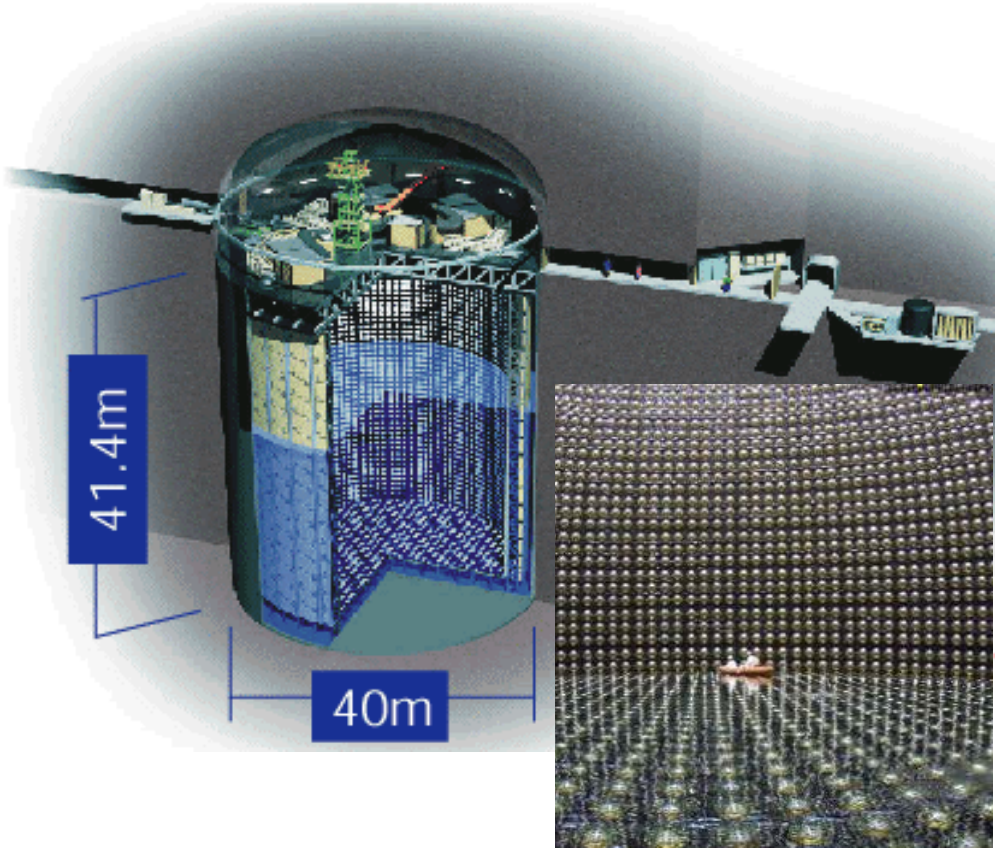
Quest for Lowest Energy Neutrinos in Super-Kamiokande

Low Radioactivity Techniques workshop 2015
Seattle, March 20 2015

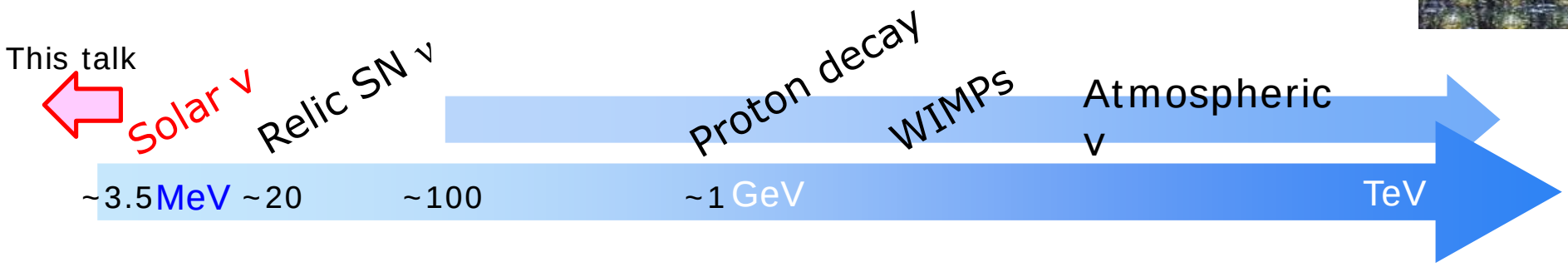
Hiroyuki Sekiya

Super-Kamiokande

- 50kton pure water Cherenkov detector
- 1km (2.7km w.e) underground in Kamioka
- 11129 50cm PMTs
  in Inner Detector
- 1885 20cm PMTs
  in Outer Detector

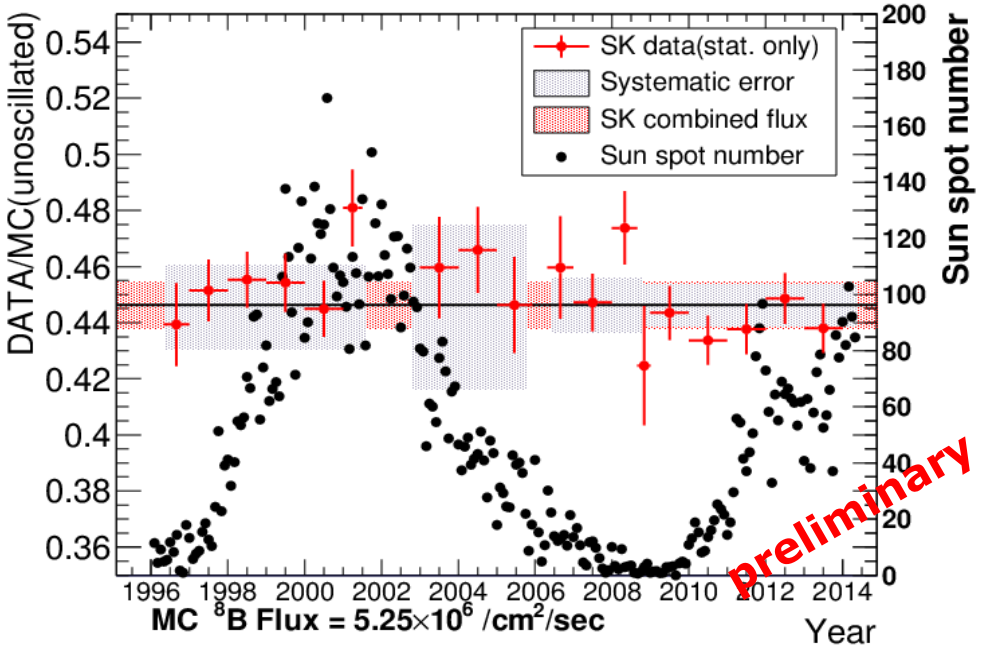


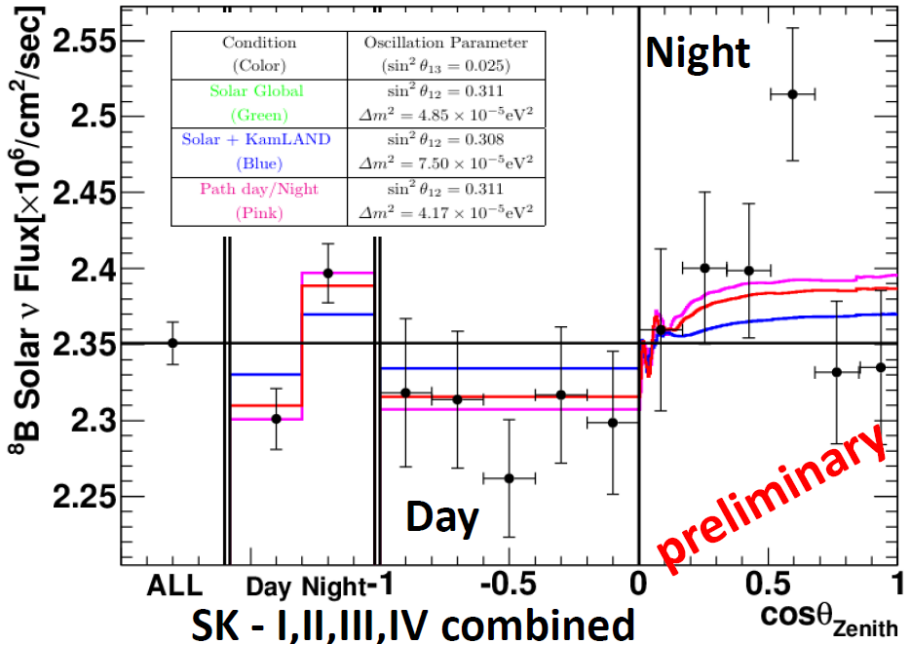
Physics targets of Super-Kamiokande



Recent SK Solar neutrino results

- SK has observed solar neutrino for 17 years(~ 1.5 solar cycle)
  - Fully consistent with a constant solar neutrino flux emitted by the Sun
- 4500days of data, ~70000 solar ν interactions
  - SK data provide the first indication (at 3.0 σ) of terrestrial matter effects on ^{8}B solar ν oscillation.



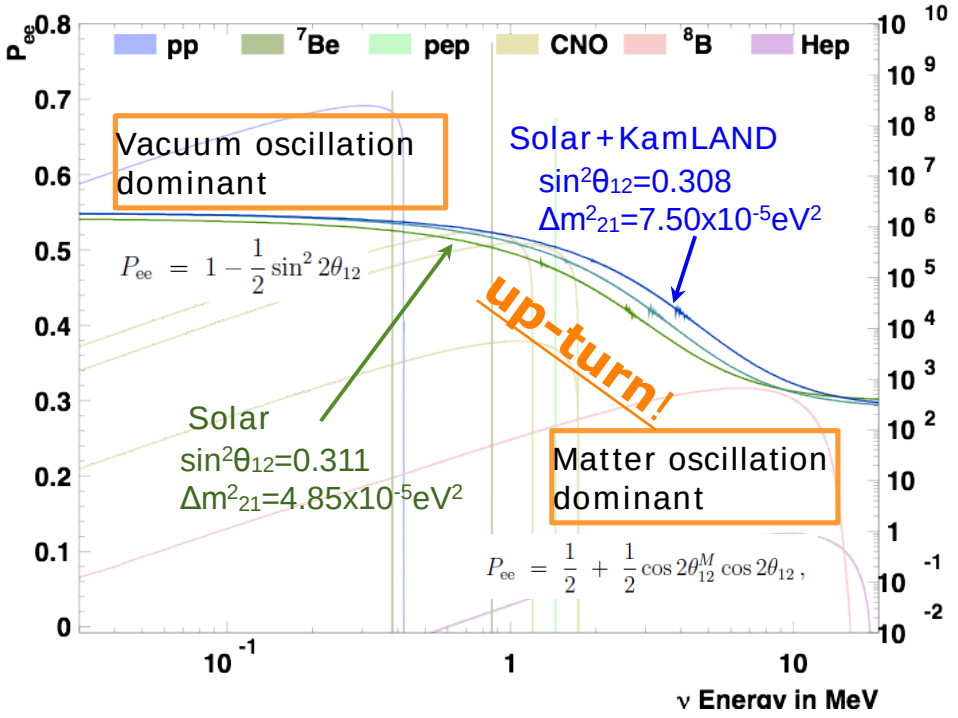


Remaining issue:

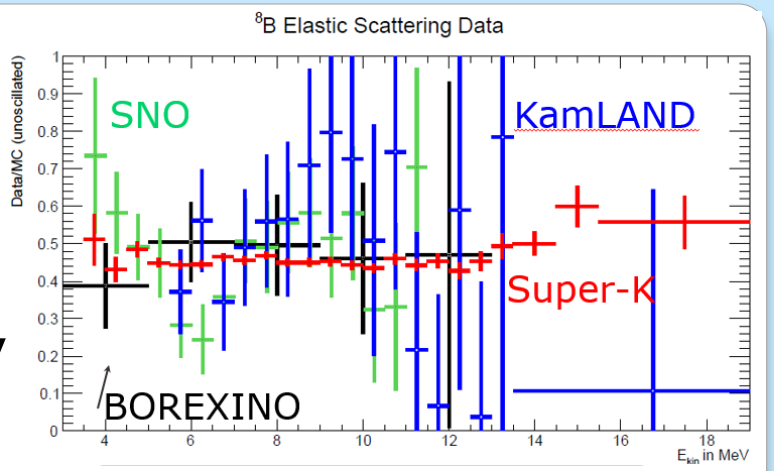
Solar matter effect
Energy spectrum distortion

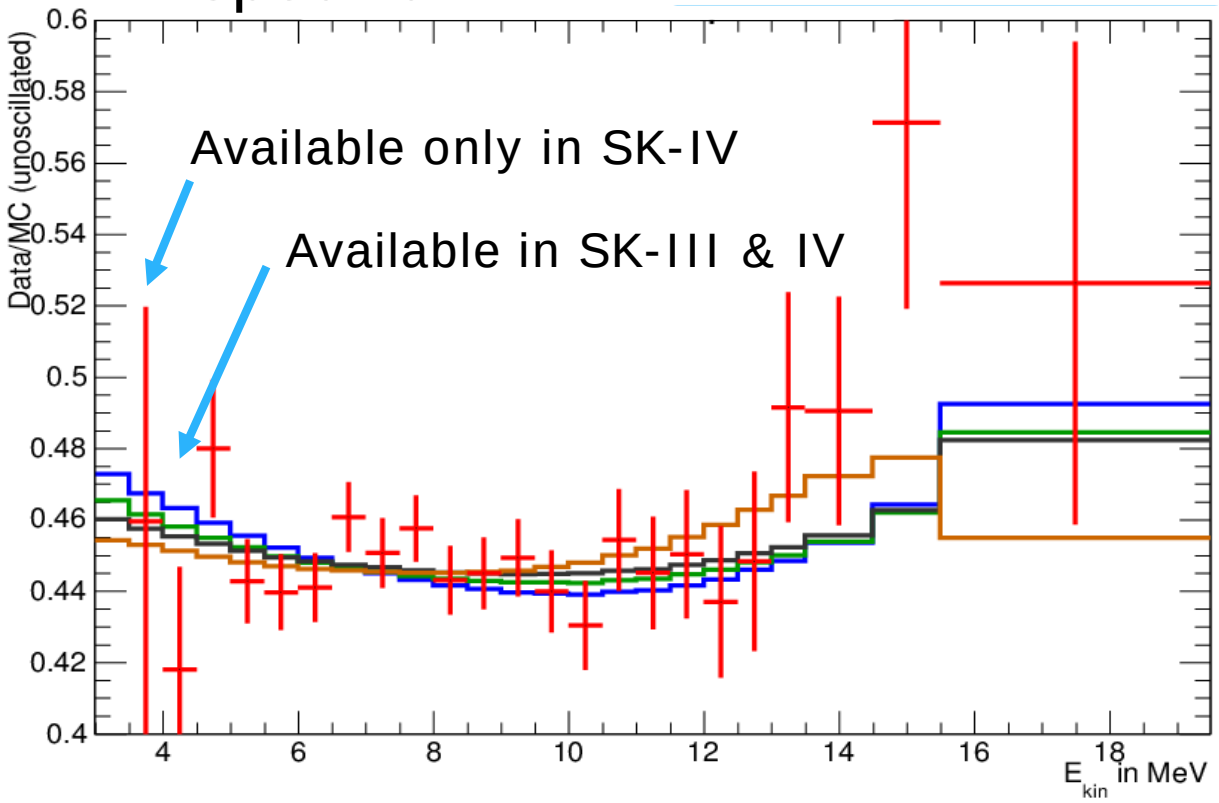
Neutrino survival probability

JHEP 0311:004(2003)



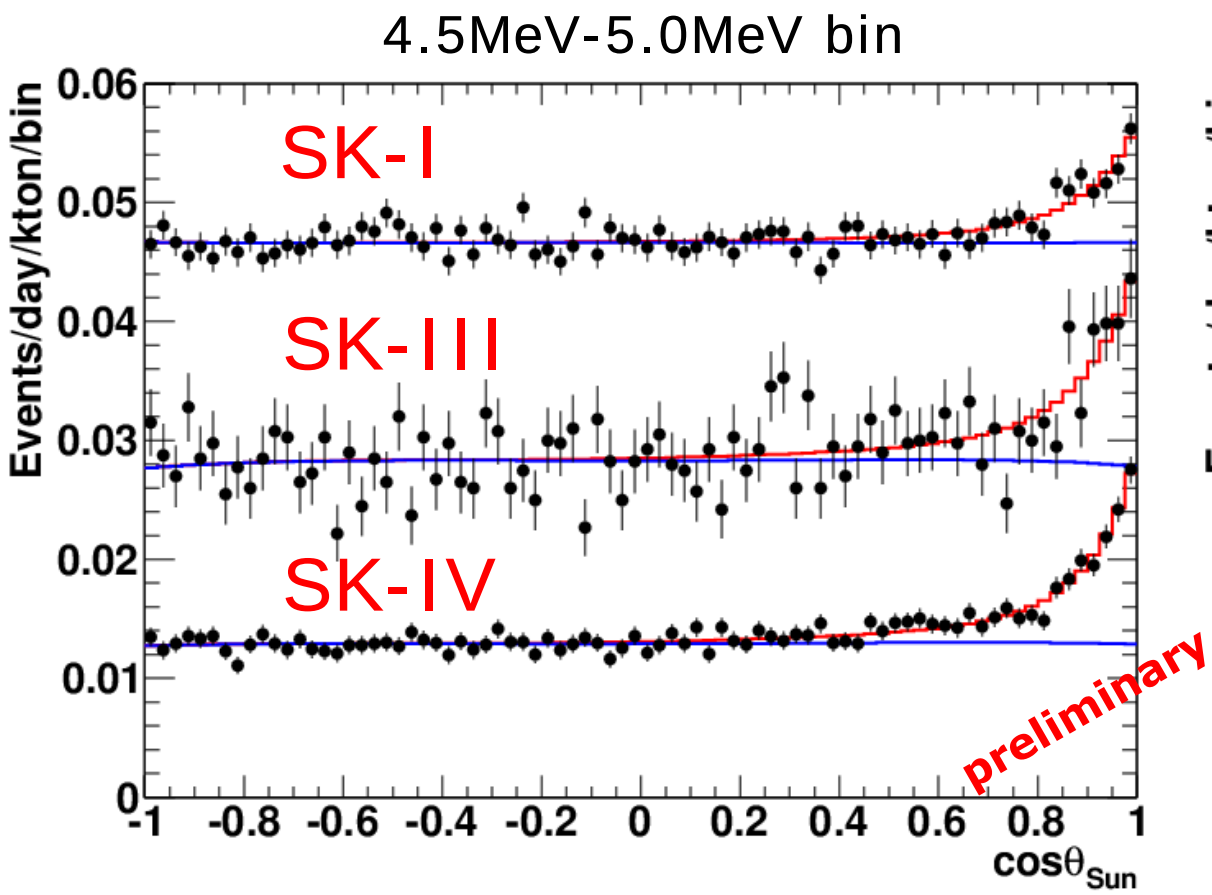
- SKI+II+III+IV ^{8}B spectrum

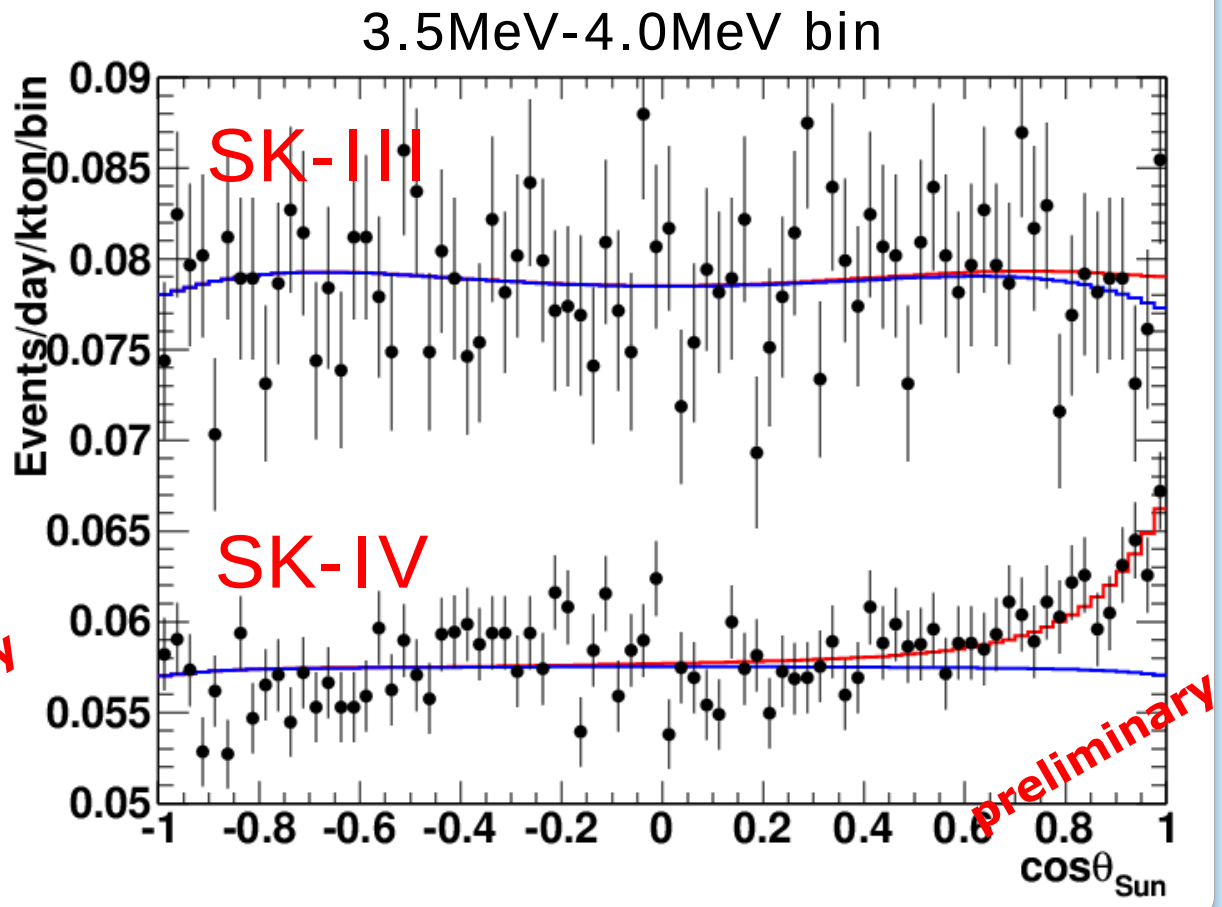




History of lowered BG and threshold

- Solar angle distributions
  - BG SK-I/SK-IV=1/4, E_{th} SK-I – SK-IV = 1MeV

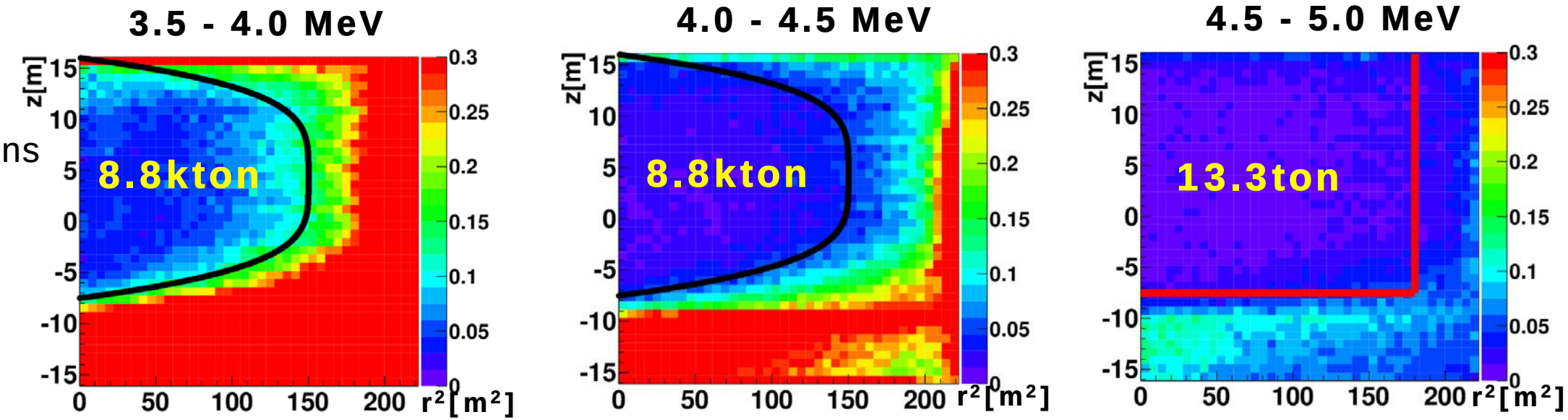




How it was achieved?

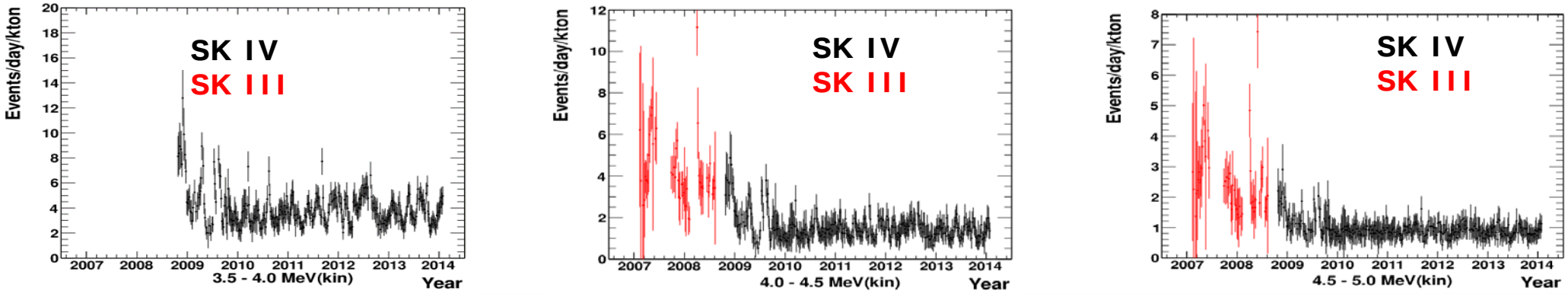
- It's easy! Just tightening the FV to reject Rn rich region.

SK-IV vertex distributions



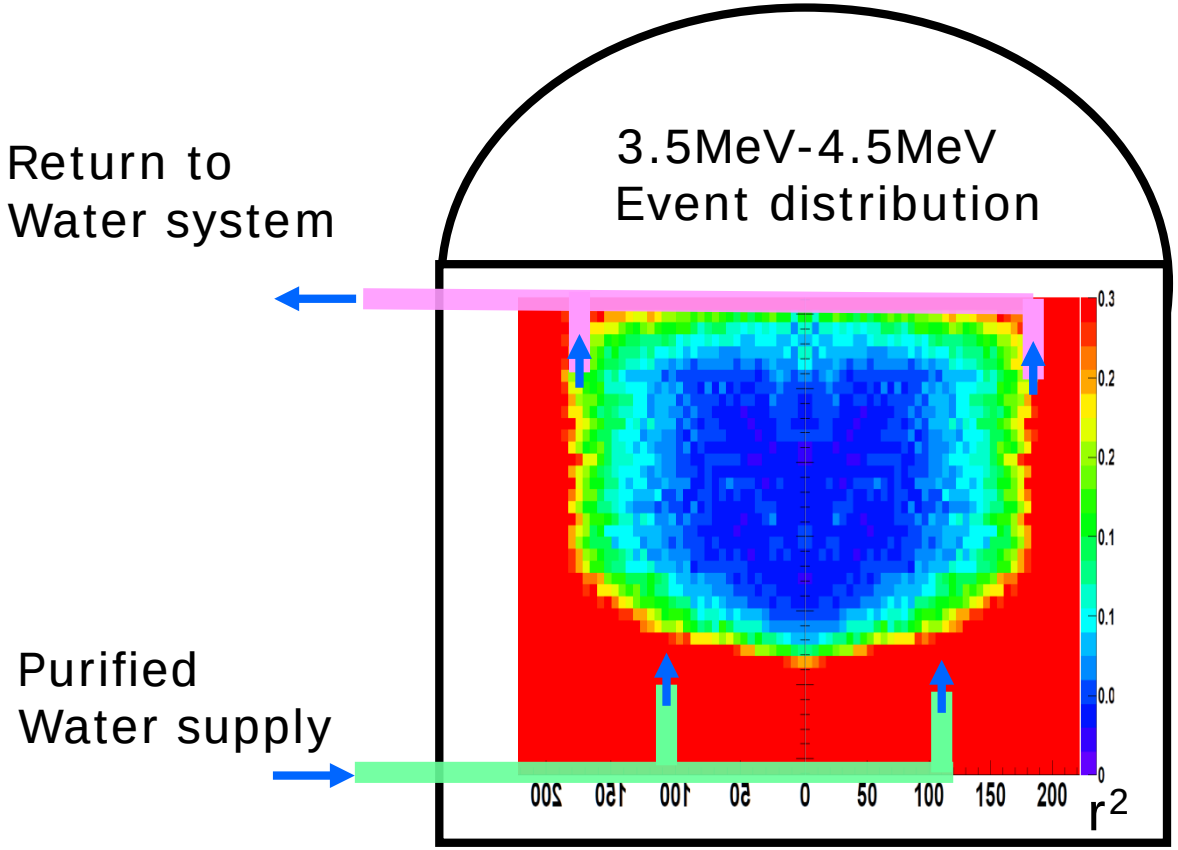
- Keeping the FV (boarder) is not easy at all!

Event rates



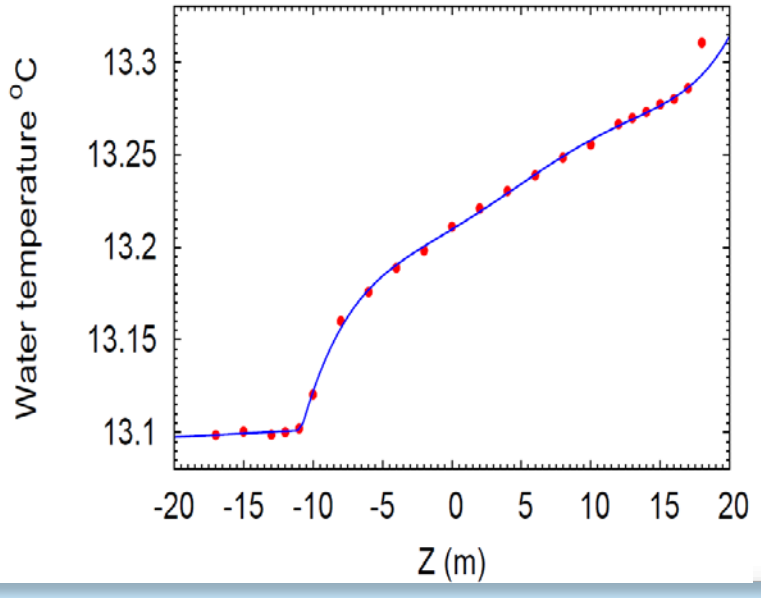
Convection suppression in SK-IV

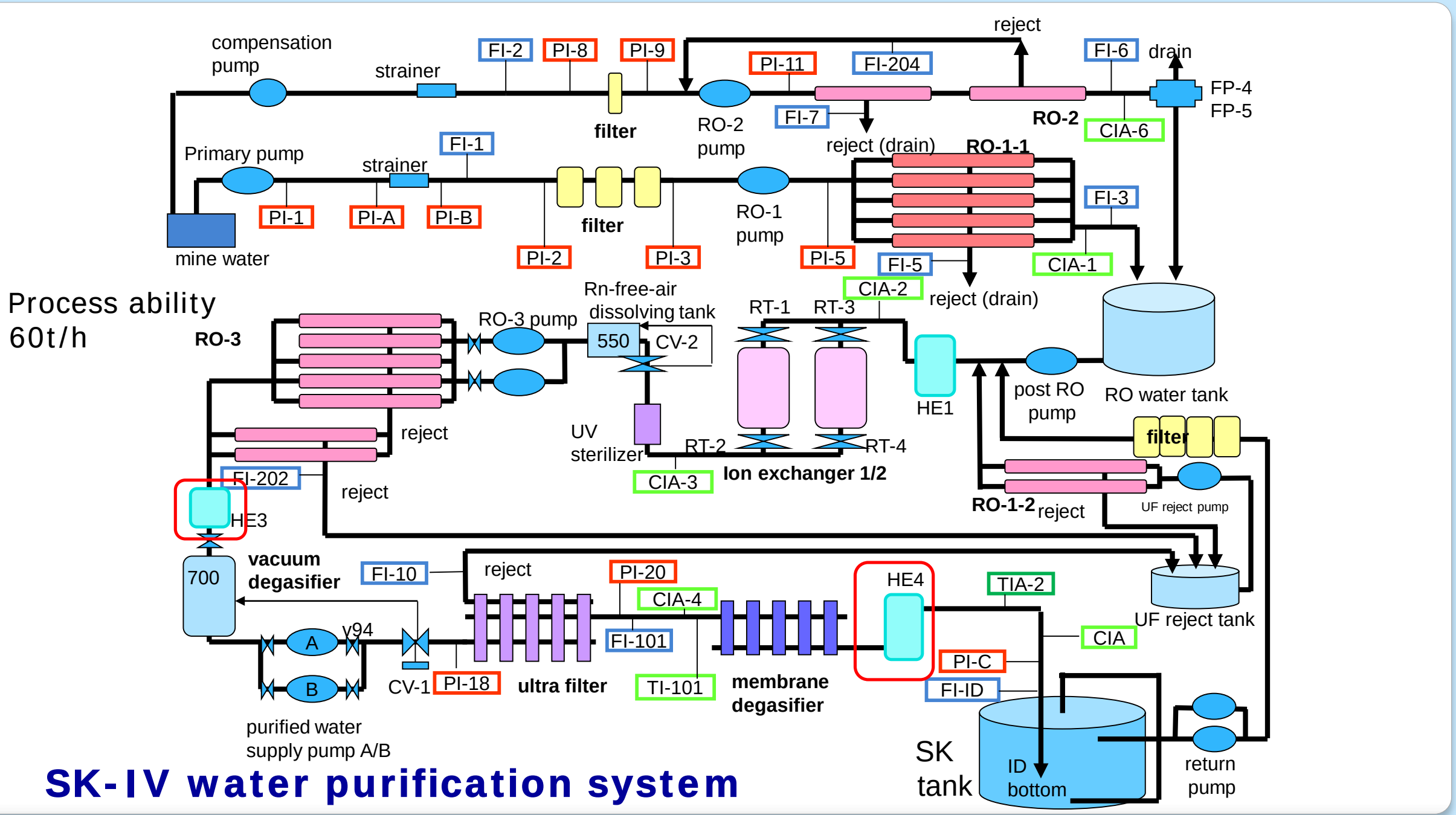
- Very precisely temperature-controlled (±0.01ºC) water must be supplied to the bottom.



Temperature in Z derection

The difference is only 0.2 ºC

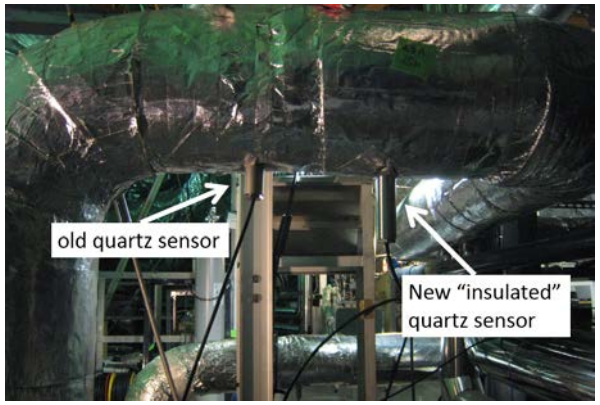


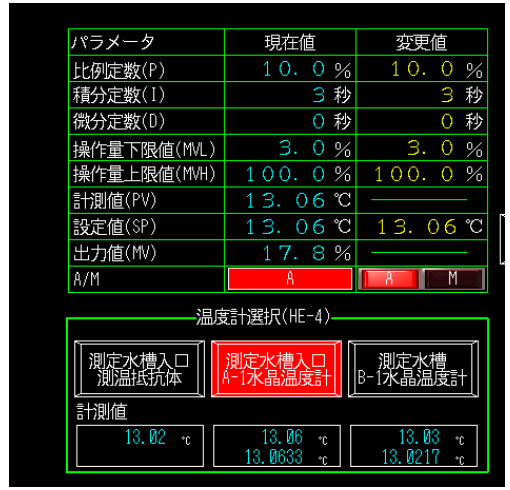


SK-IV water purification system

Temperature control unit

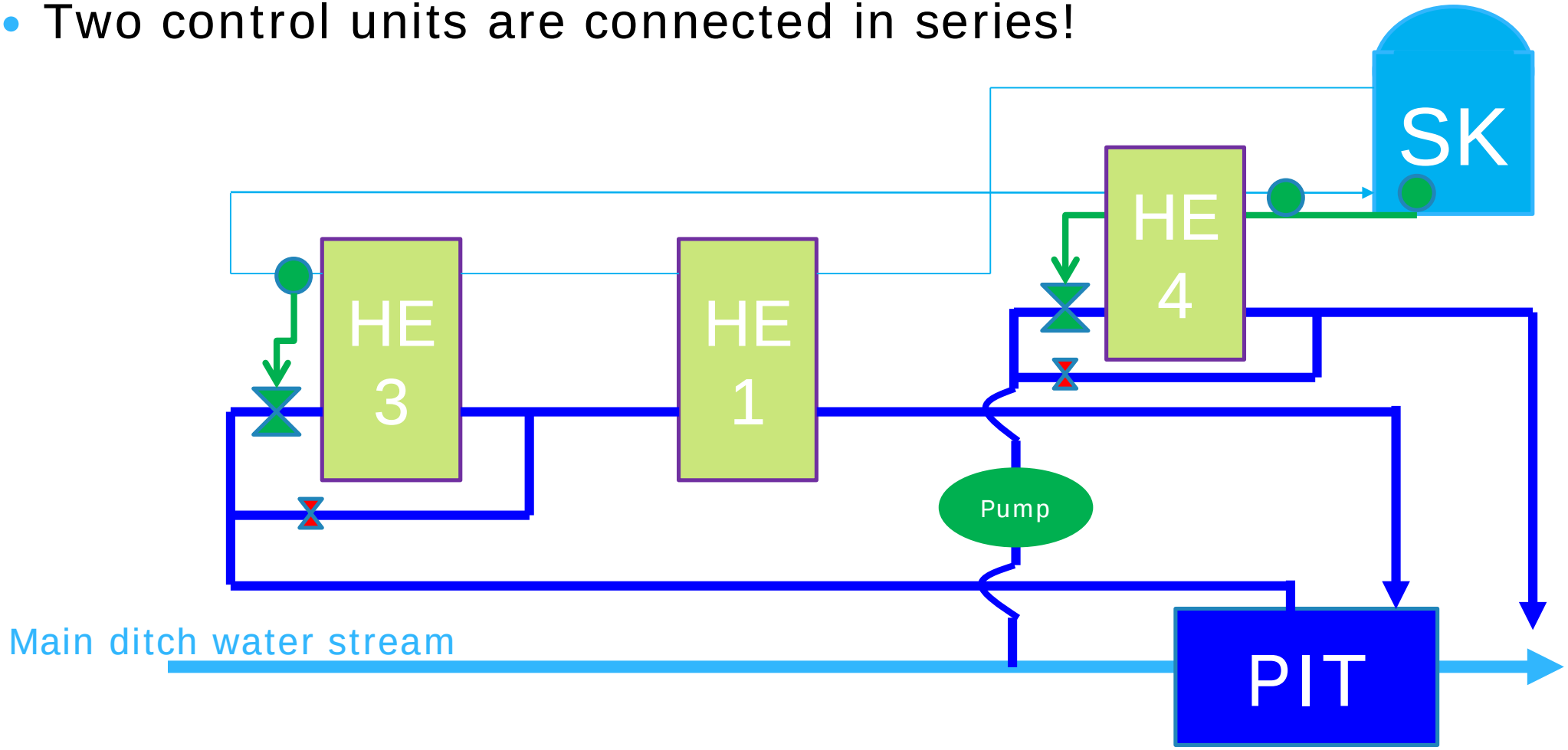
- Mine water, Heat exchanger, Flow control valve, PID controller, 5 digits thermometer

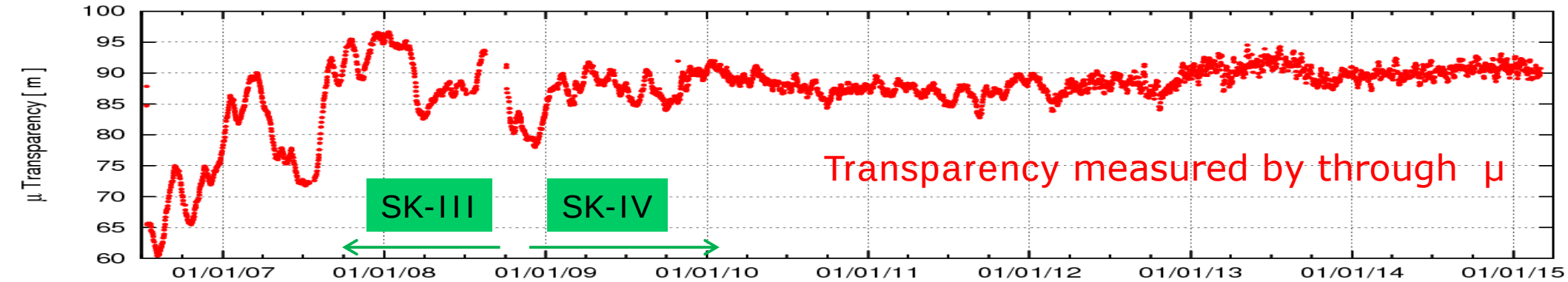


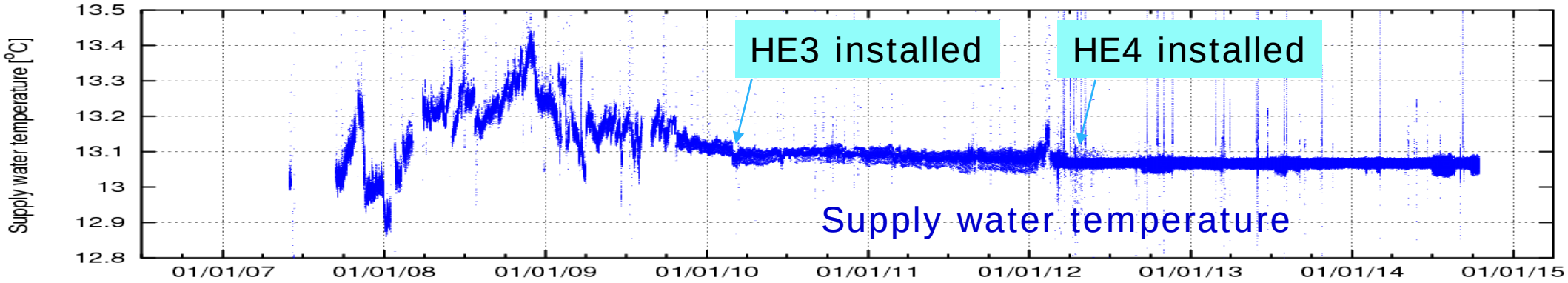


Cooling water system of SK-IV

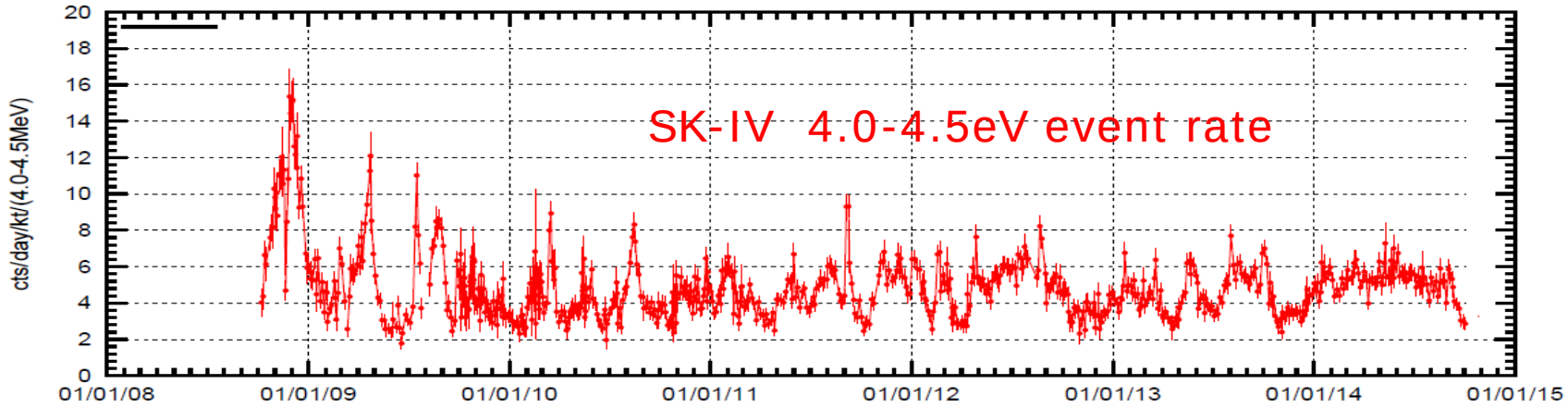
- Two control units are connected in series!







Correlations with transparency & BG level



Water flow in SK-IV

- Intentional water stagnation in FV

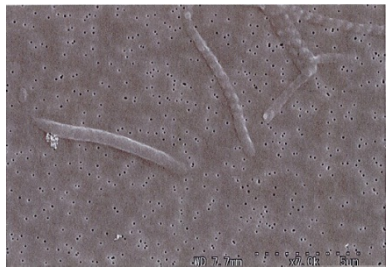
Yellow powder
in the return water pipes
which makes the water
transparency worse

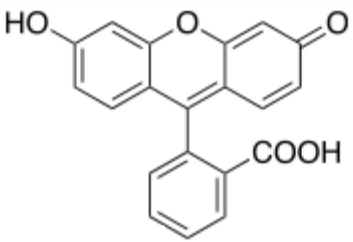
Ver.14May 2012

Bacteria-rich,
(bad water transperency)
but Rn-less region

Rn-rich
(supply water, PMT)
but good water transparency
region

According to literatures



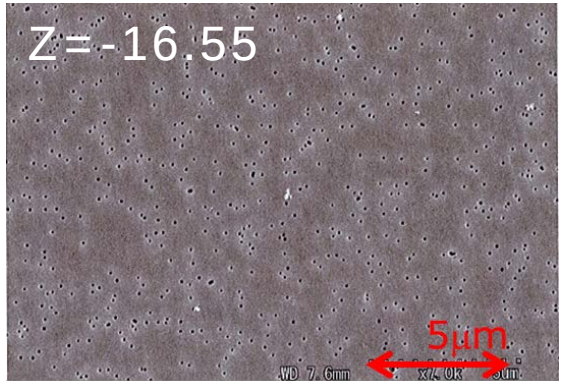


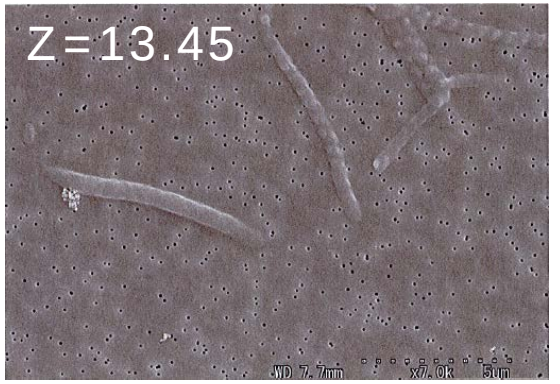
- *Pseudomonas genus*
  - Aerobic
  - Need P,K,Na,Mg,Ca,Fe,Al...
  - Many of them make fluorescent dyes (fluorescein) which absorb blue lights (peak 494nm) and emit green lights (peak 521nm).
  - On the wall(surface; tyvek, blacksheet, FRP, acrylic), there should be their nests!
- Top half region water: Air-rich , but what else is different from the water in bottom half? what is the nutrition for the bacteria?

TOC and particles

2011.10.20	Supply	Return	Z=-16.55	Z=-6.55	Z=3.45	Z=13.45
TOC μg/L(=ppb)	10	<10	10	<10	<10	<10
>0.1μm particles/ml	<50	205	313	<50	504	580
>0.2μm	<50	145	135	<50	425	378
>0.3μm	<50	103	79	<50	411	336
>0.5μm	<50	70	<50	<50	355	289

- Particles in bottom: dusts
- Particles in top: dusts+bacteria
- TOC in supply water?





Elemental analysis(ICP-MS)

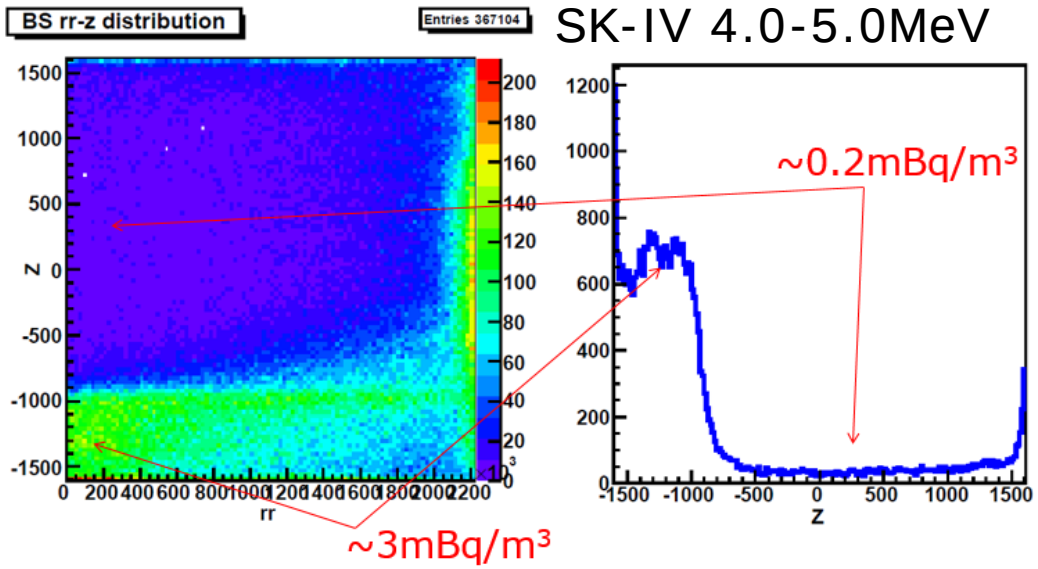
Z-dependence of the metal contamination is similar to those of particles/bacteria. Nutrition?

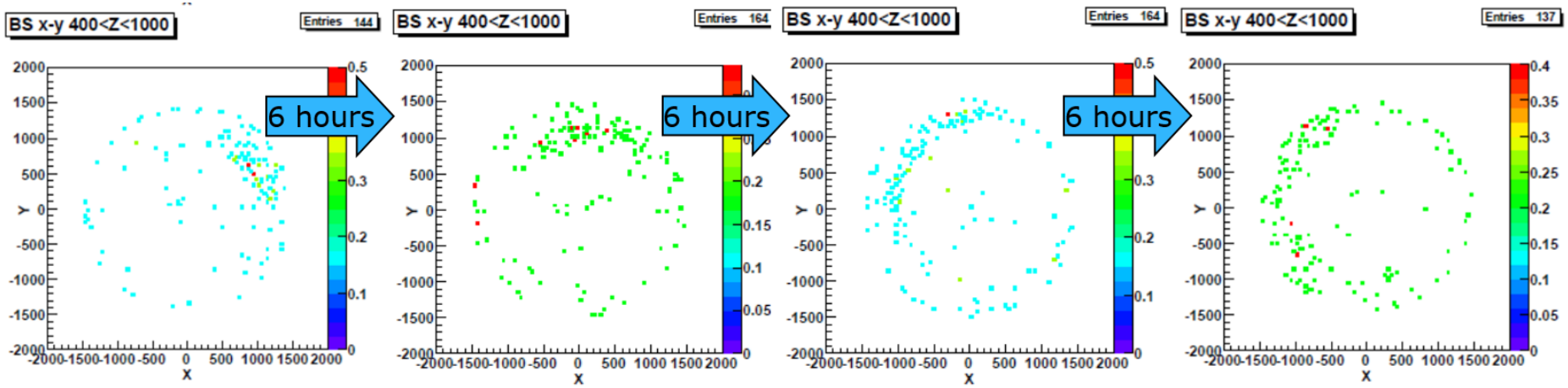
ng/L,ppt	Supply	Return	Z=-16.55	Z=-6.55	Z=3.45	Z=13.45	Mine water (ppm)
Na	<3	<20	4	4	<20	<10	4.3
K	<3	<20	<3	<3	<20	<20	0.4
Ca	<3	70	26	39	110	130	73.1
Mg	<3	<20	<3	4	<20	<20	11.4
Fe	<3	<20	<3	<3	<20	<20	<0.03
Cu	<3	<20	<3	<3	<20	<20	<0.05
Zn	<3	60	22	39	150	170	0.49
Cd	<3	<20	<3	<3	<20	<20	N/A
Ni	<3	<20	<3	<3	<20	<20	N/A
Pb	<3	<20	<3	<3	<20	<20	<0.2
Mn	<3	<20	<3	<3	<20	<20	<0.03
Al	<3	<20	<3	<3	<20	<20	0.01
Co	<3	<20	<3	<3	<20	<20	N/A
Cr	<3	<20	<3	<3	<20	<20	N/A
Ti	<1	<50	<1	<1	<50	<50	N/A

How about Rn?

- SK-IV Rn concentration estimated from event rate ~0.2mBq/m^3
  - Assuming all BG is Rn

C.f. Calibration was conducted in 2007(SK-III)
9.2Bq Rn was injected. Rotational flow!



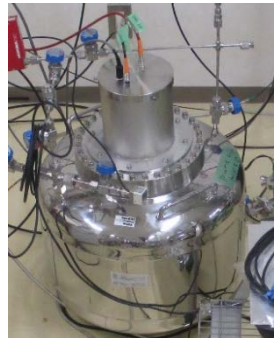


- Direct Rn measurement was necessitated!
  - Water Rn detector with sub-mBa/m^3 sensitivity must have been developed!

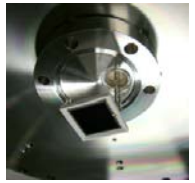
New technique 1

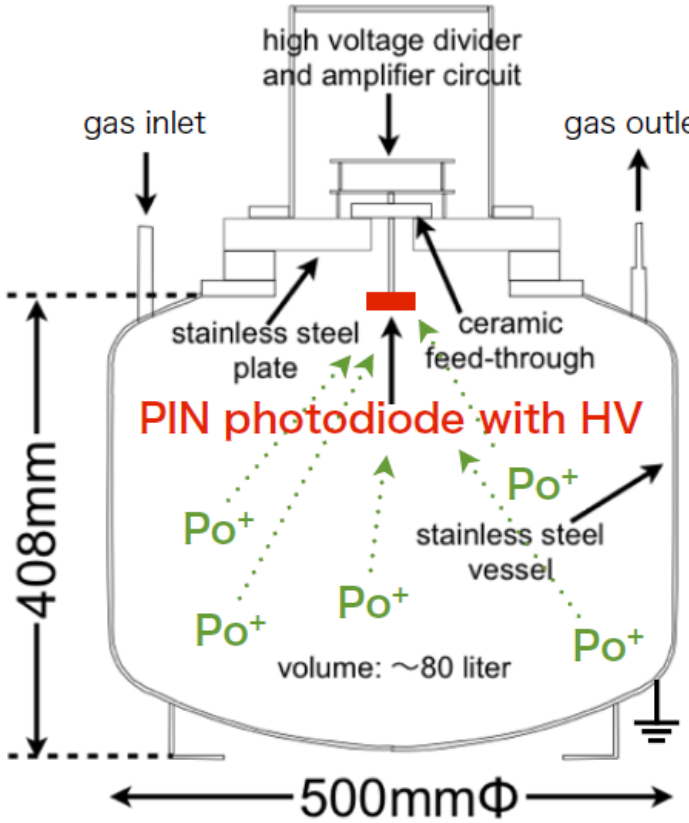
K.Hosokawa et. al., PTEP 2015 033H01
Y. Nakano et. al., in preparation for NIM-A

- New low BG electro-static collection Rn detector.

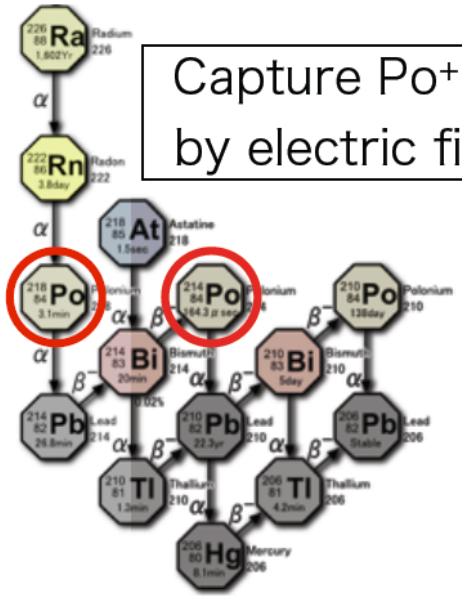


18mmx18mm
PIN PD



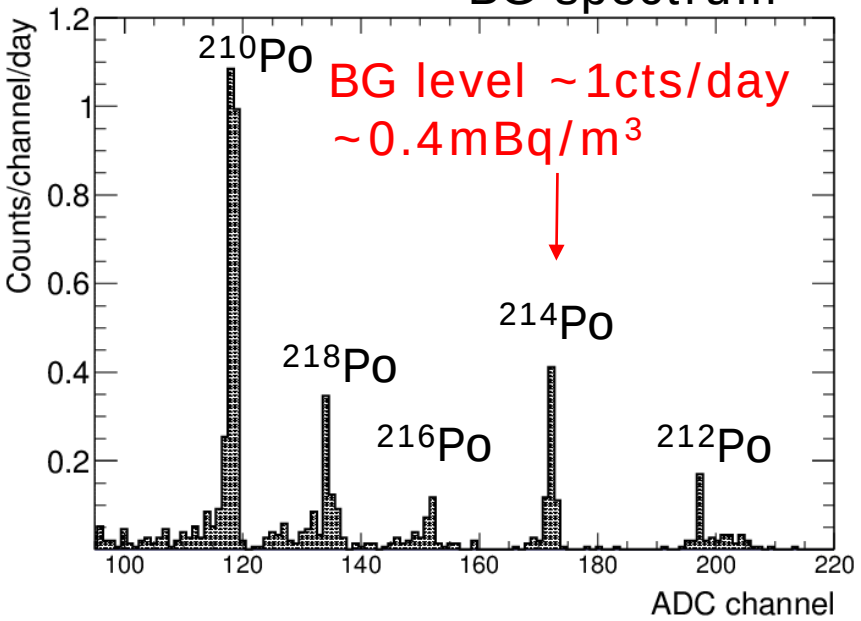


- 80L of volume
- Feedthrough with low BG alumina
- Electrochemical buffed inner surface.
- Metal gasket flanges make it possible to be evacuated down to 10^{-5}Pa.



Capture Po^+ ion by electric field.

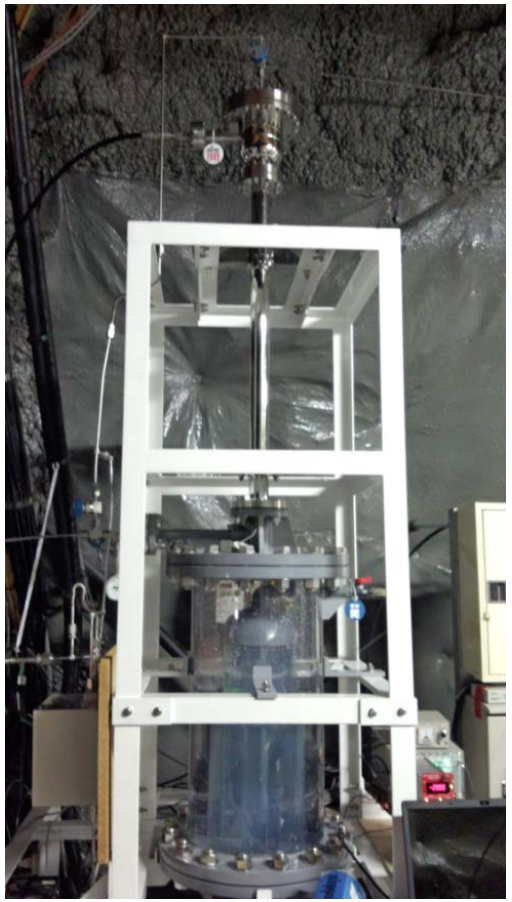
BG spectrum

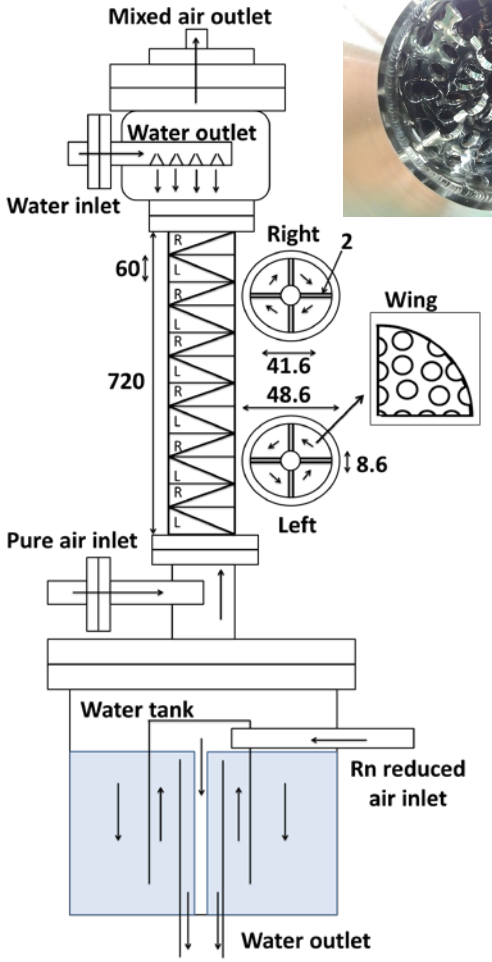


Y. Nakano et. al., in preparation for NIM-A

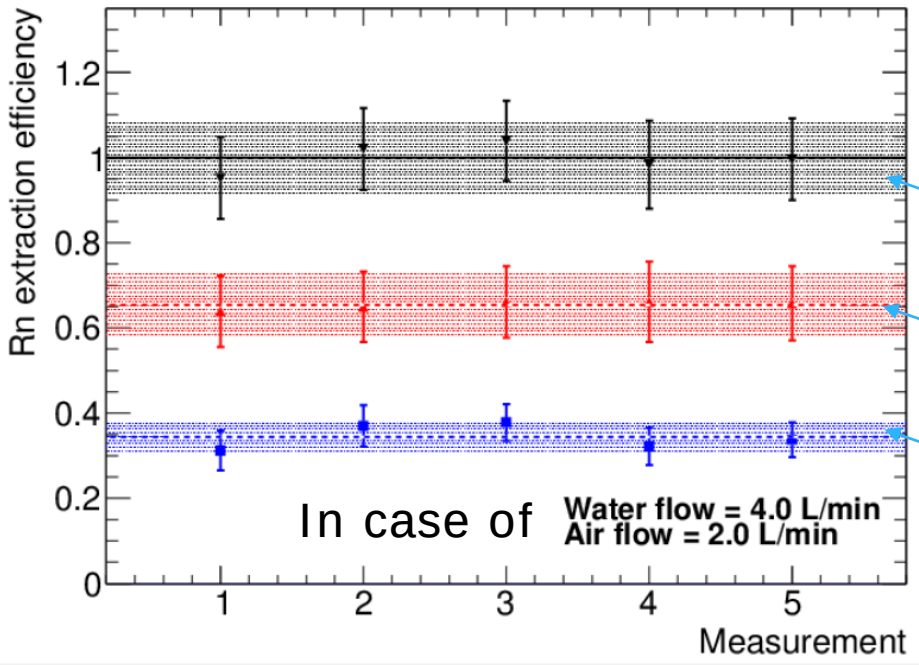
New technique 2

- New low BG Rn extraction system from water to air.





- 4 spiral electro-polished SUS fins for transferring Rn from water to air
- Rn extraction efficiency is 0.65±0.08
  - Calibrated with standard Liq. Scinti. Meth.



input water

output air

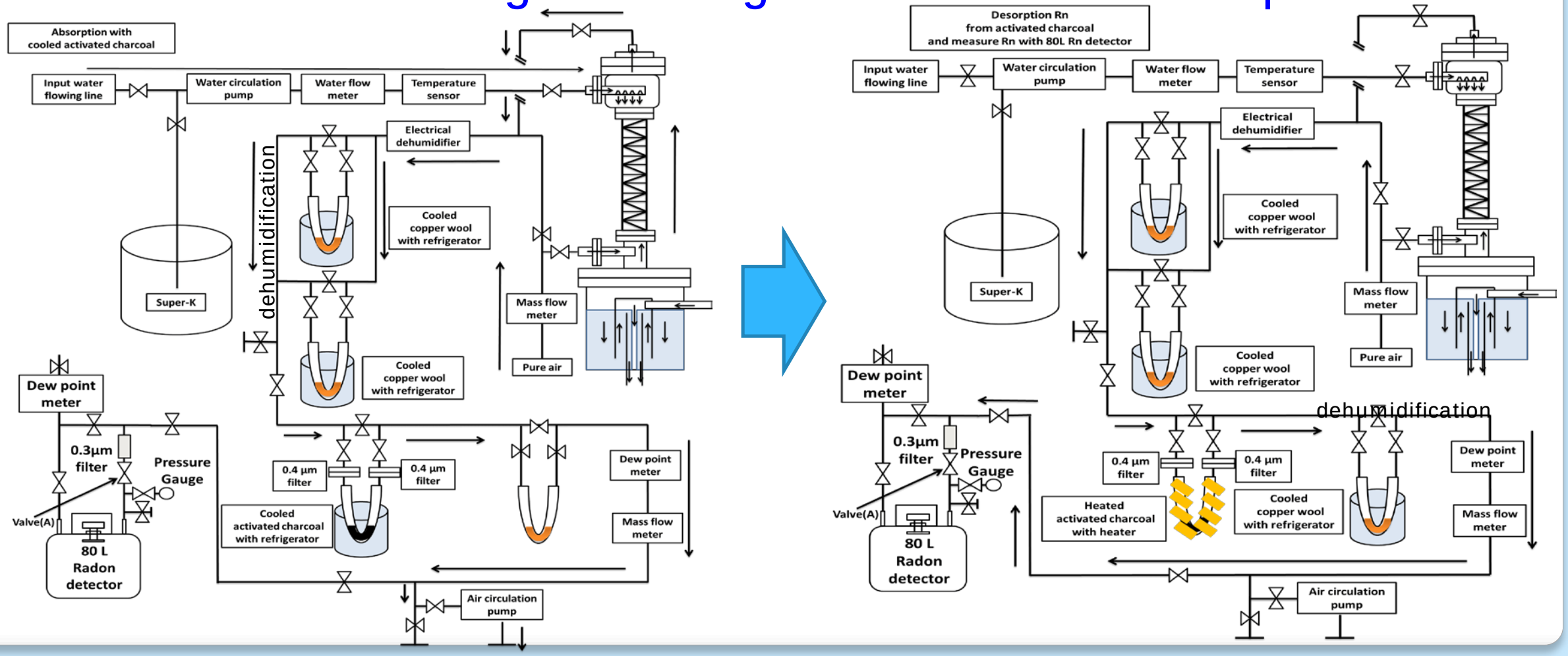
output water

Y. Nakano et. al., in preparation for NIM-A

New technique 3

- Sub mBq/m^3 Rn requires concentration and withdrawal to be measured

Cooling & Baking the charcoal Rn trap



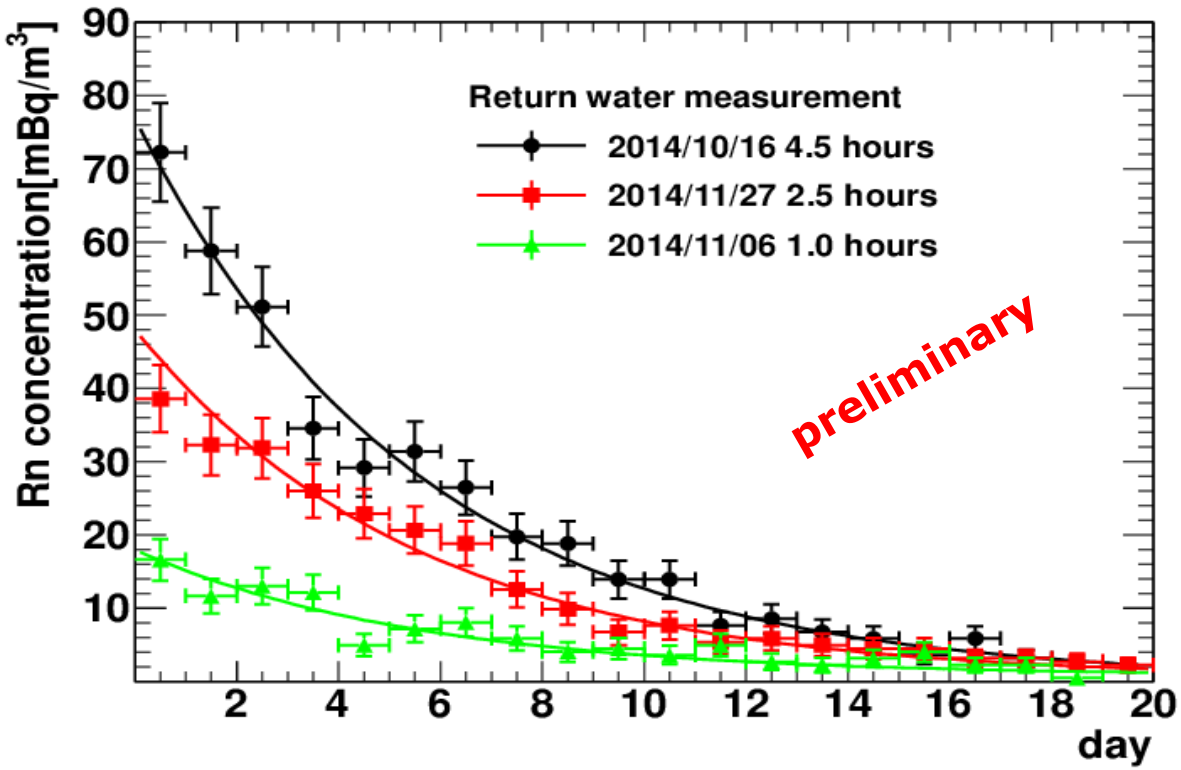
1 + 2 + 3

- Withdrawn radon is packed in the 80L detector.
- Fit the decay to get the initial concentrated Rn concentration.

$$C(t) = C(0)e^{-(\ln 2.0/3.82)t} + C_{BG}$$

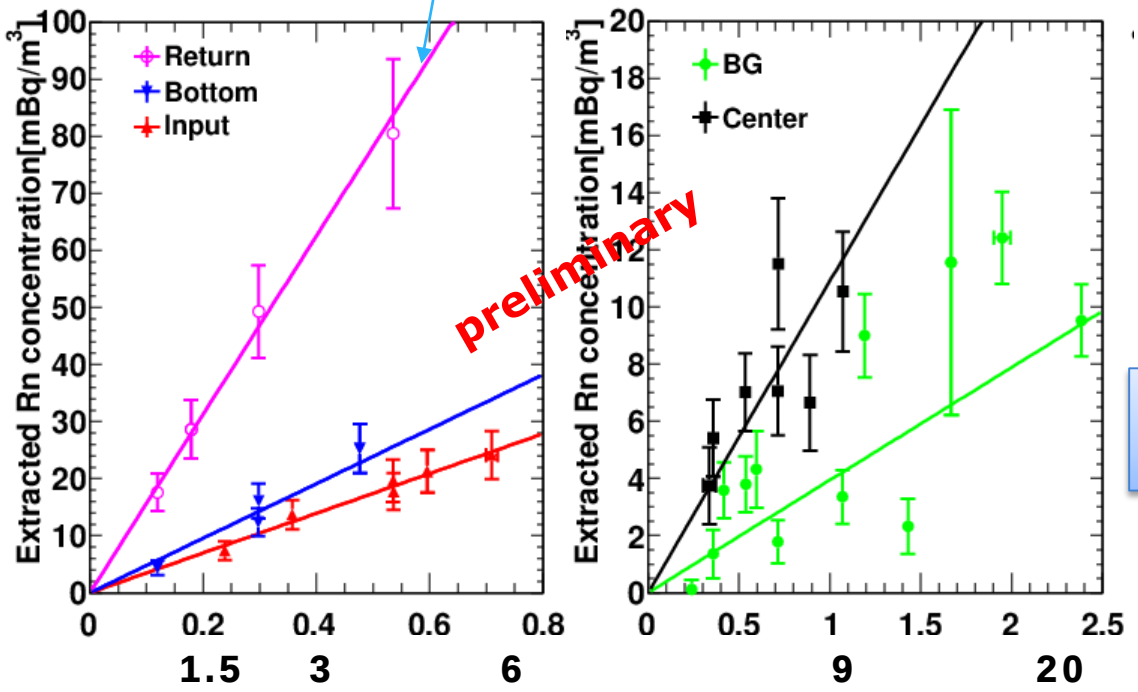
- Derive the water Rn concentration
- Repeat with different concentration time.
- Rn concentration should be in proportion to the concentrated time/total flowed air volume.

Example: Results of return water measurement

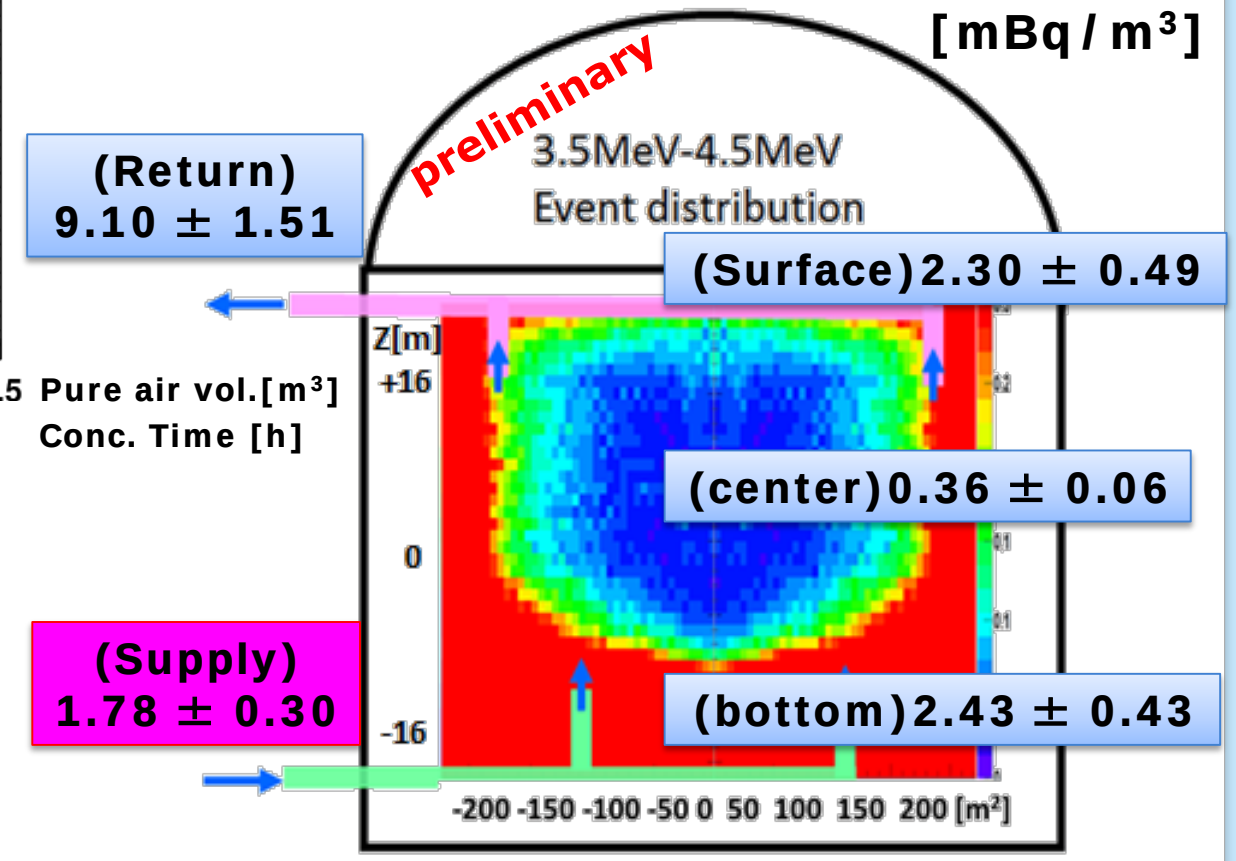


Results

This gradient itself is the Rn concentration



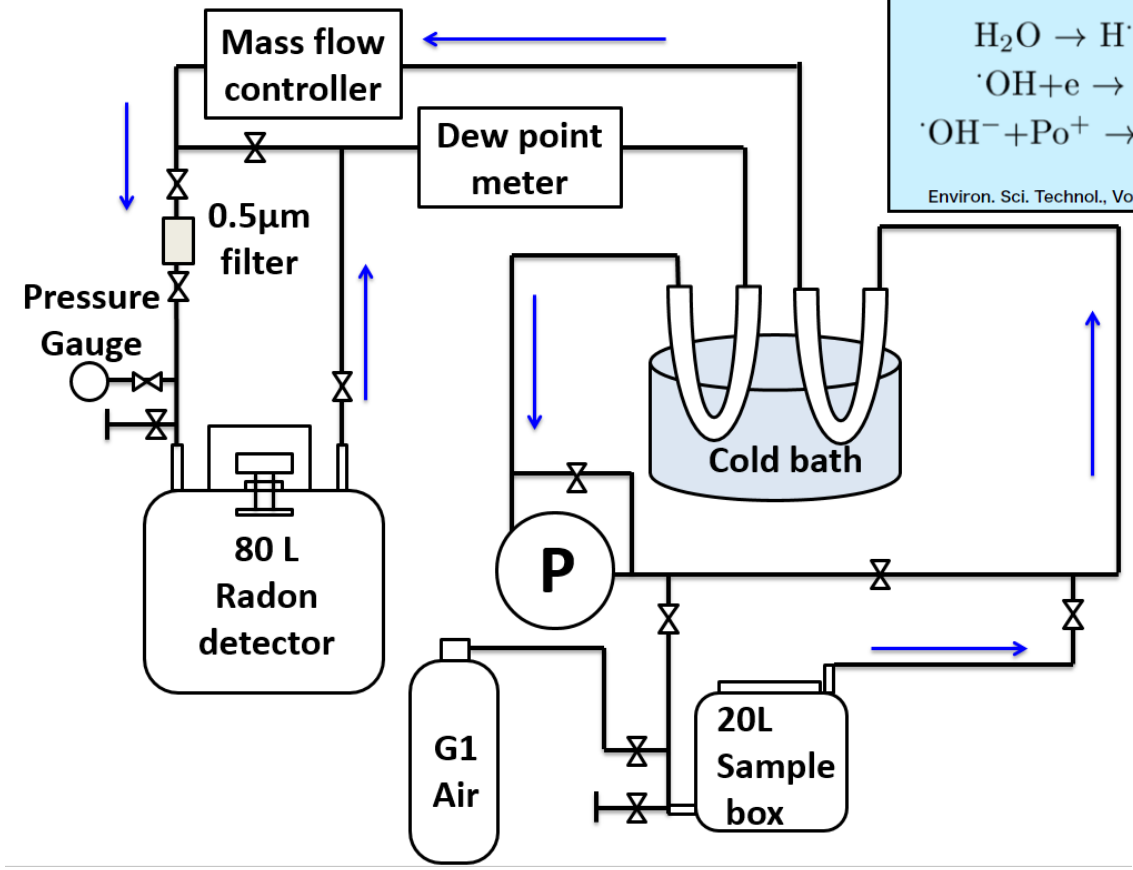
Main Rn source
10-20mBq/PMT



- Consistent with Rn concentration from the event rate
- Supply water is contaminated.
  - Rn source hunting has been started.
- Integrated-time independent BG?
  - Original Rn in Charcoal?

Rn emanation measurement setup

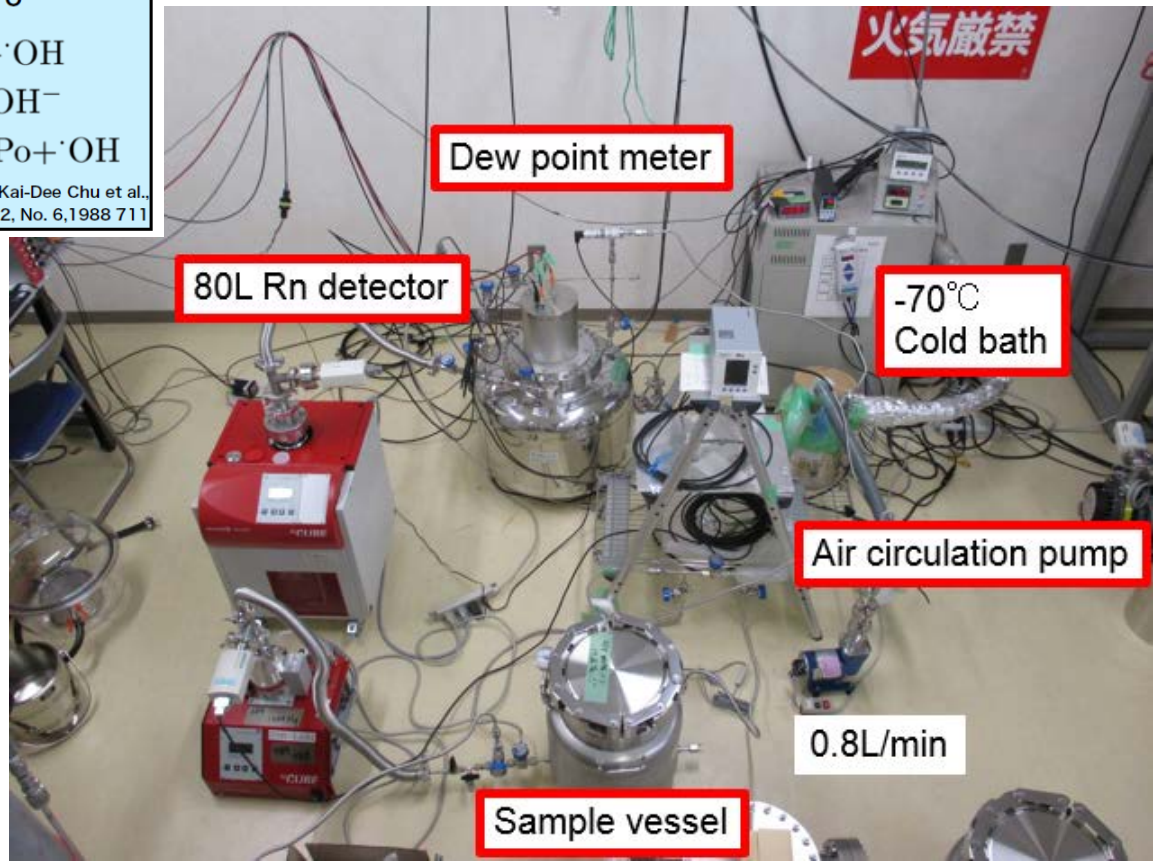
- Water system plumbing materials are tested in air.



Neutralization of Po^+

$$H_2O \rightarrow H^{\cdot} + {}^{\cdot}OH$$
$${}^{\cdot}OH + e \rightarrow {}^{\cdot}OH^-$$
$${}^{\cdot}OH^- + Po^+ \rightarrow Po + {}^{\cdot}OH$$

Kai-Dee Chu et al.,
Environ. Sci. Technol., Vol. 22, No. 6,1988 711



Rn emanation from rubber gaskets

- EPDM rubber gaskets are used in SK.

EPDM

Butyl

Urethane

rubbers	Rn emanation /1 gasket	Rn emanation / m^2
EPDM	1.82 ±0.03 mBq	0.809±0.013 Bq
Butyl	3.58 ±0.04 mBq	1.59 ±0.02 Bq
Urethane	0.013±0.004 mBq	5.8±1.8 mBq

- N.B. This is NOT the emanation to water.
- EPDM is Rn rich! Urethane is good.
- The gaskets must be replaced.

Summary

- Main Rn source in SK tank is PMT.
- By controlling the supply water temperature and the flow in SK tank, the Rn concentration in the FV is kept at ~0.3mBq/m^3
- This was confirmed by the low-BG water Rn detector that we have developed.
- SK water system reduces Rn from 9.1mBq/m^3 to 1.7/m^3 mBq, but we are still trying to reducing Rn for the spectrum upturn of Solar ^{8}B neutrino.