Nucleon decay search with Hyper-Kamiokande

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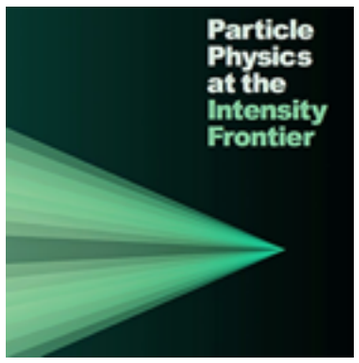
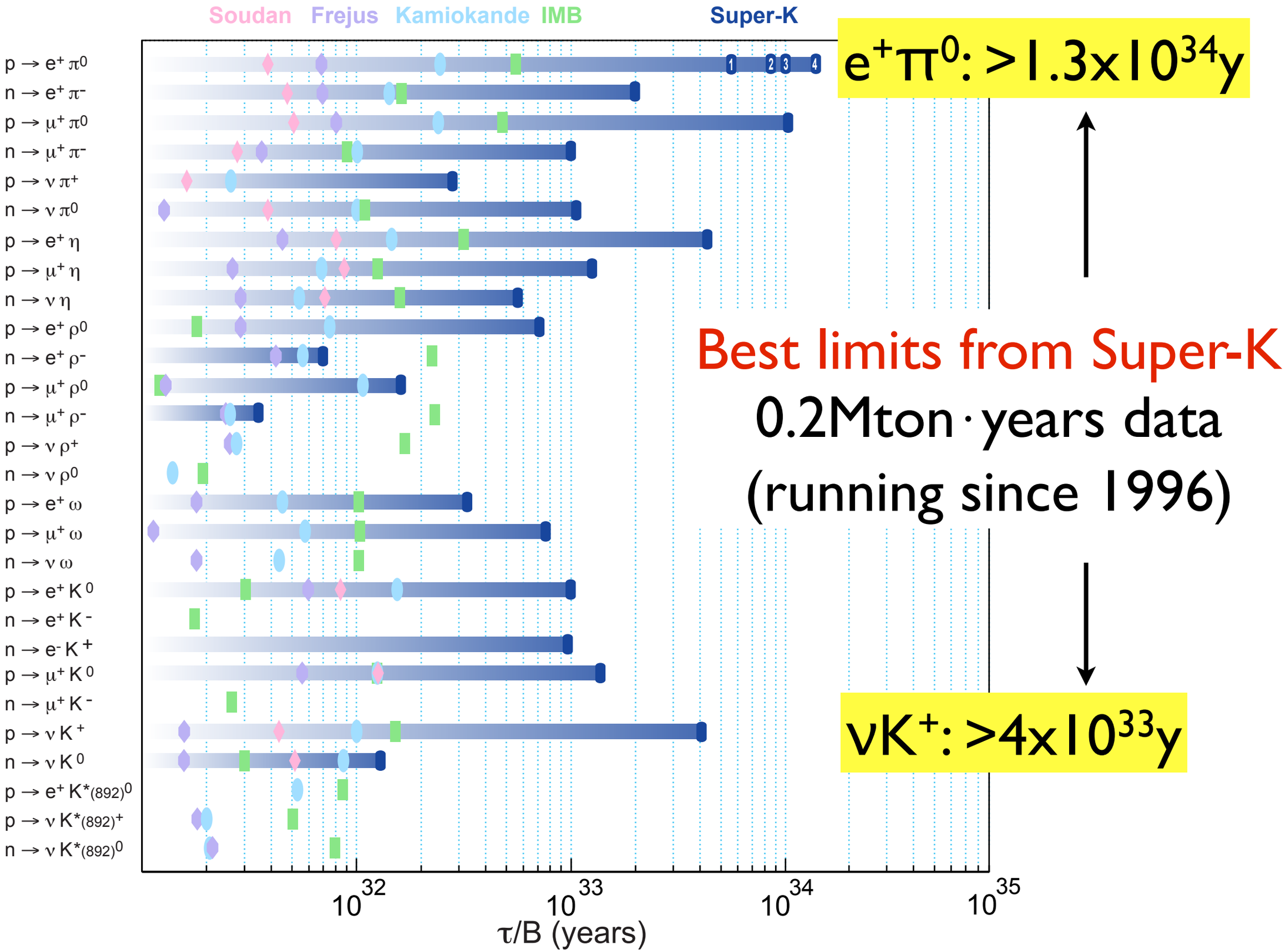


Intensity Frontier Workshop
April 25-27 2013, ANL

Nucleon decay search status



$e^+\pi^0$: $>1.3\times10^{34}$y

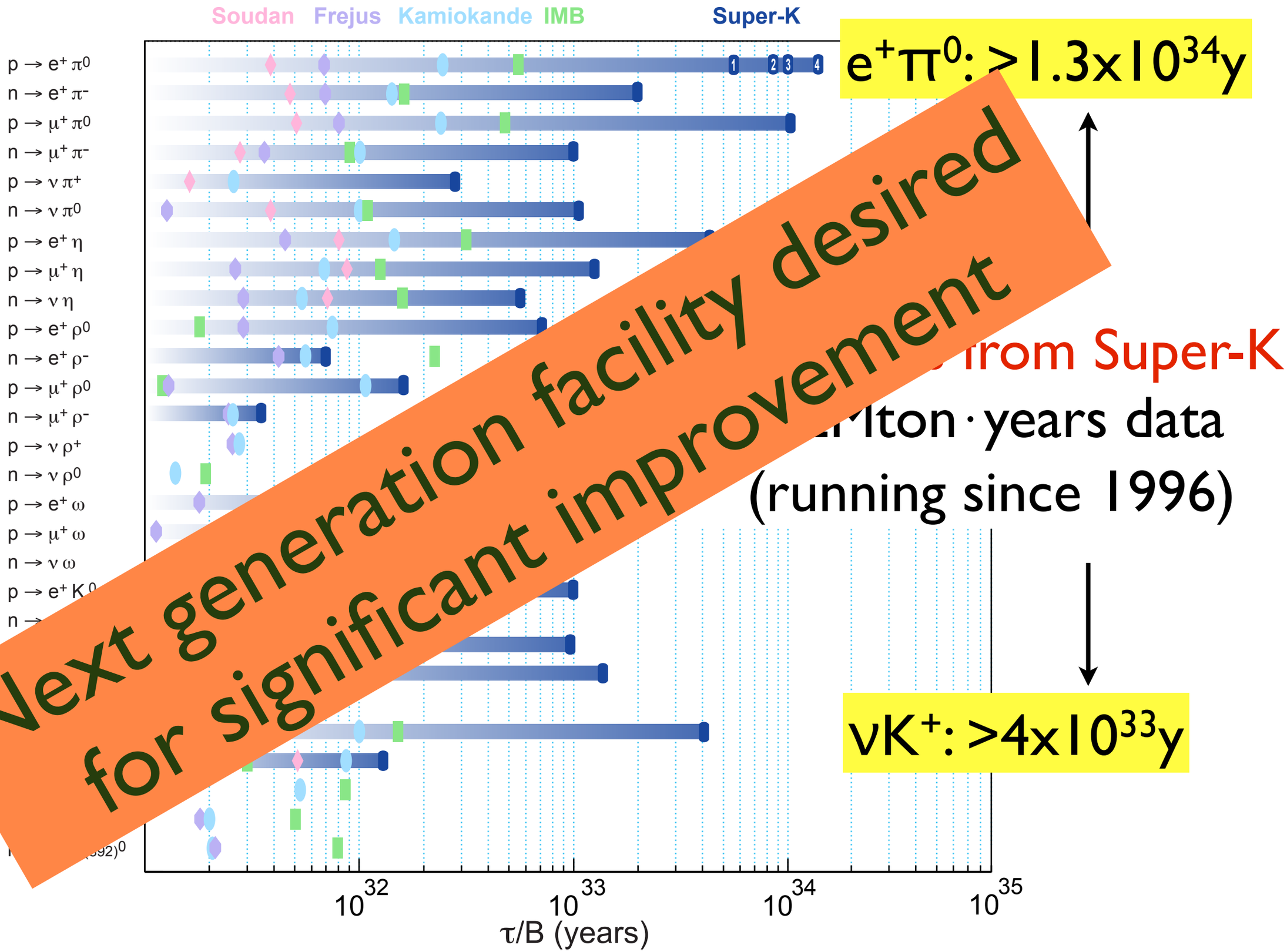
Best limits from Super-K

0.2Mton·years data

(running since 1996)

νK^+: $>4\times10^{33}$y

Nucleon decay search status



$e^+\pi^0$: >1.3x10^{34}y

from Super-K

Mton·years data

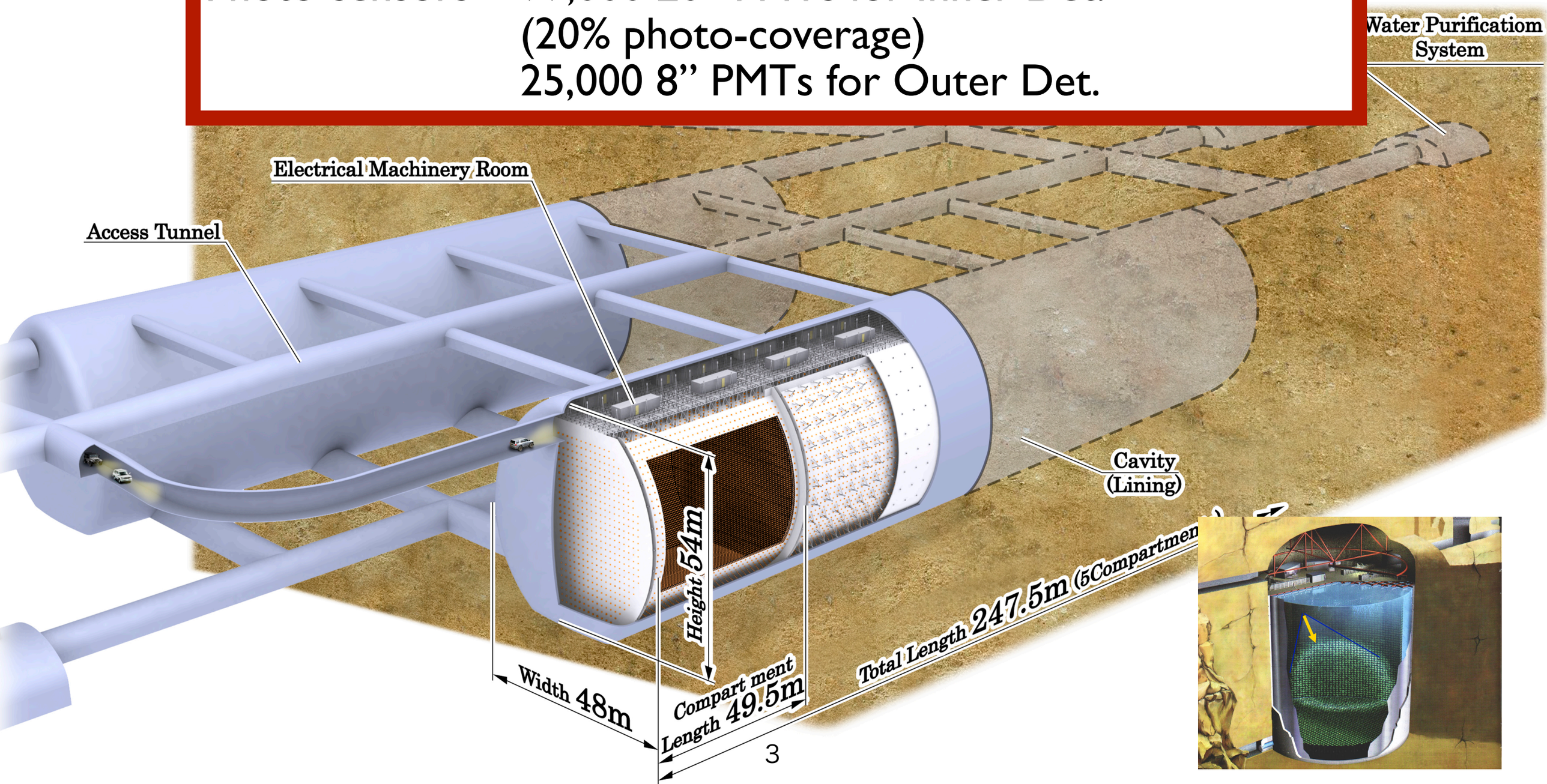
(running since 1996)

νK^+: >4x10^{33}y

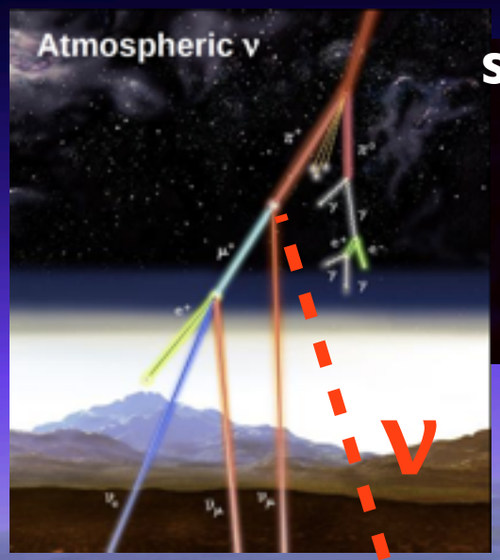
Next generation facility desired for significant improvement

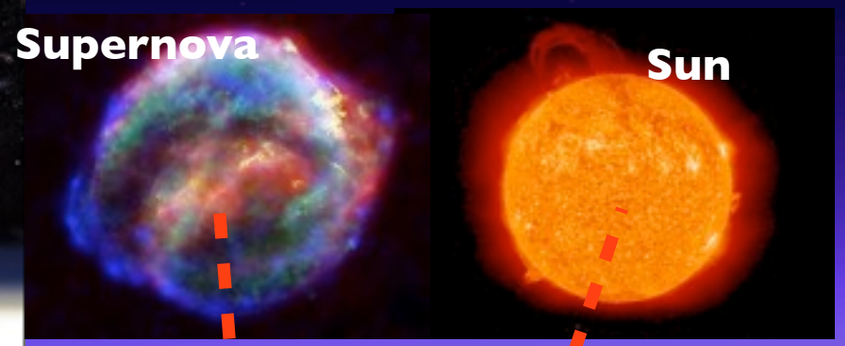
Hyper-Kamiokande

Total Volume	0.99 Megaton
Inner Volume	0.74 Mton
Fiducial Volume	0.56 Mton (0.056 Mton × 10 compartments)
Outer Volume	0.2 Megaton
Photo-sensors	99,000 20” PMTs for Inner Det. (20% photo-coverage) 25,000 8” PMTs for Outer Det.

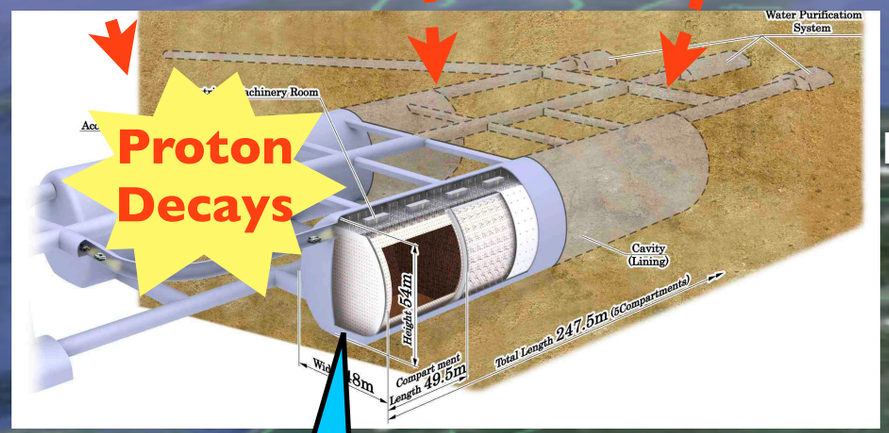


Multi-purpose detector Hyper-Kamiokande





ν ν ν



Hyper-K

Super-K

ν

J-PARC

x25 Larger ν Target
& Proton Decay Source

higher intensity ν by upgraded J-PARC

x50 of T2K

for νCP

x2 (year or power)

International open Hyper-K meetings

First meeting: Aug. 23-24, 2012

http://indico.ipmu.jp/indico/conferenceTimeTable.py?confId=7

Second meeting: Jan. 14-15, 2013

http://indico.ipmu.jp/indico/conferenceTimeTable.py?confId=10

Hyper-K is completely open to the international community

~100 participants for each of two meetings (~half from abroad)

International working group was formed

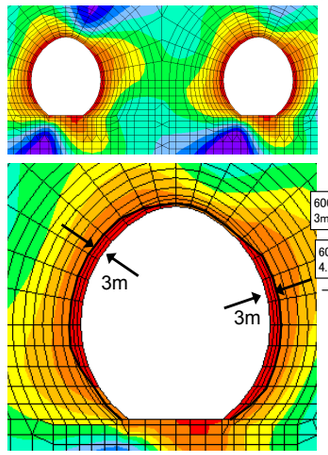
Current members from Japan, Canada, Korea, Spain, Switzerland, Russia, UK, US

More collaborators are welcome!!

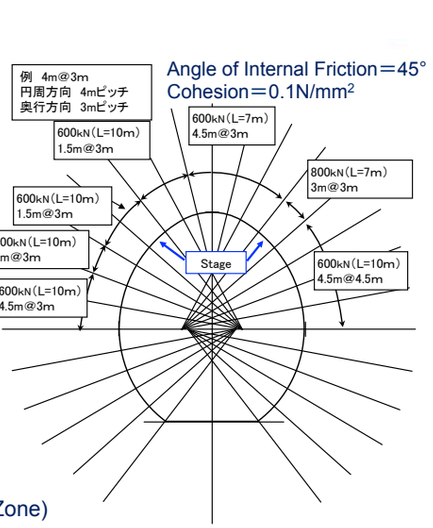
Next meeting: Jun. 21-22

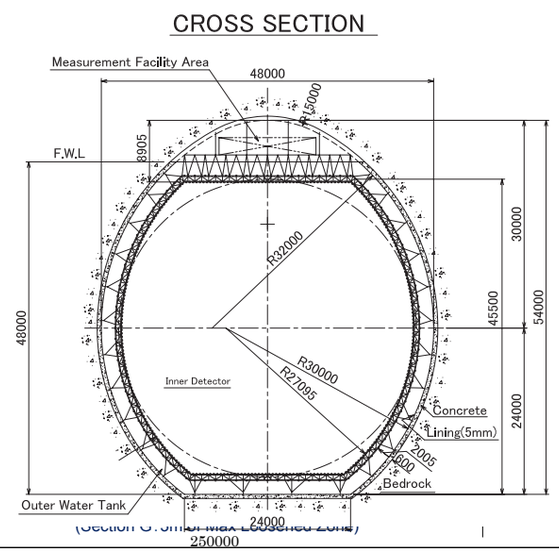
Detector design

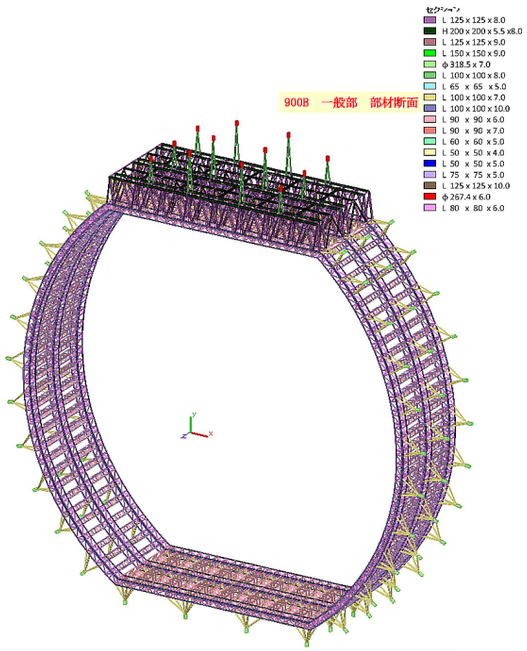
- Cavity design based on the in situ measurement of rock quality and stress
  - Feasible design established
- Optimization of cavity shape, segmentation walls, sensor support etc. ongoing

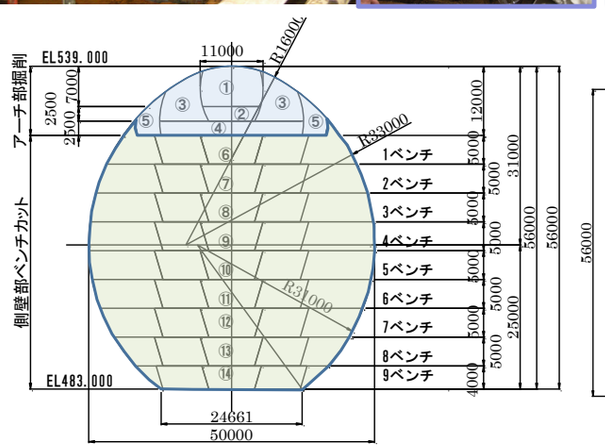


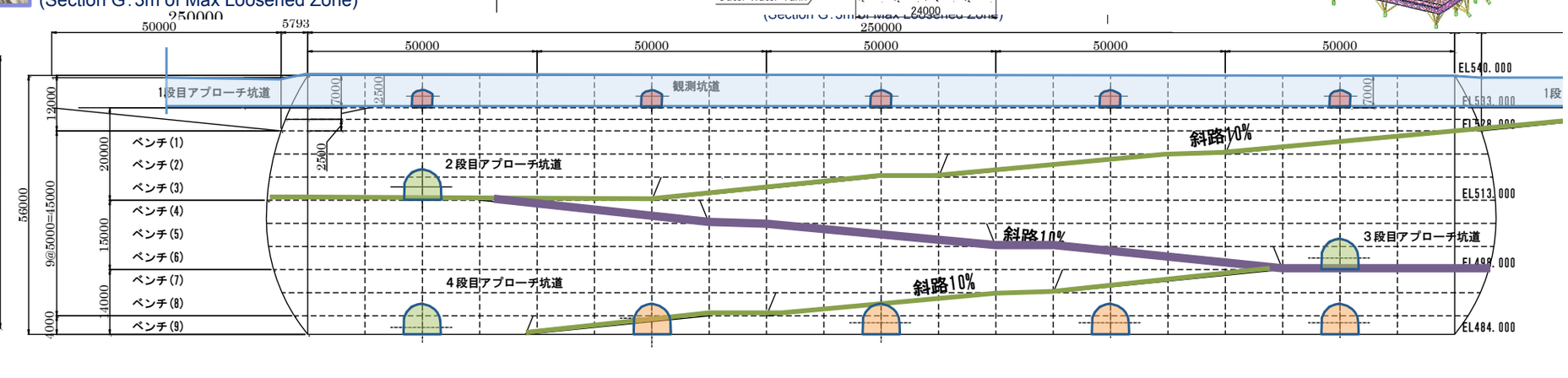
(Section G：3m of Max Loosened Zone)









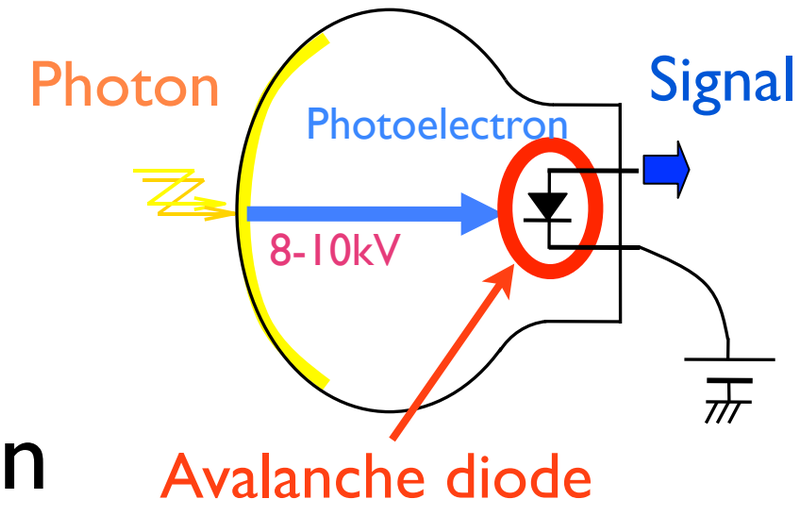


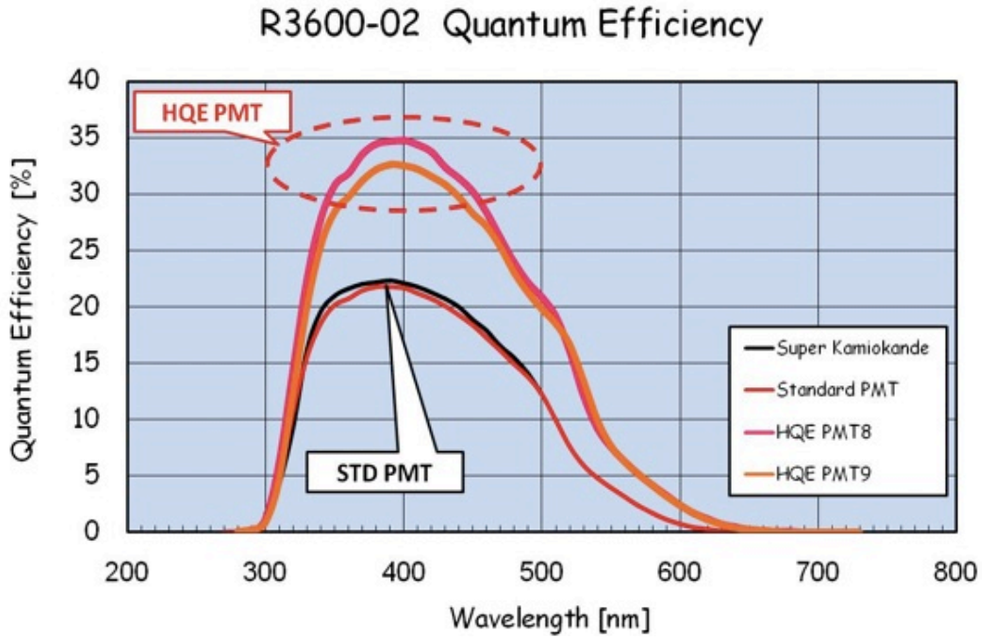
R&D of photo sensor

Developing several candidates:

- Hybrid Photodetector (HPD)
  - Photo cathode + avalanche diode
  - 8-in prototype under evaluation
  - 20-in prototype to be available soon
- 20-in PMT with improved dynode being developed in parallel
- Higher QE 20” photocathode under development
- Finish R&D and be ready for mass production in a few years

HPD

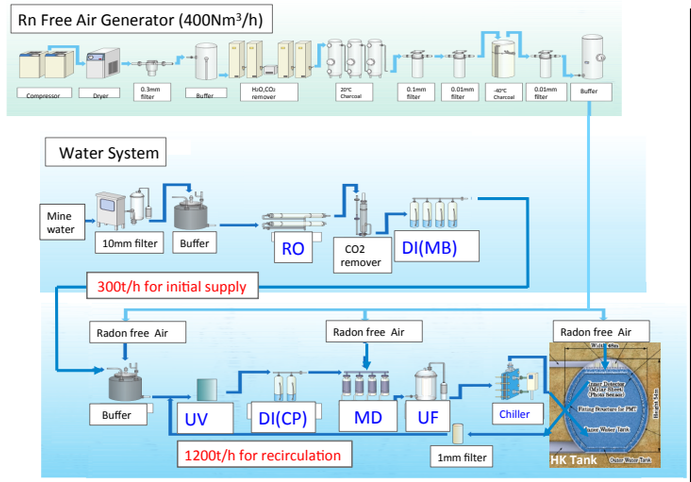


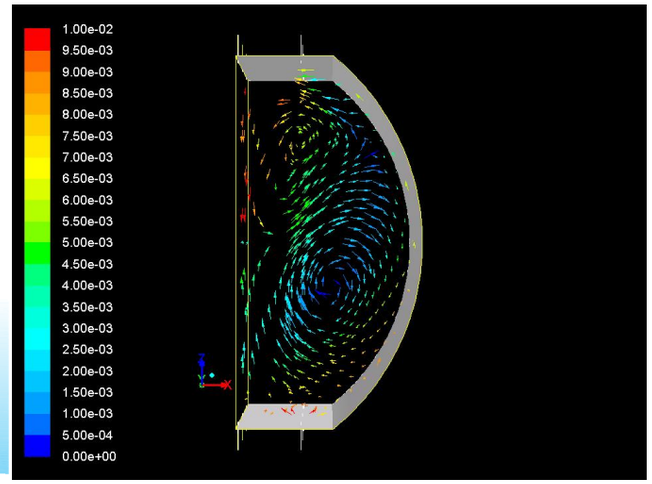


Other R&D topics

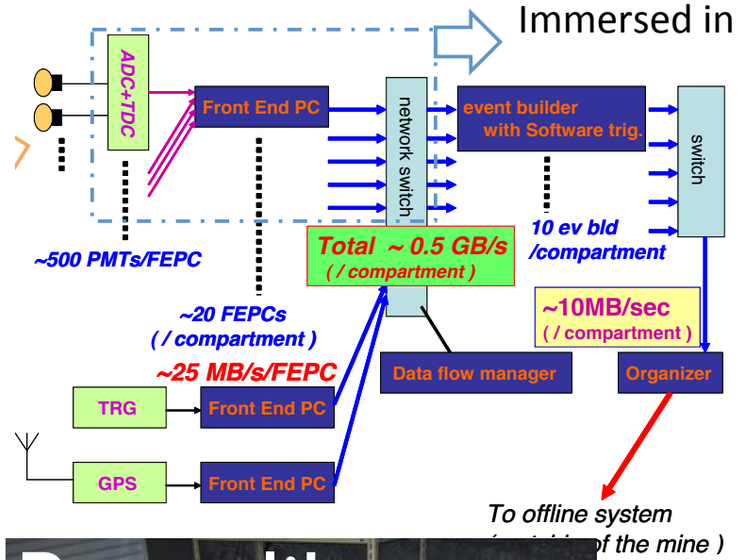
- Water system
- Readout electronics
- Calibration system
- Software development
- Physics potential
- Design of near detector(s)
- ...

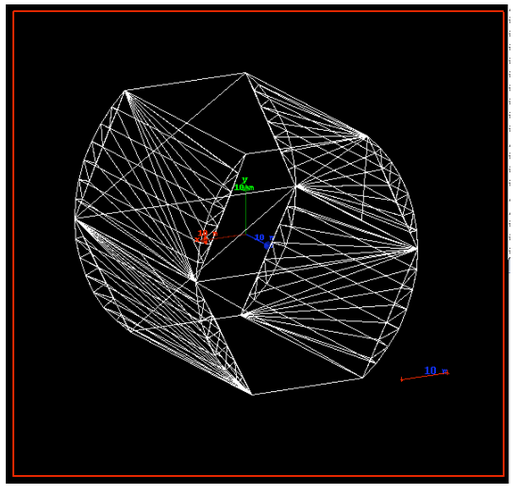
- Progress within international working group



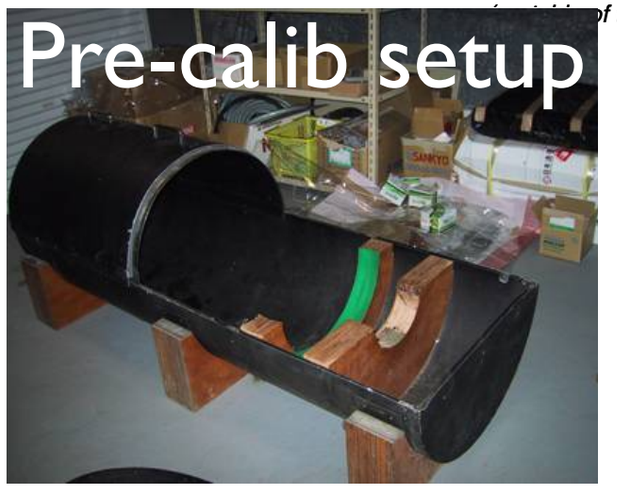


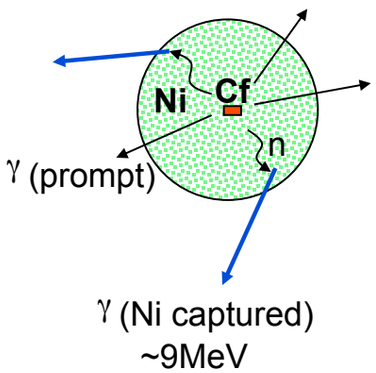
Immersed in water?





SK Nickel source





Target Schedule

Construction start

JFY2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
-4	-3	-2	-1	1	2	3	4	5	6	7	8	9

access tunnels, waste rock tunnels

cavity excavation

concrete, liner

PMT support, PMT installation

photo-sensor R&D

preparation for glass valve, PMT production

PMT production

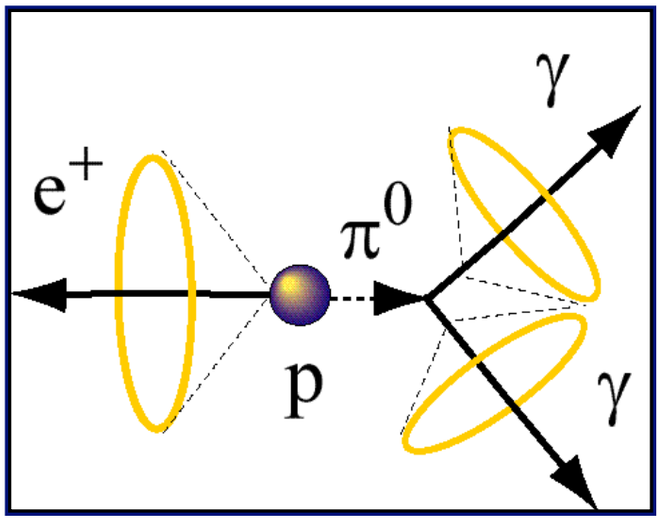
water filling

Operation

assuming budget being approved from JPY2016

Nucleon decay search with Hyper-K

$p \rightarrow e^+\pi^0$ search



$e^+\pi^0$ selection

Invariant mass of p
Momentum balance

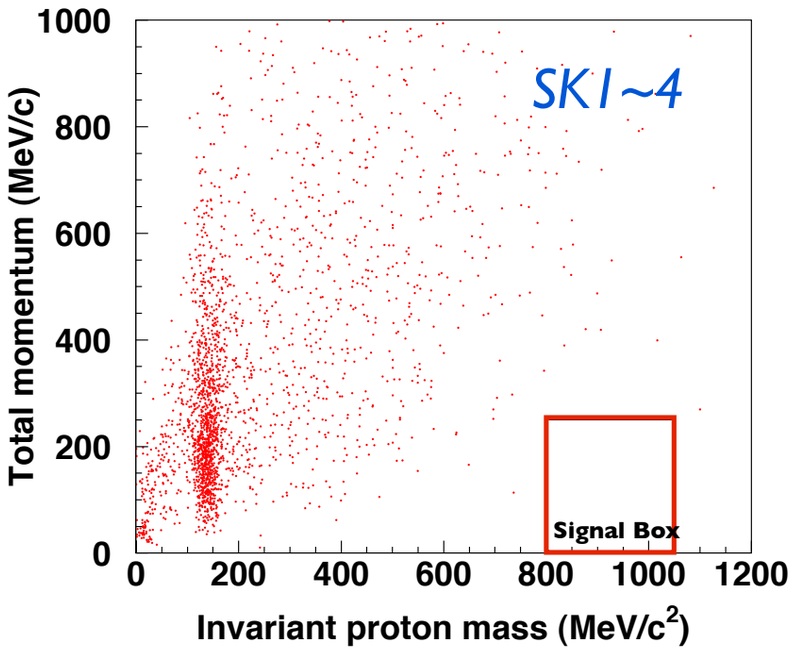
- 2 or 3 e-like rings
- No decay-e
- $85 < M\pi^0 < 185$ MeV/c^2 (3ring)
- $800 < M_p < 1050$ MeV/c^2
- $p_{tot} < 250$MeV/c

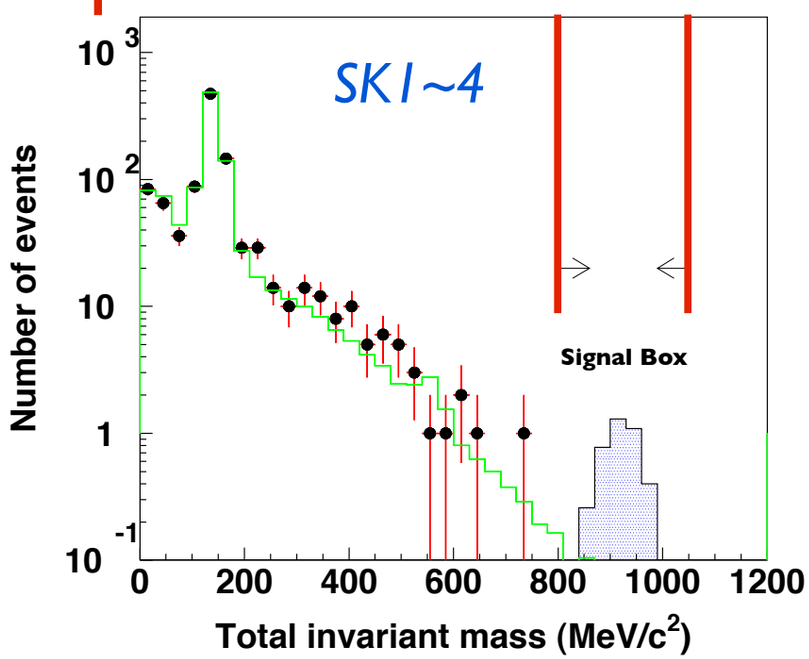
Efficiency 45%
(87% for free proton)

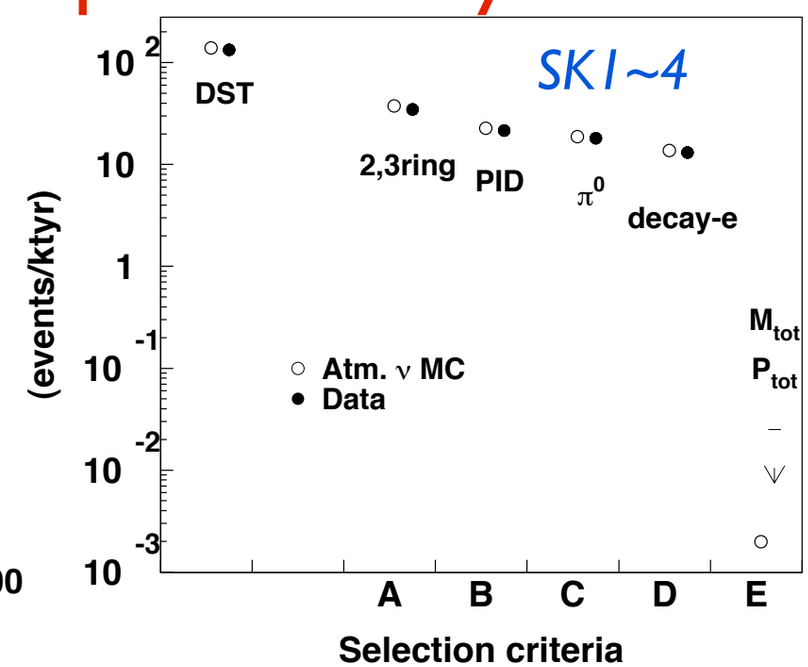
2/10 free protons in H_2O

$p \to e^+\pi^0$ search: BG (atm ν)

Super-K data are well reproduced by BG MC.

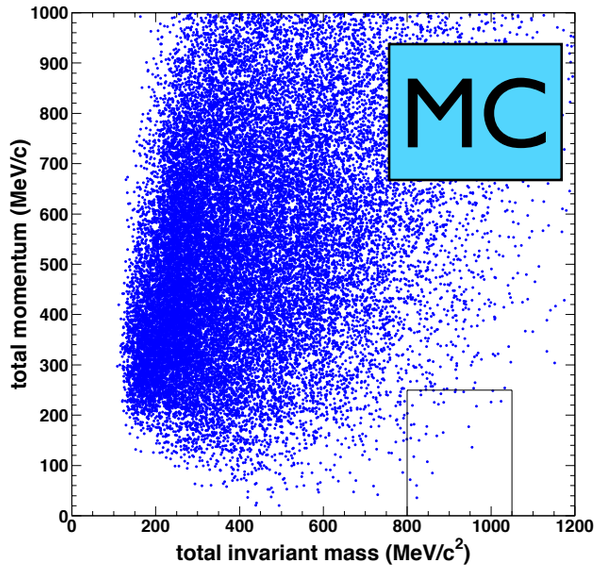


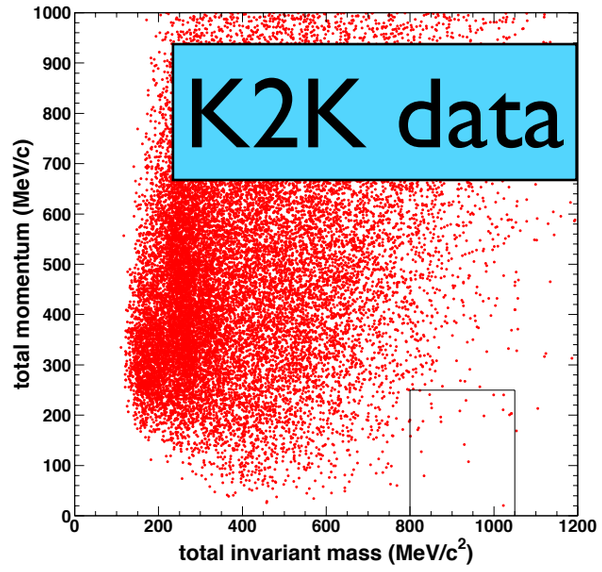




BG prediction confirmed with high statistics K2K 1kton near detector measurement

PRD 77, 032003(2008)





$1.63^{+0.42}_{-0.33}(stat.)^{+0.45}_{-0.51}(syst.)[\mathrm{Mt}\times\mathrm{years}]^{-1}(E_\nu < 3GeV)$

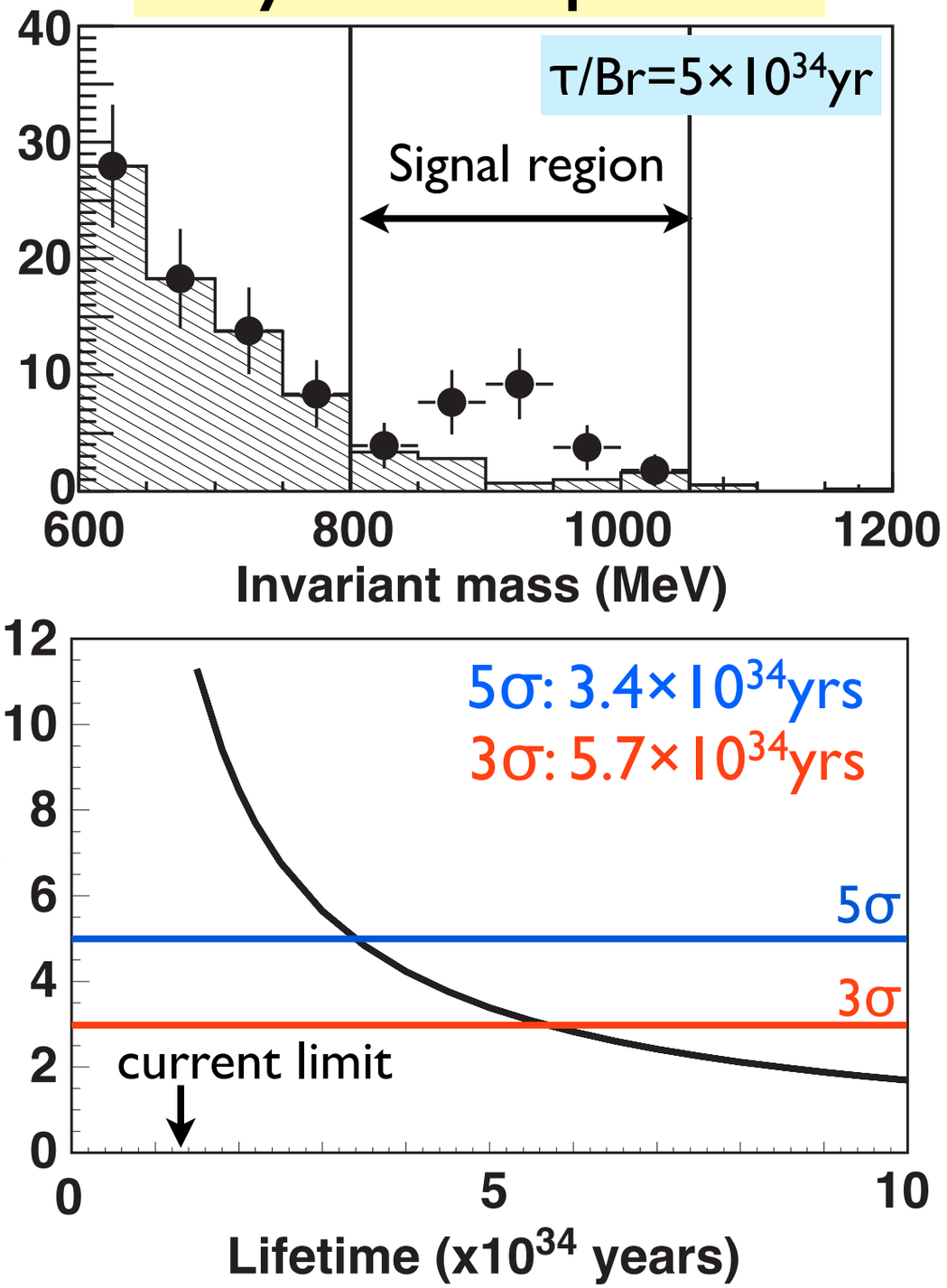
Consistent w/ simulation 1.8±0.3(stat.)

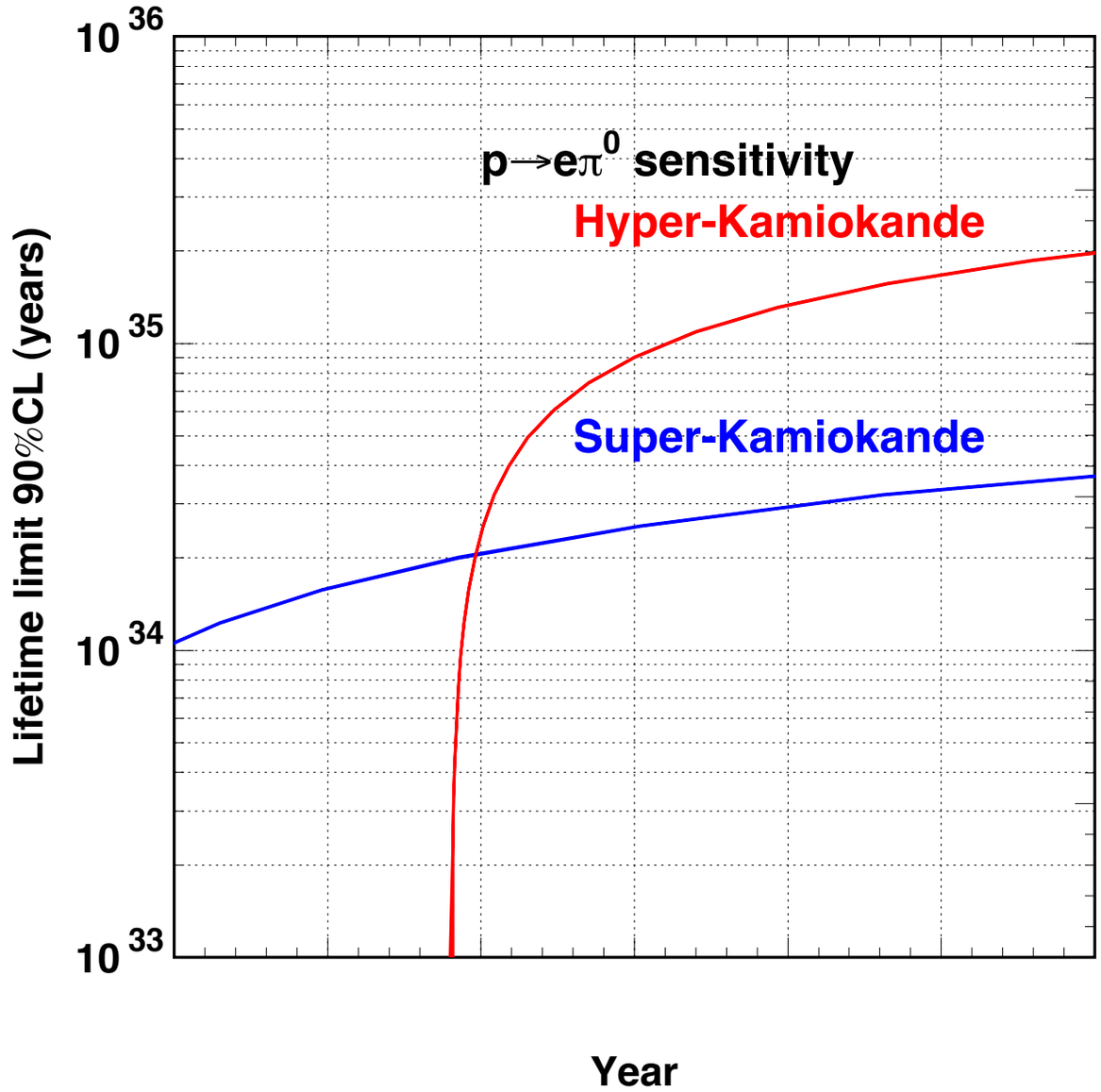
Reliable prediction of next generation experiment

Hyper-K $p \rightarrow e^+\pi^0$ sensitivity

(Using only number of events)

10 years exposure



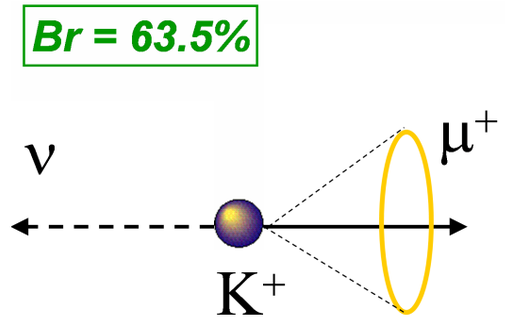


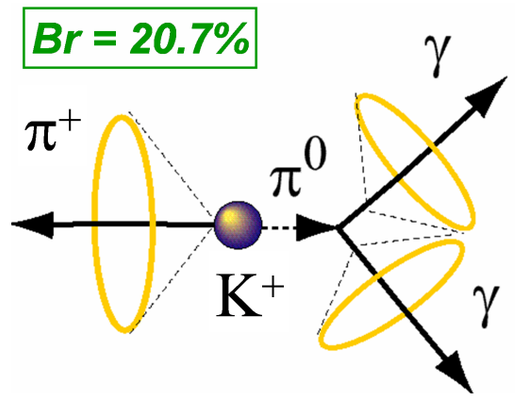
Will surpass SK limit in ~1 year.

90% limit with 10 years: 1.3×10^{35}yrs

$p \rightarrow \nu K^+$ search

- K^+ invisible (below Cherenkov threshold)
- $K^+ \rightarrow \mu\nu$ (Br: 63.5%)
  - Method 1: Tag with nuclear de-excitation γ
    - Measurement of de-excitation γ: nucl-ex/0604006
  - Method 2: Search excess in P_μ distribution
- $K^+ \rightarrow \pi^+\pi^0$ (Br: 20.7%)
  - 205 MeV/c π^0 + activity in opposite direction (π^+ just above threshold)





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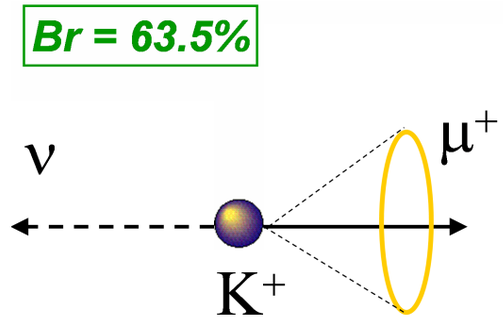

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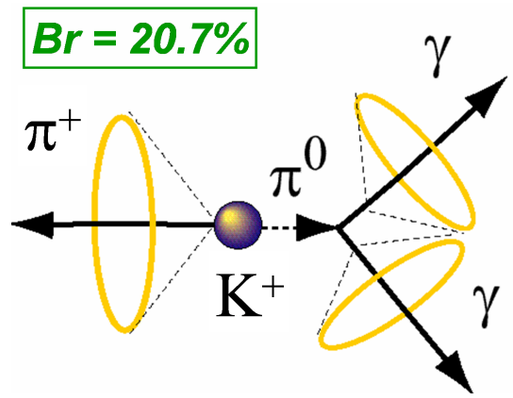
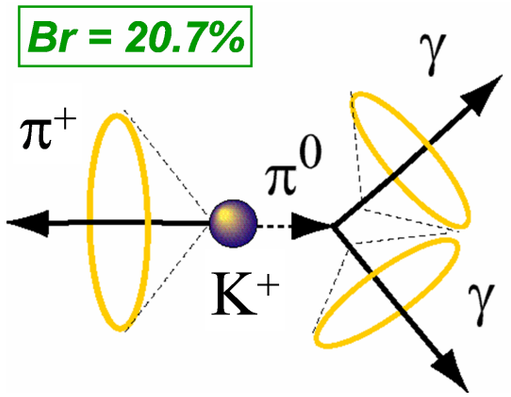


Recent improvement in analysis

$K^+ \to \pi^+\pi^0$ improvement



π^+ just above threshold
→ search for light opposite to π^0 direction

Improvements

Selection in LoI

- Two e-like rings with decay-e
- $85 < M\pi^0 < 185$ MeV/c^2
- $175 < P\pi^0 < 250$ MeV/c
- Sum of visible energy in 140°–180° from π^0 direction: 7-17MeV
- Sum of visible energy in 90°–140° from π^0 direction: <12MeV

- Add 1 ring e-like event with π^0 fitter used for T2K BG rejection

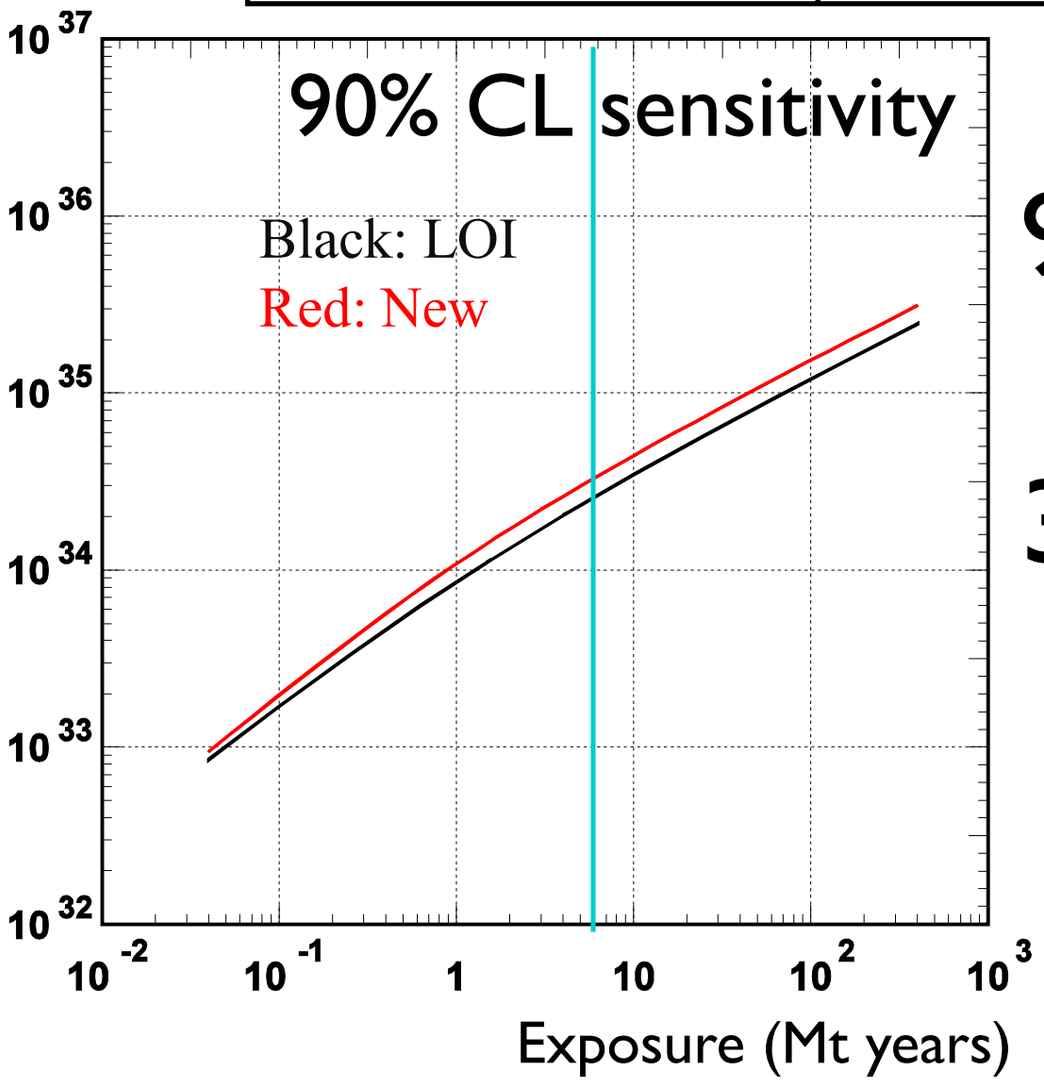
Increase efficiency

- Optimize range to 145°-180°
- Use shape information

Reduce background

$p \rightarrow \nu K^+$ sensitivity

	Efficiency (%)	BG (/Mtyr)
$K \rightarrow \mu\nu$+nucl. γ	7.1	1.6
$K \rightarrow \mu\nu$, P_μ	43	1940
$K \rightarrow \pi\pi$	~~6.7~~ 7.6	~~6.7~~ 1.8



90% CL sensitivity:

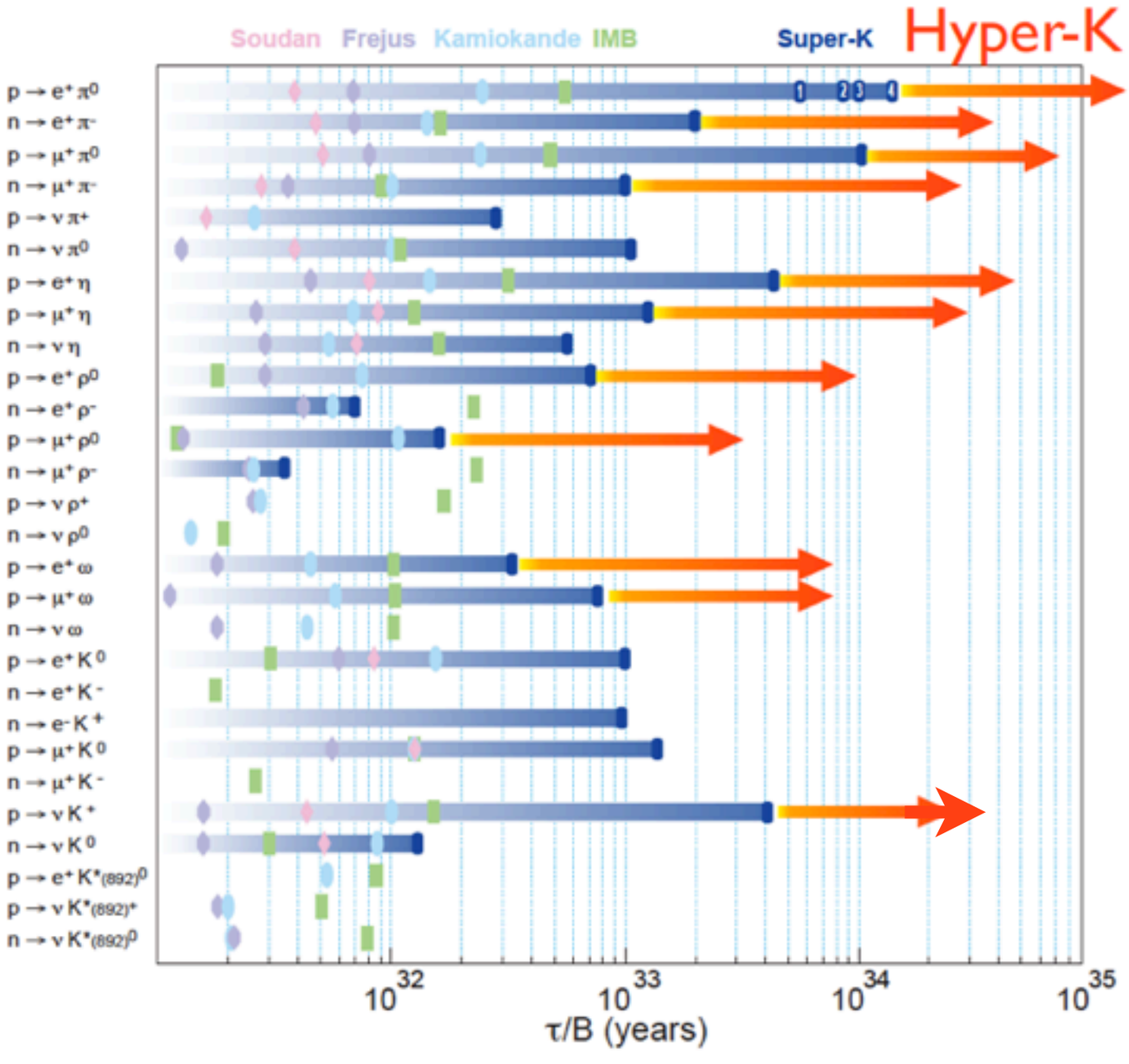
$2.5\times10^{34} \rightarrow 3.2\times10^{34}$ yrs

3σ observation potential:

$0.95\times10^{34} \rightarrow 1.2\times10^{34}$ yrs

Summary

~10 times better sensitivity than current Super-K limits!



- $p \to e^+\pi^0$:
  - 1.3×10^{35}yrs (90%CL)
  - 5.7×10^{34}yrs (3σ)
- $p \to \nu K^+$:
  - 3.2×10^{34}yrs (90%CL)
  - 1.2×10^{34}yrs (3σ)

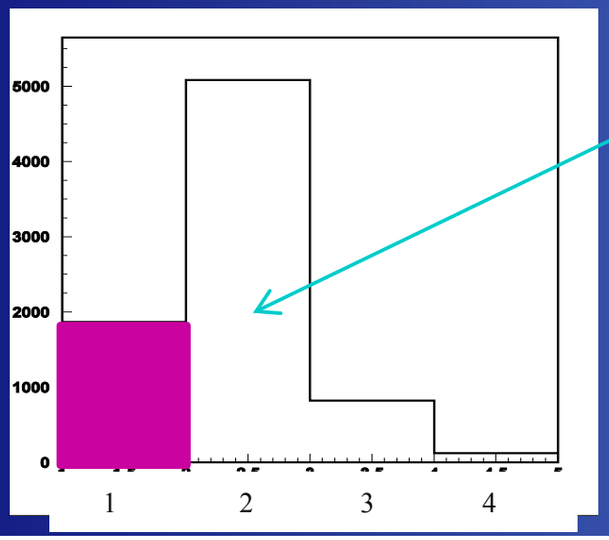
- And many other modes:
  - $(p,n) \to (e,\mu)+(\pi, \rho, \omega, \eta)$
  - K^0 modes
  - $\nu\pi^0$, $\nu\pi^+$
  - n-nbar oscillation
  - dinucleon decays

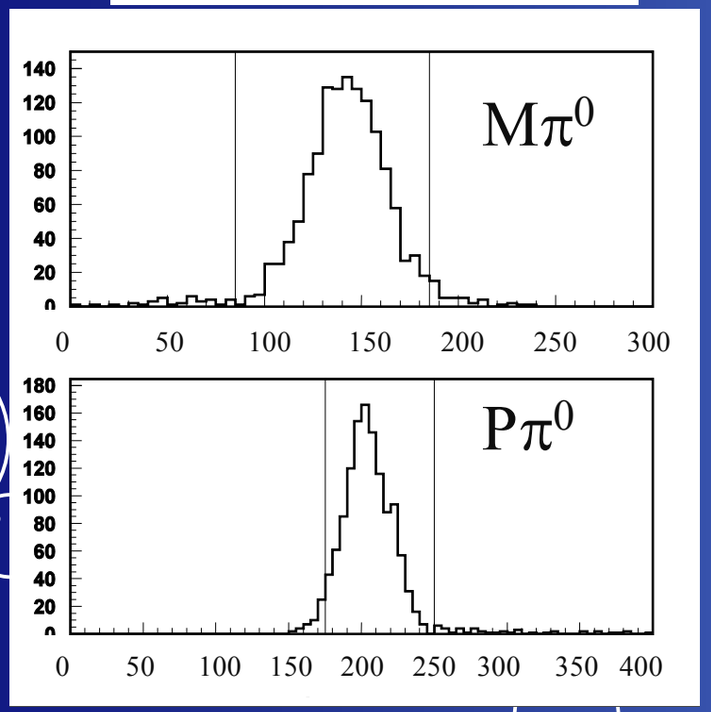
>3σ possible for lifetime above current SK limits

Backup

Recent improvement(1): $p \rightarrow \bar{\nu} K^+, K^+ \rightarrow \pi^+ \pi^0$

of Ring: $K^+ \rightarrow \pi^+ \pi^0$





Judge as 1 ring if opening angle of 2 γs is small or momentum of one γ is small,

Use "π^0 fitter"

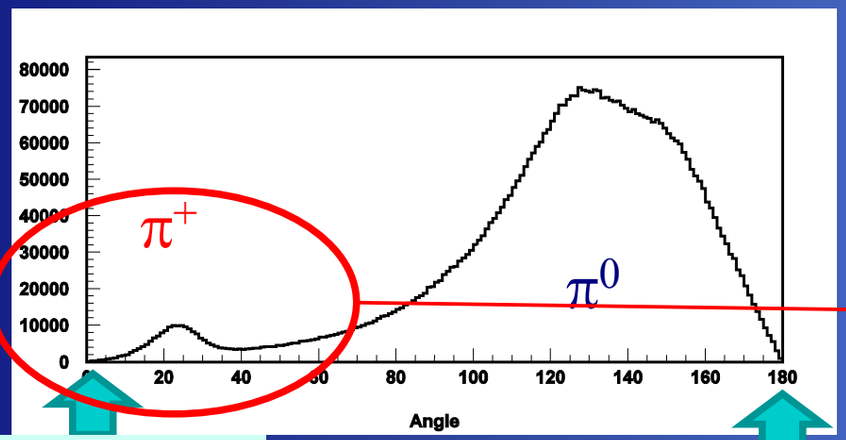
- Make likelihood assuming π^0 and search for missing ring.
- It is used for ν_e appearance analysis of T2K to reduce BKG.

It makes 1 ring sample available for this analysis!

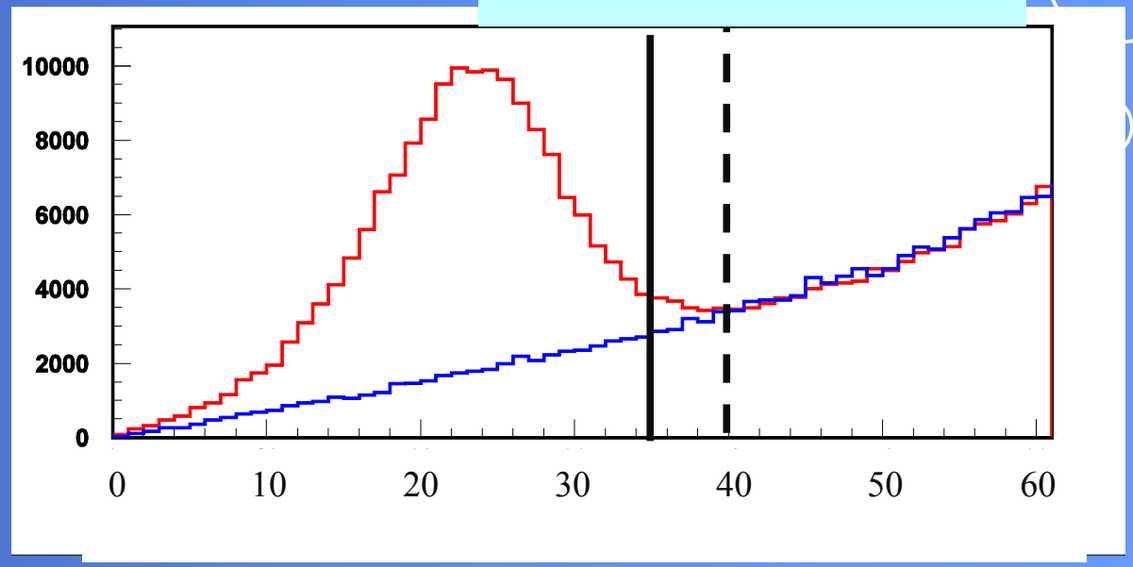
➔ efficiency increased.

Recent improvement(2): $p \to \bar{\nu} K^+, K^+ \to \pi^+ \pi^0$

Charge distribution in angle



zoom



Red: PDK MC
Blue: BKG

Opposite of π^o dir
$= \pi^+$ dir

π^0 dir

Conventional method: Use charge sum in <40°

New method: Use charge sum in < 35°

and compare shape by likelihood assuming signal and BKG.

Hyper-K in Japanese future strategy discussions

- Recommendation by HEP future projects committee (Feb.2012) http://www.jahep.org/office/doc/201202_hecsubc_report.pdf
  - Two large-scale projects recommended
    - ILC
    - Large neutrino/nucleon decay detector (Hyper-K/LAr)
- Final draft of KEK roadmap (Jan. 2013) includes Hyper-K http://kds.kek.jp/conferenceDisplay.py?confId=11728
- Cosmic ray physics community endorses Hyper-K as a next large-scale project
- ICRR future plan under discussion

Planning process in Japan

- In 2013-14, Science Council of Japan is going to update the *Master Plan* for large scale projects (for all fields of science).
  - Large neutrino/nucleon decay detector (Hyper-K/LAr) was listed on the previous versions of the *Master Plan* (2010/2011).
  - We (re-)submitted a proposal with Hyper-K as *the* project.
  - 25-30 projects will be selected as priority.
- The *Master Plan* is expected to be an important input to the Japanese government.