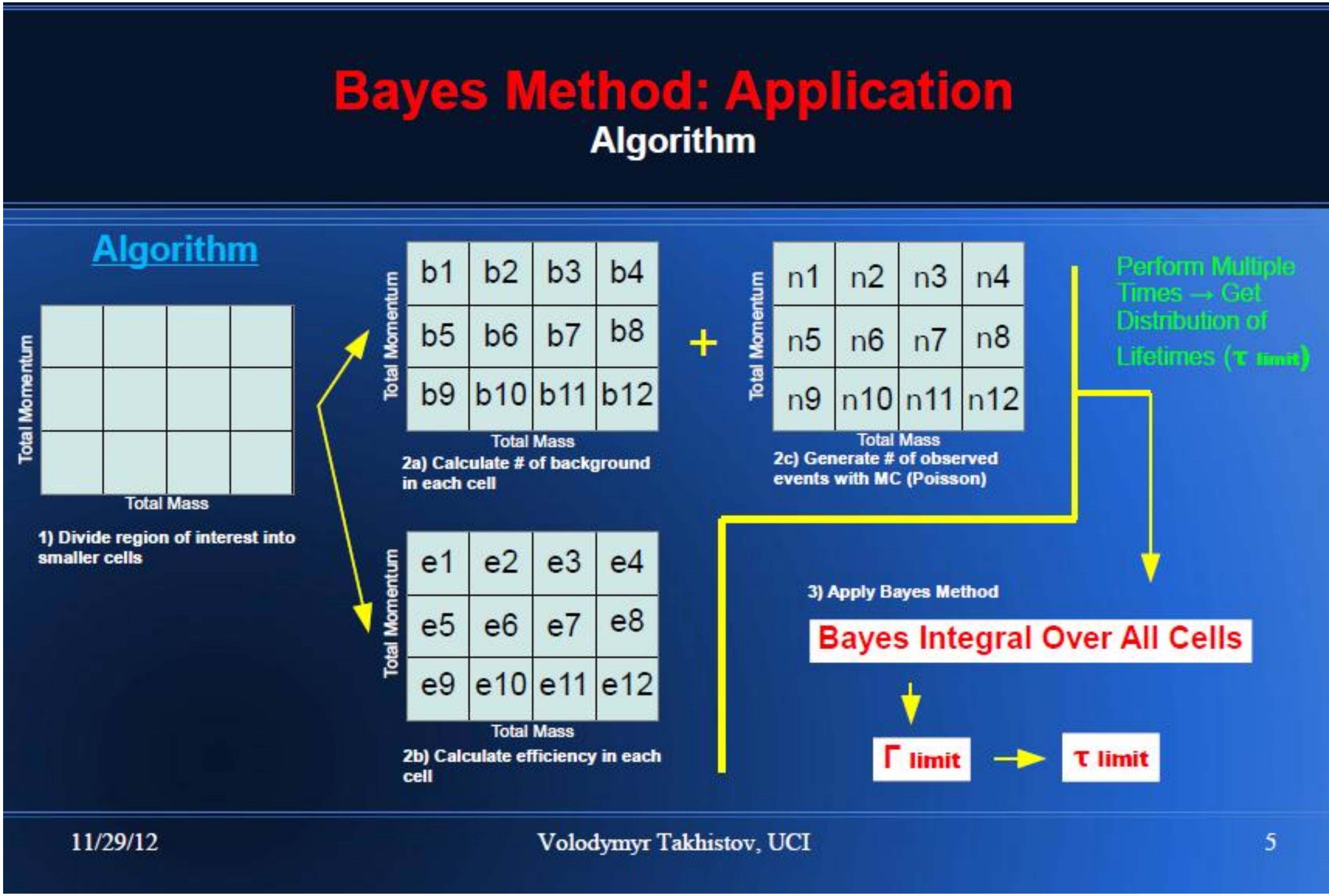
Improvement of event selection for proton decay searches

V.Takhistov, M.Smy, S.Mine (UCI)

Introduction

- Several decay modes ($p \rightarrow e\nu\nu$, $p \rightarrow \mu\nu\nu$, etc.) predicted by SO(10) GUT have not been searched yet in SK. However, unavoidable background events are expected for these modes.
- V.Takhistov is studying improvement of event selection not based on regular signal box but distribution information in SK
  - this study may be also useful in HK because of more expected background rate in signal box


Bayes Method: Application
Algorithm
Algorithm
Total Momentum
Total Mass
1) Divide region of interest into smaller cells
b1 b2 b3 b4
b5 b6 b7 b8
b9 b10 b11 b12
Total Momentum
Total Mass
2a) Calculate # of background in each cell
e1 e2 e3 e4
e5 e6 e7 e8
e9 e10 e11 e12
Total Momentum
Total Mass
2b) Calculate efficiency in each cell
+
n1 n2 n3 n4
n5 n6 n7 n8
n9 n10 n11 n12
Total Momentum
Total Mass
2c) Generate # of observed events with MC (Poisson)
Perform Multiple Times → Get Distribution of Lifetimes (τ limit)
3) Apply Bayes Method
Bayes Integral Over All Cells
Γ limit
τ limit
11/29/12
Volodymyr Takhistov, UCI
5

Bayes Method: Application

Overview

- Bayes method is commonly used to combine results of several experiments
- By analogy, break region of interest into multiple cells and combine in similar fashion
- Following SK p→μ+K0 paper (Regis et al. 2012), assume proton decay follows Poisson probability :

(1)
$$P(\Gamma|n_i) = \iiint \frac{e^{-(\Gamma\lambda_i\epsilon_i+b_i)}(\Gamma\lambda_i\epsilon_i + b_i)^{n_i}}{n_i!} \times P(\Gamma)P(\lambda_i)P(\varepsilon_i)P(b_i)d\lambda_i d\varepsilon_i db_i$$

n_i – # of observed (candidate) events in i's experiment
Γ – total decay rate
λ_i – detector exposure in i's experiment
ε_i – detection efficiency in i's experiment
b_i – # of expected background events in i's experiment

systematic errors are taken into account through prior probabilities

- Lower limit of nucleon decay rate, using 90% (CL) confidence level :

(2)
$$\mathrm{CL} = \frac{\int_{\Gamma=0}^{\Gamma_{\mathrm{limit}}} \prod_{i=1}^{N} P(\Gamma|n_i)d\Gamma}{\int_{\Gamma=0}^{\infty} \prod_{i=1}^{N} P(\Gamma|n_i)d\Gamma}$$

Γ – total decay rate
n_i – # of observed (candidate) events in i's experiment
Γ_{limit} – lower limit of nucleon decay rate
CL – confidence level
N – number of experiments

Lower lifetime limit :

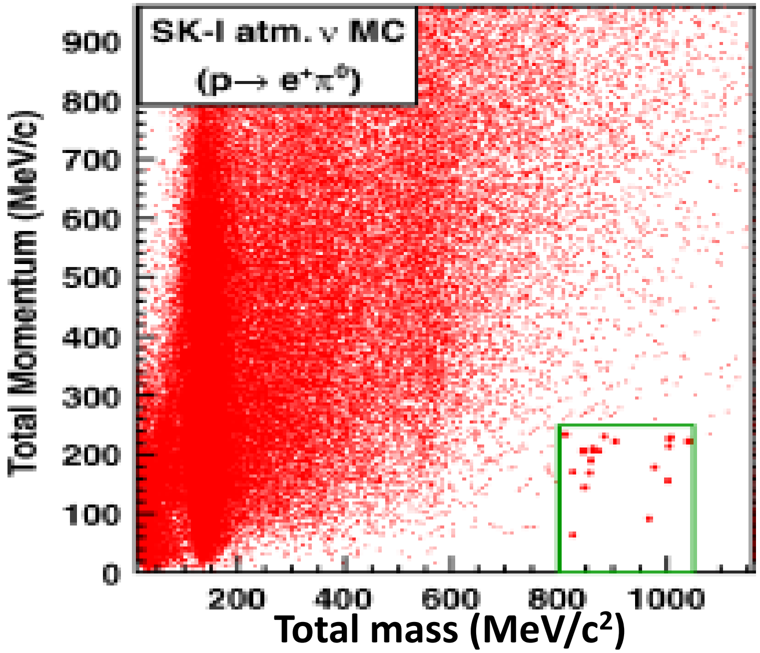
(3)
$$\tau/\mathrm{B}_{p\to\mu^+K^0} = \frac{1}{\Gamma_{\mathrm{limit}}}$$

11/29/12 Volodymyr Takhistov, UCI 6

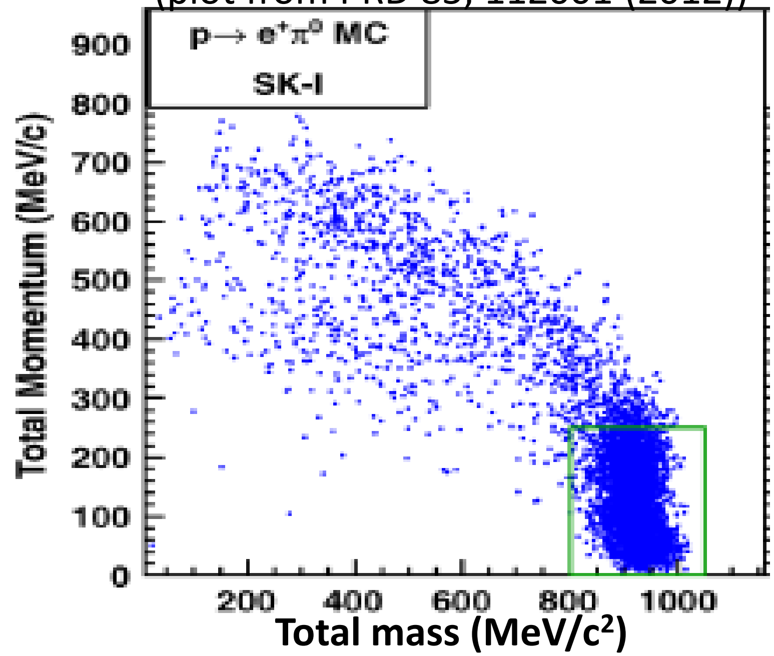
Just for demonstration

(SK-I p→eπ^0 and 500years atm.-ν MC)

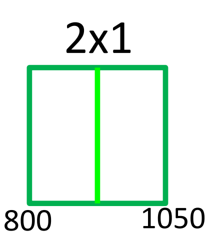
(plot from PRD 85, 112001 (2012))



(plot from PRD 85, 112001 (2012))



Lower life time limit (w/ syst. errors):



Cells in signal box	Volodymyr	official tool (reference)
1x1	**4.75x10^{33}yrs**	4.75x10^{33}yrs
2x1	**4.83x10^{33}yrs**	4.97x10^{33}yrs

- correlation among cells not taken into account
- checking difference for 2x1
- V's tool is much faster

Summary

- New event selection and limit calculation tool which would be useful both in SK/HK are being developed

Experimental study of atm.-ν background for p→eπ^0 searches in water Cherenkov detectors

Phys. Rev. D 77, 032003 (2008)

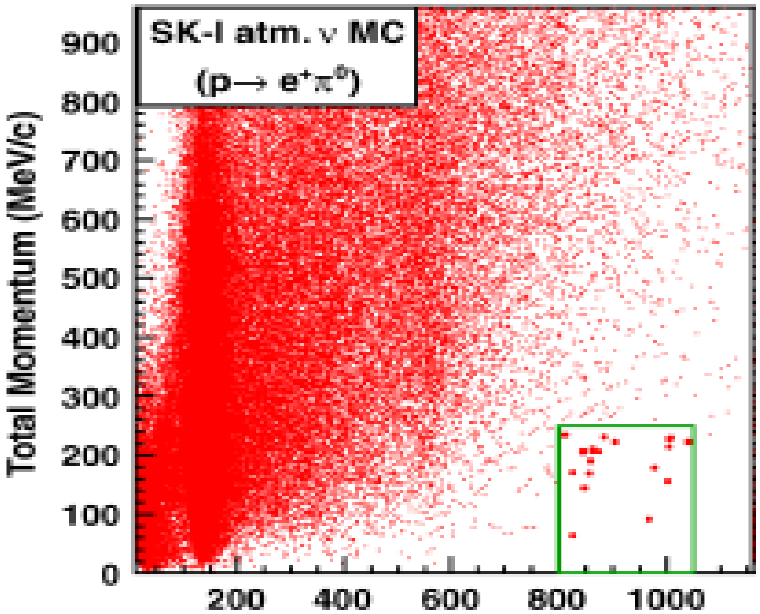
(K2K collaboration)

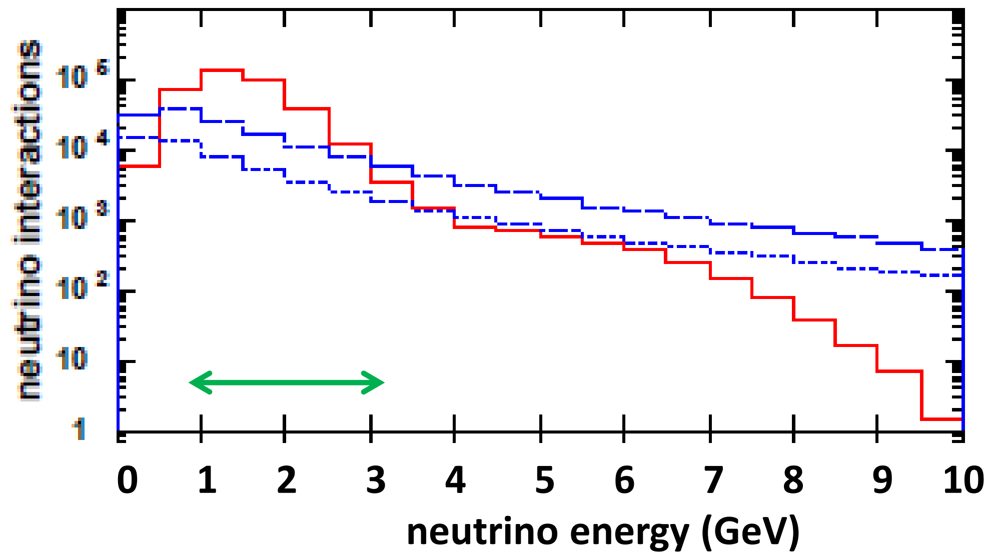
Total ν_μ int. in KT (50t, 7.4x10^{19}pot)

Total ν int. from atm.-ν in SK for 1Mt·yr

(dotted: $\nu_e+\overline{\nu_e}$, dashed: $\nu_{all}+\overline{\nu_{all}}$)

(plot from PRD 85, 112001 (2012))





Typical atm.-ν BG:

$\nu_e n \rightarrow e p \pi^0$ (CC)

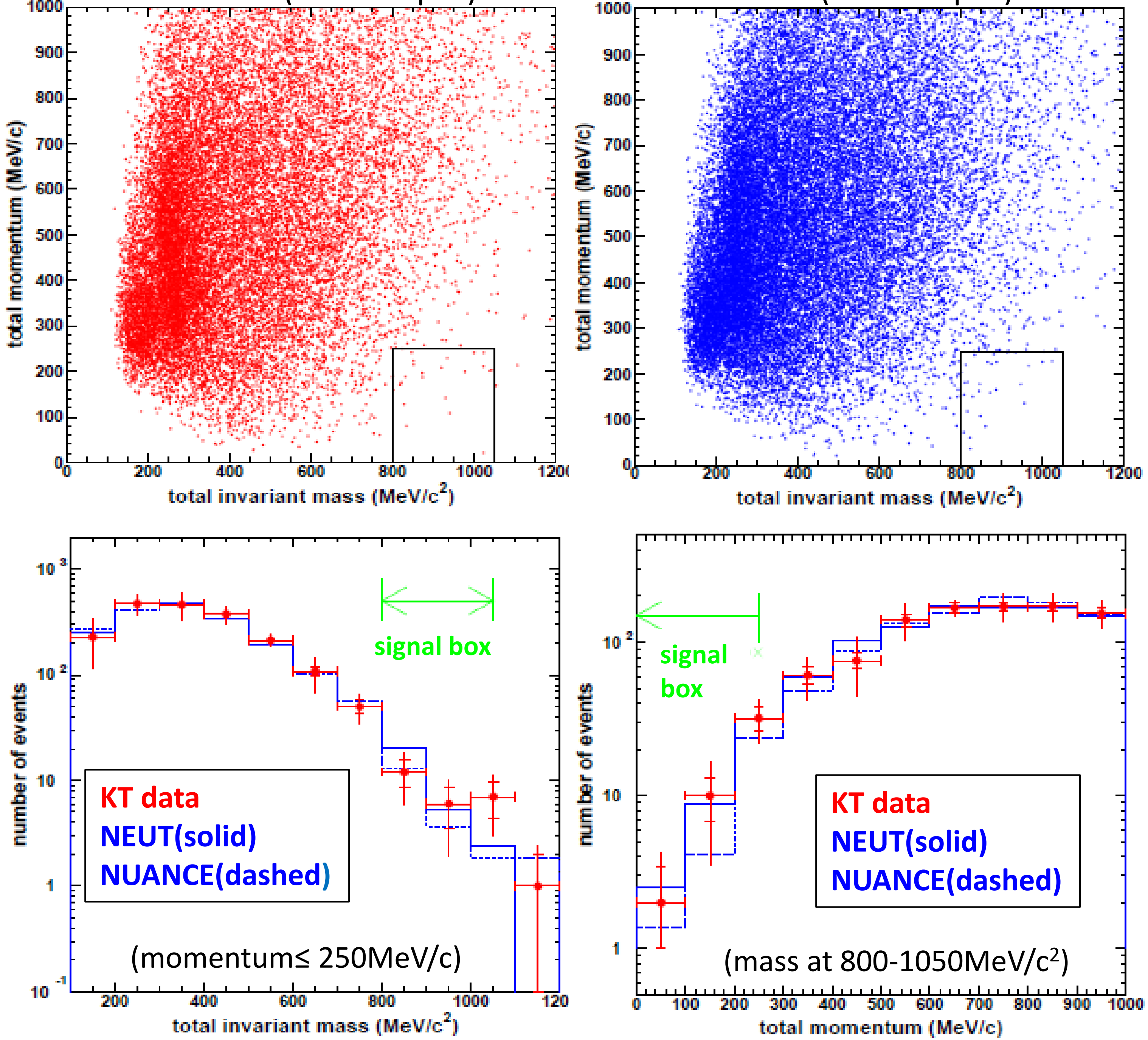
$\nu p \rightarrow \nu p \pi^0 \pi^0$ (NC)

etc. @~1-3GeV

Dynamics of π production and re-scattering process in O are similar between ν_e and ν_μ

Therefore, rare CC ν_e interaction topologies which may mimic proton decay can be checked using KT $\nu_\mu N \rightarrow \mu \pi^0 X$ events

KT data (7.4×10^{19}pot) NEUT (1.1×10^{20}pot)

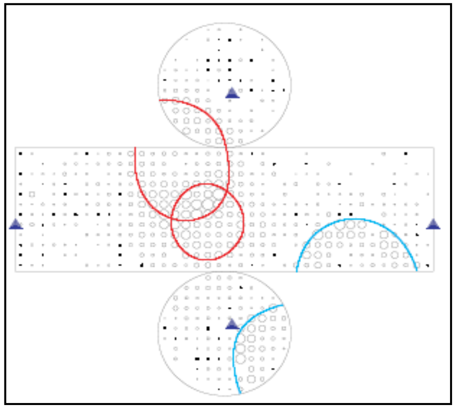


Determination of background rate to $p \rightarrow e\pi^0$ search

$$N = n_{obs}^{CC} \cdot R_{\phi}^{CC} \cdot R_{\varepsilon}^{CC} + n_{obs}^{NC} \cdot R_{\phi}^{NC} \cdot R_{\varepsilon}^{NC}$$

n_{obs}: number of observed events in KT signal box (24 for CC, 0 for NC)
R_{ϕ}: SK/KT (ν f lux, total cross section, target volume, time) estimated with MC
R_{ε}: SK/KT(detection efficiency) estimated with MC

data candidate



$$N\,(Mtyr^{-1}) = \{1.63 \pm 0.33(stat.)^{+0.43}_{-0.51}(syst.)\}(CC) + \{0.00 + 0.26(stat.) + 0.13(syst.)\}(NC) = 1.63^{+0.42}_{-0.33}(stat.)^{+0.45}_{-0.51}(syst.).$$

consistent with observed lack of candidates in SK (~0.2Mtyr)

Error source	error on n^{CC} (%)
KT vertex reconstruction	3
KT absolute energy scale	3
KT detector asymmetry of energy scale	3
KT FC event selection	1
KT ring counting	9
KT ring direction	3
KT PID	9
KT NC fraction in "$p \rightarrow \mu\pi^0$" events	+0/-4
Sub total	+14/-15

Error source	error on $R_{\phi}^{CC(NC)}$ (%)
K2K flux shape	3(6)
K2K beam ν_e contamination	<1(5)
KT MC normalization	4(4)
KT MC statistics	5(47)
atmospheric ν flux [24, 25]	10(10)
total ν cross section ratio	15(15)
lepton universality	<1(0)
atmospheric anti-ν rate	+0/-16(6)
Sub total	+25/-29(54)

Error source	error on $R_{\varepsilon}^{CC(NC)}$ (%)
Efficiency difference between SK and the KT	11(7)

Summary

- Both NEUT and NUANCE should reliably model atm.-ν background to $p \rightarrow e\pi^0$ search in HK
- About two background events per 1Mega-ton·year would be expected in $p \rightarrow e\pi^0$ search in HK. Further reduction of background events will be crucial.
  - Phys. Rev. D 77, 032003 (2008)