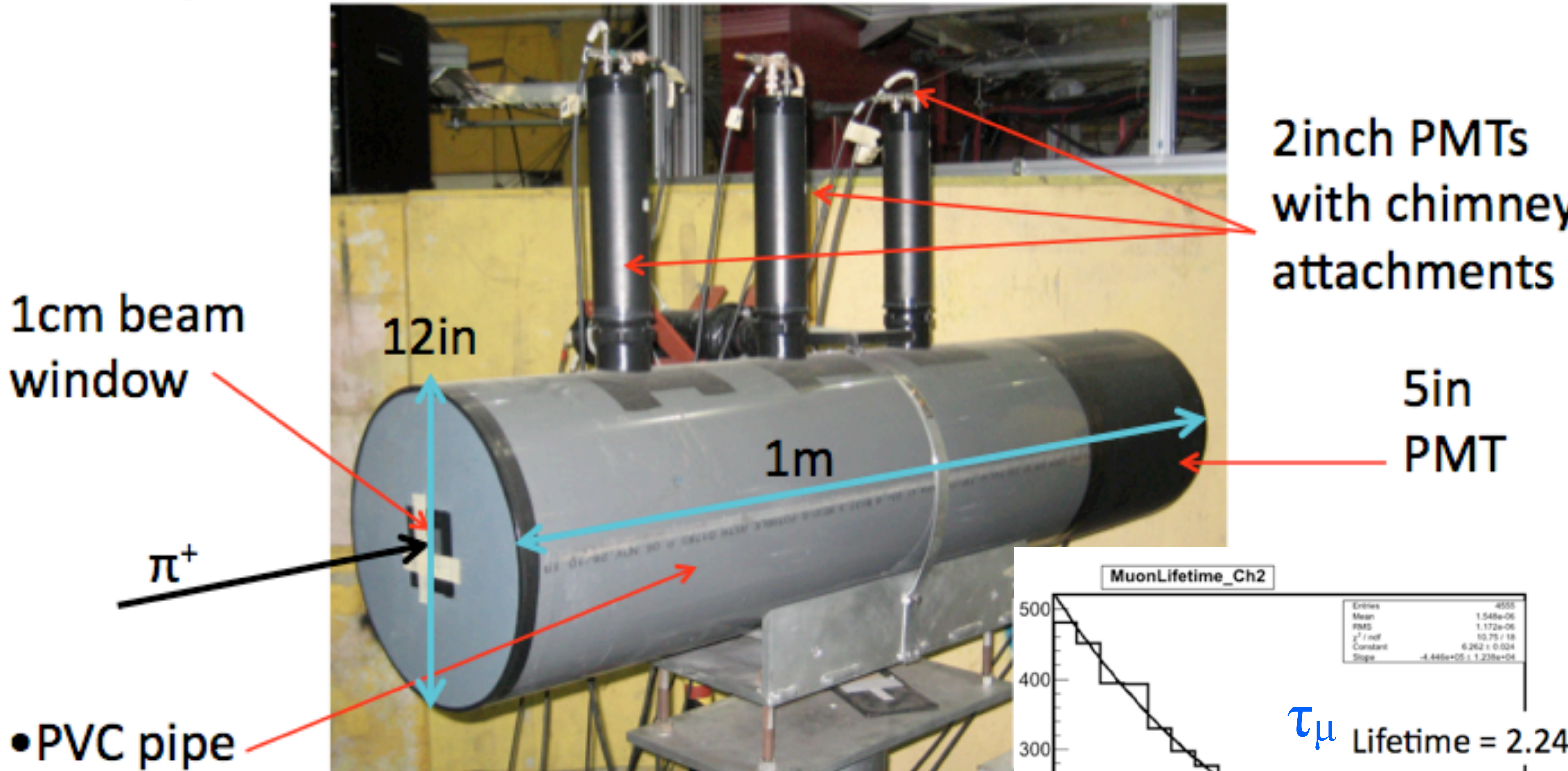
Potential Improvement: atm.ν $CC1\pi^{\pm}$

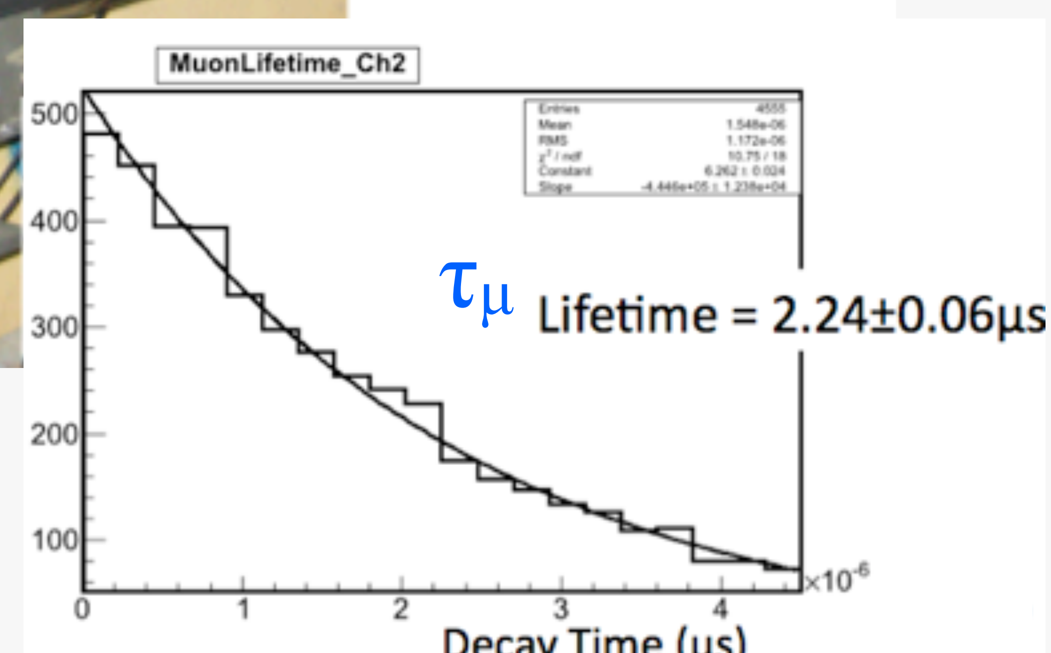
- Eclusive $CC1\pi^{\pm}$ reconst. successfully done @ MiniBooNE
  - FitQun reconstruction is based on the same method.
- Energy and zenith angle reconstruction
  - Pion Cerenkov ring before interaction → P_{π}
  - Full reconstruction except for the recoil nucleon:
    - ΔE_{ν}~50MeV : $\Delta E_{\nu}/E_{\nu}$=50/2500~2%
    - P_T(nucleon)~300MeV/c : $\Delta\theta_{\nu}/\theta_{\nu}$~300/2500~12%
- Background suppression: clean measurement
  - Particle identification
    - ν_e: $CC\pi^+$ with decay e , anti-ν_e: $CC\pi^-$ without decay e
  - NC(π^0) rejection using fitQun reconstruction
- Spectrum before oscillation given by down-ward going ν's

TRIUMF π beam test (M11)

S.Berkman et.al.

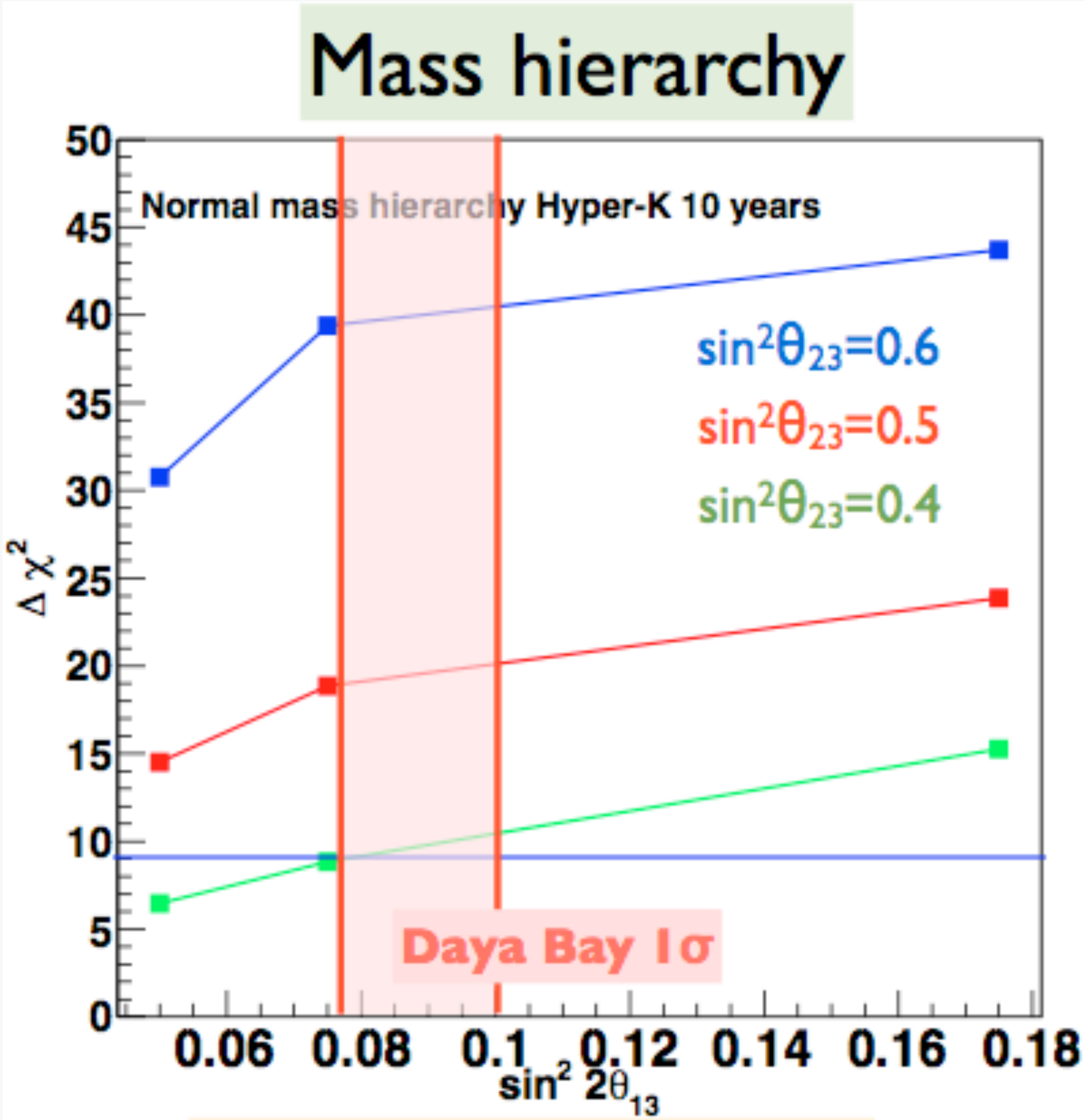
- Integrating cylinder filled with water



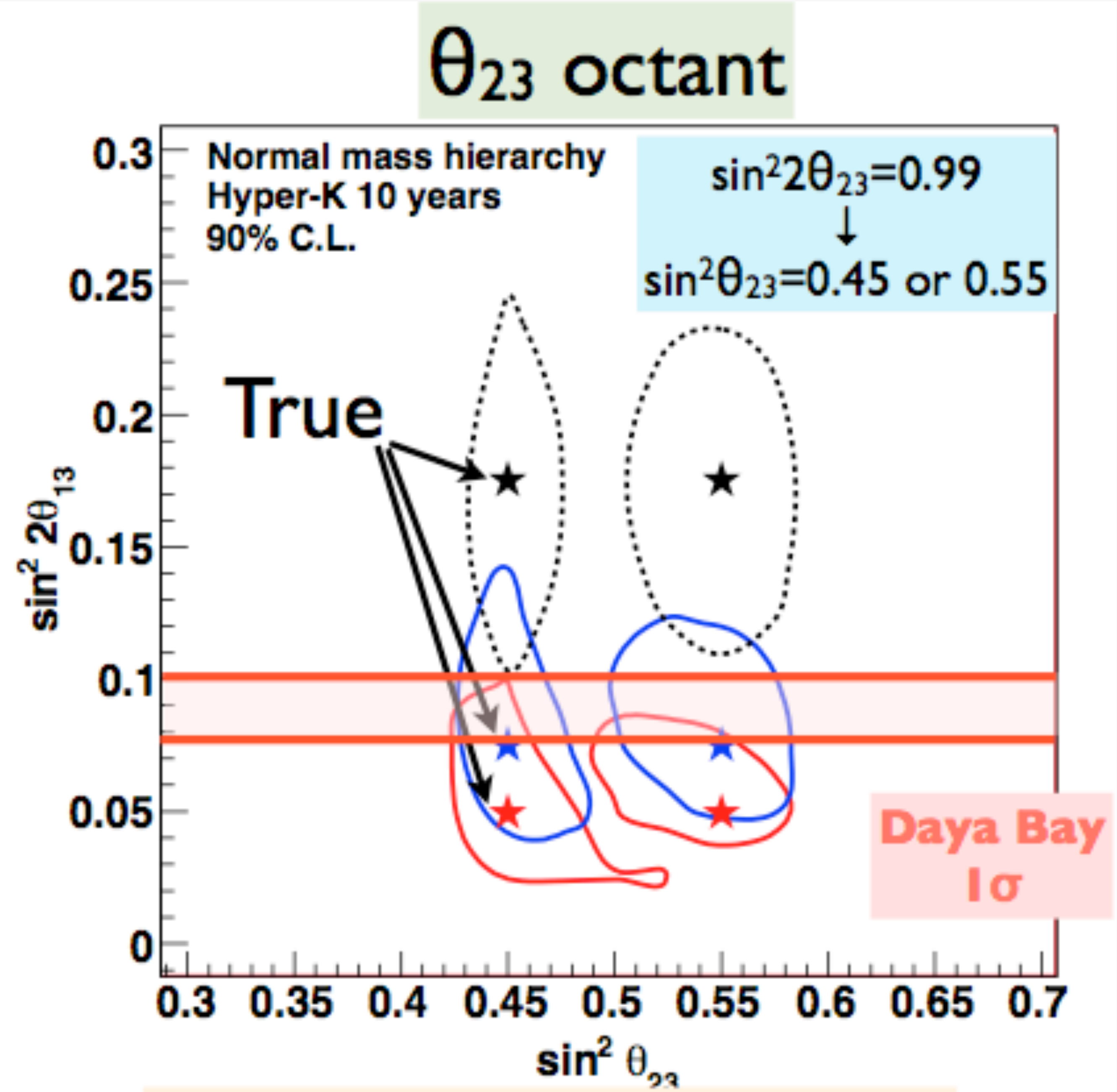


Measured probability for π to stop and decay in water for P_{π}=0.1-0.3GeV/c

Atmospheric ν at Hyper-K



>3σ with 5-10 years



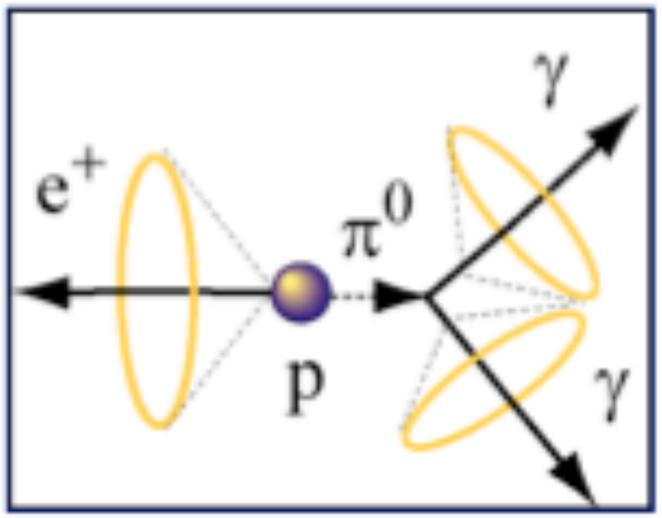
Resolved if $\sin^2 2\theta_{23}<0.99$

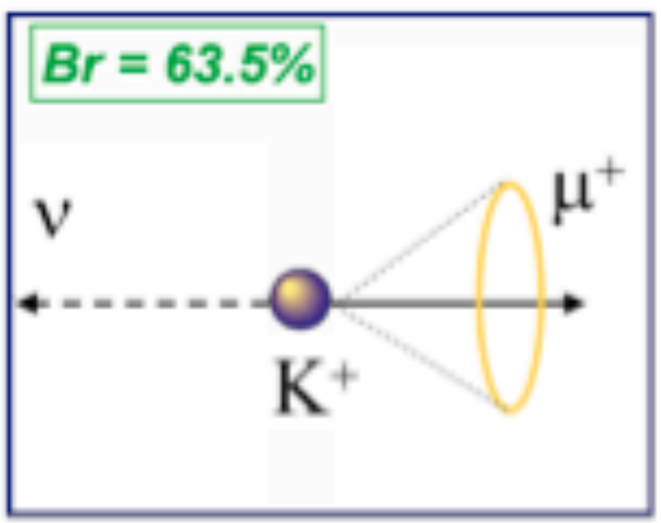
Without assuming fitQun but 5% syst.

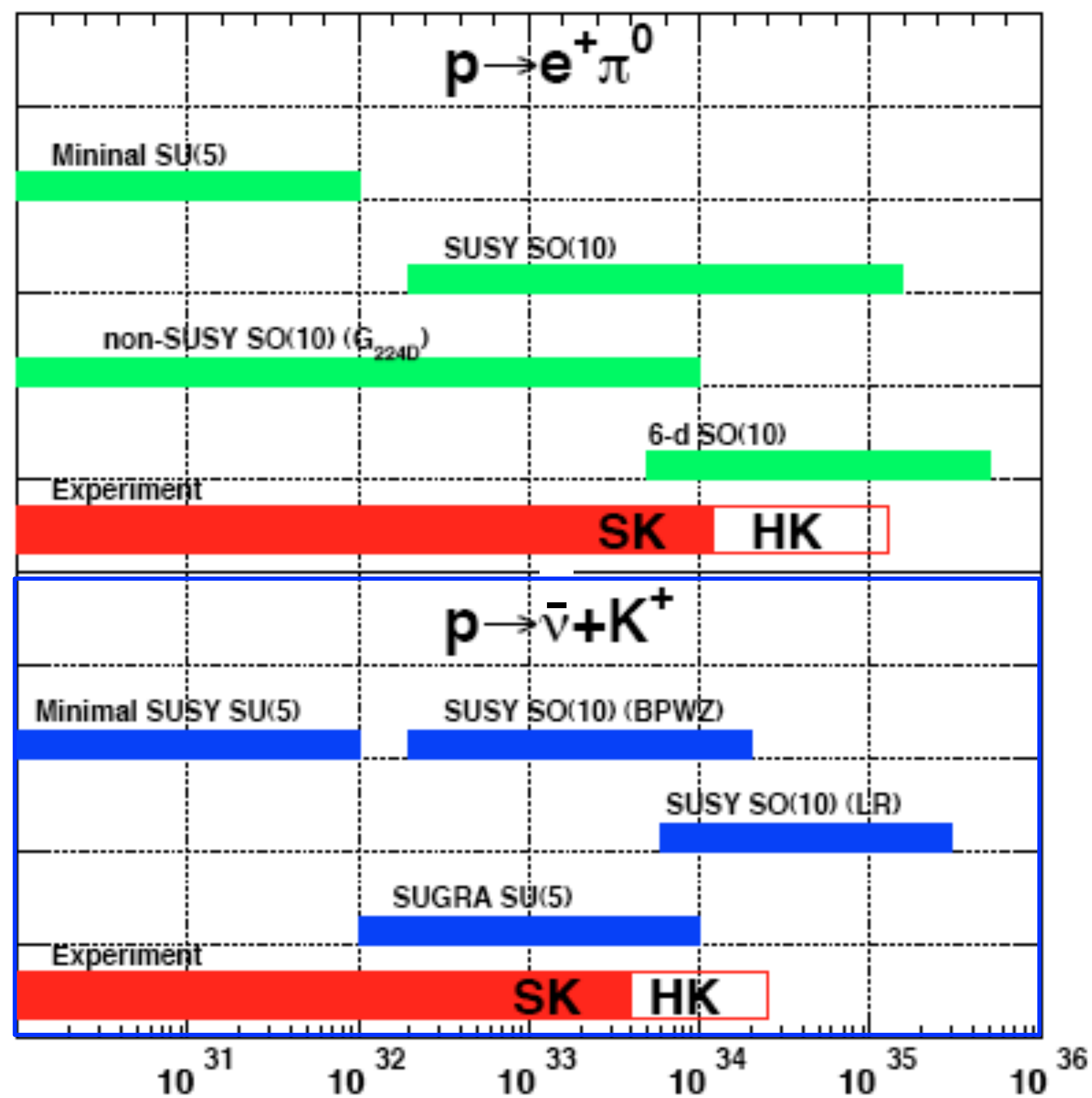
M.Yokoyama@Neutrino 2012

Proton decays

Proton decays



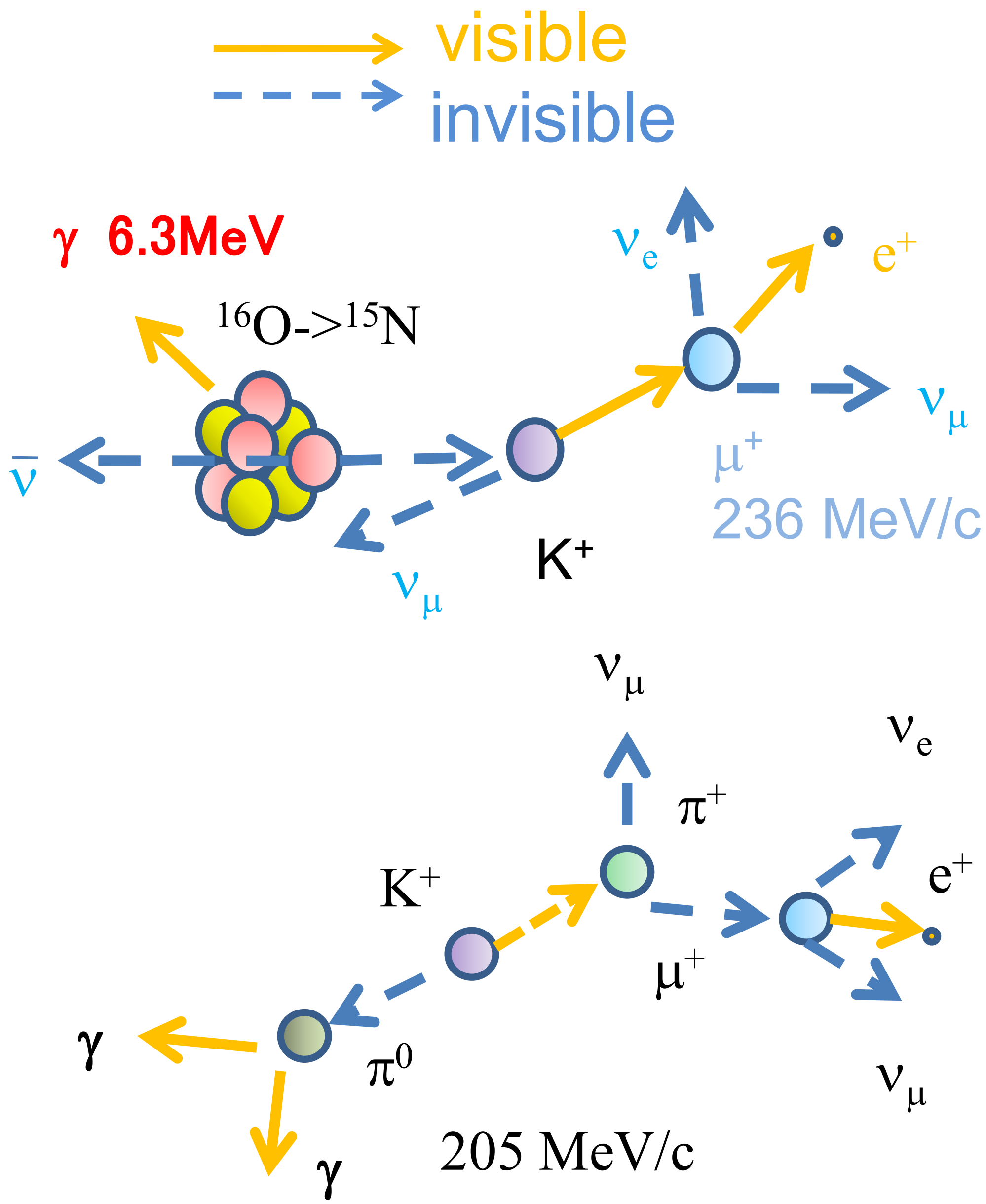




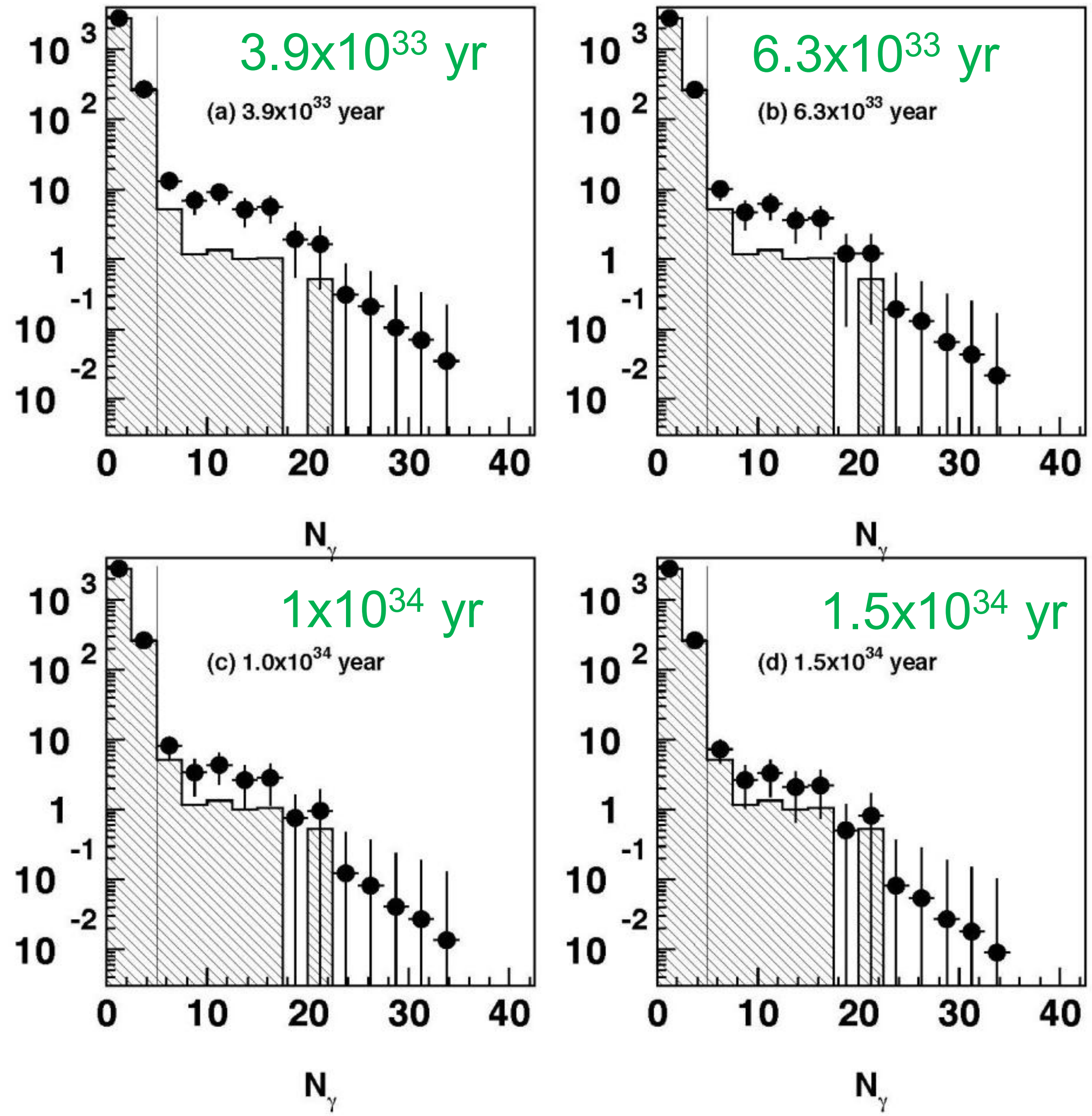
Expand search by another order of magnitude:
Getting deep into the remaining GUT window

$p \rightarrow \nu K^+$ mode at Hyper-K

Nakahata@Lyon



Number of hits of the prompt gamma signal (10 years)

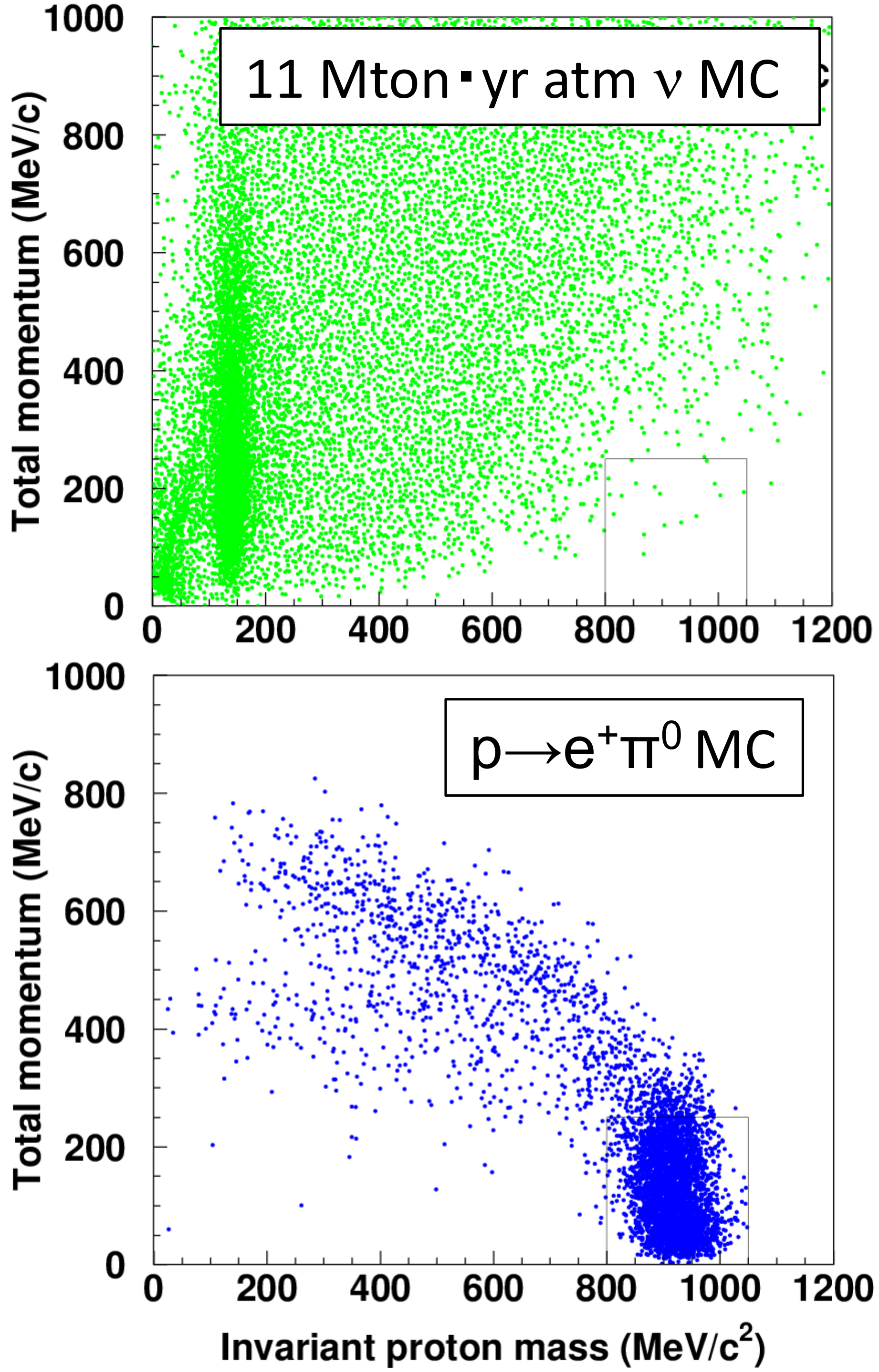


Discovery potential (3σ): 1.0x10^{34} years

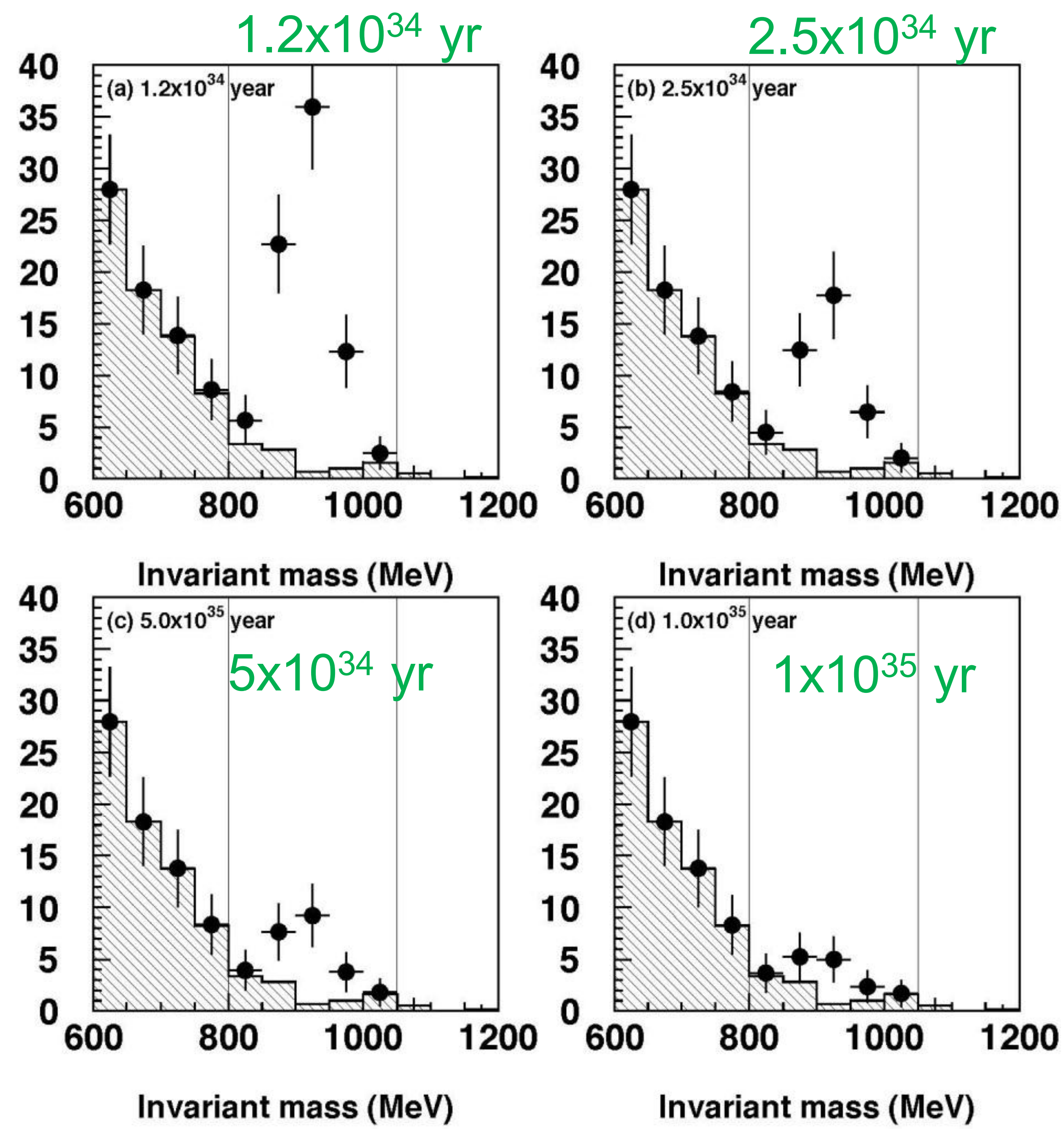
Sensitivity (90%C.L.): 2.5x10^{34} years with 10 years run (5.6 Mton・yrs)

Nakahata@Lyon

$p \rightarrow e^{+}+\pi^{0}$ mode at Hyper-K



Reconstructed proton mass(10 years)
(Total p < 250 MeV/c)



Discovery potential (3σ): 5.7×10^{34} years

Sensitivity (90%C.L.): 1.3×10^{35} years

with 10 years run (5.6 Mton・yrs)

Potential improvements

- $p \rightarrow K\nu$
  - Improved 6MeV γ tagging efficiency with fitQun
    - detect low energy γ before K decay
    - good K decay vertex reconstruction to reject fake γ
    - Full reconstruction of $K^+ \rightarrow \pi^+\pi^0$
- $p \rightarrow e\pi^0$
  - Background rejection
    - better energy/momentum resolution with fitQun
- Gd to veto associated neutrons from atm.ν BG?

Summary

- Precision ν oscillation measurements provides clues on origin of the flavour (family) structure.
- T2K continue accumulating data with increasing ν flux and future proposal of Hyper-K prepared.
  - θ_{23}: long baseline ν_μ disappearance
  - δcp: long baseline ν_e appearance
  - mass hierarchy/θ_{23} octant: atmospheric ν
  - proton decays: explore GUT

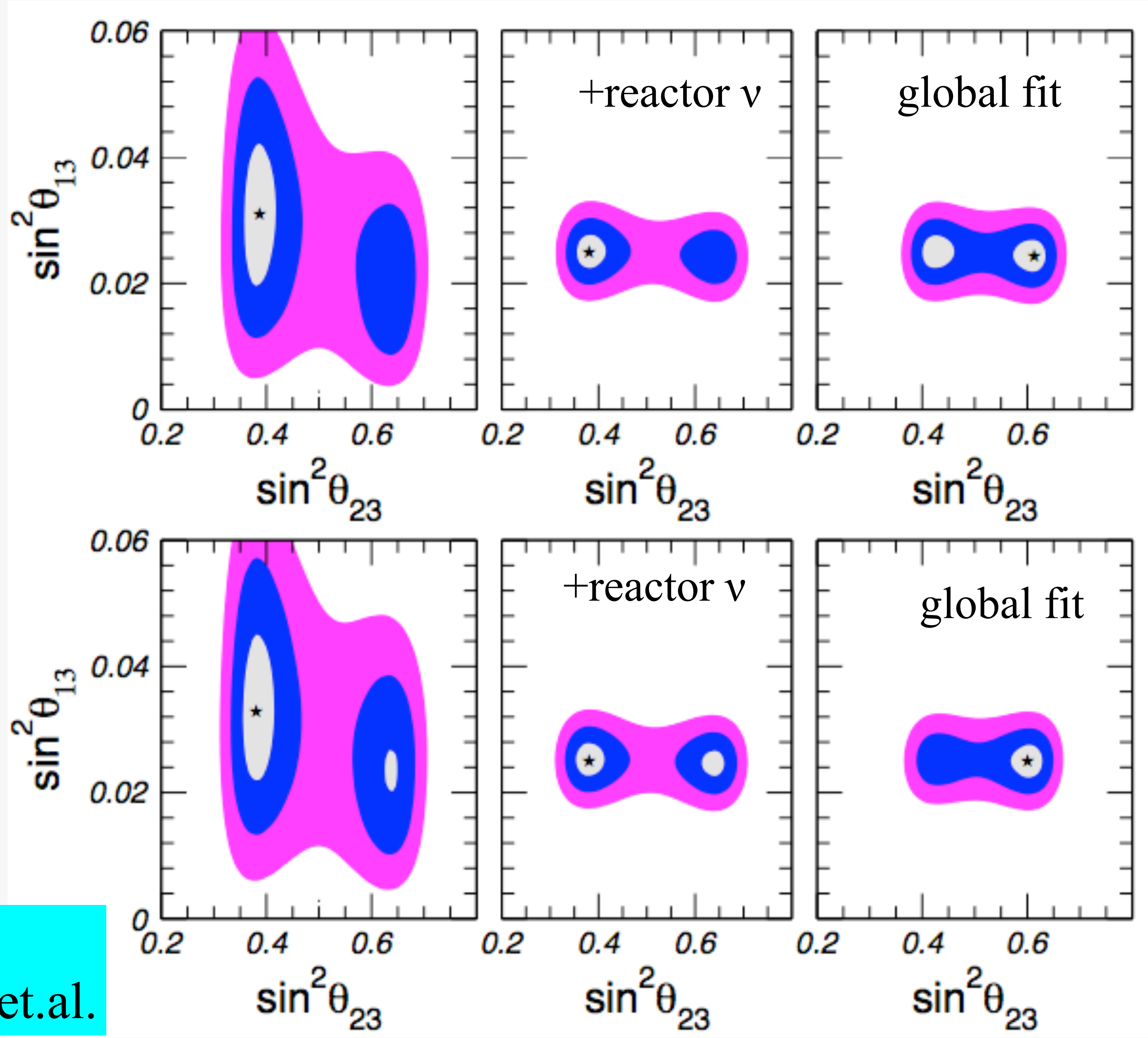
Summary (cont.)

- Controlling systematics is crucial:
  - Progress in cross section modeling/measurements
  - New reconstruction code
- New reconstruction code being prepared: fitQun
  - better reconstruction
    - momentum, vertex, particle identification
  - background tagging and rejection
    - π^0 for accelerator ν_e appearance (to less than 1/3)
    - $\pi^\pm$ for accelerator ν_μ disappearance
    - $\pi^\pm$ for atm. ν_e appearance: tag CC1π^+ and CC1π^-

Backups

Global fit (2012)

Normal hierarchy



arXiv:1205.4218 (Valencia group)

Inverted hierarchy

θ_{23}>45° preferred: different from Fogli et.al.

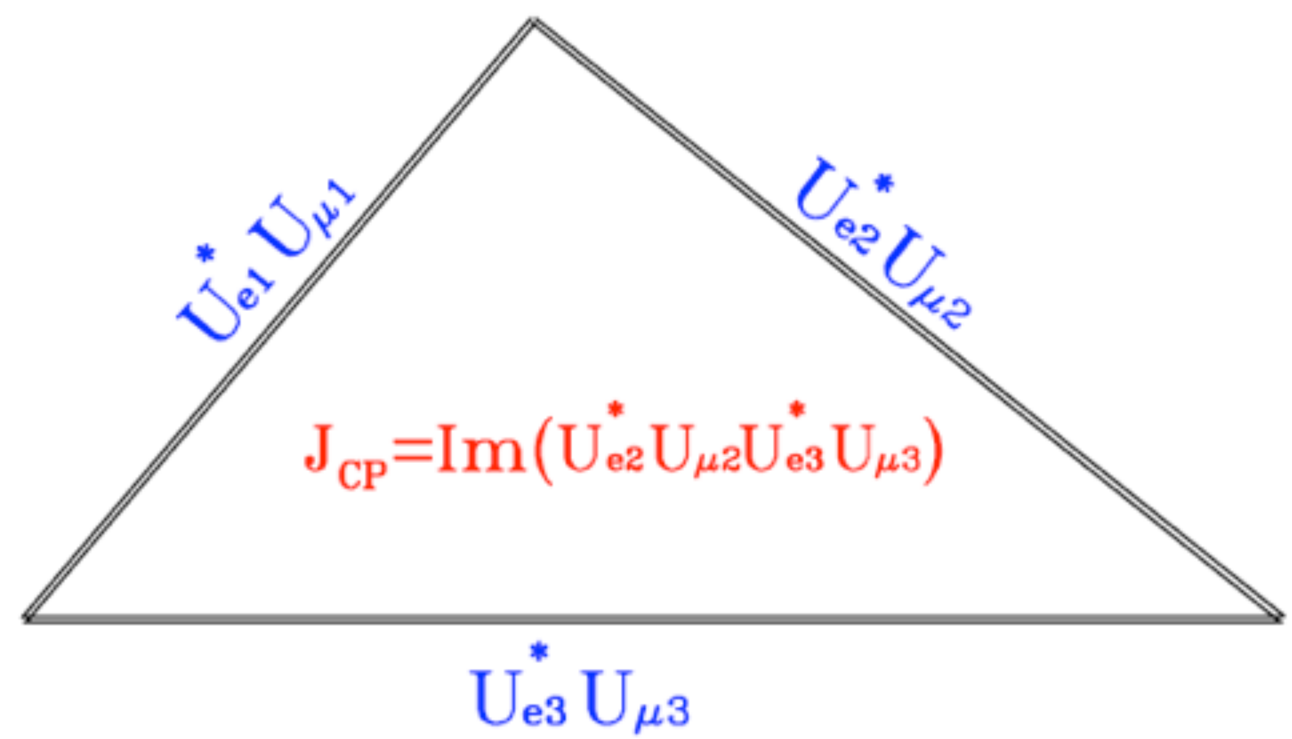
global fit

Lepton Unitary Triangle

- Large θ_{13} makes unitary triangle measurement realistic now: explore physics beyond SM
  - Sterile neutrino (right-handed ν) breaks unitarity
  - 4th generation, new interaction, etc.
  - Two speakers independently pointed out at Neutrino2012

- 4 coefficients overconstrain the unitarity triangle:

$$U_{e1}^{*}U_{\mu1} + U_{e2}^{*}U_{\mu2} + U_{e3}^{*}U_{\mu3} = 0$$



Mass hierarchy

- Matter resonance: atmospheric ν
  - SuperK/HyperK, INO, PINGU, …
- Long baseline ν
  - Comparison between short and long baselines
    - T2K/HK vs. NOνA/LBNE
- Comparison between Δm^2_{32} and Δm^2_{13}
  - Reactor Δm^2_{13} vs. T2K Δm^2_{32}
  - Daya-Bay2: Reactor Δm^2_{13} and Δm^2_{12} at 60km
- Cosmology: Σm_ν
- Double β decays

Cosmological ν mass

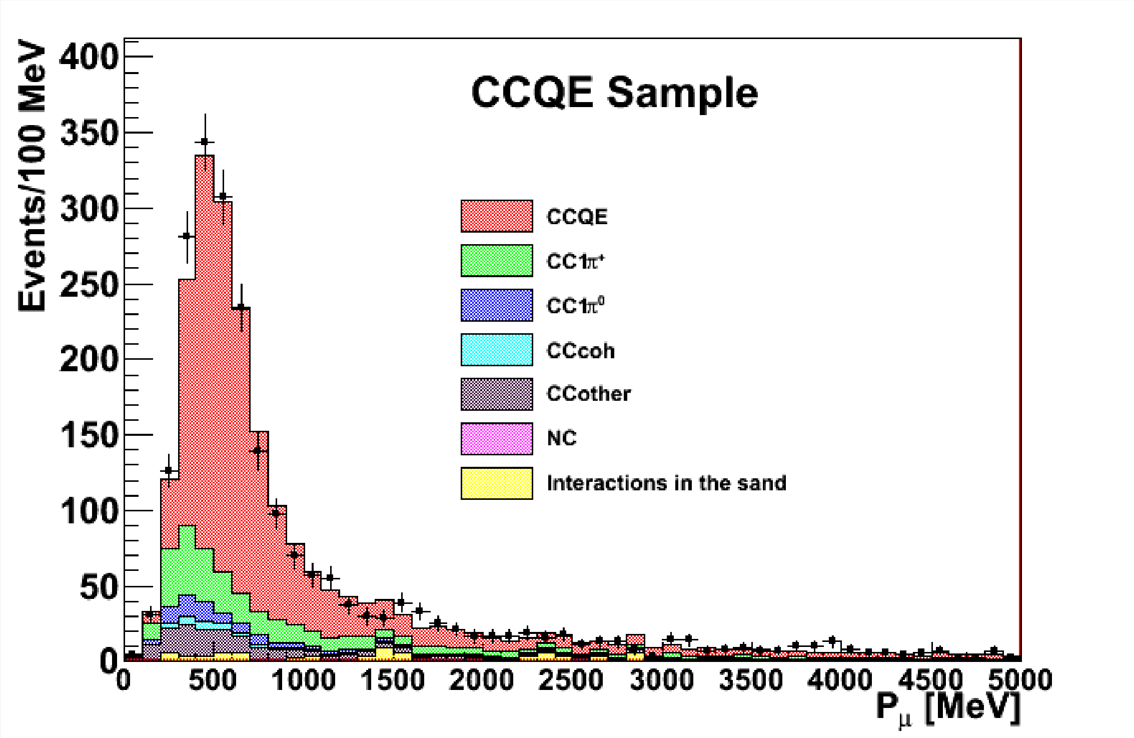
Probe	Current $\sum m_\nu$ (eV)	Forecast $\sum m_\nu$ (eV)	Key Systematics	Current Surveys	Future Surveys
CMB Primordial	1.3	0.6	Recombination	WMAP, Planck	None
CMB Primordial + Distance	0.58	0.35	Distance measurements	WMAP, Planck	None
Lensing of CMB	∞	0.2 – 0.05	NG of Secondary anisotropies	Planck, ACT [39], SPT [96]	EBEX [57], ACTPol, SPTPol, POLARBEAR [5], CMBPol [6]
Galaxy Distribution	0.6	0.1	Nonlinearities, Bias	SDSS [58, 59], BOSS [82]	DES [84], BigBOSS [81], DESpec [85], LSST [92], Subaru PFS [97], HETDEX [35]
Lensing of Galaxies	0.6	0.07	Baryons, NL, Photometric redshifts	CFHT-LS [23], COSMOS [50]	DES [84], Hyper SuprimeCam, LSST [92], Euclid [88], WFIRST[100]
Lyman α	0.2	0.1	Bias, Metals, QSO continuum	SDSS, BOSS, Keck	BigBOSS[81], TMT[99], GMT[89]
21 cm	∞	0.1 – 0.006	Foregrounds, Astrophysical modeling	GBT [11], LOFAR [91], PAPER [53], GMRT [86]	MWA [93], SKA [95], FFTT [49]
Galaxy Clusters	0.3	0.1	Mass Function, Mass Calibration	SDSS, SPT, ACT, XMM [101] Chandra [83]	DES, eRosita [87], LSST
Core-Collapse Supernovae	∞	$\theta_{13} > 0.001$*	Emergent ν spectra	SuperK [98], ICECube[90]	Noble Liquids, Gadzooks [7]

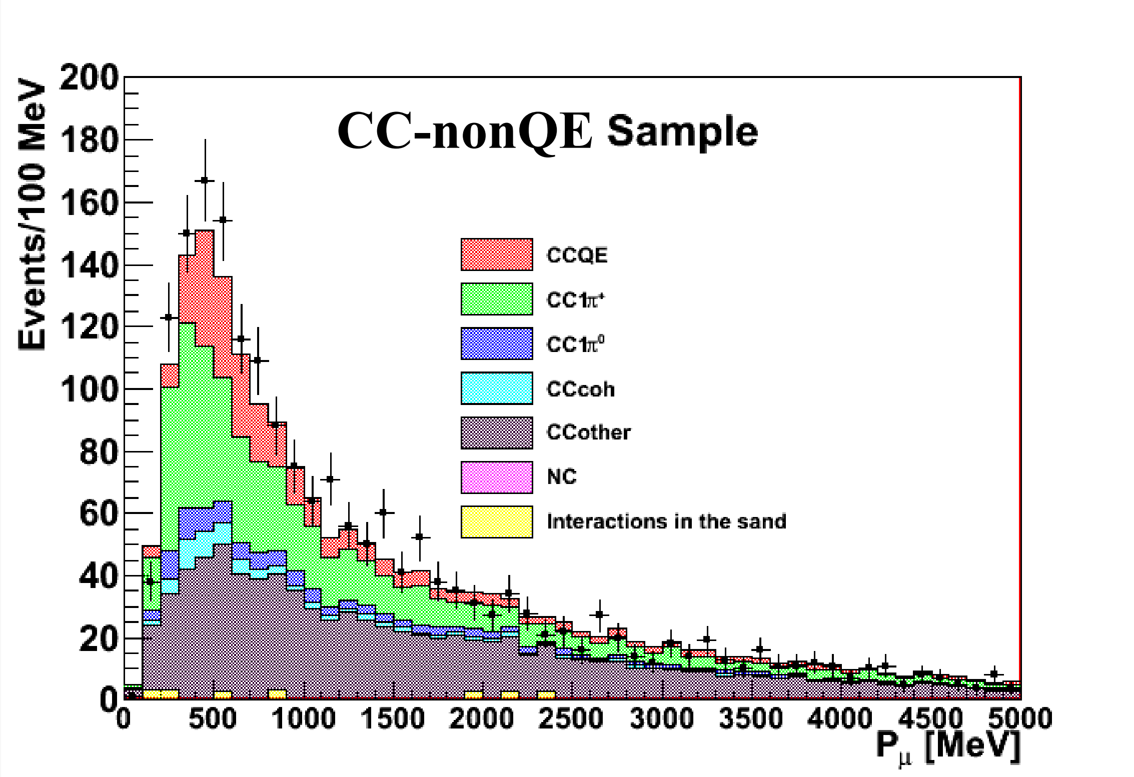
Normal hierarchy: $\Sigma m_\nu > 0.05$eV, Inverted hierarchy: $\Sigma m_\nu > 0.1$eV

Systematic uncertainties

- Cross section uncertainty dominates:
  - Precise study of cross section in the near detector is critical!

	$\sin^2 2\theta_{13}=0.1$	$\sin^2 2\theta_{13}=0.0$
Flux+Xsec in T2K fit	5.7%	8.7%
Xsec (from other exp.)	7.5%	5.9%
SK + FSI	3.9%	7.7%
Total	**10.3%**	**13.4%**

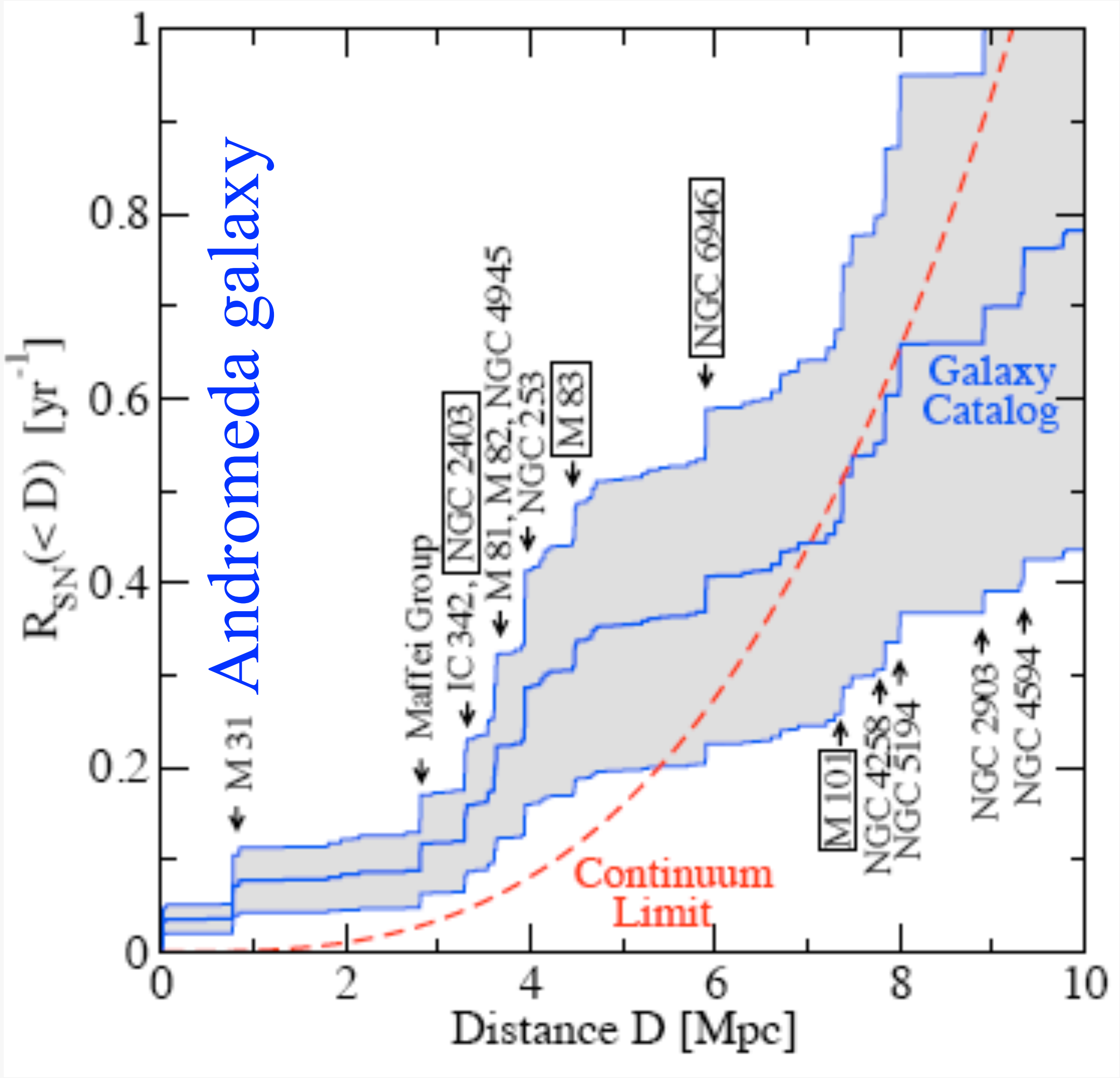


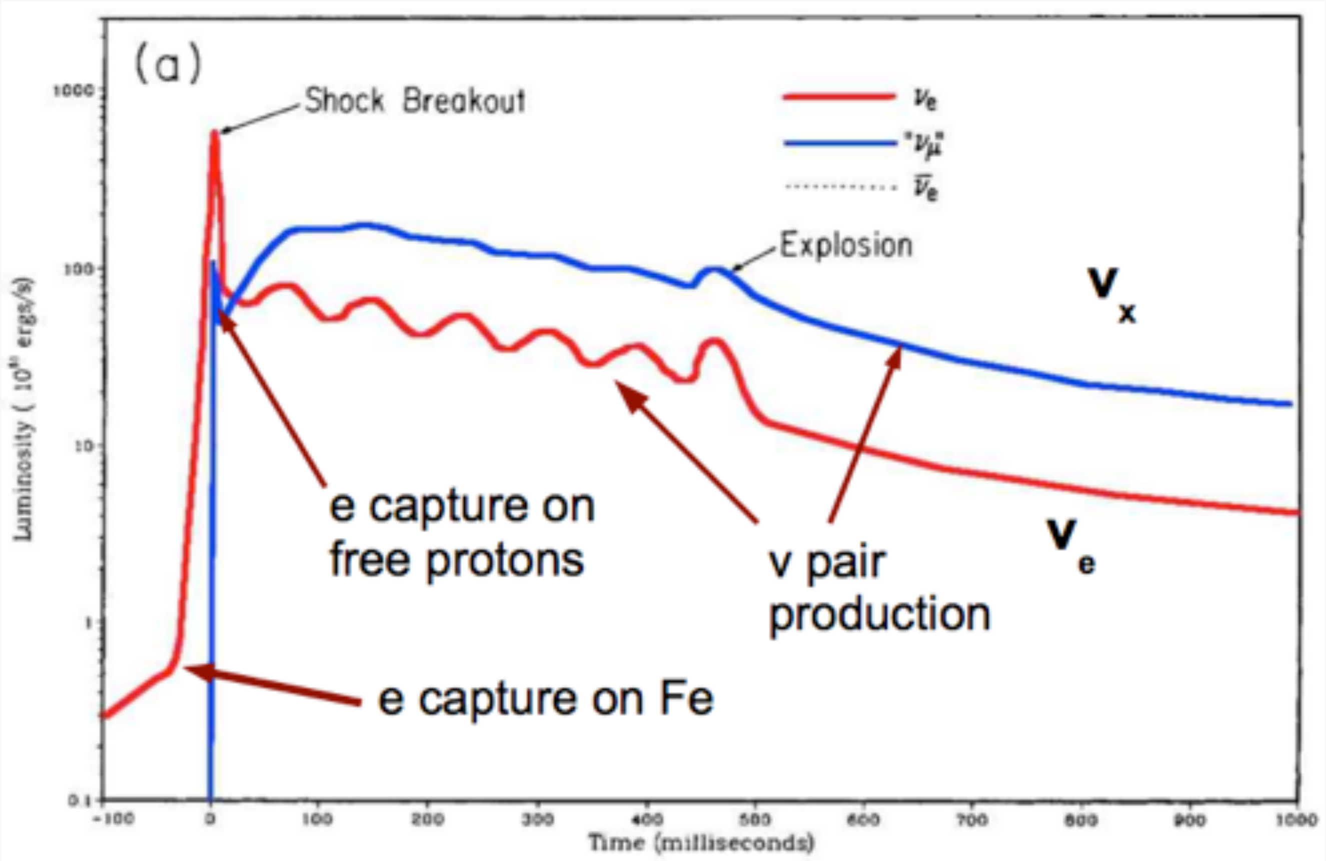


Other Physics by Hyper-K

- Supernova neutrinos
  - Sensitivity reaches beyond Andromeda Galaxy
  - Supernova Relic Neutrino detection
- Solar neutrinos
  - Day-Night asymmetry measurement
- Indirect WIMP search (solar, galactic)
  - Reaching interesting region in SD interaction
- Others
  - GRB-ν, solar flare ν, n-nbar oscil., monopole, Q-ball,...

Supernova neutrinos

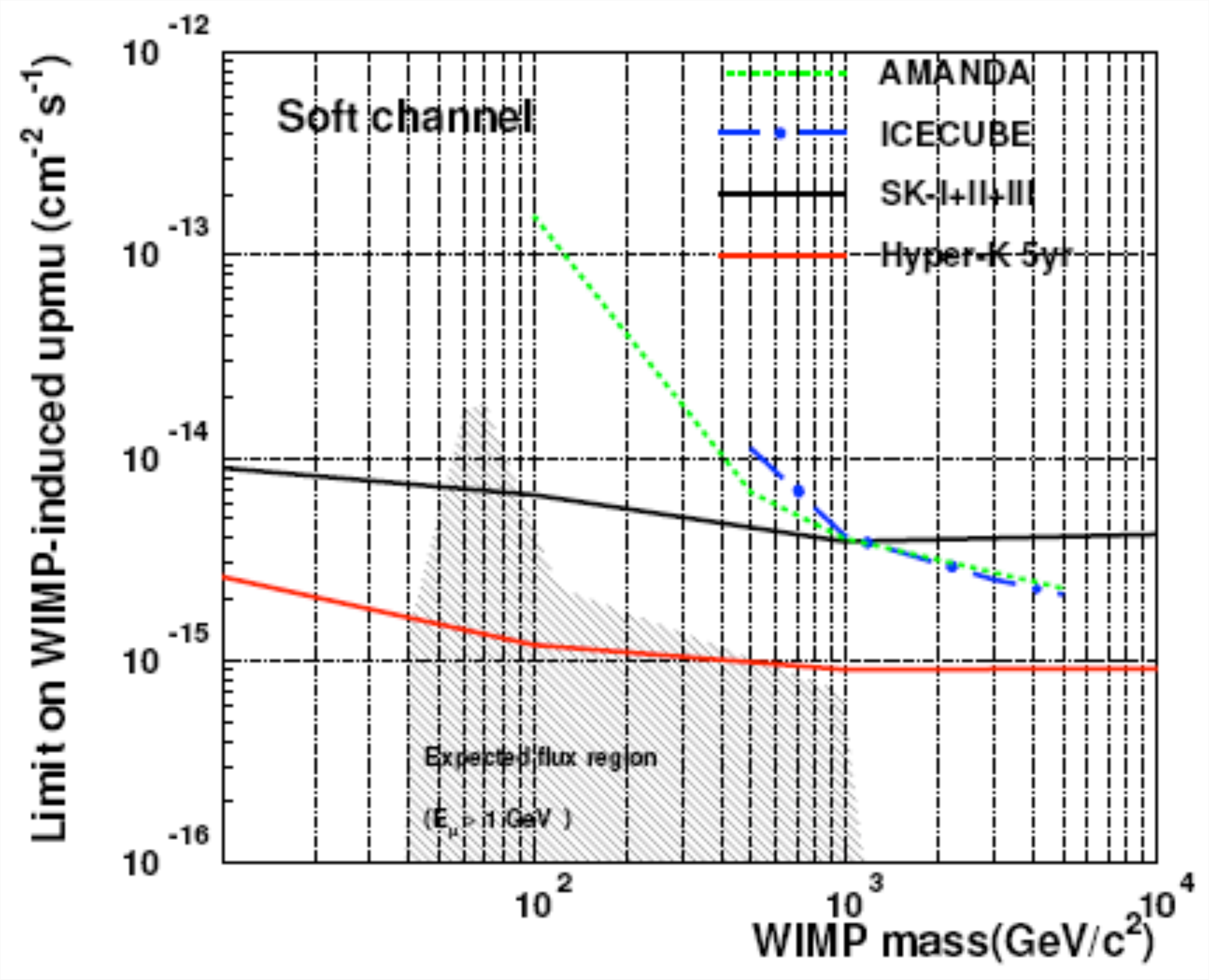


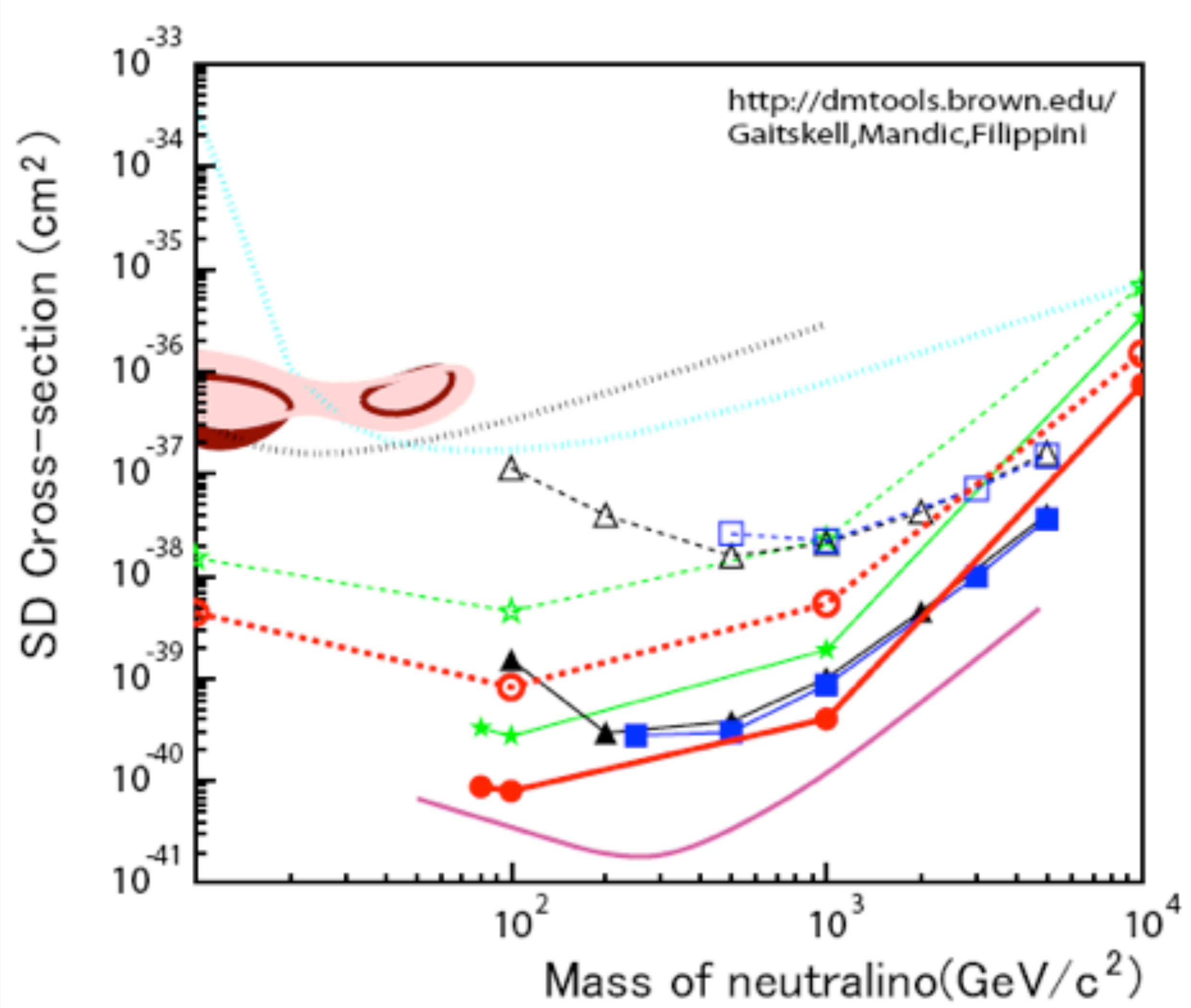


- Expect 30-50 ν events even from Andromeda galaxy
  - Every 10-20 years instead of 30-50 years from our galaxy
- Sensitivity reaches to detect supernova relic neutrinos

Indirect WIMP search

- Indirect WIMP search reaching predicted region for spin dependent interaction



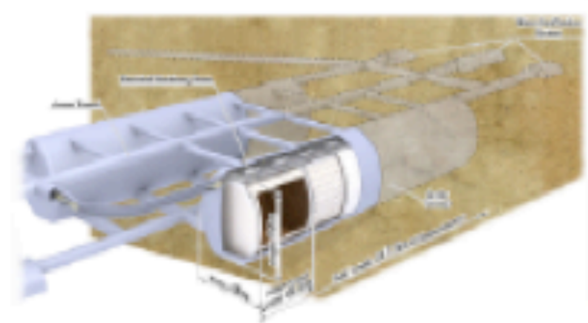


Open Meeting for the Hyper-Kamiokande Project

21-23 August 2012 *Kavli Institute for the Physics and Mathematics of the Universe (Kavli IPMU), The University of Tokyo*

Asia/Tokyo timezone

- **Overview**
- Important Dates
- Call for Abstracts
  - View my abstracts
  - Submit a new abstract
- Timetable
- Contribution List
- Registration
  - Registration Form
- Access
- Accommodation



Overview

We will hold an International Open Working Group Meeting for the Hyper-Kamiokande project. Hyper-K, which we are currently developing, is designed to be the next decade's flagship experiment for the study of neutrino oscillations, nucleon decays, and astrophysical neutrinos.

The goal of this meeting is to discuss the physics potentials of Hyper-K, the design of the detector, and necessary R&D items including:

- cavern excavation
- tank liner material and its design
- photo-sensors and their support structure
- DAQ electronics and computers
- calibration systems
- water purification systems
- software development, and so on.

Aug.21-23,2012 @ Kavli-IPMU:
http://indico.ipmu.jp/indico/conferenceDisplay.py?confId=7