Max-Planck-Institut für Kernphysik
Heidelberg

INTERNATIONAL MAX PLANCK RESEARCH SCHOOL FOR PRECISION TESTS OF FUNDAMENTAL SYMMETRIES

On-line ^{222}Rn purification for liquid xenon detectors

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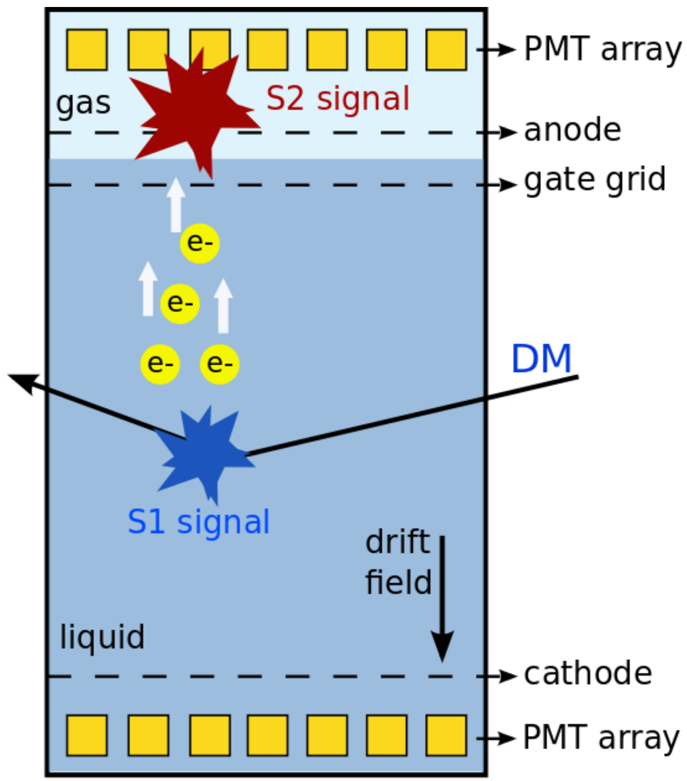
LXe Detectors in Particle Physics



Two-Phase Time-Pojection Chamber (TPC)

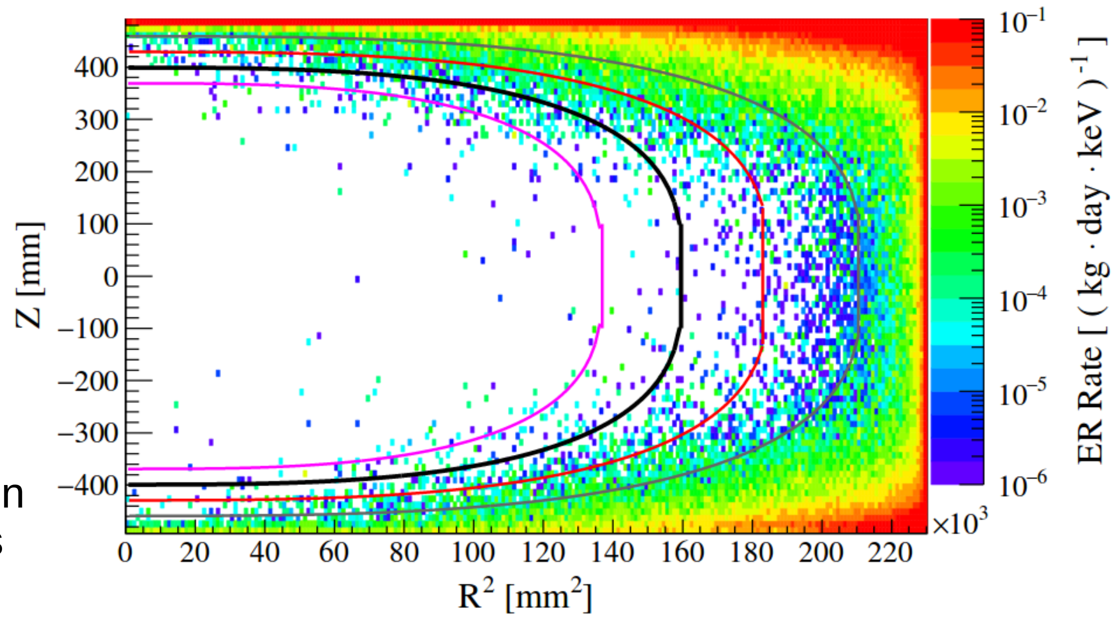
LXe based detectors

Neutrinoless Double Beta Decay (EXO)
Dark Matter direct detection (XENON1T, LUX, PandaX, XMASS)

Target material LXe

Scintillation properties for event detection
Large atomic mass
Low intrinsic radioactivity

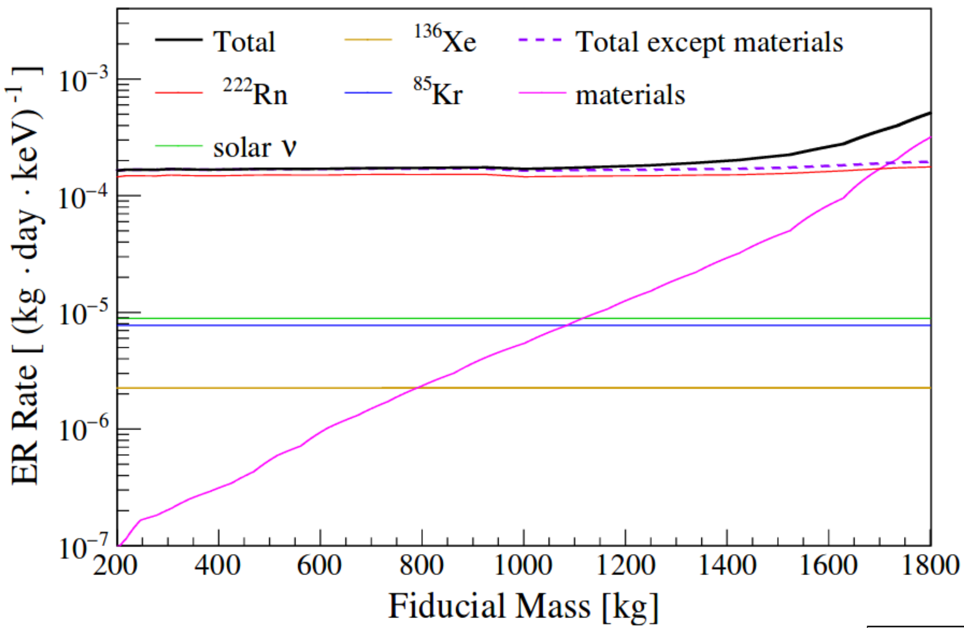
XENON collaboration: JCAP 04, 027 (2016)



Fiducialization

High stopping power shields external radiation
Only the inner most volume used for analysis

Radon – An intrinsic Background Source



Emanation as radon source

Traces of ^{238}U in every material
^{222}Rn emanates from detector materials
Emanation is a permanent radon source

Intrinsic background

Rn distributes homogeneously in the LXe target
Rn progenies (^{214}Pb) induce background
no shielding possible

^{222}Rn is a crucial background source in many liquid xenon based experiments

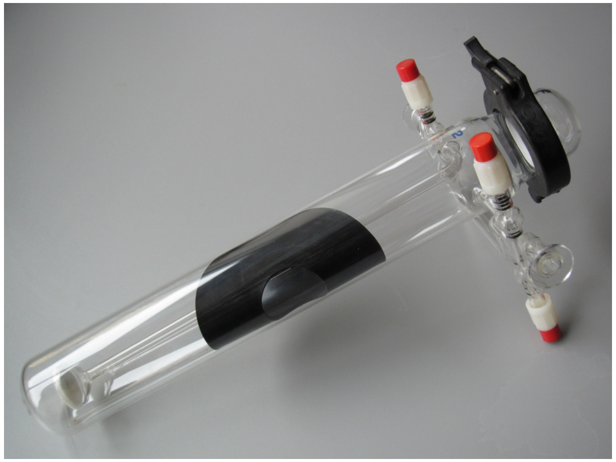
Expectation values of events in XENON1T, in 2 t·y exposure	No discrimination	99.75% ER discrimination
Signal (μ_s)		
6 GeV/c^2 WIMP ($\sigma = 2 \cdot 10^{-45}$ cm^2)	0.68	0.27
10 GeV/c^2 WIMP ($\sigma = 2 \cdot 10^{-46}$ cm^2)	4.65	1.86
100 GeV/c^2 WIMP ($\sigma = 2 \cdot 10^{-47}$ cm^2)	7.13	2.85
1 TeV/c^2 WIMP ($\sigma = 2 \cdot 10^{-46}$ cm^2)	8.85	3.54
Background		
Total ER (μ_{bER})	1300	3.25
NR from neutrons	1.10	0.44
NR from CNNS	1.18	0.47
Total NR (μ_{bNR})	2.28	0.91

XENON collaboration: JCAP 04, 027 (2016)

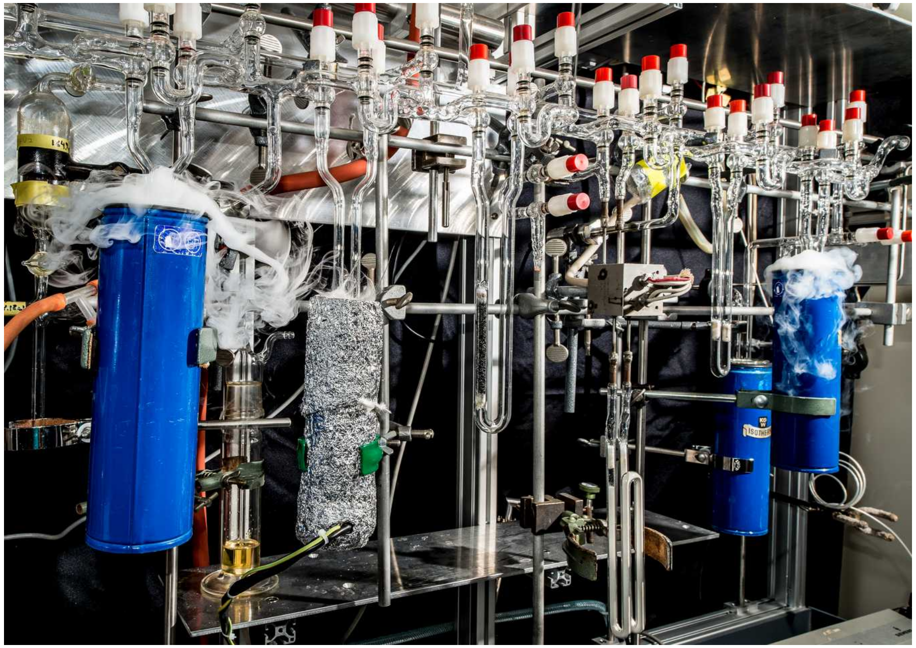
Mitigating Background - Radon Screening

Careful material selection to avoid emanation
Measurement of bulk impurities (spectrometry) often not sufficient

Radon screening at MPIK
Measurement of the radon emanation rate of every detector material



Emanation vessel with sample



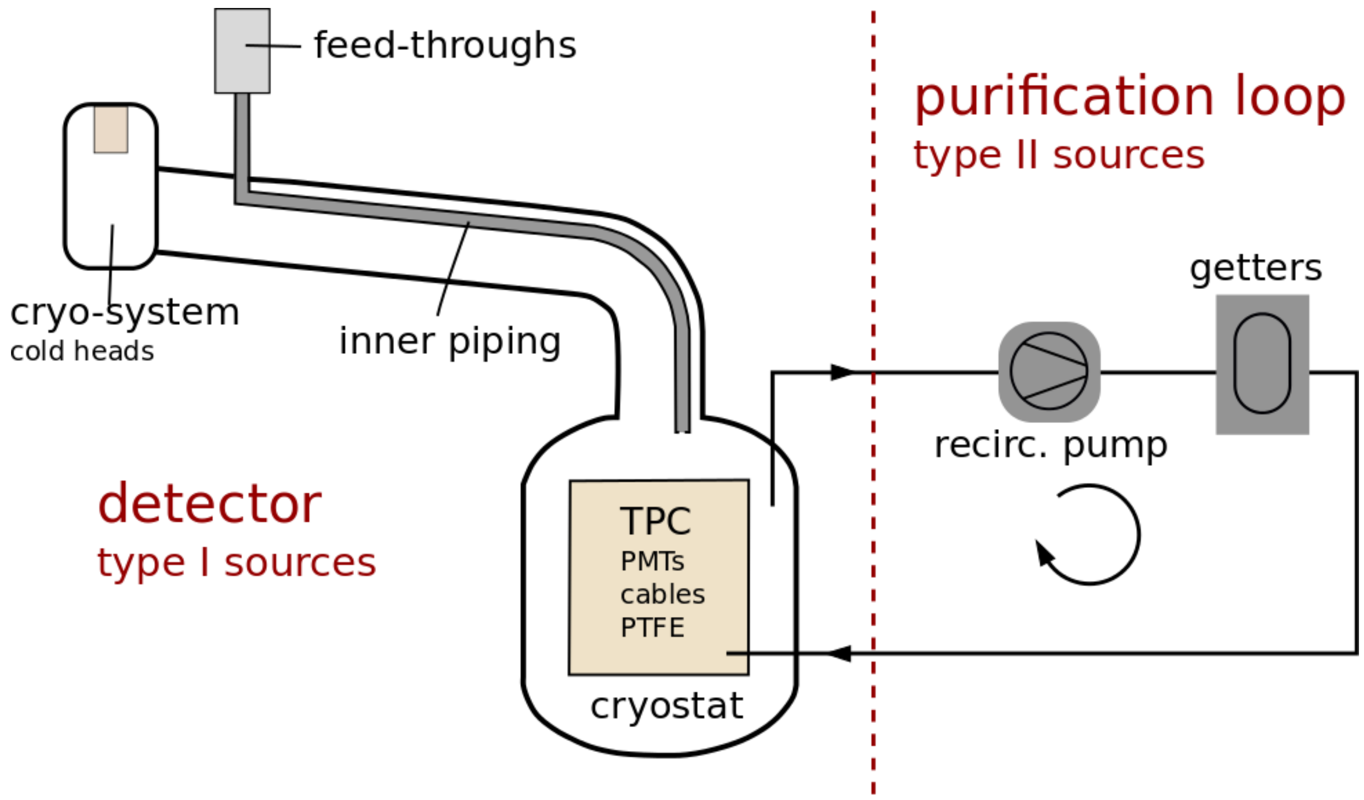
Gas-Line for counter filling

Miniaturized Porportional Counter
Background: ~1 count/day
Sensitivity: ~20 µBq

Electrostatic Rn-Monitor
Ionized Rn progenies are drifted towards a PIN diode
Sensitivity: ~1 mBq

Counter

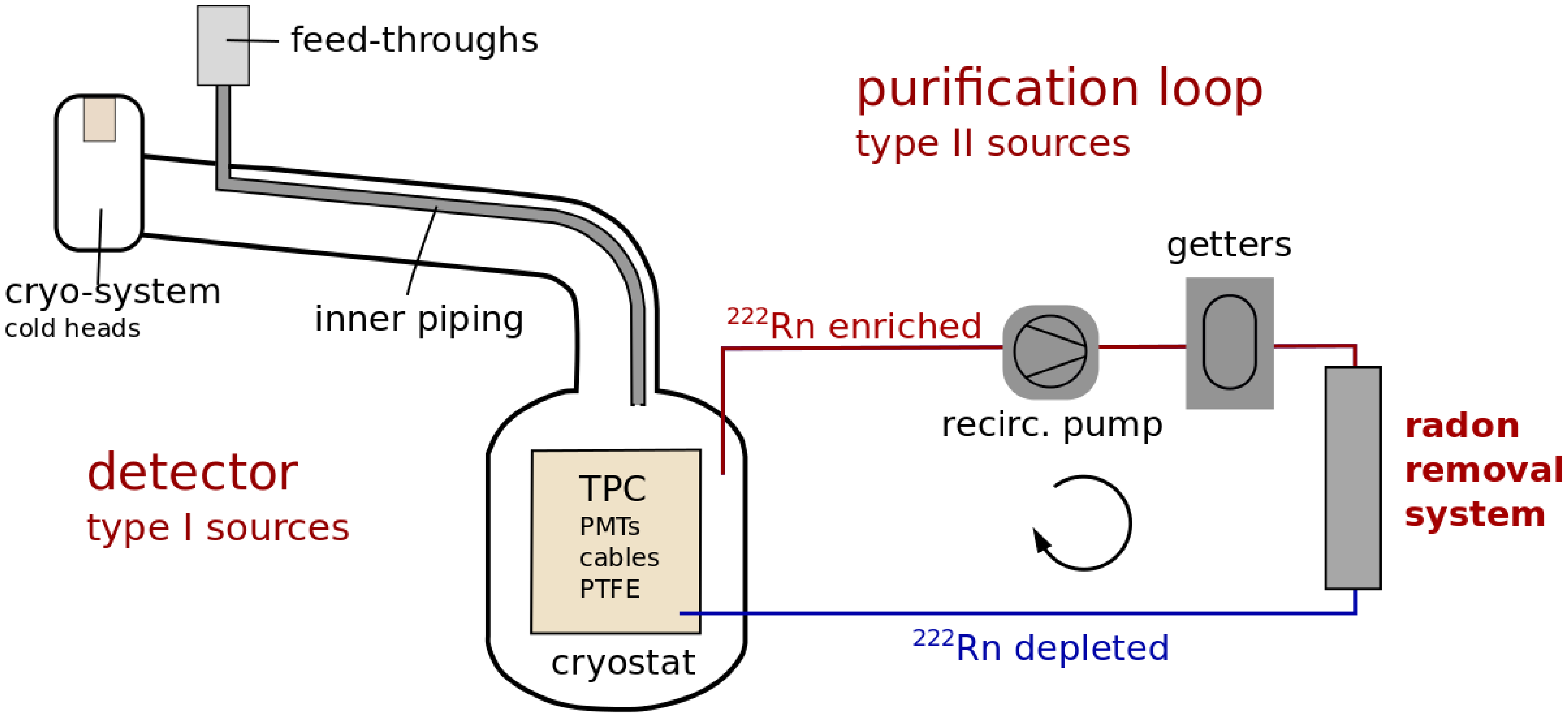
Typical Emanation Sources



Classification of ^{222}Rn emanation sources
Classification according to their position in the system

type I sources: emanation sources inside the detector, Rn directly enters the LXe target
type II sources: Rn is flushed through the purification loop before entering the LXe target

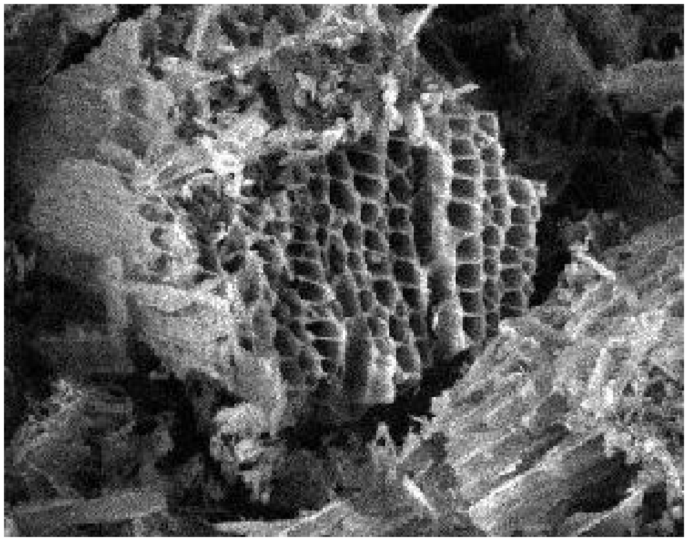
On-line ^{222}Rn removal



Online radon removal system (RRS)
Integrated into purification loop
Radon enriched gas is flushed through RRS

Separate radon from xenon
Radon retains in the RRS
Drops out naturally by radioactive decay

Radon/Xenon Separation Techniques

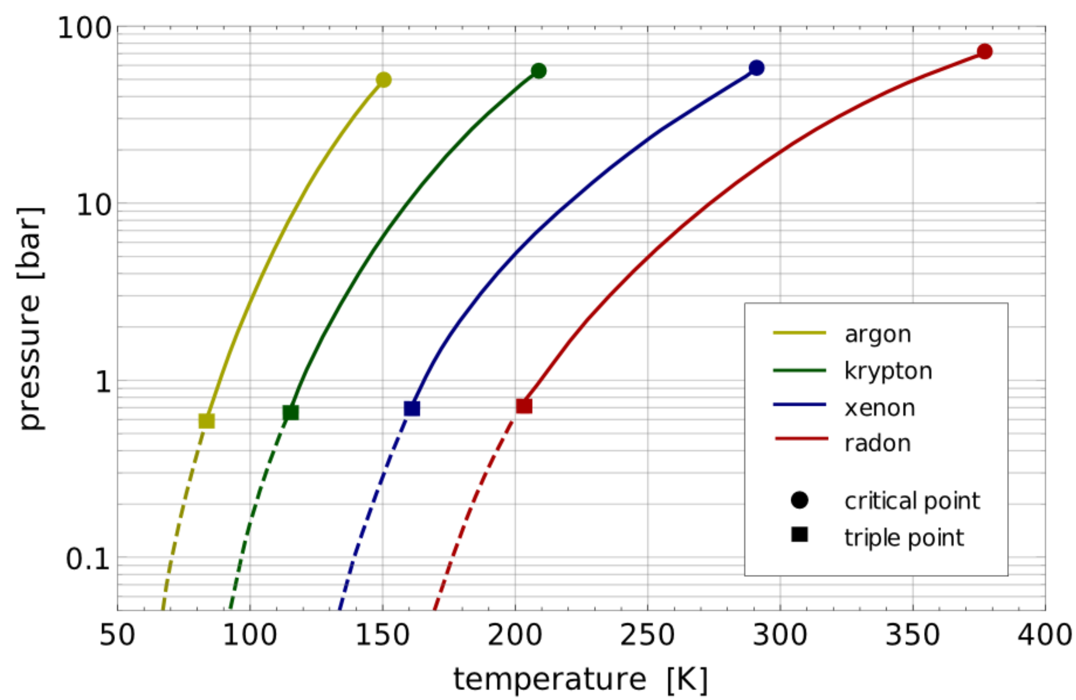


Adsorption
Radon enriched Xe is looped through adsorbent trap
Radon stays adsorbed until decay
Nucl. Instr. and Meth. in Phys.Res. A661, 50 (2012)

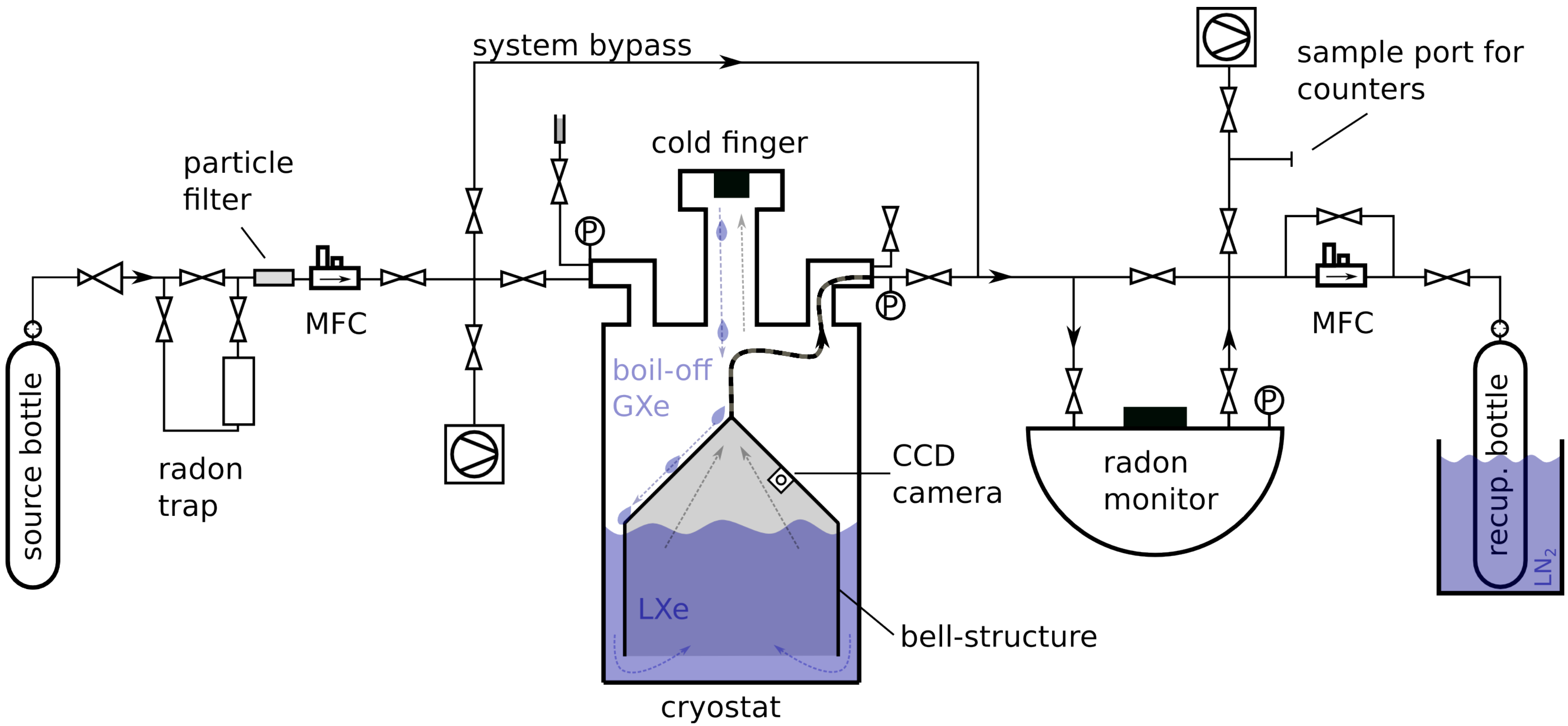
Challenges
Radon emanation of adsorbent material
Large xenon consumption due to Xe adsorption

Cryogenic distillation
Successfully used for krypton removal
Kr purification at ppq-level (x 10^{-15}) shown
EPJC 77, 275 (2017)

Radon distillation as separation technique



Radon depletion in boil-off Xenon

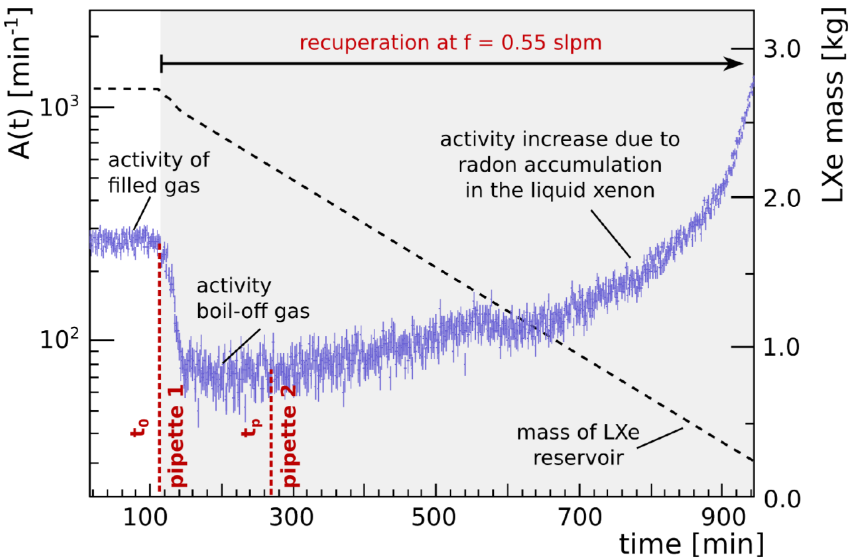


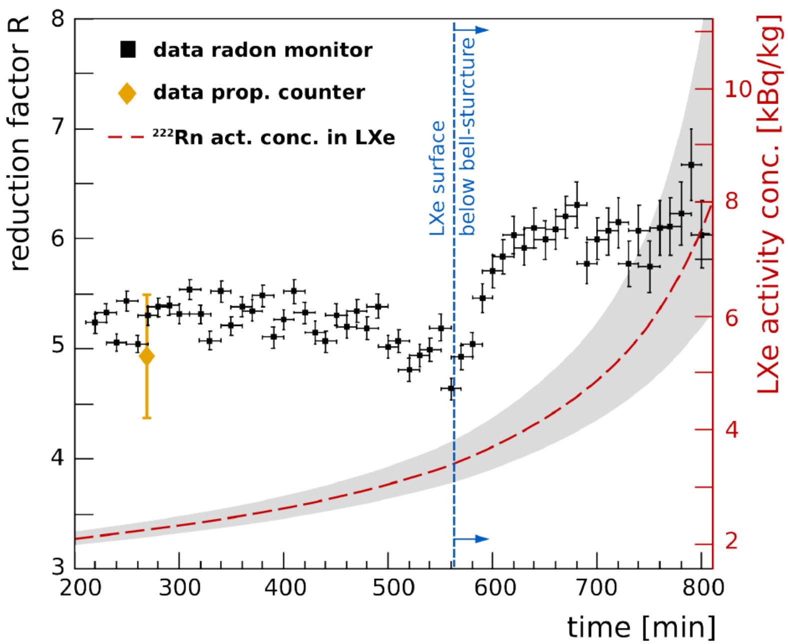
Radon reduction in a single distillation stage

Radon enriched Xe is filled into the cryostat
Xe is liquefied at the cold finger
After filling an equilibrium establishes

Pump boil-off Xe into recuperation bottle
Radon monitor measures its activity concentration
Complementary prop. counter measurements

Radon depletion in boil-off Xenon





	above bell structure	below/no bell structure
run1	$4.61 \pm 0.02_{\text{stat}}\, {}^{+0.29}_{-0.27}{}_{\text{sys}}$	$5.58 \pm 0.02_{\text{stat}}\, {}^{+0.88}_{-0.68}{}_{\text{sys}}$
	$^{*}3.75 \pm 0.50_{\text{stat}}\, {}^{+0.08}_{-0.06}{}_{\text{sys}}$	-
run2	$5.27 \pm 0.05_{\text{stat}}\, {}^{+0.22}_{-0.27}{}_{\text{sys}}$	$6.02 \pm 0.04_{\text{stat}}\, {}^{+1.12}_{-0.78}{}_{\text{sys}}$
	$^{*}4.91 \pm 0.68_{\text{stat}}\, {}^{+0.07}_{-0.05}{}_{\text{sys}}$	-
run3	-	$7.20 \pm 0.04_{\text{stat}}\, {}^{+0.50}_{-0.31}{}_{\text{sys}}$
	-	$^{*}8.12 \pm 1.35_{\text{stat}}\, {}^{+0.13}_{-0.10}{}_{\text{sys}}$
run4	-	$3.77 \pm 0.09_{\text{stat}}\, {}^{+0.12}_{-0.13}{}_{\text{sys}}$

Proof of radon reduction in boil-off gas!

Radon reduction by a **factor > 4** measured

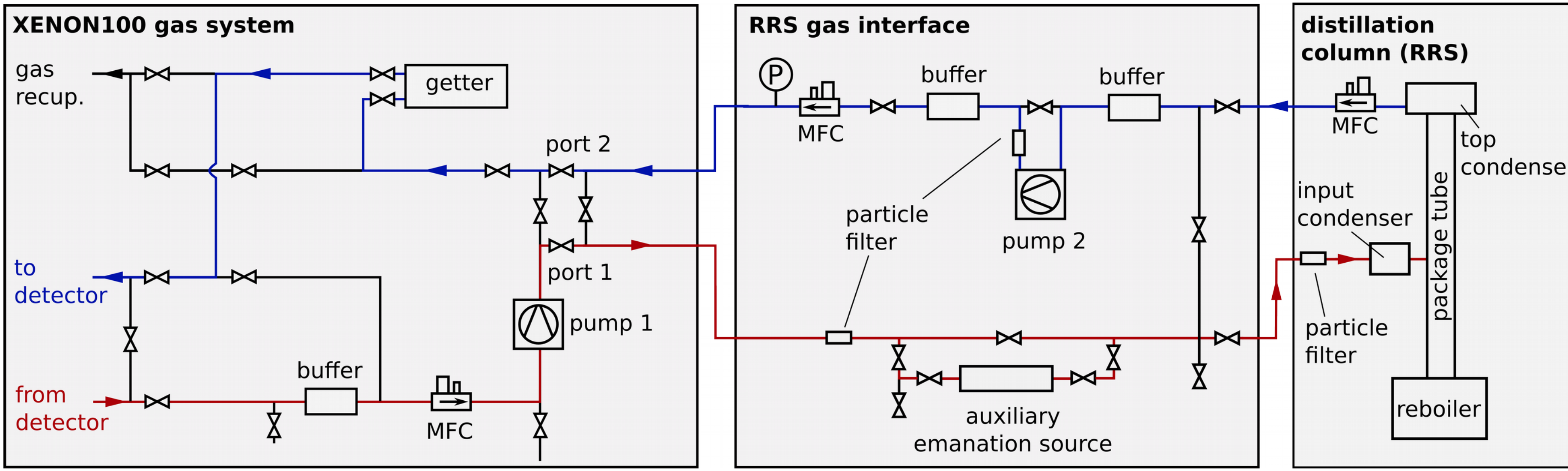
Complementary measurements with proportional counters confirm results

Measurements at higher recuperation flows of up to 6 slpm show same reduction factor

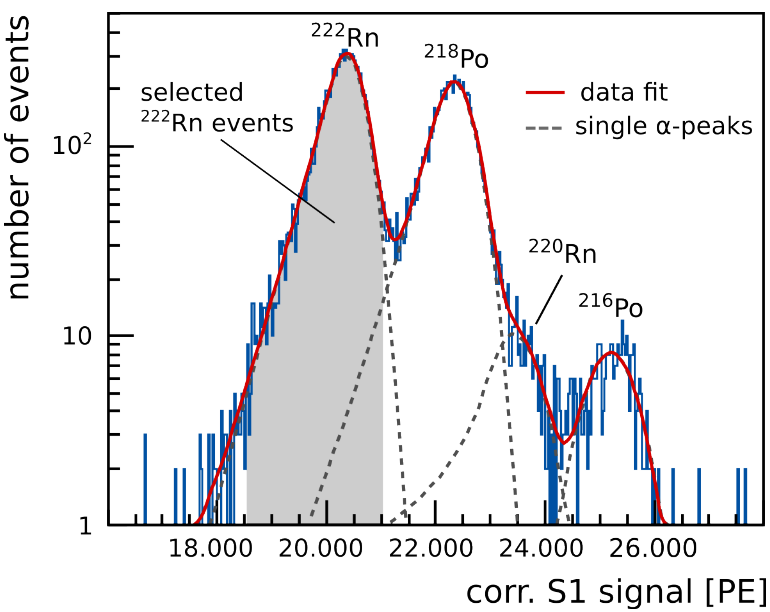
Systematic 'bell-effect' still under investigation

EPJC 77, 143 (2017)

On-line Rn distillation at XENON100



Extended XENON100 purification loop during distillation campaign



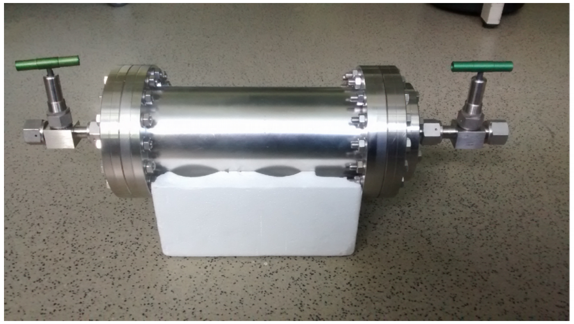
Rn-detector XENON100

Alpha-peaks of ^{222}Rn and progenies easy to identify
BiPo analysis for complementary radon monitoring

Extension of gas purification loop

Integration of XENON1T krypton column in purification loop
Integration of a radon emanation source

On-line Rn distillation at XENON100



Auxiliary radon emanation source

Radon emanation source

426 viton O-rings as auxiliary emanation source (constant emanation rate)

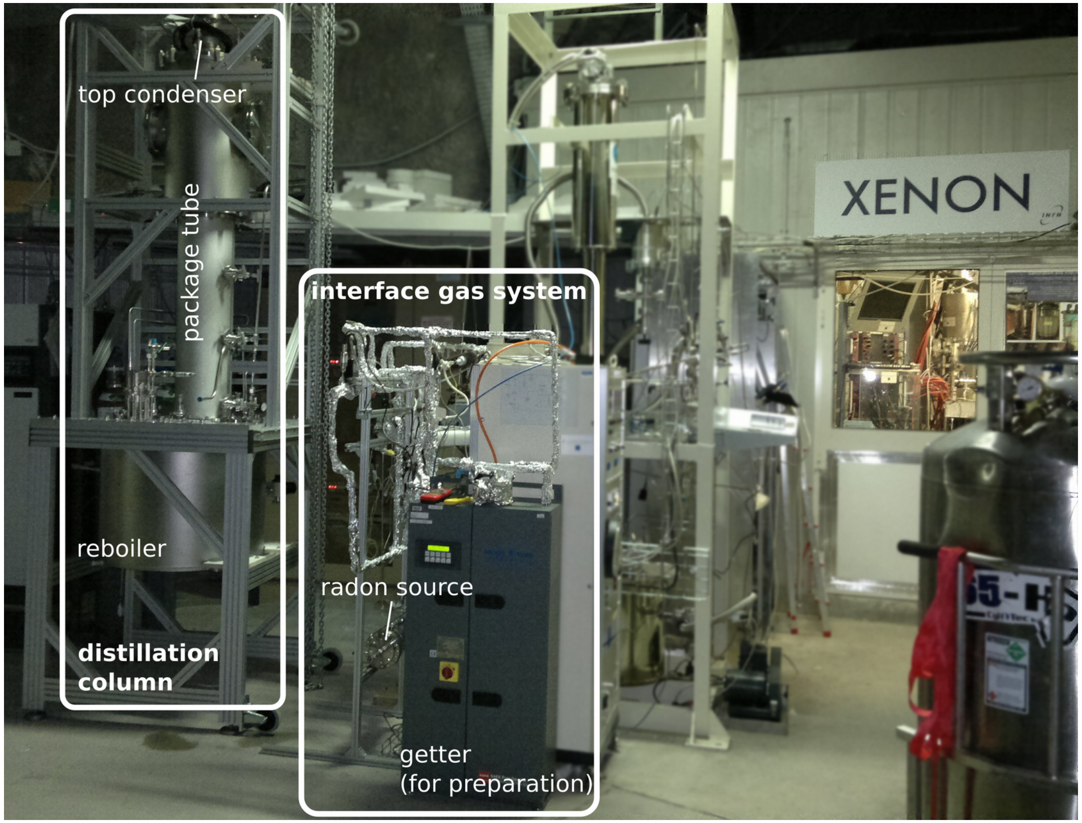
~70 mBq activity flushed into XENON100 TPC

Operation of Kr-column

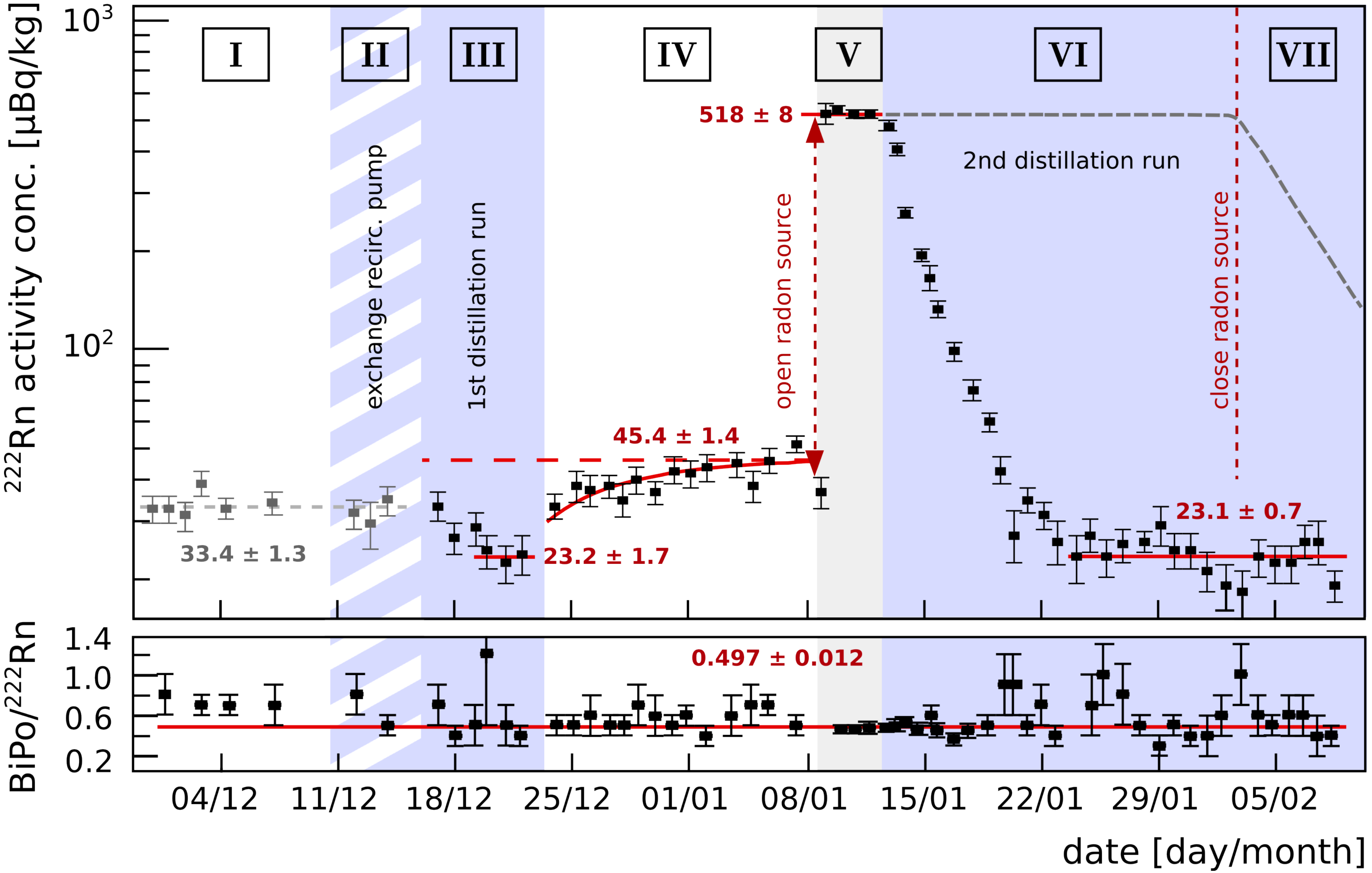
XENON1T phase I krypton column
EPJC 77, 275 (2017)

'Inverse' operation with respect to Kr distillation
Rn is enriched in the liquid reservoir (reboiler)

Purified Xe from the columns top condenser is fed back into XENON100

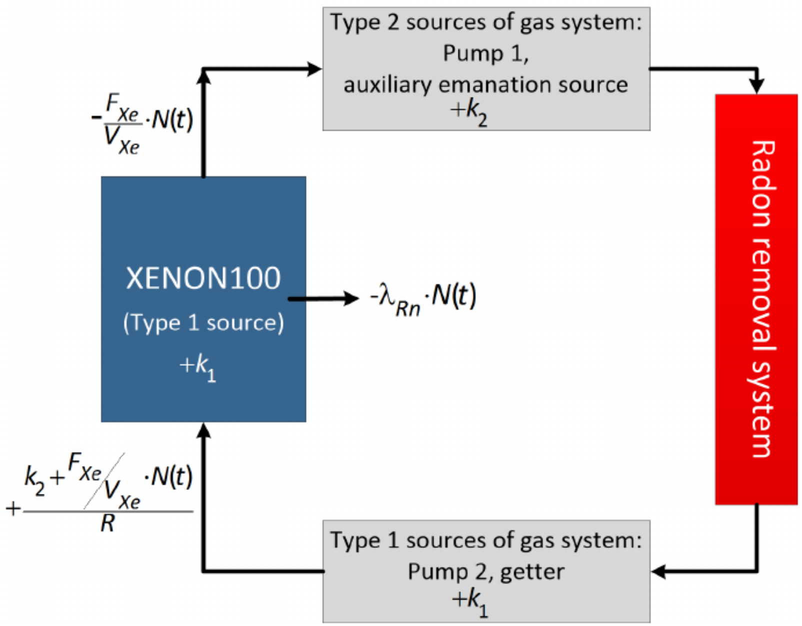


On-line Rn distillation at XENON100



arXiv:1702.06942 (accepted by EPJC)

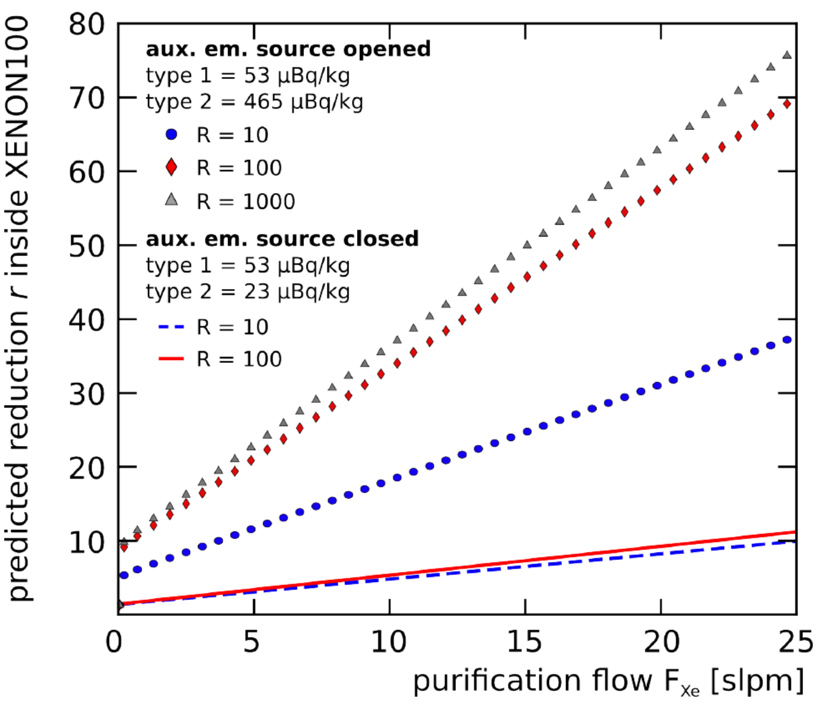
On-line Rn distillation at XENON100



Model of Rn concentration in XENON100

$$\frac{dN(t)}{dt} = k_1 - f \cdot N(t) - \lambda_{Rn} \cdot N(t) + \frac{k_2 + f \cdot N(t)}{R}$$

From fit to data:
column's reduction factor R > 27 (95% C.L.)



Achieve larger radon reduction

Larger recirculation flows needed
Prevent Rn to reach LXe detector

Purification effect larger for type II sources
Convert type I to type II sources by means of smart purge flows

Summary and Conclusions

Radon is a crucial source of background in LXe based experiments
Emanation measurements to find only detector materials having low radon emanation
Unique radon screening facility at MPIK

Radon removal by cryogenic distillation
Xenon boil-off gas is depleted in radon with respect to the liquid phase.

On-line radon removal system demonstrated with XENON100
Integration of a cryogenic distillation column into the XENON100 gas purification loop
Radon activity concentration could be reduced by a factor of 20 inside XENON100

Research and development for running experiments are ongoing

THANK YOU FOR YOUR ATTENTION