Development of a Rn removal system for future Xe-based neutrino detectors using resonant ionization

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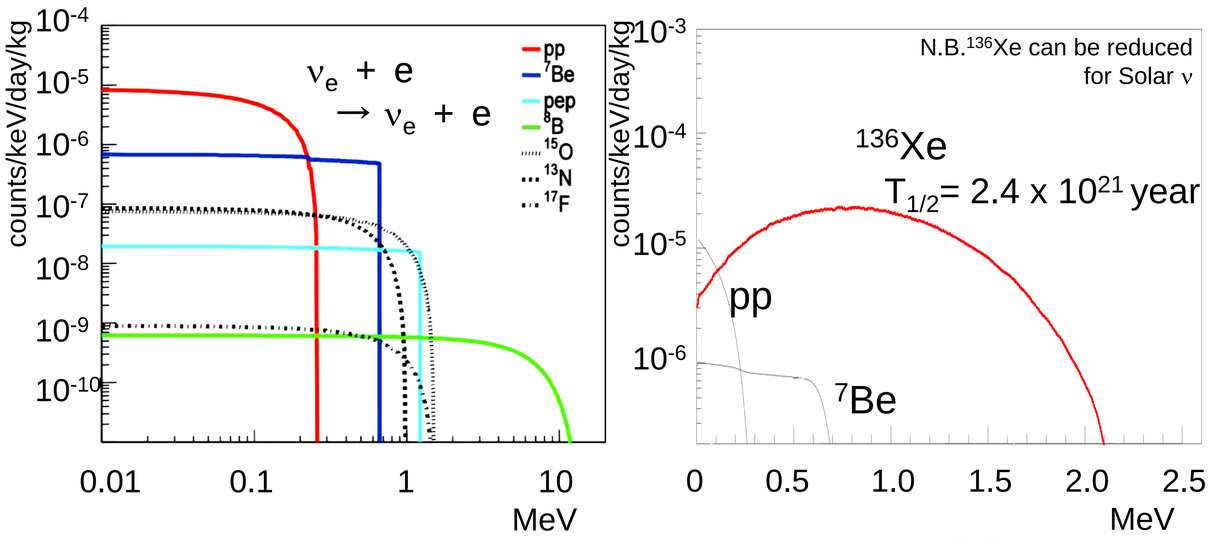
Preface: Radon is one of the major background sources in low energy neutrino experiments. Accordingly it is essential to suppress radon events in future large-scale xenon detectors aiming for neutrino-less double beta decay and pp solar neutrino measurements. Although the removal of radon from air using adsorption on activated charcoal is well established, because its chemical properties are similar to those of radon this technique cannot be used with xenon; Xenon itself adsorbs to charcoal and thereby deteriorates its radon absorption efficacy. So we propose a new radon removal method.

1. Xe-based neutrino detector

-beyond dark matter search

- solar neutrino spectra in Xe
- ^{136}Xe 2νββ spectrum

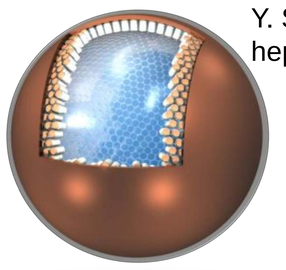


XMASS as an example

Future XMASS-II

pp 14 events/day
^{7}Be 7 events/day

24ton
10ton fiducial
Ø 2.5m



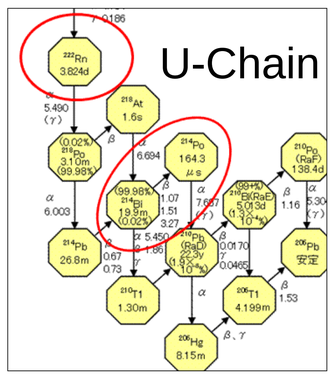
Y. Suzuki
hep-ph/0008296

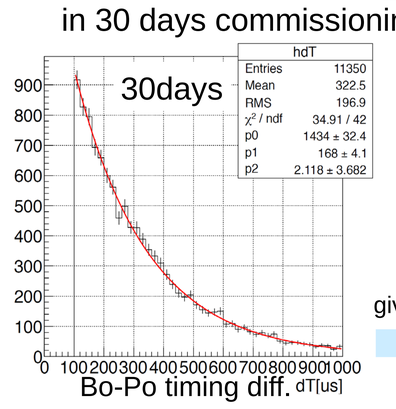
XMASS-I

1ton
100kg fiducial
Ø 80cm

- Current ^{222}Rn level in XMASS-I

From the ^{214}Bi-^{214}Po chain events (dT 164μs) in 30 days commissioning data





8.2mBq/835kg
(emanated from the detector itself)

gives BG of
10^{-4} counts/keV/day/kg

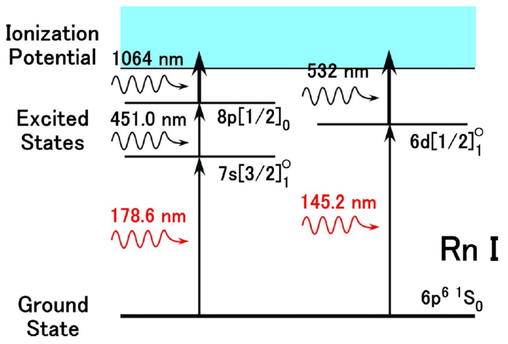
To observe pp ν (to achieve BG~10^{-6} counts/keV/day/kg),
Rn must be reduced 1/100 and continuously removed.

2. Resonant ionization of Rn

Resonance-enhanced multi-photon ionization process

- A laser is used to promote radon atoms to an electronically excited state via resonant single- or multiple-photon absorption and these excited Rn atoms are then ionized by the introduction of another photon.

Rn Resonant ionization scheme



- Excitation cross section

Assuming laser's λ shape is Gaussian,

$$\sigma = g_2/g_1 \times \lambda^2 \times A_{21} / (8\sqrt{2} \times \pi^{3/2} \times \Delta\nu)$$

Δν : Laser linewidth[Hz]
A_{21}: Einstein coefficient[s^{-1}]

In case of Rn g_2/g_1: *2J+1=3*

λ = 178.6nm or 145.2nm

A_{21} ~ 10^7 s^{-1} (no ref., assuming Xe $5p^6\ ^1S_0 \rightarrow 5d[1/2]^o_1$)

- Nano second pulse laser Δν 1~10GHz

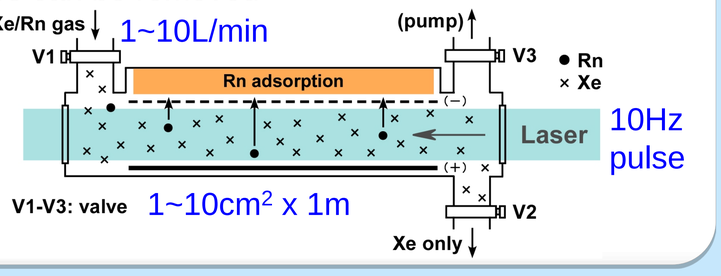
σ ~ 10^{-13}cm^2

145.2nm = 1.368 × 10^{-12}μJ

➡ ~10μJ/pulse laser is necessitated.

- Selectively ionized Rn impurities can be removed with an applied electric field.

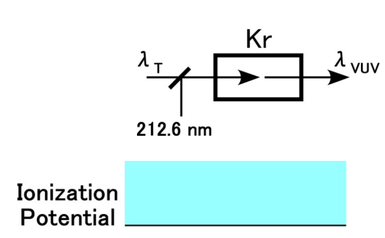
A possible system for 1/100 reduction

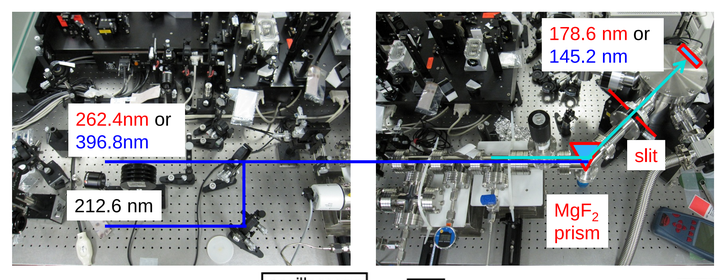


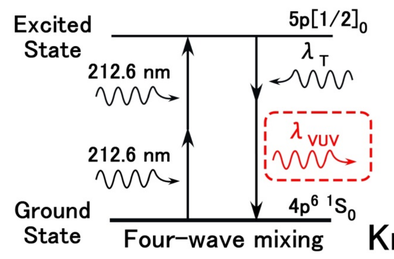
3. Development of Lasers

4 wave-mixing for making 178.6nm or 145.2nm

- Wavelength transformation in Kr gas cell

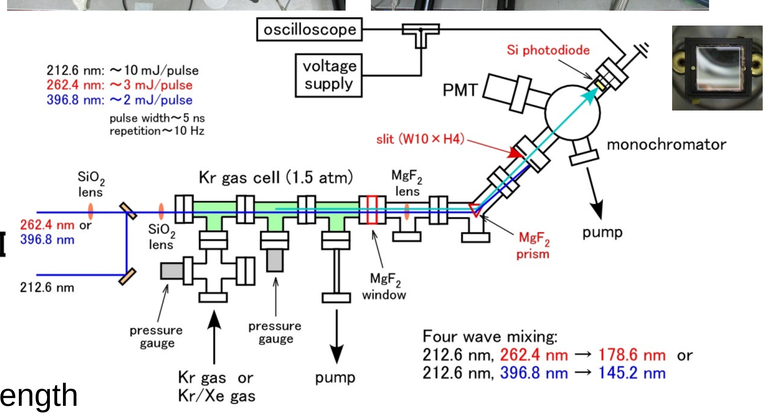






Kr I

$(\lambda_T, \lambda_{VUV}) = \begin{cases} (262.4\text{ nm}, 178.6\text{ nm}) \\ (396.8\text{ nm}, 145.2\text{ nm}) \end{cases}$



- How to make input wavelength

355nm: Continuum® Nd:YAG Laser

- 1/525nm × 2 ⇒ 1/262.4 nm

SHG OPA OPO YAG

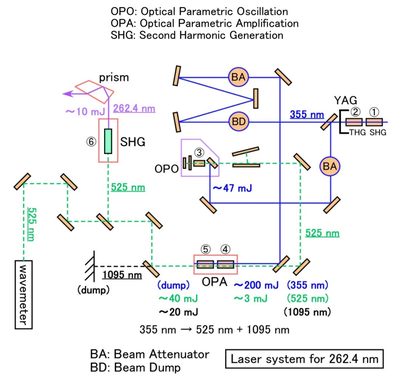
- 1/794 nm x 2 ⇒ 1/396.8 nm

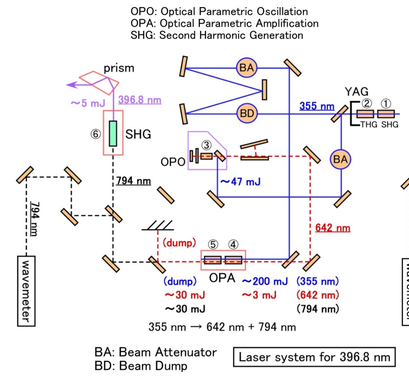
SHG OPA OPO YAG

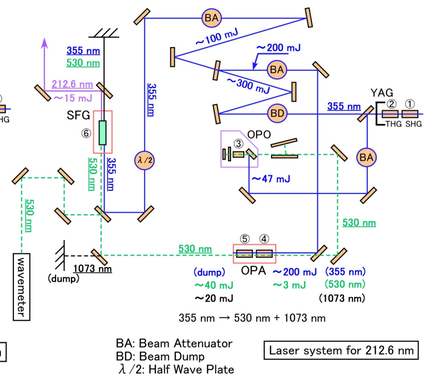
- 1/355nm + 1/530nm ⇒ 1/212.6 nm

SFG OPA OPO YAG

OPO: Optical Parametric Oscillation
OPA: Optical Parametric Amplification
SHG: Second Harmonic Generation

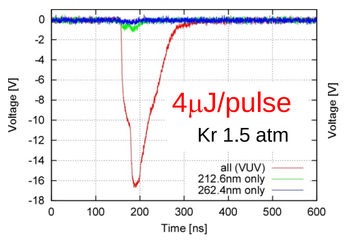




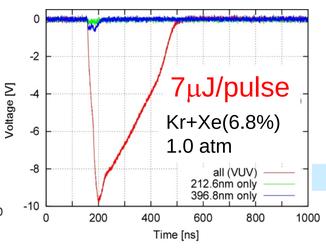


- Results measured by oscilloscope

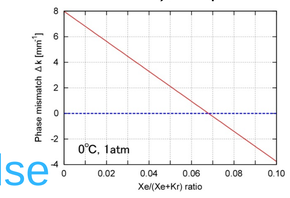
- 178.6nm



- 145.2nm



N.B. Due to the large refractive index of Kr in 145.2nm, a phase mismatch occurs. (Attenuated in Kr gas). Adding ~7% Xe (refractive index is small), the phase can be adjusted.

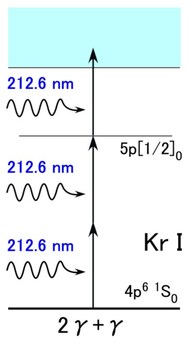


~10μJ/pulse is almost achieved.

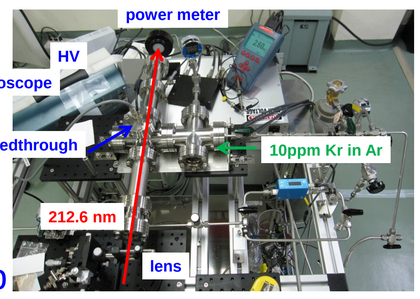
4. Test: Kr removal from Ar

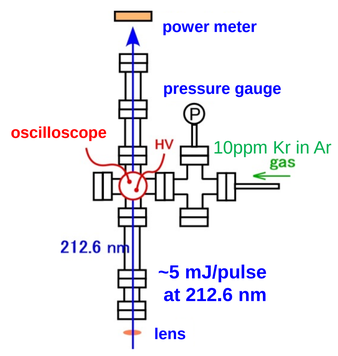
as a demonstration

- Kr can be resonantly ionized via 212.6nm 2γ+γ

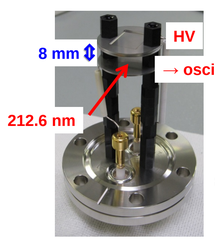


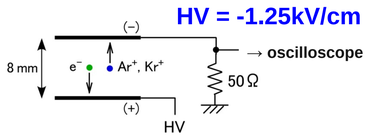
The setup



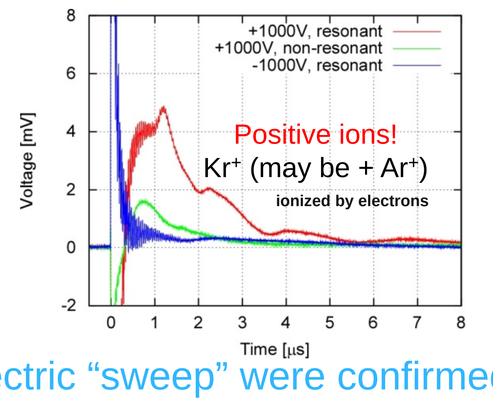


- 10ppm Kr in Ar w/ 5mJ/pulse laser





resonant 212.6 nm
HV = +1.25kV/cm
non-resonant 211.6 nm
HV = +1.25kV/cm
resonant 212.6 nm
HV = -1.25kV/cm



Resonant ionization of Kr and its electric "sweep" were confirmed.

Conclusion: A system for removing Rn from Xe has been developed. In this study, the feasibility of this method was demonstrated by removing Kr from Ar. Since the necessary laser has already been developed, tests of Rn removal from Xe will begin soon.