Update on Nucleon Decay Search In Super-Kamiokande

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UNO collaboration meeting
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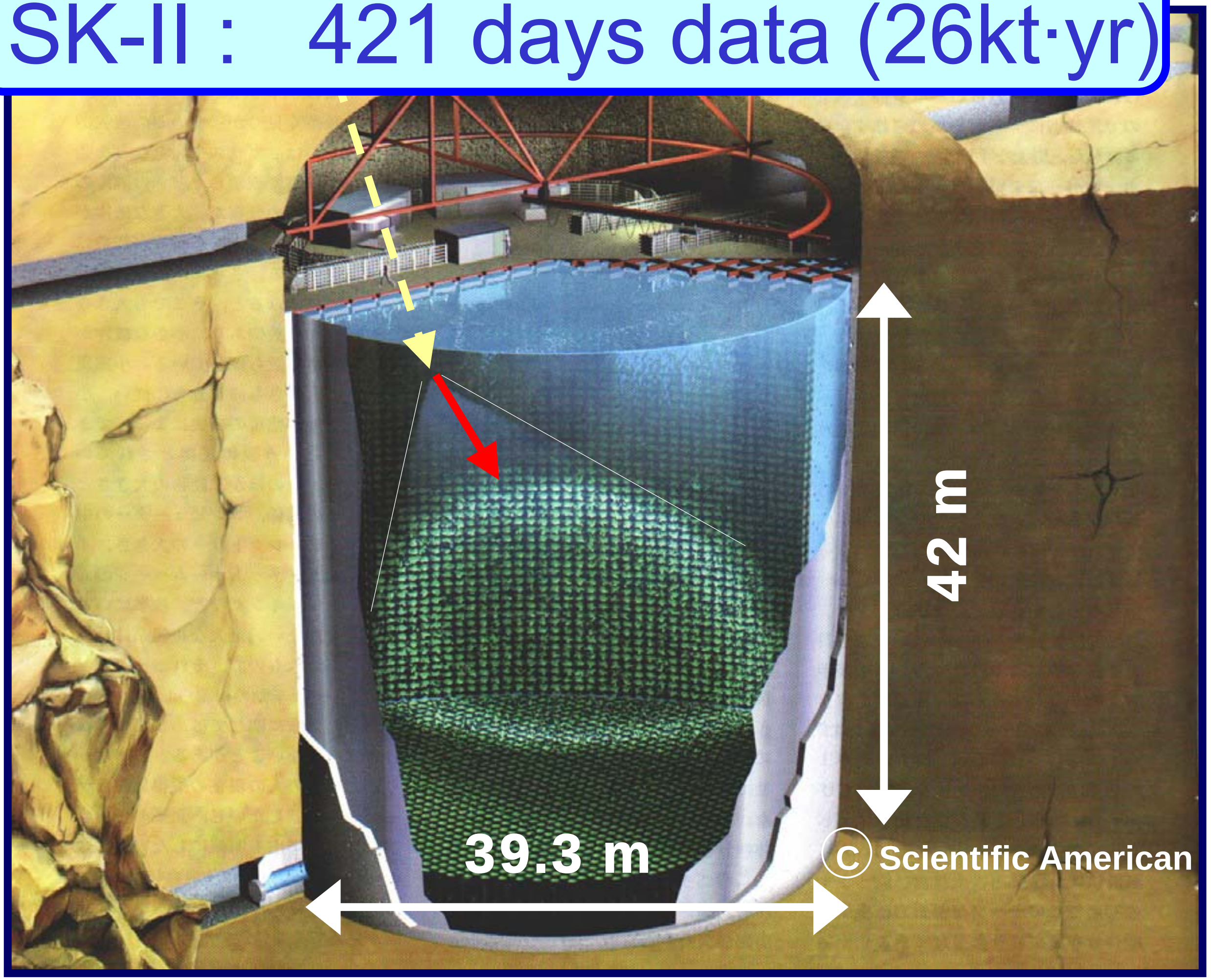
Aussois, France

Super-Kamiokande

(SK-I:May 1996 – July 2001, SK-II:Dec 2002-)

SK-I : 1489 days data (92kt·yr)
SK-II :   421 days data (26kt·yr)



large water Cherenkov detector

- 1000 m underground
- 50kton (22.5kton fid.)
- 11,146 20 inch PMTs
- 1,885 anti-counter PMTs

PMT coverage
SK-I 40%
SK-II 20%
Full recovery attempt will start from fall 2005

Detector performance

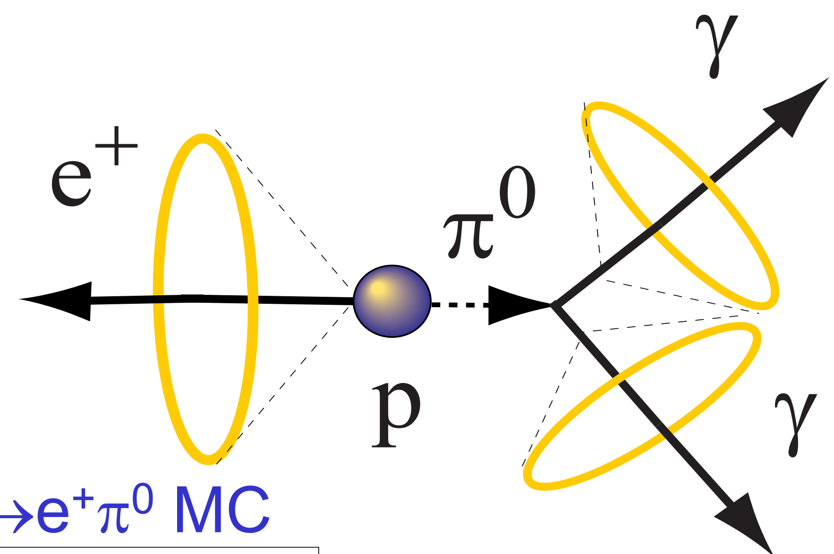
Fiducial 22.5kton H_2O
$\rightarrow 8 \times 10^{33}$protons

- 2/10 free protons
  → no nuclear effect
  → no Fermi motion
  high efficiency

- 8/10 binding protons
  → de-excitation γ-ray

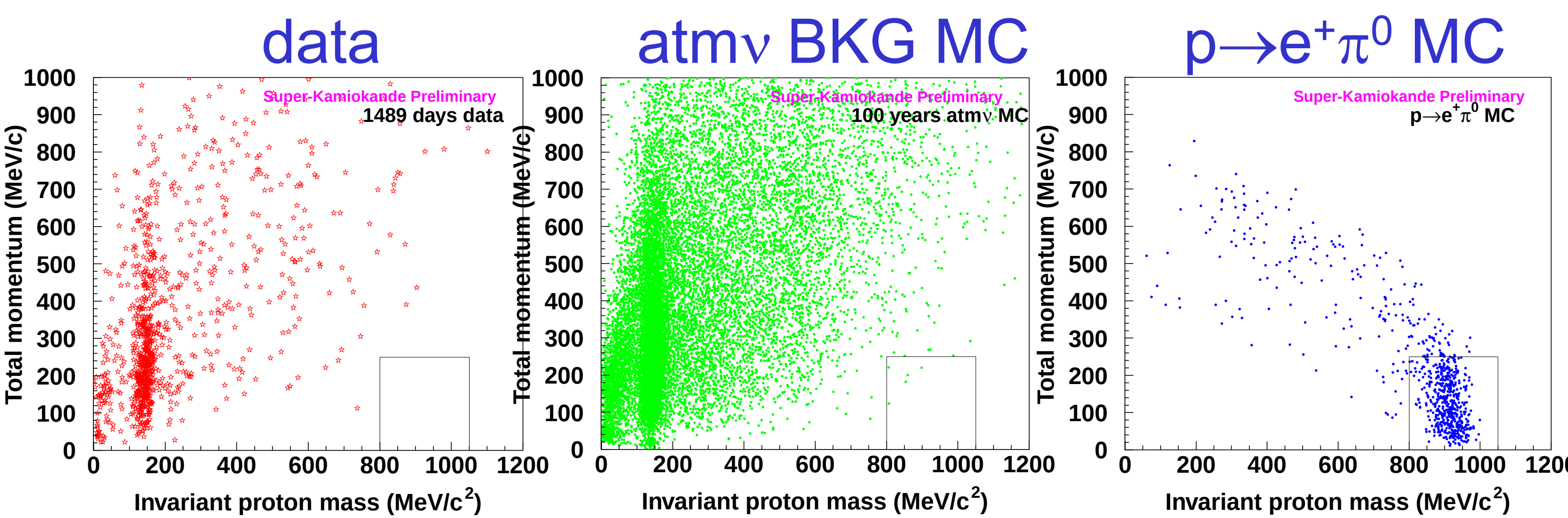
- Trigger efficiency
  … 100% (most decay modes)
- Vertex resolution
  … 30cm (1-ring)
  … 15cm ($p \rightarrow e^+\pi^0$)
- Energy resolution (ΔE/E)
  … ~ 3% (1GeV e, μ)
  … ~ 4% (236MeV μ)
- Particle identification
  … ~ 99% (1-ring e, m)
  … ~ 97% ($p \rightarrow e^+\pi^0$)

$p \to e^+\pi^0$ search (SK-I 1489 days)



selection criteria

- 2,3-ring, all e-like
- no Michel electron
- $85 < m_\pi < 185 MeV/c^2$ (3-ring)
- $p_p < 250 MeV/c$
- $800 < m_p < 1050 MeV/c^2$



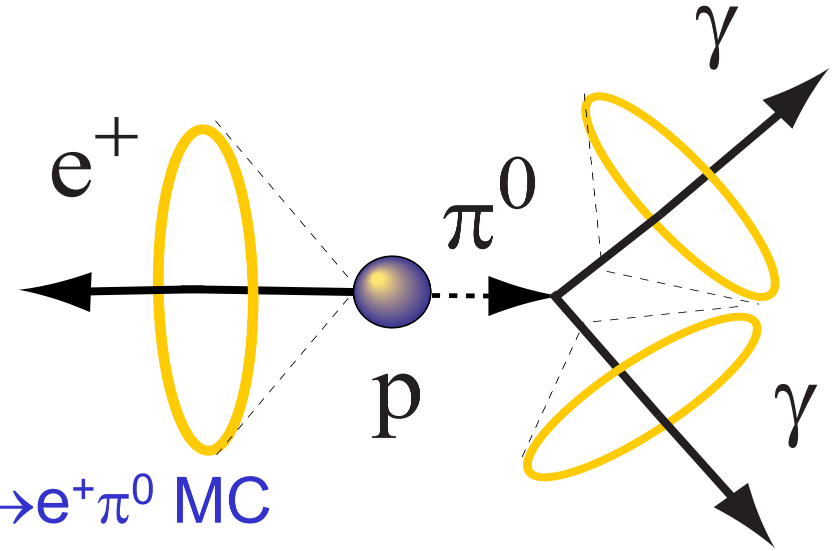
efficiency = 41%
0.3 exp'd BKG
0 candidate
(2-ring: 18.6%
3-ring: 22.3%)

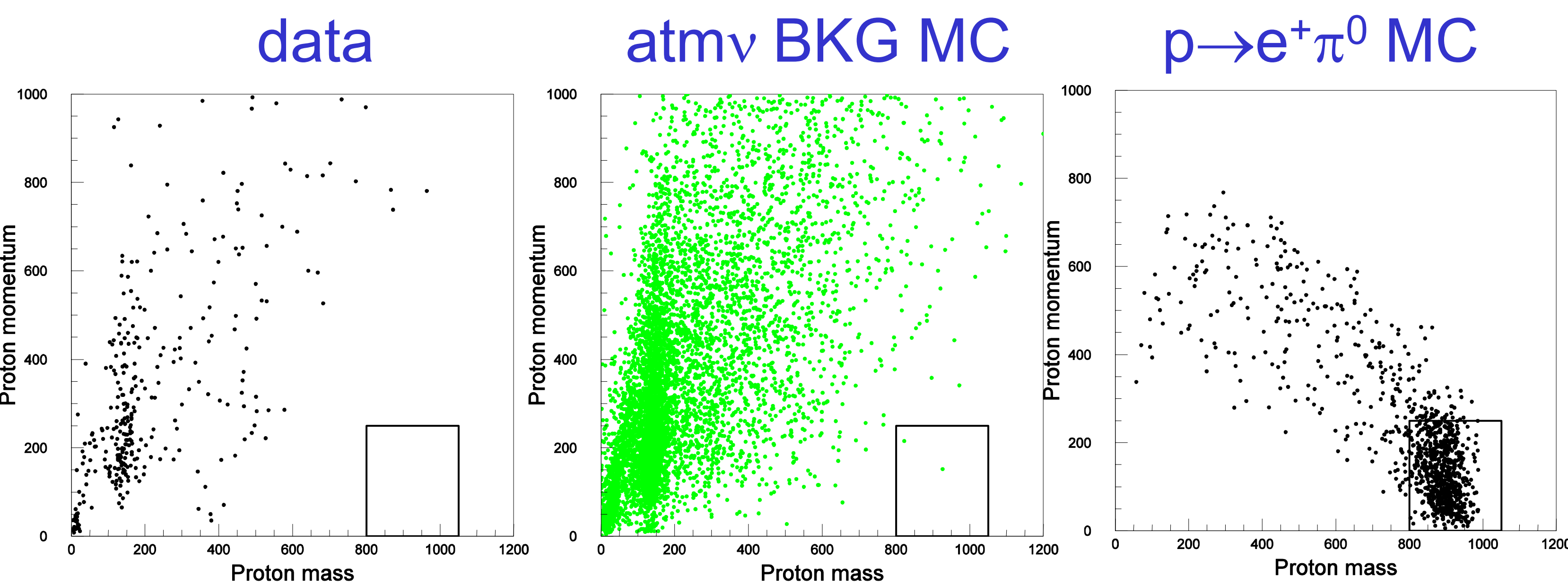
$$\tau/B(p \to e^+\pi^0) > 5.4 \times 10^{33} \text{years (90\%CL)}$$

$p \to e^+\pi^0$ search (SK-II 421 days)

selection criteria

- 2,3-ring, all e-like
- no Michel electron
- $85 < m_\pi < 185 \text{MeV}/c^2$ (3-ring)
- $p_p < 250 \text{MeV}/c$
- $800 < m_p < 1050 \text{MeV}/c^2$



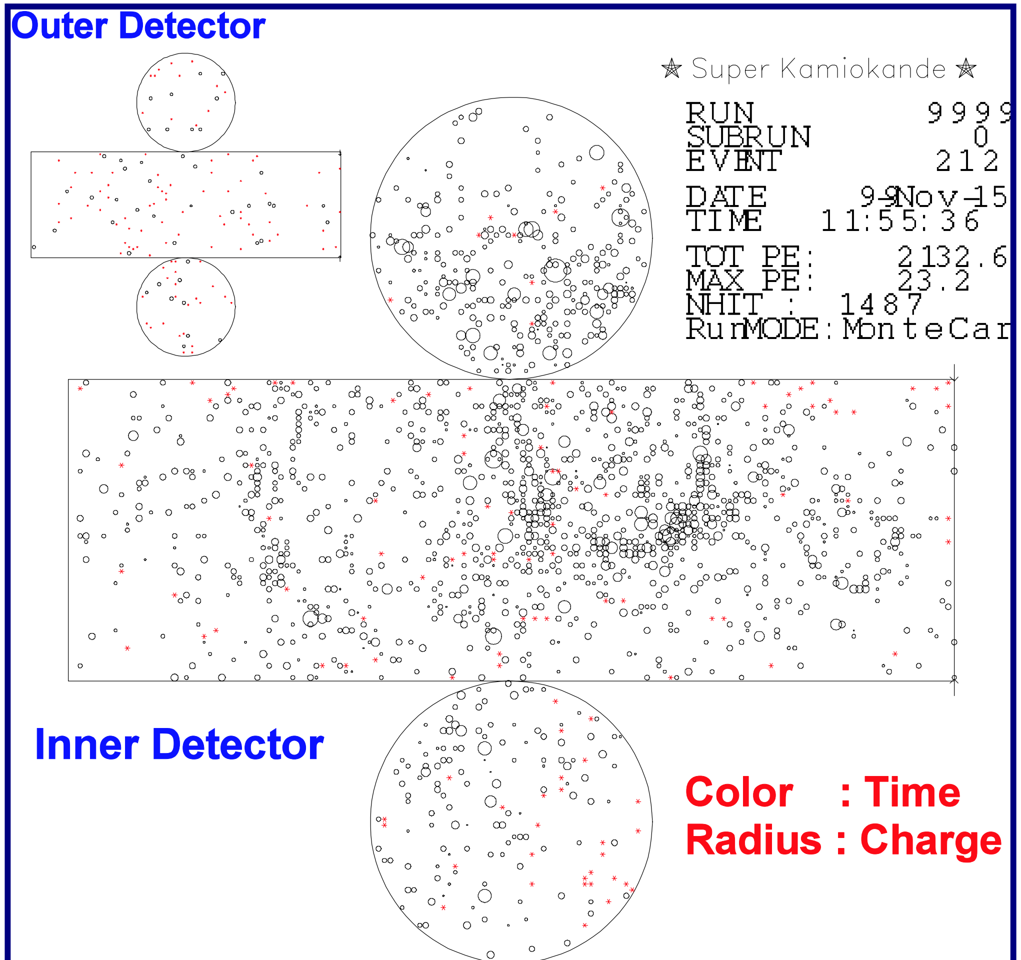


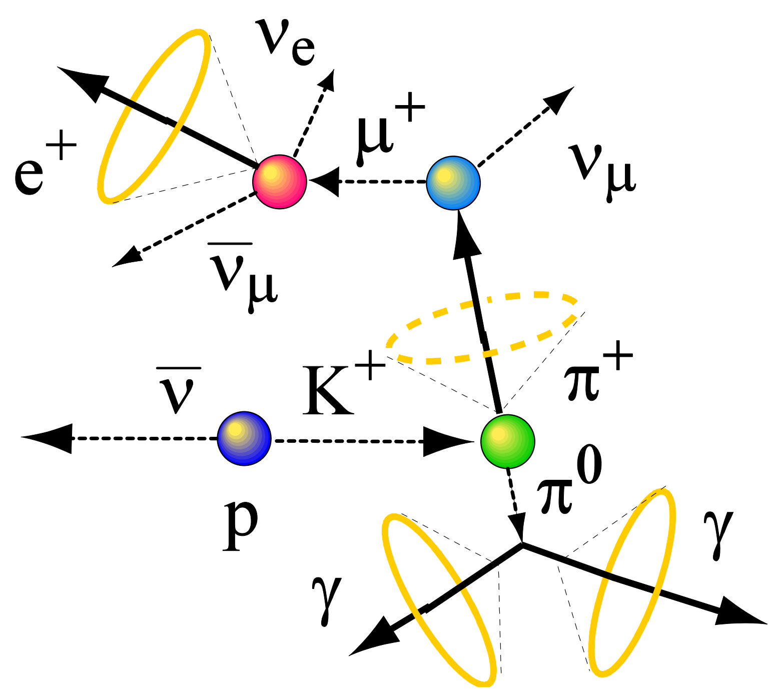
efficiency = 41%
0.1 exp'd BKG
0 candidate
(2-ring: 20.5%
3-ring: 20.5%)

$$\tau/B(p \to e^+\pi^0) > 1.5 \times 10^{33} \text{years} \ (90\%\text{CL})$$

$p \to \nu K^+$, $K^+ \to \pi^+\pi^0$ search (SK-I)

typical $p \to \nu K^+$, $K^+ \to \pi^+\pi^0$ MC event

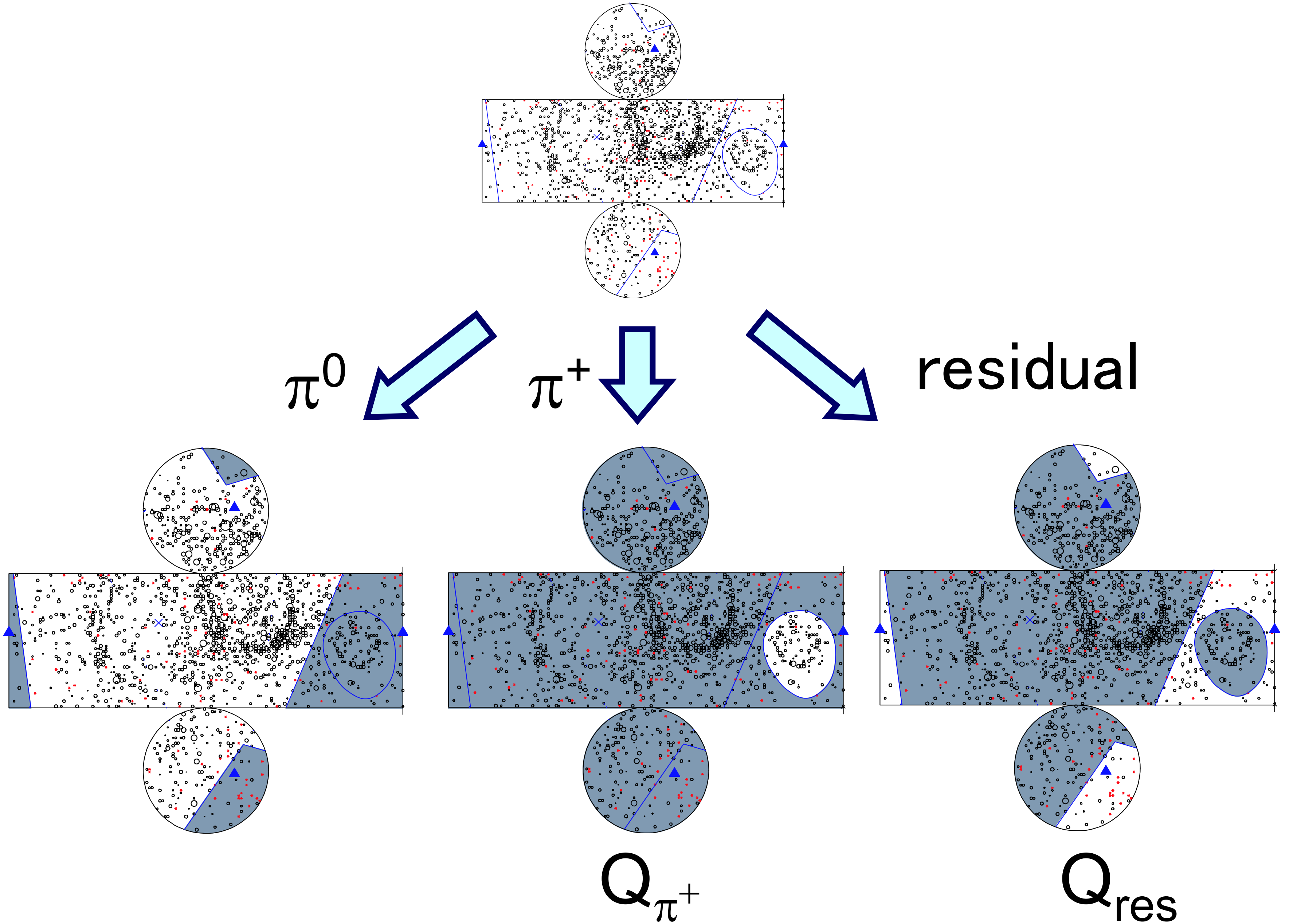




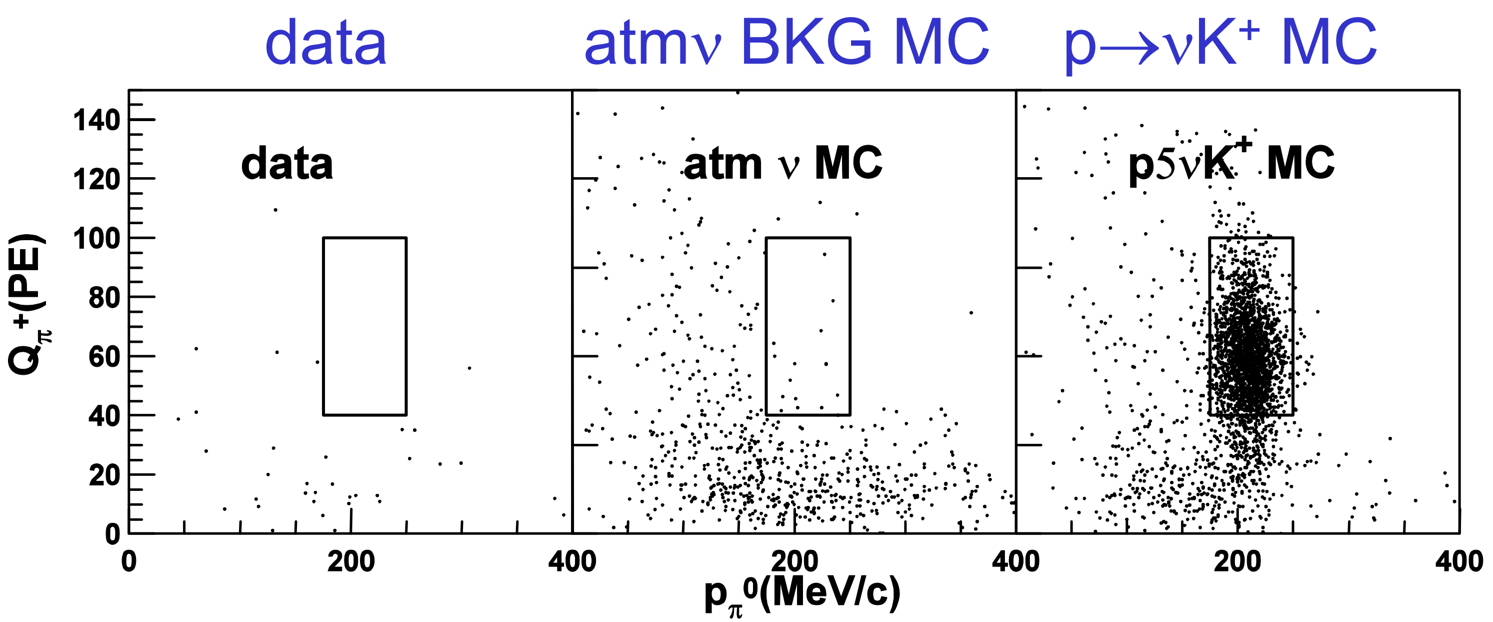
selection criteria

- 2 e-like ring
- 1 Michel electron
- $85 < m_{\pi^0} < 185$ MeV/c^2
- $175 < p_{\pi^0} < 250$ MeV/c
- $40 < Q_{\pi^+} < 100$PE, $Q_{res} < 70$PE

method of $p \rightarrow \nu K^+$, $K^+ \rightarrow \pi^+ \pi^0$ search



$p \to \nu K^+$, $K^+ \to \pi^+ \pi^0$ search (SK-I)

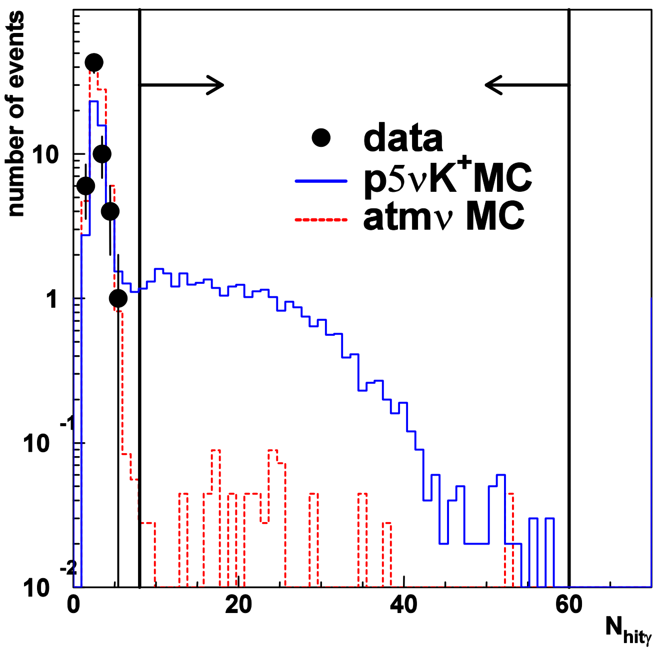


efficiency = 6.0%
0.6 exp'd BKG
0   candidate

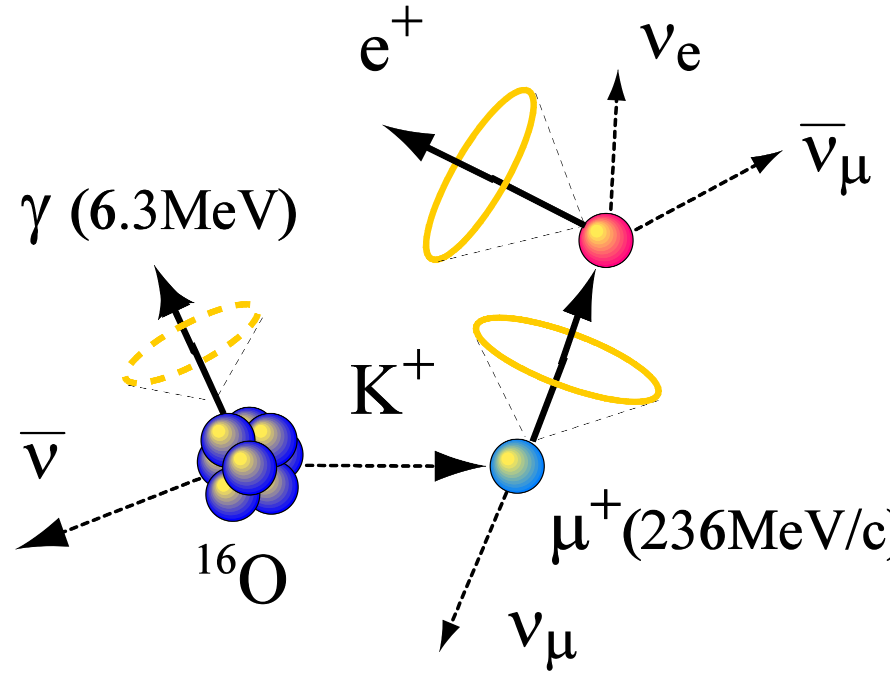
$^{16}O \to \nu K^{+} {}^{15}N\gamma$, $K^+ \to \mu^+ \nu$ search (SK-I)

selection criteria

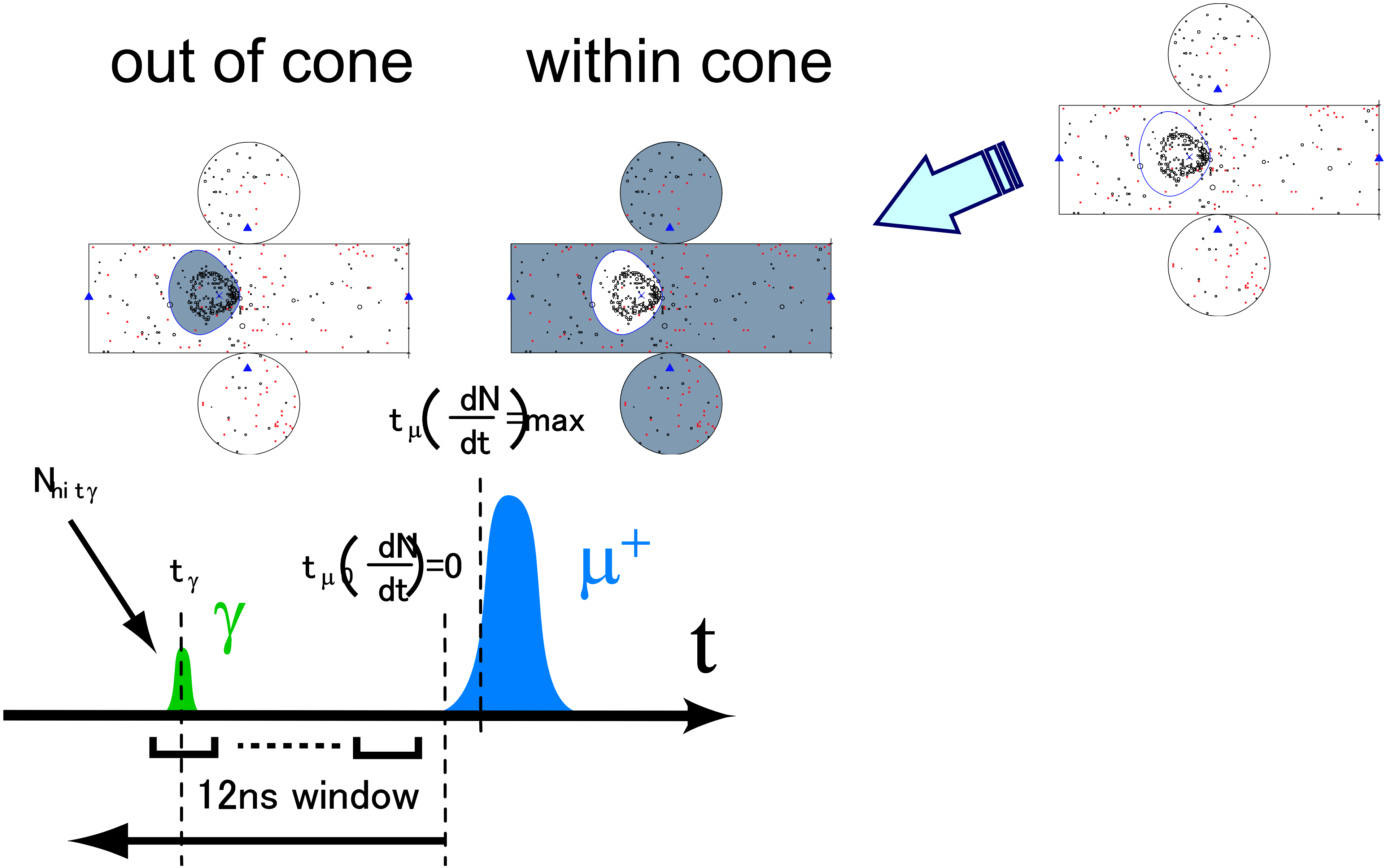
- 1 μ-like ring
- 1 Michel electron
- $210 < p_{\mu^+} < 260$ MeV/c
- proton rejection cut
- $7 < N_{hit\gamma} < 60$



efficiency = 8.6%
0.7 exp'd BKG
0 candidate



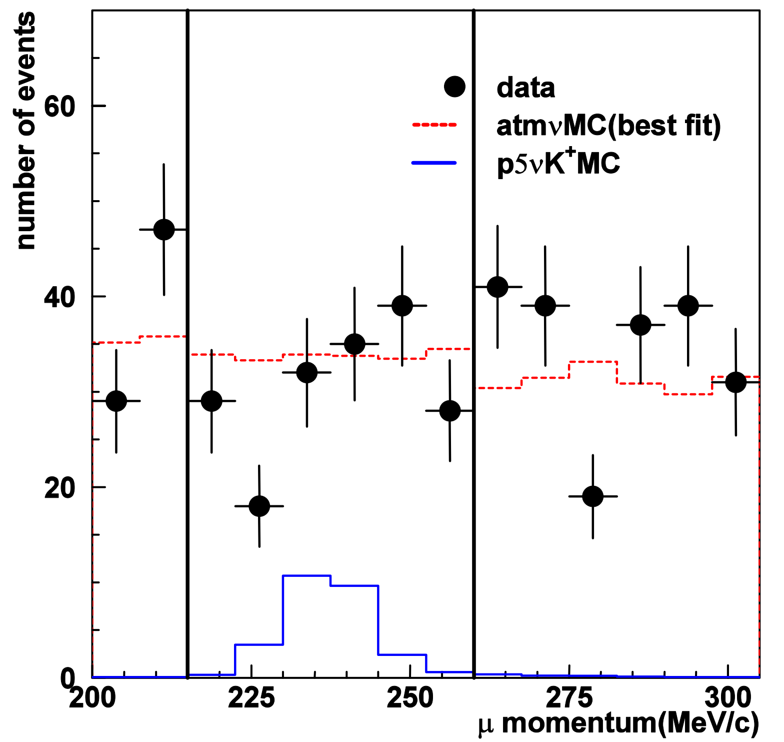
method of $^{16}O \to \nu K^{+15}N\gamma$, $K^+ \to \mu^+\nu$ search



$p \to \nu K^+$, $K^+ \to \mu^+ \nu$ search (SK-I)

selection criteria

- 1 μ-like ring
- 1 Michel electron
- $p_\mu < 300$MeV/c
- Not gamma-tag



No excess

$\to$ three searches combine

$$\tau/B(p \to \nu K^+) > 2.3 \times 10^{33} \text{years (90\%CL)}$$

systematic uncertainties in $p \to \nu K^+$ search (SK-I)

<detection efficiency>

	$K^+ \to \mu^+ \nu$ shape fit	$K^+ \to \mu^+ \nu$ γ search	$K^+ \to \pi^+ \pi^0$
π^+-^{16}O σ	---	---	4.8
water parameter	1.8	4.7	6.7
energy scale	1.4	2.6	<2.2
nuclear γ emission	---	19.	---
total	**2.5**	**20.**	**8.8**

<expected background>

	$K^+ \to \mu^+ \nu$ shape fit	$K^+ \to \mu^+ \nu$ γ search	$K^+ \to \pi^+ \pi^0$
ν cross section	30	32	39
atm ν flux	20	20	20
energy scale	1.9	32	43
particle ID	1.3	32	43
total	**36.**	**59.**	**74.**

Summary of nucleon decay searches in Super-Kamiokande-I

Summary of Nucleon Decay Searches

mode	exposure (kt· yr)	εB_m (%)	observed event	B.G.	τ/B limit (10^{32} yrs)
$p \to e^+ + \pi^0$	92	40	0	0.2	54
$p \to \mu^+ + \pi^0$	92	32	0	0.2	43
$p \to e^+ + \eta$	92	17	0	0.2	23
$p \to \mu^+ + \eta$	92	9	0	0.2	13
$n \to \bar{\nu} + \eta$	45	21	5	9	5.6
$p \to e^+ + \rho$	92	4.2	0	0.4	5.6
$p \to e^+ + \omega$	92	2.9	0	0.5	3.8
$p \to e^+ + \gamma$	92	73	0	0.1	98
$p \to \mu^+ + \gamma$	92	61	0	0.2	82
$p \to \bar{\nu} + K^+$	92				23
$K^+ \to \nu\mu^+$ (shape)		36	--	--	6.4
prompt $\gamma + \mu^+$		8.6	0	0.7	10
$K^+ \to \pi^+\pi^0$		6.0	0	0.6	7.8
$n \to \bar{\nu} + K^0$	92				1.3
$K^0 \to \pi^0\pi^0$		6.9	14	19.2	1.3
$K^0 \to \pi^+\pi^-$		5.5	20	11.2	0.69
$p \to e^+ + K^0$	92				10
$K^0 \to \pi^0\pi^0$		9.2	1	1.1	8.4
$K^0 \to \pi^+\pi^-$					
2-ring		7.9	5	3.6	3.5
3-ring		1.3	0	0.04	1.6
$p \to \mu^+ + K^0$	92				13
$K^0 \to \pi^0\pi^0$		5.4	0	0.4	7.0
$K^0 \to \pi^+\pi^-$					
2-ring		7.0	3	3.2	4.4
3-ring		2.8	0	0.3	3.6

Summary

- proton decay analysis in SK-II has been started.
- No evidence for nucleon decay
  - $\tau/B(p\rightarrow e^{+}\pi^{0})>6.9\times10^{33}$years (SK-I&II combined)
  - $\tau/B(p\rightarrow \nu K^{+})>2.3\times10^{33}$years (SK-I)

study on one of possible improvement from Super-K to UNO

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What can be improved from current Super-K to UNO?

one of the key issue for future analysis is π^0

- proton decay via $p \to e^+ \pi^0$
- proton decay via $p \to \nu K^+$, $K^+ \to \pi^+ \pi^0$ (21%)
- critical background for ν_e signal (neutrino oscillation)

How can we improve π^0 finding efficiency?

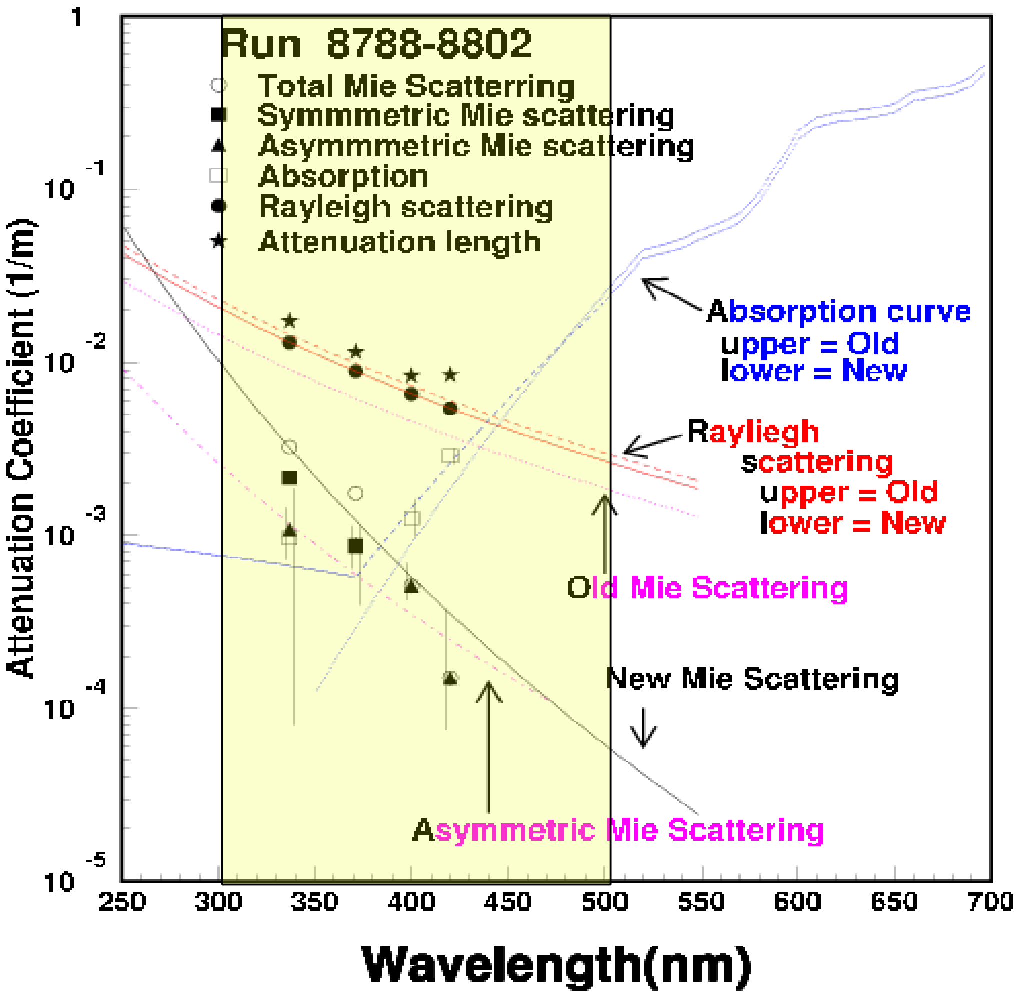
hardware

- ✓to make two gamma-ray rings clear
  - PMT finer granularity (smaller and more PMTs)
  - reduce scattering light
  - reduce reflection (black sheet, PMT)

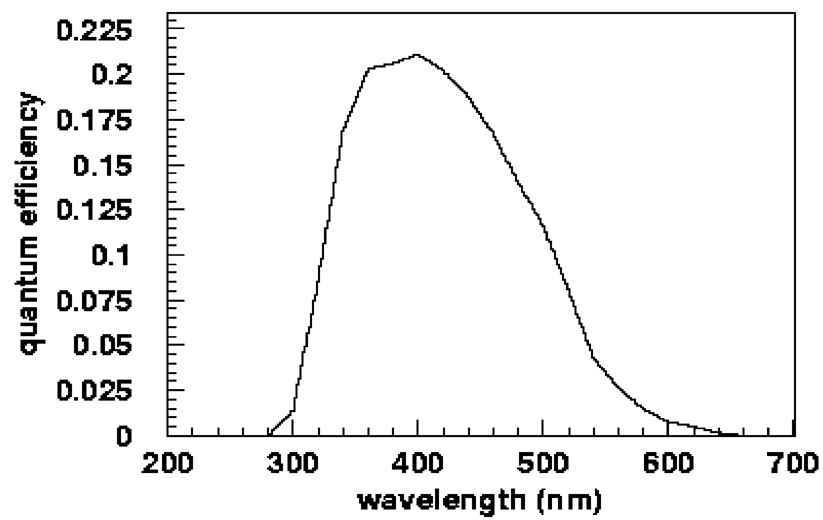
software

- ✓to make a π^0 finder by new scheme
  - polfit

current scattering parameter in Super-K MC



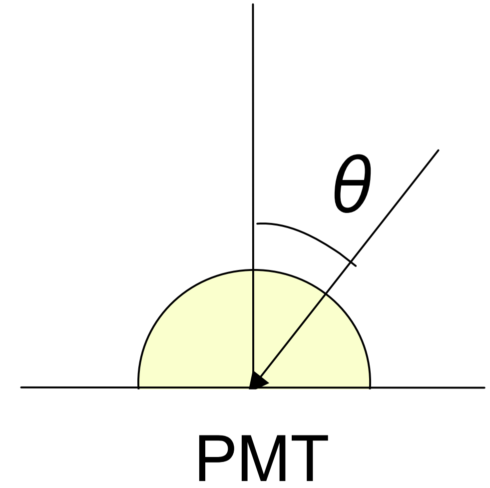
(T.Shibata, Master Thesis, Niigata univ., 2002)

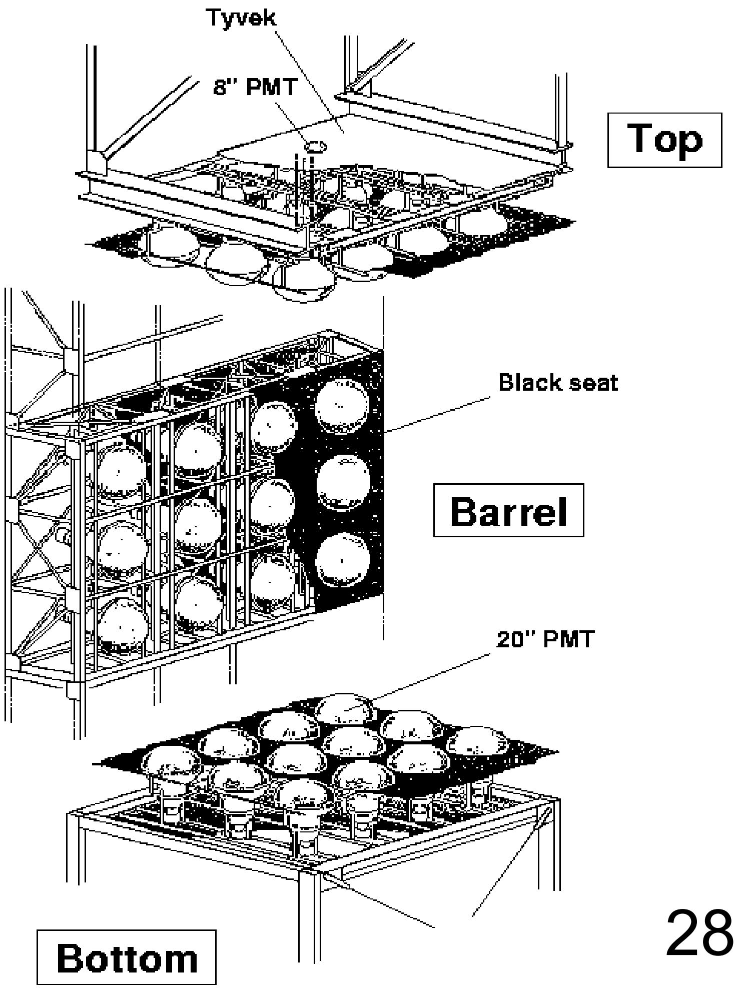


PMT quantum efficiency

attenuation length is determined
by Rayliegh scattering mainly.

PMT and black sheet reflection





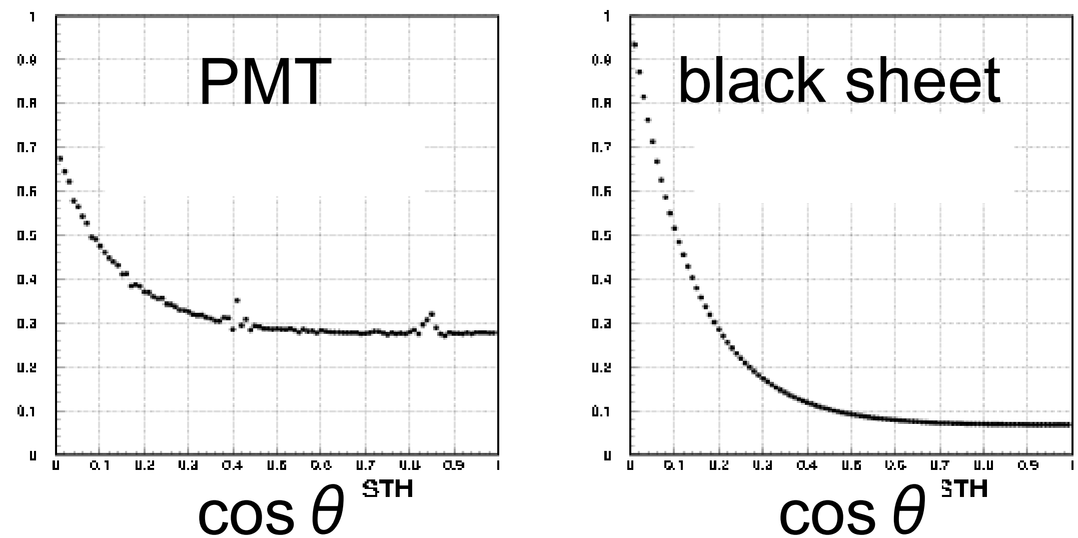


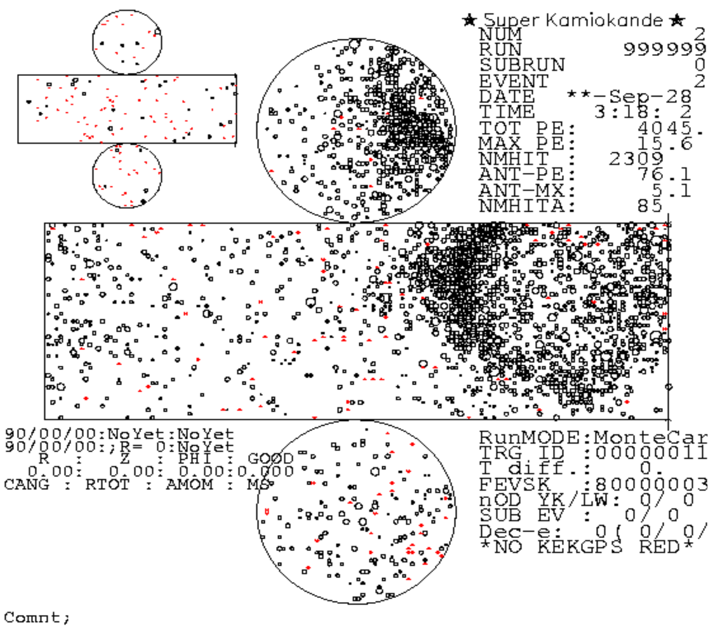
図 5.2: PMT とブラックシート上での光の反射率

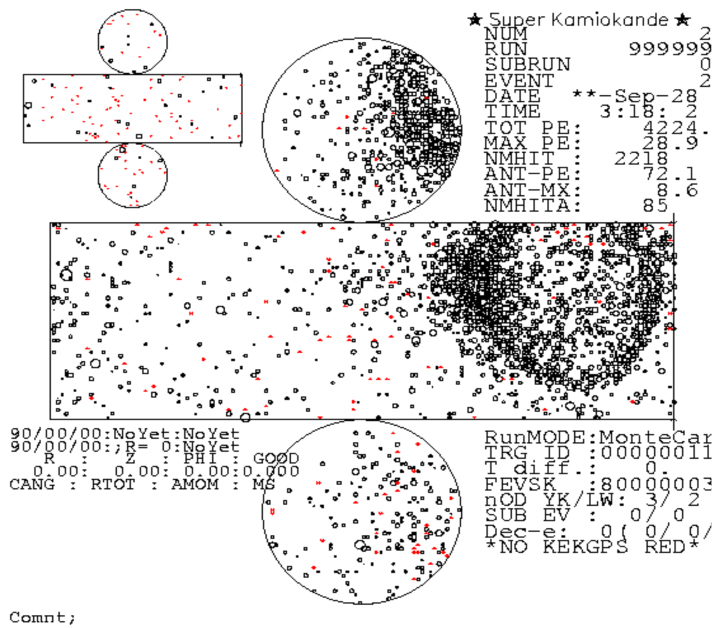
(T.Shibata, Master Thesis, Niigata univ., 2002)

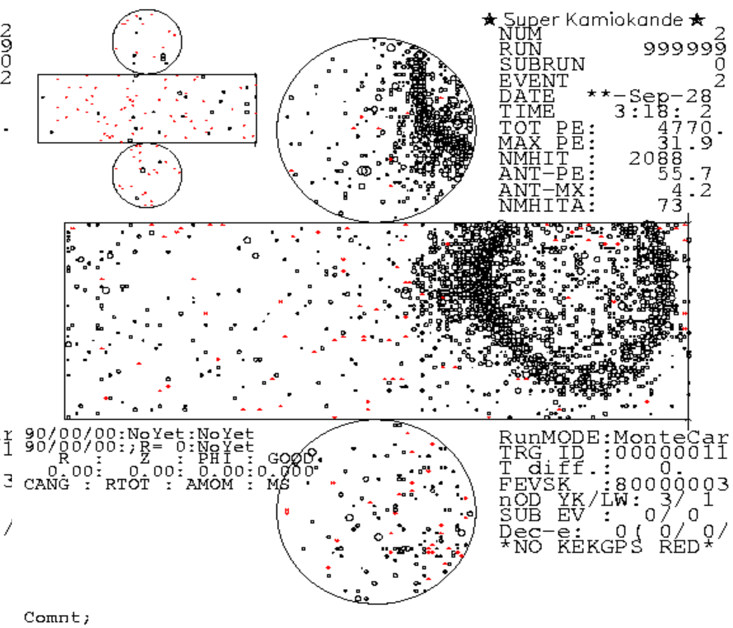
28% for PMT reflection (perpendicular)

7% for black sheet reflection (perpendicular)

electron event comparison

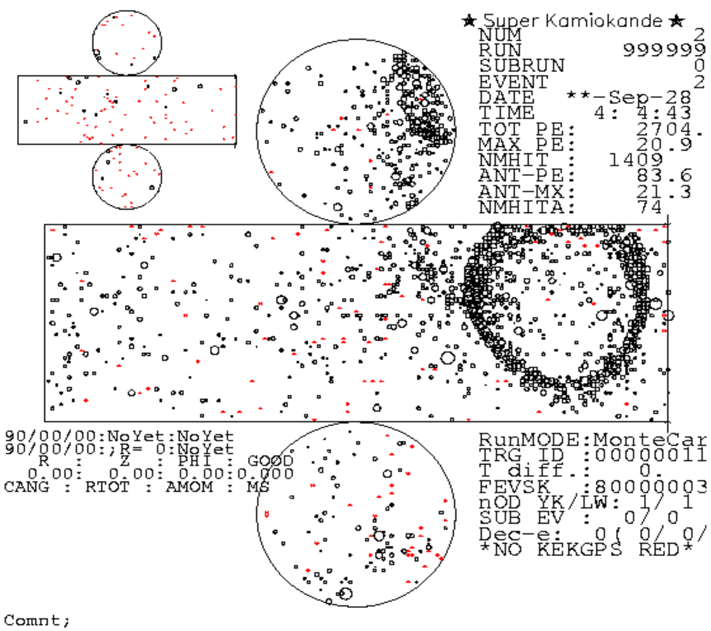


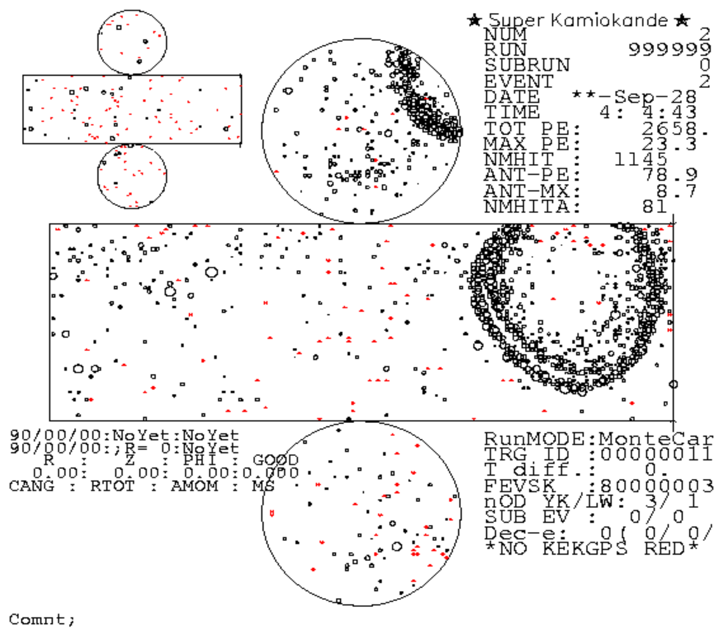


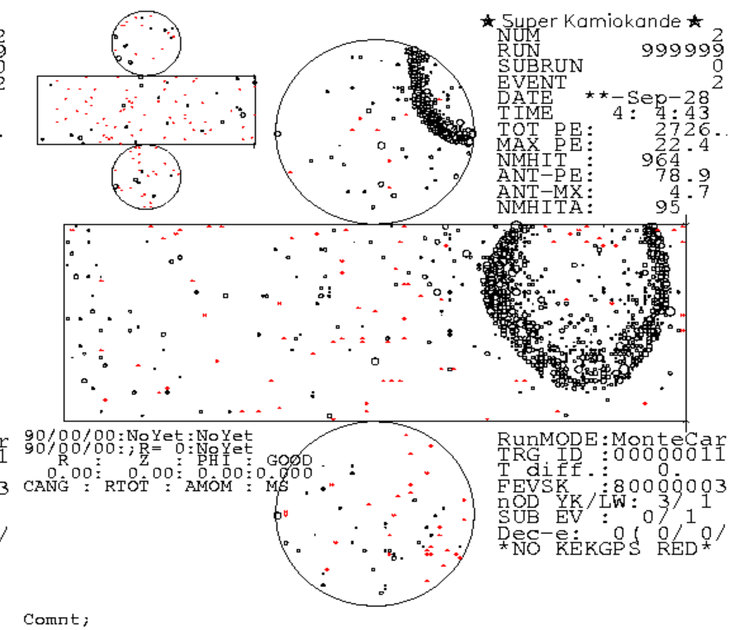


Super-K standard MC   no scattering   no scattering
no reflections

muon event comparison





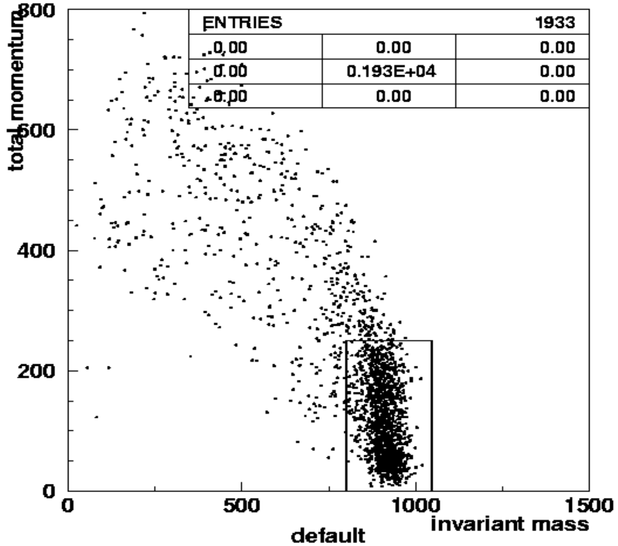


Super-K standard MC

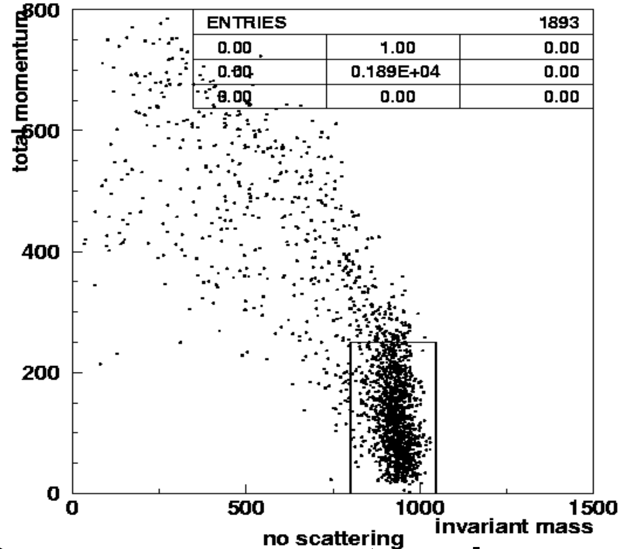
no scattering

no scattering
no reflections

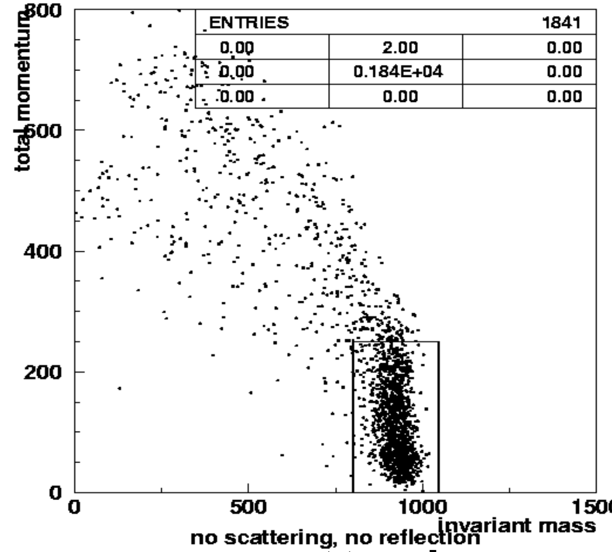
comparison of $p \rightarrow e^{+}\pi^{0}$MC



Super-K standard MC



no scattering

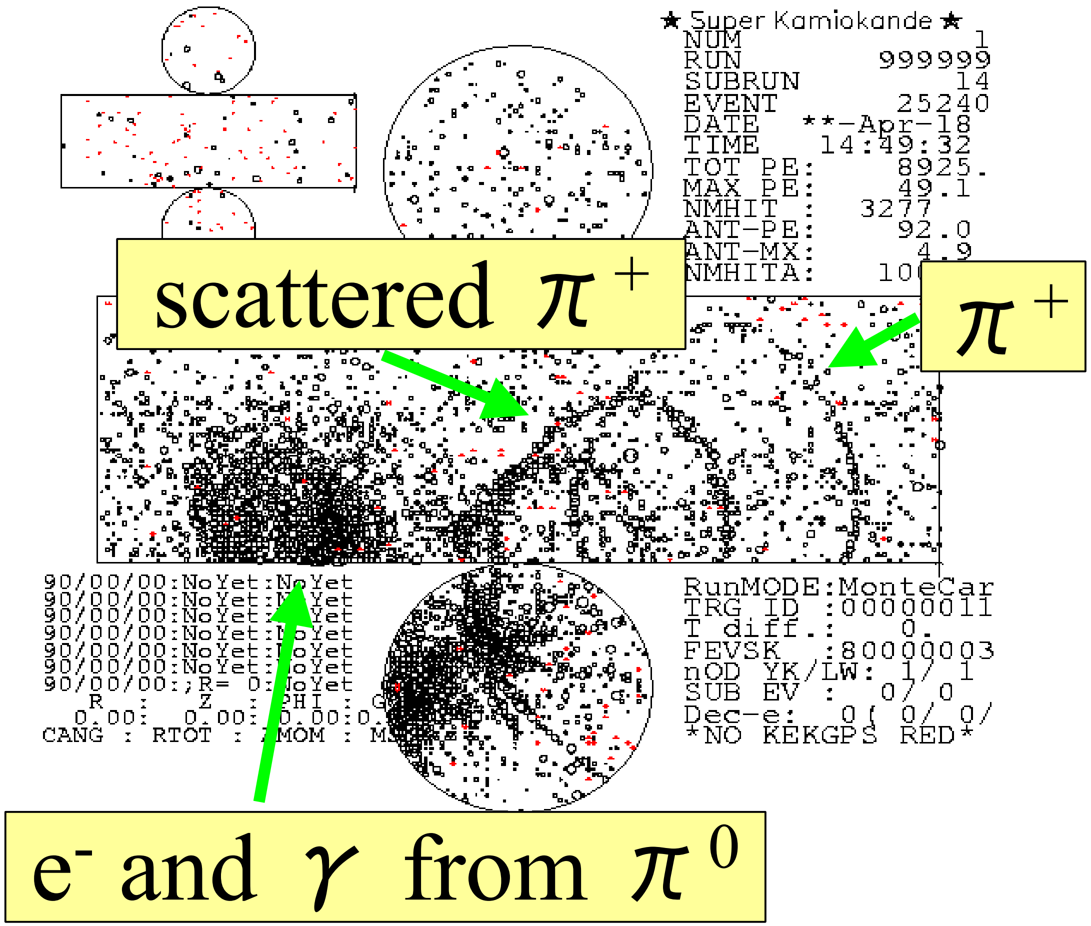


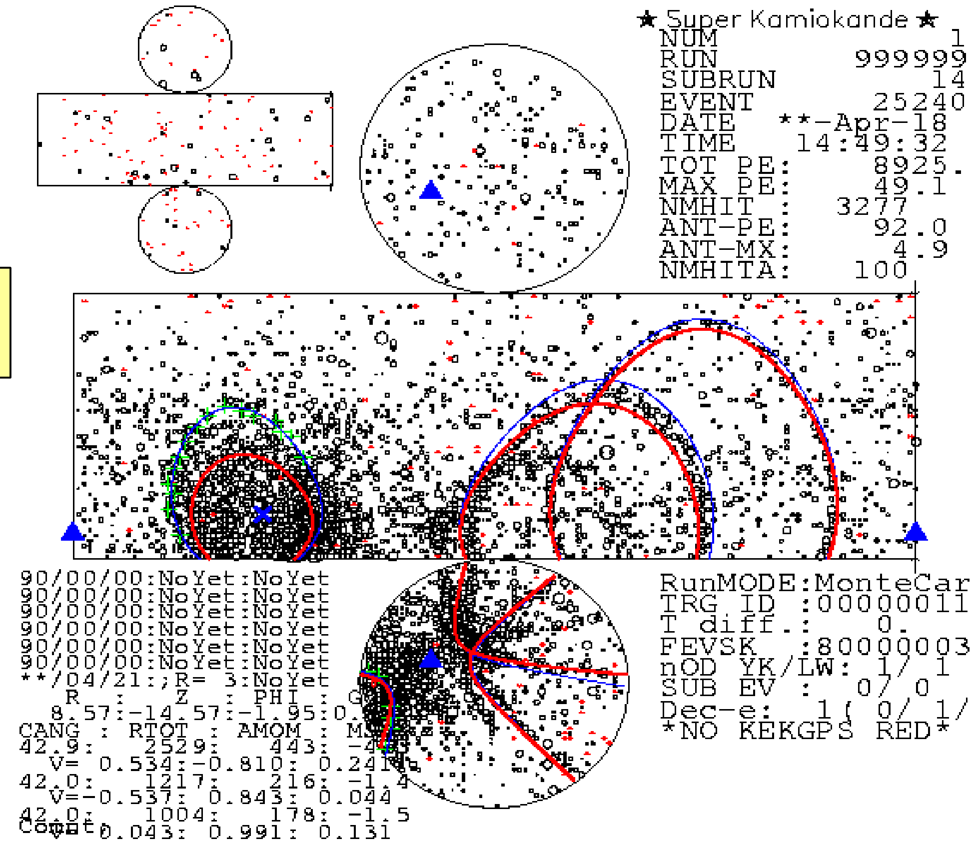
no scattering
no reflections

	detection efficiency (%)	ring finding efficiency (%) (no nuclear interactions)
Super-K standard MC	39.6±1.1	53.4±1.5
no scattering	38.5±1.0	52.9±1.5
no scatt., no reflect.	38.5±1.0	57.2±1.6

7% increase

background 1

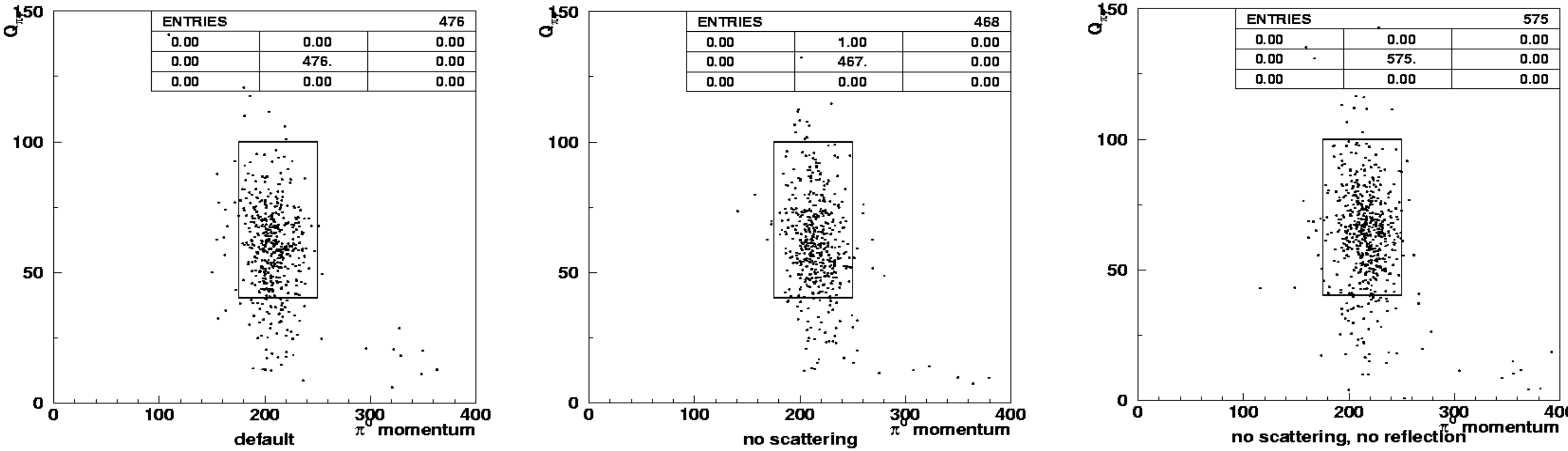




ν p→e$^-$pπ^+, proton makes π^+, π^0

detection efficiency doen't improve. But background can be reduced.

comparison of $p \to \nu K^+$, $K^+ \to \pi^+ \pi^0$ MC



Super-K standard MC | no scattering | no scattering no reflections

	detection efficiency (%)	ring finding efficiency (%) (single π0)
Super-K standard MC	5.6±0.3	62.5±2.2
no scattering	5.7±0.3	65.0±2.2
no scatt., no reflect.	7.0±0.3	67.3±2.2

25% increase | *10% increase*

Summary

- I studied one of possible improvement, light scattering in water and light reflection of PMT/black sheet. No scattering or reflections MC has higher π^0 finding efficiency by 7-10% and higher $p \to \nu K^+$, $K^+ \to \pi^+ \pi^0$ detection efficiency by 25%.
- These simulations are ideal cases. Actual detector cannot achieve no scatterings or reflections. On the other hand, reconstruction tool is not well optimized for these parameters. Improvement can be better than this result.

plan

- same study on $p \to \nu K^+$, $K^+ \to \mu^+ \nu$, γ -ray search and general π^0 events .
- effect of PMT timing resolution improvement