Distillation purification of xenon for krypton and measurement of radon contamination in liquid xenon

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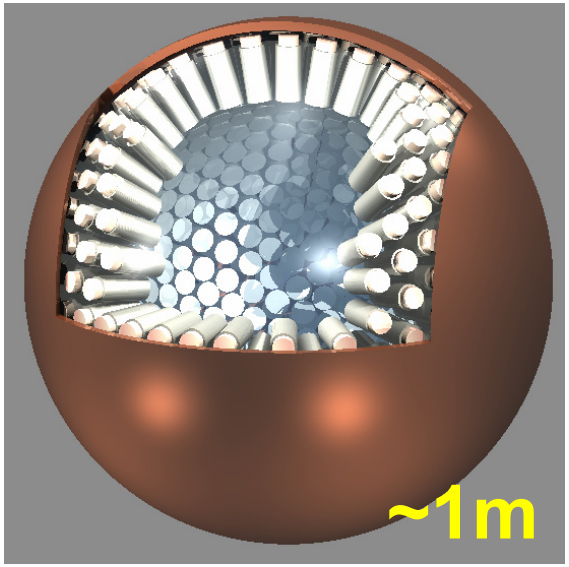
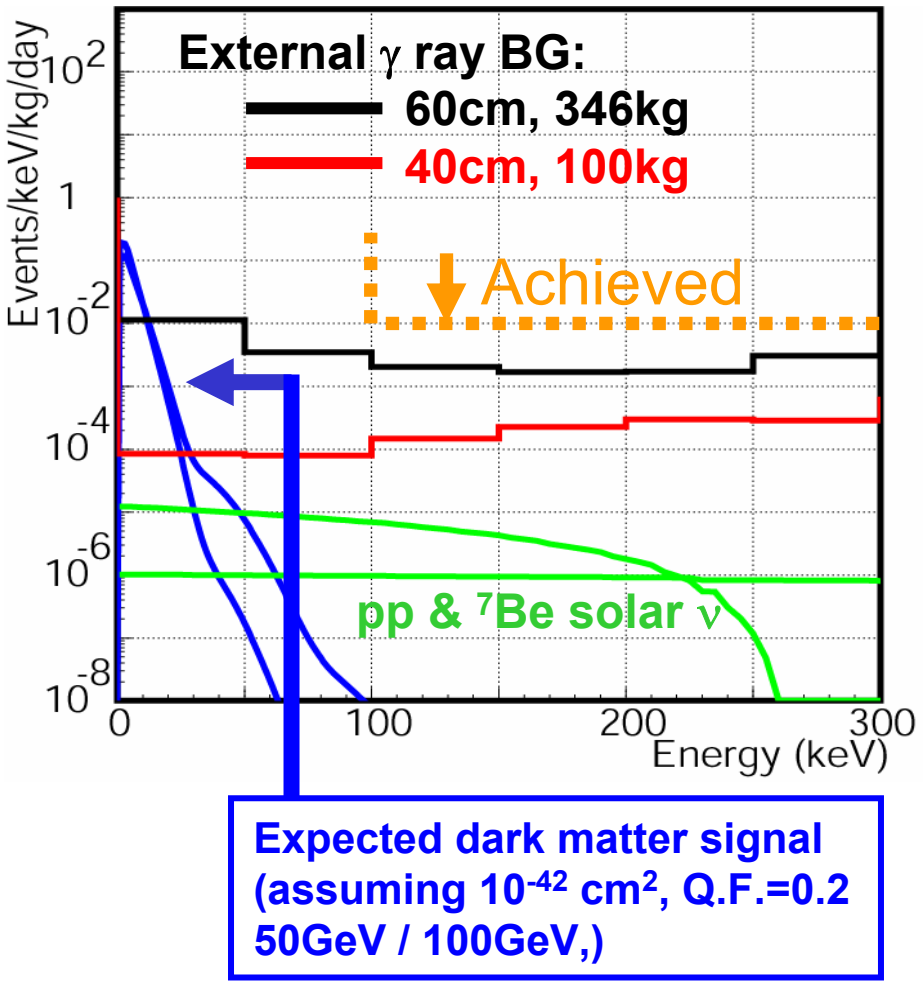
- XMASS 800kg detector
- Distillation purification of Xe for Kr
- Kr assay with API-MS detector
- Rn assay with XMASS prototype detector
- Summary

XMASS 800kg detector (in Kamioka Observatory)

Dark matter search via nuclear elastic scattering

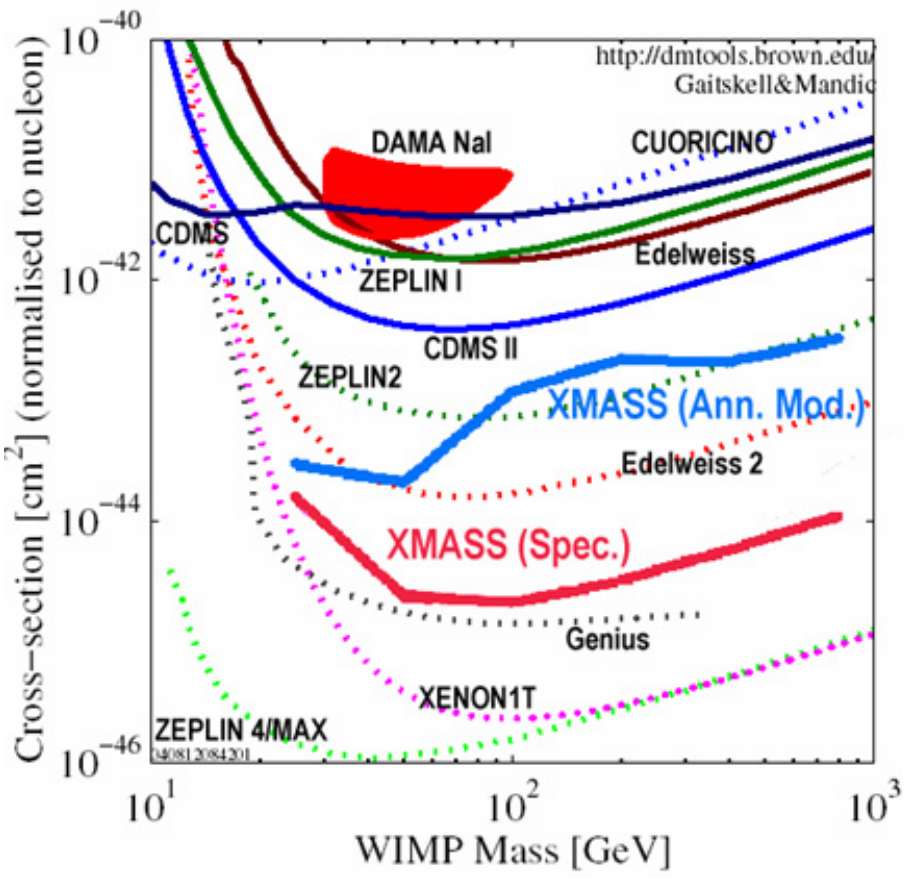


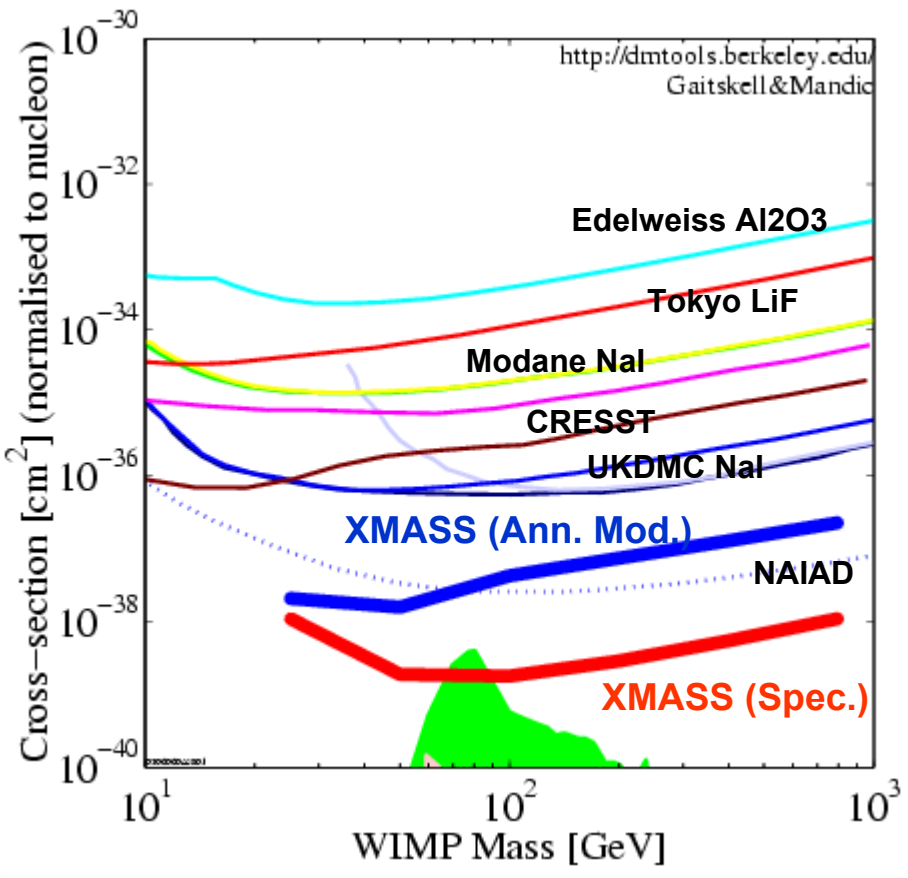


~800kg xenon (FV 100kg)
~800 of 2-inch PMT (1/10 Low BG)
~70% photo coverage
~5keVee threshold
Target internal BG levels:
< 2×10^{-5} ev/keV/kg/day

XMASS 800kg: Expected sensitivity

XMASS FV 0.5ton year
E_{th}=5keVee~25p.e., 3σ discovery
without any pulse shape info.





- **Large improvements are expected.**

Internal backgrounds

- **^{238}U series**
  - ^{222}Rn($\tau_{1/2}$ = 3.8d, 3.3MeV beta), …
  - Target (for XMASS 800kg detector): 1x10^{-14}g(^{238}U)/g(Xe)
- **^{232}Th series**
  - ^{220}Rn(55s, 2.3MeV beta[64%]), …
  - Target: 2x10^{-14}g(^{232}Th)/g(Xe)

Assay with XMASS prototype detector

- **^{85}Kr**
  - Contamination during manufacture and refinement
  - $\tau_{1/2}$ = 10.8y, 687keV beta (99.6%)
  - Target: Kr = 1 ppt (mol) (assuming ^{85}Kr/Kr = 1.2x10^{-11})

（~ppb level Kr for commercial “Kr-free” Xe） ⇒ Apply distillation

Distillation purification of Xe for Kr

Distillation of Xe for Kr

Distillation tower

Distillation system in Kamioka

Distillation of Xe for Kr

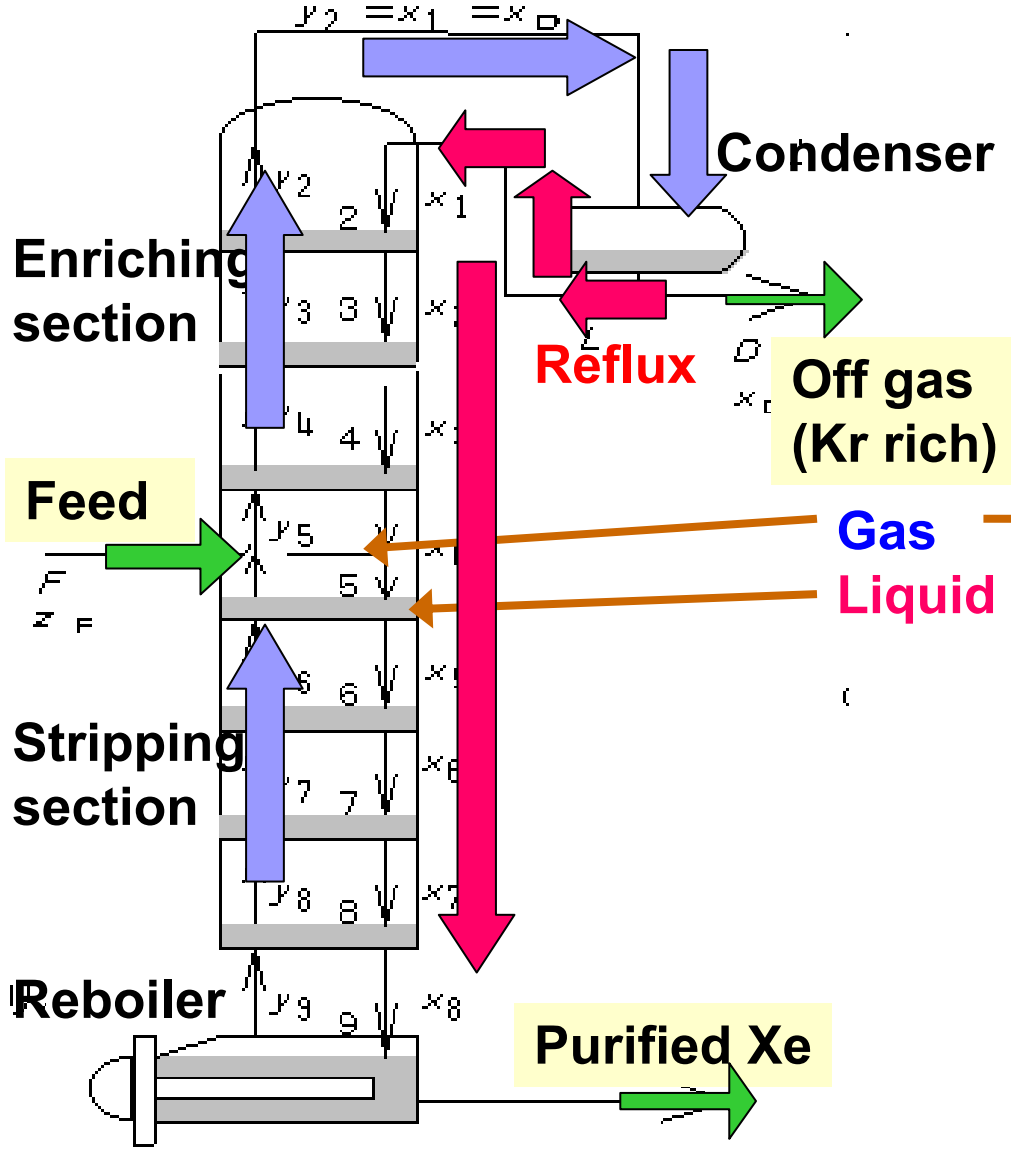
- Impurities in xenon
  - CO_2, H_2O : removed by adsorption
  - Kr, O_2, N_2, H_2, He : removed by distillation (boiling points are lower than Xe)

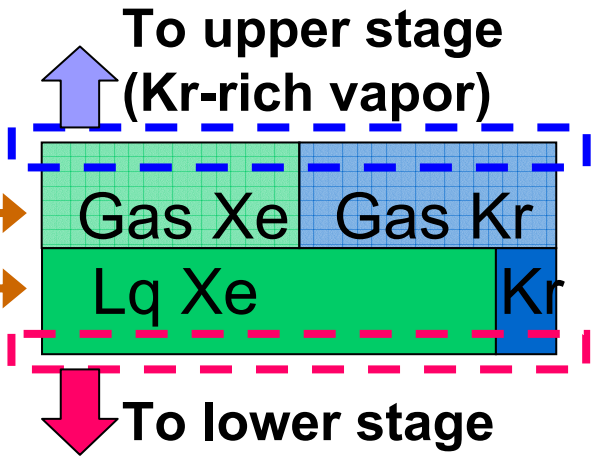
	Boiling point (@1 atm)	Boiling point (@2 atm)
Xe	165K	178K
Kr	120K	129K

- Built a Xe distillation system in Kamioka mine
  - Process speed: 0.6kg/hour (= ~100kg / 1 week)
  - 99% yield (= 99% Kr-less gas, 1% Kr-rich gas)
  - 1/1000 Kr in purified Xe (design value)
  - Operation condition: 178~180K, 2atm (measured)

Distillation tower

- Multiple stages in a tower
- Each stage is in vapor-liquid equilibrium
- Volatilities are different between Xe and Kr





Relative volatility

= (Kr in gas / Kr in lq) / (Xe in gas / Xe in lq)

= 10.4 (@178K)

Distillation system in Kamioka

- A special distillation system of Xe for Kr was built in Kamioka Observatory
- We have processed 100kg Xe in March '04

Raw Xe:
~3 ppb Kr

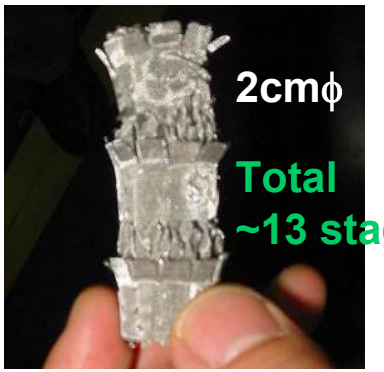
0.6 kg / hour

~1%

Off gas Xe:
330±100 ppb Kr
(measured)

Operation: 2 atm
Reflux ratio = ~190
Design factor: 1/1000 Kr / 1 pass

Sulzer Chemtech:
EX laboratory packing



~99%

Purified Xe:
3.3±1.1 ppt Kr
(measured)

Kr assay with API-MS detector

GC + API-MS system

Measurement of Kr in purified Xe

Kr assay result

GC + API-MS system

This system was developed at Taiyo Toyo Sanso Co. Ltd. (SAAN). http://www.saan.co.jp/english/

- API: Atmospheric Pressure Ionization
- Primary ionization by Corona discharge
  - Small fraction of carrier and target molecules are ionized
- Secondary ionization by Ion-molecule reaction
  - Carrier gas (C): higher ionization potential
  - Target (X): lower ionization potential

$$C^+ + X \rightarrow C + X^+$$

(Most of target molecules are ionized by charge exchange)

- Ionization potential:

	He	Ar	Kr	Xe
eV	24.6	15.8	14.0	12.3

- Need to extract Kr from Xe

⇒ Gas Chromatography (GC) + API-MS system

GC + API-MS system at SAAN

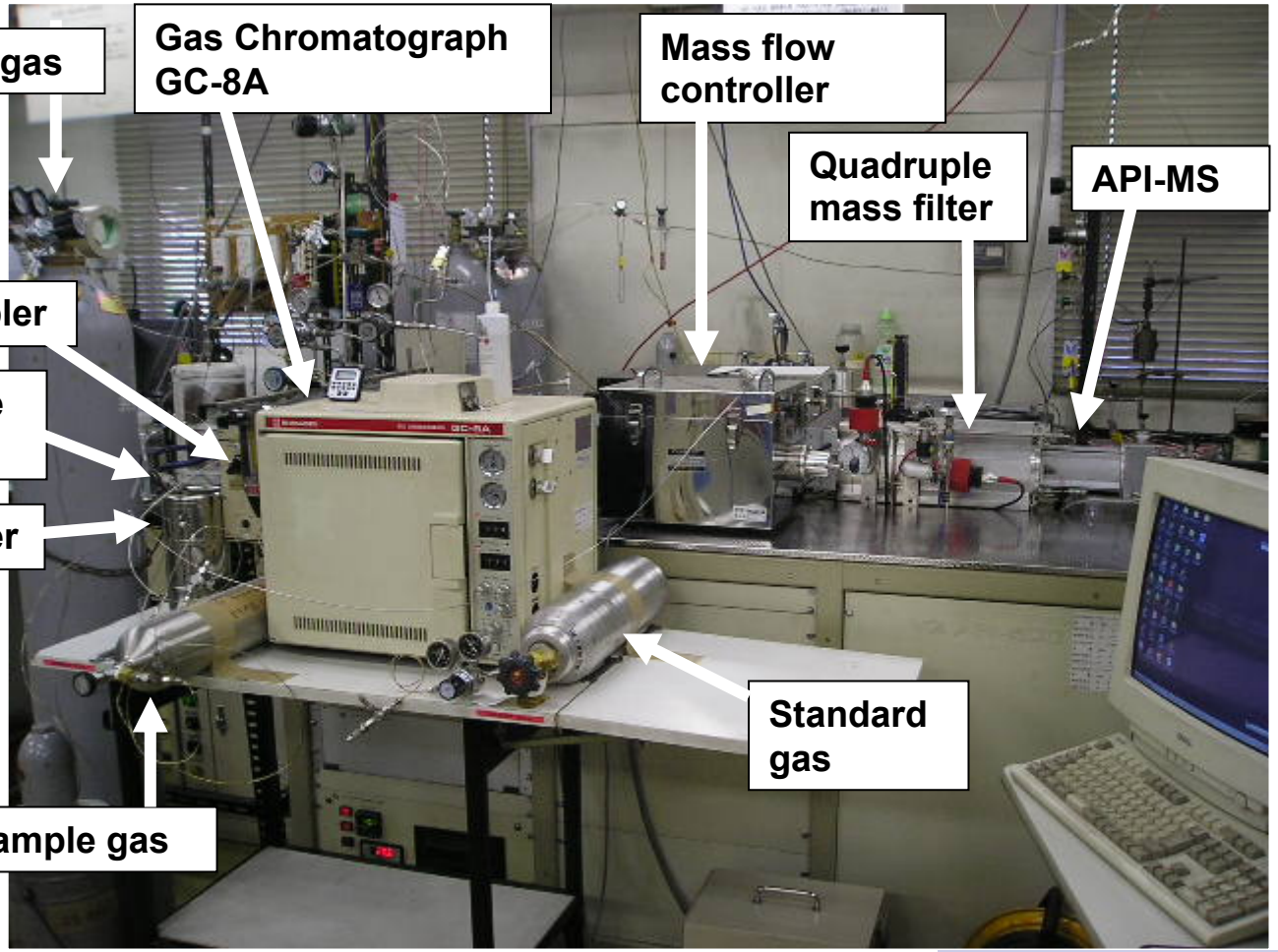
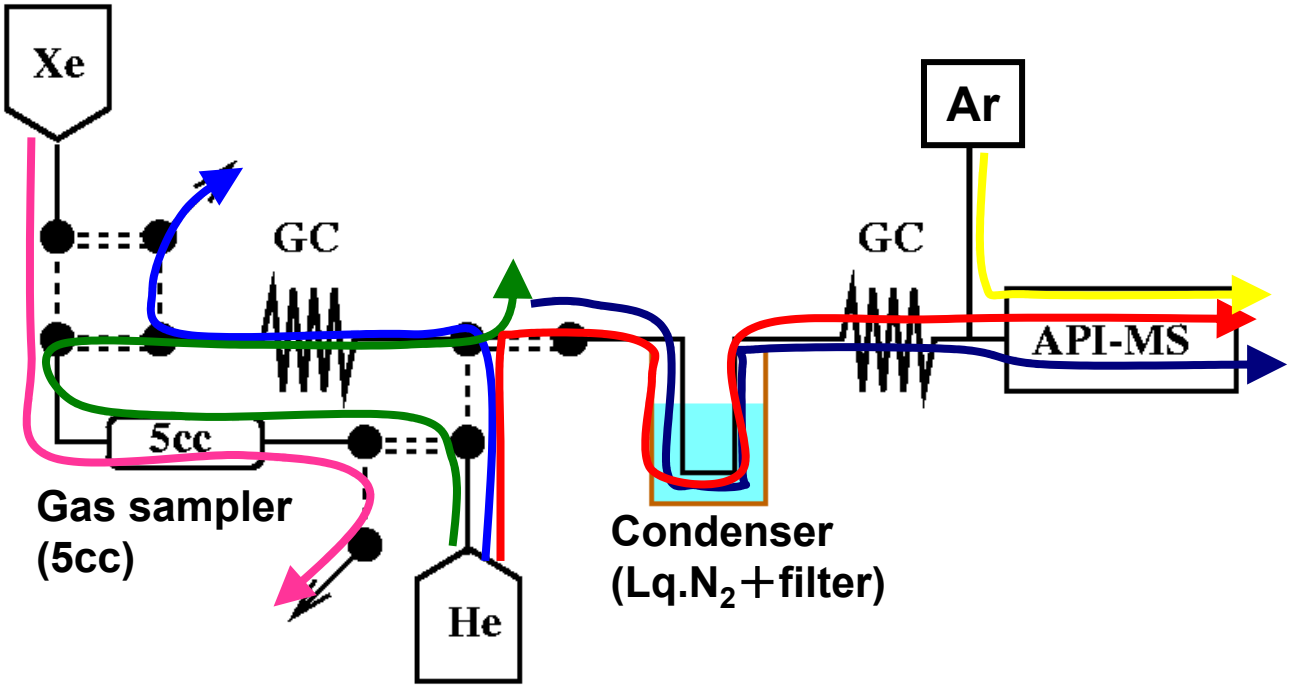


Photo by Kawaguchi Laboratory, Research & Development Division, Taiyo Toyo Sanso Co. Ltd.

Measurement of Kr in purified Xe

- Extract Kr from Xe by GC with He carrier gas, then trap Kr in the condenser. Repeat this 100 times.
- Feed the trapped Kr into API-MS with He and Ar carrier gas

~15min / cycle



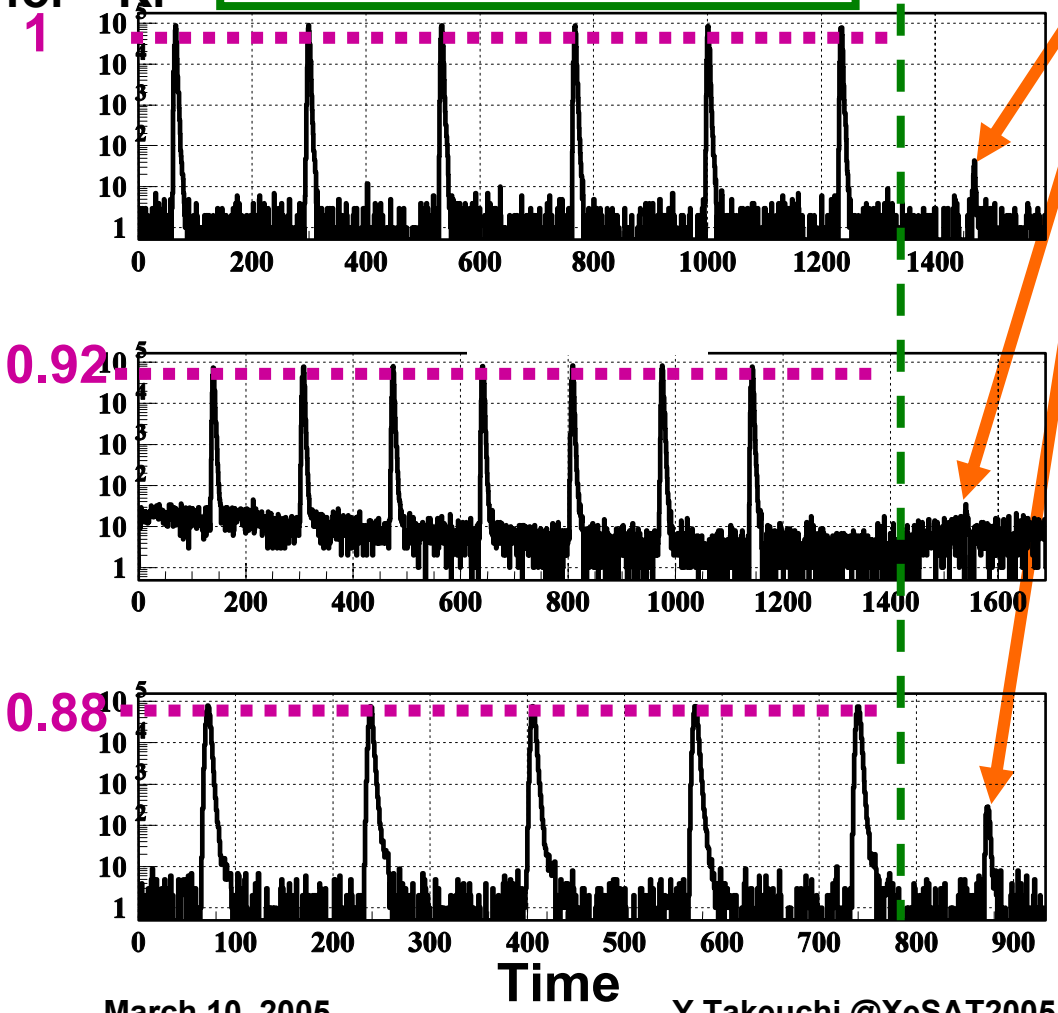
- Purge GC with He
- Sample 5cc Xe
- Feed sample Xe into GC with He carrier
- Only Kr timing, feed sample gas into the condenser.
- Repeat above
- After heat up, feed condensed Kr into API-MS (select only Kr timing by GC)

Kr assay result

Measurement after 100 times condense

API-MS count for ^{84}Kr

Calibration with 1ppm Kr standard gas



Sample Xe gas	184.0±15.8 count
Carrier He gas	(88.5±23.9) /0.92
Kr 50ppt	(1176.9±35.7) /0.88

Kr concentration =
(Sample Xe - He gas)
/ Kr50ppt gas × 50ppt
= 3.3±1.1 ppt (stat. error only)

Factor ~1/1000 / 1pass was achieved

Rn assay with XMASS prototype detector

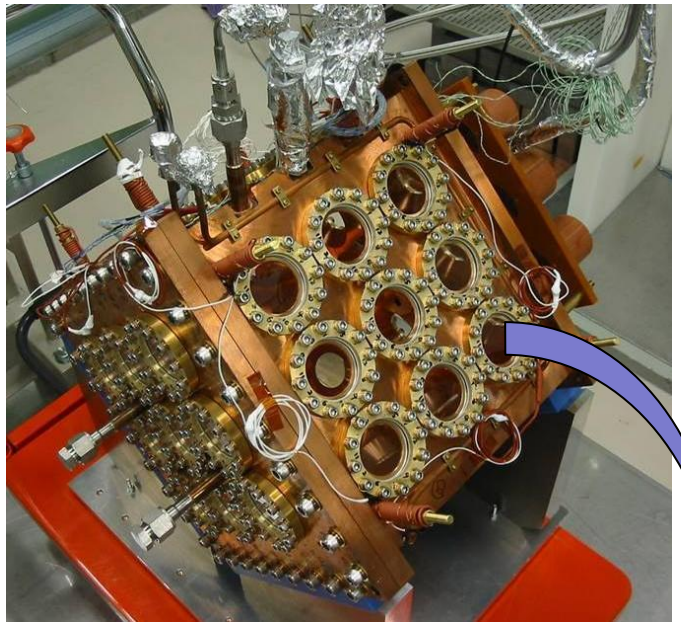
XMASS prototype detector

Rn assay with prototype detector

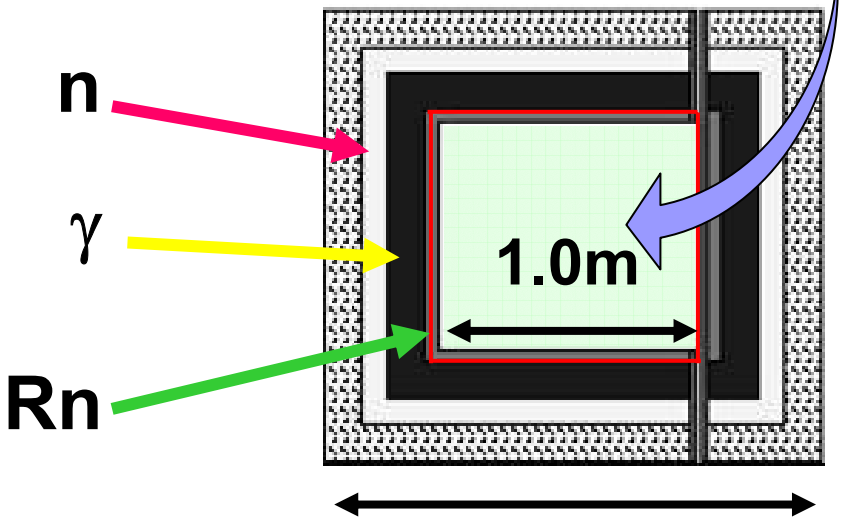
^{222}Rn measurements

Internal background sources

XMASS prototype detector



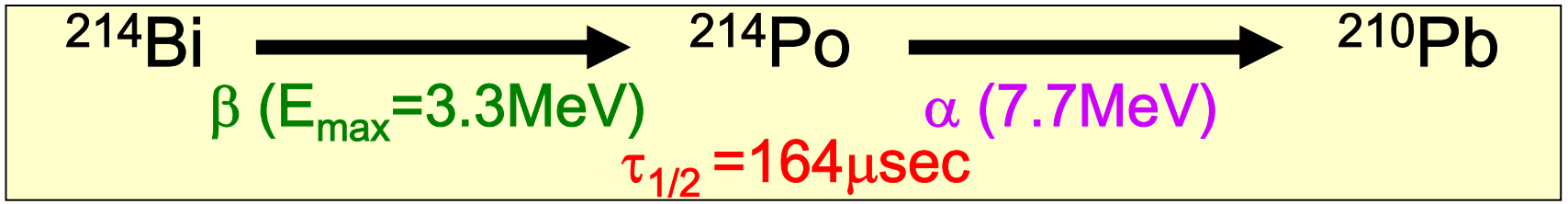
- 30 litter liquid Xenon (~100kg)
- Oxygen free copper: $(31cm)^3$
- 54 of low-BG 2-inch PMT
  - Photo coverage ~16%
- MgF_2 window, heavy shield
- in Kamioka Underground Observatory (2700m.w.e.)



- Polyethylene (15cm)
- Boric acid (5cm)
- Lead (15cm)
- EVOH sheets (30mm)
- OFC (5cm)
- Rn free air (~3mBq/m^3)

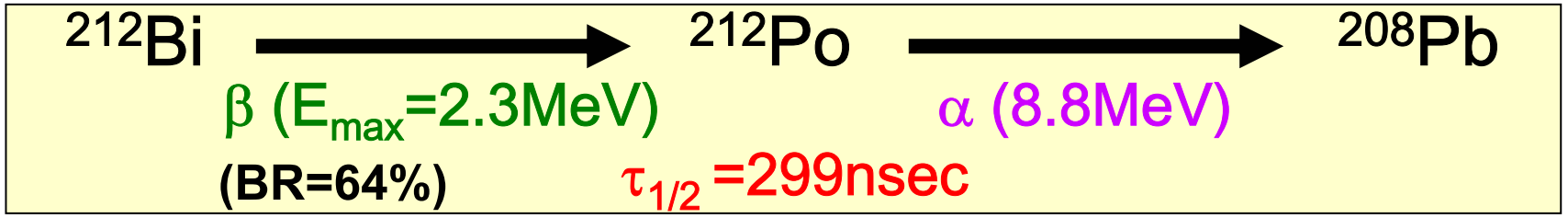
Rn assay with prototype detector

- **^{238}U series**
  - **^{222}Rn($\tau_{1/2}$ = 3.8d, 3.3MeV beta), …**



⇨ Observed coincident events

- **^{232}Th series**
  - **^{220}Rn(55s, 2.3MeV beta[64%]), …**



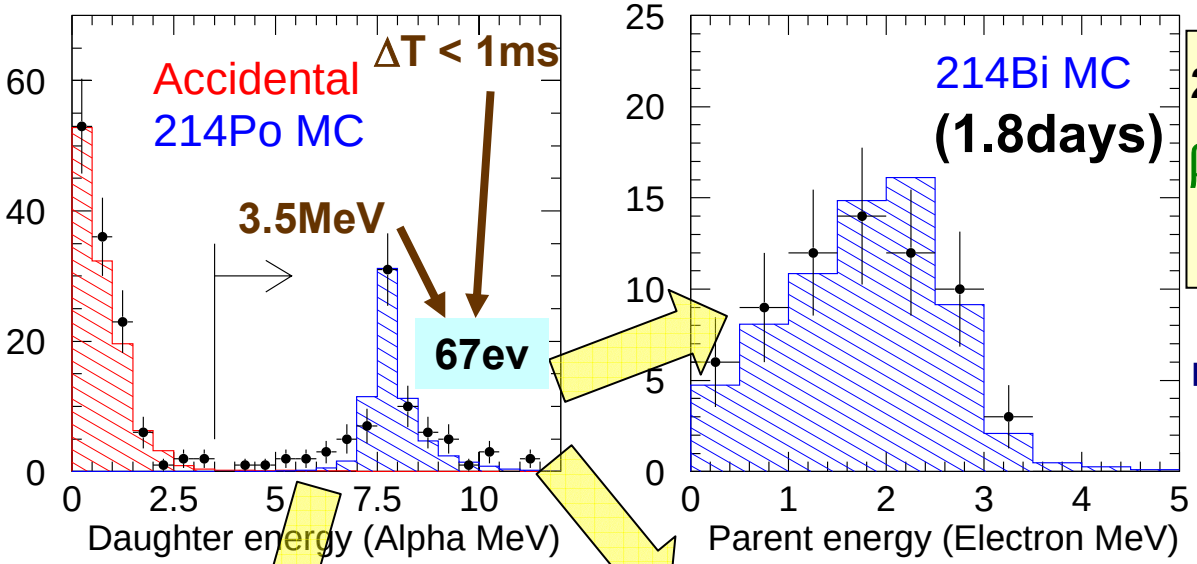
⇨ No candidate found

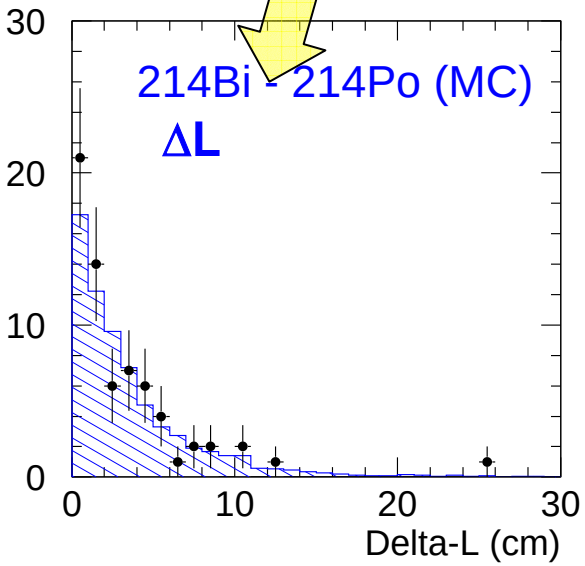
^{222}Rn measurements

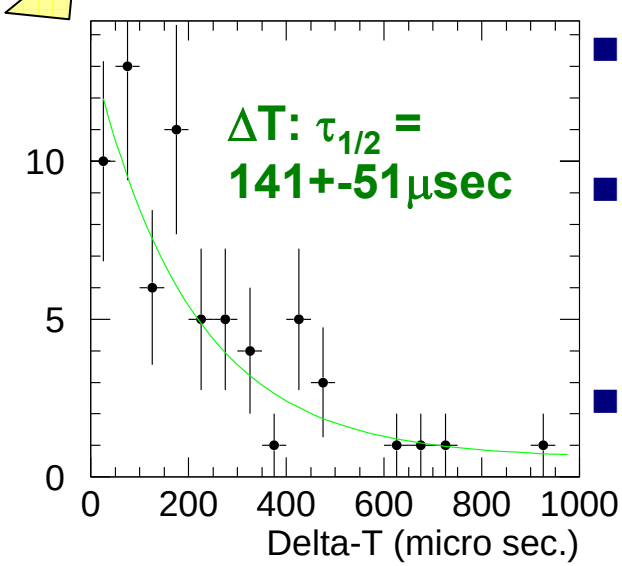
^{238}U → ^{222}Rn

Aug.04 run
Preliminary

^{214}Bi → ^{214}Po → ^{210}Pb
β (E_{max}=3.3MeV) α (7.7MeV)
$\tau_{1/2}$ =164μsec







- 2 separate runs to check ^{222}Rn decay ($\tau_{1/2}$=3.8day)
- 4th Aug. 0.8day
  ^{238}U=(72+-11)x10^{-14} g/g
- 10th Aug. 1.0day
  ^{238}U=(33+-7)x10^{-14} g/g
- Consistent with expected ^{222}Rn decay
  ((30+-5)x10^{-14})

Internal background sources

Preliminary

- **Current results**
  - ^{238}U: = $(33+-7)\times10^{-14}$ g/g
    - Factor ~30, but may decay out further
  - ^{232}Th: < 23×10^{-14} g/g
    - Factor <~10, under further study
  - Kr: ~3.3±1.1ppt
    - Would be achieved by an improved distillation system

Goal (~1ton)
1×10^{-14} g/g
2×10^{-14} g/g
1 ppt

Summary

- A distillation system of Xe for Kr was built in Kamioka Observatory. ~1/1000 Kr reduction / 1pass was achieved.
- GC + API-MS system was used for Kr assay in purified Xe.
- ^{222}Rn and ^{220}Rn in purified Xe was measured by XMASS prototype detector.
- The current remaining impurities in purified Xe for XMASS are below:
  - ^{238}U: = $(33\pm7)\times10^{-14}$ g/g
  - ^{232}Th: < 23×10^{-14} g/g
  - Kr: = 3.3±1.1 ppt

(assuming radiative equilibrium)