Analysis of de-excitation gamma from atmospheric neutrino CCQE interaction in Super-Kamiokande

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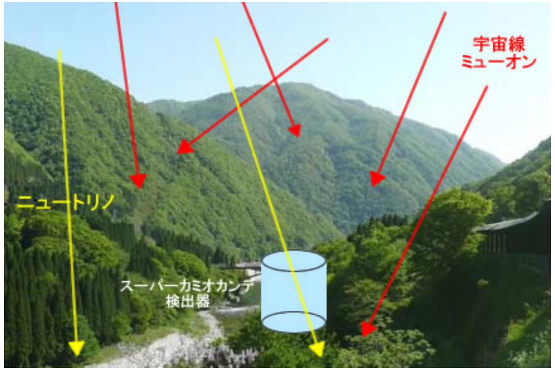
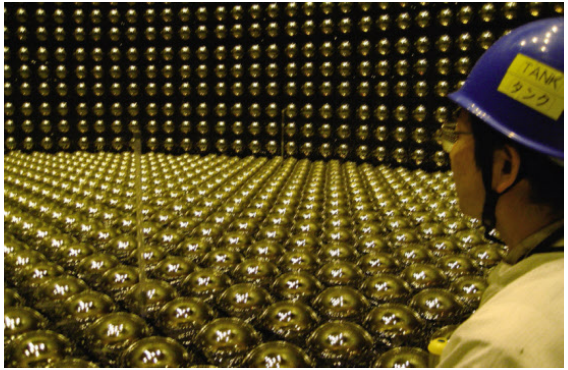
Super-Kamiokande





Key word :

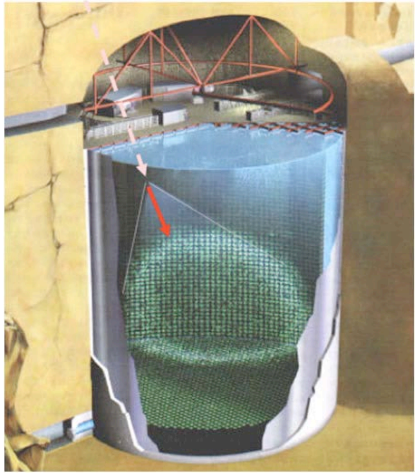
1000m Underground

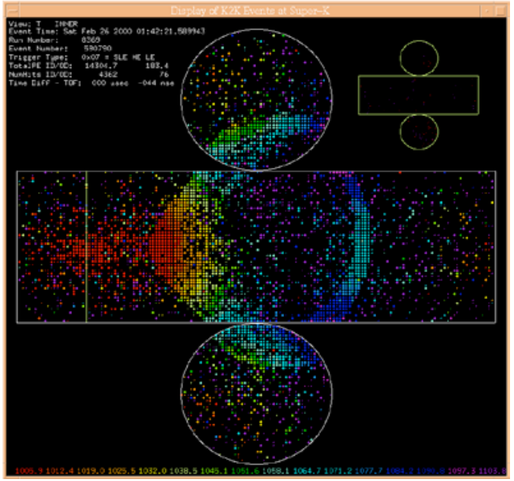
Water Cherenkov Detector

50kton pure water

22.5kton Fiducial Volume

~11100 PMTs in Inner Detector





SK phase :

SK-I : 1996~2001

SK-II : 2002~2005

SK-III : 2006~2008

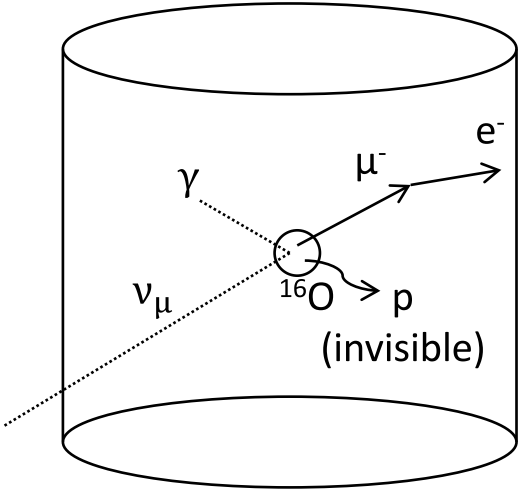
SK-IV : 2008~2018

SK-Gd : Under Work !

Atmospheric ν_μ/ $\bar{\nu}_\mu$ CCQE interaction

$$\nu_\mu + {}^{16}_{8}O \rightarrow \mu^- + {}^{15}O^* + p$$

$\mu^- \downarrow e^-$ $\quad$ ${}^{15}O^* \downarrow \gamma \sim 6\ MeV$



μ and γ at same timing/position

Decay e after ~2.2μs

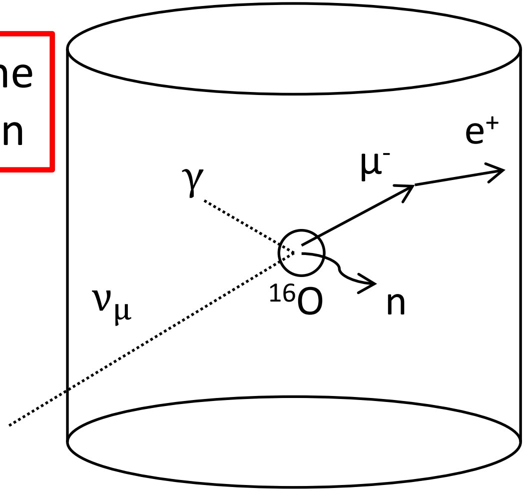
$$\bar{\nu}_\mu + {}^{16}O \rightarrow \mu^+ + {}^{15}N^* + n$$

$\mu^+ \downarrow e^+$ $\quad$ ${}^{15}N^* \downarrow \gamma \sim 6\ MeV$

μ and γ at same timing/position

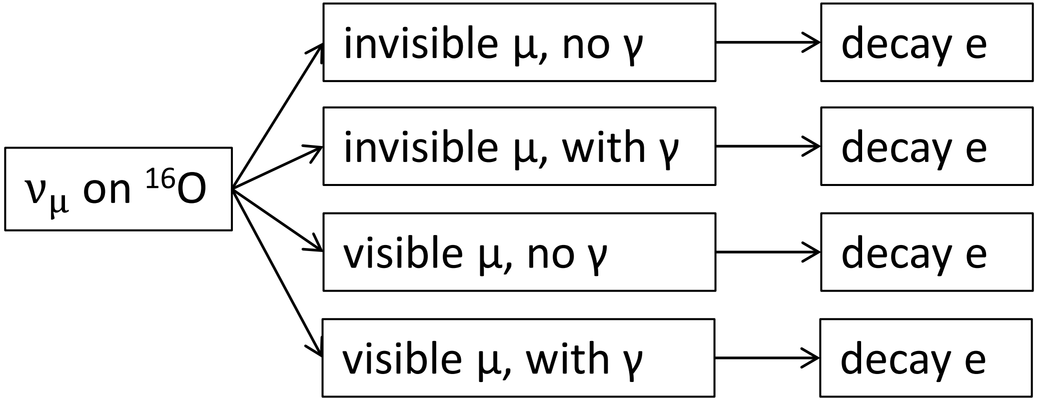
Decay e after ~2.2μs

n signal after ~200 μs



Br(γ) : 脱励起ガンマ線が出る確率

CCQE cases and Br(γ)



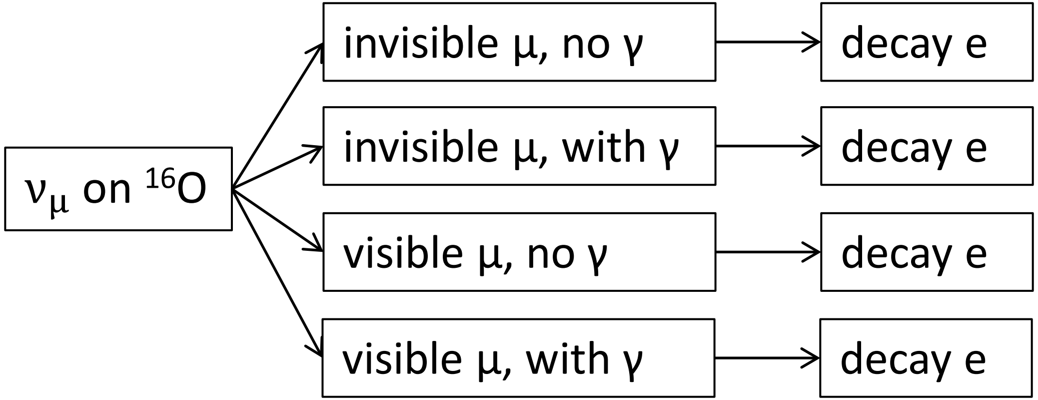
1. only e, impossible to count it
2. γ + decay e after 2.2μs
3. saved as μ event In FC data
4. saved as μ event In FC data

1で観測できるのはdecay eのみで、除去不可のバックグランドになる（主にSRN解析で）。さらに、中性子が弾き出される場合もあり、SK-Gdにおいても除去不可になる。

3&4を区別できれば、脱励起γ線が出る確率Br(γ)がわかる。（FC μ sampleを利用し、同一event内で6MeV γ を探す）

さらに2の数が分かれば、1を見積ることができる。

Plan



1. only e, impossible to count it
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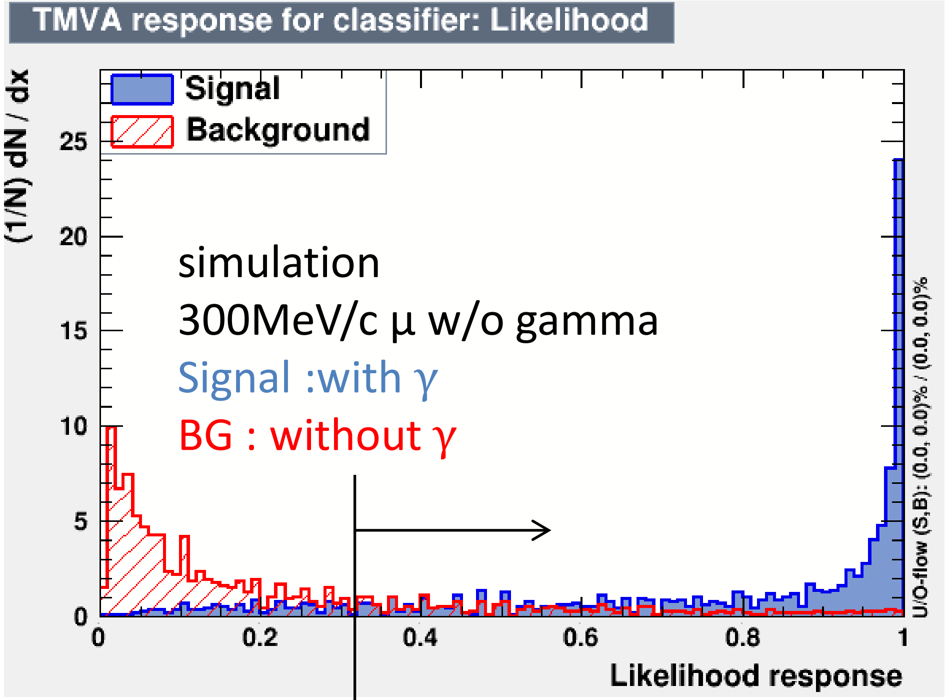
3&4を区別する可能性をSimulationで検討し、μ事象の中でγを探す手法を確立する。

2のγ + e pairを探して、脱励起ガンマ線のSampleを作る。

大気ニュートリノのFlux、CCQE反応のcross section理論値、SKの検出効率を考慮した上で、事象数の予想値を出して上記の結果と比較する。

脱励起ガンマ線のSampleを利用して、FC dataでBr(γ)を出す。

Step1: distinguish μ w/o gamma



Reported in last JPS

How to calculate Br(γ)

When cutting at max significance $L > 0.33$

Cut Efficiency : $Eff_s = 89\%$, $Eff_b = 13\%$

Br(γ) = $N_s/(N_s + N_b)$

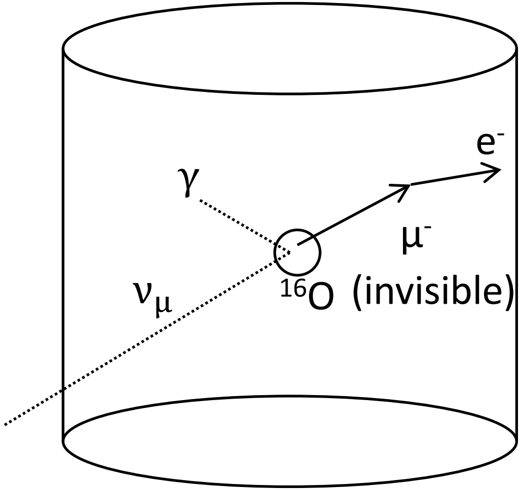
We can observe N_{total} , but don't know N_s and N_b

$$\begin{cases} N_s + N_b = N_{total} \\ N_s \times Eff_s + N_b \times Eff_b = N'_{total} \end{cases}$$

Step2: (γ + decay e) pair in SK data

When studying (γ + decay e) pair by SK-IV data, noticed an unexpected problem:

How to separate a de-excitation γ and a μ close to Cherenkov threshold ?



Signal:

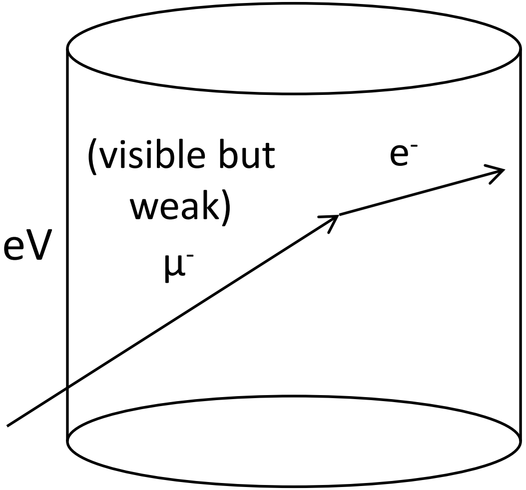
de-excitation γ

decay e

Signal:

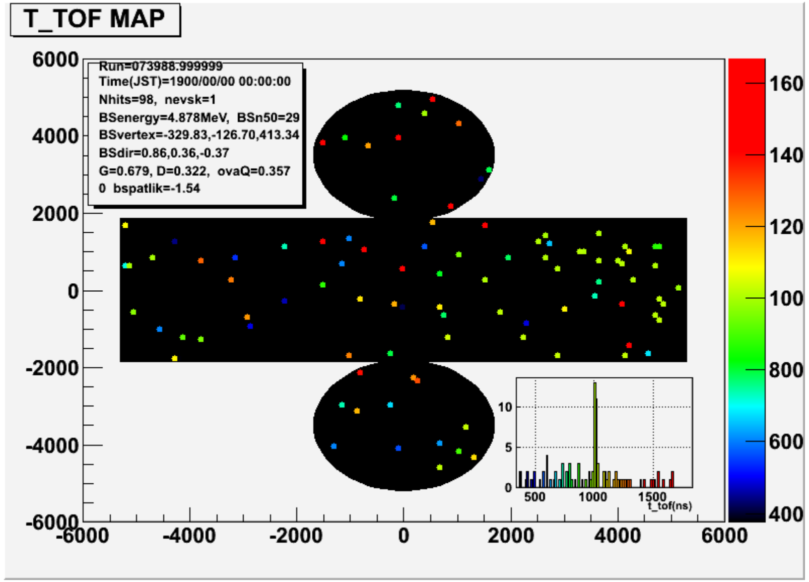
a μ close to 157.4MeV

decay e



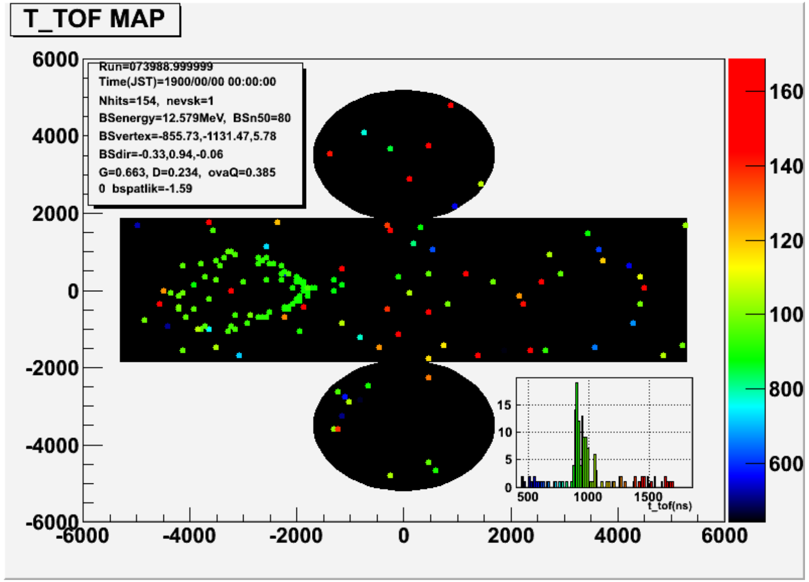
de-excitation γ VS μ close to 157.4MeV

Simulation of 6MeV gamma



1. Hard to find a clean “ring”
2. Cherenkov angle larger than 42°

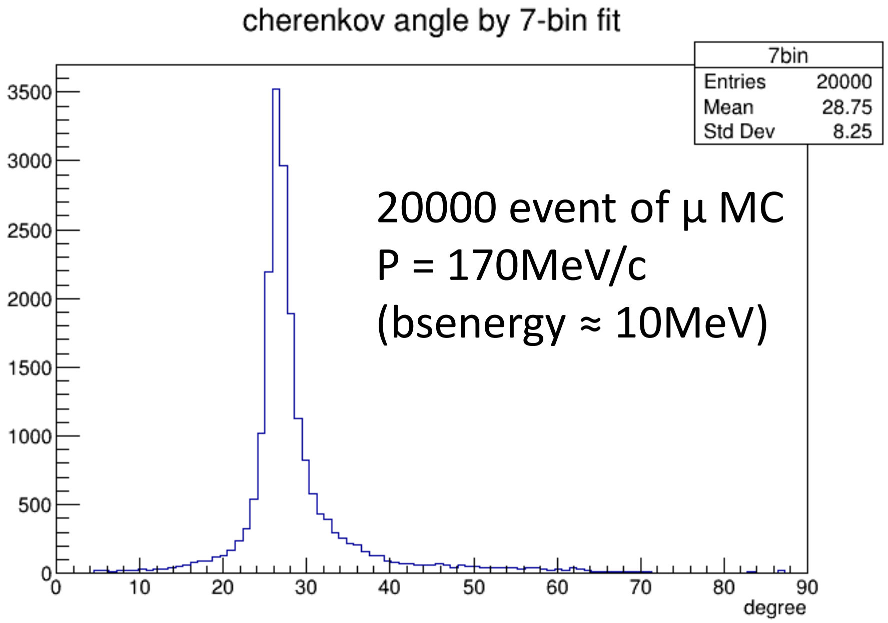
Simulation of 170MeV/c μ

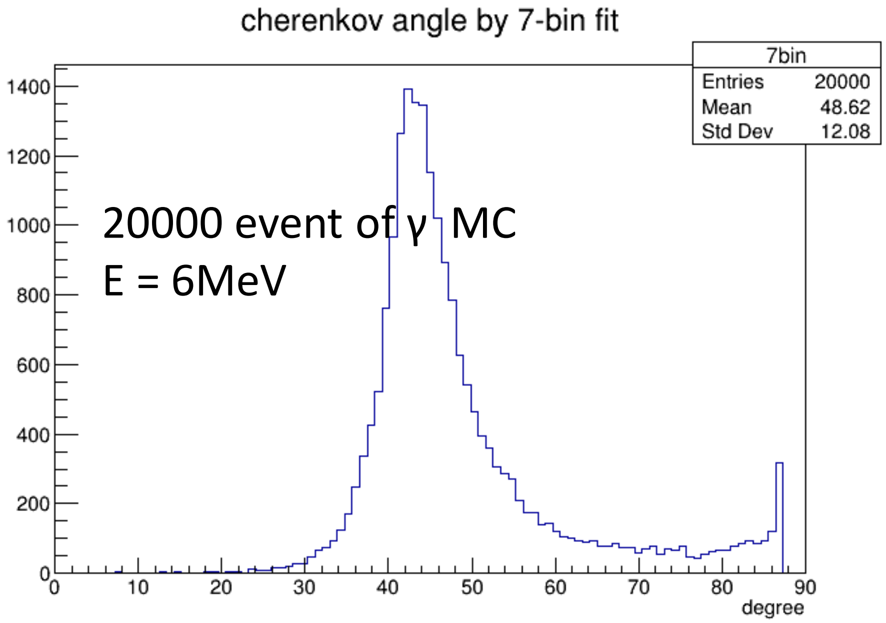


1. Have a clean “ring”
2. Cherenkov angle smaller than 42°

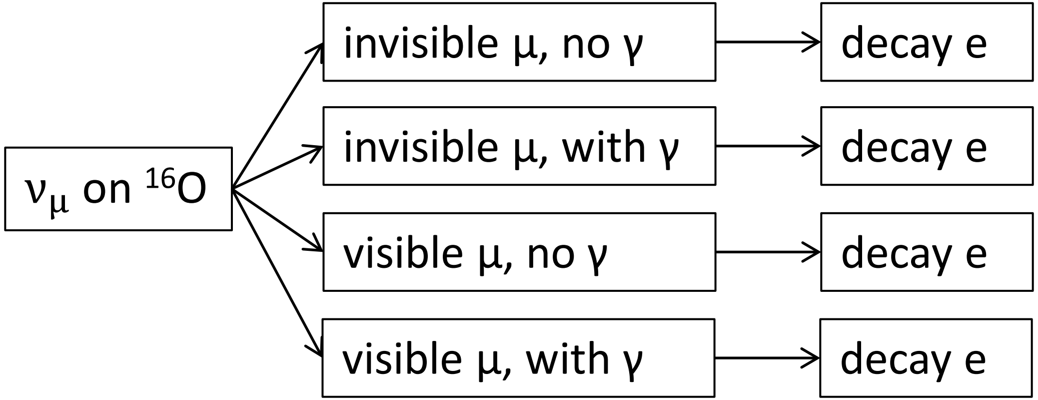
A possible way: Cherenkov Angle Fit

Reconstructed Cherenkov Angle from simulation.





Still Need To do……



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3&4を区別する可能性をsimulationで検討する。 ○

2のγ + e pairを探して、脱励起ガンマ線のSampleを作る。 △

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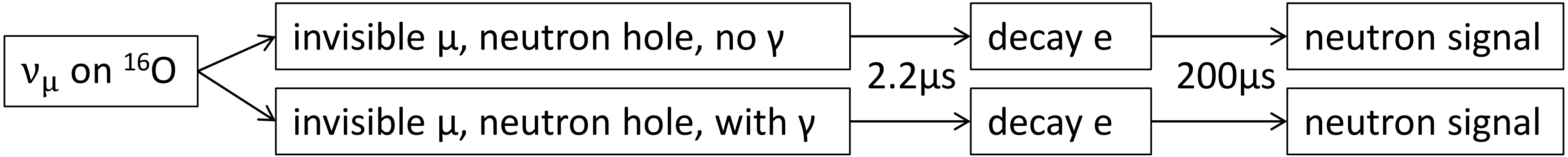
脱励起ガンマ線のSampleを利用して、FC dataでBr(γ)を出す。 ×

Summary & Future

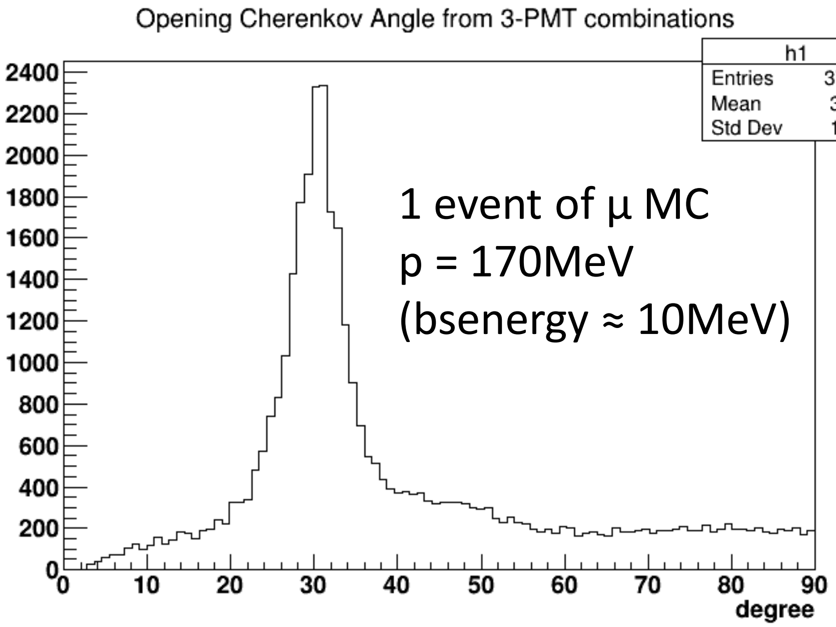
1. Introduced how to measured Br(γ) of ν_μ CCQE de-excitation γ
2. The method of how to search for a 6MeV γ inside a μ event has been introduced in last JPS presentation
3. Analyzing for (γ + decay e) pair by SK real data, but a problem is still being studied
4. In future SK-Gd, as neutron can be efficiently detected, Br(γ) can be obtained by this way:

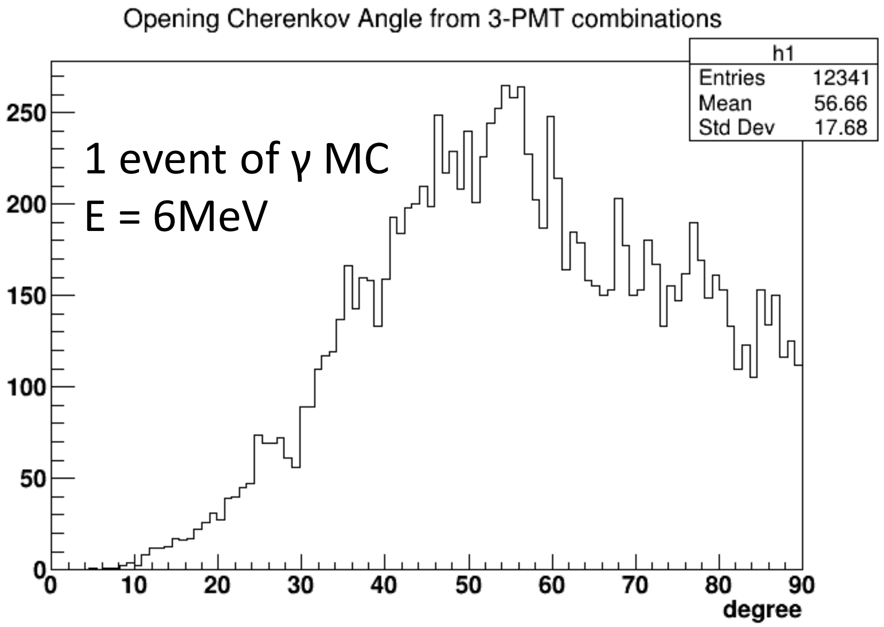


backup

A possible way: Cherenkov Angle Fit

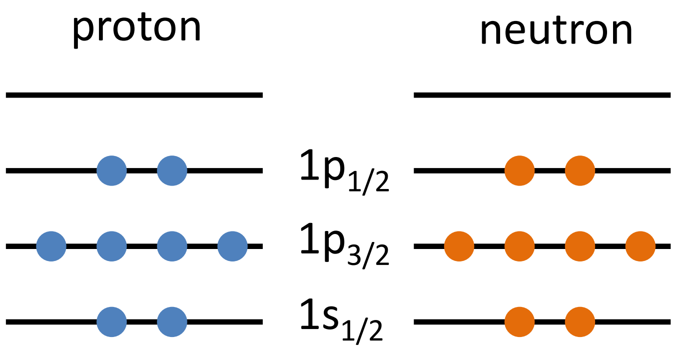
1. Select PMT hits in 15ns time window by T-Tof
2. Calculate the angle from vertex to the triangle of all 3-PMT sets
3. Search for the highest position by taking the sum of near 7-bins





Oxygen de-excitation γ

^{16}O nucleus



de-excitation occurs when $1p_{3/2}$ or $1s_{1/2}$ is knock out.

($1p_{1/2}$ case is stable)

PHYSICAL REVIEW D 90, 072012 (2014)

	$1p_{1/2}$	$1p_{3/2}$	$1s_{1/2}$
Spectroscopic factors	0.632	0.703	0.422
γ-ray branching ratios:			
$>$ 6 MeV from p hole	0%	91.8%	14.7%
$>$ 6 MeV from n hole	0%	86.9%	14.7%
3–6 MeV from either	0%	0%	27.8%

SF is from calculation, branching ratio of each state Is from electron/proton beam experiment.

Br(γ>6MeV) = 4/16 * 0.703 * 91.8% + 4/16 * 0.703 * 86.9% + 2/16 * 0.422 * 14.7% + 2/16 * 0.422 * 14.7% = 33%