Westfälische Wilhelms-Universität Münster

XeSAT2017
Khon Kaen,Thailand
03.04. – 07.04.2017

Online krypton and radon removal for the XENON1T experiment

wissen.leben
WWU Münster

Michael Murra
for the XENON collaboration
michaelmurra@uni-muenster.de

XENON Dark Matter Project

ONE

XENON1T

TWO

CRYOGENIC DISTILLATION

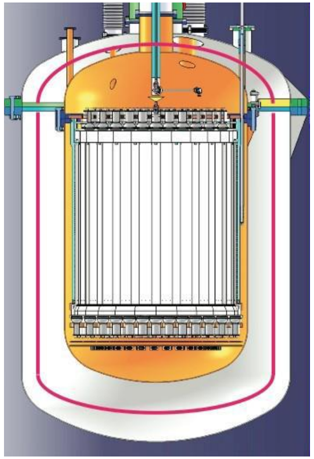
THREE

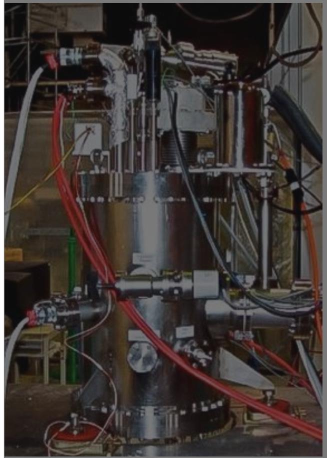
ONLINE KR REMOVAL

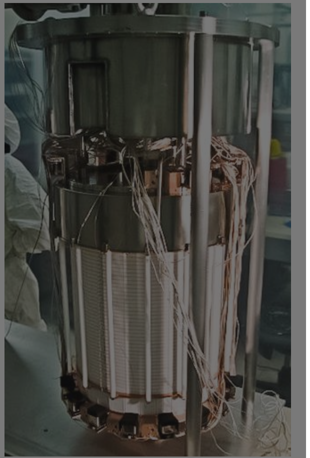
FOUR

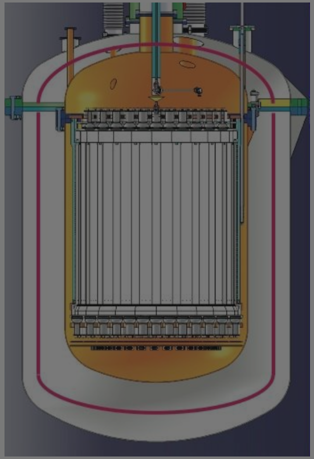
RN REMOVAL

Enlightening the dark – XENON Dark Matter Project and beyond

XENON10	XENON100	XENON1T	XENONnT	
				
2005 - 2007	2008 - 2016	2012 - 2018	2019 - 2023	2020+
25 kg	161 kg	3200 kg	7500 kg	~ 50 000 kg
$\sim 10^{-43}$ cm^2	$\sim 10^{-45}$ cm^2	$\sim 10^{-47}$ cm^2	$\sim 10^{-48}$ cm^2	$\sim 10^{-49}$ cm^2







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XENON1T Facility

See talk by Dr. J. Naganoma

XENON1T Facility

See talk by Dr. J. Naganoma

Intrinsic contamination by ^{85}Kr

Leakage events from the low energy β-spectrum with long half-life contaminate ROI for dark matter search

Commercial xenon:

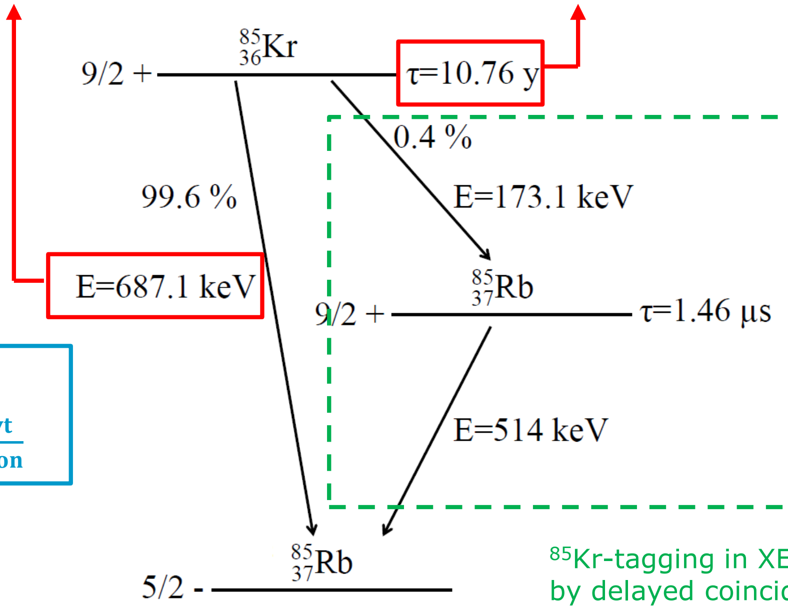
$^{nat}Kr/Xe \sim 10^{-9} - 10^{-6}$ (ppb – ppm)

$^{85}Kr/^{nat}Kr \sim 2 \times 10^{-11}$

$^{85}Kr/Xe \sim 2 \times 10^{-20} - 2 \times 10^{-17}$

For XENON1T:

$^{nat}Kr/Xe < 2 \cdot 10^{-13}$ (0.2 ppt) ←→ 0.2 $\frac{evt}{y \cdot ton}$



^{85}Kr-tagging in XENON1T by delayed coincidence analysis

- ppm = parts per million
- ppb = parts per billion
- ppt = parts per trillion
- ppq = parts per quadrillion

Intrinsic contamination by ^{222}Rn

Leakage events from the low energy β-spectrum contaminate ROI for dark matter search

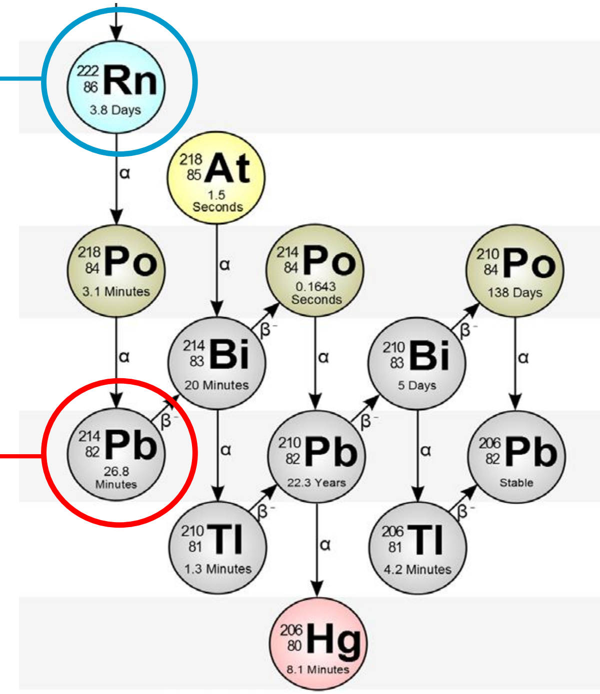
See talk by P.A. „Sander" Breur

Continuously emanating from detector material, getters, pumps, etc…:

→ Material selection
→ Continuous removal

In XENON100:
Rn/Xe: ~ 45 µBq/kg ≈ $4.5 \cdot 10^{-24}$

For XENON1T:
Rn/Xe: ~ 10 µBq/kg ≈ $1.0 \cdot 10^{-24}$



XENON1T:

Goal for 2 ton x year exposure:

$^{nat}Kr/Xe < 2 \cdot 10^{-13}$ (0.2 ppt)

$^{222}Rn/Xe = 10\ \mu Bq/kg$

TWO

CRYOGENIC DISTILLATION

THREE

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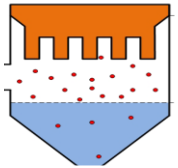
RN REMOVAL

Principle and Design

Difference in vapor pressure:

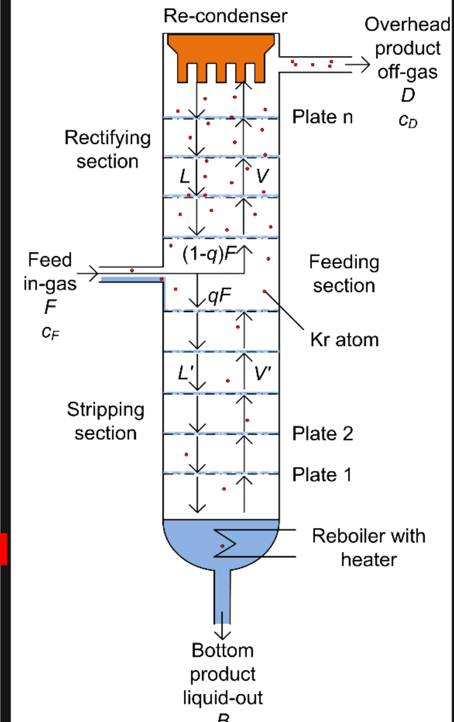
relative volatility: $\alpha = {}^{P_{Kr}}/_{P_{Xe}} \approx 10.5$ at 178 K

Single Stage DST:

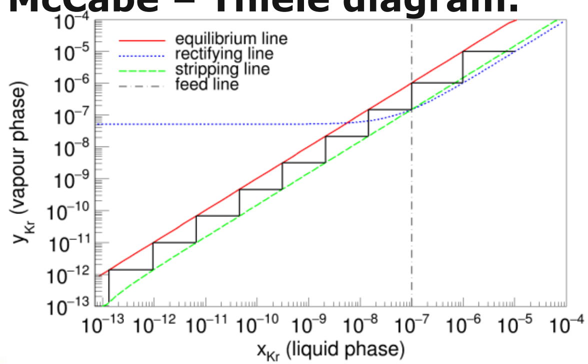


Krypton as the more volatile gas is collected at the top

Multi-stage DST with partial reflux:



McCabe – Thiele diagram:



Package column:

The XENON1T column

Design Parameter
(Performance after commissioning at XENON1T):

Feeding flow rate: 8.3 SLPM (3kg/h)
→ Thermodynamically stable up to 18 SLPM (6.5kg/h)

Separation factor: $10^4 – 10^5$
→ measured separation = $6.4 \cdot 10^5$

Kr removal: $^{nat}Kr/Xe < 0.2 \cdot 10^{-12}$ = 0.2 ppt
→ $^{nat}Kr/Xe < 0.048 \cdot 10^{-12}$ (48 ppq)
→ Lowest in Muenster: $^{nat}Kr/Xe < 0.026 \cdot 10^{-12}$ (26 ppq)

Xe recovery: 99%
→ Achieved

JINST 9 (2014) P10010
Rev Sci Instrum. 86, 115104 (2015)
J.Phys.Conf.Ser. 564 (2014) no.1, 012006
arXiv:1612.0428, accepted by EPJ C

Offline distillation

Start: ^{nat}Kr/Xe ≈ 50 ppb

Goal: ^{nat}Kr/Xe < 0.2 ppt

ReStoX (RSX)
XENON Storage
3.2 t

→

Distillation (DST)
Remove Kr with
3 kg/h (6.5kg/h)

→

Cryostat
Housing TPC

Kr removal in 44 days (21 days)

Offline distillation

Start: ^{nat}Kr/Xe ≈ 50 ppb

Goal: ^{nat}Kr/Xe < 0.2 ppt

Kr removal in 44 days (21 days)

But what do you do, when the cryostat is filled already?!?

→ Recover, warm-up, pump, distill, reach purity

TOTAL : order 90 days, 3 month downtime

XENON1T:

Goal for 2 ton x year exposure:

$^{nat}Kr/Xe < 2 \cdot 10^{-13}$ (0.2 ppt)

$^{222}Rn/Xe = 10$ µBq/kg

Cryogenic distillation:

Krypton as the more volatile gas is collected at the top

- **stable up to 18 SLPM (6.5 kg/h)**
- **measured separation = $6.4 \cdot 10^5$**
- **$^{nat}Kr/Xe < 0.048 \cdot 10^{-12}$ (<48 ppq)**

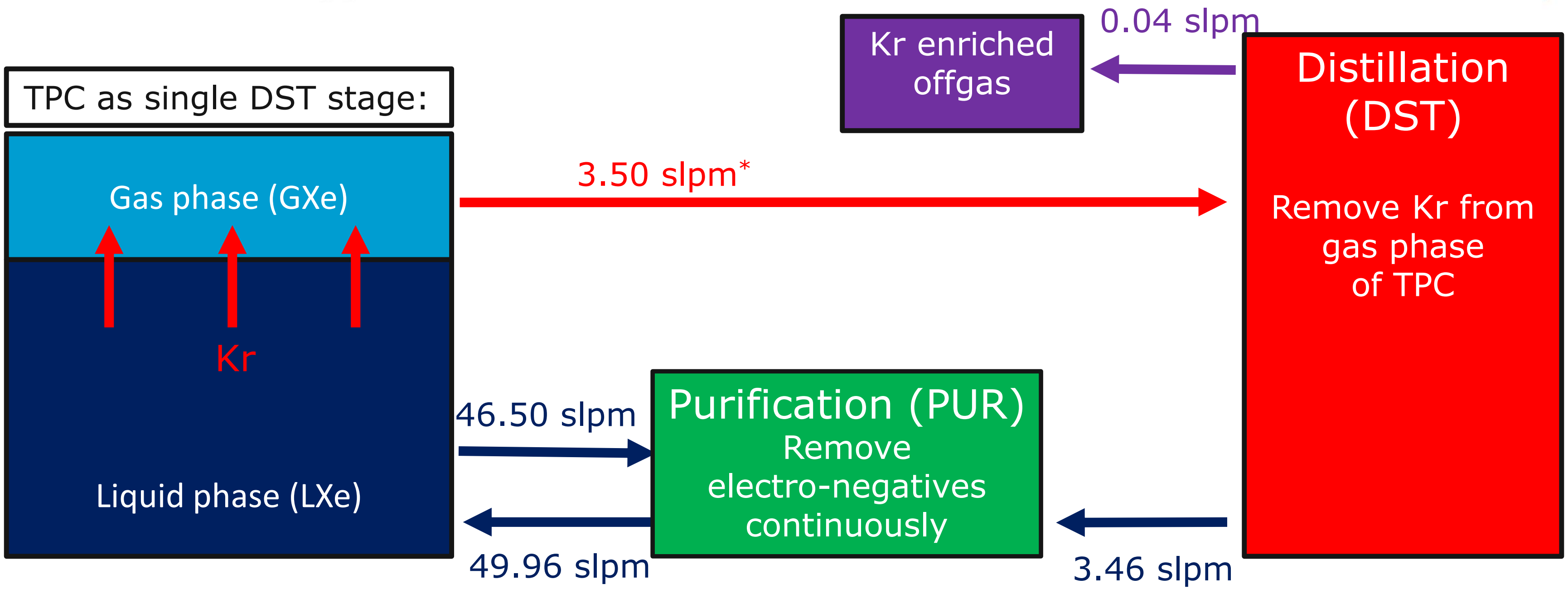
THREE

ONLINE KR REMOVAL

FOUR

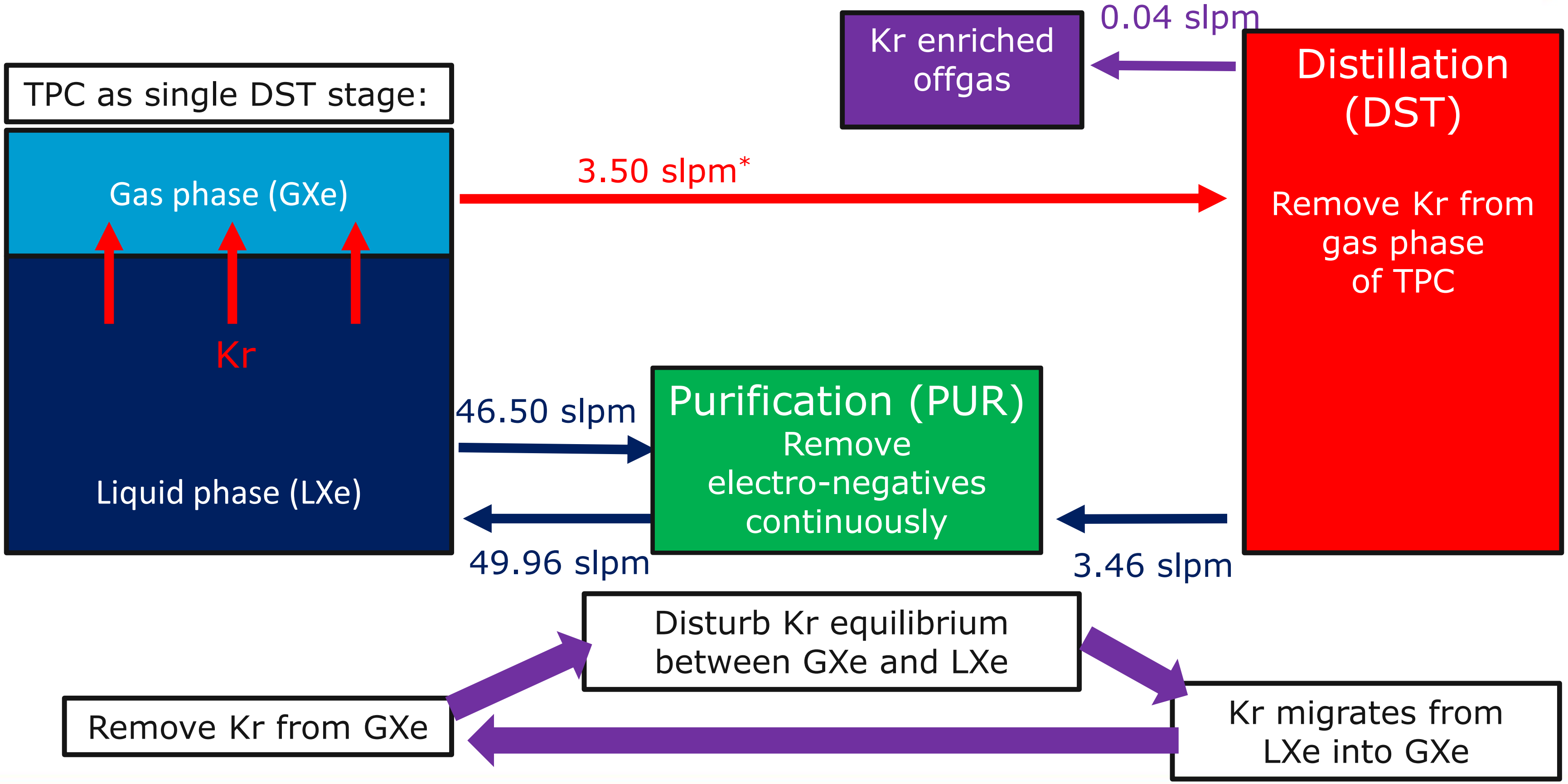
RN REMOVAL

Online Kr distillation



* Limited flow by flow controllers at cryogenic system

Online Kr distillation



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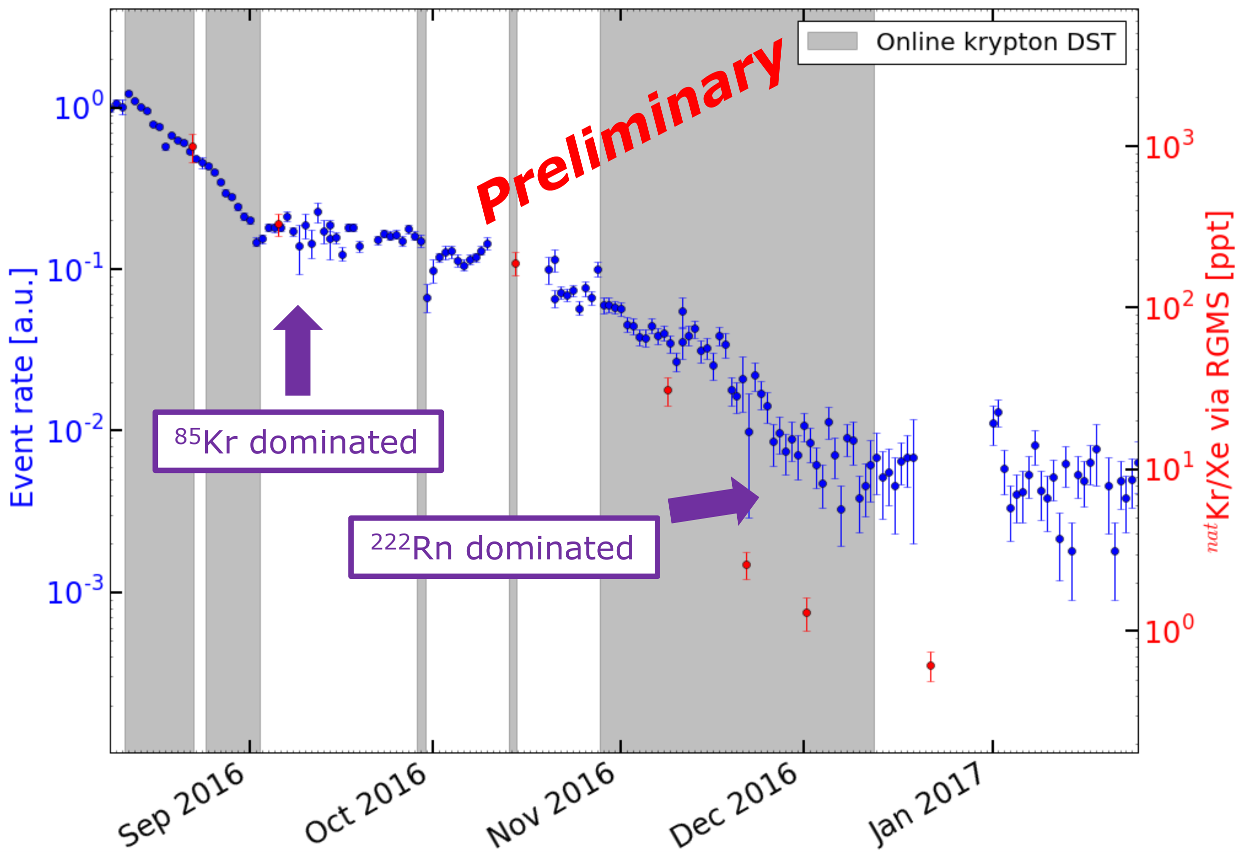
Results



Effectively: 70 days

But TPC online, in parallel:

- Kr-83m calibrations
- Rn-220 calibrations
- NR calibrations
- Purity increase
- PMT tests
- DAQ tests
- Finish commissioning
- Reached sufficient Kr level for first science run!

$^{nat}Kr/Xe$ = 0.62 ppt

RGMS : EPJ C 74, 2746 (2014)

XENON1T:

Goal for 2 ton x year exposure:

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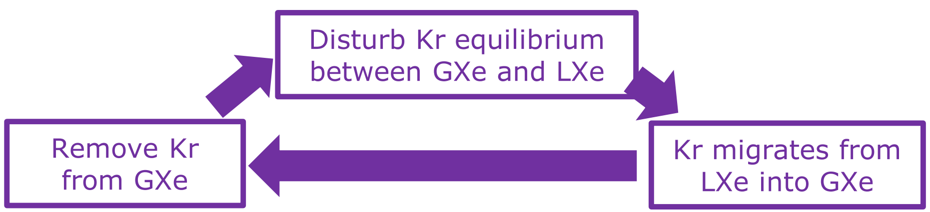
Online Kr removal:



First Science Run:

$^{nat}Kr/Xe = 0.62 \cdot 10^{-12}$ (0.62 ppt)

FOUR

RN REMOVAL

Principle of Rn distillation

Inverse krypton mode

↓

Difference in vapor pressure:

relative volatility: $\alpha = {}^{p_{Rn}}/_{p_{Xe}} \approx 0.1$ at 178 K

↓

Radon as the **LESS** volatile gas is collected at the **bottom**

↓

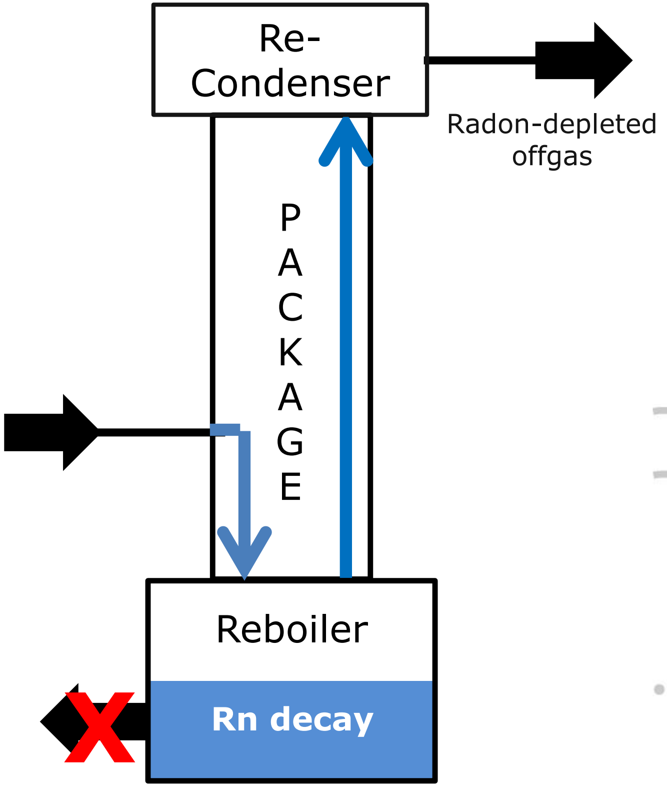
Radon trapped in LXe until desintegration

↓

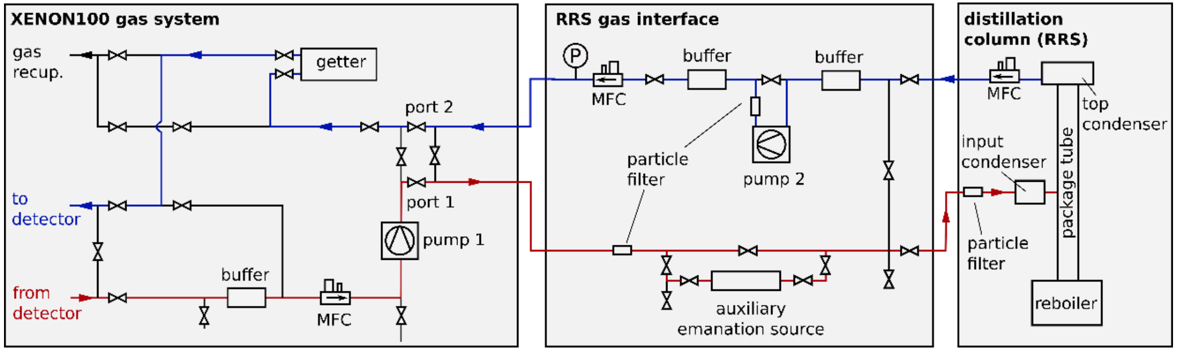
„off-gas“ is radon depleted

↓

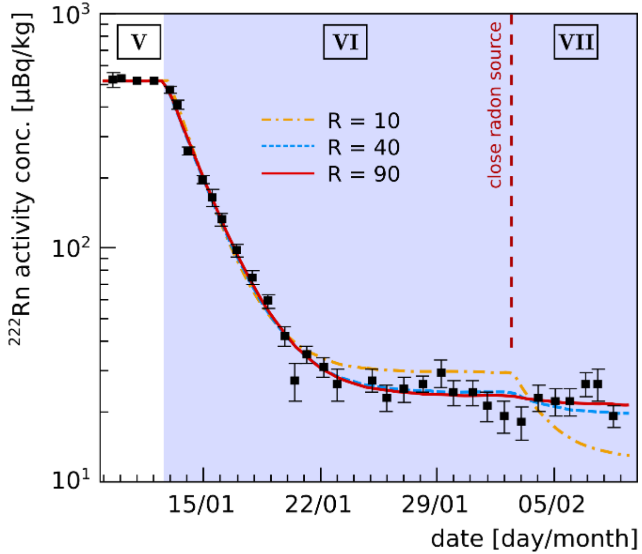
No xenon loss



Online Rn distillation XENON100



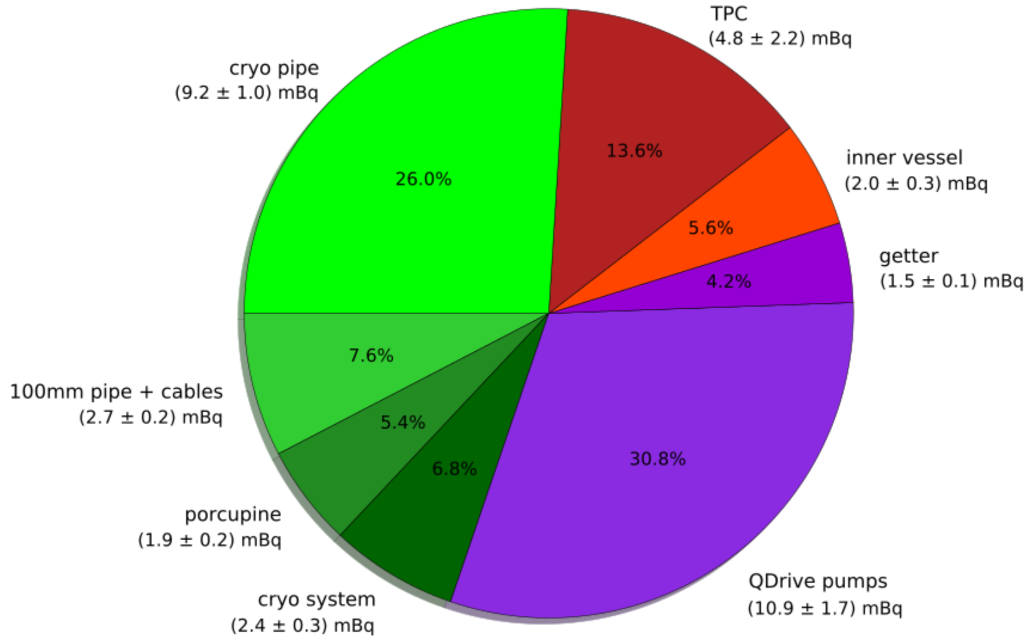
arXiv:1702.06942, submitted to EPJ C



- Total flow of 4.5 slpm (1.6 kg/h) through DST column
- Continuous removal
- Auxiliary emanation source to test reduction power of DST
- XENON100 as monitor of radon activity

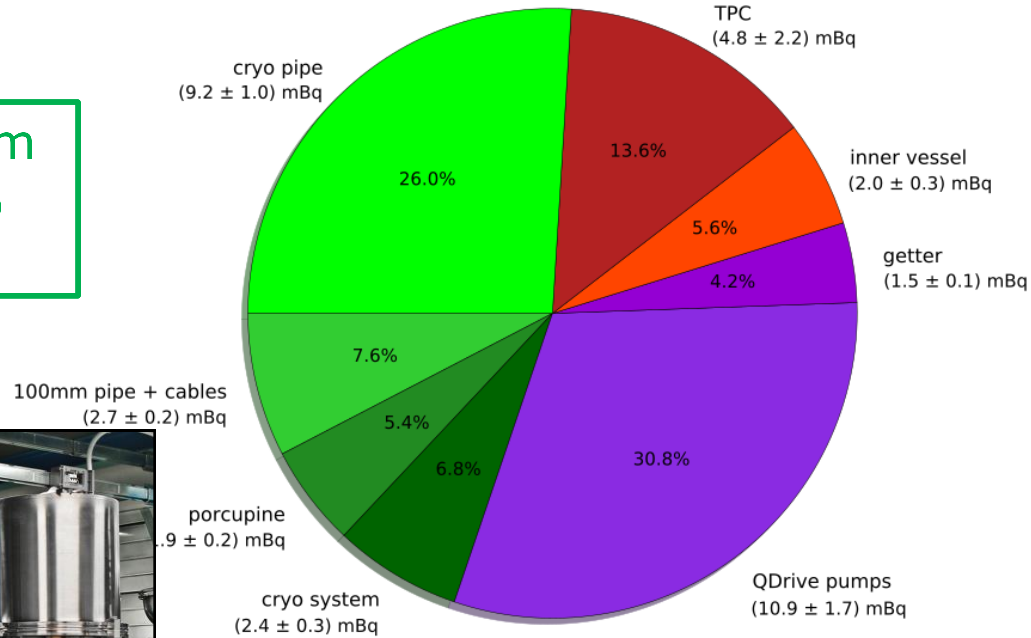
Reduction inside XENON100: $r = (22.4 \pm 0.8)$ → **Reduction factor DST: R > 27 (90% C.L.)**

Rn budget at XENON1T



Rn budget at XENON1T

Cryogenic system emanates 46% of total budget



Rn budget at XENON1T

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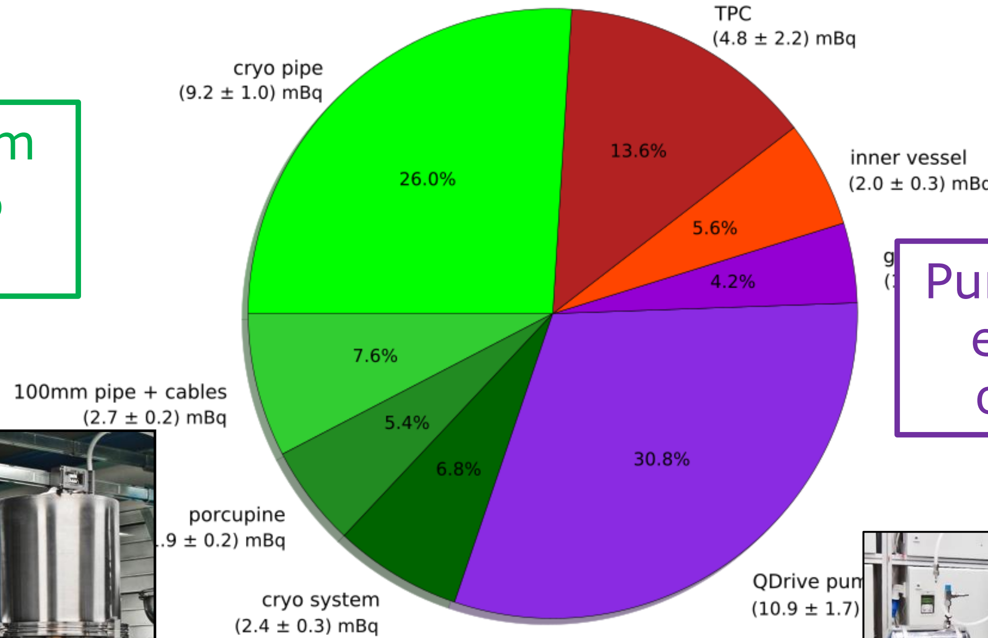
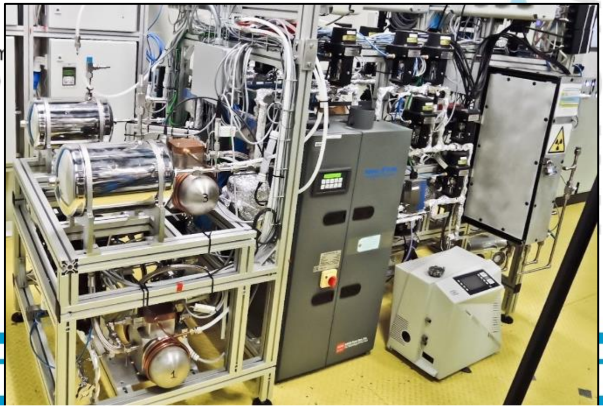
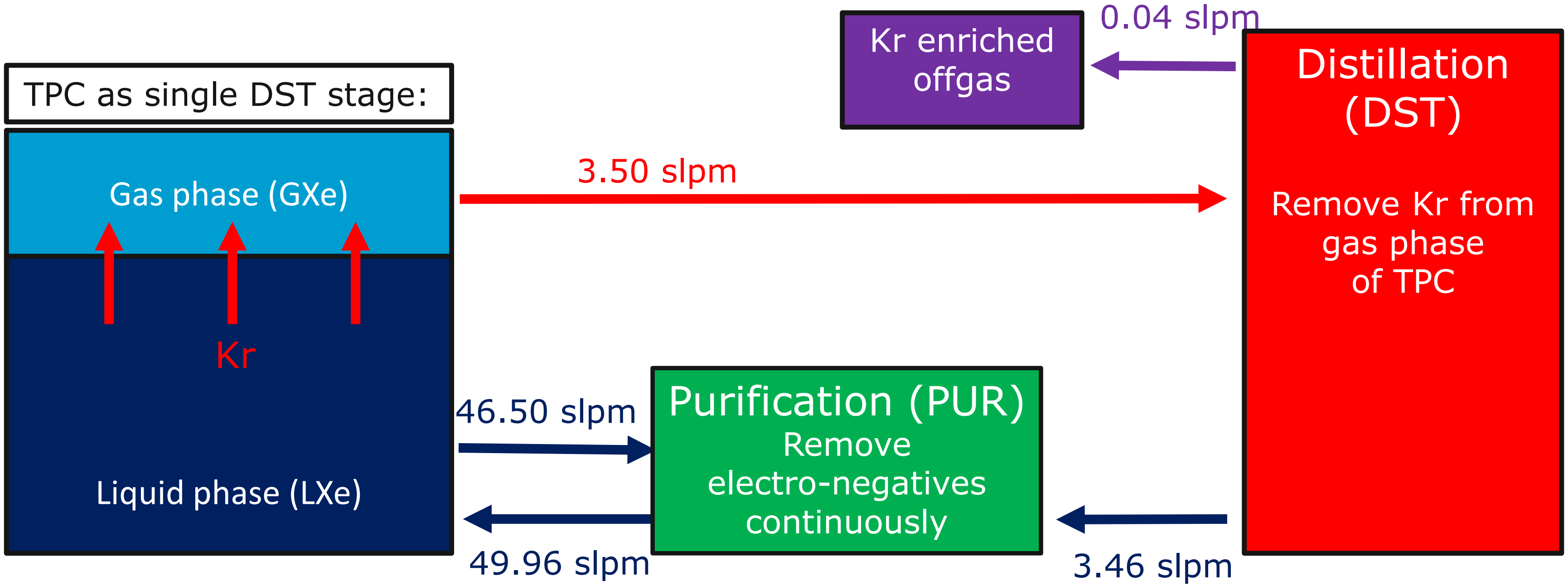


Purification system emanates 35% of total budget



Online Rn distillation at XENON1T



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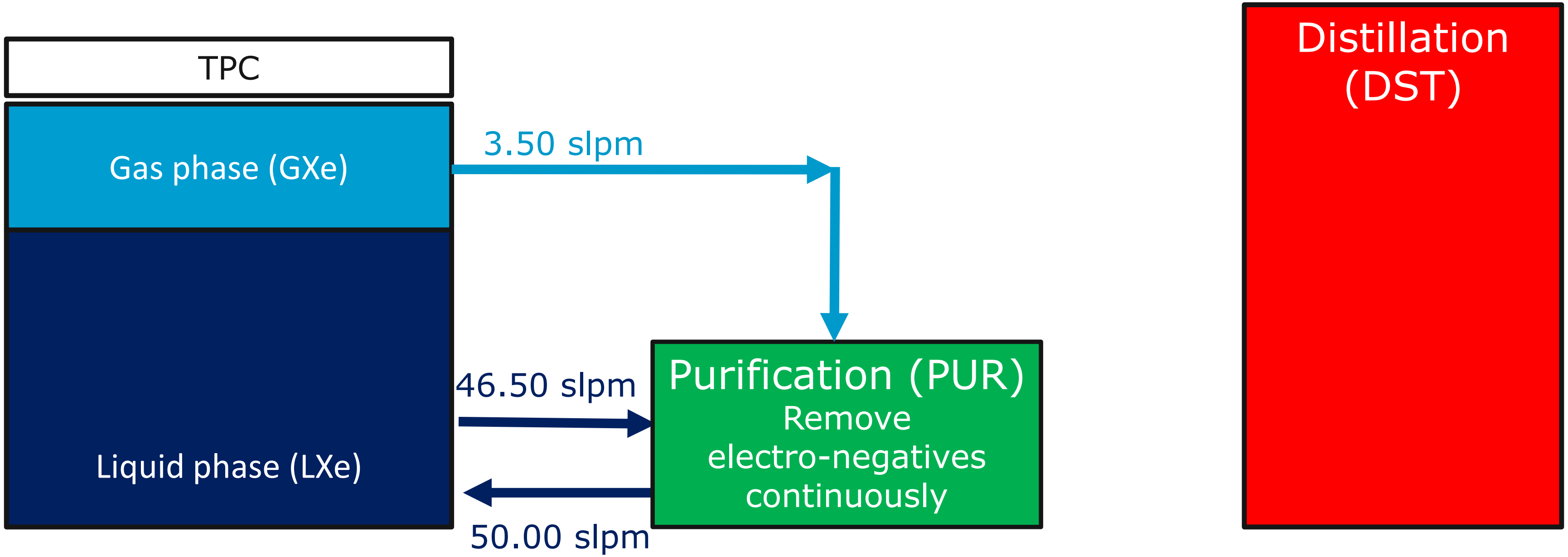

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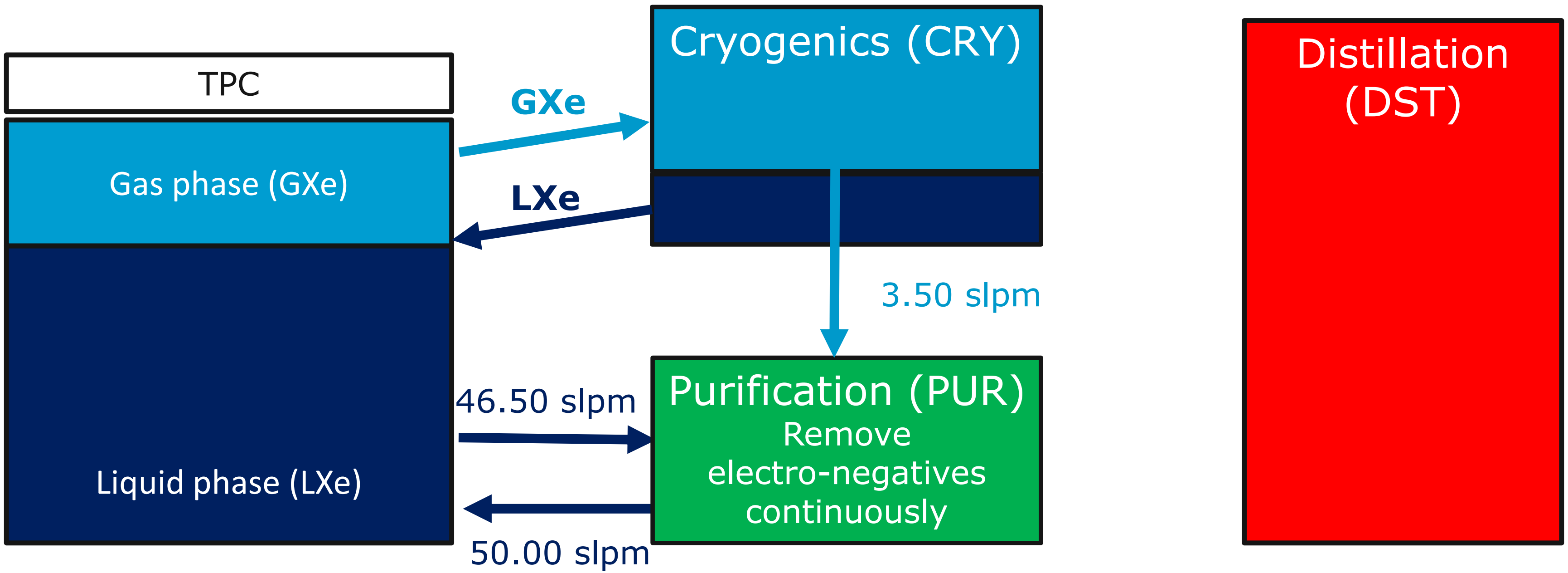

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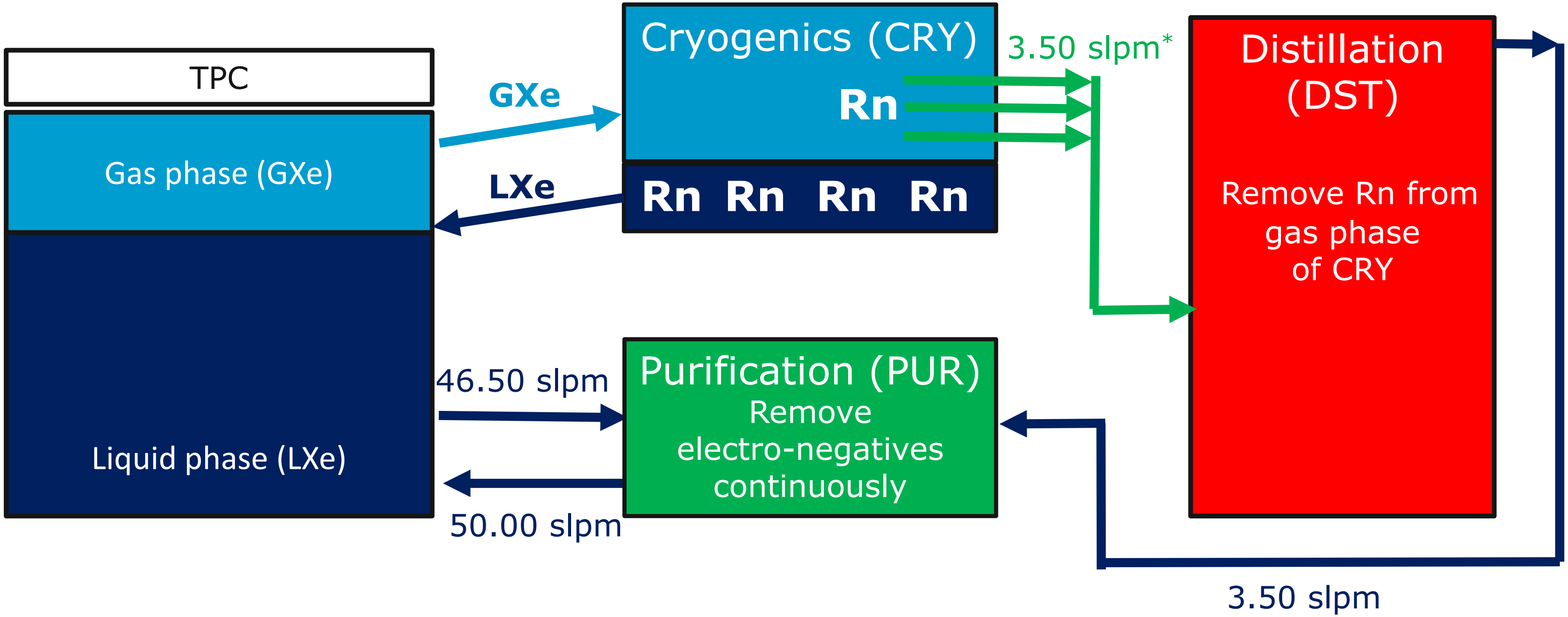
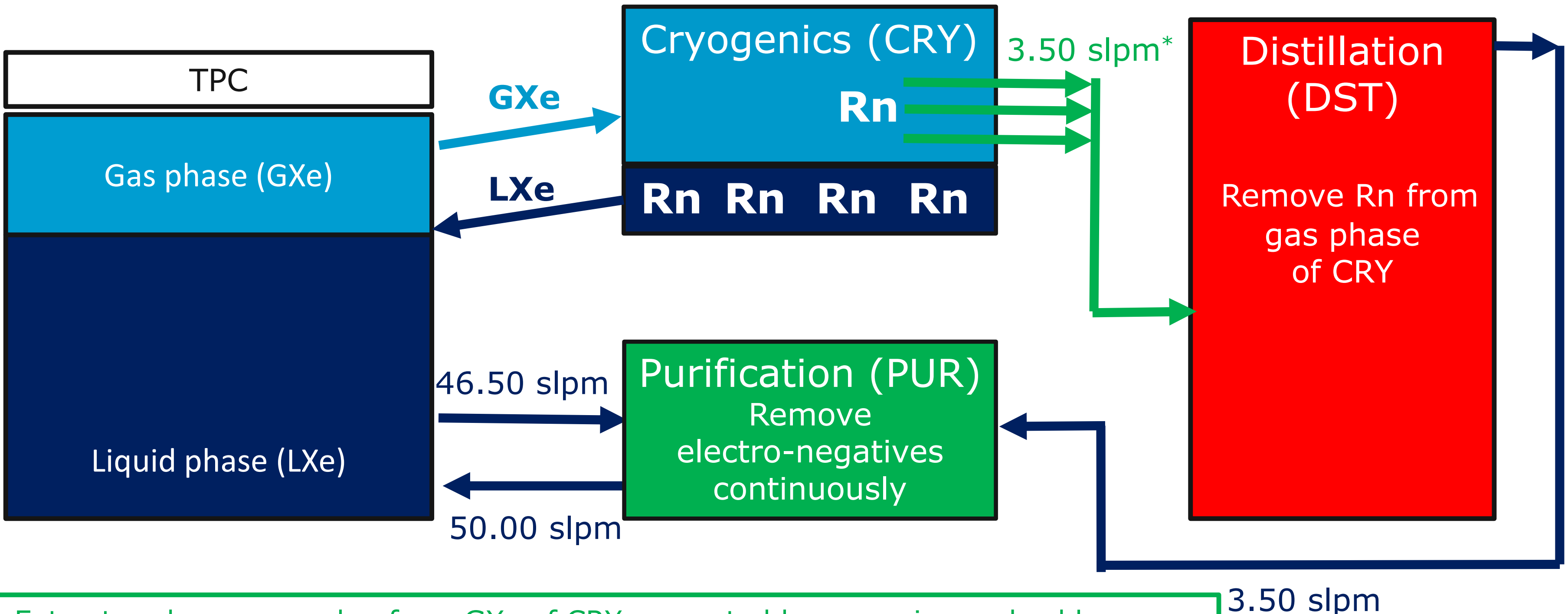


* Limited flow by flow controllers at cryogenic system

Online Rn distillation at XENON1T

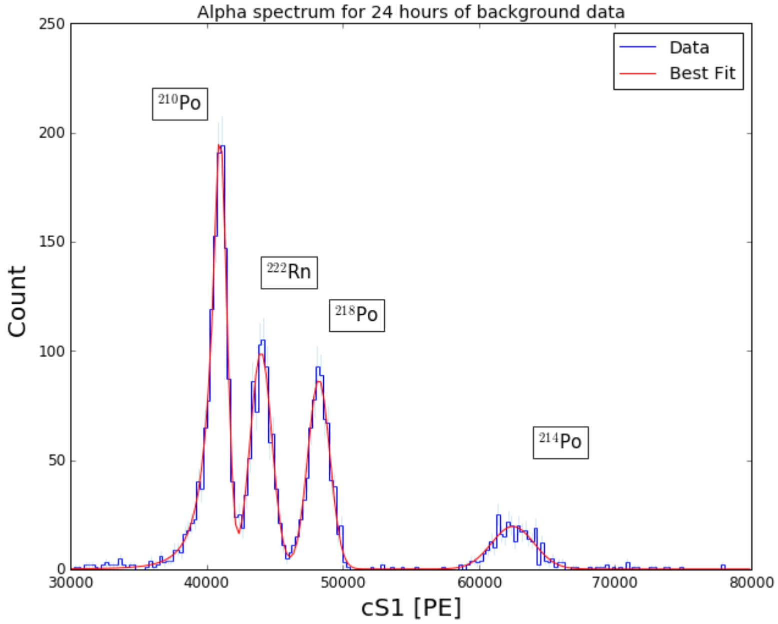


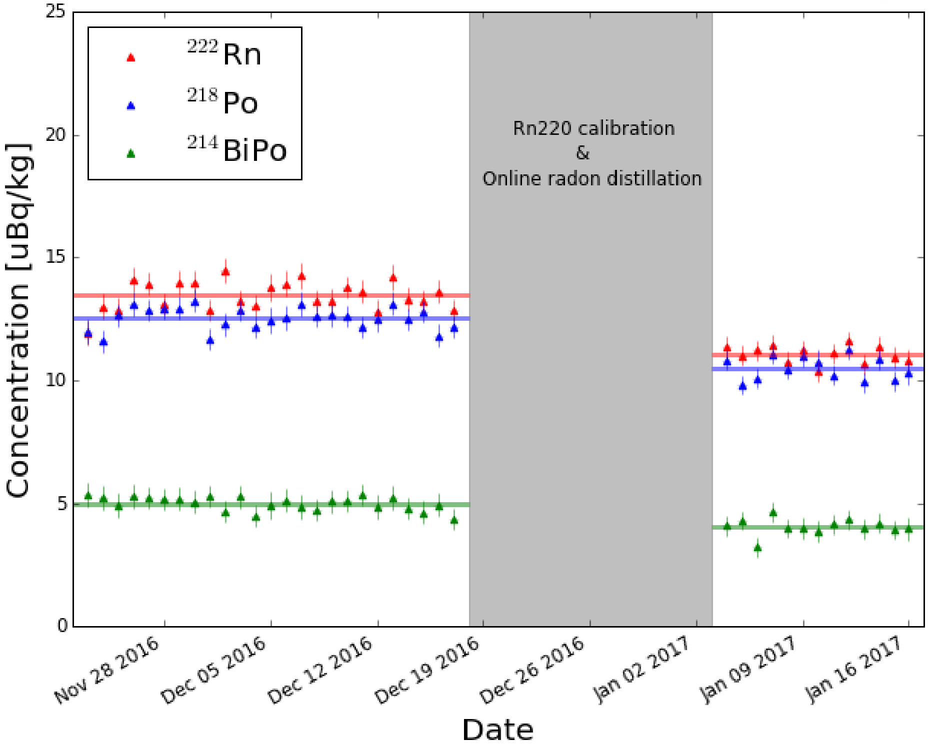
- Extract and remove radon from GXe of CRY emanated by cryo-pipe and cables
- Less Rn can enter TPC

→ **Total radon activity concentration inside TPC reduced without xenon loss**

* Limited flow by flow controllers at cryogenic system

Results





See talk by P.A. „Sander“ Breur

Radon reduction in XENON1T by almost 20%

Summary:

XENON1T:

Goal for 2 ton x year exposure:

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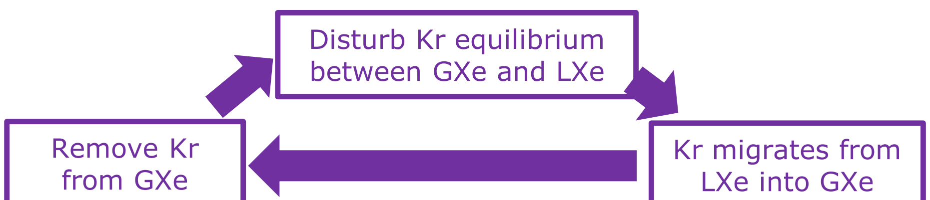

First Science Run:

$^{nat}Kr/Xe = 0.62 \cdot 10^{-12}$ (0.62 ppt)

Rn removal:

Radon as the **less** volatile gas is collected at the **bottom**

Cryogenic Distillation can remove radon as shown in XENON100 **(R > 27)**

Radon reduction in XENON1T of 20% with continuous distillation without xenon loss