

Improvement of proton decay analysis ($p \rightarrow \nu K^+$) for Hyper-K

M.Miura

2013/01/14

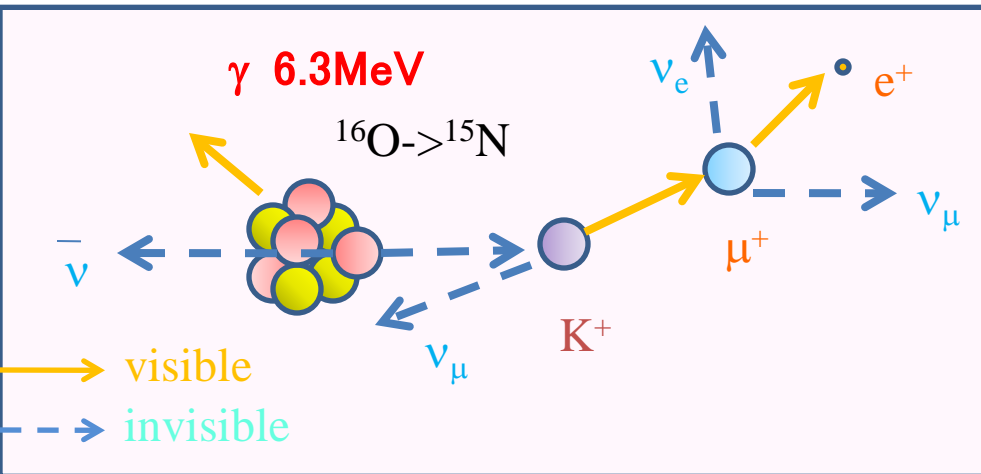
HK open meeting

1. Introduction

- $p \rightarrow \nu K^+$ is an important proton decay mode which SUSY GUTs prefers.
- Momentum of K^+ is below cherenkov threshold and most of K^+ stop in water and decay into $\mu^+\nu$ (62 %), $\pi^+\pi^0$ (23 %).
- In Super-Kamiokande, there are three methods to tag $p \rightarrow \nu K^+$,
Method 1) tag 236 MeV/c μ and 6 MeV nuclear γ .
Method 2) μ momentum distribution.
Method 3) tag $\pi^+\pi^0$.

	Efficiency (%)	BKG/Mton·yr
Method 1	7.1	1.6
Method 3	6.7	6.7

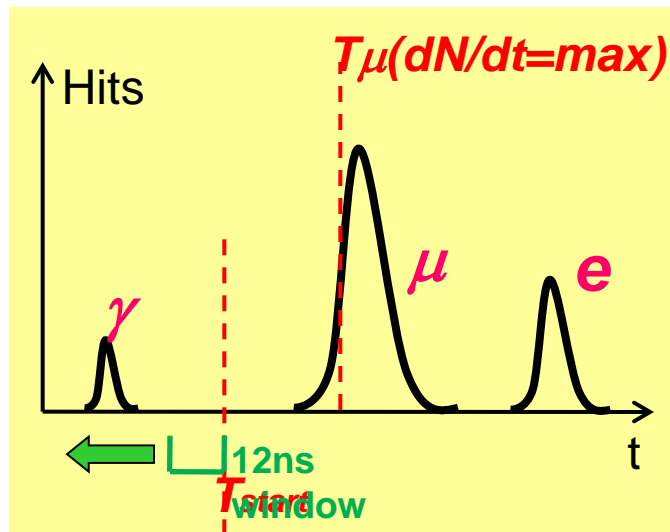
Method 1,2) $K^+ \rightarrow \nu \mu^+$



- After proton decay, remaining nucleus emits **6 MeV γ ray** ($\sim 40\%$).

- K^+ is below cherenkov threshold, mostly stop in water and decay into $\mu + \nu$ ($P_\mu = 236 \text{ MeV}/c$)

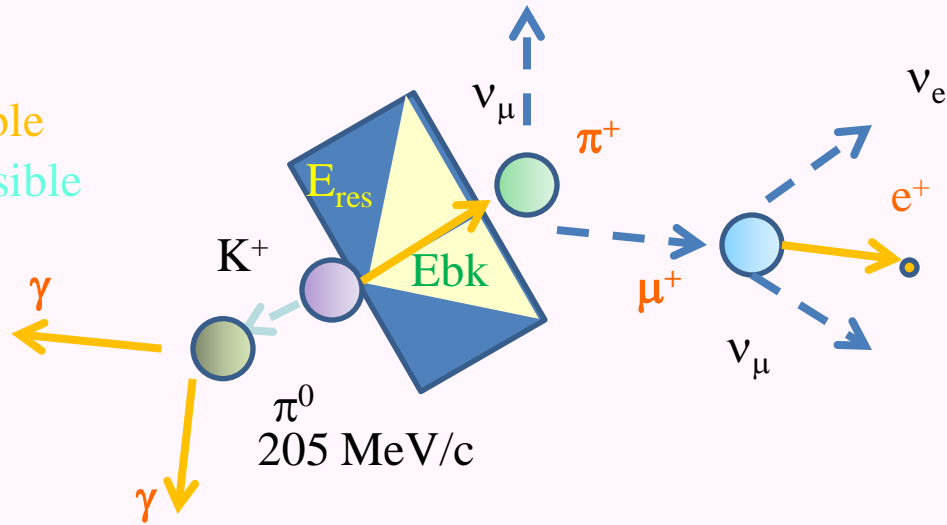
=> Tag Prompt γ to reduce BKG!



Selection:

- 1 μ -like ring with decay-e.
- $215 < P_\mu < 260 \text{ MeV}/c$
- Search Max hit cluster by sliding time window (12 ns width);
 $4 < N_\gamma < 30$ (20 % coverage)
 &
 $T_\mu - T_\gamma < 75 \text{ nsec}$

Method 3) $K^+ \rightarrow \pi^+ \pi^0$



Event features;

- Br. 21 %.
- π^0 and π^+ are back-to-back and have 205 MeV/c.
- $P\pi^+$ is just above \check{C} thres. (not clear ring).

Search for monochromatic π^0
 With PMT activity in backward of π^0 .

Selection:

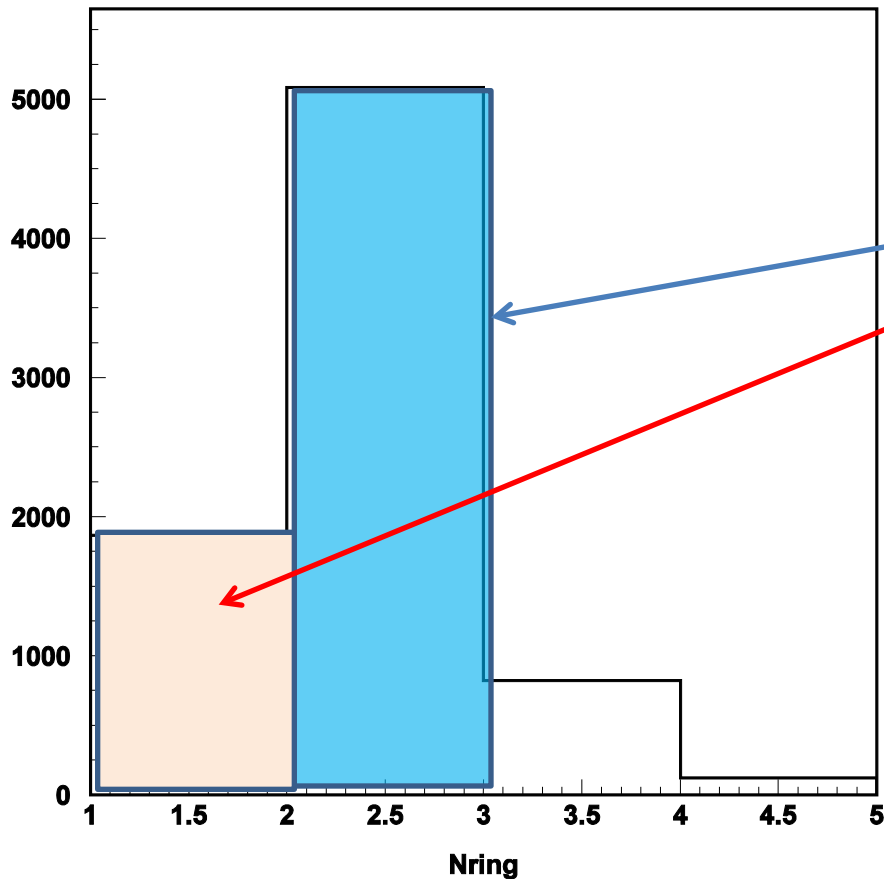
- 2 e-like rings with decay-e.
- $85 < M\pi^0 < 185$ MeV.
- $175 < P\pi^0 < 250$ MeV/c.
- E_{bk} : visible E in 140-180 deg. of π^0 dir,
 E_{res} : in 90-140 deg.
 $7 < E_{bk} < 17$ MeV & $E_{res} < 12$ MeV

In this method, there were improvements in SK.

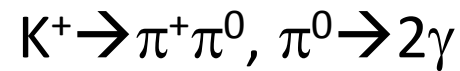
→ Apply to HK.

2. Improvement of analysis

Improvement 1: include 1 ring sample

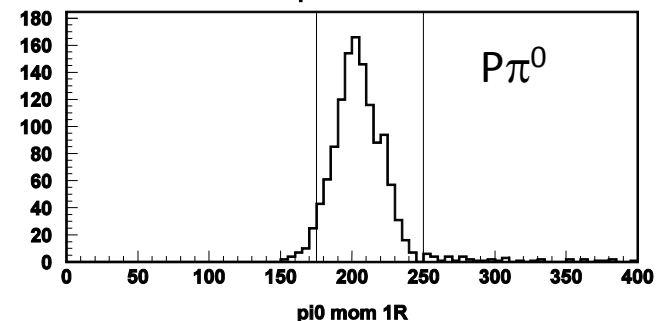
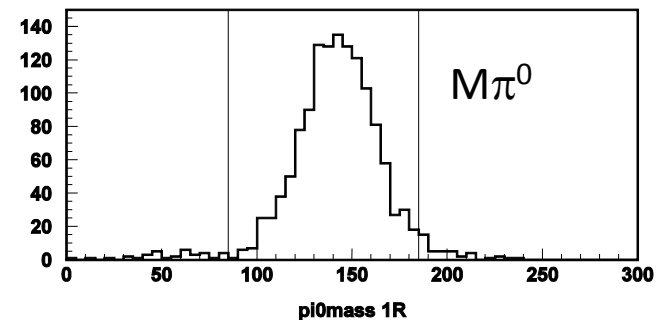


Nring (FV) of PDK after vector cut :



Current analysis: only use 2R.

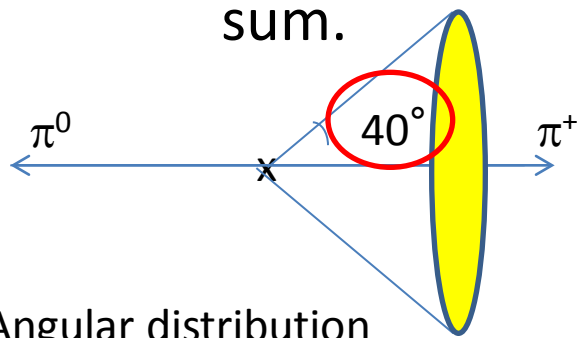
Apply polfit to 1R sample



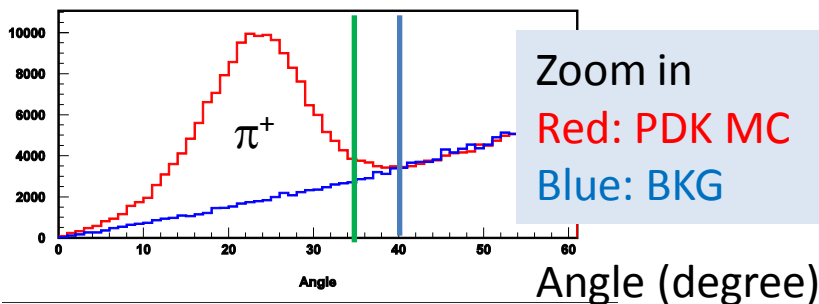
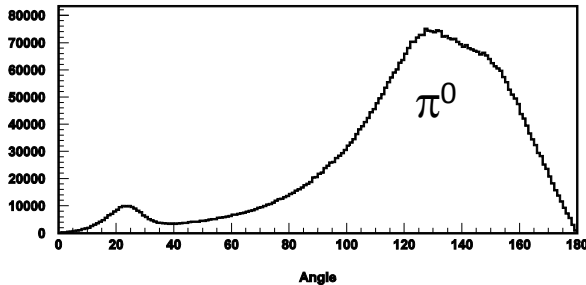
Polfit works well and we can use 1R sample also.

Improve 2: Angle cut in π^0 backward

π^+ doesn't make clear ring => tagged by backward charge



Angular distribution

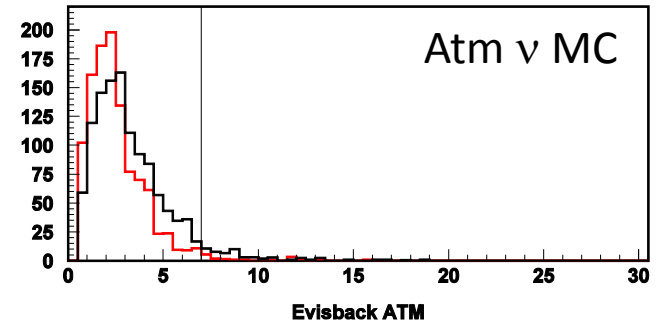
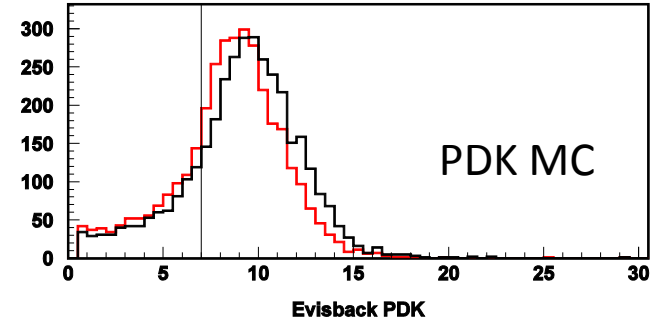


40 degree is rather loose.

→ Change to 35 degree.

Charge sum

Black: 40°
Red: 35°

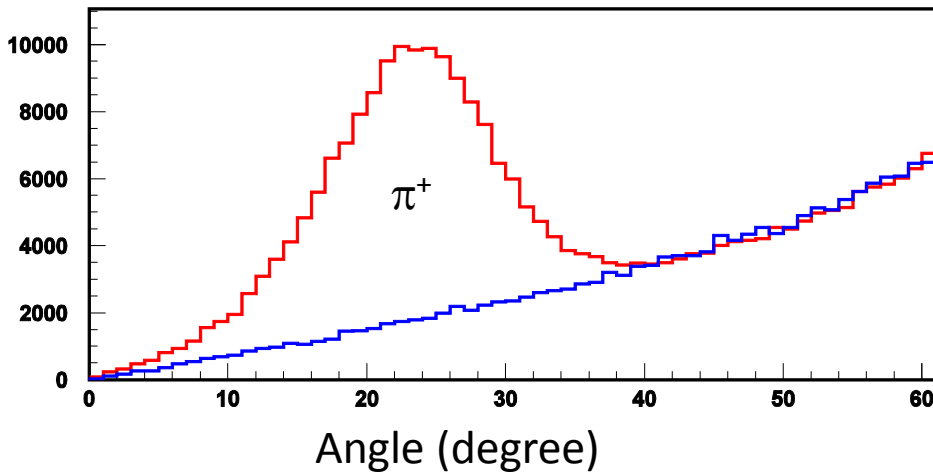


BKG can largely reduced
losing small efficiency.

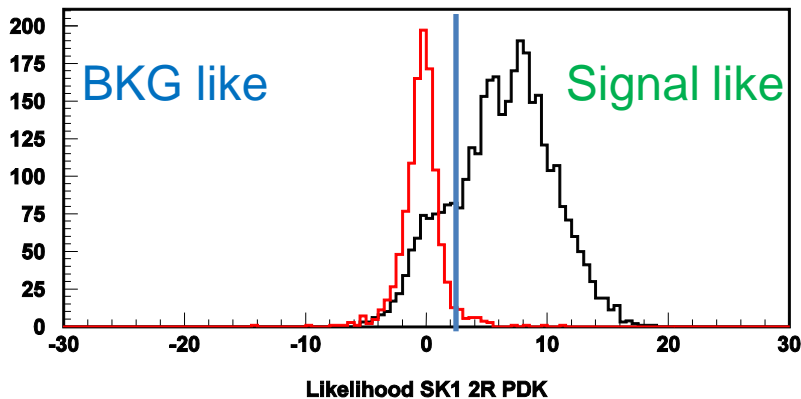
Improve 3: Compare shape of angular distribution in π^0 backward

Blue: Atm ν MC (after all cuts except Evisback cut)

Red: PDK MC



Make likelihood and compare observed dist. to expected signal and BKG.
Use both shape and charge sum in backward.



Black: PDK MC

Red: ATMC

Additional cut to reduce background more.

3. How much improved ?

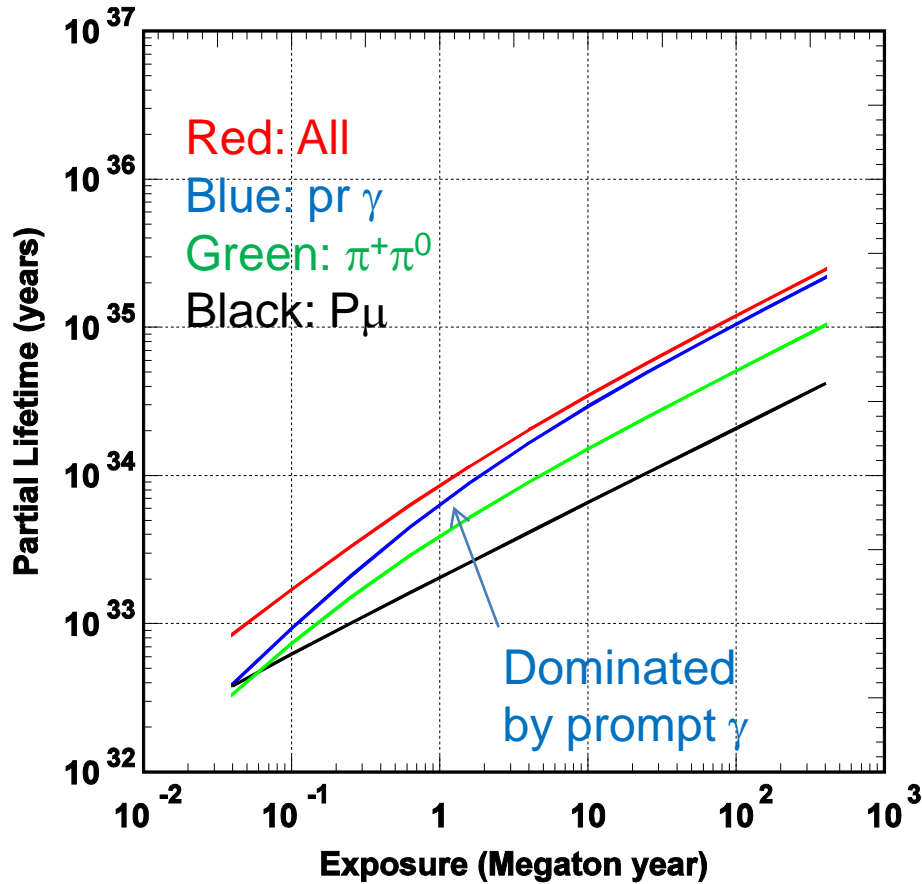
New Selection:

- 1 or 2 e-like rings with decay-e.
- $85 < M\pi^0 < 185$ MeV.
- $175 < P\pi^0 < 250$ MeV/c.
- E_{bk} : Q sum in 135-180 deg. of π^0 dir,
 E_{res} : in 90-135 deg.
 $7 < E_{\text{bk}} < 17$ MeV & $E_{\text{res}} < 12$ MeV
- Shape likelihood > 1.0

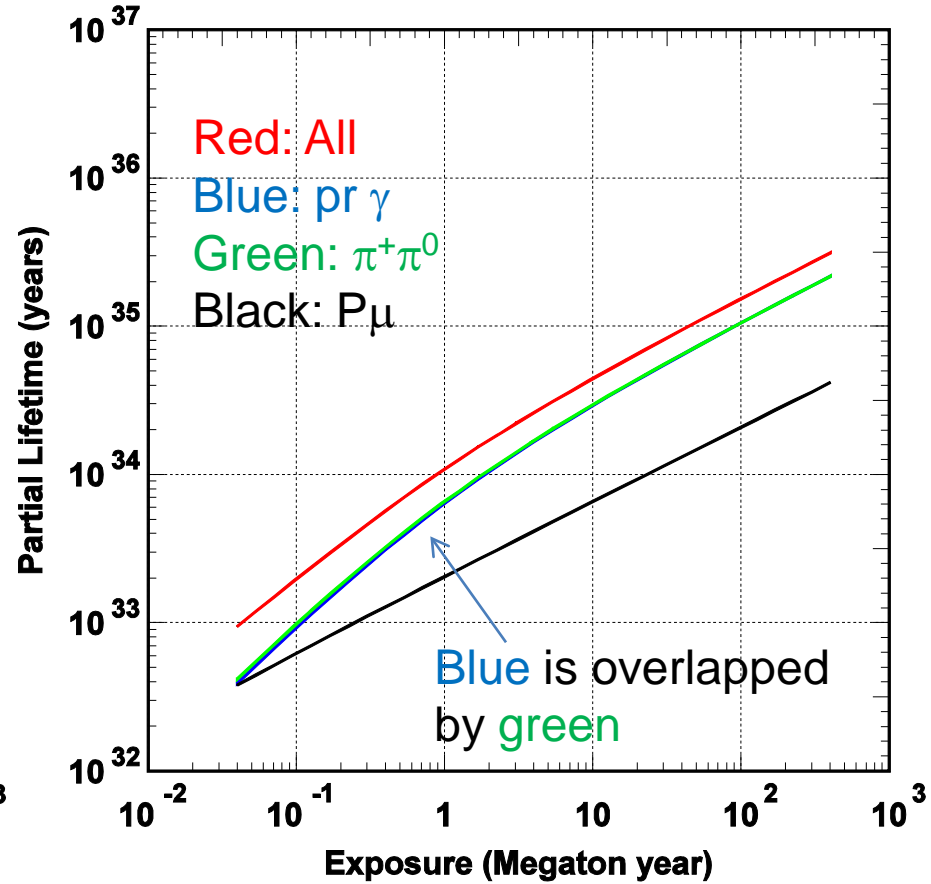
	Effi (%)	BKG/Mton·yr
$\pi^+\pi^0$	6.6 → 7.6	6.6 → 1.8
Prompt γ	7.1	1.6

- Efficiency increased by 15 %, due to 1R sample.
- BKG reduced by 72 %, due to angle cut and shape likelihood.
- $\pi^+\pi^0$ method become comparable to prompt γ method !

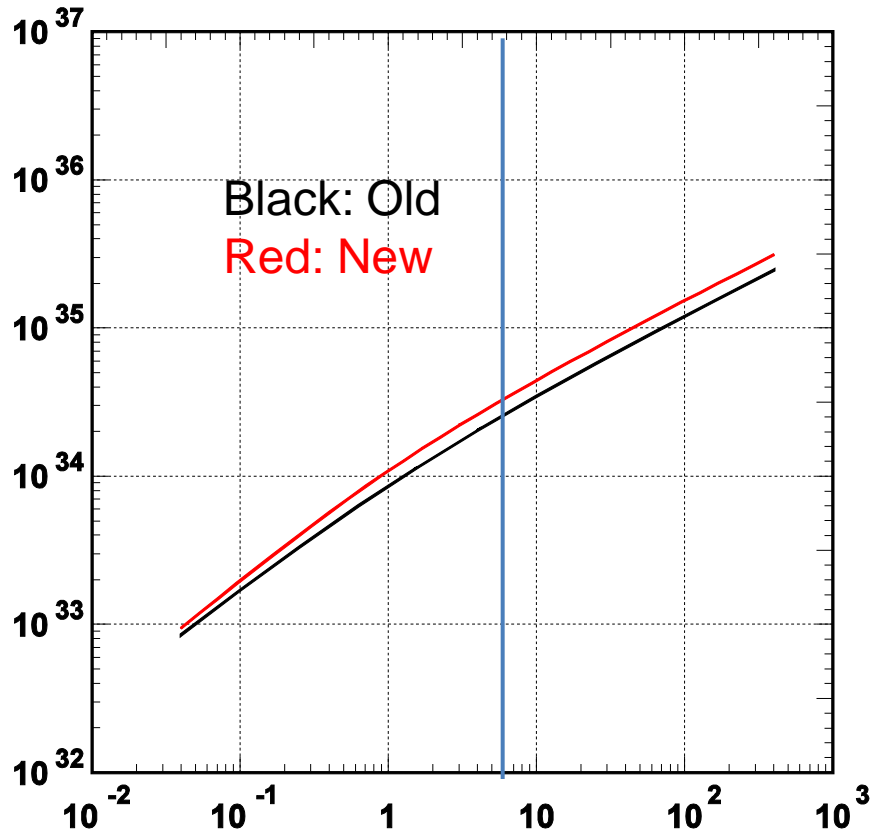
Old sensitivity



New sensitivity



Sensitivity curve (90 % C.L.), All



Sensitivity for 5.6 Mton·year exposure (10 years run)

$2.5 \times 10^{34} \rightarrow 3.2 \times 10^{34}$ year

3σ discovery potential

$0.95 \times 10^{34} \rightarrow 1.23 \times 10^{34}$ year

~ 30 % improved !

Summary

- For $p \rightarrow \nu K^+ : K^+ \rightarrow \pi^+ \pi^0$, some improvements are taken into HK analysis.
 - Add 1 R sample with polfit.
 - Angle cut for π^+
 - Likelihood for angle distribution of charge from π^+
- Efficiency: 6.6 % \rightarrow 7.6 %
- BKG: 6.6 \rightarrow 1.8 events/Mton \cdot year
- Sensitivity with 5.6Mton \cdot year exposure improved:
2.5x10³⁴ \rightarrow 3.2x10³⁴ years

Future plan

- There is another improvement in Method 1 (tagging nuclear γ) in SK.

- Mask μ to find γ
- Apply proton rejection

- Efficiency: 7.1 \rightarrow 8.4 %

BKG : 1.6 \rightarrow 2.5 ev/Mton \cdot year

Note: BKG is almost same (+3 %) for 40 % coverage case.

- Need to suppress BKG to improve sensitivity in HK.

Sensitivity for Method 1

