Max-Planck-Institut für Kernphysik
Heidelberg

Direct Dark Matter Search with XENON100 and XENON1T

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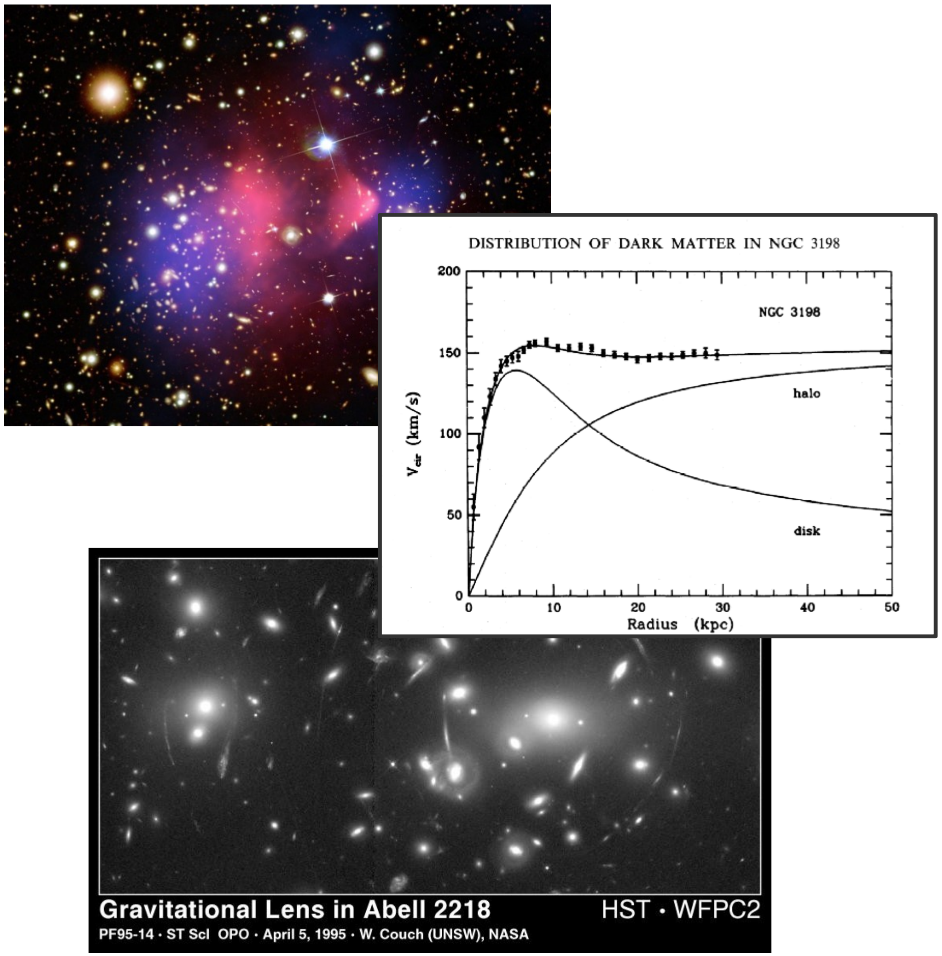
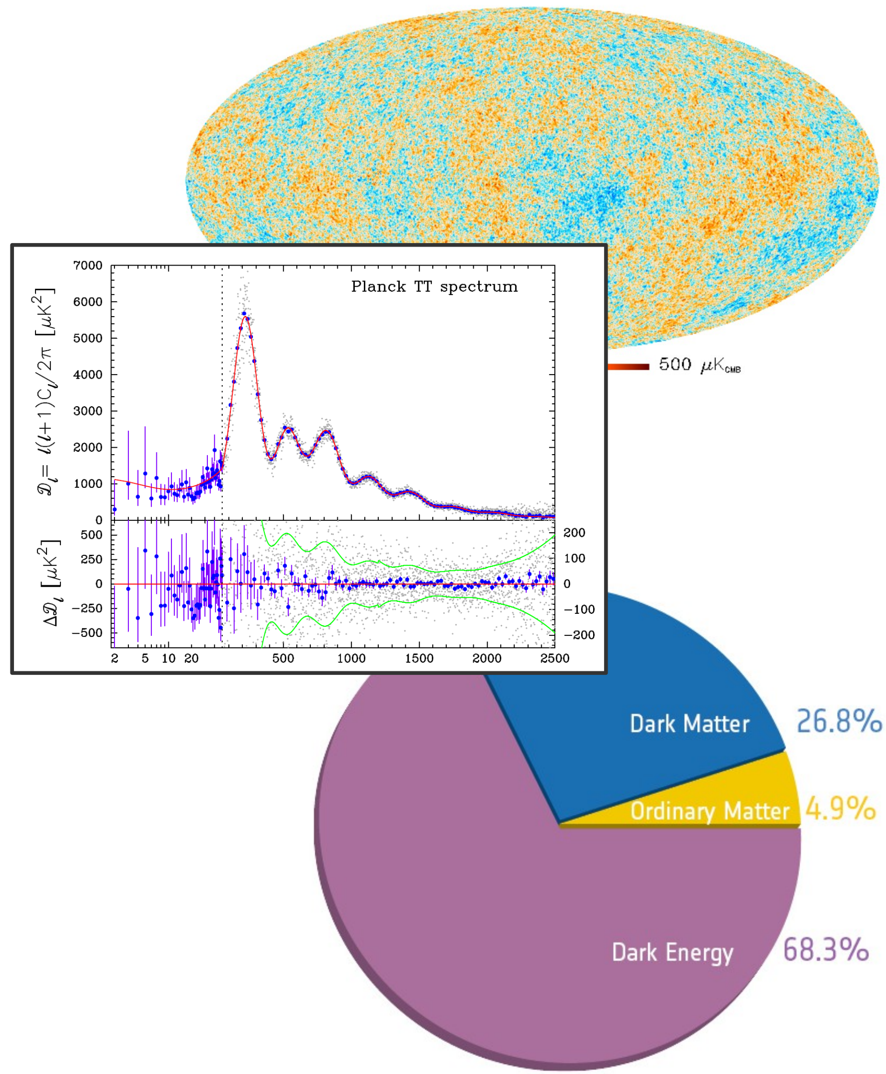
June 20, 2016

Dark Matter Indications

Astronomy



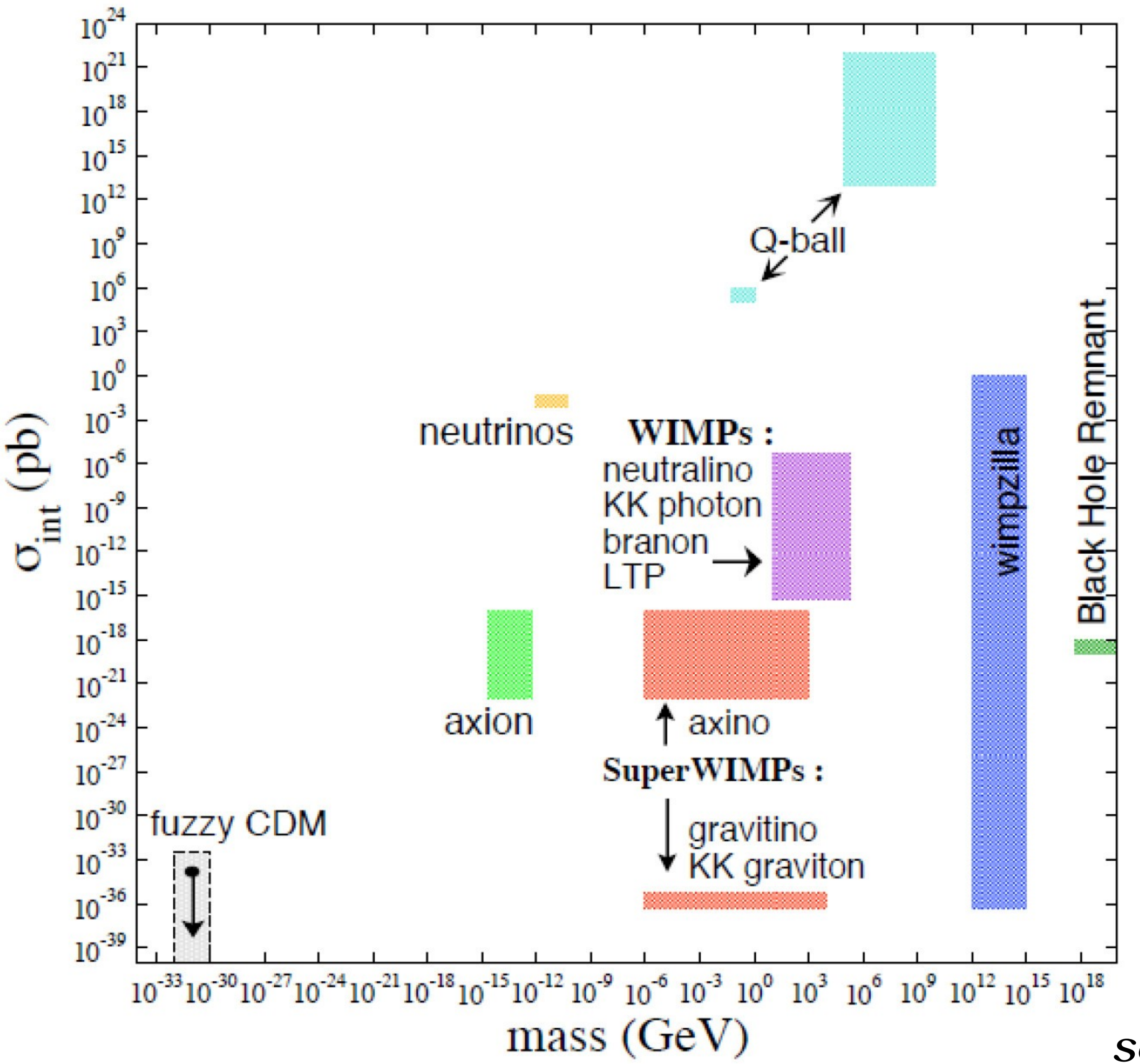
Cosmology



(Some) Dark Matter Candidates

MOND/TeVeS: fails (so far) to simultaneously describe all different scales

MACHOs: likely ~ 20% of DM are massive astrophysical compact halo objects (but not all of it)



Prerequisits:

cold (structure formation: no large free-streaming)

electrically neutral (searches for CHAMPs)

abundance of 27 % (CMB)

cosmologically stable (gravitational effects today)

no strong interaction (cluster collisions)

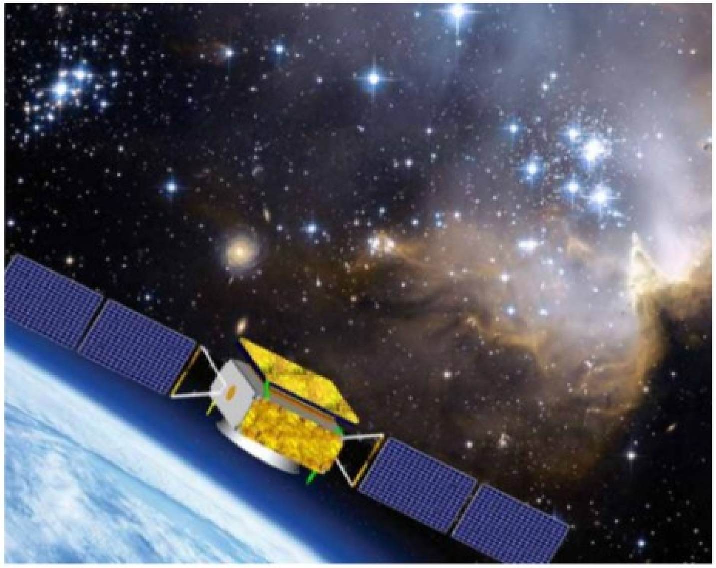
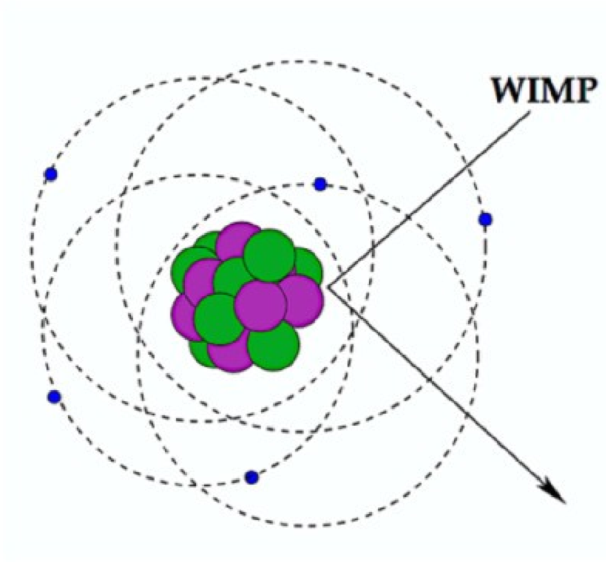
+ additional motivation (smallness of neutrino masses; hierarchy problem; weak and strong unification; ultra high-energy cosmic rays; strong CP-problem)

+ signals within reach

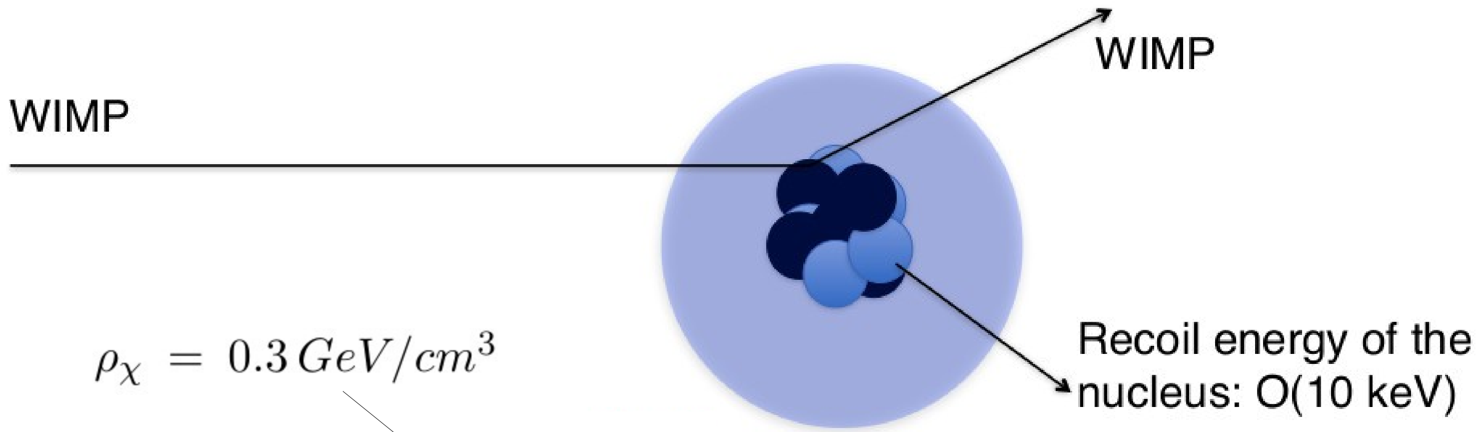
→ **WIMPs**

see last weeks talk from Nishita Desai

Dark Matter Searches

Indirect detection	Direct detection	Particle colliders
		
DM annihilation into SM particle	DM scattering off SM particle	Direct or by decay production DM
$\chi\bar{\chi} \to q\bar{q}, \gamma\gamma, \ldots$	$\chi N \to \chi N$	$pp \to \chi\bar{\chi} + X$

Direct DM Detection – What to expect?



$$\rho_\chi = 0.3\, GeV/cm^3$$

$$\overbrace{\frac{dR}{dE}}^{Scatt.\,Rate}(E,t) = \underbrace{N_T}_{Target\ Dependence} \overbrace{\frac{\rho_\chi}{m_\chi}}^{Number\ density} \int_{v_{min}} \underbrace{\frac{d\sigma}{dE}(v,E)}_{Diff.\,Cross\ Section}\, v\, \overbrace{f_E(\vec{v},t)}^{veloc.\,distribution}\, d^3\vec{v}$$

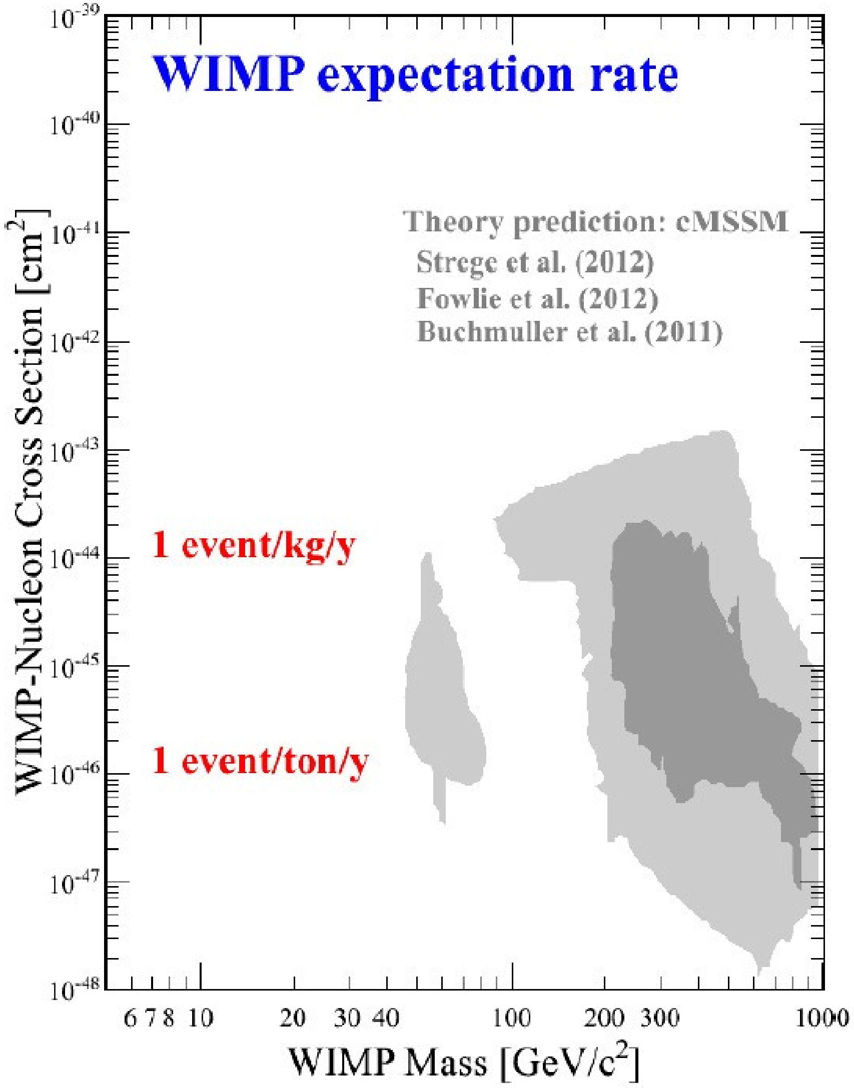
(arXiv:1605.08788)

$$\frac{d\sigma}{dE} = \frac{m_N}{2\mu^2 v^2}\left(\sigma_{SI} F^2(q) + \sigma_{SD} S(q)\right)$$

proportional to A^2

requires nucleus with non-zero spin (e.g. ^{129}Xe, ^{131}Xe)

Detector requirements



Spin independent scattering

Signatures of dark matter signals

- Nuclear recoil, single scatter
- Spectral shape: exponential
- Dependance on material
- Annual modulation of rate
- Directional dependance

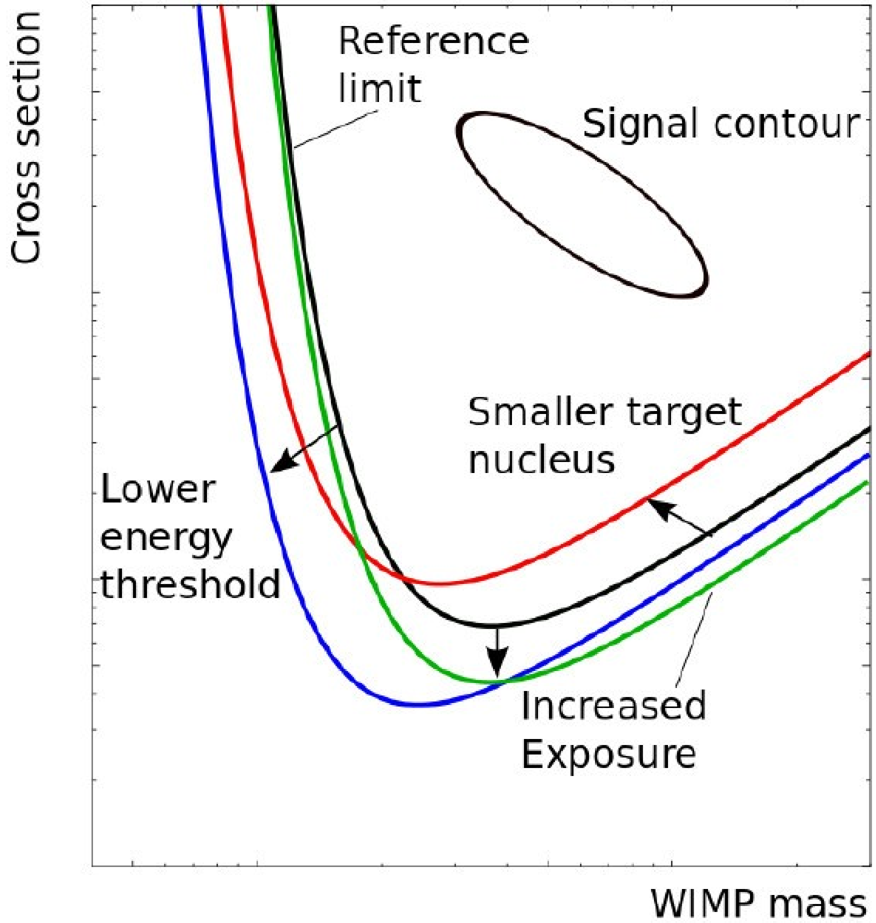
A dark matter detector

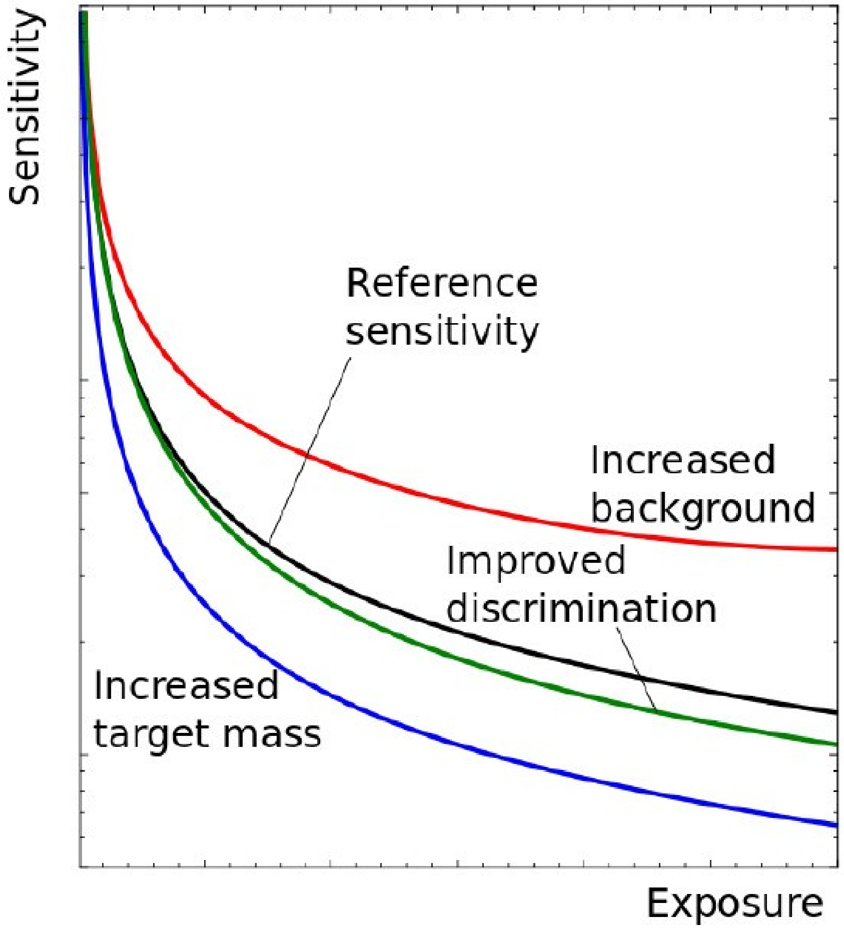
- Large target mass
- Low energy threshold
- Very low background
- good background discrimination

Signal contour and exclusion curves

N counts in ROI for a given exposure:

→ Statistically significant for given background?





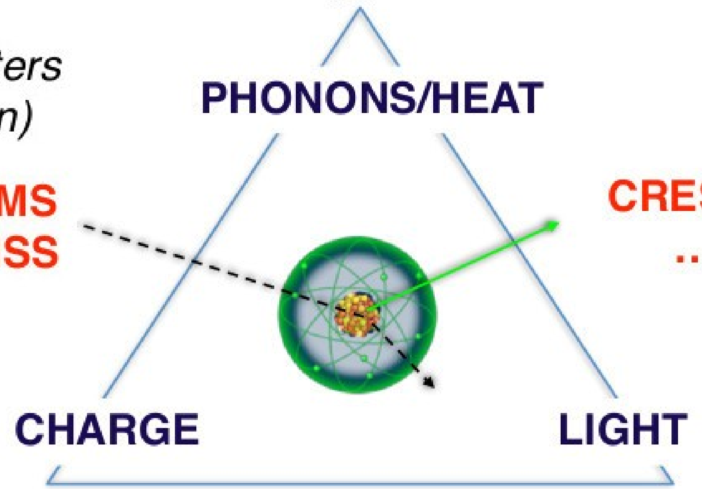
Direct detection experiments

COUPP
PICASSO
SIMPLE
PICO
...

(cryogenic bolometers/ superheated liquids)

(cryogenic bolometers +charge collection)

SuperCDMS
EDELWEISS
...



CRESST
...

(scintillating cryogenic bolometers)

(Ge detectors/ directional detectors)

COGENT
TEXONO
CDEX
DMTPC
DRIFT
MIMAC
Newage
...

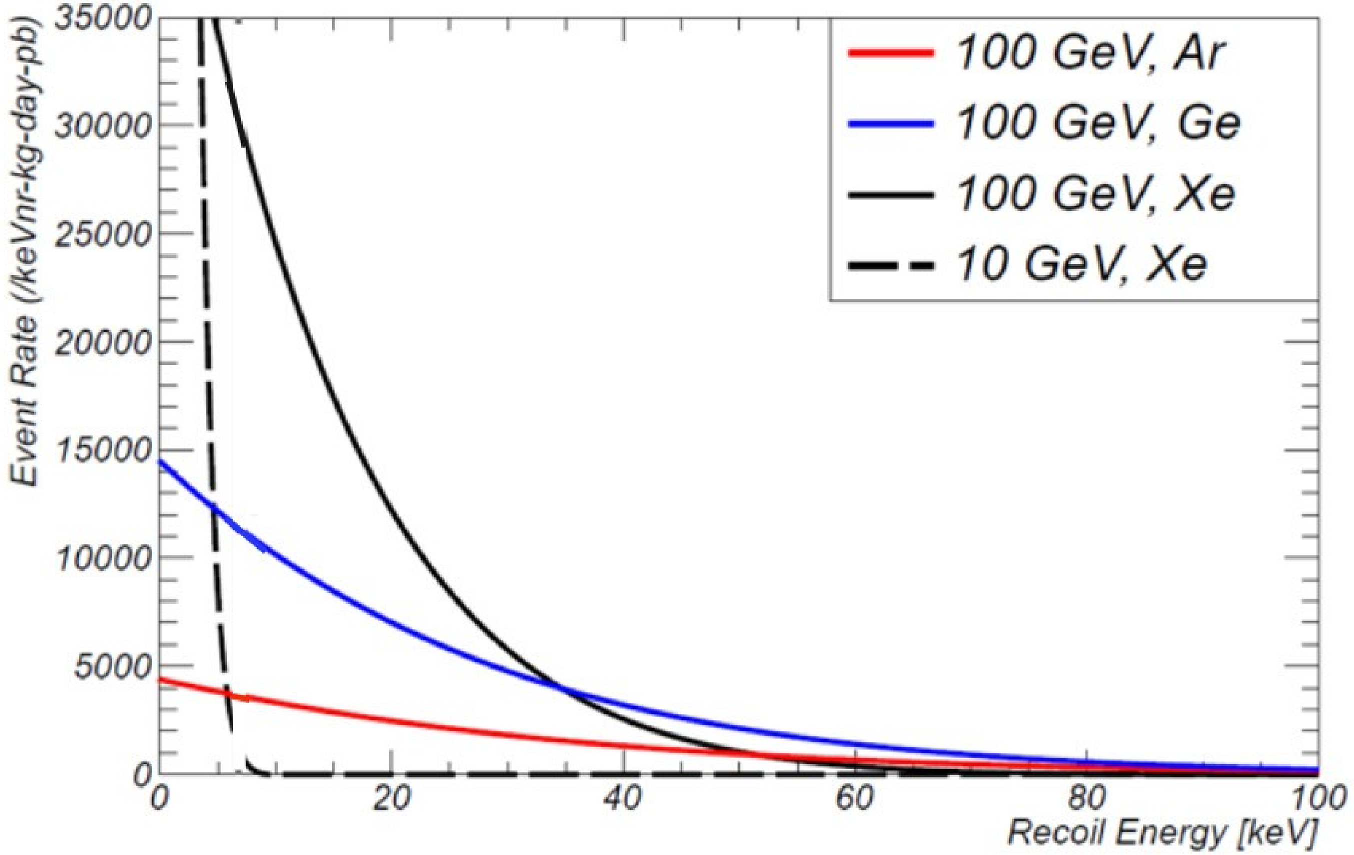
LZ
ArDM
XENON
DARKSIDE
PANDA-X
...

(dual-phase liquid noble gas detectors + TPCs)

DEAP
CLEAN
DAMA/LIBRA
XMASS
KIMS
DM-Ice
SABRE
...

(scintillating crystals/ liquid noble gas detectors)

Liquid xenon (LXe) as detection medium



- Large mass number **A (131)**, higher rate for **SI** interactions (proportional to **A²**)
- **50% odd isotopes (^{129}Xe, ^{131}Xe) for SD interactions**
- No long-lived radioisotopes (with the exception of ^{136}Xe, $T_{1/2} = 2.2 \times 10^{21}$ y)
- High stopping power ($Z = 54$, $\rho = 3$ g cm^{-3}), **self shielding**
- **Efficient scintillator** (80% light yield of NaI), light output @ 178 nm (**VUV, WLS not needed**)
- **Liquid at ~ 182 K @ 2 bar**

Xe scintillation light: excited dimers

Excitation:

$e^- + R \to R^* + e^-$ *impact excitation*

$R^* + R \to R_2^{*,v}$ *excimer formation*

$R_2^{*,v} + R \to R_2^* + R$ *relaxation*

$R_2^* \to R + R + h\nu$ *VUV emission*

Ionization:

$e^- + R \to R^+ + 2e^-$ *ionization*

$R^+ + R + R \to R_2^+ + R$

$e^- + R_2^+ \to R^{**} + R$ *recombination*

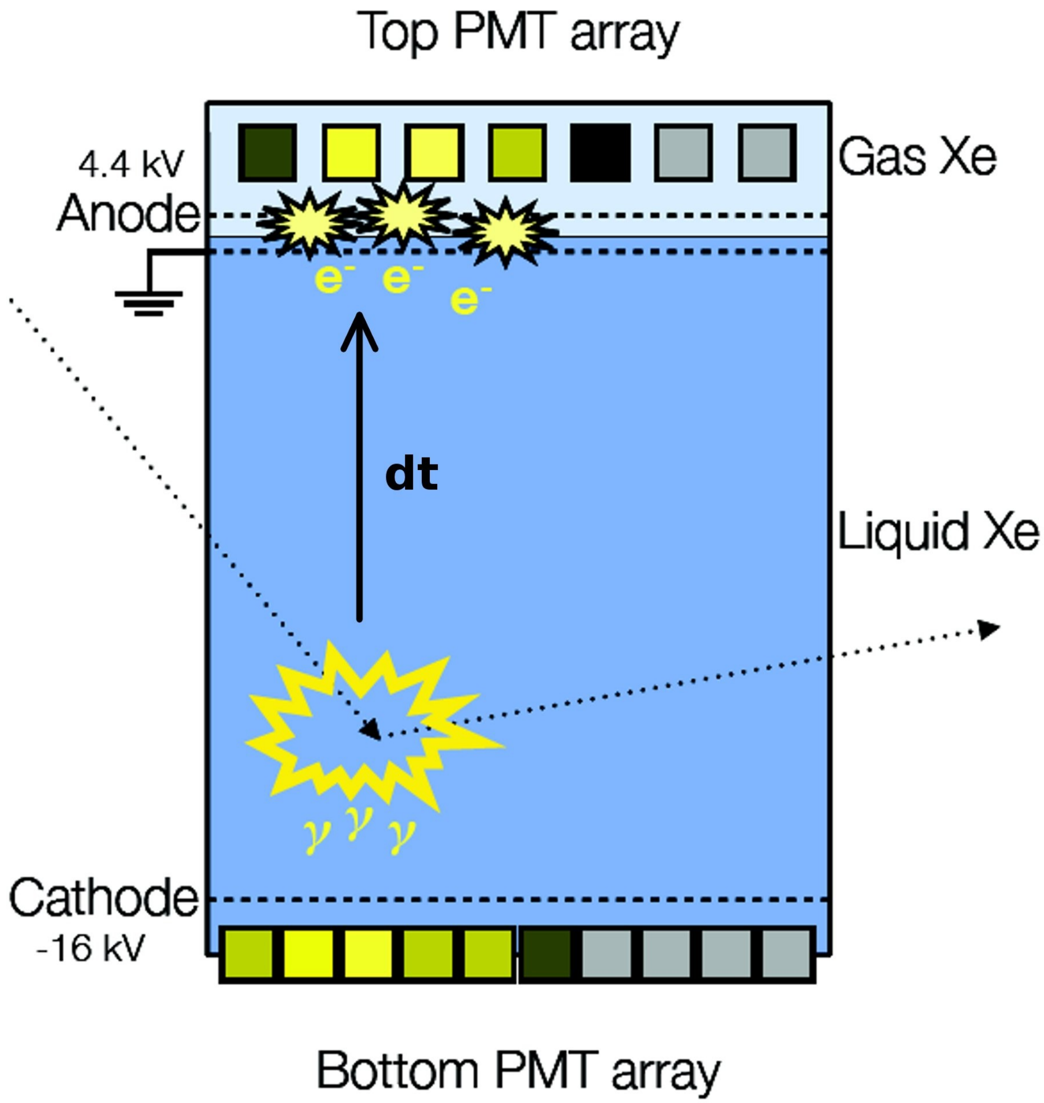
$R^{**} + R \to R^* + R + \text{heat}$

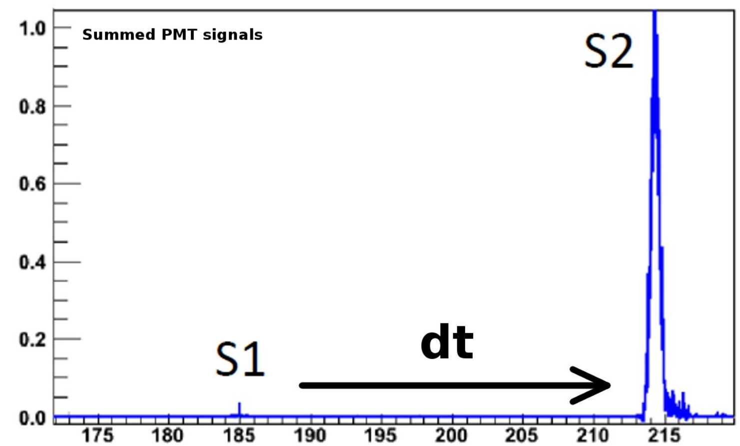
$R^* + R + R \to R_2^* + R + \text{heat}$

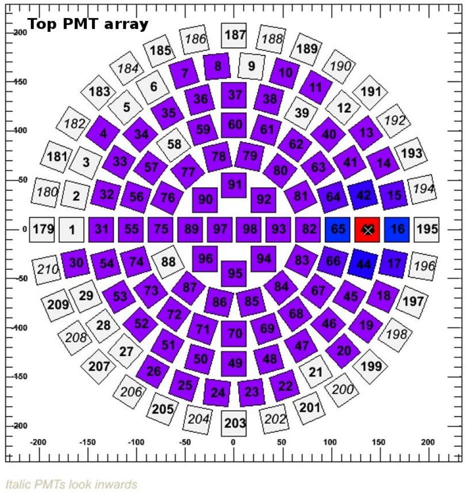
$R_2^* \to R + R + h\nu$ *VUV emission*

arXiv:1207.2292

2-phase time projection chamber (TPC)







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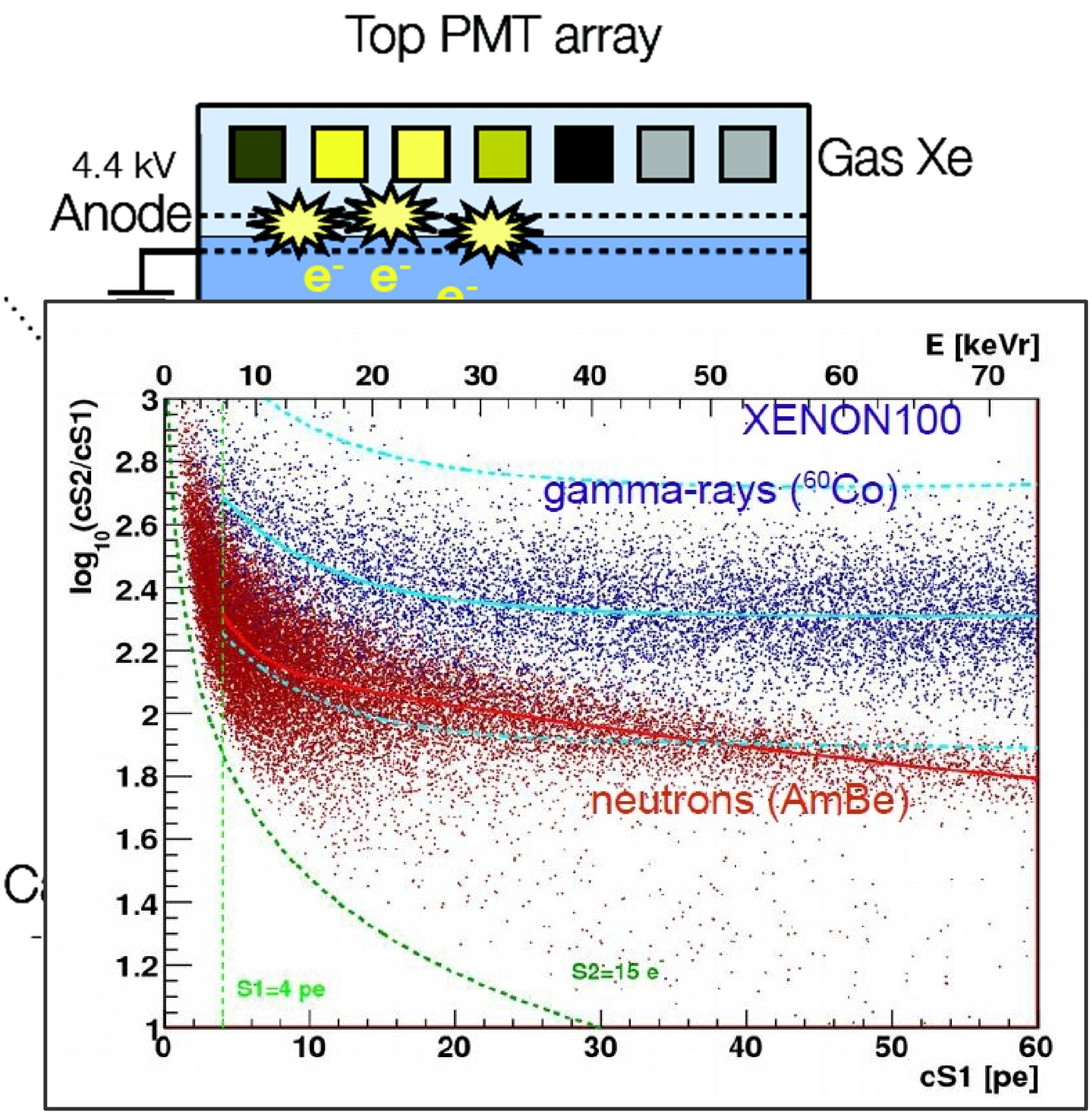

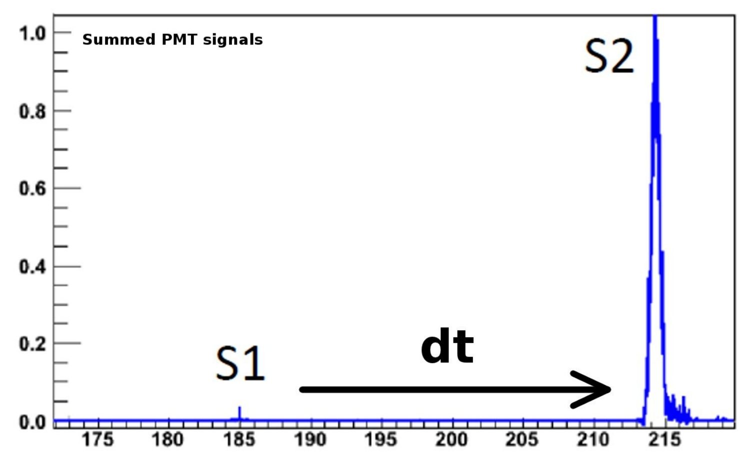

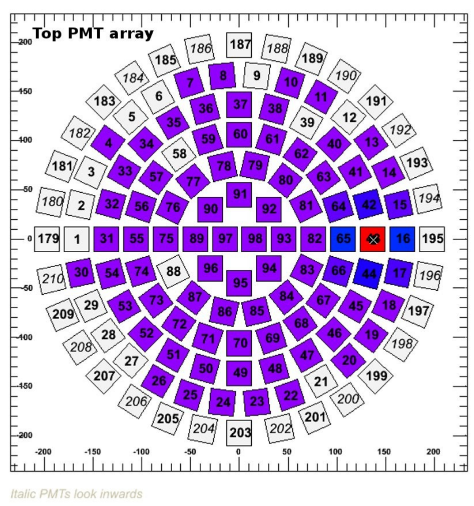

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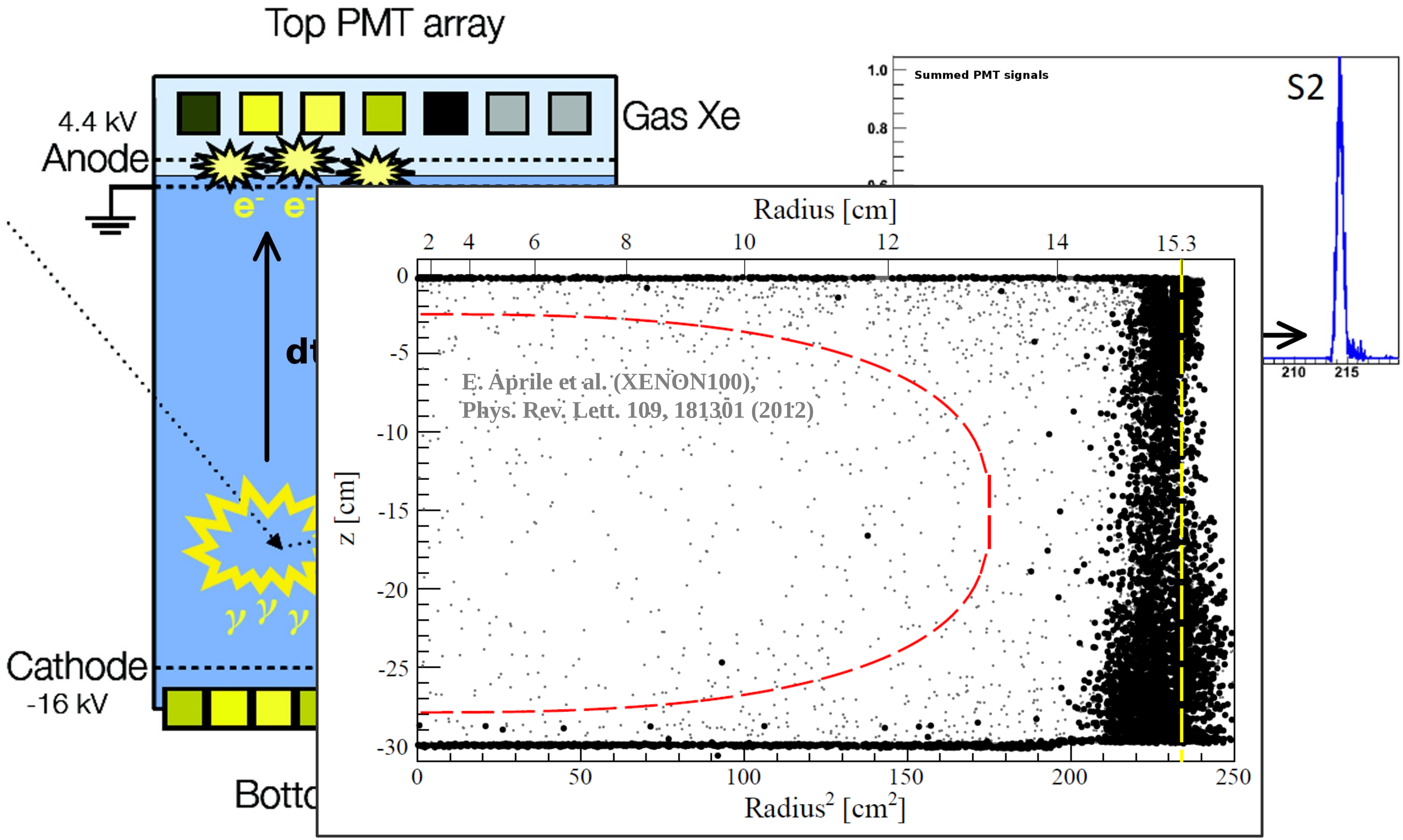


XENON Dark Matter Program @ LNGS

XENON Dark Matter Program @ LNGS

The XENON Dark Matter Program

XENON10

Livetime = 2005-2007

Xenon mass = 25 kg

Target mass = 15 kg

Achieved sensitivity

$8.8 \times 10^{-44}\ cm^2$

@ $100\ GeV$ (2007)

XENON100

Livetime = since 2008

Xenon mass = 161 kg

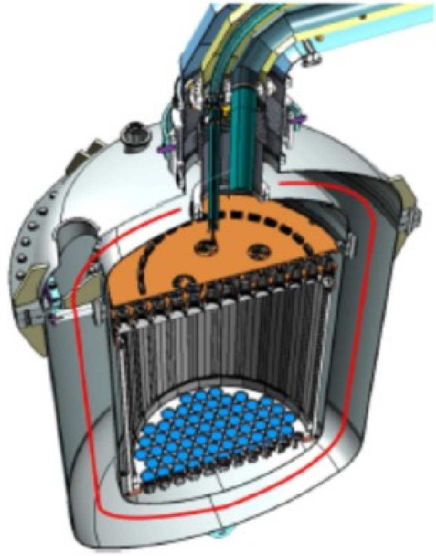
Target mass = 62 kg

Achieved sensitivity

$2.0 \times 10^{-45}\ cm^2$

@ $55\ GeV$ (2012)

XENON1T/XENONnT



Exposure = 2 t x year

Xenon mass = 3500 kg

Target mass = 2000 kg

Exposure = 20 t x year

Xenon mass = ~ 7500 kg

Expected sensitivity

$1.6 \times 10^{-47}\ cm^2$ @ $50\ GeV$ (2018) | $1.6 \times 10^{-48}\ cm^2$ @ $50\ GeV$ $(202x)$

XENON1T world map

Direct detection limits (SI model)

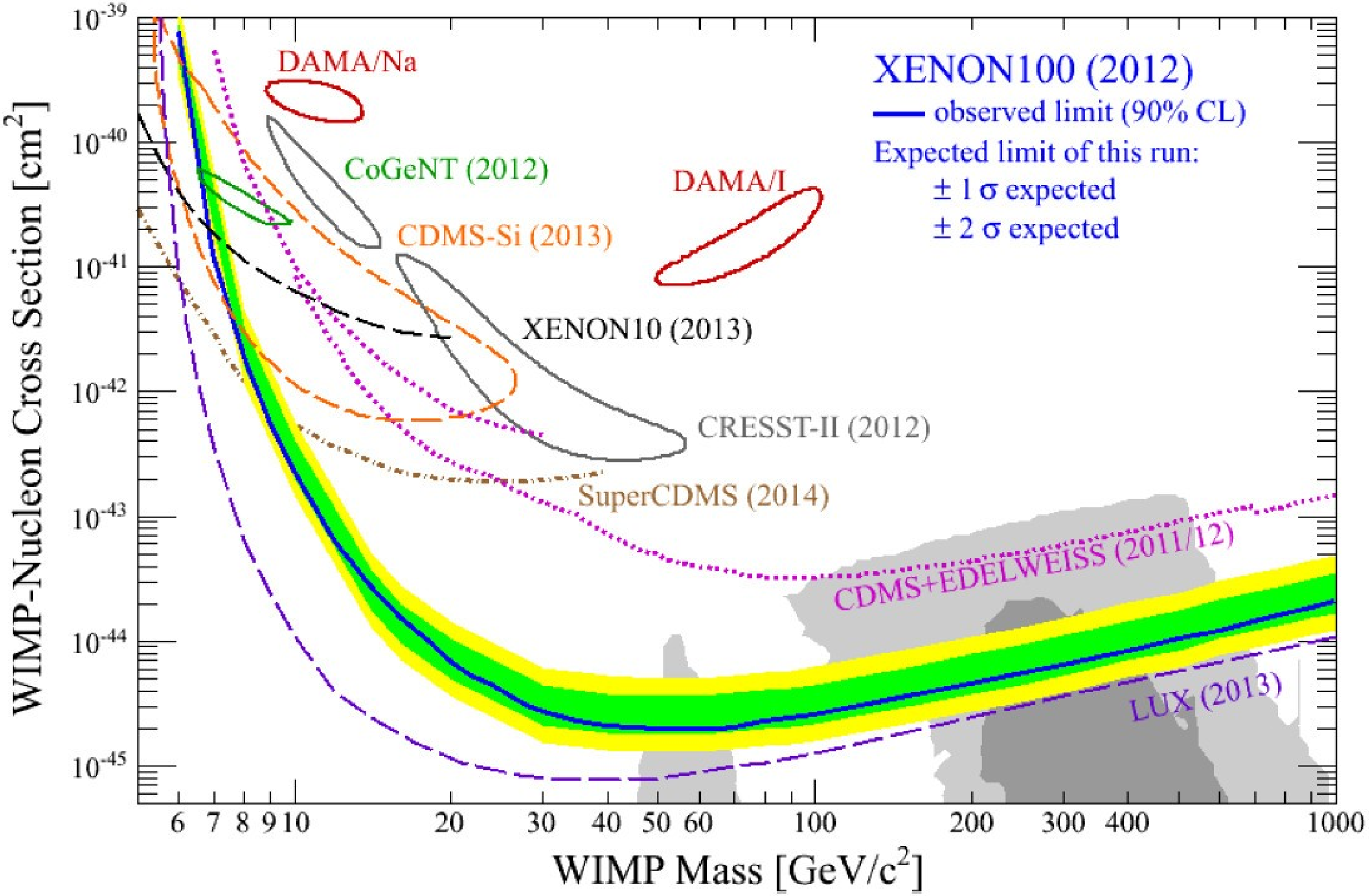
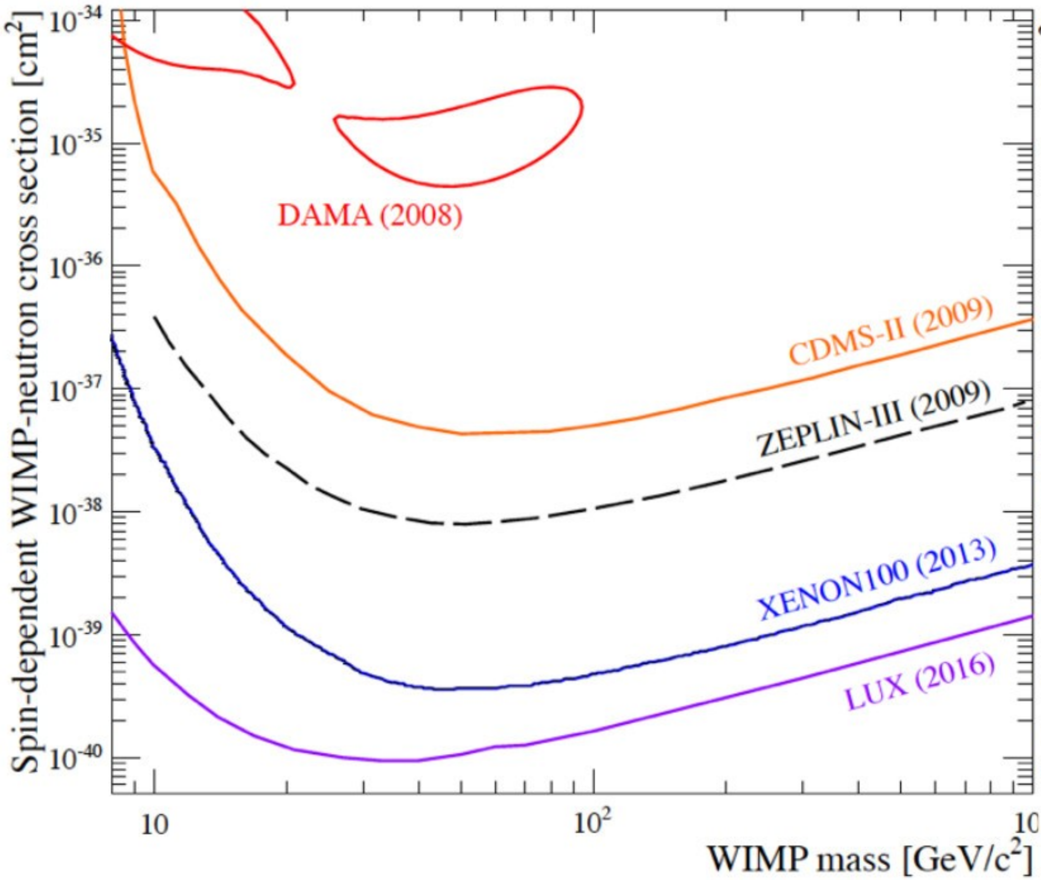
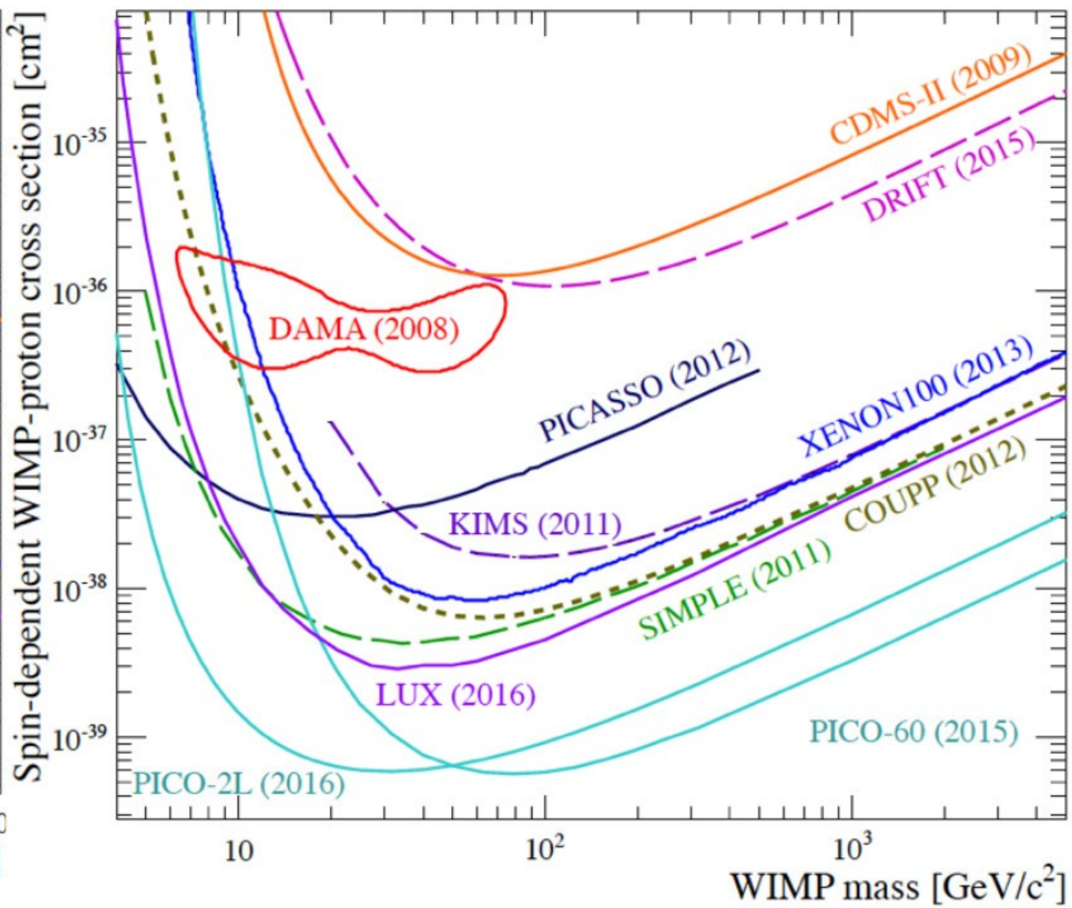


Figure adapted from XENON100 Coll., Phys. Rev. Lett. 109 (2012) 181301

Direct detection limits (SD model)



WIMP-Neutron interaction



WIMP-Proton interaction

adopted from arXiv:1509.08767

XENON1T – next generation DM detector

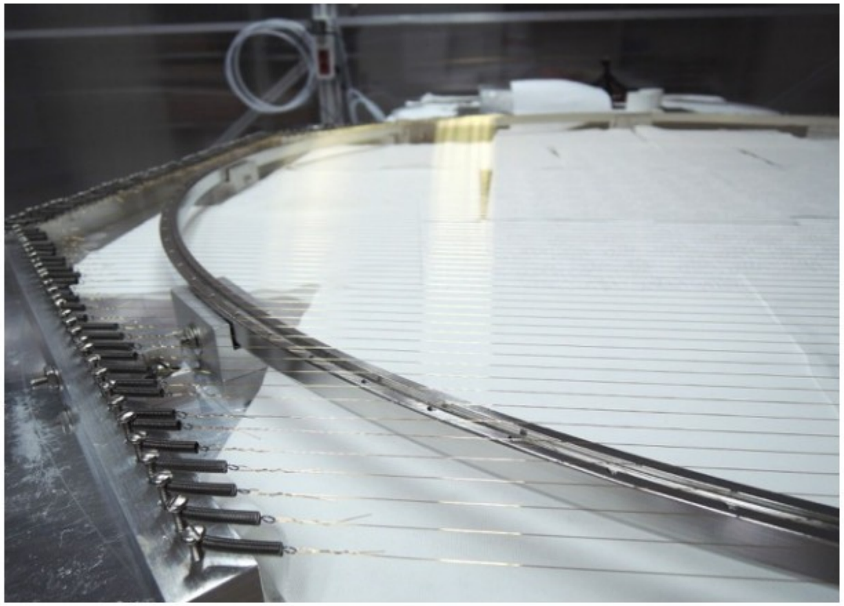
Construction of the TPC

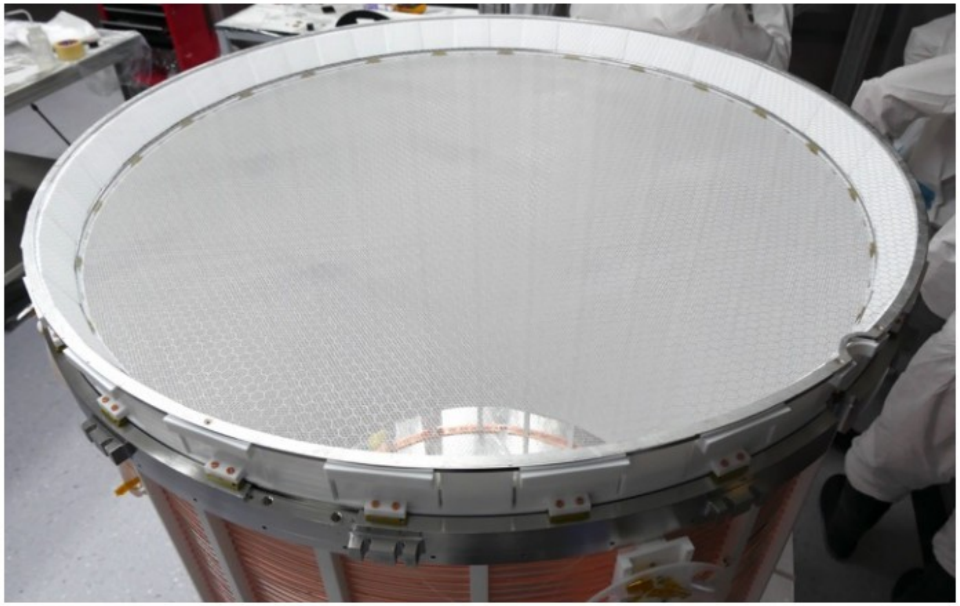
0.96 cm of drift length, 1 m diameter, 2 t of LXe in the target

~1 kV/cm drift field

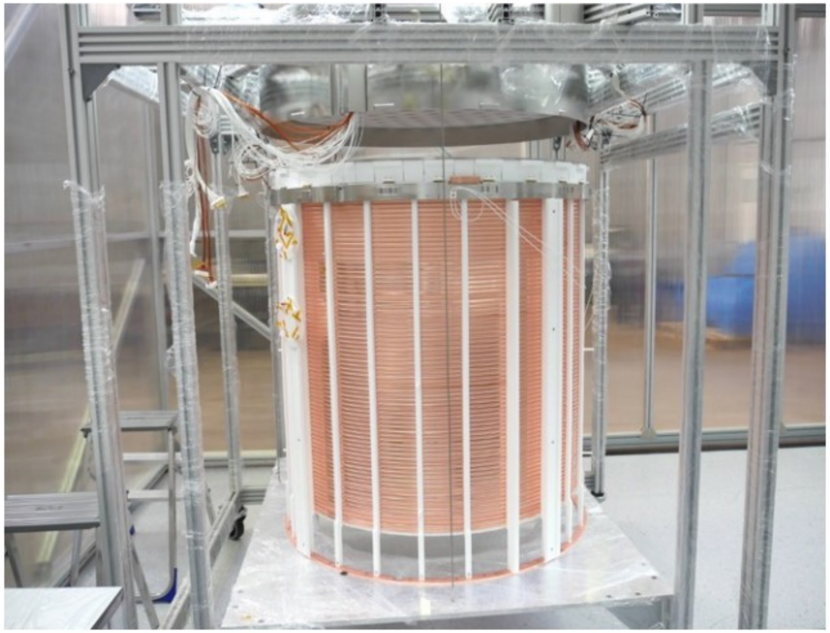
74 *ultra-radiopure* copper rings supported by 24 PTFE pillars connected to the uppermost stainless steel ring and the latest ring.

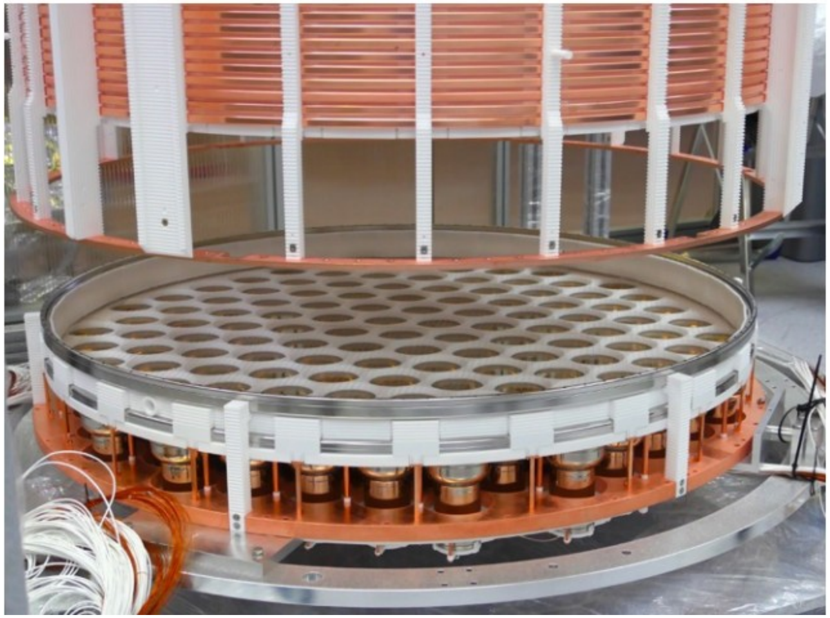
2 resistor chains connected to the shaping electrodes ring to keep the field uniform

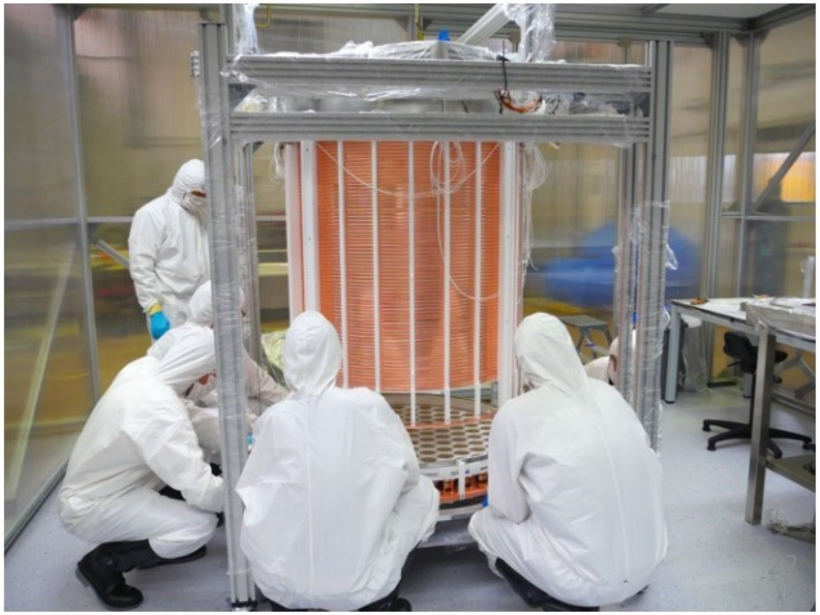




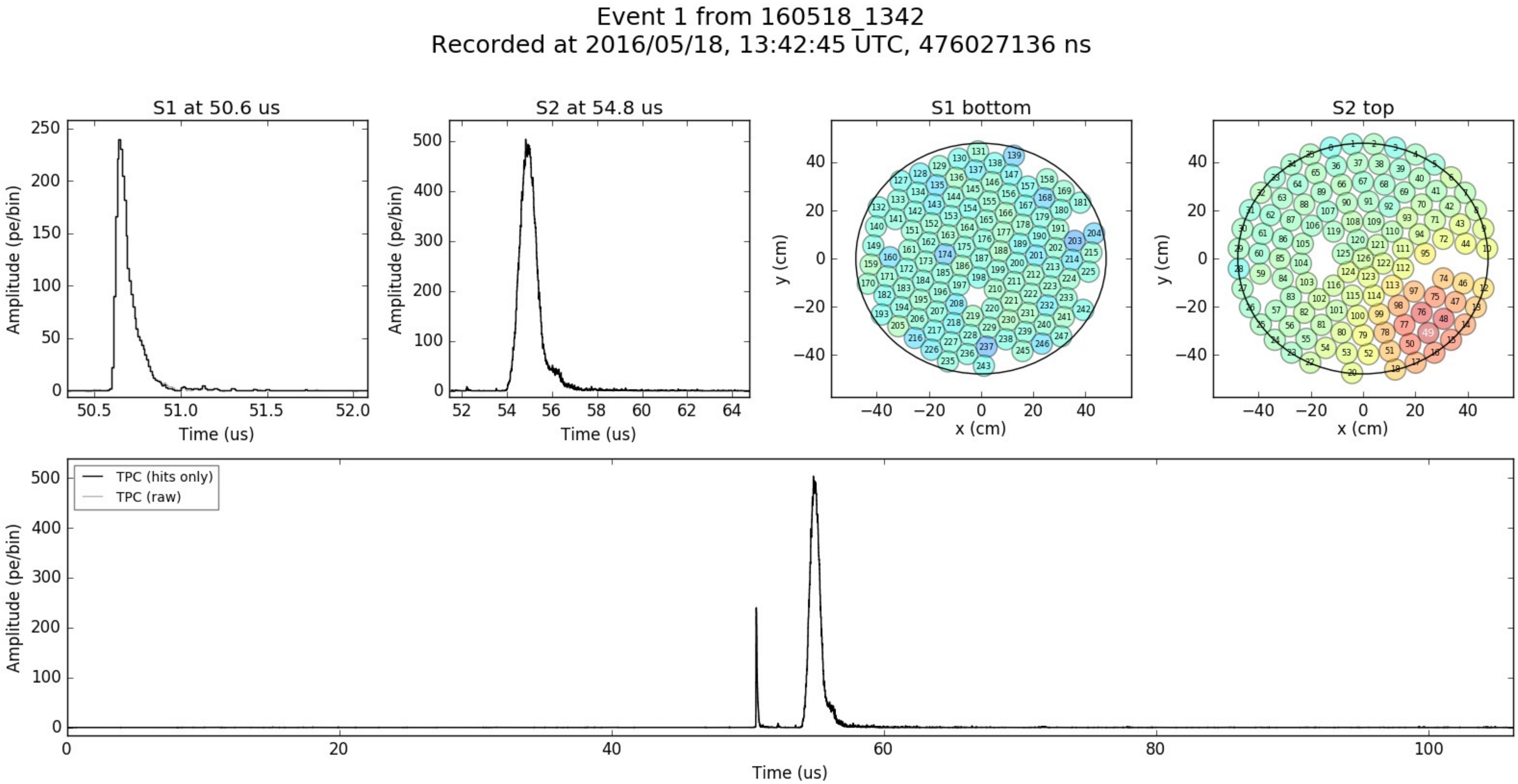
Construction of the TPC







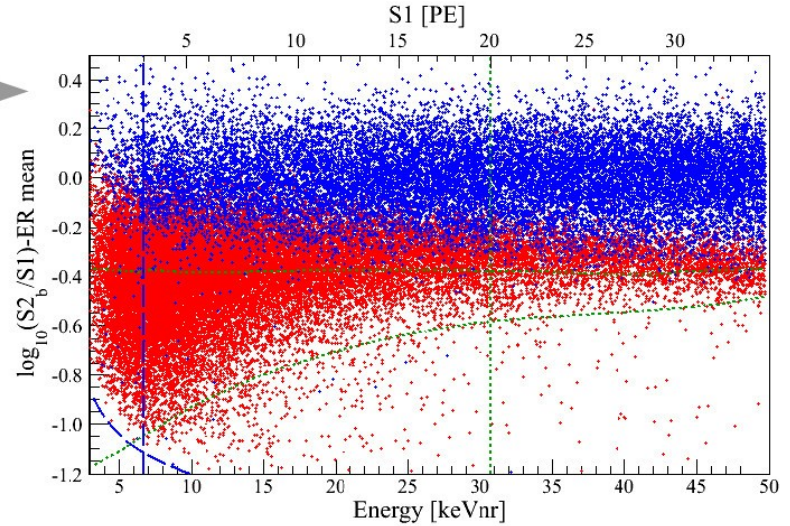
XENON1T – our first event



Backgrounds in XENON1T

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



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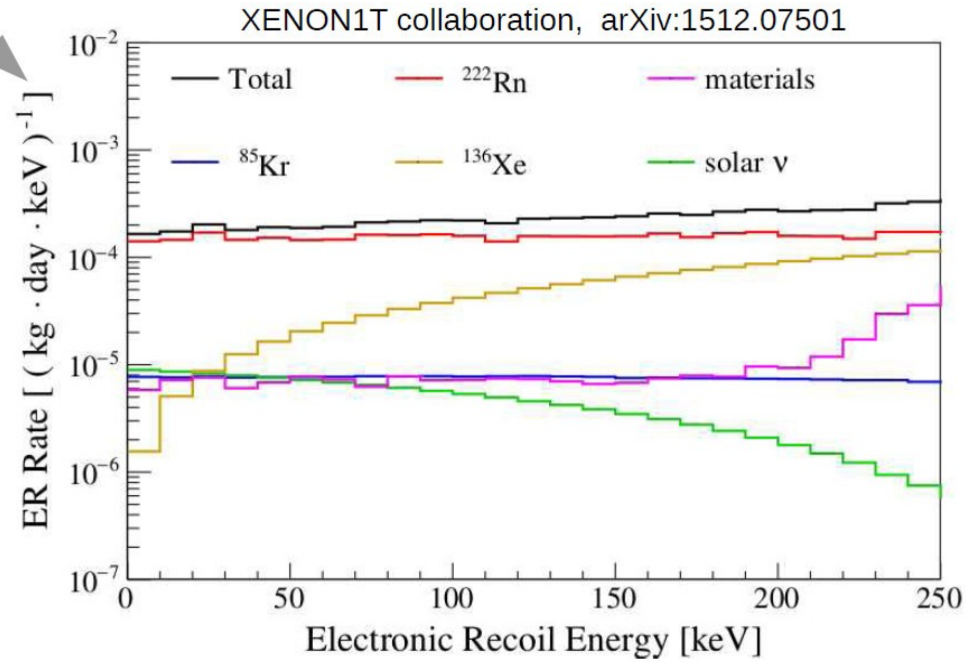


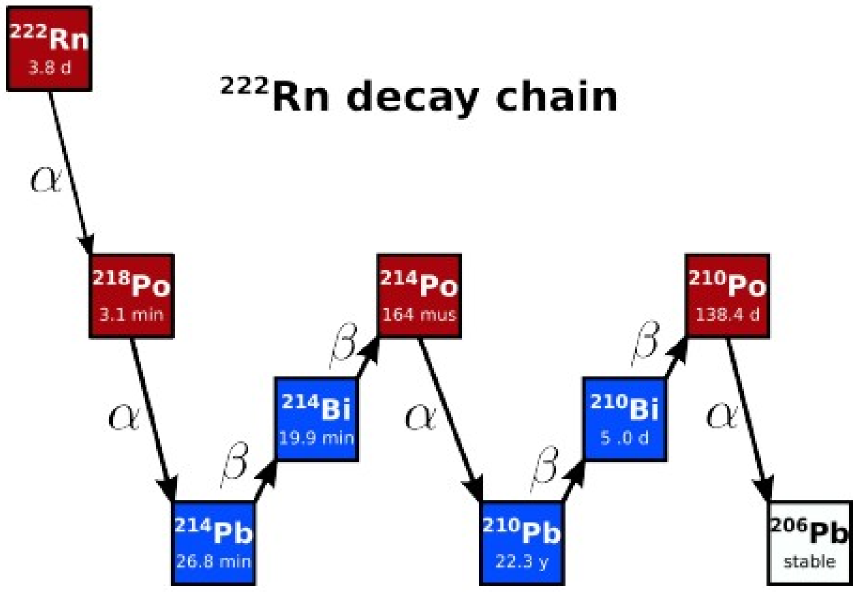
Nuclear Recoils (NR)

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 (radon) background



Intrinsic Background

Rn distributes homogeneously in the LXe target

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

No shielding possible!

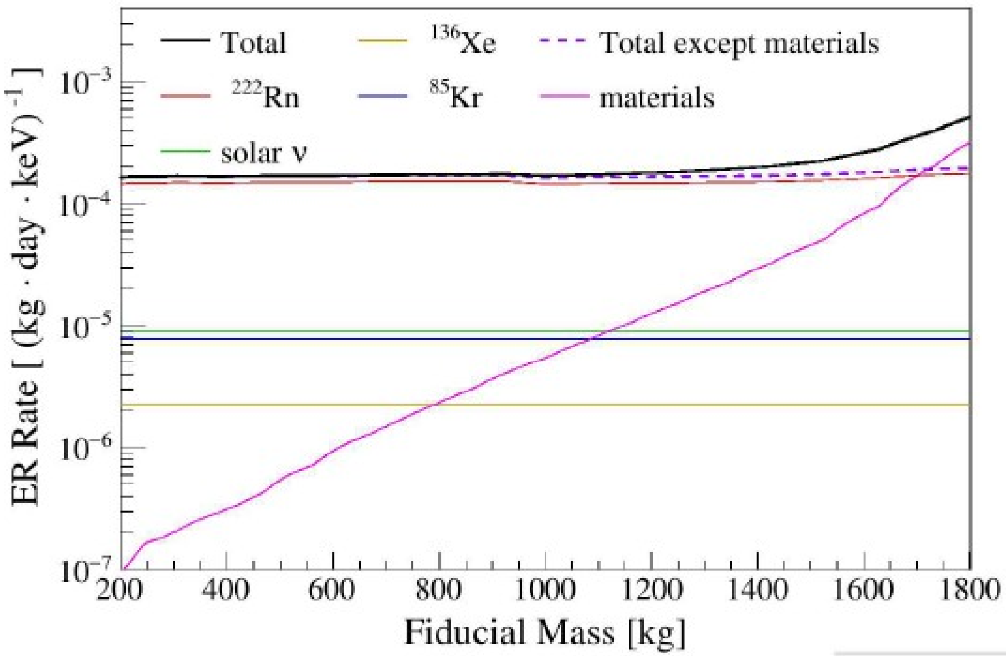
Emanation as radon source

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

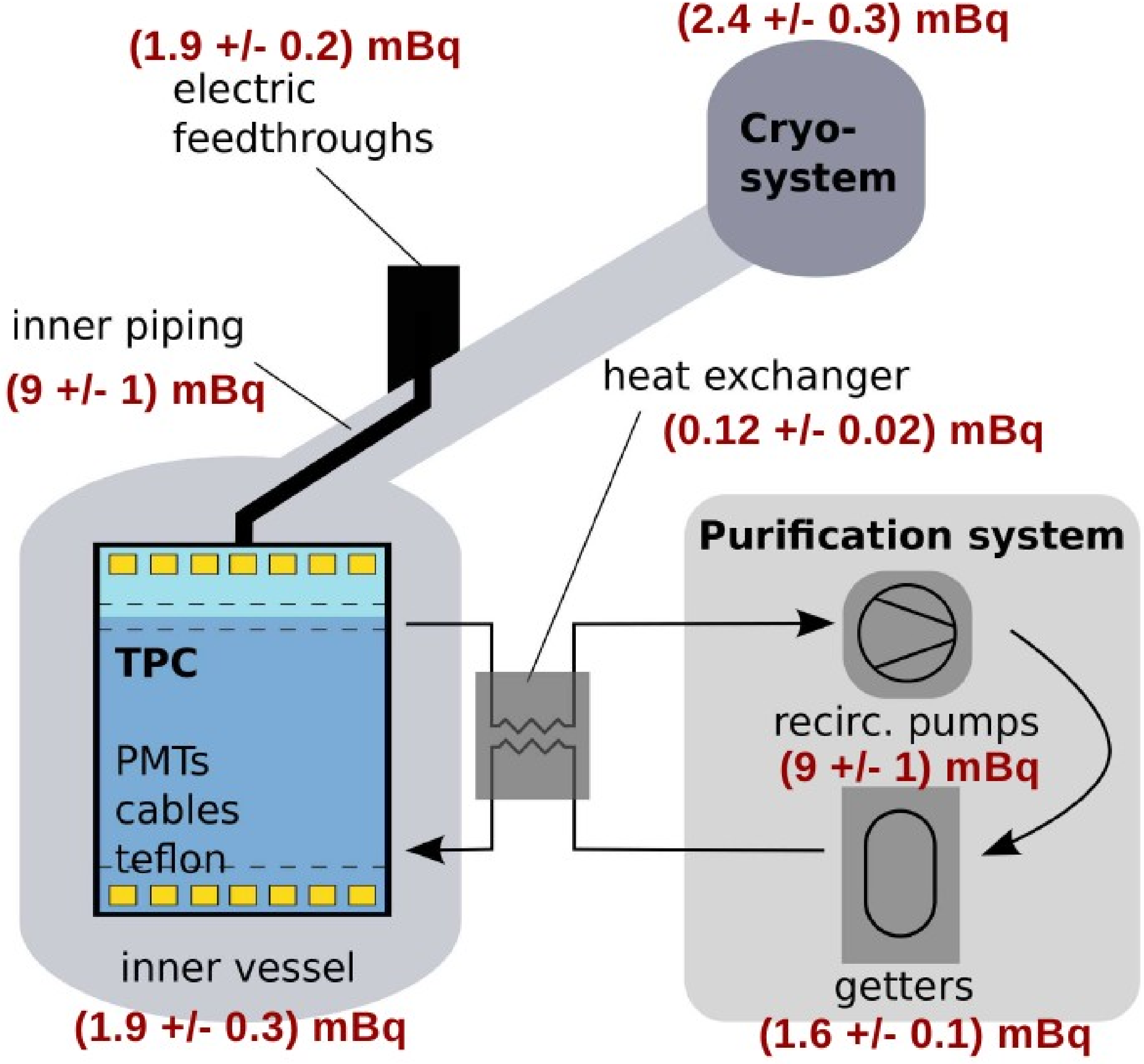


XENON1T radon budget

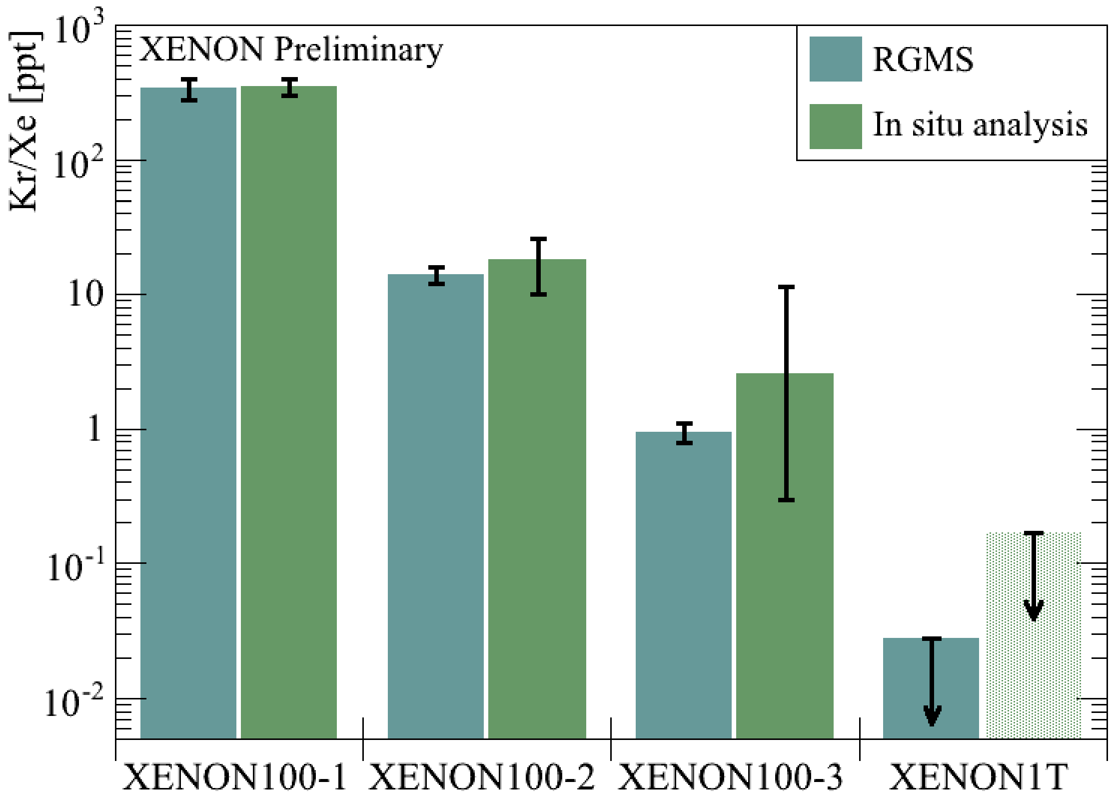
Integral measurement of the cryostat including TPC

preliminary result:

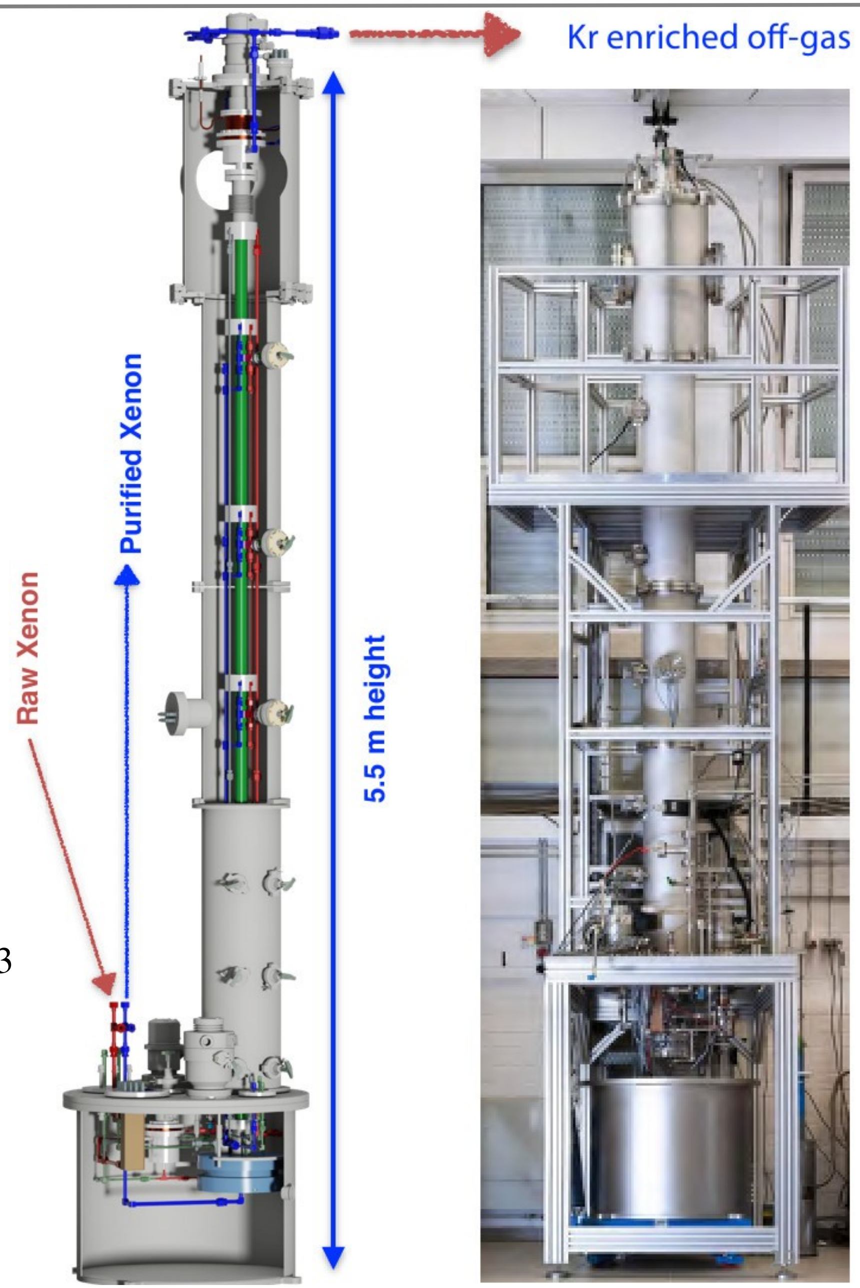
(19 +/- 4) mBq



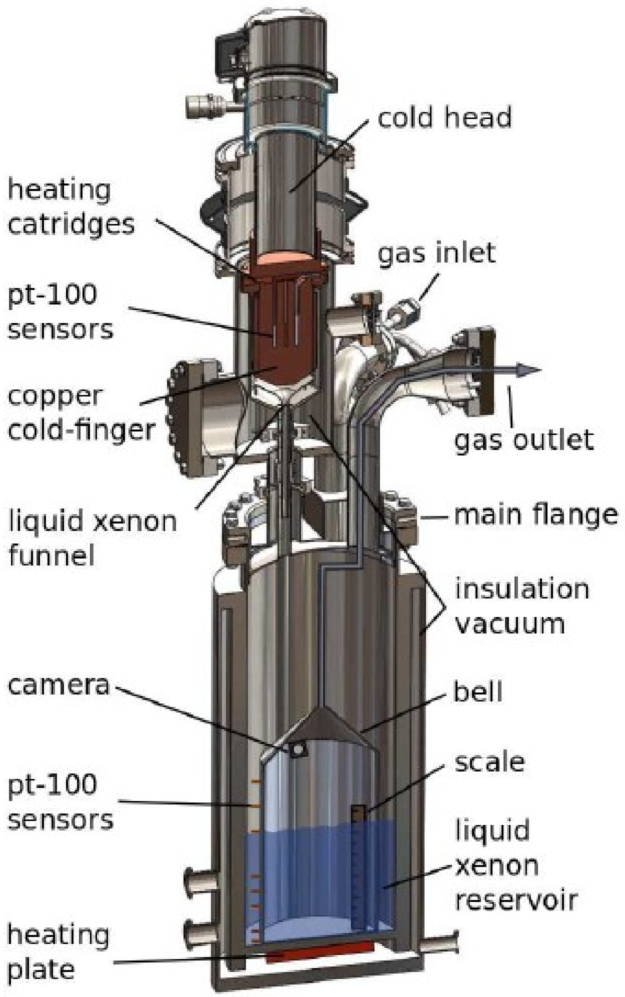
Detour: cryogenic distillation



XENON100-1: 100 Live Days publication
XENON100-2: 225 Live Days publication
XENON100-3: Beginning of SR3
XENON1T: Commissioning Run



HeXe setup – probe Rn distillation

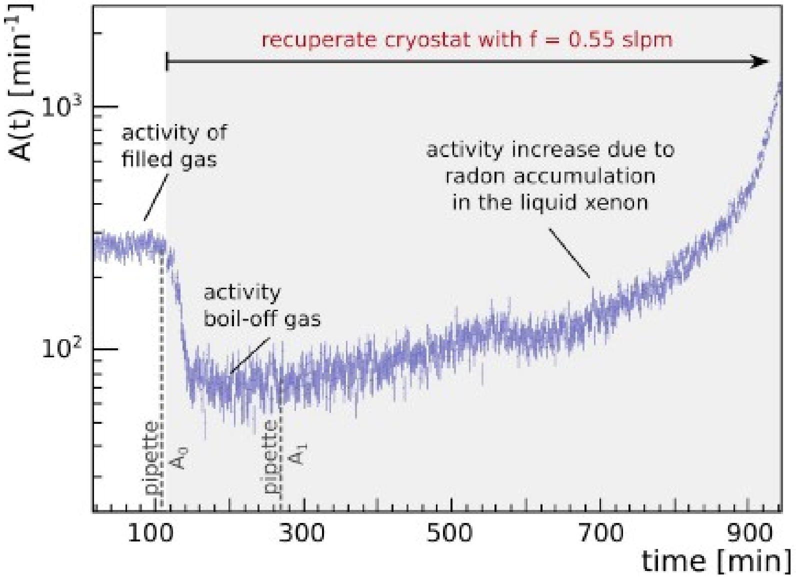


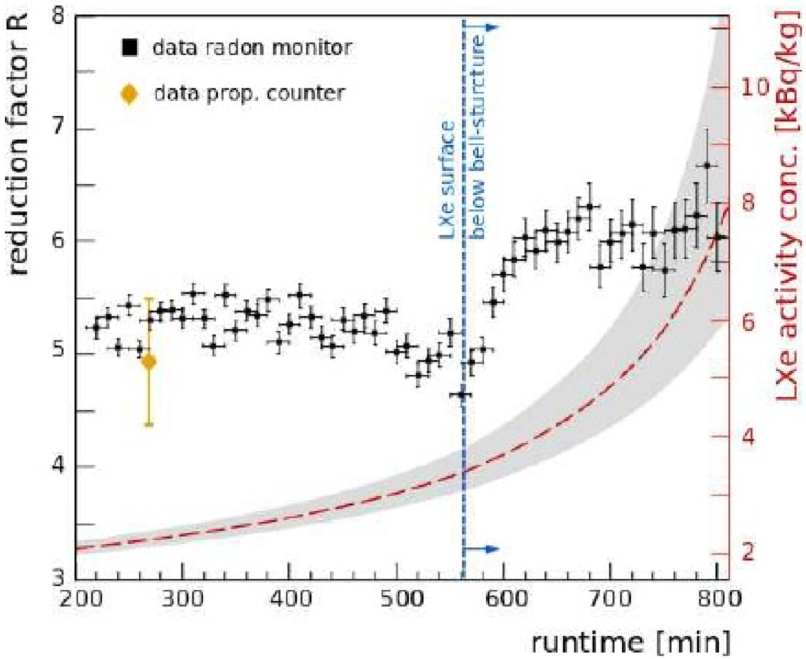
The **He**idelberg **Xe**non system (HeXe)

Single-stage distillation

Measurement of radon depletion in the boil-off gas phase
Cold-head for xenon liquefaction
Bell-structure separates gas volume

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!

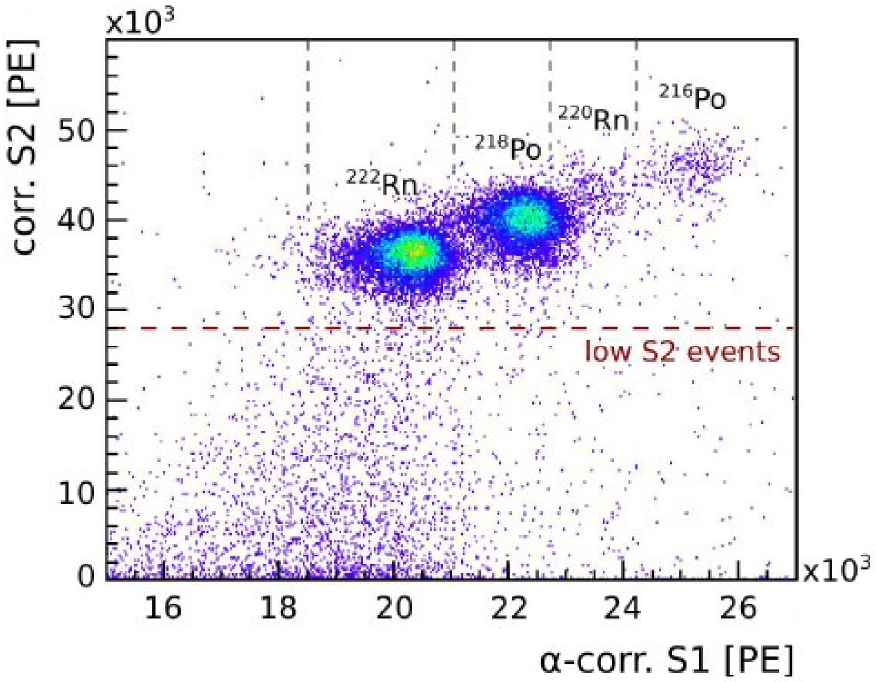
Radon reduction by a **factor ~5** measured

Complementary measurements with proportional counters confirm results

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

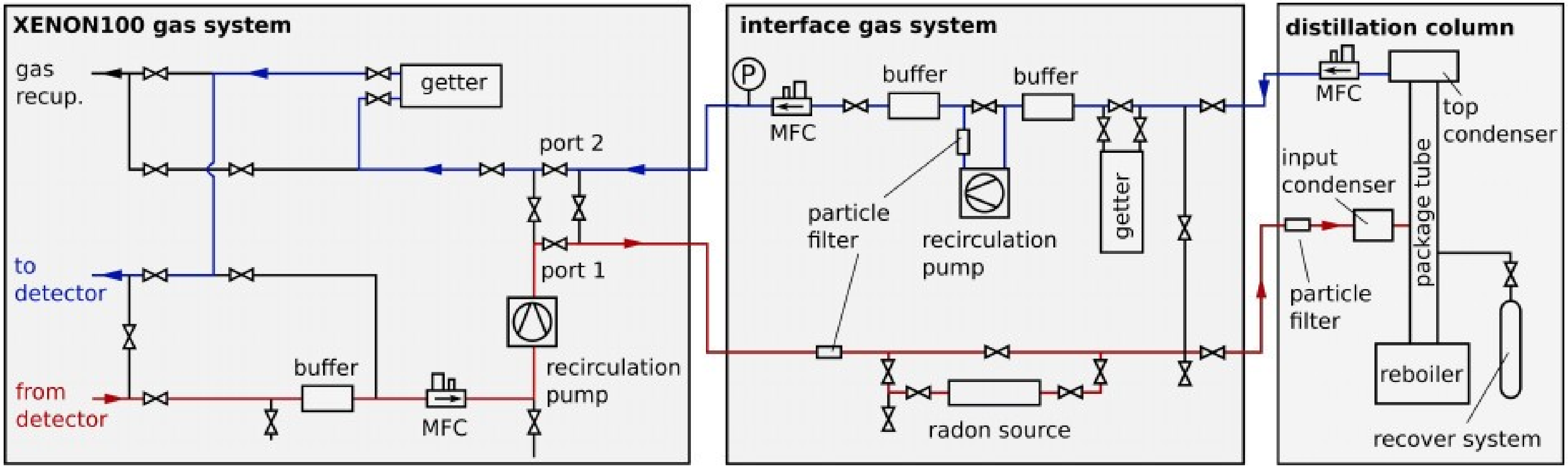
Systematic 'bell-effect' still under investigation

XENON100 distillation campaign

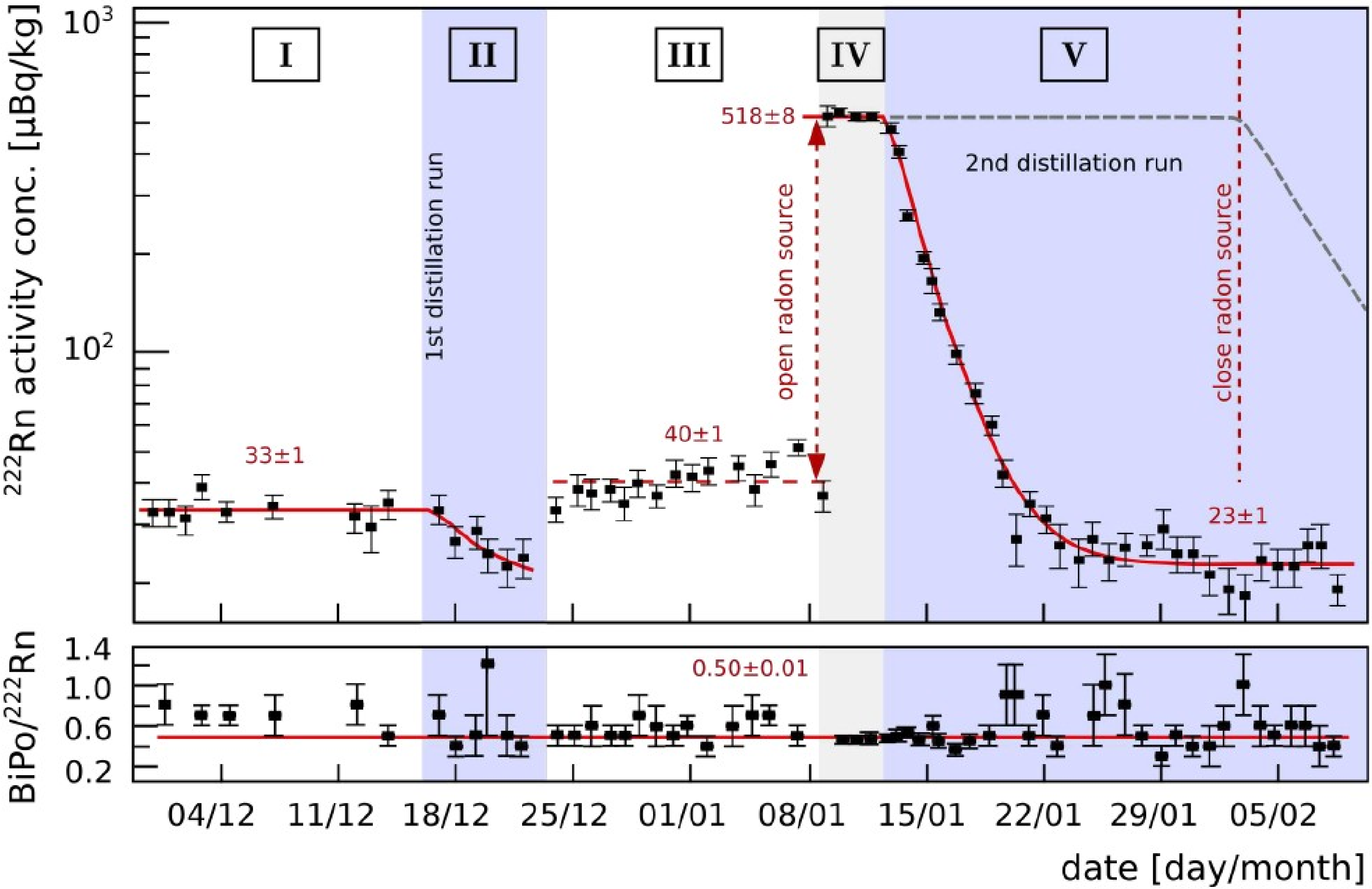


Rn-detector XENON100
Alpha-peaks of ^{222}Rn and progenies easy to identify
BiPo analysis for complementary radon monitoring

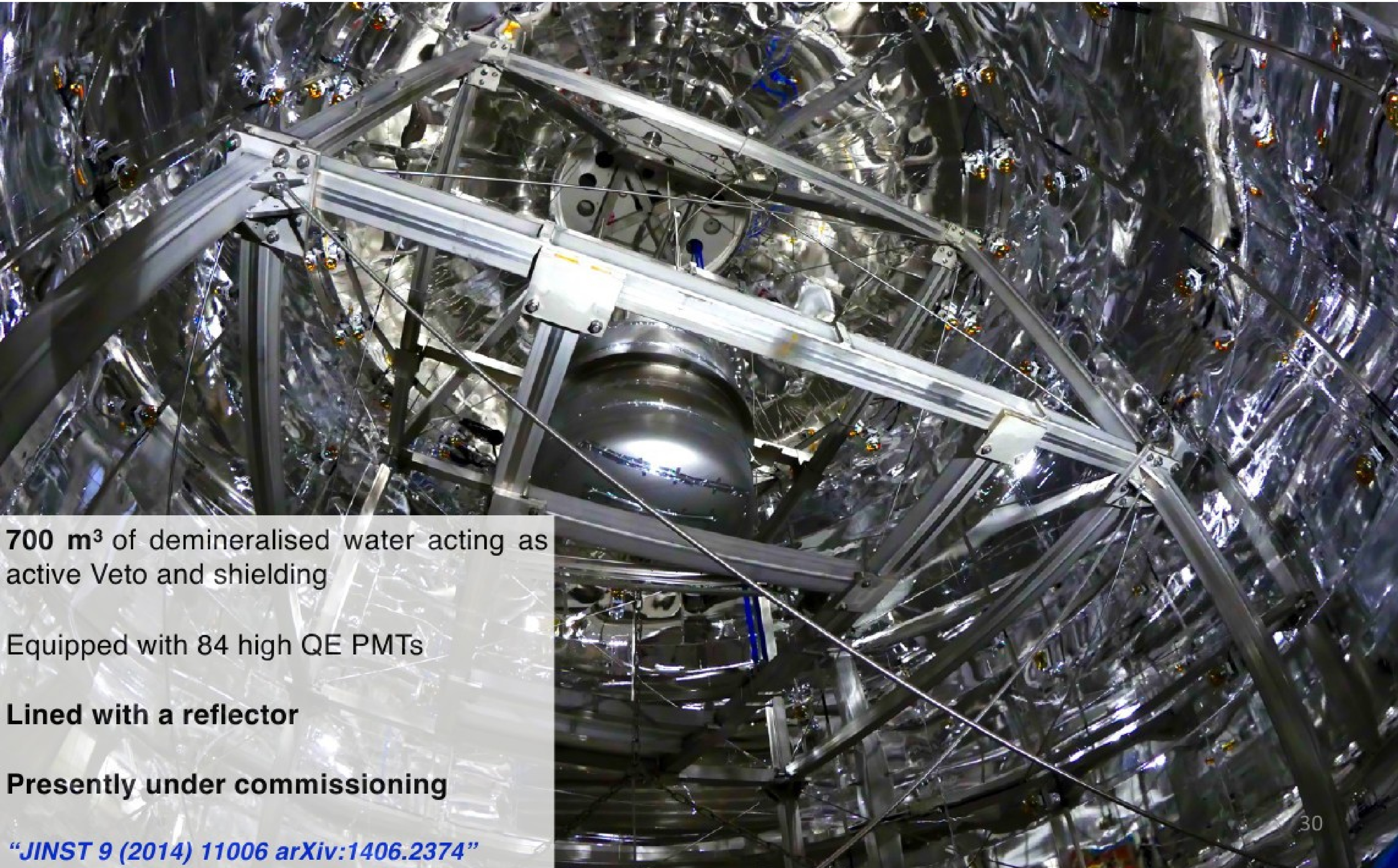
Extension of gas purification loop
Integration of XENON1T krypton column in purification loop
Integration of a radon emanation source



XENON100 distillation campaign



Active Muon Veto



700 m³ of demineralised water acting as active Veto and shielding

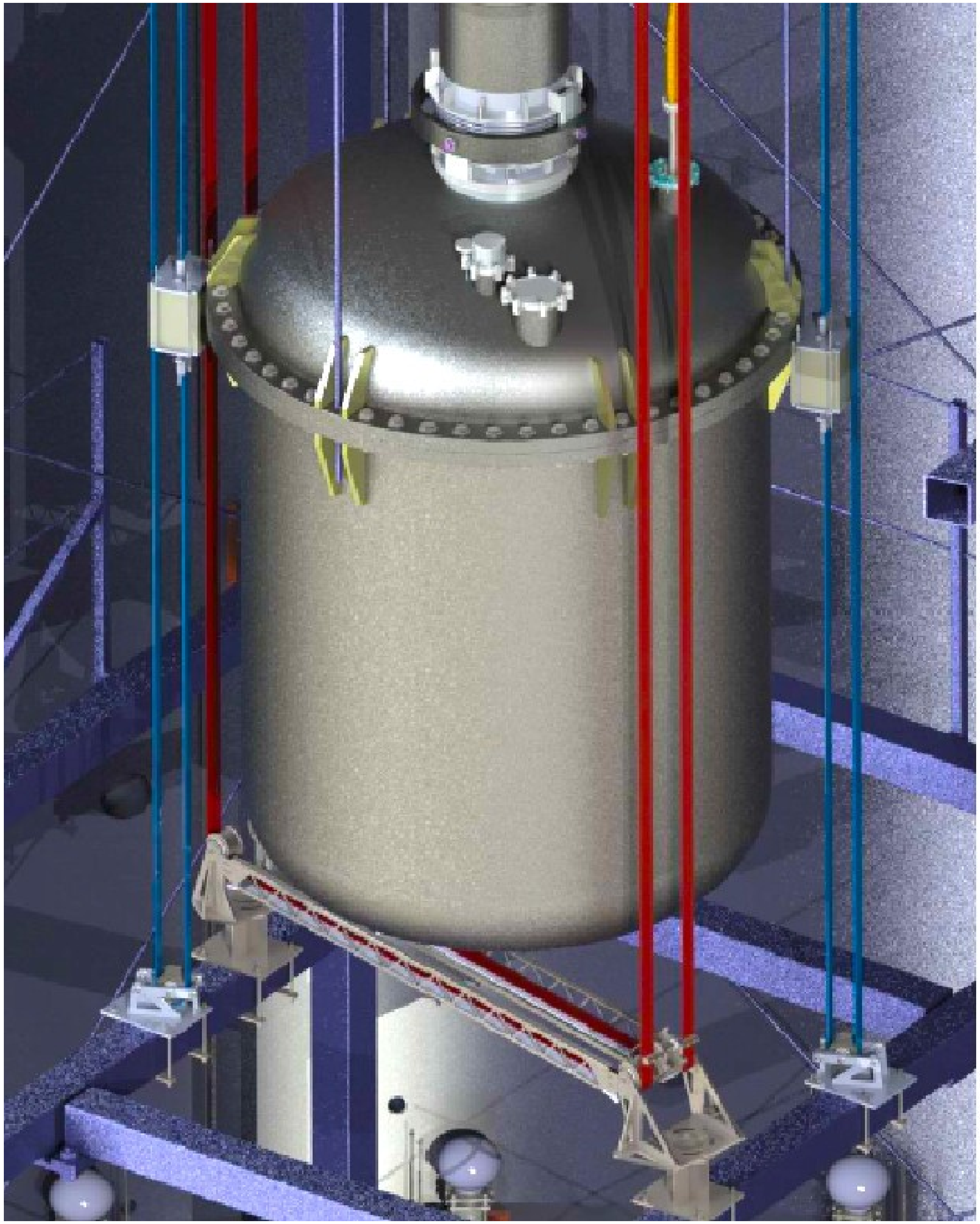
Equipped with 84 high QE PMTs

Lined with a reflector

Presently under commissioning

"JINST 9 (2014) 11006 arXiv:1406.2374"

Detector calibration



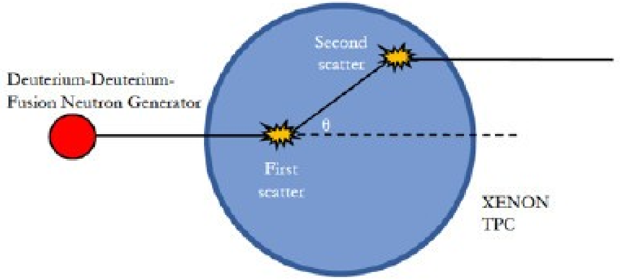
XENON1T is calibrated via:

LED: to periodically measure the gain of the PMT inside the TPC

INTERNAL CALIBRATION SOURCES: short-lived radioactive isotopes mixed to the xenon stream:

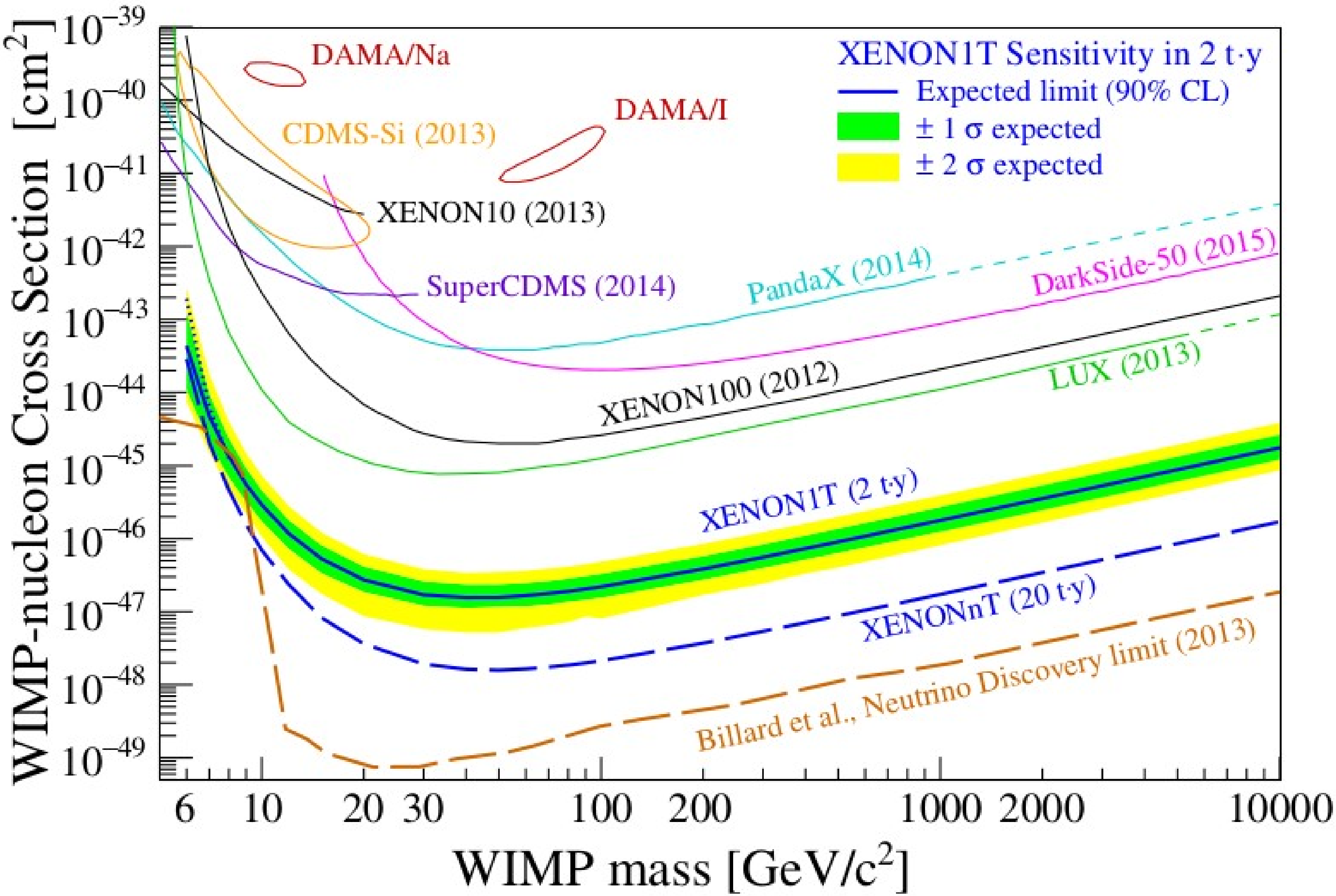
- ^{83m}**Kr** to calibrate the ER energy scale
- ^{220}**Rn and TCH$_3$** for low-energy ER

NEUTRON GENERATOR: the size of the XENON1T TPC allow to identifying double scatters of 2.5 MeV mono energetic neutrons produced by a D-D neutron generator



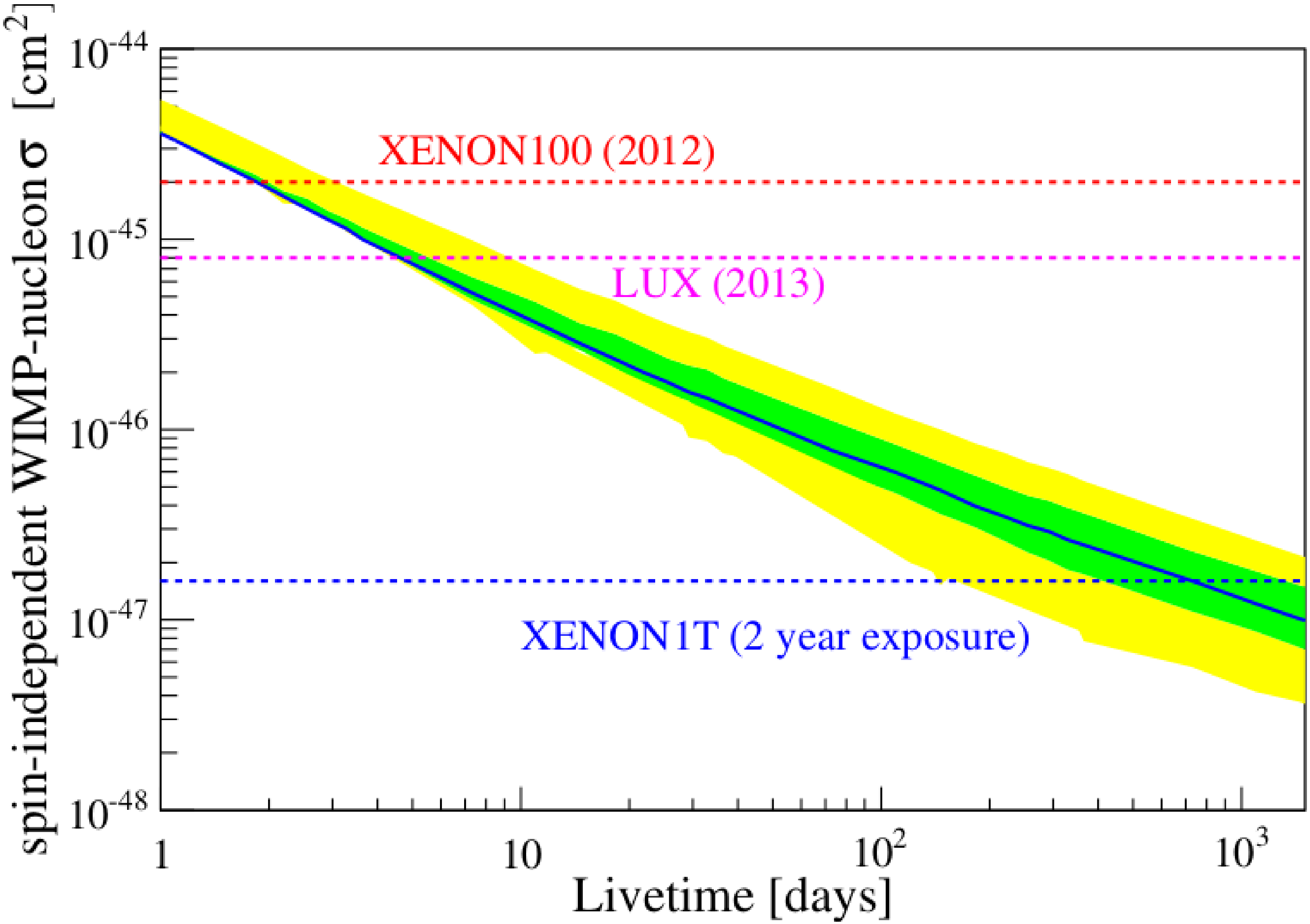
EXTERNAL CALIBRATION SOURCE to measure the purity of the LXe in the target and self shielding capability

XENON1T(-nT) enters the game



arXiv:1512.07501

Some final propaganda...



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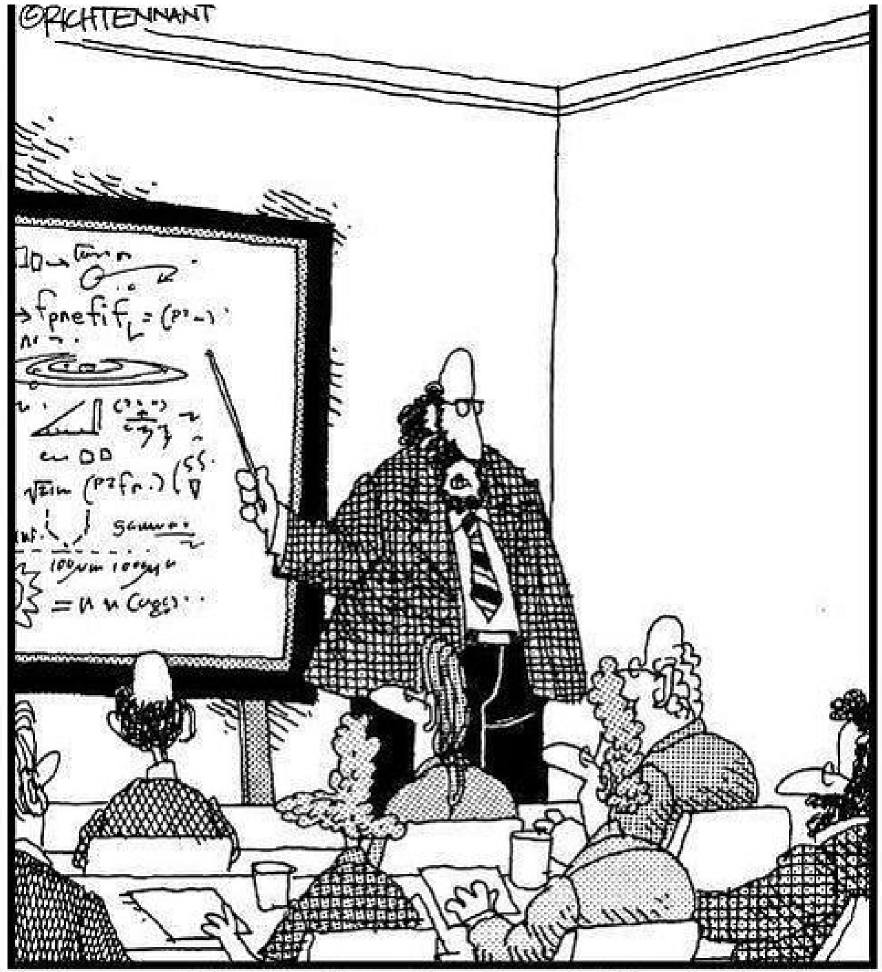
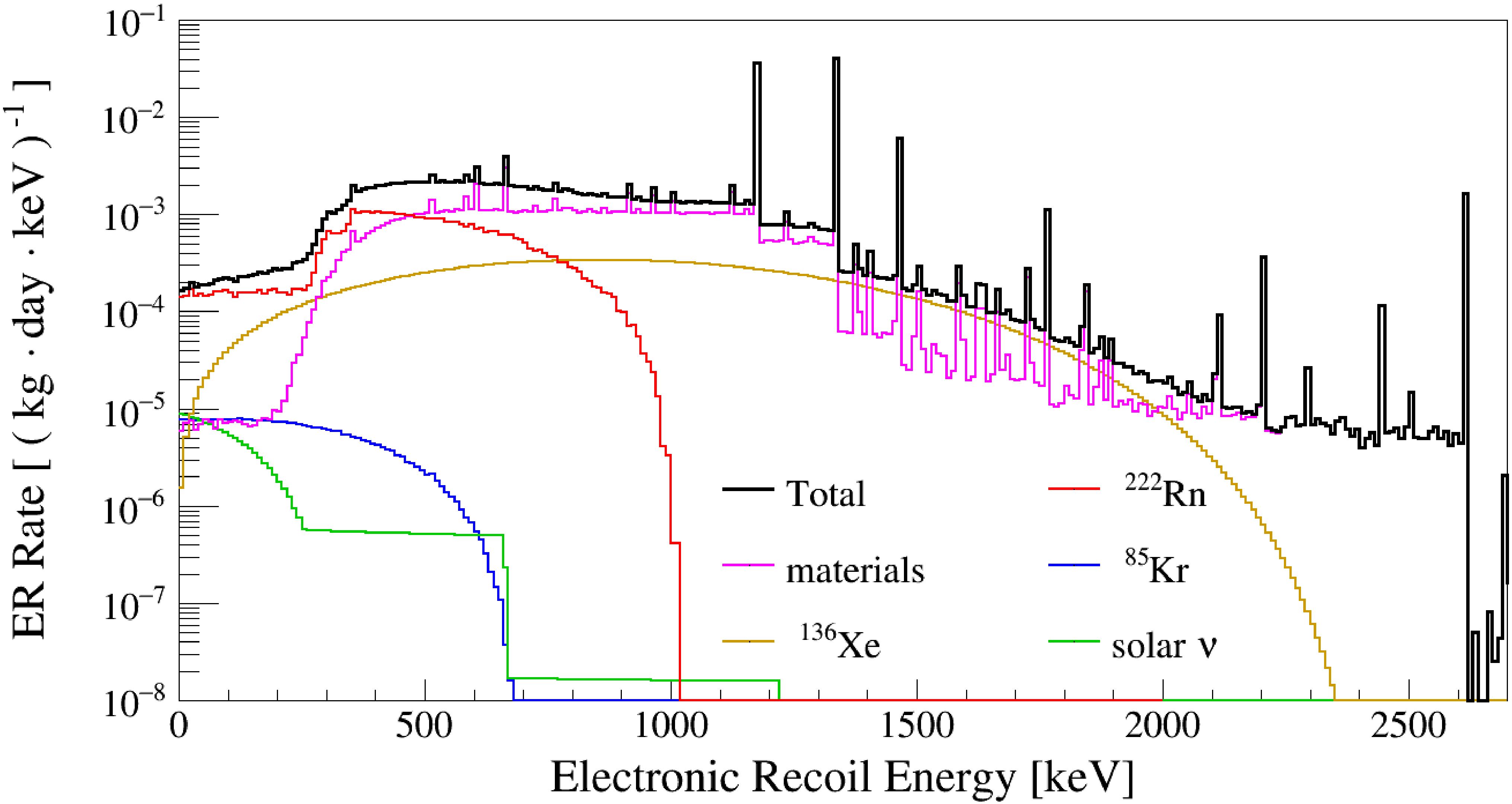


"Along with 'Antimatter,' and 'Dark Matter,' we've recently discovered the existence of 'Doesn't Matter,' which appears to have no effect on the universe whatsoever."

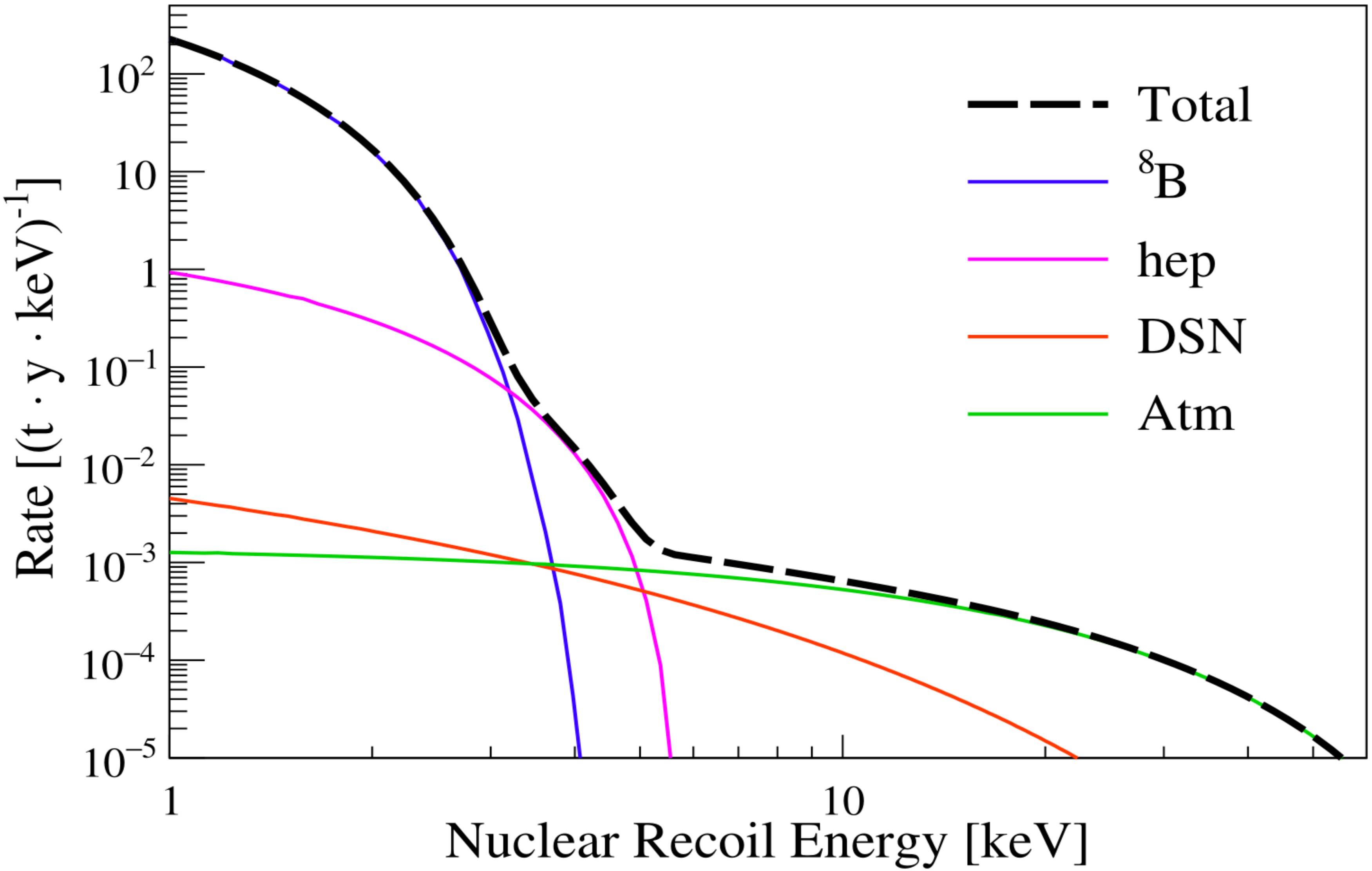
Thank you for your attention!

XENON1T – ER background



arXiv:1512.07501

XENON1T – CNNS background



arXiv:1512.07501