Introduction to physics session and CPV studies

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Second open meeting for Hyper-Kamiokande project
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Kavli IPMU, Kashiwa

Physics potential session

Physics Potential (09:50-11:45)

time	title	presenter
09:50	CP study update	YOKOYAMA, Masashi
10:10	Break	
10:35	Considerations for a Near Detector for the Tokai-to-HK experiment	TANAKA, Hirohisa A.
10:55	Off-Axis Detectors as Direct Measurements of Neutrino Energy Reconstruction	MCFARLAND, Kevin HARTZ, Mark
11:15	Atmospheric Neutrino Sensitivity Studies	WENDELL, Roger
11:30	Muon charge identification with gadolinium-loaded water	MAUGER, Christopher

Physics Potential (13:25-15:50)

time	title	presenter
13:25	Improvement of event selection of proton decay searches	MINE, Shunichi
13:40	Improvement of proton decay analysis in p-->nu-bar+K^+	MIURA, Makoto
13:55	Spallation background	TAKEUCHI, Yasuo
14:15	Solar neutrinos and supernova burst neutrinos at Hyper-Kamiokande	KOSHIO, Yusuke
14:35	SRN search with HK	YANO, Takatomi
14:55	Break	
15:20	Neutrinographic imaging of the earth	TAKETA, Akimichi

Long baseline

Atmospheric

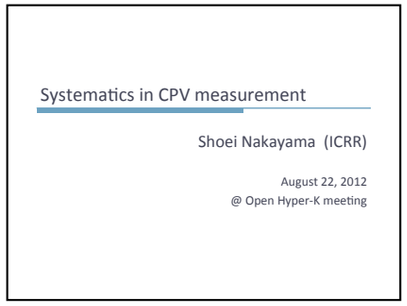
Proton decay

Low energy

Geophysics

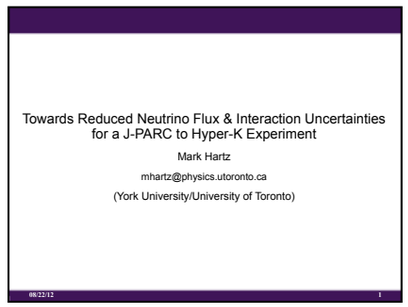
Homework from last meeting (1)

CPV measurement


Systematics in CPV measurement

Shoei Nakayama (ICRR)

August 22, 2012
@ Open Hyper-K meeting


Towards Reduced Neutrino Flux & Interaction Uncertainties for a J-PARC to Hyper-K Experiment

Mark Hartz

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(York University/University of Toronto)

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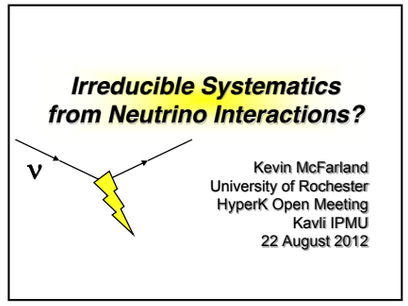


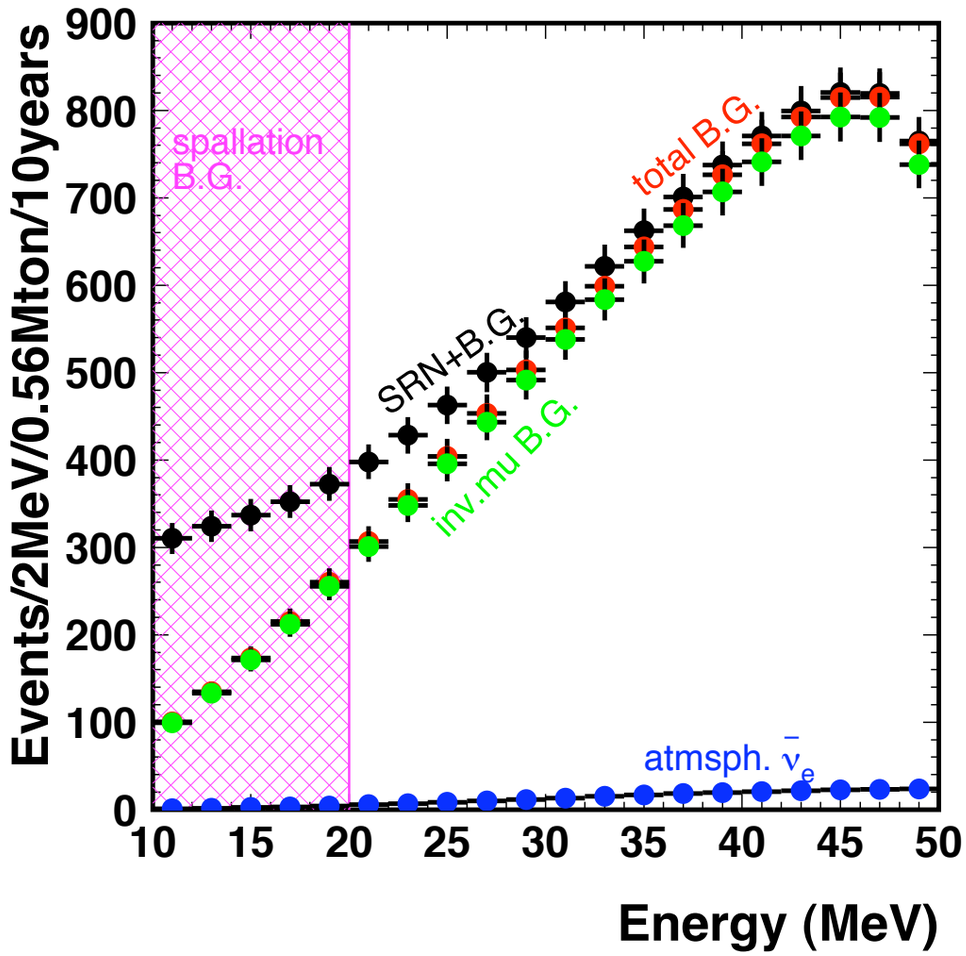
- Systematic uncertainties are important in CPV measurement
- Need to quantify and make plans
  - List possible systematics sources
  - Identify systematics with large effect
  - How and how much constrain uncertainties
  - Baseline configuration of near detector(s)

Yokoyama, Aug. 2012 HK meeting

Homework from last meeting (2)

‘Low energy’ physics

- Make clear what can be achieved with current baseline design (overburden / photocoverage)



Yokoyama, Aug. 2012 HK meeting

Looking inside the Earth with ν

F. Neutrino geophysics

In this section, the radiographic measurements of the Earth with Hyper-Kamiokande will be discussed.

1. Geophysical motivation

The Earth's internal structure and chemical composition have been estimated by analyzing seismic data to derive seismic velocities inside the Earth, in conjunction with many laboratory experiments and model calculations. Until recent years, these seismic waves had been the only probe that could penetrate the Earth. In order to constr
of models have been considered. PREM [69] and 1066A [122] are two major models, both of which describe the spherically symmetric structure of the Earth. PREM and 1066A are both parametrized models where the seismic velocities $V_p(x)$ a
relationship with the density $\rho(x)$ via the gravity g, bul
is an uncertainty regarding the absolute density distribu
to find an independent method to directly measure the d
what kind of method can be used for this purpose? Drilling and core sampling enable us to directly examine material inside the Earth. However, considering the fact that the world's deepest such

There is a section in LoI on *neutrinographic* measurement of the Earth.

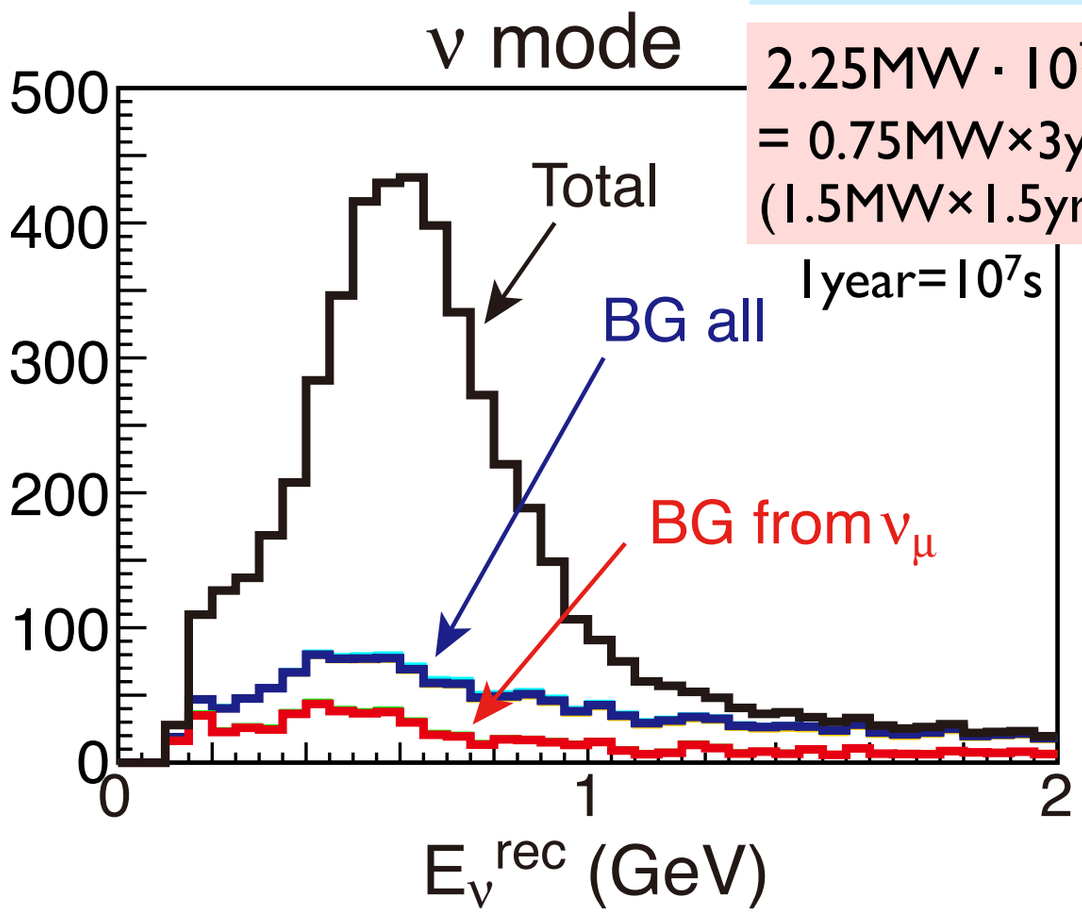
No talk in the last meeting..

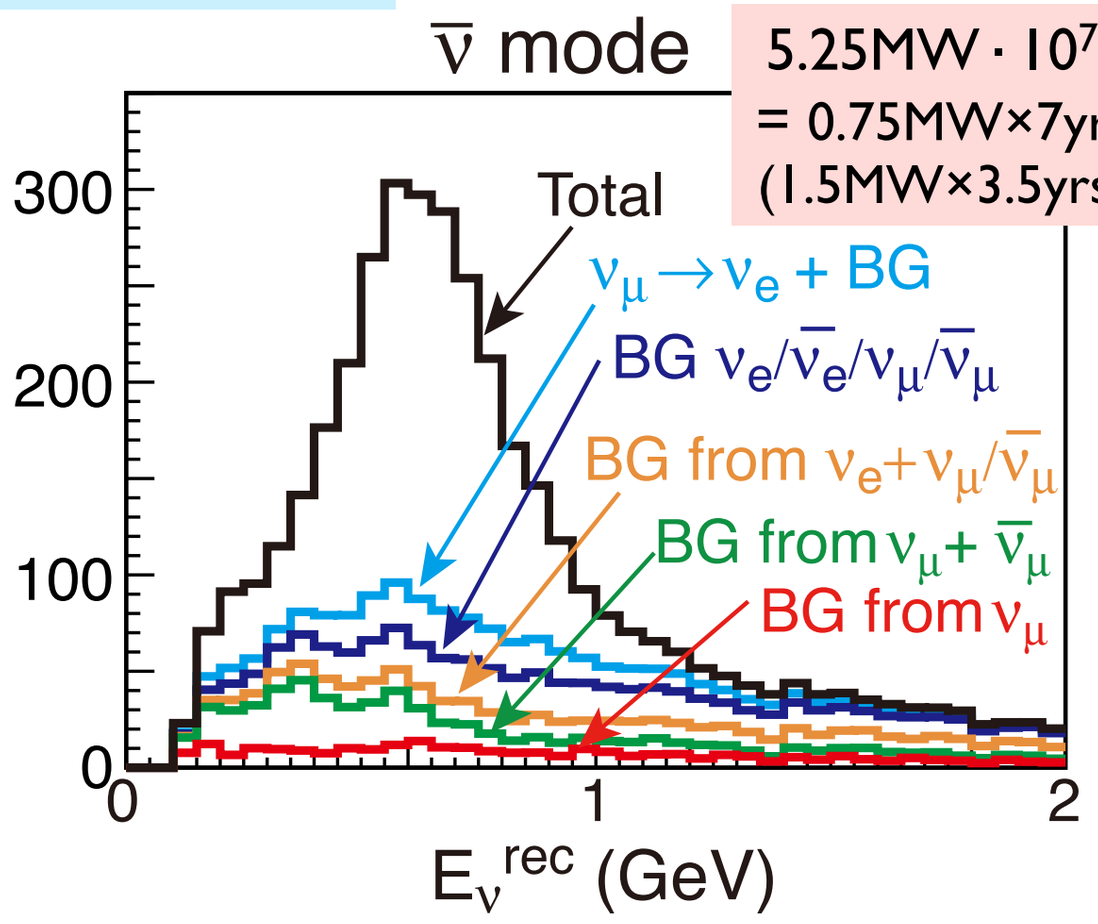
Taketa-san (Earthquake Research Institute, Univ. of Tokyo) will introduce the idea.

CPV sensitivity

ν_e candidates after selection

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





	Signal ($\nu_\mu \rightarrow \nu_e$ CC)	Wrong sign appearance	$\nu_\mu/\bar{\nu}_\mu$ CC	$\nu_e/\bar{\nu}_e$ contamination	NC
ν (2.25MW · 10^7s)	3,560	46	35	880	649
$\bar{\nu}$ (5.25MW · 10^7s)	1,959	380	23	878	678

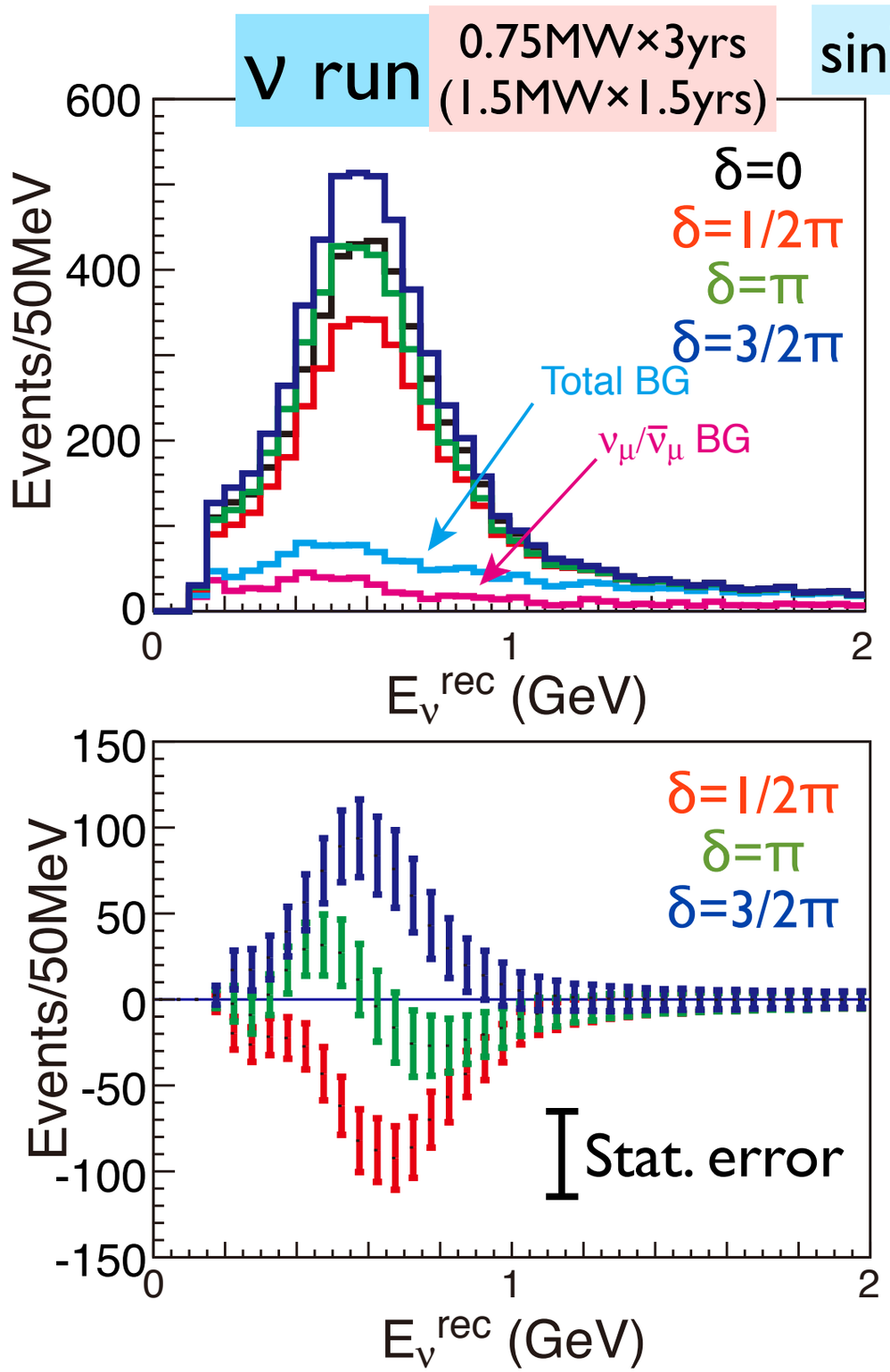
2000-3000 signal events expected for each of ν and $\bar{\nu}$

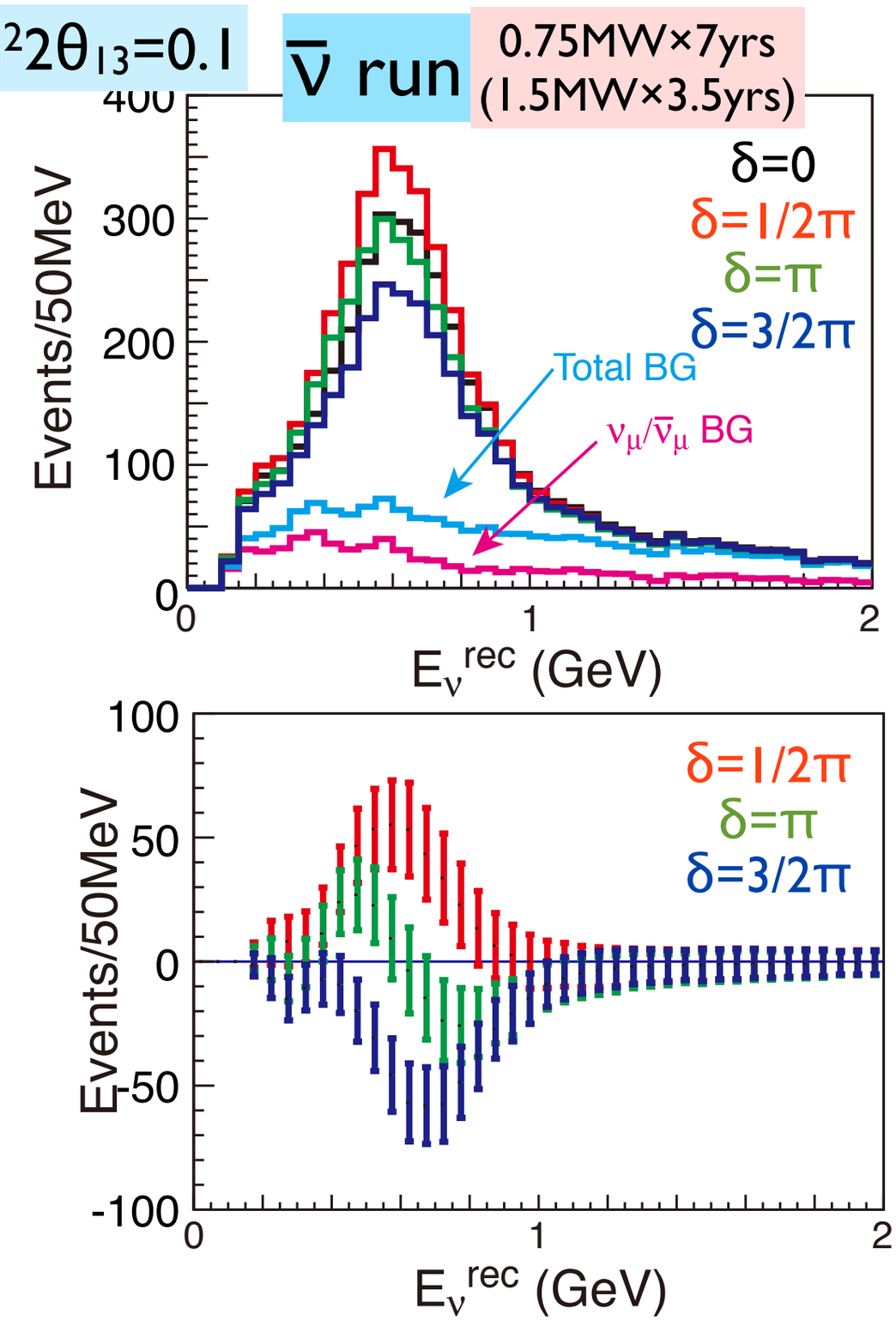
Effect of δ

1year=10^7sec

νe candidates

Difference from δ=0





Statistics for CPV meas.

7.5MWyr total, Erec<1.2GeV

ν	δ=0	π/6	π/3	π/2	π	3π/2
N(sig)	3458	3059	2719	2597	3372	4233
N/N(δ=0) ±stat	1.0 ±0.020	0.885 ±0.021	0.786 ±0.023	0.751 ±0.024	0.975 ±0.020	1.224 ±0.017

anti-ν	δ=0	π/6	π/3	π/2	π	3π/2
N(sig)	1900	2145	2335	2382	1830	1346
N/N(δ=0) ±stat	1.0 ±0.030	1.13 ±0.028	1.23 ±0.026	1.25 ±0.026	0.96 ±0.031	0.71 ±0.040

more than 10% variation for π/6<δ<5π/6, 7π/6<δ<11π/6 (~70%)

*stat. err. are for total events

S/N and systematics

7.5MWy	ν		anti-ν	
	Signal	BG	Signal	BG
N(δ=0)	3458	1145	1900	1118
Fraction	75.1%	24.9%	63.0%	37.0%
Syst. (*)	0.038	0.012	0.031	0.019

* Contribution to total error assuming 5% syst for each component.

NB: BG may be further reduced w/ new recon.

Larger θ_{13} → better S/N

Systematics on signal is more important

(signal uncertainty more reliable than BG)

T2K Experience

K. Sakashita@ICHEP2012

The predicted number of events and systematic uncertainties

The predicted # of events w/ 3.01 x 10^{20} p.o.t.

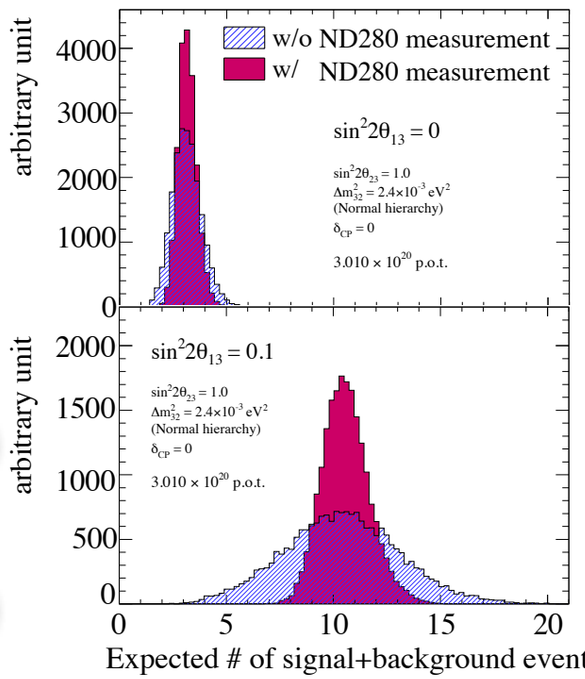
Event category	$\sin^2 2\theta_{13} = 0.0$	$\sin^2 2\theta_{13} = 0.1$
Total	3.22±0.43	10.71±1.10
ν_e signal	0.18	7.79
ν_e background	1.67	1.56
ν_μ background (mainly NCπ^0)	1.21	1.21
$\overline{\nu}_\mu + \overline{\nu}_e$ background	0.16	0.16

Systematic uncertainties

Error source	$\sin^2 2\theta_{13} = 0$	$\sin^2 2\theta_{13} = 0.1$
Beam flux+ν int. in T2K fit	8.7 %	5.7 %
ν int. (from other exp.)	5.9 %	7.5 %
Final state interaction	3.1 %	2.4 %
Far detector	7.1 %	3.1 %
Total	13.4 %	10.3 %
(T2K 2011 results:	~23%	~18%)

big improvement from the T2K 2011 results

the predicted # of event distribution



Uncertainties are reduced using ND280 measurement

10

T2K flux extrapolation and the detector uncertainties almost reach the Hyper-K requirement.

- **Total Sys. error for $\sin^2 2\theta_{13}$=0.1: ~10%**
  - Beam flux + ν int. constraint in T2K: 5.7%
  - External ν cross section uncertainty from other experiment: 7.5%
  - Super-K detector uncertainty: 3.1%

Upcoming Cross section measurements in T2K-ND280 and the cross section model improvements are critical.

Conclusions

T2K has taken significant steps to achieving the levels of systematic uncertainty that will be necessary for a CP violation measurement

Flux uncertainties should be at 5% level or better with NA61 replica target data

- Need careful study of neutrinos in anti-neutrino running
- Also energy dependent off-axis angle type errors

Near detector samples already have large statistics and allow for reduction of total errors to the 10% level

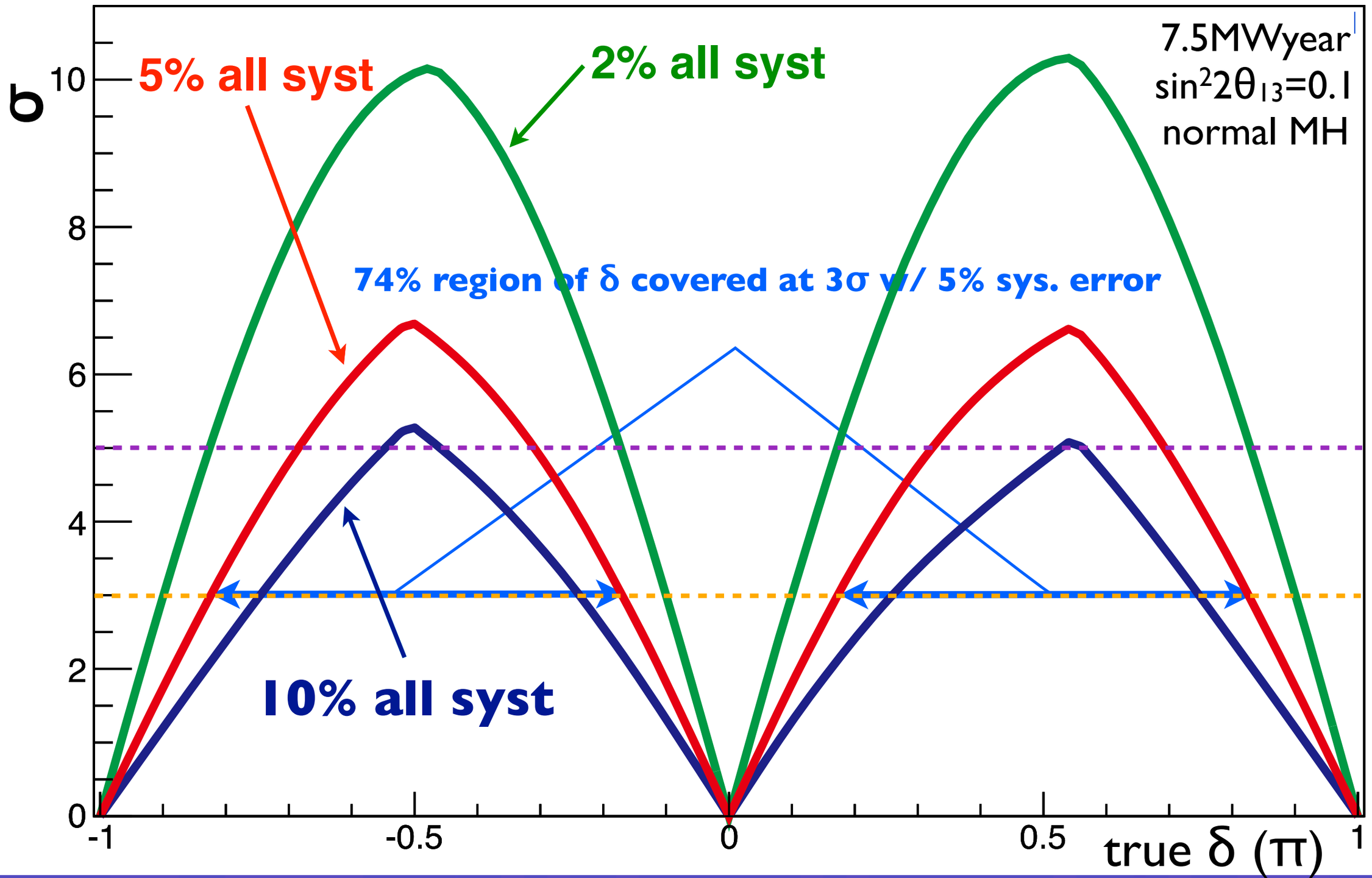
- Need to understand energy dependent constraints
- Measurements on O are important
- Need to improve angular coverage
- Ongoing work for ν_e and NCπ^0 measurements important for background

See next talk for details on cross section modeling uncertainties

With hard work, systematic uncertainties for Hyper-K appear to be within reach

We will surely work hard!

CPV Discovery Sensitivity (w/ Mass Hierarchy known)



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

0.56Mt, 0.75MW, 3.0/7.0 yrs NH

1σ region

Stat only

2% syst

5% syst

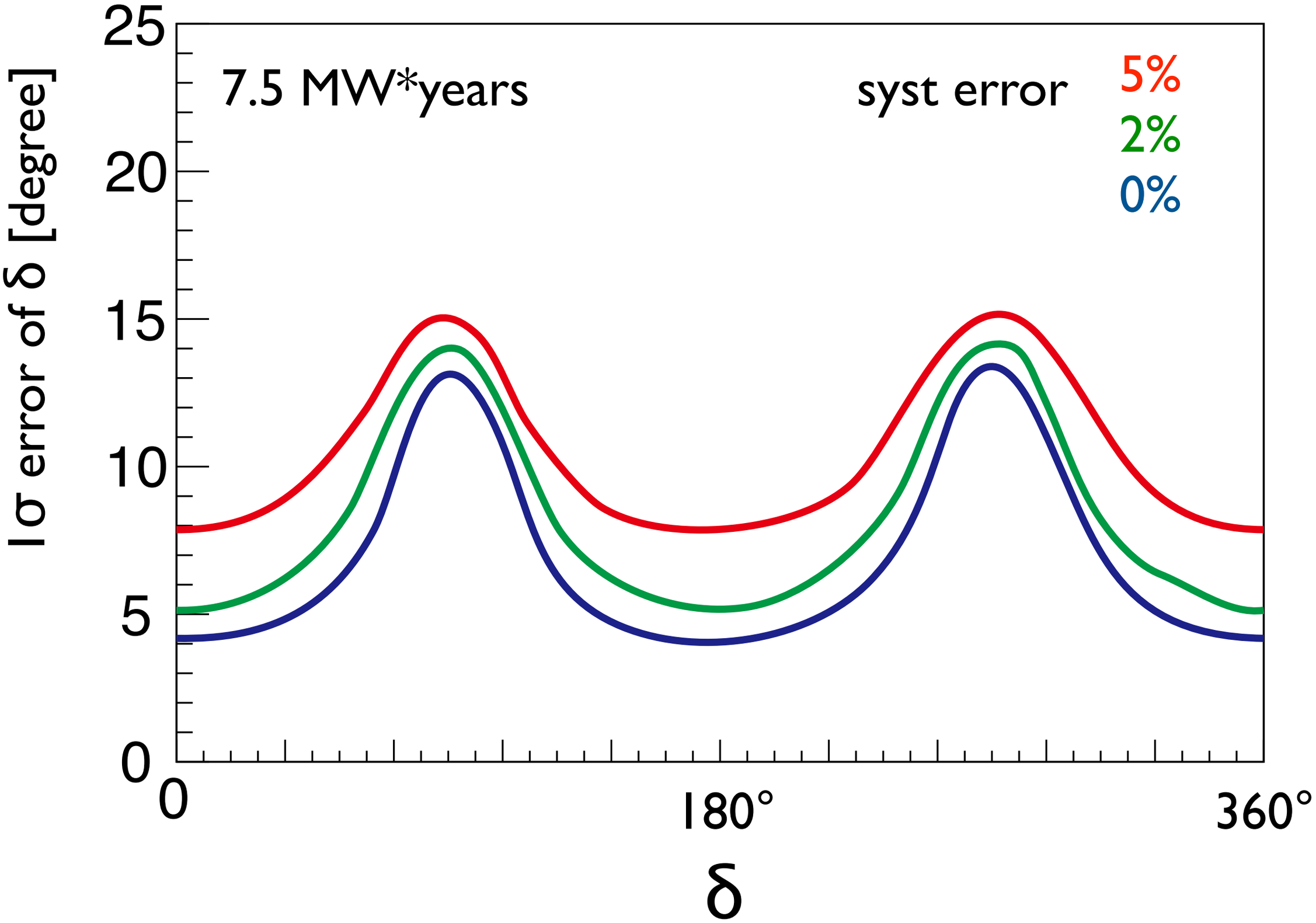
δ [π]

1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1

0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18

$\sin^2 2\theta_{13}$

1σ error of δ

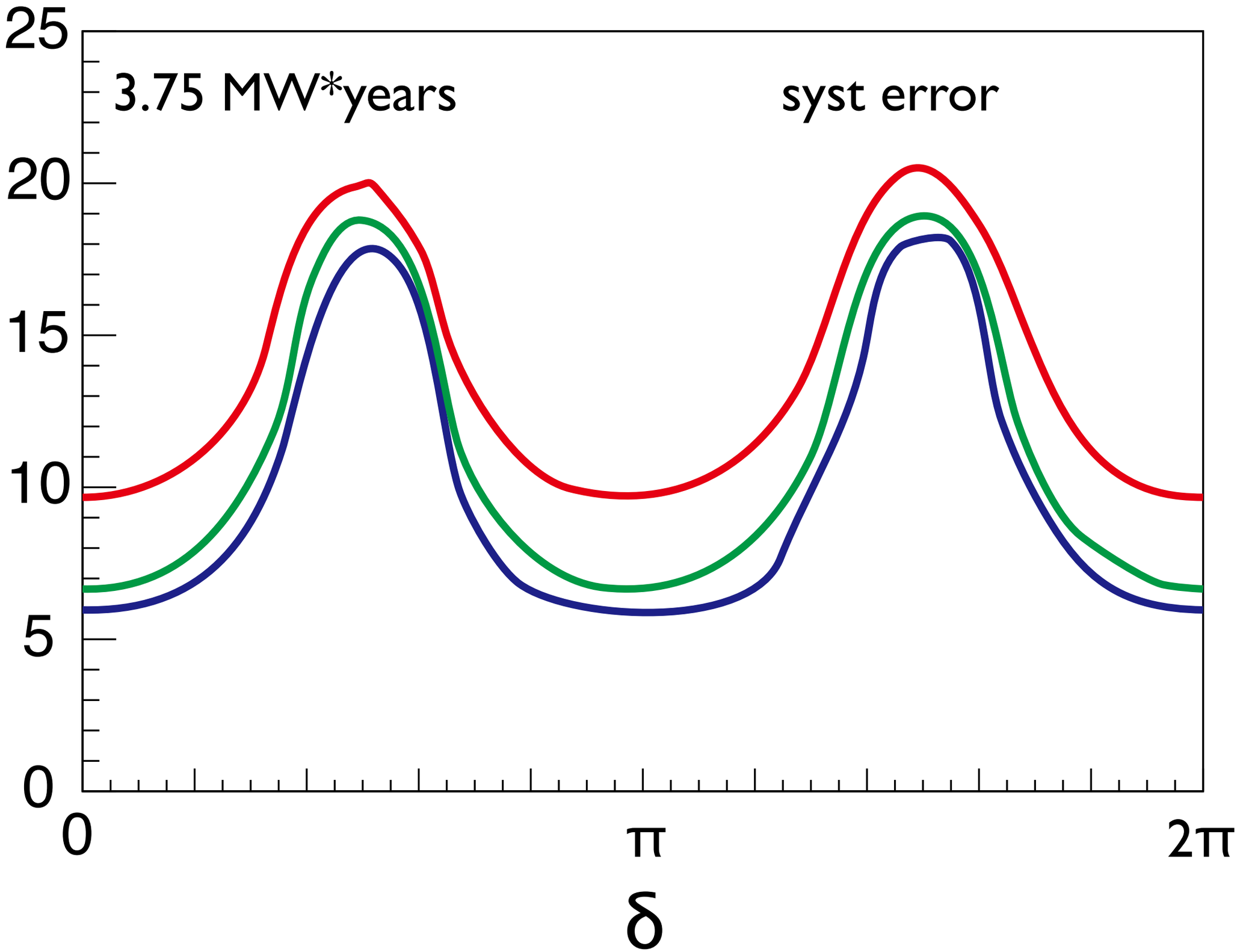

7.5 MW*years
syst error
5%
2%
0%
1σ error of δ [degree]
25
20
15
10
5
0
0
180°
360°
δ

ND configuration

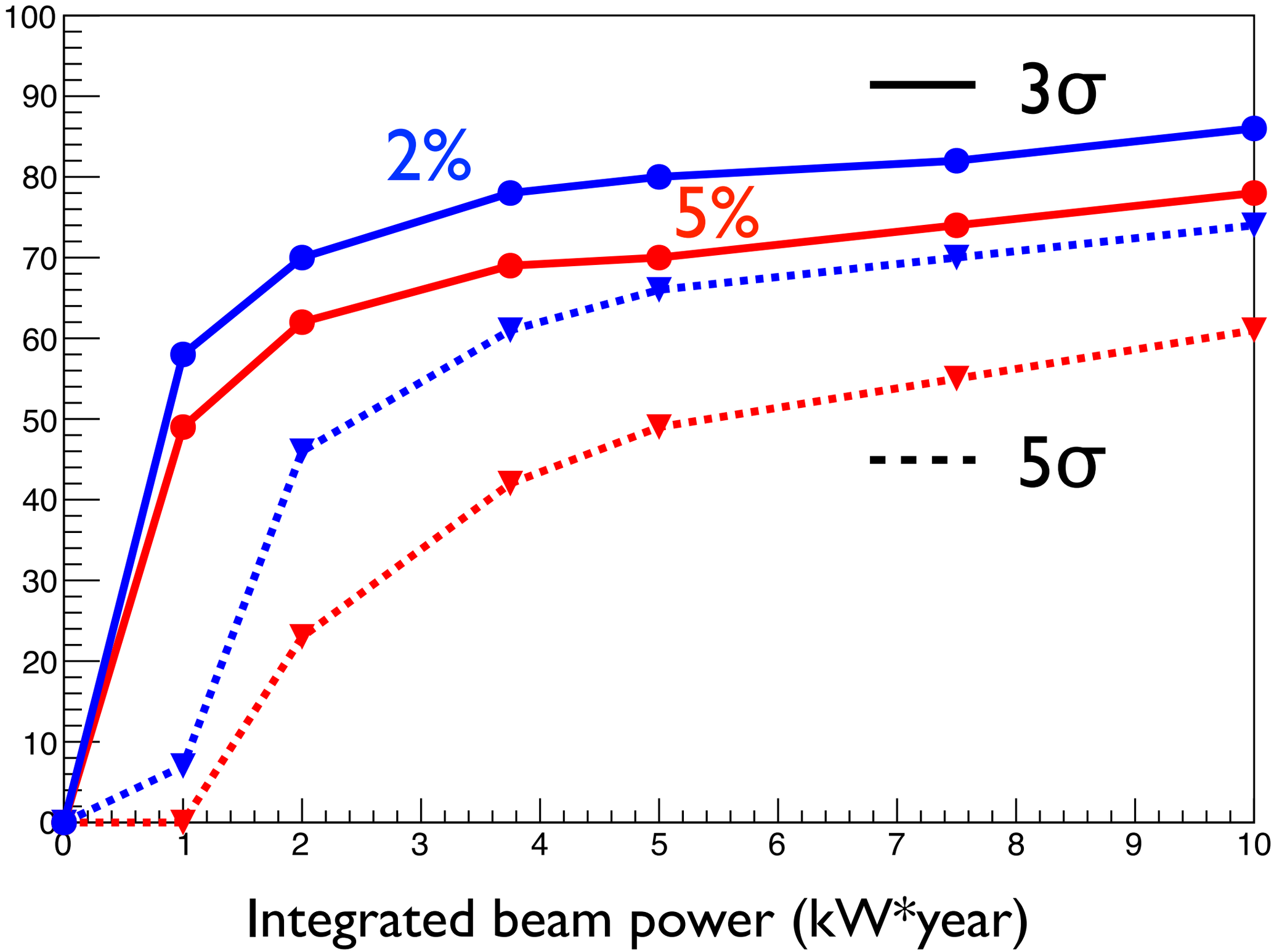
- Effect of systematics in CPV measurement
  - Syst. of signal is most important for large θ_{13}
  - Good CPV sensitivity with 5% syst. (LoI)
  - ~2% systematics to exploit full potential
- T2K-ND280 (with possible upgrade/extension): baseline
- Feasibility of 2% (≲stat) syst. error should be studied
  - Can e.g. 2km detector, Water Cherenkov ND, and/or LAr ND improve systematics down to ~2%?
  - Additional (external) measurement (e.g. νe xsec)?

Backup

1σ error of δ



CP sensitivity, 2%/5% and 3σ/5σ


100
90
80
70
60
50
40
30
20
10
0
0
1
2
3
4
5
6
7
8
9
10
2%
5%
3σ
5σ
Integrated beam power (kW*year)