LIDINE CONFERENCE 2017
SLAC NATIONAL ACCELERATOR LABORATORY

RADON BACKGROUND IN LIQUID XENON DETECTORS

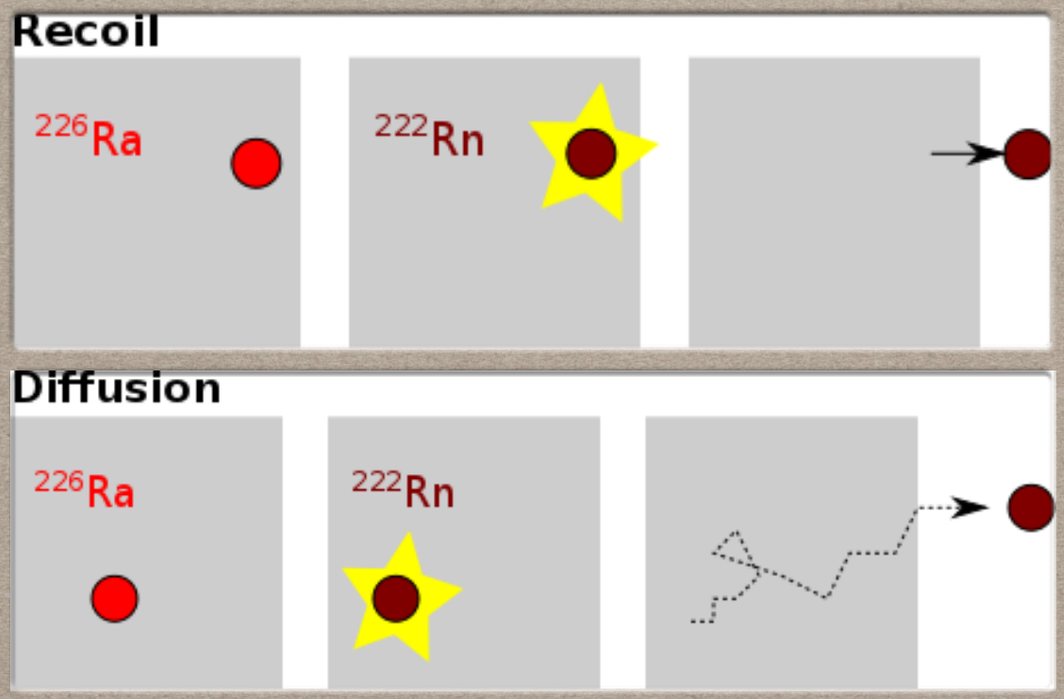
NATASCHA RUPP
MPIK HEIDELBERG

MAX-PLANCK-INSTITUT FÜR KERNPHYSIK HEIDELBERG

RADON AS BACKGROUND SOURCE

- part of primordial decay chains from Uranium and Thorium
- mother nuclei present in detector materials

enters LXe in two ways:

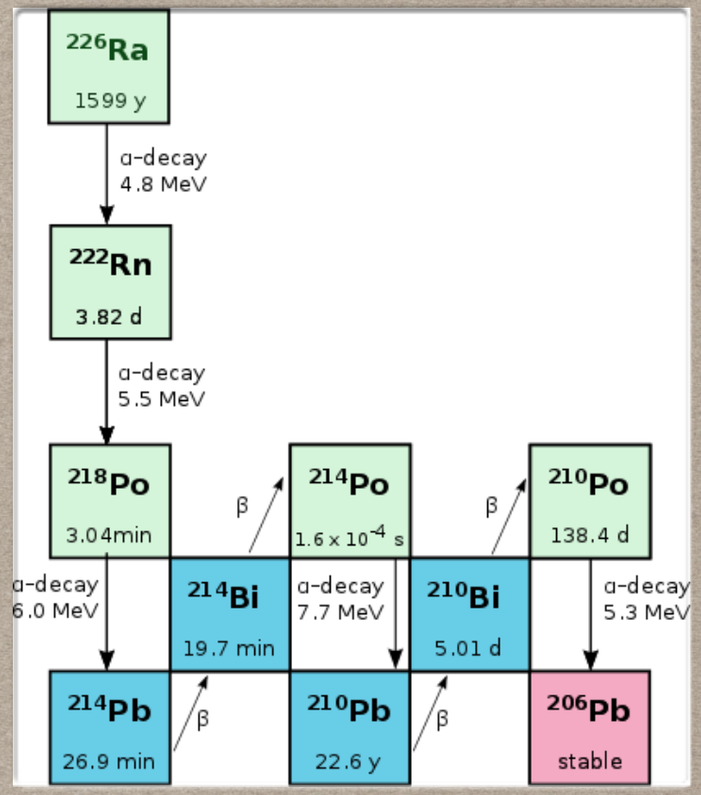


- noble gas and chemically inert
- no external shielding possible
- no stable isotope in nature
- long half-live of ^{222}Rn with 3.8 days (main focus in this talk)

RADON AS BACKGROUND SOURCE

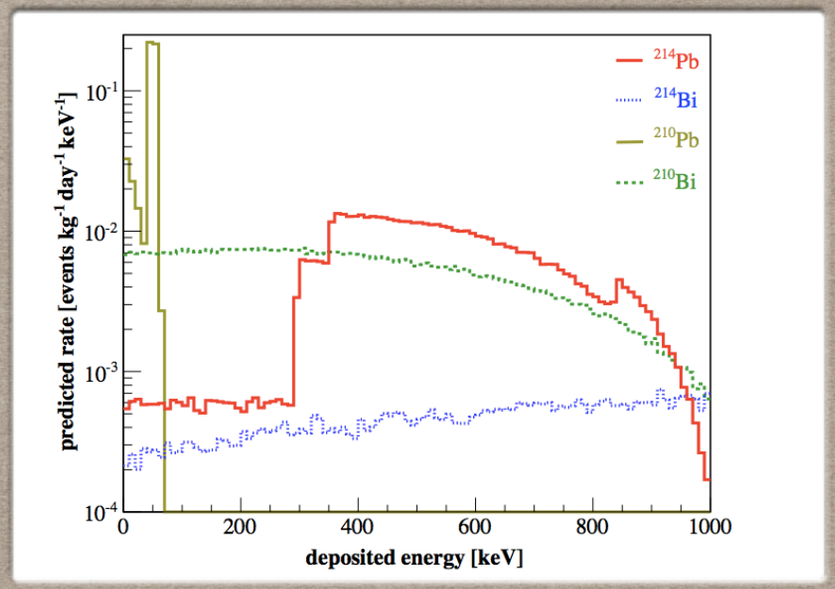
Beta decays:

- due to continuous energy spectrum constant background source
- neutrinoless double beta decay : ^{214}Bi
- dark matter search: ^{214}Pb



Alpha decays:

- usually **no** direct background due to high energies in MeV region
- used to set limits on actual radon induced background beta decays
- can be measured with dedicated alpha detectors (e.g. proportional counters, radon monitors)

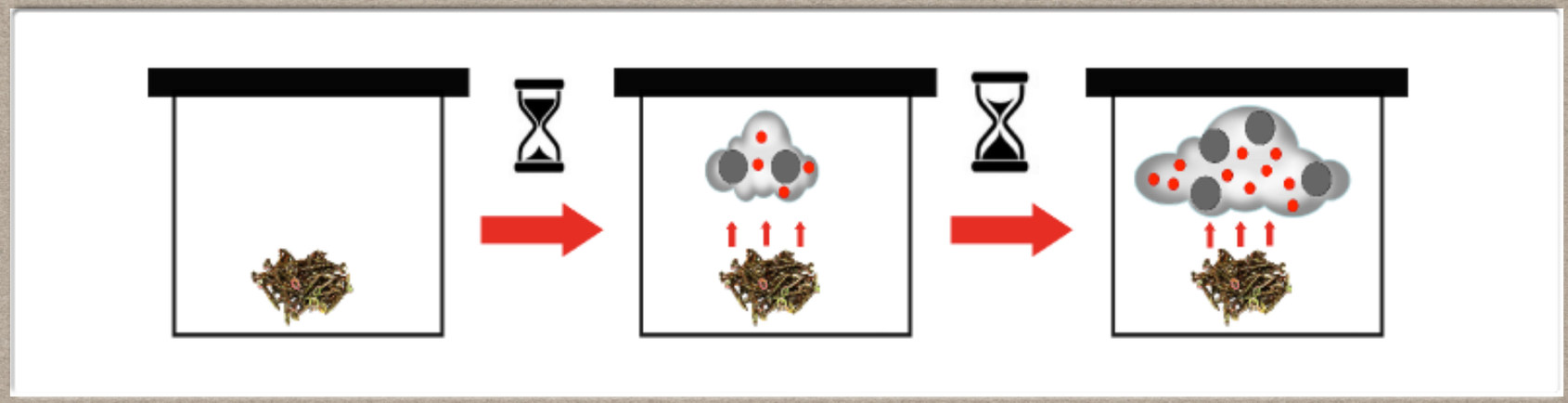


Diploma Thesis S. Brünner (2014)

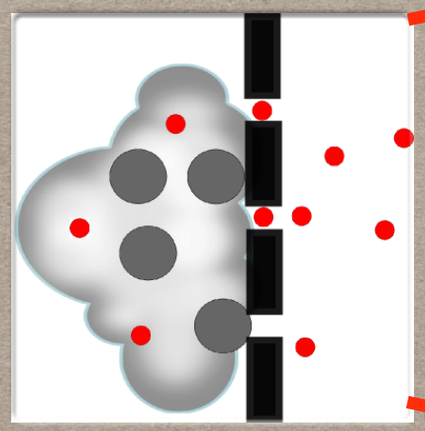
RADON SCREENING

- allows careful selection of only radio-pure materials
- gamma spectroscopy only not sufficient

collecting radon atoms:



sample purification:



- separating radon atoms from impurities with gas chromatography

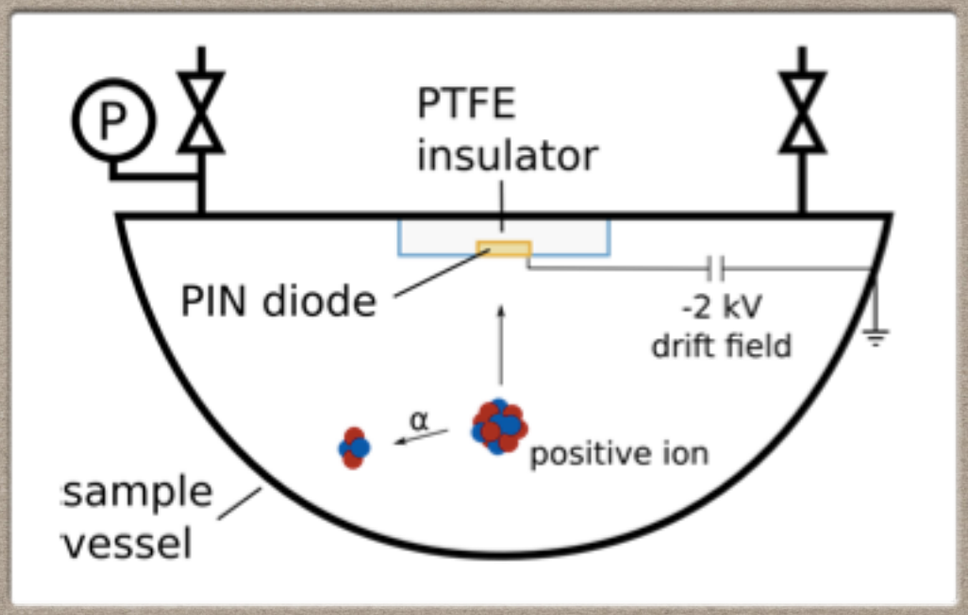
ALPHA DETECTORS

miniaturized proportional counters:

- originally developed for solar neutrino experiment GALLEX/GNO
- low intrinsic background: 1cpd
- high sensitivity: 20 μBq (10 radon atoms)
- extensive procedure of counter filling

radon monitors :

- positively charged decay products drifted to PIN diode
- sensitivity: < 1mBq
- online measurement of large gas samples possible



Phd Thesis S. Brünner (2017)

EMANATION MEASUREMENT RESULTS

- investigation of SS tubes

no surface treatment:

- (0.09 ± 0.1)μBq/cm^2

after welding:

- (0.12 ± 0.1)μBq/cm^2

after additional electropolishing:

- (0.04 ± 0.1)μBq/cm^2

→ reduction by factor 3

welded

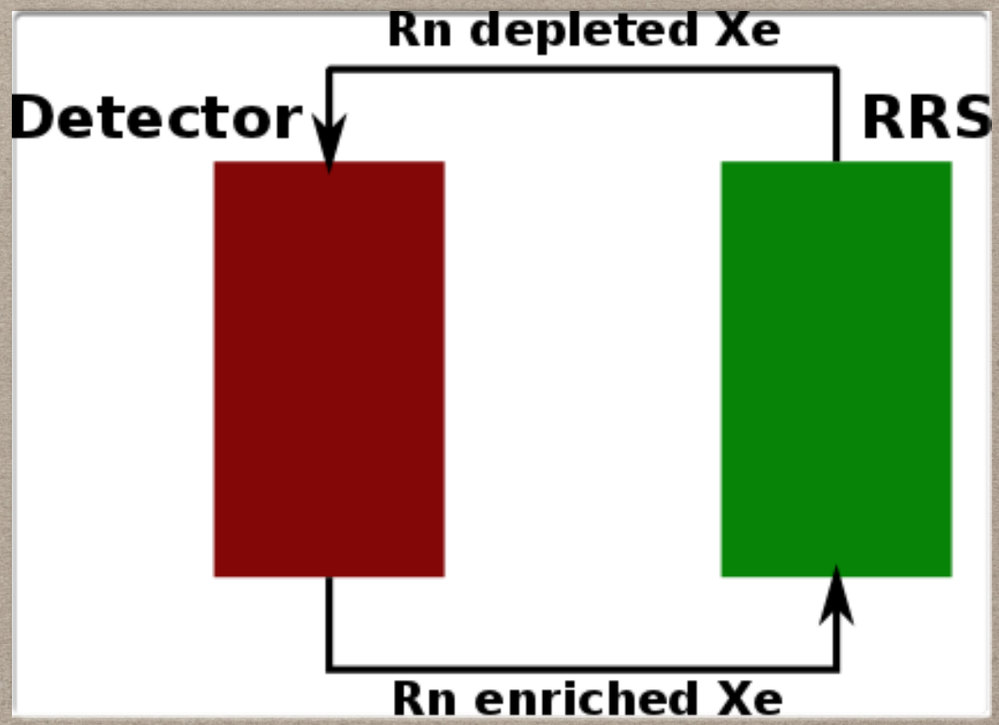
electropolished

RADON REMOVAL SYSTEM (RRS)

- xenon and radon is continuously flushed through RRS during detector operations
- radon is retained in RRS until its disintegration
- challenging due to similar physical properties of xenon and radon

methods for radon removal:

- adsorption
- cryogenic distillation



RADON REMOVAL - ADSORPTION

- based on van-der-Waals forces and polarizability of the atoms

challenges:

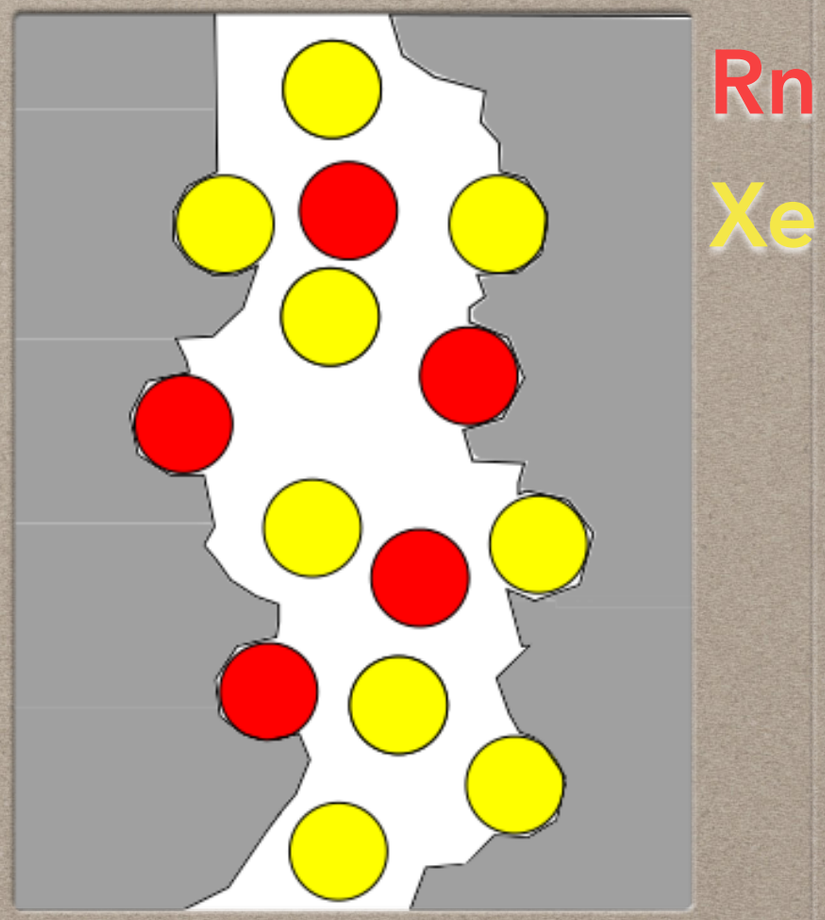
- high adsorption rate of xenon (1.3 g/g at 1bar and T = -80°C)
- radon self-emanation of adsorbent

- tested by XMASS collaboration
  K. Abe et al. (XMASS Collaboration). Radon removal from gaseous xenon with activate charcoal. Nuclear Instruments and Methods in Physics Research A, 2012.
- including self-emanation of charcoal: 40% reduction expected for XMASS, but no published data yet

- studies performed by MPIK in framework of XENON
  Diploma Thesis S. Brünner (2014)

- for XENON adsorption is not the best option

- research on similar RRS ongoing by LZ



RADON REMOVAL - DISTILLATION

- technique successfully applied xenon-krypton separation down to 10^{-15} mol/mol level

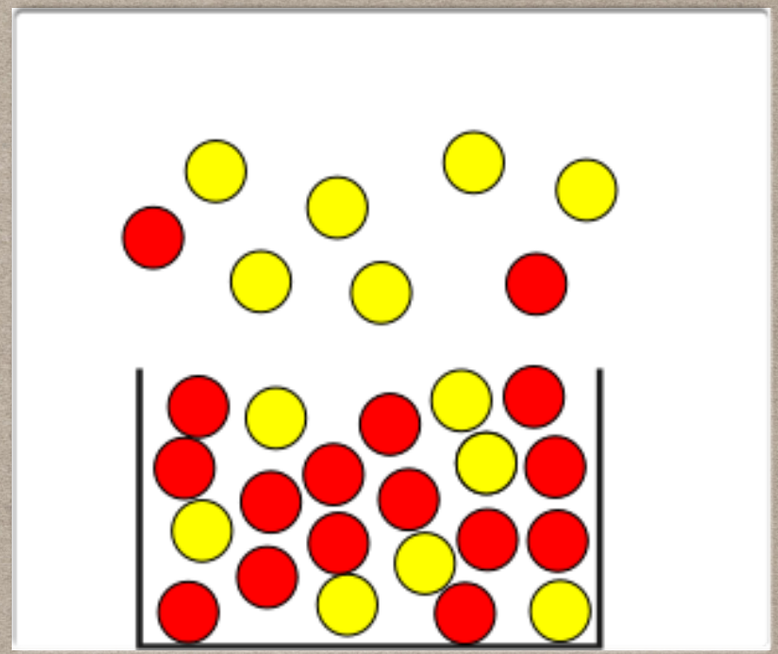
  XMASS, Astropart. Phys. 31, 290–296 (2009) Z. Wang et al,Rev. Sci. Instrum. 85, 015116 (2014)
  XENON1T , Eur. Phys. J. C 77, 275 (2017)
- radon is enriched in liquid phase due to lower vapor pressure

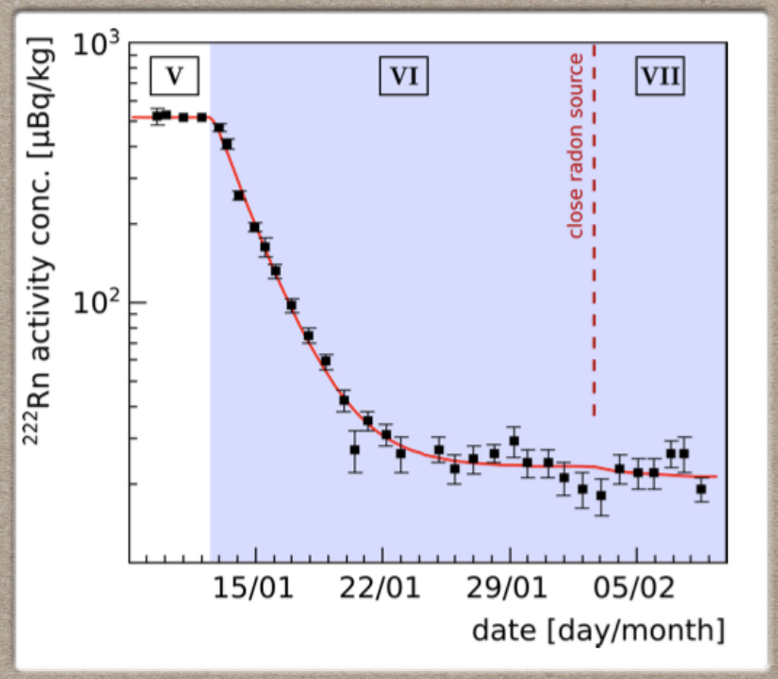
- single stage distillation shown at MPIK with reduction factor R > 4 S. Brünner et al. Eur. Phys. J. C 77: 143 (2017)

- integration of distillation column and external radon source in gas system of XENON100

- successful demonstration of radon reduction by factor R > 27 XENON100 Eur. Phys. J. C 77: 358 (2017)

- reduction of radon level in XENON1T by ~ 20% by taking small fraction of recirculation flow
  XENON1T: arXiv:1705.06655 (2017)
- design studies for dedicated radon distillation column handling higher flow are ongoing





Phd Thesis S. Brünner (2017)

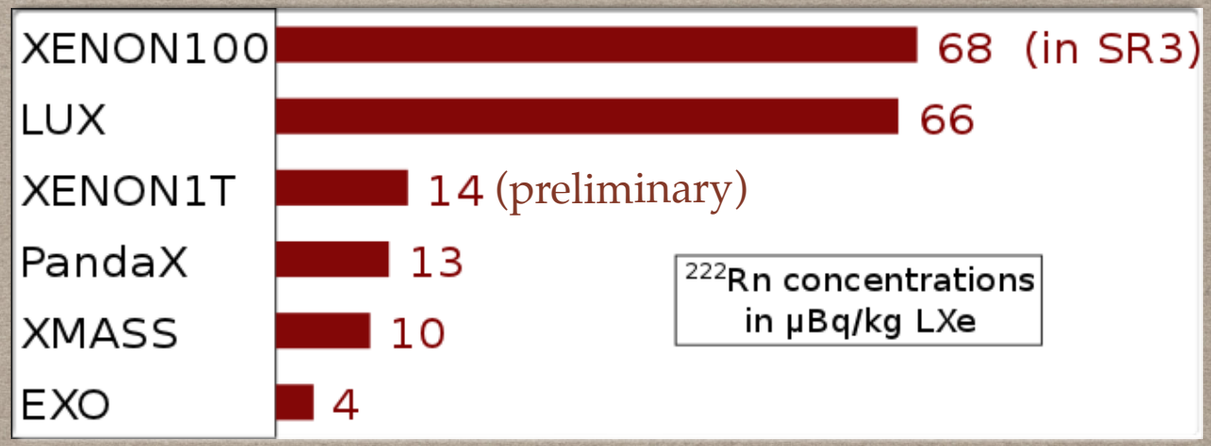
SUMMARY

- radon is one of the highest risk contaminants for low background experiments
- no shielding possible

possibilities to mitigate radon:

- material selection with radon screening
- surface cleaning methods
- online radon removal systems

radon background in LXe experiments :



references on next slide

XENON100:

- XENON COLLABORATION: „Intrinsic backgrounds from Rn and Kr in the XENON100 experiment“ arXiv:1708.03617

LUX:

- LUX COLLABORATION “Radon-Related Backgrounds in the LUX Dark Matter Search“, Physics Procedia 61 (2015) 658

XENON1T:

- internal communication, preliminary result

PANDAX:

- PANDAX COLLABORATION: „Krypton and radon background in the PandaX-I dark matter experiment“, Journal of Instrumentation, Volume 12, 2017

XMASS:

- XMASS COLLABORATION: „XMASS detector“ arXiv:1301.2815

EXO:

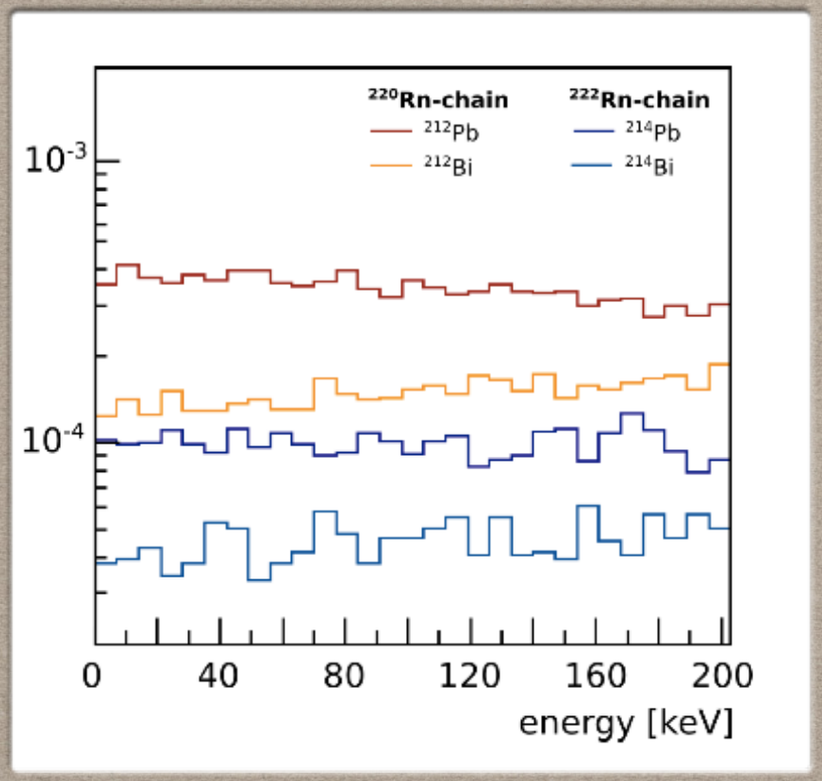
- EXO COLLABORATION: „Investigation of radioactivity-induced backgrounds in EXO-200“ PHYSICAL REVIEW C 92, 015503 (2015)

BACKUP

physical properties of noble gases

	He	Ne	Ar	Kr	Xe	Rn
mass number	2	10	18	36	54	86
boiling point (1 atm) $[K]$	4	27	87	120	165	211
Van-der-Waals radius $[pm]$	140	154	188	202	216	220
polarizability $[\text{Å}^3]$	0.2	0.4	1.6	2.5	4.0	5.3

energy spectrum of Rn220 and Rn222 progenies



decay chain ^{222}Rn

isotope	half life	α-decay energy [MeV]	β-decay energy [MeV] (intensity [%])	γ-emission energy [keV] (intensity [%])
^{222}Rn	3.8 d	5.490	-	-
^{218}Po	3.1 min	6.002	-	-
^{214}Pb	26.8 min	-	0.728 (42.2) 0.670 (48.9) 0.185 (2.8) 1.030 (6.3)[a]	352 (35.1) 295 (15.1) 242 (7.1)
^{214}Bi	19.9 min	-	3.275 (18.2)[a] 1.542 (17.8) 1.508 (17.0) 1.425 (8.2) 1.894 (7.4)	609 (44.6) 1764 (15.1) 1120 (14.7) 1238 (5.8) 2204 (5.0)
^{214}Po	164.3 μs	7.687	-	-
^{210}Pb	22.3 yr	-	0.017 (80) 0.063 (20)[a]	47 (4.3)
^{210}Bi	5.0 d	-	1.162 (99)[a]	-
^{210}Po	138.4 d	5.304	-	-
^{206}Pb			**stable**	

RADON REMOVAL SYSTEM (RRS)

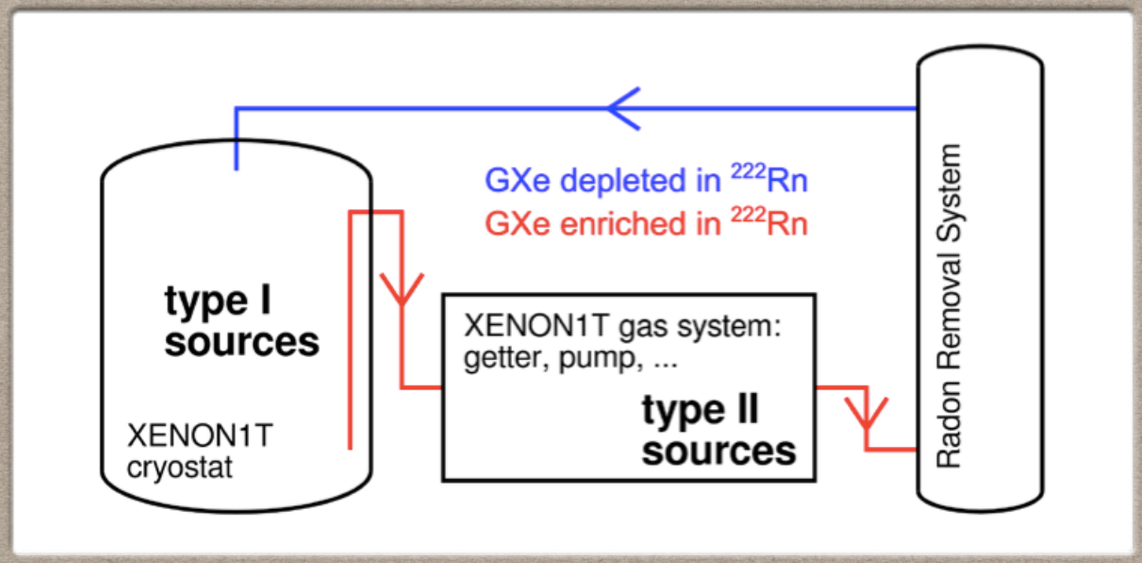
- xenon and radon is continuously flushed through RRS during detector operations
- radon is retained in RRS until its disintegration
- challenging due to similar physical properties of xenon and radon

type I source:

- located behind RRS
- removal requires high recirculation speed

type II source:

- located in front of RRS
- in principle completely removable



Phd Thesis S. Lindemann (2013)

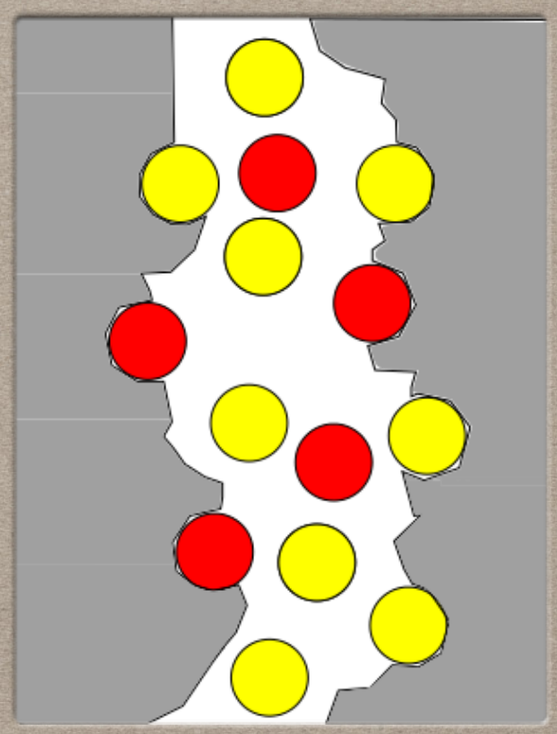
RADON REMOVAL - ADSORPTION

- based on van-der-Waals forces and polarizability of the atoms

challenges:

- high adsorption rate of xenon (1.3 g/g at 1bar and T = -80°C)
- radon self-emanation of adsorbent

example: XMASS experiment

K. Abe et al. (XMASS Collaboration). Radon removal from gaseous xenon with activate charcoal. Nuclear Instruments and Methods in Physics Research A, 2012.

- test set-up with 5.5kg of activated charcoal at -85°C
- measured radon retention time of ~ 4 x T_{222Rn}
- including self-emanation of charcoal:
  40% reduction expected for XMASS
- no published data yet
- research on similar RRS ongoing for LZ