Max-Planck-Institut für Kernphysik
Heidelberg

Radon Assay and Reduction in XENON1T

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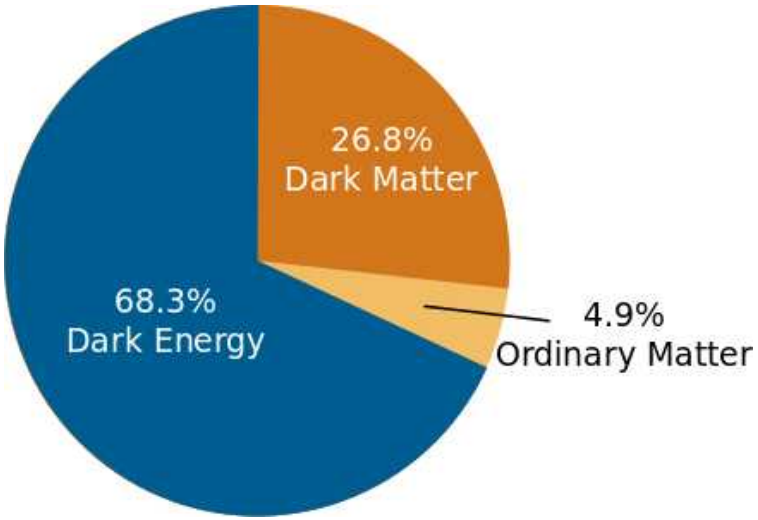
July 8, 2016

Dark Matter – The unsolved Mystery

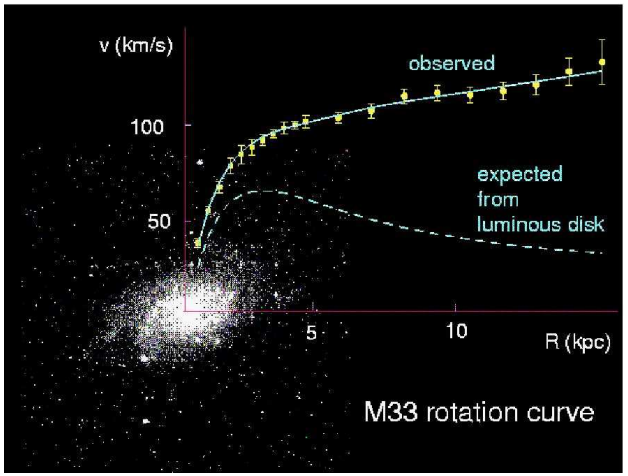


analysis of comsic microwave background

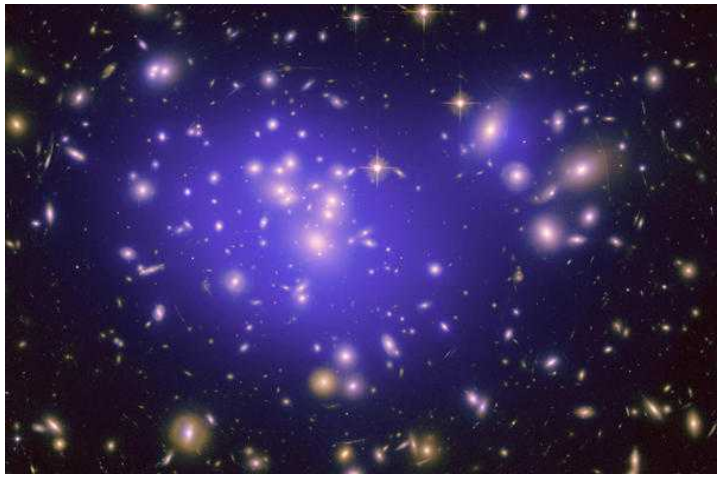
One of the most challenging questions in modern Cosmology is the identity and nature of

Dark Matter

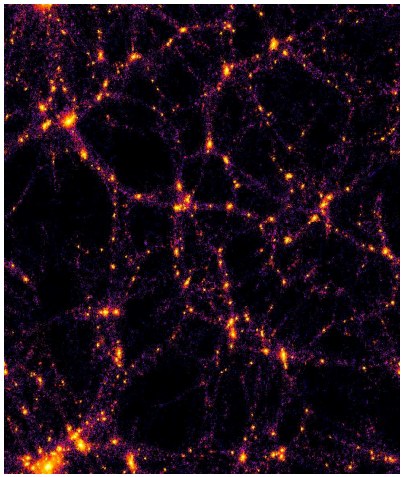
evidences on different scales



galaxy rotation curves

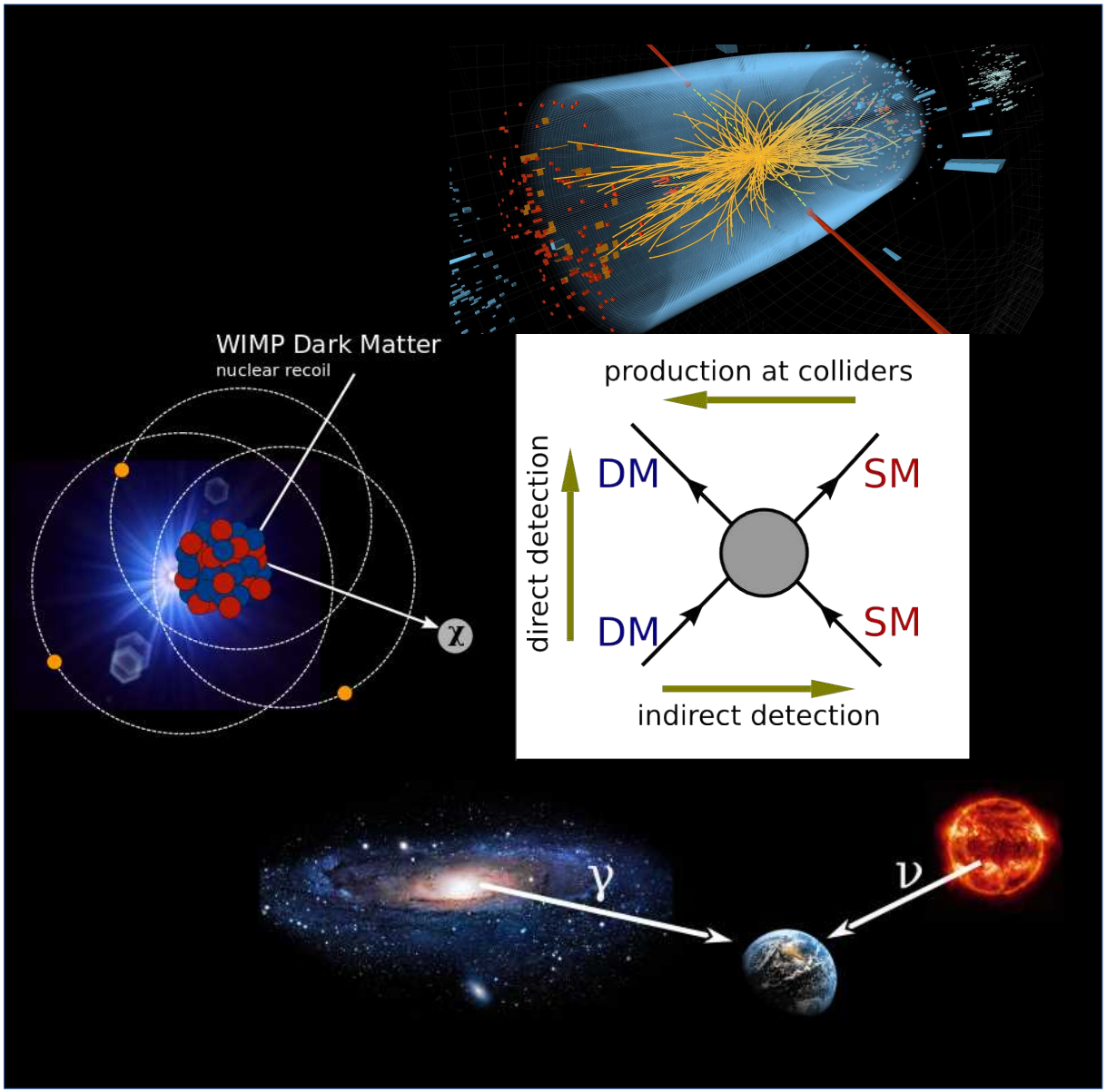


gravitational lensing



structure formation

Dark Matter - Detection Strategies



XENON
Dark Matter Project

liquid xenon for direct WIMP detection

(Weakly Interacting Massive Particles)

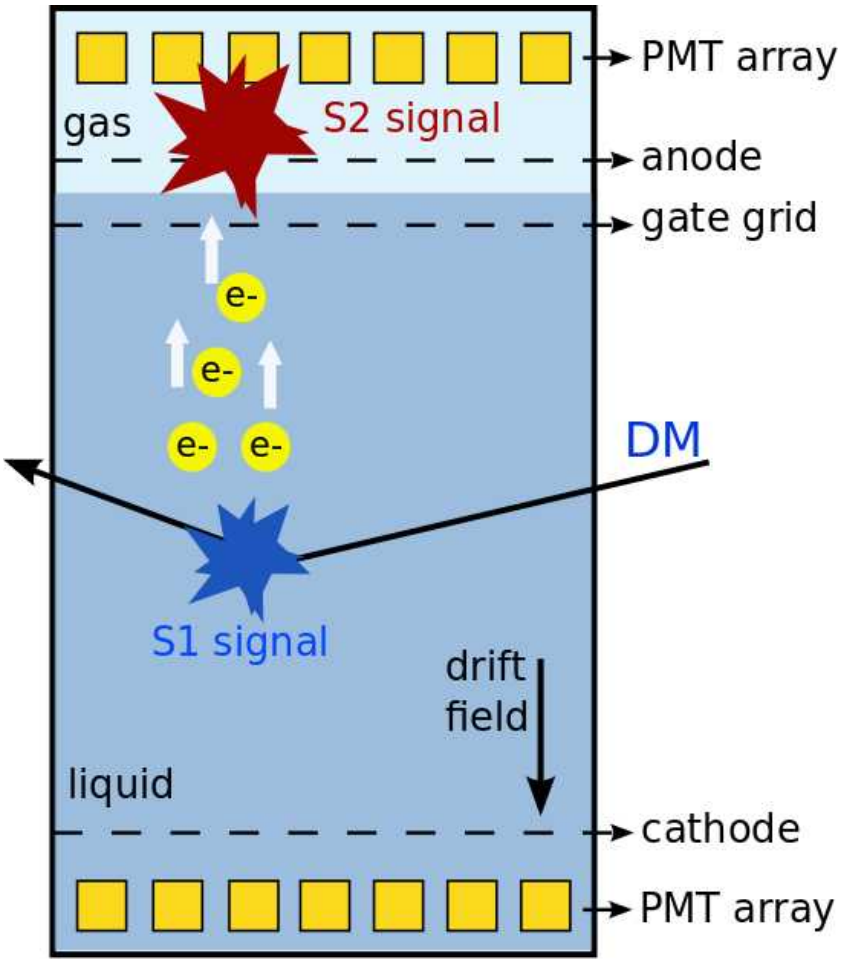
XENON10 (2006)
25kg liquid xenon

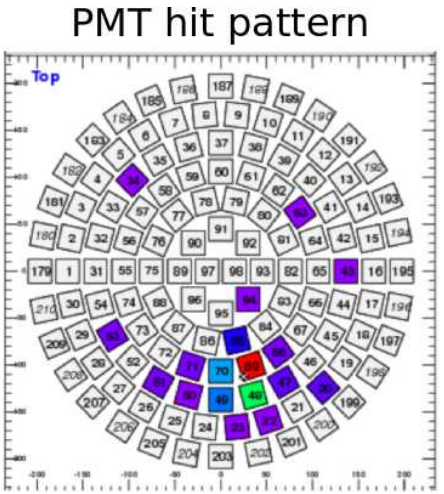
XENON100 (2008)
160kg liquid xenon

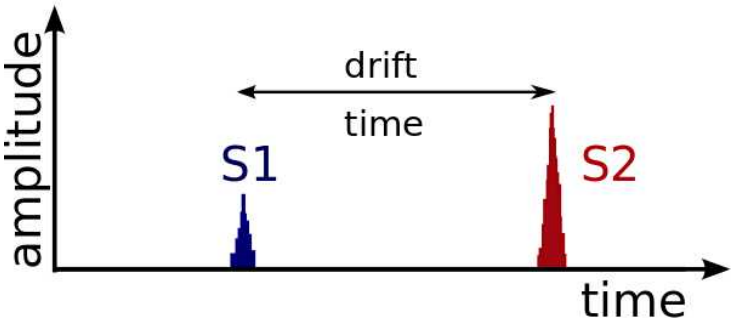
XENONnT (2006)
~7t liquid xenon

XENON1T (2015)
3t liquid xenon

Two-phase TPC detection principle







Two-phase TPC (Time Projection Chamber)

3D-position reconstruction (define fiducial volume for background discrimination)

S2/S1 ratio allows nuclear- and electronic-recoil discrimination

XENON100 – No Hint for Dark Matter

Sensitivity on WIMP-nucleon cross-section:

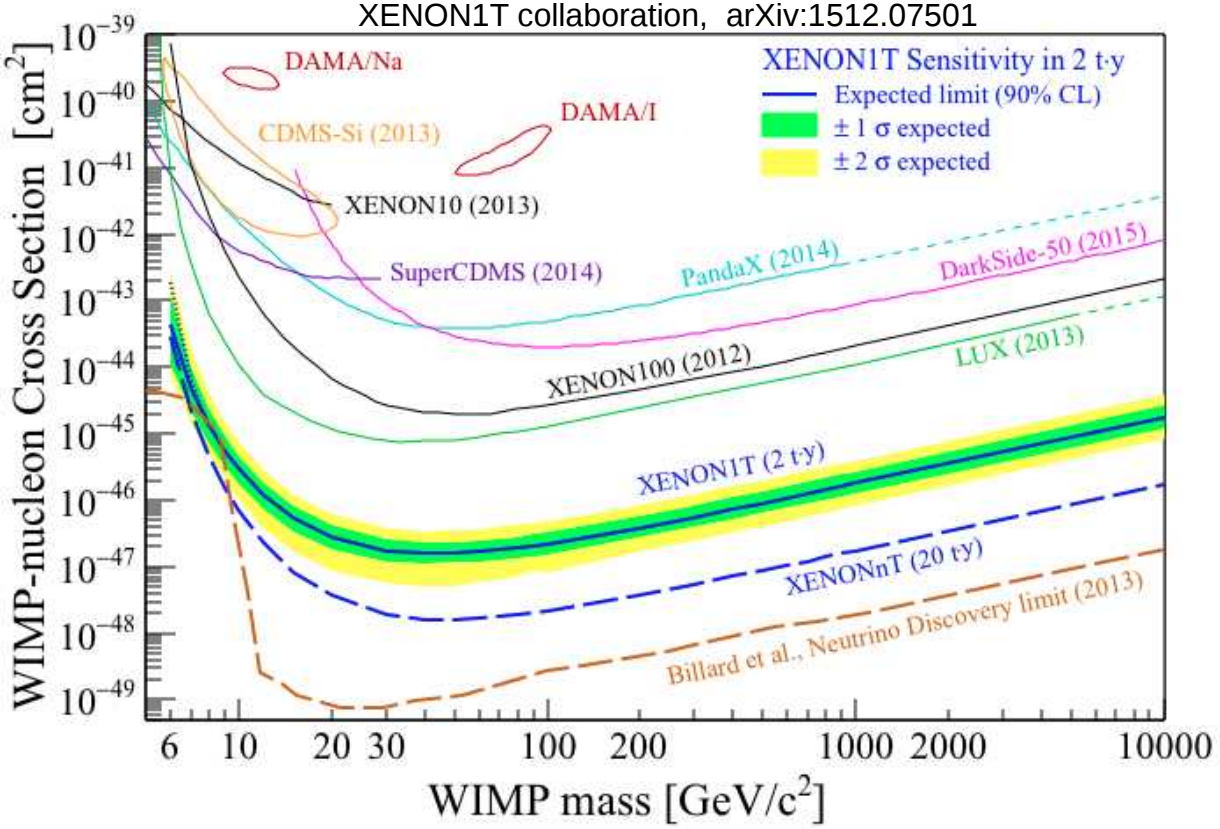
spin-independent: $\sigma_{\text{WIMP-nucleon}} = 2.0 \times 10^{-45}$ cm² ($m_\chi = 55$ GeV/c²)

spin-dependent: $\sigma_{\text{WIMP-neutron}} = 3.5 \times 10^{-40}$ cm² ($m_\chi = 45$ GeV/c²)

Background: 5.3×10^{-3} evts/kg/keV/day

excellent MC/data agreement

XENON1T collaboration, arXiv:1512.07501



XENON100 TPC

XENON1T

Sensitivity goal:

$\sigma_{\text{WIMP-nucleon}} = 1.6 \times 10^{-47}$ cm²

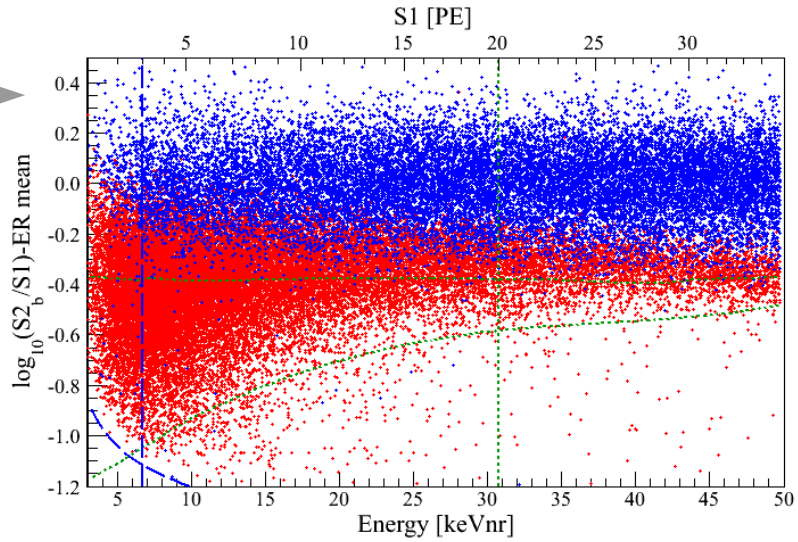
Background goal:

1.8×10^{-4} evts/kg/keV/day

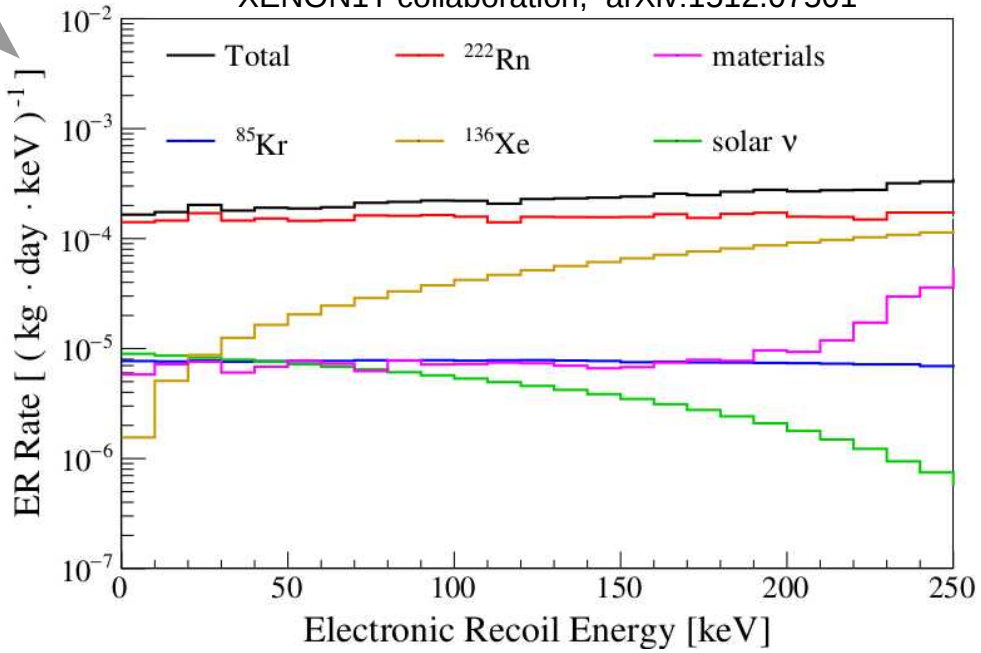
XENON1T – Background expectation

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

XENON1T collaboration, arXiv:1512.07501



XENON1T collaboration, arXiv:1512.07501



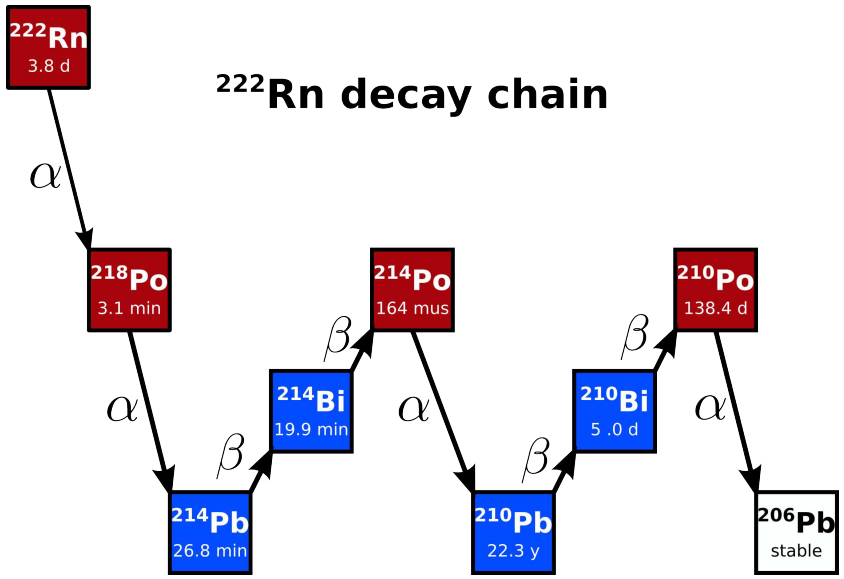
Nuclear Recoils (NR)

neutrons (radiogenic, muon-induced)
→ water tank as muon veto
coherent neutrino-nucleus scattering

Electronic Recoils (ER)

radioactivity (β,γ) from detector components
→ shielding, self-shielding of xenon
intrinsic background from ^{85}Kr and ^{222}Rn

Intrinsic Background Source ^{222}Rn



^{222}Rn decay chain

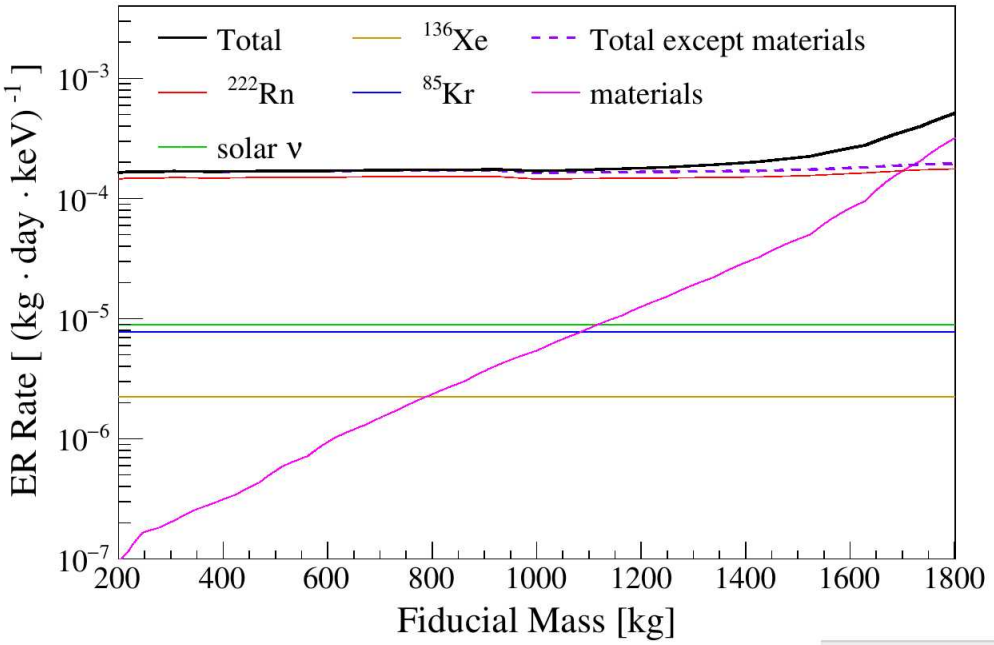
Emanation as radon source

Traces of ^{238}U in every material

Radioactive noble gas ^{222}Rn emanates from detector materials

Emanation is a permanent source of Rn

XENON1T collaboration, arXiv:1512.07501



Intrinsic Background

Rn distributes homogeneously in the LXe target

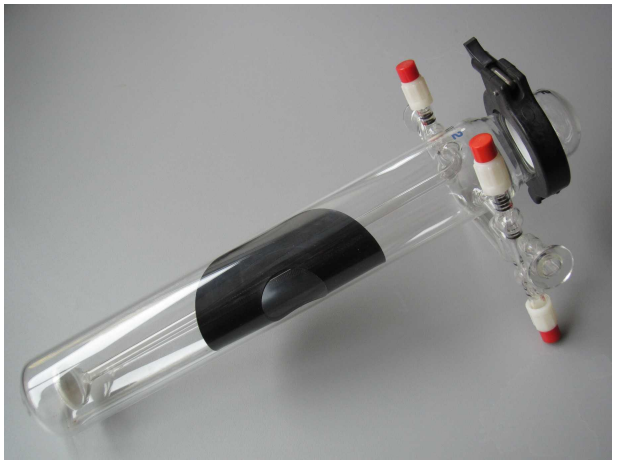
Radon progenies (^{214}Pb) can induce background

No shielding possible!

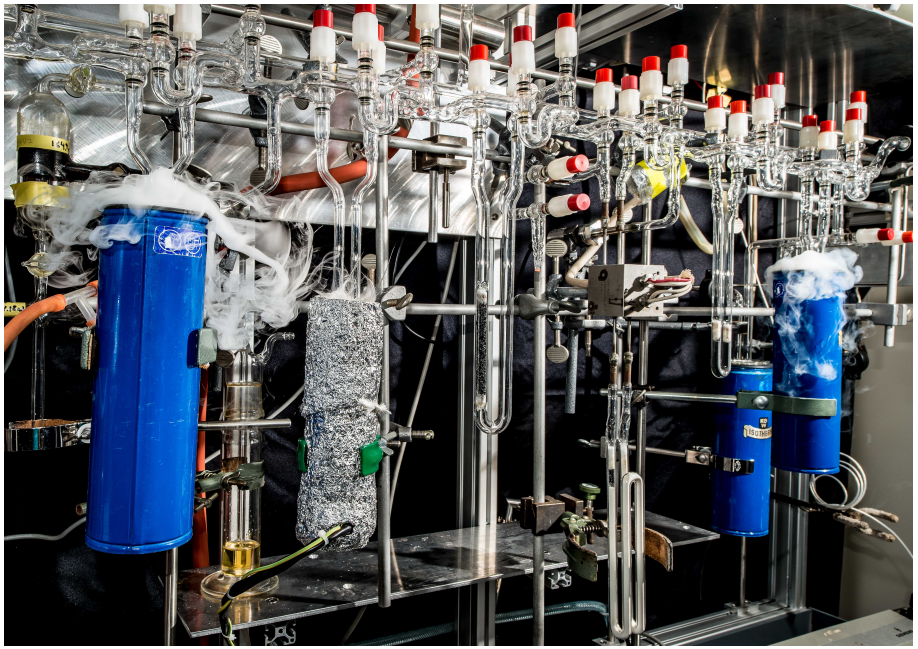
Mitigating Background - Radon Screening

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

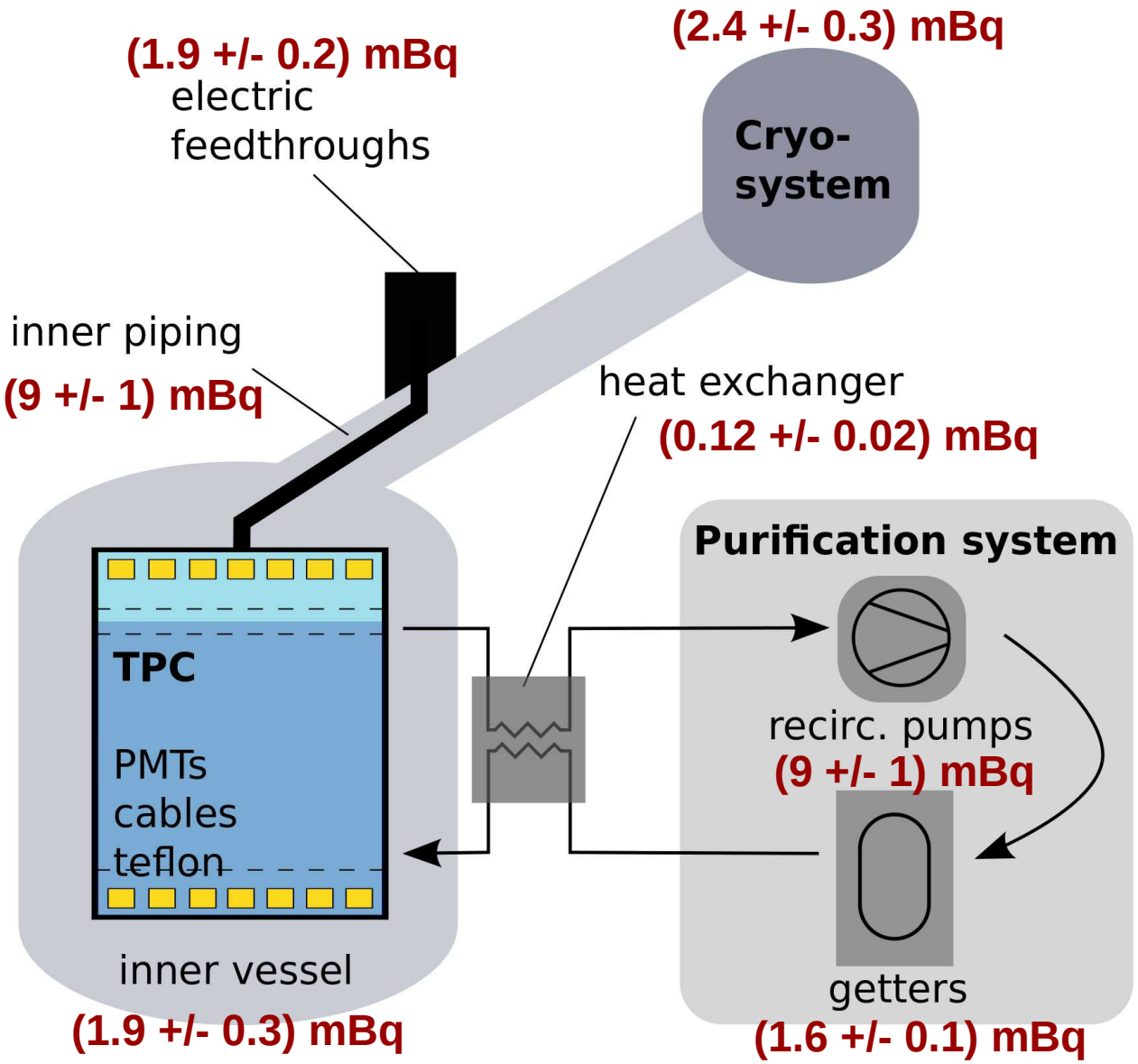
Counter

XENON1T – Emanation results

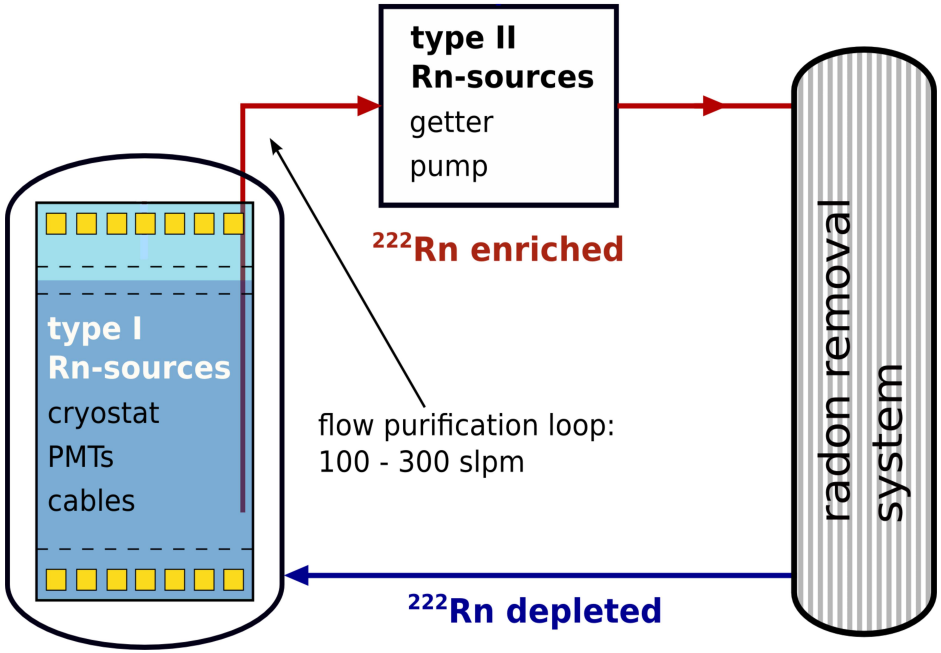
Integral measurement of the cryostat including TPC

preliminary result:

(19 +/- 4) mBq



Radon Distillation – Online Radon removal



Online radon removal system

Part of the existing gas purification loop
Needs to handle gas flow of ~100 slpm

Separate radon from xenon

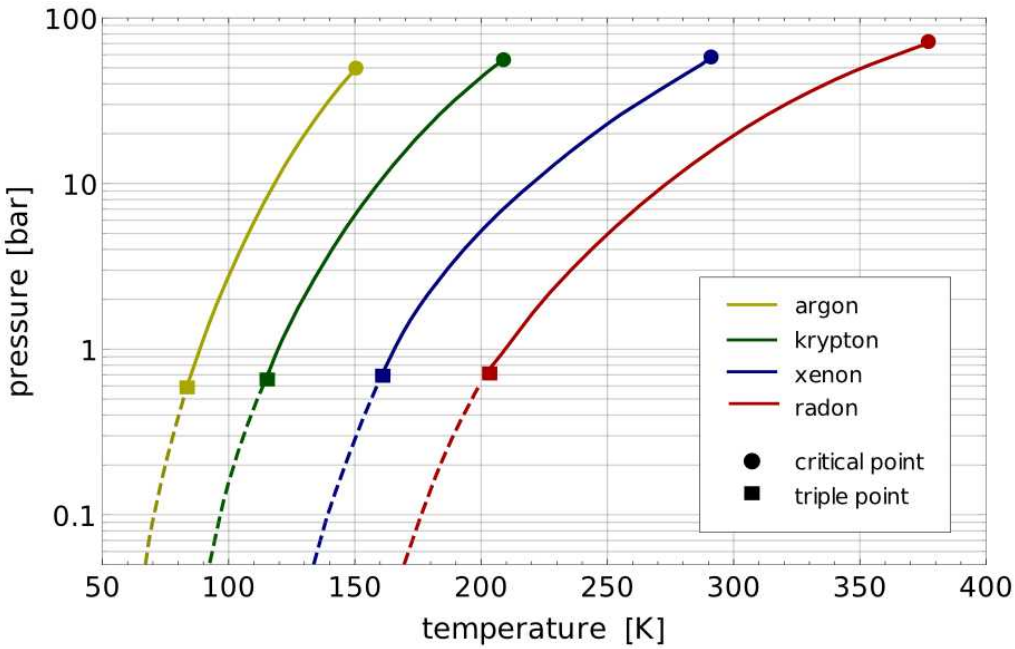
Radon retains in the removal system for several half-lives
Drops out naturally from system by radioactive decay

Krypton distillation

Successfully used in XENON100
Distillation column for XENON1T
Purification to ppq-level (x 10^{-15})

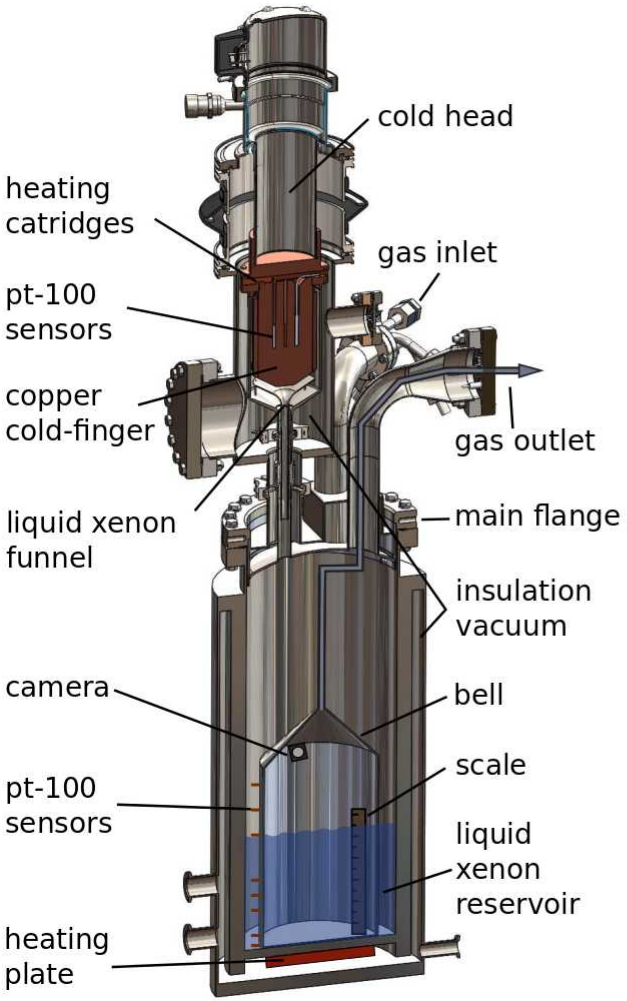
Special case: Radon distillation

Continuous distillation during detector operation
No 'off gas' allowed (no loss of xenon)
Radon is dropped out only by radioactive decay



Saturation vapor-pressures of noble gases

The HeXe Setup – probe Rn distillation



The **He**idelberg **Xe**non system (HeXe)

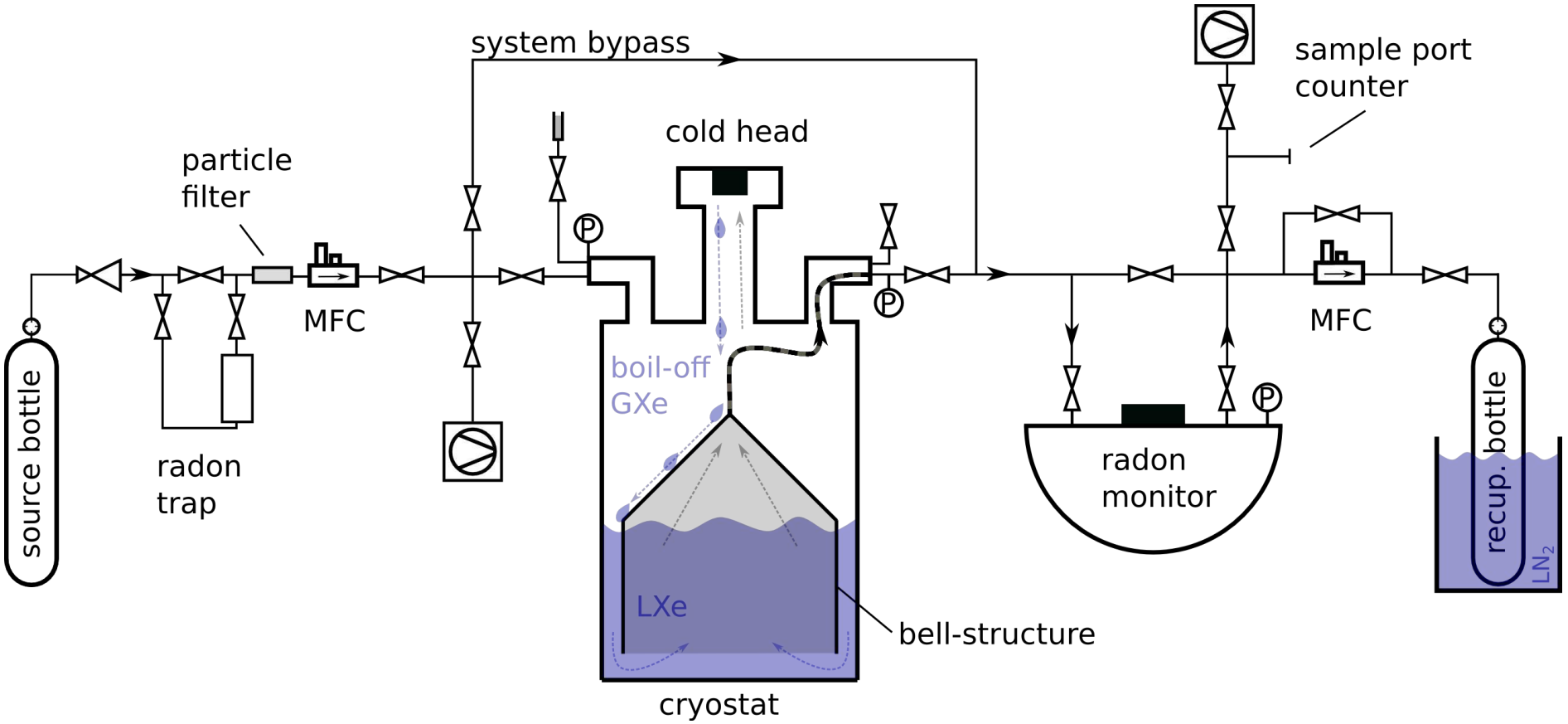
Single-stage distillation

Measurement of radon depletion in the boil-off gas phase

Cold-head for xenon liquefaction

Bell-structure separates gas volume

The HeXe Setup – probe Rn distillation



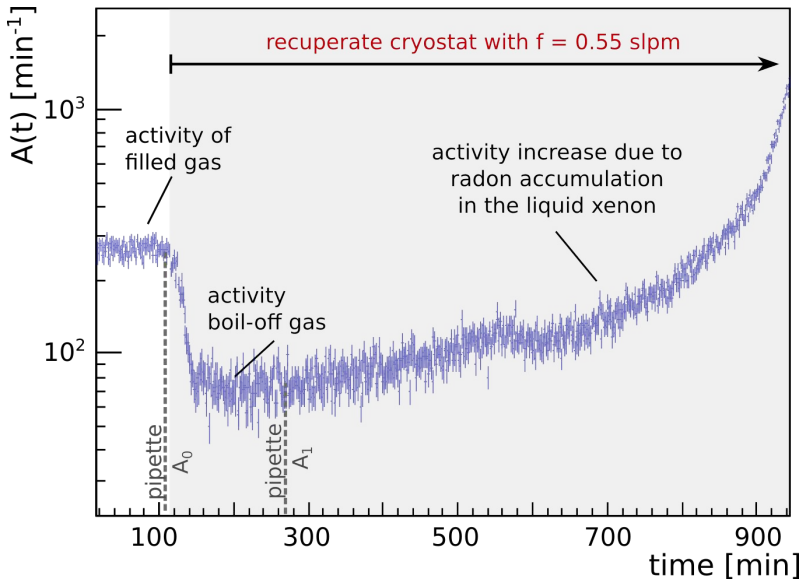
Measurement procedure

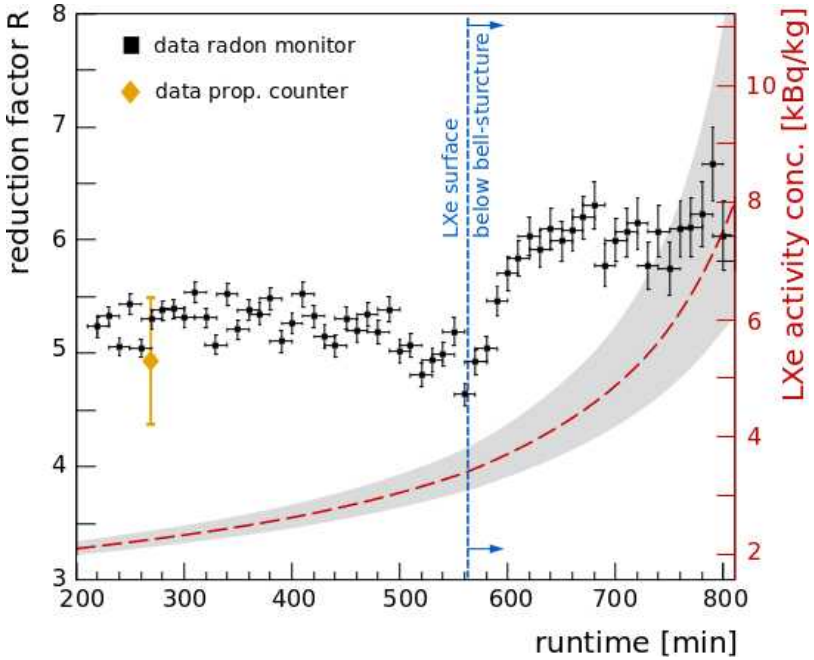
Fill HeXe with radon enriched xenon which is liquefied at the cold-head

Recuperate the boil-off xenon inside the bell-structure with a regulated mass-flow through a radon monitor

Electrostatic radon monitor measures continuously the radon activity concentration in the xenon gas

The HeXe Setup – probe Rn distillation





	hat structure rad. mon. prop. counter	no hat structure rad. mon. prop. counter
xe_run1	$4.6 \pm 0.1^{stat} \pm 0.3^{sys}$	$5.5 \pm 0.1^{stat} \pm 1^{sys}$
	3.6 ± 0.4	-
xe_run2	$5.3 \pm 0.1^{stat} \pm 0.3^{sys}$	$6.0 \pm 0.1^{stat} \pm 1^{sys}$
	4.9 ± 0.6	-
xe_run3	-	$7.7 \pm 0.1^{stat} \pm 0.4^{sys}$
	-	8 ± 1
xe_run4	-	$3.7 \pm 0.1^{stat} \pm 0.4^{sys}$
	-	-

Measured reduction factor R = Rn_{liquid} / Rn_{gas}

Proof of radon reduction in boil-off gas!

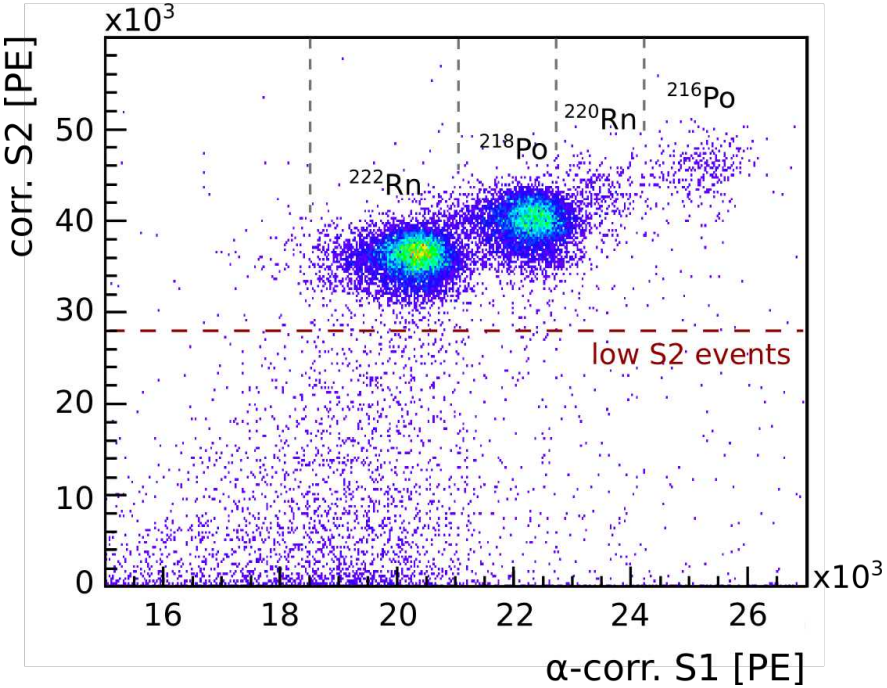
Radon reduction by a **factor ~5** measured

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

Online Rn-distillation at XENON100

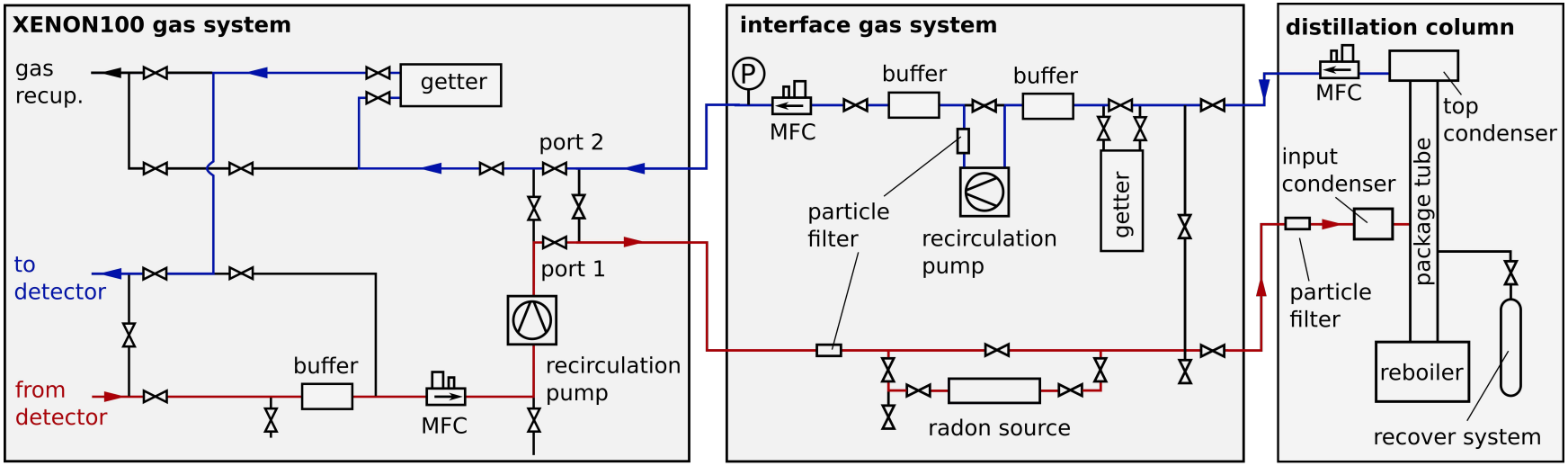


Rn-detector XENON100

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



XENON100 distillation campaign setup

Online Rn-distillation at XENON100

The radon emanation source

Radon emanation source

426 viton O-rings as radon source

~70 mBq activity brought into XENON100 TPC

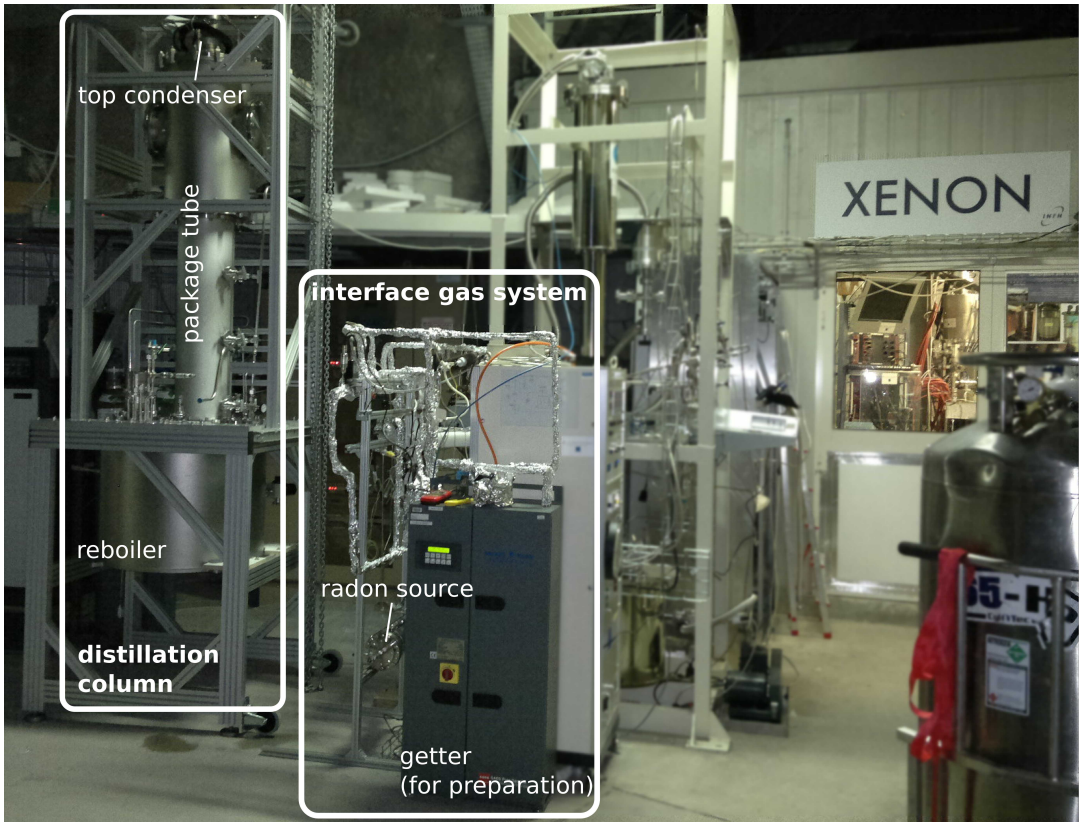
Rn-distillation setup at XENON100

Operation of Kr-column

XENON1T phase I krypton column

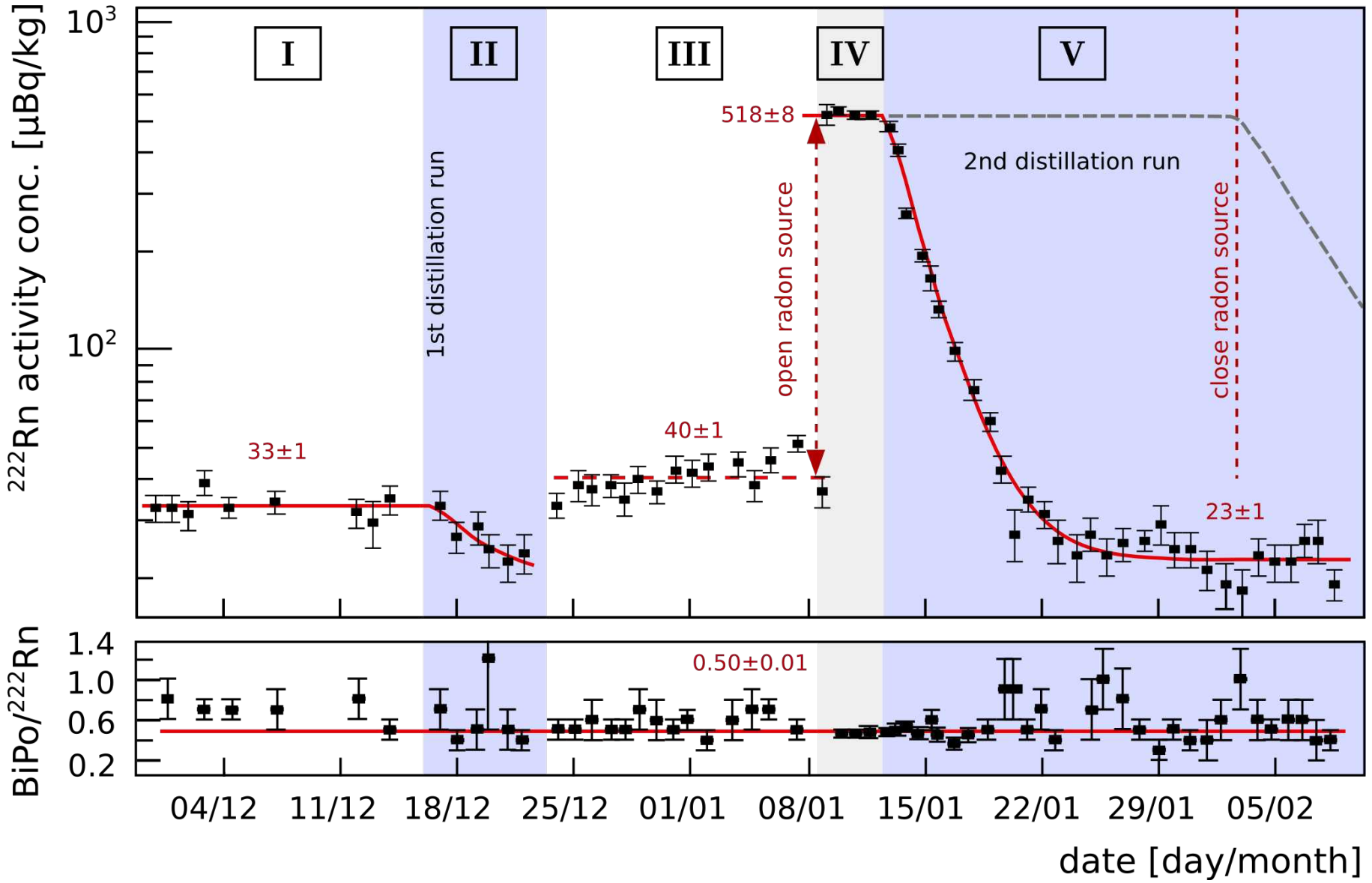
'Inverse' operation with respect to Kr distillation
Rn is enriched in the liquid reservoir (reboiler)

Purified xenon from the columns top is pumped back into XENON100

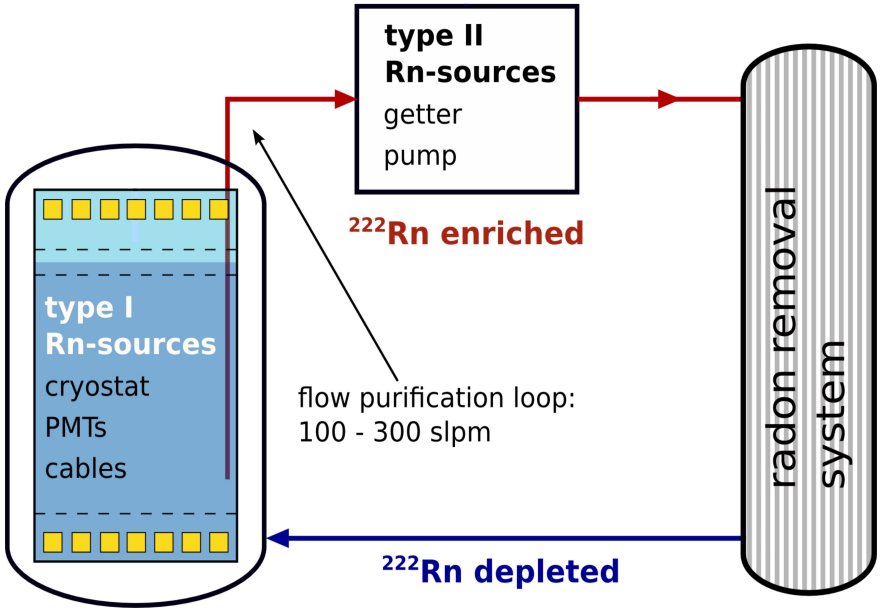


Situation at XENON100 during the distillation campaign

Online Rn-distillation at XENON100

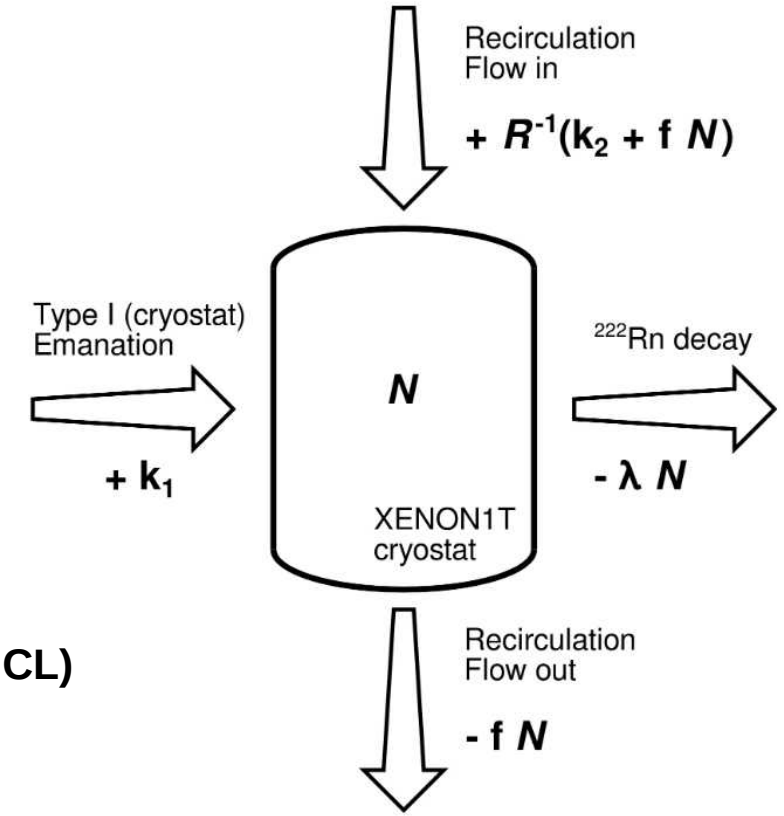


Online Rn-distillation at XENON100



Model of Rn concentration in XENON100

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



Type I and Type II emanation sources

Type I: sources inside the detector
Type II: sources placed directly before removal system

Online Rn-distillation demonstrated

Distillation column reduces radon by a **factor of 75 (95% CL)**
Reduction of type I sources strongly dependent on flow

Summary

Radon is the dominating source of background (ER) in XENON1T
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.

Online 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

THANK YOU FOR YOUR ATTENTION

Max-Planck-Institut für Kernphysik

International Max Planck Research School for Precision Tests of Fundamental Symmetries

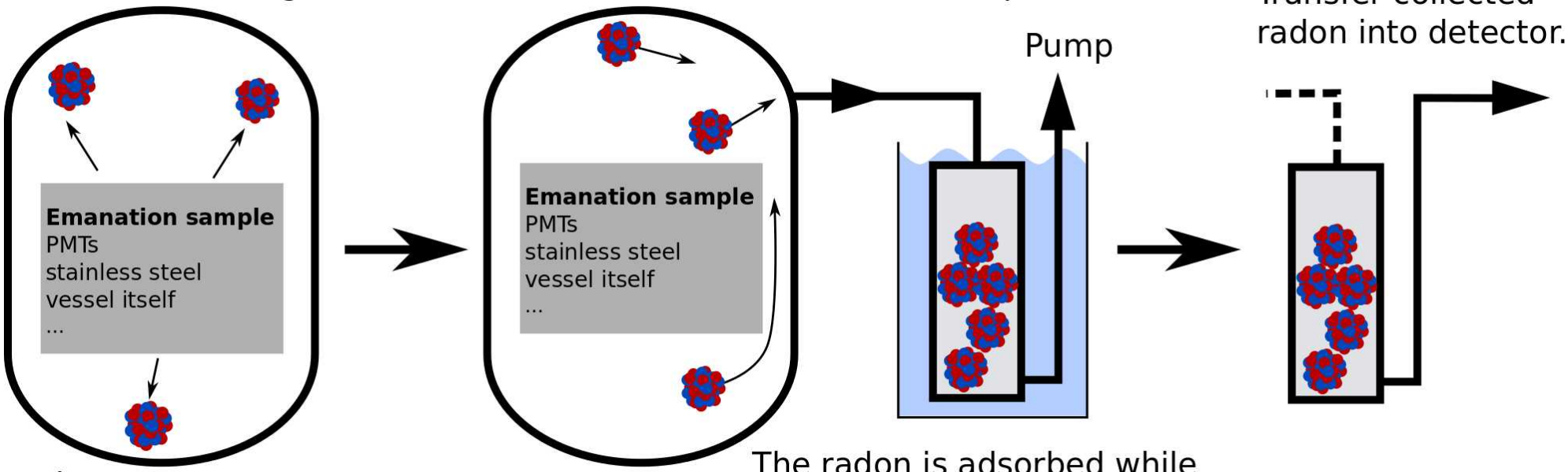
XENON Dark Matter Project

Measure Rn-Emanation at the µBq Level

Emanation vessel is filled with carrier gas.

Emanated radon is extracted via a cooled activated carbon trap.

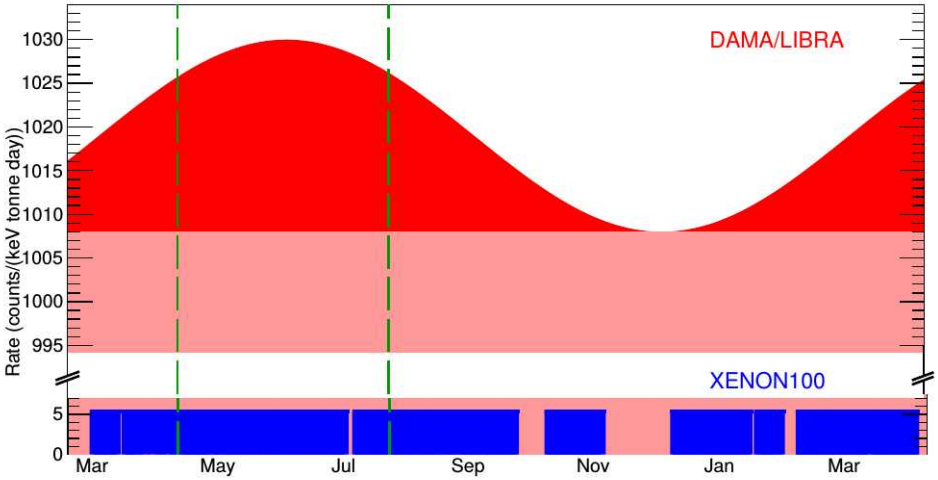
Transfer collected radon into detector.



Radon emanates from the sample.

The radon is adsorbed while the carrier gas is pumped out.

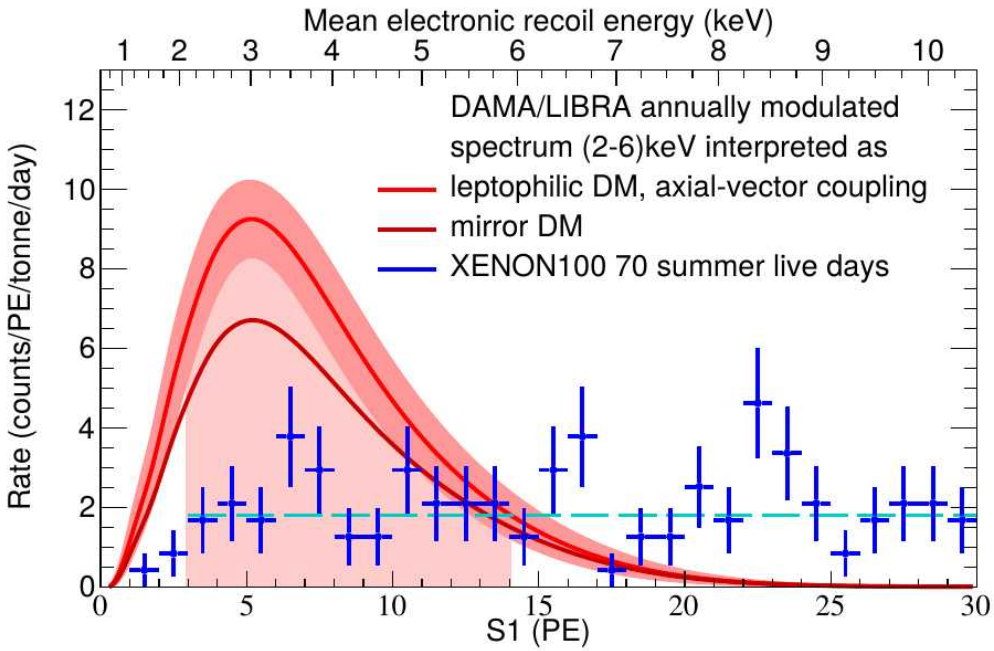
Recent XENON100 Results



Exclution of Leptophilic Dark Matter

Selection of 70 live days of electronic recoil XENON100 data, where DAMA signal is highest

mixed Mirror DM: 3.6σ Exclusion
Luminous DM: 4.6σ Exclusion
Axial-vector coupling: 4.4σ Exclusion



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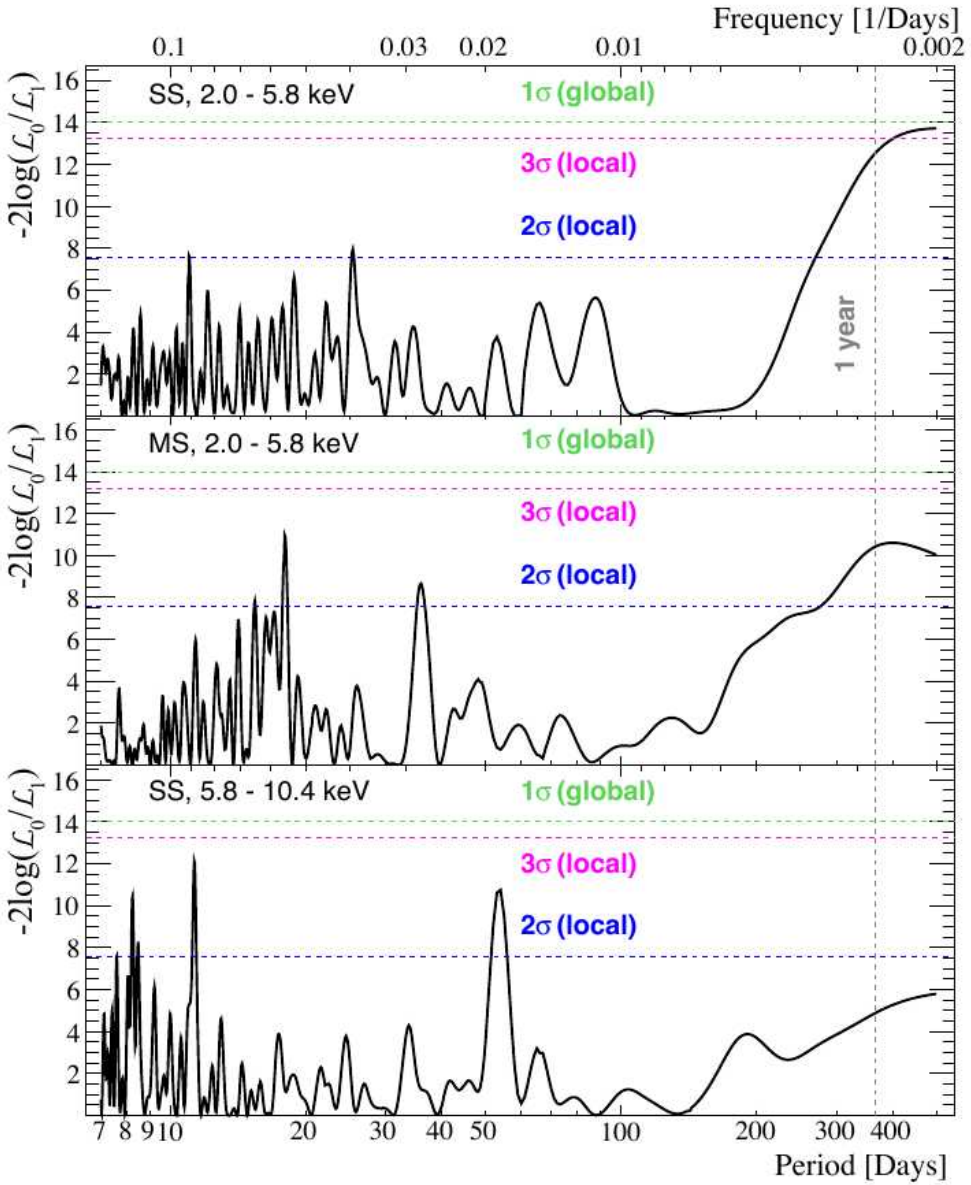

Search for Event Rate Modulation

The DM interpretation of DAMA/ LIBRA annual modulation as being due to WIMPs electron scattering through axial vector coupling is disfavored at 4.8-σ from a PL analysis