Cosmic background study for atm nu. and proton decay

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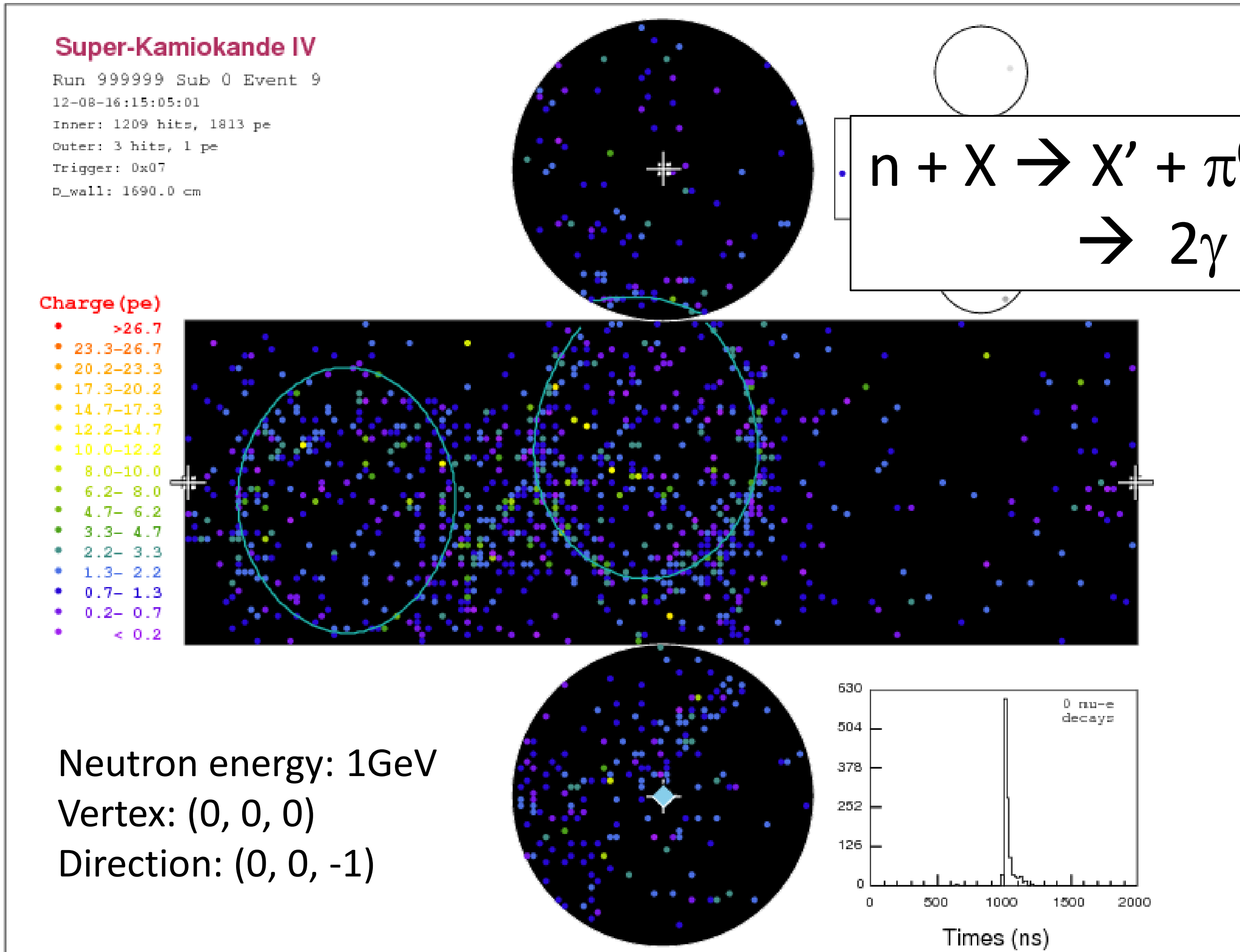
Introduction

- According to shallower site in underground at Hyper-K site, external backgrounds due to increased cosmic-ray muons should be considered
  - direct cosmic muons
  - neutral particles produced by cosmic muons
- In this talk, direct muons are not discussed since they are easily rejected by outer detector (OD)
- Also radioactive products by spallation are not problem in high energy analysis (analysis threshold: >30 MeV)
- Neutral particle like neutron will be discussed
  - can enter into detector w/o detection in OD
  - produce π^0 by hadronic interaction, and could be BG for electron-like events
  - these background does not affect beam neutrino physics

Neutron BG event (simulation)



$n + X \rightarrow X' + \pi^0$

$\rightarrow 2\gamma$

Neutron energy: 1GeV
Vertex: (0, 0, 0)
Direction: (0, 0, -1)

Super-K and Hyper-K site

	Super-K site	Hyper-K site
Depth (m.w.e.)	2,700	1,750
Muon rate ($10^{-6}/cm^2/sec$)	0.13 ~ 0.14	1.0 ~ 2.3
Effective depth (m.w.e.)	2,050	~1,170
$<E_\mu>$ (GeV)	219	~146
Φn ($10^{-9}/cm^2/sec$)	12.3	~101
(E>100MeV)	0.81	~6.7
$<E_n>$ (MeV)	76	~53

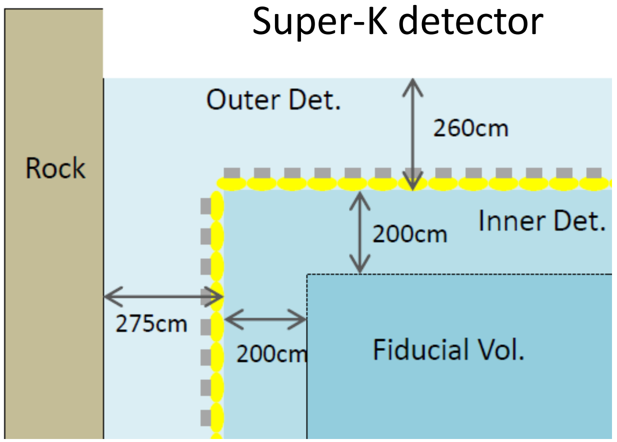
Calculation based on D.-M. Mei and A. HIME PRD 73 053004 (2006)

By rough estimation, Φ_n(E>100 MeV)·S = ~$4x10^4$ / year expected to enter Super-K detector

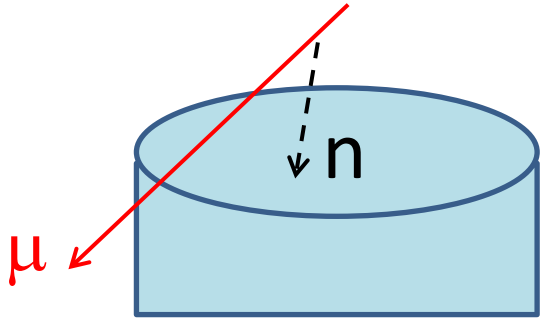
Neutron flux will increase about factor of 8 at Hyper-K site

Shielding against neutron

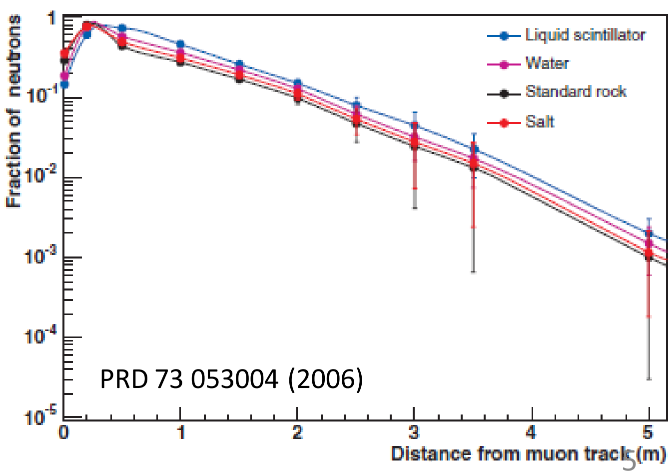
1. Self-shielding by water
   – 4.6~4.7 meter shield around fiducial volume can attenuate neutron significantly



2. Coincidence with primary cosmic muons
   – neutrons are spatially correlated with muon track
   – Using large detector, neutron events can be rejected by taking coincidence with muons



Lateral distribution from muon track



Neutron simulation

- Neutron BG is estimated by simulation using calculated flux, spectrum described in PRD 73 053004 (2006)
- In order to estimate rejection by muon coincidence, toy simulation of muon and neutron is carried out with Super-K detector geometry :
  - determine muon track from 20 meter above detector and inside R<200 meter area with calculated muon direction at SK site
  - according to neutron lateral distribution, determine neutron entering point at SK (also determine energy, direction relative to muon track)
    - If detector is far away from neutron vertex, this event is rejected
  - If muon track pass through SK detector, this event is rejected
    - about 97 % of neutron events are rejected
- For events w/o muon coincidence, neutrons are simulated from tank edge using Super-K full detector simulation
  - 50 years of neutron events are simulated in this study
  - neutron multiplicity is not considered

Neutron spectrum, angular distribution

neutron energy spectrum

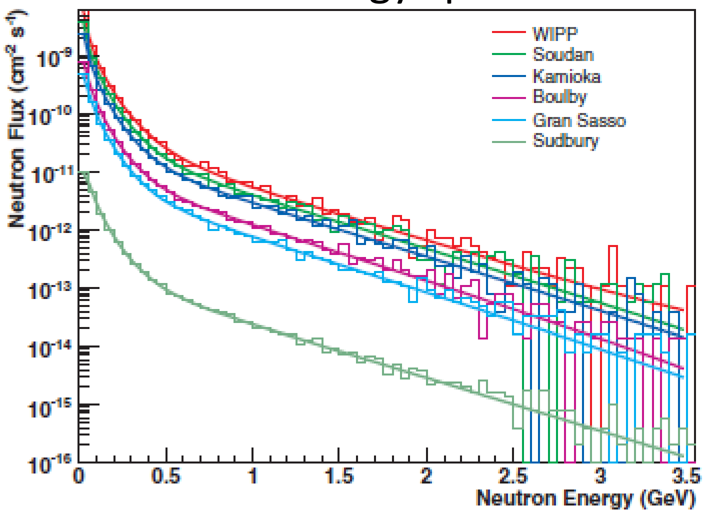


FIG. 17 (color). The differential energy spectrum for muon-induced neutrons at the various underground sites. The bin width is 50 MeV.

neutron angular distribution

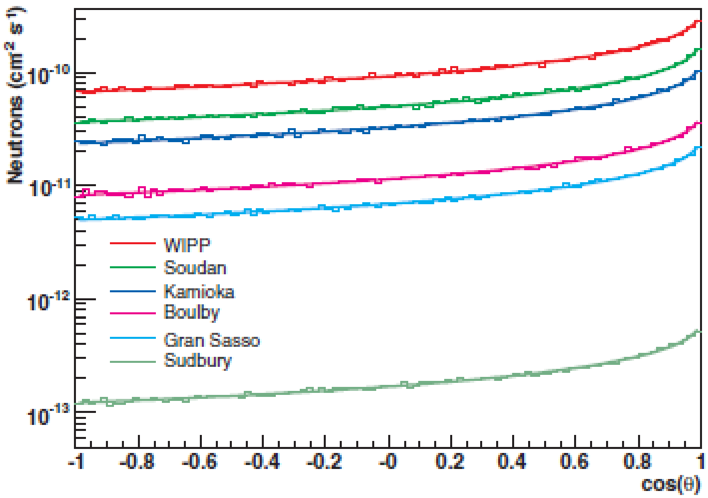
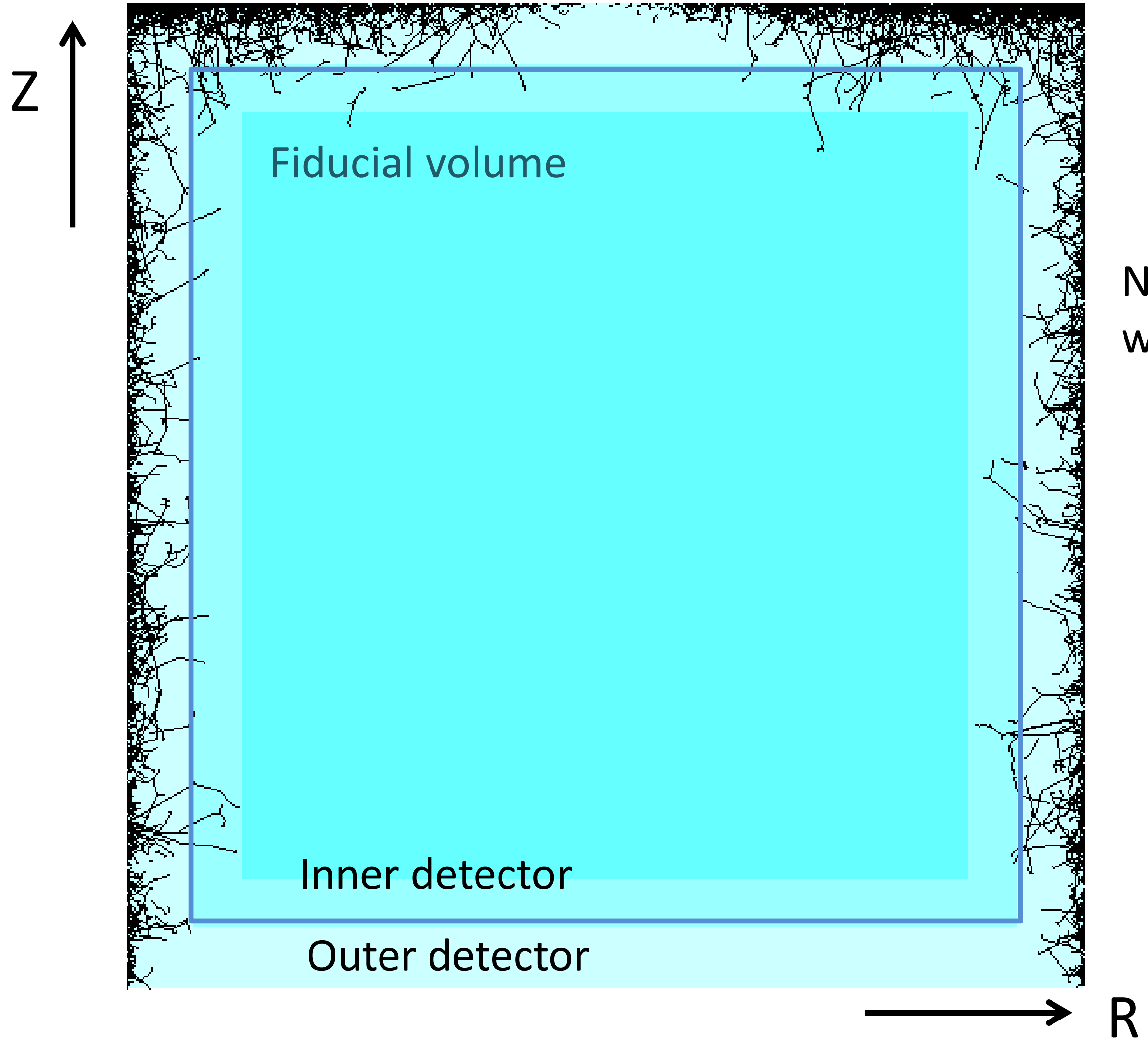
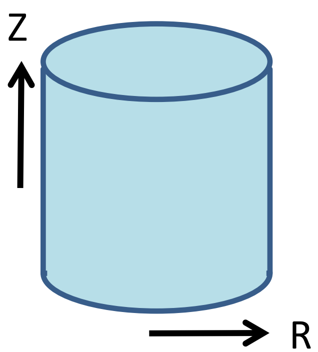


FIG. 18 (color). Simulation of the muon-induced neutron angular distribution for neutrons produced relative to the primary muon track.

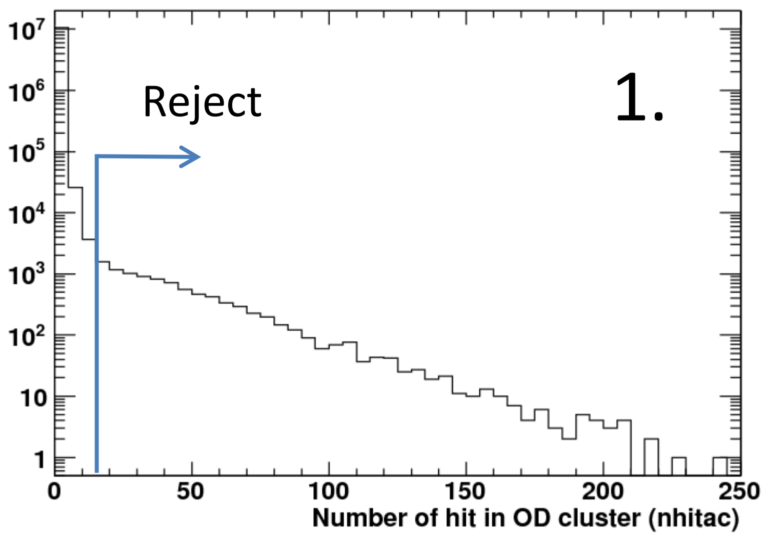
Neutron track in SK detector

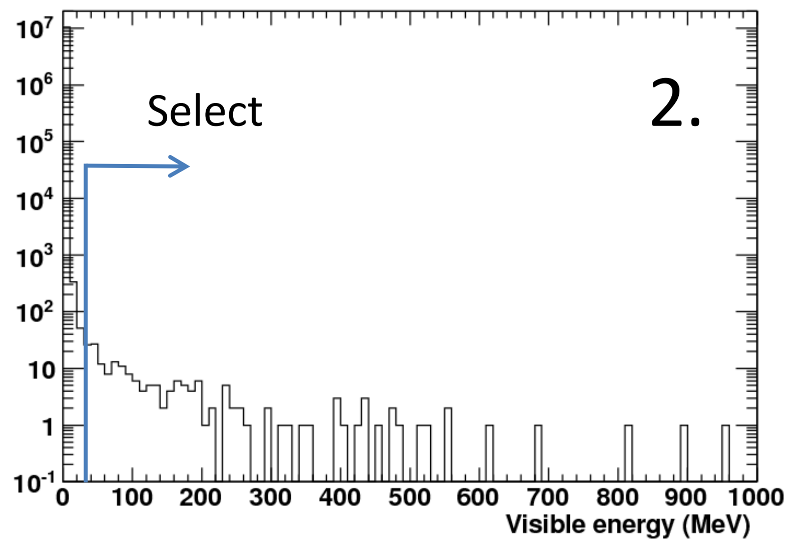


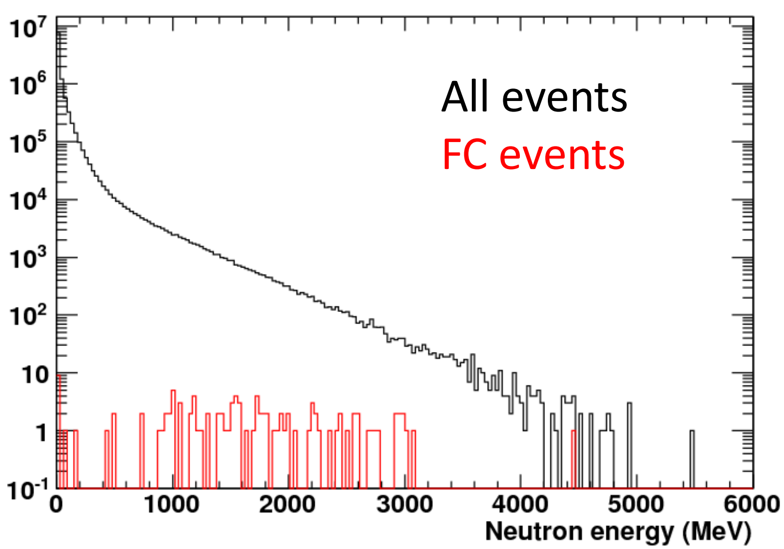
Neutrons (E>100MeV)
w/o muon coincidence



Event selection





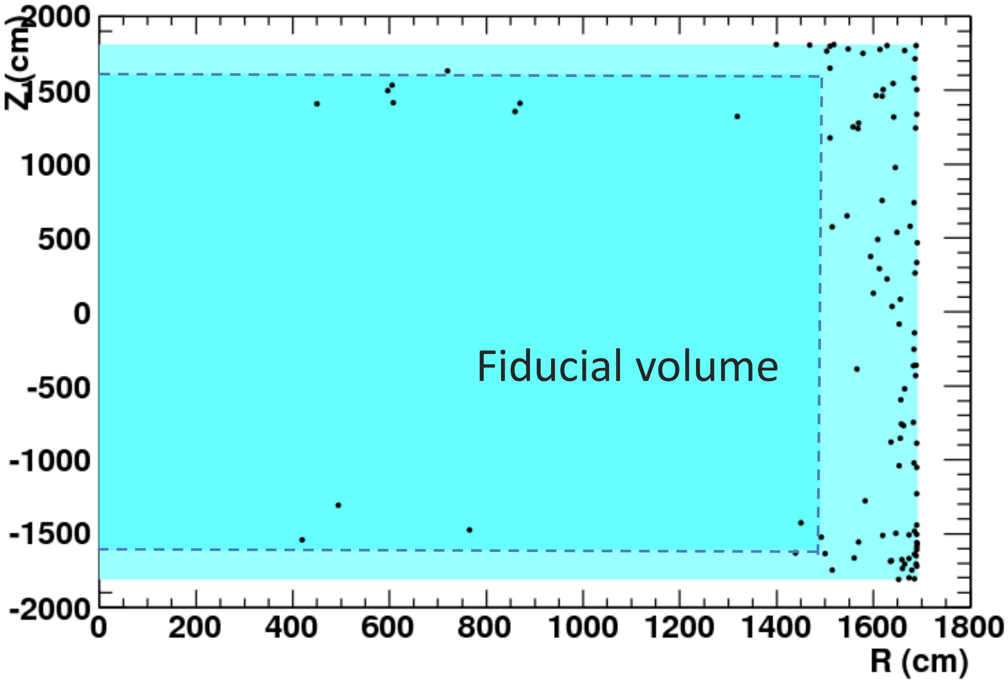


Apply SK standard full-contained (FC) selection

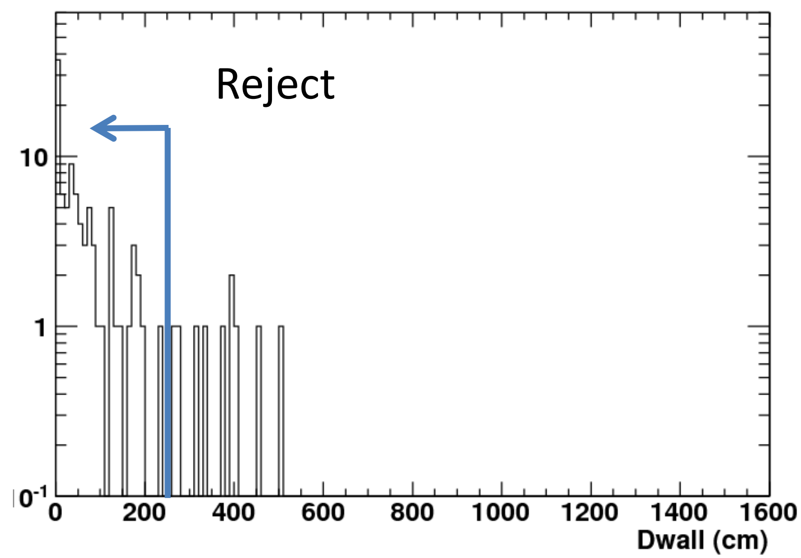
1. (Number of hits in OD) < 16
2. (Visible energy) > 30 MeV

Reconst. vertex distributions

After FC cut
(nhitac<16 && Evis>30 MeV)



Fiducial cut :
(distance to nearest detector wall : dwall) < 200 cm



Event summary and BG estimate

	N (/50yr)	Event / year (SK site)
Entering neutrons	4.5×10^{8}	8.9×10^{6}
w/o muon coincidence	1.1×10^{7}	2.1×10^{5}
FC	105	2.1
FCFV	11	0.2

Number of FVFV events in one year at Super-K:

~3000 events / year / SK

Background rate of FCFV events at Super-K site :

0.2 / ~3000 = 7×10^{-3} %

To estimate BG rate at Hyper-K site, scale by factor of 8 according to neutron flux (assuming same detector condition)

→ 7×10^{-2} %

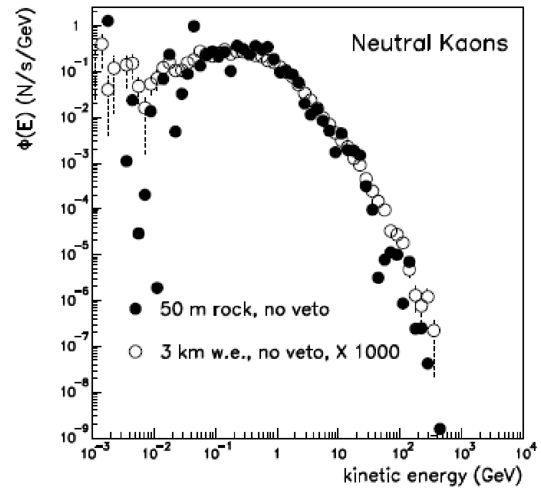
Less than 0.1% BG rate expected at Hyper-K

Neutral kaon background

JHEP04 (2007) 041

Configuration/ Depth	Simulation	Average number μ's entering LAr per 10 ms	Neutrons per year	Neutrons per μ in LAr per 10 ms	Neutral kaons per year	Neutral kaons per μ in LAr per 10 ms	Lambdas
$\simeq$ 0.5 km w.e. (188 m rock)	FLUKA	3.3	1.9×10^{6}	1.8×10^{-4}	4500	4.3×10^{-7}	$\approx 0.04 \times N_{K^0}$
$\simeq$ 1 km w.e. (377 m rock)	FLUKA	0.66	5.5×10^{5}	2.6×10^{-4}	1300	6.2×10^{-7}	$\approx 0.05 \times N_{K^0}$
$\simeq$ 3 km w.e. (1.13 km rock)	FLUKA	0.01	1.1×10^{4}	3.6×10^{-4}	25	8.2×10^{-7}	$\approx 0.06 \times N_{K^0}$
Under the hill (see figure 4)	GEANT4 FLUKA rescaled	9.6	9.7×10^{6}	3.2×10^{-4}	1.2×10^{3} $\approx1.2\times10^{4}$	4.0×10^{-8} $\approx4.0\times10^{-7}$	– $\approx 0.05 \times N_{K^0}$

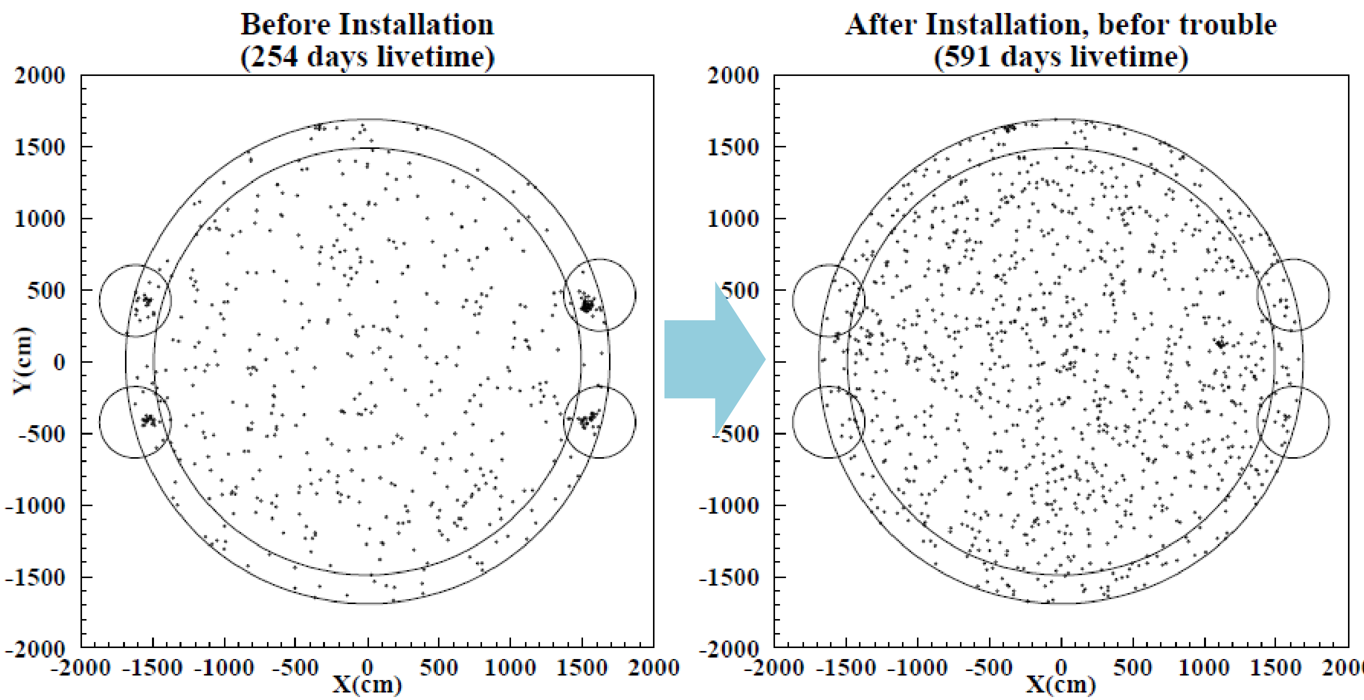
Energy spectrum of kaon

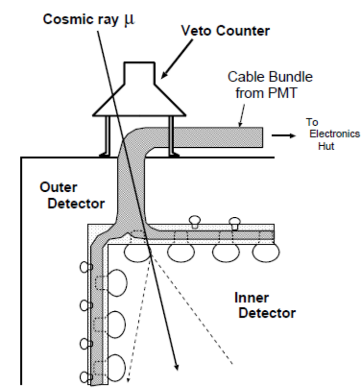


- Neutral kaon like K^0_L could be also possible background
- 0.3% of neutron flux is estimated in JHEP04 (2007) 041
- Though simulating 50yr neutral kaon backgrounds with calculated energy spectrum, backgrounds are negligible

About Muon VETO

There was dead region in SK due to PMT cable bundle :





muon counter installed above cable hole

J. Kameda, PhD thesis
Univ. of Tokyo (2002)

Need careful detector design to reduce dead region ...

Summary

- Background rate of neutral particles produced by cosmic ray muons in rock was discussed
- Due to self-shielding of water and rejection by primary muon coincidence, those backgrounds can be reduced
- By utilizing calculated neutron flux and detector simulation, background rate at Hyper-K site are estimated to negligibly small (less than 0.1%) under the assumption of same detector configuration as Super-K