Results from XENON1T

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on behalf of the XENON Collaboration

Xe
XENON
Dark Matter Project

XV International Conference on Topics in **Astroparticle and Underground Physics**

TAUP 2017

24 - 28 July 2017
Sudbury, ON, Canada

The XENON Collaboration

Columbia | RPI | Nikhef | Stockholm | Muenster | Mainz | MPIK

Chicago

Freiburg

UCLA

Zurich

UCSD

NYUAD

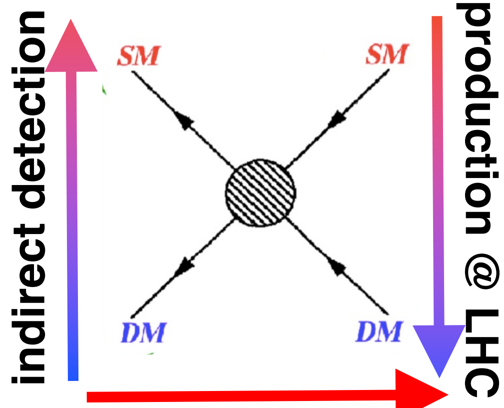
Rice

Weizmann

Purdue | Coimbra | Subatech | LPNHE | LAL | Bologna | LNGS | Torino

23 institutions
~ 135 scientists

Main goal:



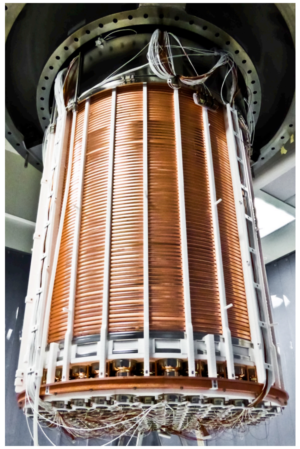
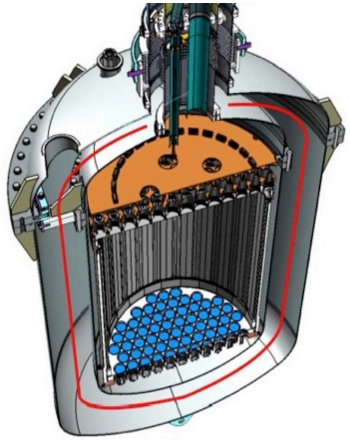
direct detection
of dark matter

➔ direct observation of the dark matter which fills the universe

➔"candidates" may be misleading (life-time, fraction of DM, …)

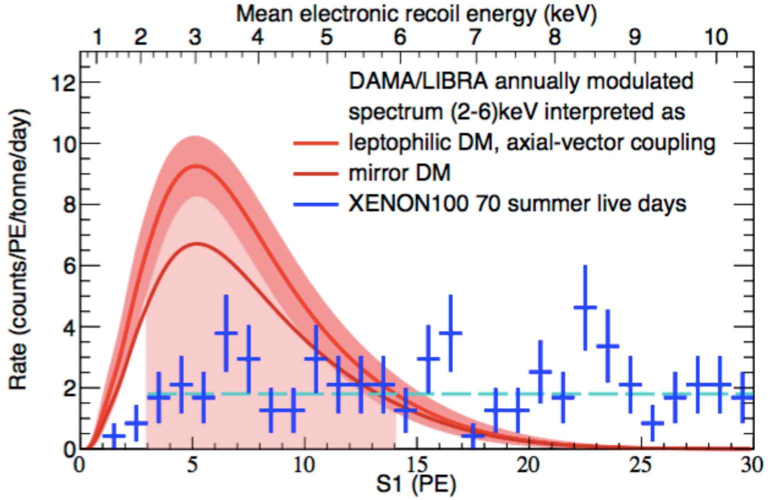
The XENON-Program @ LNGS

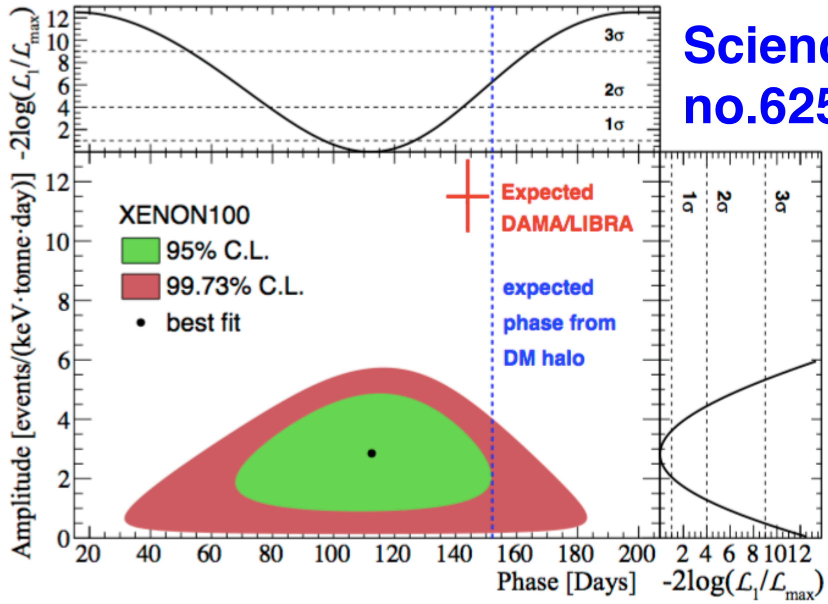
Gran Sasso, Italy (3600 mwe)

	XENON10	XENON100	XENON1T	XENONnT
				
Period	2005-2007	2008-2016	2012-2018	2019-2023
Total mass	25 kg	161 kg	3200 kg	~8000 kg
Drift length	15 cm	30 cm	100 cm	144 cm
Status	Completed (2007)	Completed (2016)	Running	Construction
σ_{SI} limit (@50 GeV/c^2)	8.8×10^{-44} cm^2	1.1×10^{-45} cm^2	1.6×10^{-47} cm^2 (2018)	1.6×10^{-48} cm^2 (2023)

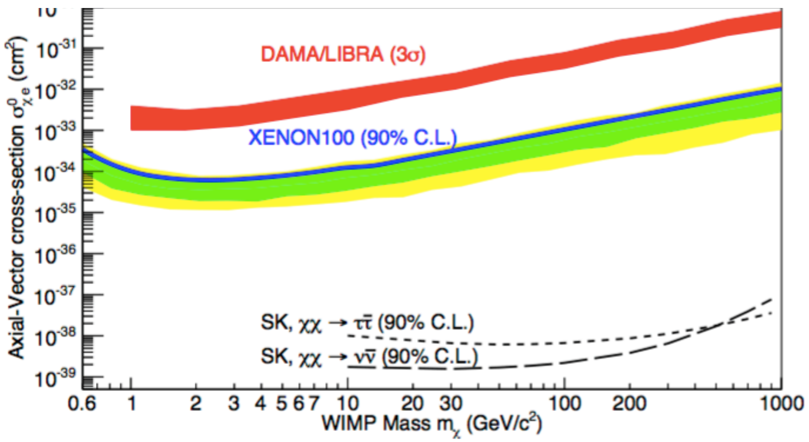
While building XENON1T: Modulation of e-Recoils

XENON100 : 477 life days (48kg*year); improved signal & bckg. modelling





Science 349 (2015) no.6250, 851



➔ **DAMA signal excluded @5.7σ**

Phys. Rev. Lett. 118, 101101 (2017)

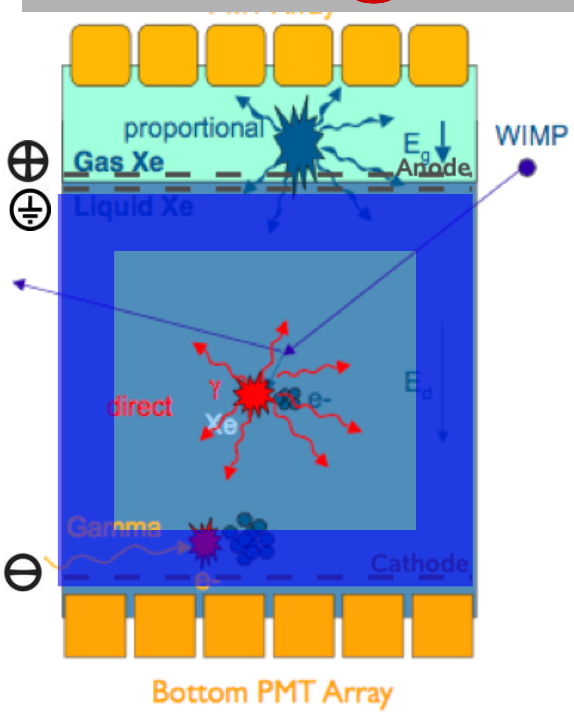
➔ leptophilic models excluded

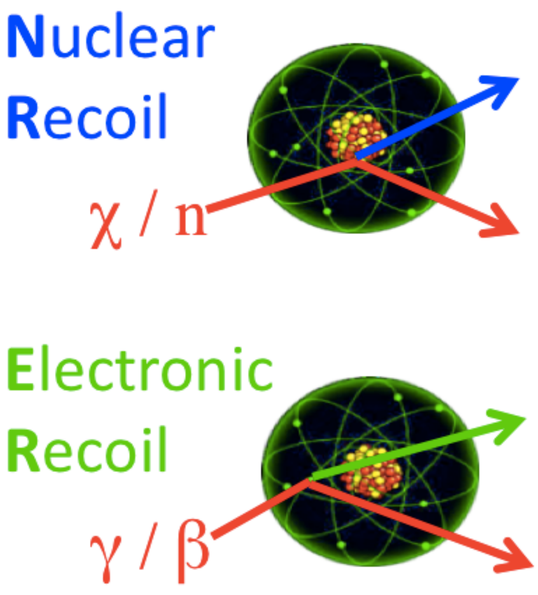
➔ modulation in DAMA not understood

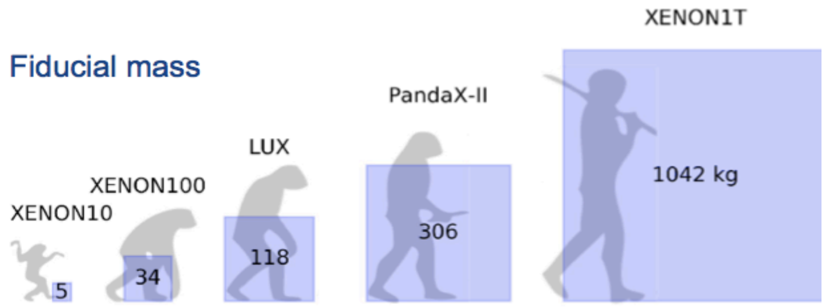
Future: New NaI projects to directly check DAMA ➔ clarify modulation

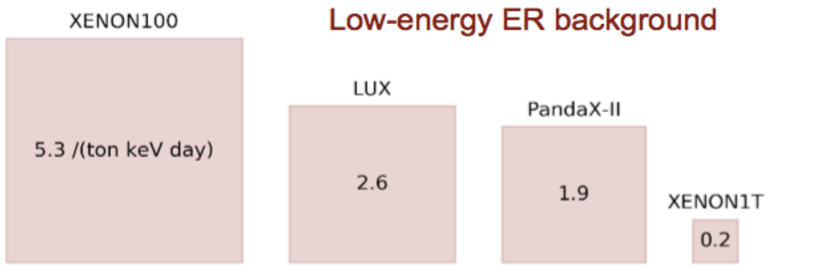
➔ SABRE, COSINUS, COSINE-100, ANAIS, KIMS-NaI, DM-Ice

Scaling Considerations





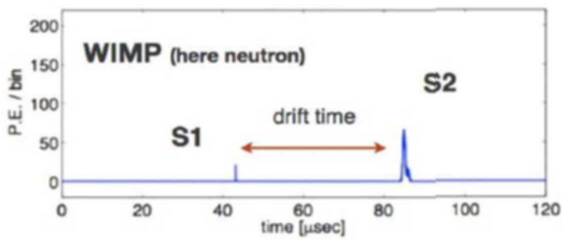


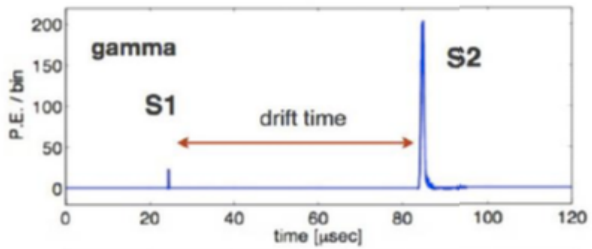


direct light signal → S1 drift of electrons → S2

→ excellent 3D position → **fiducialization**

→ cut backgrounds from 'dirty' surfaces





- S2/S1: ER > NR; pulse height & shape, …

technological challenges

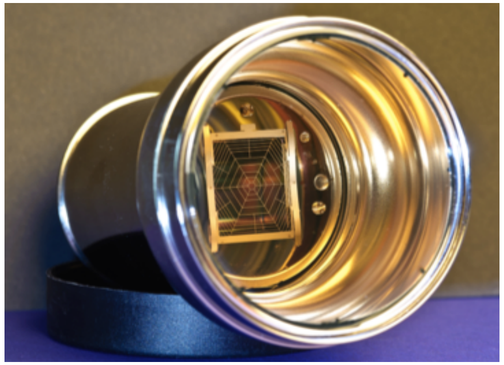
- **longer drift length → higher HV**
- **handling more Xe gas**
  → cryogenics, distillation, safety
- **engineering**
- **…**

ultra low backgrounds

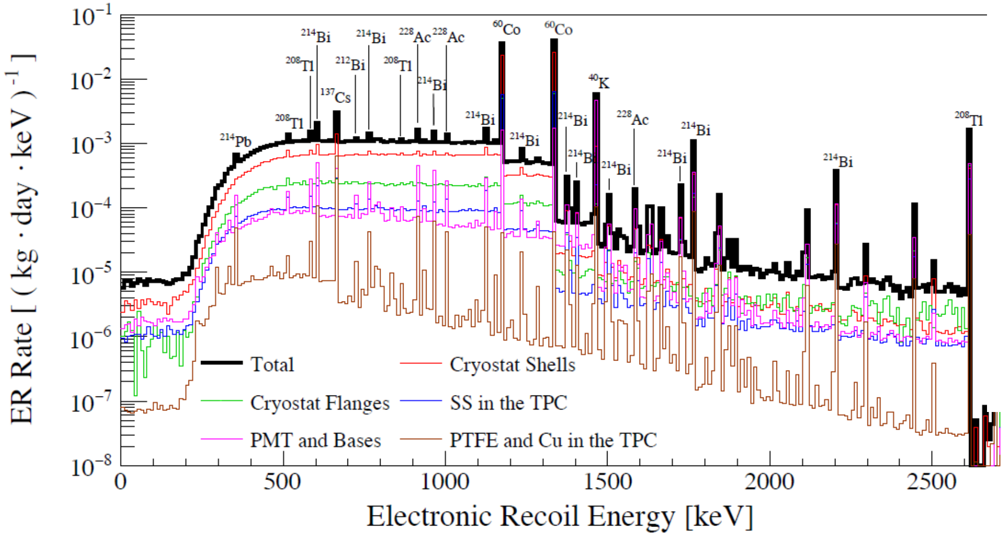
- **underground laboratory**
- **adequate μ-veto, n-shielding**
- **extremely radio-pure materials**
- **Rn emanation, outgassing**
- **very clean Xe gas**
  - **Kr & Rn reduction & analytics**
  - **electron life-time**
- **MC simulations**

Example: Radio-pure PMTs for XENON1T

Hamamatsu R11410-21
3", 248 pcs

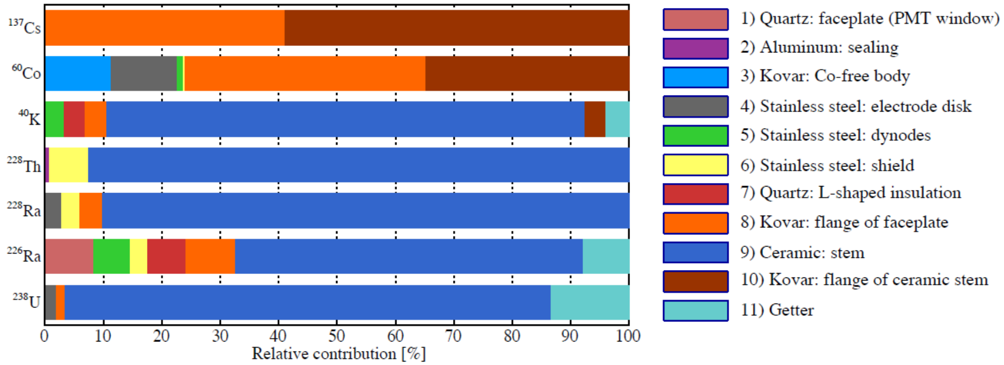


- careful material selection,
- screening of materials
- screening of final PMTs
  < 1mBq/PMT in U/Th



Intensive cooperation:

- **improvements & optimization**
- **radio-purity**



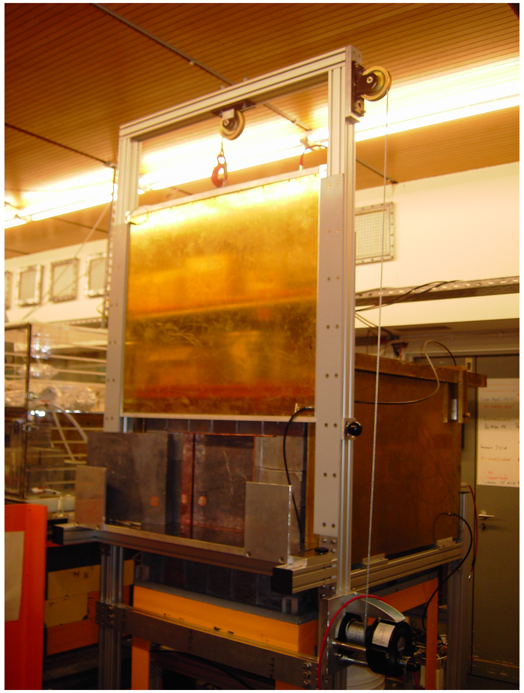
- **extensive testing at room temperature and cold**

high QE: 35% @ 175nm
stability, tightness, …
30% single PE resolution
JINST 12 P01024 (2017)

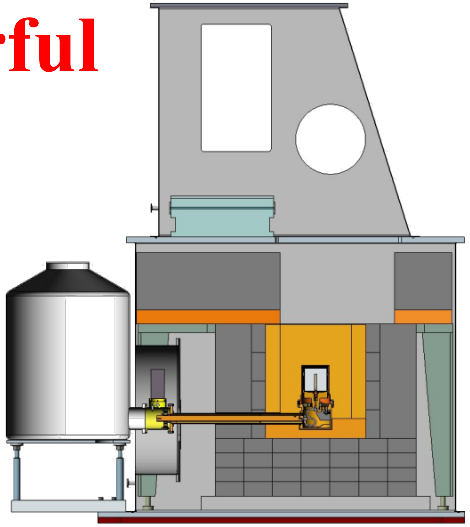
← electronic recoil BG from materials
JCAP 04 (2016) 027

XENON: γ-Screening Facilities

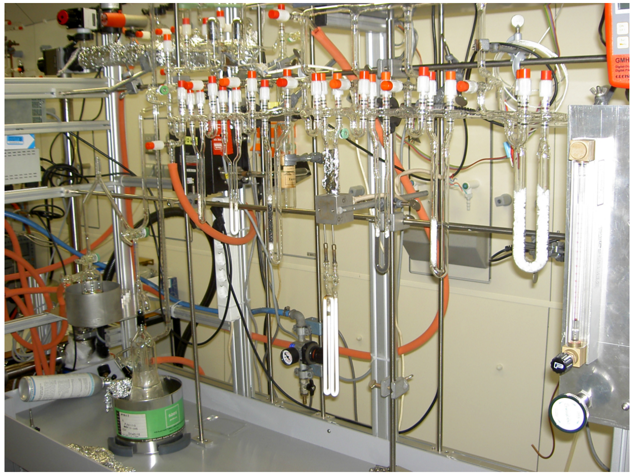
- Several screening stations @MPIK underground lab (1mBq/kg)
- GEMSE @ Freiburg (0.5 mBq/kg)
- UZH: GATOR @ LNGS (100μBq/kg)
- GIOVE @MPIK (100μBq/kg @15mwe)
- MPIK-GEMPIs @LNGS (10μBq/kg)



➔XENON has very powerful γ screening capabilities (capacity, sensitivity)



Rn Screening Facilities



Gas counting systems @LNGS and @MPIK

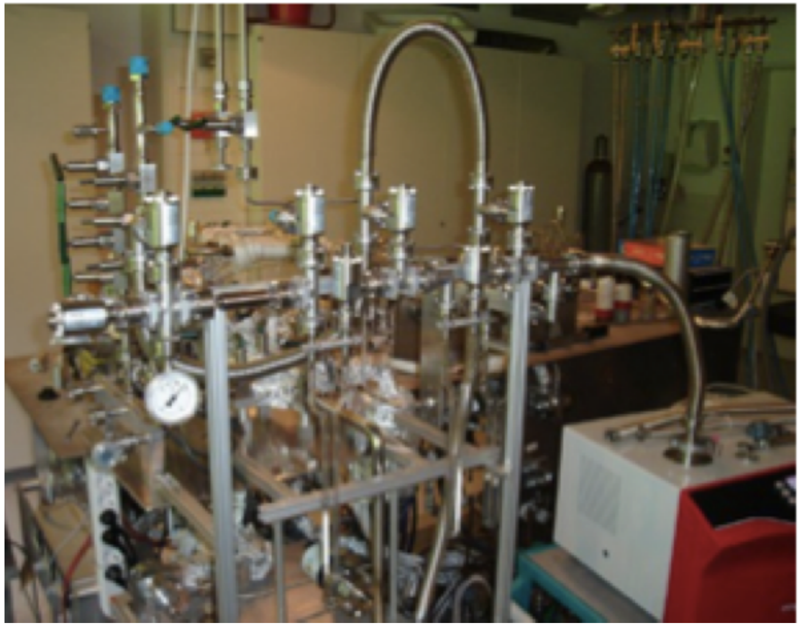
^{222}Rn emanation technique

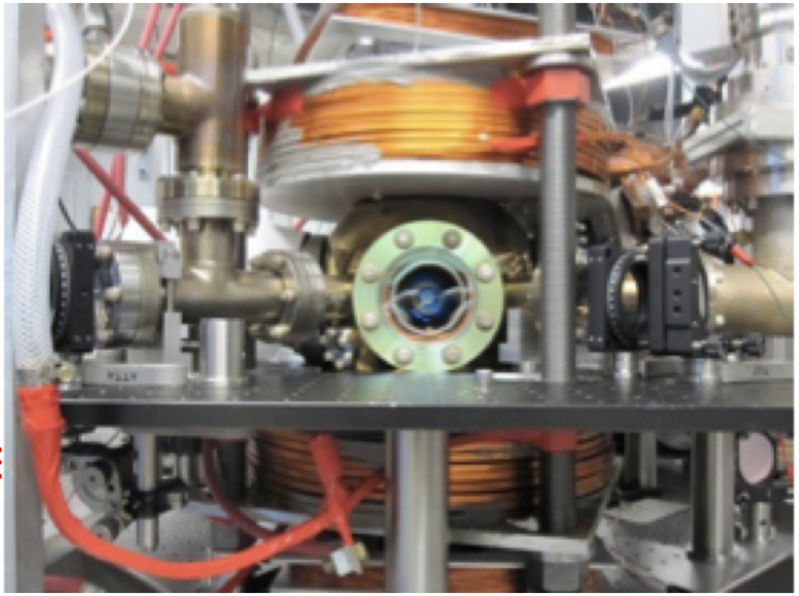
- sensitivity = few atoms/probe
- large samples ←→ absolute sensitivity
- non-trivial; not commonly available; routine @MPIK
- established numbers:

Nylon (Borexino) < 1μBq/m^2
Copper (Gerda): 2μBq/m^2
Stainless steel (Borexino): 5μBq/m^2
Titanium: (100 ± 30) μBq/m^2

New: Auto-Ema - automatized Rn screening facility @MPIK → many samples

Krypton Analytics





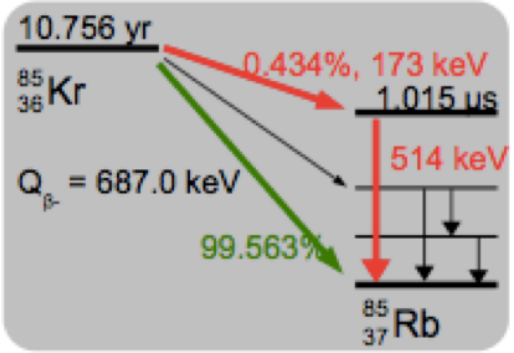
unstable ^{85}Kr in air → impurity in Xenon gas
- active removal by distillation
- control by precise measurements

Kr measurements:
- with gas chromatography
- Rare Gas Mass Spectroscopy (RGMS @MPIK)
→ measure ^{nat}Kr to ppt level
→ extrapolate: ^{85}Kr from atmospheric abundance
→ RGMS down to ppq level

- ^{84}Kr measurement with atomic trap (ATTA @ Columbia U)
→ measurement of ^{84}Kr to ppt level
→ extrapolate: ^{85}Kr from atmospheric abundance
→ atom trap operational and efficient for Ar*

Krypton Removal by cryogenic Distillation

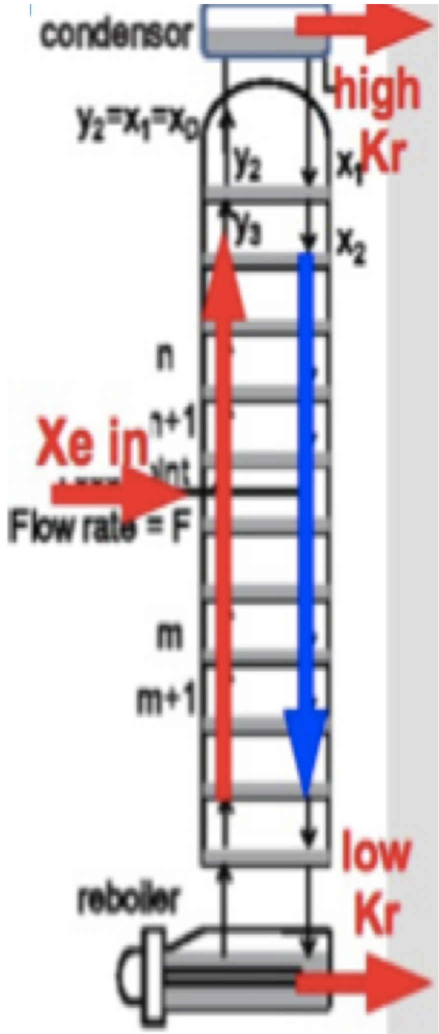
- commercial Xenon contains 1 ppm – 10 ppb of Kr
- ^{85}Kr is unstable



- goal: reduce Kr to sub ppt
- XENON100 achieved (19 ± 1) ppt

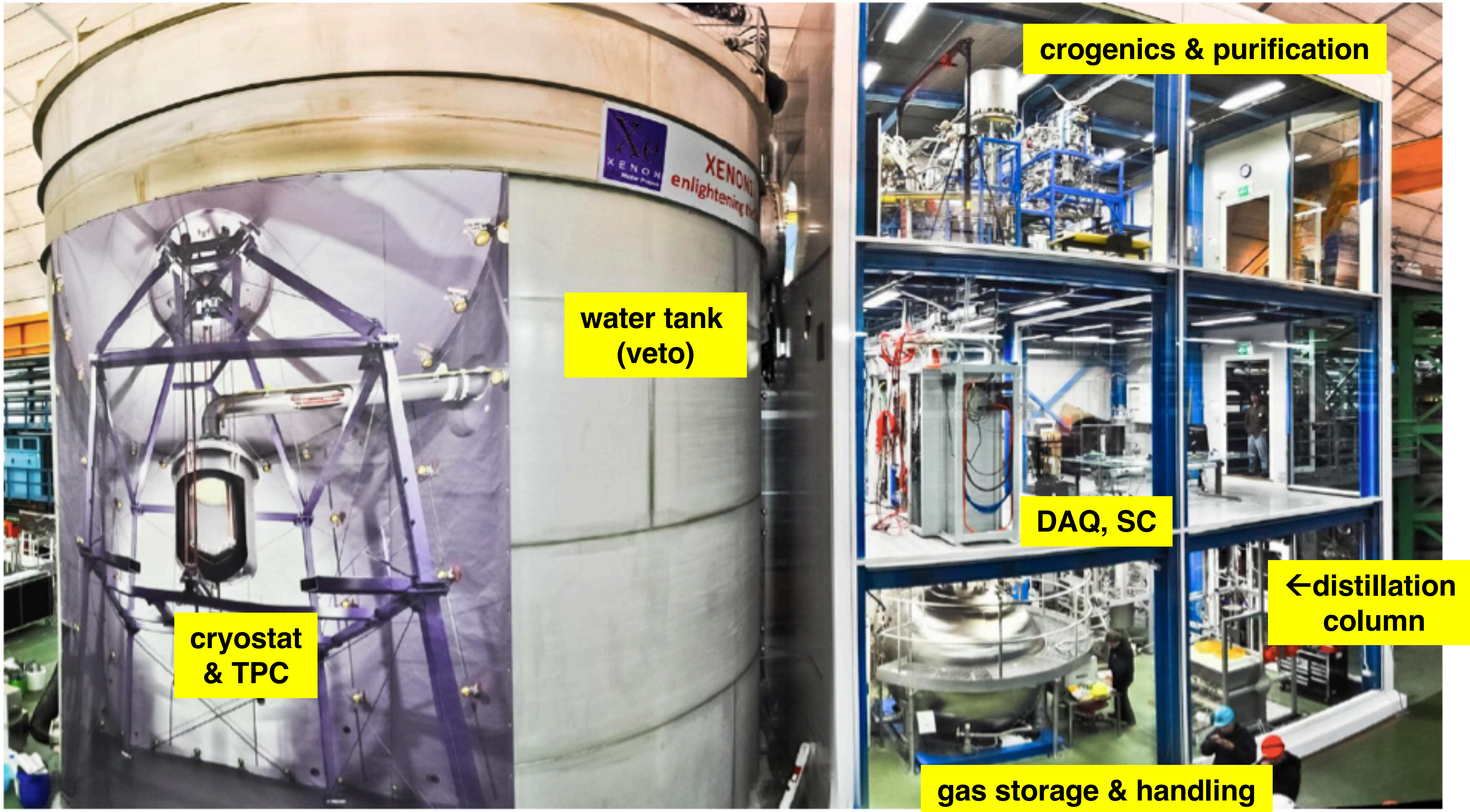
XENON1T distillation column (Münster):

- through-put up to 6.5 kg/hr
- separation factor > 6.4 10^5
- final Kr/Xe < 1 ppt
- capable to obtain an output concentration < 48 ppq
  Eur. Phys. J. C77 (2017) 275
- also operated for Rn removal

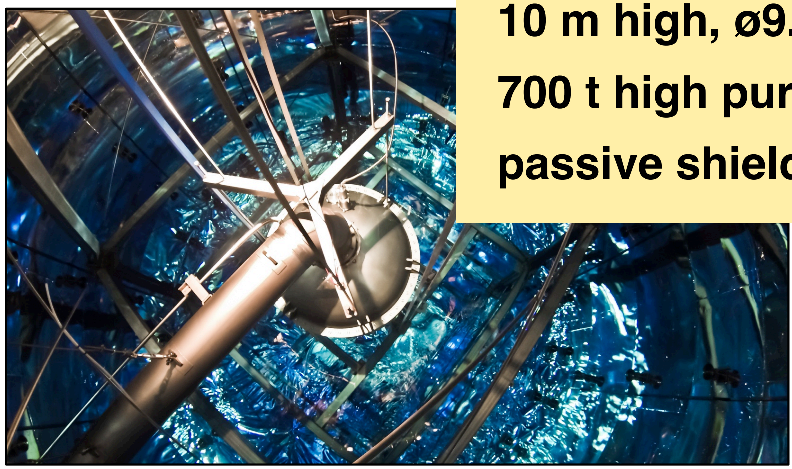


The XENON1T Detector

→ Goal: two orders of magnitude improvement in sensitivity with respect to XENON100 → commissioning in 2016 → 1st results



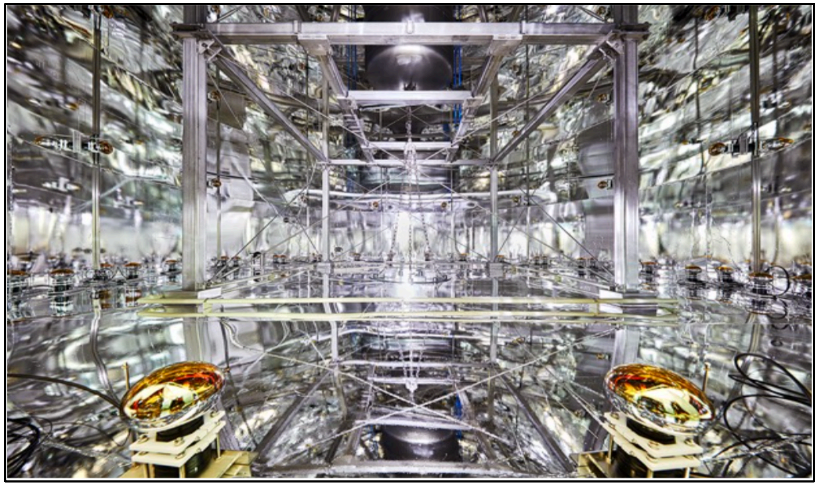
Water Shield & Muon Veto

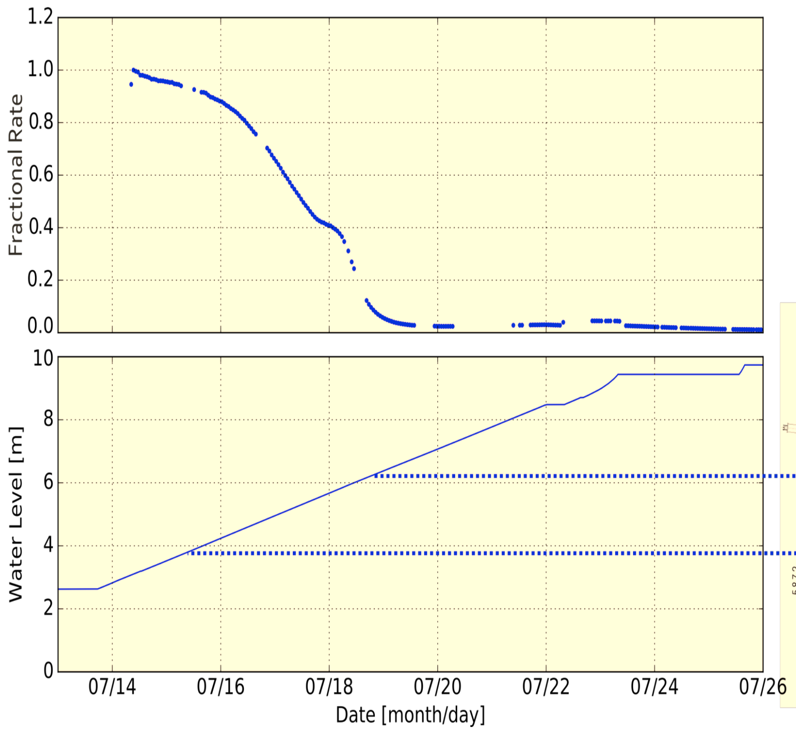


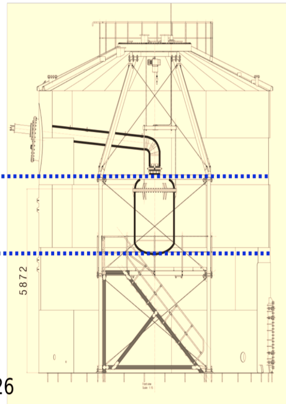
10 m high, ø9.6 m

700 t high purity water

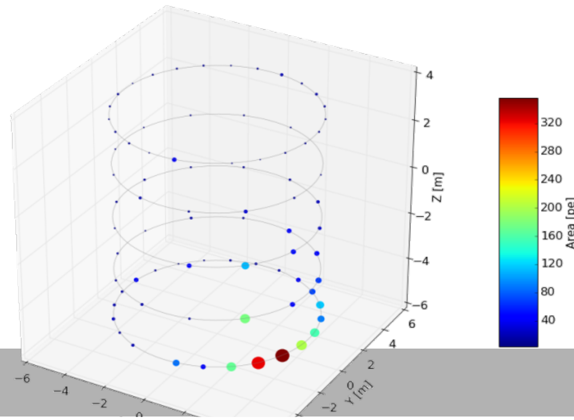
passive shield for γ's, n's







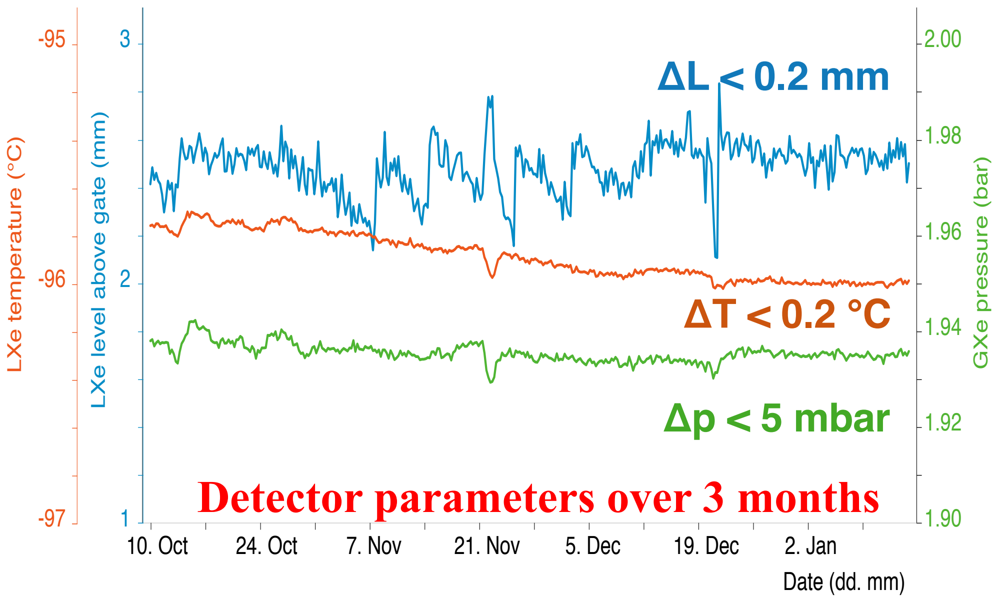
- Active shield against muons
- 84 high QE 8'' Hamamatsu R5912 PMTs
- Trigger efficiency > 99.5% for neutrons with muons in water tank
- Can suppress cosmogenic background to < 0.01 events/ton/year
- JINST 9 (2014) P11006

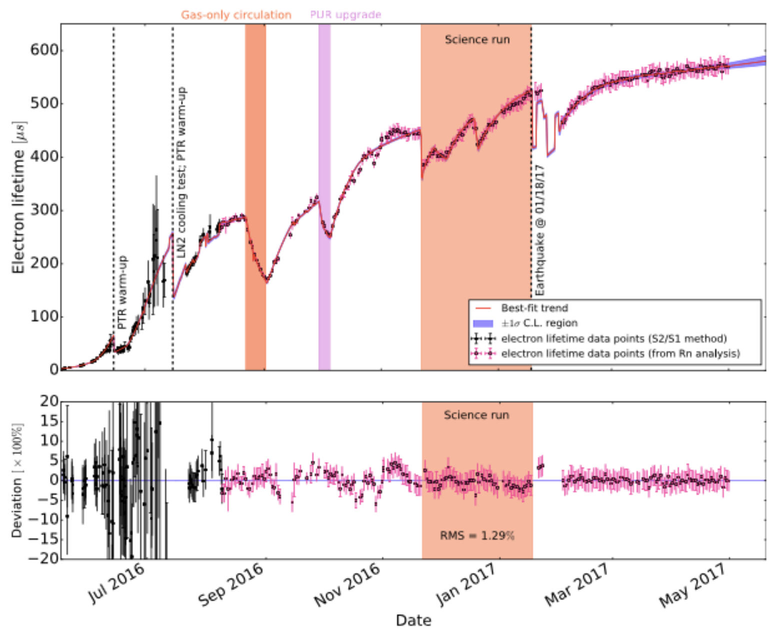


Cryogenic and Purification Systems

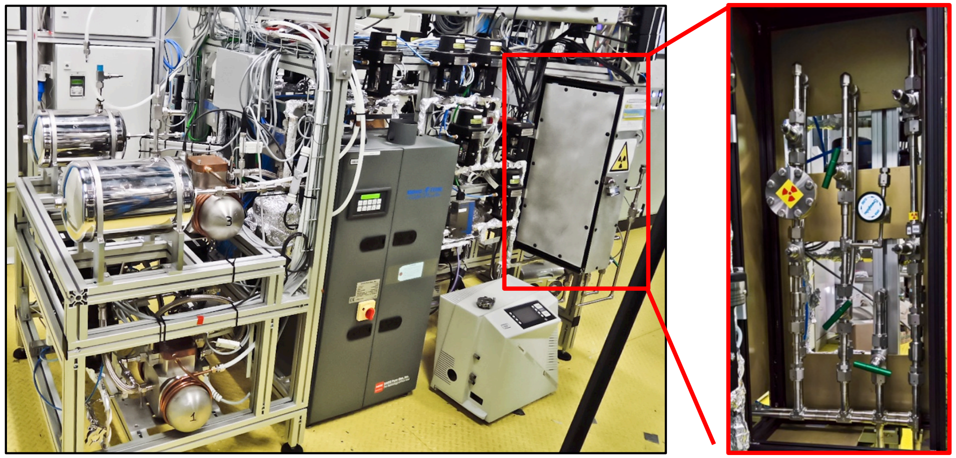
cryogenic system:
- **maintains 3.2 tons of xenon in liquid state**
  ➔ **stable conditions (T, p) for data taking**
- **backup: PTR and LN_2 cooling for emergencies**

purification system:
- **clean Xe from electronegative impurities below 1 ppb with continuous gas circulation through heated getters**
  ➔ **drifting electrons**





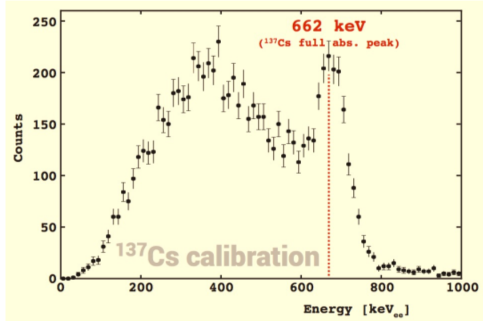
Calibration and ReStoX Systems



- **Internal sources**

Rn220
CH3T
Kr83m

- **External sources**
  - AmBe, Cs137



  - neutron generator

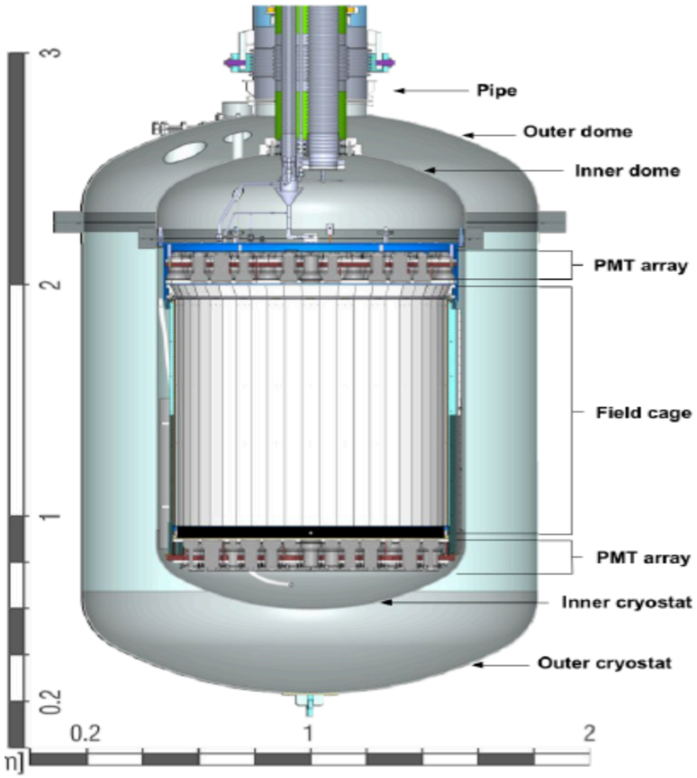
ReStoX

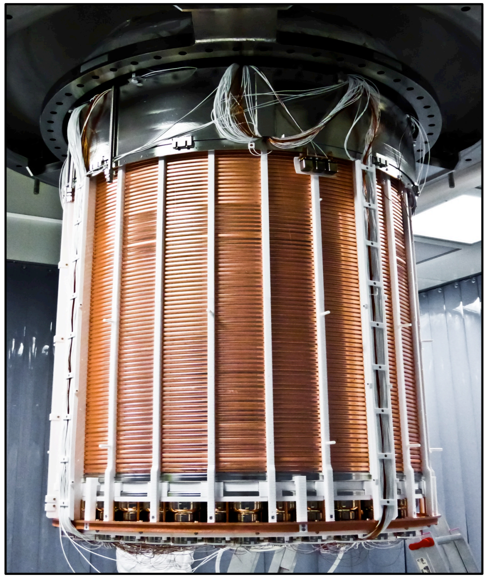
Recovery and Storage of Xenon

- double-walled, high pressure (70bar) sphere
- stores up to 7.6 t of Xe either in gas or liquid phase under high purity conditions

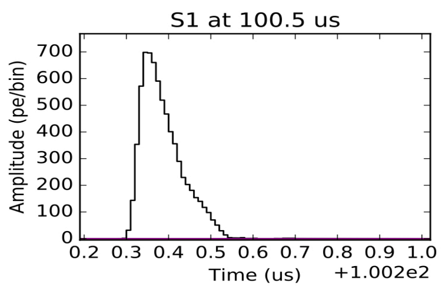
- fill LXe into detector in ultra-high-purity conditions
- recovery of all LXe if necessary in a few hours

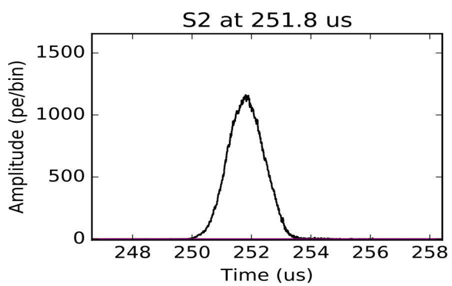
The Time Projection Chamber (TPC)



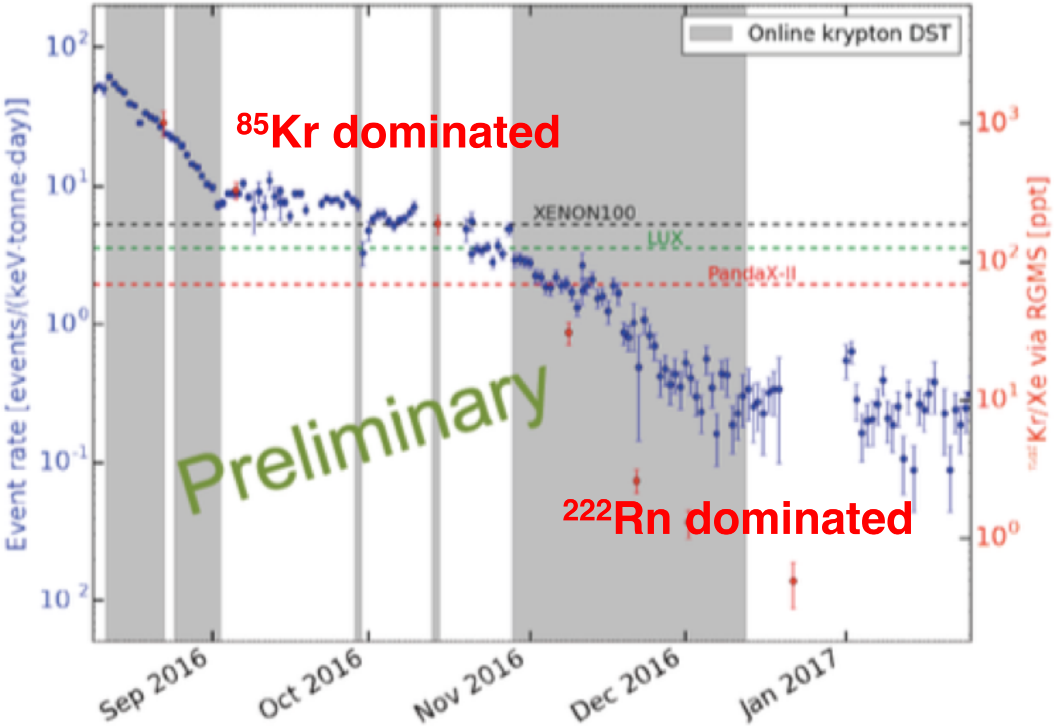


- 248 3” low-bkg PMTs
- 1 m drift × ø1 m
  - 2 tons active LXe
  - largest LXe TPC built
- filled and functional since May 2016



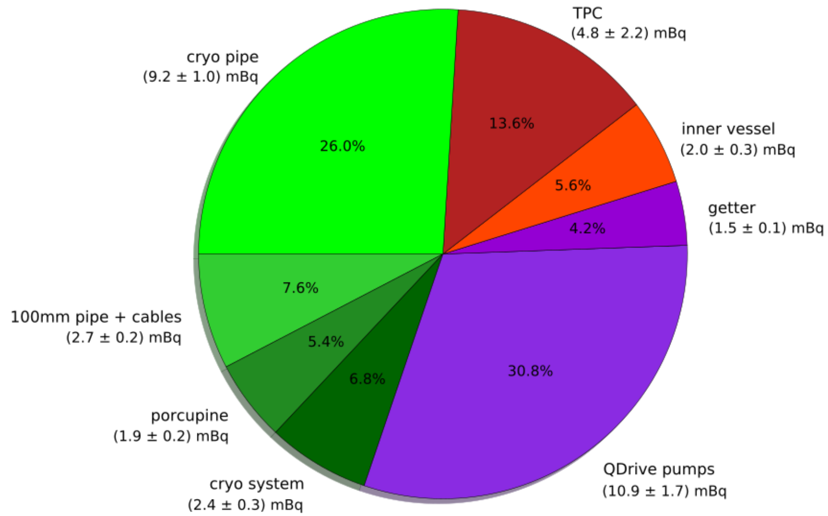


XENON1T Operation

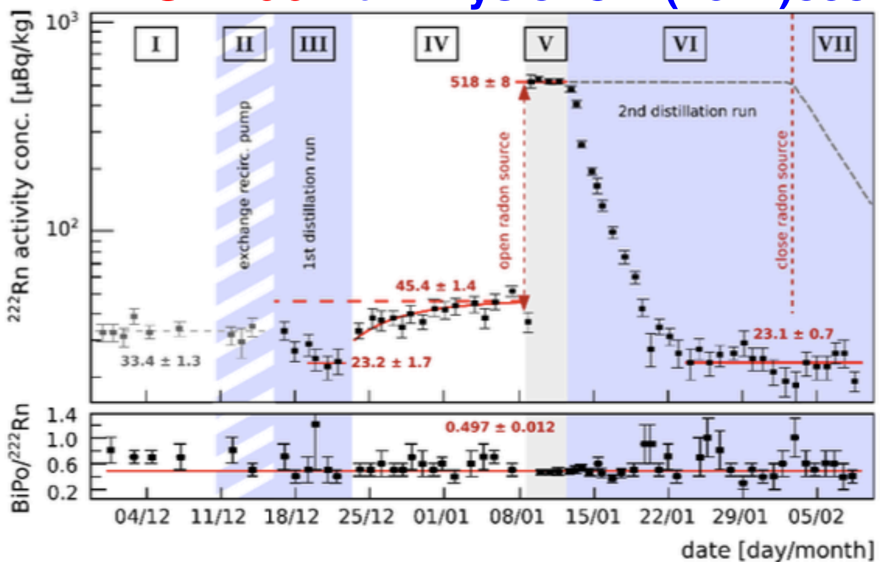


- ^{nat}Kr/Xe < 0.36 ± 0.06 ppt after 1 month of online distillation (sufficient for SR0)
- ^{222}Rn 10 μBq/kg target concentration
- lowest background level of all LXe exps.
- Kr reduction by cryogenic distillation
  Eur. Phys. J. C77 (2017) 77
- Kr level measured precisely by RGMS
  Eur. Phys. J. C74 (2014) 2746

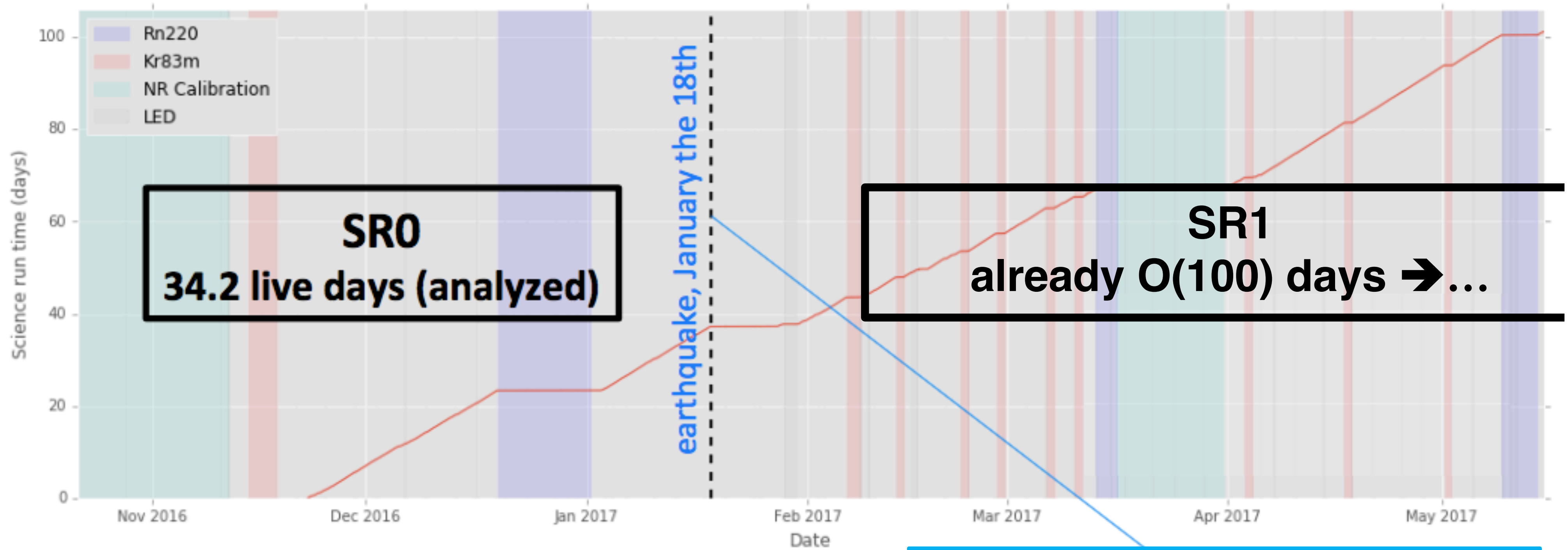
- Rn budget well understood



- demonstration of Rn distillation with XENON100 **Eur.Phys.J. C77(2017)358**

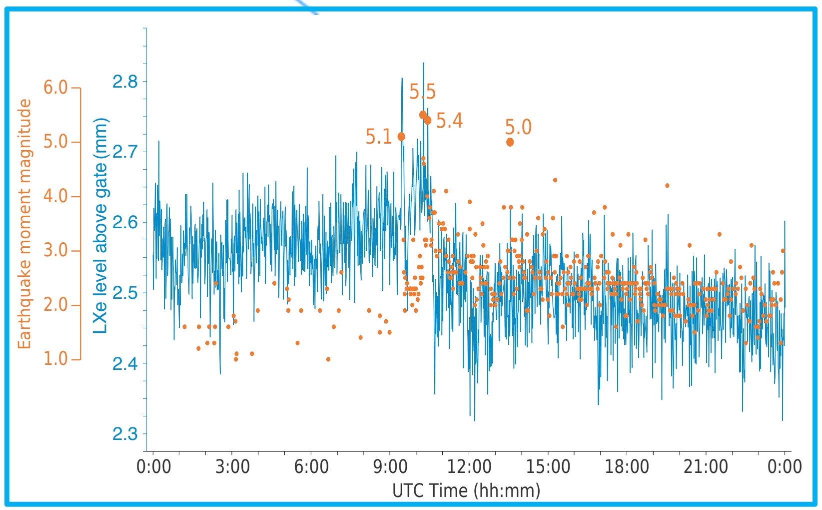


Data Taking



- **SR0: Data up to earthquake**
  ➔ 34.2 live days analyzed
  ➔ 1st results arXiv:1705.06655

- **SR1: data after earth quake**



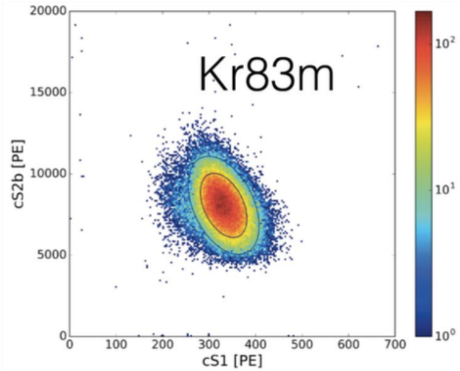
magnitude 5.6 earth quake @ d ~20 km

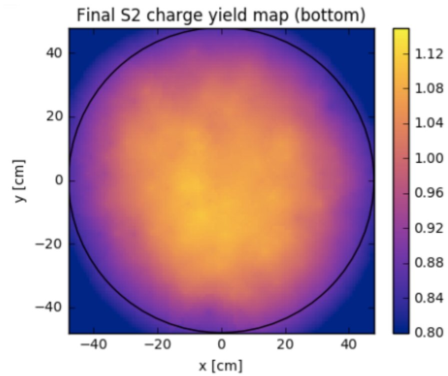
Calibration: Light Collection and Charge Yield

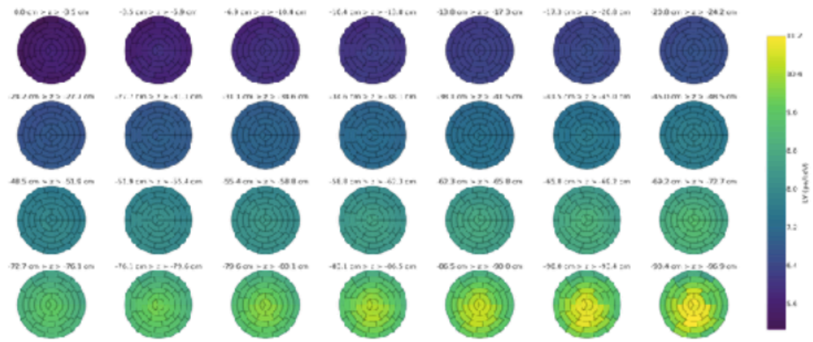
^{83m}Kr calibration:

- position-dependent
  - light collection efficiency
  - S2 amplification
- electric field uniformity
- light/charge yield stability

➔ light collection efficiency maps

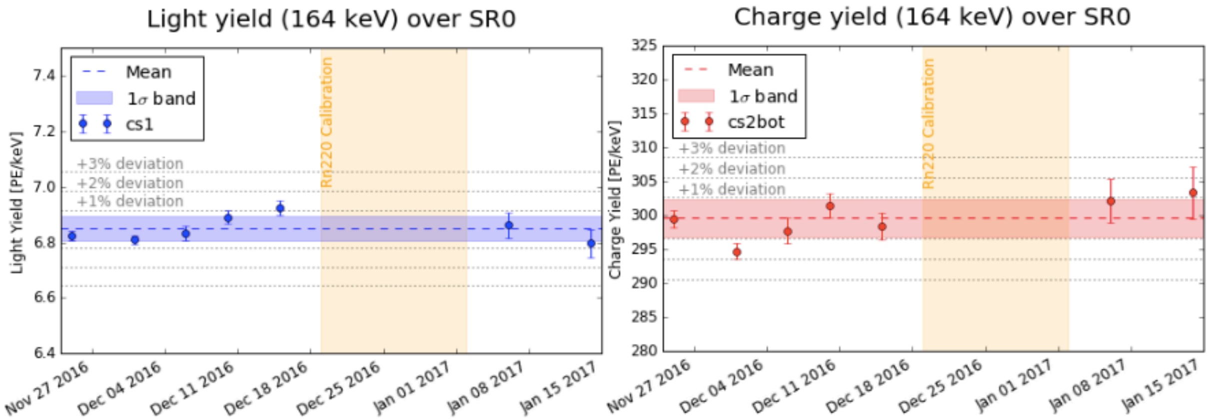






light and charge yield stability:

- monitoring with ^{131m}Xe (and ^{83m}Kr) ➔ stability
- variations at ~1%

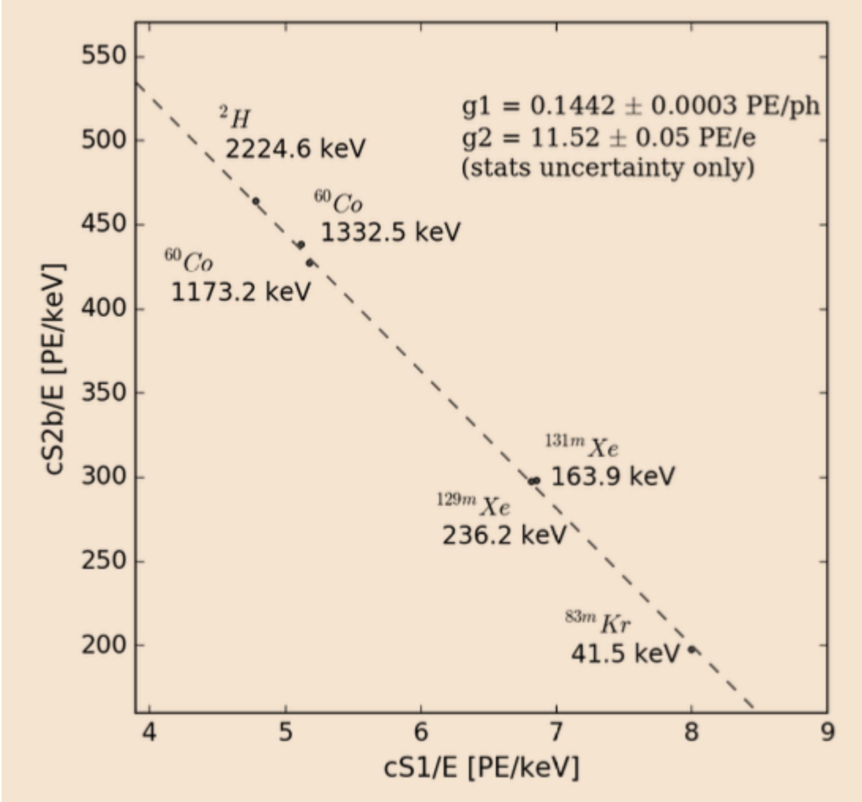


Energy Scale Calibration

calibration sources:

- ^{83m}Kr, ^{241}AmBe (^{129m}Xe, ^{131m}Xe, ^{2}H)
- background from detector material (^{60}Co)

$$E = (n_{ph} + n_e) \cdot W = (\frac{S1}{g1} + \frac{S2}{g2}) \cdot W$$



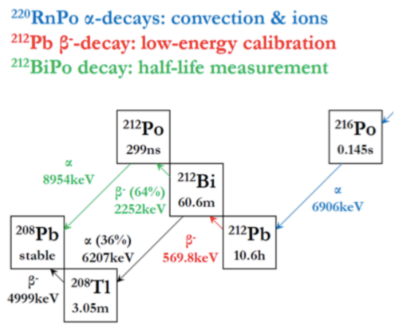
- linearity from 40 keV to 2.2 MeV
- photon gain
  g1 = 0.144 ± 0.007 (sys) PE/ph
  - light detection efficiency (12.5±0.6)%
  - MC prediction 12.1%
- electron gain g2 = 11.5 ± 0.8 (sys) PE/e-
  - corresponds to ~100% extraction of ionization charges from LXe

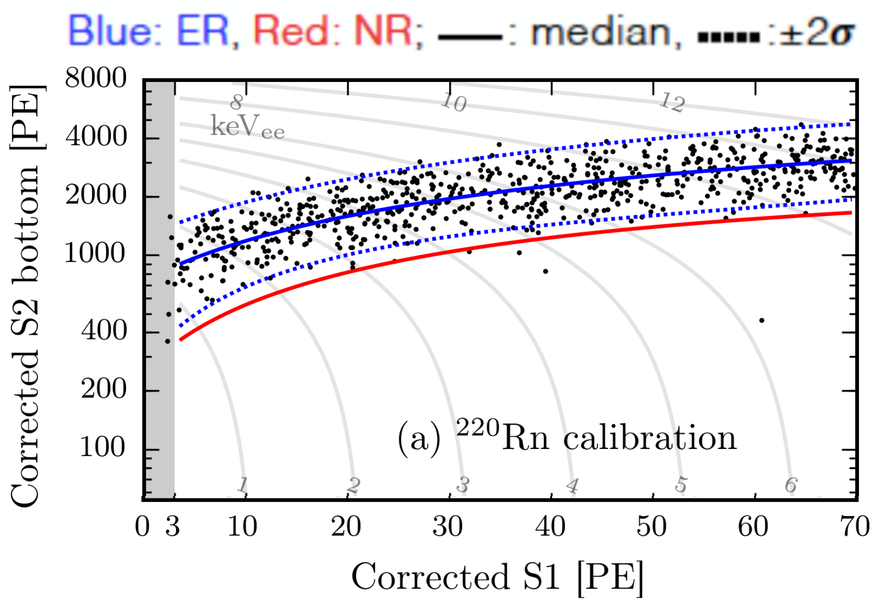
Electronic and Nuclear Recoil Calibration

Electronic Recoils (ER)

- ^{228}Th source emanates ^{220}Rn into LXe
- β-decay of ^{212}Pb to ^{212}Bi low energy events (2-20 keV)

Phys. Rev. D 95, 072008 (2017)

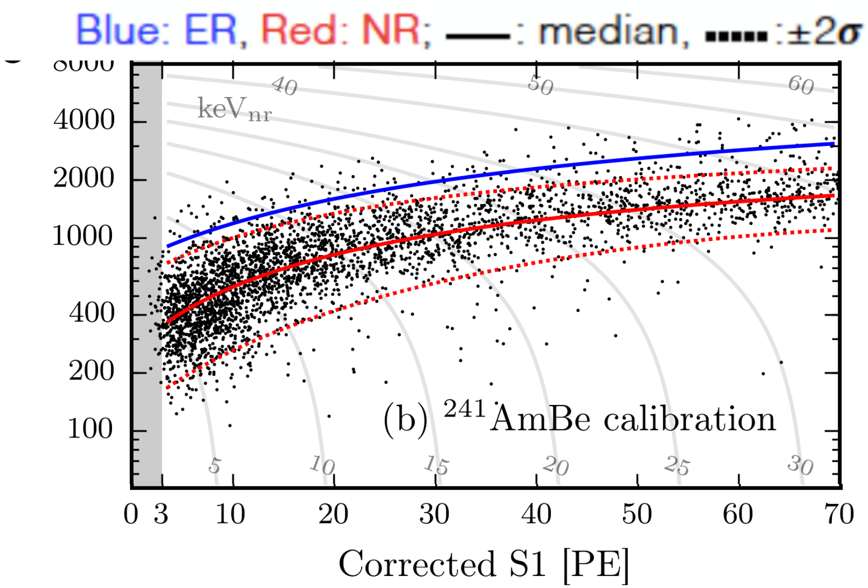




Nuclear Recoils (NR)

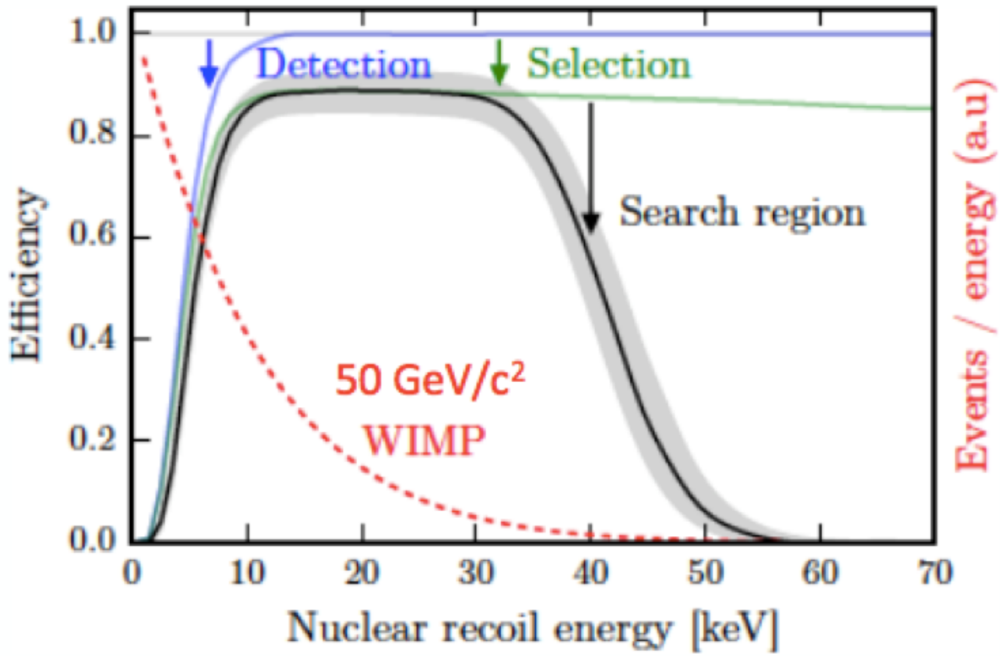
- external ^{241}AmBe source mounted on a belt
- α particles emitted by Am-decay collide with the light Be nuclei

➔ fast neutrons



Event Selection

- **signal region blinded**
  ➔ fixed selection cuts
- **NR detection efficiency**
  - reconstruction tuned with MC
  - dominated by 3-fold PMT coincidence requirement
- **event selection from control samples or simulations**
  - data quality and selection cuts tuned to calibration data
  - single scatter (WIMP-like) events
- **search region**
  - corrected S1 range 3-70 PE
- **fiducial volume: 1042 kg**
  - blindly chosen
  - conservative



Cut	Events remaining
All (cS1 < 200 PE)	128144
Selections	48955
1 t Fiducial volume	180
S1 range (3 < cS1 < 70)	63

Backgrounds

Background reduction:

- material screening & selection
- cryogenic distillation to remove Kr
- Rn distillation

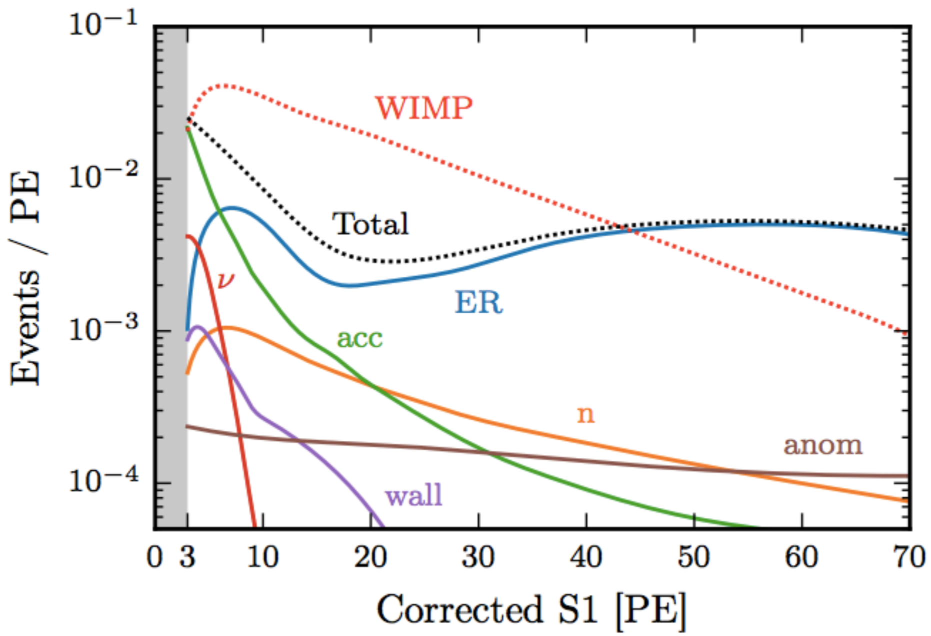
Materials: arXiv:1705.01828 (2017)

Kr: Eur. Phys. J. C77, 275 (2017)

Rn: EPJ C77 (2017) 358

Background model

- ER and NR spectral shapes derived from models fitted to calibration data
- NR energy conversion is based on the model and parametrization from NEST



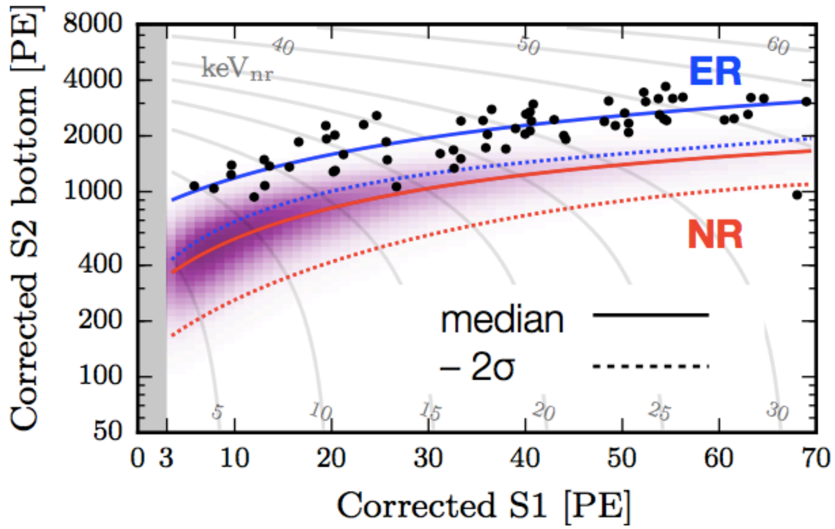
Background & Signal Rates	Full search region	Reference region
Electronic recoils (ER)	62 ± 8	0.26 (-0.07)(+0.11)
Radiogenic neutrons (n)	0.05 ± 0.01	0.02
CNNS (ν)	0.02	0.01
Accidental coincidences (ac)	0.022 ± 0.01	0.06
Wall leakage (wall)	0.52 ± 0.3	0.01
Anomalous (anom)	0.09 (-0.06)(+0.12)	0.01 ± 0.01
Total background	63 ± 8	0.36 (-0.07)(+0.11)

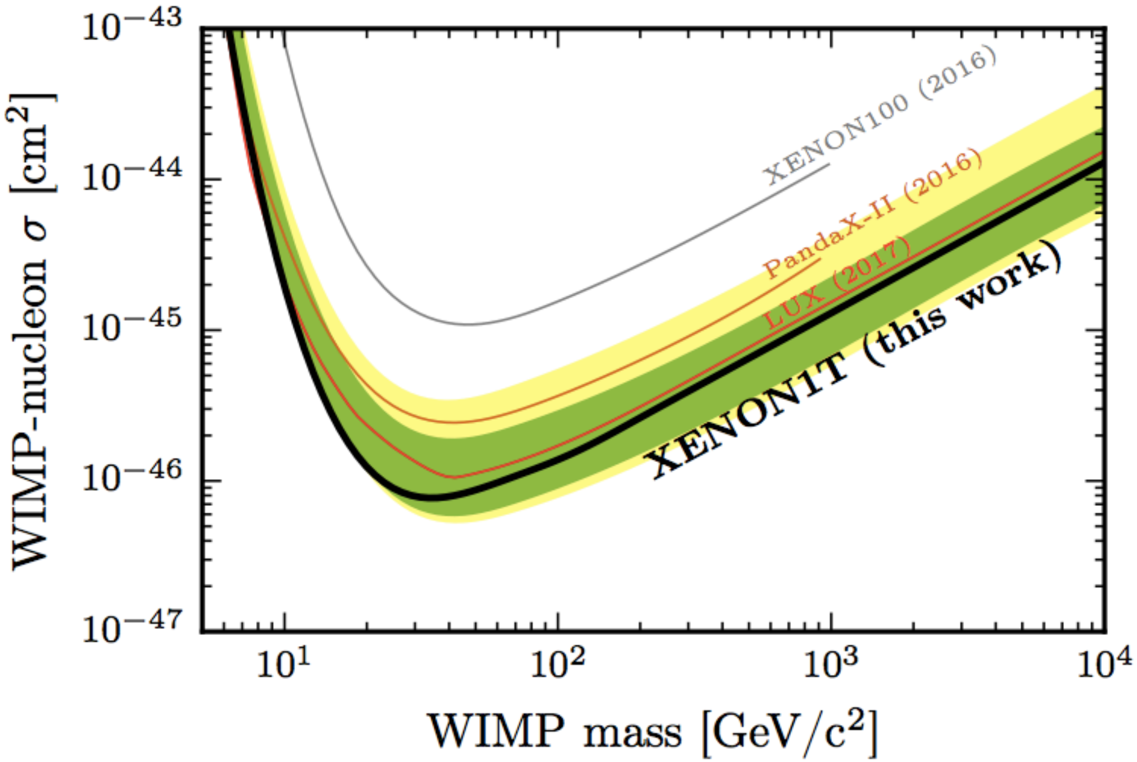
SR0 Result

background model:
63 + 8 events (62 + 8 from ER)

after applying cuts & unblinding:
63 events

➔ see talk by J. Aalbers for details of the analysis process





consistent with null hypothesis

- unbinned profile likelihood analysis including background uncertainties

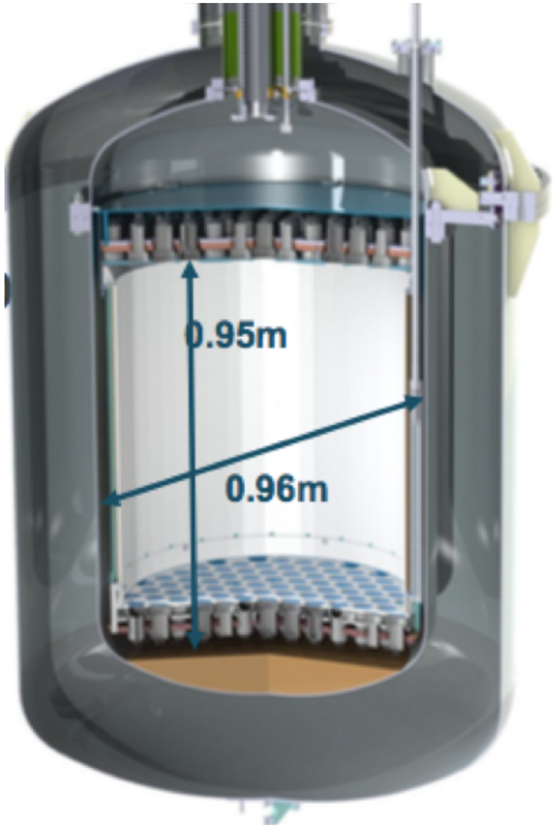
- ER/NR shape parameters from calibration fits

➔ **strongest SI exclusion limit already from SR0: 7.7 x 10^{-47} cm^2 @ 35 GeV/c^2**
arXiv:1705.06655

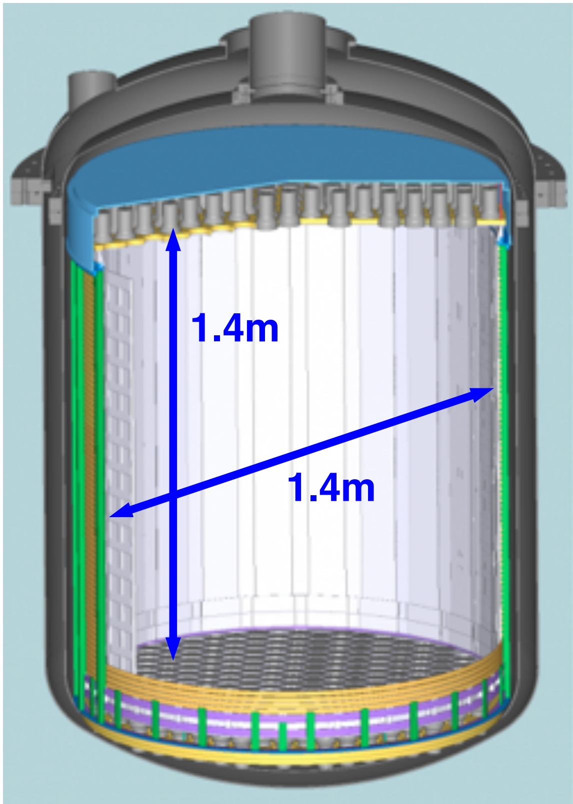
➔ **SR1: …**

The XENONnT Upgrade

XENON1T



XENONnT



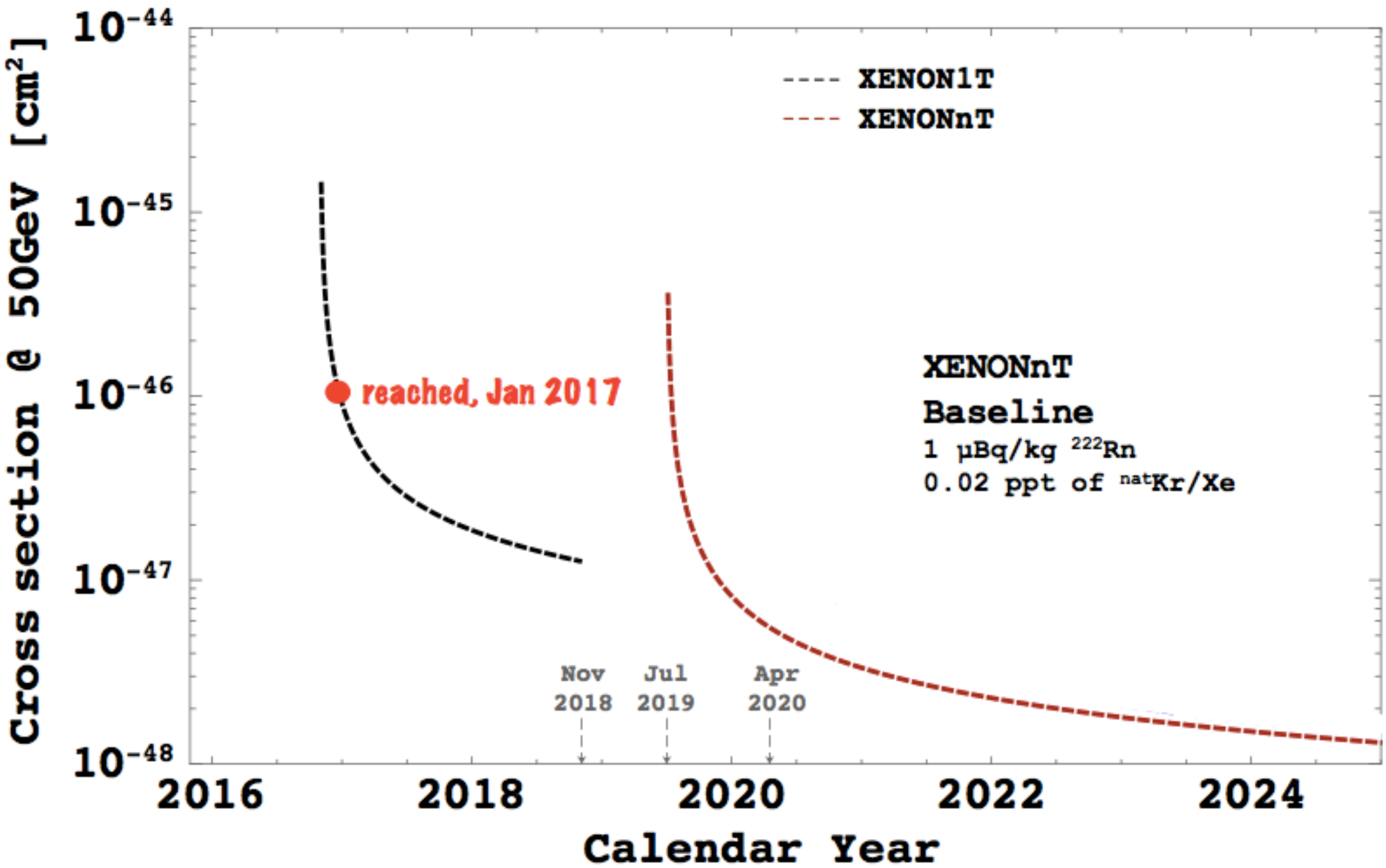
2012-2018	2019-2023
3.2t LXe	ca. 8t LXe
running	under preparation

being prepared while XENON1T runs ➔ switching gears

Existing/operational/tested:
muon veto
cryostat support
outer cryostat
in-LXe cabeling
LXe storage system (Restox)
cryogenic system
purification system
Kr removal
DAQ & 95% electronics
slow control system
calibration system
> 8t of Xenon gas & 260 PMTs
screening facilities

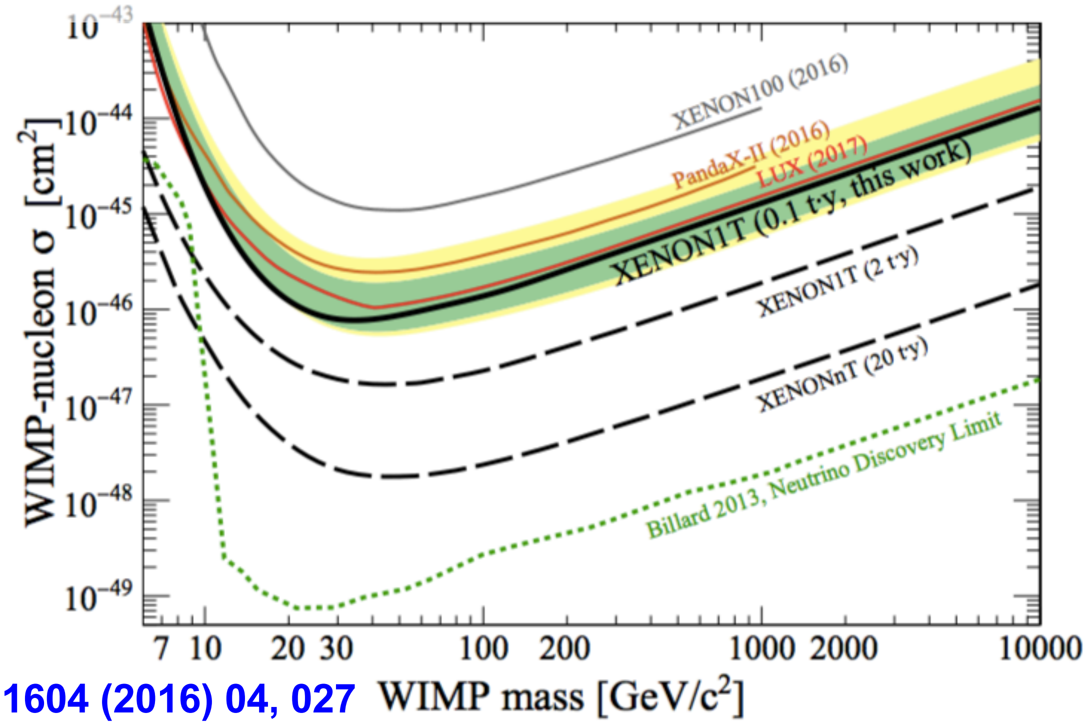
Started/design/on-going:
230 more PMTs ordered
➔ being delivered & tested
TPC & inner cryostat design
n-veto studies
material orders
γ and Rn screening
Rn reduction system
improved purification
2nd Restox & more Xe gas

XENONnT Sensitivity Reach & Schedule

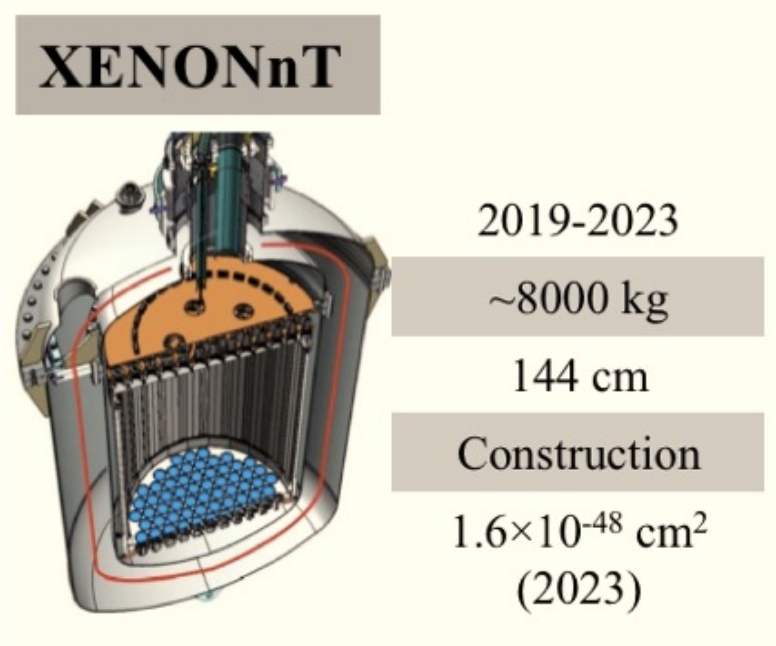


Conclusions

- XENON1T operation: detector is performing very well
- lowest background level ever achieved in a dark matter experiment:
  (1.93± 0.25) 10^{-4} evt/(kg day keV)
- 1st result from 34.2 days this spring: **7.7 ⊗10^{-47} cm^2 @35 GeV/c^2**
  ➔ **XENON1T is currently the most sensitive direct detection experiment**
- meanwhile O(100) days more data ➔ expect more in O(months)
- fast upgrade to XENONnT based on existing infrastructure ➔ end of 2018



JCAP 1604 (2016) 04, 027



➔ exciting years ahead!